Bottomonium production in pp, pPb and PbPb collisions with CMS

Dong Ho Moon
(University Of Illinois at Chicago)
for the CMS Collaboration

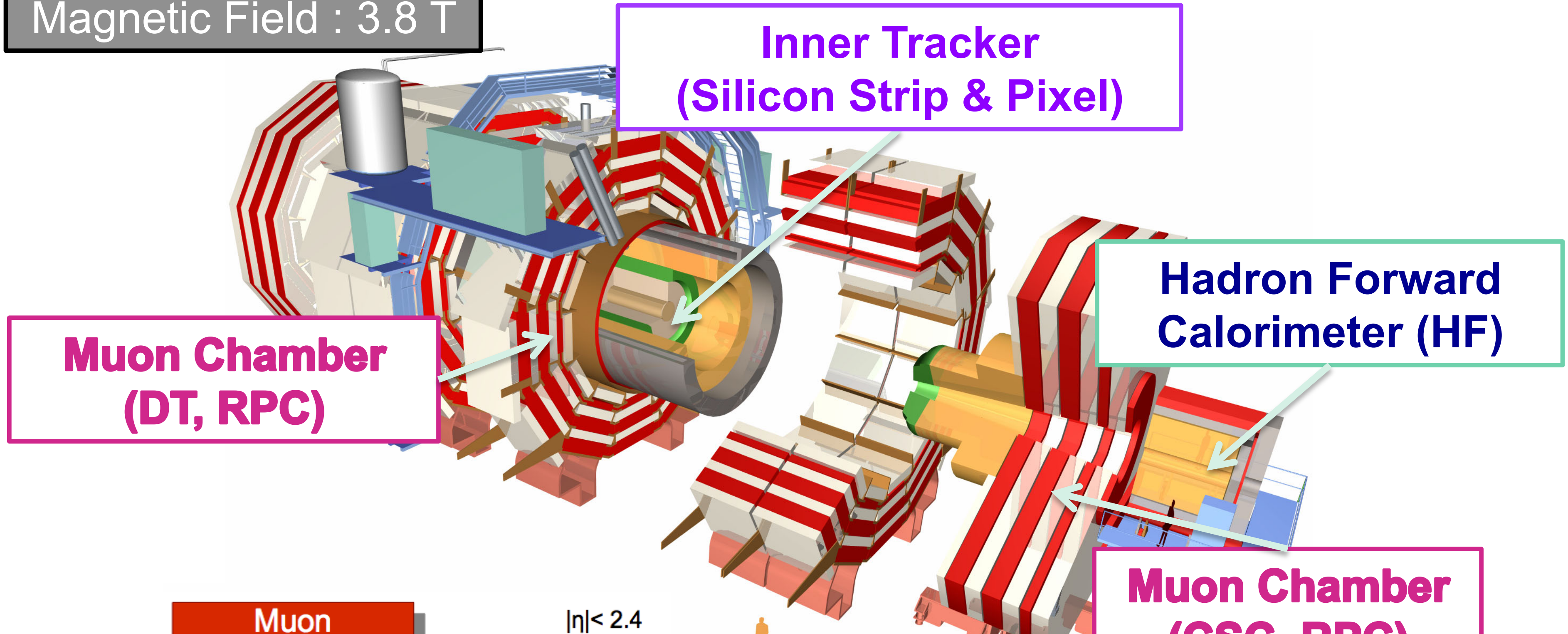
Hard Probes 2013, Cape Town
4th November, 2013

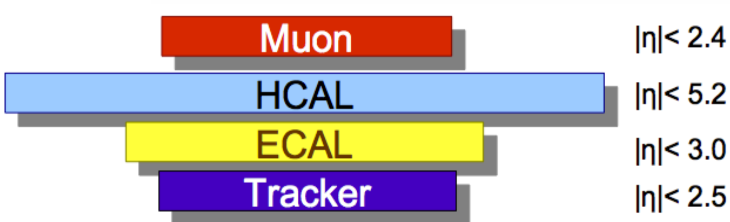
Contents

- Introduction
- Bottomonium measurements
  - pp & pPb collisions
- Bonus : recent charmonium results from PbPb
- Summary

