Recent Results of Quarkonia Production at CMS

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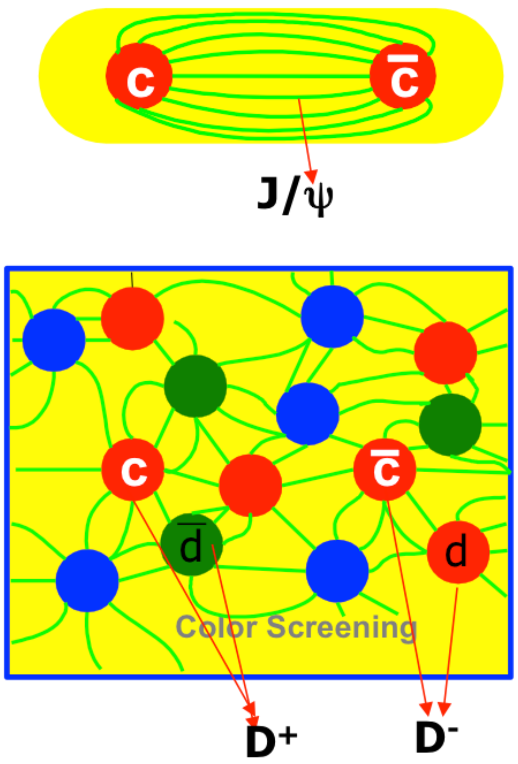
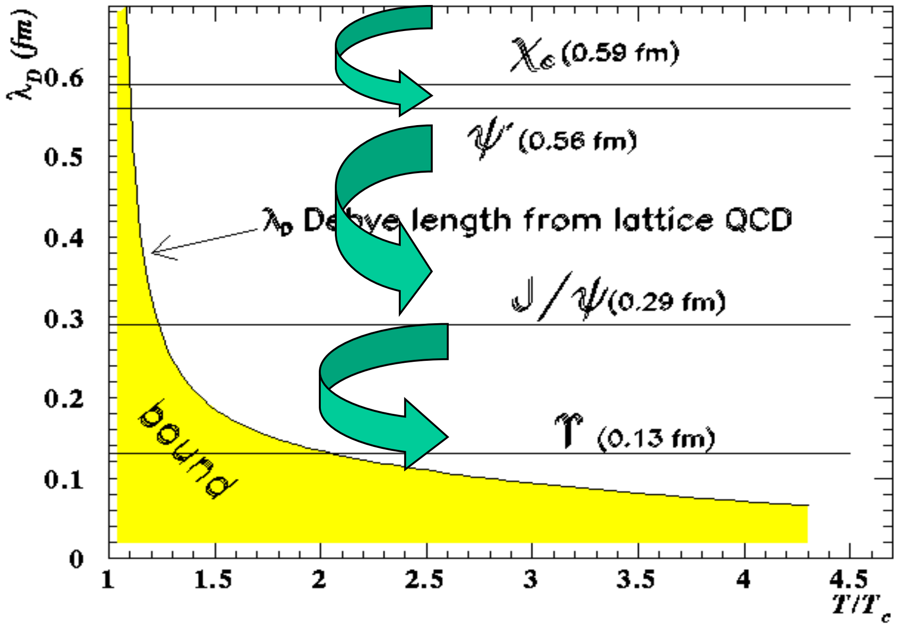
Quarkonia Suppression in Hot Medium

- One of striking signatures for Quark-Gluon-Plasma (QGP) formation
- Sequential melting : different binding energies → bound states are melt sequentially in hot medium





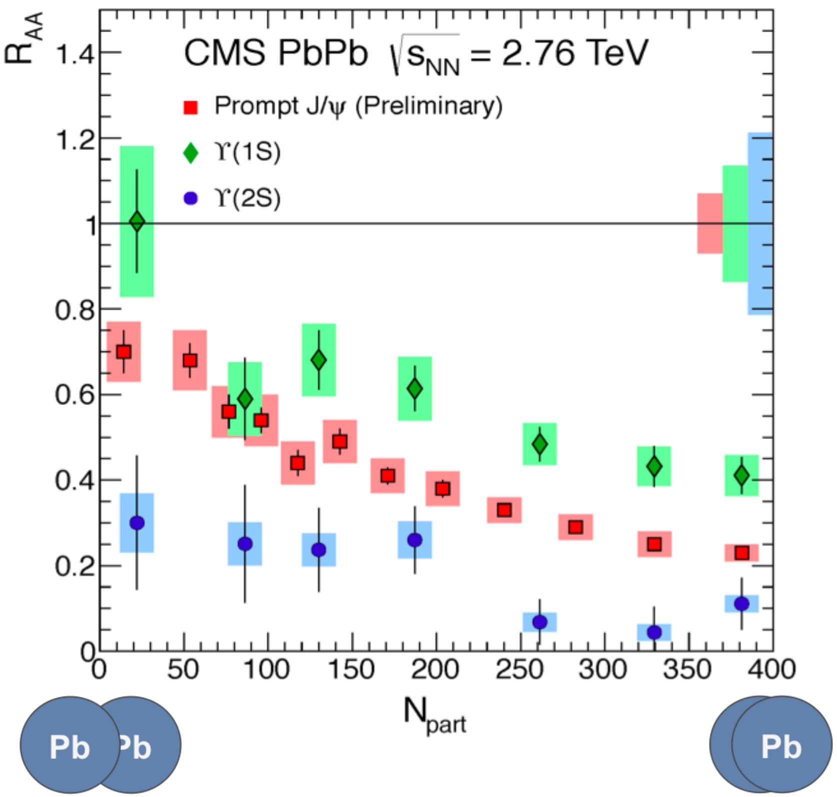
Sequential melting → a QGP thermometer

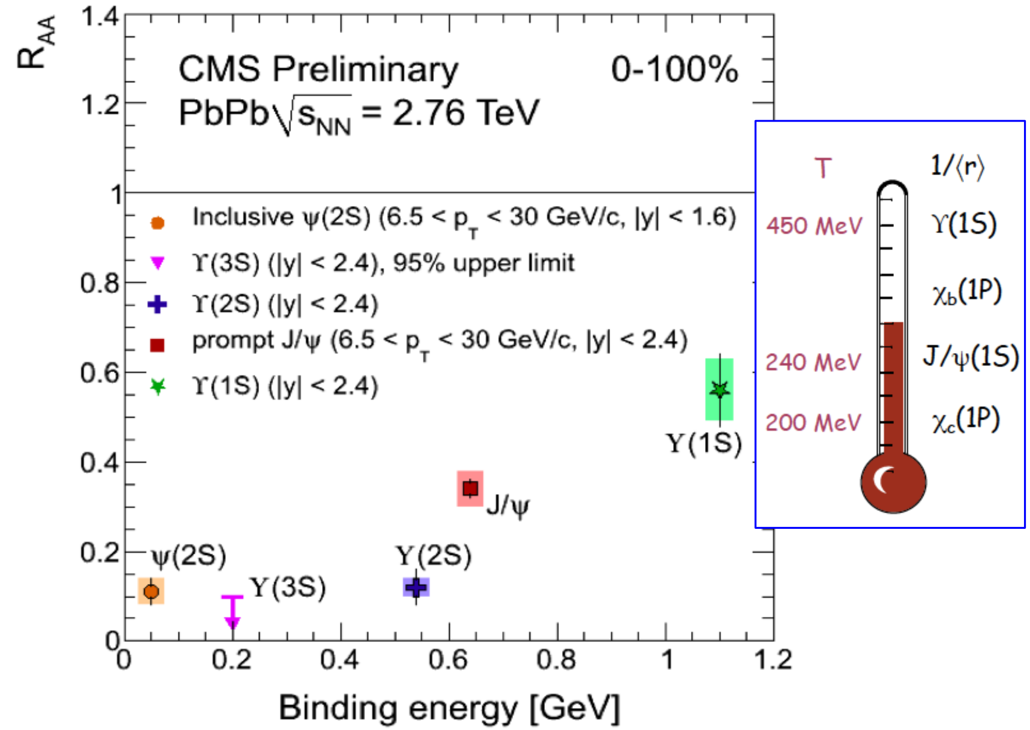
H. Satz, NPA 783 (2007) 249c.

2013 Heavy Flavor Measurements at RHIC and LHC (W. Xie)

- Quenched heavy quarks (energy loss): *A.Rothkopf,* ***PRL 108(2012) 162001***

Quarkonia Suppression in Hot Medium





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

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

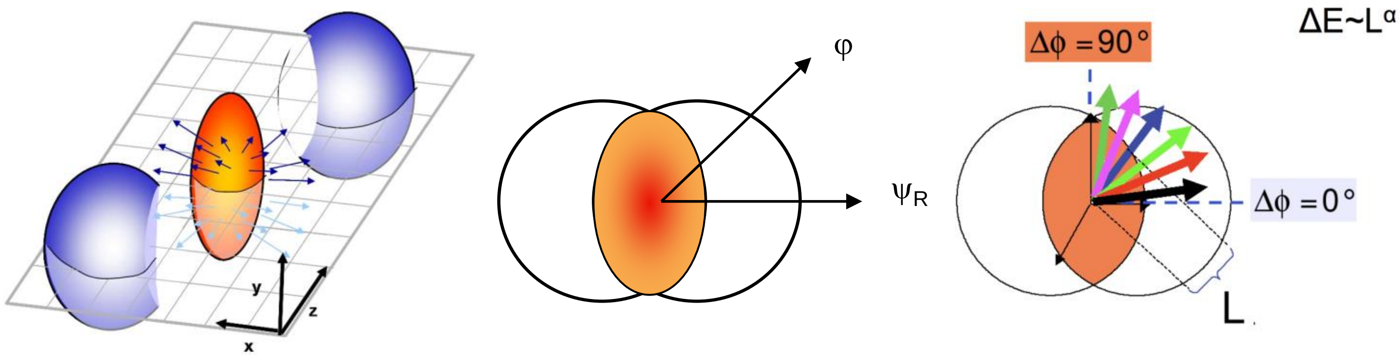
Observed

- Significant suppression of J/ψ and ϒ (1S, 2S, 3S) at PbPb collisions
- Expected hierarchy in the suppression of the states with different binding energy

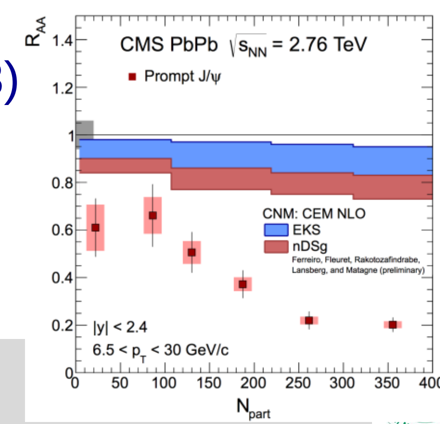
Quarkonia Study at CMS

Today focus

- In PbPb collisions :
  - Suppression of J/ψ again but dependence on new variable : reaction plane

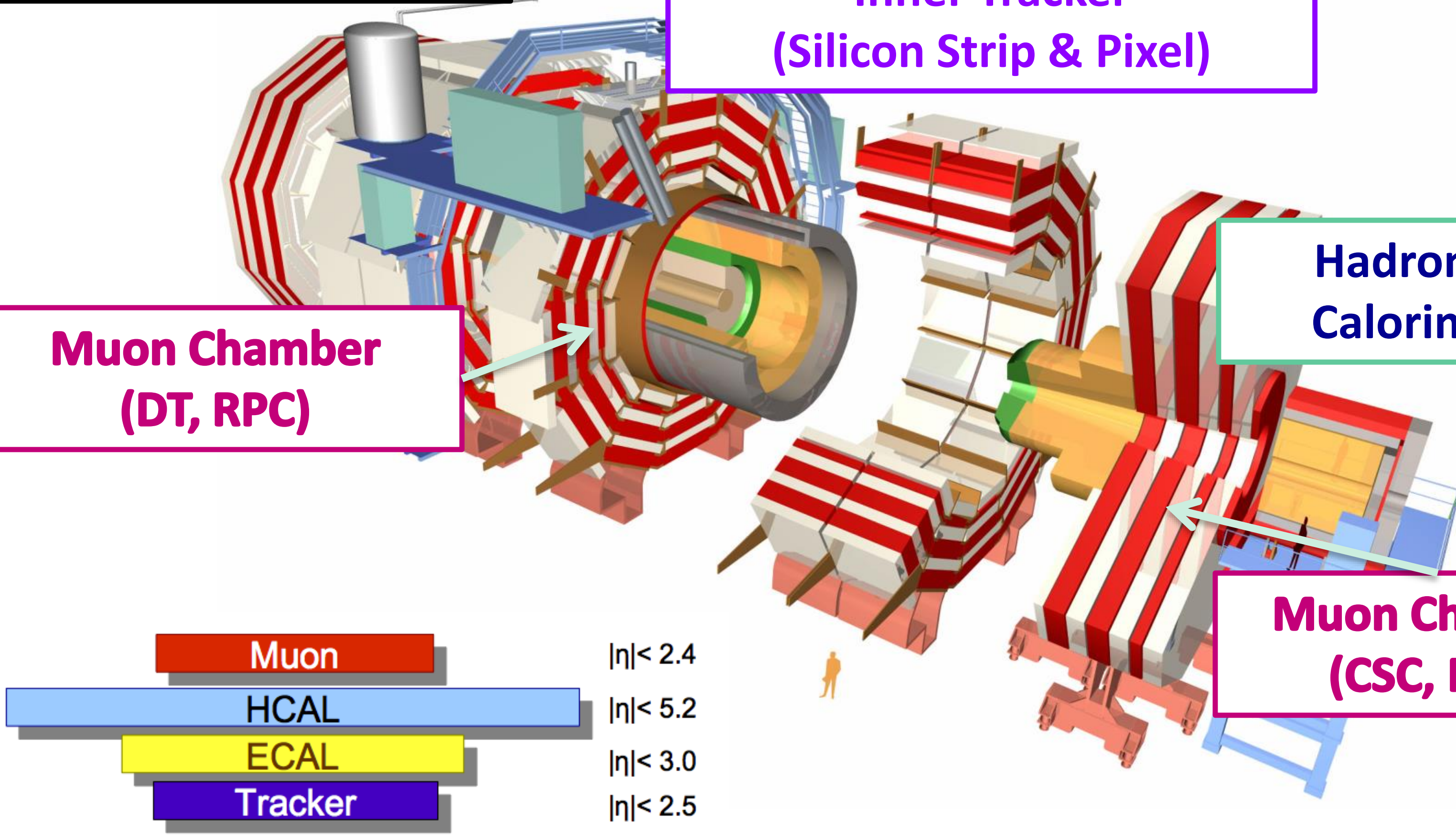


- In pPb collisions :
  - The pure suppression of quarkonia from the QGP : distinguish Cold Nuclear Matter (CNM) effect from QGP
  - ϒ (1S, 2S, 3S) : published at JHEP (JHEP 04 (2014) 103)
  - J/ψ : ongoing (KU group)

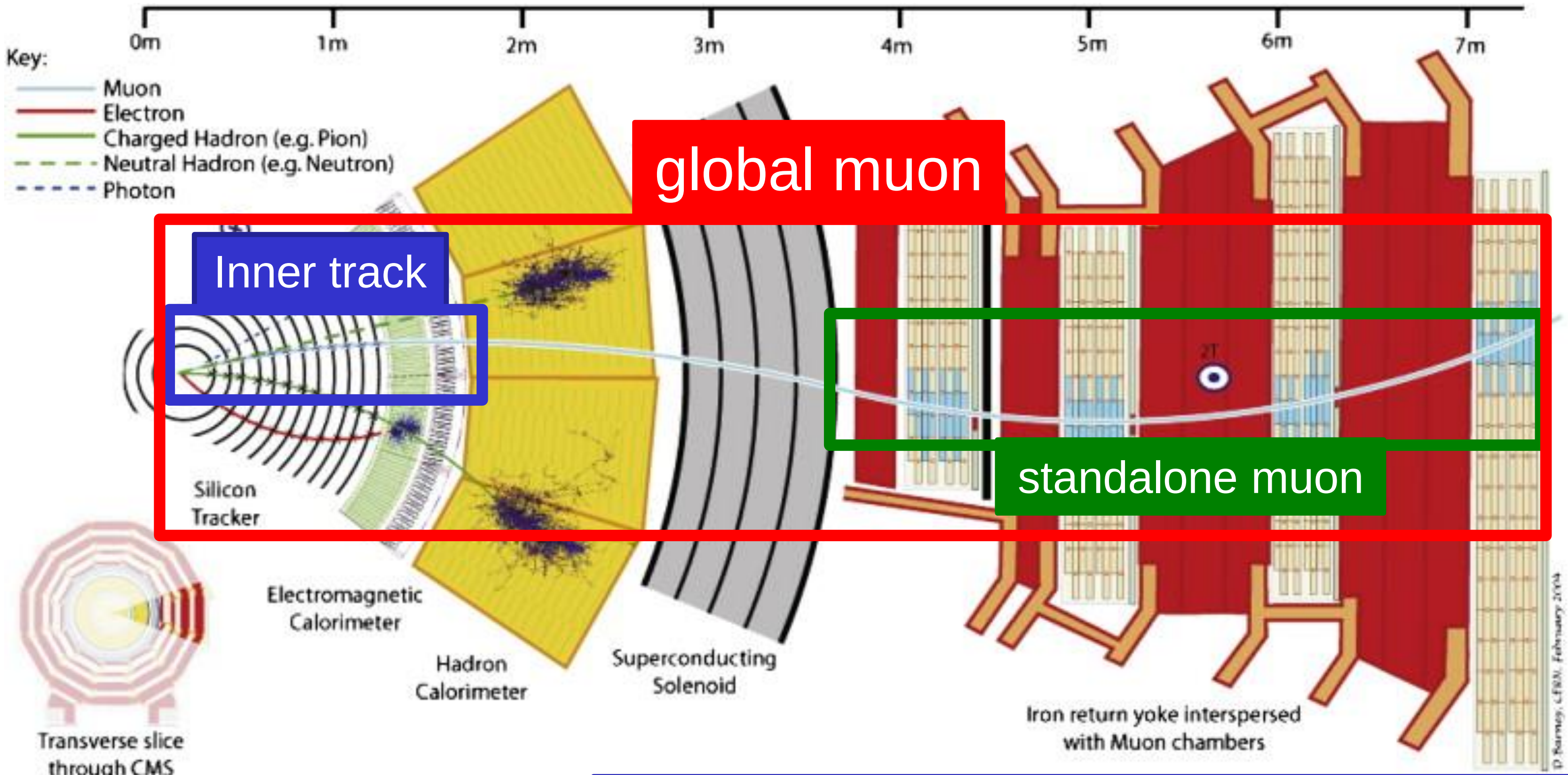


CMS detector

Magnetic Field : 3.8 T



Muon Reconstruction in CMS



- J/ψ in PbPb : reconstructed by global muon
- ϒ in pPb : reconstructed by tracker muon

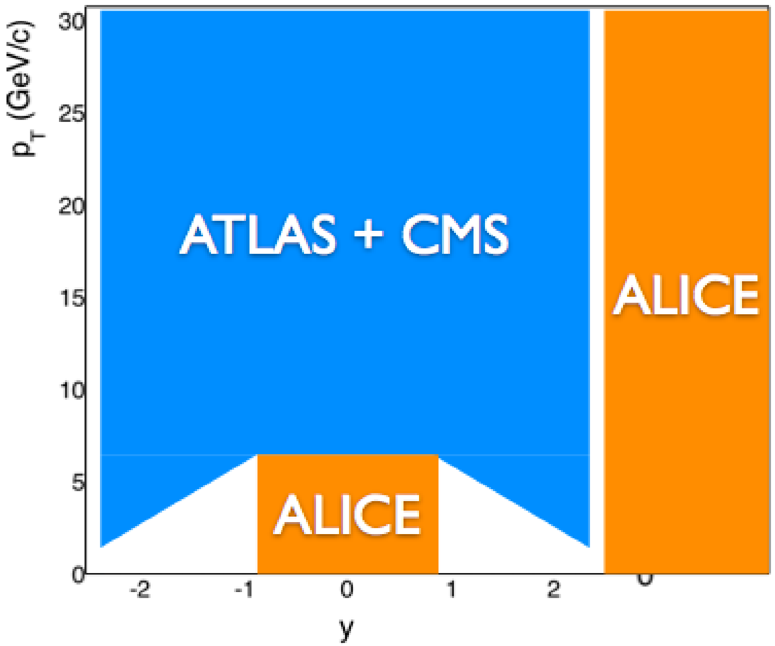
Muon Reconstructio

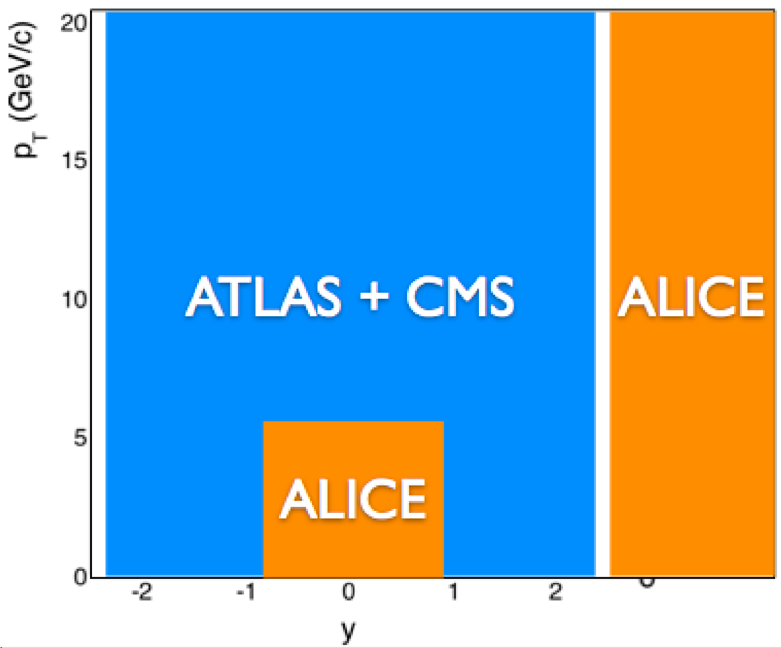
Muon tracks in muon chamber (or segments) + tracks in inner tracker

Excellent momentum resolution of tracking system.

