Υ *measurements in CMS*

in pp, pPb, PbPb collisions

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Hot Quarks 2014

Las Negras - Spain

Introductory remarks

Quarkonia : probes of the QGP medium formation in AA collisions.
Y suppression seen in AA at LHC and RHIC,
some modification in pA collisions as well.

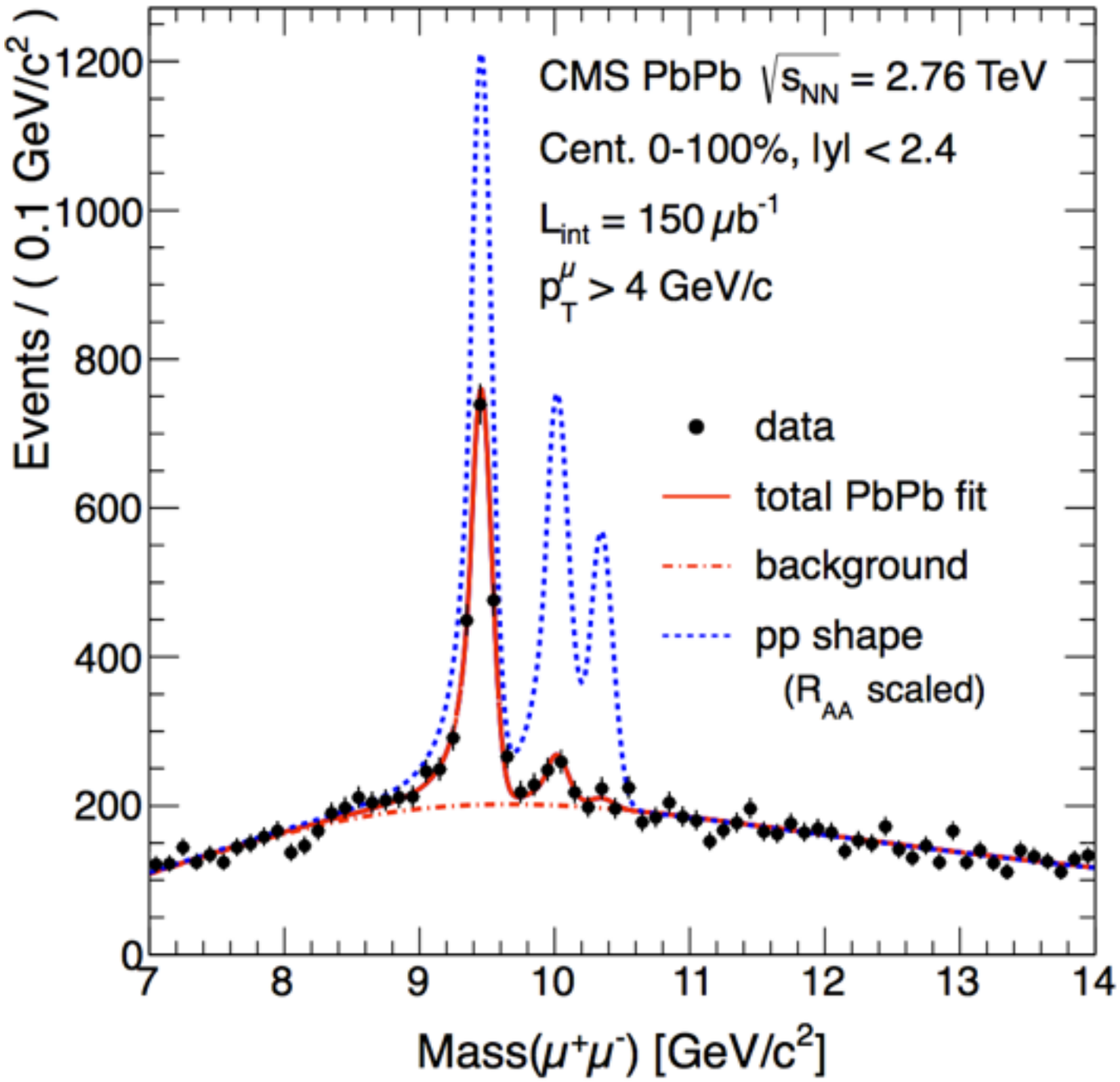
Today, two topics:

- Suppression/Modification/Melting of Y in HI collisions
- Production mechanisms in pp, and in pPb ?

Goal: Look for ‘cold-nuclear matter effects’, with a precise reference (pp)!

Υ *in PbPb*

PRL 109 (2012) 222301 : Observation of sequential suppression of Y in PbPb in CMS



This plot: simultaneous fit pp/AA

Here, the data are scaled to the R_{AA} values

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

2S,3S are suppressed with respect to 1S
significance > 5 σ.

1S yield = 0.56 * pp
-> consistent with feed-down estimates
(measured by CDF, different phase space)