CMS detector

Magnetic Field : 3.8 T

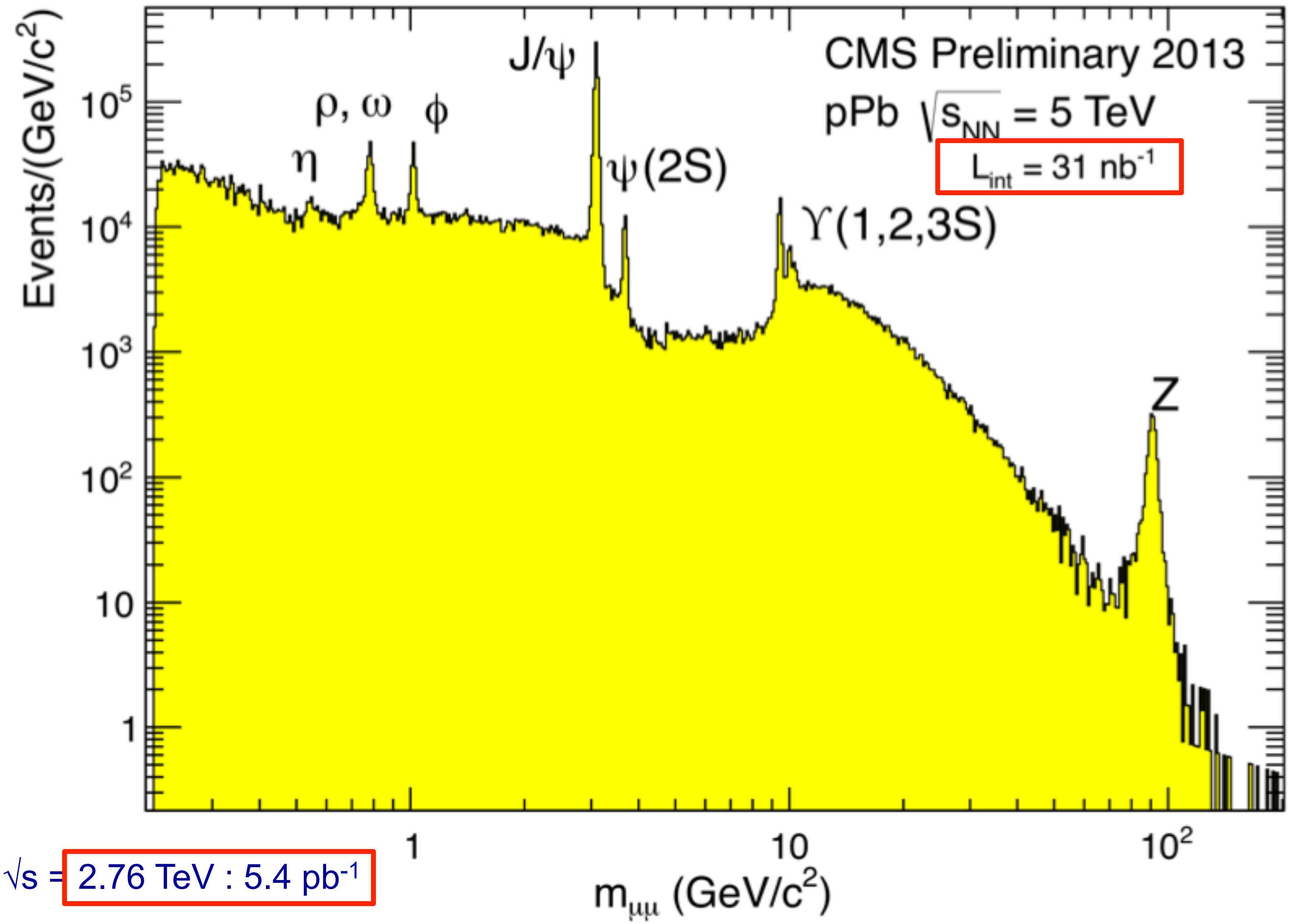




Muon Reconstruction

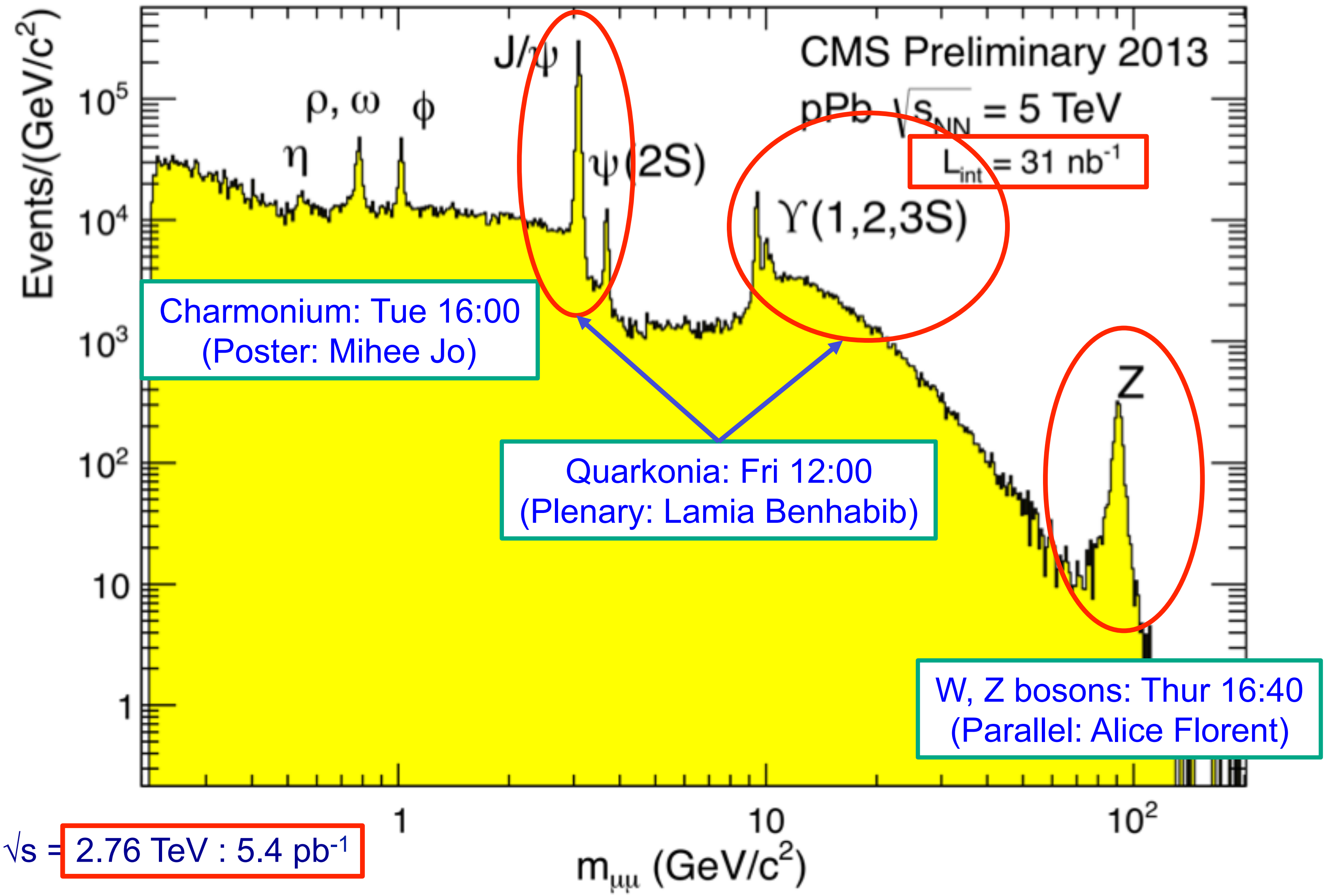
Muon tracks in muon chamber + tracks in inner tracker
Excellent momentum resolution of tracking system.
✓ Overall resolution: 1~2 %

Dimuon spectrum in 2013 pPb



- pp $\sqrt{s}$ = 2.76 TeV : 5.4 pb^{-1}

Dimuon spectrum in 2013 pPb



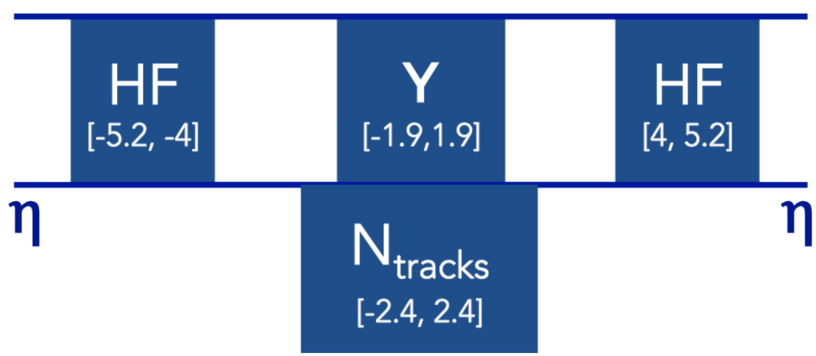
- pp $\sqrt{s}$ = 2.76 TeV : 5.4 pb^{-1}

pPb Collisions at 2013

- pPb collisions: the bridge between pp and PbPb collisions, to understand cold nuclear matter (CNM) effect from QGP.
- pPb asymmetric collisions (~0.47 rapidity boost)
  - analysis window $|y_{CM}| < 1.93$

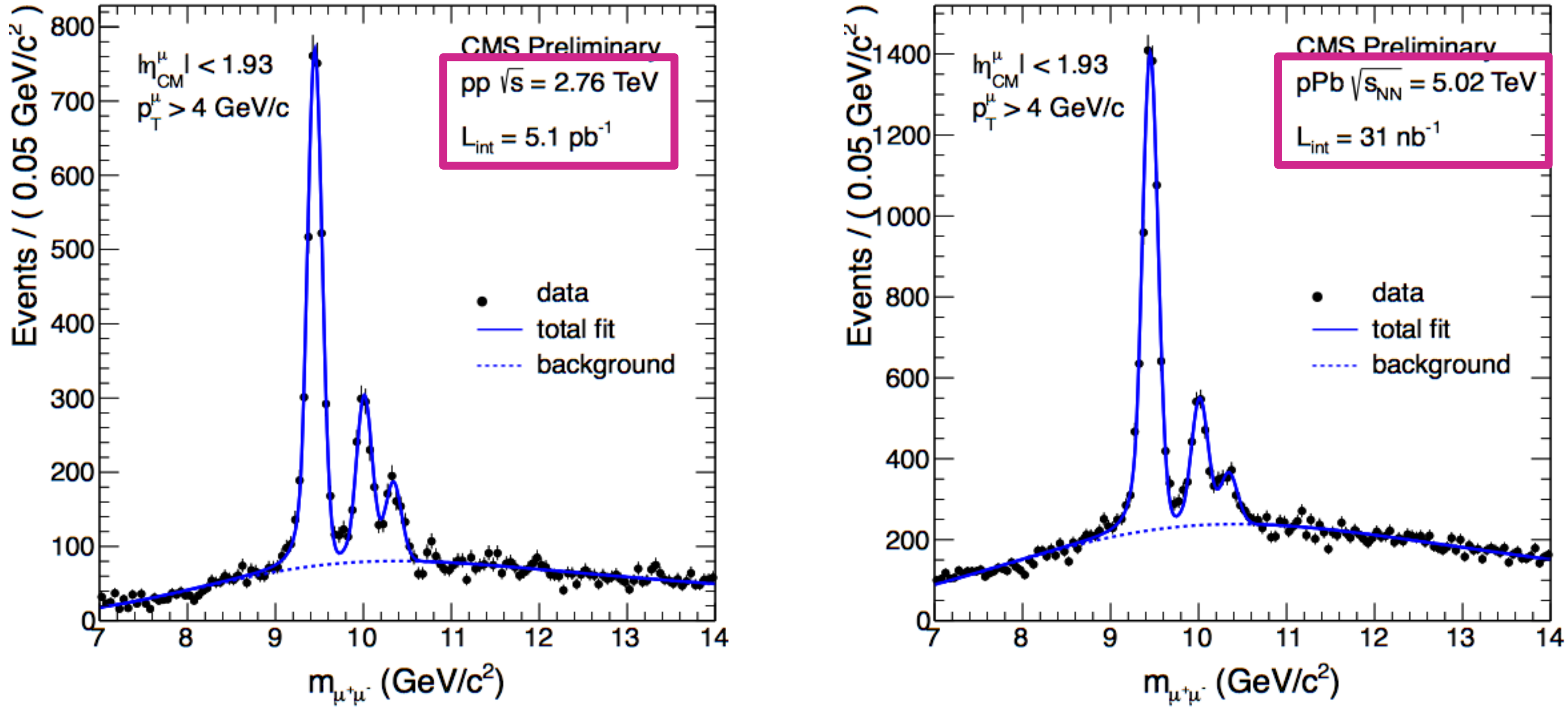
Ref. system	Pb+p			
LAB		-2.4	-0.47	1.5
Collision (CM)		-1.9	0.00	1.9