✓ Overall resolution: 1~2 %

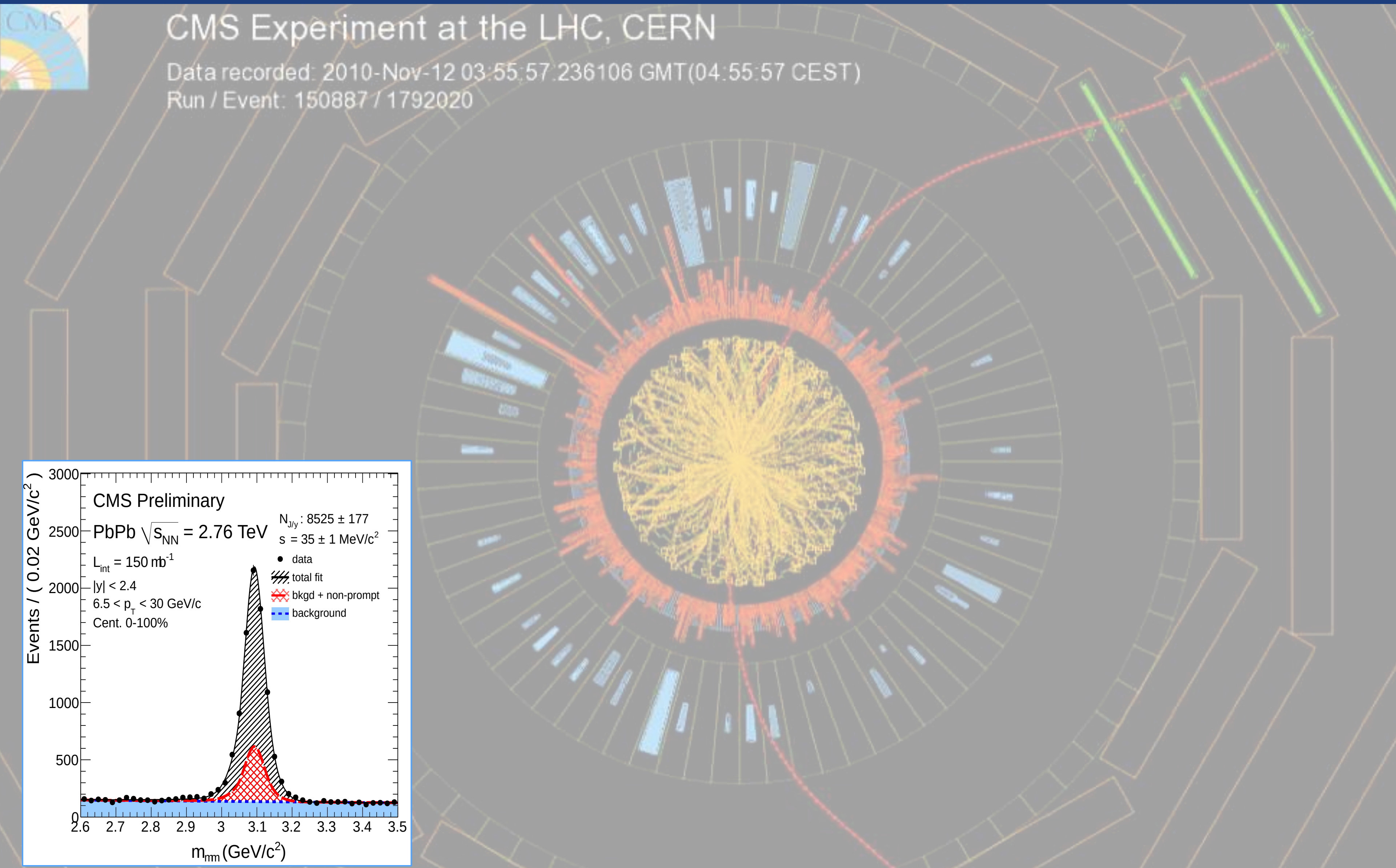
Quarkonia Acceptance



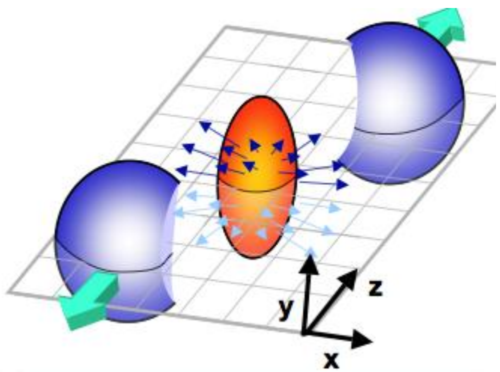


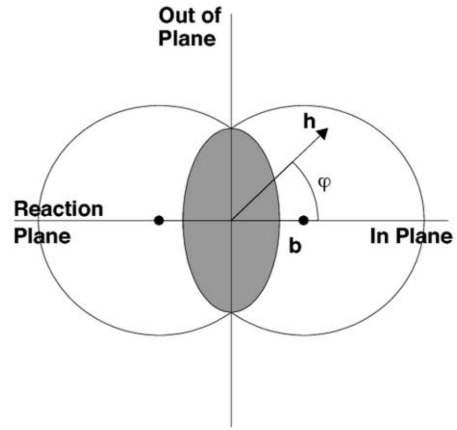
- ALICE: acceptance for $p_T > 0$
  - midrapidity: no absorber and low magnetic field
  - forward rapidity: longitudinal boost
- ATLAS and CMS: Muons need to overcome strong magnetic field and energy loss in the absorber
  - minimum total momentum p~3–5 GeV/c to reach the muon stations
  - Limits J/ψ acceptance:
    - mid-rapidity: $p_T > 6.5$ GeV/c
    - forward rapidity: $p_T > 3$ GeV/c
    - (values for CMS, but similar for ATLAS)
  - ϒ acceptance:
    - $p_T > 0$ GeV/c for all rapidity
- Complementary acceptances

Charmonium Measurements in PbPb

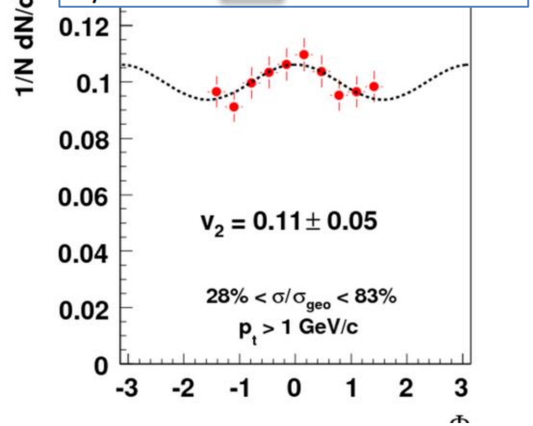


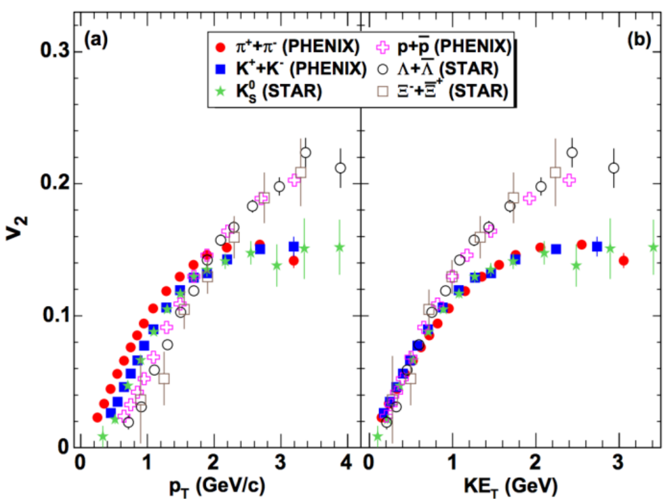
What is azimuthal anisotropy (v_2) ?

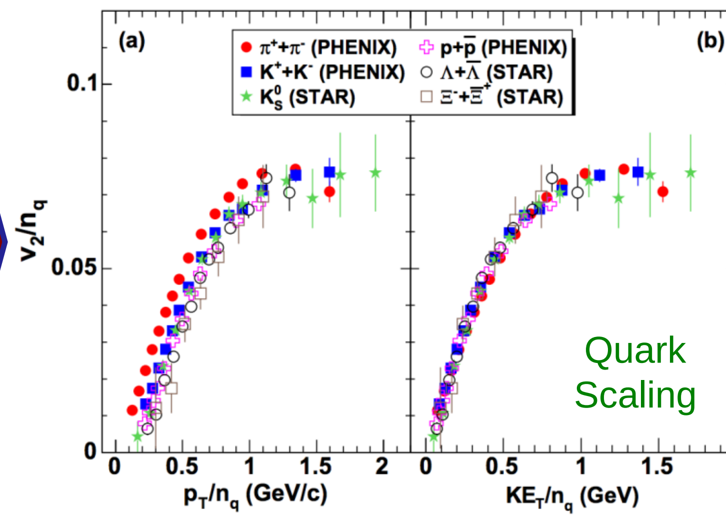




$$\frac{dN}{d\phi} \propto 1 + 2 v_2(p_T)\cos(2\phi) + \ldots$$

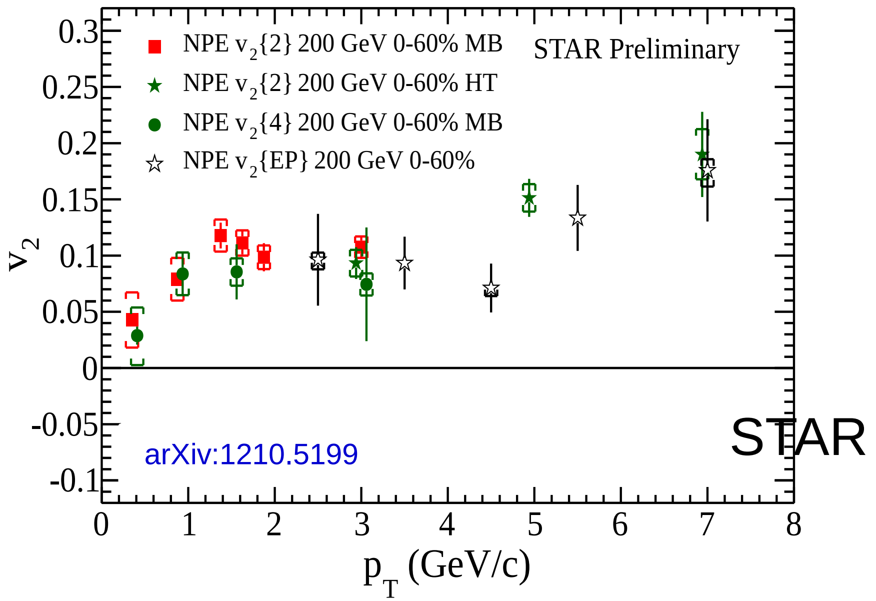






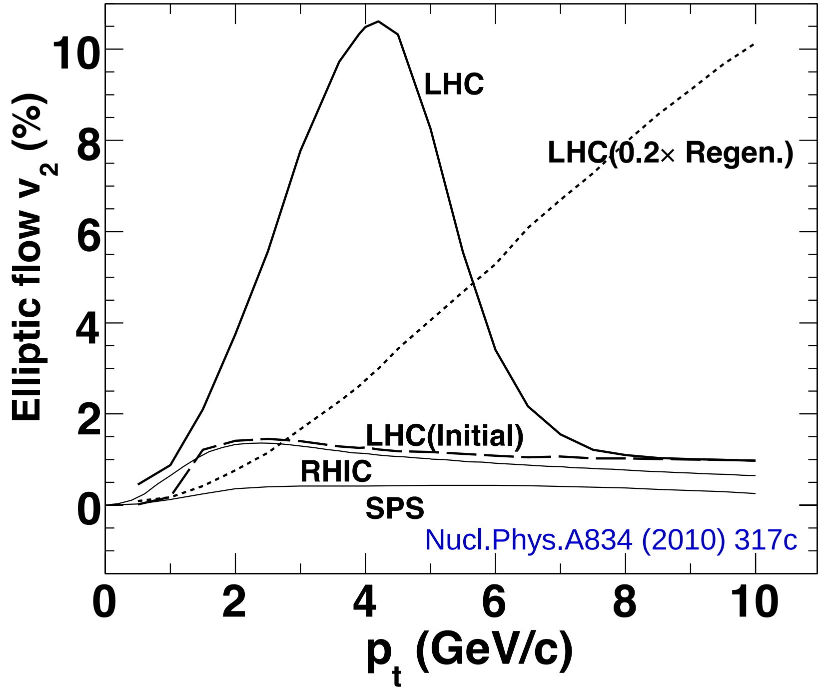
NPE v_2 at RHIC and prediction of J/ψ v_2 at LHC

NPE (Non Photonic Electron) v_2



NPE has significant elliptic flow (v_2). It should be inherited to quarkonia, which indicates the existence non-zero v_2 of quarkonia

Prediction of elliptic flow of J/ψ

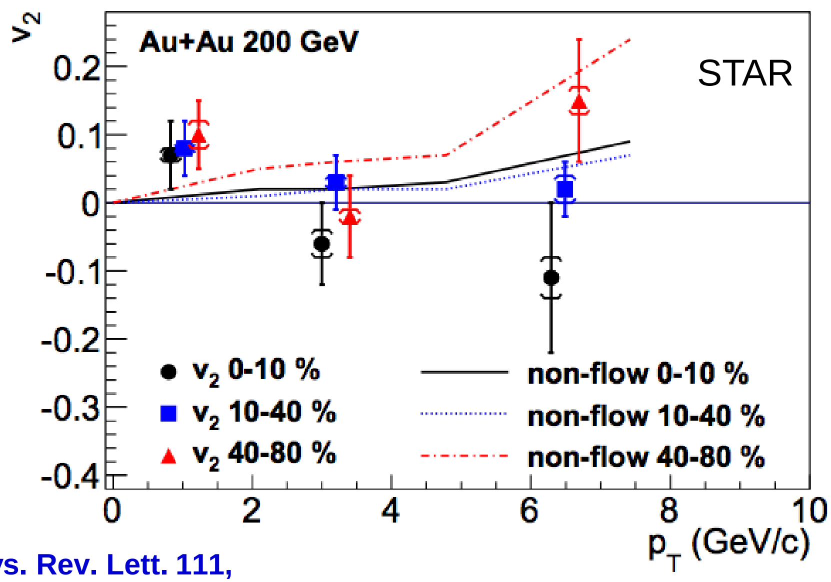


Significant elliptic flow (v_2) may be expected at LHC energy due to the significant contribution of regenerated J/ψ

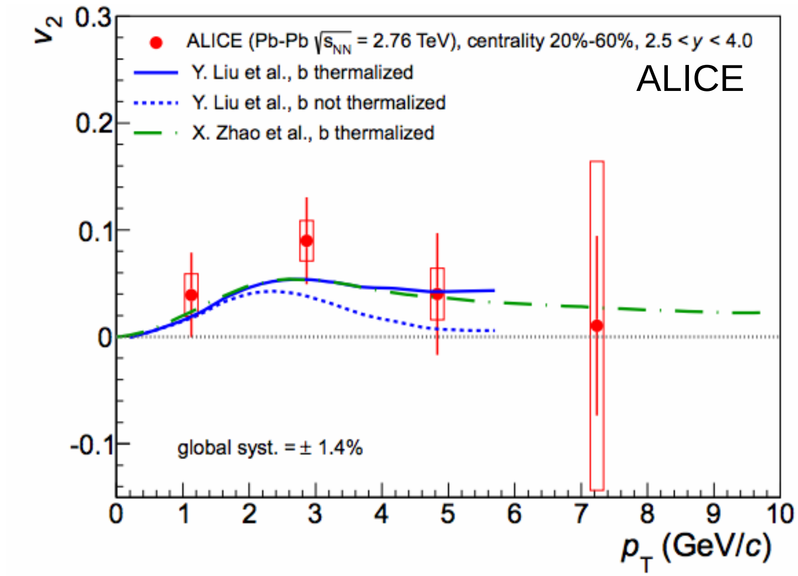
J/ψ Azimuthal Anisotropy at RHIC and LHC

- STAR and ALICE measured inclusive J/ψ v_2

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



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

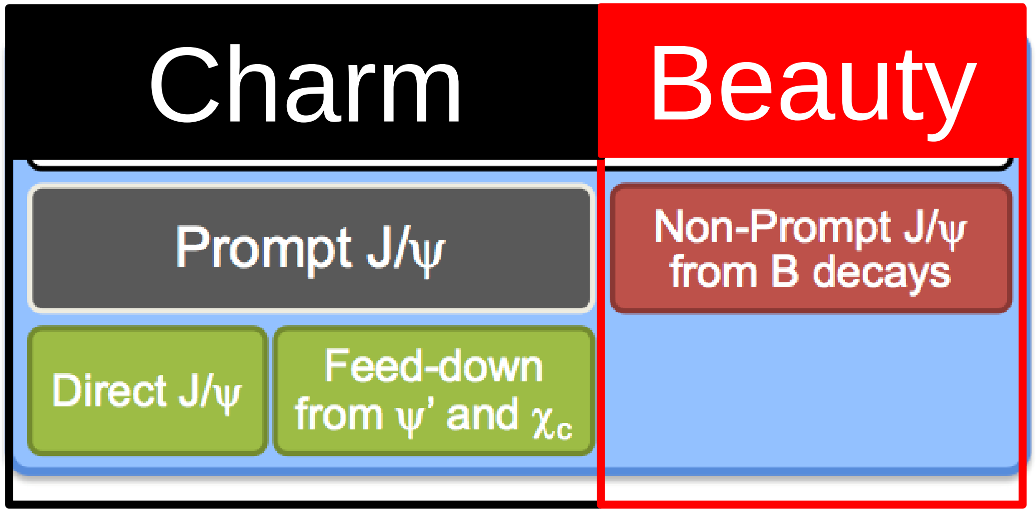


STAR measured compatible zero v_2 from 2 GeV/c in whole p_T region.

ALICE observed non-zero v_2 in 2 - 4 GeV/c region. Data covers both of b-contribution models.

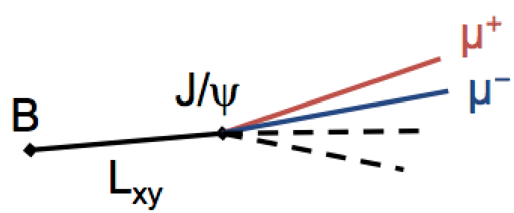
CMS challenge:
1) Prompt and non-prompt J/ψ separation
2) Extend high p_T region

Prompt & Non-prompt J/ψ Separation

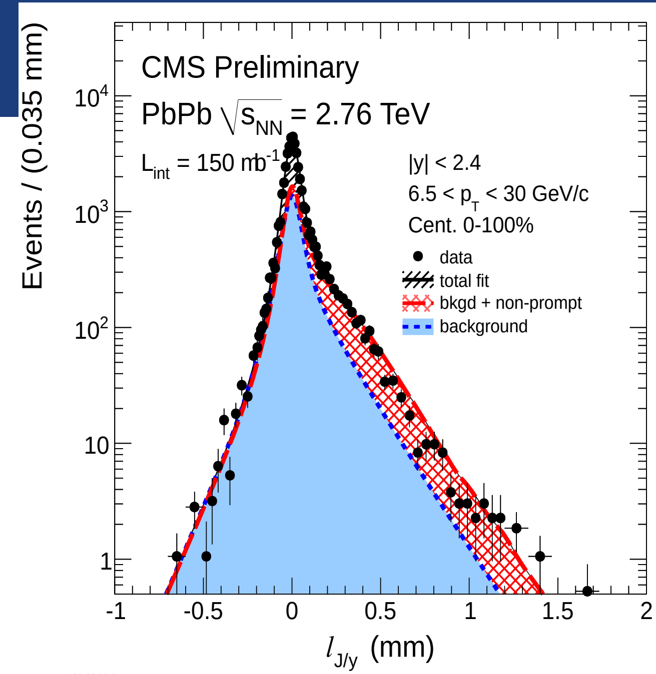


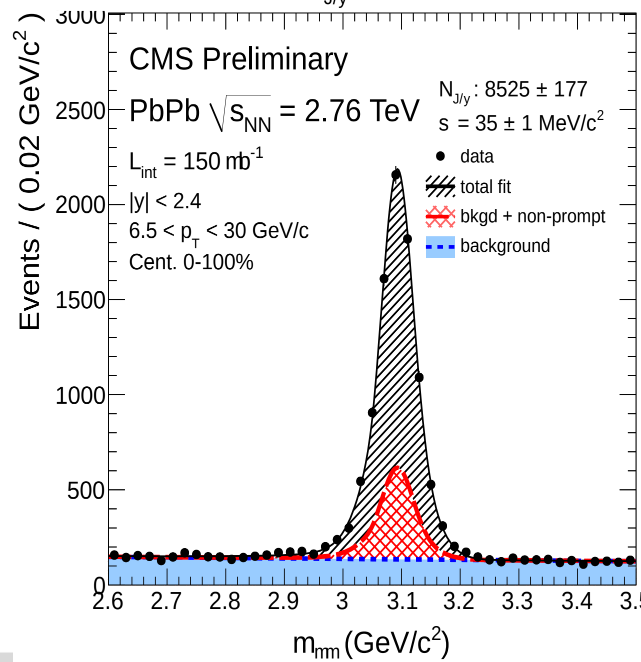
- Reconstruct opposite sign muon vertex
- 2-D unbinned maximum likelihood fit of dimuon mass and pseudo-proper decay length ($l_{J/\psi}$)

