Recent News of Quarkonia Results from CMS

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   - **J/ψ in pp and PbPb at 2.76 TeV**
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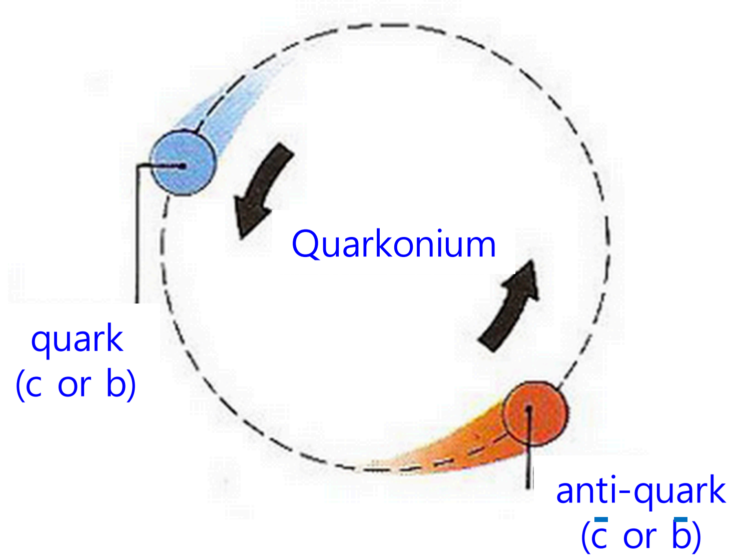
   - **Υ(ns) double Ratio at 5.02 TeV**
3. **Summary**

Quarkonia Measurement in Heavy-ion Collisions

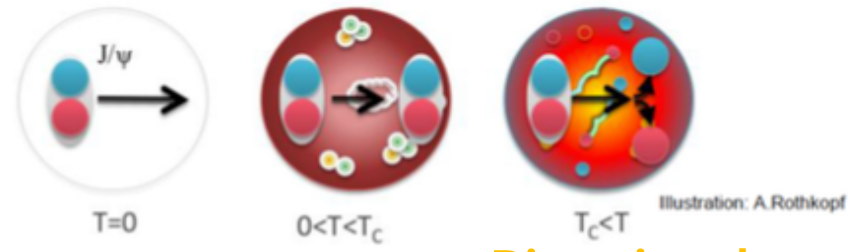
- **Quarkonia are wonderful probe of Quark-Gluon-Plasma (QGP)**
  - ➠ Produced in early stage of collisions with large momentum transfer in gluon-gluon fusion
  - ➠ Undergo through the medium created in heavy-ion collisions



Quarkonia Measurement in Heavy-ion Collisions

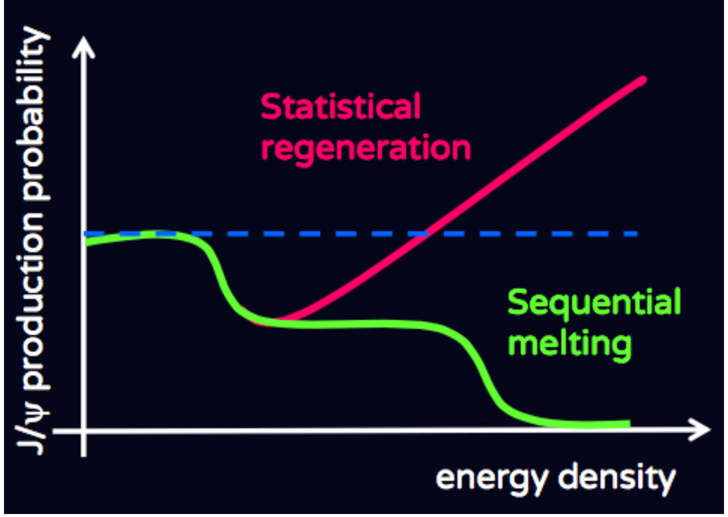
- **Quarkonia production in heavy-ion collisions**
  - ➠ **Color screening** : dissociated in the medium (***suppression***).
  - ➠ **Sequential melting** : different dissociation temperatures for different bound states (**thermometer of medium**)
  - ➠ **Energy loss (landau damping)**
  - ➠ **Regeneration** : heavy flavor quark production increases strongly with collision energy.

QGP occurs



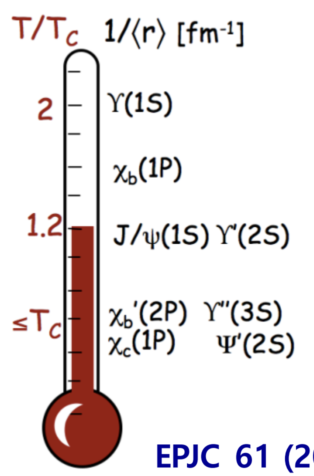
Dissociated

Central AA collisions	SPS 20 GeV	RHIC 200 GeV	LHC 2.76TeV
N_{ccbar}/event	~0.2	~10	~85



Charmonia	J/ψ	χ_c	ψ′(2S)
Mass(GeV)	3.10	3.53	3.69
ΔE (GeV)	0.64	0.20	0.05
T_d/T_c	2.1	1.16	1.12

Bottomonia	Υ(1S)	Υ(2S)	Υ(3S)
Mass(GeV)	9.46	10.0	10.36
ΔE (GeV)	1.10	0.54	0.20
T_d/T_c	> 4.0	1.60	1.17



EPJC 61 (2009) 705

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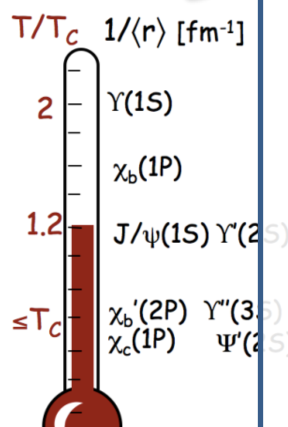

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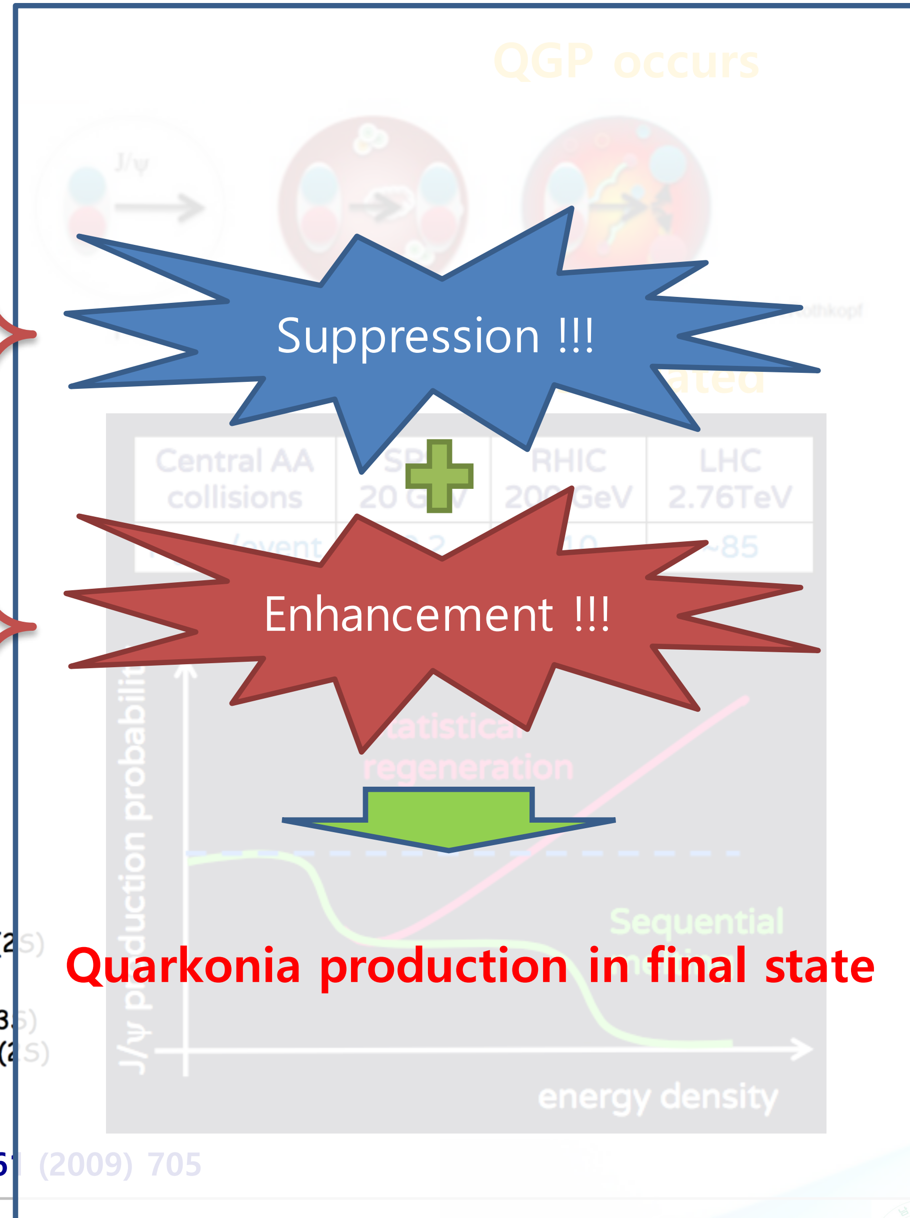
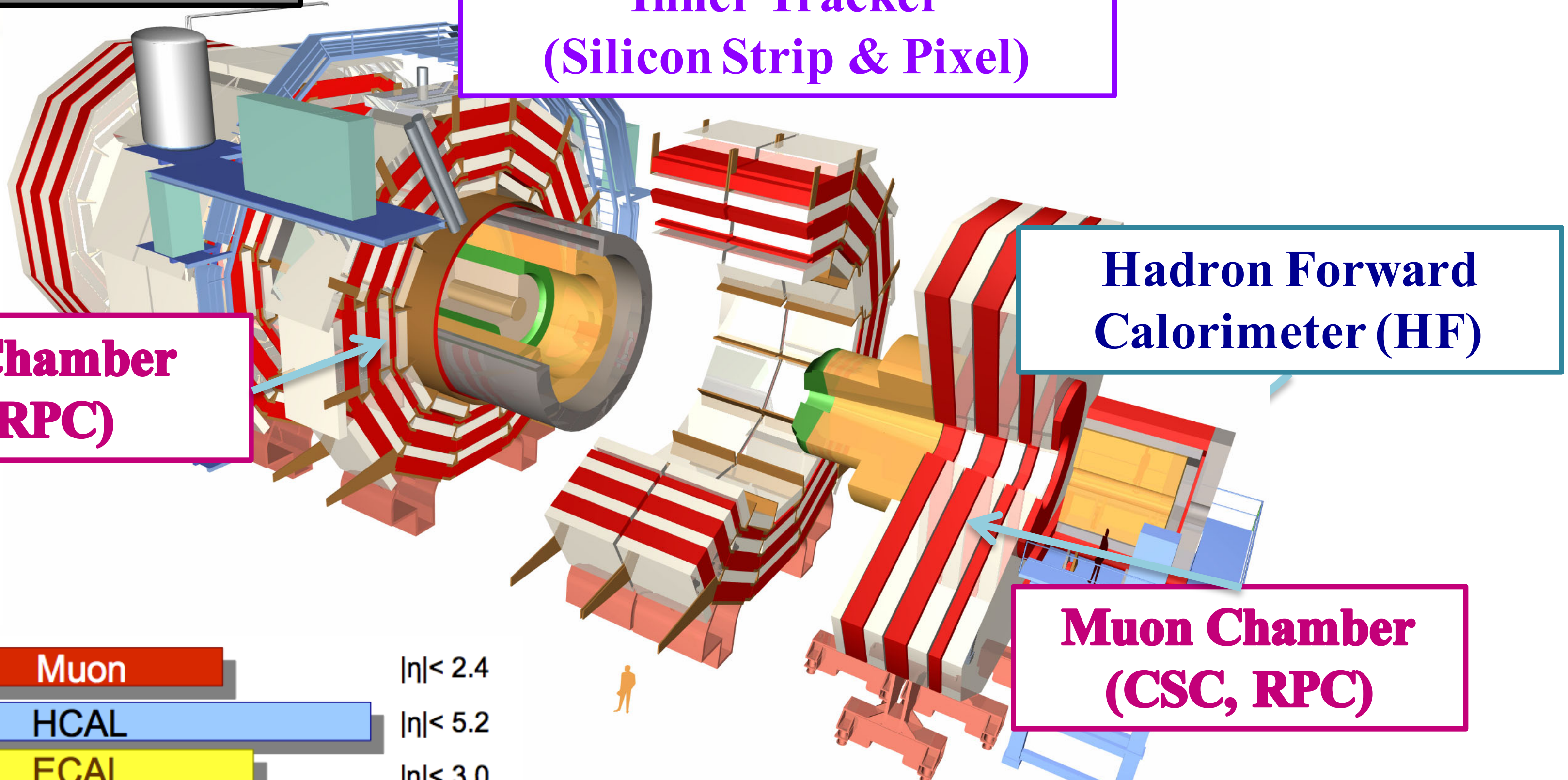
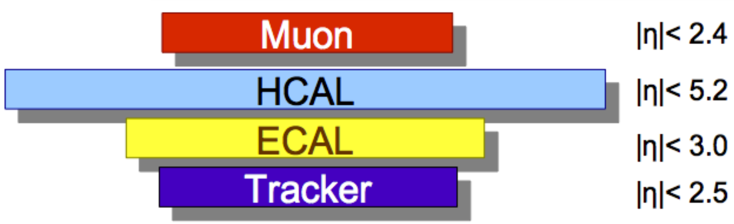


CMS Detector

Magnetic Field : 3.8 T

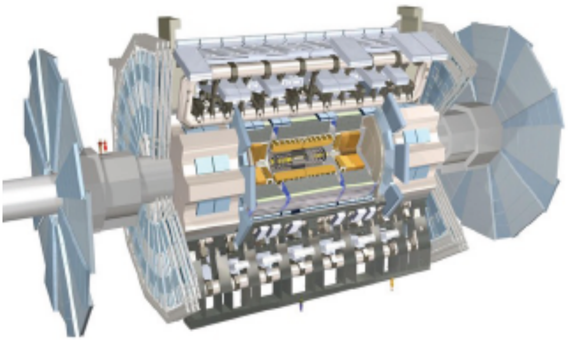




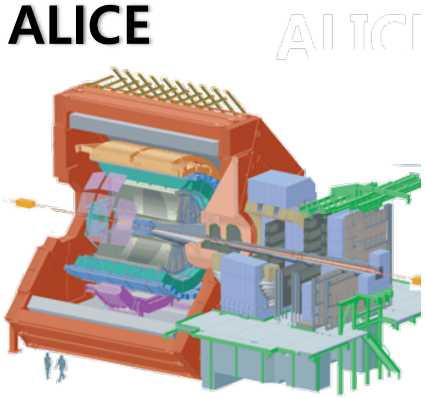
Quarkonia Acceptance

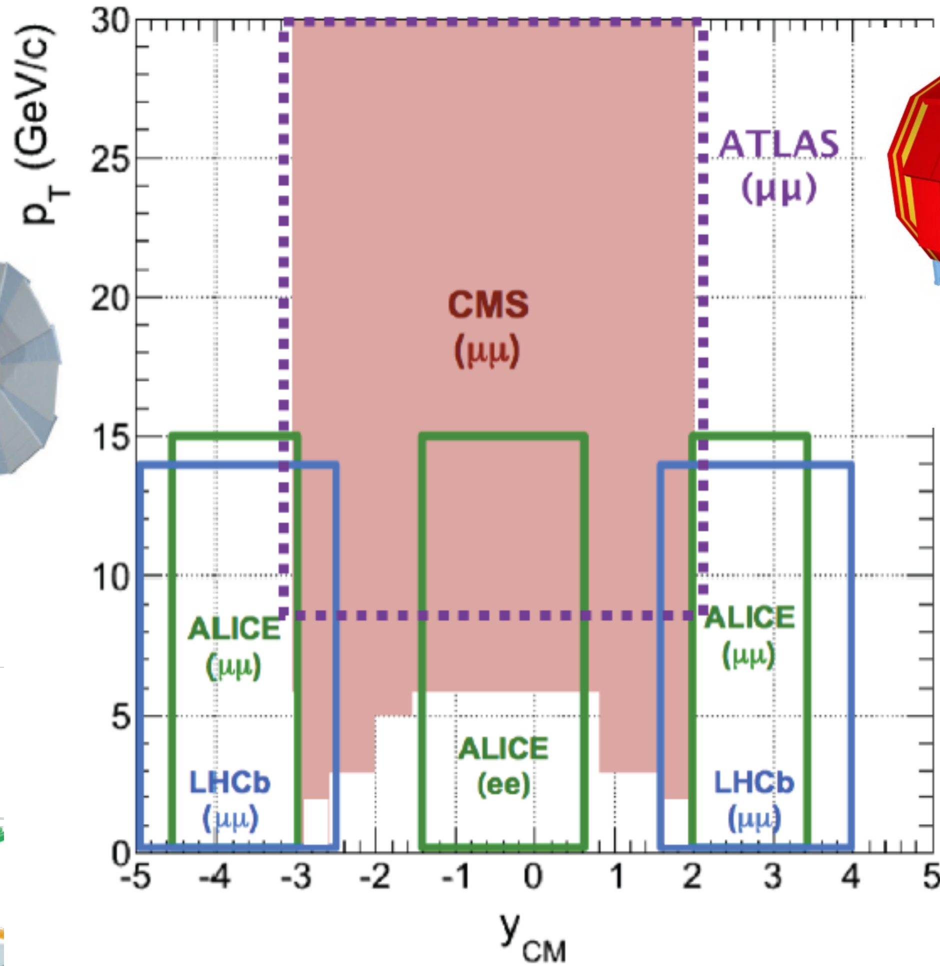
We are good friends !!!

ATLAS

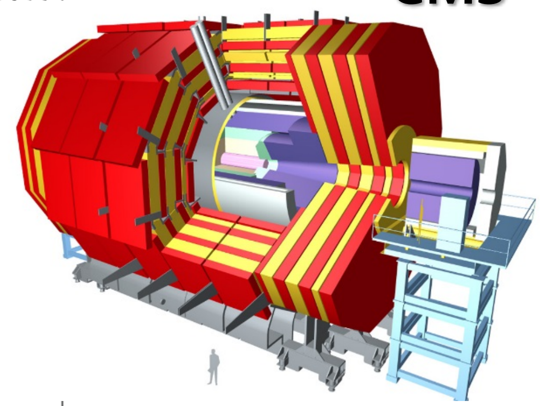


ALICE

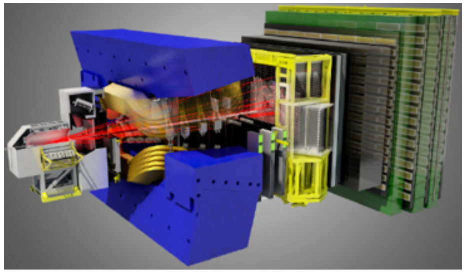




CMS



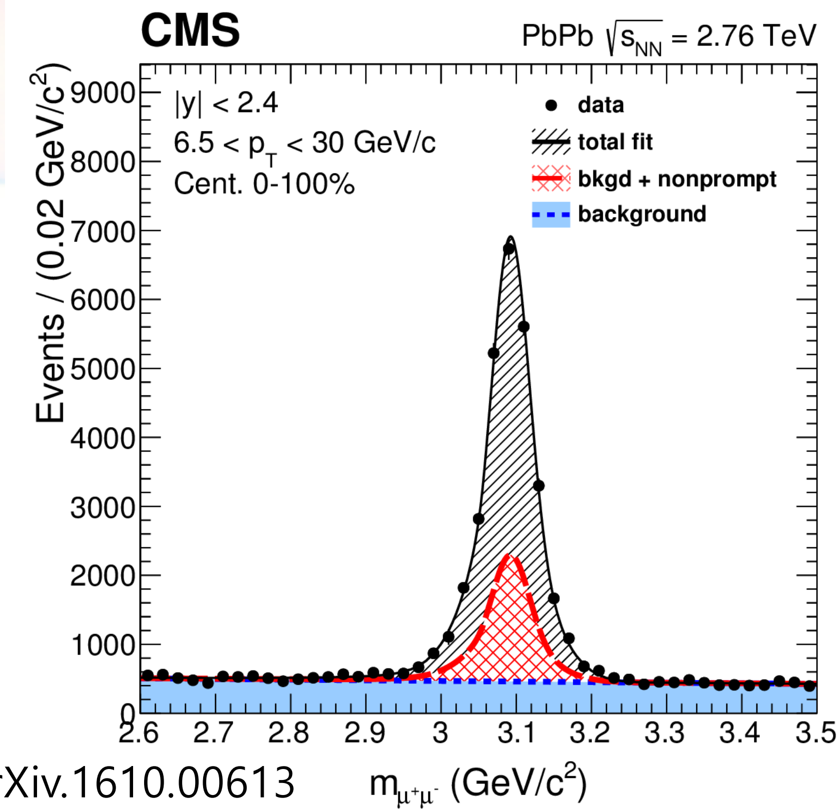
LHCb

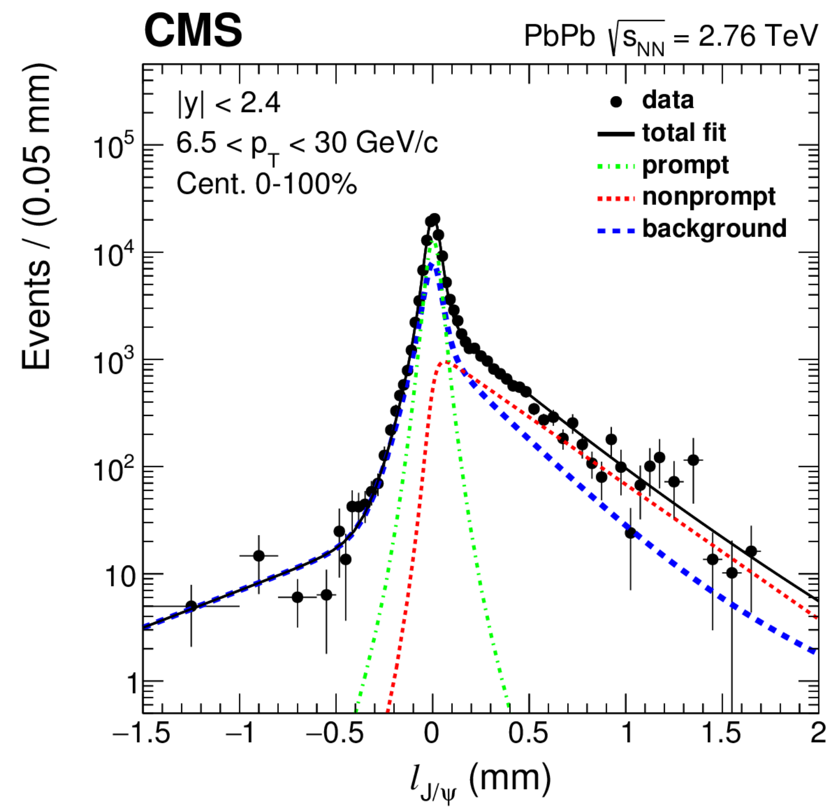


- Complimentary acceptance for LHC detectors

Prompt J/ψ in pp and PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

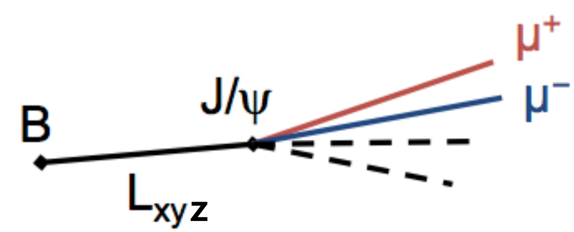
Prompt J/ψ in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV



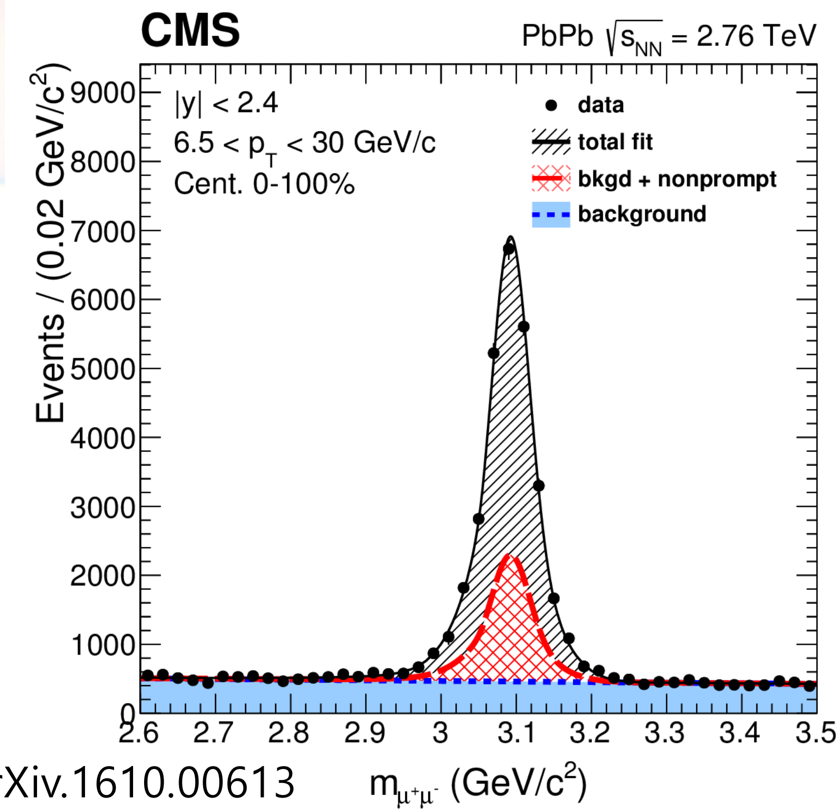


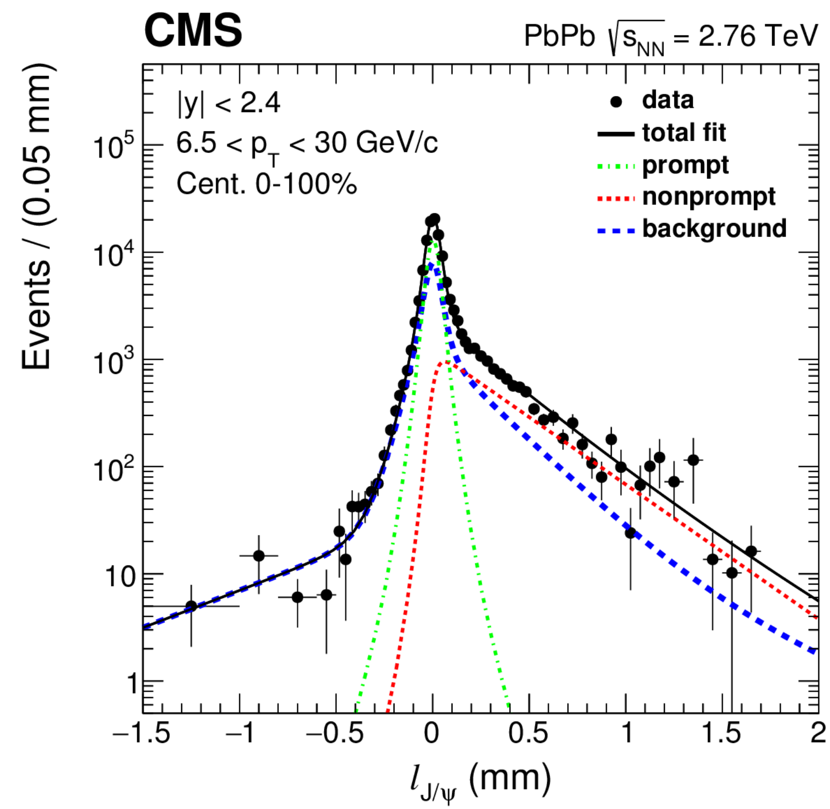
arXiv.1610.00613

- Finally HIN-14-005 was submitted to EPJC.
- Main changes are
  - Added z direction information in displacement calculation (L_{xyz}).
  - Event-by-event efficiency corrections.



