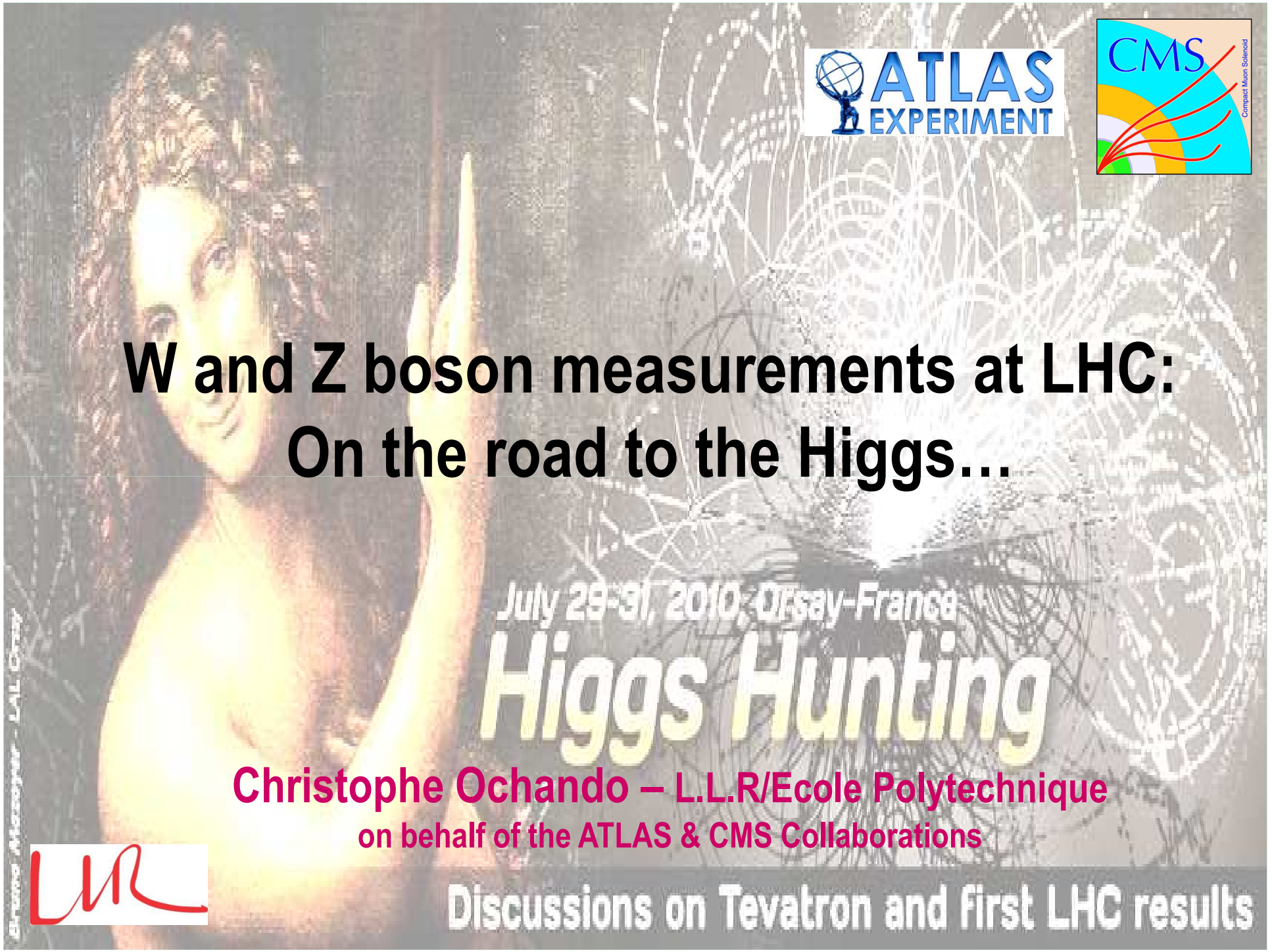
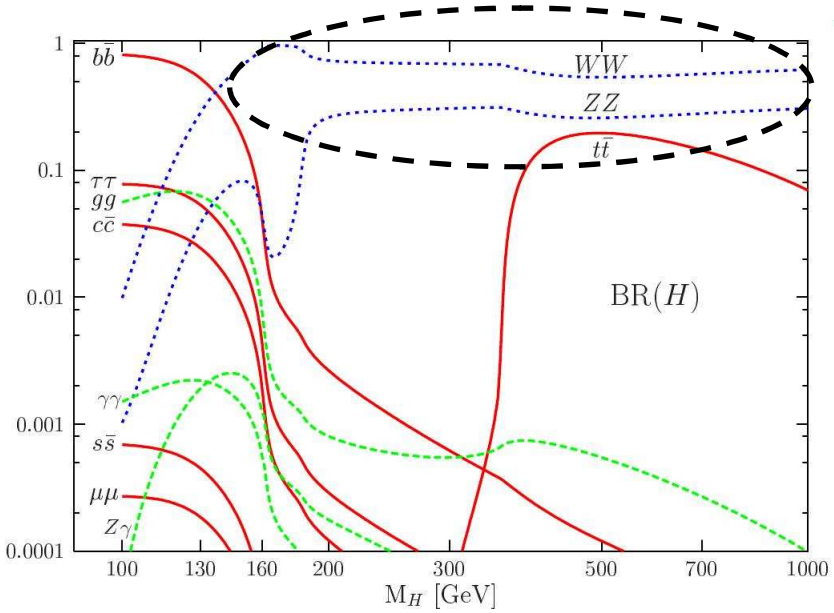


W and Z boson measurements at LHC: On the road to the Higgs…

Christophe Ochando – L.L.R/Ecole Polytechnique
on behalf of the ATLAS & CMS Collaborations

Motivations

- **Above 135 GeV**, the Higgs boson is searched for at LHC in:
  - $H \rightarrow WW^{*}(\rightarrow 2\ell 2\nu$, ℓ=electron or muon),
  - $H \rightarrow ZZ^{*}(\rightarrow 4\ell)$.

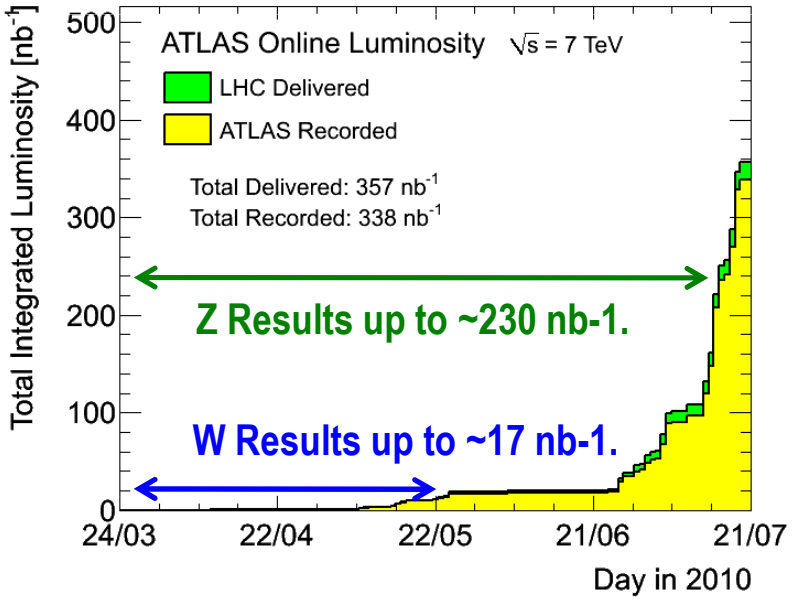


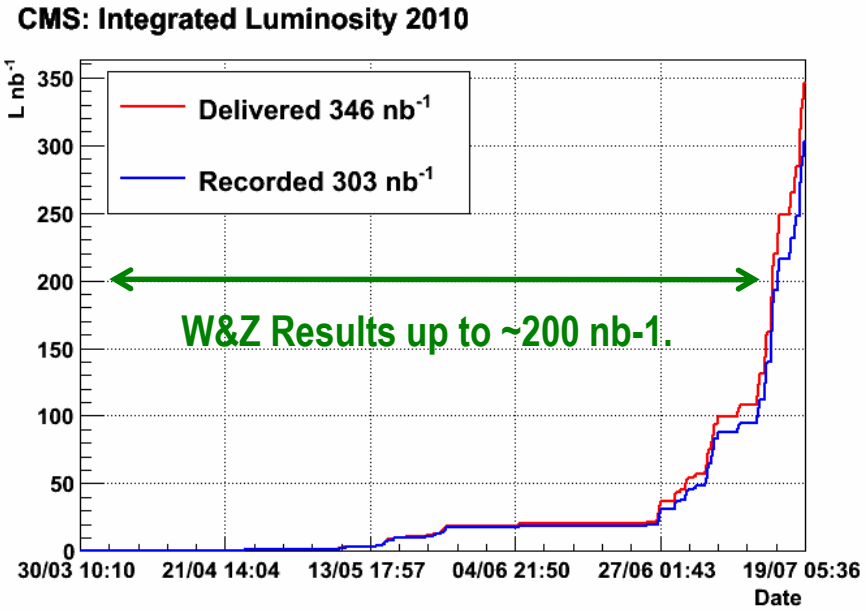
- **Moreover:**
- $W \rightarrow \ell\nu$ and $Z \rightarrow \ell\ell$ are **benchmark processes** to assess performances of detectors and develop reconstruction/identification algorithms,
- Di-bosons (WW, ZZ, WZ) and jet associated productions (W/Z+jets) are **important backgrounds for Higgs searches.** Crucial to have single boson under control:
  - ex: in $H \rightarrow ZZ^{*}$, at the time of discovery, won't have enough ZZ^{*} background events in sidebands.
    => ZZ^{*} yields will be predicted from single Z.

Understanding of W&Z production at LHC therefore of primary importance for Higgs Searches !

OutLine

- ATLAS & CMS Performances
  - Triggers
  - Leptons & MET
- W $\rightarrow \ell\nu$ measurements
- Z $\rightarrow \ell\ell$ measurements
- Conclusion



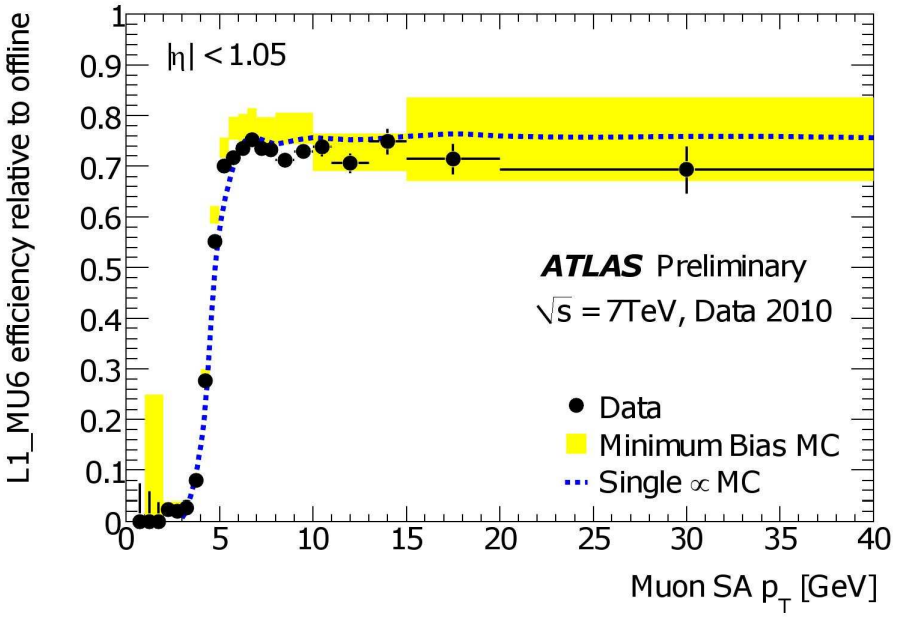


Luminosity known to 11% precision (from Van Der Meer scans).

ATLAS&CMS PERFORMANCES

Triggering on Leptons

- Events are filtered online in 2 (CMS) or 3 (ATLAS) steps.

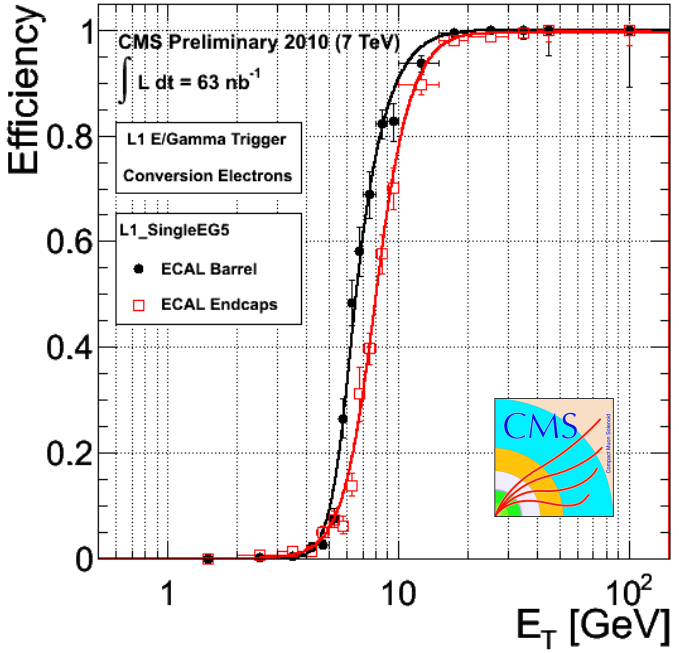


Level 1 Muon Trigger efficiency:

- Threshold at 6 GeV,
- Eff. w.r.t "Stand Alone" offline Muon (reconstructed only with the Spectrometer)

Level 1 Electron Trigger efficiency:

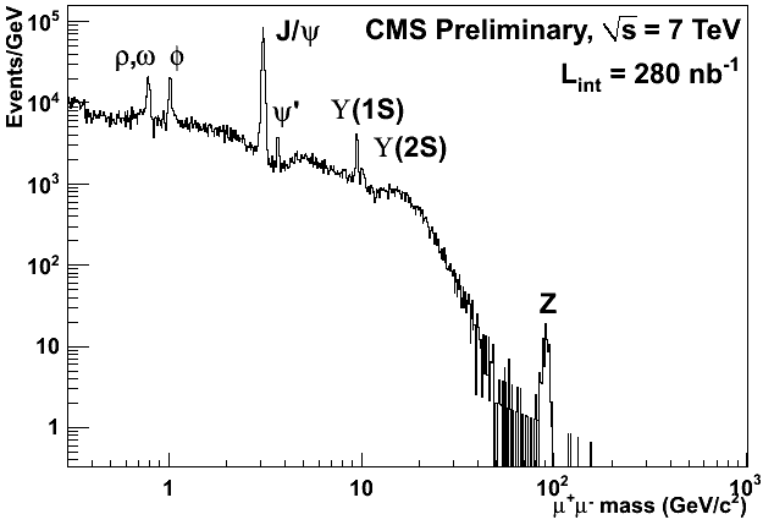
- Threshold at 5 GeV,
- Eff w.r.t ET of the ECAL super-cluster of the electron candidate
- Measured on Minimum bias events with electrons from conversions.
- Turnon gets sharper with isolated electrons from W&Z.