$$\ell_{J/\psi} = L_{xy} \frac{m_{J/\psi}}{p_T}$$

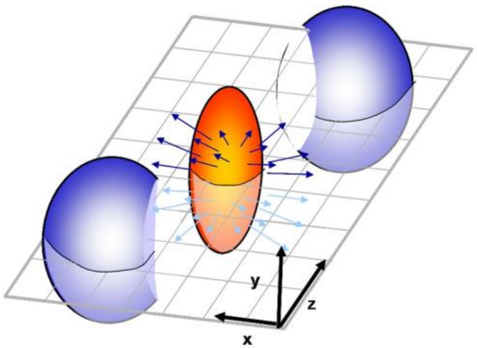


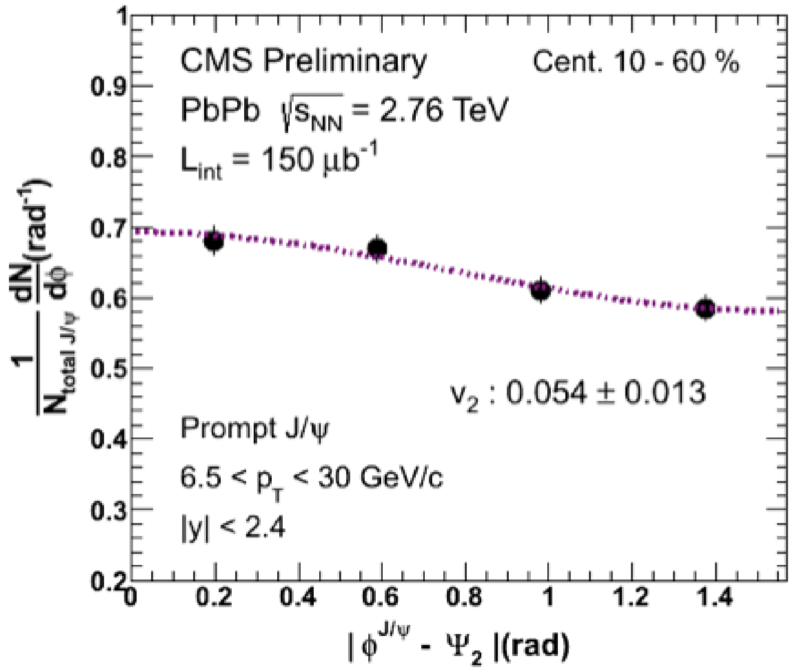
CMS-PAS-HIN-12-014

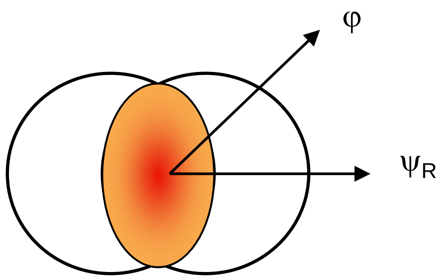




J/ψ Azimuthal Anisotropy in CMS





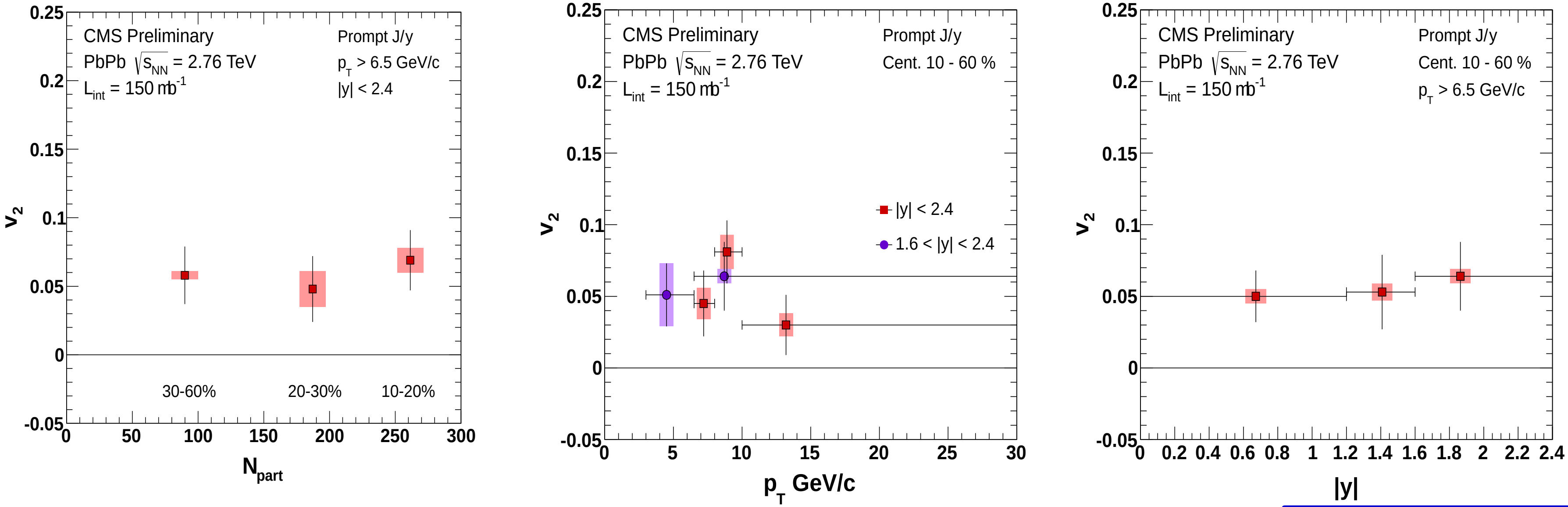


$$\frac{2}{\pi}(1+2v_2\cos(2\Delta\phi))$$

CMS-PAS-HIN-12-001

- Event plane method
- 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

J/ψ Azimuthal Anisotropy in CMS



CMS-PAS-HIN-12-001

- No strong dependences of centrality, p_T, rapidity
- Low p_T (3-6.5 GeV/c) measured in forward (1.6<|y|<2.4)

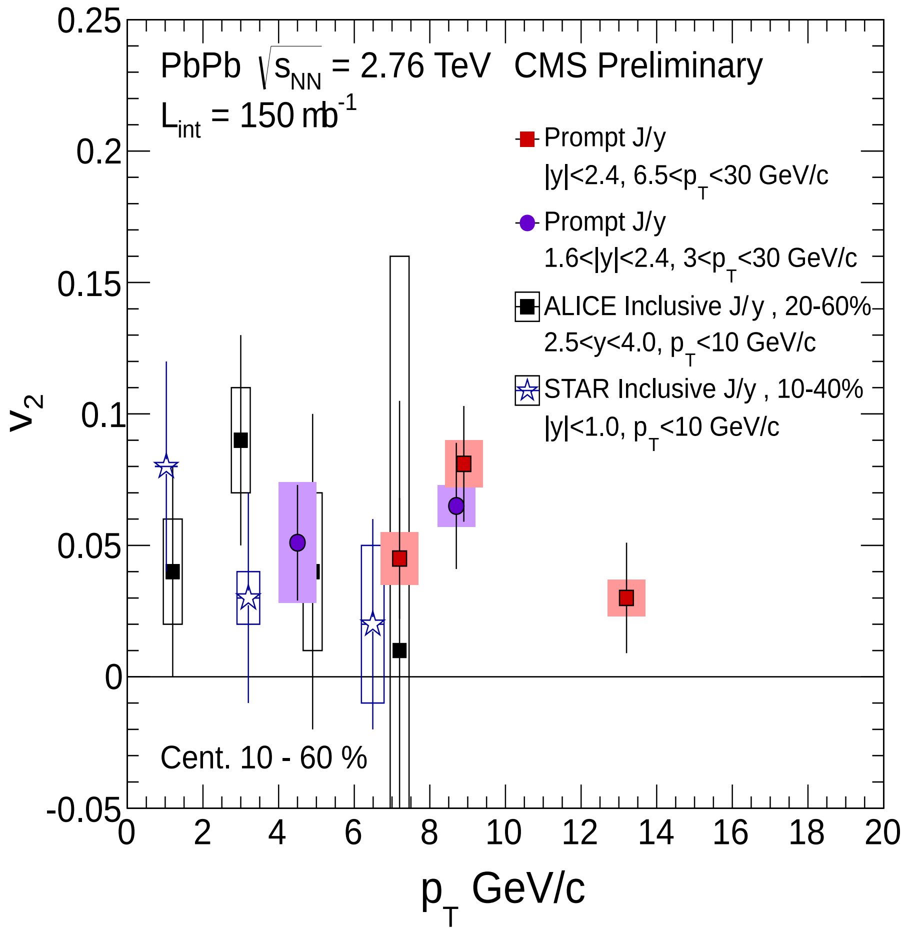
J/ψ Azimuthal Anisotropy in CMS

- Systematic uncertainty

Table 1: Relative systematic uncertainty ranges on the prompt J/ψ v_2 measured in PbPb collisions at 2.76 TeV.

	Relative systematic uncertainties variations (%)
Yield extraction	1 – 20
Efficiency corrections	0 – 42
Event plane	3.5
Total	12 – 46

J/ψ Azimuthal Anisotropy Comparison

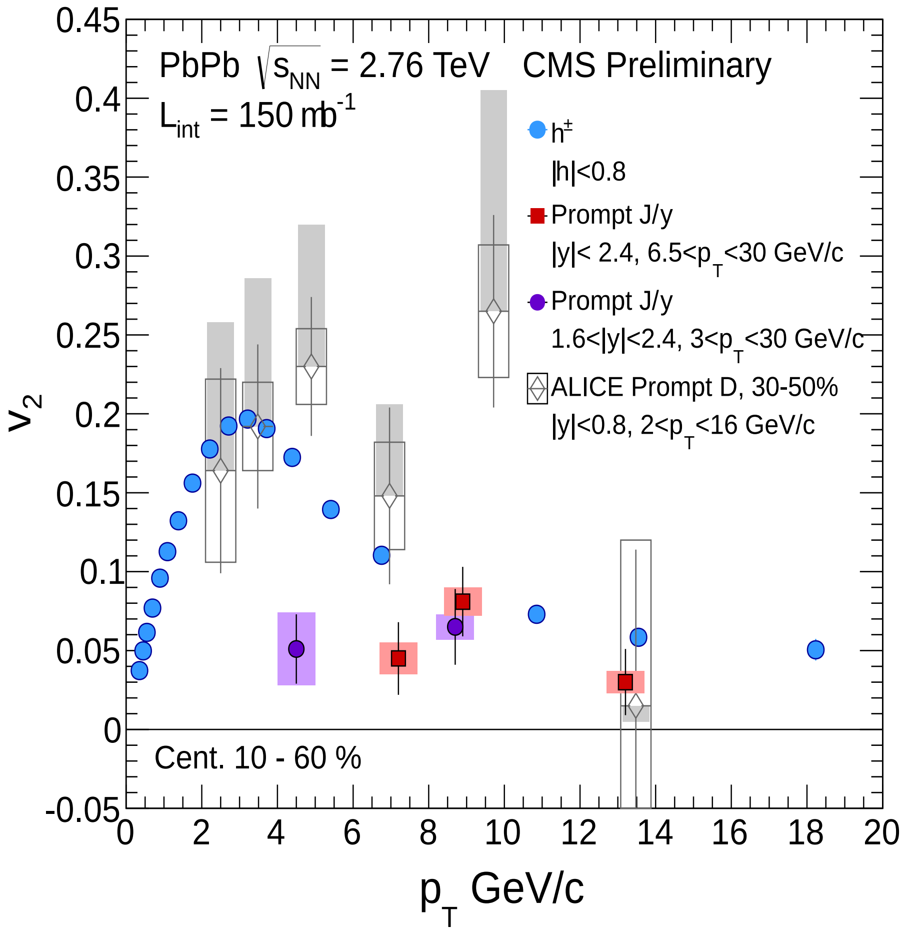


CMS-PAS-HIN-12-001
Phys. Rev. Lett. 111, 052301 (2013)
Phys. Rev. Lett. 111, 162301 (2013)

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

J/ψ Azimuthal Anisotropy Comparison



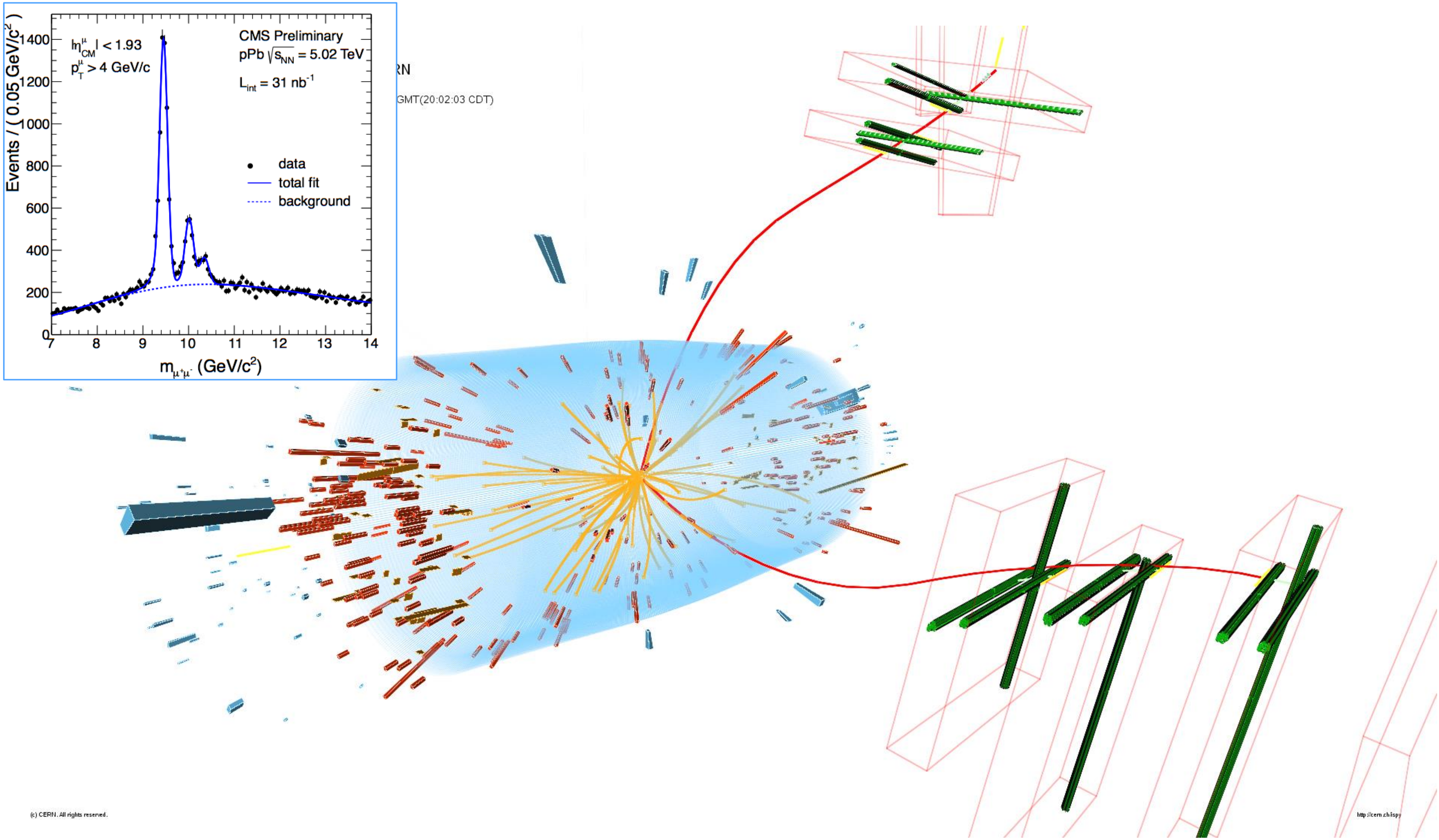
CMS-PAS-HIN-12-001
Rev. Lett. 109 (2012) 022301
Phys. Rev. Lett. 111 102301 (2013)

Comparison to charged hadrons and D mesons

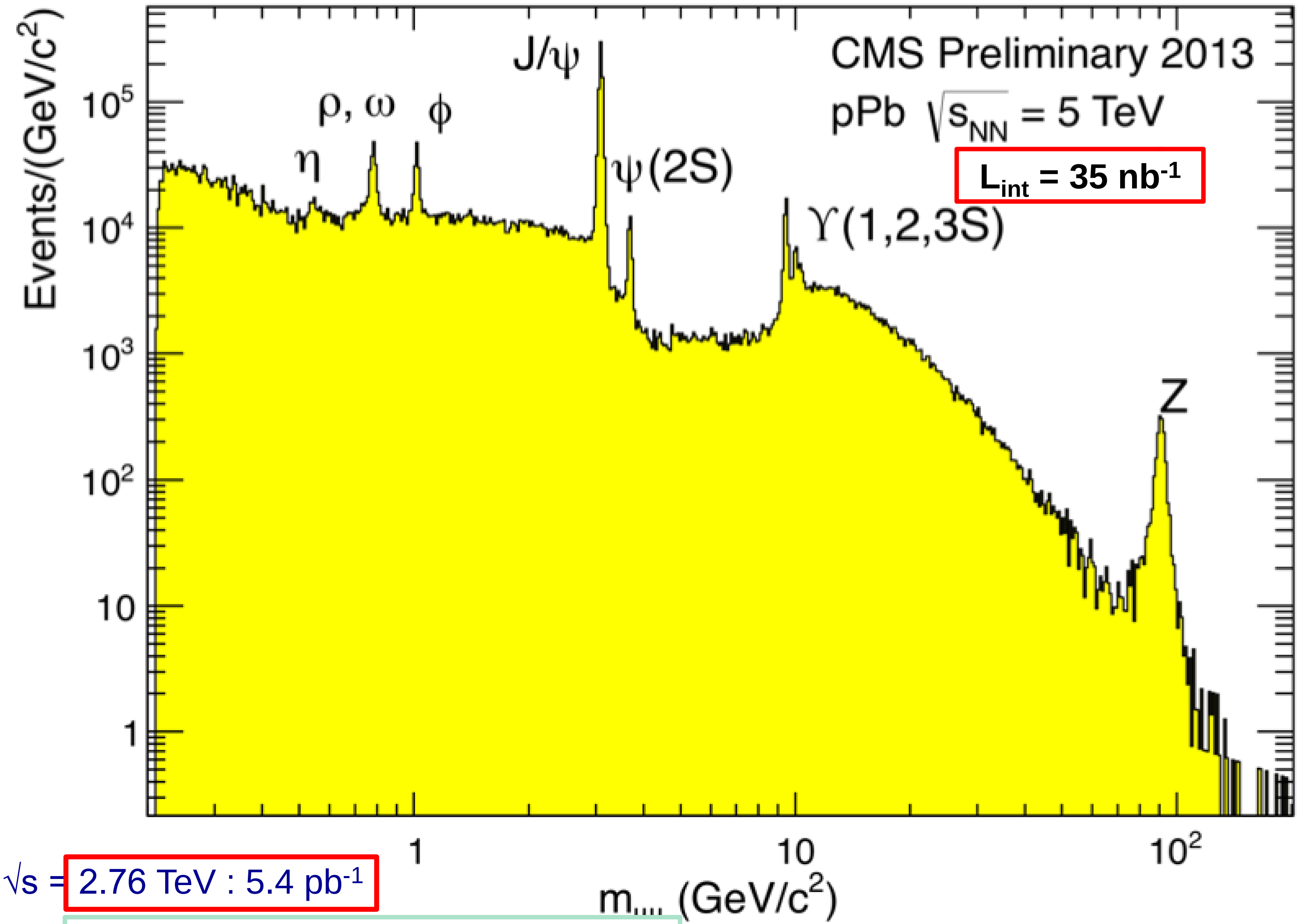
1) low p_T
light quark ≈ c+light quark > c+c quark

2) high p_T
light quark ≈ c+light quark ≈ c+c quark

Bottomonium Measurements in pPb



Dimuon spectrum in 2013 pPb



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

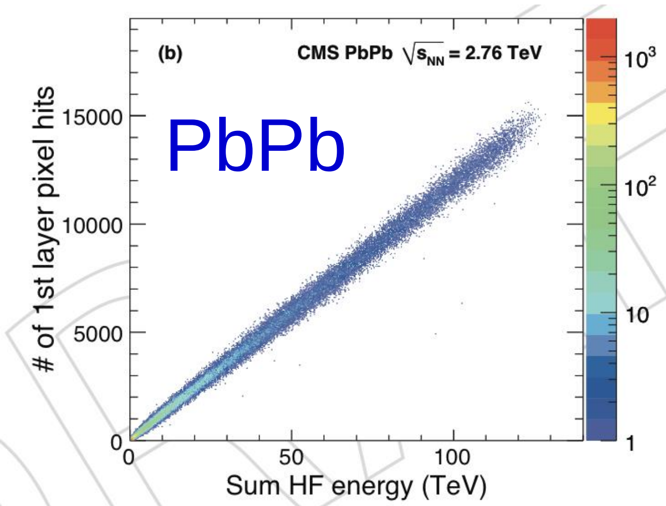
~20 times larger than 2010 (231 nb^{-1})

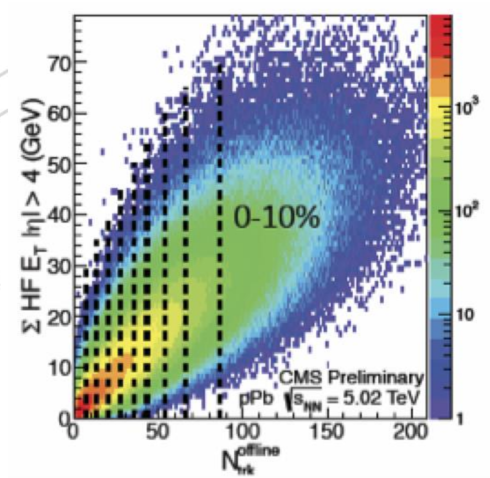
pPb Collisions at 2013

- pPb collisions: the bridge between pp and PbPb collisions, to understand 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