Prompt J/ψ in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV





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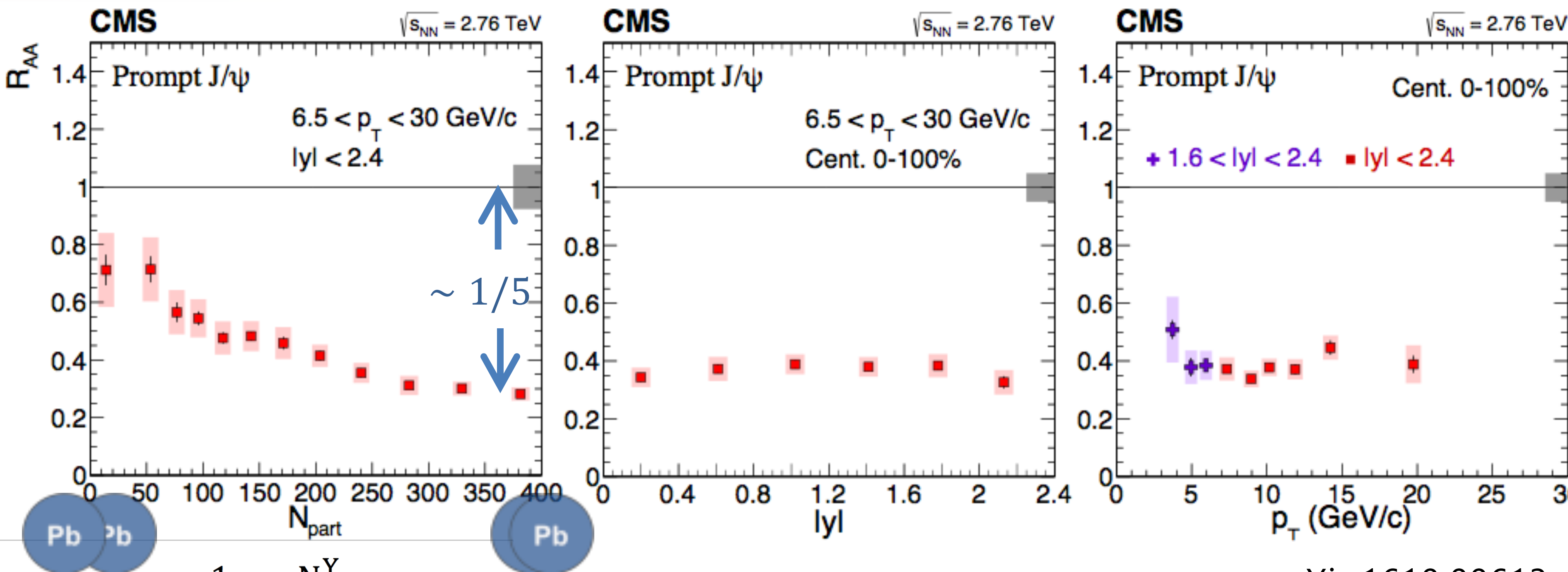
- **Successfully distinguish prompt (Cham) and nonprompt (Beauty) J/ψ**

R_{AA} of Prompt J/ψ in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV



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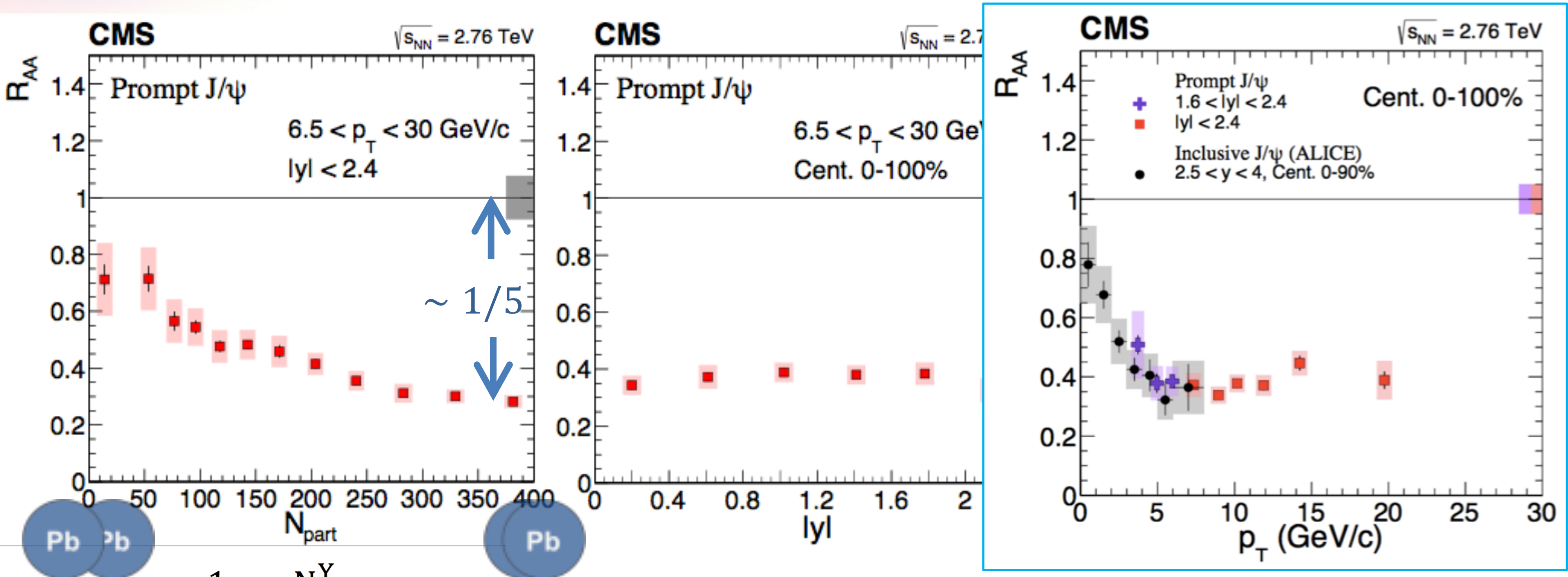
$$R_{AA} = \frac{1}{< N_{coll} >} \frac{N^{Y}_{PbPb}}{N^{Y}_{pp}}$$

- Significantly suppressed in more central collisions (by factor 5 in the most central events)
- No strong dependence on rapidity.
- No strong dependence on p_T in higher p_T region but a hint of slightly decreasing trend in lower p_T (3-6 GeV/c)

R_{AA} of Prompt J/ψ in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV



$$R_{AA} = \frac{1}{< N_{coll} >} \frac{N^{\Upsilon}_{PbPb}}{N^{\Upsilon}_{pp}}$$

- Complements ALICE (inclusive J/ψ)

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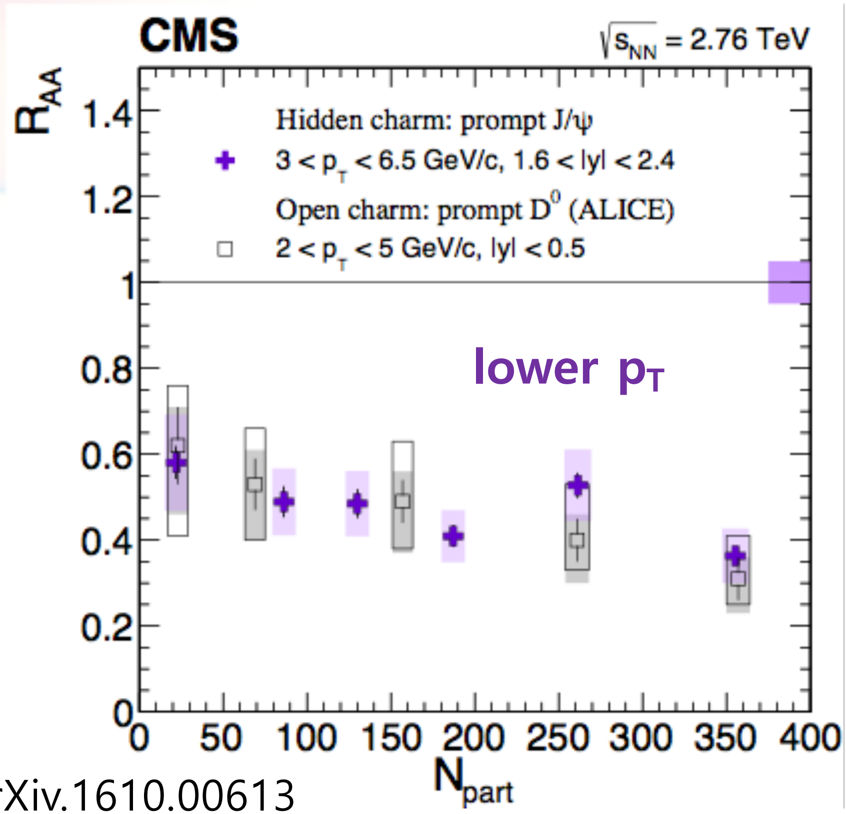
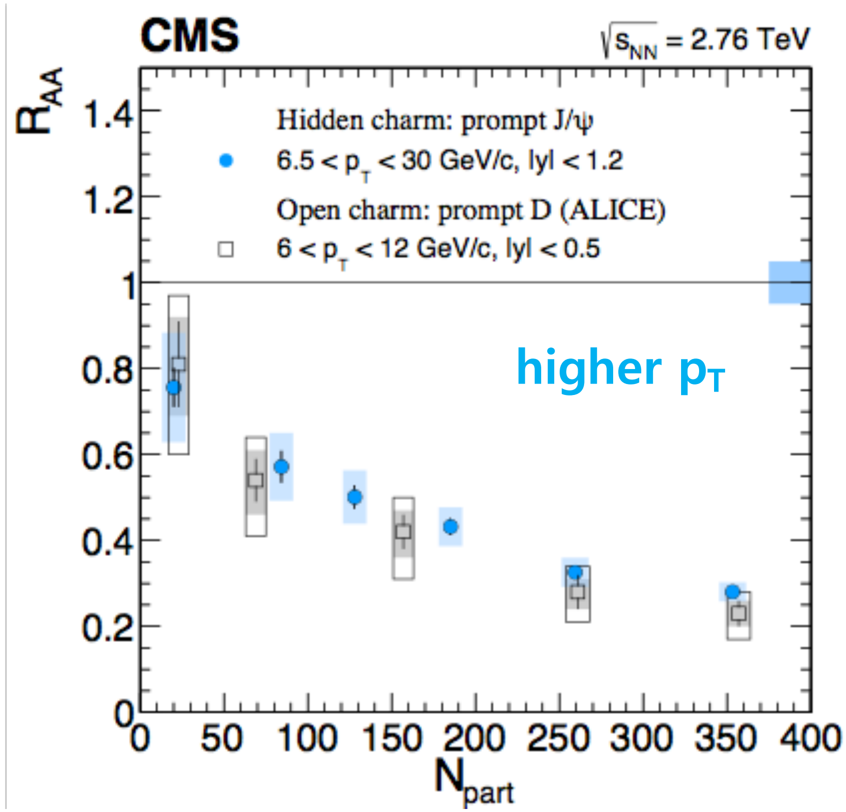
Comparison to D in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV

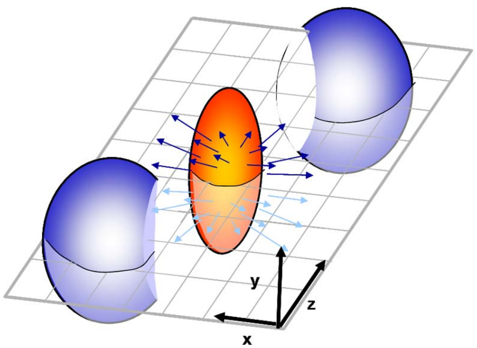


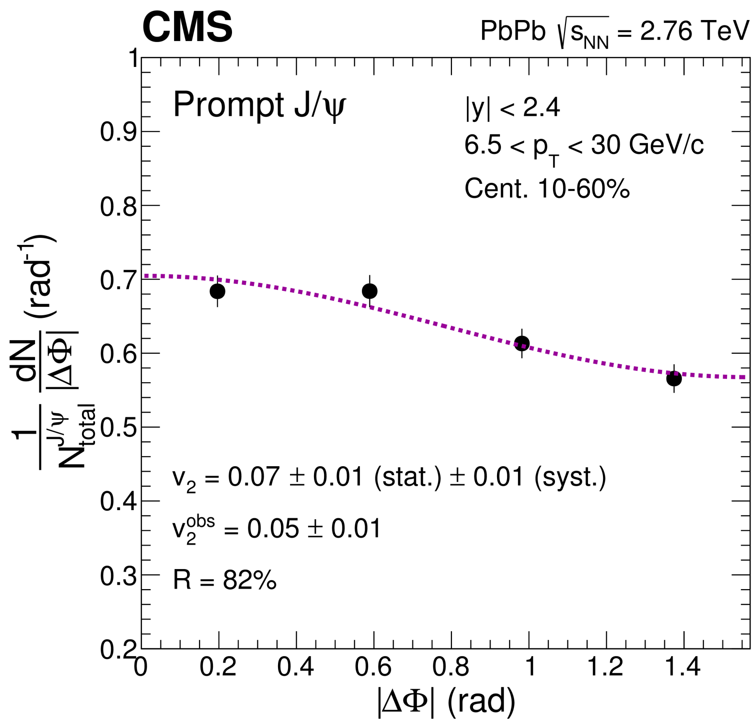


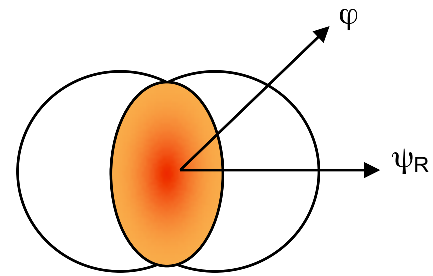
arXiv.1610.00613

- Closed and hidden chams have similar suppression feature.
- Modification would be different between them.
  - Initial state : nuclear effects (shadowing), feed-down …
  - Final state : color screening, regeneration, energy loss of parton …

Prompt J/ψ v_2 in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV





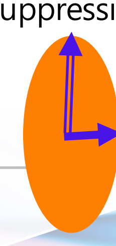


$$\frac{2}{\pi}(1 + 2v_2\cos(2\Delta\phi))$$

arXiv.1610.00613

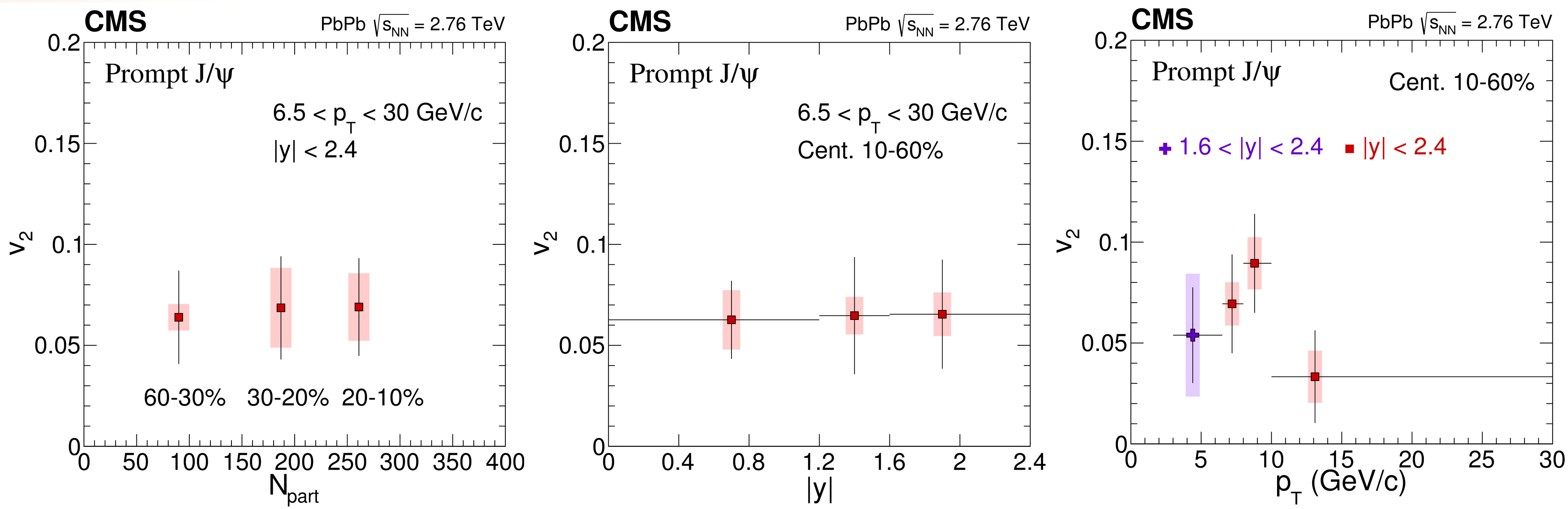
- Nonzero prompt J/ψ v_2 in |y| < 2.4, p_T > 6.5 GeV/c, 10-60 % Cent.
  - v_2 = 0.066 ± 0.014 (stat.) ± 0.014 (syst.) ± 0.022 (global)
  - Significance : 3.2 **σ**
- Path-length dependence.

More suppression



Less suppression

Prompt J/ψ v_2 in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV



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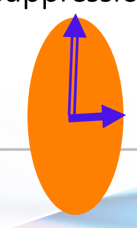
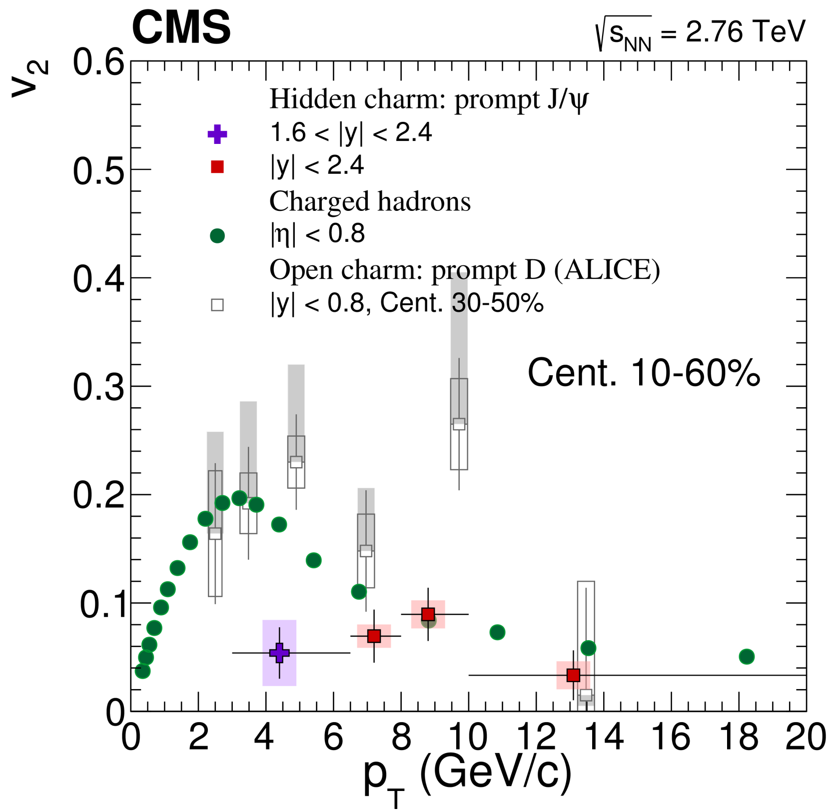


v_2 Comparison in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV



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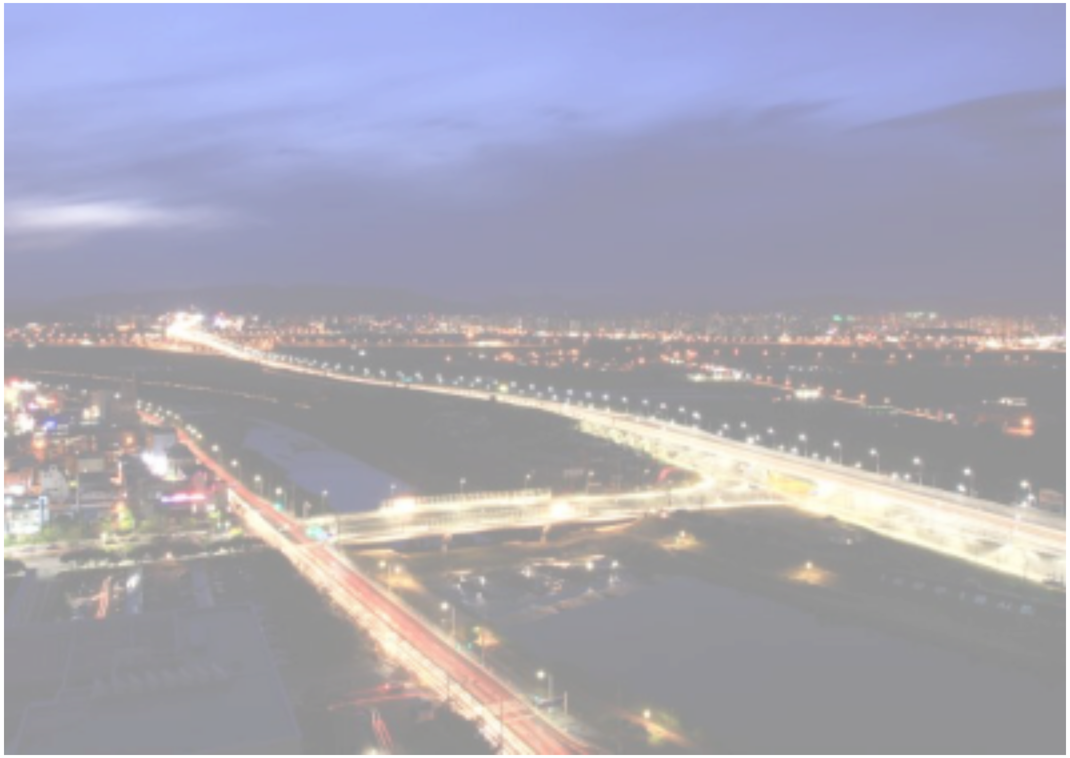
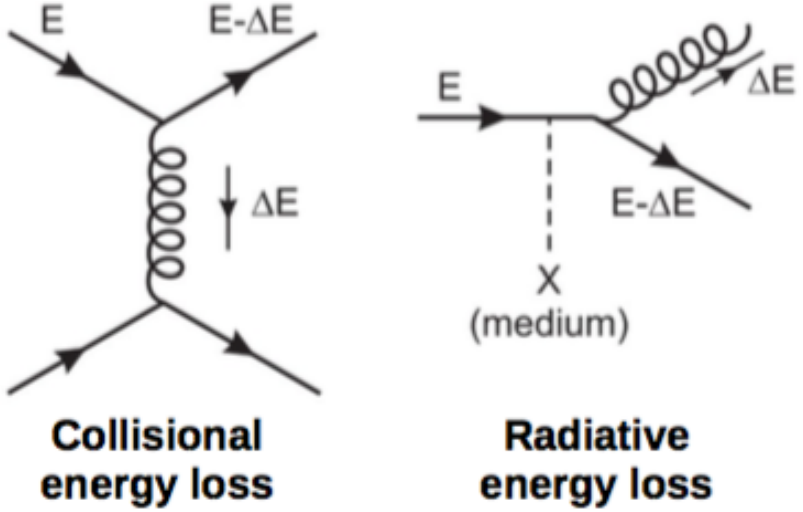
- Smaller v_2 then D and charged hadron in lower p_T
- Similar v_2 in higher p_T



Nonprompt J/ψ in pp and PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

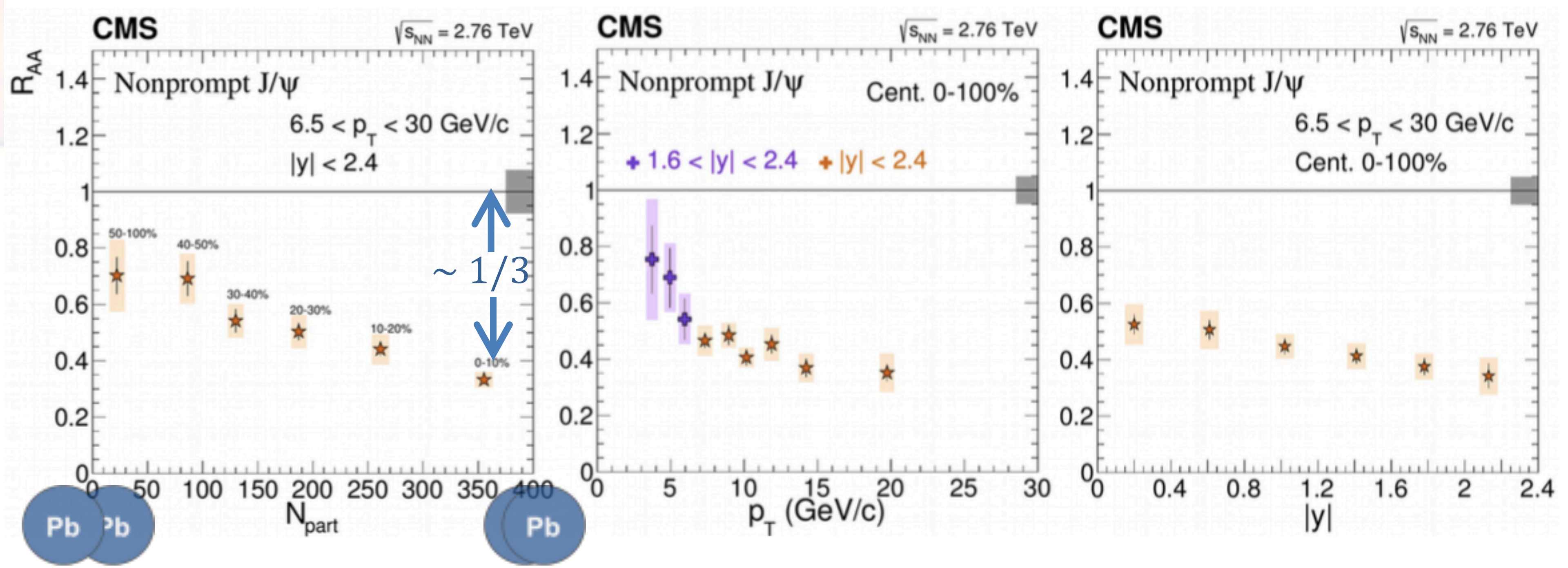
Nonprompt J/ψ in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV

- Energy loss mechanism of partons in the QGP
  - Collisional energy loss : depending on the medium thickness and initial parton energy
  - Radiative energy loss : dominant for fast partons going through the medium



- Open beauty (B meson) is a key to understand dynamics of parton interaction with the QGP.

