



# Weak Boson Results from CMS

Probing the initial stage in nuclear collisions  
using electroweak measurements

Initial Stages in High-Energy Nuclear Collisions

Napa, CA

5/Dec/2014

**UCDAVIS**  
DEPARTMENT OF PHYSICS



Manuel Calderón de la Barca Sánchez

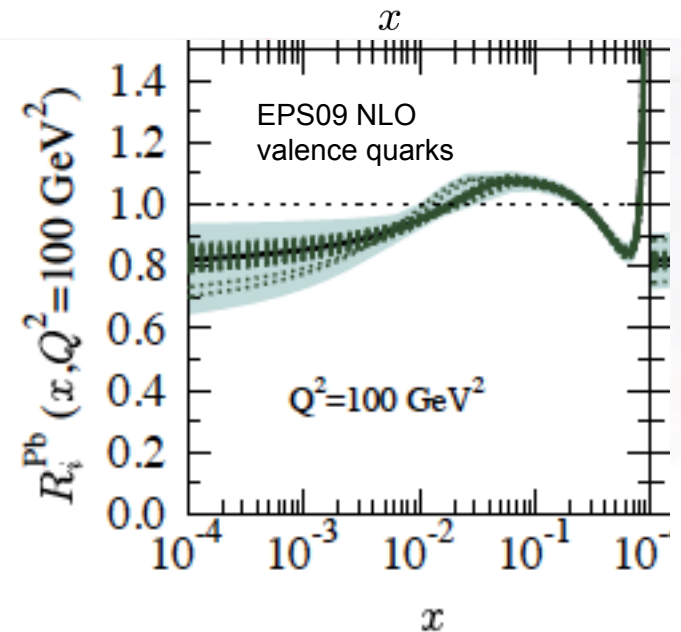
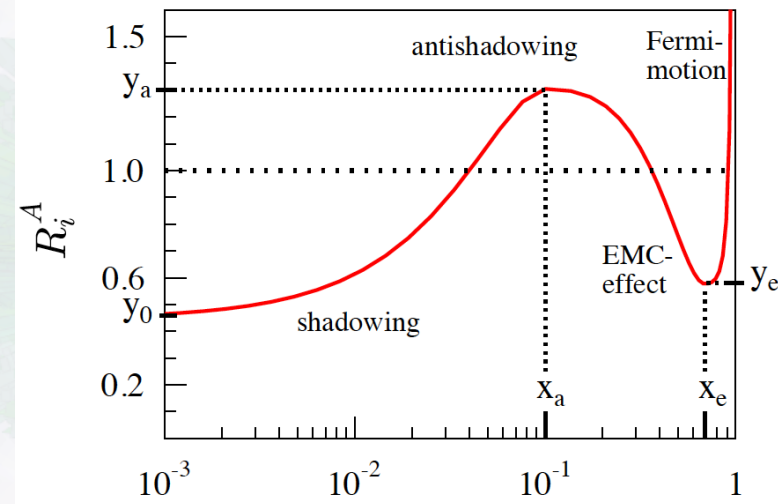
for the CMS Collaboration



# Electroweak probes: unique tools

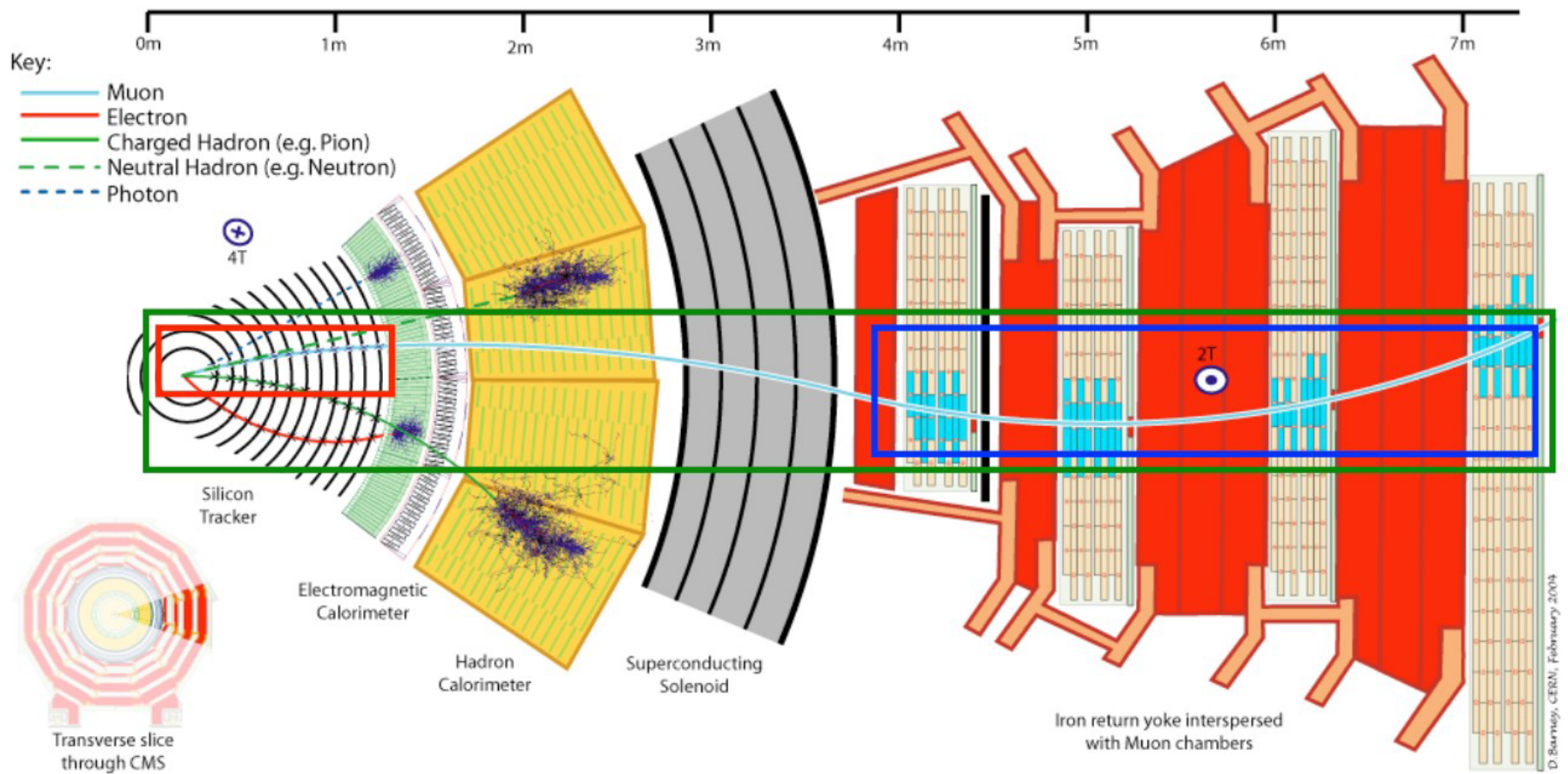
- Z, W bosons: well calibrated probe in pp
- LHC energies: access to Z, W in pA and AA
  - Electroweak bosons in dilepton channel:
  - No final state modification by QCD medium
    - Test Binary scaling hypothesis
    - 'Standard candle' for initial state
  - Sensitive to initial state
    - Constrain nuclear PDFs

JHEP 0904 (2009) 065

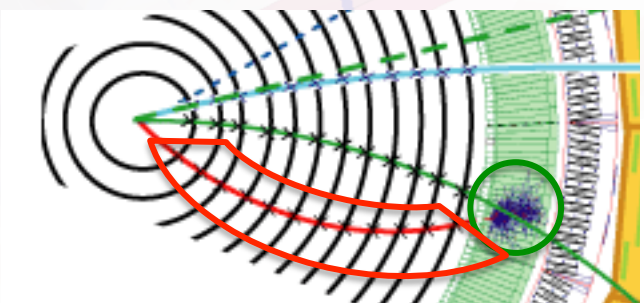




# Muon/Electron reconstruction in CMS



- **Muons:** Si tracker + muon detectors
  - $p_T$  resolution: 1-2% up to  $p_T \sim 100$  GeV/c
- **Electrons:** Si tracker + ECAL cluster
  - h/e discrimination: shower shape +  $E_{ECAL}/p_{track}$
  - $p_T$  resolution: 1-2% for  $p_T \sim 45$  GeV/c





