Bottomonia production in pp, pPb and PbPb collisions in CMS

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Outline

- **Introduction**
  - Physics Motivation
  - CMS Detector
- **Υ suppression in PbPb collisions**
  - nuclear modification factor
  - PRL 109 (201) 222301
- **Υ in pPb & pp collisions**
  - single & double ratio
  - event-activity dependence
  - arXiv:1312.6300 (accepted to JHEP)
- **Summary**

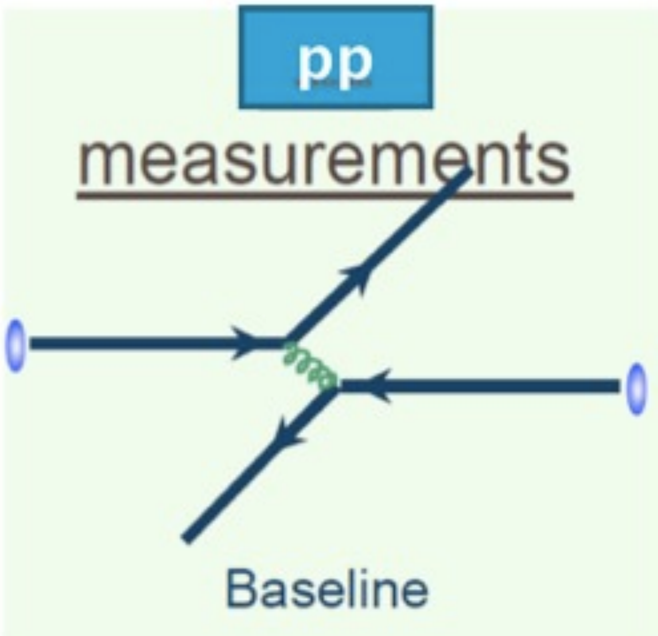
Motivation

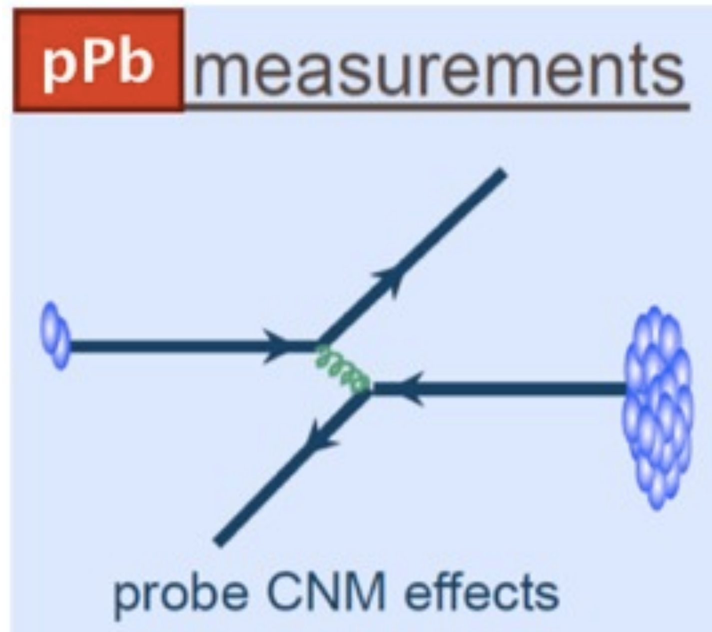
- **Quarkonia**
  - Bound states of heavy quark and antiquark
  - Large mass requires a large momentum transfer in hard gluon-gluon scattering during the early stage of the collisions.

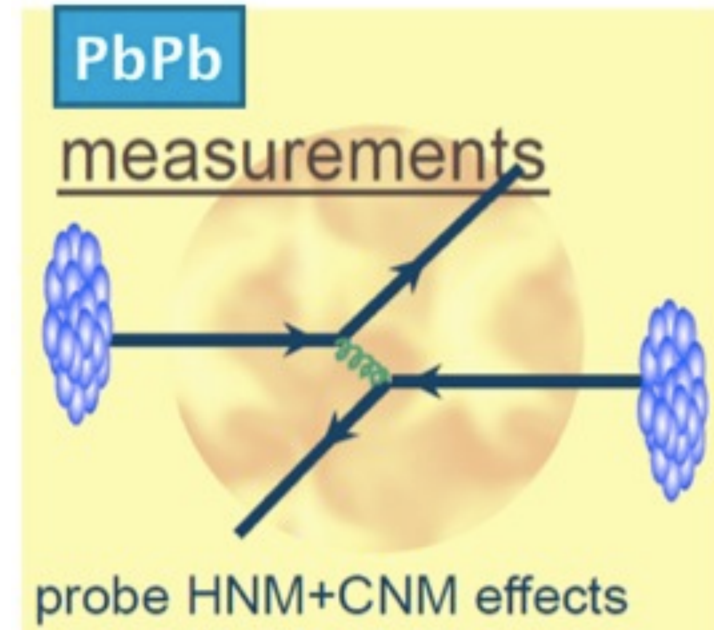
- **Bottomonia measurement in CMS**
  - Three Υ states are characterized by similar kinematics but different binding energy.
  - the excellent momentum resolution of CMS allows separation of all three states.
  - decay channel to $\mu^+\mu^-$: clean probe and easy to detect (BR ~ 2.5%)

Resonance	J/ψ	Ψ'	Υ(1S)	Υ(2S)	Υ(3S)
Mass [GeV]	3.10	3.68	9.46	10.02	10.36
ΔE [GeV]	0.64	0.05	1.10	0.54	0.20
Radius [fm]	0.25	0.45	0.14	0.28	0.39

different collision systems



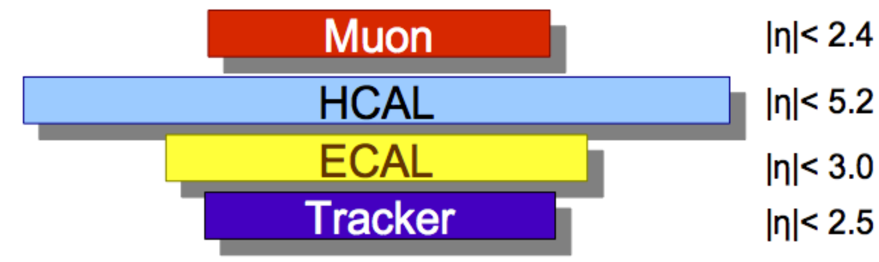


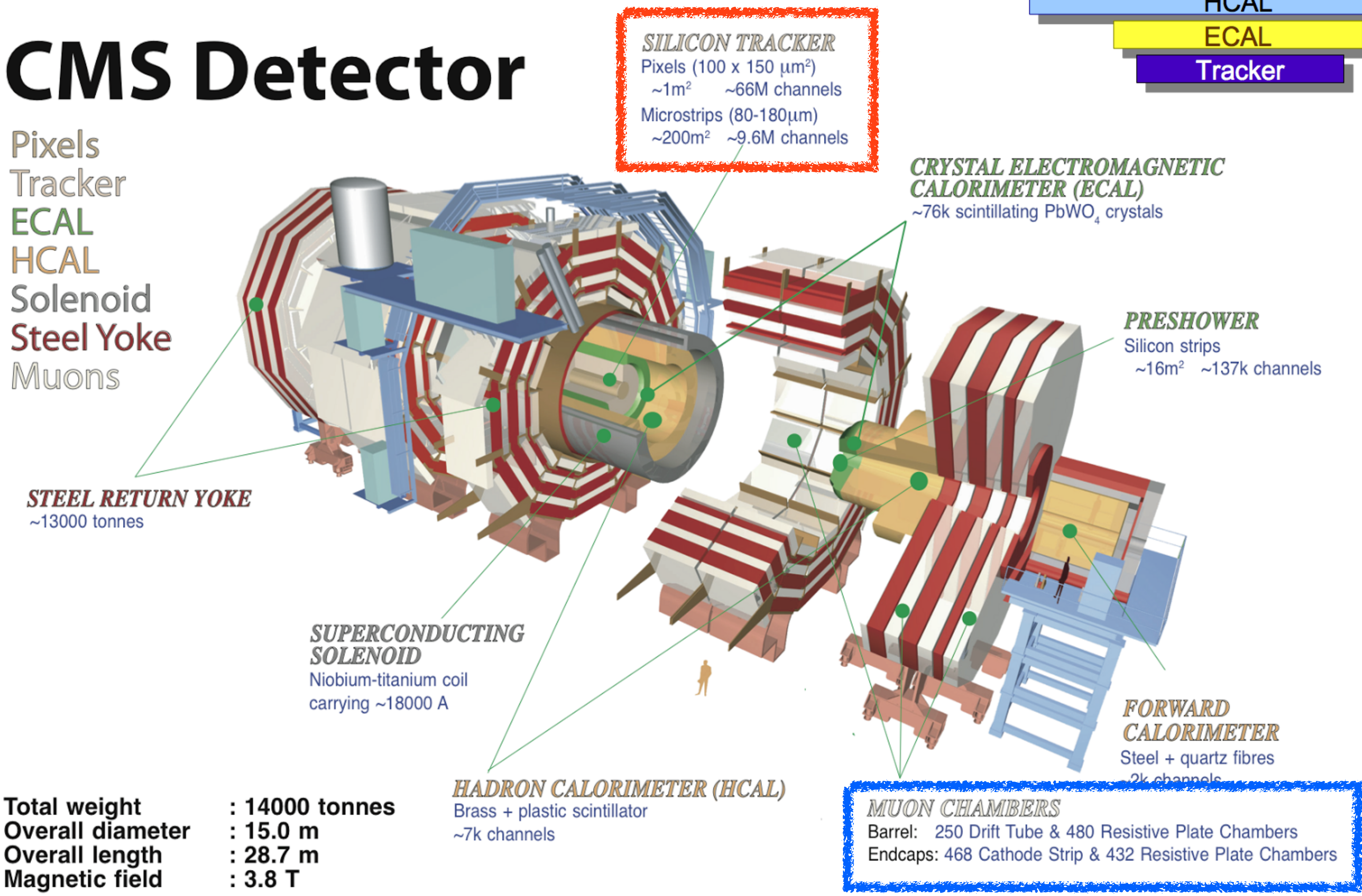


- **Deconfined medium effects in PbPb**
  - Quark-gluon plasma is formed in central collisions
  - Loosely bound states (with smaller binding energies) melt at lower temperature.
    - Sequential melting for different state is predicted.

