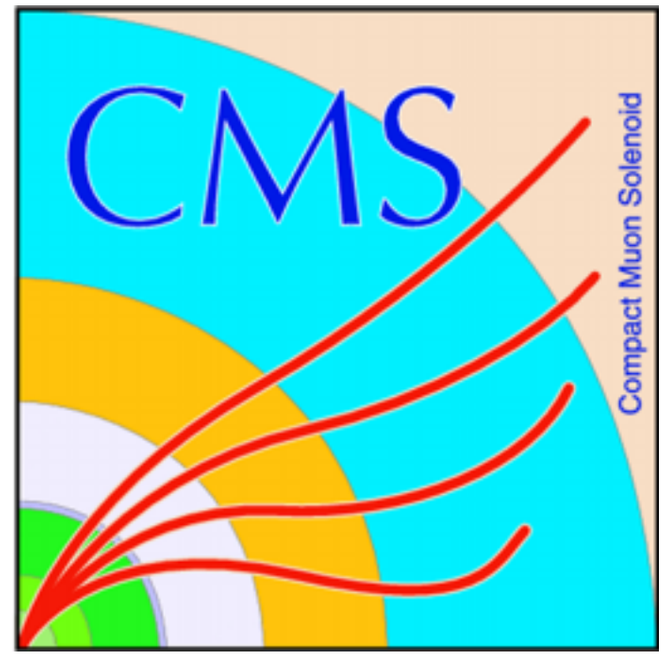


Quarkonium measurements in pPb and PbPb in CMS

Nicolas Filipovic
(ELTE)

Zimanyi School 2015, December 8th, Wigner MTA

Motivations

- One signature of QGP formation: ***sequential suppression*** of quarkonia

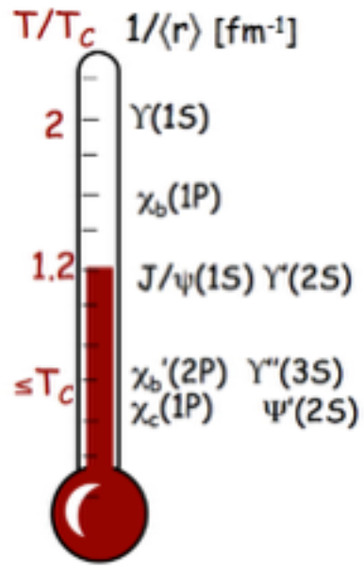
- **Charmonium**: suppressed, and (possibly) regenerated

- **Bottomonium**: heavier probe, no regeneration (yet)

  - Measure suppression via the nuclear modification factor ⇒

- In this talk, we'll also see pPb data: baseline for cold nuclear effects (no deconfined medium)

Mocsy, Eur.Phys.J. C61 (2009) 705

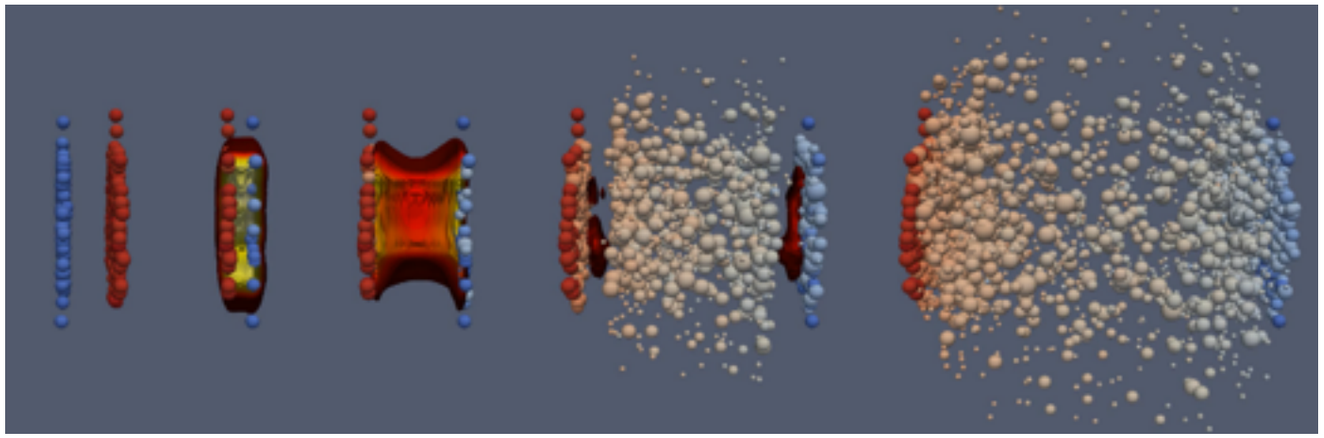


$$R_{\text{PbPb}} = \frac{\mathcal{Y}_{\text{PbPb}}}{N_{\text{coll}} \times \mathcal{Y}_{pp}}$$

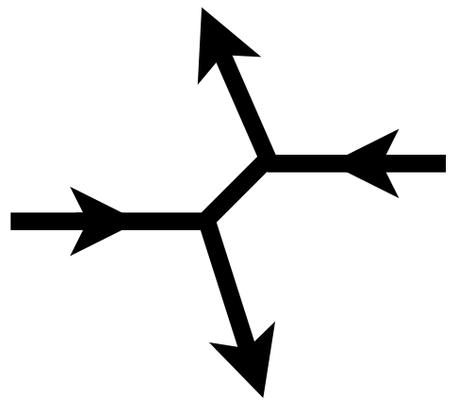
'suppression' ⇒ $R_{AA} < 1$

Collision systems

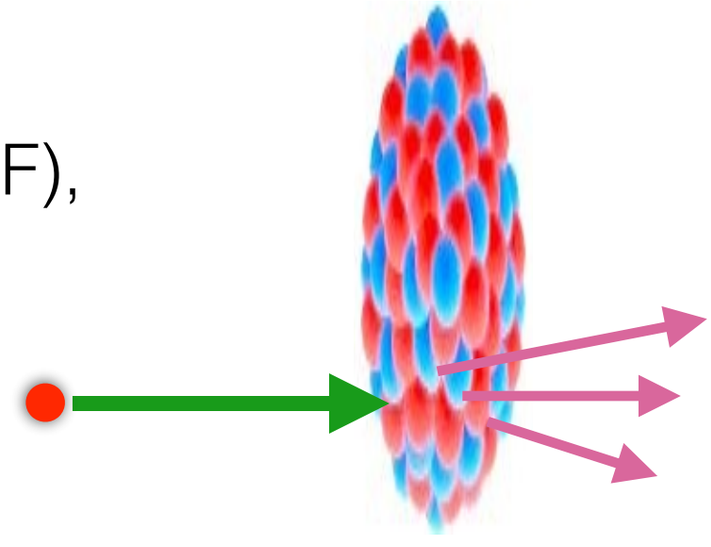
- PbPb: the main experiment
  - Hot, deconfined, and collective medium: **the QGP**



- pp: the reference
  - no deconfinement, no QGP: probe produced in ~vacuum

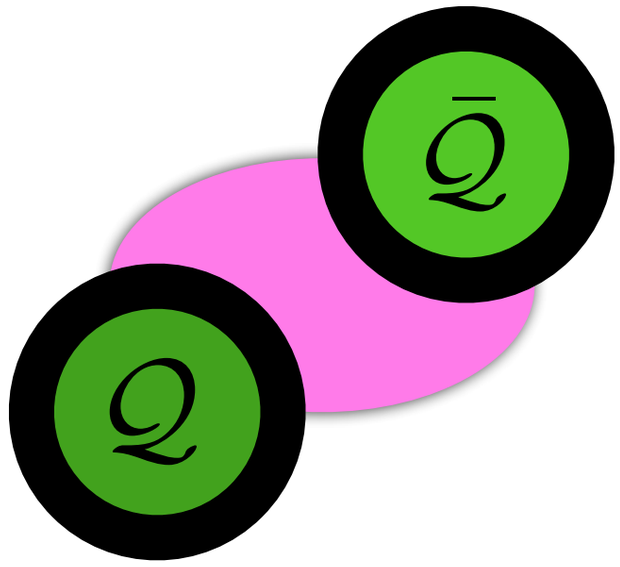


- pPb: nuclear effects in absence of QGP:
  - Nuclear modification of parton densities (nPDF),
  - Nuclear or comoving hadron absorption,
  - Coherent parton energy loss, etc.



Quarkonia

- Heavy quark-antiquark bound states

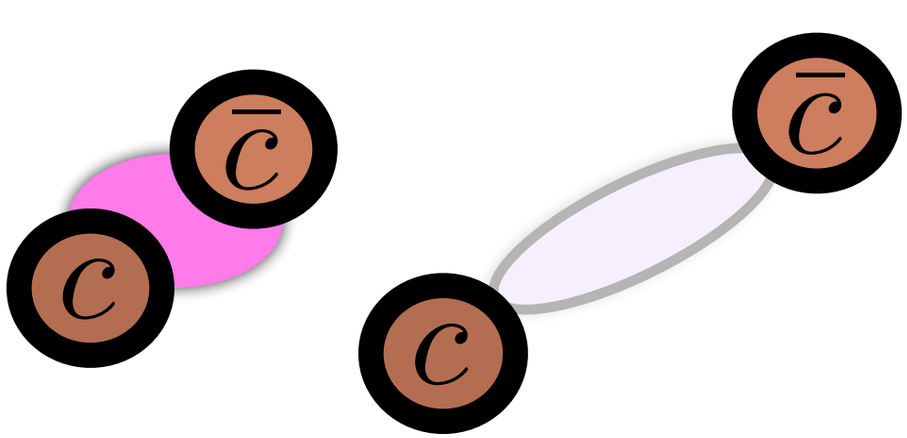


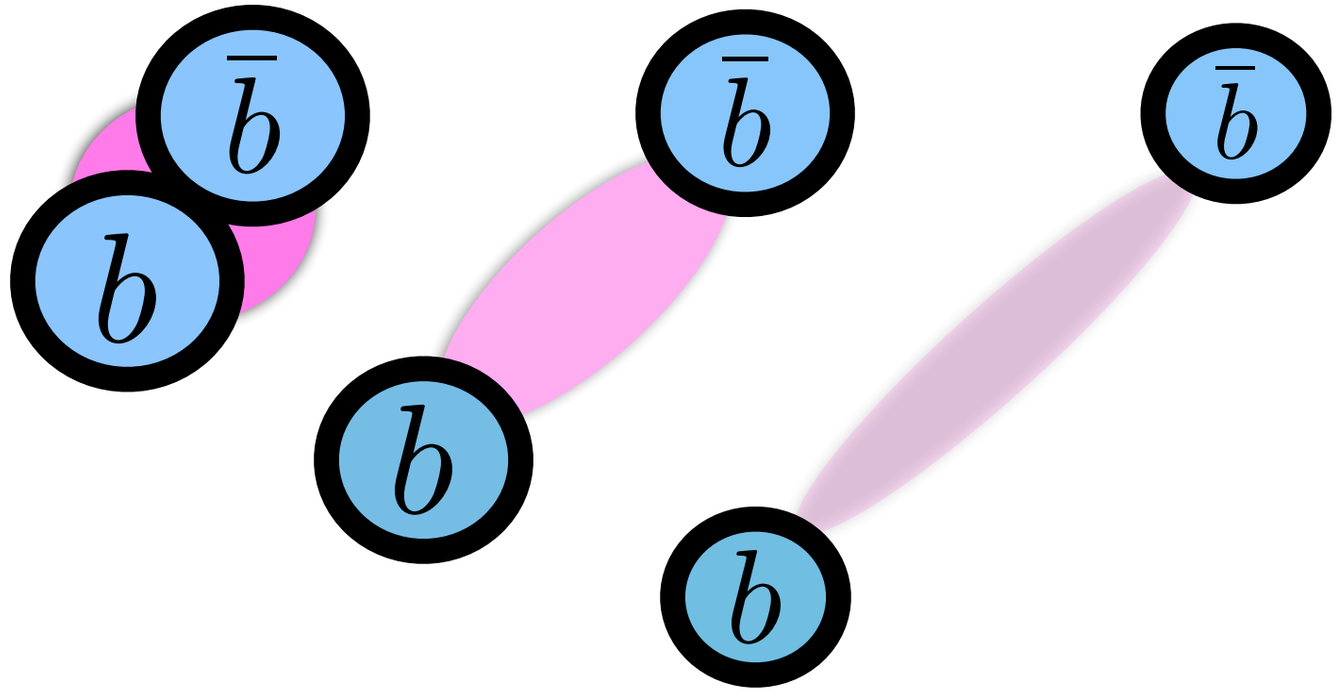
Production: gluon fusion process
Heavy quarks: ***b*** or ***c***
Detected via their dilepton decay

- Resonant states of various binding energy, mass, angular momentum

Quarkonia

- **Charmonia: the J/ψ and ψ(2S)**
- **Bottomonia: the Υ(1S,2S,3S)**

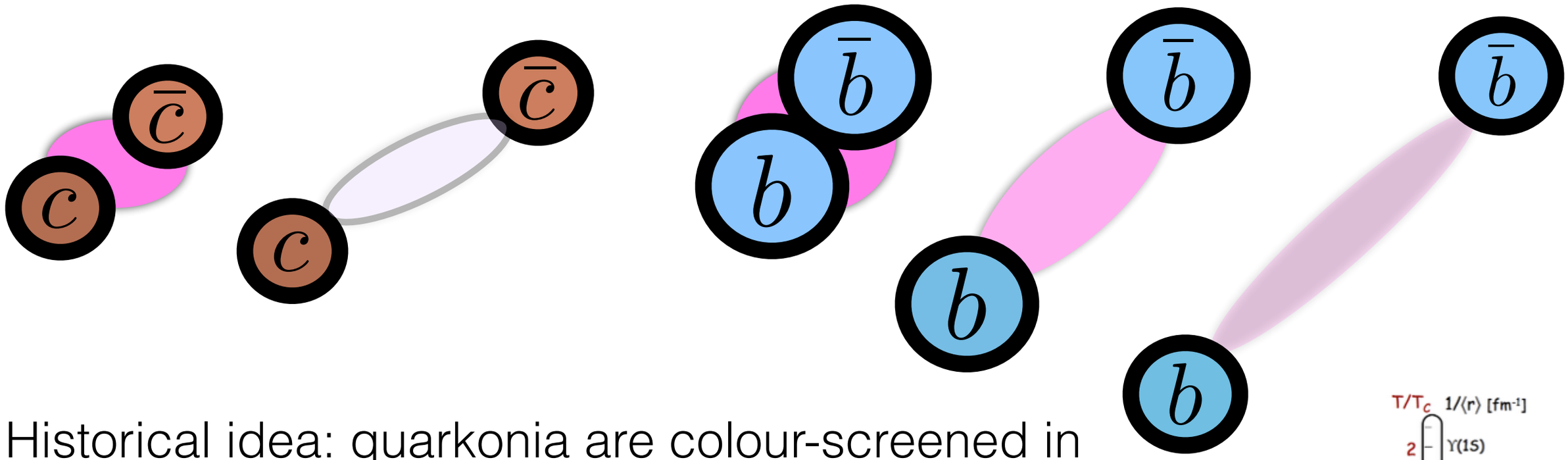




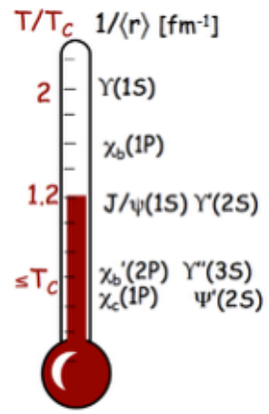
state	J/ψ	$\psi(2S)$	$\Upsilon(1S)$	$\Upsilon(2S)$	$\Upsilon(3S)$
mass	3.10	3.69	9.46	10.02	10.36
ΔE [GeV]	0.64	0.05	1.10	0.53	0.20

Satz, H. [J.Phys. G32 (2006) R25]

Quarkonia in nuclear matter



- Historical idea: quarkonia are colour-screened in the QGP



- Quarkonia of low binding energy melt first: sequential melting of « the QGP thermometer »

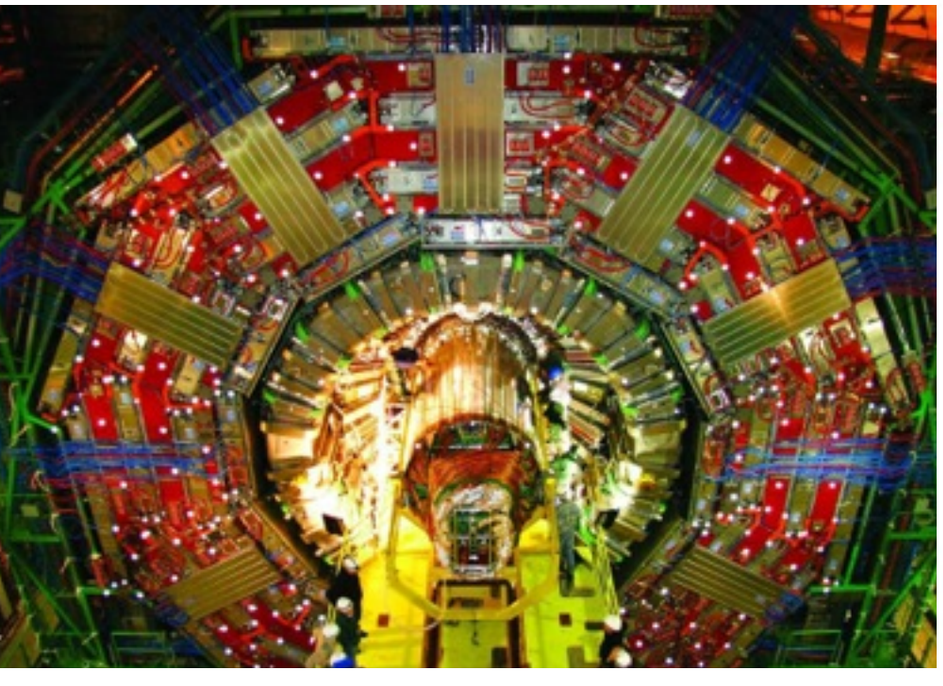
- In p-Pb: cold effects can be estimated!

