Highlights from CMS

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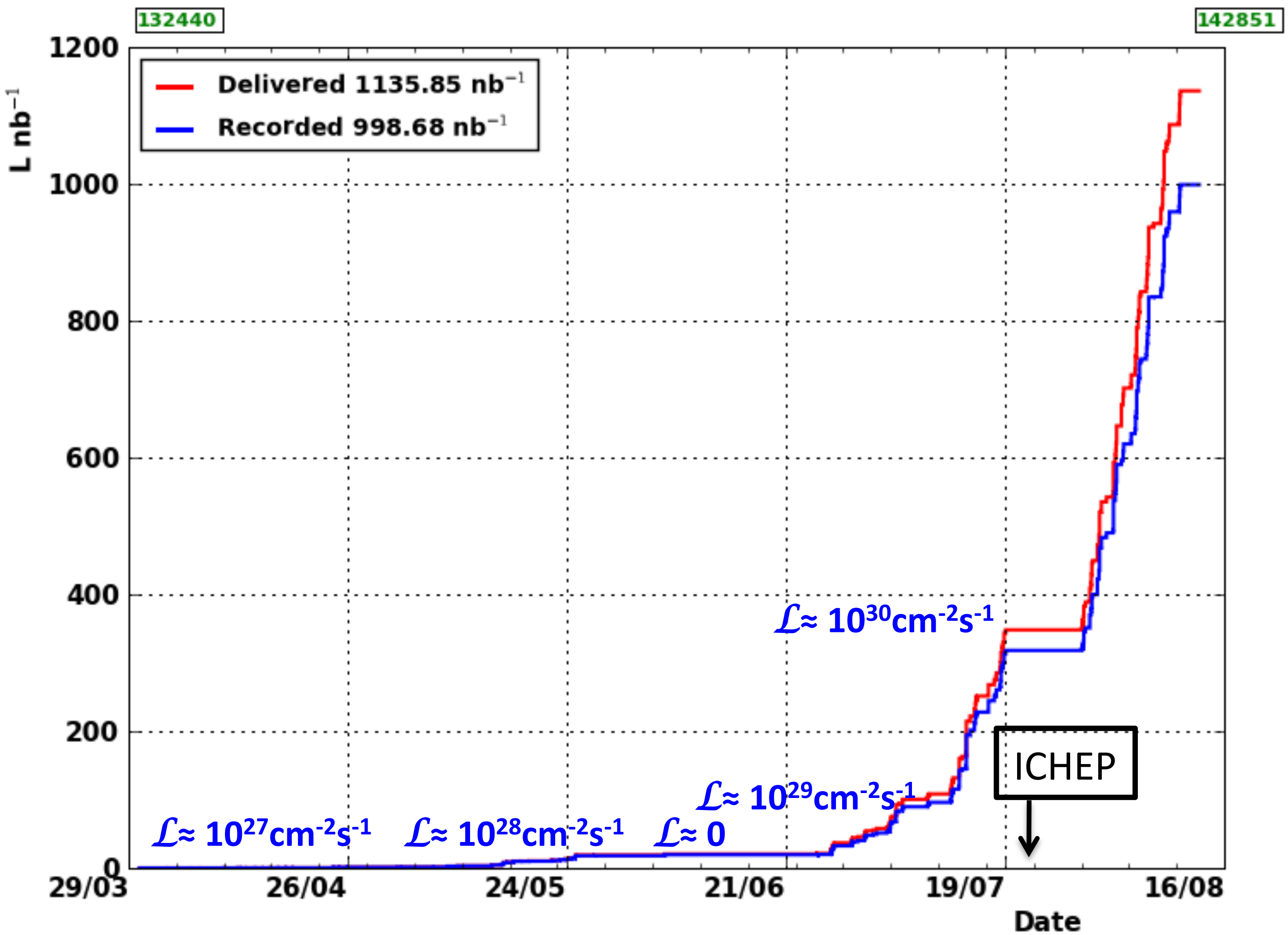
Outline

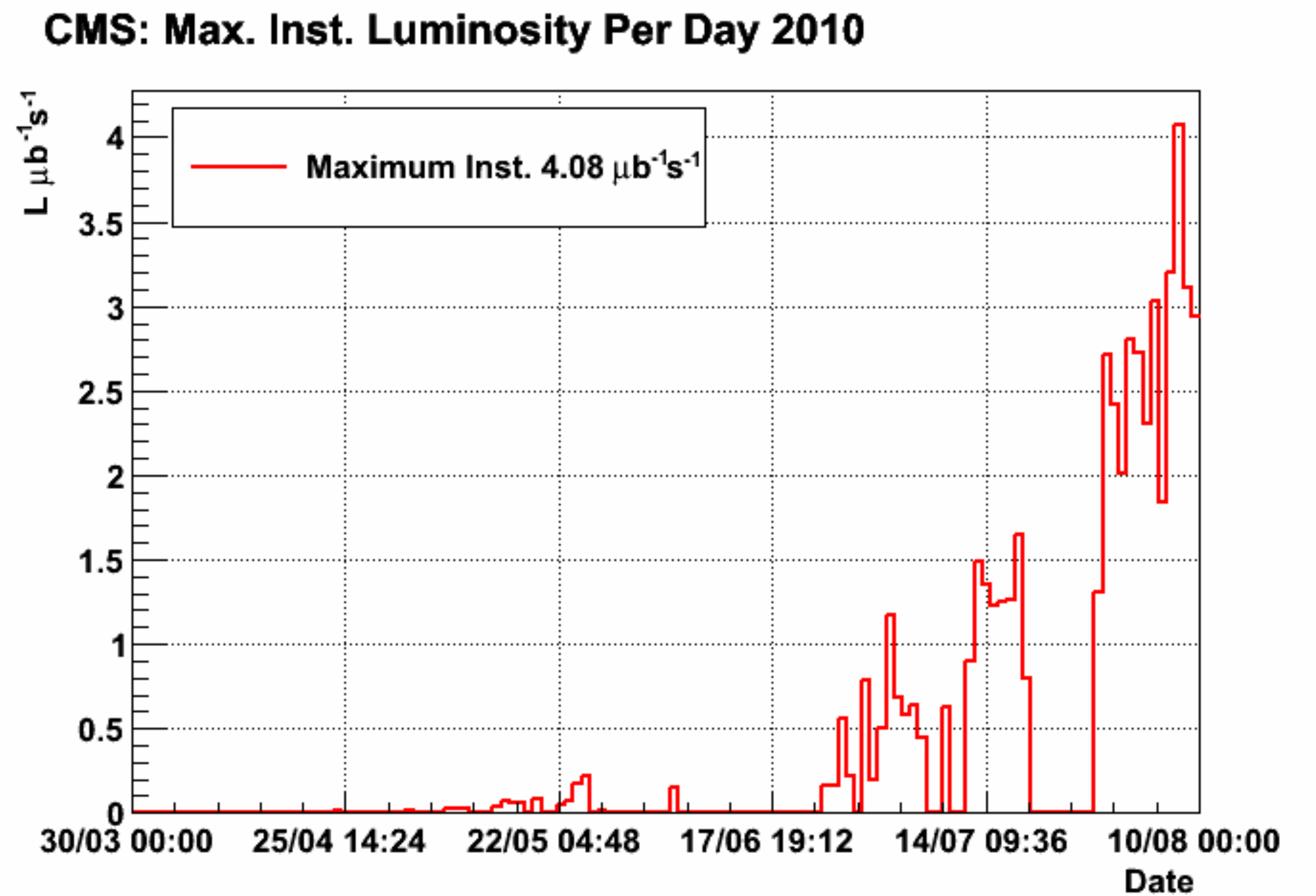
- LHC operation
- Selected results from ICHEP
  - High Level Detector Performance
  - Some early physics results
  - Early studies focussed towards preparations for searches

LHC Operation

- The LHC delivered a few weeks of collisions at 900 GeV in November/December 2009. (A few days at 2.34 TeV also) Then it shut down for the holidays.
- 7 TeV operations since March 30
  - Not continous, interspersed with machine studies
  - Started out at very low luminosity
  - now a few 10^{30} $cm^{-2}sec^{-1}$



132440
142851
Delivered 1135.85 nb⁻¹
Recorded 998.68 nb⁻¹
L nb⁻¹
1200
1000
800
600
400
200
0
29/03
26/04
24/05
21/06
19/07
16/08
Date
$\mathcal{L} \approx 10^{27} cm^{-2}s^{-1}$
$\mathcal{L} \approx 10^{28} cm^{-2}s^{-1}$
$\mathcal{L} \approx 0$
$\mathcal{L} \approx 10^{29} cm^{-2}s^{-1}$
$\mathcal{L} \approx 10^{30} cm^{-2}s^{-1}$
ICHEP



CMS: Max. Inst. Luminosity Per Day 2010
Maximum Inst. 4.08 μb-1s-1
L μb-1s-1
4
3.5
3
2.5
2
1.5
1
0.5
0
30/03 00:00
25/04 14:24
22/05 04:48
17/06 19:12
14/07 09:36
10/08 00:00
Date

Short term Objectives

Integrated luminosity of $\geq 1 fb^{-1}$ by the end of 2011

- requires a peak luminosity of $\geq 1x10^{32}$ $cm^{-2}s^{-1}$ during 2011
- → must reach ~1 $x10^{32}$ $cm^{-2}s^{-1}$ during 2010

Steve Meyers @ ICHEP

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- The results shown here are a selection of the results presented by CMS at the ICHEP conference in Paris (July 21-28)
  - 28 talks
  - (about) 35 public “Physics Analysis Notes”
    - sort of like papers
- Based on up to 0.28 pb^{-1}. (~ 0.19 pb^{-1} taken the week before ICHEP!!)

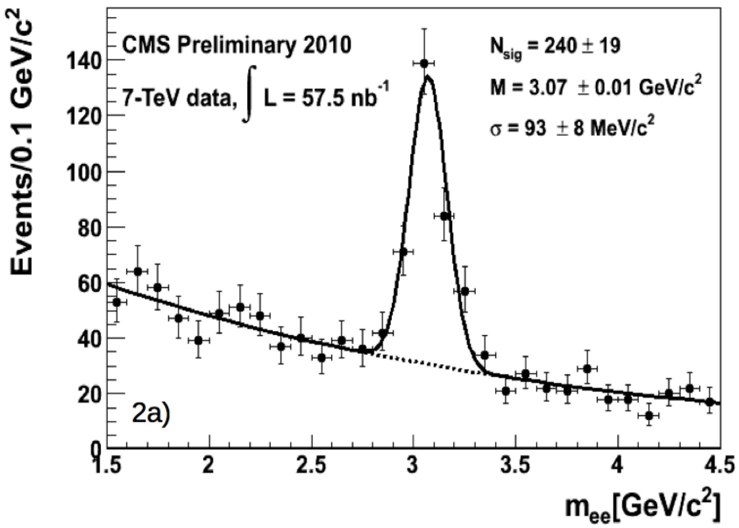
Outline

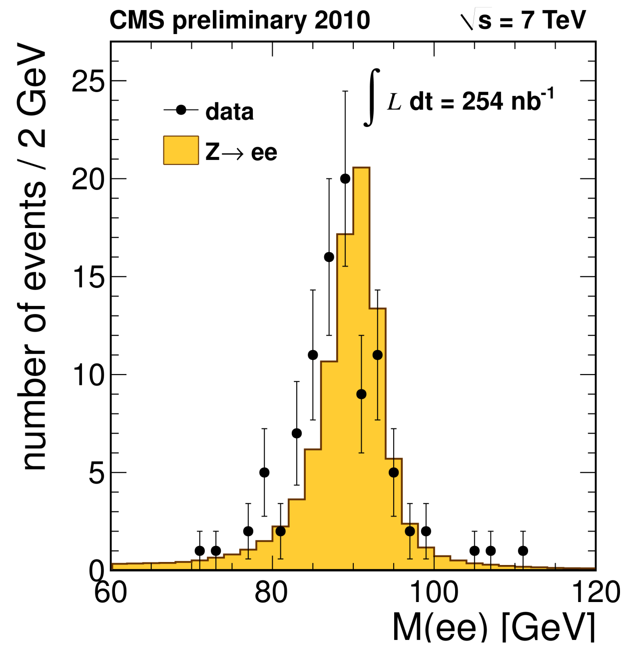
- LHC operation
- Selected results from ICHEP
  - High Level Detector Performance
  - Some early physics results
  - Early studies focussed towards preparations for searches

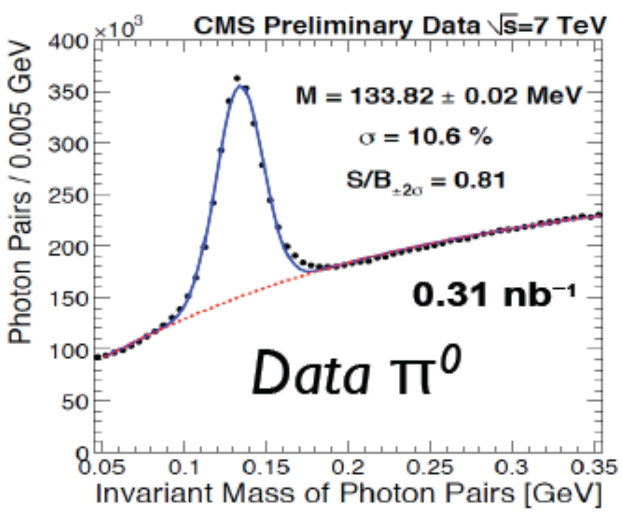
High Level Detector (Object) Performance

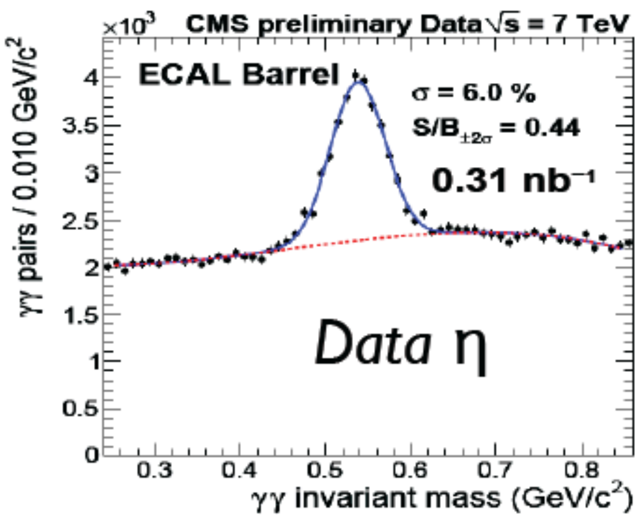
- To do physics at the LHC we need to use
  - Electrons
  - Muons
  - Jets
  - Missing Energy
  - Photons
  - B-jet identification
  - Taus
- Now a quick review of how these are working
- The bottom line: they are working extremely well. The level of understanding is in all cases impressive for a new detector. The understanding is often demonstrated by showing agreement with Monte Carlo simulation (of the detector, and in some cases also the underlying physics process)

Electron/photons….some nice peaks…

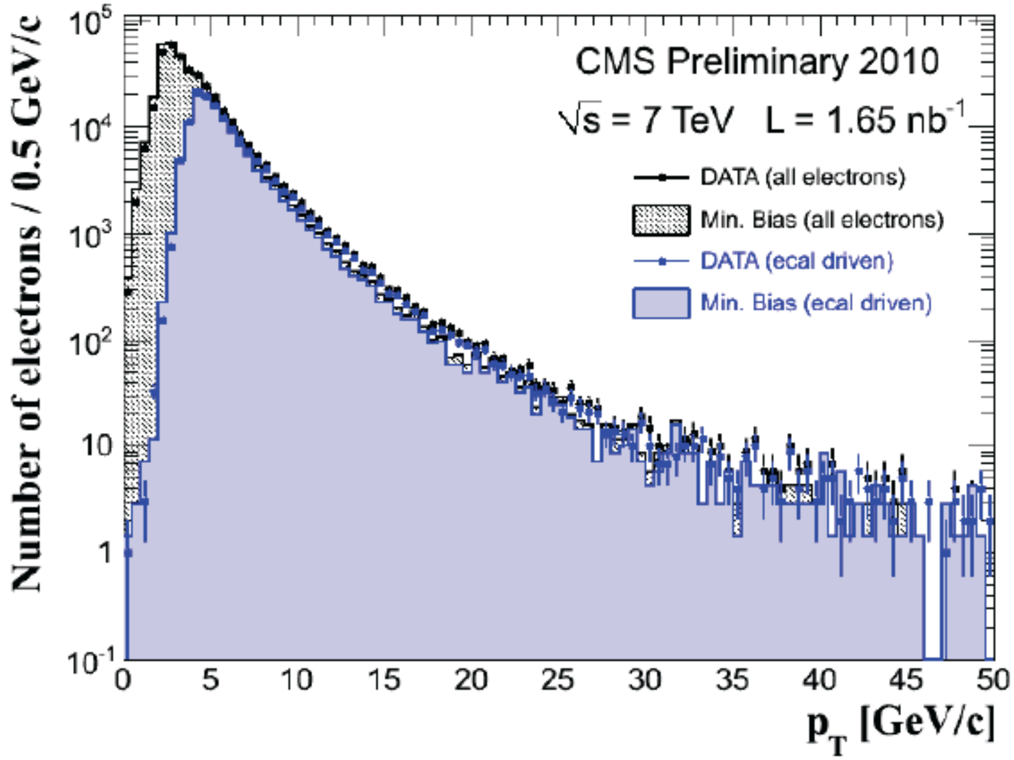








….but how is it "under the hood"?



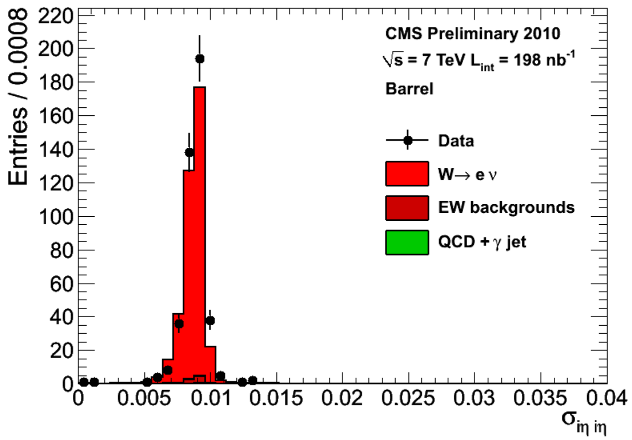
At this stage the inclusive sample of **electron candidates** is composed from
4.6% real electrons (mainly Ds/Bs decays, few J/Ψ)
33.9% gamma conversion
61.5% fakes from hadrons

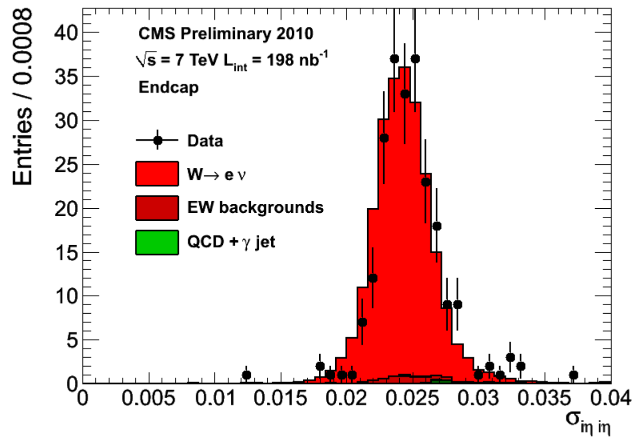
We understand reasonably well even the rate and properties of "junk" electrons…..

…moving away from junk….

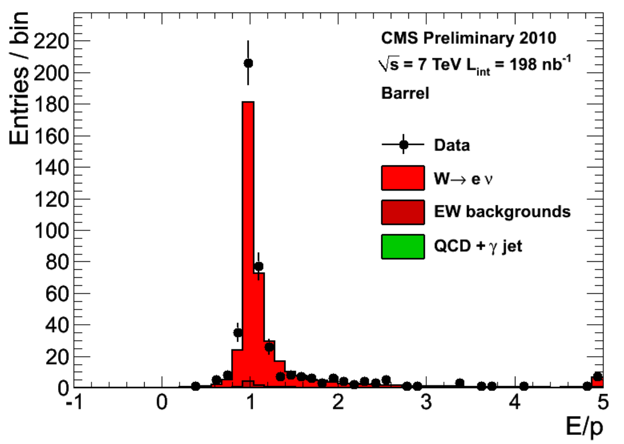
Select events with one EM cluster, missing energy, and not much else. This gives a clean $W \rightarrow e\nu$ sample. See if we understand the electron ID variables….