Electrons & Muons (1)

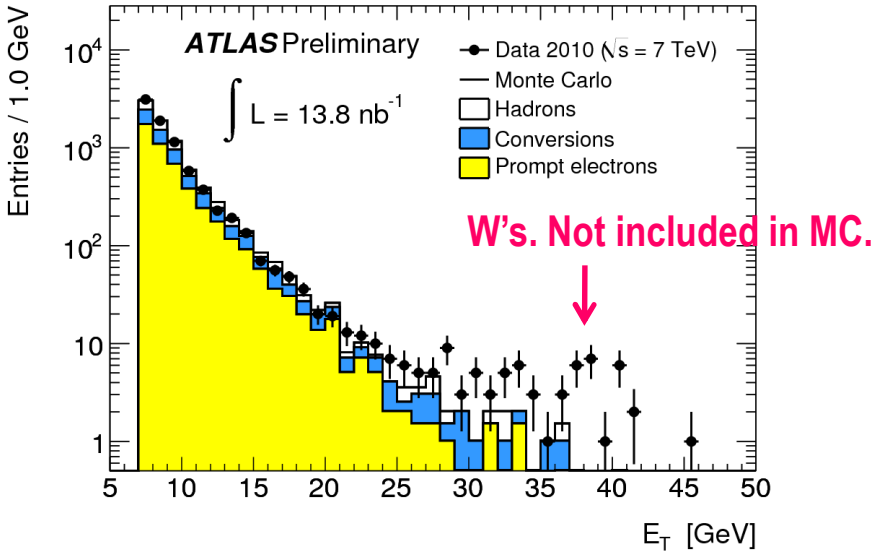
➢ All aspects of leptons (reconstruction, identification, isolation, energy scale & resolution) commissioned/measured by looking at all possible sources of leptons available:

- **leptons in Minimum bias events**
  (mainly from heavy flavour decays) ,
- **benchmark processes (J/ψ, W and Z bosons).**

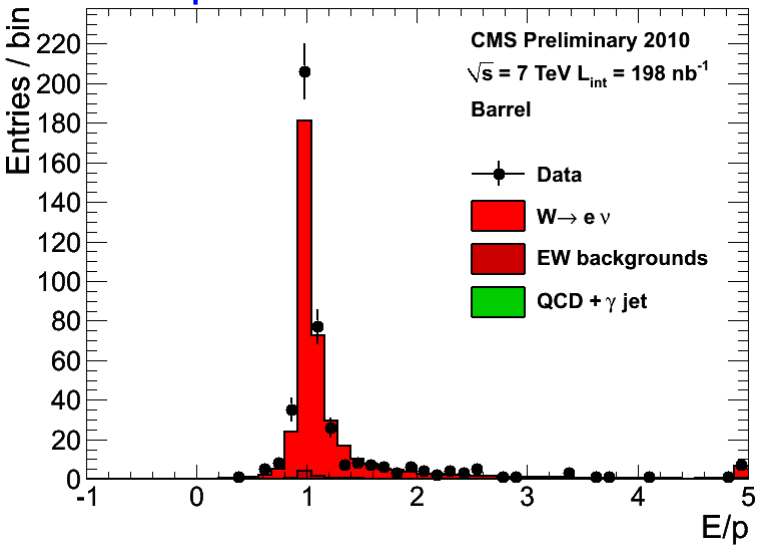


➢ Simple cuts-based selections are used to extract signal from background and study properties of leptons.

E_T of e-candidates in Minimum bias events



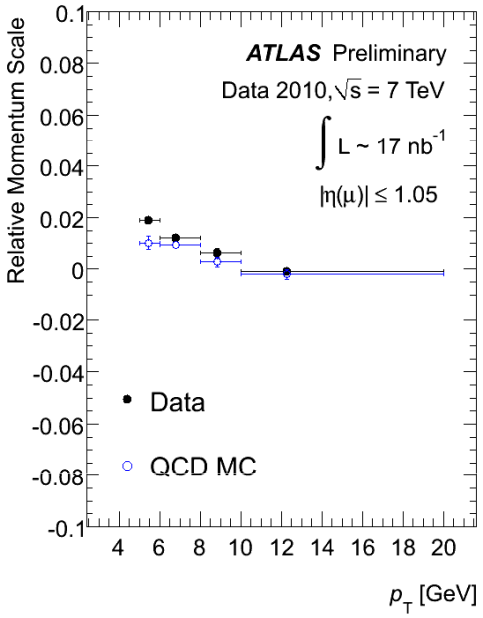
E/p of e-candidates in W→eν events

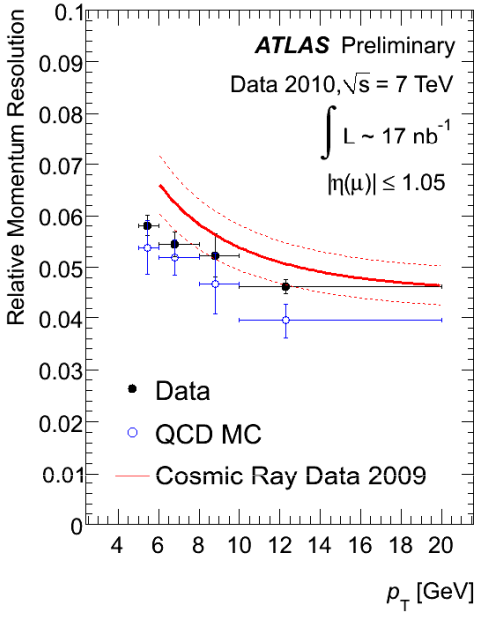


Electrons & Muons (2)

➢ Muon Relative(*) Momentum Scale (left) & Resolution (right).

BARREL

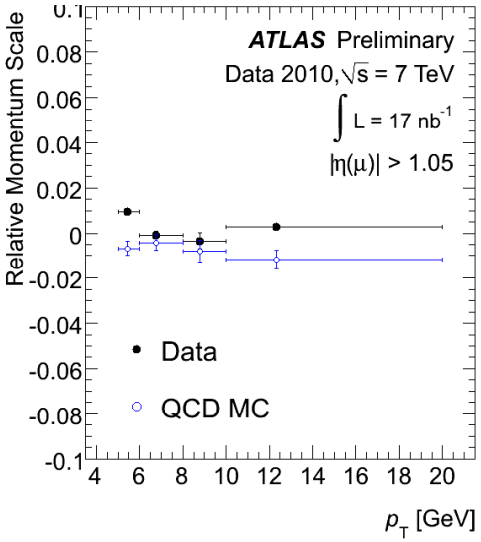


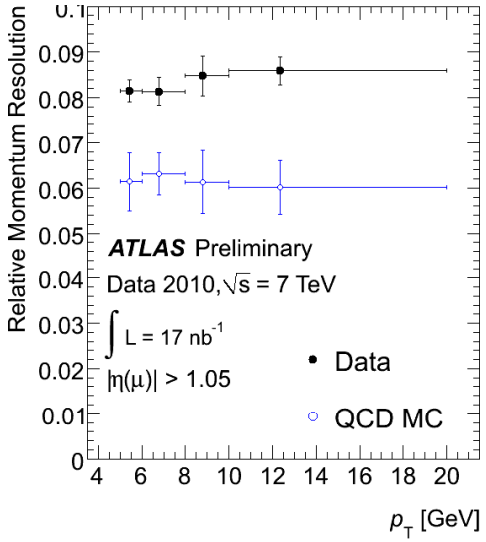


- Measured In Min. Bias events.
- Overall good agreement with MC.

(*) pT in Spectrometer relative to pT in Inner Detector

ENDCAP

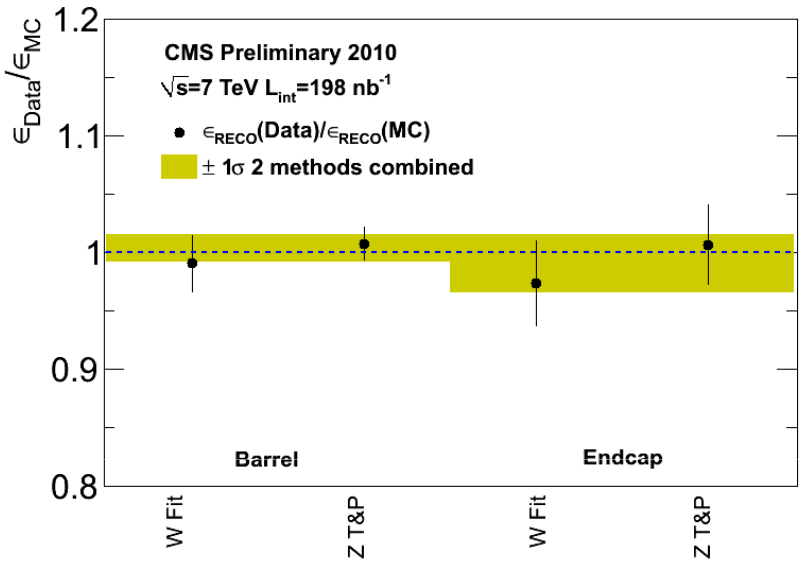




- Worse resolution in data (endcap) due to imperfect alignement.

Electrons & Muons (3)

➢ **Very high lepton reconstruction efficiency mandatory for Higgs searches** (e.g., $H \rightarrow ZZ^* \rightarrow 4l$ => ε^4 !)



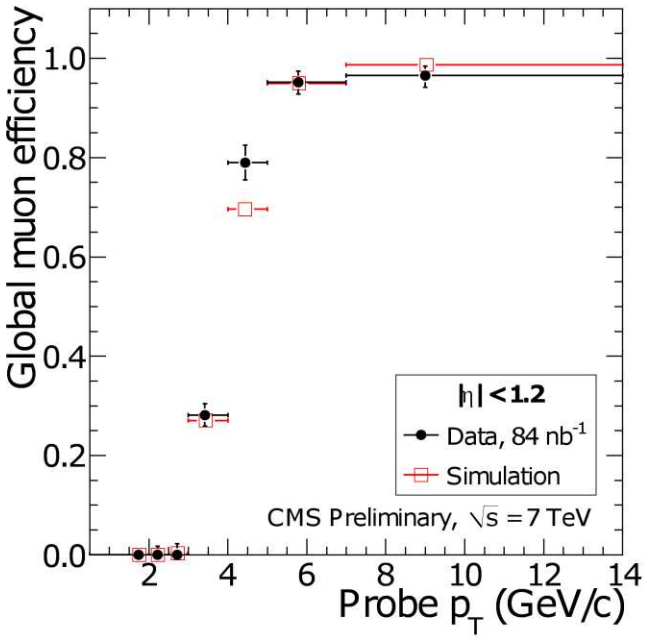
➢ **Electron reconstruction efficiency ratio ε_{RECO}(DATA)/ε_{RECO}(MC):**

- E_T>20 GeV, |η|<2.5
- Measured with Z tag & probe and W fit methods(*).
- Barrel: ε_{RECO}~99%, Endcap: ε_{RECO}~96%,

(*) The W fit method measures the efficiency with a 1D unbinned maximum likelihood simultaneous fit to the transverse mass distribution

➢ **Global Muon (muon chamber+tracker) reconstruction Efficiency**

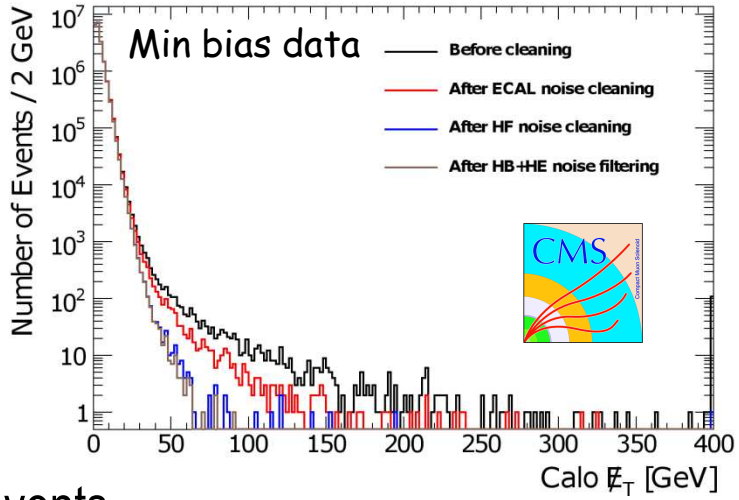
- Measured in J/ψ events with tag&probe method.
- >99% reached for pT > 6 GeV…
- … in good agreement with MC.



Missing E_T

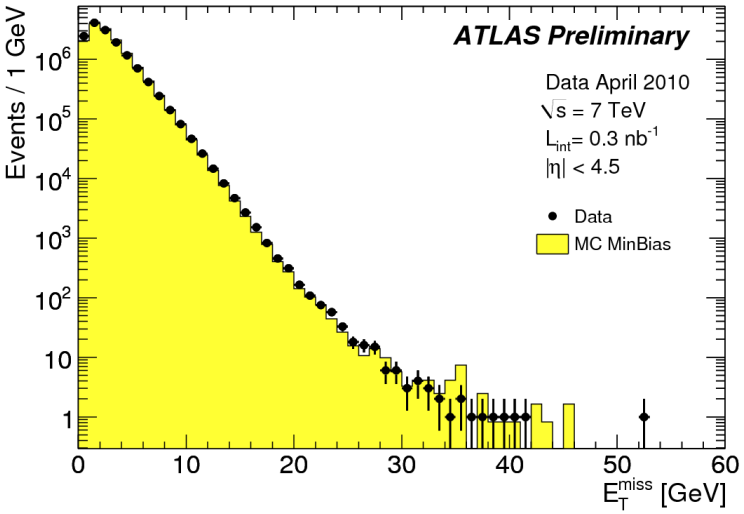
- Key variable for the W $\rightarrow \ell\nu$ analysis. (MET from escaping neutrinos).

- Very sensitive to noise, pile-up, beam-halo background.
  => Need dedicated cleaning.

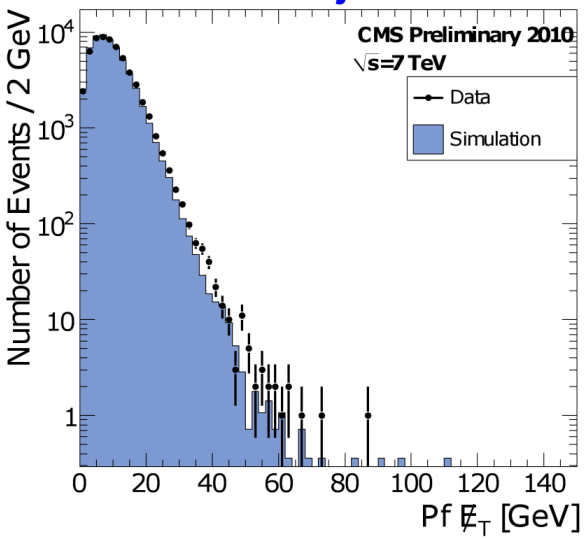


- Commissioned using Minimum Bias, Dijet (and W$\rightarrow \ell\nu$) events.