Υ *in PbPb*

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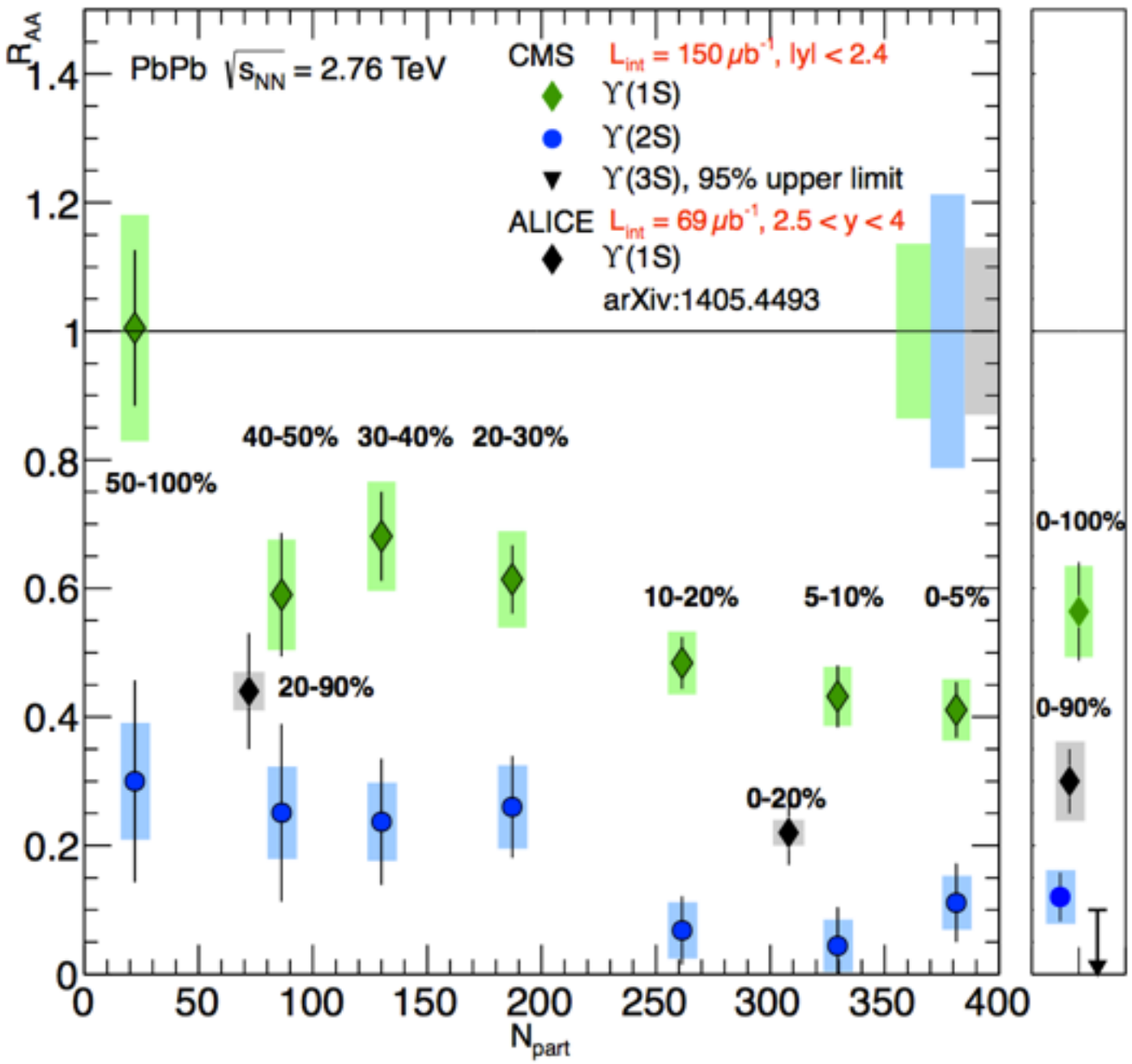

$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{MB}} \frac{\Upsilon(nS)|_{PbPb}}{\Upsilon(nS)|_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

Integrated values in the panel to the right

In the most central (< 5%) events:

$R_{AA}(1S) = 0.41 \pm 0.04\ (stat.) \pm 0.07\ (syst.)$

nPDF modifications, energy loss, shadowing should affect all states equivalently,

Looking at double ratios, initial state effects should cancel

Υ *in PbPb*

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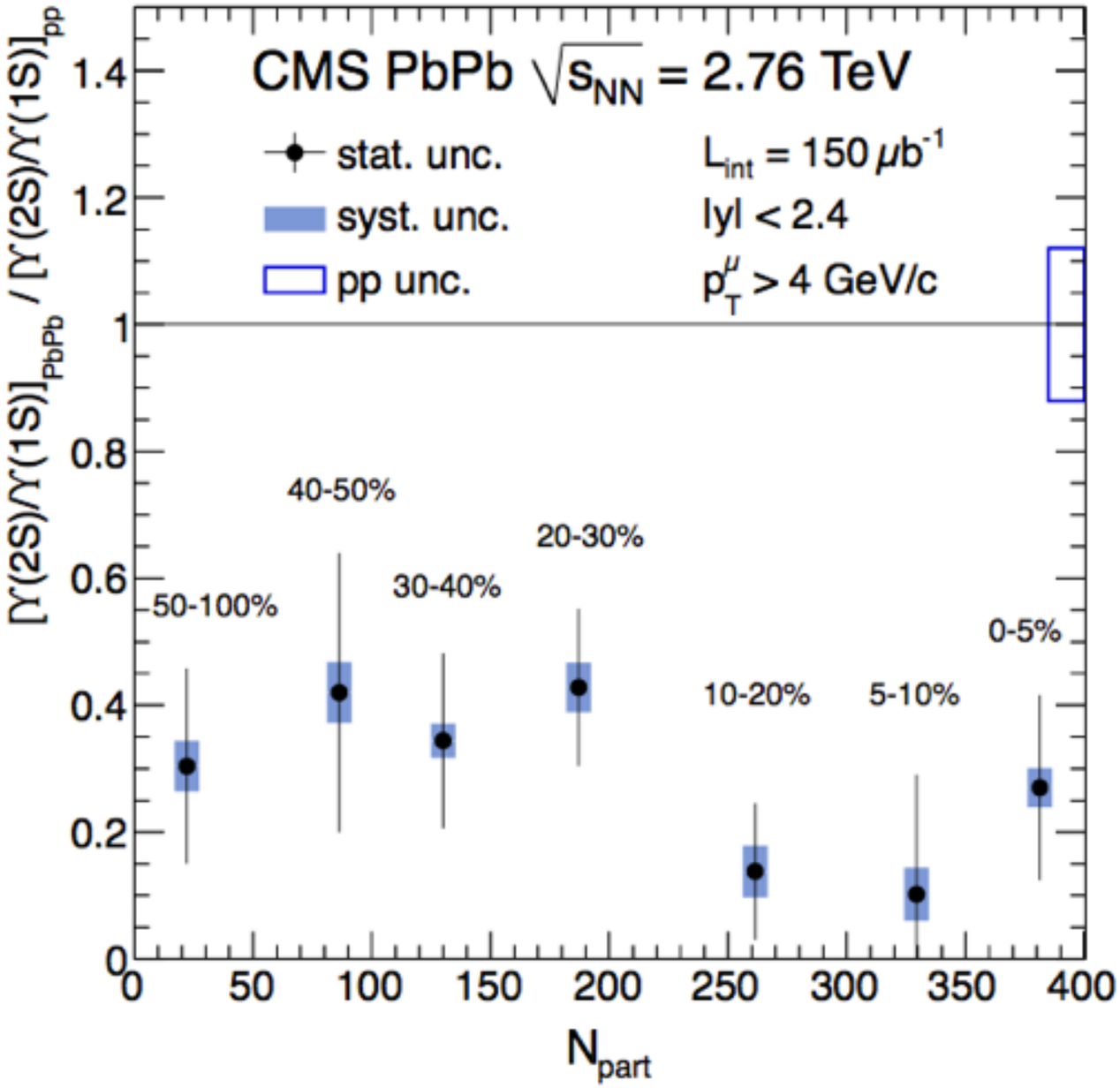