- Watch out for:
  - regeneration (N$_{c\bar{c}}$~30 in a central PbPb event @2.76TeV)
  - Feed-down from excited states

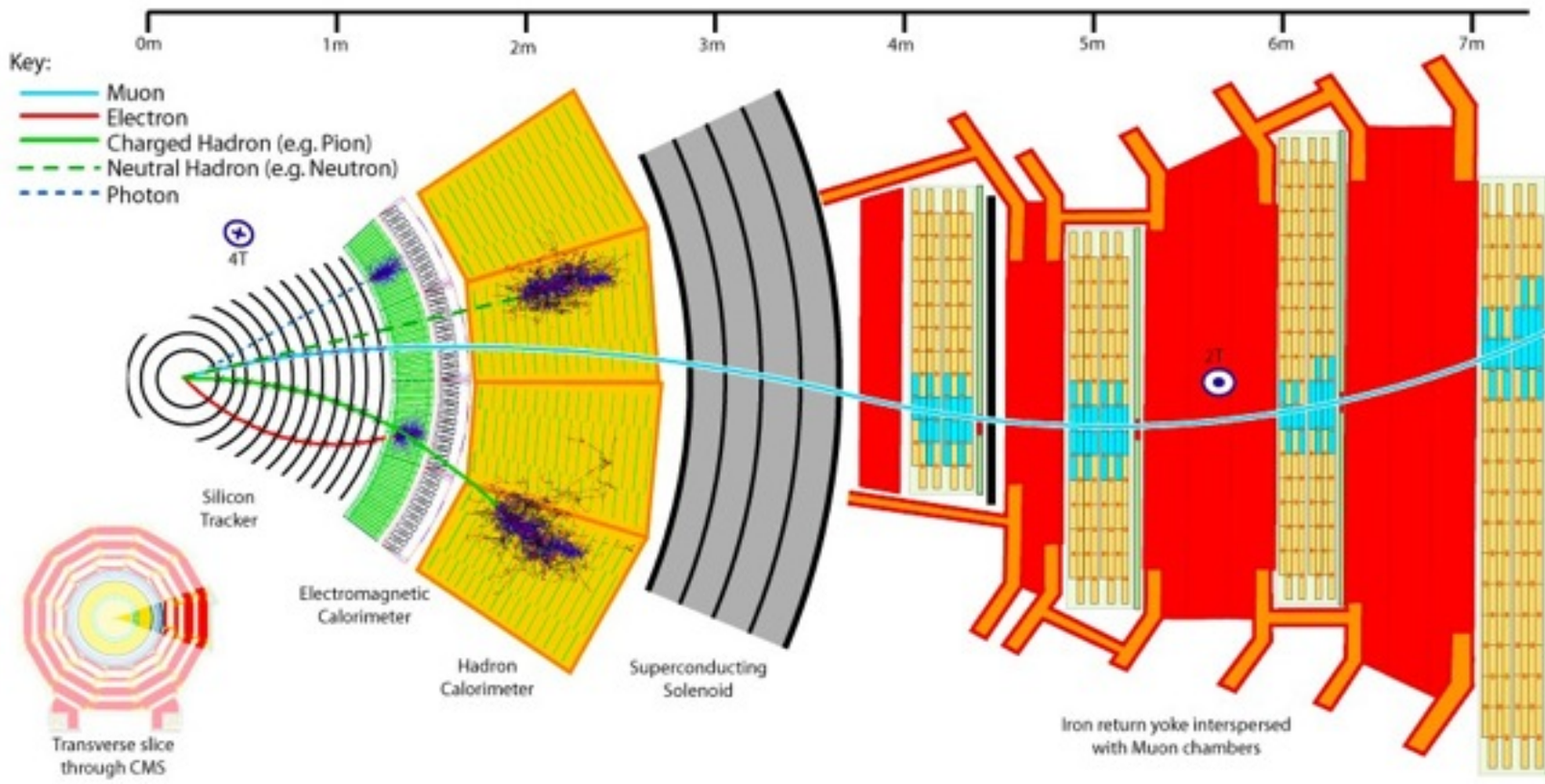
Detection

- CMS very efficient in reconstructing muon tracks
- Combine muons to make di-muon invariant mass spectrum
- Selection cuts tuned to remove uninteresting events

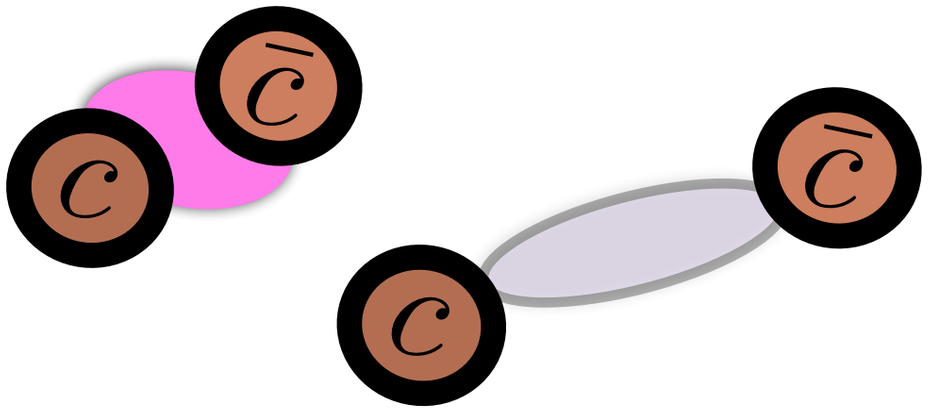
(combinatorial background, non-prompt muons, cosmics,…)



The CMS detector
(open for tracker insertion)



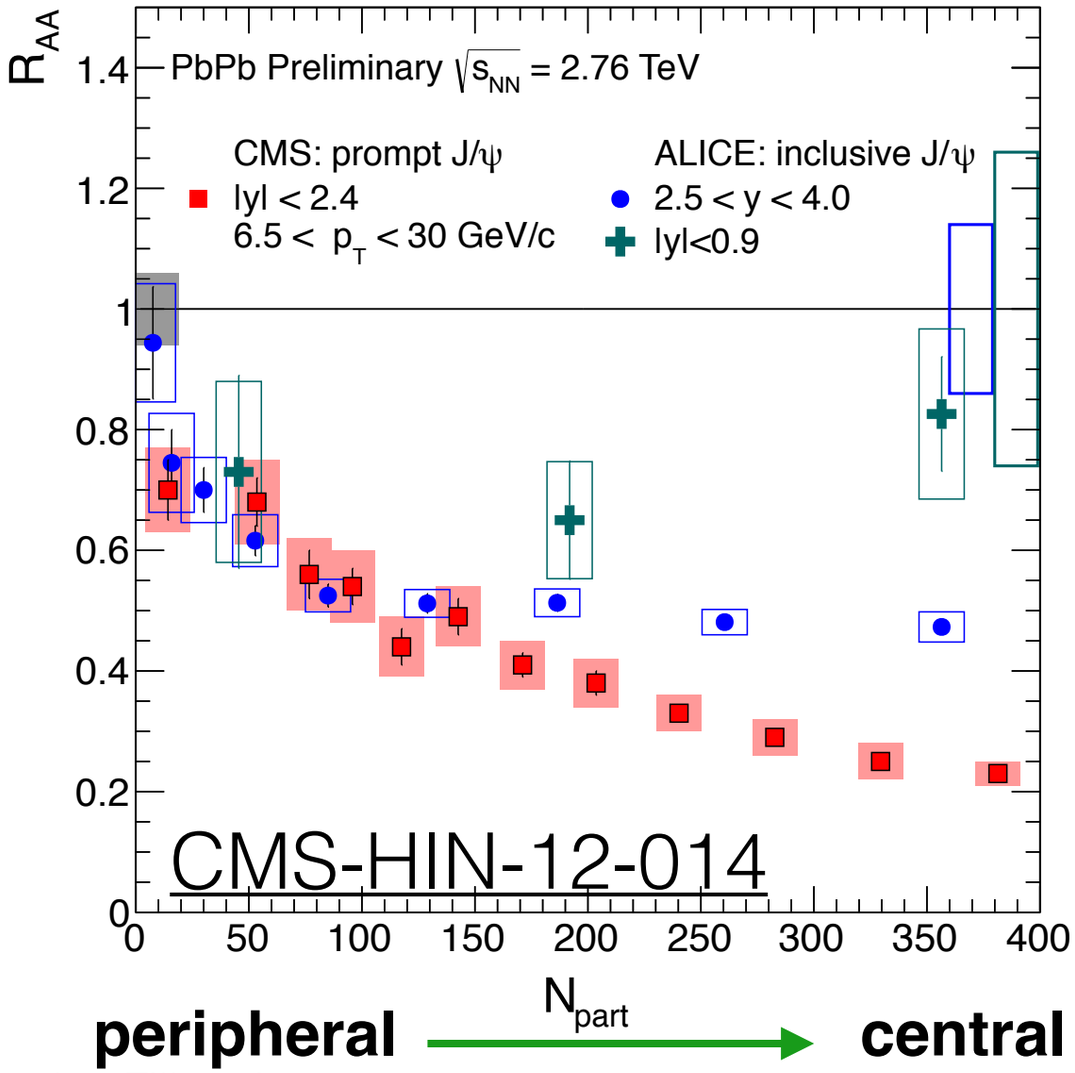
$p_T^{\mu} > 4$ GeV/c
to reach CMS muon stations

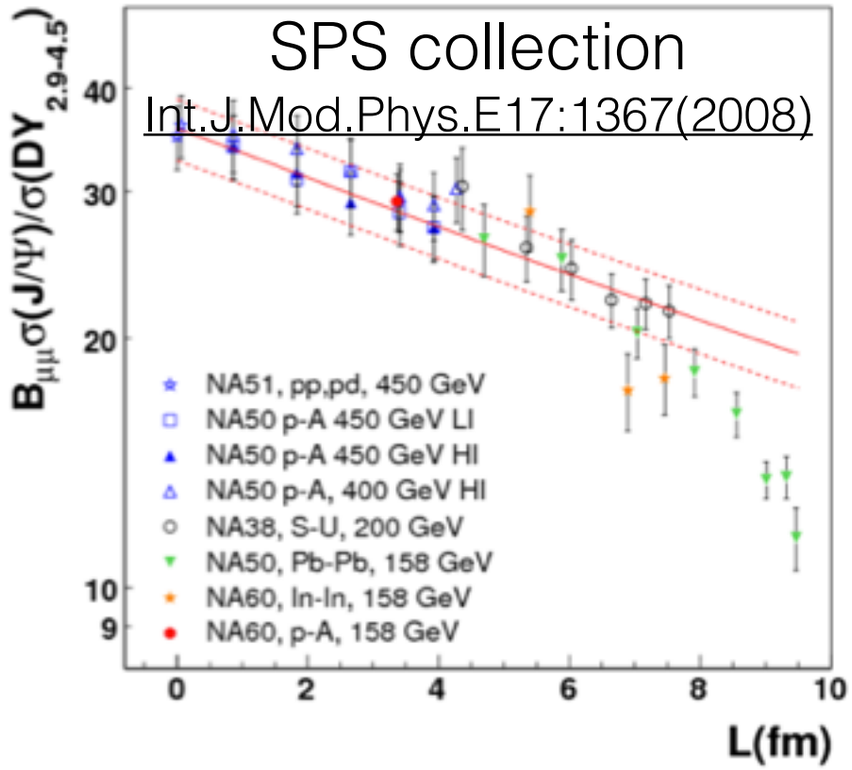


Charmonia: J/ψ, ψ(2S)

J/ψ in PbPb

- J/ψ: the historical probe for nuclear absorption
- Modification in nuclear matter observed at SPS, RHIC, then LHC





- J/ψ suppression: stronger at high-p_T
- Hints of regeneration in central PbPb events, at low-p_T

ψ(2S) in PbPb

- Excited state: smaller cross section, looser binding than J/ψ
- Compute the 'double ratio', ψ(2S) suppression relative to J/ψ

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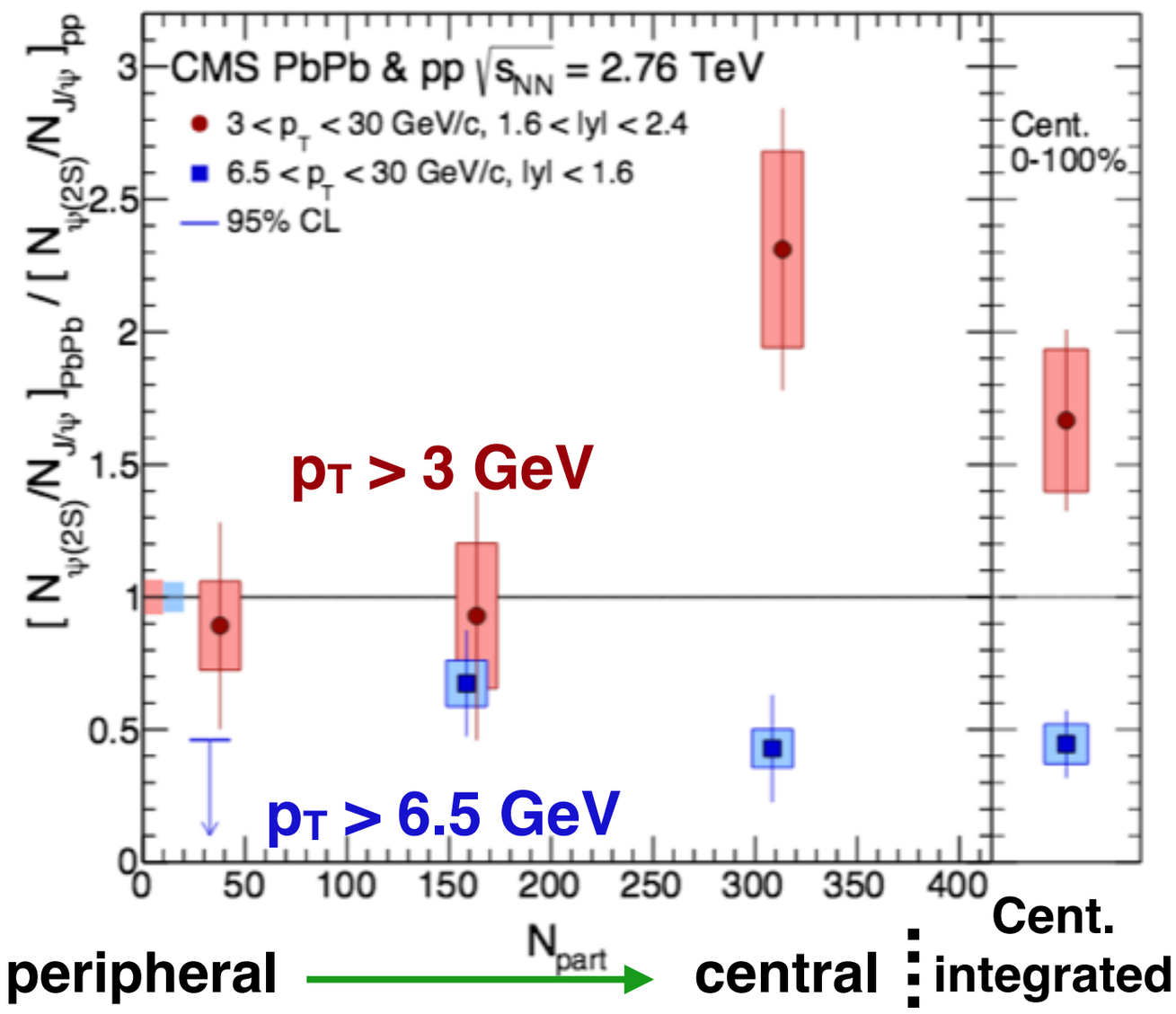


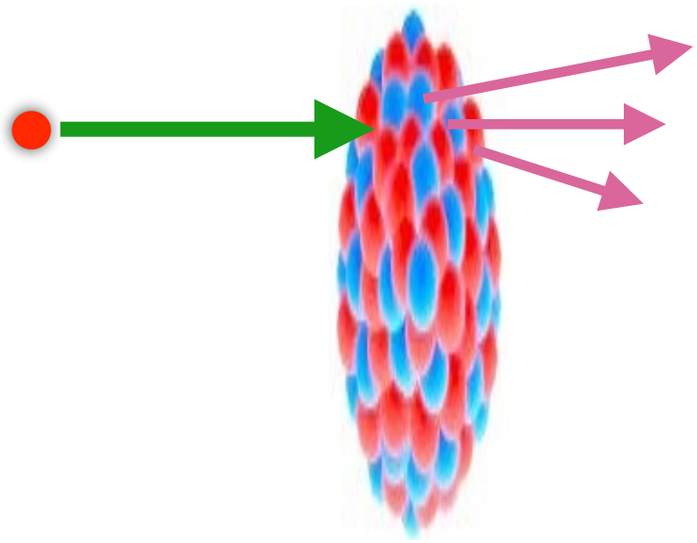
$$\frac{N_{\psi(2S)}/N_{J/\psi}|_{\text{PbPb}}}{N_{\psi(2S)}/N_{J/\psi}|_{\text{pp}}}$$

