Bottomonium production in p+p and Pb+Pb collisions with CMS

Abdulla Abdulsalam
Laboratoire Leprince-Ringuet,
École polytechnique, Palaiseau

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Quarkonia as probes of QGP

- **Quarkonia** **(**χ_c, ψ(1, 2S) and χ_b, Υ(1, 2, 3S)**):** Massive states
  - Produced at the early stage of the collision

State	J/ψ	ϒ(1S)	ϒ(2S)	ϒ(3S)
Mass (GeV)	3.1	9.46	10.02	10.36
ΔE (GeV)	0.64	1.10	0.54	0.20
Radius r_0 (fm)	0.50	0.28	0.56	0.78

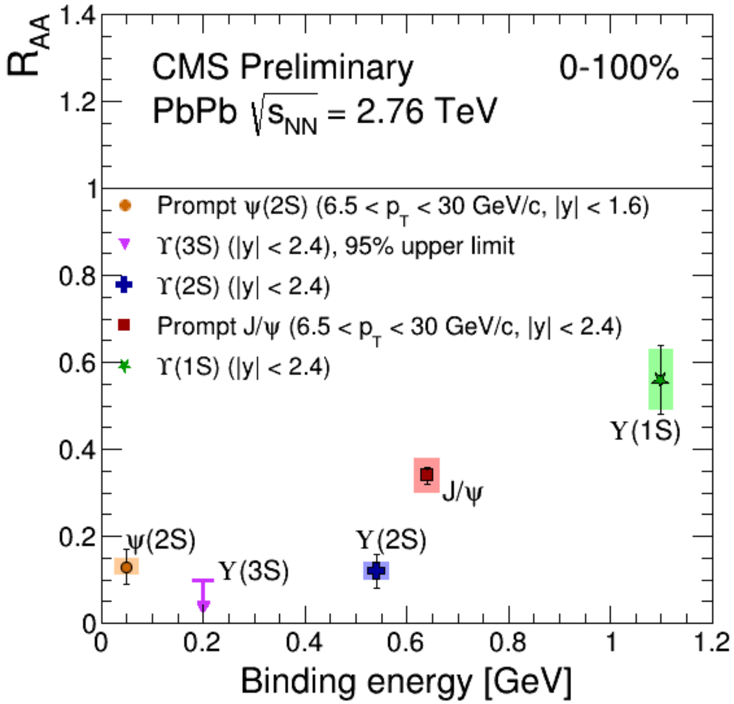
- **Sequential melting:** via Debye screening in QGP
  - Screening at different T for different states

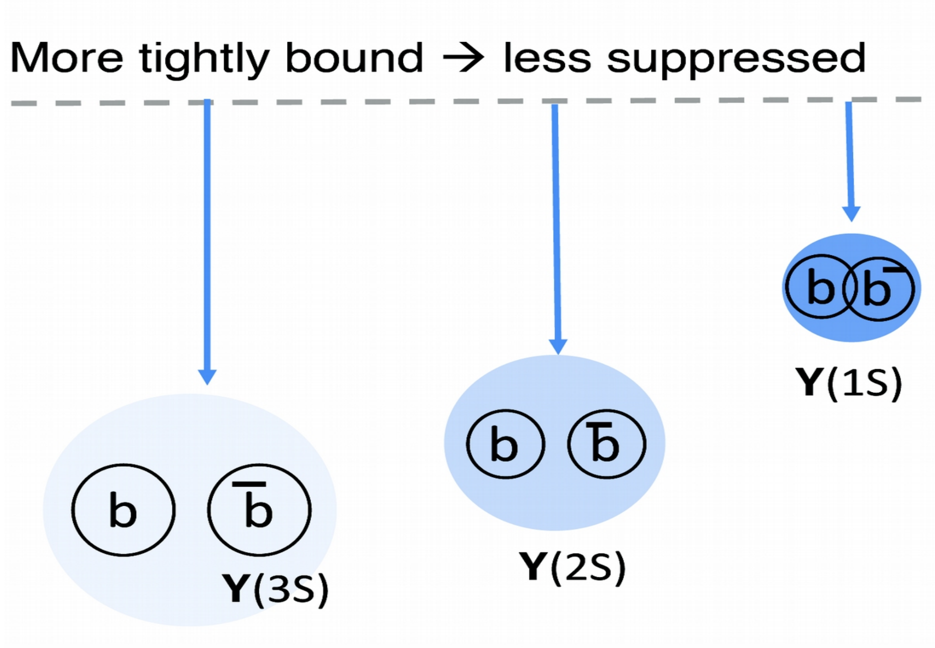
    Matsui and Satz PLB 178 416 (1986), Digal PRD 64 0940150 (2001)
  - More weakly-bound states are expected to disappear at T_c ~ 150-190 MeV.

- **Regeneration of quarkonia**:
  - From uncorrelated quarks and anti-quarks produced in bulk at LHC
  - Expected to be small for ϒ states as compared to J/ψ.

R. L. Thews Phys. Rev. C63, 054905 (2001), Andronic PLB 652(2007) 259

Bottomonia in QGP





- Sequential suppression of quarkonium states.
- Bottomonia are most tightly bound states => less suppressed in QGP
- Measure the states in most central and peripheral collisions to see the medium effect
- Measurement with 2011 and 2015 PbPb data

Observables

1) Nuclear modification factor R_{AA}

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

pp luminosity

Nuclear overlap function

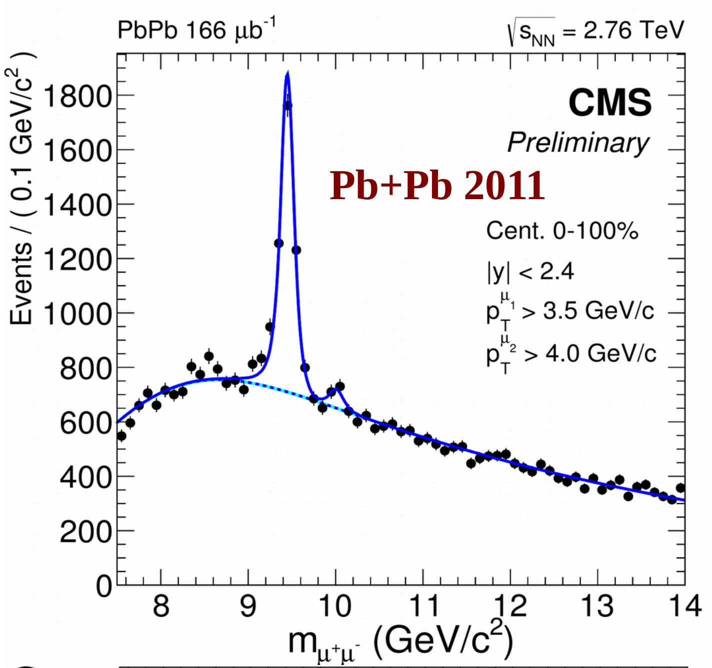
Efficiency in pp and PbPb

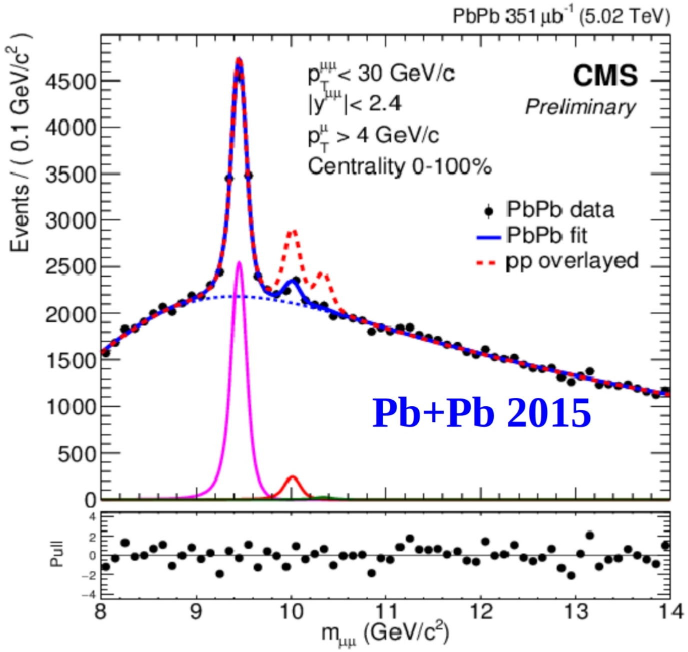
2) Double ratio

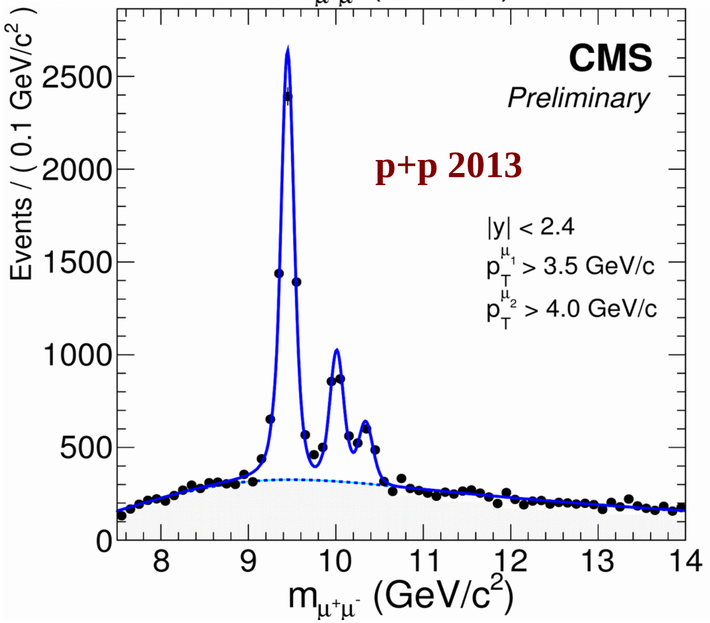
$$\mathcal{DR}_{21} \equiv \frac{(\Upsilon(2S)/\Upsilon(1S))_{\mathrm{PbPb}}}{(\Upsilon(2S)/\Upsilon(1S))_{\mathrm{pp}}}$$