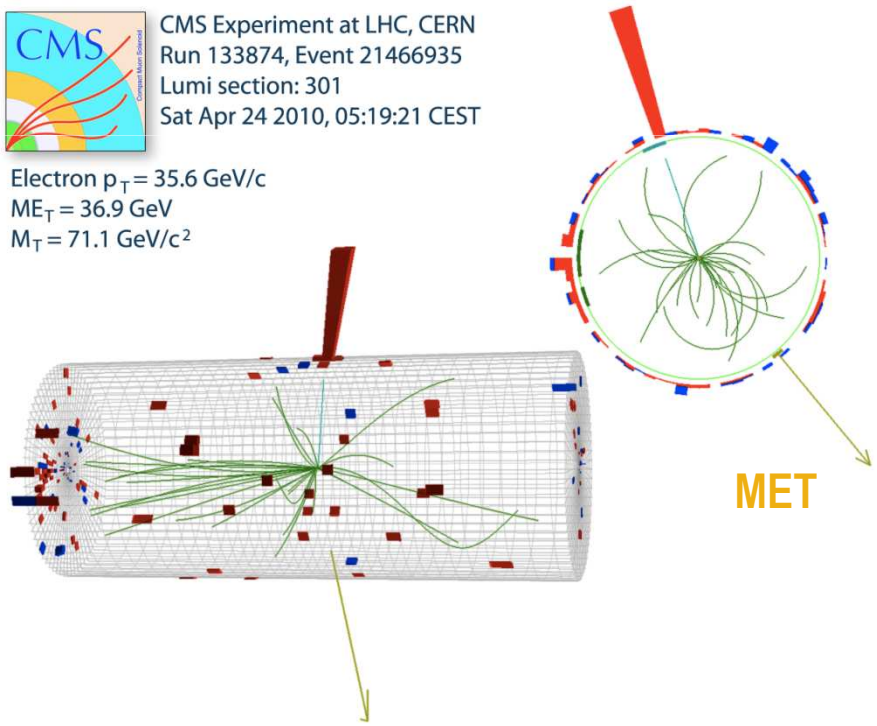
MET in Minimum Bias

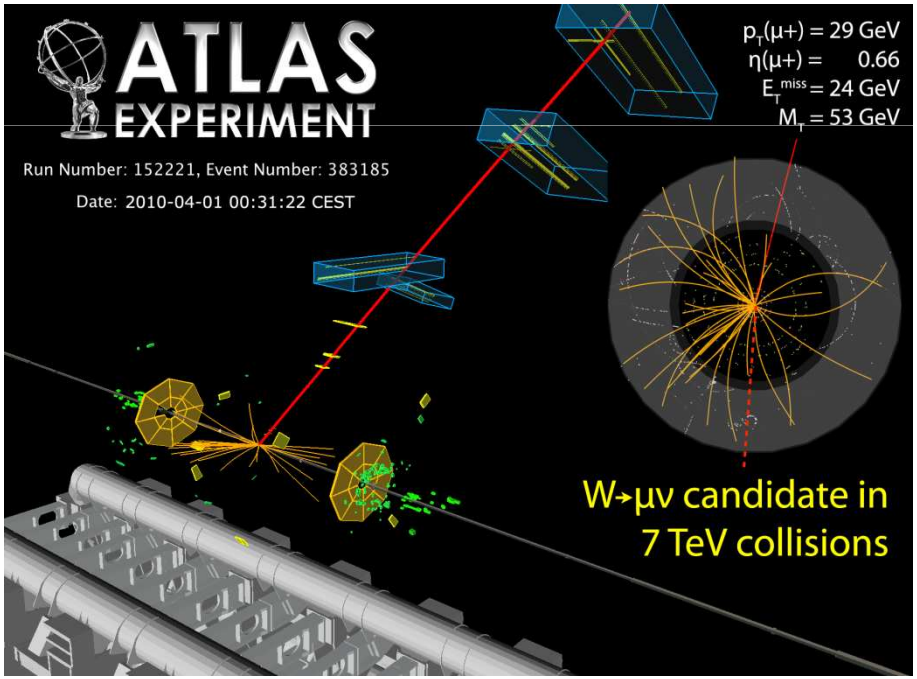


MET in Dijet Events



$W \rightarrow \ell\nu$ Measurements





Overview on W/Z at LHC

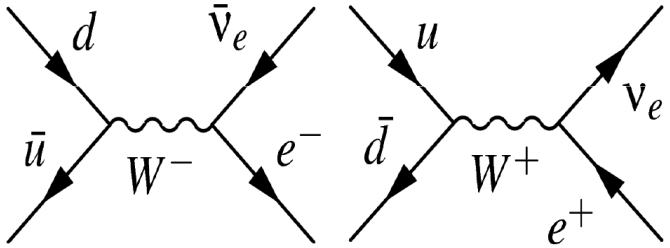
➢ **W/Z Inclusive cross-section is known up to ~4%** (dominated by PDF uncertainties):

$$\sigma^{NNLO}_{W\to\ell\nu} = 10.46 \text{ nb} \qquad \sigma^{NNLO}_{Z/\gamma^*\to\ell\ell} = 0.99 \text{ nb}$$

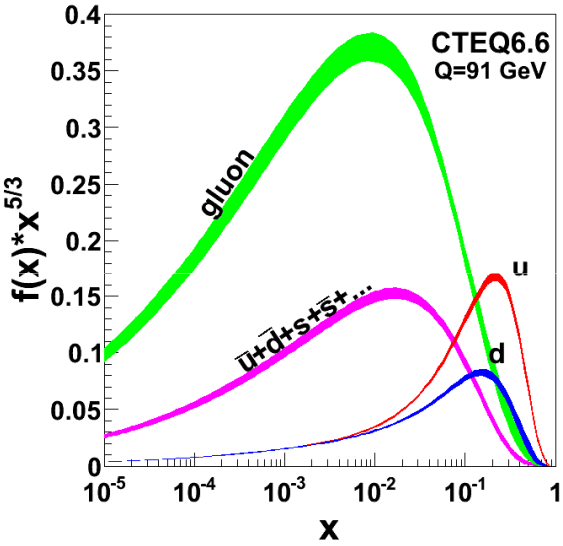
- Computed with FEWZ and MSTW2008.

➢ **Produce more W+ than W-** (prevalence of u quarks over d quarks).

$$\sigma^{NNLO}_{W^+\to\ell^+\nu} = 6.16 \text{ nb} \qquad \sigma^{NNLO}_{W^-\to\ell^-\bar{\nu}} = 4.30 \text{ nb}$$



- Charge asymmetry measurement very important (**see later**).



➢ **ATLAS & CMS used different methods to extract cross-sections:**

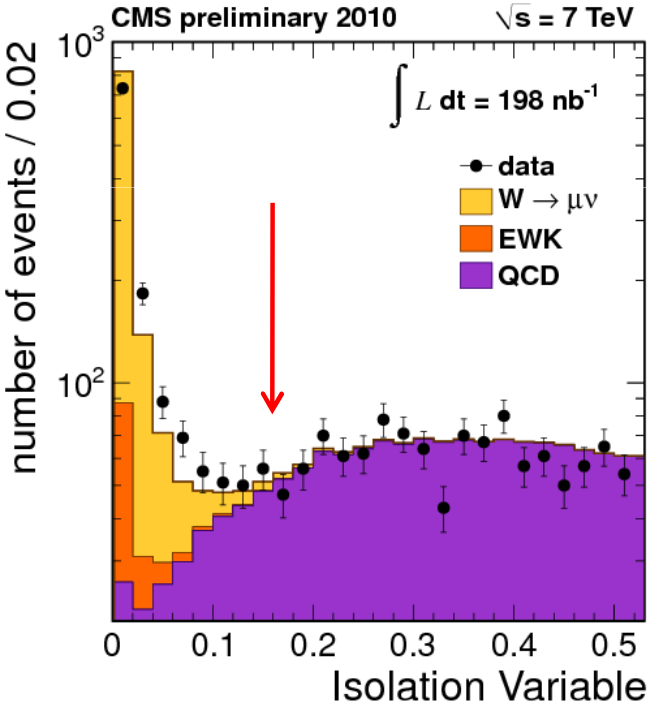
- Cut & count **[ATLAS for W&Z, CMS for Z]**.
- Extraction of yields trough a binned Likelihood fit to a discriminating variable (simultaneously for Signal + QCD & EWK backgrounds) **[CMS for W]**.
- Acceptance are computed with MC **[both]**, efficiencies from data **[CMS]** or mostly from MC **[ATLAS].**

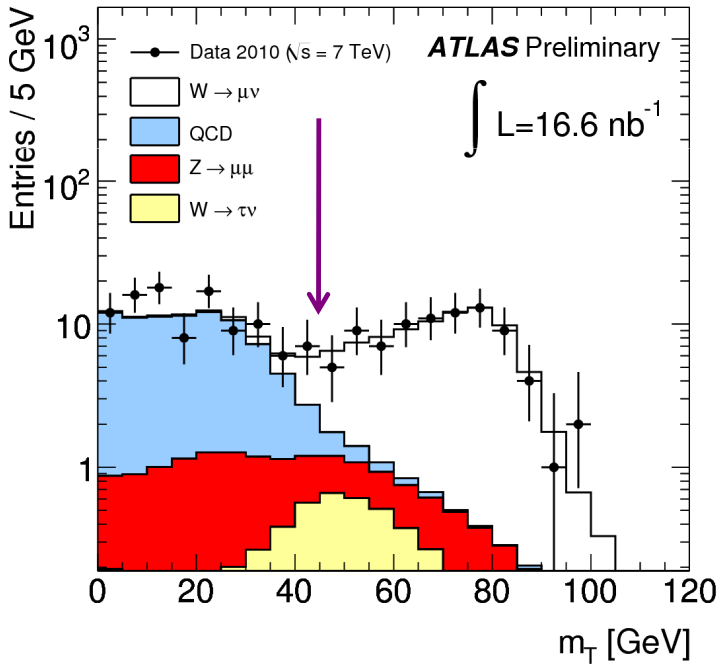
Inclusive W boson measurements: Muon Channel

- Muon Trigger (pT>9 GeV)
- Muon pT>20 GeV, |η|<2.1
- Combined Isolation (tracker, ECAL, HCAL)
- Drell-Yan veto
- (no MET or M_T cut)

- Muon Trigger (pT>15 GeV)
- Muon pT>20 GeV, |η|<2.4
- Track-Isolation
- (+MET>25 GeV +M_T > 40 GeV)

Transverse Mass: $M_T = \sqrt{2p_T(\mu)\not{E}_T * (1 - \cos(\Delta\phi_{\mu,\not{E}_T}))}$





- W and EWK background estimated from MC (POWHEG, Pythia, MC@NLO).
- QCD shape estimated from data

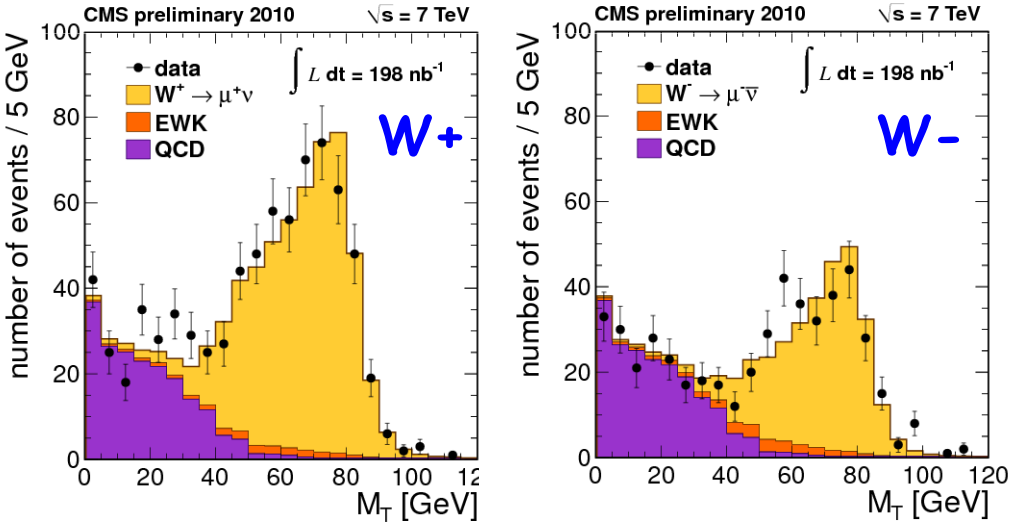
Inclusive W boson measurements: Muon channel (2)

$\sigma(pp \to W+X \to \mu\nu+X) =$

9.14 ± 0.33 (stat) ± 0.58 (syst) ± 1 (lumi) nb — **10.3 ±1.3 (stat) ±0.8(syst)±1.1(lumi) nb**

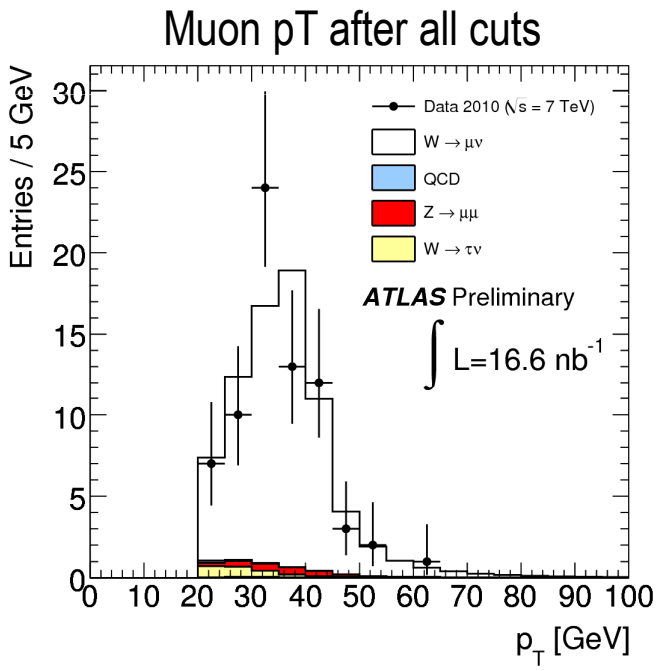
- $\sigma(W^+ \to \mu^+\nu) = 5.75 \pm 0.26$ nb
- $\sigma(W^- \to \mu^-\nu) = 3.39 \pm 0.15$ nb
- $R(W^+/W^-) = 1.69 \pm 0.12$

$\sigma(W^+ \to \mu^+\nu) = 6.6 \pm 1.0$ (stat) ± 0.5 (syst) ± 0.7 (lumi) nb
$\sigma(W^- \to \mu^-\nu) = 3.6 \pm 0.8$ (stat) ± 0.3 (syst) ± 0.4 (lumi) nb



W+ Yield: 529 ± 24
(statistical error only)

