Current Status and Prospects for W and Z Cross Section Measurements at CMS

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on behalf of the CMS Collaboration

The Physics of W and Z Bosons

RIKEN BNL Research Center Workshop

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Outline

- Motivation
- CMS Performance
- Inclusive Production of Z and W
  - Z → μμ / ee
  - W → μν / eν
- Z Rapidity & W Charge Asymmetry
- W/Z + Jets

Detector Commissioning :

- Muons
- Electrons
- Jets
- MET

Data!

Data-driven Techniques :

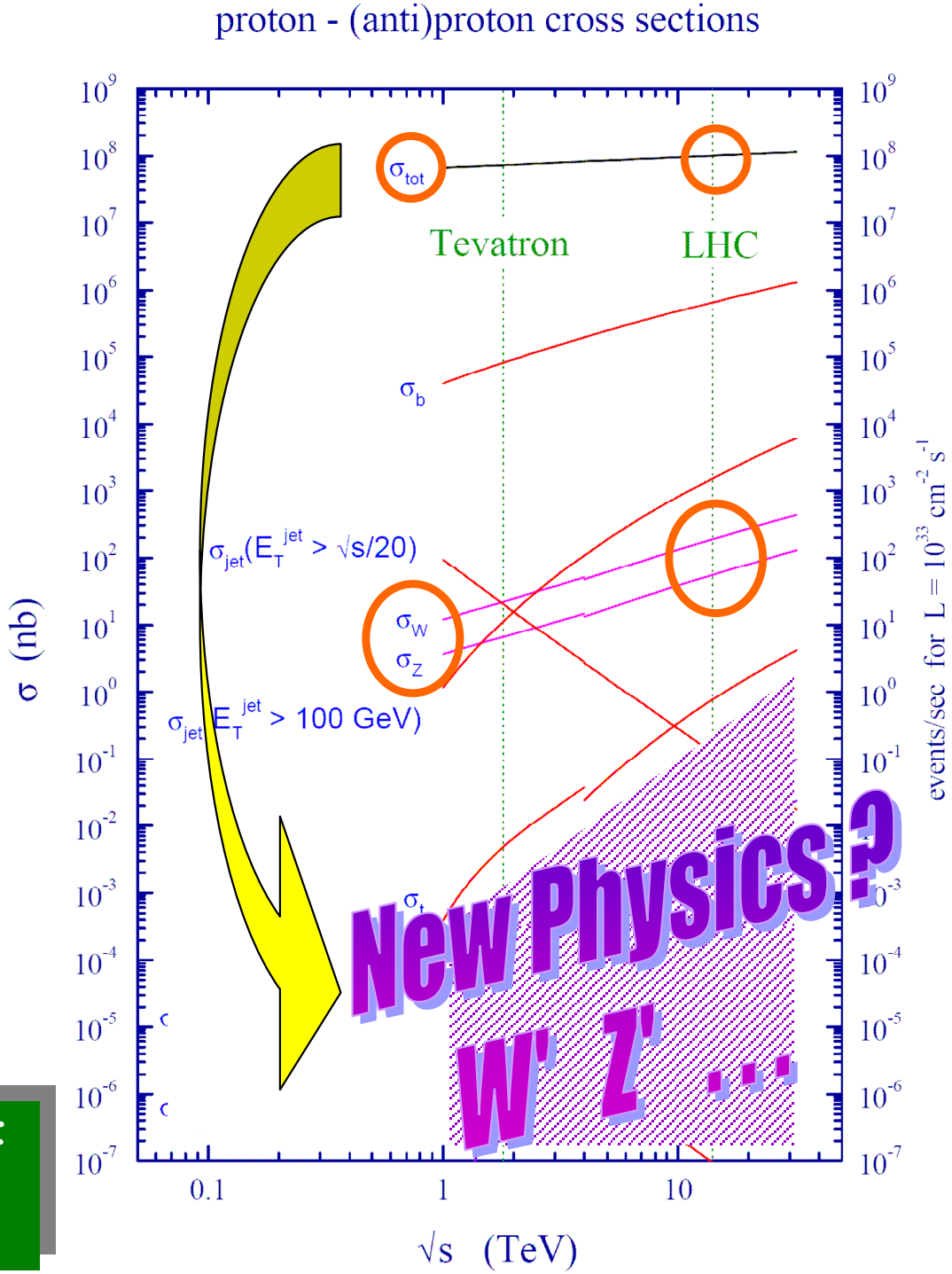
- Tag-and-Probe Method
- Matrix Method
- Template Method

Motivation

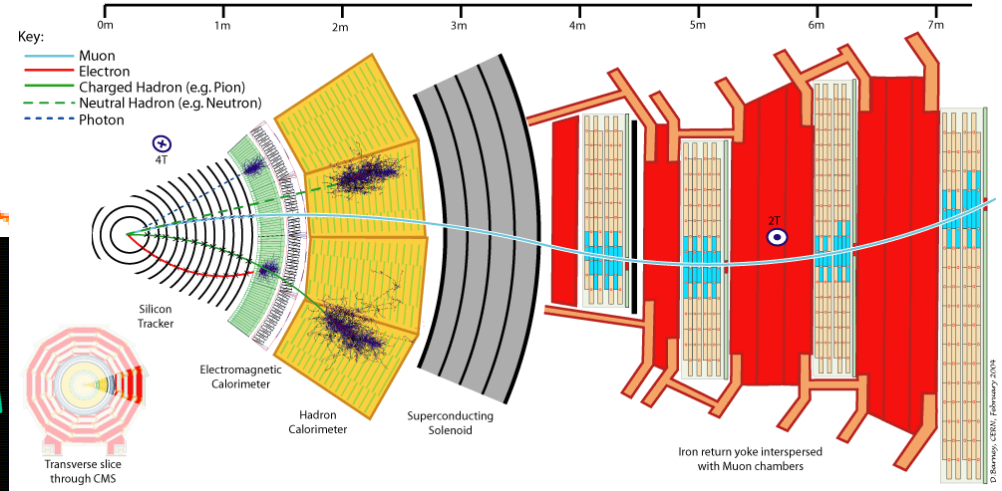
Properties of W, Z are <u>well known</u>
- mass & width
- production & decay modes
- cross sections

>> Can use W, Z as „**candles**" to understand
- detector
- luminosity (~machine)
- initial state (PDF)
- backgrounds
- data-driven methods

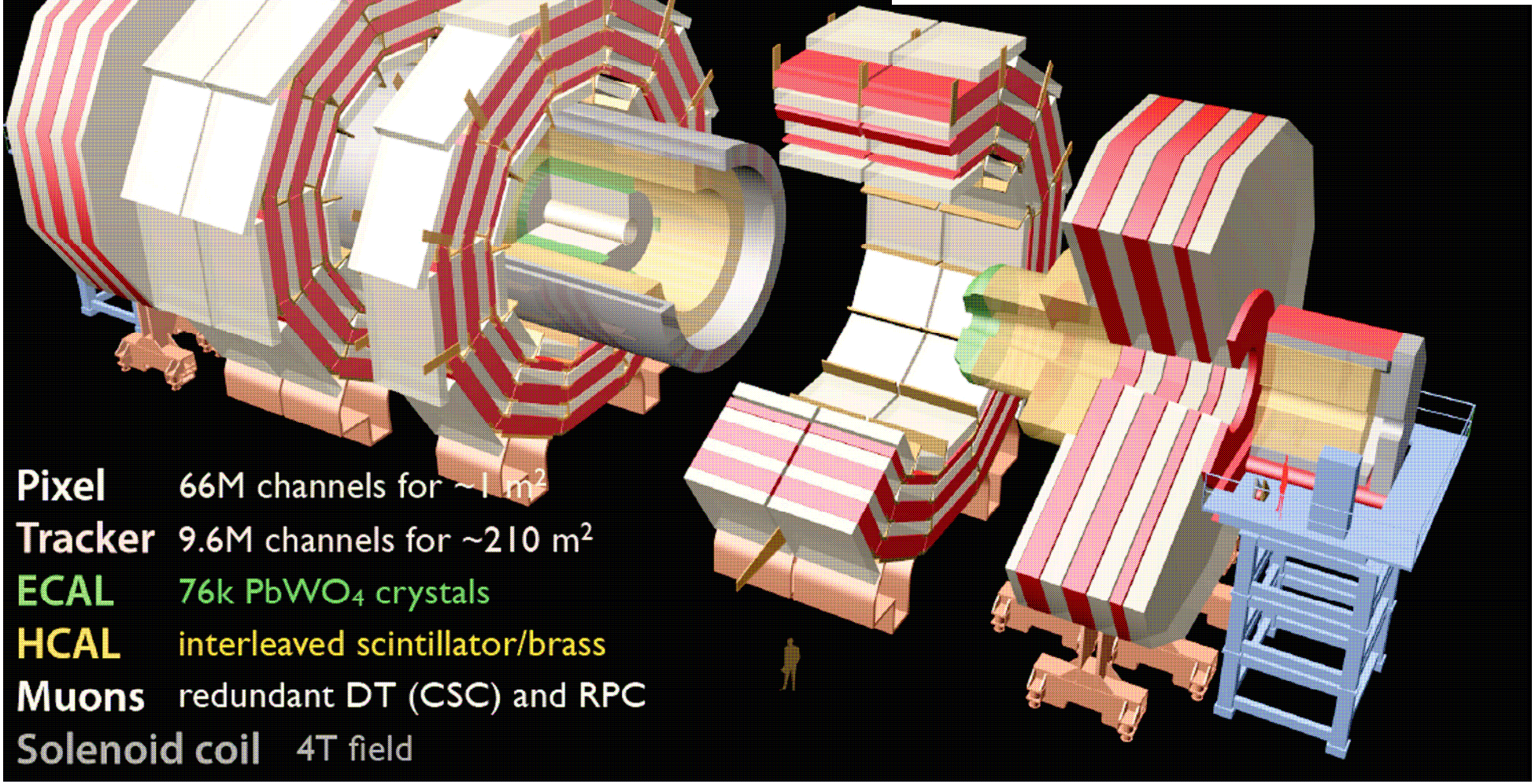
>> Clean signals for analysis of first nb^{-1} ... pb^{-1} of data



CMS Detector



Total weight 12500 t
Overall diameter 15 m
Overall length 21.6 m

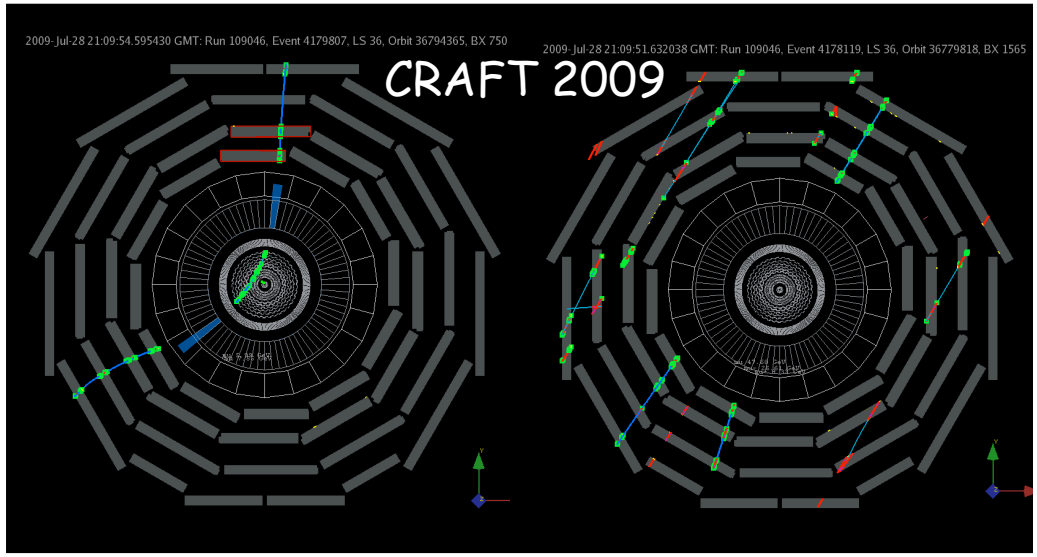


Pixel 66M channels for ~1 m²
Tracker 9.6M channels for ~210 m²
ECAL 76k $PbWO_4$ crystals
HCAL interleaved scintillator/brass
Muons redundant DT (CSC) and RPC
Solenoid coil 4T field

CMS - A brief historical overview . . .

Cosmic Ray Runs

- Fall 2008, 2009
- months-long commissioning runs
- 23 detector commissioning papers (Special issue of JINST 05)



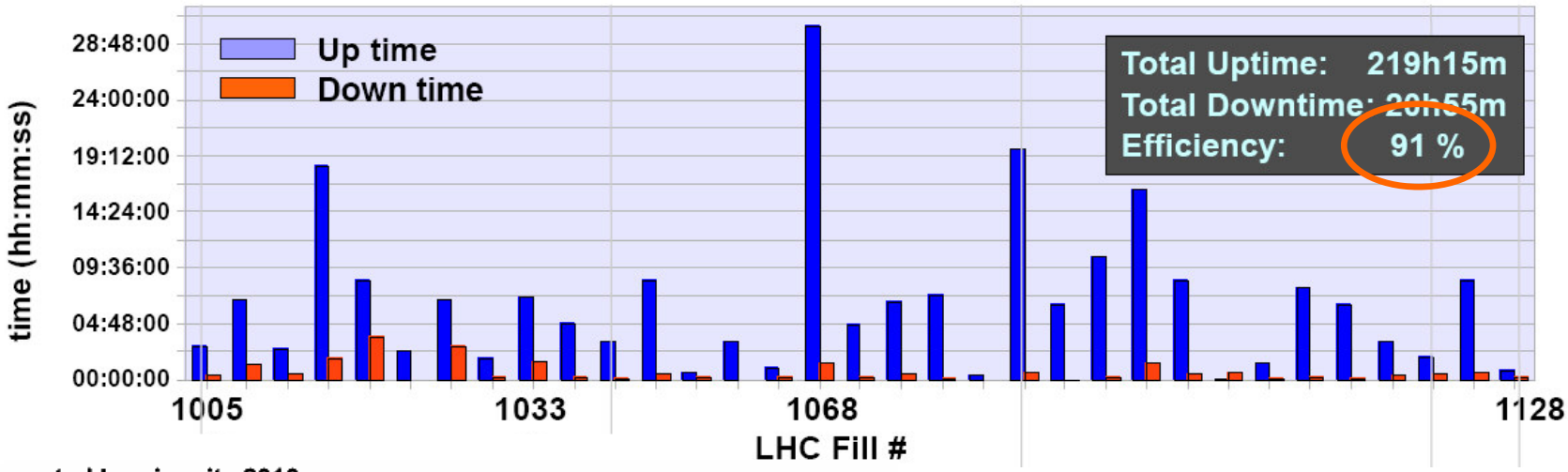
Beam Collisions

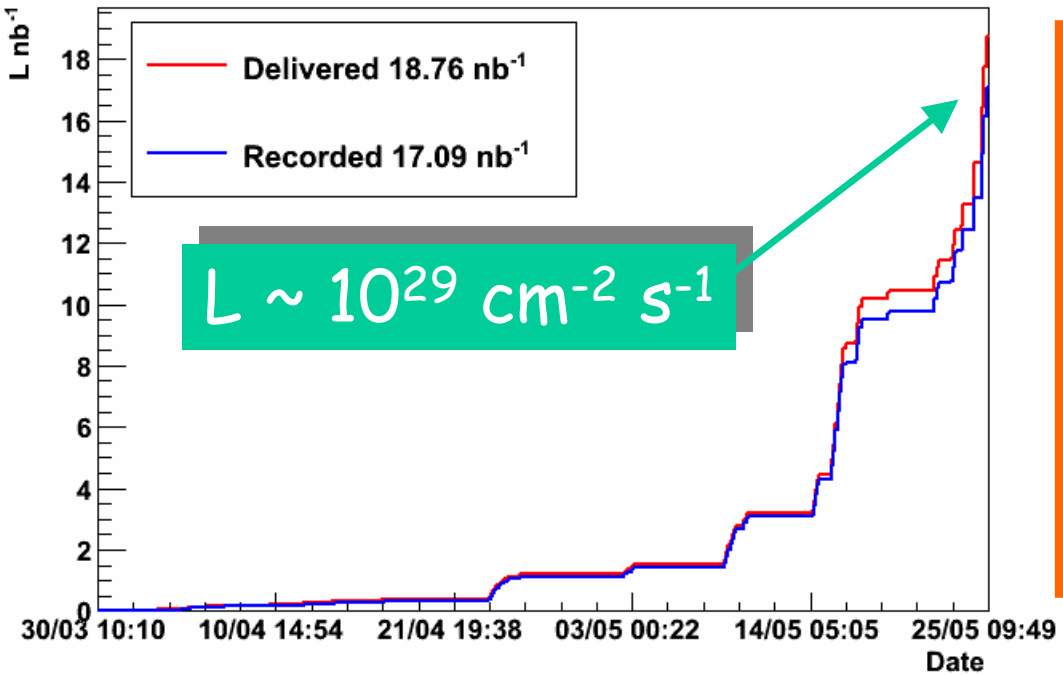
- Nov/Dec 2009
  @ 900 GeV center-of-mass energy
  (LHC injection energy)
  @ 2.36 TeV

- since March 30, 2010
  @ 7 TeV (+ some runs @ 900 GeV)

March 30, 2010 1st Collision seen @ CMS

CMS Performance



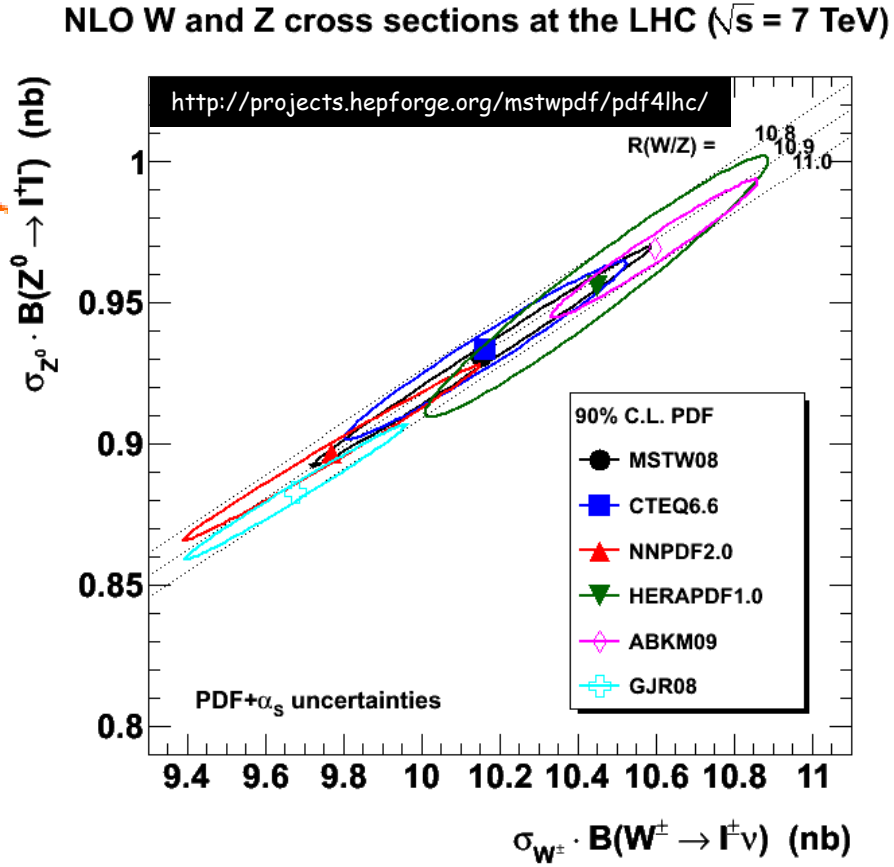


Detector	In readout (%)
Pixel	98.2
Strips	98.1
ECAL Crystals	99.2 (EB=99.3%, EE=98.9%)
ECAL Preshower	99.8
HCAL	99.2 (HB=99.9%, HE=100.0% HF=99.9%, H0=96.9%)
DT	99.8
RPC	98.8
CSC	98.5

W/Z : General Remarks

Rather large cross sections into leptons

Process ($\sqrt{s}$=7 TeV)	$\sigma_{(CTEQ6.6)}$	PDFs ⊕ α_s uncertainties
W^-	38.0 nb	+1.33 nb -1.39 nb
W^+	56.05	+1.90 nb -1.96 nb
Z^0	28.11	+0.91 nb -0.95 nb



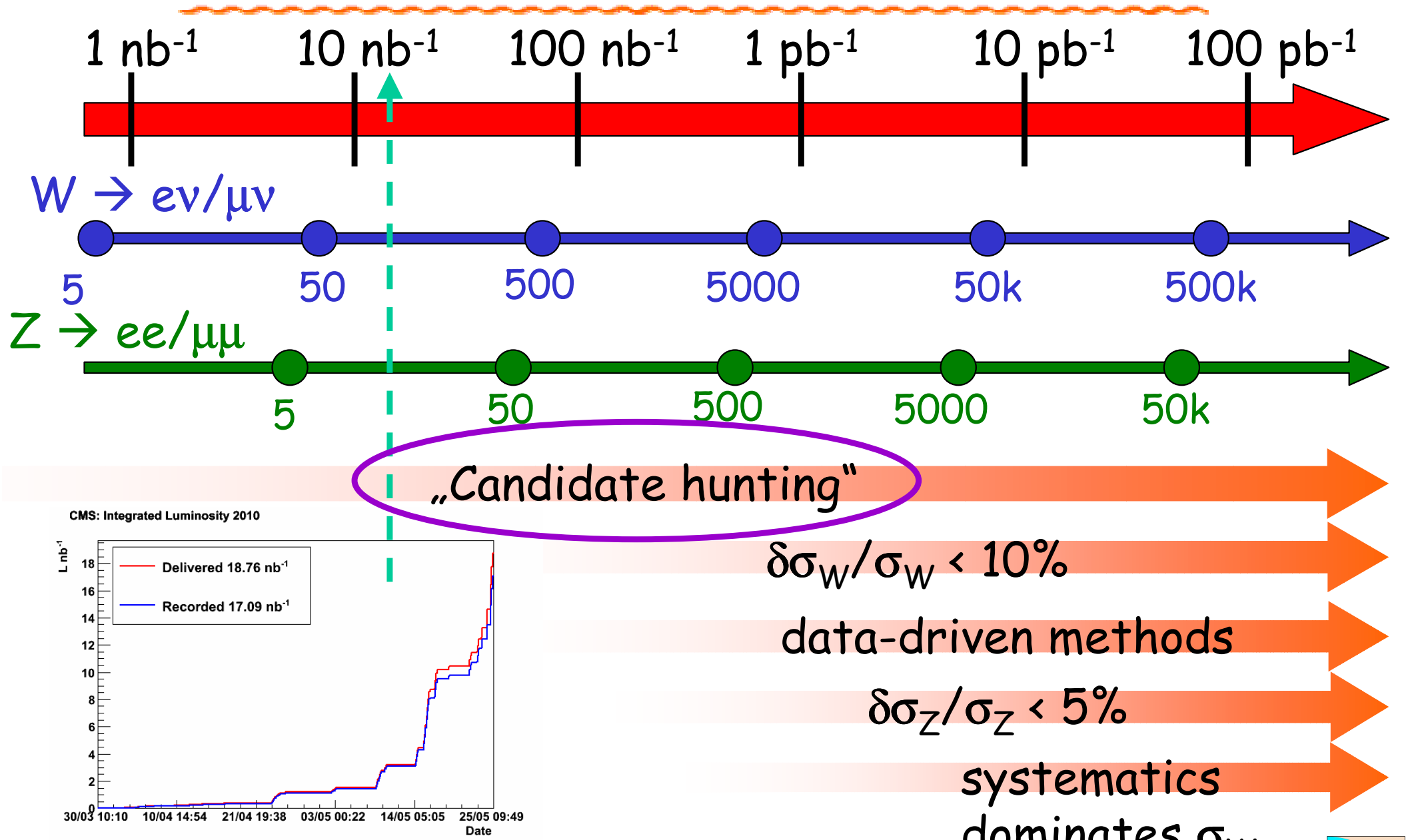
Masterformula :

$$\sigma \times Br(\ W/Z \rightarrow \text{leptons}\ ) = \frac{\#\text{observed events} - \#\text{background events}}{\text{efficiency} \times \text{acceptance} \times \text{luminosity}}$$

cross section measurement ←→ luminosity measurement

First data :
simple object identification with **high** purity
→ understand data & determine efficiencies from data