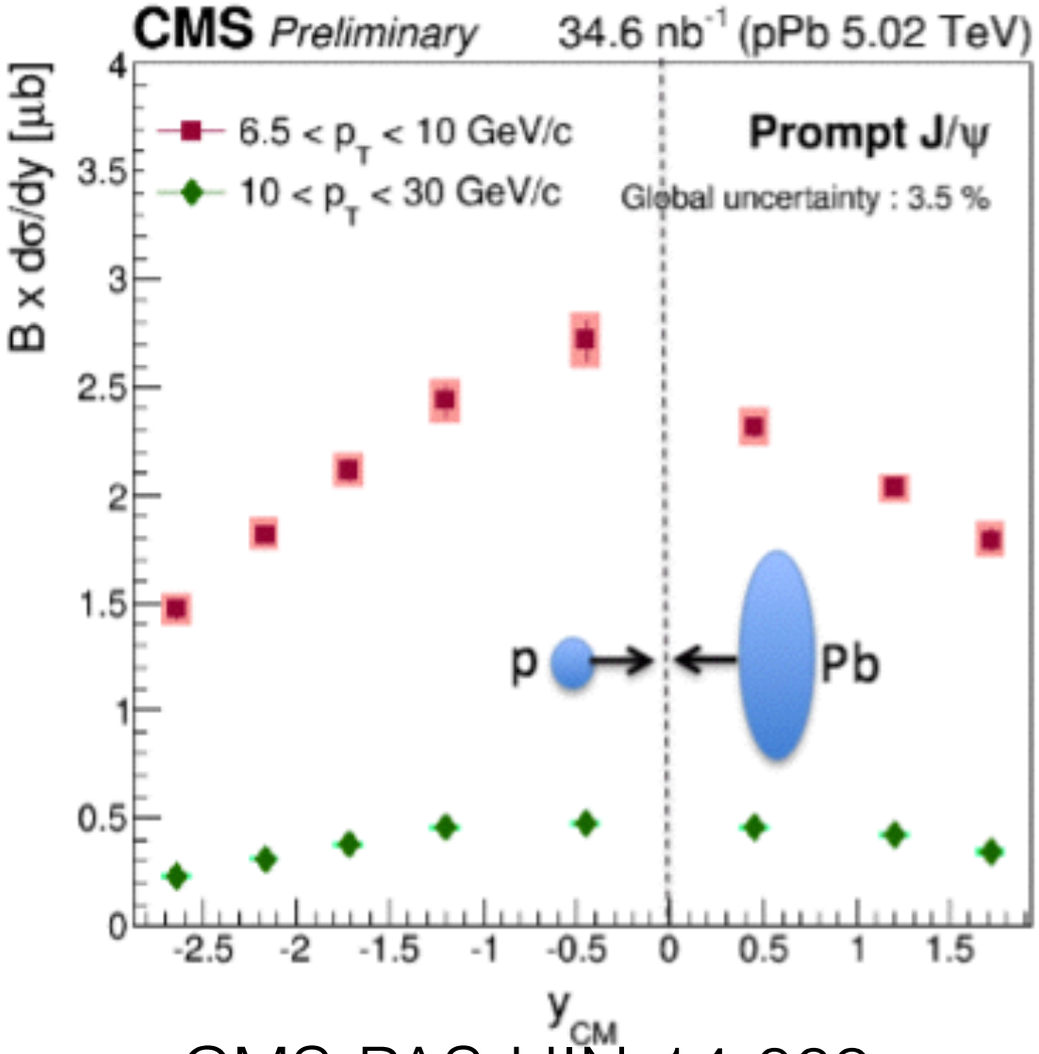
Indication of enhanced ψ(2S)-to-J/ψ ratio in PbPb relative to pp.

Can Run2 data solve the puzzle?

J/ψ in pPb

- Nuclear absorption in pA collisions:
  - R_{pA} (ratio relative to pp)
  - **R_{FB}** (forward-backward ratio)





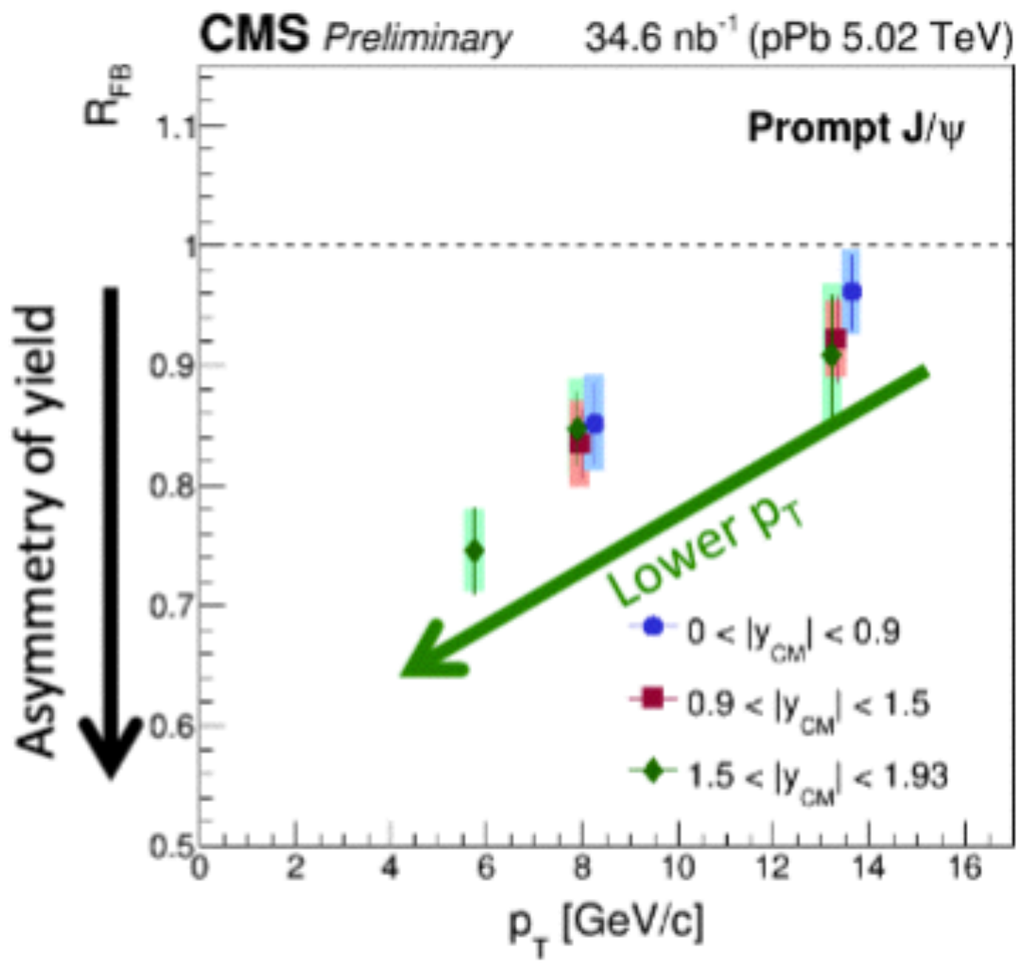
CMS-PAS-HIN-14-009

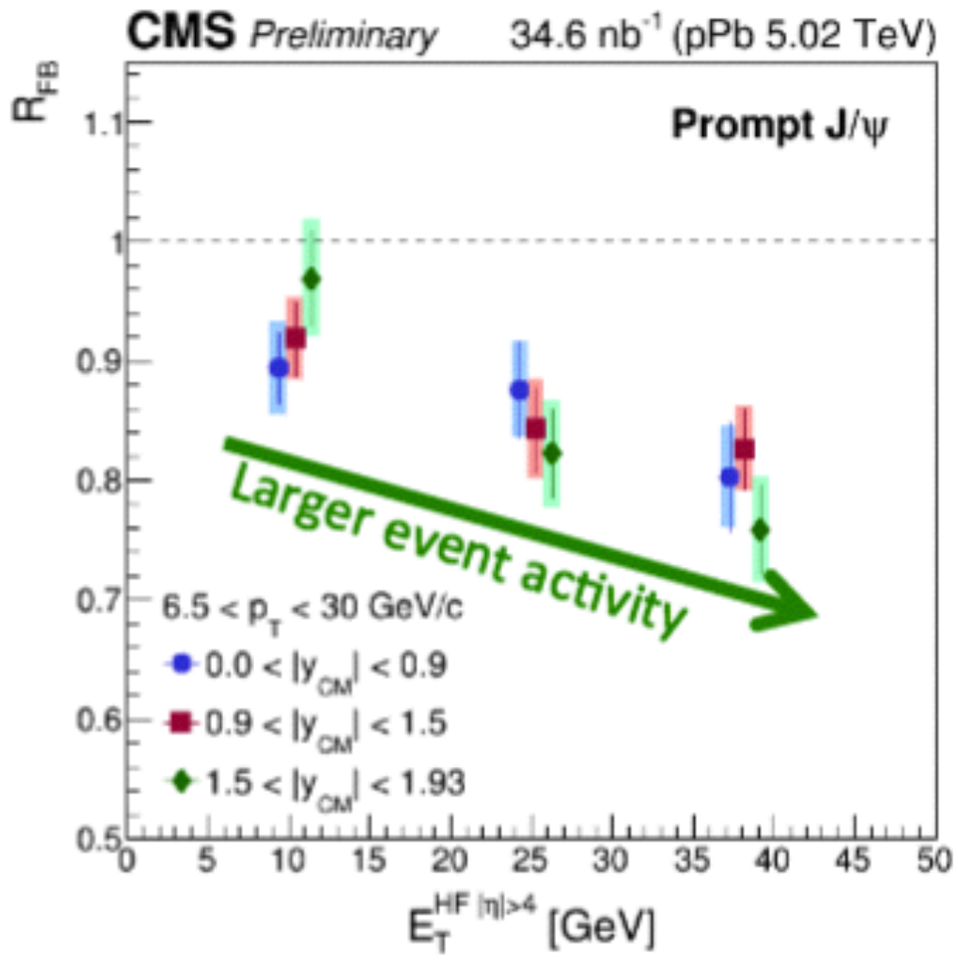
$$R_{FB} = \frac{\text{Yield in } (p_T, +y)}{\text{Yield in } (p_T, -y)}$$

R_{FB} estimates the effects seen by the quarkonium on the p-going side relative to the pb-going side

J/ψ in pPb

- Clear asymmetry of prompt J/ψ spectra in pPb
  - when decreasing p_T or increasing event activity





- Preliminary result, including non-prompt J/ψ (not covered here)

CMS-PAS-HIN-14-009

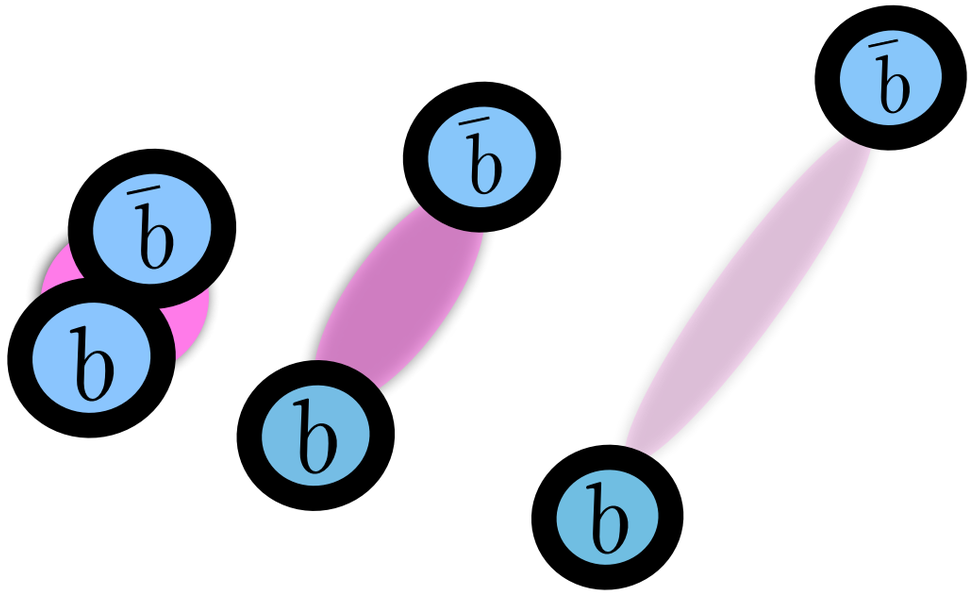
Charmonia in pPb, PbPb

- CMS measures J/ψ and ψ(2S) in PbPb
  - from p_T > 3 GeV in the forward direction (1.6 < y < 2.4),
  - from p_T > 6.5 GeV in the mid-rapidity region

J/ψ suppressed in the mid-rapidity, high momentum region
ψ(2S) is further suppressed with the same kinematics.
but less suppressed than J/ψ in central, low p_T PbPb events !

- pPb data exhibits final state effects
  - R_{FB} < 1 at low-p_T and high event activity
  - Need a 5 TeV pp reference to compute R_{pA}

  - Stay tuned for charmonia in CMS with Run 2 data at 5 TeV !

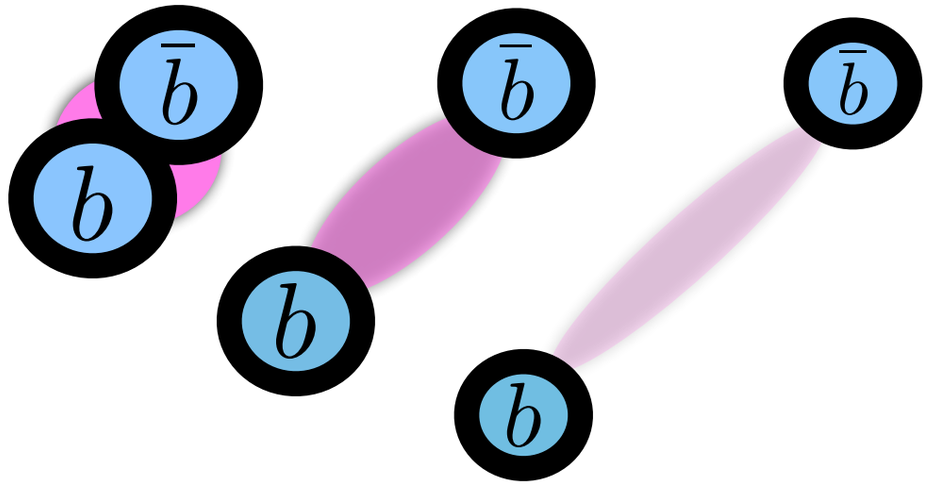


Bottomonia: Υ(1S,2S,3S)

Bottomonia: ϒ(1S,2S,3S)

- Some pros…
  Heavier quark mass - a priori smaller effect of regeneration, nuclear absorption,
  in CMS, can be reconstructed from $p_T = 0$
  Can measure the sequential suppression of **three states**

- …some cons:
  20 x smaller rate than ψ
  Feed-down from χ_b states (10~40%)*



Strategy:
  PbPb: measure
  pPb: double ratios

state	**Y(1S)**	**Y(2S)**	**Y(3S)**
M	9.46	10.02	10.36
ΔE [GeV]	1.10	0.53	0.20

*: Feed-down fractions in back-up

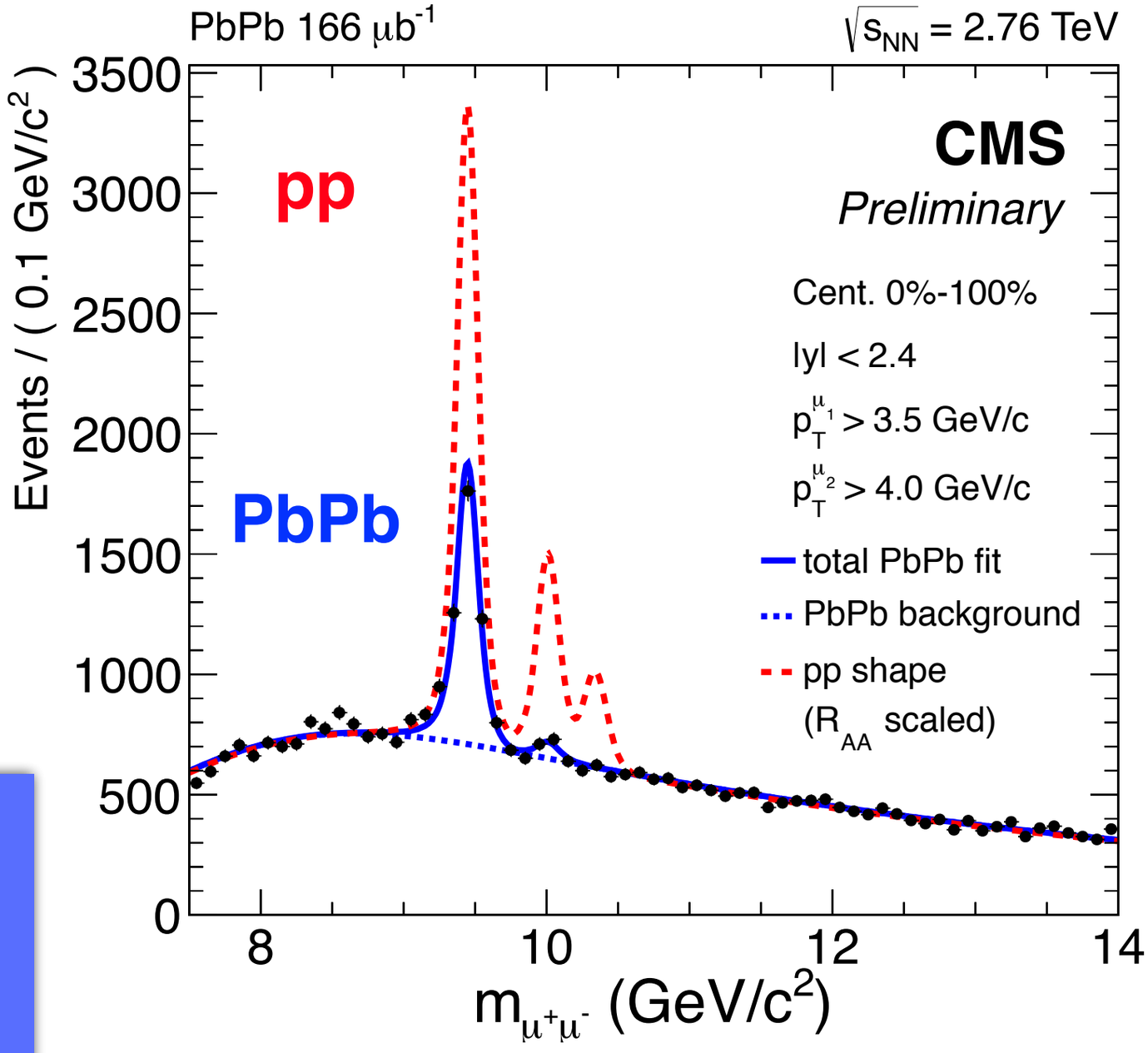
First look at ϒ suppression

- On display: ϒ(nS) mass in di-muon channel

ϒ(1S): suppressed,
~2500 events in PbPb,
~5000 events in pp

ϒ(2S): more suppressed!

