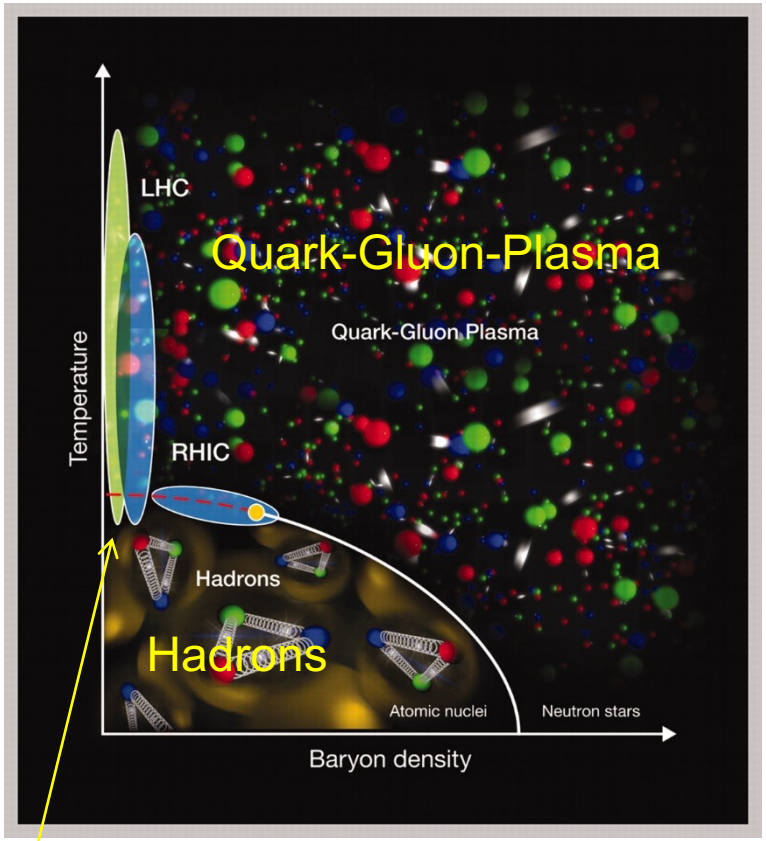
Collectivity of Quarkonium in PbPb with CMS

Dong Ho Moon
On behalf of the CMS collaboration
Chonnam National University

2022/09/02 CIPANP 2022 @ Orlando Florida

Quark-Gluon-Plasma (QGP)

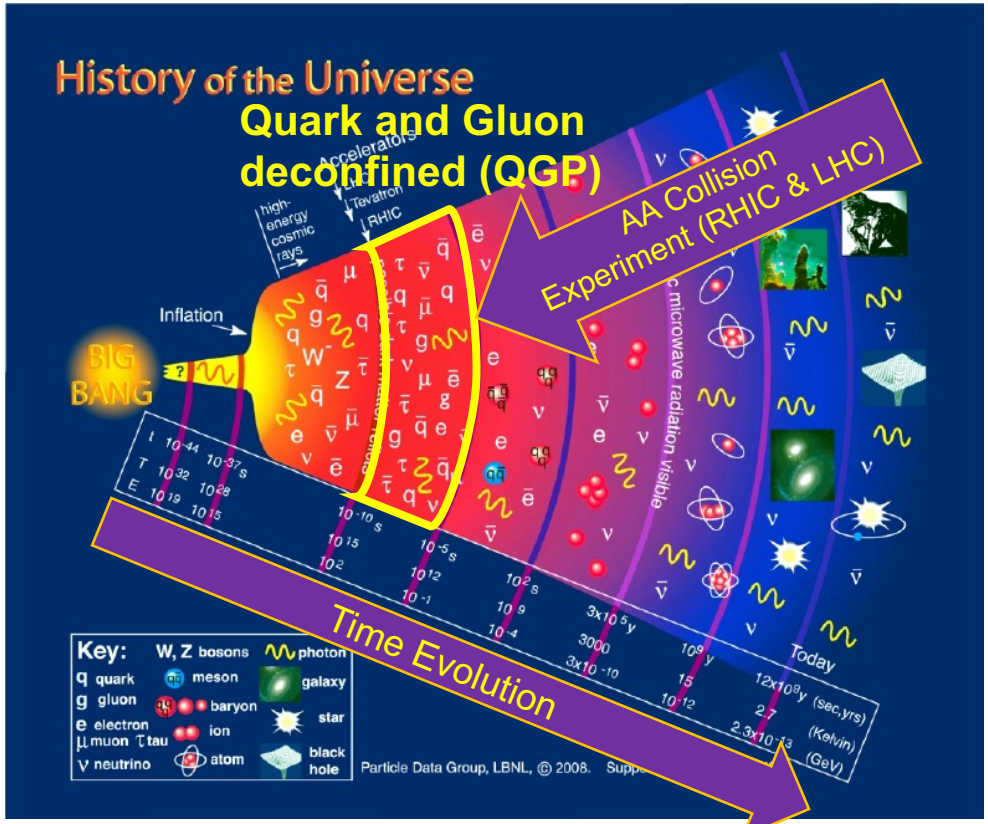
- QCD phase diagram



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

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



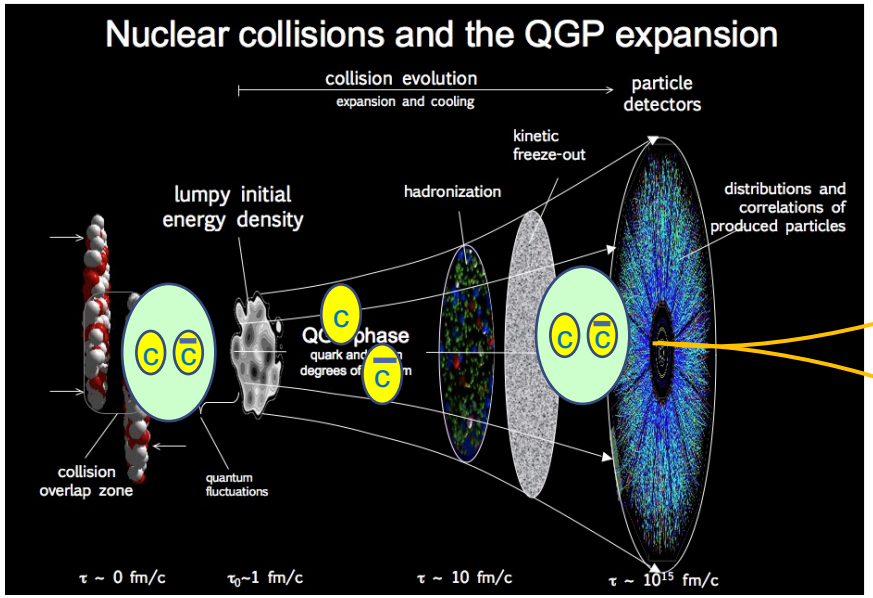
Exploring QGP means exploring our early universe

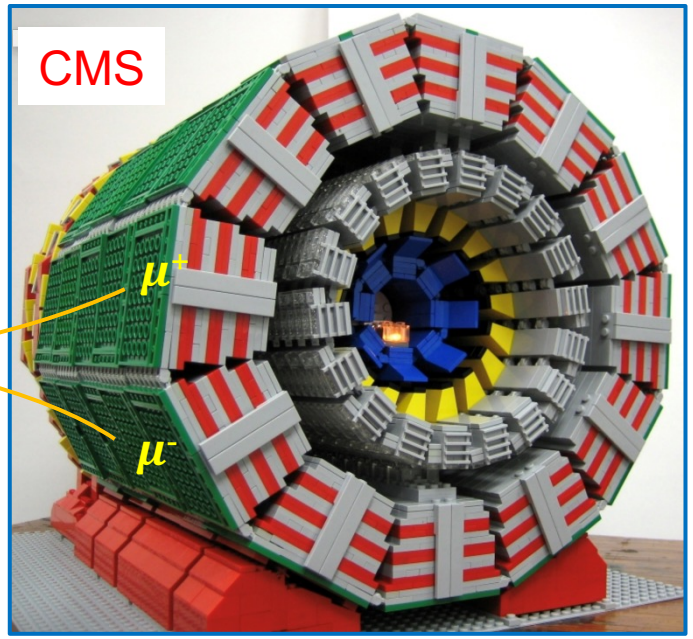
Quarkonia in Heavy ion Collisions

- Quarkonia : Excellent Probe for the Quark-Gluon-Plasma
  - Massive and early production by hard scattering
    - pQCD can estimate production rate

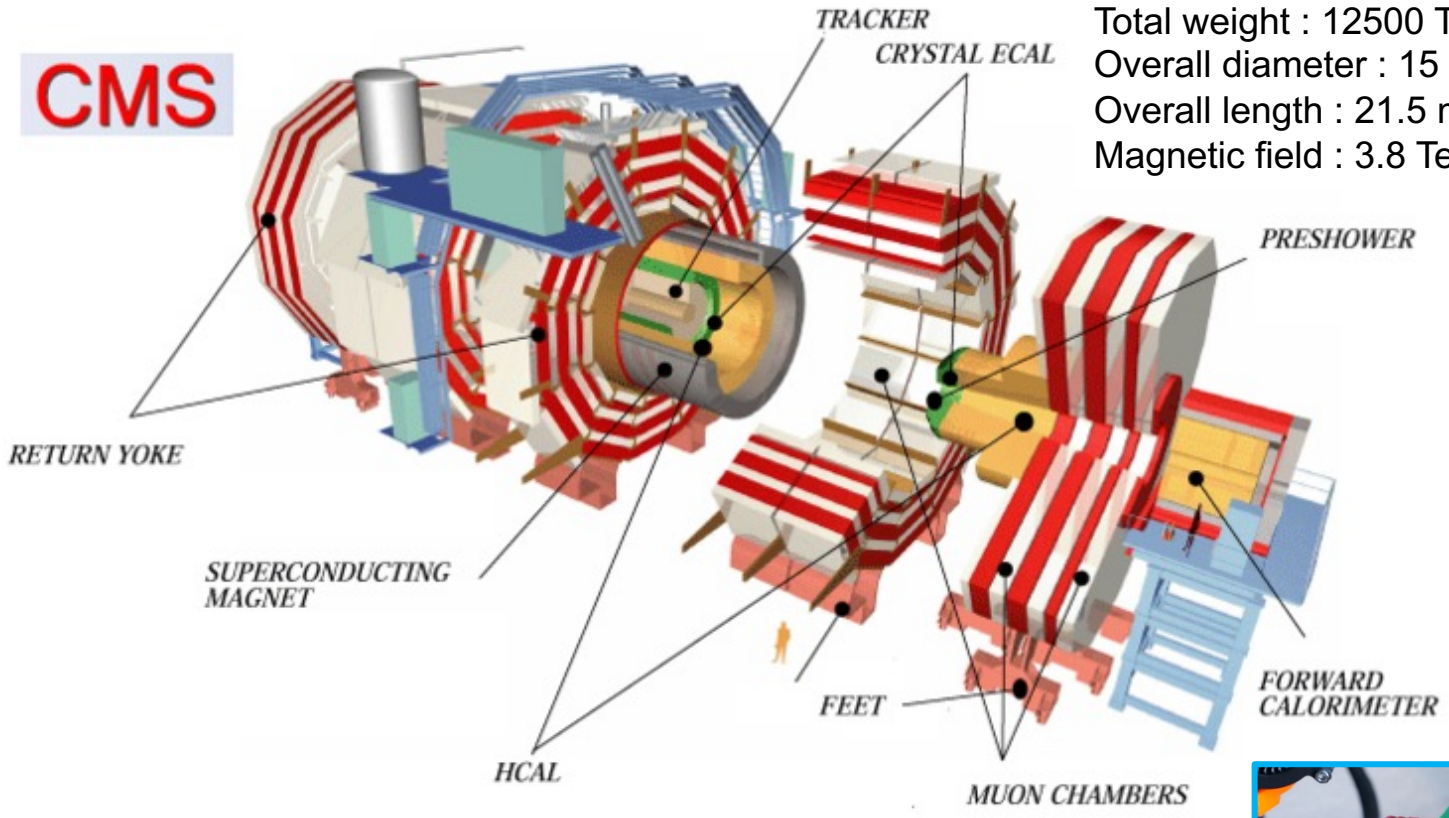
$$\tau_{formation}(q\bar{q}) \leq \tau_{formation}(QGP) < \tau_{life\ time}(QGP) < \tau_{decay\ time}(q\bar{q})$$