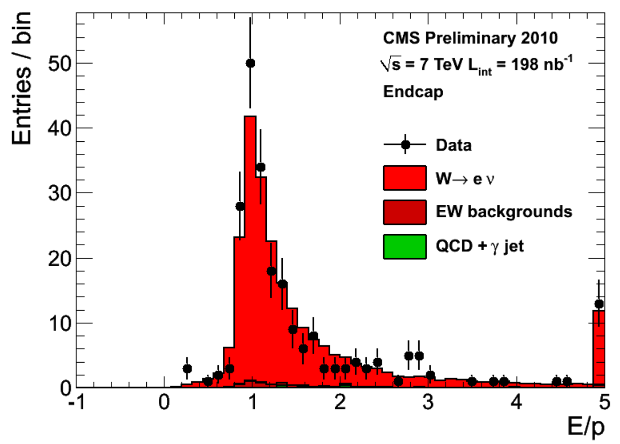
BARREL | ENDCAP



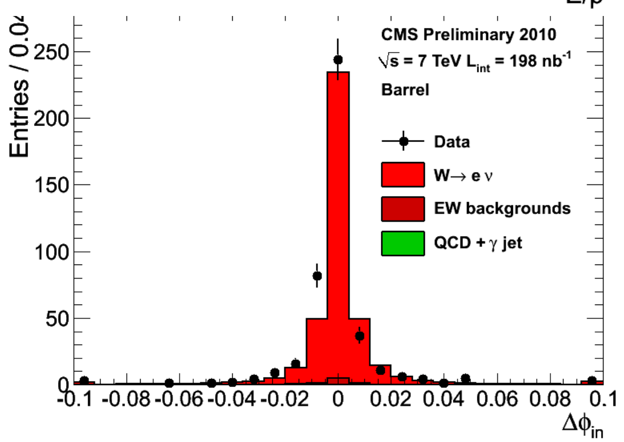


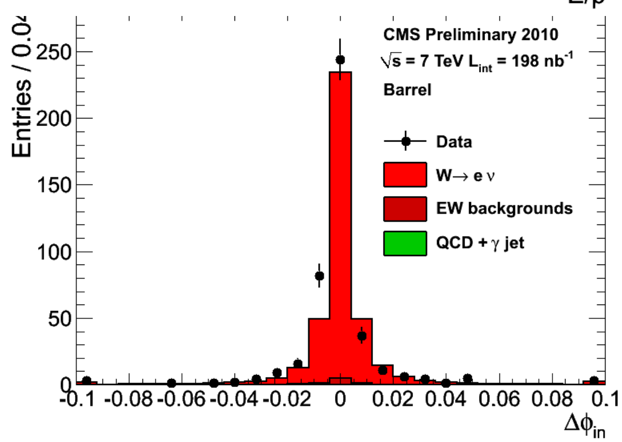
Size of the cluster in η





E/P = Energy measured in The ECAL divided by momentum measured in the tracker





Φ of the track at the calorimeter face minus Φ of the cluster

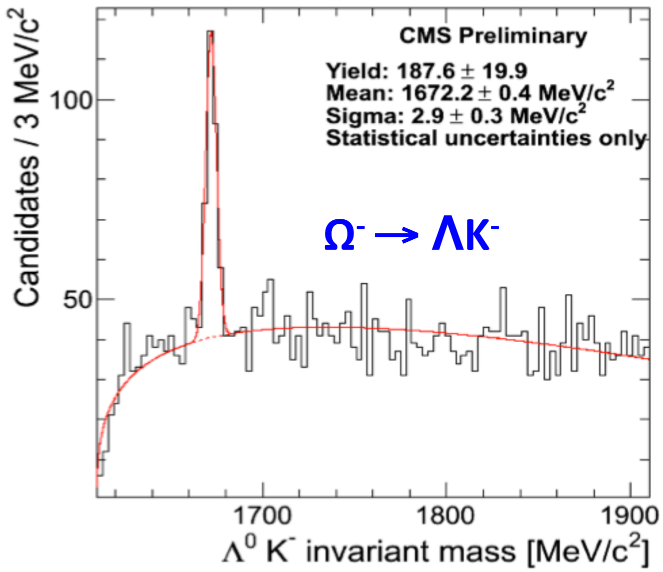
Bottom line: measure efficiency of electron identifications using Z sample, compare with MC

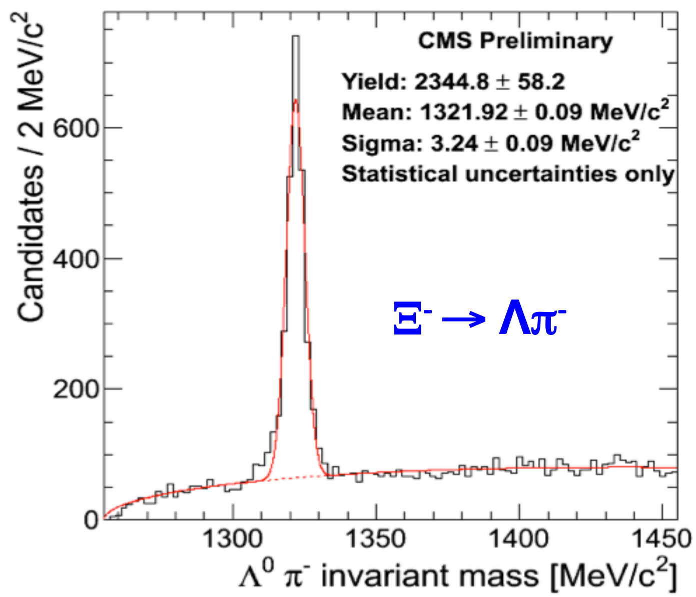
different operating points
(tradeoffs of efficiency vs BG rejection)

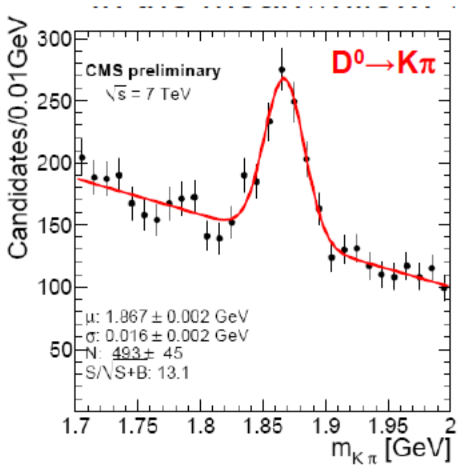
Z Tag & Probe	Measured efficiency	Error (stat. + syst)	MC efficiency
WP95 Barrel	92.5%	3.2%	95.4%
WP95 Endcap	86.4%	6.7%	92.9%
WP80 Barrel	77.5%	4.7%	85.1%
WP80 Endcap	75.1%	8.6%	76.2%
Cic Loose Barrel	96.4%	2.1%	97.0%
Cic Loose Endcap	94.1%	4.7%	95.3%
Cic Tight Barrel	89.3%	3.4%	89.3%
Cic Tight Endcap	85.5%	6.5%	79.4%

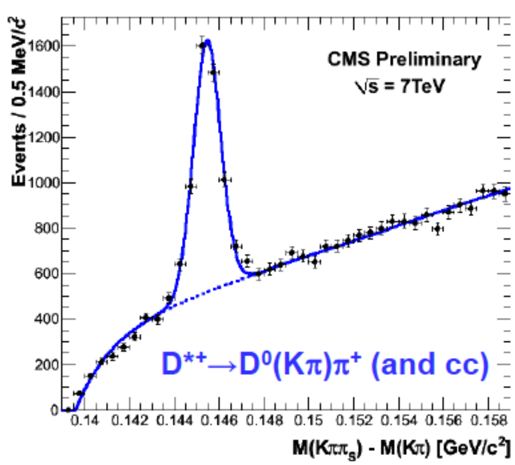
Tracking

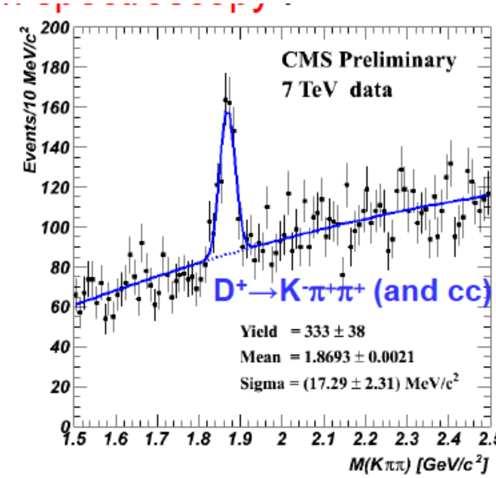
Resonances seen as soon as machine turned on





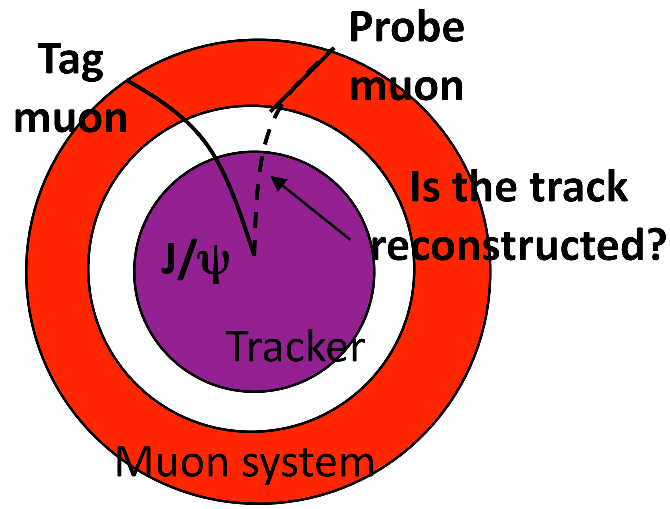




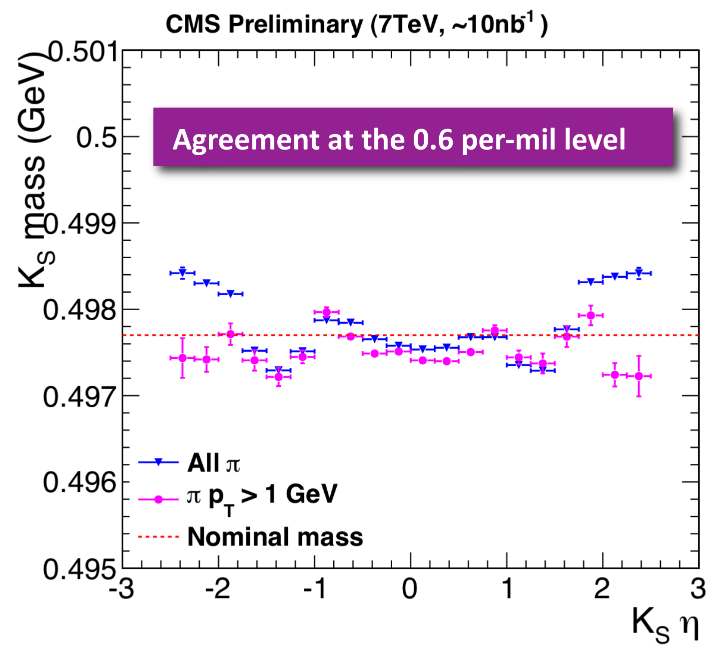


But let’s see how the nitty gritty is working….

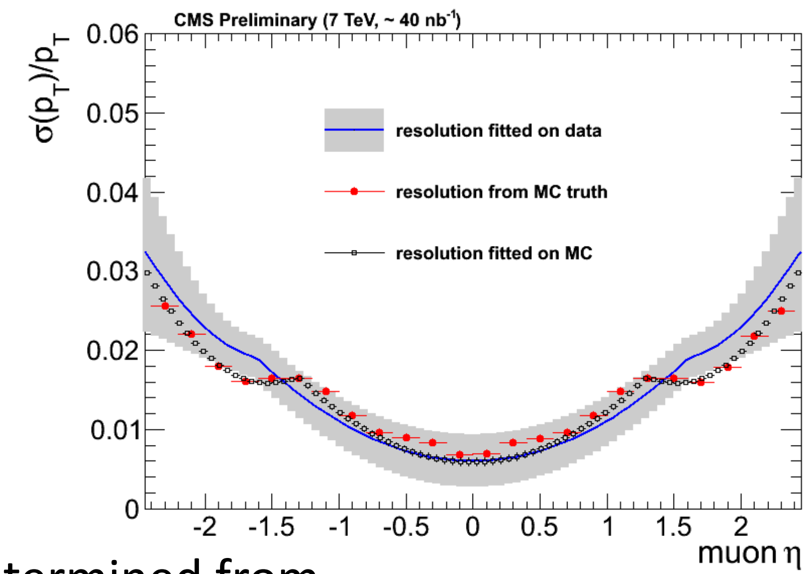
- Tracking efficiency from J/Psi→μμ reconstructed with one muon that does not use tracker is 99%



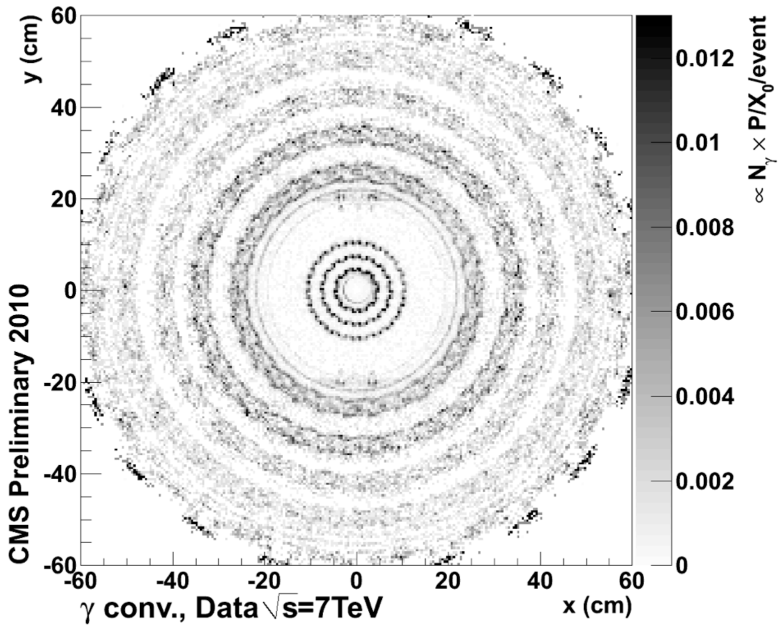
- Momentum scale tested with resonances, eg, $K_S \rightarrow \pi\pi$

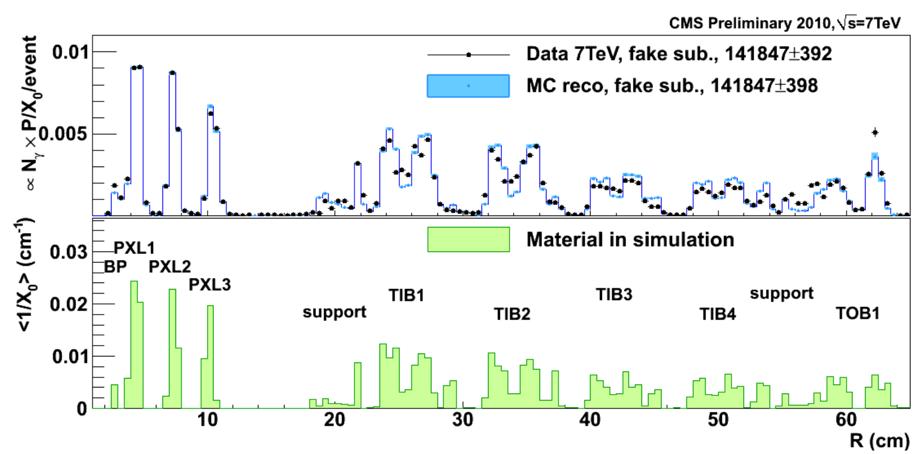


- Momentum resolution extracted from width of J/ψ peak. It is as expected

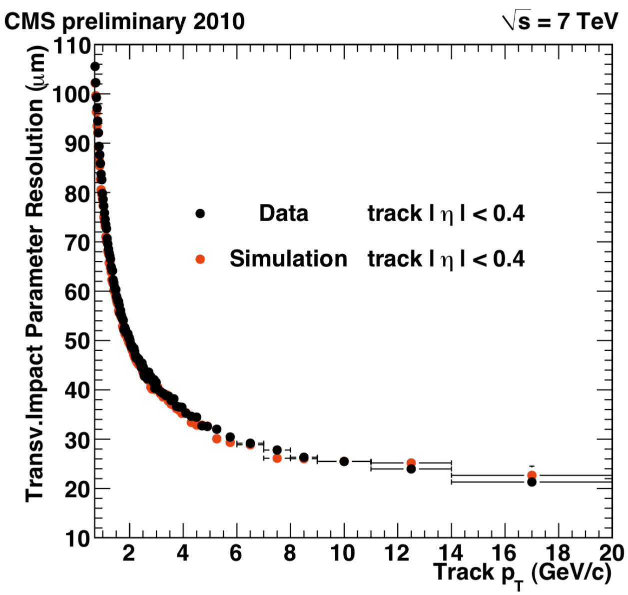


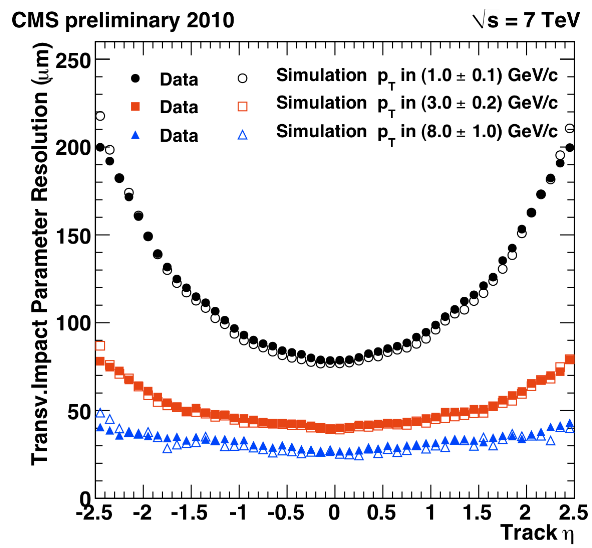
- Distribution of material in the tracker determined from reconstructed photon conversions. It is as expected

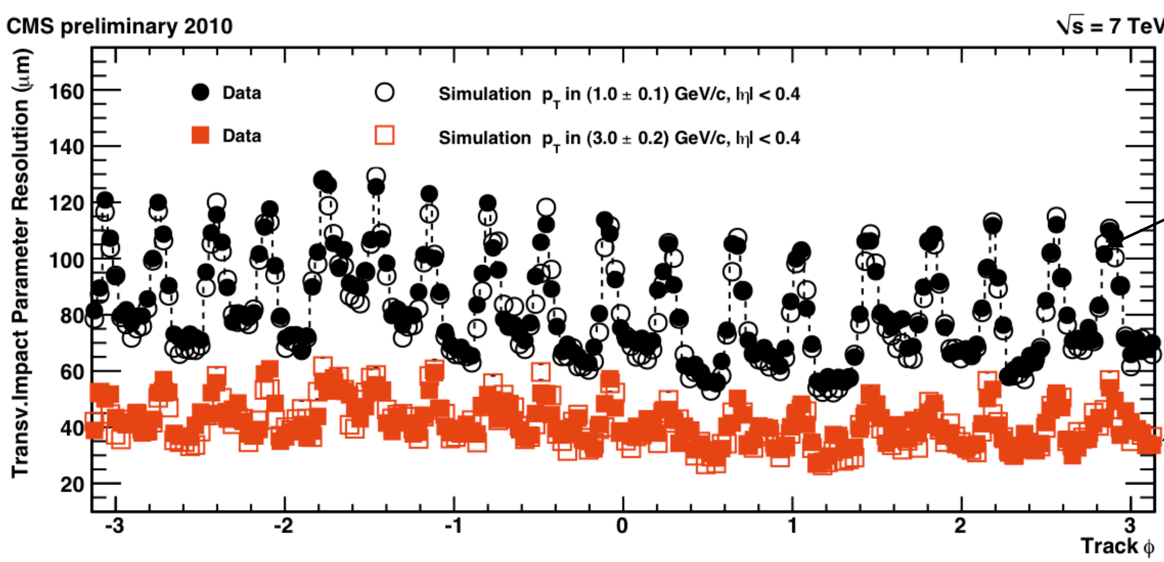




Impact parameter (distance of closest approach to interaction point)





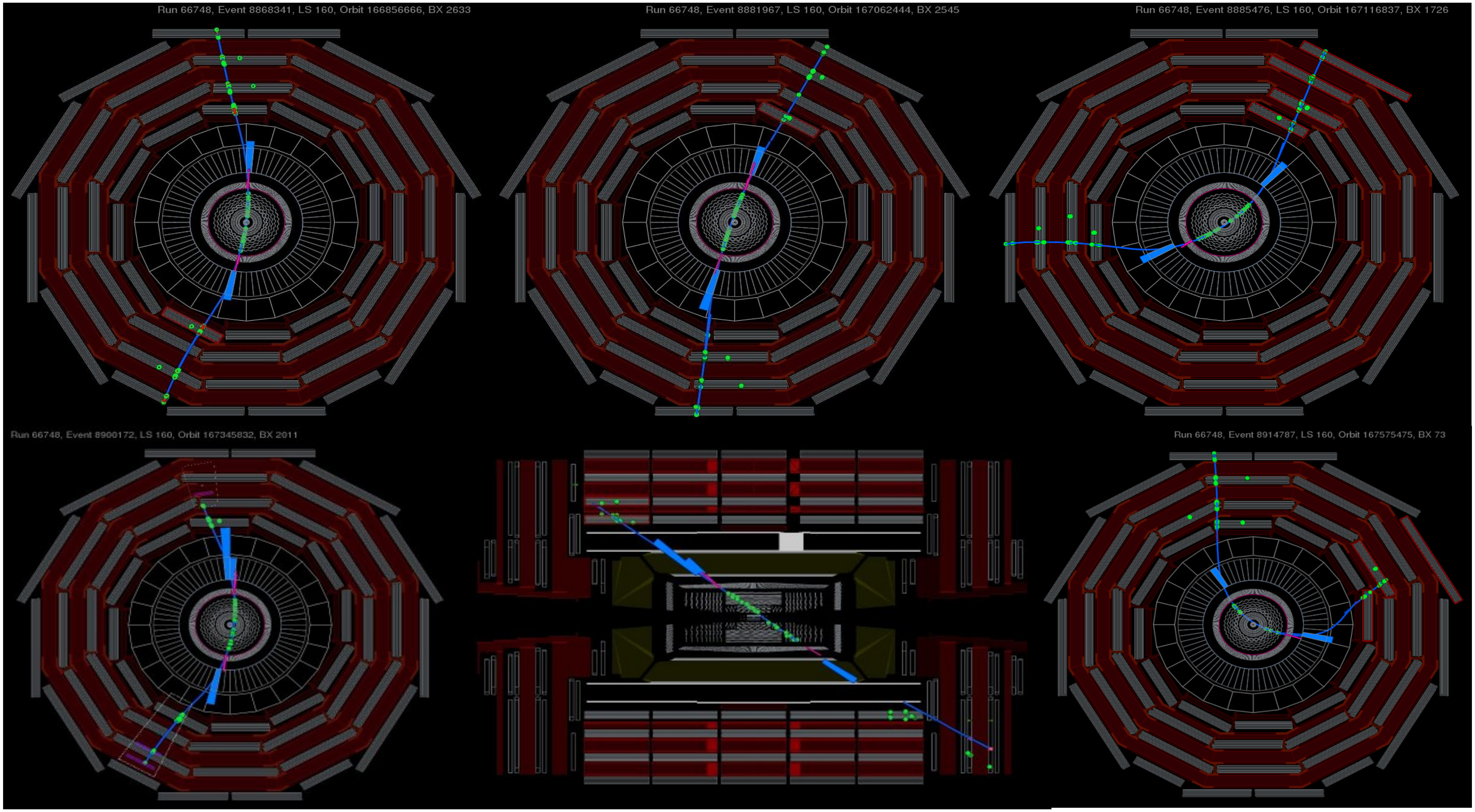


p_T=1 GeV tracks

p_T=3 GeV tracks

The 18 peaks in the resolution correspond to the 18 cooling pipes on the innermost detecting layer of the pixel system.

Muons



Before collisions: more than 1 billion cosmic muon events where recorded…..
So it is perhaps not surprising that muons work pretty well….