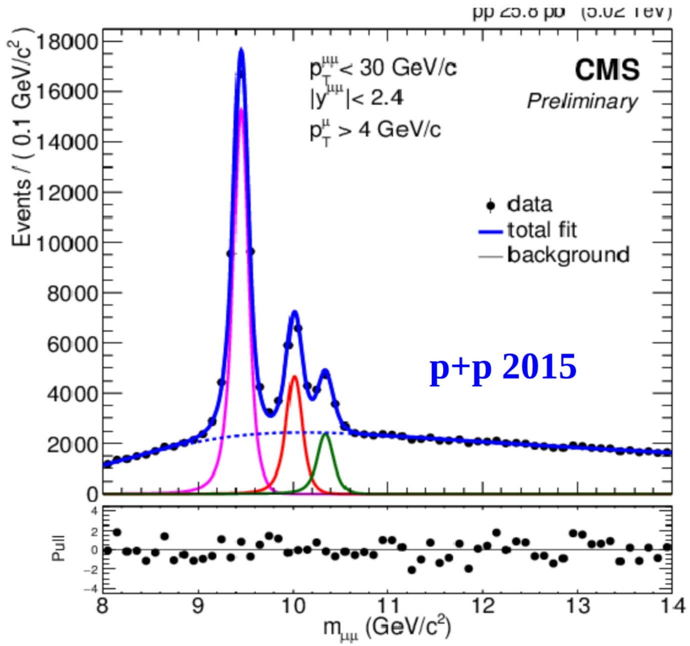
- Many theoretical and experimental quantities/uncertainties cancel in this ratio

LHC Runs of Heavy Ion Interest





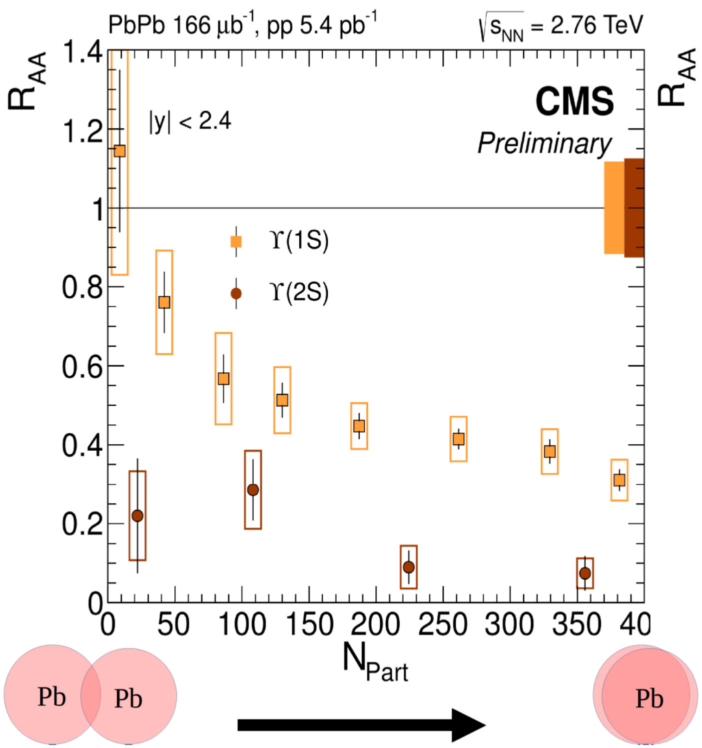


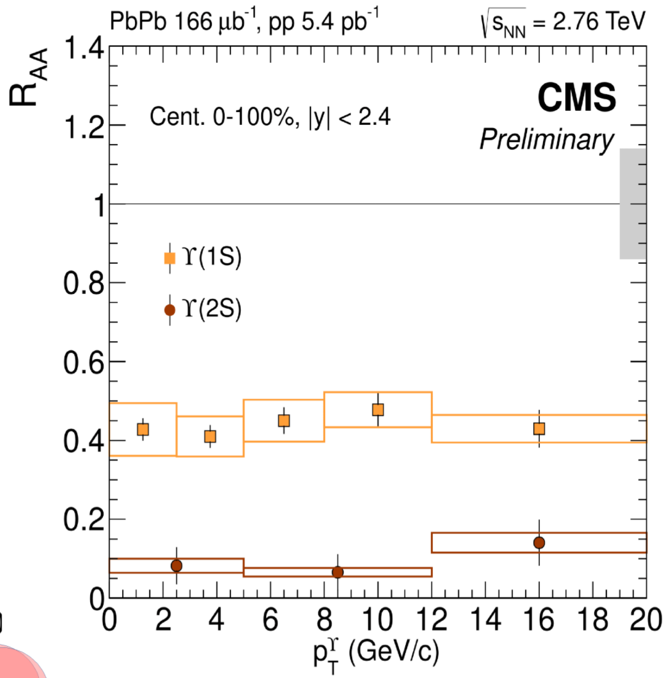


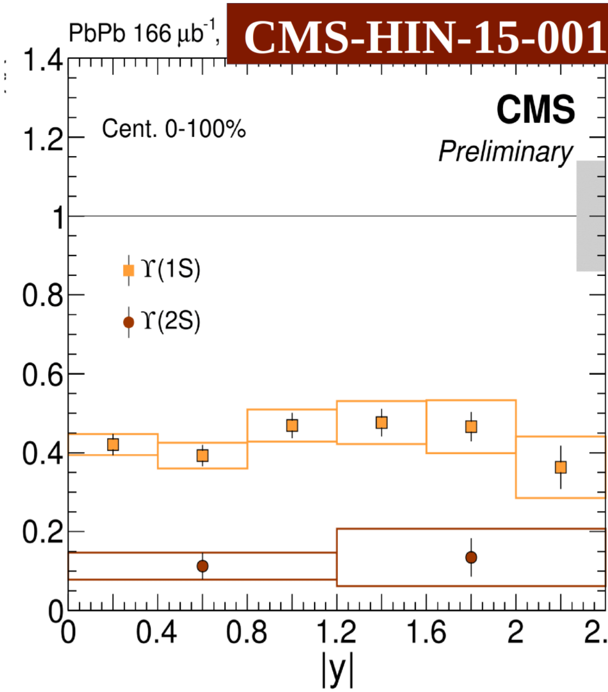
Υ measurement with *Pb+Pb* at 2011

R_{AA} at 2.76 TeV

CMS-HIN-15-001



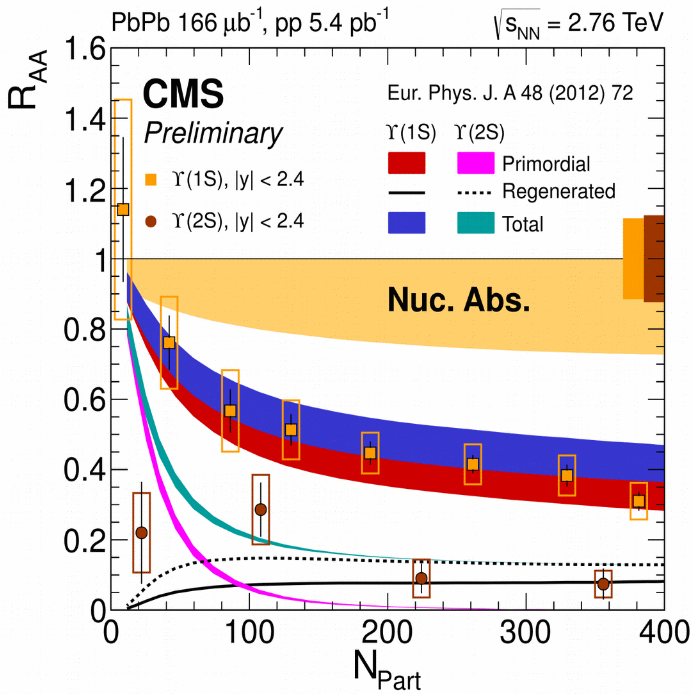




- Υ(1S) shows gradual centrality dependence
- Υ(2S) largely suppressed at all centralities
- Both R_{AA} are flat over |y| < 2.4 and pT < 20GeV/c
- Υ(3S) not observed R_{AA}(3S) < 0.14 at 95% confidence level

