# $W$ bosons in pPb collisions in the CMS experiment

Émilien Chapon

Laboratoire Leprince-Ringuet, École Polytechnique, Palaiseau

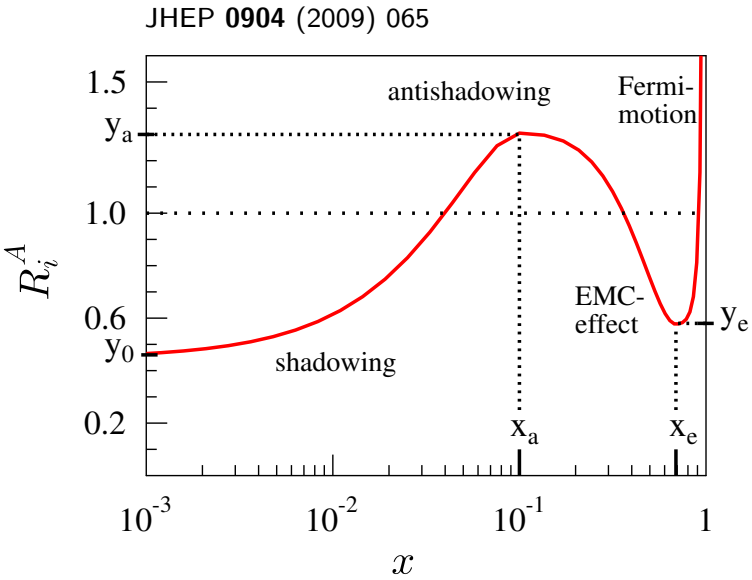
QCD dans les collisions pA et AA:
GDR-PH-QCD meeting, WG 3
LPSC Grenoble, Nov. 5-7, 2014



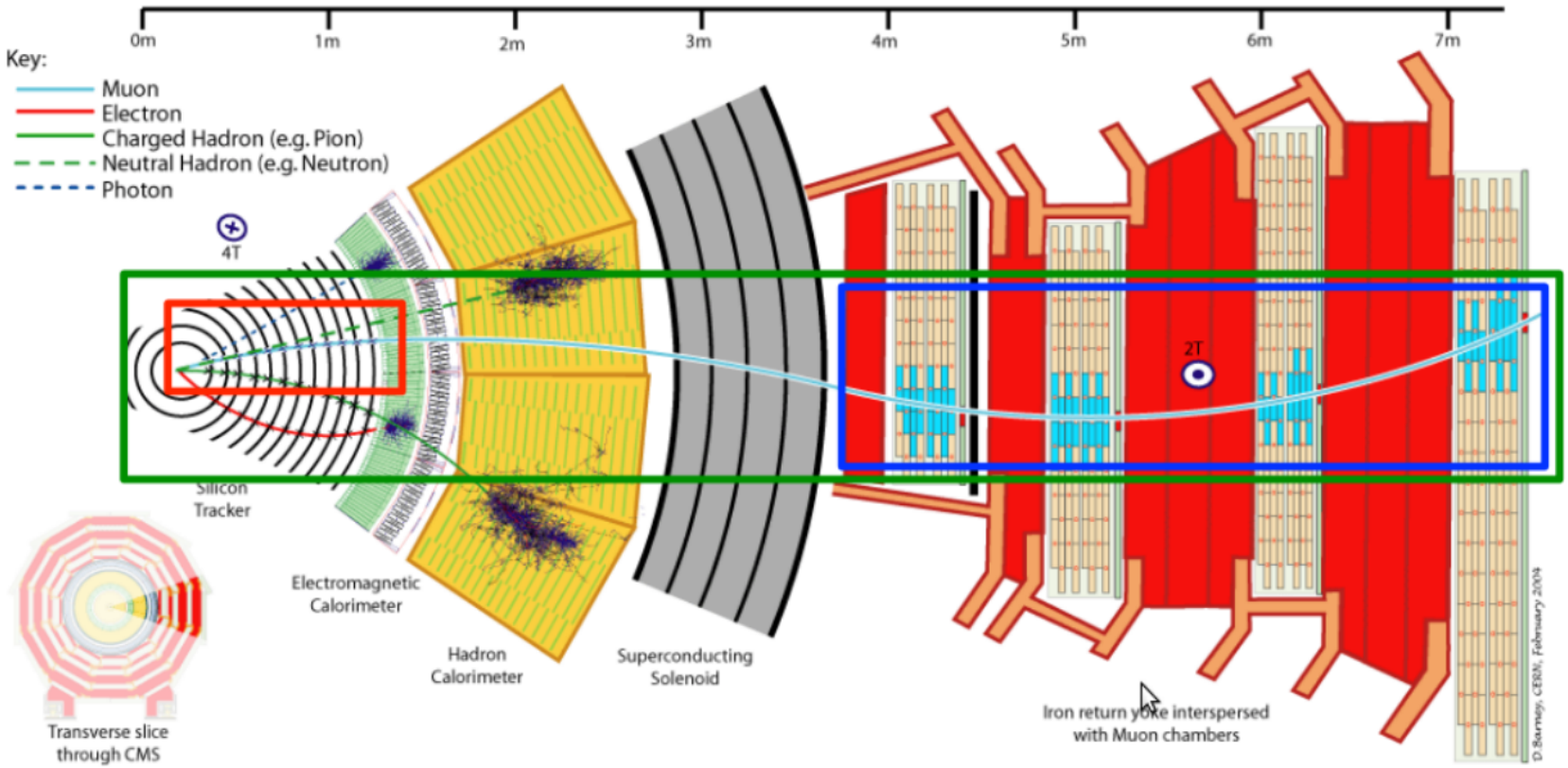
European Research Council
Established by the European Commission

# Motivation

- Electroweak bosons are produced and decay very early in the collision.
- They are not affected by the medium.
- Isospin effect for $W$ (different between pp, pn and nn binary collisions).
- However they are sensitive to nuclear modifications of the parton distribution functions.
  - Good probes for nuclear effects in PDFs (shadowing / anti-shadowing).



# The CMS experiment

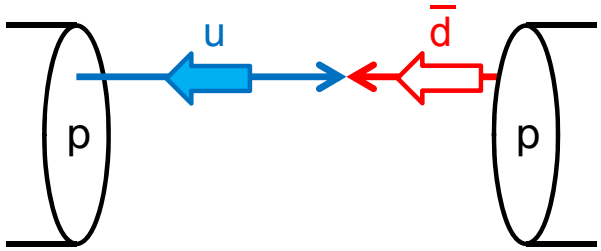



- Muon reconstruction: silicon tracker + muon sub-detectors
  - Tracker $p_T$ resolution: 1-2% up to $p_T \sim 100\,\mathrm{GeV}/c$:
- Electron reconstruction: tracks associated with an ECAL cluster.
  - $h/e$ discrimination: shower shape + fraction of energy in ECAL.

# $W$ production

## Leading order

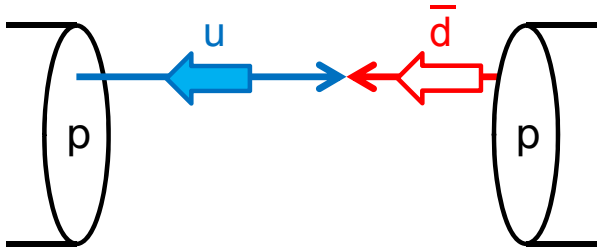
$$u\bar{d} \to W^+, \quad d\bar{u} \to W^-$$



# $W$ production

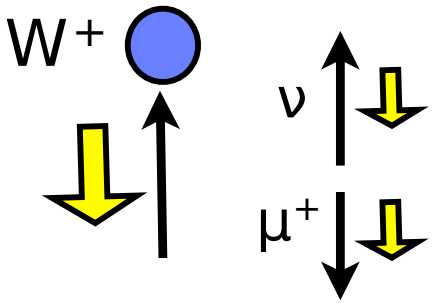
## Leading order

$$u\bar{d} \to W^+, \quad d\bar{u} \to W^-$$



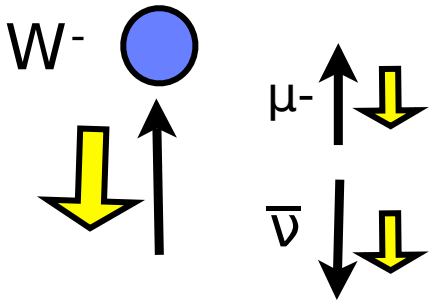

## Yields

- Expect 2× more $W^+$ than $W^-$ in pp.
- Expect more balanced production in pPb.