Effects at the $b\bar{b}$ stage should cancel here

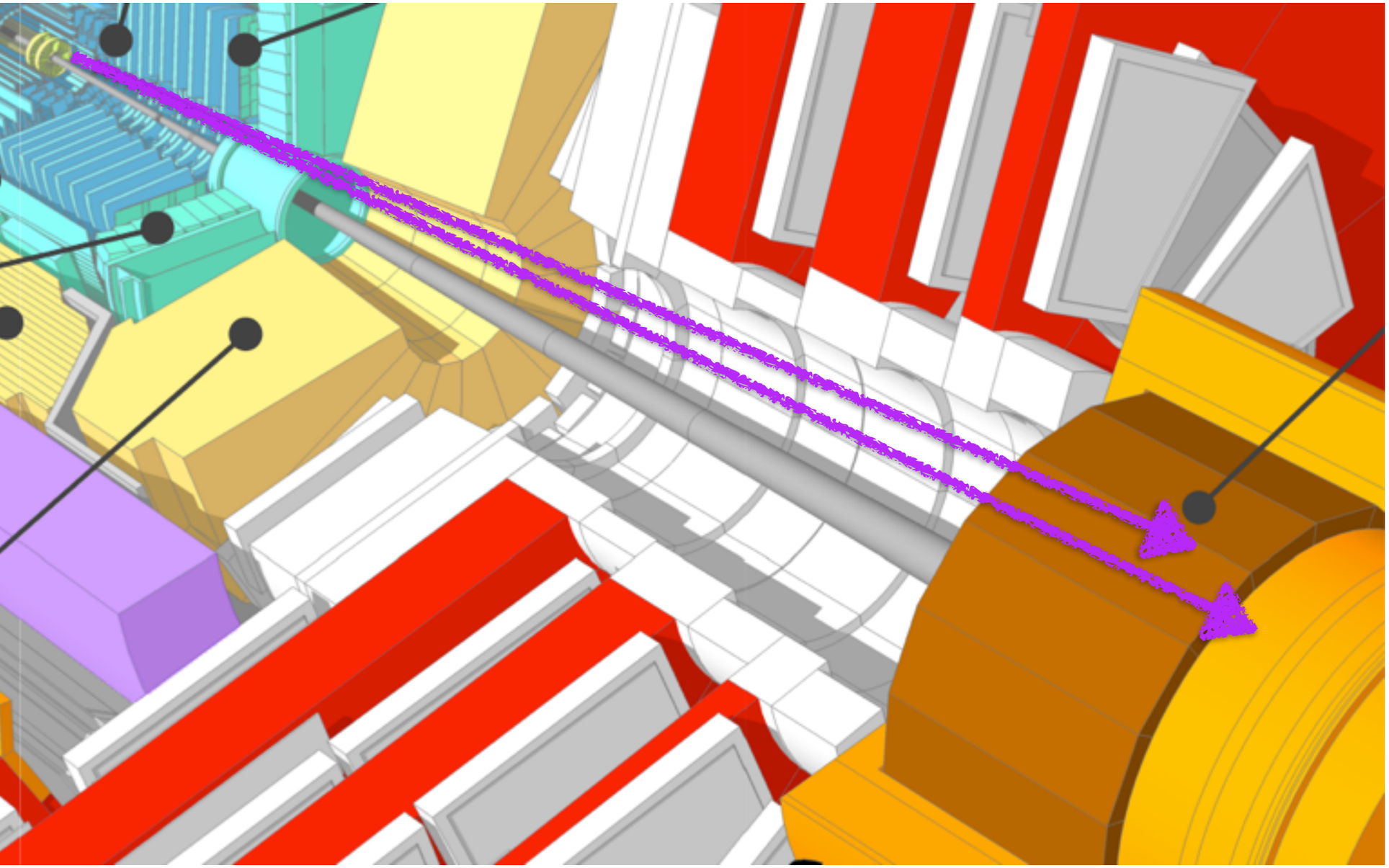
The 2S/1S double ratio reported shows strong suppression of the 2S compared to the 1S

