# Photon and electroweak boson production in PbPb collisions

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ERC grant "QuarkGluonPlasmaCMS"
*for the CMS Collaboration*

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August 16th, 2012

# The CMS unmodified talk

- Electro+weak bosons are essentially not perturbed by the hot QCD medium
  - At 1st order, check the binary scaling hypothesis,
  - Serve as a reference to modified processes (jets…),
  - 2nd order modif. ultimately constrain initial state (npdf)

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  - At 1st order, check the binary scaling hypothesis,
  - Serve as a reference to modified processes (jets…),
  - 2nd order modif. ultimately constrain initial state (npdf)

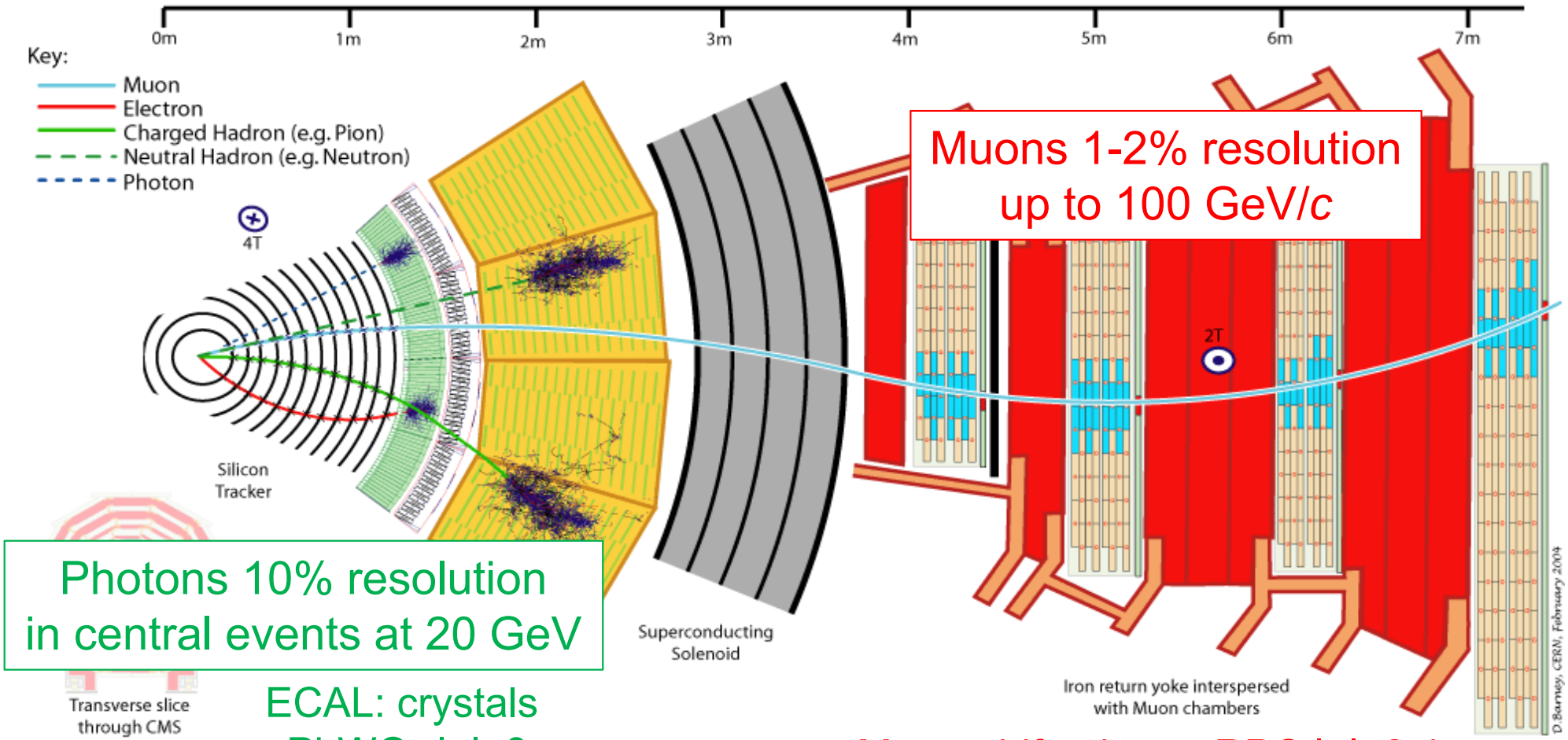
1. Z → μμ
   - From 2010: PRL 106 (2011) 212301
   - From 2011: PAS-HIN-12-008 (new)

Wed, 4C, L. Benhabib

2. W → μν
   - From 2010: PLB 715 (2012) 66
3. Isolated photons
   - From 2010: PLB 710 (2012) 256
   - From 2011: 1205.0206, gamma+jet