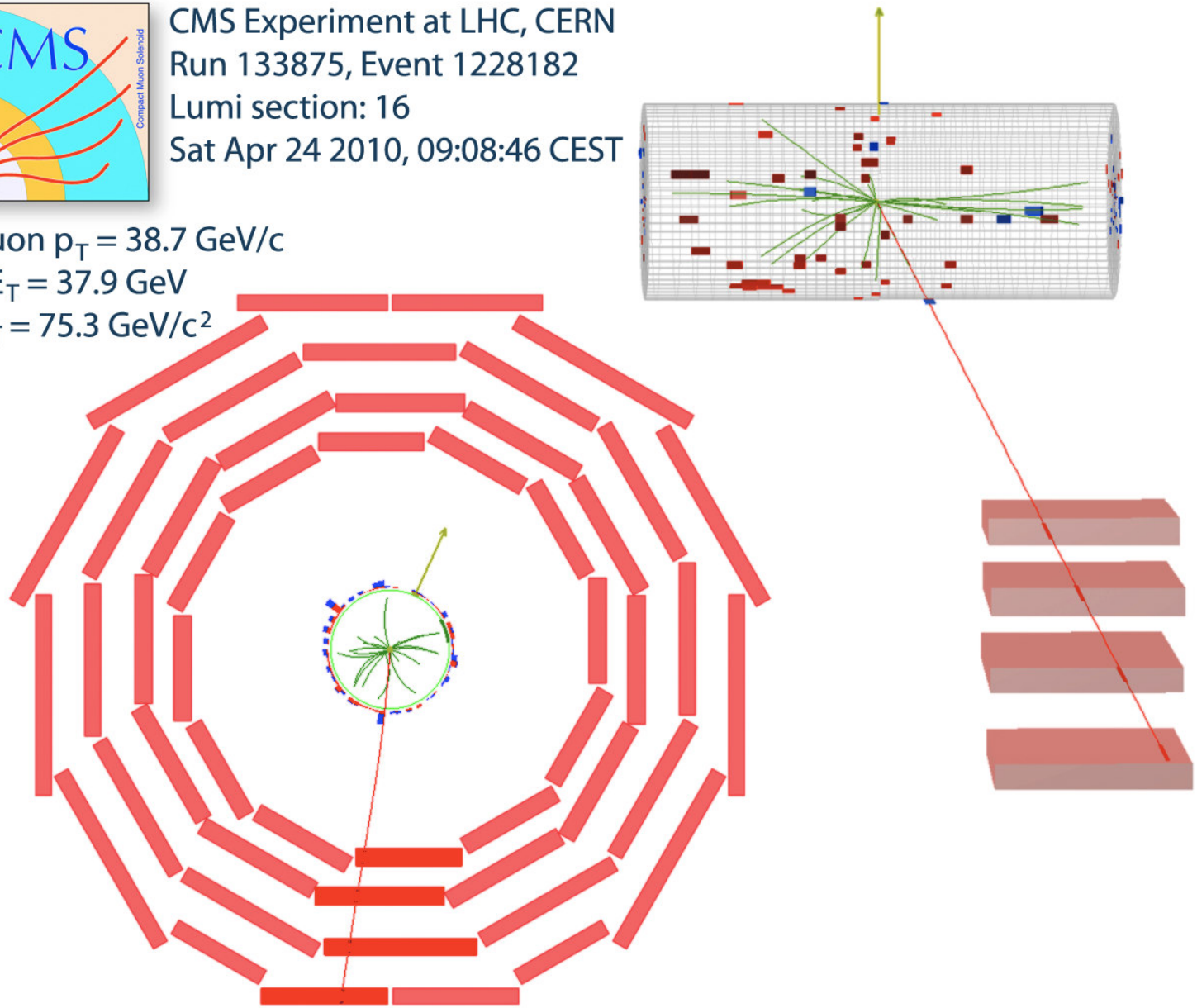
Roadmap


1 nb-1
10 nb-1
100 nb-1
1 pb-1
10 pb-1
100 pb-1
W → eν/μν
5
50
500
5000
50k
500k
Z → ee/μμ
5
50
500
5000
50k
„Candidate hunting"
CMS: Integrated Luminosity 2010
L nb-1
Delivered 18.76 nb-1
Recorded 17.09 nb-1
30/03 10:10
10/04 14:54
21/04 19:38
03/05 00:22
14/05 05:05
25/05 09:49
Date
δσW/σW < 10%
data-driven methods
δσZ/σZ < 5%
systematics
dominates σW

W → μ ν : Candidate Event

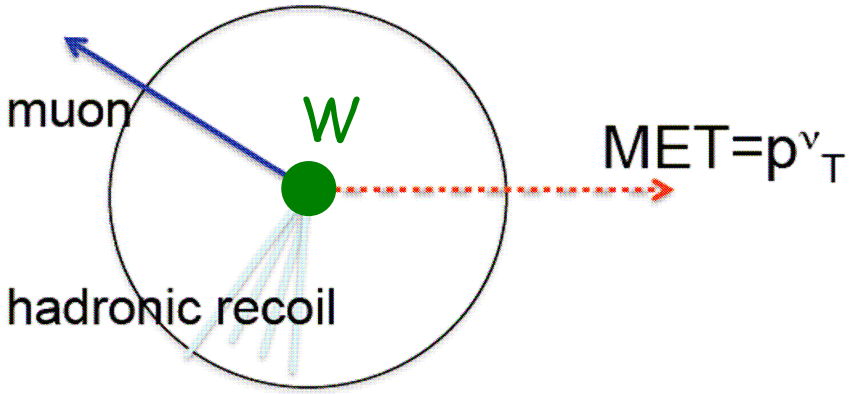
CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST

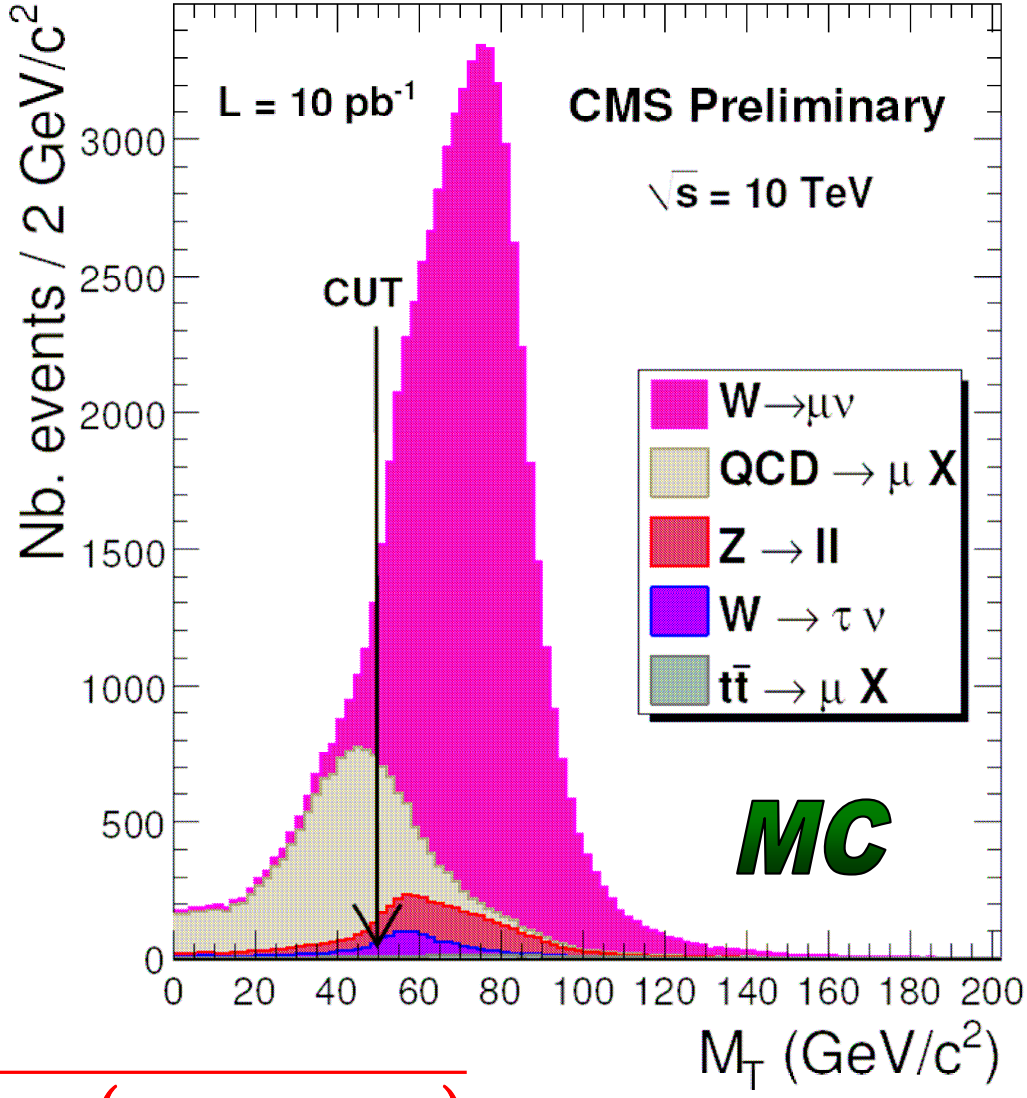
Muon $p_T = 38.7$ GeV/c
$ME_T = 37.9$ GeV
$M_T = 75.3$ GeV/c^2



W → μ ν : Selection

Selection :
1 Muon with p_T > 25 GeV in |η| < 2,
isolated (tracker),
muon fired trigger

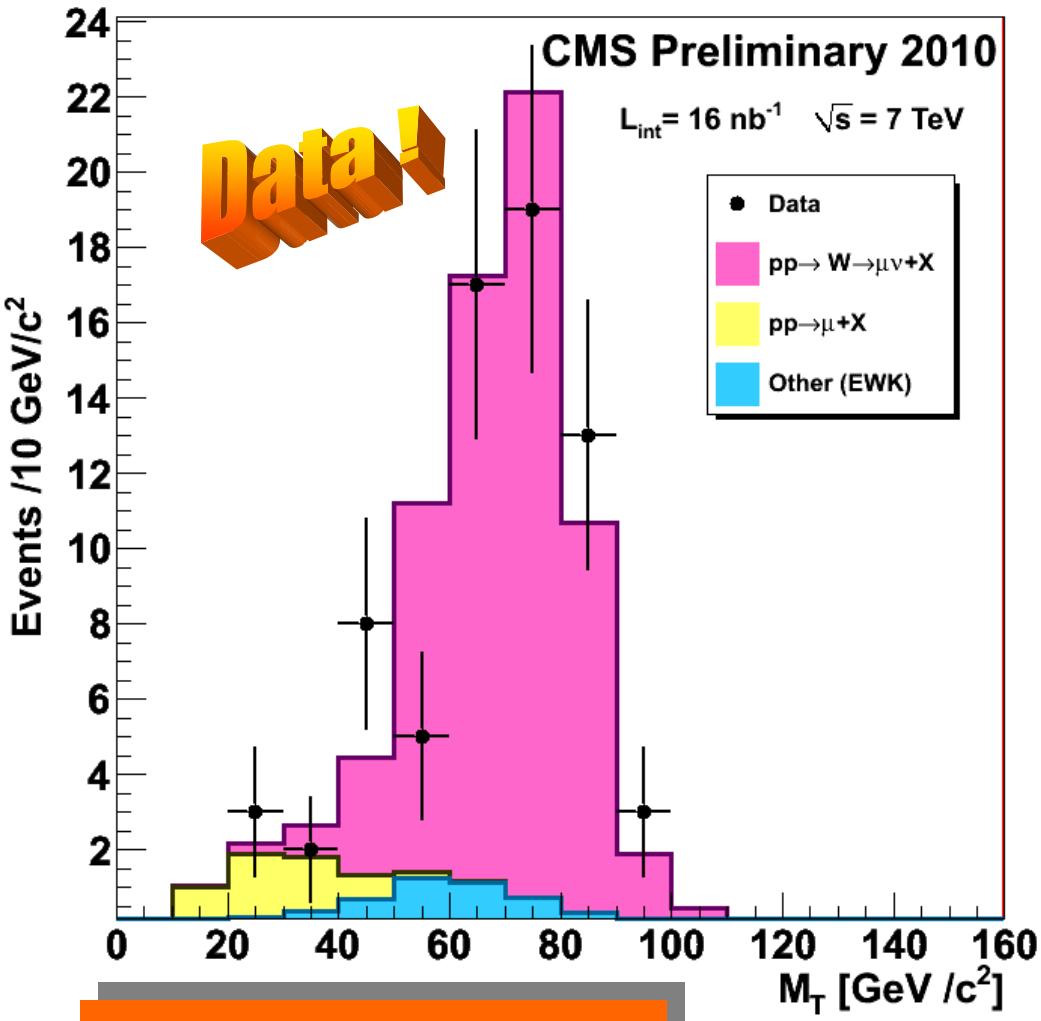




Neutrino escapes
→ observe missing energy in transverse plane (MET)

Reconstruct :
Transverse mass $m_T = \sqrt{2 \not{E}_T p_T^{\mu} (1 - \cos \Delta\varphi)}$

W → μ ν : Data - Monte Carlo Comparison



Total : 70
m_T > 50 GeV : 57

EWK Cross sections :
MCFM NLO using
MSTW08 NLO PDF

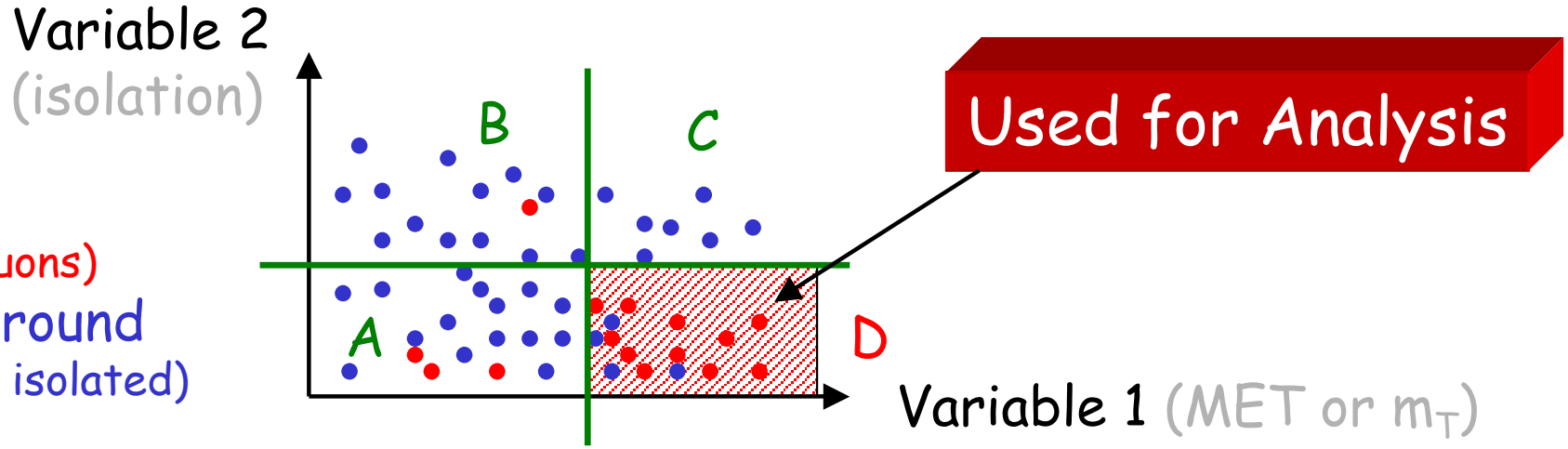
W Signal shape :
POWHEG NLO
EWK shapes :
mixed (POWHEG, PYTHIA)
QCD shape :
PYTHIA LO (k = 1)

Data-Driven (later)

W → μ ν : Matrix Method

Contributions from QCD processes difficult to predict
→ Estimate from data using the **Matrix Method**

Signal
(isolated muons)
QCD Background
(usually not isolated)



Assume :
Two variables are uncorrelated

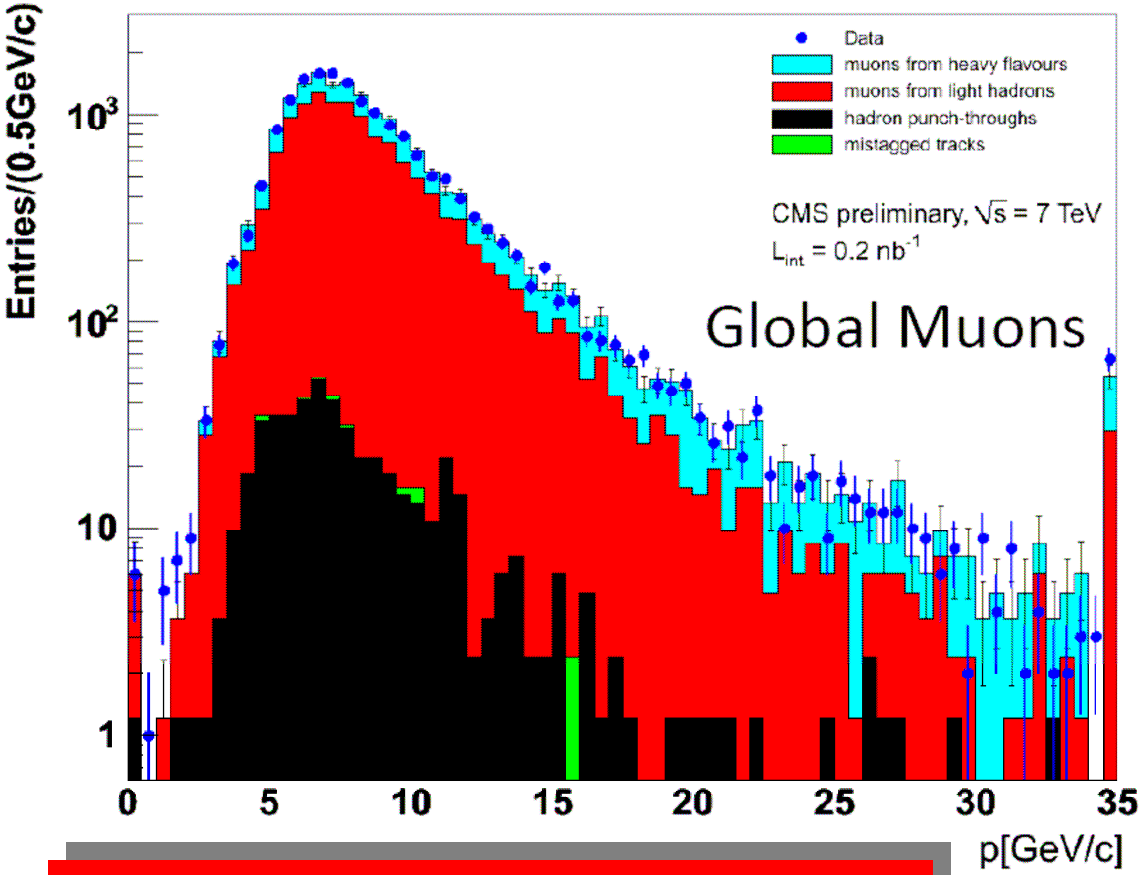
$$N_{QCD} \equiv N_D = N_A \cdot \frac{N_C}{N_B}$$

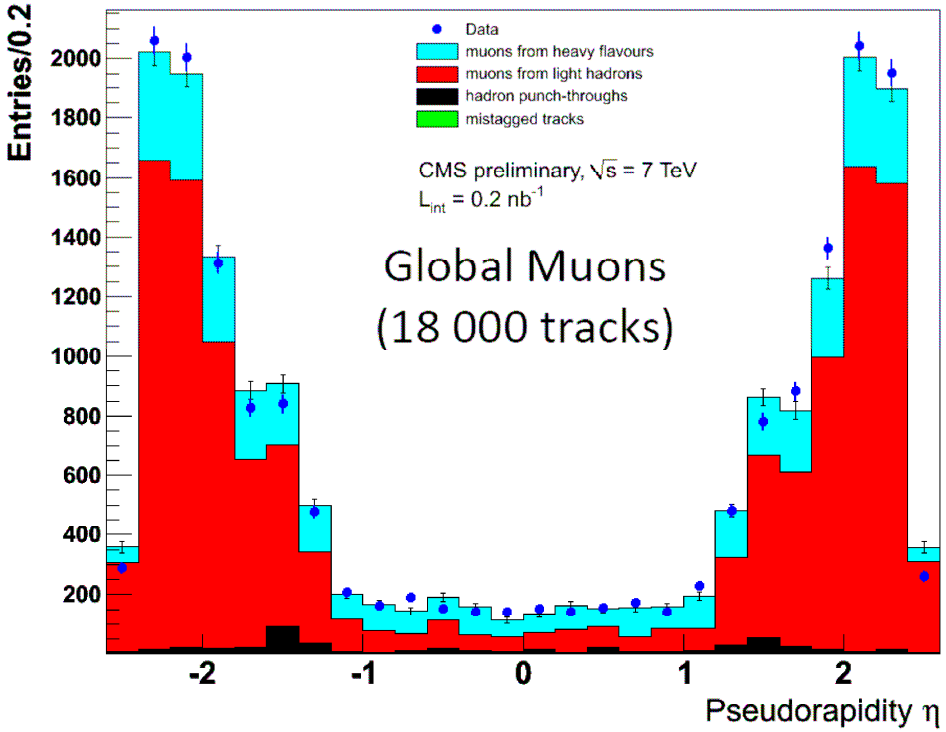
Important :
Correct for correlations & signal contamination in A, B, C

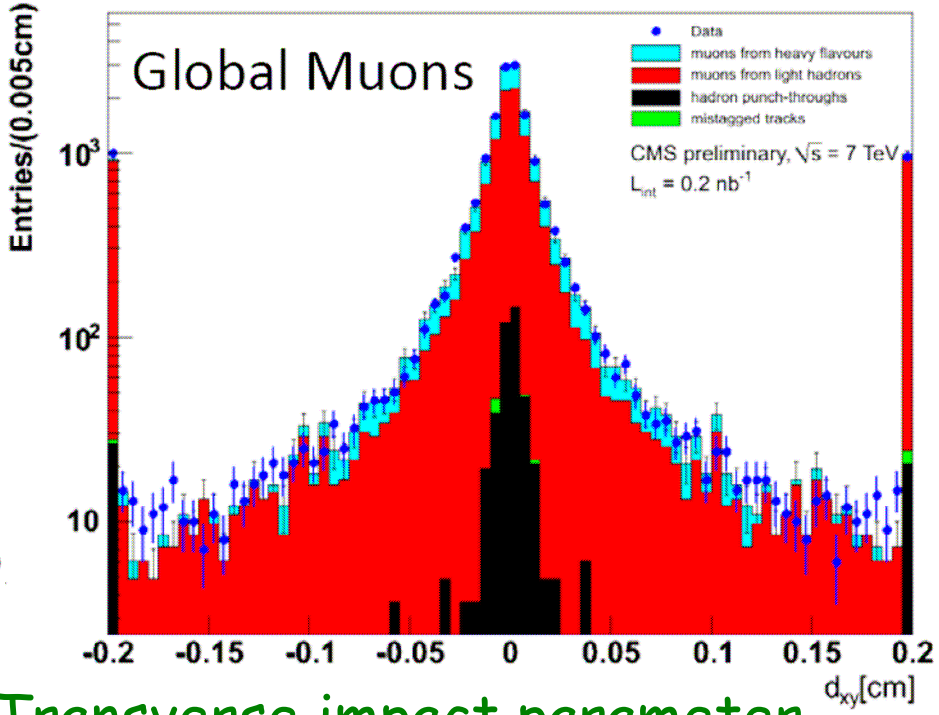
Muon Performance

„Global Muon“ : combined fit of all tracker and muon hits

Data!