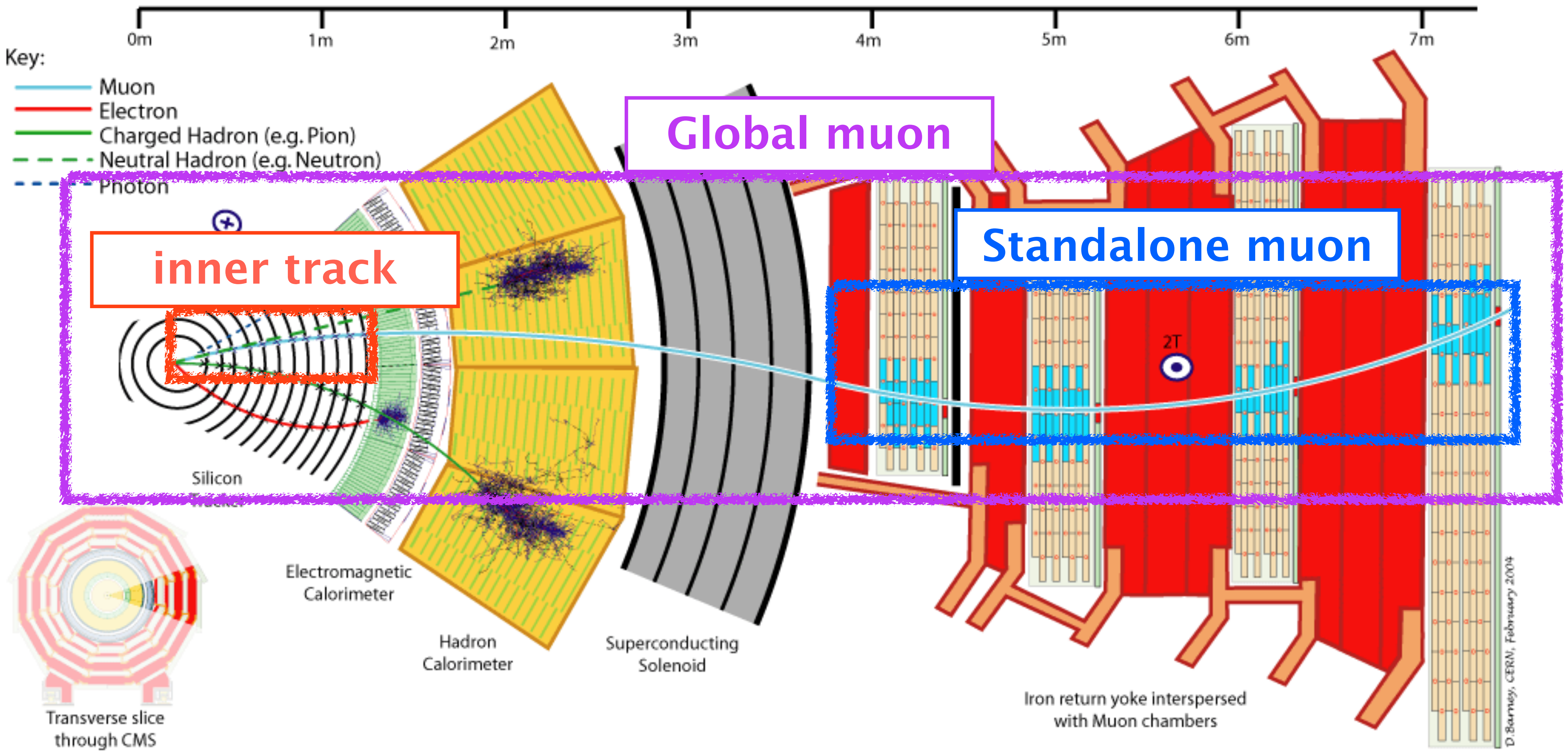
- **Cold nuclear matter effects in pPb**
  - Initial state energy loss, comover break up, modification of nPDF, etc.
  - provide a better understanding of the effects from QGP
  - CNM itself is a interesting matter.

CMS detector





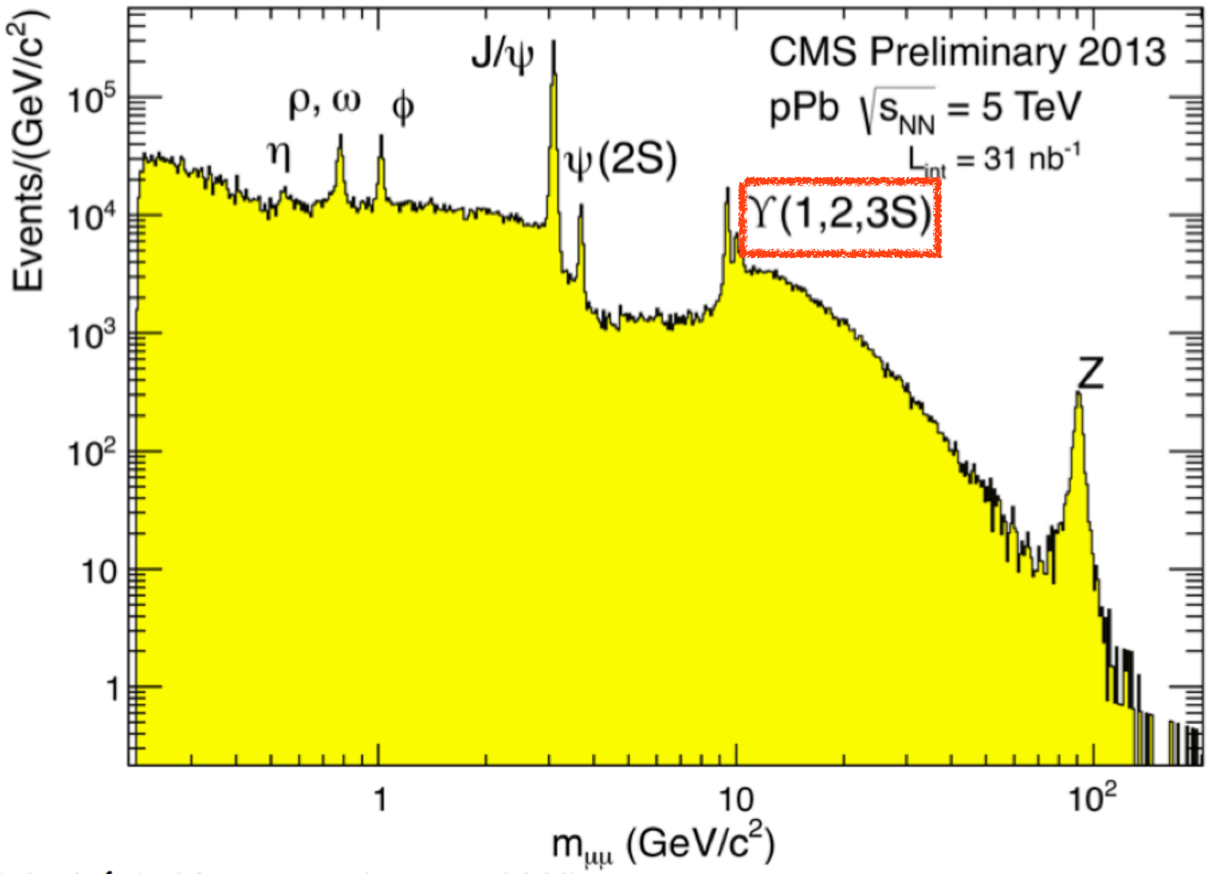
Muon Reconstruction



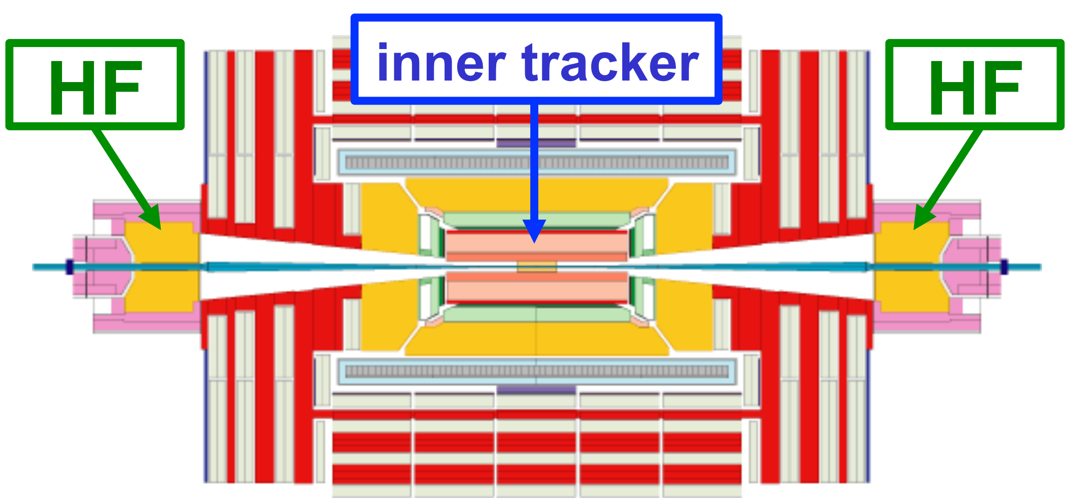
- Excellent muon Identification and triggering in the muon system
- Outstanding momentum and vertex resolution of the tracking system

pPb collisions in 2013

- **1st pPb run @ LHC in Jan.–Feb. 2013**
  - $\sqrt{S_{NN}}$ = 5.02 TeV
  - L_{int} = 34.7 nb^{-1}
- **pp run in 09–14th Feb. 2013**
  - $\sqrt{S_{NN}}$ = 2.76 TeV
  - L_{int} = 5.4 pb^{-1}
  - x20 more statistics than 2011 pp data



- **Two event-activity variables**
  - N_{tracks} : charged particle multiplicity in **inner tracker** (|η|<2.4, p_T>0.4 GeV/c)
  - E_T^{HF} : raw transverse energy deposited in forward region **HF** (4<|η|<5.2)

