Early SUSY Searches at the LHC

Amir Farbin
CERN

- LHC/ATLAS Introduction
- Early SUSY Searches at LHC
- Analysis Computing in ATLAS

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Extra material on at the end on Hadronic Calorimeter Level-Trigger Hardware, Data Modeling, Jet Calibration, ...
if anyone is interested.

Introduction

Standard Model of

FUNDAMENTAL PARTICLES AND INTERACTIONS

The Standard Model summarizes the current knowledge in Particle Physics. It is the quantum theory that includes the theory of strong interactions (quantum chromodynamics or QCD) and the unified theory of weak and electromagnetic interactions (electroweak). Gravity is included on this chart because it is one of the fundamental interactions even though not part of the "Standard Model."

FERMIONS

matter constituents
spin = 1/2, 3/2, 5/2, ...

Leptons spin = 1/2

Flavor	Mass GeV/c^2	Electric charge
ν_e electron neutrino	$<1\times10^{-8}$	0
e electron	0.000511	–1
ν_μ muon neutrino	<0.0002	0
μ muon	0.106	–1
ν_τ tau neutrino	<0.02	0
τ tau	1.7771	–1

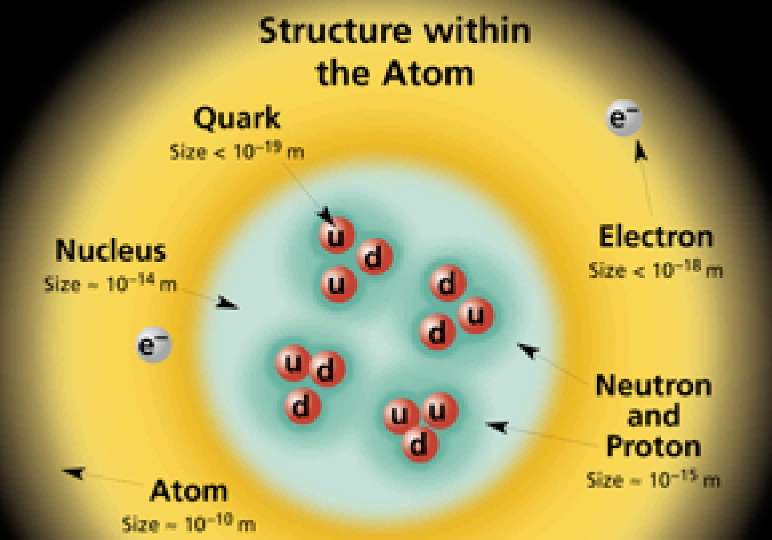
Quarks spin = 1/2

Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

Spin is the intrinsic angular momentum of particles. Spin is given in units of $\hbar$, which is the quantum unit of angular momentum, where $\hbar = h/2\pi = 6.58\times10^{-25}$ GeV s $= 1.05\times10^{-34}$ J s.

Electric charges are given in units of the proton's charge. In SI units the electric charge of the proton is 1.60×10^{-19} coulombs.

The **energy** unit of particle physics is the electronvolt (eV), the energy gained by one electron in crossing a potential difference of one volt. **Masses** are given in GeV/c^2 (remember $E = mc^2$), where 1 GeV $= 10^9$ eV $= 1.60\times10^{-10}$ joule. The mass of the proton is 0.938 GeV/c^2 $= 1.67\times10^{-27}$ kg.



If the protons and neutrons in this picture were 10 cm across, then the quarks and electrons would be less than 0.1 mm in size and the entire atom would be about 10 km across.

BOSONS

force carriers
spin = 0, 1, 2, ...

Unified Electroweak spin = 1

Name	Mass GeV/c^2	Electric charge
γ photon	0	0
W^-	80.4	–1
W^+	80.4	+1
Z^0	91.187	0

Strong (color) spin = 1

Name	Mass GeV/c^2	Electric charge
g gluon	0	0

Color Charge

Each quark carries one of three types of "strong charge," also called "color charge." These charges have nothing to do with the colors of visible light. There are eight possible types of color charge for gluons. Just as electrically-charged particles interact by exchanging photons, in strong interactions color-charged particles interact by exchanging gluons. Leptons, photons, and ***W*** and ***Z*** bosons have no strong interactions and hence no color charge.

Quarks Confined in Mesons and Baryons

One cannot isolate quarks and gluons; they are confined in color-neutral particles called **hadrons**. This confinement (binding) results from multiple exchanges of gluons among the color-charged constituents. As color-charged particles (quarks and gluons) move apart, the energy in the color-force field between them increases. This energy eventually is converted into additional quark-antiquark pairs (see figure below). The quarks and antiquarks then combine into hadrons; these are the particles seen to emerge. Two types of hadrons have been observed in nature: **mesons** $q\bar{q}$ and **baryons** qqq.

Residual Strong Interaction

The strong binding of color-neutral protons and neutrons to form nuclei is due to residual strong interactions between their color-charged constituents. It is similar to the residual electrical interaction that binds electrically neutral atoms to form molecules. It can also be viewed as the exchange of mesons between the hadrons.

PROPERTIES OF THE INTERACTIONS

Property \ Interaction	Gravitational	Weak (Electroweak)	Electromagnetic (Electroweak)	Strong: Fundamental	Strong: Residual
Acts on:	Mass – Energy	Flavor	Electric Charge	Color Charge	See Residual Strong Interaction Note
Particles experiencing:	All	Quarks, Leptons	Electrically charged	Quarks, Gluons	Hadrons
Particles mediating:	Graviton (not yet observed)	W^+ W^- Z^0	γ	Gluons	Mesons
Strength relative to electromag for two u quarks at: 10^{-18} m	10^{-41}	0.8	1	25	Not applicable to quarks
Strength relative to electromag for two u quarks at: 3×10^{-17} m	10^{-41}	10^{-4}	1	60	
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Baryons qqq and Antibaryons $\bar{q}\bar{q}\bar{q}$

Baryons are fermionic hadrons.
There are about 120 types of baryons.

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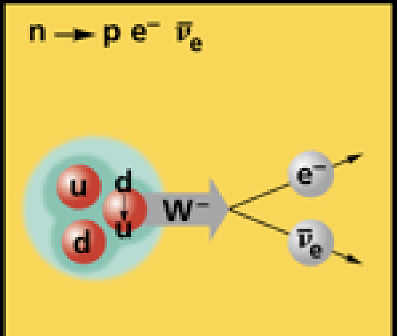
η_c	eta-c	$c\bar{c}$	0	2 .980	0

Matter and Antimatter

For every particle type there is a corresponding antiparticle type, denoted by a bar over the particle symbol (unless + or – charge is shown). Particle and antiparticle have identical mass and spin but opposite charges. Some electrically neutral bosons (e.g., Z^0, γ, and $\eta_c = c\bar{c}$, but not $K^0 = d\bar{s}$) are their own antiparticles.

Figures

These diagrams are an artist's conception of physical processes. They are *not* exact and have *no* meaningful scale. Green shaded areas represent the cloud of gluons or the gluon field, and red lines the quark paths.



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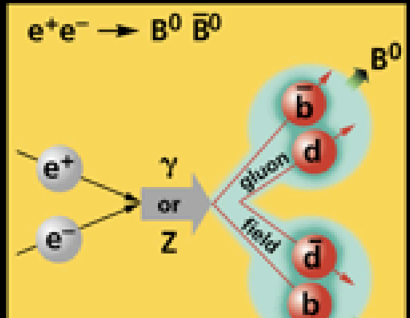
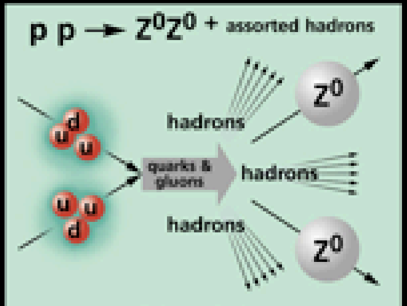


An electron and positron (antielectron) colliding at high energy can annihilate to produce B^0 and $\bar{B}^0$ mesons via a virtual Z boson or a virtual photon.



Two protons colliding at high energy can produce various hadrons plus very high mass particles such as Z bosons. Events such as this one are rare but can yield vital clues to the structure of matter.

The Particle Adventure

Visit the award-winning web feature *The Particle Adventure* at
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This chart has been made possible by the generous support of:
U.S. Department of Energy
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Stanford Linear Accelerator Center
American Physical Society, Division of Particles and Fields
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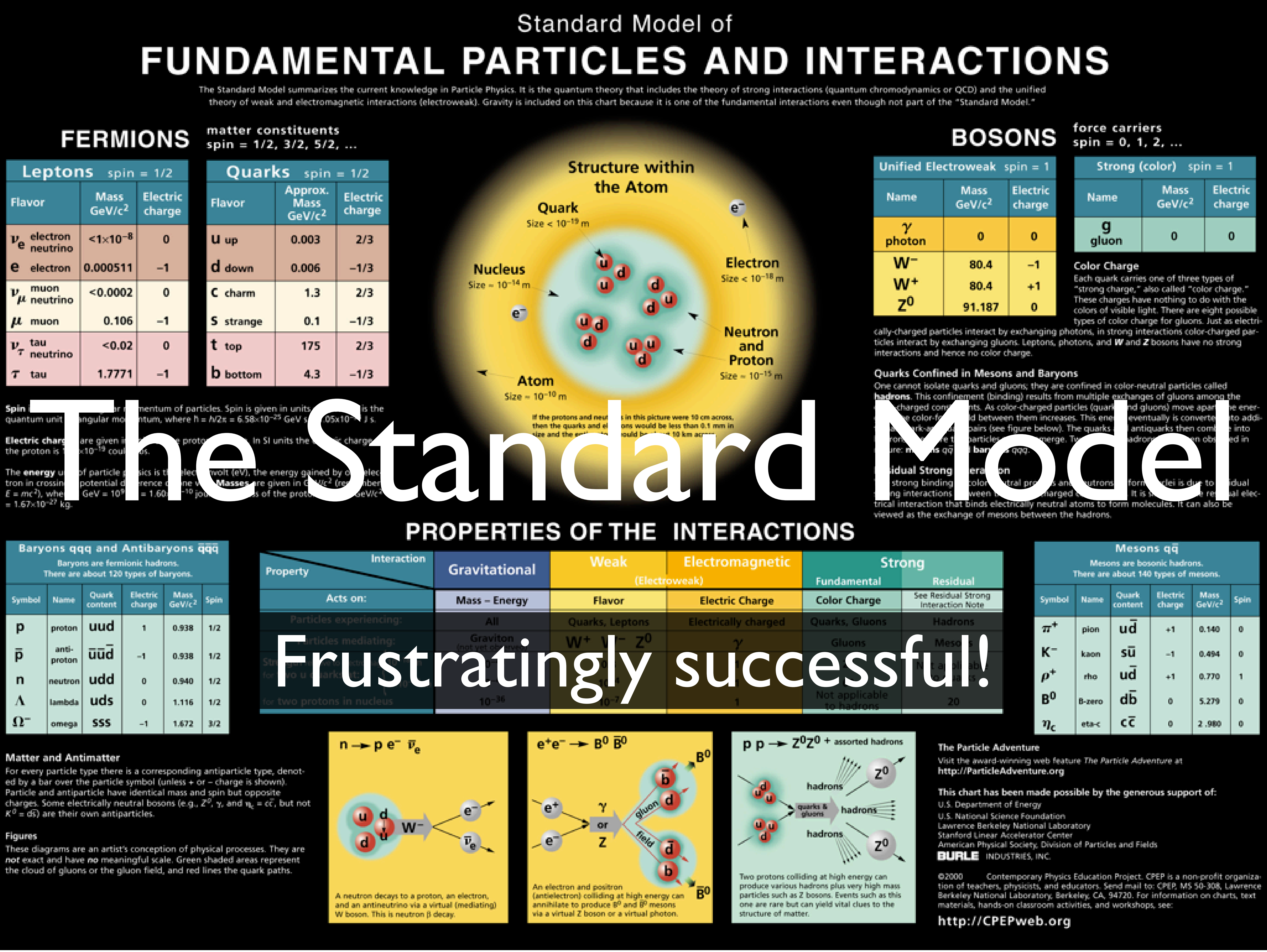

The Standard Model

Frustratingly successful!

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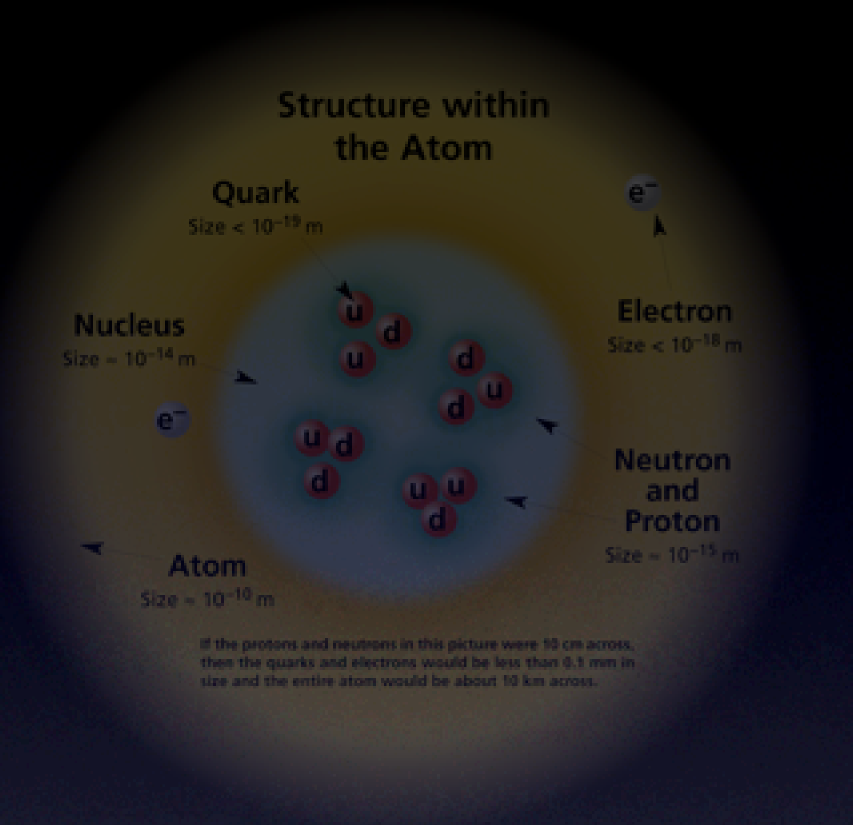

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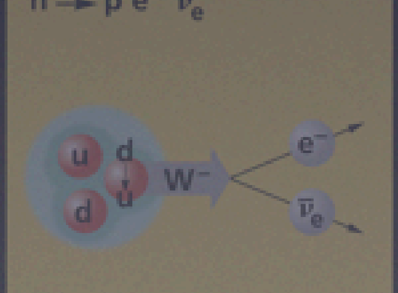

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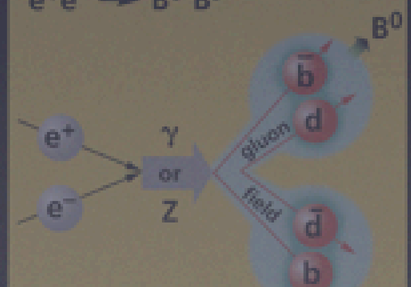

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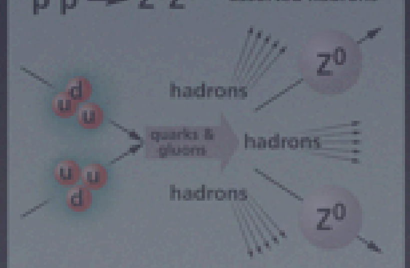
$p\, p \rightarrow Z^0 Z^0$ + assorted hadrons



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This chart has been made possible by the generous support of:

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American Physical Society, Division of Particles and Fields
BURLE INDUSTRIES, INC.

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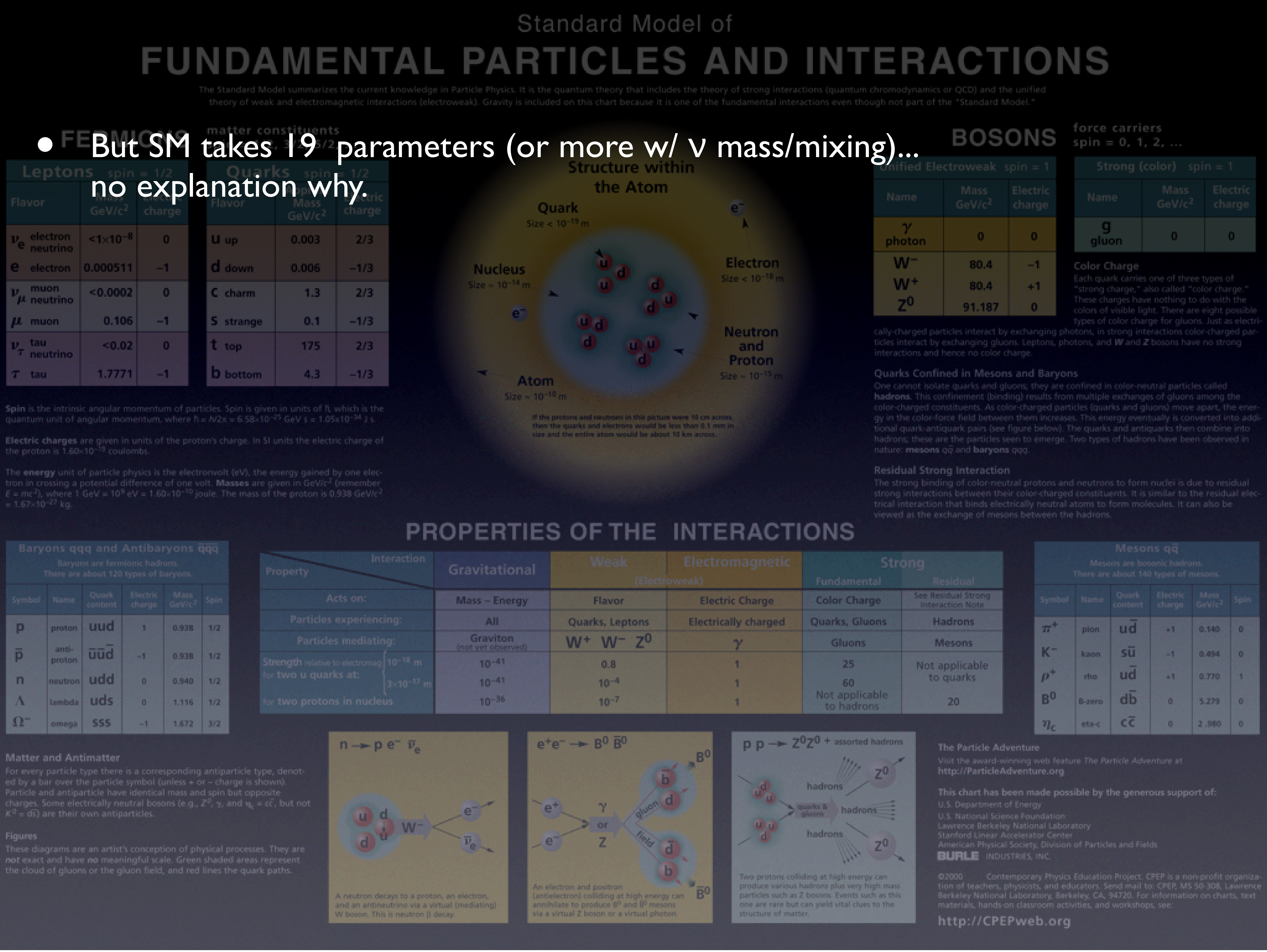

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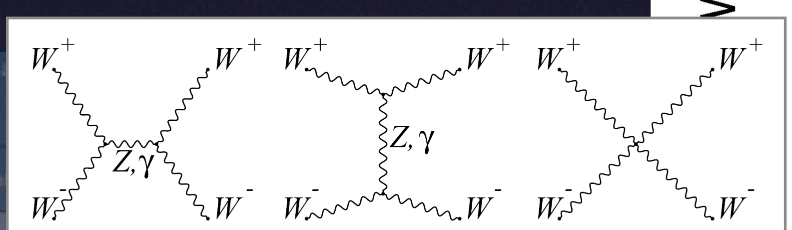

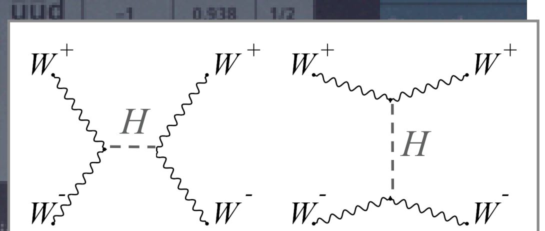

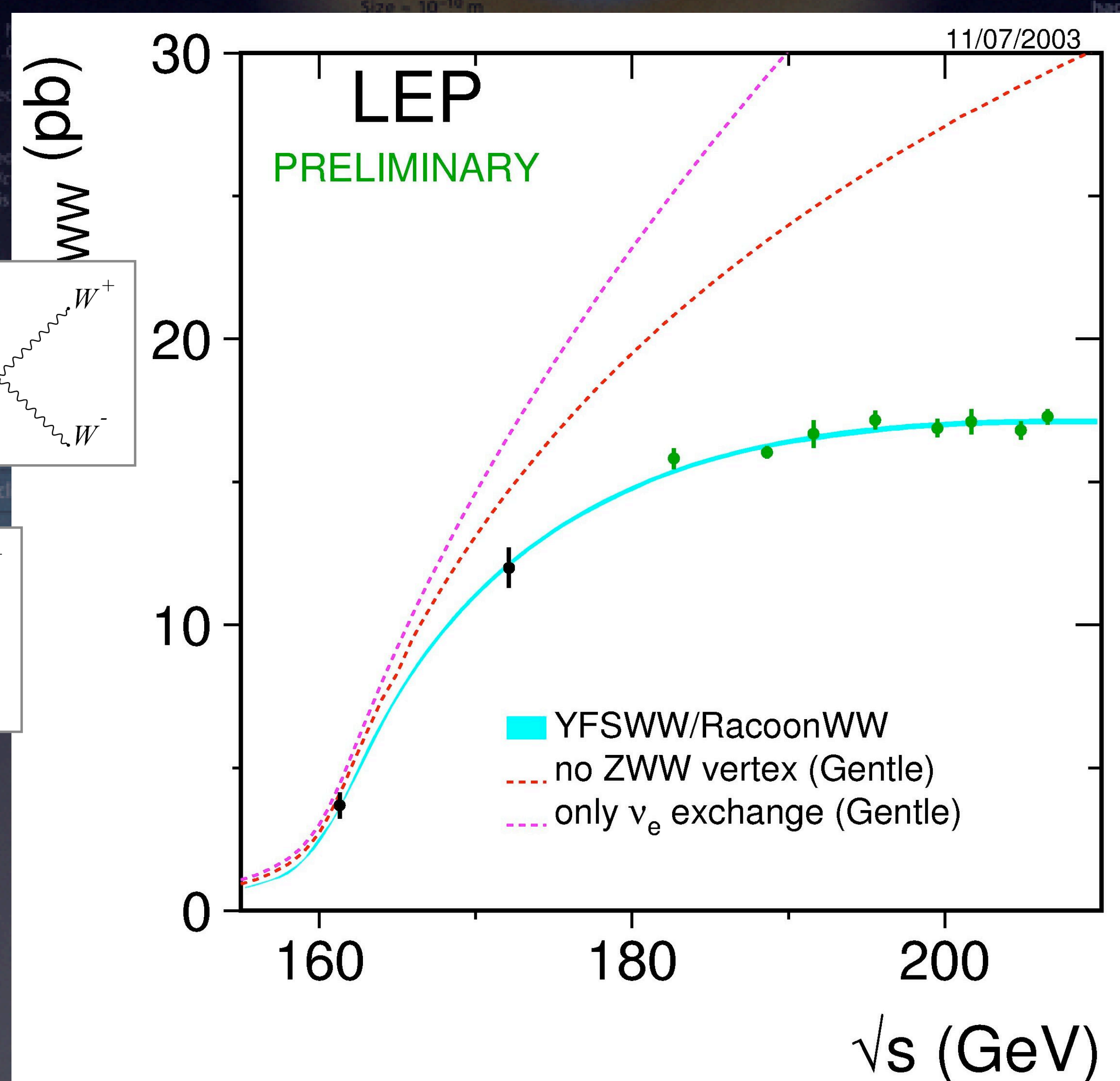

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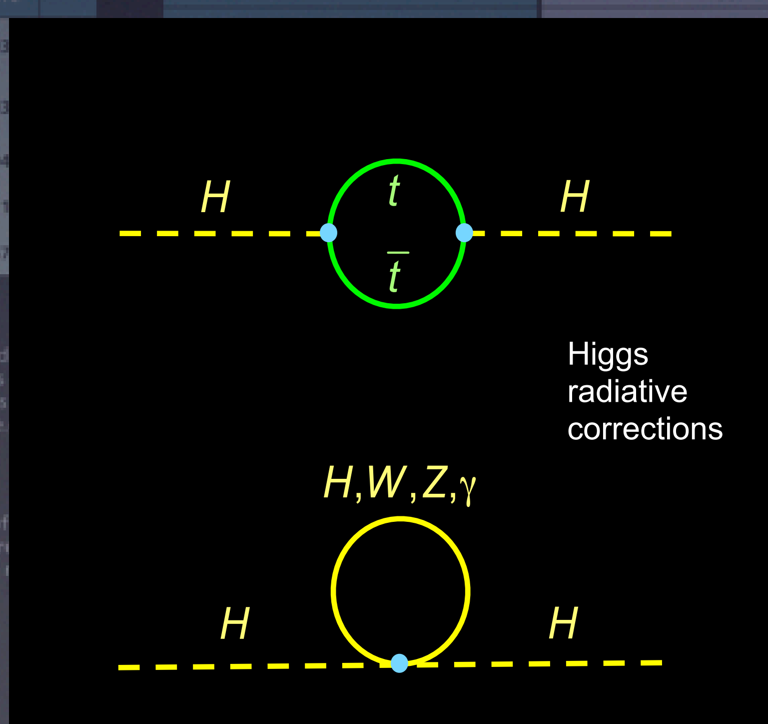

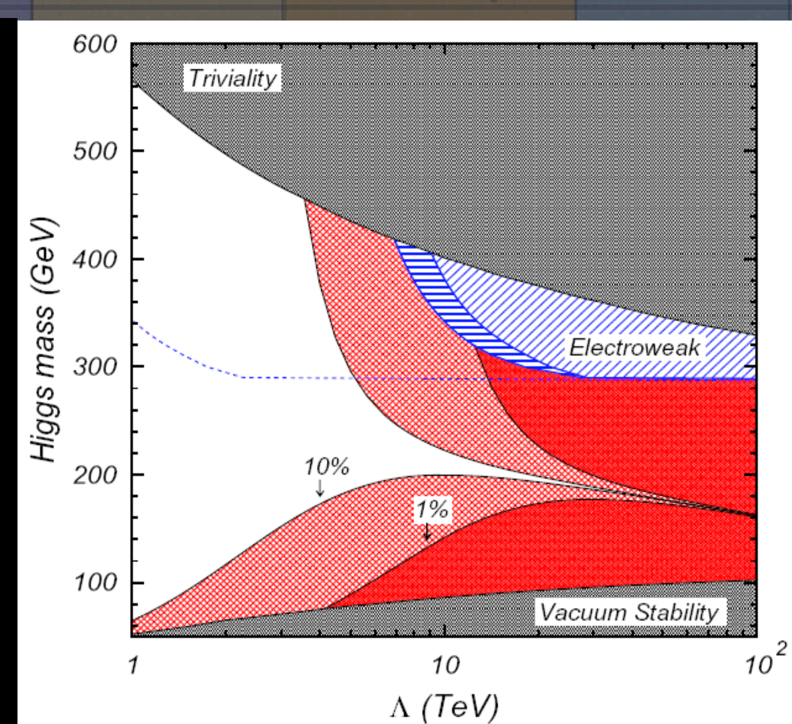

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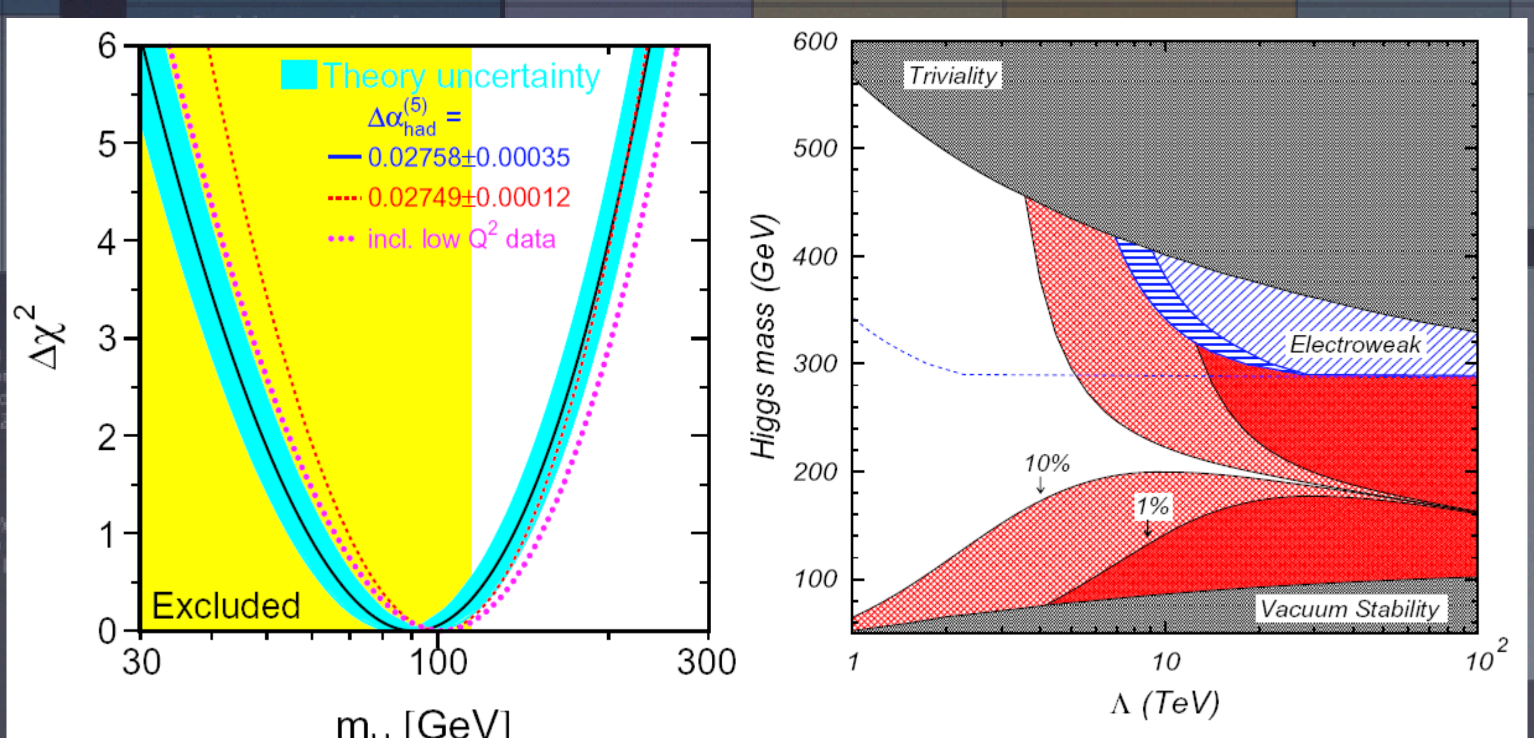

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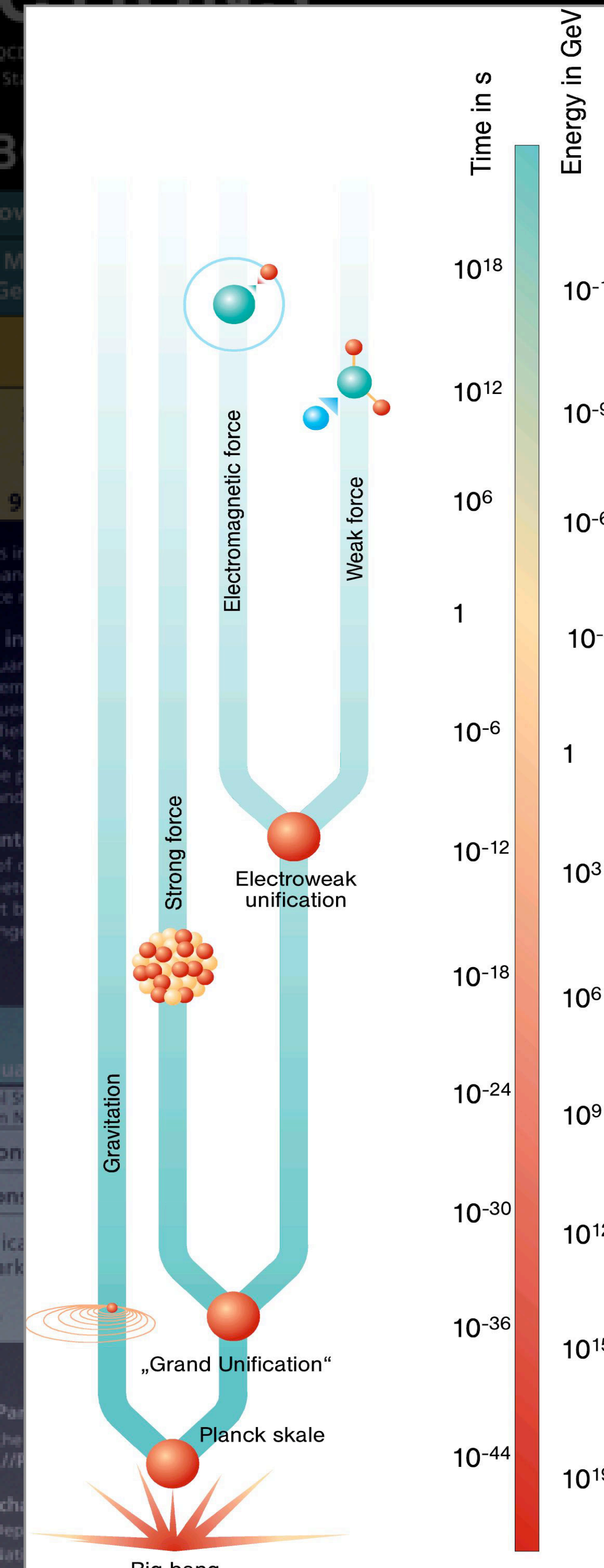

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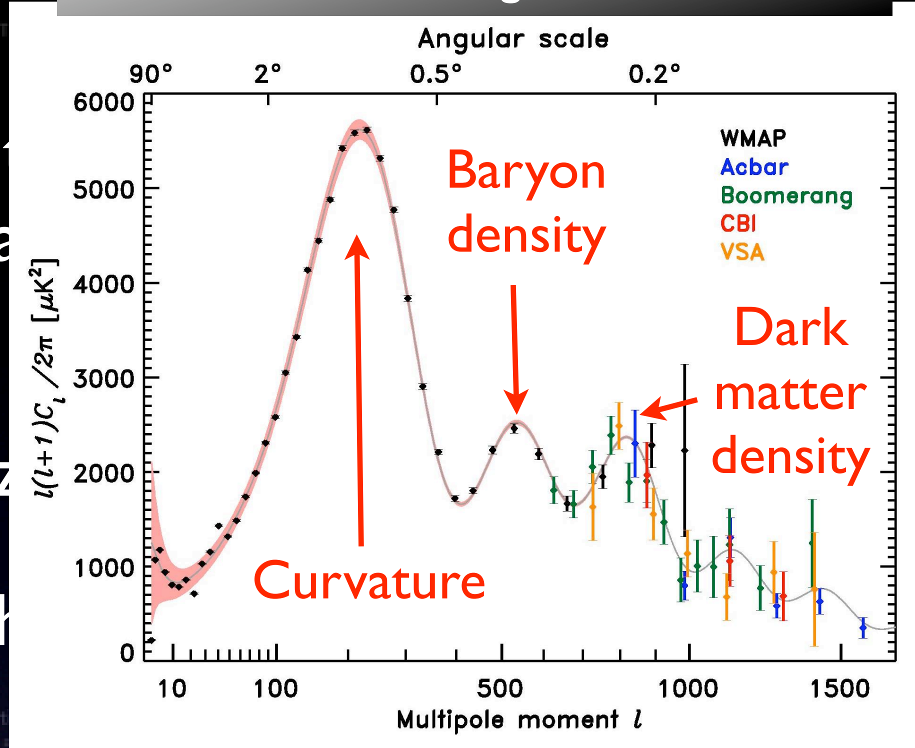
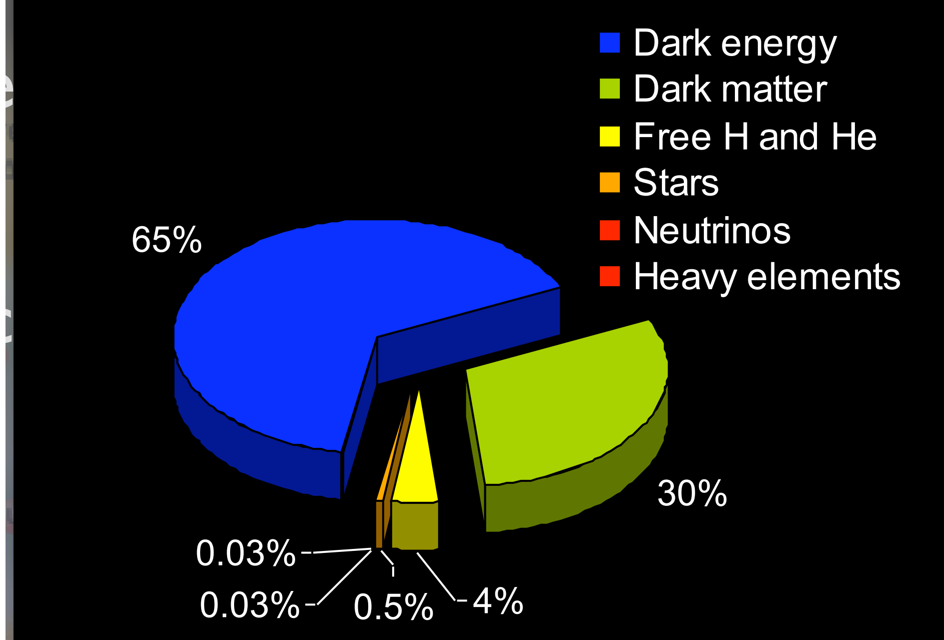
anisotropy of cosmic microwave background





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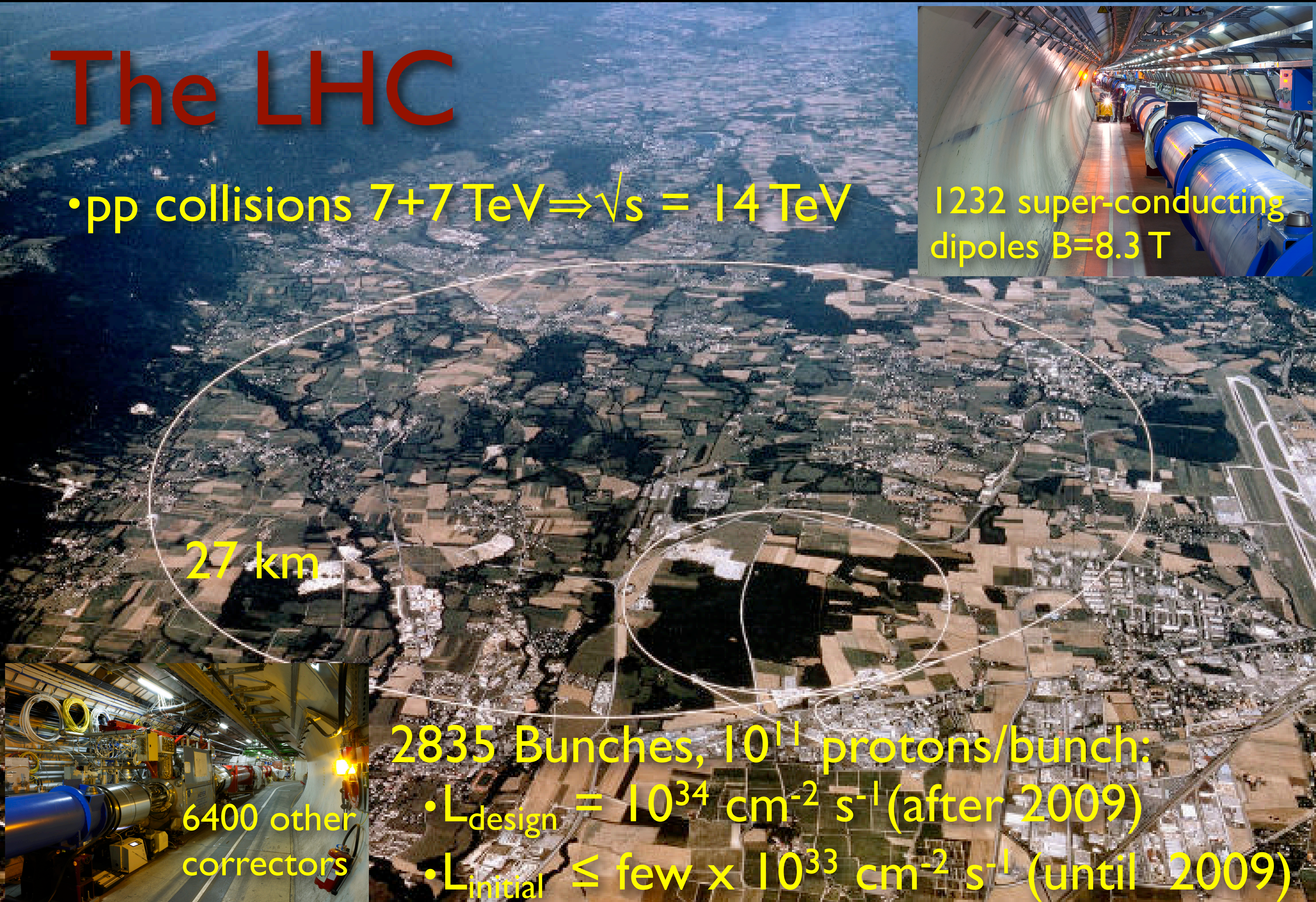
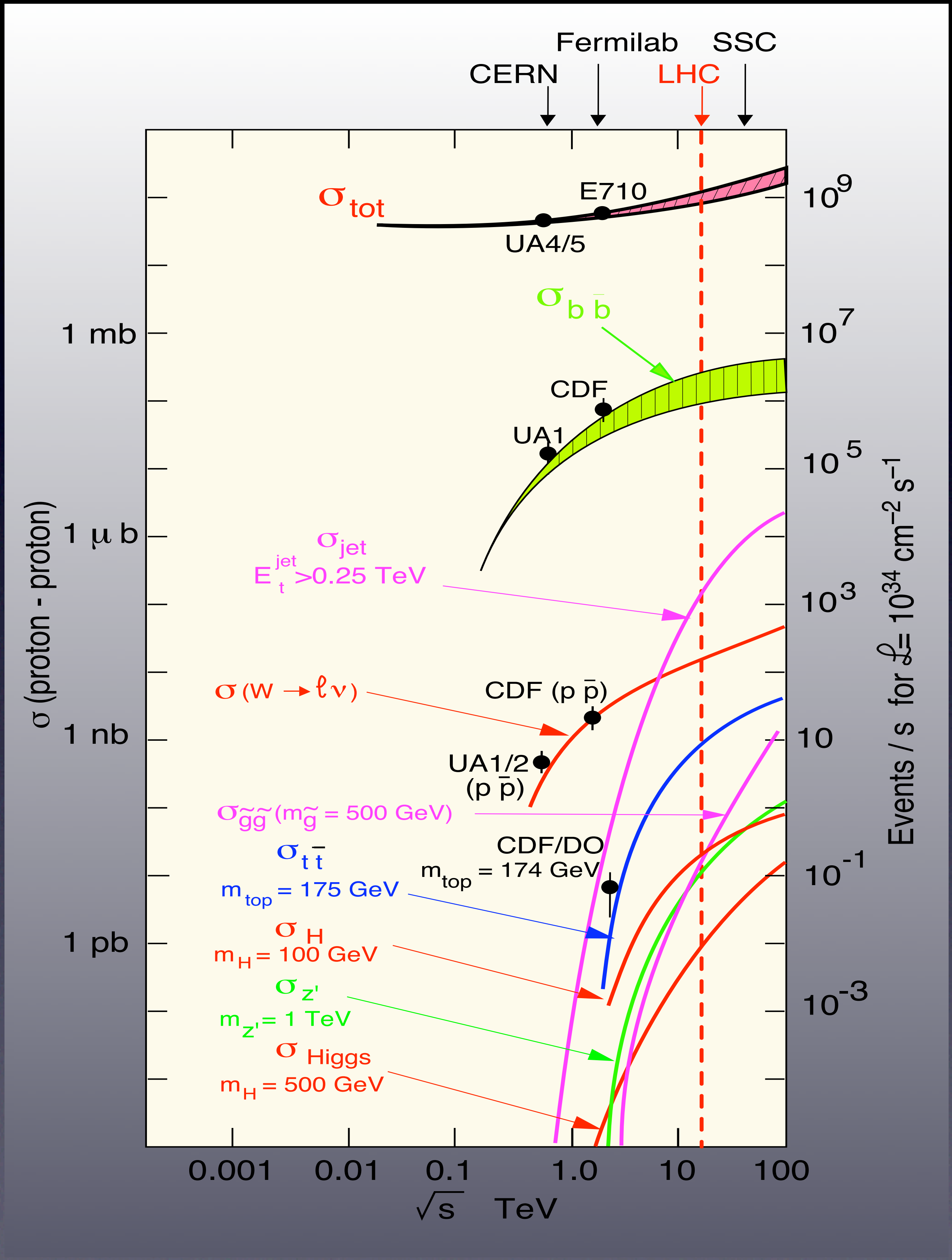
- Doesn't have enough CP violation (or Baryon # violation) for matter/anti-matter asymmetry in Universe.


The LHC
•pp collisions 7+7 TeV⇒√s = 14 TeV
1232 super-conducting
dipoles B=8.3 T
27 km
6400 other
correctors
2835 Bunches, 10^{11} protons/bunch:
•L_{design} = 10^{34} cm^{-2} s^{-1}(after 2009)
•$L_{initial}$ ≤ few x 10^{33} cm^{-2} s^{-1} (until 2009)

What will the LHC produce?

- Total σ(pp)~ 70mb at 14 TeV.
- At L=10^{34} cm^{-2} s^{-1}:
  - Beam crossing at 4 $\cdot 10^7$ Hz
  - 23 interactions/crossing ⇒ pp collisions at 10^9 Hz
  - W→lν, Z→ll ~10^2 Hz
  - top at 10 Hz
  - Higgs at 1- 10^{-1} Hz (m_H=100 - 600 GeV)
  - SUSY up to 10 Hz (depending on scale)



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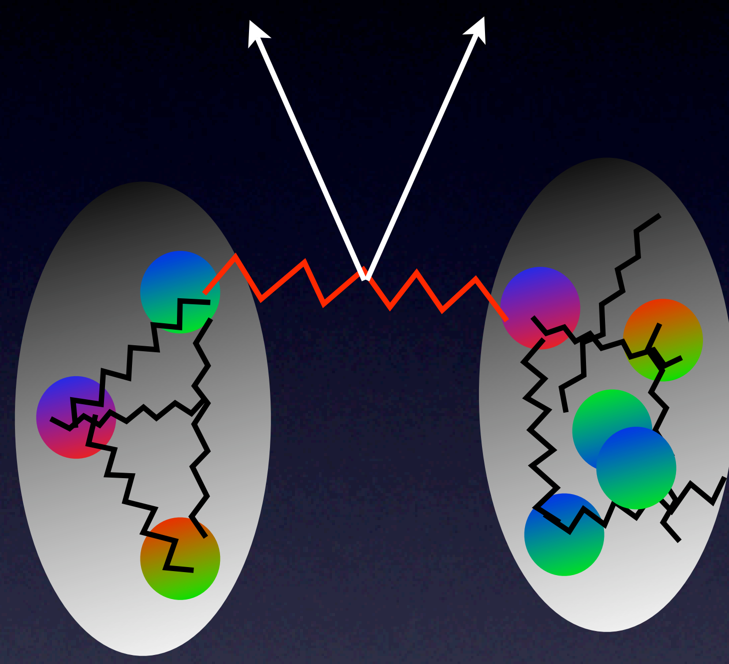

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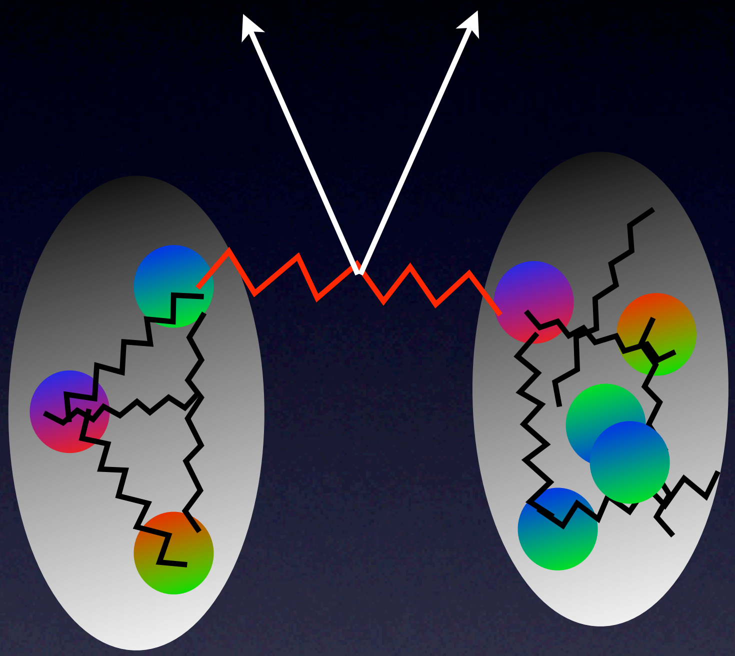

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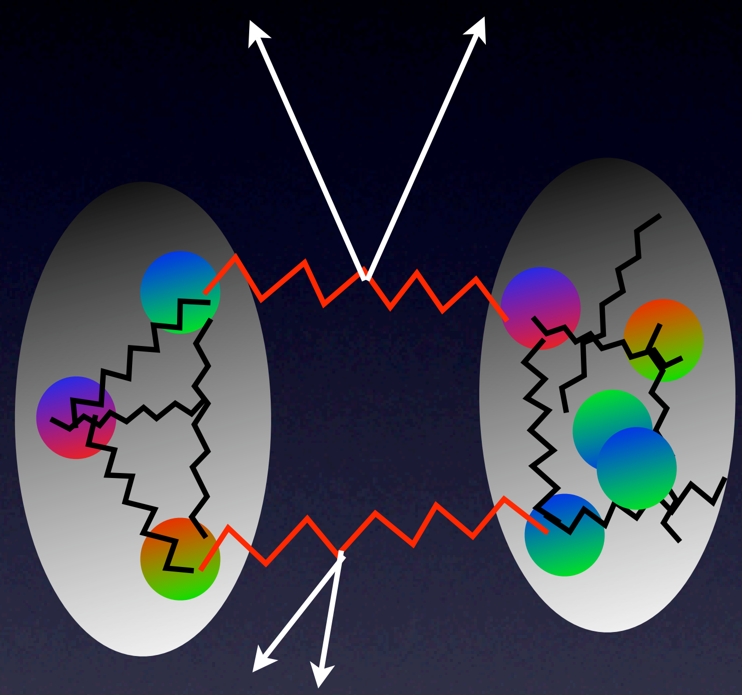

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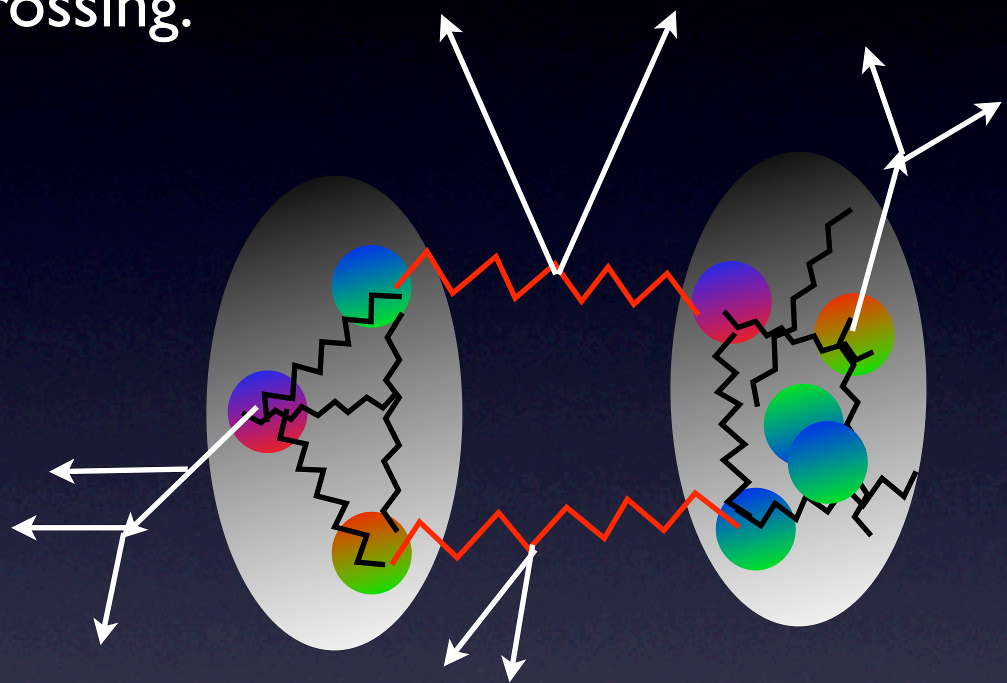

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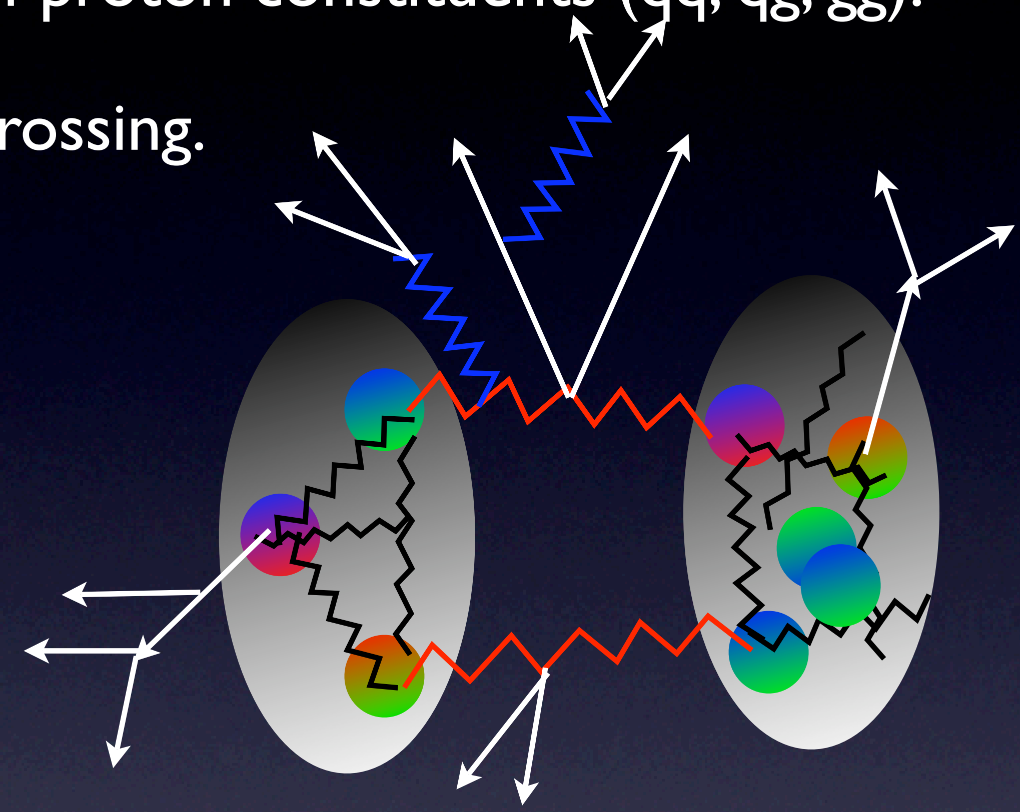
  - Initial/Final State radiation



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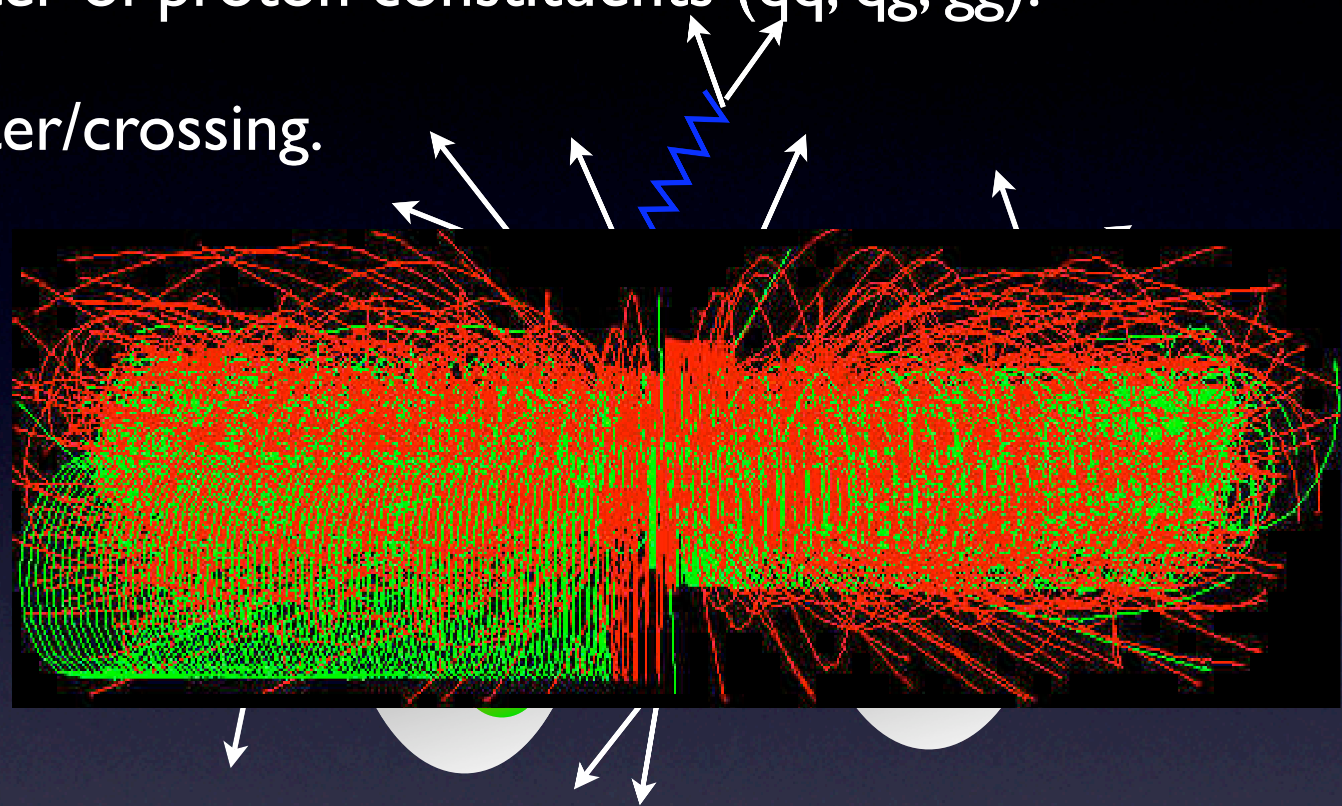

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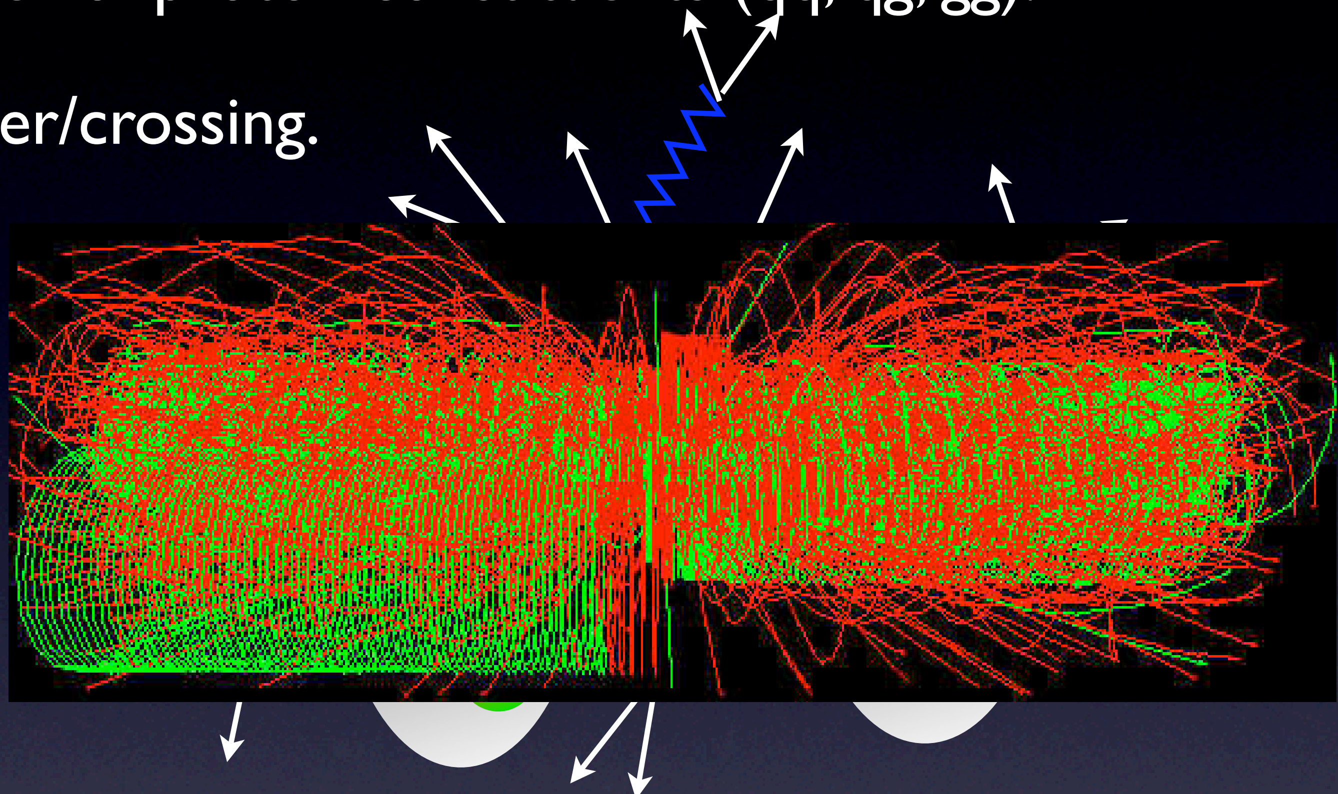

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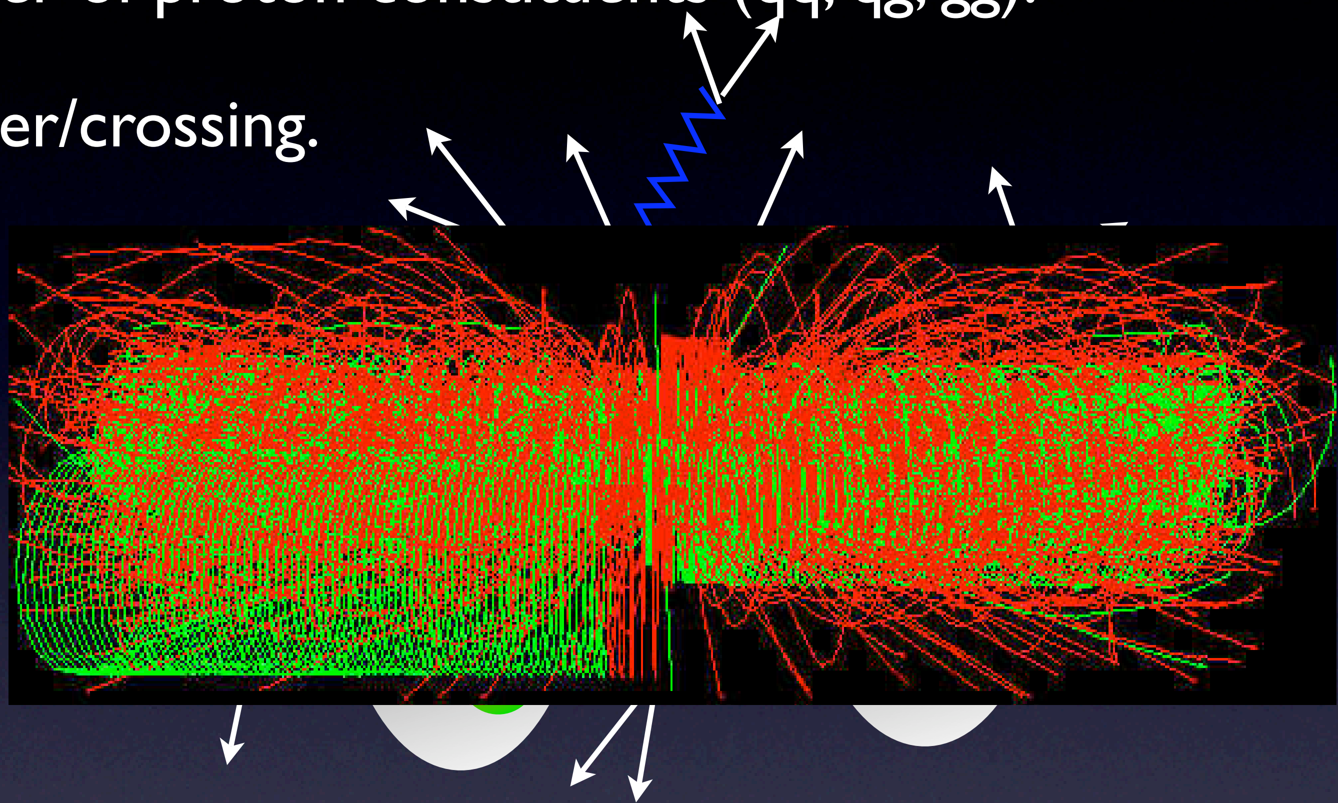

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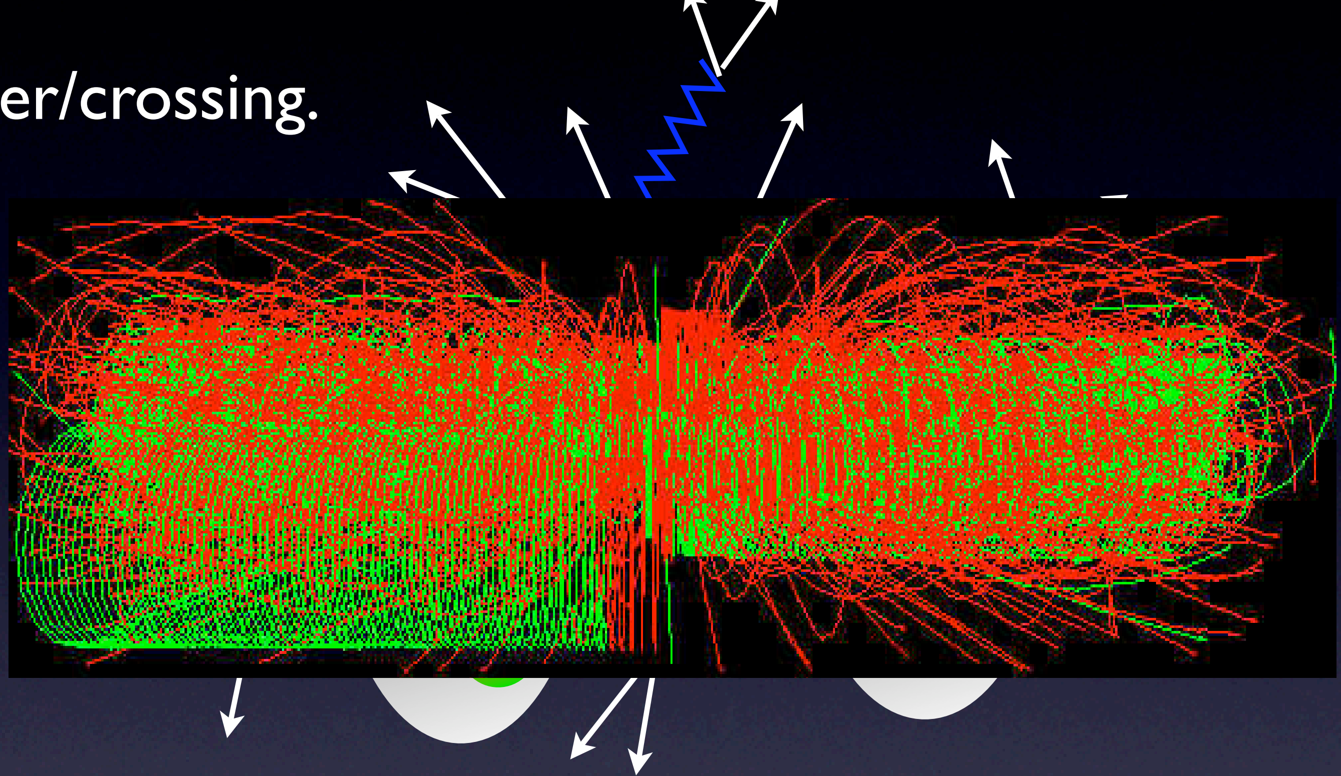

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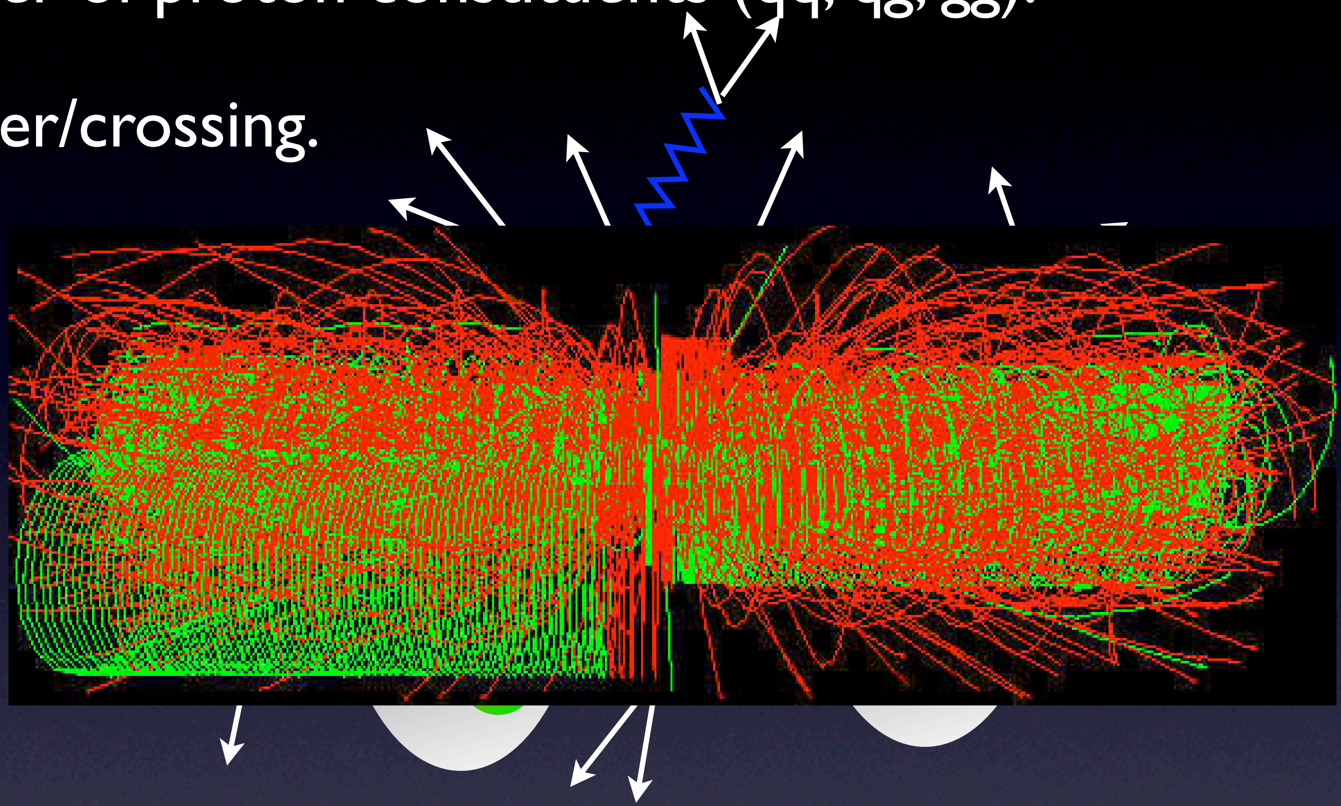

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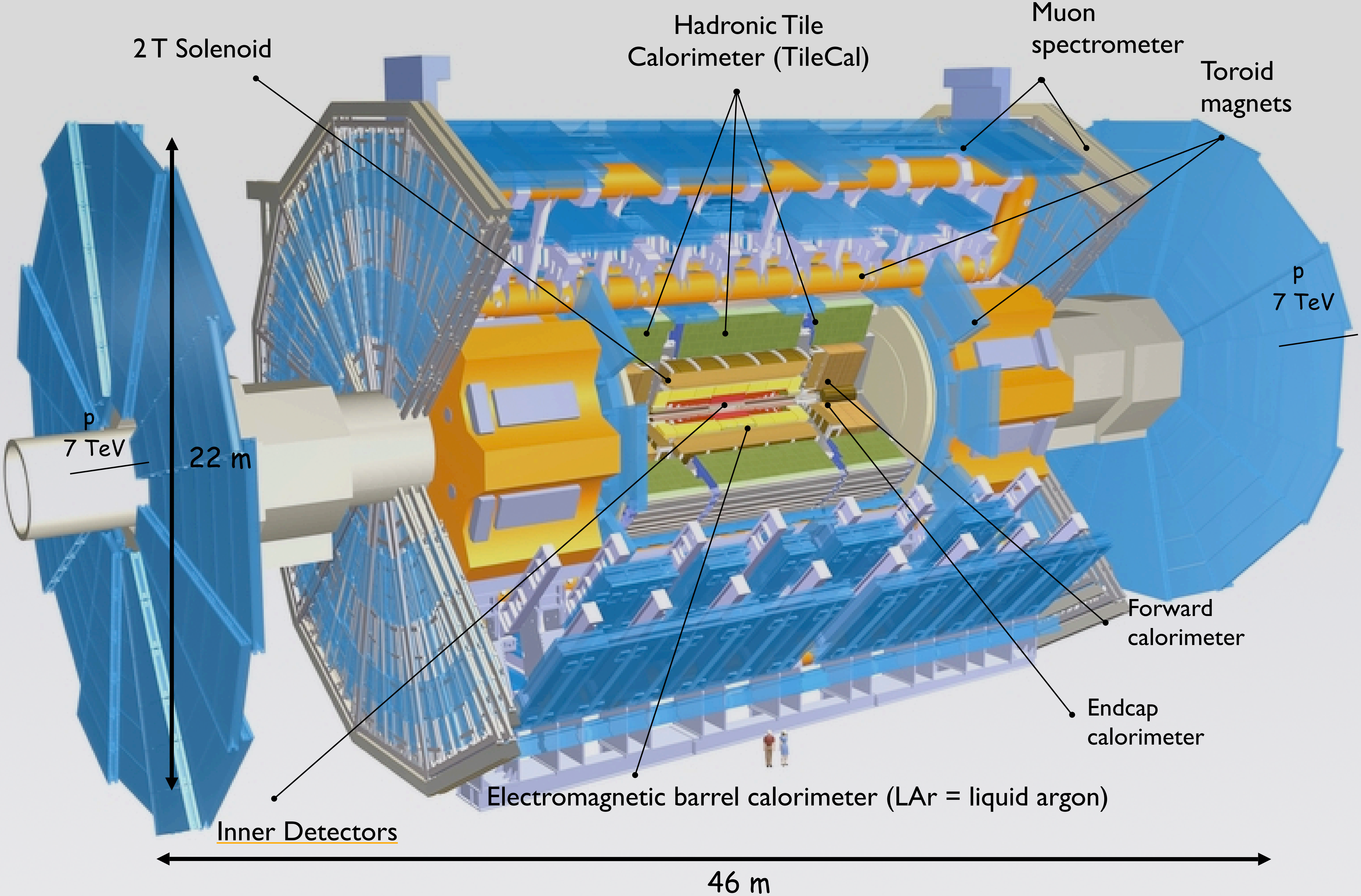
Pileup

➡ Detector: Needs fast response (to catch everything), highly granularity (minimize overlap), radiation hardness (survive 10 years)...