➠ expected to experience whole QGP evolution

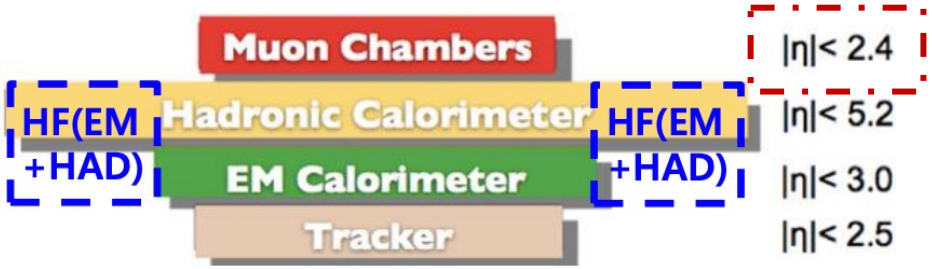


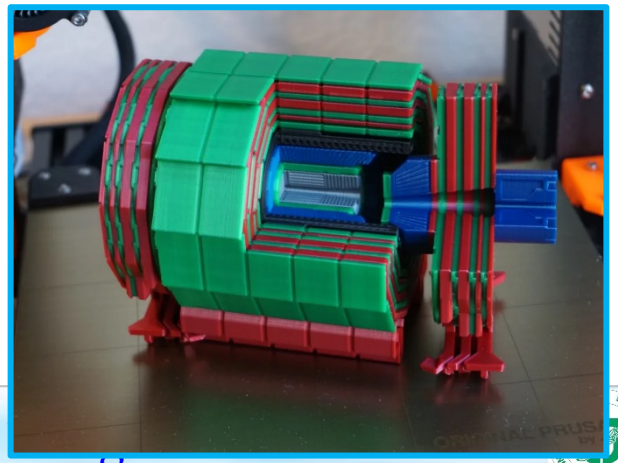


CMS Detector



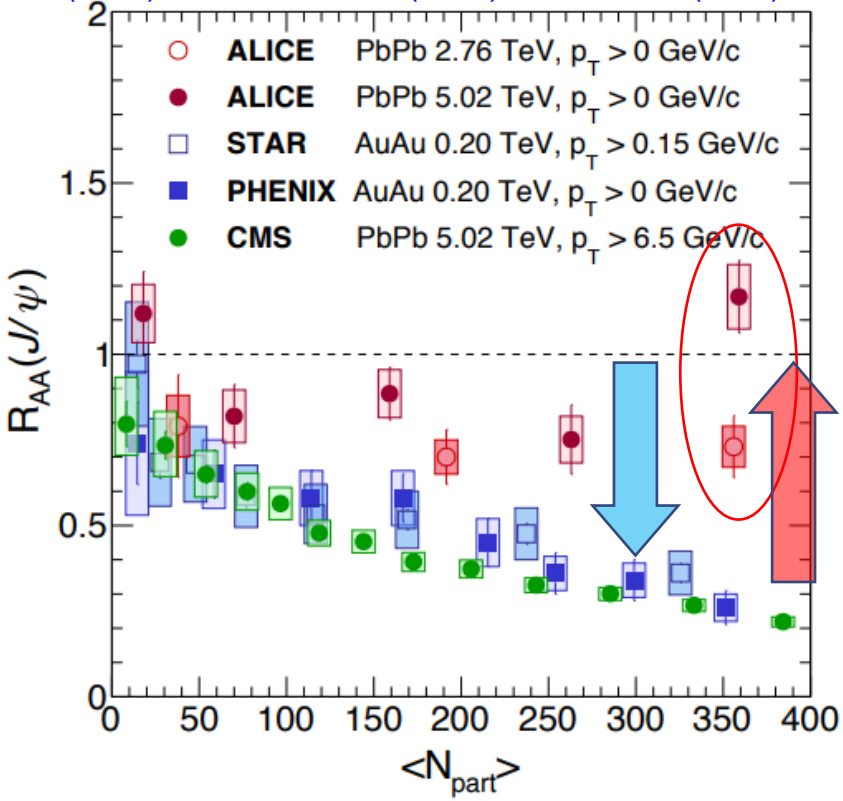
Total weight : 12500 T
Overall diameter : 15 m
Overall length : 21.5 m
Magnetic field : 3.8 Tesla

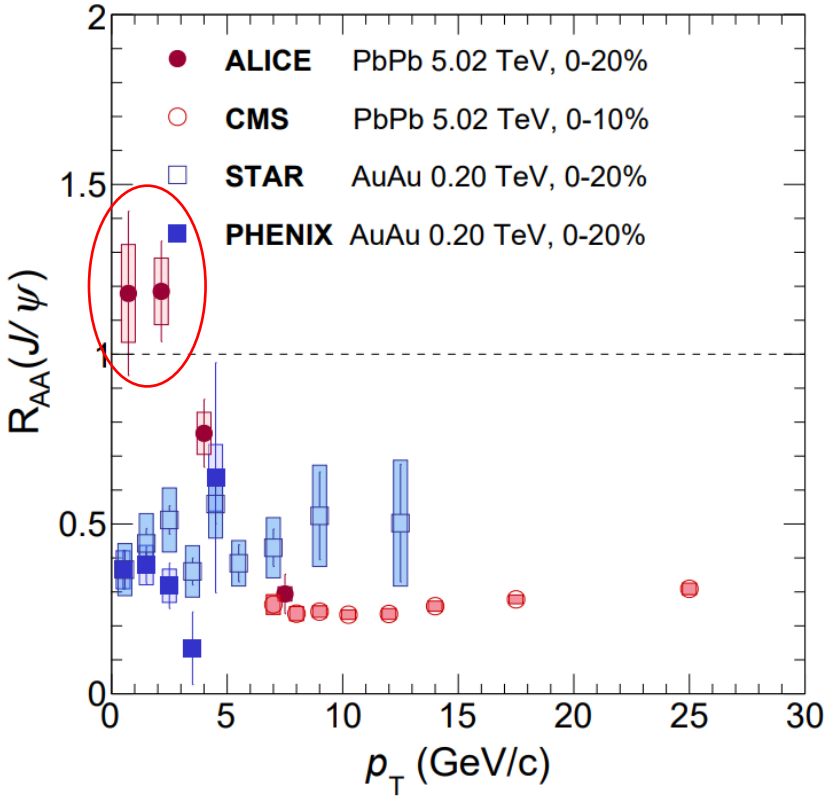




J/ψ in Heavy ion Collisions

PLB 805 (2020) 13434, EPJC 78 (2018)509, PRC 84 (2011) 054912. PLB 797 (2019) 134917. JHEP 05 (2016) 179





- Suppression PLB 178 (1986) 416, JHEP 0703 (2007) 0541, PRD 78 (2008) 014017, IJMP E 24 (1015) 1530008
  - Color screening (sequential melting), landau-damping, gluo-dissociation, cold nuclear matter effects (nPDF, comover breakup, absorption etc..)
- Enhancement PLB 490 (2000) 196, NPA 789 (2007) 334
  - Statistical recombination : uncorrelated and correlated quark pairs

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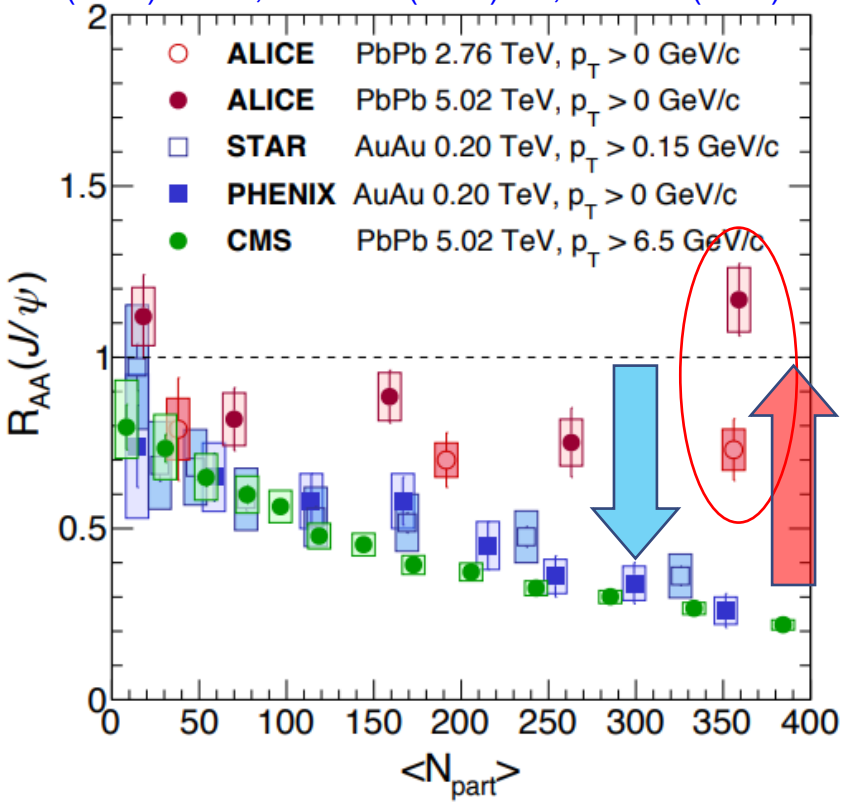
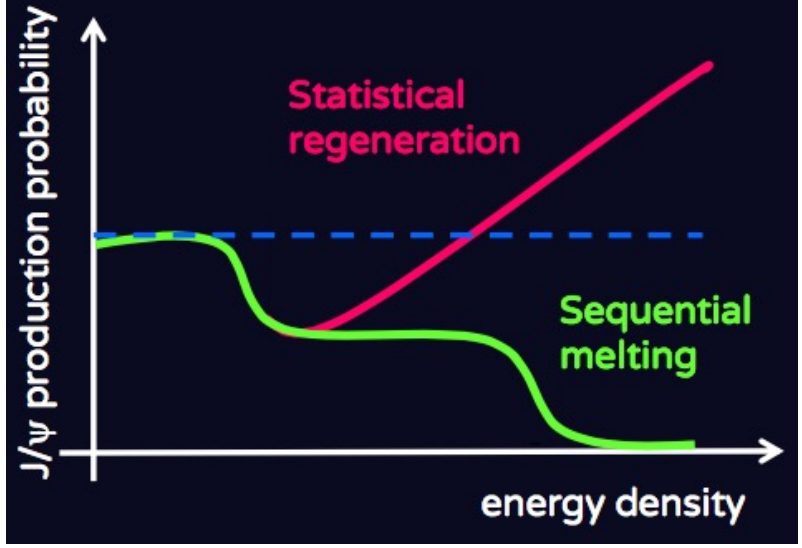


Central AA collisions	SPS 20 GeV	RHIC 200 GeV	LHC 2.76TeV
N_{ccbar}/event	~0.2	~10	~85



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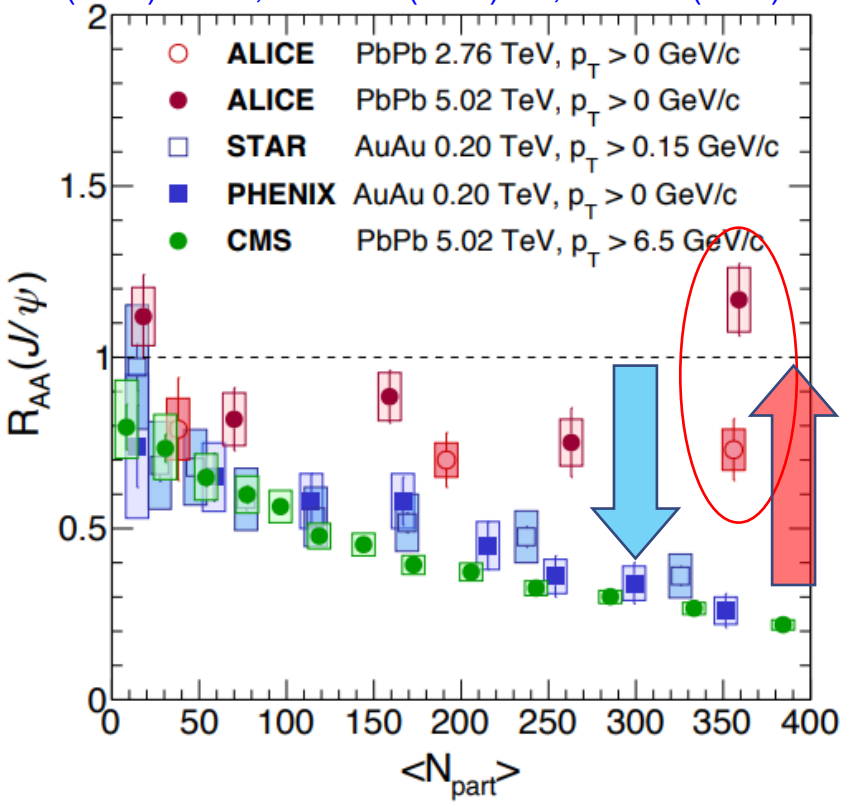

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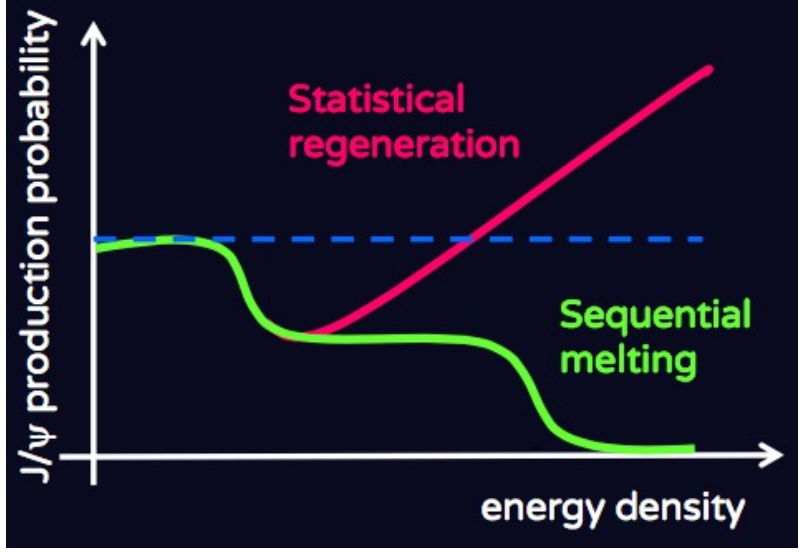