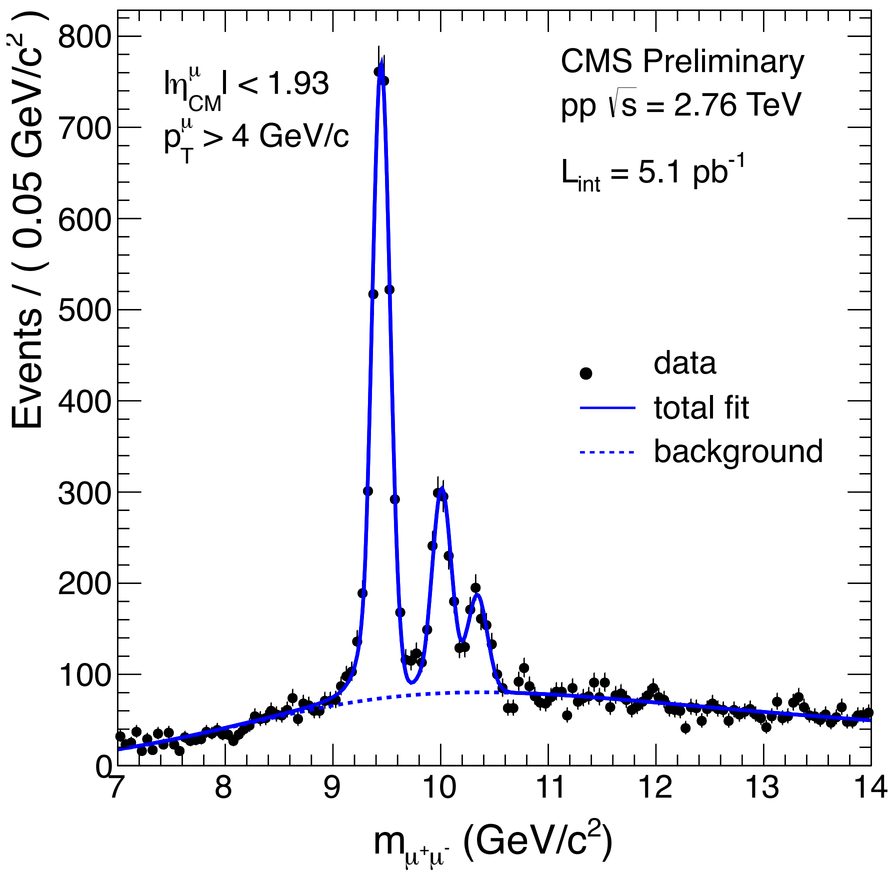


Invariant mass distributions

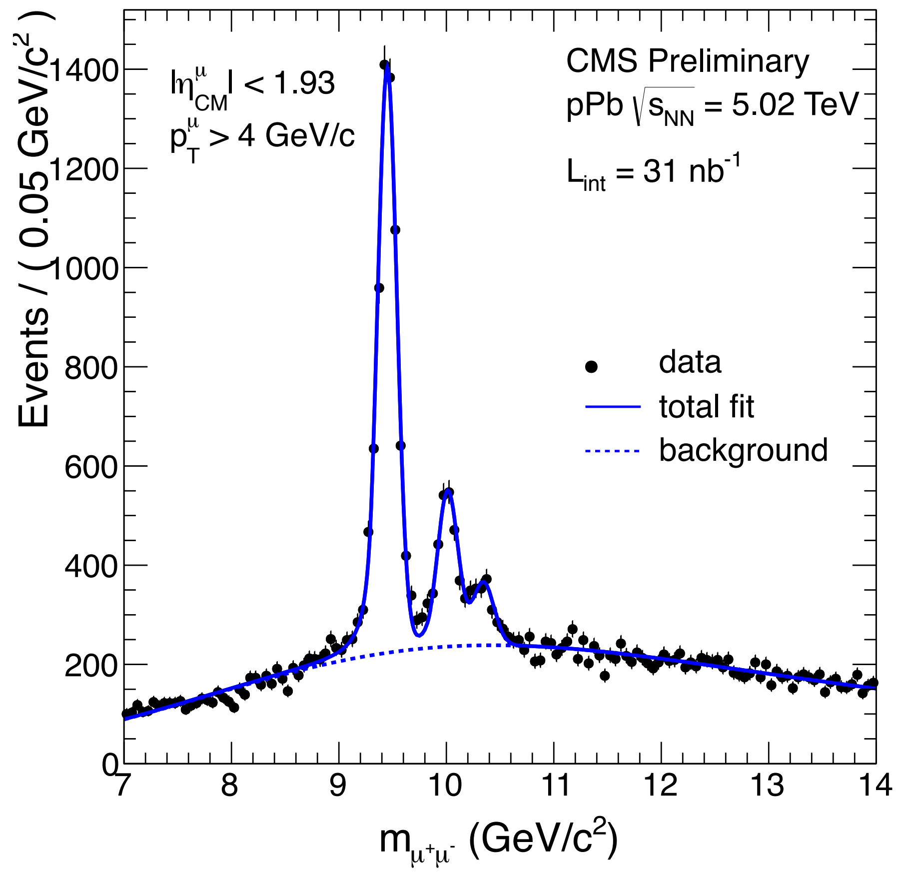
PRL 109 (2012) 222301

arXiv:1312.6300

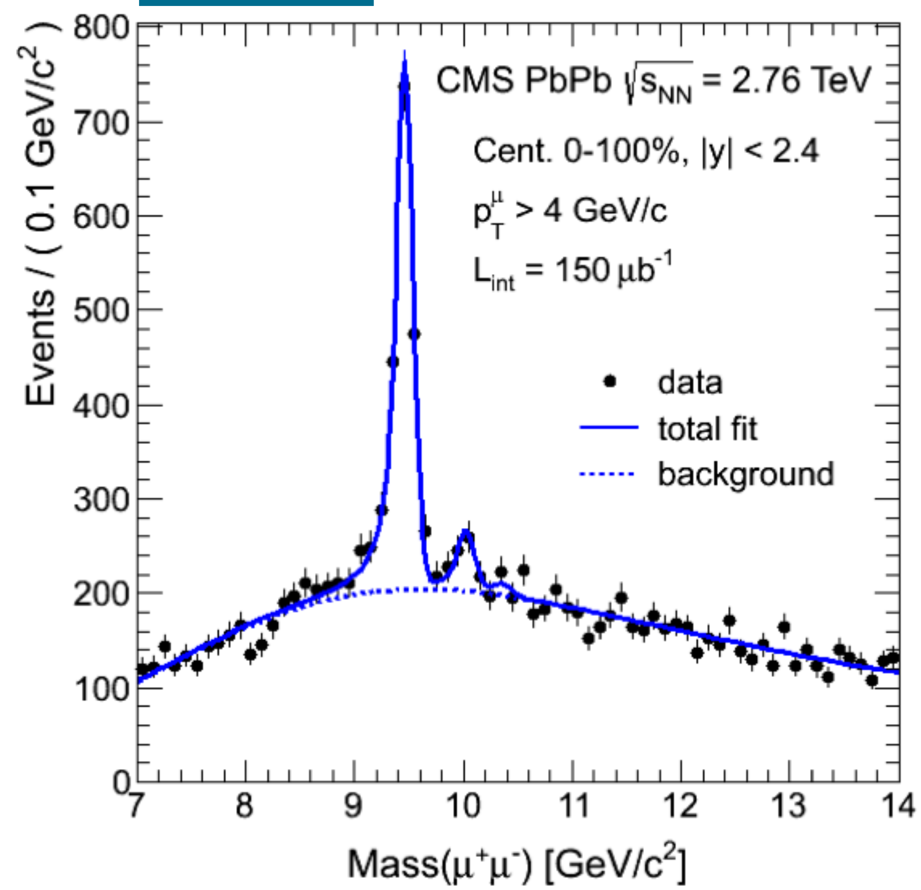
2013 pp



pPb



PbPb



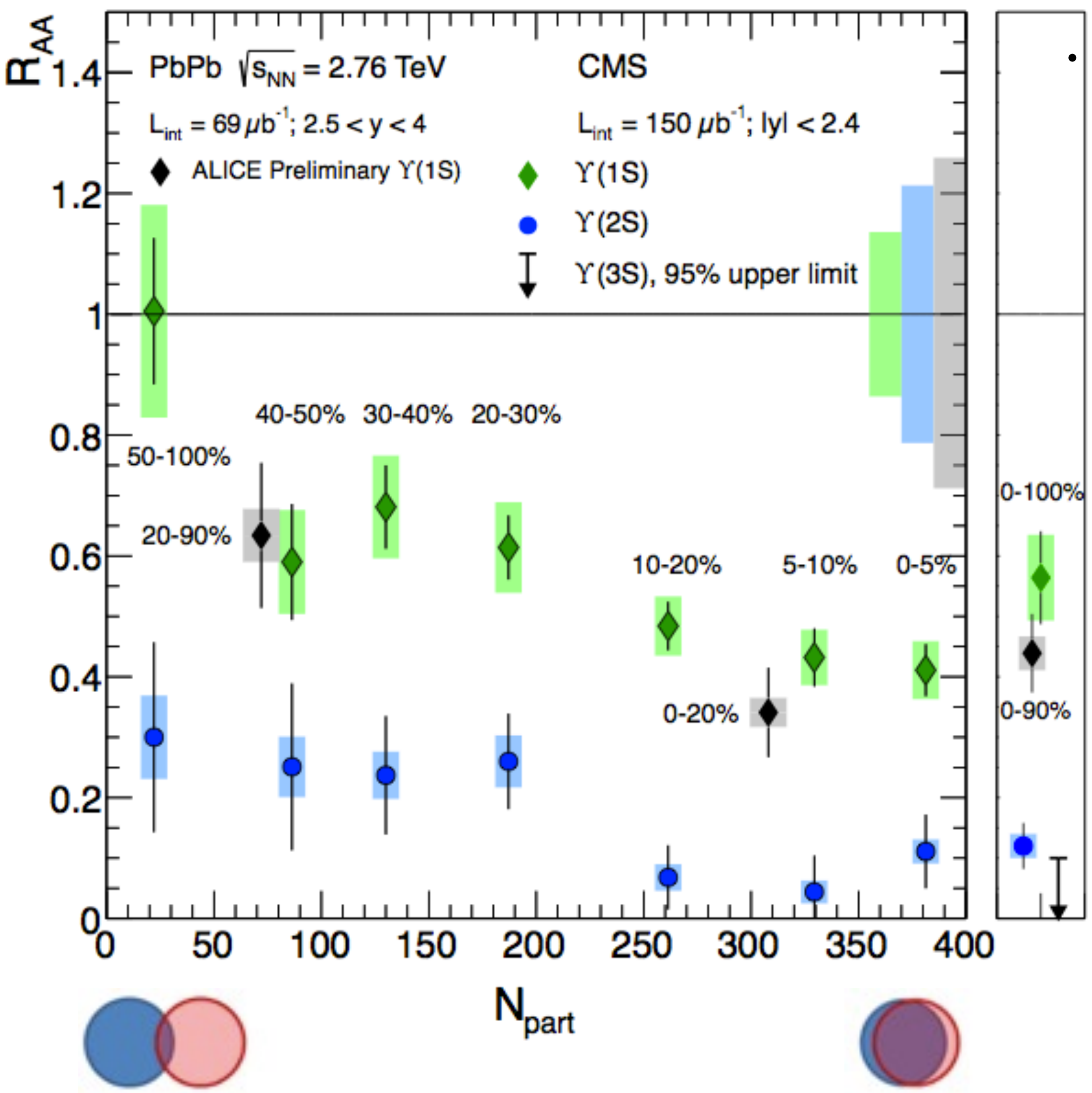
- Fitting procedure is same in pp, pPb, and PbPb analysis.
- In PbPb, ϒ(2S) is mildly suppressed and the peak for ϒ(3S) is hardly visible.