Wed, 4C, G. Stephans
Tue, 1B, Y.S. Lai

# Particle detection (|η|<2.4)




Muons 1-2% resolution up to 100 GeV/*c*

Photons 10% resolution in central events at 20 GeV

ECAL: crystals $PbWO_4$ |η|<3

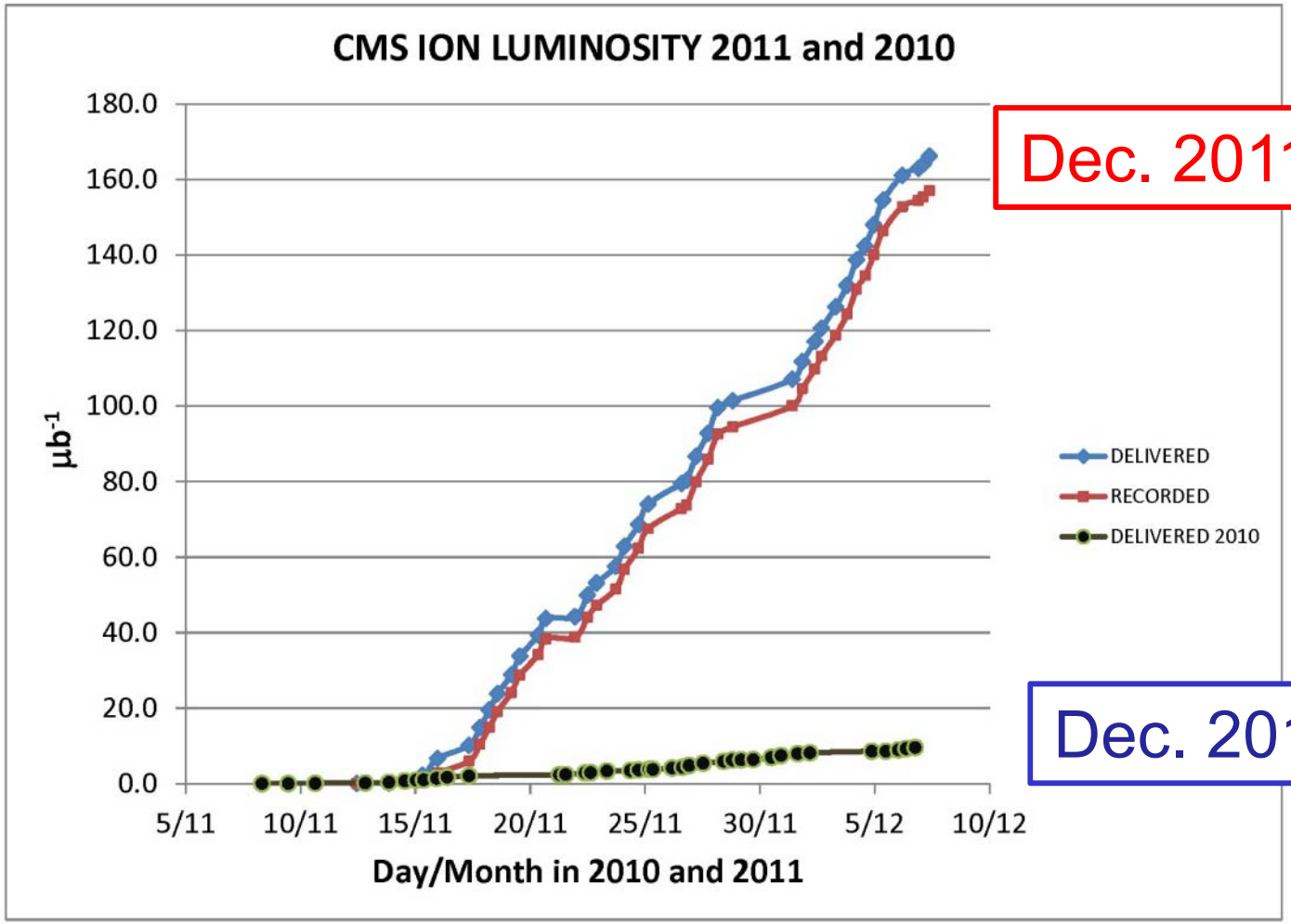
Muon: drift tubes + RPC |η|<2.4

Silicium: pixels (3) and strips (10) |η|<2.4

HCal: Scintillation |η|<5

+ Higher pseudo-rapidity calorimetry extension

# Luminosities




Dec. 2011: ≈ 150 $\mu b^{-1}$ PbPb

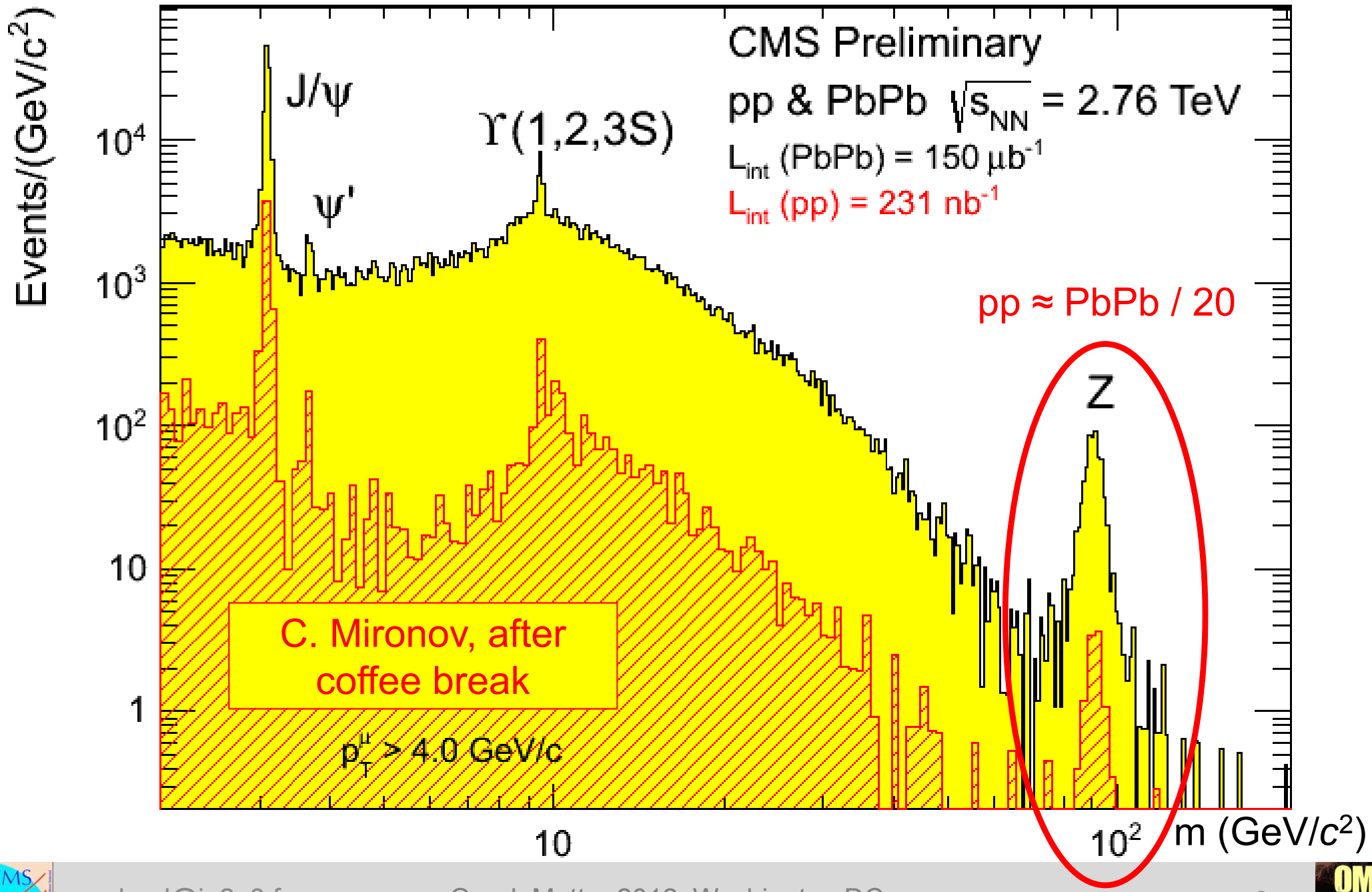
x 20

Dec. 2010: ≈ 7 $\mu b^{-1}$ PbPb

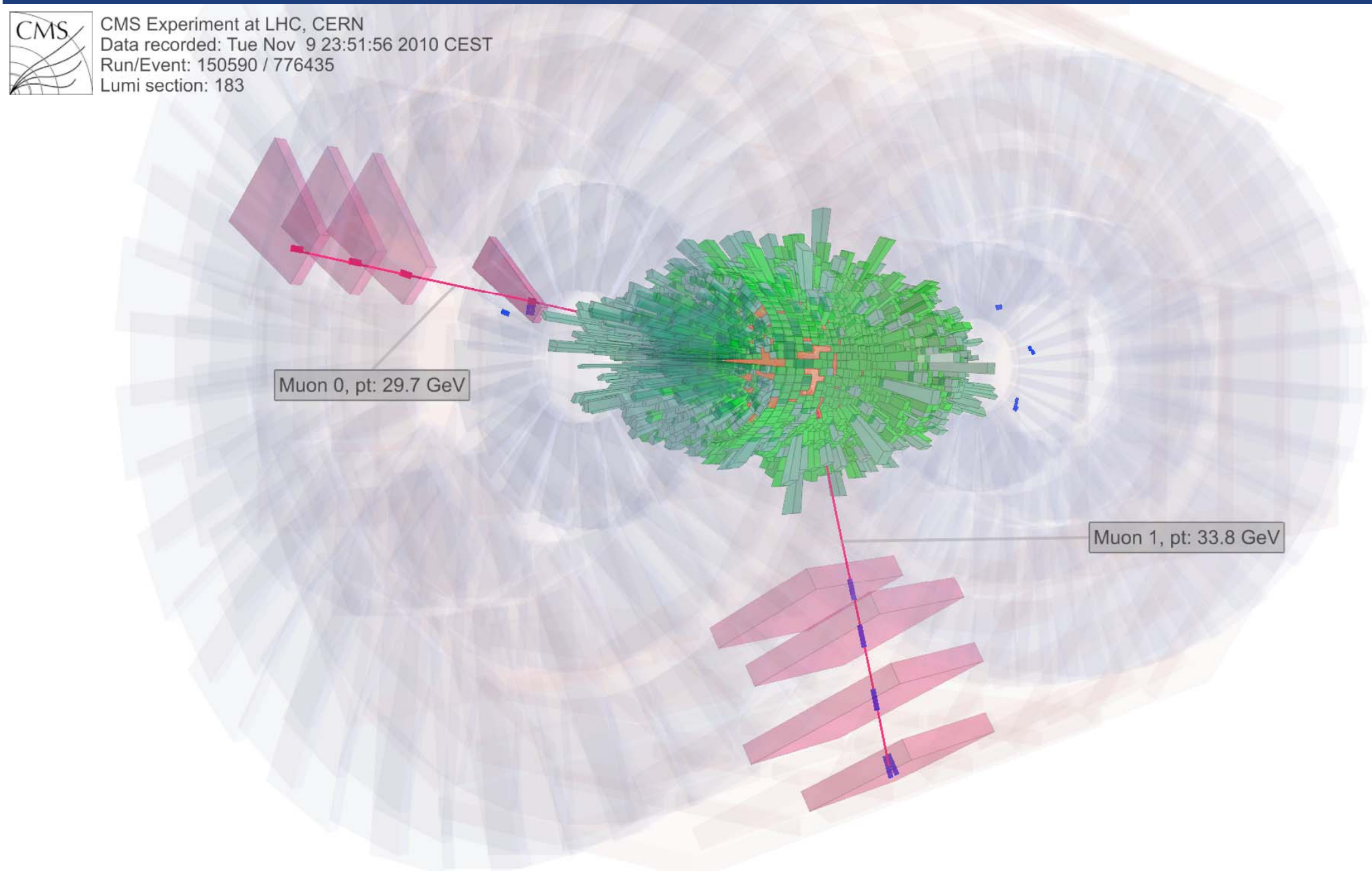
Binary-scaled equivalent → as many Z, W, photons…

+ Mar. 2011 ≈ 230 $nb^{-1}$ pp at 2.76 TeV

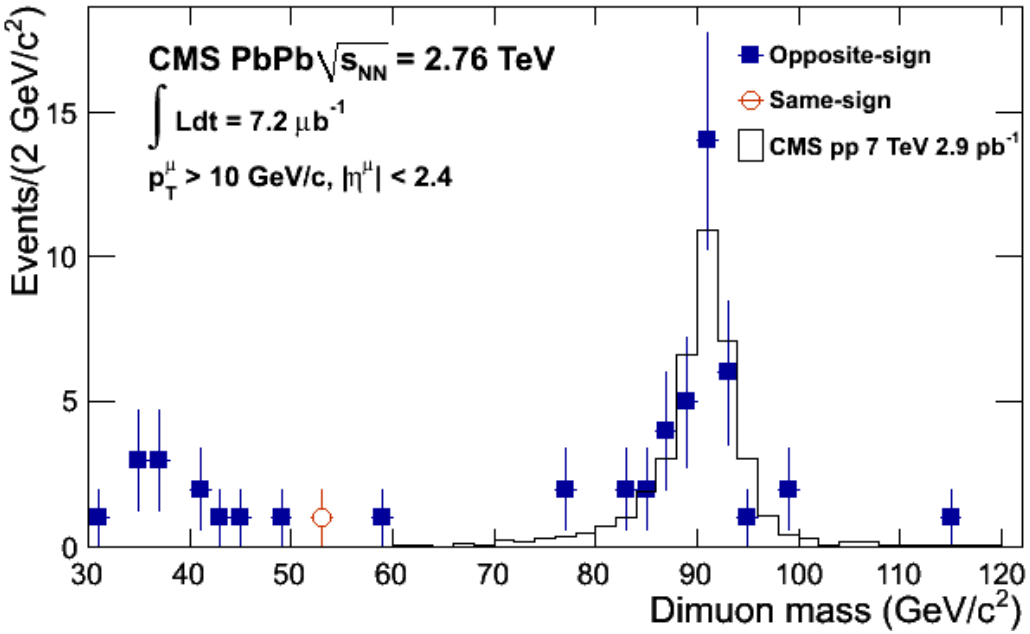
# PbPb vs pp dimuon mass



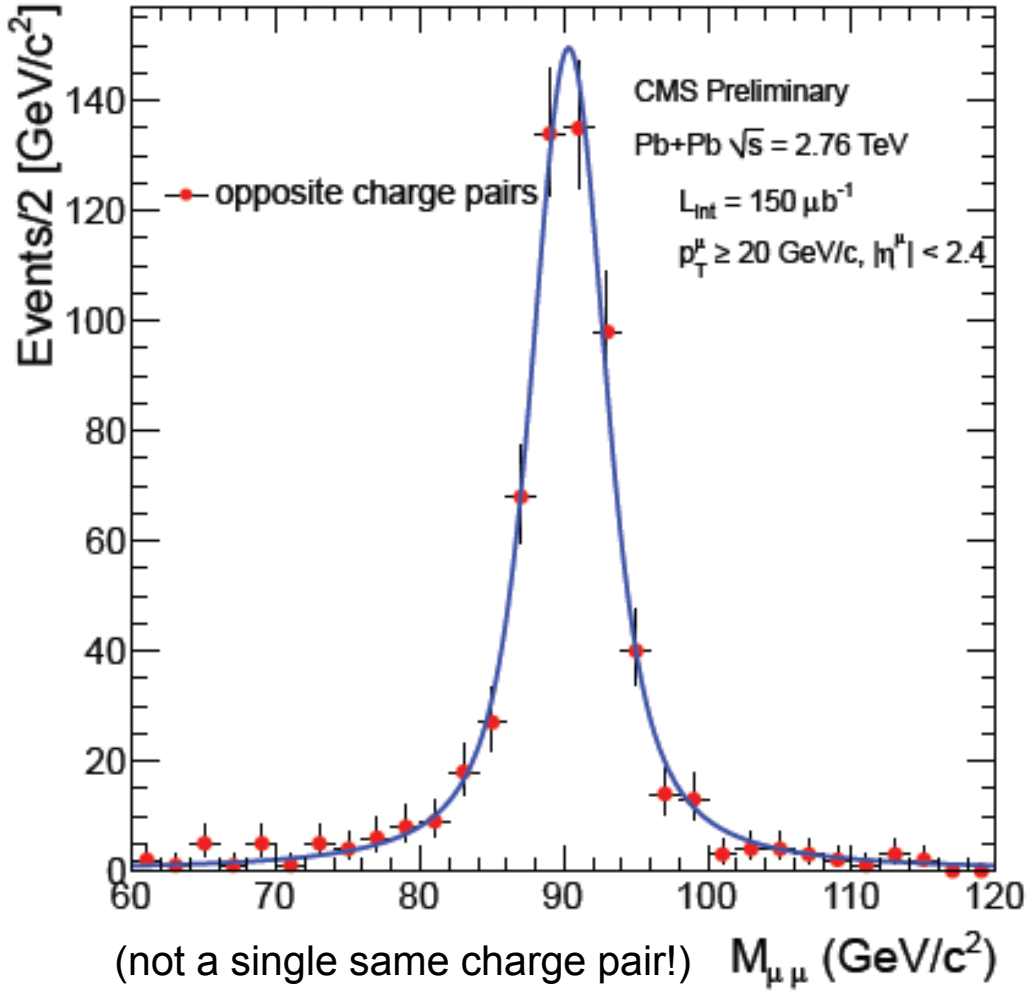
# 1. Z bosons


CMS Experiment at LHC, CERN
Data recorded: Tue Nov 9 23:51:56 2010 CEST
Run/Event: 150590 / 776435
Lumi section: 183
Muon 0, pt: 29.7 GeV
Muon 1, pt: 33.8 GeV

# Z → μμ




PRL 106 (2011) 212301
CMS-PAS-HIN-12-008




(not a single same charge pair!)

- 39 candidates in 2010
  - $p_T^\mu$ > 10 GeV/*c*
- 616 candidates in 2011
  - $p_T^\mu$ > 20 GeV/*c*

# Centrality independence

$$R_{AA} = \frac{dN^{AA}}{d\sigma_{PP} \times T_{AA}}$$

- Very low pp statistics available at 2.76 TeV
  - ≈ 20 times less Z than PbPb

# Centrality independence

CMS-PAS-HIN-12-008

$dN_{AA} / T_{AA}$

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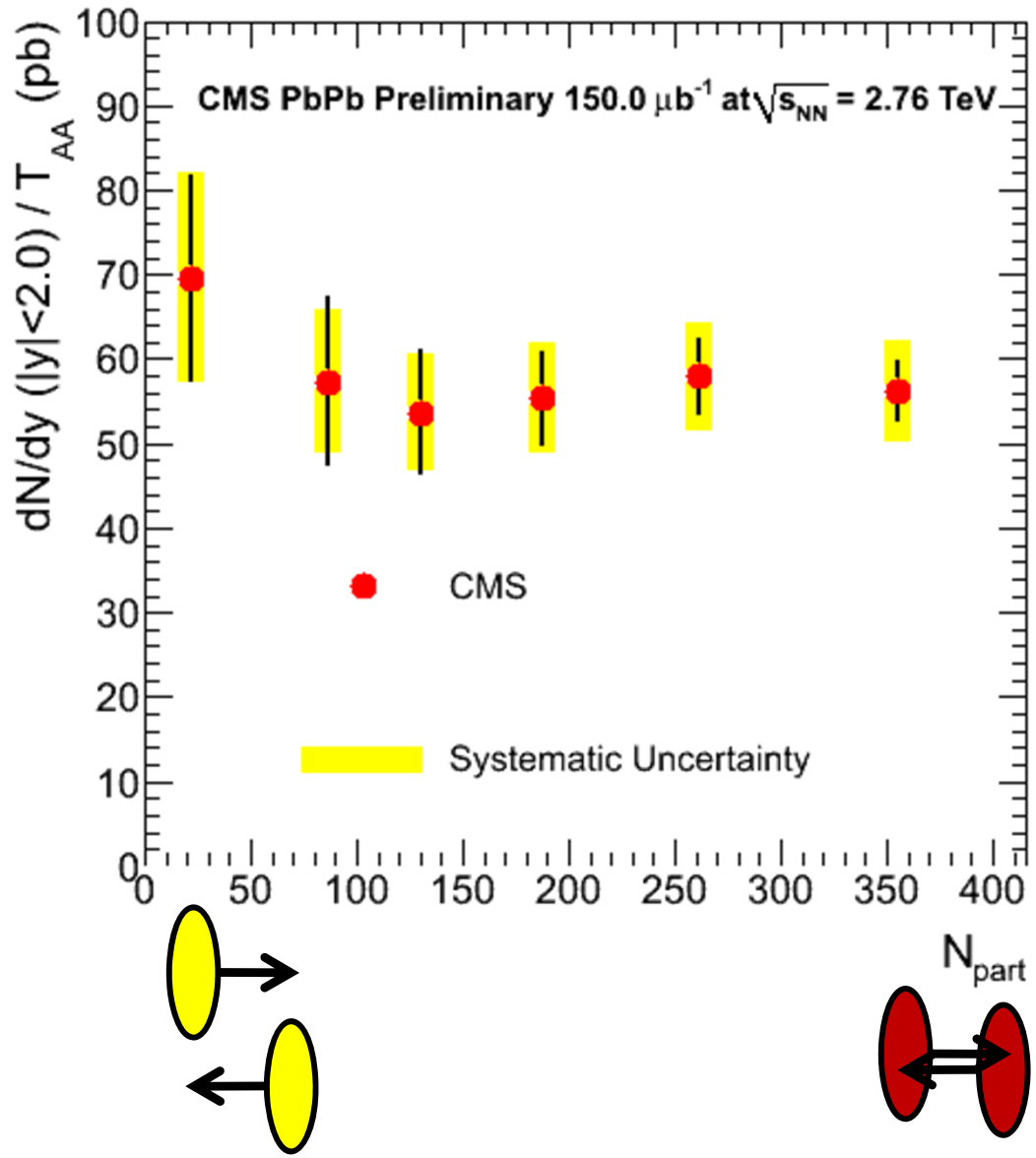

