A novel way to search for new physics in the Z + Jets+ MET final state: The Jet-Z-Balance Analysis

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19 March 2012, Dallas, Texas
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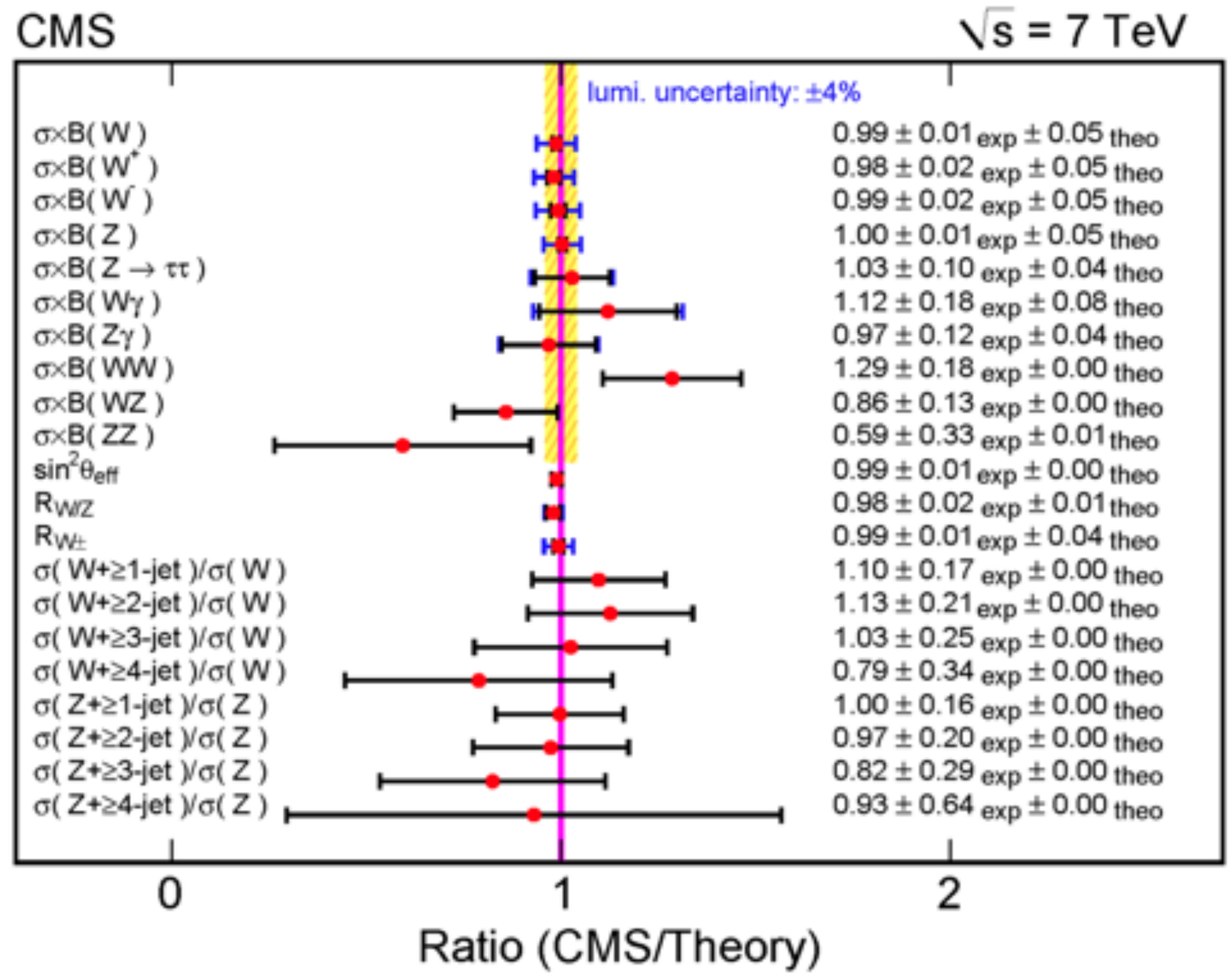
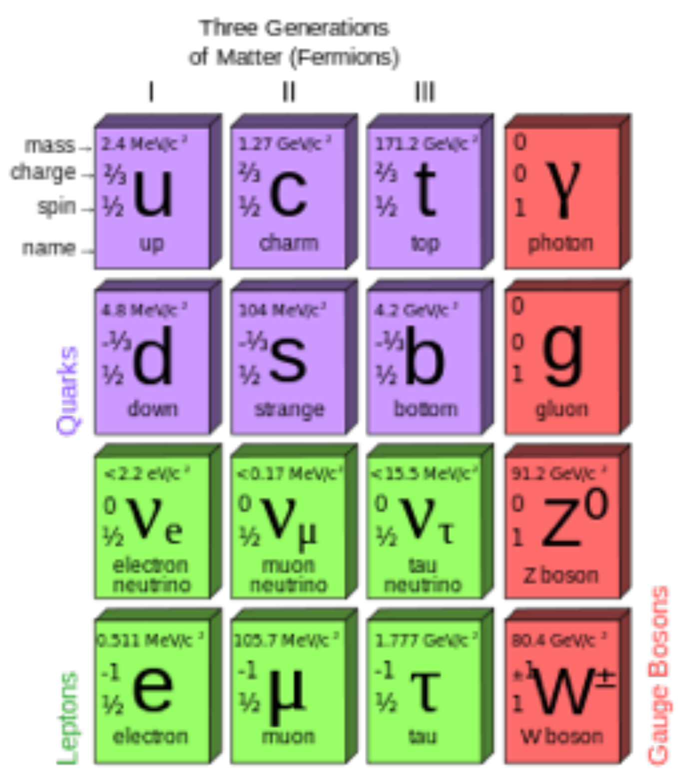
Standard Model

Highly successful physics theory:
- Under stress test over several decades
- Always in agreement with the experimental data

Nevertheless it is known to be incomplete:
- Accounts just for 4% of visible Universe
- Why particles are massive?
- Too many different scales involved
- ...





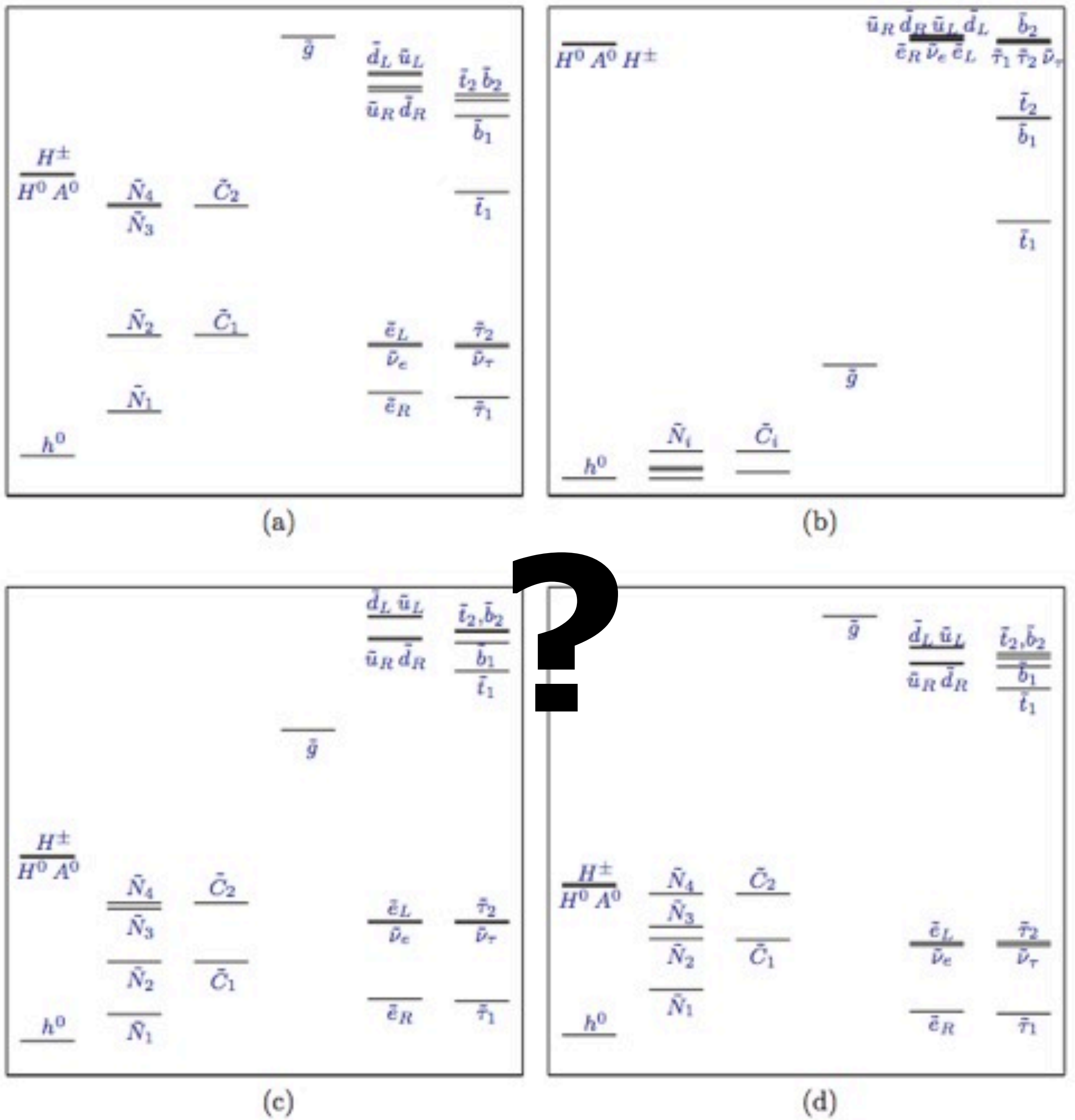
Provokes us to think that **this is not yet the final** Physics Theory

Boson-Fermion Symmetry ?

Supersymmetry:
- Hierarchy problem, unification, dark matter candidate;experimental signature in a pp collider: production of events with **large missing momentum** due to the weakly interacting massive particles

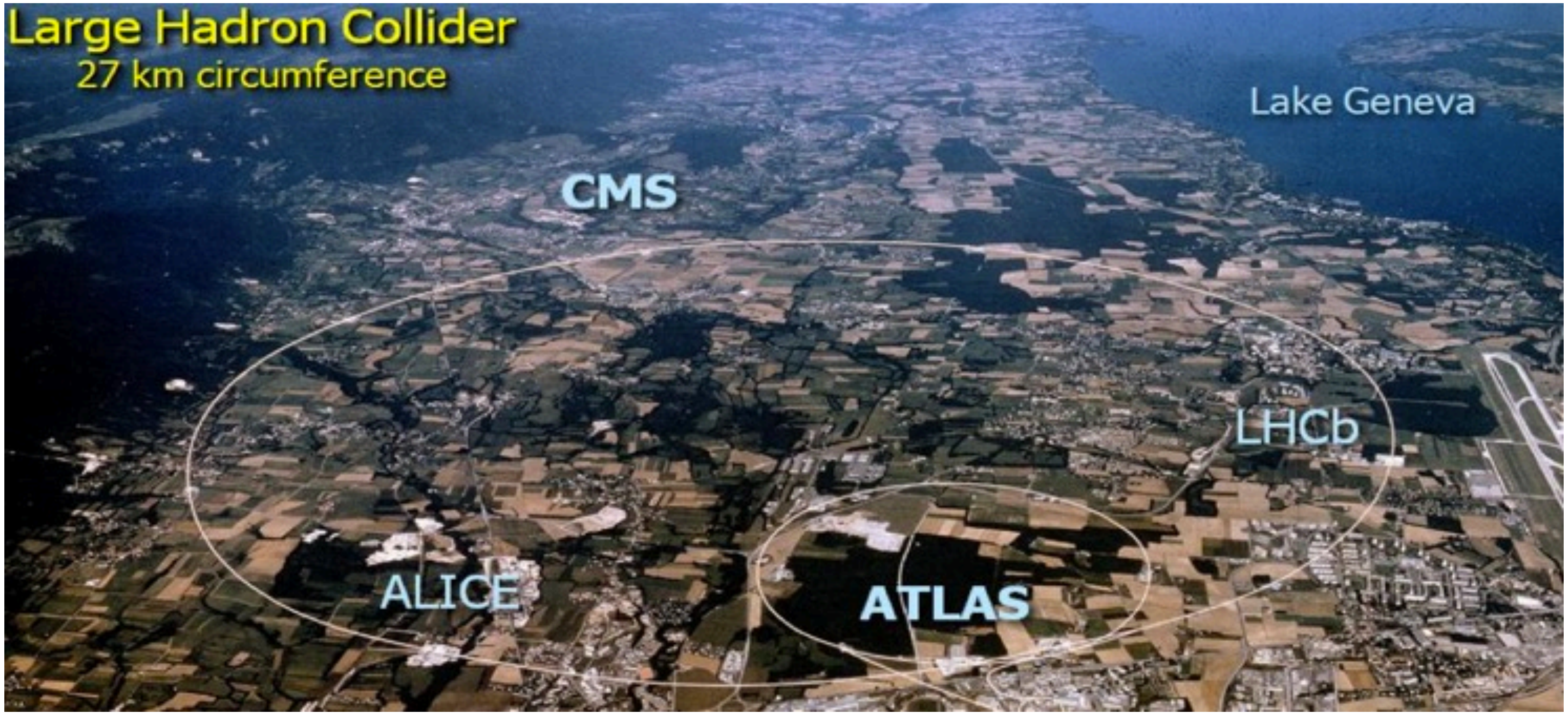
Why experimentalist love SUSY:
- Most challenging experimental signature
- Need to master the reconstruction of:
  - muons, electrons, & photons
  - jets, b-jets, taus
  - Missing E_T (neutrinos or LSPs)
- We don't have a particular preference among the plethora of available SUSY benchmark models

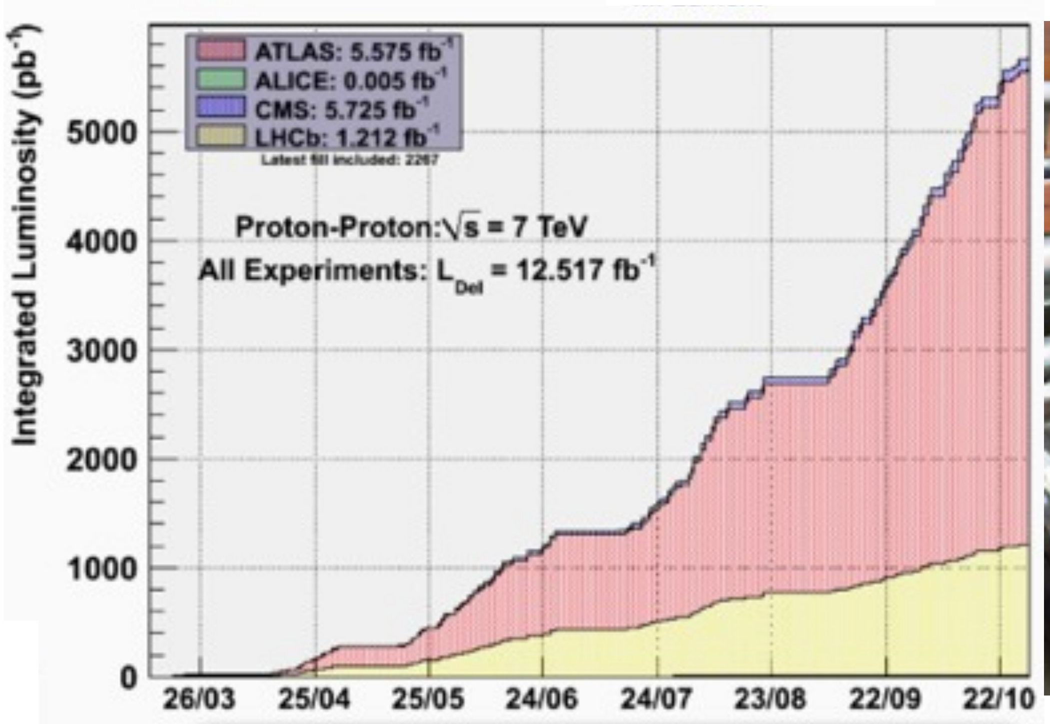
SUSY benchmark models usage:
- Spot weak points/reduce number of blind corners in our physics search program
- Develop new analysis strategies, make all possible tests to our LHC data

