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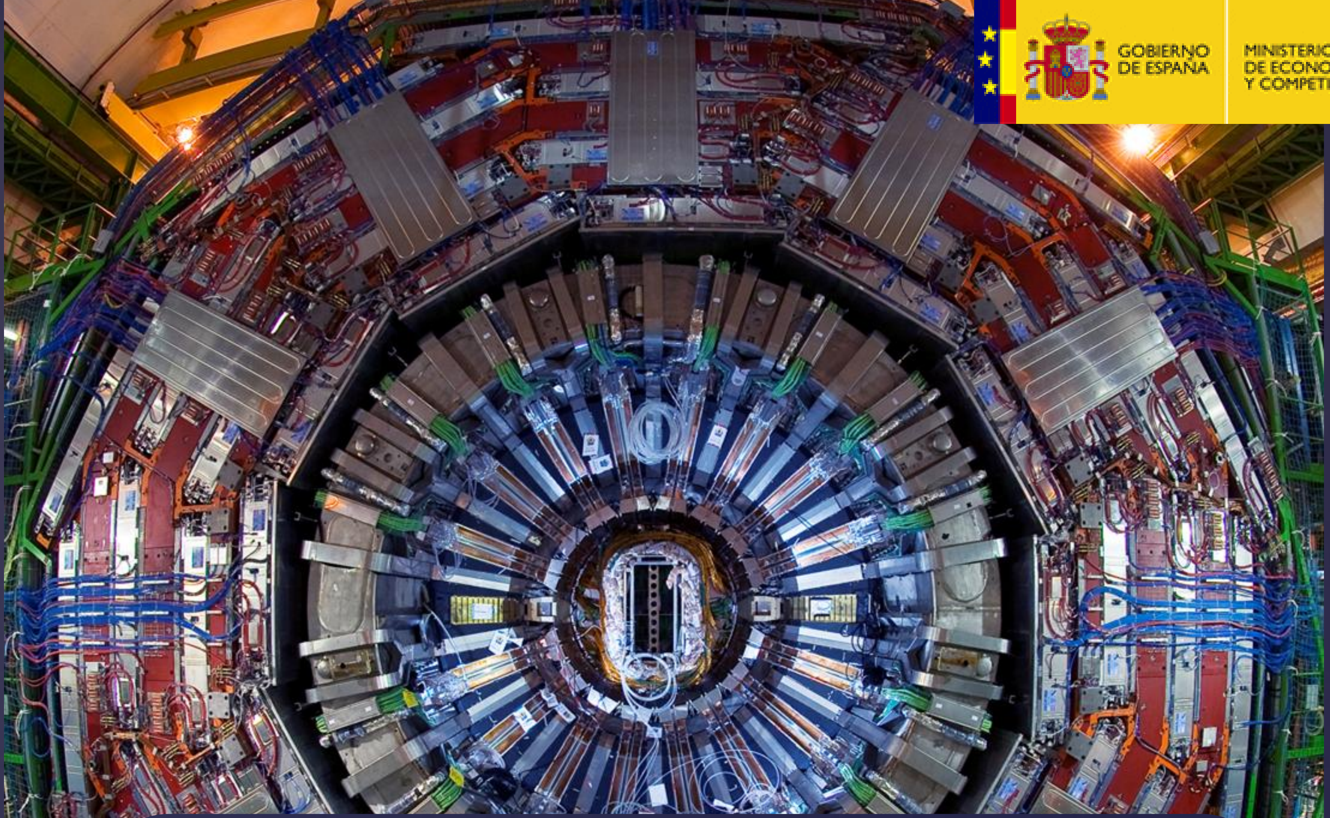
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas



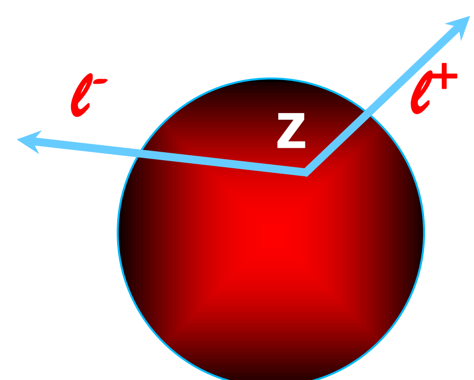
ElectroWeak bosons in Heavy Ion Collisions with CMS

Begoña de la Cruz (CIEMAT, Madrid, Spain)
on behalf of the CMS Collaboration

High p_T Physics at LHC
Frankfurt 2012

EWK Probes in HI collisions

- LHC PbPb collisions energy and luminosity allow EWK bosons (W, Z) production in sizeable quantities for first time in Heavy Ion collisions.
- EWK bosons (weak interaction) predicted not to be modified by nuclear medium ➔ scale with number of binary collisions ➔ $R_{AA} = 1/T_{AA}\ N(PbPb)/\sigma(pp) \cong 1$??
- Z,W are created before QGP formation and decay in the medium.
- The study of their leptonic decay is interesting as:
  - leptons lose negligible energy in the medium (be it partonic or hadronic)
  - experimentally clean to detect and measure.
- Can the Z,W bosons become the new and cleaner reference (together with direct photons) in HI collisions, providing information on the initial system?
- Study as a function of event centrality ➔ constrain nuclear (neutron) PDFs



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- CMS detector (Muon detection)
- Z bosons:
  - $Z \to \mu^+\mu^-$
  - $Z \to e^+e^-$
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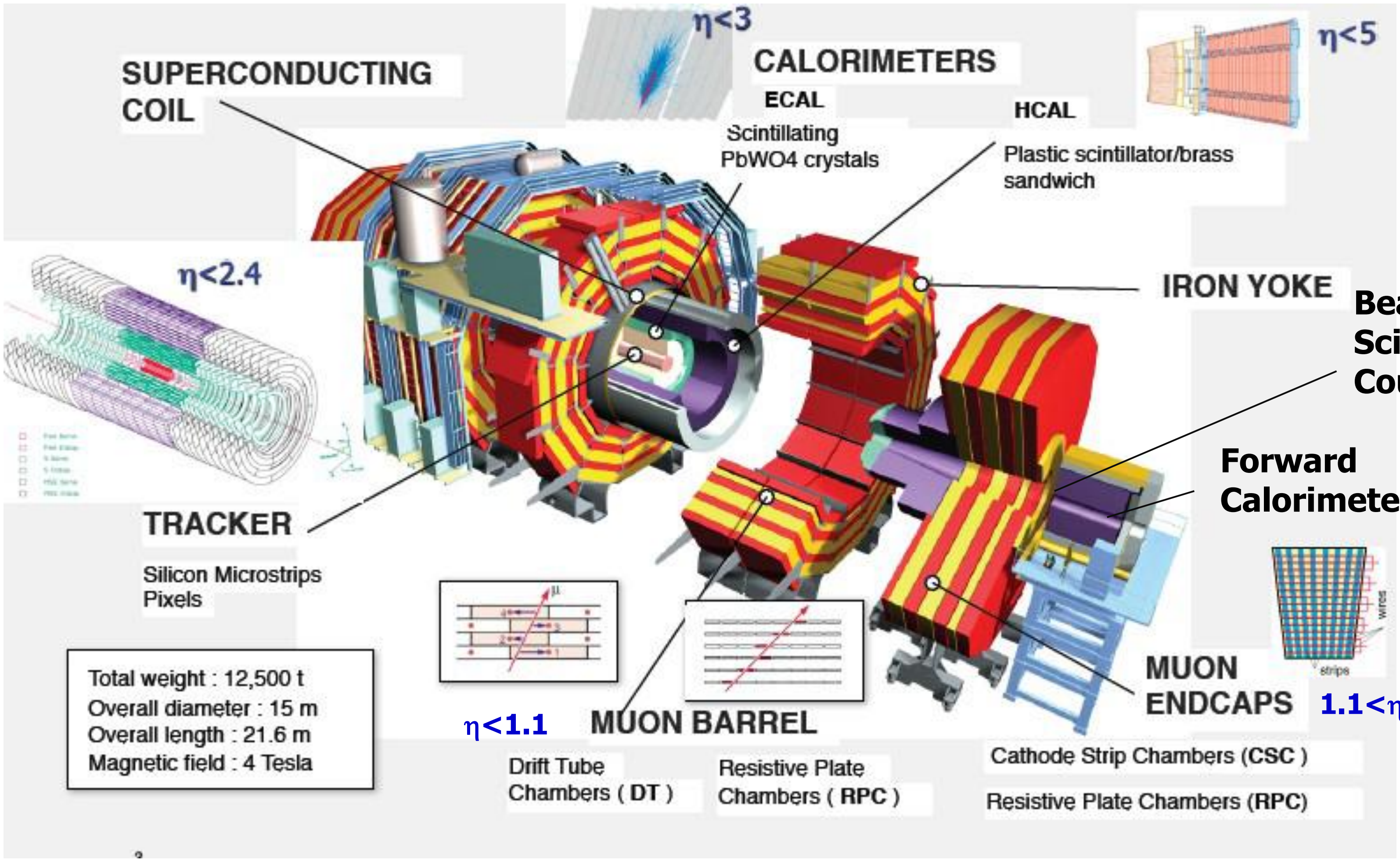
  - $W^\pm \to \mu^\pm \nu$
- Conclusions

