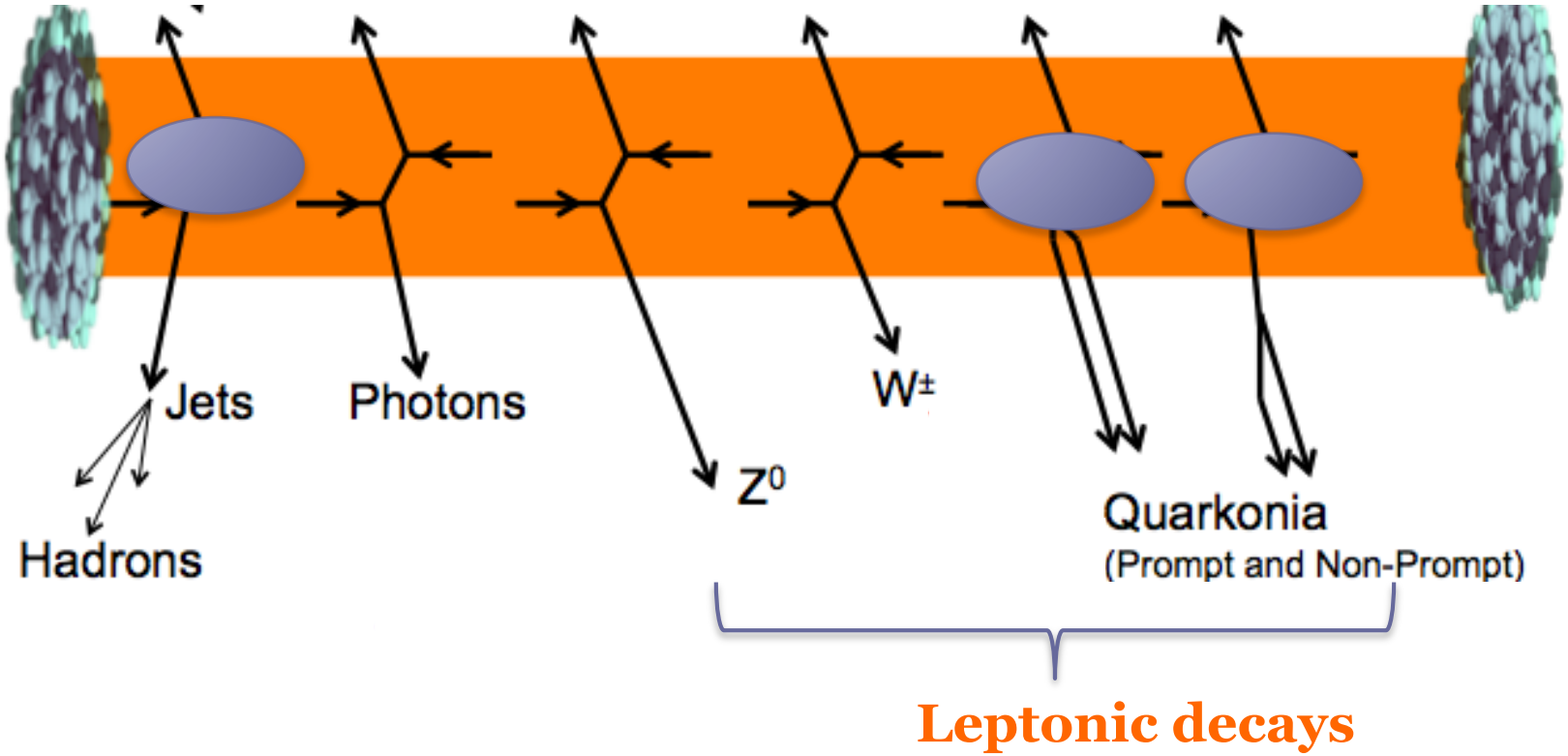
Latest CMS results on heavy flavor and electroweak production

LHCP 2014, New York

Alice Florent
On behalf of the CMS collaboration

Hard processes in QCD medium

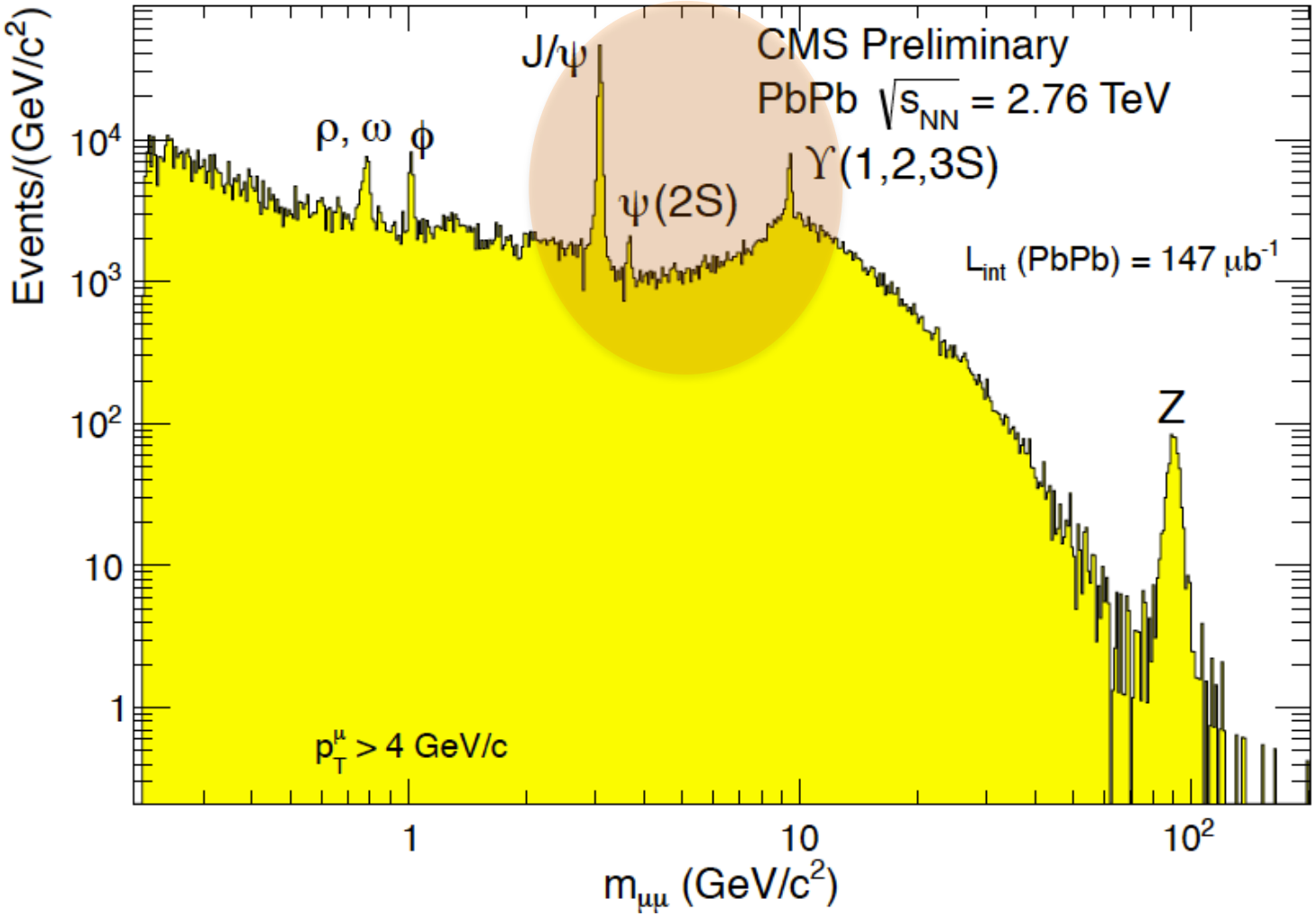


What do we learn with the dilepton probes:

- Creation of a dense and hot medium in PbPb collisions:
  - Melting of the quarkonia
  - Electroweak probes are reference processes
- Cold nuclear effects in pPb collisions

New

Five quarkonia



Quarkonia suppression

- Comparison of J/Ψ and ϒ production in PbPb and pp collisions
- High p_T J/ψ are suppressed
- Upsilon (1S, 2S, 3S) are all suppressed

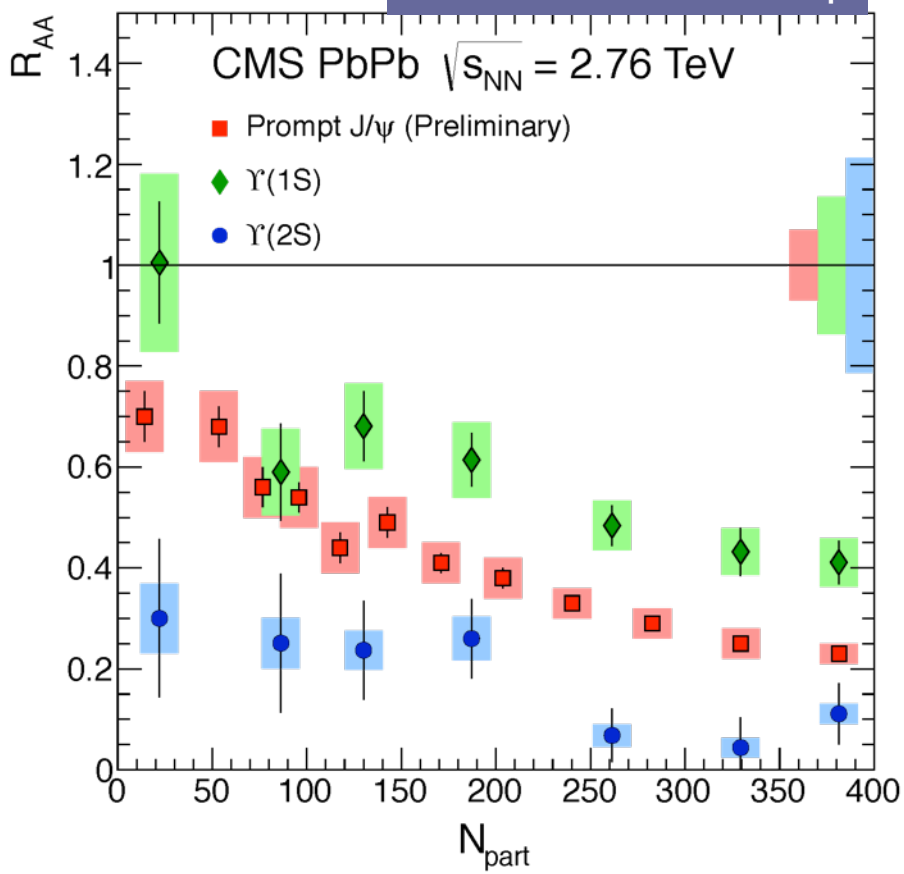
Determined with the Glauber model

$$R_{AA} = dN_{AA}/(T_{AA} * d\sigma_{pp})$$

PbPb 2.76 TeV
L_{int} =150 μb^{-1}

pp 2.76 TeV
2011: L_{int} = 230 nb^{-1}
2013: L_{int} = 5.4 pb^{-1}

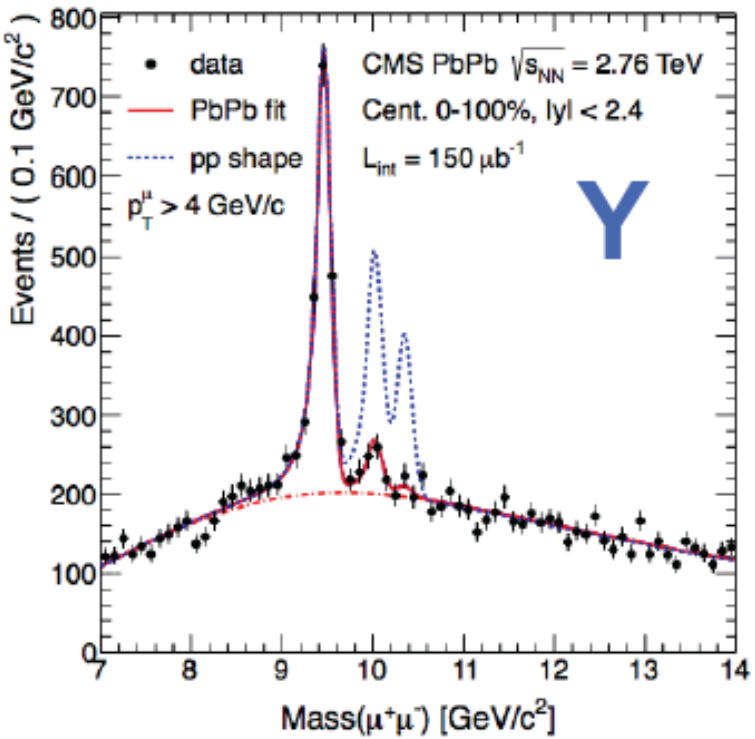
CMS PAS HIN-12-014



State of the Art

- Upsilon (1S, 2S, 3S) are all suppressed
- What about high p_T charmonia? Is there a suppression pattern?
- What is happening for low p_T quarkonia?
- How to disentangle QGP effects from cold nuclear matter ones?