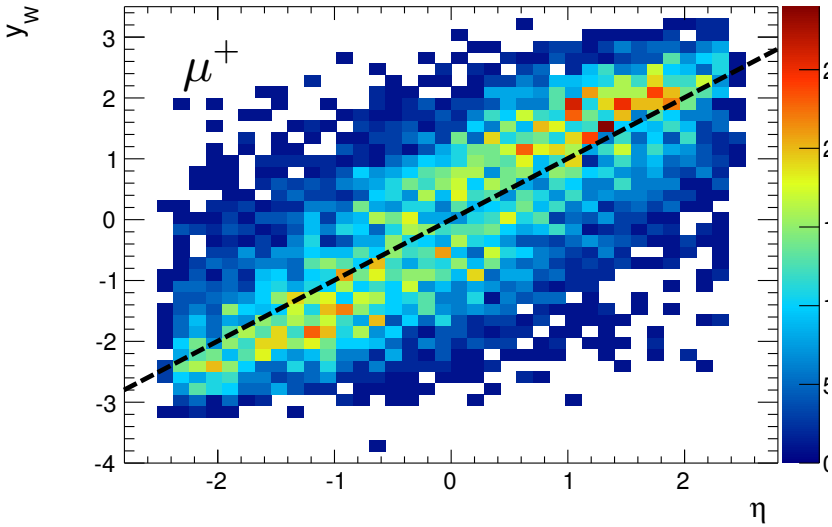

## Rapidity

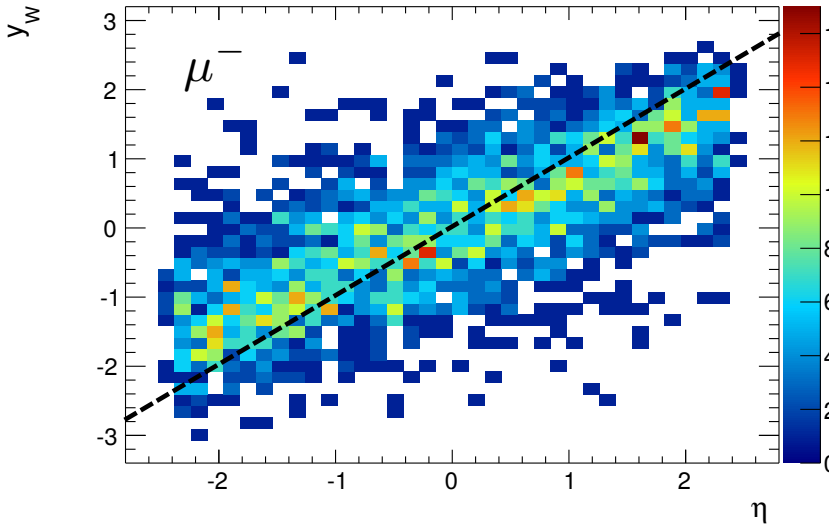
- $W$ boosted towards the valence quark.
- Spin conservation + parity violation: $\mu^+$ ($\mu^-$) boosted back to (away from) midrapidity.
  - $\Rightarrow$ different rapidity distributions between $\mu^+$ and $\mu^-$.



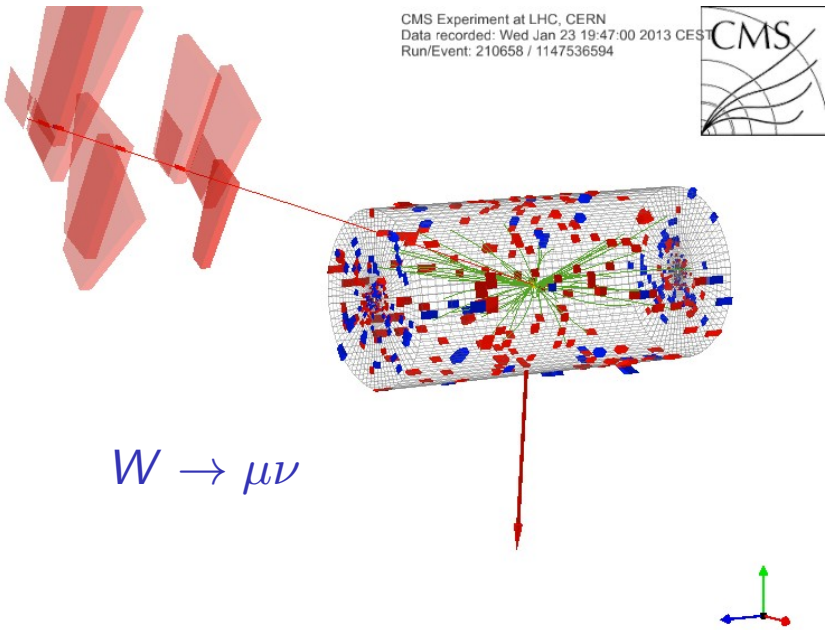
# Kinematics

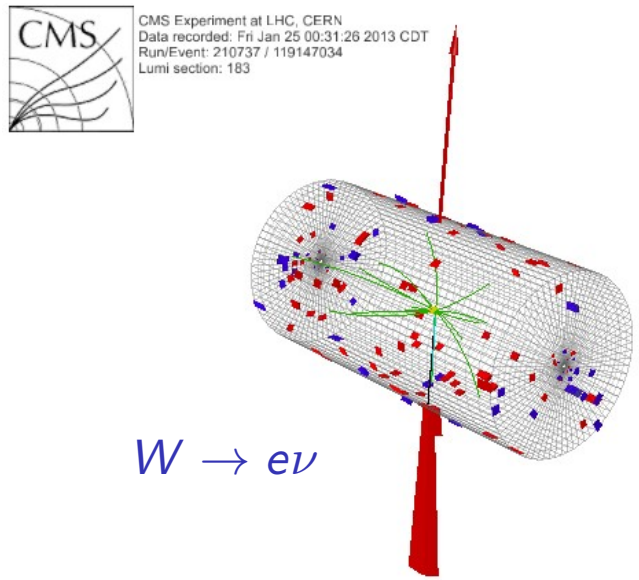
- Remember that we don't reconstruct the full kinematics of the $W$ boson (because of the escaping undetected neutrino)