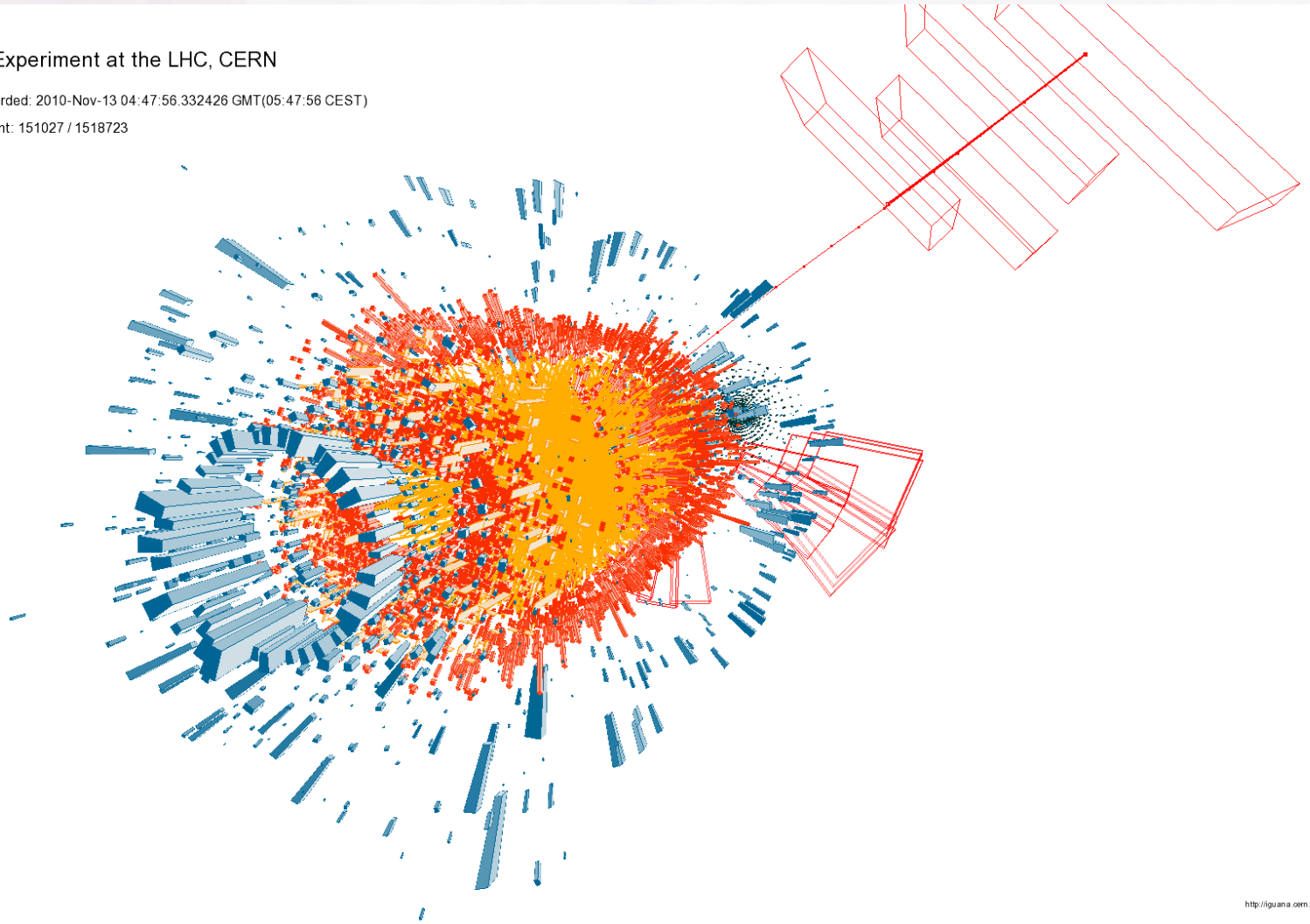
# $W \rightarrow \mu \nu$ event display



CMS Experiment at the LHC, CERN

Data recorded: 2010-Nov-13 04:47:56.332426 GMT(05:47:56 CEST)

Run / Event: 151027 / 1518723



(c) CERN 2009. All rights reserved.

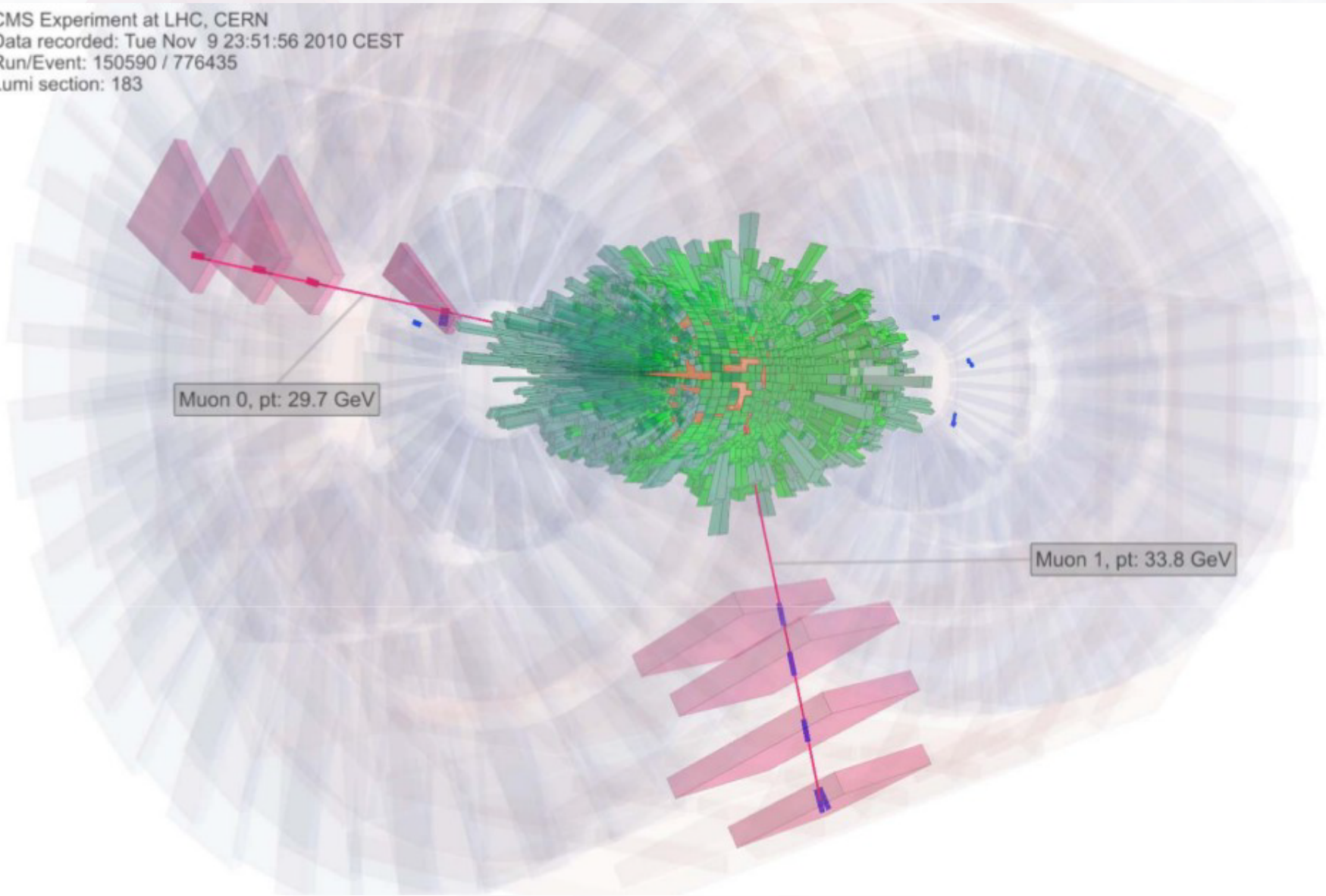
<http://iguana.com.ch/spy>



# $Z \rightarrow \mu\mu$ event display



CMS Experiment at LHC, CERN  
Data recorded: Tue Nov 9 23:51:56 2010 CEST  
Run/Event: 150590 / 776435  
Lumi section: 183