PRL 109 222301 (2012)



R_{AA} of Υ(1S)>Υ(2S)>Υ(3S)

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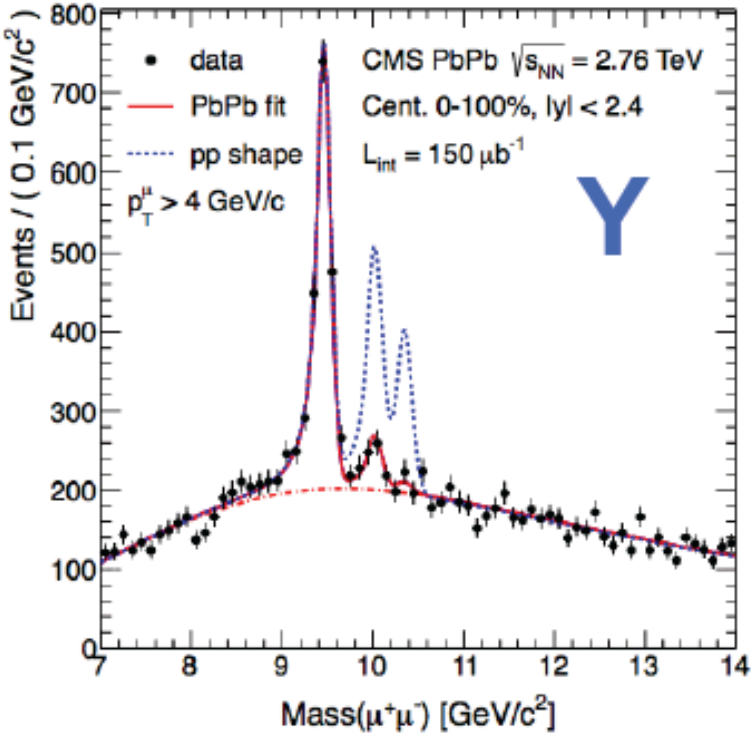

Charmonia ?

R_{AA} of Υ(1S)>Υ(2S)>Υ(3S) → R_{AA} of J/ψ(1S)??ψ(2S)

State of the Art

- Upsilon (1S, 2S, 3S) are all suppressed
- What about high p_T charmonia? Is there a suppression pattern?
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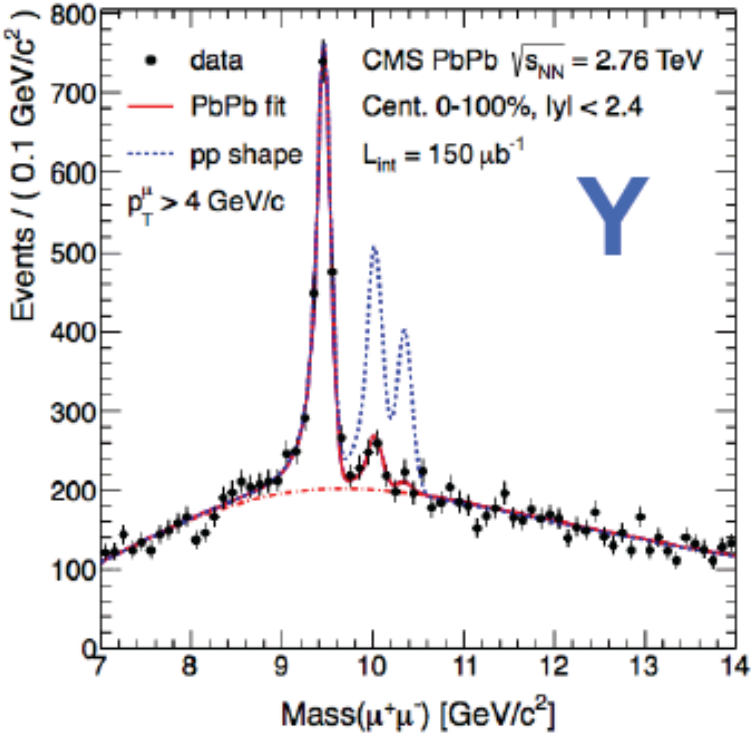
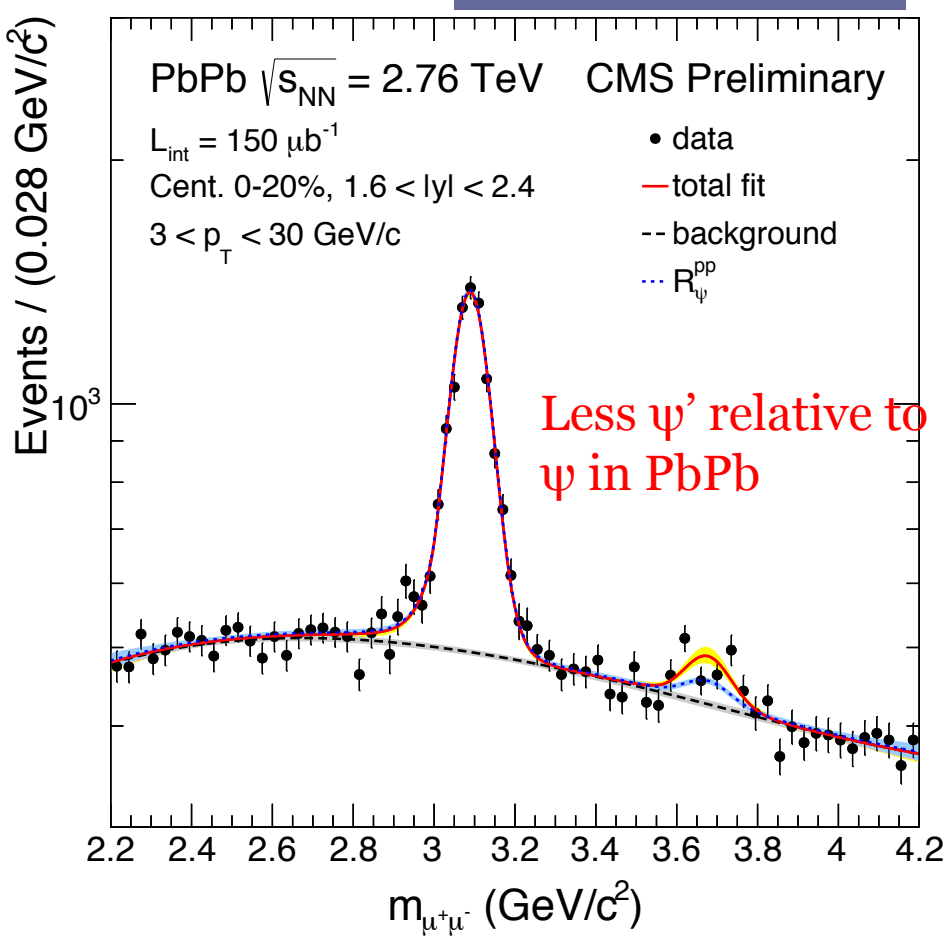


R_{AA} of Υ(1S)>Υ(2S)>Υ(3S)