ϒ(3S): unobserved in PbPb!
integrated upper limit



What are the kinematics of the remaining ϒ(1S)?
Answer: bins of p_T, rapidity, centrality

Sequential ϒ(nS) suppression

$$R_{\mathrm{PbPb}} = \frac{\mathcal{Y}_{\mathrm{PbPb}}}{N_{\mathrm{coll}} \times \mathcal{Y}_{pp}}$$

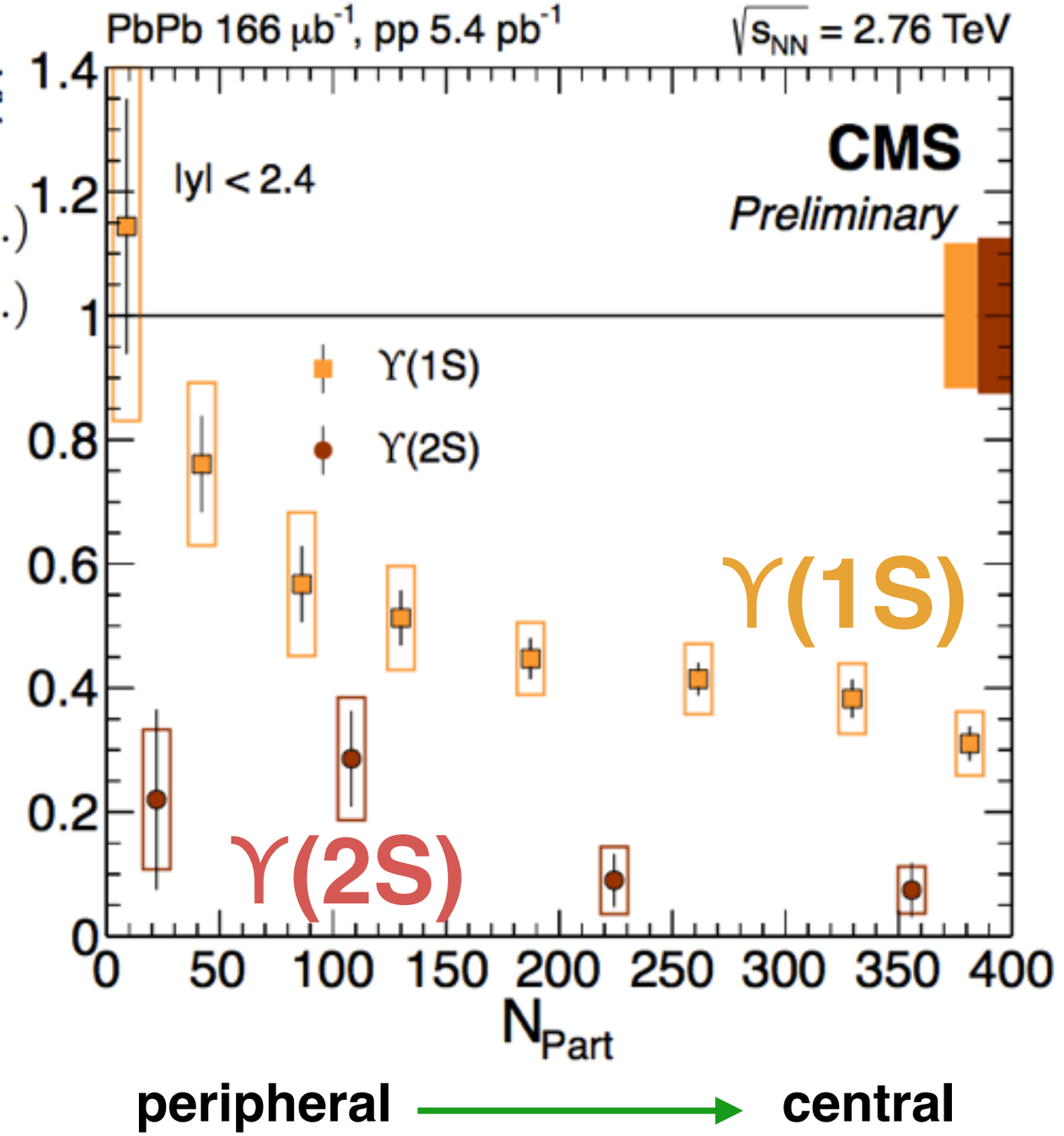
- On display: **R_{AA} vs. centrality**

- Centrality integrated results:

$$R_{\mathrm{AA}}(\Upsilon(1\mathrm{S})) = 0.425 \pm 0.029\ (\mathrm{stat.}) \pm 0.070\ (\mathrm{syst.})$$
$$R_{\mathrm{AA}}(\Upsilon(2\mathrm{S})) = 0.116 \pm 0.028\ (\mathrm{stat.}) \pm 0.022\ (\mathrm{syst.})$$
$$R_{\mathrm{AA}}(\Upsilon(3\mathrm{S})) < 0.14 \text{ at } 95\%\ \mathrm{C.L.}$$

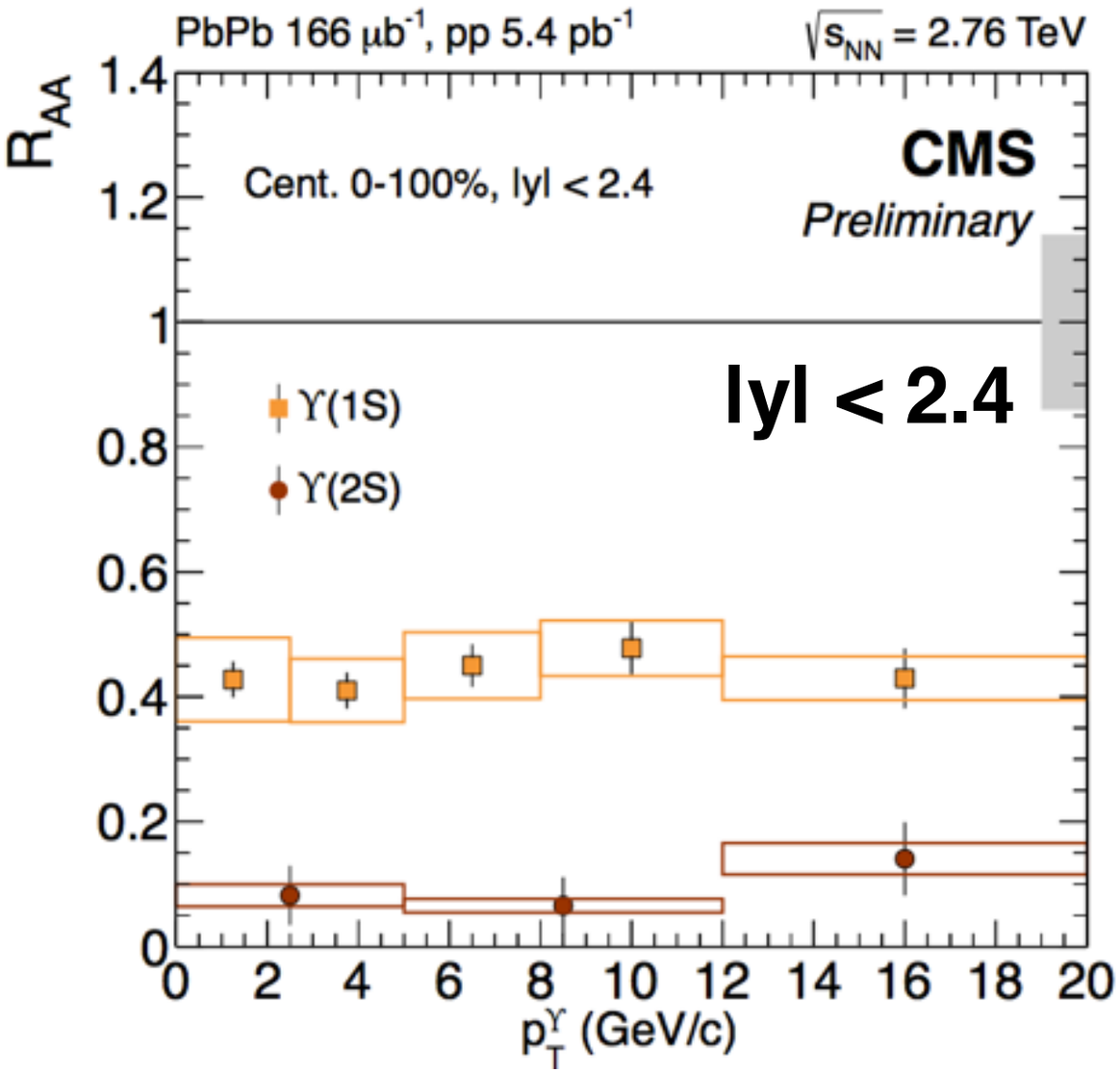
- Suppression is *ordered:*
  ϒ(1S) > ϒ(2S) > ϒ(3S)

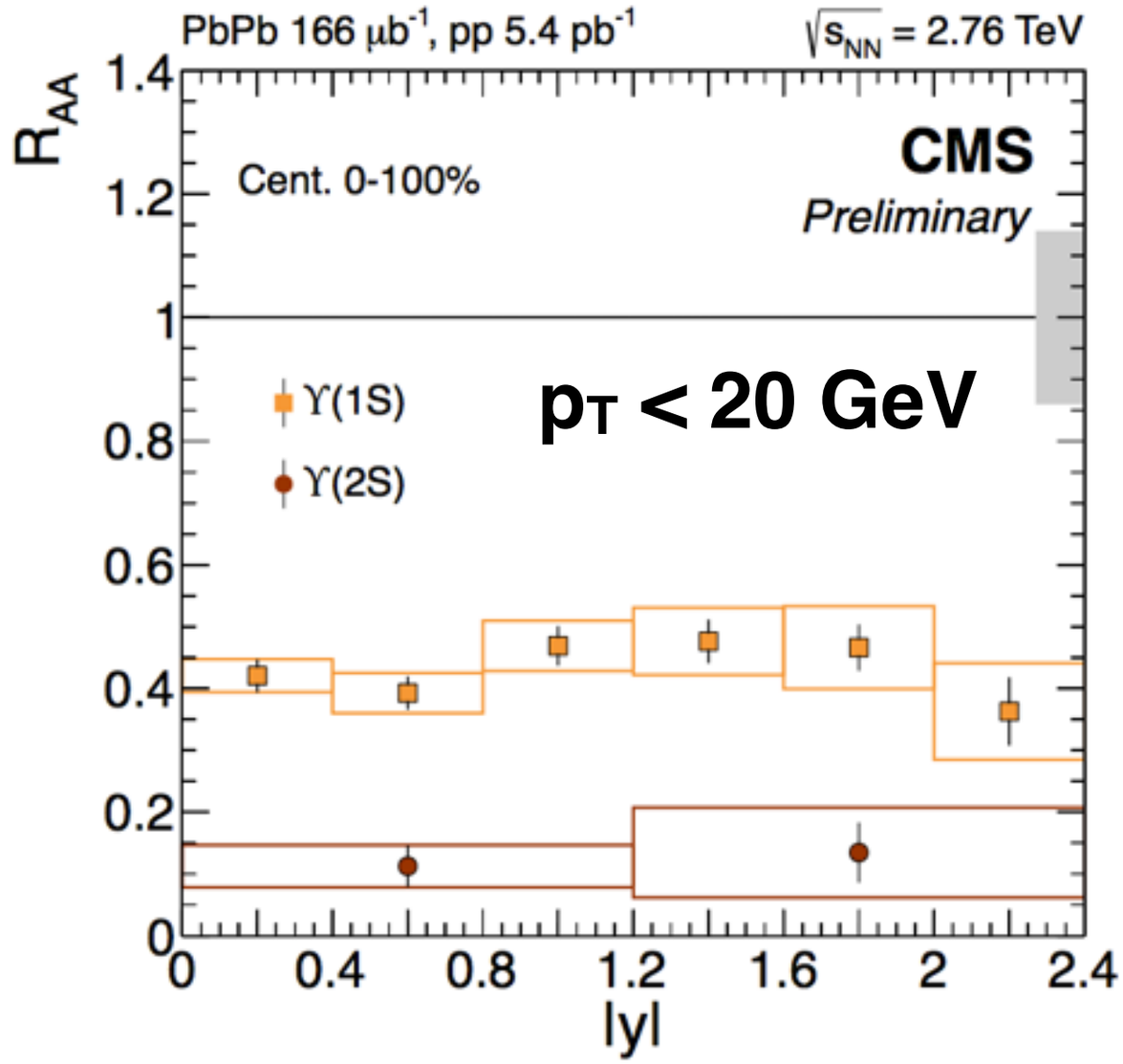
- Central ϒ(1S), R_{AA} ~ 0.30 !
  Is the ϒ(1S) melting ?



Kinematics of ϒ suppression

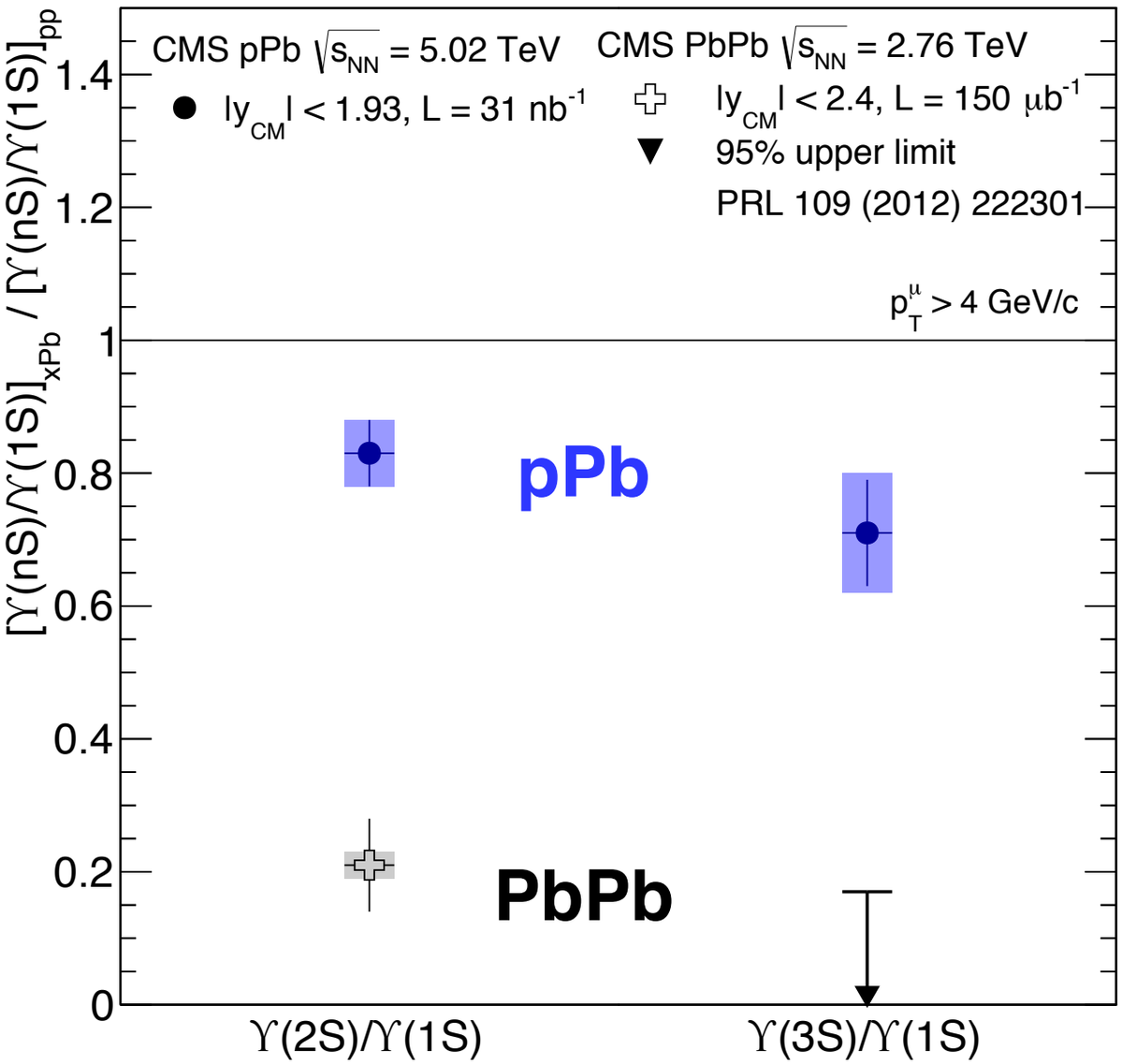
- On display: **R_{AA} vs. p_T and rapidity**
- Suppression appears *flat* on the full analysis range