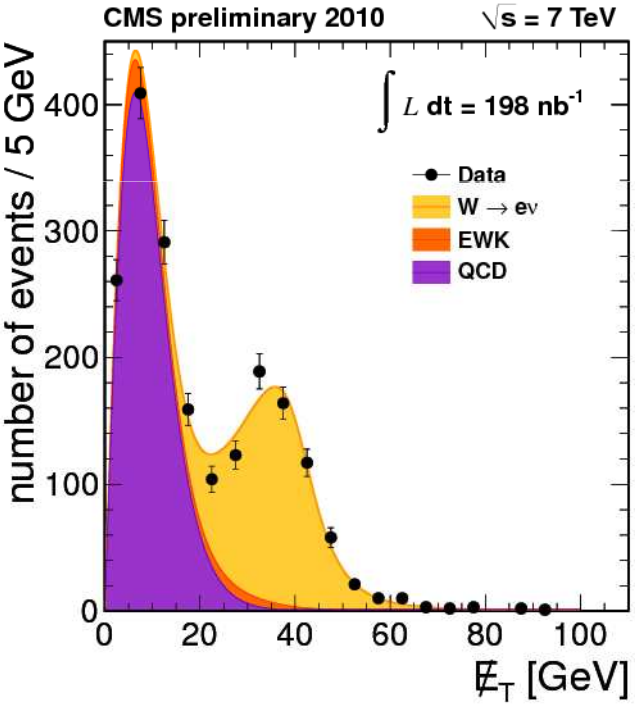
W- Yield: 289 ± 13

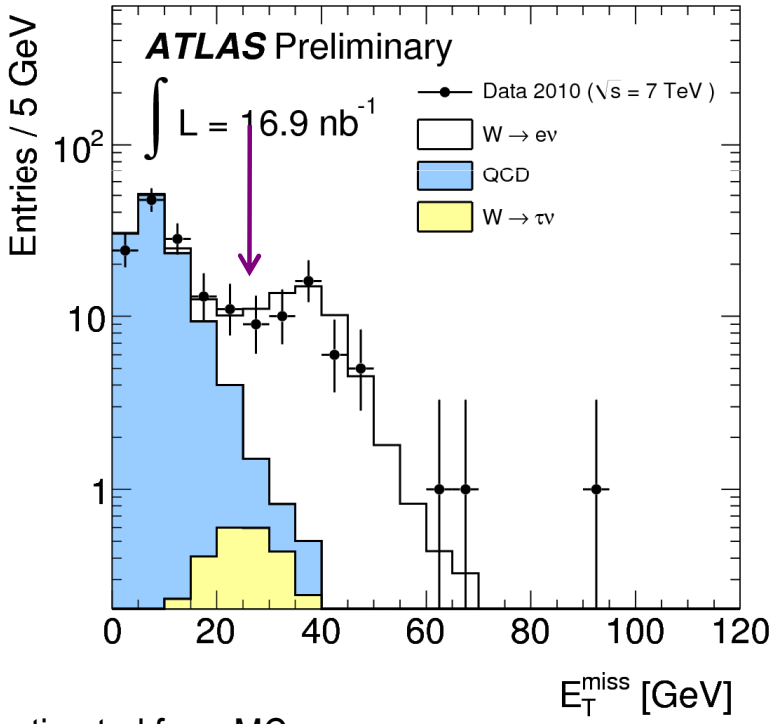


Inclusive W boson measurements: Electron Channel (1)

- Photon trigger (E_T>15 GeV),
- Electron E_T> 20 GeV,
- |η|<2.5 (excluding Barrel-Endcap transition),
- Combined Isolation,
- Drell Yan rejection.
- (no MET or M_T cut)

- L1 Calo Trigger (E_T>5 GeV),
- Electron pT>20 GeV,
- (+MET>25 GeV +M_T > 40 GeV)





- W and EWK background estimated from MC.
- QCD shape estimated from data.

Inclusive W boson measurements: Electron Channel (2)

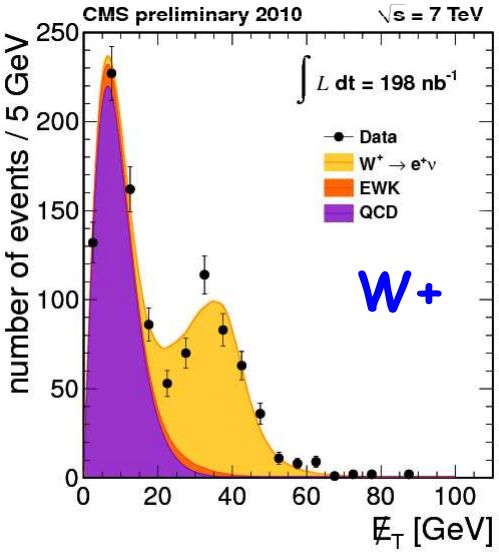
$\sigma(pp \to W+X \to e\nu+X)$ =

CMS: $9.34 \pm 0.36\ (stat) \pm 0.70\ (syst) \pm 1\ (lumi)$ nb

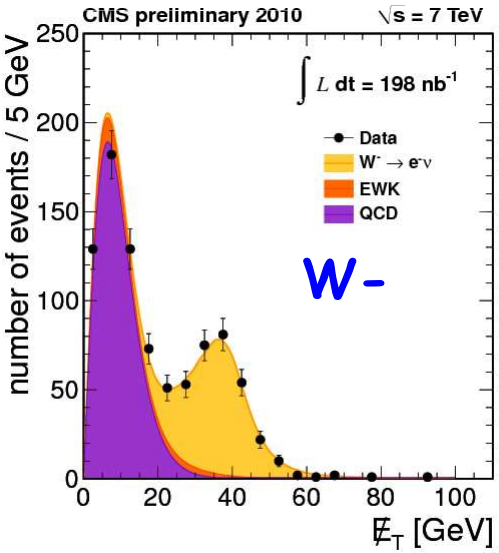
ATLAS EXPERIMENT: $8.5 \pm 1.3\ (stat) \pm 0.7\ (syst) \pm 0.9\ (lumi)$ nb

- $\sigma(W^+ \to e^+\nu) = 5.18 \pm 0.26$ nb
- $\sigma(W^- \to e^-\nu) = 4.13 \pm 0.24$ nb
- $R(W^+/W^-) = 1.26 \pm 0.10$

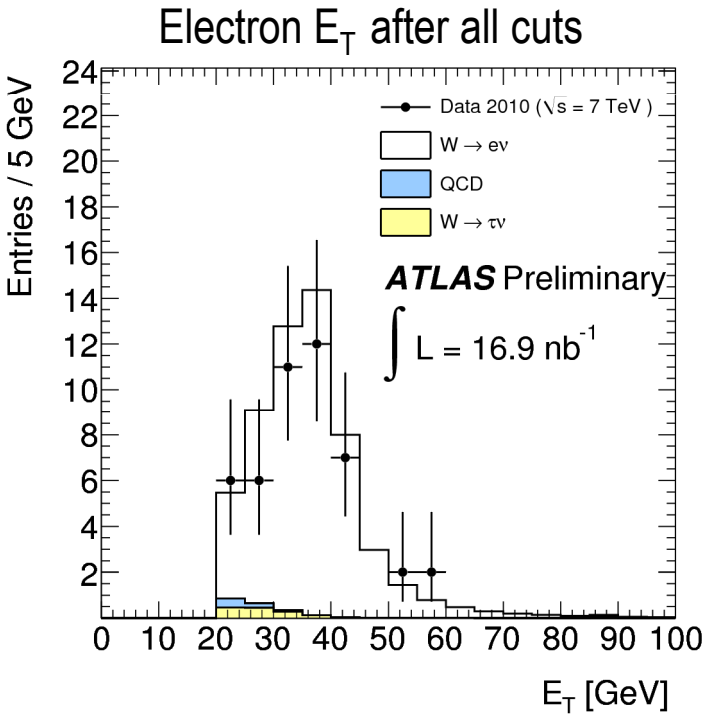
$\sigma(W^+ \to \mu^+\nu) = 5.0 \pm 1.0\ (stat) \pm 0.4\ (syst) \pm 0.5\ (lumi)$ nb
$\sigma(W^- \to \mu^-\nu) = 3.5 \pm 0.9\ (stat) \pm 0.3\ (syst) \pm 0.4\ (lumi)$ nb



W+ Yield: 458±23



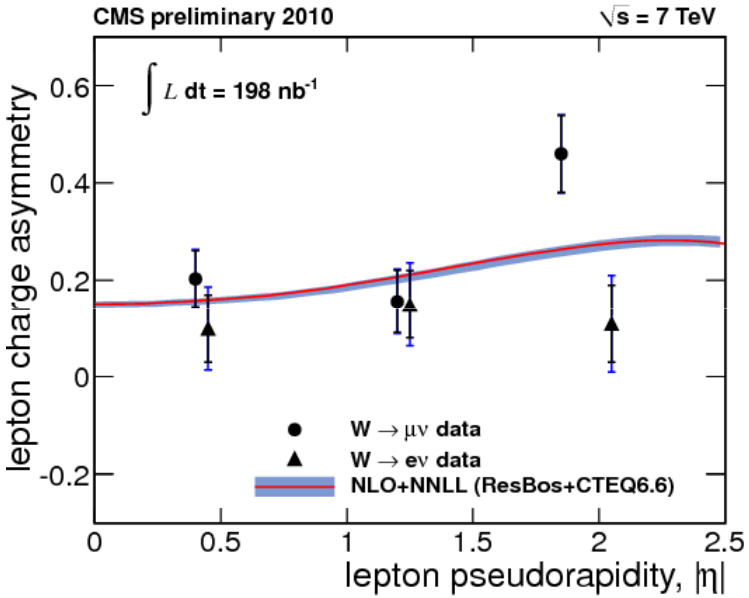
W- Yield: 339±20

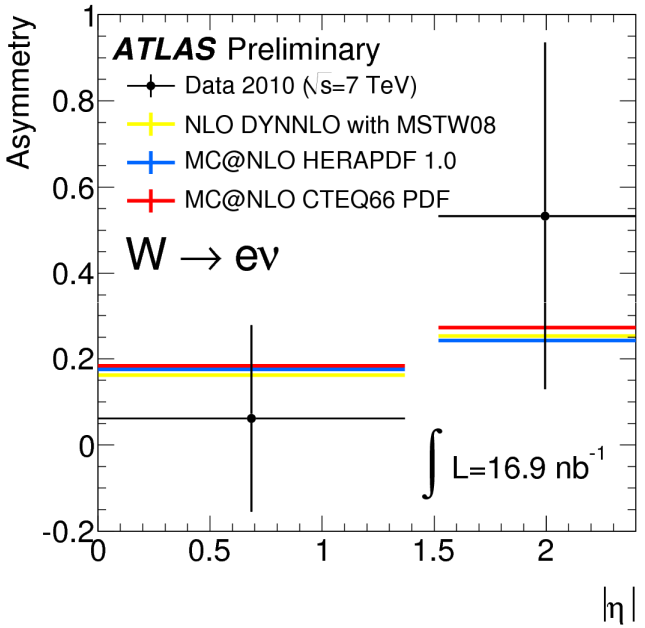


W Charge Asymmetry

- W charge asymmetry as a function of lepton pseudo-rapidity will improve our knowledge of Parton Density Functions (PDFs)

$$A(\eta) = \frac{d\sigma^{(+)}/d\eta_\ell - d\sigma^{(-)}/d\eta_\ell}{d\sigma^{(+)}/d\eta_\ell + d\sigma^{(-)}/d\eta_\ell}$$



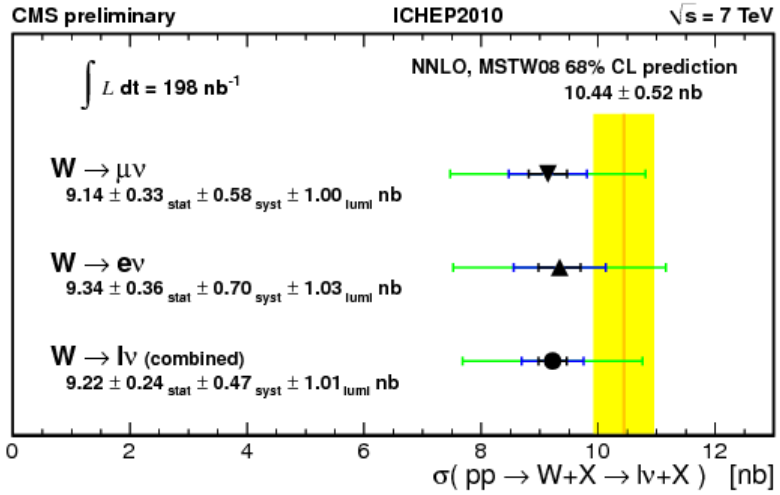


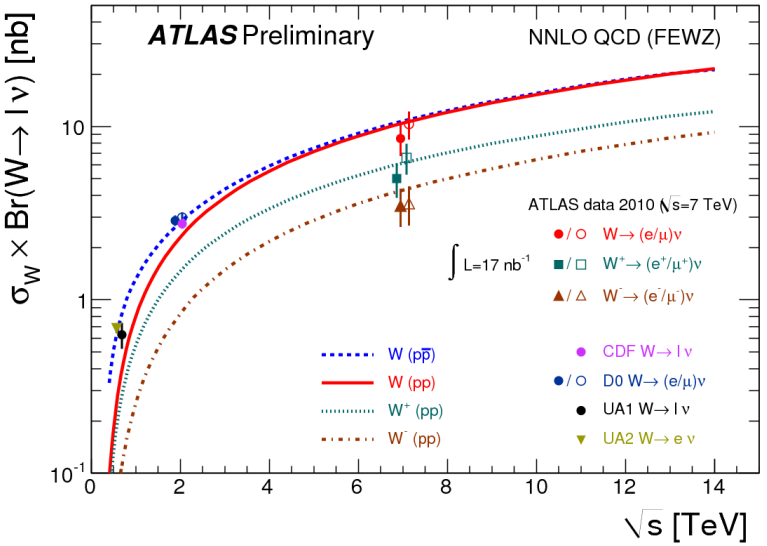
- **Remarks:**
  - Ratio (W^++n jets)/(W^-+n jets) theoretically very stable w.r.t EWK parameter values and higher-order corrections (QCD&EWK)
  - Any deviation from SM expectations could sign the presence of charge-symmetric New Physics…
    - Note that ttbar→WbWb and H→WW* also produce $W^{+/-}$ in equal quantities…

=> Use charge asymmetry as a new tool for searches ?