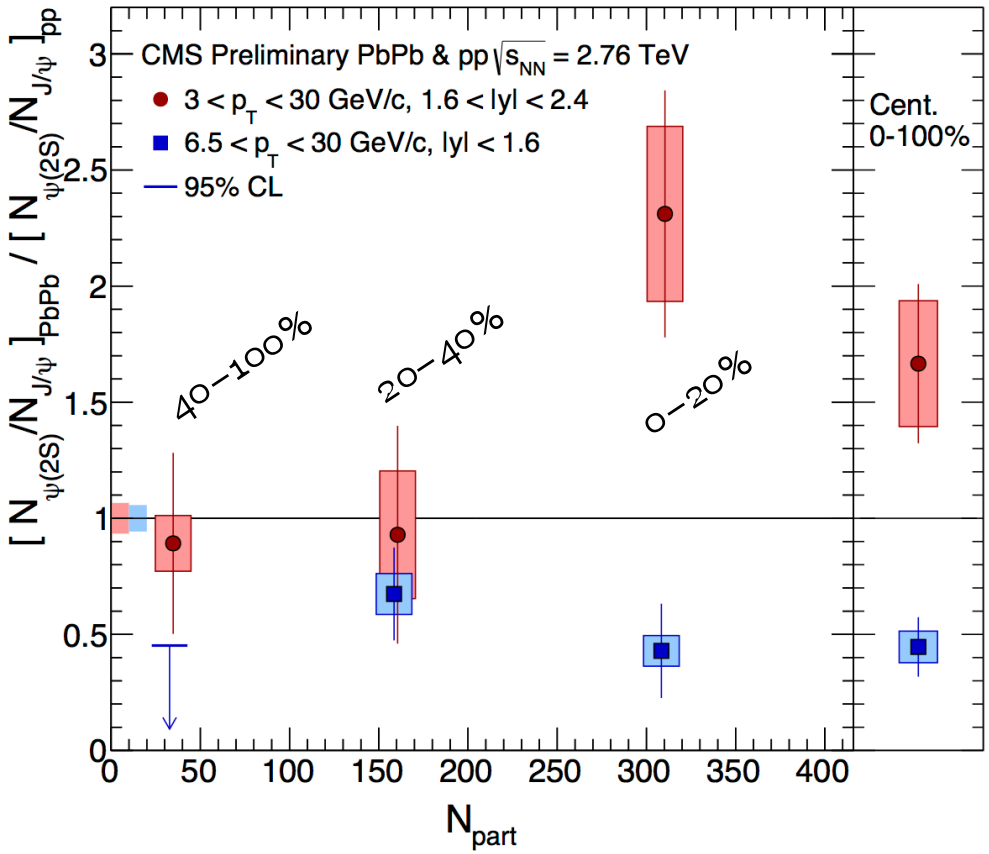
CMS PAS HIN-12-007



ψ' in PbPb collisions

New

Relative suppression of ψ' compare to ψ in PbPb and pp
High and low p_T

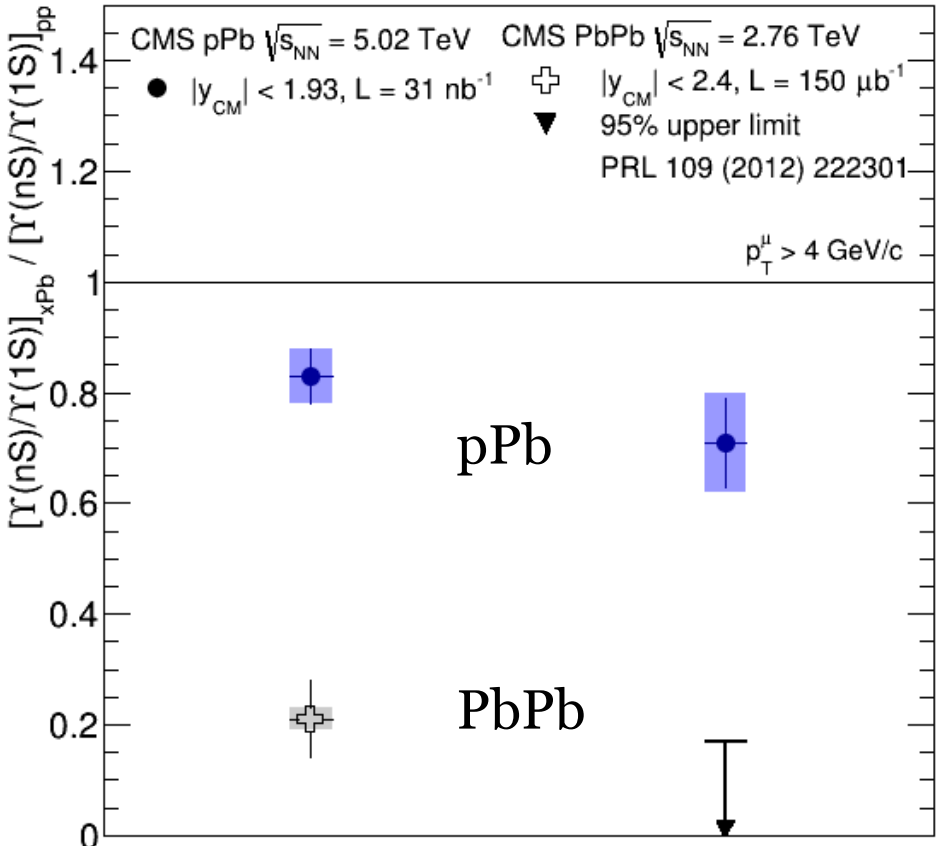


CMS PAS HIN-12-007

- Surprisingly large $(\psi'/\psi)_{PbPb}$ / $(\psi'/\psi)_{pp}$ ratio confirmed:
  - new pp reference, 20 times larger, now negligible uncertainty
  - non-prompt component subtracted
- ψ' very suppressed at high p_T (more than ψ)
  → $R_{AA}(\psi') = 0.13 \pm 0.05$
- Much less at lower p_T
  → $R_{AA}(\psi') = 0.67 \pm 0.19$
  (Centrality-integrated R_{AA})

Upsilon in pPb: cold nuclear effect?

- Excited states less suppressed than in PbPb: confirming the quarkonia suppression
- Still the pPb double ratio is not 1: cold nuclear effect?



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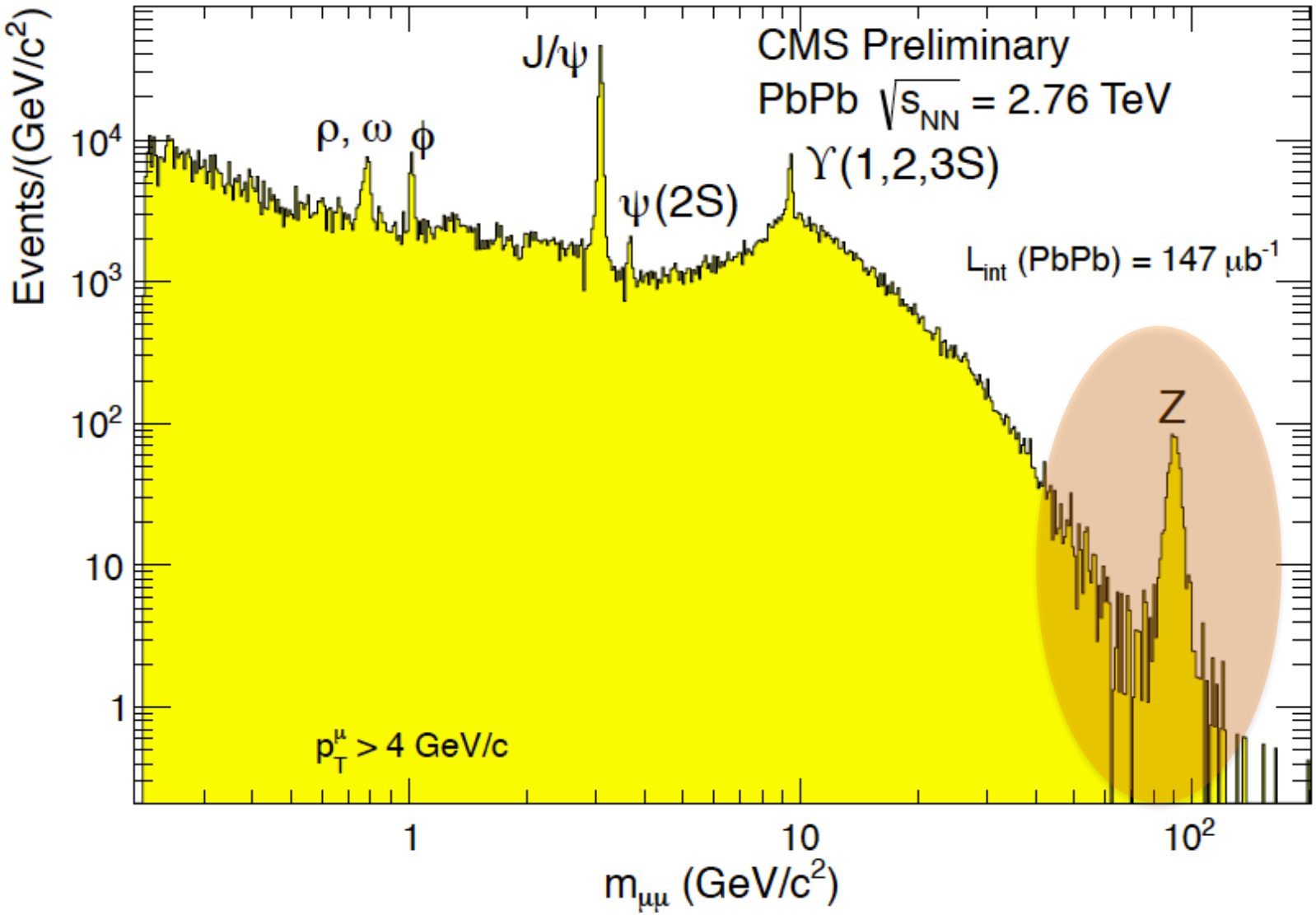
$\frac{\Upsilon(2S)}{\Upsilon(1S)}$ $\frac{\Upsilon(3S)}{\Upsilon(1S)}$

Conclusion 1/2

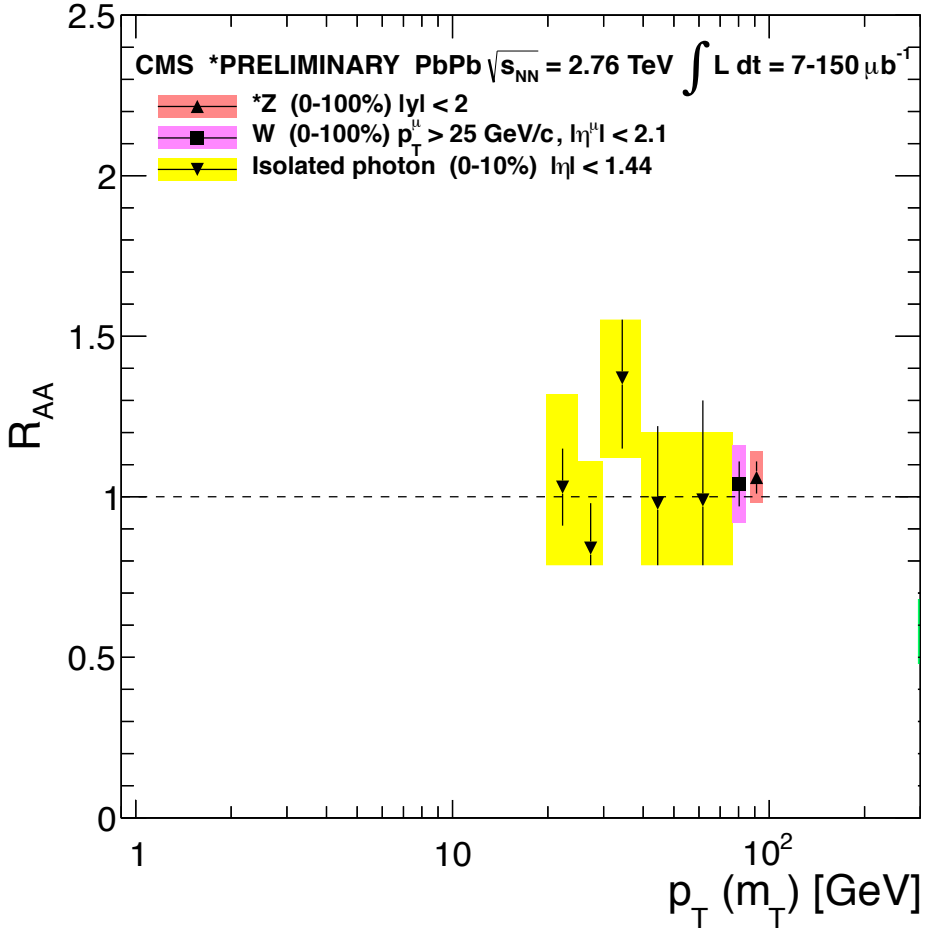
- Signature of hot medium in PbPb
  - Suppression of 5 high p_T quarkonia
  - Sequential suppression along the binding energy
  - Enhancement at low p_T: $\psi'/\psi > 1$ (regeneration?)
  - The upsilon double ratio are less suppressed in pPb than in PbPb

- Cold nuclear effect
  - Upsilon in pPb double ratio ≠ 1, loss of excited states due to cold nuclear effect?

Z and W


CMS Preliminary
PbPb $\sqrt{s_{NN}}$ = 2.76 TeV
J/ψ
ρ, ω φ
ψ(2S)
ϒ(1,2,3S)
L_{int} (PbPb) = 147 μb^{-1}
Z
p_T^{μ} > 4 GeV/c
Events/(GeV/c^2)
$m_{\mu\mu}$ (GeV/c^2)
10^4
10^3
10^2
10
1
1
10
10^2

Z and W boson: medium blind

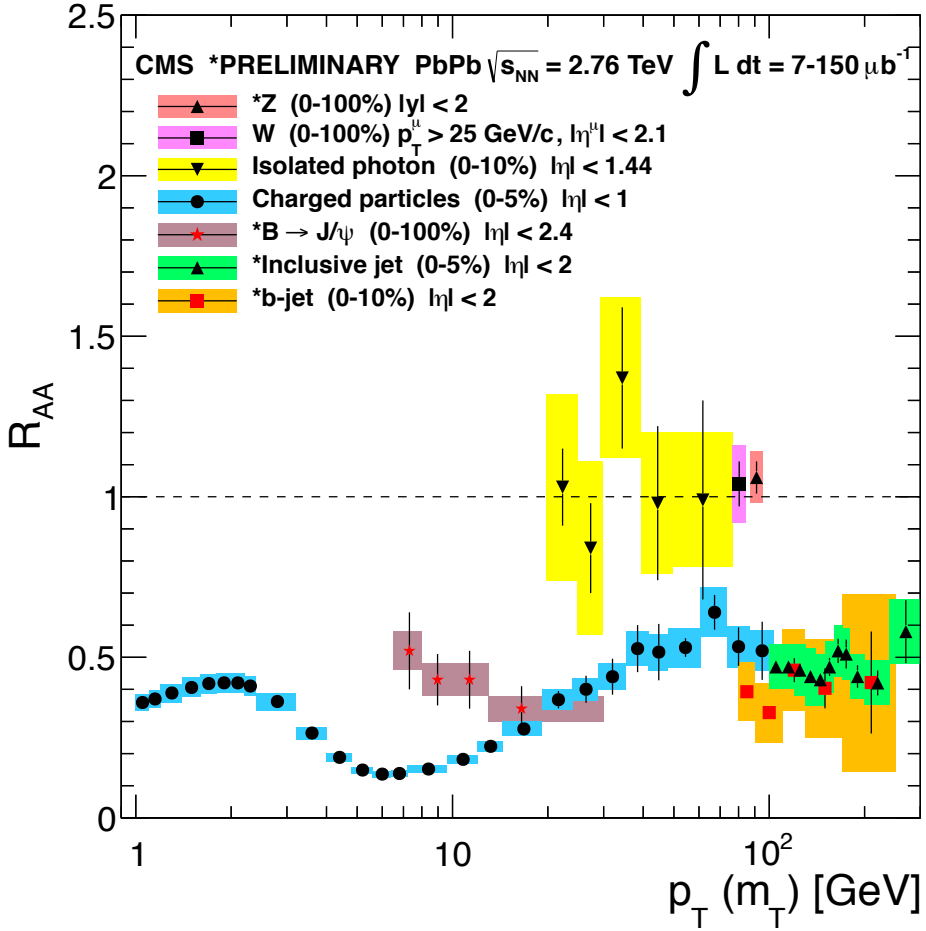


Z and W R_{AA}:

- Compatible with binary scaling (RAA=1)
- A R_{AA} compatible with 1 indicates that there are no strong nuclear effect

PLB 710 (2012) 256
PLB 715 (2012) 66
CMS PAS HIN-13-004

Z and W boson: medium blind



Z and W R_{AA}:

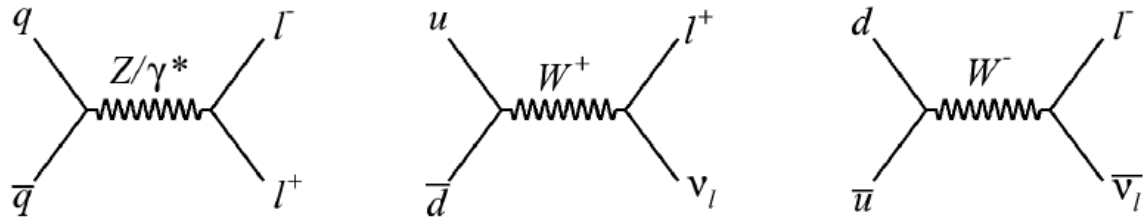
- Compatible with binary scaling (RAA=1)
- A R_{AA} compatible with 1 indicates that there are no strong nuclear effect
- Large difference between electroweak bosons and QCD probes

PLB 710 (2012) 256
PLB 715 (2012) 66
CMS PAS HIN-13-004

EPJC 72 (2012) 1945
JHEP 10 (2012) 087
PRC 84 (2011) 024906
CMS PAS HIN-12-003

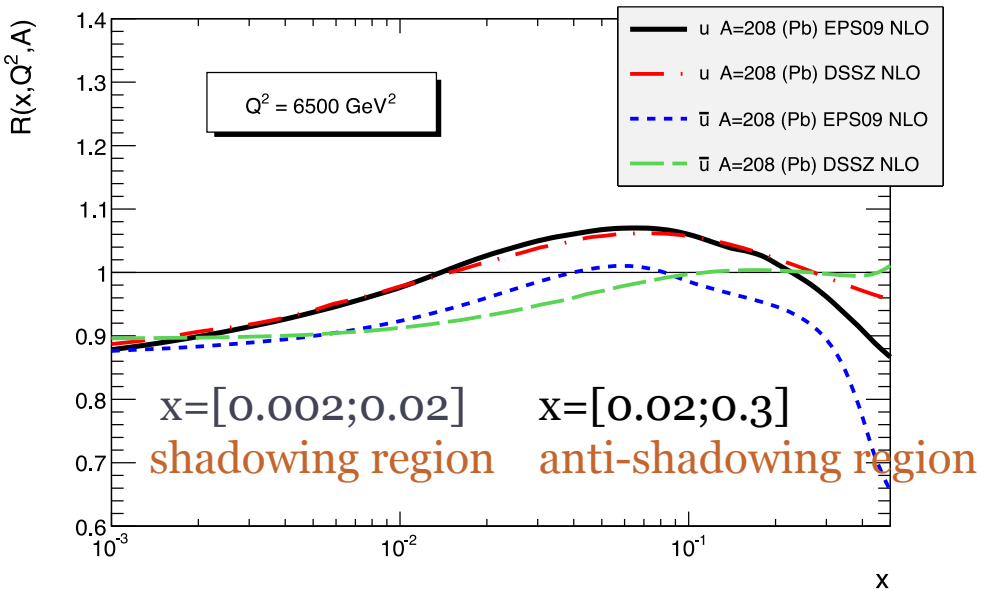
Z and W in pPb collisions: Initial State

Dominant processes (LO)



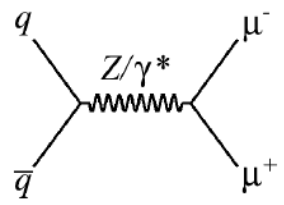
- pPb providing the best opportunity to probe (valence) q and (sea) $\bar{q}$ nPDF

$$f^{\text{proton,A}} = R_f(x, Q^2) f^{\text{free proton}}(x, Q^2)$$



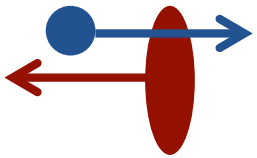
Z in pPb

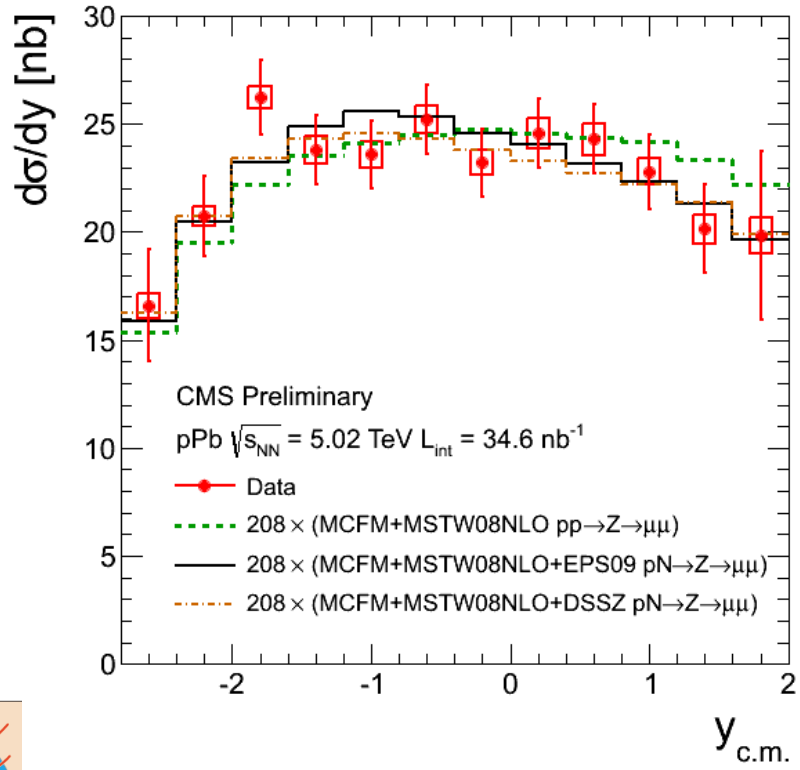
New

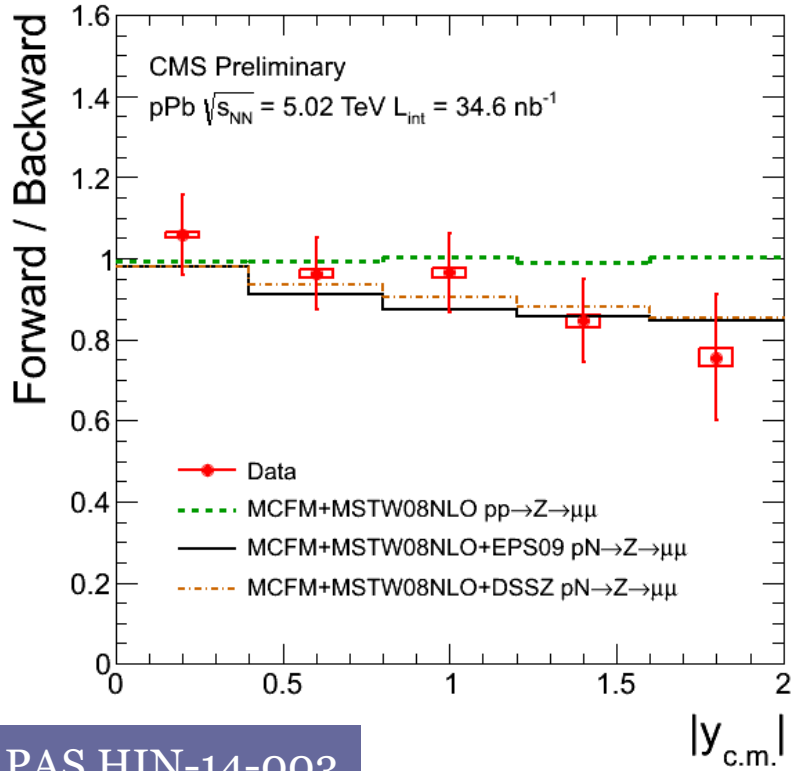


≈ 2200 Z → $\mu^+\mu^-$ showing little nuclear effect

- Hint of forward/backward asymmetry







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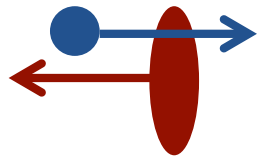
W^+ and W^- in pPb

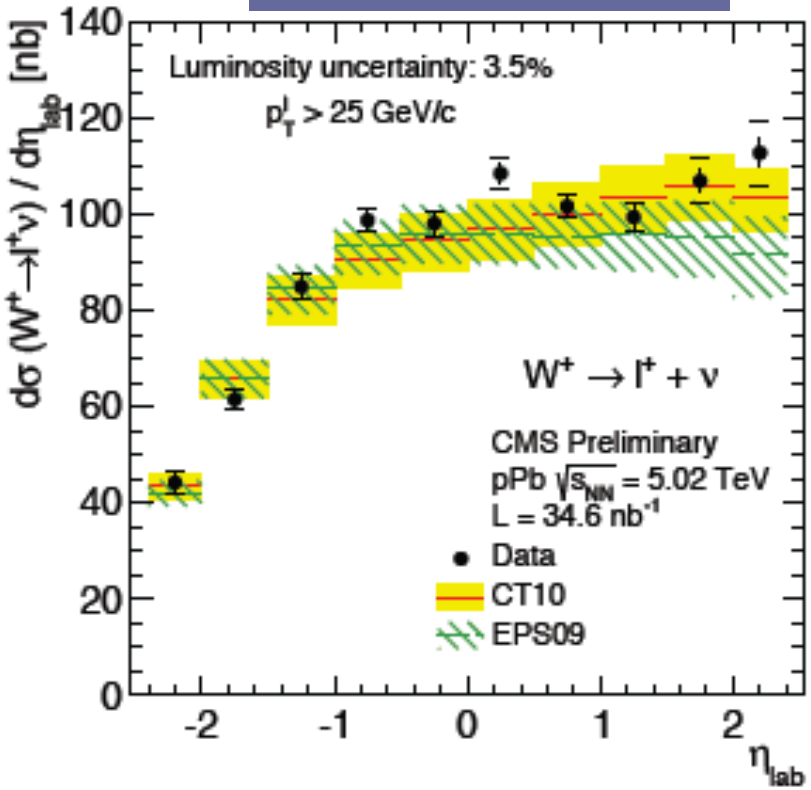
New

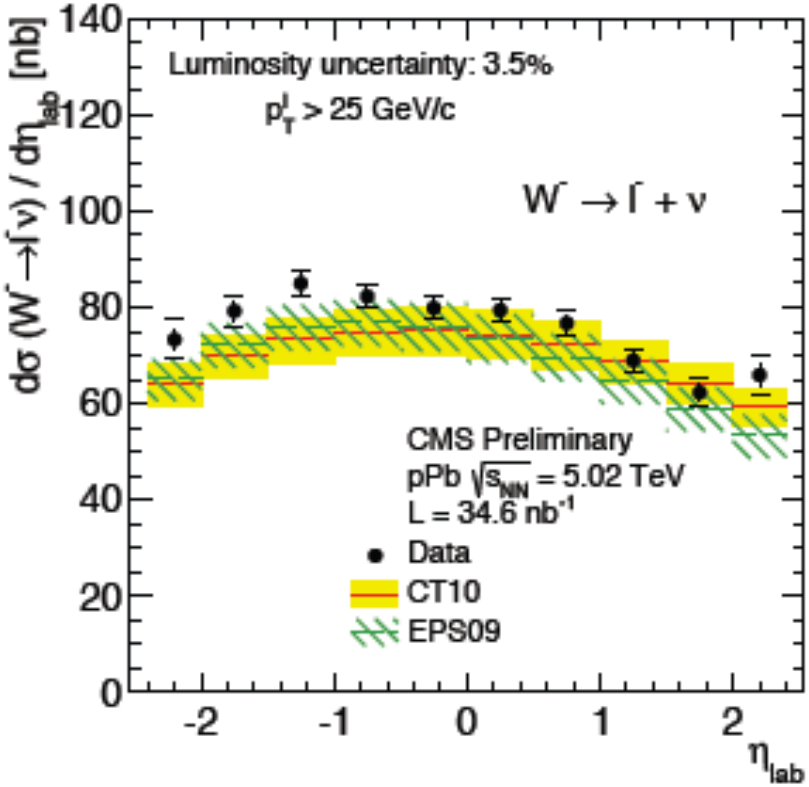
- Analysis performed in 2 channels and combined
- ≈ 21000 W → μ + ν & 16000 W → e + ν