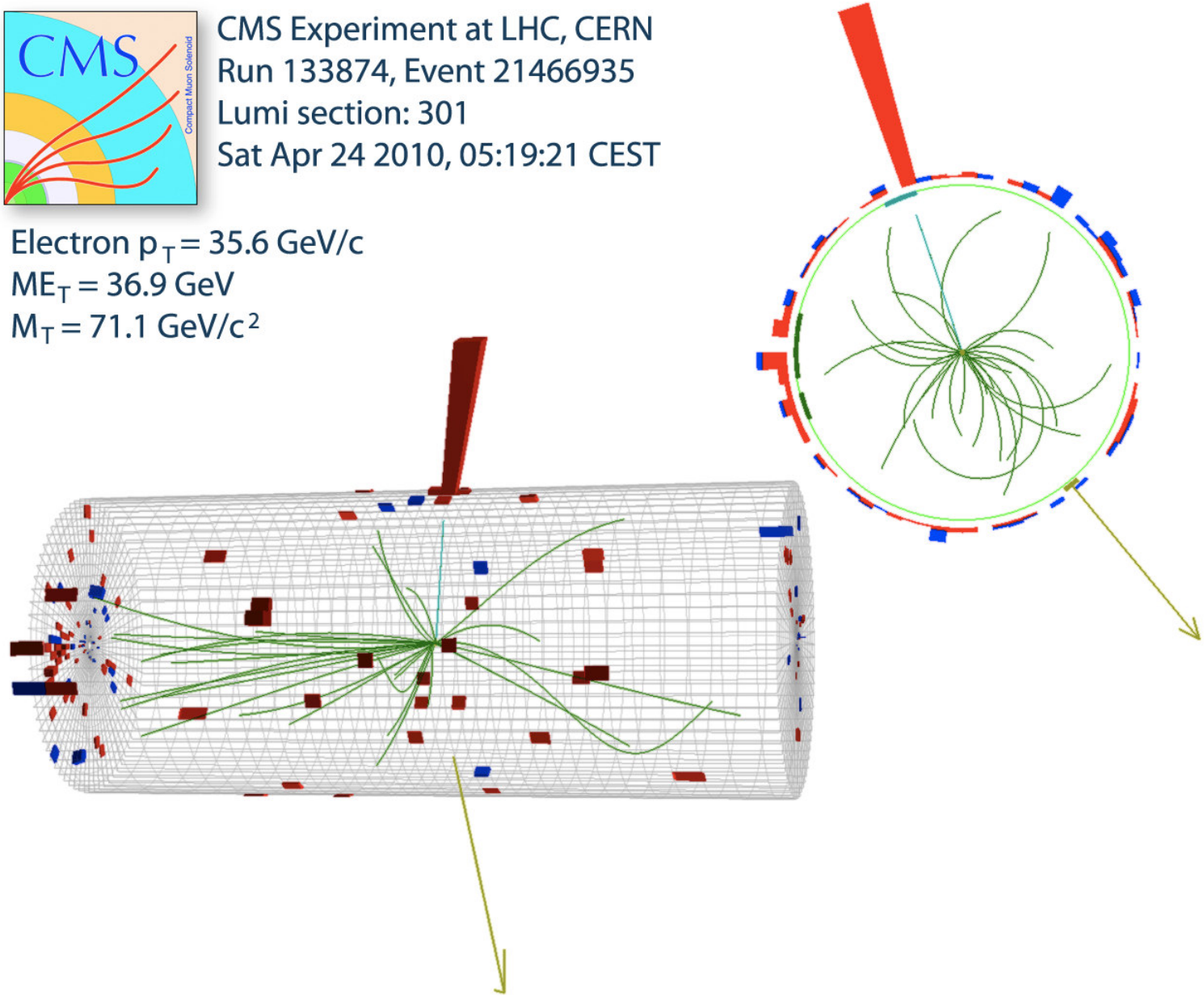
Very good agreement

Transverse impact parameter

W → e ν : Candidate Event

CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

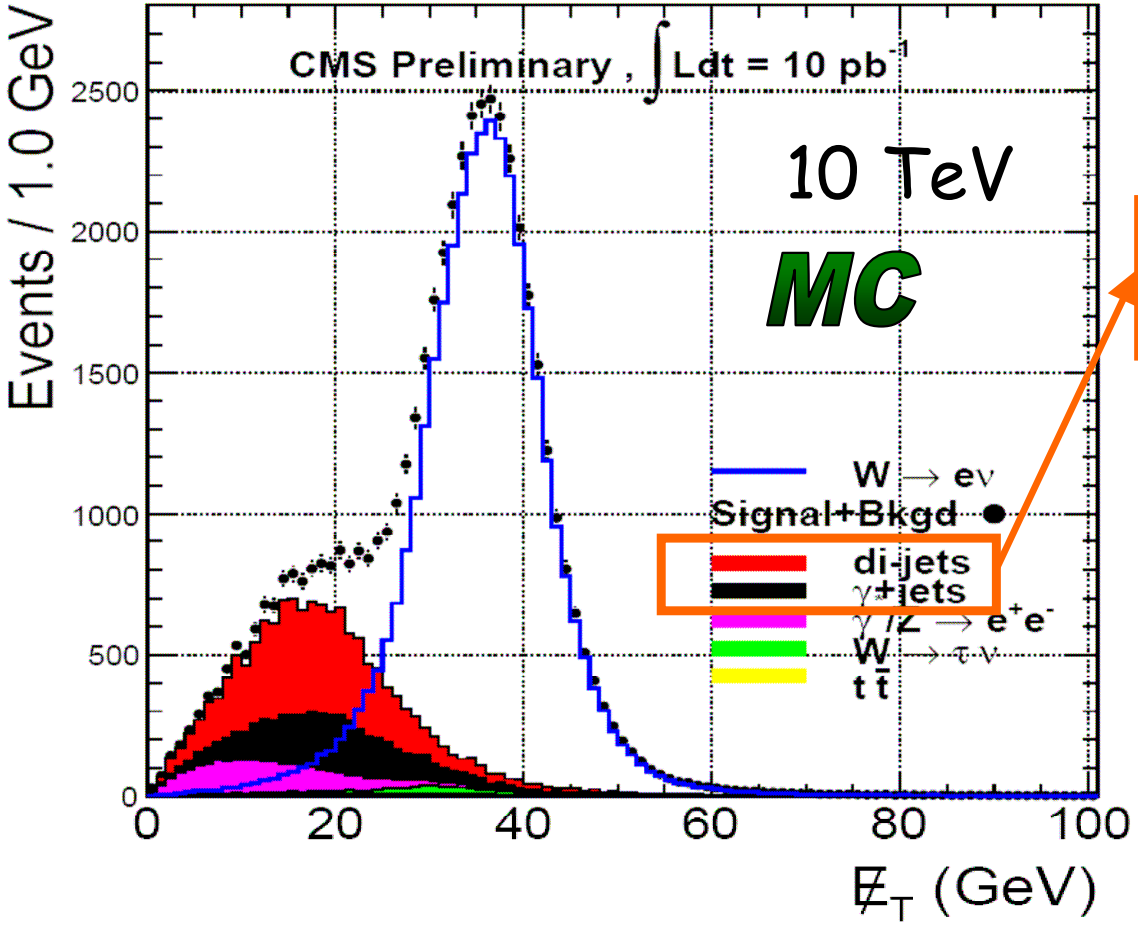
Electron $p_T = 35.6$ GeV/c
$ME_T = 36.9$ GeV
$M_T = 71.1$ GeV/c^2



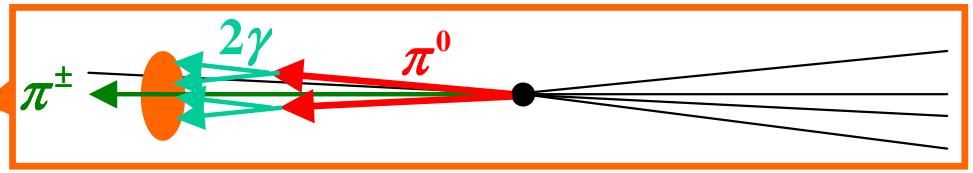
W → e ν : Selection

Selection :

single electron trigger fired, 1 Electron with p_T > 30 GeV in $|\eta|$ < 2.5, identified via track matched to ECal cluster (Gaussian Sum Filter) and cuts on shape variables, veto on further electrons with p_T > 20 GeV



Extract QCD background from **data**



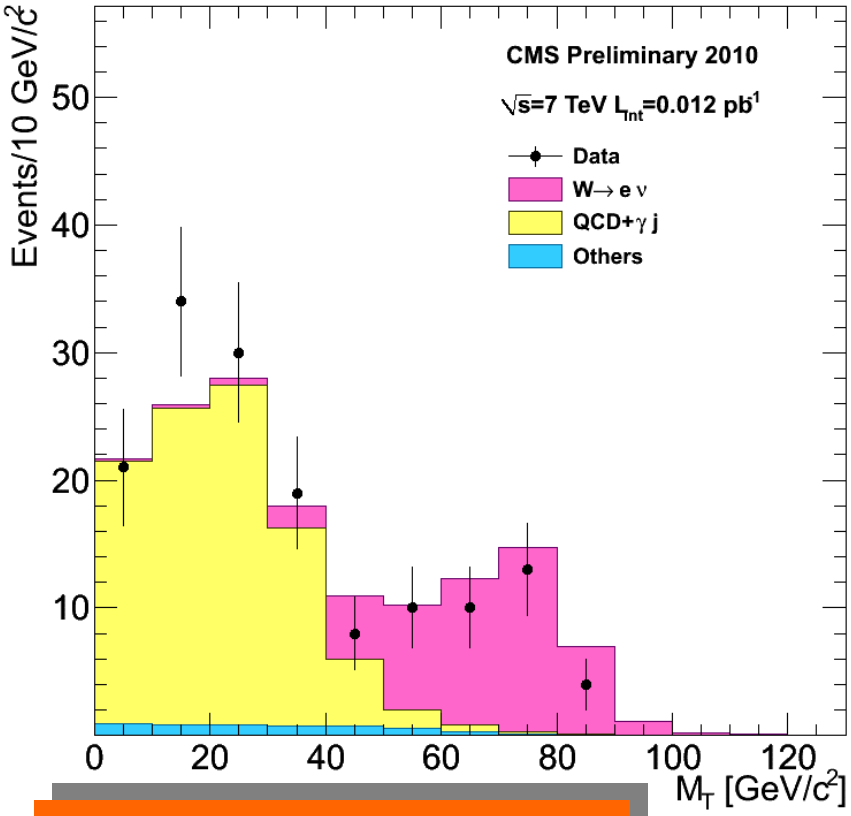
→ Invert isolation cuts within electron ID

Expect total systematic uncertainty 2.4% (method) and 10% for luminosity

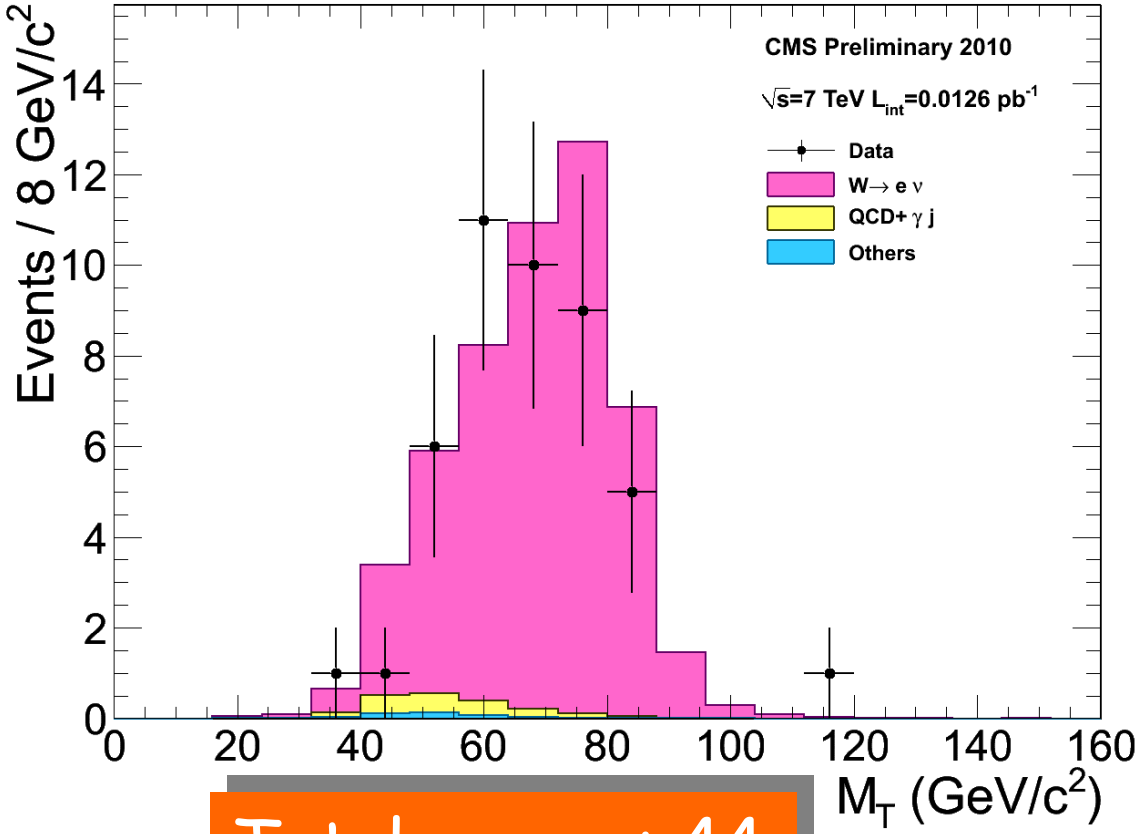
W → e ν : Data – Monte Carlo Comparison

No cut on MET,
robust electron ID

Cuts on MET and Sum(ET),
sophisticated electron ID



Total : 94
m_T > 50 GeV : 37



Total : 44
m_T > 50 GeV : 40

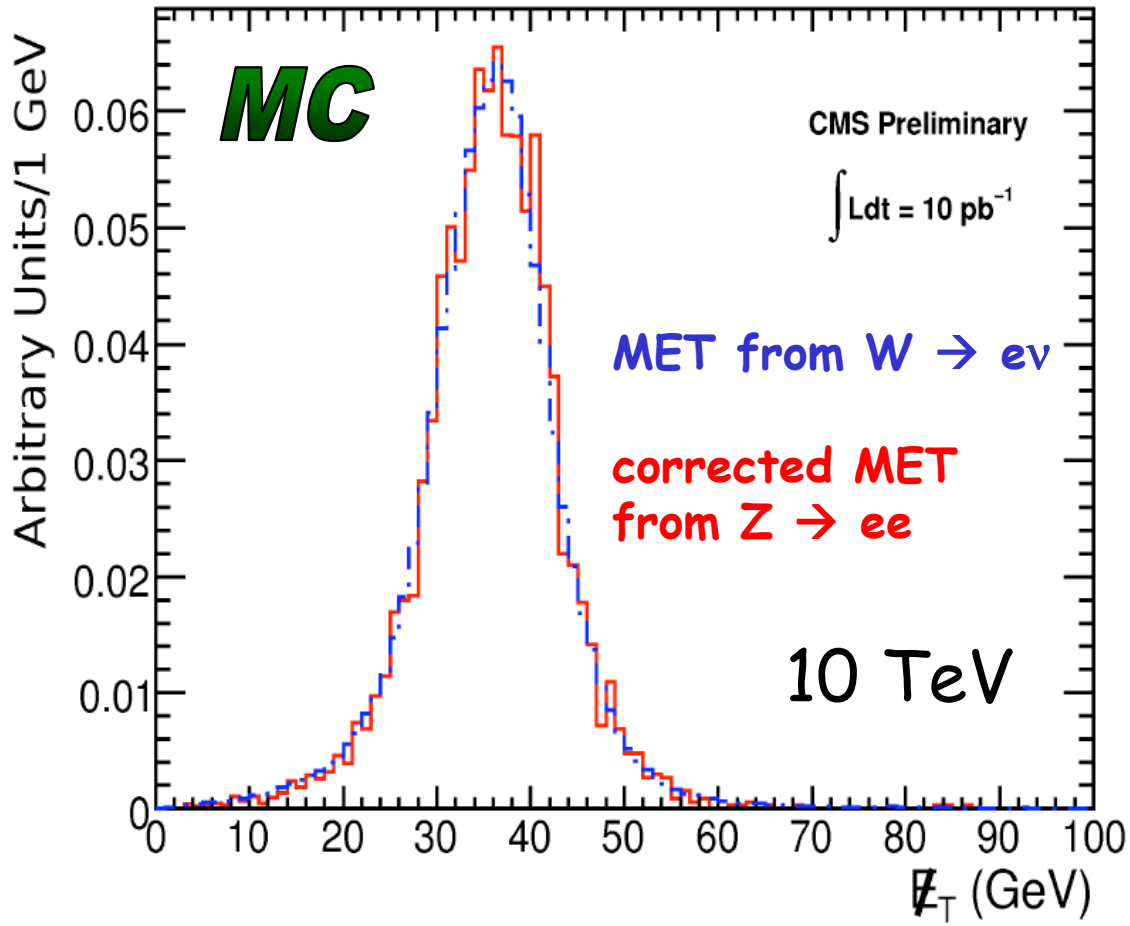
W → e ν : Template Method

MET sensitive to **everything** (real objects, noise) in the detector

→ Use Z events as **„templates"** to estimate MET in W events

- Remove one electron in Z → ee sample
- Take different kinematics into account

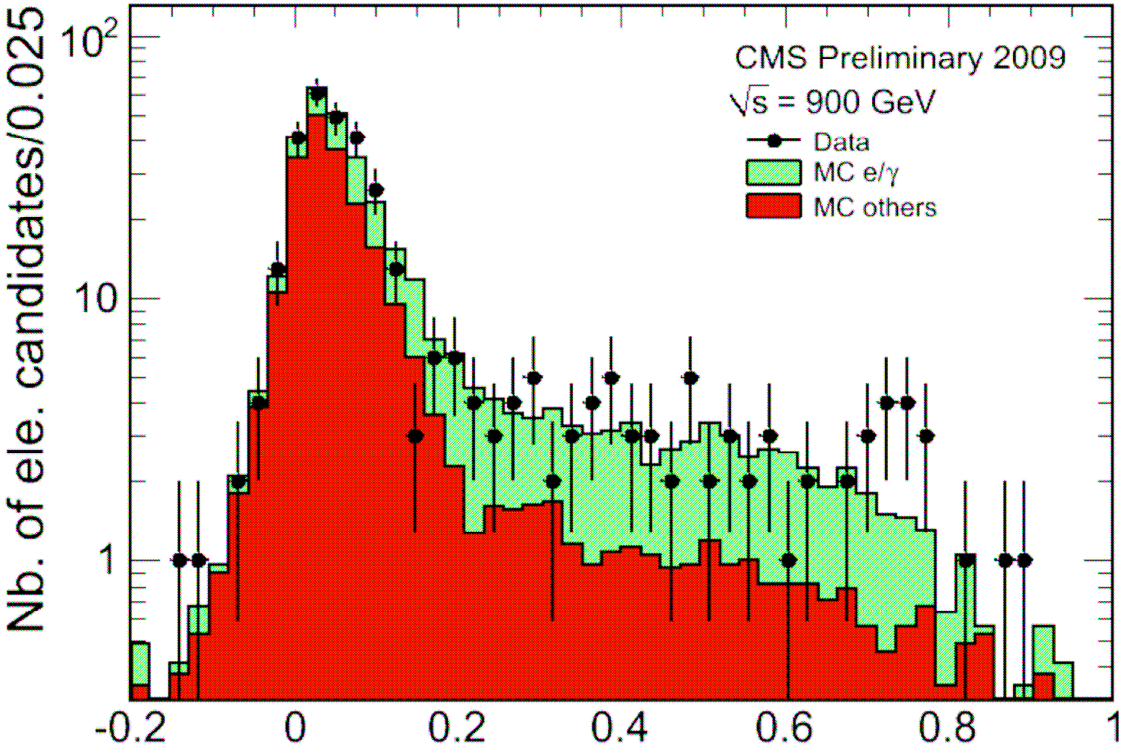
→ Good description of MET



Electron Performance (1)

Gaussian Sum Filter

makes use of high granular tracking Detectors (track seeding)

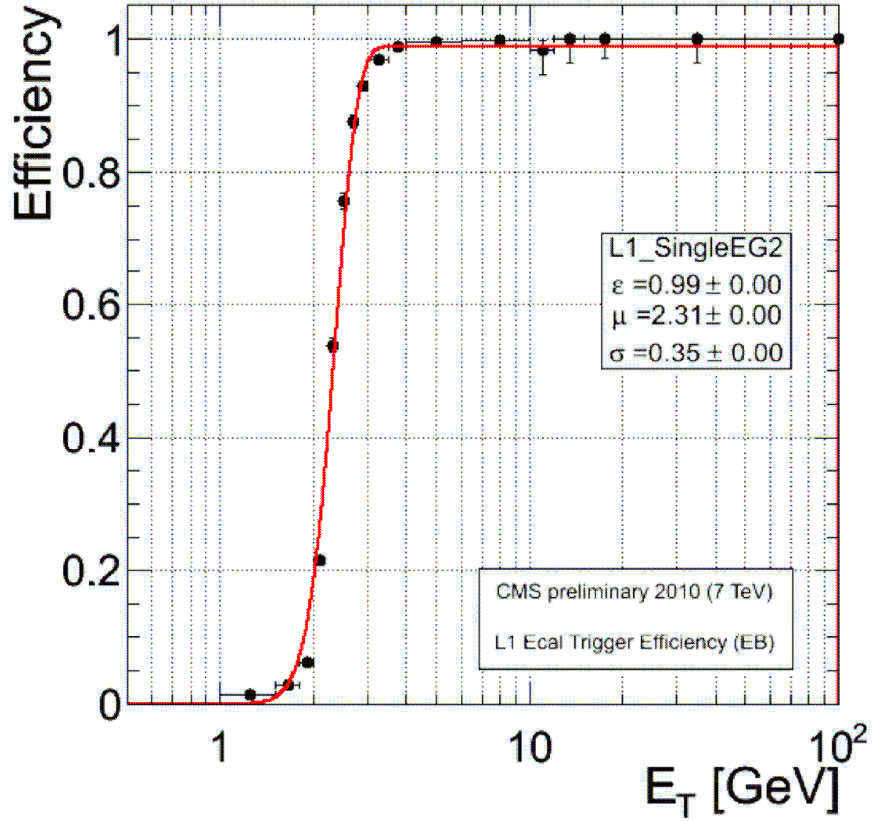


$$f_{brem} = \frac{p_{in} - p_{out}}{p_{in}}$$

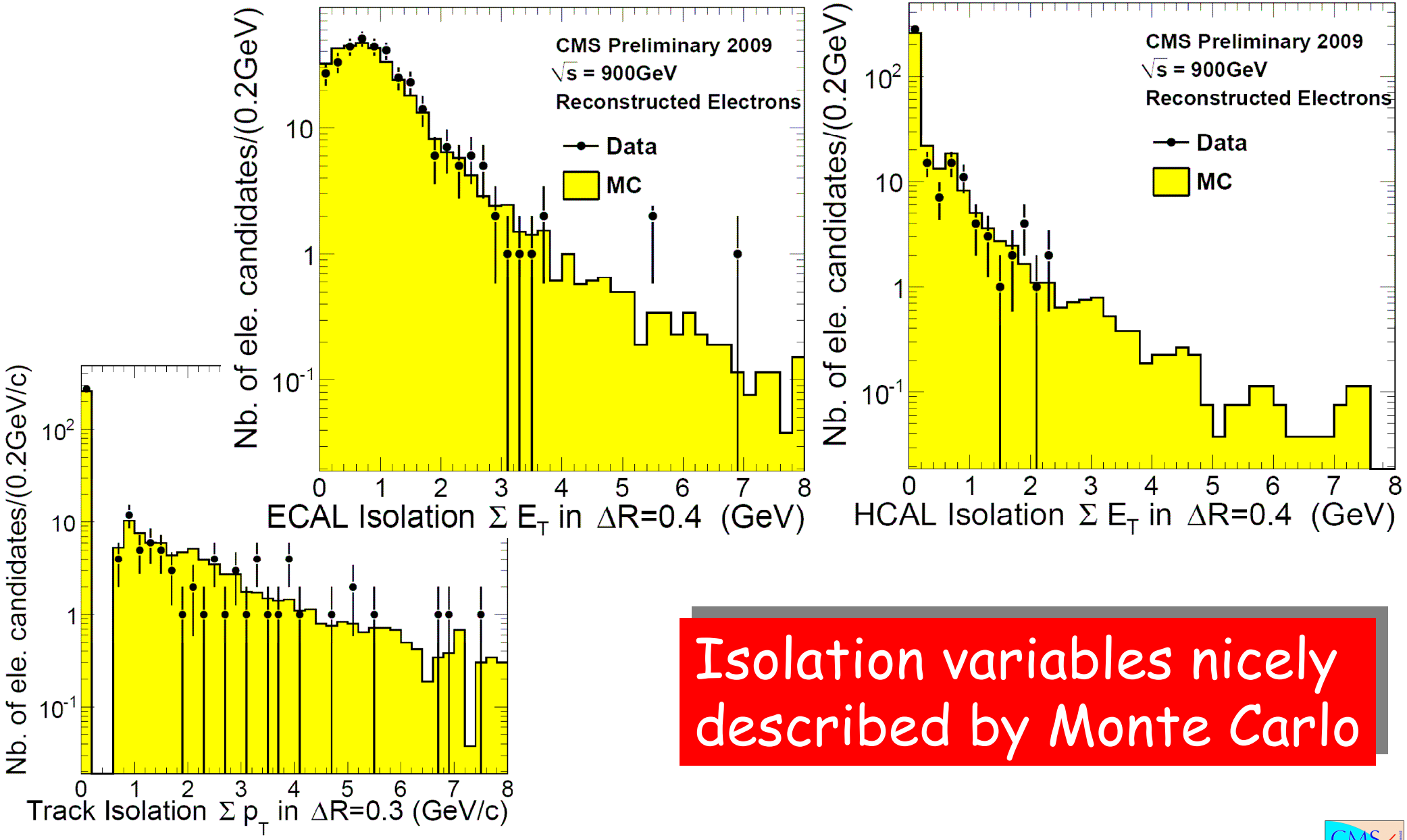
Level 1 trigger efficiency

L1 candidate found offline ?