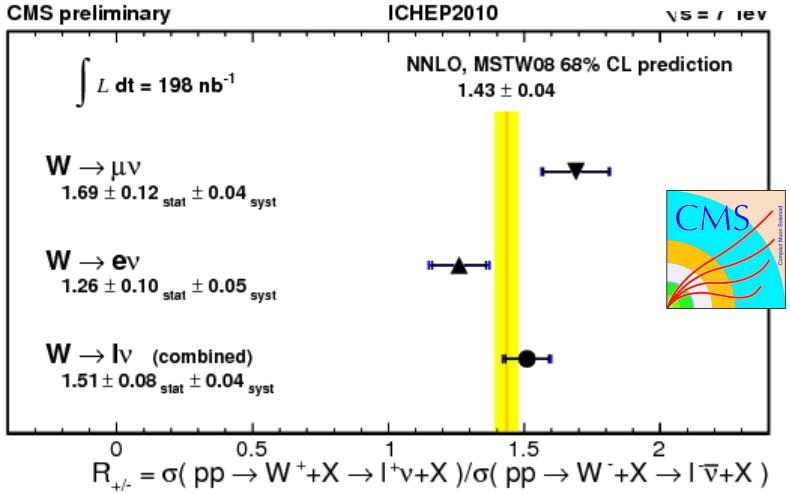
Inclusive W boson measurements: Summary

W→ℓν cross section





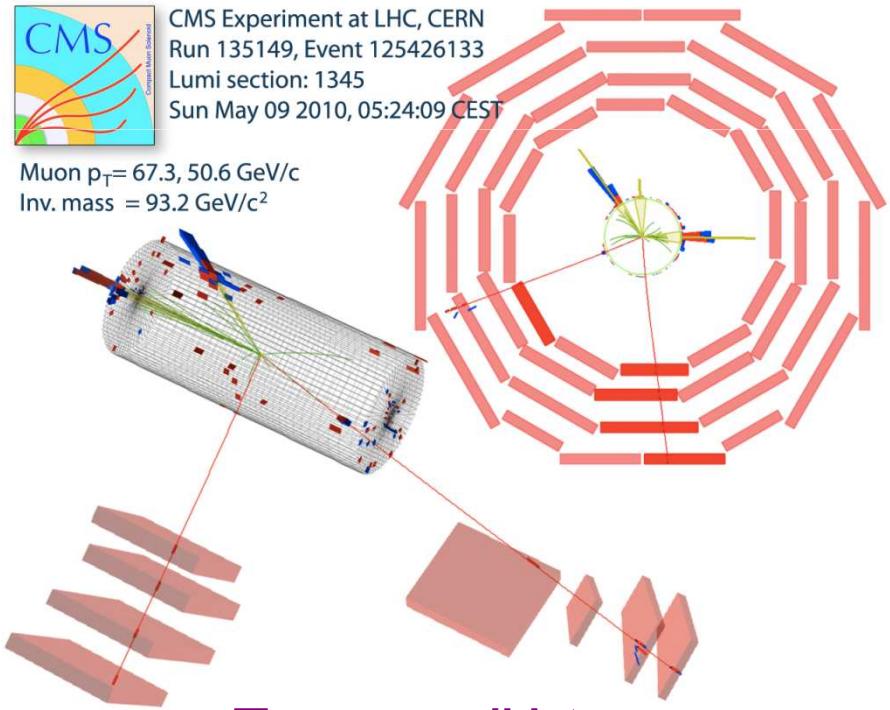
Ratio W+/W-



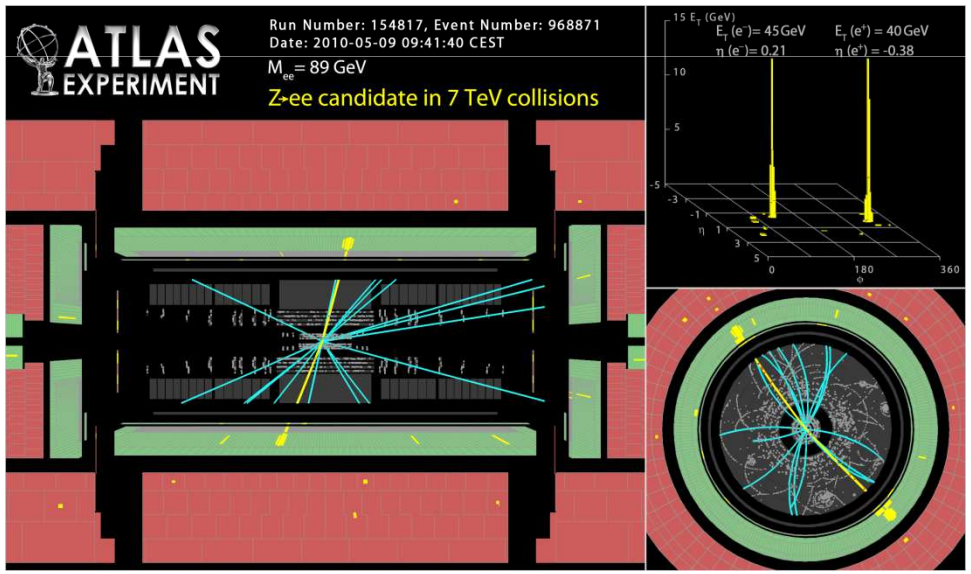
All the results are in agreement with the Standard Model expectations.

$Z \rightarrow \ell\ell$

Measurements



$Z \rightarrow \mu\mu$ candidate

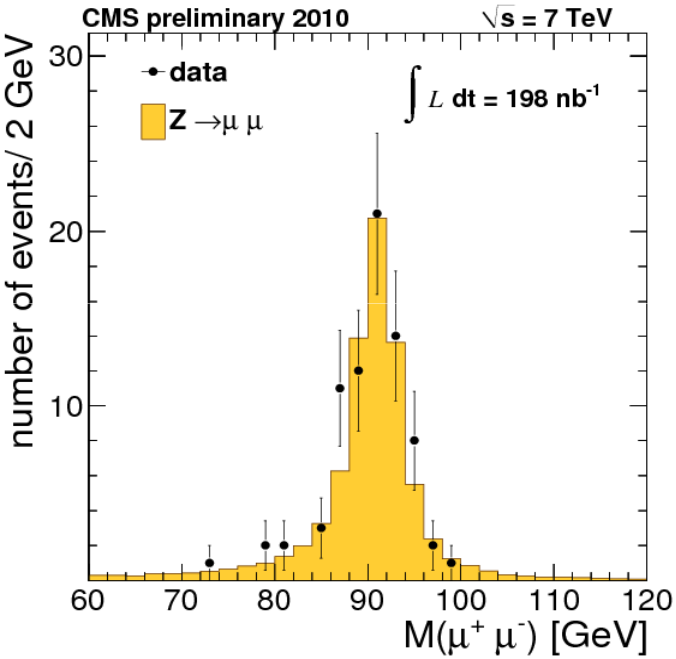


$Z \rightarrow ee$ candidate

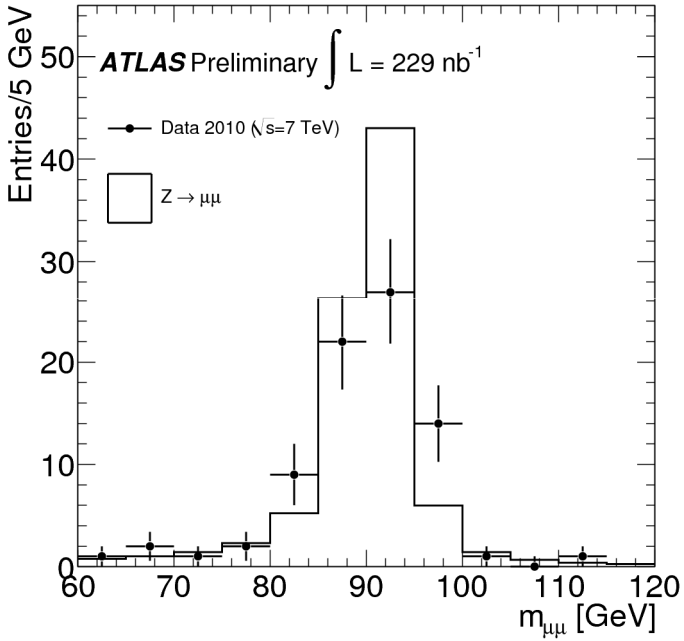
Inclusive Z boson measurements: Muon Channel

- Muon Trigger (pT>9 GeV),
- 2 opposite charge muons, ET>20 GeV,
- Track Isolation

- Muon Trigger (p_T>15 GeV),
- 2 opposite charge electrons, ET>20 GeV,
- Track Isolation.



77 candidates (60-120 GeV)



79 candidates (66-116 GeV)

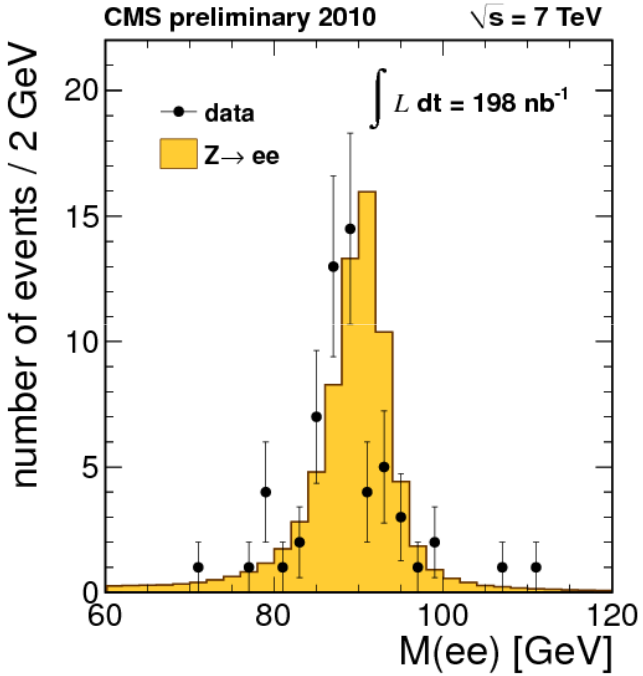
$\sigma(pp \rightarrow Z+X \rightarrow \mu\mu+X) =$

0.88 ±0.10 (stat) ±0.04 (syst) ±0.10 (lumi) nb

0.89 ±0.10 (stat) ±0.07(syst) ±0.10 (lumi) nb

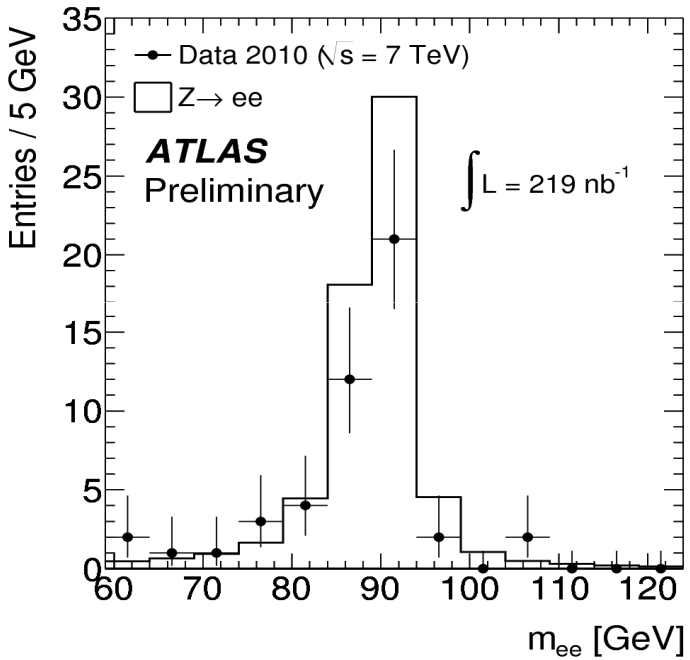
Inclusive Z boson measurements: Electron channel

- ECAL Trigger (E_T>15 GeV),
- 2 opposite charge electrons, E_T>20 GeV,
- Combined Isolation



61 candidates (60-120 GeV)

- L1 Calo Trigger (E_T>5 GeV),
- 2 opposite charge electrons, E_T>20 GeV.



46 candidates (66-116 GeV)

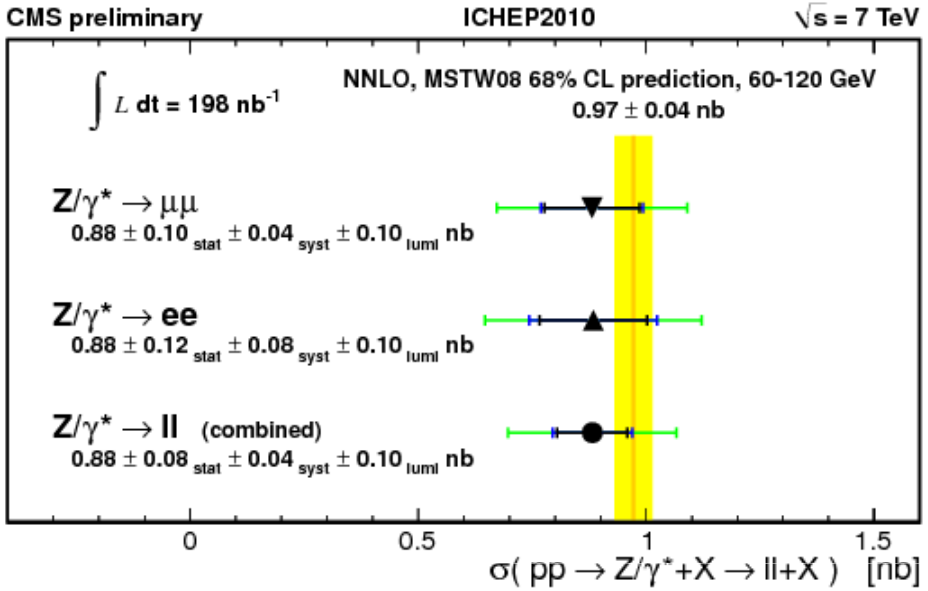
σ(pp→Z+X→ee+X) =

0.88 ±0.11 (stat) ±0.07 (syst) ±0.10 (lumi) nb

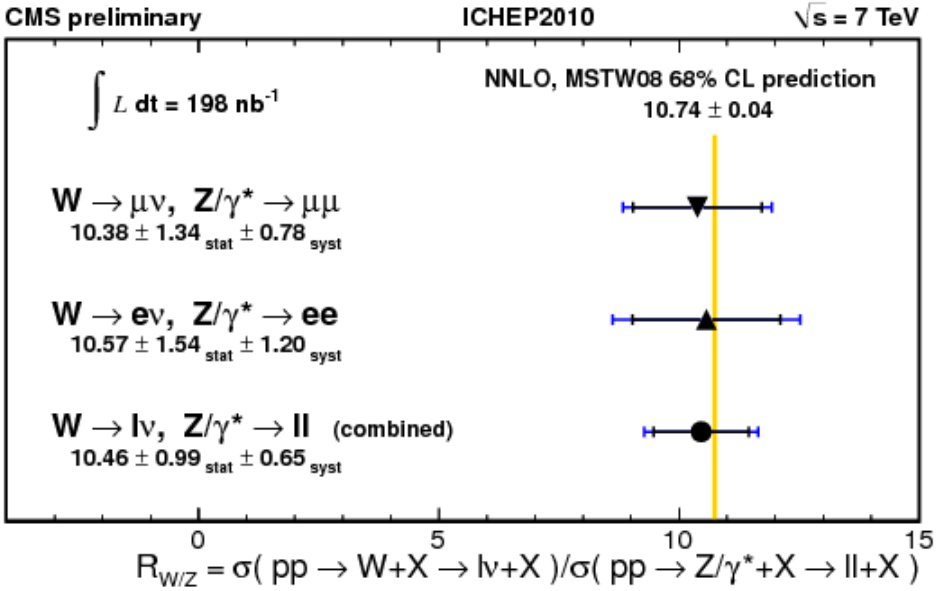
0.72 ±0.11 (stat) ±0.10 (syst) ±0.08 (lumi) nb

W&Z measurements summary (1)