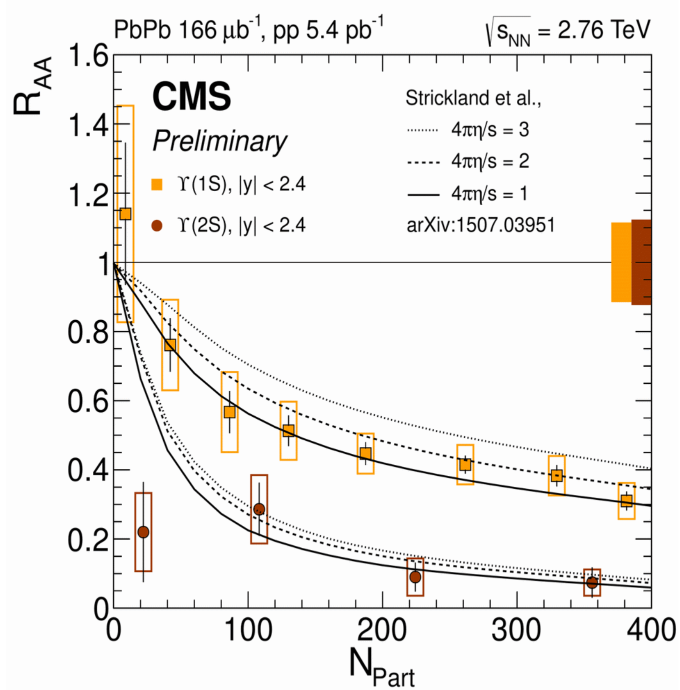
Sequence of suppression: $R_{AA}^{Υ(3S)} < R_{AA}^{Υ(2S)} < R_{AA}^{Υ(1S)}$

R_{AA} : Comparison with models



Kinetic Theory Model

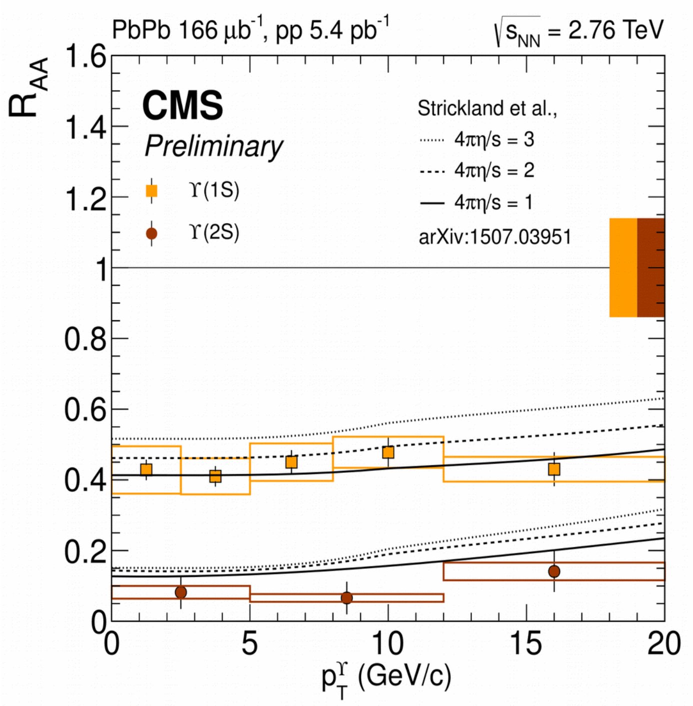
- Strong and weak-binding scenarios
- ϒ(1S) not affected by color screening at LHC
- Significant regeneration contributions

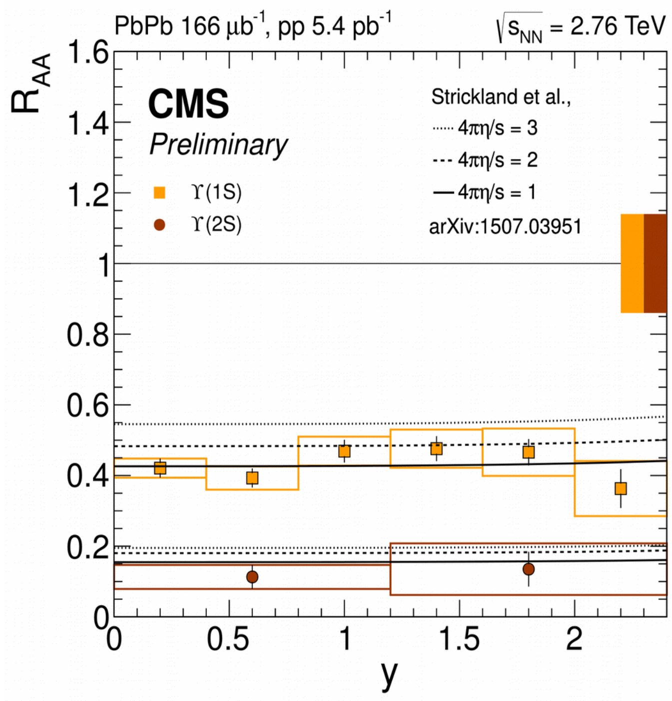


Hydrodynamics model

- Thermal parameters are constrained by data
- Good agreement with CMS data
- Data preferring small shear viscosities in the range $1 < 4\pi\eta/s < 2$

R_{AA} : Comparison with models





Hydrodynamics model

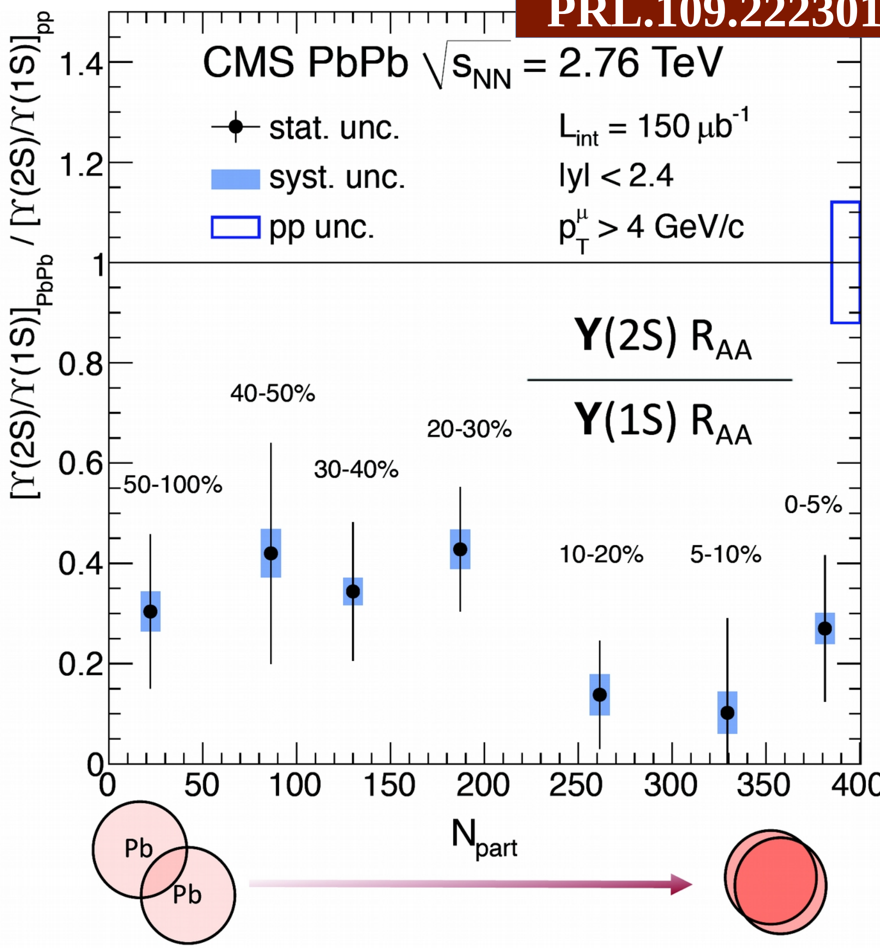
- As a function of rapidity and pT, model reproducing the trends seen in the data
- As a function of pT, bottomonia spectra are unaffected due to the lack of thermalization
- Preferring low shear viscosity to entropy density ratio => QGP created in HIC behaves like a nearly perfect fluids ?

Υ measurement with *Pb+Pb* at 2015

Double ratio from 2.76 TeV PbPb

- At 2.76TeV, ϒ(2S) is more suppressed than ϒ(1S) at all centralities
- Is there any centrality dependence?
- Is new data at 5.02 TeV can give the answer ?