Nominal trigger threshold : 2 GeV



Electron Performance (2)

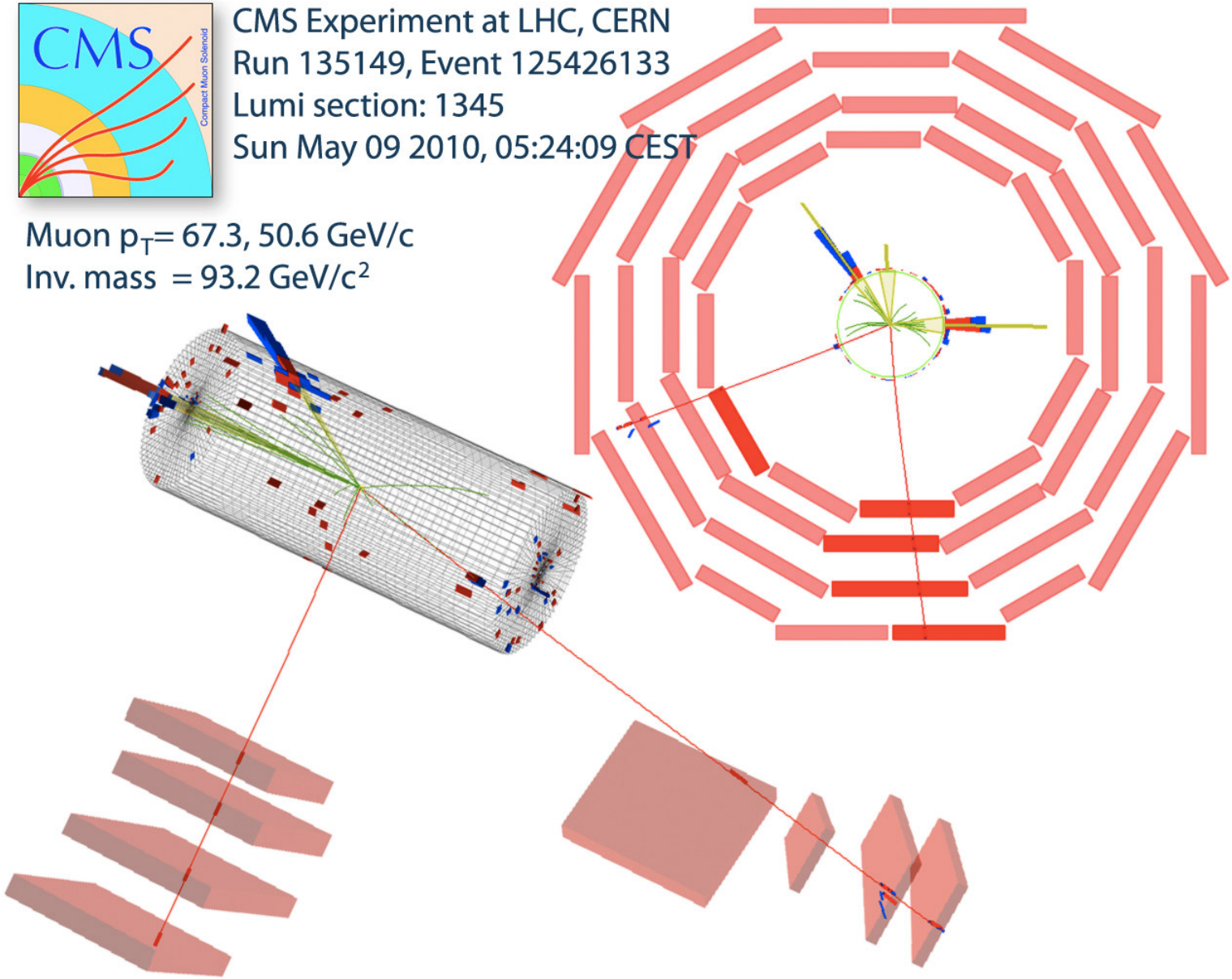


Isolation variables nicely described by Monte Carlo

Z → μ μ : Candidate Event

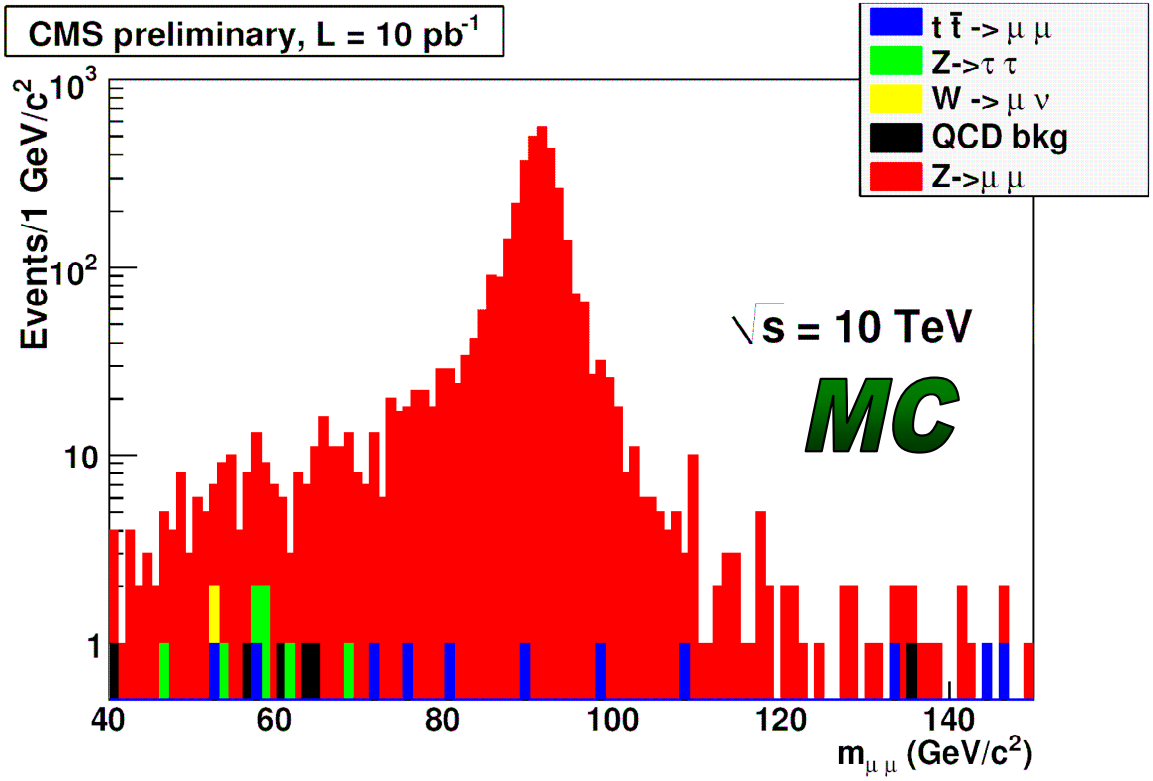
CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

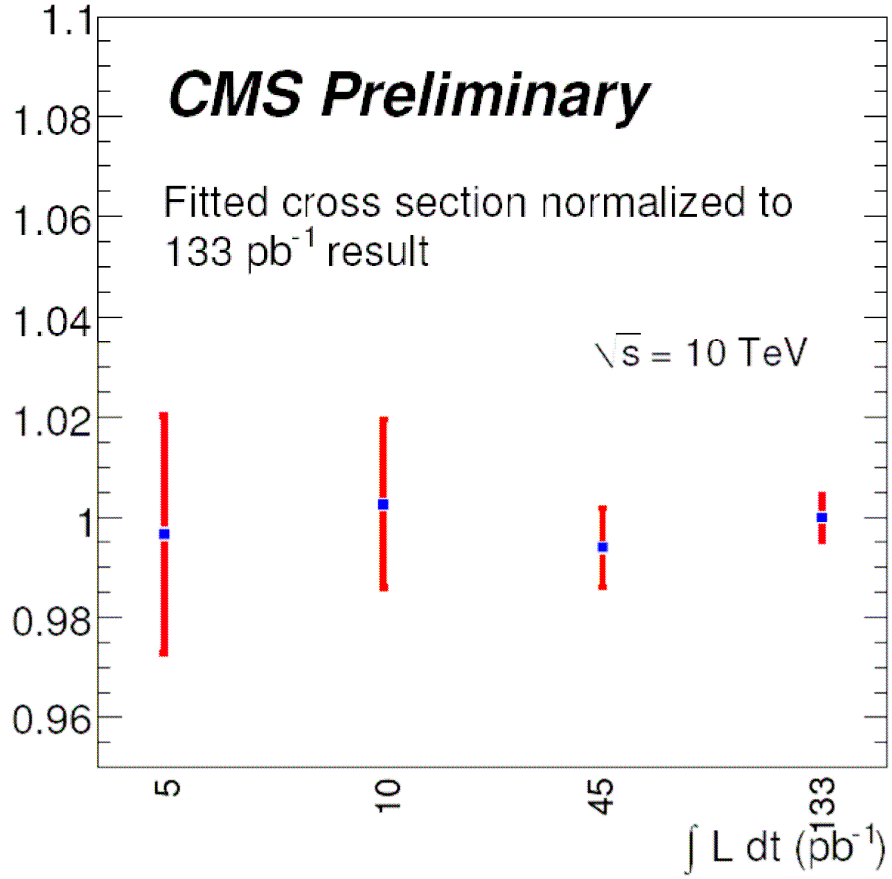
Muon p_T= 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c^2



Z → μ μ : Selection

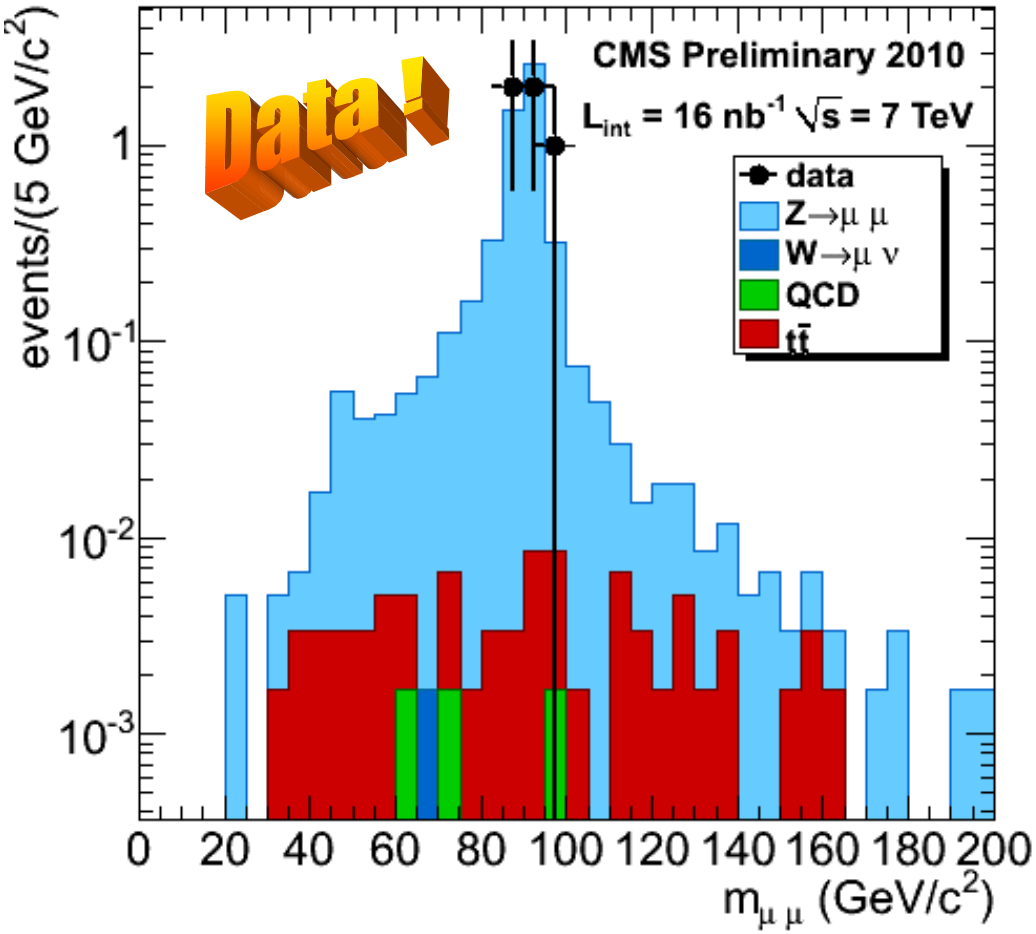
Selection :
2 Muons with p_T > 20 GeV in |η| < 2, isolated (tracker), opposite charge, >= 1 Muon fired trigger





Statistical precision ~0.5% with 100 pb^{-1}

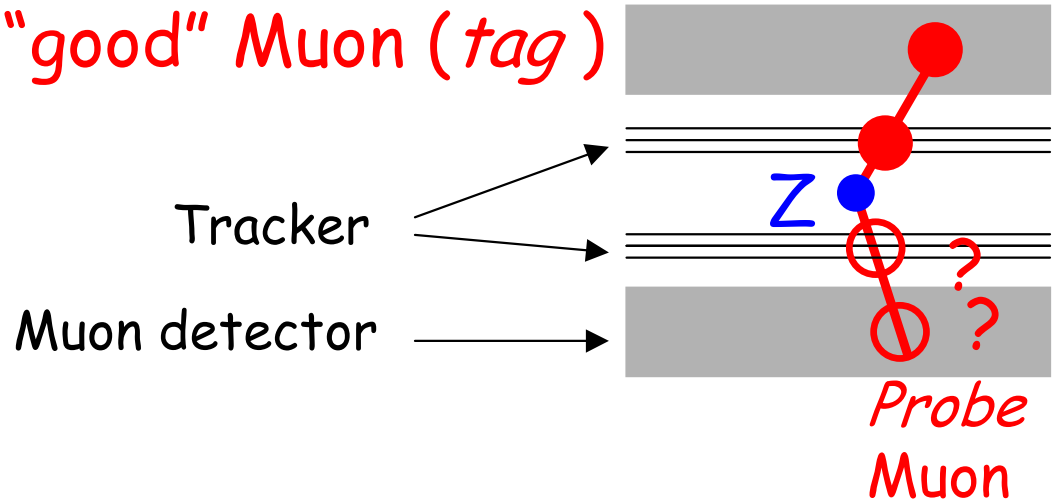
Z → μ μ : Data - Monte Carlo Comparison



Total : 5

Measure efficiencies from data using **Tag-and-Probe Method**

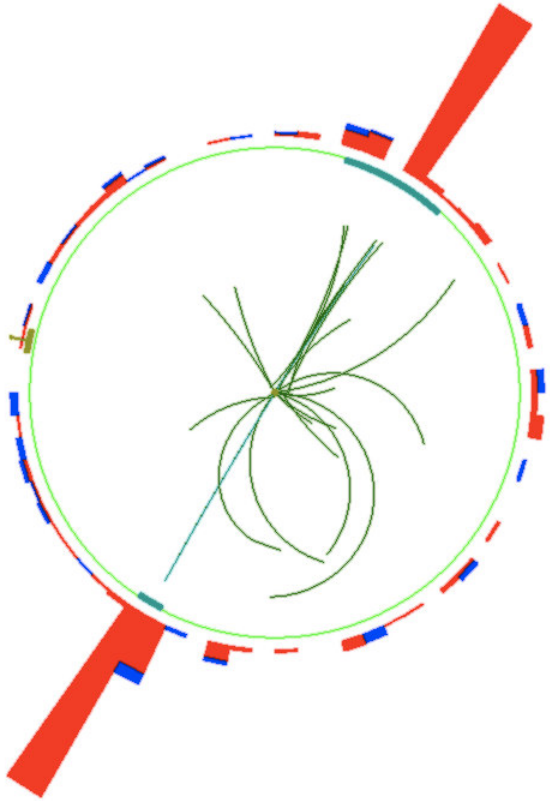
Z decays provide such samples used for muon (and electron) efficiency measurements

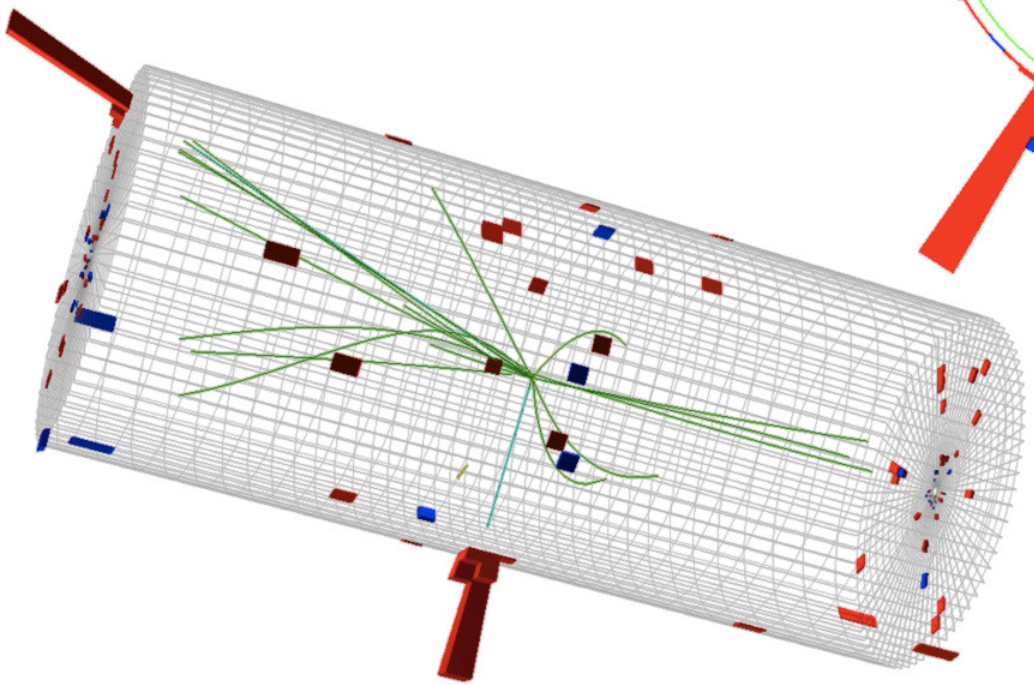


Z → e e : Candidate Event

CMS Experiment at LHC, CERN
Run 133877, Event 28405693
Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST

Electrons p_T = 34.0, 31.9 GeV/c
Inv. mass = 91.2 GeV/c^2

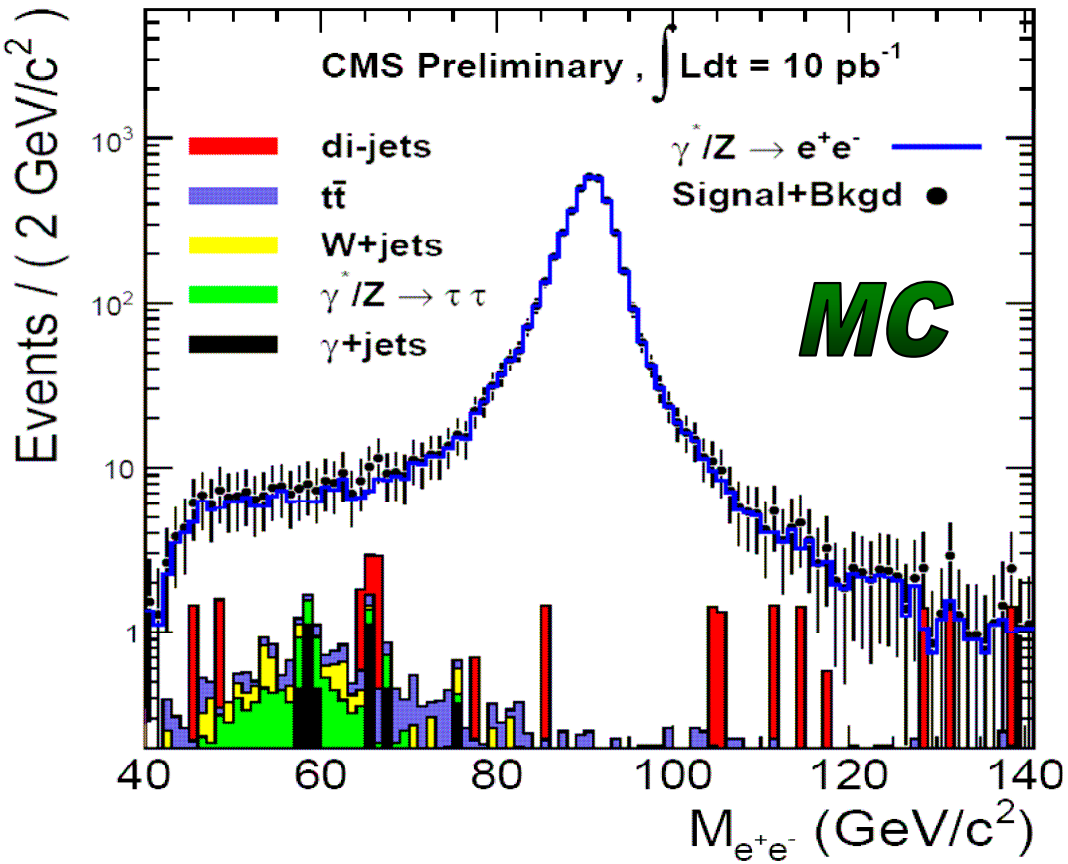




Z → e e : Selection

Selection :

single electron trigger fired, 2 Electrons with $p_T > 20$ GeV $|\eta| < 2.5$, identified via track matched to ECal cluster (Gaussian Sum Filter) and cuts on shape variables



Efficiencies :

ε_{trig} = ~100%

ε_{ID} = 90 %

$\varepsilon_{Tot} = \varepsilon_{ID}^2 * (1 - (1 - \varepsilon_{trig})^2)$

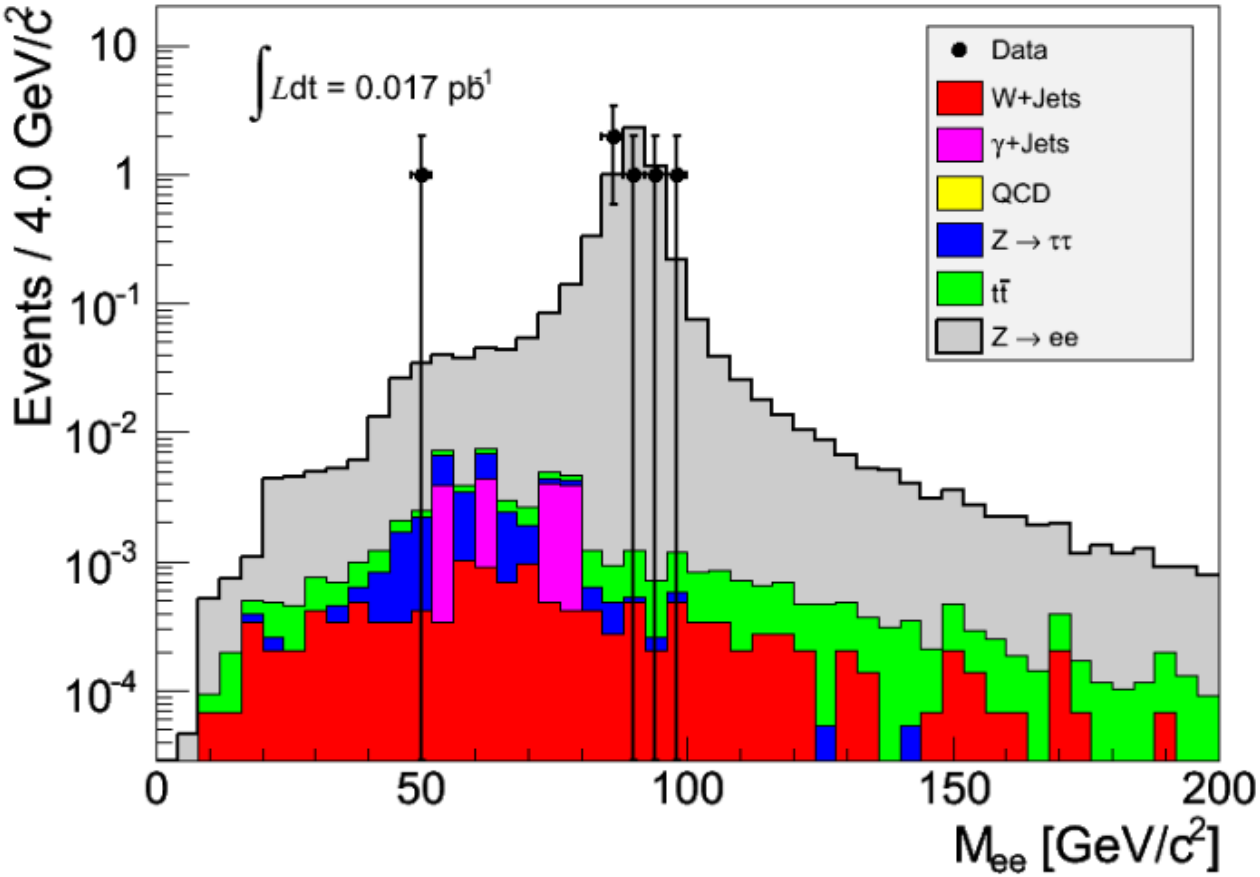
= 82 %

Acceptance : 40 %

Efficiencies again via Tag-and-Probe Method

Expect total systematic uncertainty 4% (method) and 10% for luminosity

Z → e e : Data – Monte Carlo Comparison



Data !