ϒ in pPb

- No pp reference at 5 TeV: look at the excited state ratio



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$$\frac{N_{\Upsilon(nS)}/N_{\Upsilon(1S)}\big|_{\text{pPb or PbPb}}}{N_{\Upsilon(nS)}/N_{\Upsilon(1S)}\big|_{\text{pp}}}$$

- In pPb, slight extra modification of excited states vs. ground state

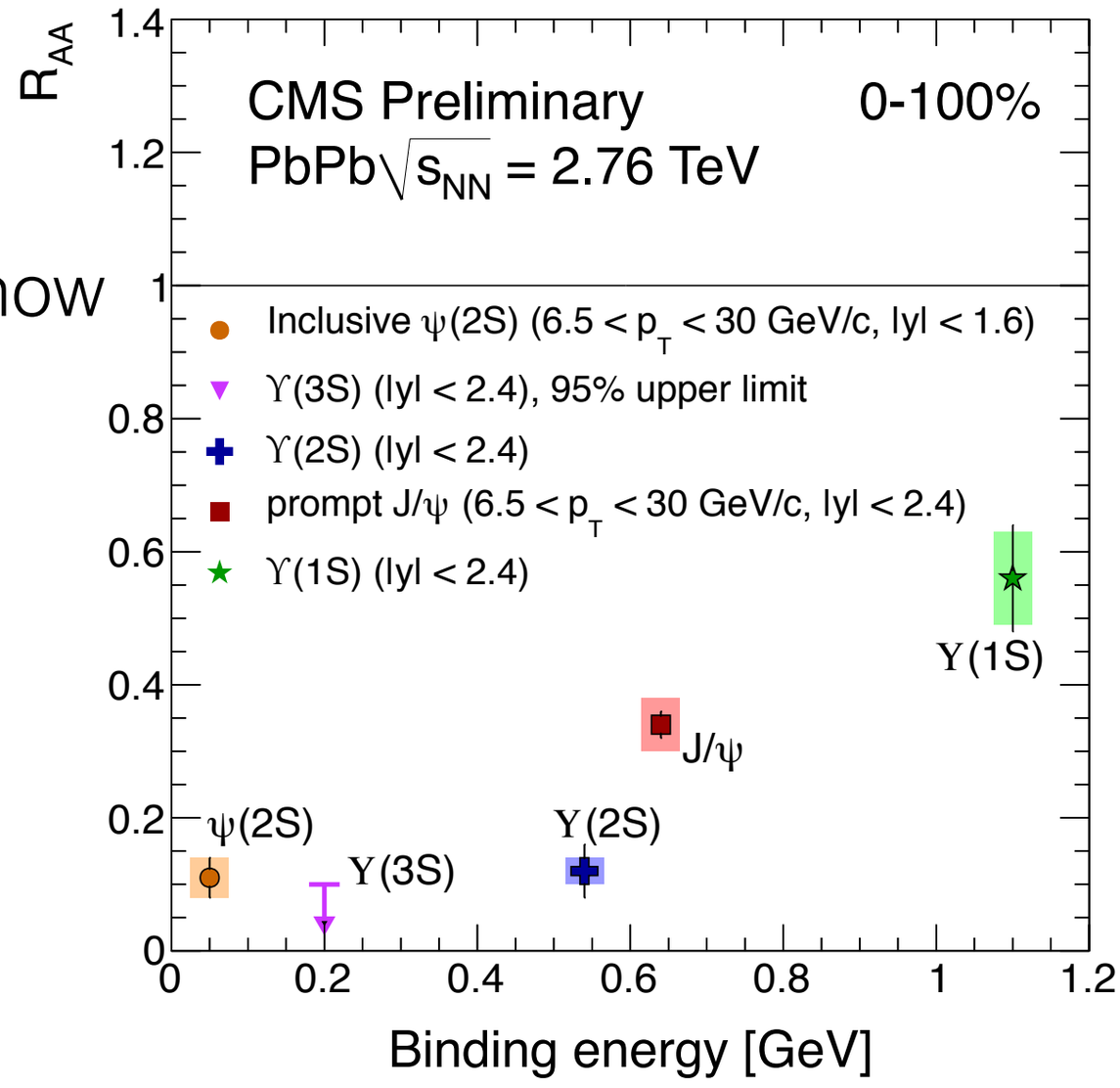
Conclusions

- Quarkonia in the QGP are
  - Suppressed, in orderly fashion
  - Consistent with sequential melting hypothesis

- Low p_T ψ's: hints of regeneration
- Υ's: same suppression for all p_T

- Prepare for the future:
- 5 TeV pp and PbPb data coming now
- Plenty of physics still to unveil

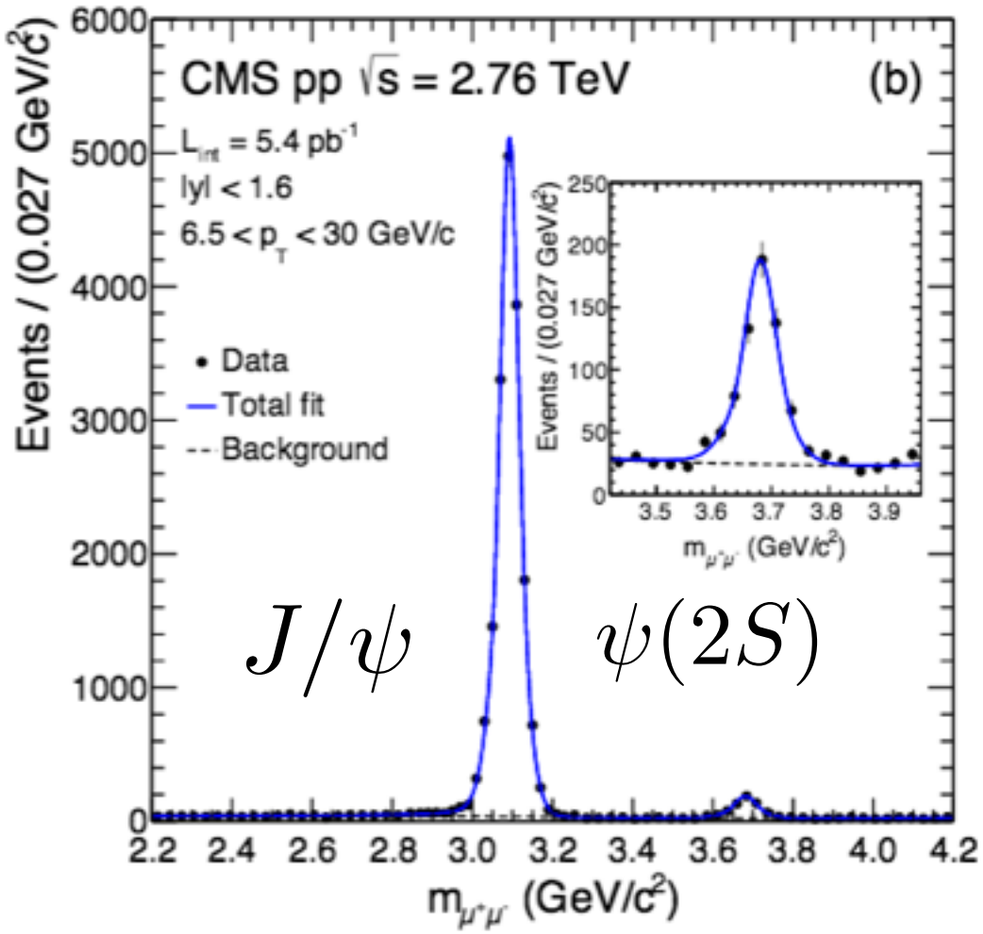
Thank you!
(Köszönöm szépen!)



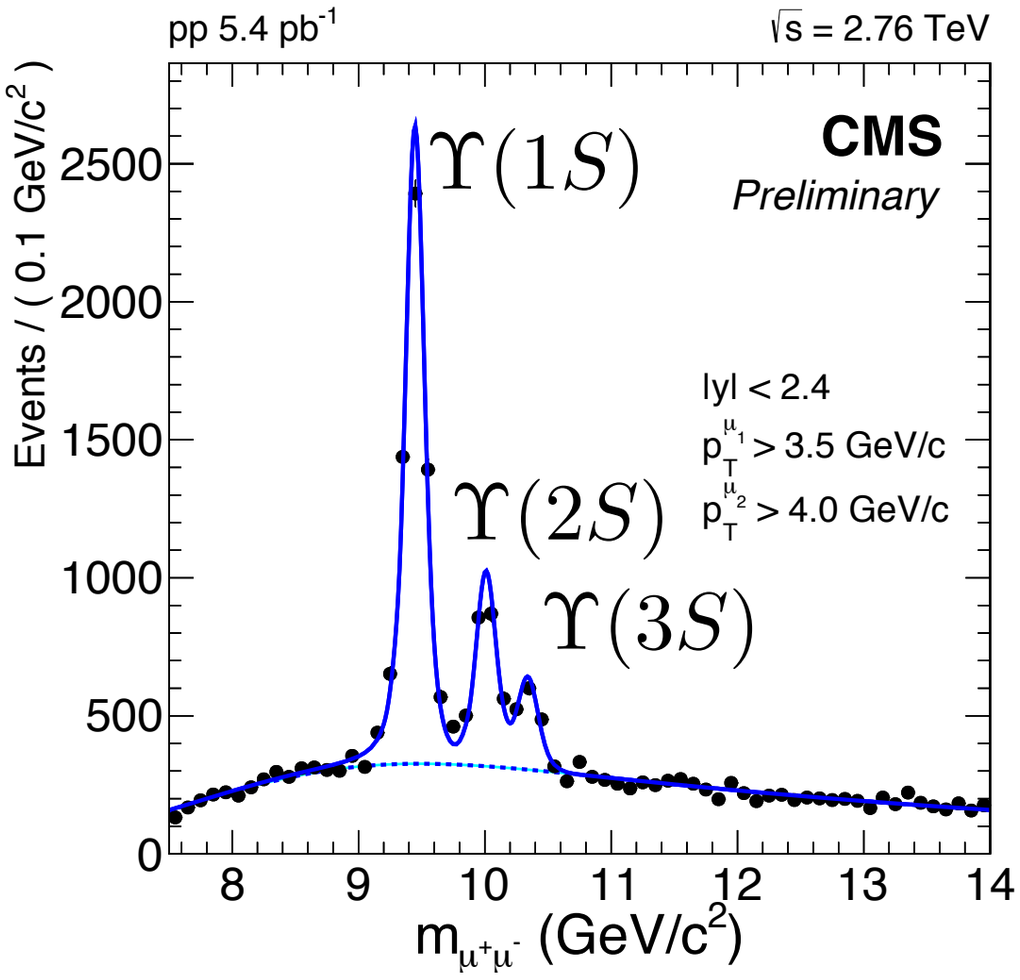
Backup

Analysis in a nutshell

- Quarkonia decay to two muons (*B(μμ)* ~ 3 %)
- Dimuon invariant mass is fitted in pp, pPb and PbPb
- Example in pp:



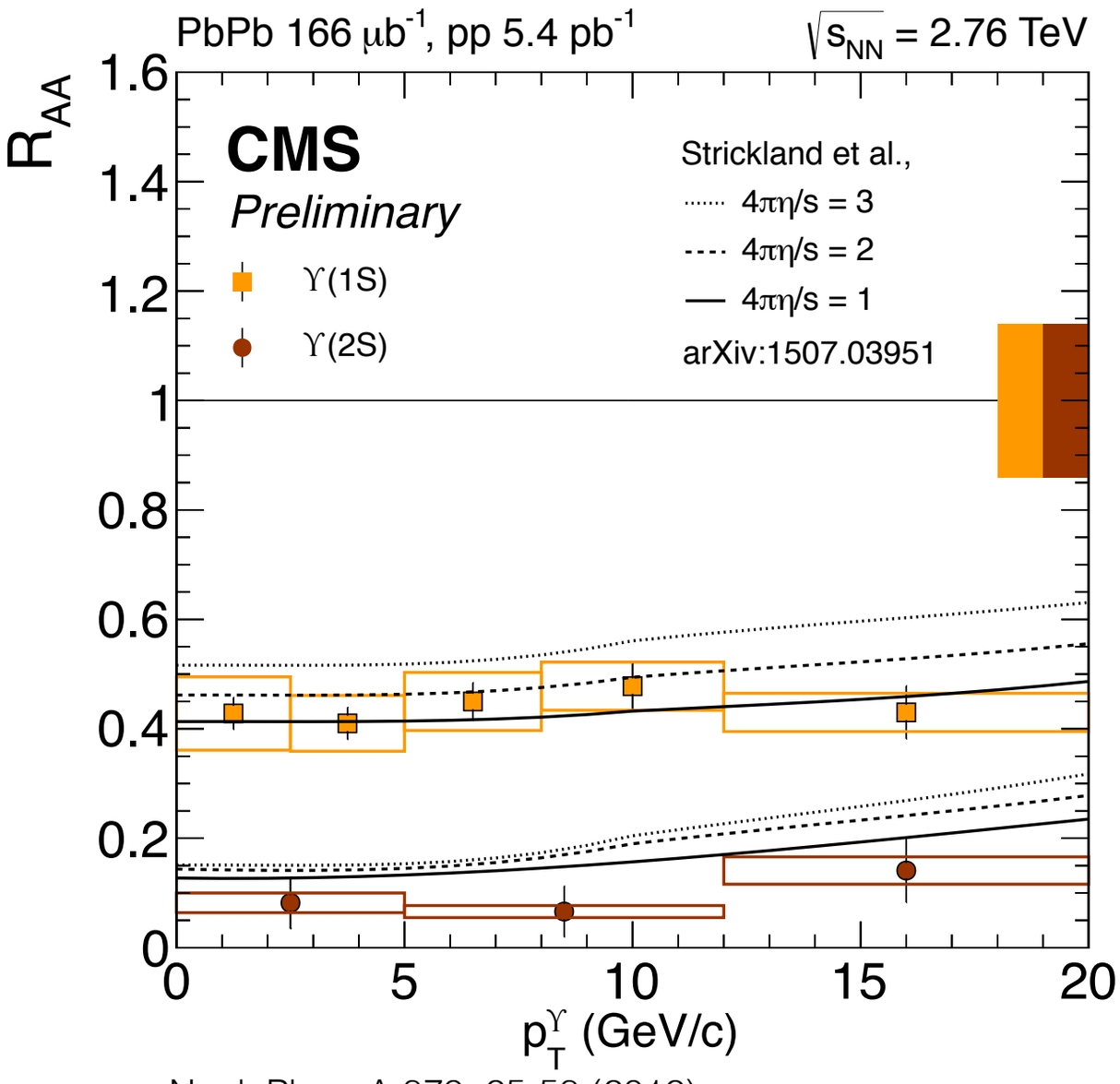
PRL 113 (2014) 262301



CMS-PAS-HIN-15-001

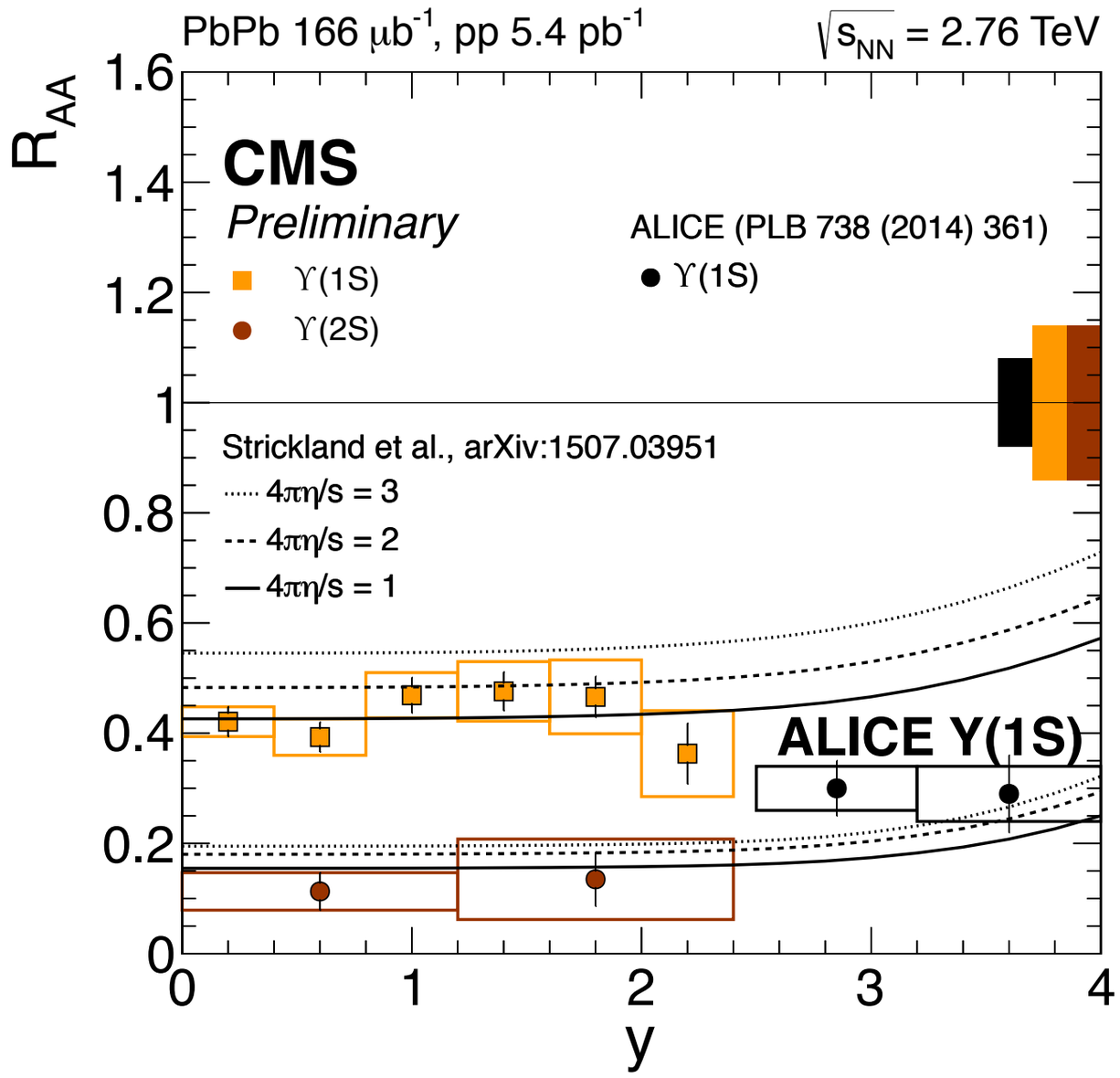
Theory comparisons in PbPb

- Strickland: Sequential melting in a hot + anisotropic QGP
- Satisfactory vs. pT