- Binning in 2 event-activity variables:
  - Corrected N_{tracks} ($|\eta| < 2.4$, $p_T > 400$ MeV/c)
  - Raw transverse energy measured in HF, E_T ($|\eta| > 4.0$)



Invariant Mass Distributions

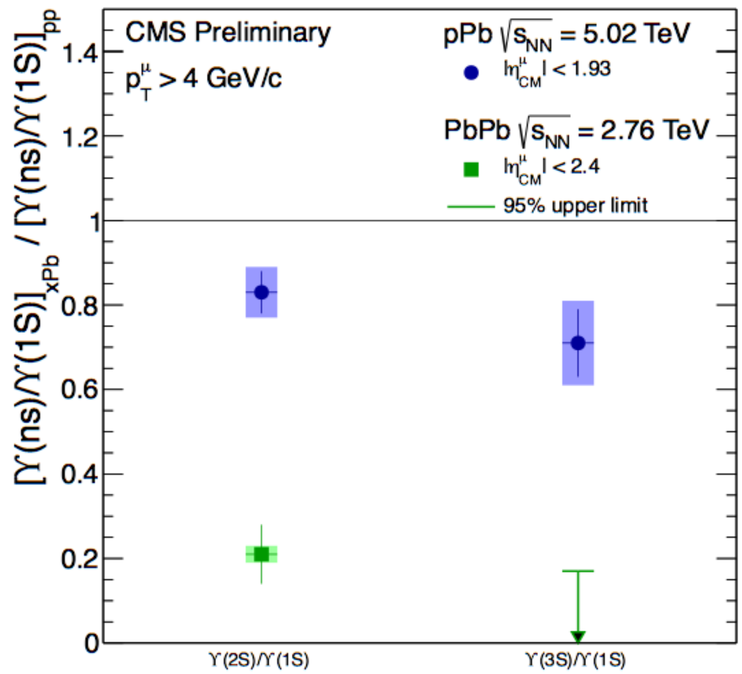
- Signal extractions



- Un-binned maximum log likelihood fit
  - ➢ Signal : 3 Crystal-Ball function (Gaussian with low-side tail with power-law)
  - ➢ Background : error function * exponential (all background parameters free)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003

Double Ratio

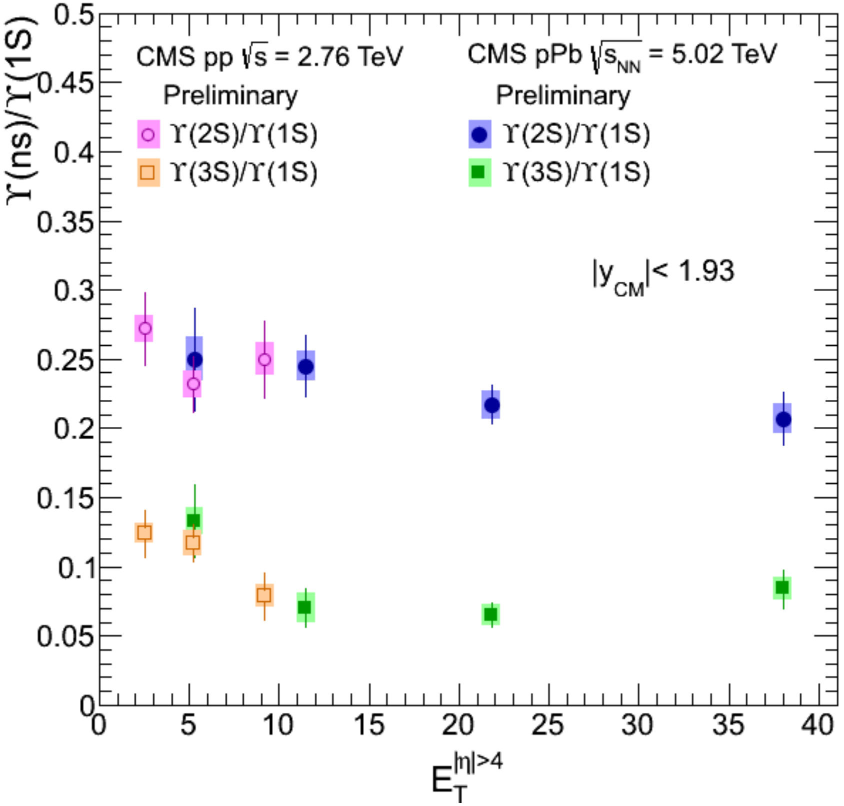


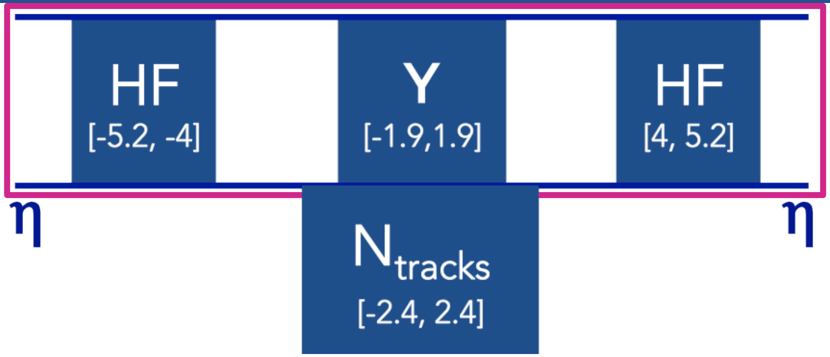
$$\frac{[\frac{\Upsilon(nS)}{\Upsilon(1S)}]_{pPb}}{[\frac{\Upsilon(nS)}{\Upsilon(1S)}]_{pp}} = \frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$

- pPb vs PbPb: stronger final state effects in PbPb compared to pPb
- pPb vs pp: indication (significance < 3σ) of additional effects on the excited states in pPb

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003

Υ(nS)/Υ(1S) vs E_T (|η| > 4)



