Quarkonia production in heavy-ion collisions in CMS

Songkyo Lee
(Korea University)
for the CMS collaboration

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Outline

- **Introduction**
  - Motivation, CMS Detector
- **Charmonia in PbPb collisions**
  - Prompt J/ψ : R_{AA}
  - Prompt J/ψ : azimuthal anisotropy
- **Bottomonia in PbPb & pPb collisions**
  - ϒ(1S), ϒ(2S) and ϒ(3S)
- **Summary**

Motivation

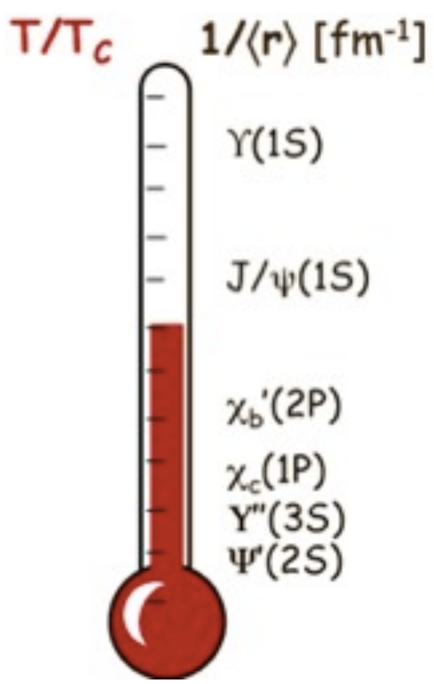
- **Quarkonia**
  - Bound states of heavy quark and antiquark
  - Large mass requires a large momentum transfer only during the early stage of the collisions.

  ⇒ Powerful tool to probe QGP

- **Debye screening**
  - Loosely bound states (with smaller binding energies) melt at lower temperature.
  - Sequential melting of the quarkonia

  ⇒ Thermometer of QGP

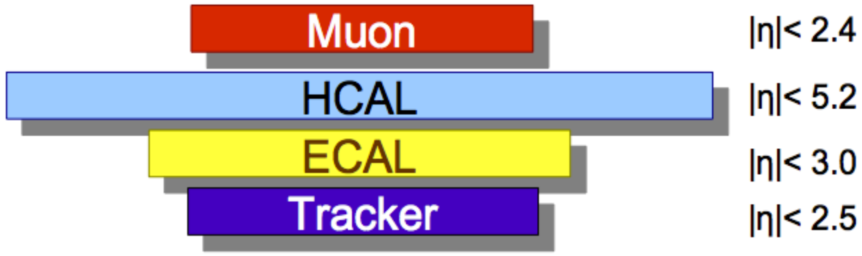
Resonance	J/ψ	Ψ'	Υ(1S)	Υ(2S)	Υ(3S)
Mass [GeV]	3.10	3.68	9.46	10.02	10.36
ΔE [GeV]	0.64	0.05	1.10	0.54	0.20
Radius [fm]	0.25	0.45	0.14	0.28	0.39



T. Matsui & H. Satz, PLB 178 (1986) 416

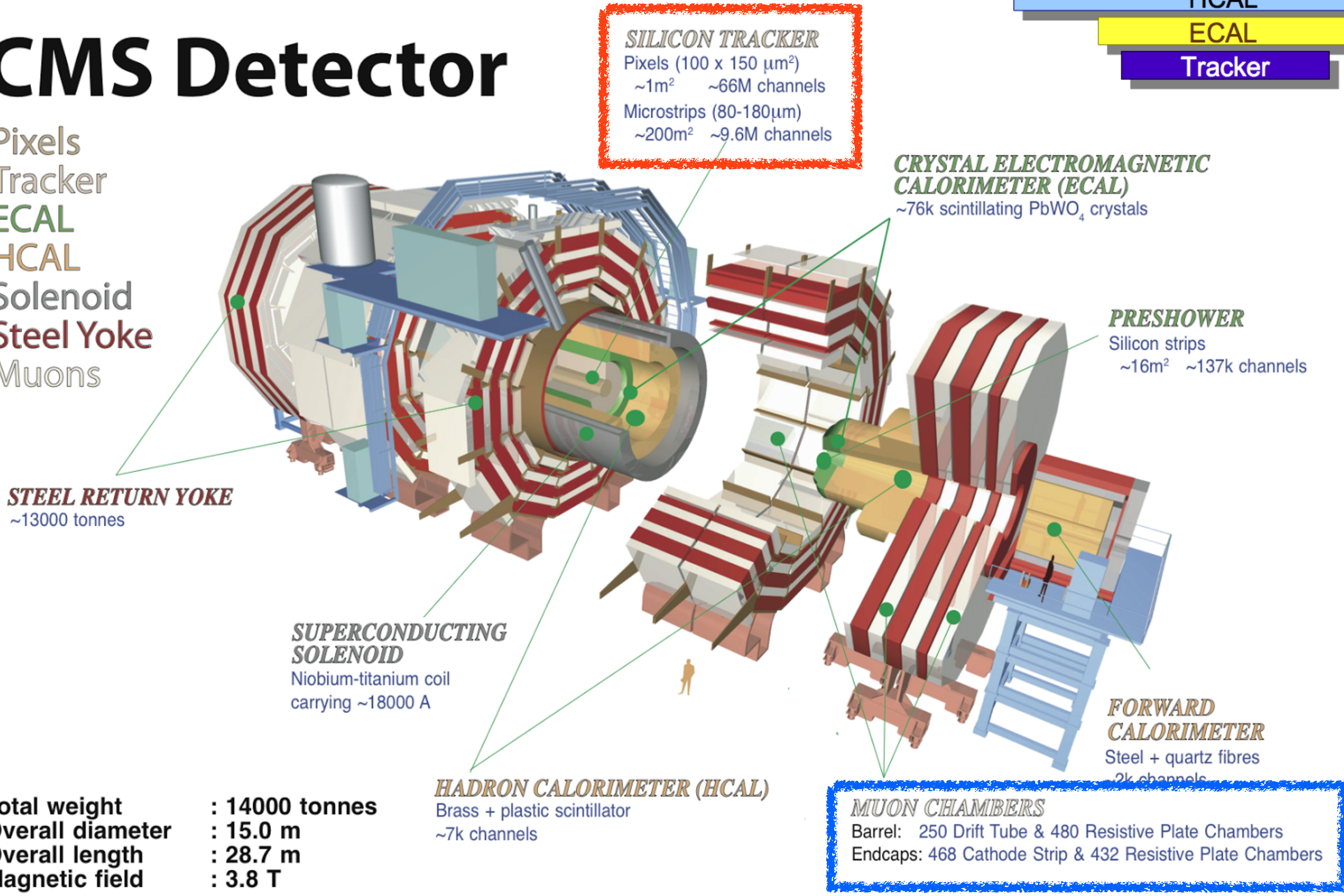
Mocsy, EPJC 61 (2009) 705

CMS Detector



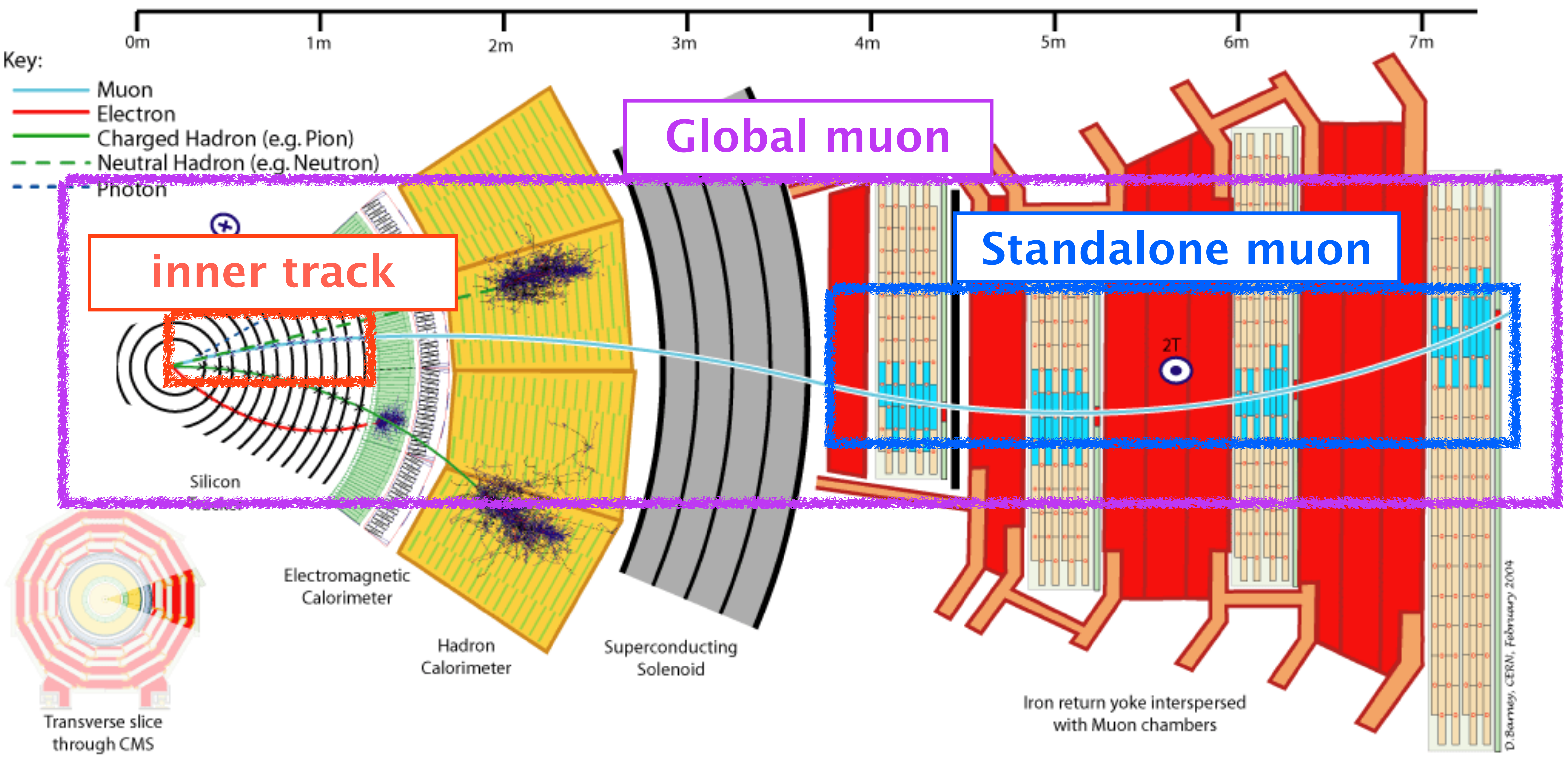
CMS Detector

Pixels
Tracker
ECAL
HCAL
Solenoid
Steel Yoke
Muons



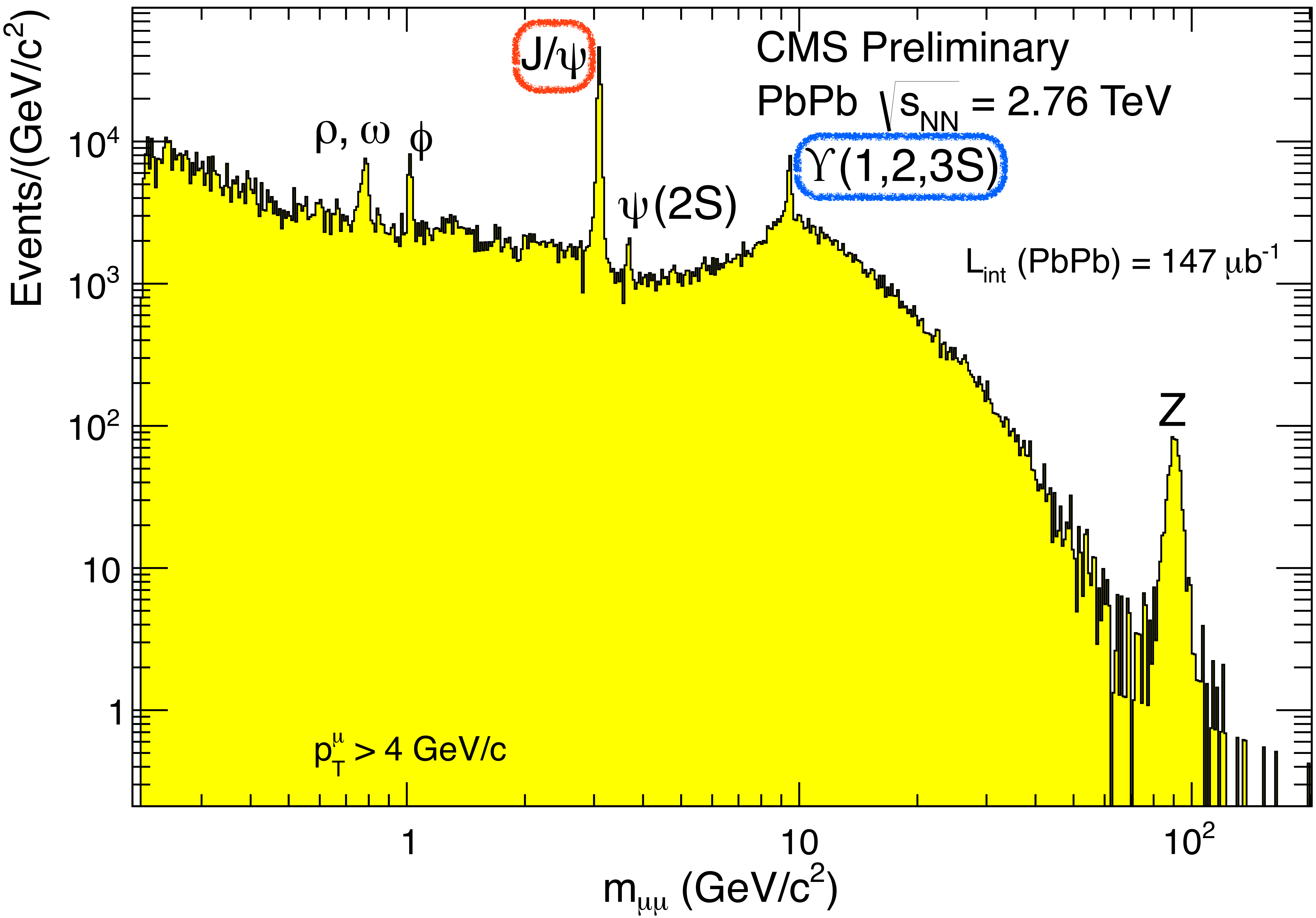
Total weight	**: 14000 tonnes**
Overall diameter	**: 15.0 m**
Overall length	**: 28.7 m**
Magnetic field	**: 3.8 T**