Contents lists available at ScienceDirect

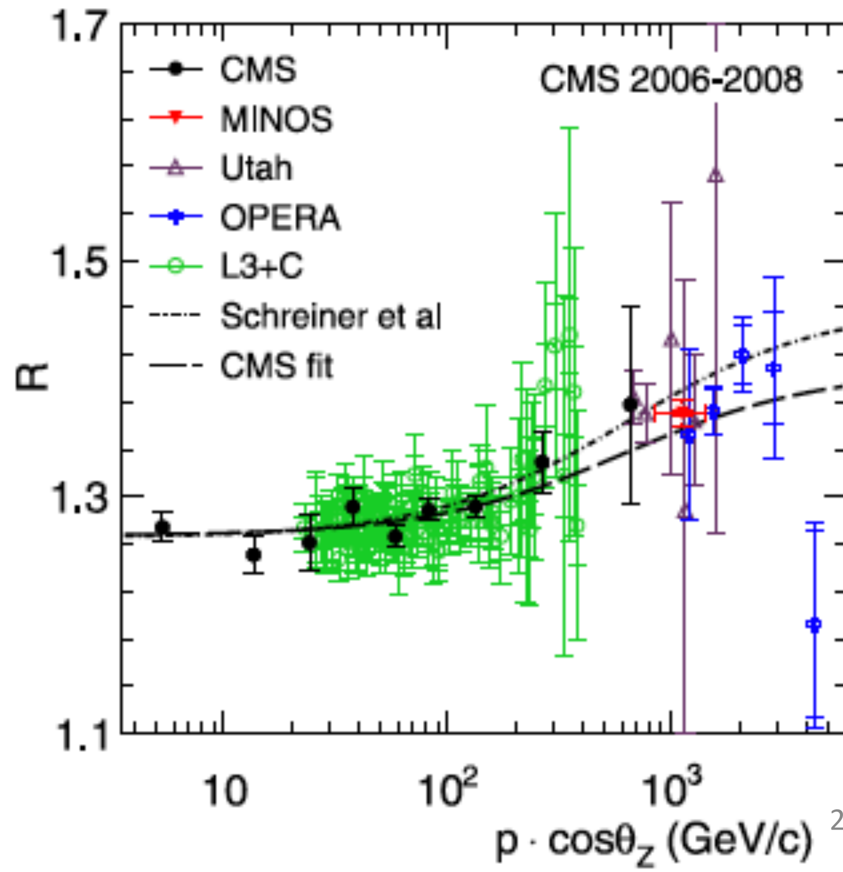
Physics Letters B

www.elsevier.com/locate/physletb

Measurement of the charge ratio of atmospheric muons with the CMS detector ☆,☆☆

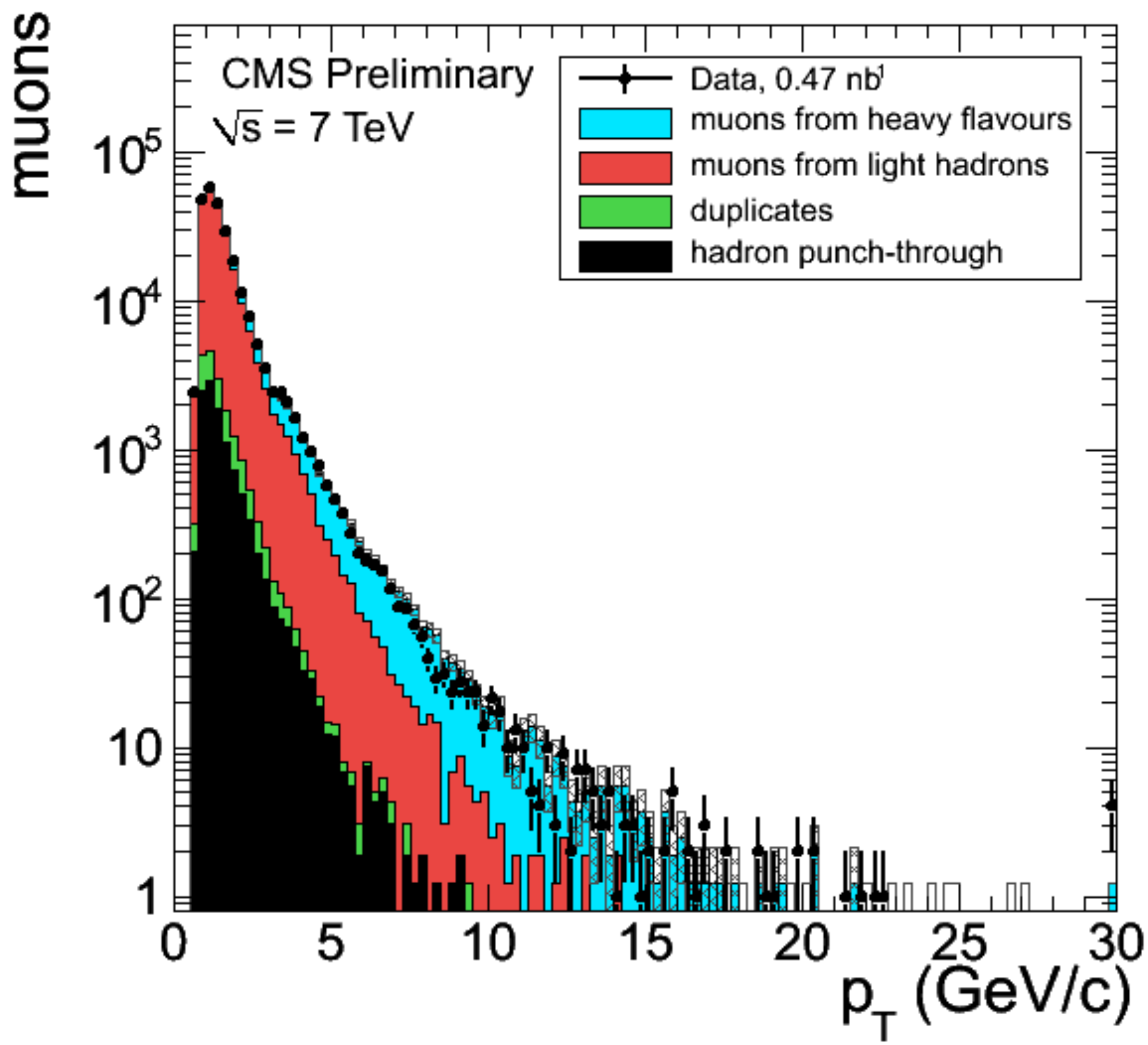
CMS Collaboration *

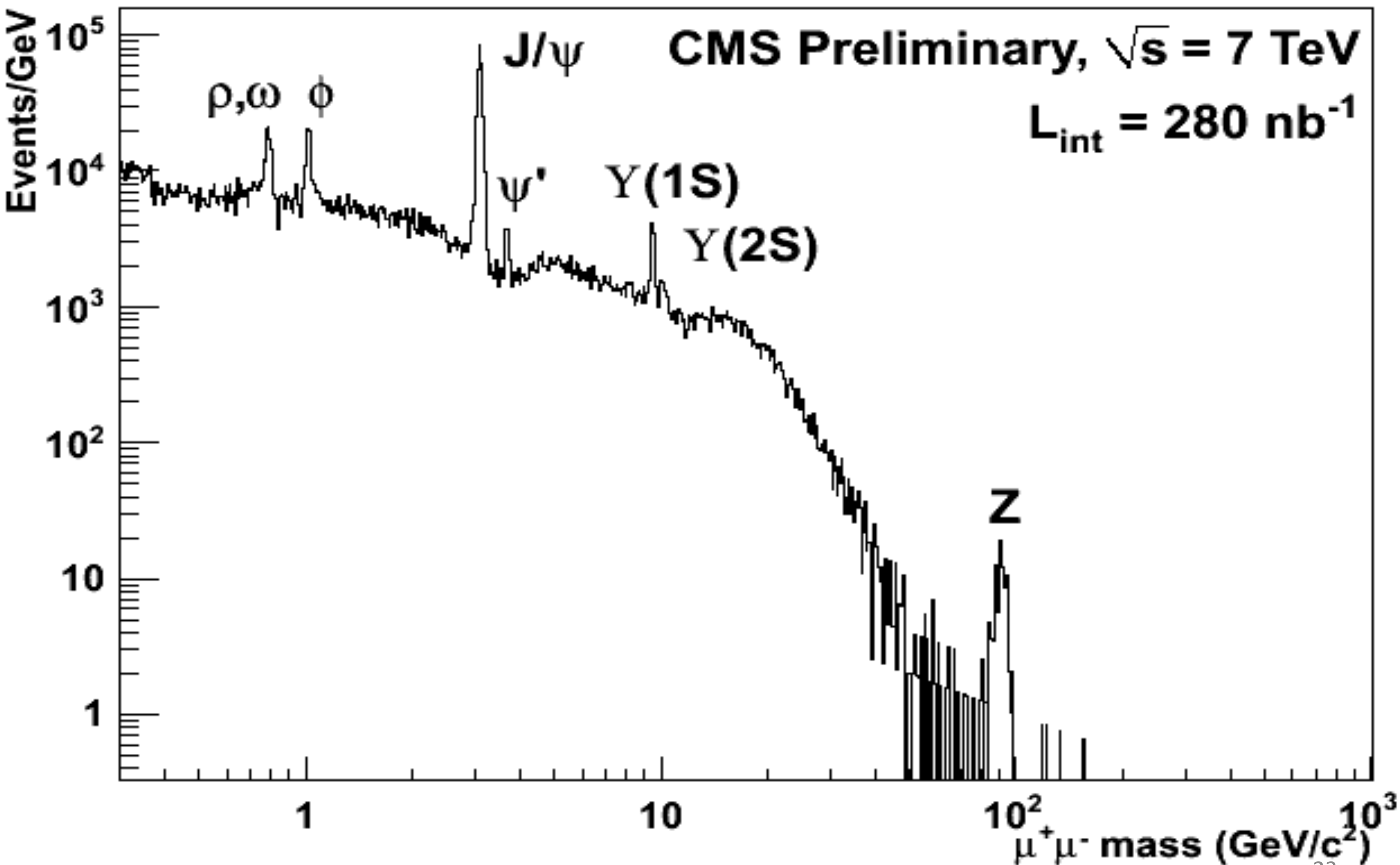
CERN, Switzerland



I bet you did not know that CMS has been doing cosmic ray physics…..

Muons are reconstructed down to very low transverse momentum (~ 1 GeV).
The rate and composition is well understood

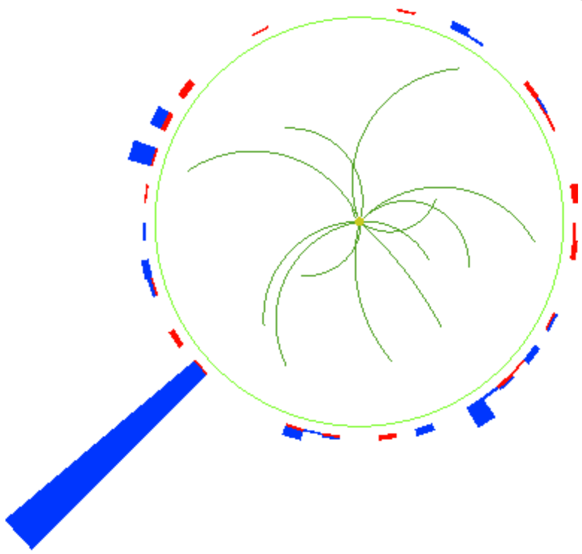


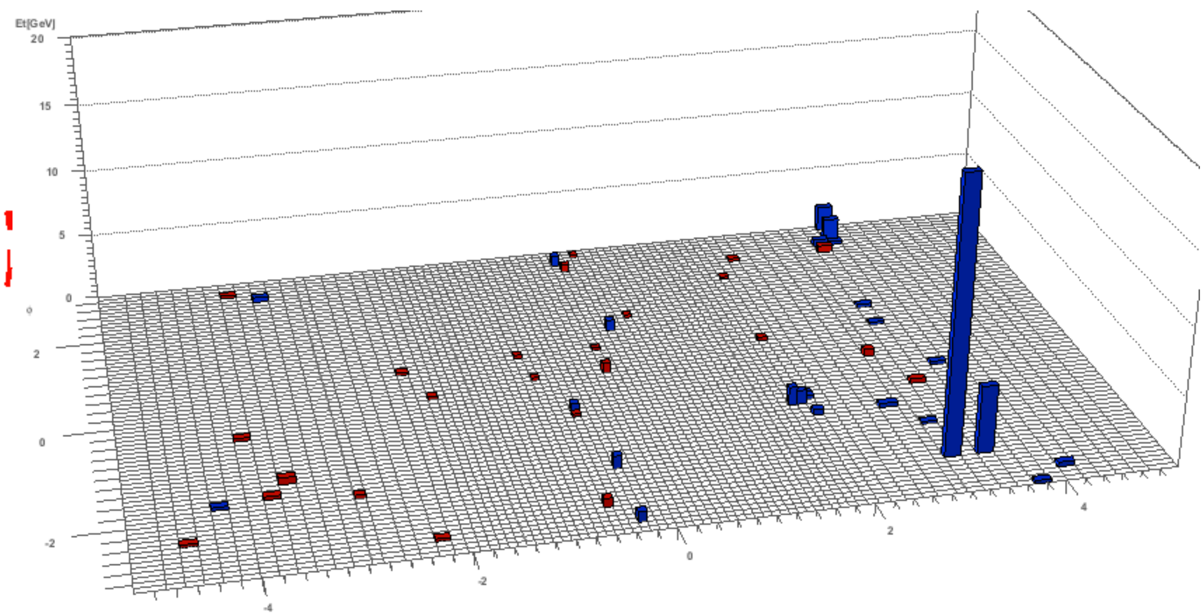

CMS Preliminary, √s = 7 TeV
L_int = 280 nb^-1
Events/GeV
ρ,ω
φ
J/ψ
ψ'
Υ(1S)
Υ(2S)
Z
μ+μ- mass (GeV/c2)
1
10
10^2
10^3
10^4
10^5

Missing Energy

- It is often said: missing energy is delicate, takes a long time to commission, a long time to eliminate all the spurious detector contributions

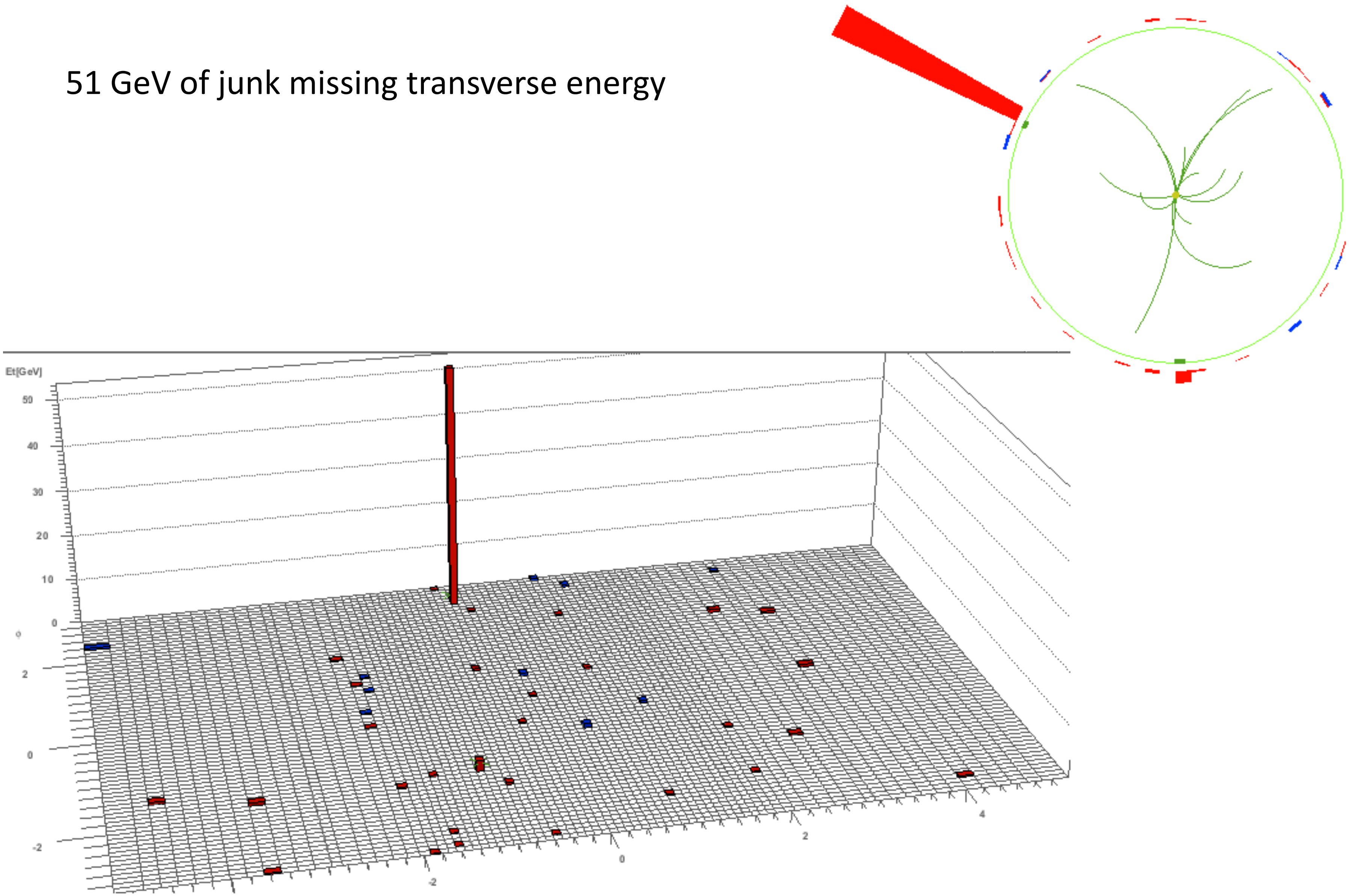
Do we have detector pathologies? Sure!





16 GeV of junk missing transverse energy

51 GeV of junk missing transverse energy

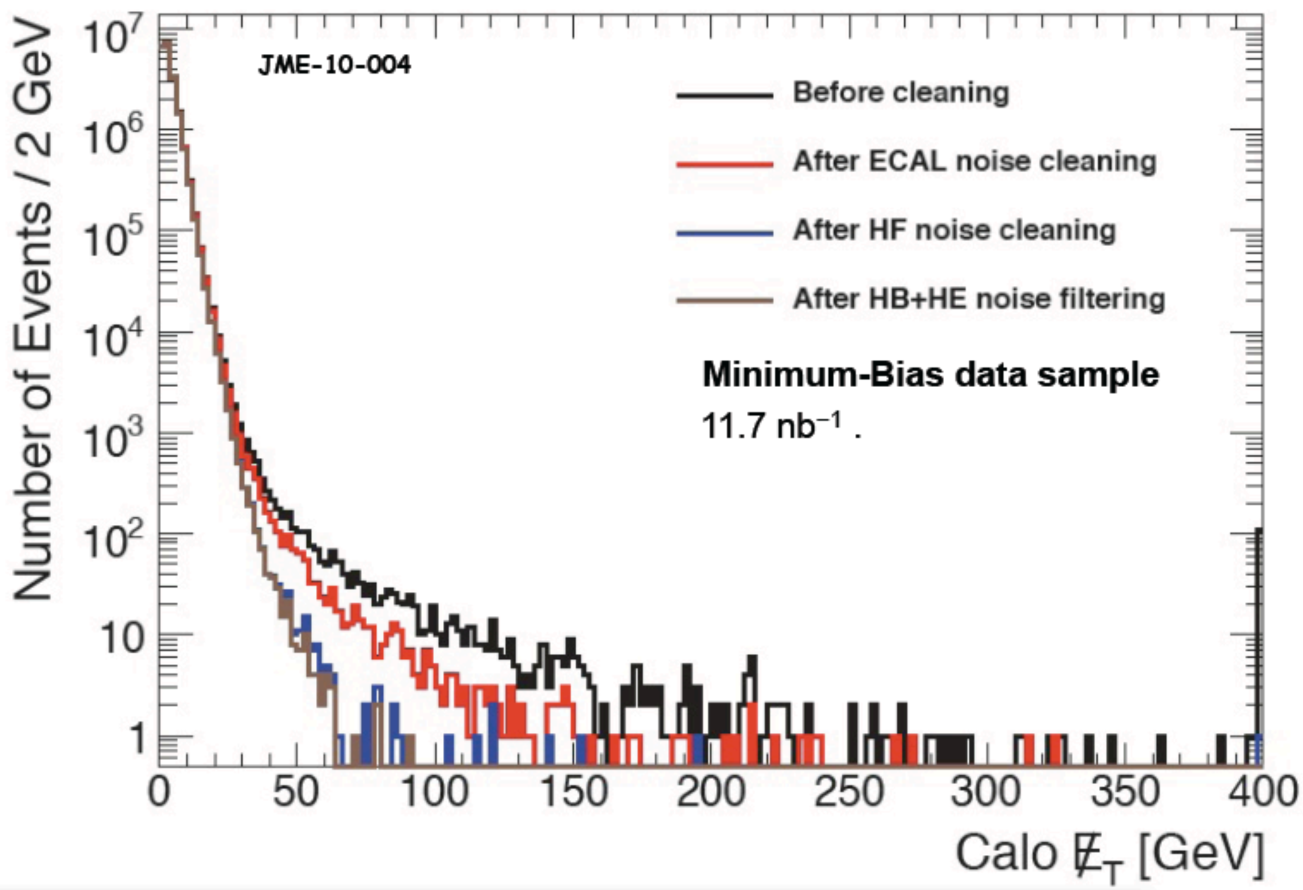


Things like this happen at the 1e-4 level

....so, we clean up the mess.....

Basic cleaning strategy: identify anomalous signals based on :

- Unphysical charge sharing of neighboring channels
- Timing/pulse shape information



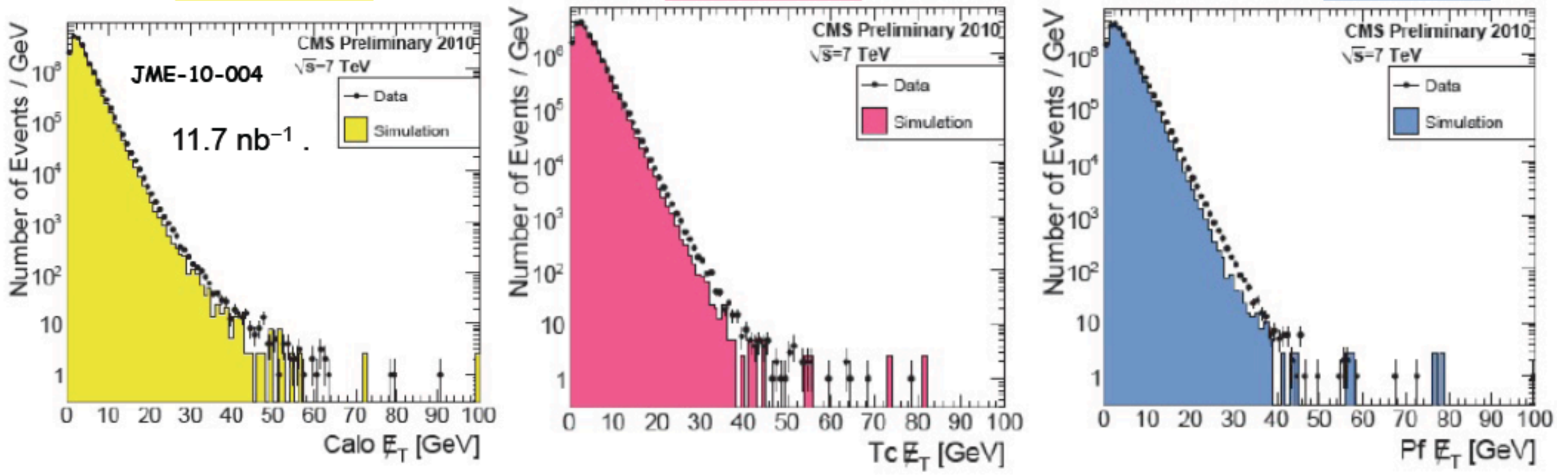
Missing Transverse Energy (MET)

Three algorithms

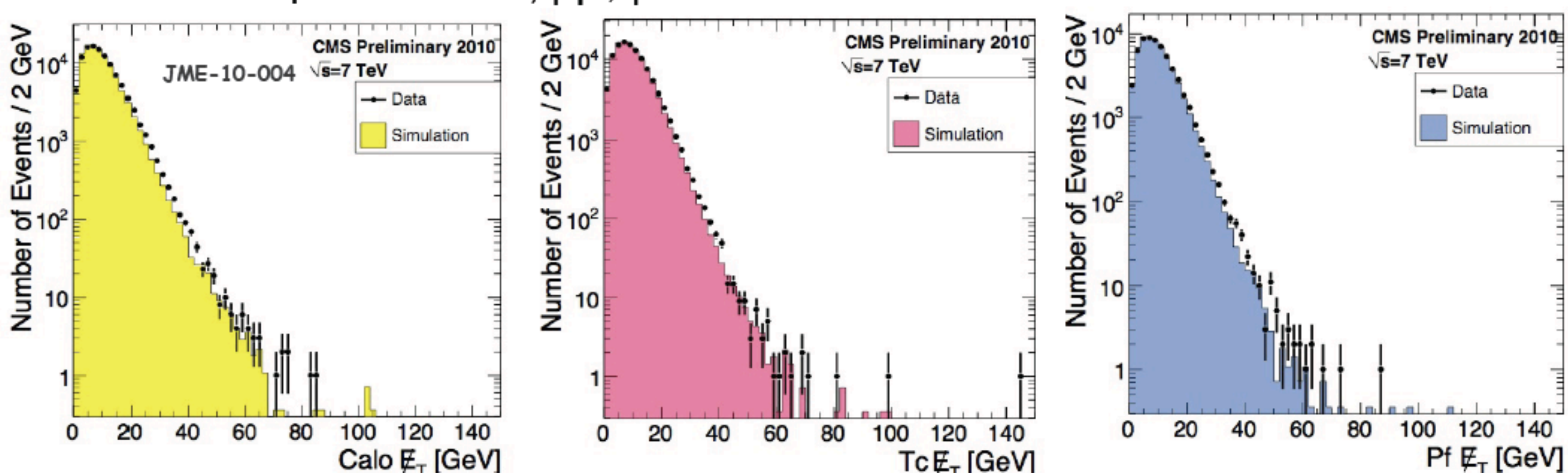
1. CaloMET: use calorimeter only
   – Simple, tried and true method. Not so good.
2. tcMET: use tracks to correct calo information in an average way
   – A bit more sophisticated. Much better
3. pfMET: “particle flow”, associate tracks to calo depositions, try to reconstruct individual particles
   – Much more sophisticated. Even better

How do does it work?