CMS Detector

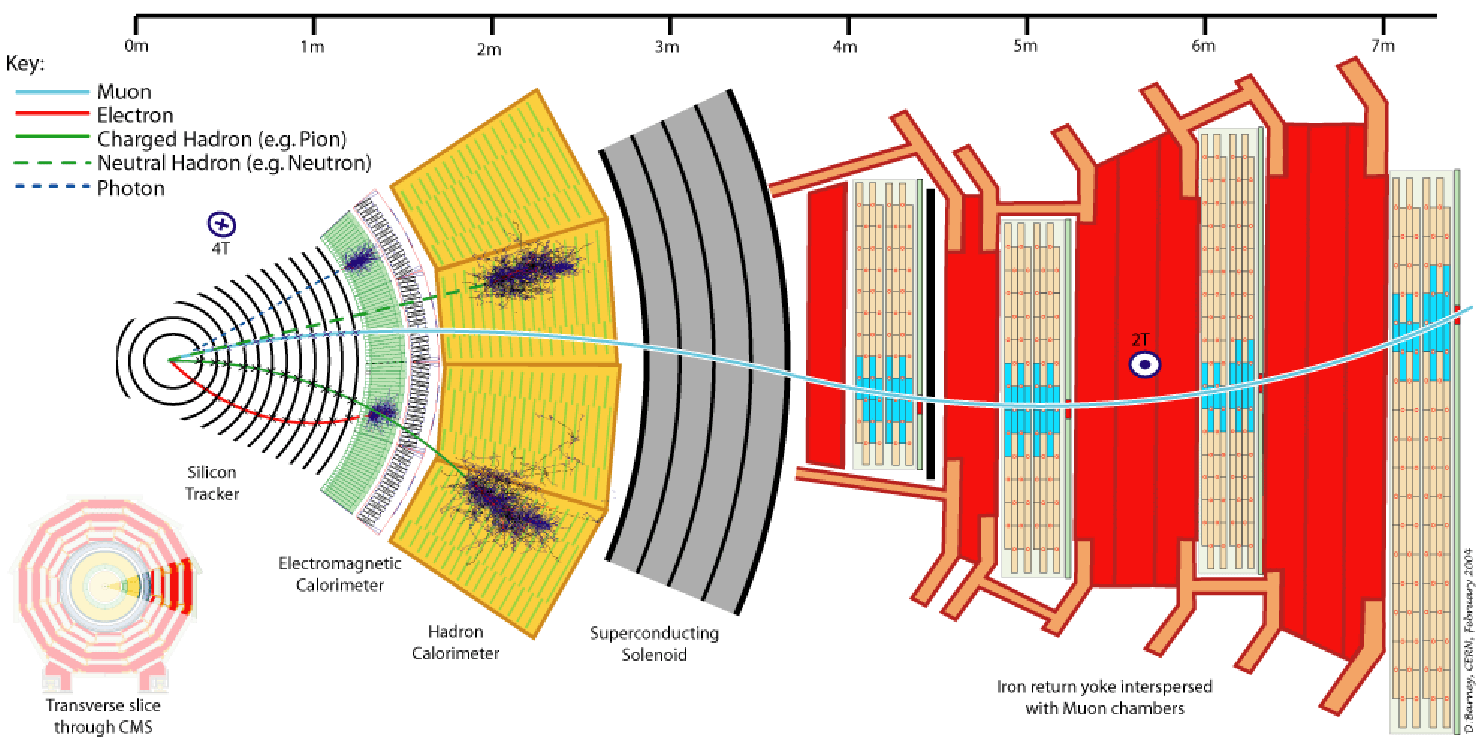


Muon Detection

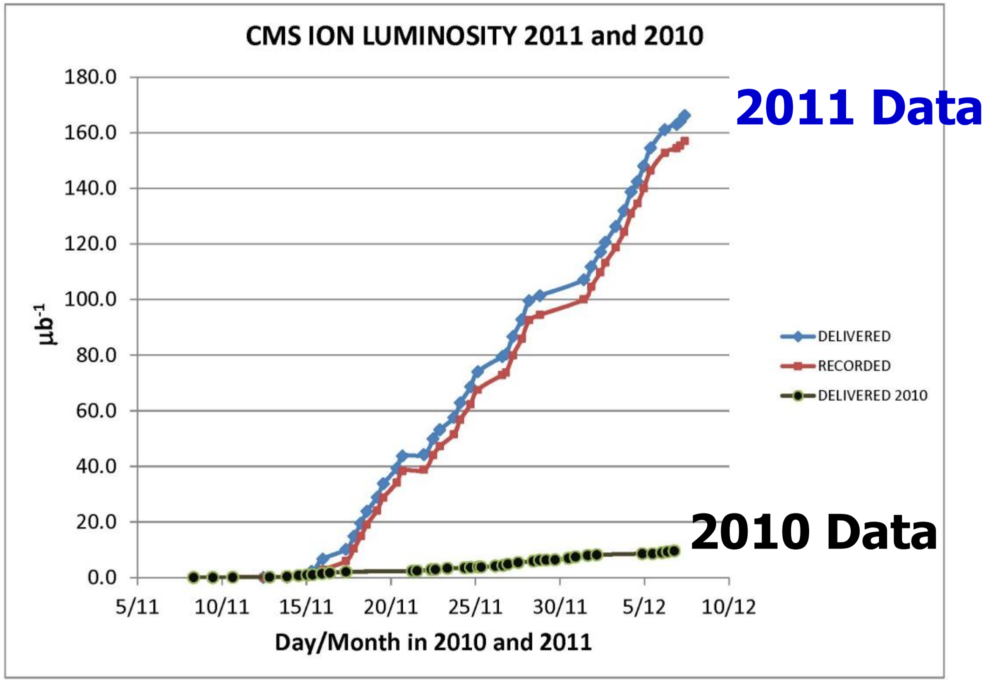
Excellent ❖ Muon Triggering and Identification (Muon Chambers)

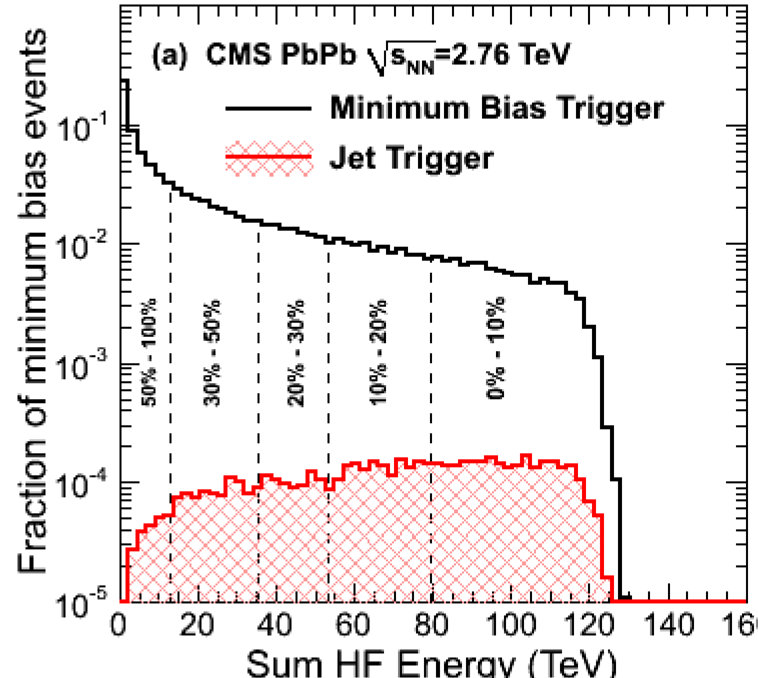
❖ Muon reconstruction performance (p_T resolution ~1-2 %) (Si-Tracker)

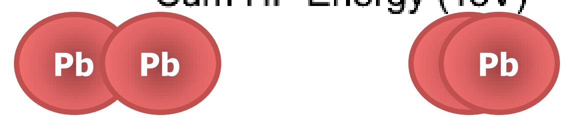
Inner tracking in HI optimized for high density track environment