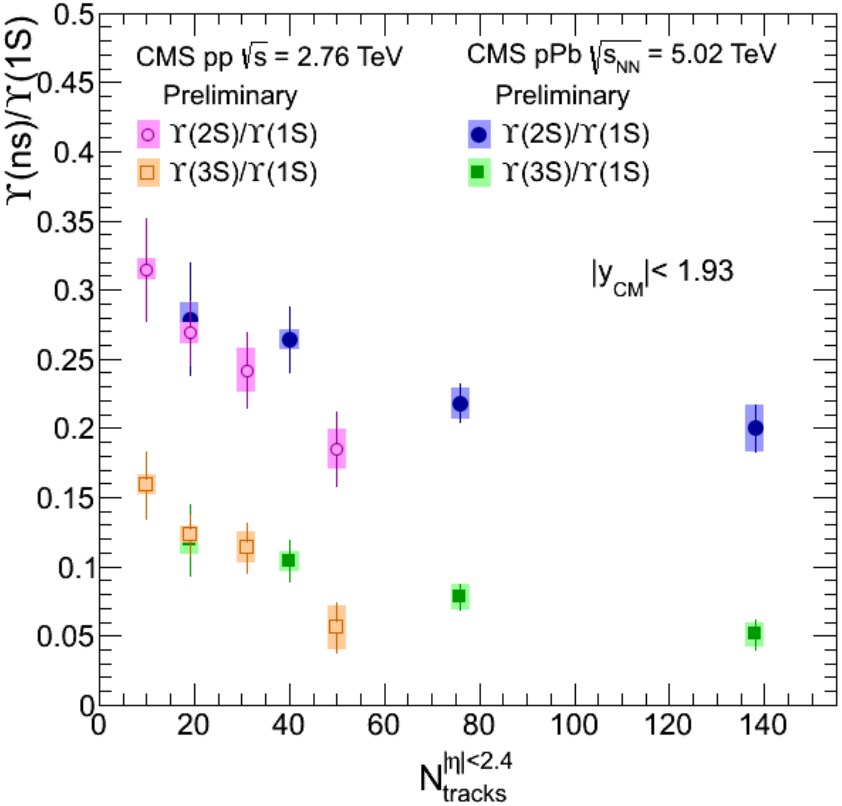


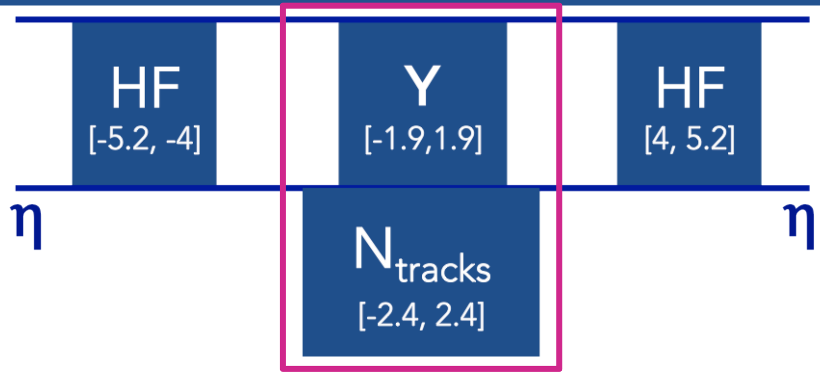
$$\left[\frac{\Upsilon(nS)}{\Upsilon(1S)}\right]_{pp,pPb}$$

- Weak dependence of excited to the ground state ratio with respect to the E_T(|η|>4)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003

Y(nS)/Y(1S) vs N_{tracks} (|η| < 2.4)



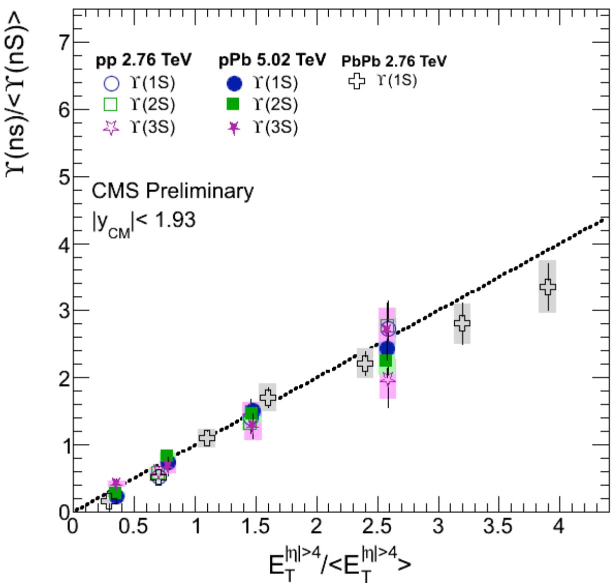


$$\left[\frac{\Upsilon(nS)}{\Upsilon(1S)}\right]_{pp,pPb}$$

- Significant decrease of Y(nS)/Y(1S) with increasing multiplicity, in pPb and pp
- Possible ways to produce this dependence
  - Y would affect the multiplicity or Multiplicity would affect the Y

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003

Self-normalized Yields: Y(nS)/<Y(nS)>



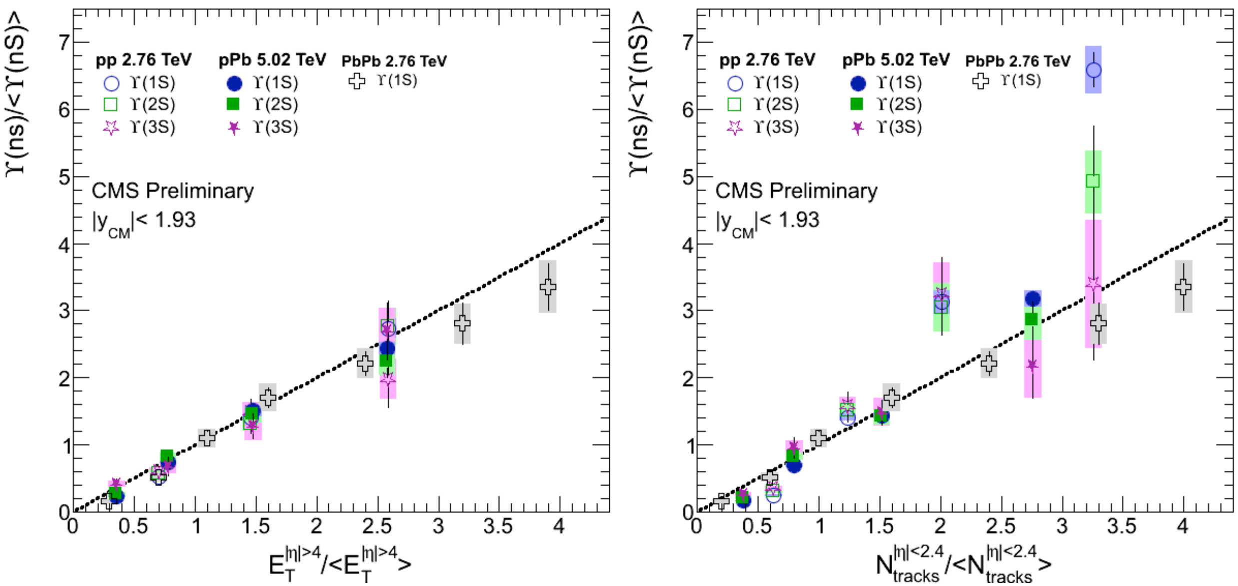
$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{MB}} \frac{Y(nS)|_{PbPb}}{Y(nS)|_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

$$\frac{R^i_{AA}}{R_{AA}} = \frac{T_{AA}}{T^i_{AA}} * \frac{\Upsilon(nS)^i}{\langle\Upsilon(nS)\rangle} * \frac{\epsilon}{\epsilon^i}$$

- Y(nS)/<Y(nS)>: in the line at the whole E_T(|η|>4)

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003

Self-normalized Yields: Y(nS)/<Y(nS)>



$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{MB}} \frac{Y(nS)|_{PbPb}}{Y(nS)|_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

$$\frac{R^i_{AA}}{R_{AA}} = \frac{T_{AA}}{T^i_{AA}} * \frac{\Upsilon(nS)^i}{\langle \Upsilon(nS) \rangle} * \frac{\epsilon}{\epsilon^i}$$

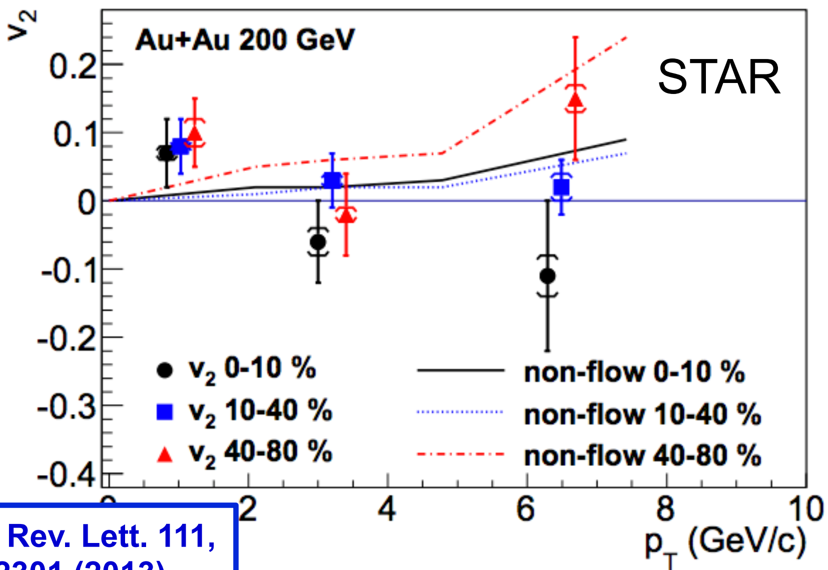
- Y(nS)/<Y(nS)>: in the line at the whole E_T(|η|>4)
- Y(nS)/<Y(nS)> vs N_{tracks}
  - Less consistent behavior (related to the Y(nS)/Y(1S) variations)
  - Multi parton interaction : should be same in 1S, 2S and 3S but even pp with high multiplicity shows differences