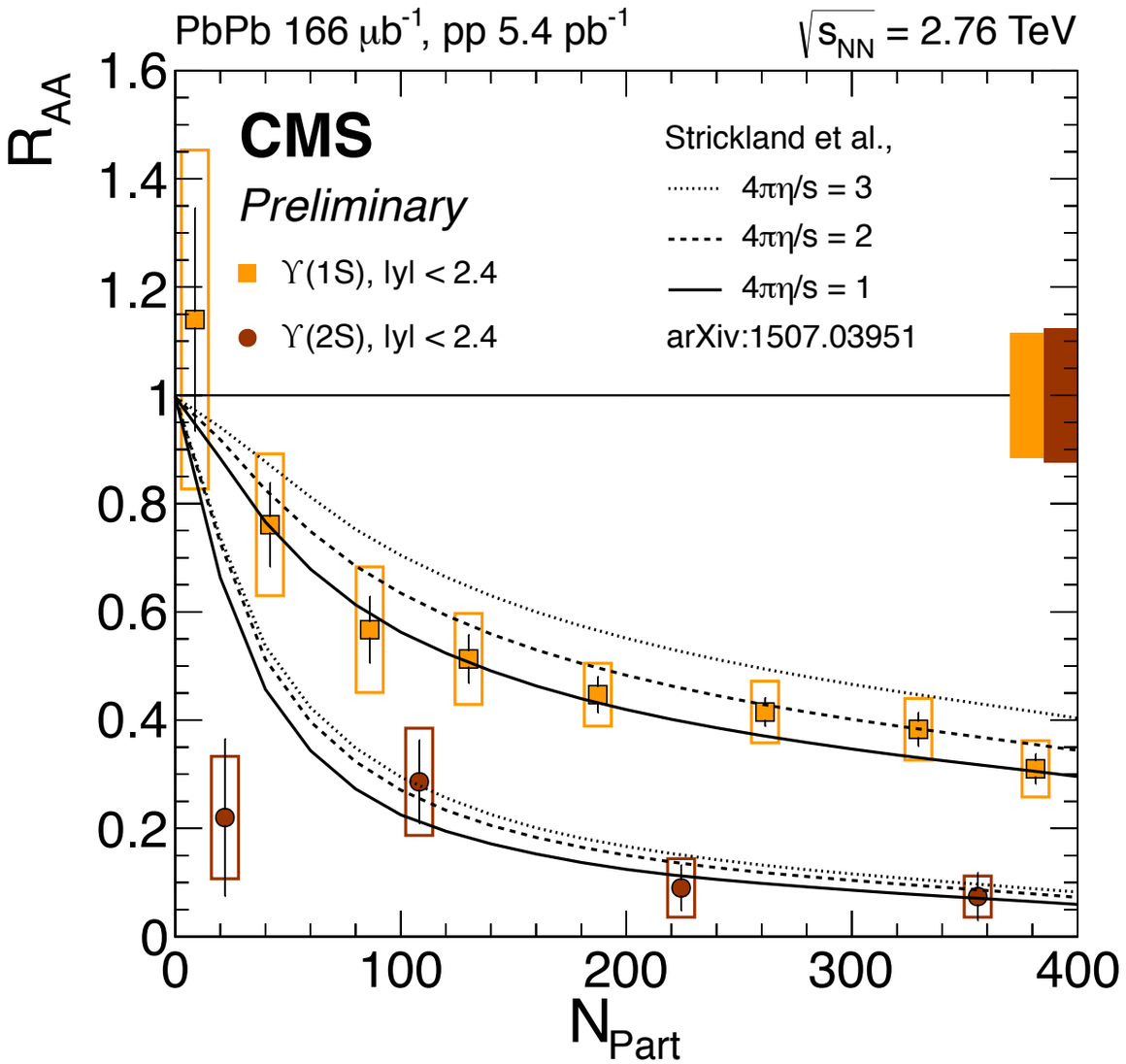
Nucl. Phys. A 879, 25-58 (2012)

- However fails to reproduce the forward full rapidity (non-)trend*!*

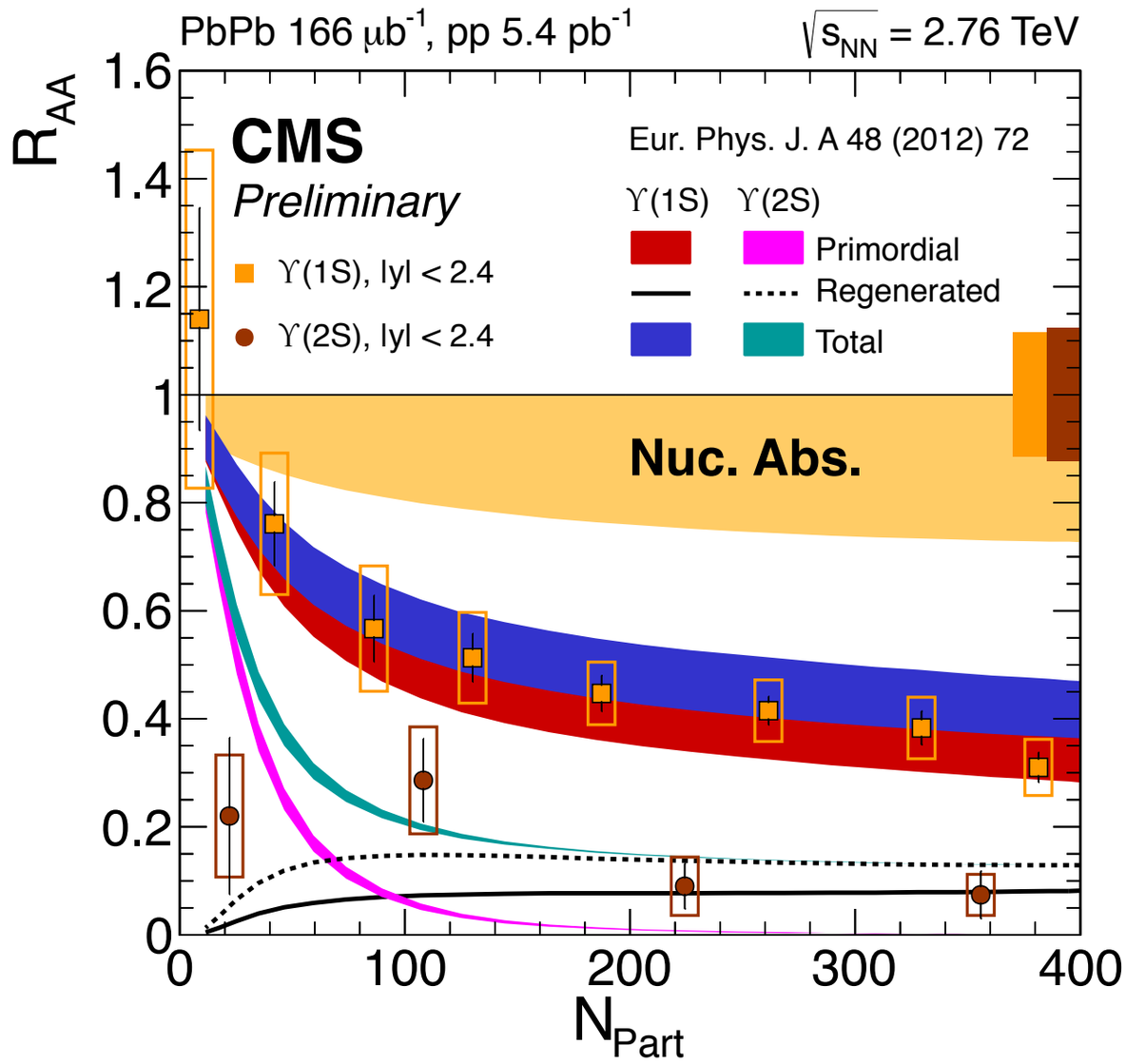


Theory vs. Experiment vs. Centrality

- Strickland vs. N_{part}
- Satisfactory agreement



- Another model: TAMU
- Surprising regeneration component for Υ(2S)



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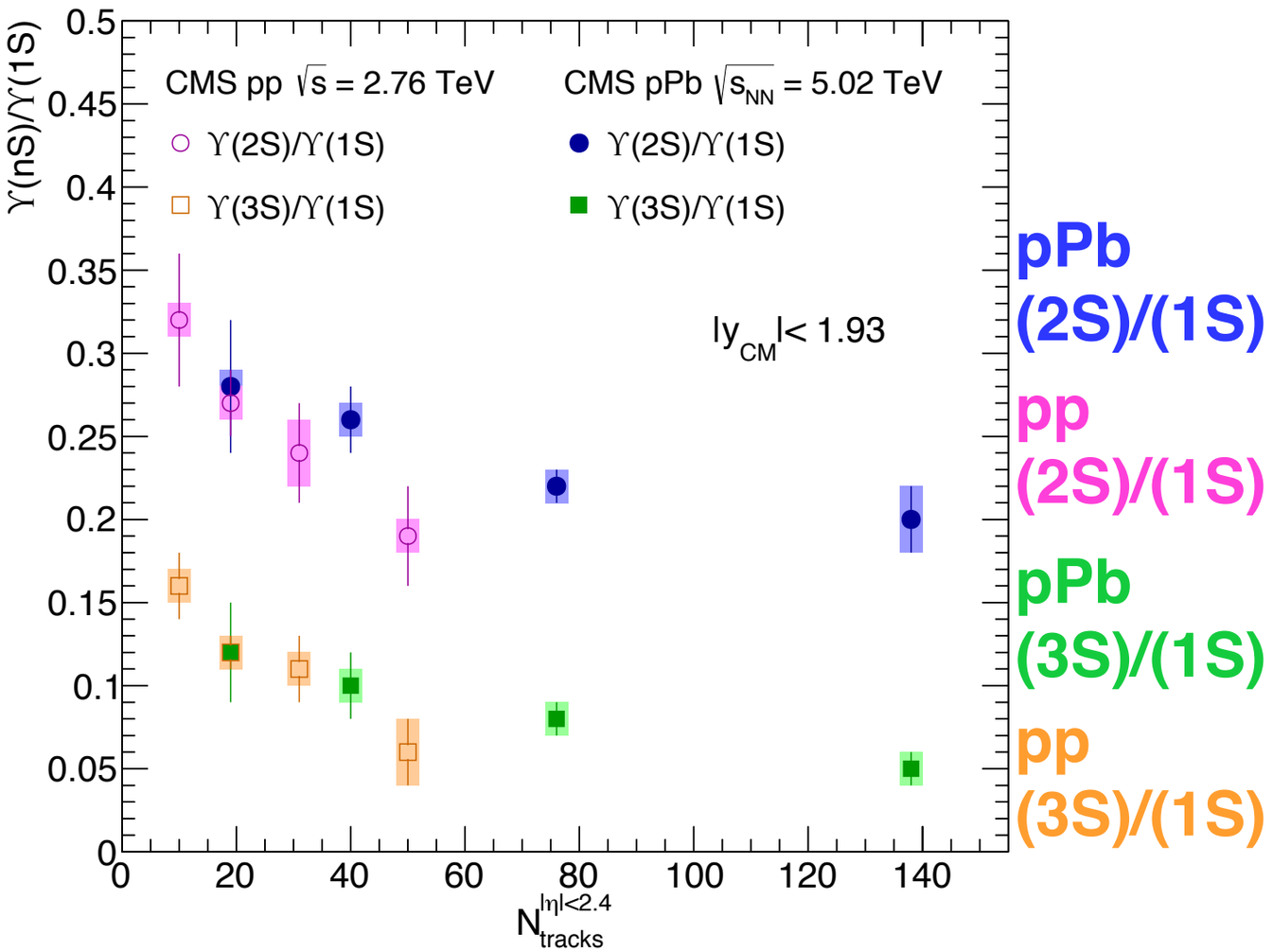
Relative production in pp, p-Pb

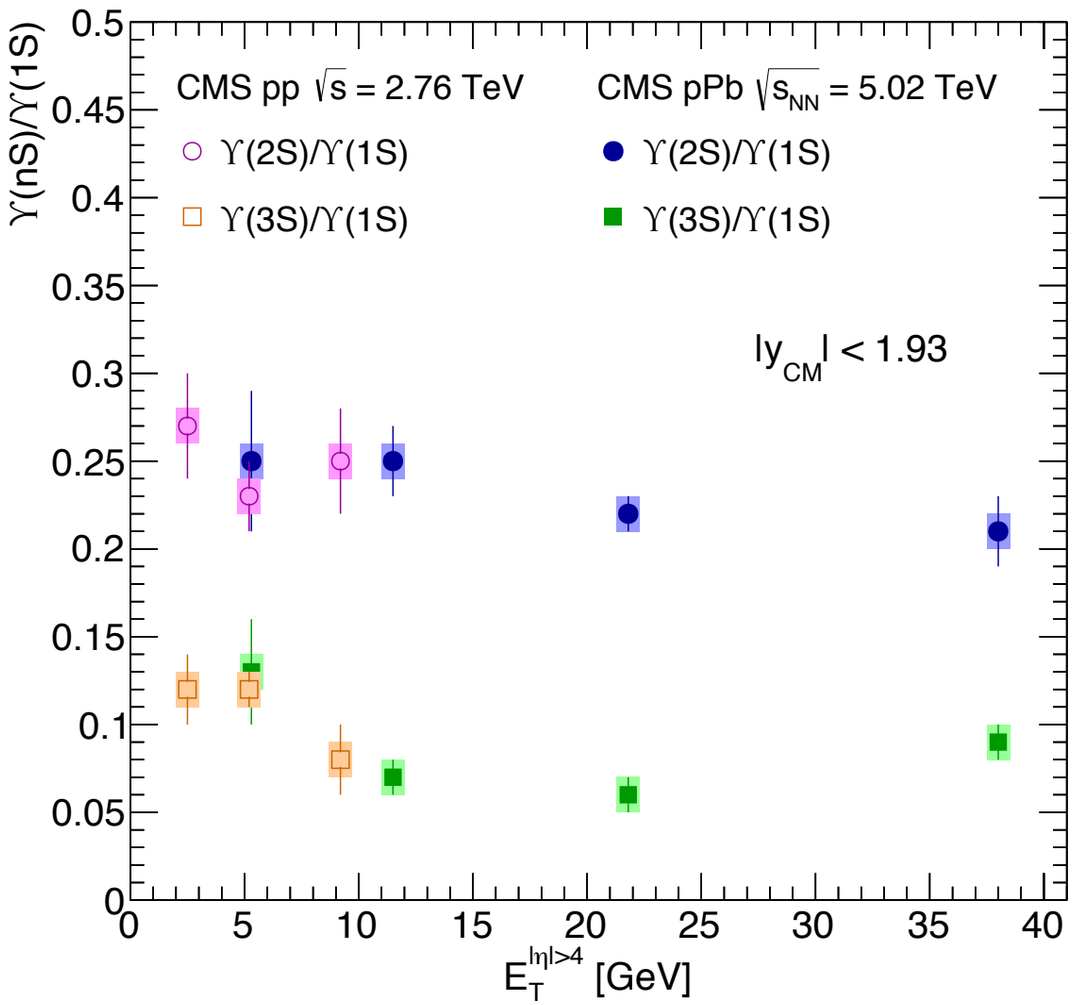
- Excited-over-1S single ratio
- Super interesting multiplicity dependent effect in pp & pPb…