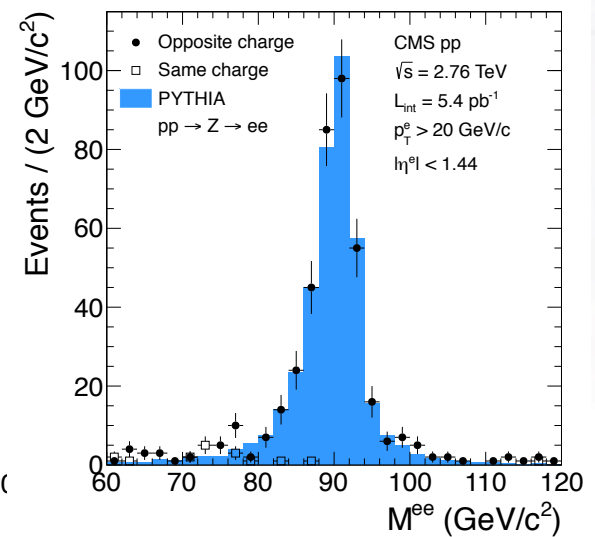
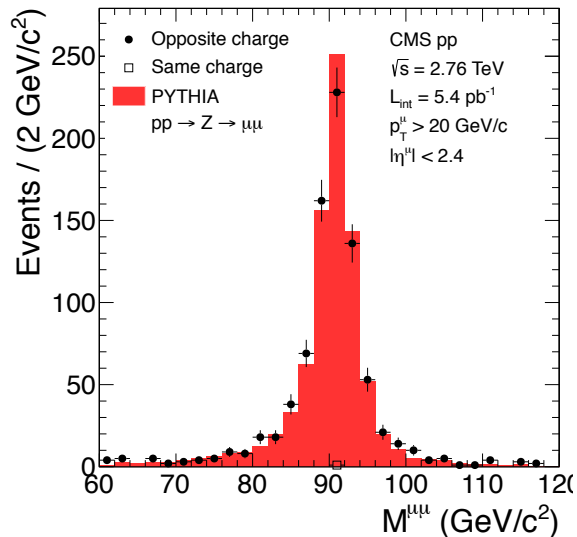
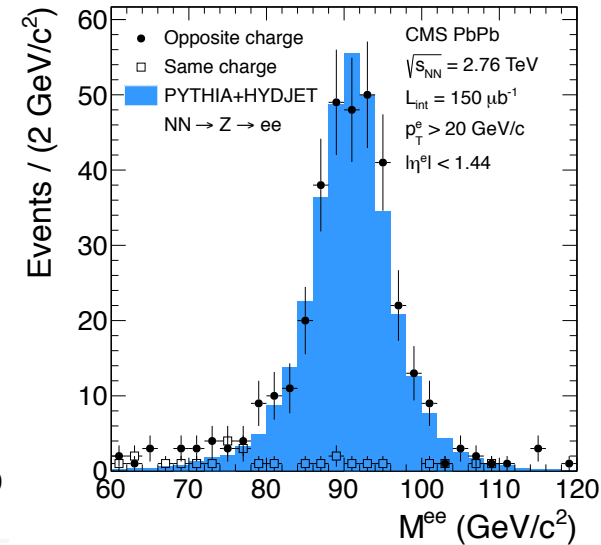
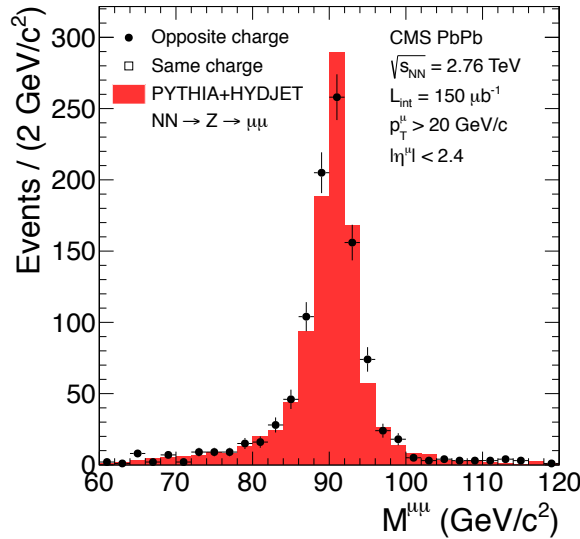




# Z in PbPb and pp @ 2.76 TeV

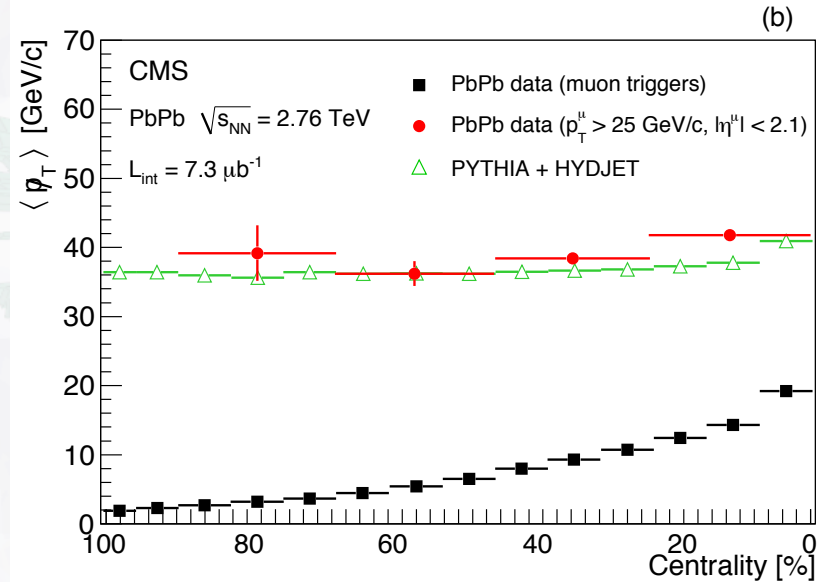
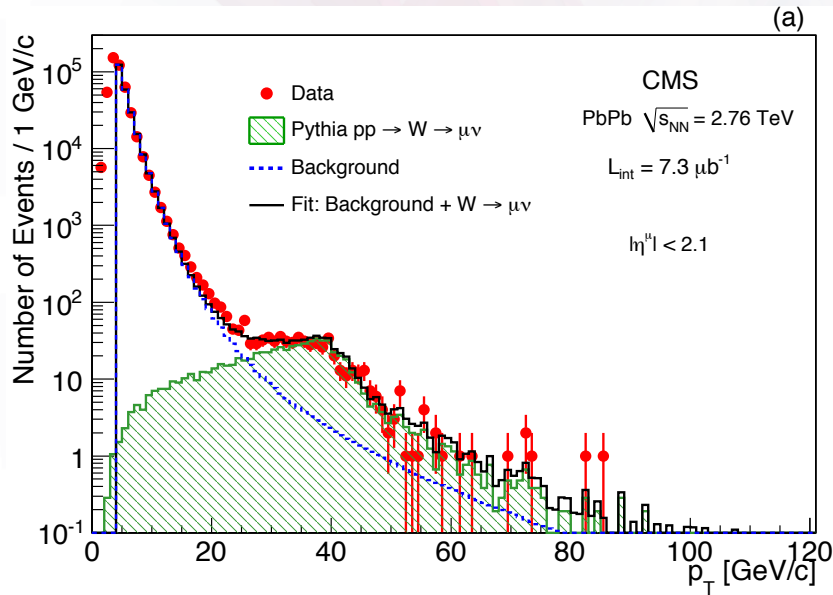
- PbPb data, 2011 run
- pp data, 2013 run
- **Muon** and **electron** channels.
- Lepton selection
  - $p_T > 20 \text{ GeV}/c$
  - $|\eta^{m(e)}| < 2.4$  (1.44)

- Excellent S/B
- Signal shape agrees with simulation in both channels and both collision systems!