R_{AA} of Nonprompt J/ψ in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV

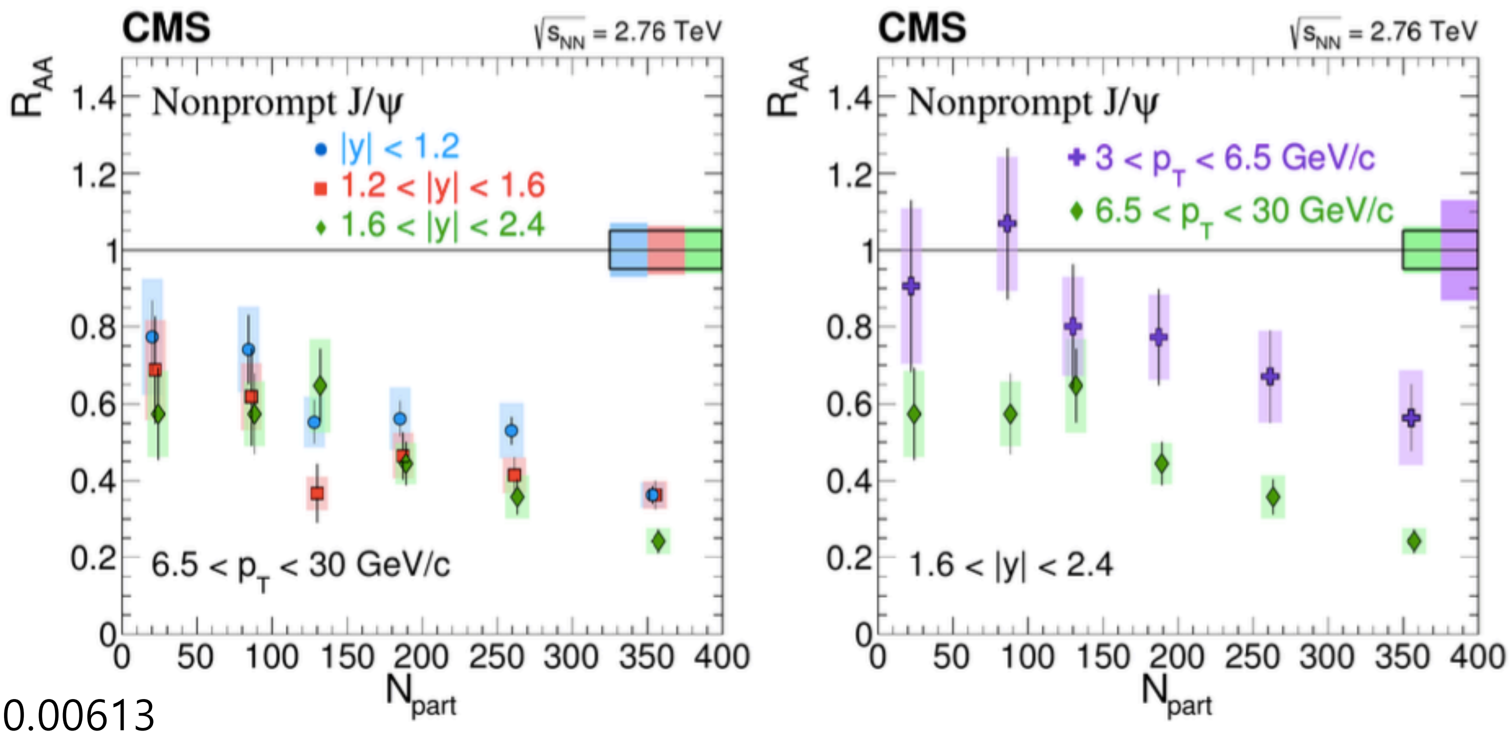


arXiv.1610.00613

- 0-10 %
  - R_{AA} : 0.33 ± 0.02 (stat.) ± 0.03 (syst.)

- Stronger suppression with both increasing p_T and rapidity.

R_{AA} of Nonprompt J/ψ in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV

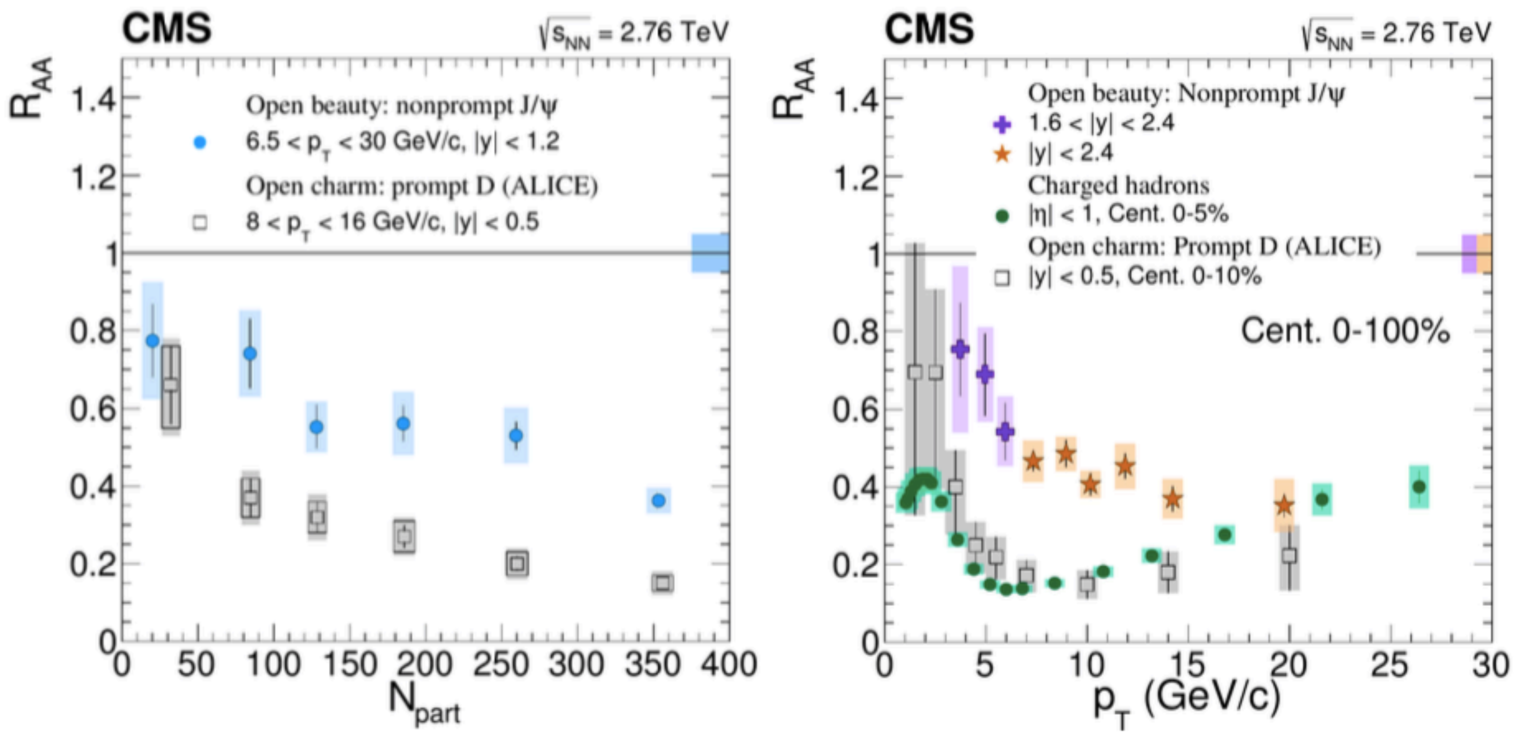


arXiv.1610.00613

- Global uncertainties are separated into
  - Blank box : luminosity, event selection, tracking efficiency
  - Colored box : systematic uncertainty from pp

- No strong dependence on rapidity
- Lower p_T nonprompt J/ψ is less suppressed than one in higher p_T.

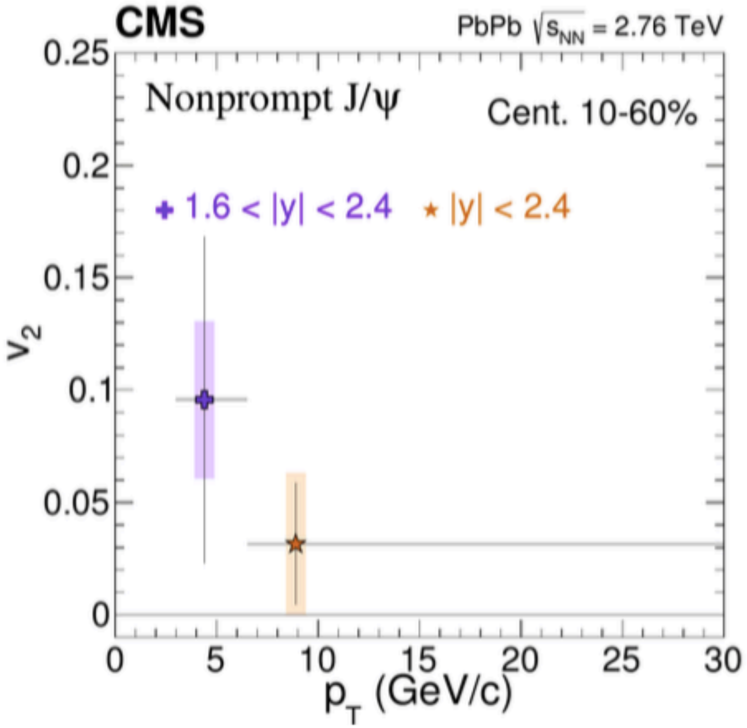
R_{AA} of Nonprompt J/ψ in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV



arXiv.1610.00613

- R_{AA} (nonprompt J/ψ) > R_{AA} (D) ≈ R_{AA} (light partons)
  - Hint of smaller energy loss for b quark at p_T < 20 GeV/c in PbPb

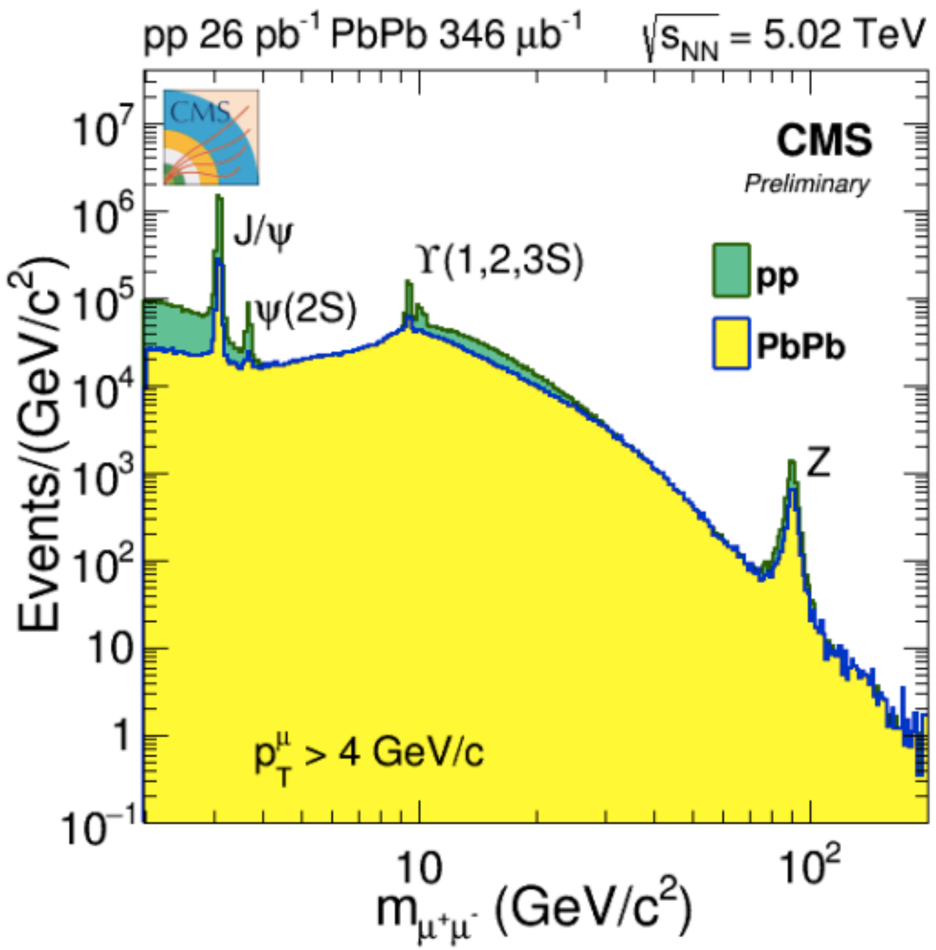
Nonprompt J/ψ v_2 in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV

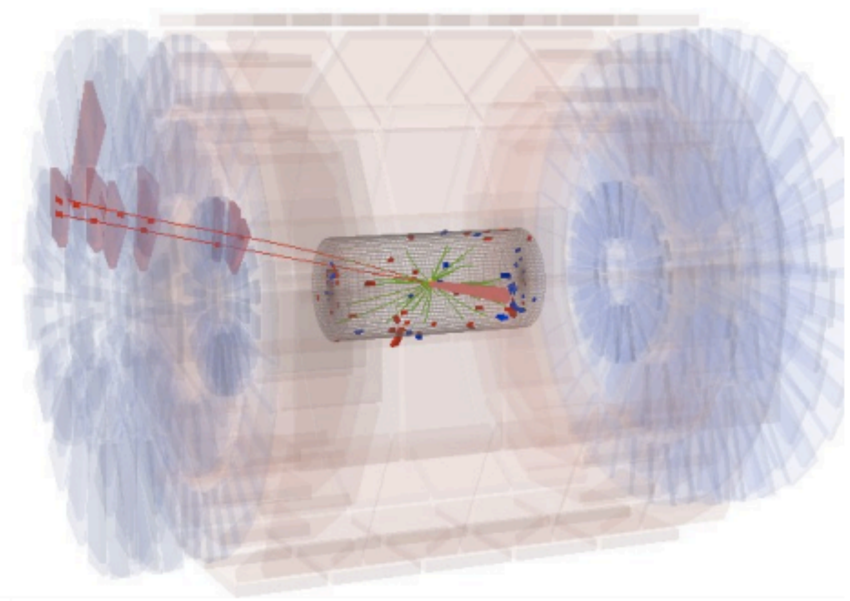


arXiv.1610.00613

- Nonprompt J/ψ v_2 has been measured for the first time.
- Slightly decreasing trend but statistical error quite large (need more data)
- Close to zero in high p_T region.

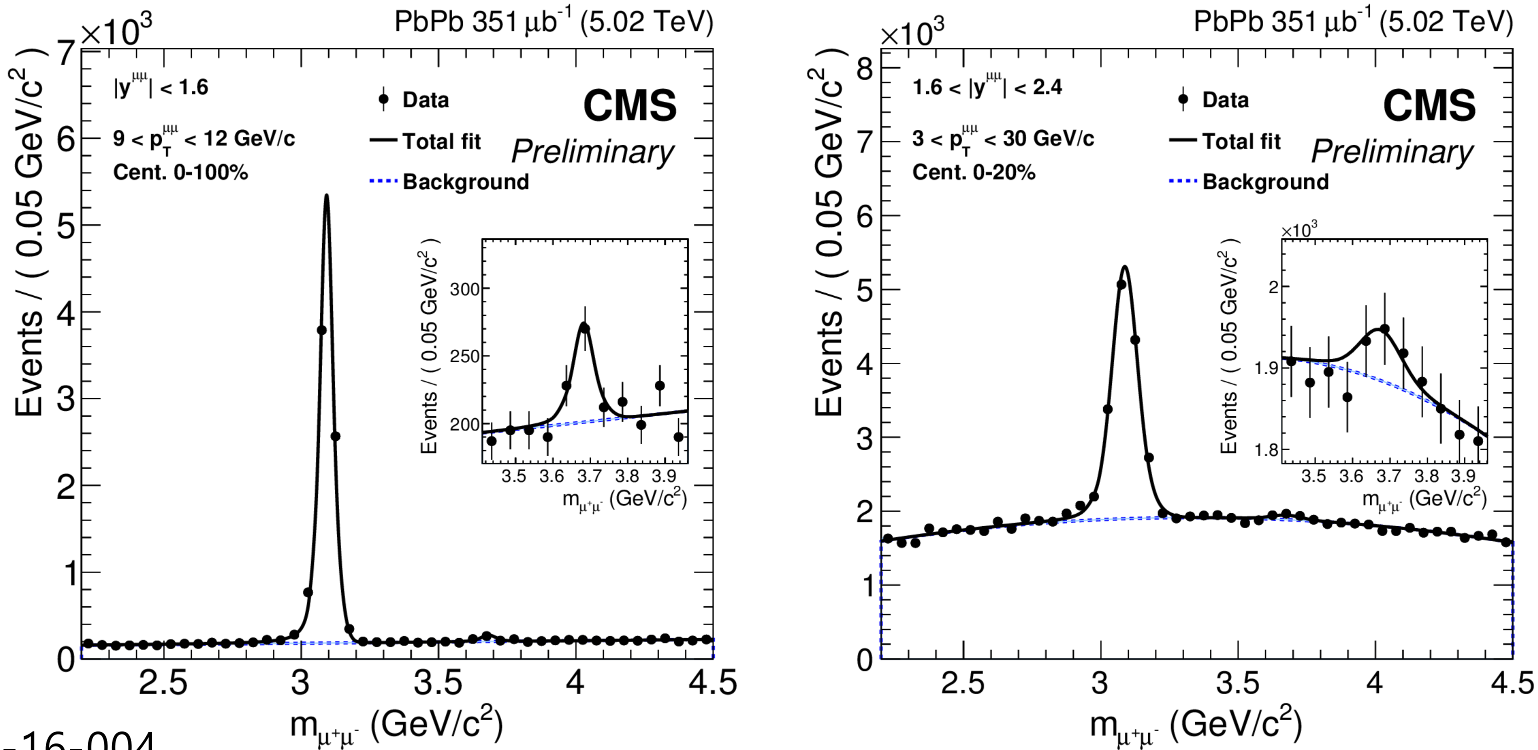
Run II (5.02 TeV) Results





ψ(2S) in pp and PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

ψ(2S) in pp and PbPb at $\sqrt{s_{NN}}$ = 5.02 TeV



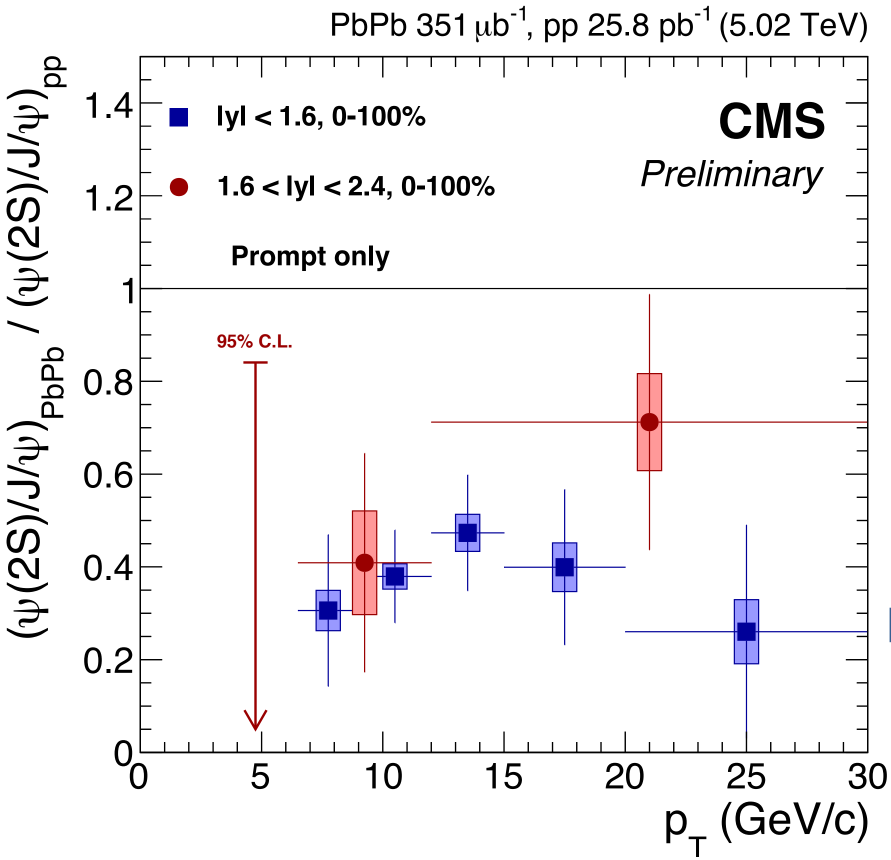
CMS-HIN-16-004

- Separate b quark contributions using life time information
  - Not easy due to low S/B ratio
- Applied life time cut based on MC study
  - Keep ~90 % of prompt
  - Remove ~80 % of nonprompt

Double ratio of ψ(2S) at $\sqrt{s_{NN}} = 5.02$ TeV

$$\frac{\left[\frac{\psi(2S)}{J/\psi}\right]_{PbPb}}{\left[\frac{\psi(2S)}{J/\psi}\right]_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$$

DR < 1
more suppressed than J/ψ
DR = 1
same suppression
DR > 1
less suppressed than J/ψ



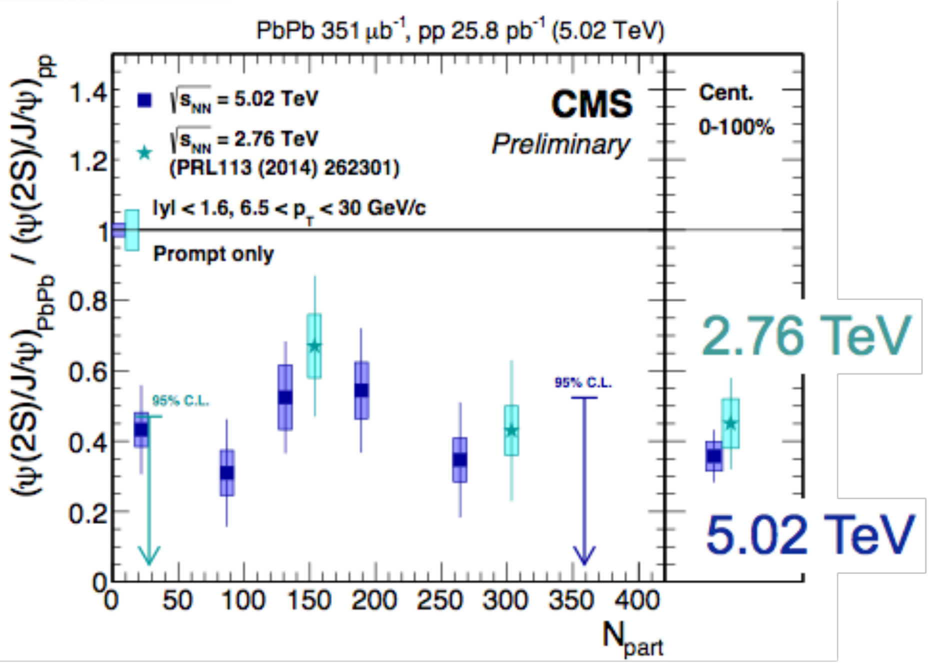
Forward

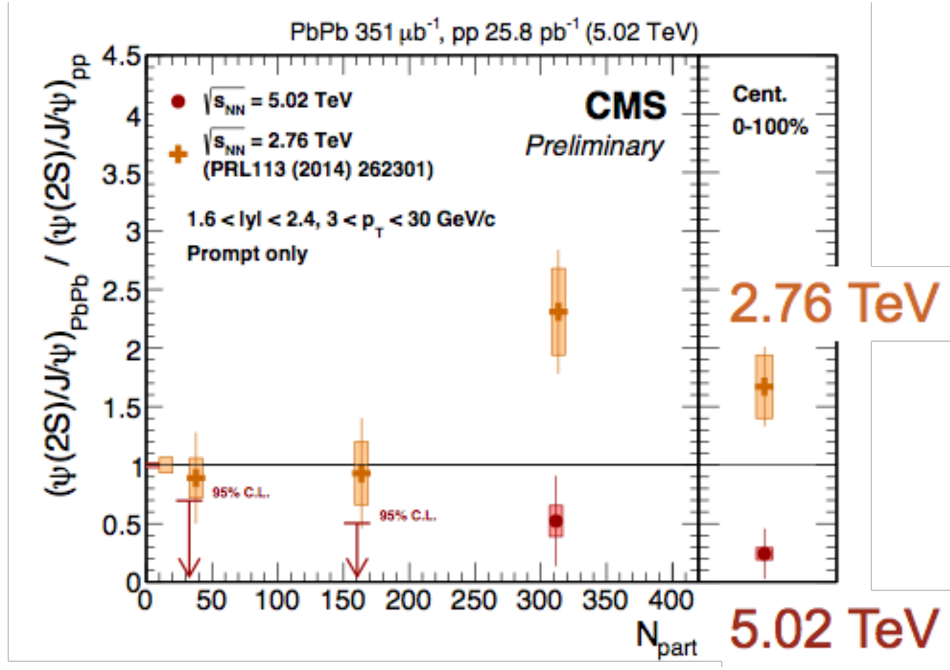
Mid-rapidity

CMS-HIN-16-004

- ψ(2S) is suppressed than J/ψ in all p_T-y bins.
- No significant p_T dependence.