- Total transverse energy in HF calo
- No apparent dependence in E_T(HF)

- *tracks in letal<2.4*



- *transverse energy 4<letal<5*



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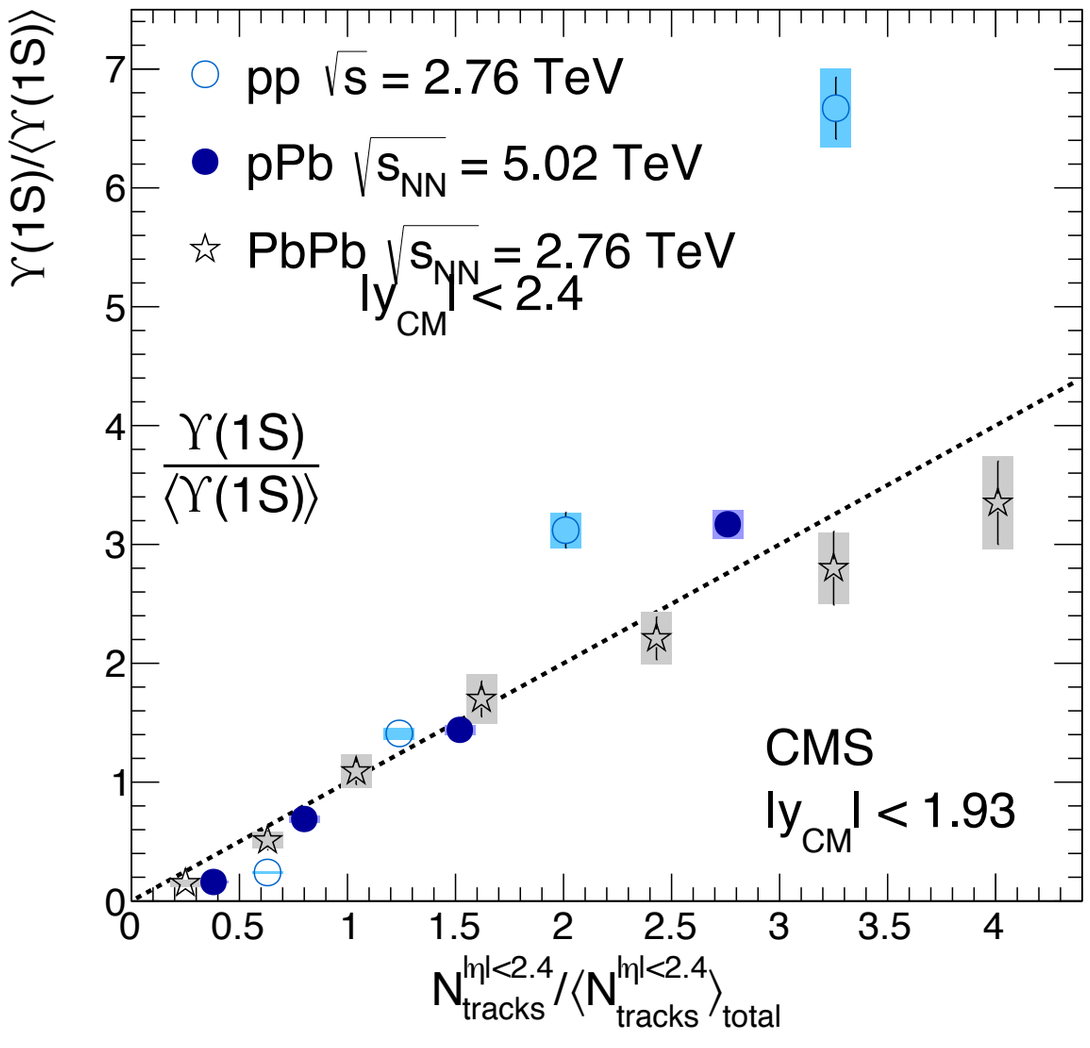
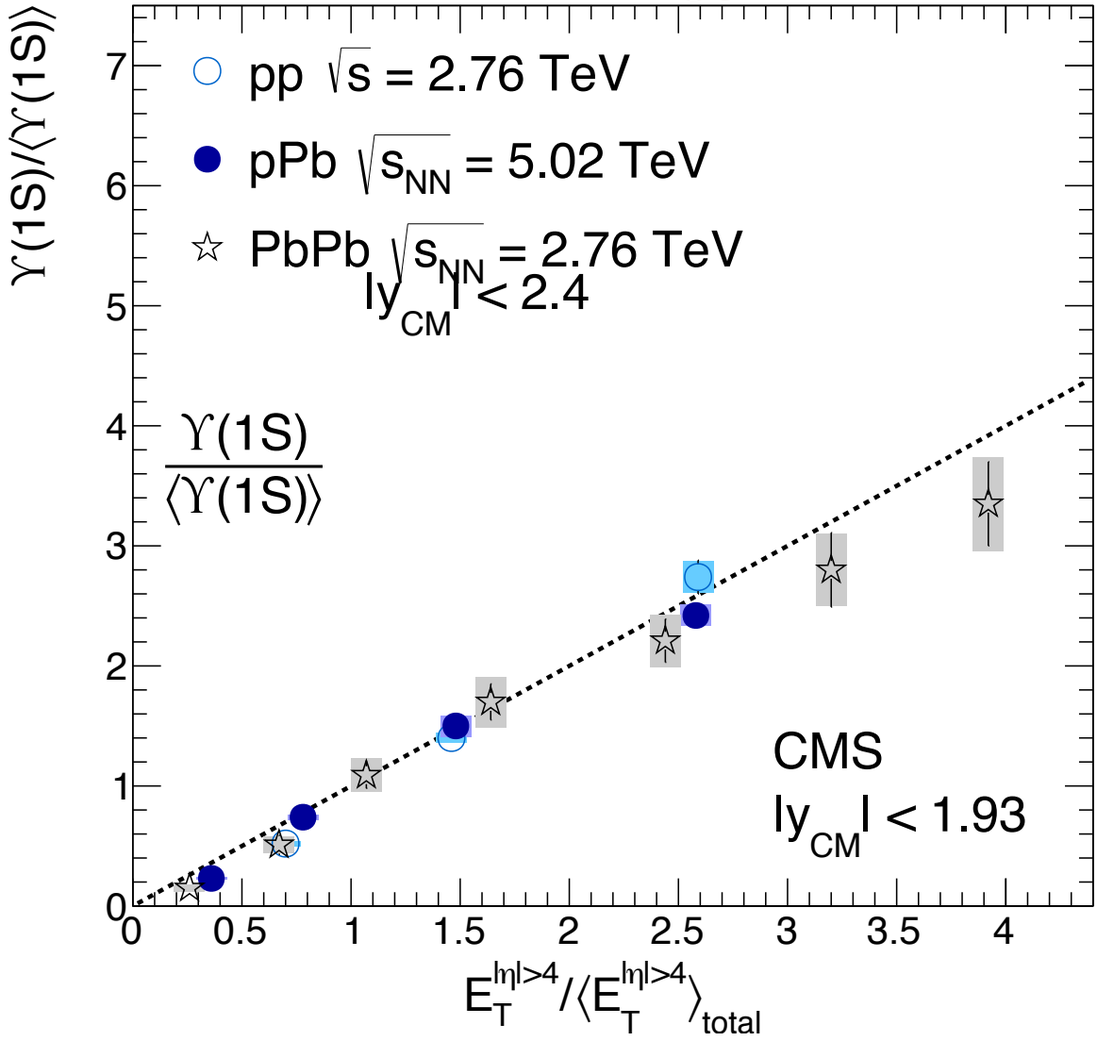
Self-normalised cross-sections

- ‘event activity variable’ normalised to average
- y axis: Cross section as a function of multiplicity, normalised by its integrated value

- *tracks in letal<2.4*

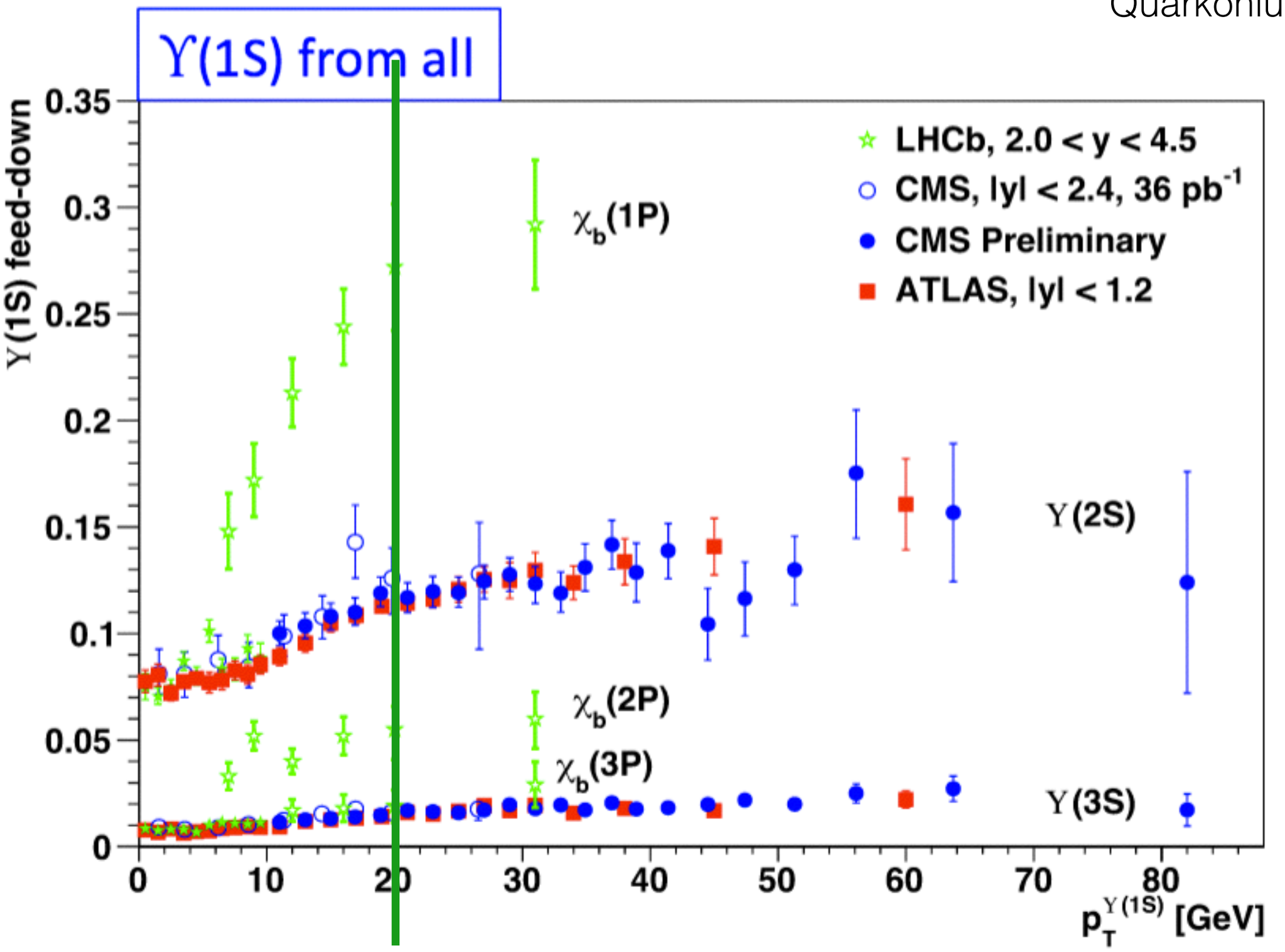


- *transverse energy 4<letal<5*

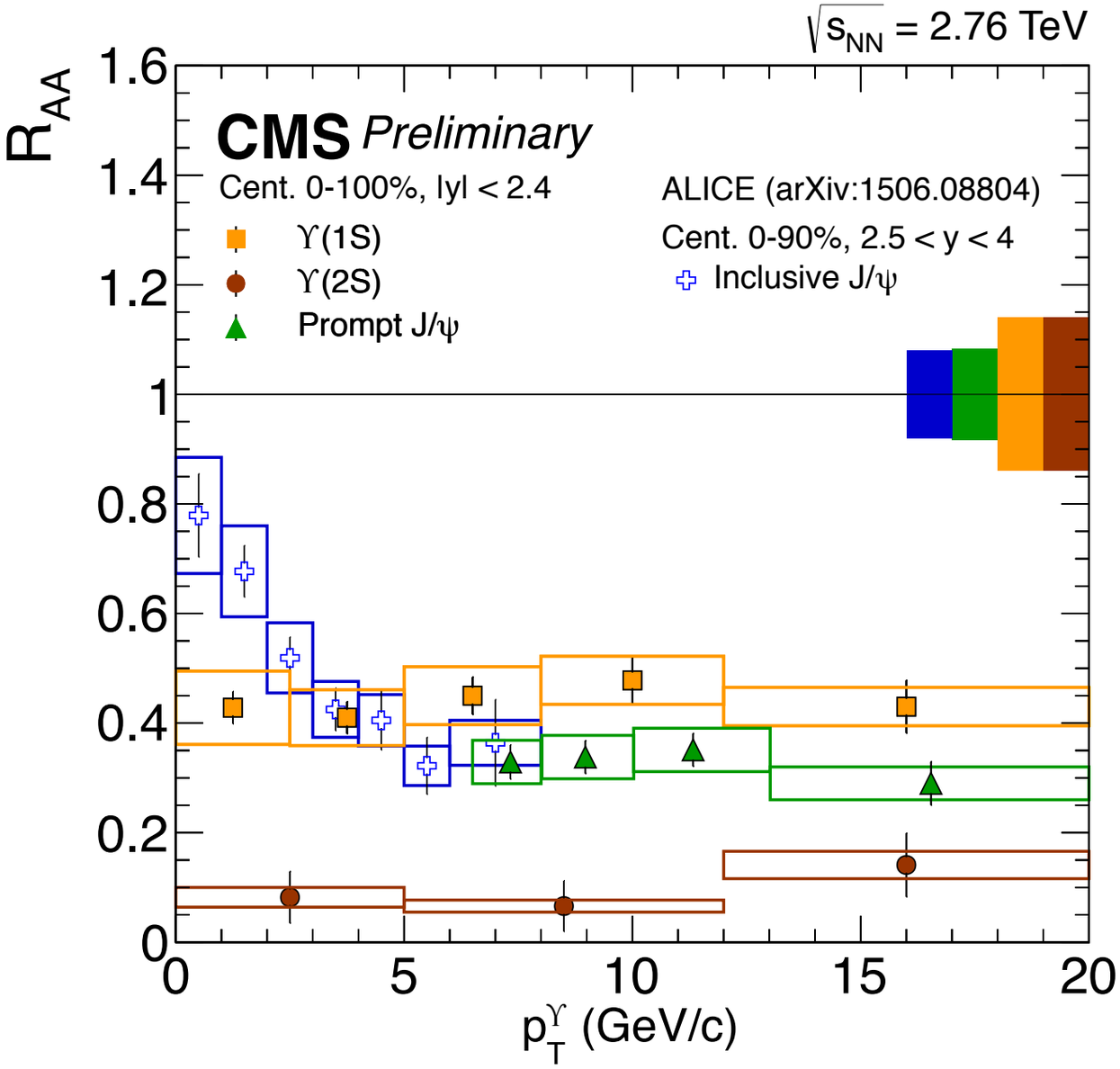


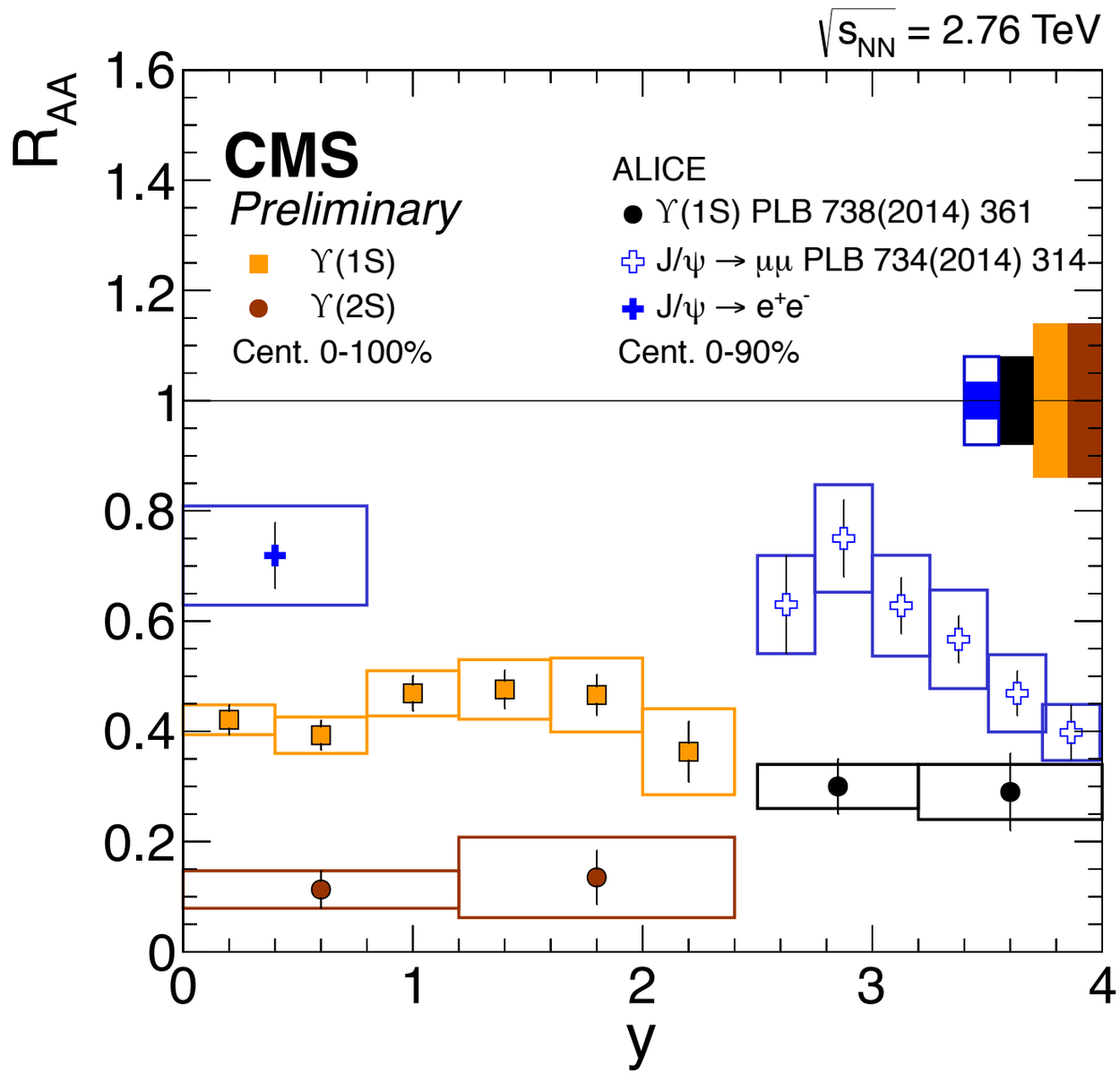
Feed down of Upsilons

Derived by H.Wöhri,
Quarkonium 2014



J/psi vs. Upsilons ?