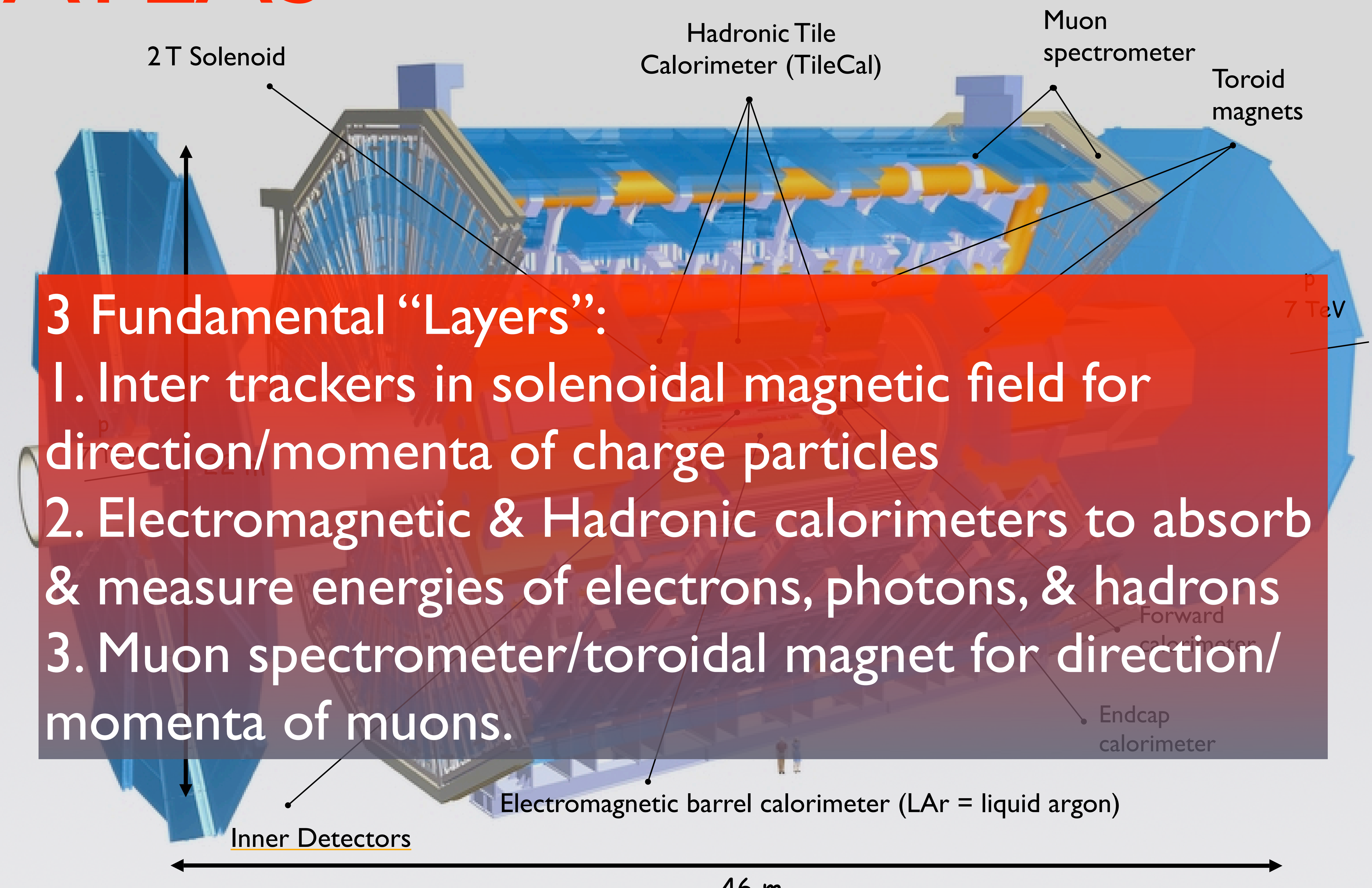
➡ Analysis: Need to properly account for minimum bias and underlying event (specifically Jets)

ATLAS



Total mass ~ 7000 tonnes, installed 92 m underground.

ATLAS

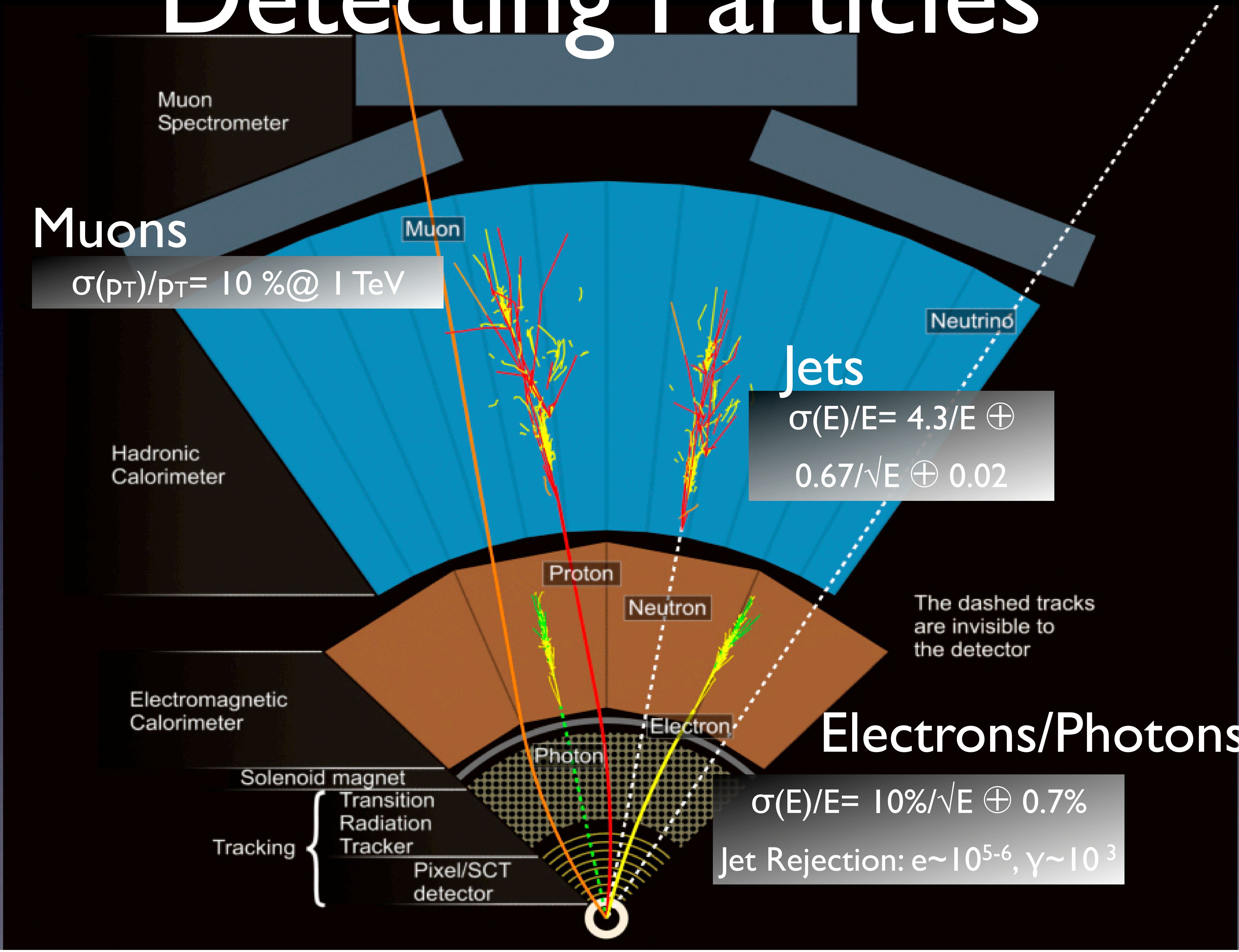


3 Fundamental "Layers":

1. Inter trackers in solenoidal magnetic field for direction/momenta of charge particles
2. Electromagnetic & Hadronic calorimeters to absorb & measure energies of electrons, photons, & hadrons
3. Muon spectrometer/toroidal magnet for direction/ momenta of muons.

Total mass ~ 7000 tonnes, installed 92 m underground.

Detecting Particles



Muons

$\sigma(p_T)/p_T = 10\,\%$@ 1 TeV

Jets

$\sigma(E)/E = 4.3/E \oplus 0.67/\sqrt{E} \oplus 0.02$

Electrons/Photons

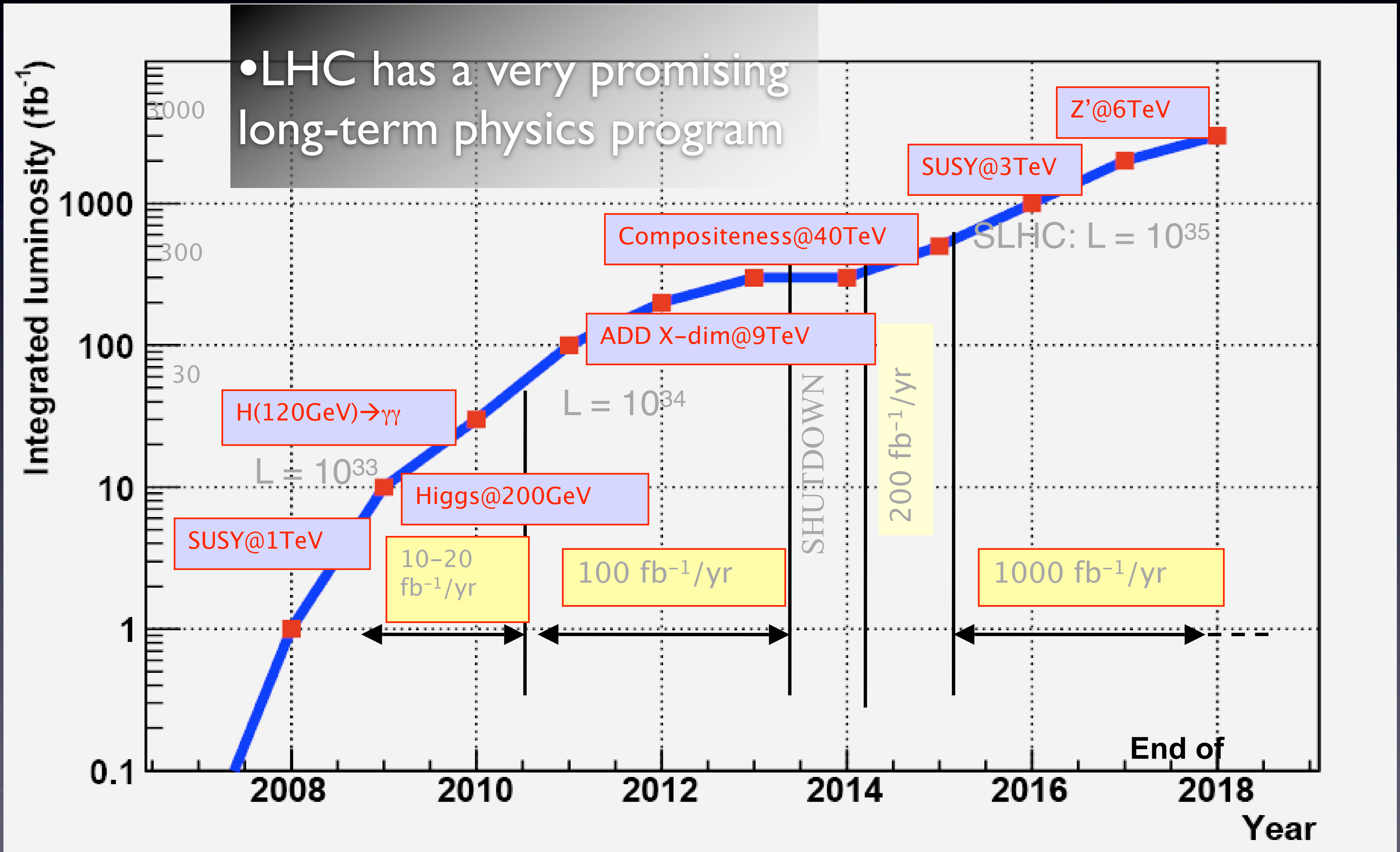
$\sigma(E)/E = 10\%/\sqrt{E} \oplus 0.7\%$

Jet Rejection: $e \sim 10^{5\text{-}6}$, $\gamma \sim 10^{3}$

LHC Schedule

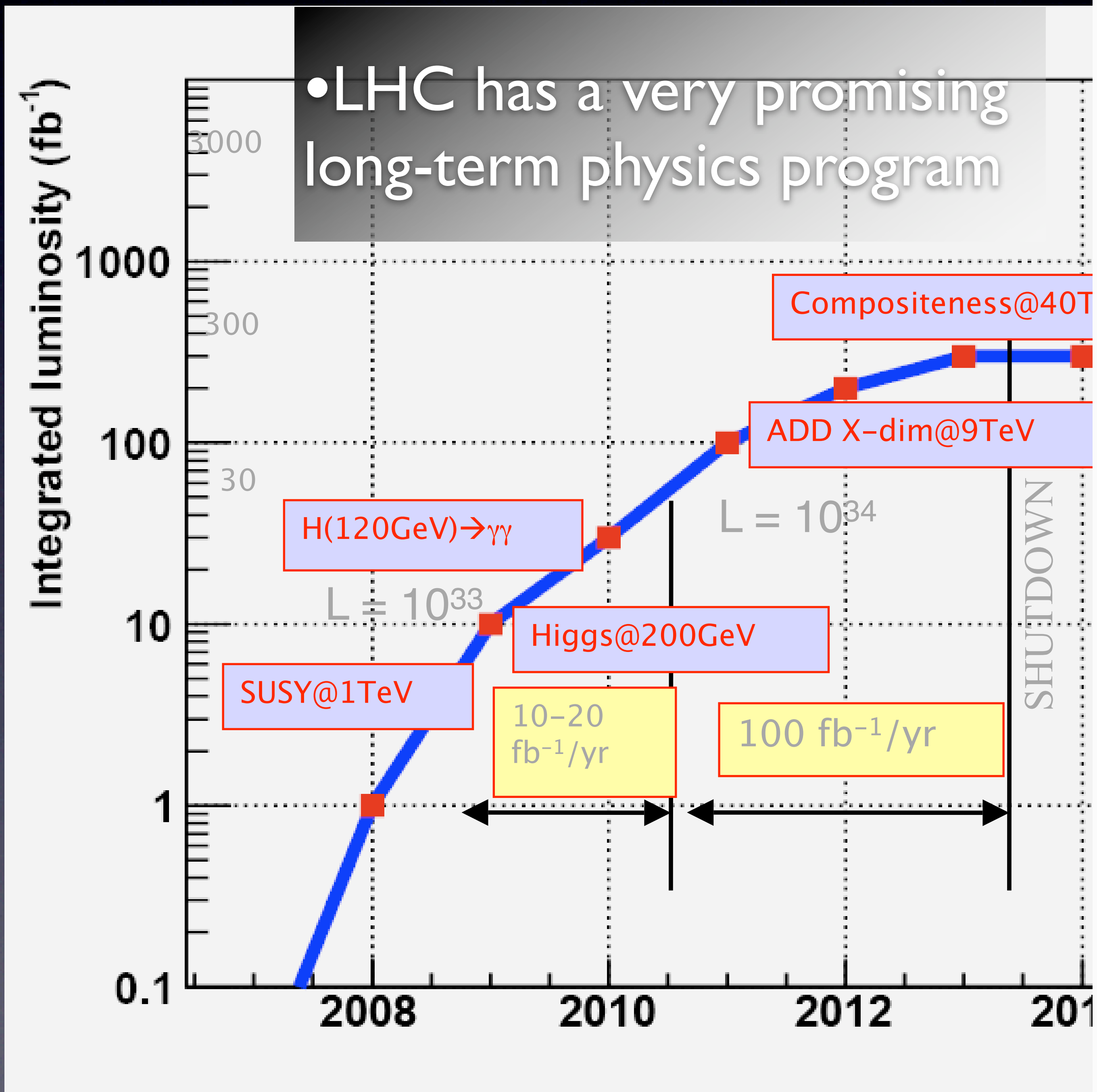
- This month: Last LHC Magnet will be installed
- End of summer: Machine+experiments closed
- Before end of 2007: First collisions $\sqrt{s}$=900 GeV, L~10^{29} cm^{-2} s^{-1}
- Summer 2008: $\sqrt{s}$ = 14 TeV, Goal: L=10^{32} cm^{-2} s^{-1} (6 months for 1 fb^{-1})
- Work towards L=10^{33} cm^{-2} s^{-1} $\Rightarrow$ Low Luminosity Run: 10-20 fb^{-1}/year
- 2010: L=10^{34} cm^{-2} $s^{-1}$$\Rightarrow$High Luminosity Run: ideally 100 fb^{-1}/year

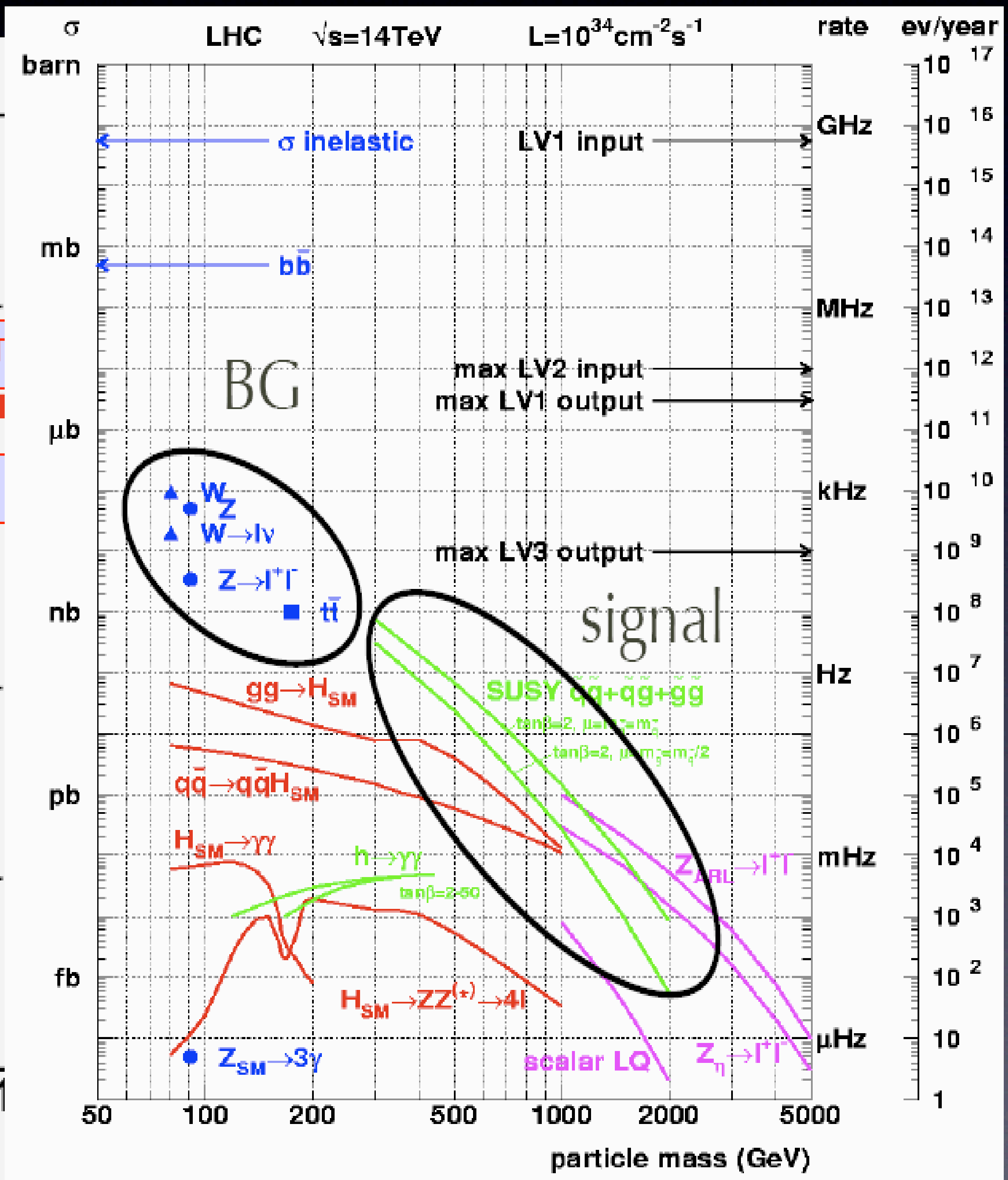
New Physics Discovery in 2008?



New Physics Discovery in 2008?

- LHC has a very promising long-term physics program





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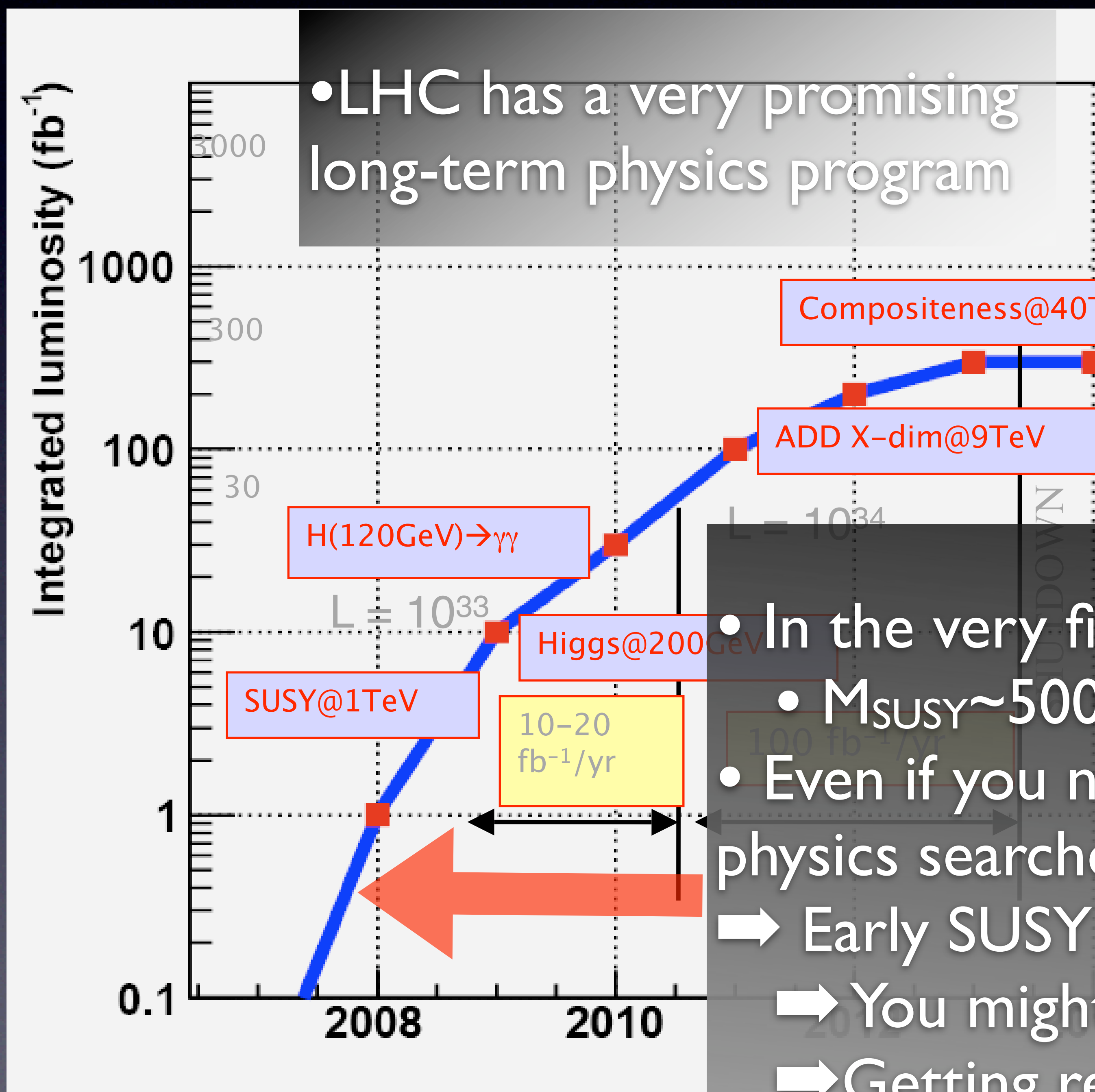

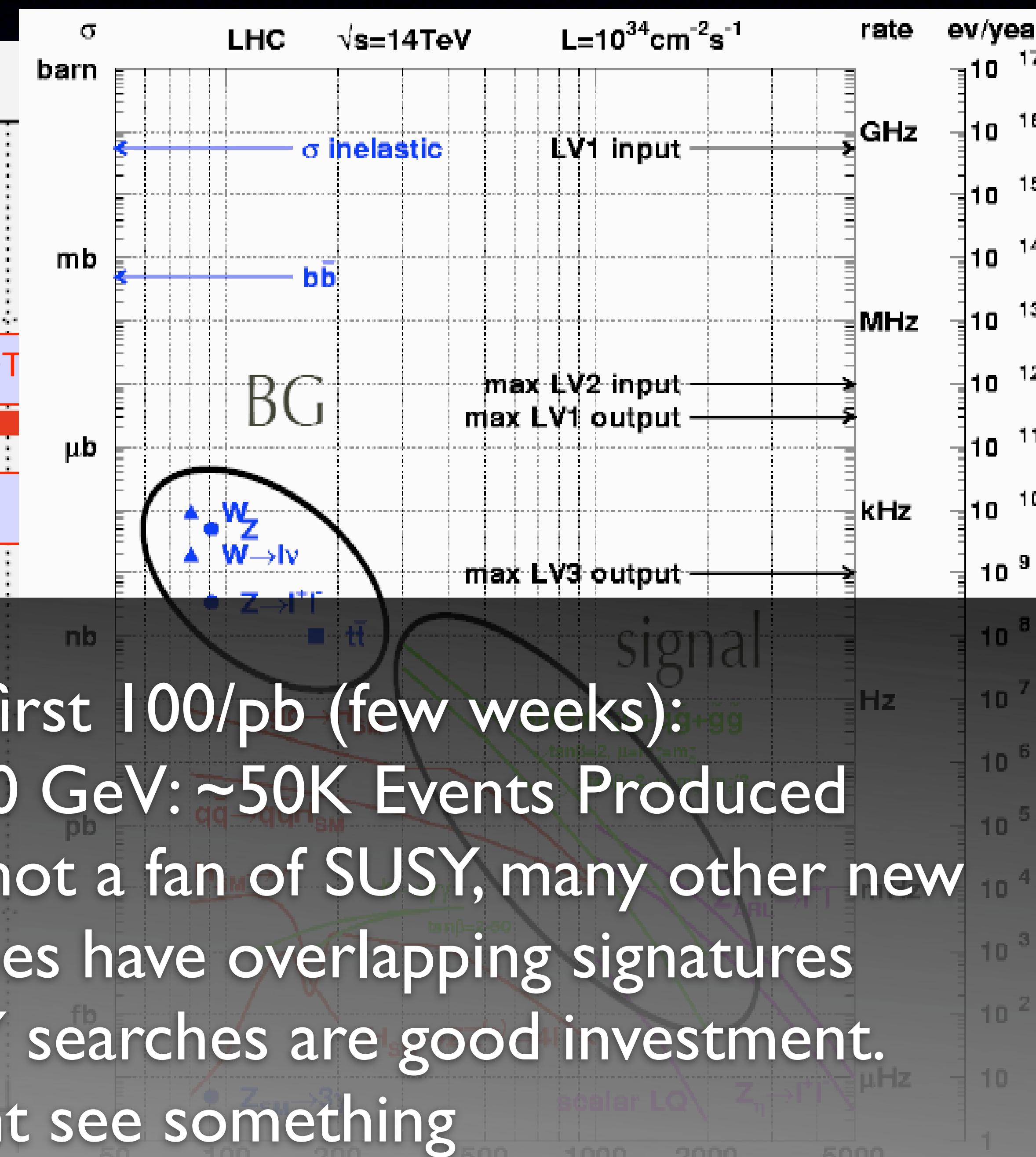

•LHC has a very promising long-term physics program

- In the very first 100/pb (few weeks):
  - M_{SUSY}~500 GeV: ~50K Events Produced
- Even if you not a fan of SUSY, many other new physics searches have overlapping signatures

➡ Early SUSY searches are good investment.

➡ You might see something

➡Getting ready for other interesting things

Looking for SUSY in early LHC data

SUSY Motivation

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SM

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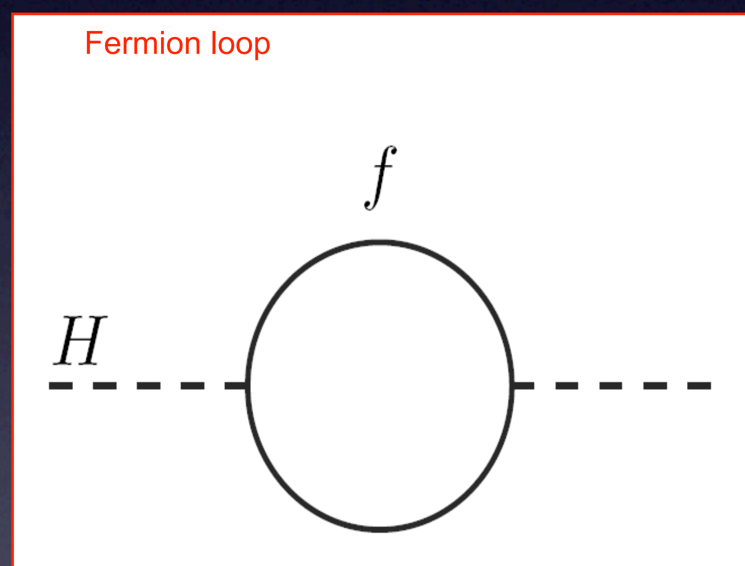

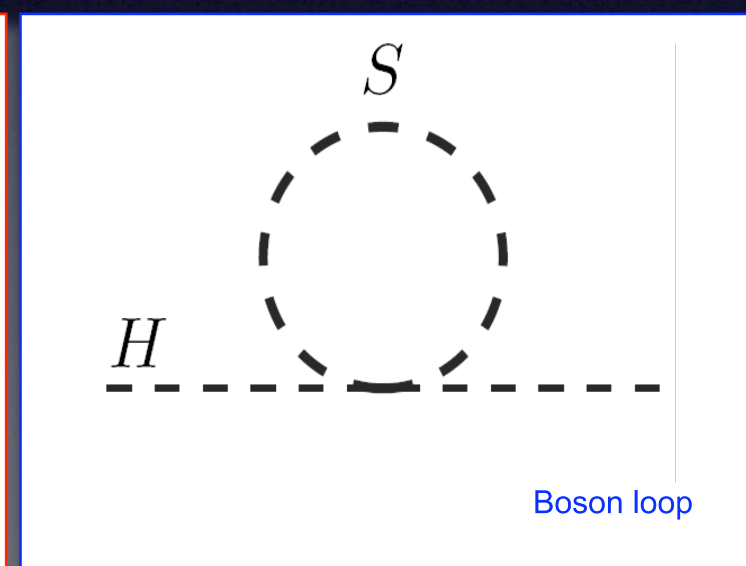

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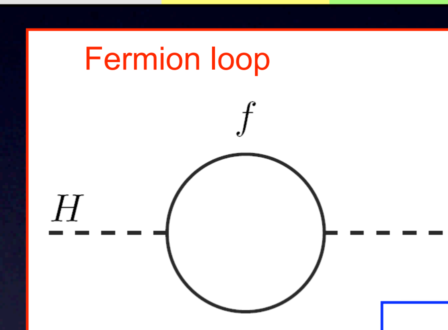

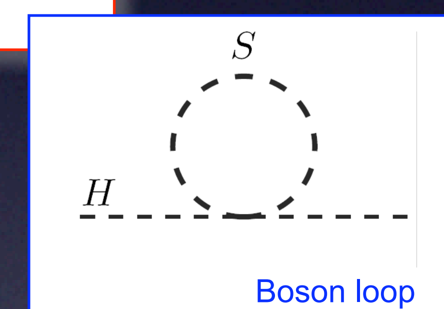

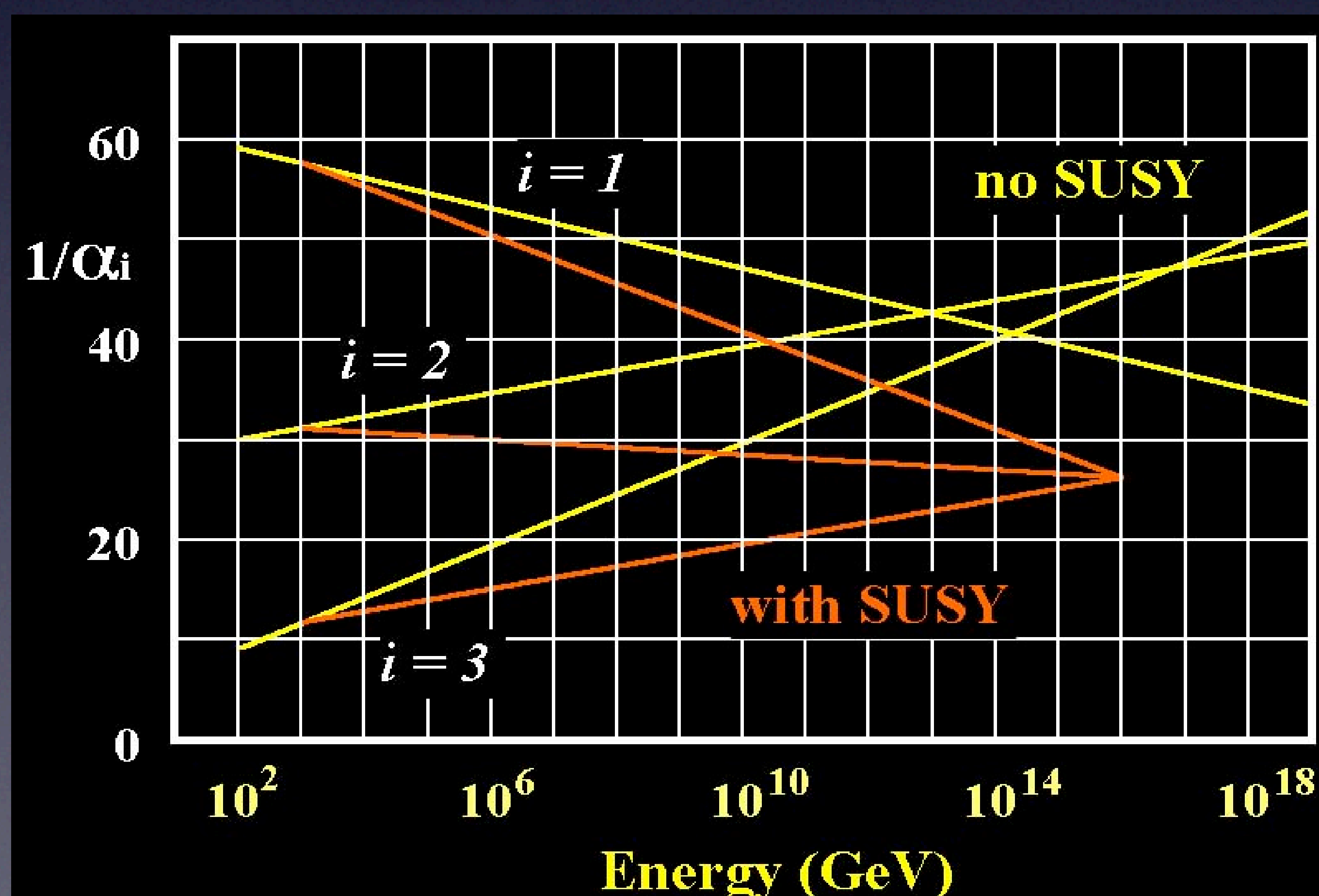

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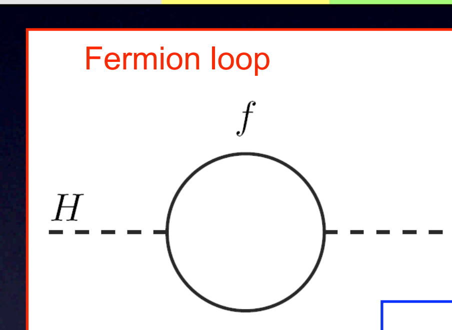

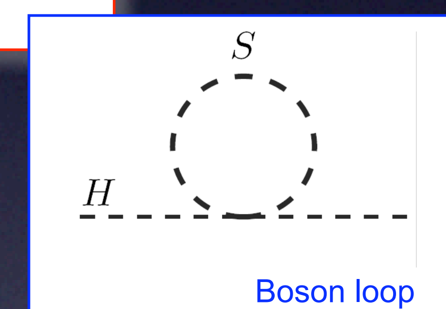

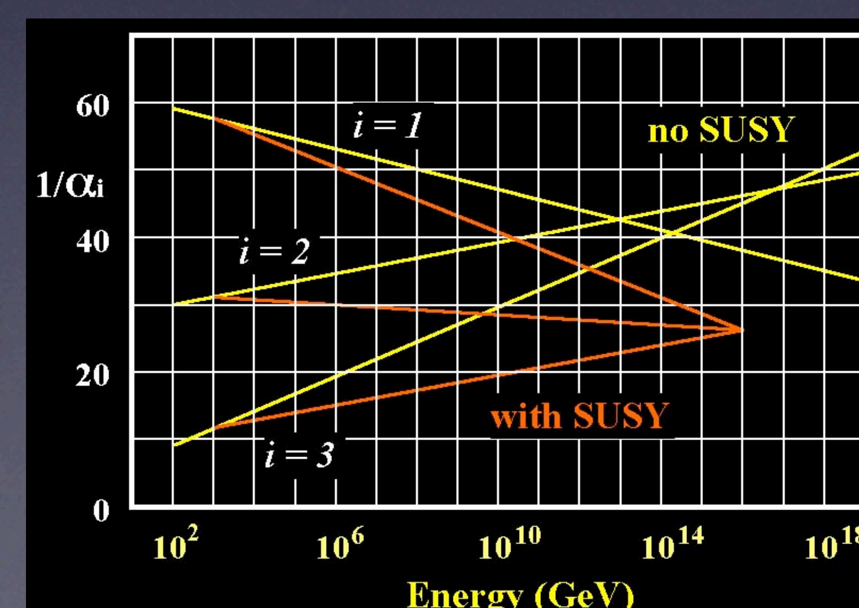

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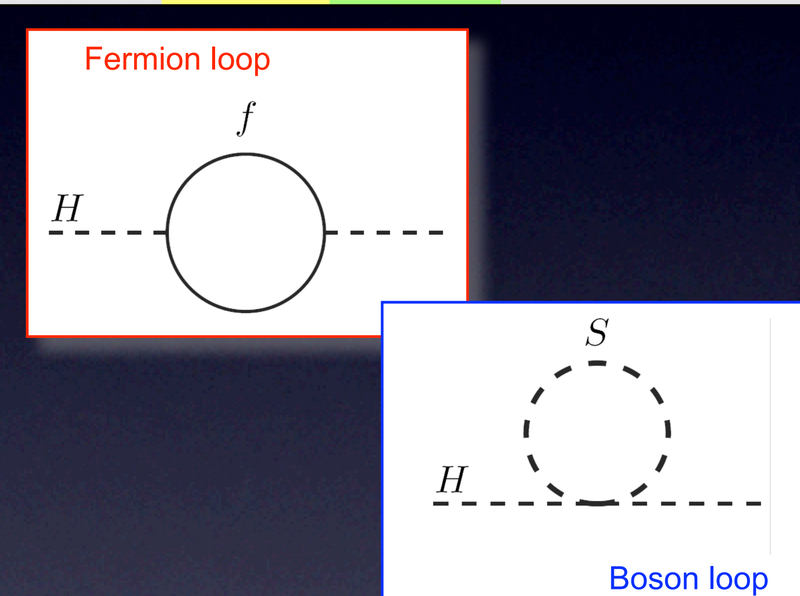

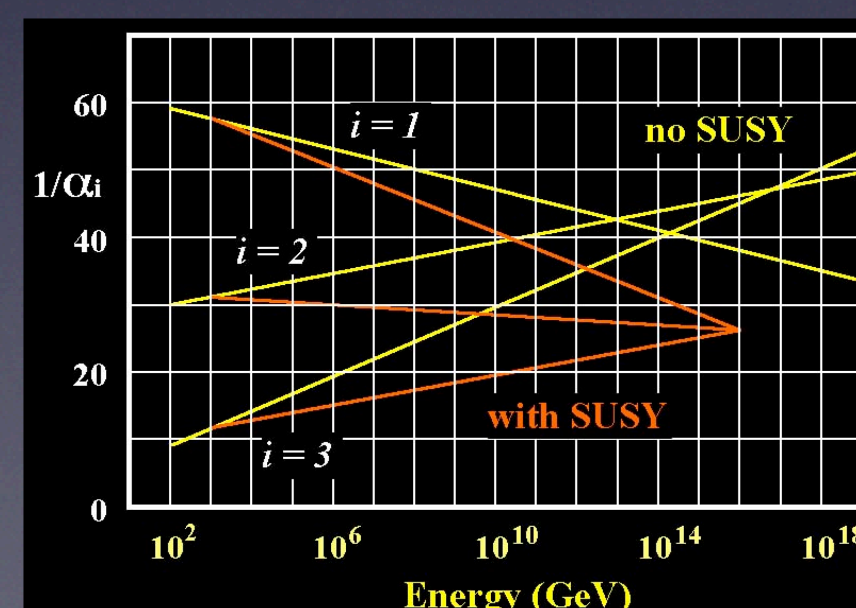

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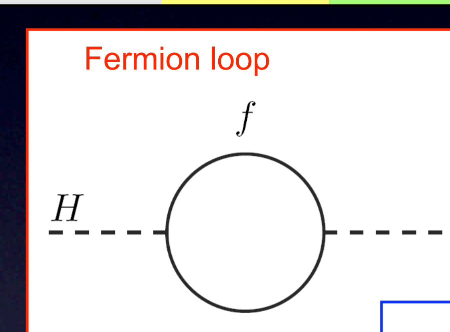

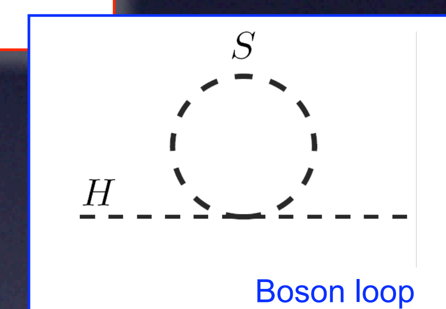

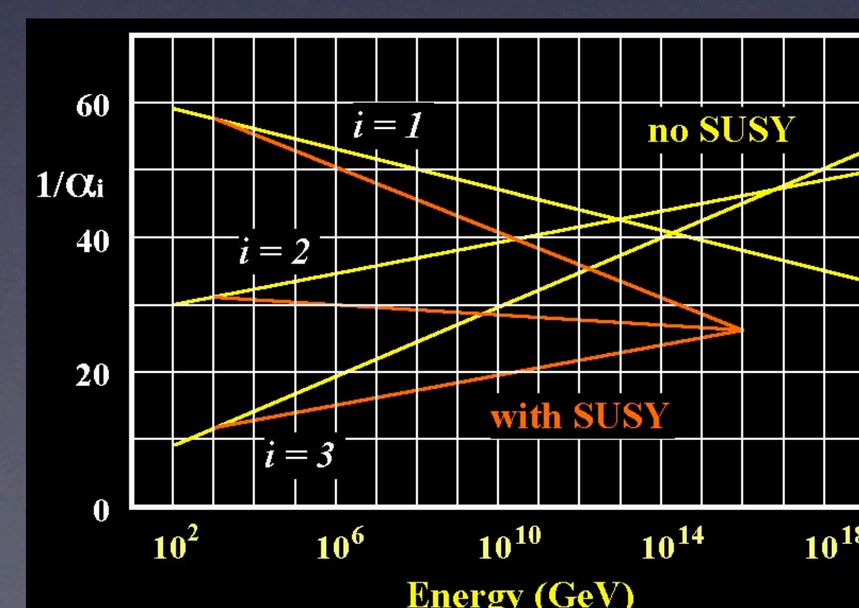

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- Note: no explanation of the origin of SM parameters (masses, CP), or neutrino masses.

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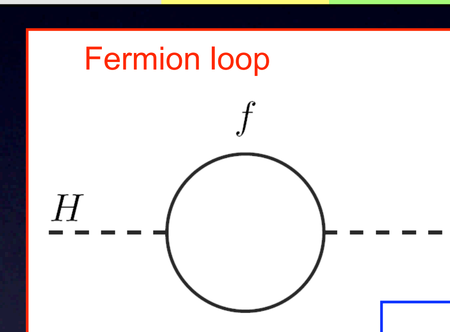
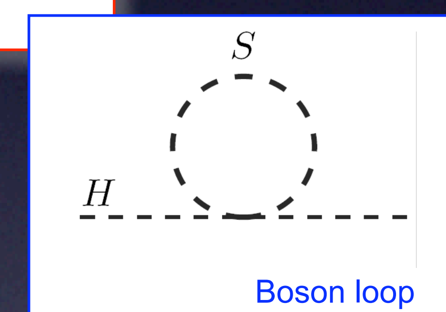
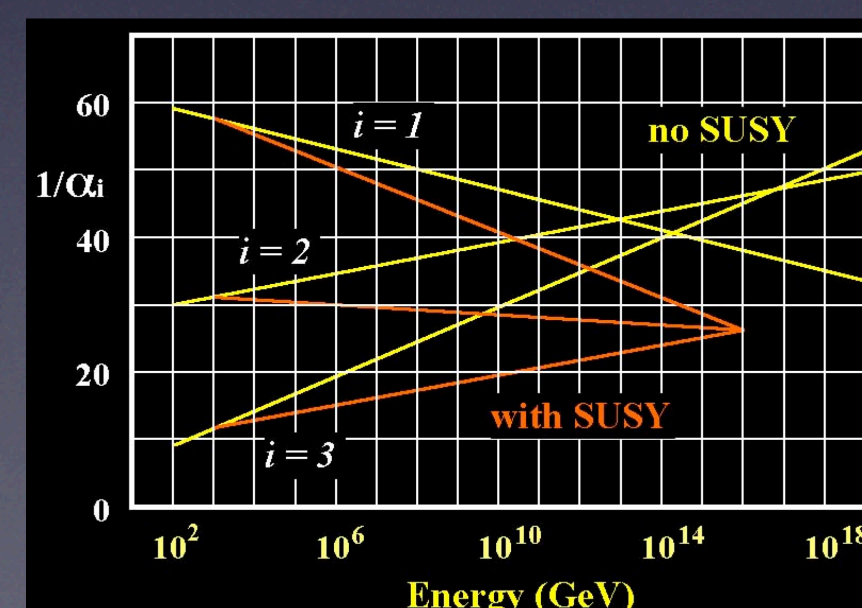




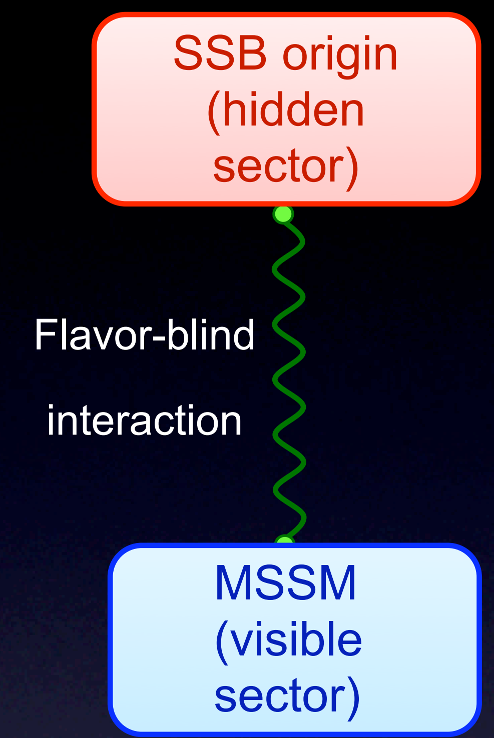


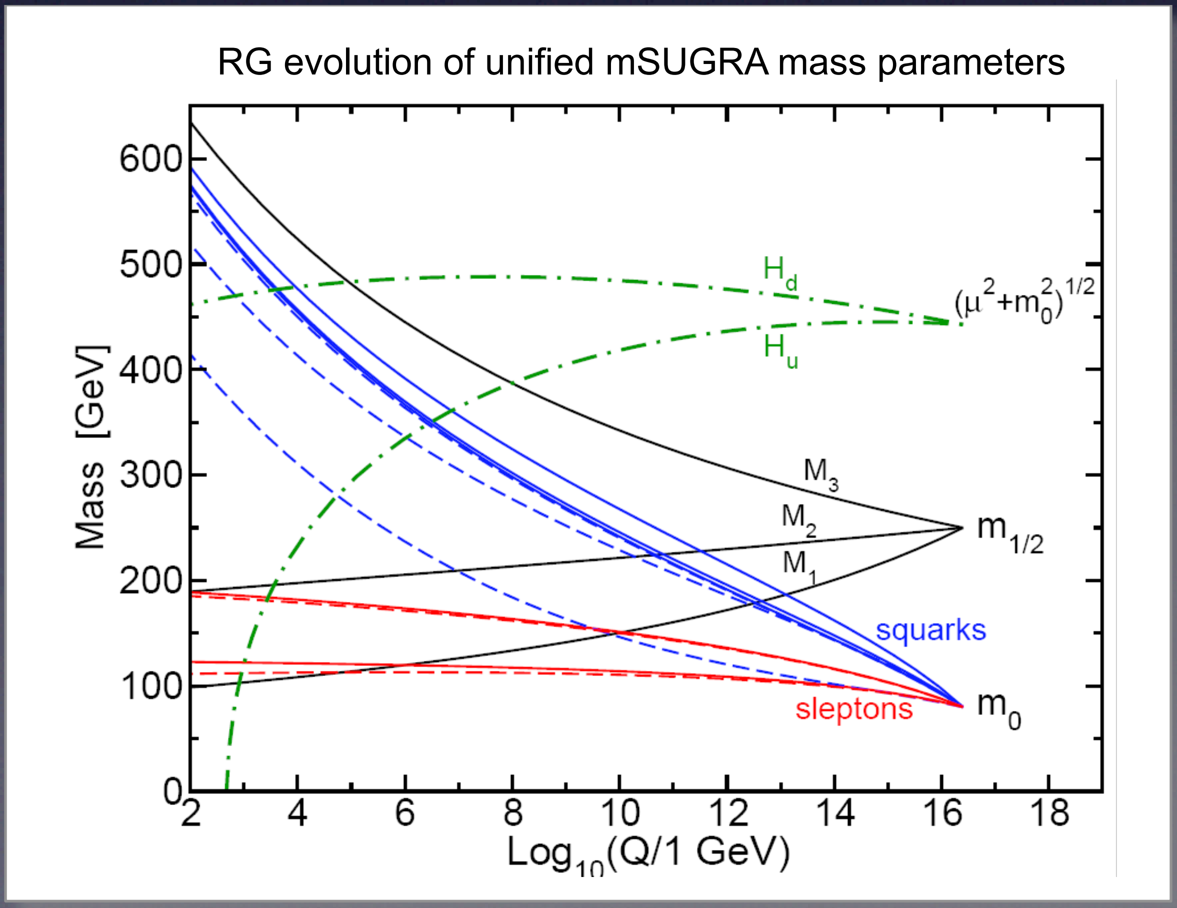
SUSY Phenomenology

- No scalar electron partner ⇒ SUSY broken
- If want SUSY to preseve EW naturalness ⇒

  SUSY broken in hidden sector at scale $F < M_{Pl}$
- SUSY has 105 parameters...
- Some SUSY Breaking Models take parameters to a practical handful, example:
  - Minimal Gravity Mediated (mSUGRA): m_0, $m_{1/2}$, sig(μ), tan β, A_0

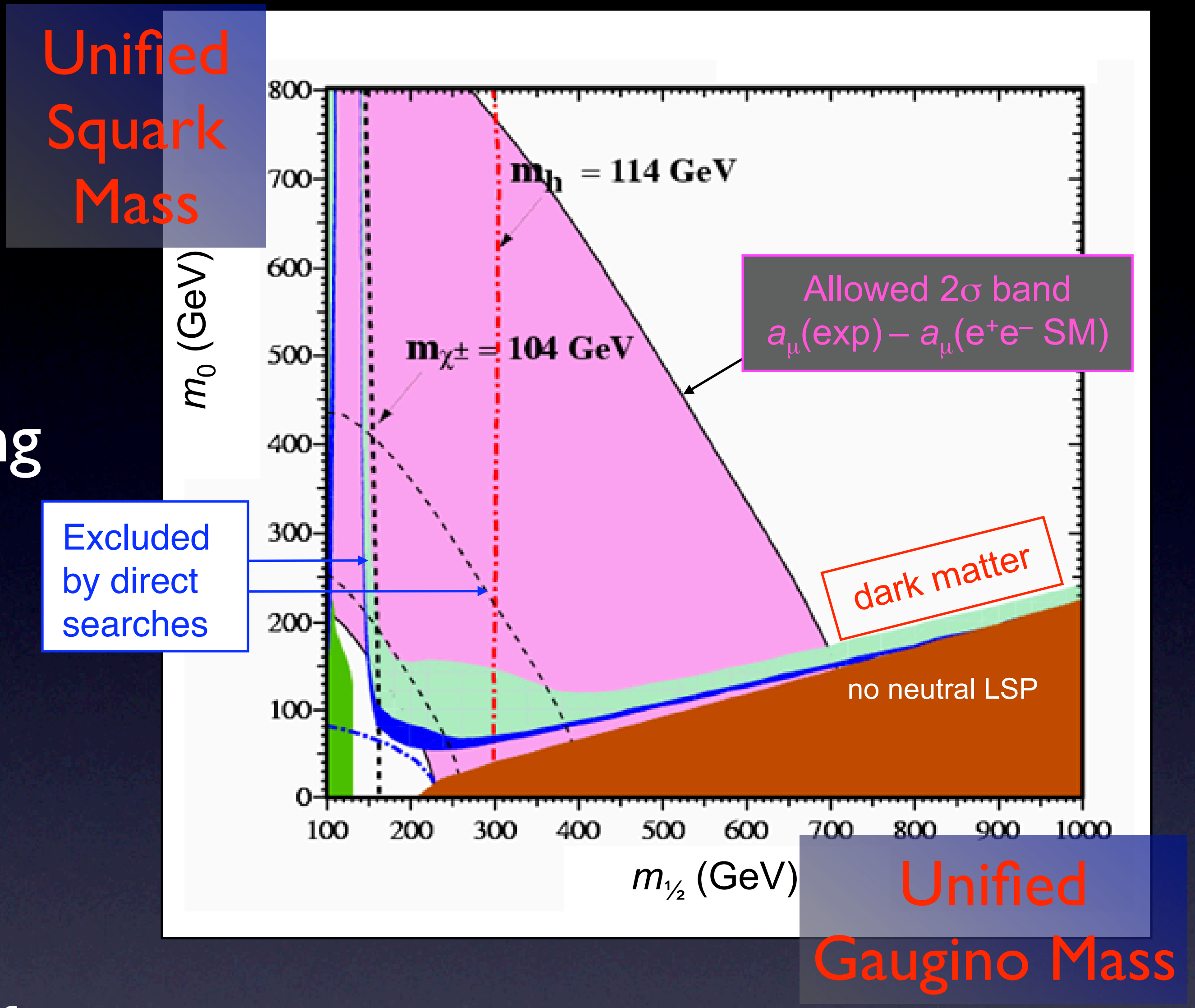
  ➡ Just a useful framework for searches
- R-Parity = +1 (-1) for SM (SUSY) particles
  - RPC: no proton decay, dark matter (LSP), SUSY produced in pairs
  - RPV: Lose MET signature... wide-array of couplings (production) in different models





Looking for SUSY

- Constrains on SUSY come from:
  - From cosmology: cold dark matter density
  - Direct Accelerator Searches: looking for sparticles
  - Indirect Accelerator Searches:
    - Precision Electroweak: W mass, weak mixing angle
    - Anomalous magnetic moment of muon (g-2)
    - Studying flavor-changing neutral currents: eg b→sγ
- Generally speaking, setting SUSY limits require assuming some breaking model

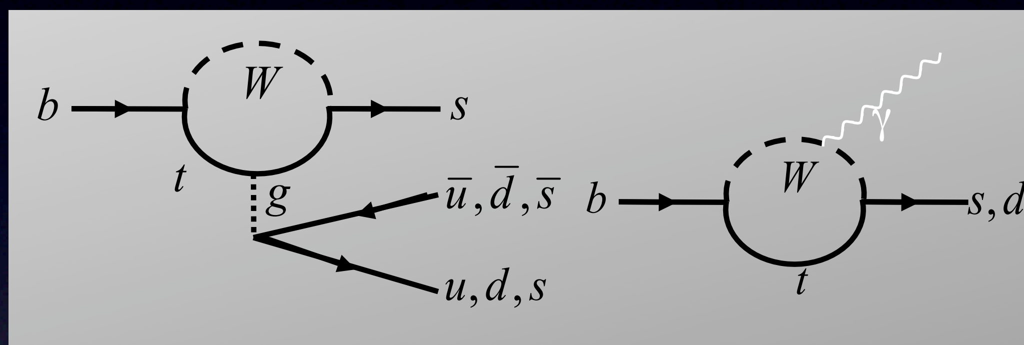


- For example, mSUGRA's five parameters are very constraining...
- But the parameter/model space so large that it difficult to rule out SUSY

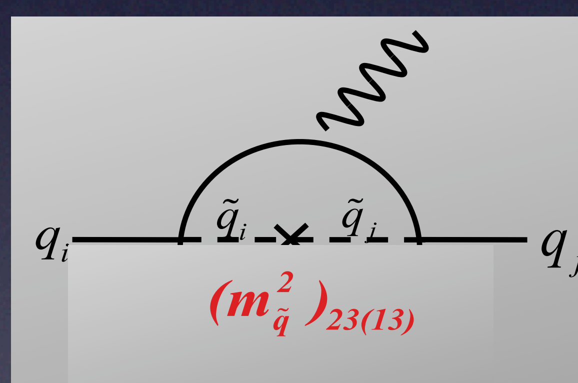
Digression

Indirect SUSY Searches with B mesons

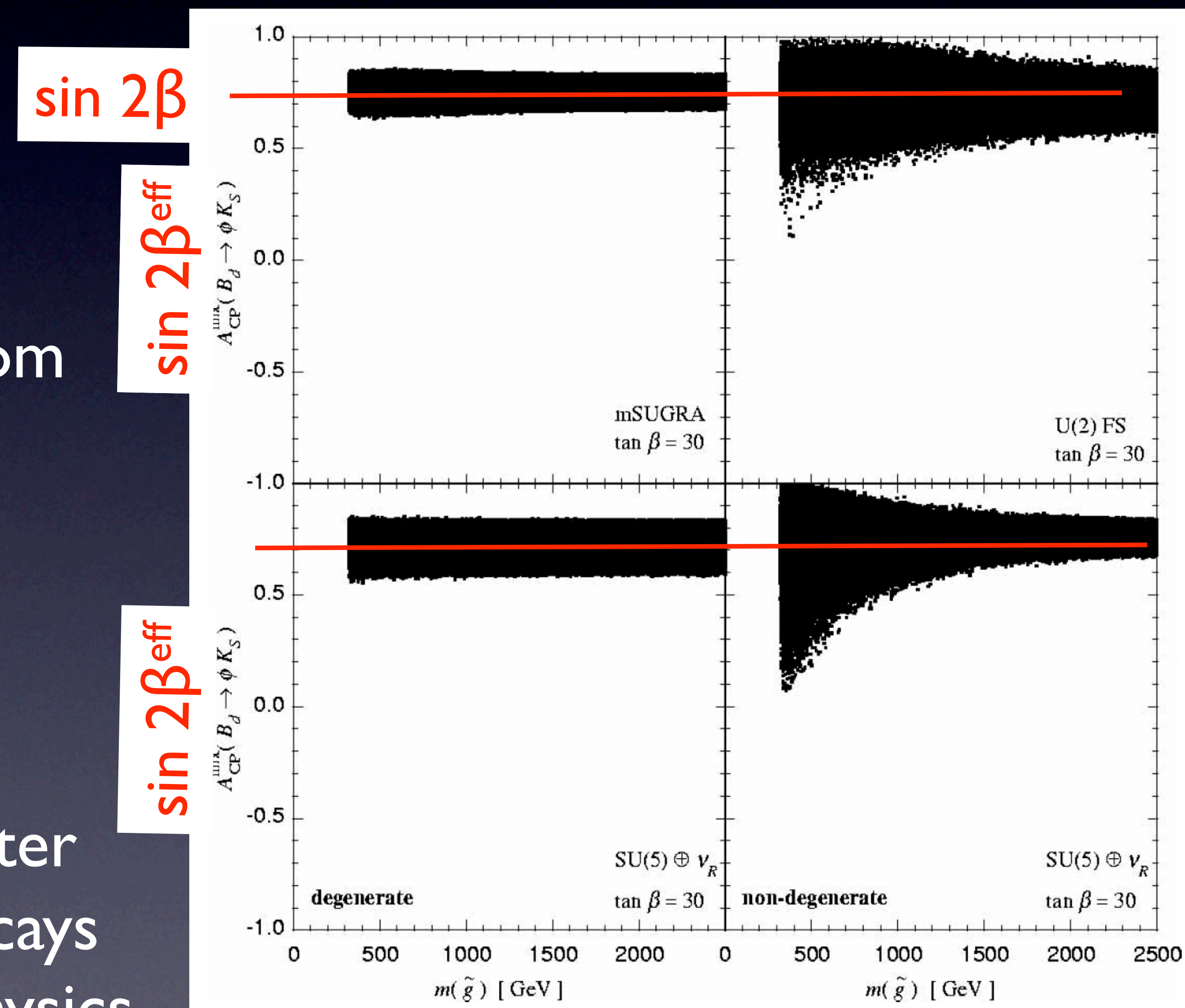
- FCNC: Loop dominated B-decays:



- Can get additional contributions from SUSY:



- Resulting in CKM Unitarity parameter sin $2\beta^{eff}$ from loop-dominated B decays ≠ sin 2β from tree decays if new physics contributes.