Double ratio of ψ(2S) at $\sqrt{s_{NN}}$ = 5.02 TeV

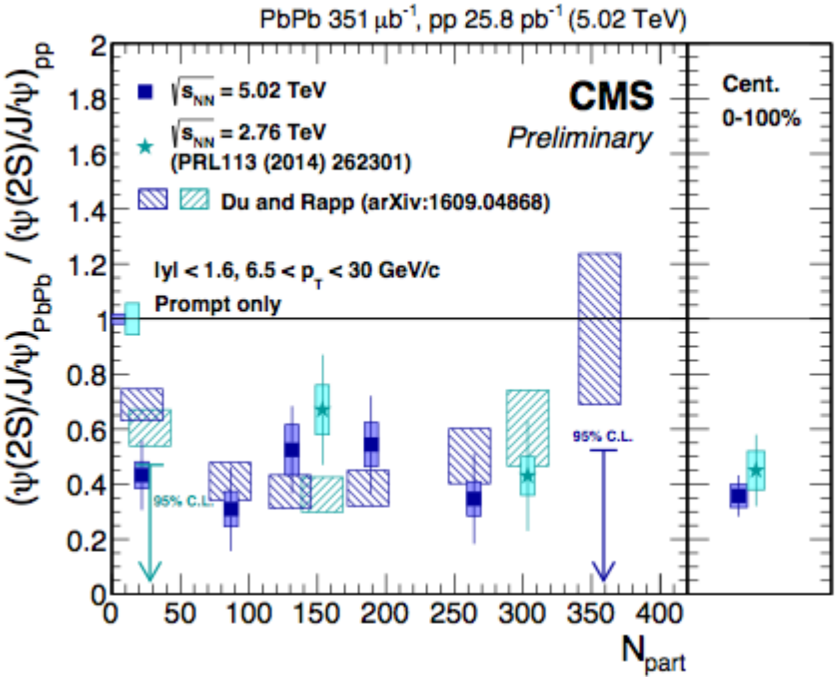


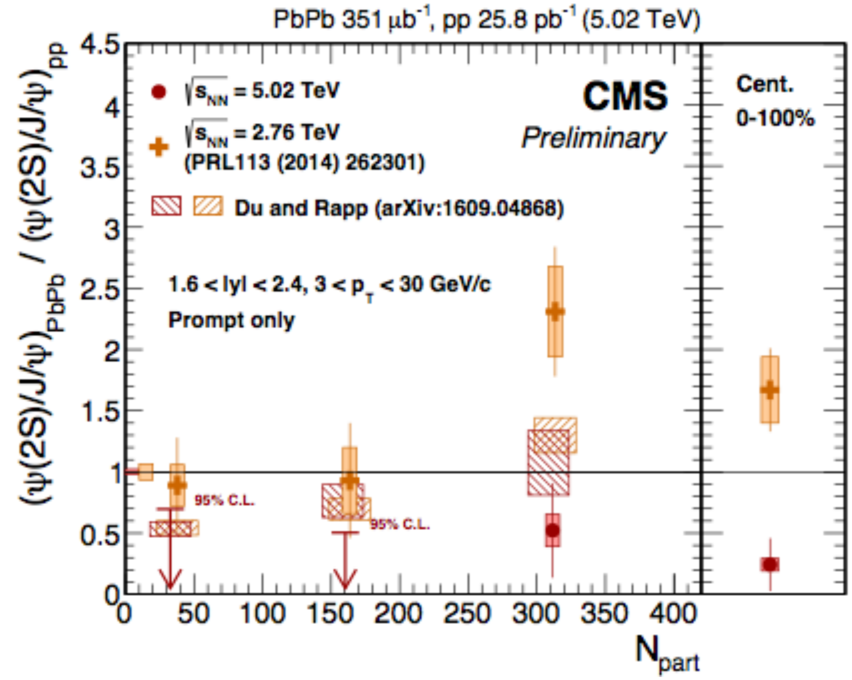


- No strong dependence on centrality
- Almost of bins are good agreed within error bars.
- 2.76 and 5.02 TeV psi(2S) are different in 0-20 % centrality with ~3**σ**
  - Fluctuations ? Collision energy dependence ? …

CMS-HIN-16-004

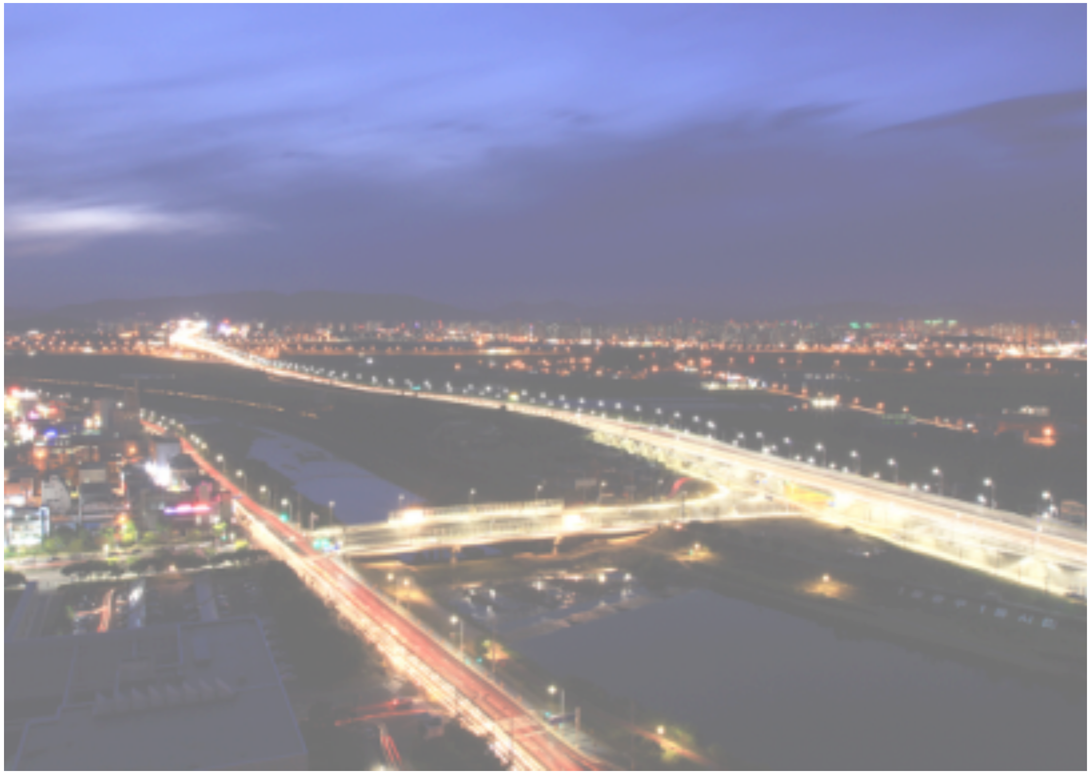
Double ratio of ψ(2S) at $\sqrt{s_{NN}}$ = 5.02 TeV





CMS-HIN-16-004

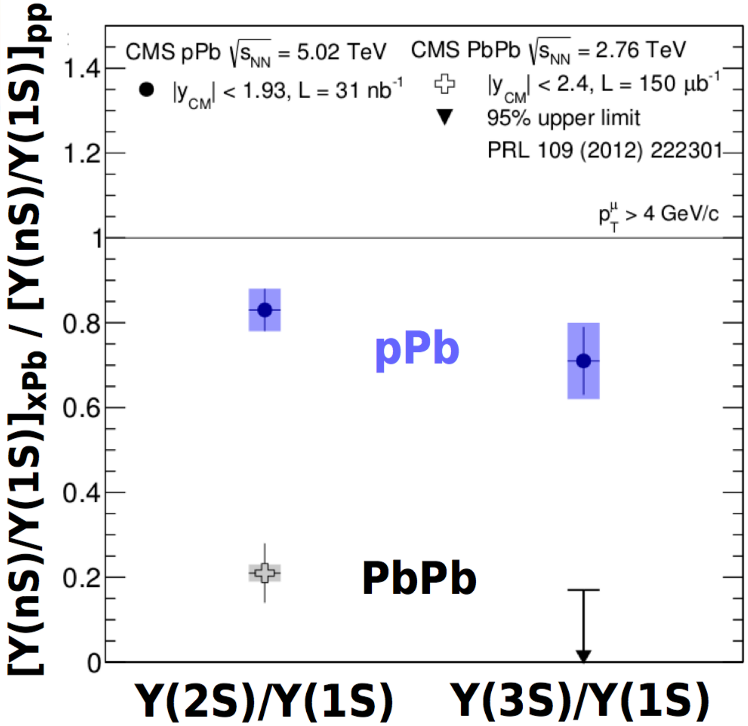
- Compatible with theory in mid-rapdity and forward high p_T region.
- Theory can still not cover the 2.76 TeV most central events in forward and lower p_T region.

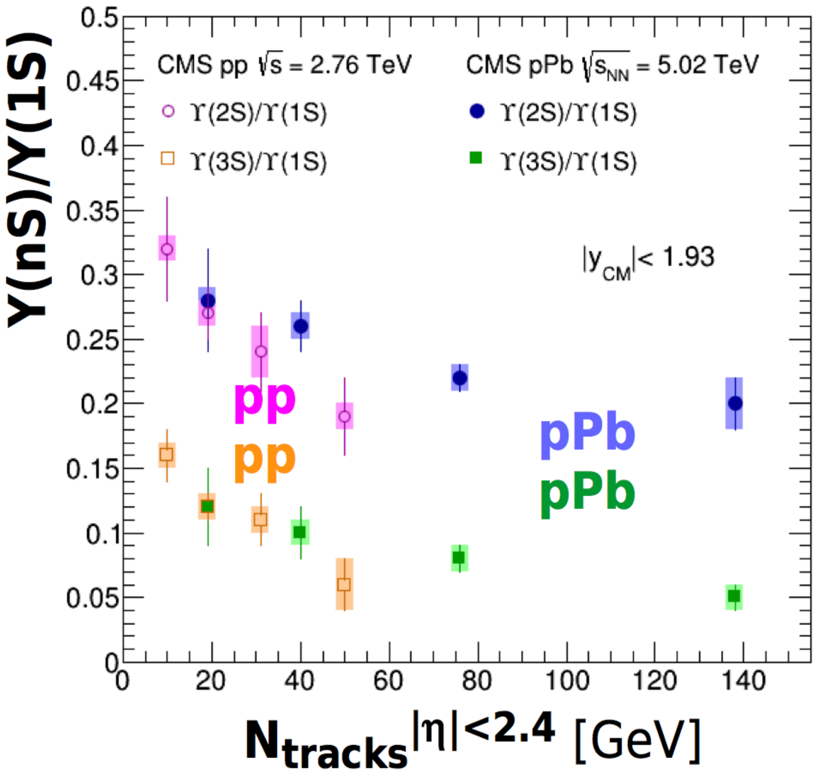


Υ in pp and PbPb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV

Υ in pp and pPb

$$\frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$



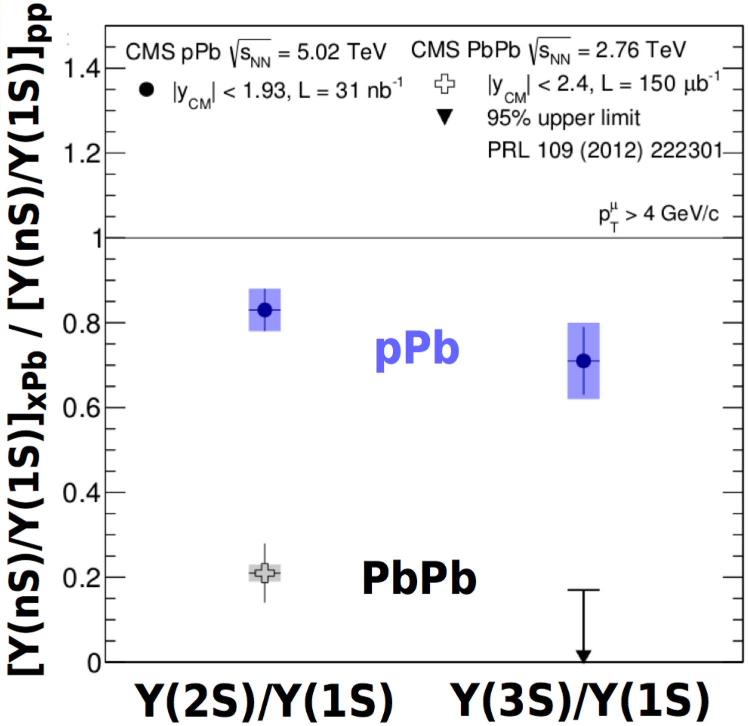


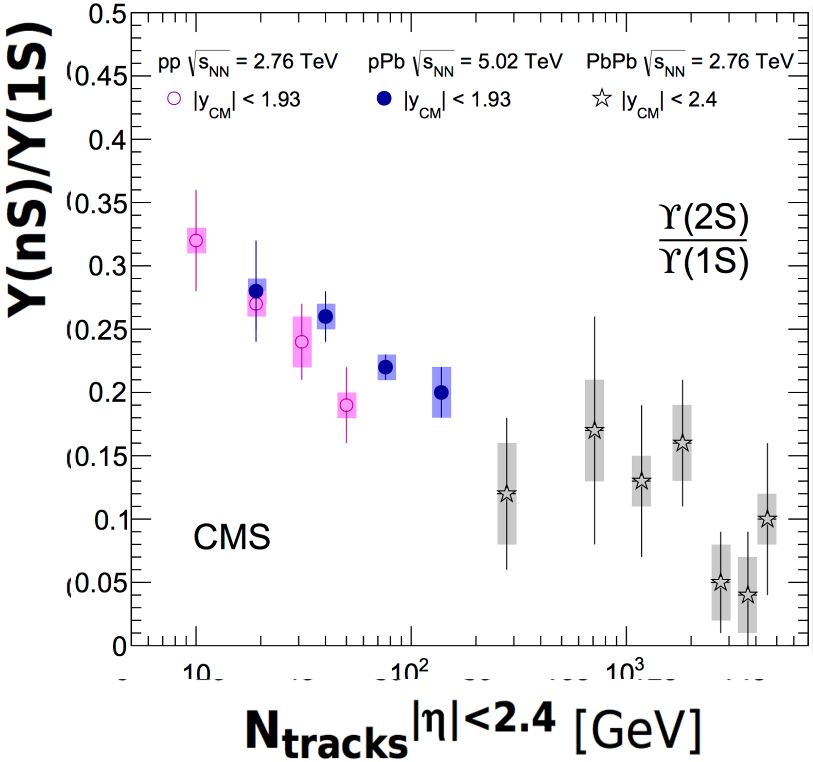
PRL 109 (2012) 222301

- Indication of initial suppression in pPb
- Y(nS)/Y(1S) has clear dependence on N_{trks} for pp & pPb

Υ in pp, pPb and PbPb

$$\frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$





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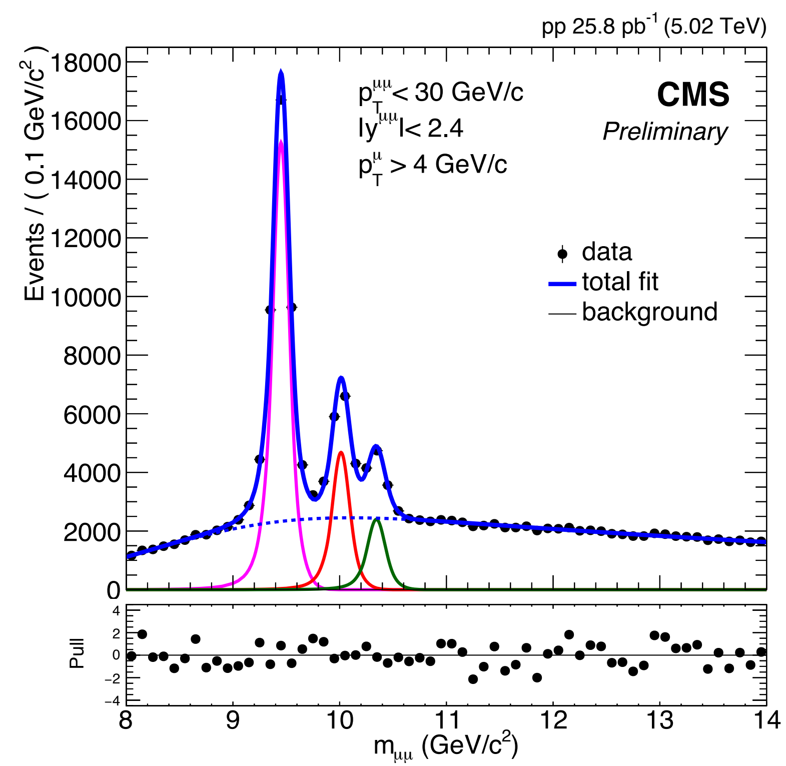
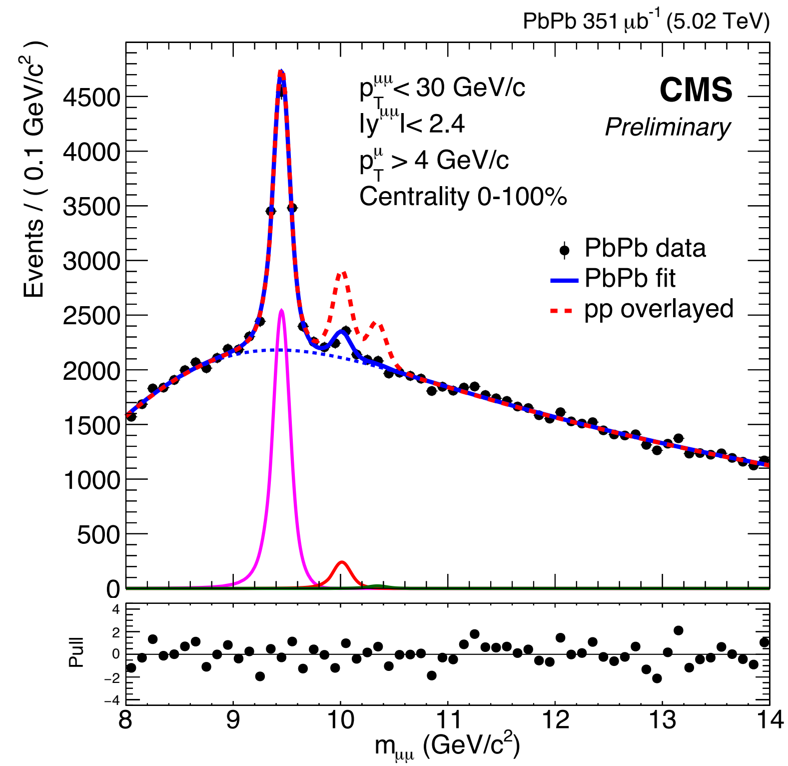
Υ in pp and PbPb at $\sqrt{s_{NN}}$ = 5.02 TeV

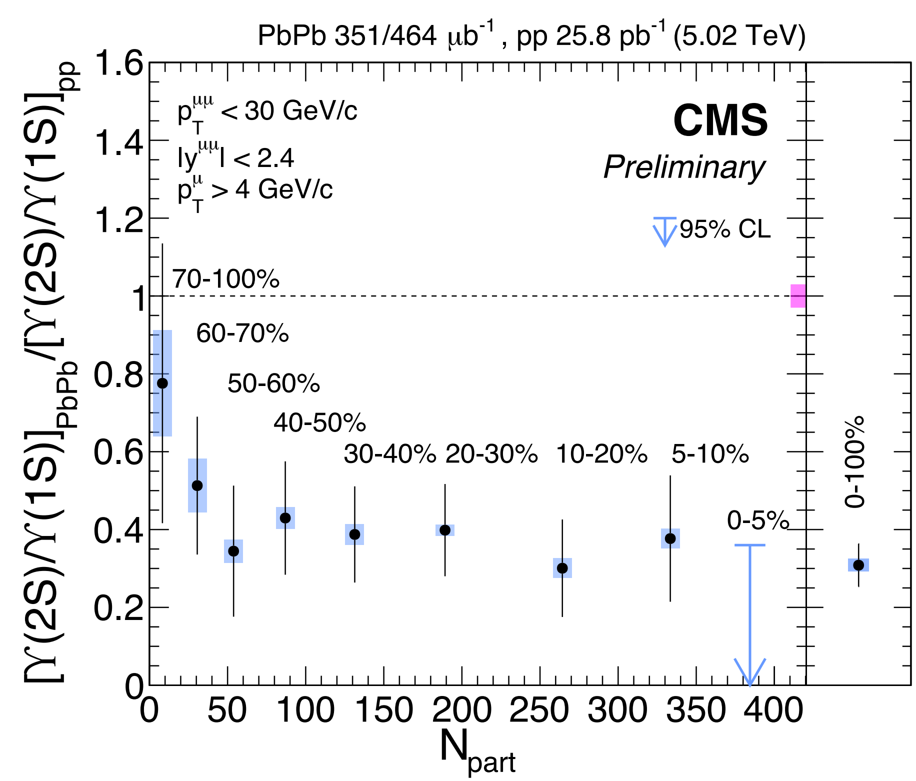




CMS-HIN-16-008

- Clean signals for 3 states of Υ
- Hard to find Υ(3S) in PbPb

Double ratio of Υ(nS) at $\sqrt{s_{NN}} = 5.02$ TeV



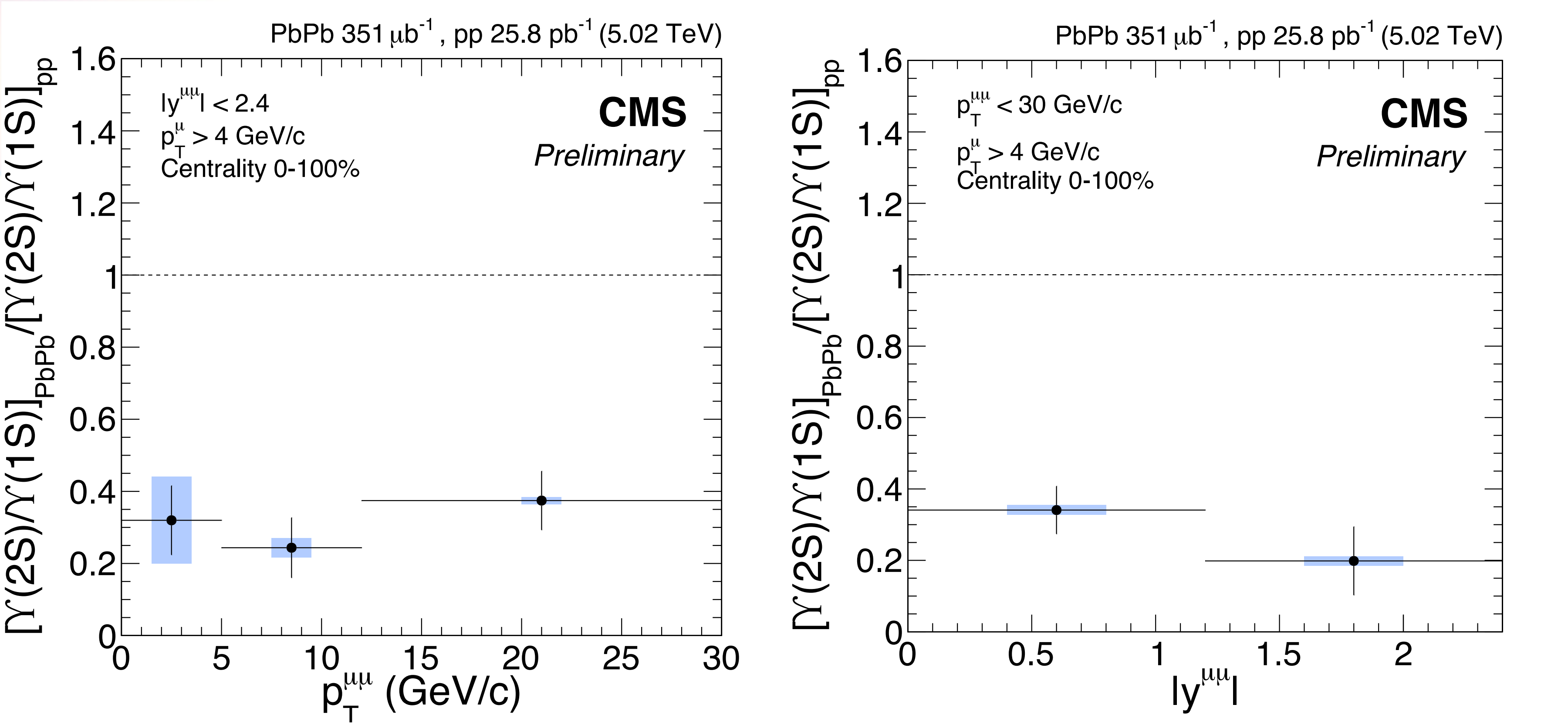
$$DR = \frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$