Cross section in the laboratory frame



CMS PAS HIN-13-007



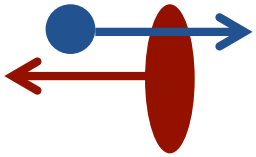


W^+ and W^- in pPb

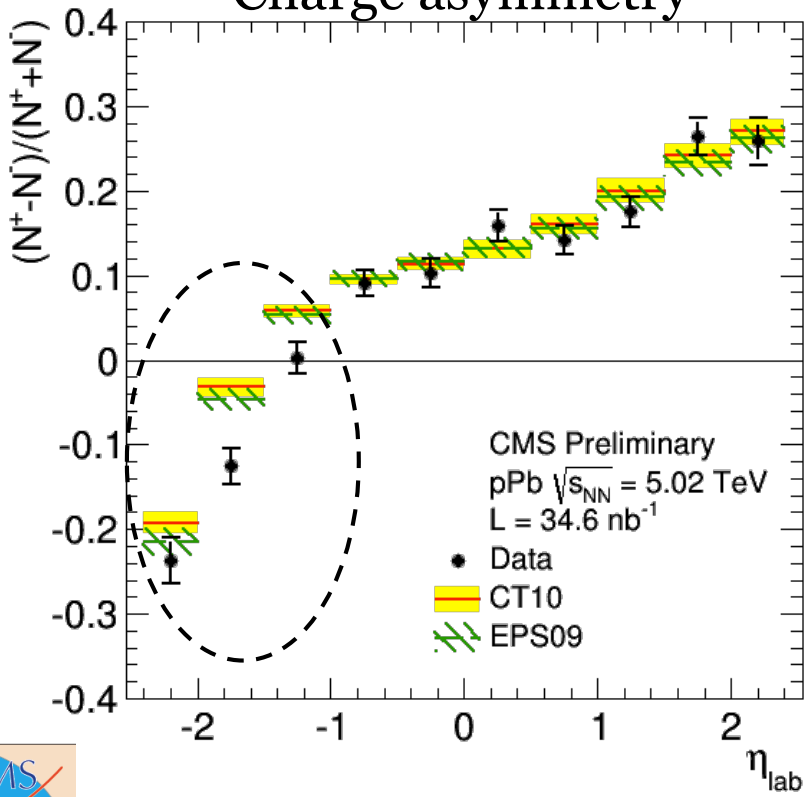
New

- Showing small deviations from unmodified PDFs
- A hint of a different u/d nuclear modification factor?

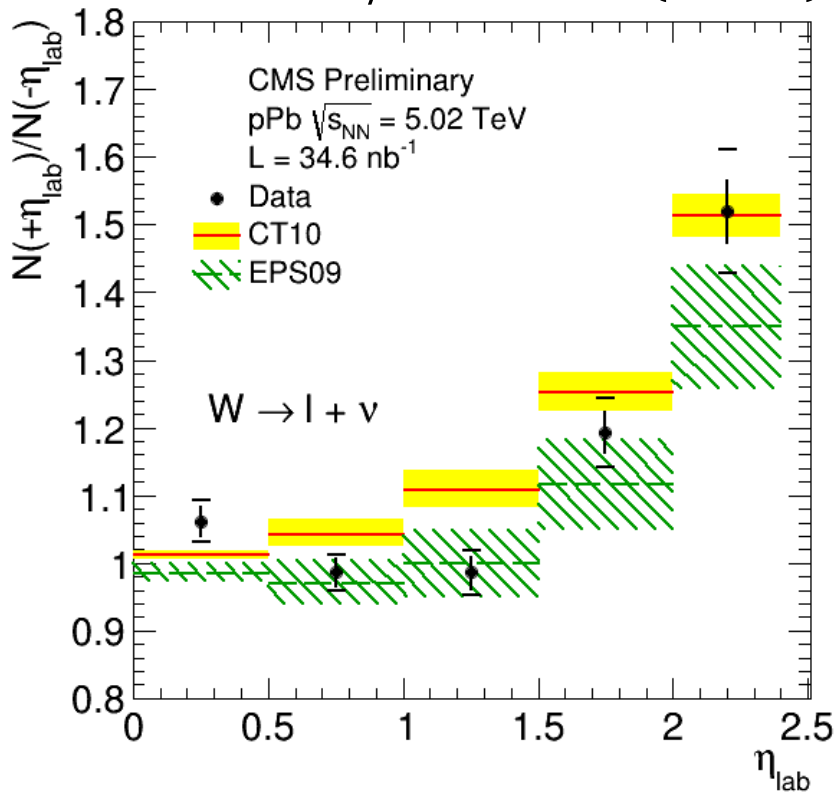
CMS PAS HIN-13-007



Charge asymmetry



Forward/Backward (in lab)



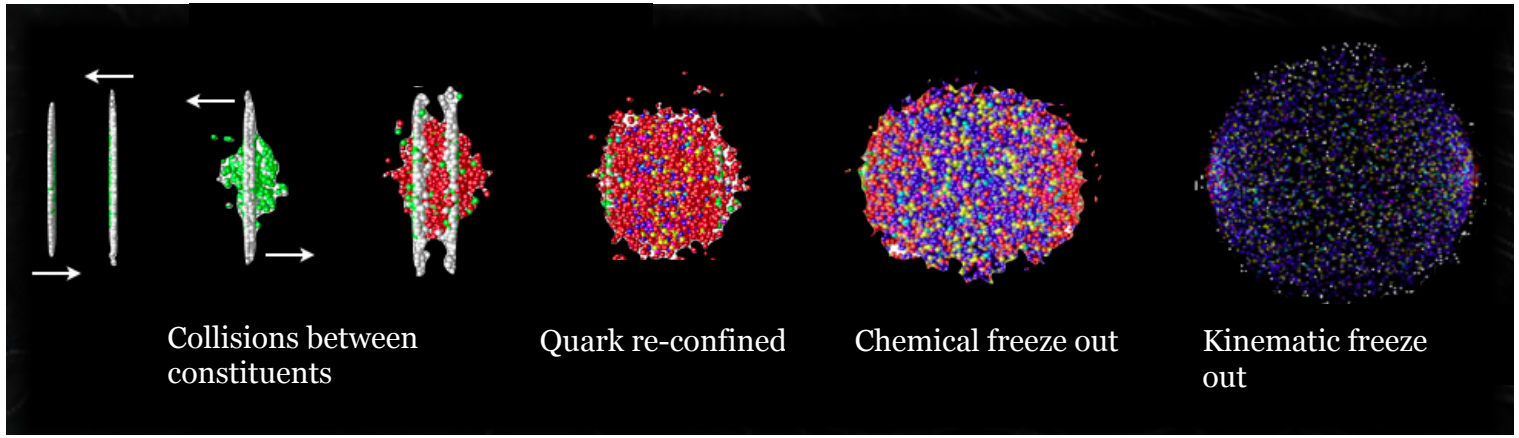
Conclusion 2/2

- Signature of hot medium in PbPb
  - Suppression of 5 high p_T quarkonia
  - Sequential suppression along the binding energy
  - Enhancement at low p_T: $\psi'/\psi > 1$ (regeneration?)
  - The upsilon double ratio are less suppressed in pPb than in PbPb
  - Electroweak probes are insensitive to QGP

- Cold nuclear effect
  - Upsilon in pPb double ratio ≠ 1, loss of excited states due to cold nuclear effect?
  - The W and Z in pPb measurements set significant constraints for nPDFs
  - In particular the u and d quarks seem to have different nuclear modifications: R(u) ≠ R(d) ?