Little is known of the production of associated particles with Υ

Calls for event-activity measurements

Event activity in pPb

1. Transverse energy deposit in ‘hadron forward’ calorimeters



‘HF±’ calorimeters:

Steel absorbers with embedded quartz fibres:

Čerenkov light from particles in quartz collected at PMTs downstream

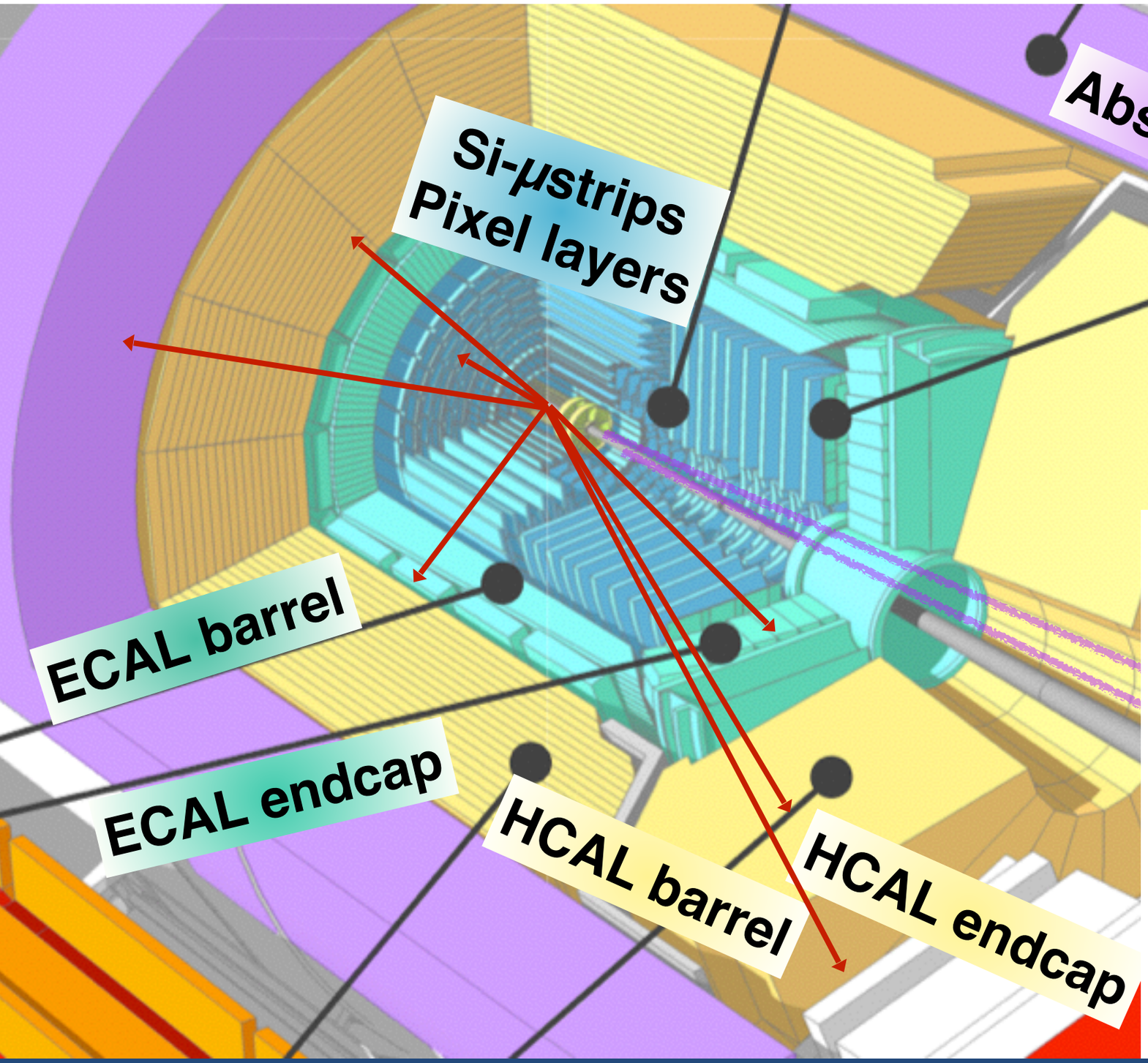
Used for:
jet tagging (e.g. VBF H^0)
Mueller-Navelet jets
Centrality measurements

- E_T^{HF} provides an event activity estimation
- Rapidity gap with respect to the ϒ