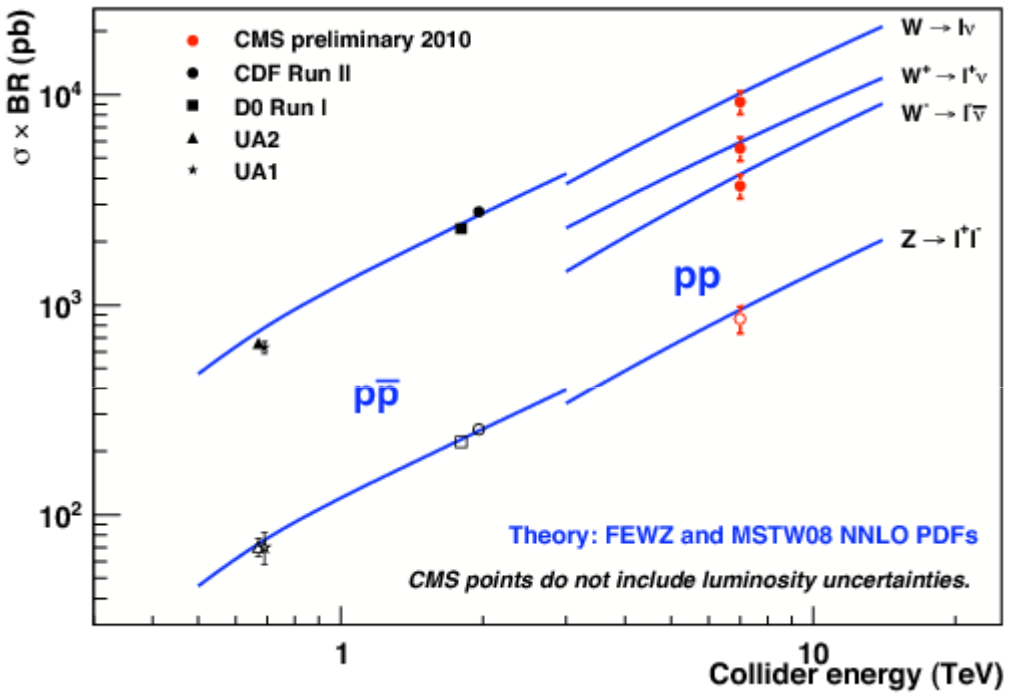
Z→ll cross section

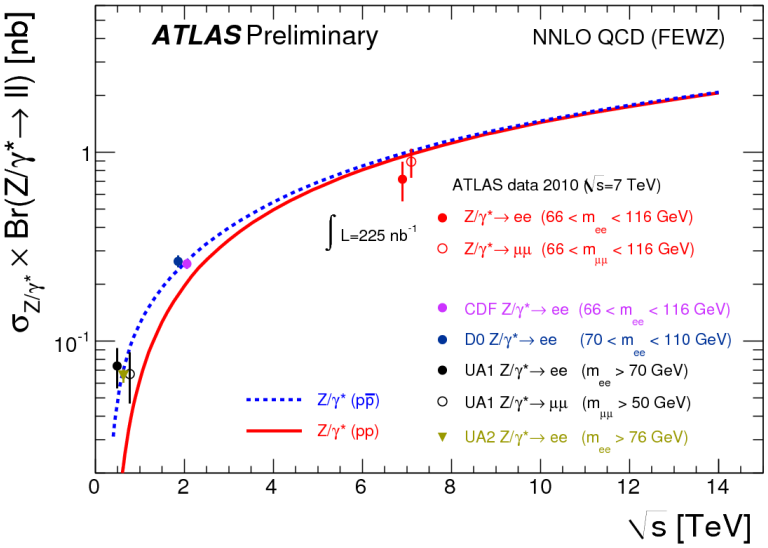


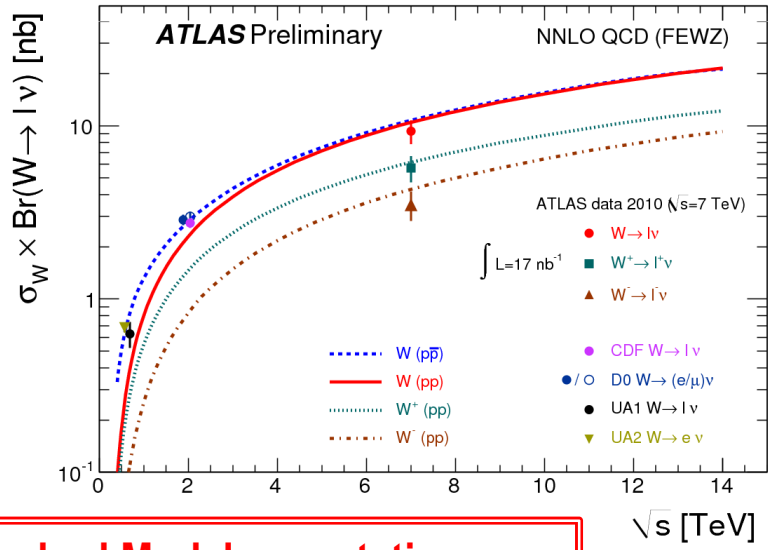
Ratio W/Z



W&Z measurements summary (2)

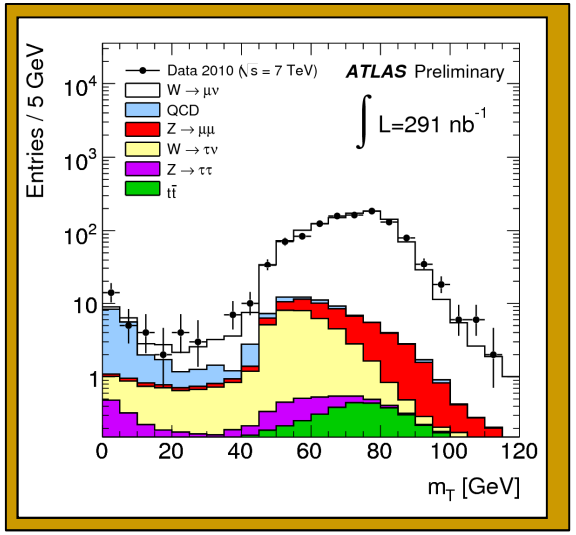




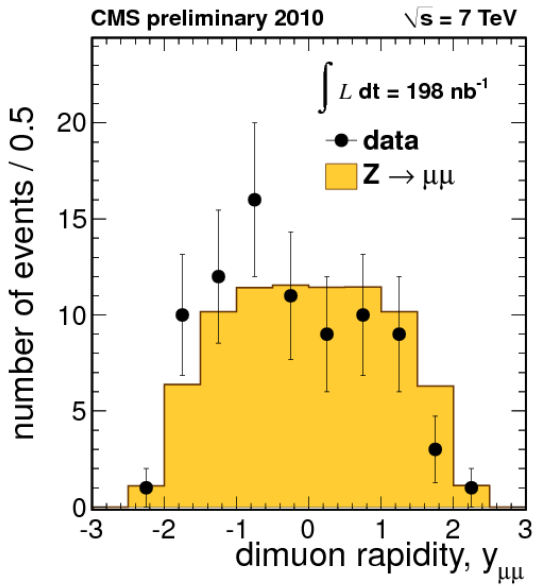


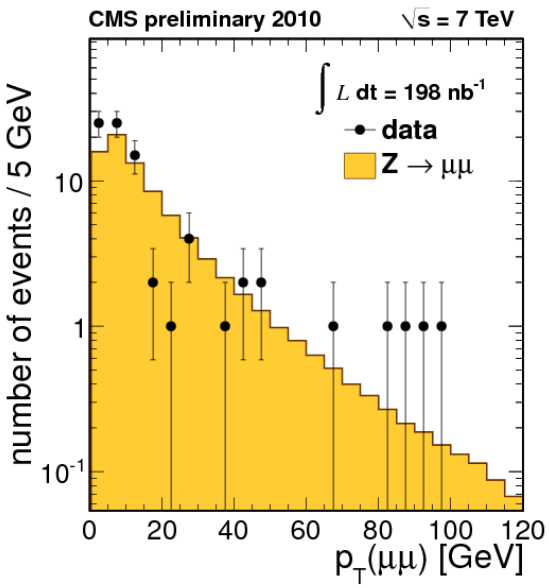
All the results are in agreement with the Standard Model expectations…
let's move further !

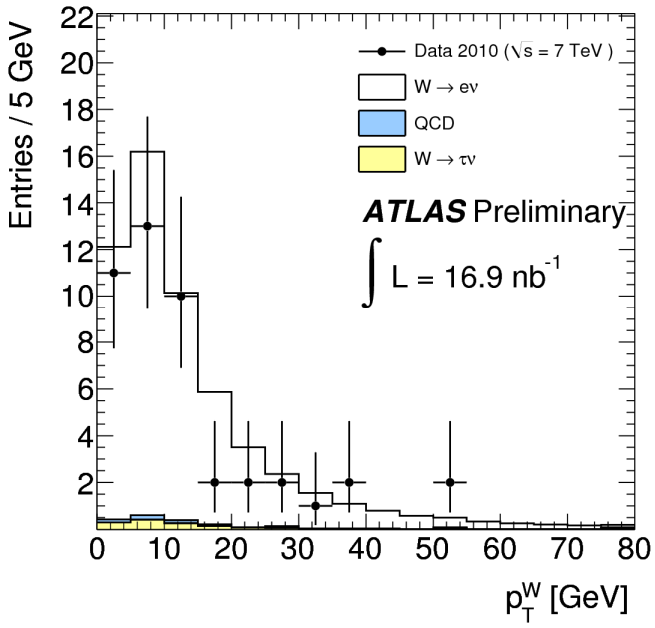
More measurements to come !



- **With increasing luminosity to come,** many more measurements will be performed:
  - differential distributions,
  - forward/backward asymmetry in Z, etc …







Towards the Higgs...

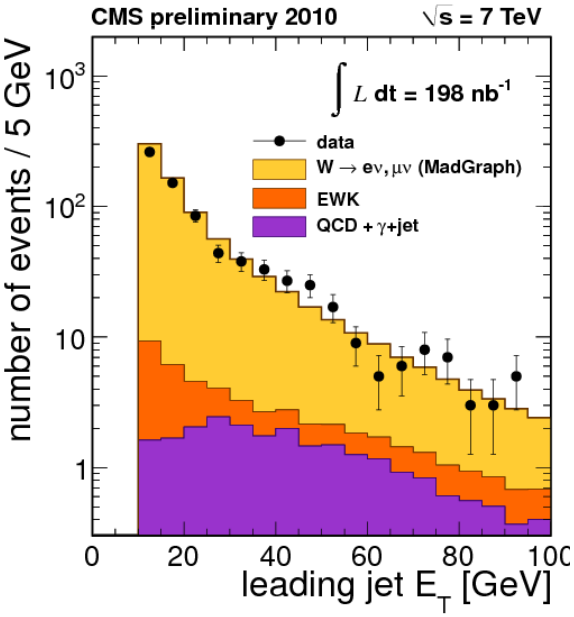
First look at W+jets

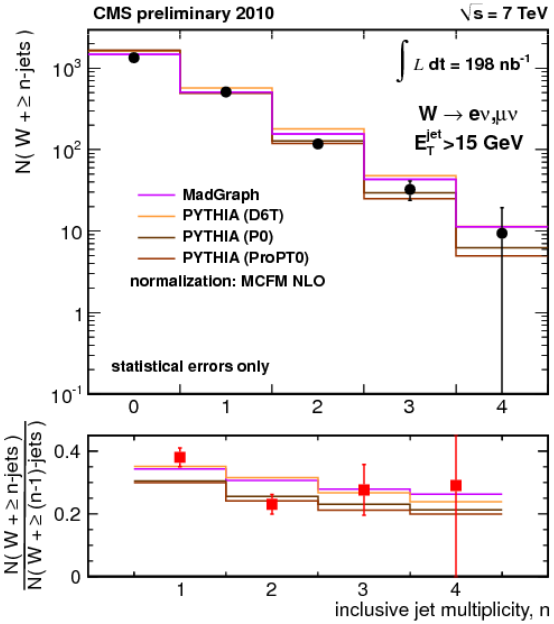
- **W+jets important background to Higgs Searches (e.g. H→WW*).**

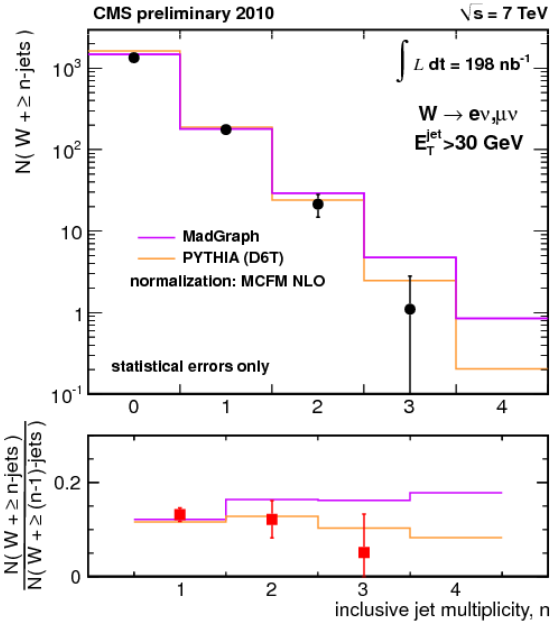
- Follow selection of inclusive cross section measurements…

… but add a focus on jets: Anti-kT, D=0.5, $|\eta|<2.5$, $E_T>15$ and 30 GeV.