# $W$ bosons in pPb collisions

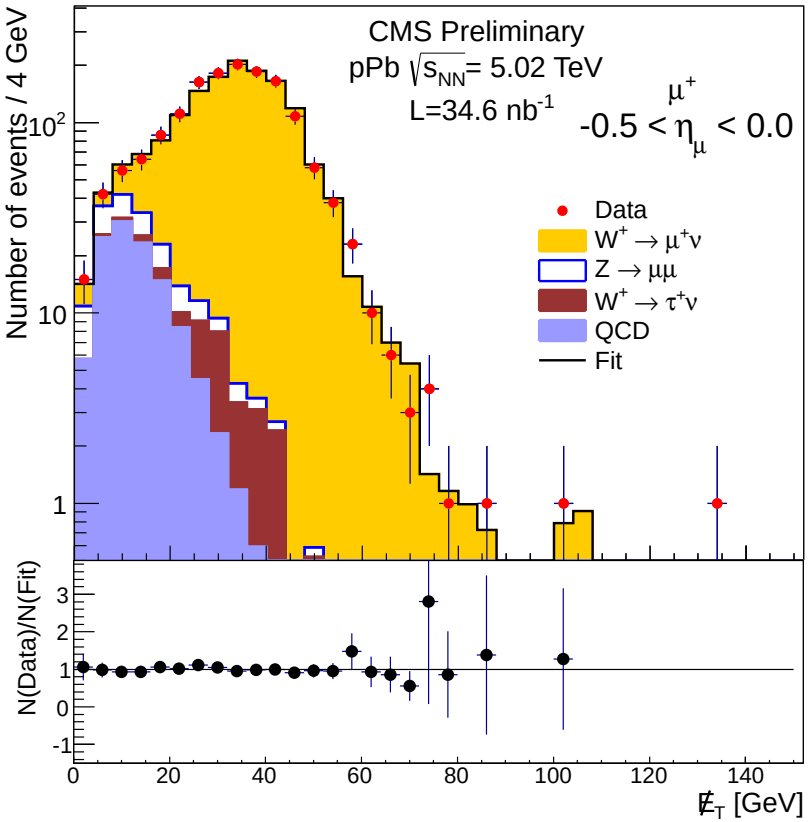


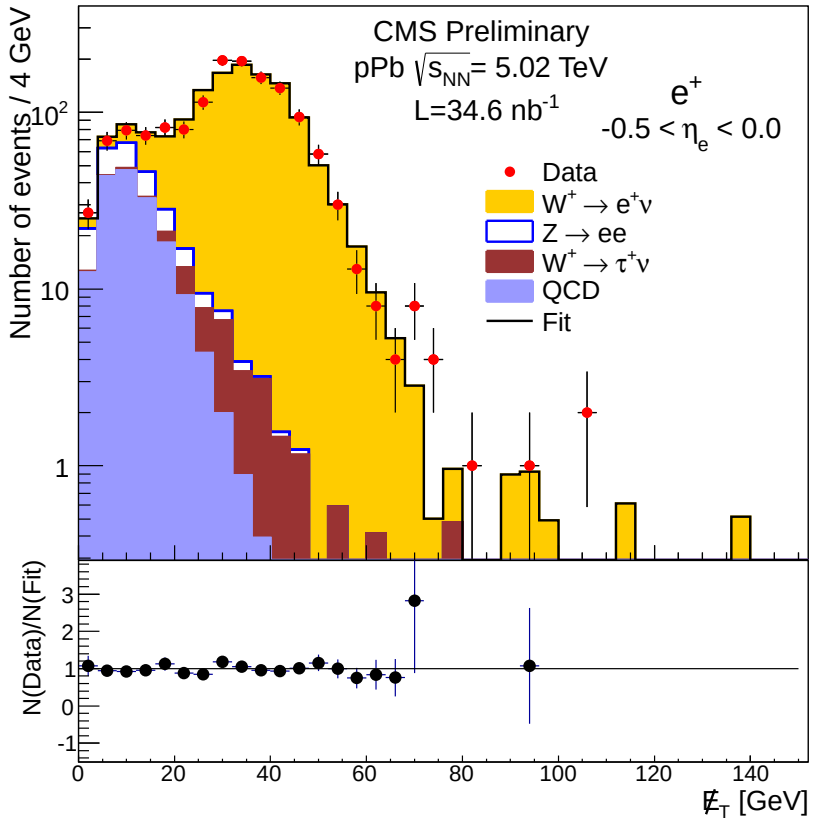




- Asymmetric collisions: new observables compared to PbPb (e.g. forward / backward asymmetries)
  - Better sensibility to nPDF
- higher cross section as compared to PbPb, because of $\sqrt{s_{NN}}$ ($\sqrt{s_{NN}} = 2.76\,\text{TeV}$ in PbPb $\to$ $\sqrt{s_{NN}} = 5.02\,\text{TeV}$ in pPb)

# Selection

CMS-HIN-13-007

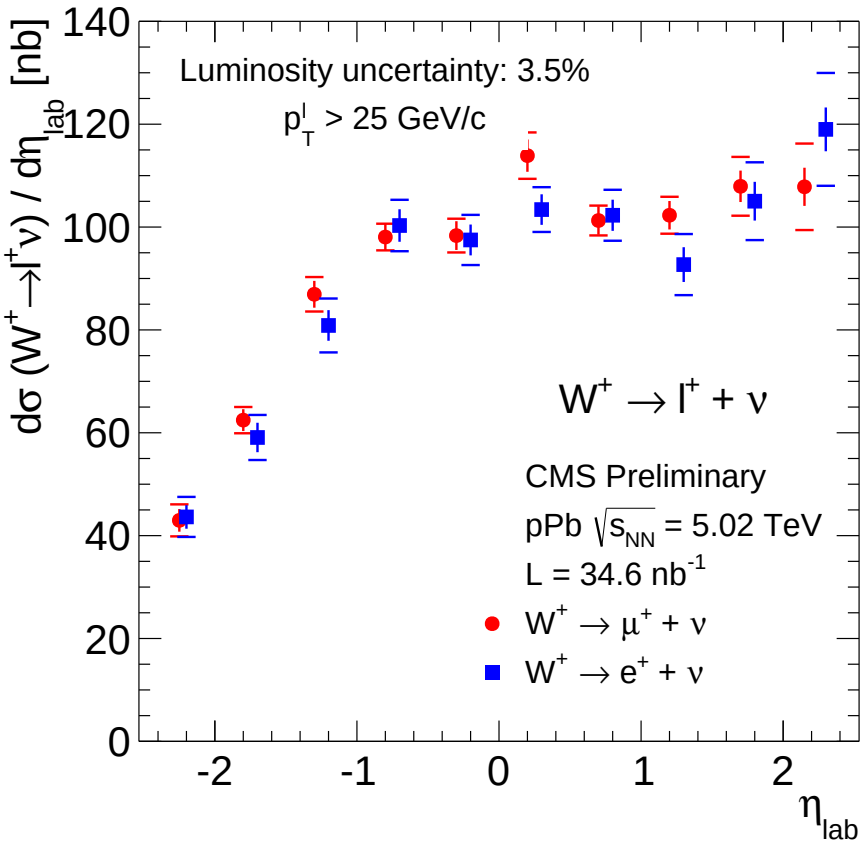


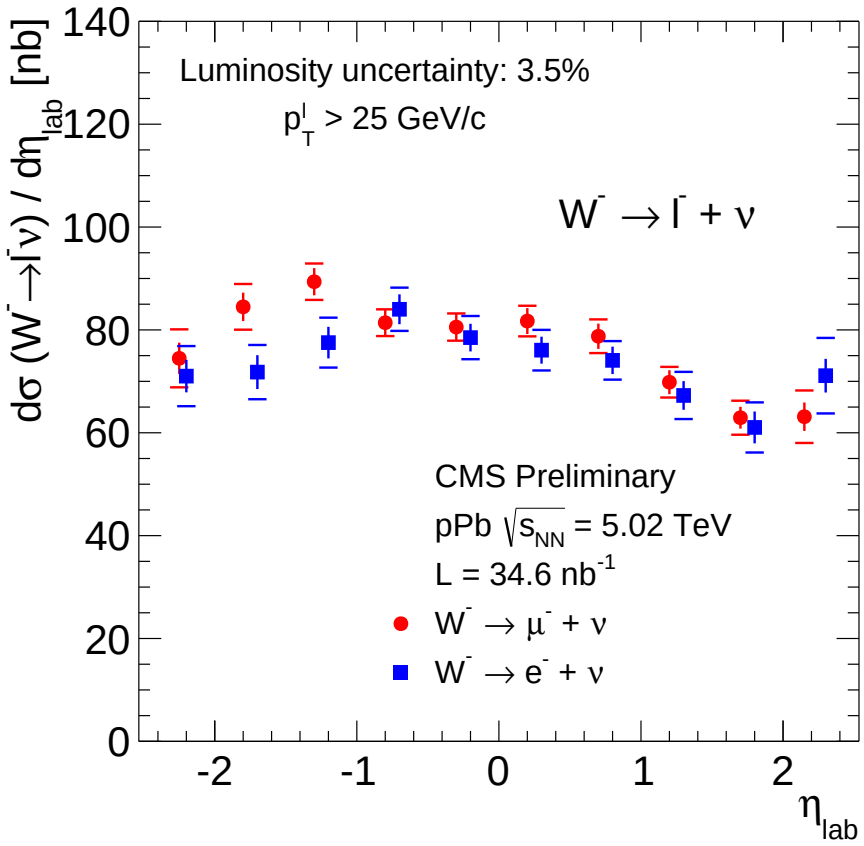




- Electron and muon channels.
- $p_T > 25\,\text{GeV}$, $|\eta^\mu| < 2.4$, $|\eta^e| < 2.5$, no $\not{E}_T$ cut.
- Requiring isolated lepton (to reject the HF and jet backgrounds)