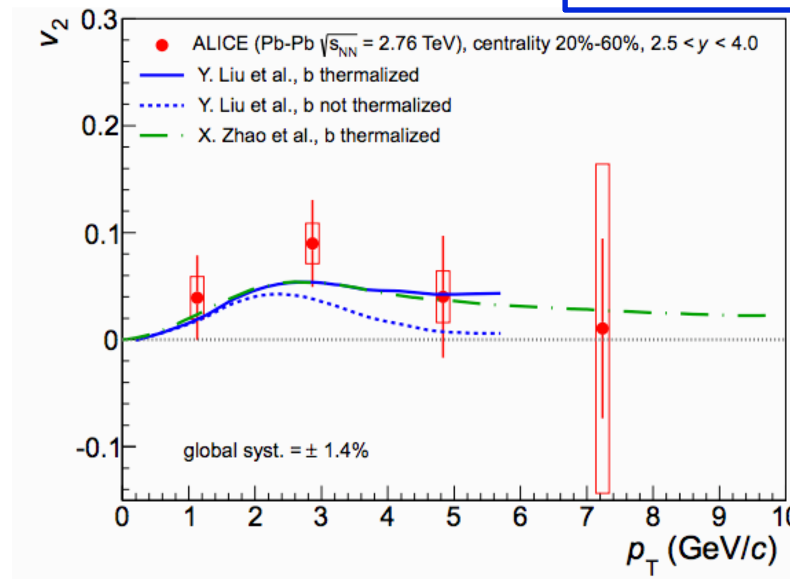
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003

J/ψ Azimuthal Anisotropy in CMS

- STAR and ALICE measured inclusive J/ψ's v_2

Phys. Rev. Lett. 111, 102301 (2013)





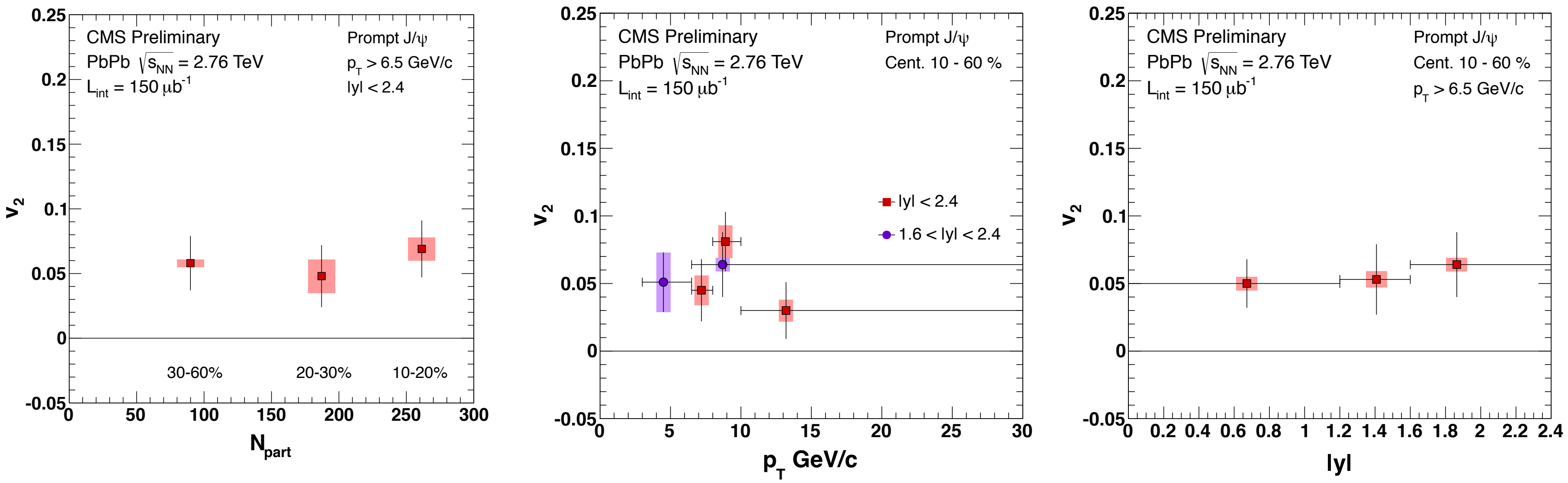
Phys. Rev. Lett. 111, 052301 (2013)

- STAR measured compatible zero v_2 from 2 GeV/c in whole p_T region
- ALICE observed non-zero v_2 in 2 - 4 GeV/c region

- Possible scenarios : regeneration of J/ψ or path-length dependence of suppression (less suppressed in-plane than out-plane)

- Prompt and non-prompt J/ψ separation is important: one from charm or bottom

J/ψ Azimuthal Anisotropy in CMS

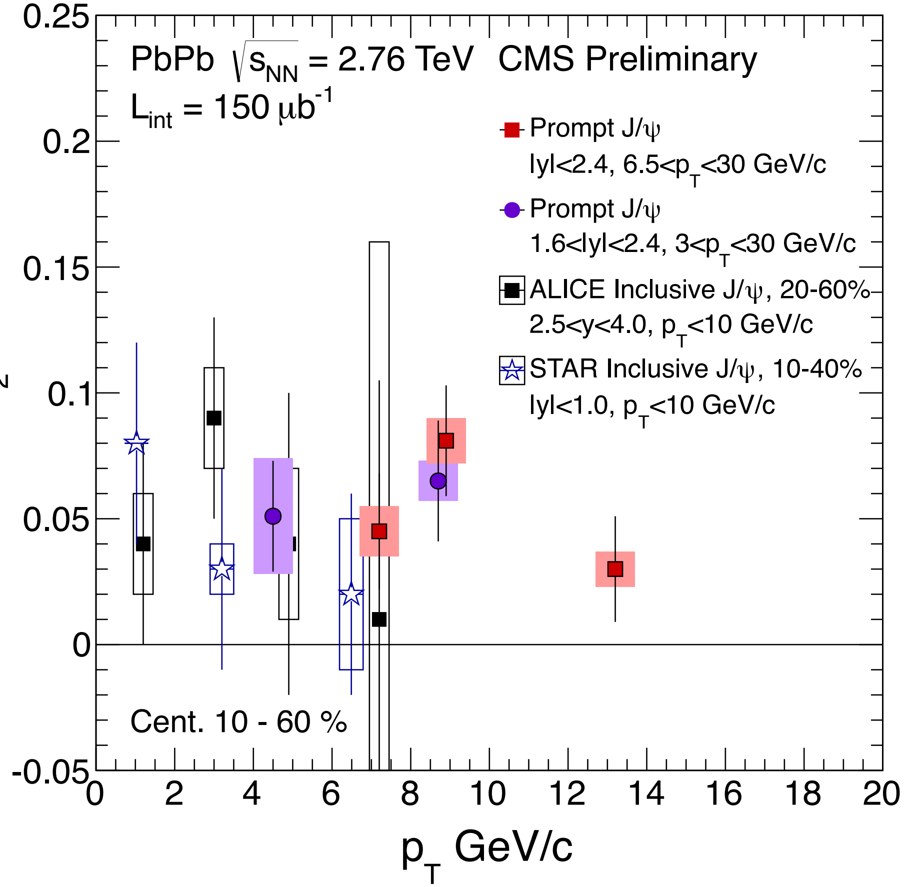


CMS-PAS-HIN-12-001

- Integrated v_2 for Prompt J/ψ (p_T > 6.5 GeV/c)
  - ➠ 0.054 ± 0.013 (stat.) ± 0.006 (syst.) in |y| < 2.4, 10-60 %
  - ➠ significant (3.8σ) v_2 at high-p_T prompt J/ψ

See Mihee Jo's poster in Tuesday

J/ψ Azimuthal Anisotropy in CMS



CMS-PAS-HIN-12-001
Phys. Rev. Lett. 111, 052301 (2013)
Phys. Rev. Lett. 111, 162301 (2013)

Extended available measurement up to high p_T region (6.5 – 30 GeV/c) and observed non-zero v_2