Muon Reconstruction

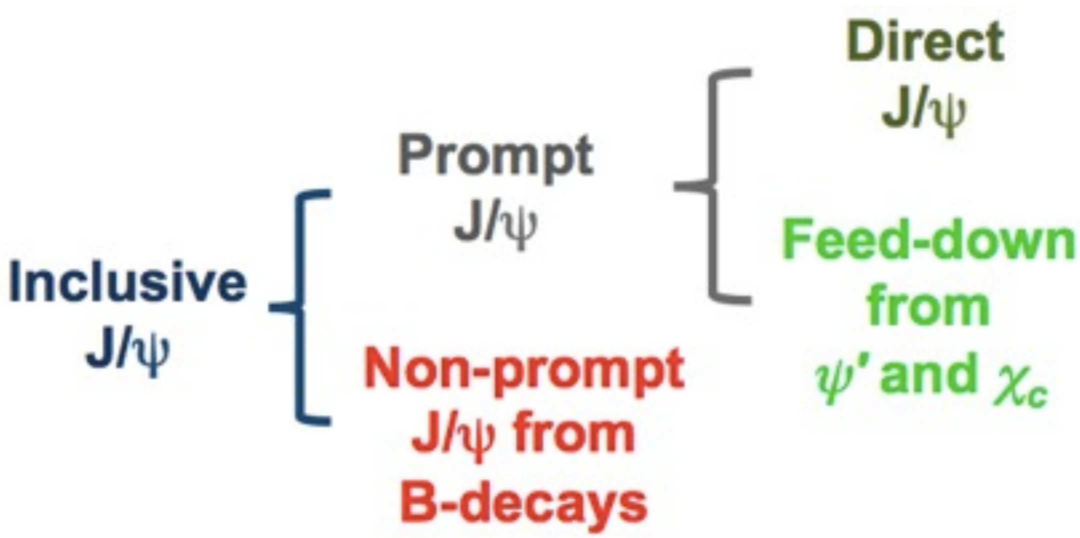


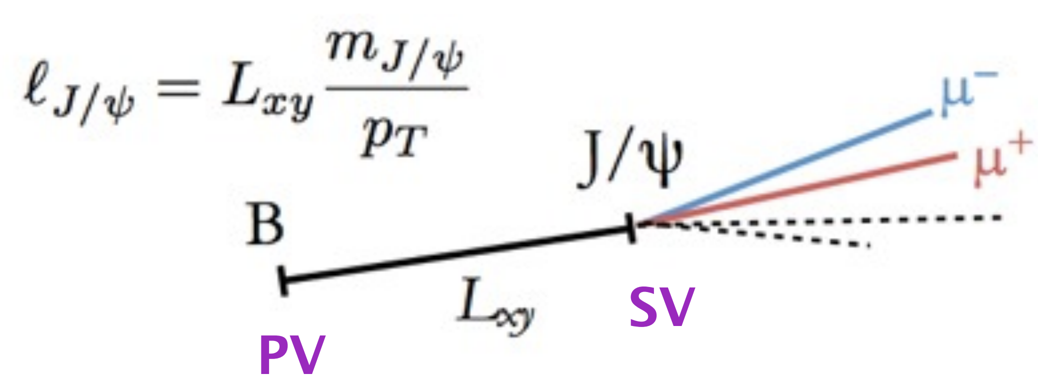
- Excellent muon Identification and triggering in the muon system
- Outstanding momentum and vertex resolution of the tracking system

Dimuons in PbPb @ 2.76 TeV

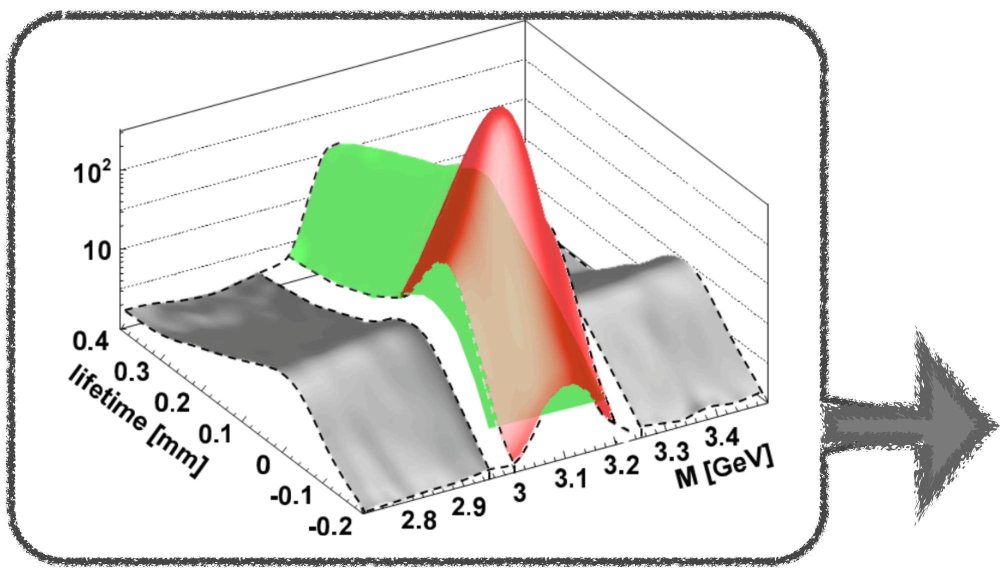


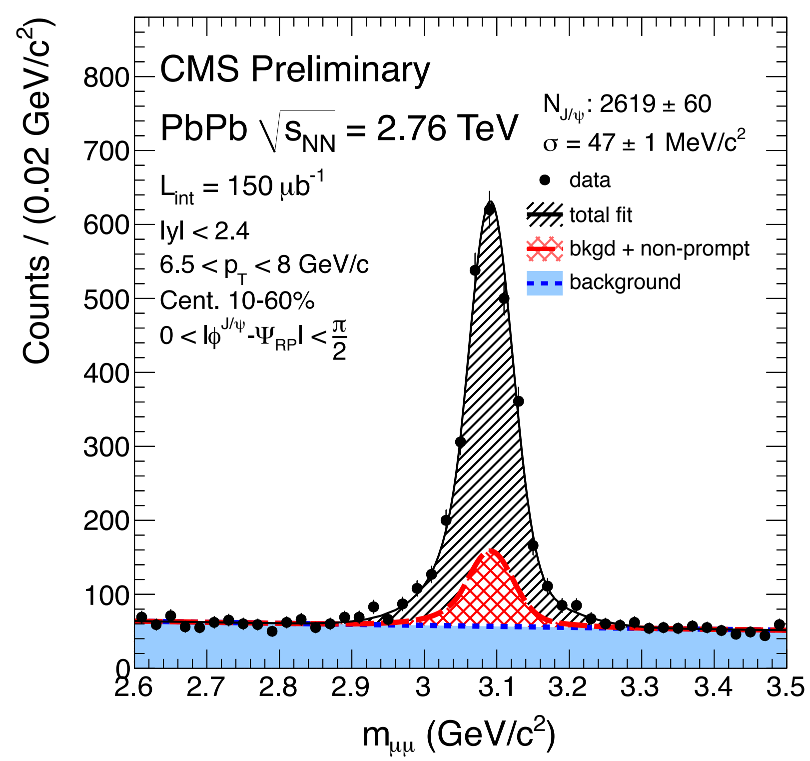
- **Separation of prompt J/ψ and non-prompt J/ψ**
  - 2-Dimentional simultaneous fit for $m_{\mu\mu}$ & $\ell_{J/\psi}$

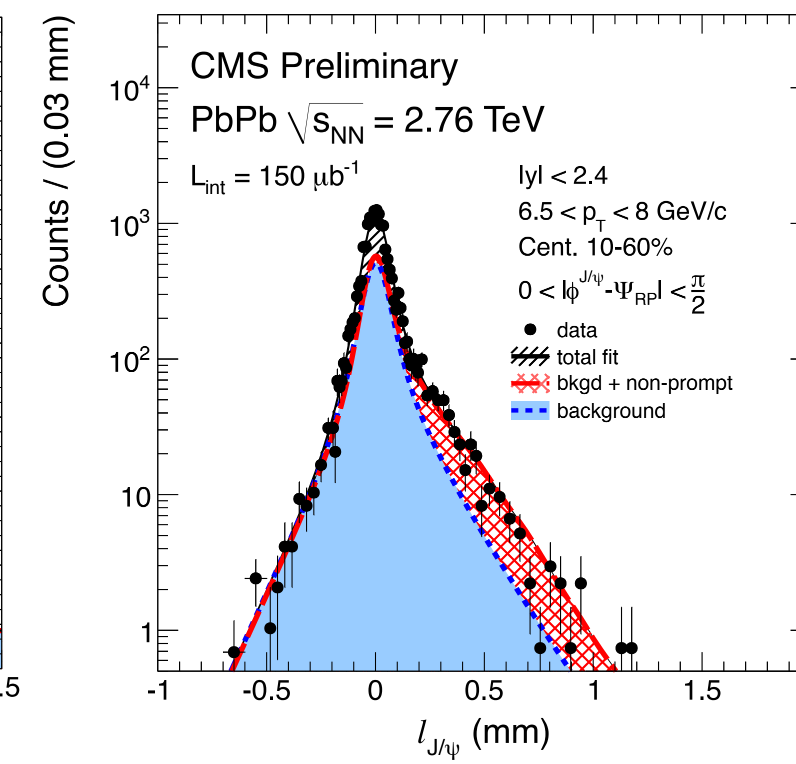




lifetime of the b hadrons ($\mathcal{O}(500)\ \mu m/c$)







CMS-PAS HIN-12-014

JHEP 05 (2012) 063

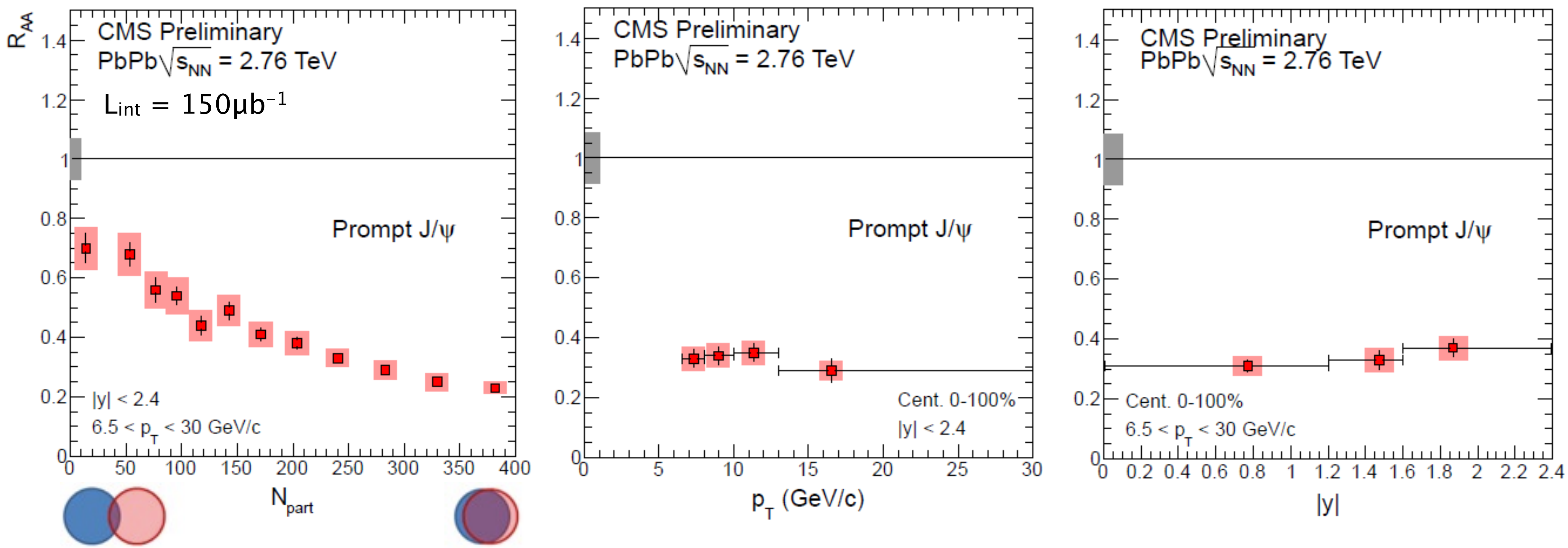
Prompt J/ψ R_{AA}

CMS-PAS HIN-12-014

- **Nuclear modification factor**

$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}}{N_{pp}} \cdot \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

: $R_{AA} = 1$ No modification compared to pp collisions



- Suppressed by factor ~5 in the most central bin
- No p_T and y dependent suppression is observed.

J/ψ Azimuthal Anisotropy

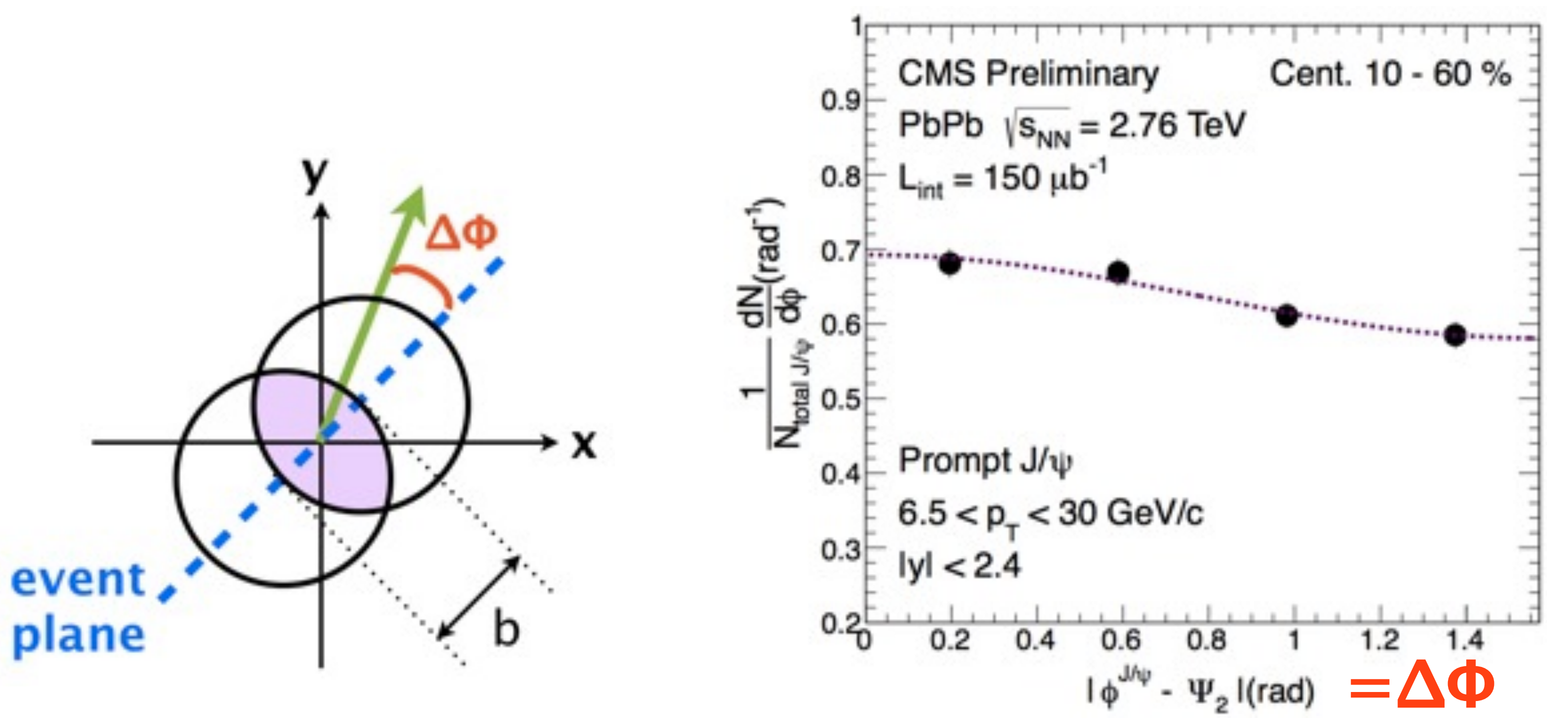
CMS-PAS HIN-12-001

- **Elliptic flow (v_2)**
  - Important to understand the dynamics of heavy-ion collision