Digression

Indirect SUSY Searches with B mesons

- FCNC: Loop dominated B-decays:

• Potential for discovery of new physics in such measurements were a key motivation for the impressive B physics programs of the recent past.

• The observed consistencies with SM tells us about the flavor-structure of new physics...

• Future B physics (eg LHCb, super B-factories) important compliment to any discovery at LHC... allow differentiation different models.

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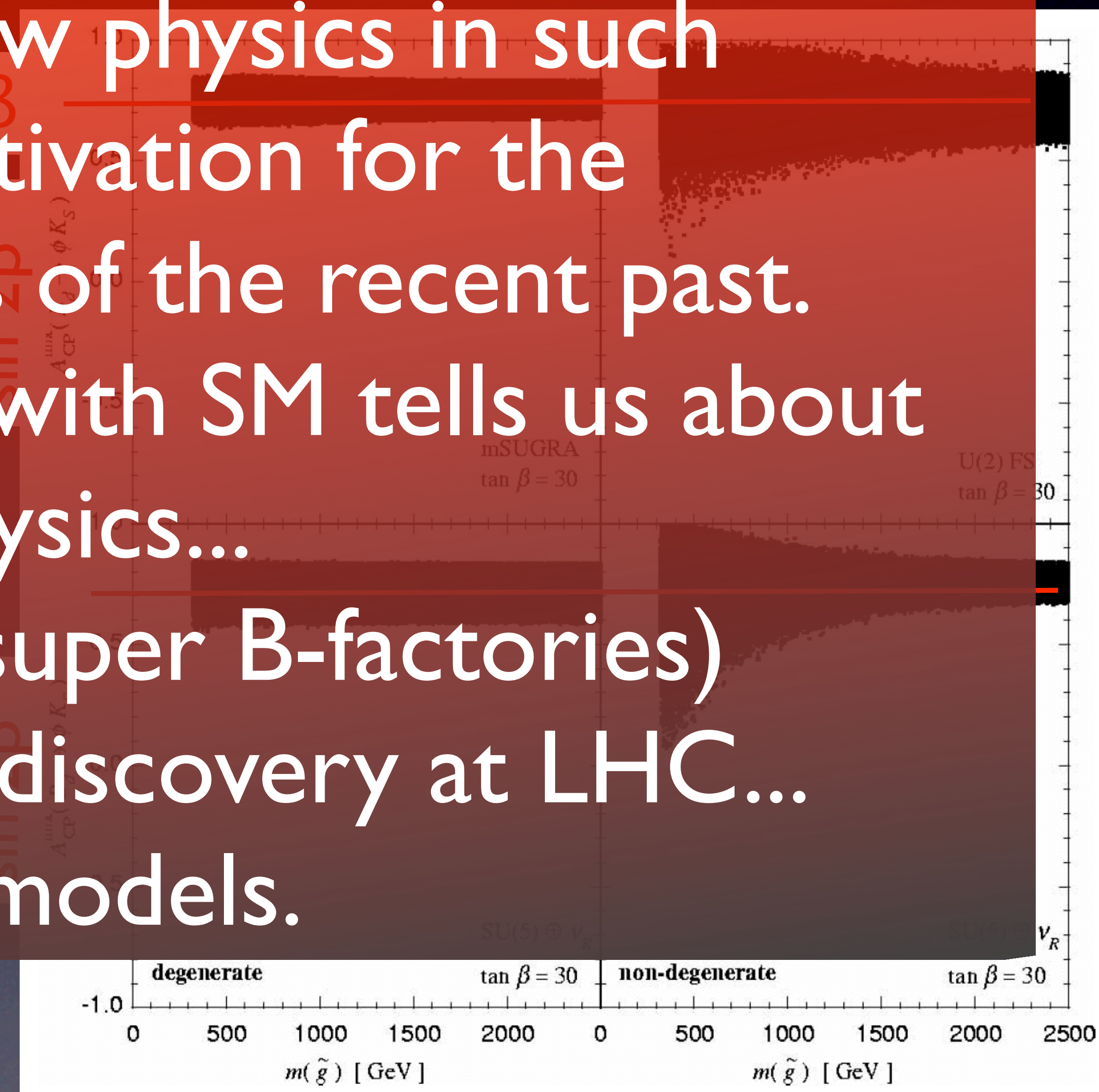
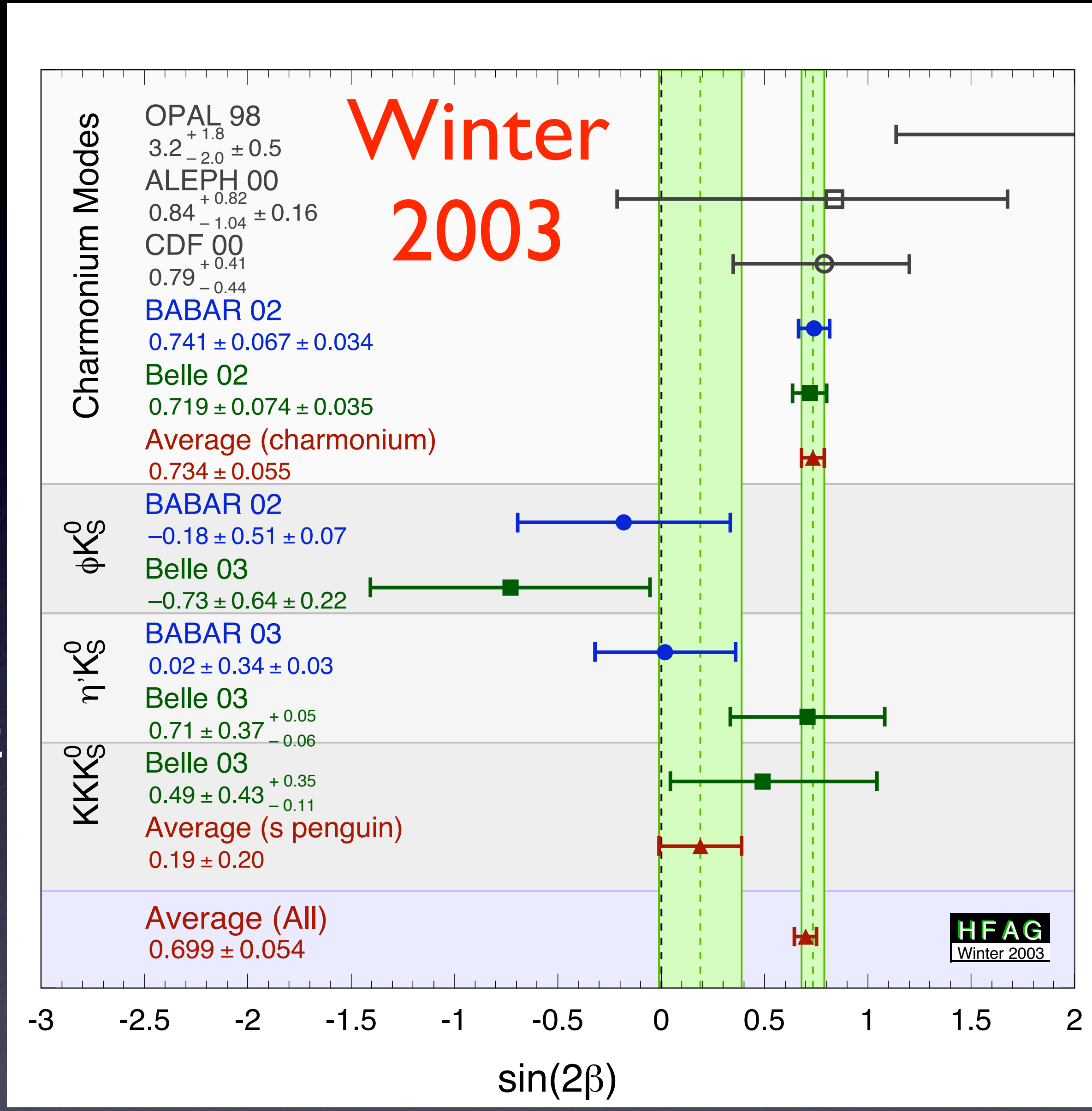


History

A New Technique!

- Excitement in 2003: Signs of deviation in $B \to \varphi K_s$.
- Many of the loop-dominated B decays to CP eigenstates were inaccessible to extraction of $\sin 2\beta^{eff}$ because their decay products had no tracks pointing to the B decay vertex.
- In summer 2003 BaBar invented a new vertexing technique to allow time-dependent analysis for decays with K_s in final state.
- First measurement in $B \to K_s\pi^0$, then $B \to (K_s\pi^0)\gamma$, ...
- Lead 50% increase in the number of such measurements.
- Today: Taking all modes, deviations at 2.6σ (ignoring theoretical uncertainties).



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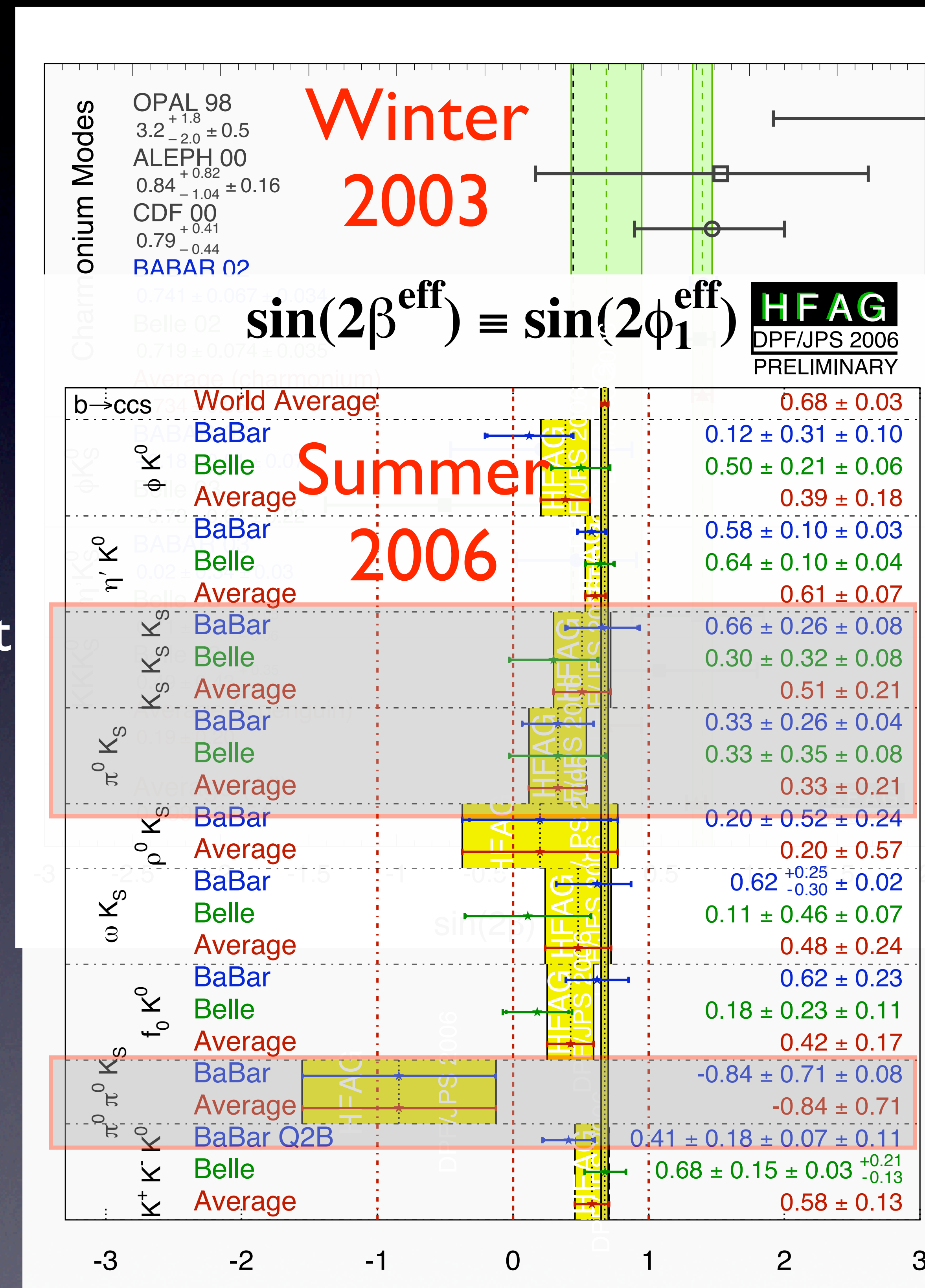

Time-dependent CPV in b→sγ

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- The dominant SM amplitude gives opposite photon helicities for B/Bbar

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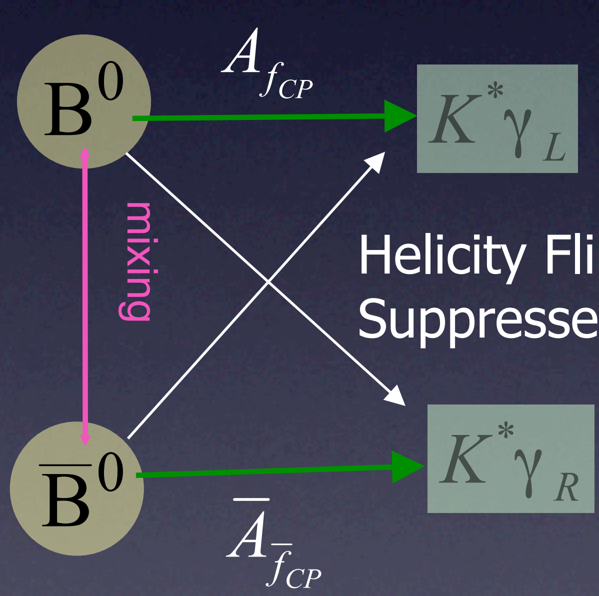
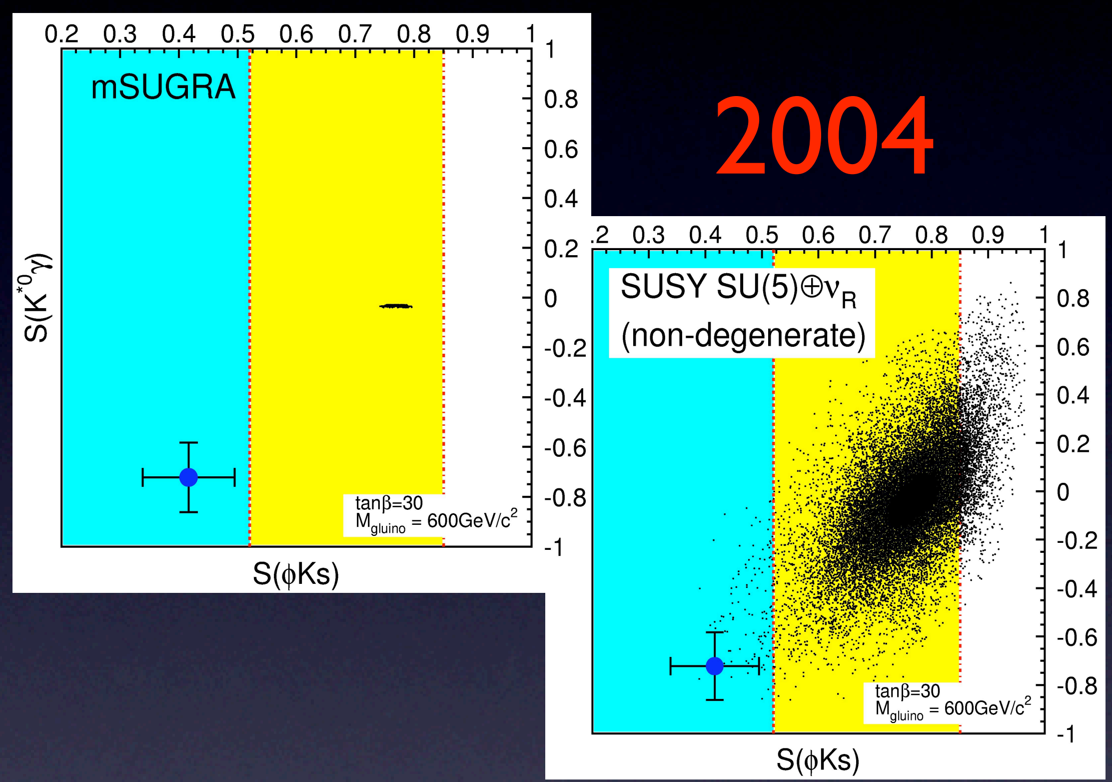


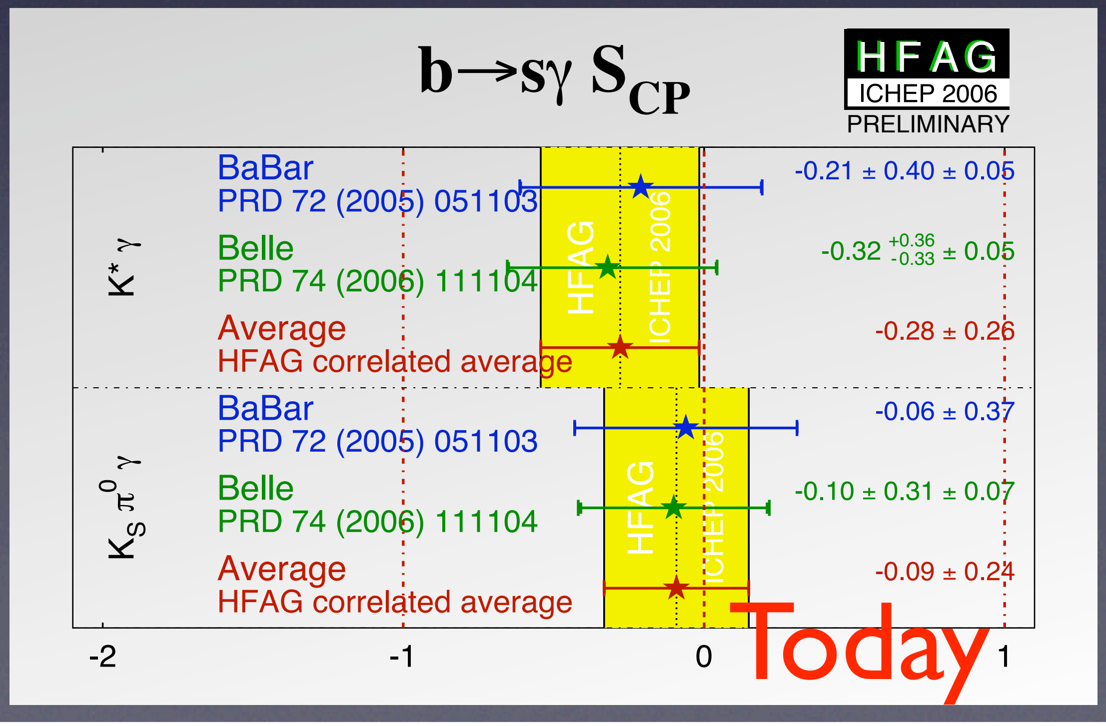
David Atwood, Michael Gronau, Amarjit Soni (1997) (hep-ph/9704272)

Helicity Flip
Suppressed by m_s/m_b

→ Expect:

$$S_{K^*\gamma} = 2\frac{m_s}{m_b}\sin 2\beta \approx 0$$





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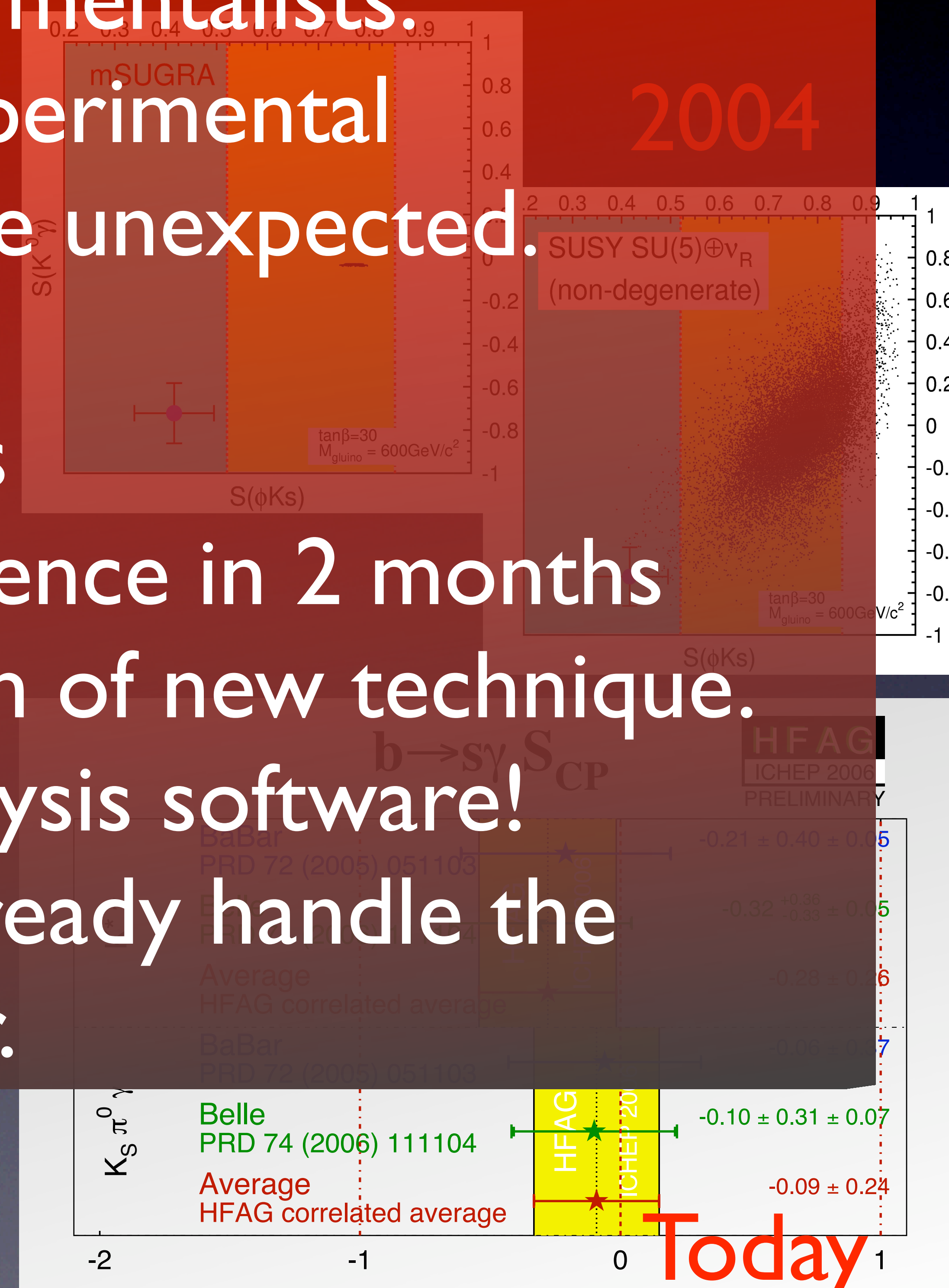


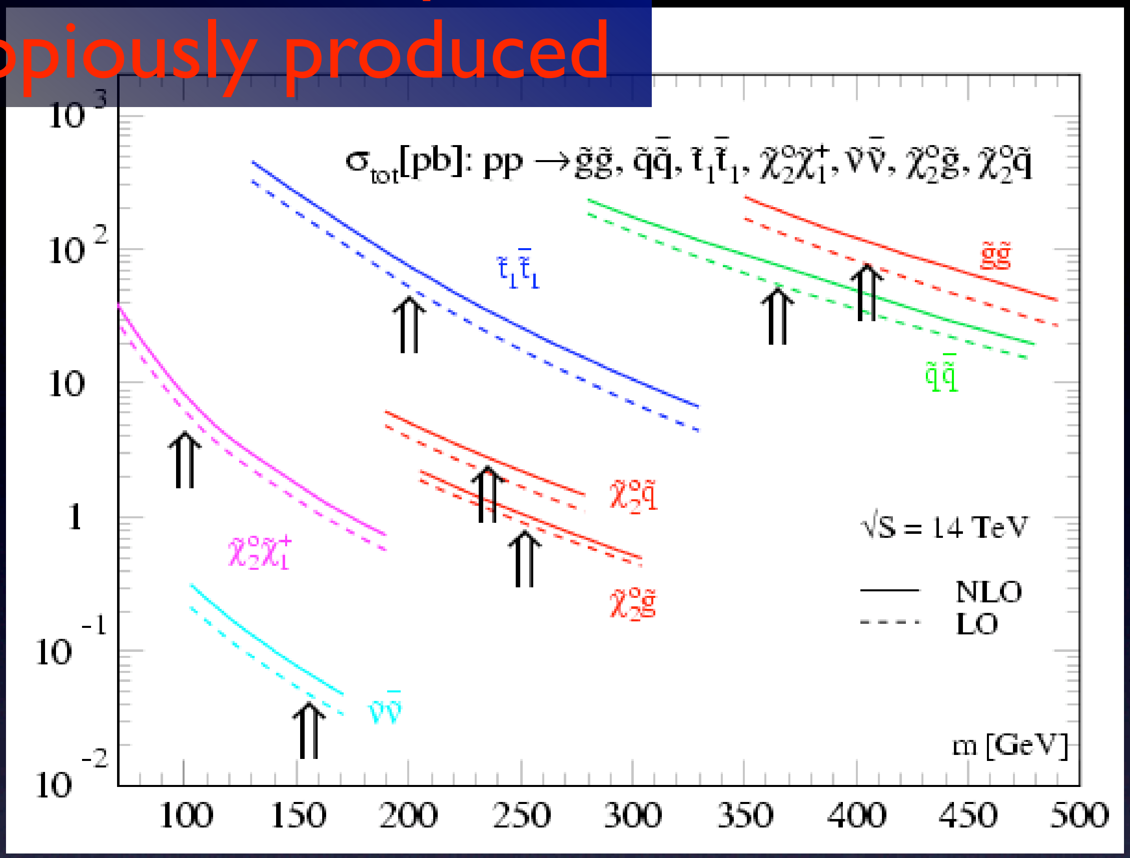
Quick digression for HEP experimentalists:

- Message: Stay open to new experimental techniques... and be ready for the unexpected.
- This technique:
  - Idea → feasibility in 24 hours
  - → first new result in conference in 2 months
- Hard to convince collaboration of new technique.
- Reason for success: Good analysis software!

➡ Important to have software ready handle the unexpected.... more on this later.

SUSY at LHC

Gluinos and squarks copiously produced



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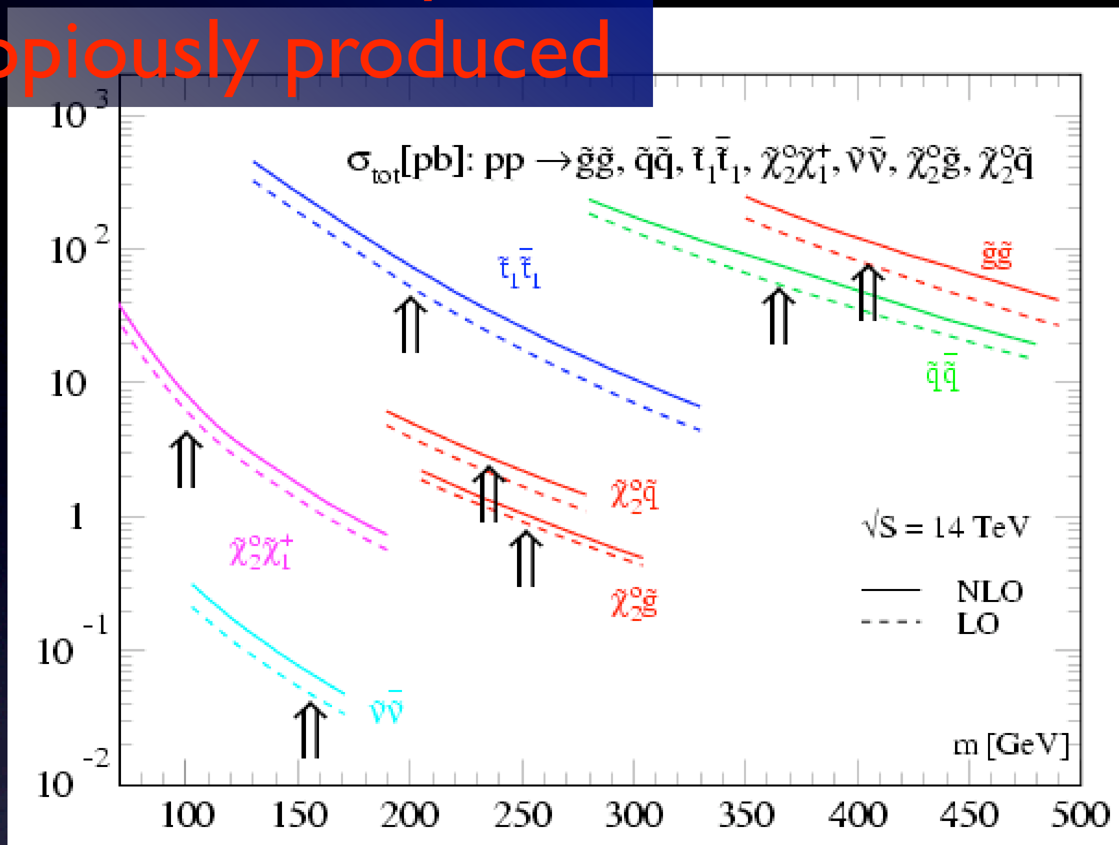

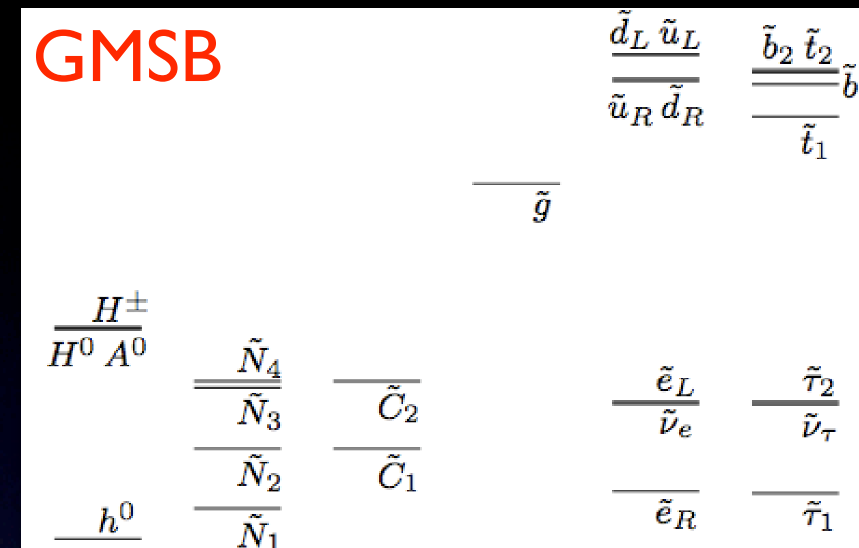

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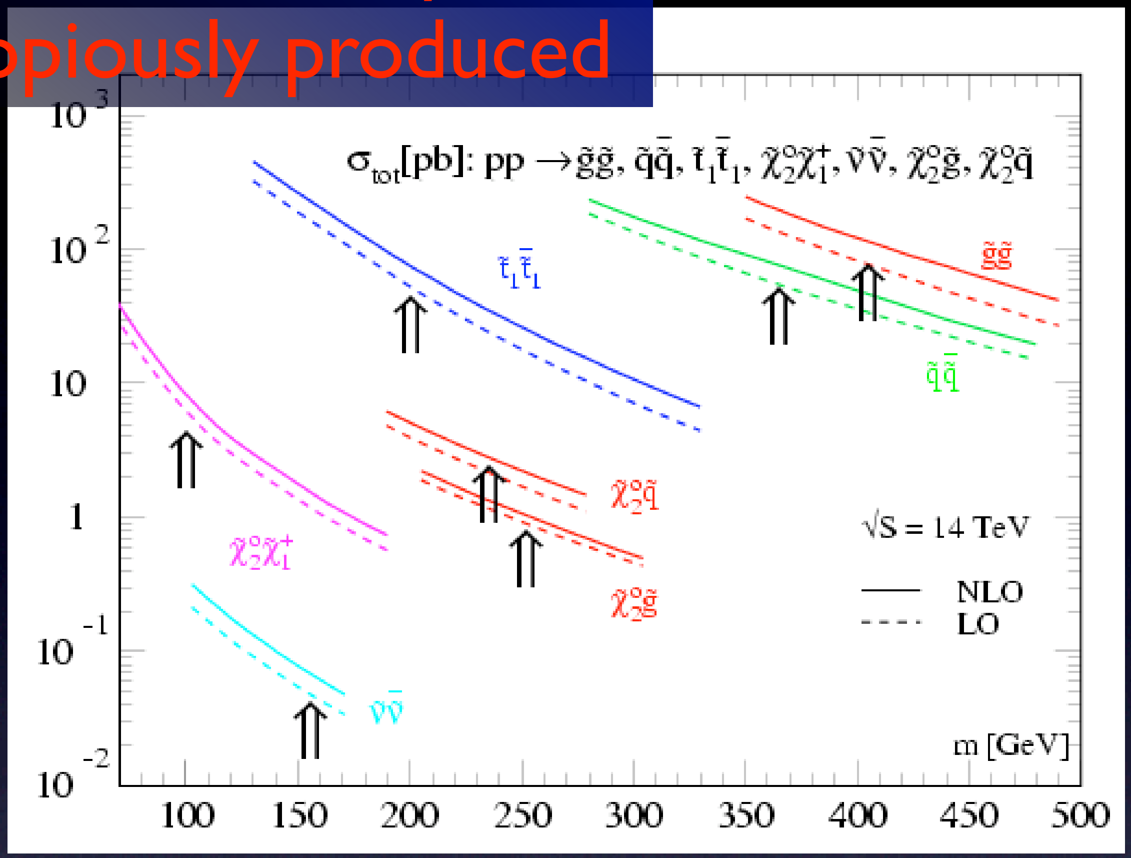

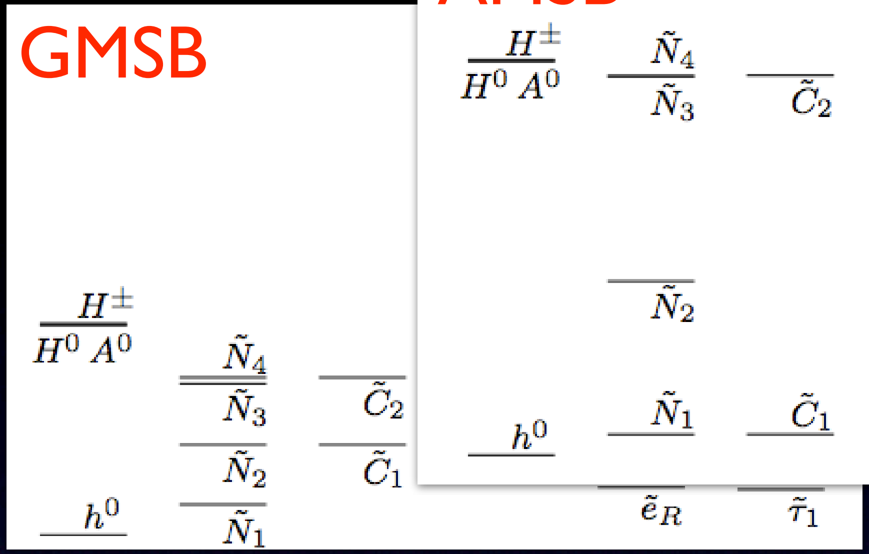

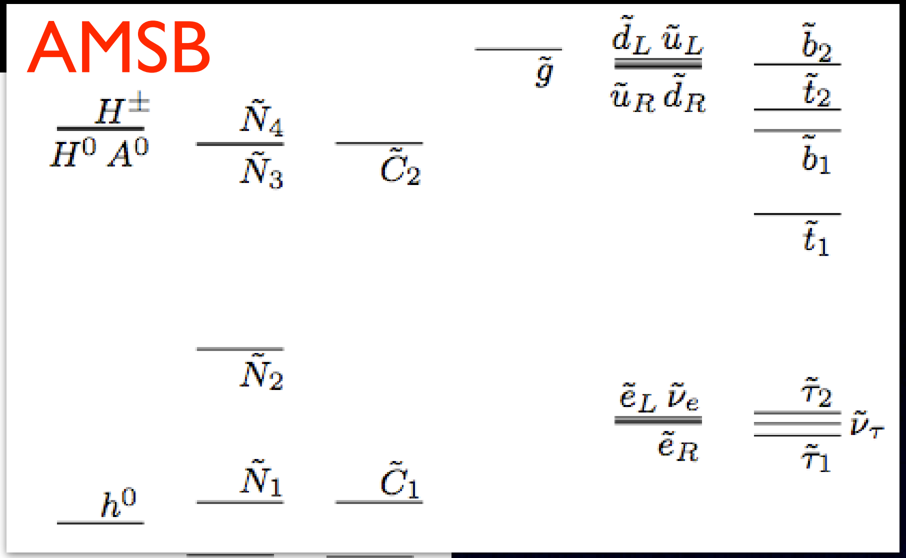

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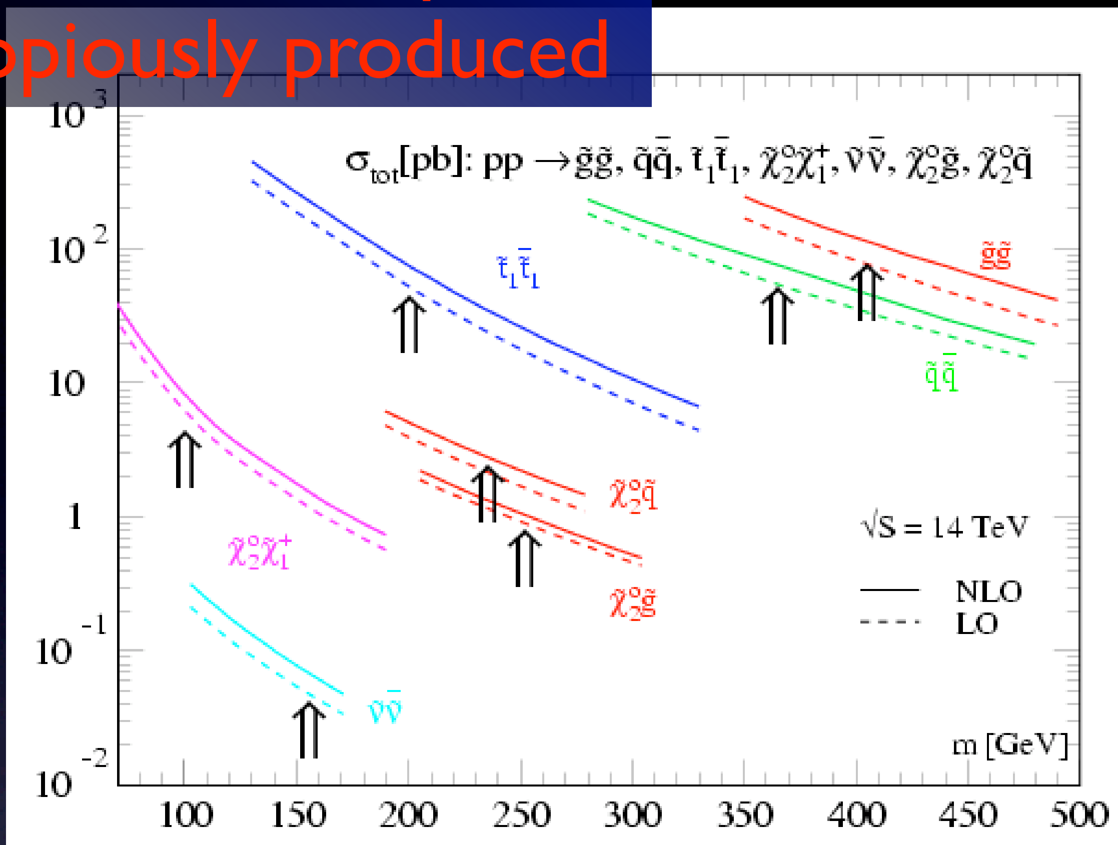

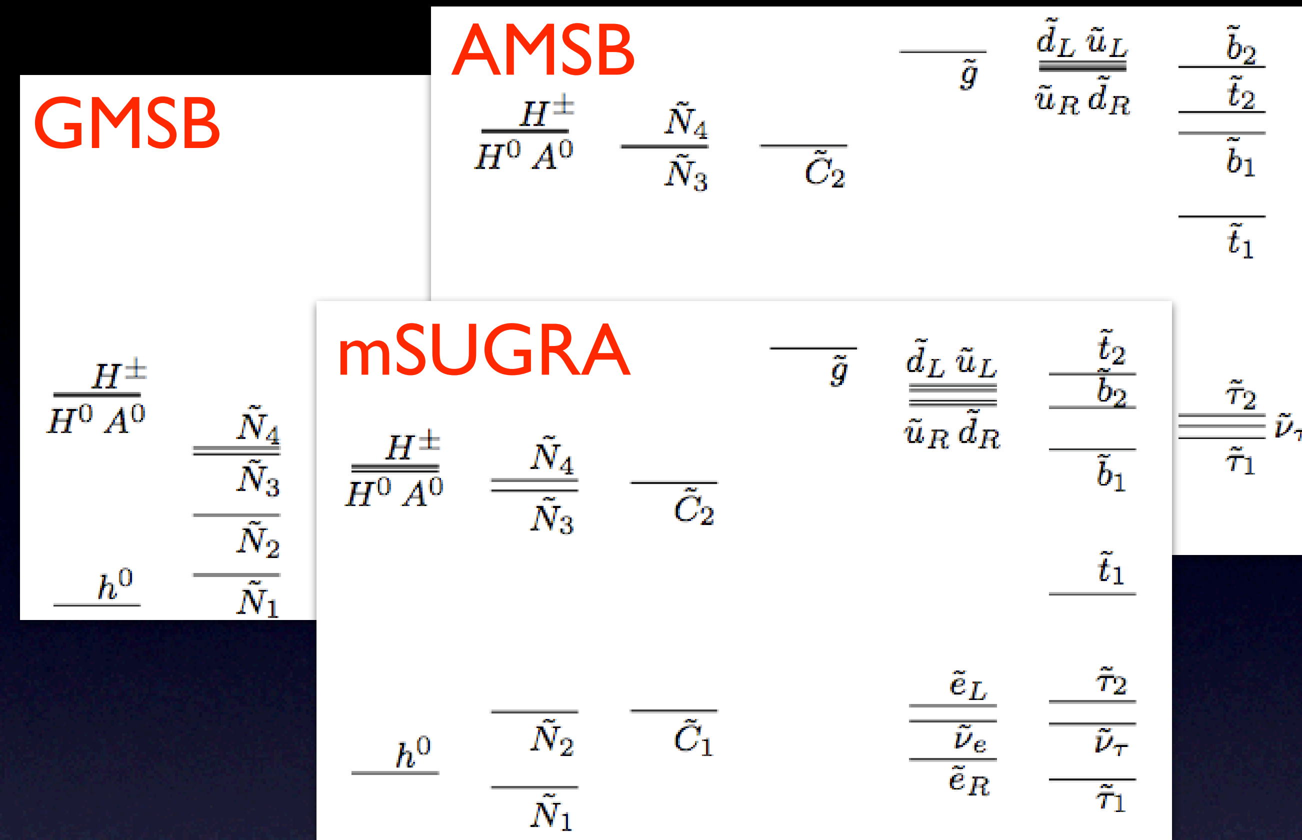

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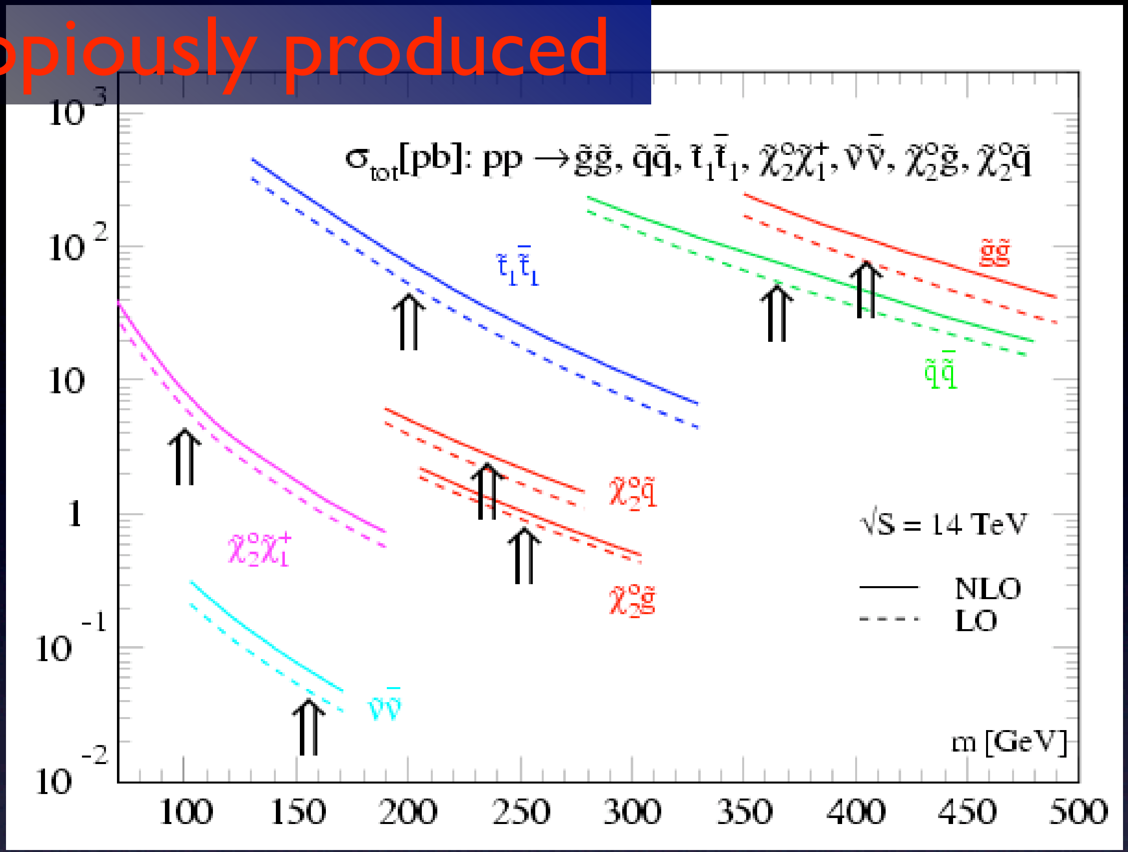

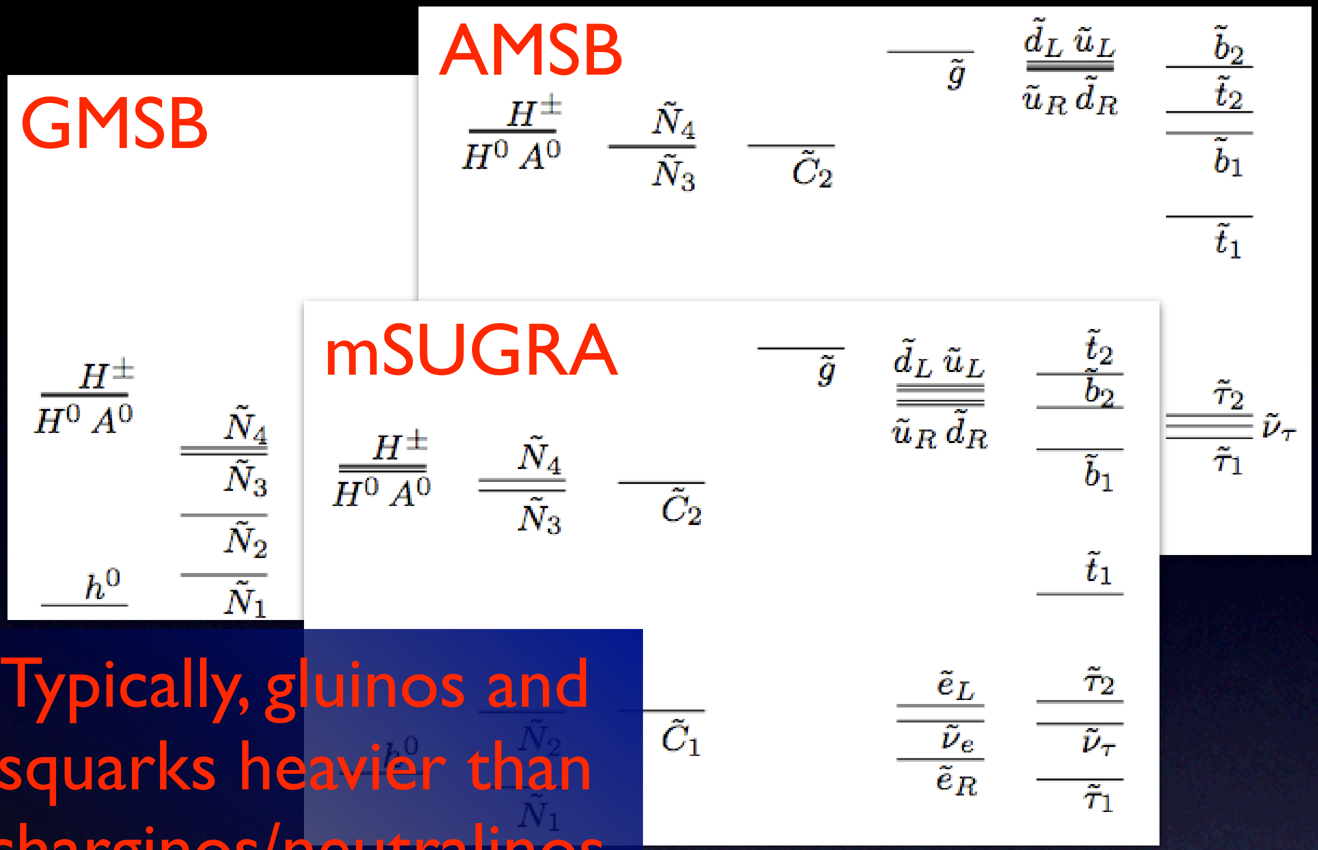

Typically, gluinos and squarks heavier than charginos/neutralinos

SUSY at LHC

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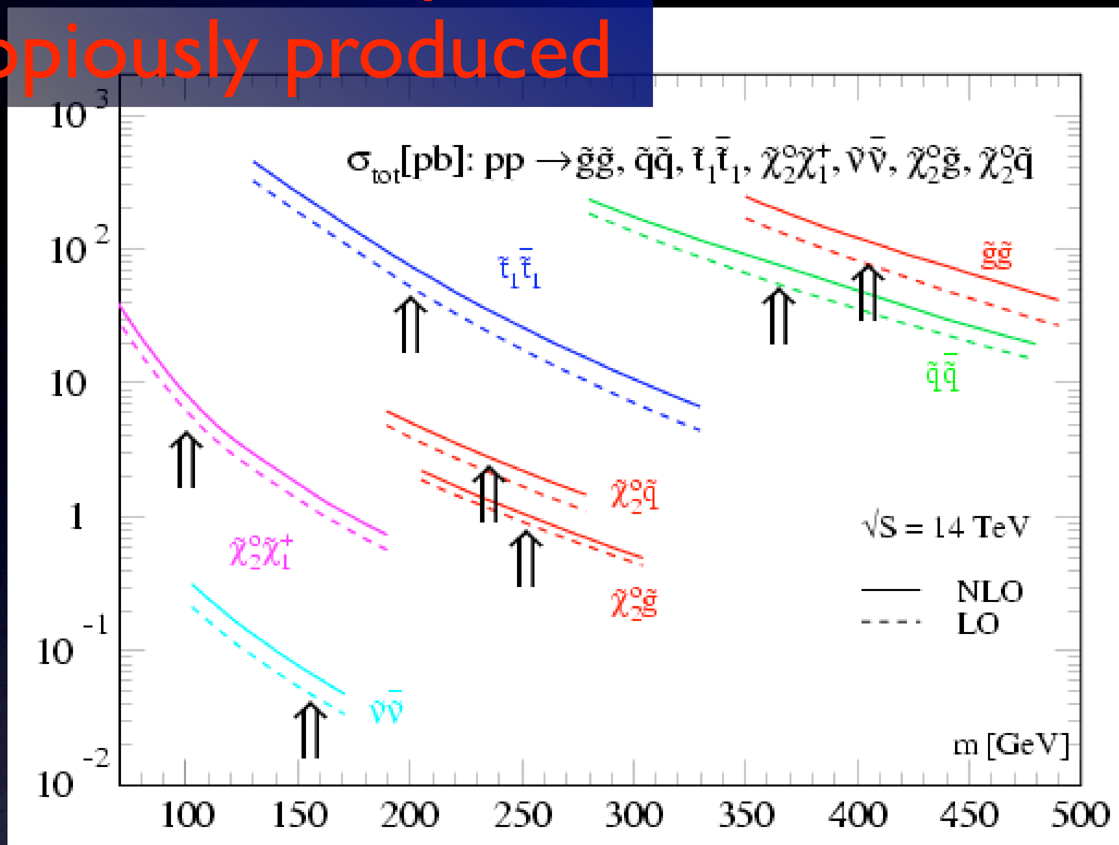

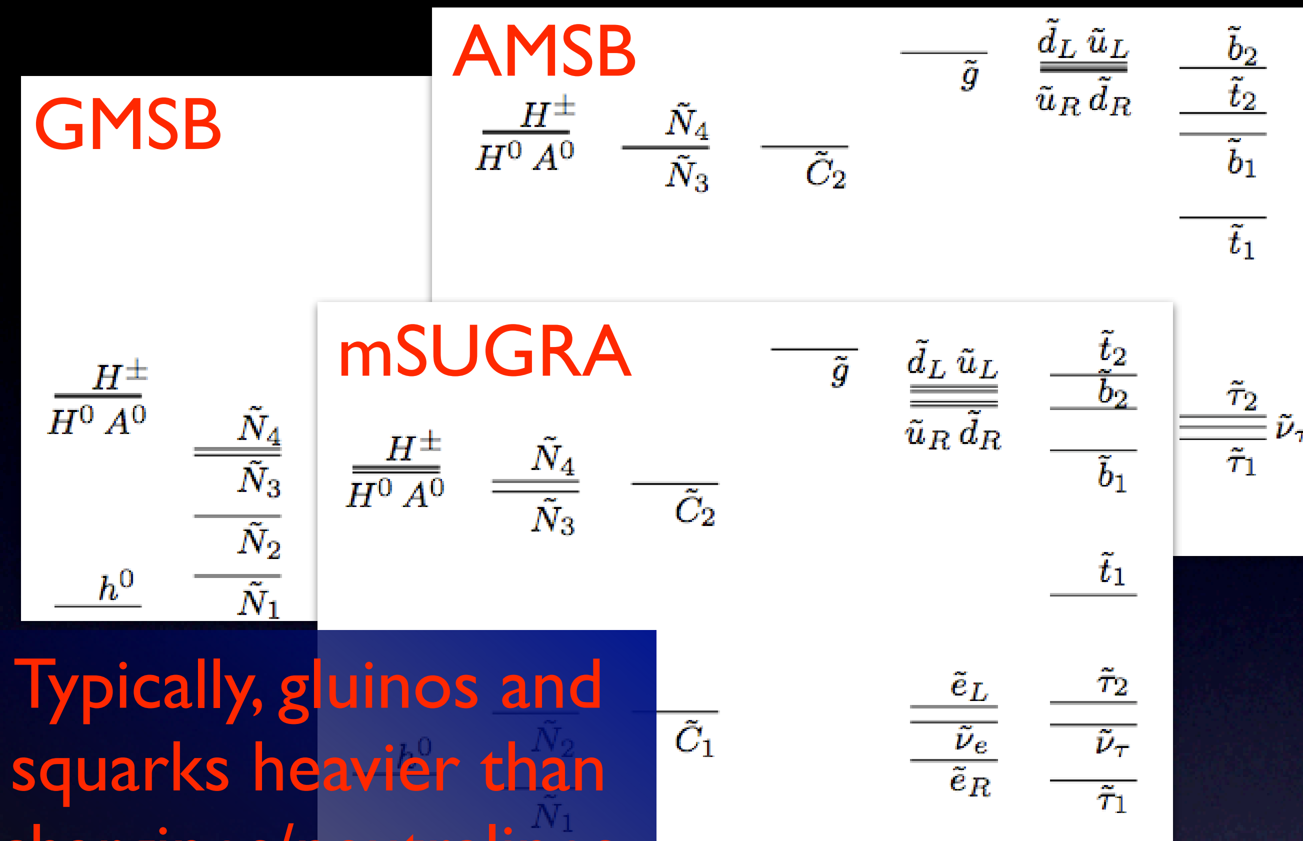

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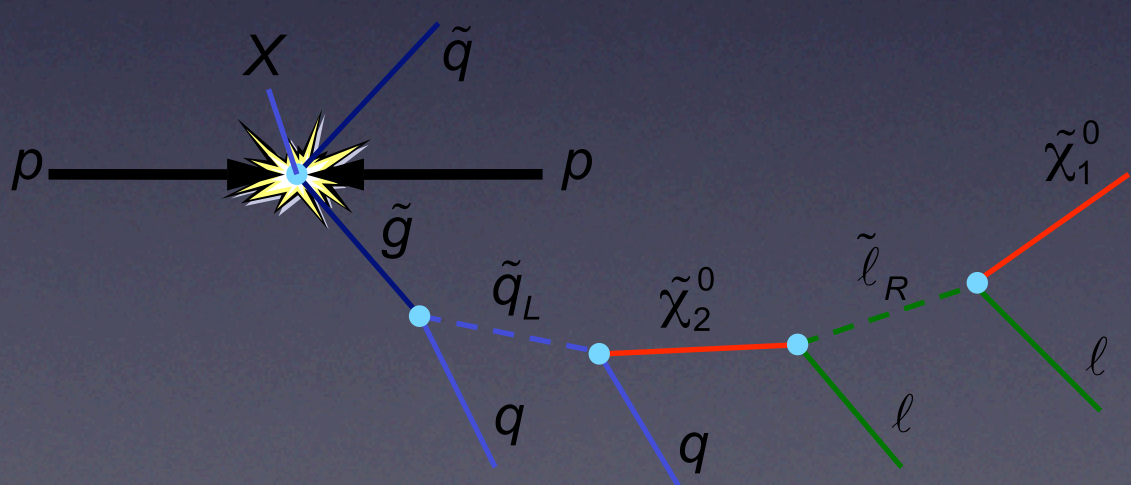

Long Cascades

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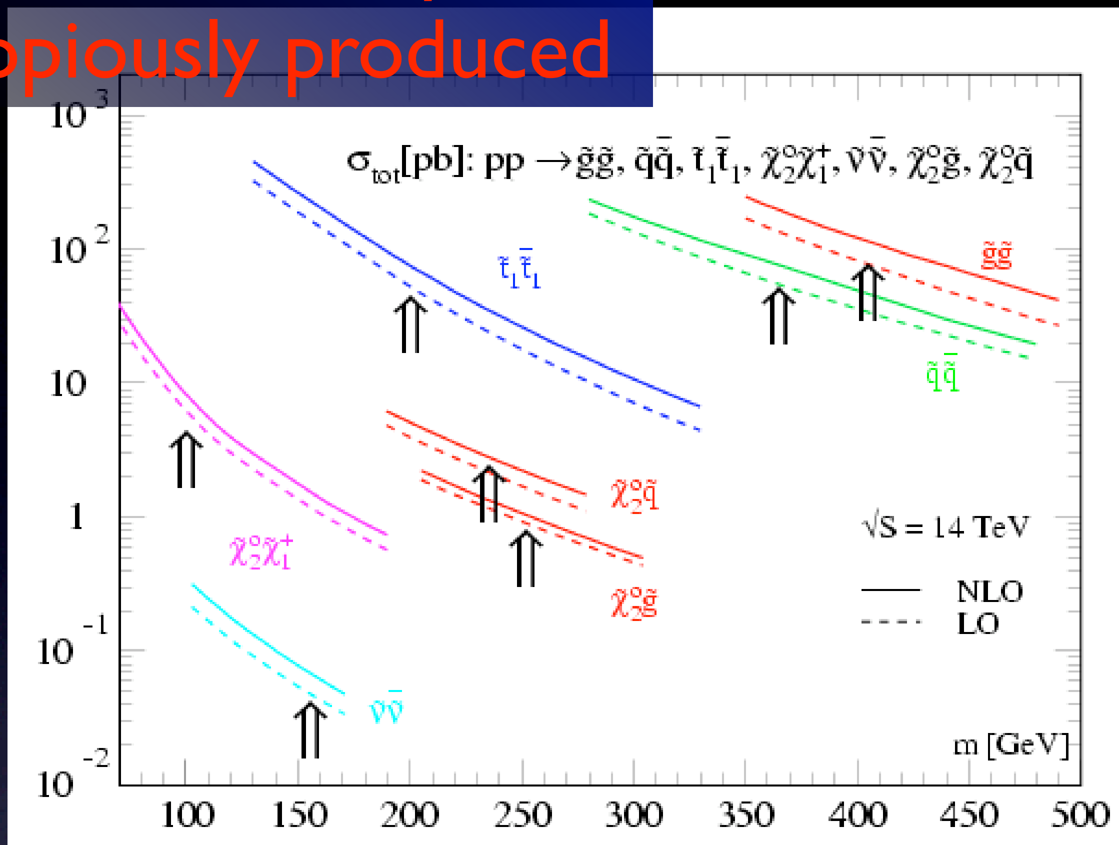

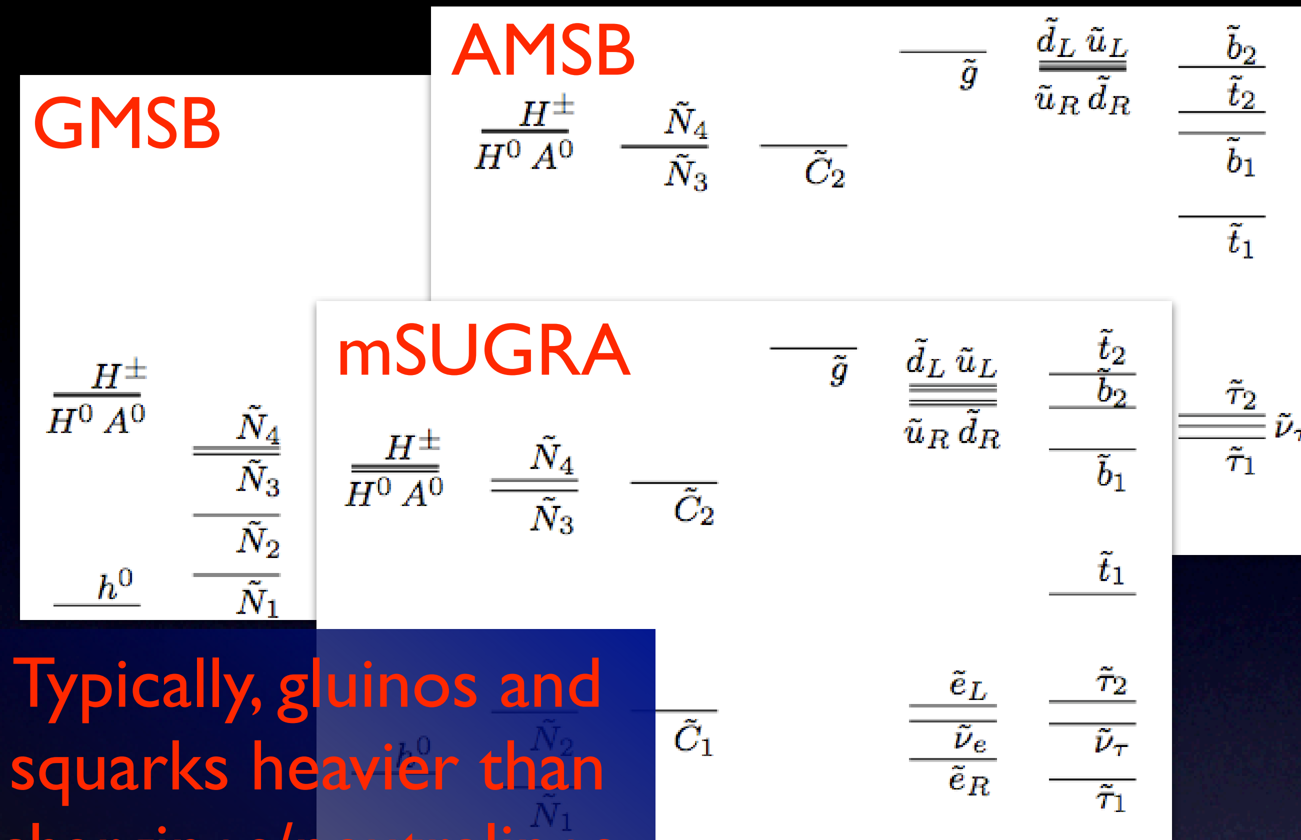

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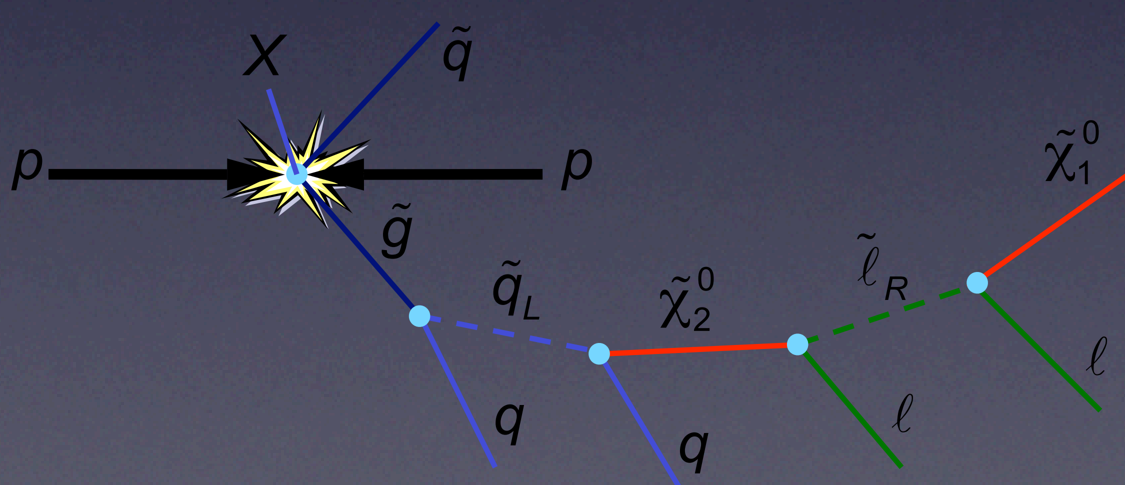