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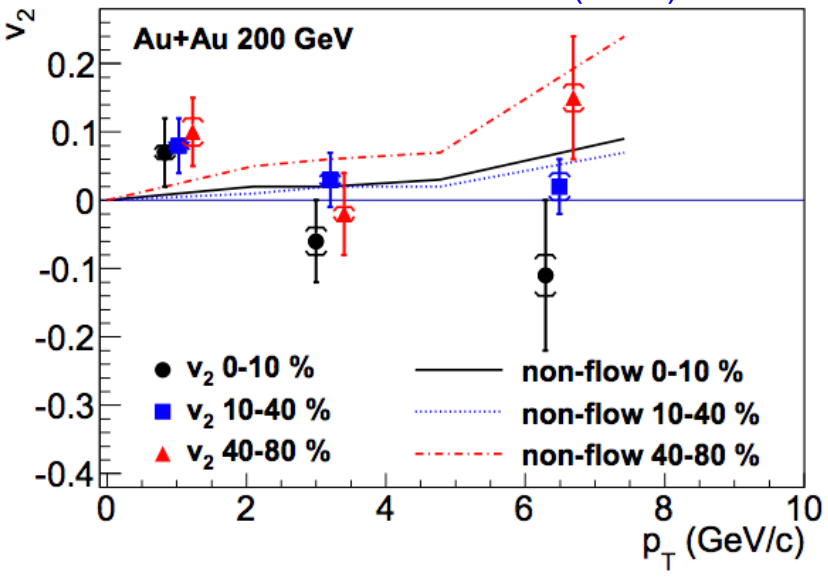
  - Color screening (sequential melting), landau-damping, gluo-dissociation, co
- Enhan
  - Statistical recombination : uncorrelated and correlated quark pairs

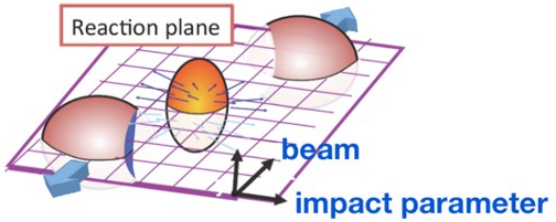
Final observed results are the mixture of all those effects. .)

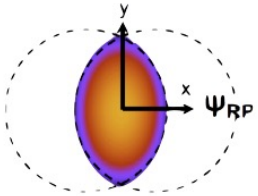
Not simple to distinguish suppression and recombination.

J/ψ flows

PRL 111 (2013) 052301



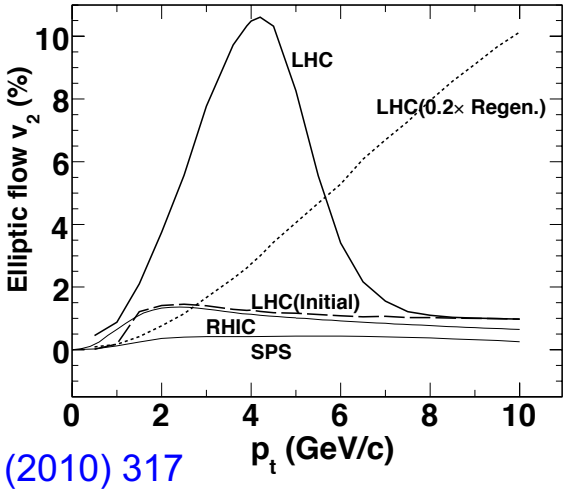




$$\frac{dN}{d\phi} \sim [1 + 2v_2 cos(2(\phi - \psi_2)) \quad ..]$$

v_2 : Elliptic flow

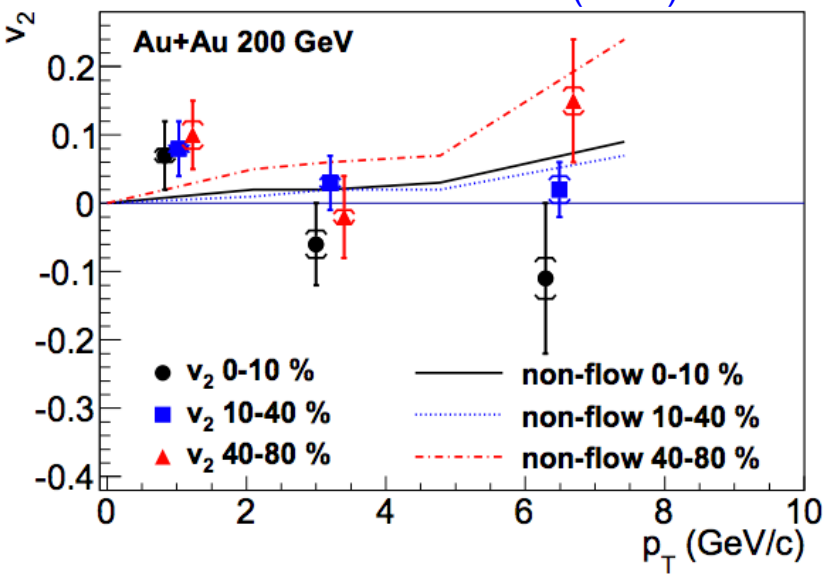
- Almost zero flow at RHIC
- But significant elliptic flow (v_2) may be expected at LHC energy due to the significant contribution of regenerated J/ψ
  - ✓ Good recombination signal

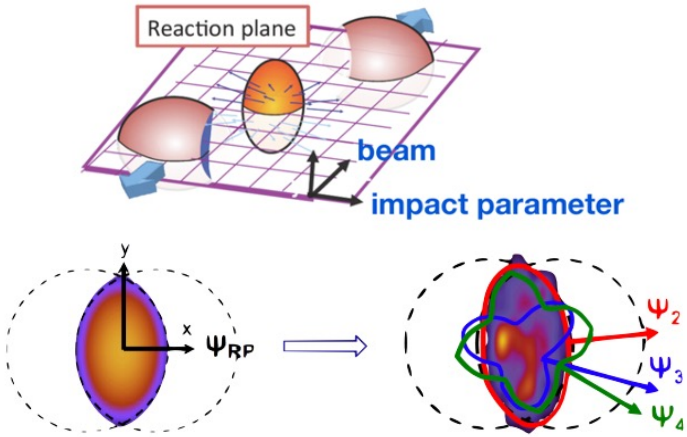


NPA 834 (2010) 317

J/ψ flows

PRL 111 (2013) 052301

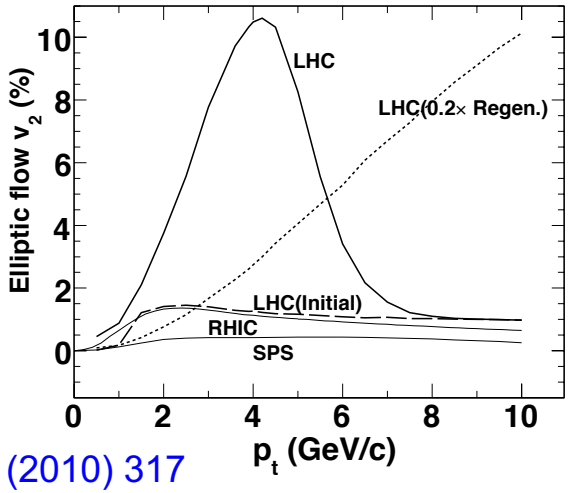




$$\frac{dN}{d\phi} \sim [1 + 2v_2 cos(2(\phi - \psi_2)) + 2v_3 cos(3(\phi - \psi_3))\ldots]$$

v_2 : Elliptic flow v_3 : Triangular flow

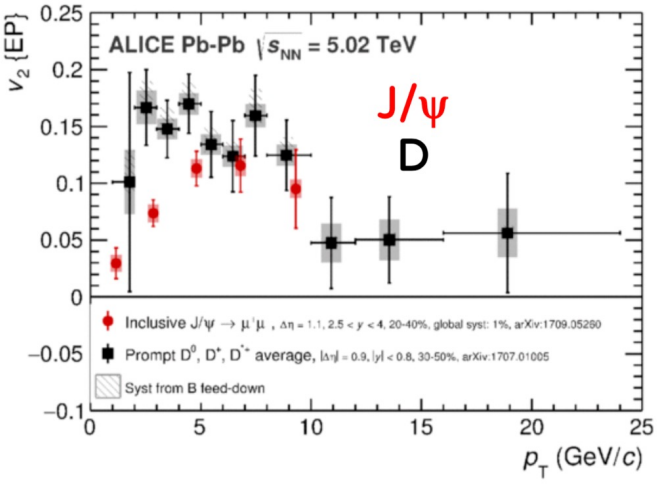
- Almost zero flow at RHIC
- But significant elliptic flow (v_2) may be expected at LHC energy due to the significant contribution of regenerated J/ψ
  - ✓ Good recombination signal
- Triangular flow (v_3) : initial geometry fluctuation



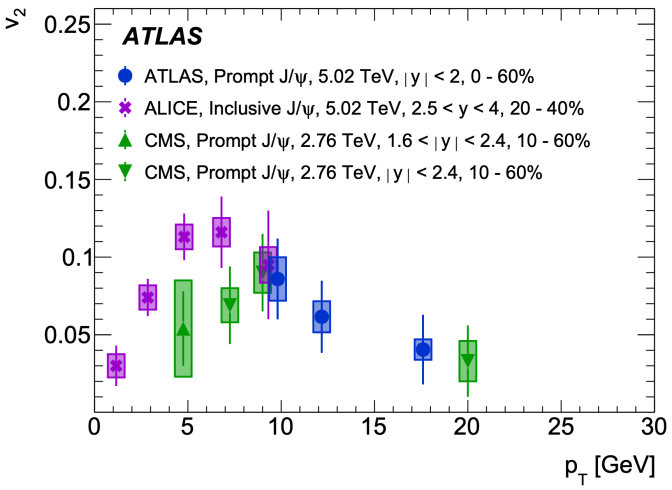
NPA 834 (2010) 317

J/ψ Elliptic flow in PbPb

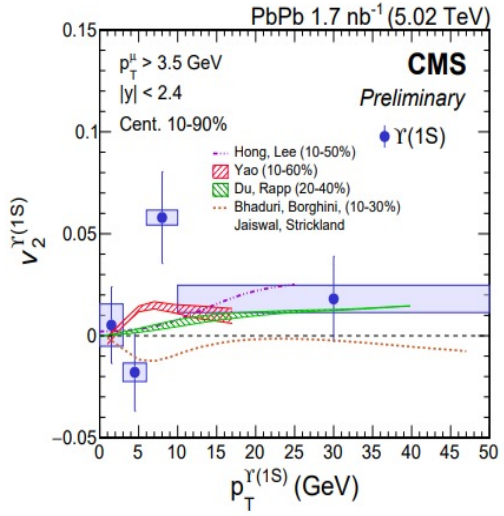
JHEP 10 (2020) 141



EPJC 78 (2018) 784



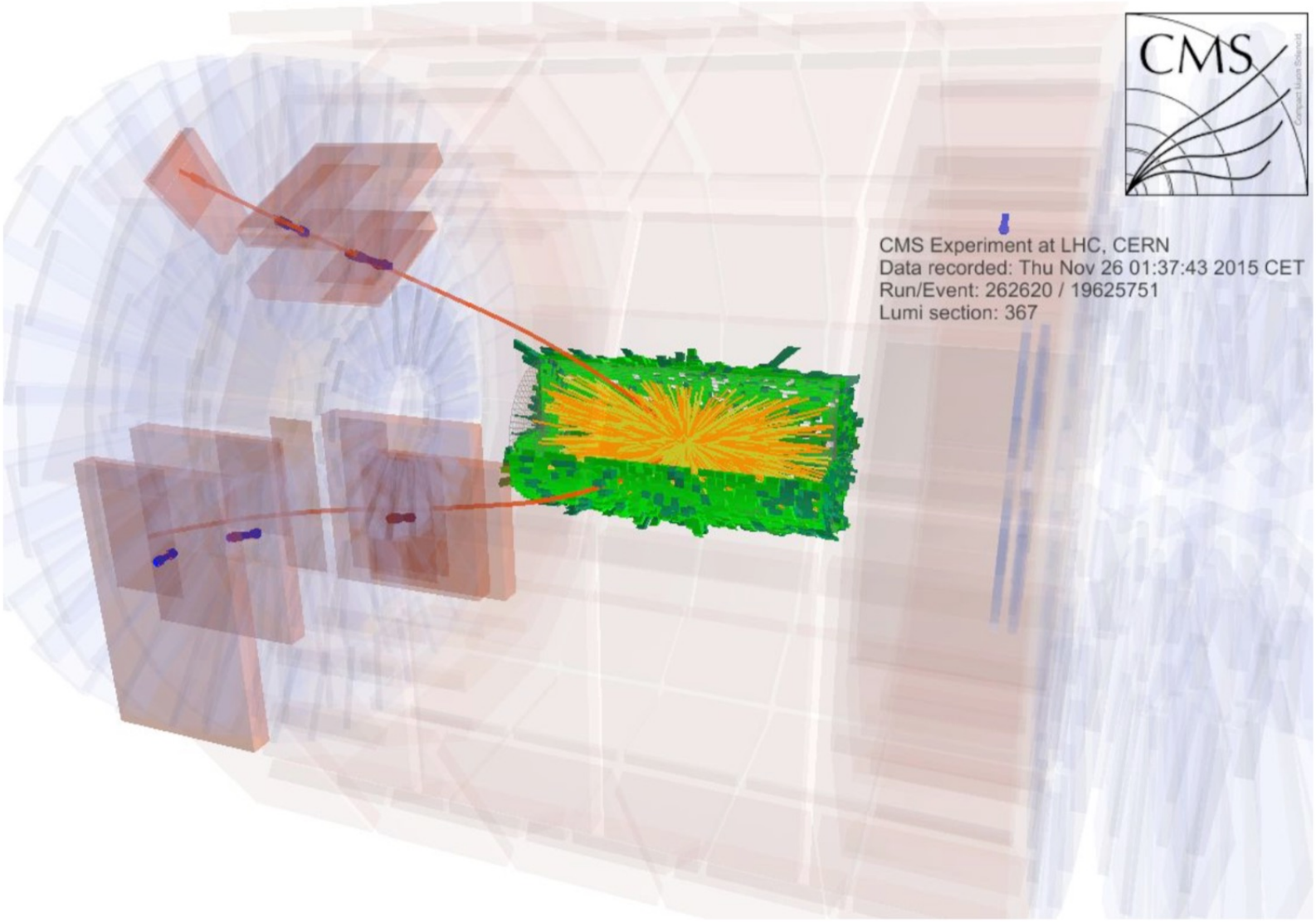
PLB 819 (2021) 136385



- ALICE inclusive J/ψ v_2 is similar with open charm flow (p_T > 5 GeV/c)
  - Compatible with the results of ATLAS and CMS (2.76 TeV) (p_T > 7 GeV/c)
- ATLAS measured prompt and non-prompt J/ψ's flow at 5.02 TeV
  - Prompt J/ψ's flow is larger than that of non-prompt J/ψ
- CMS Υ v_2 is consistent with zero within uncertainties.
- CMS prompt and nonprompt J/ψ can be a good bridge between ALICE and ATLAS >> useful to probe c vs b quark flow.