Suppression of Υ(nS) in PbPb

- **Nuclear modification factor**

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

- $R_{AA} = 1$, No modification compared to pp collisions
- $R_{AA} < 1$, There is a 'suppression'



- **Centrality integrated results**

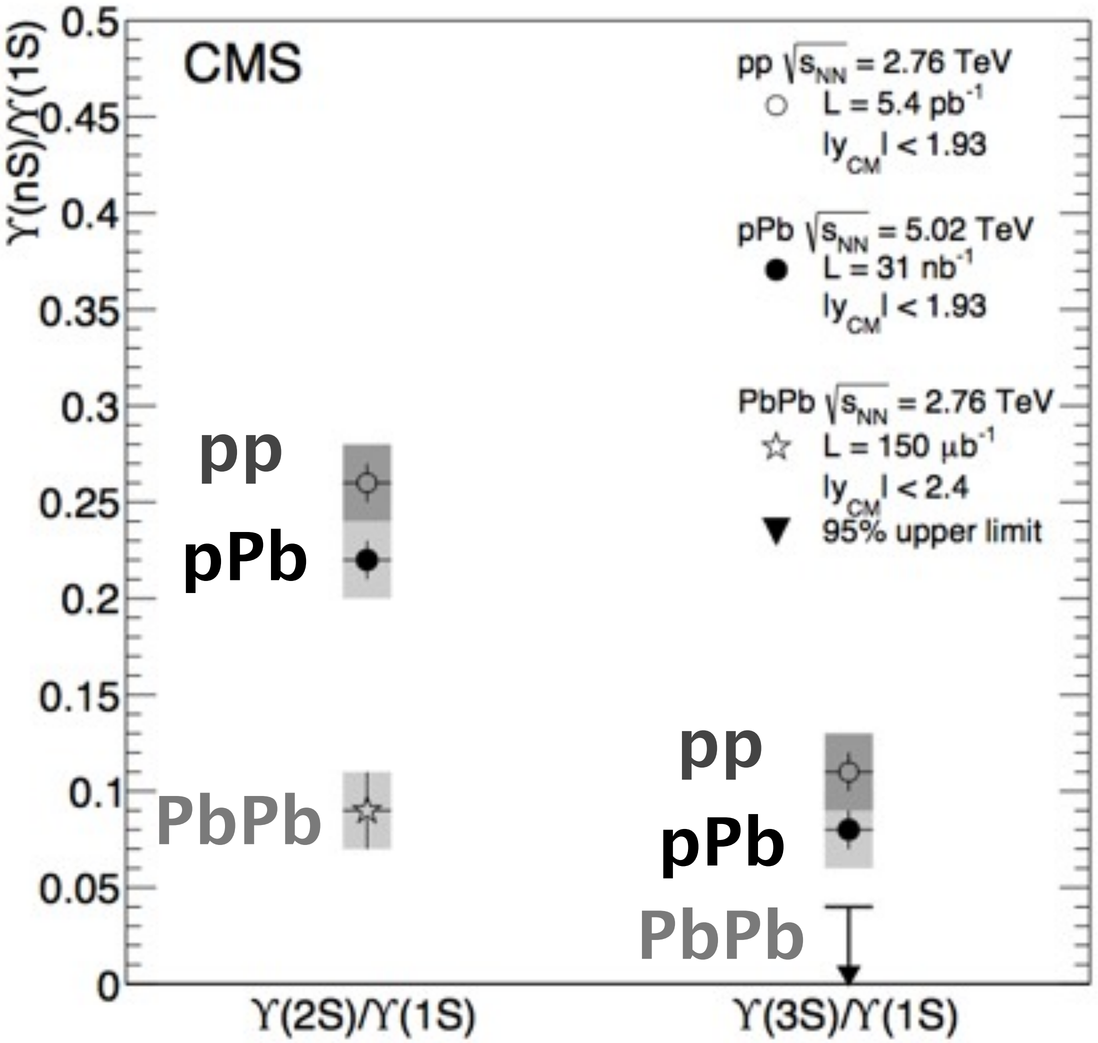
$$R_{AA}(\Upsilon(1S)) = 0.56 \pm 0.08\,(\text{stat.}) \pm 0.07\,(\text{syst.})$$
$$R_{AA}(\Upsilon(2S)) = 0.12 \pm 0.04\,(\text{stat.}) \pm 0.02\,(\text{syst.})$$
$$R_{AA}(\Upsilon(3S)) = 0.03 \pm 0.04\,(\text{stat.}) \pm 0.01\,(\text{syst.})$$
$$(< 0.10 \text{ at } 95\% \text{ CL})$$

- **Υ states suppressed sequentially**

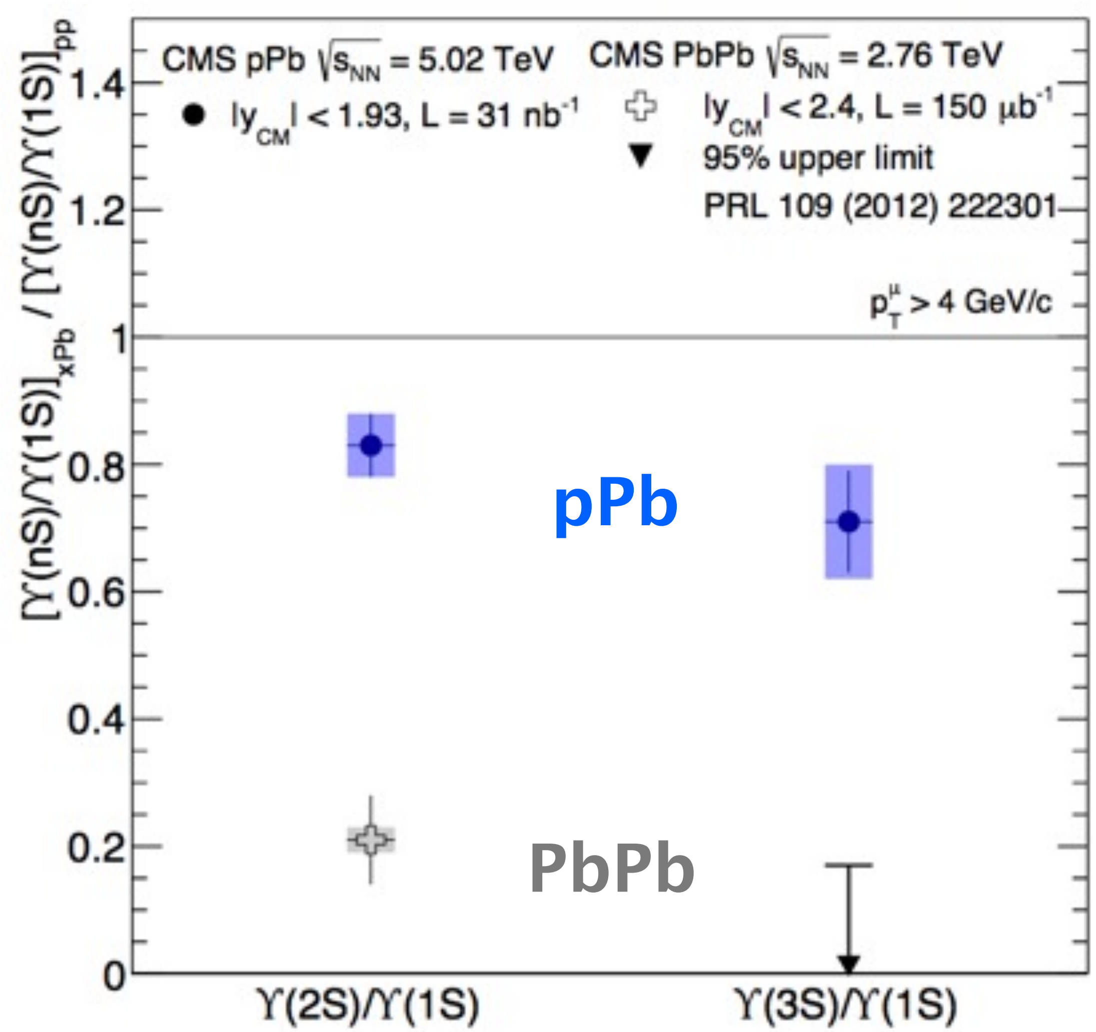
$R_{AA}[\Upsilon(1S)] > R_{AA}[\Upsilon(2S)] > R_{AA}[\Upsilon(3S)]$

Double & Single ratios

- **Single Ratios**
  : excited to ground state



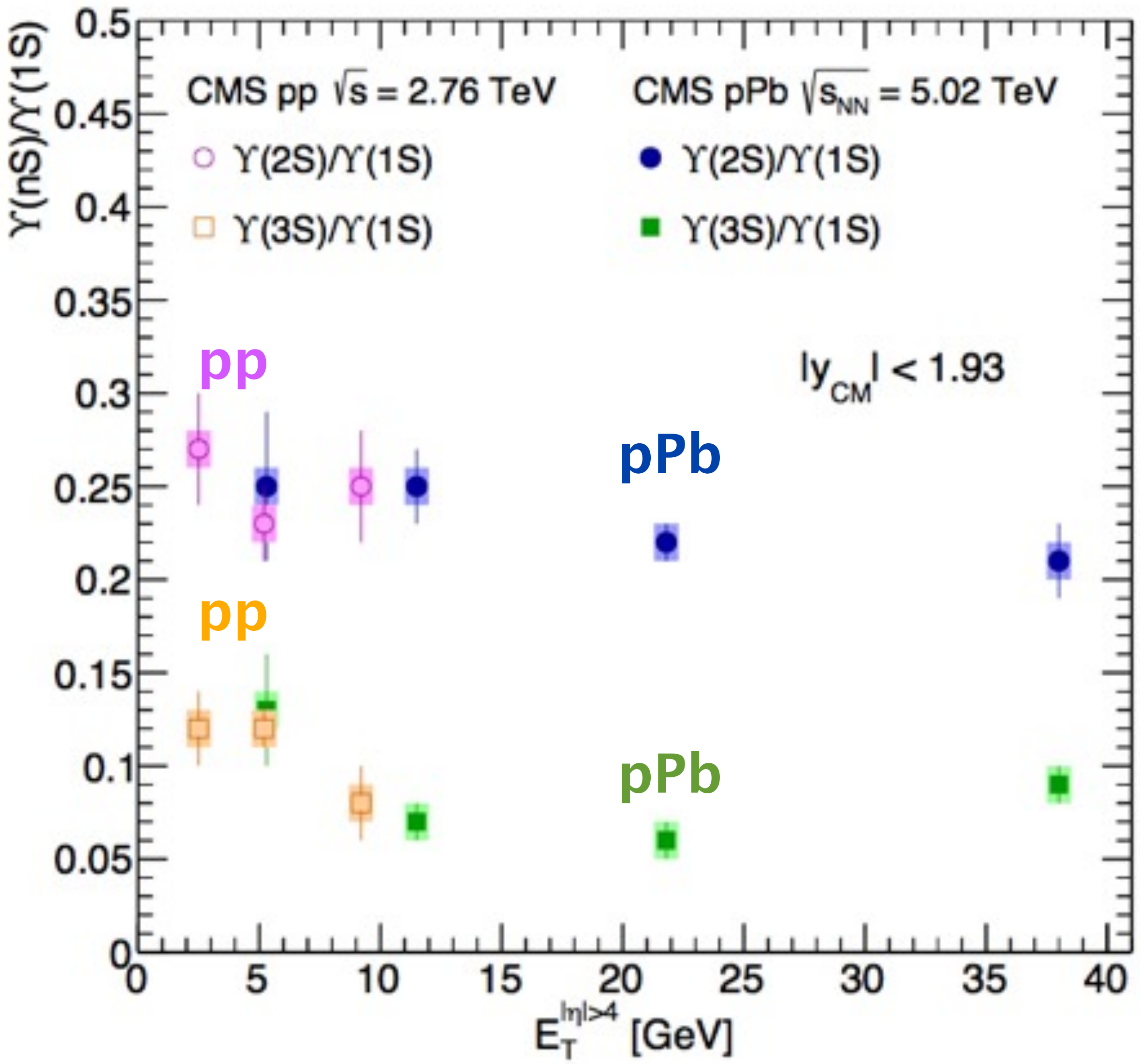
- **Double Ratios**
  : Compare single ratios in pp, pPb, PbPb