Minimum Bias: Calo MET | tc MET | PF MET



Dijet events with corr. $p_T^{1,2}$>25 GeV, $|\eta_{1,2}|$<3:



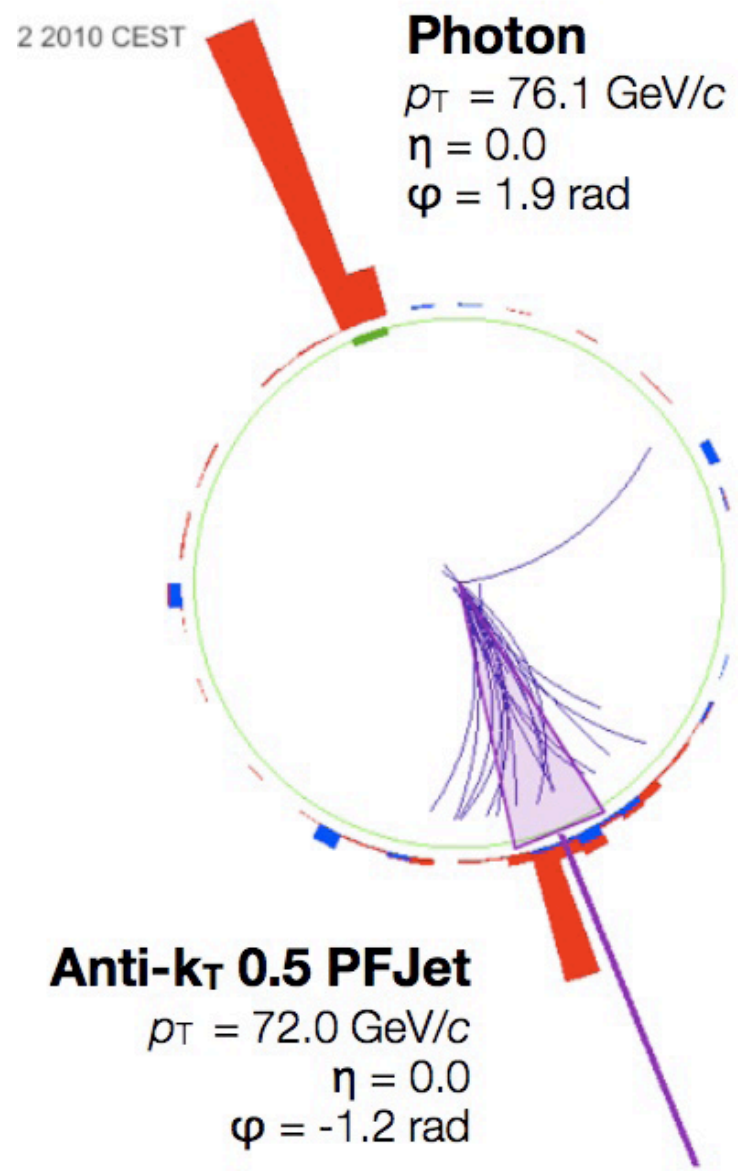
Ready to be used for physics

Jets

- A spray of ~ collimated particles from the fragmentation of a parton (quark or gluon)
- The direction and energy of the jet is related to the direction and energy of the original parton (which is what we care about)
- Two important issues
  - Energy scale
  - Resolution

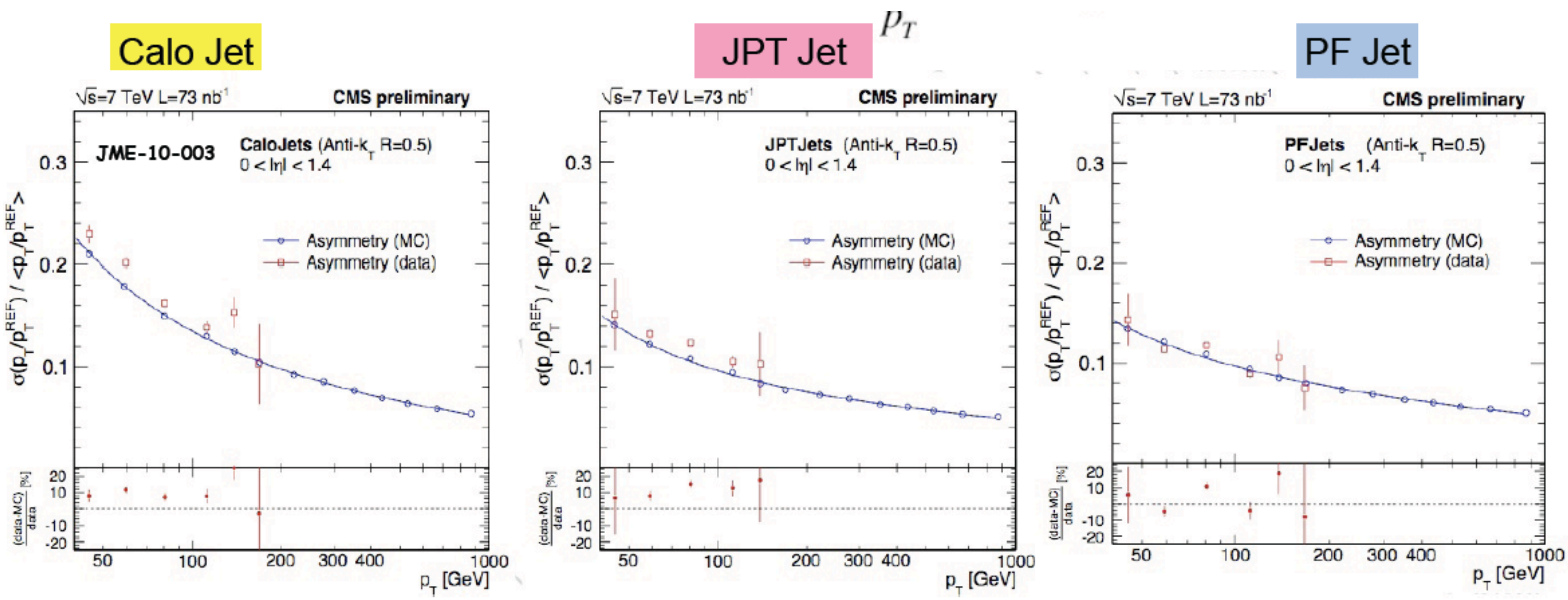
Energy Scale

- Estimated to be good to ~ 5-10% from understanding of detector response to single particles
- Verified by studying photon+jet events
- Will improve….



Resolution

- Take pp→j1 j2 events.
- In a perfect world the PT of j1 and j2 are the same.
- In reality they are not. From the PT unbalance, extract the PT resolution.   It is as expected.

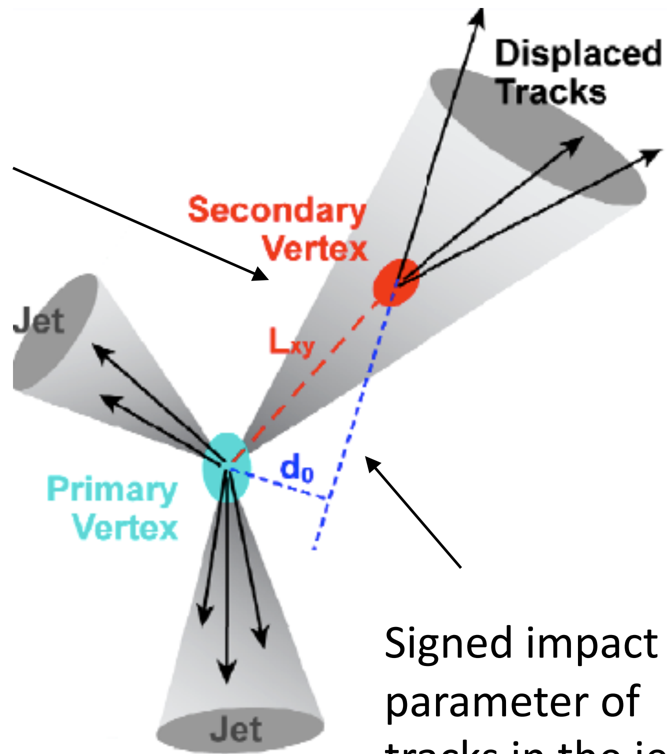


Resolutions are understood

B-tagging

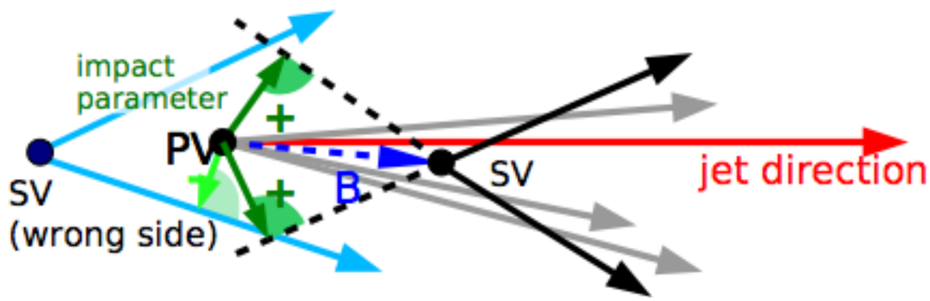
Main observables used to identify jets from b-quarks:

Signed decay length of secondary vertexes

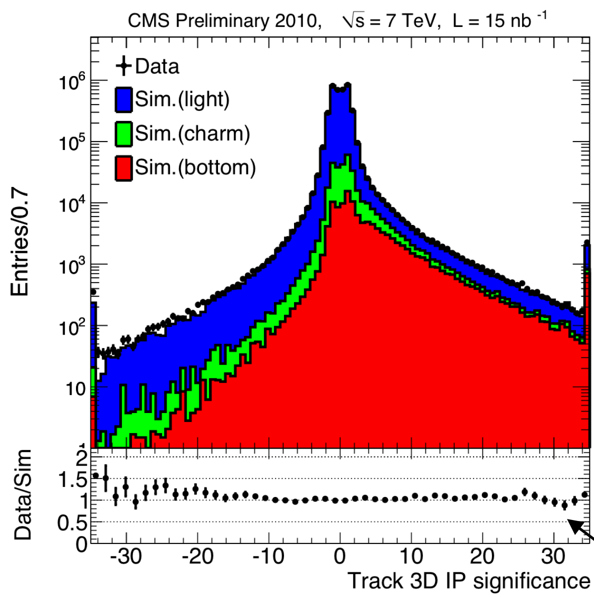


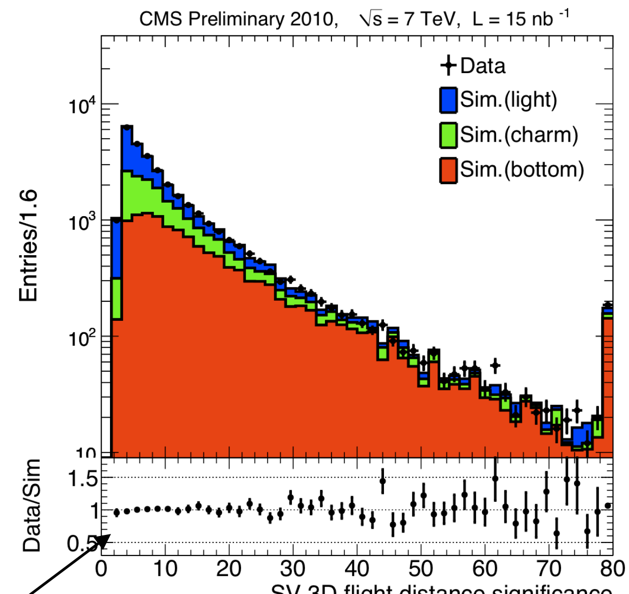
Signed impact parameter of tracks in the jet

Signs of Impact parameter and of vertex decay length are defined according to jet direction

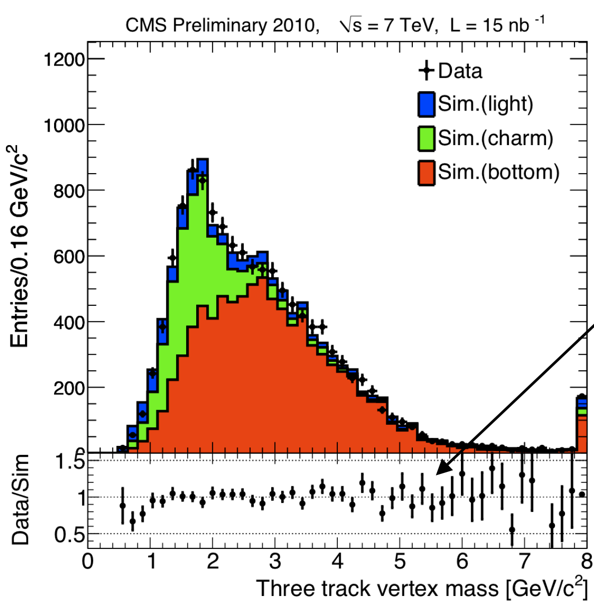


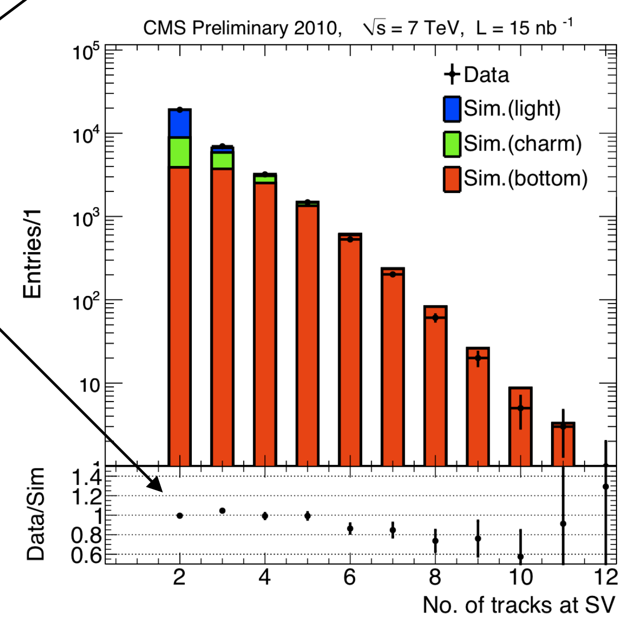
Data/MC comparison for B-Tagging observables



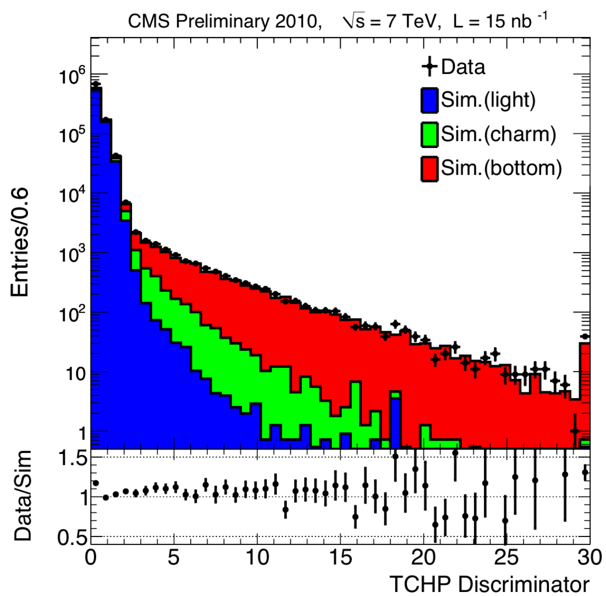


DATA/MC ratio is close to 1 for all observables (including those not shown)





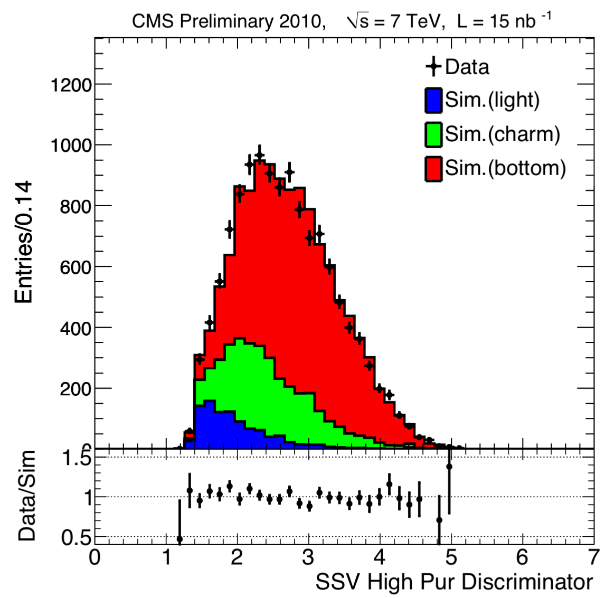
Data/MC comparison for Tagging Discriminators



Track Counting Algorithm

tags jets containing N tracks with Impact Parameter (IP) significance exceeding S

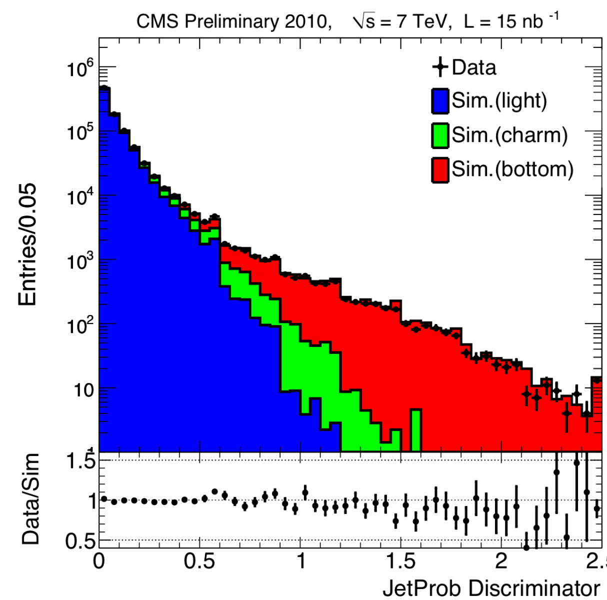
High Purity configuration: N=3



SSV Algorithm

tags jets according to the 3D flight distance significance of the reconstructed secondary vertex

High Purity configuration: Vertices with 3 or more tracks



Jet Probability Algorithm

tags jets according to the probability of <u>all</u> the tracks in the jet to originate from the primary vertex, given their IP significances

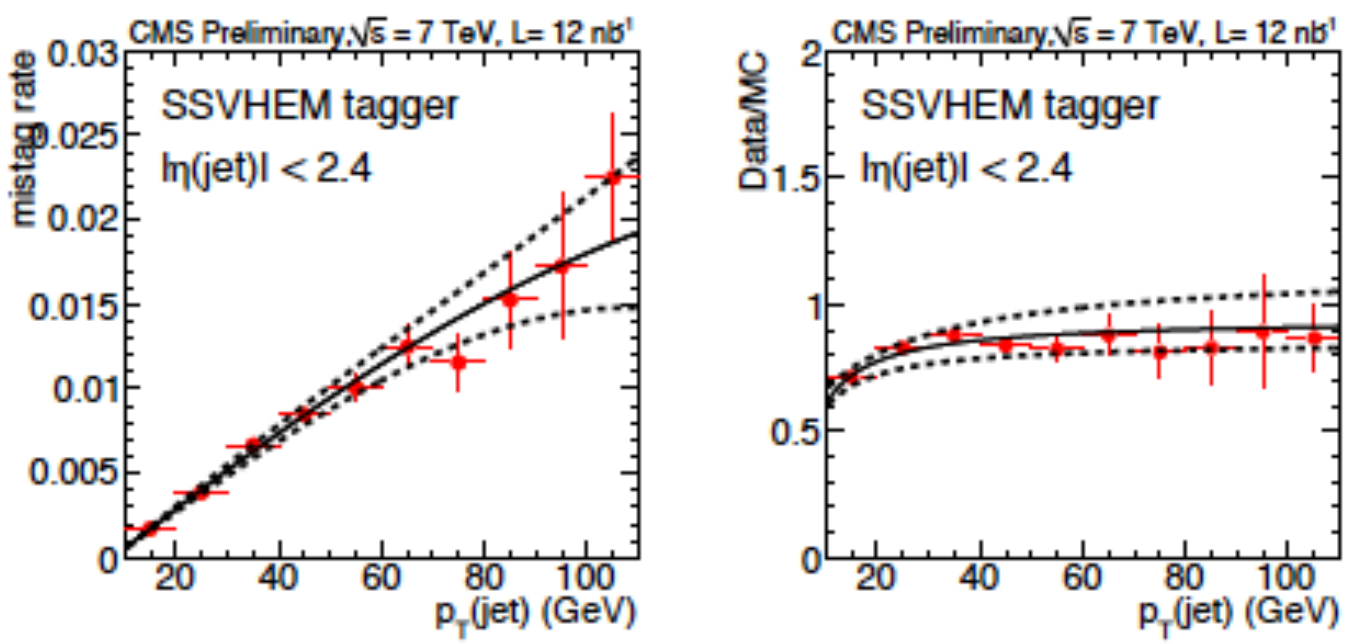
Measuring the b-tag efficiency

- Select jets containing a muon
- These are enriched in b→μ
- See how often these jets are tagged by various btagging algorithms
- Careful because actually only about ½ of these jets are b→μ. The rest is mostly gluon jets with a K→μ decay. The transverse momentum of the μ wrt to the jet axis can be used to measure the b-fraction

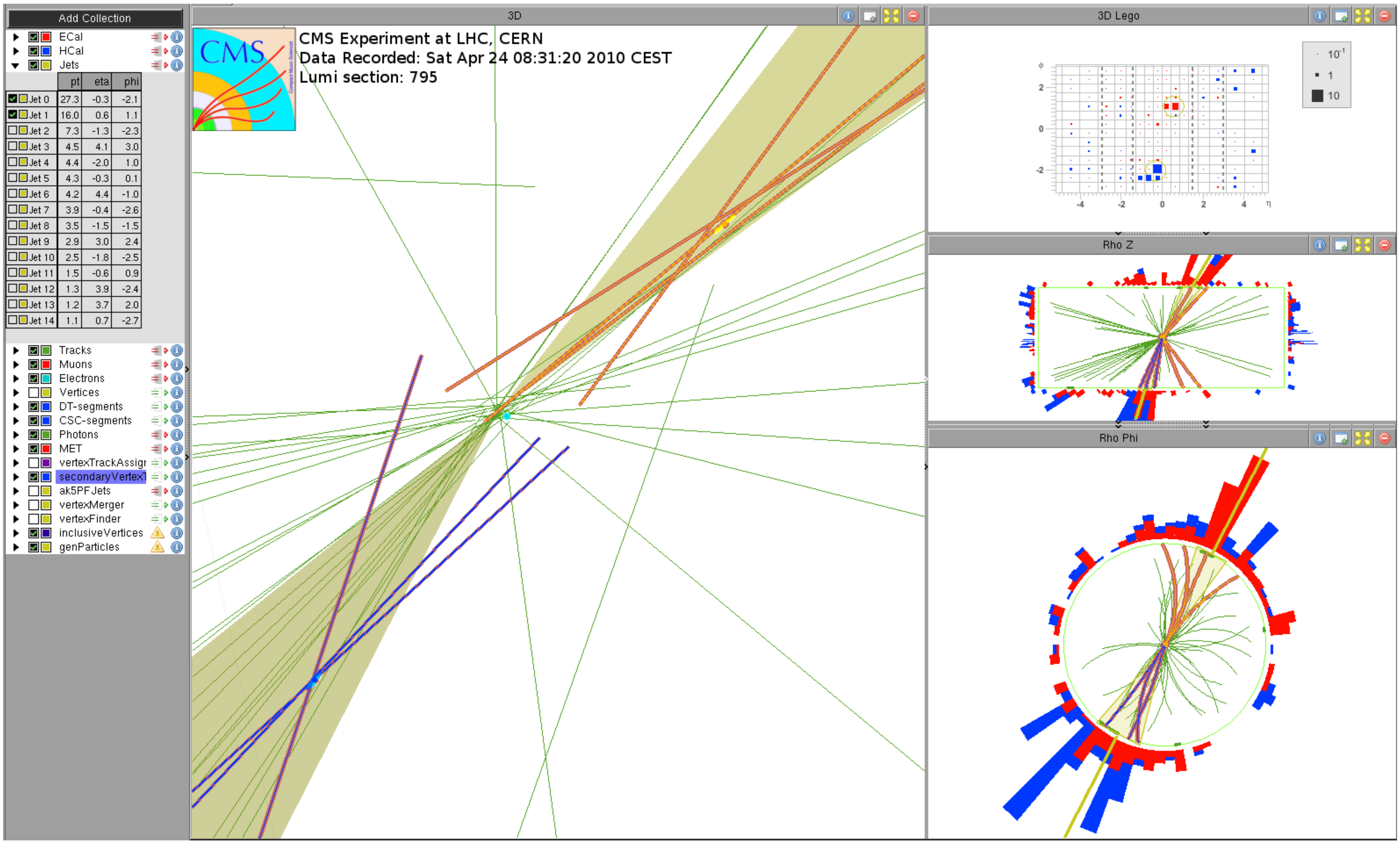
Tagger+Operating Point	ϵ_b^{data}	ϵ_b^{MC}	SF_b
SSVHPT	0.203 $\pm$ 0.015	0.207$\pm$ 0.002	0.98$\pm$ 0.08$\pm$ 0.18
SSVHEM	0.405 $\pm$ 0.016	0.417$\pm$ 0.003	0.97$\pm$ 0.04$\pm$ 0.19
SSVHET	0.127 $\pm$ 0.017	0.131$\pm$ 0.002	0.97$\pm$ 0.13$\pm$ 0.21
TCHPL	0.404 $\pm$ 0.018	0.444$\pm$ 0.003	0.91$\pm$ 0.04$\pm$ 0.19
TCHPM	0.303 $\pm$ 0.015	0.331$\pm$ 0.003	0.92$\pm$ 0.05$\pm$ 0.19
TCHPT	0.233 $\pm$ 0.014	0.244$\pm$ 0.002	0.95$\pm$ 0.06$\pm$ 0.19
TCHEL	0.562 $\pm$ 0.020	0.636$\pm$ 0.003	0.88$\pm$ 0.03$\pm$ 0.19
TCHEM	0.455 $\pm$ 0.016	0.494$\pm$ 0.003	0.92$\pm$ 0.03$\pm$ 0.20
TCHET	0.151 $\pm$ 0.015	0.150$\pm$ 0.002	1.01$\pm$ 0.10$\pm$ 0.19

