Search techniques

Alan Barr

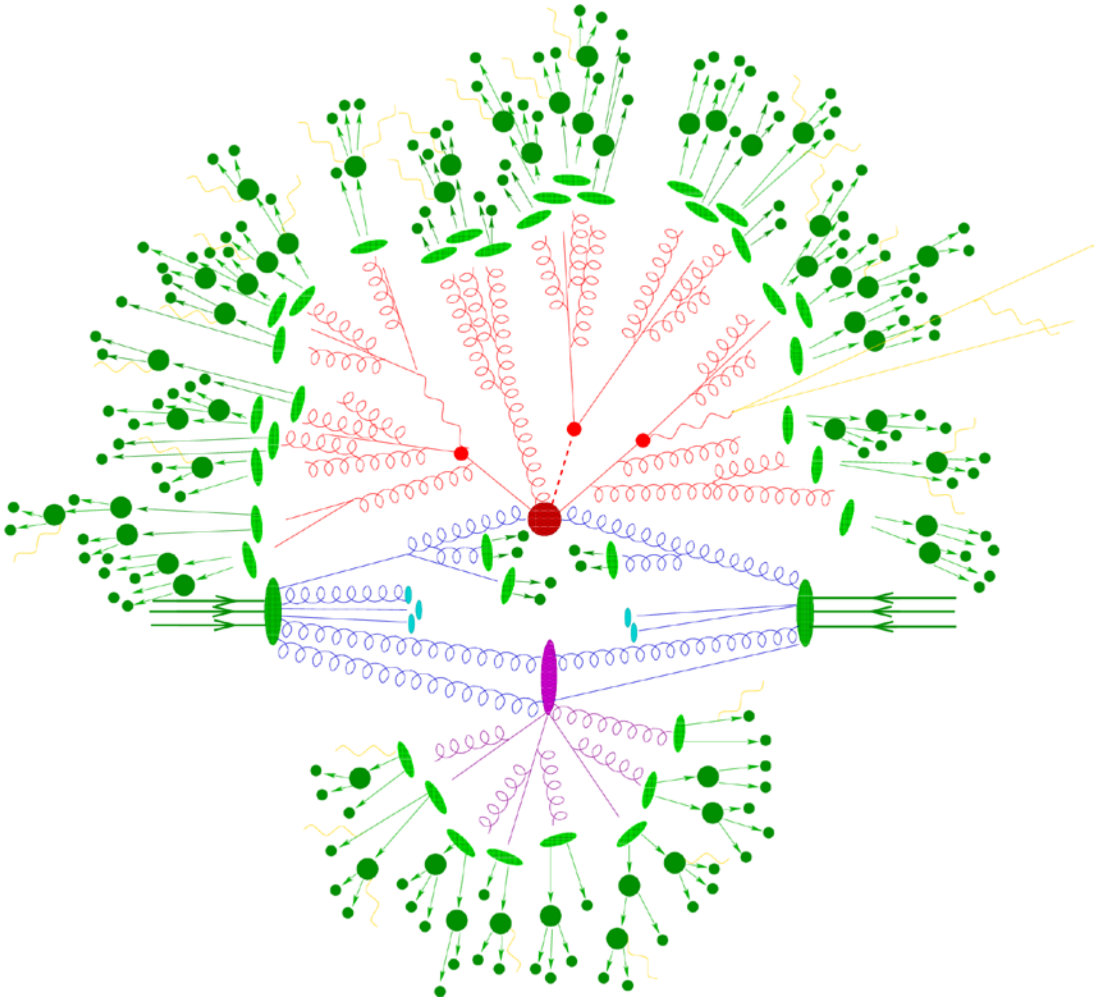
UNIVERSITY OF OXFORD

A very busy week

	Wed 06 July	Thursday 07 July	Friday 08 July	Saturday 09 July	Sunday 10 July	Monday 11 July	Tuesday 12 July	Wed 13 July	Thursday 14 July	Friday 15 July	Saturda y 16 July
DAY	0	1	2	3	4	5	6	7	8	9	10
9:00-9:30		Introduction QCD	Introduction QCD	Introduction QCD	HQ@LHC,TOP	free	Intro MC	Jets Theory	jet substructure	Future colliders	
30-10:00		**D. Soper**	**D. Soper**	**D. Soper**	**R. Tenchini**	day	**T. Sjostrand**	**M. Dasgupta**	**M.Dasgupta**	**J. Fuster**	
:00-10:30											
:30-11:00		Introduction QCD	Heavy Quarks 1	W/Z@ LHC	Introduction MC		match&merge	Jets@LHC	Applied	BSM Higgs	
:00-11:30		**D. Soper**	**G. Hiller**	**M. Schott**	**T. Sjostrand**		**S. Plätzer**	**M. Voutilainen**	**M. Beinker**	**M. Kraemer**	
:30-12:00											
:00-12:30		Intro EW+Higgs	Parton Distribution Functions	Dark matter	Intro MC		Intro MC	match&merge		student	
:30-13:00		**S. Pozzorini**	**R. Placakyte**	**M. Bartelmann**	**T.Sjostrand**		**T. Sjostrand**	**S. Plätzer**		talks	
:00-14:30		lunch	lunch	lunch	lunch		lunch	lunch	lunch	lunch	
:30-15:00		Intro EW+Higgs	XFitter Tutorial	Astroparticle	MC Tutorial		MC Tutorial	Model-Independent	MC Tutorial	Future accelerators	
:00-15:30		**S. Pozzorini**		**T. Lohse**				Measurements **J.Butterworth**		**R. Assmann**	
:30-16:00	Regstration										
:00:16:30		SM Higgs@LHC		Heavy Quarks 2						Search Strategies	
:30-17:00		**K. Jakobs**	**S. Camarda /**	**S.- O. Moch**						**A. Barr**	
:00-17:30			R. Placakyte								
:30-18:00											

Much learned

- QCD
- Electroweak physics
- Higgs
- PDFs
- Jets
- Matching
- Substructure



Searches also rely on MC

4 Monte Carlo data samples

Monte Carlo (MC) data samples are used to develop the analysis, optimise the selections, estimate backgrounds and assess sensitivity to specific SUSY signal models. The SM background processes considered are those which can lead to events with jets and missing transverse momentum. The processes considered together with the MC generators, cross-section calculations and parton distribution functions (PDFs) used are listed in table 1. The γ+jets MC data samples are used to estimate

Even for “data-driven” methods, MC often used to test assumptions

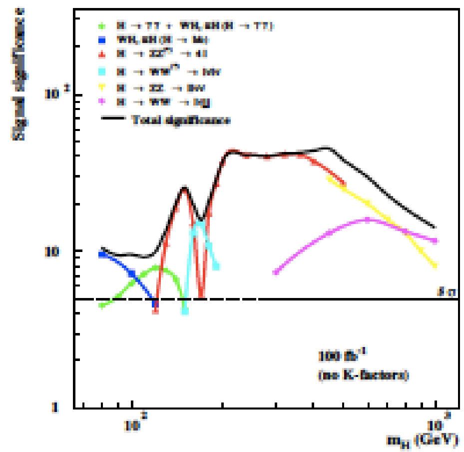
MC almost always used in analysis design and optimisation

MC central to interpretation

A brief retrospective

CERN/LHCC 99-15

ATLAS DETECTOR AND PHYSICS PERFORMANCE

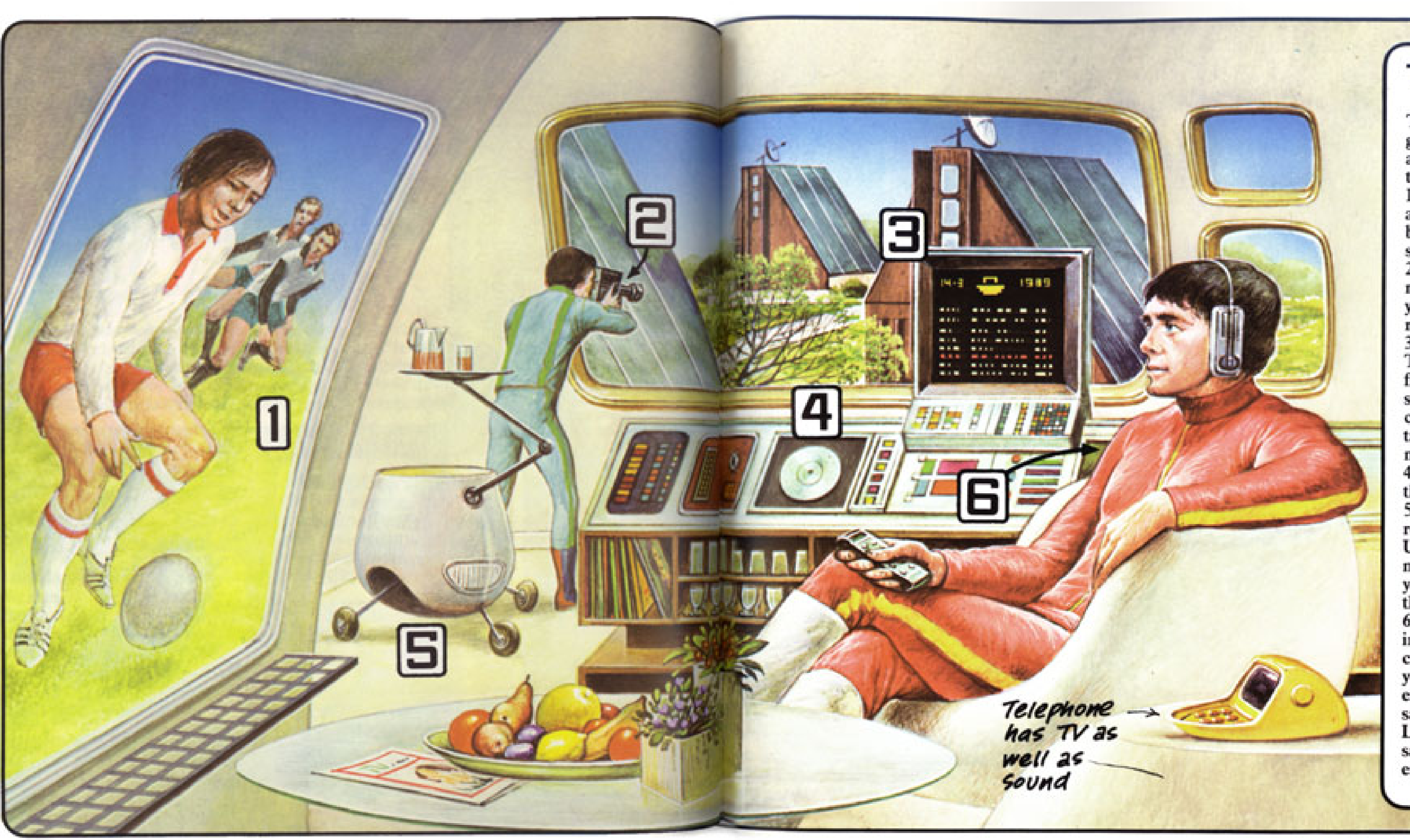


Technical Design Report

Volume II

Issue:	1
Revision:	0
Reference:	ATLAS TDR 15, CERN/LHCC 99-15
Created:	25 May 1999
Last modified:	25 May 1999
Prepared By:	ATLAS Collaboration


THE USBORNE BOOK OF
THE FUTURE
A TRIP IN TIME TO THE YEAR 2000 AND BEYOND


1
2
3
4
5
6
Telephone has TV as well as sound

Our technology has also moved on…

Since the main background for SUSY is SUSY itself, it is essential to generate the whole SUSY cross section, not just specific channels of interest. Typically, samples of 10^5 or more events have been generated for each point studied here using either ISAJET [20-15] or SPYTHIA [20-16]. Large samples of Standard Model events are also needed to assess potential backgrounds. Such large event samples necessitate using a fast detector simulation rather than a detailed, GEANT-based one. Most of the results given here are based on ATLFAST [20-17] or comparable particle-level detector simulations. These correctly describe the gross resolution and acceptance of ATLAS but not the effects of resolution tails, cracks, *etc.* The backgrounds for SUSY signatures after reasonable cuts appear however to be dominated by real physics events and not by such detector effects.