- Comparison to Madgraph & Pythia (with various tunes)

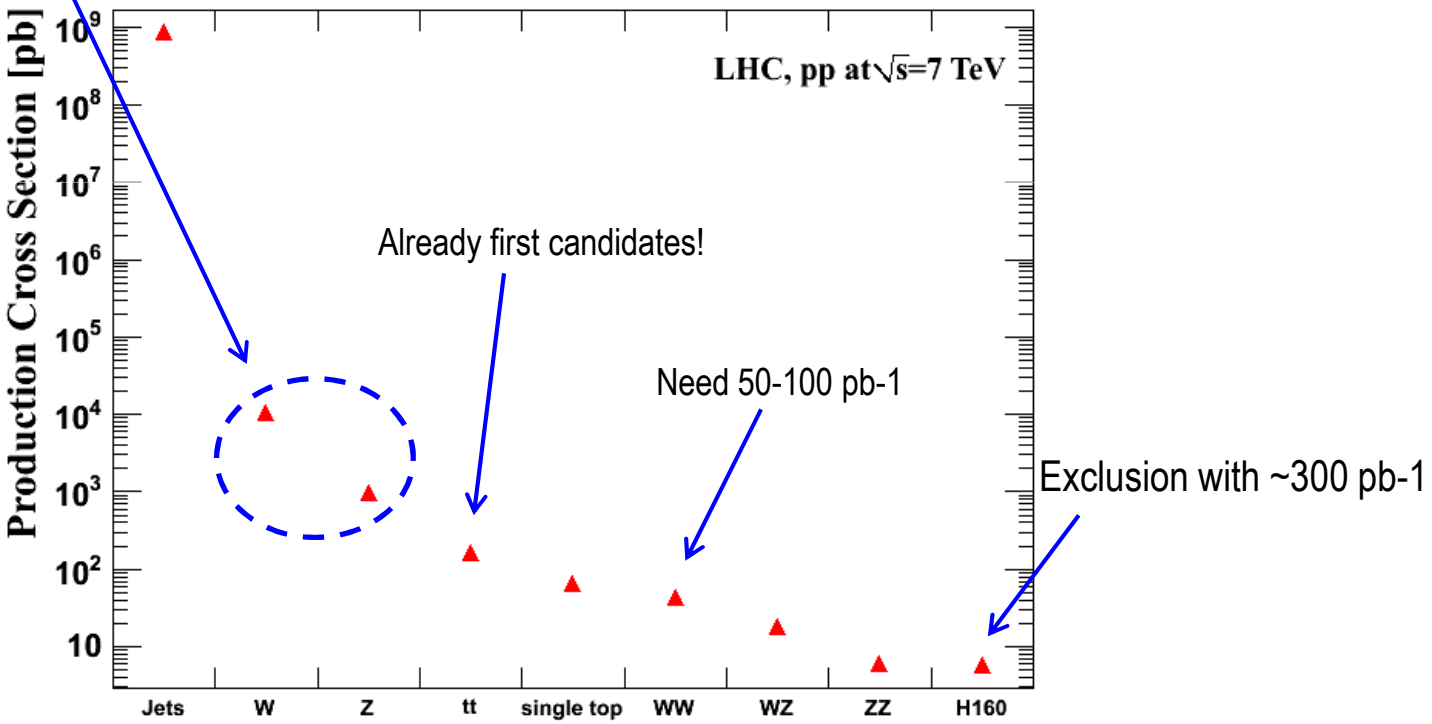






Conclusion/Prospects

- **After a few months of data taking, ATLAS & CMS started to rediscover the Standard Model:**
  - First measurements of W&Z cross section at $\sqrt{s}$=7 TeV with up to 230 nb^{-1} of data, already performed (in the muon & electron channels).
  - **All the results are agreement with theory expectations (within the current uncertainties).**
  - Ready for tau channels ! (Need (O)10 pb^{-1} for $Z \rightarrow \tau\tau$ observation)
  - W&Z (as well as J/ψ) are used to **validate ingredients and strategies for the upcoming Higgs searches.**



The upcoming months will be exciting !

BACK UP

SLIDES

Références

CMS PAS EWK-10-002: *"Measurements of Inclusive W and Z Cross Sections in pp Collisions at √s = 7 TeV".*
CMS PAS JME-10-004: *"Missing Transverse Energy Performance in Minimum-Bias and Jet Events from pp Collisions at √s=7 TeV".*
CMS PAS MUO-10-002: *"Performance of muon identification in pp collisions at √s=7 TeV" .*
CMS DPS DP-2010-032: *"Electron Reconstruction and Identification at √s= 7TeV".*

ATLAS-CONF-2010-051: *"Measurement of the W -> lnu production cross-section and observation of Z -> ll production in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector ".*
ATLAS-CONF-2010-076: *"Measurement of the Z -> ll production cross section in proton-proton collisions at sqrt(s) = 7 TeV with the ATLAS detector".*
ATLAS-CONF-2010-073: *"Observation of inclusive electrons in the ATLAS experiment at $\sqrt{s}$ =7 TeV"*
ATLAS-CONF-2010-064: *«Muon Reconstruction Performance »*
ATLAS-CONF-2010-057: *"Performance of the Missing Transverse Energy Reconstruction and Calibration in Proton-Proton Collisions at a Center-of-Mass Energy of $\sqrt{s}=7$ TeV with the ATLAS Detector"*

arXiv:1004.3404v2[hep-ph]: *"Charge asymmetry in W + jets production at the LHC",* C. H. Kom, W. J. Stirling

W&Z systematic uncertainties: Muon Channel (CMS)

- Reconstruction and Lepton ID from data–driven studies
- Momentum Scale and Resolution from J/Psis, cosmic studies, Z Mass spectrum
- ET scale/resolution from W recoil studies
- QCD Background uncertainty from the difference between isolated MC distribution and non-isolated data template
- PDF uncertainties evaluated via CTEQ66, MSTW08NLO, NNPDF2.0 sets

Source	W channel (%)	Z channel (%)
Muon reconstruction/identification	3.0	2.5
Trigger efficiency	3.2	0.7
Isolation efficiency	0.5	1.0
Muon momentum scale/resolution	1.0	0.5
$\not\!\!E_T$ scale/resolution	1.0	-
Background subtraction	3.5	-
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties	1.4	1.6
TOTAL (without luminosity uncertainty)	6.3	3.8
Luminosity	11.0	11.0

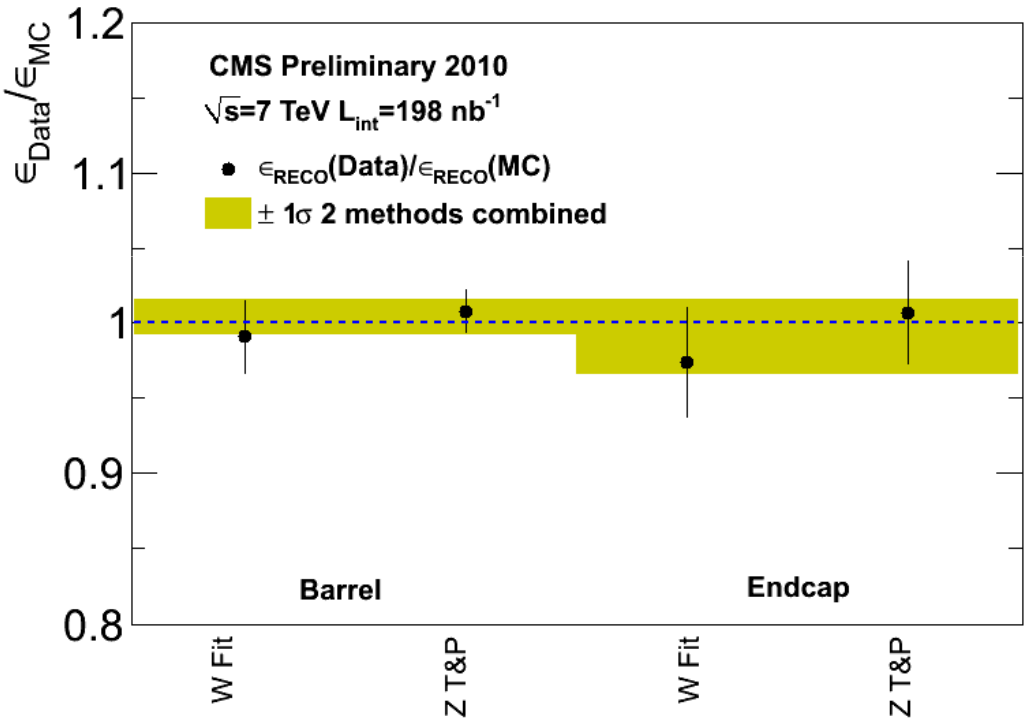
W&Z systematic uncertainties: Electron Channel (CMS)

Source	W channel (%)	Z channel (%)
Electron reconstruction/identification	6.1	7.2
Trigger efficiency	0.6	-
Isolation efficiency	1.1	1.2
Electron momentum scale/resolution	2.7	-
$\not\!\!E_T$ scale/resolution	1.4	-
Background subtraction	2.2	-
PDF uncertainty in acceptance	2.0	2.0
Other theoretical uncertainties	1.3	1.3
TOTAL (without luminosity uncertainty)	7.7	7.7
Luminosity	11.0	11.0

Electron Reconstruction Efficiency (ε_{RECO})

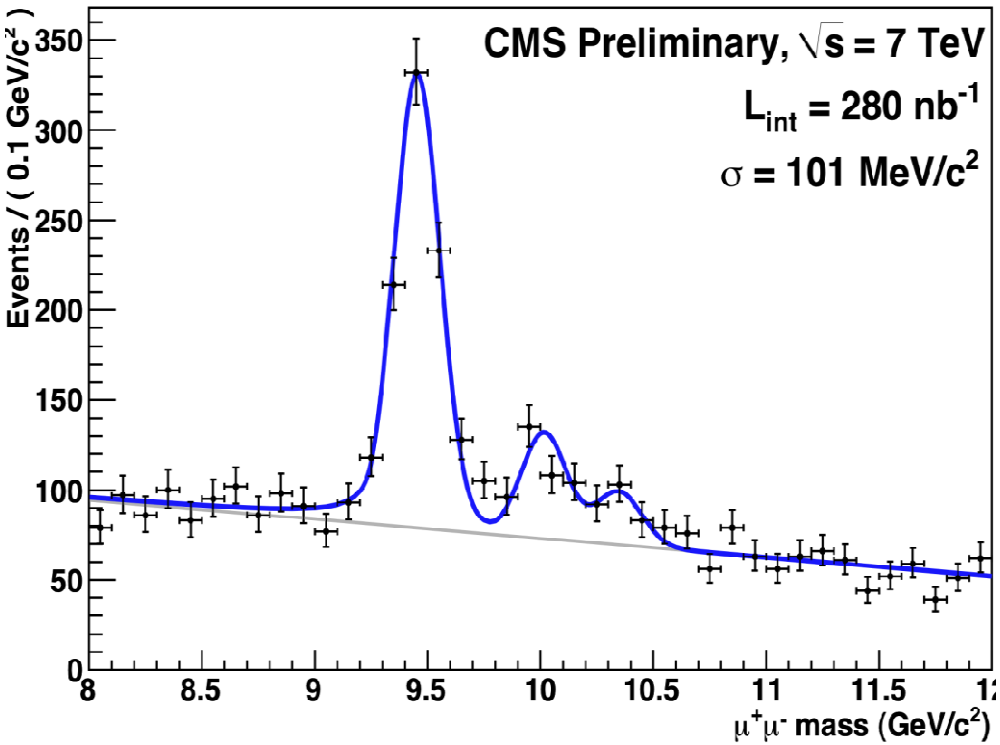
Z Tag & Probe	Measured efficiency	Error (stat. + syst)	MC efficiency
Reco Eff Barrel	**99.3%**	**1.4%**	**98.5%**
Reco Eff Endcap	**96.8%**	**3.4%**	**96.1%**

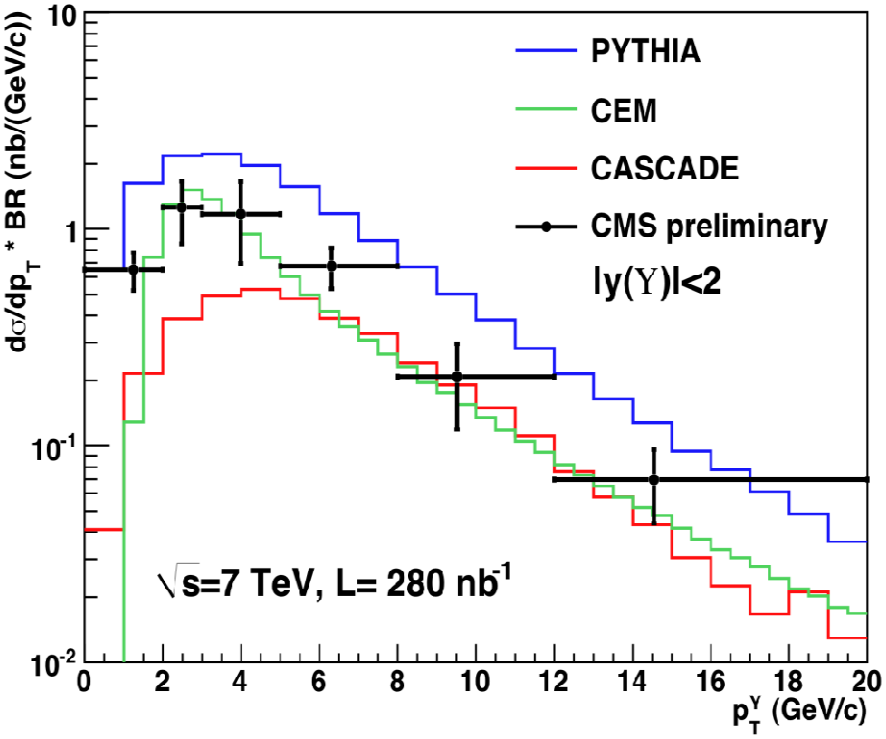
The W fit method measures the efficiency with a 1D unbinned maximum likelihood simultaneous fit to the transverse mass distribution obtained from requiring an isolated and identified ECAL SuperCluster E_T>20 GeV and a transverse missing energy in the event such that MET/E_T>0.3. Signal from W signal and background from QCD components and their electron reconstruction efficiencies are obtained from the fit.
The reconstruction efficiency is defined as reconstructed electrons per reconstructed ECAL superclusters.



Electron reconstruction efficiency ratio ε_{RECO}(DATA)/ε_{RECO}(MC) from Z tag and probe and Wfit results are compared

Υ(1s, 2s and 3s)→μ+μ-





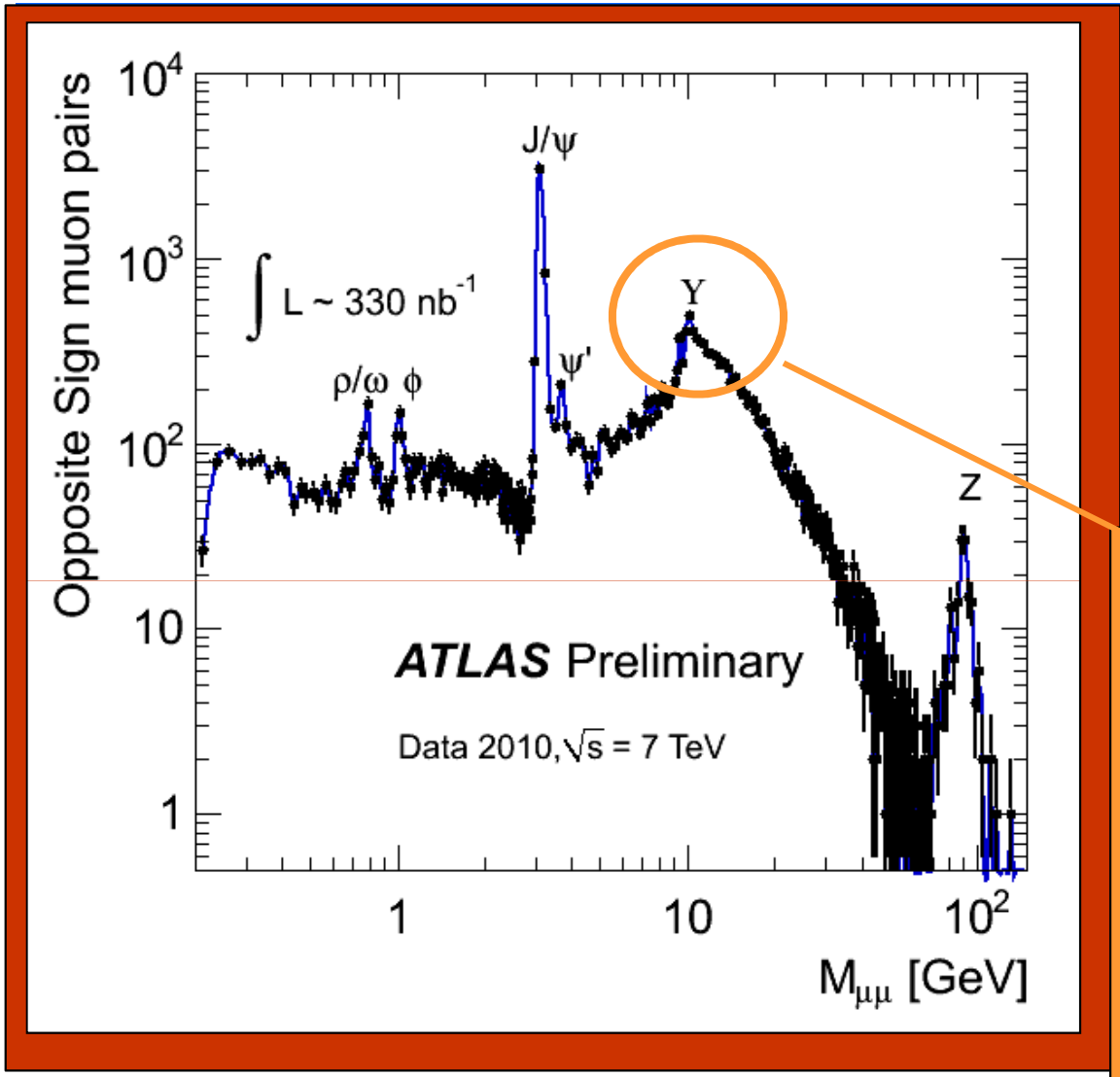
The Y family is there and with enough statistics we will be able to resolve well the Y2s from the Y3s (we have measured 67MeV resolution for |y| <0.7).
Meanwhile we have measured the Y(1s) cross sectionxBR in dimuons and the corresponding differential cross section.