# W: $\mu$ + missing $p_T$ in PbPb

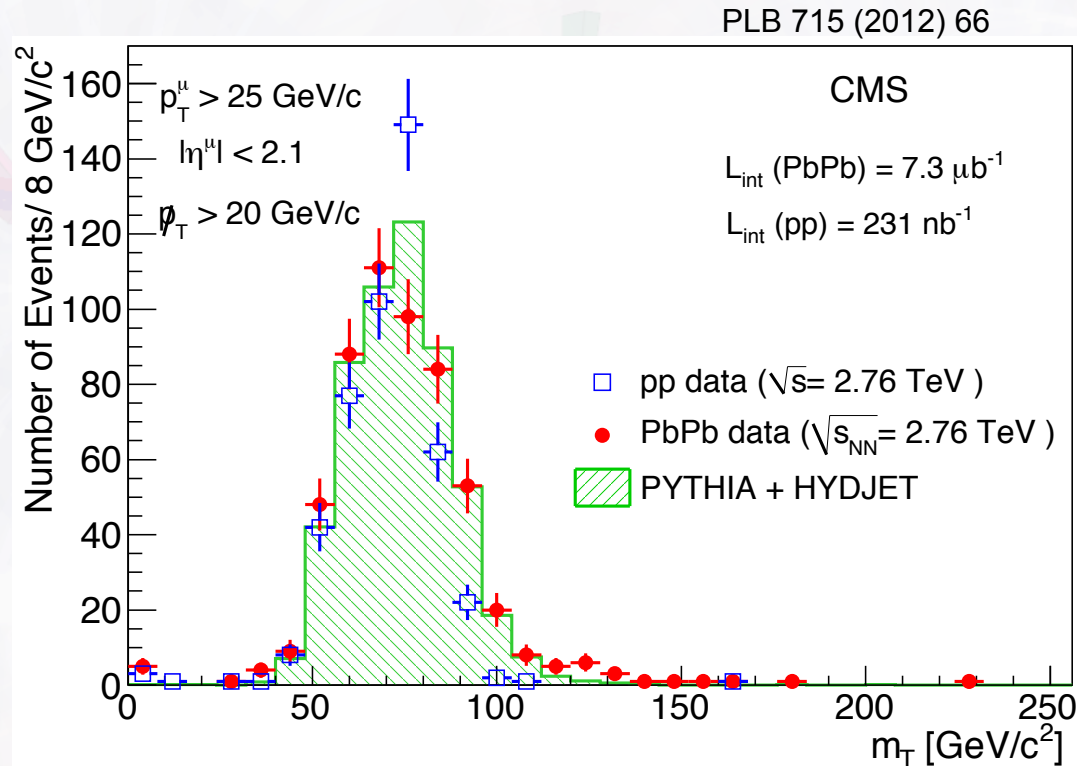
PLB 715 (2012) 66



- W signal in muon spectrum at high  $p_T$ 
  - Require good quality muons + Z veto
- Missing  $p_T$  : obtained from tracking
  - All muon triggers: momentum is balanced
    - Some centrality dependence: resolution for missing  $p_T$
  - Signal events with high  $p_T$  muon: large imbalance
    - No centrality dependence, agrees with simulation

# W transverse mass in PbPb

- Excellent S/B
- Good agreement between data and simulation
- Shape is consistent between pp and PbPb
  - modulo resolution difference