Measuring the fake tagging probability

- Probability of a udsg jet to be tagged as a b-jet
- Extracted from tagging with negative impact parameters and negative decay distances
- Here is an example:



b-tagging at work

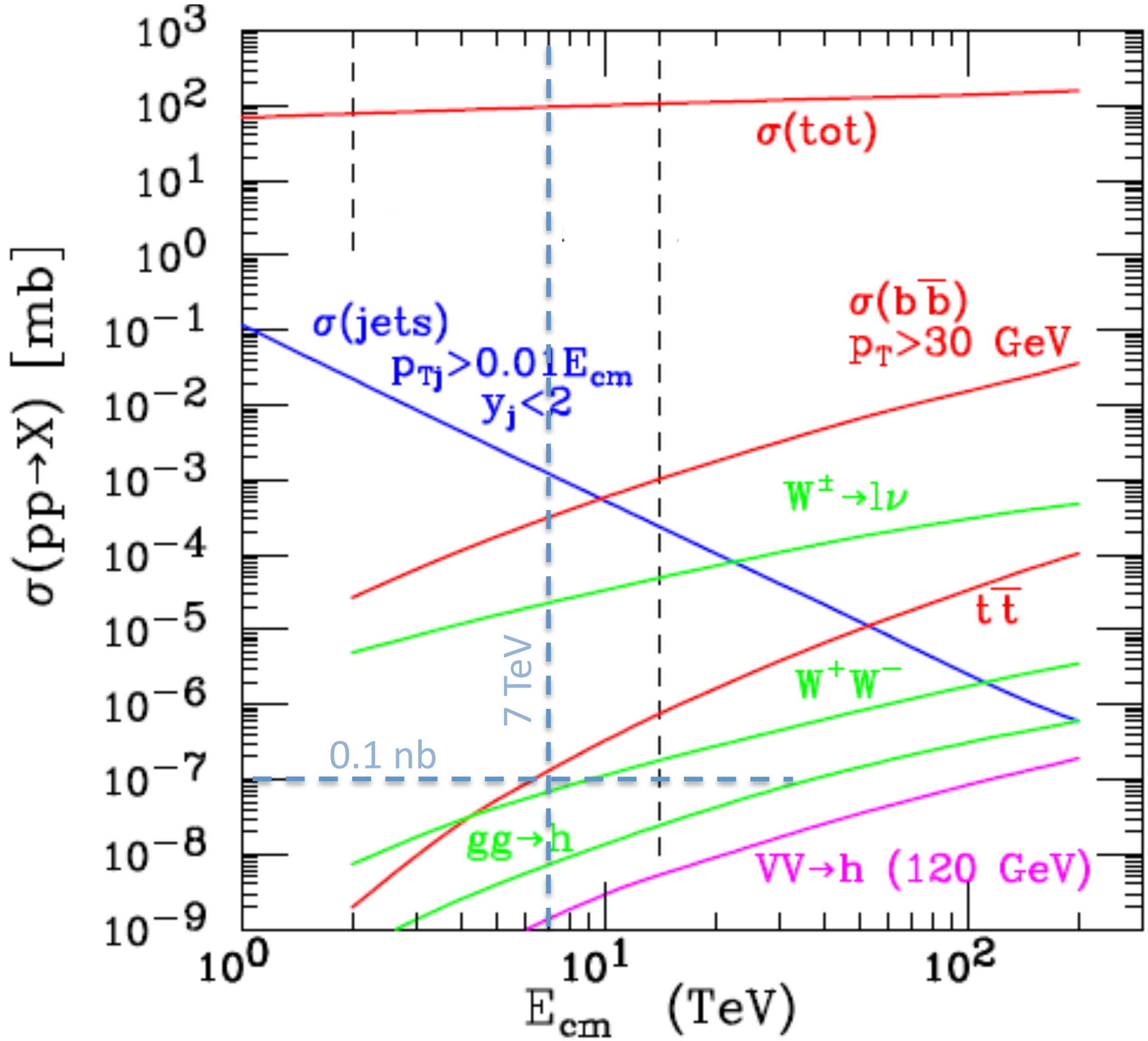


Two b-jets candidate

Outline

- LHC operation
- Selected results from ICHEP
  - High Level Detector Performance
  - Some early physics results
  - Early studies focussed towards preparations for searches

What can you expect to do with 250 nb^{-1}

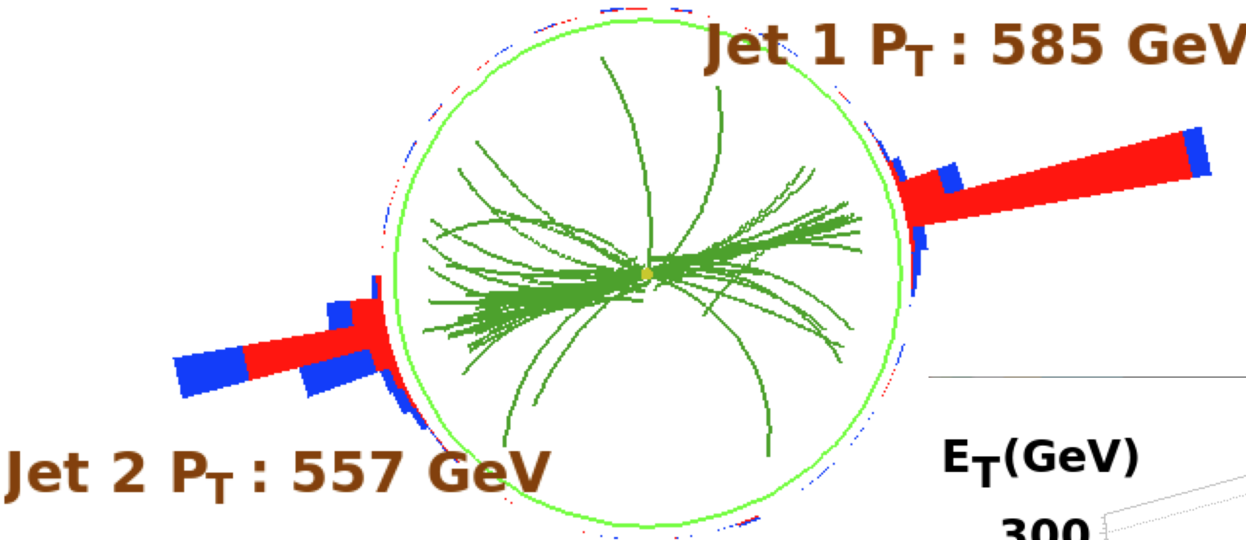


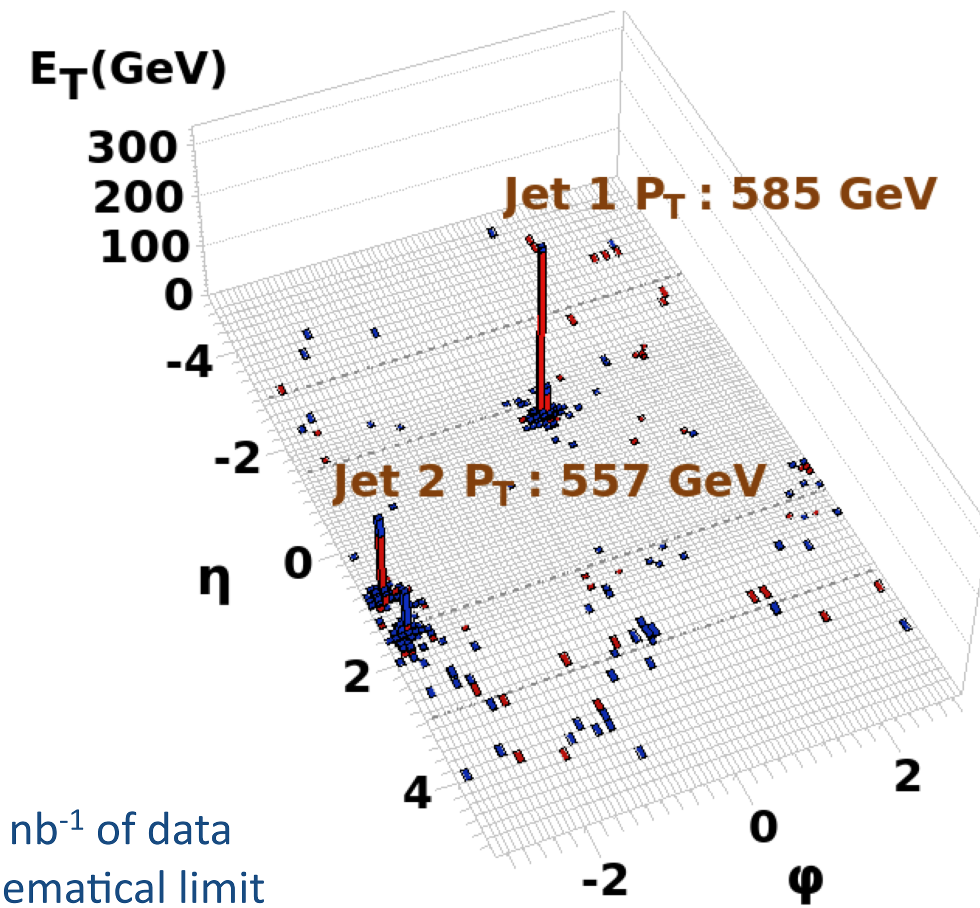
- QCD jets
- bottom and charm
- W and Z
- a bit of ttbar

Basically: HEP as of 1995

Jet physics: why should you care?

- If you are a QCD aficionado
  - Test QCD to your heart's content
- If you are not (I am not)
  - Pay attention to what happens at high mass
    - Are there resonances?
    - Are there deviations from QCD?
      - eg: much like Rutherford's experiment, deviations from theory at high PT can signal quark compositeness
  - If the new physics couplings are like QCD color couplings, then the effect are large and could be seen fairly early on

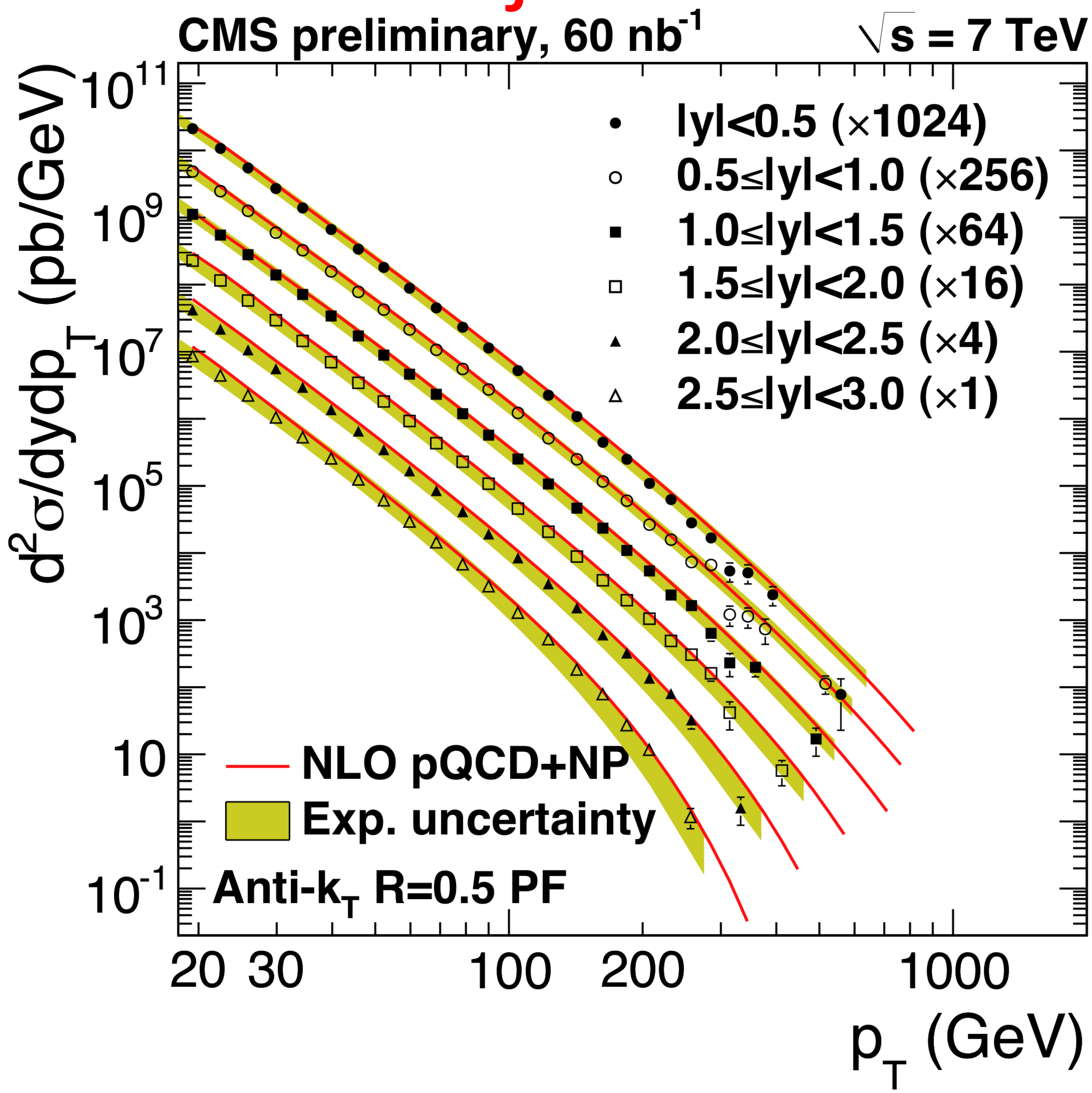




Run : 138919
Event : 32253996
Dijet Mass : 2.130 TeV

The highest mass dijet event in the first 120 nb^{-1} of data
Already getting events past the Tevatron kinematical limit

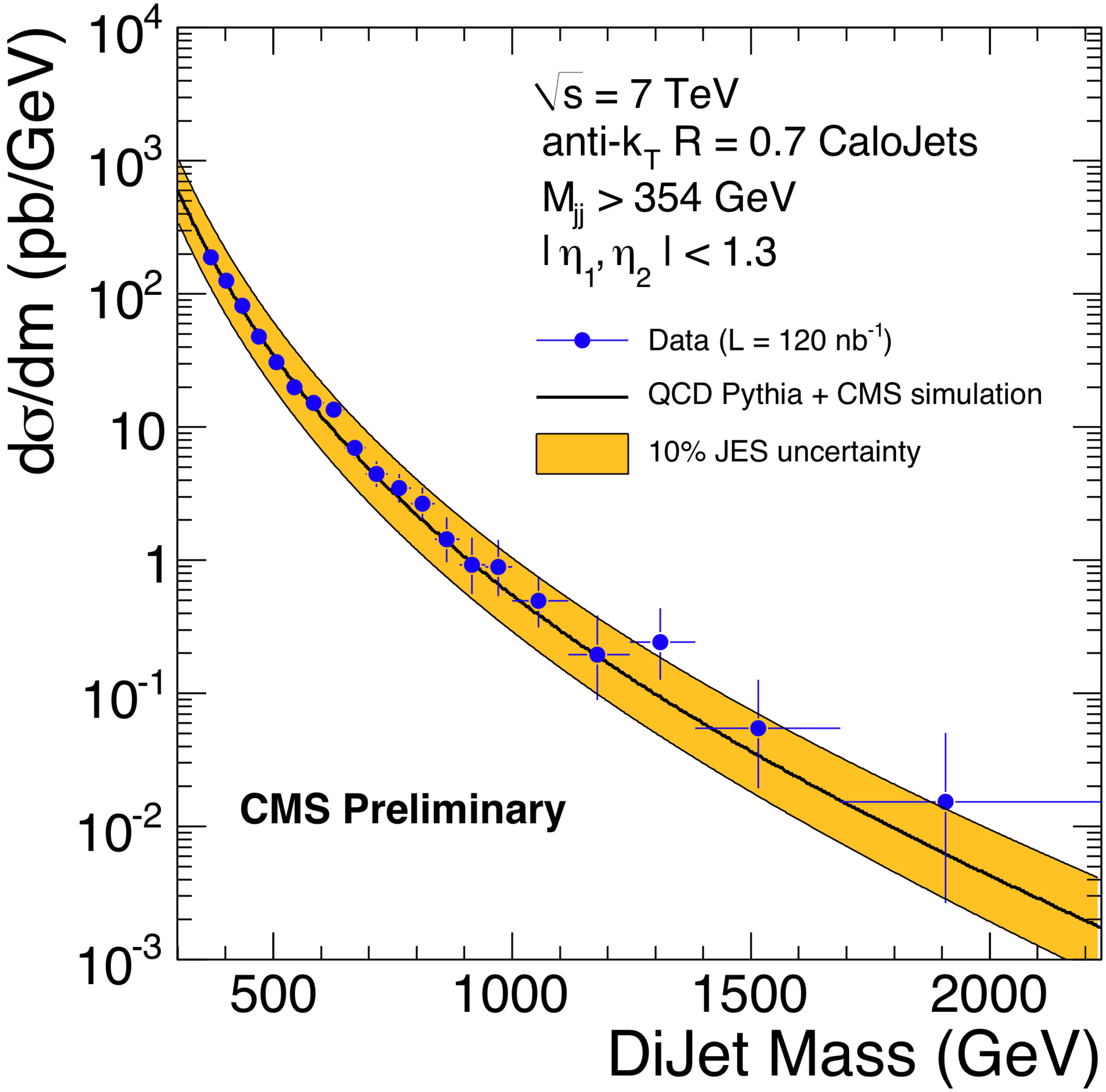
Inclusive jet cross section



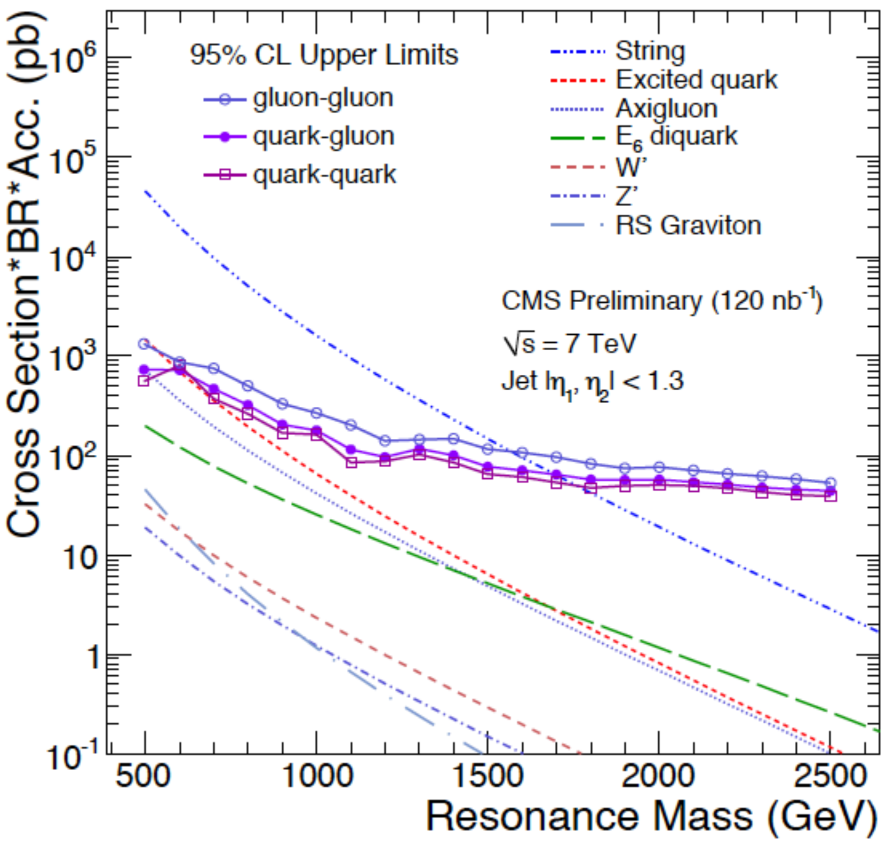
Decent agreement with QCD over 8 orders of magnitude

Contact term excluded with Λ>1.9 TeV (Tevatron excludes Λ>2.8 TeV)