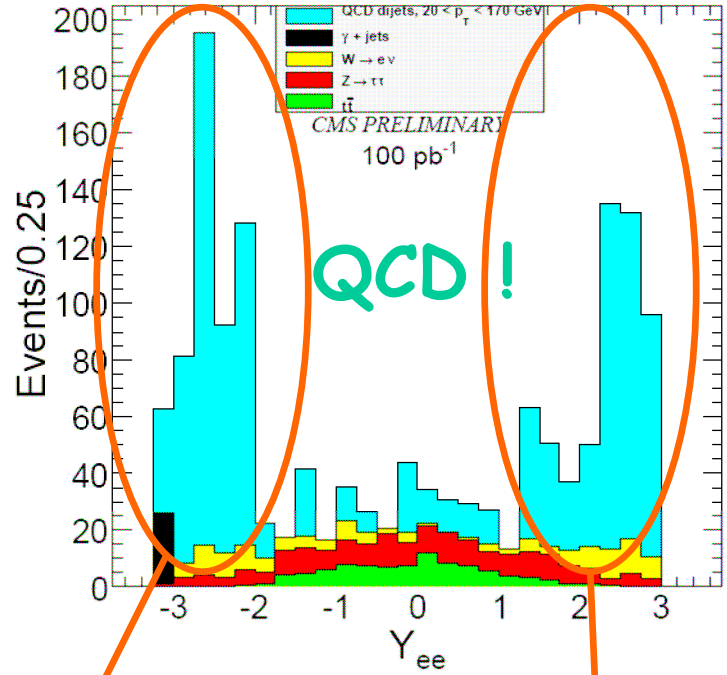
Total : 6

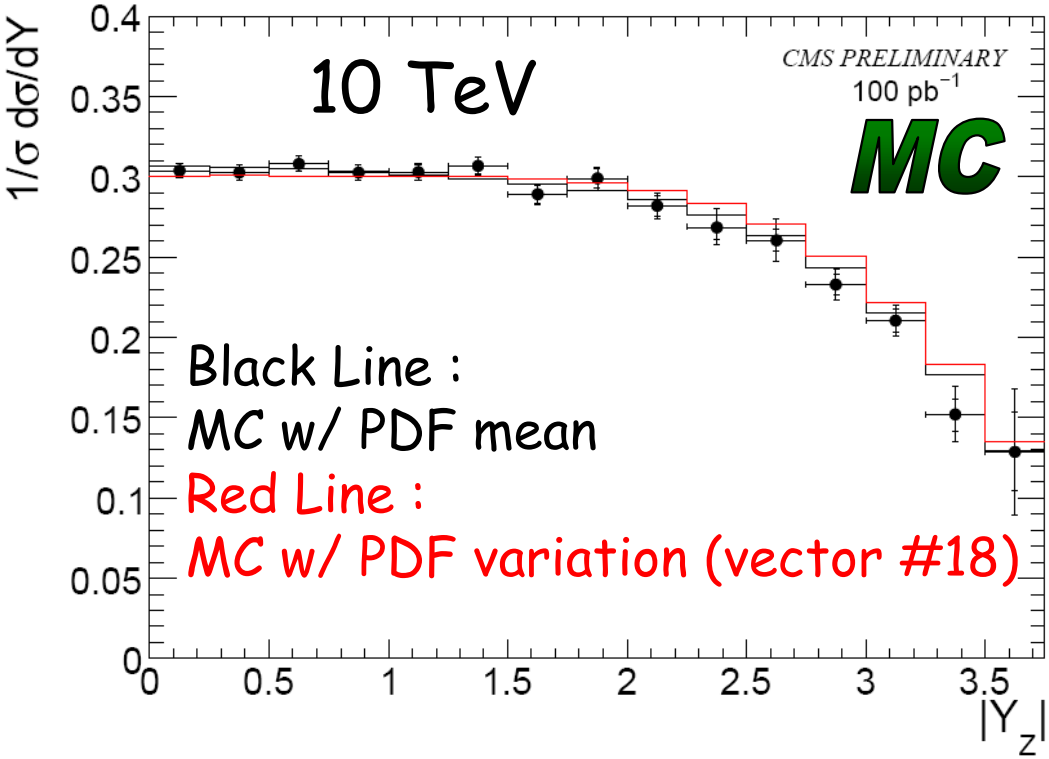
. . . this is just the beginning . . .

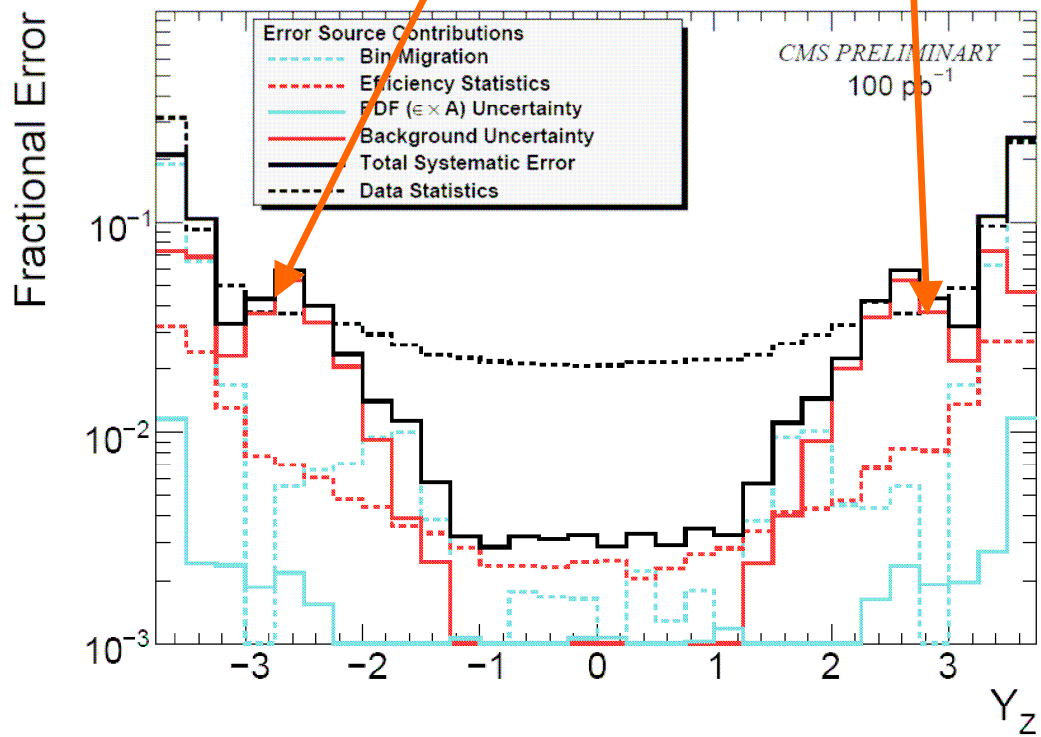
Z → e e : Rapidity

Cross section as a function of Z Boson rapidity $Y = \frac{1}{2}\ln\frac{E+p_z}{E-p_z}$

→ Constrain PDF uncertainties







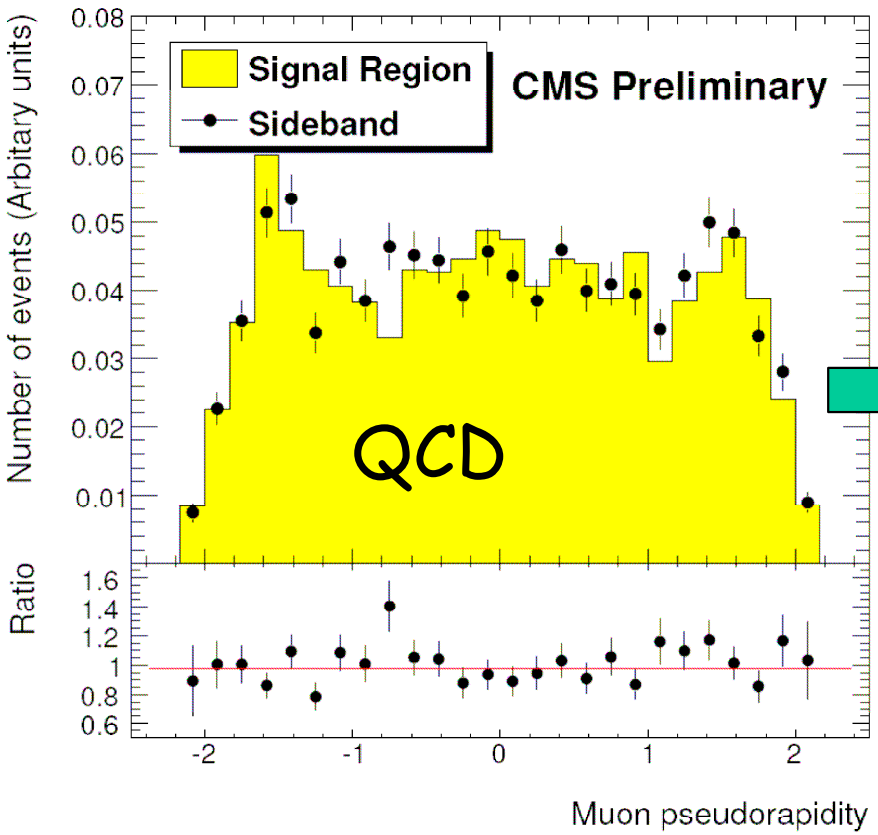
Muon Charge Asymmetry

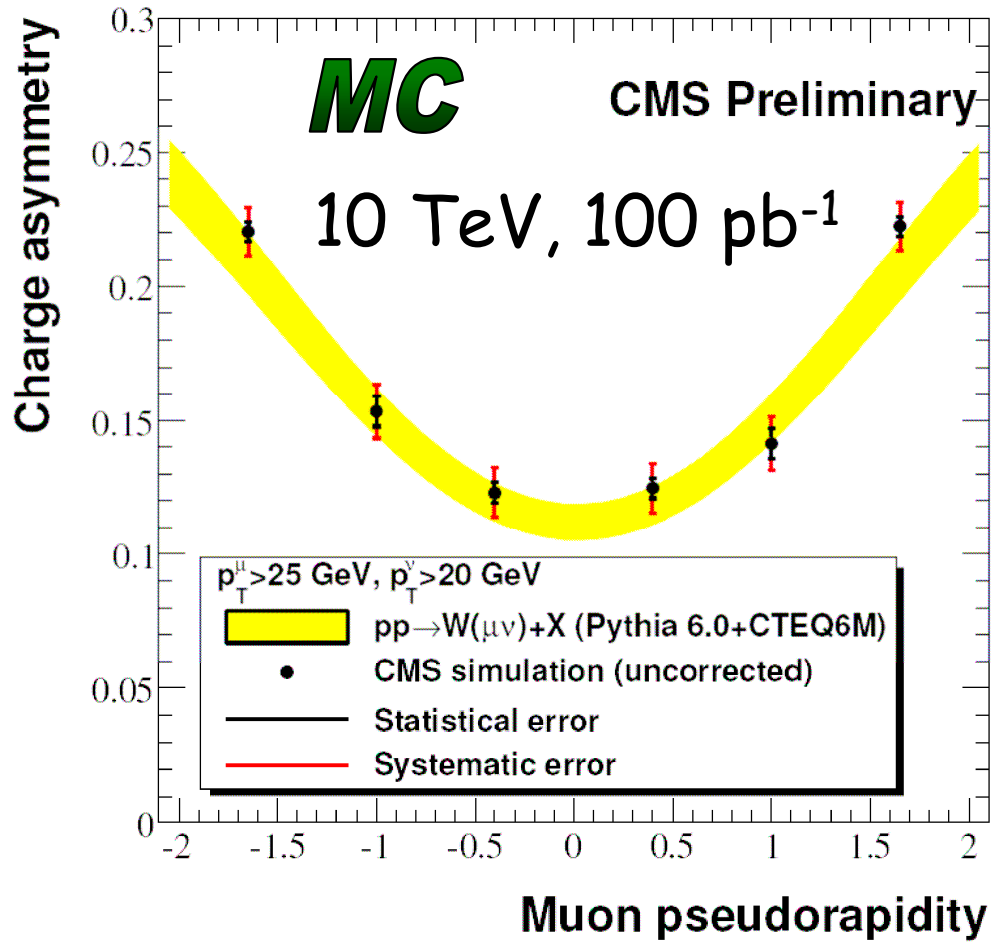
$$A(\eta) = \frac{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\bar{\nu}_\mu) - \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu_\mu)}{\frac{d\sigma}{d\eta}(W^+ \to \mu^+\bar{\nu}_\mu) + \frac{d\sigma}{d\eta}(W^- \to \mu^-\nu_\mu)}$$

Provides **robust** measurement

→ clean observable, no knowledge of luminosity required

→ Sensitive on PDF

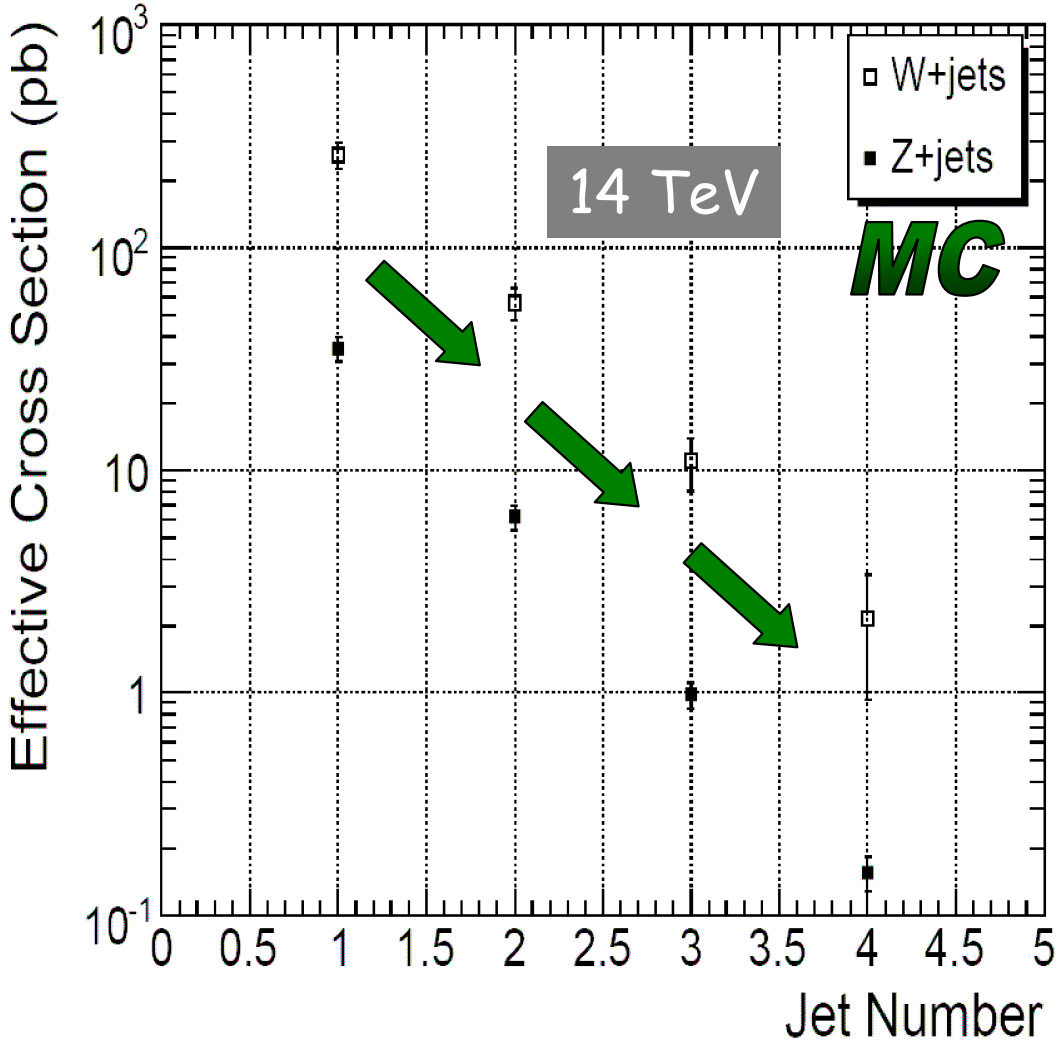




Matrix method for QCD Background estimation

Dominant systematic uncertainties due to efficiency measurements

W and Z with Jets



Important channels :
- test QCD
- background for searches
- Jet Energy Scale (Z + Jets)

W/Z + Jets analyses need estimates of :
- Jet Energy Scale
- QCD background
- top background (!)

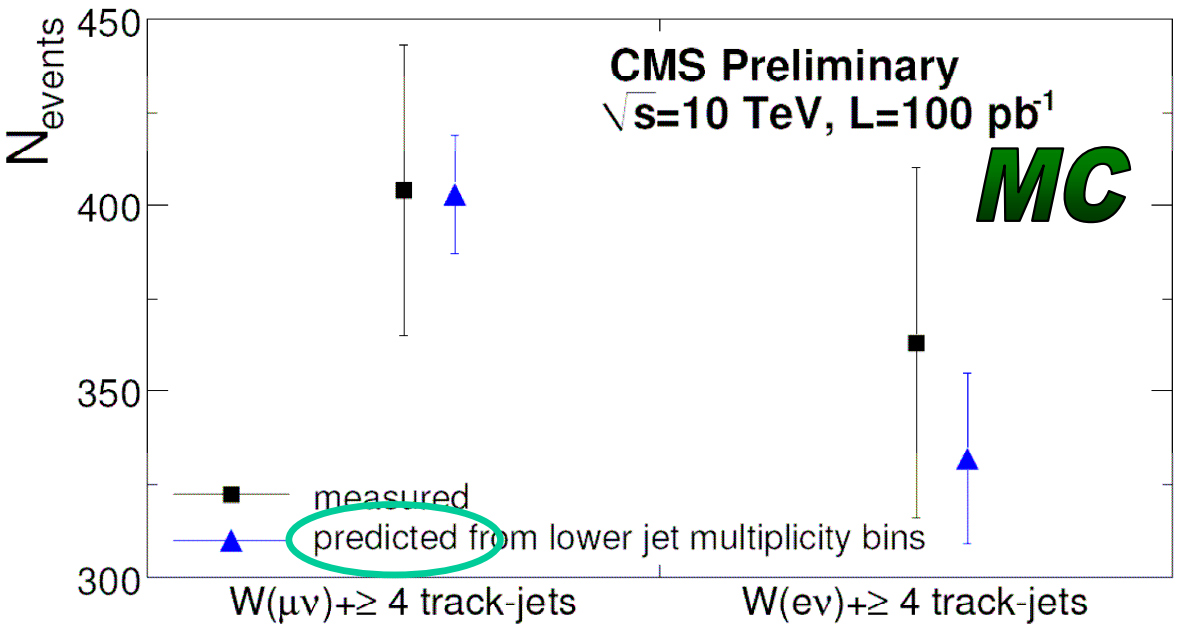
$$\frac{\sigma(W/Z+(N+1)\,Jets)}{\sigma(W/Z+N\,Jets)} \approx \alpha_s$$

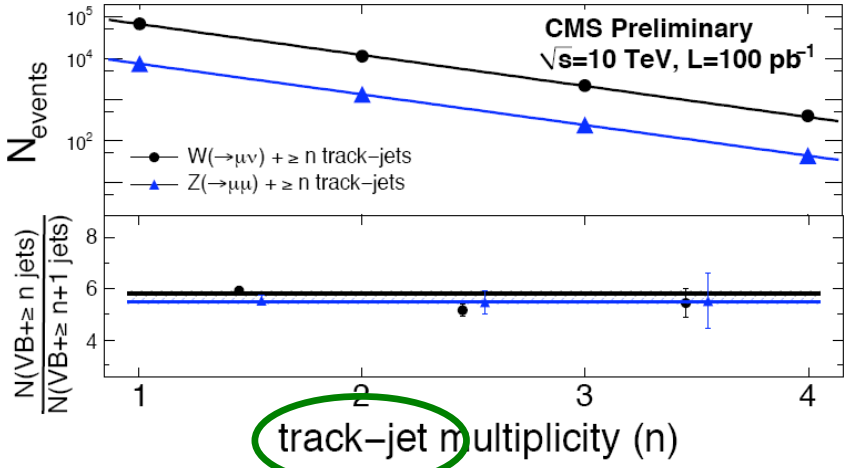
W/Z + Jets : Ratio

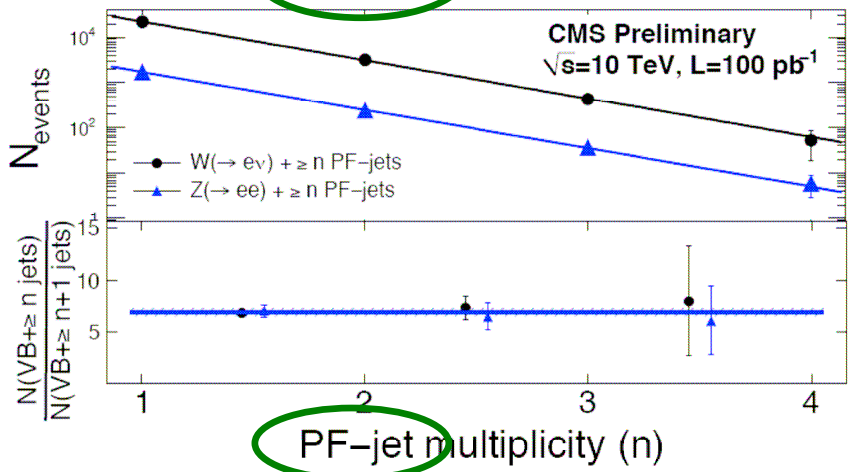
Interesting : Double Ratio

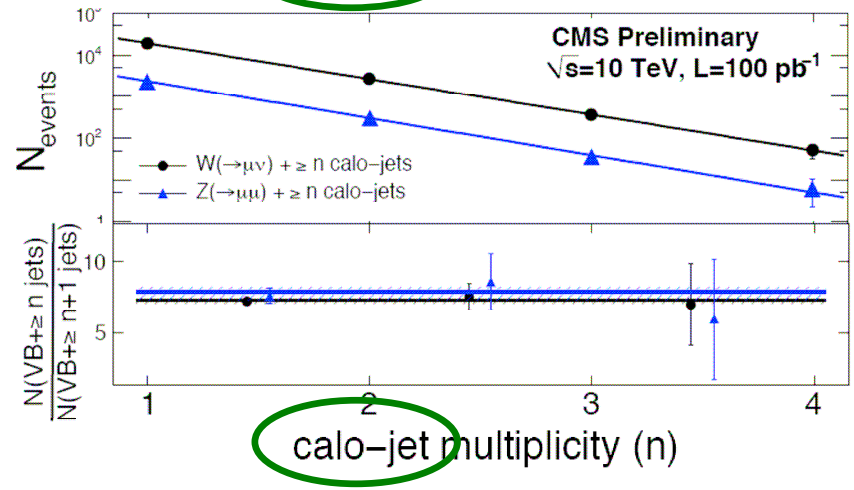
$$\frac{C_W}{C_Z} = \frac{\dfrac{W+n\text{ jets}}{W+(n+1)\text{ jets}}}{\dfrac{Z+n\text{ jets}}{Z+(n+1)\text{ jets}}}$$