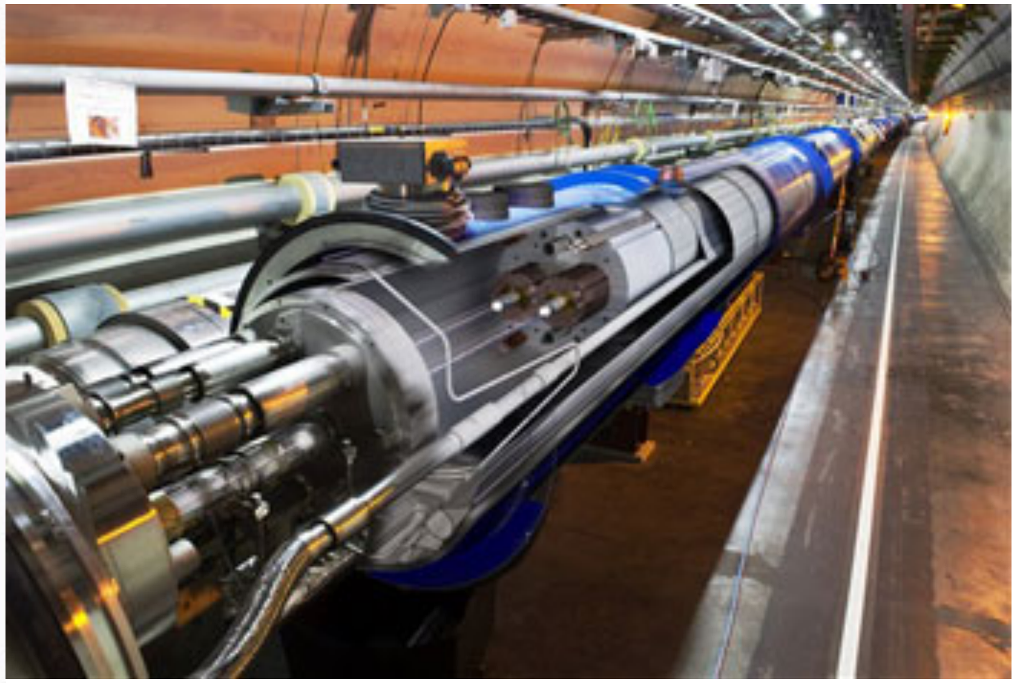


Stephen Martin (SUSY primer)
http://arxiv.org/pdf/hep-ph/9709356v6.pdf

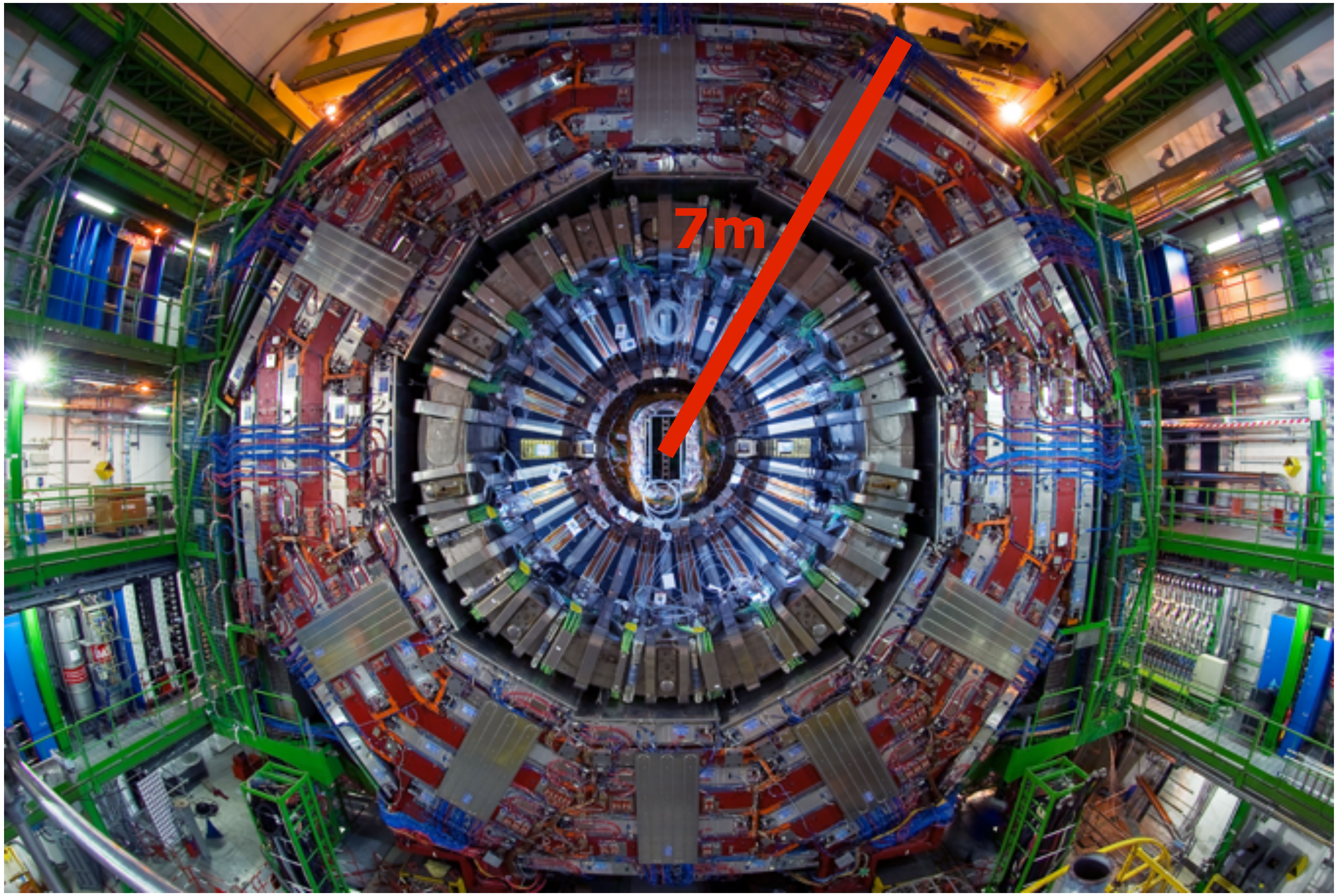
The Large Hadron Collider







The Compact Muon Solenoid



All-Silicon Tracker
- pixel/strips

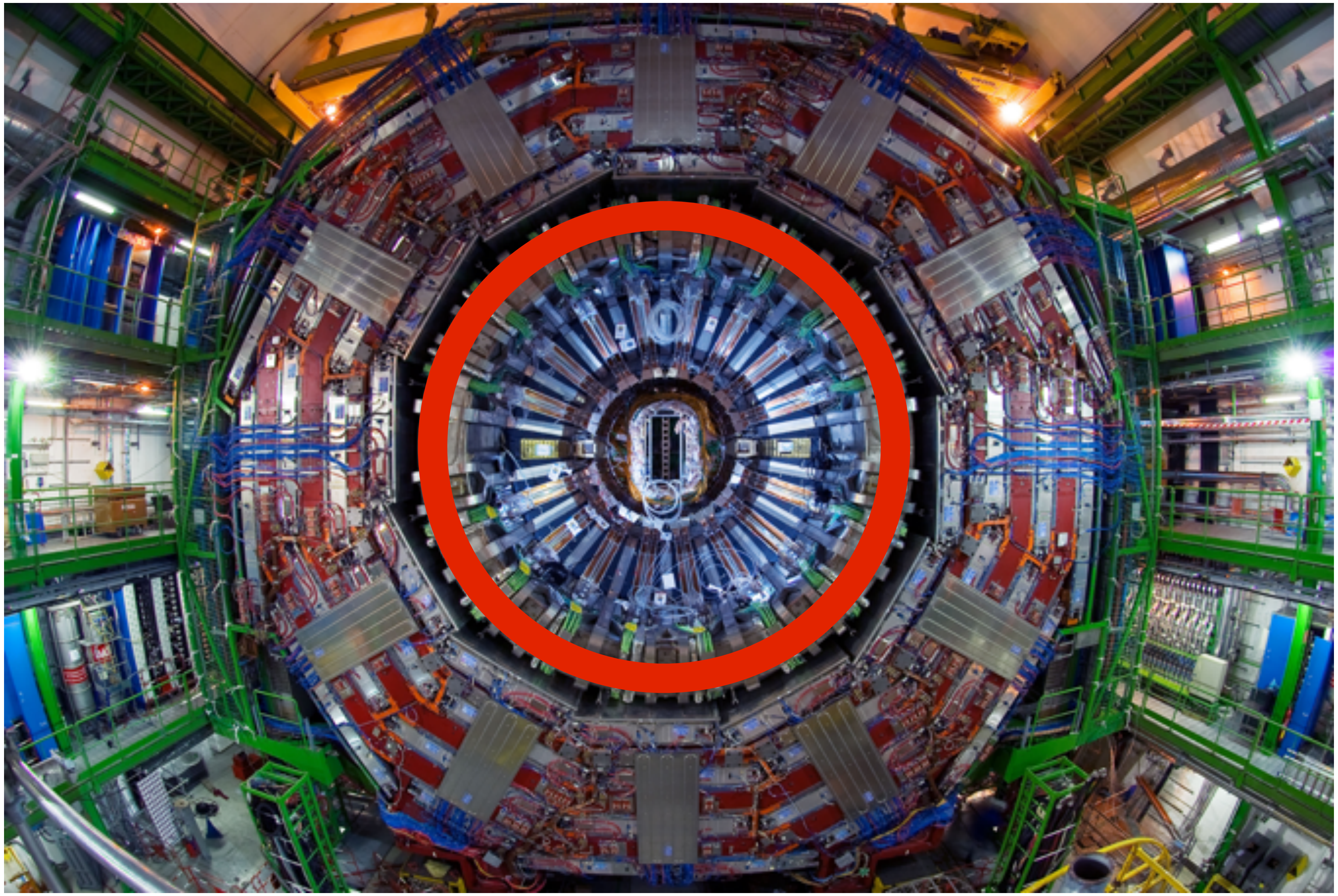
E/M Calorimeter-ECAL
- Lead tungsten crystals
- $\Delta E/E \sim 0.5$ % at high E

Hadronic Calorimeter-HCAL
- scintillator/brass
- $|\eta|<5.2$

Redundant Muon Systems
- RPCs, Drift Tubes, CSC

- One of the two general purpose detectors installed in the LHC
- Compact (all subsystems within R=7m)
- Precisely aligned detector (sub millimeter precision)

The Compact Muon Solenoid



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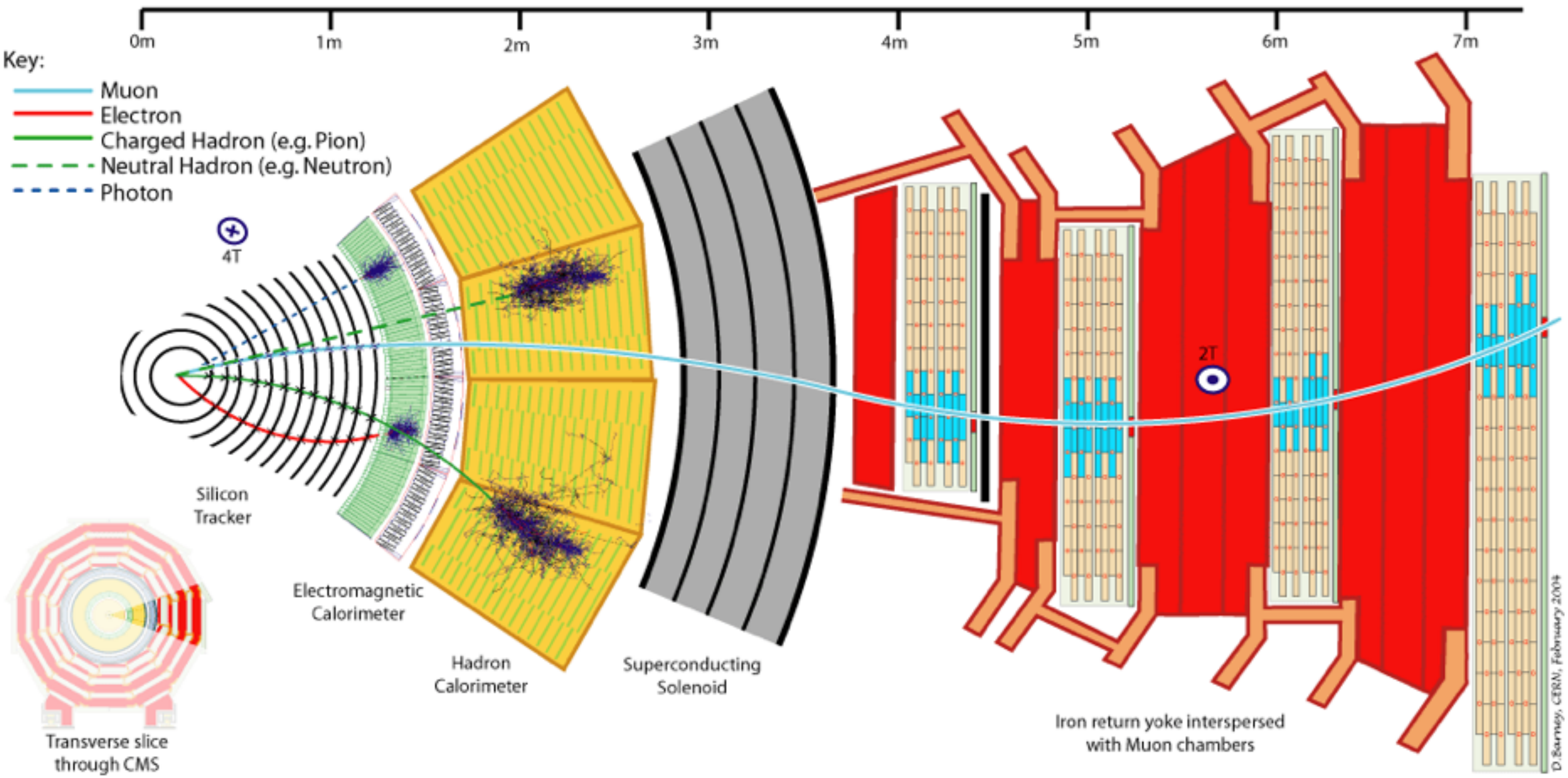
- One of the two general purpose detectors installed in the LHC
- Compact (all subsystems within R=7m)
- Precisely aligned detector (sub millimeter precision)
- Calorimeters are placed inside the **CMS Magnet B=3.8 T**

Event Reconstruction



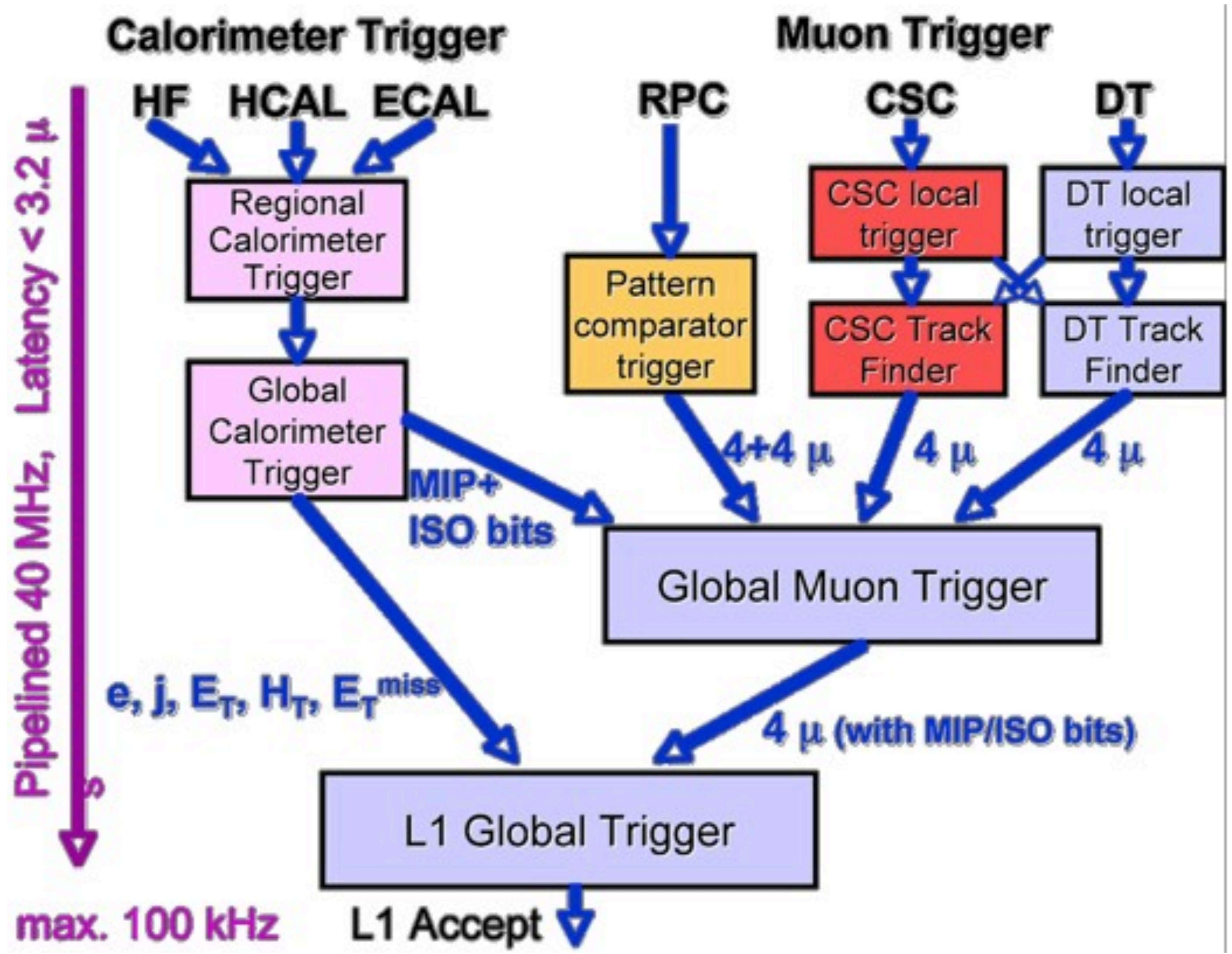
- Reconstruction efficiency i.e. P(read-out | particle)
- Particle ID: complementary info from more than one subsystem
- Reconstruct what you don't see, MET = Missing E_T = P_T^{miss}
- Understand your background means know your P(read-out | ~~particle~~)

Think Fast & Decide

LHC bunch crossing (40 MHz)

L1 Trigger (40 MHz →100 KHz)**:**
- On-detector (radiation resistant) electronics calculating energy,hits
- Info transmitted with optical cables to the counting room ~ 100m
- Data are kept in a buffer until a L1 accept is received, can't wait much
- coarse reconstruction & fast algo are used to evaluate the event

HLT Trigger (100 KHz →100Hz)**:**
- Regional reconstruction with more precise algo, closer to offline



What do we trigger on?
- the basics: jets, electrons, photons, HT, MET
- the not so basic: jet-electron, HT-MET and other cross-triggers
  - cross-triggers: lower rate and hence p_T thresholds
  - complexity of trigger path: harder to understand (efficiency, rate stability)

Which Trigger to Use?

Common triggers (used for SUSY & high p_T exotic searches):

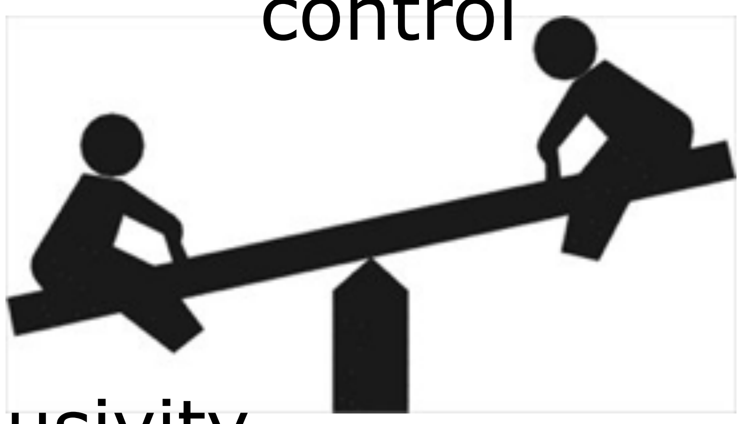
- multijets, HT AND/OR MET (hadronic analysis)
- leptons + HT, di-leptons (leptonic analysis)
- photons + HT (photon analysis)
- single-lepton, single-jet, single-photon: too high p_T thresholds OR are pre-scaled (used for background & efficiency studies)

Di-leptons: perhaps the simplest trigger for a SUSY search

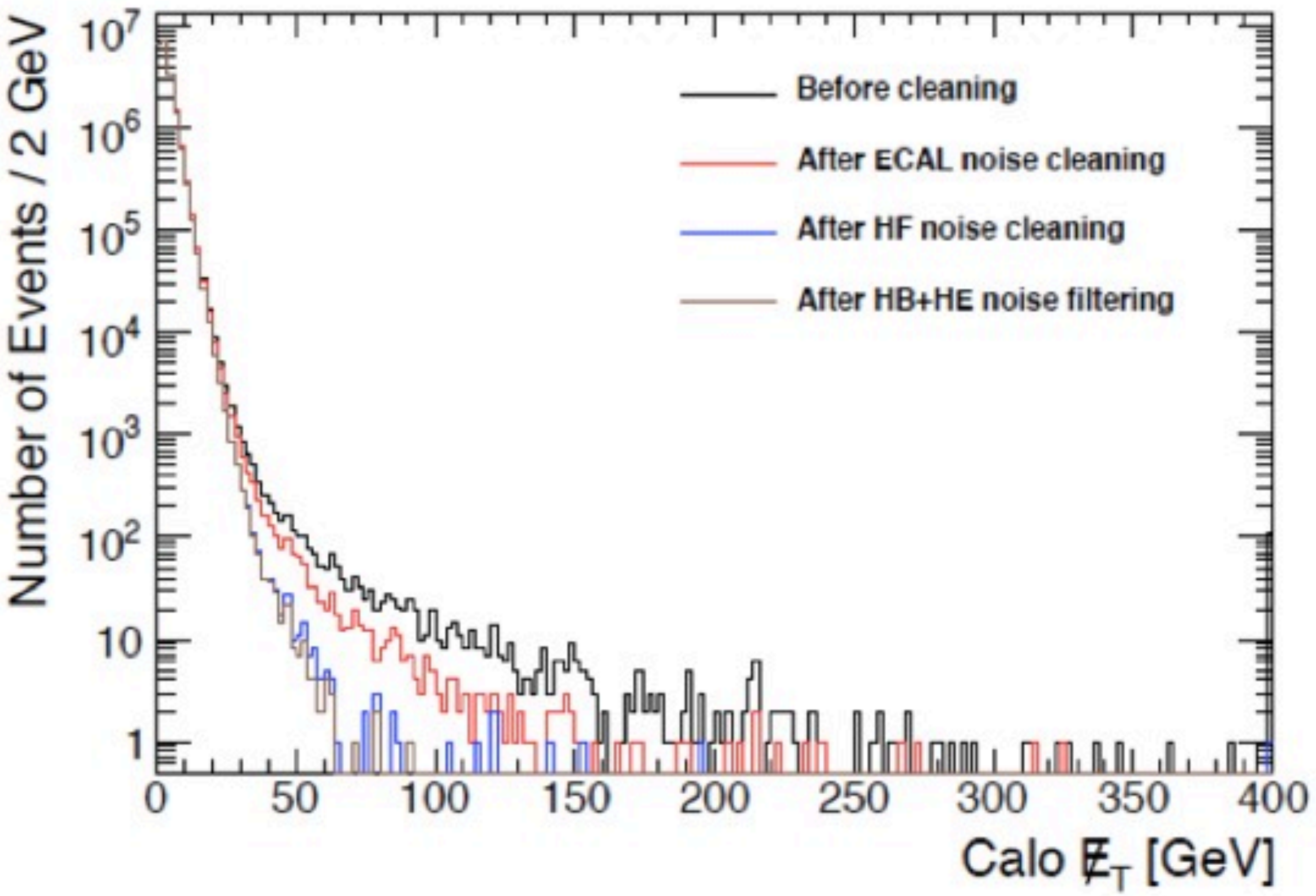
- di-leptons are clean experimental signatures
- rate is acceptable with a medium p_T threshold ~20 GeV on both leptons
- trigger rate monitored by EWK SM candles
- don't bias the MET distribution with online cuts