PRL.109.222301

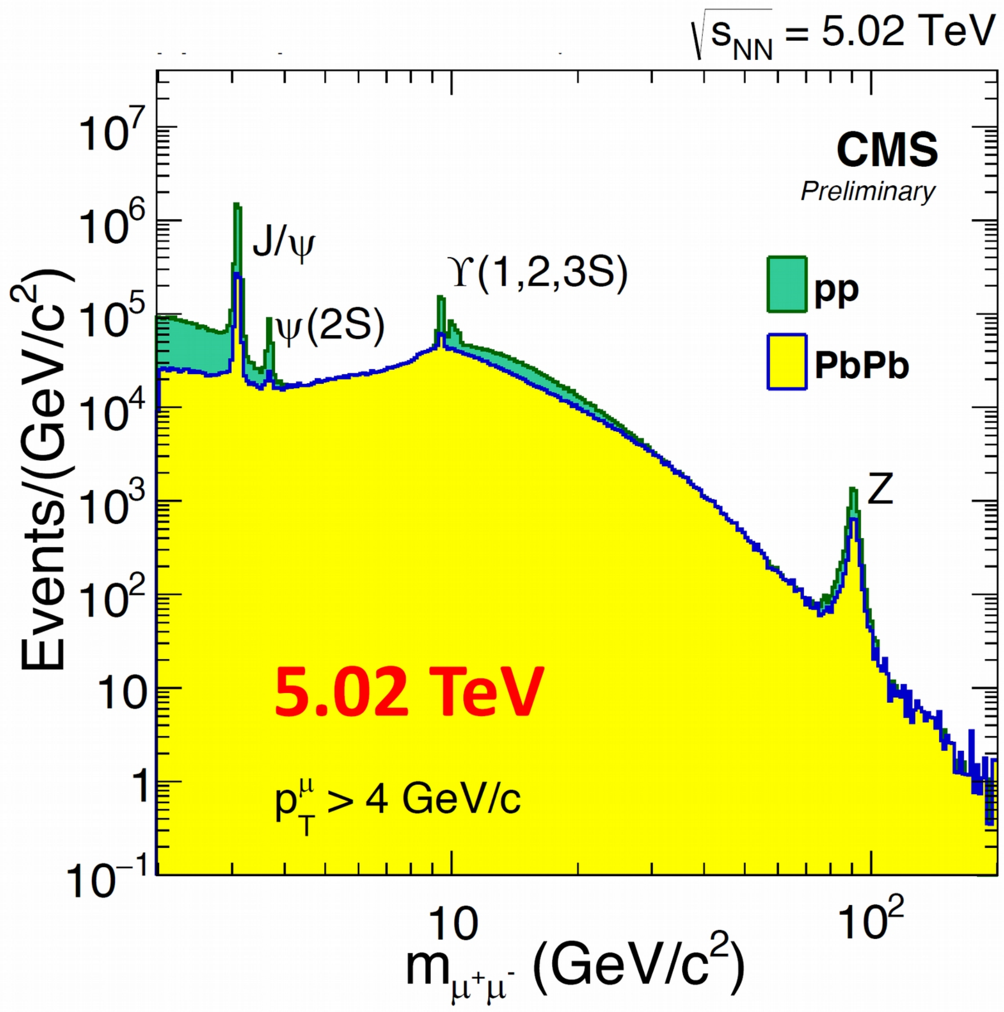


5.02 TeV Data from 2015 Run

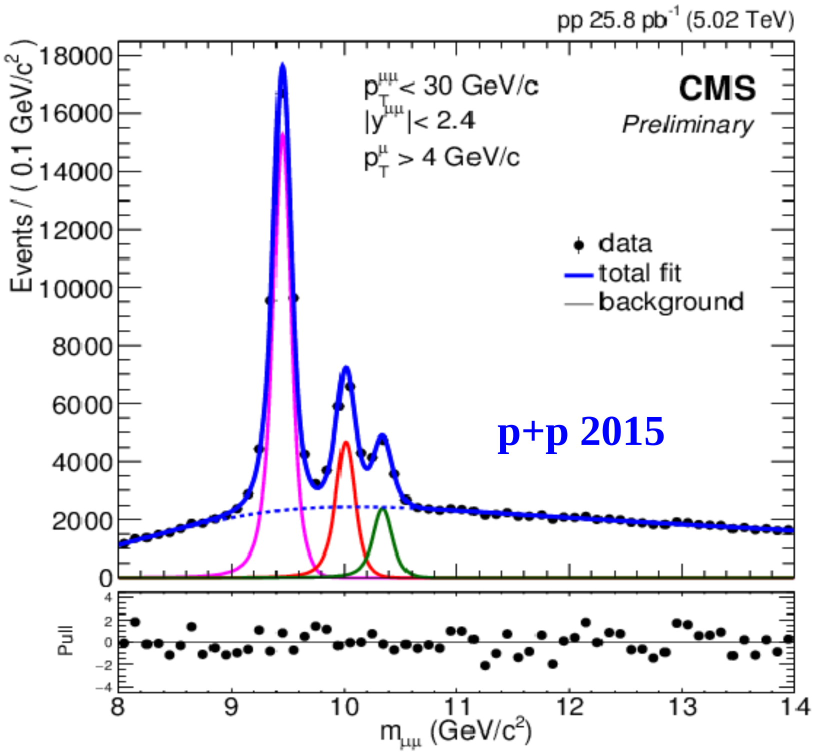
- PbPb and pp data collected in Nov, Dec 2015 @5.02 TeV
- Double muon trigger implemented at L1 (hardware based algorithm)

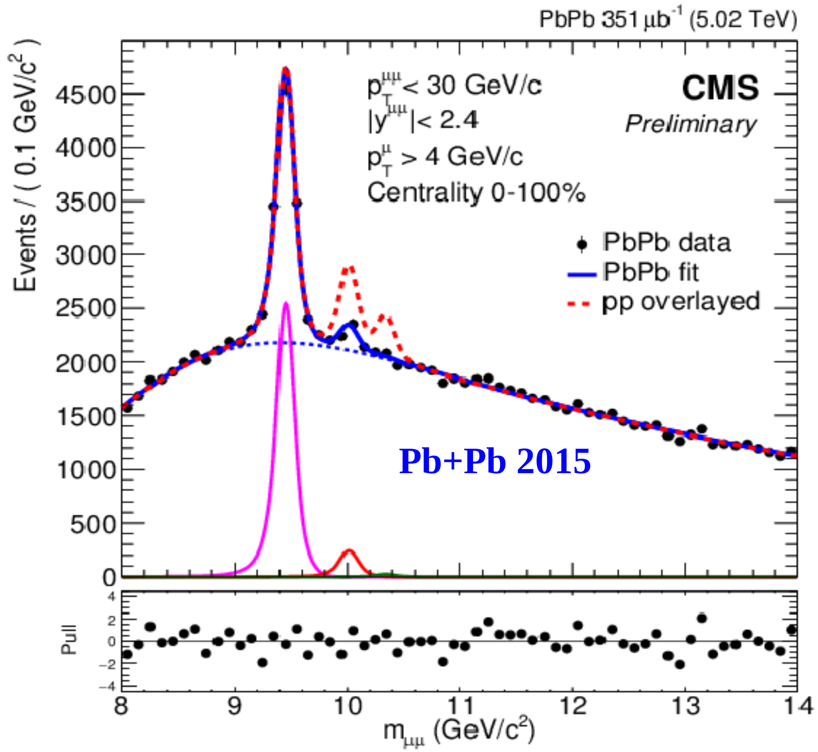
- pp luminosity ~ 25.8 pb^{-1}
- PbPb have two datasets
  -351 μb^{-1} for 0-30% interval
  - 464 μb^{-1} for other intervals

- ~3 times more upsilons collected than from 2.76TeV



Inv Mass from 5.02 TeV



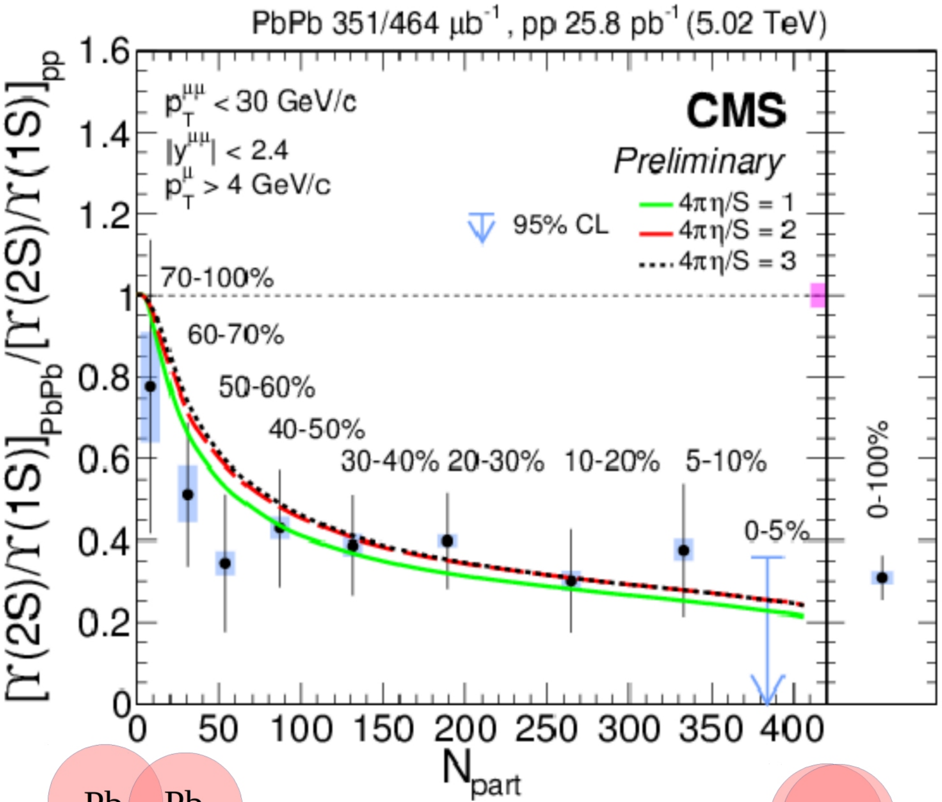


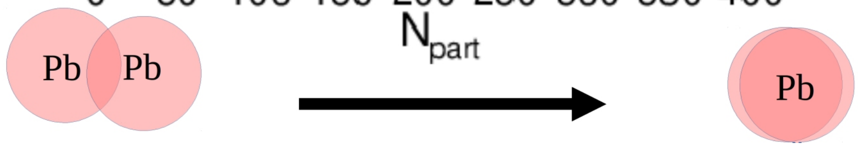
Signal: double Crystal-Ball function
Bkg : an error function multiplied by an exponential function

➔ ϒ(1S) in pp collisions (red dashed line) normalized to PbPb ϒ(1S)
➔ ϒ(3S) in PbPb consistent with zero!