- Centrality dependence
  - Not easy to determine centrality in pPb collisions





pPb

pPb Collisions at 2013

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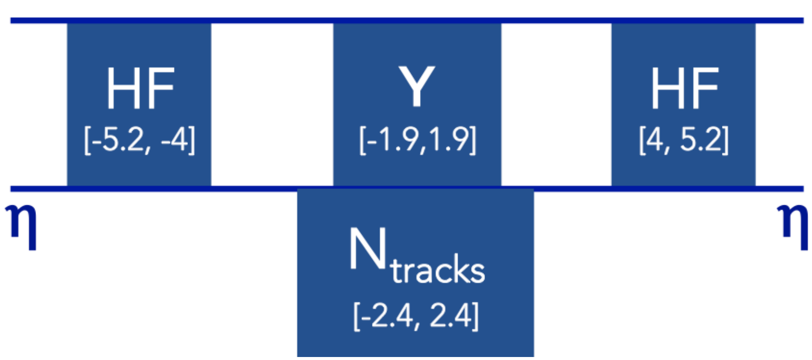
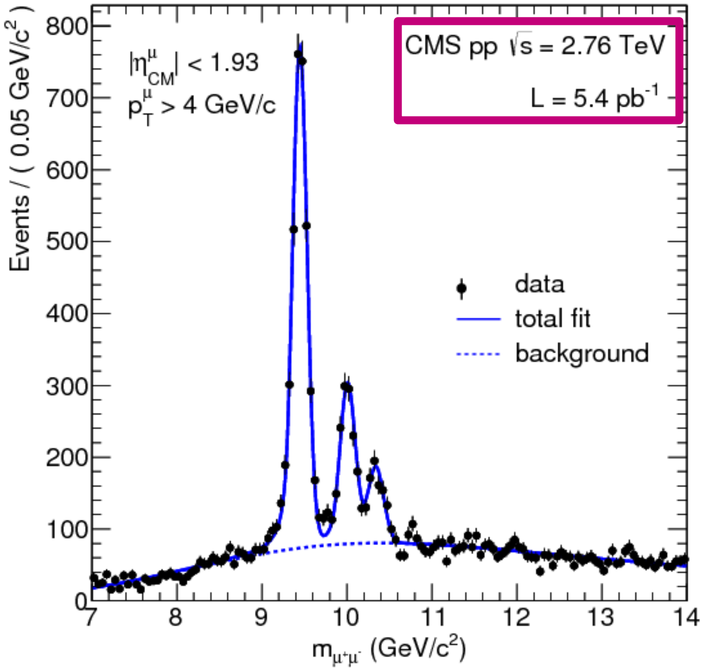
Ref. system	Pb+p			
LAB		-2.4	-0.47	1.5
Collision (CM)		-1.9	0.00	1.9

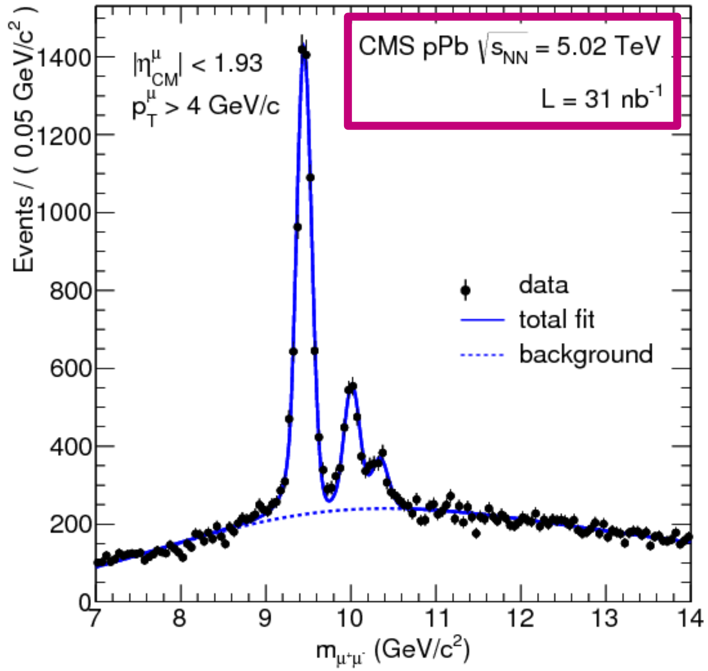
- Binning in 2 event-activity variables:
  - Corrected N_{tracks} ($|\eta| < 2.4$, $p_T > 400$ MeV/c)
  - Raw transverse energy measured in HF, E_T ($|\eta| > 4.0$)



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)

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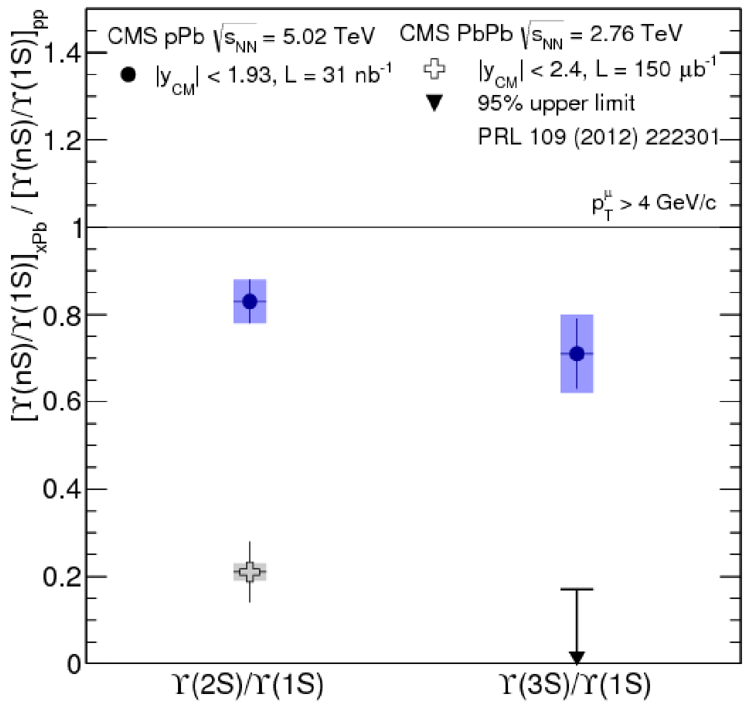
Double Ratio



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

- 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

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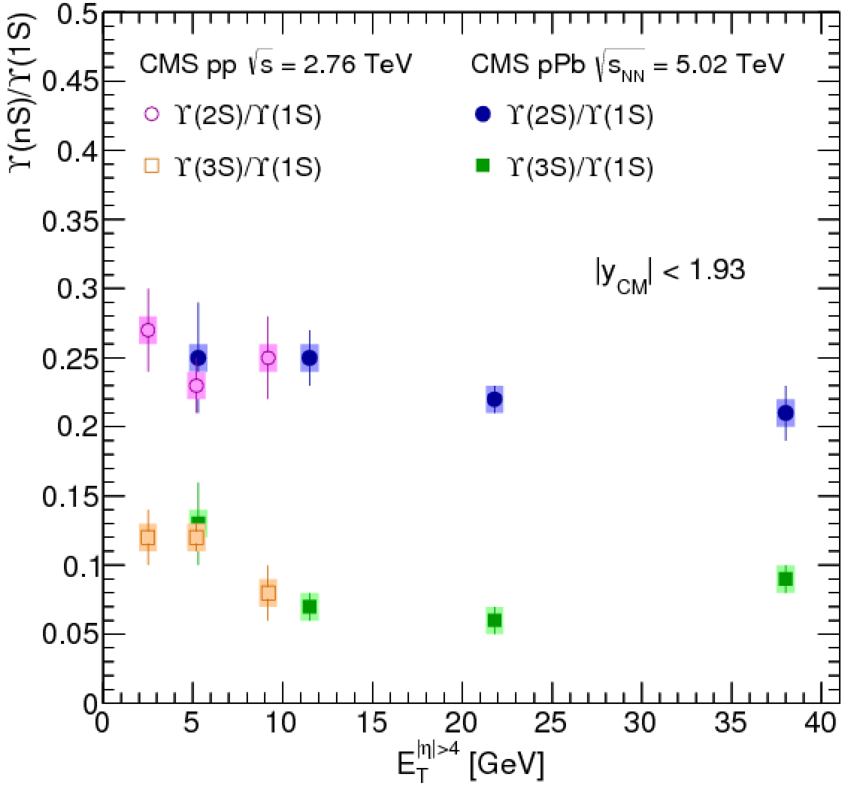
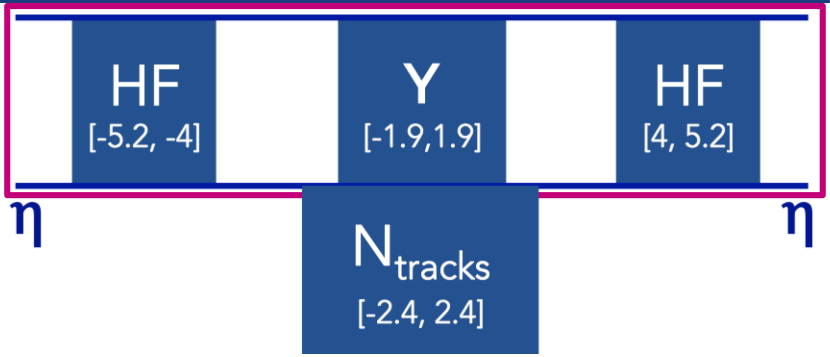
Υ(nS)/Υ(1S) vs E_T (|η| > 4)





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

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

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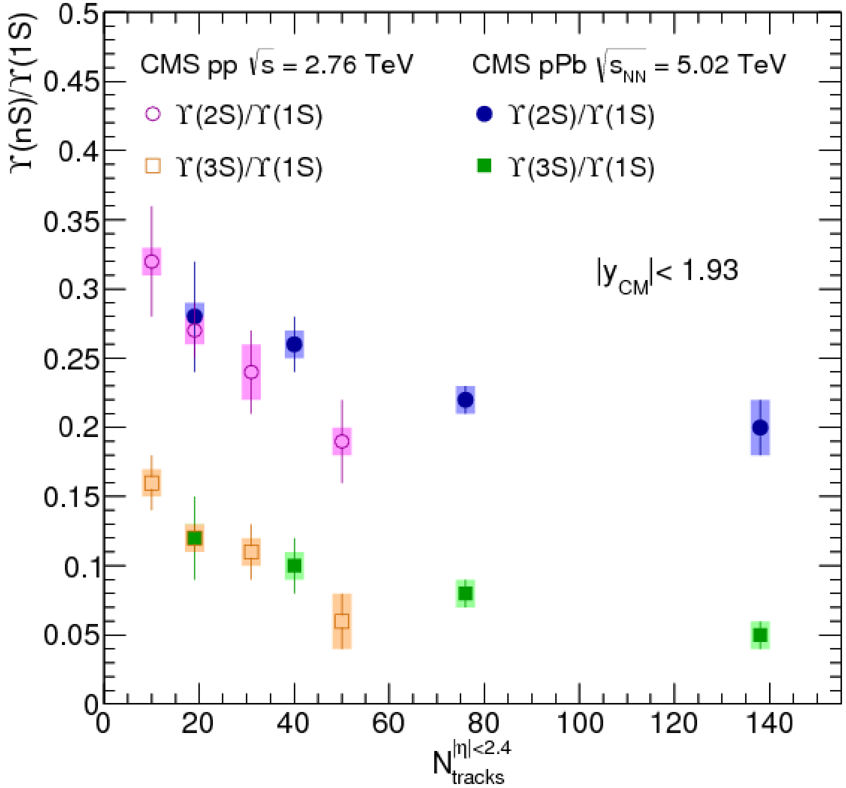
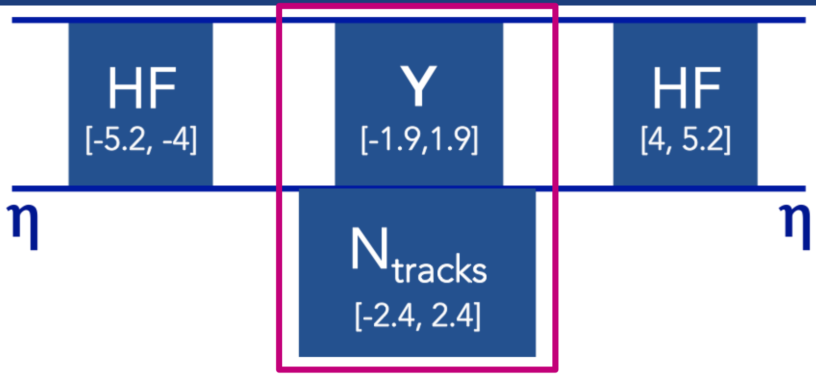
Υ(nS)/Υ(1S) vs N_{tracks} (|η| < 2.4)





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

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

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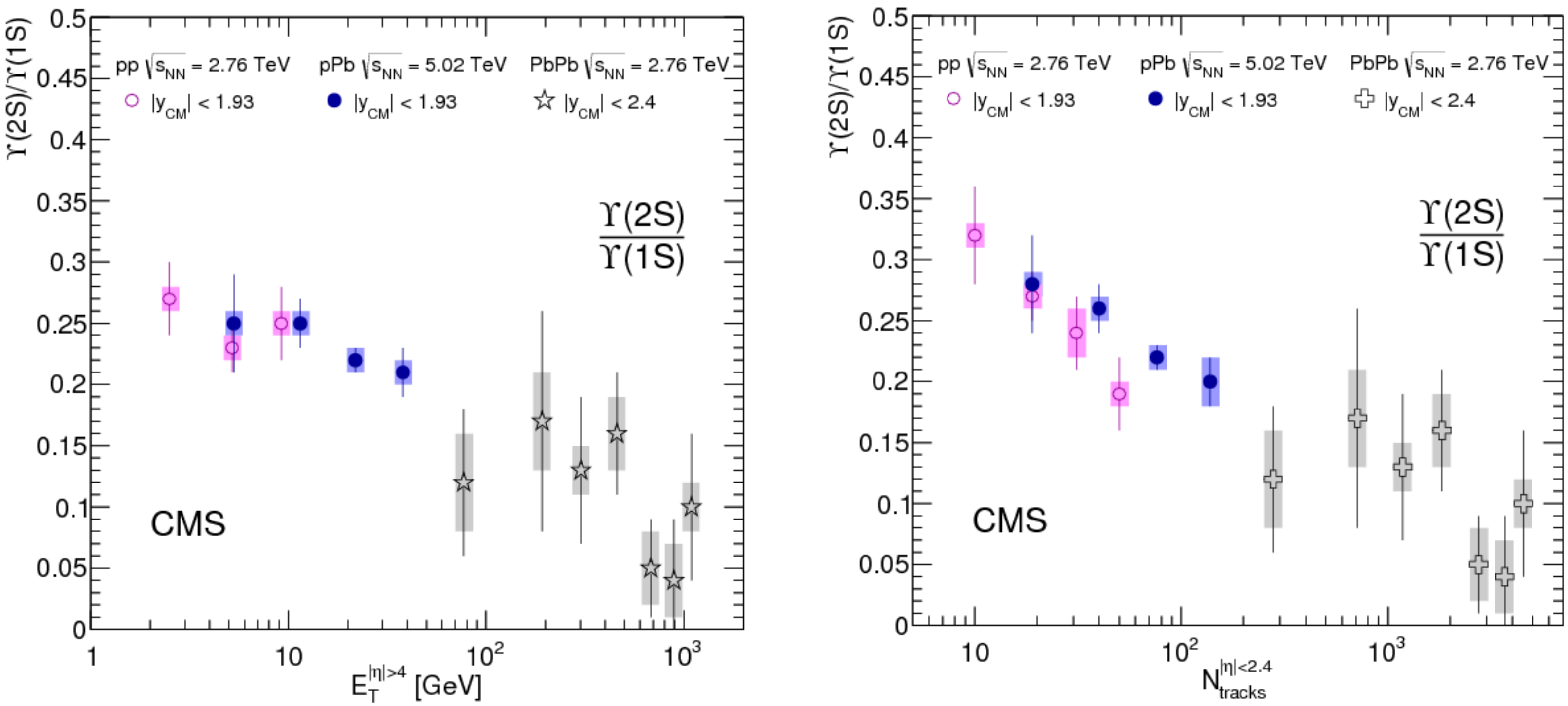
Υ(2S)/Υ(1S) compare PbPb



- PbPb : no significant dependence on $E_T(|\eta|>4)$ and 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

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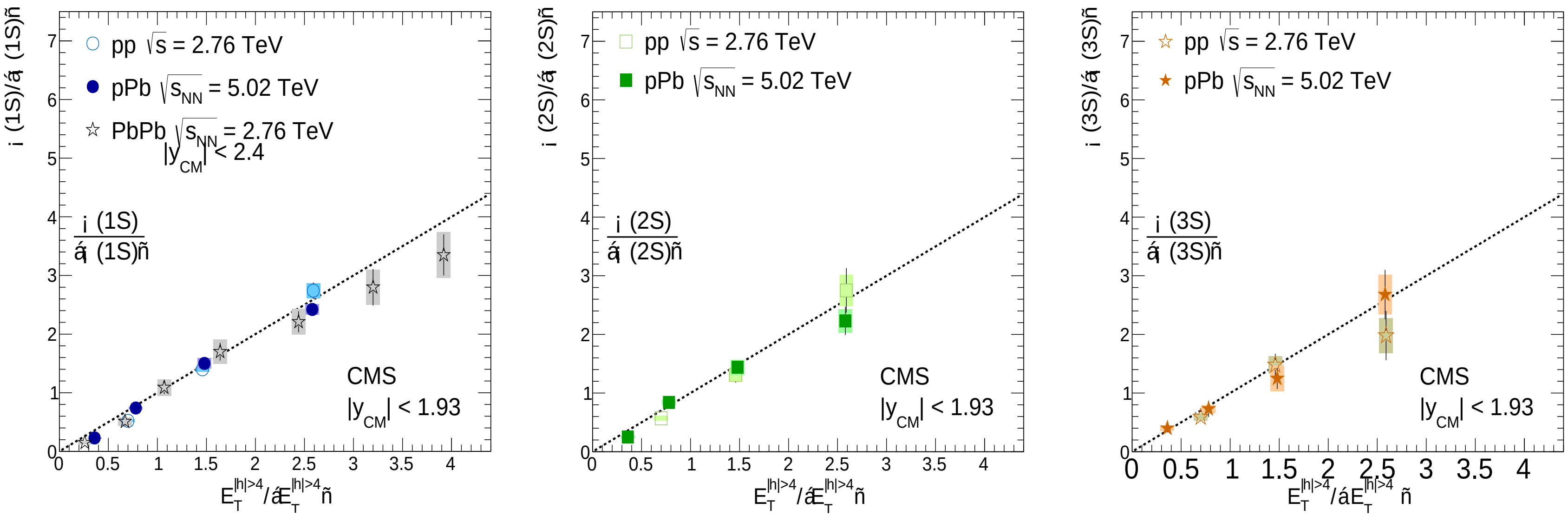
Self-normalized Yields: Υ(nS)/<Υ(nS)>



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

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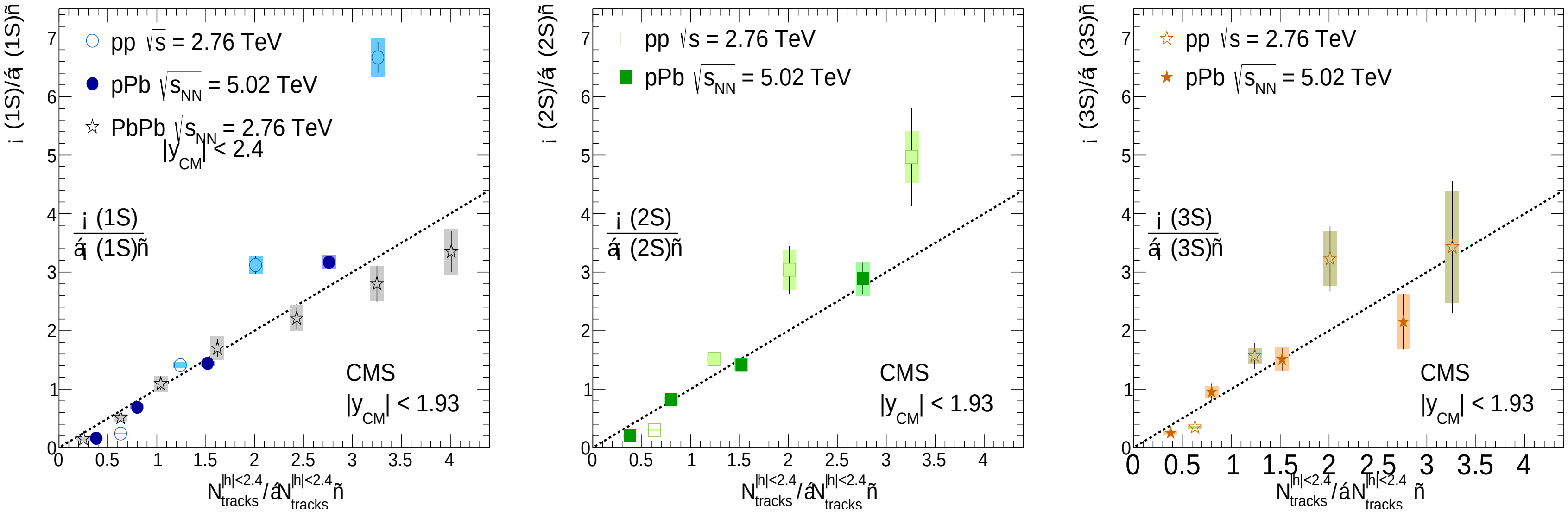
Self-normalized Yields: Υ(nS)/<Υ(nS)>



- Υ(nS)/<Υ(nS)> vs N_{tracks}
  - Less consistent behavior (related to the Υ(nS)/Υ(1S) variations)

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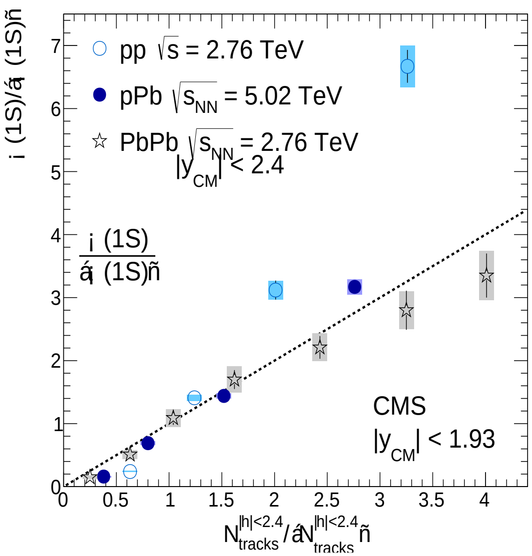
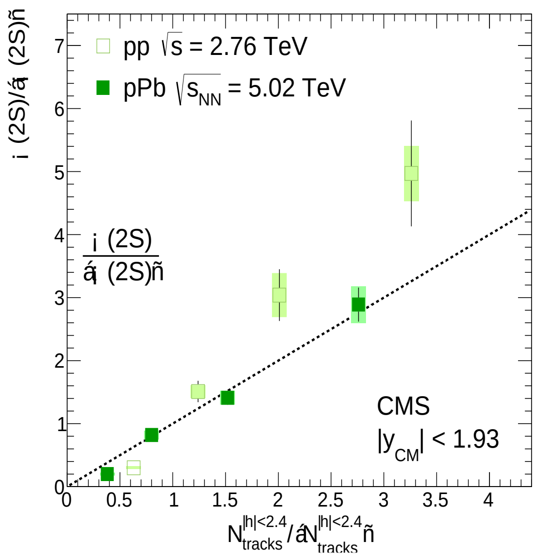
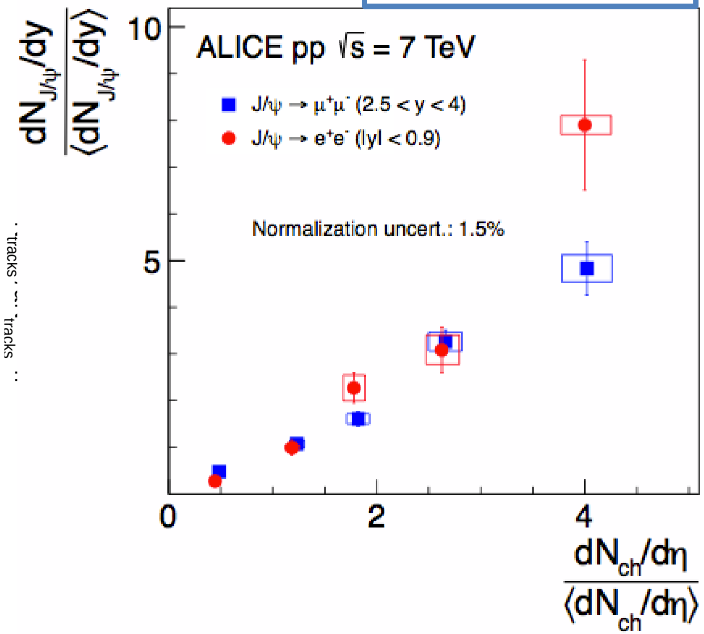
Self-normalized Yields: Y(nS)/<Y(nS)>