Back up

Evolution of a heavy-ion collision



- Hard processes (High Q^2)
- **Production of hard probes**

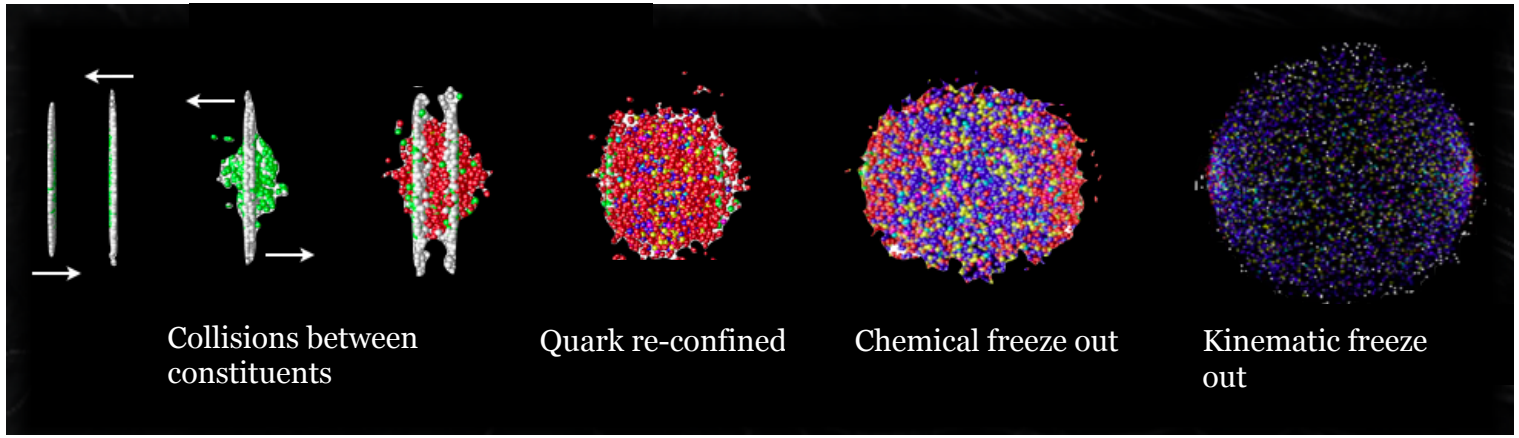
Quarkonia, jets, Z,W,γ

QGP formation
1 fm/c
10^{-15} m
$T_c \approx 190$ MeV

No more inelastic collision
Number of particles is set

- **Final state**
- Detection

Evolution of a heavy-ion collision



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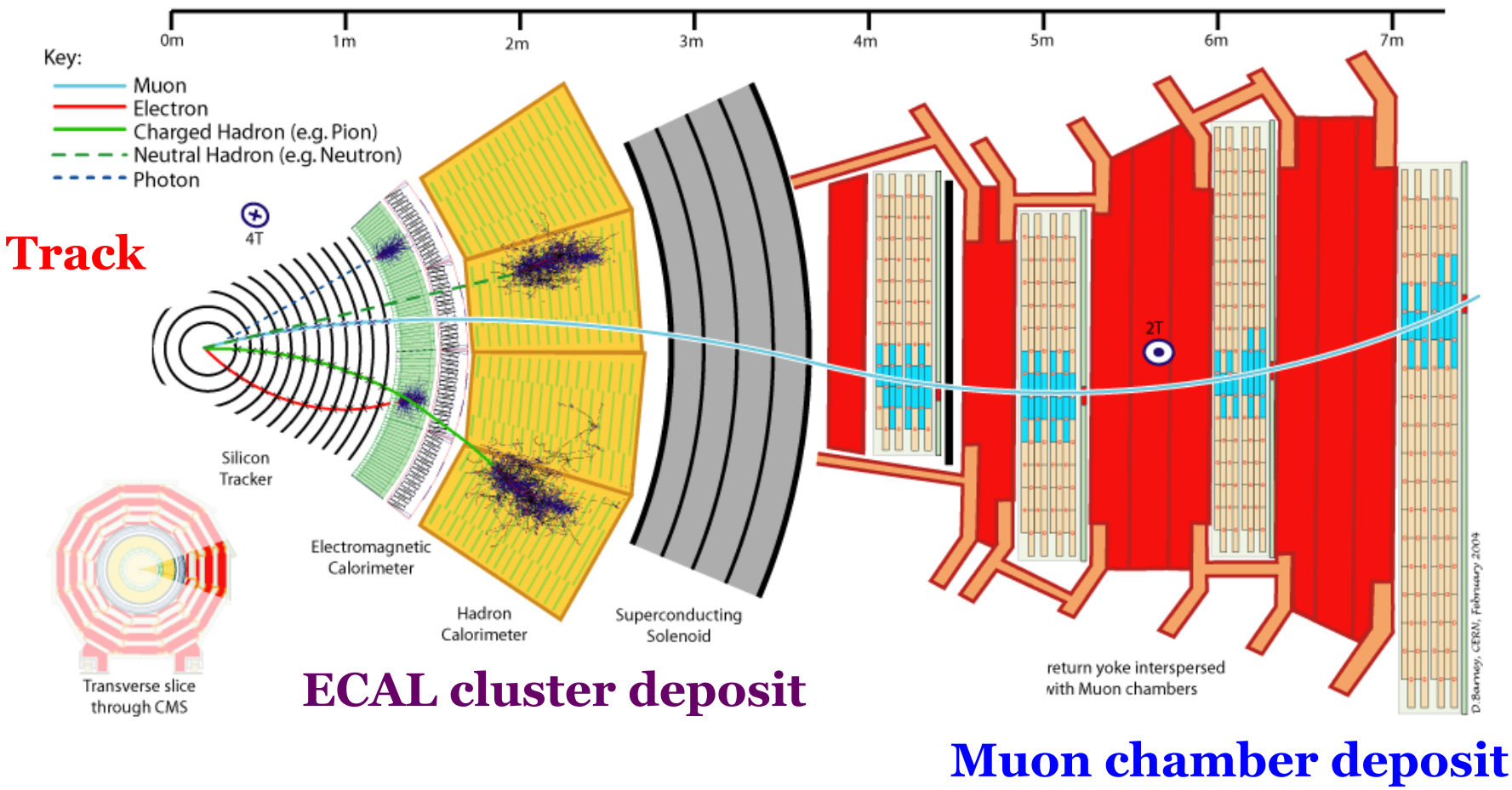
1 fm/c
10^{-15} m
$T_c \approx 190$ MeV

No more inelastic collision
Number of particles is set

- **Final state**
- Detection

- We look for signatures of a dense and hot medium created when high energy density and temperature are reached: PbPb collisions at LHC
- pp collisions are used as reference
- As compared to pp, medium modification from QGP and cold nuclear matter

Lepton reconstruction

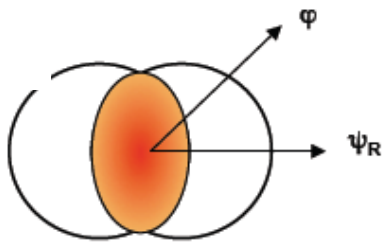


- Muon pattern: hits in the tracker + muon seed in the muon stations
- New muon reconstruction for PbPb collision: from 85% to **98%** efficiency
- Electron pattern: tracks associated with a cluster in the calorimeter (ECAL)

J/ψ azimuthal anisotropy

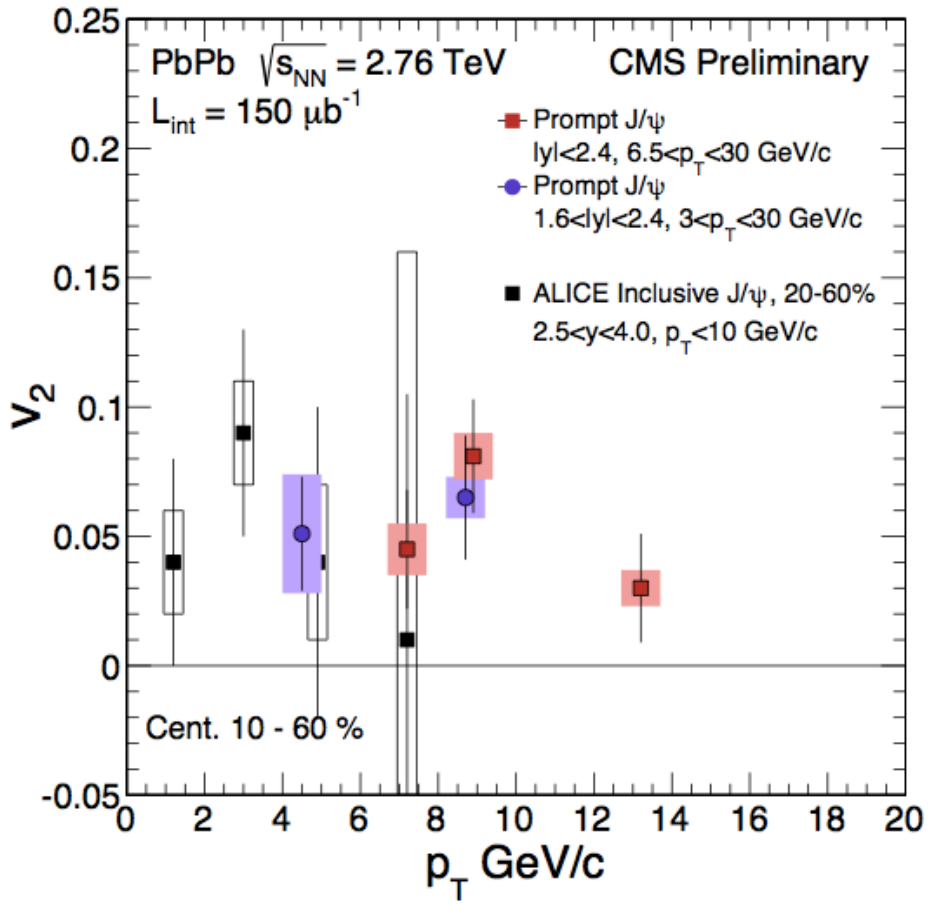
23

Regeneration explanation is supported by a positive elliptic flow coefficient (thermalization?)
What about high p_T v2?



$$\frac{dN}{N_{total\ J/\psi} d\Delta\phi} = \frac{2}{\pi}(1 + 2v_2 \cos(2\Delta\phi))$$

- Significant v_2 at high p_T
  - Need more data to resolve the p_T dependence
  - From regeneration to path-length dependence of J/ψ suppression?



CMS PAS HIN-12-001

State of the Art

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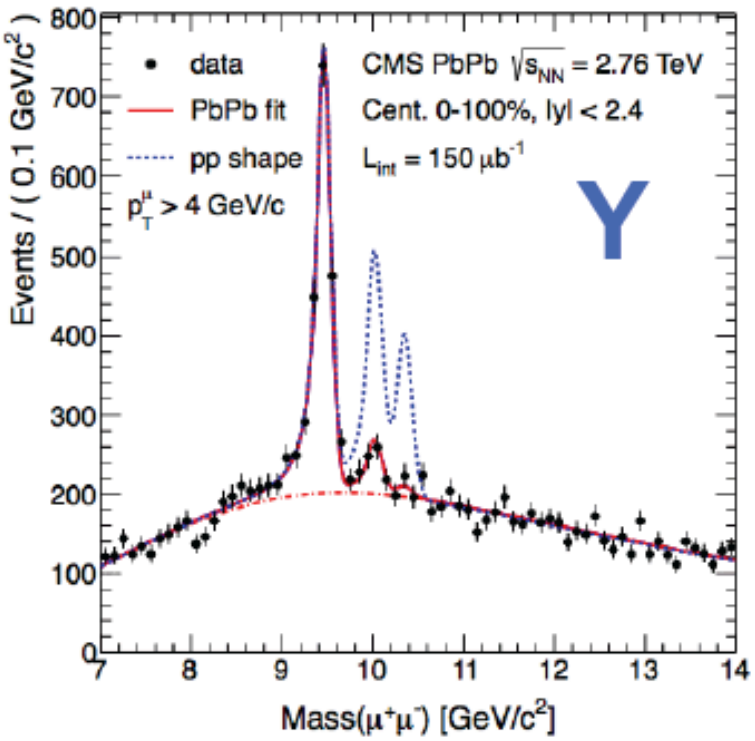

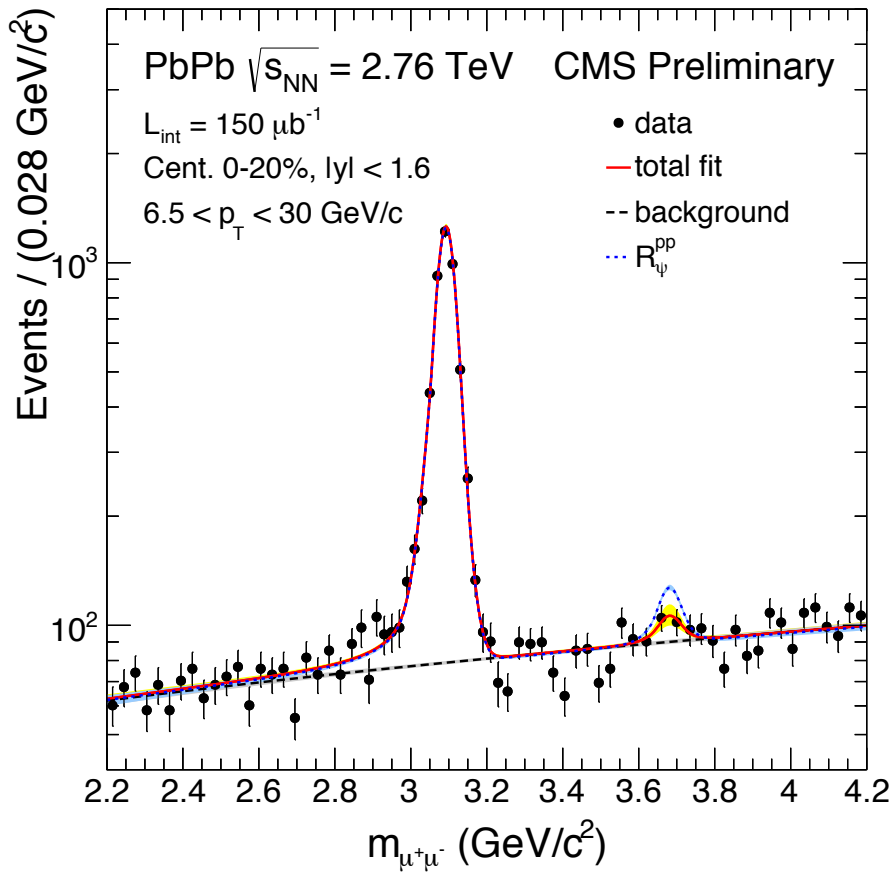

R_{AA} of Υ(1S)>Υ(2S)>Υ(3S)

Upsilon in pPb: cold nuclear effect?