→ uncertainties cancel







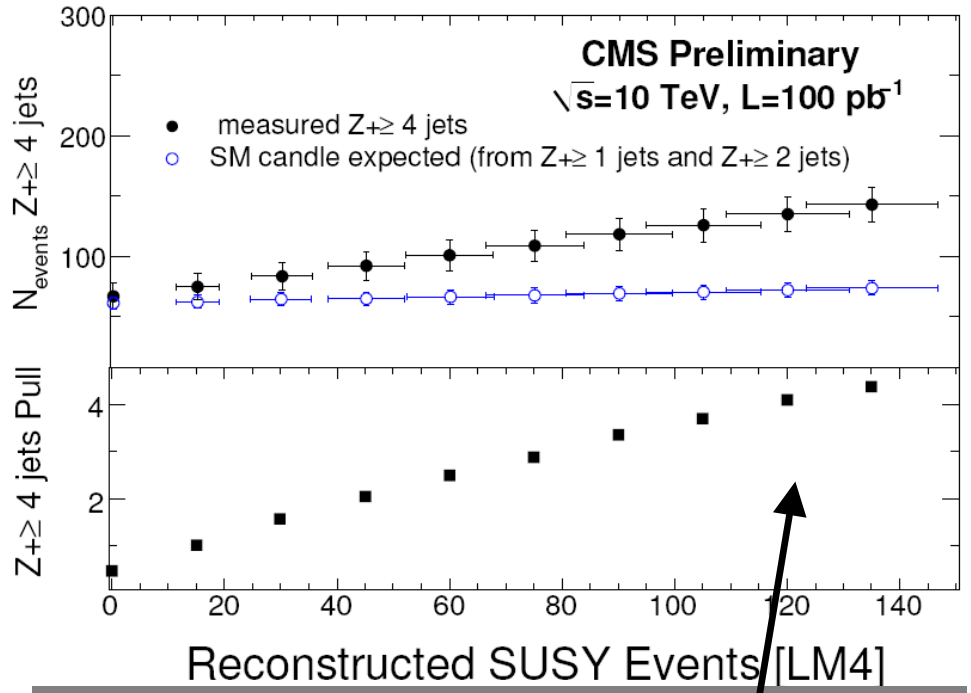


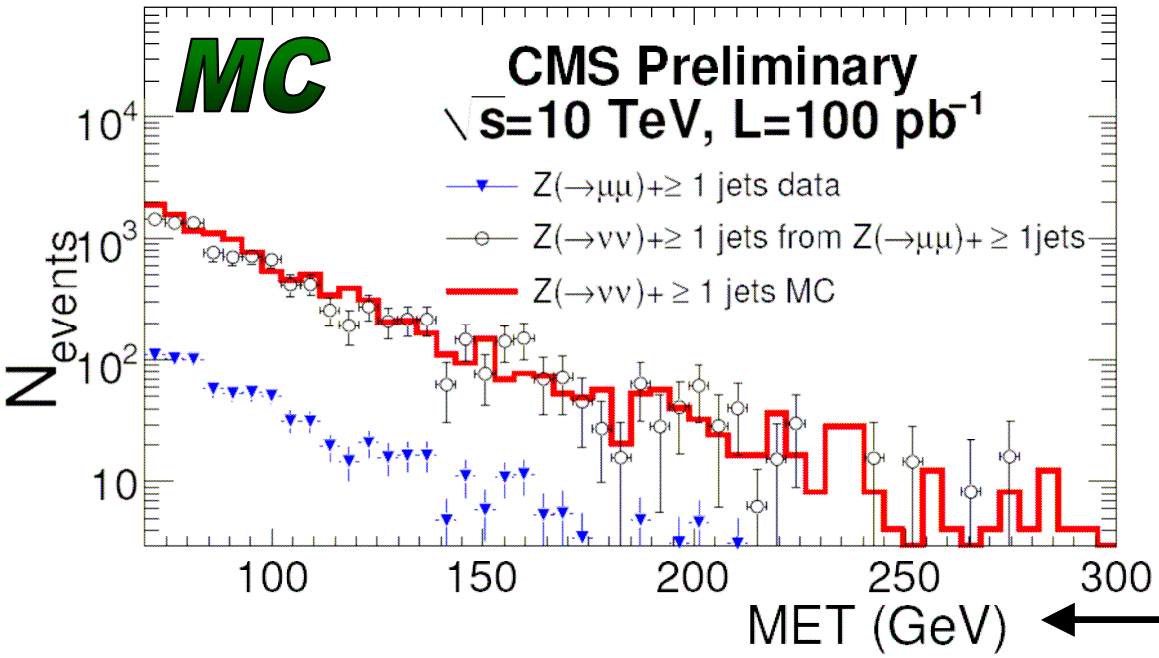
Understand/estimate ttbar background !

3 Jet Algorithms checked

Z + Jets : Tool for New Physics

- ✓ Z + jets → ee and μμ + jets
- ✓ loose selection
- ✓ different jet reconstruction algorithms
- ✓ cross section and ratio



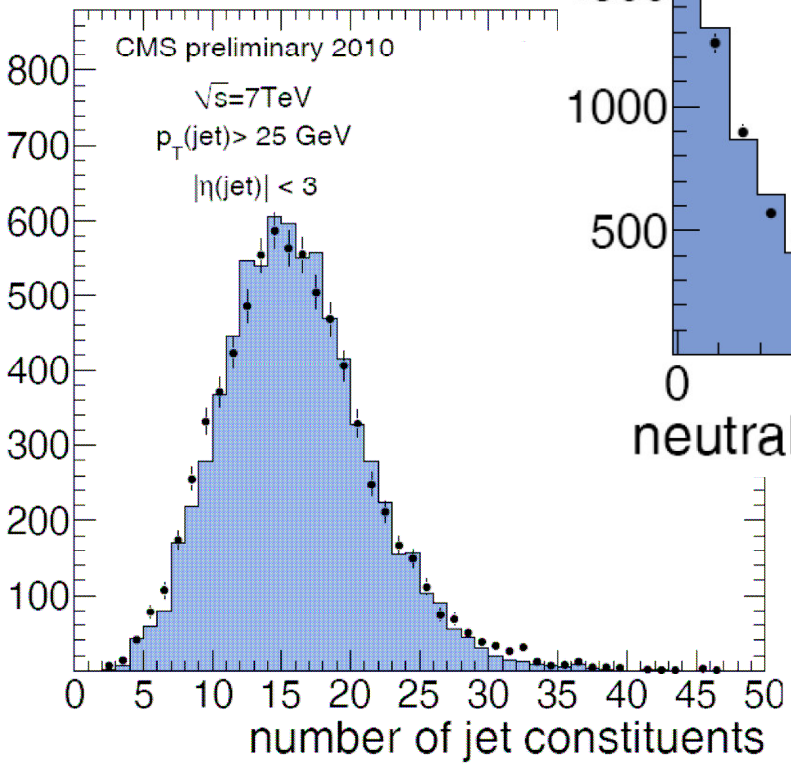


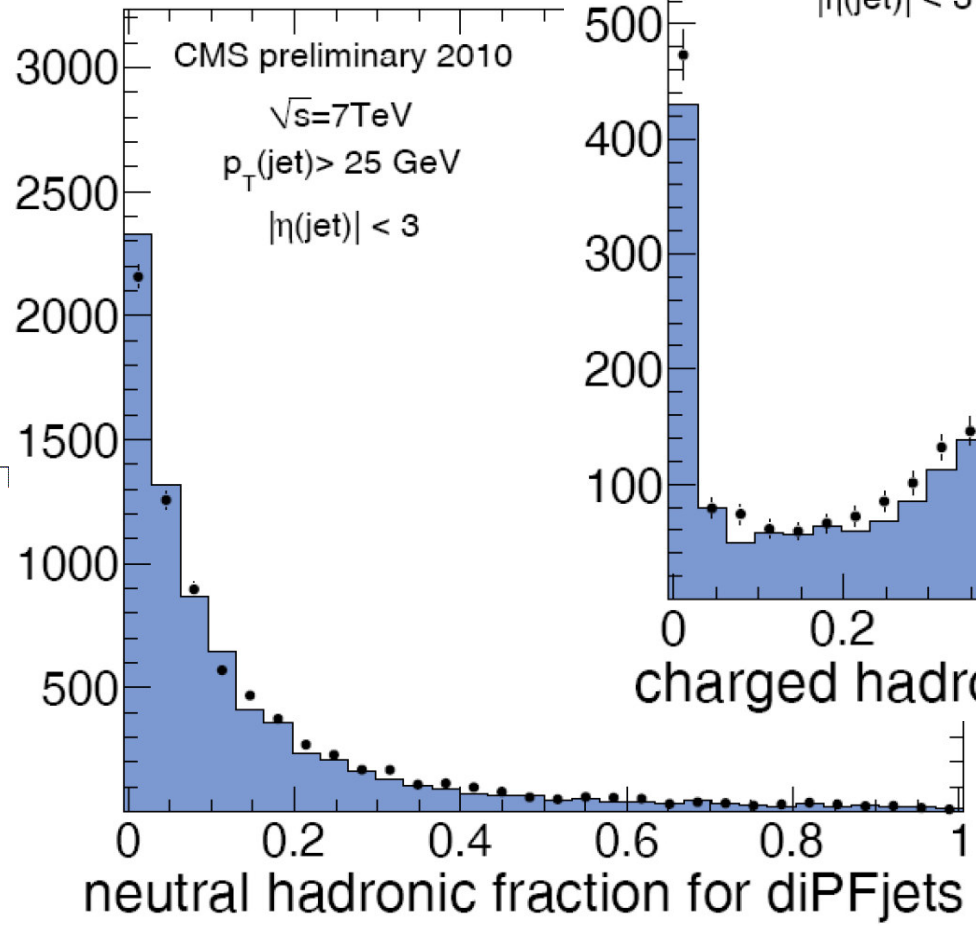
Applications :

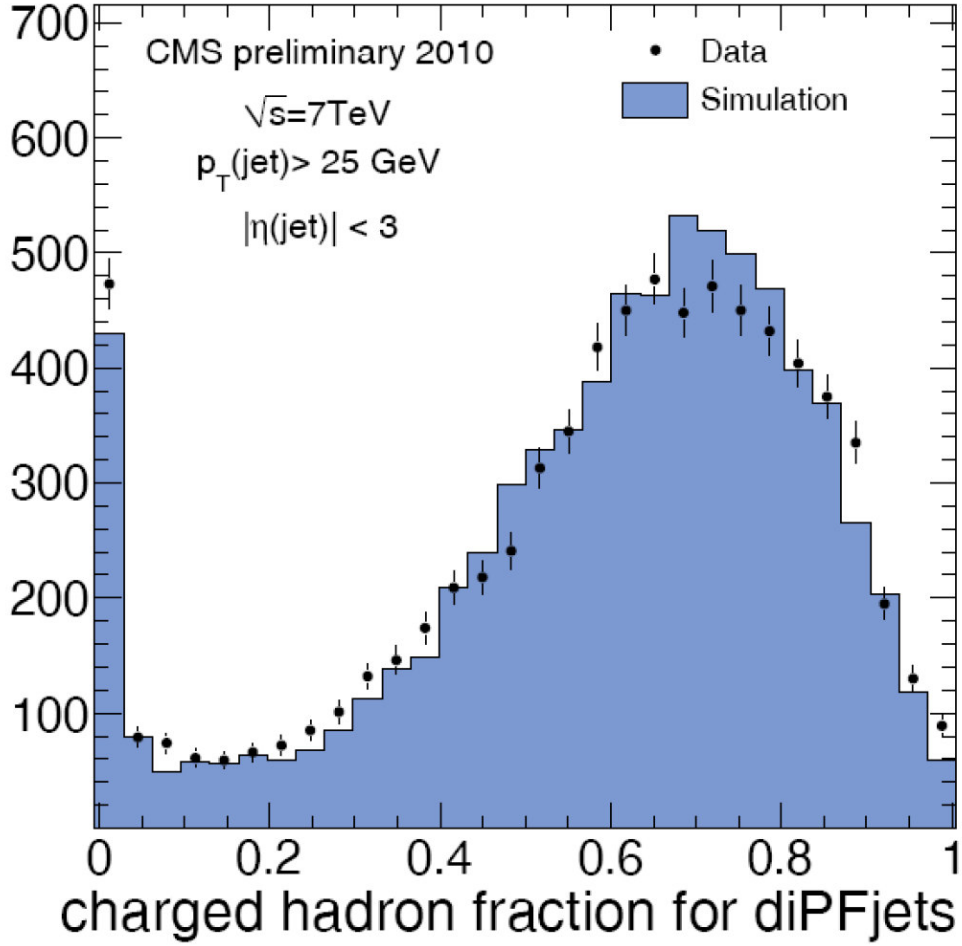
- ➢ look for deviations at high jet multiplicites
- ➢ calibrate (W → μν) +jets using (Z → μμ) + jets
- ➢ predict MET in (Z → νν) +jets using (Z → μμ) + jets

Jet Performance Data!

Jet Algorithm :
Particle Flow
anti-kt R = 0.5

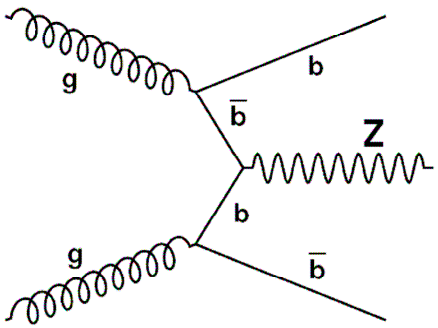






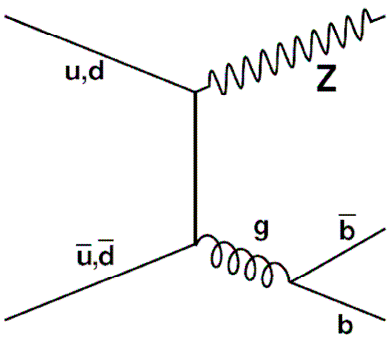
Very good agreement between Data and Monte Carlo

Z (→ ee, μμ) + $b\bar{b}$: Outlook

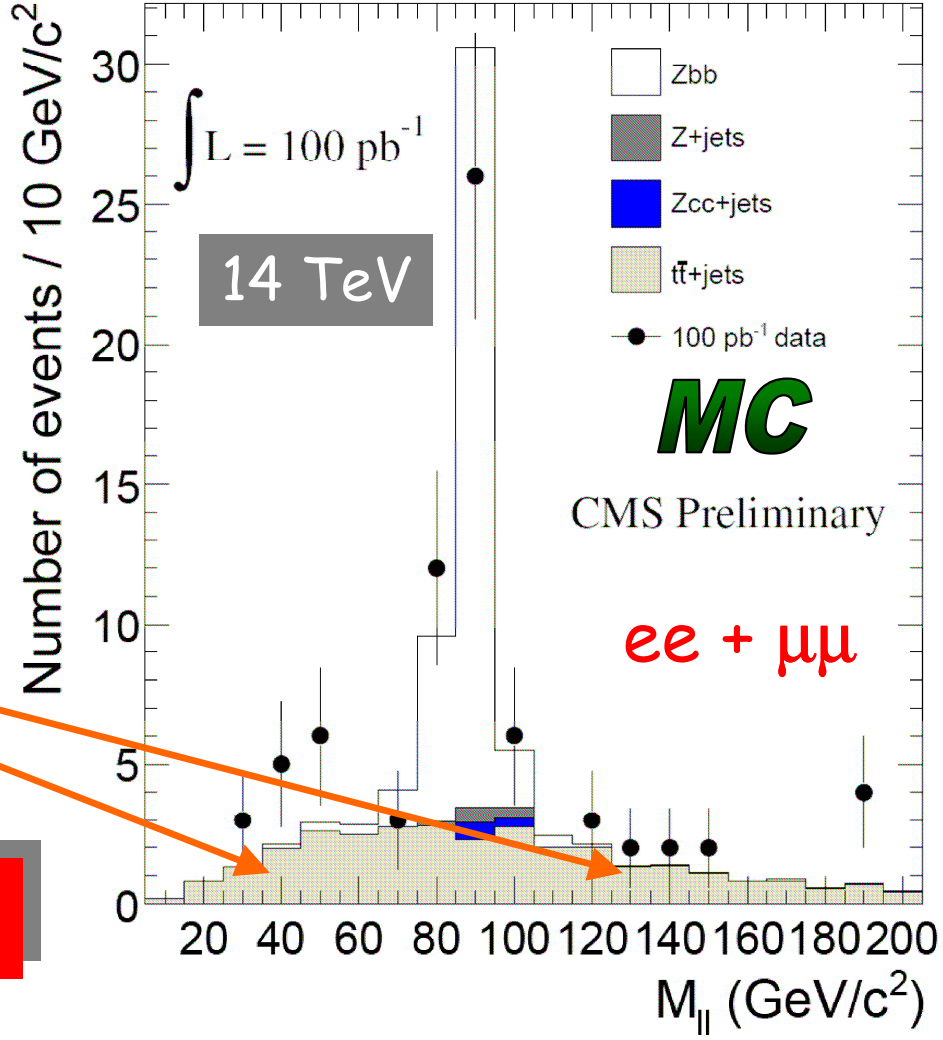


(dominant)

+

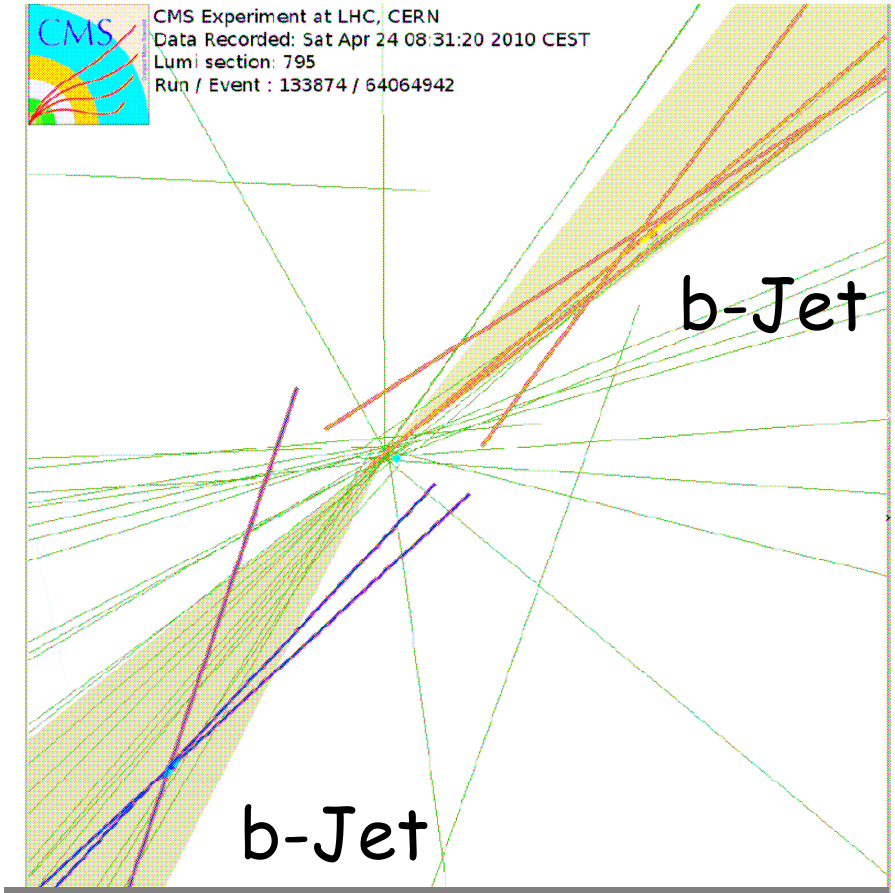


Top background estimated from data from side-bands

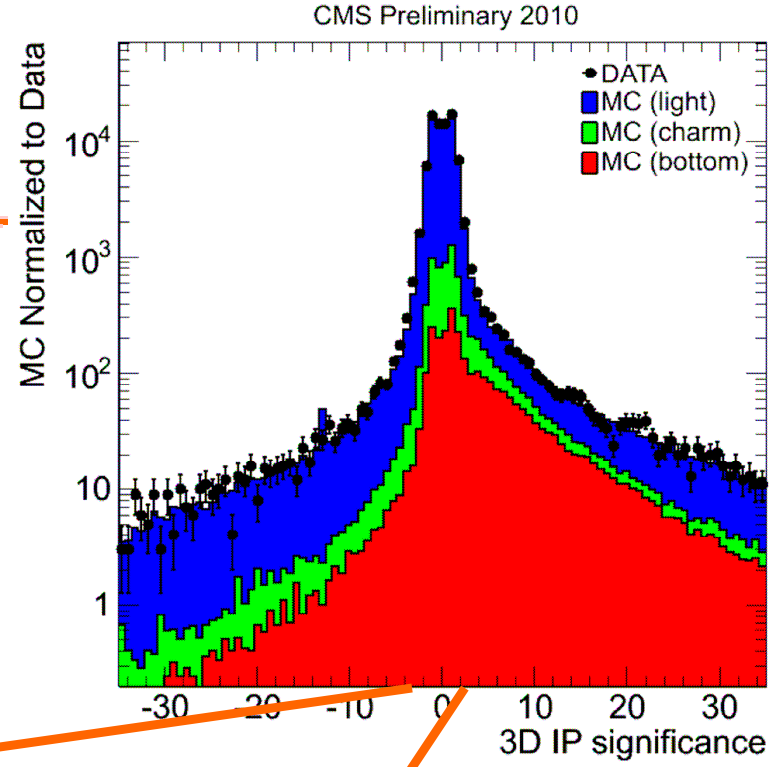


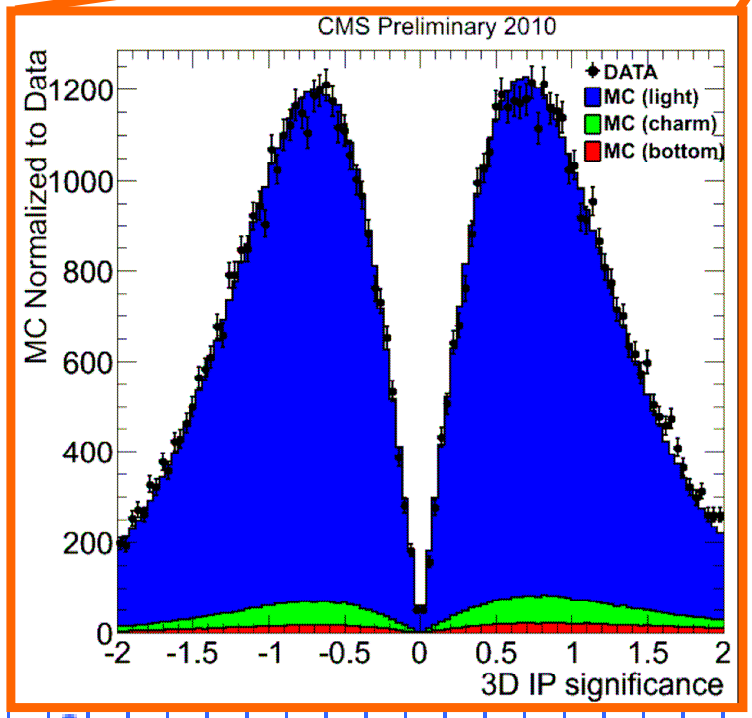
Requires two b-tagged Jets

b - Tagging Performance



Data!