PLB 712 (2012) 165







- Y(nS)/<Y(nS)> vs N_{tracks}
  - Less consistent behavior (related to the Y(nS)/Y(1S) variations)

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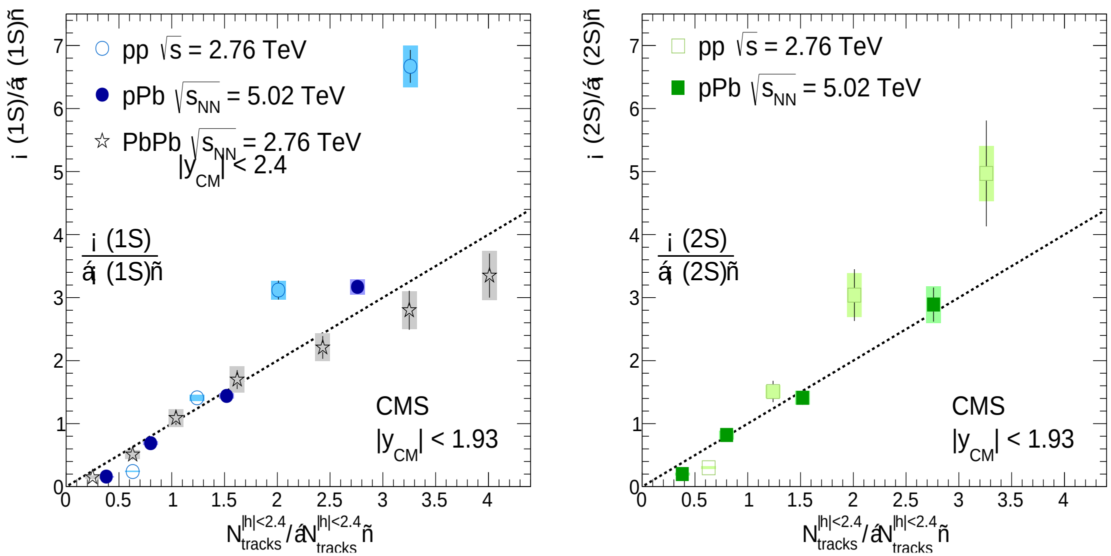
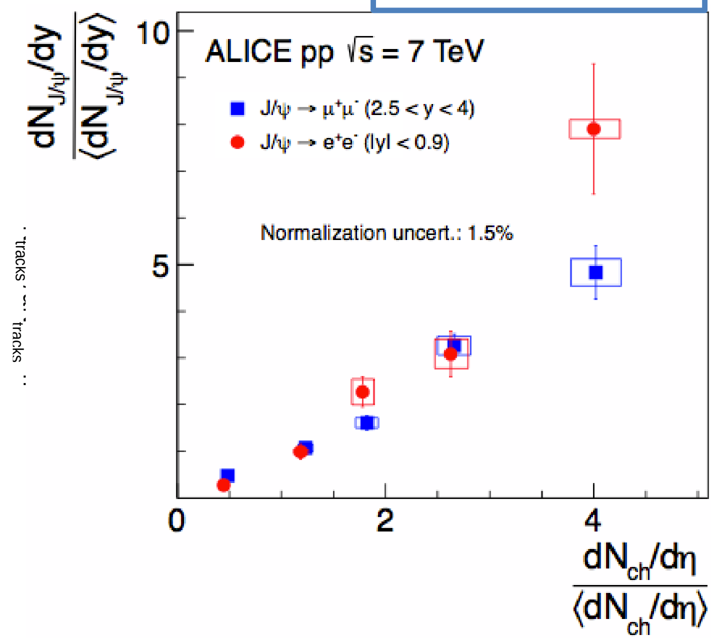
Self-normalized Yields: Y(nS)/<Y(nS)>

PLB 712 (2012) 165





- 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

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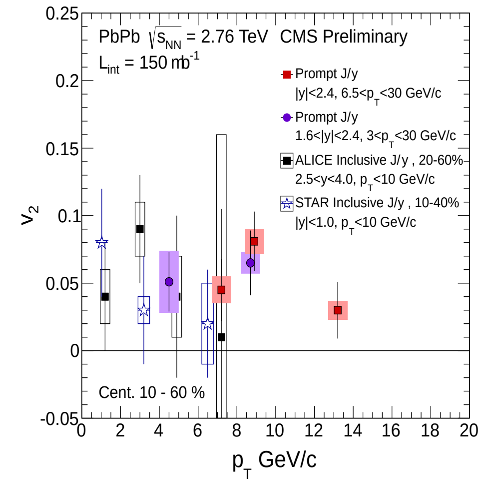
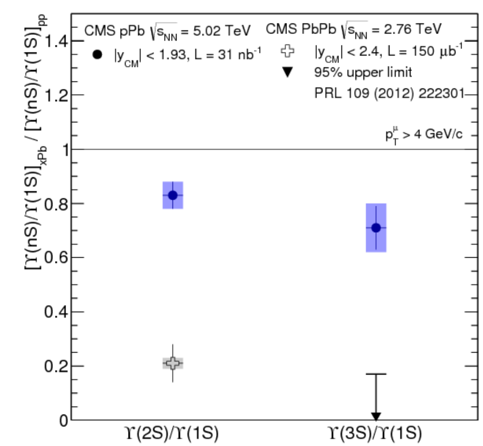
Summary

- Observed non-zero v_2 of prompt J/ψ and even in high p_T region (> 6.5 GeV/c)
  - Find proper fit setting in low p_T and forward region
  - First time to measure v_2 of non-prompt J/ψ



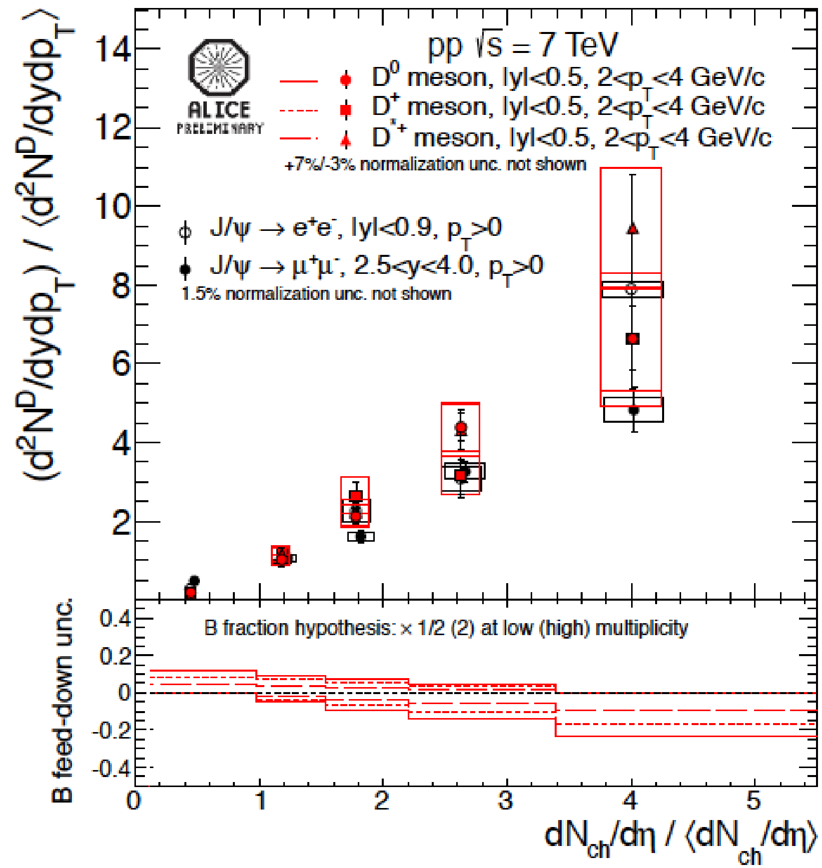
- ϒ results in pPb would give us some indications of initial state effect on the suppression in PbPb



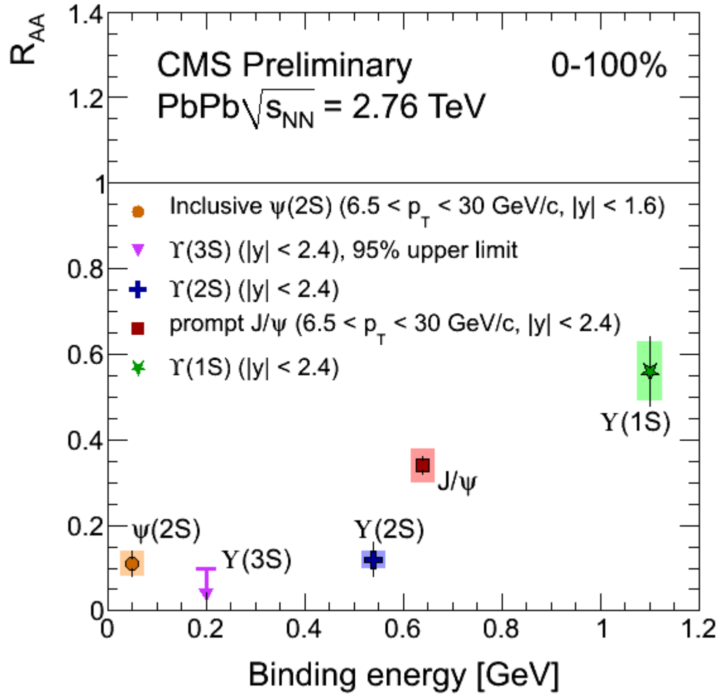
Back up

ALICE Multiplicity dependence

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



R_{AA} vs binding energy



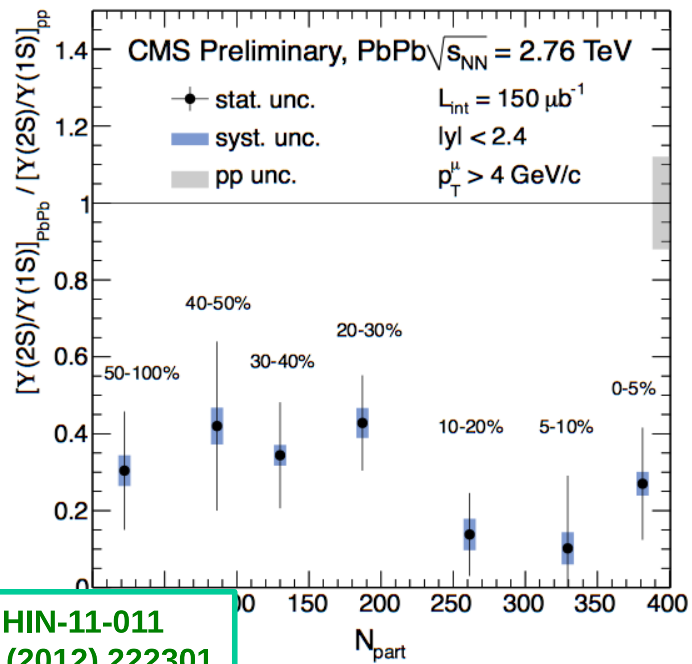
state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
r_0 [fm]	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

Table 3: Quarkonium Spectroscop

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

Results from PbPb Collisions

Double Ratio



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

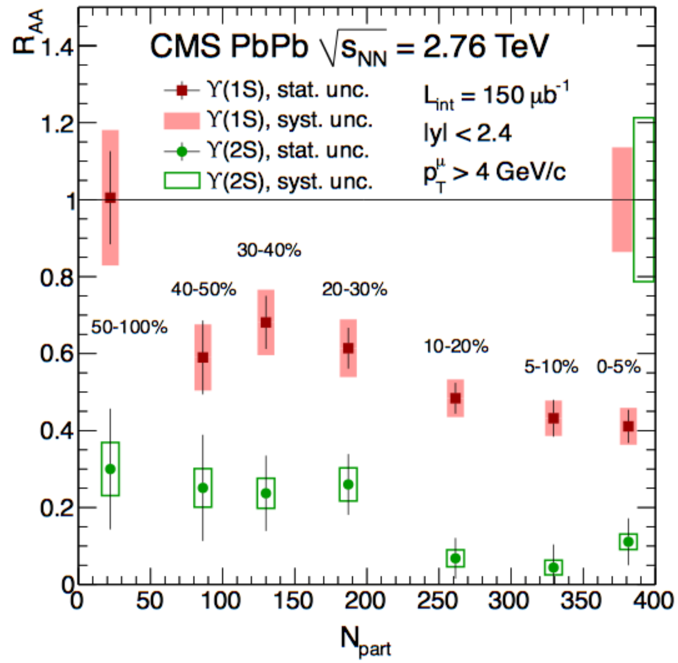
$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{\text{PbPb}}}{\Upsilon(2S)/\Upsilon(1S)|_{pp}} = 0.21 \pm 0.07(\text{stat}) \pm 0.02(\text{syst}),$$

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

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

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

R_{AA}



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

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

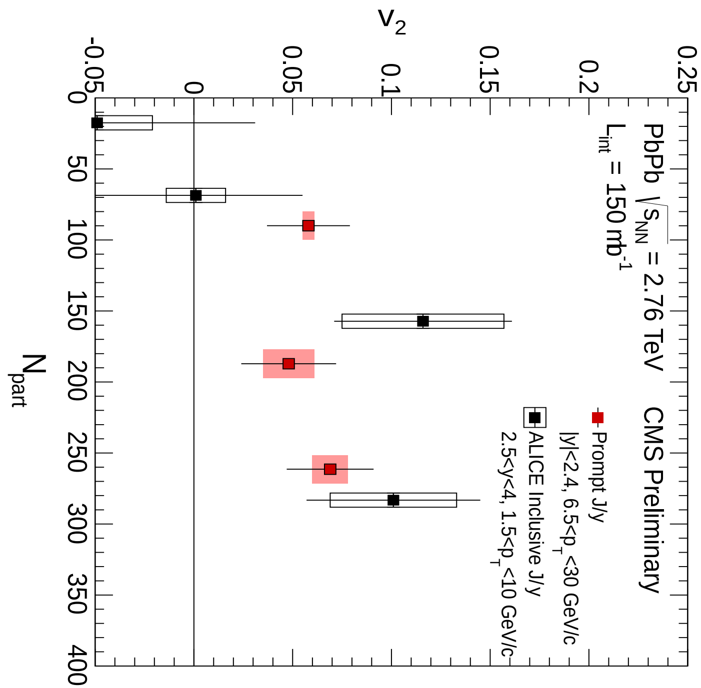
$$R_{AA}(\Upsilon(3S)) = 0.03 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})$$

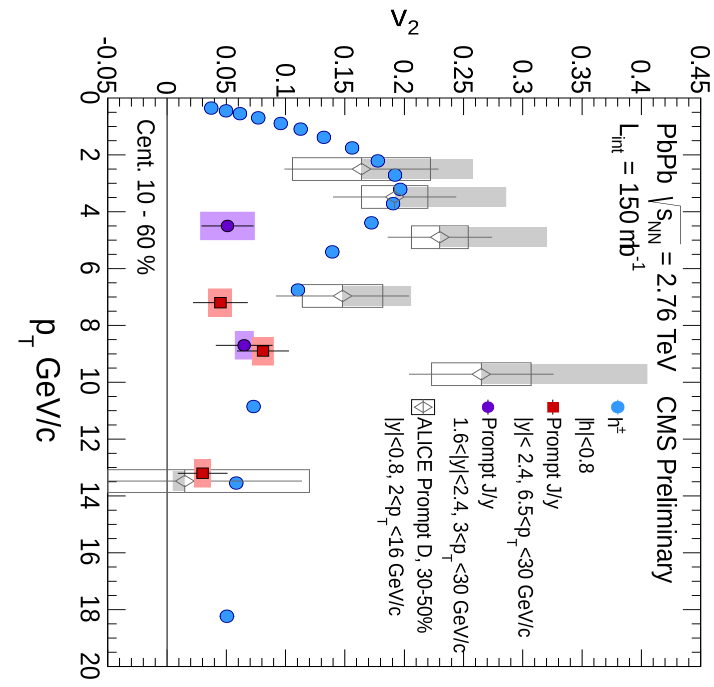
$$< 0.10(95\%\text{CL}).$$

Υ(3S) are more suppressed than Υ(2S).

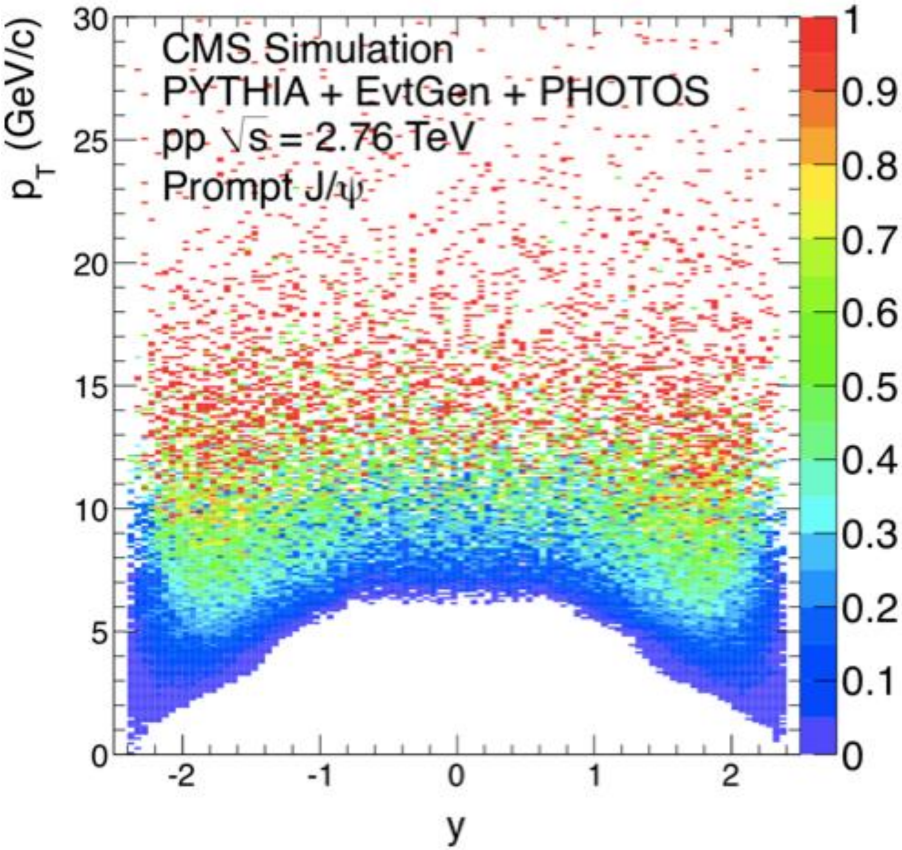
Ordering: R_{AA}(Υ(3S)) < R_{AA}(Υ(2S)) < R_{AA}(Υ(1S))