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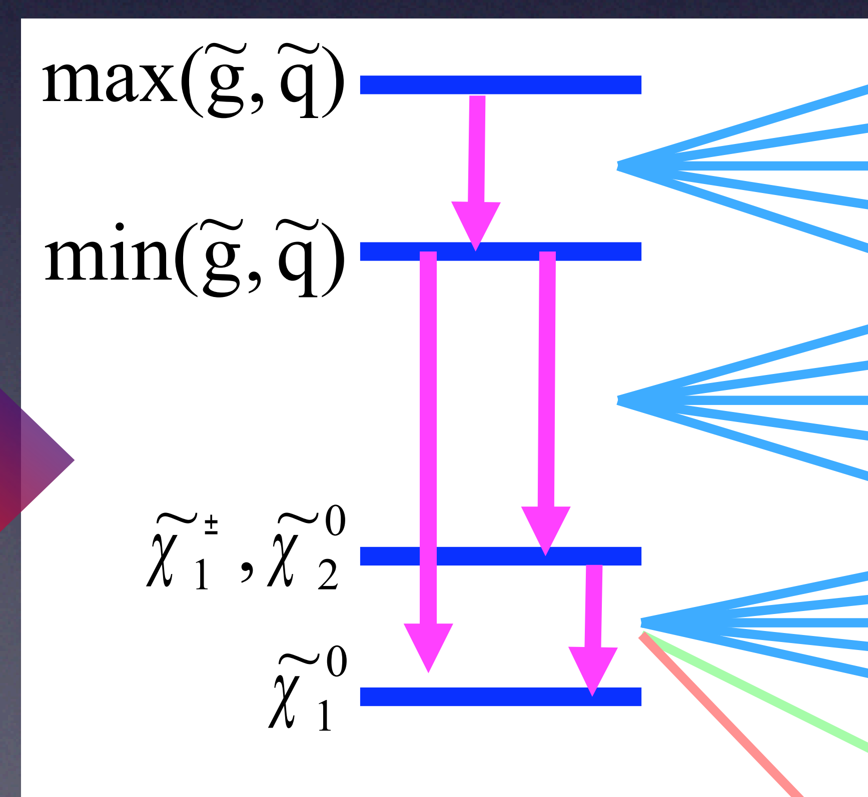

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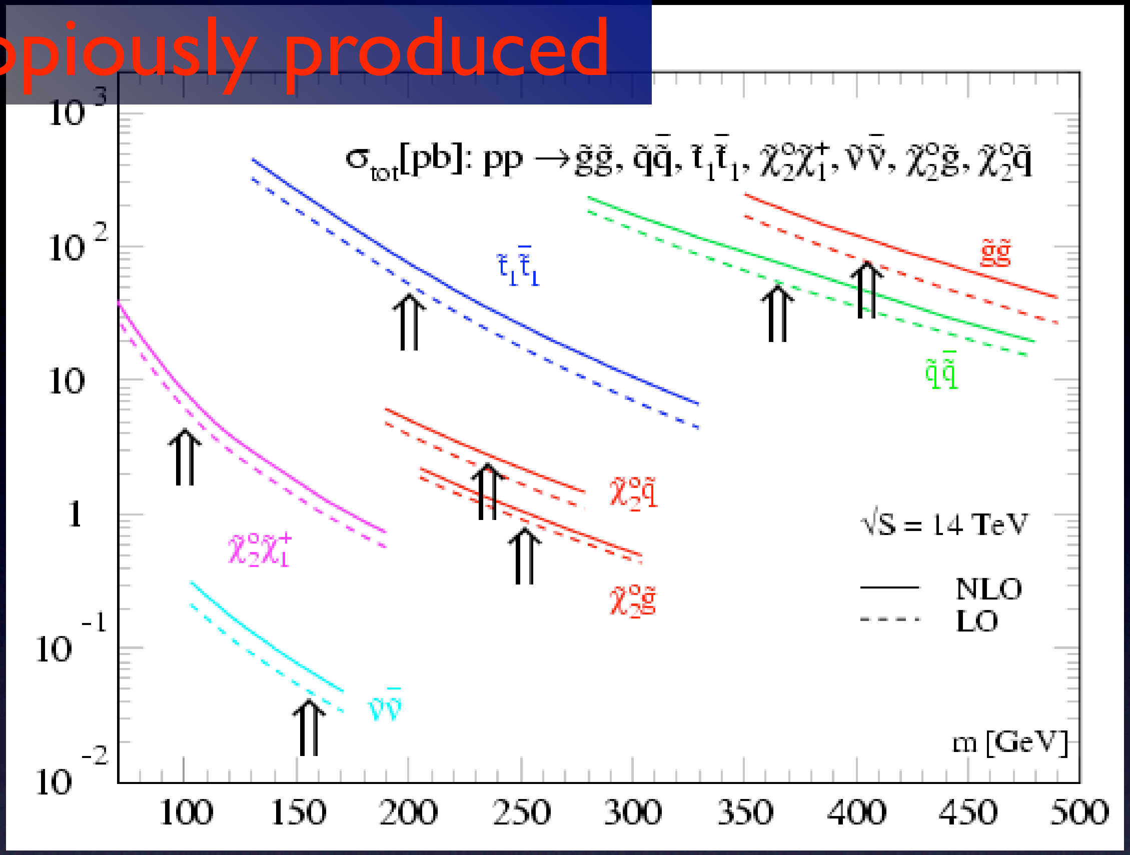

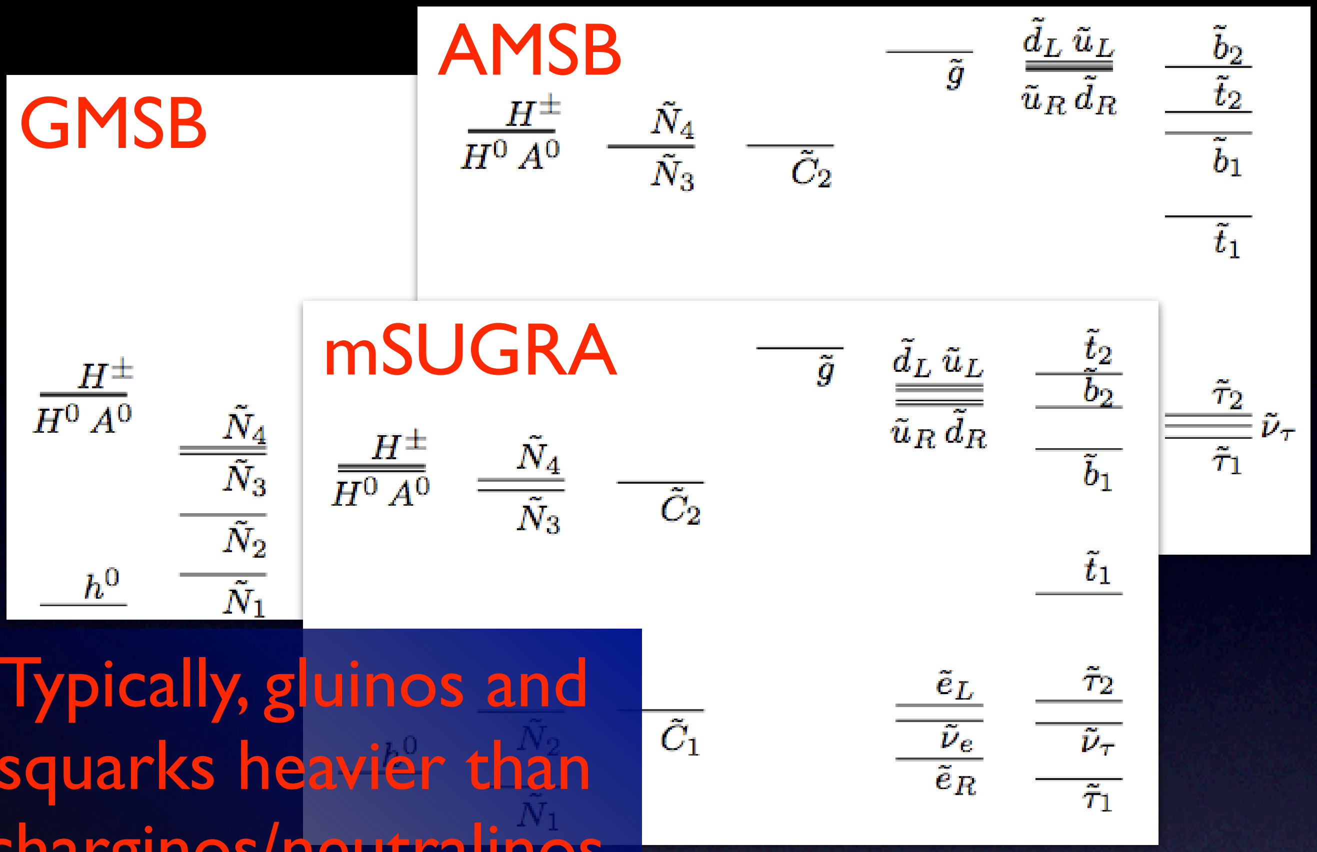

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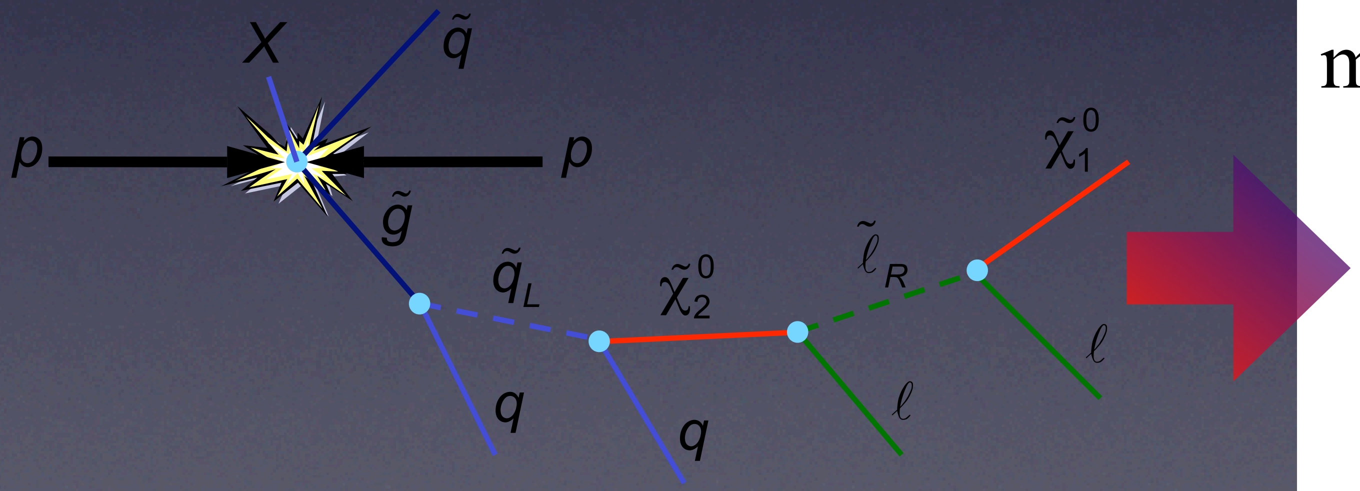

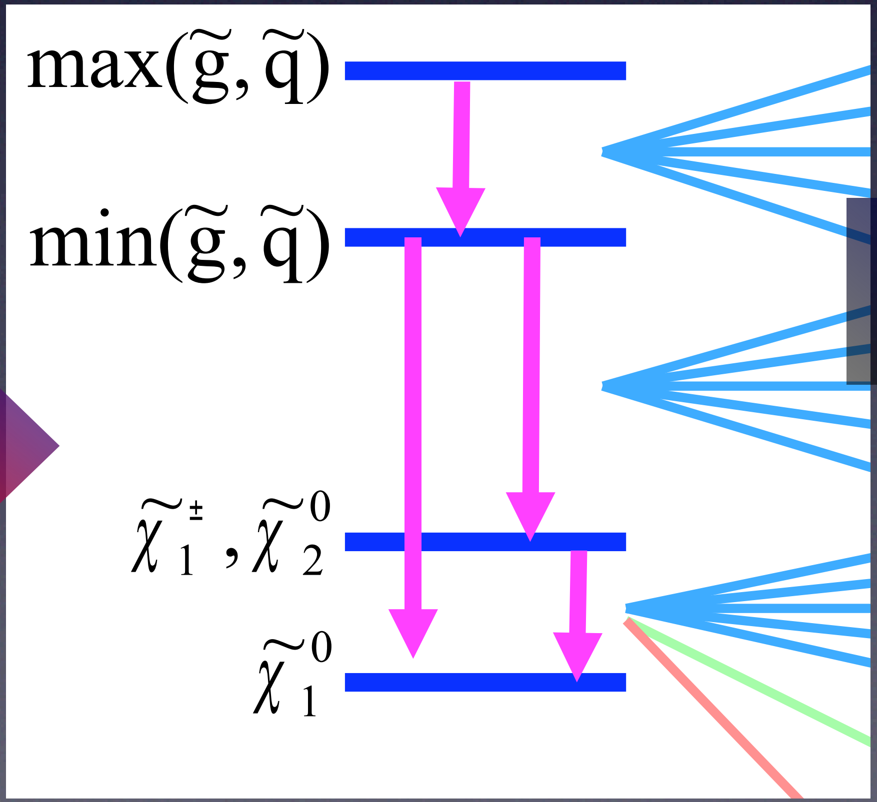

Many Jets (100's of GeV)

Long Cascades

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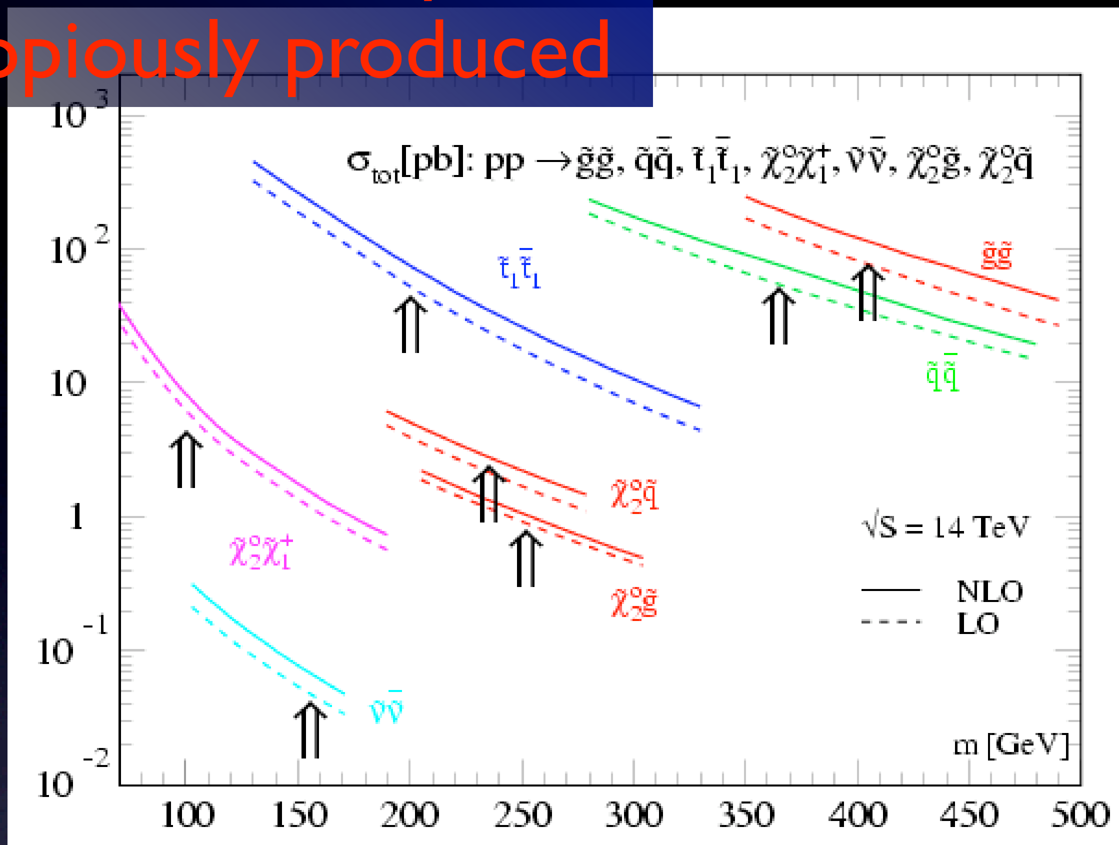

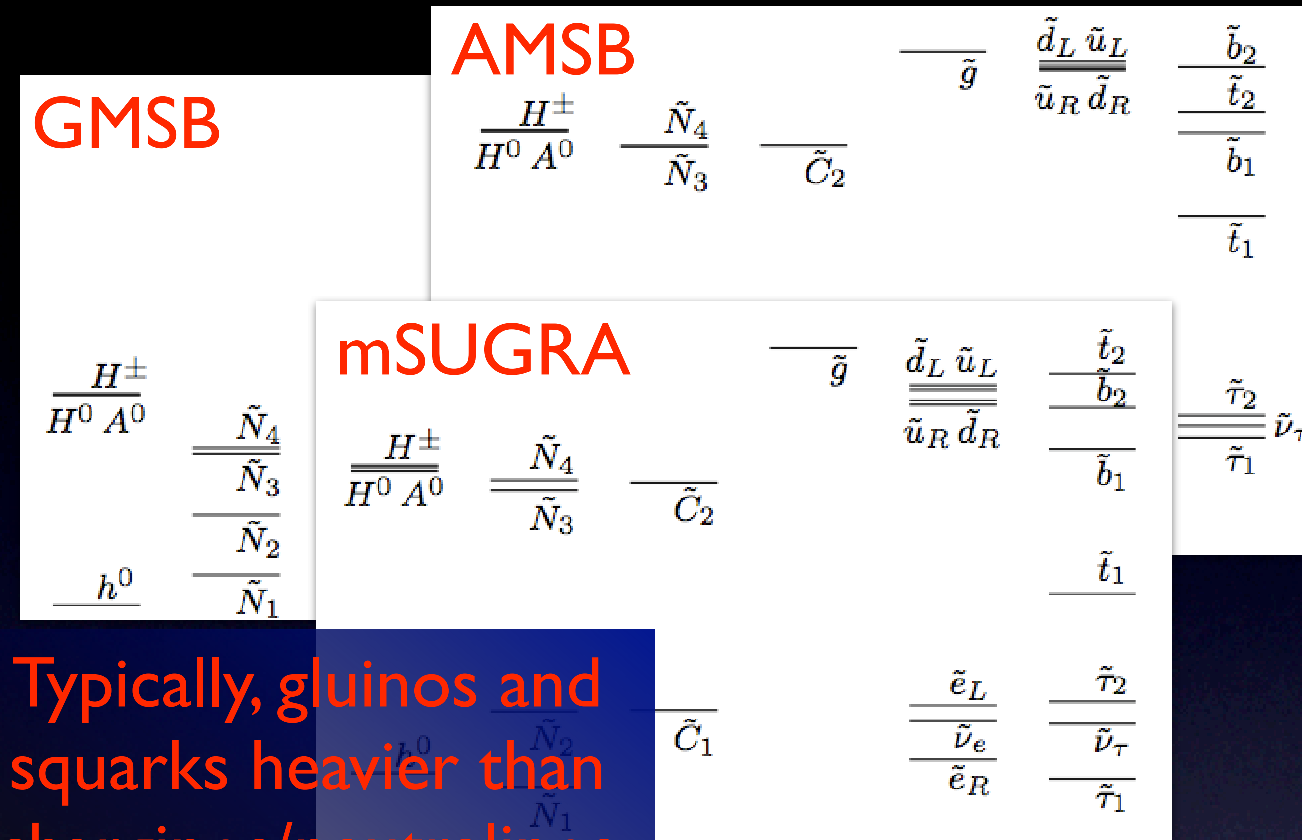

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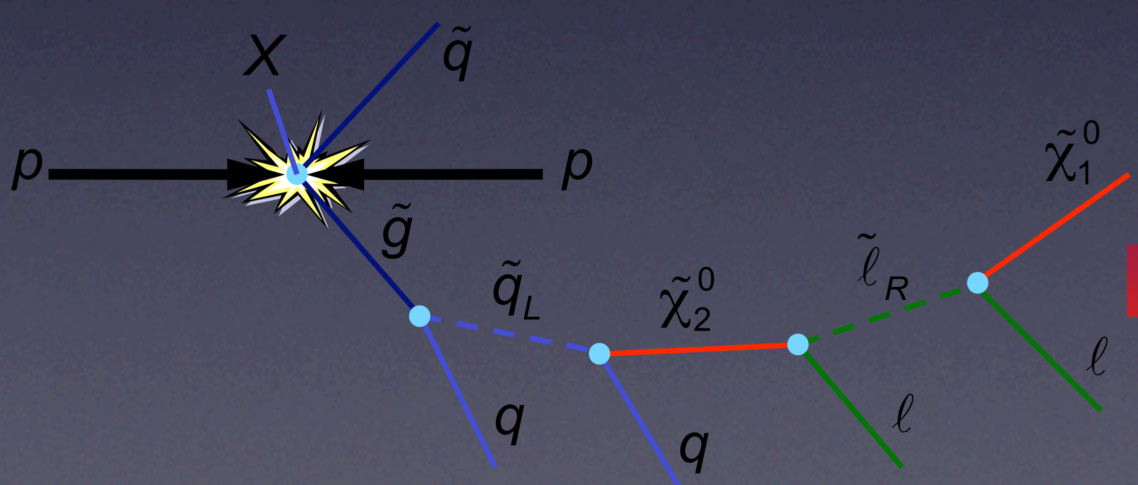

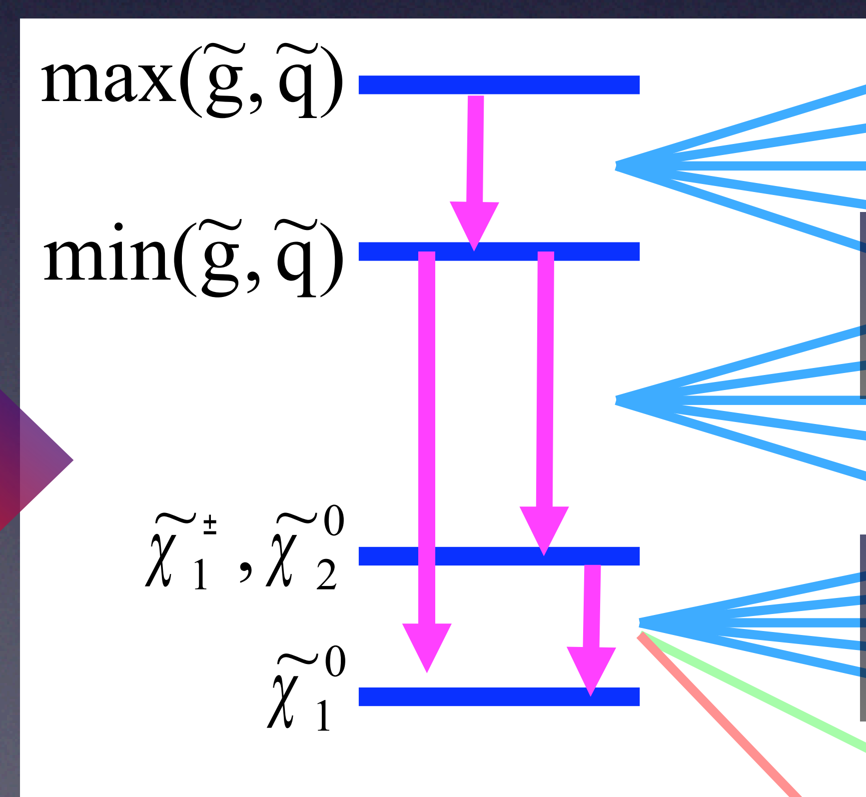

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Leptons (10's of GeV)

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SUSY at LHC

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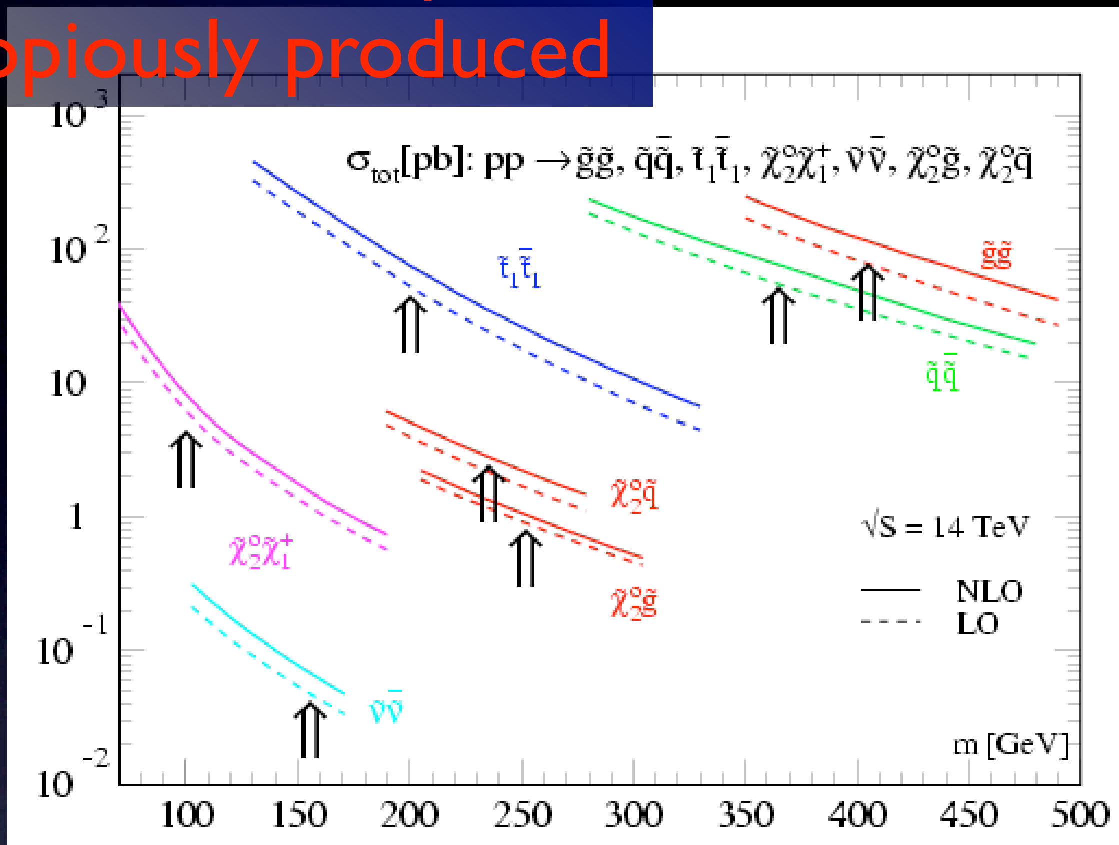

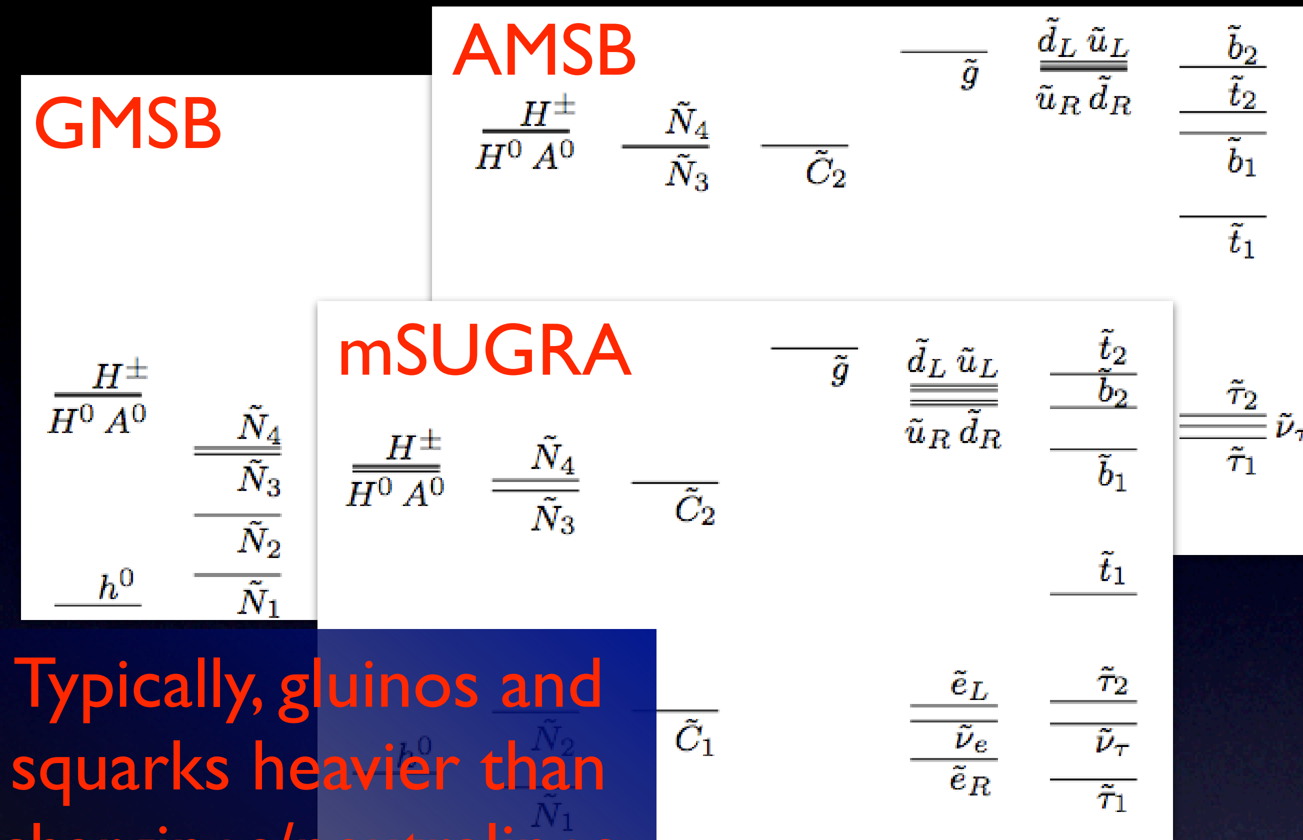

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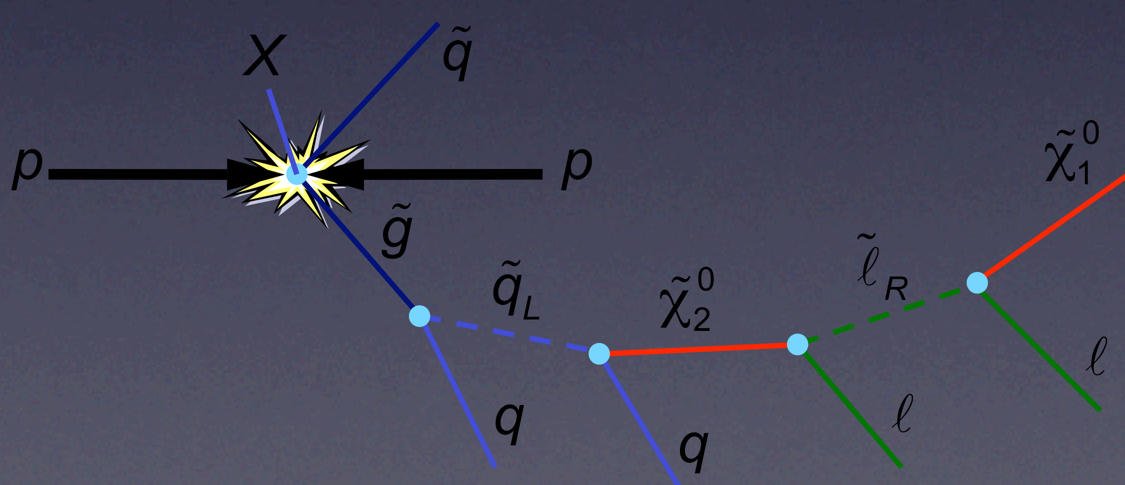
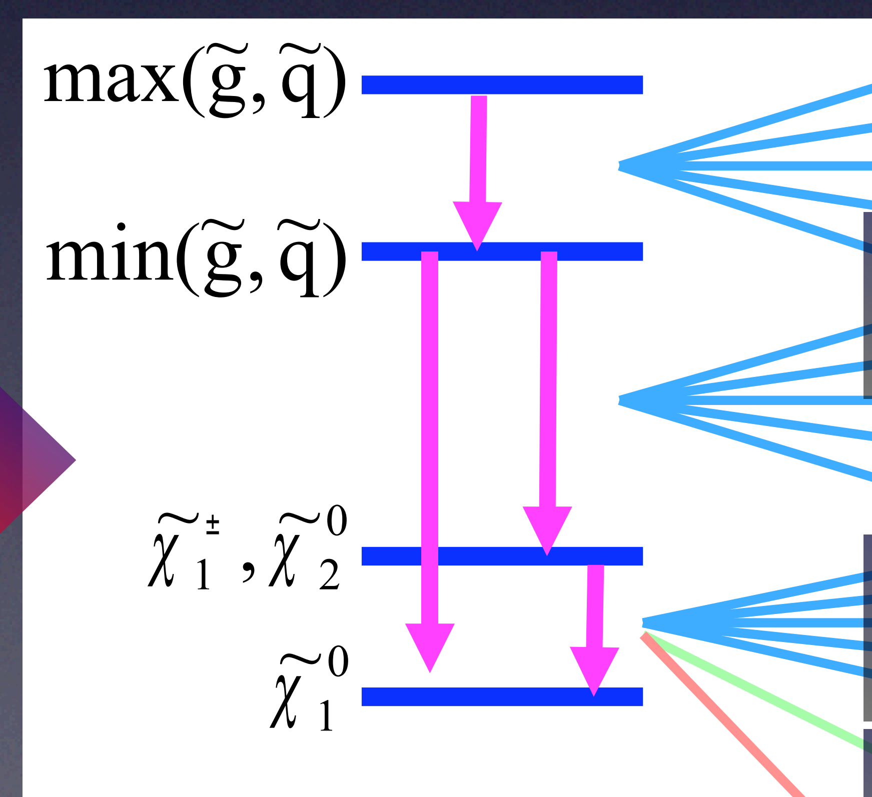




Many Jets (100's of GeV)

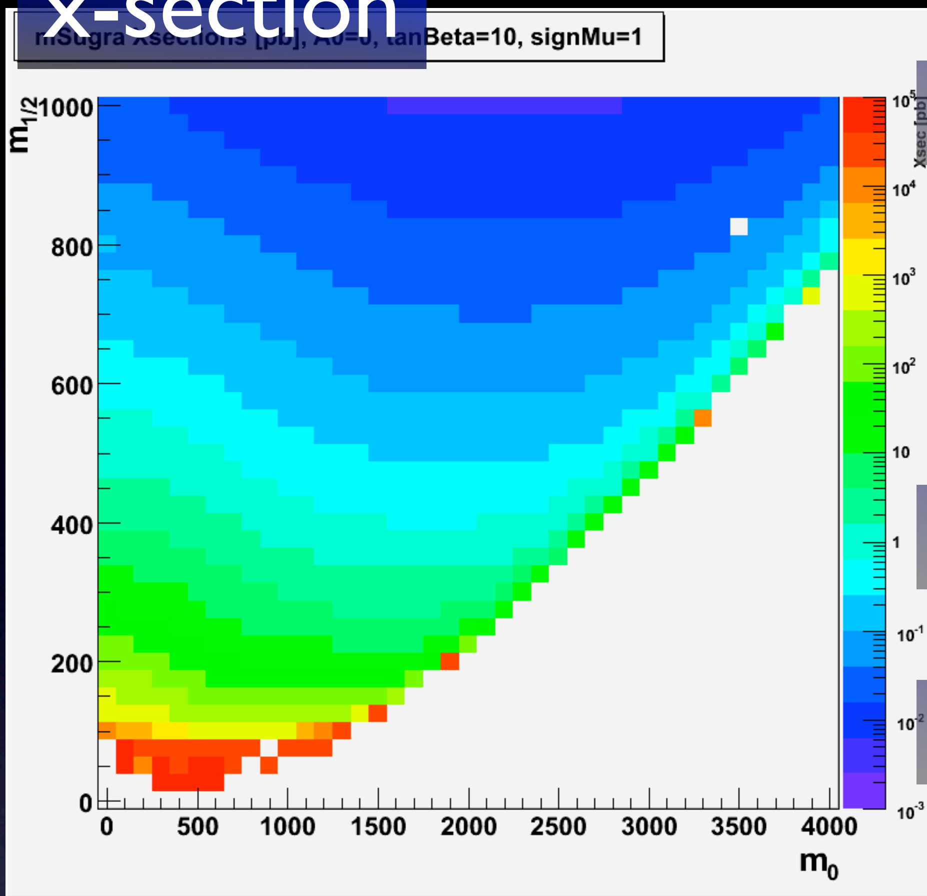
Leptons (10's of GeV)

Missing Energy (100's of GeV)

Long Cascades

Details

x-section

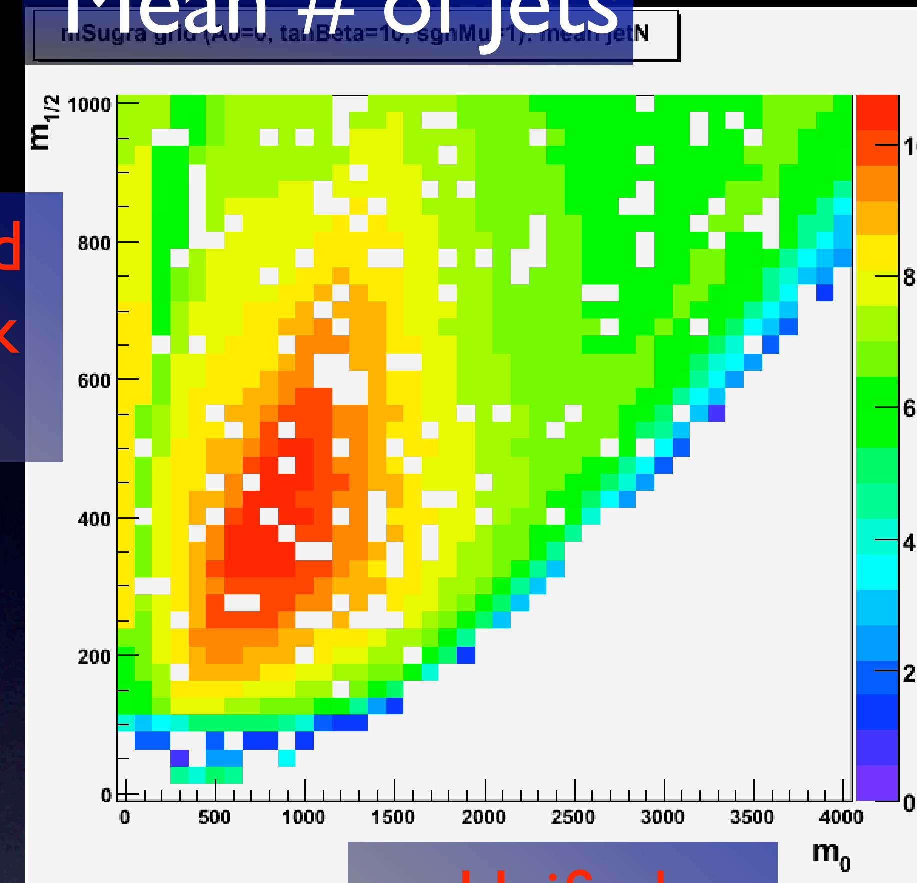


10^5 pb

1 pb

10^{-2} pb

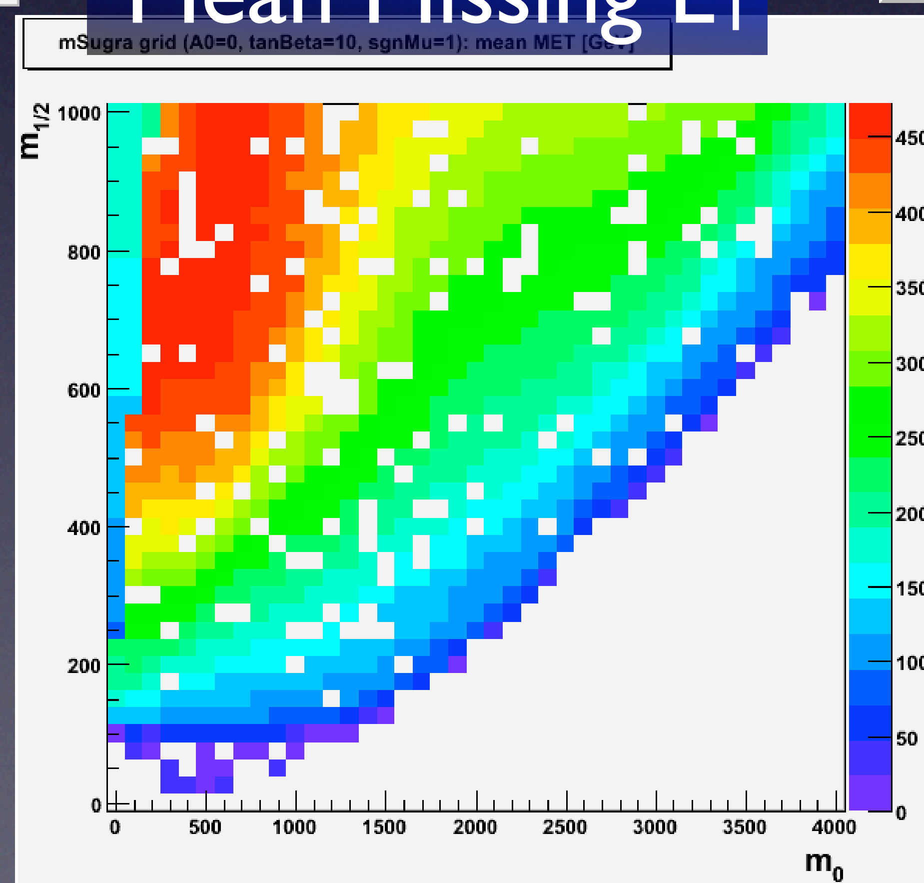
Mean # of Jets



Unified Squark Mass

Unified Gaugino Mass

Mean Missing E_T



- Sensitivity is model/parameter dependent

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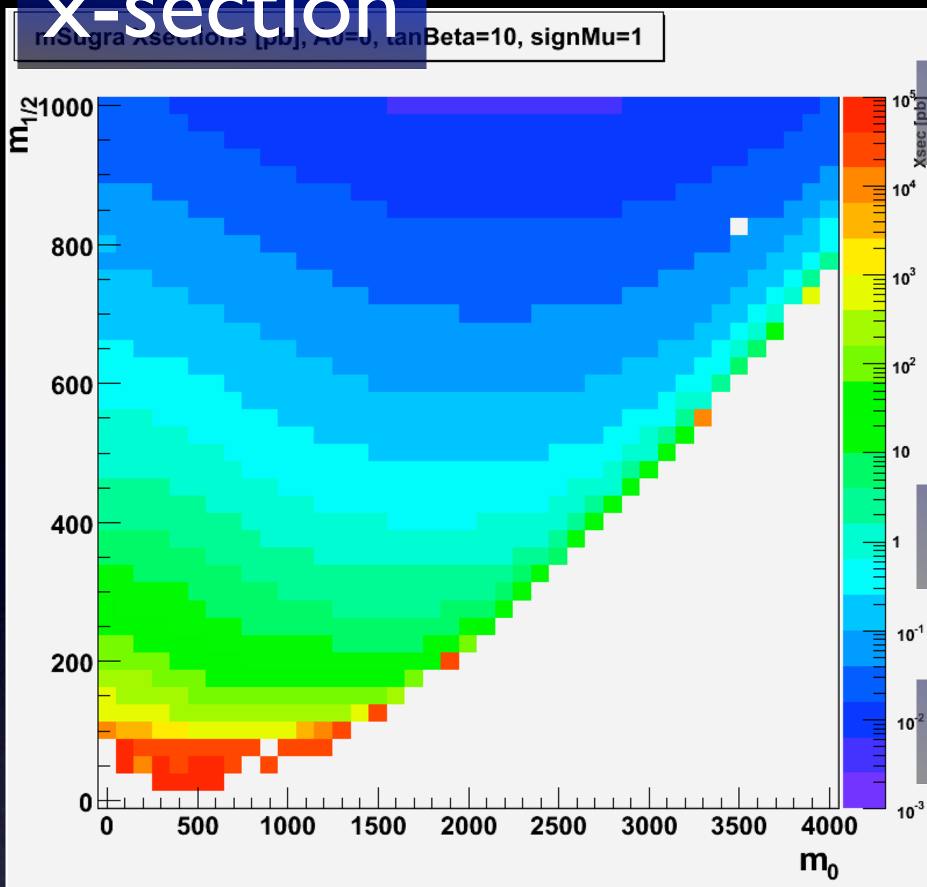

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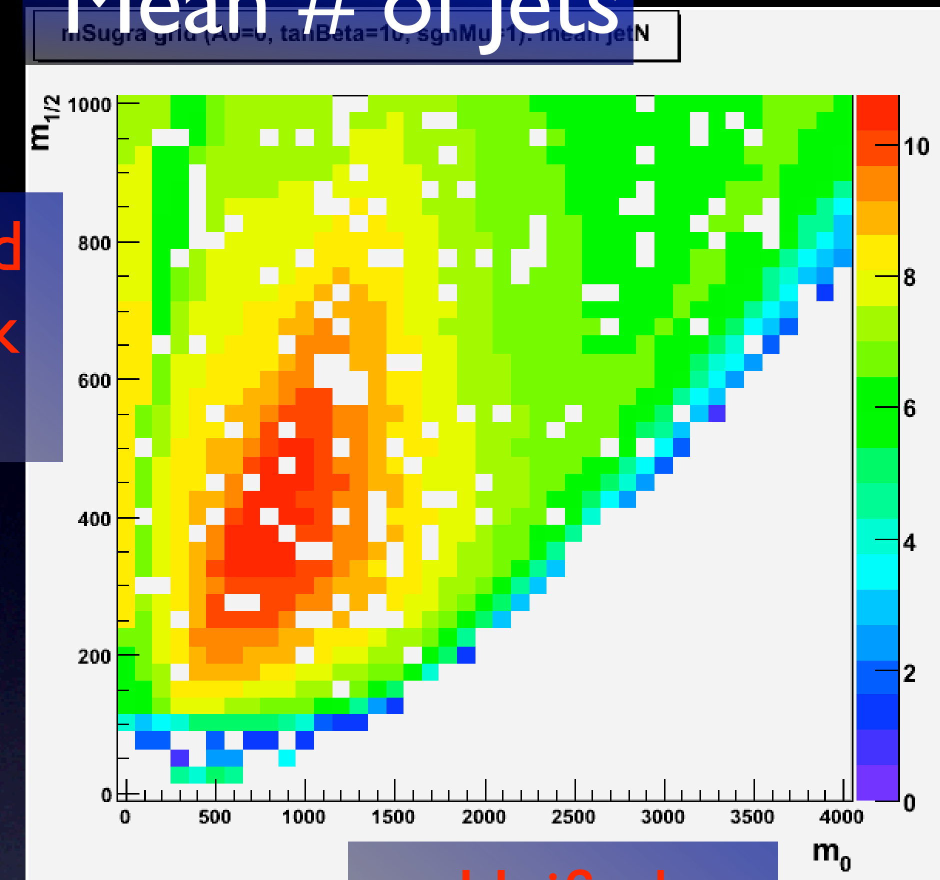

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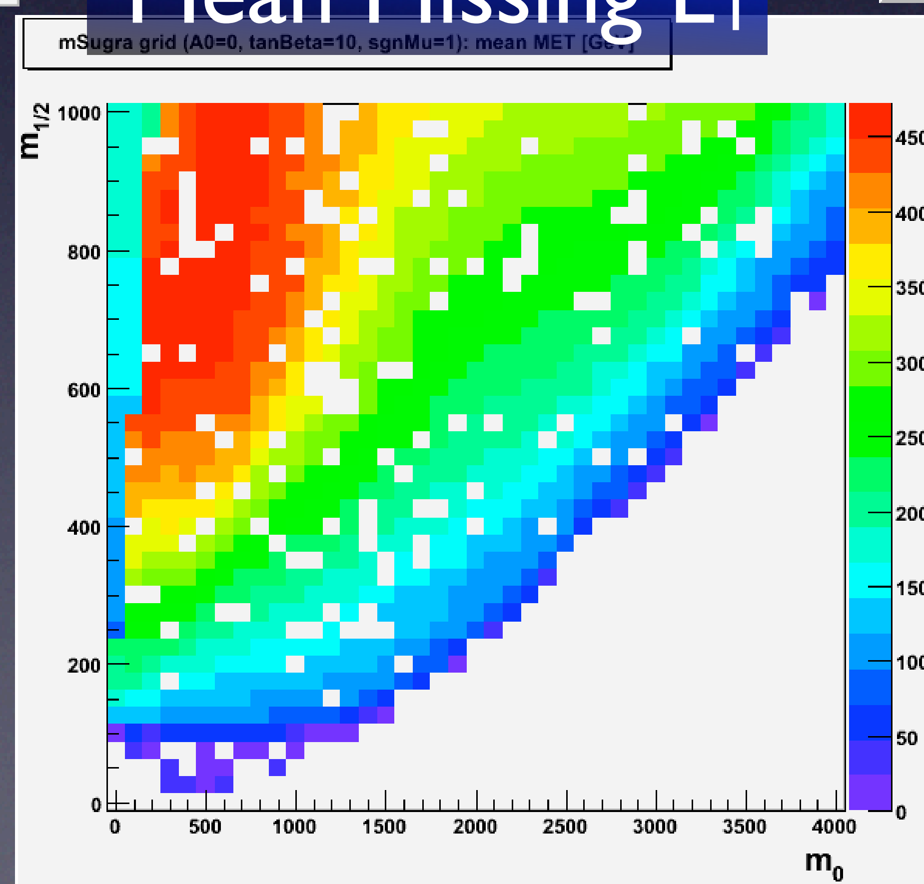
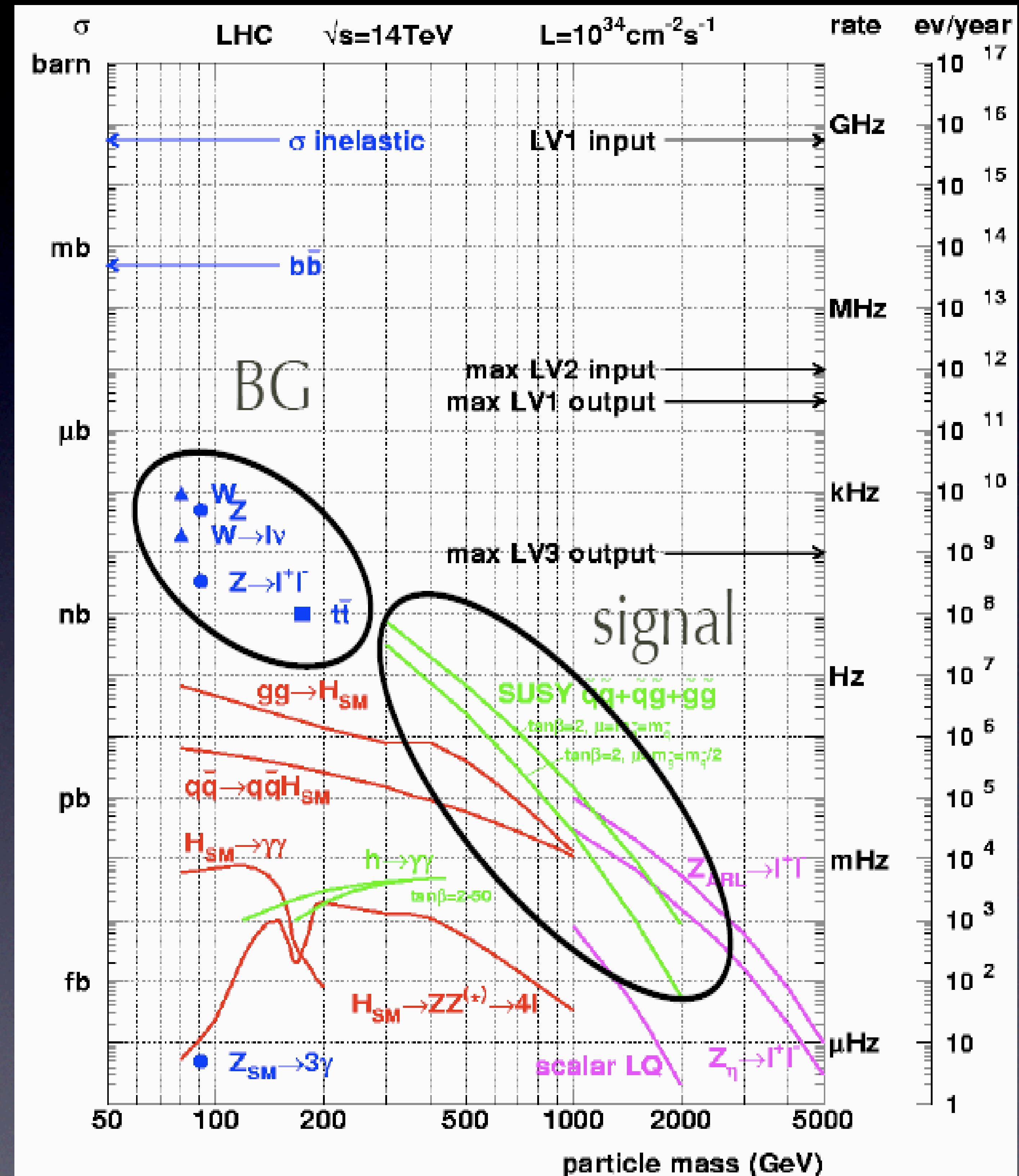


White (missing) SUSY grid points due to data transfer problems on *the* GRID

- Sensitivity is model/parameter dependent

Backgrounds

- SM signatures w/ large $\not{E}_T$, Jets, leptons
  - $Z \rightarrow \nu\nu$ + Jets
  - $W \rightarrow l\nu$ + Jets
  - $tt \rightarrow$ bb lν qq, bb lν lν
  - Missing lepton in W or top.
  - QCD
    - Large $\not{E}_T$ from neutrinos (b jets)
    - Fake $\not{E}_T$ (detector)
- SUSY is a background to SM backgrounds to SUSY... affects data driven bkg estimation techniques



Target: Winter 2009

- Question: what are the signatures which are most likely to indicate BSM physics, provided:
  - < 1/fb of data
  - imperfect understanding of
    - detector performance
    - standard model backgrounds
  - unmanageably large SUSY model/parameter space with variety of phenomenology.

Discovery Strategy

- What signature do we choose?
- WIMP DM ⇒ Assume RPC ⇒ MET ⇒ Main weapon against QCD backgrounds.
- Jets... balance:
  - Less jets: smaller SM background uncertainties (more on this later)... but more backgrounds.
  - More Jets: smaller backgrounds, but larger uncertainties.
- Leptons:
  - No/Less Leptons: larger x-section
  - More Leptons: less QCD backgrounds

Standard SUSY Analyses

- Require:
  - Large $\not{E}_T$ (> 100 GeV)
  - 4 Hard Jets
  - Sphericity?
- Look at: $M_{eff} = \sum^4_{jets} p_T + \not{E}_T$

for N=0,1,2 (SS/OS) leptons

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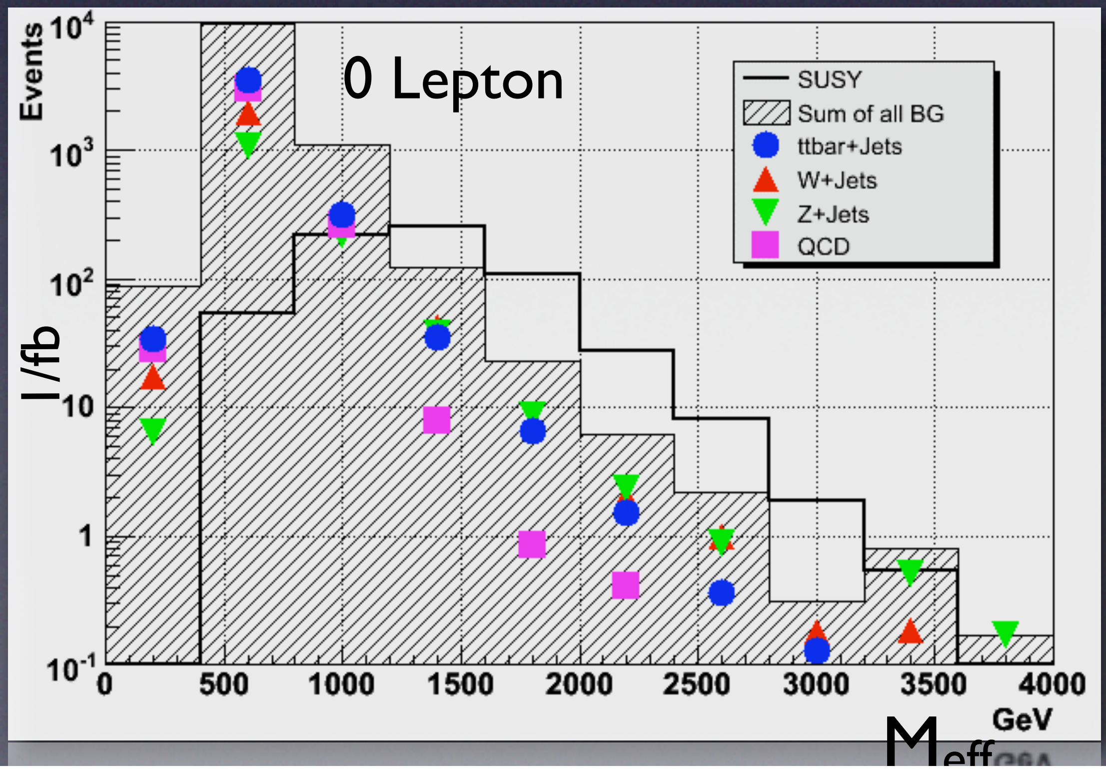

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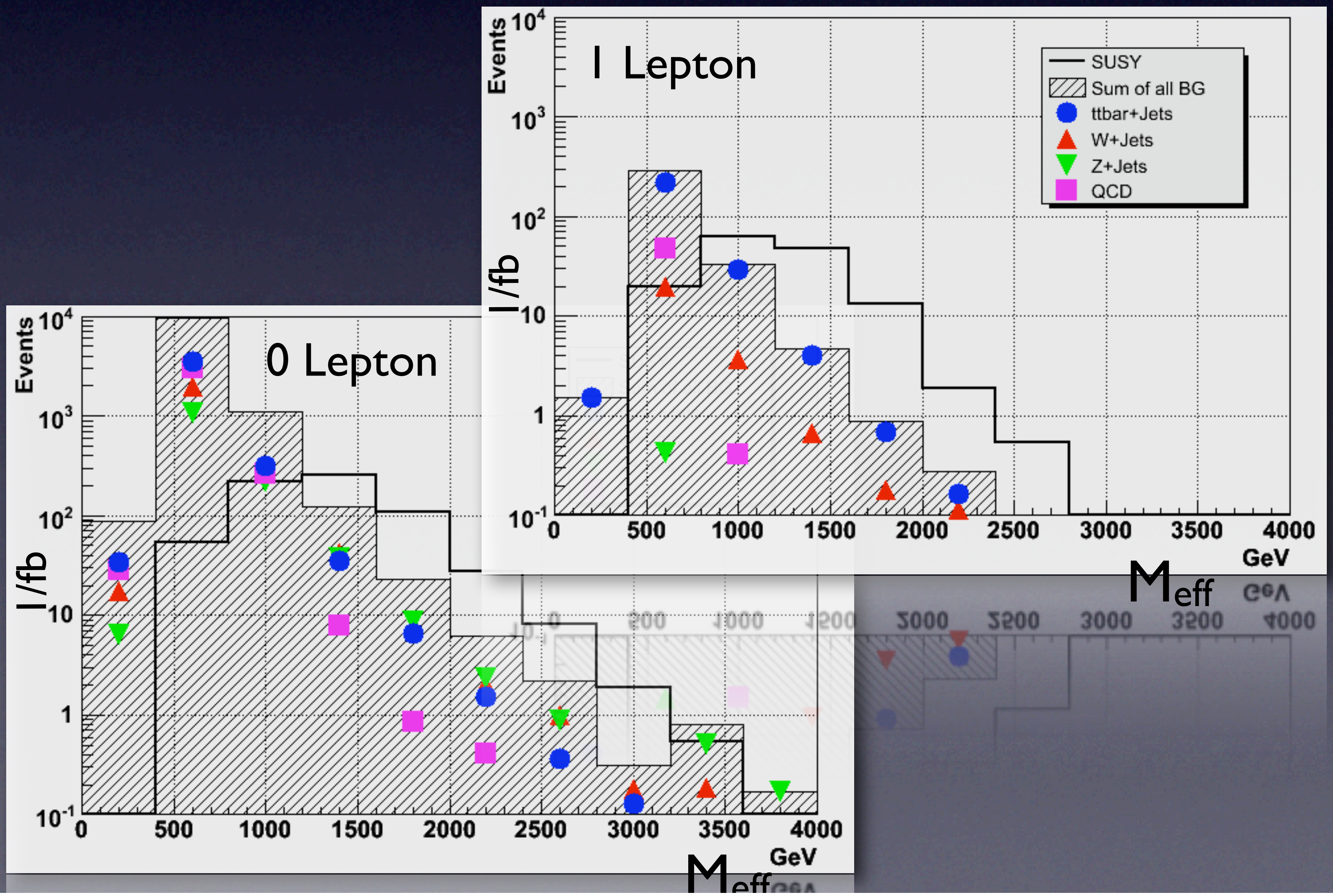

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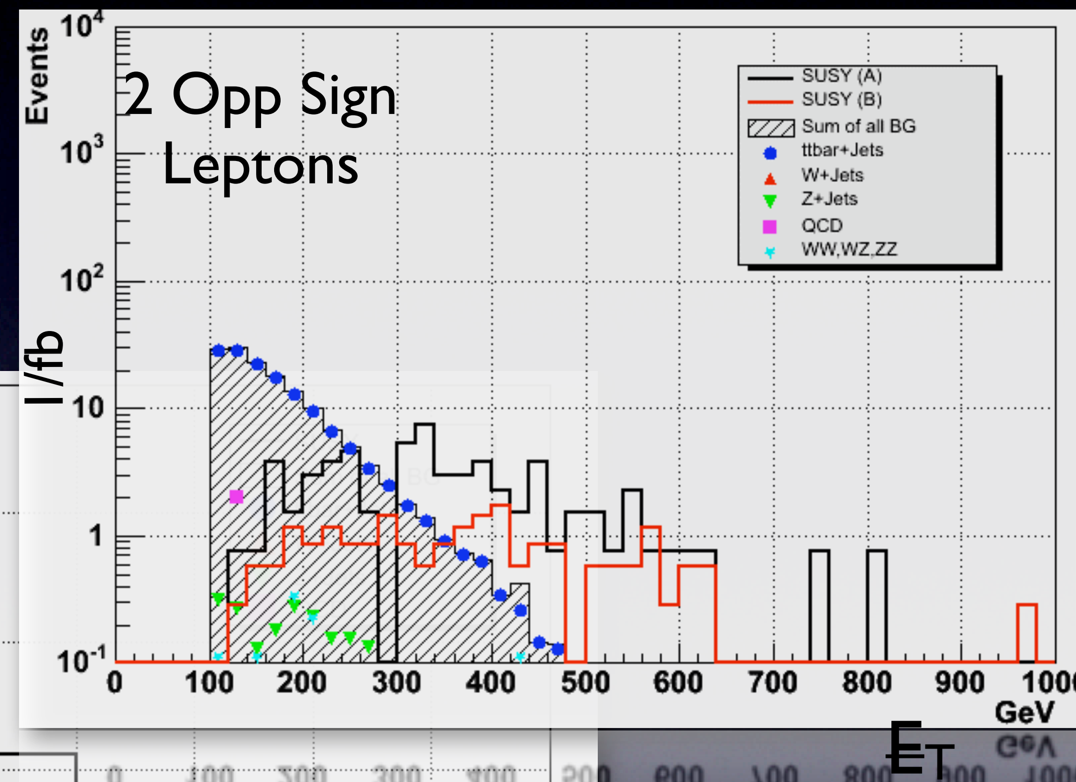