In non-central collisions

→ Asymmetry in the collective expansion
→ Path-length dependent absorption

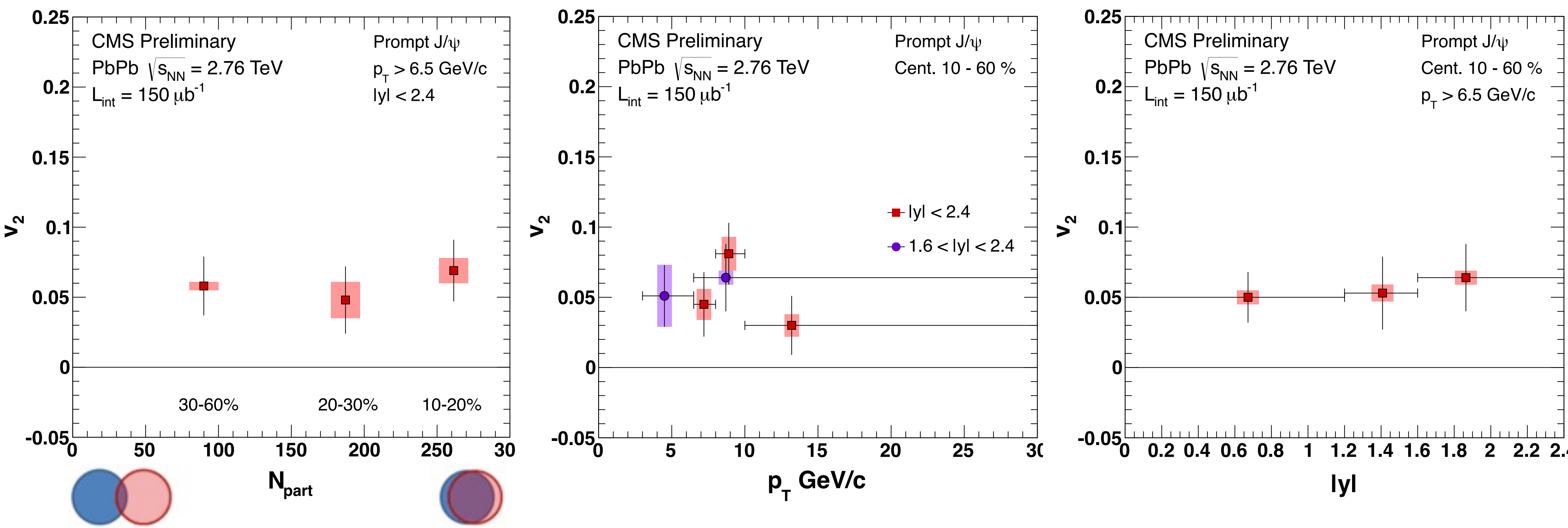
- Reflected in the azimuthal distribution of particle yields



$$\frac{1}{N_{total}} \cdot \frac{d^2N}{d\phi} \propto 1 + 2v_2\cos(2\Delta\phi)$$

Prompt J/ψ v_2

CMS-PAS HIN-12-001



- No strong centrality, p_T, and rapidity dependence
- Integrated v_2 value (10–60%, 6.5 < p_T < 30 GeV/c, |y| < 2.4)

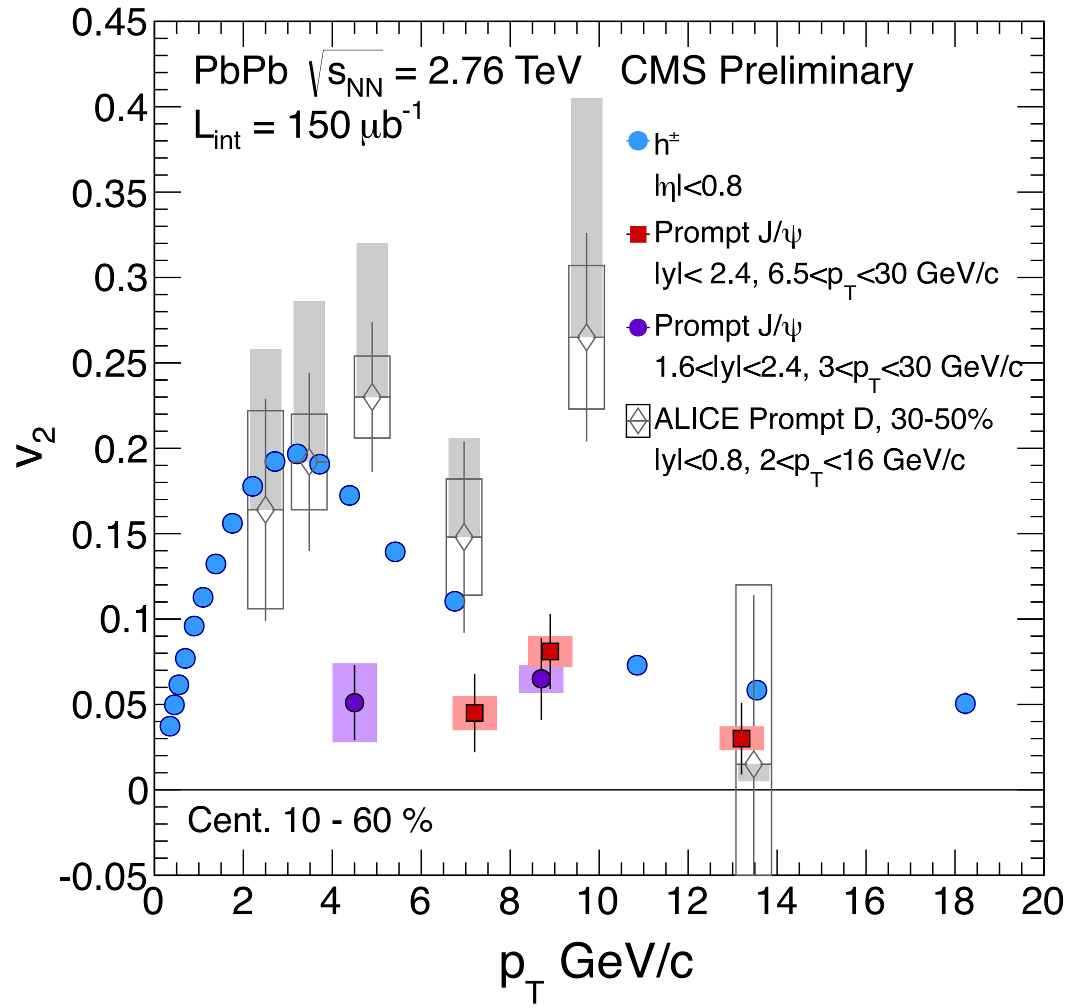
$$v_2 = 0.054 \pm 0.013(stat.) \pm 0.006(syst.)$$

'First' significant measurement of prompt J/ψ v_2

Comparison with other hadrons

CMS-PAS HIN-12-001

JHEP 1209 (2012) 112

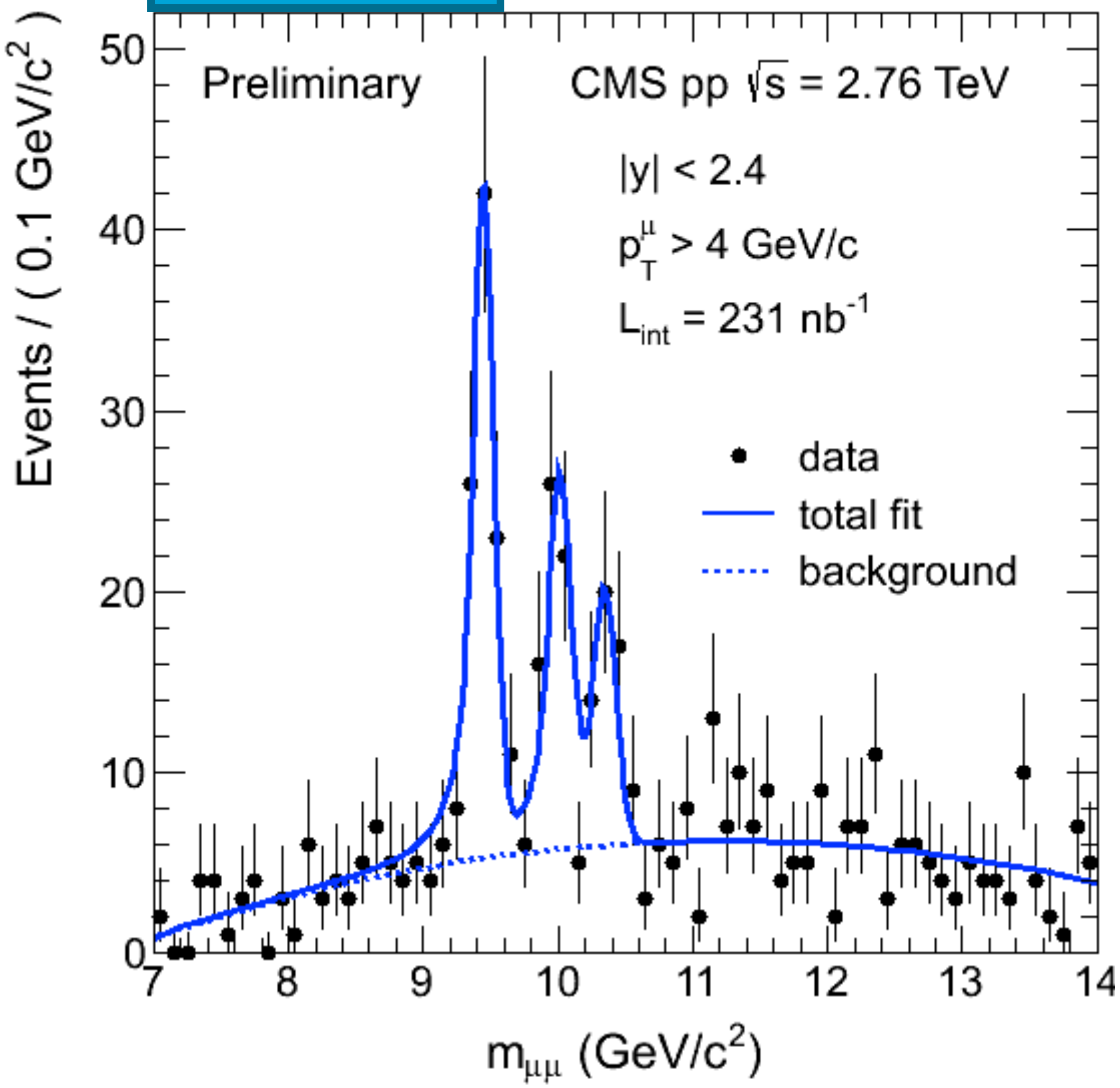


- J/ψ v_2 at lower p_T region is much smaller than hadron v_2 while higher p_T region shows similar v_2 values.
- D meson v_2 has similar trend to hadron rather than J/ψ.