DR < 1
more suppressed than Y(1S)
DR = 1
same suppression
DR > 1
less suppressed than Y(1S)

CMS-HIN-16-008

- Supporting sequential melting scenario : excited Ys are more suppressed than ground state of Y.
- Peripheral events close to 1 : similar size of excited suppression to pp

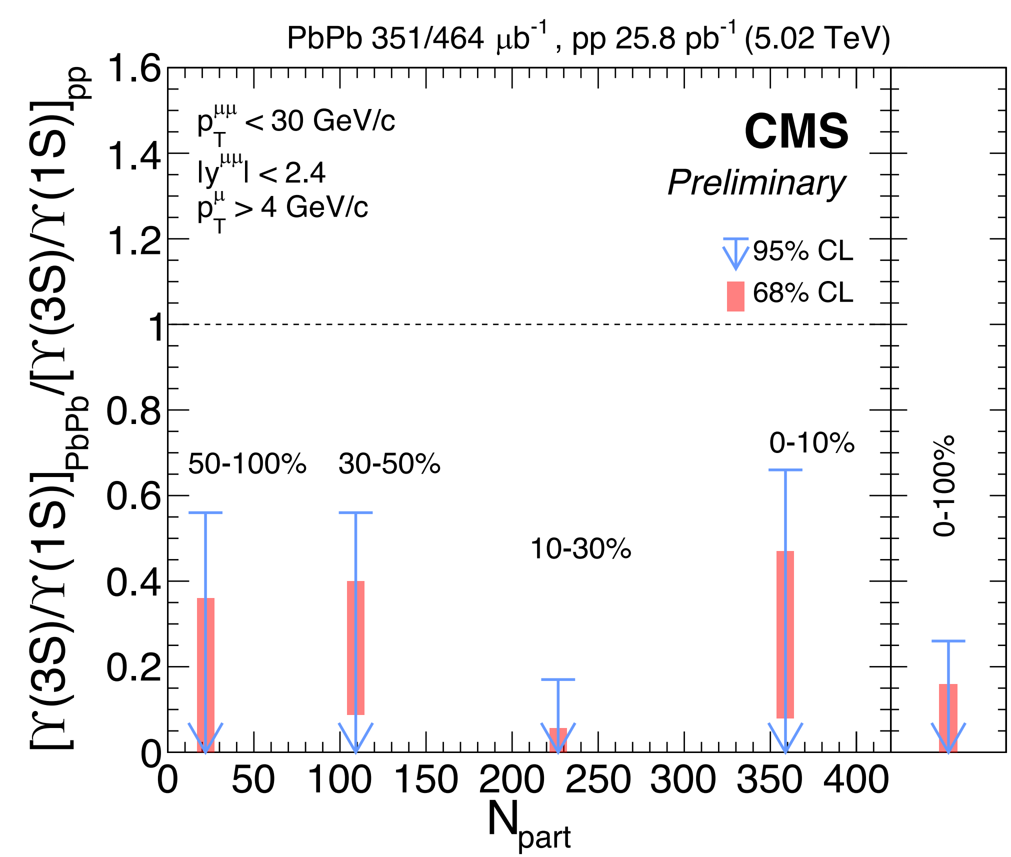
Double ratio of Υ(nS) at $\sqrt{s_{NN}}$ = 5.02 TeV

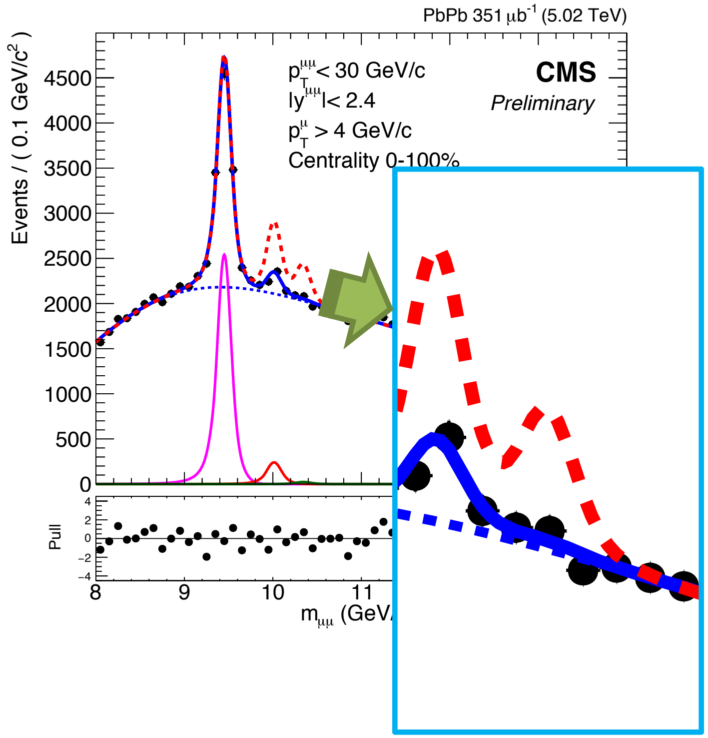


CMS-HIN-16-008

- No significant dependence on p_T & rapidity

Double ratio of $\Upsilon(3S)$ at $\sqrt{s_{NN}} = 5.02$ TeV





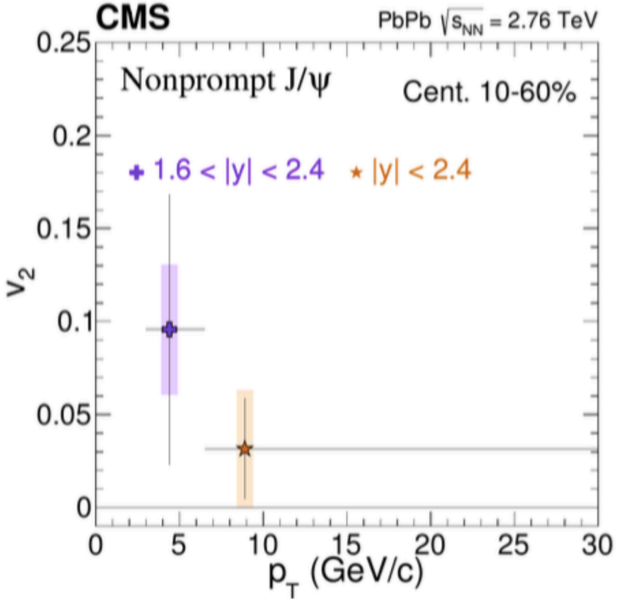
Almost melt in 5.02 TeV ?

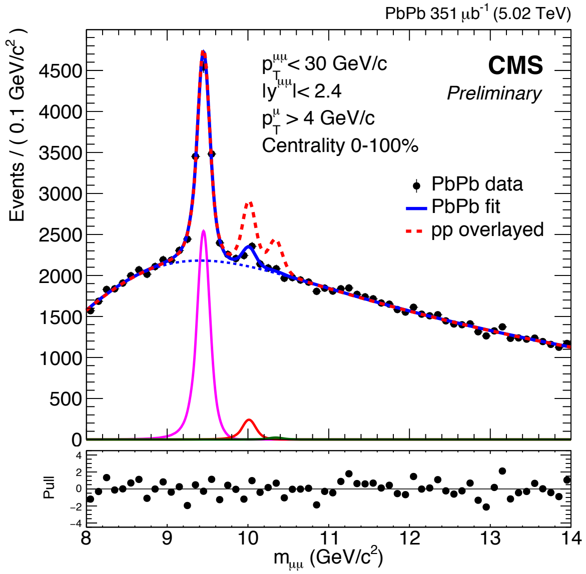
CMS-HIN-16-008

- Set upper limit on $\Upsilon(3S)$.
- Weaker bound state is more suppressed than stronger bound state.

Summary

- Nonprompt J/ψ v_2 has been measured for the first time.
- Excited charmonia and bottomonia double ratio results follow sequential melting scenario in 5.02 TeV.
  - ψ(2S) is more suppressed than J/ψ in all of kinematics
  - Υ(3S) is almost melt ?
- More exciting results will come up soon !!!

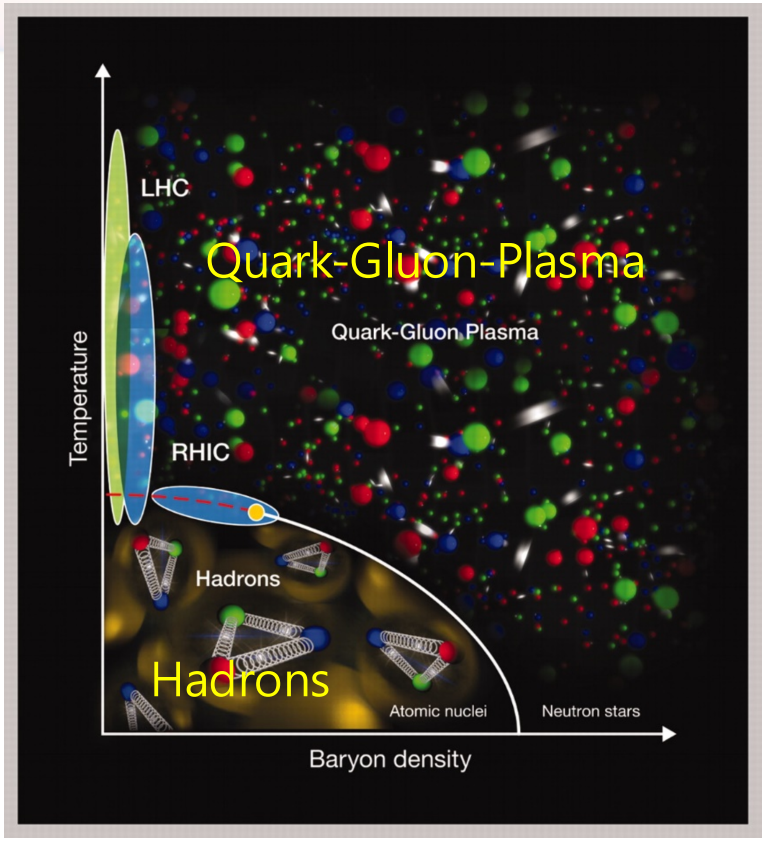




THANK YOU!!!

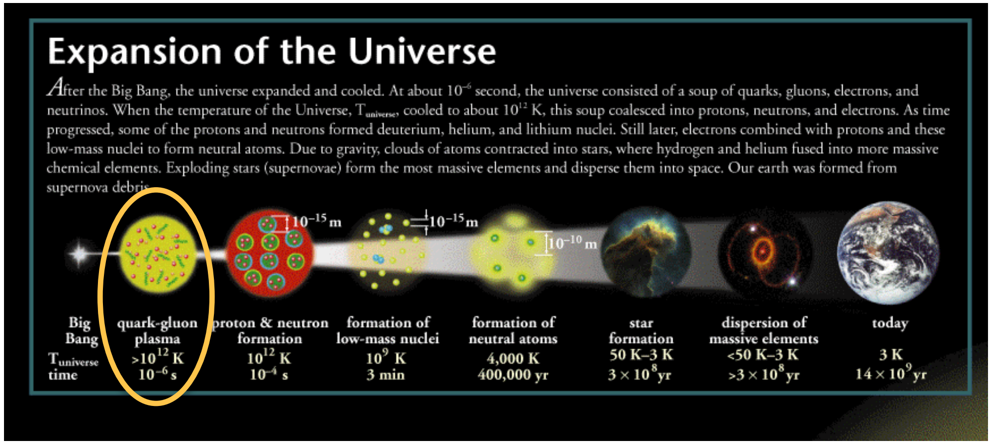
Quark-Gluon-Plasma (QGP)

❖ QCD phase diagram



What is Quark-Gluon-Plasma ?

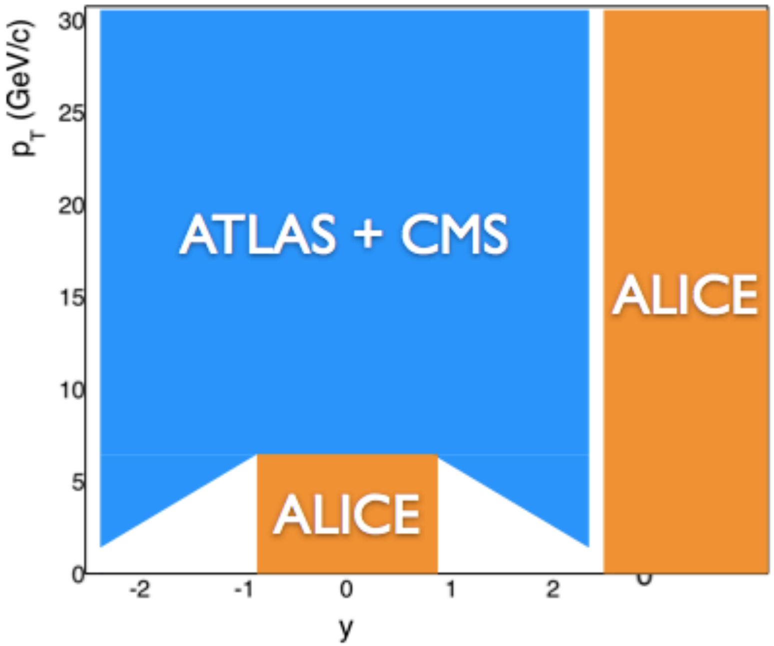
- A phase of Quantum Chromodynamics (QCD)
- Consist of asymptotically free quarks and gluons
- Exist at extremely high temperature and density
- Live in only a few milliseconds after Big Bang

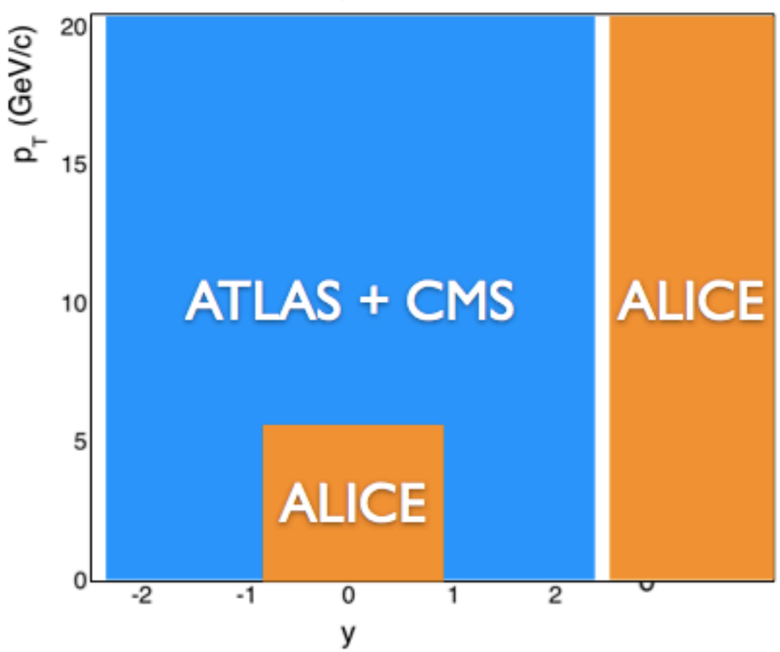


T_c (Critical temperature)
: 150~200 MeV(Lattice QCD)

- Exploring QGP means exploring our early of universe

Quarkonia Acceptance

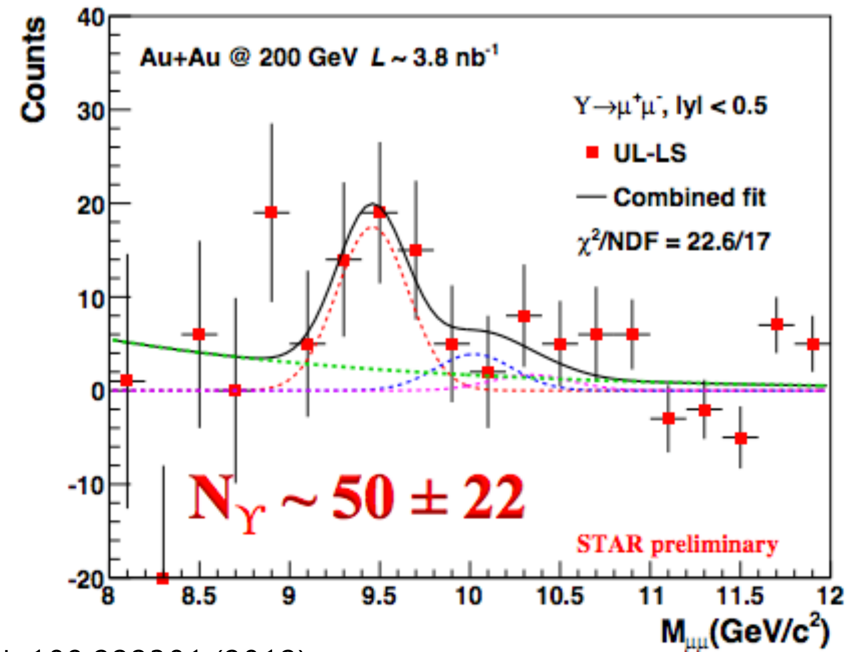




- ALICE: acceptance for $p_T > 0$
  - midrapidity: no absorber and low magnetic field
  - forward rapidity: longitudinal boost
- ATLAS and CMS: Muons need to overcome strong magnetic field and energy loss in the absorber
  - minimum total momentum p~3–5 GeV/c to reach the muon stations
  - Limits J/ψ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

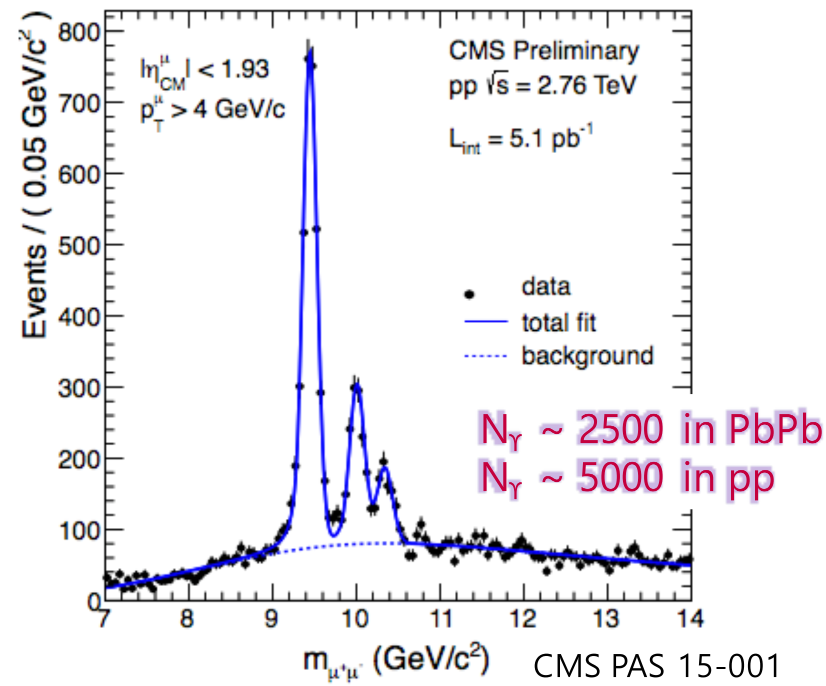
Quarkonia Measurement in pp, pPb and PbPb

RHIC



PRL 109 222301 (2012)

LHC

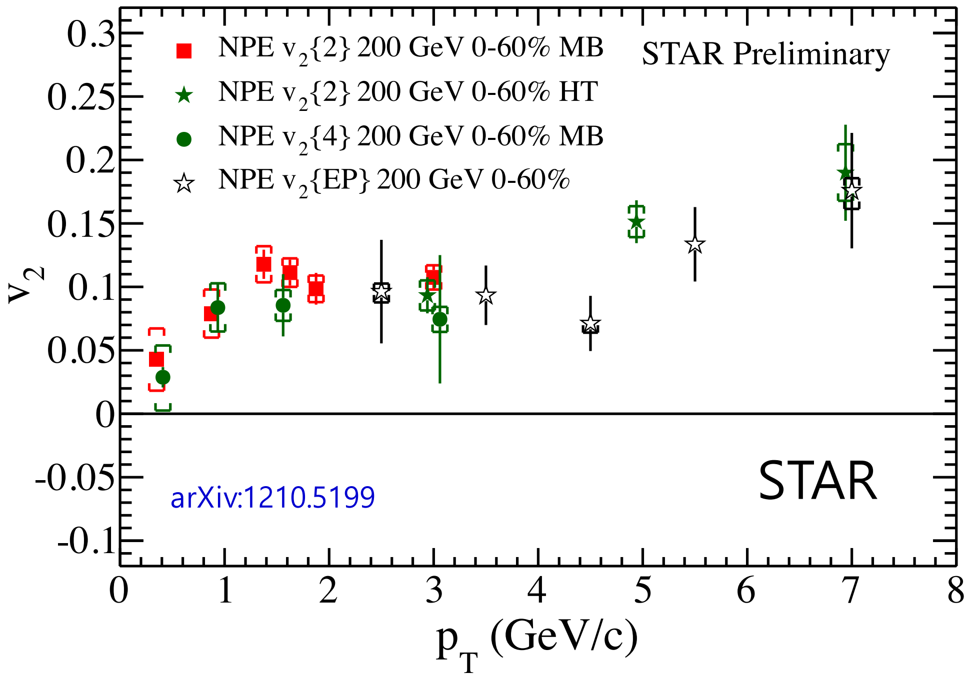


CMS PAS 15-001

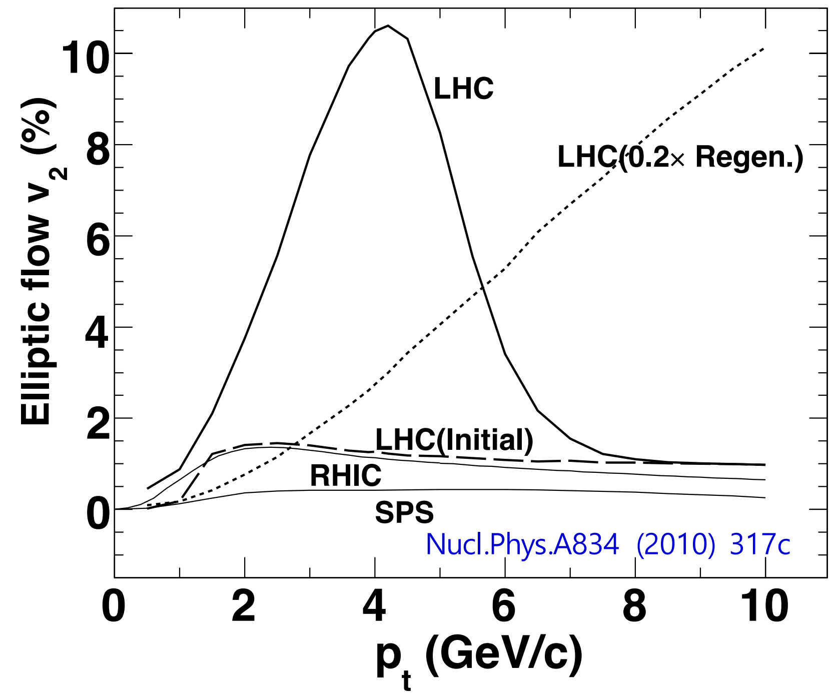
- **Quarkonia** (heavy flavor (charm, bottom) quark-antiquark bound states)
  - Large momentum transfer required to produce by hard gluon-gluon fusion at early stage of collisions : good probe of initial and final state of evolution of extremely hot and dense matter created in high energy heavy-ion collisions
- **Bottomonia** ($b\bar{b}$ bound state : ϒ (1S, 2S, 3S), X_b …) have been actively used as new possible probes since 2010 LHC era.