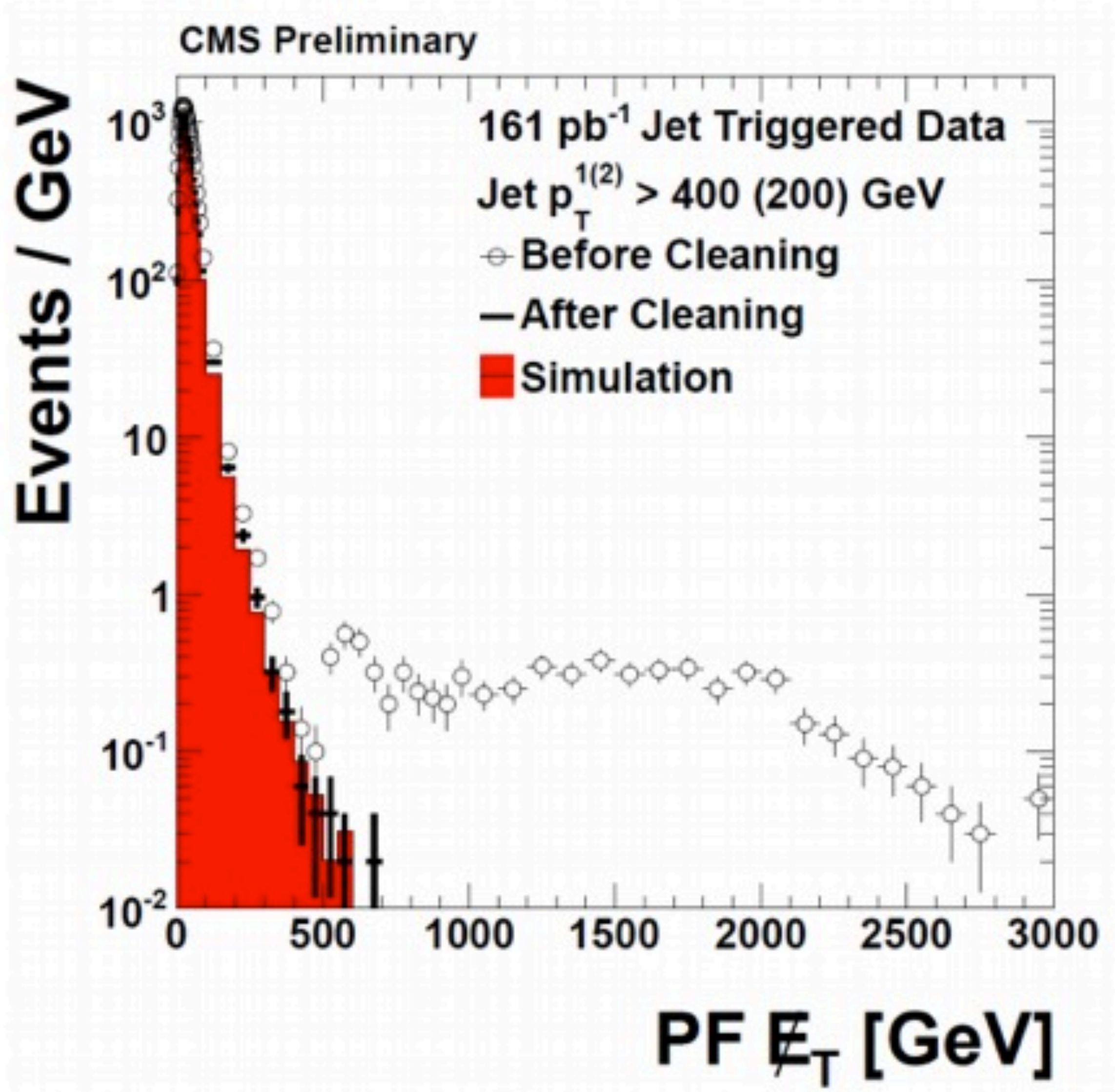
Event selection strategy (signal region):

- start from your favorite trigger
- select hard (high p_T) jets
- select high MET events
- select leptons
- select photons



Search in the MET tail





MET is the most discriminating variable of S against B:

- We need to be careful (cleaning w/o removing the signal)
- As far as we don't see an excess we are OK (MC-driven analysis can publish limits)
- BUT **exclusion limits don't translate in readiness** for a ***discovery***
- If an excess of DATA over the MC is observed, we are not going to get excited unless a **data-driven** analysis confirms the excess

Why search in Z+Jets+MET ?

Main background (Z→ll + jets) at parton level MET~0

Cons:

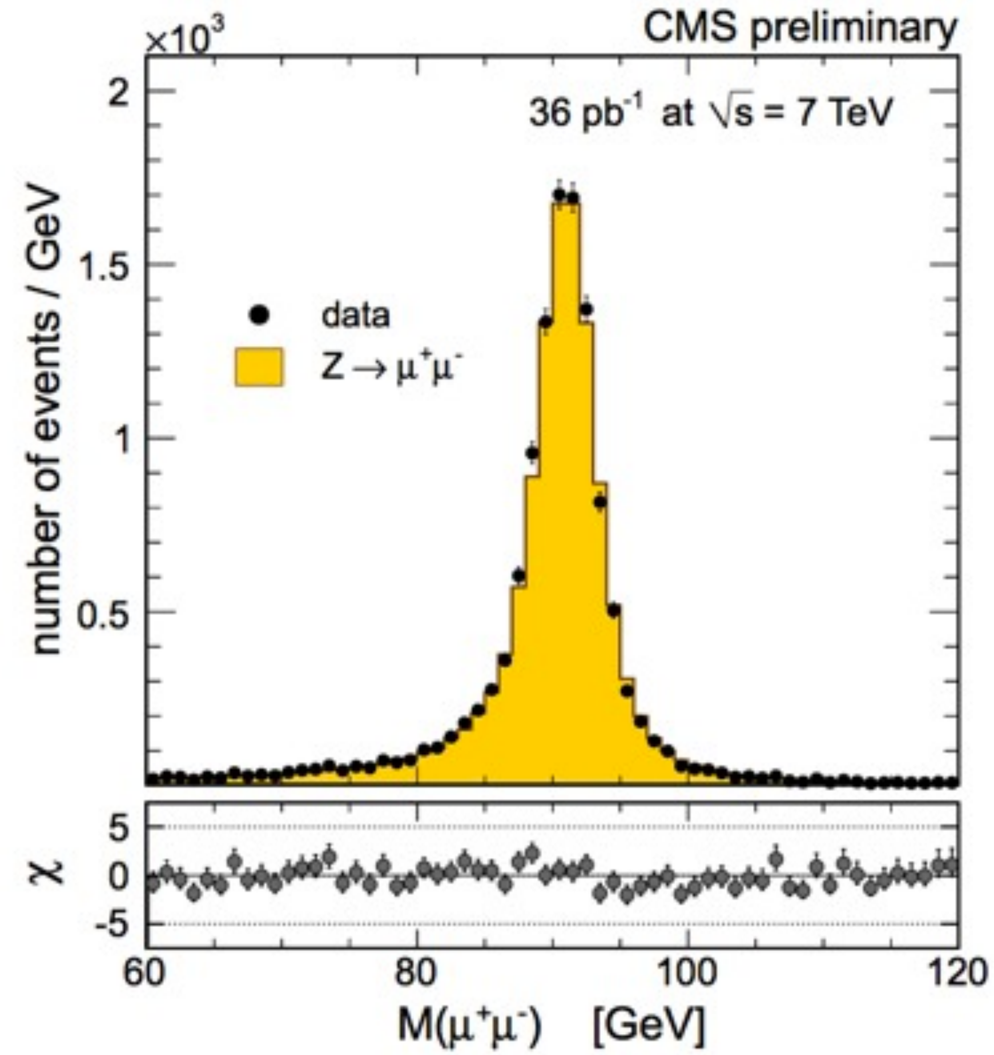
- MET is apparent due to detector resolution and reconstruction effect
- Detector response (p^T_{reco}/p^T_{true}): hard for MC sim
- Rare mis-measurements x σ_{EWK} = can give sizable MET tail
- If an excess is observed extreme tails of SM Z+jets will have to be ruled out, how?

Pros:

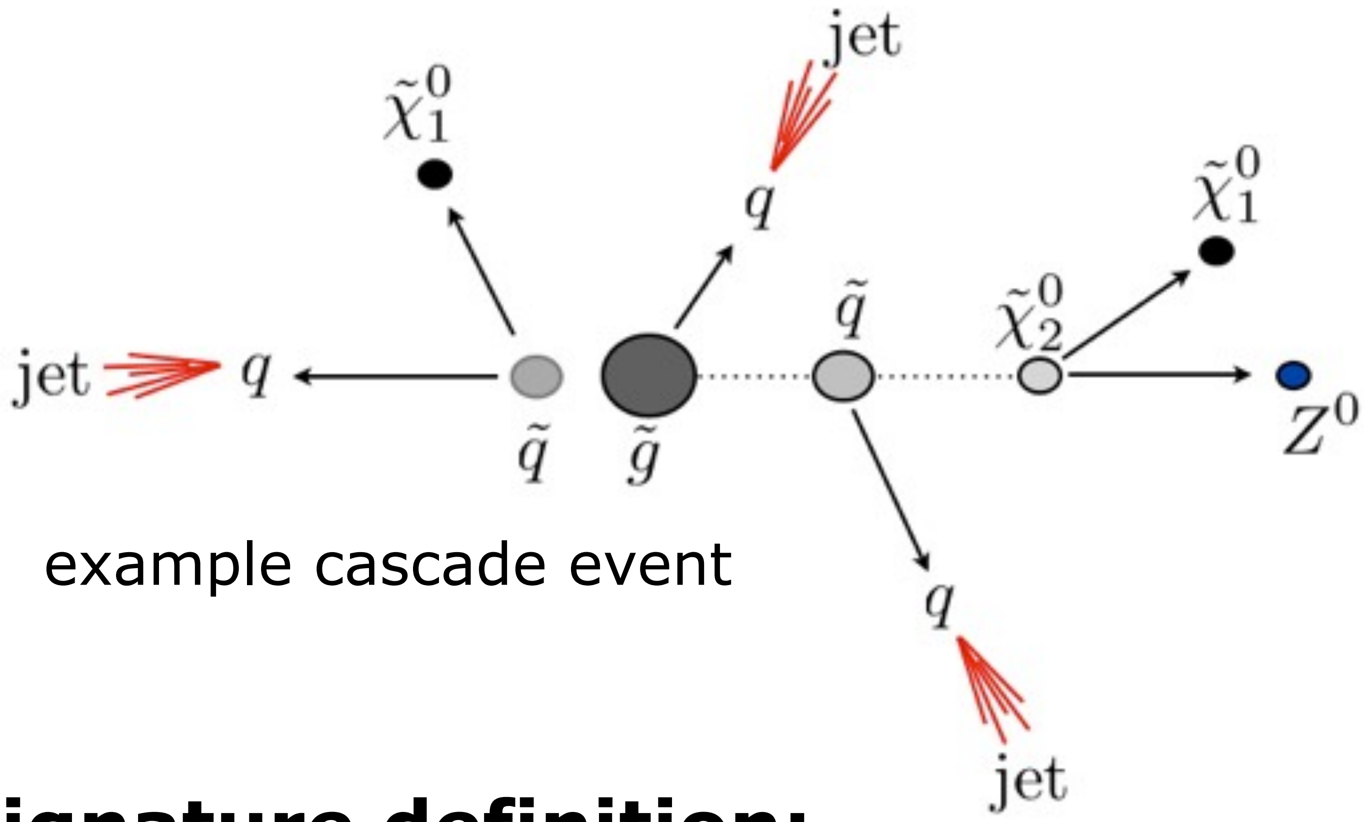
- Best studied SM process (NNLO)
- Best understood experimental data
- Cleanest SM candle: used for calibration
- High purity event selection & easy trigger

It's like searching for your keys under the light lamp

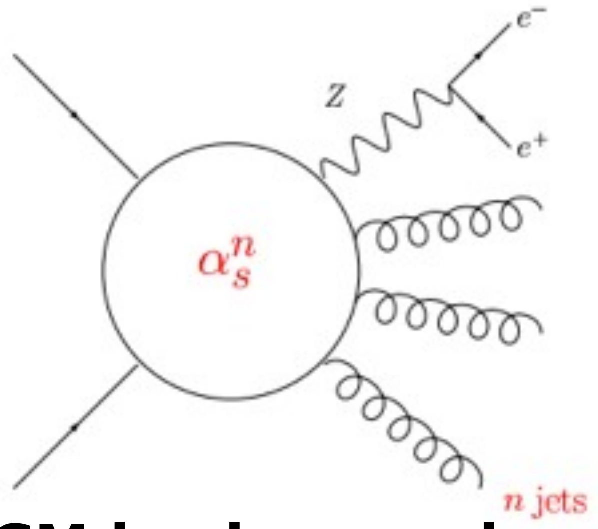
✓always a good starting point :-)



Signal vs Background



example cascade event



SM background
(prompt Z^0)

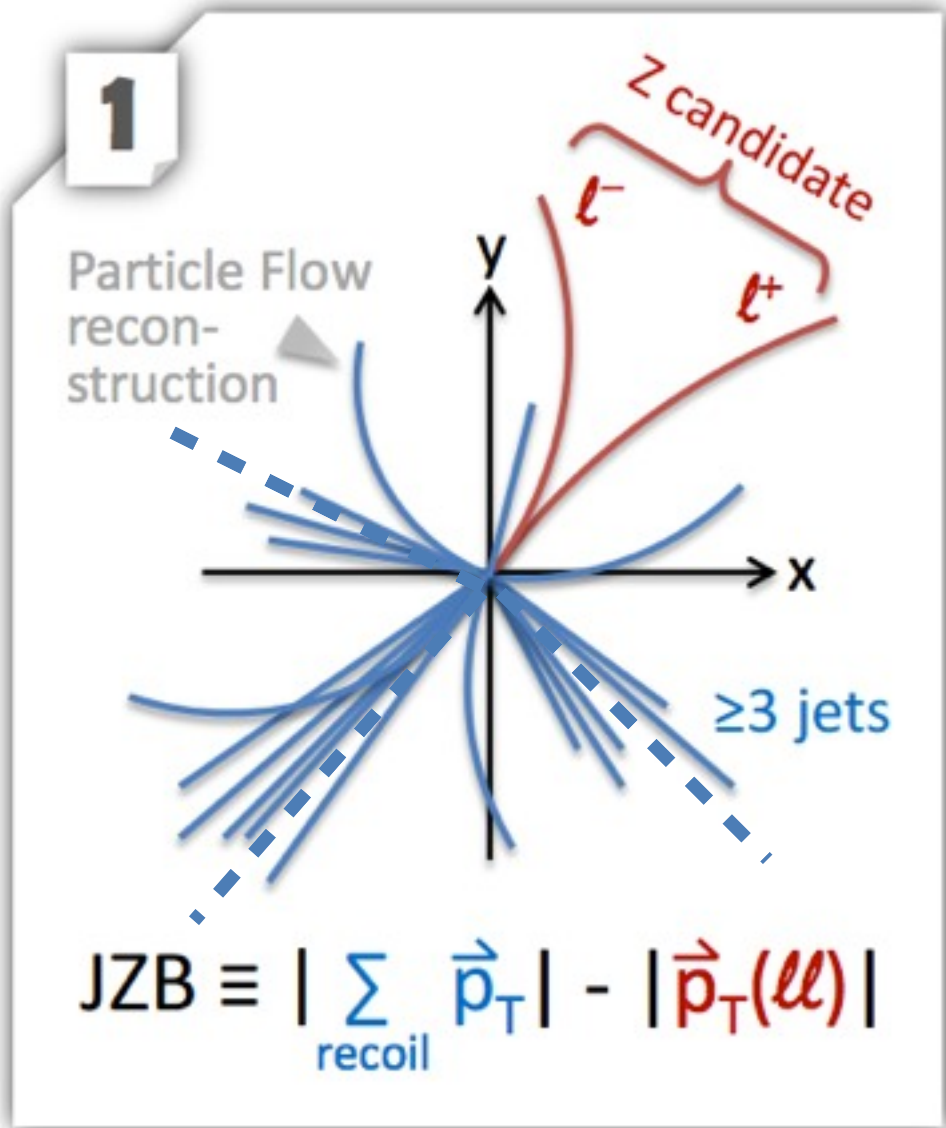
Signature definition:

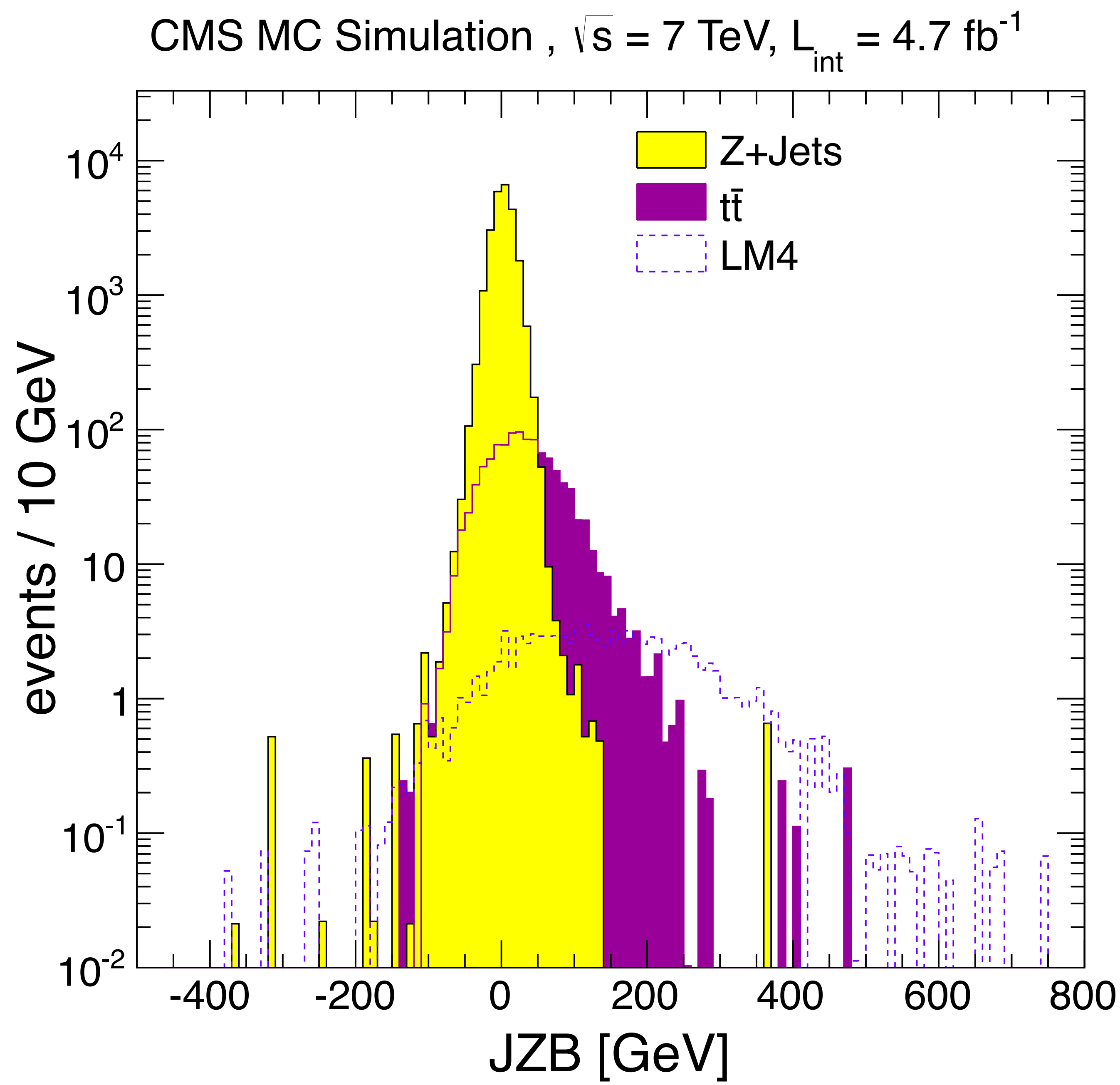
- Large MET due to LSPs
- Multi-cascade topology
- Z^0 is non prompt

Traditional MET searches just ask Z + MET>200 GeV:

- don't exploit fully the kinematic information (multi cascade)
- don't exploit angular correlations