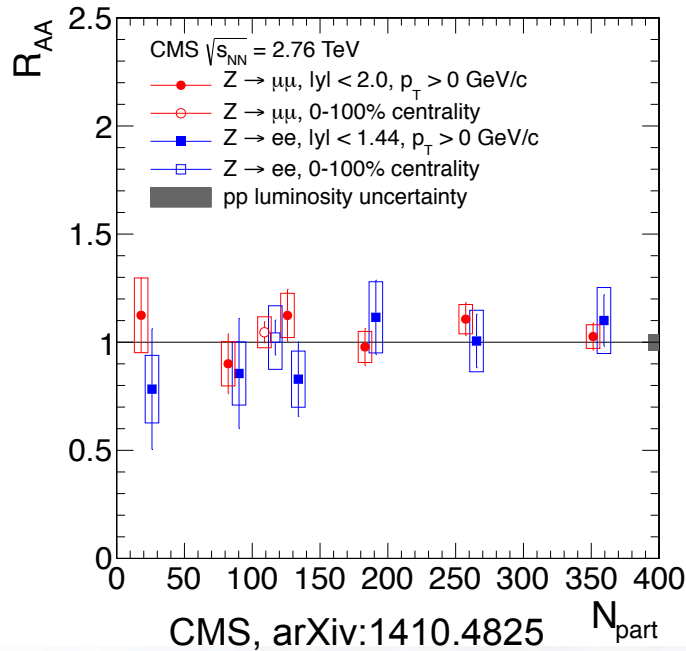


$$m_T = \sqrt{2 p_T^\mu p_T (1 - \cos \theta)}$$

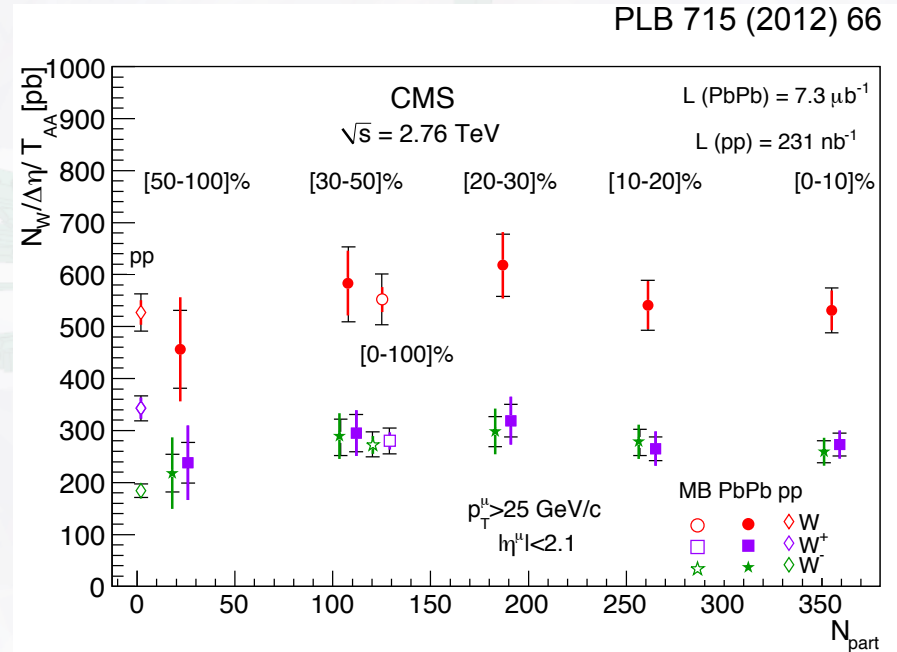




# Electroweak bosons in PbPb vs. $N_{part}$



$$R_{AA}(Z) = 1.10 \pm 0.05 \pm 0.09$$

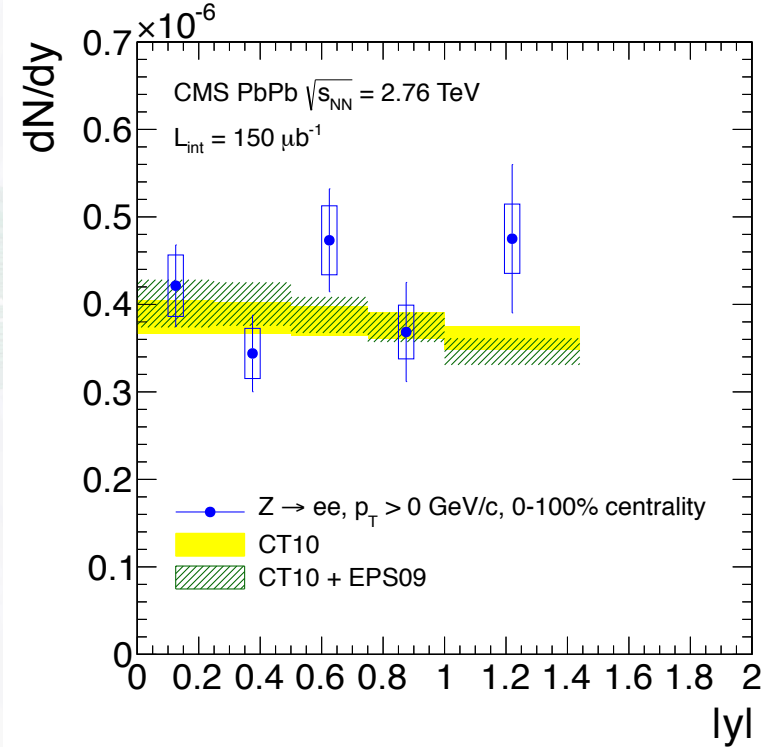
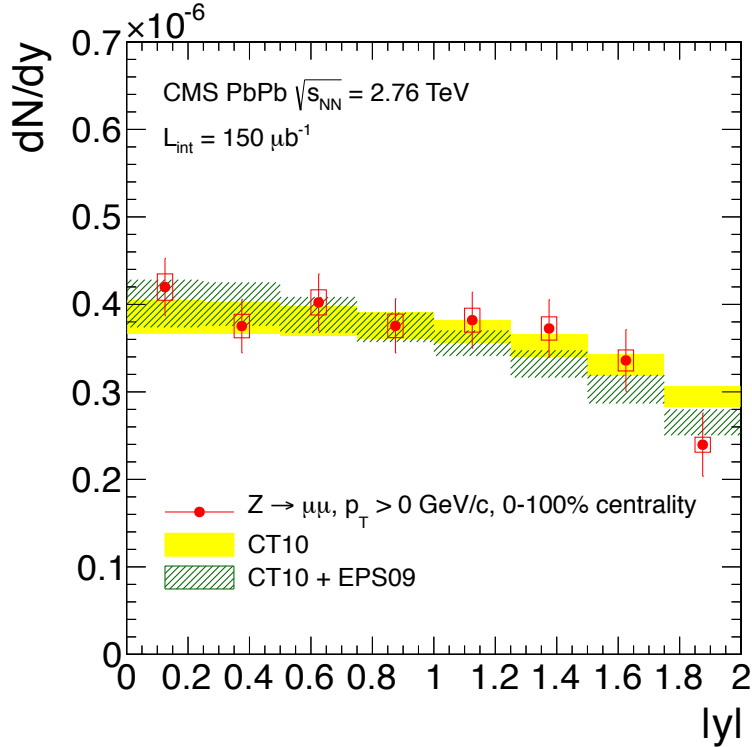


$$R_{AA}(W) = 1.04 \pm 0.07 \pm 0.12$$

- $R_{AA} \sim 1$ , no centrality dependence: Standard candles!
  - Best test of binary-collision scaling hypothesis
- Can study finer initial-state nuclear effects via kinematics