CMS PbPb Data





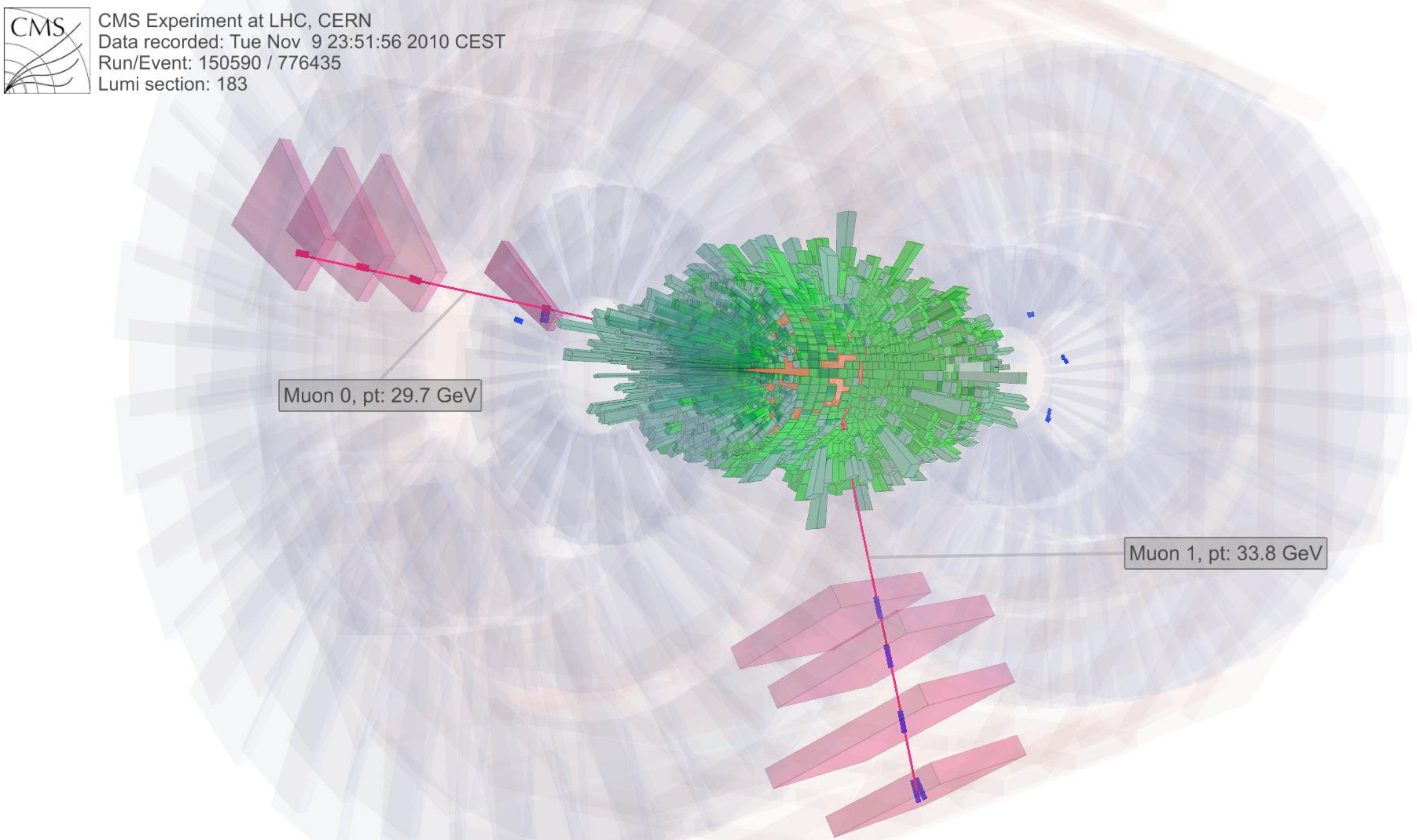


2010 PbPb data ($\sqrt{s_{NN}}$=2.76 TeV): 8.7 μb^{-1} delivered; ~7 μb^{-1} used in EWK probes analysis.

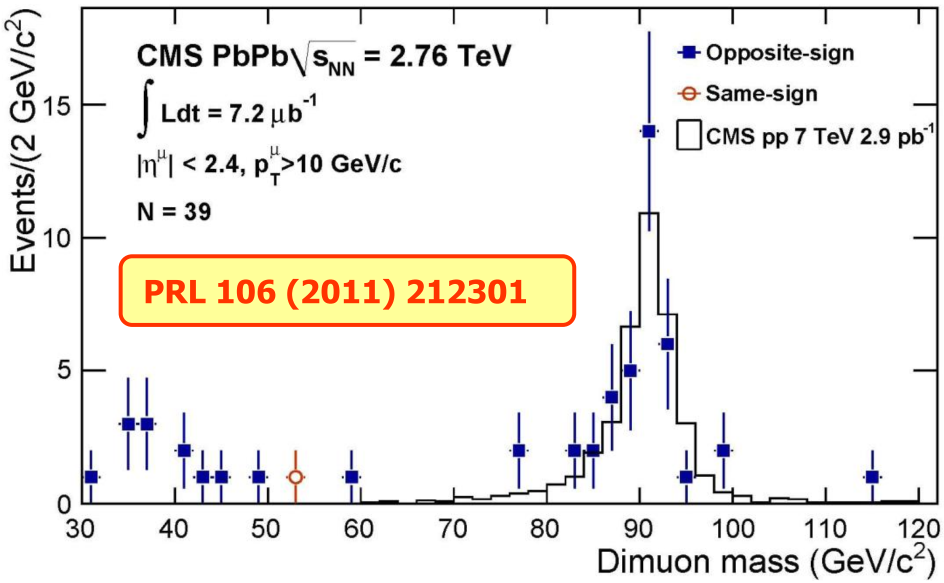
2011 pp data ($\sqrt{s}$=2.76 TeV) : 241 nb^{-1} delivered; 231 nb^{-1} used for reference (statistics are comparable)

2011 PbPb data ($\sqrt{s_{NN}}$=2.76 TeV) :~160 μb^{-1} delivered ➔ **>x20 increase on statistics!!**

$Z \rightarrow \mu^+\mu^-$



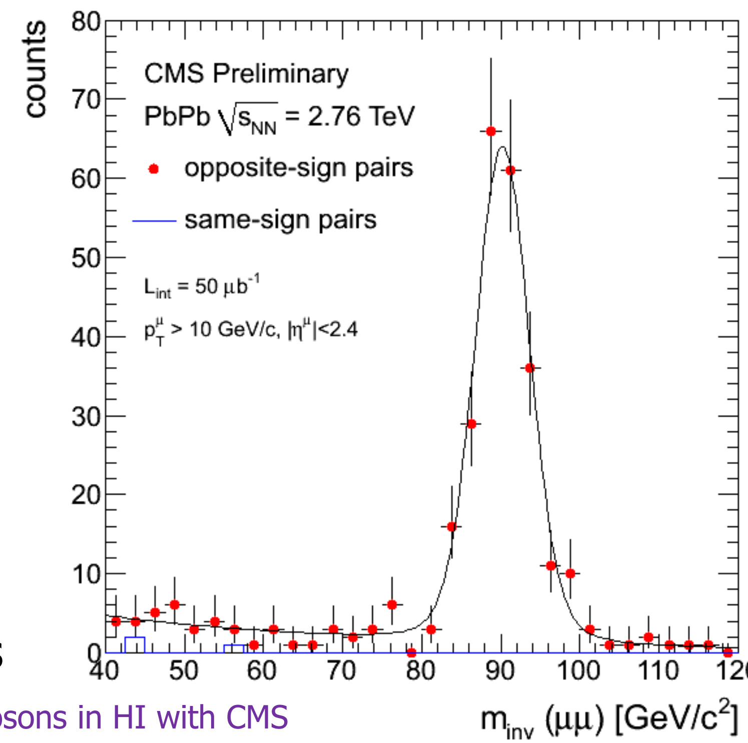
$Z \rightarrow \mu^{+}\mu^{-}$



2010 Data: LHC first measurement of Z production in Heavy Ion collisions

Selection: opposite sign high p_T dimuon events (p_T^{μ} > 10 GeV/c)

- Clean Z signal with very low background
- Z mass peak in PbPb agrees with pp data (mass resolution close to pp one)



- First look at 2011 data
- Beautiful increase of statistics

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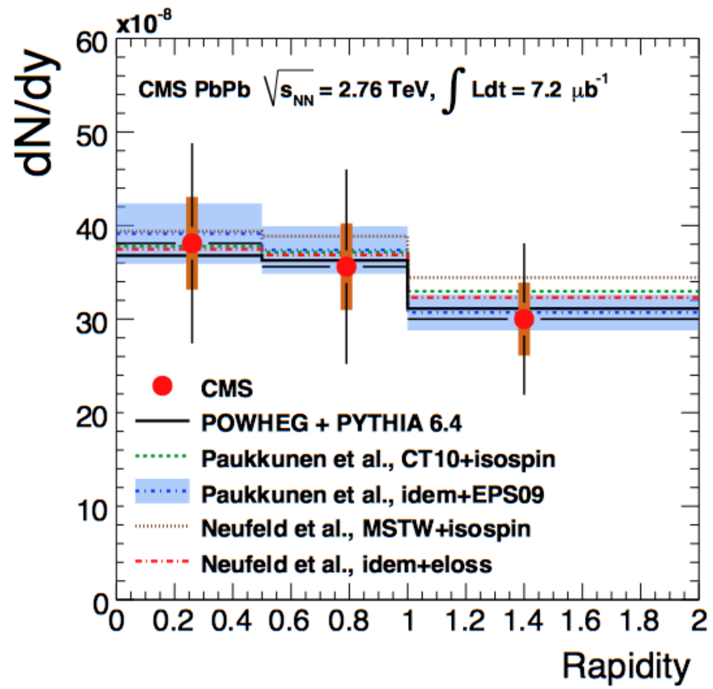
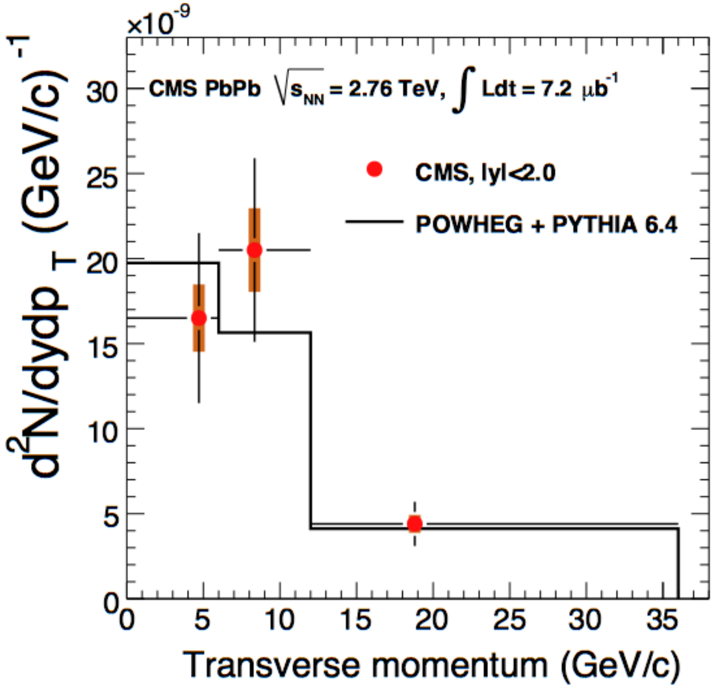
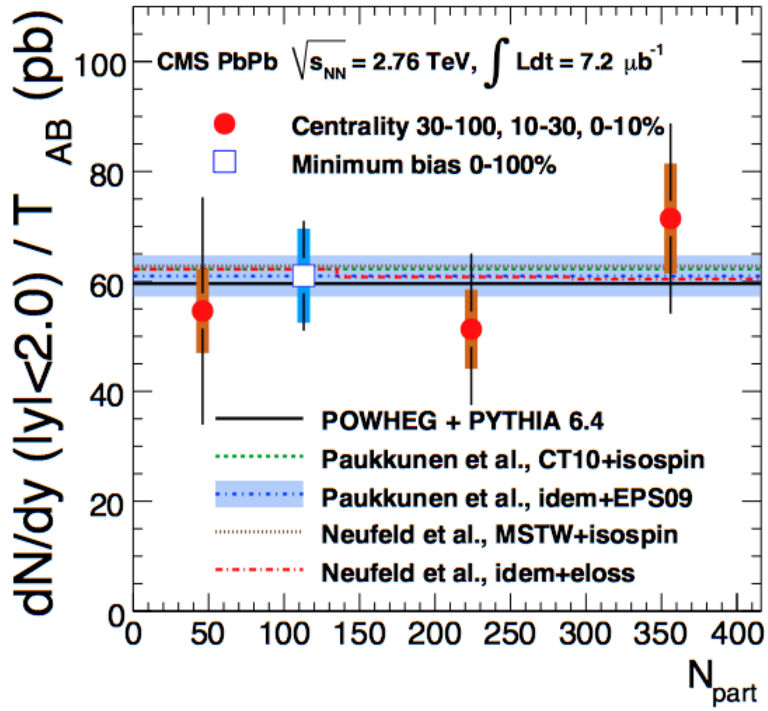
$Z \rightarrow \mu^+\mu^-$