The Jet-Z-Balance Variable



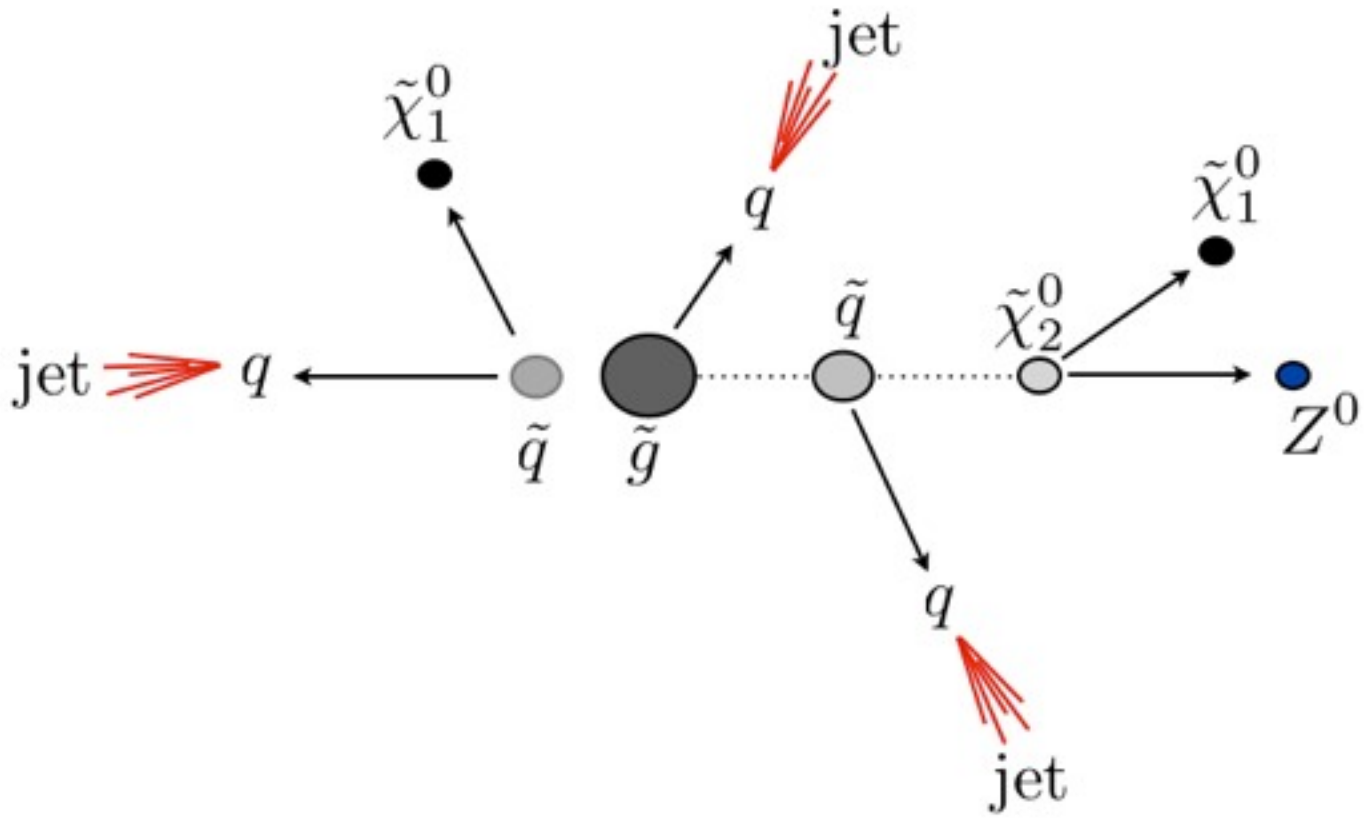


JZB is ~ like signed MET:

- Positive signed for signal (real MET)
- Random sign for the Z+Jets background (no real MET)

1) nice diagram from S.A. Koay

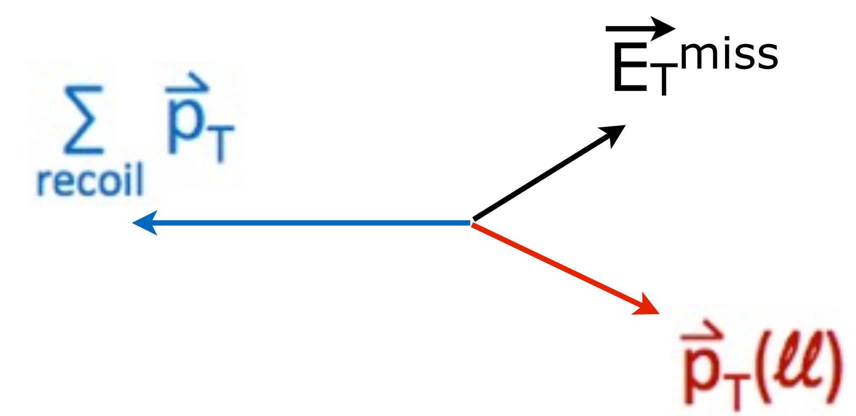
How does JZB work?



Z^0 and LSP have a common mother which introduces an angular correlation $\Delta\Phi$(Z,LSP). Results in **large JZB** when $p^* < p_M$

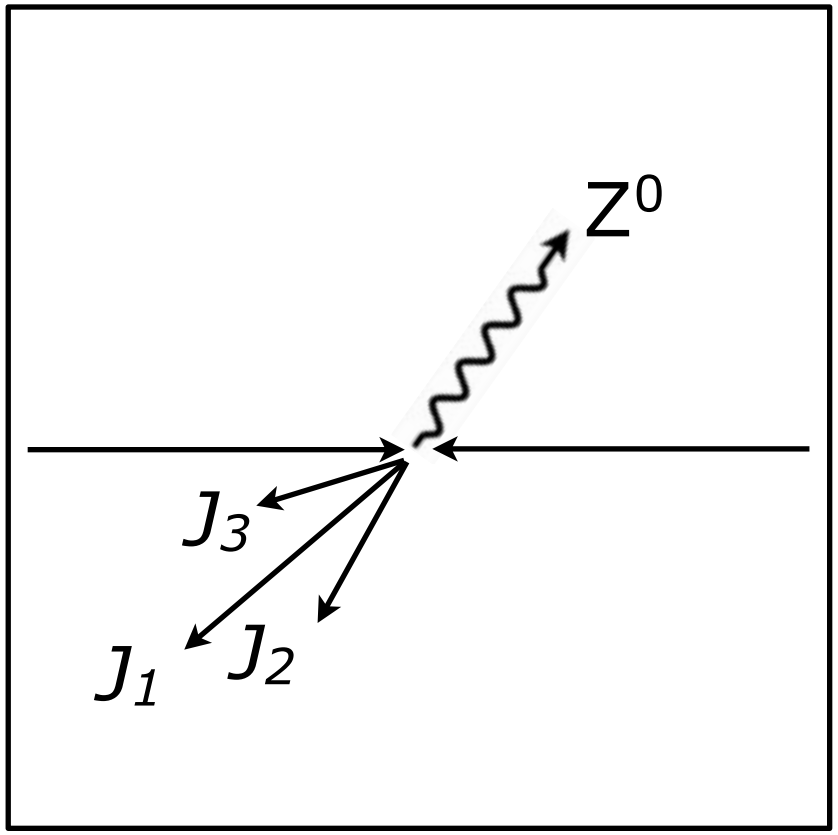
$$p^* = \frac{[(M^2 - (m_X + m_Z)^2)(M^2 - (m_X - m_Z)^2)]^{1/2}}{2M}$$

p_M = LAB momentum of Z^0 's mother

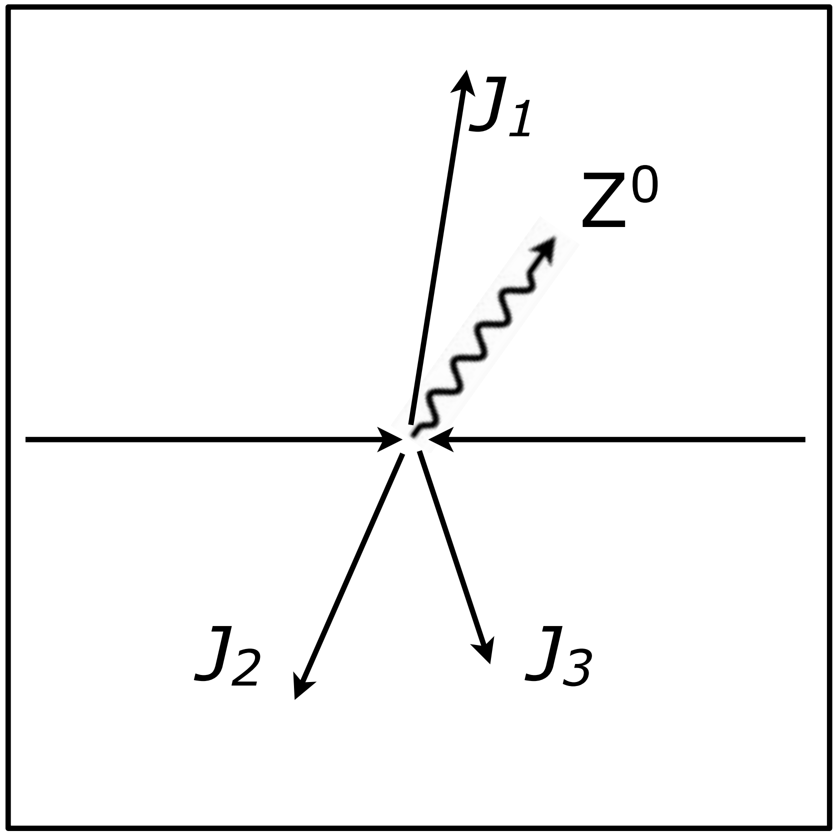


Z^0 helps LSP to balance the event

JZB for the Background



leading Z



spectator Z

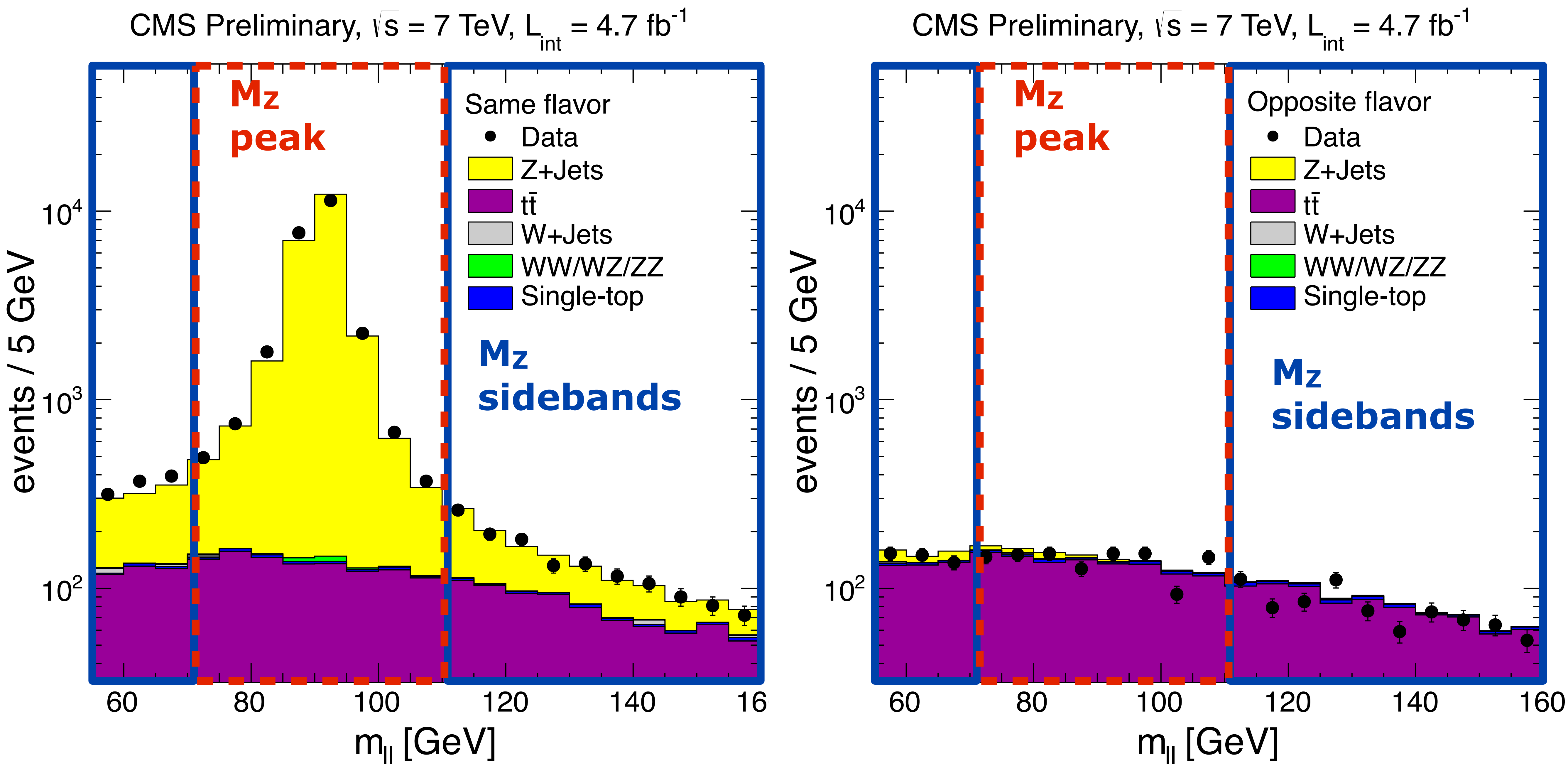
Background phase space

- Leading Z: can be negatively JZB signed (conservative in discovery mode)
- Spectator Z: jets counter balance, angular correlations $\Delta\Phi(Z,J_n)$ are lost

At high jet multiplicity Z becomes a spectator

- Systematic effects on $p_T^{(reco)}/p_T^{(true)}$ counter-cancel
- JZB distributions approaches normality (angular randomization)

What about other B? (eg ttbar)



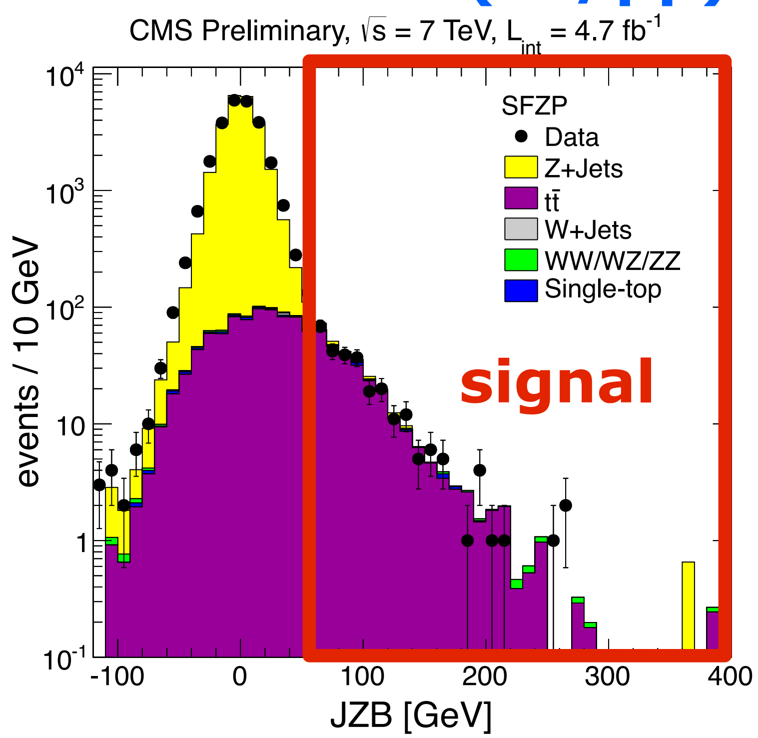
Same Flavor (ee/μμ) **Opposite Flavor (eμ)**

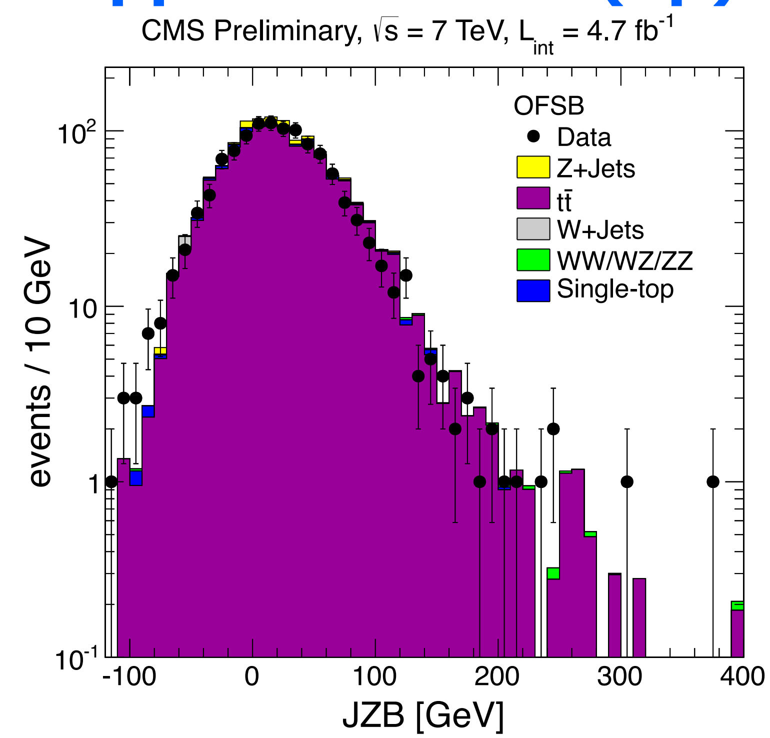
- W decays in a ttbar event are uncorrelated in flavor
- ttbar does not peak in mll and is flat below M_Z

JZB Analysis Strategy

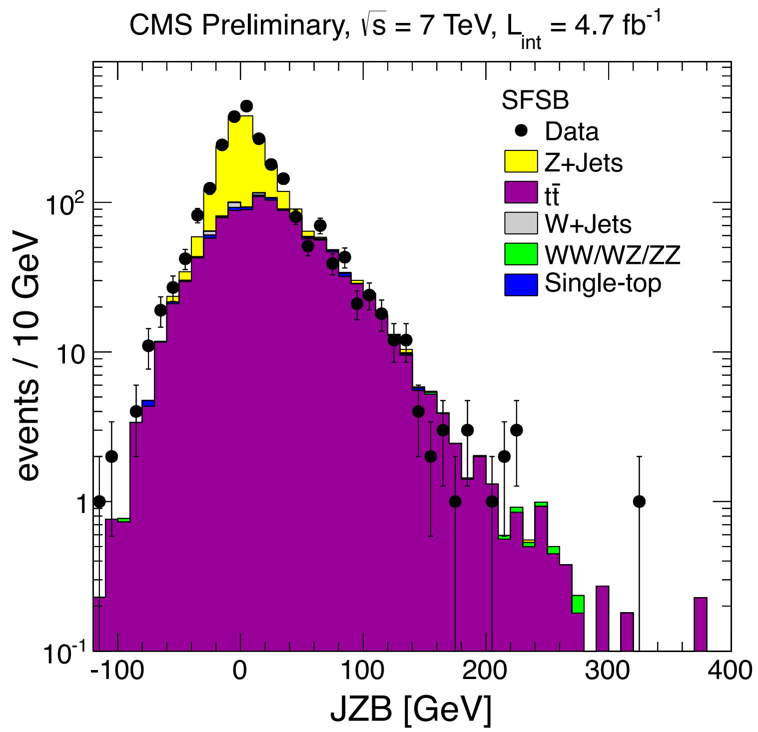
Same Flavor (ee/μμ) | **Opposite Flavor (eμ)**