# Z boson rapidity distribution in PbPb



- Comparison to POWHEG

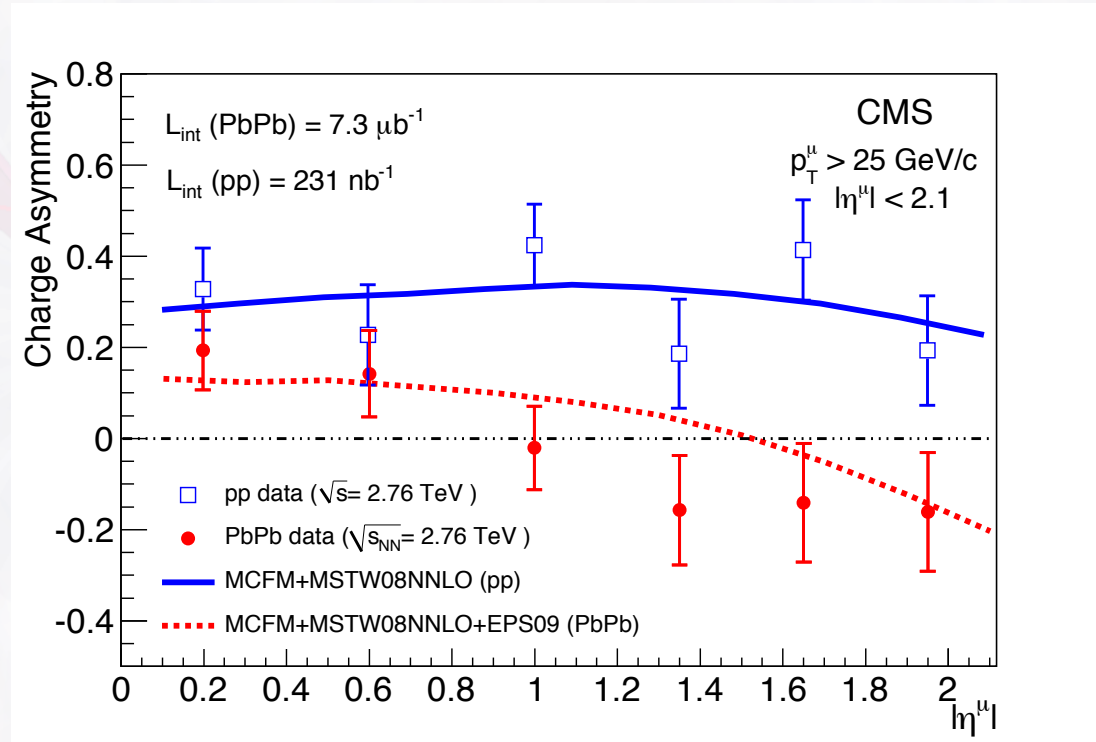
- No nuclear effects: CT10

- With nuclear effects: CT10 + EPS09

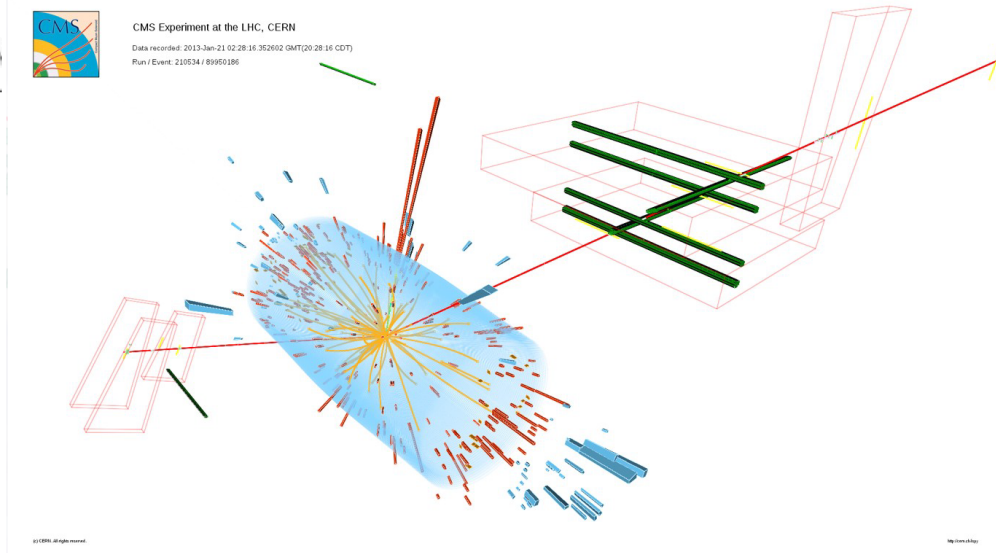
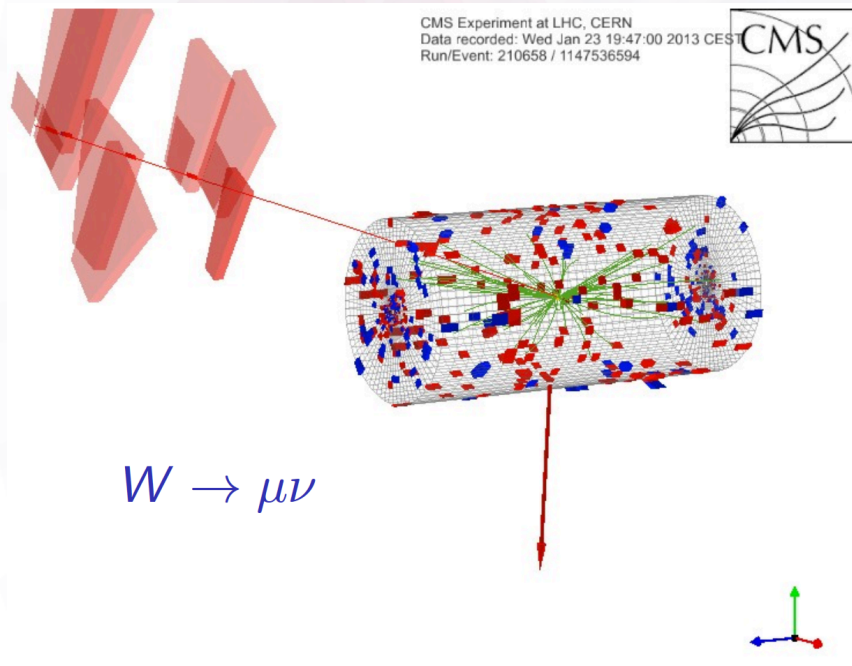
- Differences between models are small in PbPb

# W boson charge asymmetry in PbPb

- pp:
  - little dependence of asymmetry on  $\eta$ .
- PbPb:
  - asymmetry is smaller
  - larger dependence on  $\eta$ .
- Comparison between pdfs:
  - Clear preference for nuclear pdf in PbPb



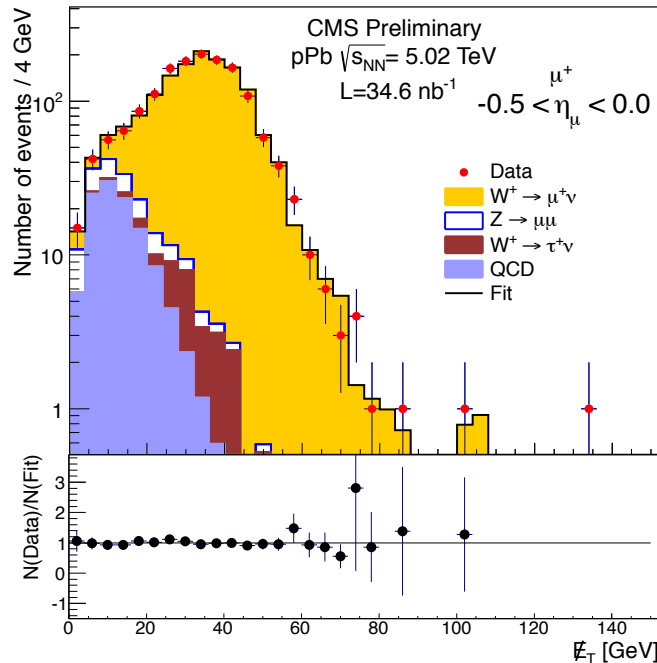
# Z and W bosons in pPb



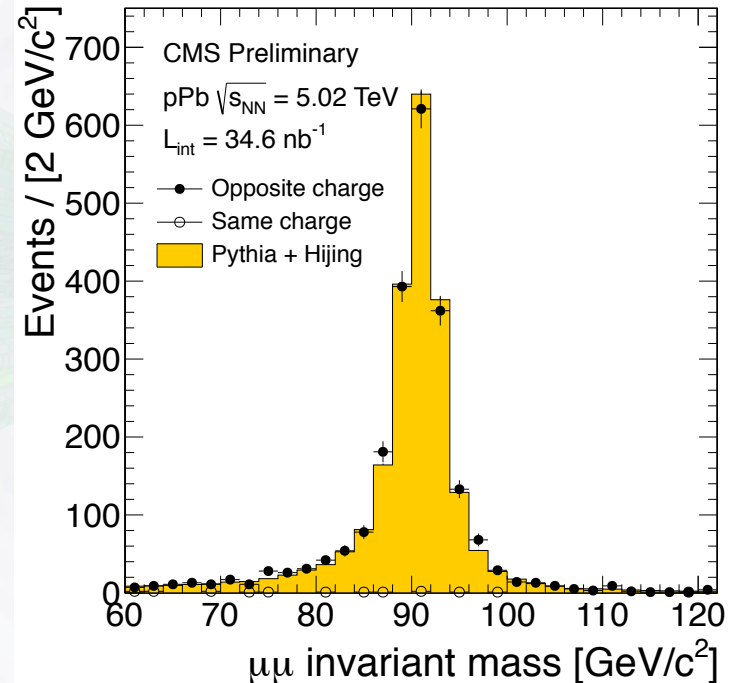
- Higher cross sections in pPb:  $\sqrt{s}=5.02$  TeV
- Asymmetric collisions: new observables
  - forward/backward asymmetries
  - better sensitivity to nPDF

# W and Z Data in pPb

CMS-HIN-13-007

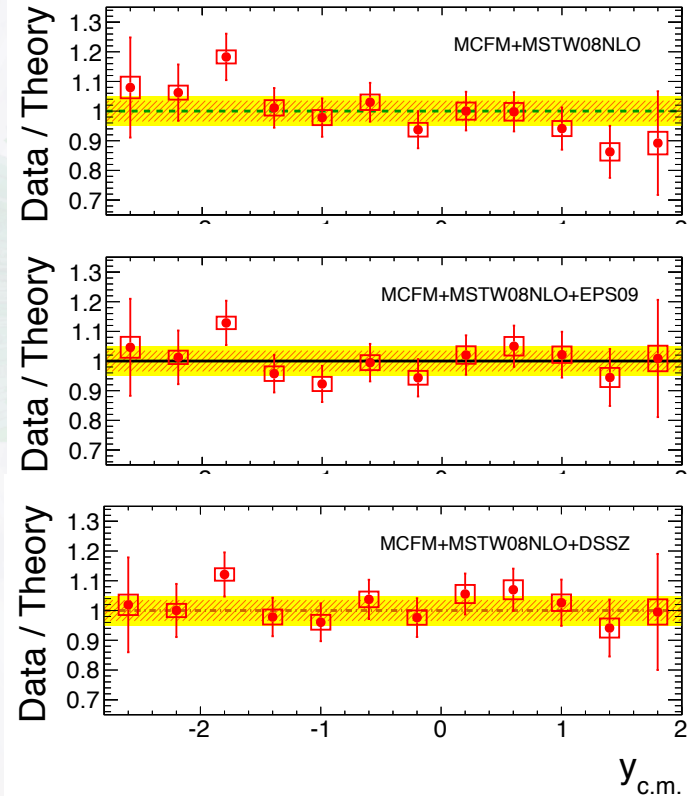
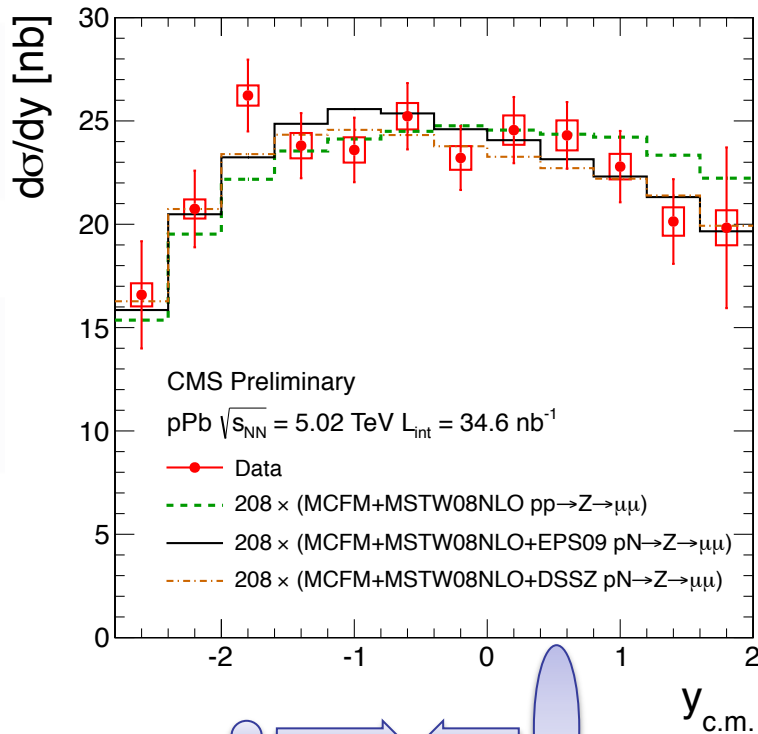