ϒ(2S) double ratio with Pb+Pb

- DR is the ratio of R_{AA} of (2S) and (1S)
- In 0-5% bin, ϒ(2S) signal is consistent to zero < 0.36 at 95% CL
- DR is compatible with unity in the most peripheral bins (70-100%),
- Theory curves use hydrodynamics and lattice-based potential
  - Obtained from the ratio of R_{AA} predictions of ϒ(1S) and ϒ(2S)
- What about ϒ(3S) ?

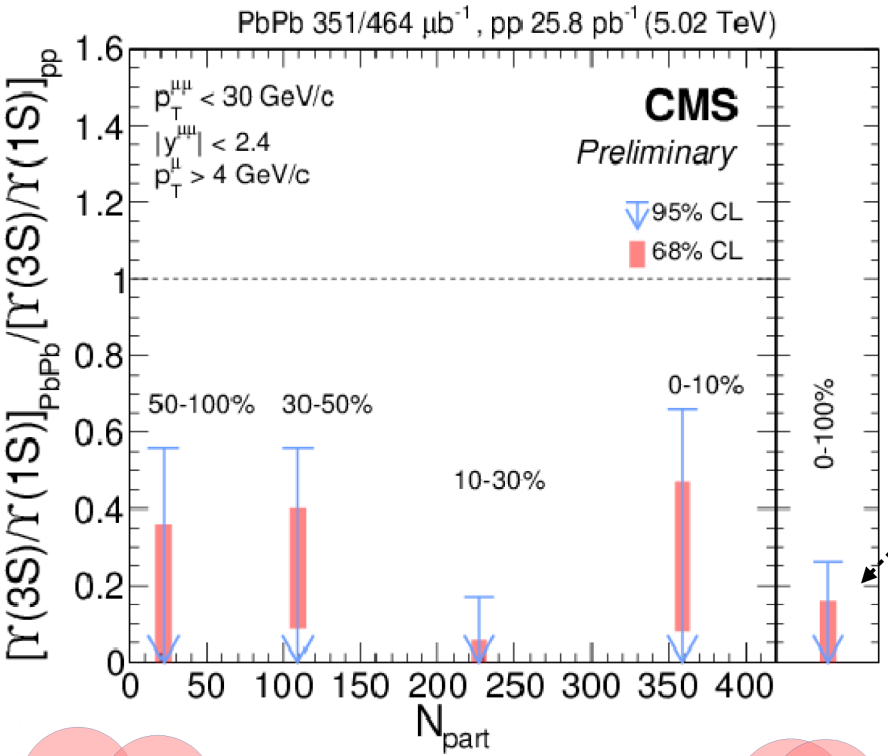


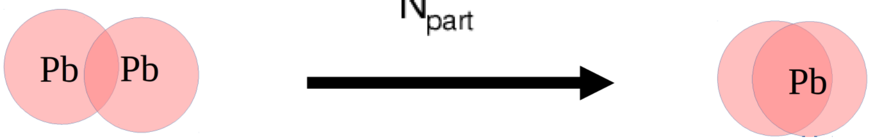


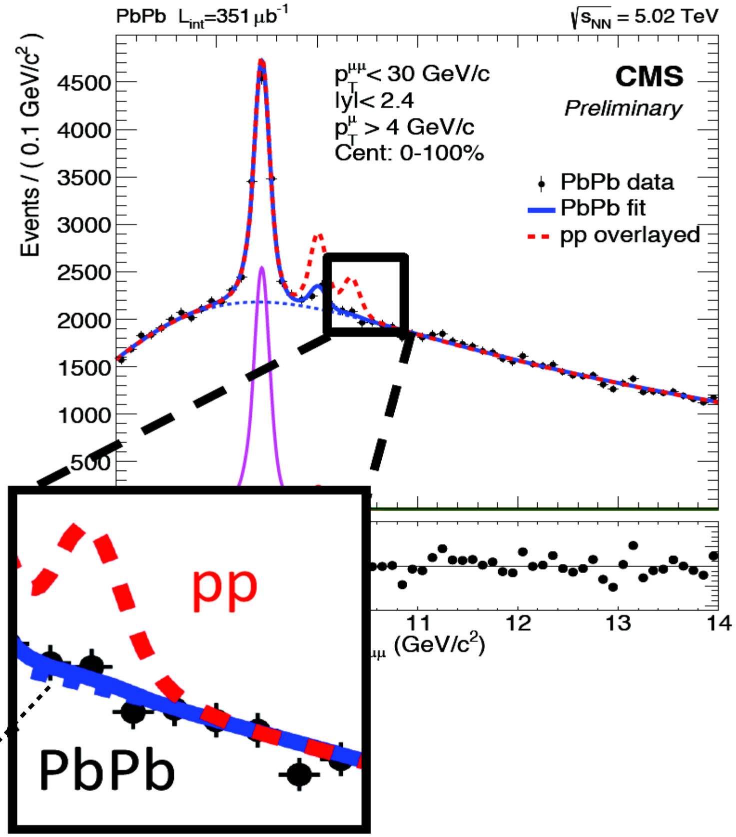
$$\frac{\mathbf{Y}(2S)\ R_{AA}}{\mathbf{Y}(1S)\ R_{AA}}$$ is 0.308 ± 0.055(stat) ± 0.017(syst)

ϒ(3S) double ratio vs centrality

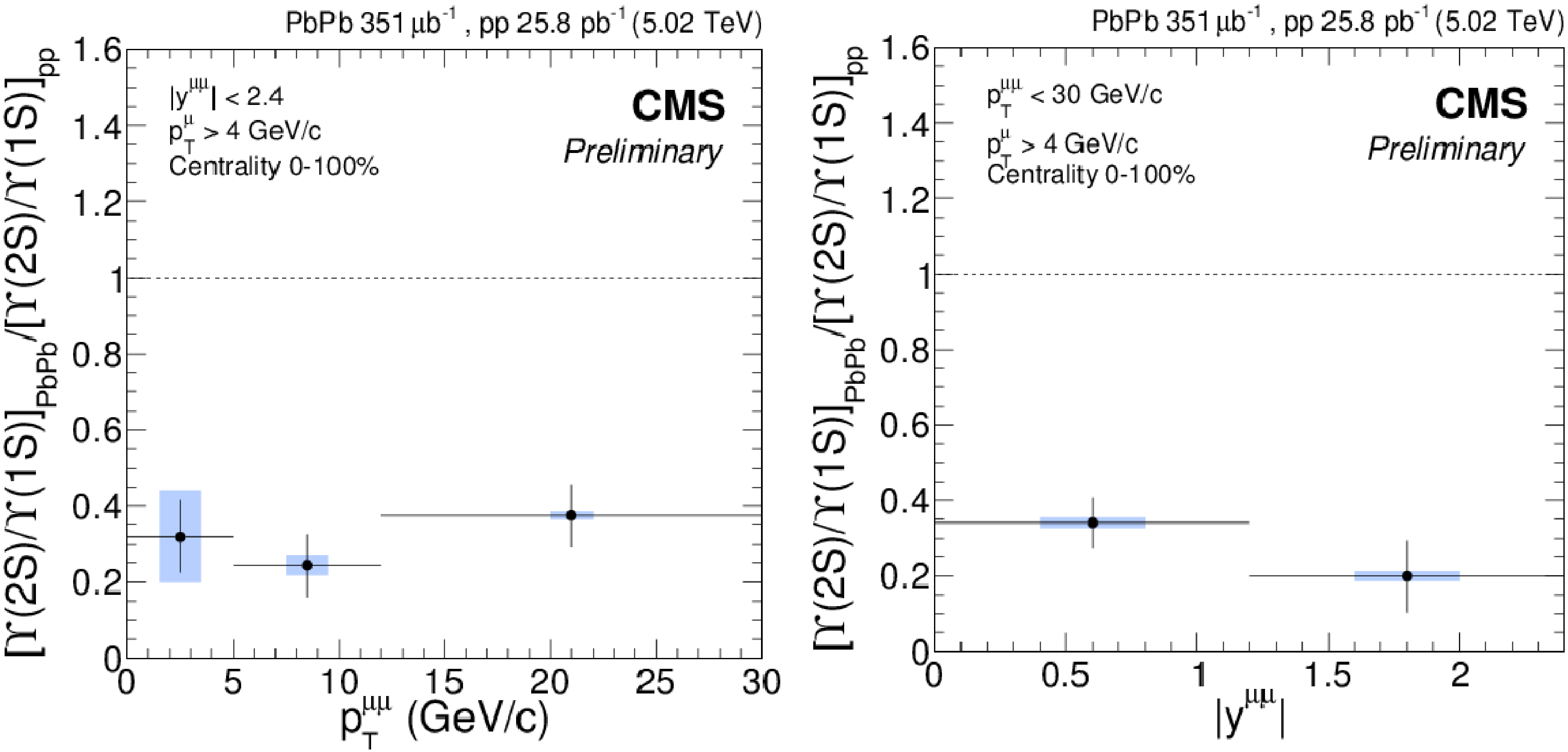
- The ϒ(3S) double ratio is lower than unity in all centrality bins
  - → no indication that the suppression is weaker in the most peripheral events
- $DR_{31} < 0.26$ at 95% CL
- Arrows are 95% CL and boxes are 68% CL