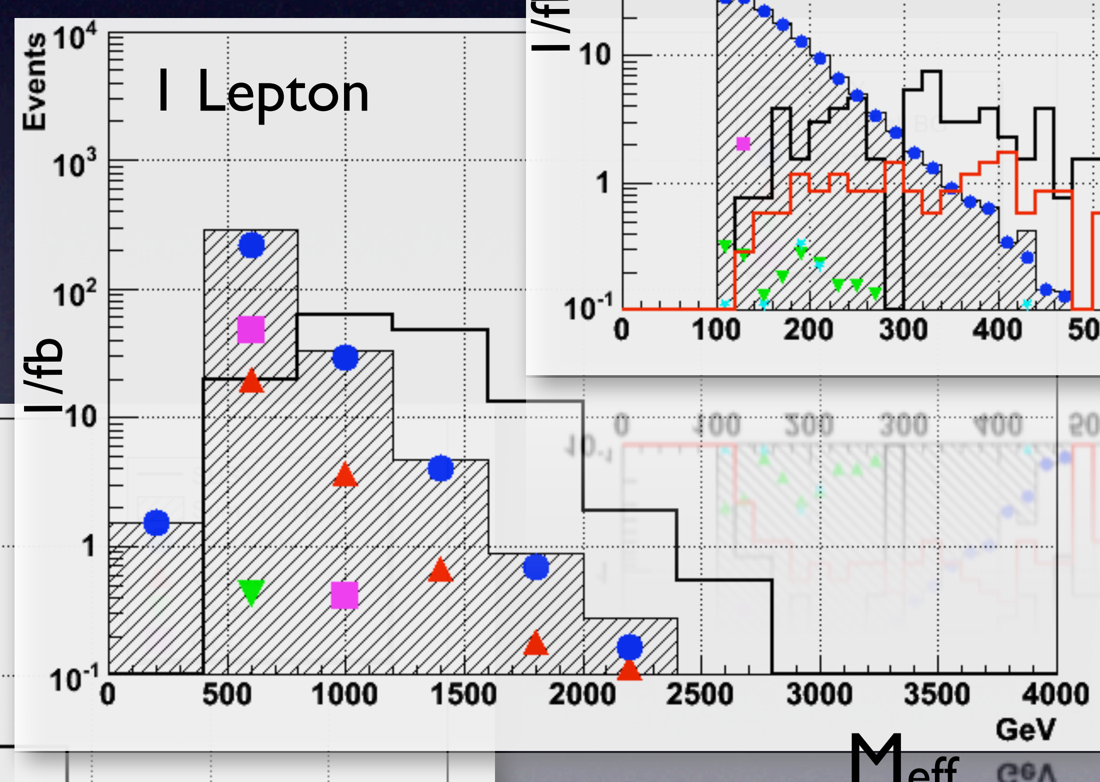

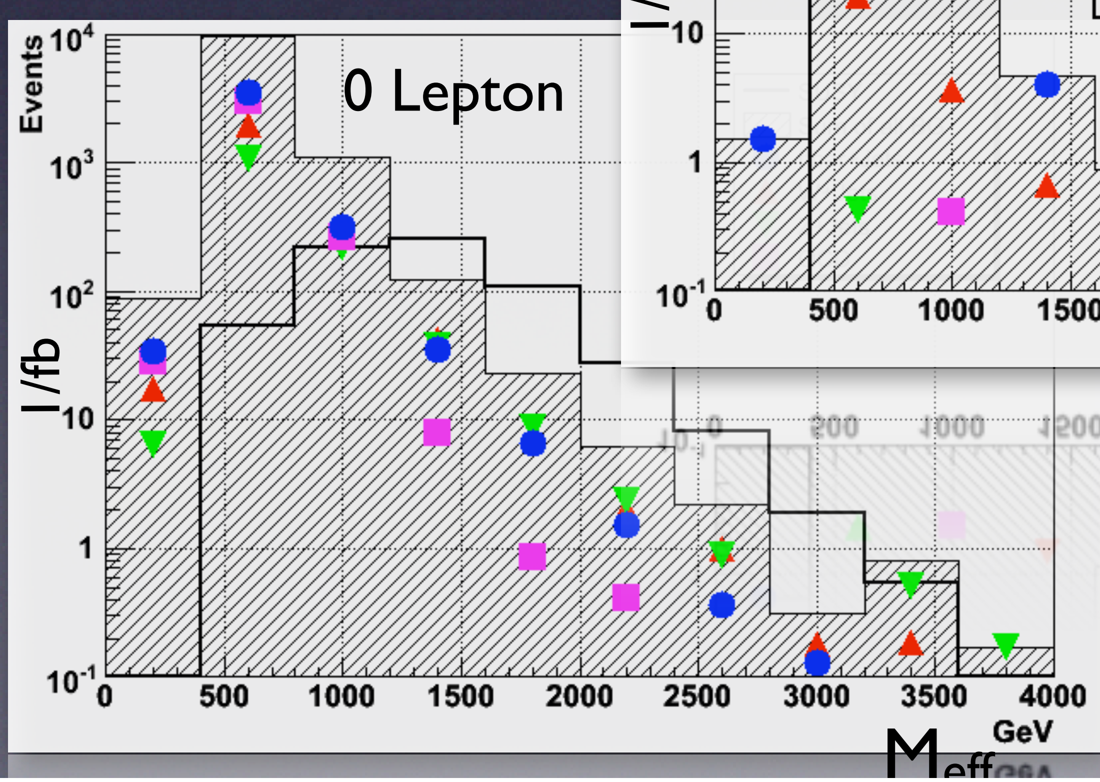

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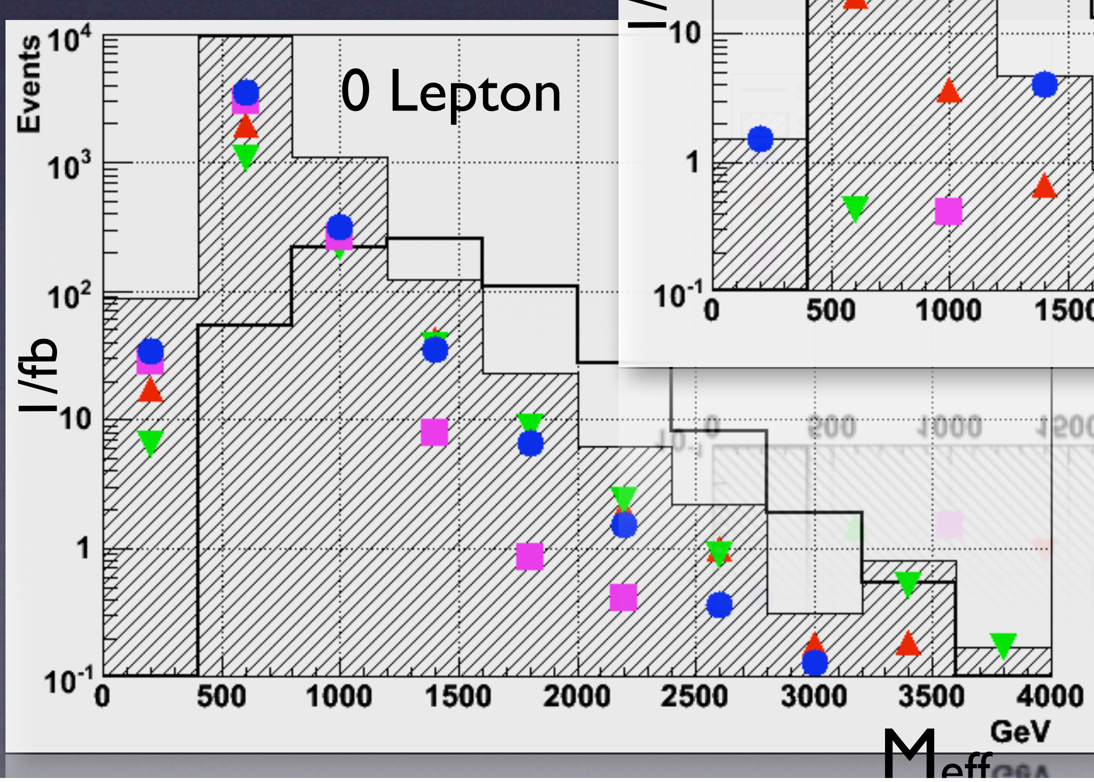

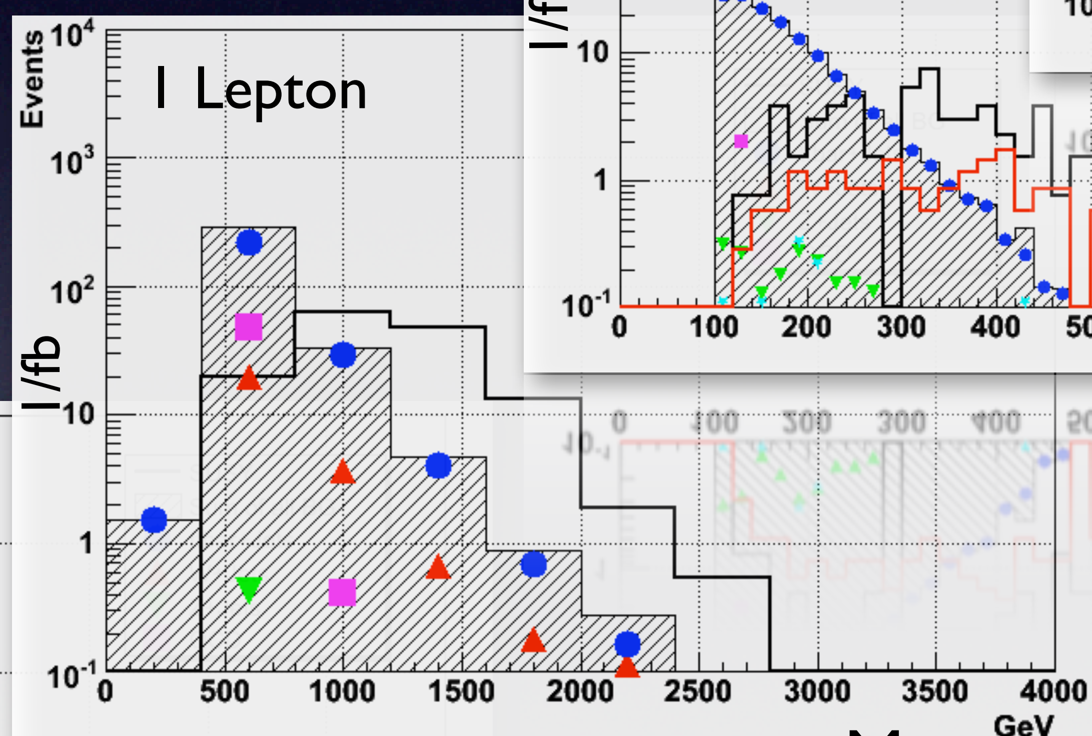

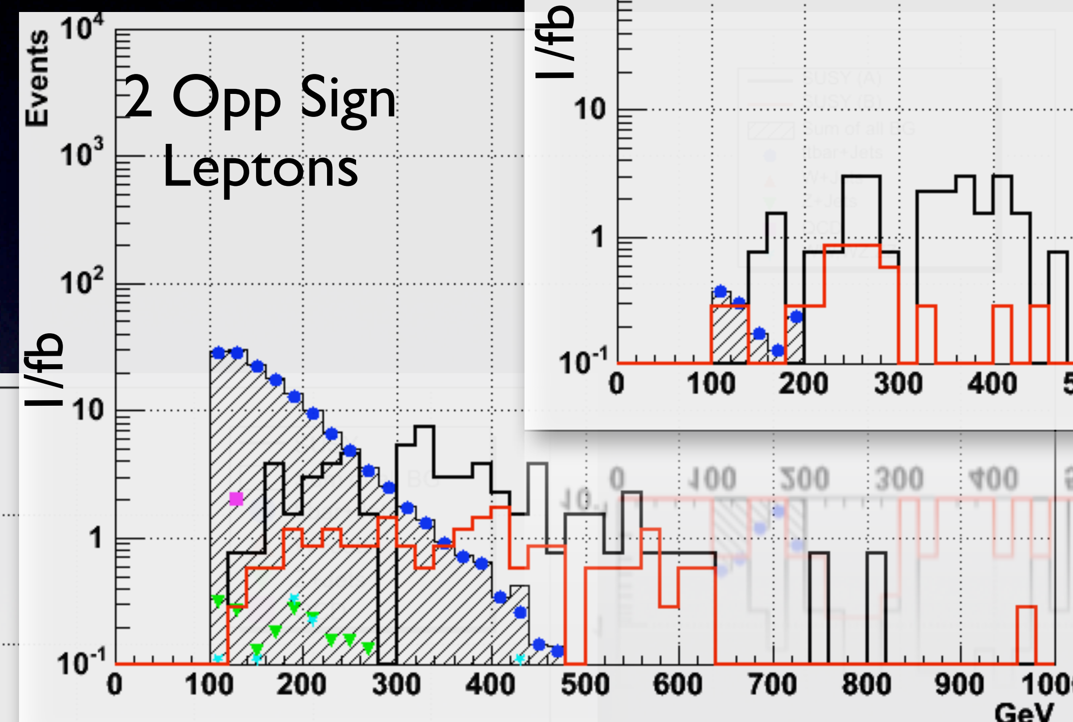

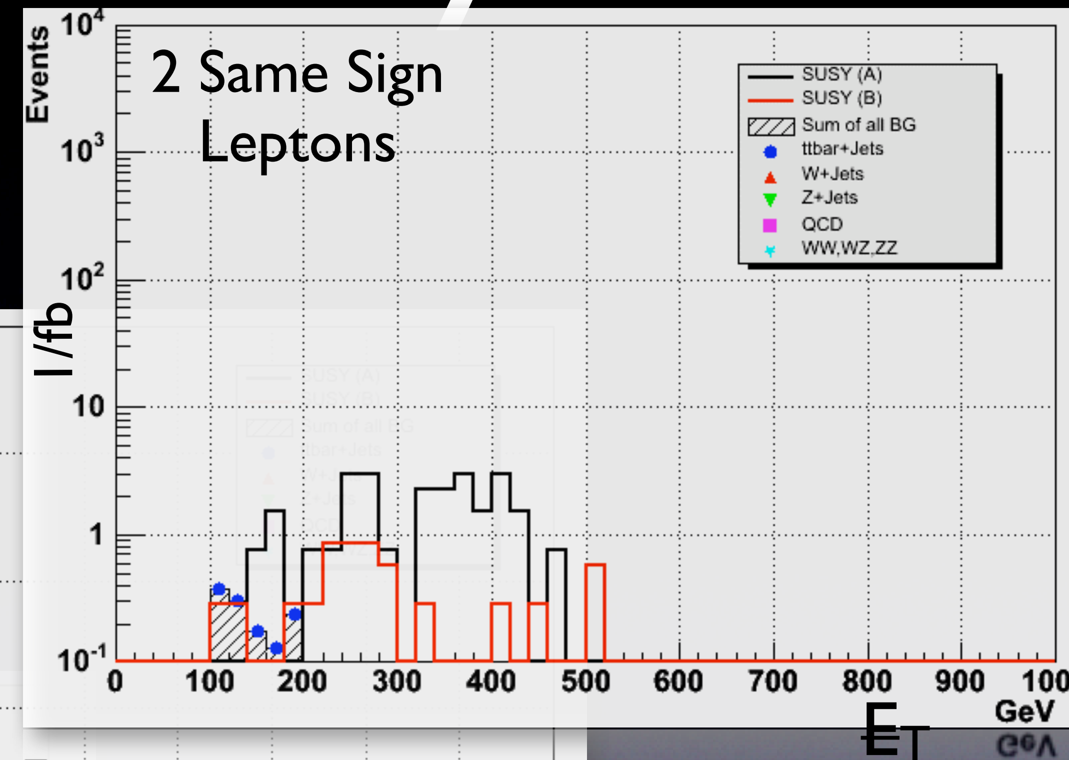

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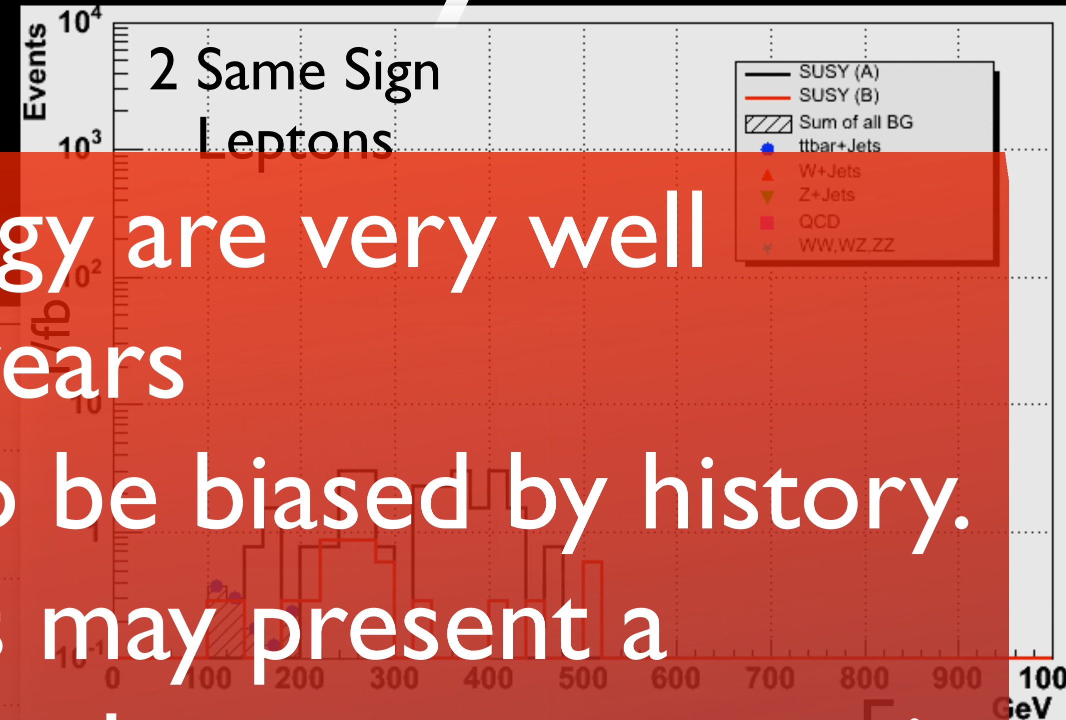

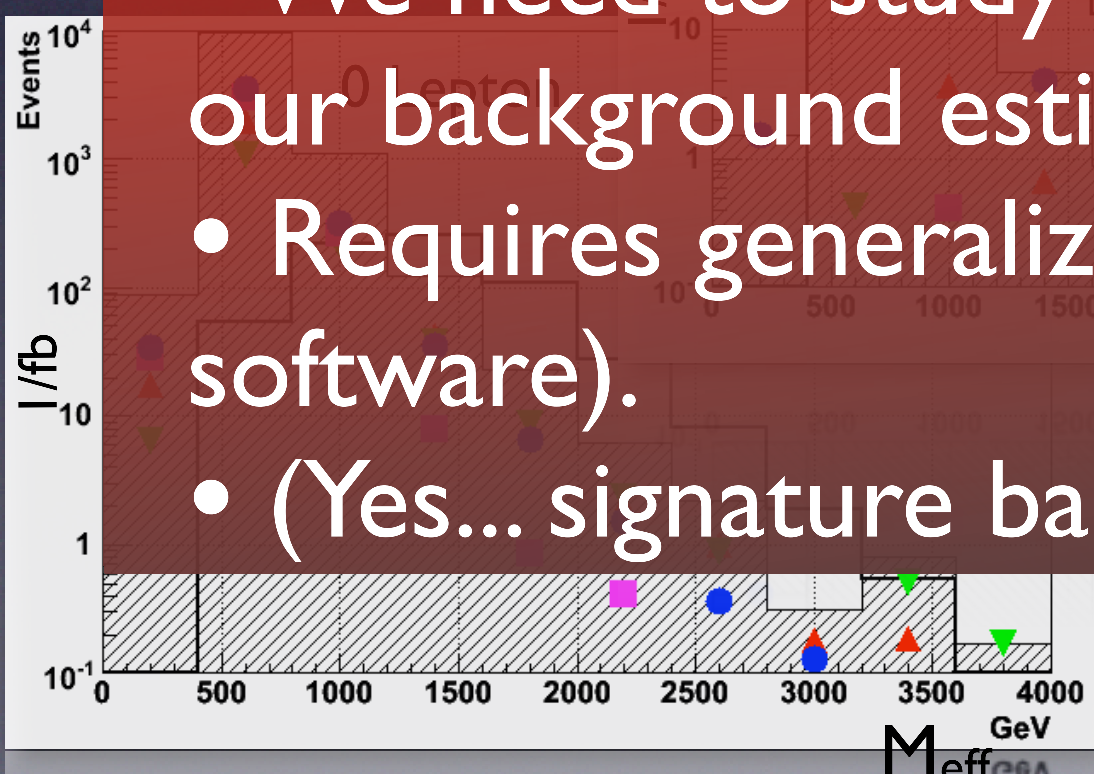

- Adding Leptons reduces QCD Background
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- MET + 4 Jets [+ leptons] strategy are very well motivated and been studied for years
- But we should be careful not to be biased by history.
- Ex: 2 or 3 Jets + MET + leptons may present a promising balance of statistical reach versus systematic on backgrounds.
  - We need to study these regions anyway as we test our background estimation
  - Requires generalizing our approaches (good software).
  - (Yes... signature based searches).

Nature may not be kind

- Many regions of model/parameter space (eg large tan β) where τ decay dominate

➡ leptonic τ decays make e,μ analyses still sensitive even if τ reconstruction isn't ready

- Degenerate sparticle masses produce softer jets, leptons, and MET

➡ Harder to isolate SUSY signal... generally requires more data and much better background understanding

- R-parity conserve... similar to above

- SUSY may present special features: photons not from IP, heavy charged tracks, kink tracks, R-hadrons, long life-times

➡ some preserve or mimic the standard SUSY scenario

➡ efforts to ensure proper detection (and triggering) of such signatures

- No SUSY at TeV scale... other new physics scenarios often produce similar signatures.

Nature may not be kind

- Many regions of model/parameter space (eg large tan β) where τ decay dominate
  - ➡ leptonic τ decays make e,μ analyses still sensitive even if τ reconstruction isn't ready

- Such scenarios typically require more data and good understanding of detector/backgrounds.
- Ultimately all will be explored...
- But obviously the best bet in the very beginning is looking for the standard scenarios

- Degenerate sparticle masses produce softer jets, leptons, and [illegible]
  - ➡ Harder to isolate SUSY signal... generally requires more data and much better background understanding
- R-parity conserve... similar to above
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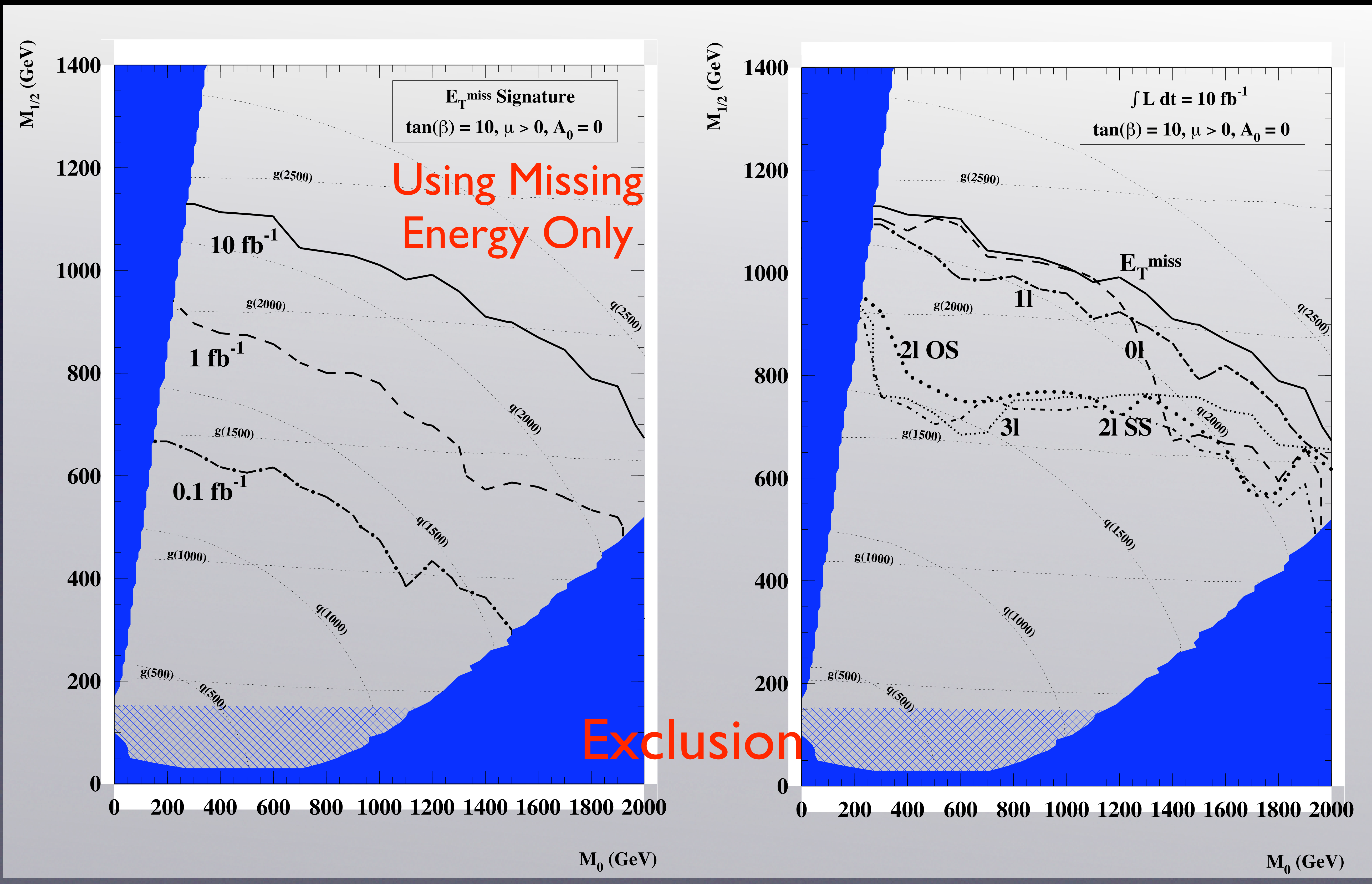
Sensitivity



SUSY Discovery Strategy

SUSY Discovery Strategy

- It will take steps:

SUSY Discovery Strategy

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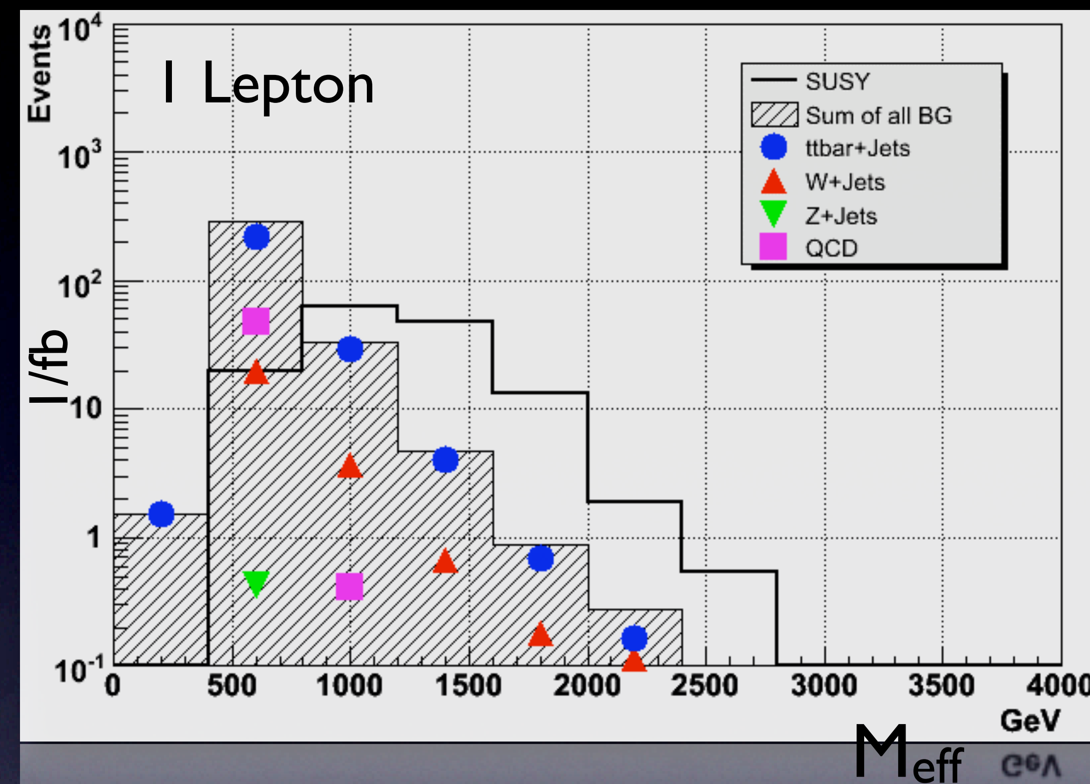
  - Inclusive searches ⇒ Beyond SM Discovery.



SUSY Discovery Strategy

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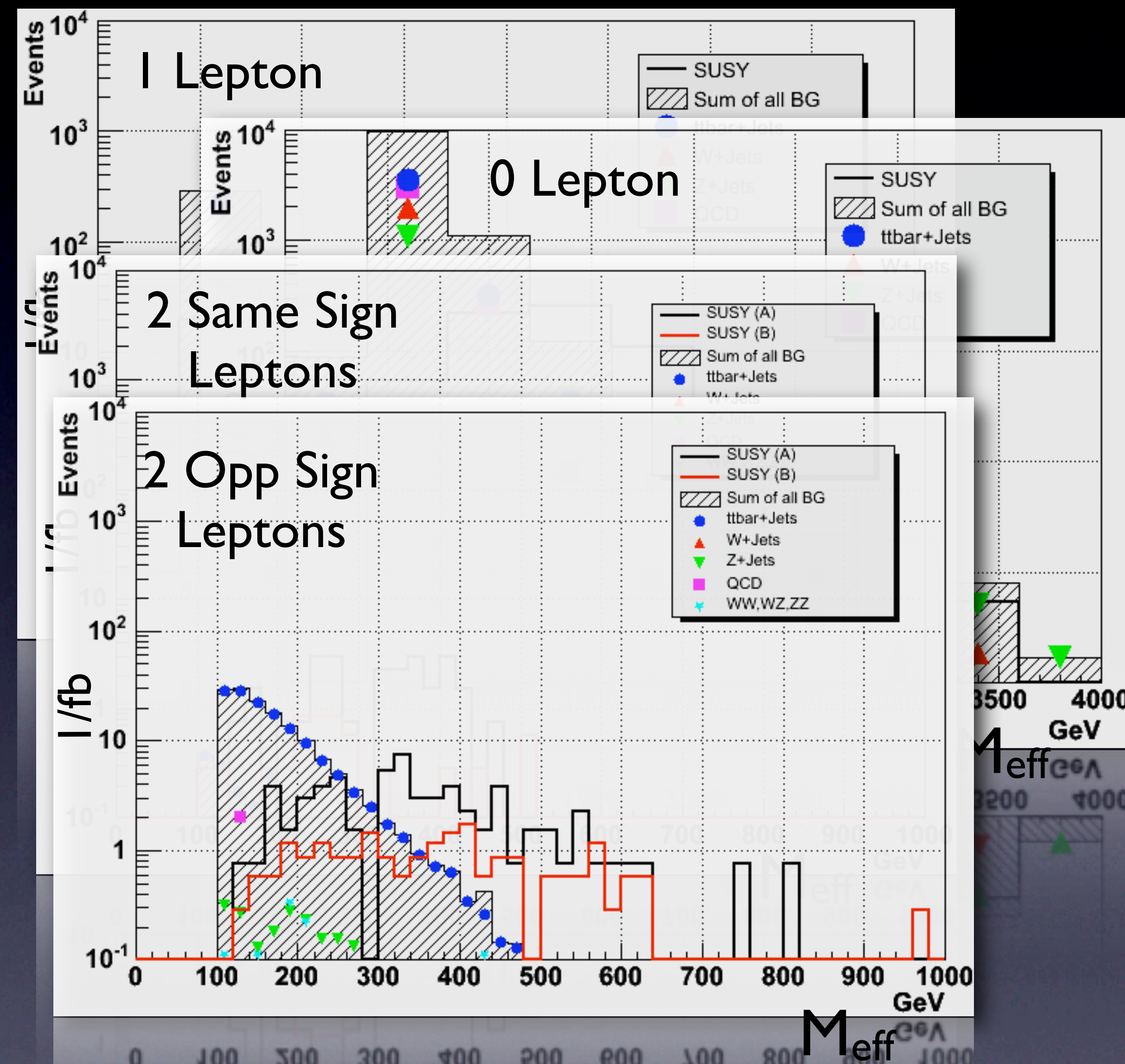
  - Which inclusive channels at what rates? ⇒

    Characterization



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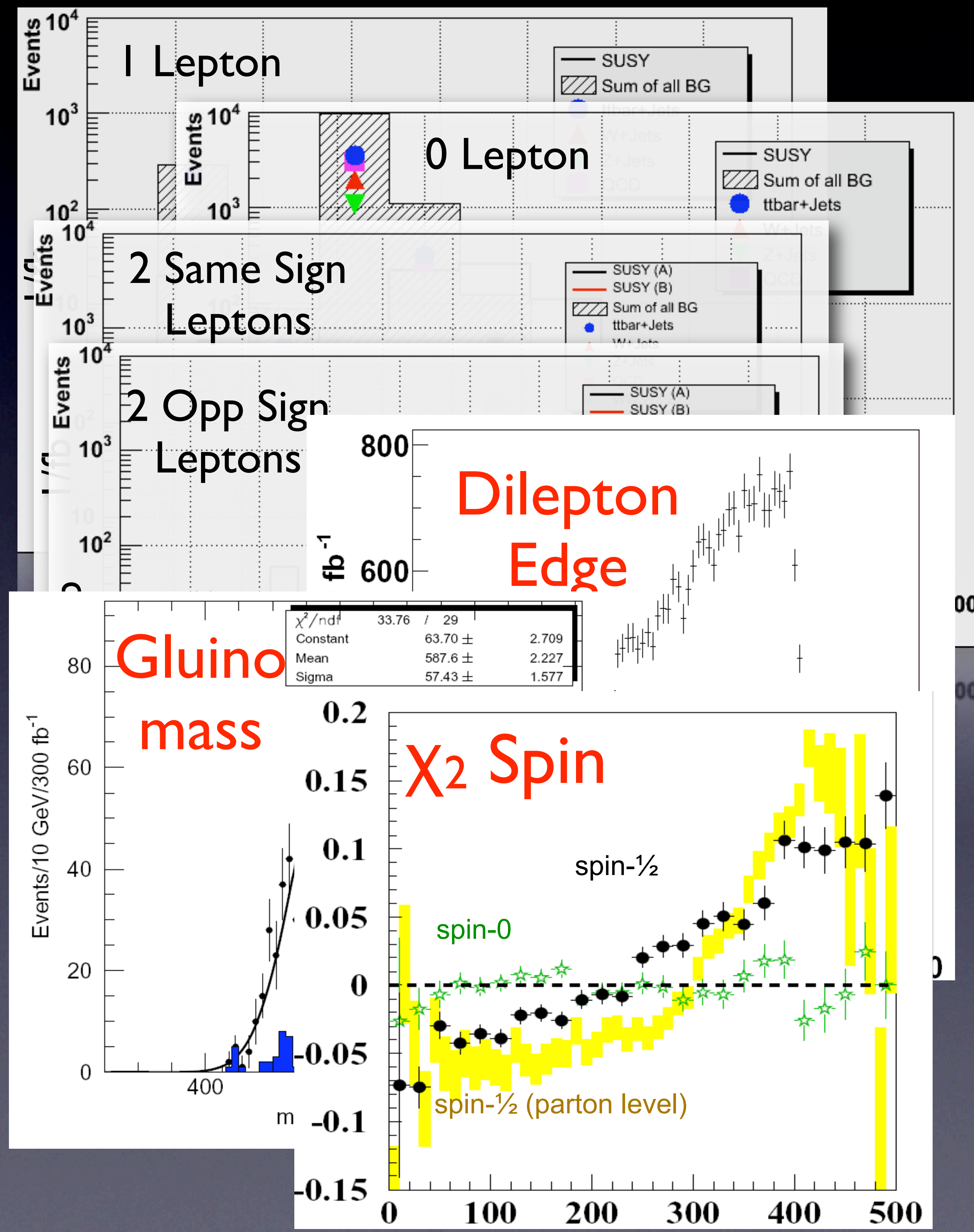
  - With sufficient data start reconstructing masses, decay rates, spins ⇒ is it SUSY?



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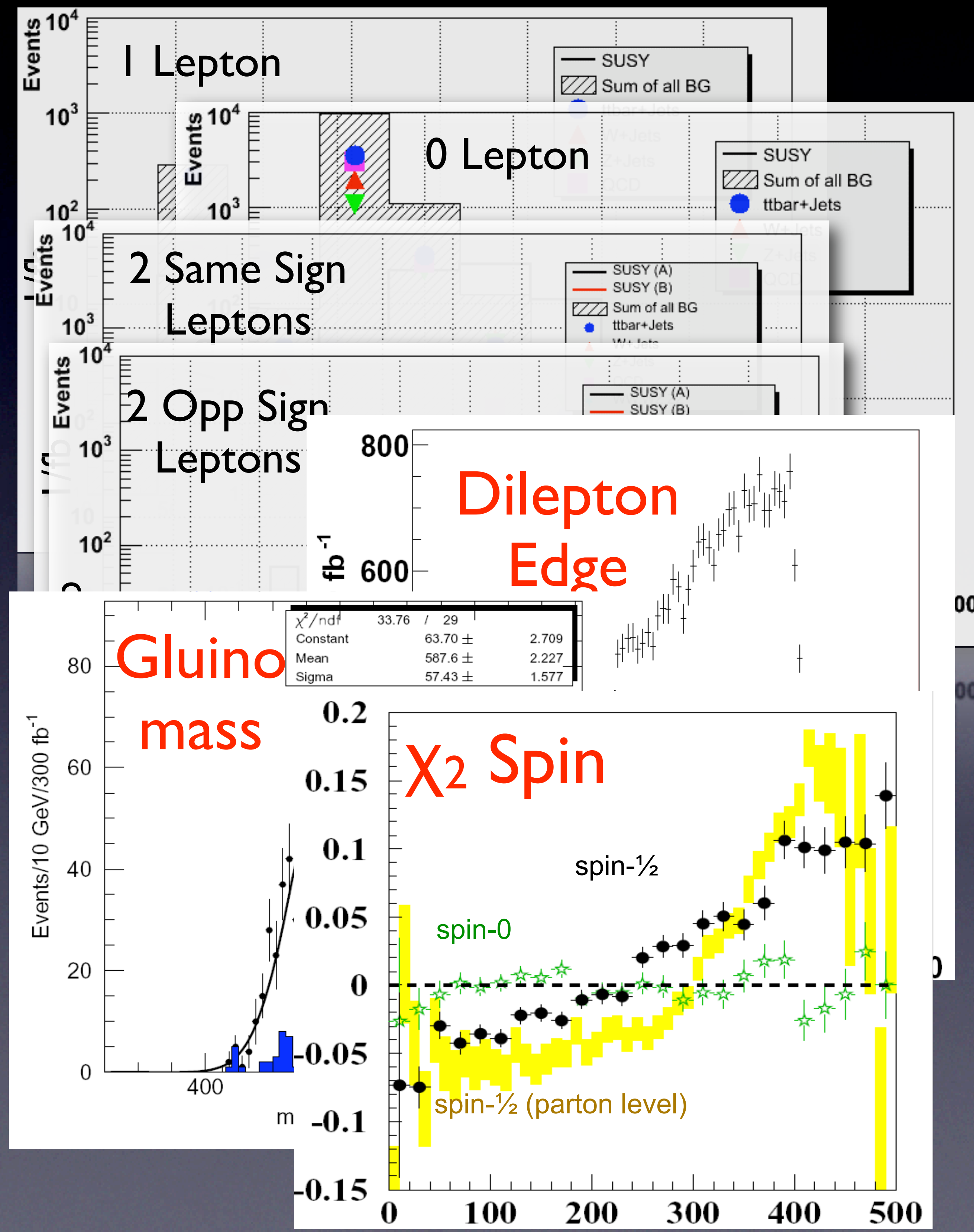

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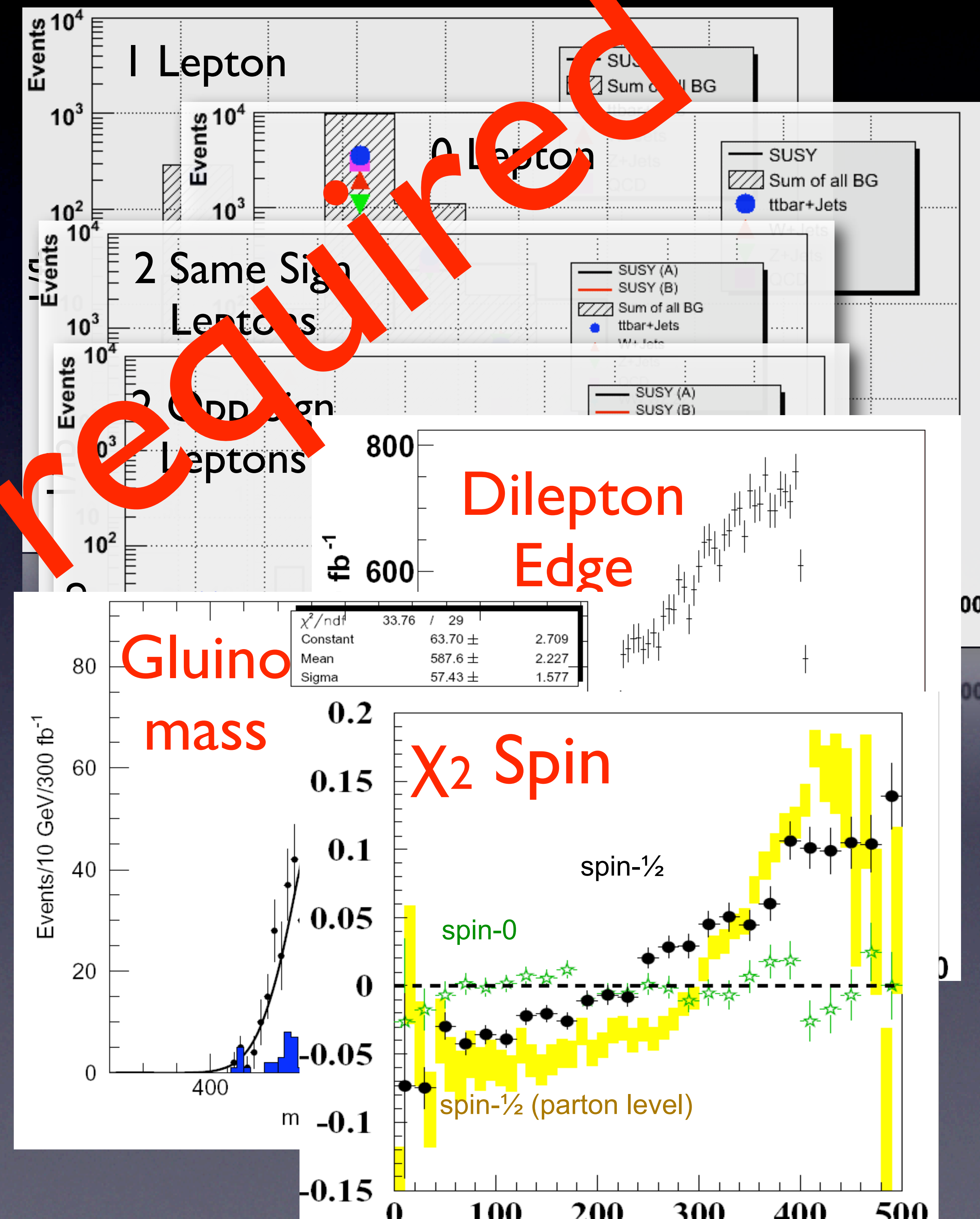
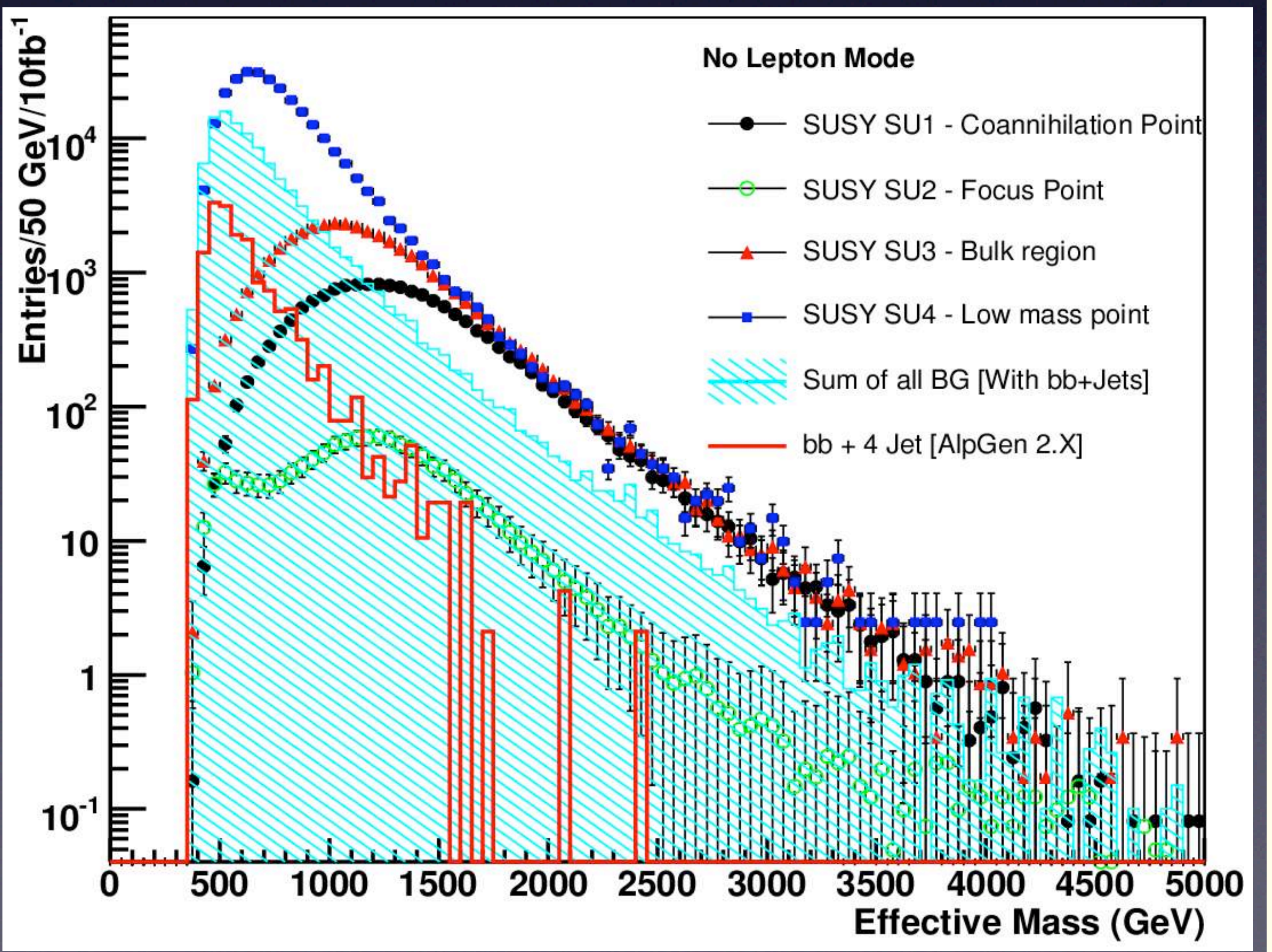
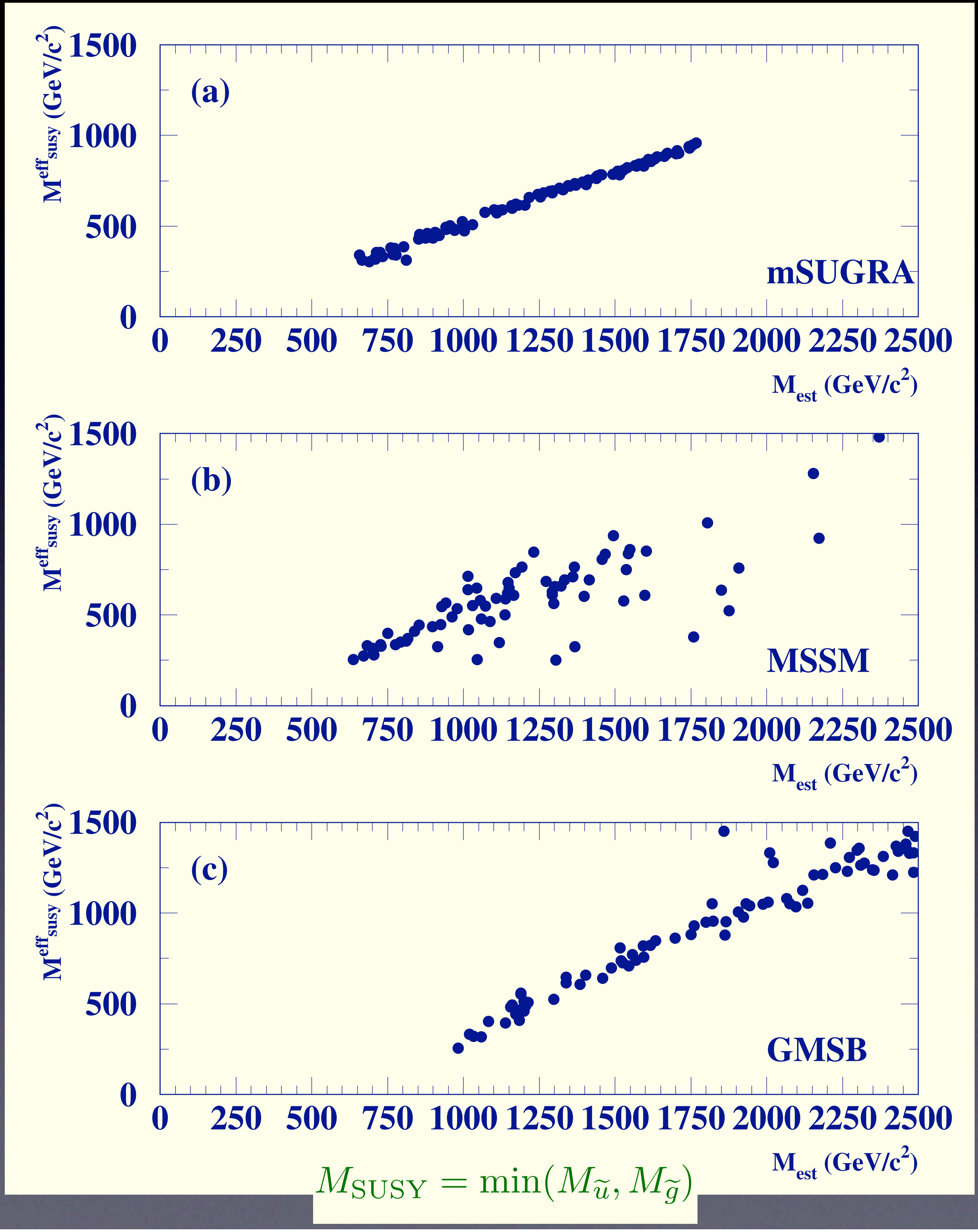


First Steps After Discovery

- M_{eff} peak correlated with SUSY "scale"
- The pattern/rate helps direct where to look next.





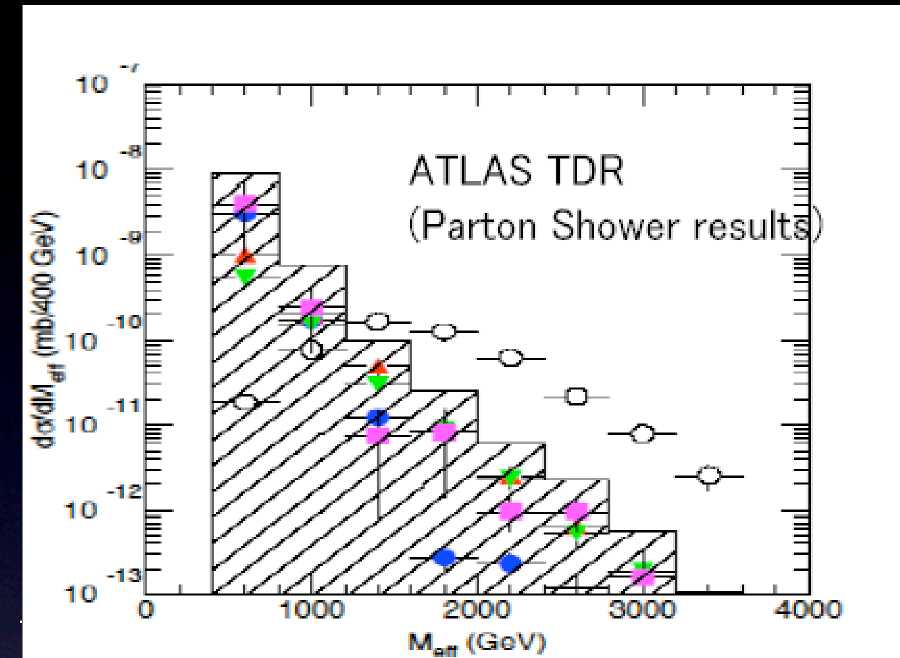
Estimating Backgrounds

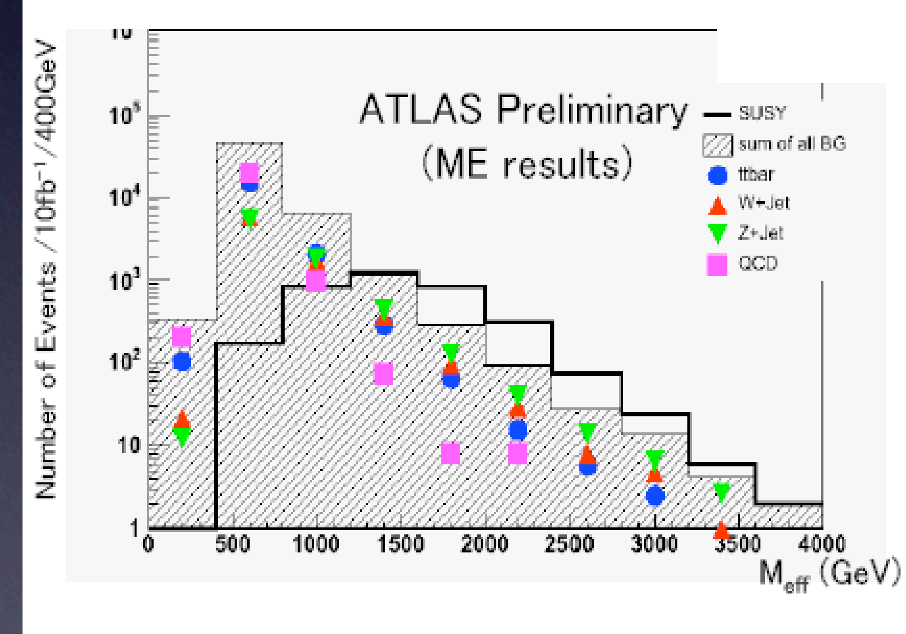
- While SM decay processes (t, W, Z) are understood, production is not.
- Parton Distribution Functions, Underlying event, hard-scatter not tuned at 14 TeV
- And it gets harder when final state has lots of jets... which is the case for SUSY bkgs.

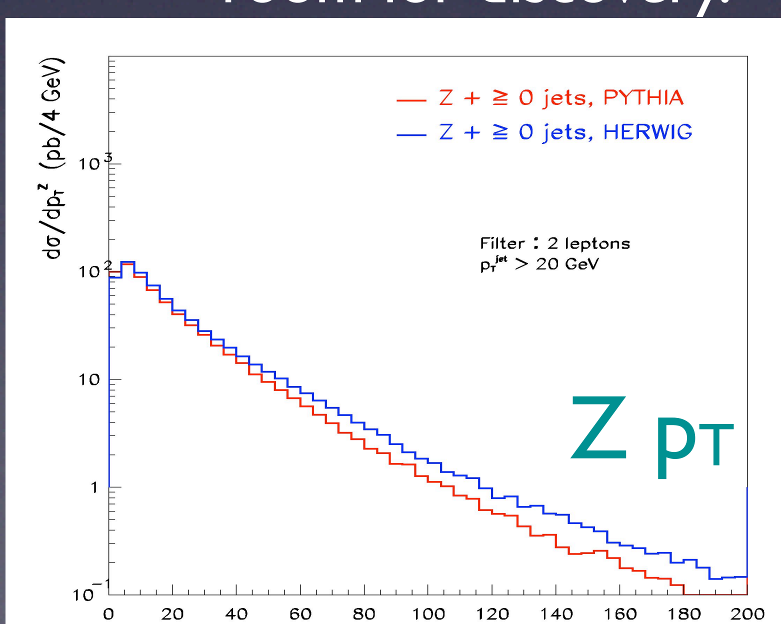
➡ Large uncertainties in cross-sections and kinematic distributions

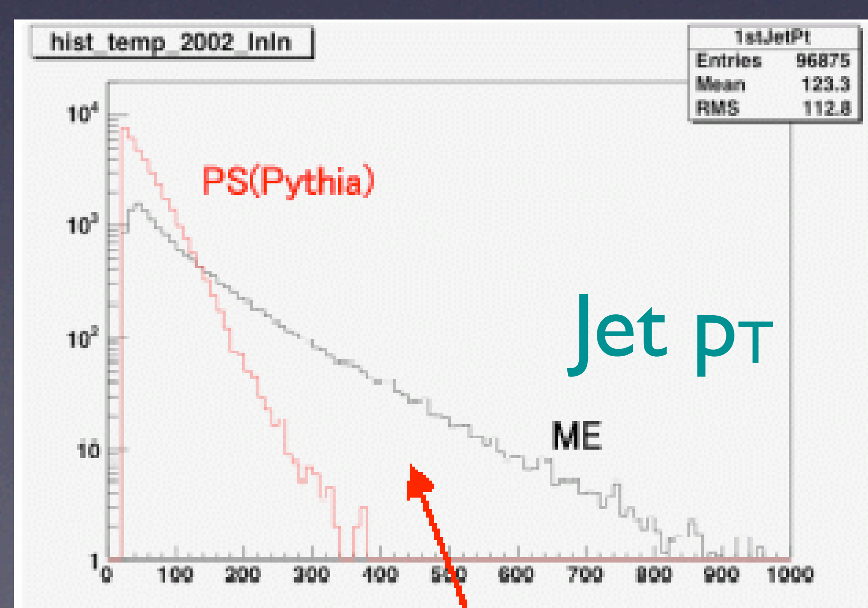
➡ Cannot rely only on MC to estimate backgrounds

➡ Fortunately 100% error on background rates still leaves room for discovery.









Background Estimation Strategies

- Monte Carlo estimates:
    - Make lots of SM measurements, retune the best MC ⇒ make new samples ⇒ estimate your background... long process
    - Just try lots of tuning of the MC, compare with data ⇒ systematics...
    - Re-weight you MC with data...
- Data driven estimates which minimize dependence on MC:
    - Extrapolate from signal free → signal rich regions
    - Replace one decay (eg $Z \to ll$) with another (eg $Z \to \nu\nu$)
    - Re-decay: Reconstruct one decay (eg $tt \to bqq\ bl\nu$), replace a piece w/ another decay from MC (eg $bqq \to bl\nu$ results in $tt \to bl\nu\ bl\nu$).

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Extras:
Data driven SUSY background estimation techniques

Background Estimation Strategies

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  - Replace one decay (eg Z→ll) with another (eg Z→νν)
  - Re-decay: Reconstruct one decay (eg tt→bqq blν), replace a piece w/ another decay from MC (eg bqq→blν results in tt→blν blν).

- There really isn't any purely data or MC driven background estimation technique.
- MC or data driven, we must reconstruct lots of SM signatures in data.

Extras:
Data driven SUSY background estimation techniques

Data Control Samples

Red=Missing

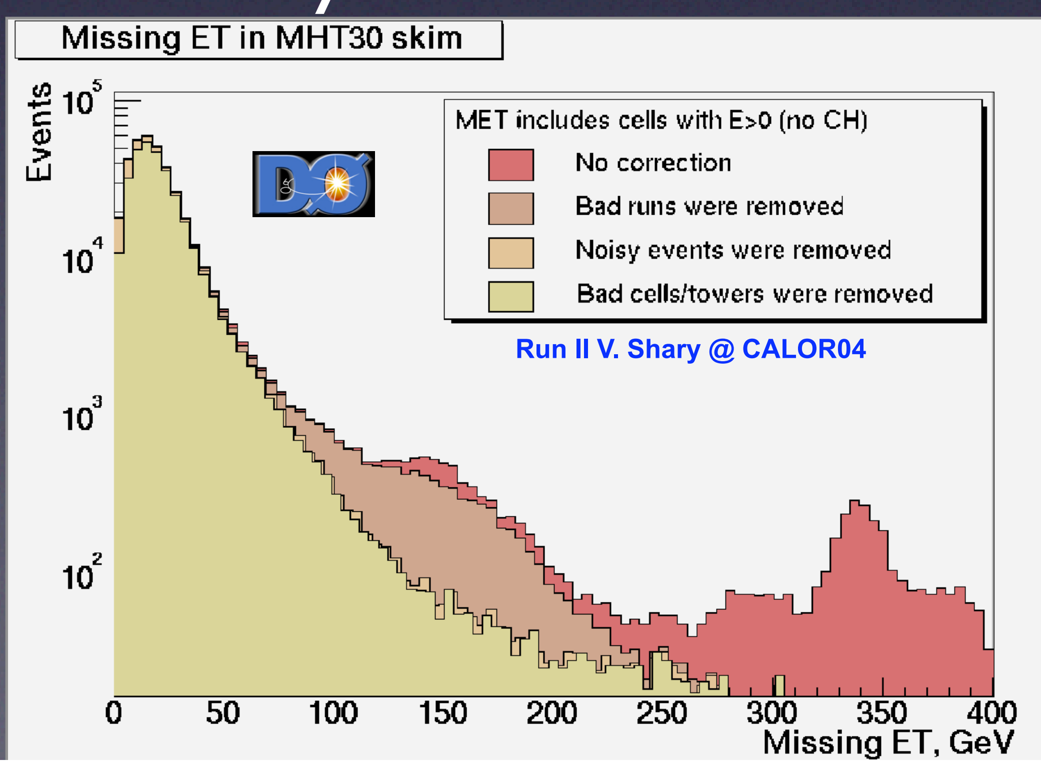
Control	Target
$Z \to ll$ + Jets	$Z \to \nu\nu$, $Z \to \tau\tau$, $W \to l\nu$, $W \to \tau\nu$ (All + Jets)
$W \to l\nu$ + Jets	
$tt \to bbqql\nu$ (leptonic t reco only)	$tt \to bbqql\nu$, $bbqq\tau\nu$
$tt \to bbqql\nu$ (full reco)	$tt \to bbl\nu l\nu$, $bbl\nu\tau\nu$, $bb\tau\nu\tau\nu$
$tt \to bbl\nu l\nu$ (full reco)	$tt \to bbl\nu l\nu$, $bbl\nu\tau\nu$, $bb\tau\nu\tau\nu$

Data Control Samples

- SM Backgrounds are produced copiously enough at LHC to create good control samples.
- The different SM control samples are often backgrounds to each-other ⇒ complicates things...
- The general trick is replacing a lepton with neutrino, τ, or missing lepton.
- Understanding lepton efficiency, acceptance, fake-rate in data is a key prerequisite. Requires:
  - Extrapolating lepton performance assessed in the clean $Z \rightarrow ll$ events to the much busier top, Z/W+jet environment.
  - Modelling how leptons are missed.
  - Isolating samples of Jets to assess lepton fake rate.