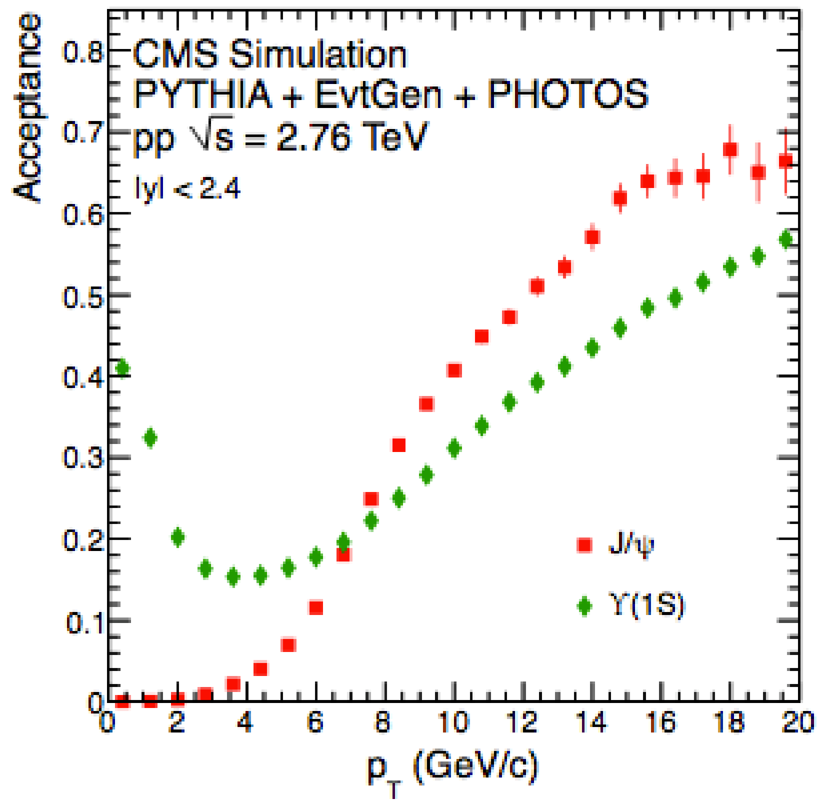
J/ψ Azimuthal Anisotropy in CMS



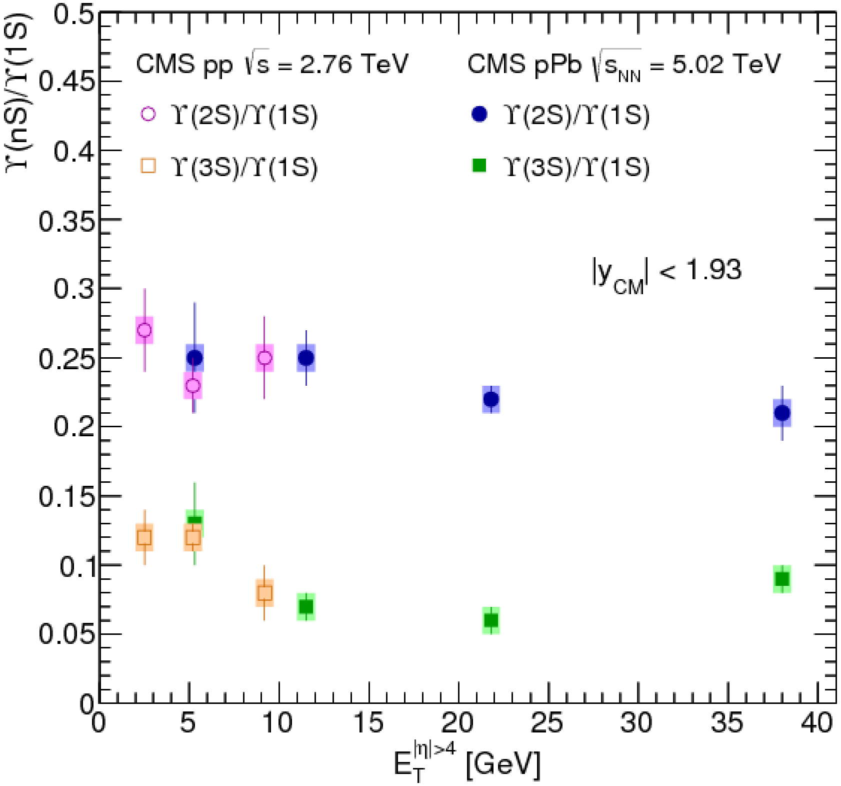


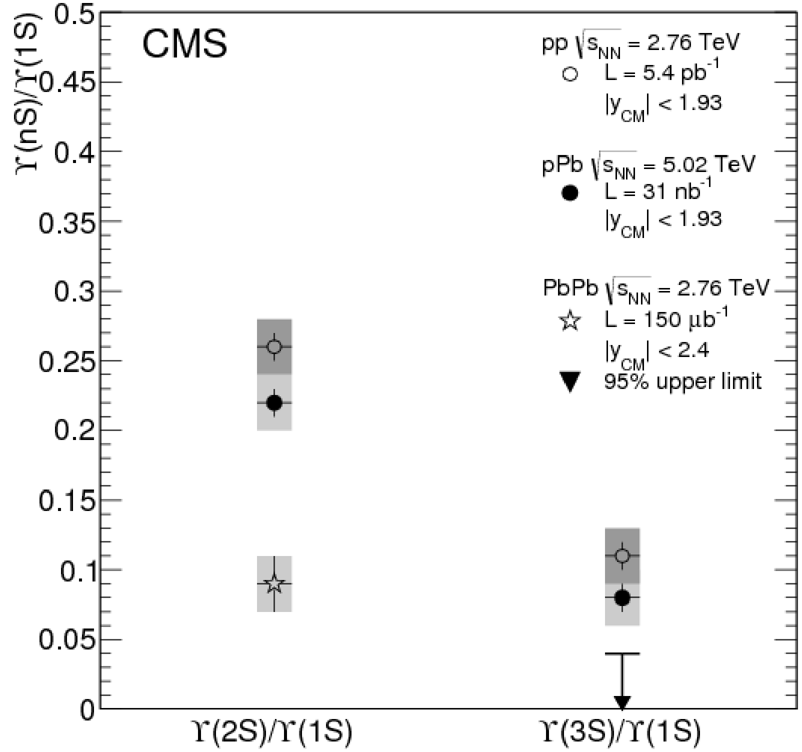
Muon Pair Acceptance

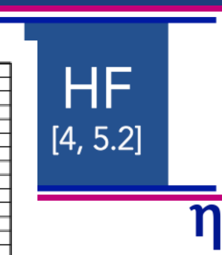




Υ(nS)/Υ(1S) vs E_T (|η| > 4)







pp,pPb

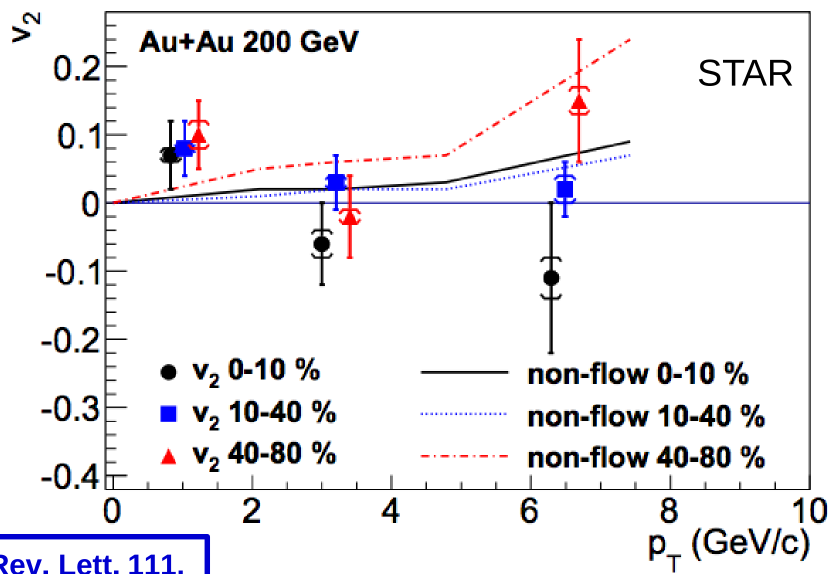
- Weak dependence of excited to the ground state ratio with respect to the E_T(|η|>4)

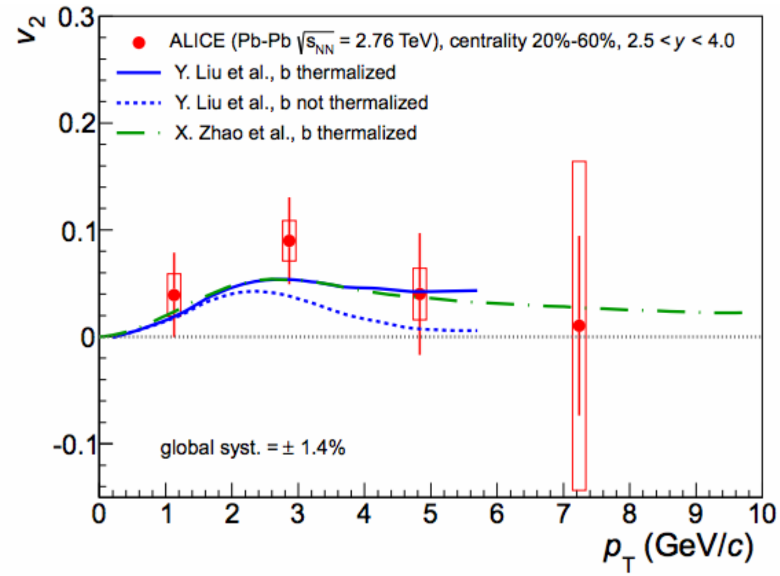
CMS-PAS-HIN-13-003
arXiv:1312.6300

J/ψ Azimuthal Anisotropy in CMS

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

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

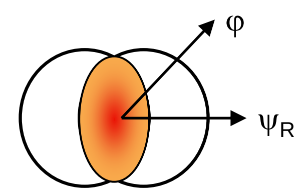




Phys. Rev. Lett. 111, 052301 (2013)

- 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)



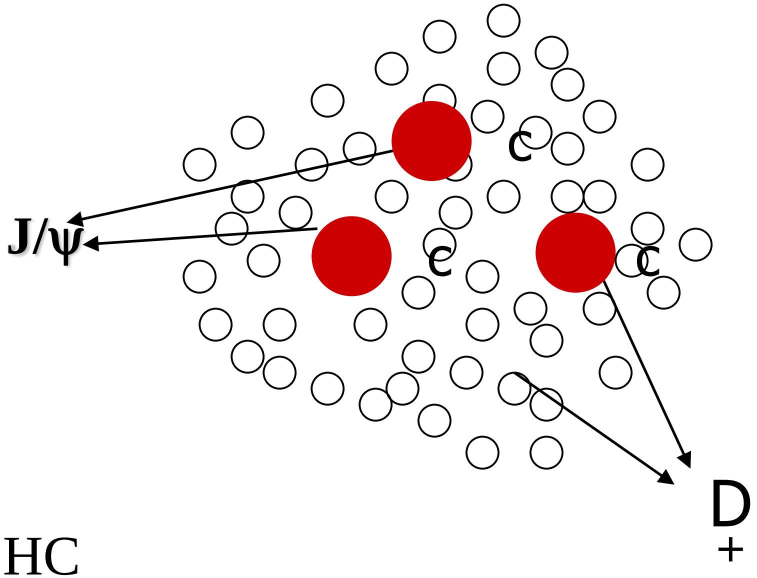
- Prompt and non-prompt J/ψ separation is important: charmonium vs open bottom

The life of Quarkonia in the Medium can be Complicated

- Observed J/ψ is a mixture of direct production+feeddown (R. Vogt: Phys. Rep. 310, 197 (1999)).
  - All J/ψ ~ 0.6J/ψ(Direct) + ~0.3 χ_c + ~0.1ψ'
  - B meson feed down.
    - Important to disentangle different component

- Suppression and enhancement in the "cold" nuclear medium
  - Nuclear Absorption, Gluon shadowing, initial state energy loss, Cronin effect and gluon saturation (CGC)
  - Study p+A collisions

- Hot/dense medium effect
  - J/ψ, ϒ dissociation, i.e. suppression
  - Recombination, i.e. enhancement
  - Study different species, e.g. J/psi, ϒ
  - Study at different energy, i.e. RHIC, LHC

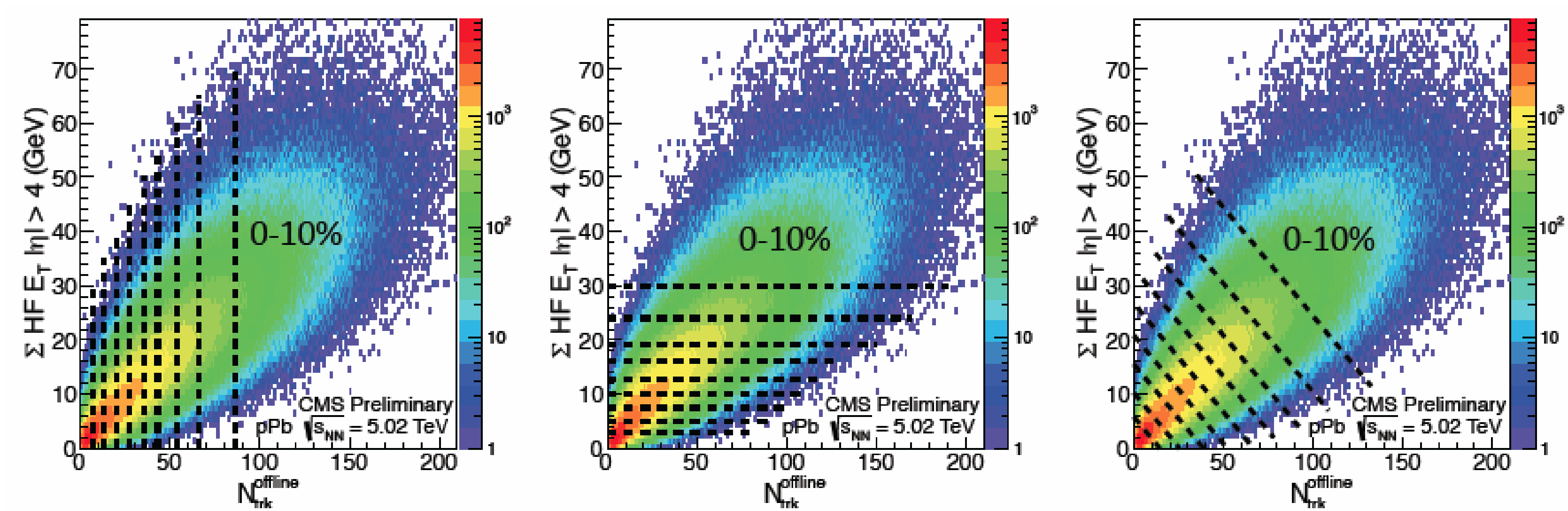


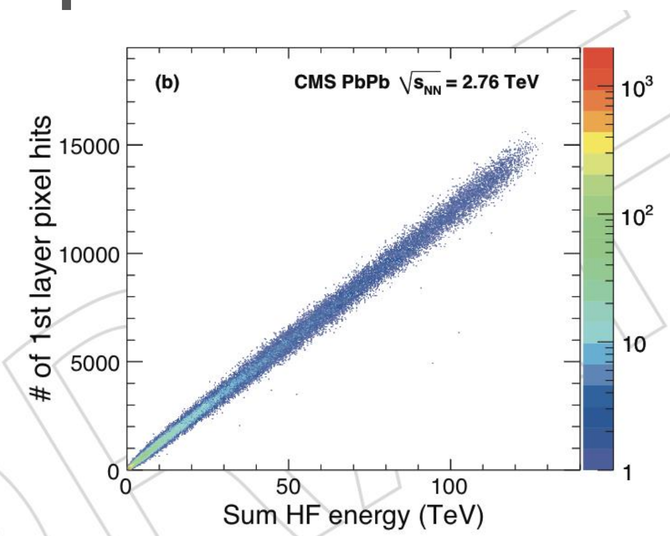
Summary

- Charmonium in PbPb
  - Prompt J/ψ integrated v_2 (10-60%, $|y| < 2.4$ and $6.5 < p_T < 30$ GeV/c)
    - 0.054 ± 0.013 (stat.) $\pm$ 0.006 (syst.) (3.8σ)
- 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
  - Υ(nS)/Υ(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
  - Υ(nS)/<Υ(nS)>: increase with increasing event activity in pp, pPb and PbPb

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

Defining centrality from different methods:





nd ΣHF E_T |η|>4 means selecting very

;. 0-10% in the plots), but $\langle N_{coll} \rangle$ are the same

of centrality determination are about how to

real data (which η range to use?) for an

ossible biases

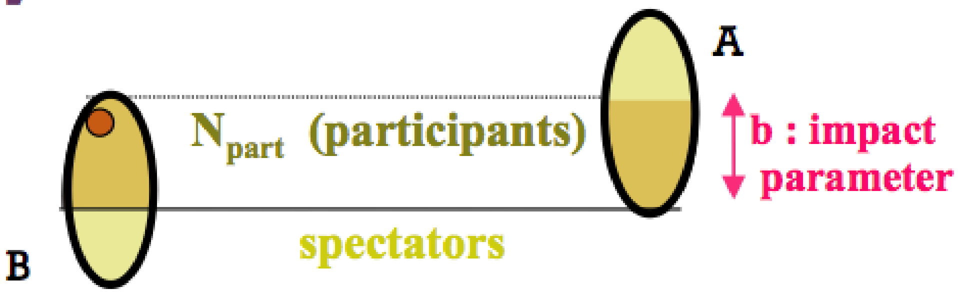
Systematics

Table 1: Relative systematic uncertainty ranges on the prompt J/ψ v_2 measured in PbPb collisions at 2.76 TeV.

	Relative systematic uncertainties variations (%)
Yield extraction	1 – 20
Efficiency corrections	0 – 42
Event plane	3.5
Total	12 – 46

+ How do we quantify medium effects ?

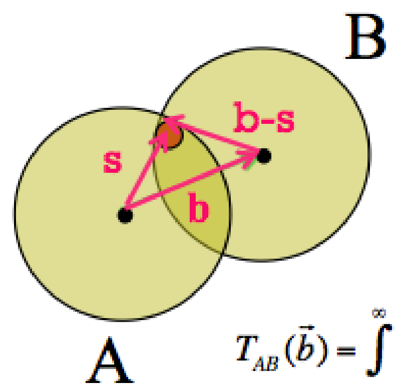
- N_{part} : number of nucleons which undergo at least one collision



- N_{coll} : number of n+n collisions taking place in A+B collision
- Modification nuclear factor $R_{AA} = \dfrac{1/N_{evnts} d^2N^Z/dydp_T}{<T_{AB}> d^2\sigma_{pp}/dydp_T}$

quantifies the effect of the medium on a particle production

- To compare measured PbPb yields to theoretical pp cross sections, we need T_{AB} : nuclear overlap function
  - In absence of medium effects
    - R_{AA} = 1 for perturbative probes
  - T_{AB} is proportional to N_{coll}
    - 30-100% : $T_{AB} = 1.45 \pm 0.18$ mb^{-1}
    - 10-30% : $T_{AB} = 16.6 \pm 0.7$ mb^{-1}
    - 0-10% : $T_{AB} = 23.2 \pm 1.0$ mb^{-1}



$$T_{AB}(\vec{b}) = \int_{-\infty}^{\infty} d\vec{s}\; T_A(\vec{s})\, T_B(\vec{b}-\vec{s})$$

Lamia, B. “Observation of Z Boson Production in Heavy Ion Collisions at CMS”
Moriond QCD and High Energy Interactions, 2011

J/ψ v_2 at ALICE

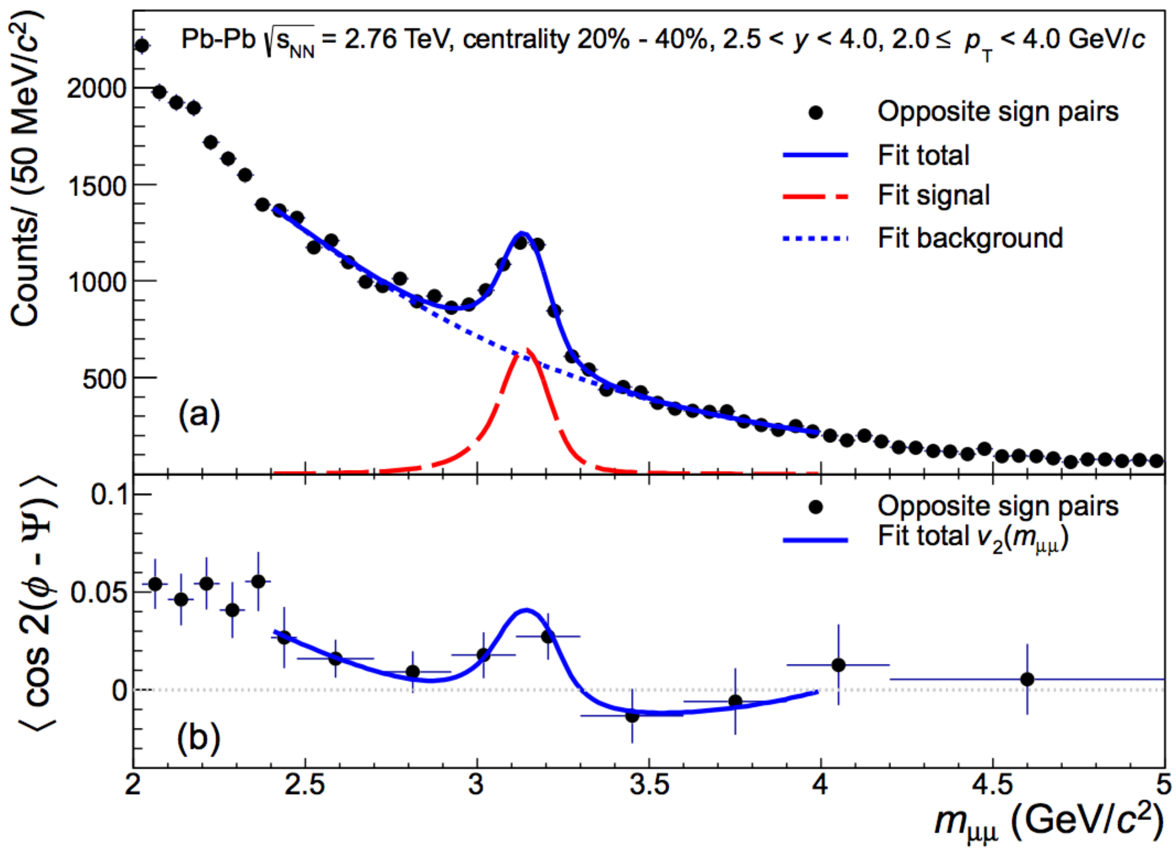
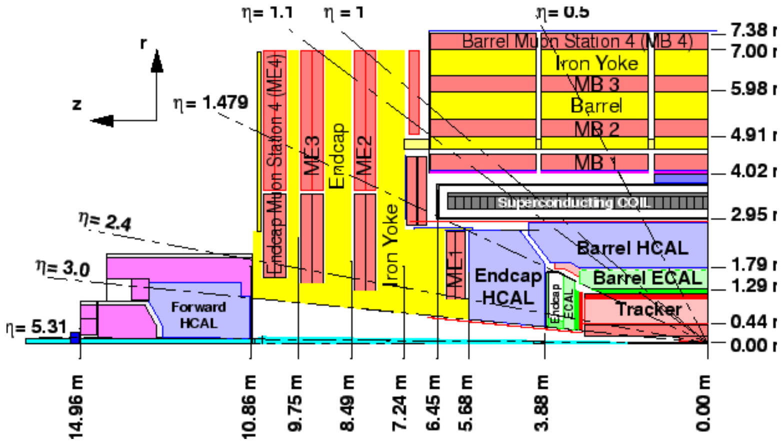
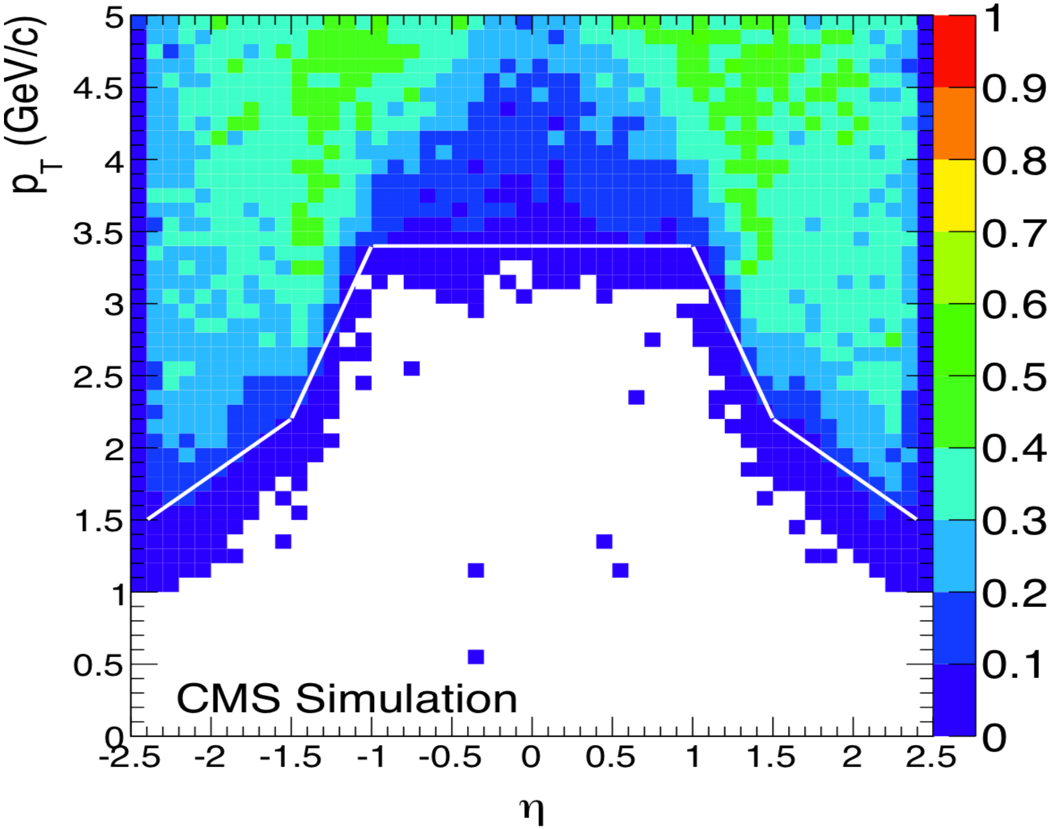


Fig. 1: (color online) Invariant mass distribution (a) and $\langle\cos 2(\phi - \Psi)\rangle$ as a function of $m_{\mu\mu}$ (b) of OS dimuons with $2 \leq p_T < 4$ GeV/c and $2.5 < y < 4$ in semi-central (20%–40%) Pb-Pb collisions.