ATLAS physics TDR 1999

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"the main background to SUSY is SUSY itself"

ATLAS physics TDR 1999

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“large MC samples of order 10,000 events”

ATLAS physics TDR 1999

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smeared truth as detector simulation

ATLAS physics TDR 1999

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2 -> 2 MC for jets backgrounds

ATLAS physics TDR 1999

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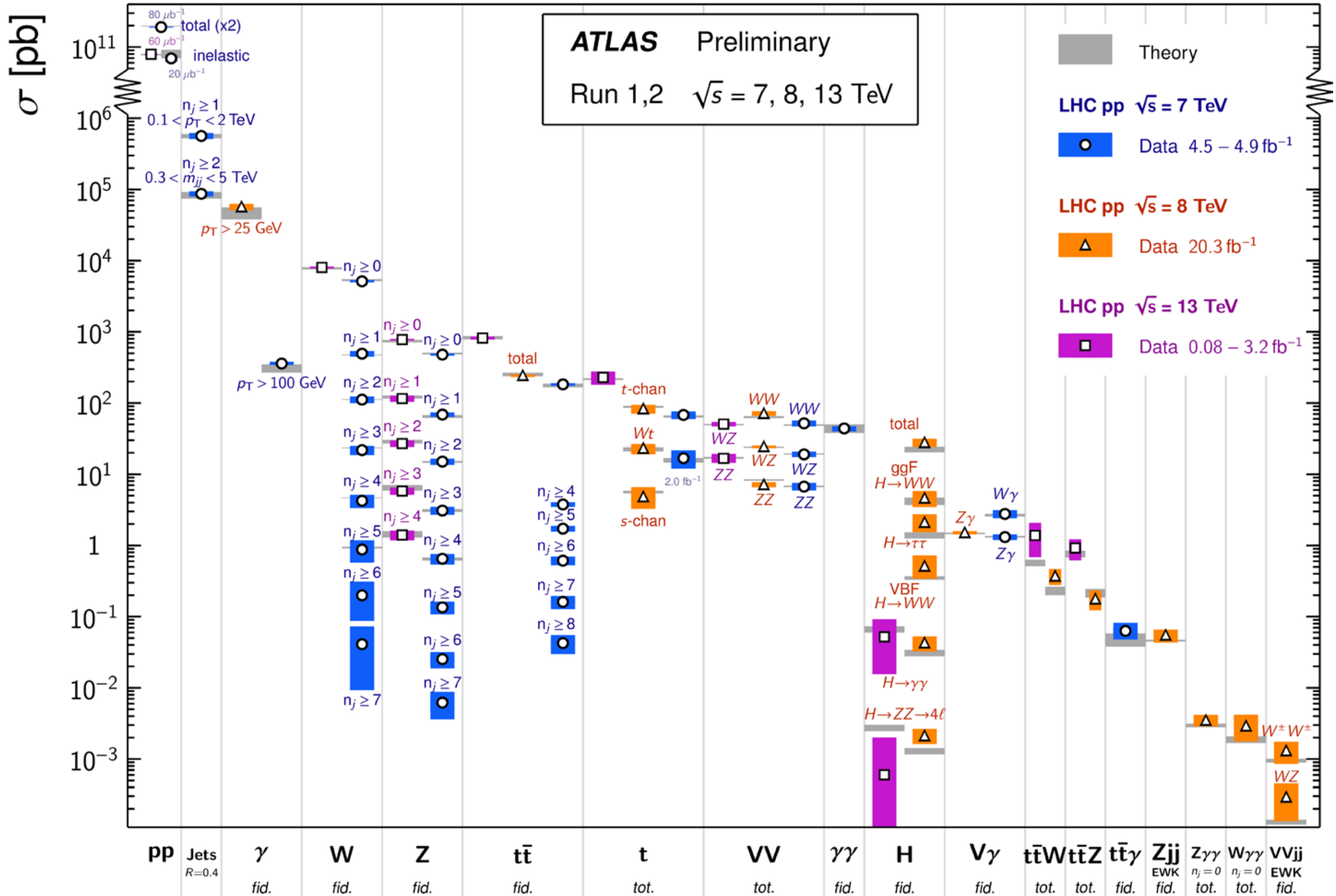
Boson + (Jets only from Parton Shower)

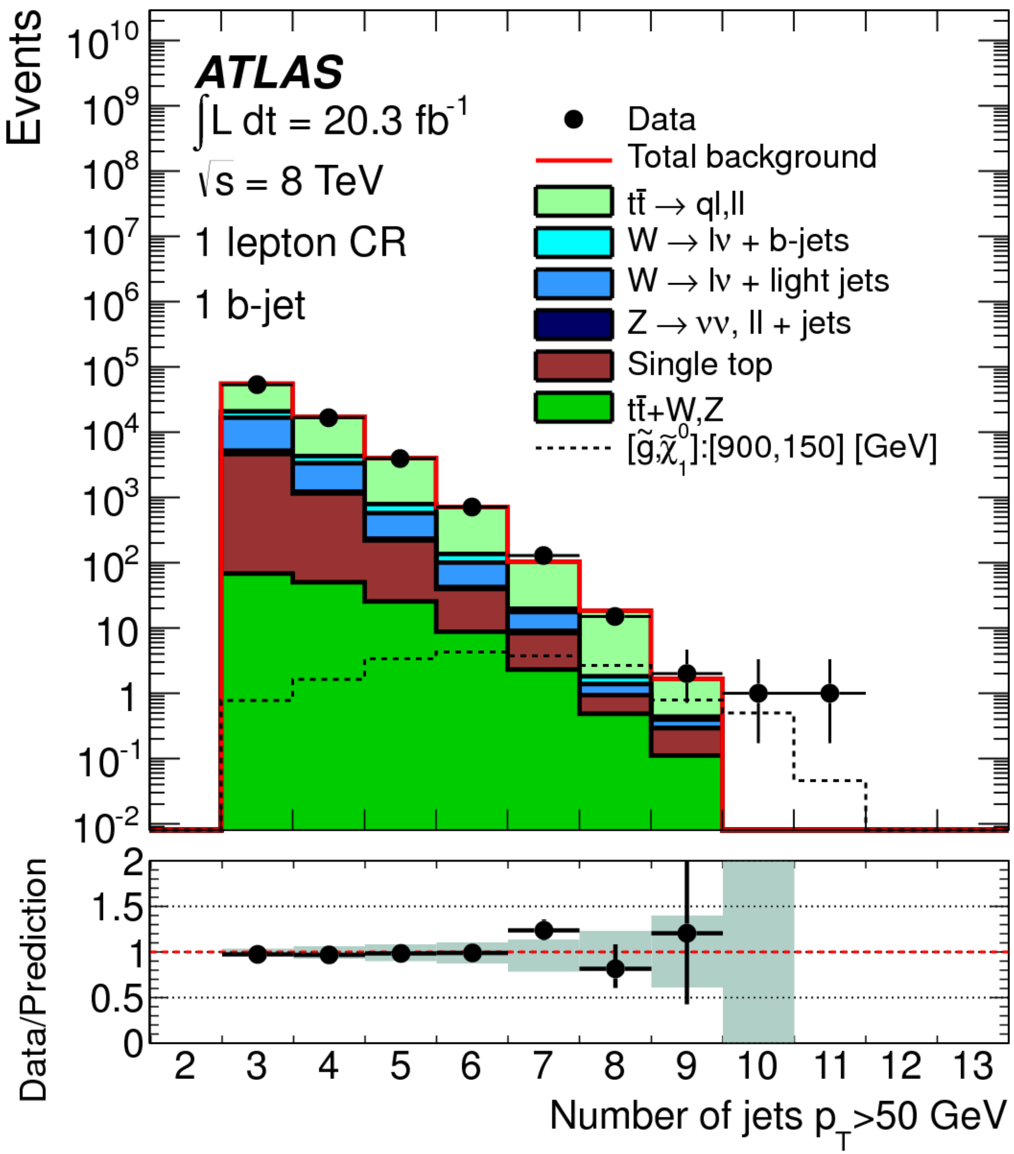
ATLAS physics TDR 1999

Standard Model Production Cross Section Measurements

Status: June 2016



High multiplicity MC



arXiv:1308.1841

ttbar MC is Sherpa-1.4.1 with up to 4 additional partons

High Precision MC

http://arxiv.org/pdf/1406.5375v2.pdf

Scalar top mass around m(t)?

The inclusive top quark pair ($t\bar{t}$) production cross-section $\sigma_{t\bar{t}}$ has been measured in proton–proton collisions at $\sqrt{s} = 7$ … ng $t\bar{t}$ events with an opposite-charge … the 2011 7 TeV dataset corresponding to an integrated luminosity of 4.6 fb^{-1} and the 2012 8 TeV dataset of 20.3 fb^{-1}. The numbers of events with exactly one and exactly two b-tagged jets were counted and used to simultaneously determine $\sigma_{t\bar{t}}$ and the efficiency to reconstruct and b-tag a jet from a top quark decay, thereby minimising the associated systematic uncertainties. The cross-section was measured to be:

$$\sigma_{t\bar{t}} = 182.9 \pm 3.1 \pm 4.2 \pm 3.6 \pm 3.3\,\text{pb}\ (\sqrt{s} = 7\,\text{TeV})\ \text{and}$$
$$\sigma_{t\bar{t}} = 242.4 \pm 1.7 \pm 5.5 \pm 7.5 \pm 4.2\,\text{pb}\ (\sqrt{s} = 8\,\text{TeV}),$$

where the four uncertainties arise from data statistics, experimental and theoretical systematic effects, knowledge of the integrated luminosity and of the LHC beam energy. The results are consistent with recent theoretical QCD calculations at next-to-next-to-leading order. Fiducial measurements corresponding to the experimental acceptance of the leptons are also reported, together with the ratio of cross-sections measured at the two centre-of-mass energies. The inclusive cross-section results were used to determine the top quark pole mass via the dependence of the theoretically predicted cross-section on m_t^{pole} giving a result of $m_t^{\text{pole}} = 172.9^{+2.5}_{-2.6}\,\text{GeV}$. By looking for an excess of $t\bar{t}$ production with respect to the QCD prediction, the results were also used to place limits on the pair-production of supersymmetric top squarks $\tilde{t}_1$ with masses close to the top quark mass, decaying via $\tilde{t}_1 \to t\tilde{\chi}^0_1$ to predominantly right-handed top quarks and a light neutralino $\tilde{\chi}^0_1$, the lightest supersymmetric particle. Top squarks with masses between the top quark mass and 177 GeV are excluded at the 95 % confidence level.

High Precision MC

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% level QCD calculations at NNLO

Technology is nothing. What's important is that you have a faith in people, that they're basically good and smart, and if you give them tools, they'll do wonderful things with them.

Steve Jobs

So what do I do…?

So what do I do…?

Be skeptical of your predecessors

… and …

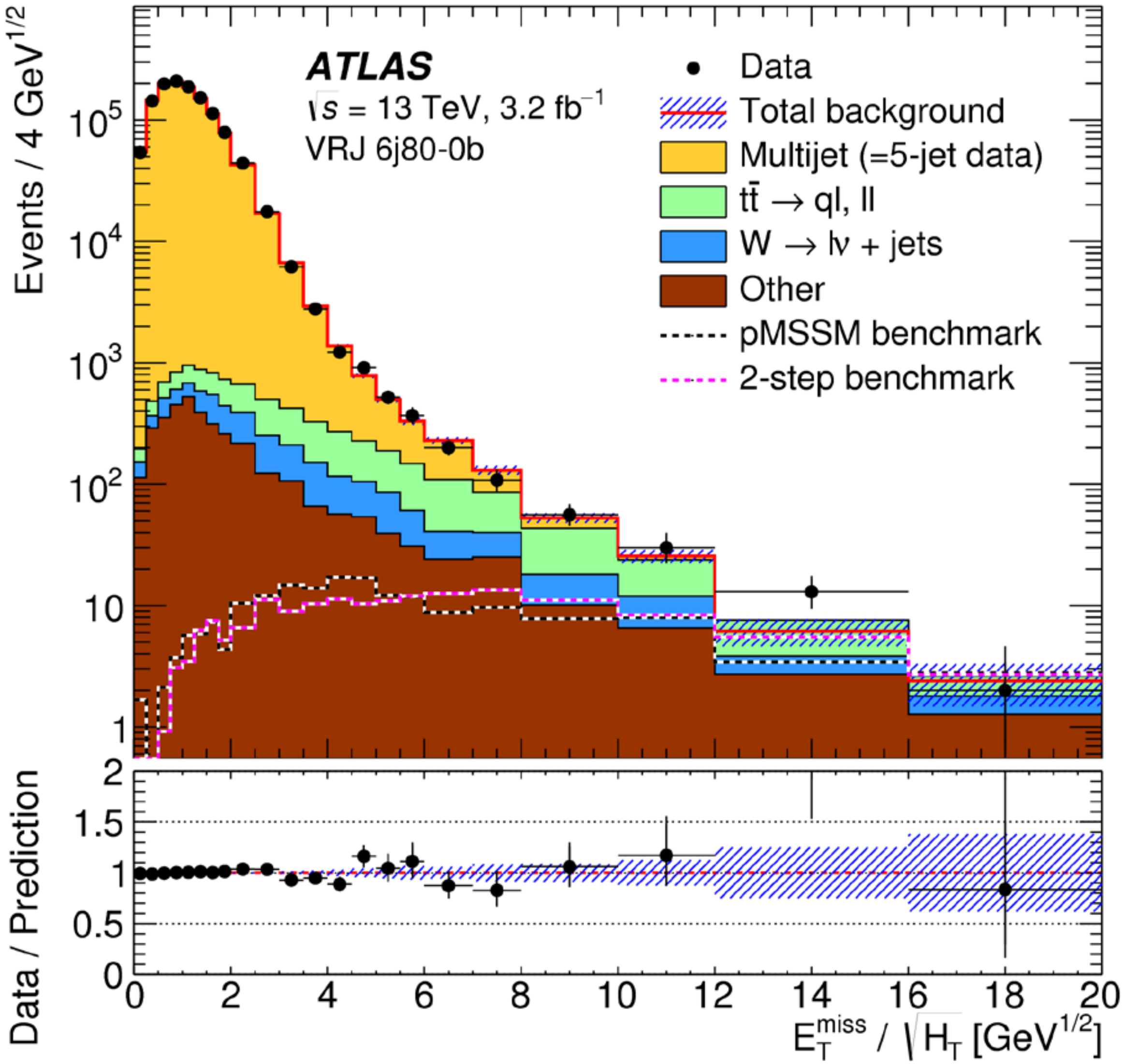
Improve things!