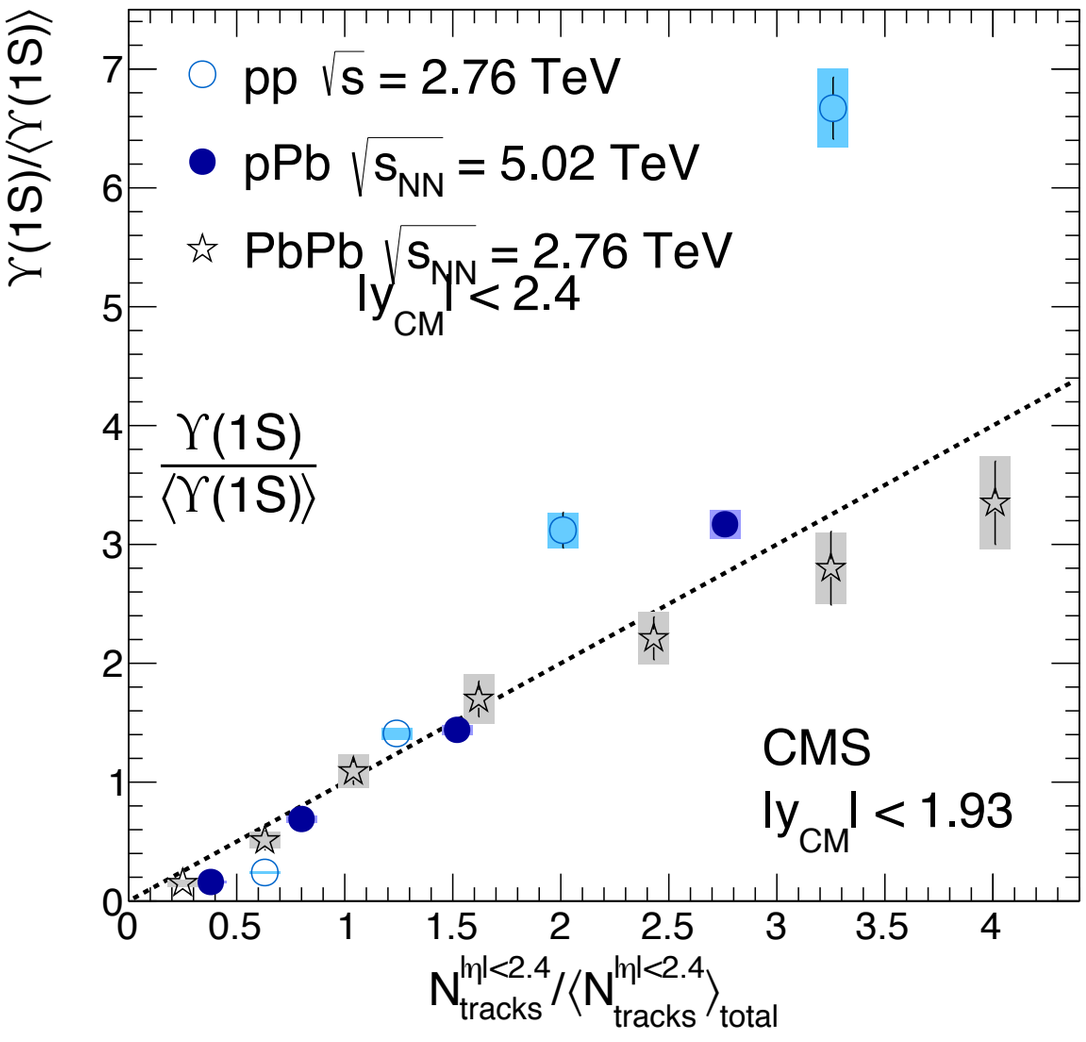


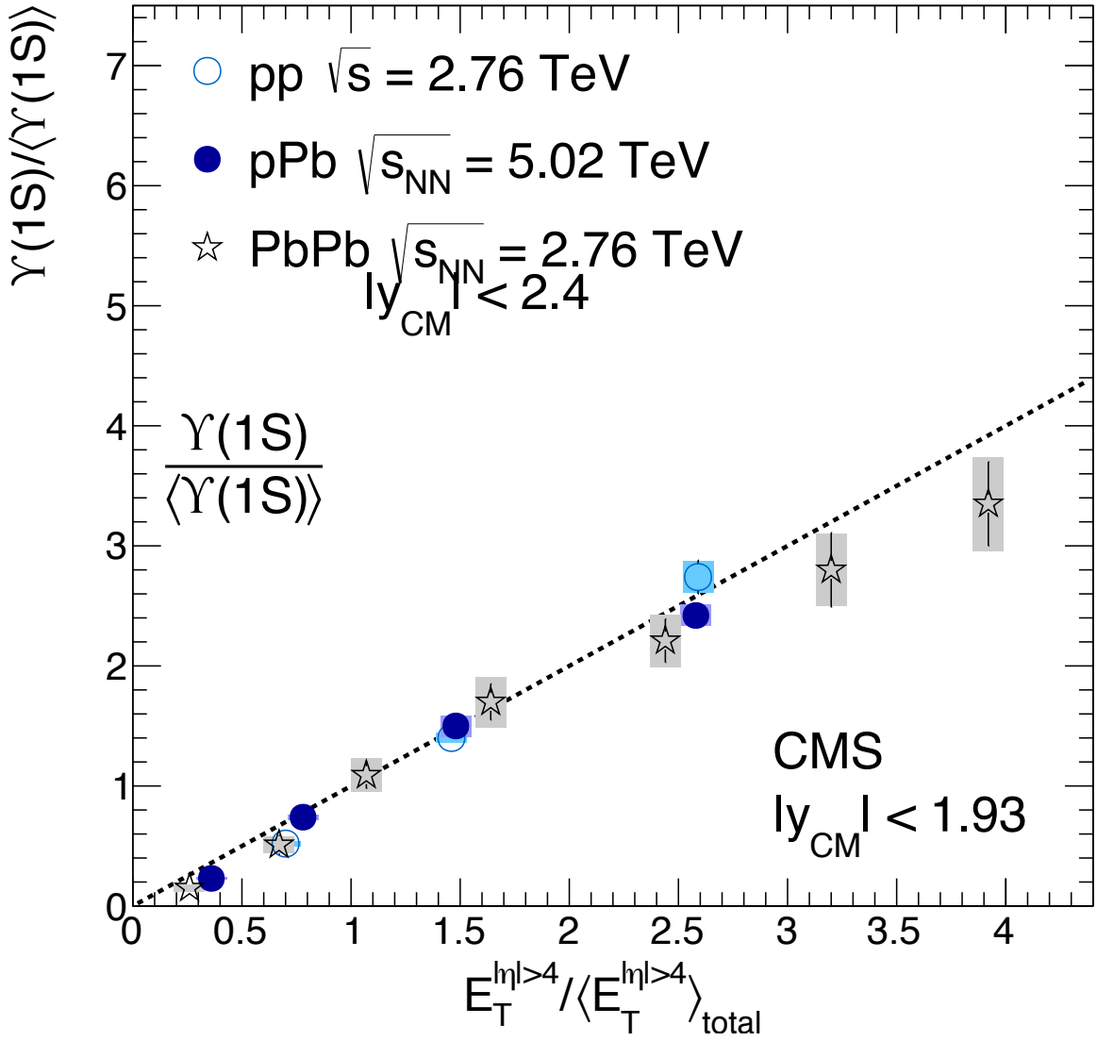


- Wish list for Xmas 2015:
- ALICE's Y(2S) and psi(2S)
- CMS's psi(2S)

Self-normalised cross-sections

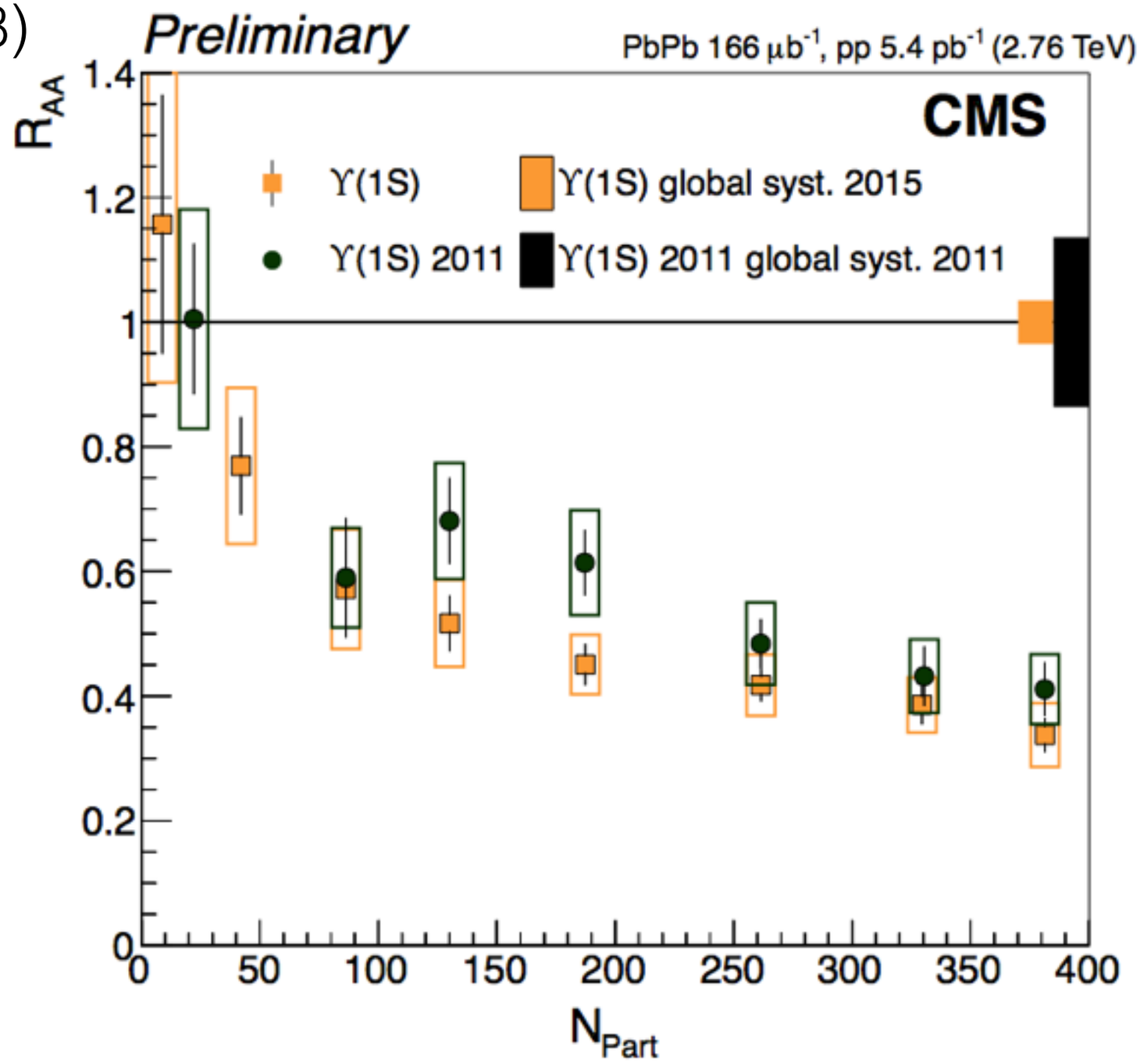
- x axis: Tracker multiplicity (|eta|<2.4) normalised by average
- y axis: Cross section as a function of multiplicity, normalised by its integrated value





RAA Y(1S) compared with past results

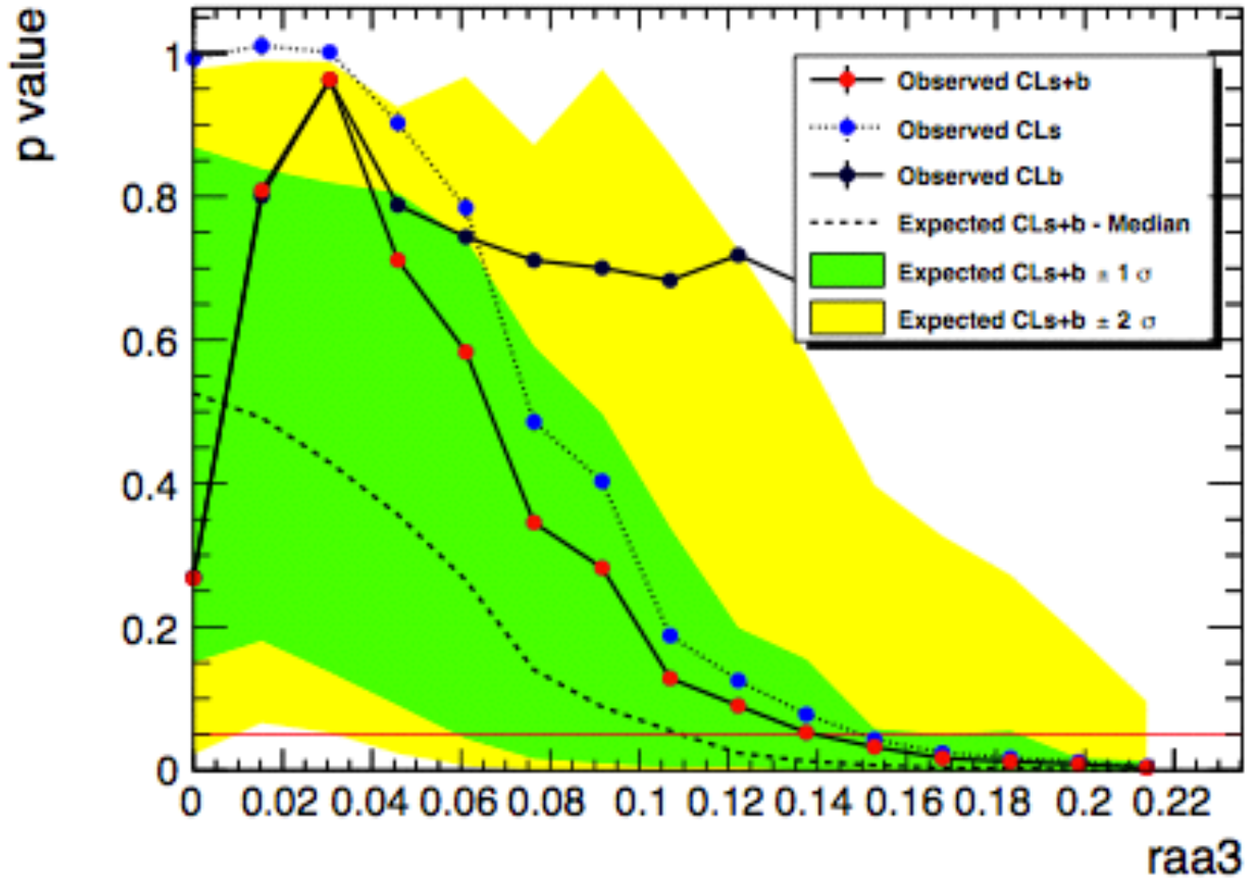
Orange: this result
Black: 2011 result (cf. slide 38)



RAA Y(3S)

- Feldman-Cousins method provides a set of well-defined confidence intervals for any true value of RAA Y(3S)
- Allows a smooth transition from one-sided to two-sided intervals in case of significant measurement

$$R_{AA}(\Upsilon(3S)) \quad < \quad 0.014 \text{ at } 95\% \text{ CL.}$$



Fully-frequentist result