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

NPE (Non Photonic Electron) v_2



Prediction of elliptic flow of J/ψ



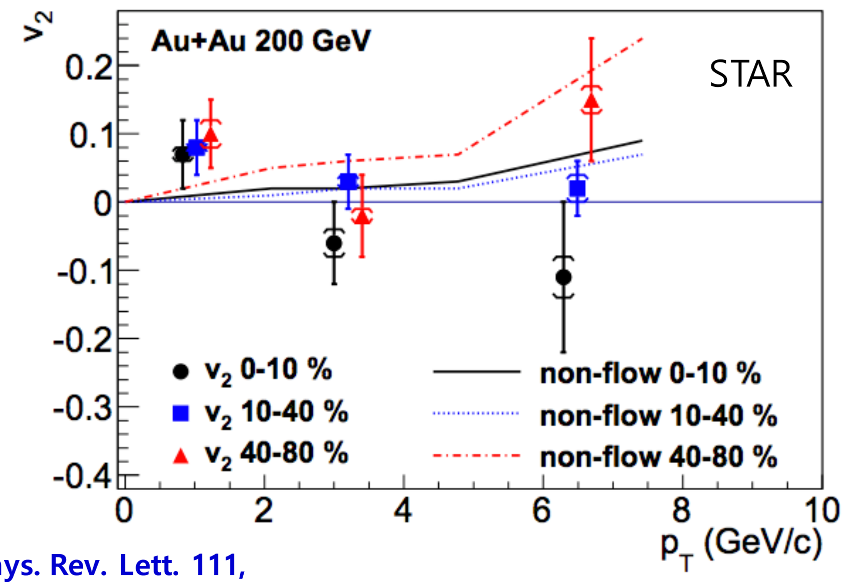
NPE has significant elliptic flow (v_2).
It should be inherited to quarkonia,
which indicates the existence
non-zero v_2 of quarkonia

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

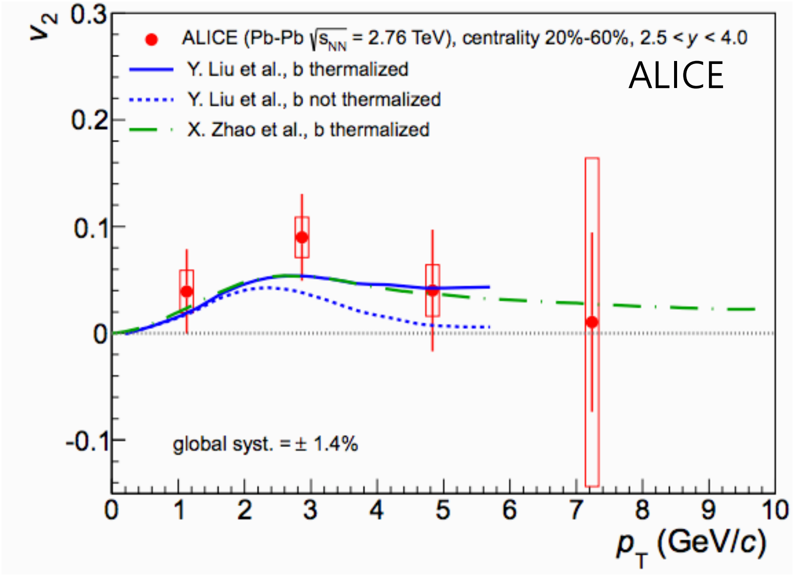
J/ψ Azimuthal Anisotropy at RHIC and LHC

- STAR and ALICE measured inclusive J/ψ v_2

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



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



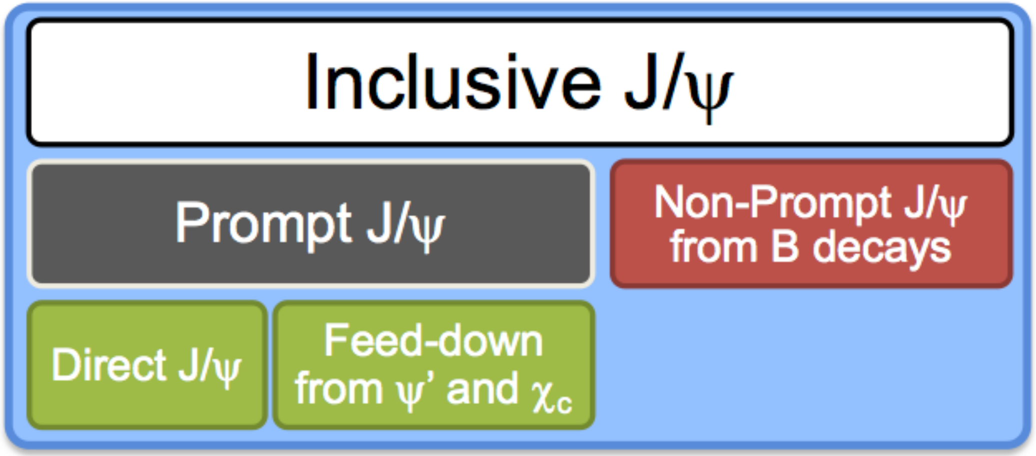
STAR measured compatible zero v_2 from 2 GeV/c in whole p_T region.

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

CMS challenge:

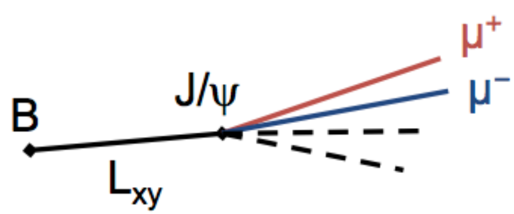
1) Prompt and non-prompt J/ψ separation
2) Extend high p_T region

Prompt & Non-prompt J/ψ Separation

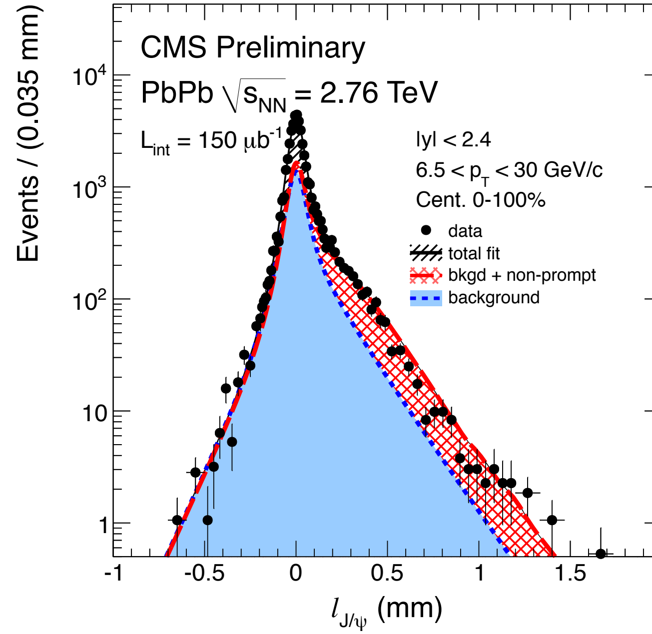


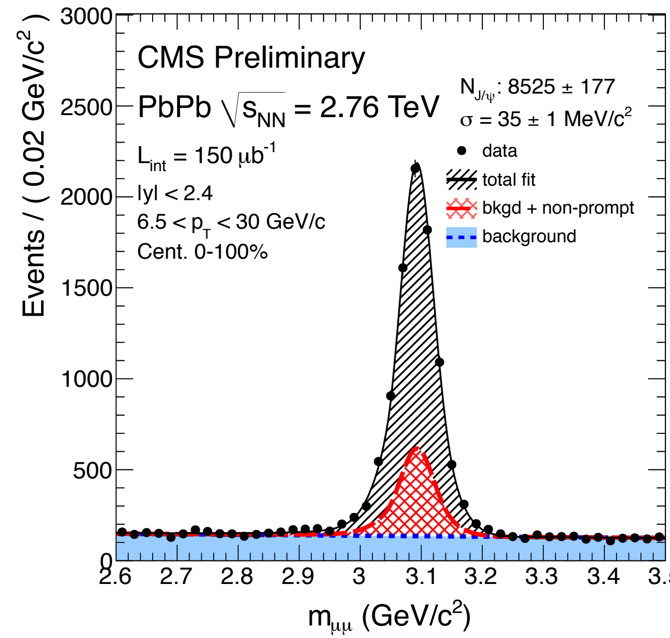
- Reconstruct opposite sign muon vertex
- 2-D unbinned maximum likelihood fit of dimuon mass and pseudo-proper decay length ($l_{J/\psi}$)

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

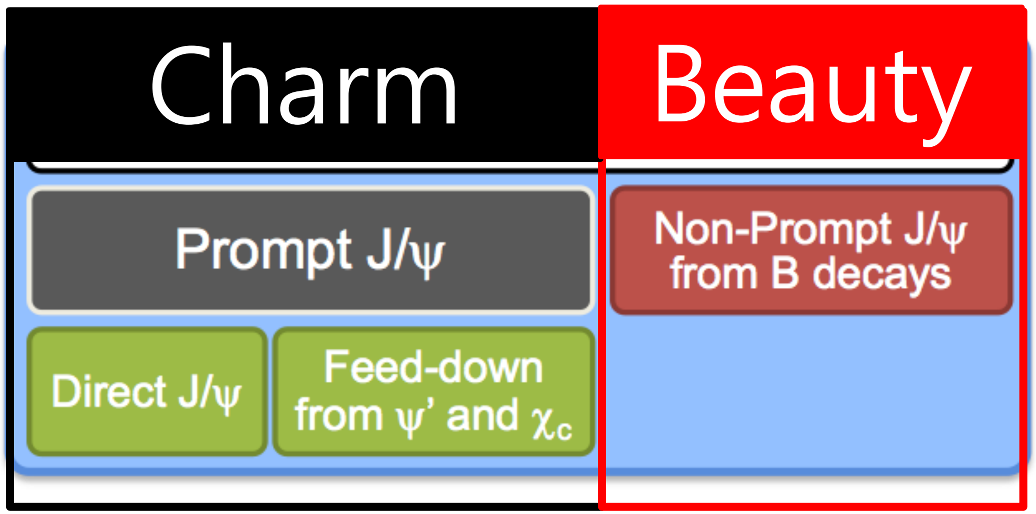


CMS-PAS-HIN-12-014



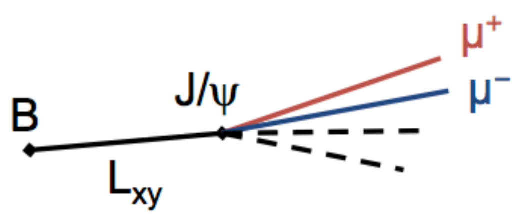


Prompt & Non-prompt J/ψ Separation

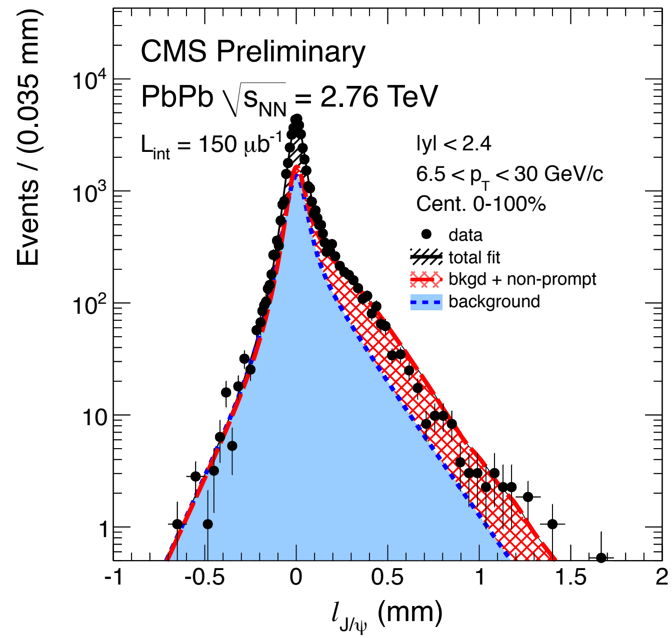


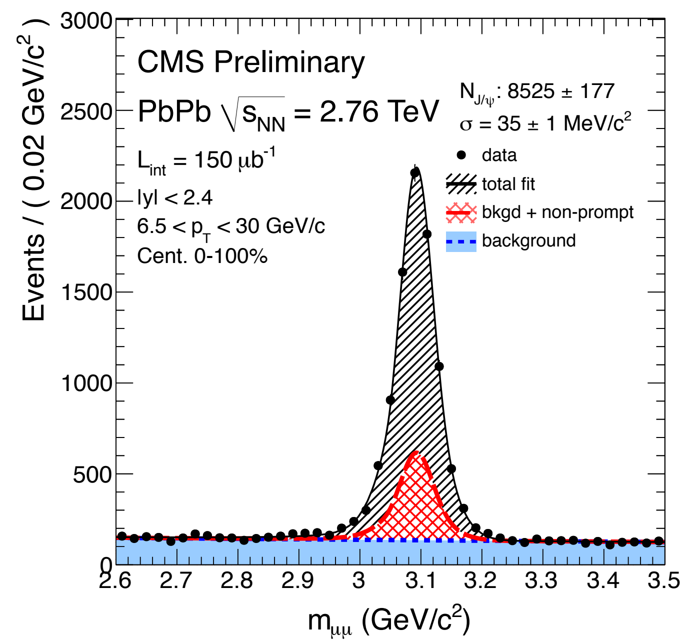
- Reconstruct opposite sign muon vertex
- 2-D unbinned maximum likelihood fit of dimuon mass and pseudo-proper decay length ($l_{J/\psi}$)

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

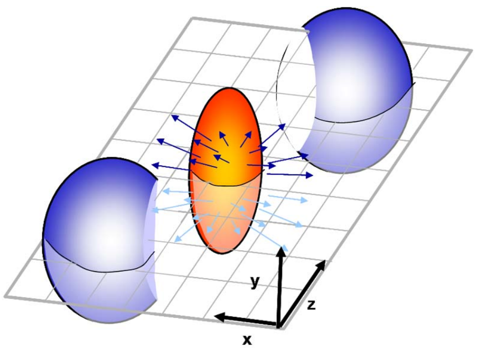


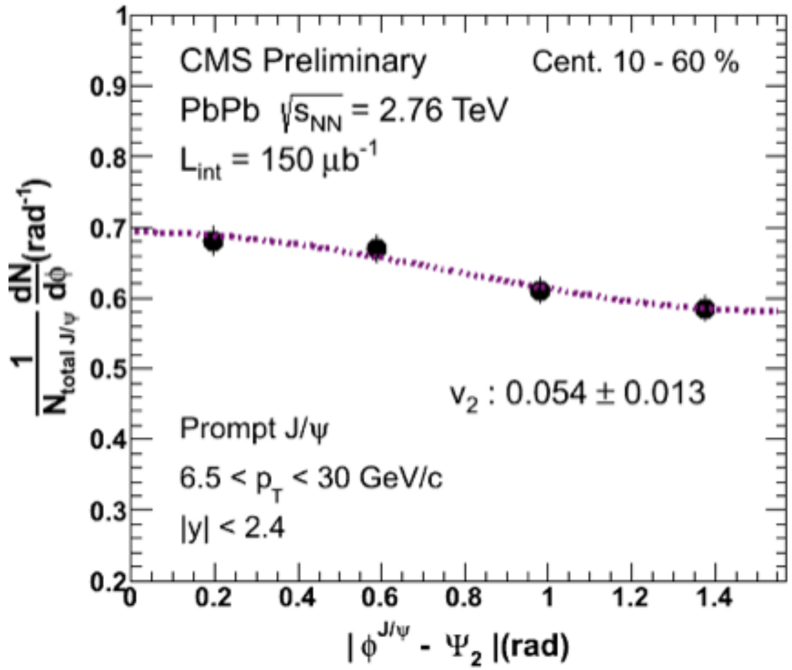
CMS-PAS-HIN-12-014

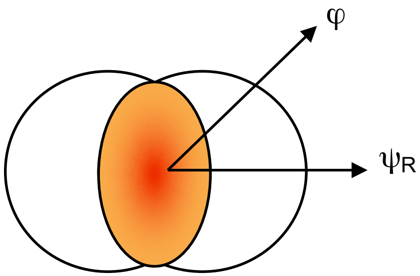




J/ψ Azimuthal Anisotropy in CMS







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

CMS-PAS-HIN-12-001

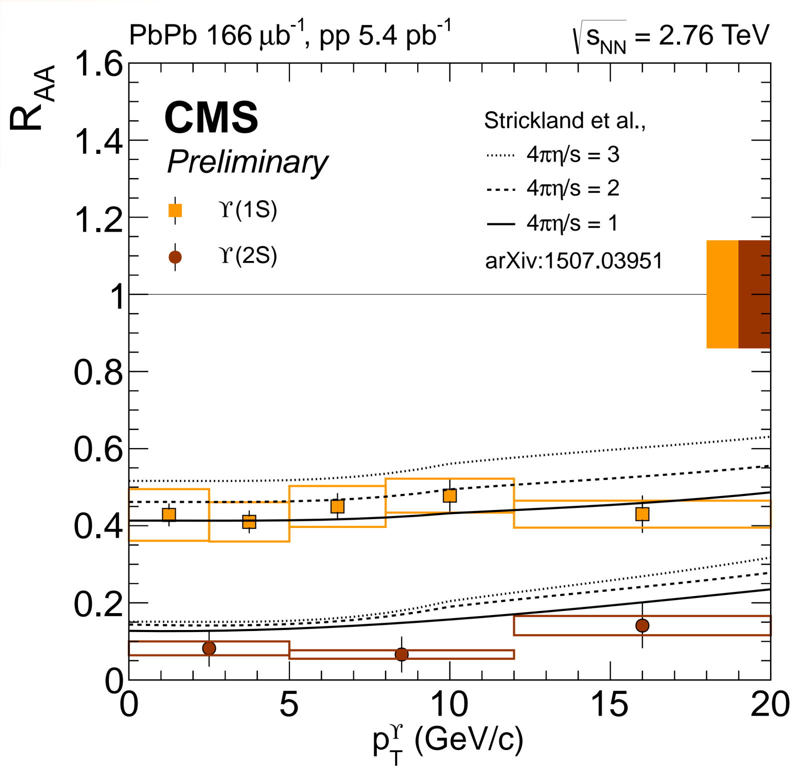
- Event plane method
- Integrated v_2 for Prompt J/ψ (p_T > 6.5 GeV/c)
  - ➠ 0.054 ± 0.013 (stat.) ± 0.006 (syst.) in |y| < 2.4, 10-60 %
  - ➠ significant (3.8σ) v_2 at high-p_T prompt J/ψ

J/ψ Azimuthal Anisotropy in CMS

- Systematic uncertainties

	Systematic uncertainties (%)
Yield extraction	1 - 20
Efficiency corrections	0 - 42
Event plane determination	3.5
Total	12 - 46

R_{AA} p_T dependence

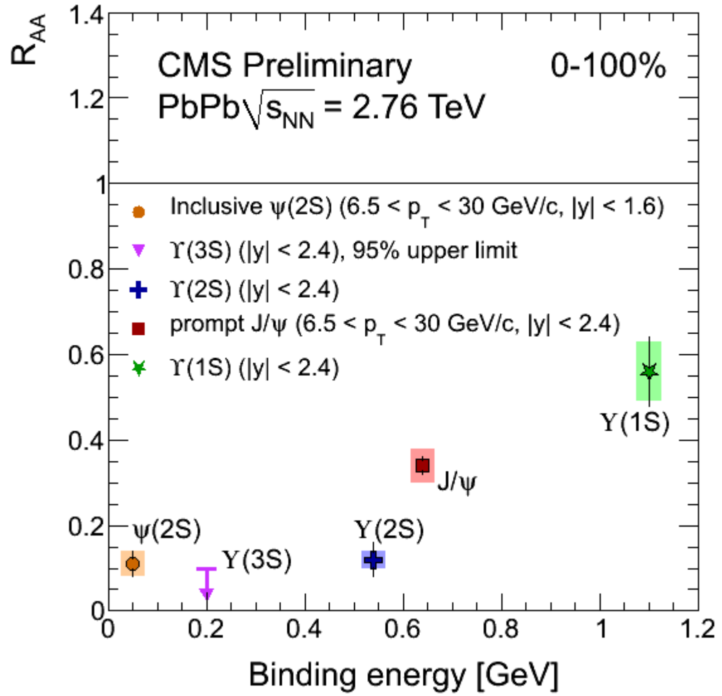


CMS PAS 15-001

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

- No strong dependence for p_T in the measured region.
- ϒ(1S) is described well but some tension with ϒ(2S).

R_{AA} vs binding energy



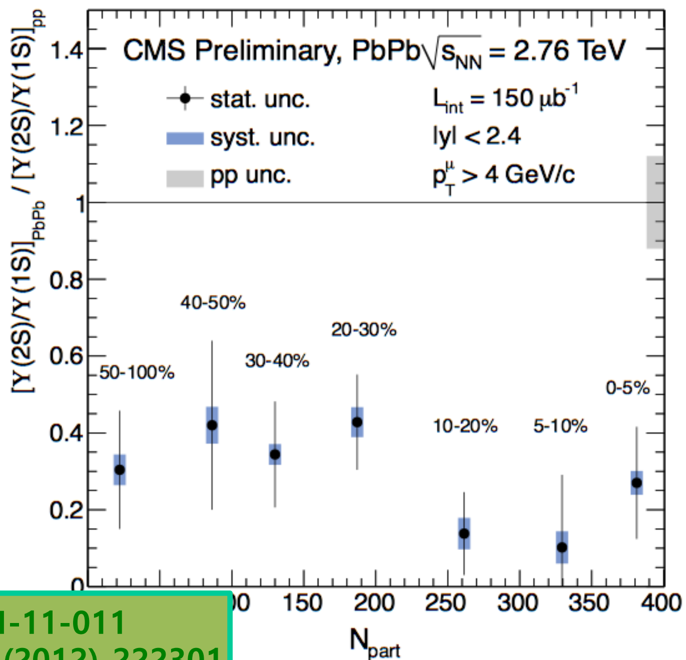
state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
r_0 [fm]	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

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

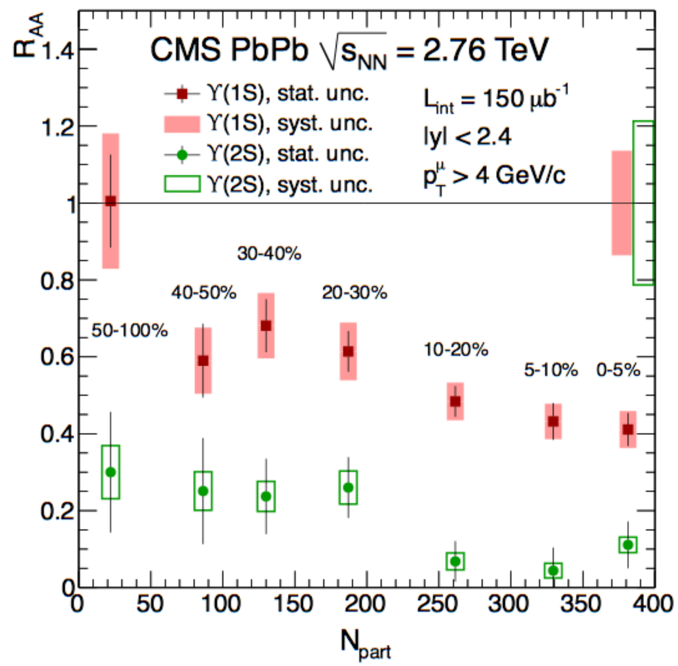
$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{\mathrm{PbPb}}}{\Upsilon(2S)/\Upsilon(1S)|_{pp}} = 0.21 \pm 0.07(\mathrm{stat}) \pm 0.02(\mathrm{syst}),$$

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

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

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

R_{AA}



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

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

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

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

Υ(3S) are more suppressed than Υ(2S).