# Cross section

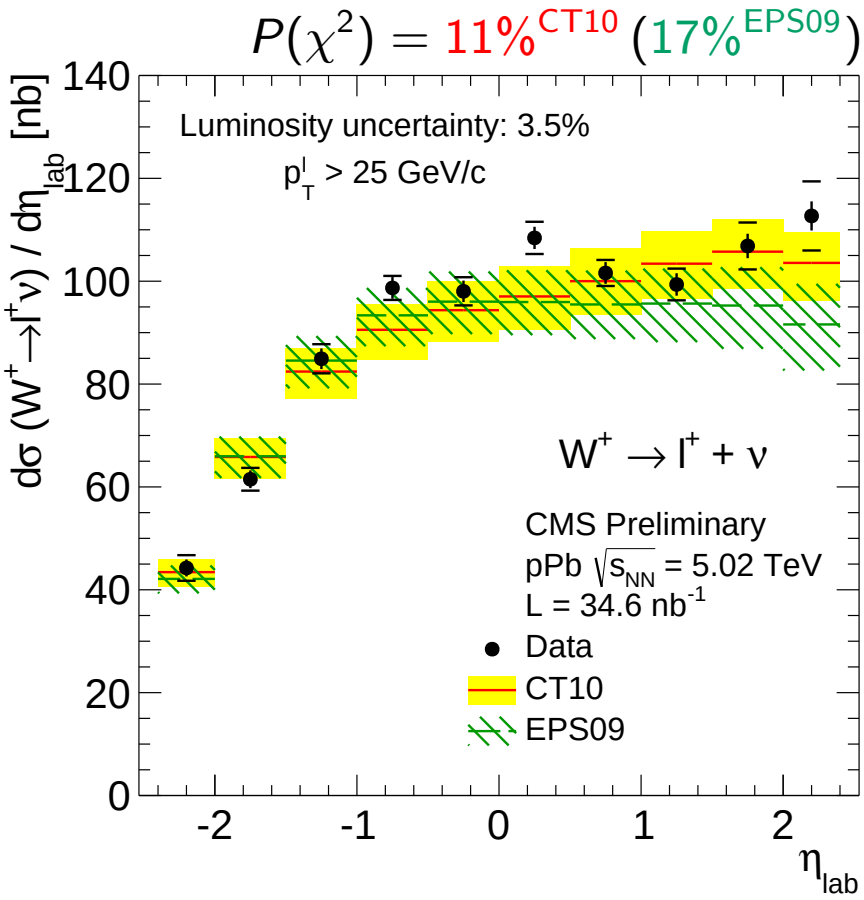
CMS-HIN-13-007

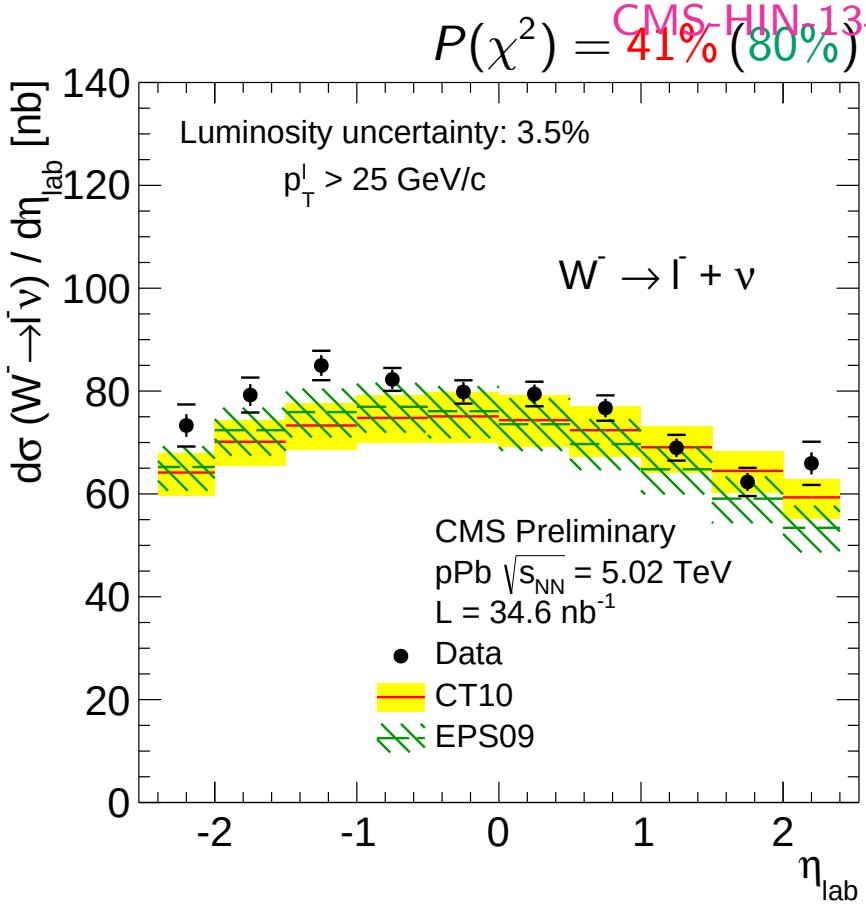



- Good agreement between the electron and muon channels.
- Combine the two channels for a better precision.

# Cross section



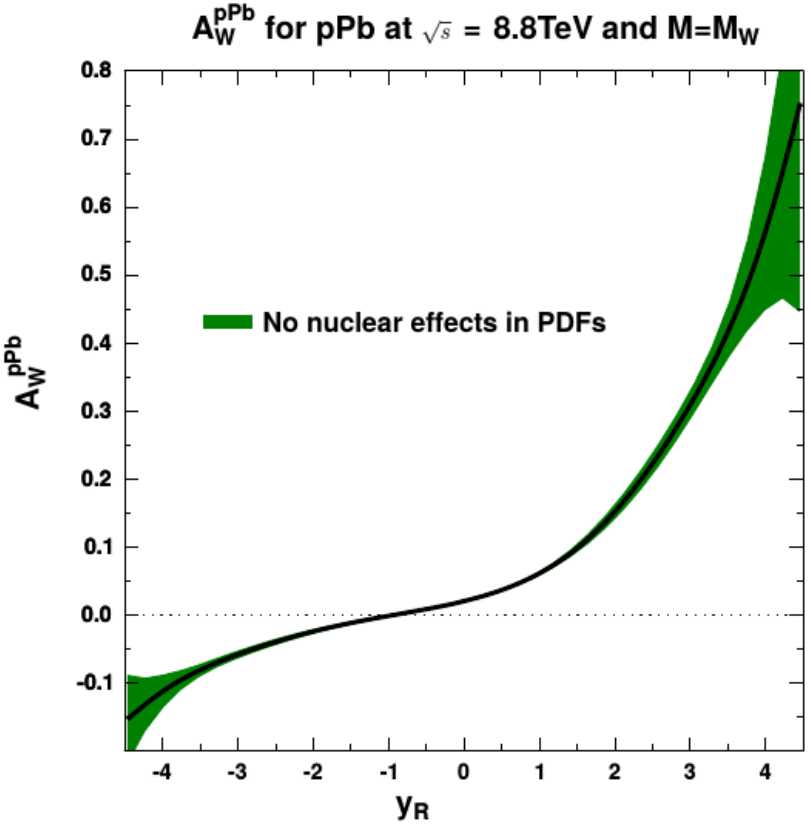




- NLO theory predictions with or without nuclear effects from EPS09[1].
- Good agreement with prediction.
- Poor discrimination between CT10 and CT10+EPS09: build asymmetries.

[1] Predictions from H. Paukkunen and C. A. Salgado, JHEP **1103** (2011) 071

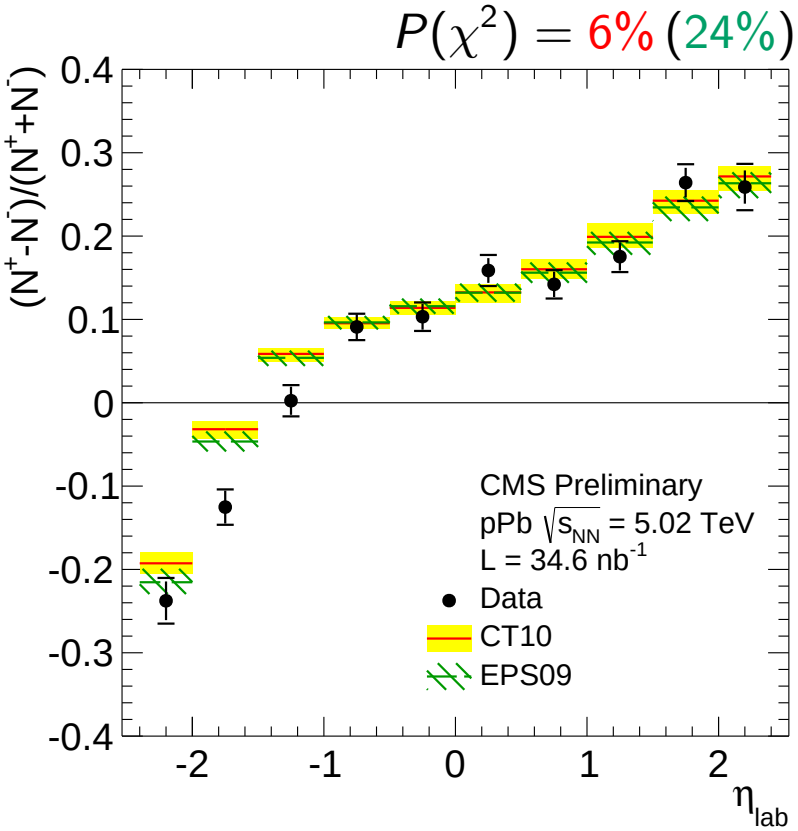
# Charge asymmetry $(N^+ - N^-)/(N^+ + N^-)$

CMS-HIN-13-007



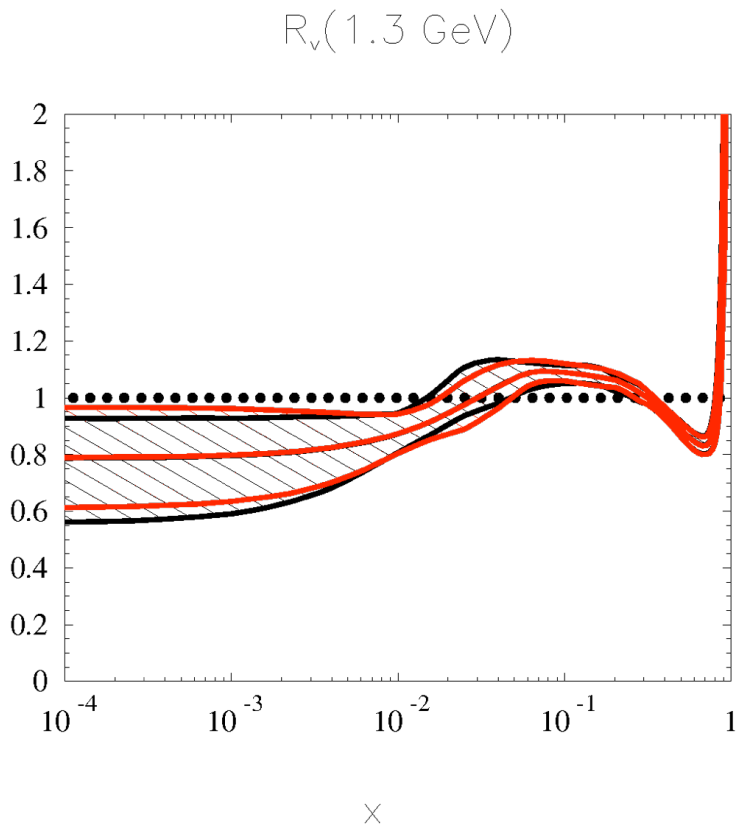
# Charge asymmetry $(N^+ - N^-)/(N^+ + N^-)$