Focus on charmonium flow
Today talk

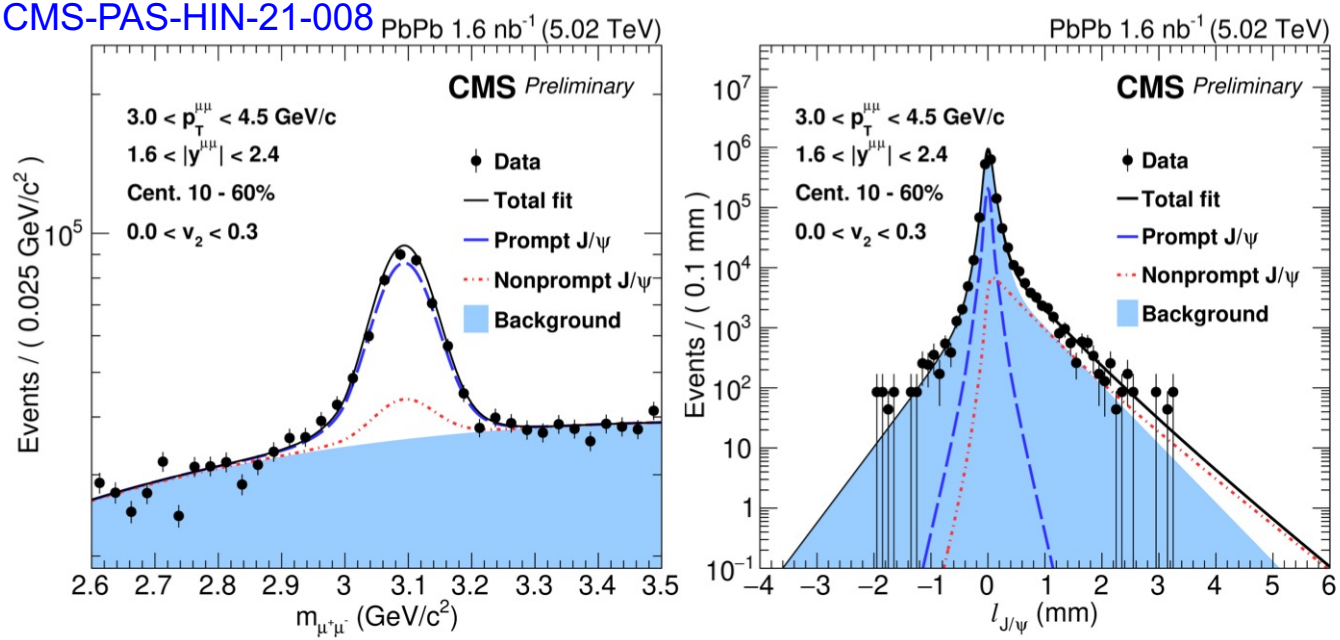
Charmonia in PbPb

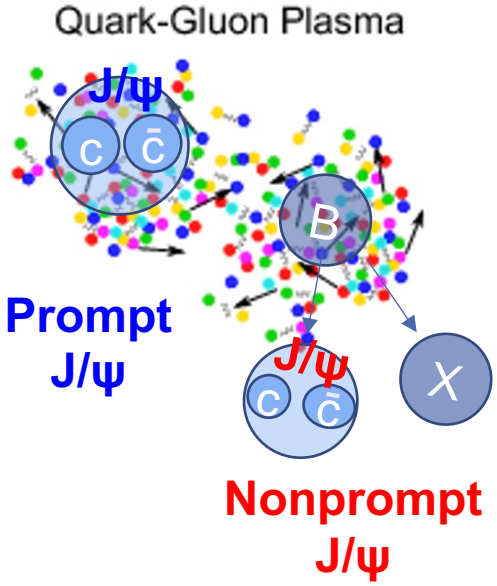


Signal Extractions

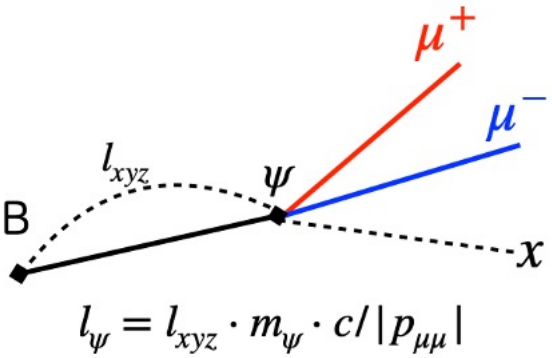
J/ψ : 2D fit on mass & decay length

CMS-PAS-HIN-21-008

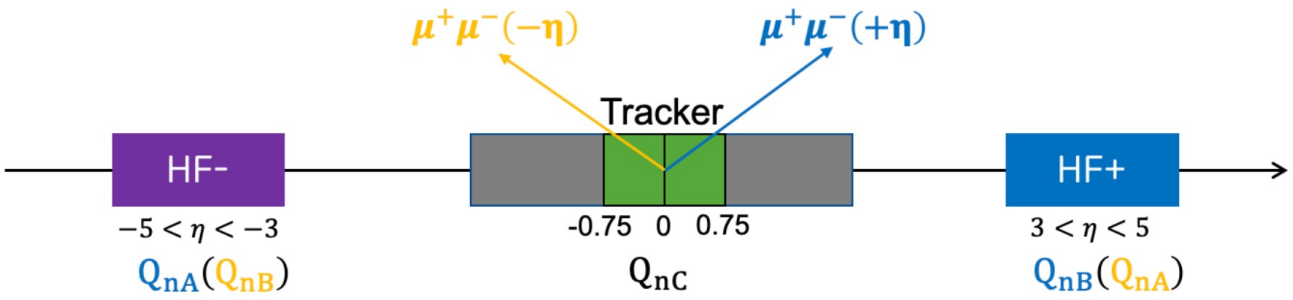




- 2 dimensional simultaneous fit to separate prompt and nonprompt J/ψ
- Two CrystalBall (Signal) + nth order polynomials (Background)



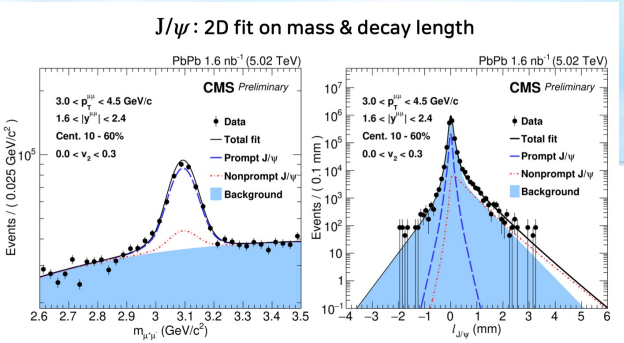
Scalar Product Method



$$v_n = \frac{< Q_n Q_{nA}^* >}{\sqrt{\frac{< Q_{nA} Q_{nB}^* > < Q_{nB} Q_{nC}^* >}{< Q_{nA} Q_{nC}^* >}}}$$

- Scalar product method using Q-vectors
  - Qn : Dimuon flow vector
  - QnA (QnB) : Event plane vector for the HF$\pm$
  - AnC : Event plane vector in the tracker for $|\eta| < 0.75$

v_n Extraction for J/ψ



prompt J/ψ, b → J/ψ

v_n profiling method

- no description needed for v_n background

mean of b → J/ψ v_n

mean of Prompt J/ψ v_n

b → J/ψ yield from 2D fit in each bin

Prompt J/ψ yield from 2D fit in each bin

0.3

v_n

$$v_n = \frac{Q_n Q_{nA}^*}{\sqrt{\frac{< Q_{nA} Q_{nB}^* > < Q_{nB} Q_{nC}^* >}{< Q_{nA} Q_{nC}^* >}}}$$

Slice v_n bin with 0.3 >> apply 2D fit >> Can separate prompt and nonprompt J/ψ

Mean (average) value of each J/ψ distribution = v_n

Results : J/ψ Elliptic flow

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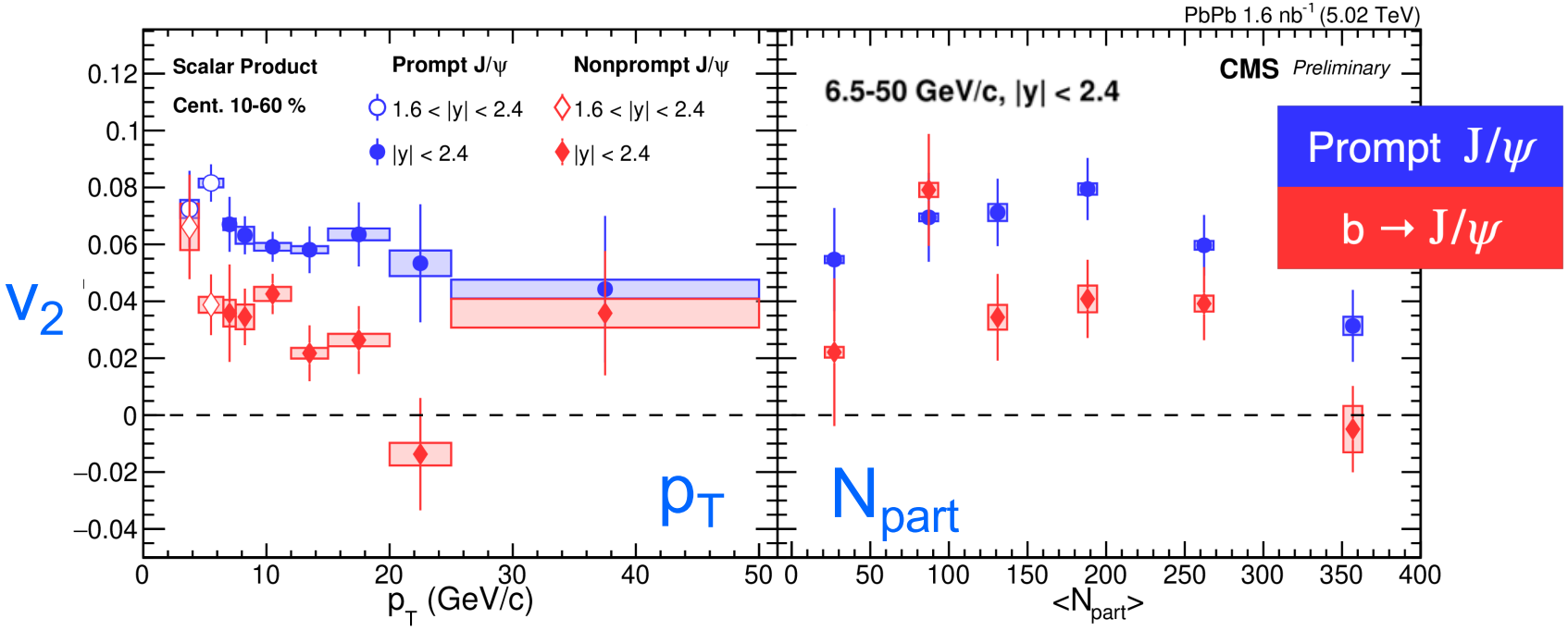
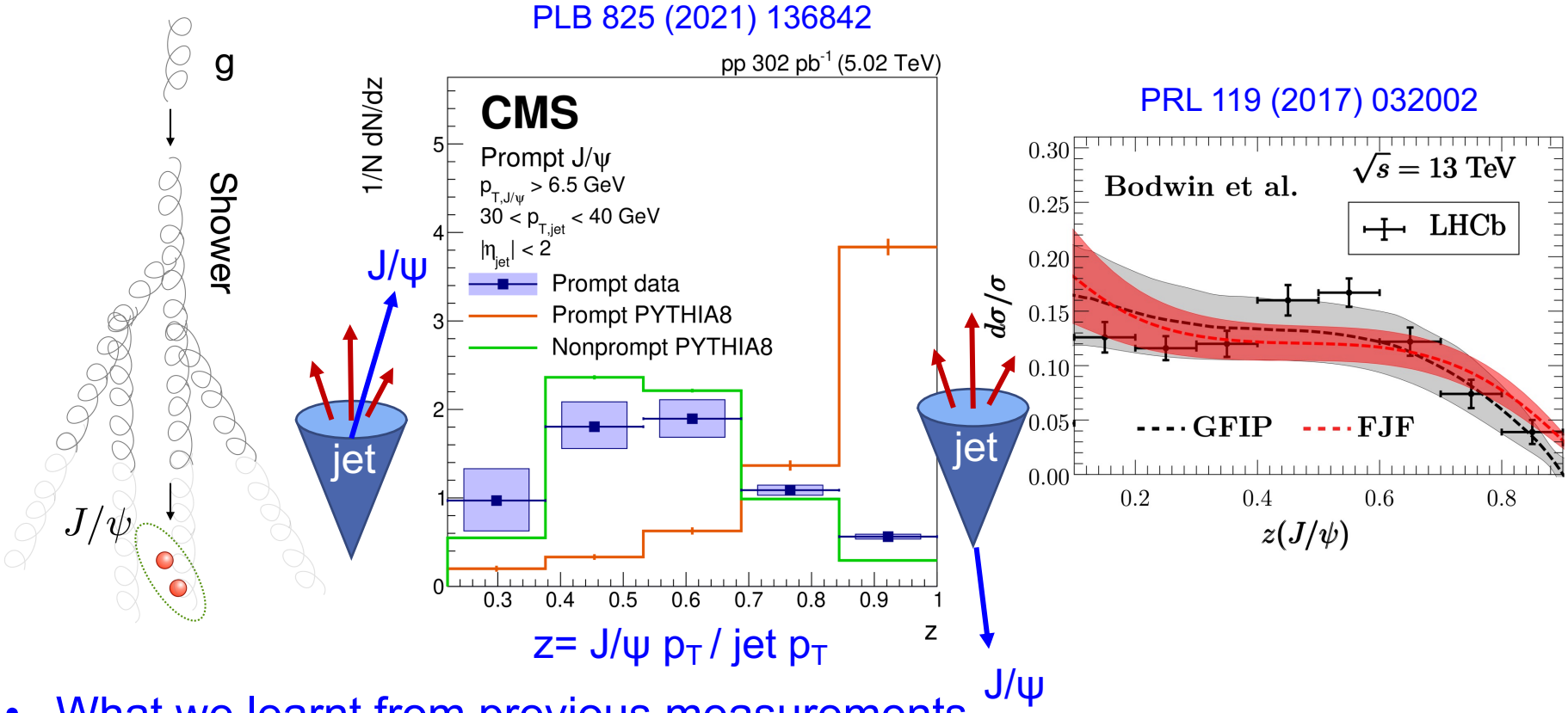