$4 < |\eta| < 5.2$

Event activity in pPb

2. Number of charged particle tracks in the inner trackers



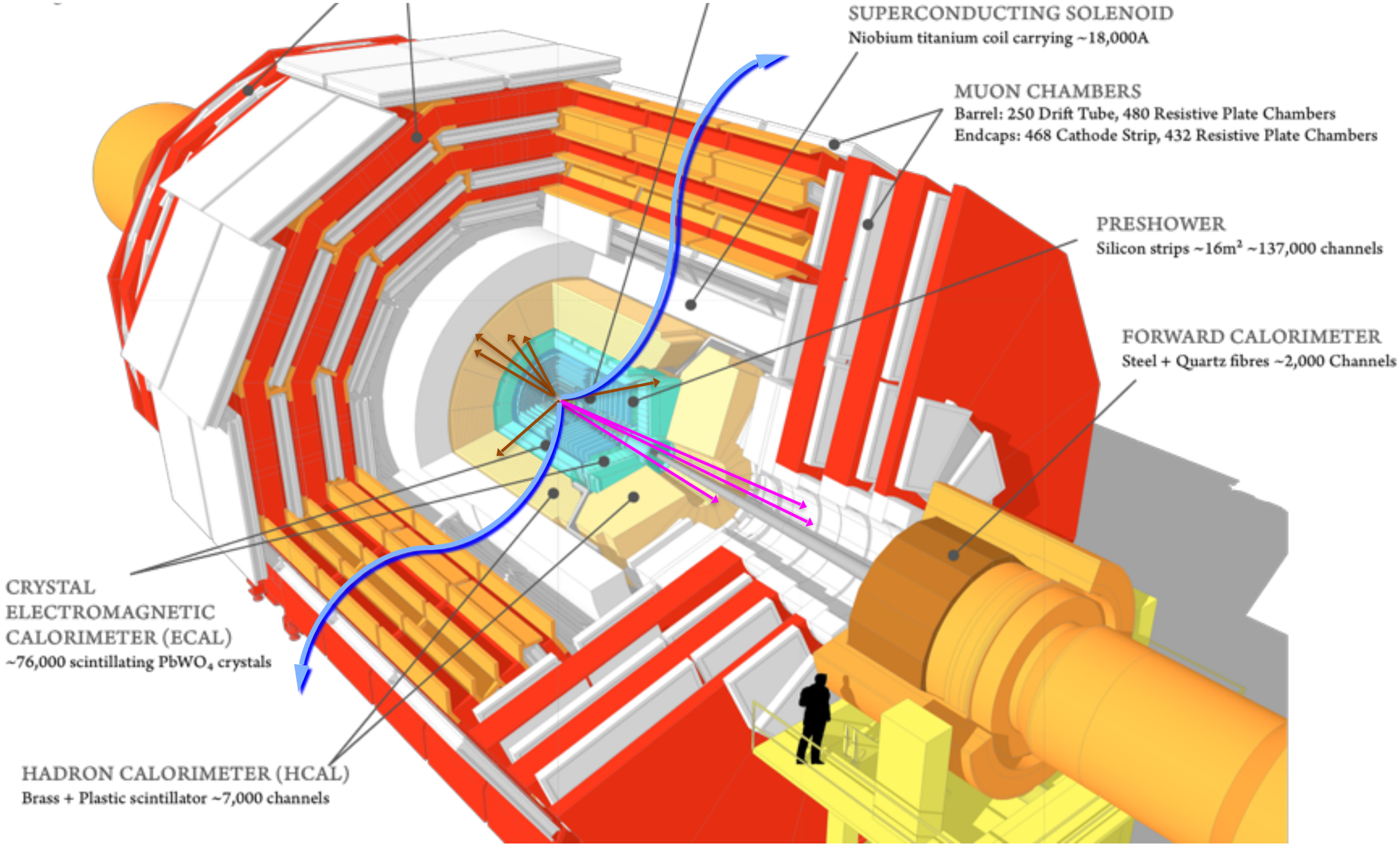
Silicon microstrips
9.9M channels
10 to 14 hits /charged particle

Pixel detectors
66M pixels
3 layers (4th to come circa 2018)

Charged particles within $|\eta| < 2.4$
$p_T > 400$ MeV threshold

and here comes an Upsilon

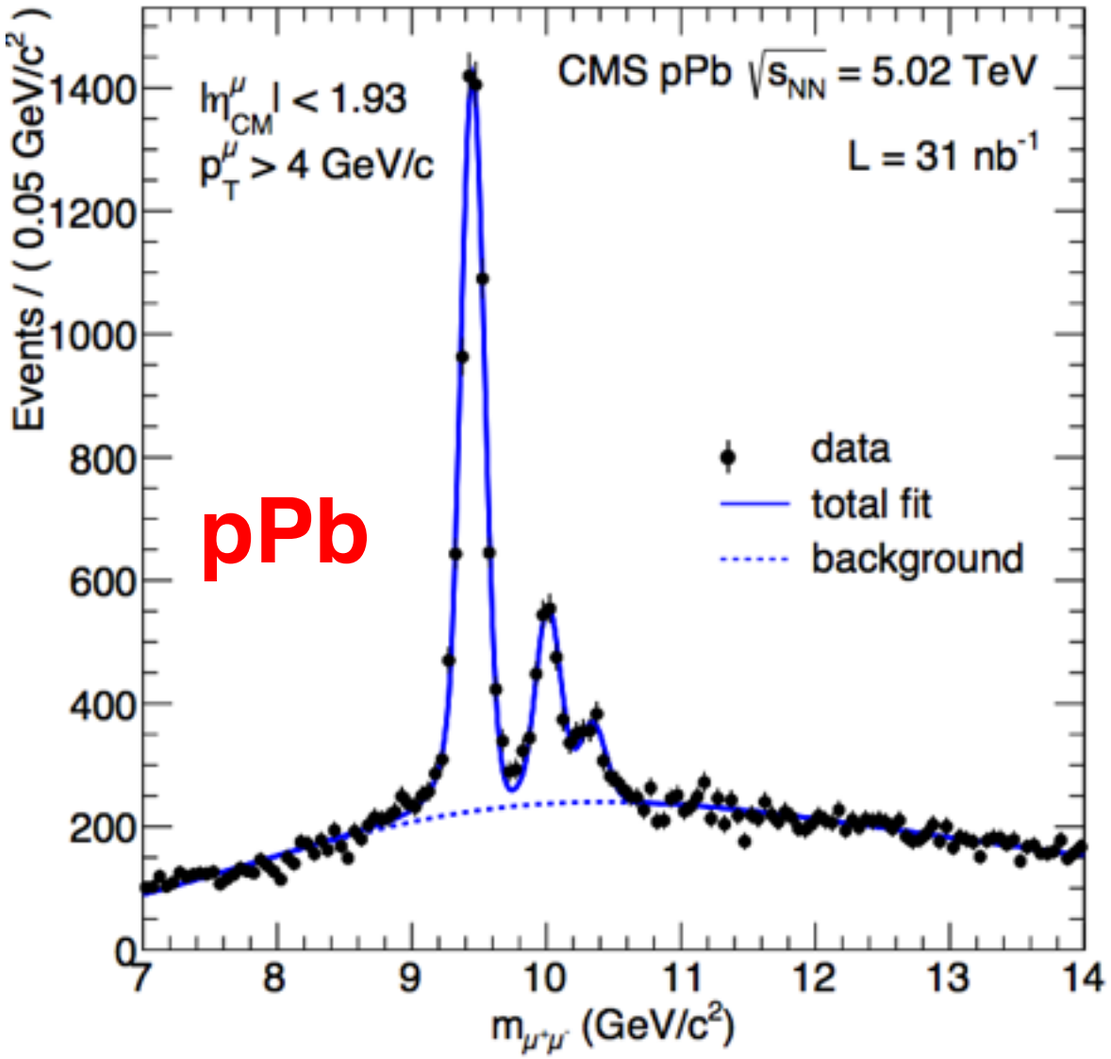
3. Muon tracks that have at least one valid hit in the muon chambers
$|\eta_{CM}| < 1.93$ $p_T > 4$ GeV/c