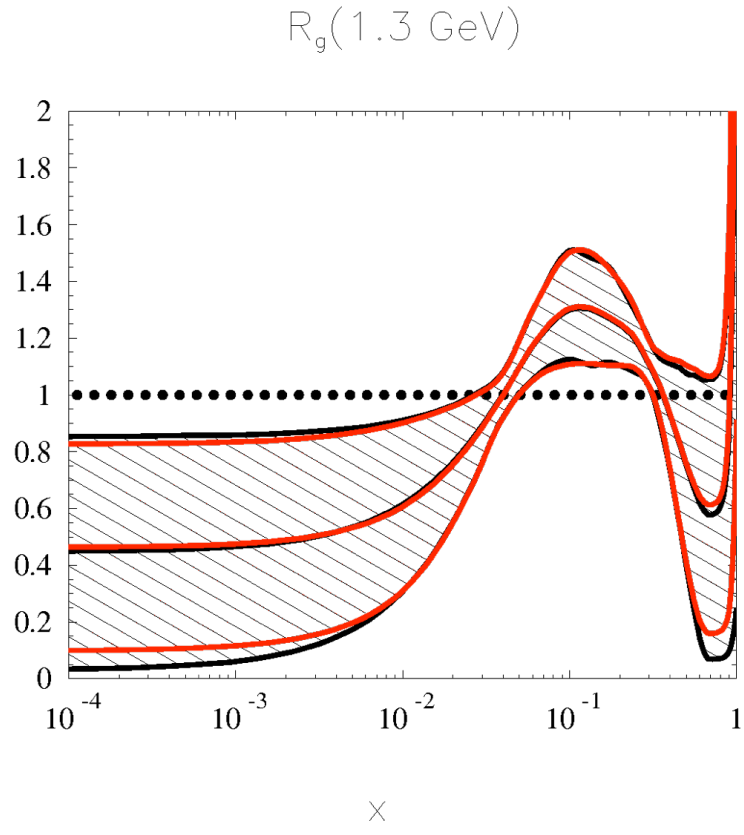
CMS-HIN-13-007




- Deviation at large negative $\eta$: different $u$ vs. $d$ quark modification?

# Charge asymmetry doesn't seem to bring anything change in the sea

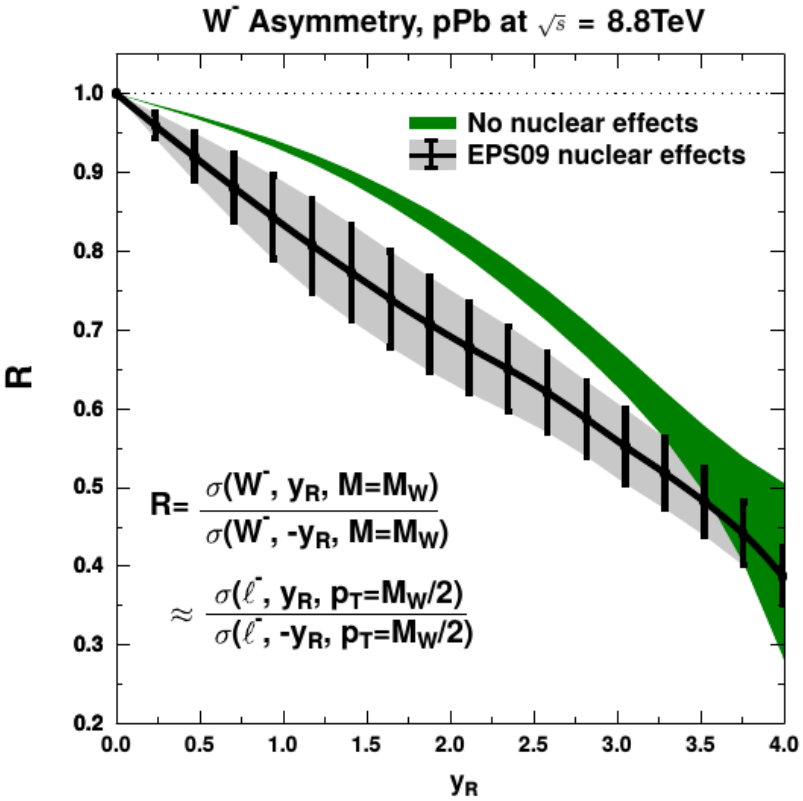


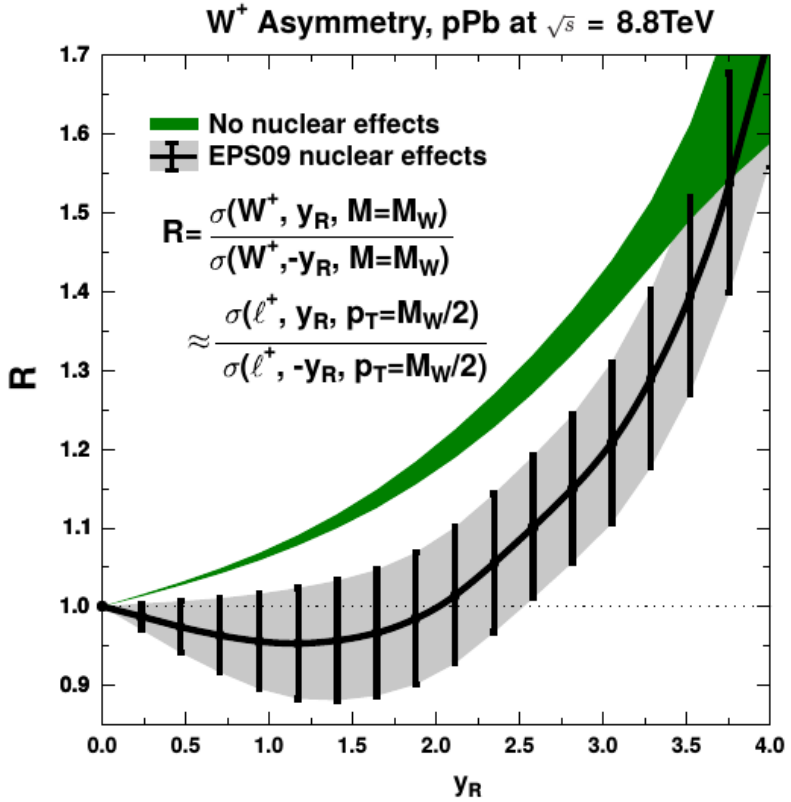




black: original EPS09
red: re-weighted

Pía Zurita, HQ 2014

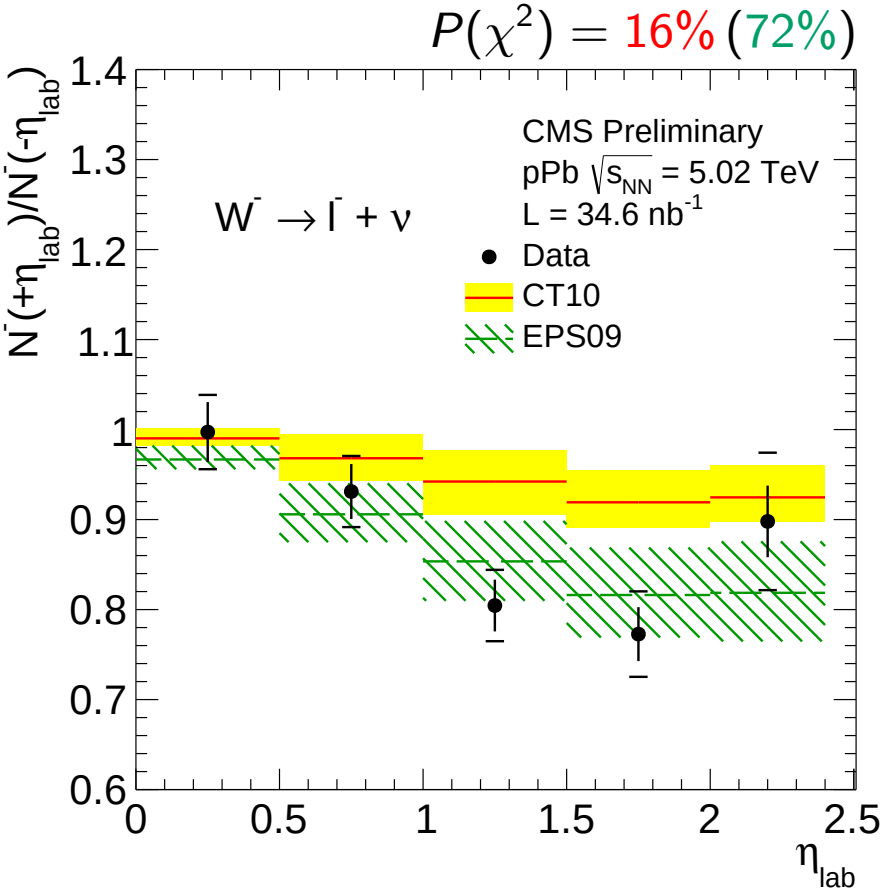
# Forward-backward asymmetry $N^{\pm}(+\eta_{\text{lab}})/N^{\pm}(-\eta_{\text{lab}})$