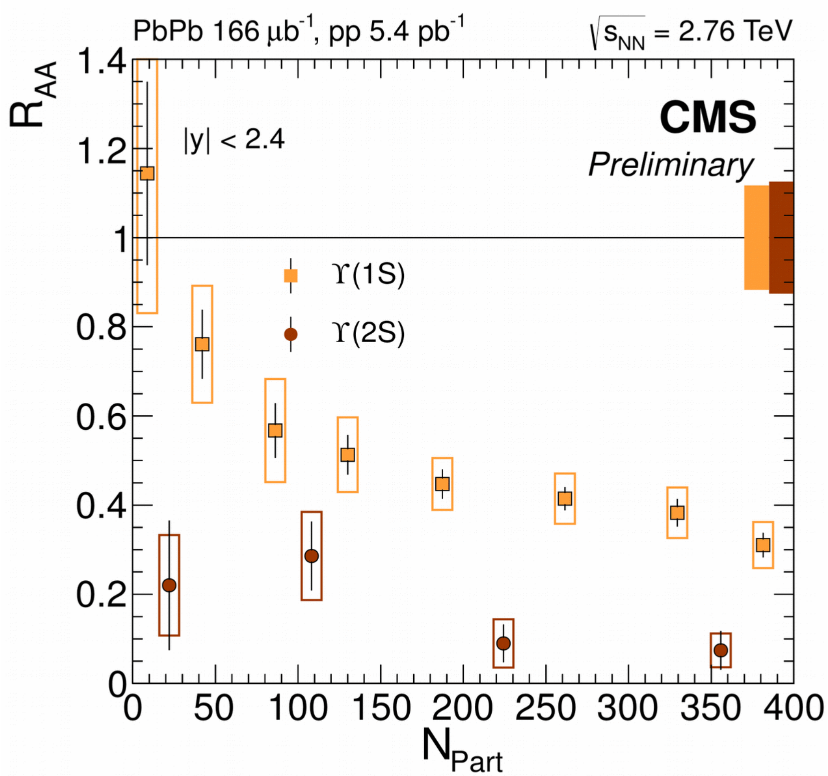


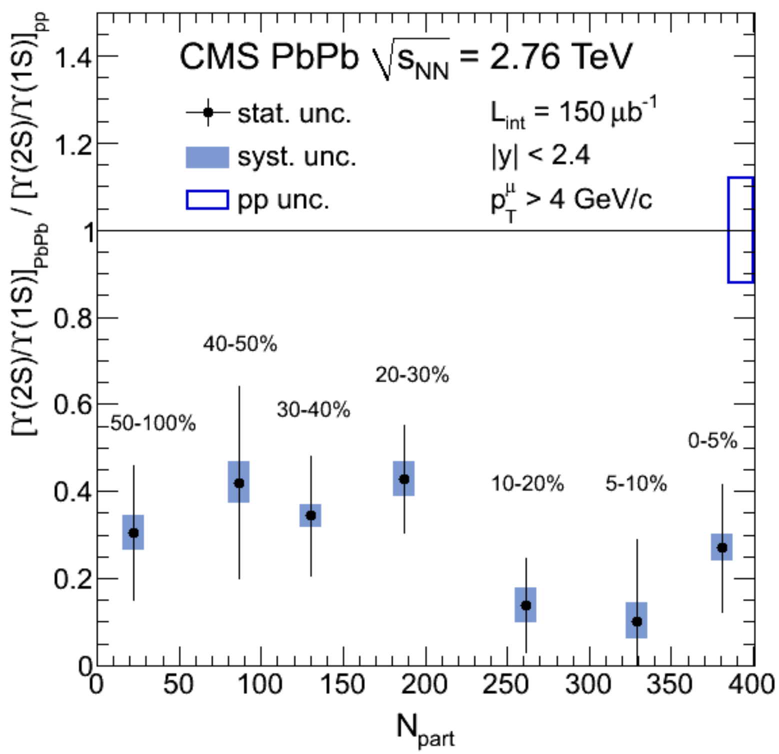
Double ratio of $\Upsilon(2S)$ in p_T and y bins



- DR has no clear dependence on pT or rapidity
- Similarly to 2.76TeV result

Summary (1/2)

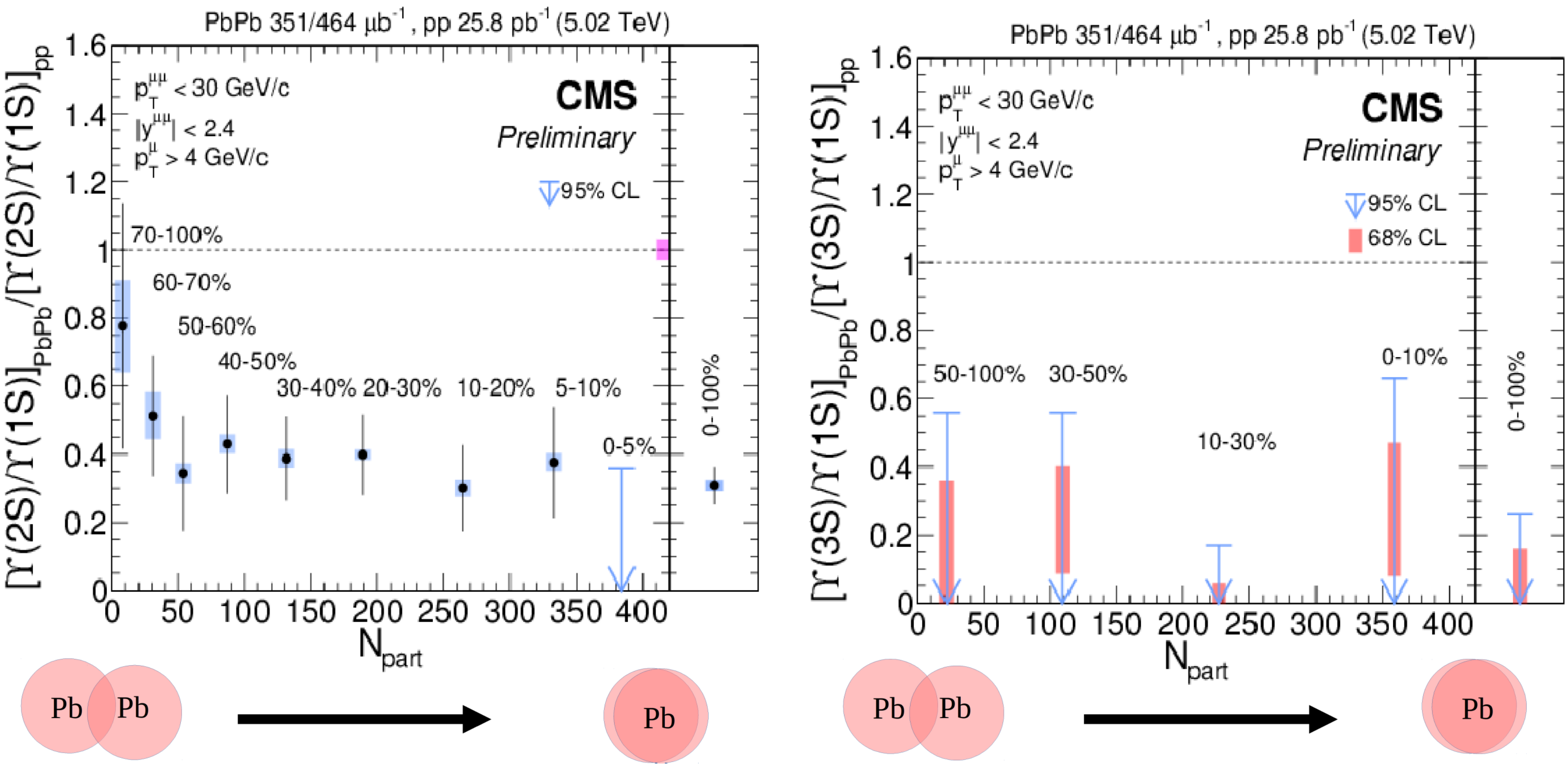




- Υ(1S) shows gradual centrality dependence
- Υ(2S) largely suppressed at all centralities
- Sequential suppression of bottomonium states

$$R_{AA}(\Upsilon(1S)) = 0.425 \pm 0.029 \pm 0.070,$$
$$R_{AA}(\Upsilon(2S)) = 0.116 \pm 0.028 \pm 0.022,$$
$$R_{AA}(\Upsilon(3S)) < 0.14 \text{ at } 95\% \text{ CL},$$