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$$dN_{AA} / T_{AA} = d\sigma_{pp}$$

- Very low pp statistics available at 2.76 TeV
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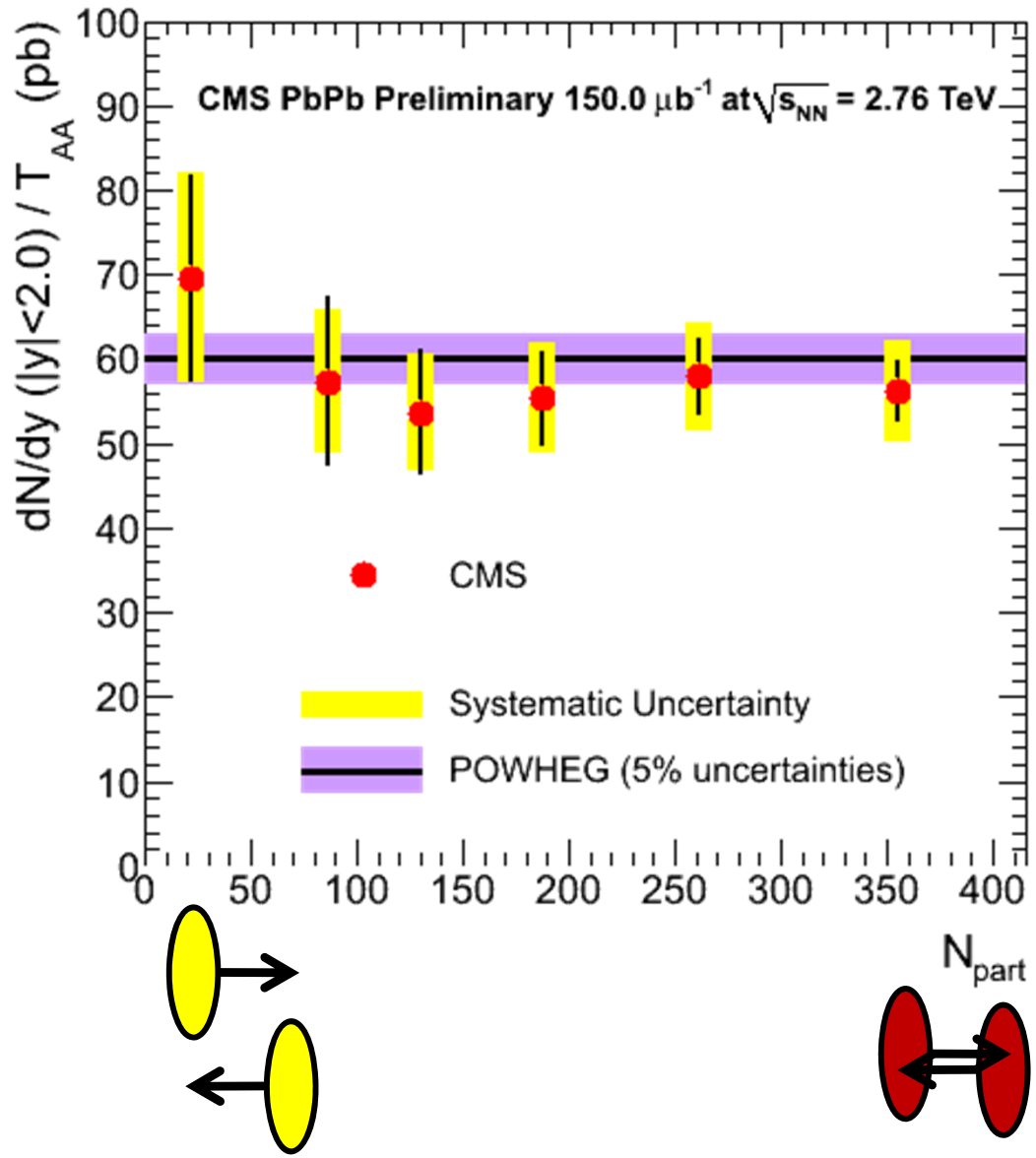
- Compare to POWHEG (NLO generator) instead
  - Well tested at Tevatron (2 TeV) and LHC (7 TeV)
  - 5% uncertainty from NNLO, pdfs, etc.

CMS-PAS-HIN-12-008



# Centrality independence

$$dN_{AA} / T_{AA} = d\sigma_{pp} \times R_{AA}$$

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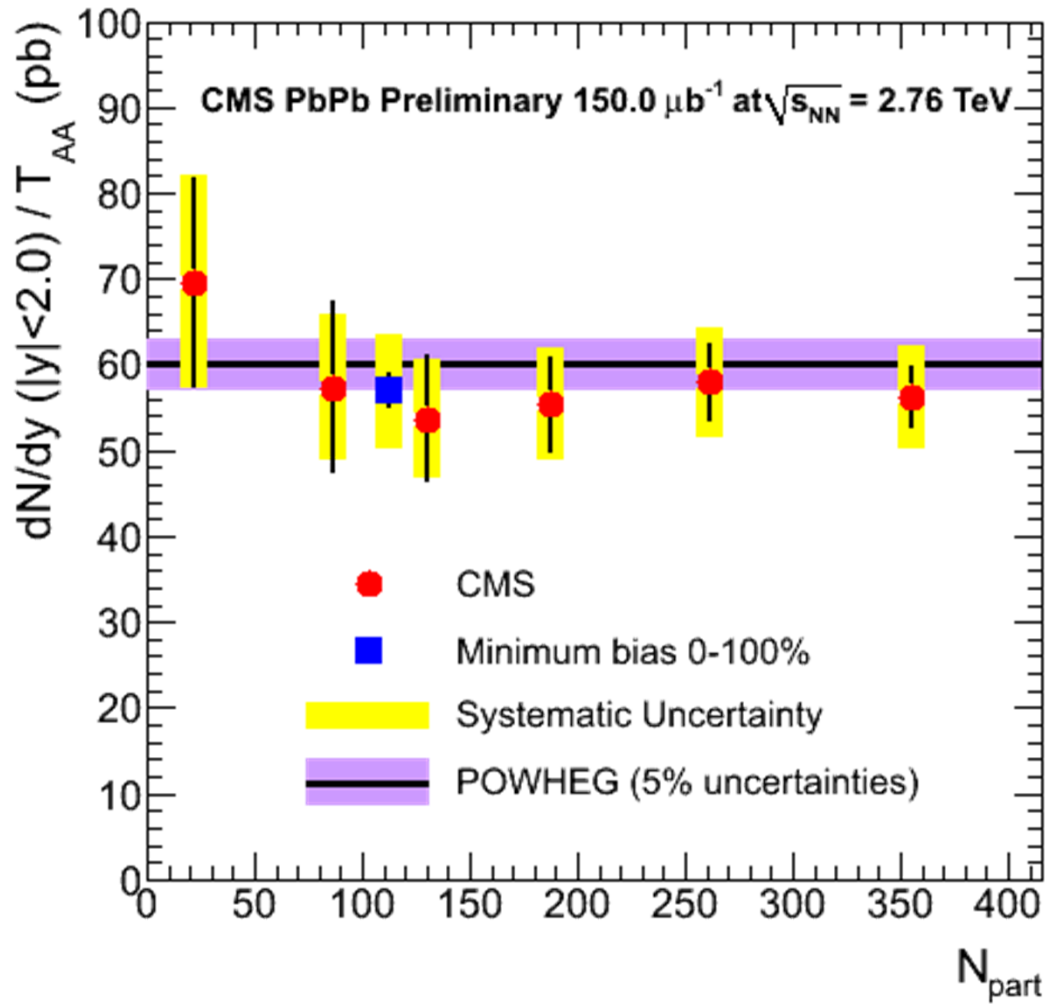
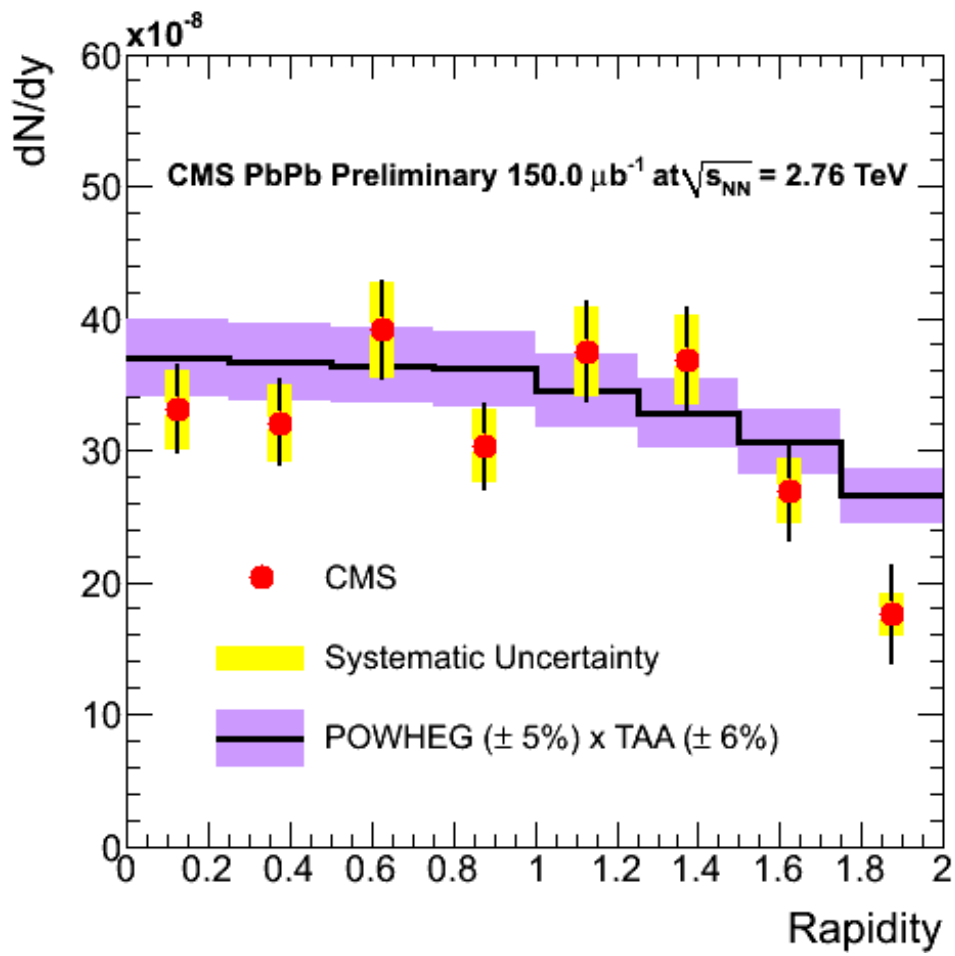
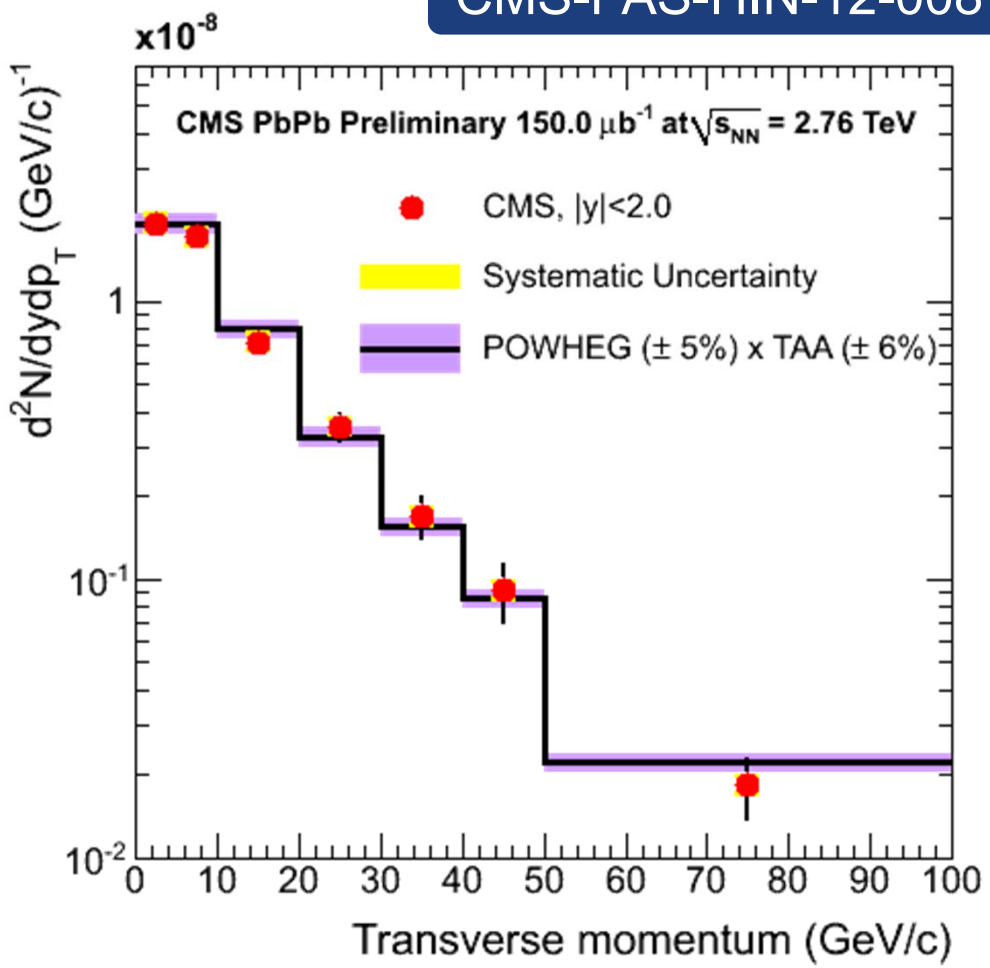