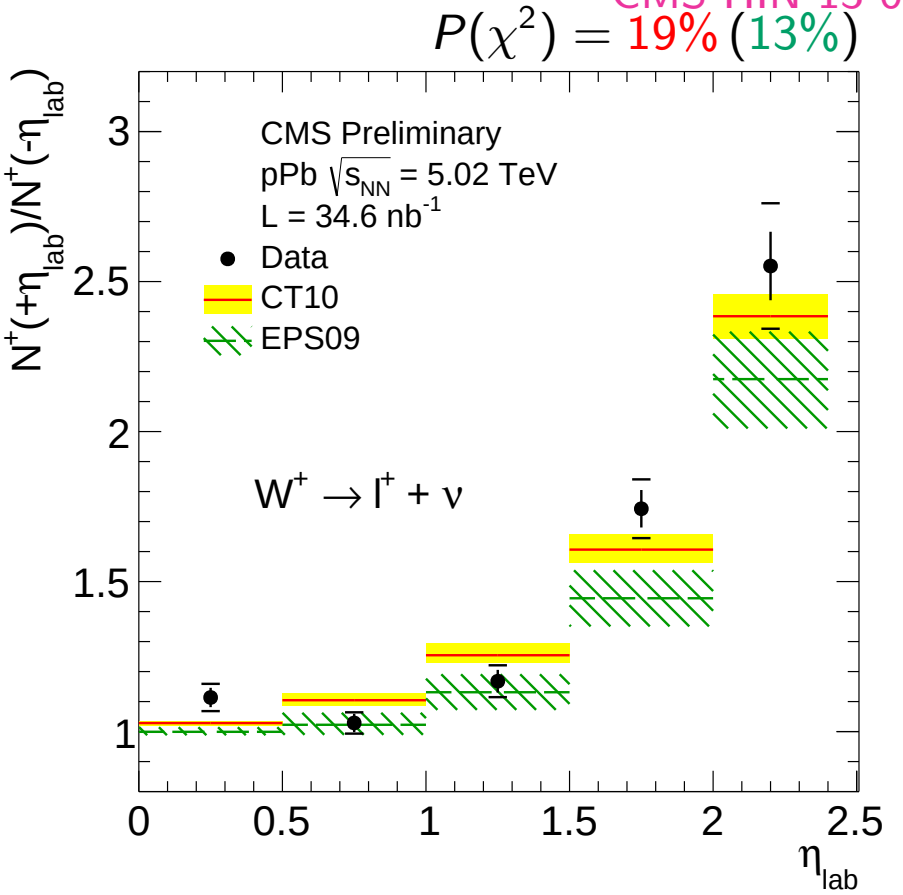


# Forward-backward asymmetry $N^{\pm}(+\eta_{\text{lab}})/N^{\pm}(-\eta_{\text{lab}})$

CMS-HIN-13-007



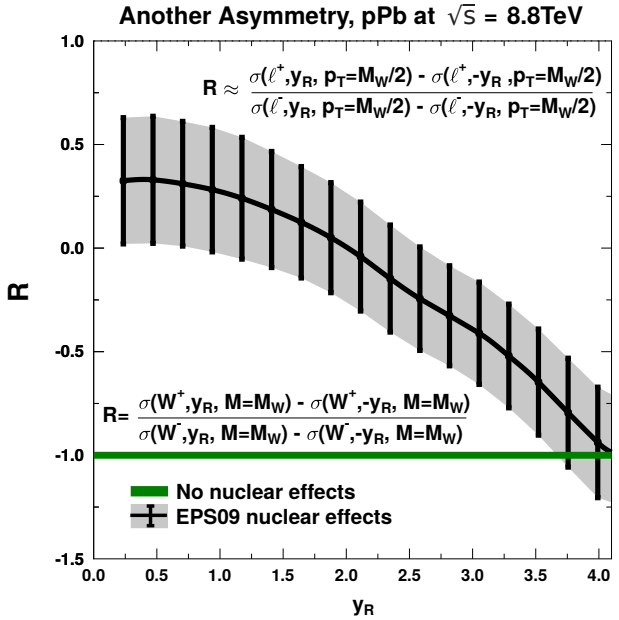




- F/B asymmetries are more sensitive to nuclear modifications.
- Negative leptons favor EPS09.
- Unclear conclusion for positive leptons.

# A sensitive but difficult asymmetry

**$A_2$**

$$A_2 = \frac{N^+(+\eta) - N^+(-\eta)}{N^-(+\eta) - N^-(-\eta)}$$

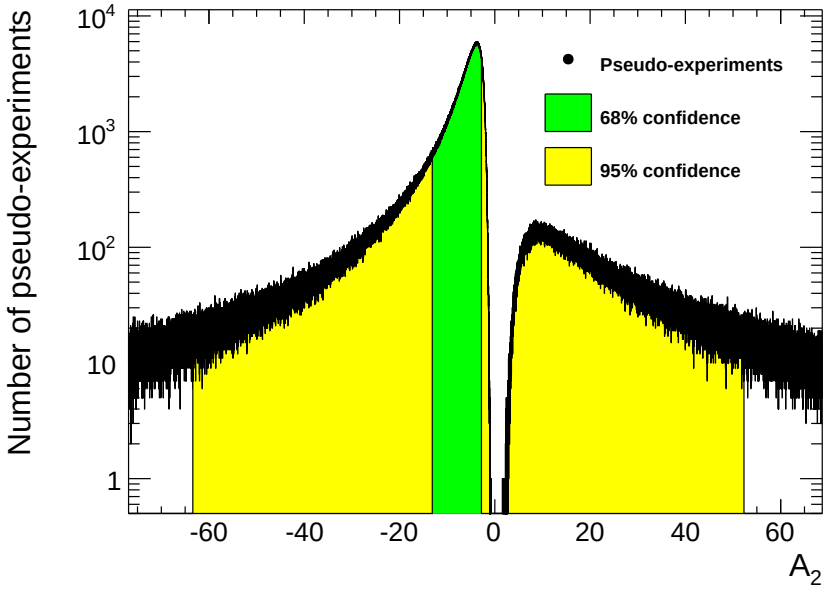



- Proposed by Hannu and Carlos (JHEP **1103** (2011) 071).
- Sensitive to nuclear effects.
- Potentially small number at the denominator: very non Gaussian statistical behavior, difficult to make sense of the measured value.
- Propose the forward-backward asymmetry for combined charges: $\frac{N^+(+\eta)+N^-(+\eta)}{N^+(-\eta)+N^-(-\eta)}$, with similar sensitivity but better statistical behavior.

# A sensitive but difficult asymmetry

**$A_2$**

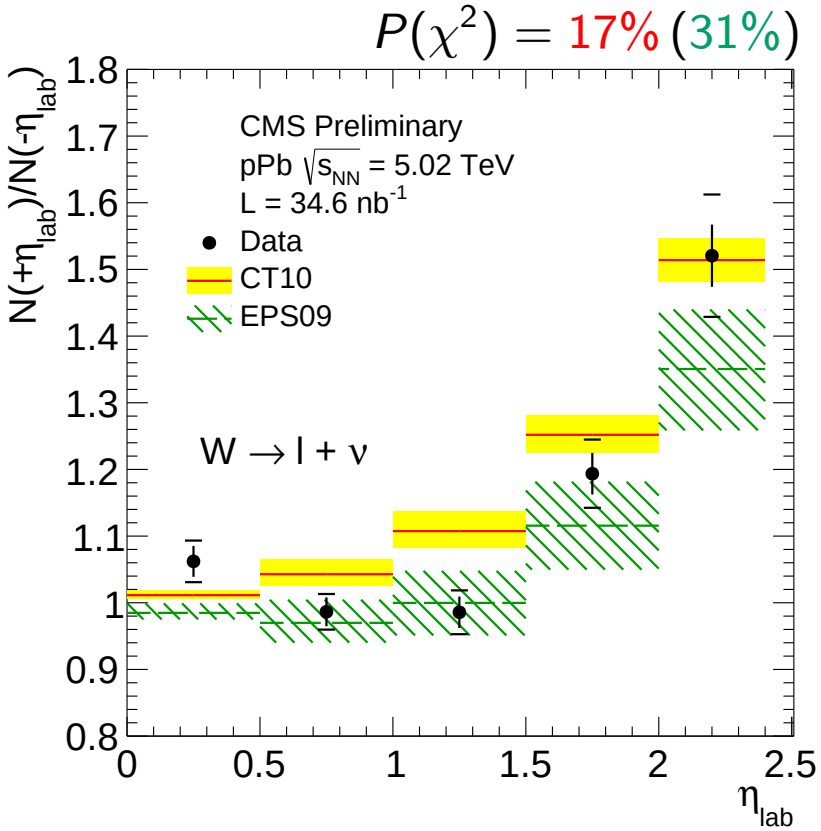
$$A_2 = \frac{N^+(+\eta) - N^+(-\eta)}{N^-(+\eta) - N^-(-\eta)}$$




- Proposed by Hannu and Carlos (JHEP **1103** (2011) 071).
- Sensitive to nuclear effects.
- Potentially small number at the denominator: very non Gaussian statistical behavior, difficult to make sense of the measured value.
- Propose the forward-backward asymmetry for combined charges: $\frac{N^+(+\eta)+N^-(+\eta)}{N^+(-\eta)+N^-(-\eta)}$, with similar sensitivity but better statistical behavior.