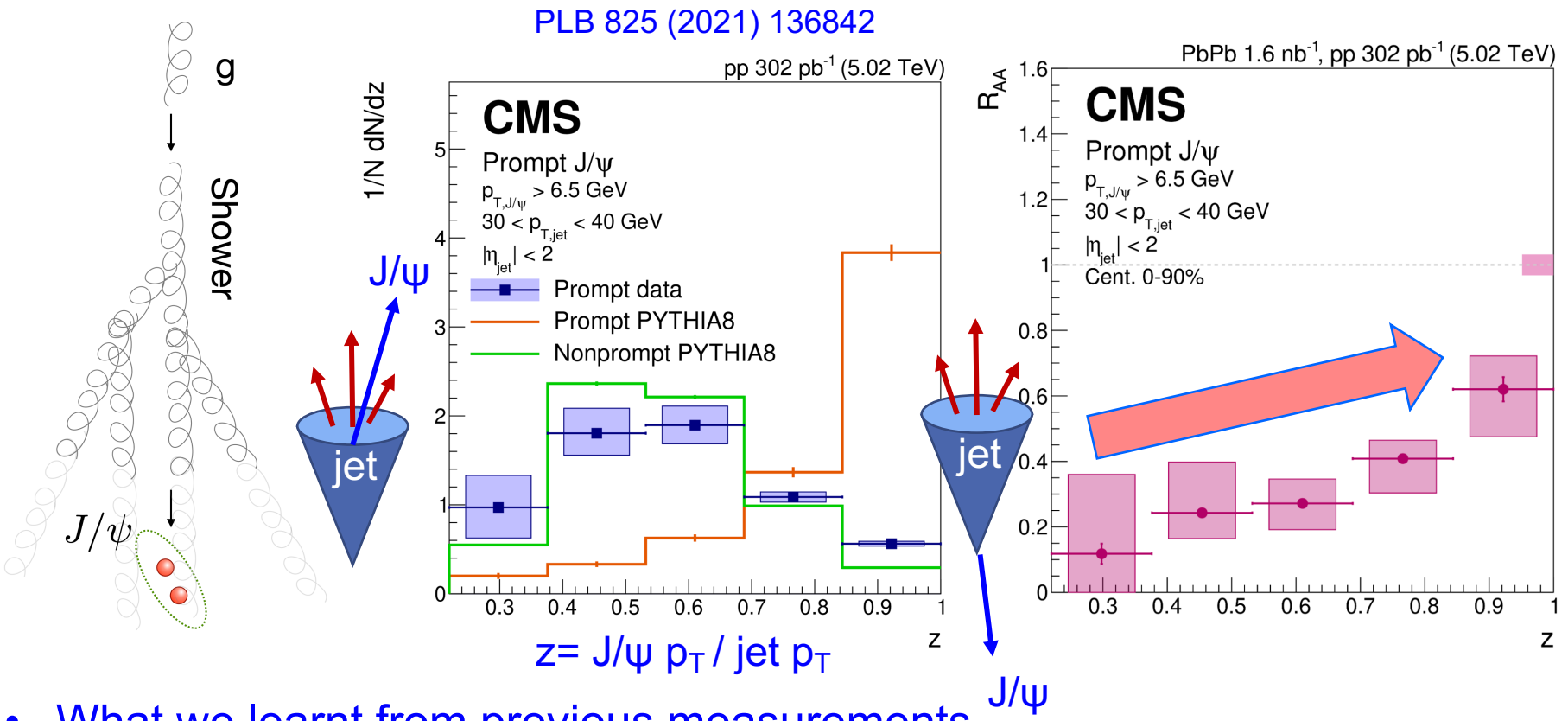
- Measured sizable v_2 up to 50 GeV/c
- Prompt J/ψ v_2 > B → J/ψ v_2 (p_T > 4 GeV/c)
- No strong dependence on p_T
- Indication of different dynamics for charm and beauty quarks

Trying to understand …



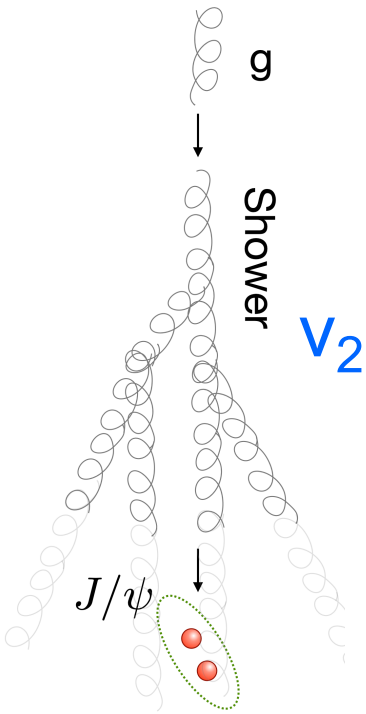
- What we learnt from previous measurements
  - ✓ Large fraction of prompt J/ψ are produced in parton shower confirmed in data differently from PYTHIA8

Trying to understand …



- What we learnt from previous measurements
  - ✓ Large fraction of prompt J/ψ are produced in parton shower confirmed in data differently from PYTHIA8
  - ✓ Large suppression is observed in low z : increasing R_{AA} as increasing z >> large suppression happens from Jet quenching

Trying to understand …



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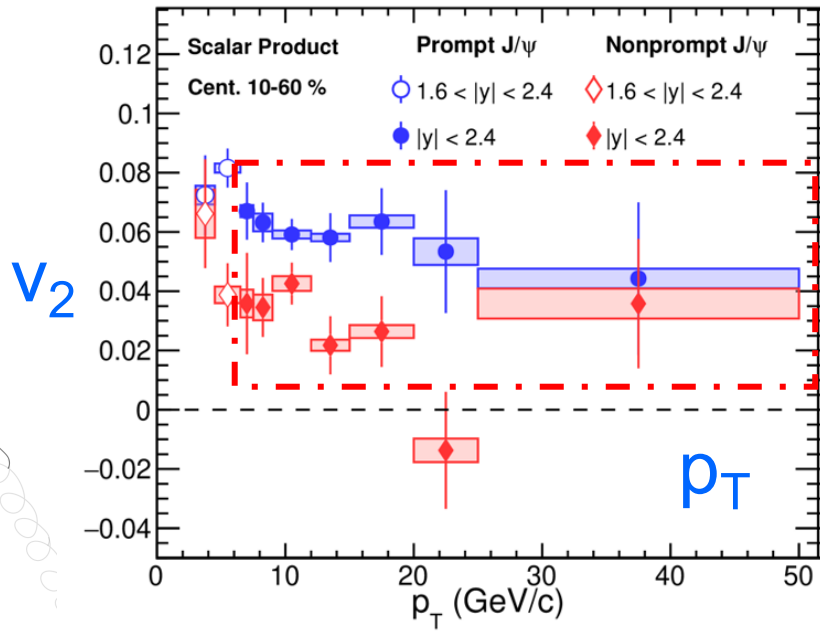
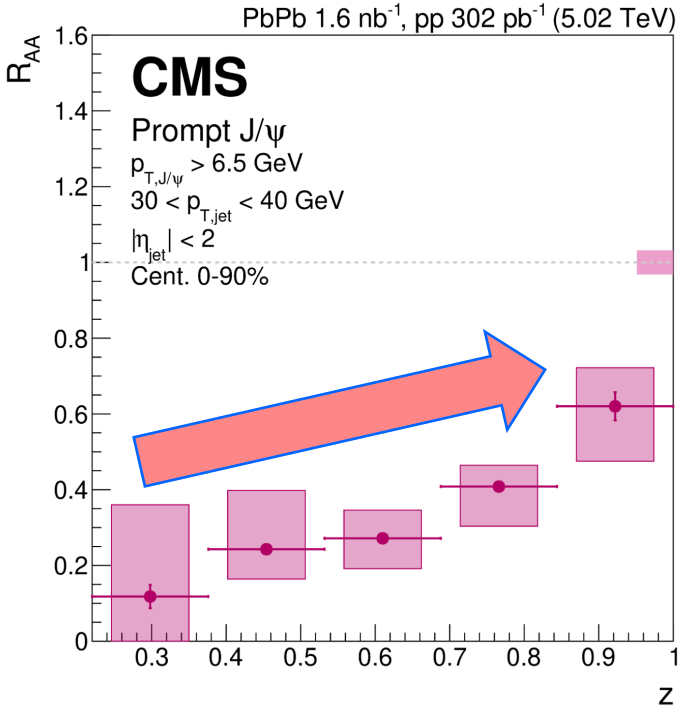


PLB 825 (2021) 136842



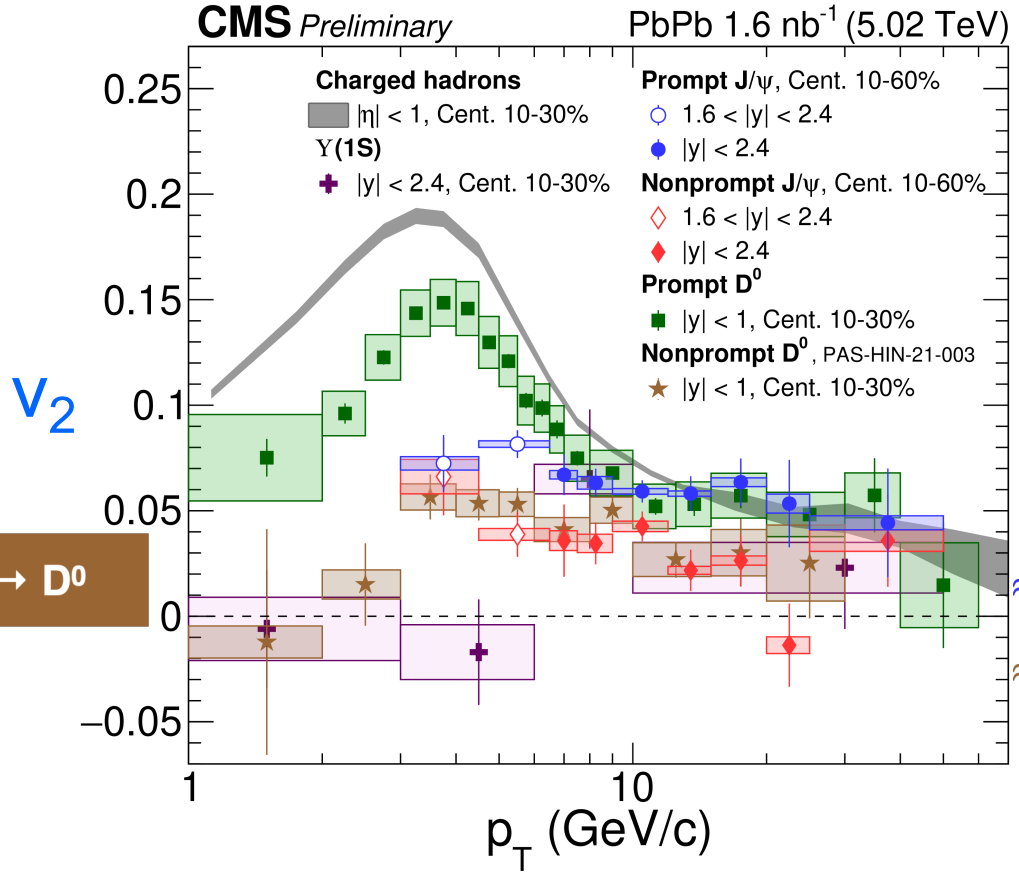
- What we learnt from previous measurements
  - ✓ L… f… c…
  - ✓ L… increasing z >> large suppression happens from Jet quenching

Prompt J/ψ flow in high p_T may be connected to the Jet quenching.