- Uncertainties: 16% statistical, 14% systematic
- Z bosons produced in $q\bar{q}$ interactions ➡ isospin effects not very relevant
- Kinematic distributions are consistent with pQCD NLO (Powheg) calculations and PbPb predictions including small nuclear effects (shadowing, isospin, energy loss)
- Z p_T dependence consistent with that from pp interactions (& Powheg).

$Z \rightarrow \mu^+\mu^-$



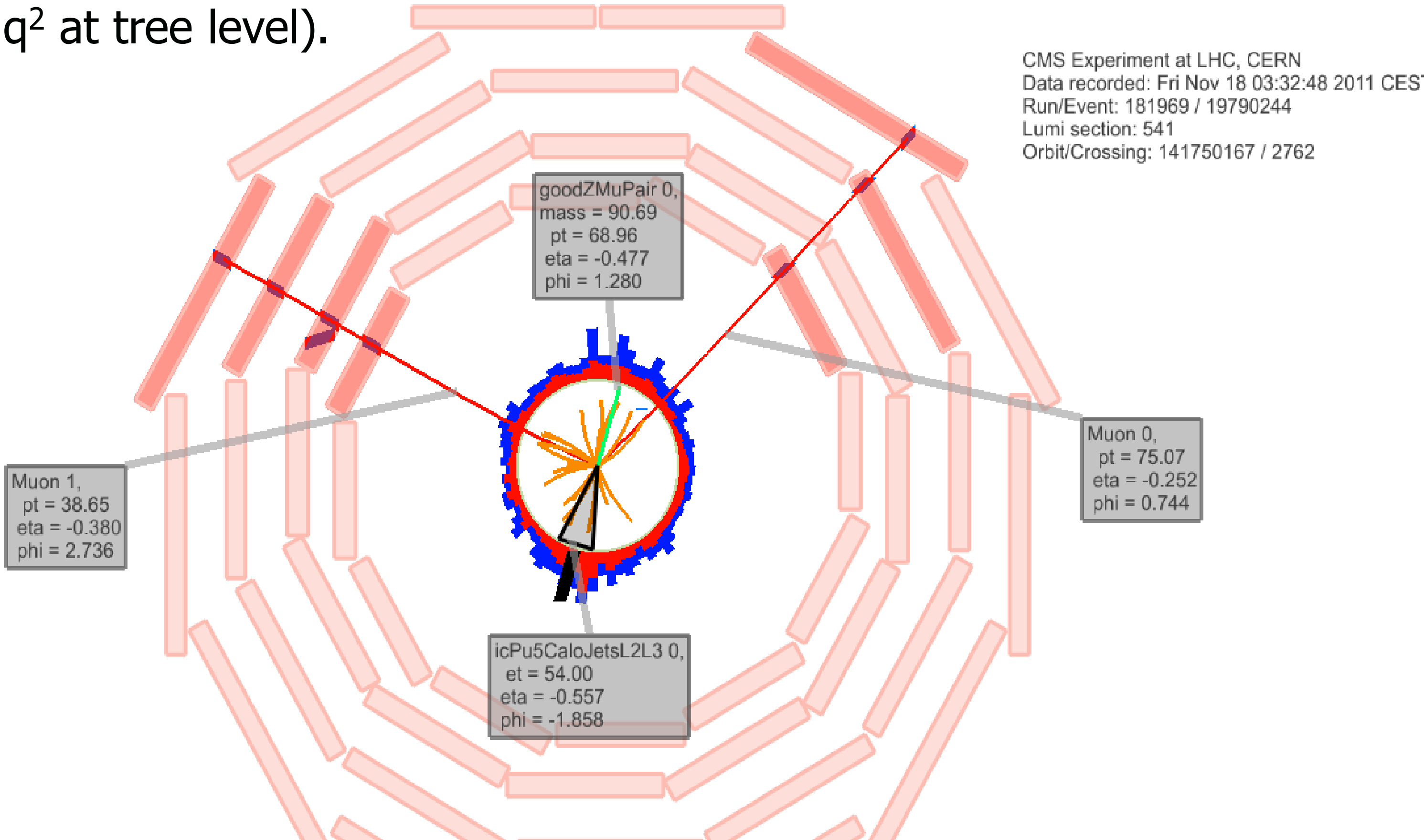
- No dependence with centrality observed.
- Within uncertainties, no violation of binary NN collision scaling is observed,

  ➡ R_{AA}=1.00±0.16±0.14 referred to pp Powheg.

$Z \rightarrow \mu^+\mu^-$ +1 jet

First look at exclusive Z production with jets

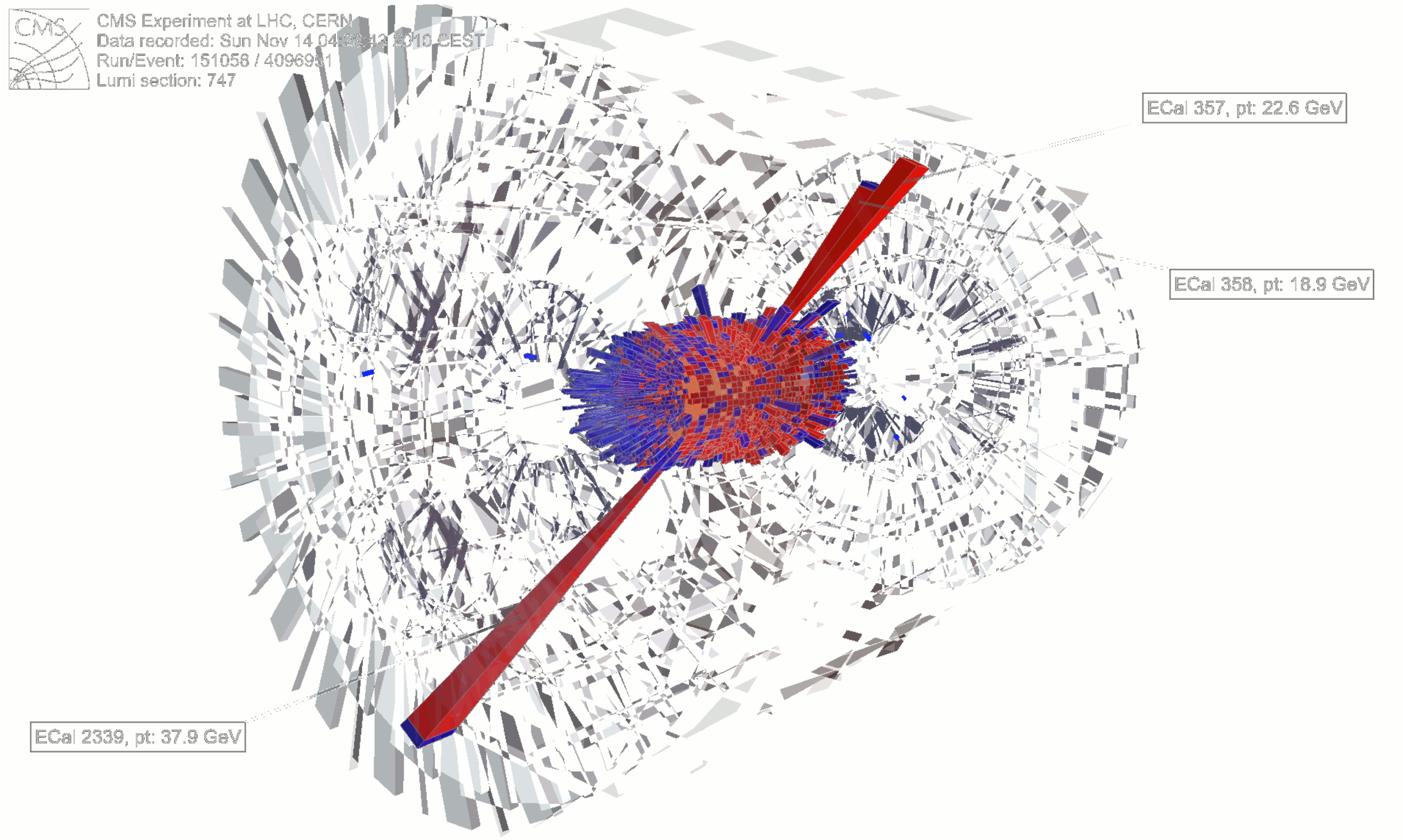
Can be used to calibrate parton traversing the medium (gives access to q^2 at tree level).



... Only a handful events expected in 2011 data...