Single Muon Acceptance





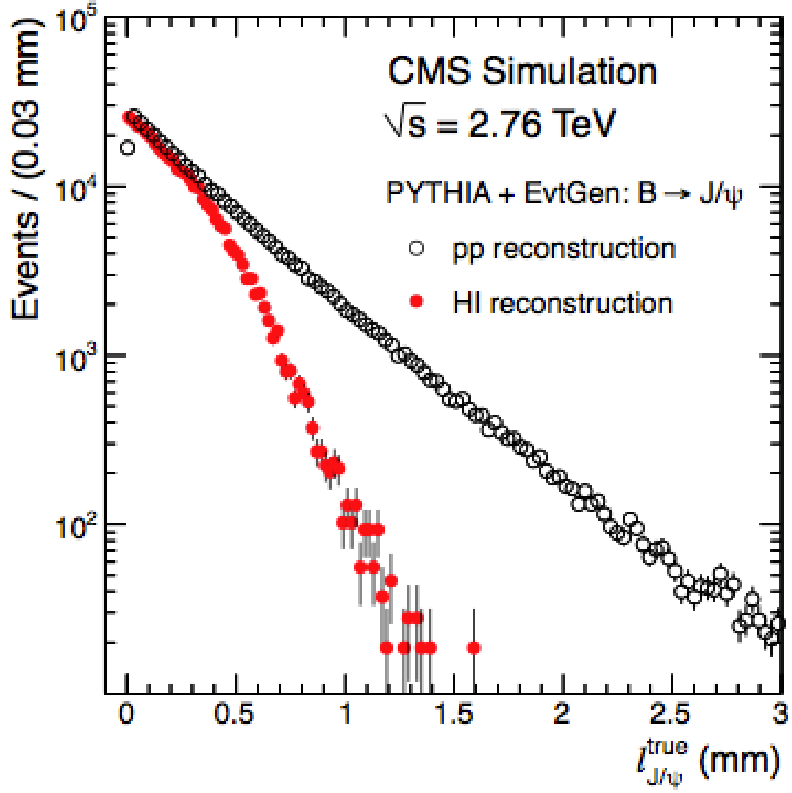
✔ Acceptance definition:
Range of p_T and eta of reconstructable muon
(RecoMu/GenMu ≥ 10%)

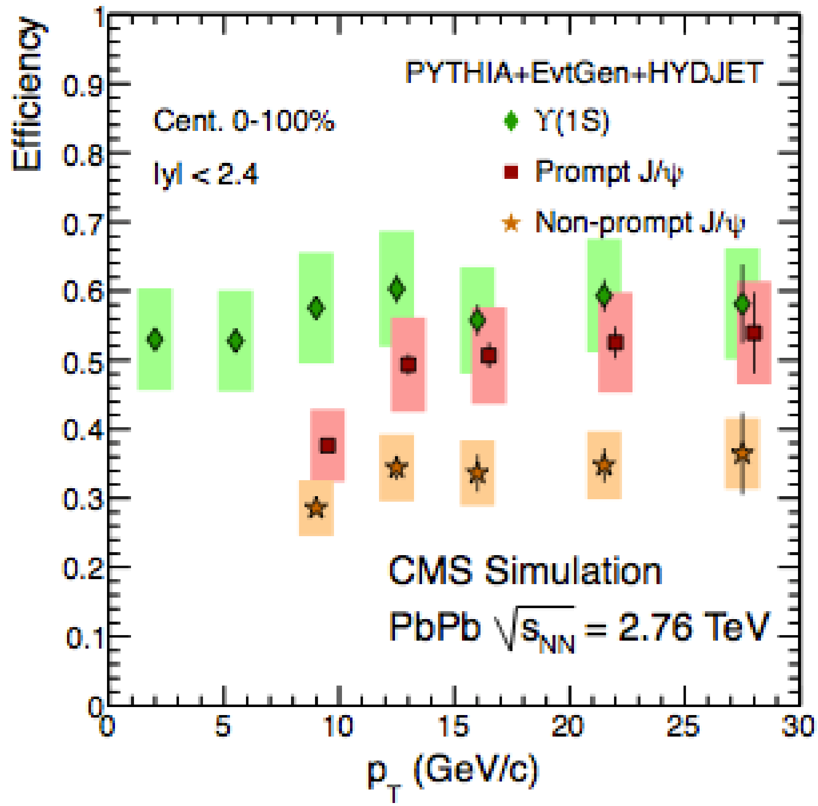
$$|\eta^{\mu}| < 1.0 \rightarrow p_T^{\mu} > 3.4 \text{ GeV}/c$$

$$1.0 \leq |\eta^{\mu}| < 1.6 \rightarrow p_T^{\mu} > 5.8 - 2.4 \times |\eta^{\mu}| \text{ GeV}/c$$

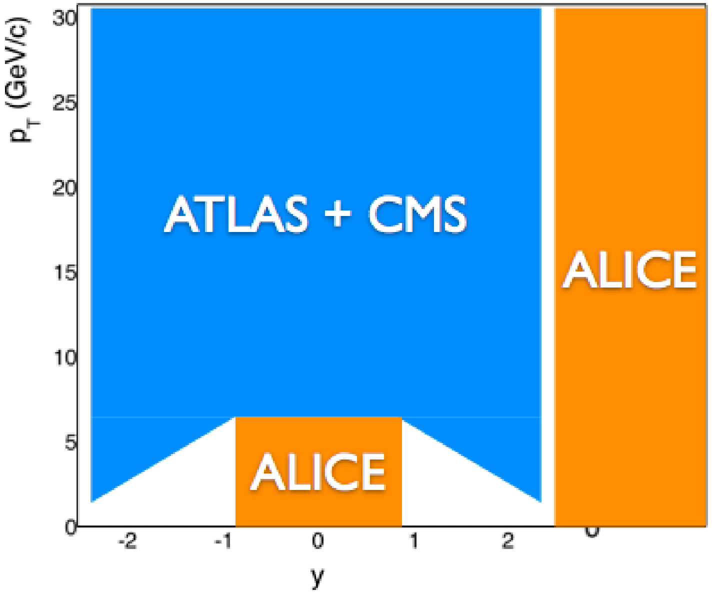
$$1.6 \leq |\eta^{\mu}| < 2.4 \rightarrow p_T^{\mu} > 3.3667 - 7/9 \times |\eta^{\mu}| \text{ GeV}/c$$

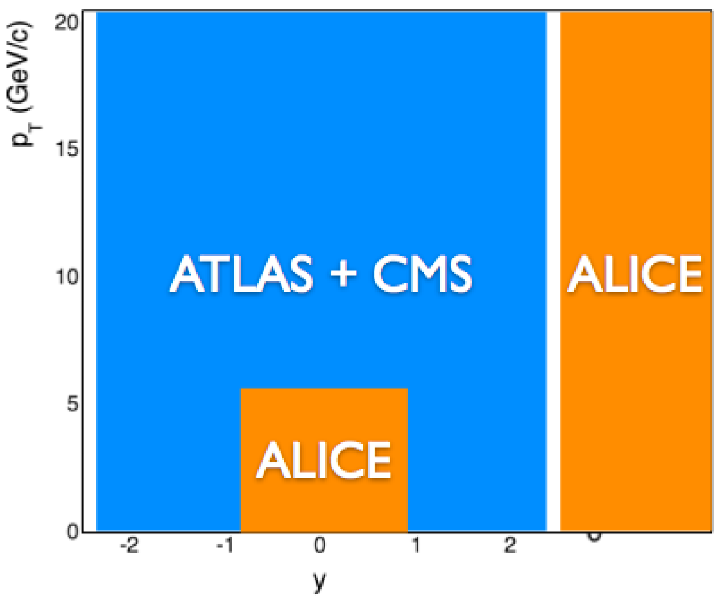
Reconstruction Efficiency





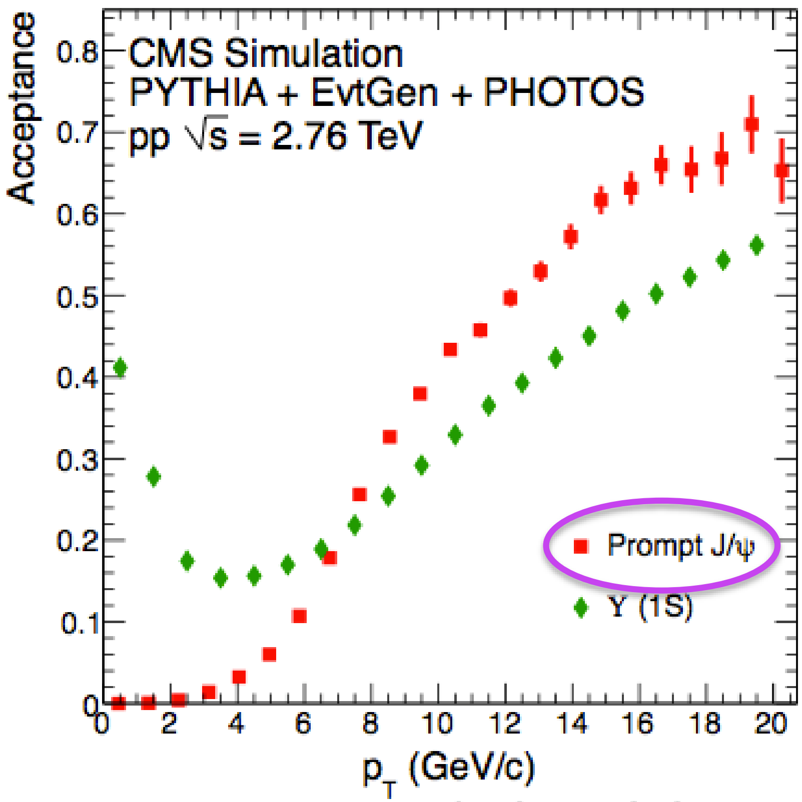
Quarkonia Acceptance

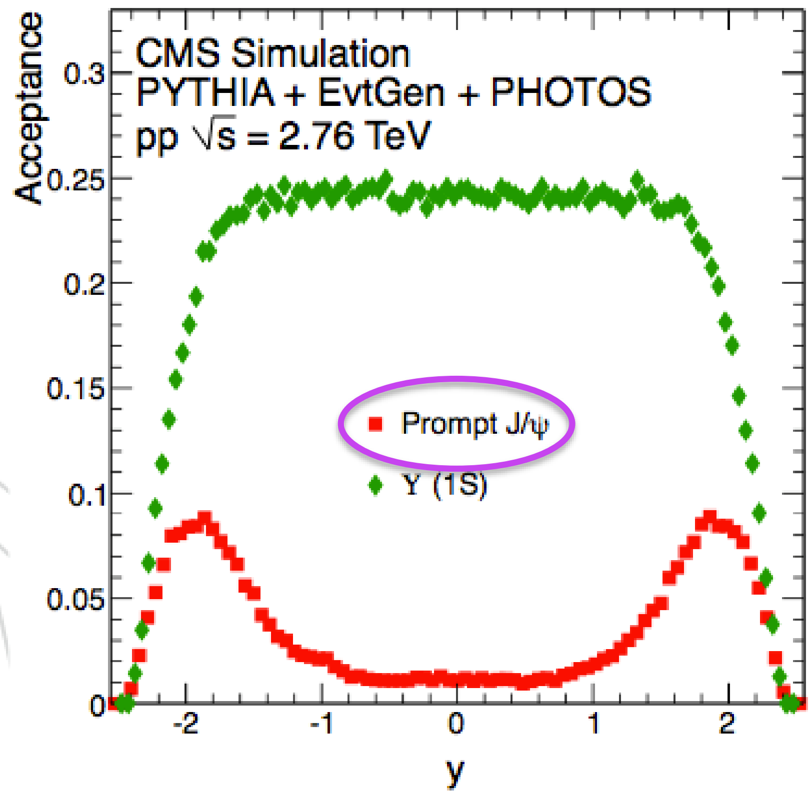




- ALICE: acceptance for $p_T > 0$
  - midrapidity: no absorber and low magnetic field
  - forward rapidity: longitudinal boost
- ATLAS and CMS: Muons need to overcome strong magnetic field and energy loss in the absorber
  - minimum total momentum p~3–5 GeV/c to reach the muon stations
  - Limits J/ψ acceptance:
    - mid-rapidity: $p_T > 6.5$ GeV/c
    - forward rapidity: $p_T > 3$ GeV/c
    - (values for CMS, but similar for ATLAS)
  - Υ acceptance:
    - $p_T > 0$ GeV/c for all rapidity
- Complementary acceptances

Correction (Acceptance)

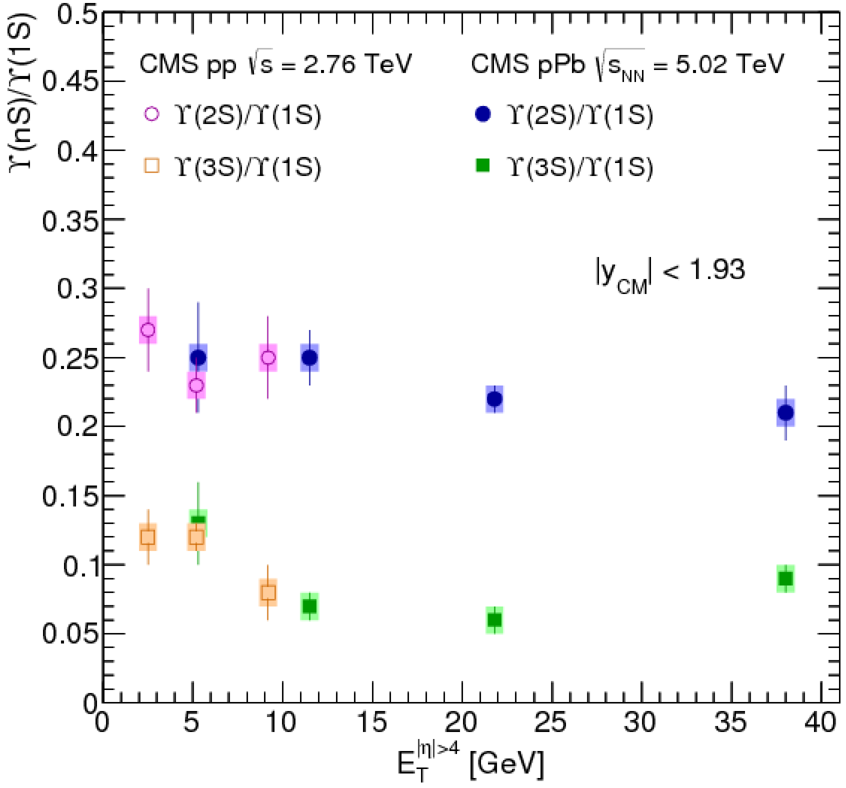


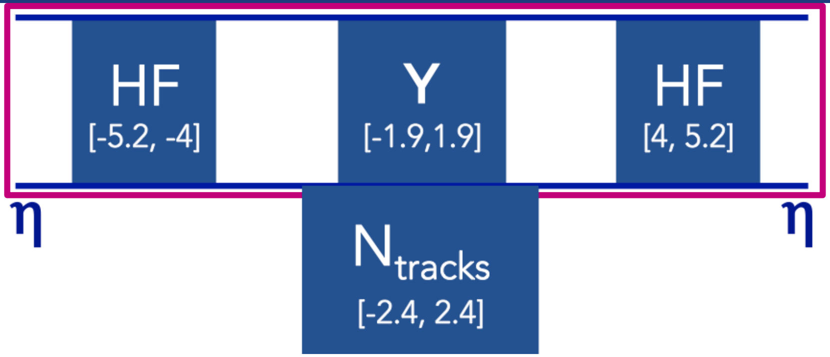


✔ **PYTHIA+EventGen+PHOTOS simulation at $\sqrt{s}$ = 2.76 TeV**

✔ **Total acceptance : 0.296, $0.0 \le |y| < 2.4$, $6.5 \le p_T < 30.0$ (GeV/c)**

Υ(nS)/Υ(1S) vs E_T (|η| > 4)



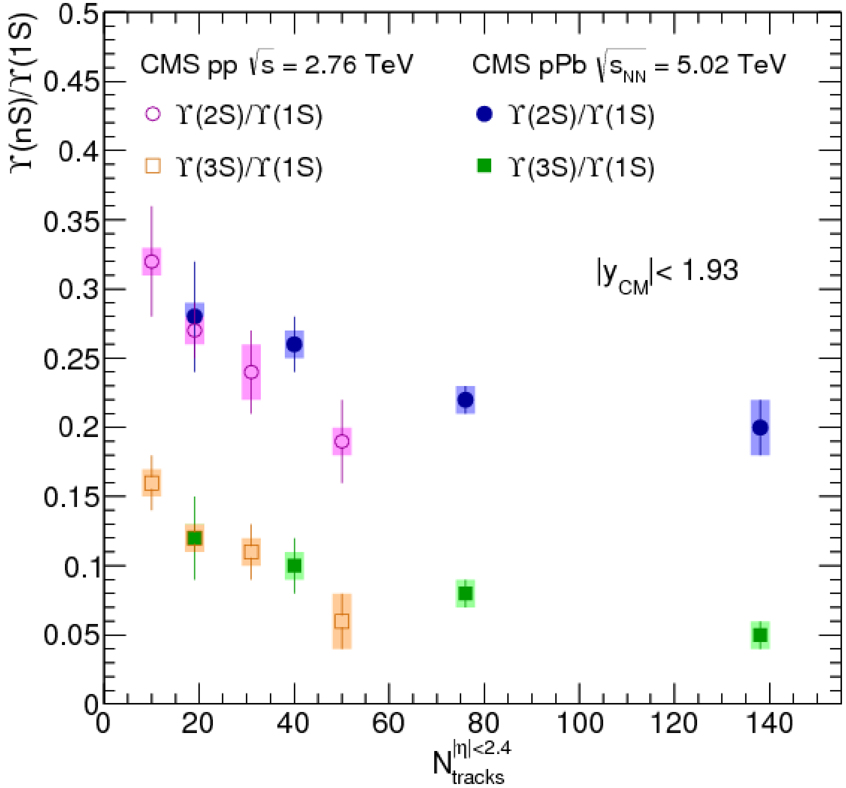


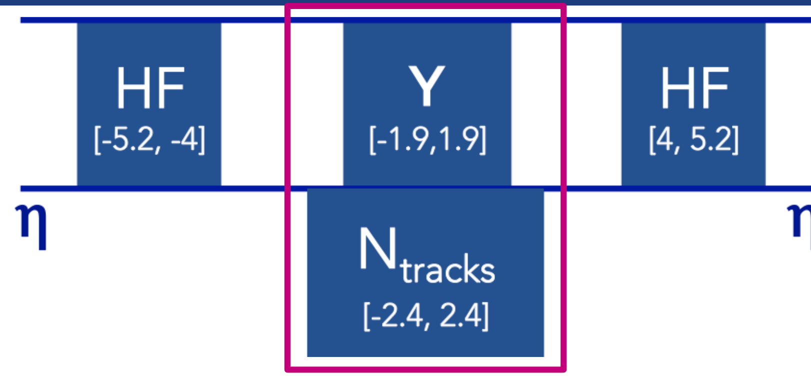
$$\left[\frac{\Upsilon(nS)}{\Upsilon(1S)}\right]_{pp,pPb}$$

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

CMS-PAS-HIN-13-003
arXiv:1312.6300

Y(nS)/Y(1S) vs N_{tracks} (|η| < 2.4)