Results : Elliptic flow zoo

CMS-PAS-HIN-21-008
CMS-PAS-HIN-21-003
PLB 816 (2021) 136253
PLB 819 (2021) 136385
PLB 776 (2017) 195

charged hadrons
Prompt D^0
Prompt J/ψ
$b \to J/\psi$
$\approx$
$b \to D^0$
$\Upsilon(1S)$

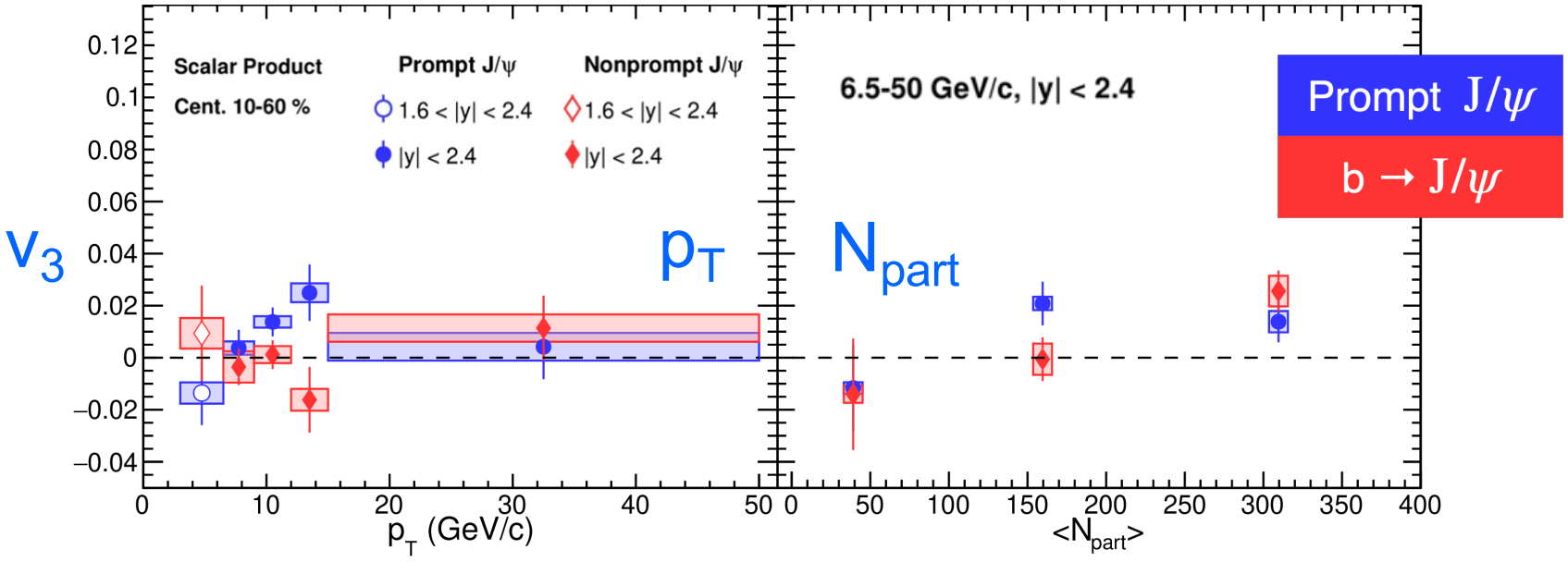


charged hadrons $\approx$ Prompt D^0
Prompt J/ψ $\approx$ $b \to J/\psi$
$b \to D^0$ $\approx$ $\Upsilon(1S)$

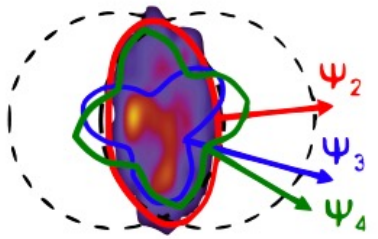
- Low p_T : light > charm > beauty (mass ordering)
- High p_T : universal behaivor for all hadron species

Results : Triangular flow

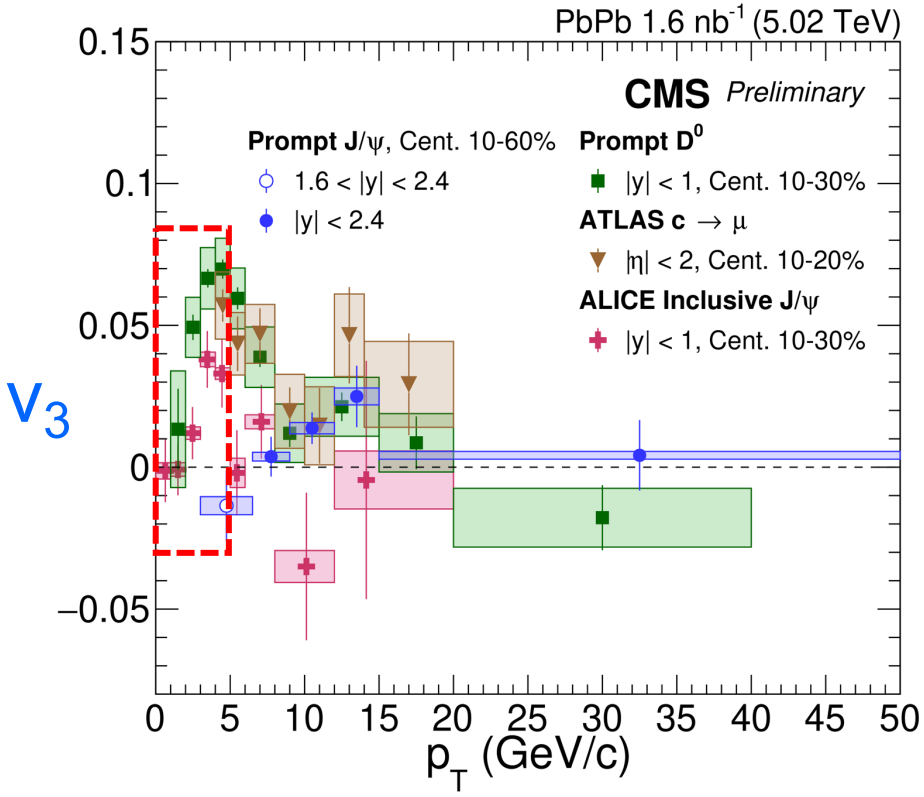
CMS-PAS-HIN-21-008



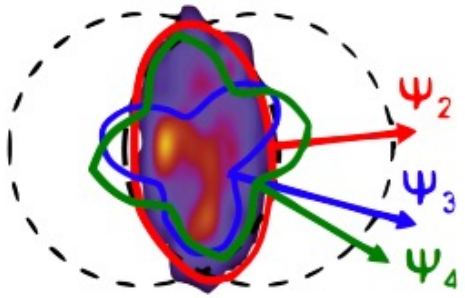
- First separation of Prompt J/ψ and B → J/ψ for triangular flow.
- No significant dependence on p_T and centrality.
- Triangular v_3 are consistent with zero within uncertainties.
  - J/ψ less sensitive to the initial geometry.



Results : Triangular flow



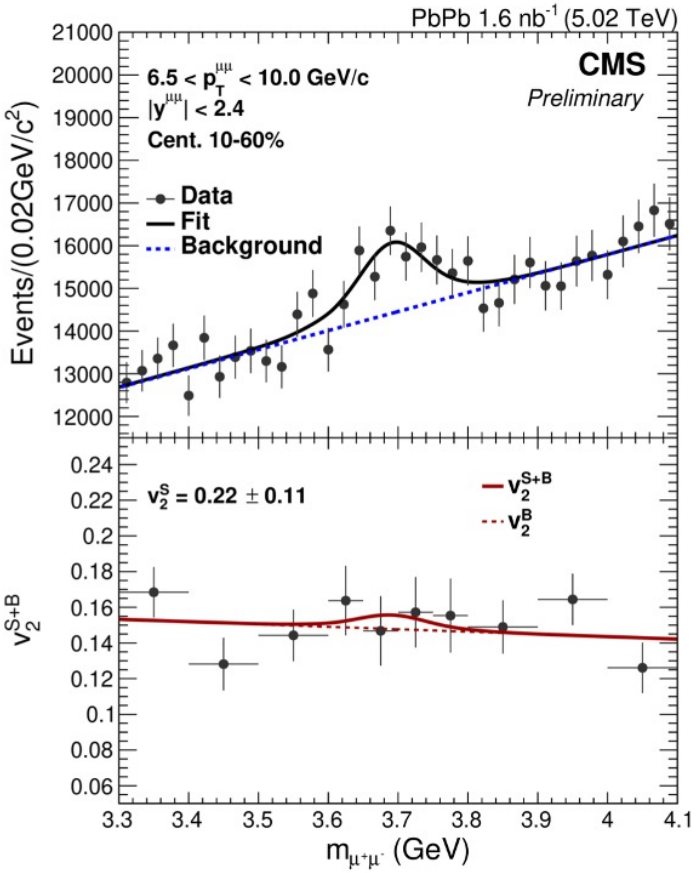
- Consistent v_3 between CMS and ALICE for p_T > 3 GeV/c
- Low-p_T
  - ✓ Open charm v_3 > hidden charm v_3
  - ✓ Initial geometry sensitivity larger for open charm (due to light quarks?)
- High-p_T
  - ✓ v_3 converges and all data are compatible with zero

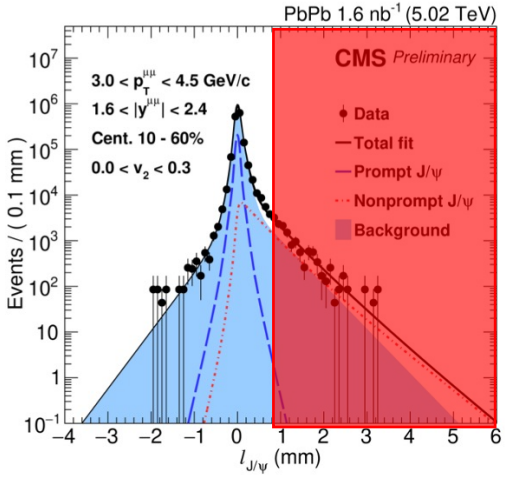


CMS-PAS-HIN-21-008
PLB 816 (2021) 136253
JHEP 10 (2020) 141
PLB 807 (2020) 135595

v_n Extraction for prompt ψ(2S)

CMS-PAS-HIN-21-008





Remove longer decay length ψ(2S)