Understanding Detector

- MET is a garbage collector.
- Understanding jet response is critical.
- Avoid/understand:
  - The hardware
  - cracks
  - funny events



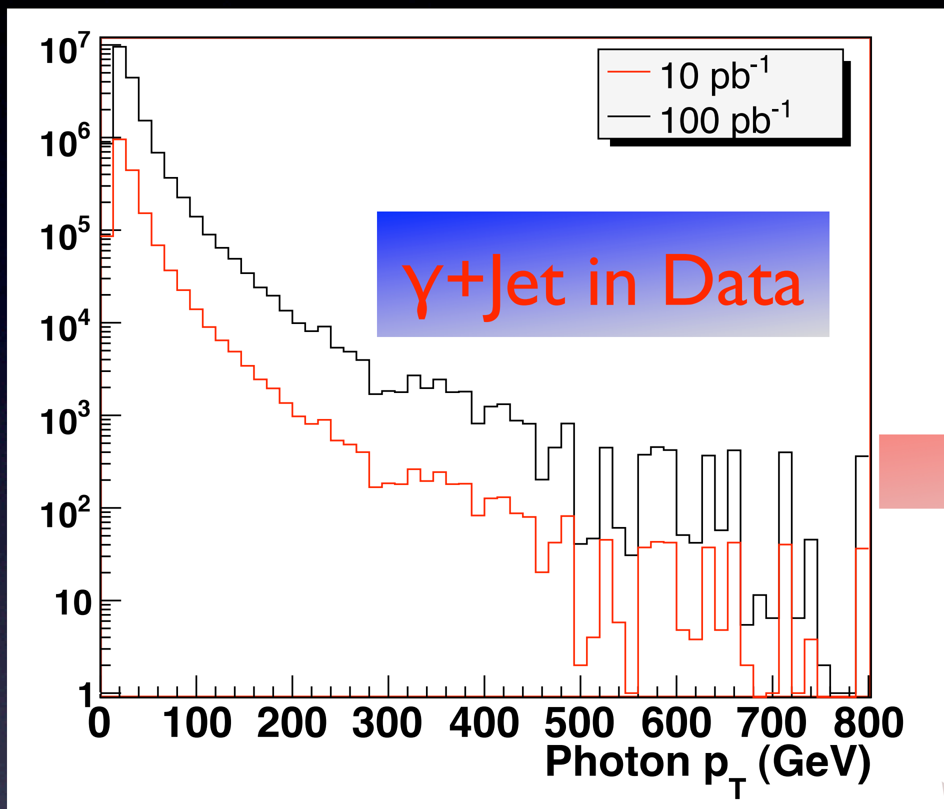
Example

Jet Calibration with Data

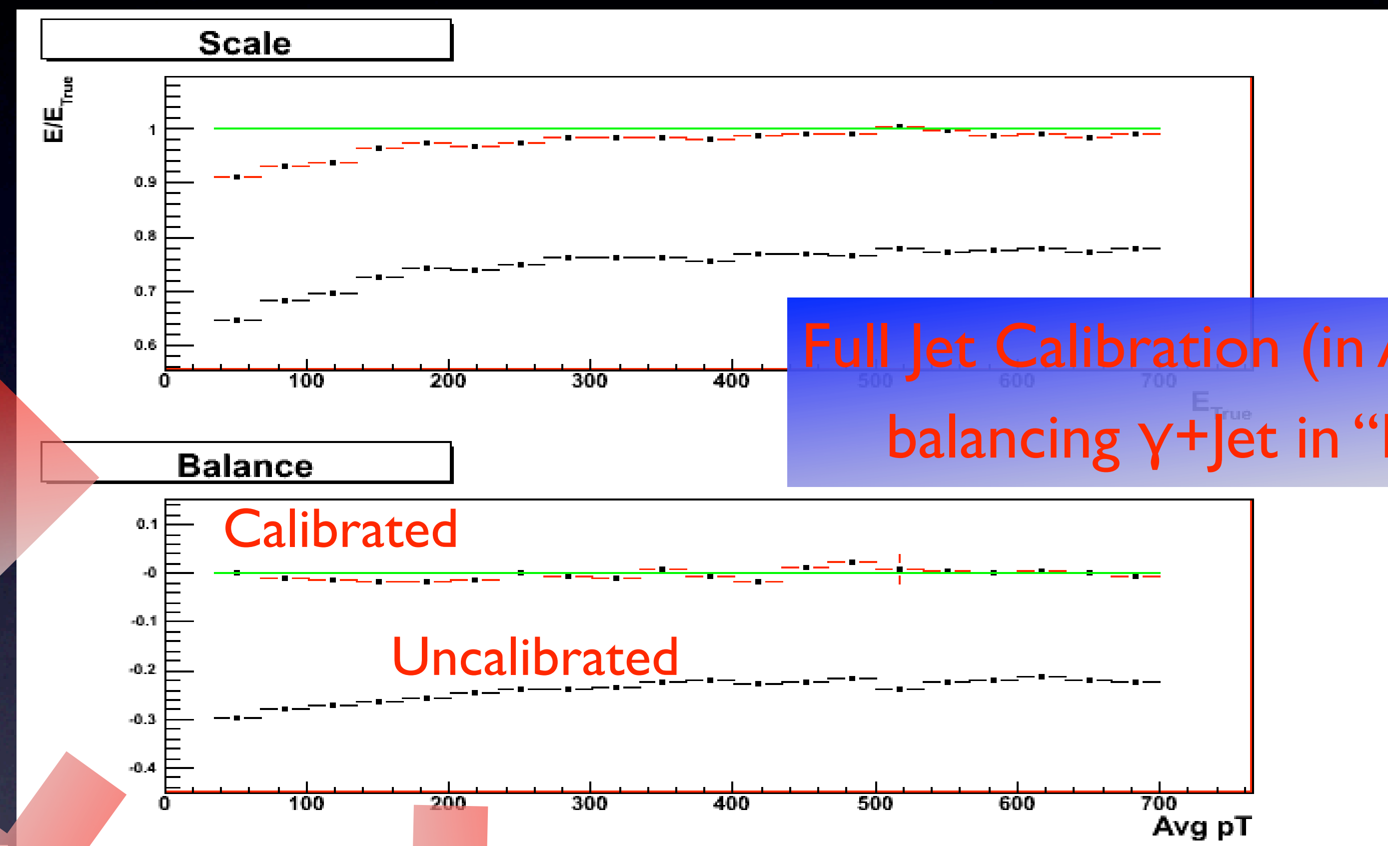
- The primary ATLAS Jet Calibration strategy is rather ambitious
  - Relies heavily on Geant 4 simulation
  - Aims for obtaining optimal performance...
  - Not necessary for SUSY discovery.
- Determining scale and understanding performance is most critial for SUSY... don't need perfect performace.
- Rely on momentum conservation... balance: γ+Jet for scale, dijet for uniformity, 2 jet+jet (boot-strap) for high p_T, Z+Jet for validation/systematics
- Simultaneously calibrate and measure resolution & tails
- Use measured jet response for fast simulation

Example

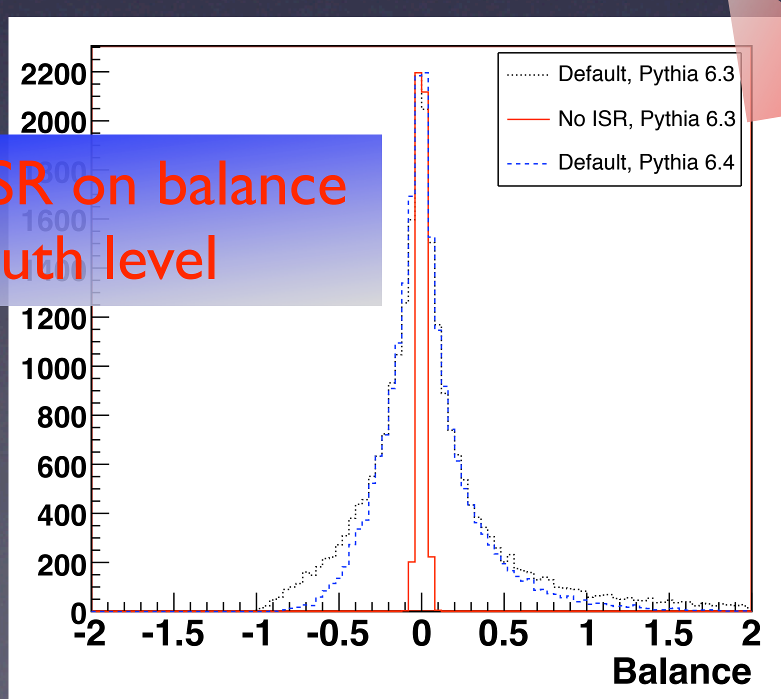
Jet Calibration with Data



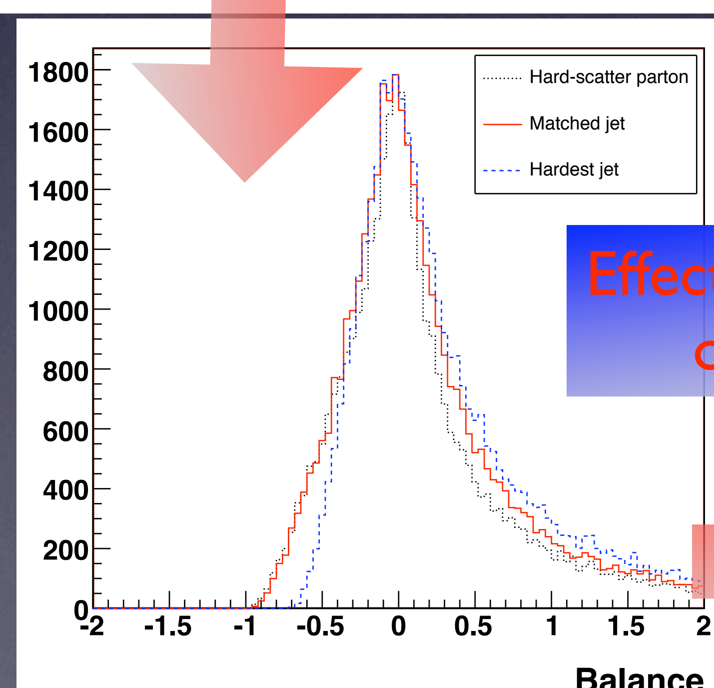
γ+Jet in Data



Full Jet Calibration (in AOD) by balancing γ+Jet in "Data"



Effect of ISR on balance on truth level



Effect of Jet Alg/selection on truth balance

Build better model

From Data to Measurement

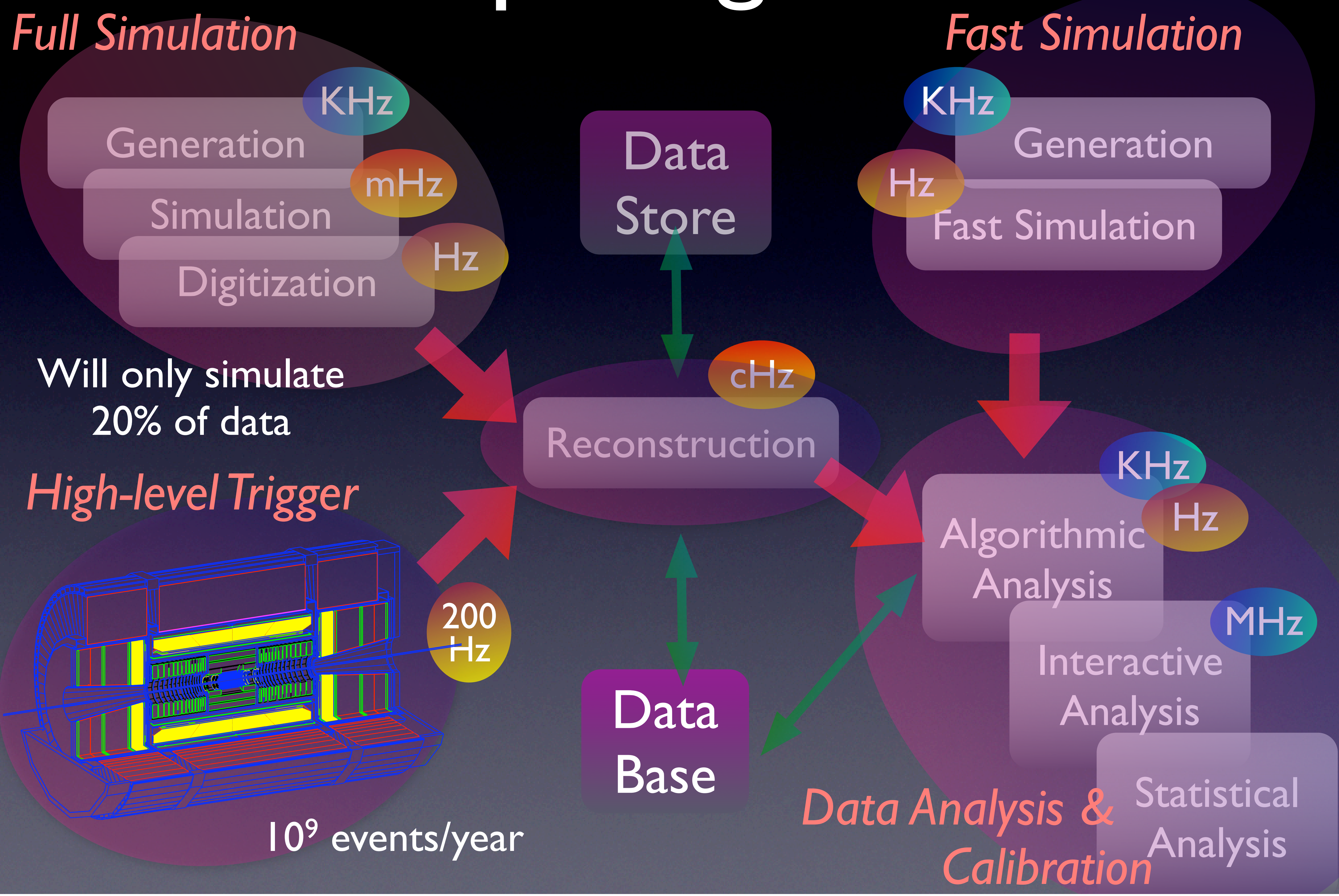
- Early SUSY discovery analyses will need to be comprehensive:
  - Detector sub-systems, reconstruction algs, calibrations: Electrons, Muon, Jets, Missing Energy.
  - Issues: efficiencies/acceptance, fake rates, scale, resolution, tails.
  - Data: must ultimately analyze most of the collected data samples: W (+Jets), Z (+Jets), top, Jet+Jet, γ+Jet.

  ➡ Key is understanding and controlling systematics... not precision. Different priorities than SM, top, or Higgs measurements.

  ➡ These is work should be done with in the context SUSY.
- Once the data is recorded extracting results is a matter of
  - man-power + organization
  - software + computing infrastructure
- Early discovery (eg by winter 2009) is contingent on preparation today.

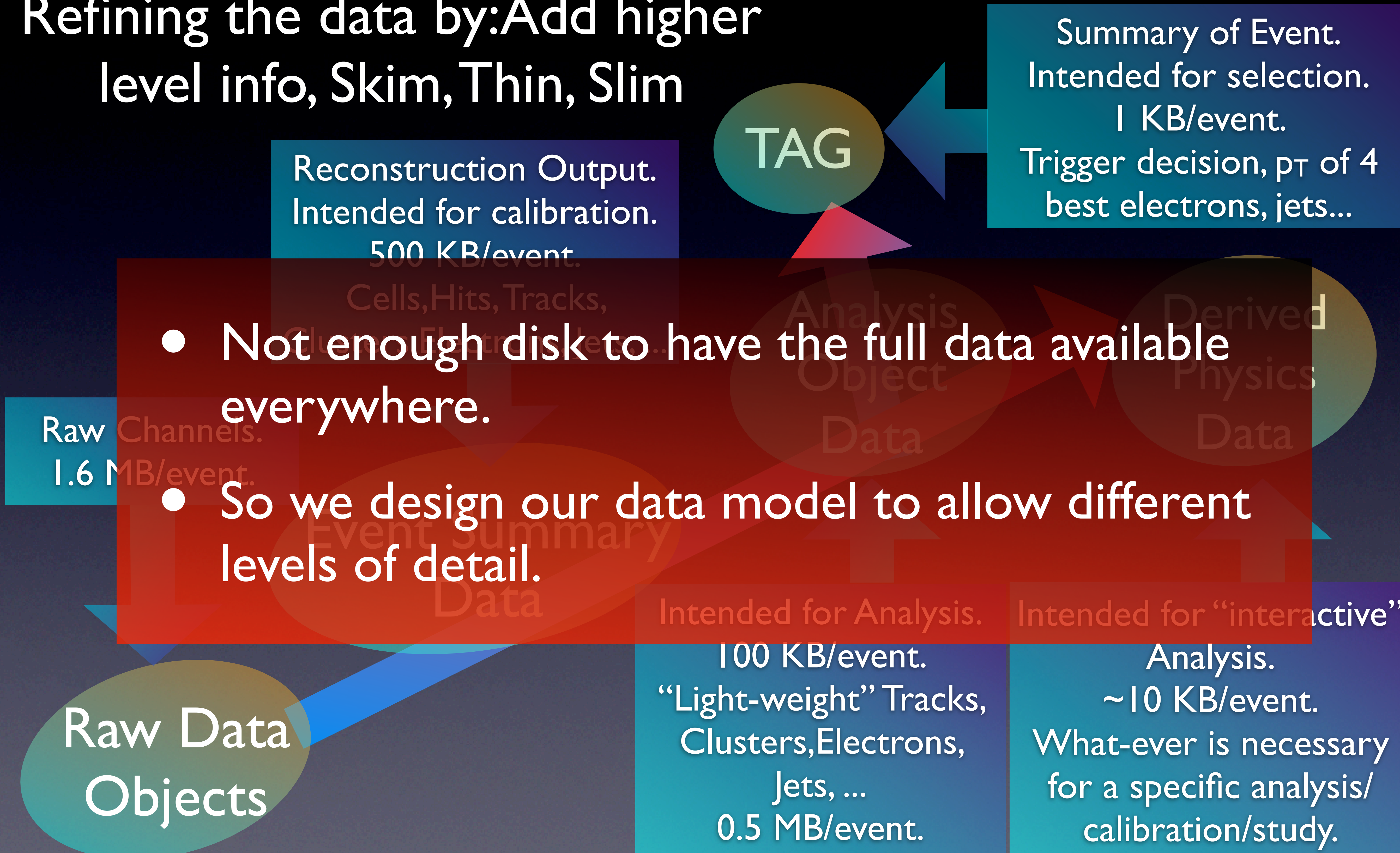
Analysis Computing

Computing in HEP



The Event Data Model

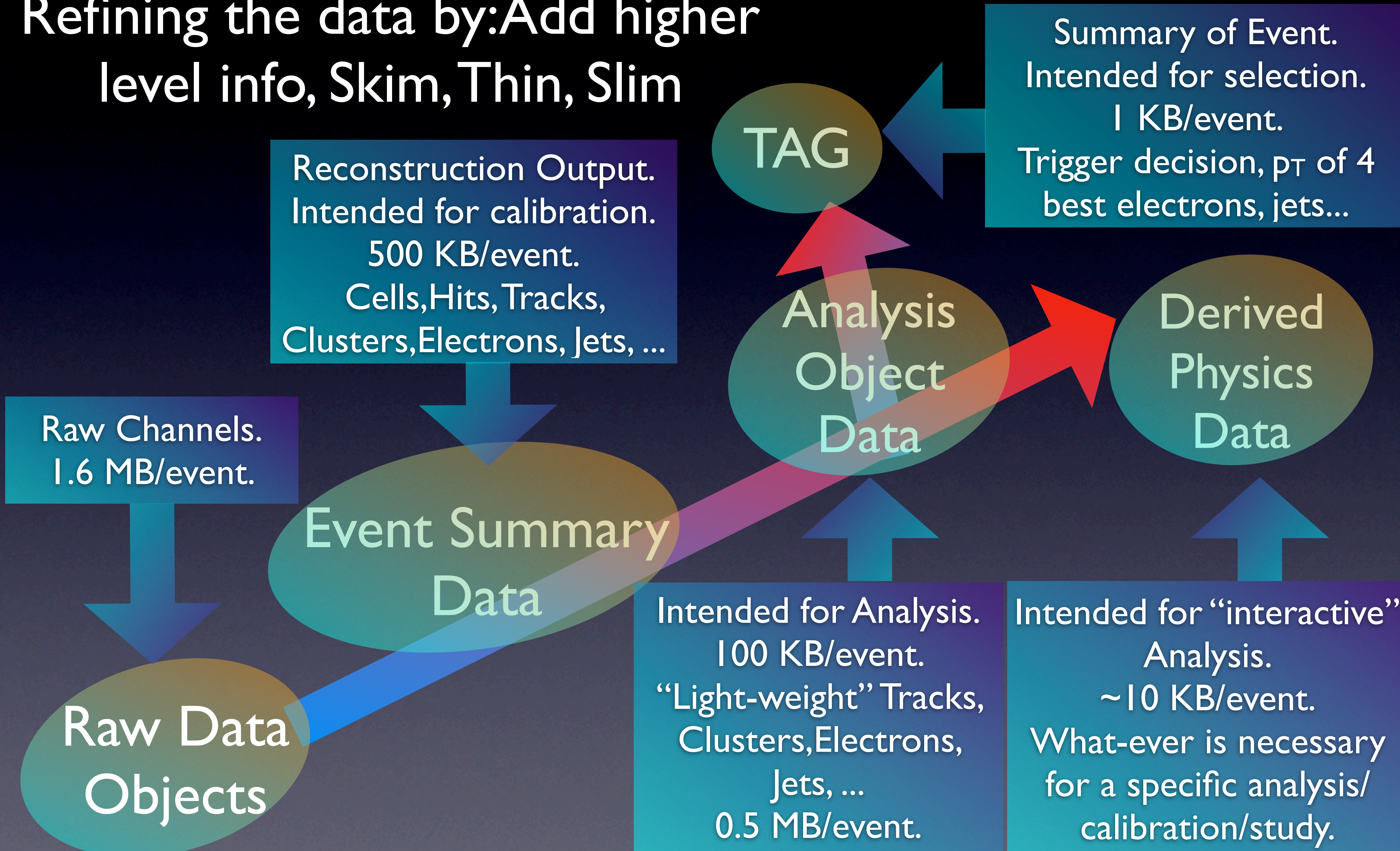
Refining the data by:Add higher level info, Skim, Thin, Slim



- Not enough disk to have the full data available everywhere.
- So we design our data model to allow different levels of detail.

The Event Data Model

Refining the data by:Add higher level info, Skim, Thin, Slim



Event Data Model (EDM)

EDM Level	Contents	Primary Intent	Size/ Event (KB)	Max Ideal Input rate (Hz)	Access-ibility
Raw Data Objects	Raw Channels	Reconstruction (calibration)	1600	N/A	Central Reco/ Reprocessing: Tier 0/1
Event Summary Data	Cells, Hits, Clusters, Tracks, MET, Electron, Jet, Muon, Tau, Truth	Re-reconstruction, Re-calibration	500		CERN CAF (access limited), Tier 1 (on tape)
Analysis Object Data	Clusters, Tracks, MET, Electron, Jet, Muon, Tau, Slimmed Truth	Limited Re-reconstruction (eg Jets, b-tag), limited re-calibration, Analysis	100	1000	Full: Tier 1,2 (disk) Subset: Tier 3
Derived Physics Data	Any of the above + composites (eg top) + derived quantities (sphericity)	Interactive Analysis: Making plots, performing studies	Typically ~10	10^6	Tier 3: eg your laptop
TAG	Summary. Ex: p_T, η of 4 best e,γ,μ,τ,jet	Selection Events for analysis	1	10^8	Everywhere

The GRID

- Resources Spread Around GRID

•Reprocessing of full data with improved calibrations 2 months after data taking.
•Managed Tape Access: RAW, ESD
•Disk Access: AOD, fraction of ESD

•Derive 1st pass calibrations within 24 hours.
•Reconstruct rest of the data keeping up with data taking.

30 Sites Worldwide

Tier 2

AOD

Tier 1

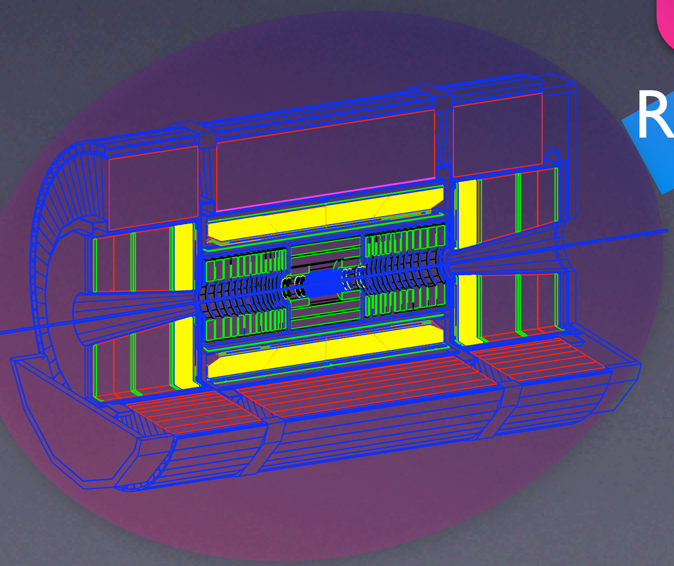
10 Sites Worldwide

RAW/
AOD/
ESD

Tier 0

•Production of simulated events.
•User Analysis: 12 CPU/Analyzer
•Disk Store: AOD

RAW



CERN Analysis Facility

•Primary purpose: calibrations
•Small subset of collaboration will have access to full ESD.
•Limited Access to RAW Data.

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30 Sites Worldwide

Tier 2

•Derive 1st pass calibrations within 24 hours.
•Reconstruct rest of the data keeping up with data taking.

- The ATLAS Computing Model cannot handle analysis activity on the ESD.
- Analysis must be performed on the AOD.

➡ Important to make sure that the AOD meets analysis requirements.

➡ Important to provide sufficient redundancy and flexibility in AOD to recover from unexpected problems.

AOD

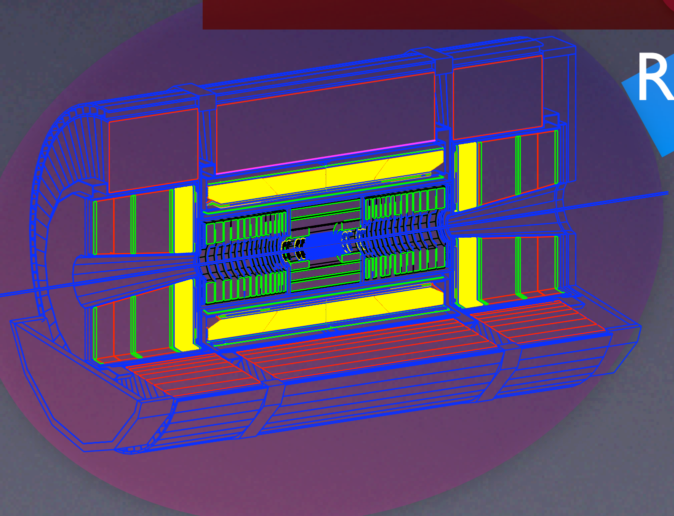
Tier 1

10 Sites Worldwide

Tier 0

RAW/AOD/ESD

•Production of simulated events.
•User Analysis: 12 CPU/Analyzer
•Disk Store: AOD



RAW

CERN Analysis Facility

•Primary purpose: calibrations
•Small subset of collaboration will have access to full ESD.
•Limited Access to RAW Data.

Delayed Response

- ATLAS will collect data at constant rate (200Hz) regardless of luminosity. ⇒ 10^9 events/year.
- Experience from other experiments: speed is critical factor to analyzers... important ingredient to success of computing model.
- Optimistic estimate of % of 10^9 events (1year) analyzed in realistic analysis (~100x slower today):

Analysis job run time	1 CPU (1 MB/s) Laptop	25 CPUs (25 MB/s) 2 people	100 CPUs (100 MB/s) 4 people	1000 CPUs (1 GB/s) WG	
1 hr	.016%	.41%	1.7%	16%	Interactive Analysis (final step)
1 day (12 hrs)	.2%	5%	20%	All	Batch Interactive Analysis (final step)
1 wk. (150 hrs)	2.7%	70%	All	All	Batch Analysis (intermediate step)
1 mo. (700 hrs)	12%	All	All	All	Centralize Skim (intermediate step)

- Scaling issues at computing sights will also be an important factor.
  - ➡ Running analysis on every available CPU will break the system.

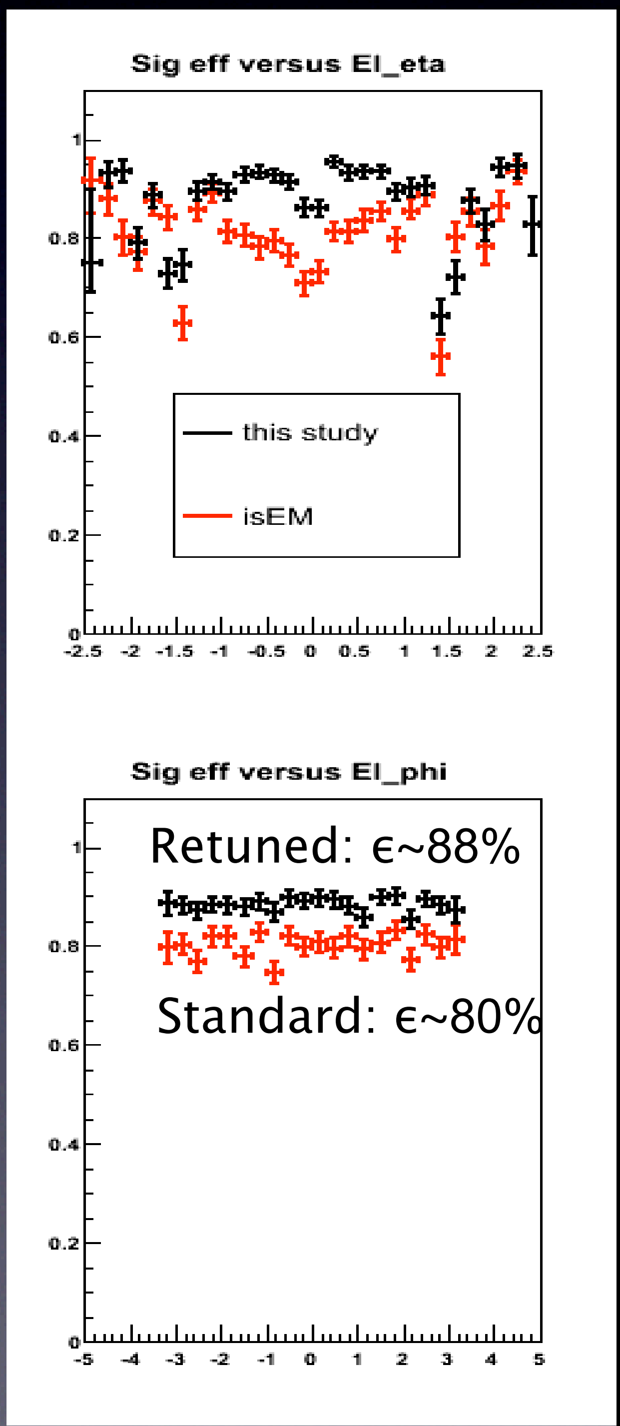
➡ Users need to be smart about their analysis strategy:

- Perform analyses collectively
- Analyze in multiple steps: slow steps a few times ⇒ DPD ⇒ fast steps many times

Analysis Model

- Given these constraints and the complexity of the tasks ahead... it is important to have a plan of how to analyze LHC data.
- Analysis Model: An attempt to ensure physics needs are met by the ATLAS software.
- Lots of recent developments based on experience from other experiments:
  - Fundamental software framework features
  - Organization of our data
  - Tools to collaboratively tackle complex tasks

The Right Data in the Right Place



- A Simple Example:
  - The standard ATLAS Electron identification selection is coded into the Electron reconstruction and stored with the Electron
    - ➡ Difficult to retune.
    - ➡ Remained the same for 2 years while software/understanding improved.
  - So we made the necessary electron variables available at analysis time (AOD).
    - ➡ Electron Selection tuned in context of analysis.
    - ➡ 8% better selection efficiency for same jet rejection on SUSY events.
    - ➡ Improvement can be distributed to others w/o reprocessing the data.

Redundant Solutions

Analysis Model Basics

	Jets	Electrons	Missing Et
ESD All Calo Cells (not	Default Calibrate clusters to	Default Calibrate cells to EM	Default Build Missing Et from calibrated clusters + rgy in
Al (C +u sam cells clusters (available for analysis)	Build Jets From uncalibrated clusters, calibrate based on energy samplings	Choose electron cluster, recalibrate cells, re-calc shower shapes, re-calibrate electron	from tions. from re-calibrated hard objects (eg jet, electron) + remaining contributions.

- Hypothetical Scenario:
  - 2 months from target conference, ATLAS discovers low level calorimeter calibration problem which hinders various measurements.
  - Not enough time to correct, reprocess, and redistribute data.

Analysis Model Basics

Redundant Solutions

	Jets	Electrons	Missing Et
ESD All Calo Cells (not available for analysis)	Default Calibrate clusters to hadronic scale based on cells	Default Calibrate cells to EM scale	Default Build Missing Et from calibrated clusters + out of cluster energy in cells. Save in components.
AOD All Clusters (Calibrated +uncalibrated samplings), All cells in electron clusters (available for analysis)	Build jets from calibrated clusters, apply "out-of-cone"/Jet Alg Corrections	Choose electron cluster size, calibrate electrons based on samplings in clusters	Build Missing Et from individual contributions.
	Plan B Build Jets From uncalibrated clusters, calibrate based on energy samplings	Plan B Choose electron cluster, recalibrate cells, re-calc shower shapes, re-calibrate electron	Plan B Build Missing Et from re-calibrated hard objects (eg jet, electron) + remaining contributions.

Redundant Solutions

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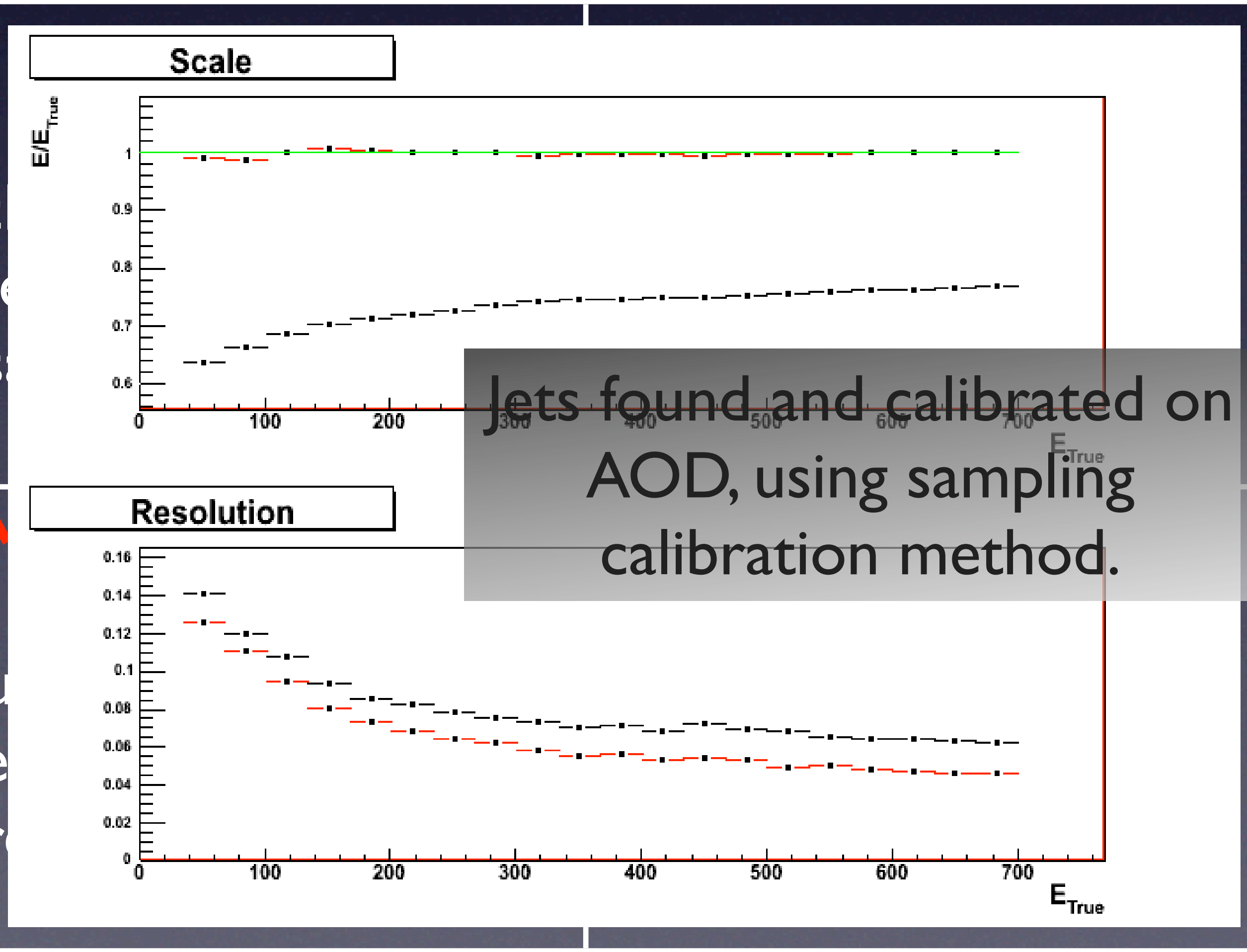

Jets found and calibrated on AOD, using sampling calibration method.

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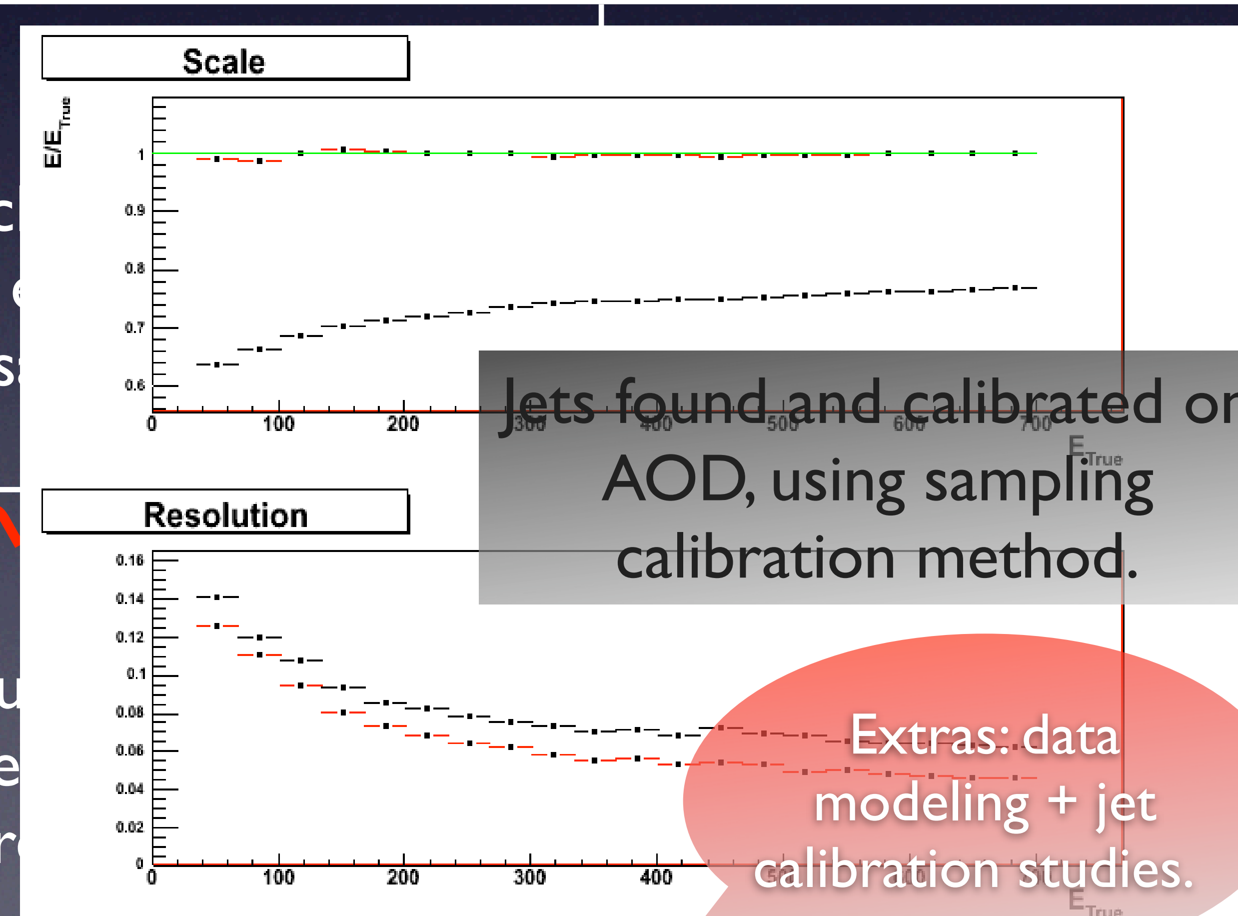

Jets found and calibrated on AOD, using sampling calibration method.

Extras: data modeling + jet calibration studies.

Analysis Model Basics

Redundant Solutions

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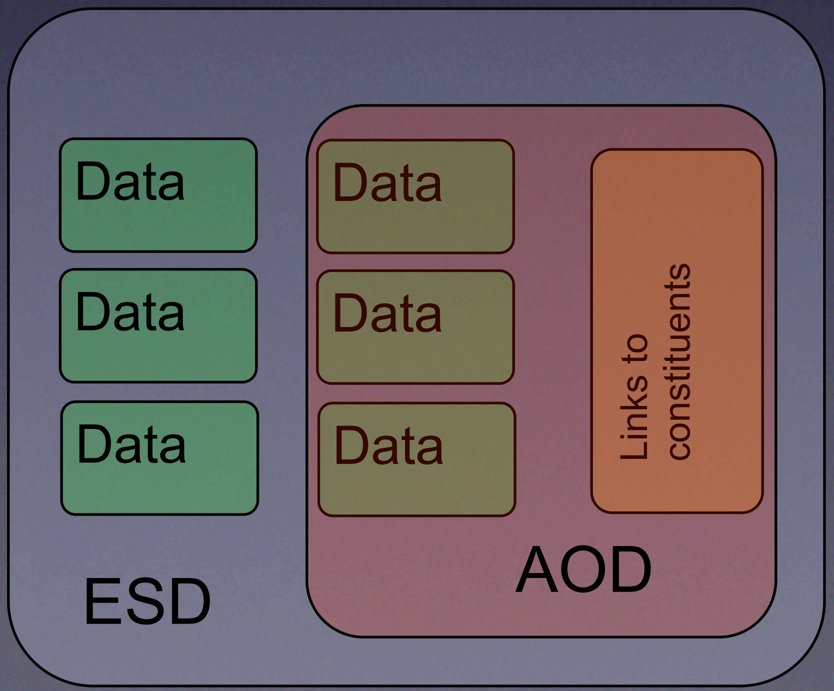
EDM Lessons from Other Experiments I

Observations from:
BaBar, CDF, D0, H1
ATLAS Analysis Model Workshop (Oct 2006)

- *Observation:* Tasks naively thought to be addressed by "ESD"-based analysis or reprocessing (eg: calibration, alignment, track-fit, re-clustering) are routinely performed in the highest level of analysis.
  - ➡ As experiments evolve:
    - "ESD" bloated and too difficult to access ⇒ dropped
    - "AOD" is gradually augmented with some "ESD" quantities (eg: hits in roads/ cells) to provide greater functionality at analysis time.
- Build a flexible data model by merging ESD/AOD format... but keeping separate levels of detail:
  - Analyzers can seamlessly switch between ESD/AOD.
  - Jobs read on demand... speed
  - Anyone can reconfigure data model w/o schema change
    - Move data between levels by changing configuration.
    - No compiled code involved!
    - Seamlessly read data before/after the change.



EDM Lessons from Other Experiments II

Observations from:
BaBar, CDF, D0, H1
ATLAS Analysis Model Workshop (Oct 2006)

- Derived Physics Data (DPD) is Traditionally an "ntuple" which can analyzed standalone (eg in ROOT) without the experiment's software framework.
- *Observation:* Any hick-up the experiment software or computing, and physicists by-pass the framework & copy all of the data into DPD format:
    - BaBar: more data in proprietary DPD than AOD. A primary contributor to a complete redesign of computing model.
    - Tevatron: DPD became the AOD. Proprietary frameworks developed by users.
- BaBar (CM2), CMS, and *now* ATLAS solutions:
    - allow the EDM to be easily extendible with UserData
    - allow the EDM to be read in both framework and ROOT.

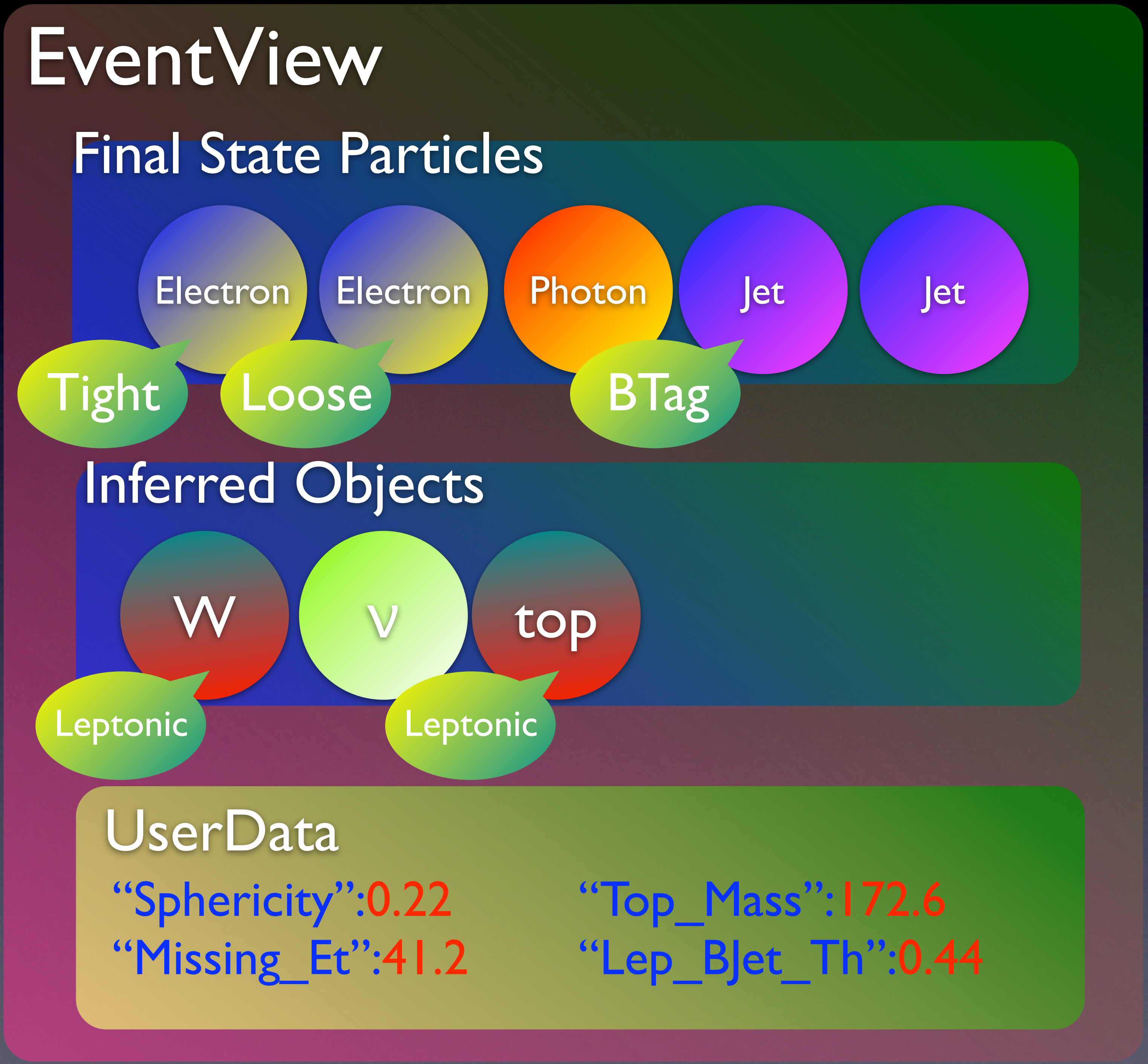
Collaborative Analysis

- Problem: how do you get 2000 physicists to
  - perform analysis in consistent ways
  - easily share & compare their work
- Similar problem as event reconstruction ⇒ fundamental reason for HEP experiment software frameworks.
- Reconstruction ideas (and some recycling from BaBar!) ⇒ EventView Analysis Framework (next few slides):
  - A generic analysis data object: "The EventView"
  - A framework for modular analysis.
  - A large library of general tools.

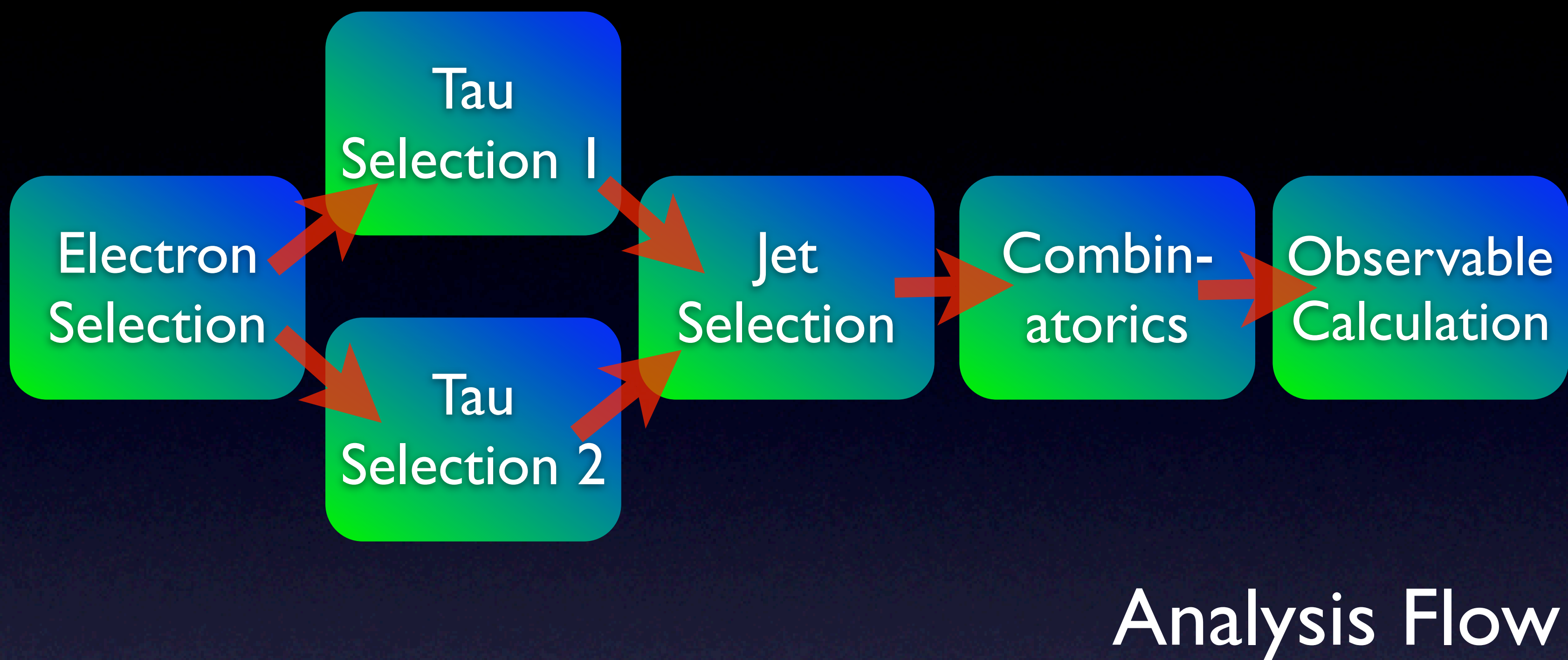
➡ Not only a common analysis software, but a common language.

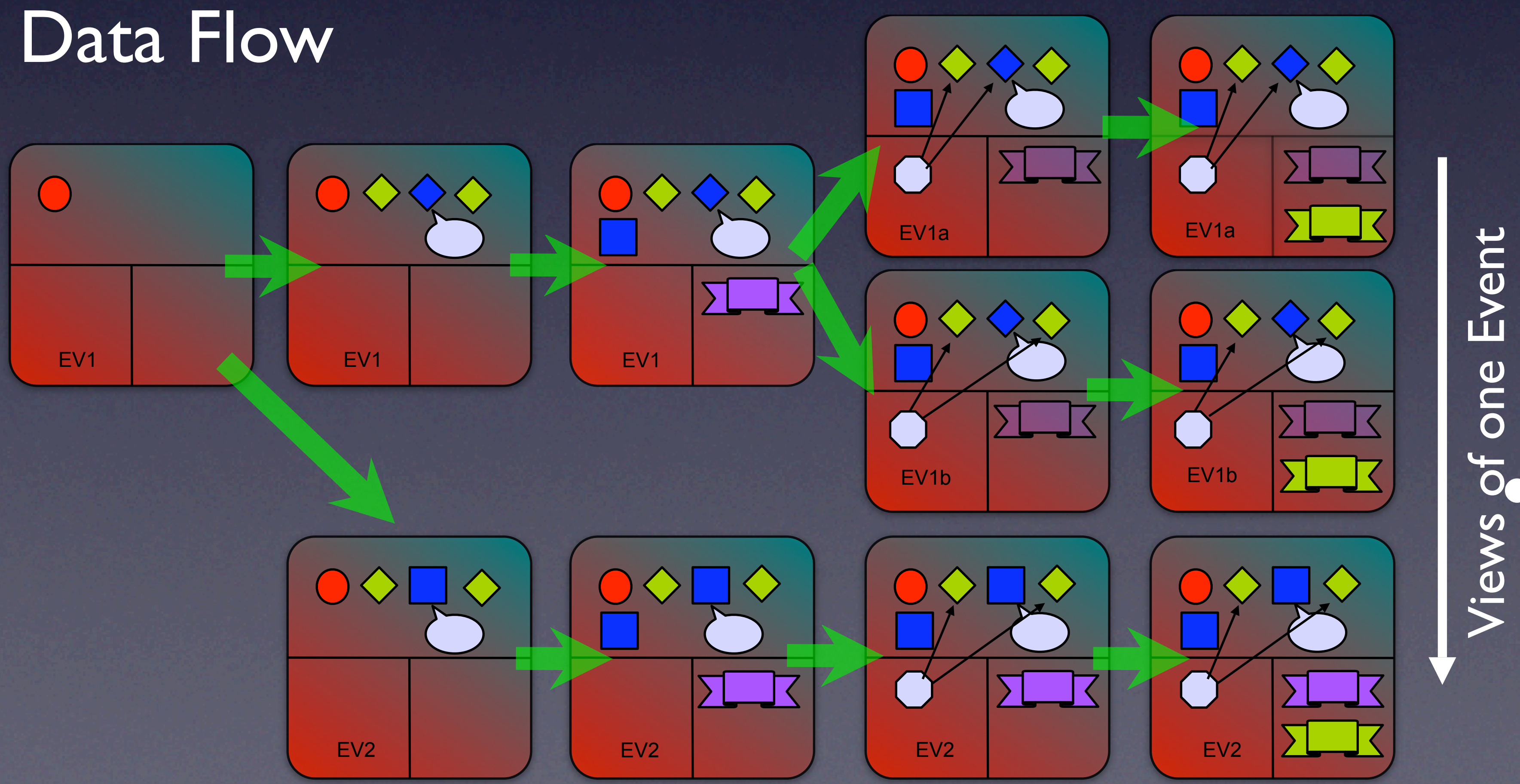
The EventView

- Holds the "state" of an analysis.
  - Objects in the AOD + Labels.
  - Objects created in the coarse of analysis + Labels.
  - UserData: Anything other data generated during analysis.
- Can be written/read from file and shared (even with a theorist!)
- Convention: each EventView holds *one* interpretation of an event... very natural book keeping tool.



EventView Framework





- Analysis is a series of EventView Tools executed in a particular order.
- Framework generates multiple Views of an event representing
  - Different analysis paths
  - Different combinatorics choices
  - Different input (eg: generator, full reconstruction, fast simulation)
- Everything consistent within one EventView ⇒ Framework handles bookkeeping.

EventView Toolkit

- 100's of generalized tools which can be configured to perform specific tasks
- Tools gradually become standard/ tested/understood
- Provide the language for basic analysis concepts: "inserter", "looper", "associator", "calculator", "combiner", "transformer".
- Easy to build on existing tools: Users routinely extend the toolkit.

‘View” Packages

- EventView popularity:
  - In top 11 most visited Atlas web page for past 3 months
  - #9/125 HyperNews forum in # of subscribers
  - #2/125 Hypernews forum in postings...

- ATLAS now has lots of analysis packages are mostly configurations of standard tools.
- HighPtView: Generic Analysis package running in production ⇒ Standard:
  - Particle selections
  - Truth/Trigger Match
  - Output
  - ➡ Serves as benchmark/starting point for analyses
- Many physics groups customizing HighPtView for specific analyses ⇒

  SUSYView, TopView, ...
- Performance packages also coming: egammaView, JetView, MuonView

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- EventView popularity:
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- With EventView ATLAS has an analysis framework which
  - Makes building complex analyses easier.
  - Allows sharing and comparing ideas, code, and results.
  - Provides a common language (and tools) across wide array of analyses.
  - Is deployed in production, adopted by physics working groups, and widely used by the physics community.

Final Remarks

- The LHC will deliver sufficient 14 TeV data in 2008 to allow discovery of SUSY signatures into the ~1 TeV range.
- At the same time, LHC will produce lots of Z, W, and tops to help understand the detector and the SM at 14 TeV.
- Actually making such a SUSY measurement in short time-scale is a matter of organization and preparation within the experiments.
- So ATLAS is feverishly:
    - Installing and commissioning the detector.
    - Building software which anticipates the fundamental issues.
    - Running Data Challenges to test and explore calibration and analysis strategies.
- If we don't do this now, we won't have the chance after we get data.
- But we cannot predict all of details of the physics, detector, computing, or software challenges that will confront ATLAS or LHC.
- Hopefully having flexible and redundant software which allow physicists work collectively will allow us to be successful... faster.

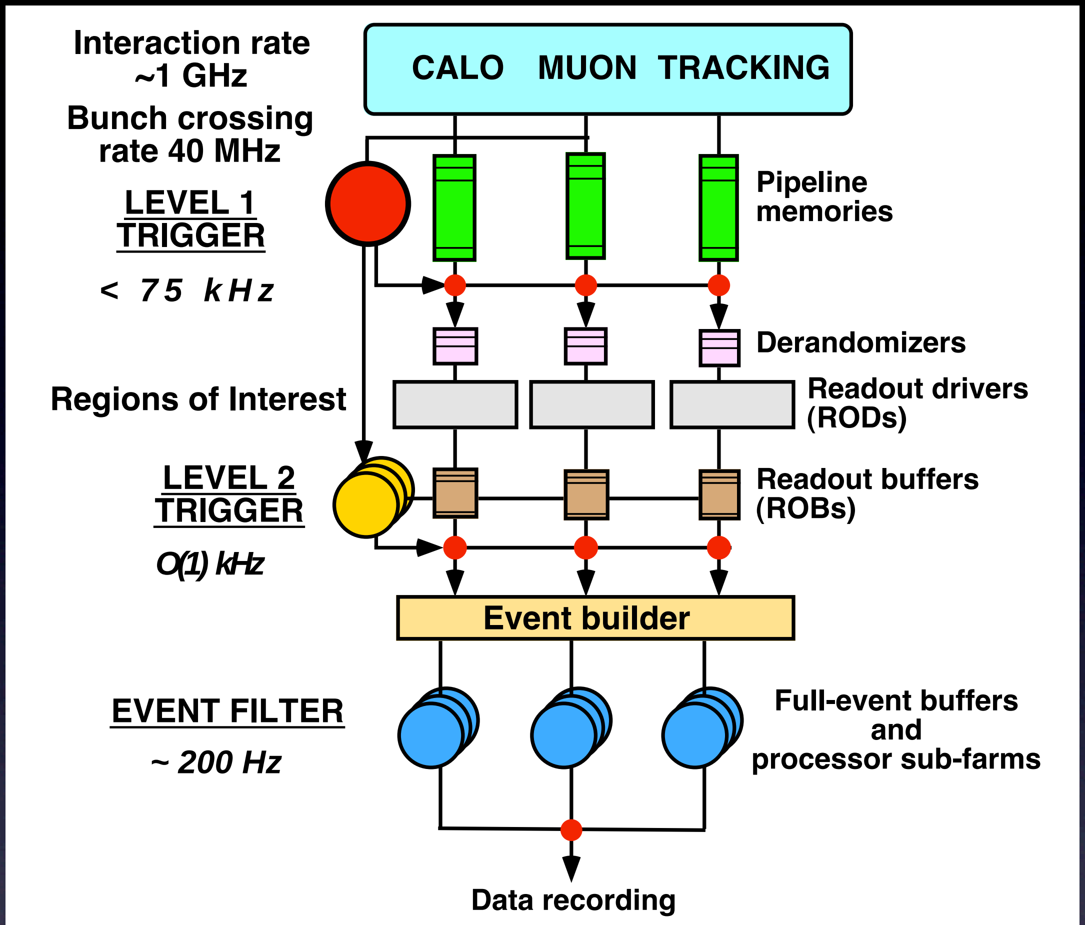
Extra Topics

TileCal L1 Trigger Hardware

Data Modeling and Jet Calibration

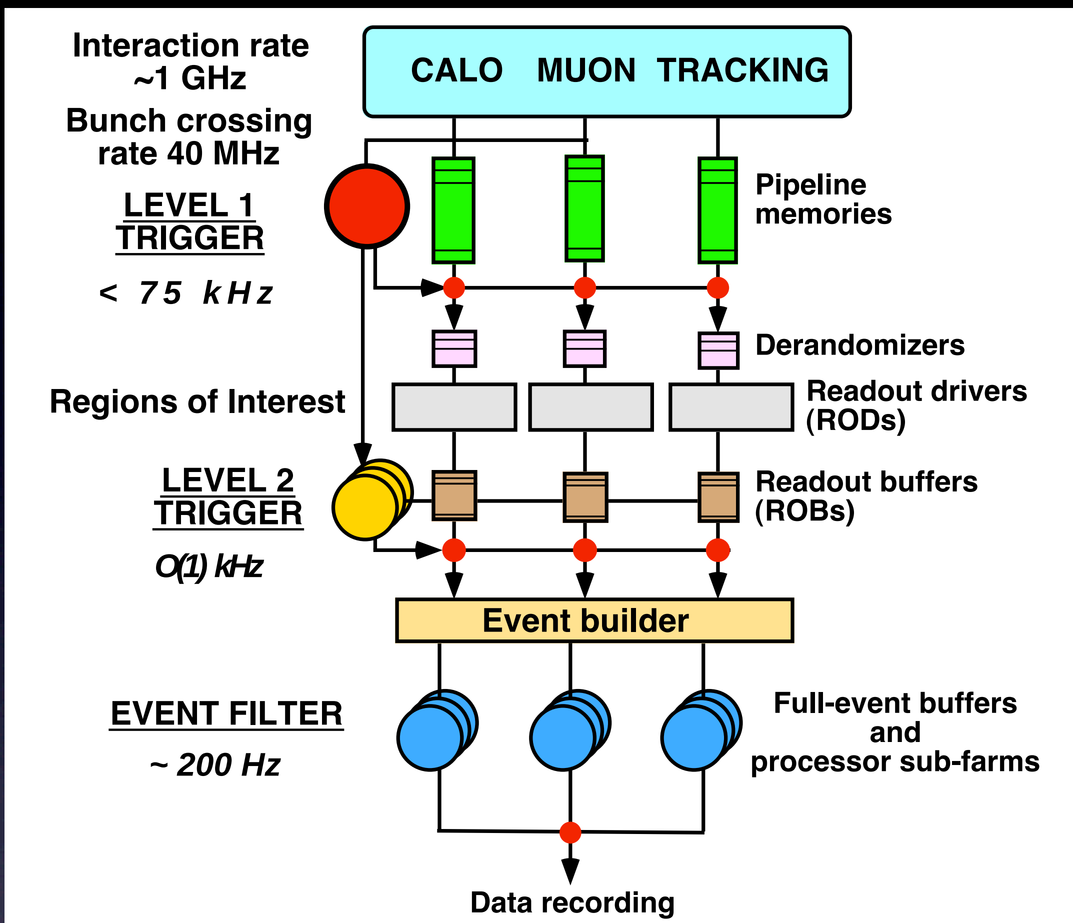
TileCal L1 Trigger

Trigger



- Get from 40MHz beam crossing to 200Hz storage...
- With pileup & branching fractions, interesting signatures are ⇒ ultimately need 10^{11} rejection in trigger + analysis.
- The key: identify high p_T leptons.
- Successive refinements:
    - Level 1 Hardware- Output ~ 100 kHz - Analogue signals from Calo + Muon systems (w/ lower granularity). Analyzed by back-end electronics. 2.5-3 μs latency budget (most in transmission).
    - Level 2 Software- Output ~ 1 kHz- Reconstruction of "regions of interest" from Level 1. Add tracking.
    - Event Filter Software- Output ~ 200 Hz- Full Event Reconstruction.

Trigger



- Get from 40MHz beam crossing to 200Hz storage...
- With pileup & branching fractions, interesting signatures are ⇒ ultimately need 10^{11} rejection in trigger + analysis.
- The key: identify high p_T leptons.
- Successive refinements:
  - Level 1 Hardware- Output ~ 100 kHz - Analogue signals from Calo + Muon systems (w/ lower granularity). Analyzed by back-end electronics. 2.5-3 μs latency budget (most in transmission).
  - Level 2 Software- Output ~ 1 kHz- Reconstruction of "regions of interest" from Level 1. Add tracking.
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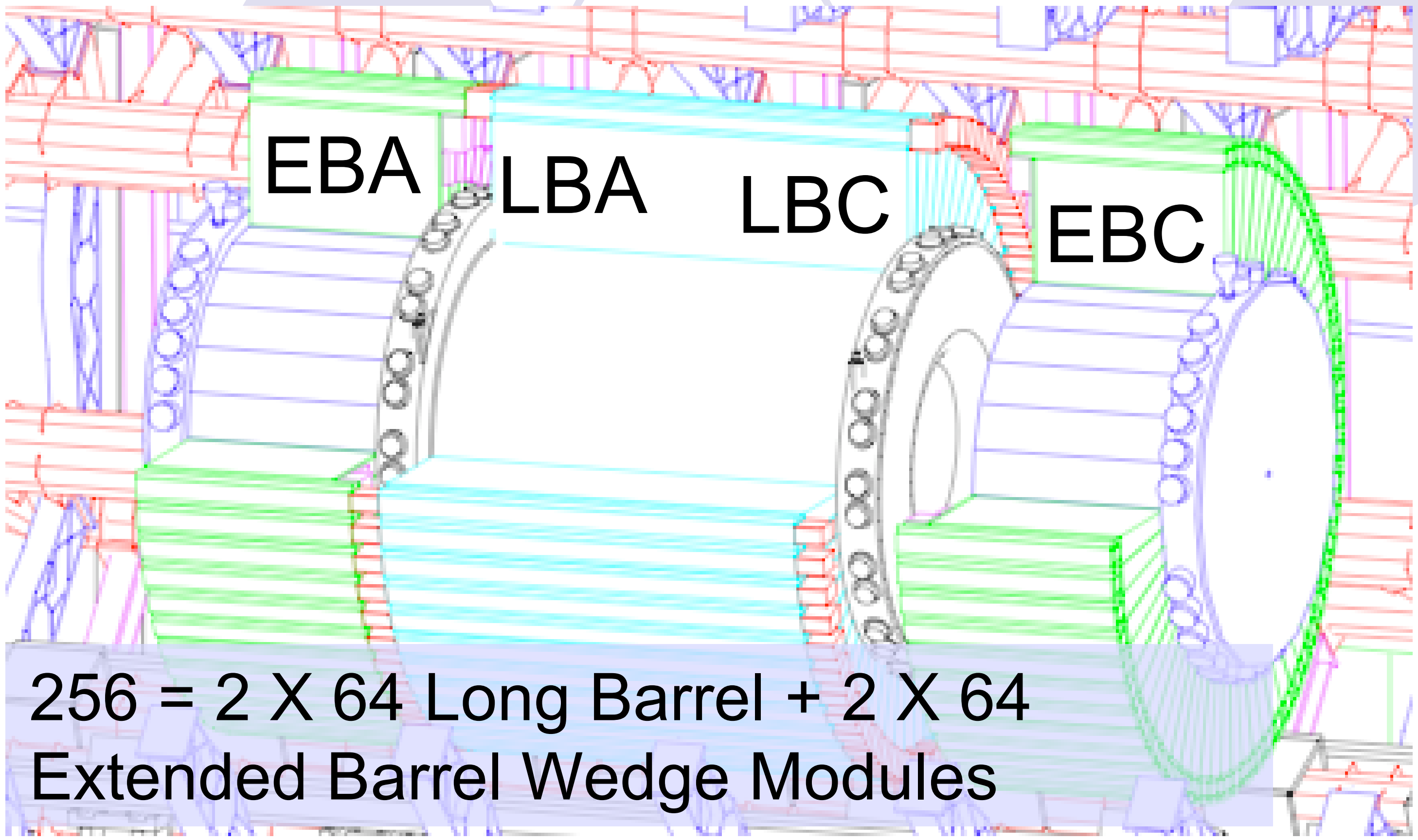
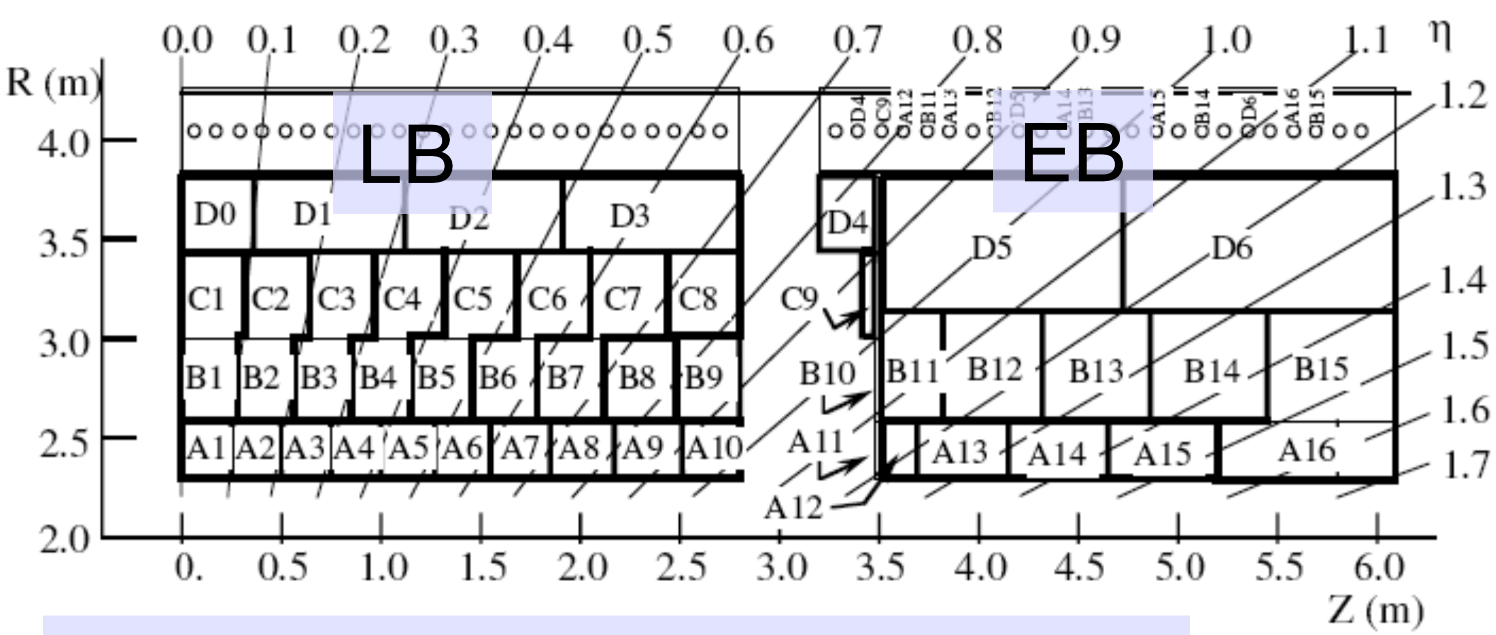
Extra material:
Hadronic Calorimeter
Level-1 Trigger Hardware

From my Tile Commissioning talk at 2005 ATLAS Overview week

TileCal Overview

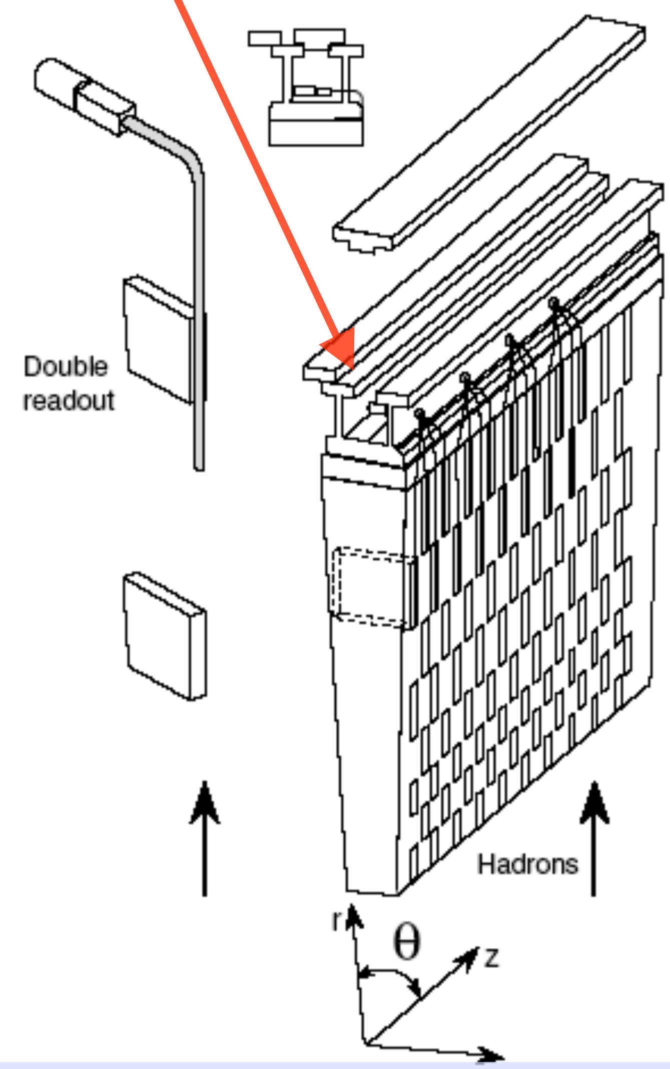


256 = 2 X 64 Long Barrel + 2 X 64 Extended Barrel Wedge Modules



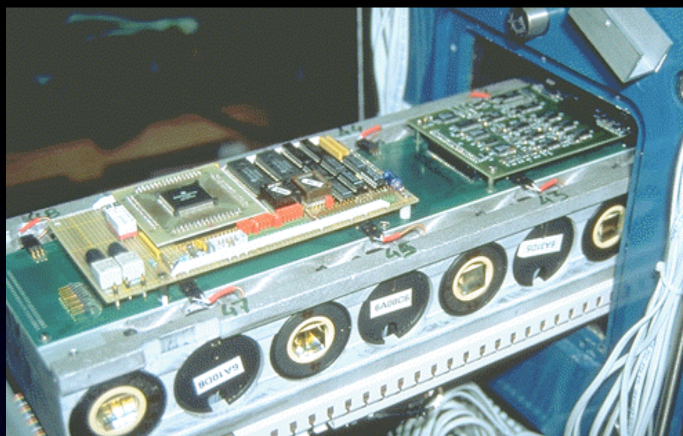
3 Radial Sampling layers (A, B/C, D)

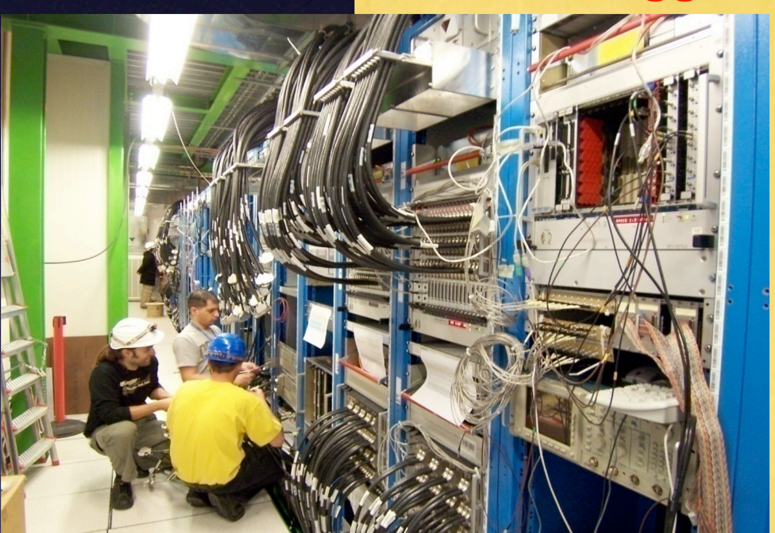
PMT/Front End electronics mounted on removable "drawer" sitting inside in the back-beam region of module, accessible through "finger".