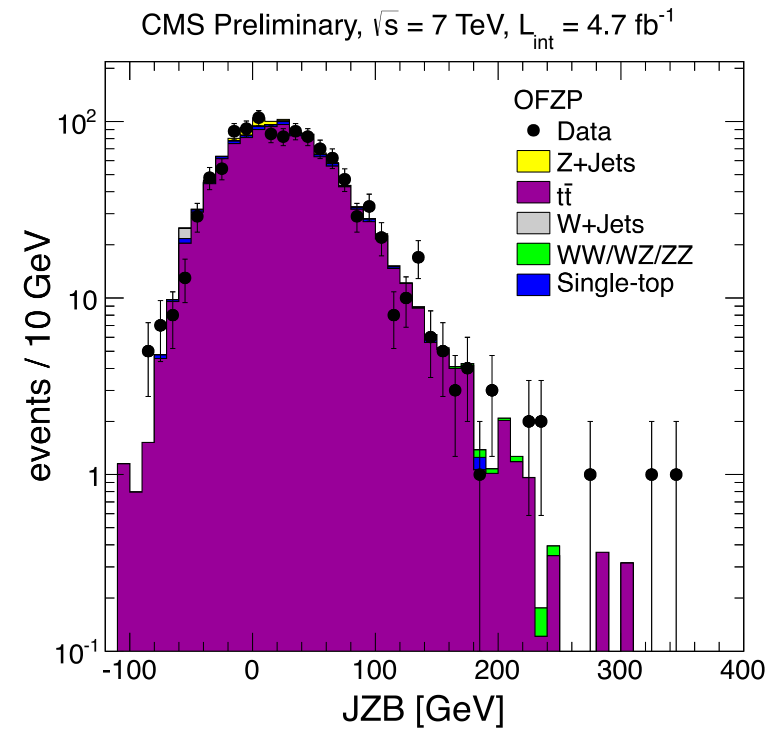
M_Z peak





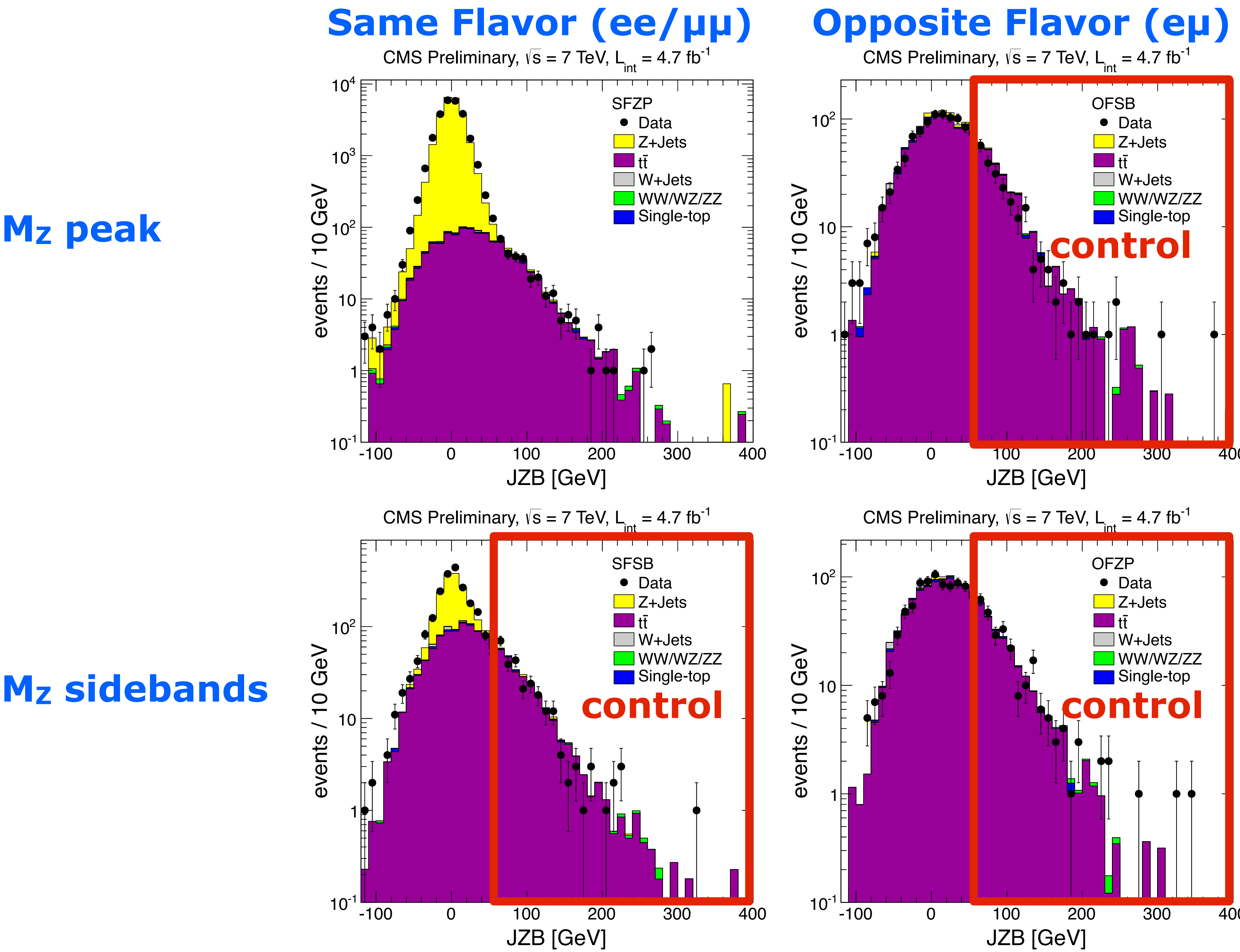
M_Z sidebands





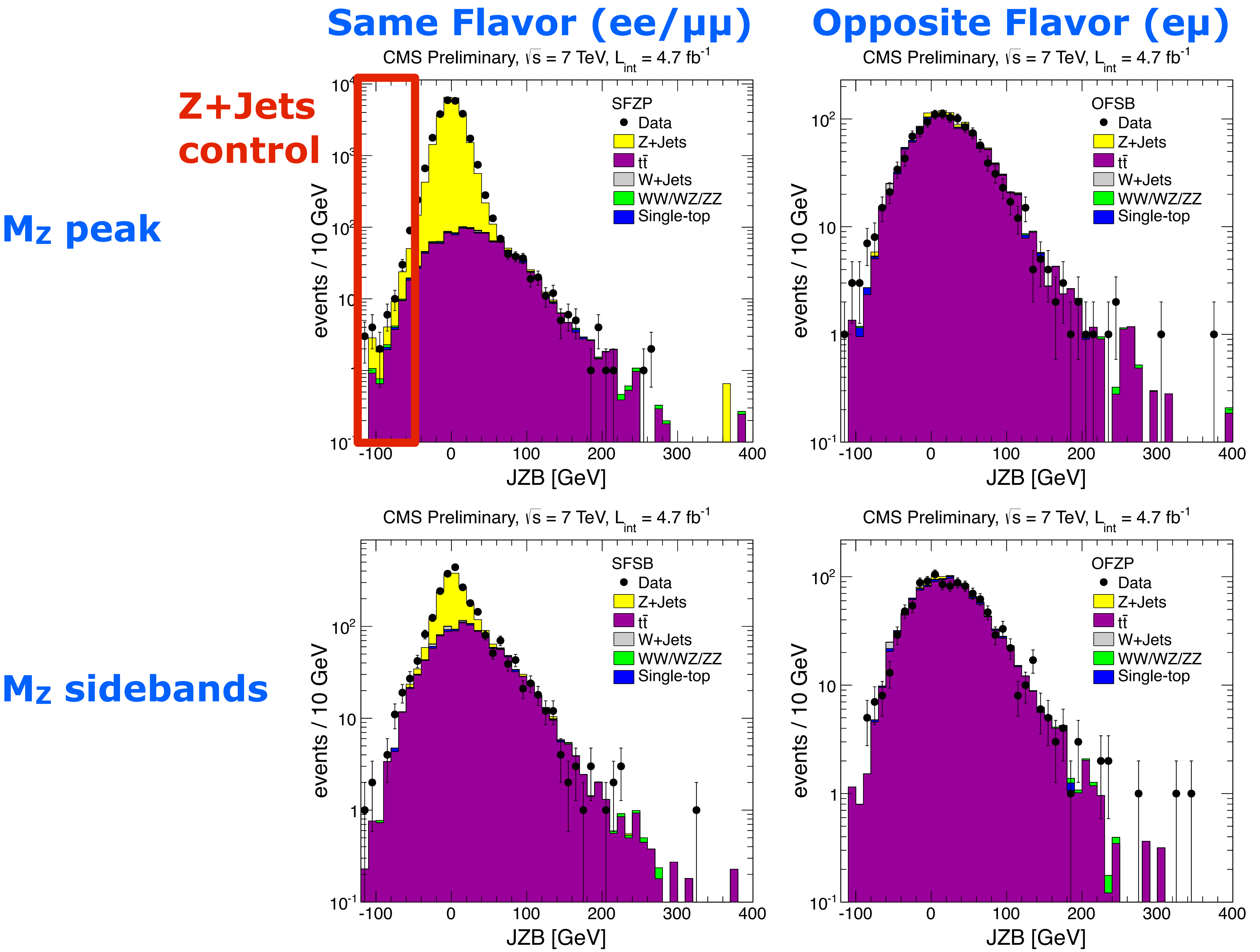
Divide di-lepton data in 4 sub-samples (2 flavor comb. x 2 mass window)

JZB Analysis Strategy



B w/o Z^0 (mostly TTbar): estimate it from 3 control samples (1/3 Σ B_i)

JZB Analysis Strategy



B with real Z^0 evenly populates SFZP: estimate it from JZB<0

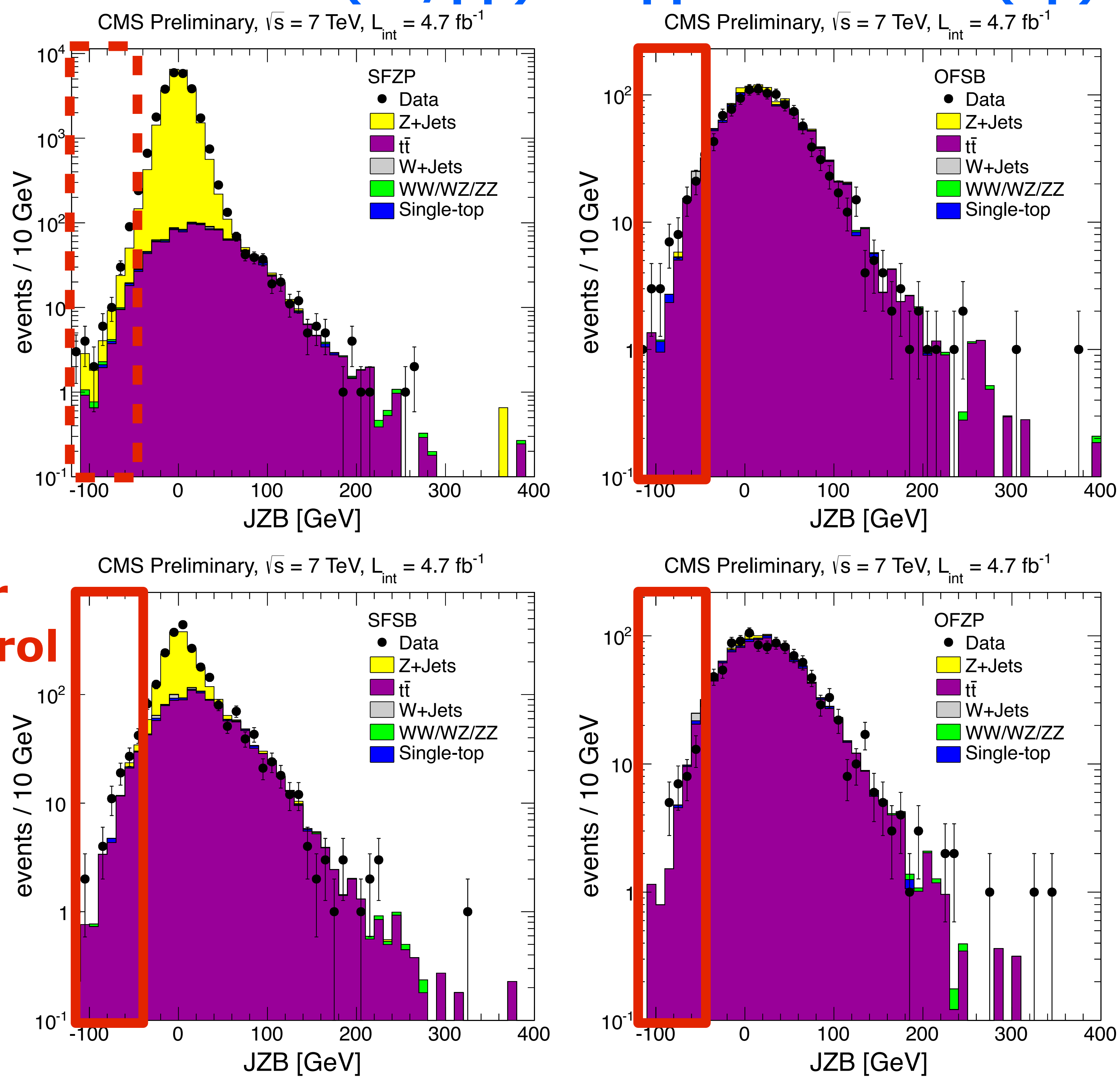
JZB Analysis Strategy

Same Flavor (ee/μμ) **Opposite Flavor (eμ)**

M_Z peak

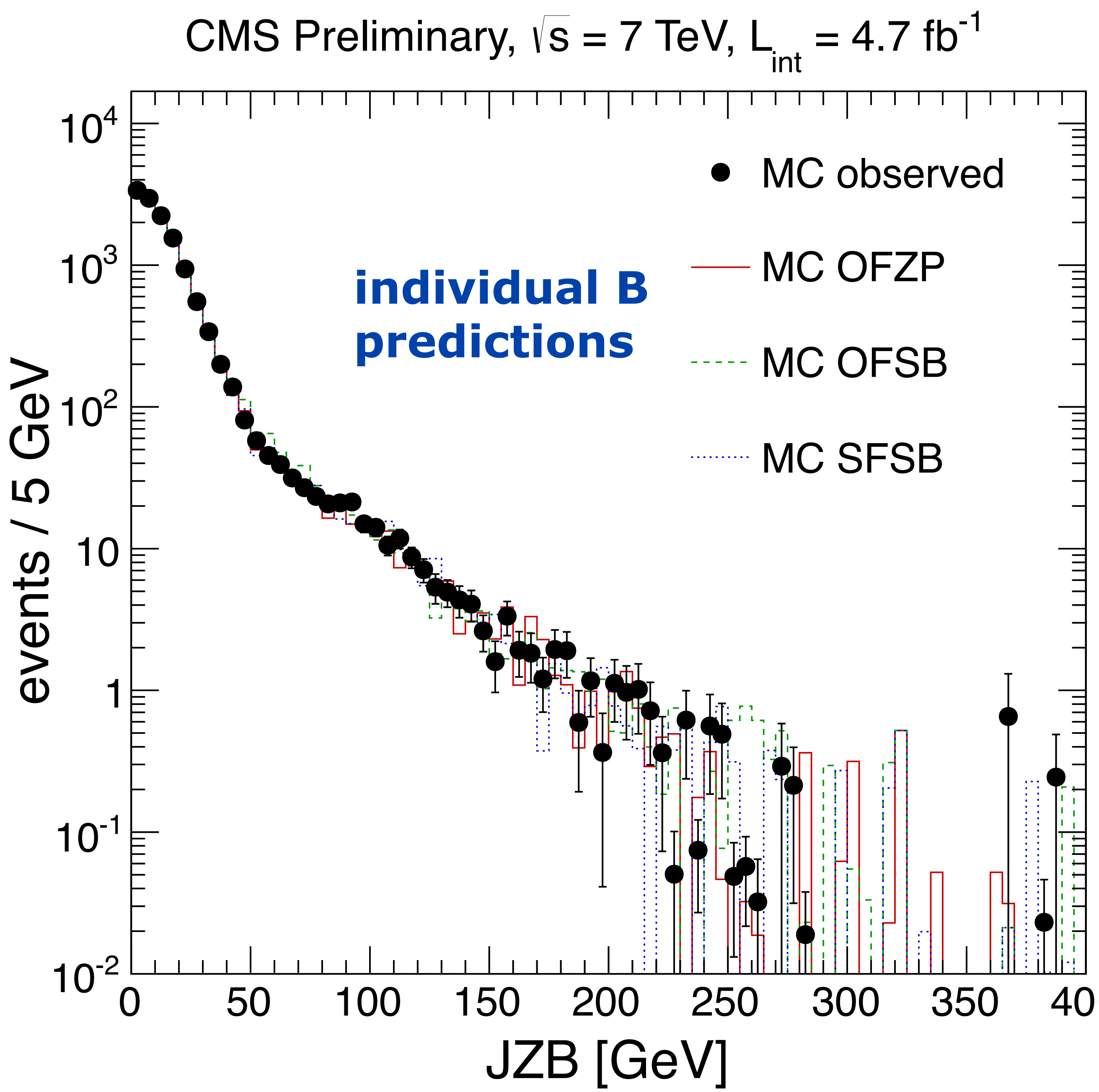
ttbar control

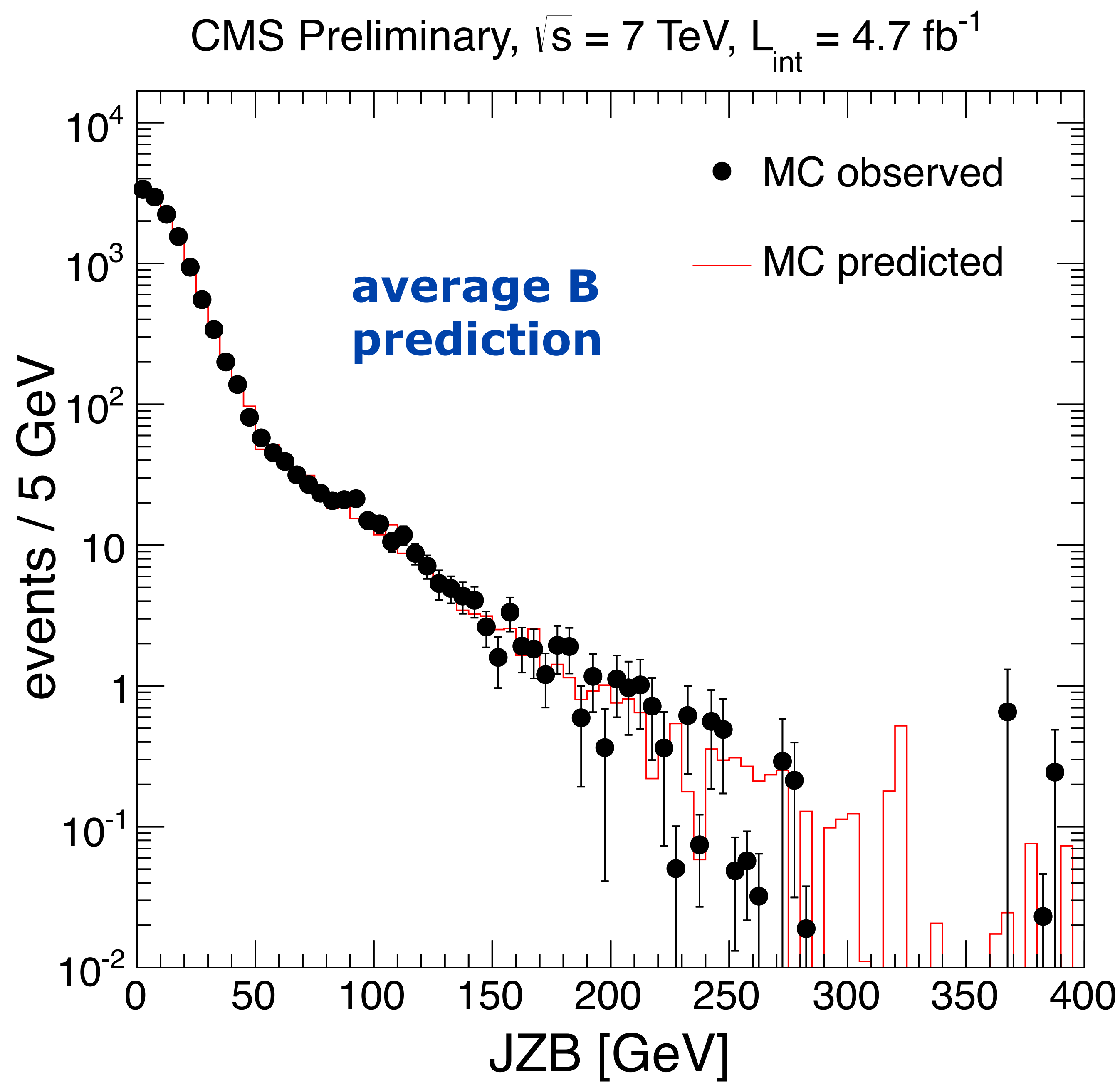
M_Z sidebands



Statistically subtract B w/o Z in the JZB<0 using the 3 regions $-1/3\ \Sigma\ B'_i$