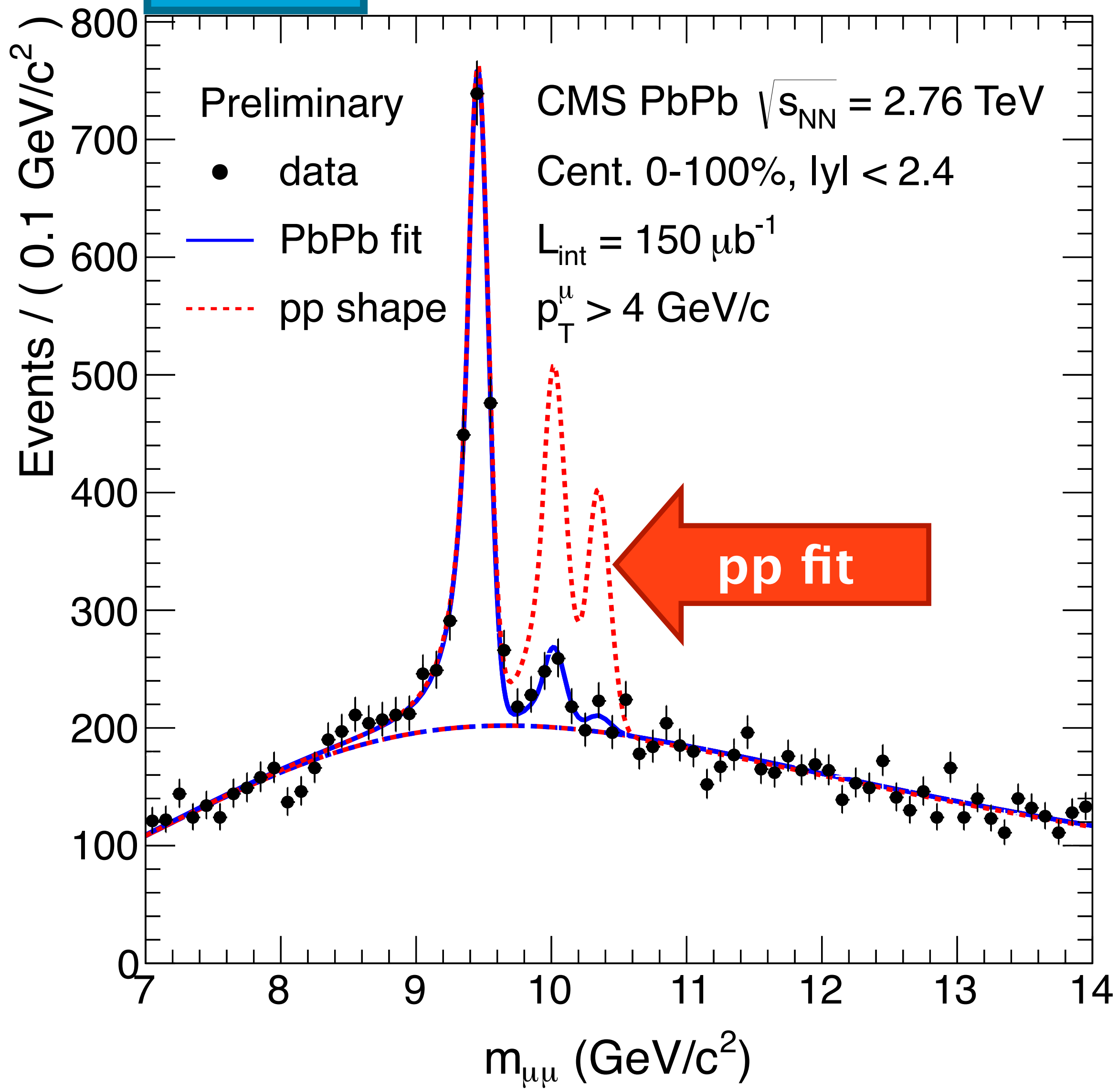
Υ(nS) in PbPb

PRL 109 (2012) 222301

2011 pp

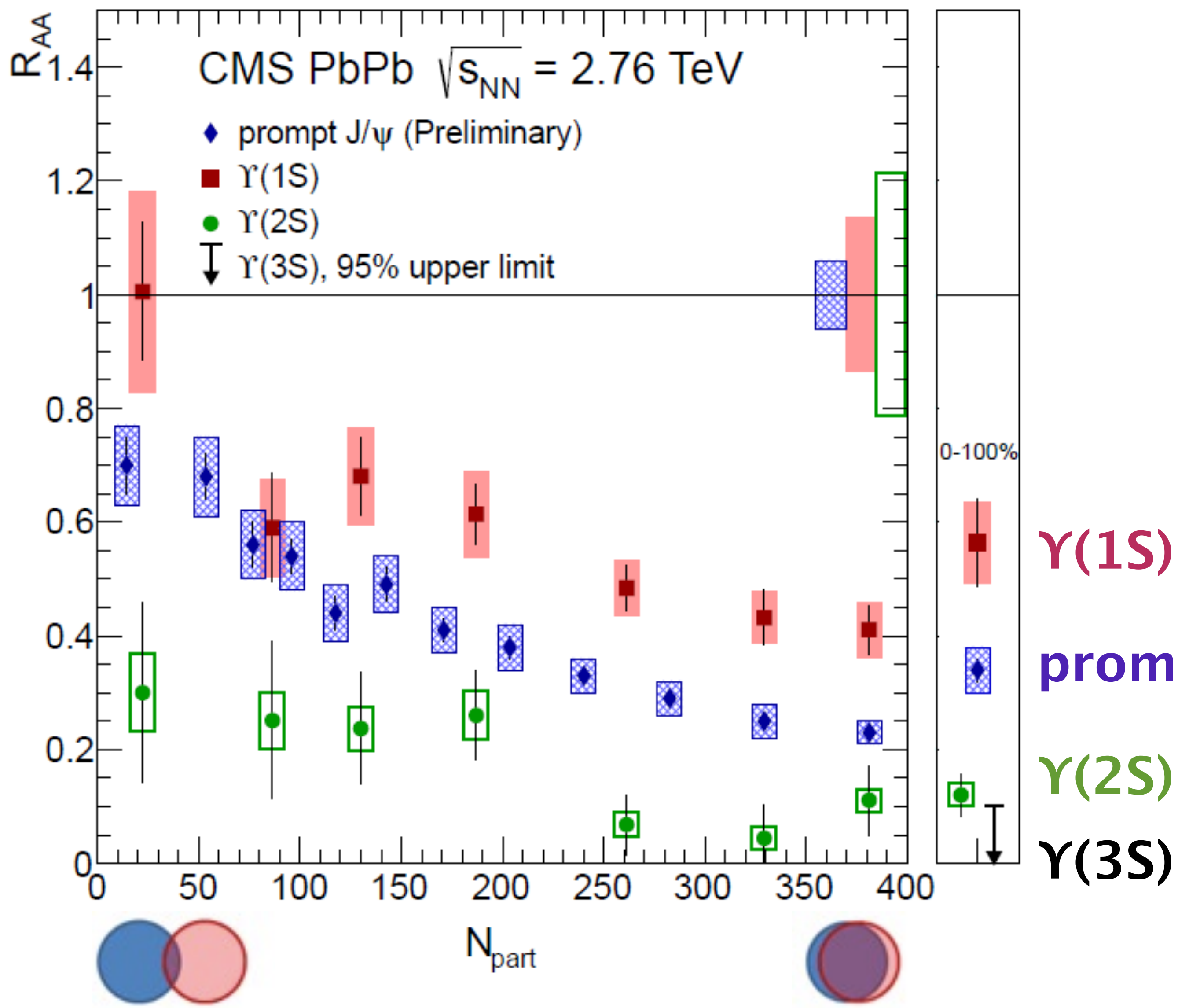


PbPb



- In PbPb, Excited states are suppressed relative to the ground state.
- The peak for Υ(3S) is hardly visible.

R_{AA} for Υ(nS)



- **Centrality integrated results**

$$R_{AA}(\Upsilon(1S)) = 0.56 \pm 0.08\,(\text{stat.}) \pm 0.07\,(\text{syst.})$$
$$R_{AA}(\Upsilon(2S)) = 0.12 \pm 0.04\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$
$$R_{AA}(\Upsilon(3S)) = 0.03 \pm 0.04\,(\text{stat.}) \pm 0.01\,(\text{syst.})$$
$$(< 0.10 \text{ at } 95\% \text{ CL})$$

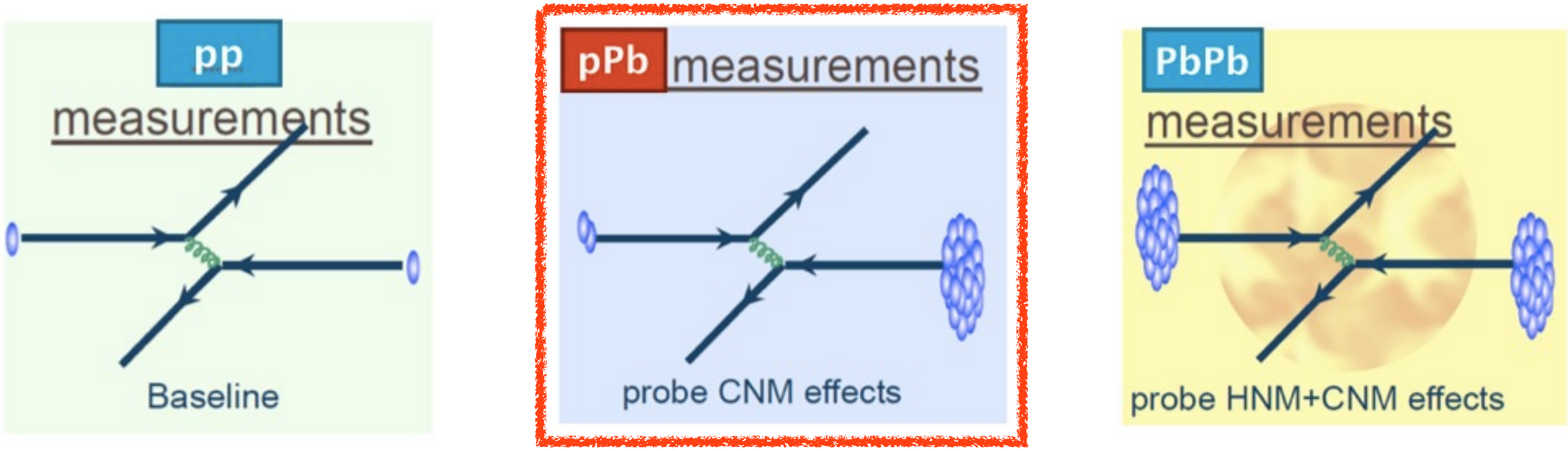
- **Υ states are suppressed sequentially.**

$R_{AA}[\Upsilon(1S)] > R_{AA}[\Upsilon(2S)] > R_{AA}[\Upsilon(3S)]$

PRL 109 (2012) 222301

CMS-PAS HIN-12-014

pPb collisions



- **Cold nuclear matter effects in pPb**
  - Initial state energy loss, comover break up, shadowing, etc.
  - provide a better understanding of the effects from QGP
  - CNM itself is a interesting matter.

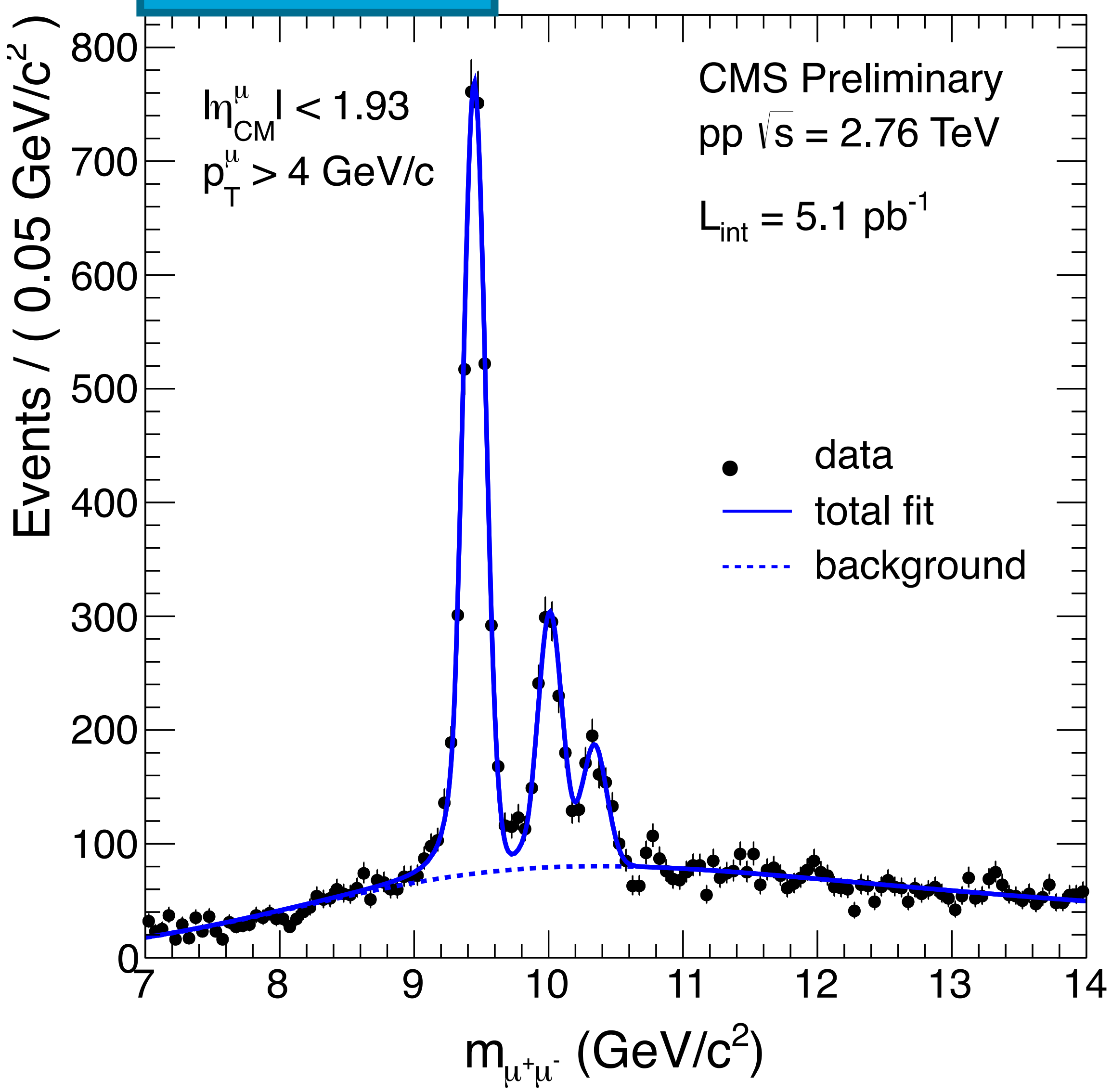
- **1st pPb run @ LHC in Jan.–Feb. 2013**
  - $\sqrt{S_{NN}}$ = 5.02 TeV
  - Recorded luminosity by CMS : 31.7 nb^{-1}