Dijet mass

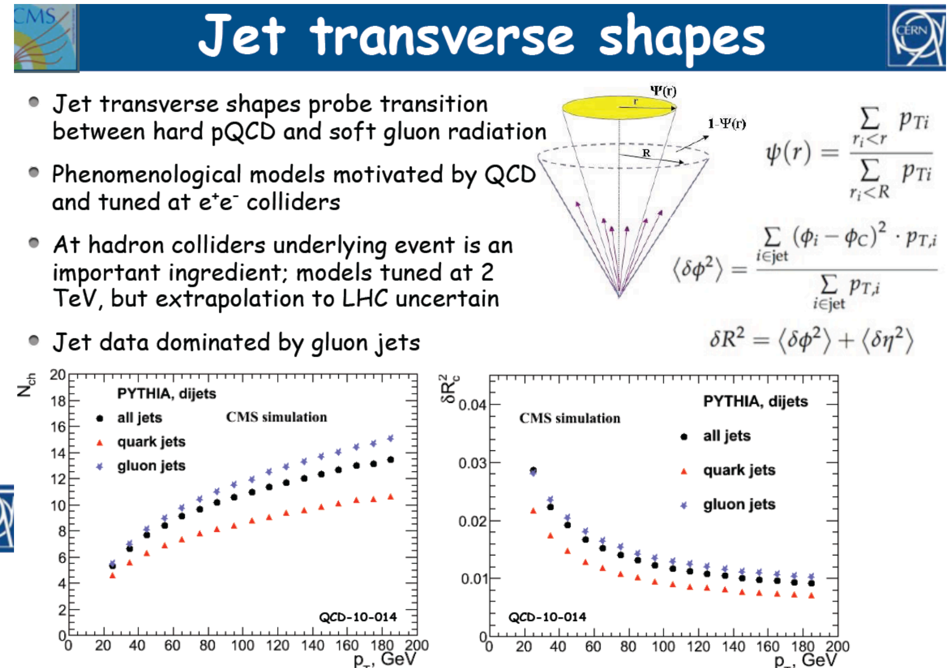


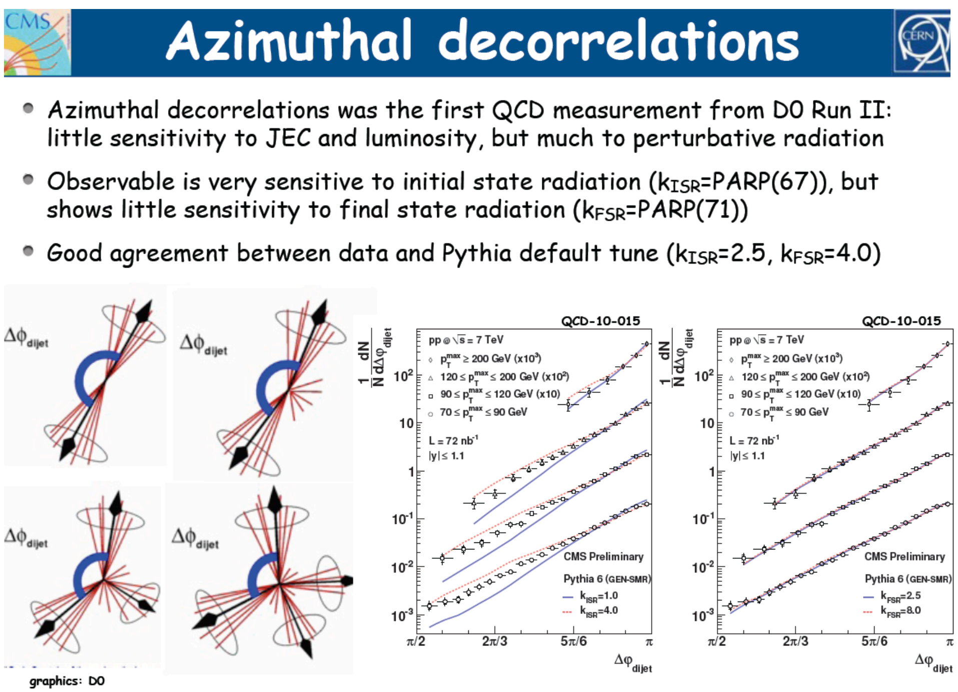
dσ/dm (pb/GeV)
10^4
10^3
10^2
10
1
10^-1
10^-2
10^-3
√s = 7 TeV
anti-k_T R = 0.7 CaloJets
M_jj > 354 GeV
|η_1, η_2| < 1.3
Data (L = 120 nb^-1)
QCD Pythia + CMS simulation
10% JES uncertainty
CMS Preliminary
500
1000
1500
2000
DiJet Mass (GeV)



- ✦ We have **generic, cross-section upper limits** on quark-quark, quark-gluon and gluon-gluon resonances.
- ✦ The upper limits are compared to the expected cross-section for 7 resonance models.
- ✦ We exclude **excited quarks** (qg resonance) with mass **M < 0.59 TeV.** Tevatron limit is 0.87 TeV.
- ✦ We exclude **Axigluons/Colorons** (qq resonance) with **M < 0.52 TeV**. Tevatron limit is 1.25 TeV.
- ✦ **We exclude a string resonance with mass M<1.67 TeV**
  - string resonance decays predominantly to qg (75%).
  - we have taken into account its branching ratio to gg (12%) and qqbar (13%) as well.
  - more stringent than the Tevatron limit on string resonances of about 1.4 TeV (our evaluation of cross-section).

For QCD aficionados only





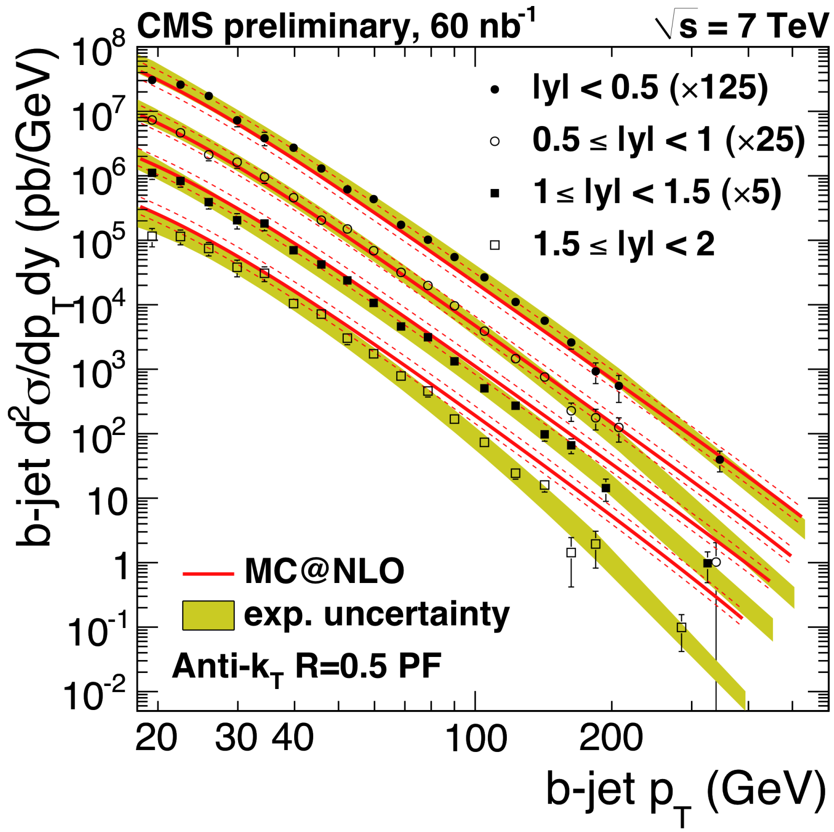
etc. etc. etc.

Bottom and charm physics: why should you care

- If you are a QCD aficionado
  - Even more test of QCD: cross-sections, polarization, etc
- If you are a B-physics aficionado (I used to be one)
  - Can do some cool measurements that cannot be done at B-factories
    - eg: anything involving B_s and b-baryons
- In addition: commission and exercise tools that we need for high PT physics
    - eg: b-tagging

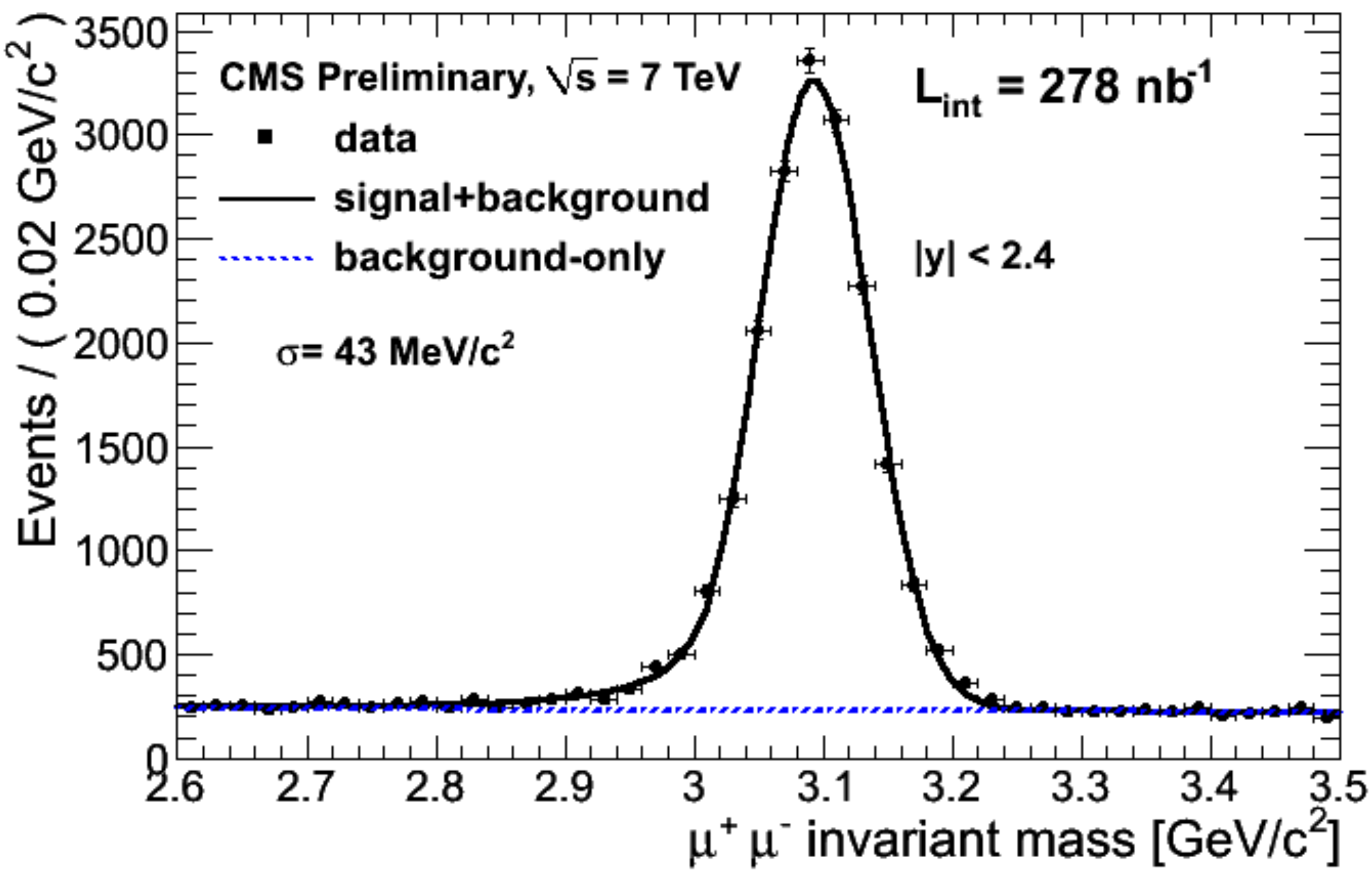
Inclusive b-cross section

Checkered history at the TeV. Was quite a bit off, then both exp and theo moved to bring into agreement. How does it work at the LHC?

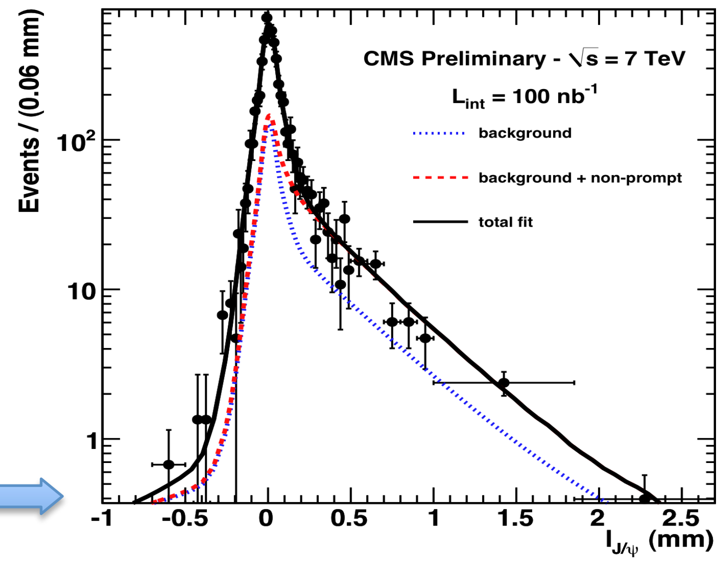


Reasonable agreement with NLO but discrepancy in η and PT

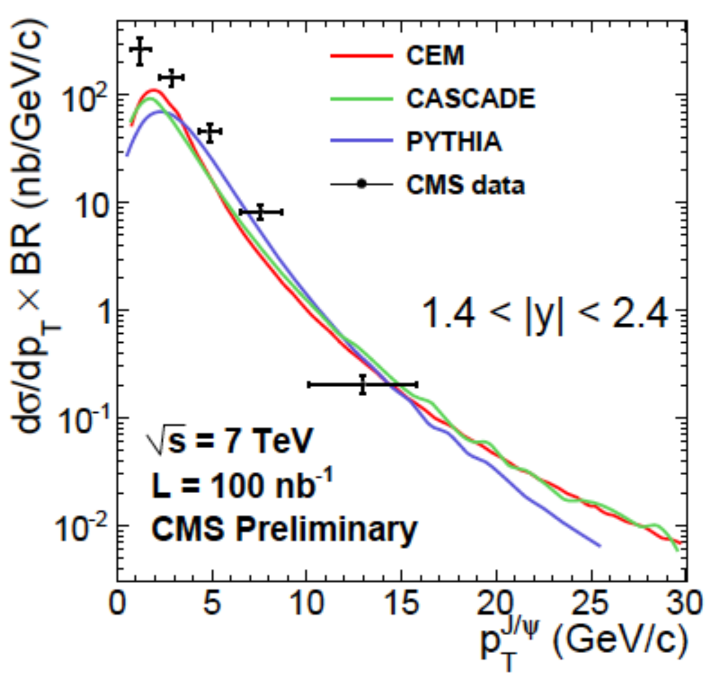
J/Ψ→μμ

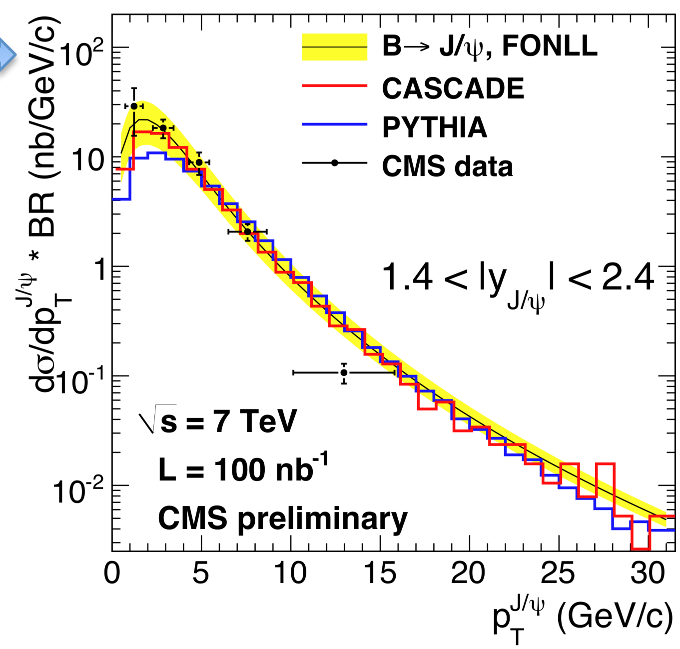


Lots of events (17K)

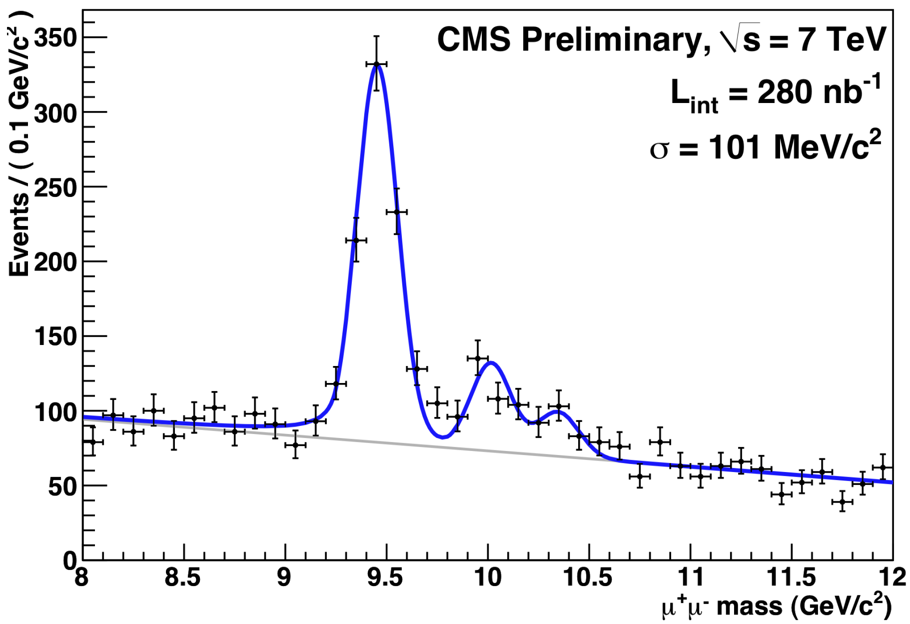


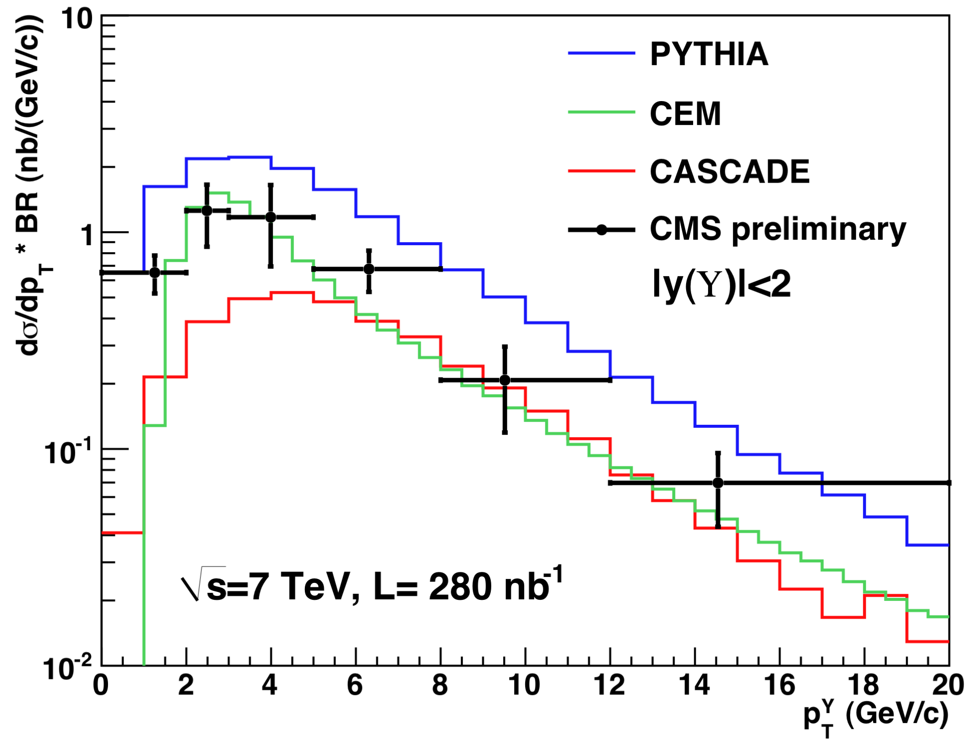
Use the distance from the interaction point to measure the differential cross-section for prompt and B→J/Ψ



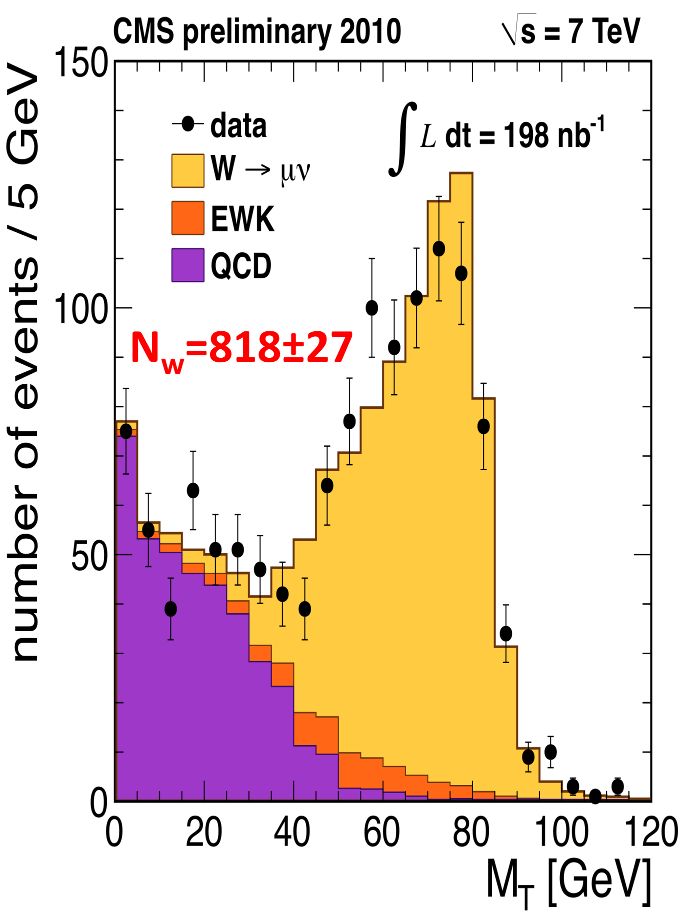


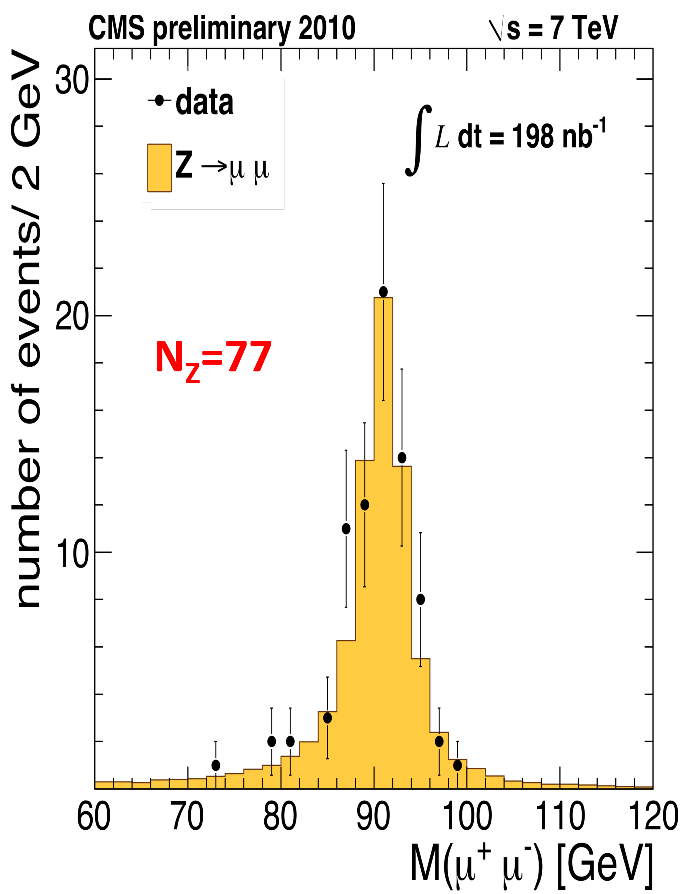
Υ(1S,2S,3S) → μμ


CMS Preliminary, $\sqrt{s}$ = 7 TeV
L_{int} = 280 nb^{-1}
σ = 101 MeV/c^2
Events / (0.1 GeV/c^2)
$\mu^+\mu^-$ mass (GeV/c^2)
0
50
100
150
200
250
300
350
8
8.5
9
9.5
10
10.5
11
11.5
12


PYTHIA
CEM
CASCADE
CMS preliminary
|y(Υ)|<2
$\sqrt{s}$=7 TeV, L= 280 nb^{-1}
dσ/dp_T * BR (nb/(GeV/c))
p_T^{Υ} (GeV/c)
10^{-2}
10^{-1}
1
10
0
2
4
6
8
10
12
14
16
18
20