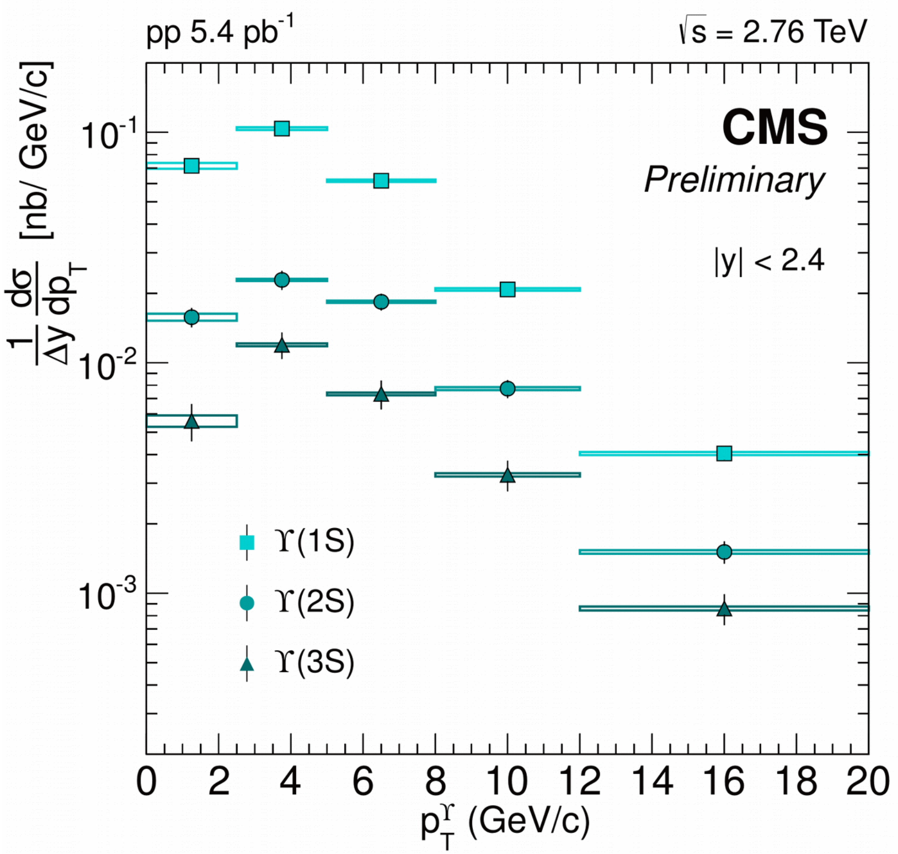
Summary (2/2)

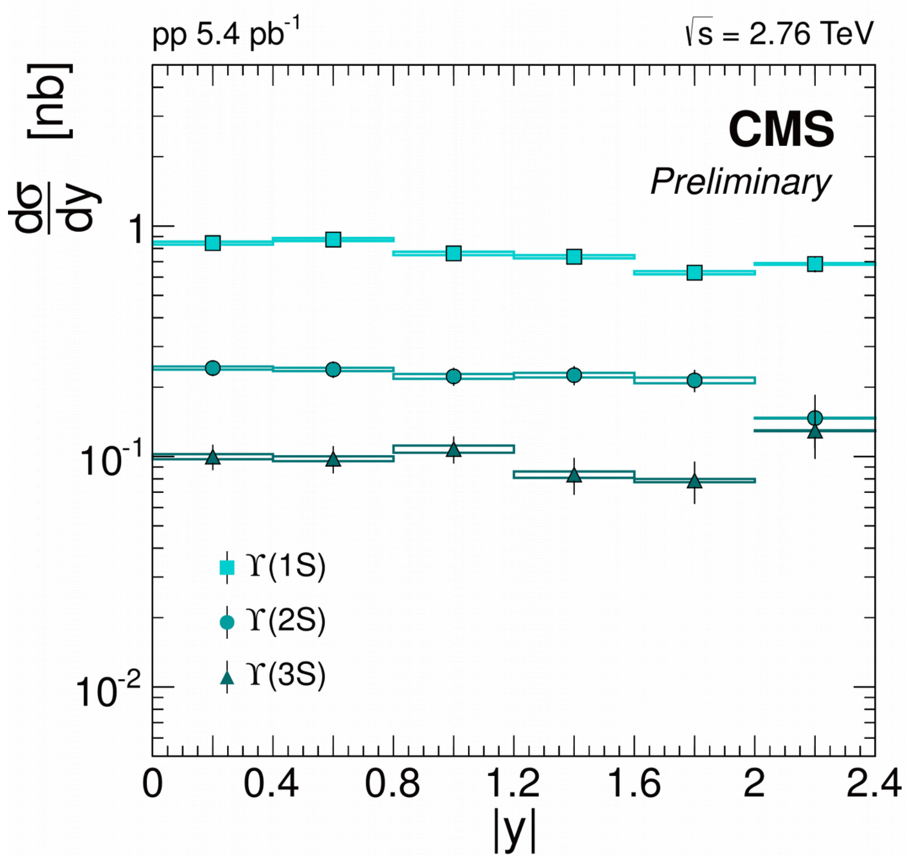


- Υ(2S) strongly suppressed from mid-central collisions
- Υ(2S) is less suppresses in the peripheral collisions ?
- Υ(3S) is completely dissolved ?