Υ(nS) in pPb from 2013

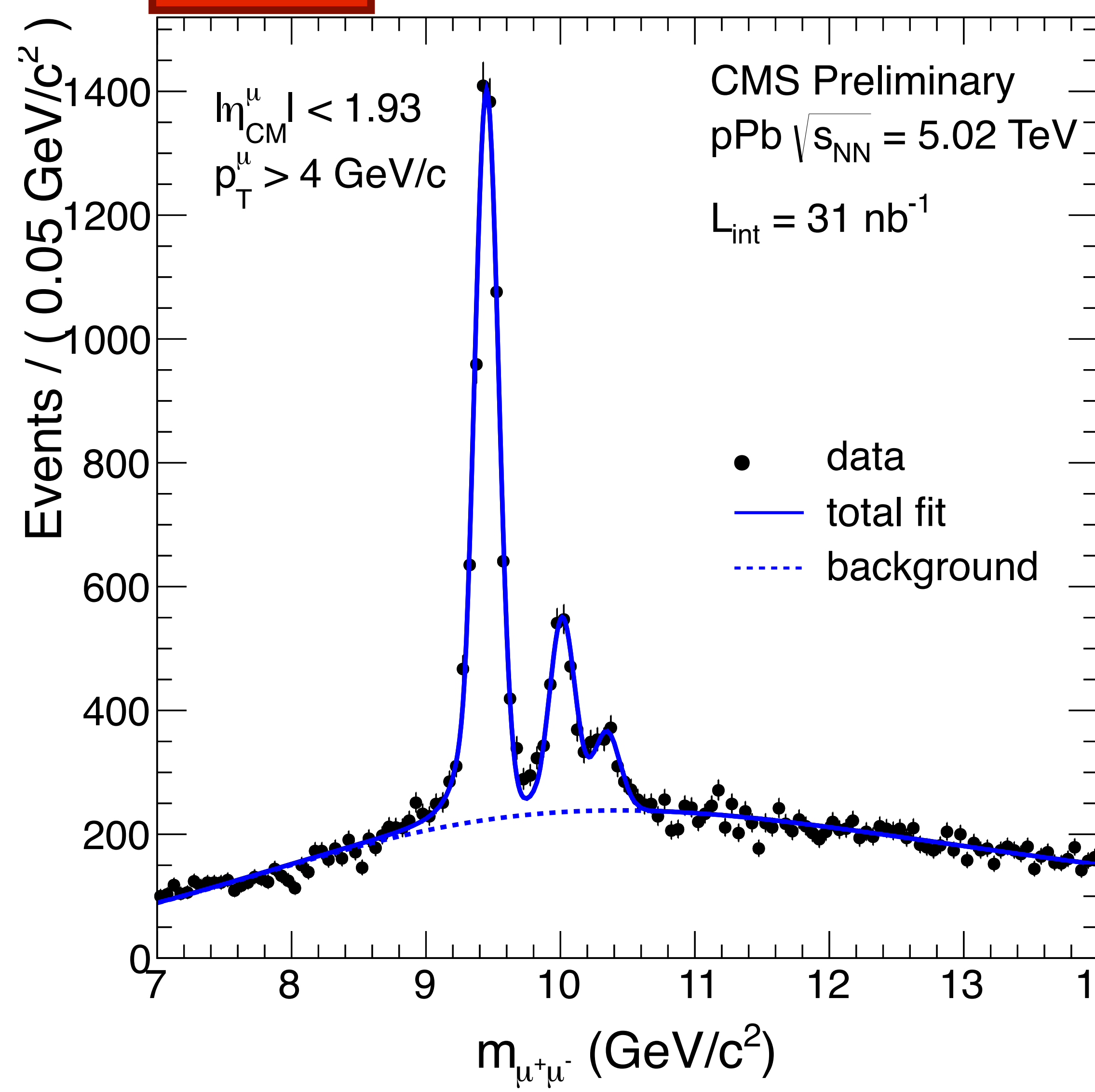
CMS-PAS HIN-13-003

2013 pp

X20 more statistics than 2011 pp data



pPb

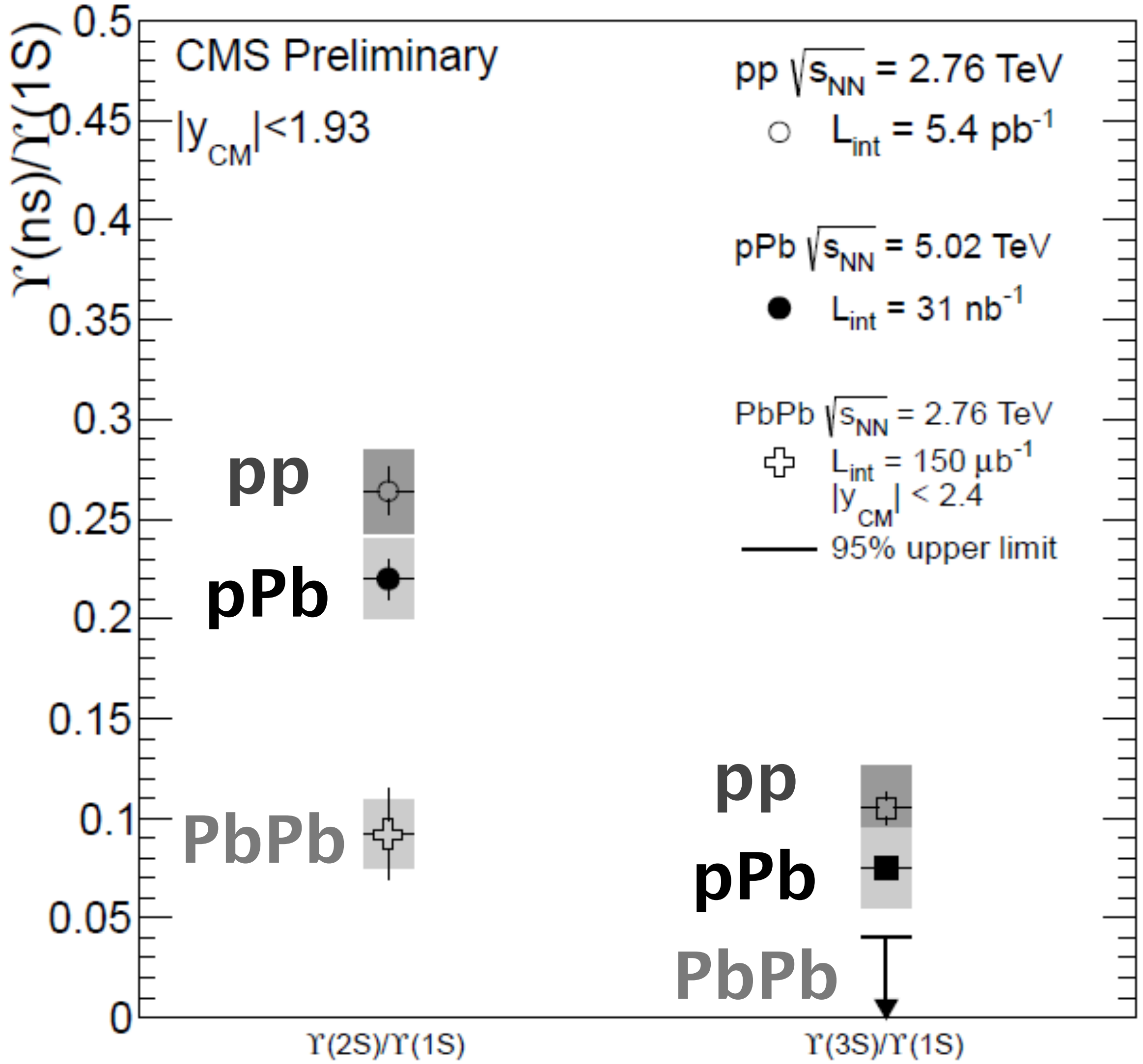


- Limited kinematic range($|y_{CM}| < 1.93$) due to the rapidity shift in the asymmetric p+Pb collisions
- Fitting procedure is same in pp, pPb, and PbPb analysis.

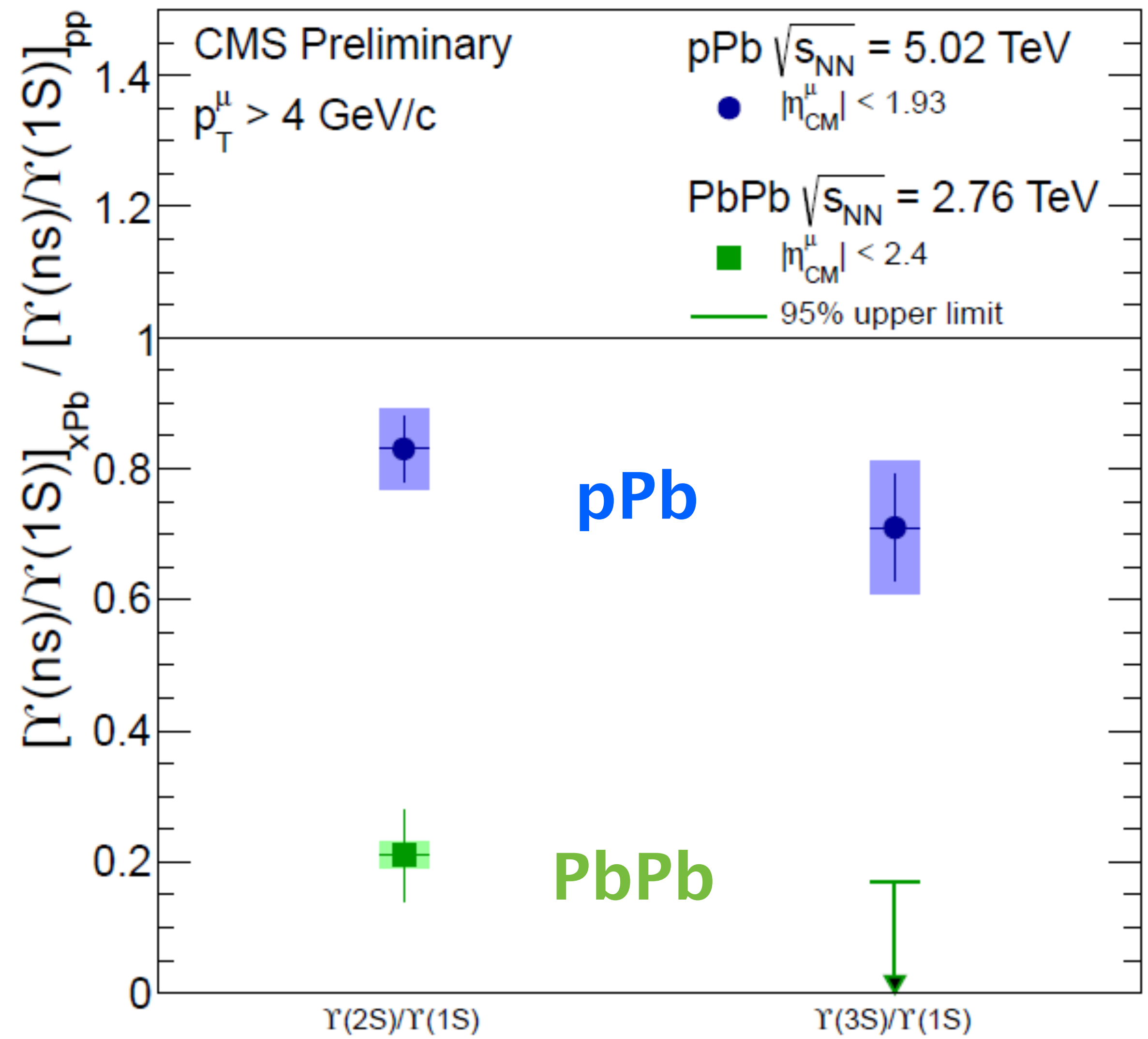
Double & Single ratios

CMS-PAS HIN-13-003

- **Single Ratio**

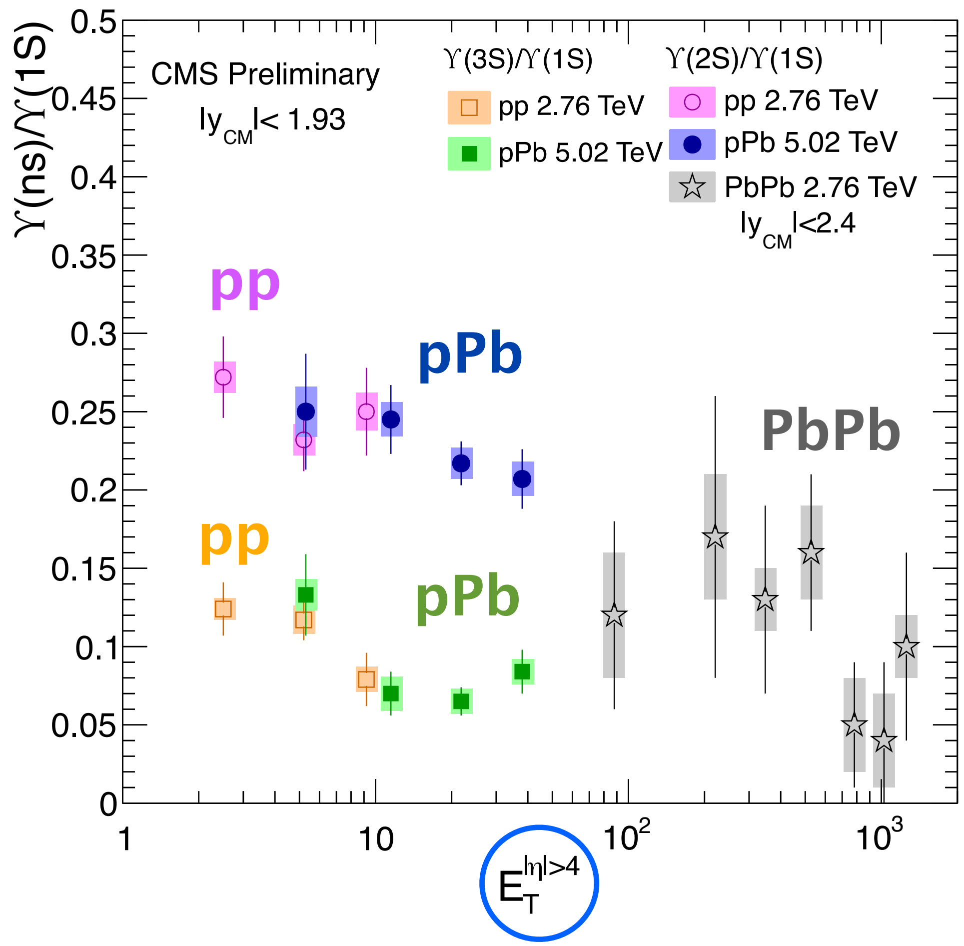


- **Double Ratio**

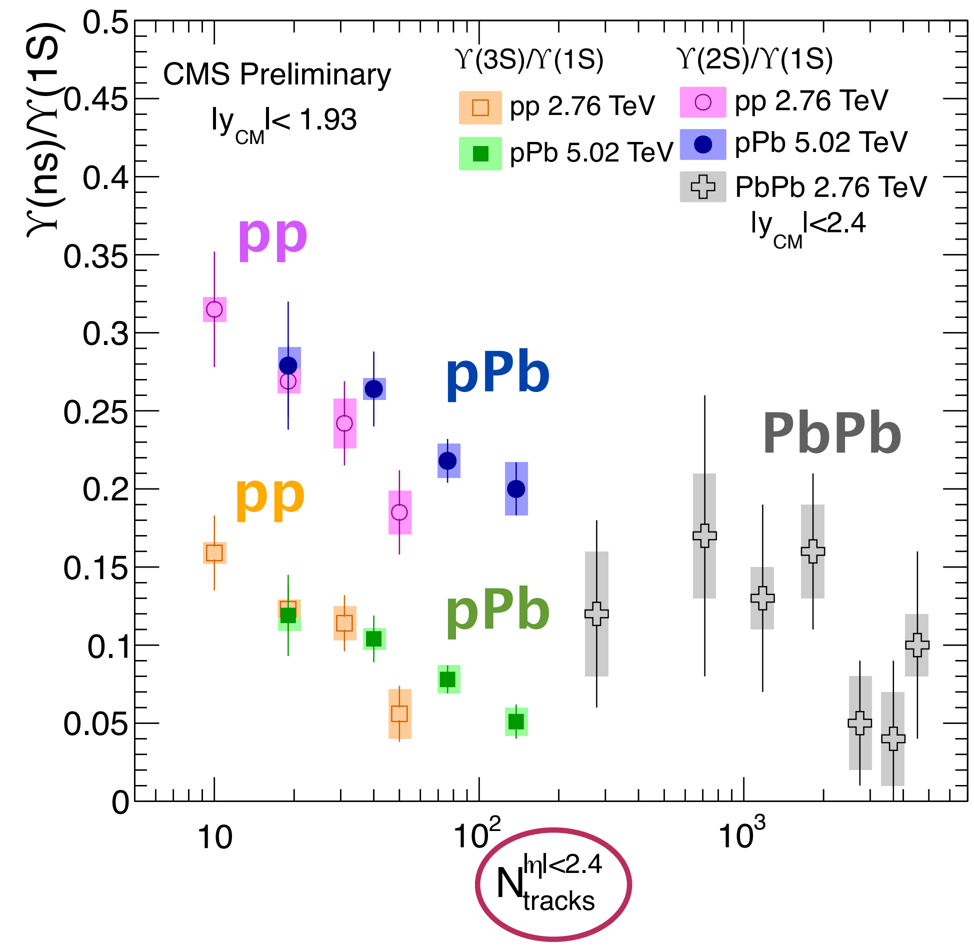


- **pPb vs pp** : Excited states are suppressed more than the ground state in pPb compared to pp.
- **PbPb vs pPb** : Additional final state effects in PbPb that affect the excited states more than the ground state.

Event activity variables

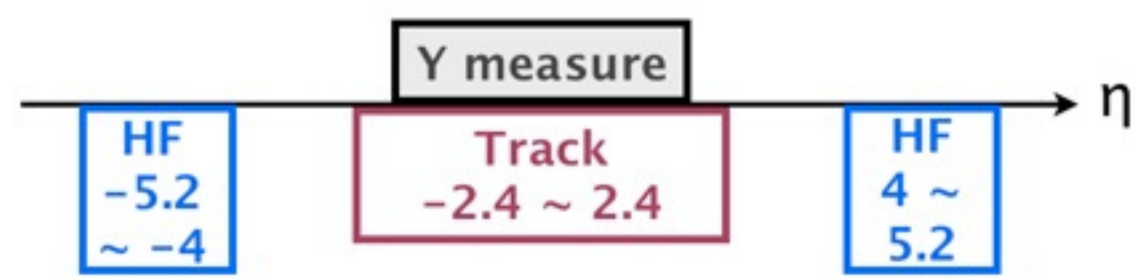


raw transverse energy measured in HF



corrected N_{tracks} in inner tracker

- Single ratios in all cases show the weaker dependence on E_T.
- In pp and pPb, the significant decreasing dependence on N_{tracks}.
  - Υ would affect the multiplicity ?
  - Multiplicity would affect the Υ ?