I never thought this would happen

Results are reported of a search for new phenomena, such as supersymmetric particle production, that could be observed in high-energy proton–proton collisions. Events with large numbers of jets, together with missing transverse momentum from unobserved particles, are selected. The data analysed were recorded by the ATLAS experiment during 2015 using the 13 TeV centre-of-mass proton–proton collisions at the Large Hadron Collider, and correspond to an integrated luminosity of 3.2 fb^{-1}. The search selected events with various jet multiplicities from ≥ 7 to ≥ 10 jets, and with various b-jet multiplicity requirements to enhance sensitivity. No excess above Standard Model expectations is observed. The results are interpreted within two supersymmetry models, where gluino masses up to 1400 GeV are excluded at 95% confidence level, significantly extending previous limits.

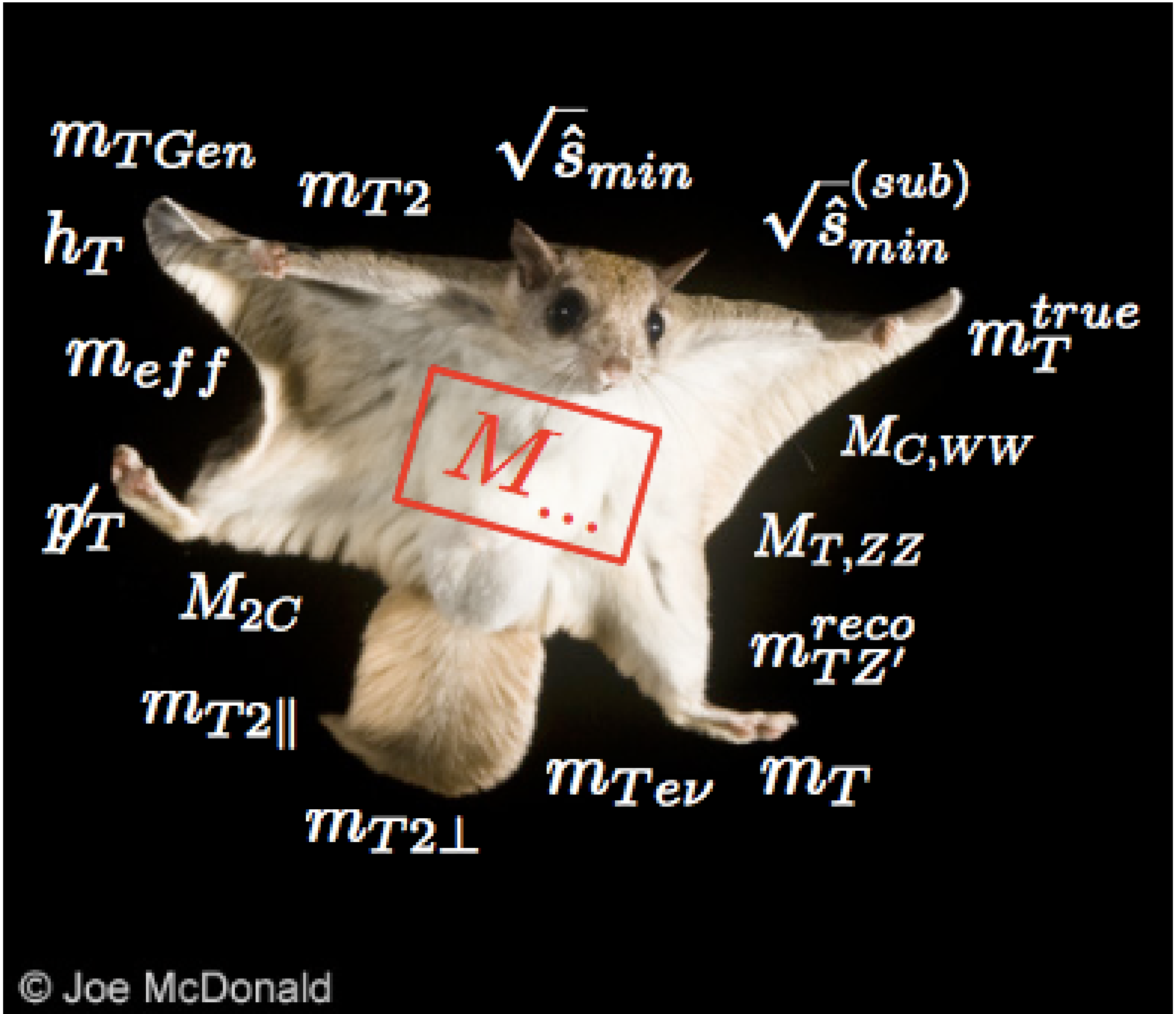
Search with >=10 jets!

http://arxiv.org/pdf/1602.06194v3.pdf



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/SUSY-2015-07/

Better kinematic variables?



http://arxiv.org/pdf/1105.2977.pdf

Philosophy behind these things

White board

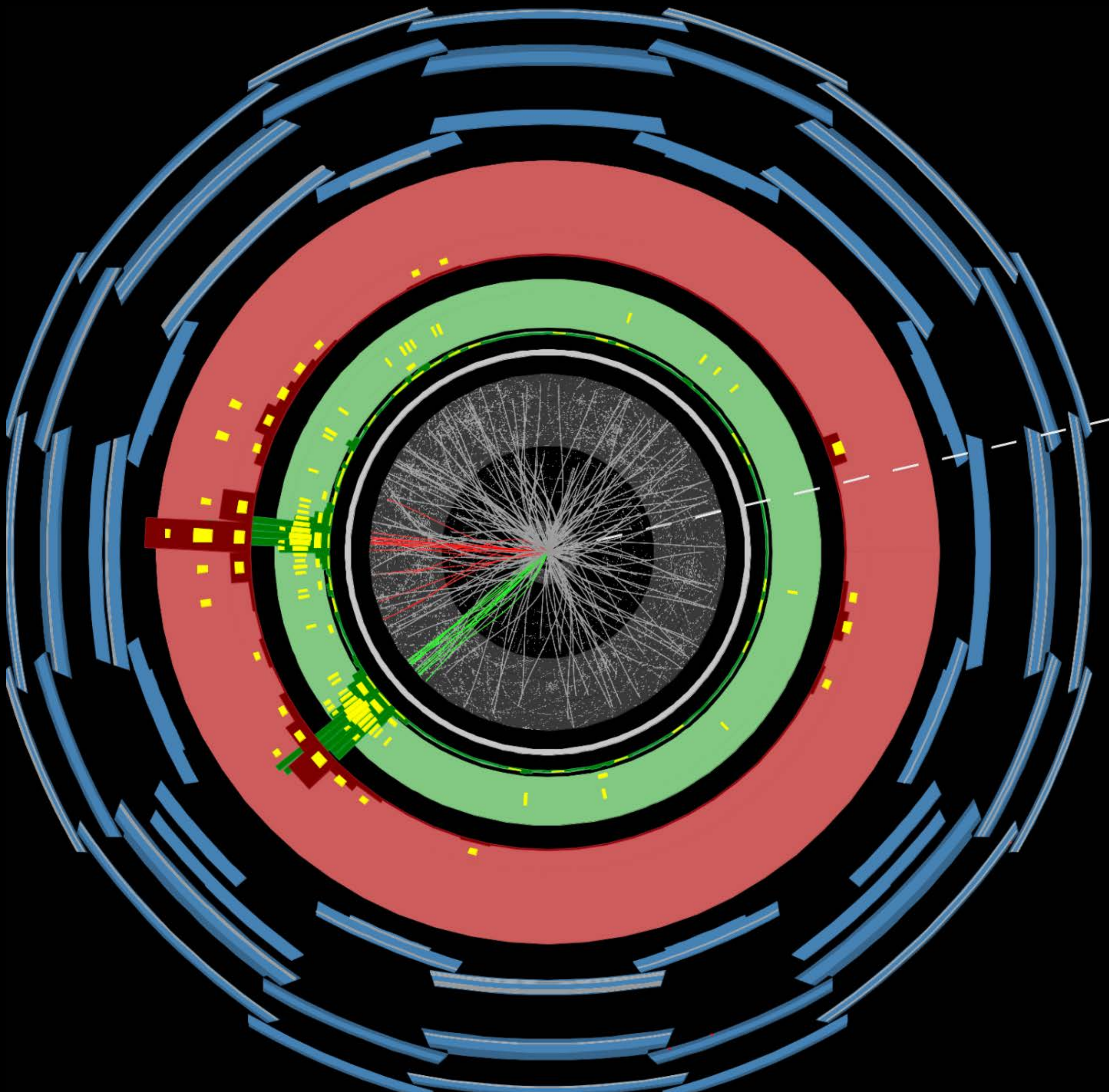
So what do I do...?

So what do I do…?