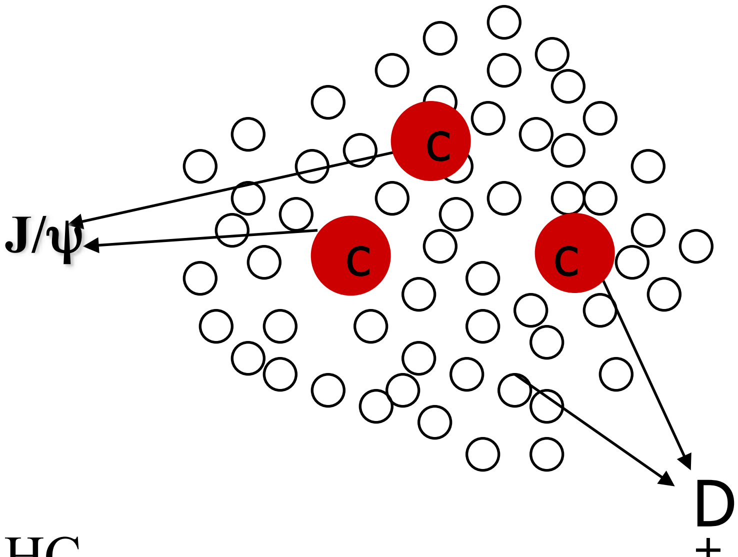
Ordering: R_{AA}(Υ(3S)) < R_{AA}(Υ(2S)) < R_{AA}(Υ(1S))

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

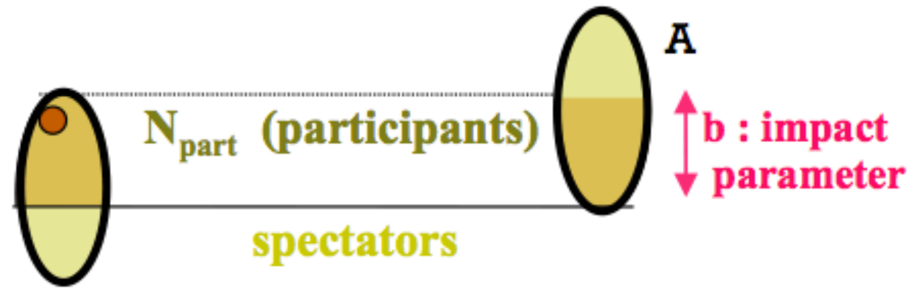
- Suppression and enhancement in the "cold" nuclear medium
  - Nuclear Absorption, Gluon shadowing, initial state energy loss, Cronin effect and gluon saturation (CGC)
  - Study p+A collisions

- 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



+ How do we quantify medium effects ?

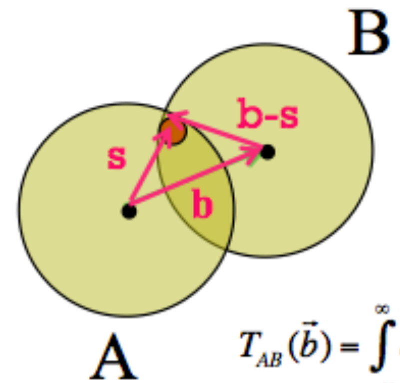
- N_{part} : number of nucleons which undergo at least one collision
- N_{coll} : number of n+n collisions taking place in A+B collision



- 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

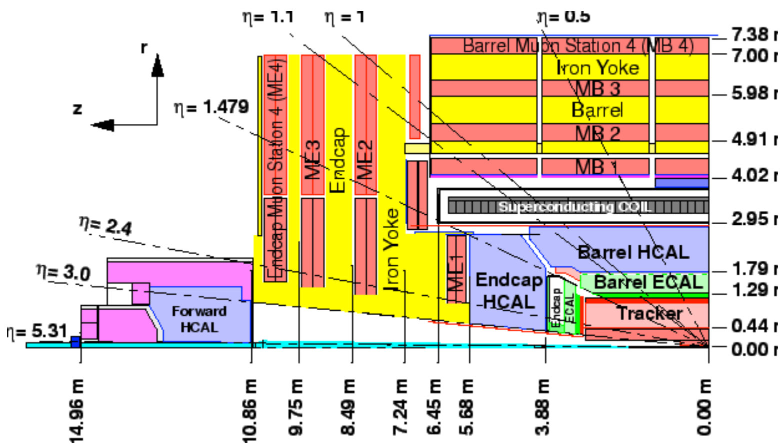
- To compare measured PbPb yields to theoretical pp cross sections, we need T_{AB} : nuclear overlap function
  - In absence of medium effects
    - $R_{AA} = 1$ for perturbative probes
  - T_{AB} is proportional to N_{coll}
    - 30-100% : $T_{AB} = 1.45 \pm 0.18$ mb^{-1}
    - 10-30% : $T_{AB} = 16.6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

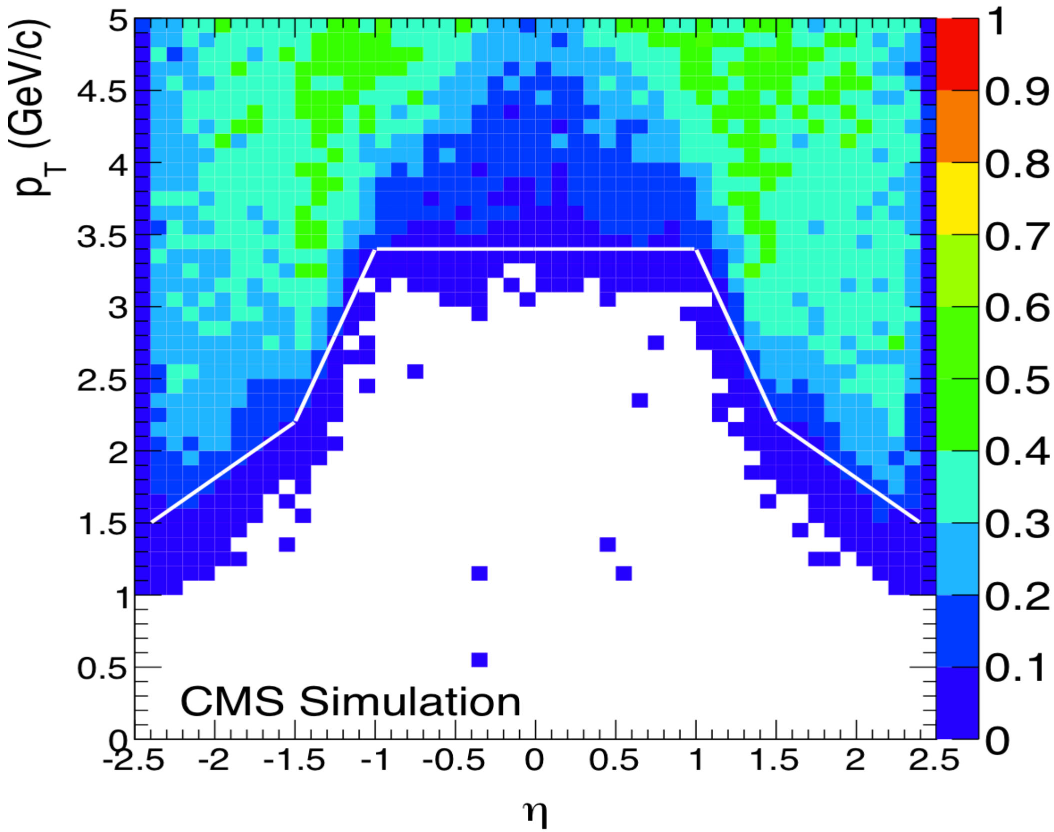


$$T_{AB}(\vec{b}) = \int_{-\infty}^{\infty} d\vec{s}\, T_A(\vec{s}) T_B(\vec{b} - \vec{s})$$

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

Single Muon Acceptance





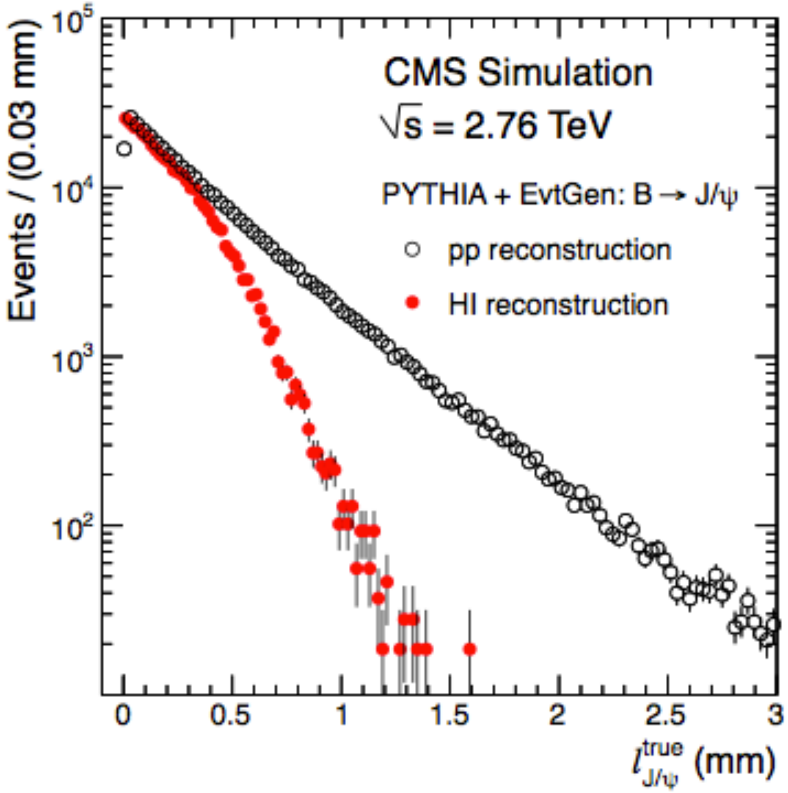
✔ Acceptance definition: Range of p_T and eta of reconstructable muon (RecoMu/GenMu ≥ 10%)

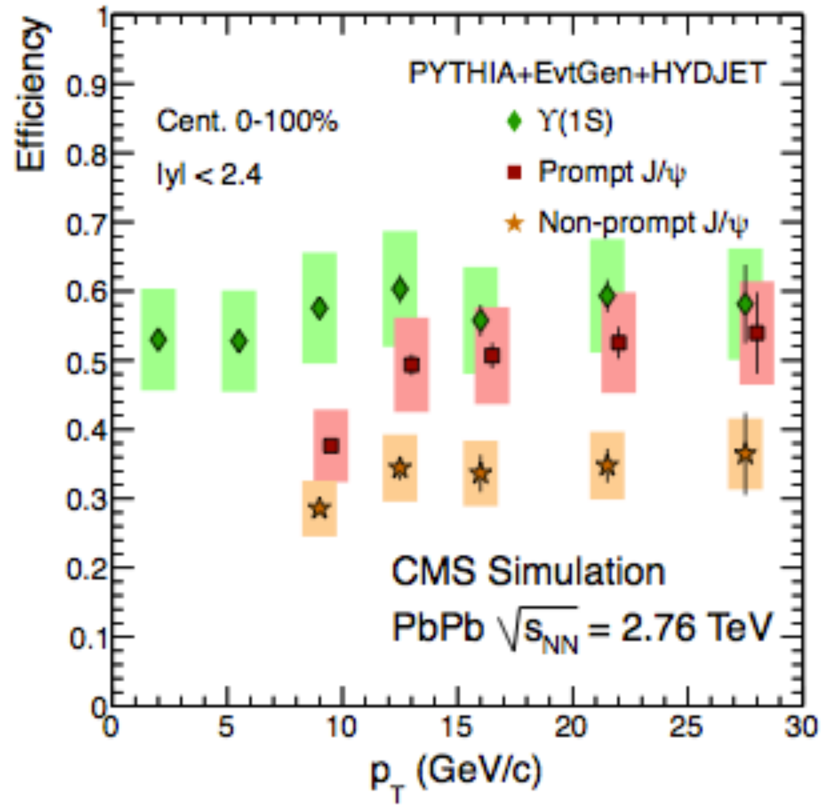
$$|\eta^{\mu}| < 1.0 \rightarrow p_T^{\mu} > 3.4 \text{ GeV}/c$$

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

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

Reconstruction Efficiency



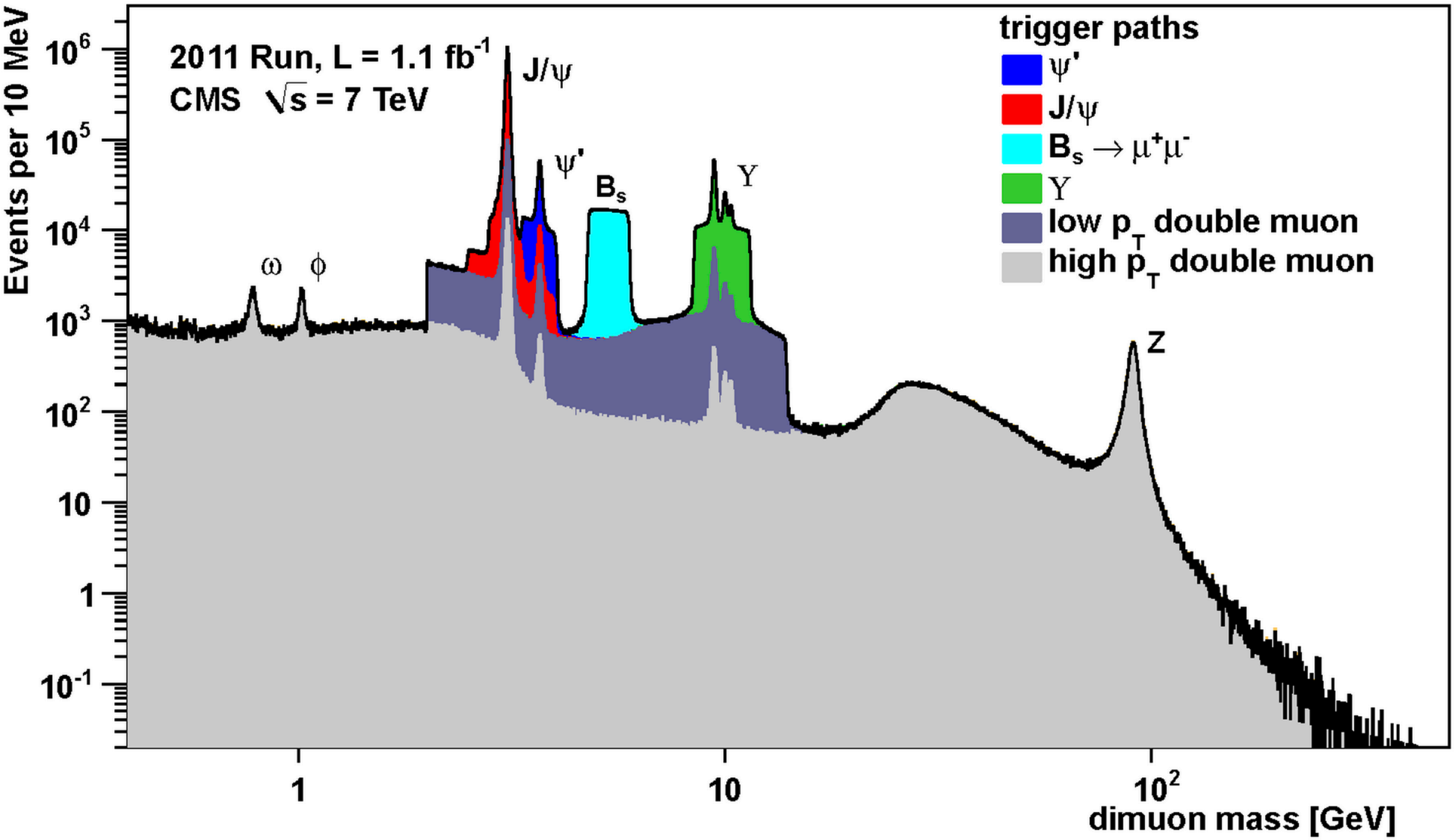


Binding Energy of Quarkonia

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

pp DiMuon

-



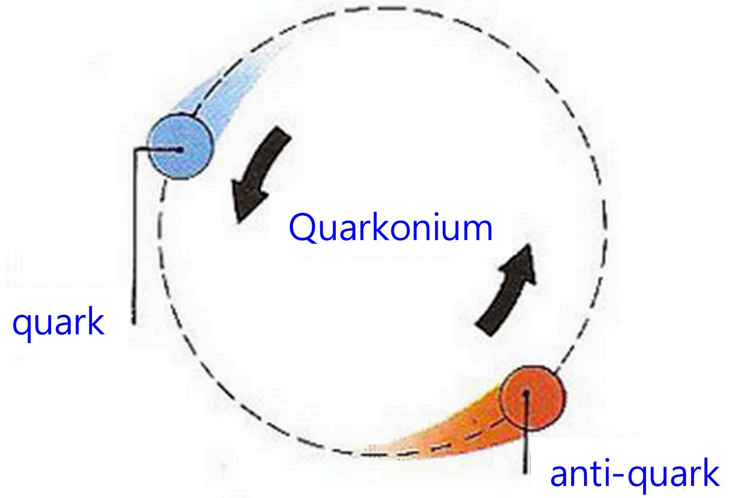
trigger paths
ψ'
J/ψ
$B_s \to \mu^+\mu^-$
Υ
low p_T double muon
high p_T double muon
2011 Run, L = 1.1 fb^{-1}
CMS $\sqrt{s}$ = 7 TeV
J/ψ
ψ'
B_s
Υ
ω
ϕ
Z
Events per 10 MeV
10^6
10^5
10^4
10^3
10^2
10
1
10^{-1}
1
10
10^2
dimuon mass [GeV]

Quarkonia Measurements

❖ **Quarkonia** : plural of quarkonium (c, b)

Charmonia : bound state of charm and anti-charm (J/ψ, ψ′(2S), χ_c(1P) etc..)

Bottomonia : bound state of bottom and anti-bottom (ϒ(1S, 2S, 3S), χ_b(1P) etc..)

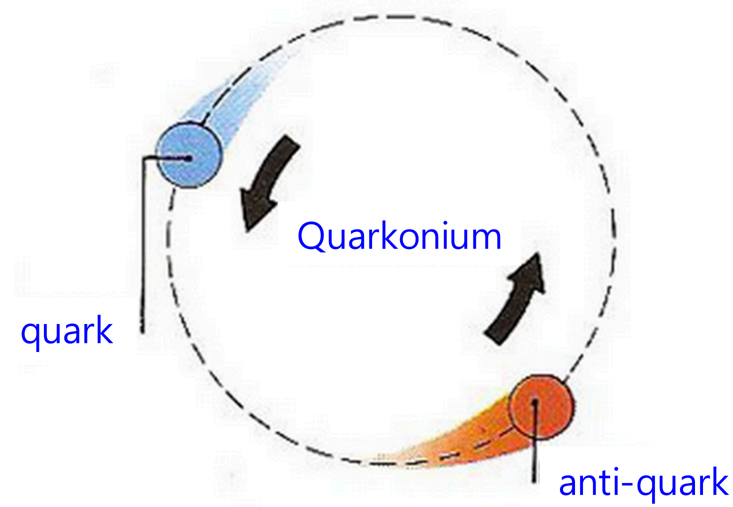


Quarkonia Measurements

❖ **Quarkonia** : plural of quarkonium (c, b)

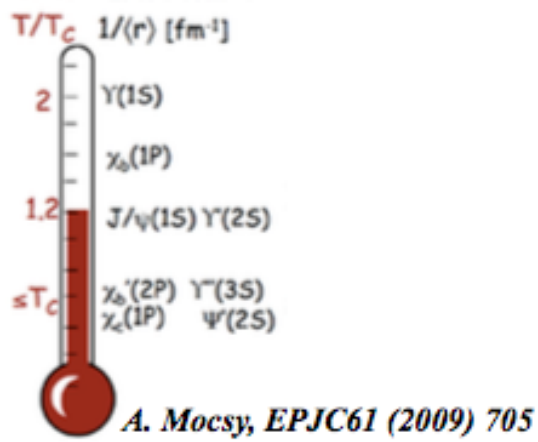
Charmonia : bound state of charm and anti-charm (J/ψ, ψ′(2S), χ_c(1P) etc..)

Bottomonia : bound state of bottom and anti-bottom (ϒ(1S, 2S, 3S), χ_b(1P) etc..)



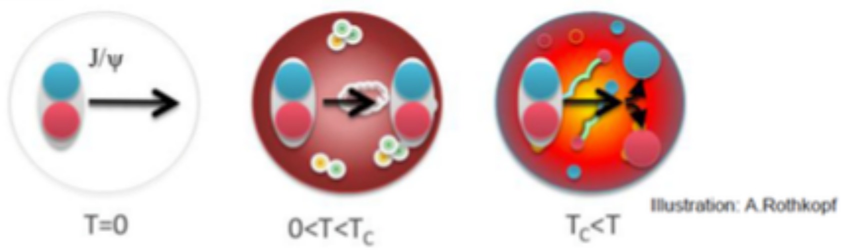
state	J/ψ	χ_c	ψ′(2S)
Mass(GeV)	3.10	3.53	3.69
ΔE (GeV)	0.64	0.20	0.05
T_d/T_c	2.1	1.16	1.12

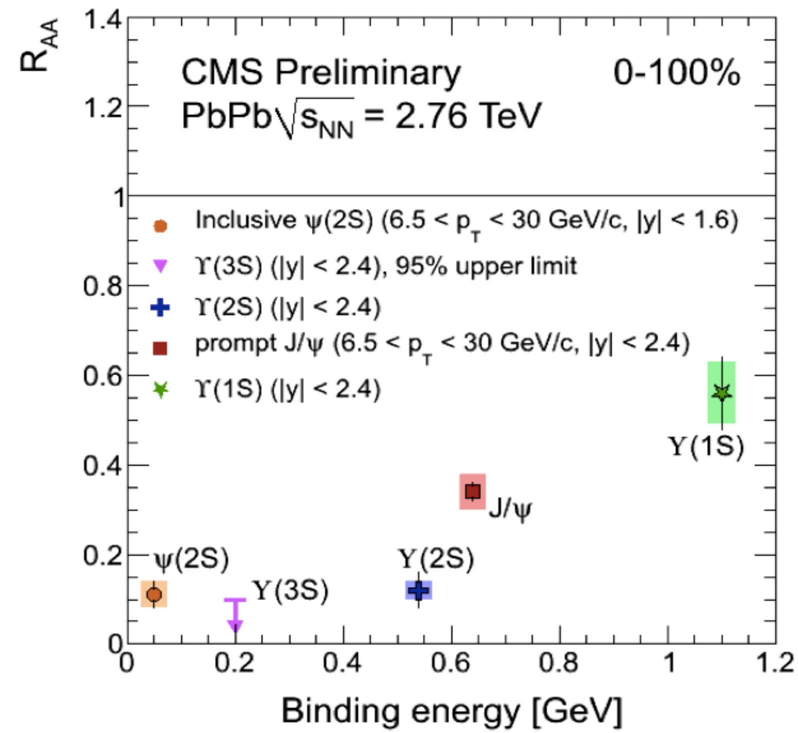
state	ϒ(1S)	ϒ(2S)	ϒ(3S)
Mass(GeV)	9.46	10.0	10.36
ΔE (GeV)	1.10	0.54	0.20
T_d/T_c	> 4.0	1.60	1.17



Quarkonia Measurements

❖ **Quarkonia** : plural of quarkonium (c, b)
  Charmonia : bound state of charm and anti-charm (J/ψ, ψ′(2S), χ_c(1P) etc..)
  Bottomonia : bound state of bottom and anti-bottom (ϒ(1S, 2S, 3S), χ_b(1P) etc..)