Summary

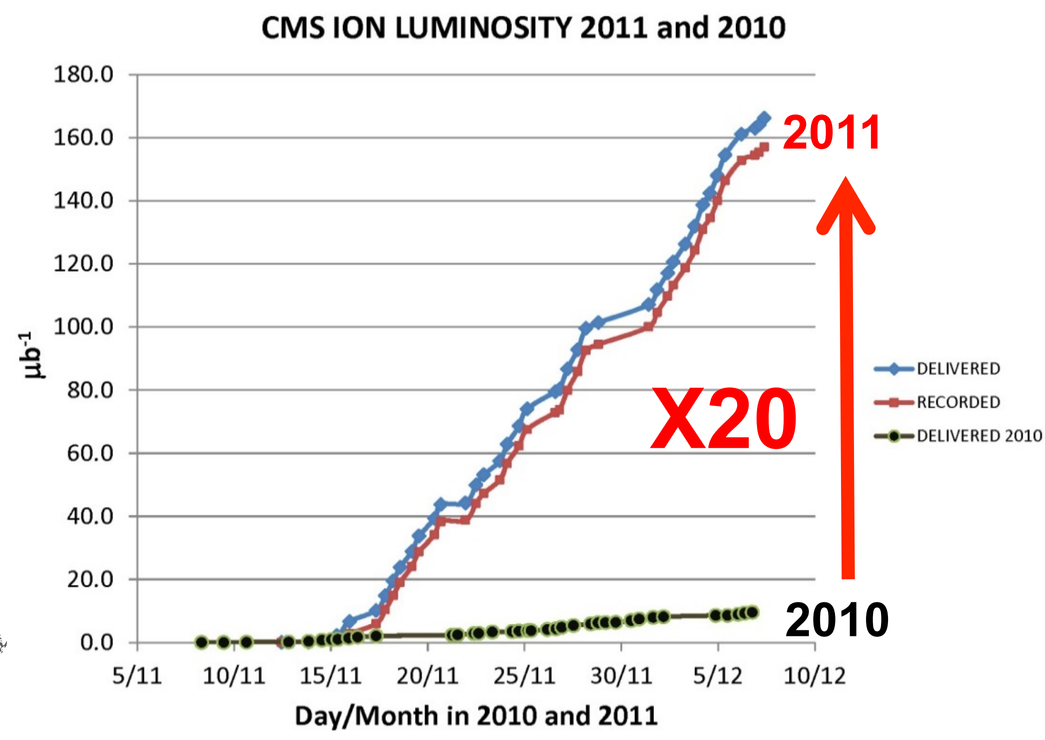
- **Charmonia in PbPb collisions**
  - prompt J/ψ is suppressed by factor 5 in the most central bin.
  - Significant anisotropy of prompt J/ψ in 10-60%, $6.5 < p_T < 30$ GeV/c, $|y| < 2.4$

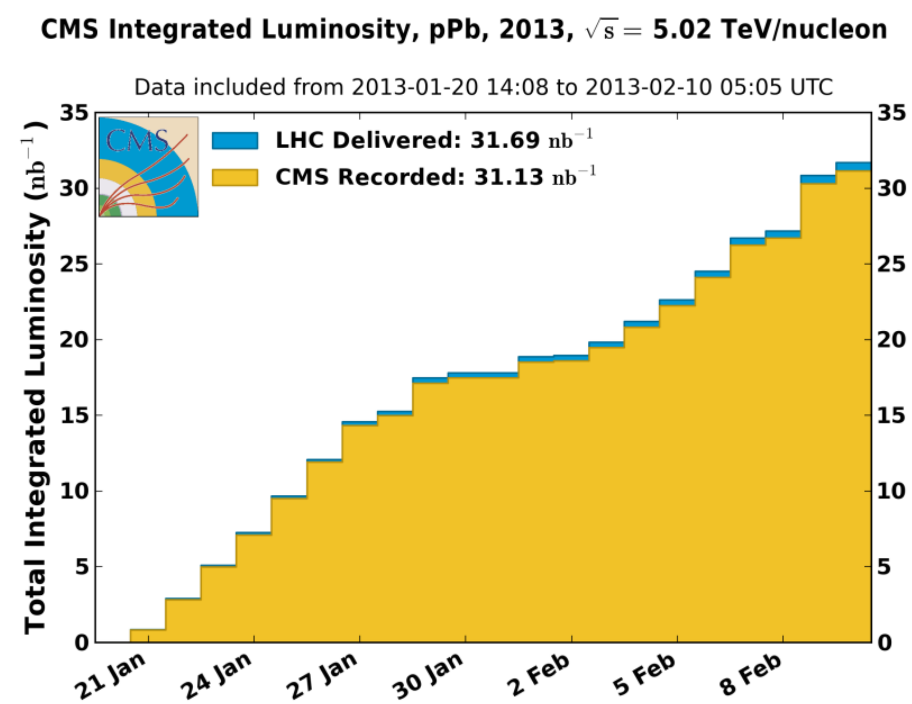
- **Bottomonia in PbPb & pPb collisions**
  - Sequential melting of ϒ(nS) is observed in PbPb.
  - Indication for the cold nuclear matter effect in pPb.

BACK-UP

pp, pPb, PbPb run at LHC & CMS

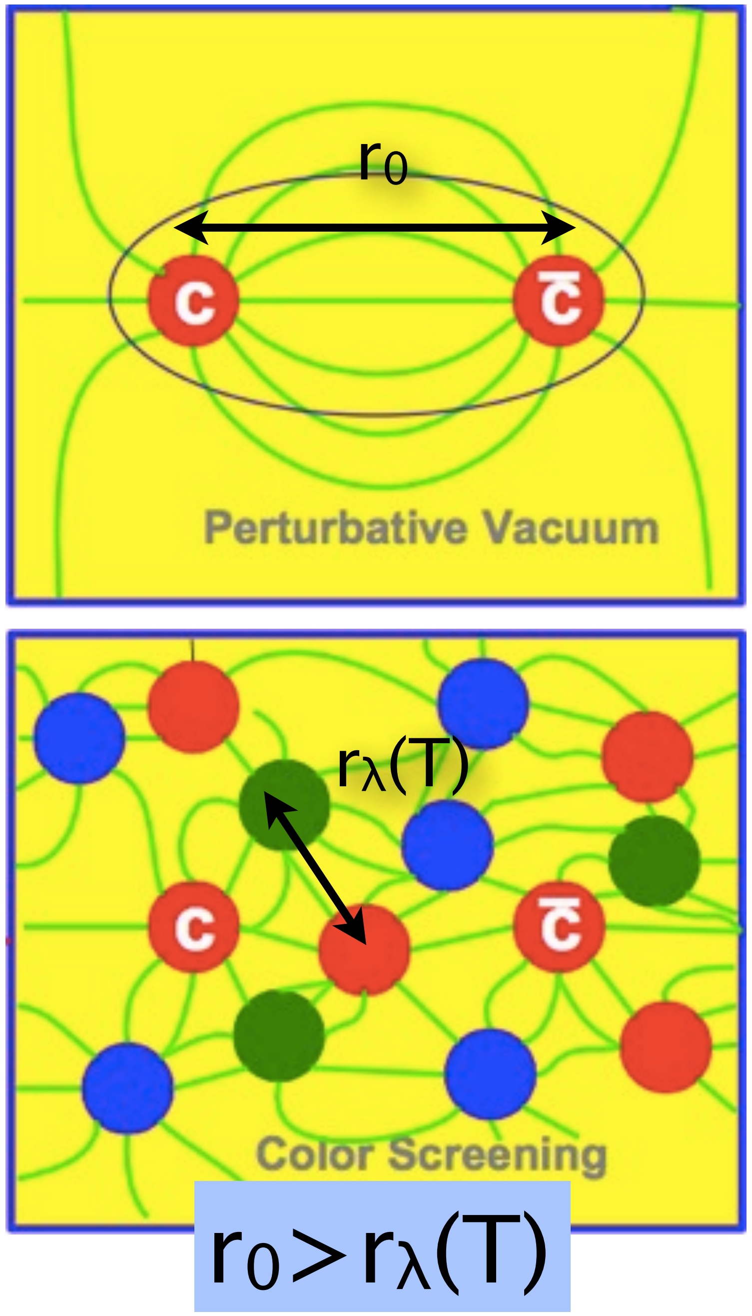
- **1st PbPb run @ $\sqrt{S_{NN}}$ = 2.76 TeV**
  - Nov. – Dec. 2010
  - Recorded luminosity by CMS : 7.28 μb^{-1}
- **1st pp run @ $\sqrt{S_{NN}}$ = 2.76 TeV**
  - March 2011
  - Recorded luminosity by CMS : 225 nb^{-1}
- **2nd PbPb run @ $\sqrt{S_{NN}}$ = 2.76 TeV**
  - Nov. – Dec. 2011
  - Recorded luminosity by CMS : 150 μb^{-1}
- **pPb run @ $\sqrt{S_{NN}}$ = 5.02 TeV**
  - Jan. – Feb. 2013
  - Recorded luminosity by CMS : 31.7 nb^{-1}
- **2nd pp run @ $\sqrt{S_{NN}}$ = 2.76 TeV**
  - Feb. 2013 (3 days)
  - Recorded luminosity by CMS : 5.41 pb^{-1}

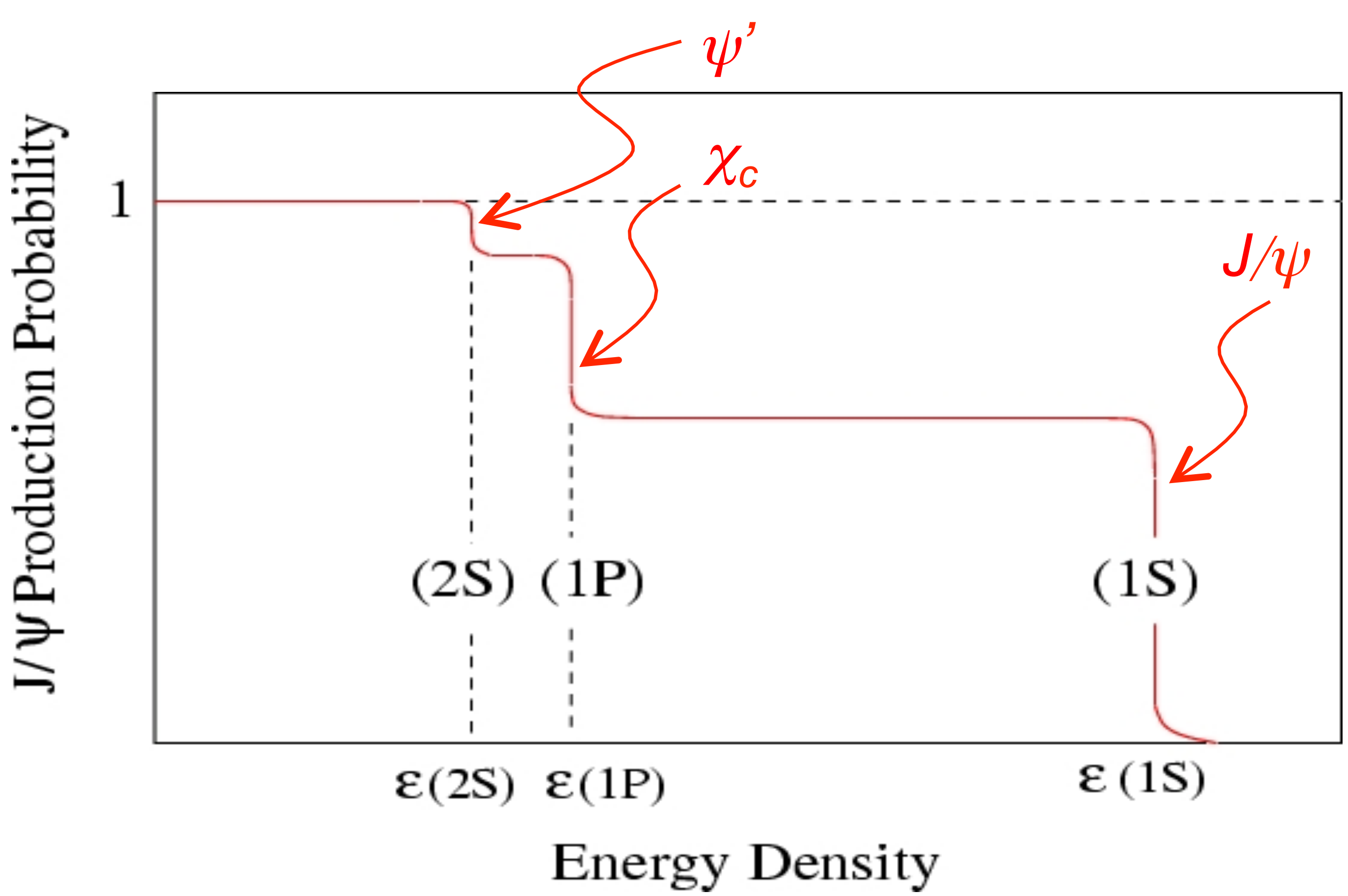




Sequential melting scenario

- **Cartoon for Debye screening**
  - The larger the binding energy, the higher the dissociation temperature T_d.
  - As temperature goes up, Debye length $r_\lambda(T)$ decreases.





Non-prompt J/ψ R_{AA}

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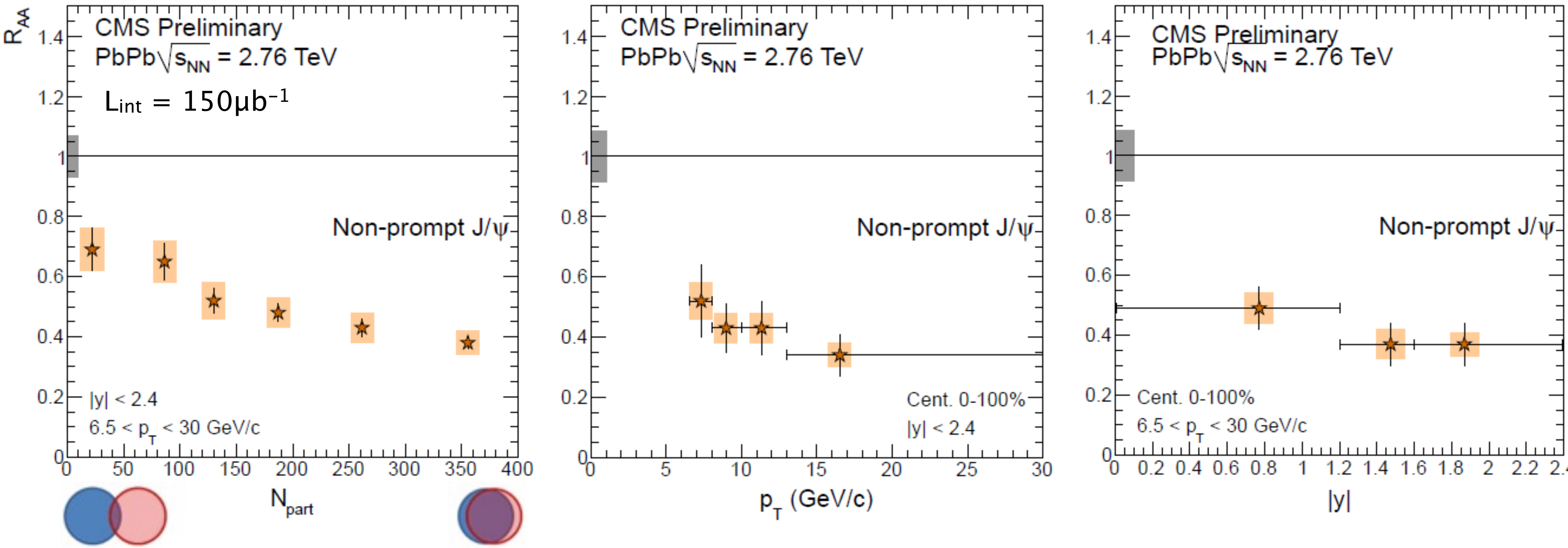
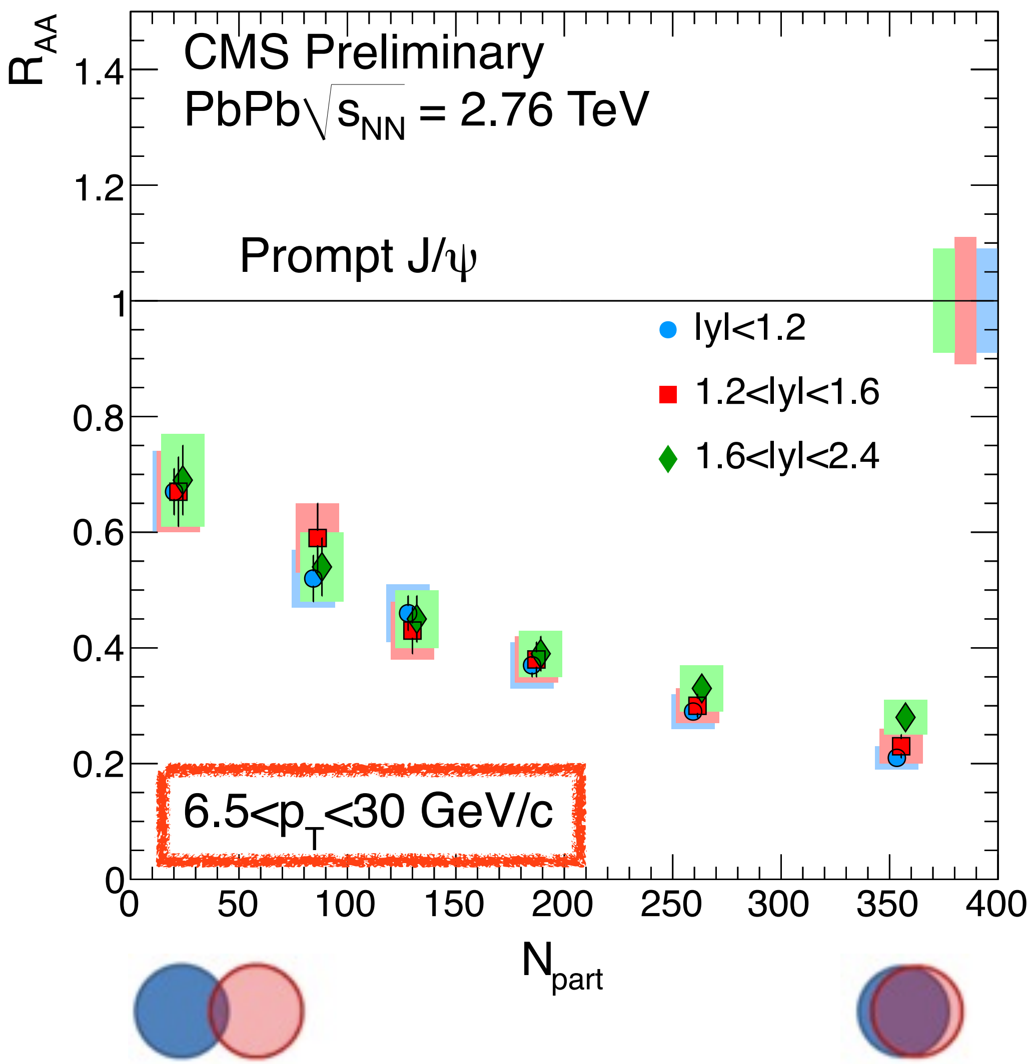