$$R_{AA} = 0.95 \pm 0.03 \pm 0.13$$

# Dependence on y and $p_T$

CMS-PAS-HIN-12-008



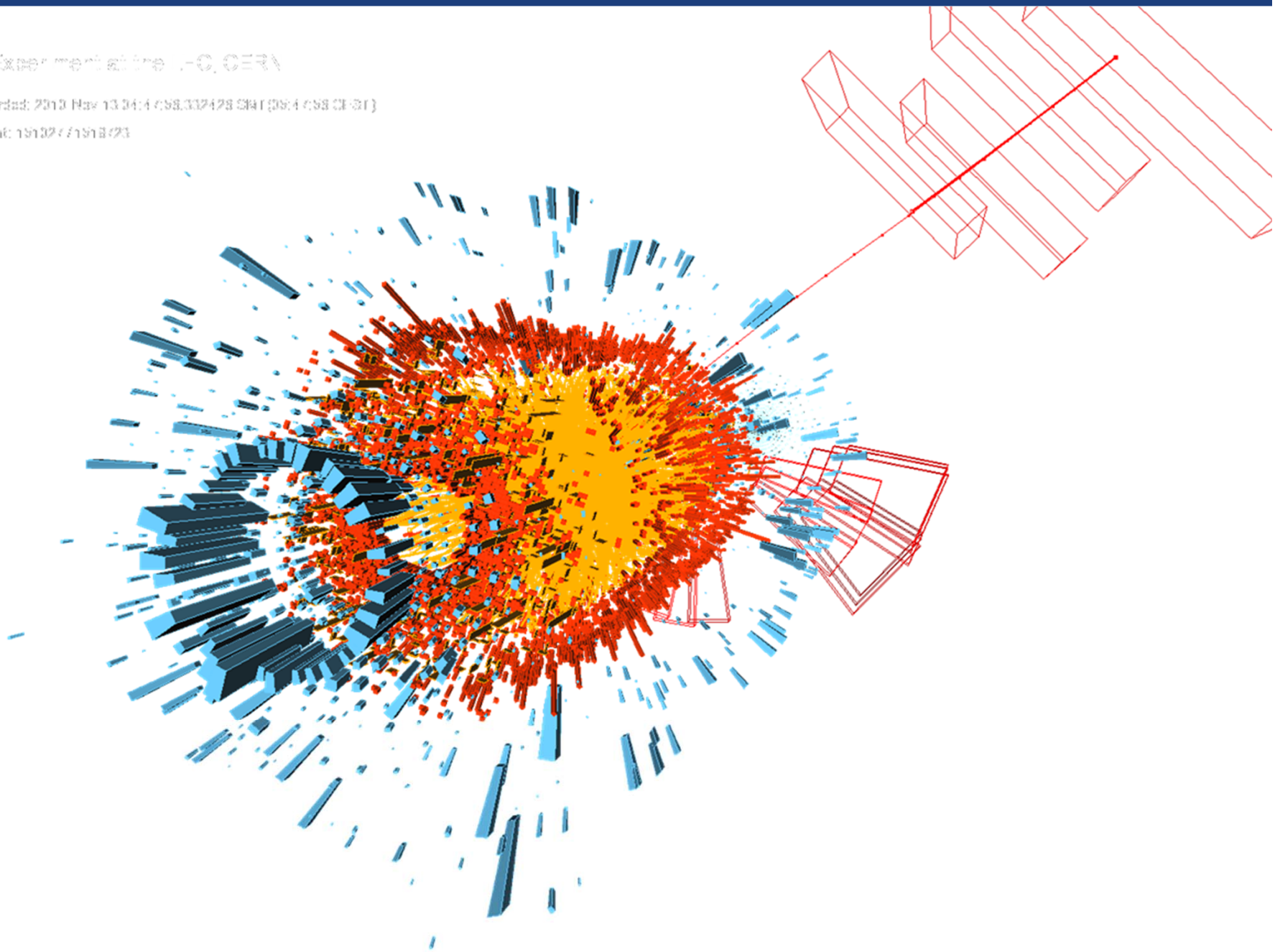




- Centrality-integrated $dN_{PbPb}$ vs $d\sigma_{pp} \times T_{AA}$ ($5.67 \pm 0.32$ mb$^{-1}$)
- No strong deviation from absolutely-normalised reference

# Conclusions (1/3)

1. $Z \rightarrow \mu\mu$
   - Proportional to binary collisions,
   - Nuclear effects (isospin, shadowing…) small wrt uncertainties

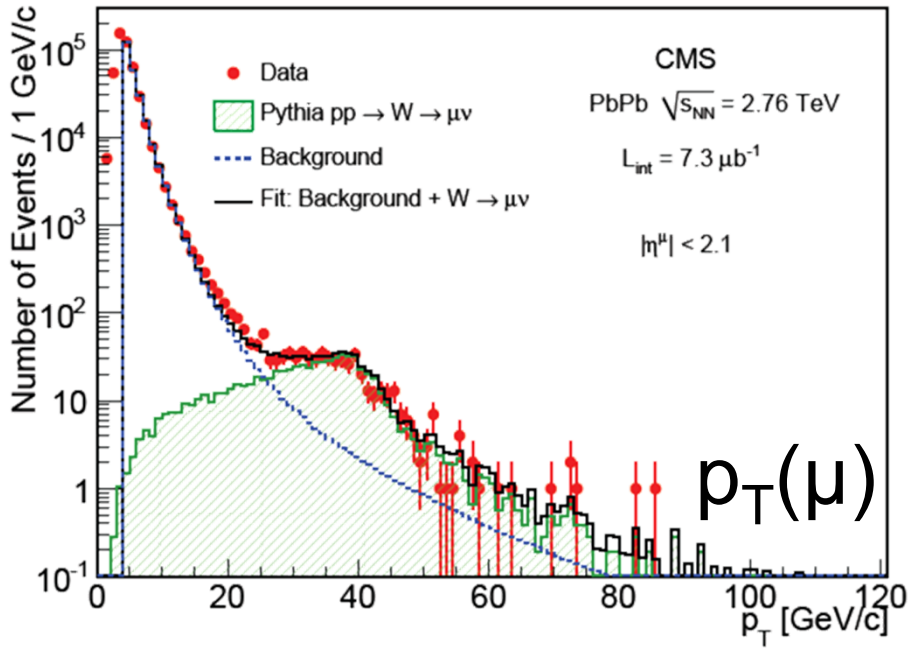
# 2. W bosons



# W → μν (2010)

PLB 715 (2012) 66

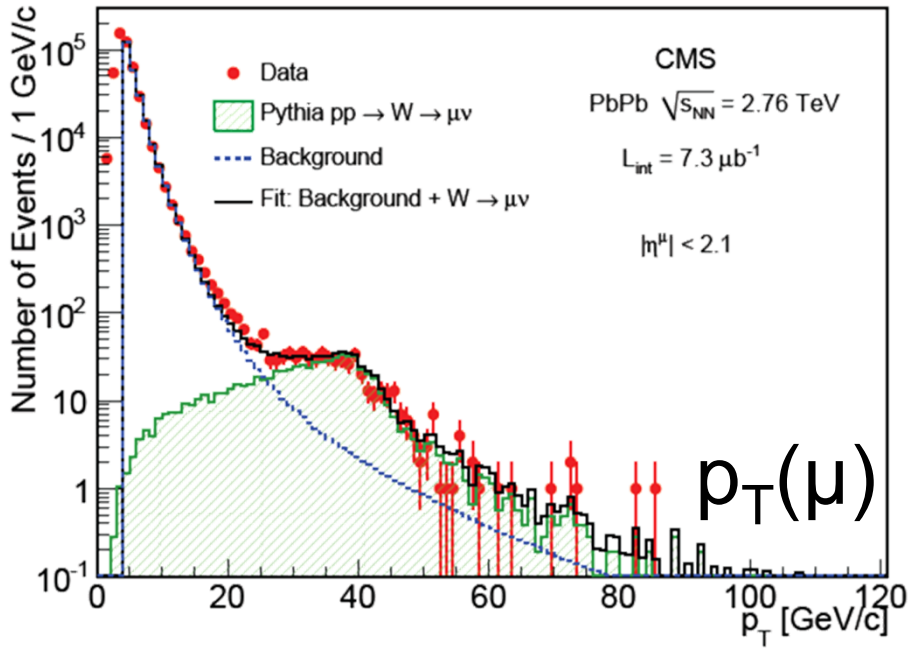
- Signal already visible in muon $p_T$ spectrum →



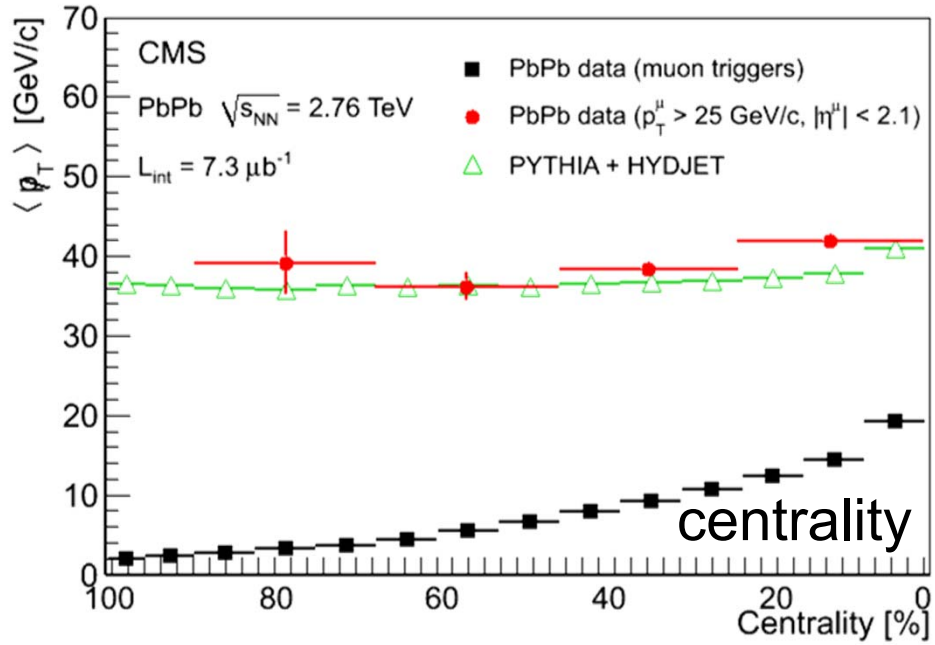
# W → μν (2010)

PLB 715 (2012) 66

- Signal already visible in muon $p_T$ spectrum →
- Simple missing $p_T$ from tracks ($p_T$ > 3 GeV/*c*) ↘