Question your assumptions

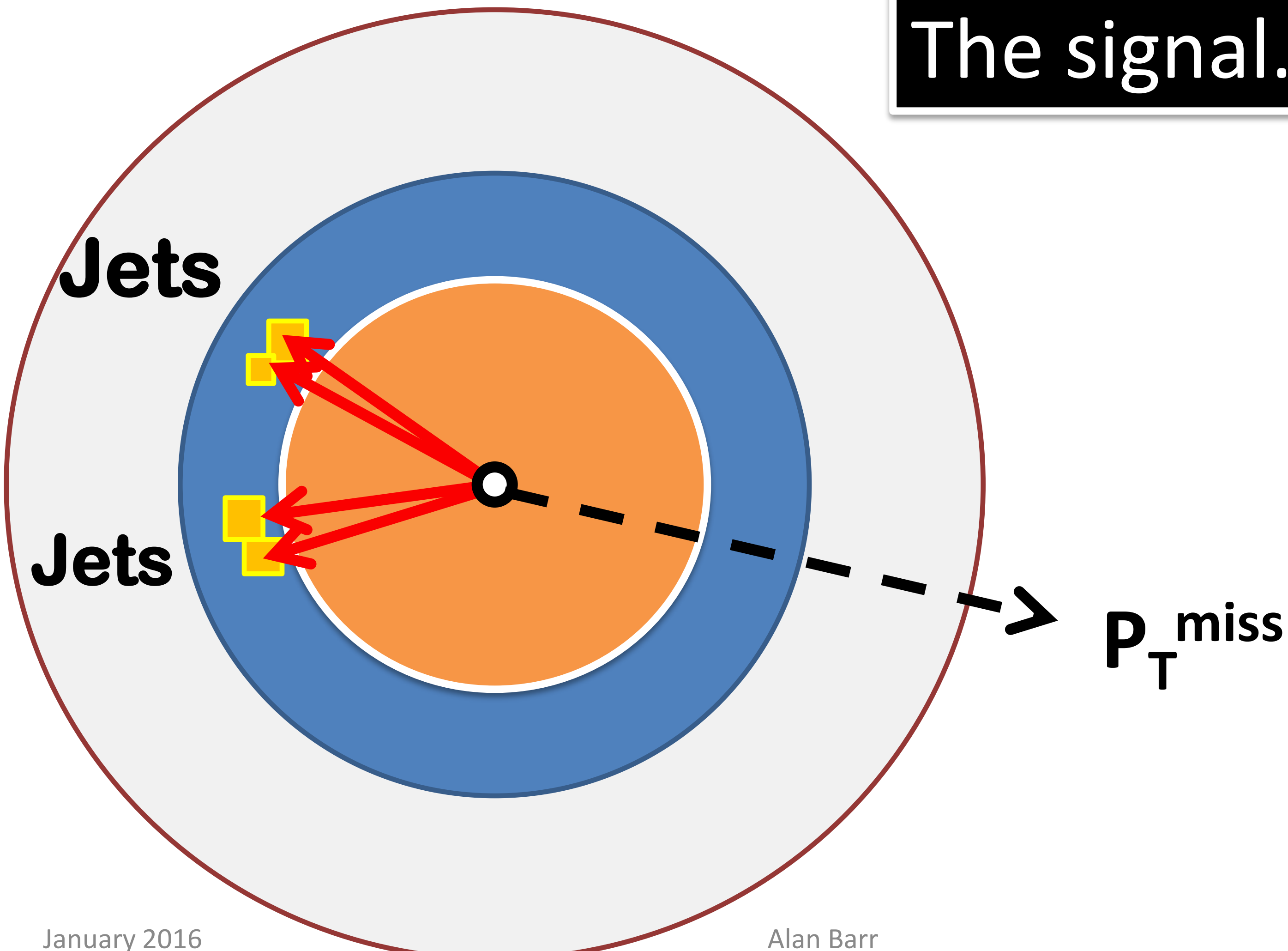
… and …

Measure things!

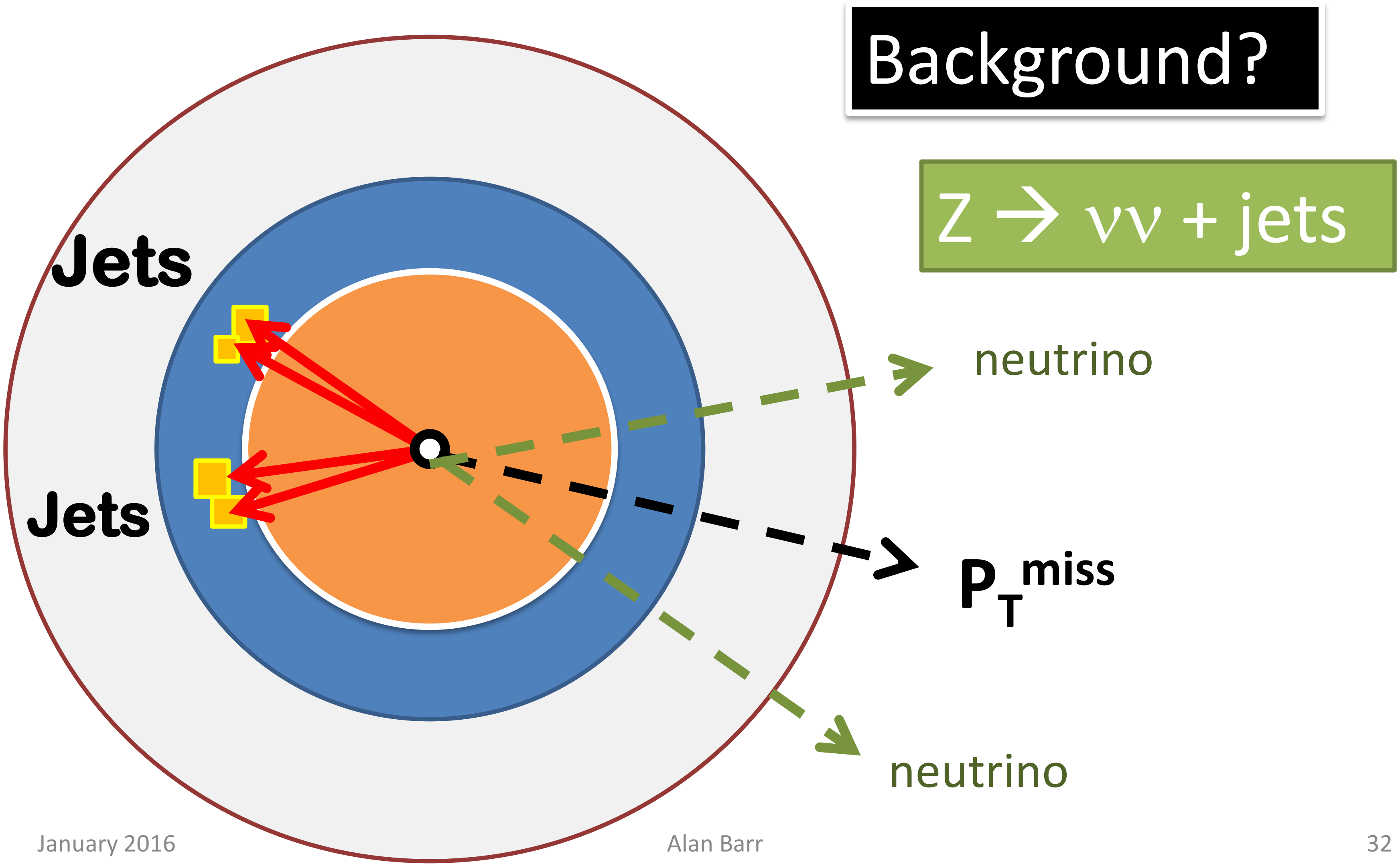


JETS + MISSING MOMENTUM

The signal…



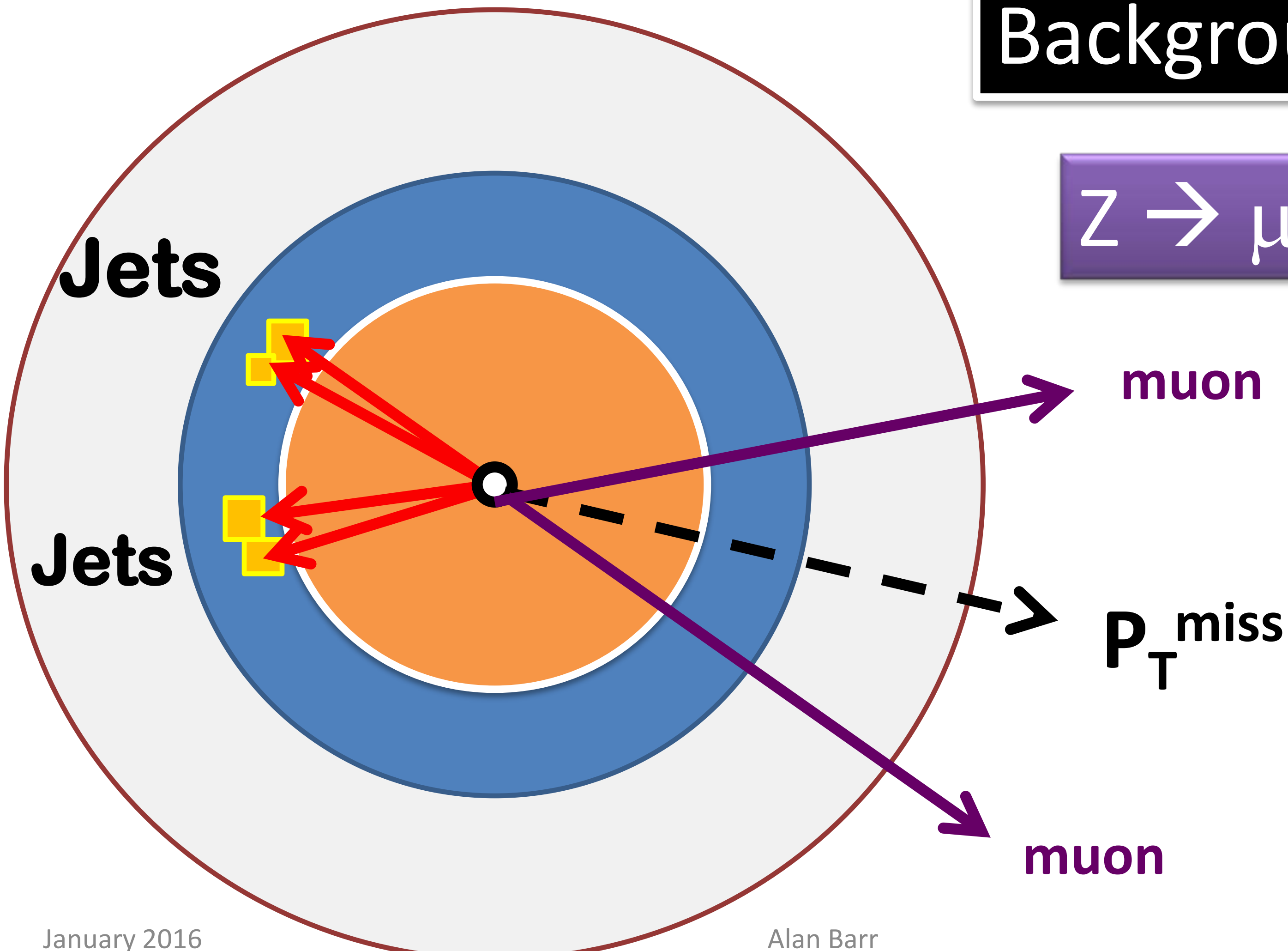
JETS + MISSING MOMENTUM



JETS + MISSING MOMENTUM

Background?

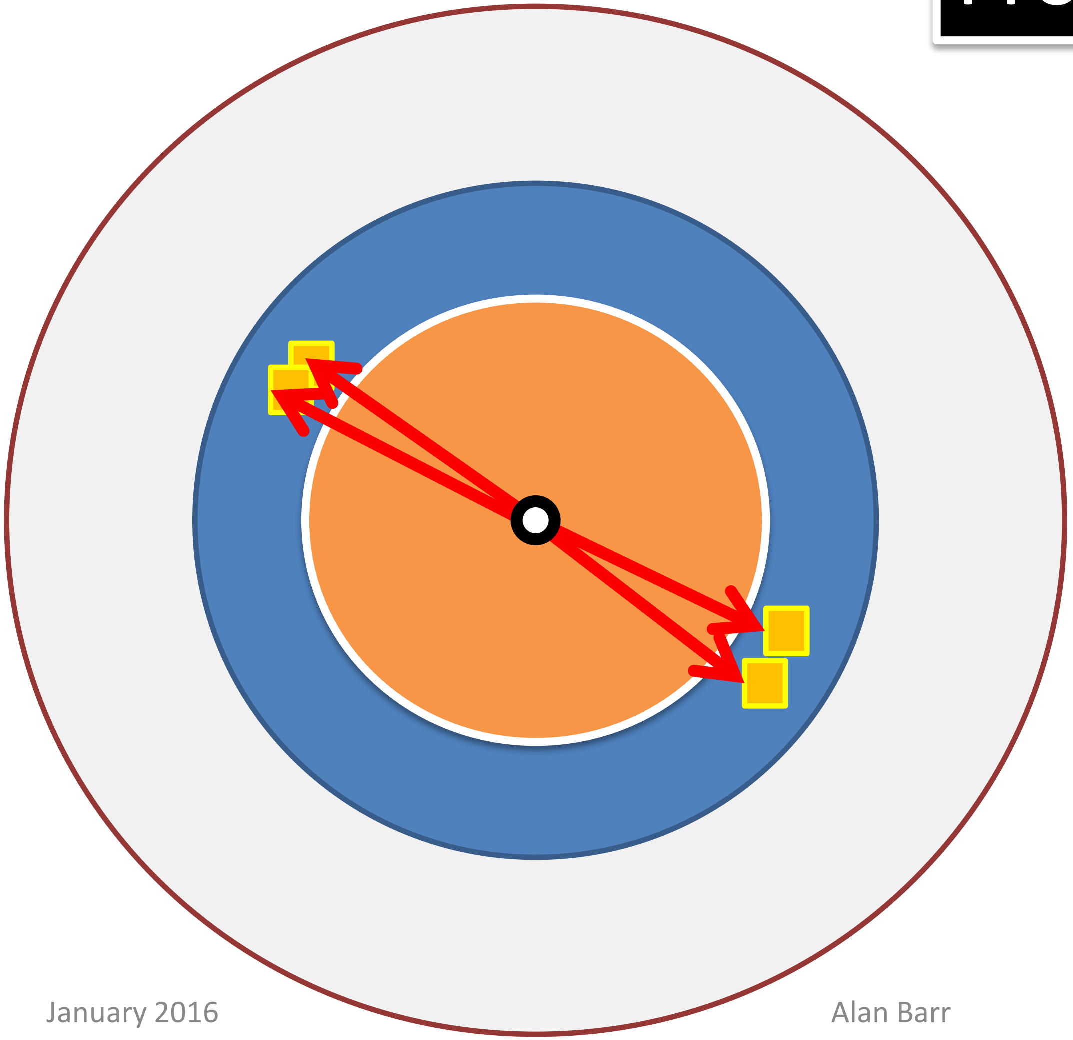
$Z \rightarrow \mu\mu$ + jets



When does this break down?