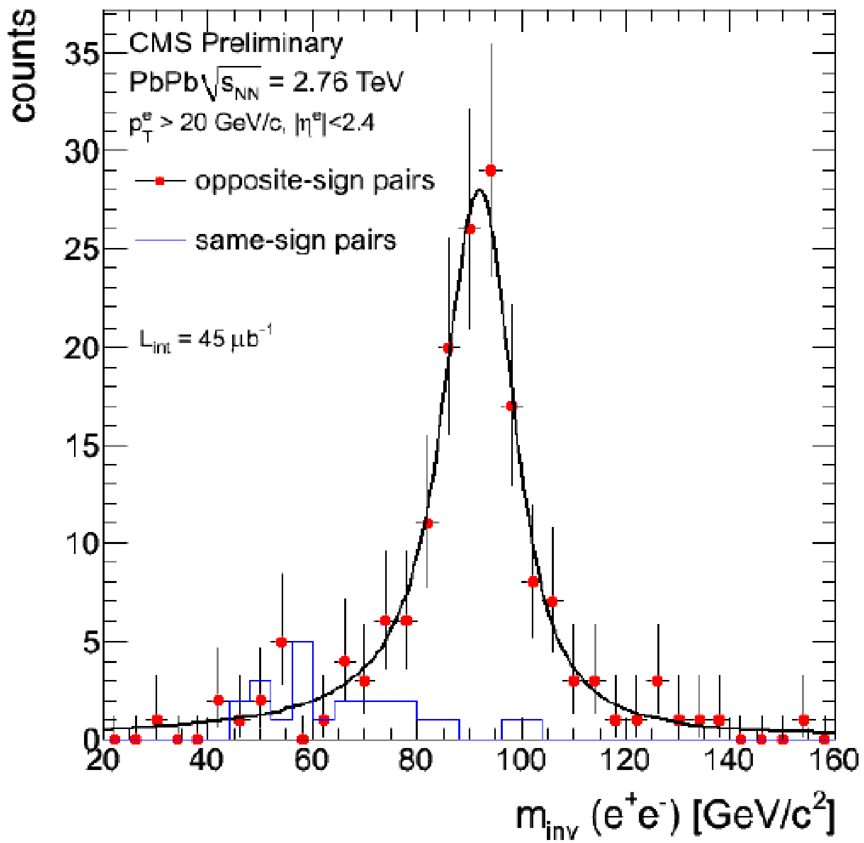
Z→e^+e^-

First observation in 2010 PbPb data



Z→e⁺e⁻

Already very promising Z boson mass peak with part of 2011 data



$W^{\pm}\rightarrow\mu^{\pm}\nu$ in PbPb

Main (naive) differences between W and Z boson:

- W decays leptonically into 2 leptons (as Z boson) but one of the leptons is a neutrino, $W\rightarrow l\ \nu$, which is undetected experimentally.
- No mass peak (dilepton invariant mass) available for W bosons.
- Z bosons are neutral, while W bosons are charged ➔ two different populations appear, W^{+} and W^{-}

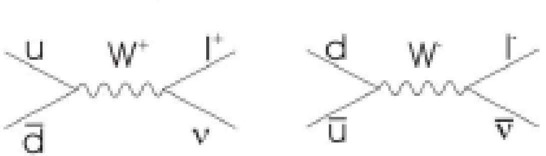
Experimental signature: a high p_T muon recoiling to (undetected) neutrino in transverse plane ➡ significant imbalance in energy/momentum in event.

$W^{\pm} \to \mu^{\pm}\nu$ in PbPb

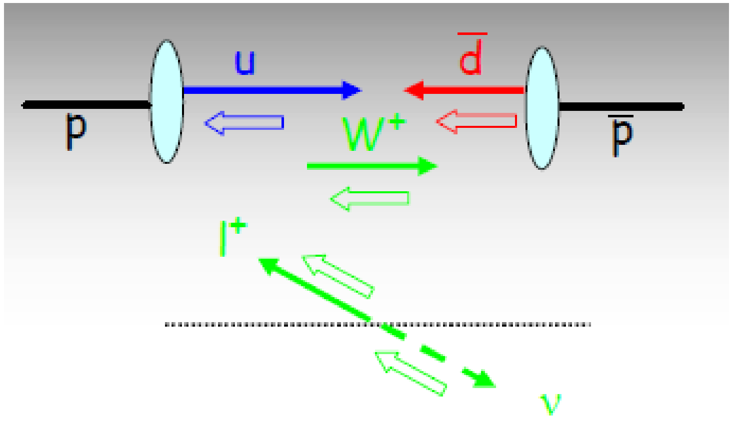
Three effects make W^+ different from W^- production:

- $q\bar{q}' \to W$: $u\bar{d} \to W^+$ and $d\bar{u} \to W^-$ (valence quark against a sea antiquark)
  W is boosted in valence quark direction: ➡ W^+ (W^-) in u(d) direction

  ➡ Different phase space (rapidity) for W^+ and W^-



- $W^{\pm}$ decay into lepton+neutrino is not charge symmetric, due to V-A EWK coupling (ν lefthanded) ➡ different angular distributions for decay μ^+ and μ^-

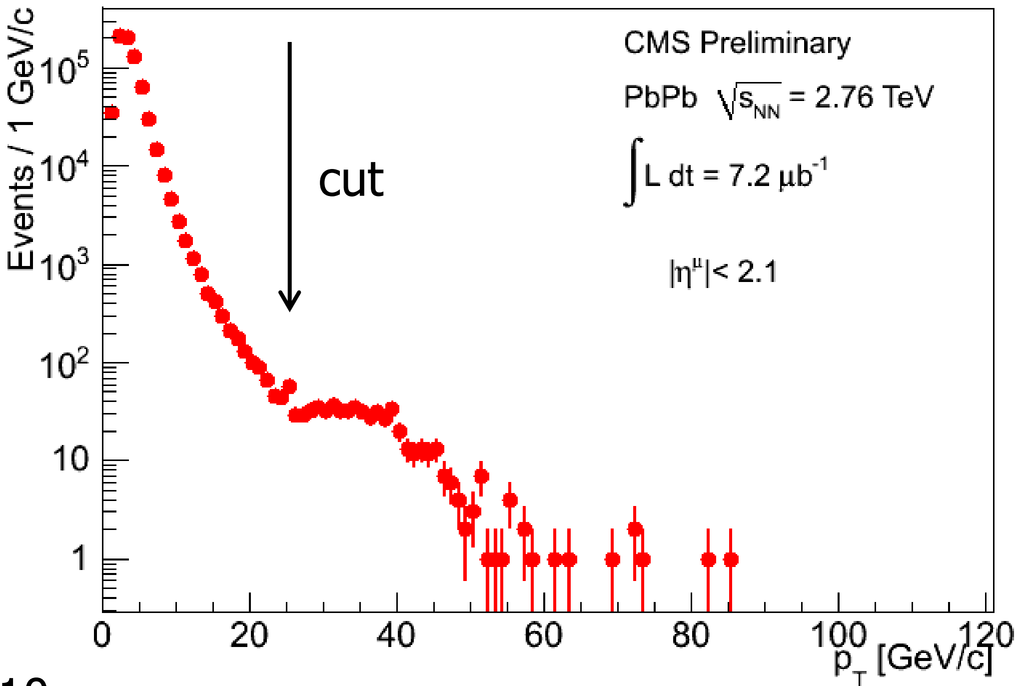


- W^+ and W^- production sensitive to isospin effects (different quark content in proton and neutron, more d quarks available than u quarks in collision, and pdf(u)≠ pdf(d))

$W^{\pm} \rightarrow \mu^{\pm}\nu$: Muons

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN11008

- Events recorded by muon triggers, $p_T \geq$ 2-3 GeV/c
- Muon reconstructed offline ($|\eta|<2.1$) with good quality:
  - Minimum N. Hits (Si-pixel, Si-strips, muon detectors)
  - χ^2 cut on track fit (tracker-muon systems)
  - Compatible with primary vertex (dca < 0.3 mm)
- Z veto: reject events with 2nd μ (p_T> 10 GeV/c and $60<m_{\mu\mu}<120$ GeV/c^2)



Excess of events in the muon p_T region (>30 GeV/c) where W (EWK) decay products are expected

Require p_T^{μ} > 25 GeV/c

$W^{\pm} \to \mu^{\pm}\nu$: Missing p_T

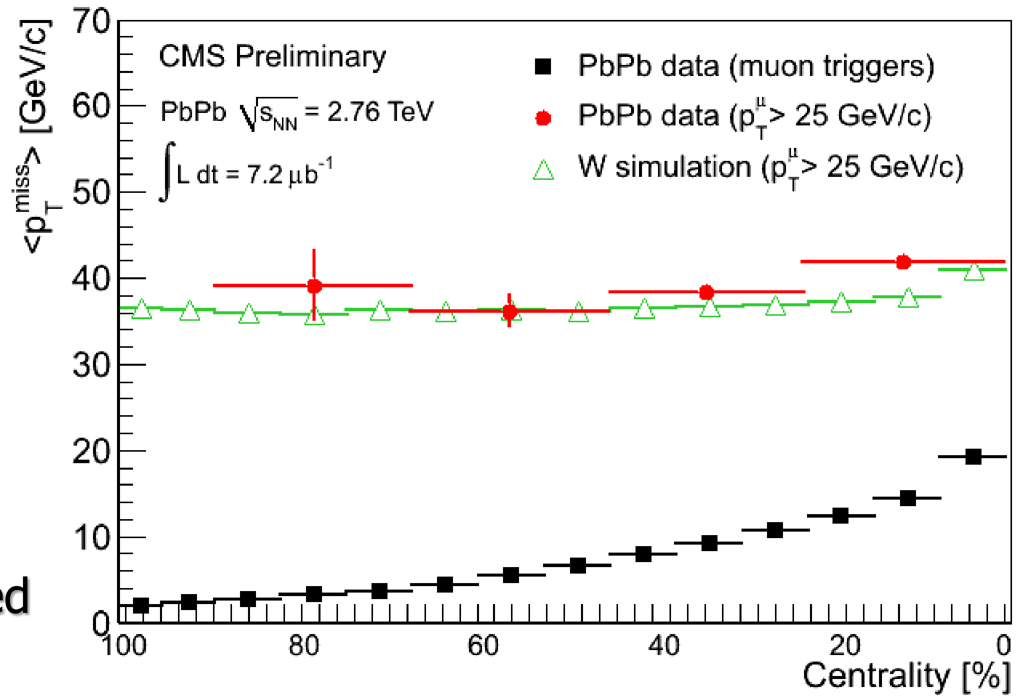
Energy/momentum imbalance in event measured as

Missing-p_T = - $\Sigma\ \vec{p}_T$ of all charged tracks with $p_T > pt_{thresh}$ with pt_{thresh} = 3 GeV/c

On Muon triggered events:

- Before selection:
  - Missing p_T dependent on collision centrality ➡ worse resolution
- After high p_T muon selection:
  - Missing p_T ~40 GeV/c, significantly larger than Missing-p_T resolution
  - Almost independent of centrality

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN11008



W simulation: $W \to \mu\nu$ signals embedded in Hydjet PbPb simulated events.