No significant dependence of p_T

See Mihee Jo's poster in Tuesday

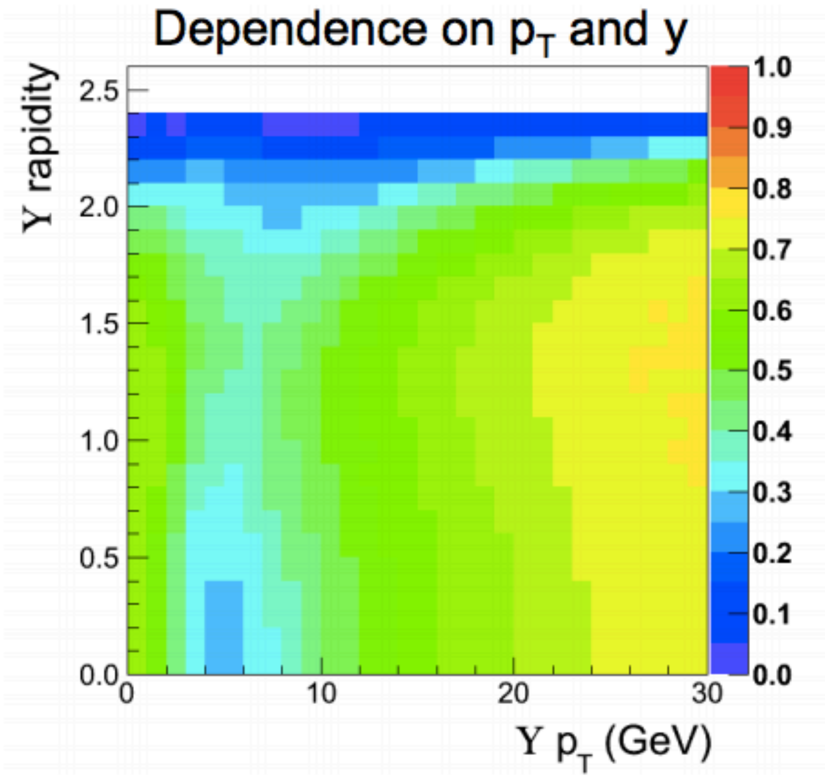
Summary

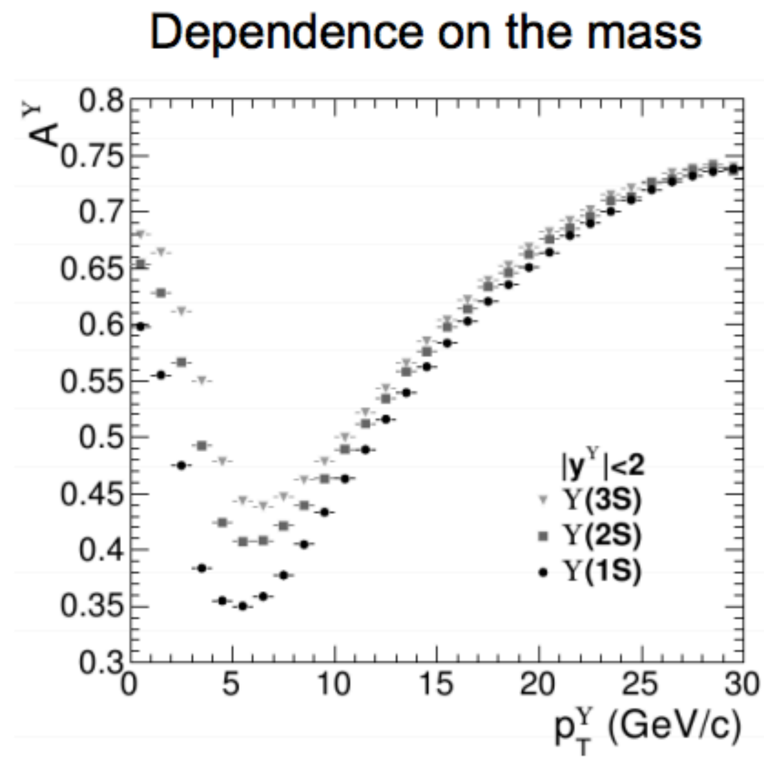
- Bottomonia in pp & pPb
  - Double ratios $[\Upsilon(nS)/\Upsilon(1S)]_{pPb}/[\Upsilon(nS)/\Upsilon(1S)]_{pp}$
    - Higher than in PbPb: stronger final state effects in PbPb than in pPb
    - Hint to the presence of additional effects (like CNM) in pPb than in pp
  - $\Upsilon(nS)/\Upsilon(1S)$: decrease with increase of particle multiplicity in both pp and pPb
    - Reflect an influence of the ‘medium’ on the Υ
    - Reflect a different multiplicity associated with the Υ states production
  - $\Upsilon(nS)/\langle\Upsilon(nS)\rangle$: increase with increasing event activity in pp, pPb and PbPb

- Prompt J/ψ: significant anisotropy in 10-60%, $|y|<2.4$ and $6.5<p_T<30$GeV/c
  - Integrated v_2 : 0.054 ± 0.013 (stat.) ± 0.006 (syst.) (3.8σ)