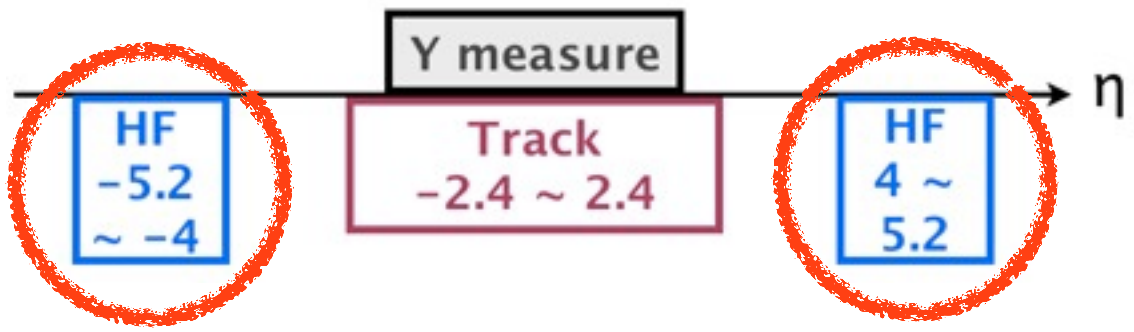


- **pPb vs pp** : Excited states are suppressed more than the ground state in pPb compared to pp.
- **PbPb vs pPb** : Additional final state effects in PbPb that affect the excited states more than the ground state.

Event activity - E_T^{HF}

- **Single ratio vs E_T**



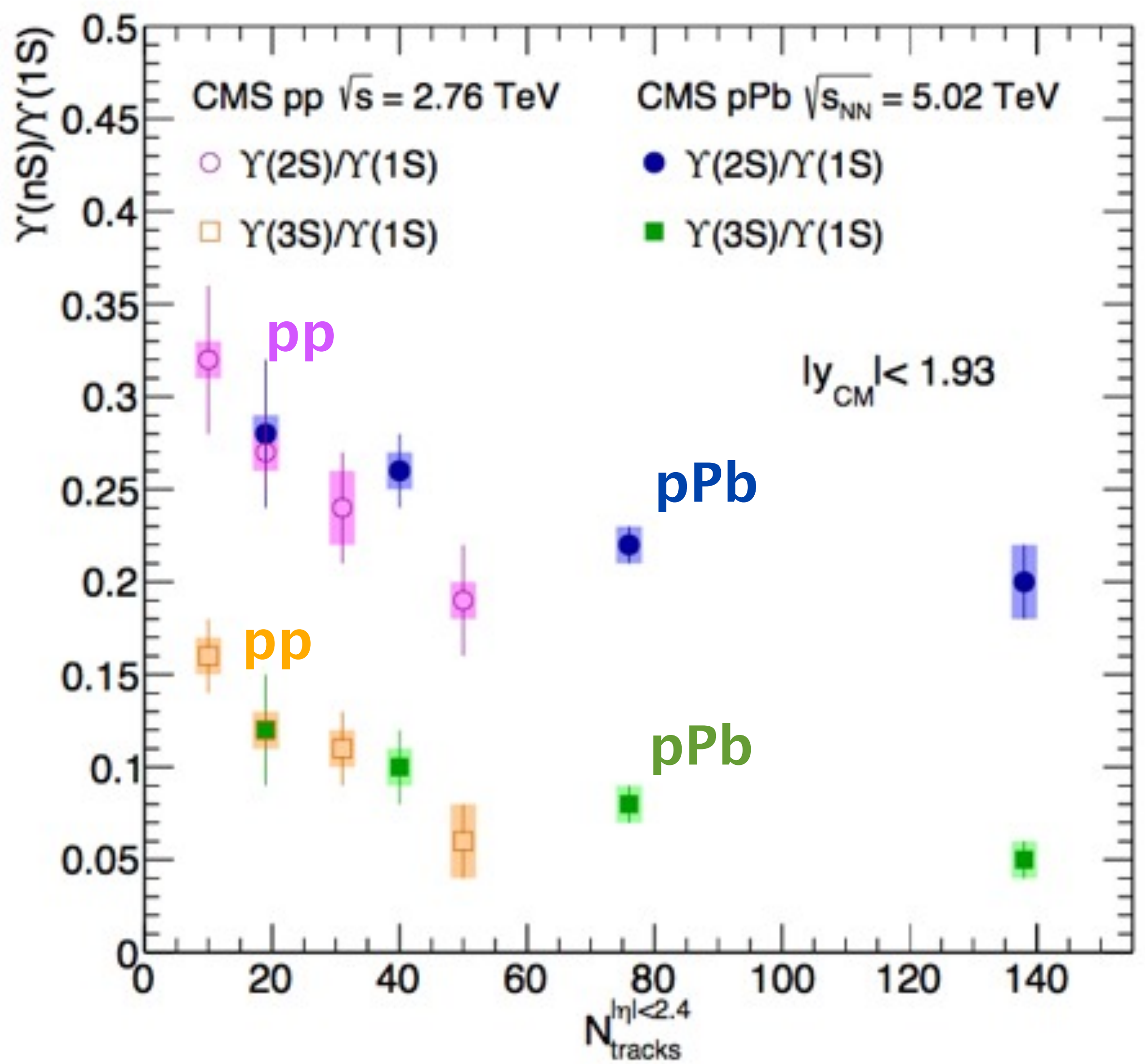


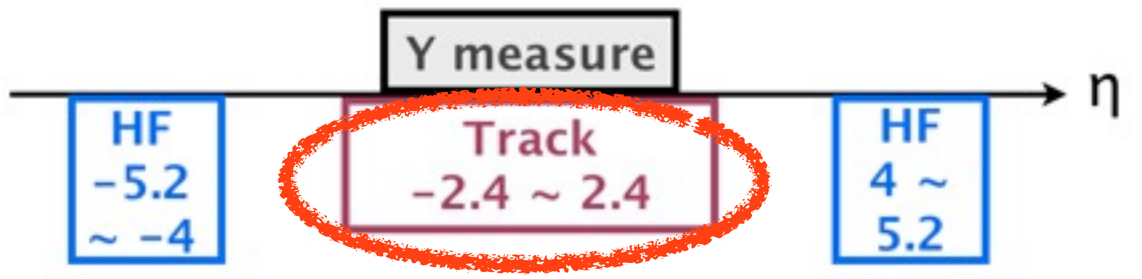
Event activity is measured far from Υ

- Single ratios for both pp and pPb show very weak dependence on E_T.