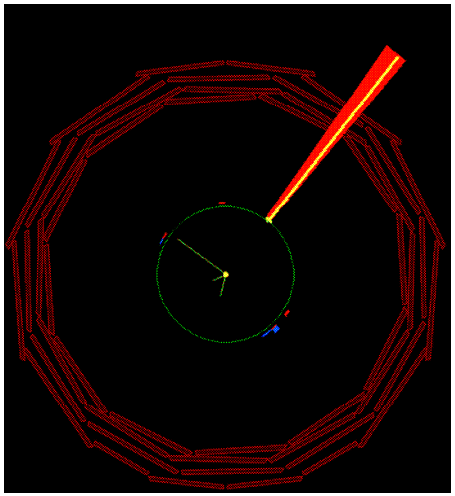


- Anti-kt 0.5
- PF
- $p_T > 40$ GeV
- $|\eta| < 1.5$

Very good agreement between Data and Monte Carlo

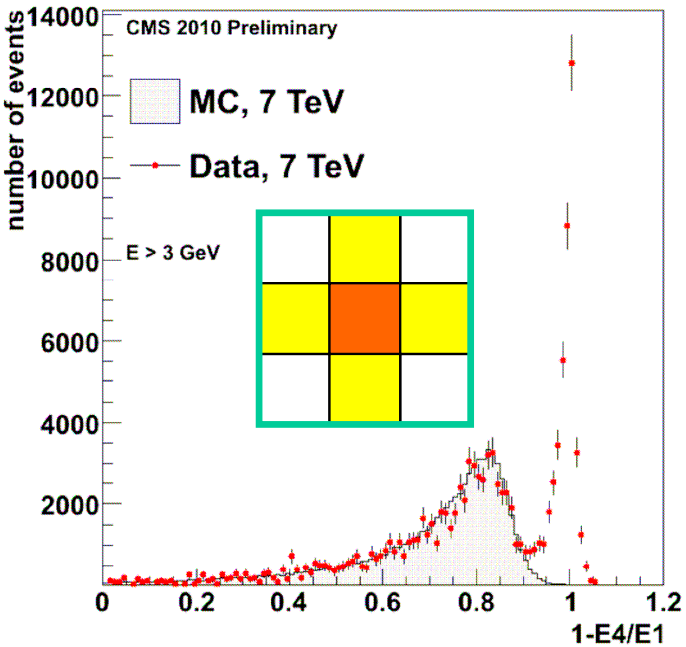
MET Commissioning <-> Understand Detector

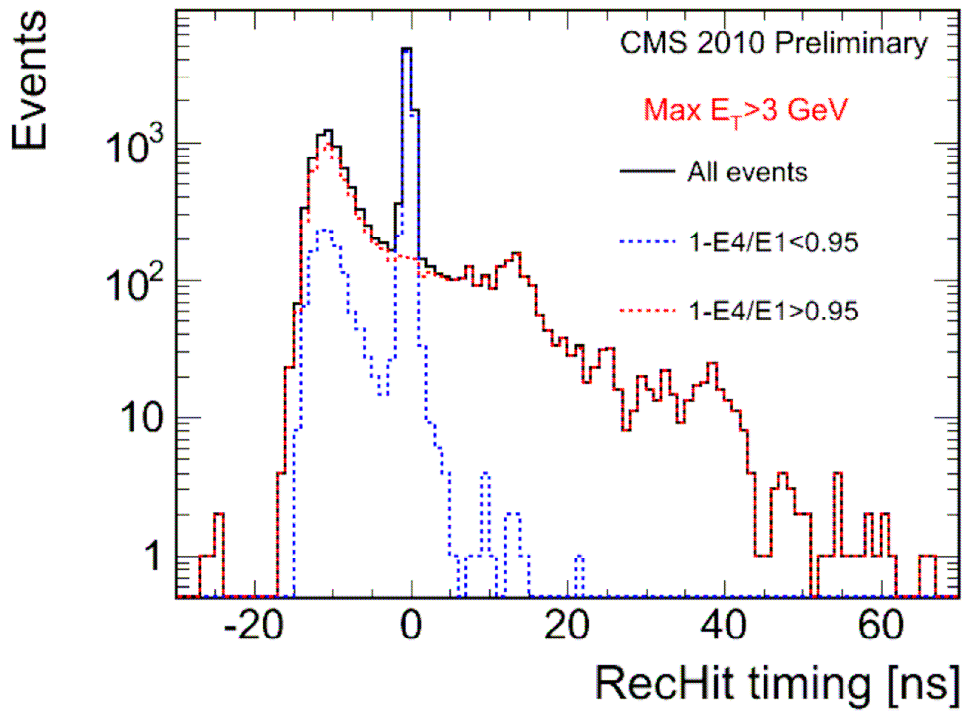
„Nice" detector feature :
Noise in the ECal
→ caused by heavily ionizing particles in the APD



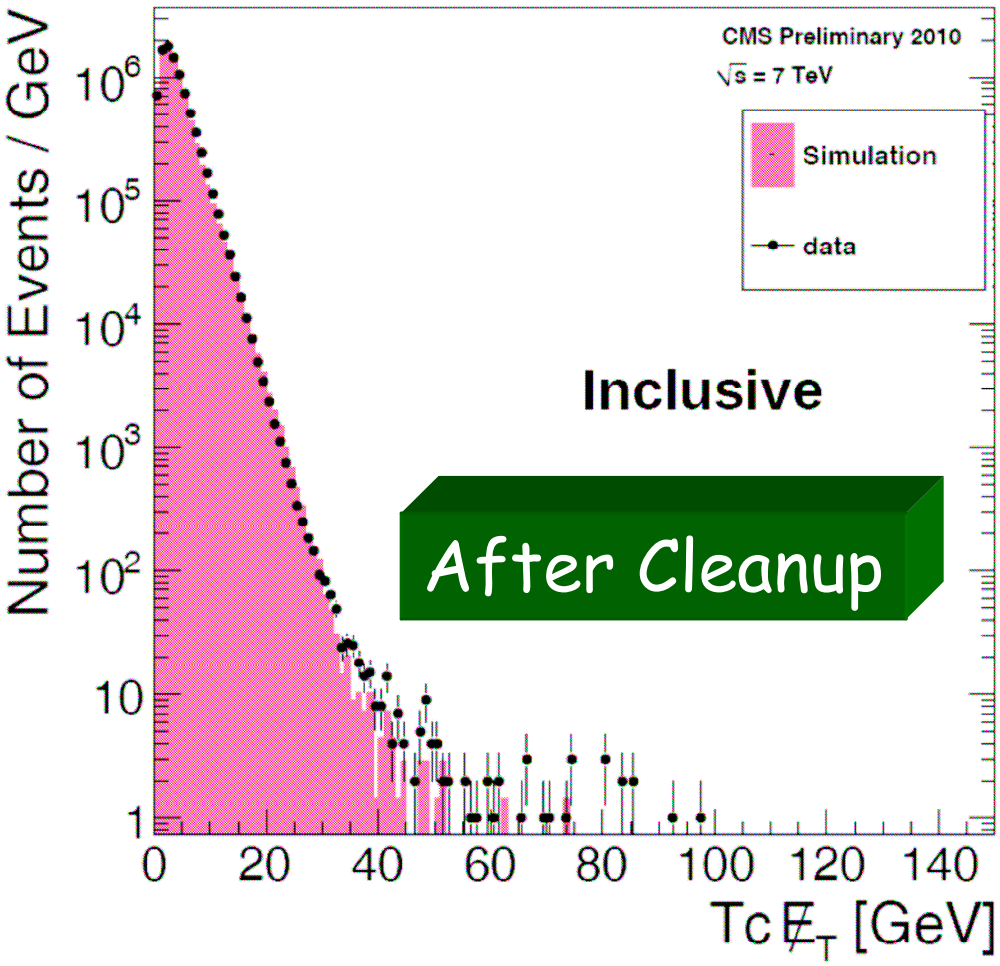
-> fake electrons
-> fake photons
-> *fake MET*

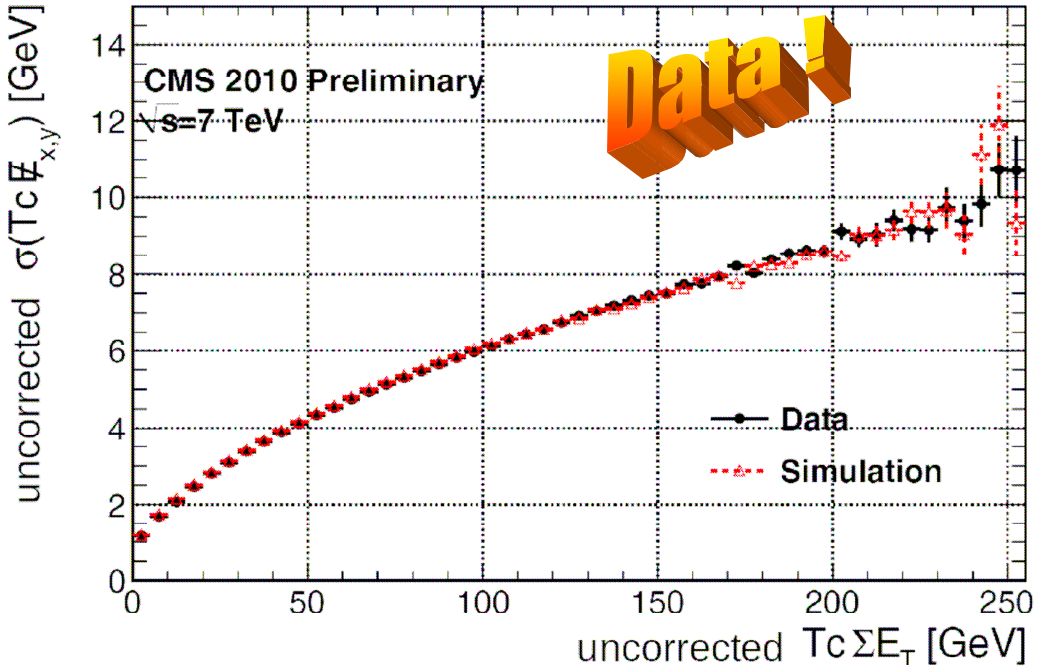
Tag the noisy events and apply cleanup :

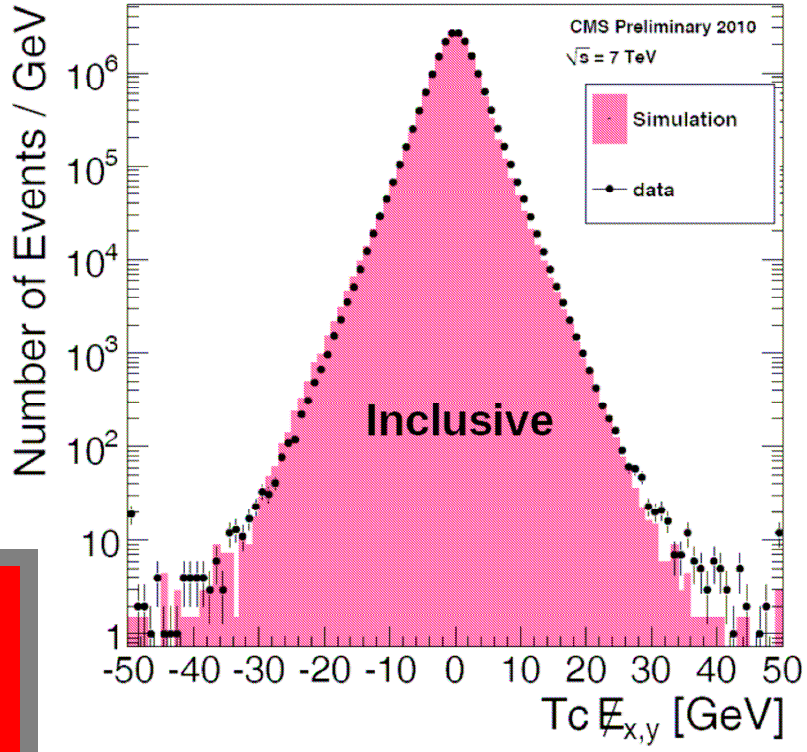




MET Performance





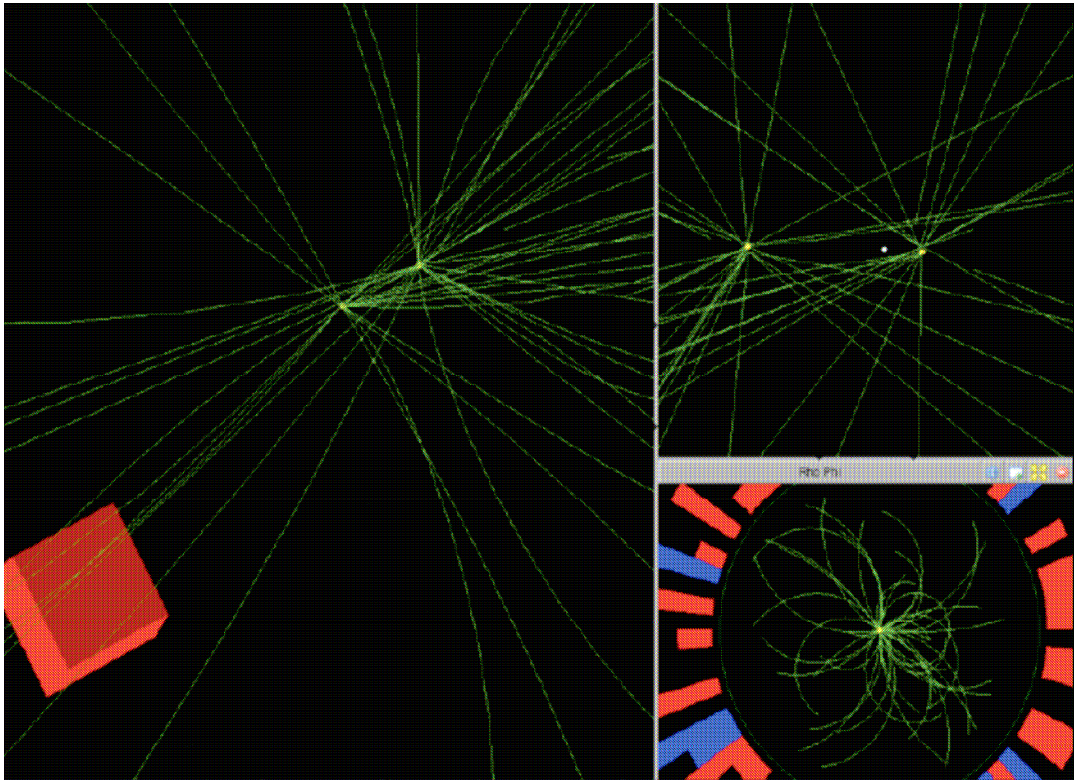


Very good agreement between Data and Monte Carlo

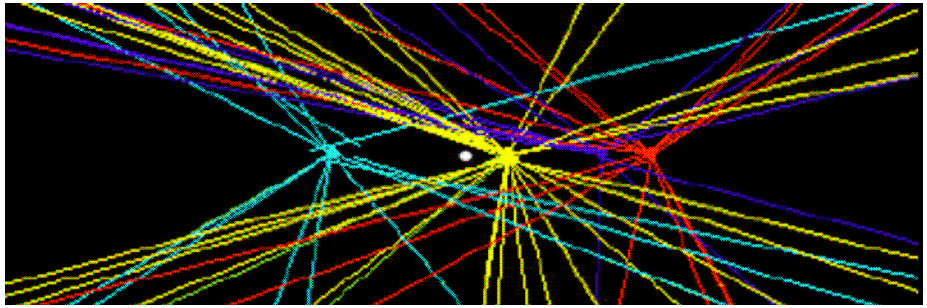
Challenge : Pile-up

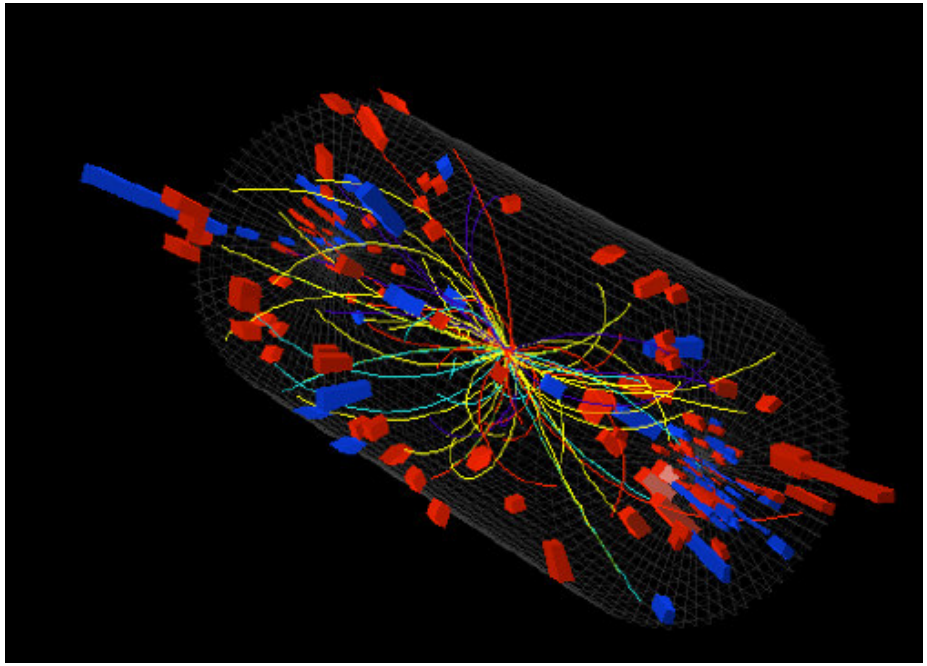
Data !

2-Vertex Event



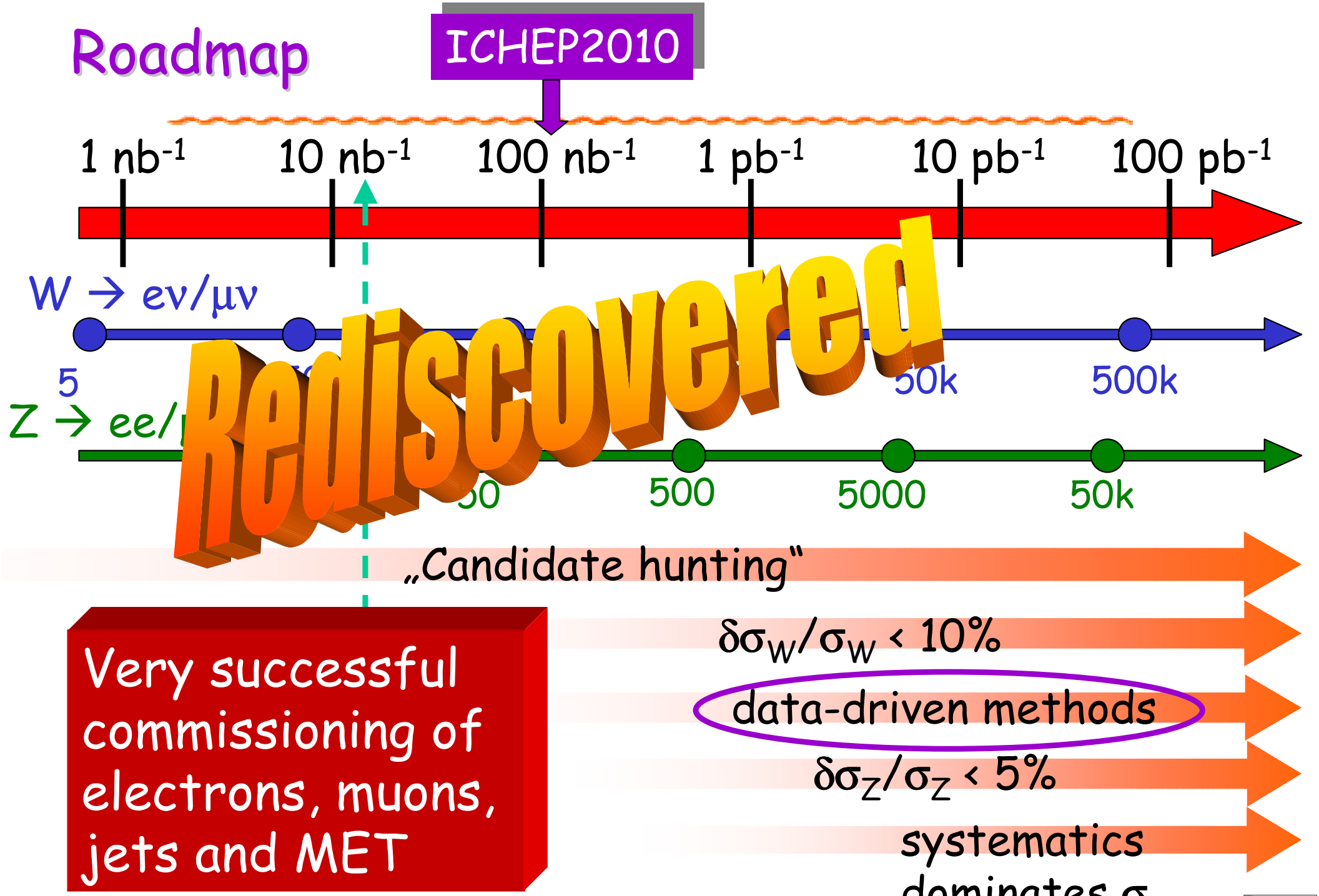
3-Vertex Event





. . . Impact on MET ?

Roadmap



Very successful commissioning of electrons, muons, jets and MET

Summary

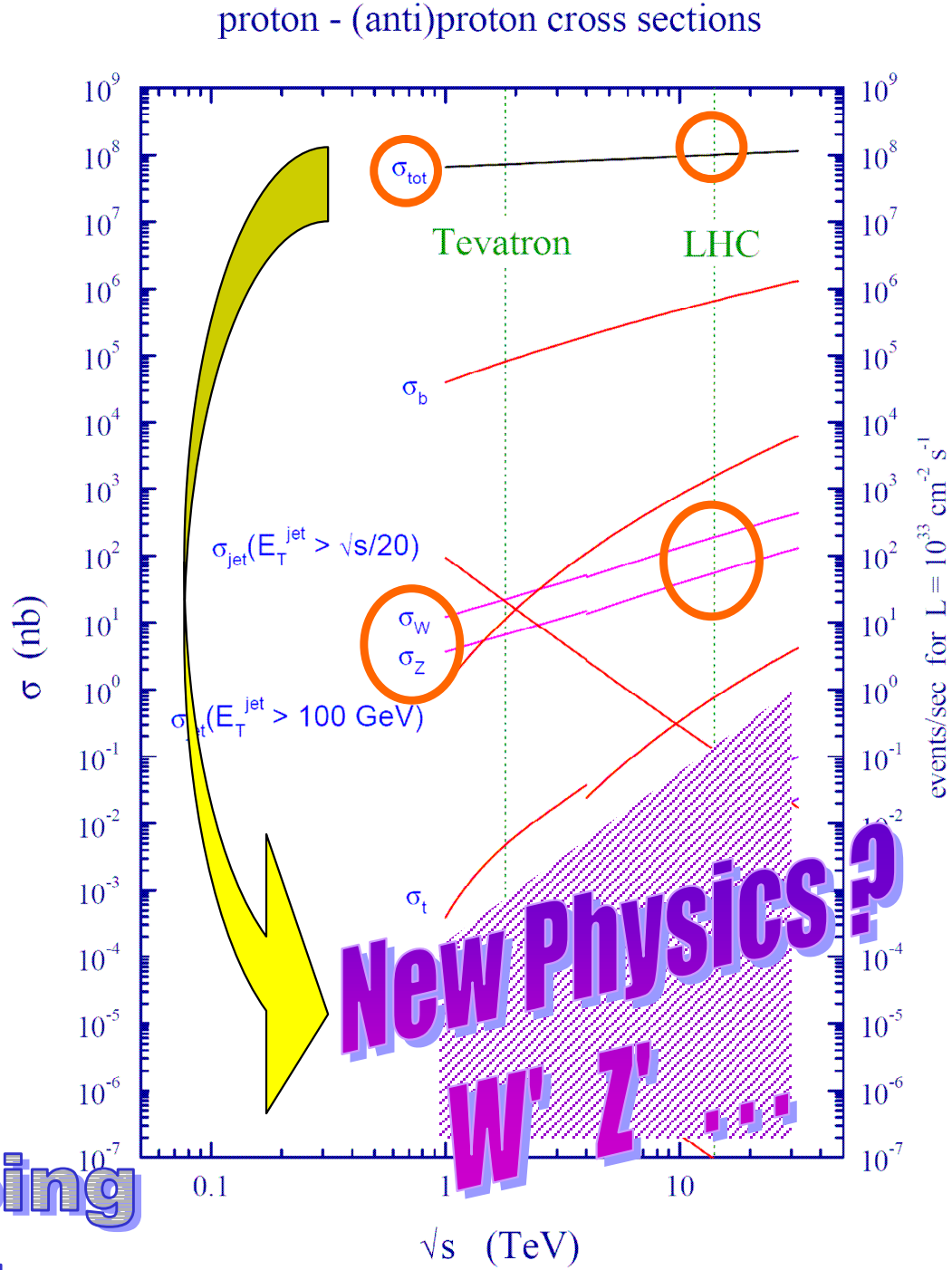
Analysis of inclusive W and Z events essential :
- understand detector
- measure efficiencies
- test data-driven methods
- cross-check luminosity