- Excited states less suppressed than in PbPb: confirming the quarkonia suppression
- Still the pPb double ratio is not 1: cold nuclear effect?
- Excited/ground state ratio appears to vary with the event multiplicity:
  - Excited states adding multiplicity?
  - Activity suppressing the excited states? Already in pp

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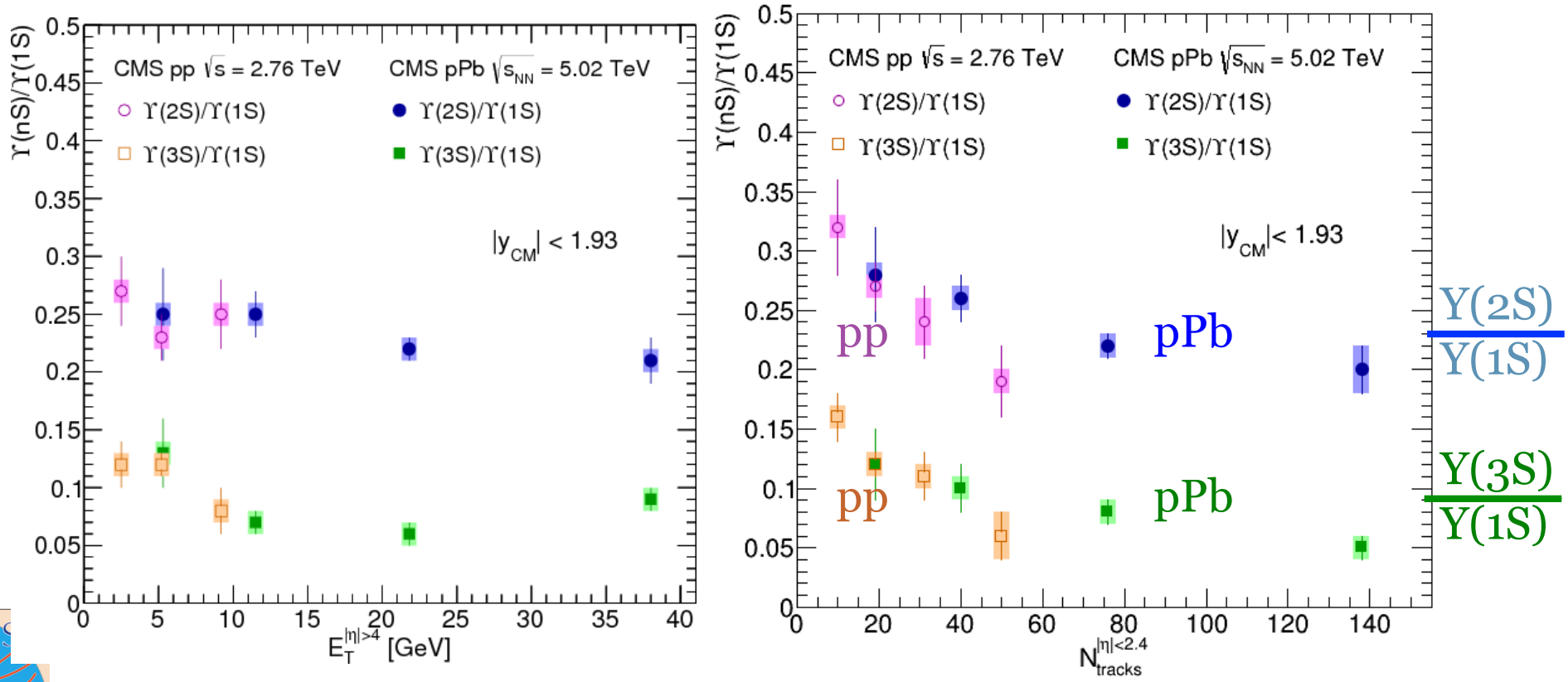
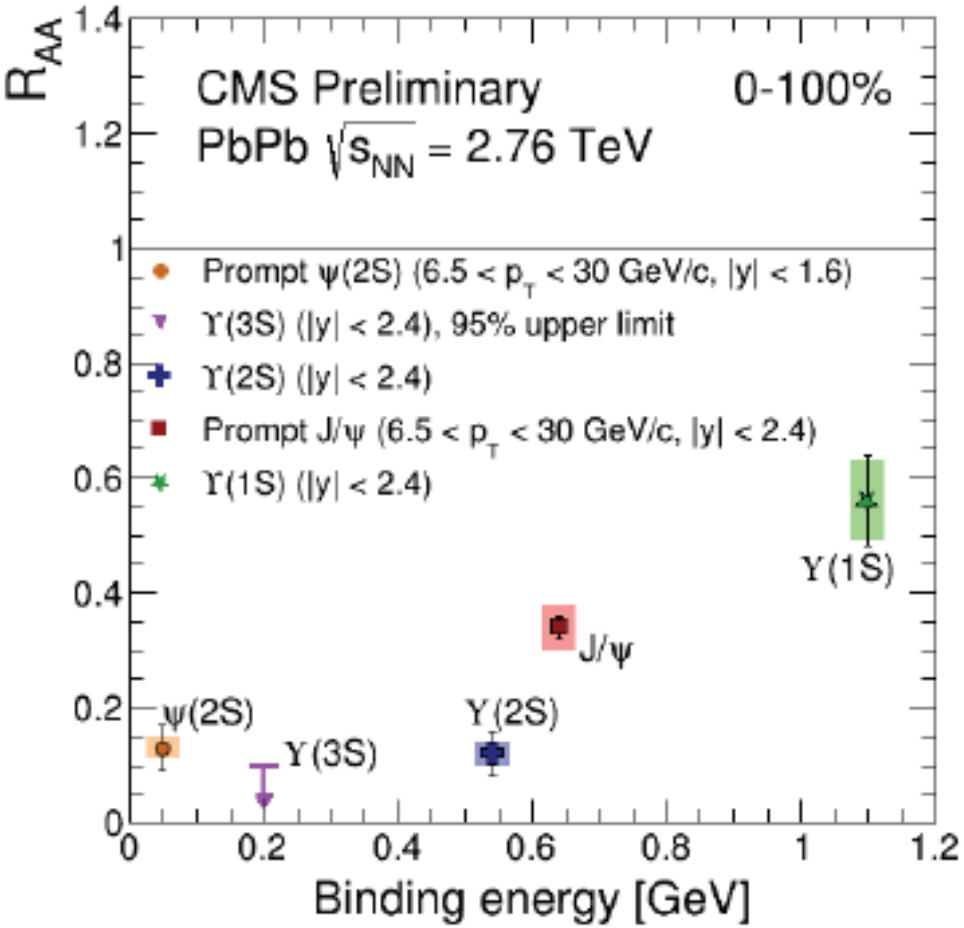
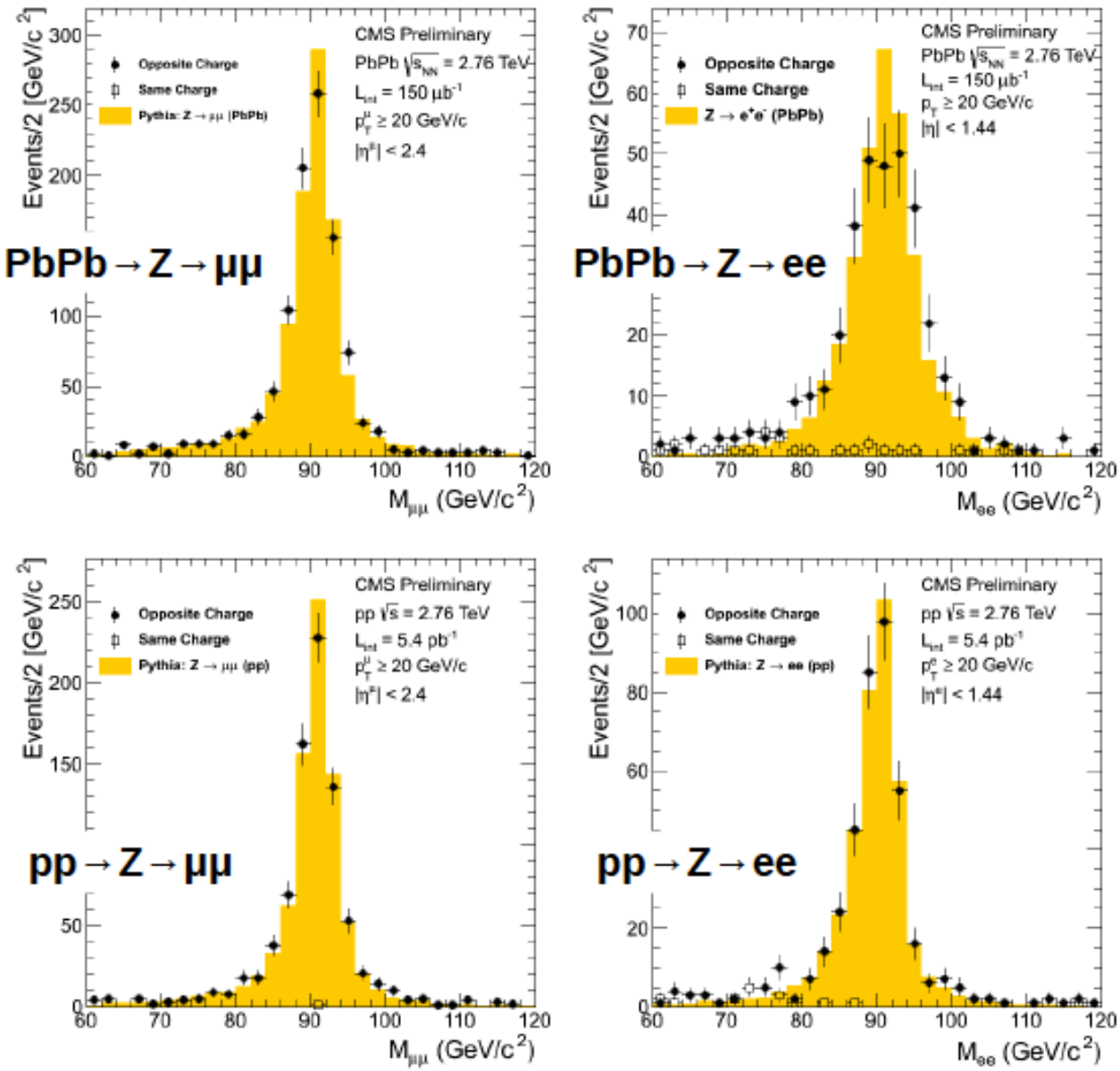


Hierarchy suppression?