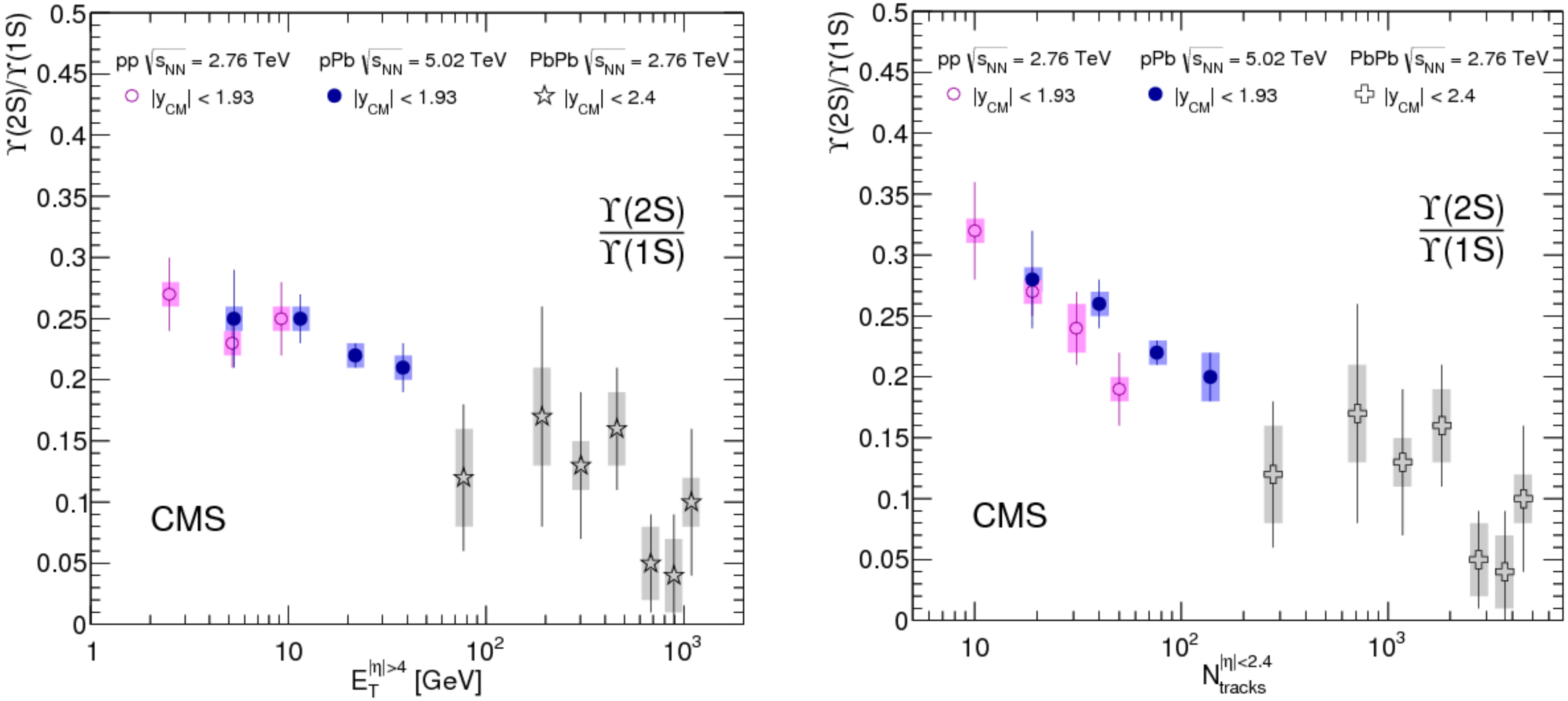


$$\left[\frac{\Upsilon(nS)}{\Upsilon(1S)}\right]_{pp,pPb}$$

- 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

CMS-PAS-HIN-13-003
arXiv:1312.6300

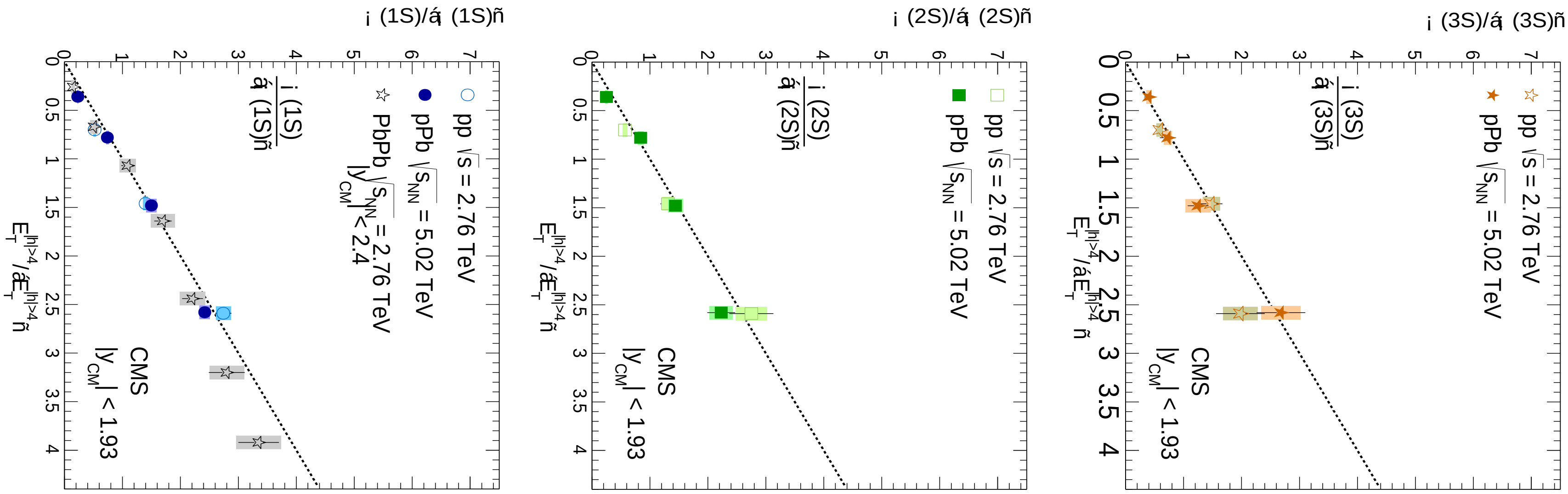
Y(2S)/Y(1S) compare PbPb



- PbPb : no significant dependence on E_T(|η|>4) and 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

CMS-PAS-HIN-13-003
arXiv:1312.6300

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



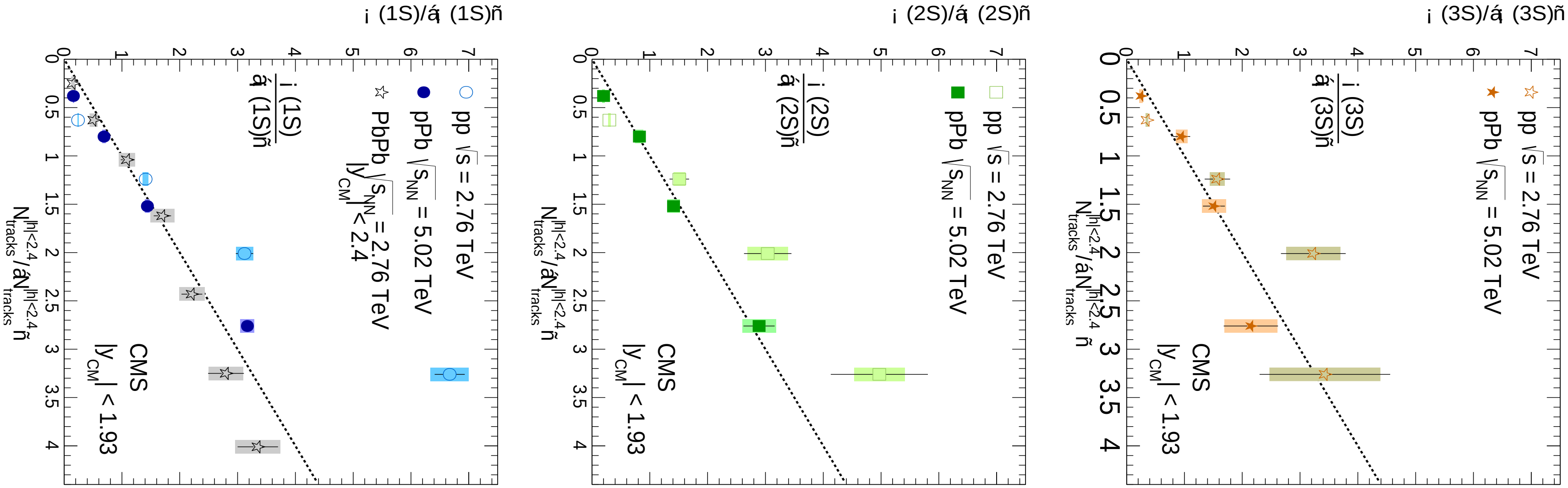
$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{MB}} \frac{Y(nS)|_{PbPb}}{Y(nS)|_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

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

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

CMS-PAS-HIN-13-003
arXiv:1312.6300

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



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

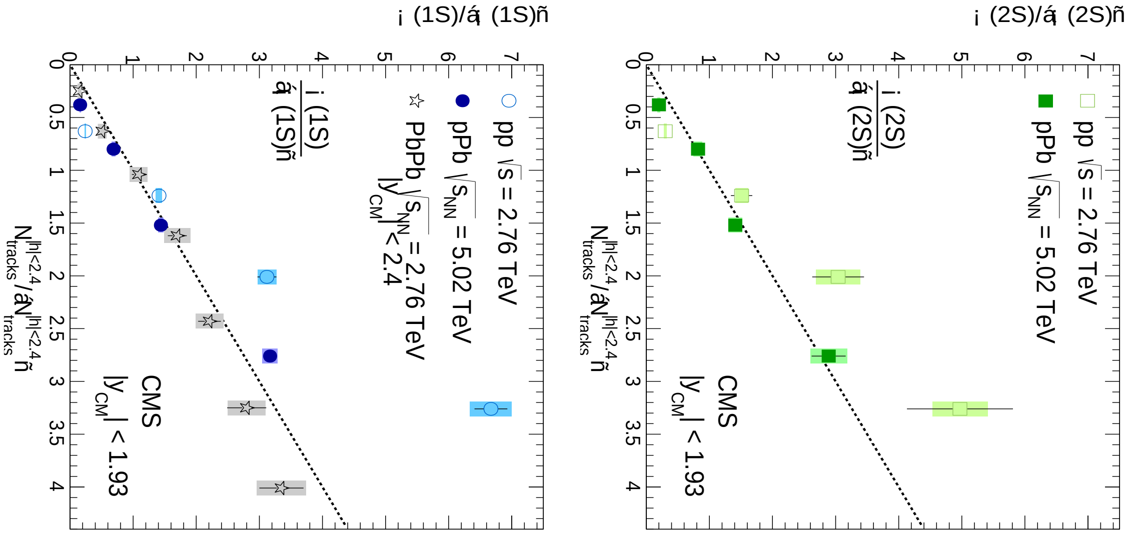
$$\frac{R^i_{AA}}{R_{AA}} = \frac{T_{AA}}{T^i_{AA}} * \boxed{\frac{\Upsilon(nS)^i}{\langle \Upsilon(nS) \rangle} * \frac{\epsilon}{\epsilon^i}}$$

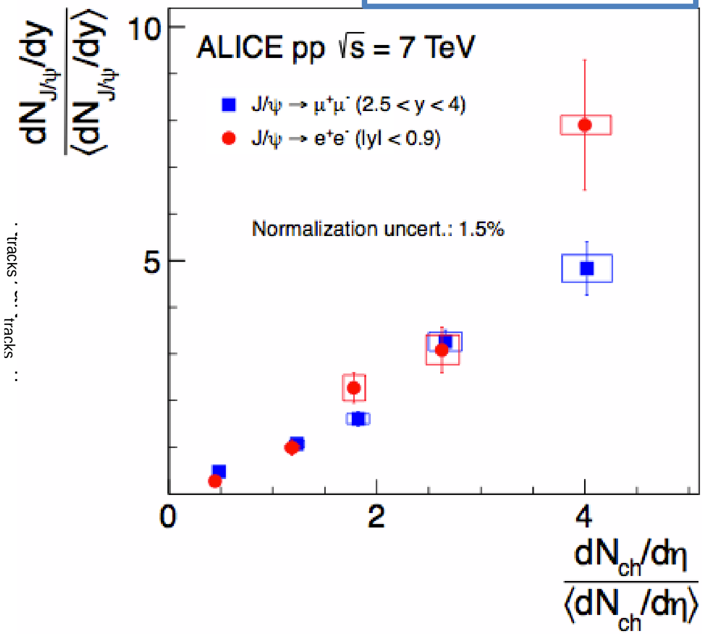
- Y(nS)/<Y(nS)> vs N_{tracks}
  - Less consistent behavior (related to the Y(nS)/Y(1S) variations)

CMS-PAS-HIN-13-003
arXiv:1312.6300

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

PLB 712 (2012) 165





$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{\Upsilon(nS)|_{PbPb}}{\Upsilon(nS)|_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

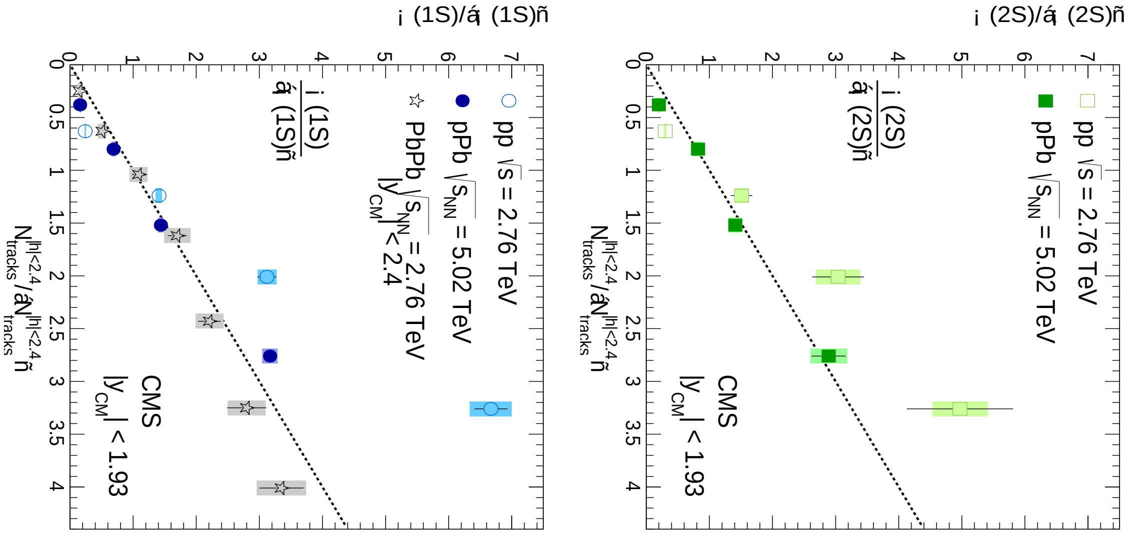
$$\frac{R^i_{AA}}{R_{AA}} = \frac{T_{AA}}{T^i_{AA}} * \frac{\Upsilon(nS)^i}{\langle \Upsilon(nS) \rangle} * \frac{\epsilon}{\epsilon^i}$$

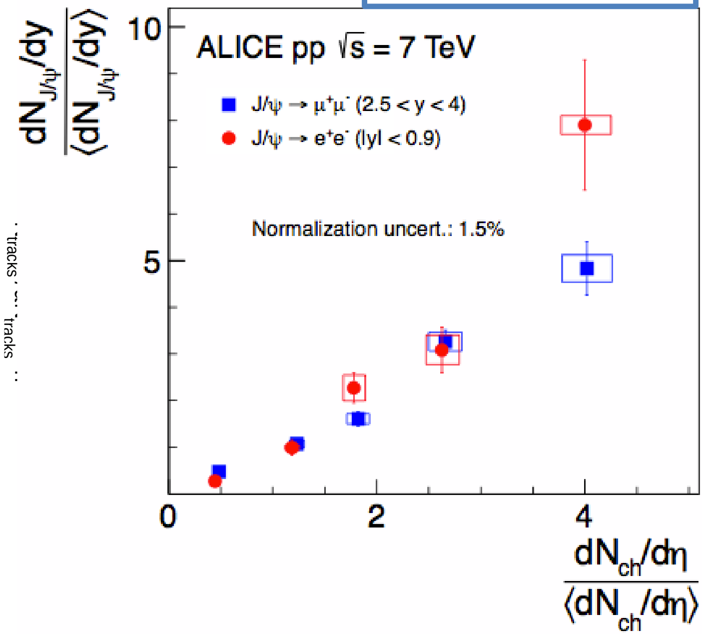
- Y(nS)/<Y(nS)> vs N_{tracks}
  - Less consistent behavior (related to the Y(nS)/Y(1S) variations)

CMS-PAS-HIN-13-003
arXiv:1312.6300

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

PLB 712 (2012) 165





$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{\Upsilon(nS)|_{PbPb}}{\Upsilon(nS)|_{pp}} \frac{\epsilon_{pp}}{\epsilon_{PbPb}}$$

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

- Y(nS)/<Y(nS)> 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

CMS-PAS-HIN-13-003
arXiv:1312.6300

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

•

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
radius [fm]	0.25	0.36	0.45	0.14	0.22	0.28	0.34	0.39

Heavy ion program timeline

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

LS1 ~0.3-1.5 nb^{-1} PbPb LS2 ~2-4 nb^{-1} PbPb LS3 ~10 nb^{-1} PbPb

CMS request

Also corresponding pp reference: PbPb 5.1TeV | PbPb 5.1TeV | pPb? 8.2TeV

Also corresponding pp reference: ArAr pPb PbPb 5-8 TeV

PbPb pp (?) 5.5 TeV

L1 trigger upgrade

Pixel detector upgrade

3 layers → 4 layers

Extended tracker coverage |η|<4 (?)

- PbPb statistics: 1.5nb^{-1} and 10nb^{-1} PbPb
- What is the expected pp statistics we should use?

Contents

- Introduction
- Charmonium measurements
  - Prompt J/ψ azimuthal anisotropy in PbPb collisions
- Bottomonium measurements
  - pp & pPb collisions
- Summary

pp DiMuon

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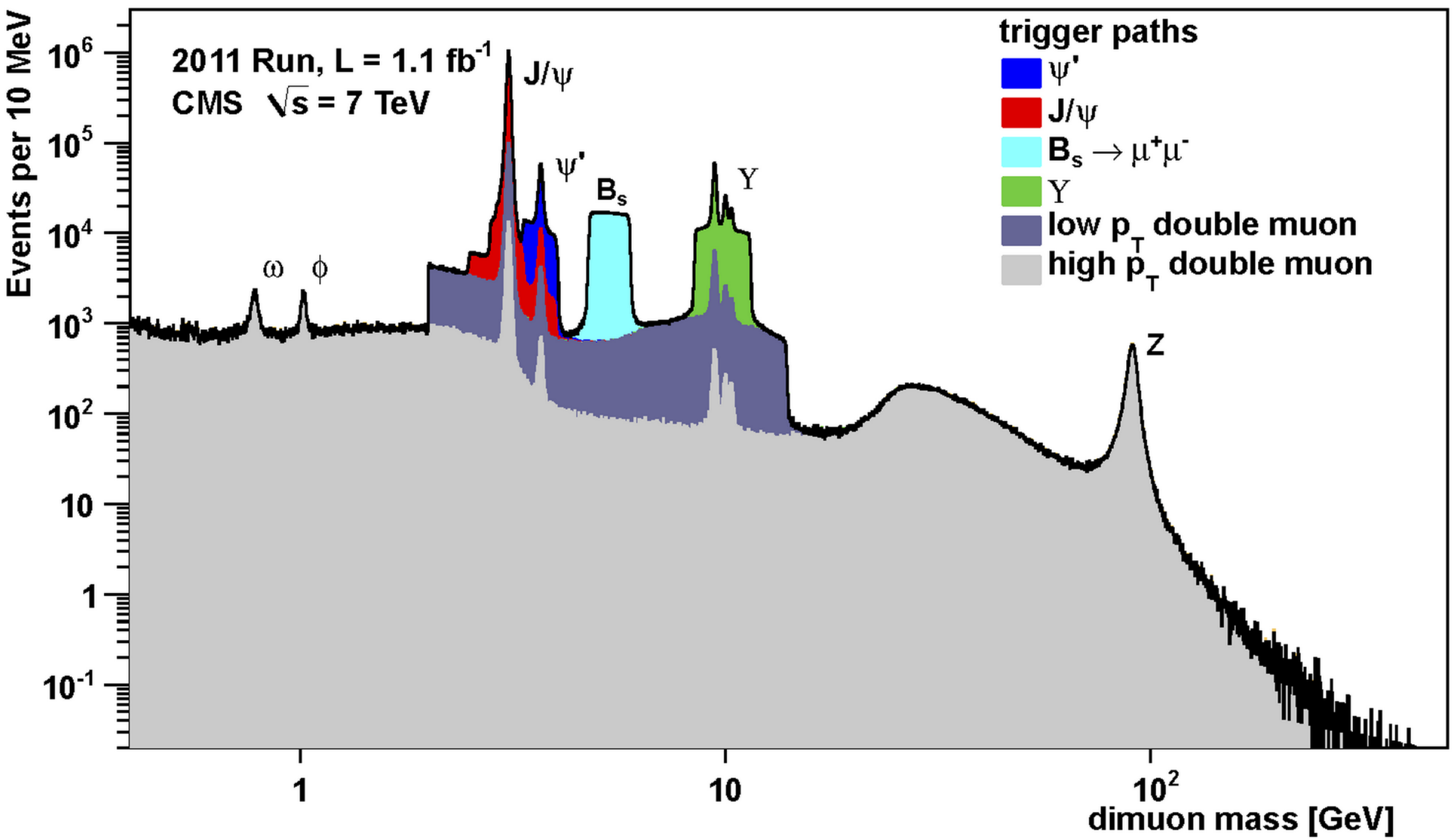
2011 Run, L = 1.1 fb-1
CMS √s = 7 TeV
trigger paths
ψ'
J/ψ
Bs → μ+μ-
Υ
low pT double muon
high pT double muon
J/ψ
ψ'
Bs
Υ
ω
φ
Z
Events per 10 MeV
dimuon mass [GeV]
10^6
10^5
10^4
10^3
10^2
10
1
10^-1
1
10
10^2