Event activity - N_{tracks}

- **Single ratio vs N_{tracks}**

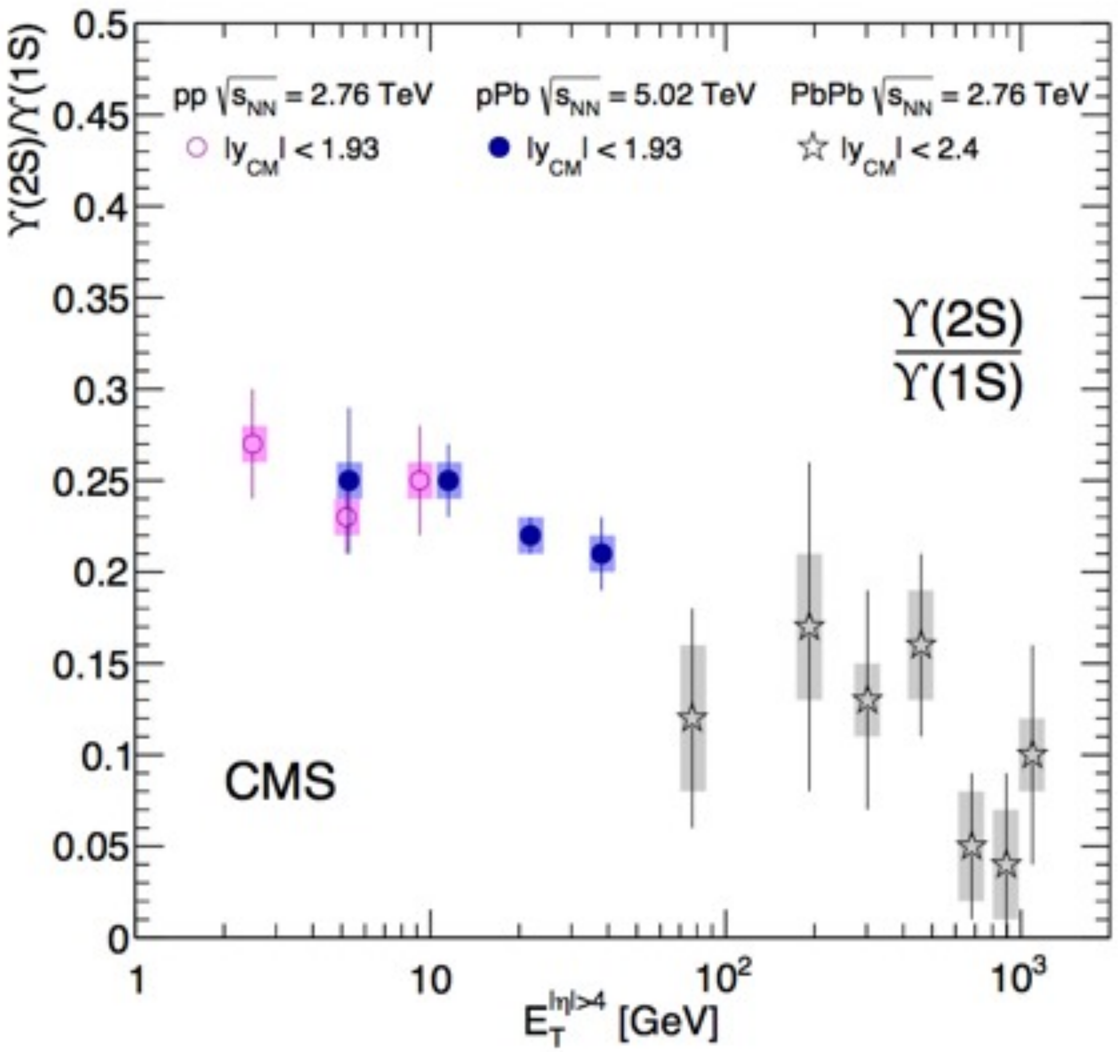


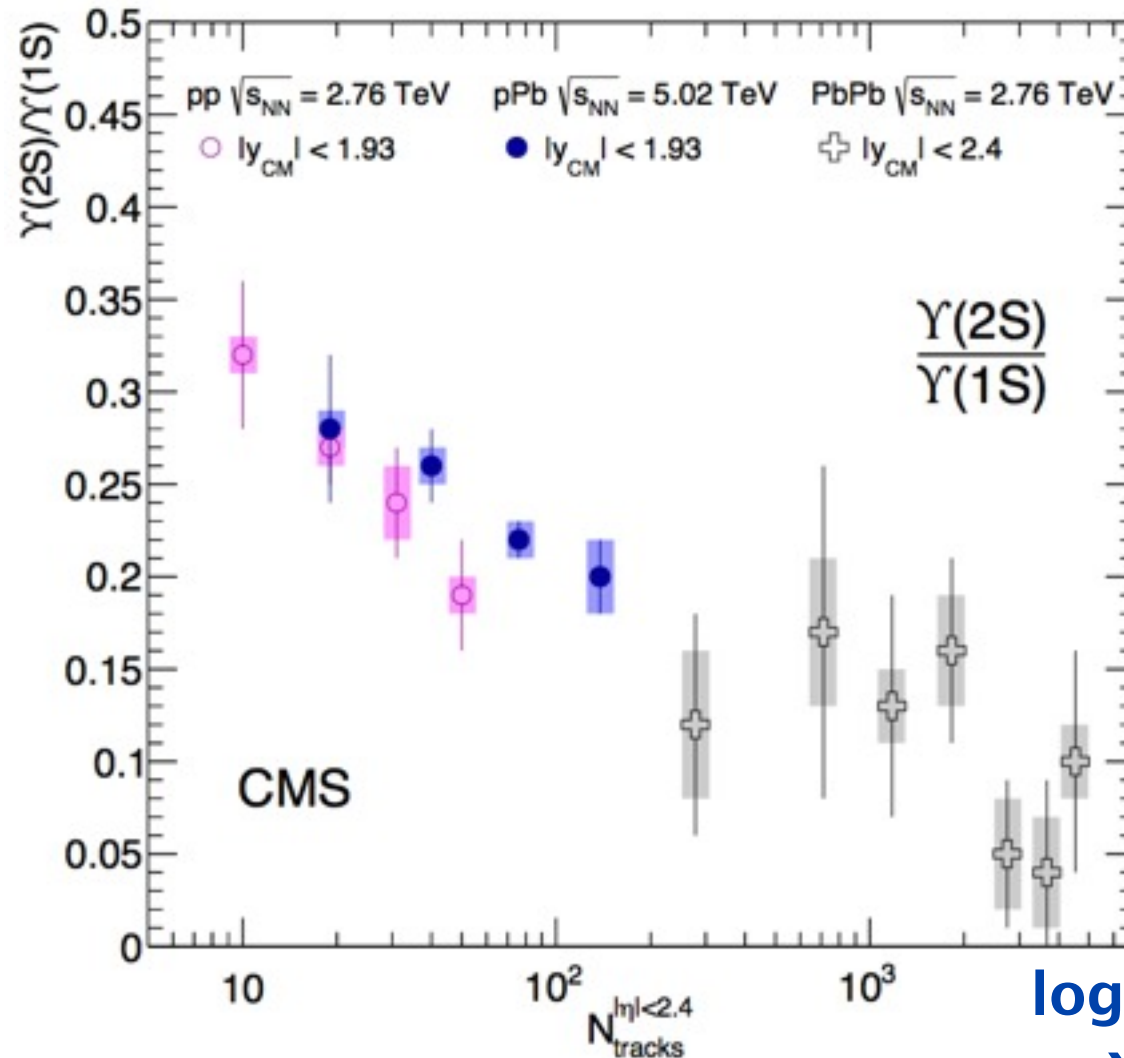


Event activity is measured near Υ

- Significant decreasing trend with increasing N_{tracks}.
  - Two possible scenarios – Υ would affect the multiplicity ?
    – Multiplicity would affect the Υ ?

Event activity : pp vs pPb vs PbPb





logarithmic x-axis

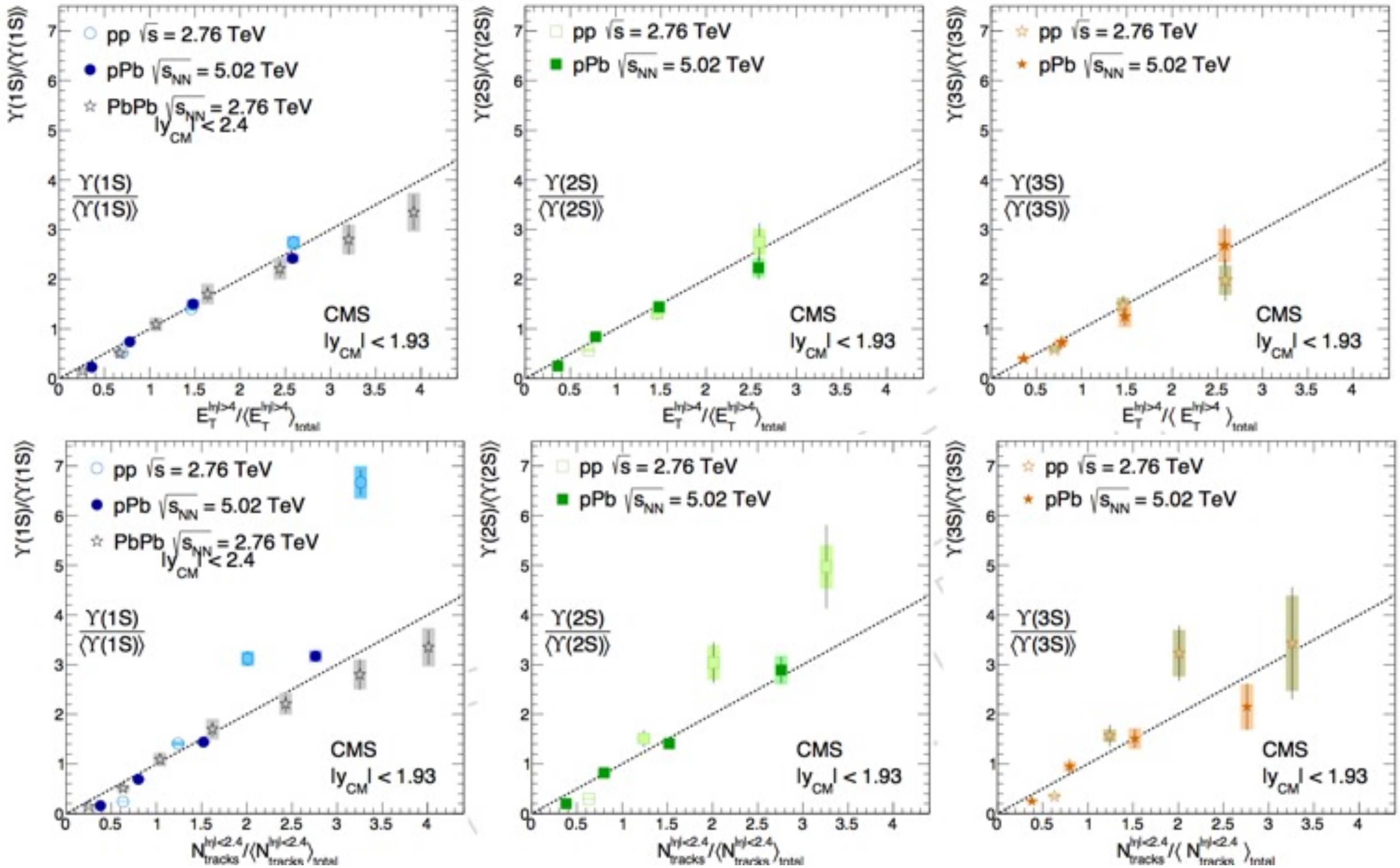
- PbPb bin has little overlap with pPb, preventing direct comparison.
- In PbPb, centrality dependence is not pronounced.
- In pp and pPb, single ratios are above PbPb

Self-normalized cross-sections

self-normalized to their activity integrated value

$$\frac{E_T^{|\eta>4|}}{\langle E_T^{|\eta>4|}\rangle_{total}}$$

$$\frac{N_{tracks}}{\langle N_{tracks}\rangle_{total}}$$



- Rising trends with increasing E_T and N_{tracks}
  - pp : possible interpretation is the multi-parton interactions
  - pPb, PbPb : trends arise from the increase in N_{coll}
- E_T: For each of 3 colliding systems, the slope consistent with ~ 1