$W^{\pm}\rightarrow\mu^{\pm}\nu$: m_T

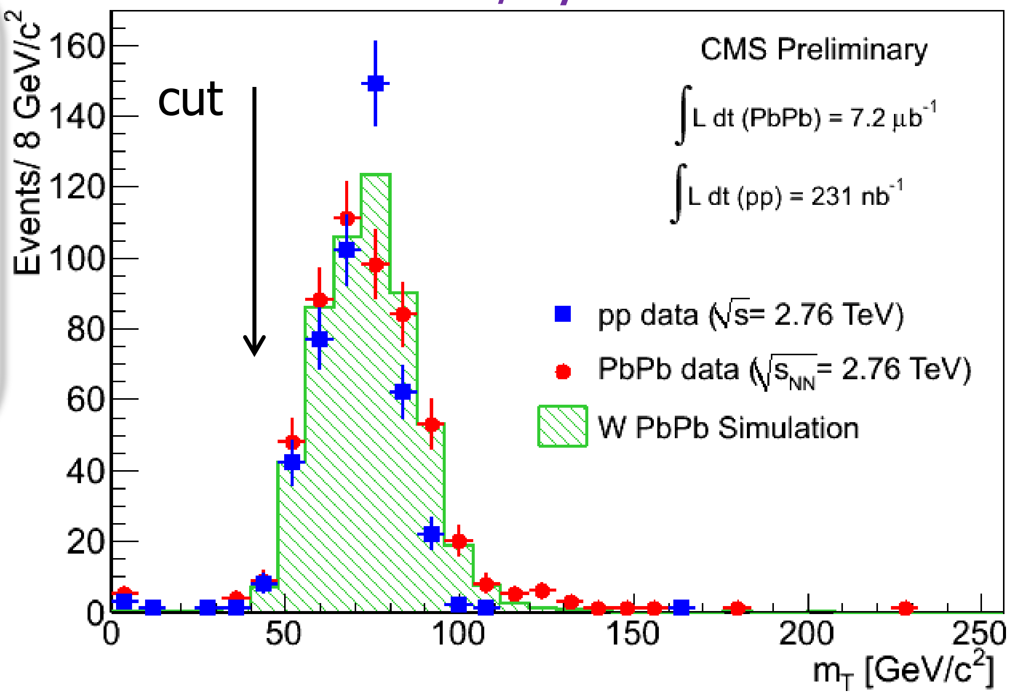
No mass peak available for W bosons, but Transverse Mass,

$$m_T = \sqrt{2 p_T^{\mu}\, p_T^{miss}\,(1 - \cos\phi)}$$

$$\phi = \phi(\mu) - \phi(p_T^{miss})$$

Sharp Jacobian peak at $m_T = m_W$, smeared by detector resolution.

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN11008

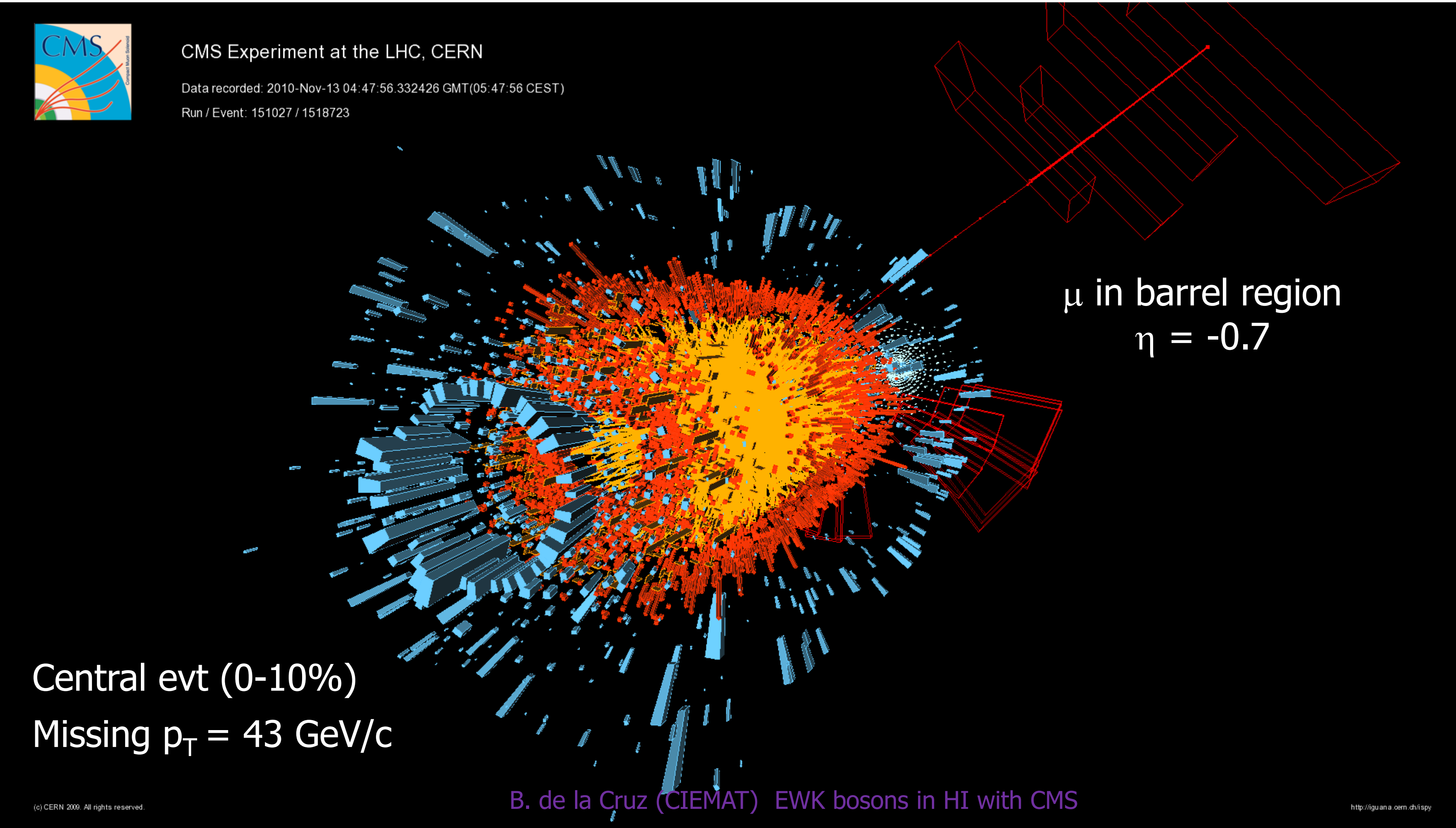


Build m_T for events with high p_T muons (p_T>25 GeV/c) and p_T^{miss} > 20 GeV/c.

2011 pp data @ √s=2.76 TeV analyzed with same procedure.

- compatible W signals in PbPb and pp, almost background free.
- Residual contamination ($Z\rightarrow\mu^+\mu^-$, $W^{\pm}\rightarrow\tau^{\pm}\nu$) subtracted (2%); QCD (<1%) included in systematic uncertainty for both pp and PbPb.
- slightly better m_T resolution in pp than in PbPb (as expected)

$W^{\pm} \rightarrow \mu^{\pm}\nu$: Event Display



μ in barrel region
η = -0.7

Central evt (0-10%)