- Suppressed by factor ~3 in the most central bin
- Hints of smaller suppression at lower p_T region, mid-rapidity region

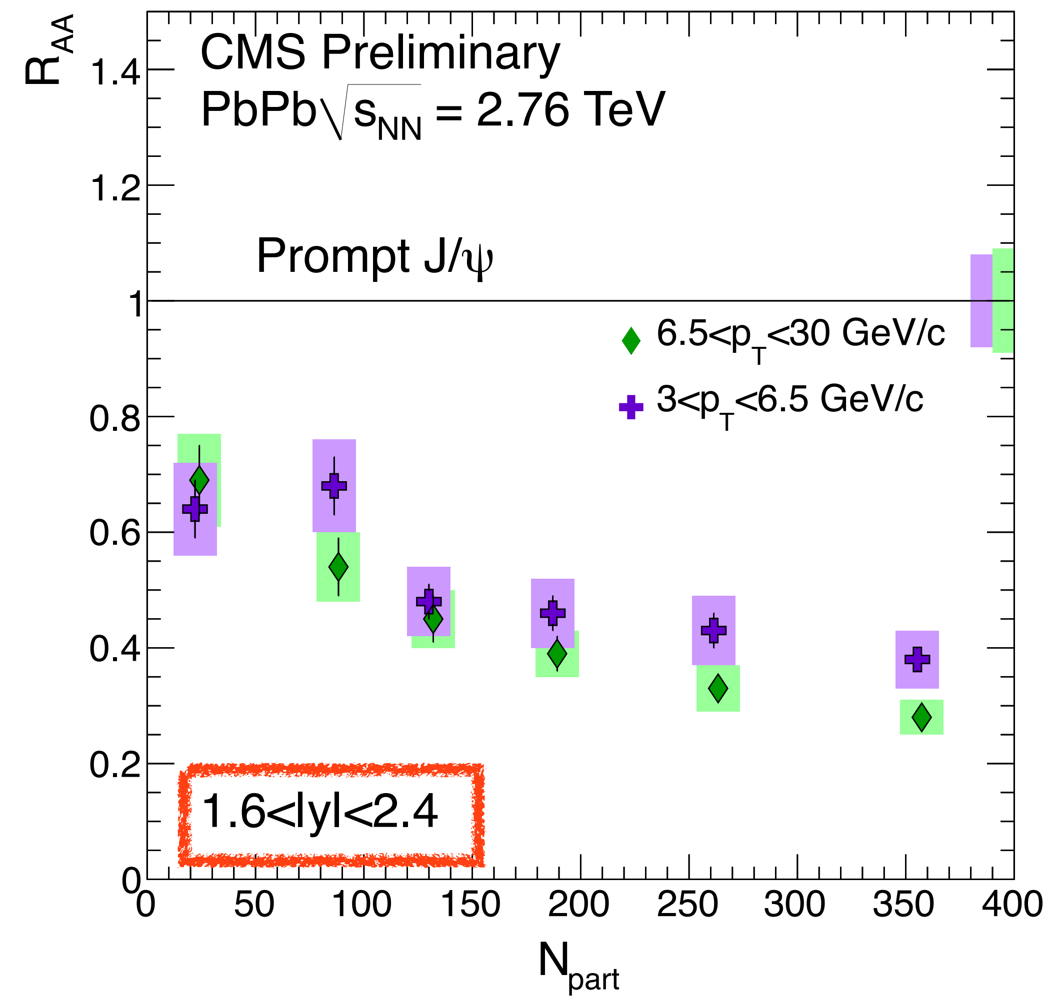
Information on the b-quark energy loss in medium

Prompt J/ψ R_{AA}

- **Rapidity dependence**



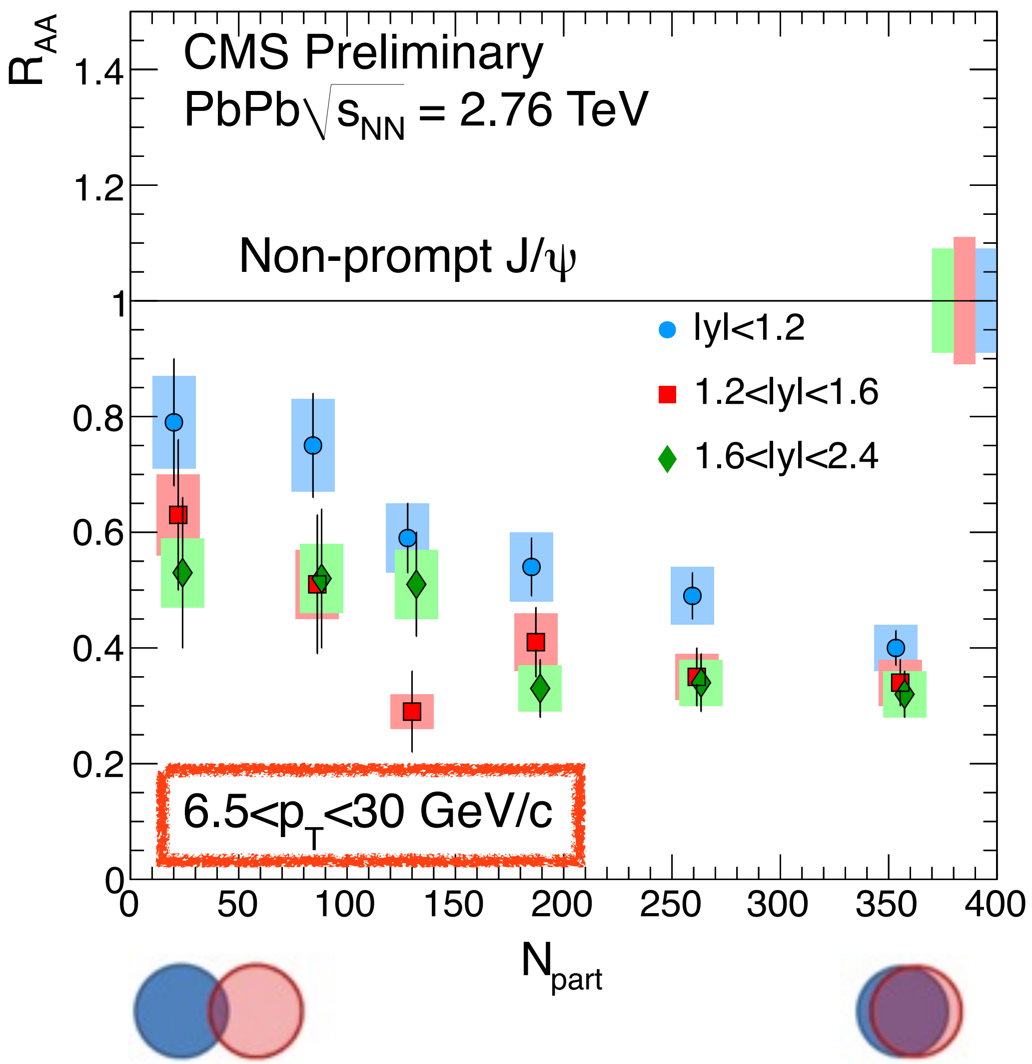
- **p_T dependence**



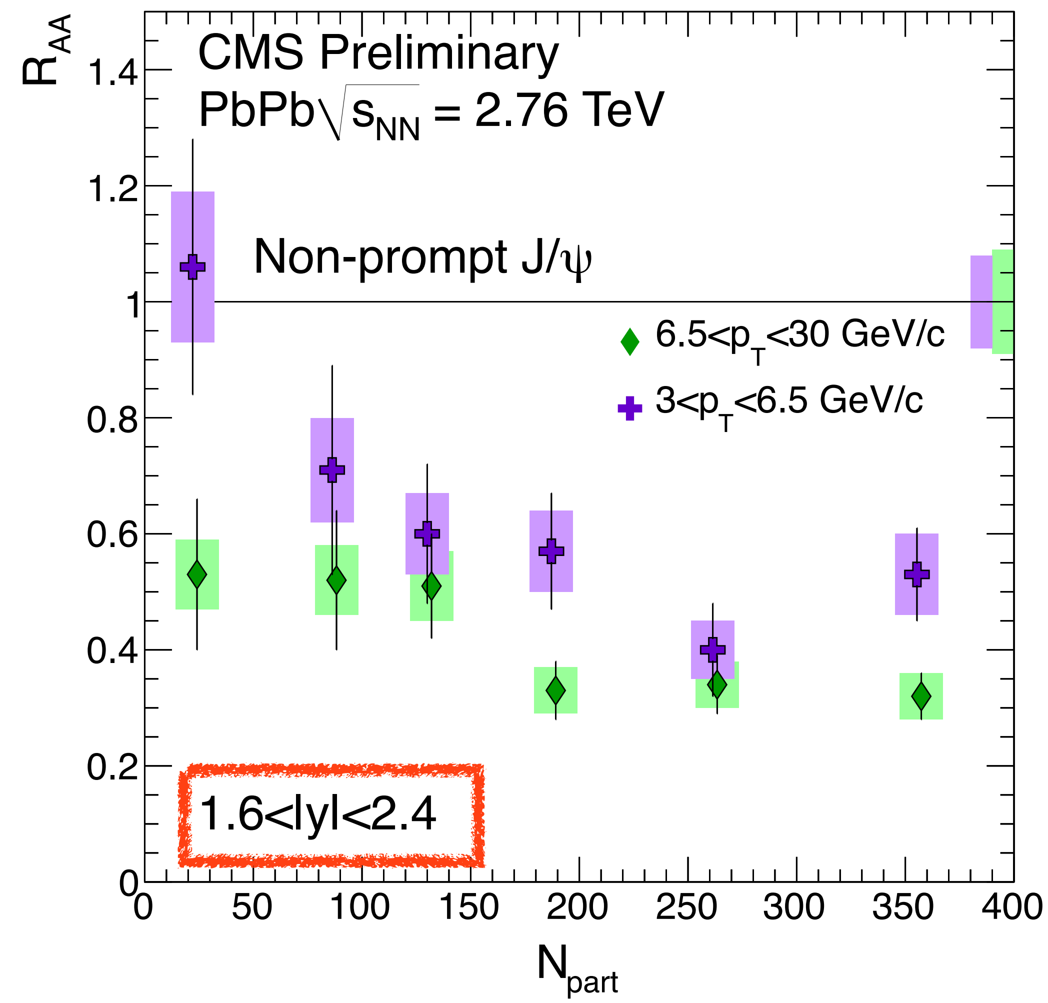
- Left : No strong dependence on rapidity at high p_T region
- Right : At forward rapidity region, lower p_T J/ψ is slightly less suppressed in the most central bins.

Non-prompt J/ψ R_{AA}

- **Rapidity dependence**



- **p_T dependence**



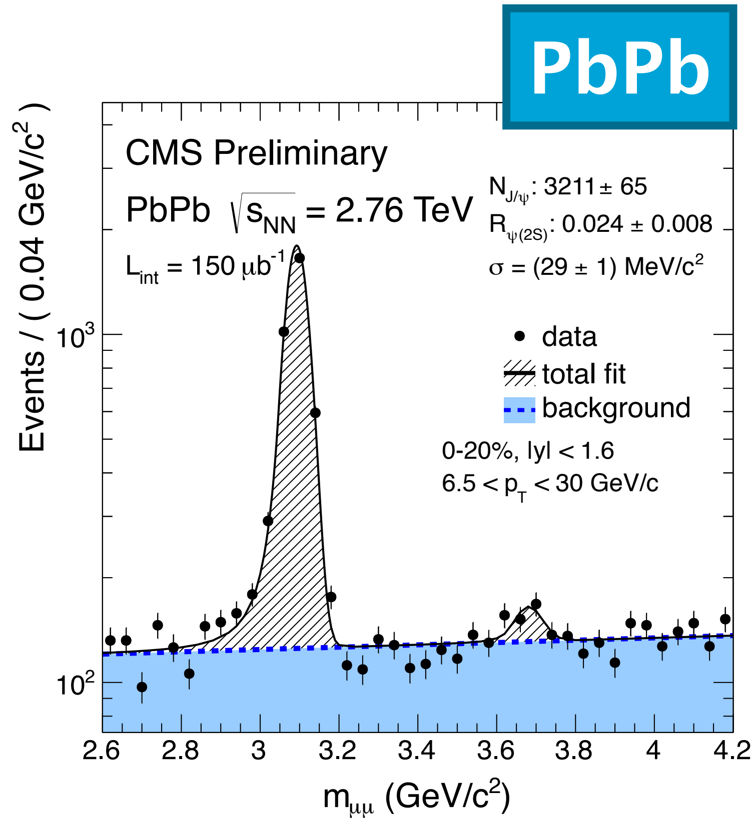
- **Left** : In all rapidity bins at high p_T region, centrality dependent suppression is shown.
- **Right** : In the forward region, lower p_T J/ψ has strong centrality dependence and less suppressed than high p_T J/ψ.