Presented a robust program for start-up @ CMS

First data looks very promising

Many analyses ongoing

... stay tuned



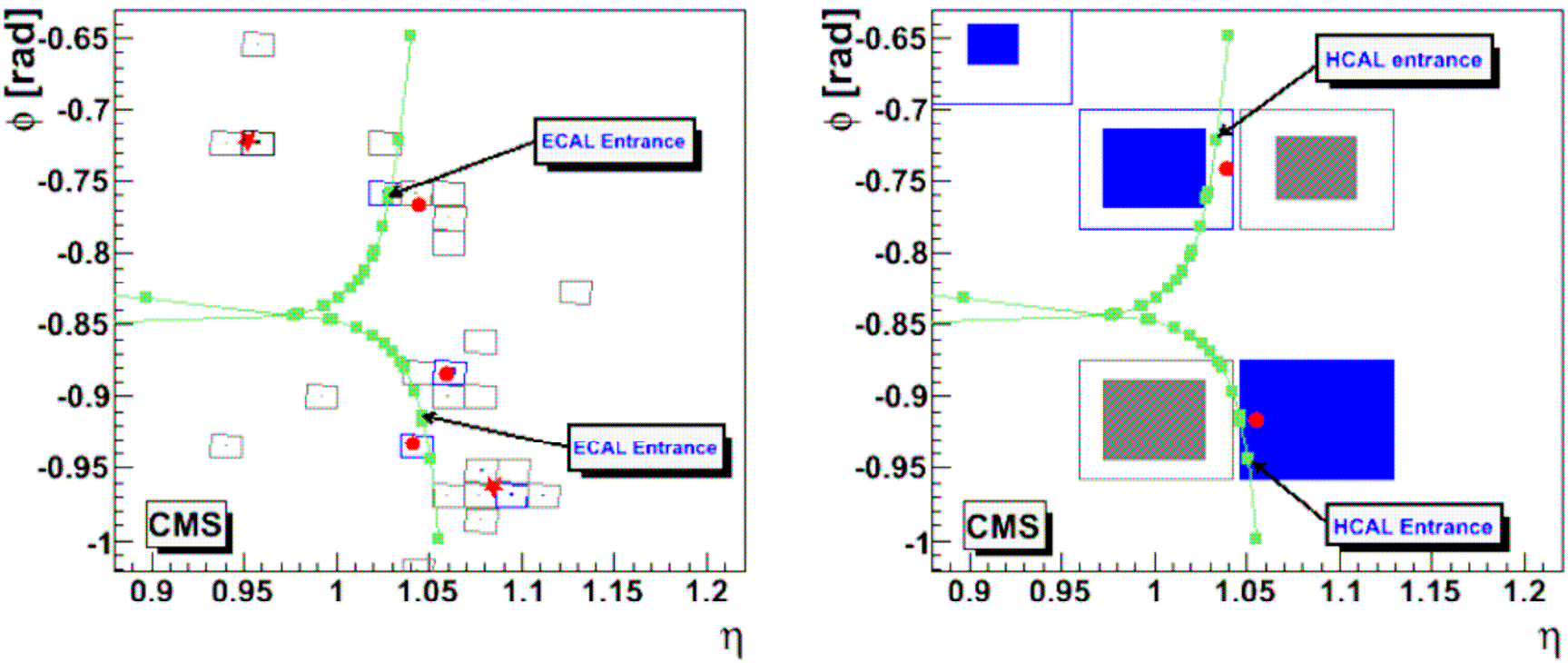
References

All Results shown in this talk can be found
at the CMS Physics Results Twiki

https://twiki.cern.ch/twiki/bin/view/CMS/PublicPhysicsResults

[Next Slides : Additional Material]

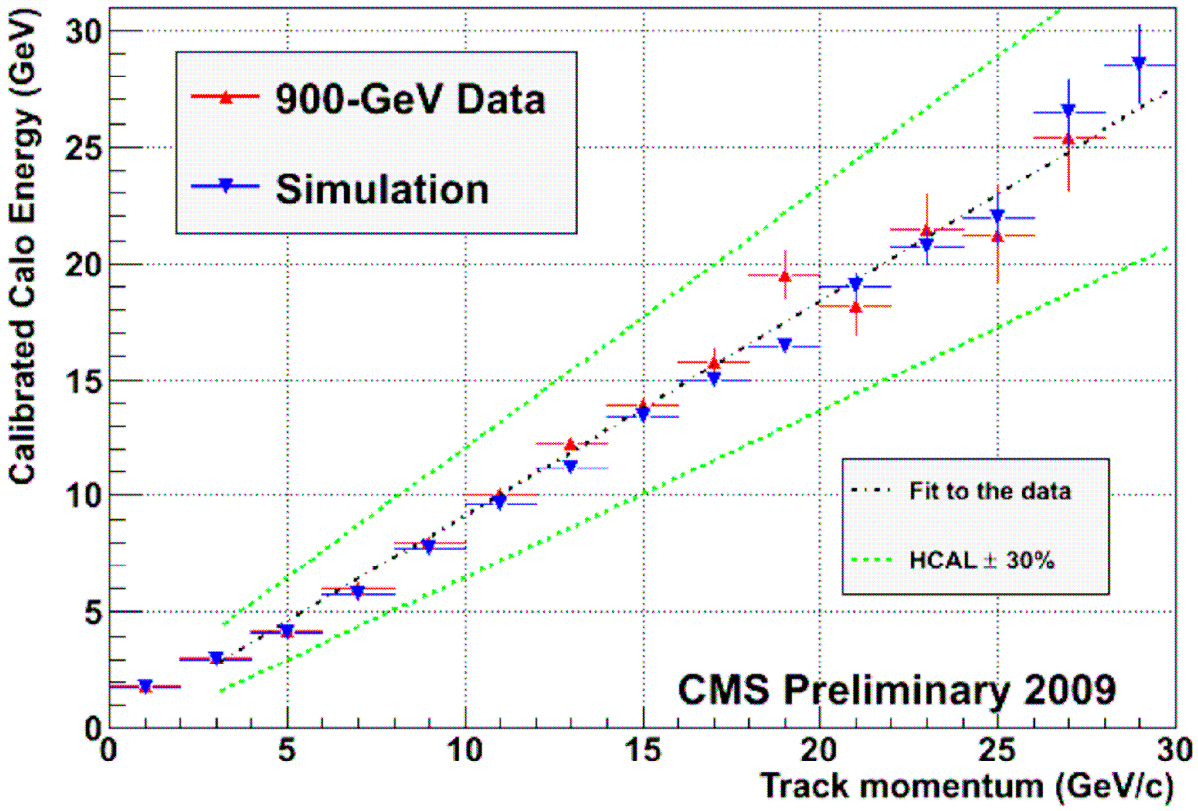
Particle Flow (1)

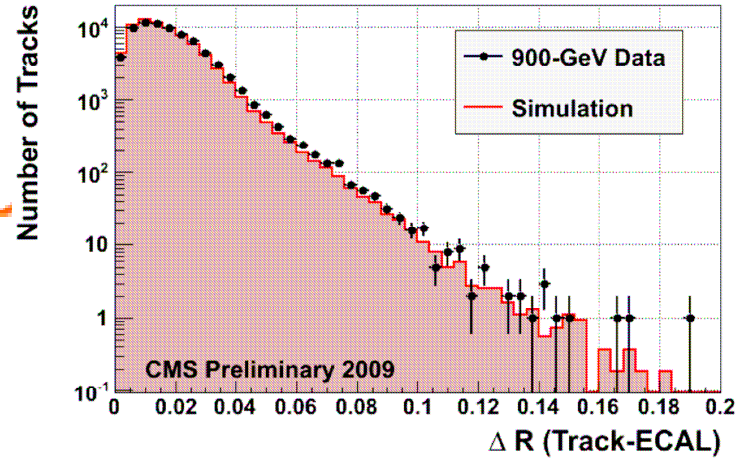


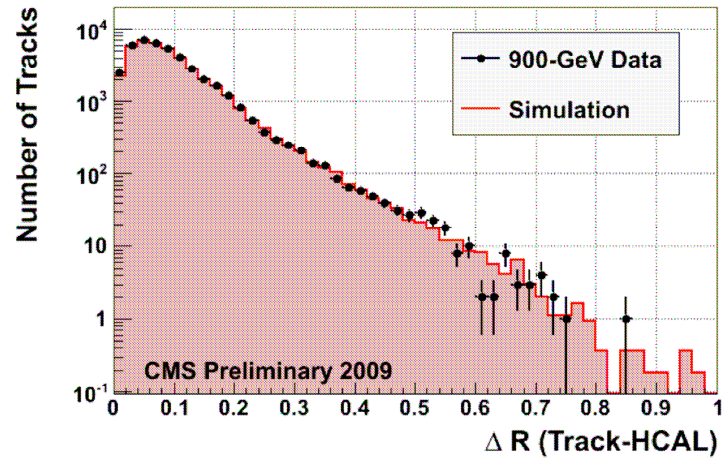
(a) (b)

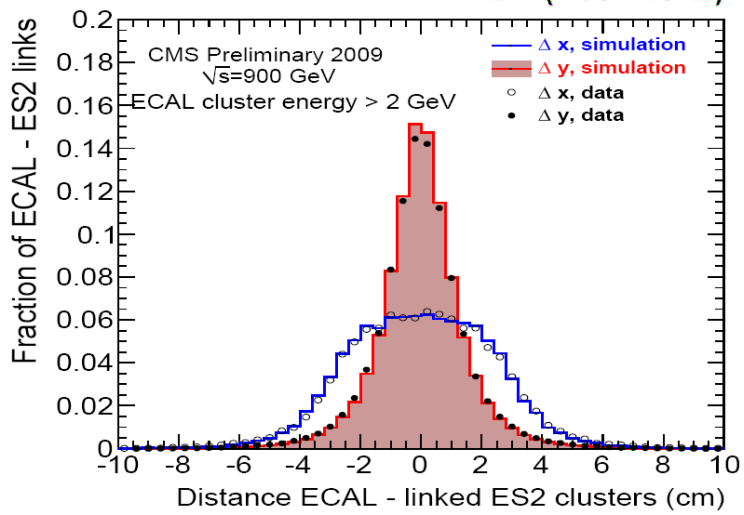
Figure 3: Charged-hadron tracks (lines with squares, representing the hits measured in the tracker and the various extrapolation positions to the ECAL and HCAL) each linked to (a) one or two ECAL clusters and (b) an HCAL cluster (dots). Each square represents a calorimeter cell. The grey area is proportional to the logarithm of the energy measured in each cell. The clusters represented by a star are linked to neither of the two tracks, and are therefore photon candidates.

Particle Flow (2)

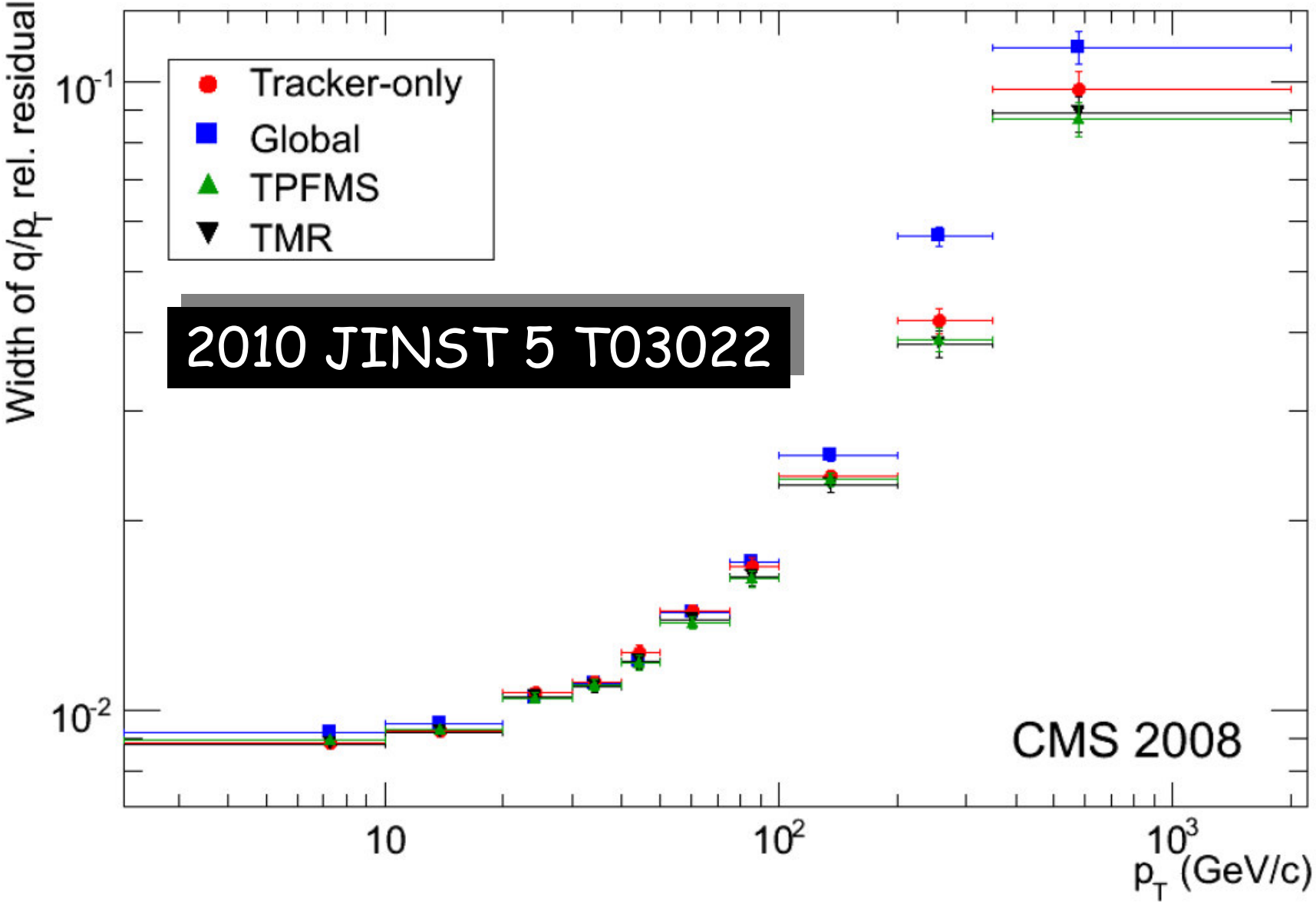






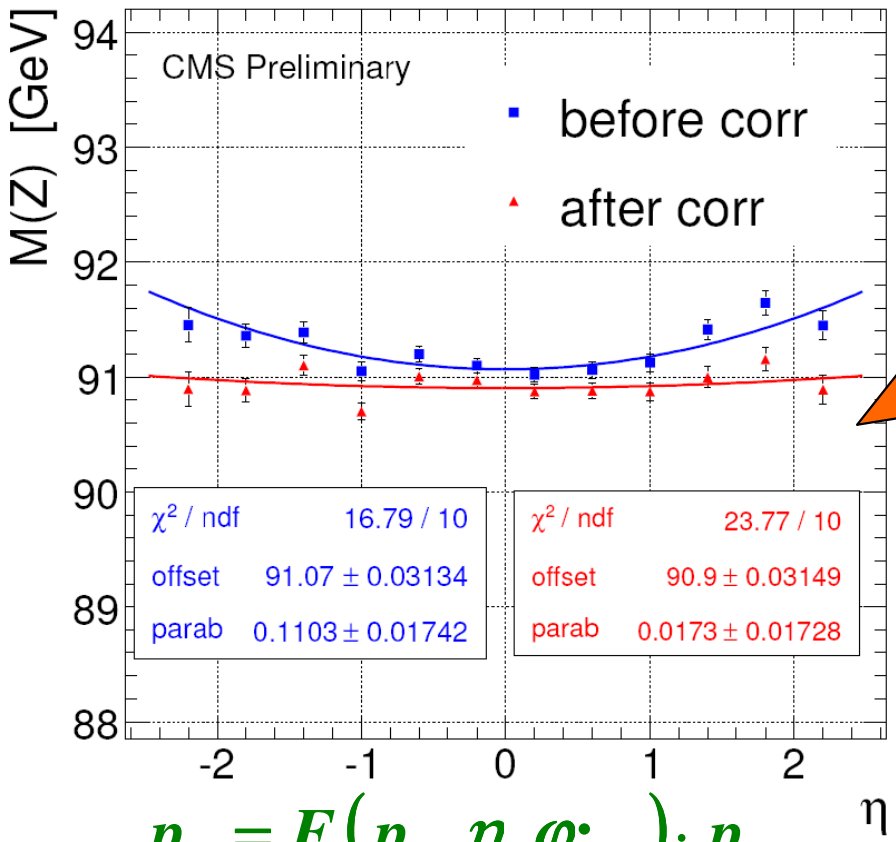


Muon Momentum Reconstruction

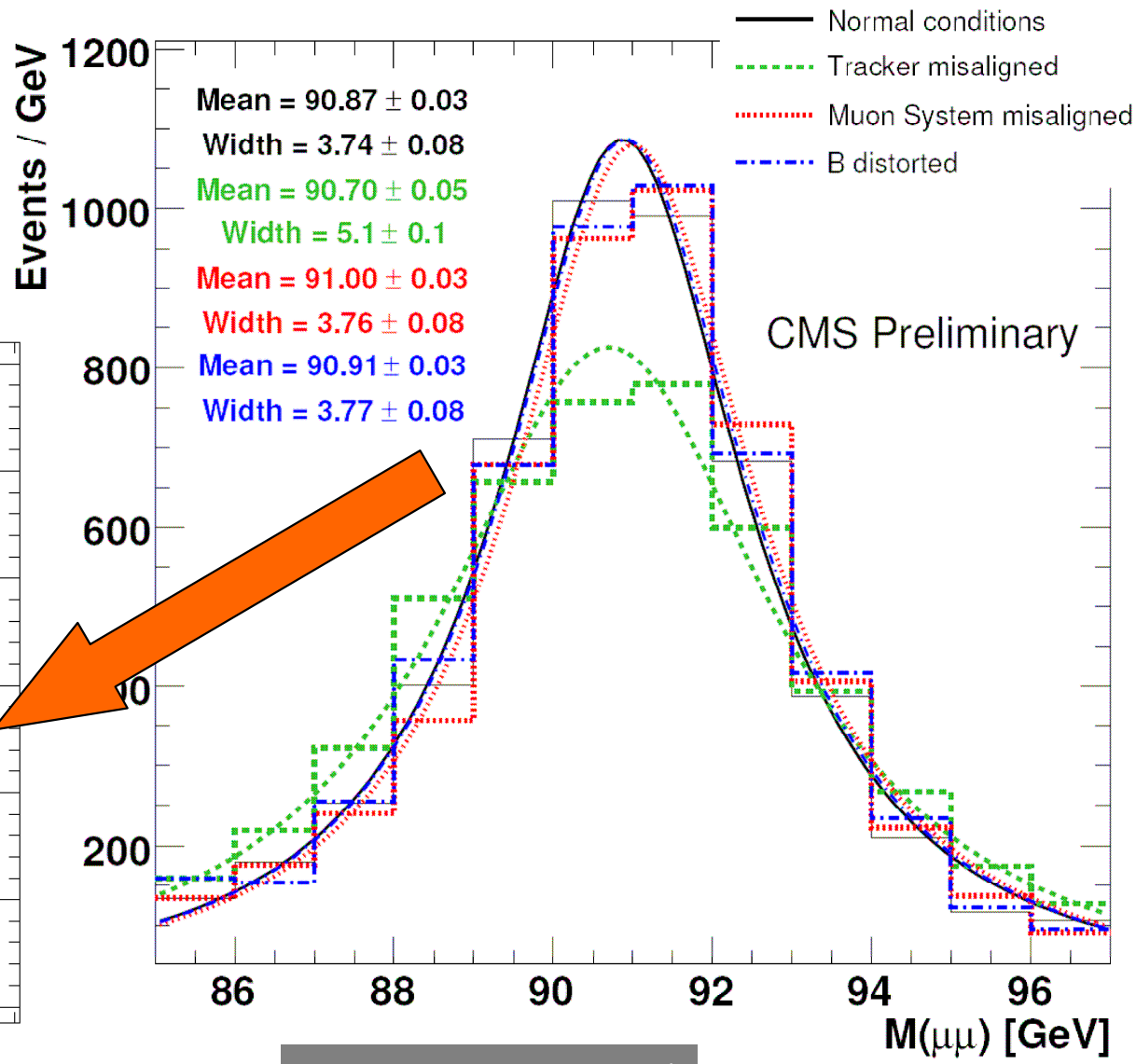


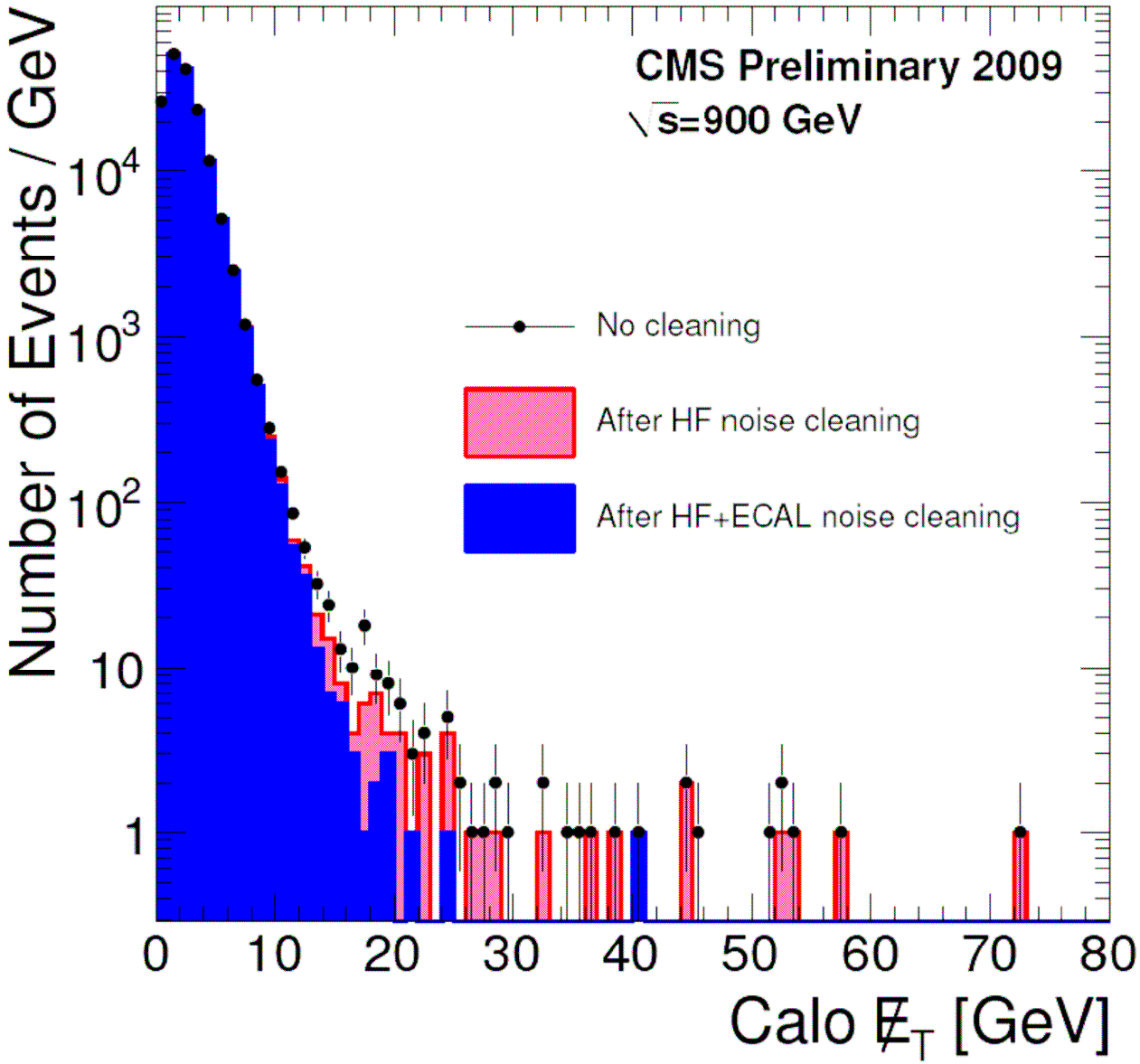
Z → μμ : Momentum Scale

Use Z events to correct for **muon scale** biases due to e.g. imperfect detector knowledge



$$p_T = F(p_T, \eta, \varphi; \ldots) \cdot p_T$$



14 TeV, 10 pb^{-1}

Noise Cleaning <-> MET