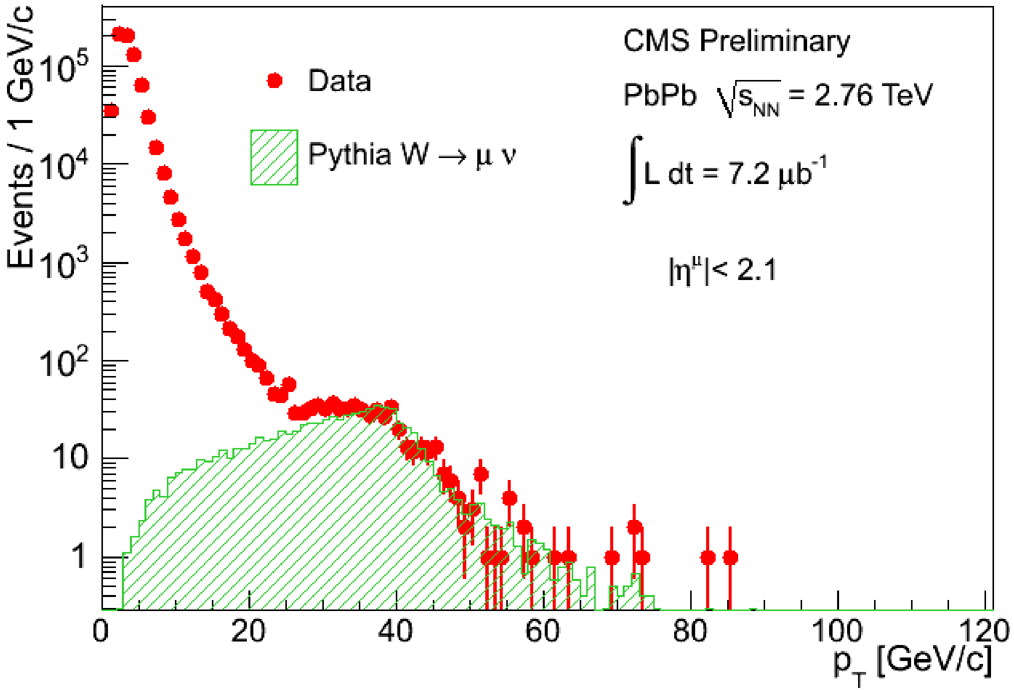
Missing p_T = 43 GeV/c

$W^{\pm} \rightarrow \mu^{\pm} \nu$

Selected events

	PbPb	pp
W^+	275	301
W^-	264	165

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN11008



Pythia simulation $pp \rightarrow WX \rightarrow \mu\nu X$ @$\sqrt{s}$=2.76 TeV normalized to the number of selected candidates

PbPb: Good description of the muon high p_T region!

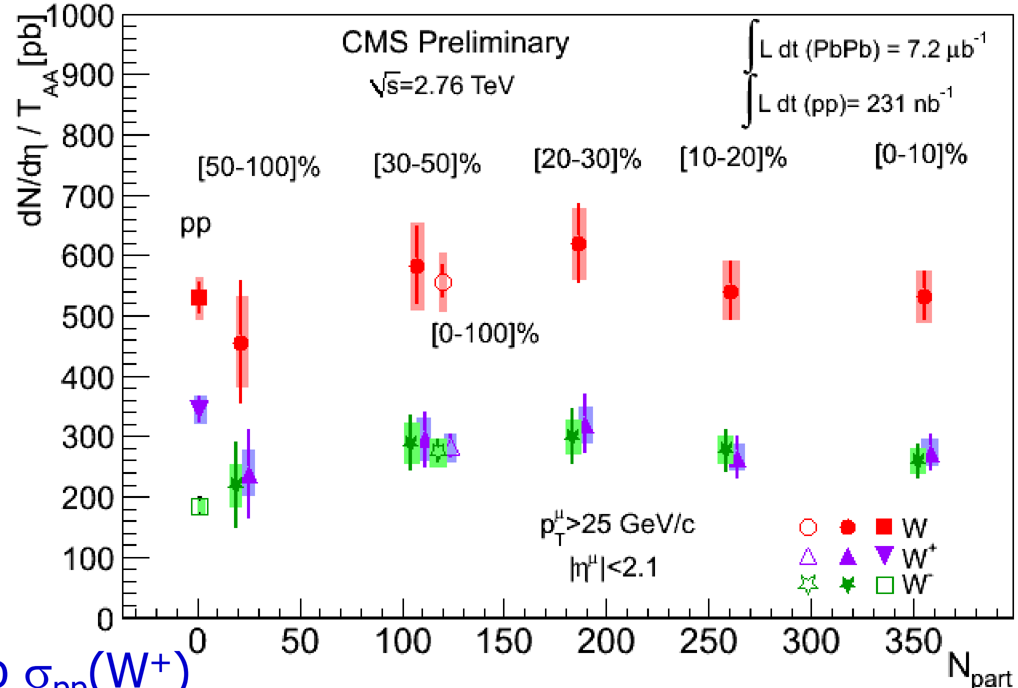
Centrality Dependence

$W^{\pm} \rightarrow \mu^{\pm}\nu$

Yields $1/T_{AA}\, dN/d\eta$ evaluated separately for W^+, W^- and $W^{\pm}$ in PbPb

- Within uncertainties , no dependence on centrality observed.
- Cross sections from pp data shown at $N_{part} = 2$
- Significant change in W^+ and W^- cross sections between pp and PbPb systems ➡ isospin effect

$T_{AA} = \langle Ncoll \rangle / \sigma^{inel}_{pp}$



- ➢ $\sigma_{PbPb}(W^+)$ reduced with respect to $\sigma_{pp}(W^+)$
- ➢ $\sigma_{PbPb}(W^-)$ enhanced with respect to $\sigma_{pp}(W^-)$

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN11008

- But total cross sections ($W=W^++W^-$), consistent at LO with binary NN scaling

$R_{AA} = dN/(T_{AA} \times \sigma_{pp}) = 1.04 \pm 0.07 \pm 0.12$

Muon Charge Asymmetry
$W^{\pm} \to \mu^{\pm} \nu$

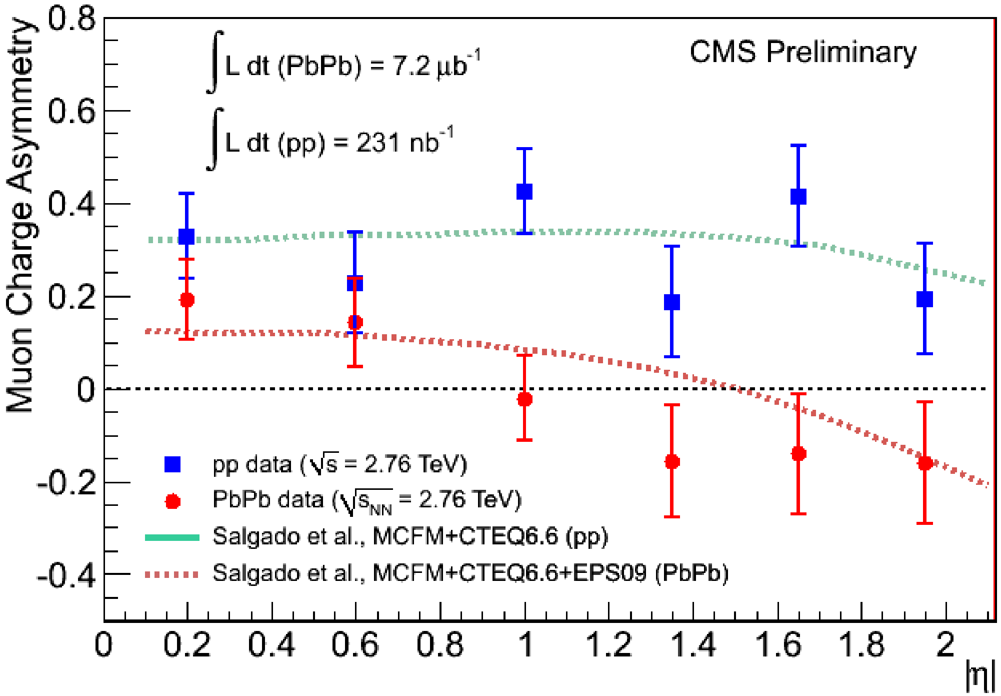
Muon charge asymmetry

$(dN(W^+) - dN(W^-)) / (dN(W^+) + dN(W^-))$

as a function of muon pseudorapidity (η) for PbPb and pp @ $\sqrt{s}$ = 2.76 TeV collisions

- PbPb: Predominance of W^- production at low polar angles over W^+
- pp: Larger W^+ production than W^- one at all muon pseudorapidity studied.
- Asymmetry measured values compatible with theoretical predictions (MCFM + CTEQ6.6+EPS09 (nuclear PDFs))

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN11008



H. Paukkunen & C. Salgado
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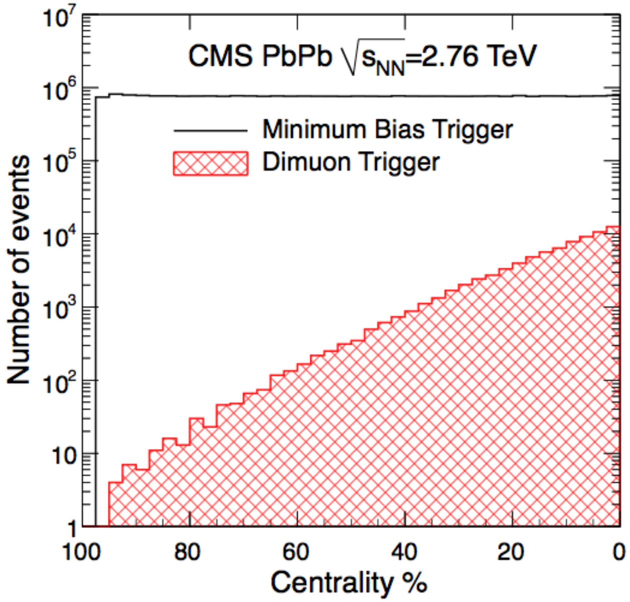
Conclusions

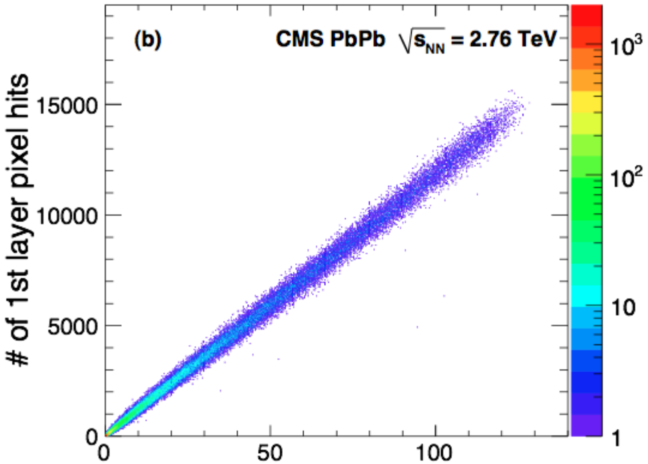
- Z & W boson production studied for the first time in history of HI collisions.
- They are established as unmodified with respect to both theoretical and experimental nucleon-nucleon cross sections, scaled by Ncoll → confirms validity of Glauber scaling.
- Z kinematic distributions agree with NLO pQCD calculations and pp ($\sqrt{s}$= 7 TeV) results.
- Individual W^+ & W^- yields in PbPb interactions manifest the isospin effect, enhancing W^- production and reducing W^+ one, with respect to that measured in pp collisions at same $\sqrt{s}$, but total W yield results unmodified.
- Muon charge asymmetry evaluated in PbPb and pp interacting systems. In agreement with expectations from NLO pQCD calculations.
- W detailed and precise studies will open the window to neutron and its PDF determination.
- Thus, EWK bosons are established as reference particles for future studies.
- Many exciting measurements awaiting us in 2011 data!!