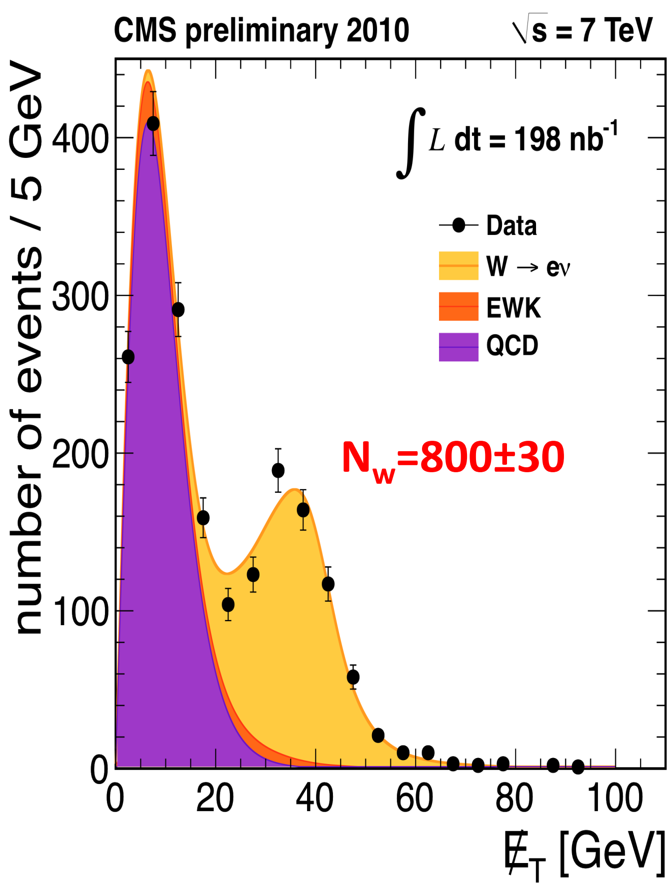
W→μν and Z→μμ



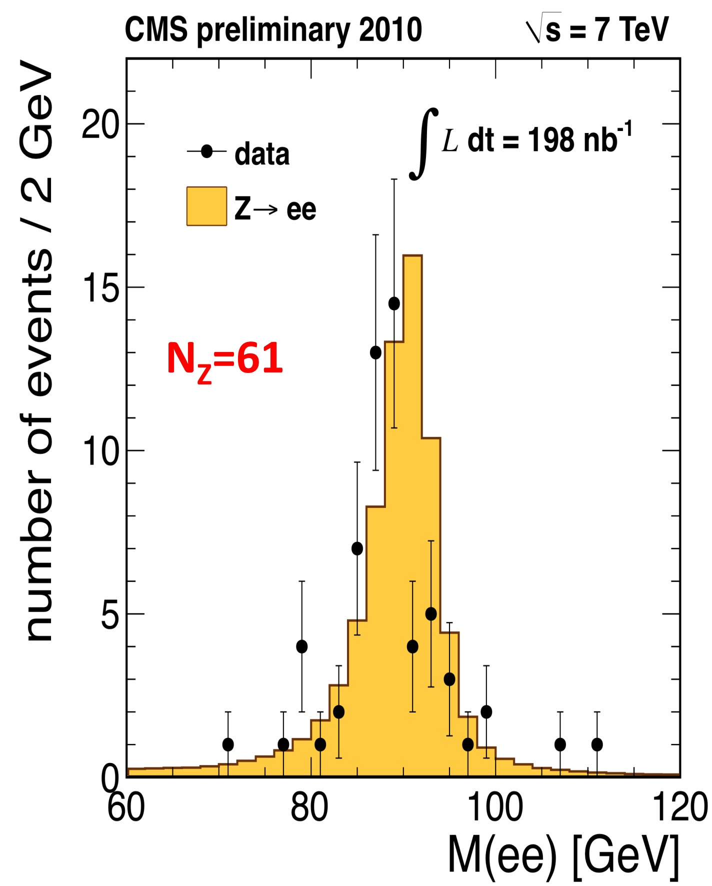


M_T = "transverse mass" = (pseudo) invariant mass computed from muon (ignoring longitudinal component) and neutrino transverse momentum inferred from the MET.

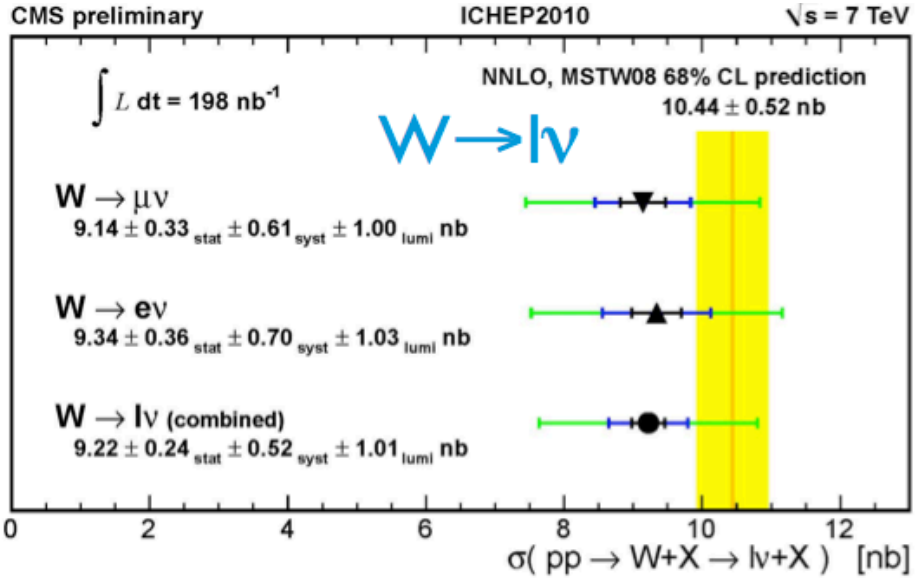
W→eν and Z→ee

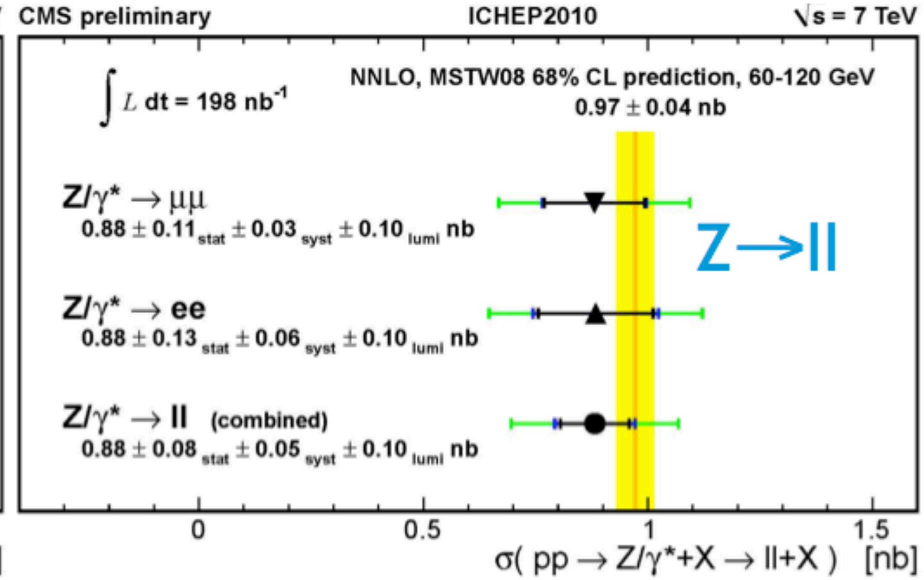


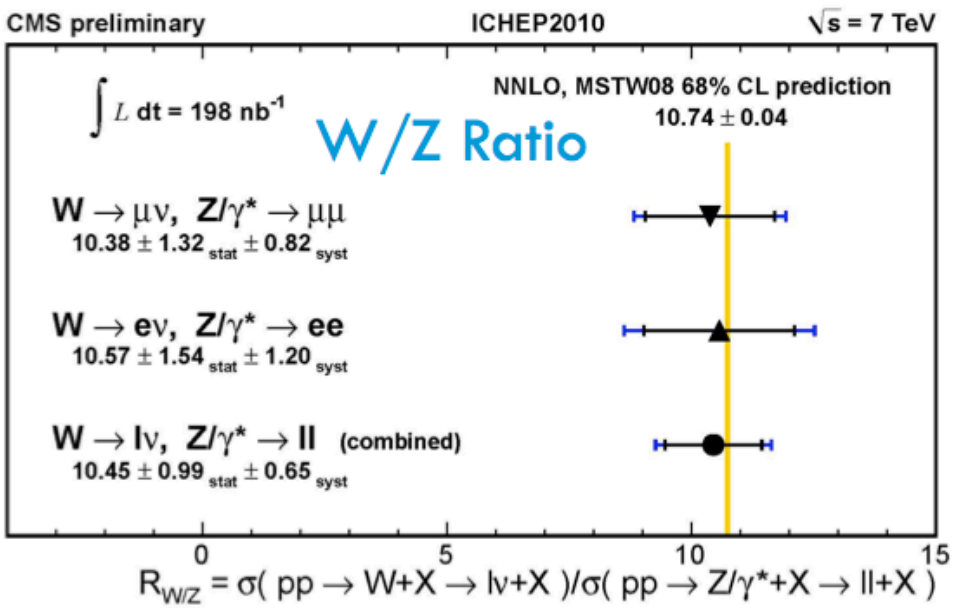
CMS preliminary 2010
√s = 7 TeV
∫L dt = 198 nb-1
Data
W → eν
EWK
QCD
Nw=800±30
number of events / 5 GeV
0
100
200
300
400
0
20
40
60
80
100
E̸T [GeV]



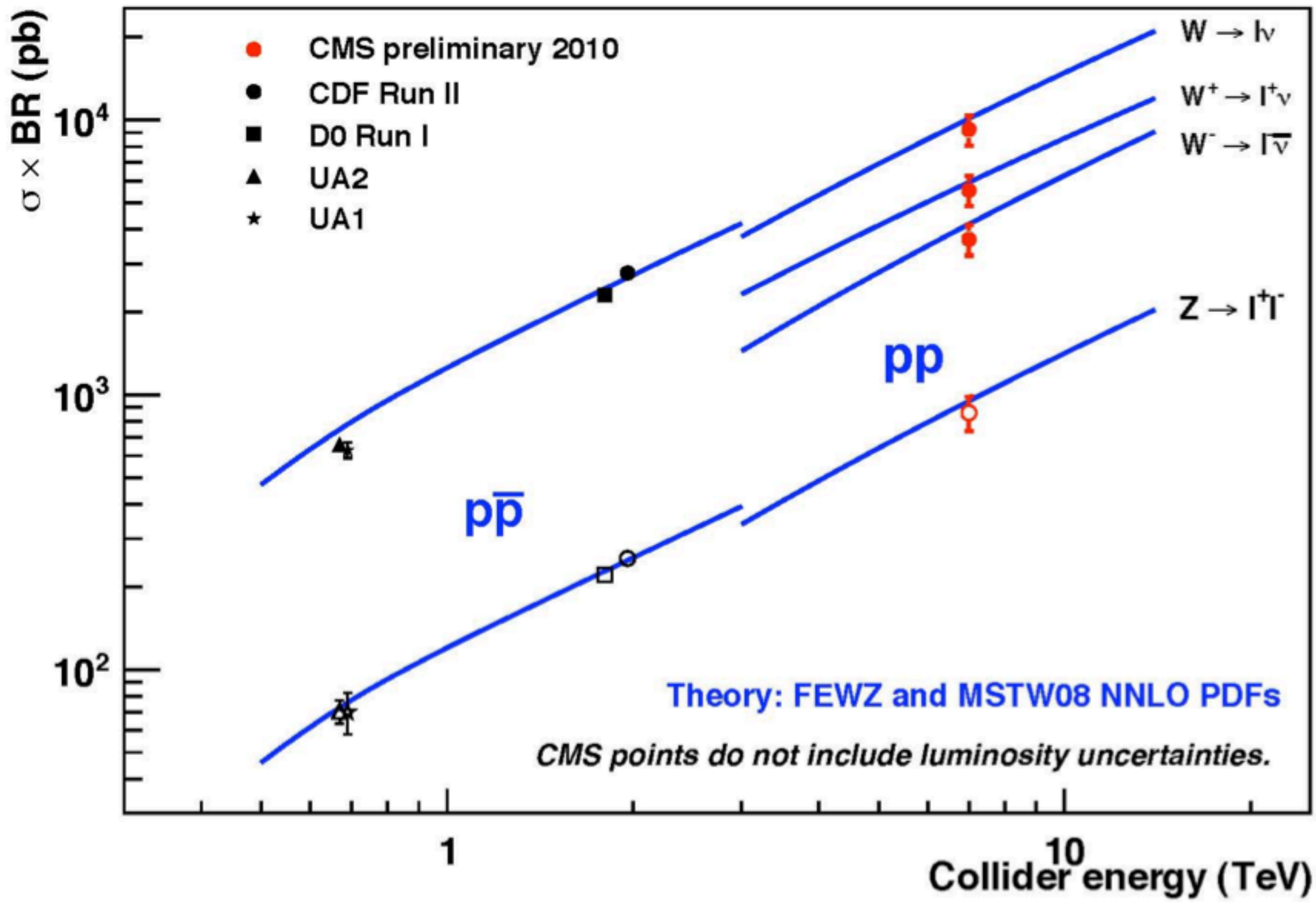
CMS preliminary 2010
√s = 7 TeV
∫L dt = 198 nb-1
data
Z→ ee
NZ=61
number of events / 2 GeV
0
5
10
15
20
60
80
100
120
M(ee) [GeV]



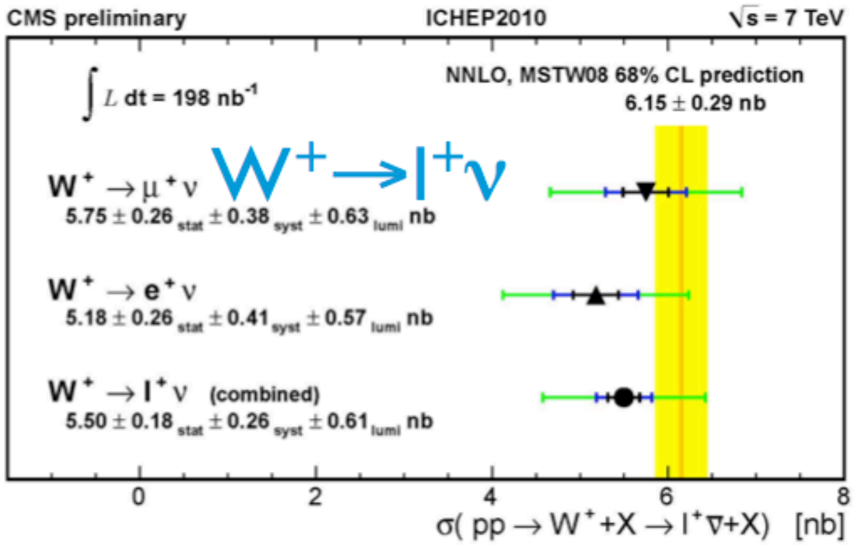


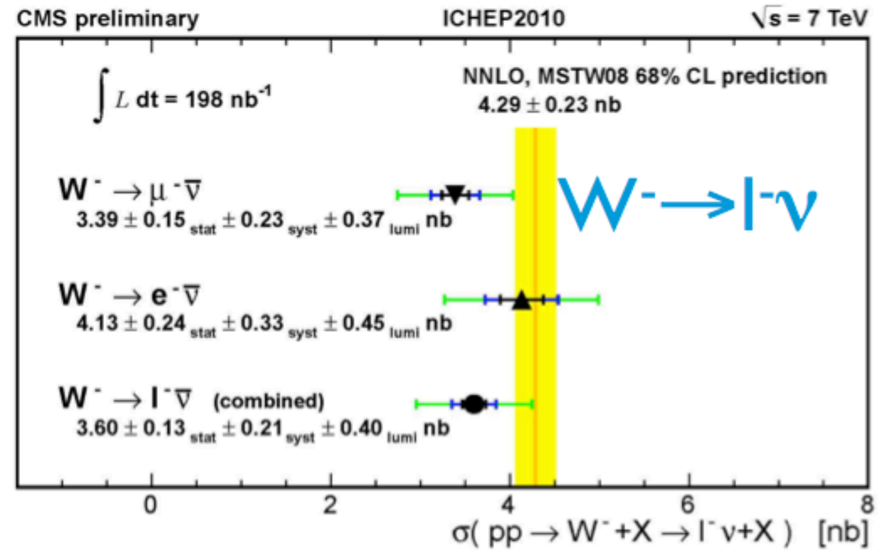


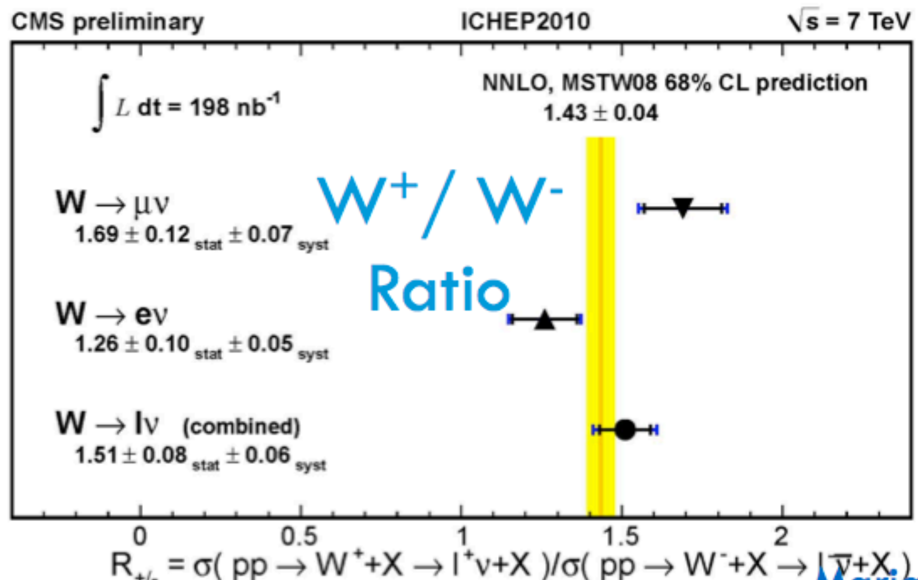
Measurements in agreement with SM predictions



$\sigma \times$ BR (pb)
10^4
10^3
10^2
CMS preliminary 2010
CDF Run II
D0 Run I
UA2
UA1
$W \rightarrow l\nu$
$W^+ \rightarrow l^+\nu$
$W^- \rightarrow l\bar{\nu}$
$Z \rightarrow l^+l^-$
pp
$p\bar{p}$
Theory: FEWZ and MSTW08 NNLO PDFs
CMS points do not include luminosity uncertainties.
1
10
Collider energy (TeV)

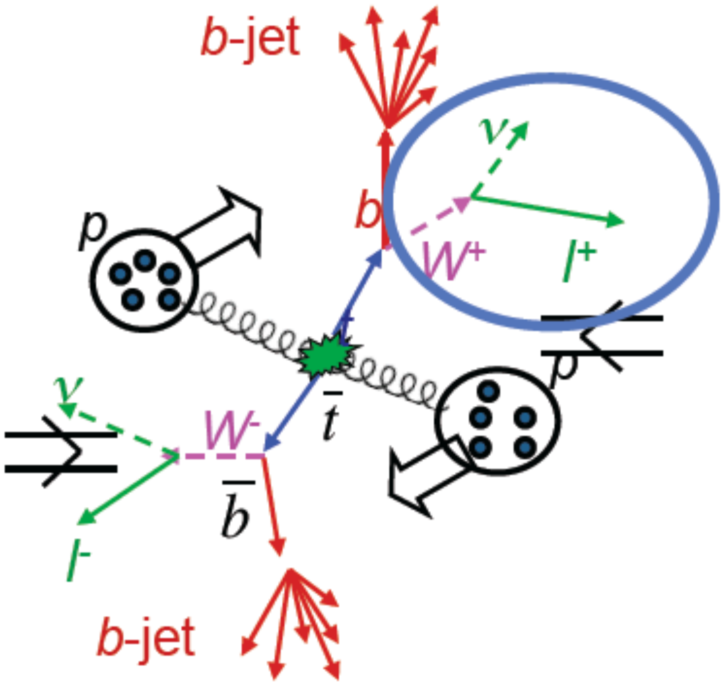


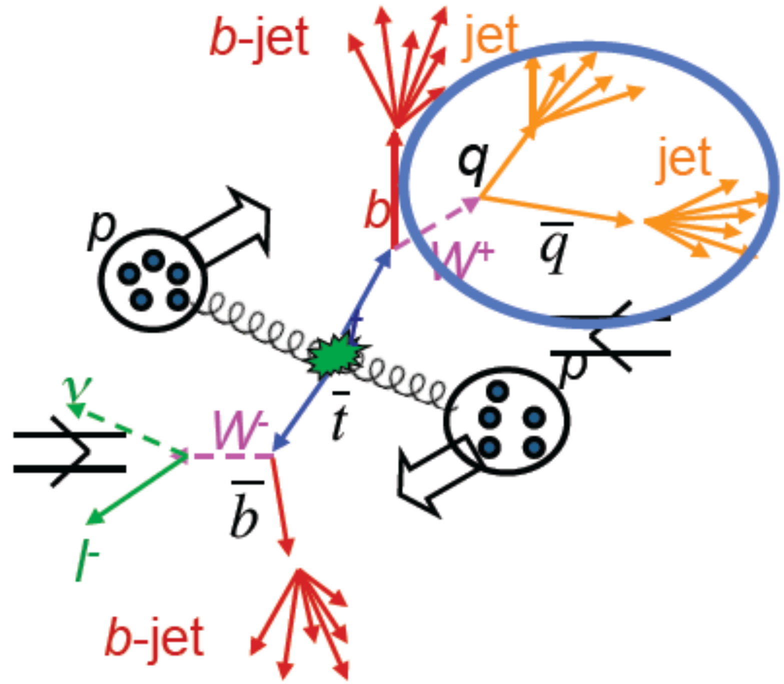




Maria Cepeda, ICHEP2010

Top-antitop

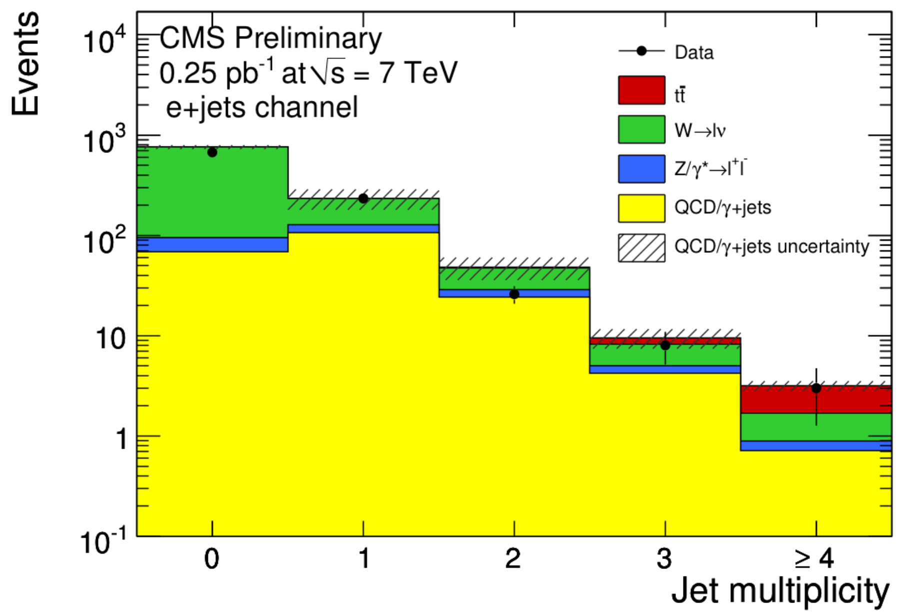


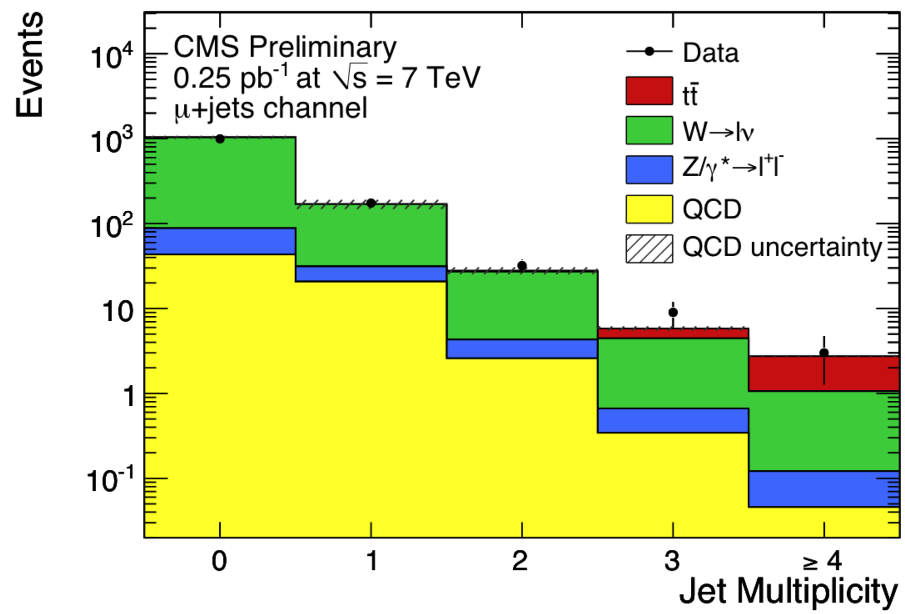


Dilepton channel:
- two leptons
- MET
- (ideally) two b-jets

Lepton + jets channel
- one lepton
- MET
- (ideally) two b-jets
- (ideally) two light quark jets