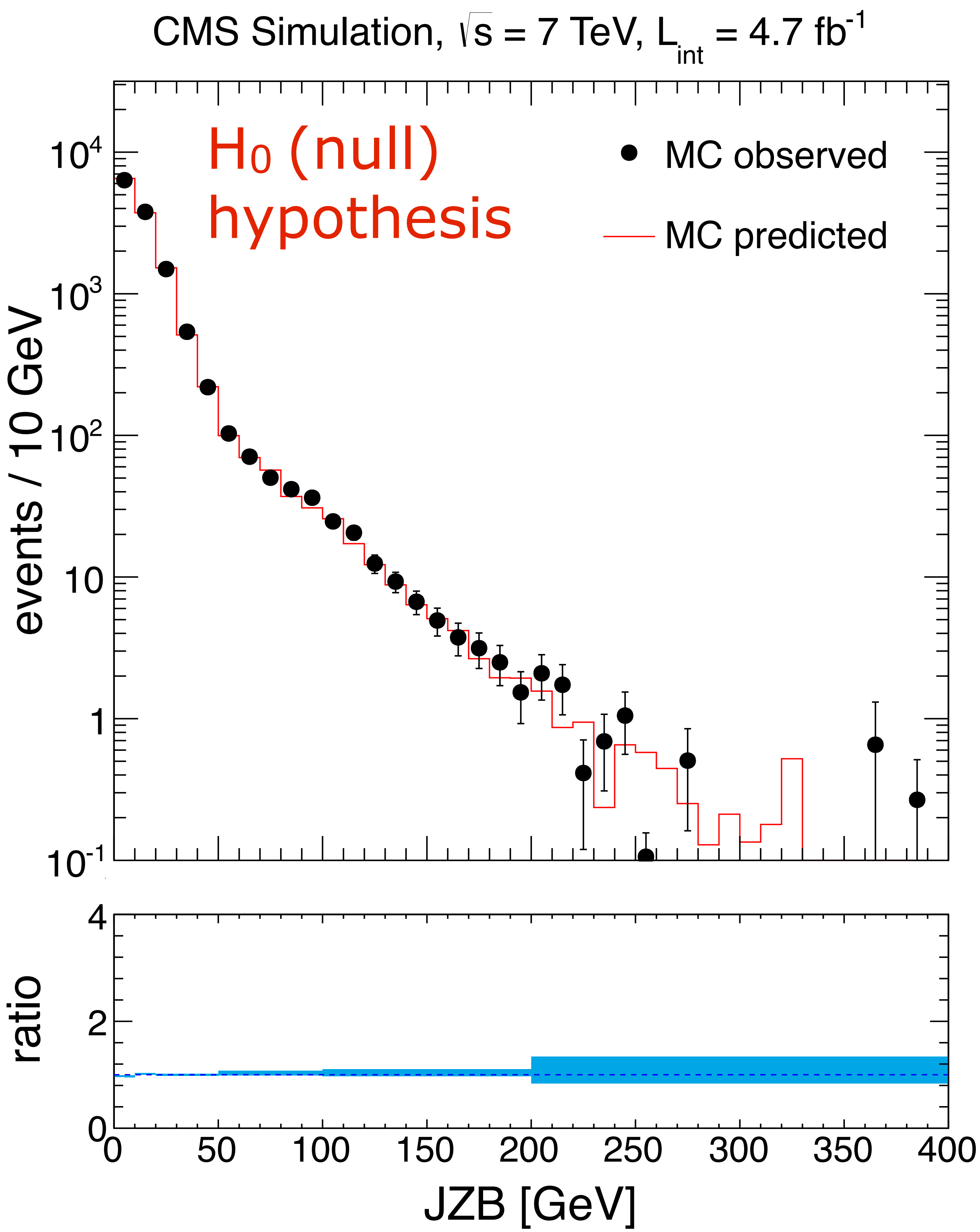
B-prediction (making of)





First we check the individual shapes from the 3 + 1 control regions, then we average to gain ~40 % precision in the tail

First Things First: MC Closure



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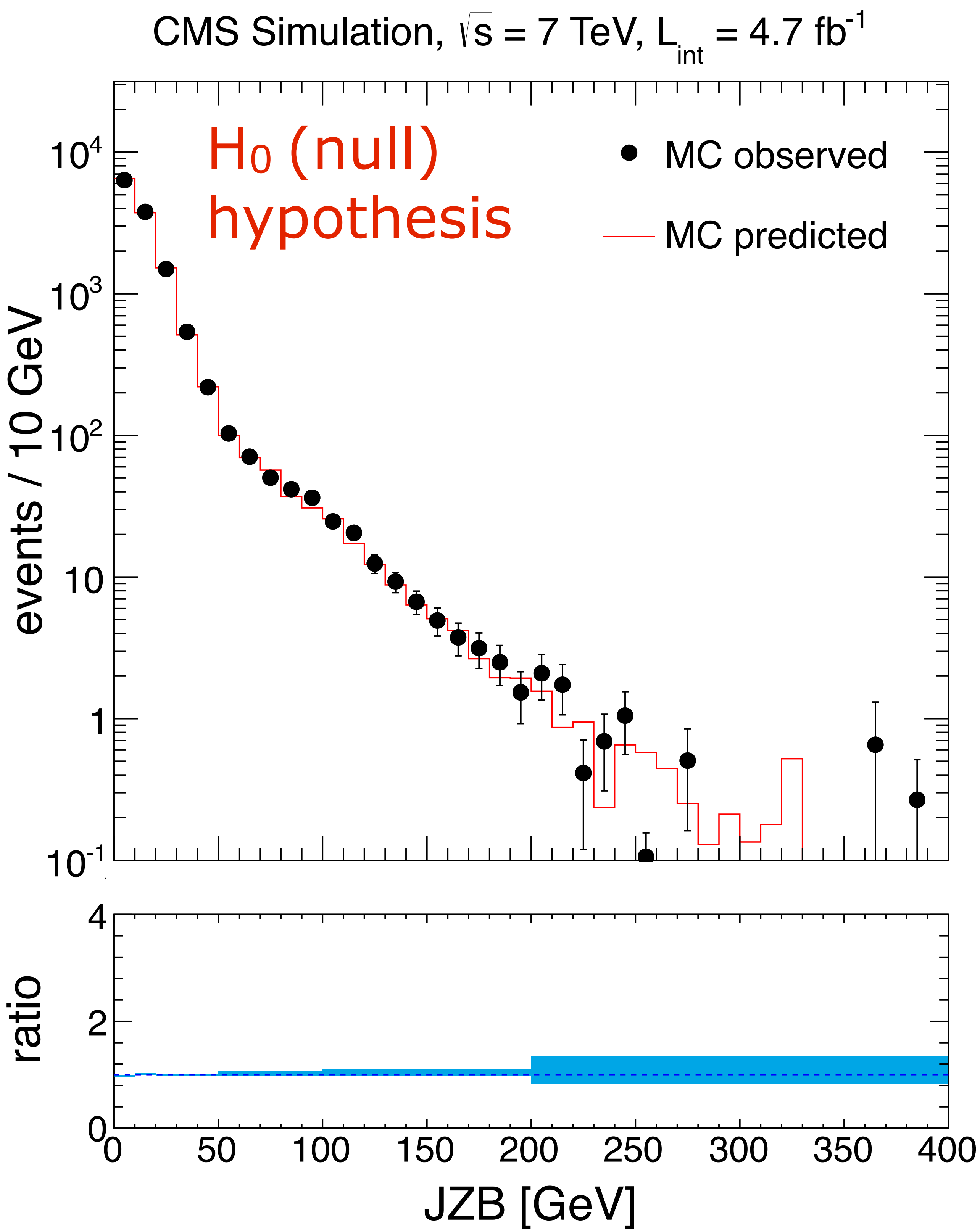
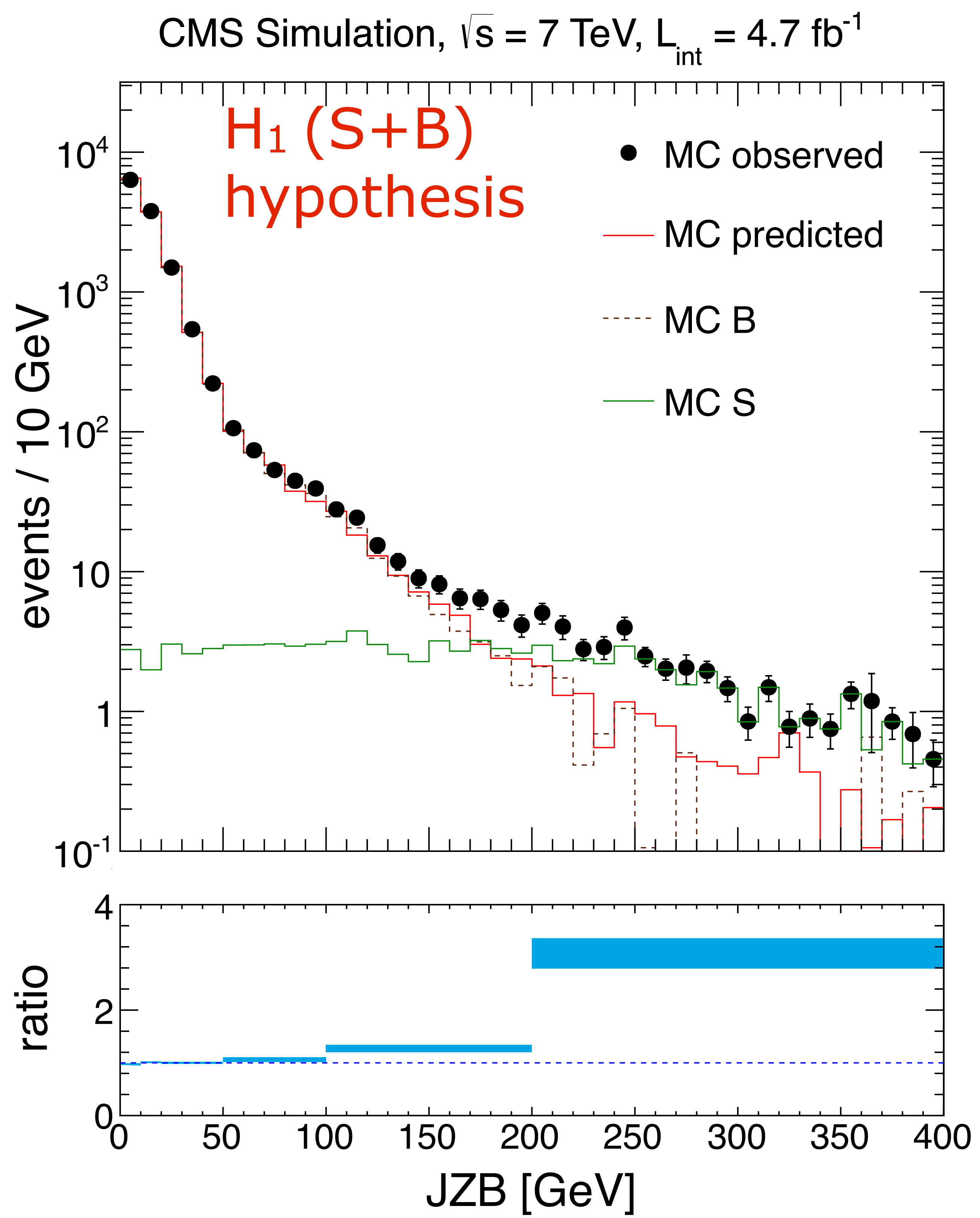
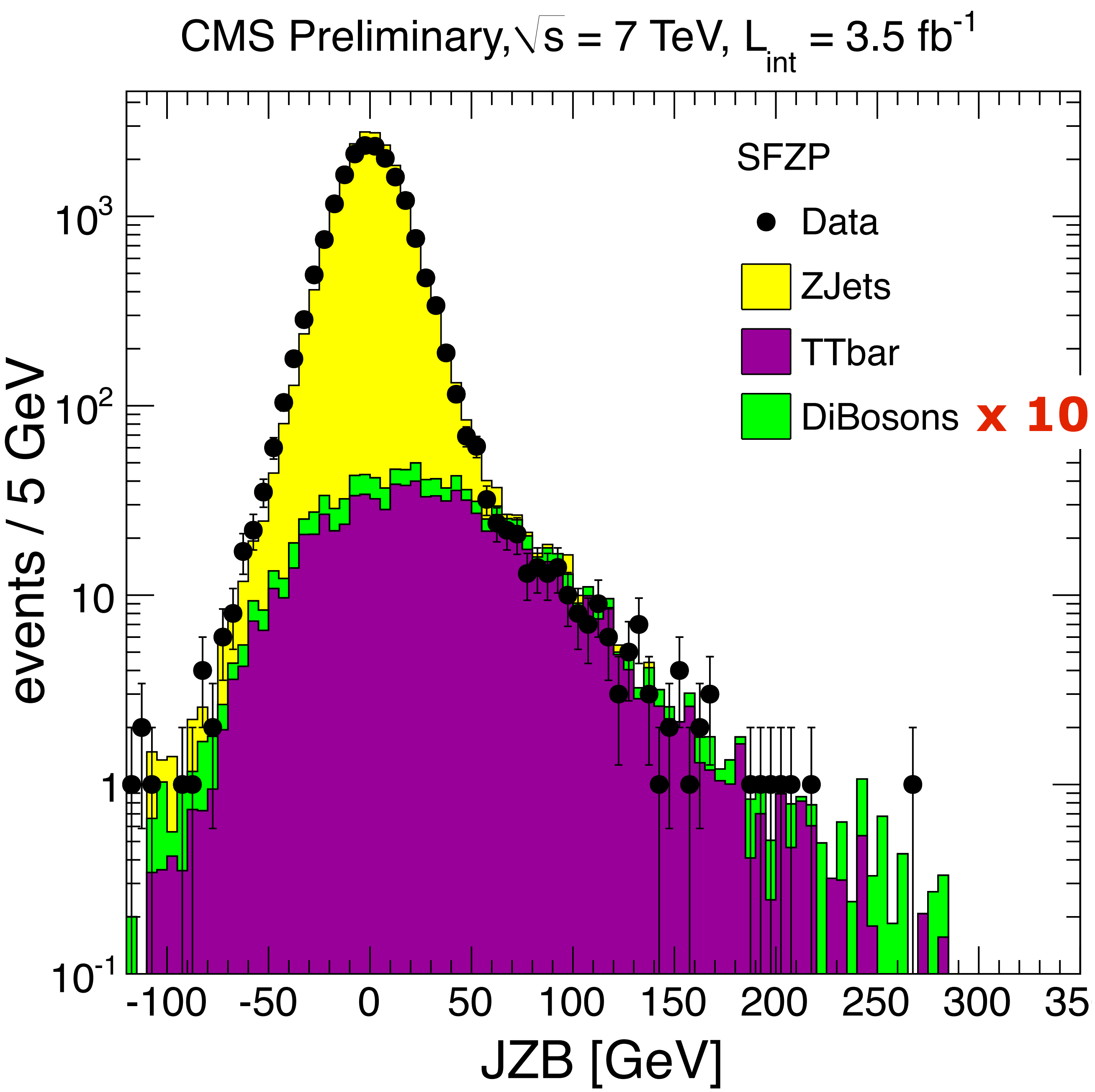
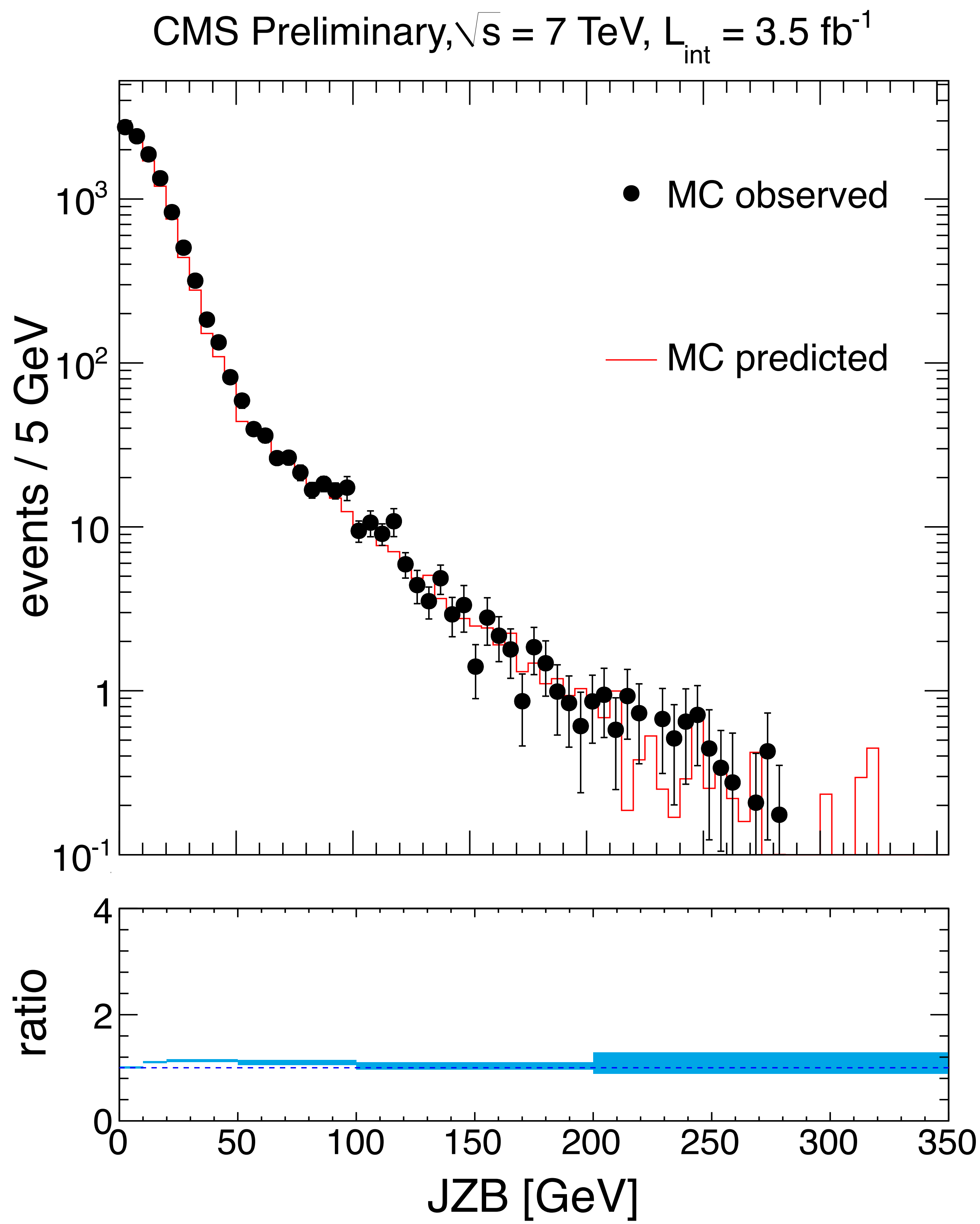




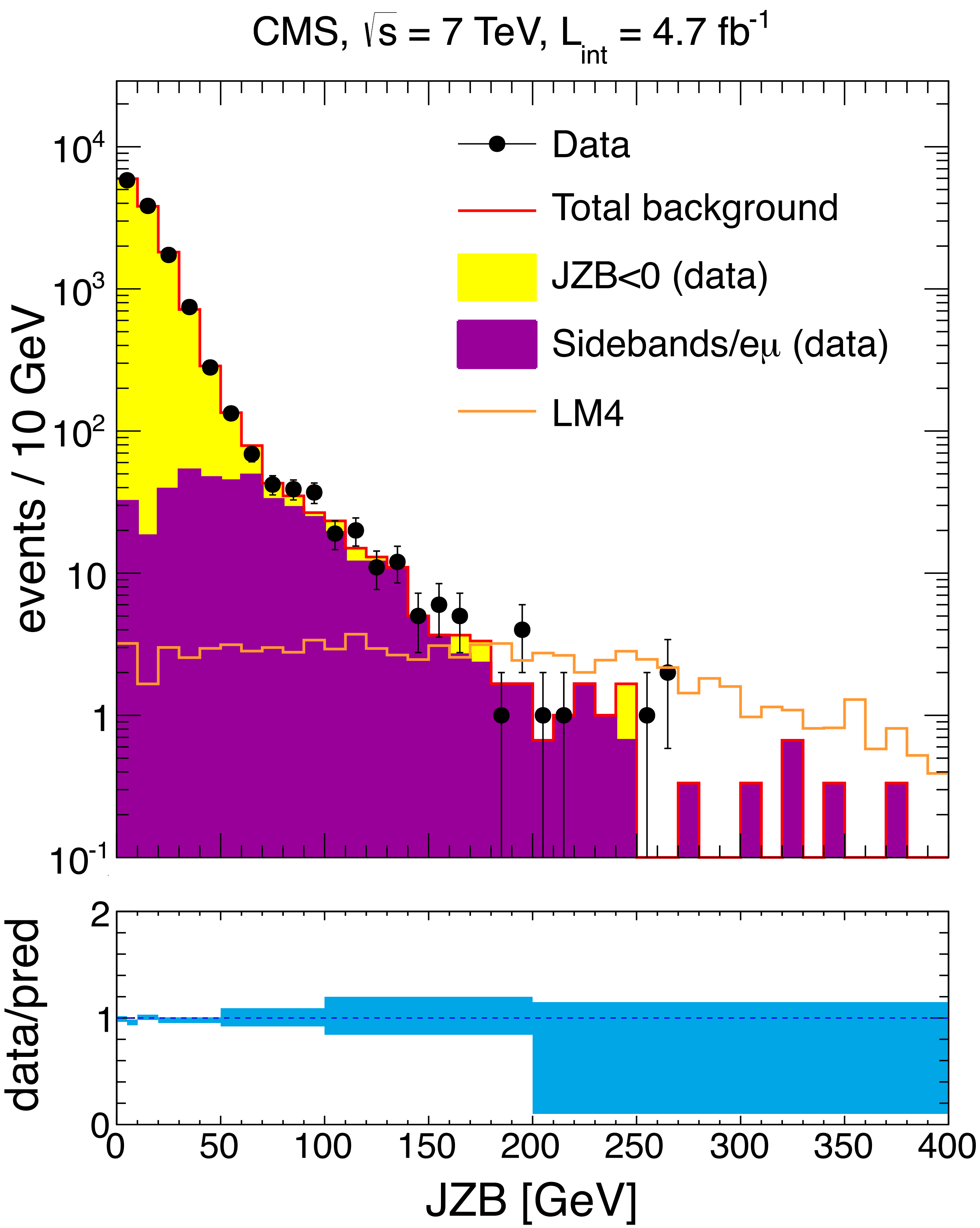
DiBosons(WW/WZ/ZZ)?