CMS-PAS-HIN-12-014
PRL 109 (2012) 222301

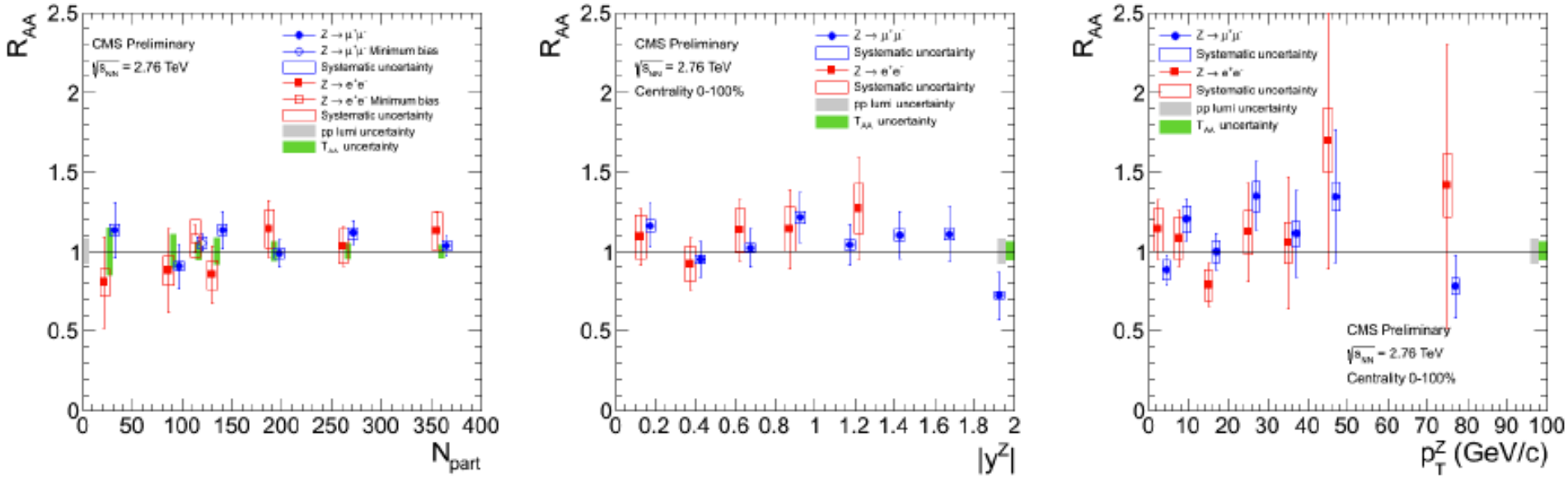
Z in PbPb



- 2011 PbPb data
- 2013 pp data
- Both muon and electron channels included
- Lepton selection:
  - p_T > 20 GeV/c
  - $|\eta^{\mu\,(e)}|$ < 2.4 (1.44)
- Dilepton mass in [60, 120] GeV/c^2

CMS-PAS-HIN-13-004

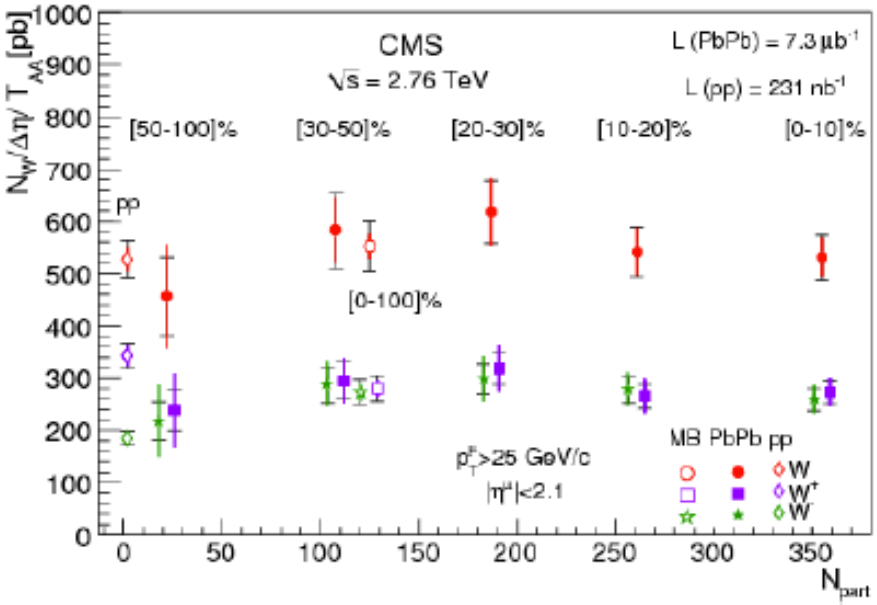
Z RAA

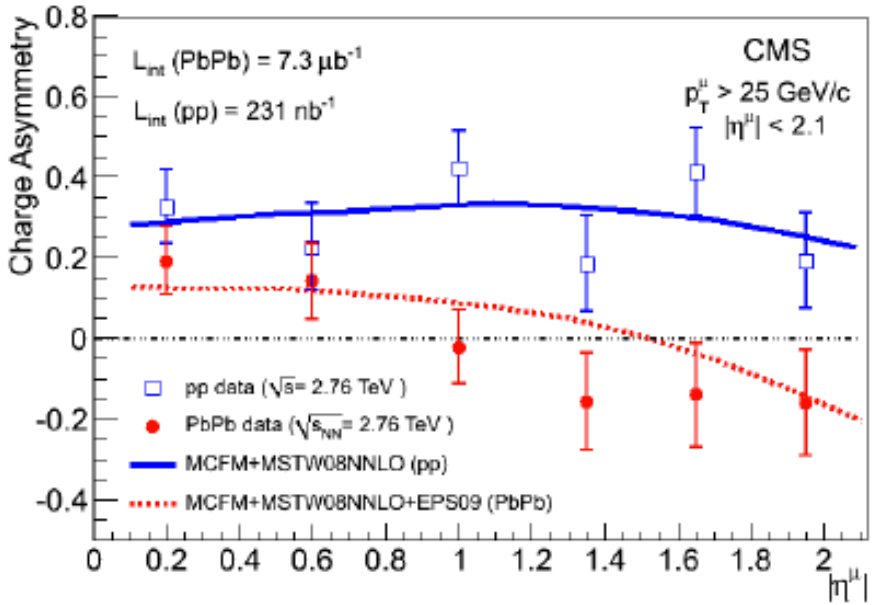


CMS-PAS-HIN-13-004

- Muon and electron results agree
- R_{AA} consistent with 1
- Scaling with number of binary collisions confirmed
- Possible nuclear effects on the p_T or rapidity spectrum are within the uncertainties of the measurement

W in PbPb





- R_{AA} (W) = 1.04 ± 0.07 ± 0.12
- R_{AA} (W^+) = 0.82 ± 0.07 ± 0.09
- R_{AA} (W^-) = 1.46 ± 0.14 ± 0.16
- Consistent with isospin effect

- Charge asymmetry in pp and PbPb
- Experimental values compatible with NLO pQCD predictions

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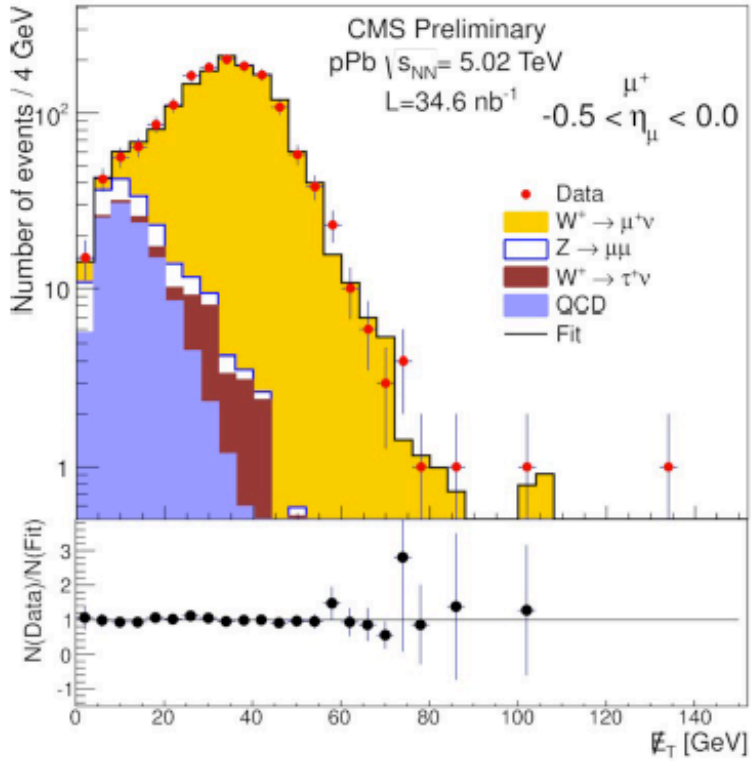
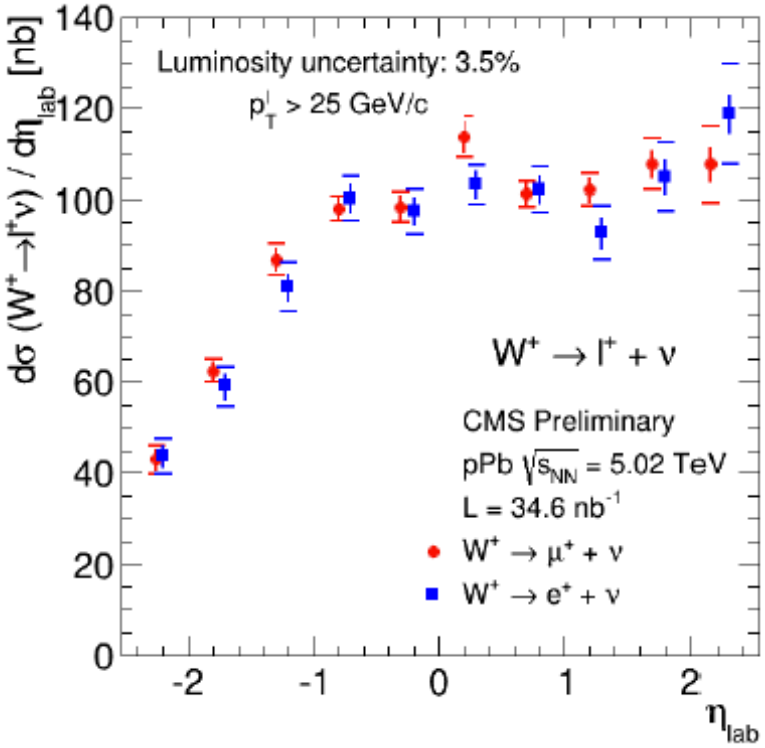
W in pPb

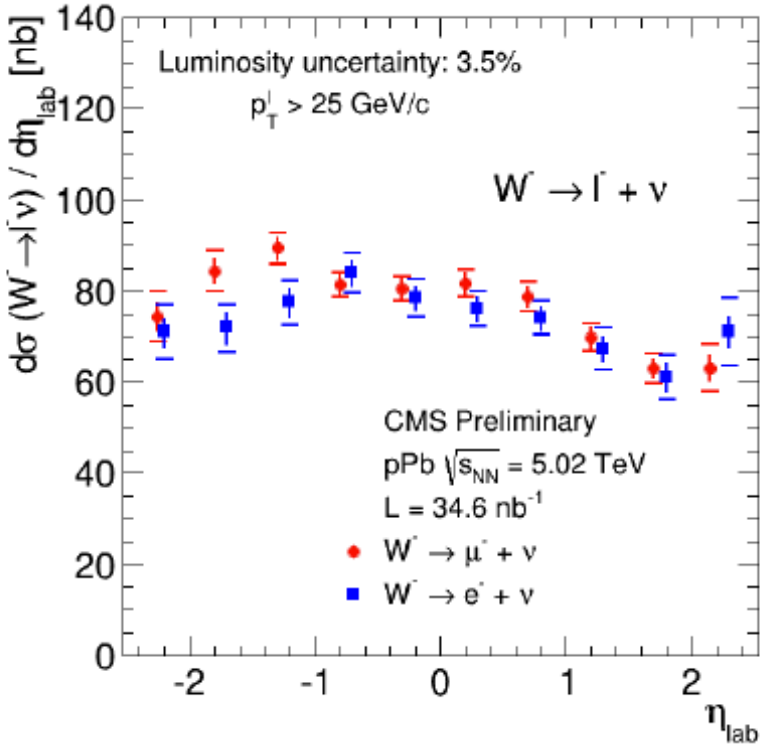
- Event selection
  - $p_T^{\mu/e} > 25$ GeV/c
  - $|\eta^{\mu(e)}_{lab}| < 2.4$ (2.5)
  - Quality and isolation requirements
  - Veto on dilepton events
- Fitting the missing transverse energy for both charges and every η bin
- Templates for QCD from data-based method and electroweak ($Z \to \mu\mu$ / ee, $W \to \tau\nu$) from simulation



CMS-PAS-HIN-13-007

W in pPb





- Cross section as a function of η in laboratory frame
- Electron and muon results agree → combination is performed

CMS-PAS-HIN-13-007