σ(pp →Y(1S)X)·B(Y(1S)→μ+ μ−)=(8.3±0.5±0.9±1.0)nb

(*Assuming no polarization and integrated over* |y| <2.0)

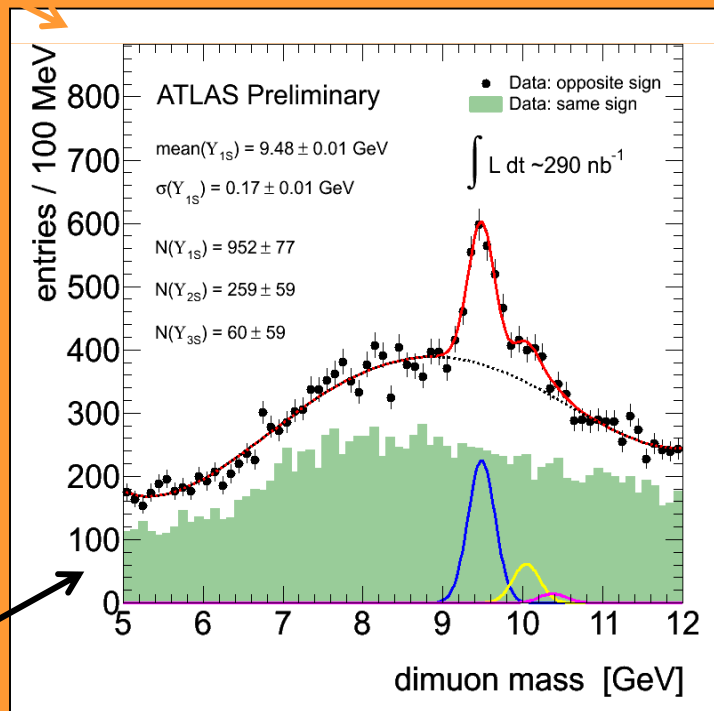
Di-muon resonances

Full data sample



Simple analysis:

- LVL1 muon trigger with p_T ~ 6 GeV threshold
- 2 opposite-sign muons reconstructed by combining tracker and muon spectrometer
- both muons with |z|<1 cm from primary vertex



- Looser selection: includes also muons made of Inner Detector tracks + Muon Spectrometer segments
- Distances between resonances fixed to PDG values; Y(2S), Y(3S) resolutions fixed to Y(1S) resolution

ZZ extrapolation from data

Typical procedure consists of choosing a **control region** outside the signal phase space and then verifying that the events rate changes according to the expectations from MC:

$$N_{ZZ}^{predicted}(\Delta m) = \rho(m_H) \cdot N_{CR}^{measured}$$

$$\rho(m_H) = \frac{N_{ZZ}^{theory}(\Delta m) \cdot \varepsilon_{ZZ}}{N_{CR}^{theory} \cdot \varepsilon_{CR}} \leftarrow \text{From MC}$$

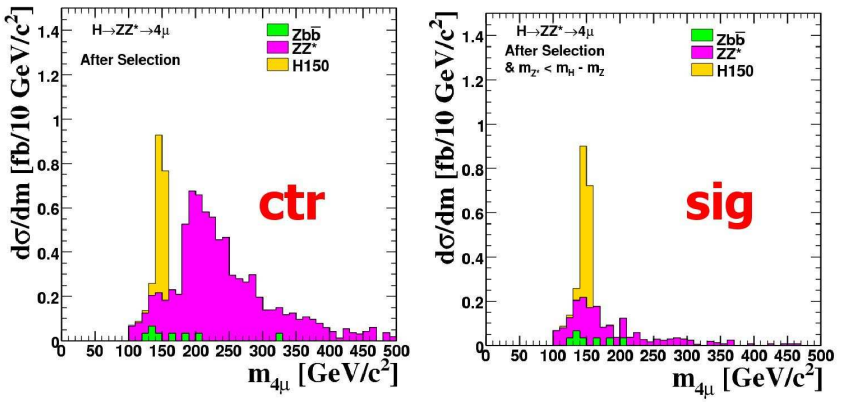
- Normalization to the **Z → ll** data:

N_{ZZ}/N_Z: $R = \dfrac{(\sigma_{ZZ\to 4e} * \varepsilon_{4e} * \int Ldt)}{(\sigma_{Z\to 2e} * \varepsilon_{2e} * \int Ldt)}$

- Luminosity and (partially) reconstruction uncertainty cancellations
- **0.1 million Z→ee events at 200 pb^{-1}**
- **total uncertainty ≈ 0.3 %**

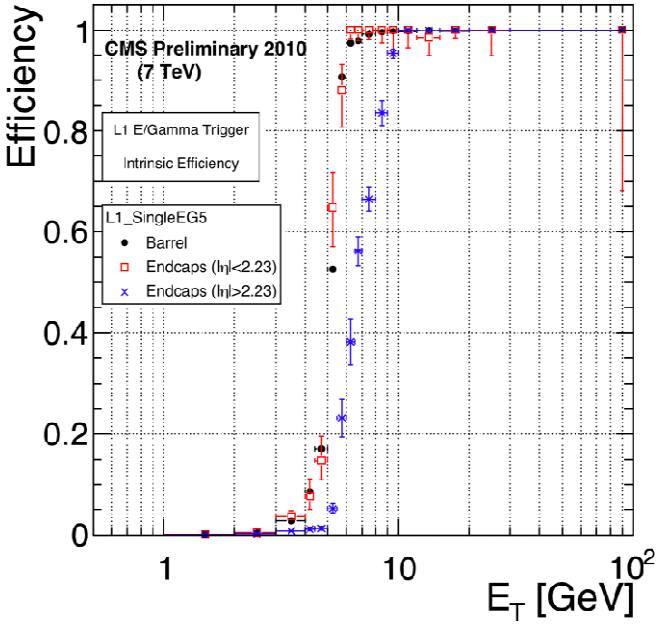
- Normalization to the **sidebands:**

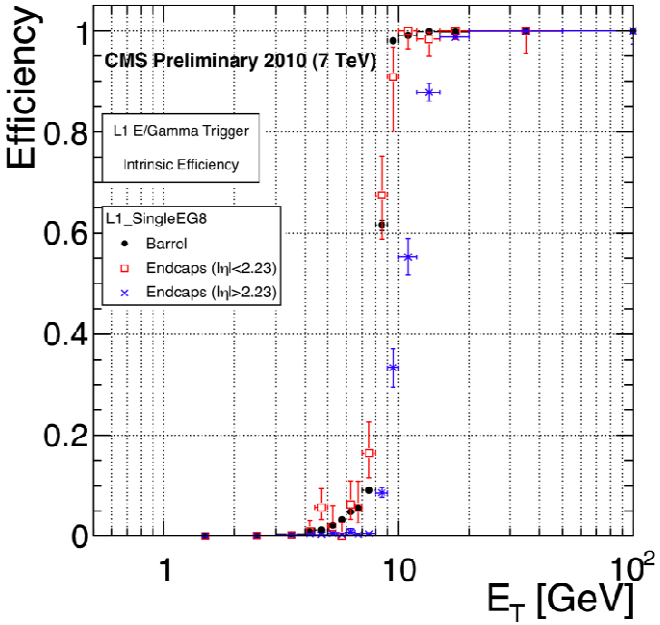
- Luminosity and (totally) reconstruction uncertainty cancellations
- **4 ZZ→4l events at 200 pb^{-1}**
- **total uncertainty ≈ 58 %**



L1 EG intrinsic efficiency

- from Clémentine Broutin
- Sample of ECAL Activity HLT triggers (seeded by L1 ZeroBias)
  - Anomalous ECAL signals removed using standard cuts
- Intrinsic efficiency for finding a L1 candidate, given an ECAL supercluster compatible with L1 EG algorithm
  - Supercluster reconstructed time within trigger window
  - Masked trigger towers/regions excluded
  - Cover 1 or 2 trigger towers only
  - L1 threshold of 5 GeV (top), 8 GeV (bottom)
- Three η ranges shown
  - Barrel
  - Endcaps $|\eta| < 2.23$
  - Endcaps $|\eta| > 2.23$

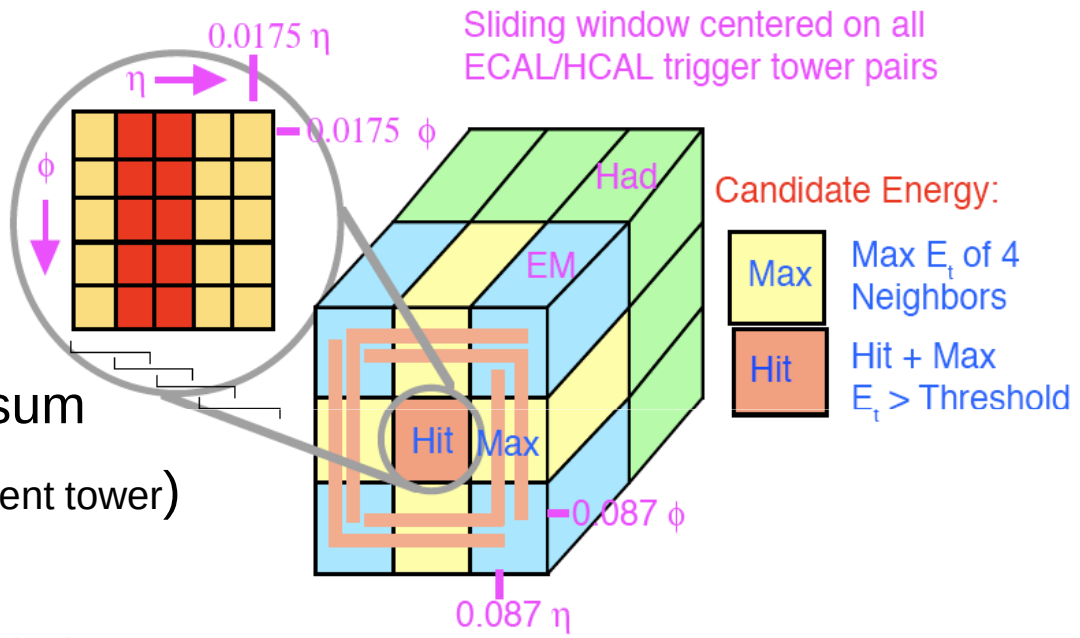




L1 EG Algorithm Geometry

- From Clémentine Broutin

- Calorimeter geometry
  - 1 tower = 5x5 crystals
  - 1 region = 4x4 towers



- L1 EG algorithm uses 2 tower sum

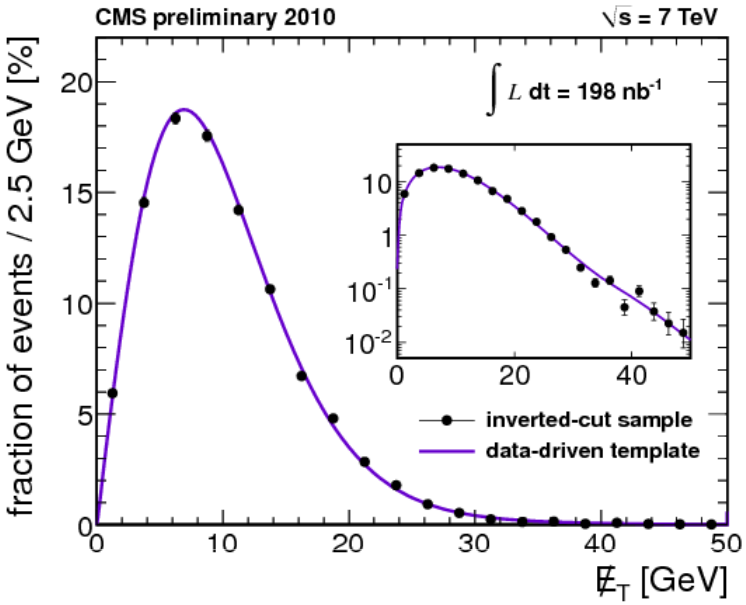
$E_T(L1) = E_T(\text{Hit tower}) + E_T(\text{Max adjacent tower})$

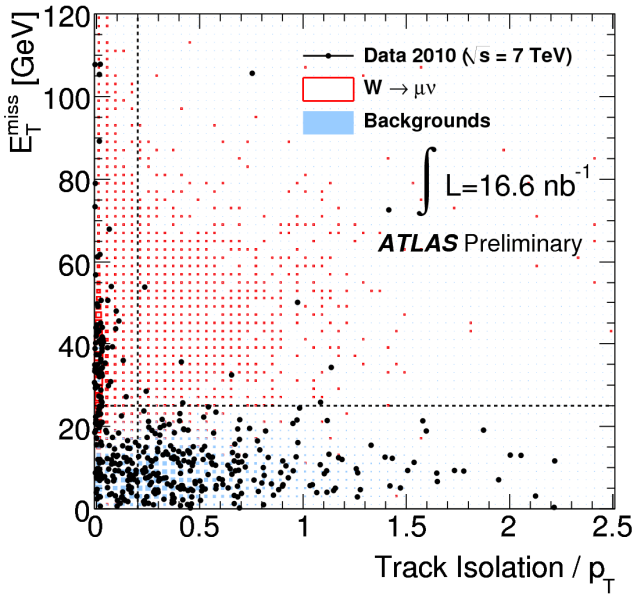
- Supercluster offline algorithm will in general spread over many more towers
- But isolated electron/photon candidates will have narrower/smaller superclusters

QCD Background Modeling

➢ **QCD (in Electron channel):**

QCD shape is checked in a QCD-enriched sample selected by inverting cut on isolation & track-cluster matching.





➢ **Multi-jets background estimation from DATA with the ABCD method.**

- MET vs Track Isolation plan.
- Validated in W→μν cross-section analysis.