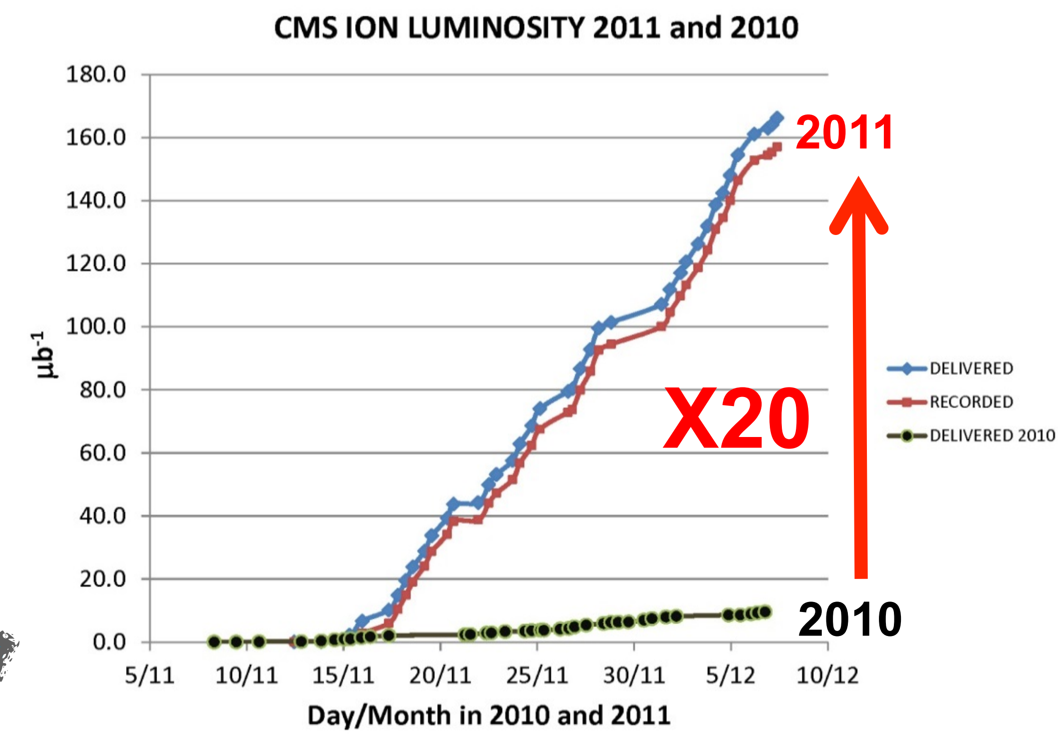
Summary

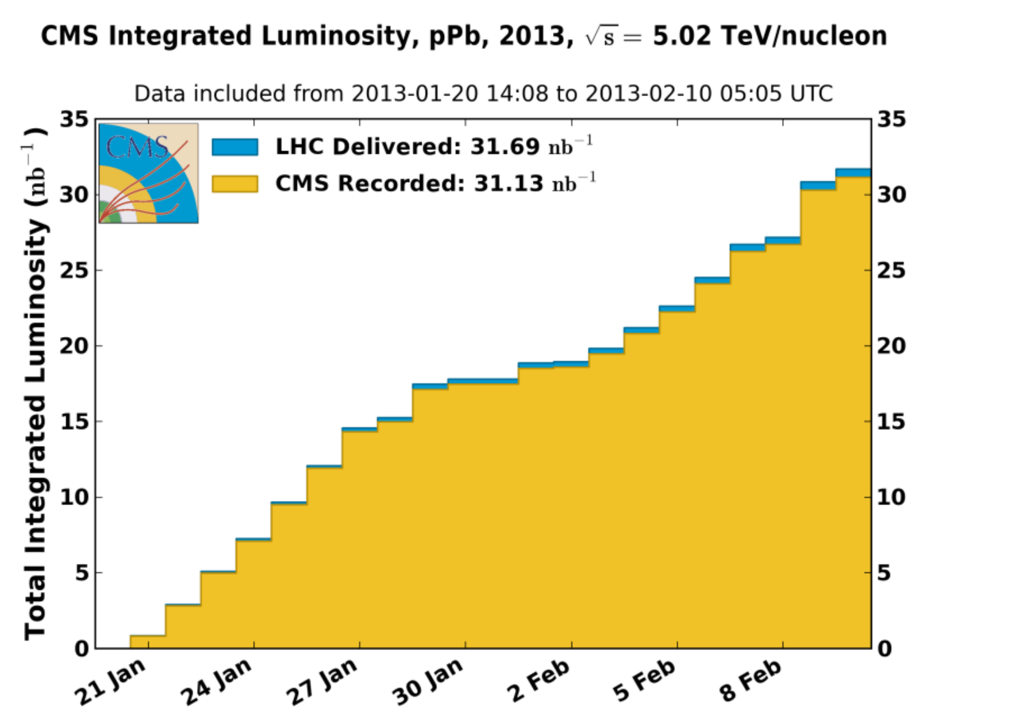
- Bottomonia are clean probes of in-medium modification.
- In PbPb, Sequential melting of $\Upsilon(nS)$ has been observed.
- In pp & pPb, a significant decrease of excited states production has been observed.
- pp & pPb show a multiplicity dependence.
- A deeper study for the kinematical aspects of Υ yields in pp, pPb, and PbPb is needed to understand production mechanisms better.

BACK-UP

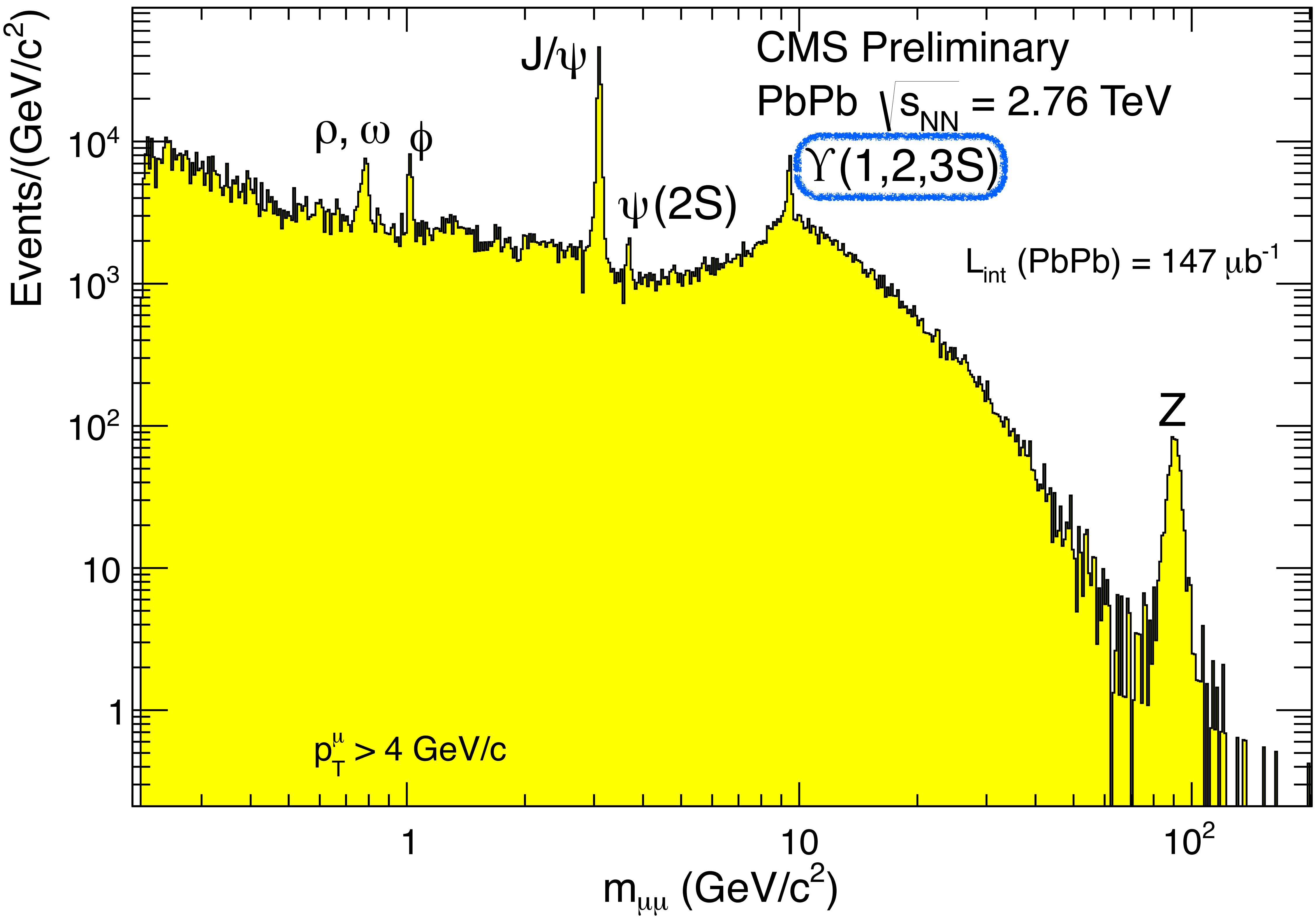
pp, pPb, PbPb run at LHC & CMS

- **1st PbPb run @ $\sqrt{S_{NN}}$ = 2.76 TeV**
  - Nov. – Dec. 2010
  - Recorded luminosity by CMS : 7.28 μb^{-1}
- **1st pp run @ $\sqrt{S_{NN}}$ = 2.76 TeV**
  - March 2011
  - Recorded luminosity by CMS : 225 nb^{-1}
- **2nd PbPb run @ $\sqrt{S_{NN}}$ = 2.76 TeV**
  - Nov. – Dec. 2011
  - Recorded luminosity by CMS : 150 μb^{-1}
- **pPb run @ $\sqrt{S_{NN}}$ = 5.02 TeV**
  - Jan. – Feb. 2013
  - Recorded luminosity by CMS : 31.7 nb^{-1}
- **2nd pp run @ $\sqrt{S_{NN}}$ = 2.76 TeV**
  - Feb. 2013 (3 days)
  - Recorded luminosity by CMS : 5.41 pb^{-1}