Υ *in pPb*

JHEP 04 (2014) 103 - Event activity dependence of Y(nS) production
in $\sqrt{s_{NN}}$ = 5.02 TeV pPb and $\sqrt{s}$ = 2.76 TeV pp

Method: Fit to Y(1S,2S,3S) data
to extract the **yield ratios Y(nS)/Y(1S)**



Υ *in* pp *and* pPb

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Method: Fit to Y(1S,2S,3S) data
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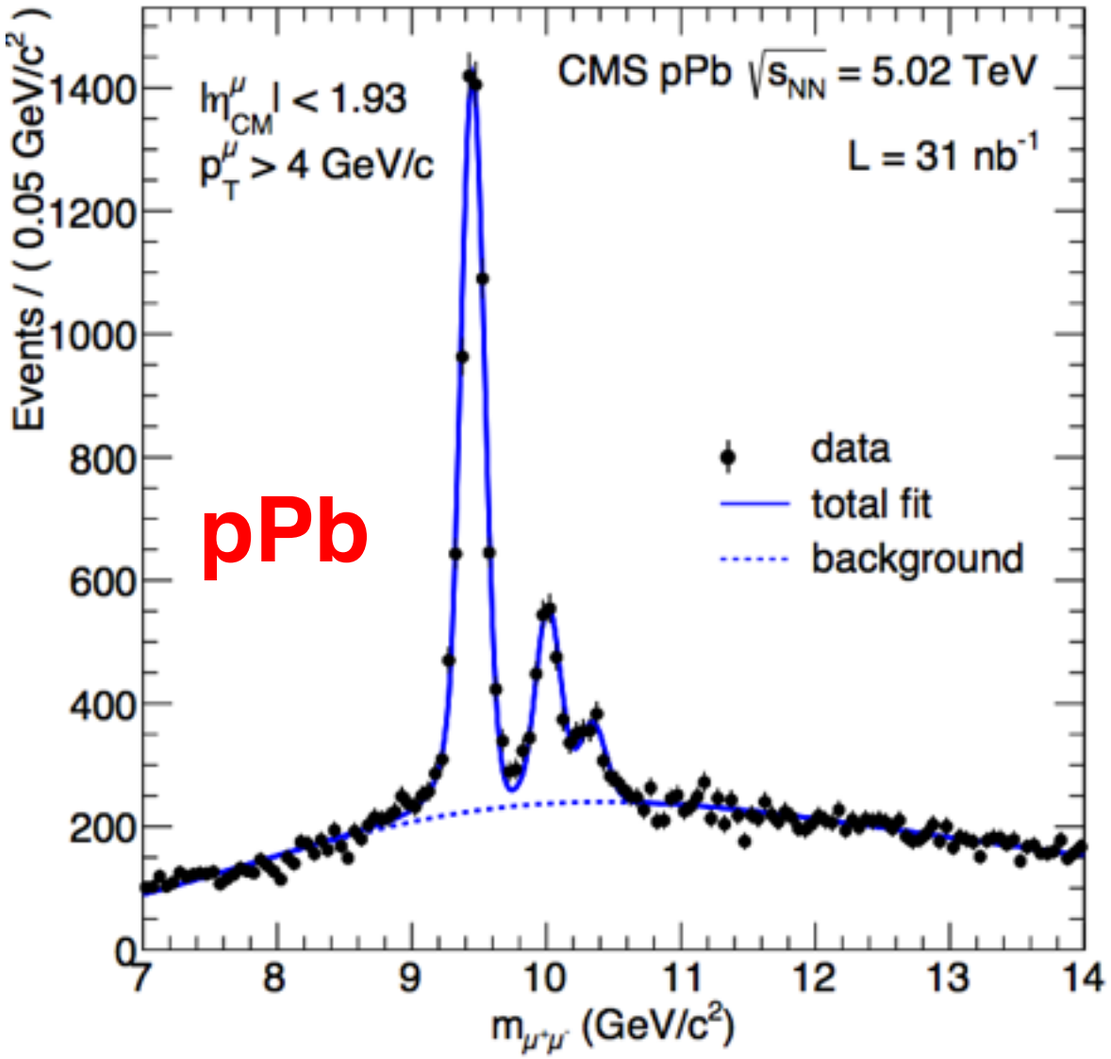
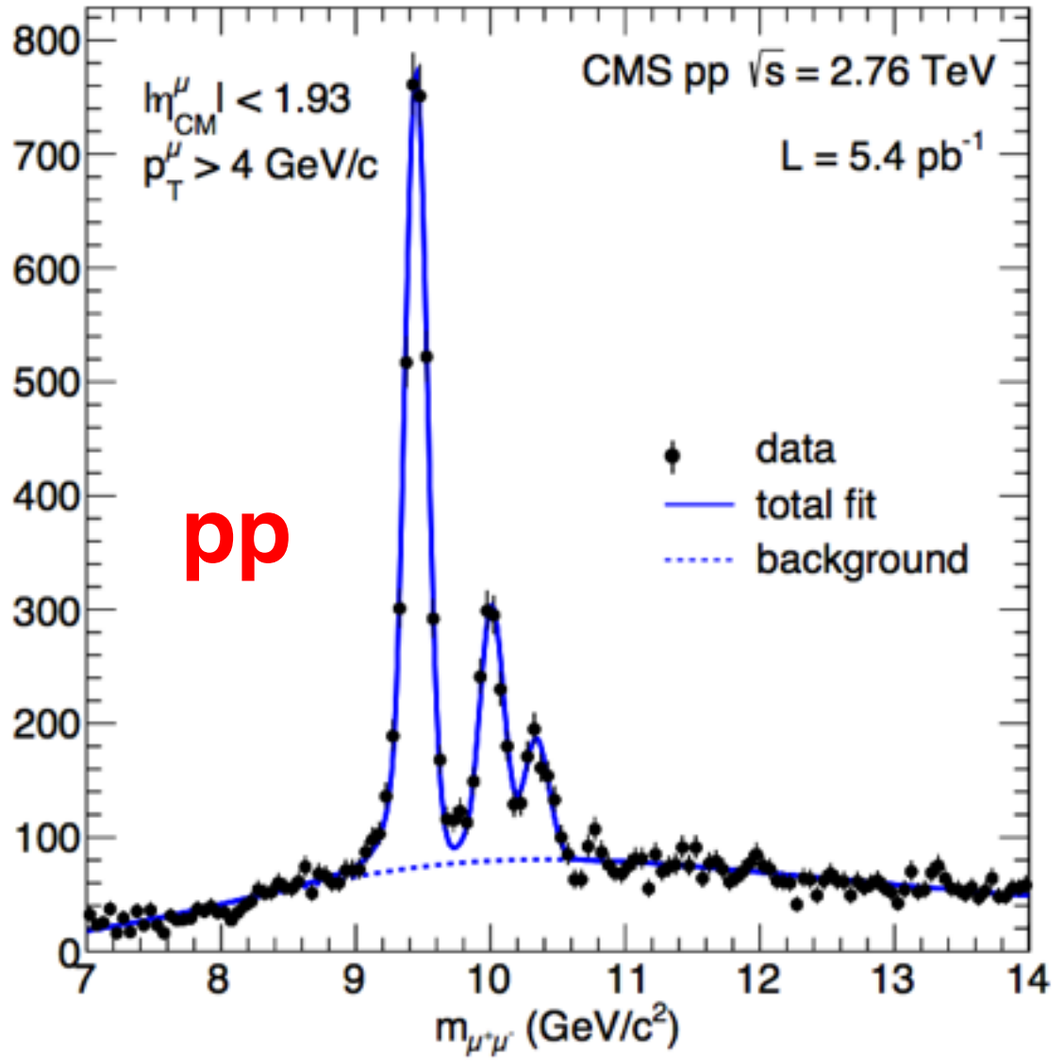