JETS

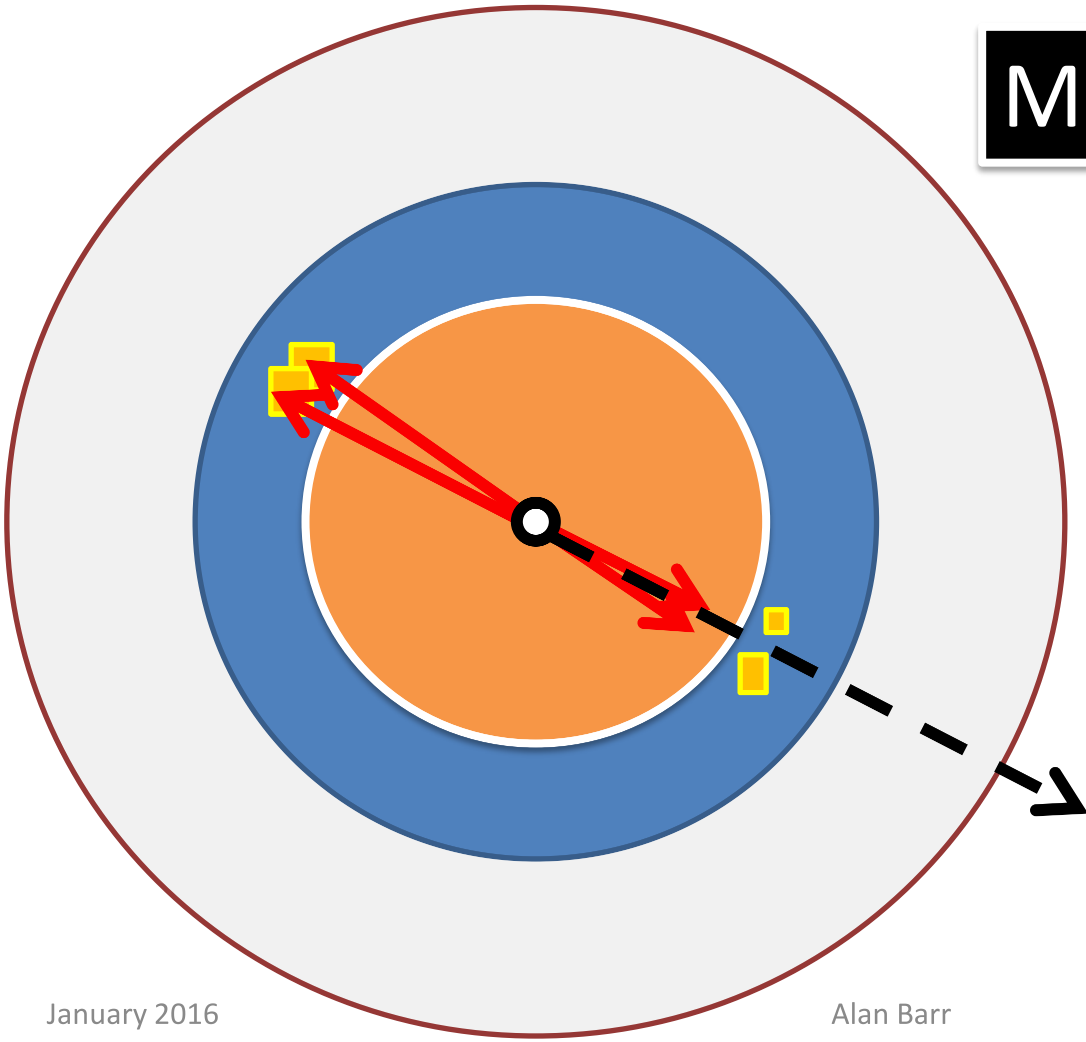
From collisions



Jets:
Had. Calorimeter
E.M. Calorimeter
Tracks from vertex
In-time

b,c quark jets
➔ can decay
to neutrinos

JETS + MISSING MOMENTUM



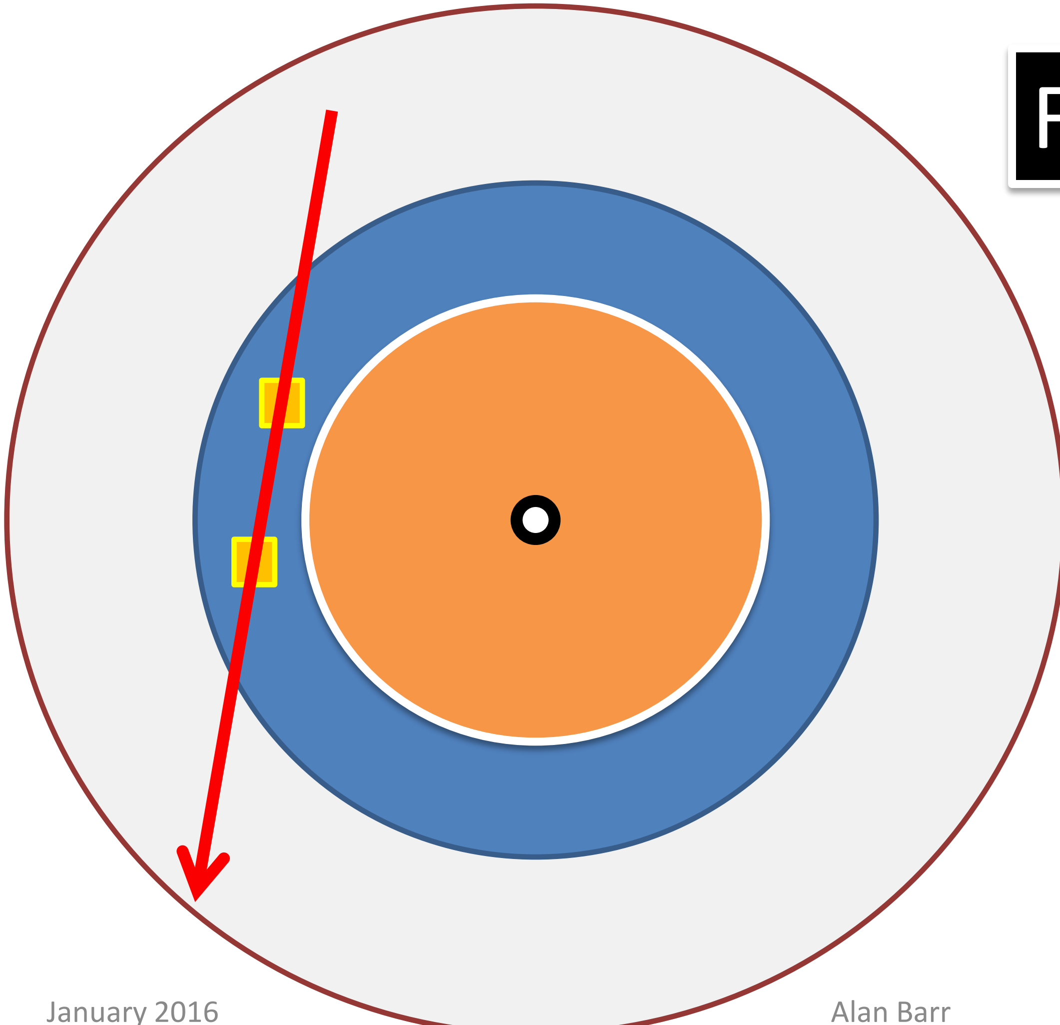
Measurements

Jets:
Δϕ cut

Reduce:
Had. Calorimeter
E.M. Calorimeter
Tracks from vertex

Measure remainder at small Δϕ

JETS + MISSING MOMENTUM



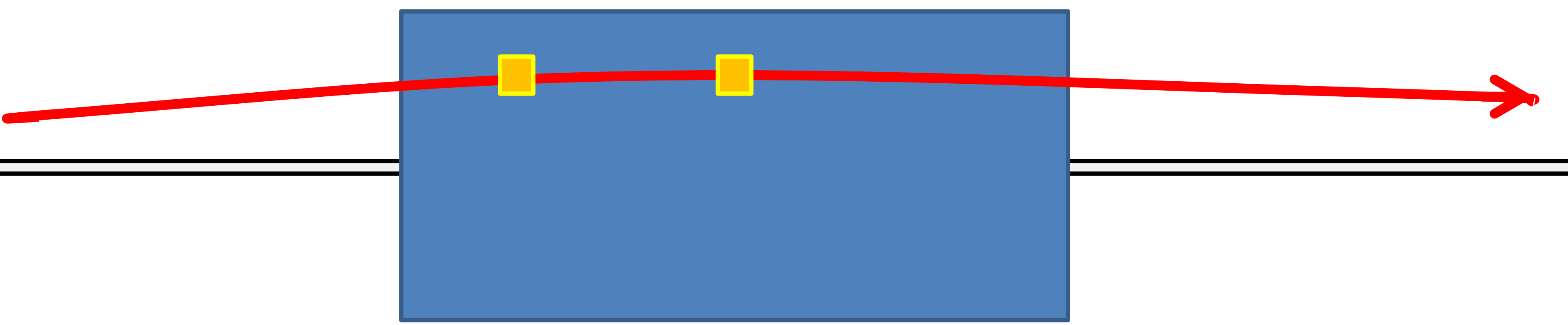
From cosmics

Reduce by:
(a) requiring tracks with jets
(b) look for muon hits

Measure remainder:
(a) no beam
(b) timing

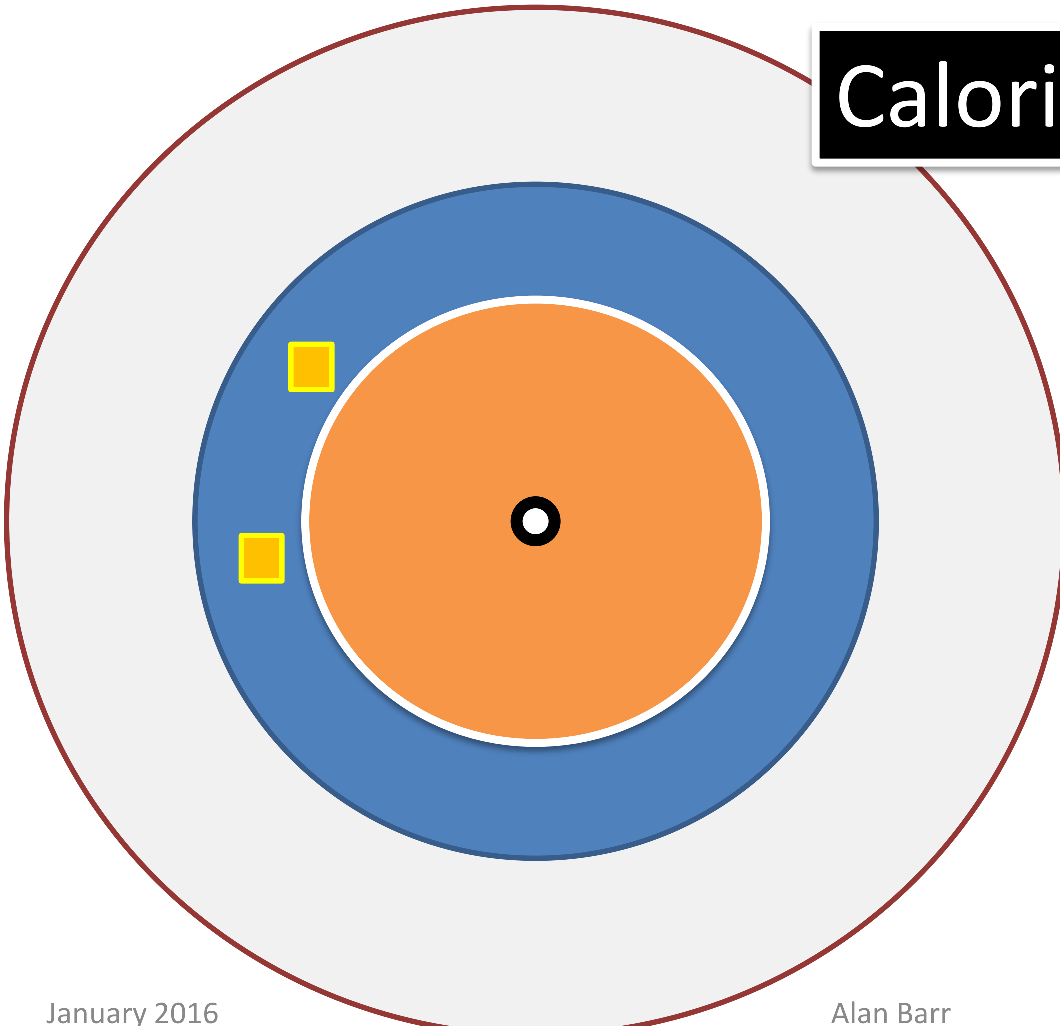
JETS + MISSING MOMENTUM

From beam halo



Reduce by requiring tracks with jets
Measure remainder with single beam / timing

JETS + MISSING MOMENTUM

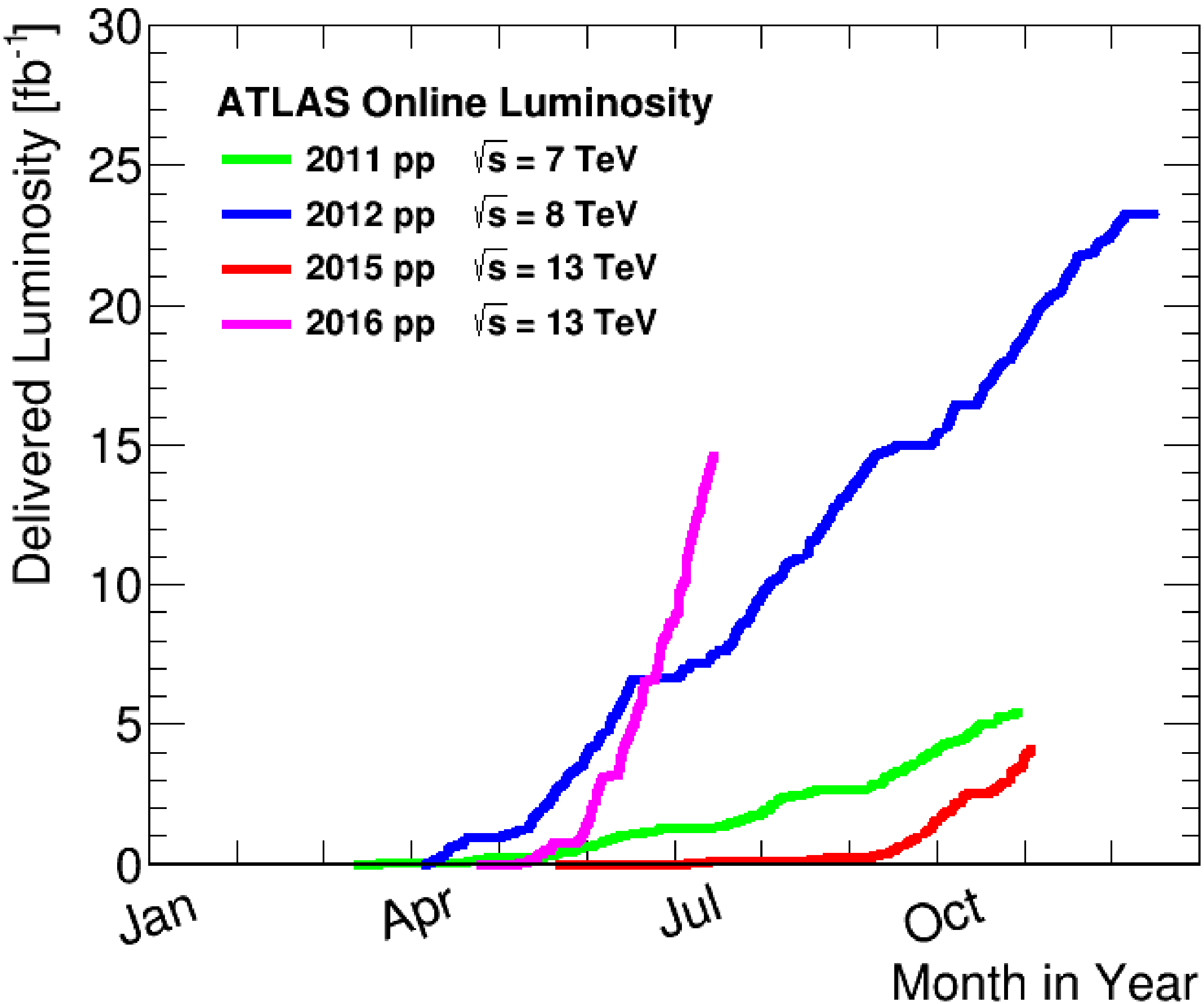


Calorimeter noise

Reduce by requiring tracks with jets

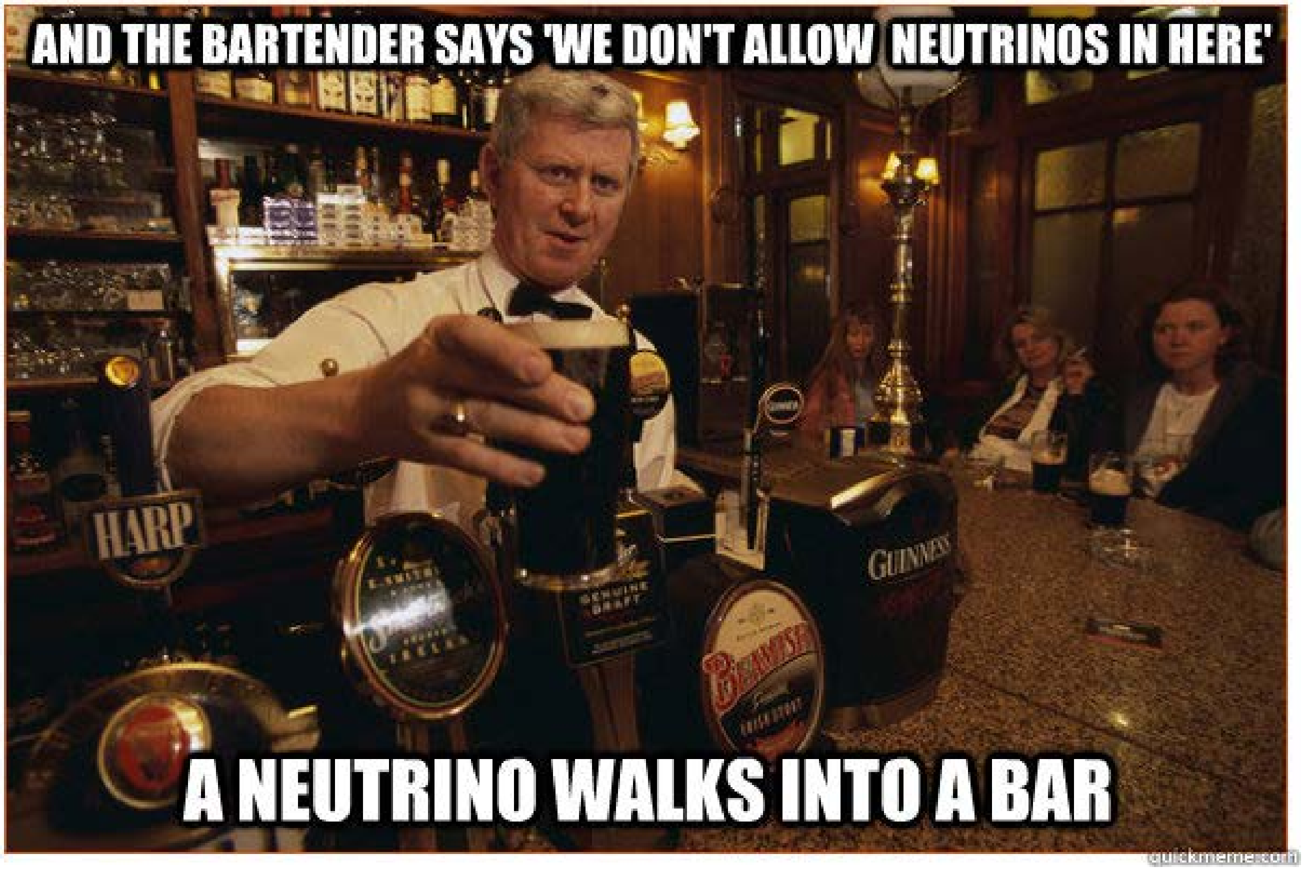
Measure remainder
(a) no beam
(b) timing

It’s very easy to get it wrong…

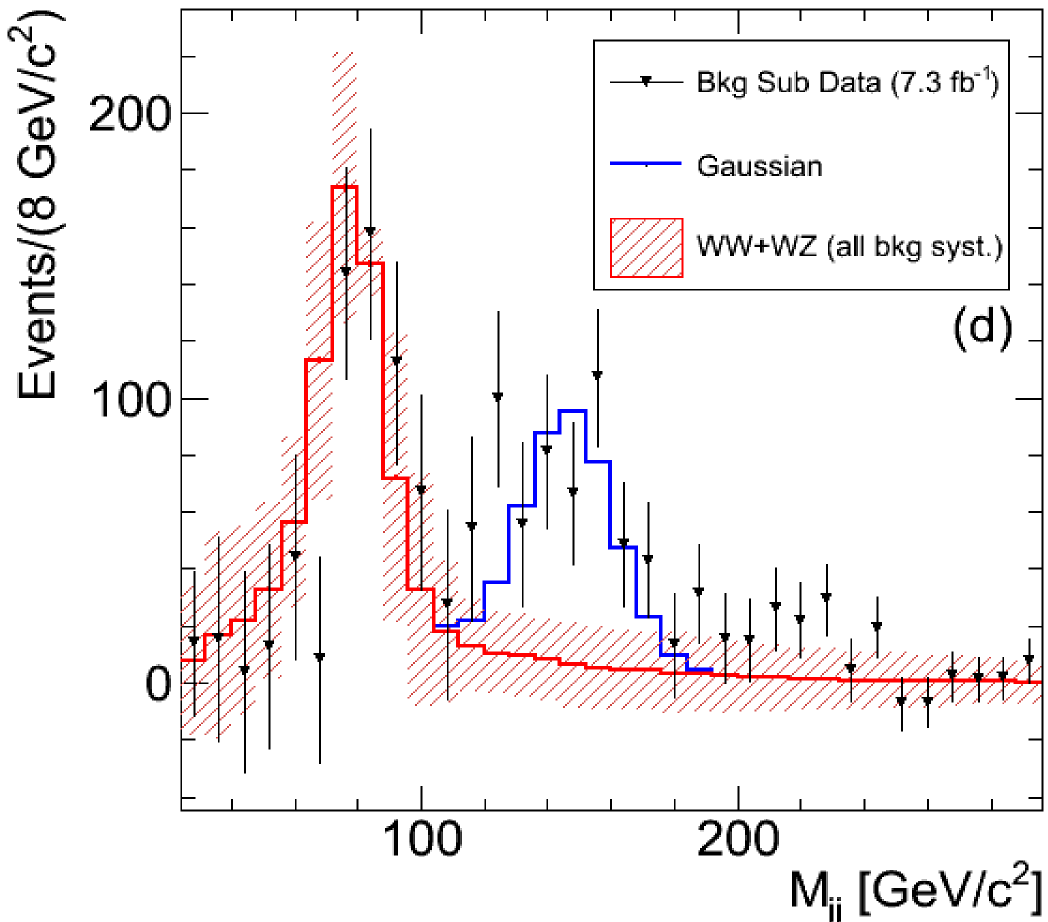


…and getting easier (to get it wrong)