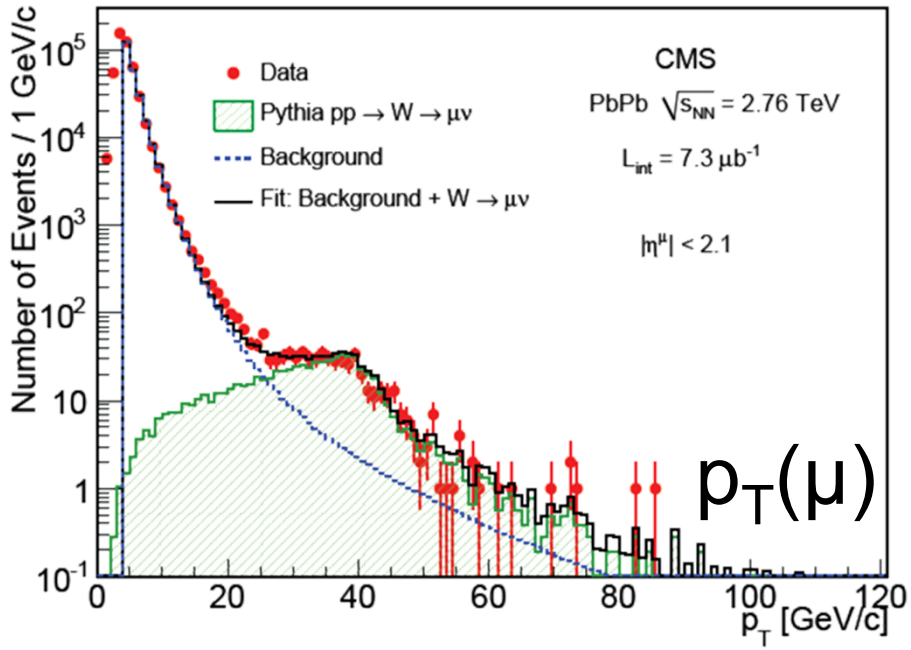

< missing $p_T$ >

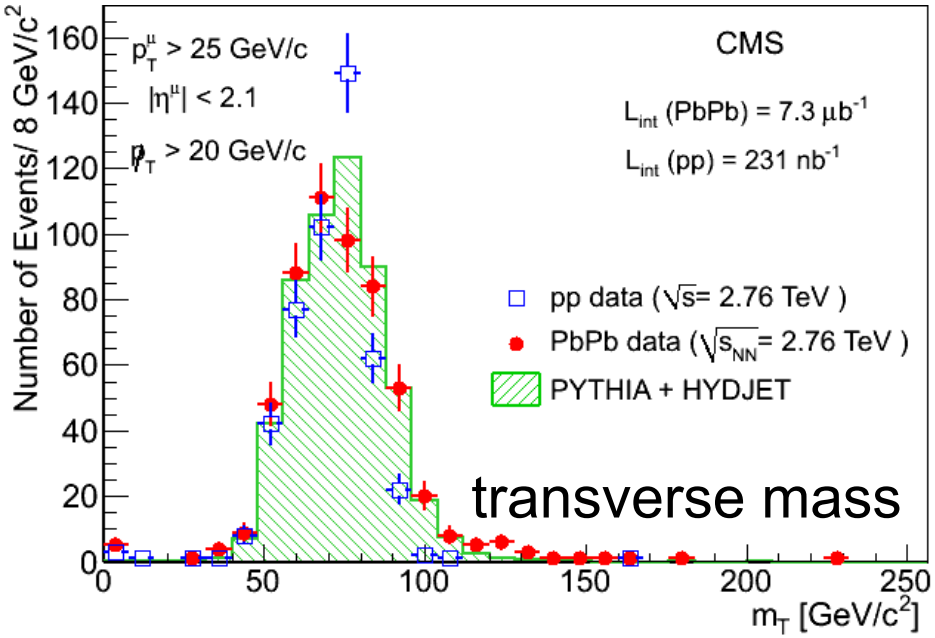


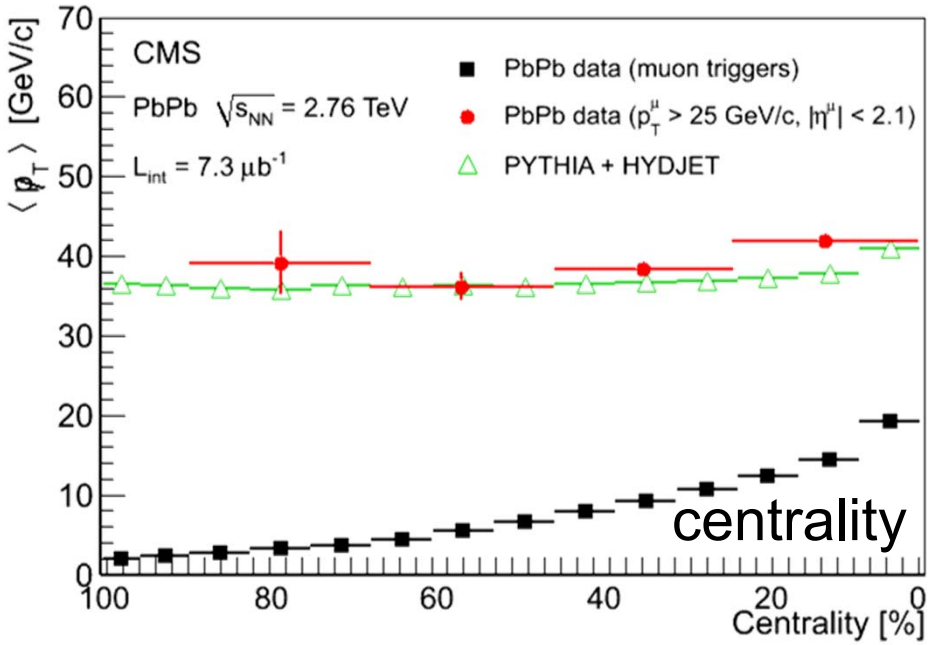
# W → μν (2010)

PLB 715 (2012) 66

- Signal already visible in muon $p_T$ spectrum →
- Simple missing $p_T$ from tracks ($p_T$ > 3 GeV/*c*) ↘
- Then transverse mass ↓



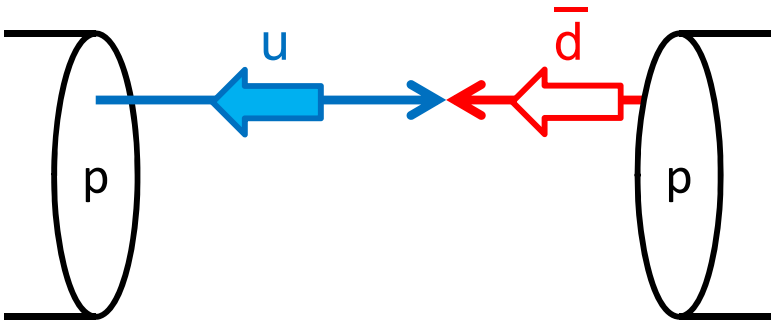



# W boson production

$$@\ \mathrm{LO} : u\bar{d} \rightarrow W^{+}\ \&\ \bar{u}d \rightarrow W^{-}$$

→ Less $W^{+}$ and more $W^{-}$ in PbPb than in pp (*isospin* effect)

- Cancels for $W^{+} + W^{-}$



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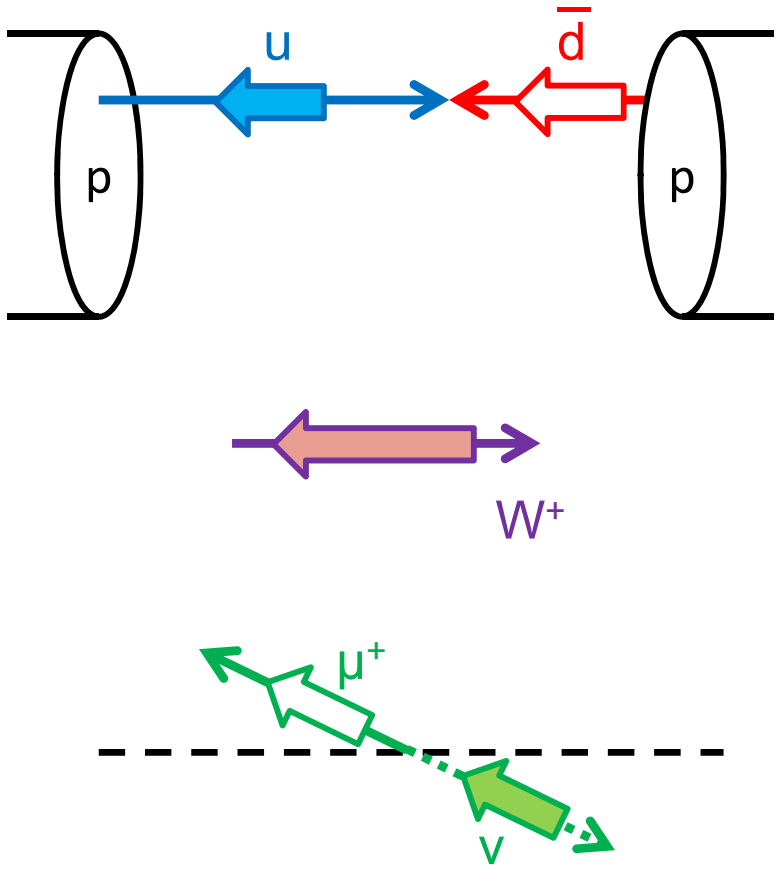
$$@\ \mathrm{LO} : u\bar{d} \rightarrow W^{+}\ \&\ \bar{u}d \rightarrow W^{-}$$

→ Less $W^+$ and more $W^-$ in PbPb than in pp (*isospin* effect)

- Cancels for $W^+ + W^-$

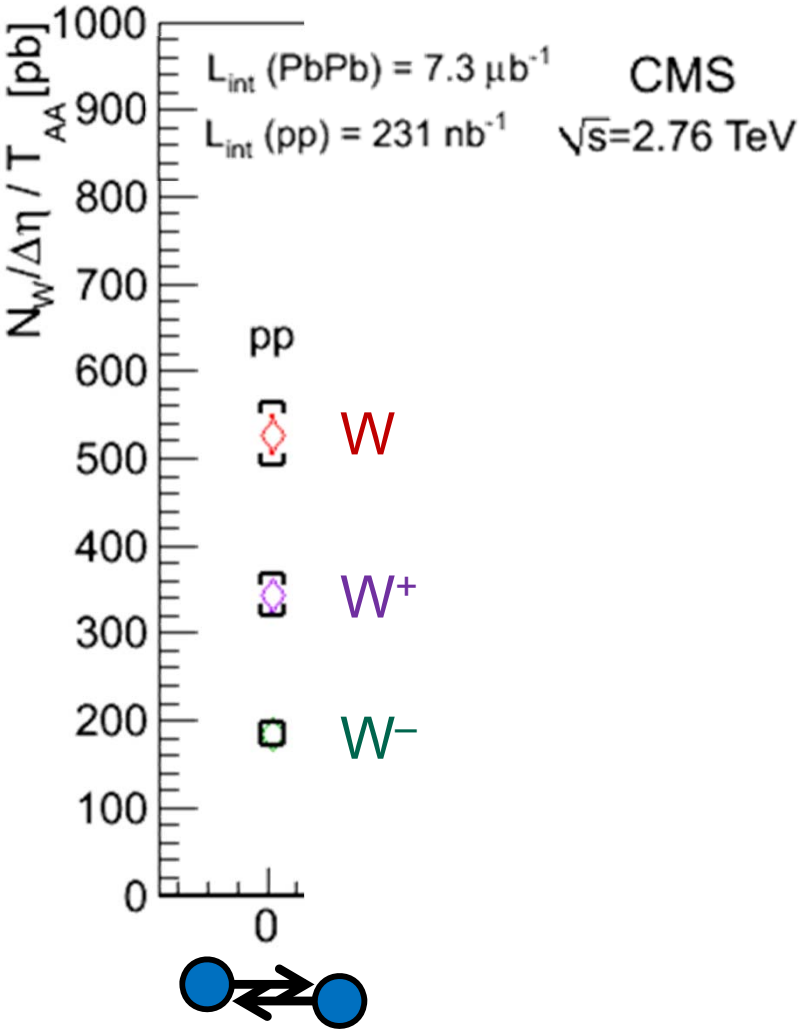
- W boosted towards the valence quark (higher rapidity)
- Spin conservation → $\mu^+$ ($\mu^-$) boosted back to (away from) midrapidity

→ Different muon rapidity distributions (not heavy-ion specific) between $W^+$ and $W^-$



# Centrality independence

$d\sigma_{pp}$

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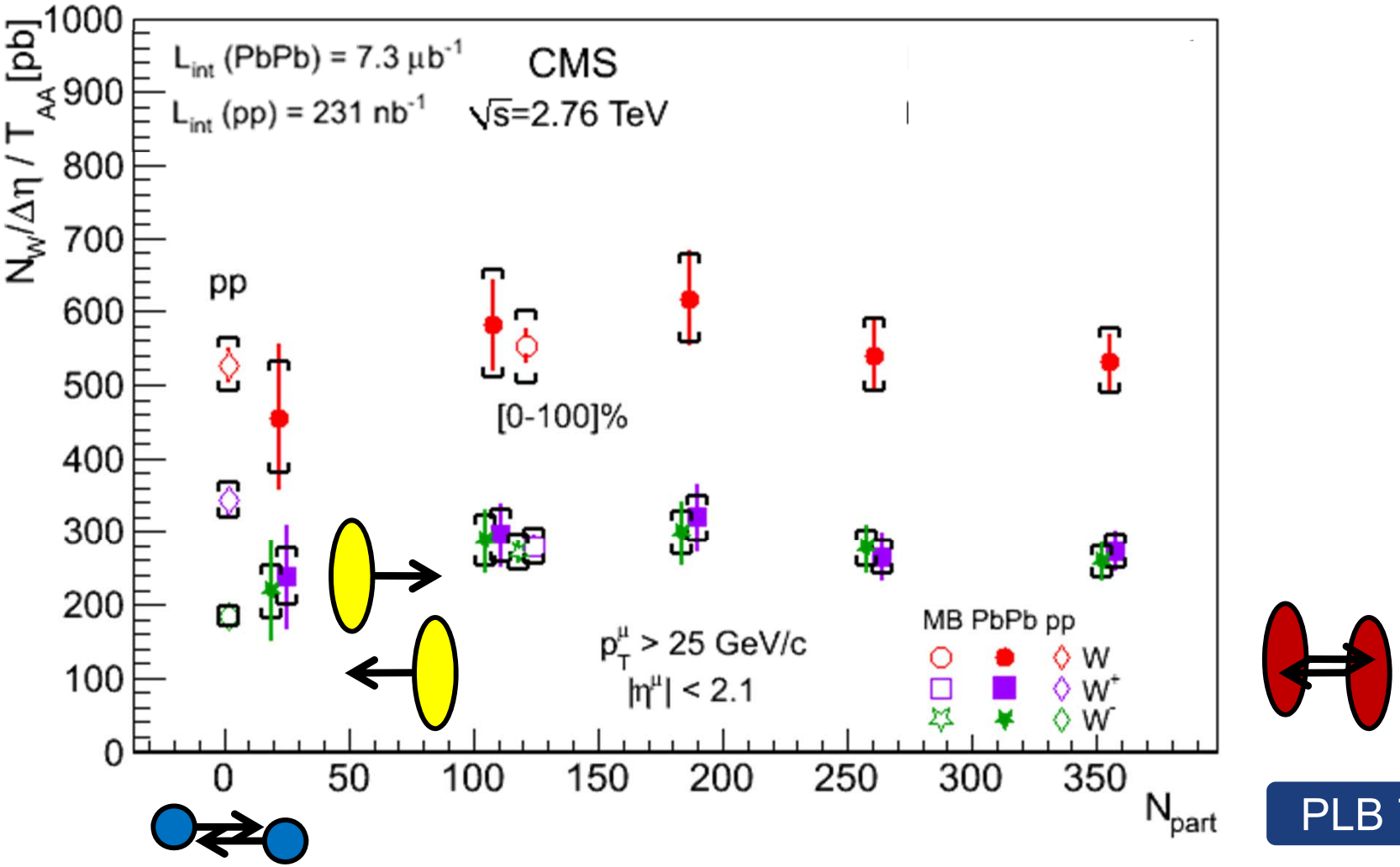
# Centrality independence