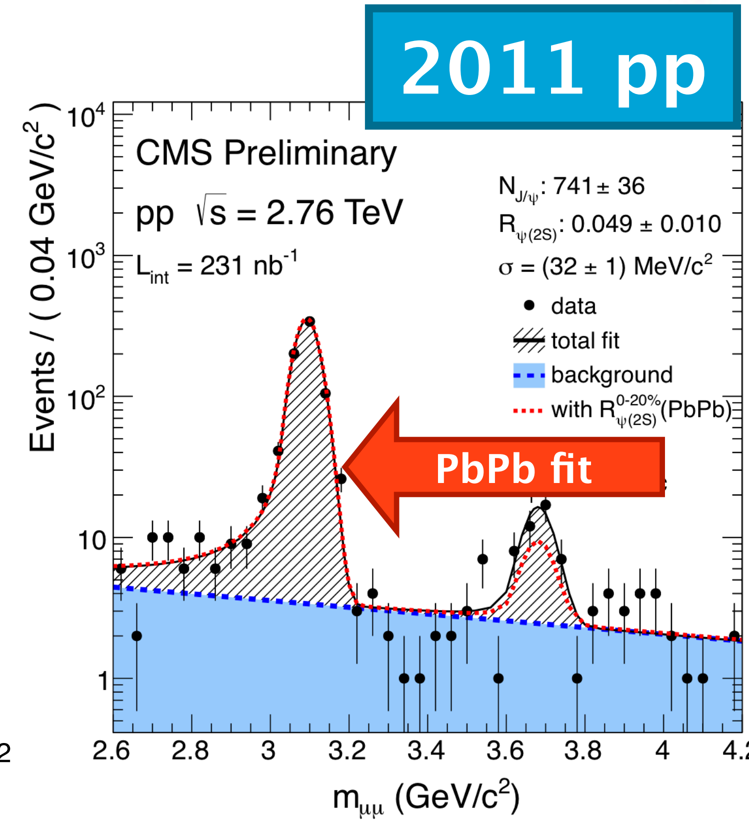
ψ(2S) Single ratio

- **Single ratio :** $R_{\psi(2S)} = \dfrac{N_{\psi(2S)}}{N_{J/\psi}}$

  - $6.5 < p_T < 30$ GeV/c
  - $|y| < 1.6$

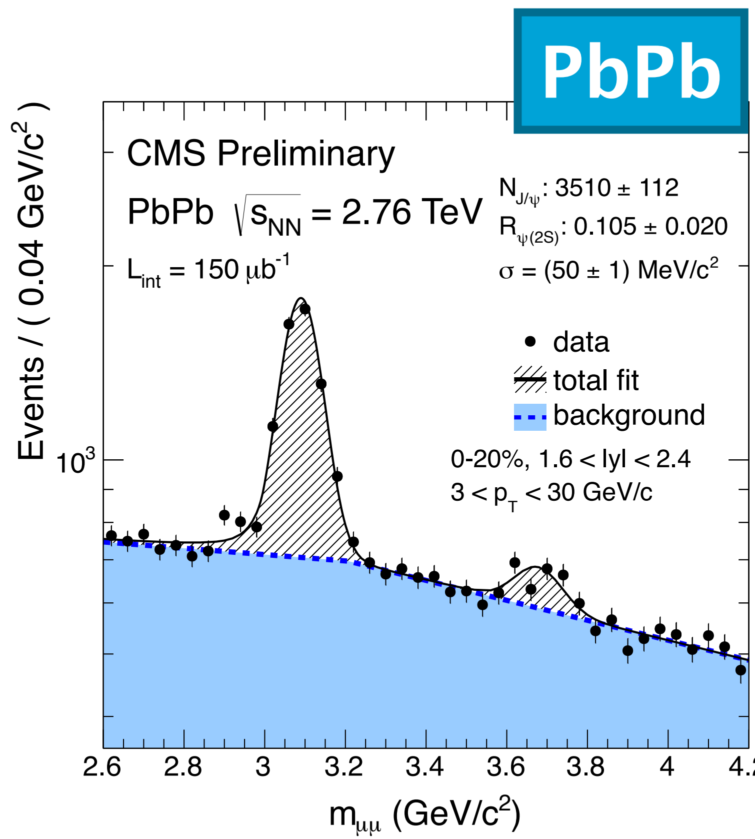
  - $R_{\psi(2s)}$ in 0–20% PbPb
    ~ 2 times smaller than in pp

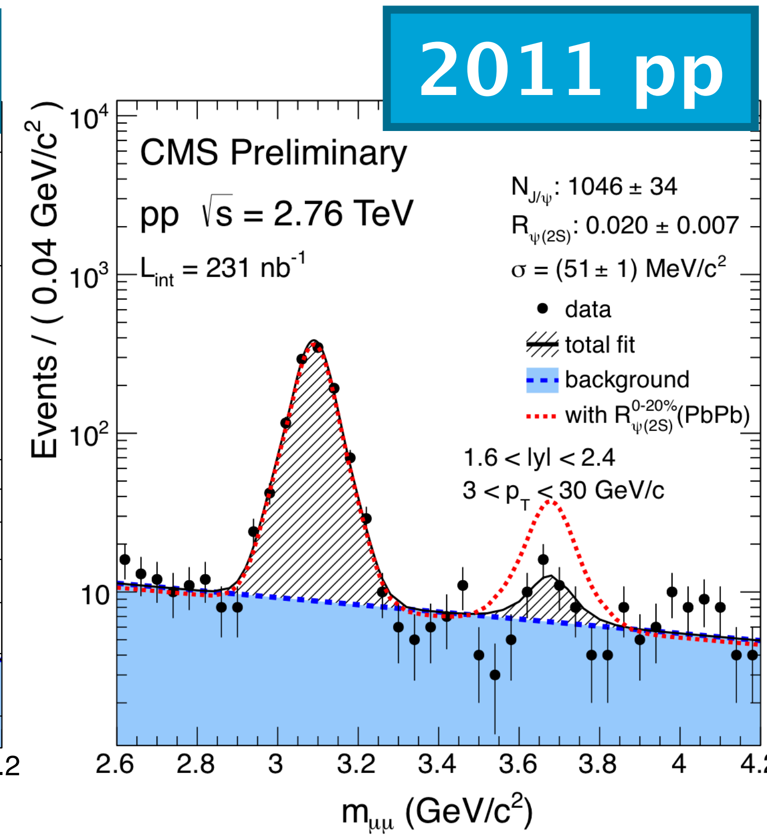




  - $3 < p_T < 30$ GeV/c
  - $1.6 < |y| < 2.4$

  - $R_{\psi(2s)}$ in 0–20% PbPb
    ~ 5 times larger than in pp





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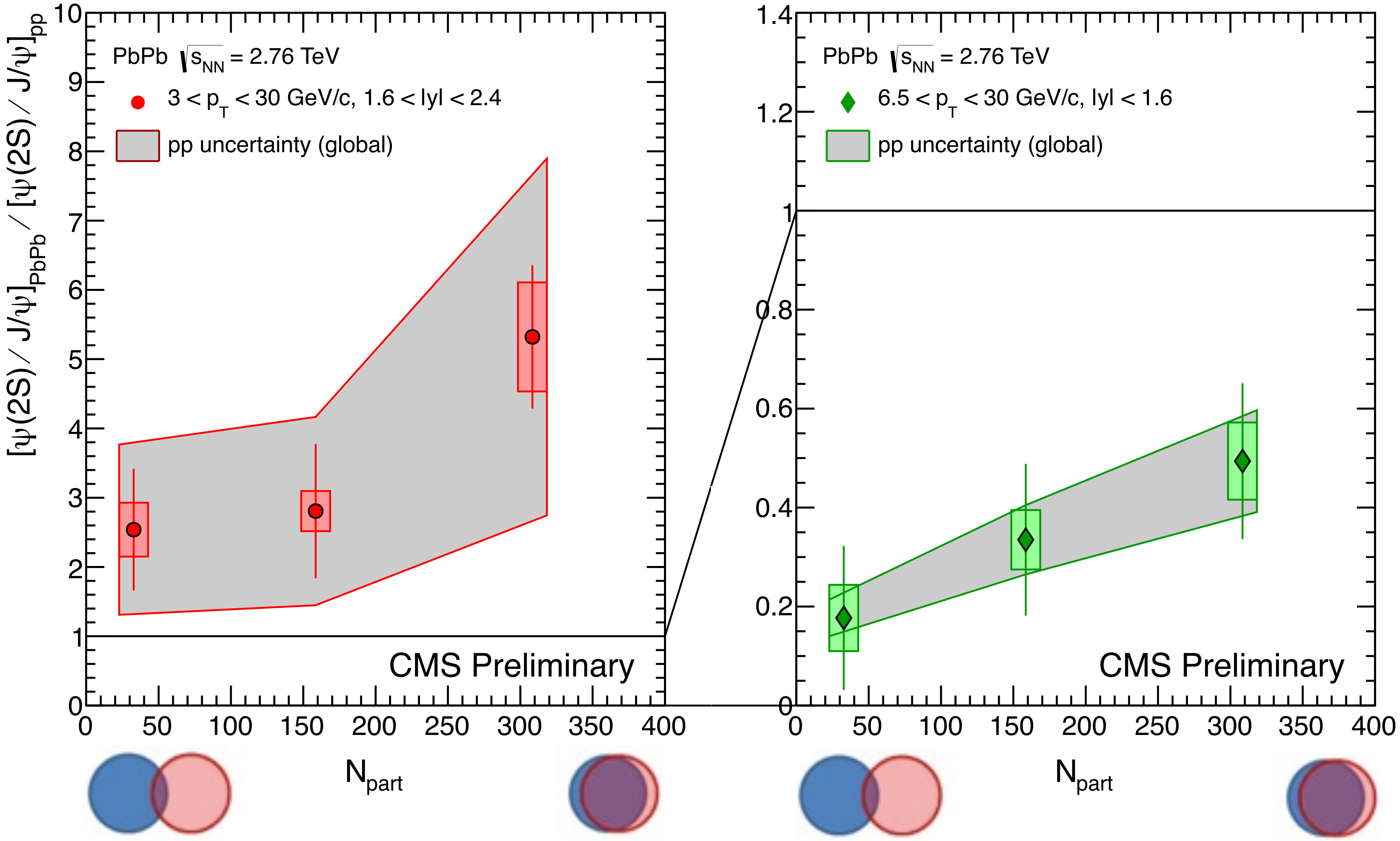
ψ(2S) Double ratio & R_{AA}

CMS-PAS HIN-12-007

- **Double ratio :** $\frac{(N_{\psi(2S)}/N_{J/\psi})_{PbPb}}{(N_{\psi(2S)}/N_{J/\psi})_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$

lower p_T forward region

$3<p_T<30$ GeV/c
$1.6<|y|<2.4$



high p_T mid rapidity region

$6.5<p_T<30$ GeV/c
$|y|<1.6$

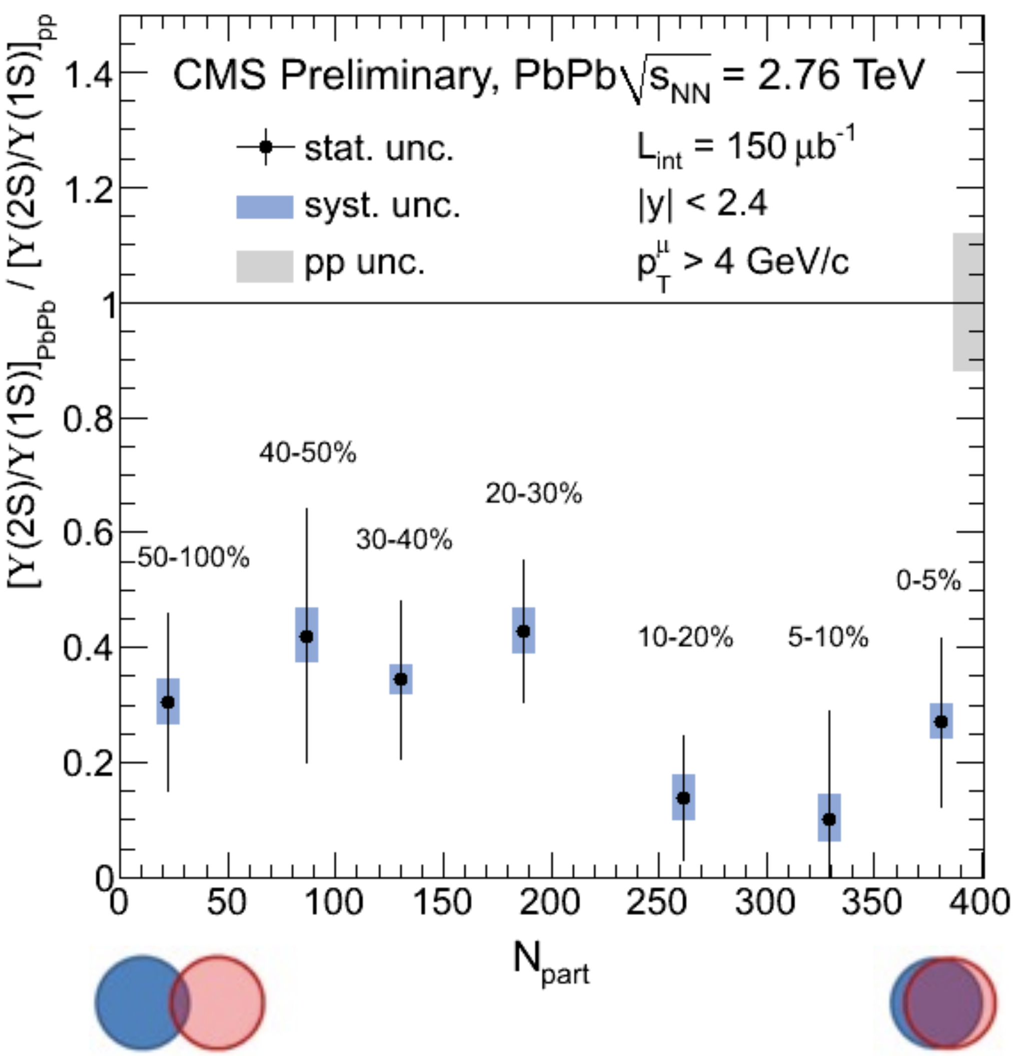
- **Centrality integrated results**

$$R_{AA}^{0-100\%}(\psi(2S)) = 1.54 \pm 0.32(\text{stat}) \pm 0.22(\text{syst}) \pm 0.76(\text{pp})$$

limited by pp statistics

$$R_{AA}^{0-100\%}(\psi(2S)) = 0.11 \pm 0.03(\text{stat}) \pm 0.02(\text{syst}) \pm 0.02(\text{pp})$$

Υ(nS) Double ratio in PbPb



- **Υ(2S) double ratio vs centrality**
  - No strong centrality dependence
  - Suppressed even in the most peripheral bin

$$\frac{N_{\Upsilon(2S)}/N_{\Upsilon(1S)}|_{PbPb}}{N_{\Upsilon(2S)}/N_{\Upsilon(1S)}|_{pp}} = 0.21 \pm 0.07(\text{stat.}) \pm 0.02(\text{syst.})$$

- **Υ(3S) double ratio vs centrality**
  - Peak at PbPb is hard to distinguish.
    → Set the upper limit

$$\frac{N_{\Upsilon(3S)}/N_{\Upsilon(1S)}|_{PbPb}}{N_{\Upsilon(3S)}/N_{\Upsilon(1S)}|_{pp}} = 0.06 \pm 0.06(\text{stat.}) \pm 0.06(\text{syst.})$$
$$< 0.17 \text{ at } 95\% \text{ C.L.}$$

Remark for pPb Υ analysis

- Since the beam energy of proton and Pb nucleus is asymmetric, C.M frame is boosted by $\Delta y \sim 0.47$ w.r.t. lab frame.

- Symmetric range in C.M.frame [-1.93, 1.93] is selected for muon's η and dimuon's rapidity.
  : for the 1st run (proton going to -) : [-2.4, 1.47]
  : for the 2nd run (proton going to +) : [-1.47, 2.4]

- Binning in 2 event activity variables
  : corrected N_{tracks} in inner tracker ($|\eta|<2.4$, $p_T>0.4$ GeV/c)
  : raw transverse energy(E_T) measured in HF ($4<|\eta|<5.2$)