CMS-HIN-14-003



- W selection:  $p_T > 25 \text{ GeV}/c$ ,  $|\eta_{lab}^{\mu}| < 2.4$ ,  $|\eta_{lab}^e| < 2.5$
- Z selection:  $p_T > 20 \text{ GeV}/c$ ,  $|\eta_{lab}^{\mu}| < 2.4$
- Asymmetric acceptance in rapidity
- CM Frame is boosted

# Z Cross section vs. rapidity in pPb

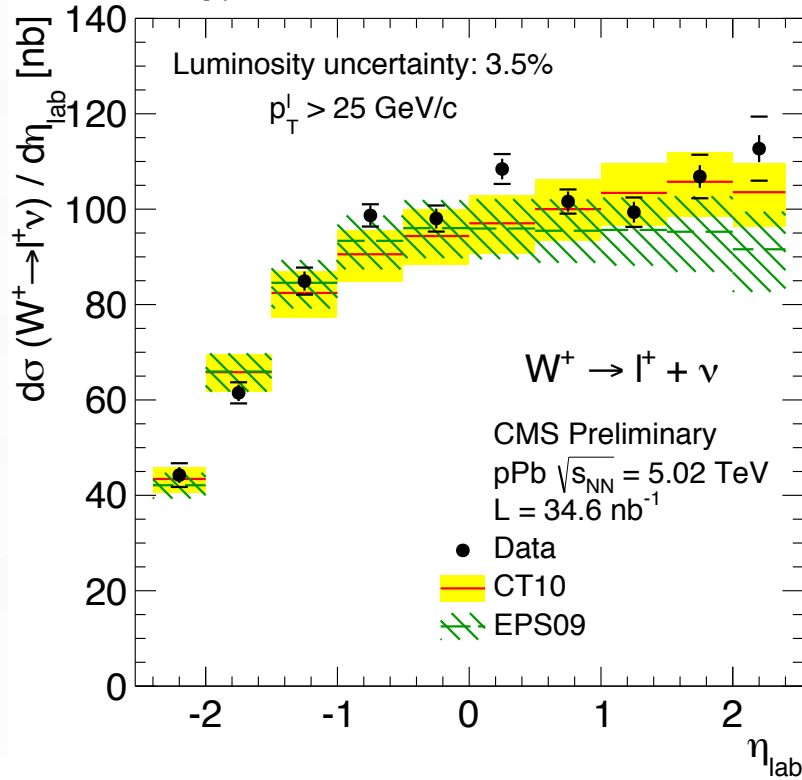


- Distribution shifted to c.m. frame
- Scaling  $\sigma_{p\text{Pb}} = A \sigma_{pp}$  works well: scaled pp predictions consistent with data

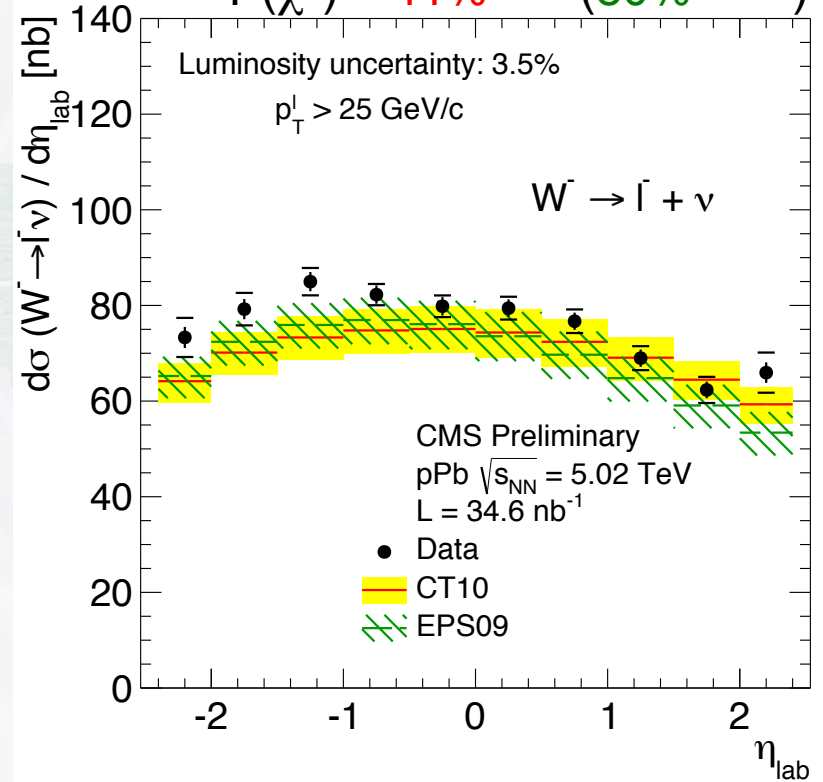


# W cross sections vs. $\eta$ in pPb

$P(\chi^2) = 11\%^{CT10} (17\%^{EPS09})$



$P(\chi^2) = 41\%^{CT10} (80\%^{EPS09})$

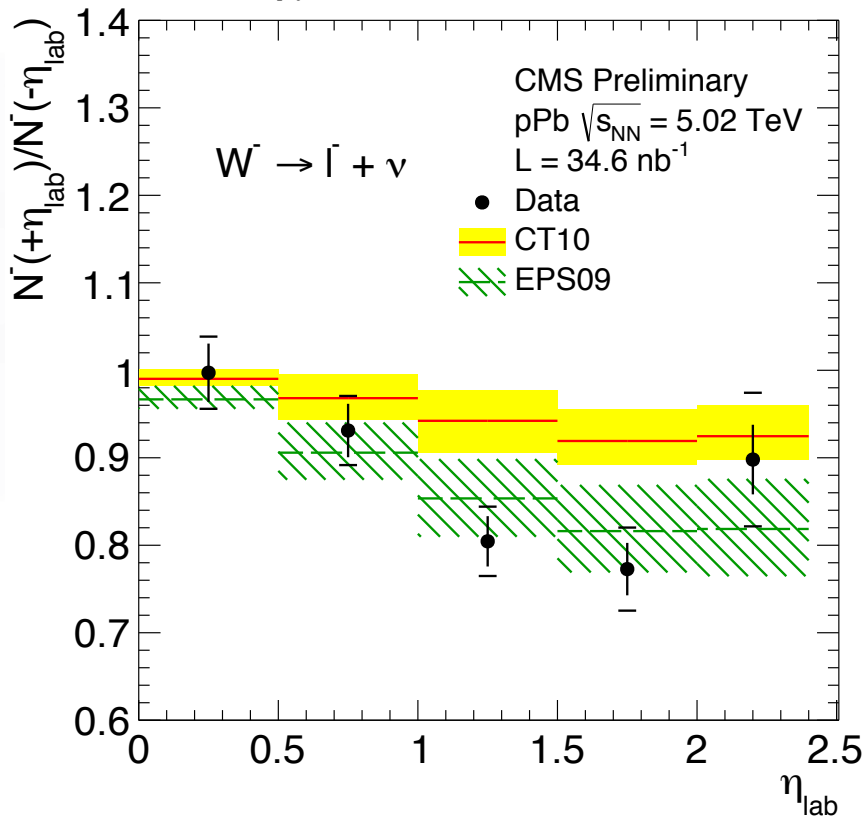


- Distribution displayed in lab frame
- pp predictions in good agreement with data
- Nuclear effects are too small for discriminating: use asymmetries.