Back up

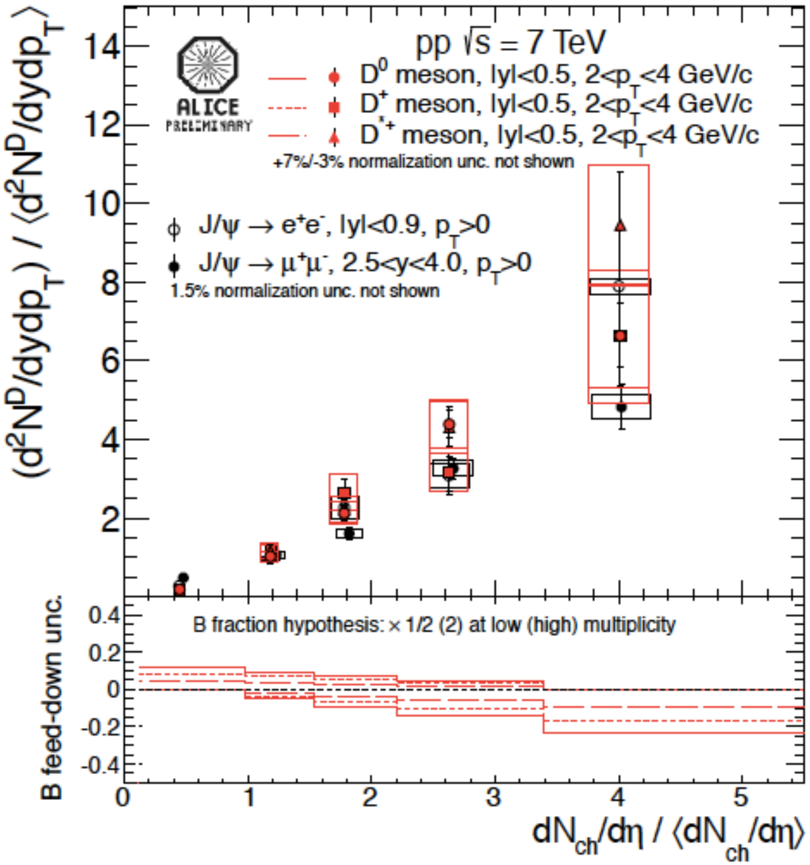
Upsion Acceptance



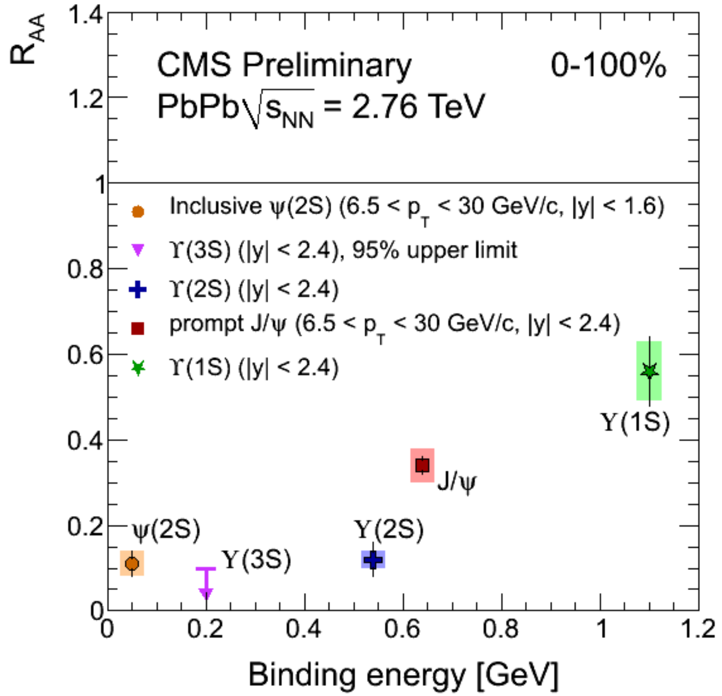


ALICE Multiplicity dependence

J/ψ: PLB712 (2012) 165
Charm: preliminary



R_{AA} vs binding energy



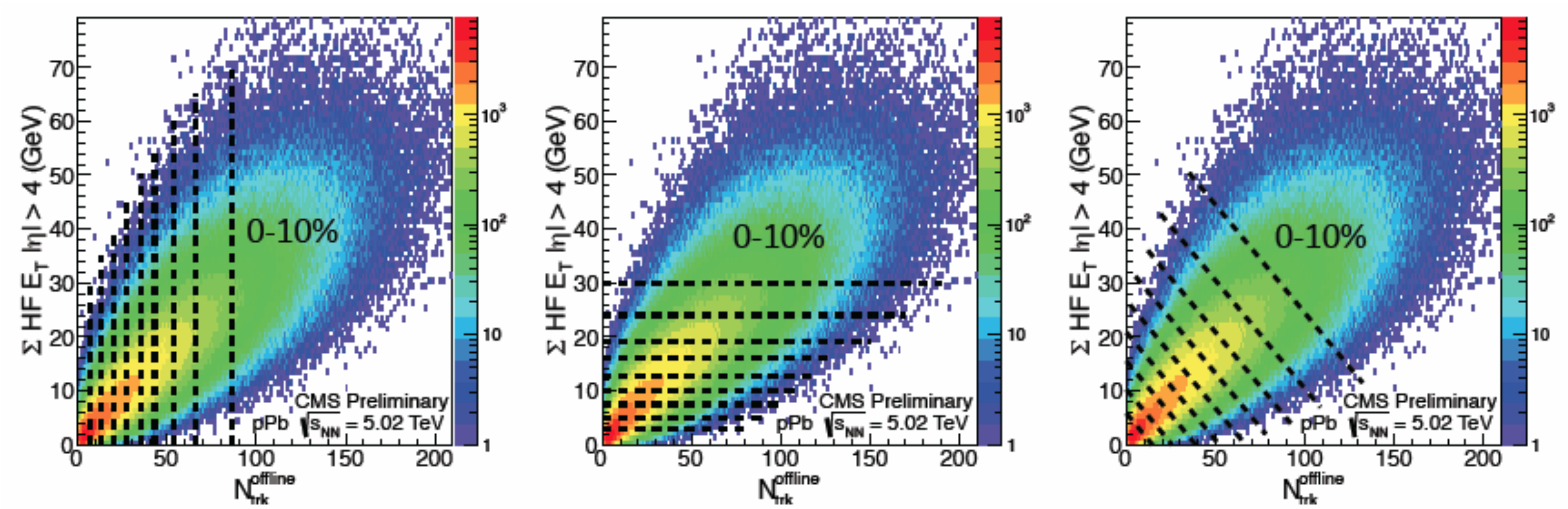
state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
r_0 [fm]	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

Table 3: Quarkonium Spectroscop

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

$\langle N_{coll} \rangle$ from different methods agree well

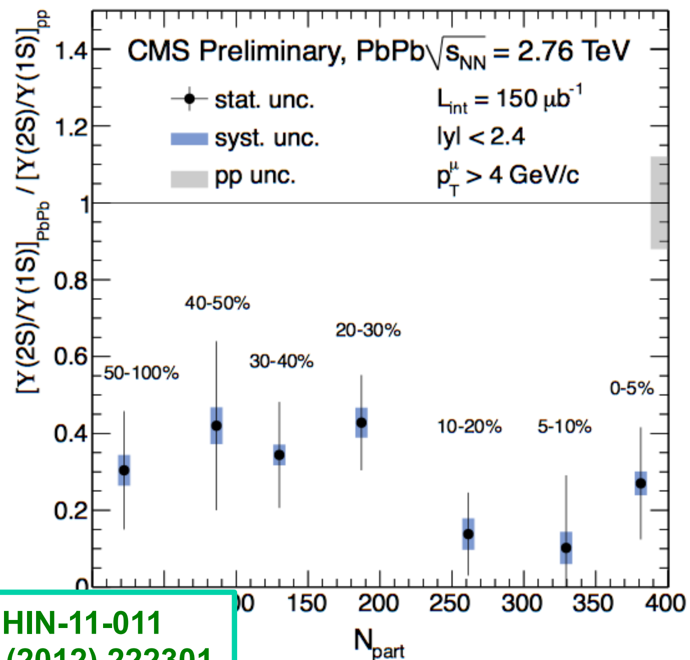
Defining centrality from different methods:



- Slicing multiplicity and ΣHF E_T $|\eta|>4$ means selecting very different events (e.g. 0-10% in the plots), but $\langle N_{coll} \rangle$ are the same
- The real difficulties of centrality determination are about how to define centrality in real data (which η range to use?) for an analysis and study possible biases

Results from PbPb Collisions

Double Ratio



CMS HIN-11-011
PRL 109 (2012) 222301

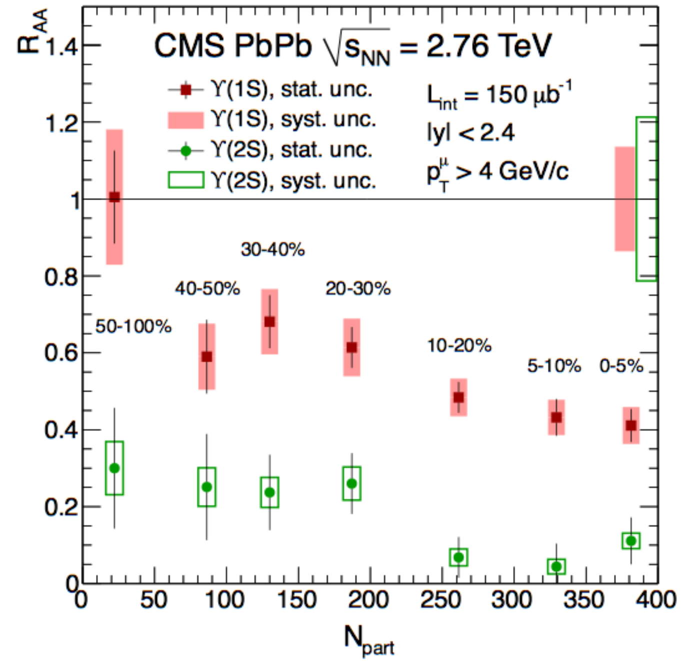
$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{PbPb}}{\Upsilon(2S)/\Upsilon(1S)|_{pp}} = 0.21 \pm 0.07(\text{stat}) \pm 0.02(\text{syst}),$$

$$\frac{\Upsilon(3S)/\Upsilon(1S)|_{PbPb}}{\Upsilon(3S)/\Upsilon(1S)|_{pp}} = 0.06 \pm 0.06(\text{stat}) \pm 0.06(\text{syst})$$

$$< 0.17(95\%\text{CL}).$$

Υ(2S) and Υ(3S) are more suppressed than Υ(1S)

R_{AA}



$$R_{AA}(\Upsilon(1S)) = 0.56 \pm 0.08(\text{stat}) \pm 0.07(\text{syst}),$$

$$R_{AA}(\Upsilon(2S)) = 0.12 \pm 0.04(\text{stat}) \pm 0.02(\text{syst}),$$

$$R_{AA}(\Upsilon(3S)) = 0.03 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})$$