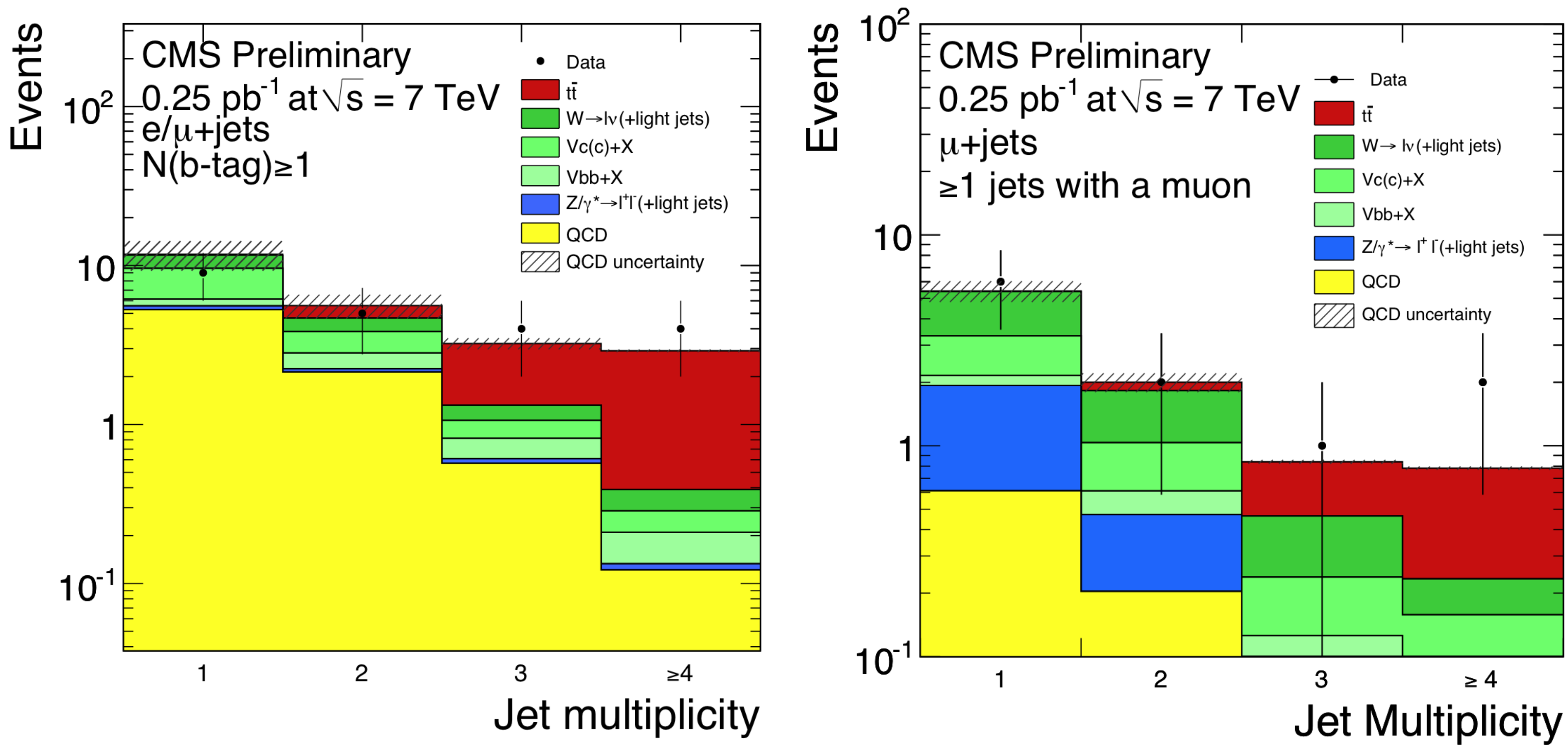
Lepton + jets sample: compare with MC





hmmm….we may not trust the MC much, but looks suggestive……

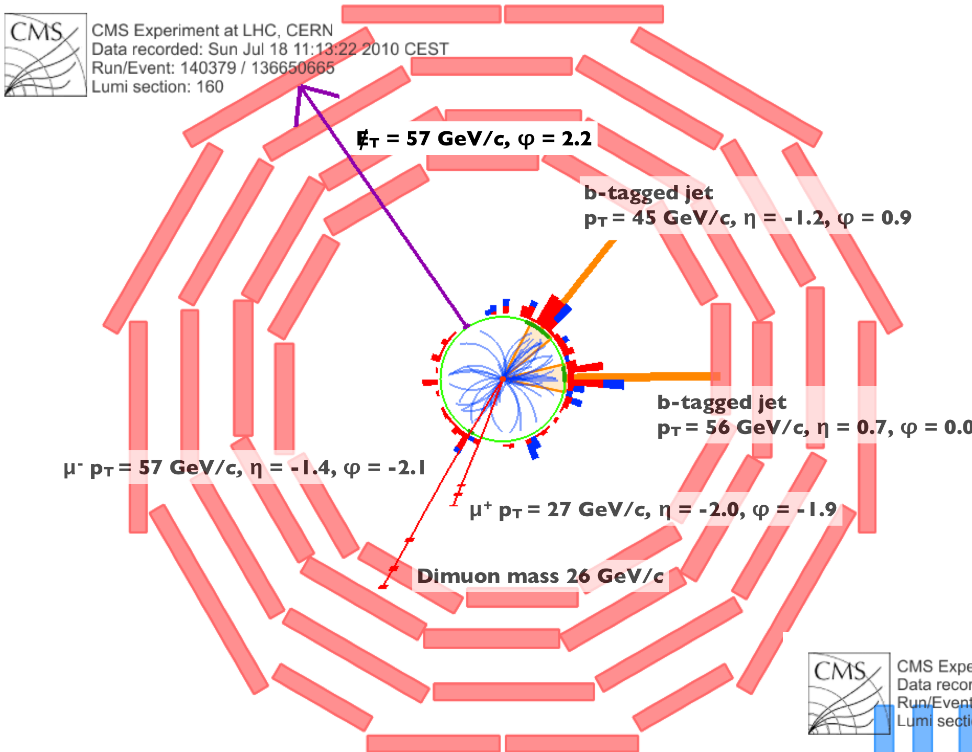
Now ask for btags....

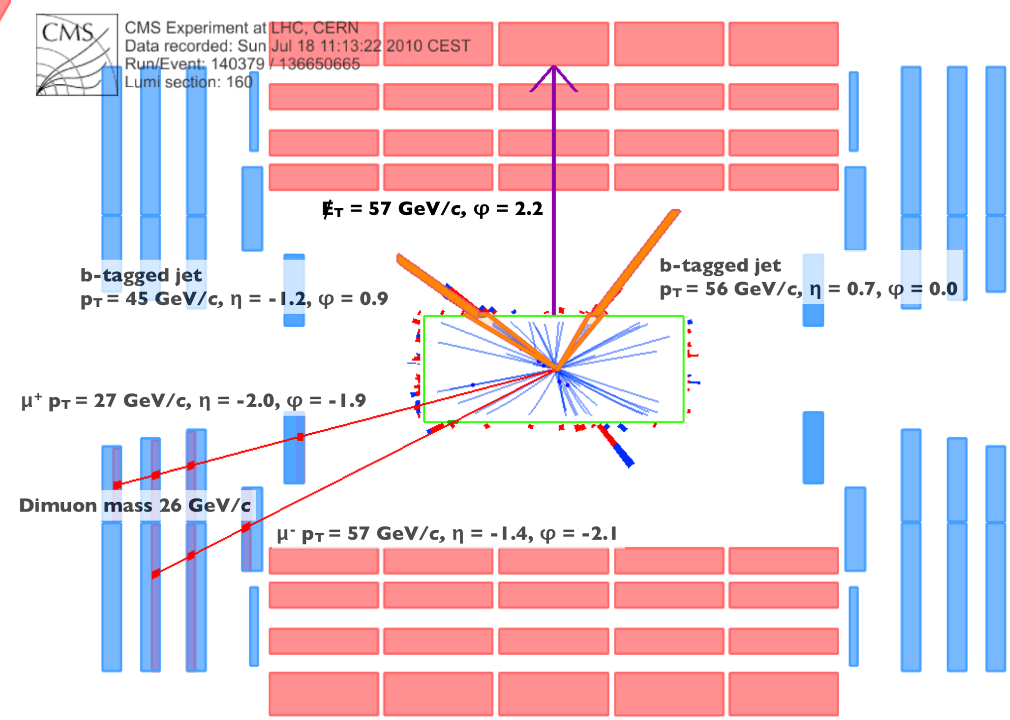


Comparison with "out-of-the-box" Monte Carlo.
Not quantitative yet, but looks like we are starting to see top.

Dilepton channel

- One an only one event with two isolated high PT leptons and MET. This event has two jets.
- Both (!) jets are btagged.
- It is a golden top candidate


CMS Experiment at LHC, CERN
Data recorded: Sun Jul 18 11:13:22 2010 CEST
Run/Event: 140379 / 136650665
Lumi section: 160
$\not{E}_T$ = 57 GeV/c, φ = 2.2
b-tagged jet
p_T = 45 GeV/c, η = -1.2, φ = 0.9
b-tagged jet
p_T = 56 GeV/c, η = 0.7, φ = 0.0
μ^- p_T = 57 GeV/c, η = -1.4, φ = -2.1
μ^+ p_T = 27 GeV/c, η = -2.0, φ = -1.9
Dimuon mass 26 GeV/c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b-tagged jet
p_T = 45 GeV/c, η = -1.2, φ = 0.9
b-tagged jet
p_T = 56 GeV/c, η = 0.7, φ = 0.0
μ^+ p_T = 27 GeV/c, η = -2.0, φ = -1.9
Dimuon mass 26 GeV/c
μ^- p_T = 57 GeV/c, η = -1.4, φ = -2.1

Outline

- LHC operation
- Selected results from ICHEP
  - High Level Detector Performance
  - Some early physics results
  - Early studies focussed towards preparations for searches

Searches. General statements

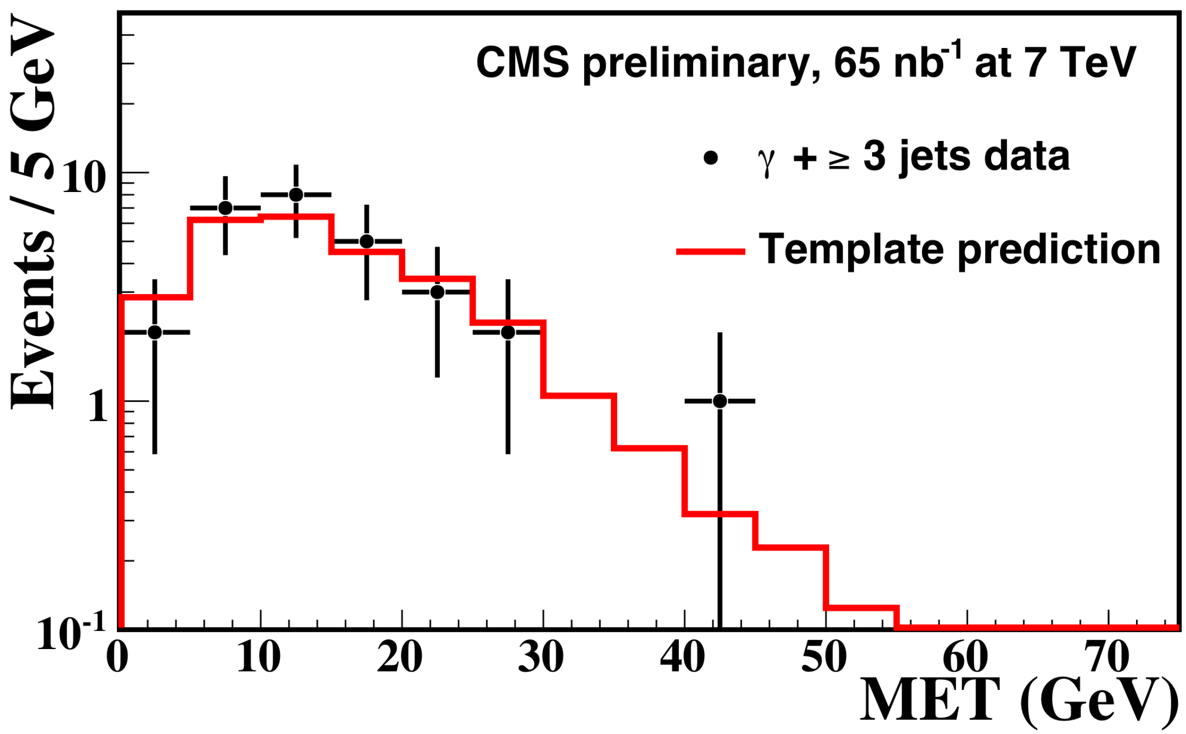
- I just showed you how well our MC reproduces all sorts of distributions
- **<u>However</u>**: to claim a signal for New Physics we want to go beyond saying: "we see N events with such and such properties, our SM Monte Carlo predicts that we should show many fewer such events, therefore we have seen New Physics"
  - Unless it is something "obvious" like a mass peak
- We want to develop "data-driven" techniques to predict SM background with minimal reliance on Monte Carlo and theory
- A lot of preparatory work has been done over the last years
- Now we can test some of these techniques on real data.
- Because of the low luminosity these tests are in kinematical regions where we do not expect any new physics.

Signals with MET

- Because of dark matter, searches for events with MET are particularly well motivated
- Many flavors
  - Jets + MET
  - Photon(s) + MET
  - Photon(s) + jets + MET
  - (1,2,3) lepton(s) + jets + MET
  - Z + jets + MET
  - Etc
- Generally, SM produces no real MET (or less real MET). Can we predict the MET distribution of the SM background?

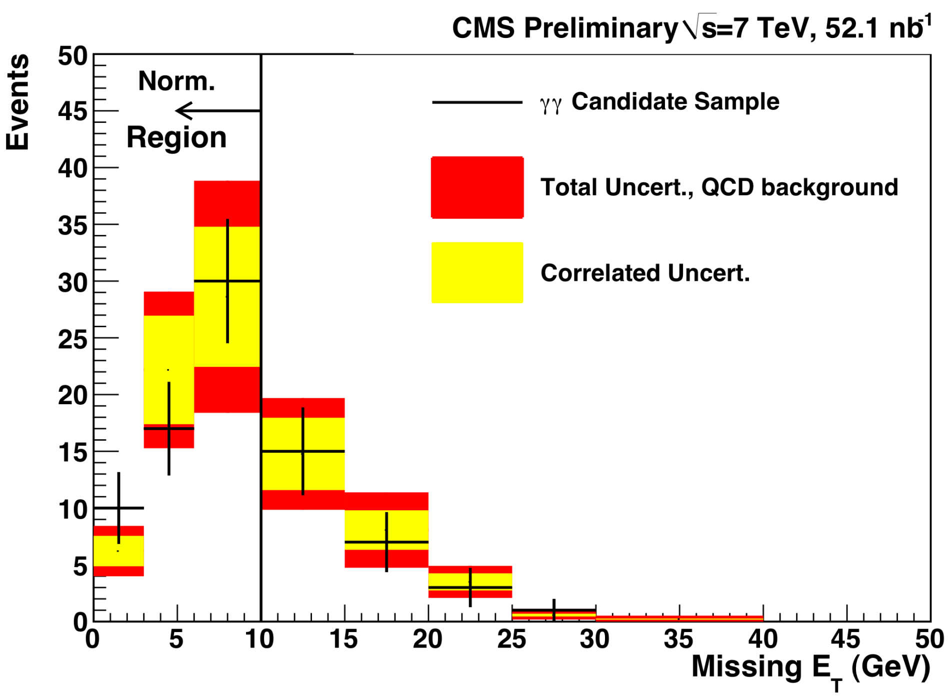
One example

- Could have Z + jets + MET
- Use pp→jets to parametrize MET distribution as a function of jet activity in a Z event
- Test this idea on γ+jets+MET…seem to work for now



Another example

- Could have $\gamma\gamma$ + MET
- Major BG is jet-jet + fake MET
- Measure MET in control sample with 2 fake photons selected by inverting some γ ID requirement
- Can we use the MET in the control sample to predict the BG?



✓ **Prediction consistent with number of observed events,**
For MET > 20 GeV:
Predicted = 4.2 ± 1.5
Observed = 4 events

Fake leptons

- Fake leptons or leptons from bottom decays are a major source of BG in searches for SUSY in final states with same-sign isolated dileptons
- Can we use the probability for a lousy (background) lepton candidate to pass the tight analysis cuts to predict the BG?
- Test this idea by trying to predict the rate of same sign dileptons (PT>10 GeV) in data

Channel	Predicted	Observed
ee	$0.43^{+0.18}_{-0.14}$	0
$e\mu$	$0.14^{+0.18}_{-0.09}$	1
$\mu\mu$	$0.22^{+0.51}_{-0.18}$	0

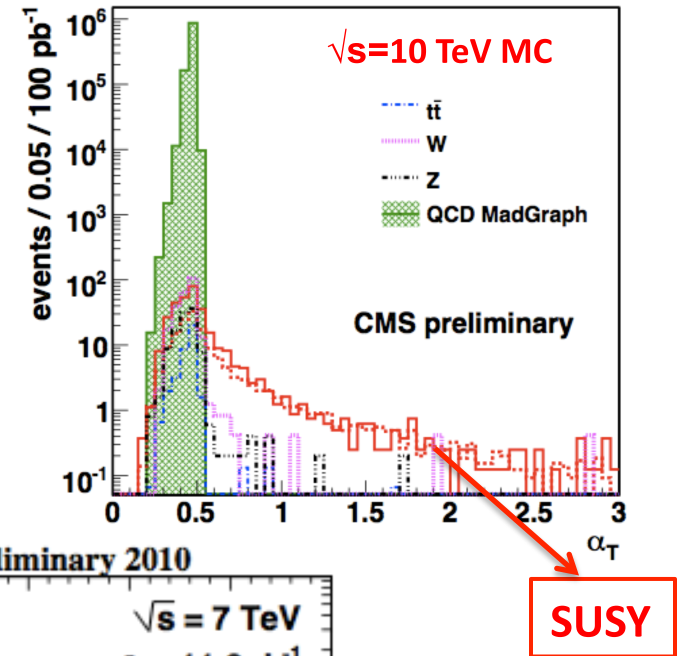
Predict ~ 0.8 events, see 1

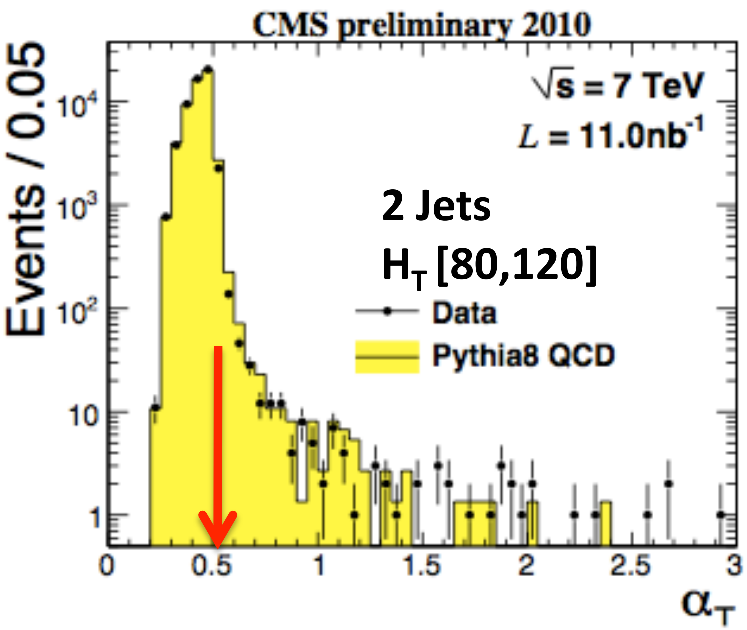
Two jets + MET search

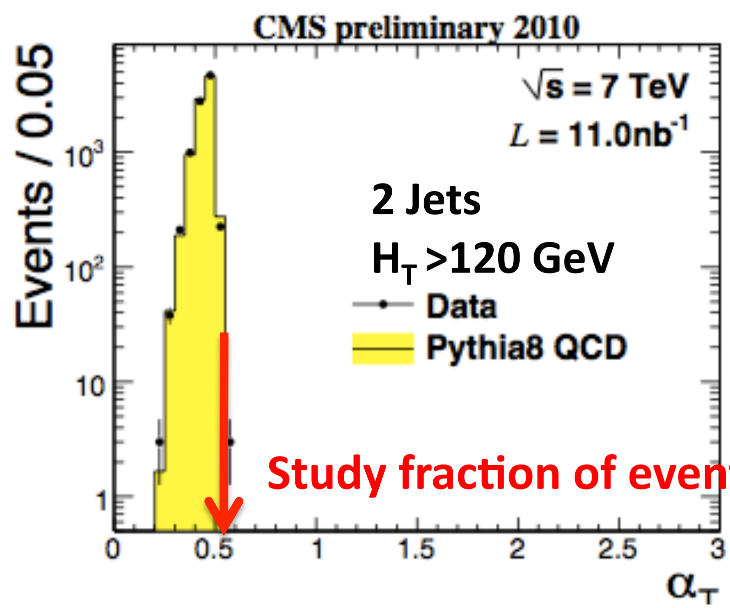
- A powerful variable for suppressing mis-measured QCD

$$\alpha_T \equiv \frac{p_{T2}}{M_T} \qquad \alpha_T = \frac{\sqrt{p_{T2}/p_{T1}}}{\sqrt{2(1-\cos\Delta\phi)}}$$

- Well measured back-to-back di-jet system $\alpha_T \approx 0.5$, if one jet is mis-measured $\alpha_T < 0.5$







H_T =Sum{p_T(jets)}

Study fraction of events with $\alpha_T > 0.55$

✓ **The data shows the expected sharp fall around $\alpha_T \sim 0.5$, improves for higher H_T**

Conclusion

- CMS is working well
- We need luminosity…
  - More energy would be good too, but for that we have to wait a couple more years