CMS-PAS-HIN-12-014
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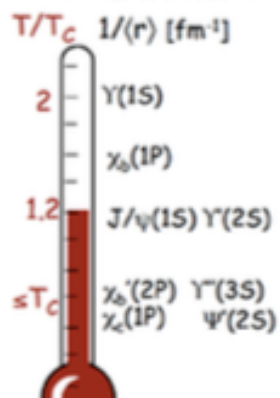
state	J/ψ	χ_c	ψ′(2S)
Mass(GeV)	3.10	3.53	3.69
ΔE (GeV)	0.64	0.20	0.05
T_d/T_c	2.1	1.16	1.12

state	ϒ(1S)	ϒ(2S)	ϒ(3S)
Mass(GeV)	9.46	10.0	10.36
ΔE (GeV)	1.10	0.54	0.20
T_d/T_c	> 4.0	1.60	1.17



A. Mocsy, EPJC61 (2009) 705

Quarkonia Measurement in pp, pPb and PbPb

- **Quarkonia** : plural of quarkonium (c, b)
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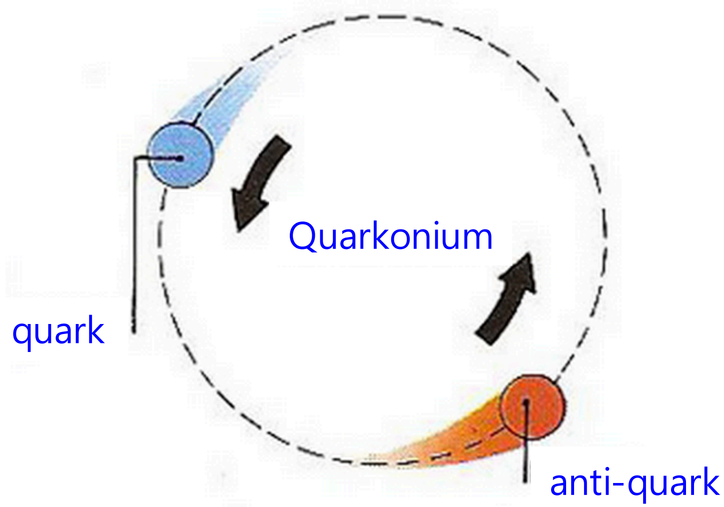

Quarkonia Measurement in pp, pPb and PbPb

- **Quarkonia** : plural of quarkonium (c, b)
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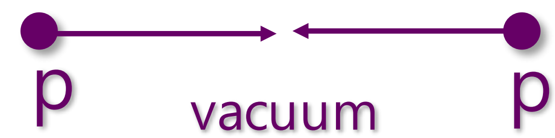
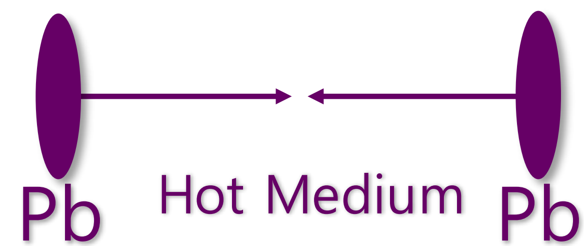
- **pp collisions**
  - Cross section, understanding polarization



- **PbPb collisions**
  - Exploring new nuclear matter known as Quark-Gluon-Plasma (QGP)
  - Characterize and quantify the properties of QGP
  - Observed strong quarkonia suppression



- **pPb collisions**
  - Create Cold Nuclear Matter (CNM)
  - Understanding initial state effect on production
  - Examine pure suppression from observation in PbPb collisions

Quarkonia Measurement in pPb Collisions

- Cold Nuclear Matter
  - Quarkonia productions are sensitive to gluon PDF
  - Initial state effects : nPDF (Nuclear Shadowing), Comover break-up, energy loss due to multiple scattering … etc

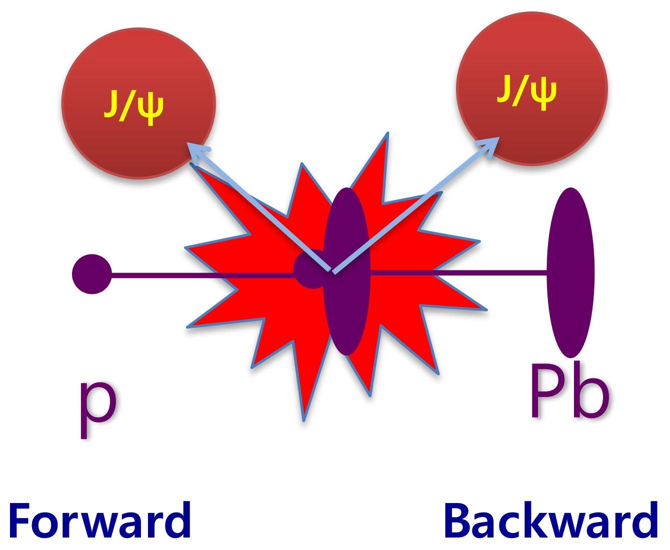
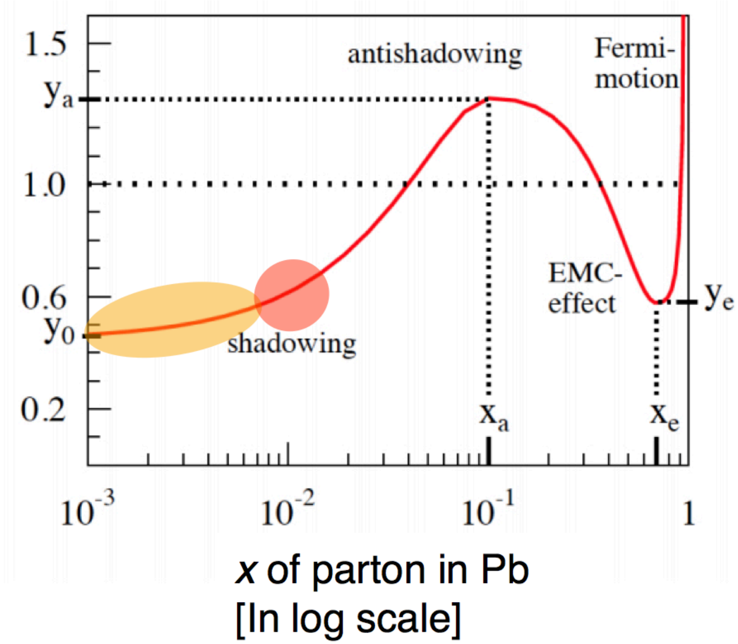
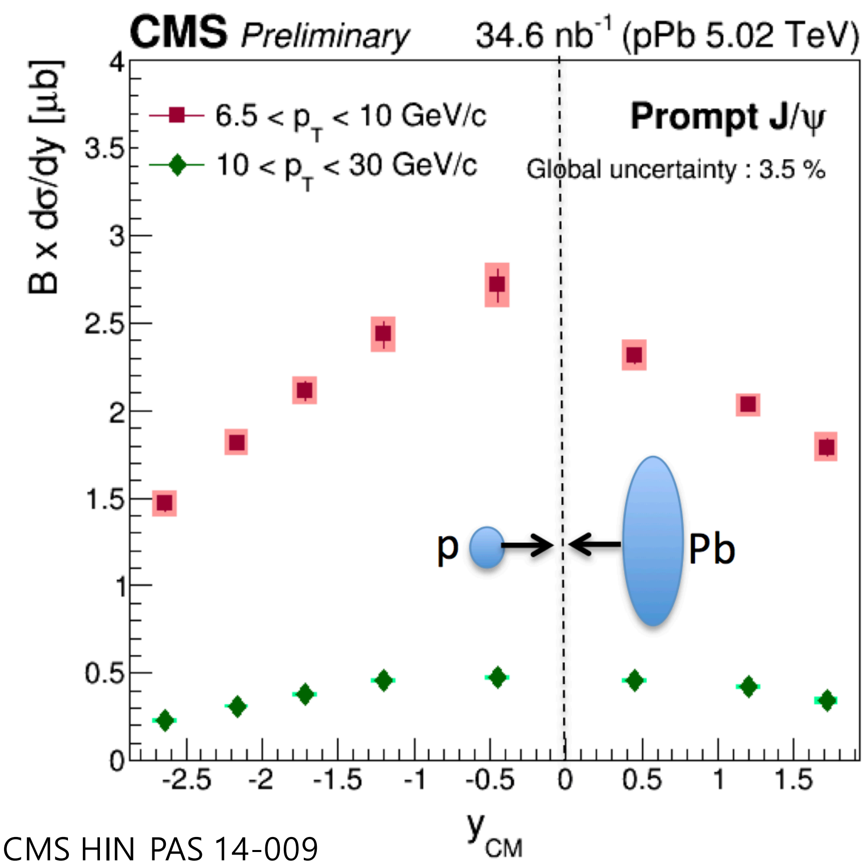


Illustration of nPDF fit
JHEP 0904 (2009) 065



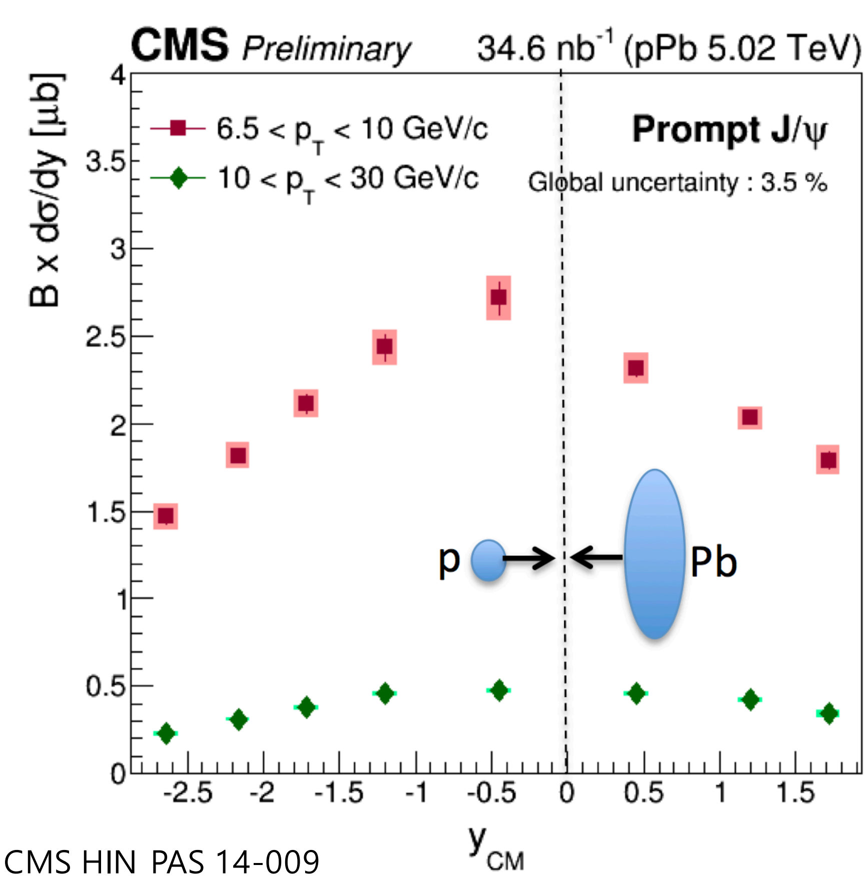
Charmonia in pPb



CMS HIN PAS 14-009

$$R_{FB}(p_T, y) = \frac{\text{Yield in } (p_T, +y)}{\text{Yield in } (p_T, -y)}$$

Charmonia in pPb



CMS HIN PAS 14-009

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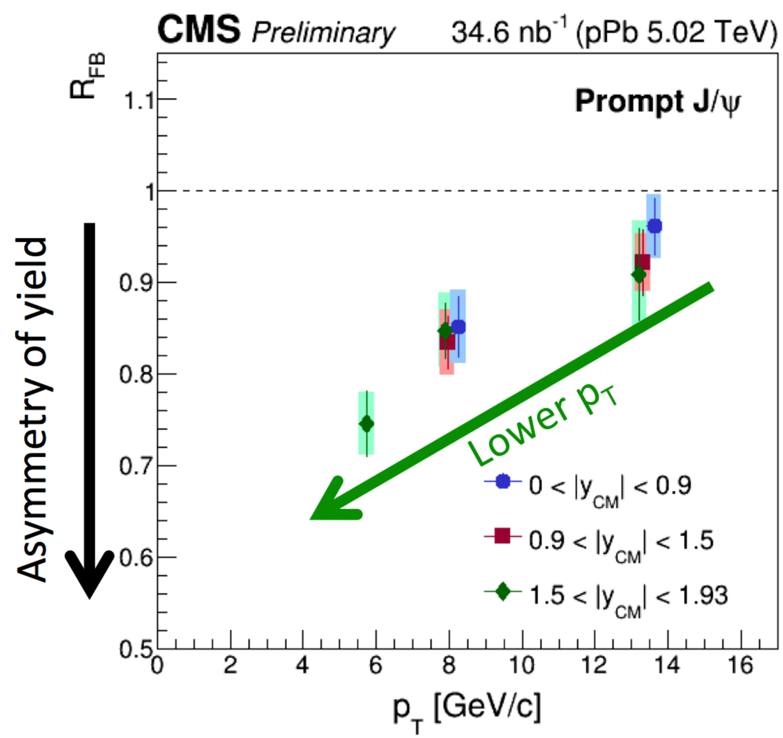
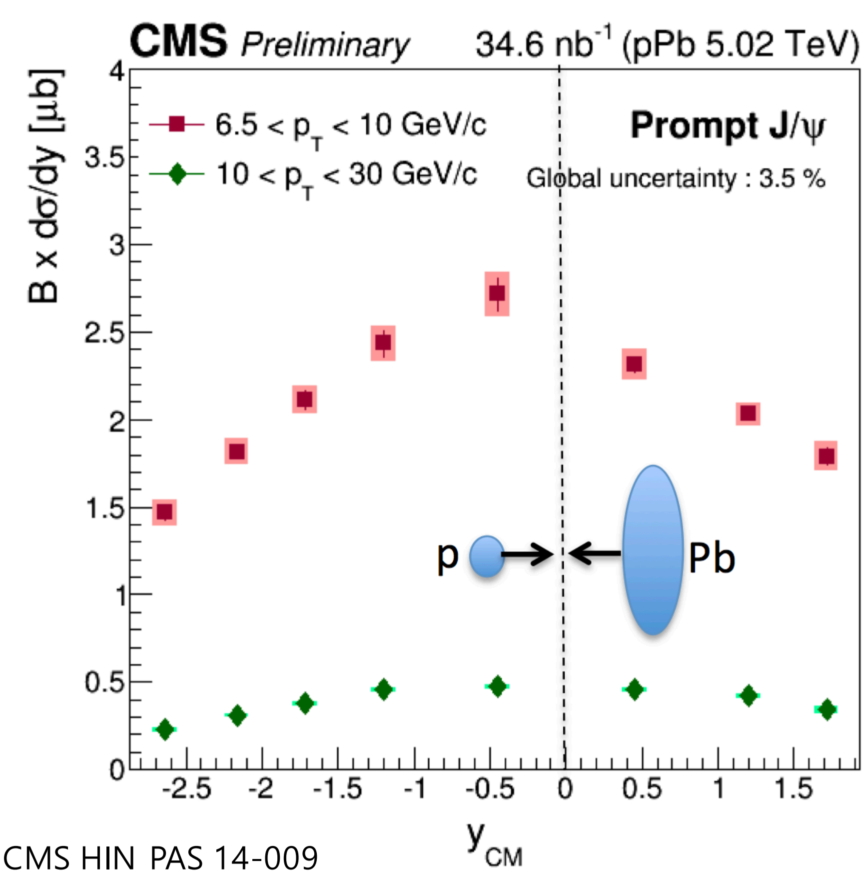


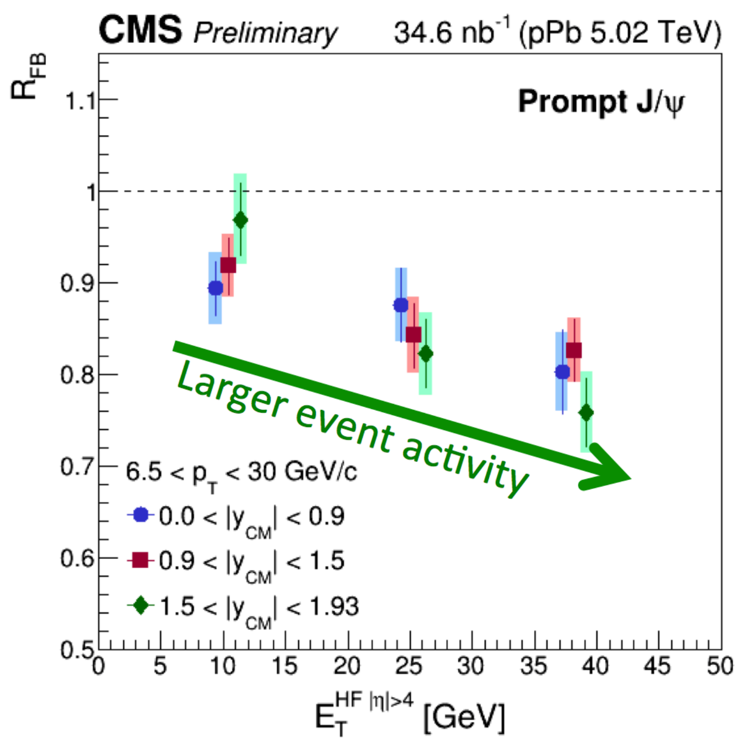
- Clear dependence of p_T : more suppression for forward in lower p_T
- No strong dependence on |y|

Charmonia in pPb



CMS HIN PAS 14-009

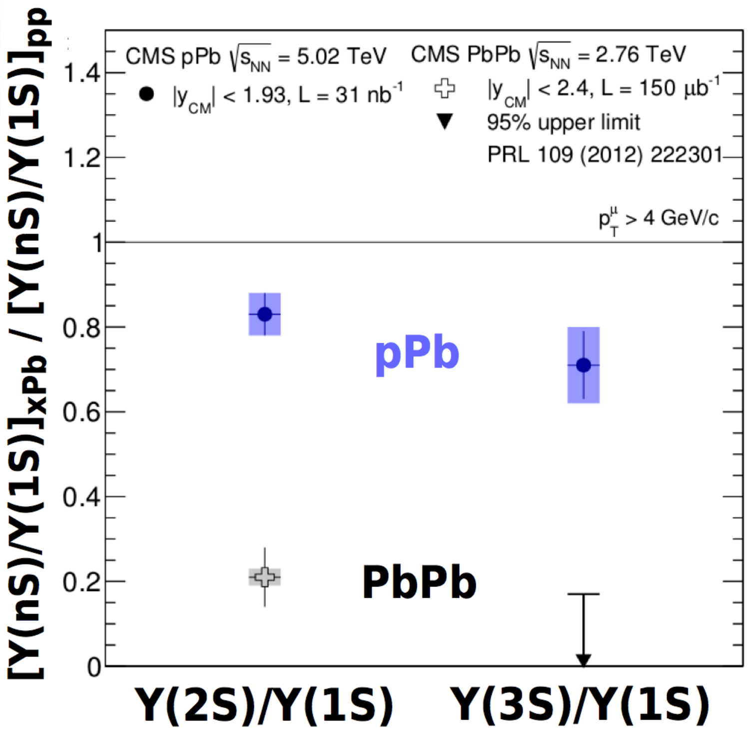
$$R_{FB}(p_T, y) = \frac{\text{Yield in } (p_T, +y)}{\text{Yield in } (p_T, -y)}$$

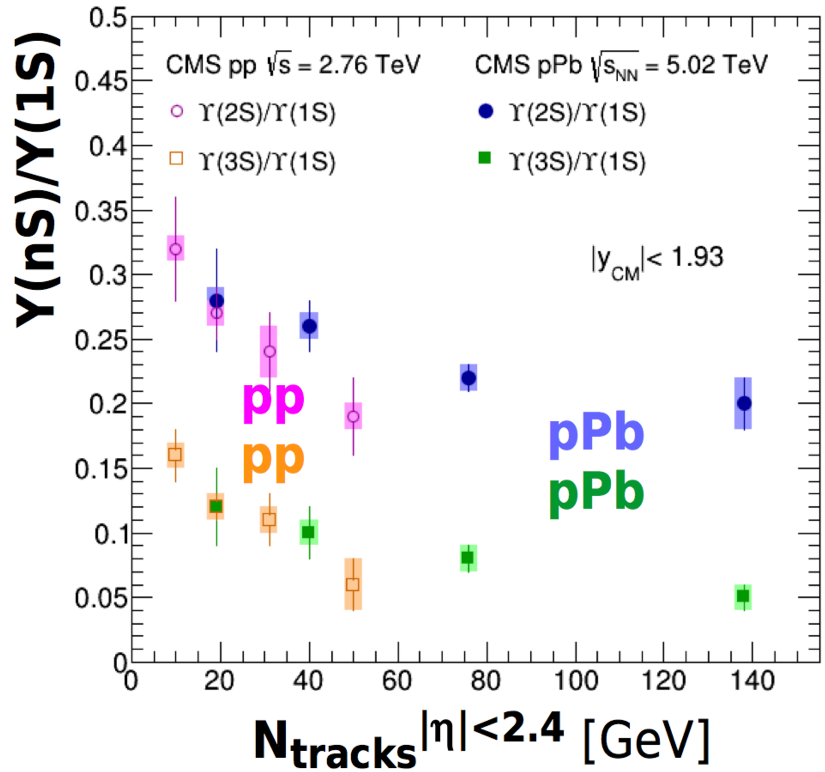


- Clear dependence of event activity : more suppression for forward in larger event activity
- No strong dependence on |y|

$$\frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$

Bottomonia in pPb





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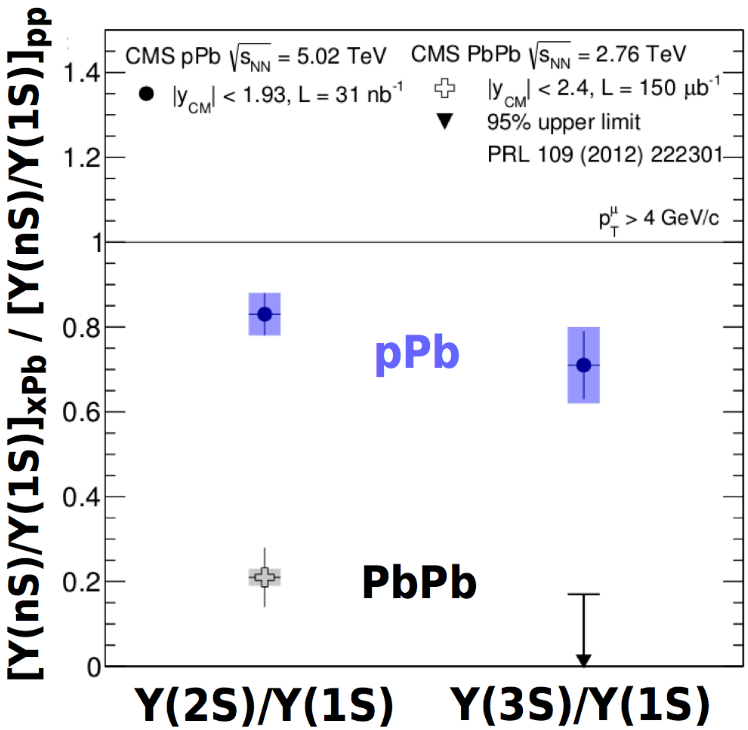
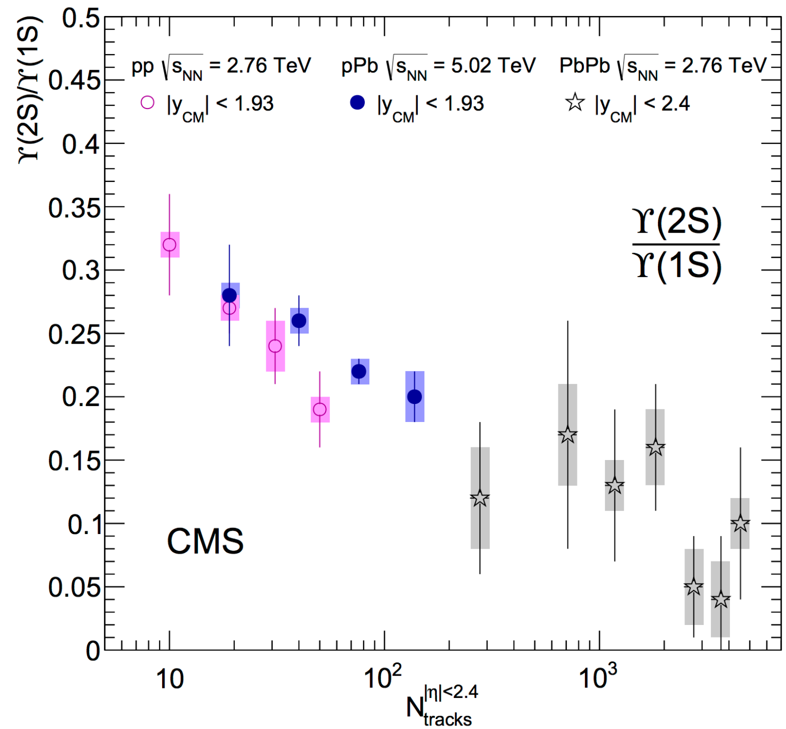
- Indication of initial suppression in pPb
- Y(nS)/Y(1S) has clear dependence on N_{trks} for pp & pPb

Bottomonia in pPb

$$\frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$



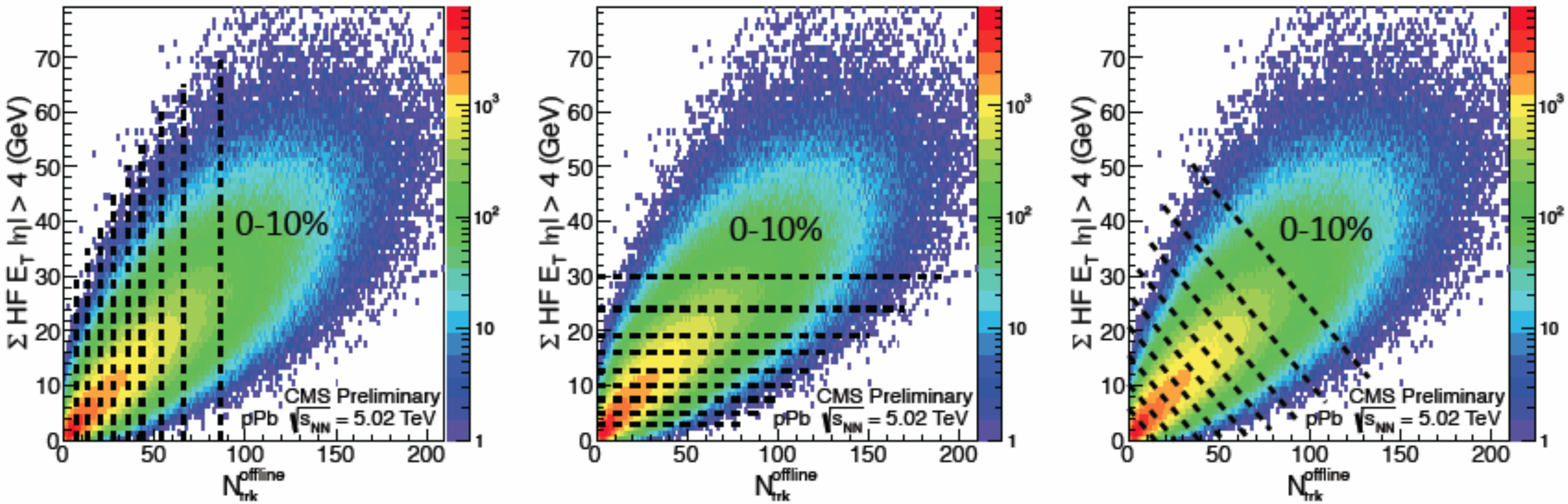


PRL 109 (2012) 222301

- Indication of initial suppression in pPb
- Y(nS)/Y(1S) has clear dependence on N_{trks} for pp & pPb & PbPb

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

Defining centrality from different methods:



- Slicing multiplicity and ΣHF E_T |η|>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