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

CMS-HIN-13-007




- Disfavoring the absence of nuclear modifications of PDFs.

# Conclusion

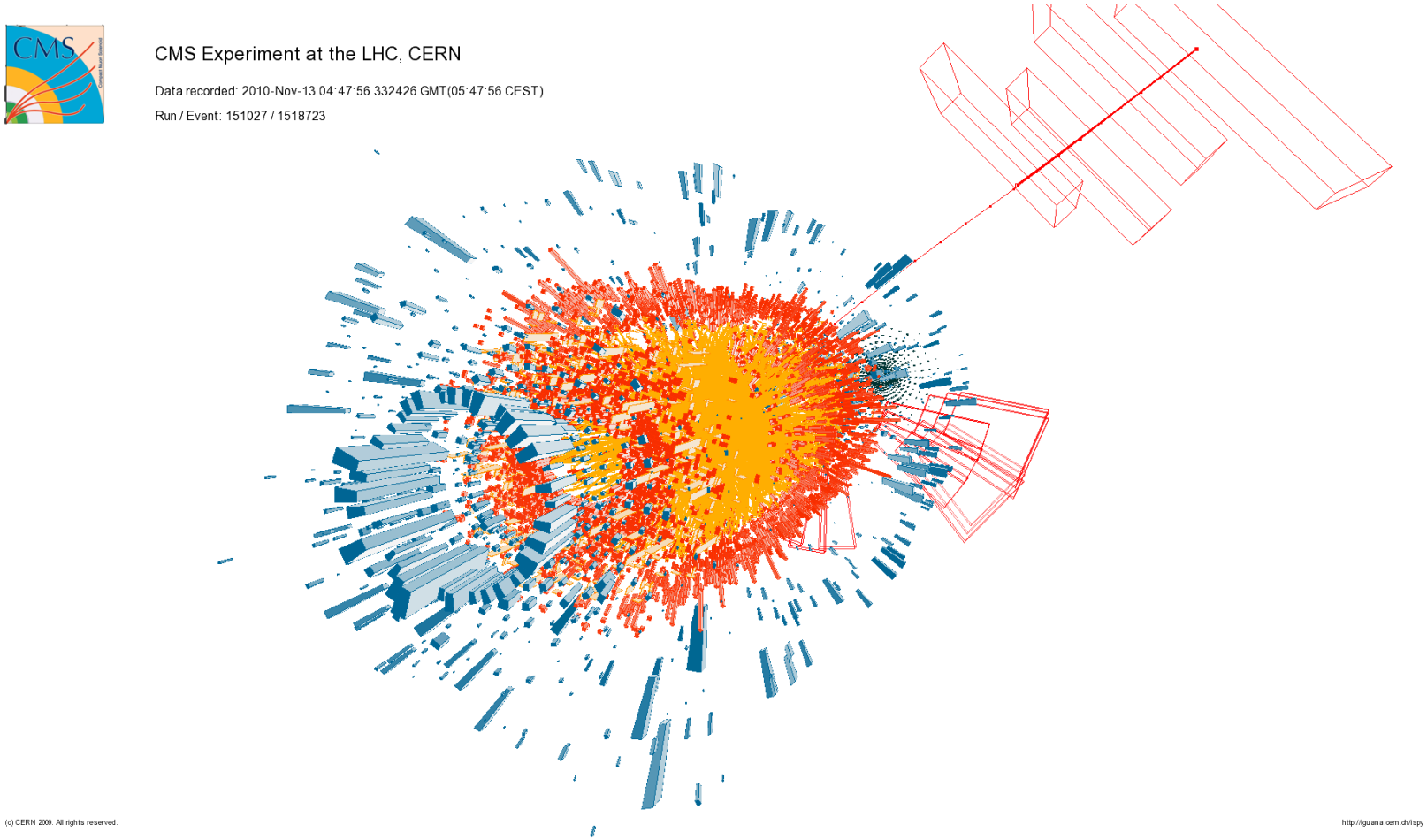
- Sensitivity to nuclear modifications of the PDFs.
  - What additional constrains do this data bring to current nPDF sets?
- Some tension between data and theory in the charge asymmetry (different $u$ and $d$ PDF modifications?).
  - How easy / hard is it for nPDF to accomodate for this?

# Additional material

# Systematics (pPb)

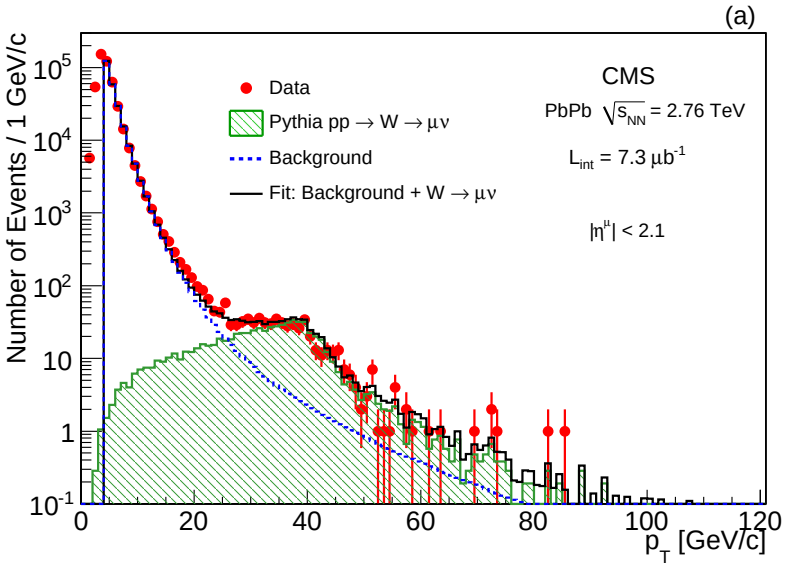
| Sources | $W \to \mu\nu$ (%) | $W \to e\nu$ (%) |
|---|---|---|
| EWK background normalization | $1.1 - 2.0$ | $1.1 - 2.0$ |
| QCD background template | $0.1 - 2.0$ | $0.5 - 3.8$ |
| Data / MC efficiencies | $2.2 - 7.5$ | $3.4 - 12.7$ |
| Electron energy scale | – | $0.1 - 2.0$ |
| Pile-up rejection filter | 0.5 | 0.5 |
| Luminosity | 3.5 | 3.5 |

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

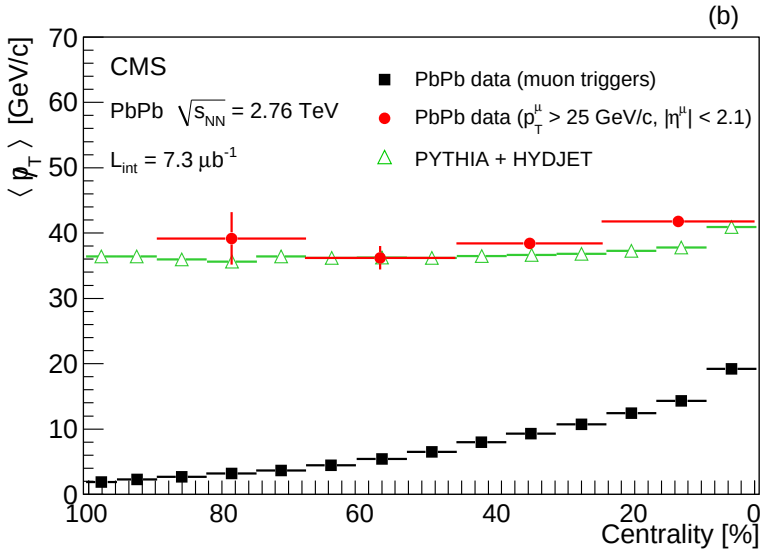


# $W \rightarrow \mu\nu$: event kinematics

Phys. Lett. B **715** (2012) 66




- Signal visible in $p_T$ spectrum of good quality muons.
- Background concentrated at low $p_T$.