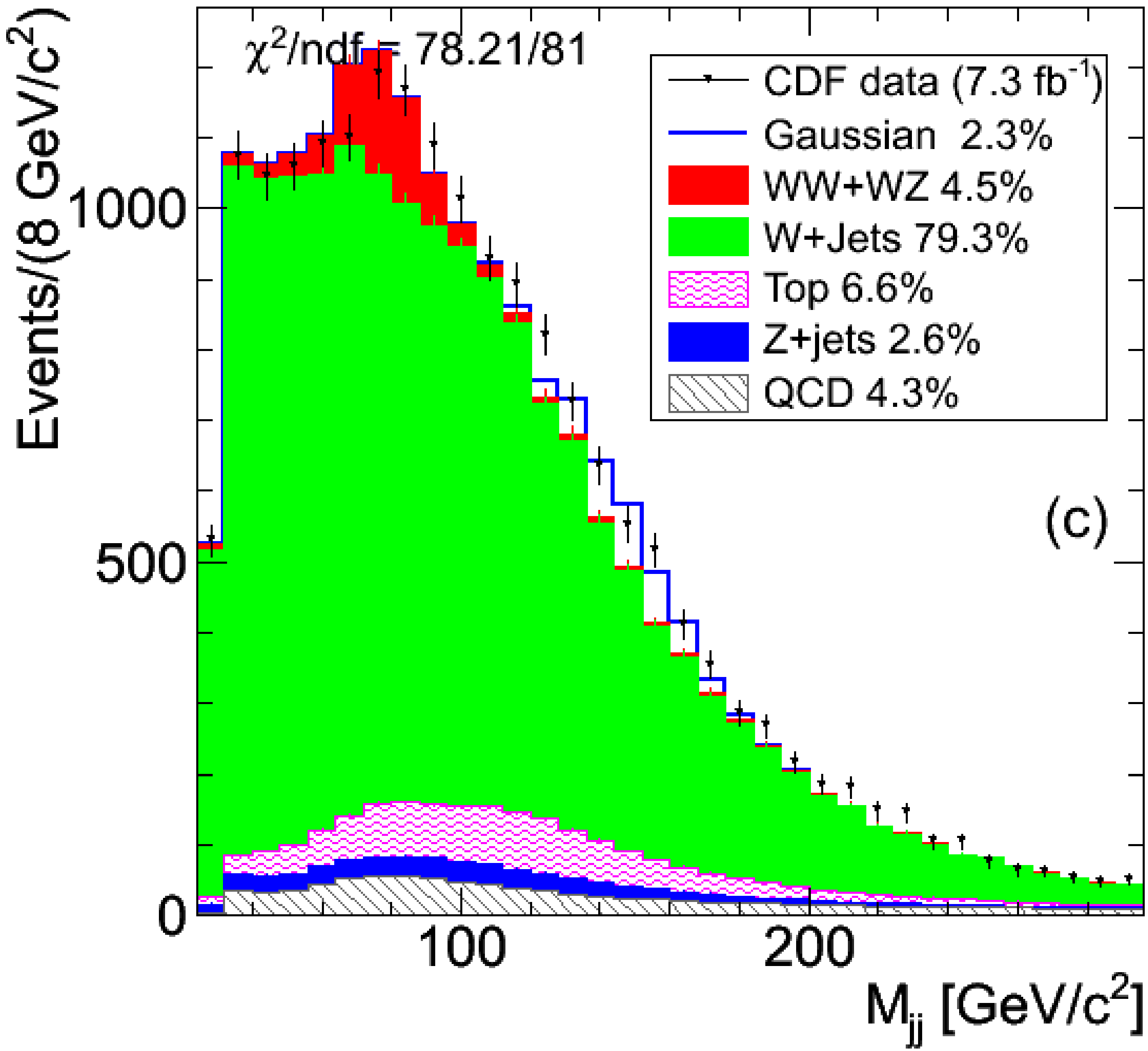
A loose cable…



Something goes bump in the night…



W+ di-jet events @ Tevatron



χ^2/ndf = 78.21/81
CDF data (7.3 fb^{-1})
Gaussian 2.3%
WW+WZ 4.5%
W+Jets 79.3%
Top 6.6%
Z+jets 2.6%
QCD 4.3%
(c)
Events/(8 GeV/c^2)
1000
500
0
100
200
M_{jj} [GeV/c^2]

Lies, damn lies, and statistics…

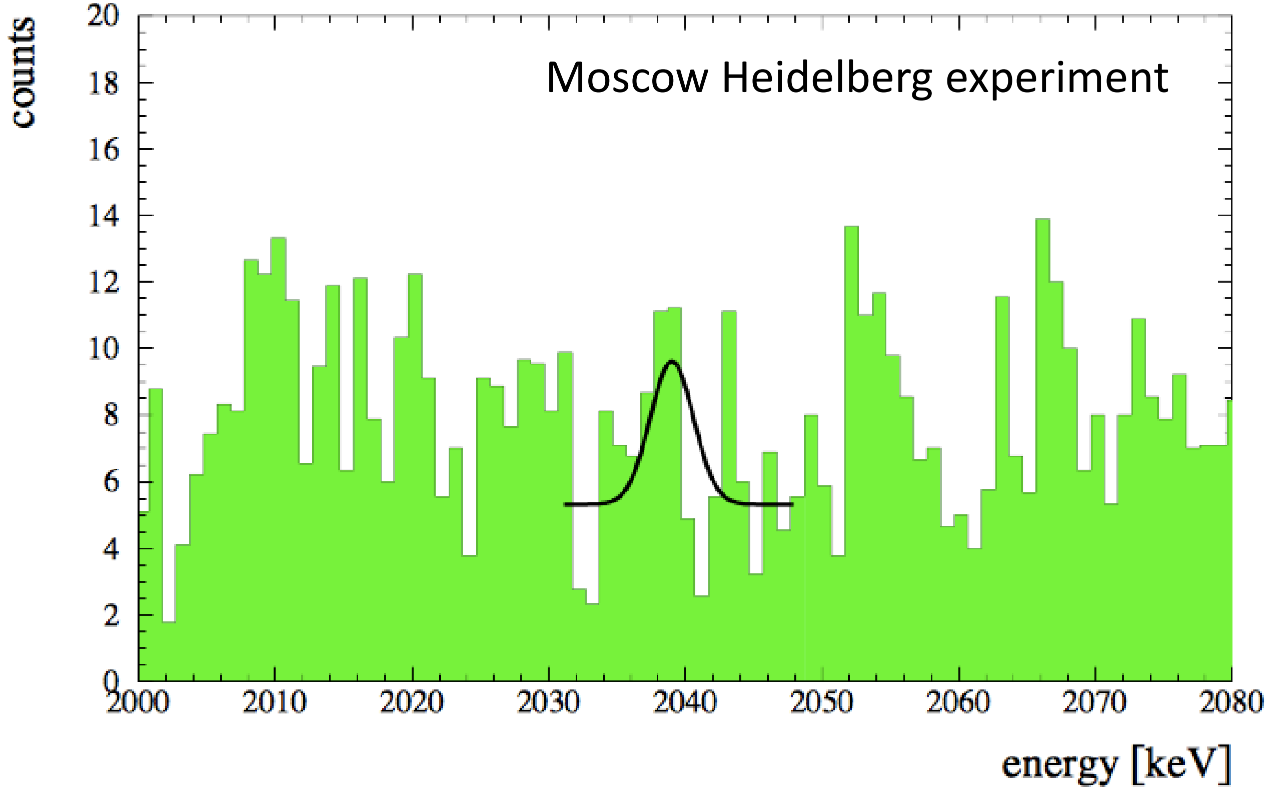
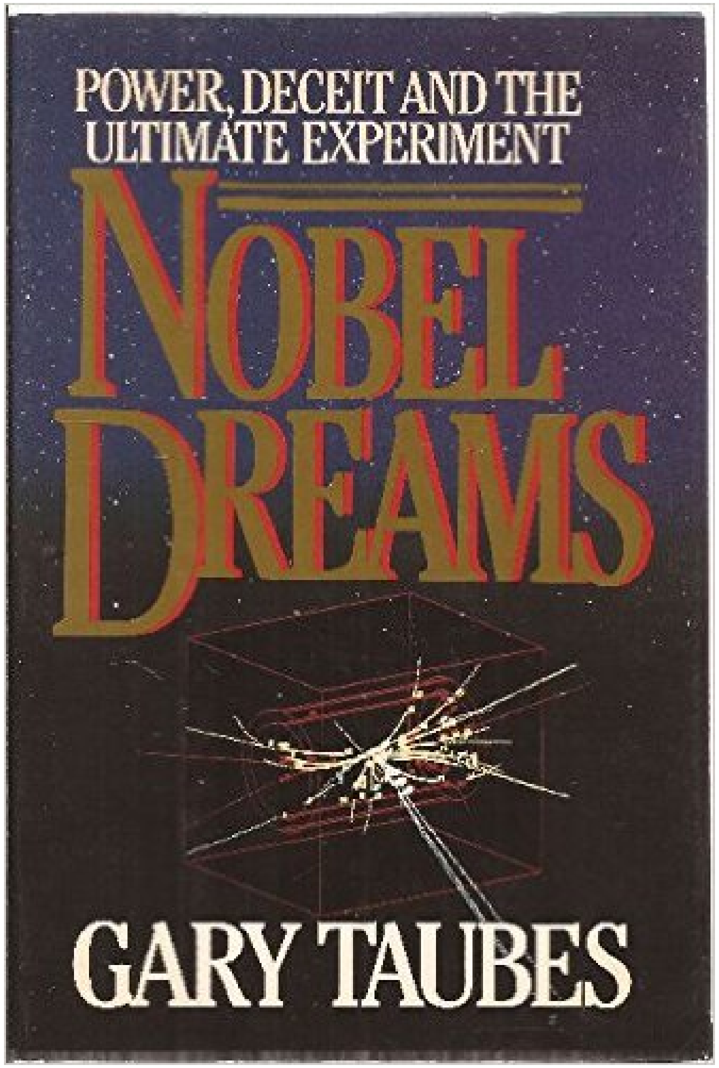


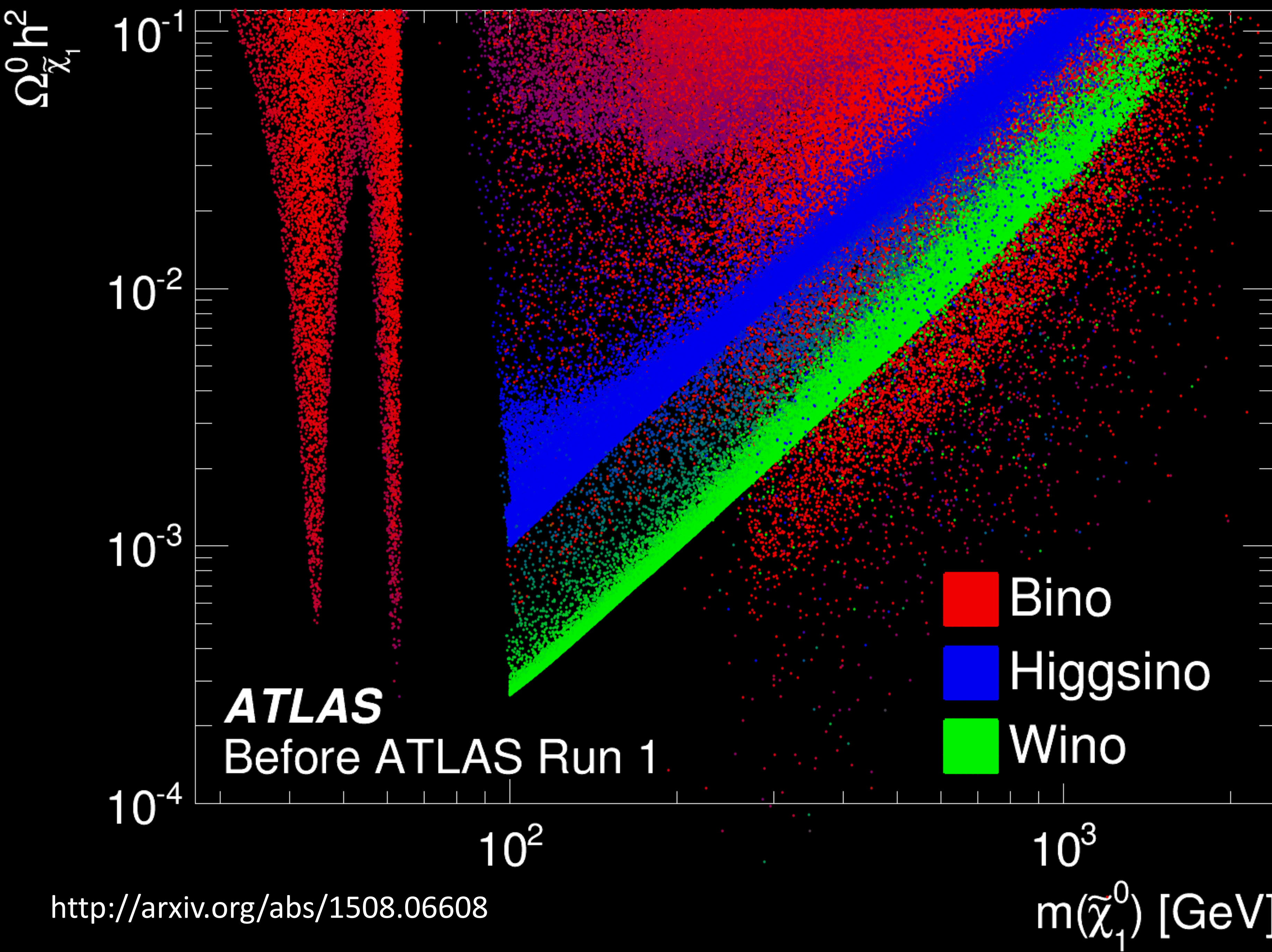
Figure 2. Sum spectrum of the ^{76}Ge detectors Nr. 1,2,3,5 over the period August 1990 to May 2000, 46.502 kg y. The curve results from Bayesian inference in the way explained in the text. It corresponds to a half-life $T^{0\nu}_{1/2}$=(0.75 - 18.33)× 10^{25} y (95% c.l.).