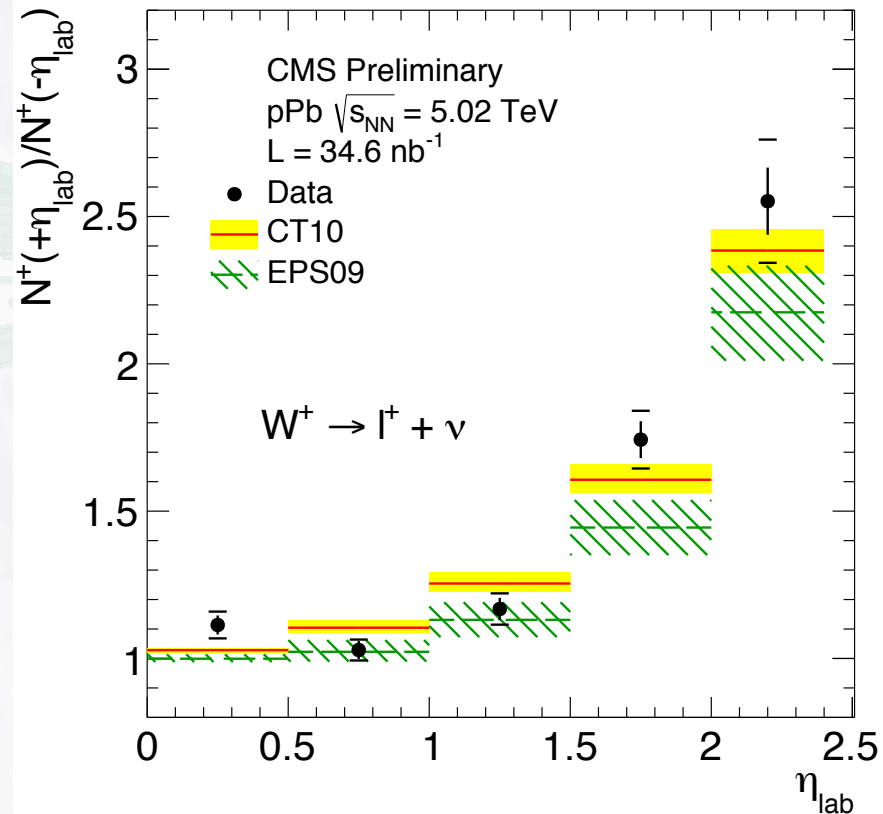


# Forward-backward asymmetry: $N(+\eta_{lab}) / N(-\eta_{lab})$ .

$P(\chi^2) = 19\%_{CT10} (13\%_{EPS09})$



$P(\chi^2) = 16\%_{CT10} (72\%_{EPS09})$



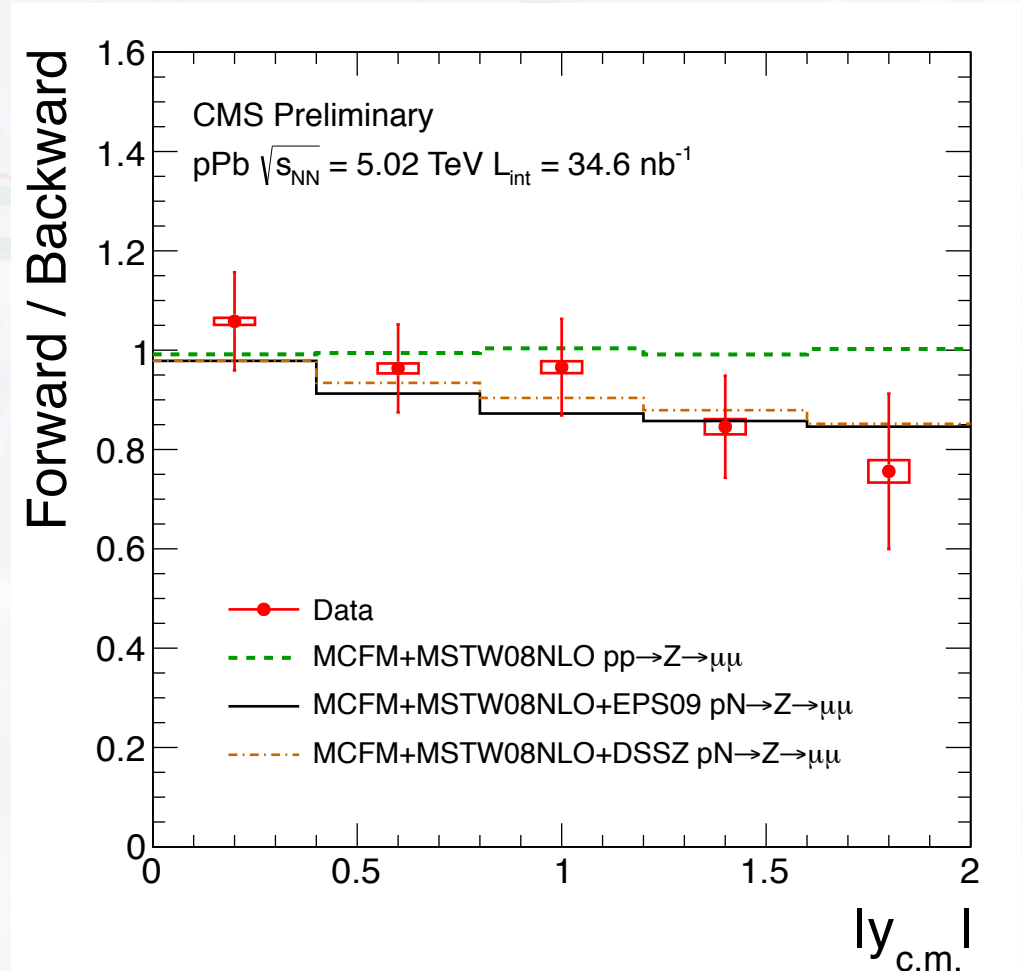
- Better sensitivity to nuclear modification.
- $W^-$  data show preference for nuclear effect
- $W^+$  data: no pdf is preferred





# Z Forward-Backward ratio in pPb

- For Z boson, F/B ratio should be 1 if no nuclear effects present
- Data: hint of nuclear effects
  - Uncertainties are still large
    - Data: statistical uncertainty dominates
    - nPDF: uncertainty band not shown





# Conclusion

- We are beginning to explore nuclear modification in heavy-ion collisions using electroweak probes!
- To first order: Z and W production scales with binary collisions in pPb and PbPb
  - Initial-state nuclear effects on quark PDFs  $O(10\%)$
  - Hints of nuclear effects in W & Z data
    - Asymmetries vs. rapidity show promise for discriminating power
    - More luminosity would help distinguish between nPDFs
  - Z,W Cross sections and asymmetries can be used as part of global fits of nPDFs