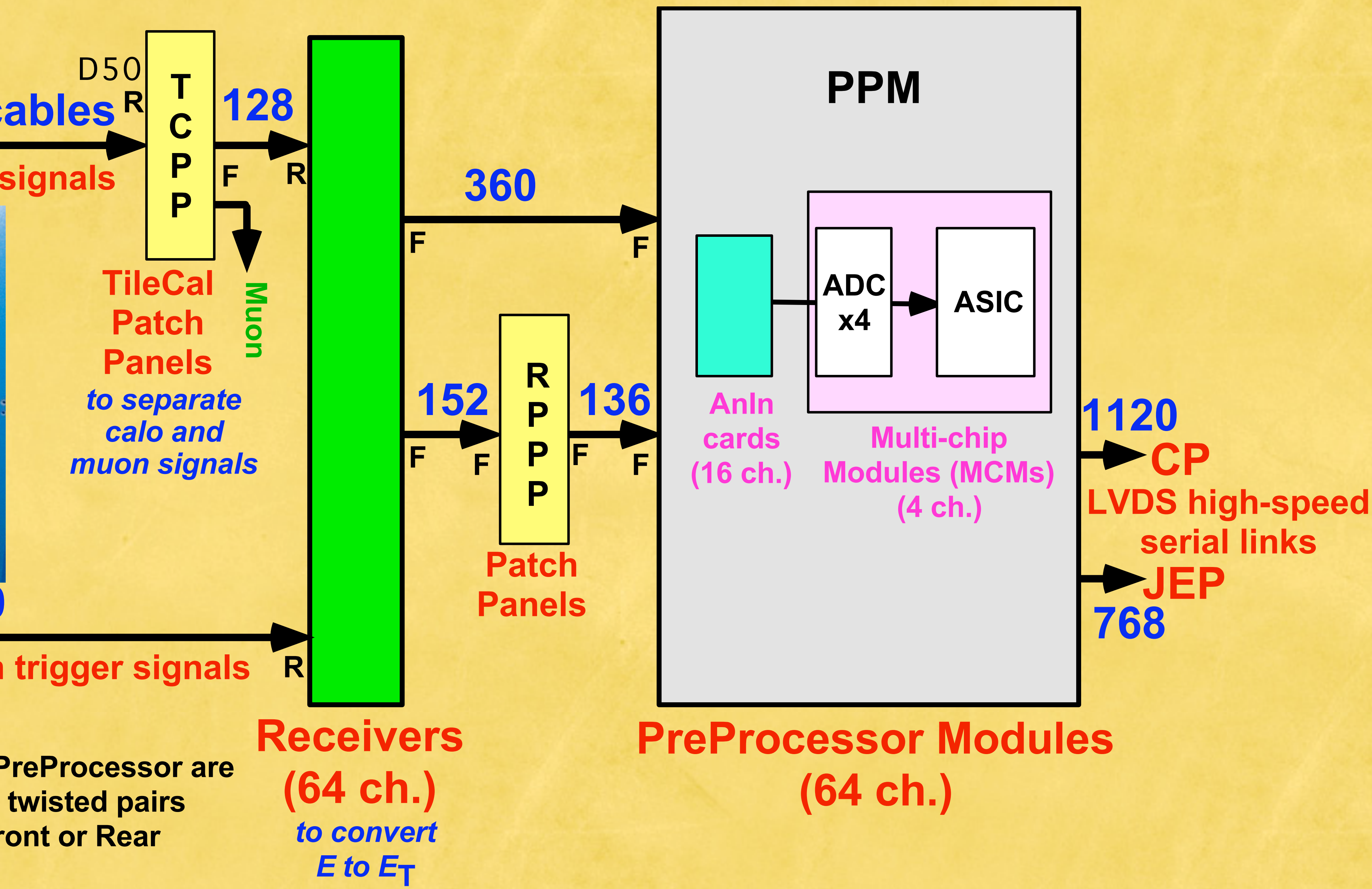


particle➔Energy deposit in steel absorber➔sampled by scintillating tiles➔read out by wavelength shifting fibers

Beginning of the L1Calo Chain



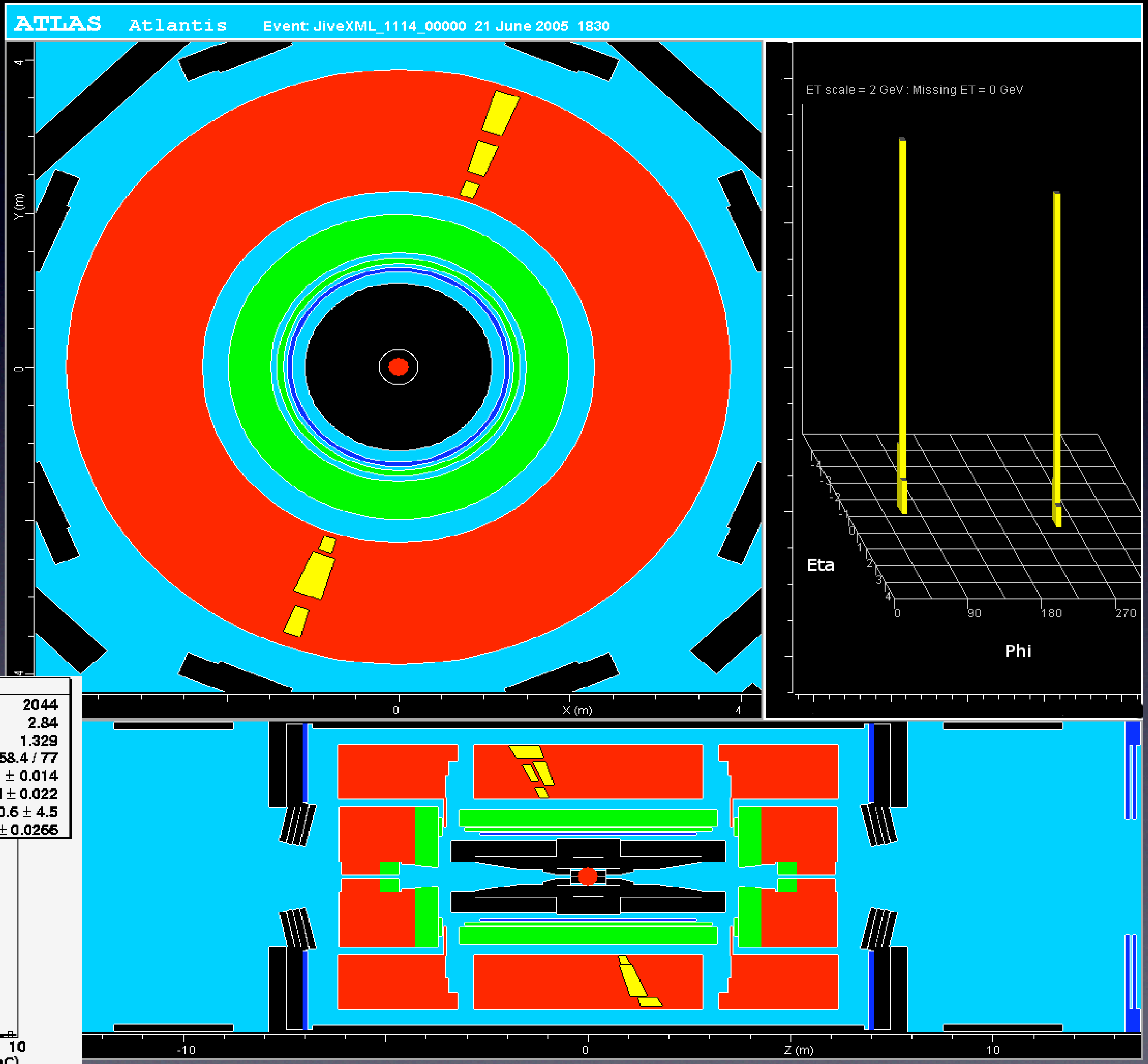


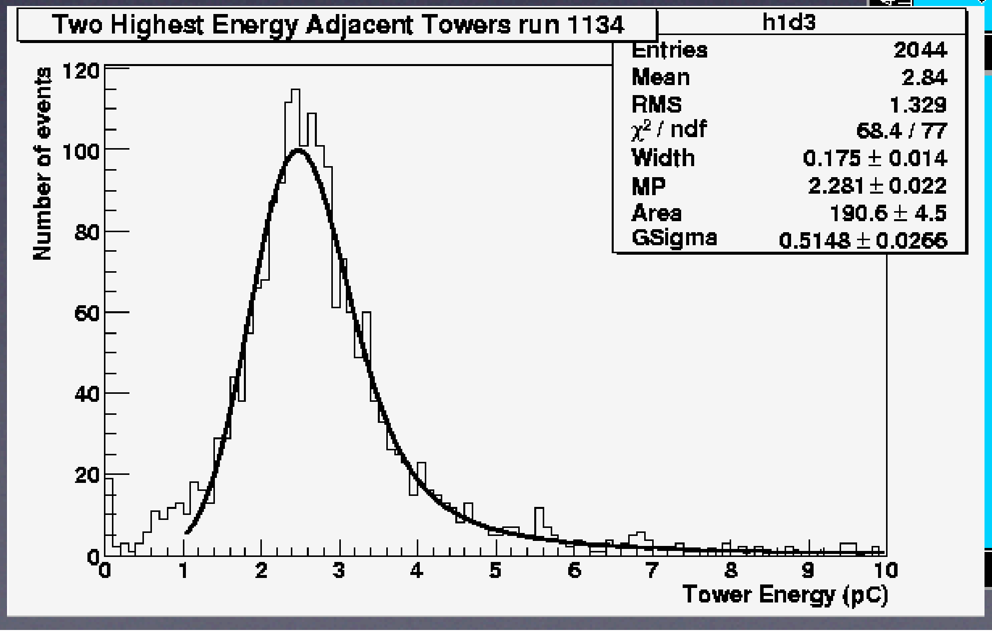


Notes:
¥ Cables up to PreProcessor are all 16 shielded twisted pairs
¥ F, R denote Front or Rear of modules
¥ All connectors are D37 except TCPP inputs, which are D50

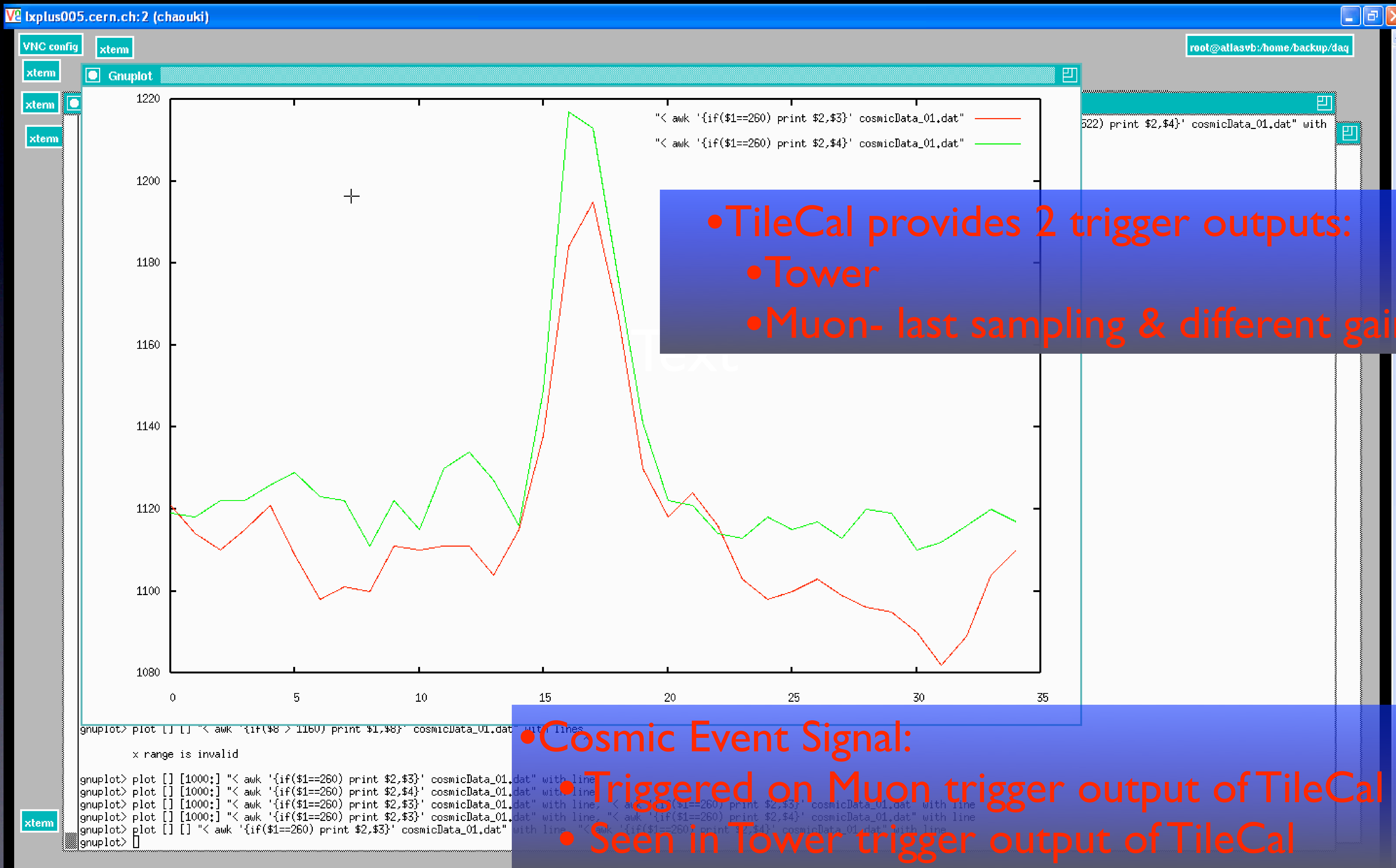
Cosmic Trigger with TileCal

- Cosmic coincidence boards build by U Chicago
  - Provide first cosmic events recorded in ATLAS pit (June 21, 2005)
  - Now providing triggers for EM Cal, Muon, and inner detector





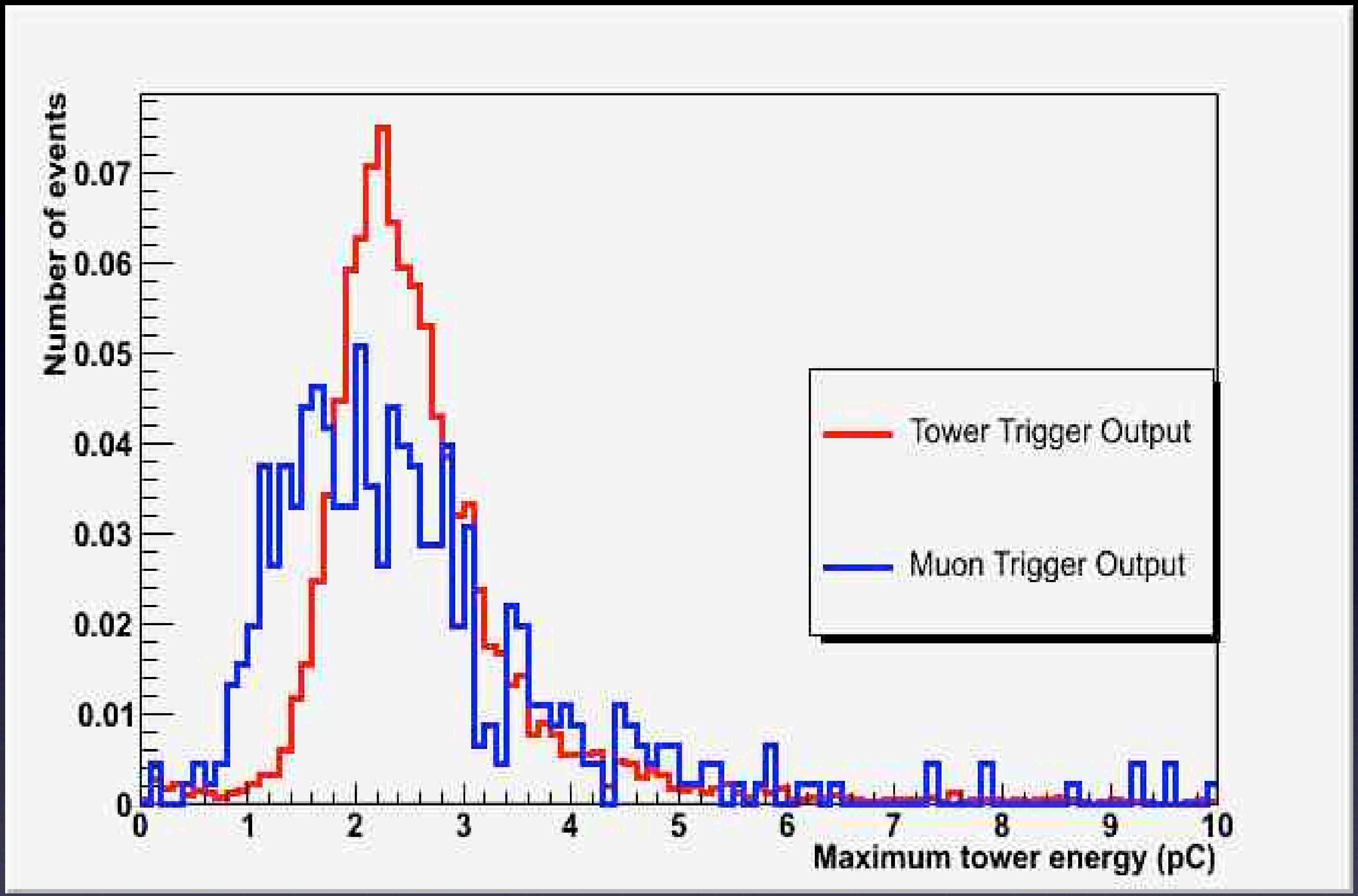
Cosmic Ray Seen by Tile Trigger



- TileCal provides 2 trigger outputs:
  - Tower
  - Muon- last sampling & different gain

- Cosmic Event Signal:
  - Triggered on Muon trigger output of TileCal
  - Seen in Tower trigger output of TileCal

Exploring Alternatives

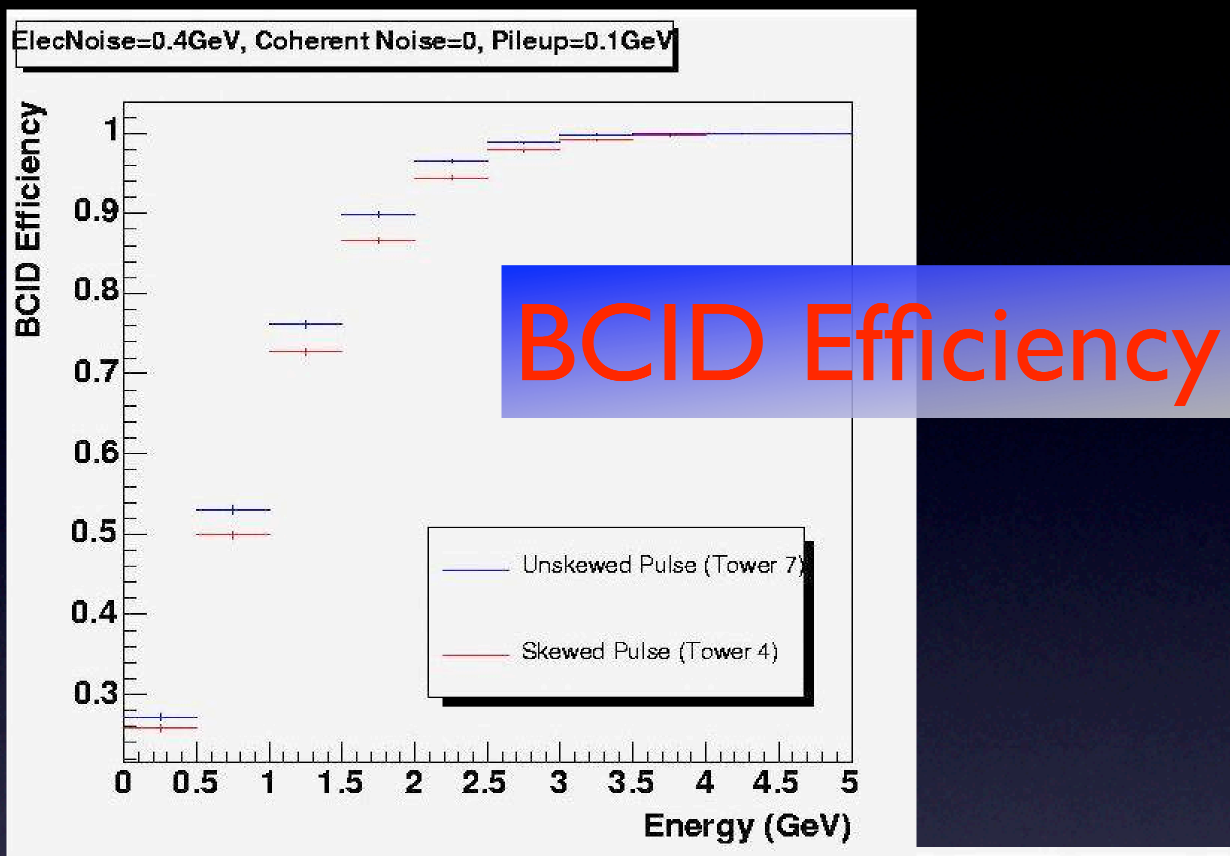


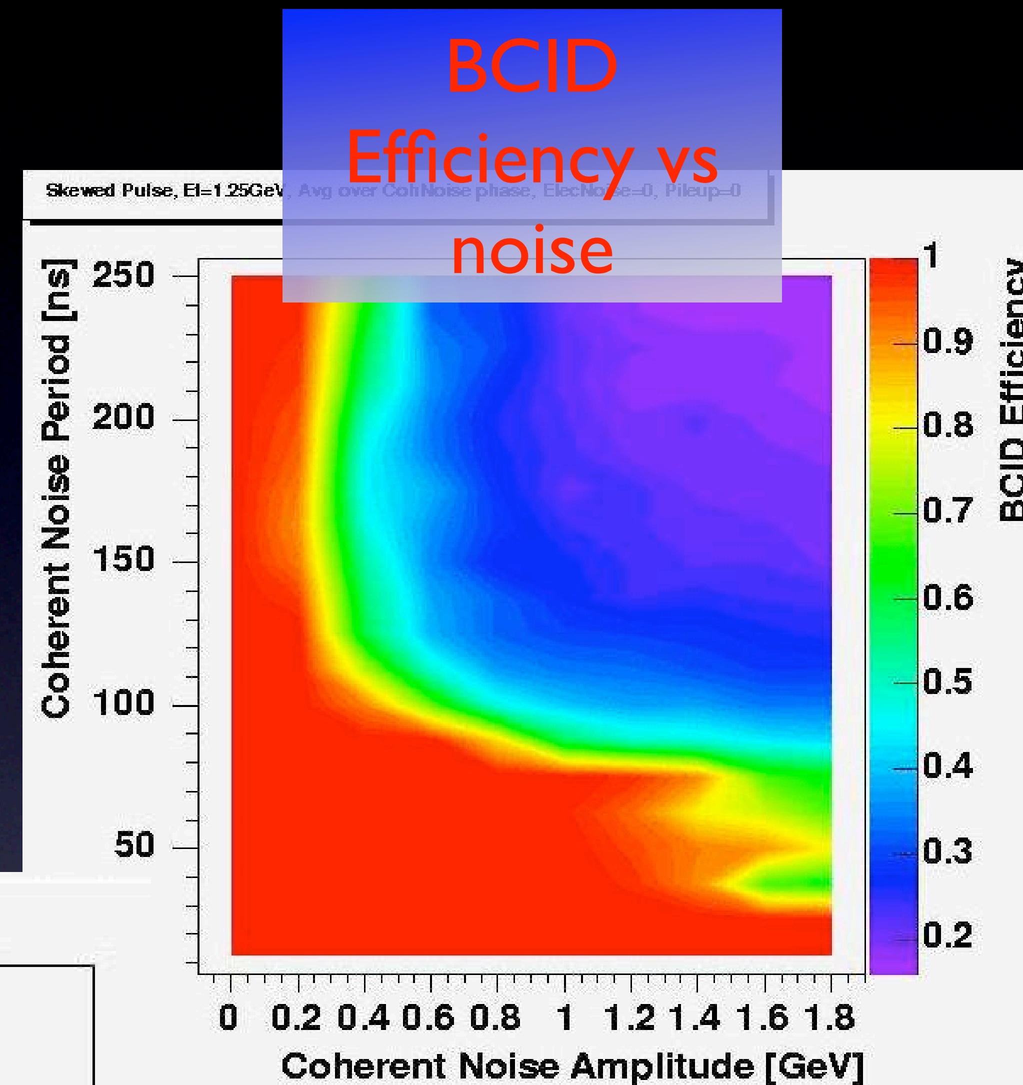
- TileCal Cosmic trigger is now based on Tower trigger output.
- L1Calo trigger system will eventually need these outputs.
- Can we use the TileCal muon output for ATLAS wide cosmic trigger?
  - Independent of Muon system
  - Can be kept until trigger upgrade.

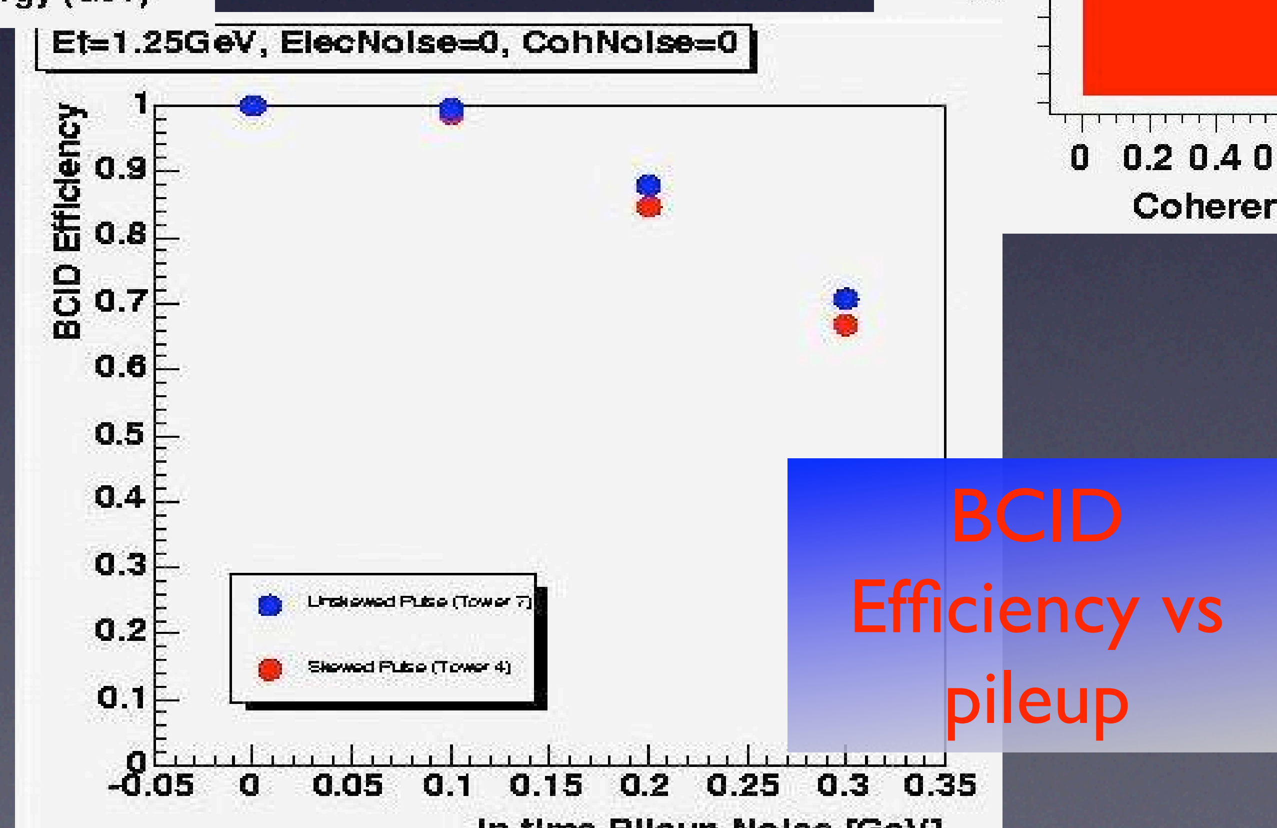
- Preliminary results (real cosmics recorded in the pit):
  - Tower trigger: 73% good cosmics
  - Muon trigger: 23% good cosmics

  ➡~ 8x less good cosmics with Muon trigger

L1Calo Issues

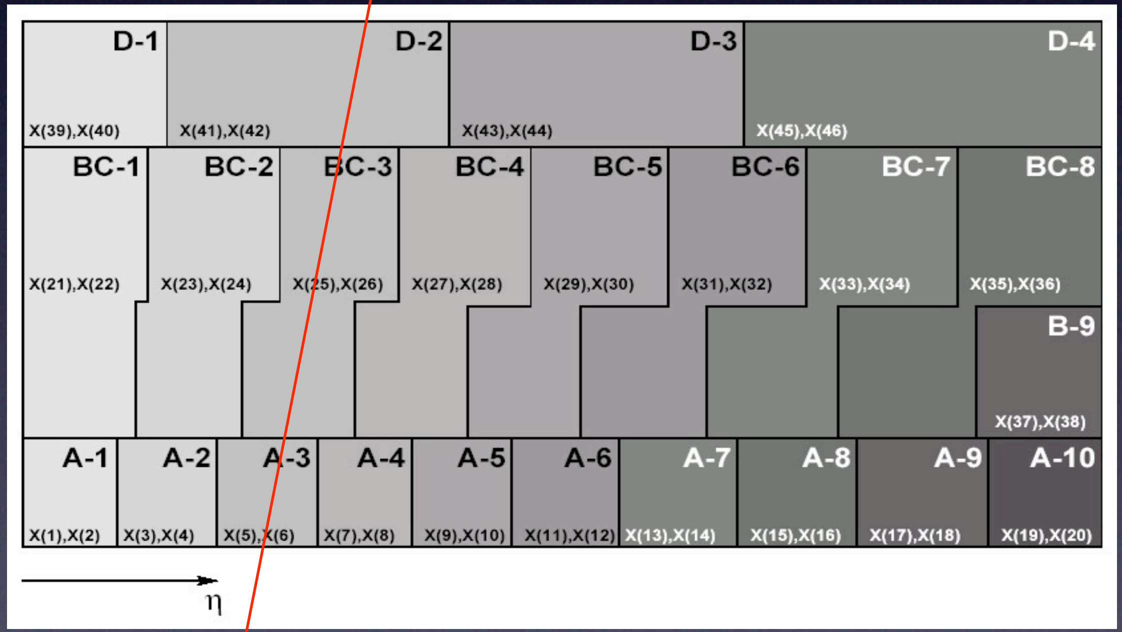


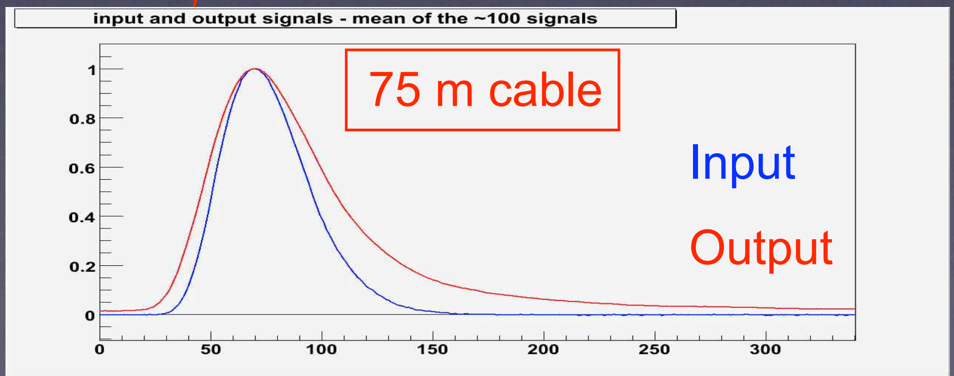




L1 Calibration Issues

- TileCal sends analogue sums of channels in projective towers down long cables to L1Calo hardware.
- PPMs- Digitize signals, extract time (BCID) and energy in tower.
- PPM Calibration (BCID/E_T) ~ determining expected signal shape
- For optimal BCID/E_T performance:
  - Timing is most important: Get the expect peak in the correct place (within few ns)
  - Shape is 2nd: Make sure expected shape represents the specific channel
- TileCal calibration via charge injection (CIS) into front-end electronics.
- Fundamental issues:
- CIS is not Physics pulse
  - CIS is ~10% narrower than physics
  - Cell→PMT Fibers and front-end optimized so that the 5 signals from particle passing through a tower simultaneously arrive at for summing. Not the case for CIS.
  - CIS happens after PMT.
  - CIS timing is sensitive to clock synchronization/ propagation within front-end.
  - CIS includes leakage pulse from capacitors.
- Cables distort pulses.





Tool for L1 Calibration

TileCIS Package

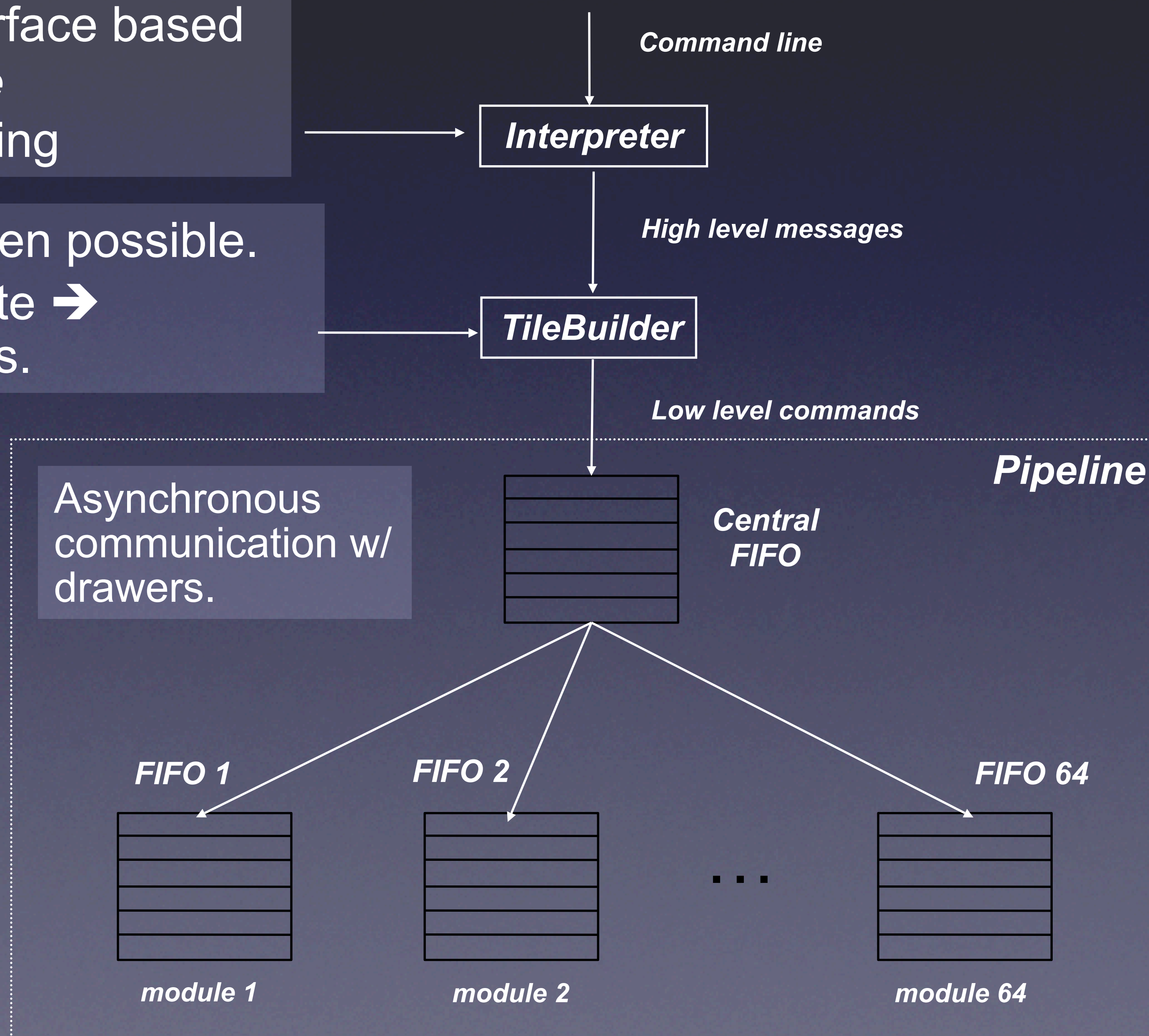
- User friendly interface based on TDAQ *CmdLine*
- Support for scripting

- Automatic broadcasting when possible.
- Keeps track of detector state ➔ generates minimal messages.

Example: *Set different DAC values in all PMTs*

- Standard tools → 20 *ms* x 45 x 64 ≈ 58 sec.
- TileCIS → 20 *ms* x 45 x 64 ≈ 1 sec.

Asynchronous communication w/ drawers.



Current activity: Interface/ integration with Run Control

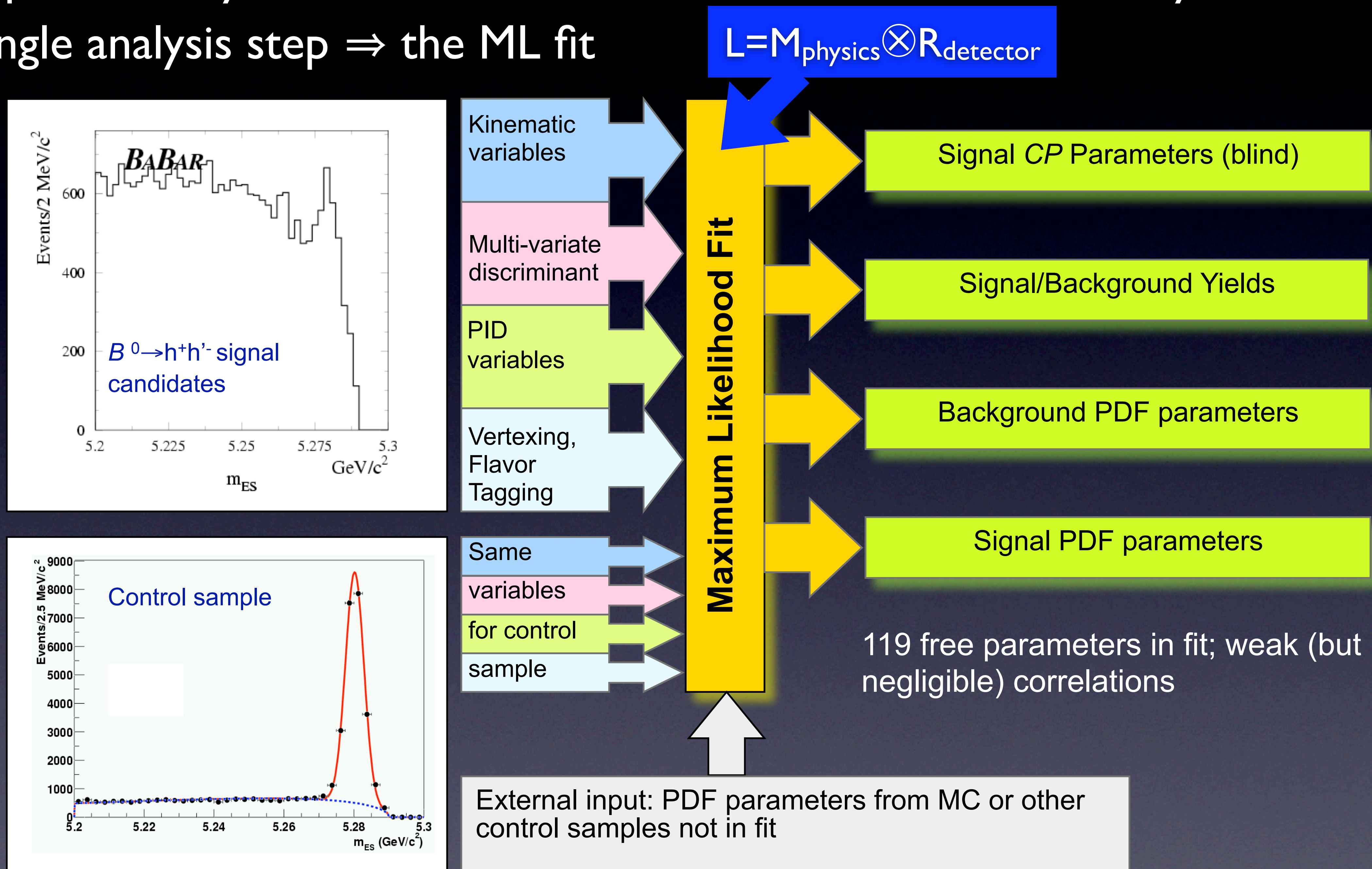
Goal: Inject simulated jets into TileCal Front end & study trigger response.

Data Modeling/Jet Calibration

Quick Note

Data Modeling

- Optimal Analysis: Measurement, validation, and evaluation of systematics in single analysis step ⇒ the ML fit



- Great deal of software tools developed at BaBar to make such complicated analyses practical (CPU time) and easy (development/collaboration).
- Knowledge and tools ⇒ RooStats (General Stats framework for LHC)

Quick Note

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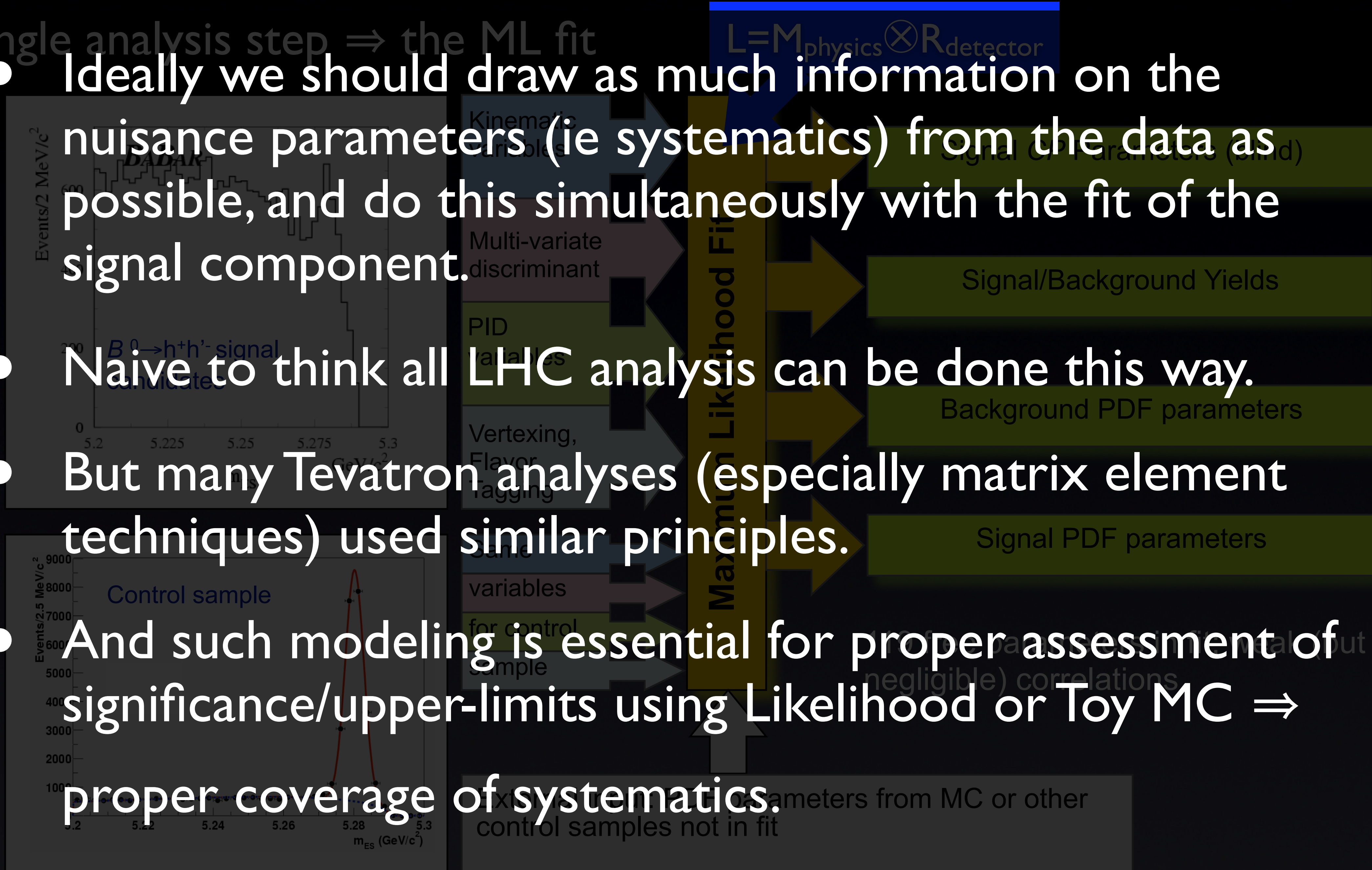

- Ideally we should draw as much information on the nuisance parameters (ie systematics) from the data as possible, and do this simultaneously with the fit of the signal component.
- Naive to think all LHC analysis can be done this way.
- But many Tevatron analyses (especially matrix element techniques) used similar principles.
- And such modeling is essential for proper assessment of significance/upper-limits using Likelihood or Toy MC ⇒ proper coverage of systematics.
- The tools are in development...

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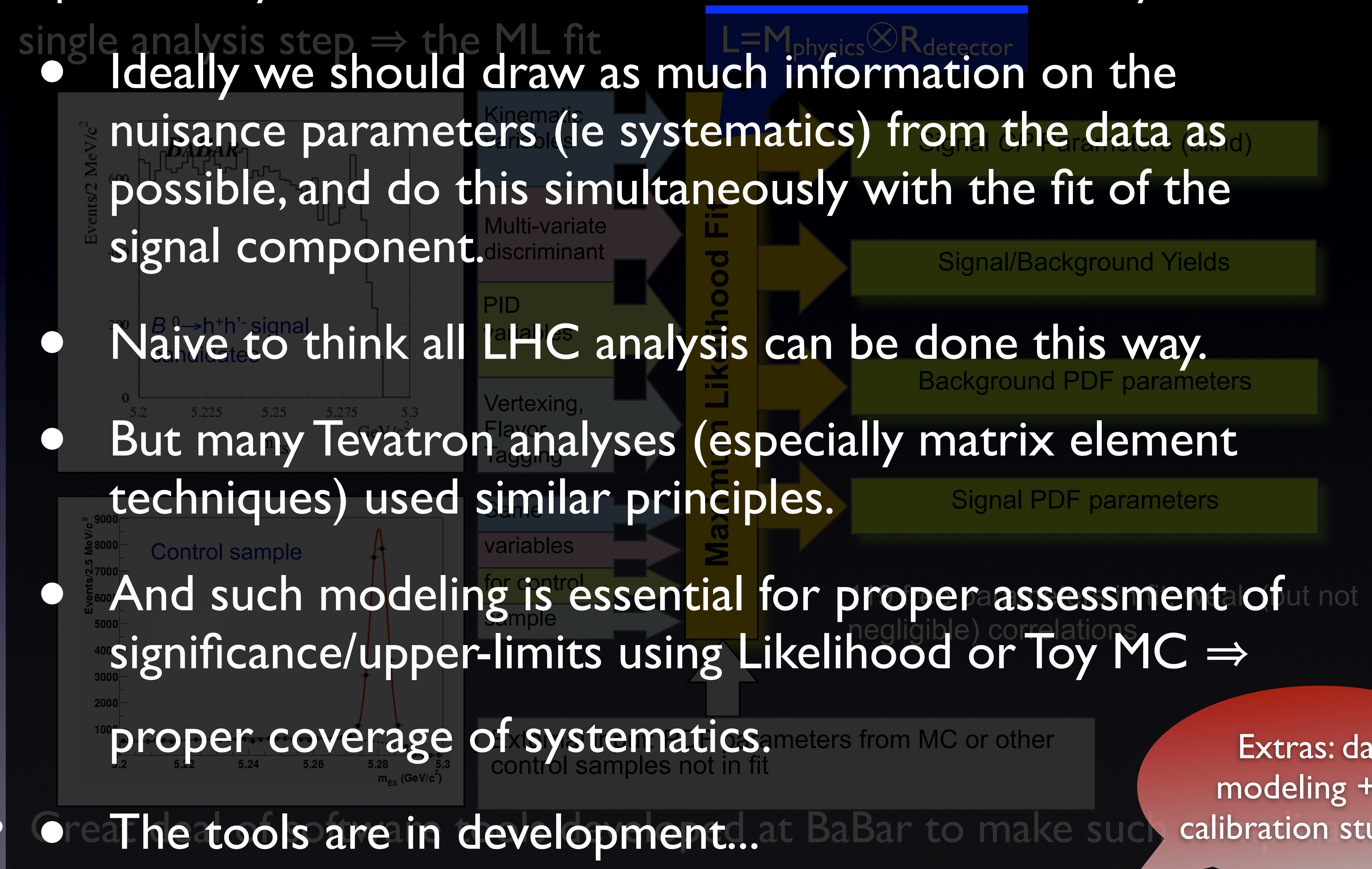

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Extras: data modeling + jet calibration studies.

Data Modeling

- Simplistic view of Matrix element methods in Tevatron top analyses:
    - $L_{Sig,Bkg}(obs) \sim M(kin) \otimes R(JES, ...)$
    - Matrix element maximally uses physicist knowledge of signal/ background processes.
    - Resolution functions maximally uses physicist knowledge of detector performance.
    - Allowing Jet Energy Scale (JES) to be simultaneously determined from W mass constraints $\Rightarrow$ 40% reduction of systematics.

Data Modeling and Jet Calibration

- Our typical source of calibration, validation, and correction of Jets: Jet + (Jet, Gamma,Z) balance and W mass.
- Complex problem... must account for: hadronic response, particle → parton, Underlying Event, pile-up (minimum bias), ISR/FSR, Clustering Alg, Jet Alg, noise.
- The physics nor detector are well modeled/simulated.
- Typically we separate the problem into: calibration, correction, validation/systematics
- Why not try to build a jet model:
  - $E_{Measured} = M(E_{parton}, UE, ...) \otimes R(\text{Calibration/correction Parameters})$
  - Include control samples + model in signal fits
- Calibration, validation, and systematics in one step!
- Toy MC generated from model is a better representation of Data than full/fast simulation... faster than fast simulation... requires no tuning.
- Overlap with Missing Energy Significance techniques.

A Jet Resolution Model

Account for dependencies in previous slide into res func.

Double Gaussian Resolution function

$$L = (1-f)G\left(\frac{\Delta p_T}{\sigma_\eta}\right) + fG\left(\frac{p_T^{Jet} - A_m - B_m p_T^\gamma}{A_s + B_s\sigma_\eta}\right)$$

Quadratic in fraction

$$f(E) = A_f + B_f E + C_f E^2$$

Linear in mean and resolution

$$\Delta p_T \equiv p_T^{Jet} - p_T^\gamma \qquad G(x) = \frac{1}{N}\exp\{-\frac{1}{2}x^2\}$$

$$\sigma_\eta = \sigma/\cosh(\eta)$$

$$p_T^{Jet} = \frac{E_{Calib}^{Jet}}{\cosh\left(\eta^{Jet}\right)}$$

$$\sigma = E \times \left[\frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}\right]$$

$$E_{Calib}^{Jet} = \left(A1 + A2\ln\left(E^{gj}\right)\right)E_{EM}^{Jet} + \left(B1 + B2\ln\left(E^{gj}\right)\right)E_{Had}^{Jet}$$

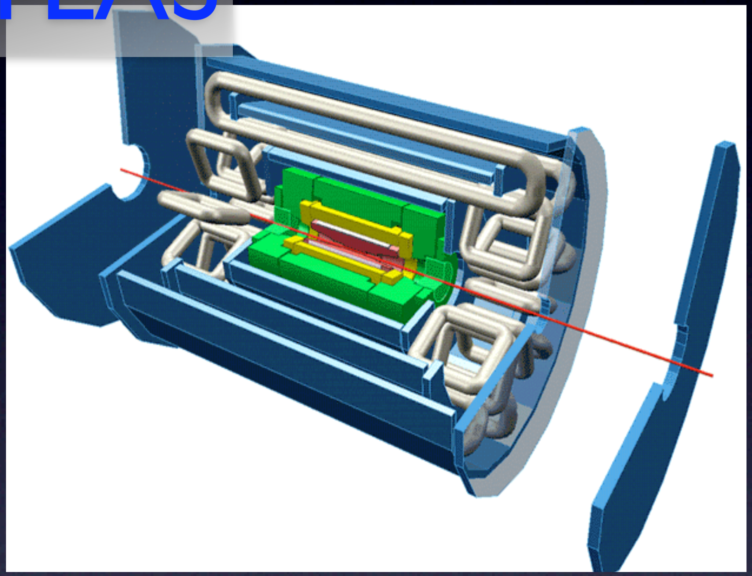
Extra Slides

Introduction Related

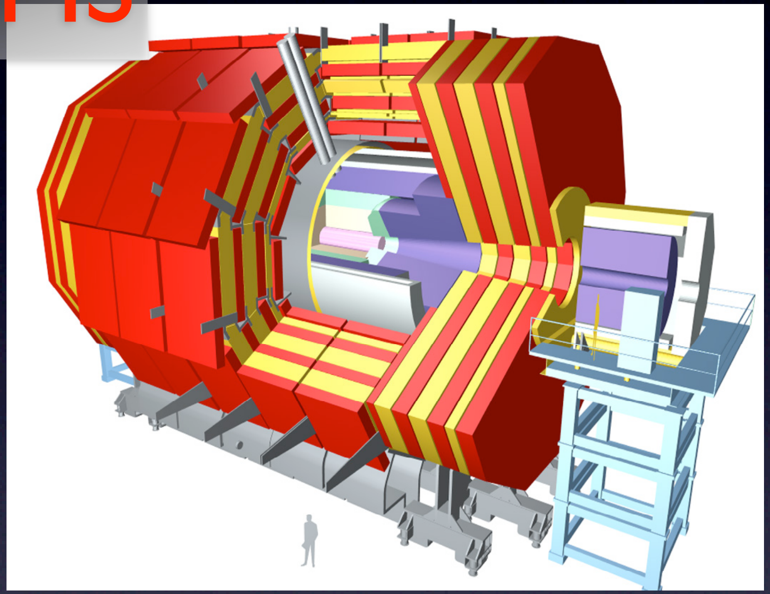
The LHC General-purpose Detectors

The LHC General-purpose Detectors

ATLAS



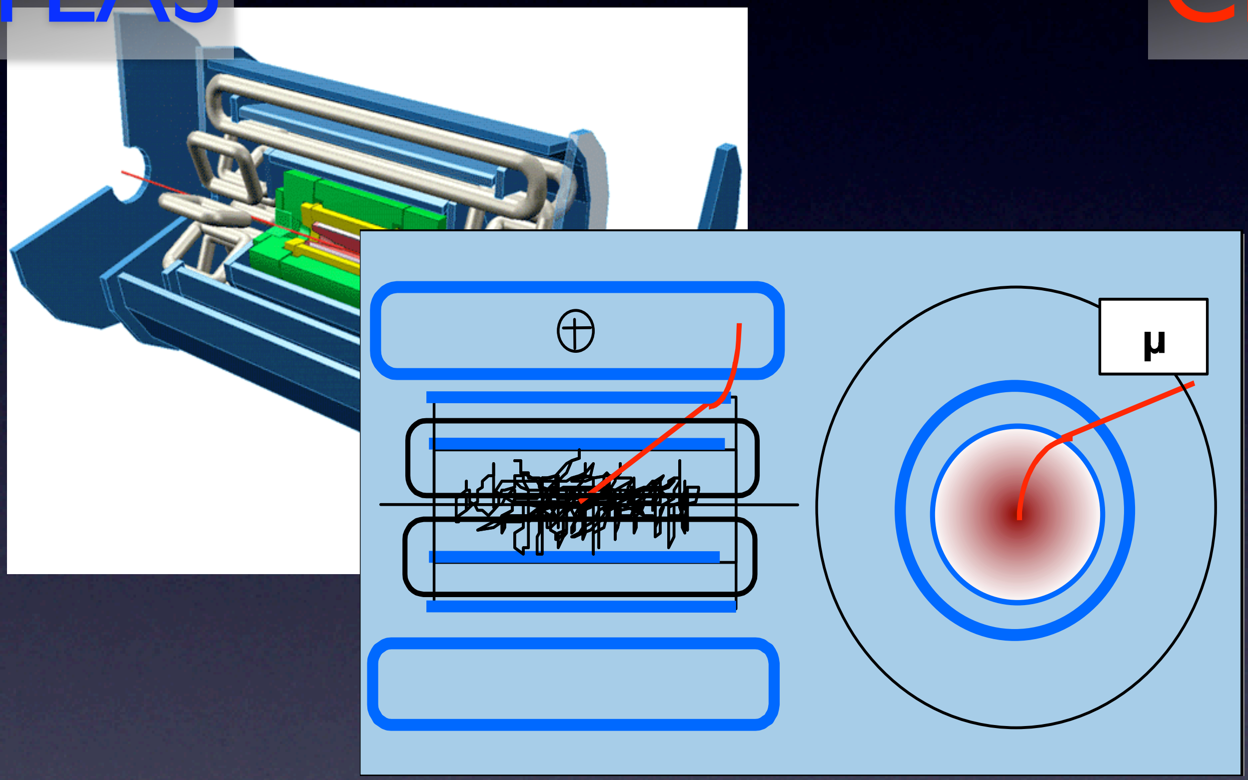
CMS

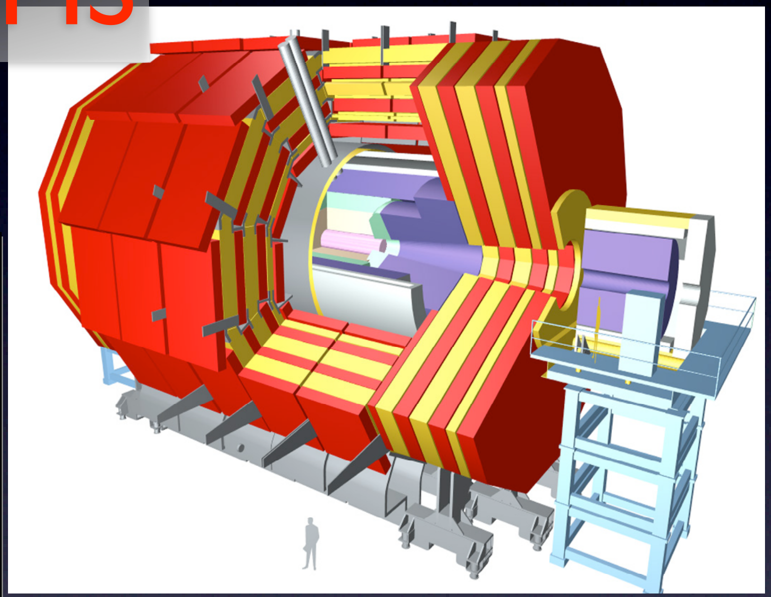


The LHC General-purpose Detectors

ATLAS

CMS

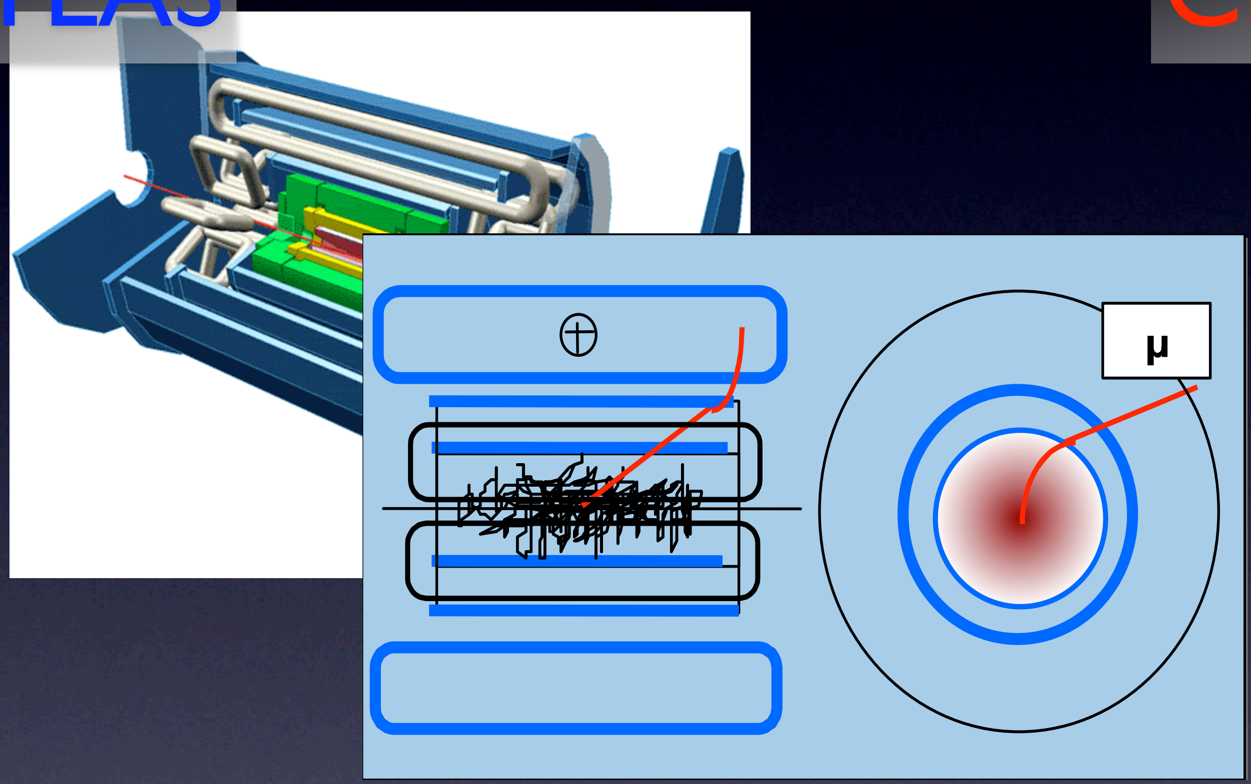




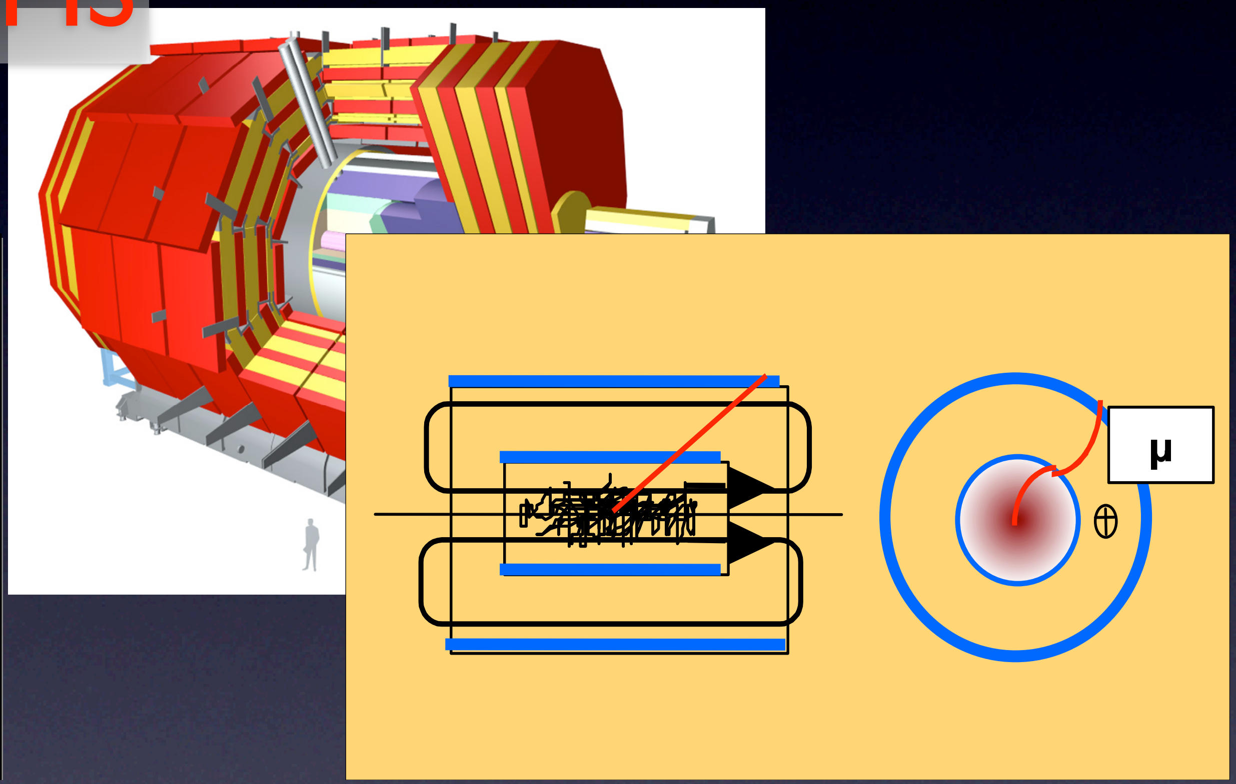
- Solenoid (2T) + Large Toroidal Magnate System
- Standalone muon tracking
- Calorimeters outside solenoid

The LHC General-purpose Detectors

ATLAS



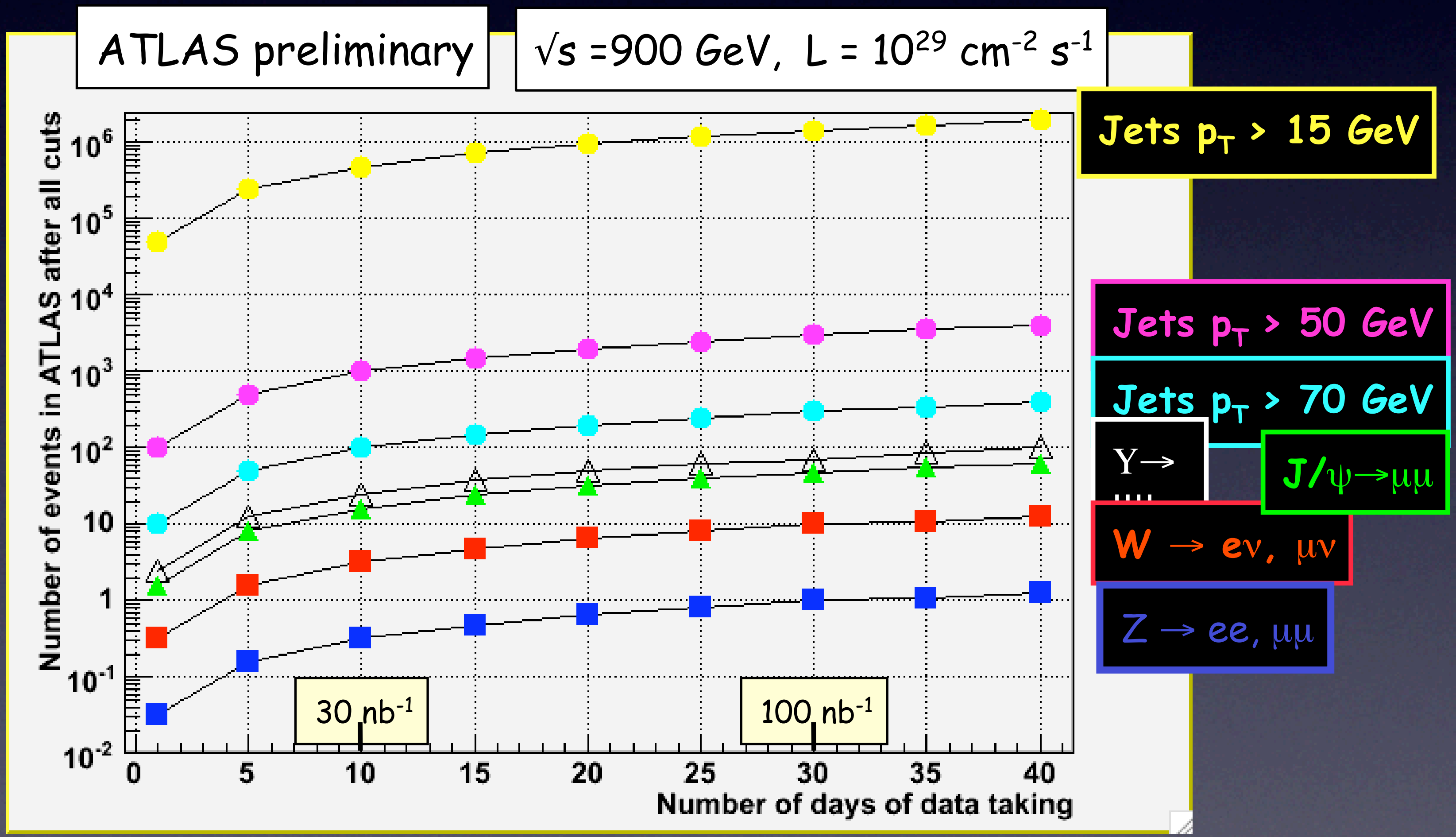
CMS



- Solenoid (2T) + Large Toroidal Magnate System
- Standalone muon tracking
- Calorimeters outside solenoid

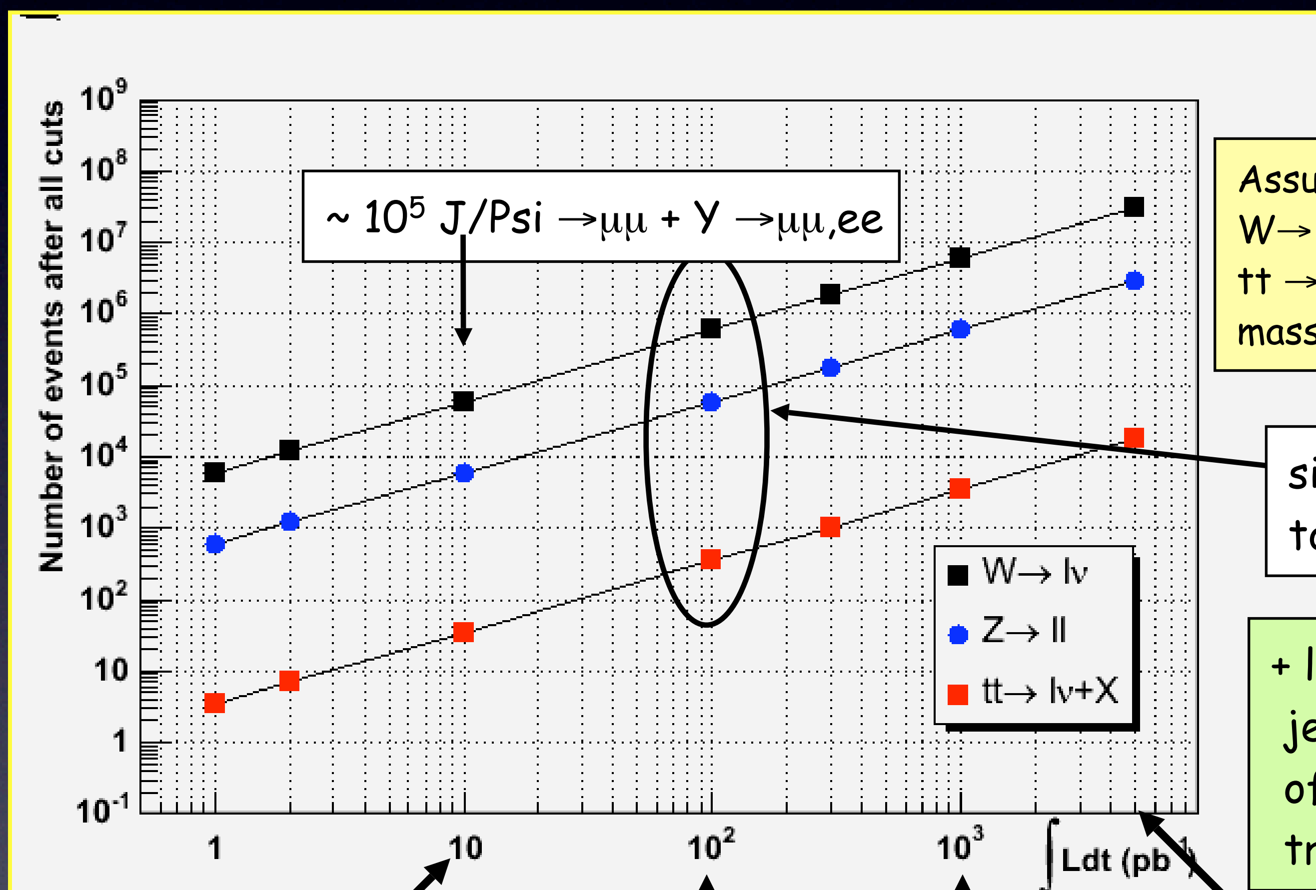
- Powerful Solenoid (4T)
- Muon bend in return flux
- Calorimeters inside solenoid⇒constraint on HCal

900 GeV Run



ATLAS preliminary
√s =900 GeV, L = 10^29 cm^-2 s^-1
Number of events in ATLAS after all cuts
Number of days of data taking
30 nb^-1
100 nb^-1
Jets pT > 15 GeV
Jets pT > 50 GeV
Jets pT > 70 GeV
Υ→
J/ψ→μμ
W → eν, μν
Z → ee, μμ

How many events of each type in 100/pb?