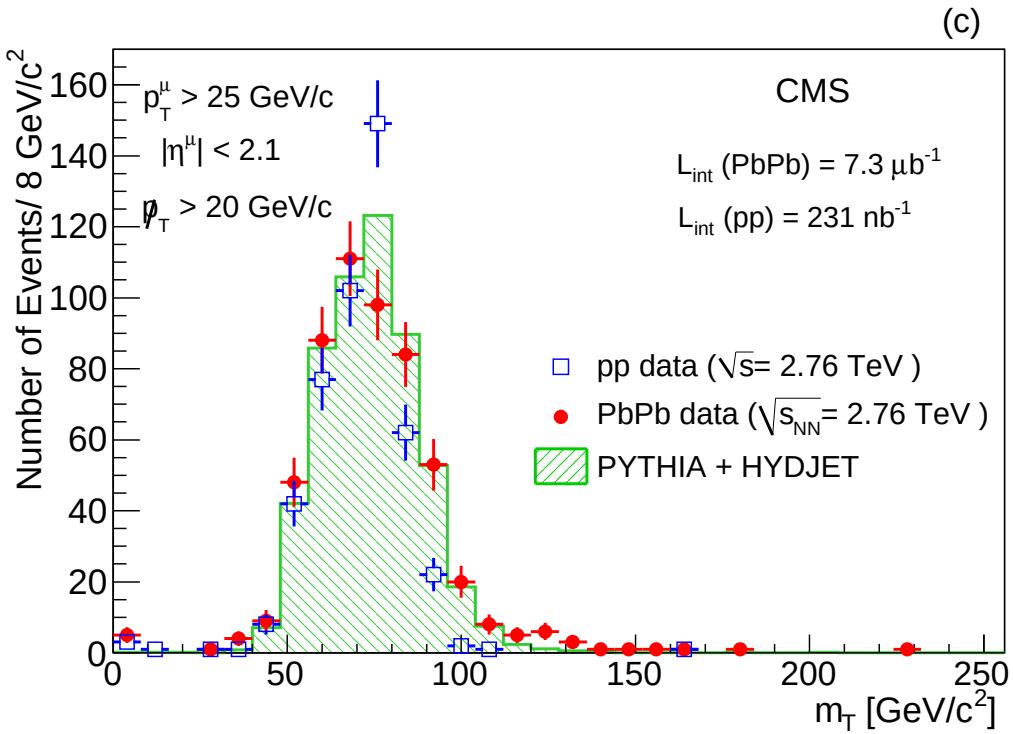

- Missing momentum from tracks.
- Signal: no dependence of $\not{p}_T$ with centrality.
- Balanced energy in background events.

# $W \to \mu\nu$: transverse mass

Phys. Lett. B **715** (2012) 66

## Selection of events

One good quality muon ($|\eta^\mu| < 2.1$, $p_T^\mu > 25\,\mathrm{GeV}/c$) and significant momentum imbalance ($\not{p}_T > 20\,\mathrm{GeV}/c$).



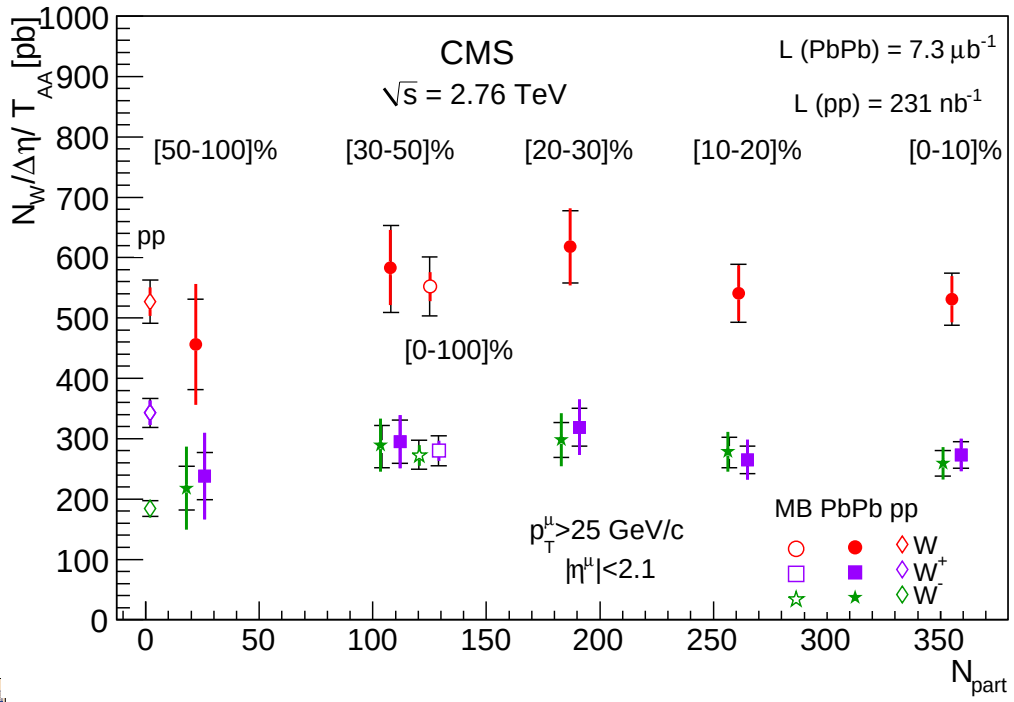

$$m_T = \sqrt{2 p_T^\mu \not{p}_T (1 - \cos\phi)}$$

- Almost background-free sample.
- Good agreement between PbPb data and simulation.
- Consistent shapes between pp and PbPb data.
  - Sightly worse resolution in PbPb.

# $W \to \mu\nu$: nuclear modification factor

Phys. Lett. B **715** (2012) 66

$$
\begin{aligned}
R_{AA}(W) &= 1.04 \pm 0.07 \pm 0.12 \\
R_{AA}(W^+) &= 0.82 \pm 0.07 \pm 0.09 \\
R_{AA}(W^-) &= 1.46 \pm 0.14 \pm 0.16
\end{aligned}
$$

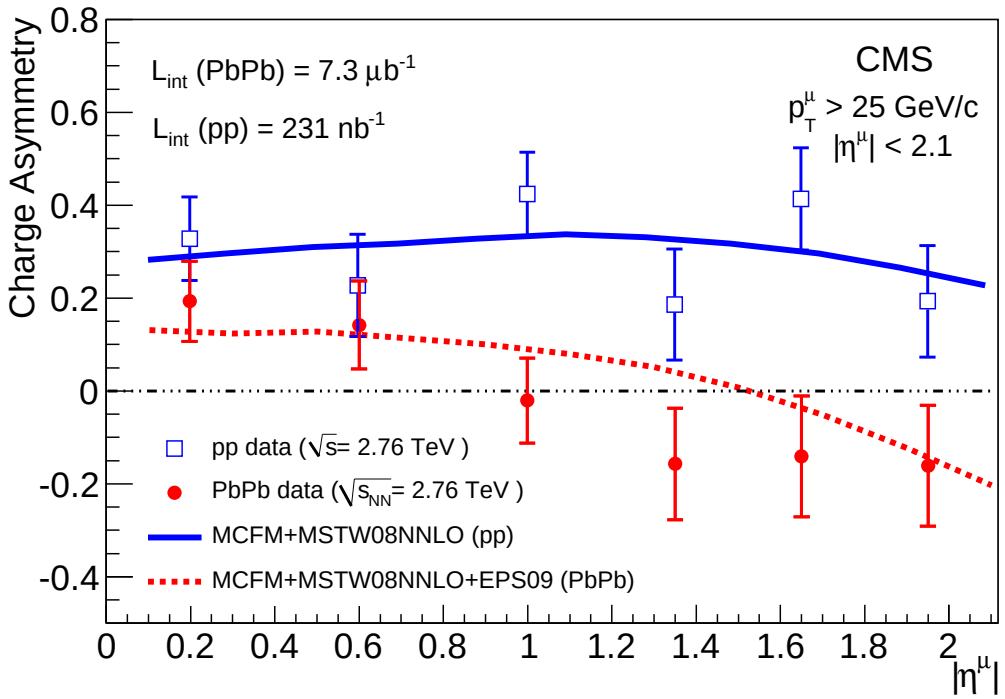



- No centrality dependence.
- Expect $\sim 2$ times more $W^+$ than $W^-$ in $pp$ (isospin).
- More balanced production in PbPb (mixture of protons and neutrons).

# $W \to \mu\nu$: charge asymmetry

Phys. Lett. B **715** (2012) 66

$$\text{Charge asymmetry} = \frac{dN(W^+) - dN(W^-)}{dN(W^+) + dN(W^-)}$$




- pp: small dependence on $\eta$, asymmetry $\sim 1/3$.
- PbPb: asymmetry closer to 0, larger dependence with $\eta$.