$$dN_{AA} / T_{AA} = d\sigma_{pp}$$

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# Centrality independence

$$dN_{AA} / T_{AA} = d\sigma_{pp} \times R_{AA}$$

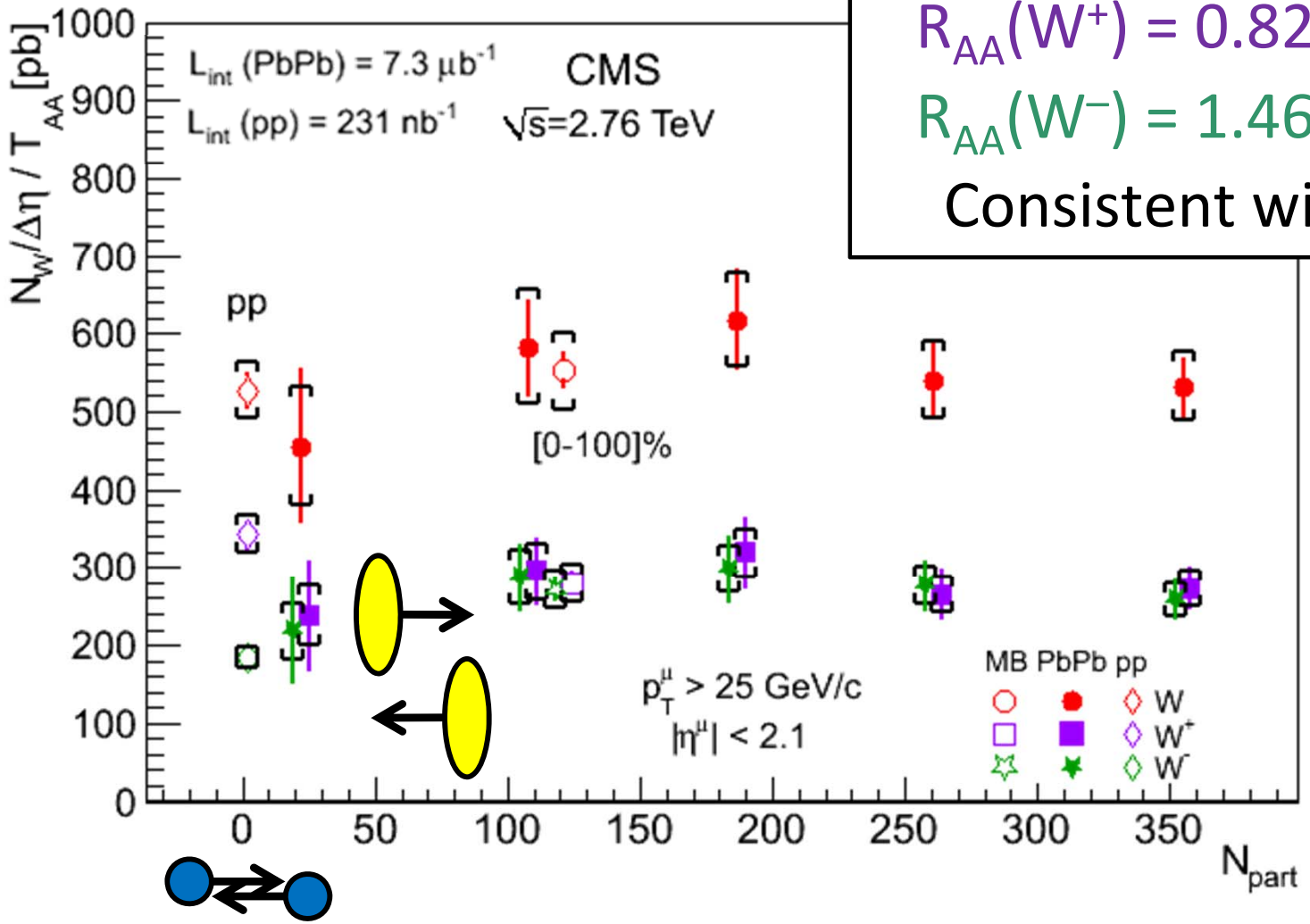
2010 PbPb ≈ pp data

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

$R_{AA}(W^{+}) = 0.82 \pm 0.07 \pm 0.09$

$R_{AA}(W^{-}) = 1.46 \pm 0.14 \pm 0.16$

Consistent with pure isospin

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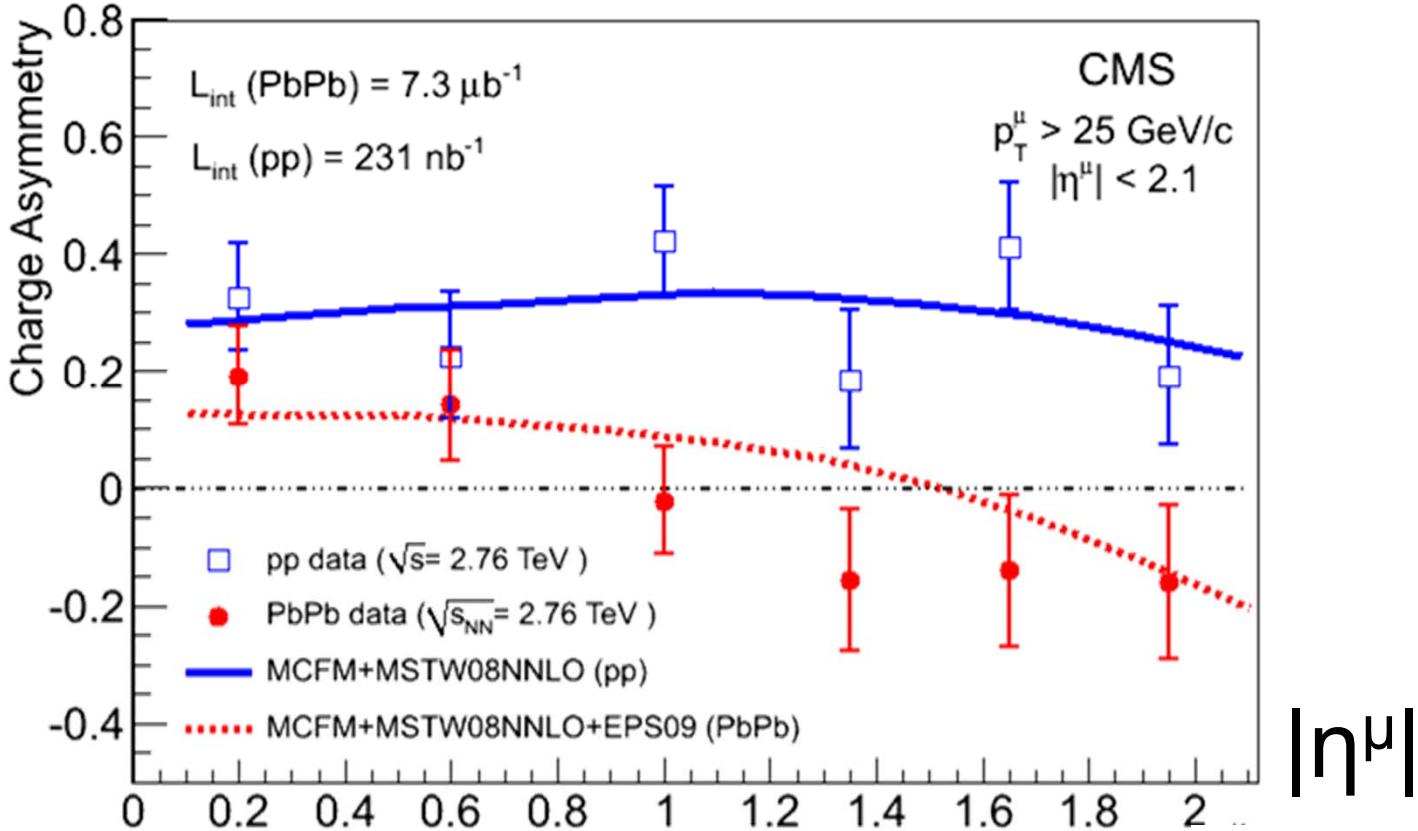
# Muon charge asymmetry

- Less up quarks make less $W^+$ in PbPb than in pp

$$\frac{N^+ - N^-}{N^+ + N^-}$$




- Isospin effect bringing down asymmetry by 0.2 to 0.4
- (EPS09 modifications are 0.03 at most)

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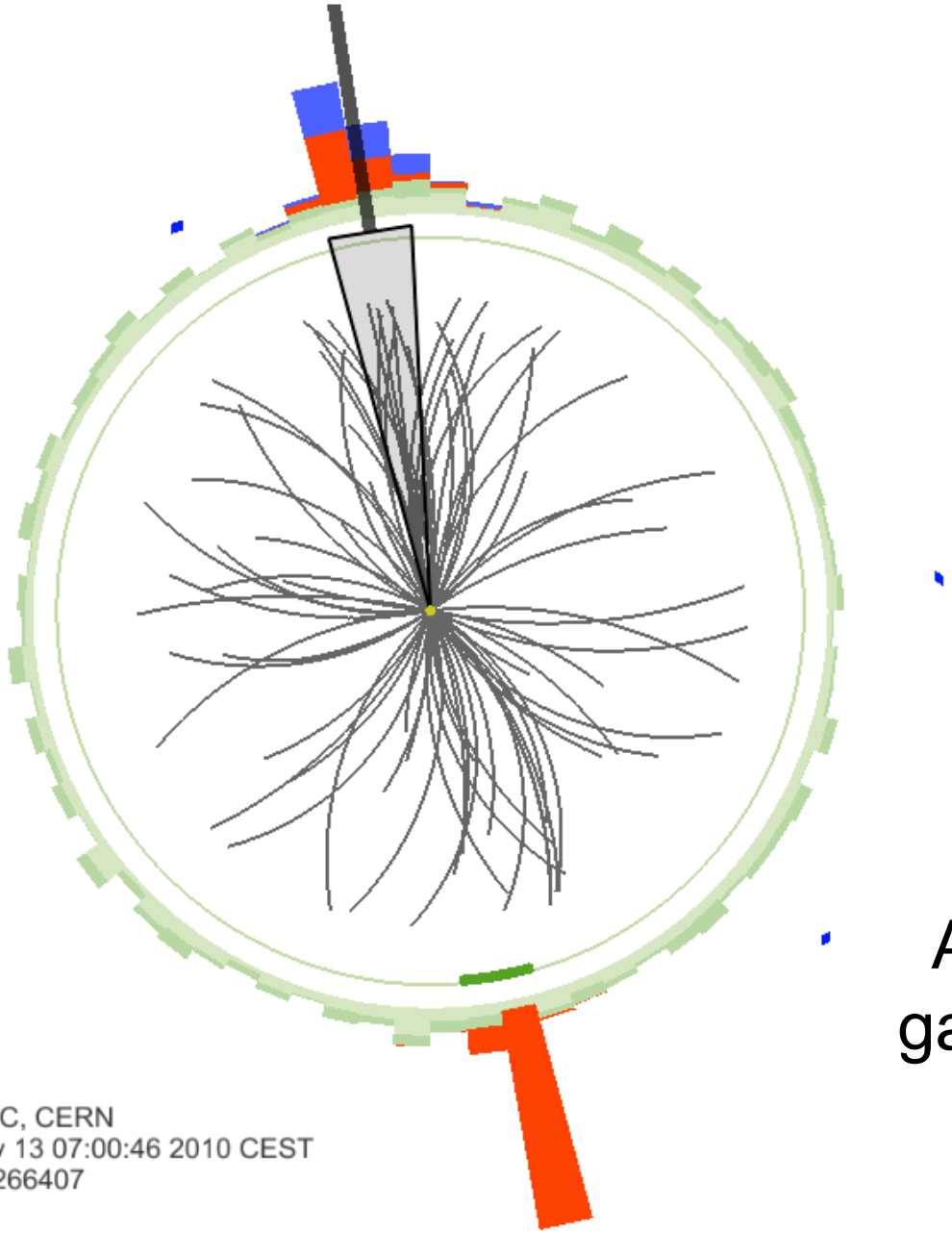
# Conclusions (2/3)

1. $Z \rightarrow \mu\mu$
   - Proportional to binary collisions,
   - Nuclear effects (isospin, shadowing…) small wrt uncertainties
2. $W \rightarrow \mu\nu$
   - Proportional to binary collisions,
   - Expected strong isospin effect when separating $W^+$ and $W^-$
   - Shadowing (4%) small wrt uncertainties