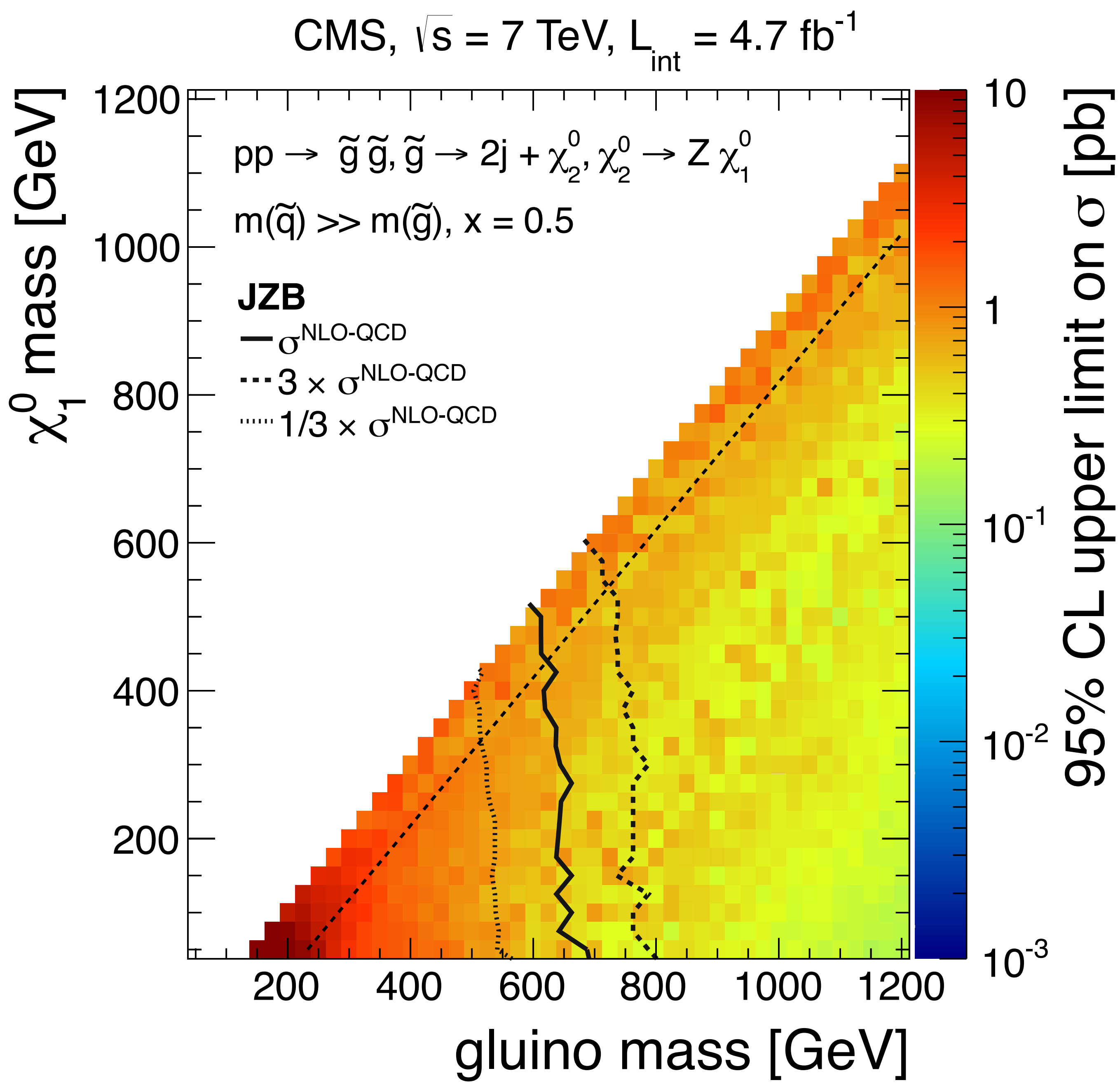




Repeat MC closure test after artificially amplifying (**x10**) the cross-sections of the VV+jets

Results in CMS 2011 Data





no excess found, interpretation of the result (exclusion limits)

JZB Analysis Summary

Analysis Properties:

- 3 + 1 control samples model the B in the signal region
- Extrapolation of the B to the signal region is straightforward
- **No reliance on MC** in any part of the B estimation
- B extraction solely done with **in-situ data** from CMS

Pros:

- All higher orders are included, up to infinite ;-)
- Realistic detector model is used, the real CMS
- Not sensitive to luminosity uncertainties
- Transient experimental conditions are embedded in the control data
- What is transient? pileup, channel masking, hot towers, inter channel calibration & synchronization, p_T^{reco}/p_T^{true} response & resolution

Cons:

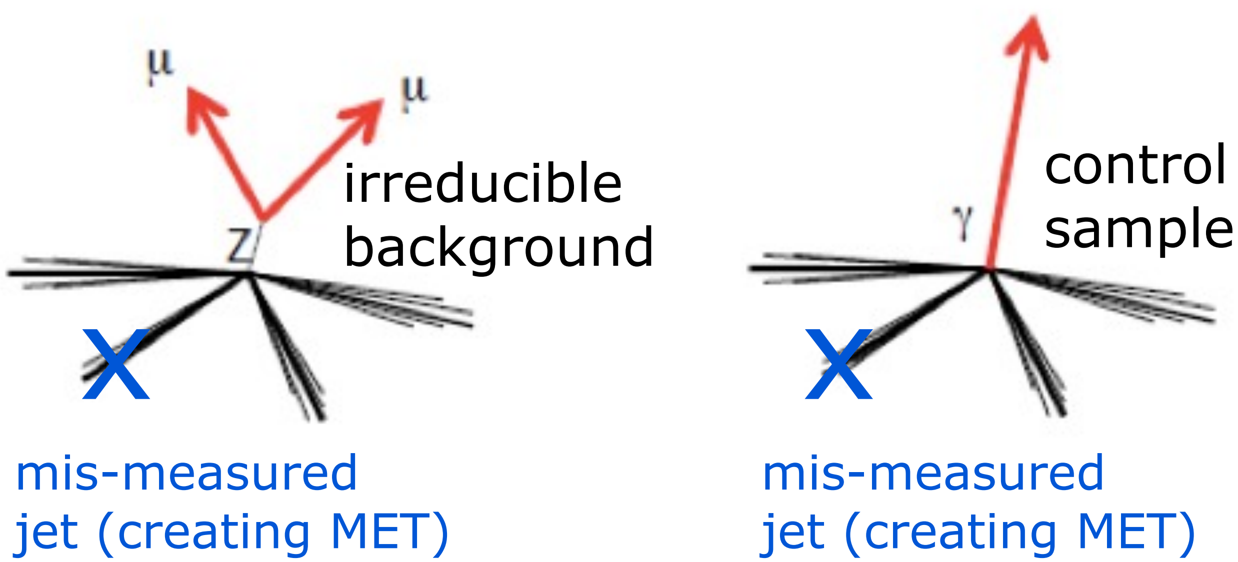
- Not as inclusive as a Jet + MET analysis
- JZB analysis is blind to JZB symmetric signals

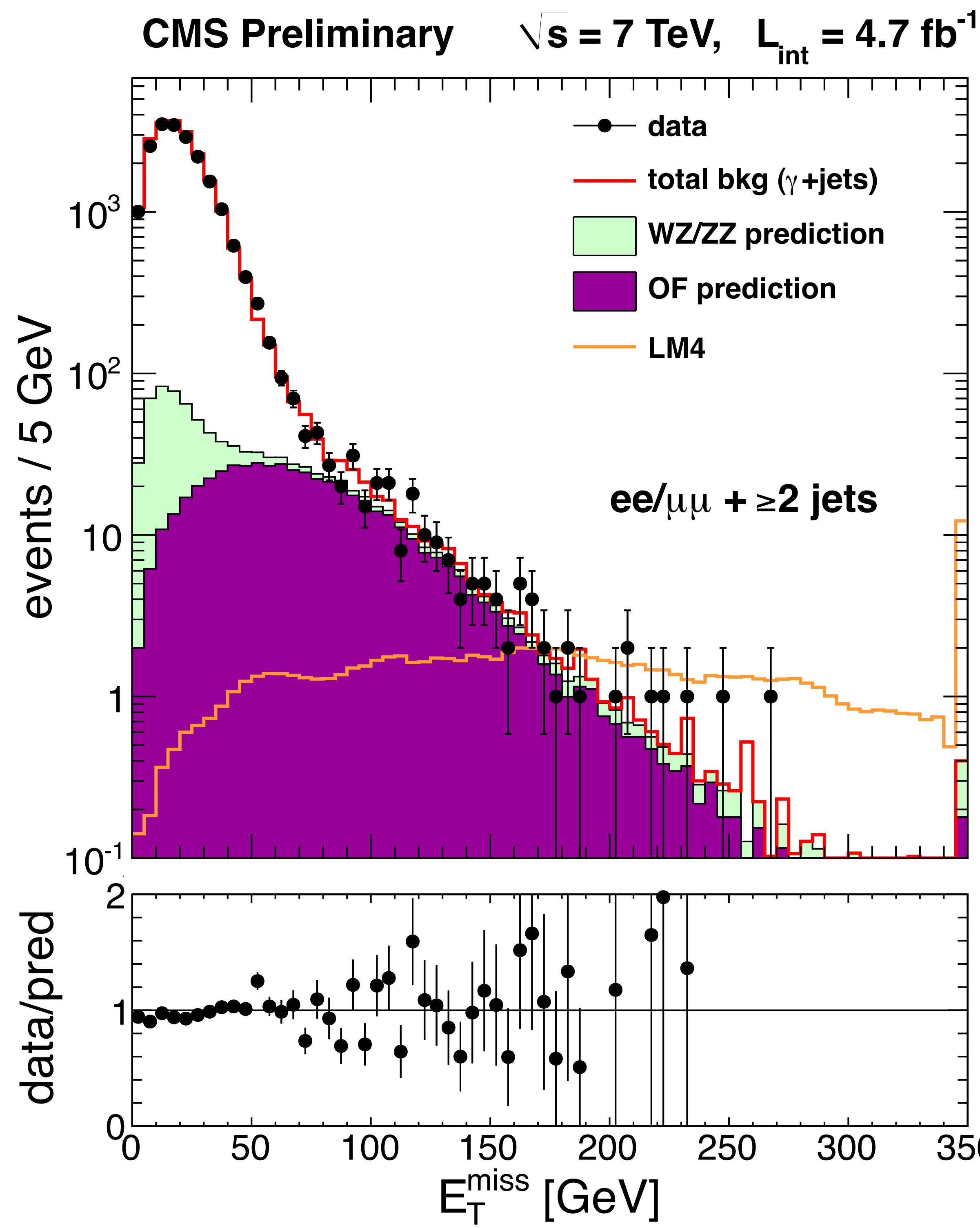
Complementary Analysis

references: SUS-11-017 & SUS-11-021

SUSY with Z→ll + MET

- Irreducible background: **SM Z→ll + fake MET**
- Use **gamma+jet+MET** data to model instrumental background

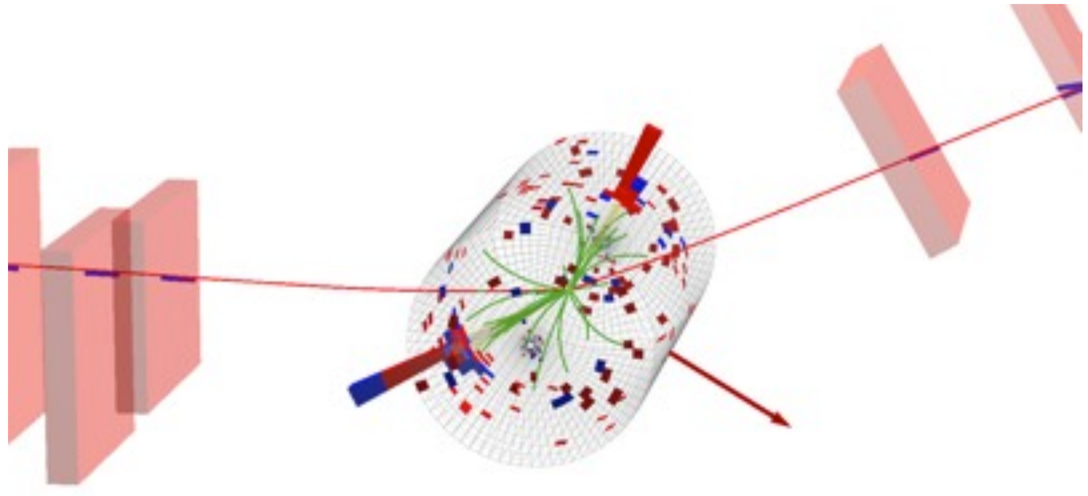




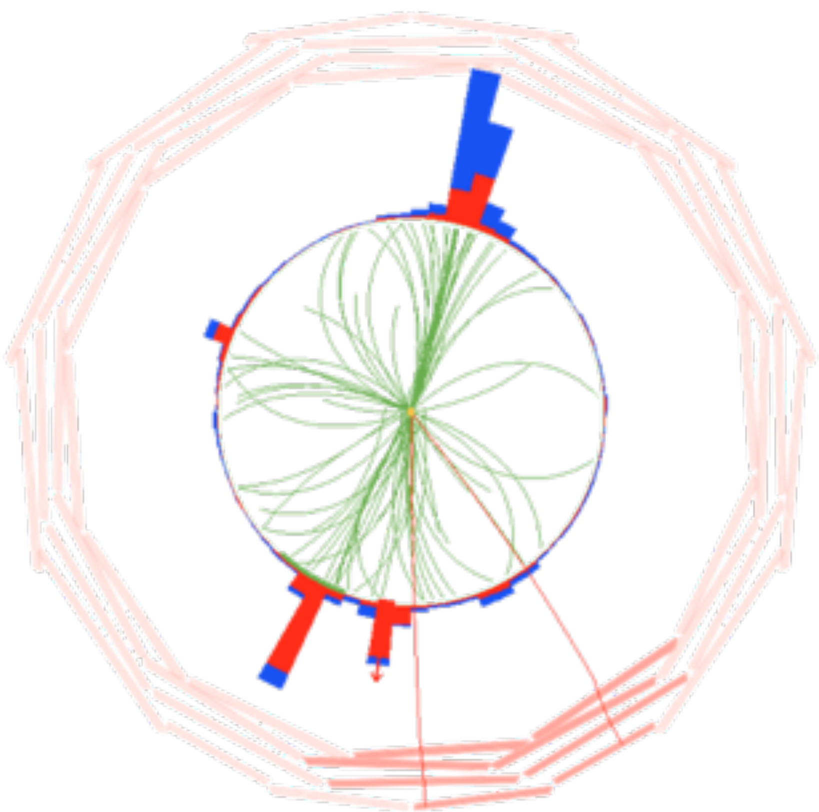
- MET templates analysis a very powerful complementary to JZB
- Can capture JZB symmetric signals if new physics don't contribute to gamma+jets+MET

Summary

JZB analysis:
- Exploits kinematical info to control the background with **in-situ data**
- No excess in the first 4.7 fb-1 data



high JZB event 2010 data



high JZB event 2011 data

References :
- K.Theofilatos PhD thesis 2009
- SUS-10-010 (34 pb-1)
- SUS-11-012 (190 pb-1)
- SUS-11-019 (2.1 fb-1)
- SUS-11-021 (4.7 fb-1)

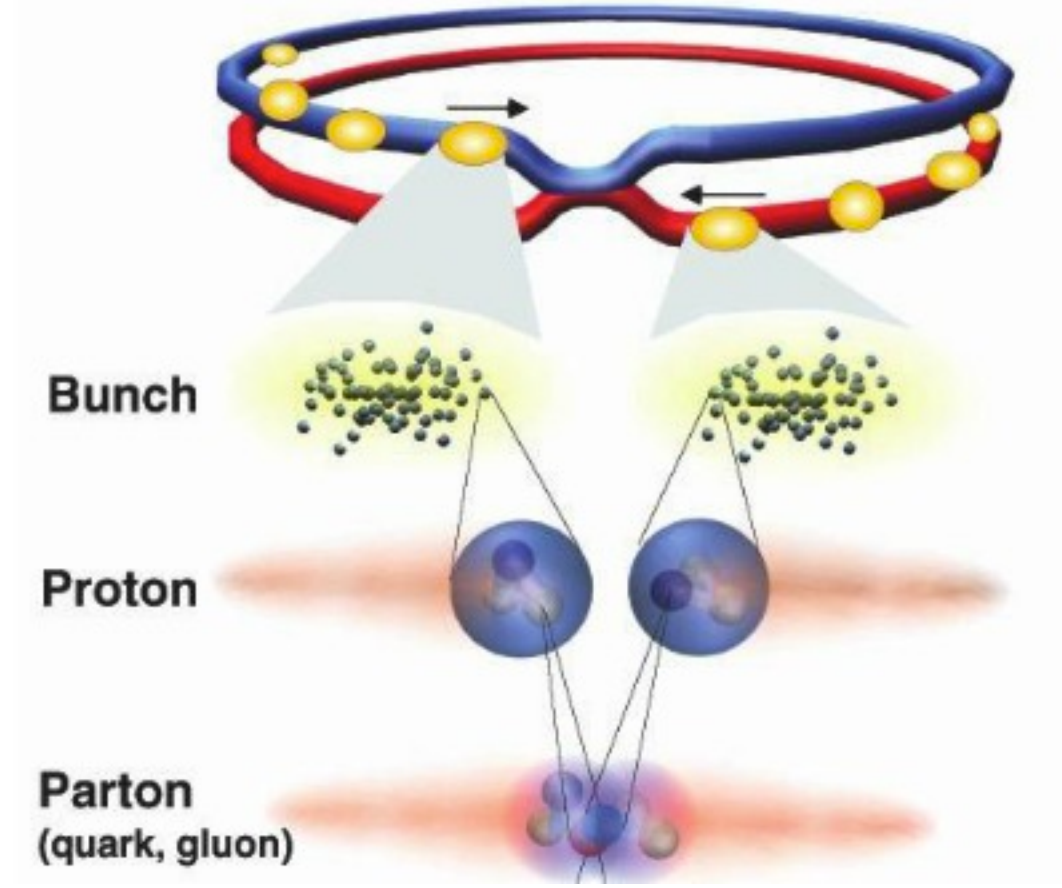
SUS-1*-*** are available in CMS Public twiki
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

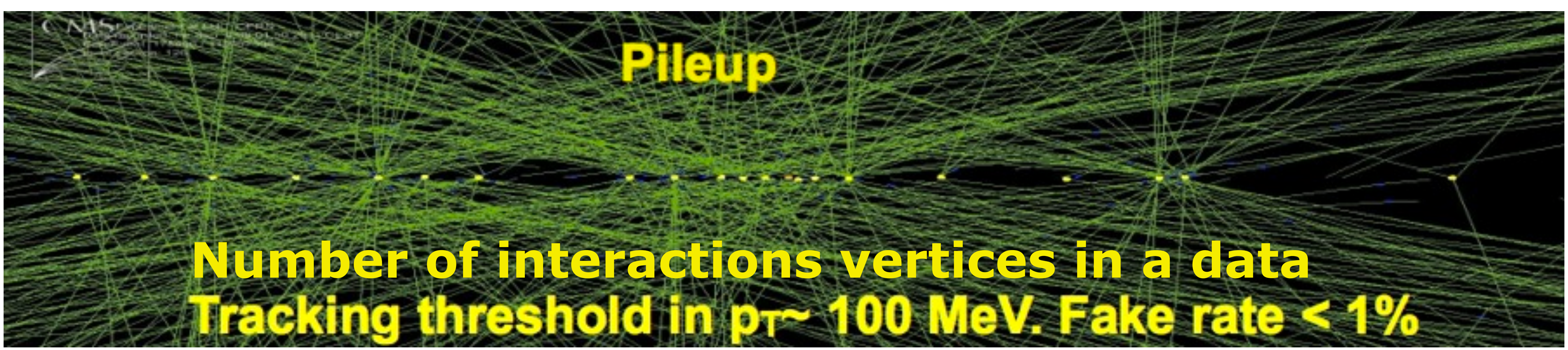
Backup Slides

Pile-up (PU)