http://arxiv.org/pdf/hep-ph/0201231v1.pdf

With great power…



It has an impact…

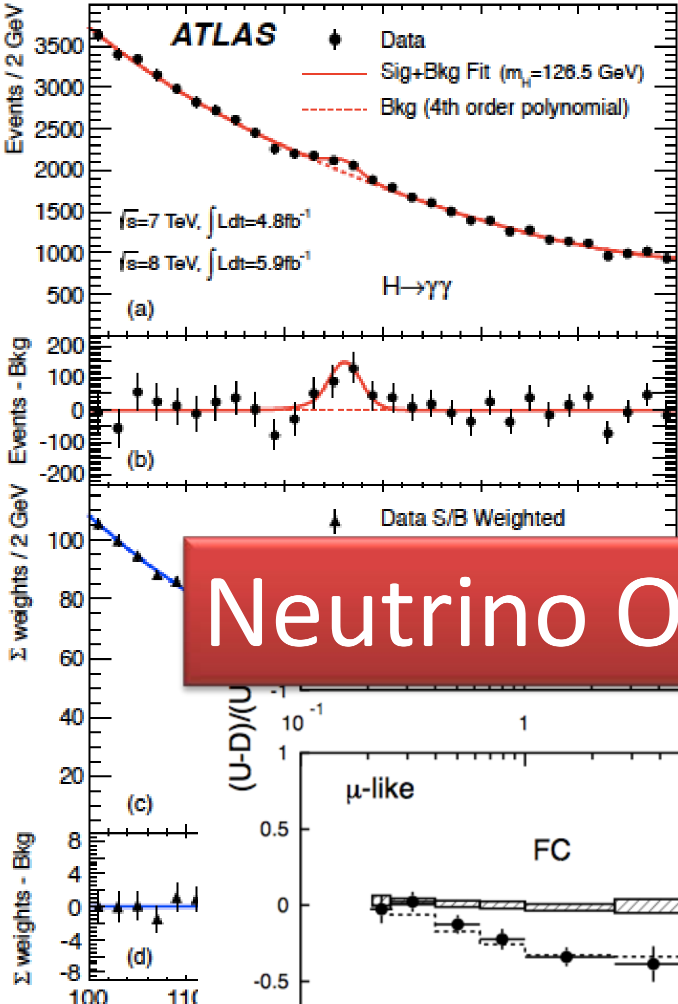


http://arxiv.org/abs/1508.06608

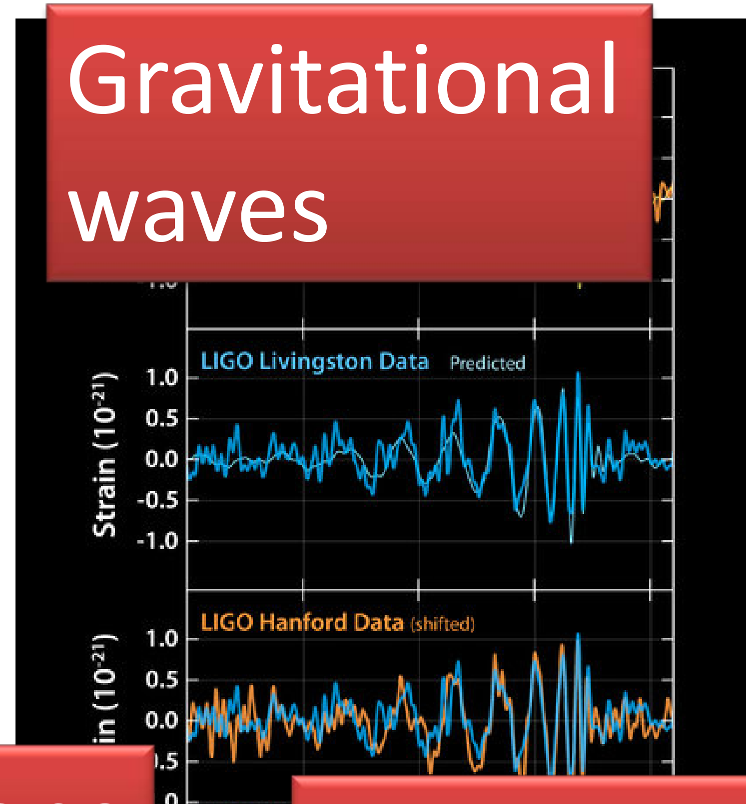
Unexpected things <u>do</u> happen


UEFA EURO 2016

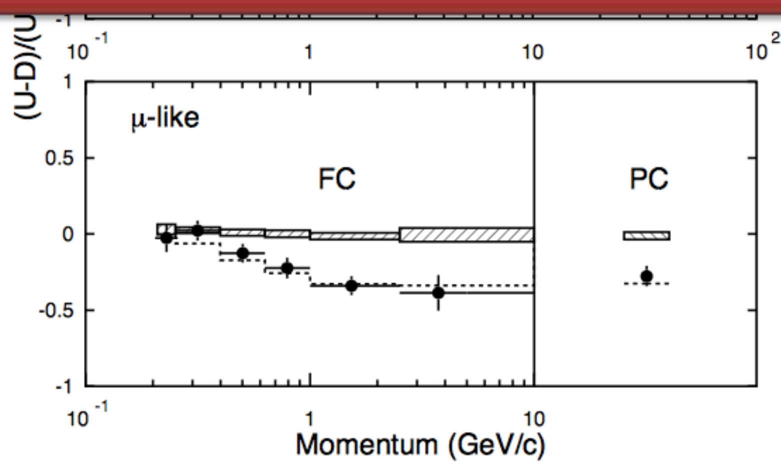
Higgs Boson



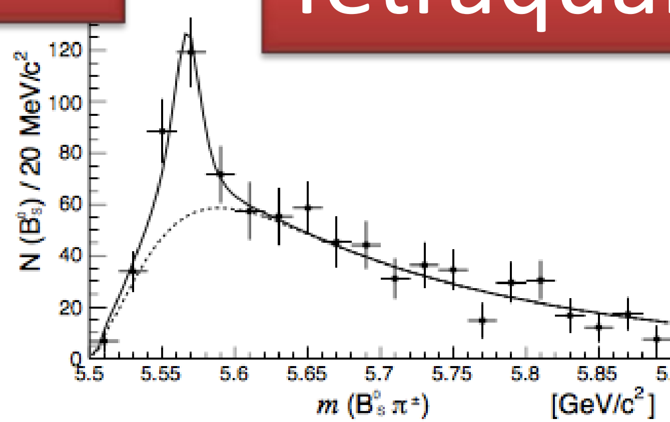
Gravitational waves



Neutrino Oscillations



Tetraquarks



Lots of questions…

What is Dark Matter?

Why is it stable? Is it even stable?

What is Dark Energy?

What shapes the Higgs potential?

Are there more Higgs bosons?

Does SUSY solve the naturalness problem?

If so, where are the sparticles hiding?

If not, what does?

Are neutrinos their own anti-particles?

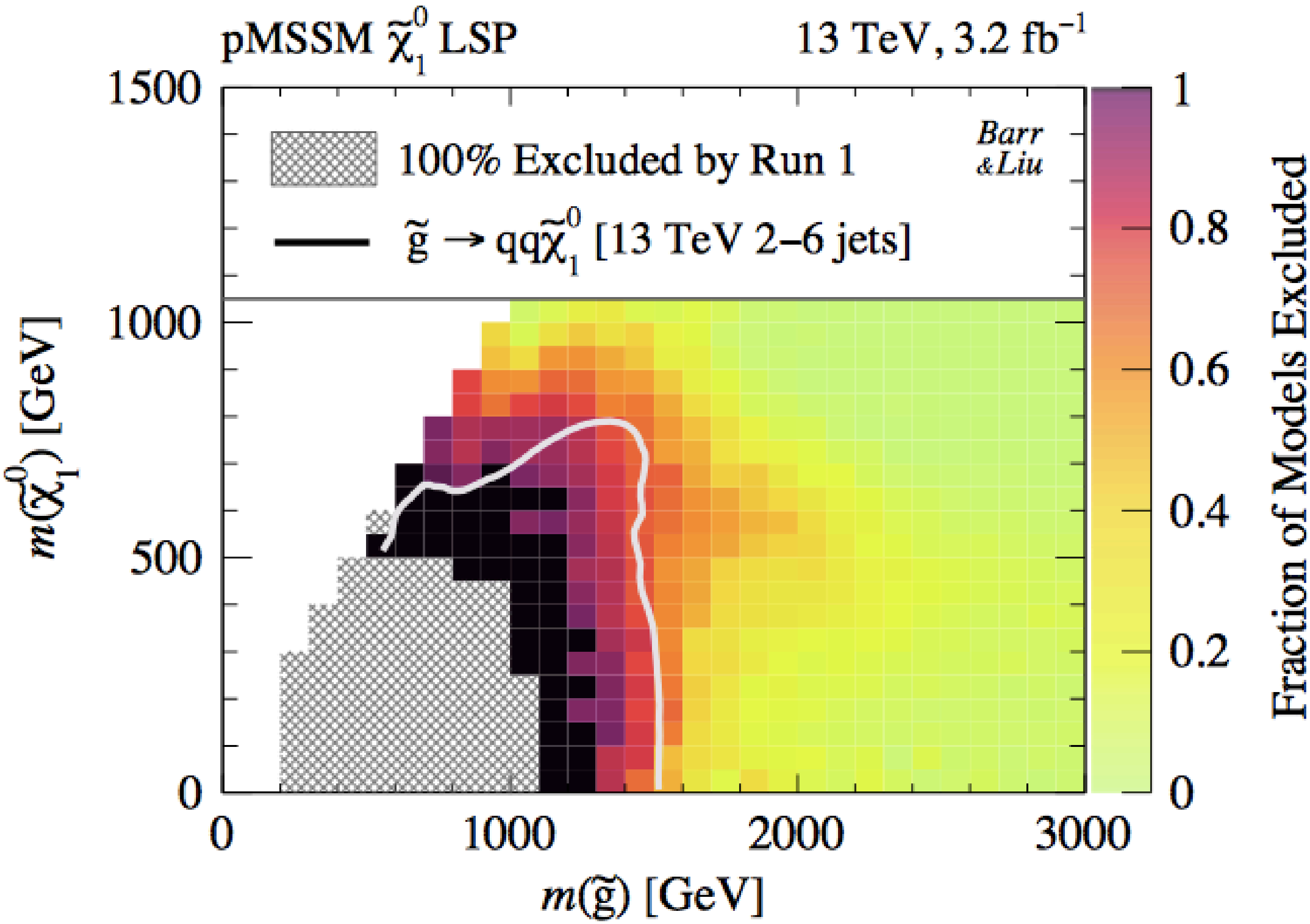
Are there other forces?

What causes the baryon asymmetry?

HAPPY HUNTING!

EXTRAS

http://arxiv.org/pdf/1605.09502.pdf



Run-2 searches already expanding the reach of the LHC

Select appropriate models