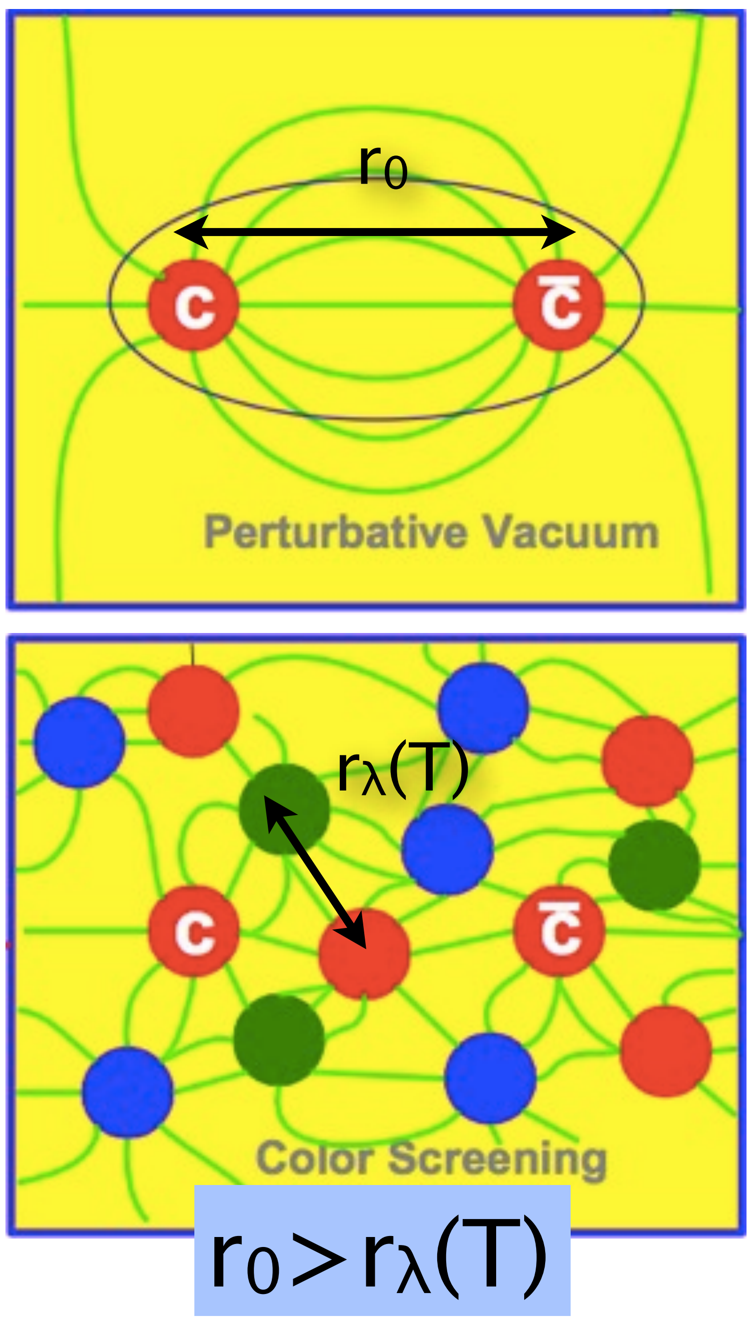


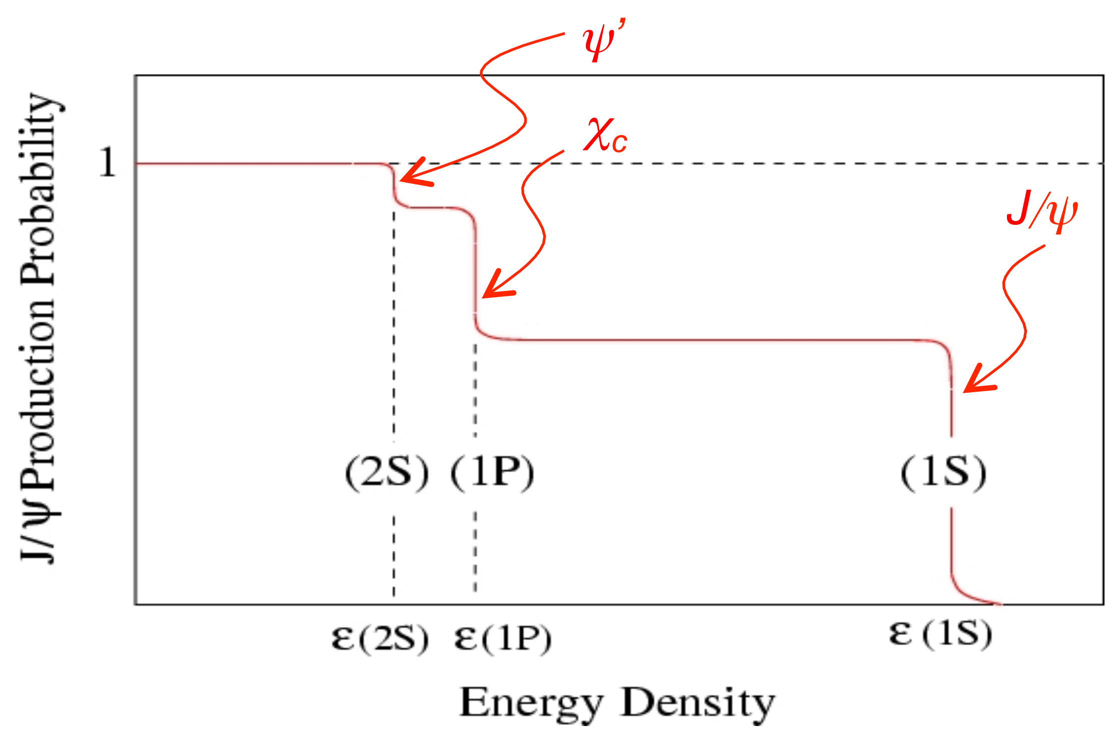
Dimuons in PbPb @ 2.76 TeV

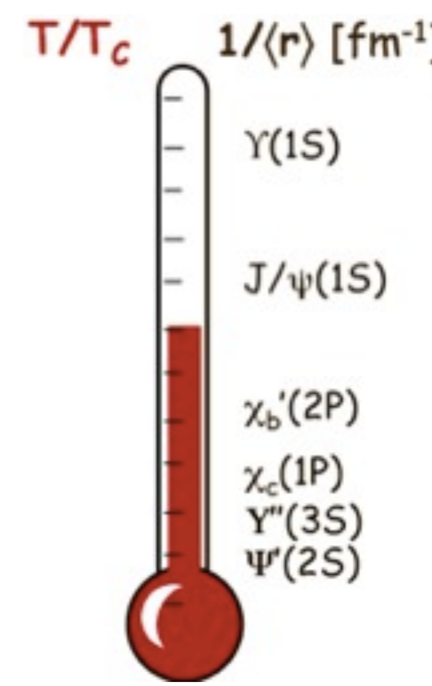


Sequential melting scenario

- **Cartoon for Debye screening**
  - The larger the binding energy, the higher the dissociation temperature T_d.
  - As temperature goes up, Debye length $r_\lambda(T)$ decreases.







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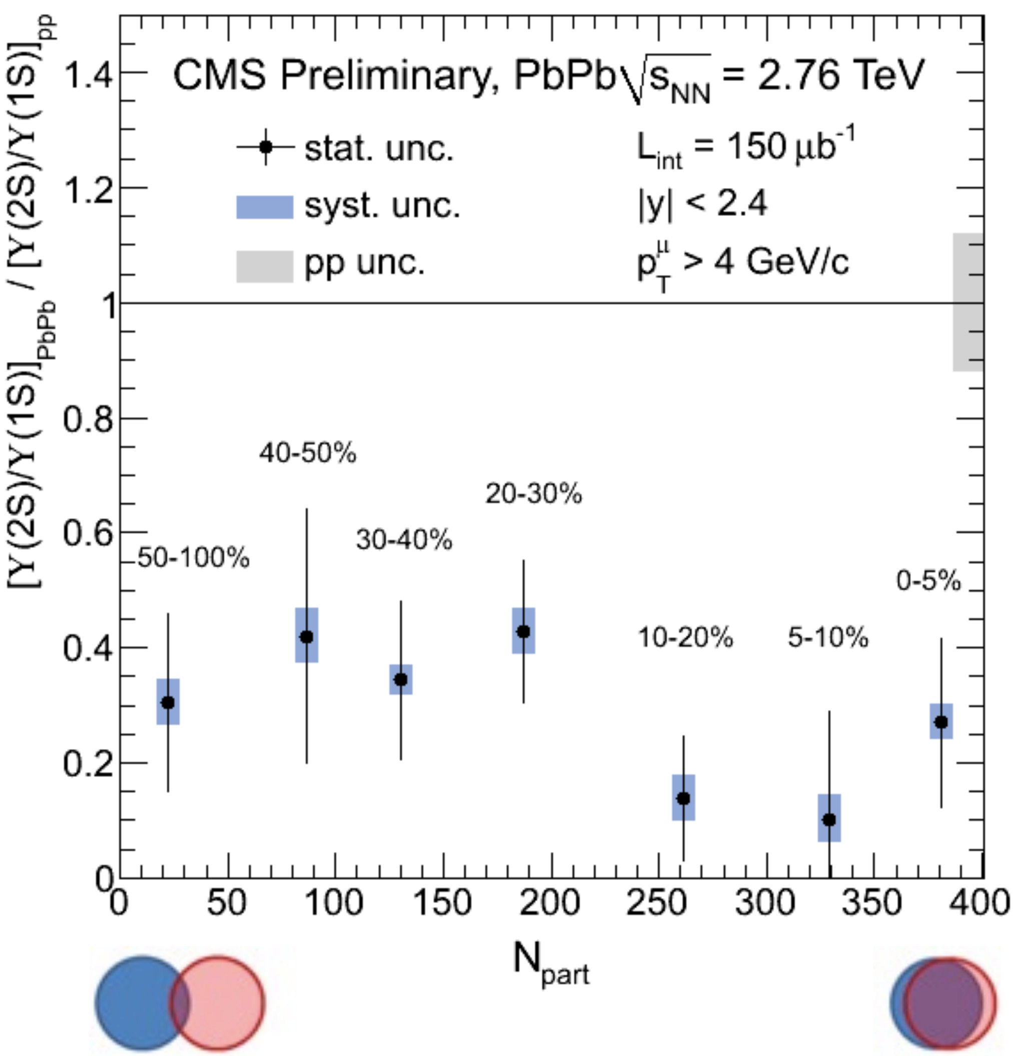
Υ(nS) Double ratio in PbPb



- **Υ(2S) double ratio vs centrality**
  - No strong centrality dependence
  - Suppressed even in the most peripheral bin

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

- **Υ(3S) double ratio vs centrality**
  - Peak at PbPb is hard to distinguish.
    → Set the upper limit

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

$$< 0.17 \text{ at } 95\% \text{ C.L.}$$

Remark for pPb Υ analysis

- Since the beam energy of proton and Pb nucleus is asymmetric, C.M frame is boosted by $\Delta y \sim 0.47$ w.r.t. lab frame.

- Symmetric range in C.M.frame [-1.93, 1.93] is selected for muon's η and dimuon's rapidity.
  : for the 1st run (proton going to -) : [-2.4, 1.47]
  : for the 2nd run (proton going to +) : [-1.47, 2.4]

N_{tracks} dependence

- **Scenario 1 : Υ state affects multiplicity differently**
  - Υ(1S) is produced with more particles than Υ(2S) and Υ(3S) and affect the underlying distributions.

- **Scenario 2 : Multiplicity affects Υ state differently**
  - Υ(1S), the most tightly bound state, is less affected than Υ(2S) and Υ(3S) when interacting with surrounding environment.