Backup

Data selection

- Minimum Bias Trigger
  - BSC coincidence or
  - HF coincidence
- Dimuon Trigger
  - 3 GeV/c p_T cut per muon
- Offline selection
  - Veto on beam halo events
  - At least a 2-track primary vertex
  - Vertex compatibility with pixel cluster length
  - At least 3 HF towers on each side





$W^{\pm}\rightarrow\mu^{\pm}\nu$: Background

Backgrounds expected:

Signal region: remaining $Z\rightarrow\mu^{+}\mu^{-}$ (1 μ fail detection), $W^{\pm}\rightarrow\tau^{\pm}\nu$.

ttbar, diboson production (WW, WZ, ZZ) negligible ($\sigma\sim$10-2, 10-3)

Evaluated from simulation (Pythia) and subtracted: 2%

QCD processes: light (pions, kaons) and heavy quark (D, B) decays

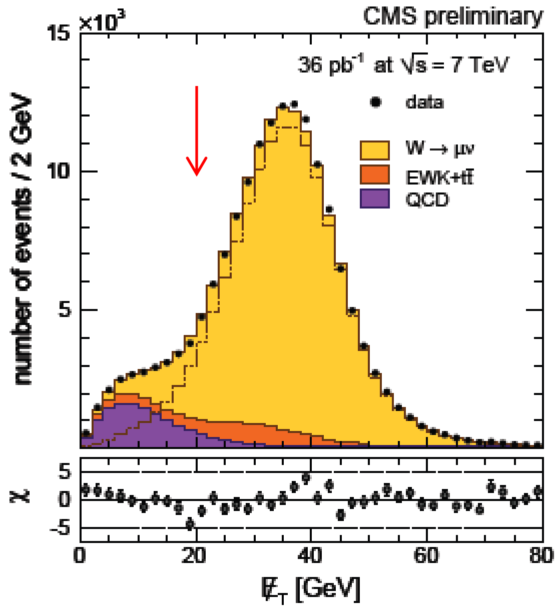
Evaluated from data : pp and PbPb data.

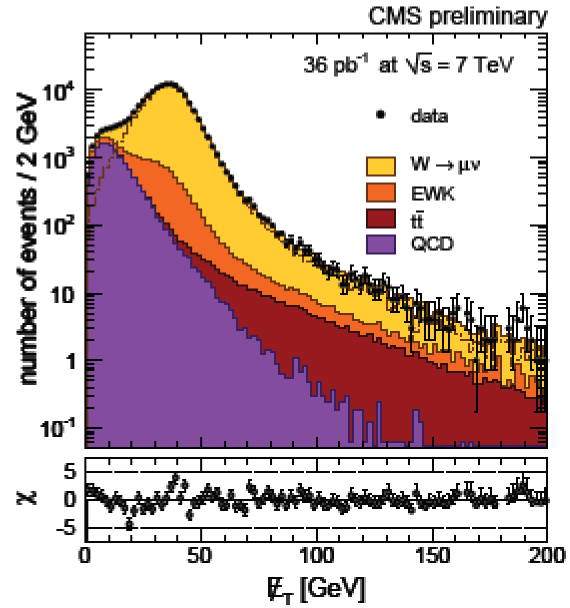
Not subtracted, but included in systematic uncertainties: 1%

Background estimation

2. From inclusive $\sigma(W)$ measurement in pp@7TeV: (AN-10-395)

QCD backgd is 5.1% of total selected sample (without cut in MET).





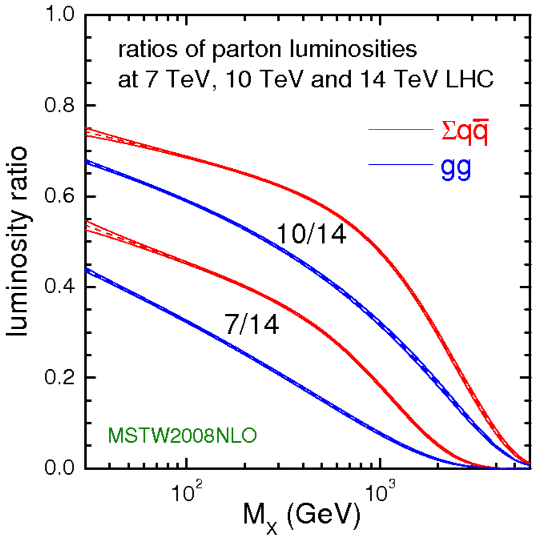
source	$N_{bg}/(N_W + N_{bg})$	N_{bg} in 36. pb^{-1}
QCD multi-jet	5.1%	8896
$Z \to \mu^+\mu^-$	3.5%	6163
$W \to \tau\nu$	2.7%	4667
$Z \to \tau^+\tau^-$	0.5%	911
WW+WZ+ZZ	0.1%	205
$t\bar{t}$	0.3%	592
EWK + $t\bar{t}$	7.1%	12538
total	12.2%	21434
$W \to \mu\nu$ signal	87.8%	153940

QCD Backgd: Additional checks

Less QCD backgd expected at √s= 2.76 TeV than at 7 TeV (in pp collisions).

- b production proceeds via qqbar→bb & gg→bb, while W come primarily from qq’bar→W. The component gg→bb rises faster than qqbar with √s

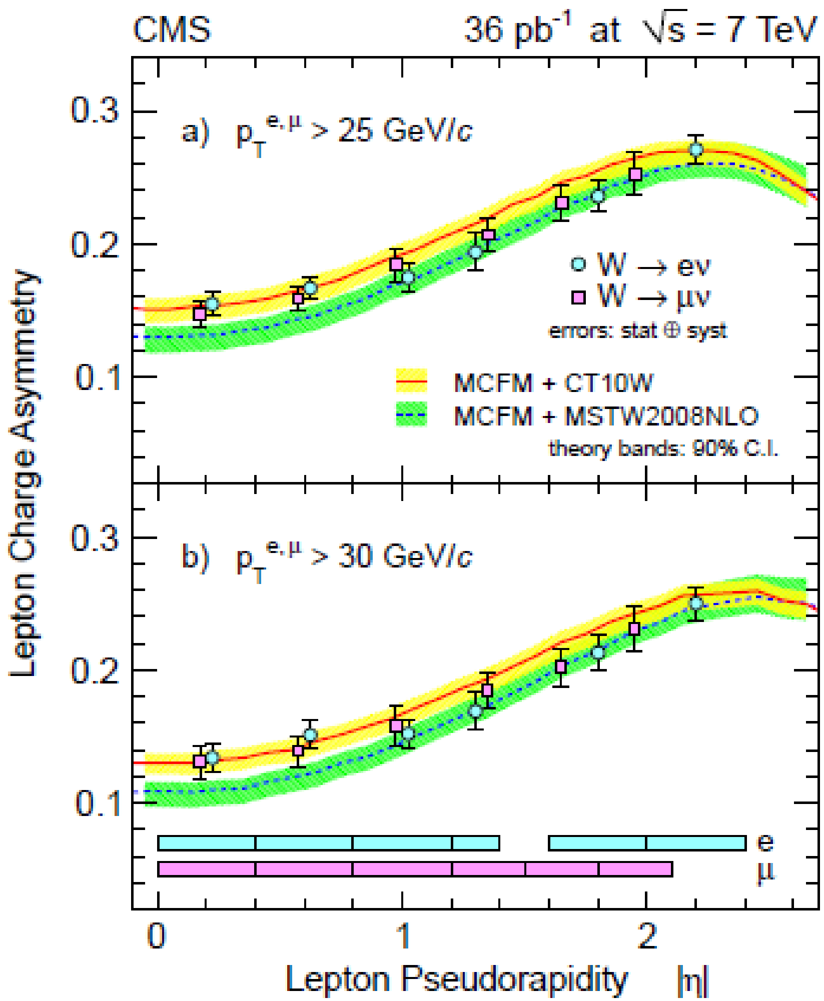
- Additionally, in PbPb collisions there might be a further reduction factor coming from the probable heavy quark energy loss (quenching), measured by CMS, R_{AA}~ 0.2 to 0.5 depending on the pt region and event centrality (CMS PAS HIN-10-006)



Conclusion on Background: ■ EWK contribution (2.1%) subtracted
■ QCD accounted in syst. Uncert. from backgd (1%)

Muon charge asymmetry

$(\sigma(W^+) - \sigma(W^-)) / (\sigma(W^+) + \sigma(W^-))$



Published by CMS pp data @ sqrt(s) = 7 TeV

$R^{\pm} = \sigma^+ / \sigma^- = 1.423 \pm 0.008\,(\text{stat}) \pm 0.019\,(\text{syst}) \pm 0.031(\text{theo})$

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