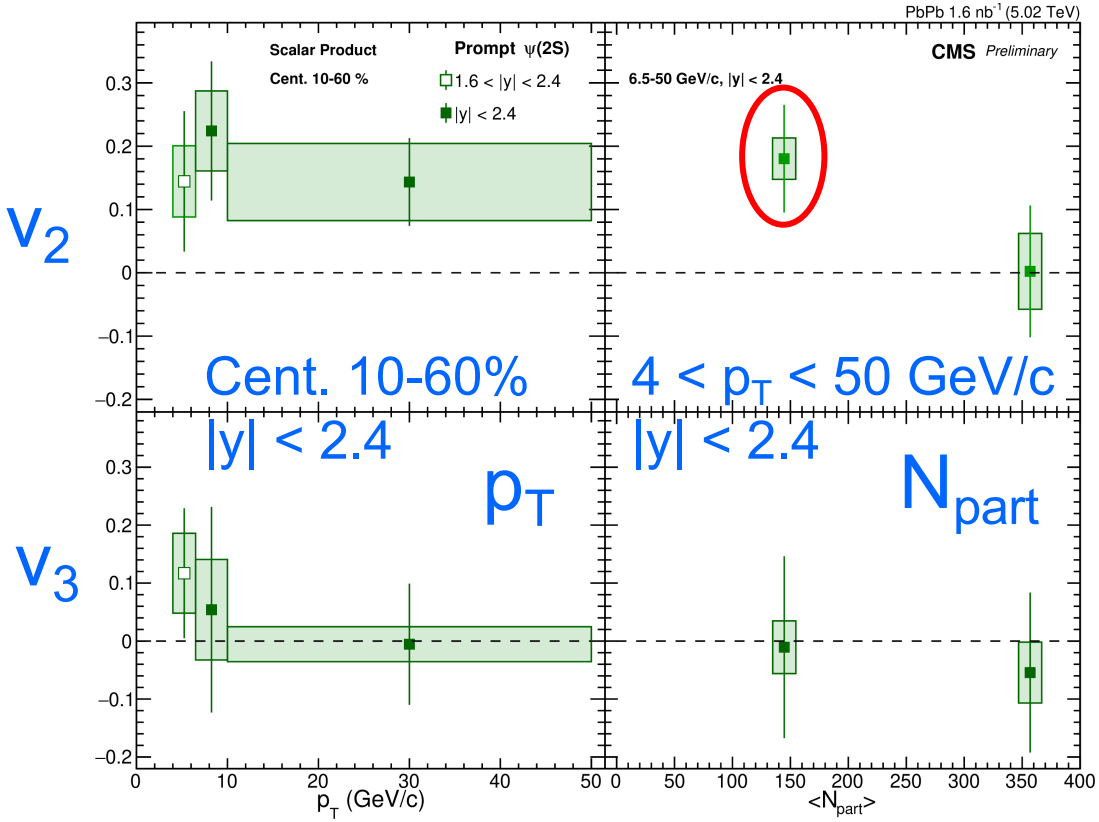
- Prompt enriched sample by rejecting longer decay length (keep 90% prompt ψ(2S))
- Mass and v_n simultaneous fit : two CrystalBall (Sgn) + 1st order polynomial (Bkg)

$$v_n^{Sig+Bkg}(m_{inv}) = \alpha(m_{inv})v_n^{Sig} + (1-\alpha(m_{inv}))v_n^{Bkg}(m_{inv})$$

$$\alpha(m_{inv}) = \frac{Sig(m_{inv})}{Sig(m_{inv}) + Bkg(m_{inv})}$$

Results : Prompt ψ(2S) flows

CMS-PAS-HIN-21-008

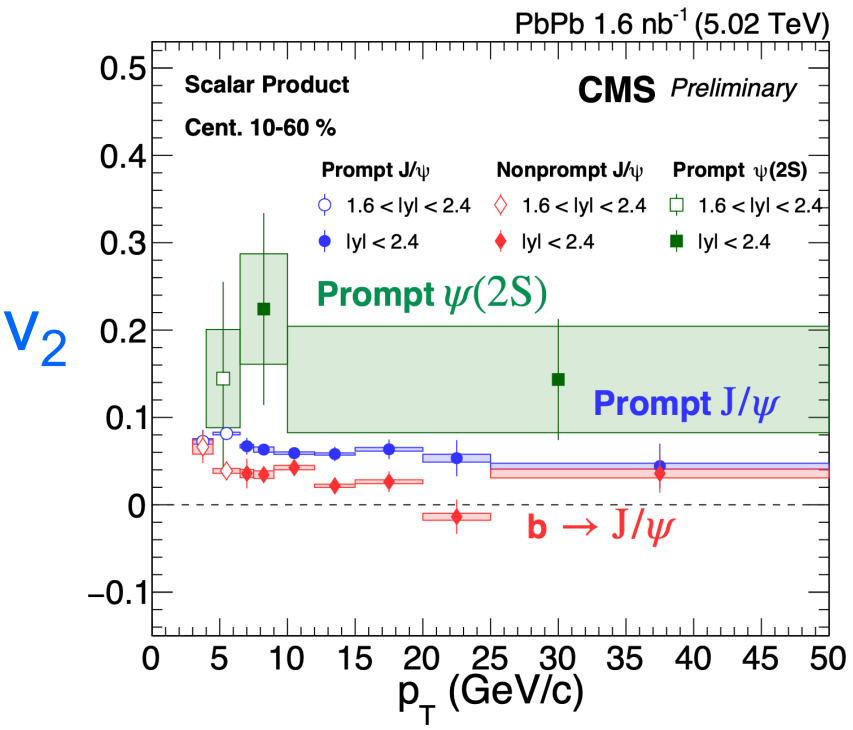


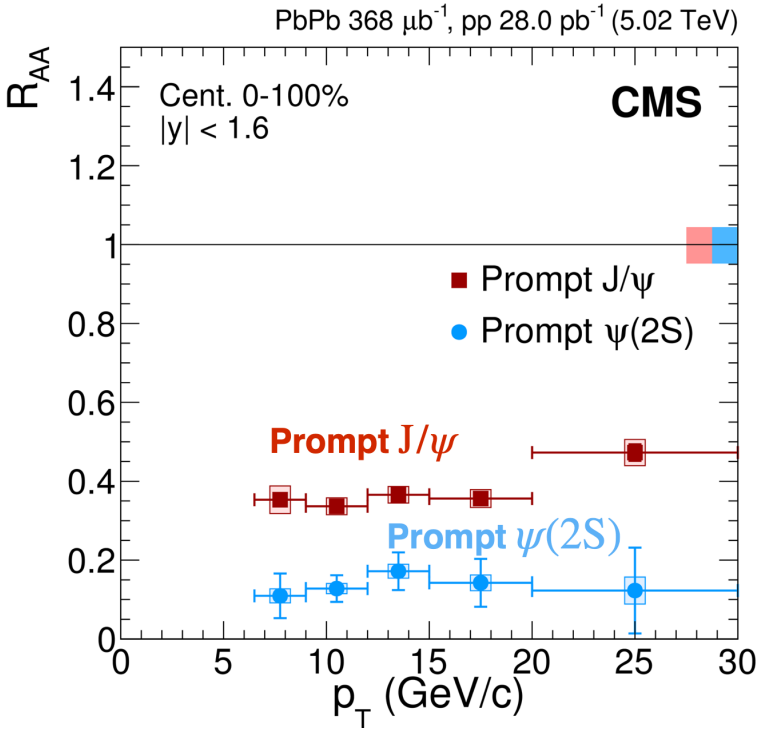
- First measurement in heavy ion collisions.
- Indication of nonzero v_2 in $4 < p_T < 50$ GeV/c and 10-60 % Cent.
- v_2 in ($6.5 < p_T < 50$ GeV/c, 10-60 %) ≈ 0.18 with 2.2 σ significance.
- v_3 values are consistent with zero.

Results : Prompt ψ(2S) flows

CMS-PAS-HIN-21-008

EPJC 78 (2018) 509

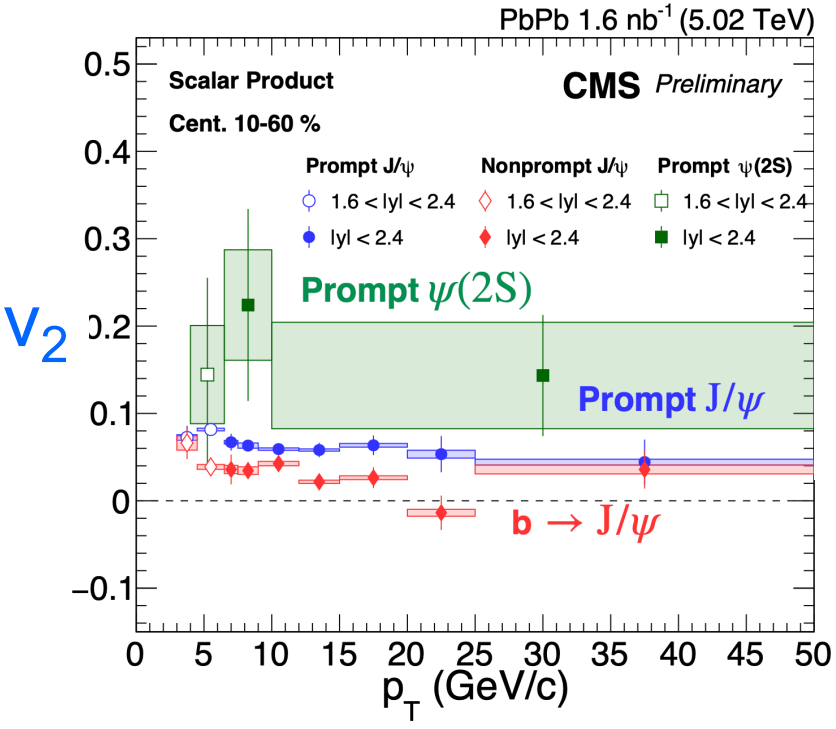




- ψ(2S) v_2 > Prompt J/ψ v_2 ?
- Hard to make any strong conclusion due to large statistical uncertainties, yet.
  - ✓ Need to be revealed with precision data in the future.

Summary

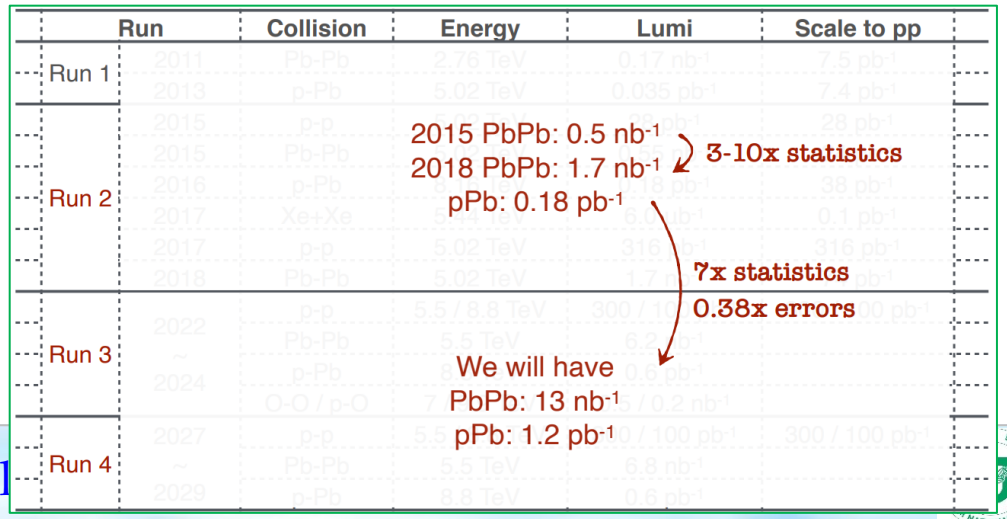
CMS-PAS-HIN-21-008



- Studied azimuthal anisotropy with charmonia in PbPb.
- Prompt J/ψ v_2 > b → J/ψ v_2
- Sizable prompt J/ψ v_2 at high p_T (~ 50 GeV/c)
- First measurements of prompt ψ(2S) v_n !
- Prompt ψ(2S) v_2 ≥ prompt J/ψ v_2

New data coming soon !!!

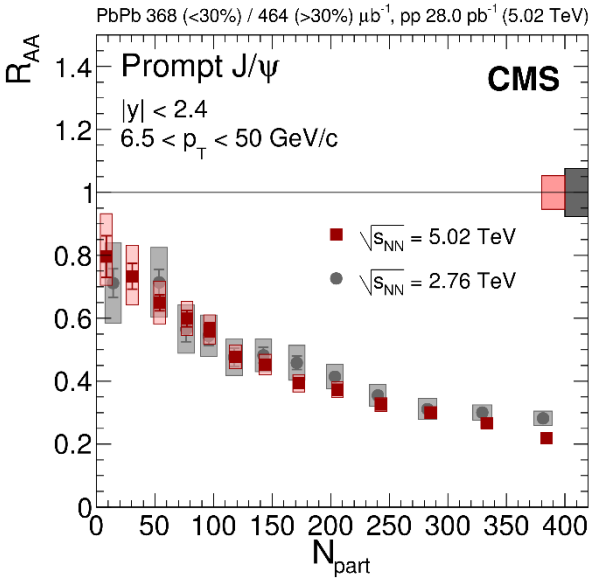
More interesting results will come.

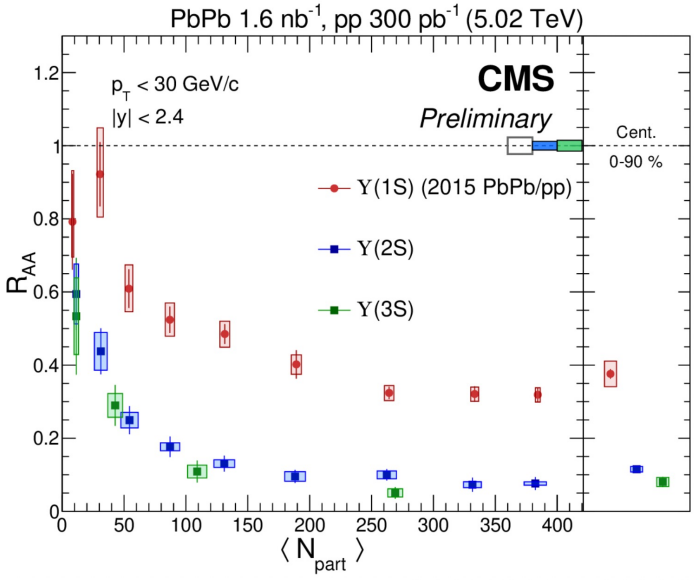


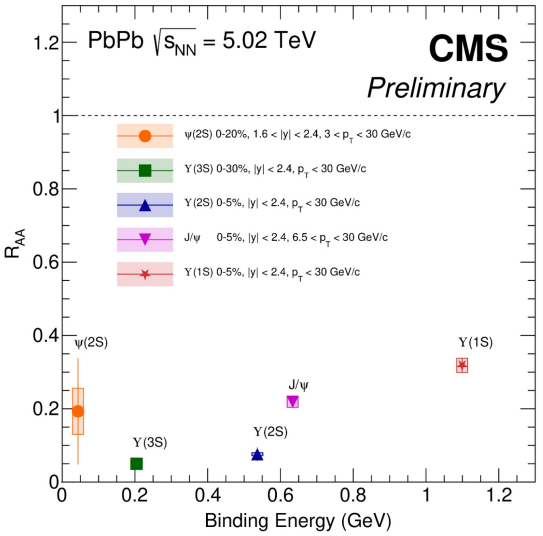
Thank You Very Much
for your attention !!!