Thank You

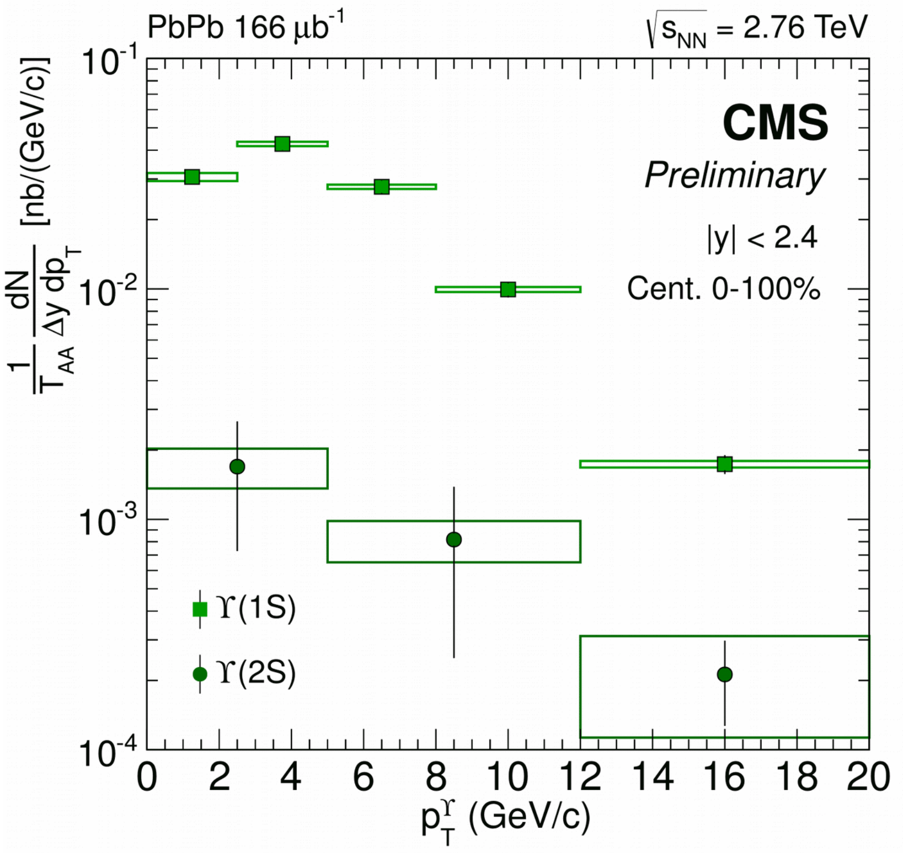
Differential cross section in pp

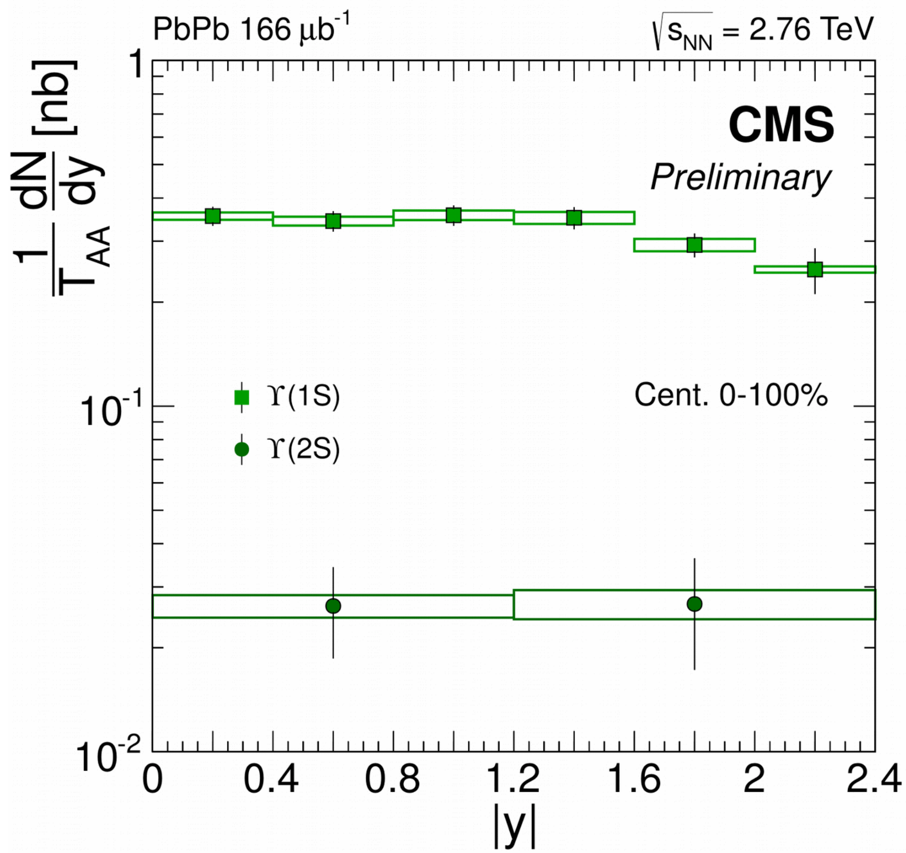




$\mathcal{B}_{\mu\mu} \cdot \sigma^{pp}_{\Upsilon(1S)}$	=	$0.738 \pm 0.013 \pm 0.036 \pm 0.028$ nb
$\mathcal{B}_{\mu\mu} \cdot \sigma^{pp}_{\Upsilon(2S)}$	=	$0.215 \pm 0.009 \pm 0.009 \pm 0.008$ nb
$\mathcal{B}_{\mu\mu} \cdot \sigma^{pp}_{\Upsilon(3S)}$	=	$0.091 \pm 6.10^{-3} \pm 5.10^{-3} \pm 3.10^{-3}$ nb

Differential cross section in PbPb





Efficiency and Acceptance of Υ(1S) in pp

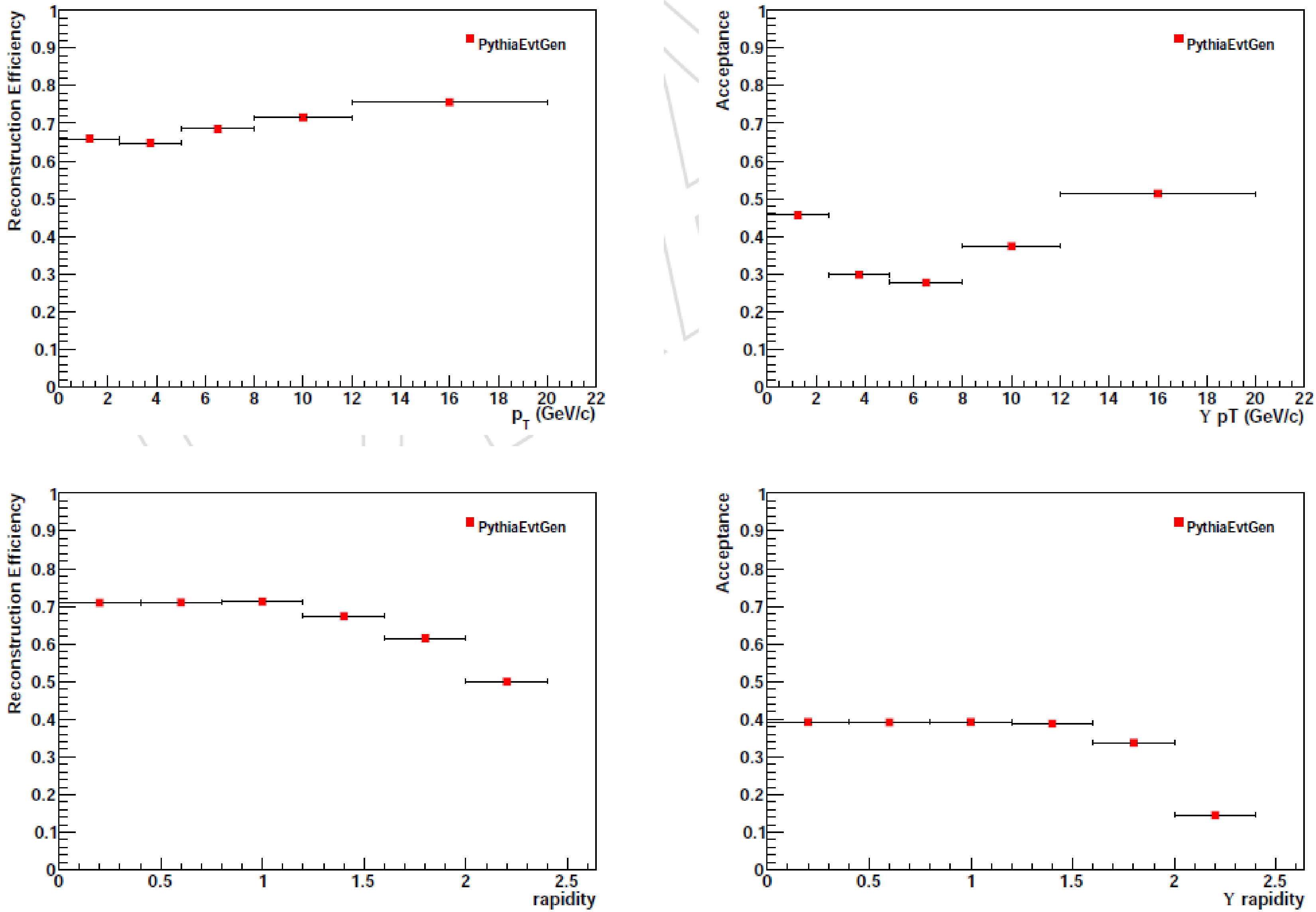


Figure 28: Efficiency (Left) and Acceptance (Right) as a function of p_T (Upper) and Rapidity (Lower) for pp Υ(1S) with loose p_T cuts.

Efficiency and Acceptance of Υ(1S) in PbPb

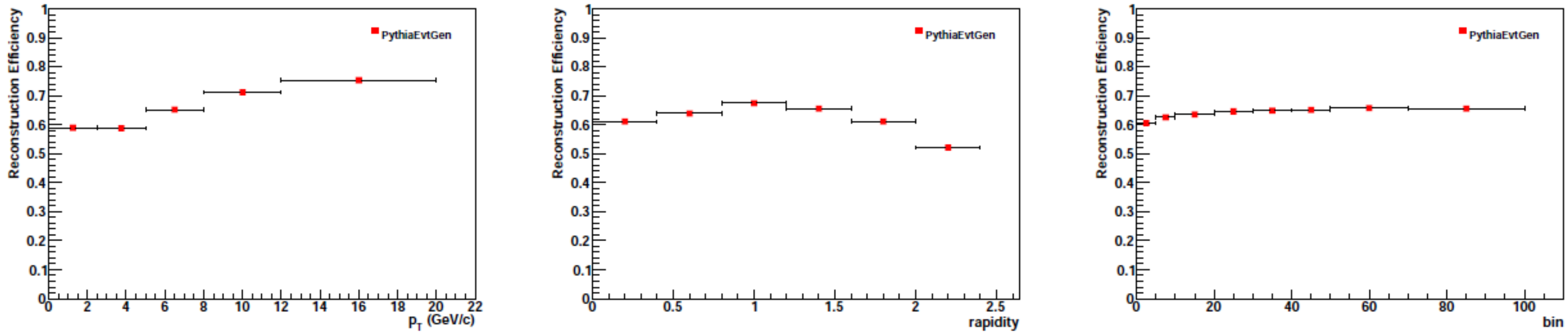


Figure 31: Efficiency as a function of p_T, Rapidity and Centrality for Pb+Pb Υ(1S) with loose p_T cuts.

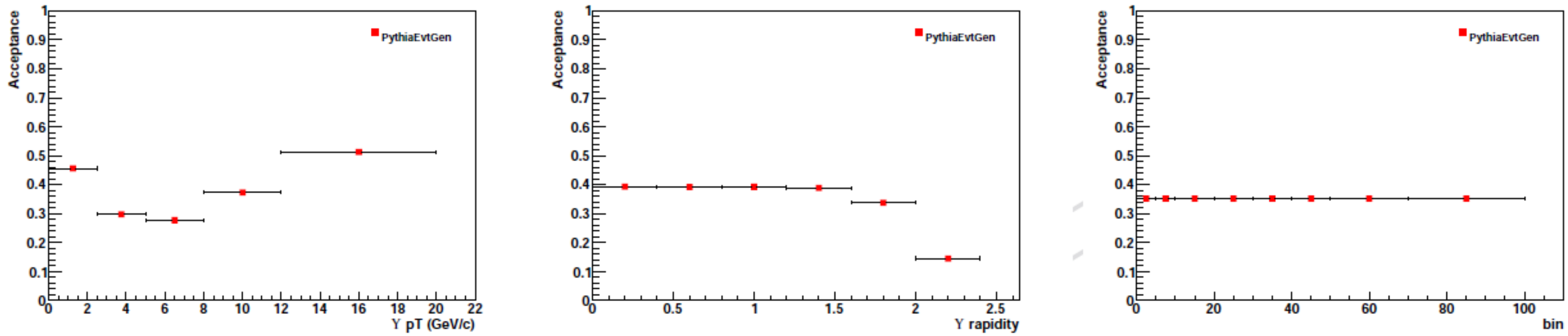


Figure 32: Acceptance as a function of p_T, Rapidity and Centrality for Pb+Pb Υ(1S) with loose p_T cuts.