PU a necessary complexity

- **N = σ x L x ε**
- for small **σ** better be **ε** and have a lot of **L**
- increase **L** by more **#protons/bunch**
- BUT that increases the number of in-time **#PU-interactions/event**
- Need more Lumi ? increase **#bunches/ LHC fill** (reduced bunch spacing)
- Out-of-time PU (readout voltage pulses coming from different bunch crossings)
- (OOT PU) IT PU mix different physics event with different timing properties

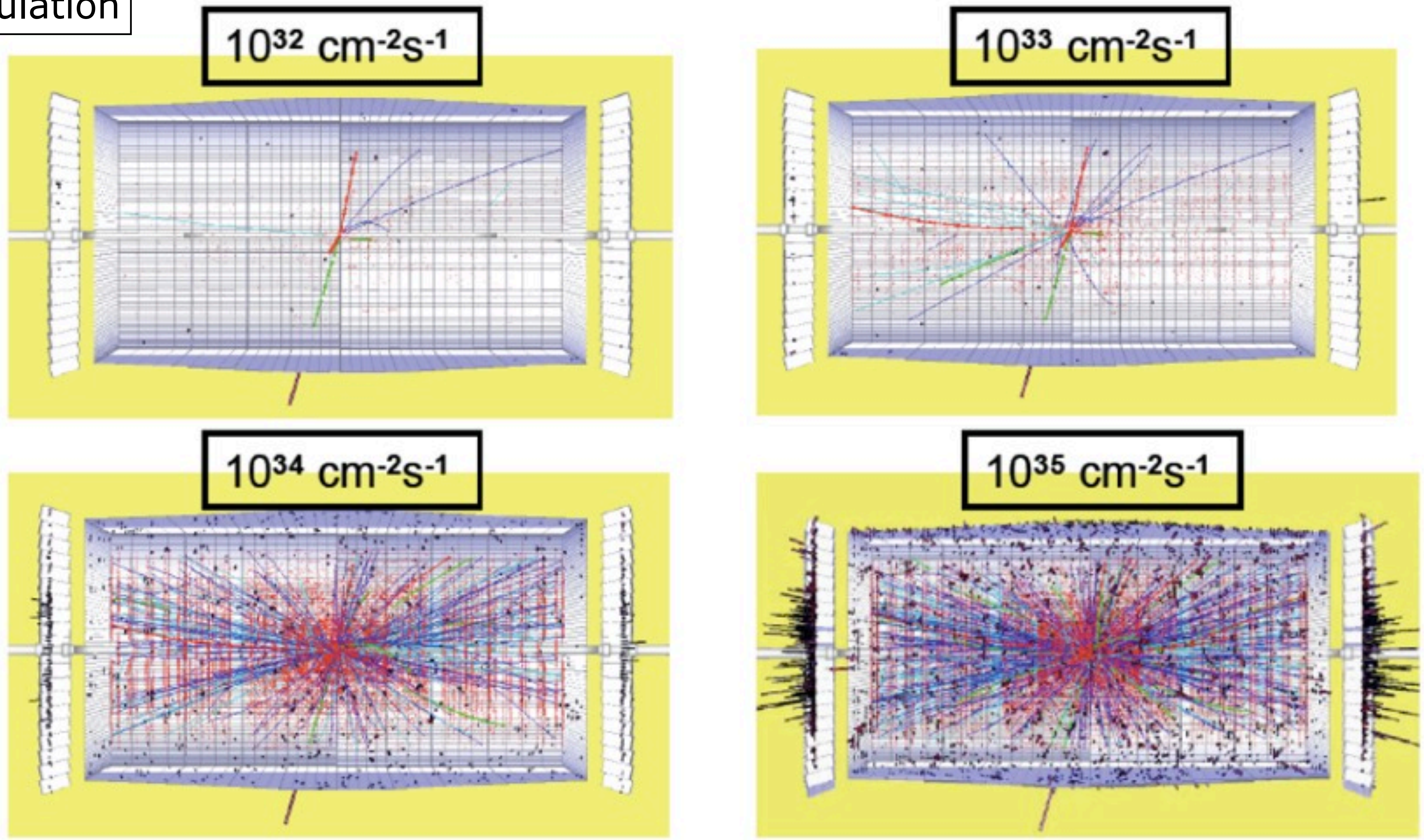




A cloud of soft mesons

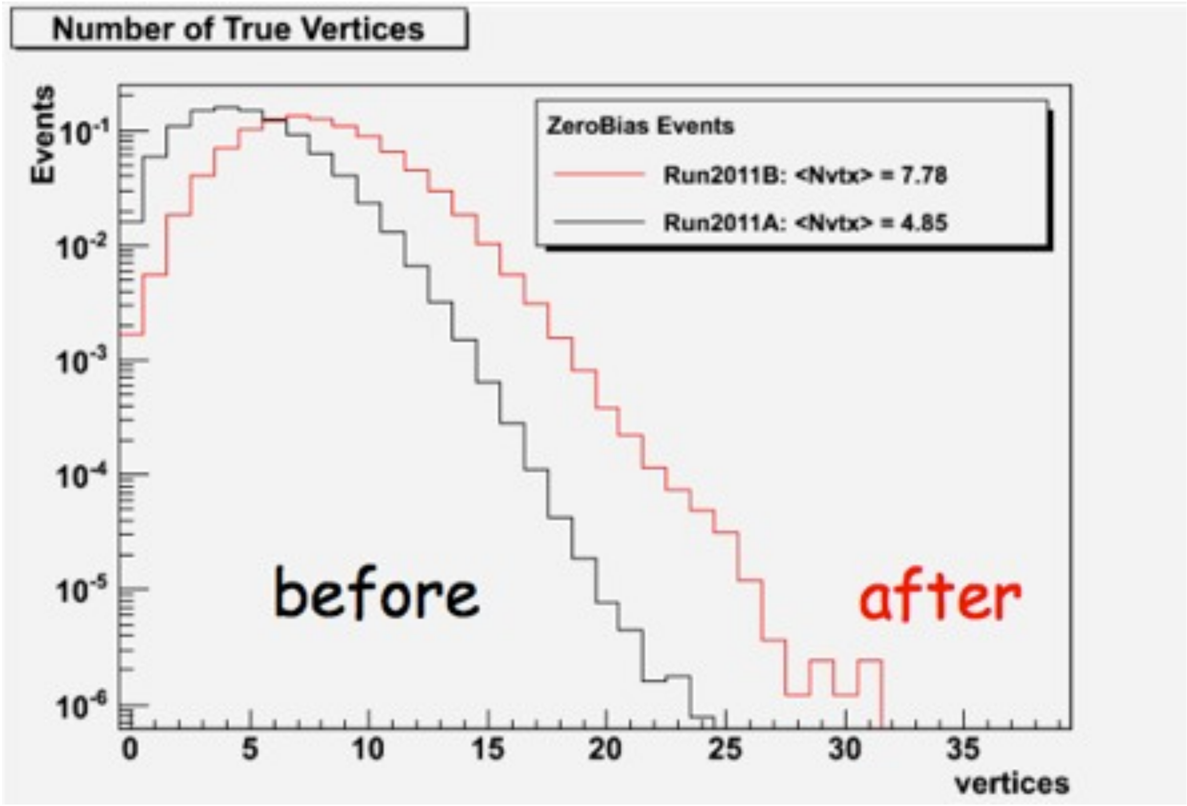
H→ZZ → μμee, M_H= 300 GeV for different luminosities in CMS

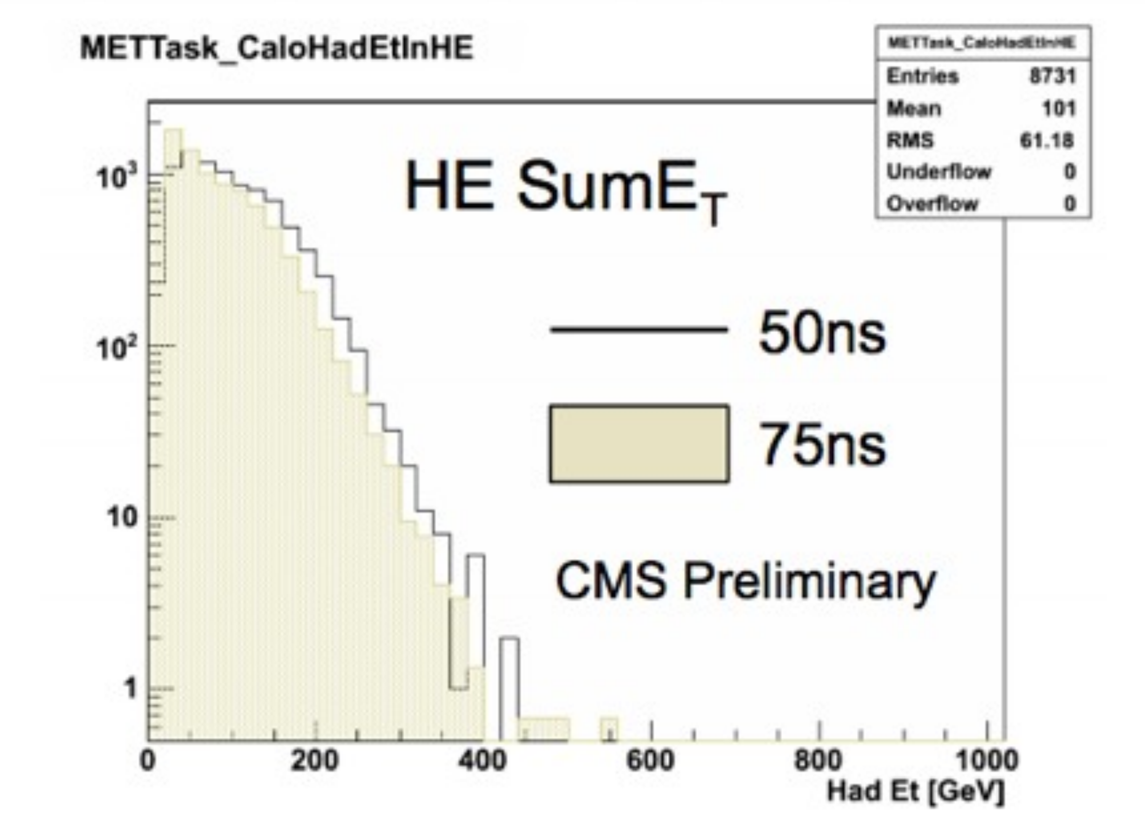
MC simulation

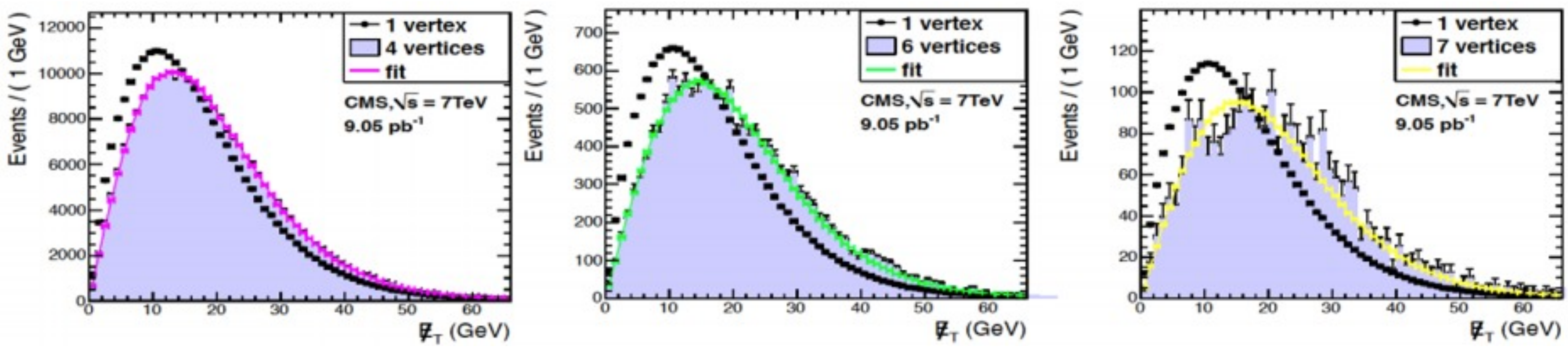


PU is not good for the event reconstruction, can kill the signal

PU and MET in 2011 DATA







remember: we want to search for NP in the tail of the MET

Collider Physics Analysis

Basic equation is simple:

- $N = (\sigma_{NP} + \sigma_{SM}) \times L \times \varepsilon$
  - ε = detector efficiency
  - L = integrated luminosity
  - σ_{SM} = Standard Model cross-section O(mb)
  - σ_{NP} = New Physics cross-section <pb

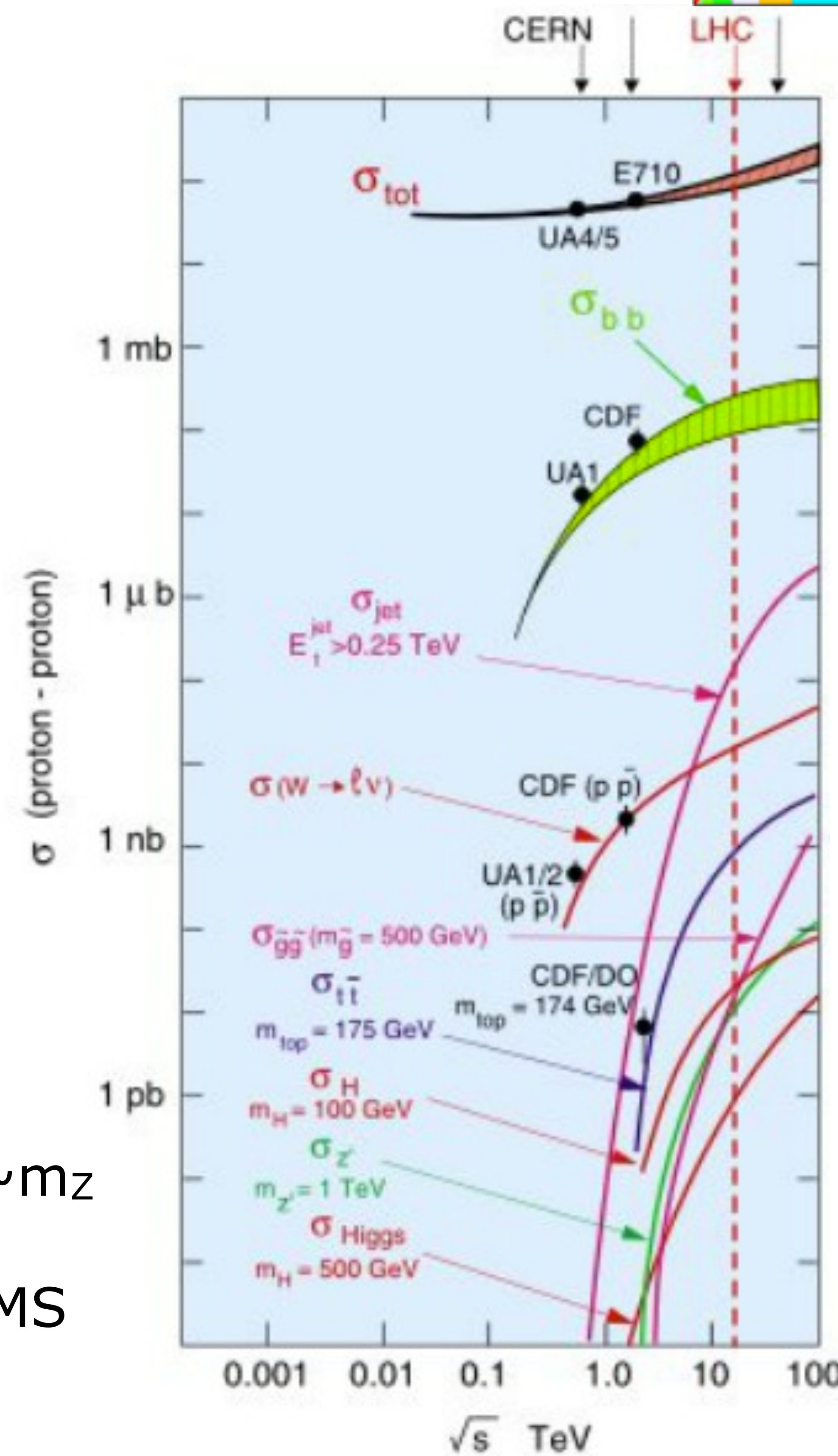
S/B ratio (S/B = σ_{NP}/σ_{SM}):

- pb/mb = 10^{-9} = 0.000000001
- but most of SM events is just a soft cloud of hadrons better not to store them on disk :-)

Need an event preselection:

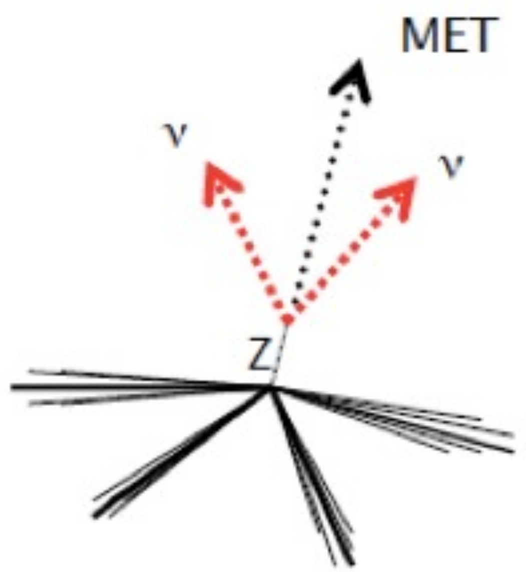
- Concentrate in corners of phase space where $O(\sigma_{NP}')\sim O(\sigma_{SM}')$ → look for high p_T events
- An example selection:
  - 3 jets (pt>30 GeV && |η|<2.4)
  - 2 leptons (pt>20 GeV && |η|<2.4) with mll~m_Z
  - MET> 300 GeV

We recorded 0 such events in the whole 2011 CMS dataset → placed a limit on the σ_{NP}'



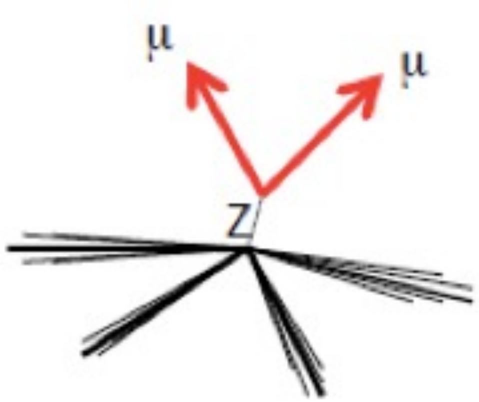
Example:Z→vv from DATA

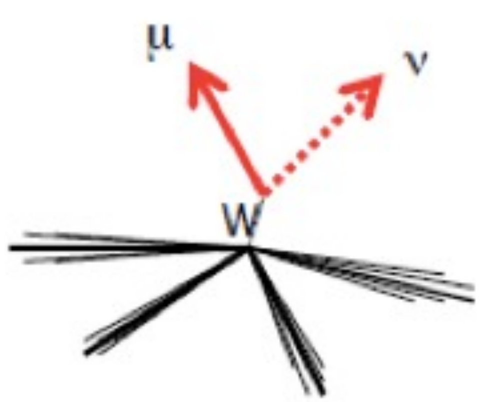
SUS-11-004
and references within

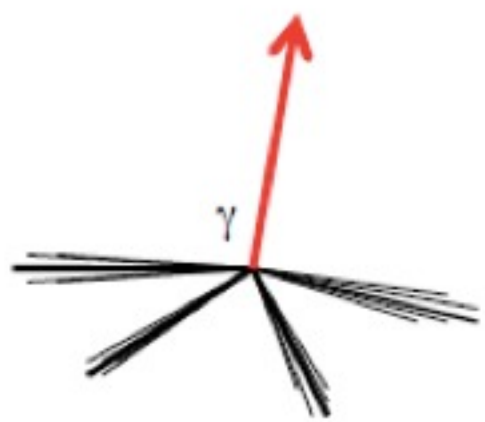


Z→vv + jets is irreducible
background for hadronic SUSY
Jets + MET inclusive search

control samples for data-driven analysis?







Z→μμ + jets
MET′ = $p_T(\mu\mu)$
best but not enough

W→μv + jets
MET′ = $p_T(\mu)$+ MET
not so clean

gamma + jets
MET′ = p_T(gamma)
R(Z/gamma) ?