Backup

Quarkonia in Heavy ion Collisions

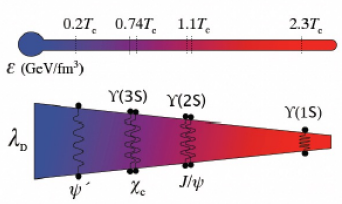


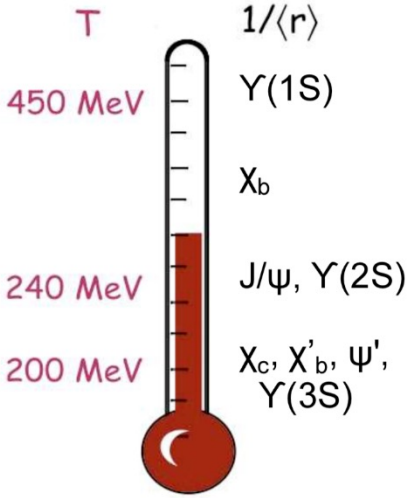




EPJC 77 (2017) 252
CMS-PAS-HIN-21-007

$$R_{AA} = \frac{\text{Yield}_{AA} / \langle N_{Coll} \rangle}{\text{Yield}_{pp}}$$



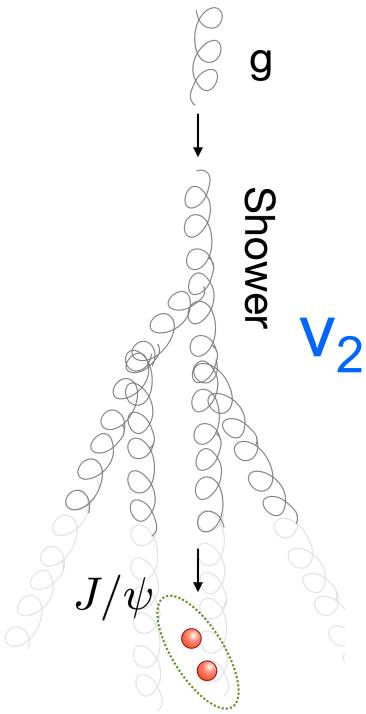


Mocsy, EPJC61 (2009) 705
BNL workshop in June

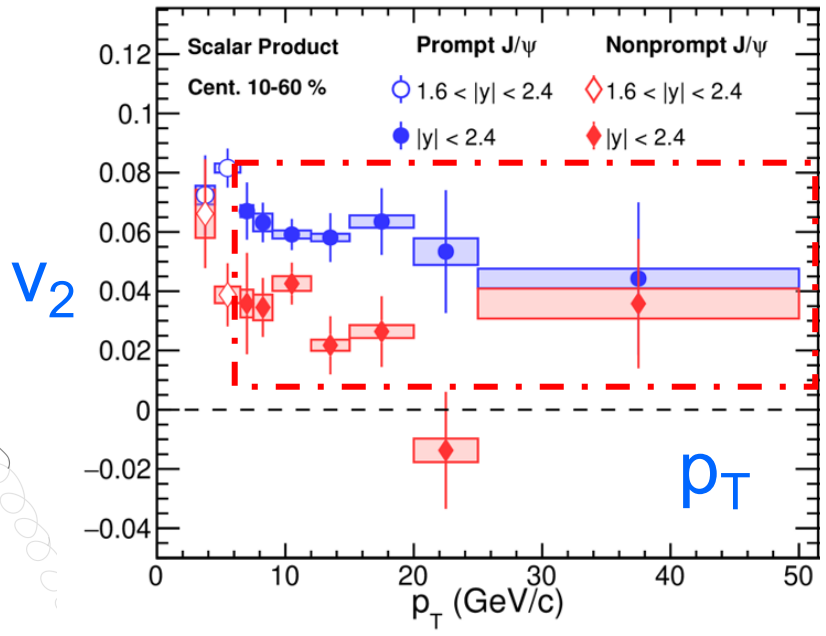
Charmonia	J/ψ	χ_c	ψ'(2S)
Mass(GeV)	3.10	3.53	3.69
ΔE (GeV)	0.64	0.20	0.05
T_d/T_c	2.1	1.16	1.12

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

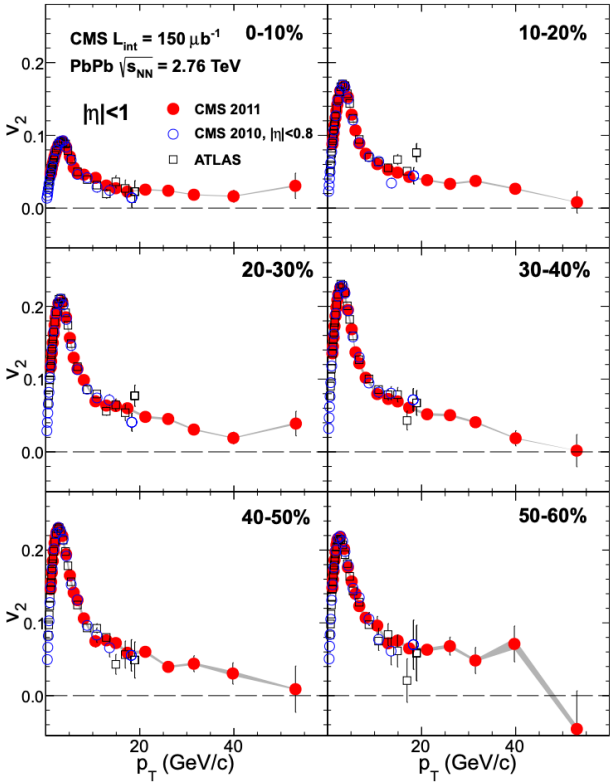
Trying to understand …



CMS-PAS-HIN-21-008



PRL 109 (2012) 022301

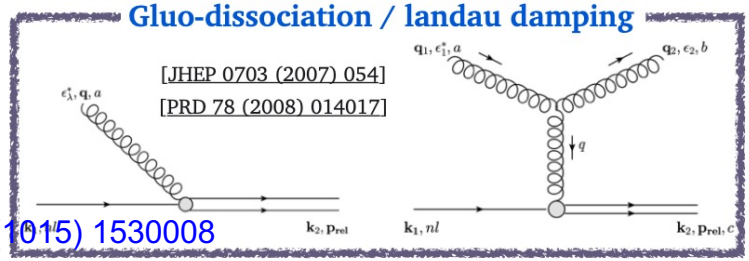


- What we learnt from previous measurements
  - ✓ L… fraction of prompt J/ψ … co…
  - ✓ L… suppression is observed in low z … increasing R_{AA} as increasing z >> large suppression happens from Jet quenching

Prompt J/ψ flow in high p_T may be connected to the Jet quenching.

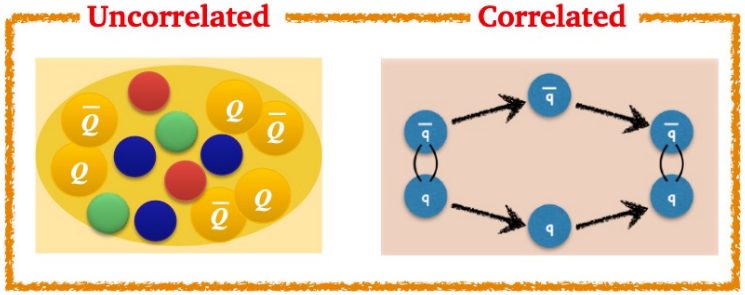
Various in-medium effects

- **Dissociation**
  - Gluo-dissociation / Landau-damping



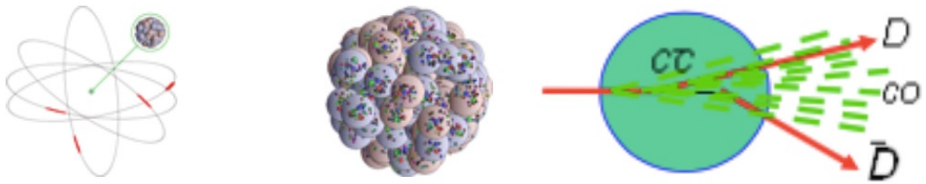
IJMP E 24 (1015) 1530008

- **Recombination (Regeneration)**
  - Uncorrelated (off-diagonal) recombination
  - Correlated (diagonal) recombination

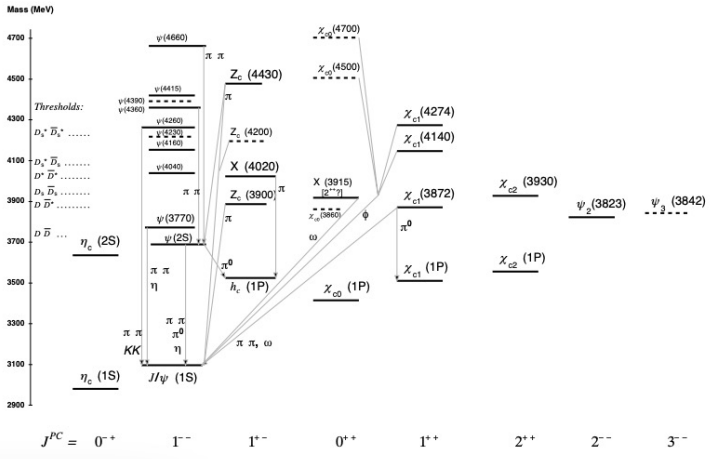


- **Initial/Final state effects of nucleus**
  - nPDF, CGC, coherent energy loss (initial/final)
  - co-mover breakup, nuclear absorption

[IJMP E 24 (2015) 1530008]

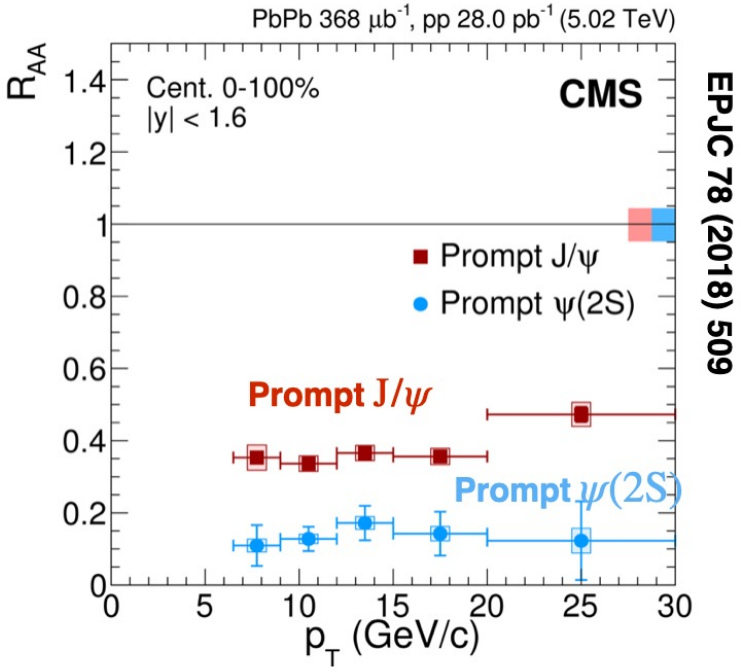


- **Feed-down contributions**

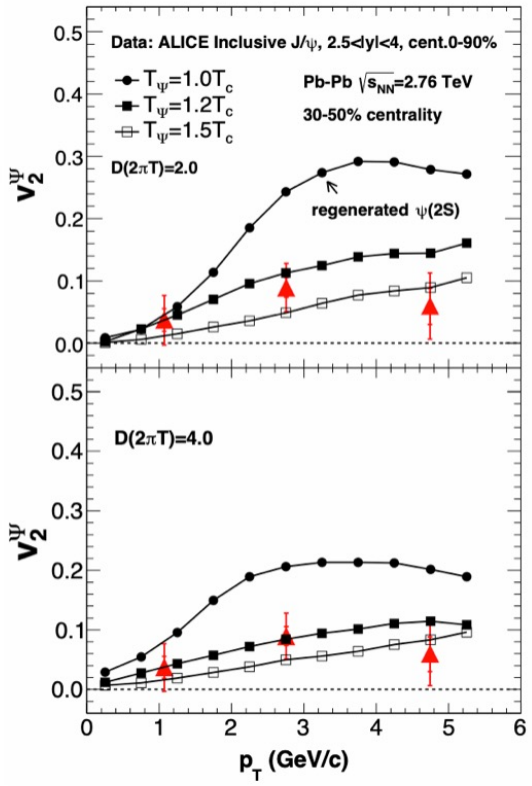


SQM 2022 J. Park

Possible scenario for ψ(2S) v_2



EPJC 78 (2018) 509



Phys. Rev. C 95 (2017), 034908

- $\psi(2S)$ **flow**
  - Not been measured yet in any collision system
  - Different amount of recombination for excited state?