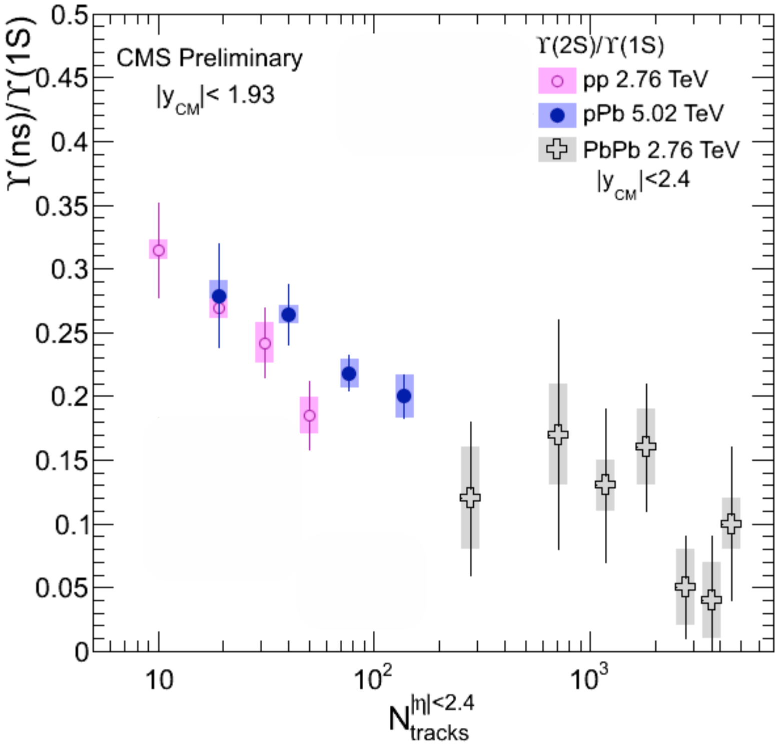
$$< 0.10(95\%\text{CL}).$$

Υ(3S) are more suppressed than Υ(2S).

Ordering: $R_{AA}(\Upsilon(3S)) < R_{AA}(\Upsilon(2S)) < R_{AA}(\Upsilon(1S))$

Υ(2S)/Υ(1S) compare PbPb

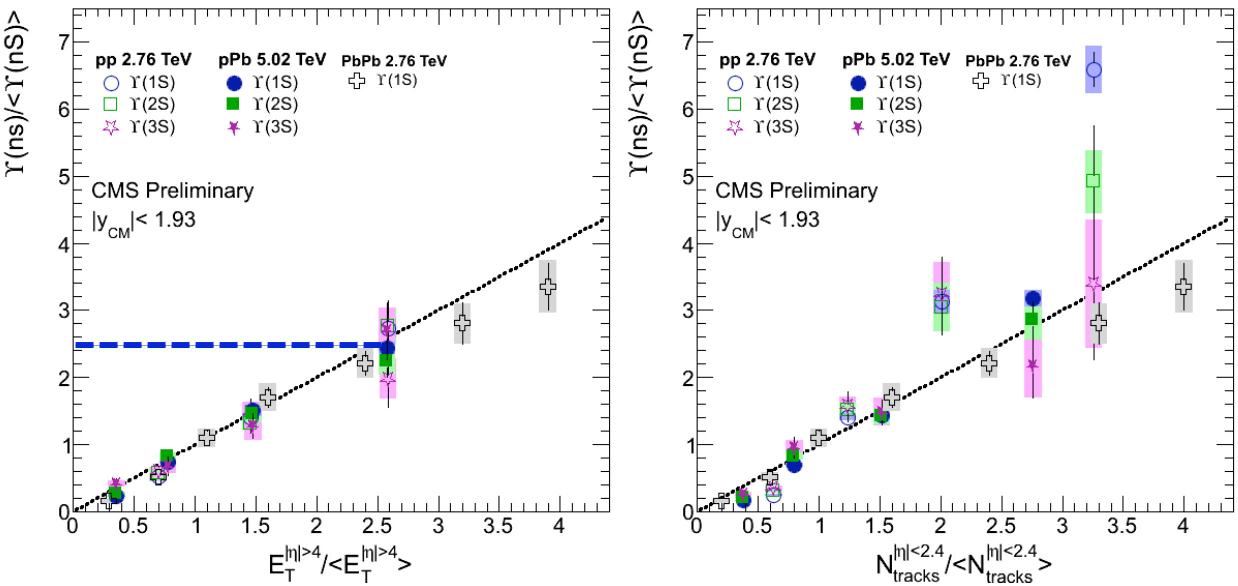
- 2011 PbPb single ratios



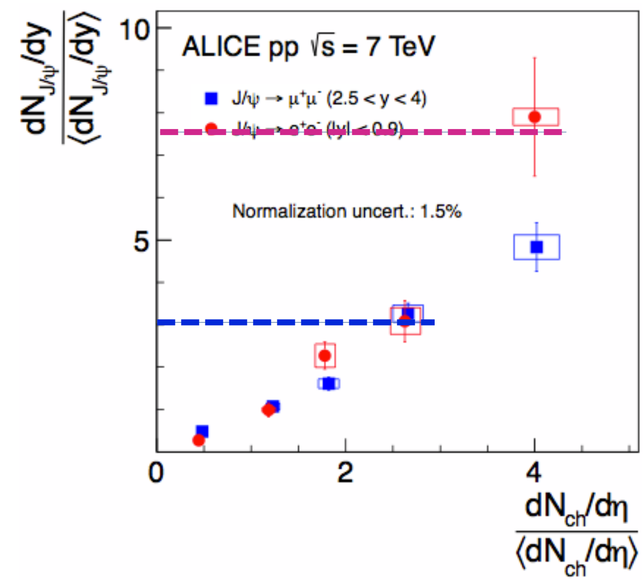
- PbPb : no significant dependence on N_{tracks}, but large uncertainties
- PbPb points are below all the pPb data but large uncertainties to tell if already in most central pPb the level of suppression is the same as in PbPb peripheral

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003

Self-normalized Yields: Y(nS)/<Y(nS)>



PLB 712 (2012) 165



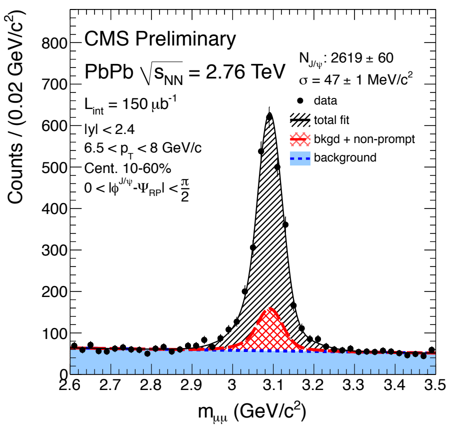
- Y(nS)/<Y(nS)>: in the line at the whole E_T(|η|>4)
- Y(nS)/<Y(nS)> vs N_{tracks}
  - Less consistent behavior (related to the Y(nS)/Y(1S) variations)
  - Multi parton interaction : should be same in 1S, 2S and 3S but even pp with high multiplicity shows differences

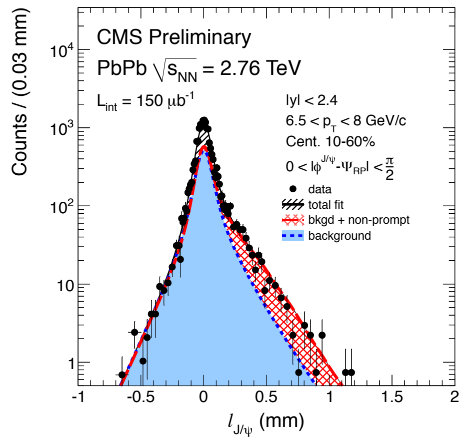
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003

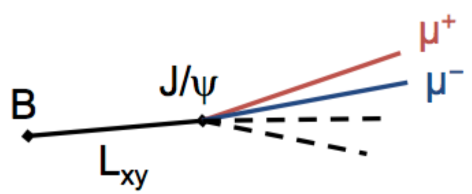
J/ψ Azimuthal Anisotropy in CMS

CMS-PAS-HIN-12-001

- Signal extraction







Systematics

- Yield extraction: 1 – 20 %
- Efficiency correction: 0 – 42 %
- Event plane: 3.5 %
- Total : 12 – 46 %

J/ψ Azimuthal Anisotropy in CMS

-