Assumed selection efficiency:
W→ lν, Z→ ll : 20%
tt → lν+X : 1.5% (no b-tag, inside mass bin)

similar statistics to CDF, D0 today

+ lots of minimum-bias and jets (10^7 events in 2 weeks of data taking if 20% of trigger bandwidth allocated)

10 pb^{-1} ≡ 1 month at 10^{30} and < 2 weeks at 10^{31}, ε=50%

100 pb^{-1} ≡ few days at 10^{32} , ε=50%

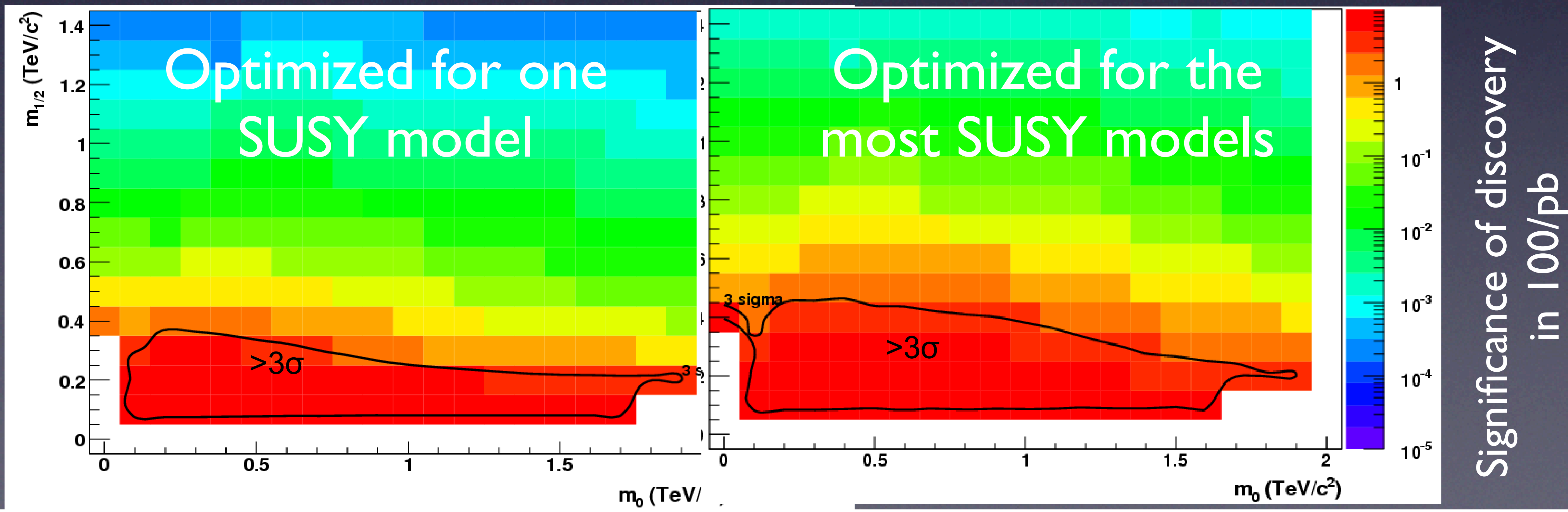
1 fb^{-1} ≡ 6 month at 10^{32}, ε=50%

5 fb^{-1} ≡ 3 month at 10^{32} and 3 month at 10^{33}, ε=50%

SUSY Related

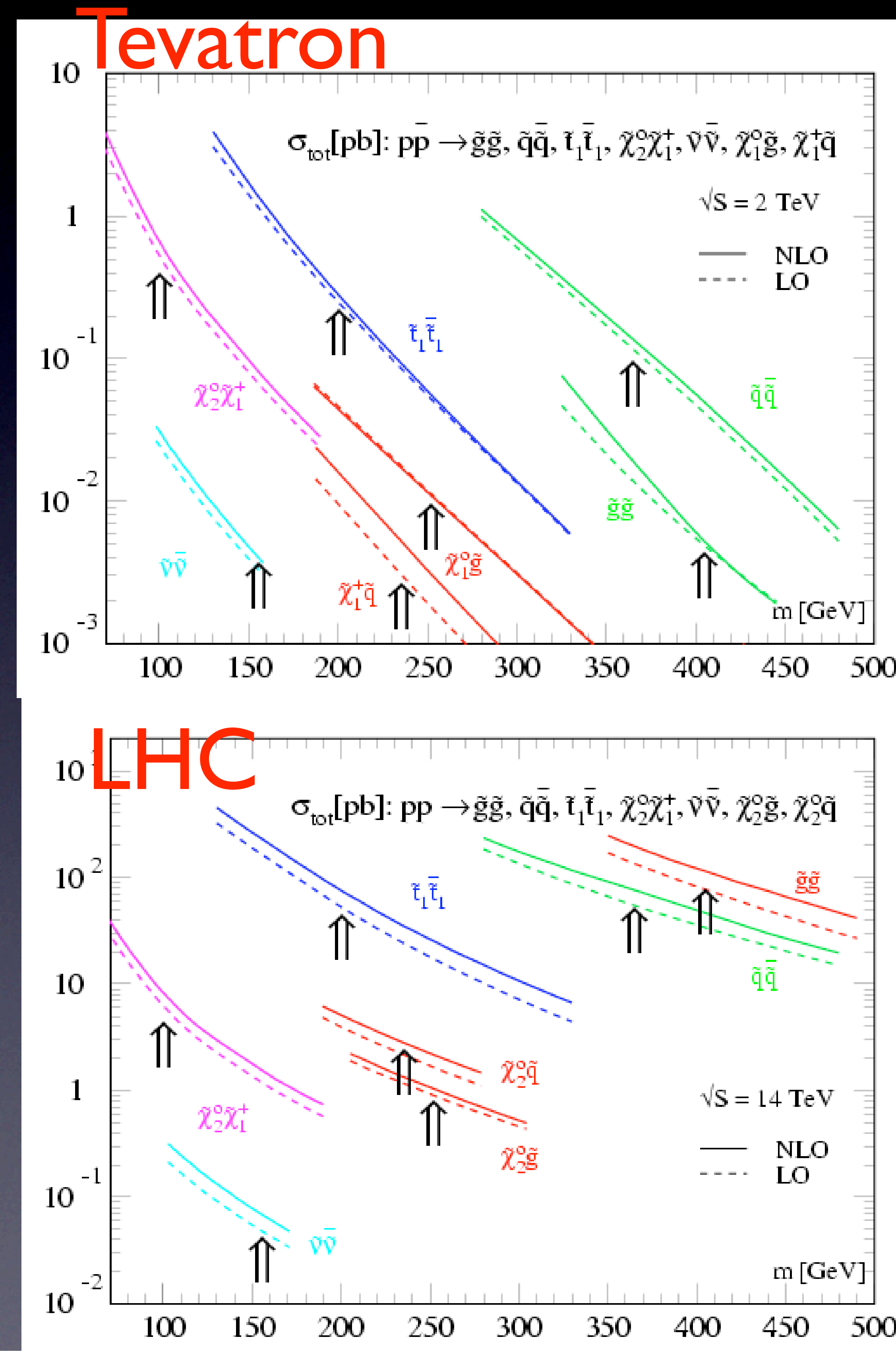
Analysis Strategy

- Large SUSY parameter space... we may optimize our analyses for the wrong place and miss SUSY in our data.
- Cannot look in too many places:
  - More analyses, more susceptible to statistical fluctuations.
  - If we discover something, accounting for correlations between measurements requires assuming a SUSY model.
- ATLAS is exploring various strategies... must properly account for systematics.
- Example: optimize analyses for greatest discovery potential.



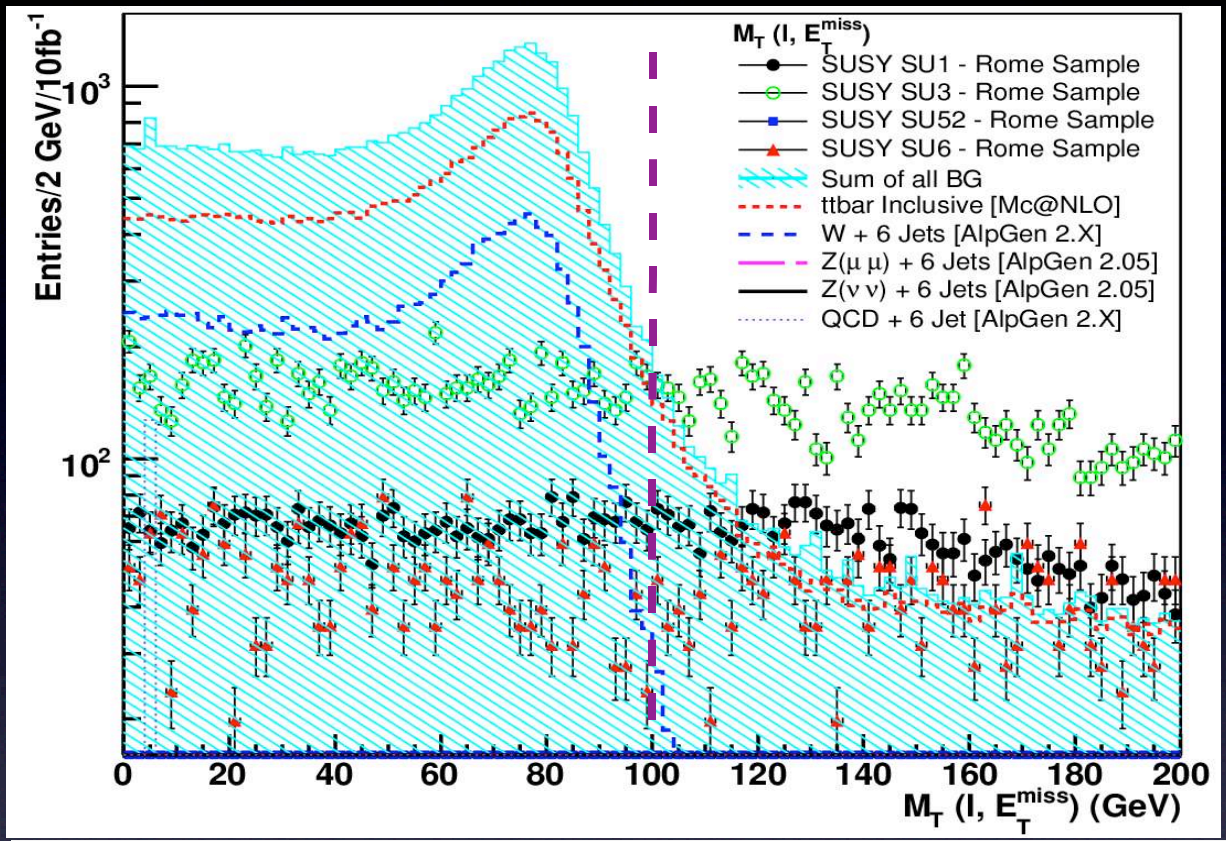
SUSY Production at LHC

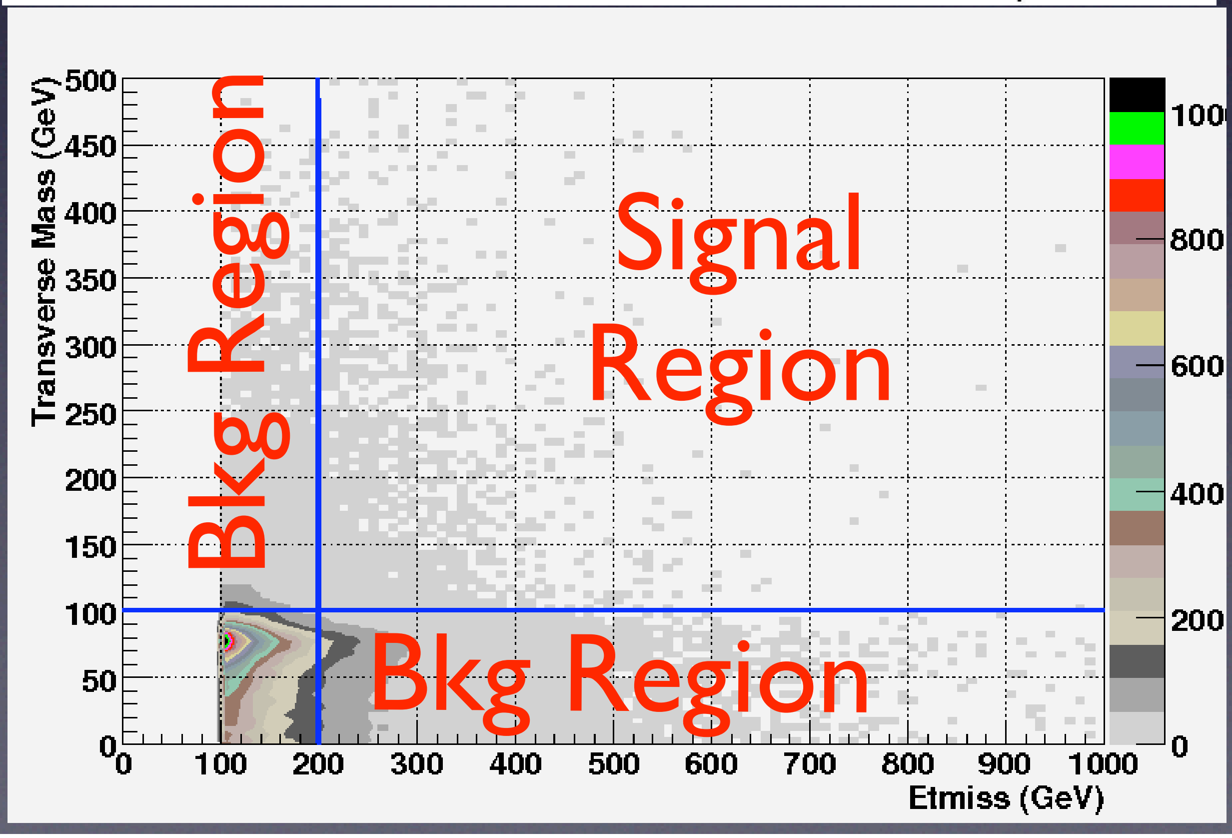
- Of course LEP & Tevatron were able to *directly* look for SUSY.
- LHC will have much higher production cross-section.
- SUSY is Produce strongly
- squarks and gluinos dominate production

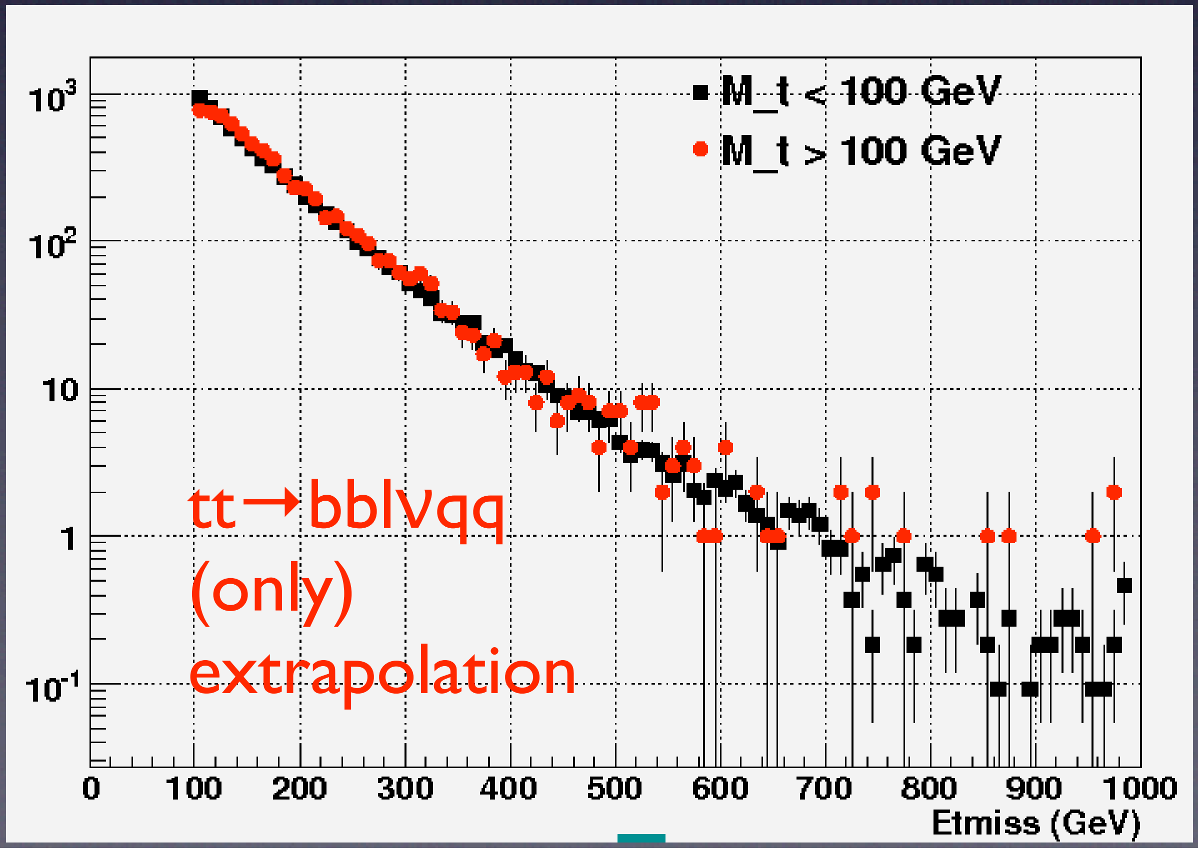


Extrapolation in Data for Single Lepton Signature

- Perform SUSY selections
- Cut on M_T=mass (lepton + MET) and MET
- Complications:
  - $tt \rightarrow bblnqq$ and $tt \rightarrow bbl\nu l\nu$ exhibit different $M_T \Rightarrow$ separate the two contributions
  - W+Jets is a background to top

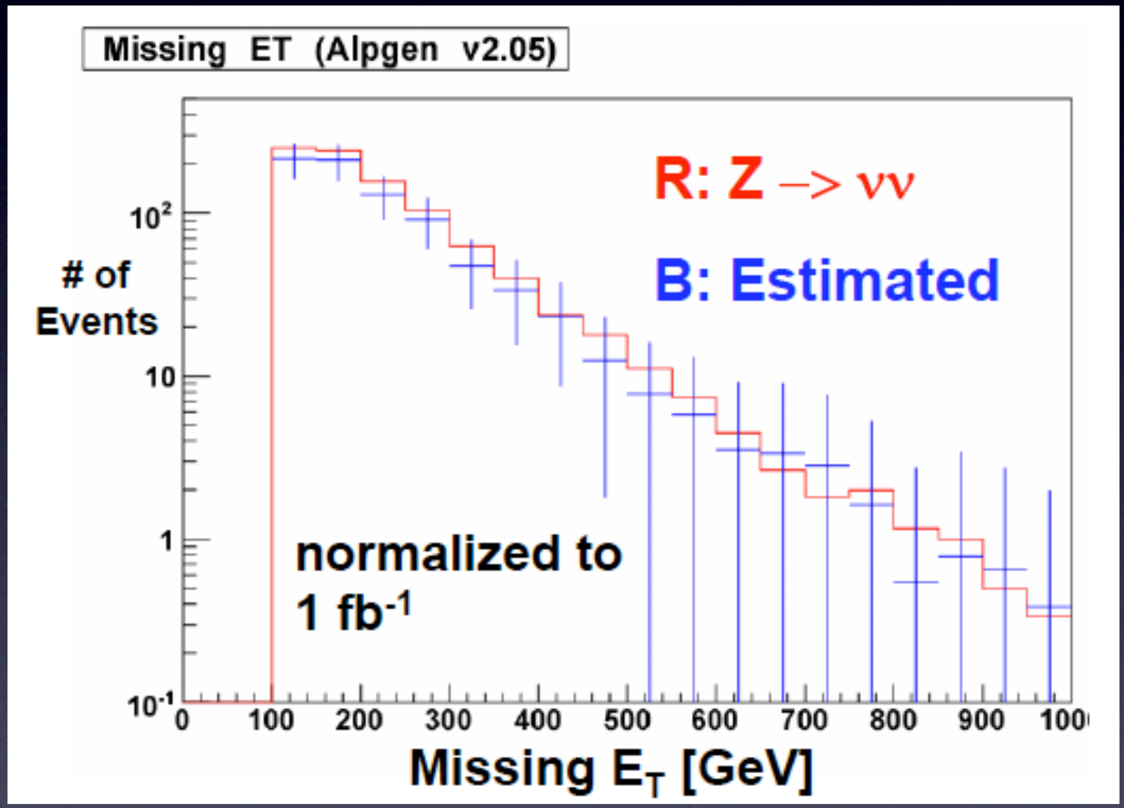




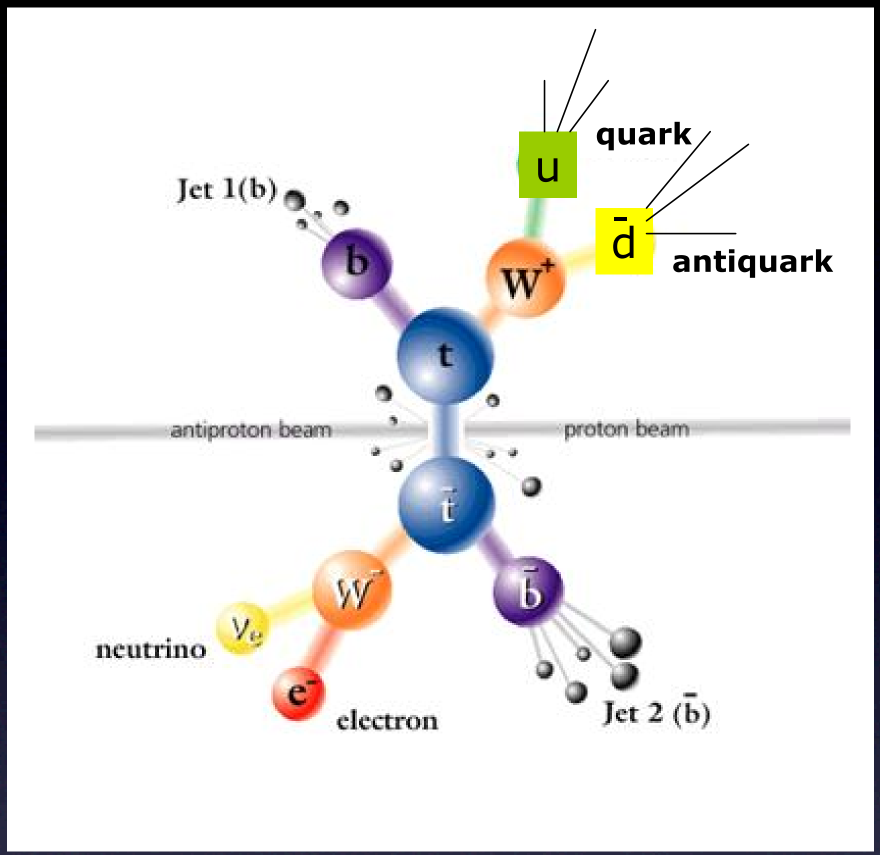


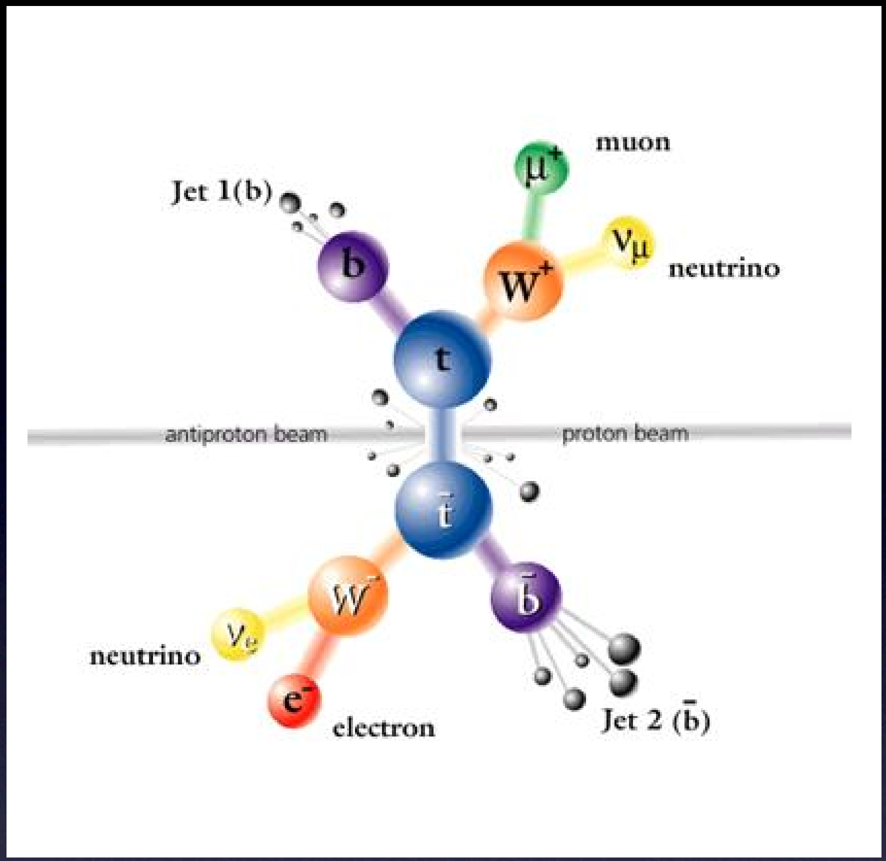
Replacement

- Reconstruct Z->ll + jets...
- Move pT(Z) to MET ⇒ Z->nn + jets
- Statistics limited... can use W->lv
- Must properly account for lepton acceptance/efficiency



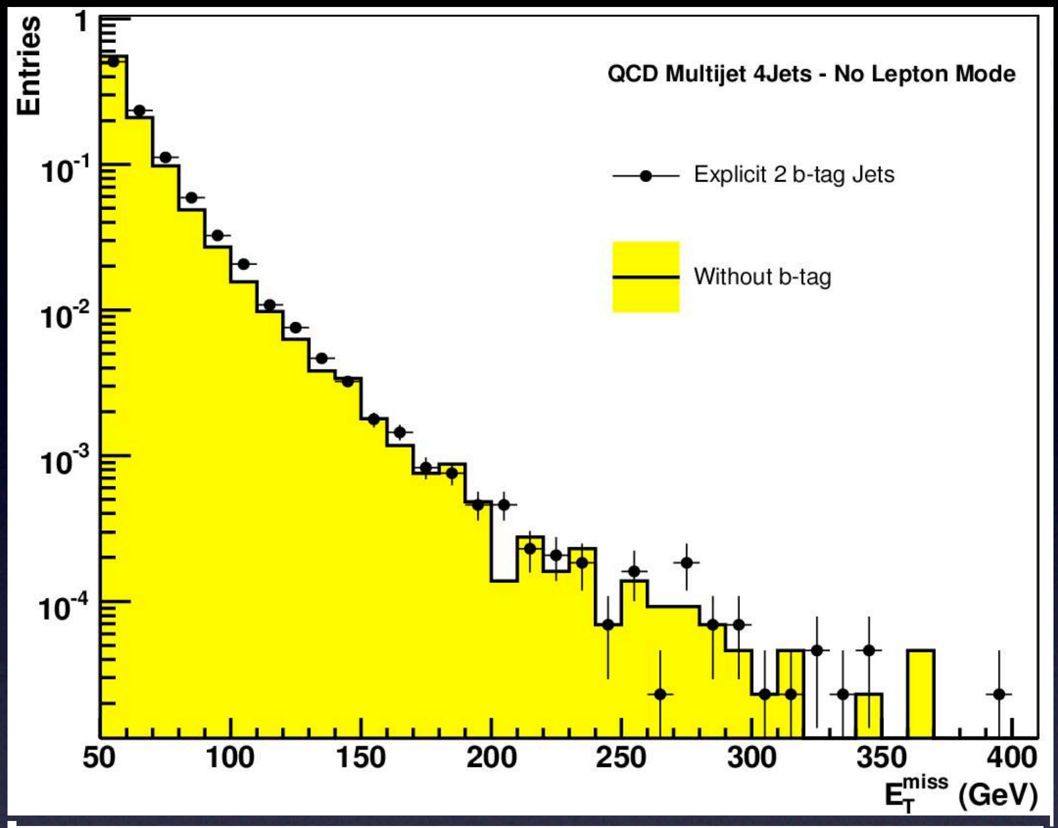
Re-decay

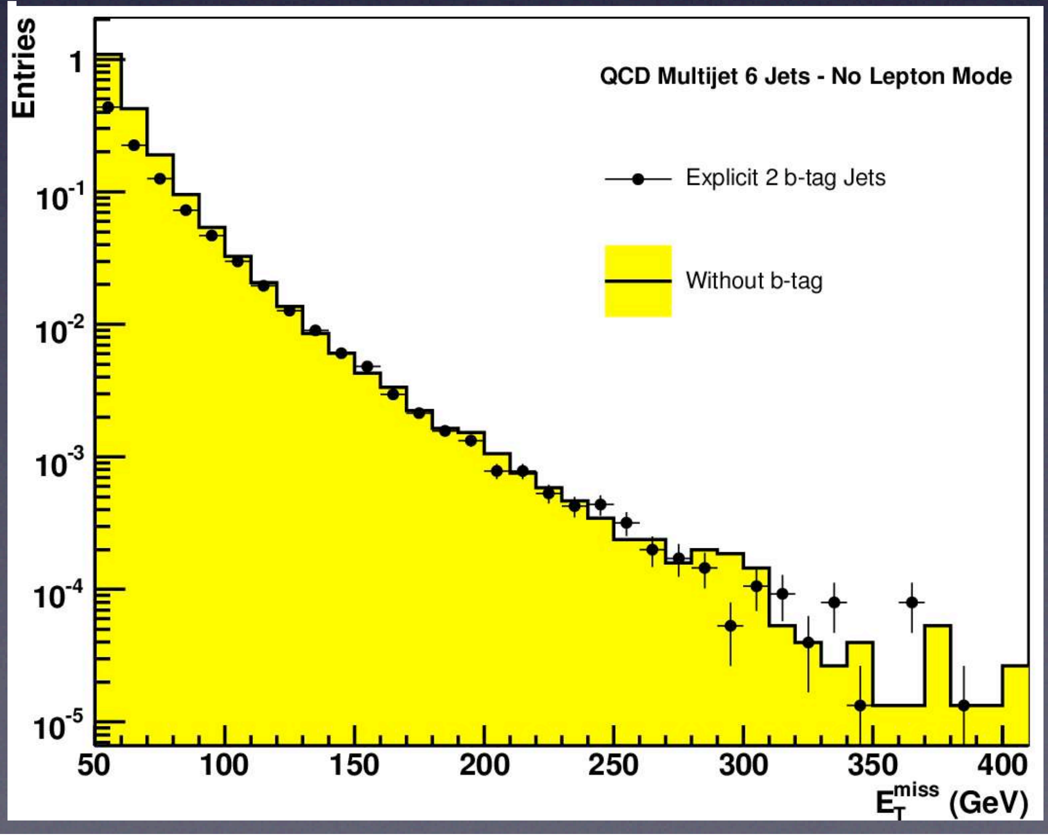




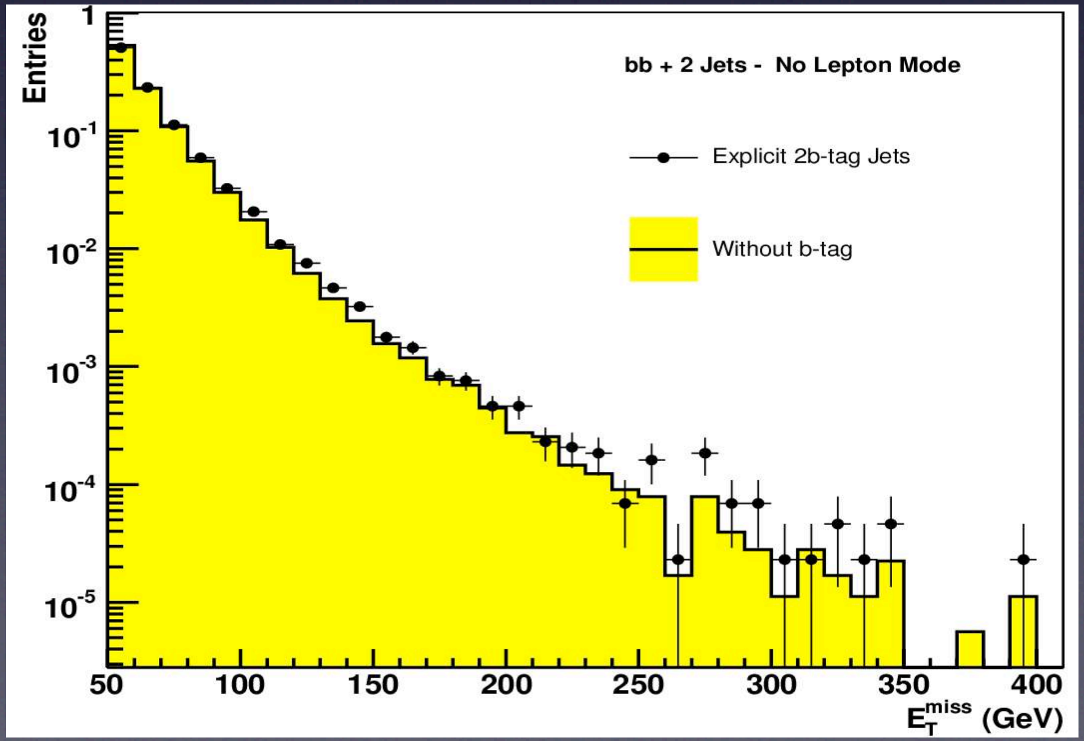
- Fully reconstruct an event (eg bbqqln) to obtain hard-scatter kinematics (eg t→bqq)
- Use MC to produce alternative decay (eg bln) w/ same kinematics. Replace.
- Result: production from data, decay from generator, response from simulation

QCD Backgrounds



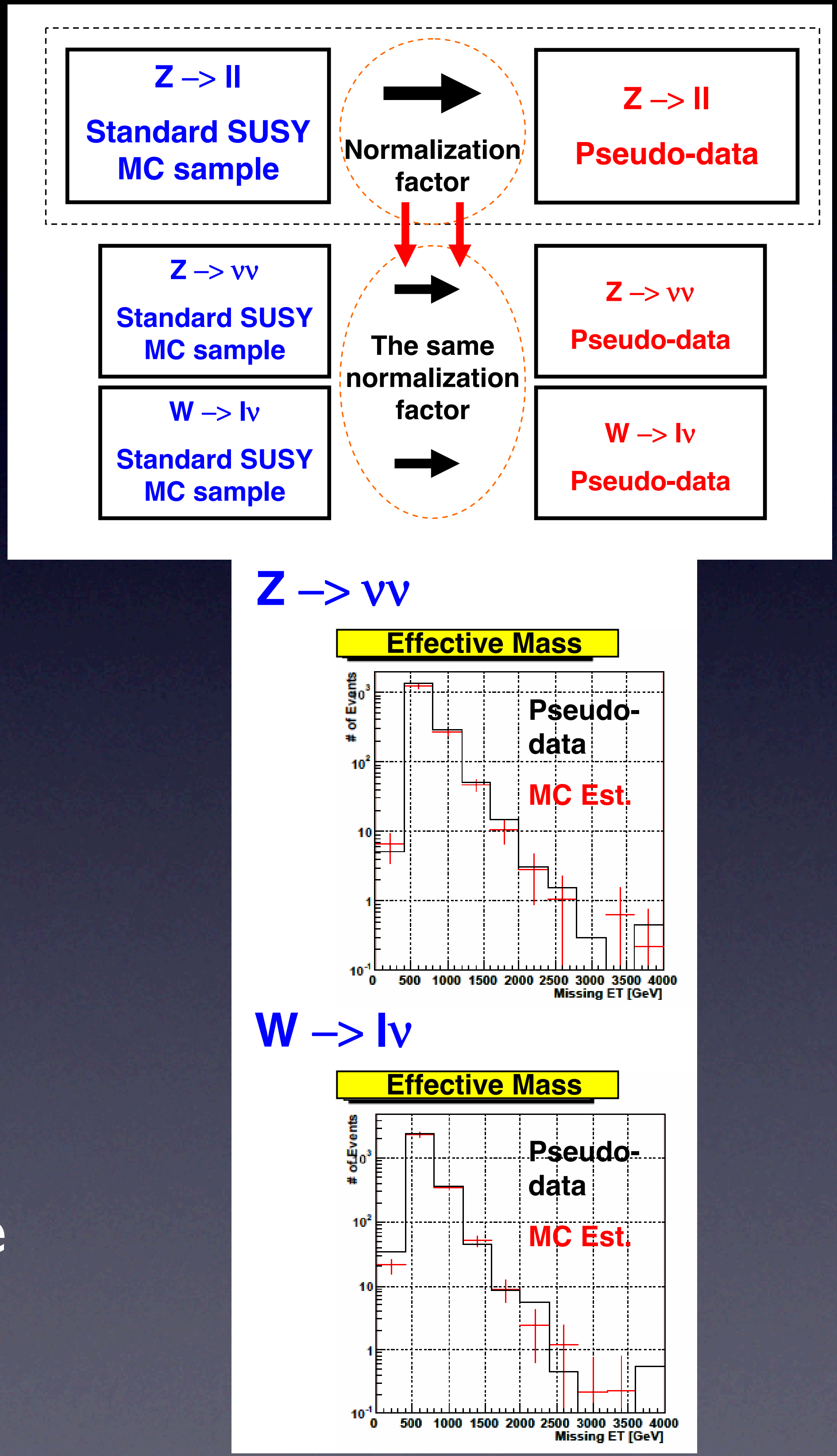


- Main source of Large missing Et is b-jets



Monte Carlo Estimation

- Most relevant for 0 lepton where other techniques have difficulties
- Vary parameters of Alpgen: (renormalization scale (at each pT), factorization scale (m Z 2+ pT_Z2), ME partons (pT> 40GeV, dRij>0.7), MLM Jet Matching (ET> 40 GeV, R = 0.7), PDF (CTEQ6L)
- Appears that shapes do not depend on input... but rates do.
- Use Z->ll in data to determine determine Z->ll normalization in MC ⇒ Z->νν W->ln
- The normalization factor is common among Z−>ll, Z−>νν, W−>lν because they have the same production mechanisms.



Building a SUSY Discovery Analysis

Optimize Strategy

Understanding Detector

SUSY Discovery Analysis

Understand Backgrounds

Missing Energy

Jets

Leptons (e,μ)

Scale, Resolution, Tails

Efficiency/ fake rate

Z→ll (+ Jets)

W→lν (+ Jets)

tt→bqqblν, blνblν

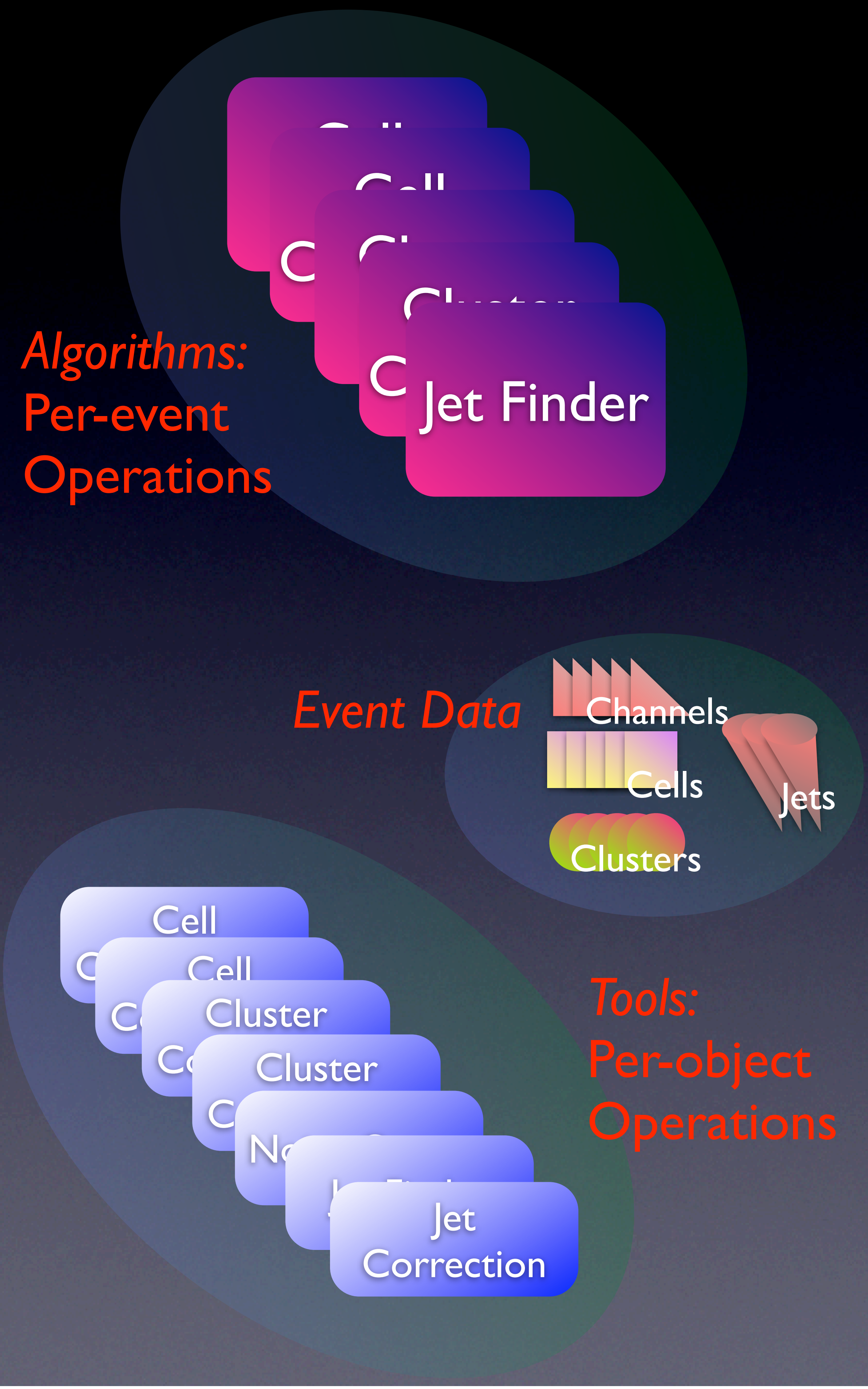
Jet + Jet + Jet

γ,Jet + Jet

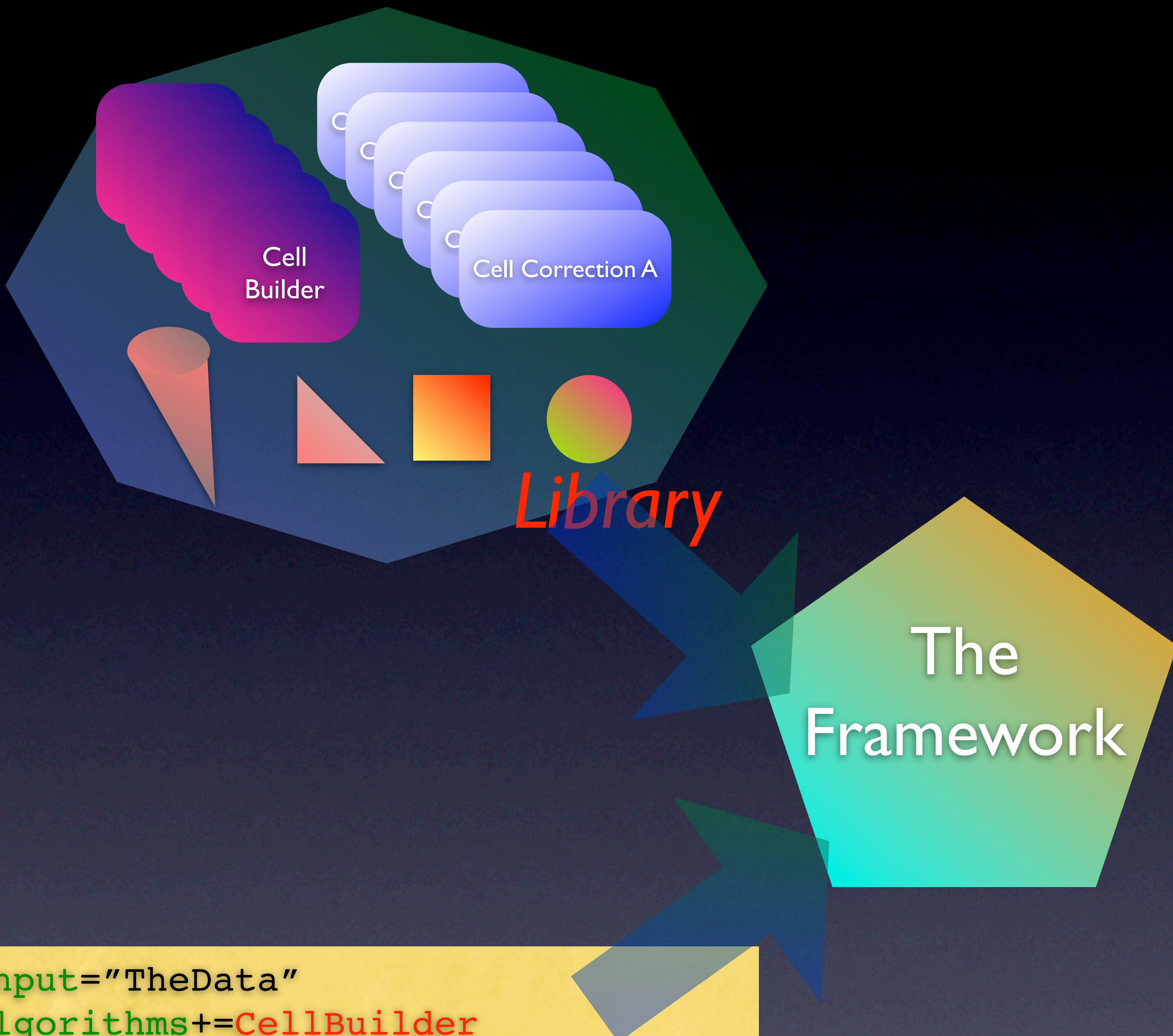
Analysis Computing Related

Example: Reconstruction

- HEP software frameworks are designed for event reconstruction.
- The reconstruction software is simultaneously developed by 100's of people over many years.
- A common set of framework elements form the basic language of event processing.



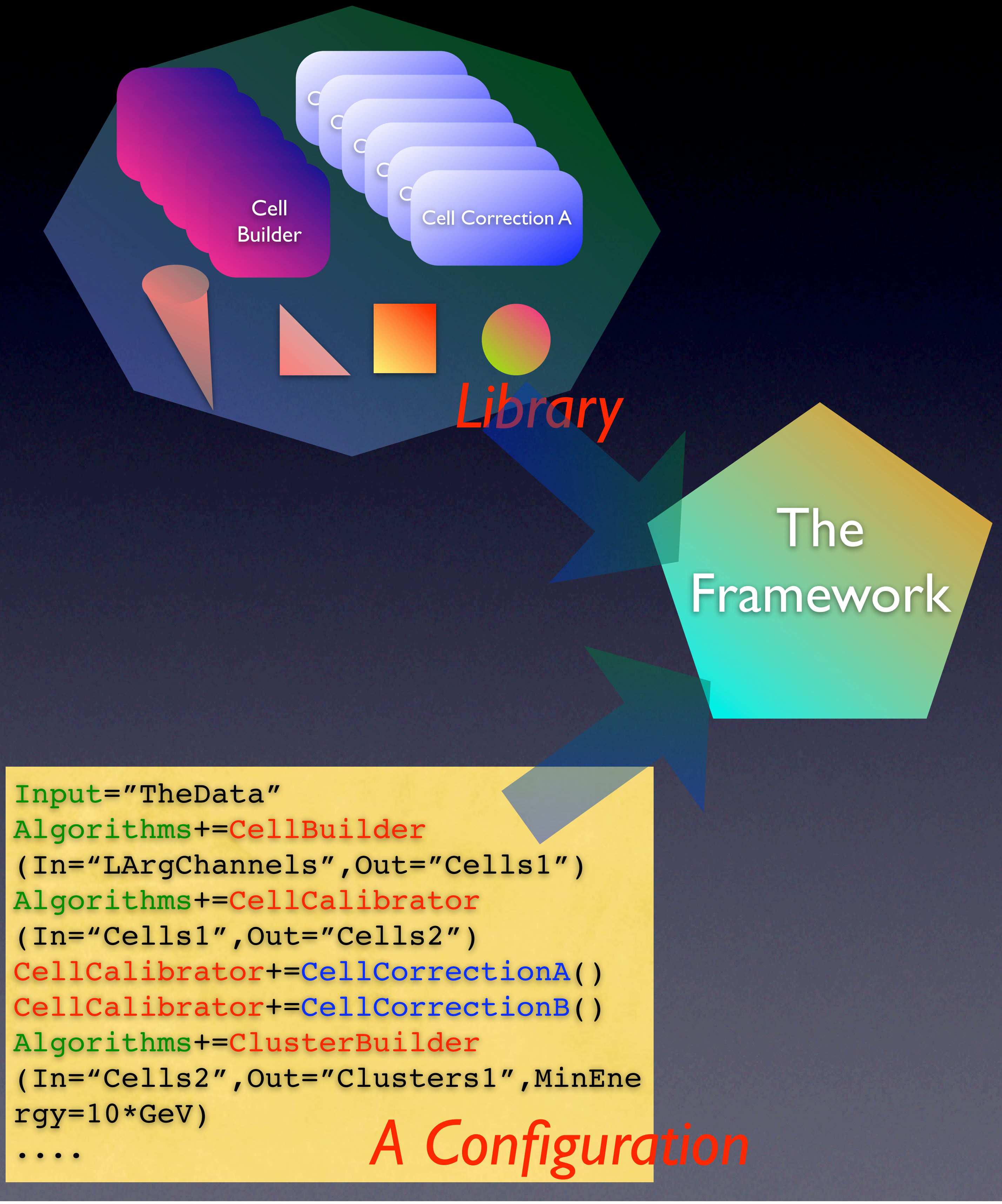
- The reconstruction application is a specific configuration of a library of framework elements.

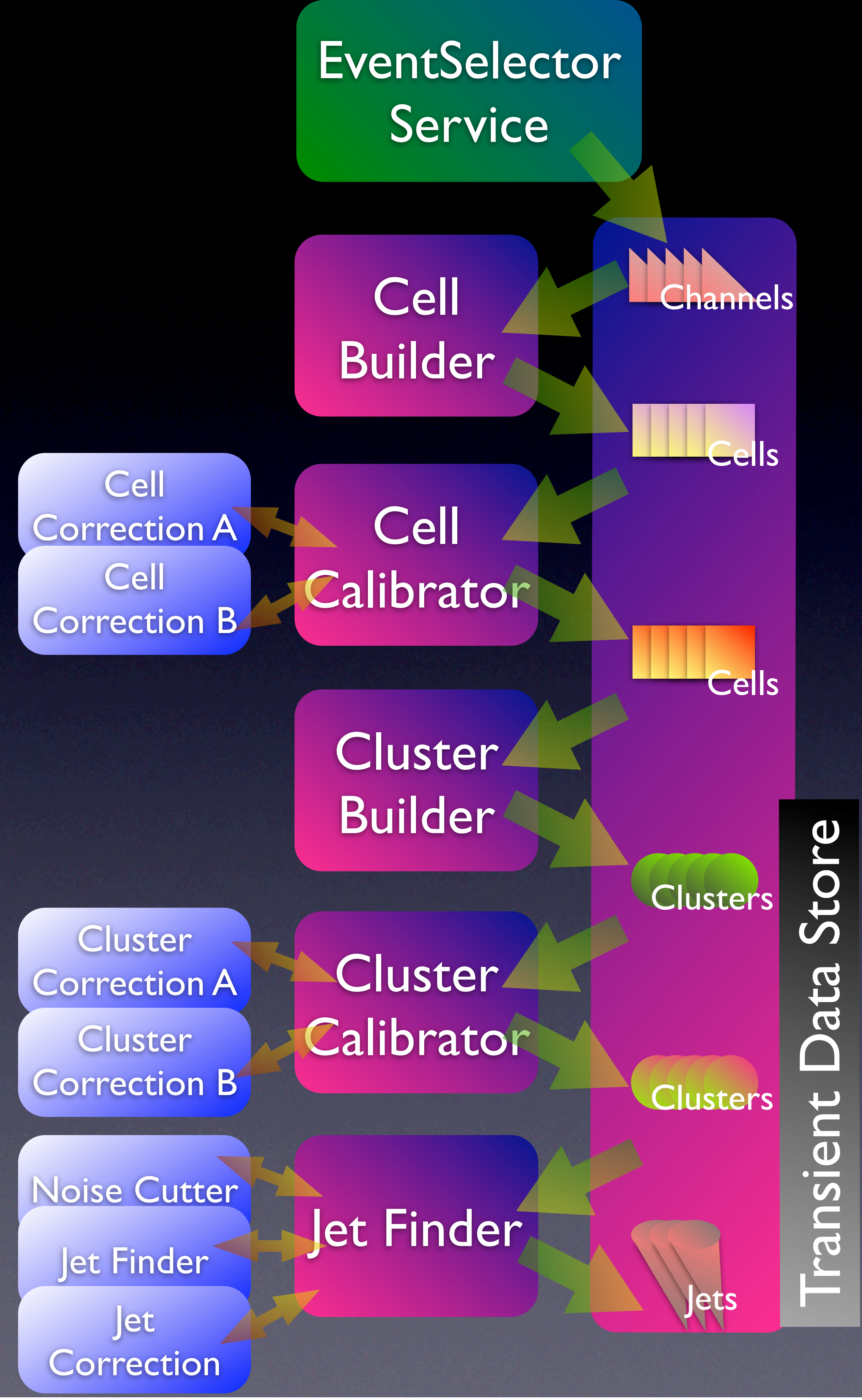



```
Input="TheData"
Algorithms+=CellBuilder
(In="LArgChannels",Out="Cells1")
Algorithms+=CellCalibrator
(In="Cells1",Out="Cells2")
CellCalibrator+=CellCorrectionA()
CellCalibrator+=CellCorrectionB()
Algorithms+=ClusterBuilder
(In="Cells2",Out="Clusters1",MinEne
rgy=10*GeV)
....
```

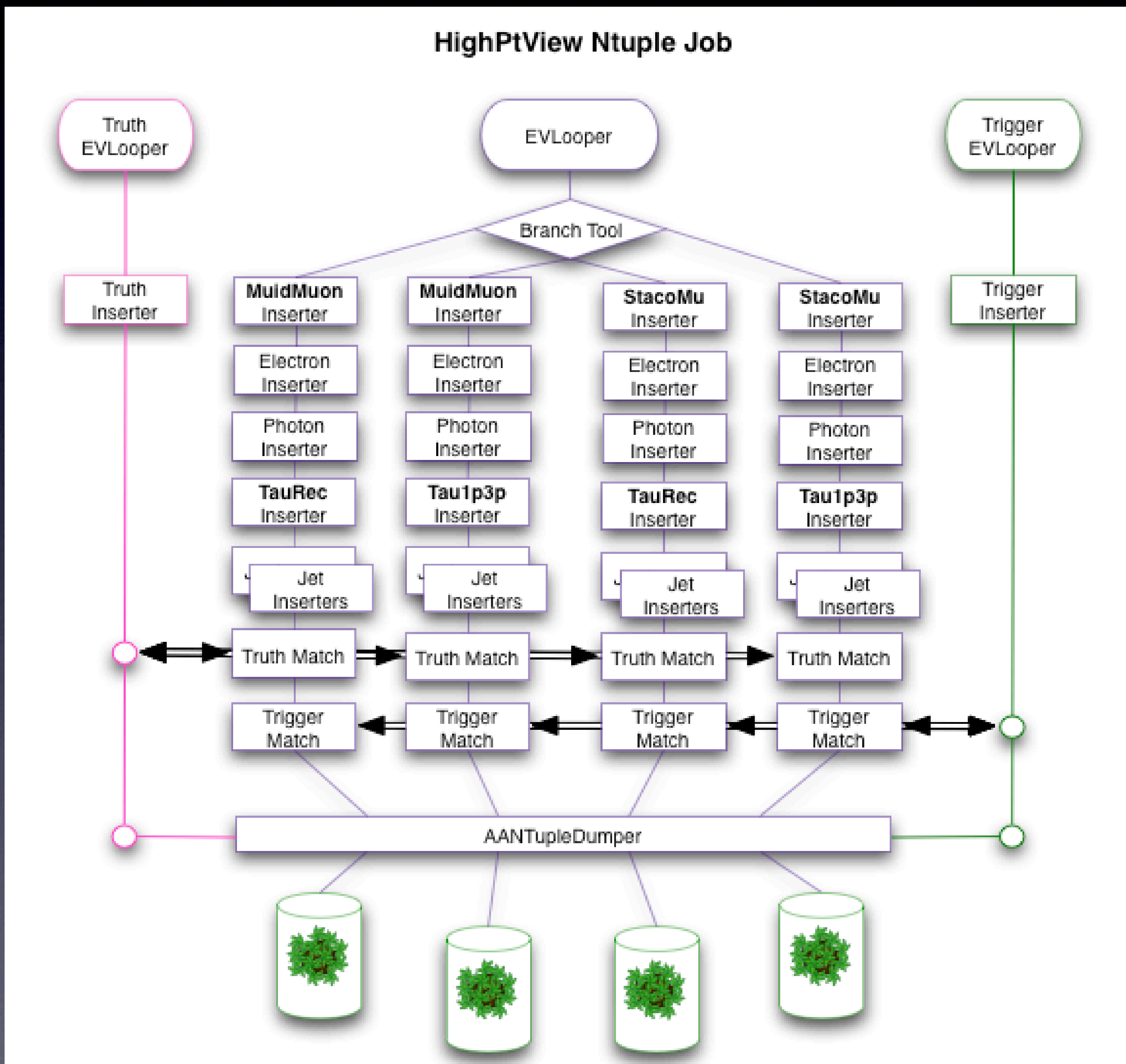
A Configuration

- The reconstruction application is a specific configuration of a library of framework elements.





More on HighPtView



- Analyses are mostly configuration of standard EventView tools + some analysis specific tools.

Comprehensive SUSY Analysis

- Requires multiple sources of information
  - MET resolution, lepton ID, Jet/lepton scale/resolutions
  - Various estimates of backgrounds
  - Optimization of Analysis procedure
  - Many groups of people will each contribute some element.
- Need:
  - Consistency in data samples, algorithms, configuration, selections.
  - Communication of results of one step to another.
  - Ability to recover from show-stoppers. Make measurements with detector, calibrations, and software at hand...

Statistical Analysis

- Building Discriminants
- Calculating Significance/upper limits
- Properly handling Systematics
- Building Fits
- Building toy MC

Interactive Analysis

- Need a place to make plots, study, etc
- Book keep large number of samples.
- Everyone knows how... but why do it again?
- Examples.
- Interactive Athena: seamless ESD/AOD/ DPD in/out framework access