# 3. Isolated photons

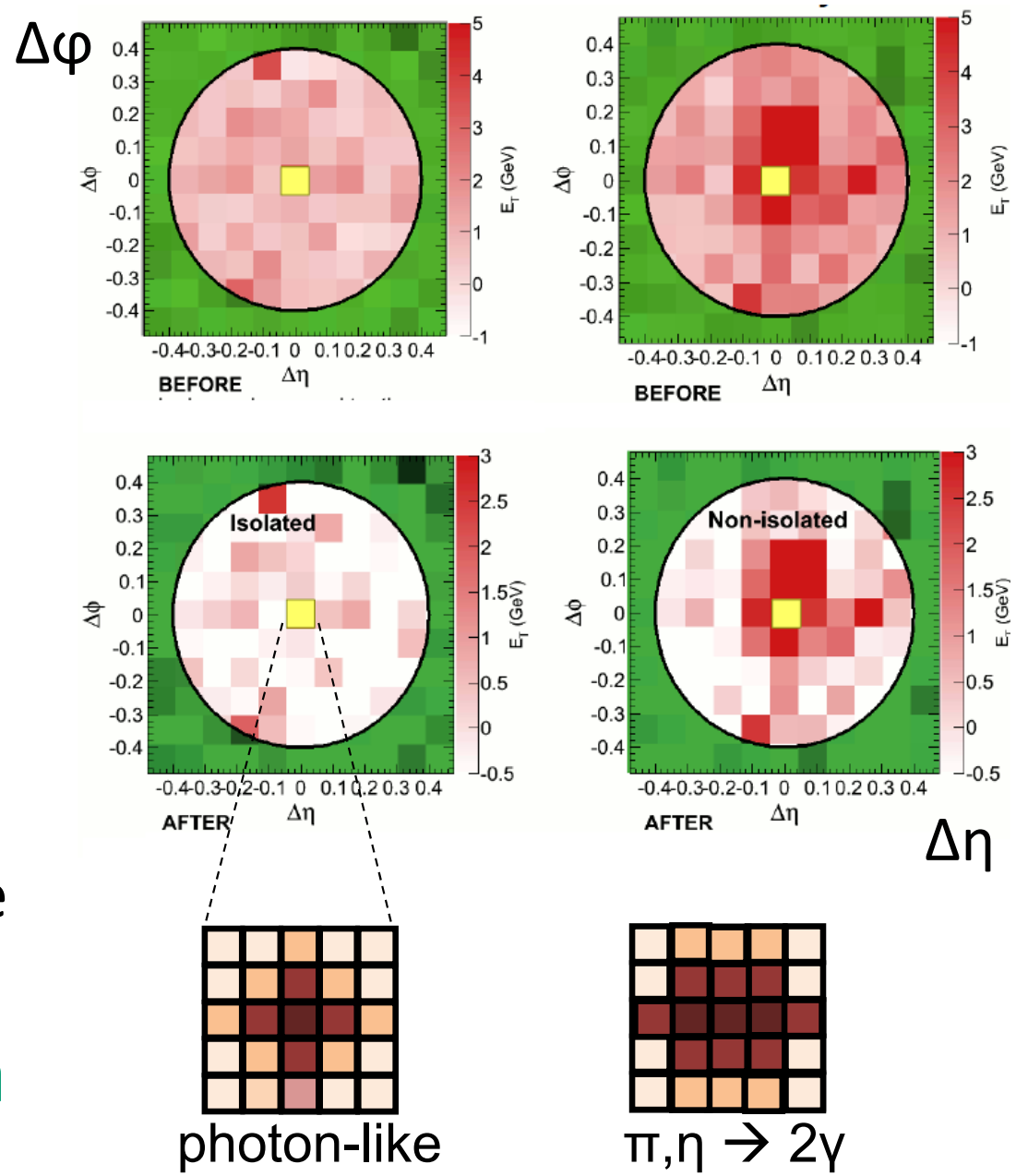


CMS Experiment at LHC, CERN
Data recorded: Sat Nov 13 07:00:46 2010 CEST
Run/Event: 151027 / 2266407
Lumi section: 546

An early 2010 gamma-jet event
Much more from 2011…

# How to find photons?

- Trigger on ECAL clusters
  - Uncorrected $E_T$ > 15 GeV, fully efficient for $E_T$ > 20 GeV
- Subtract underlying event
  - From same pseudorapidity strip, event by event
- Look for isolated cluster
  - Remove photons from bremsstrahlung and jet fragmentation…
- Look at shower shape in the highly segmented ECAL
  - Further remove isolated $\pi^0$, $\eta$



# Photon spectrum (2010)

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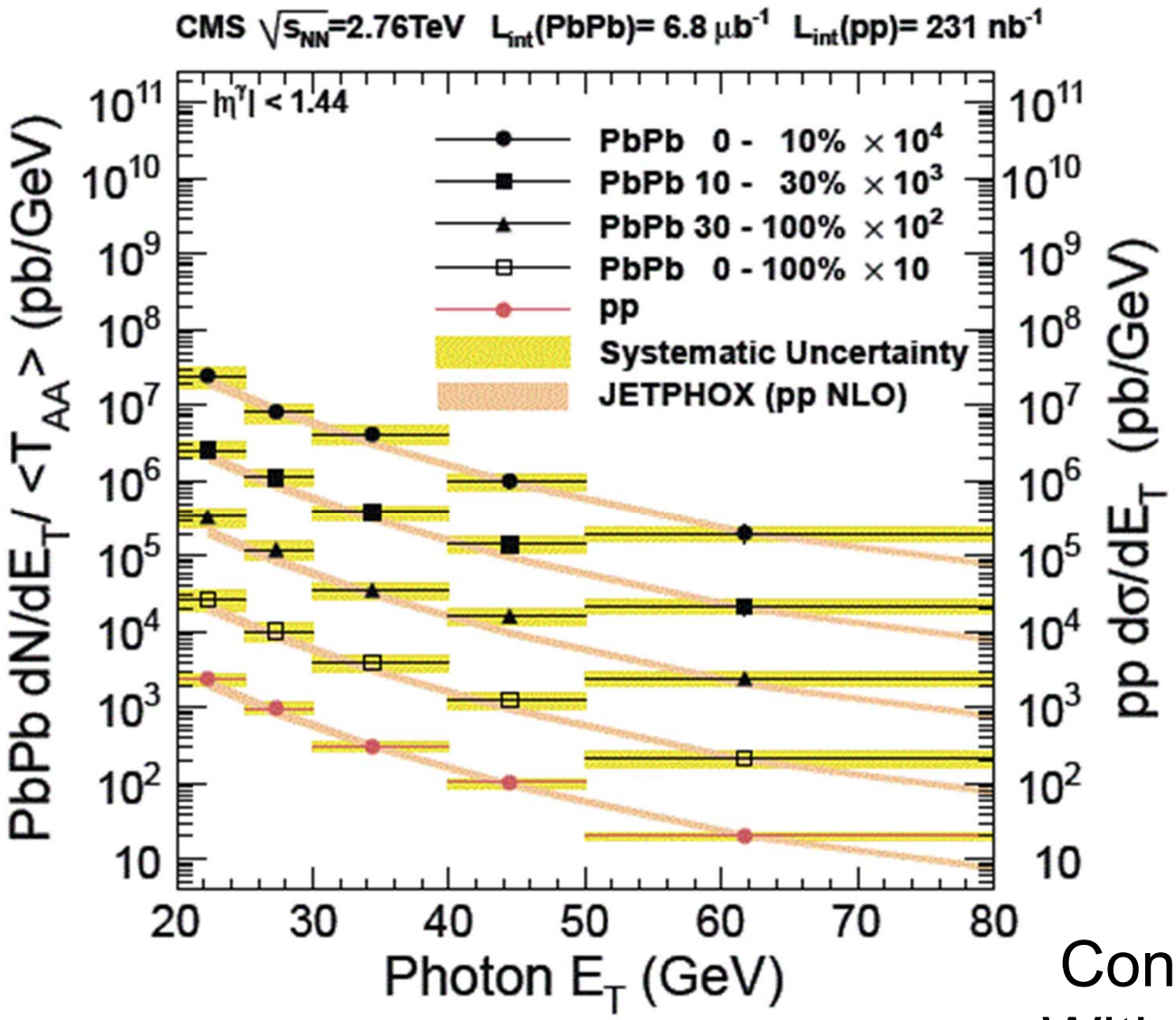
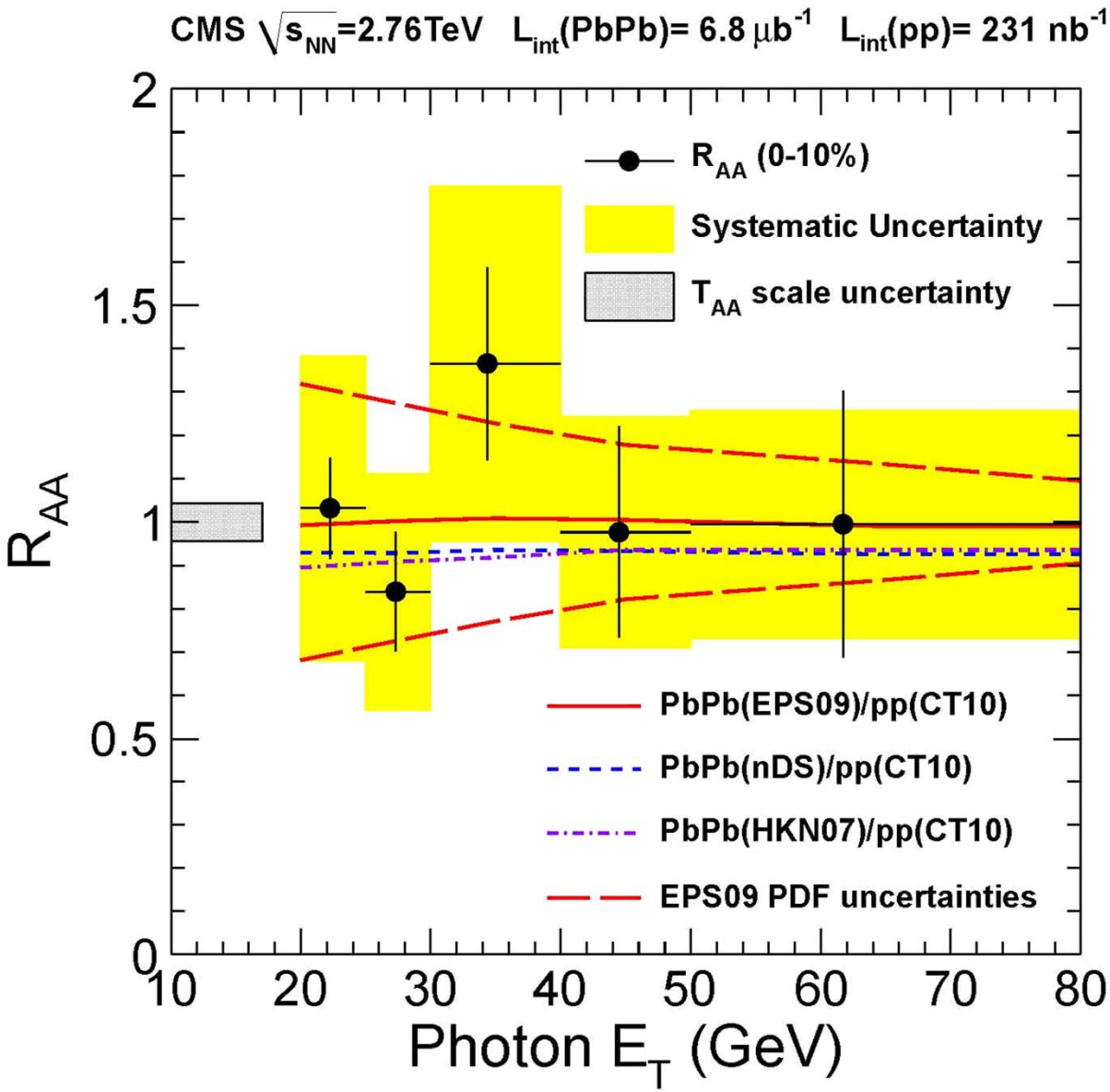



Consistent with JETPHOX
With unmodified pdf (CT10)

# Unmodified photons

PLB 710 (2012) 256




- Normalised by pp!
- Consistent with unity!
- Uncertainties still larger than modified pdf uncertainties…

# Centrality independence

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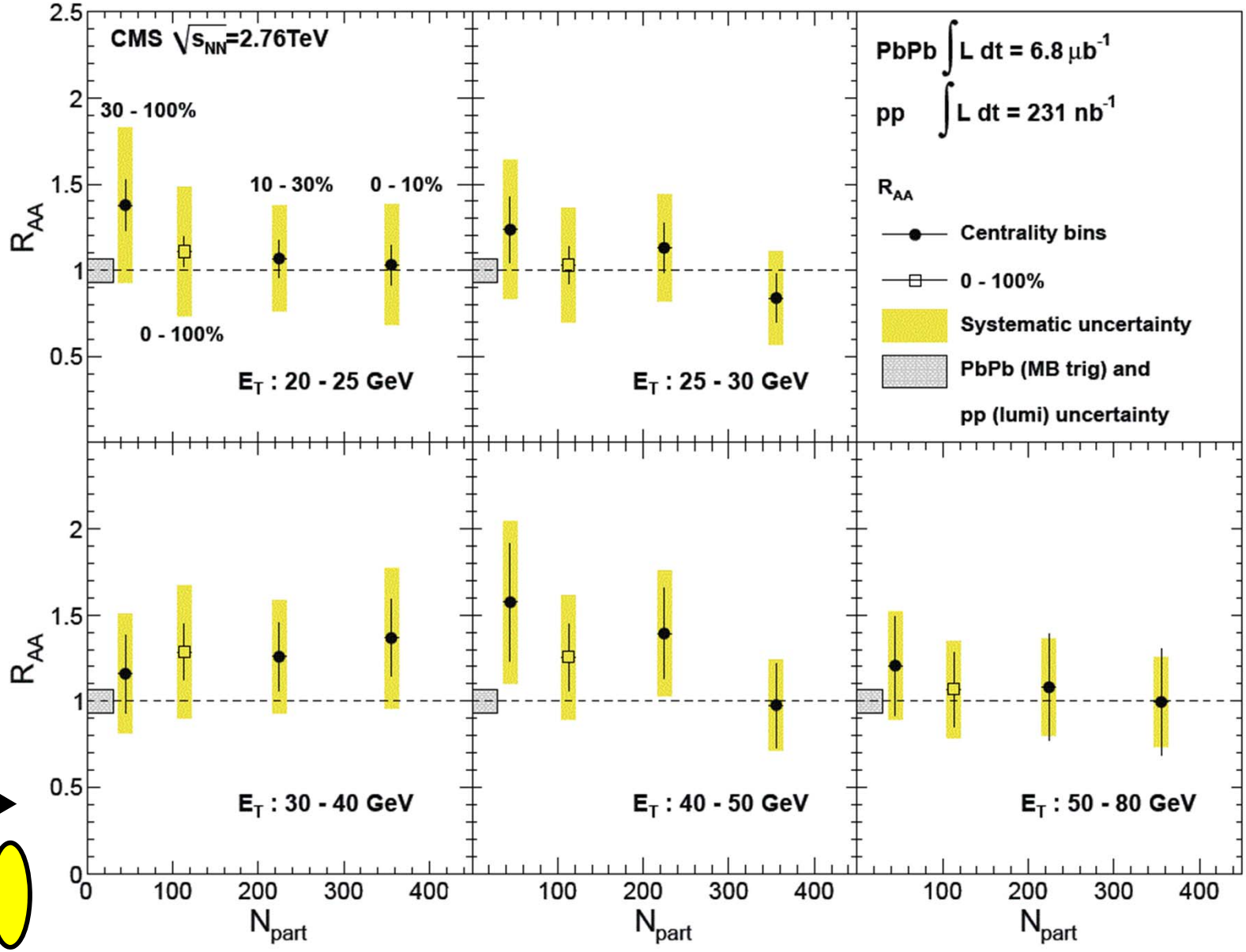
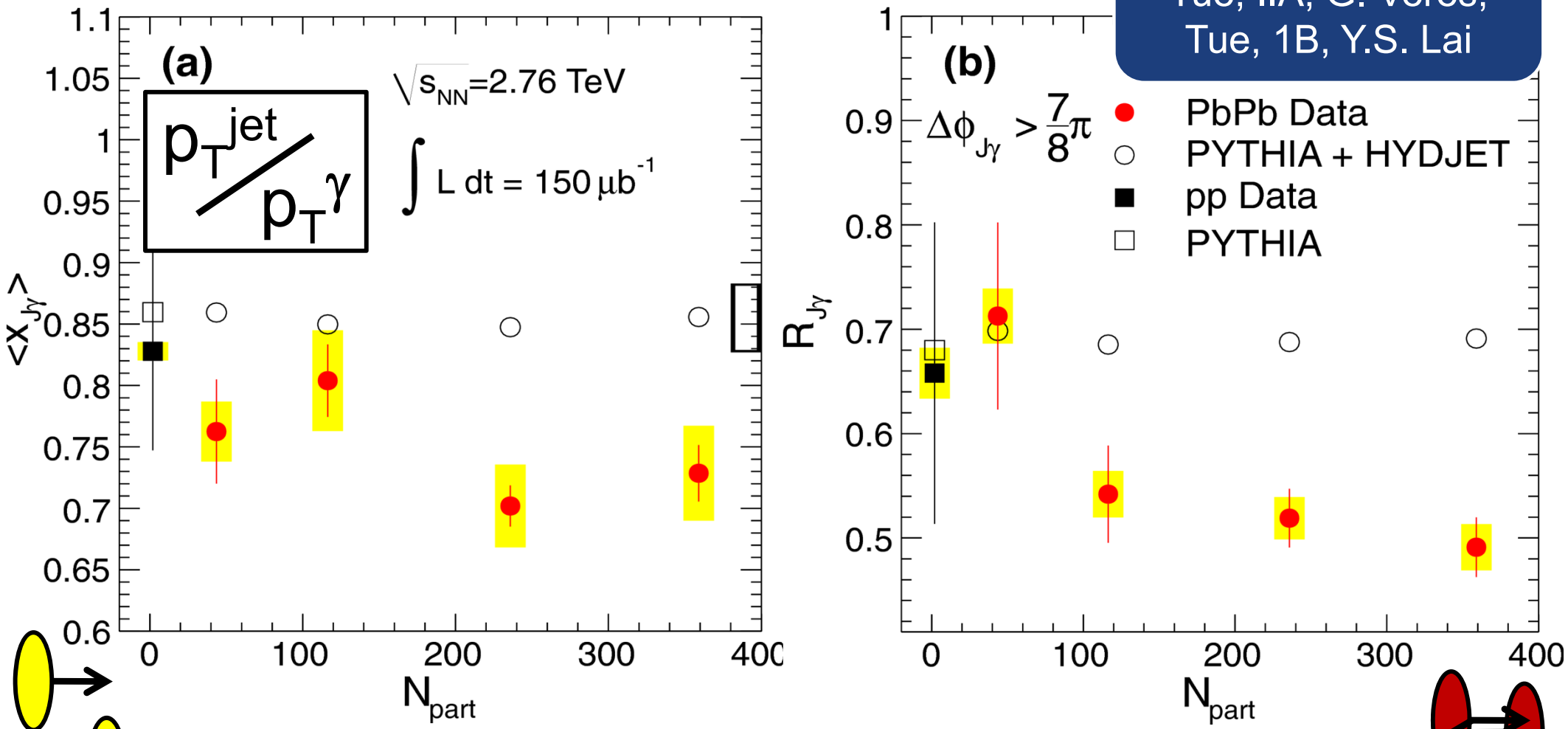


# 2011: look at opposite side

arXiv:1205.0206
Tue, IIA, G. Veres,
Tue, 1B, Y.S. Lai




For photon $p_T > 60$ and jet $p_T > 30$ GeV/$c$

(a) Opposite jets are 14% less energetic in PbPb than pp

(b) 20% more are not associated to a reconstructed jet

# Conclusions (3/3)

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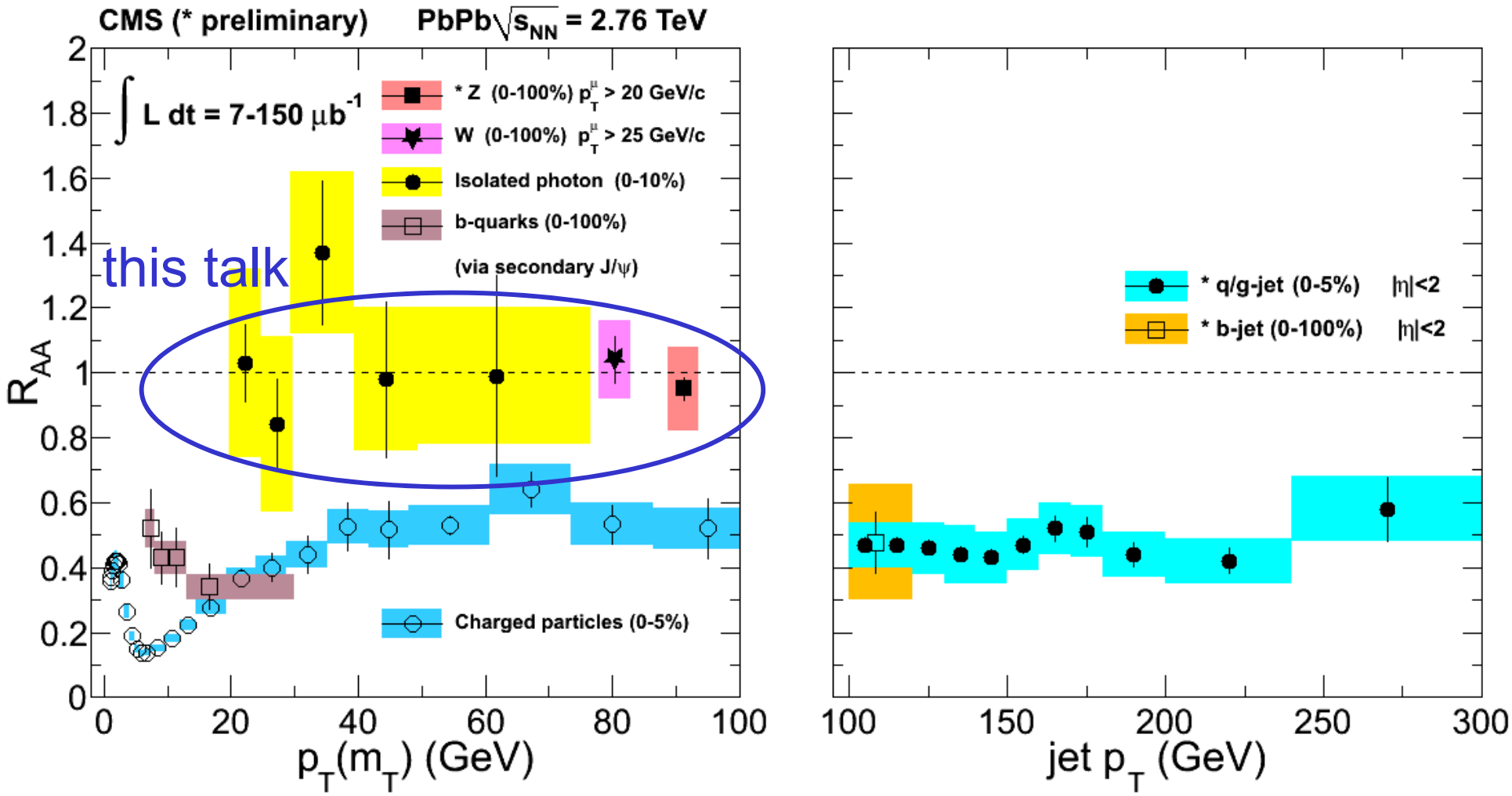
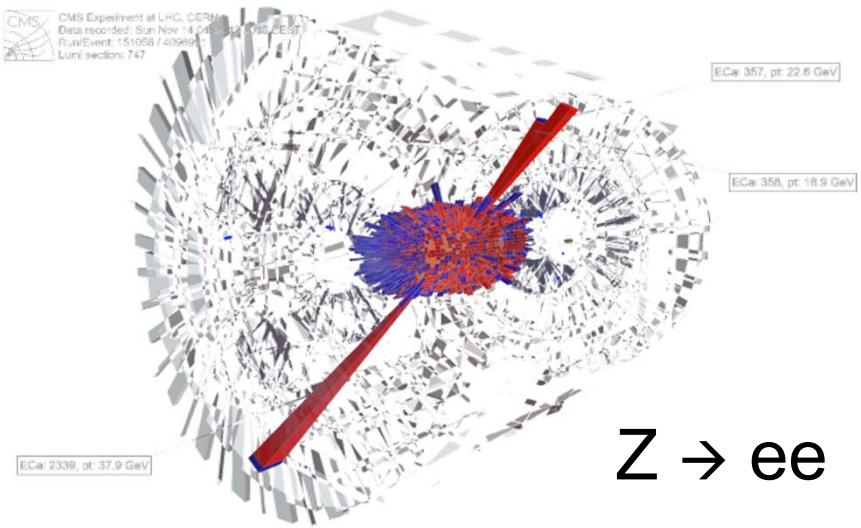
2. $W \rightarrow \mu\nu$
   - Proportional to binary collisions,
   - Expected strong isospin effect when separating $W^+$ and $W^-$
   - Shadowing (4%) small wrt uncertainties
3. Isolated photons
   - Proportional to binary collisions,
   - Nuclear effects (isospin, shadowing…) small wrt uncertainties
   - Serving as reference to opposite-side suppressed jets

# Summary


CMS (* preliminary)
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
$\int$ L dt = 7-150 $\mu b^{-1}$
* Z (0-100%) $p_T^{\mu}$ > 20 GeV/c
W (0-100%) $p_T^{\mu}$ > 25 GeV/c
Isolated photon (0-10%)
b-quarks (0-100%)
(via secondary J/ψ)
this talk
Charged particles (0-5%)
$R_{AA}$
$p_T(m_T)$ (GeV)
* q/g-jet (0-5%) |η|<2
* b-jet (0-100%) |η|<2
jet $p_T$ (GeV)

# The future…

- More on tape from 2011
  - $Z \rightarrow e^+ e^-$
  - 20 times more W…
  - $W \rightarrow e\ \nu$




Z → ee

- Similar statistics from upcoming pPb run
  - And hopefully pp reference runs!
- Longer term
  - Much more gamma+jet

  ≈ one Z+jet of $p_T$ > 50 GeV/*c* per /μb @ 5.5 TeV…

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

follow us

# The future…

## Z+jet