compare with pp ratios Y(nS)/Y(1S)



Υ(nS) *ratios in* pp, pPb *and* PbPb

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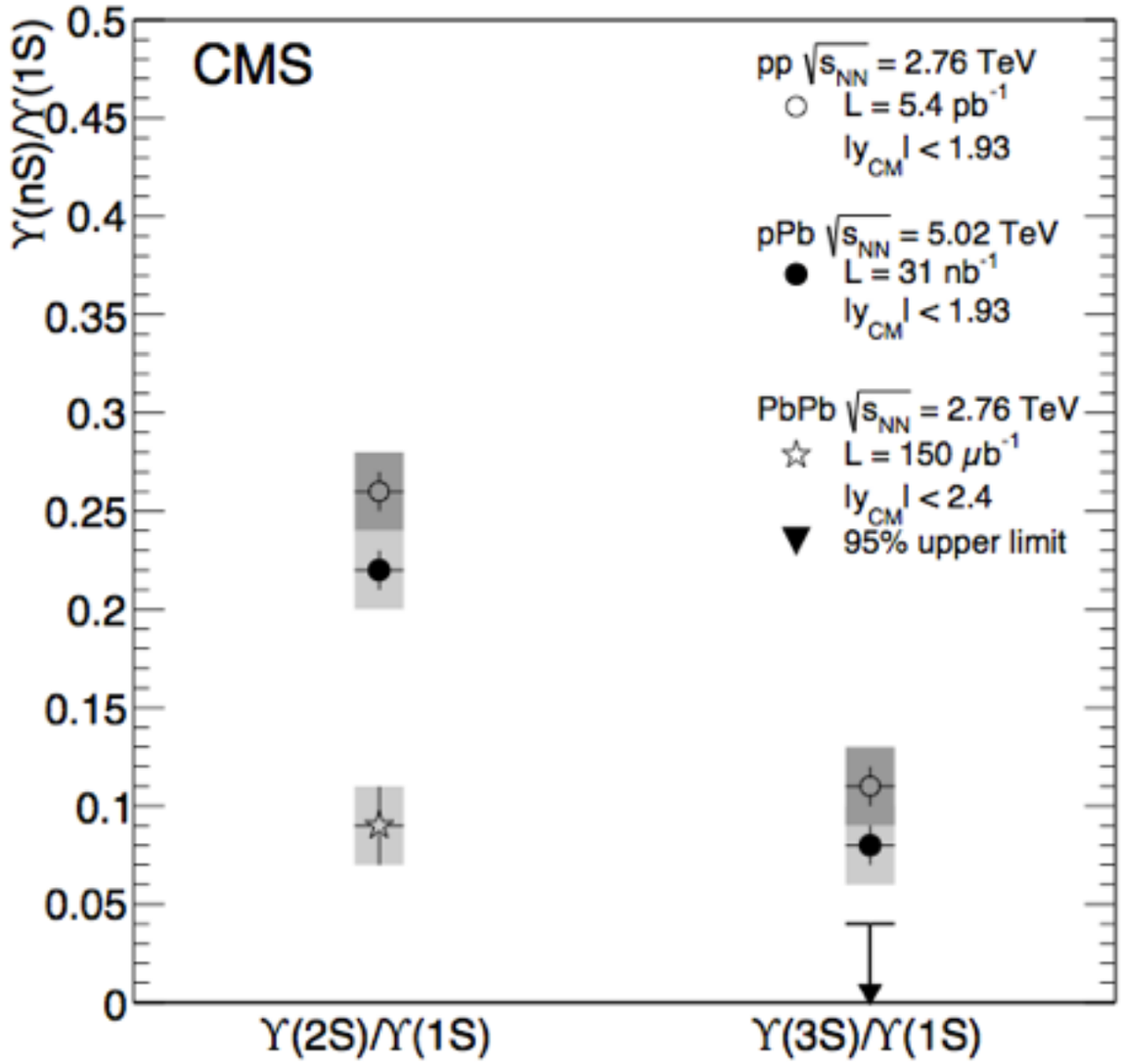
nS/1S ratio comparisons:



$\Upsilon(nS)$ ratios *in* pp

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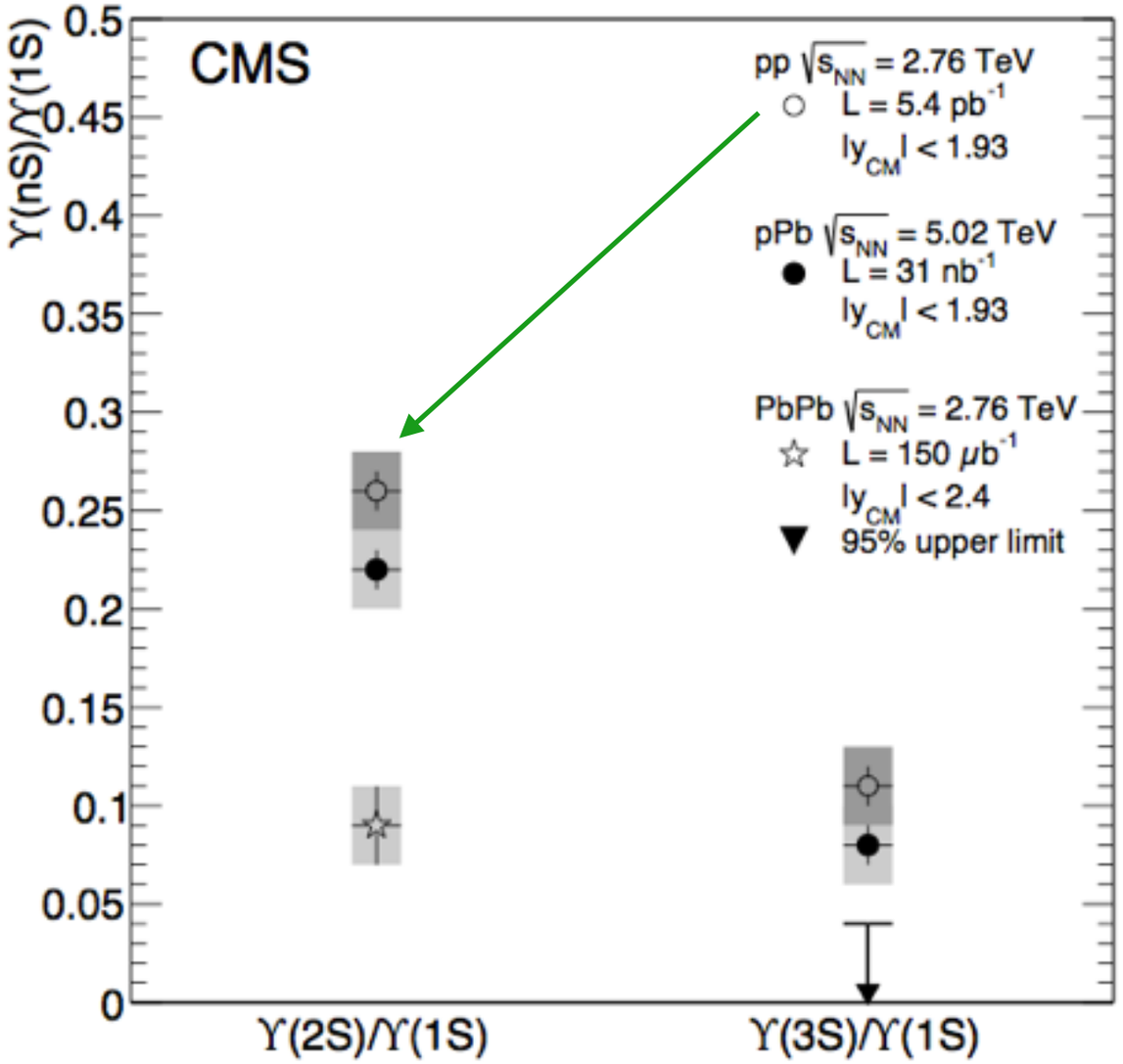
2S/1S ratio comparisons:

pp: Y(2S)/Y(1S) = 0.26 ± 0.01± 0.01± 0.02



ϒ *in* pPb

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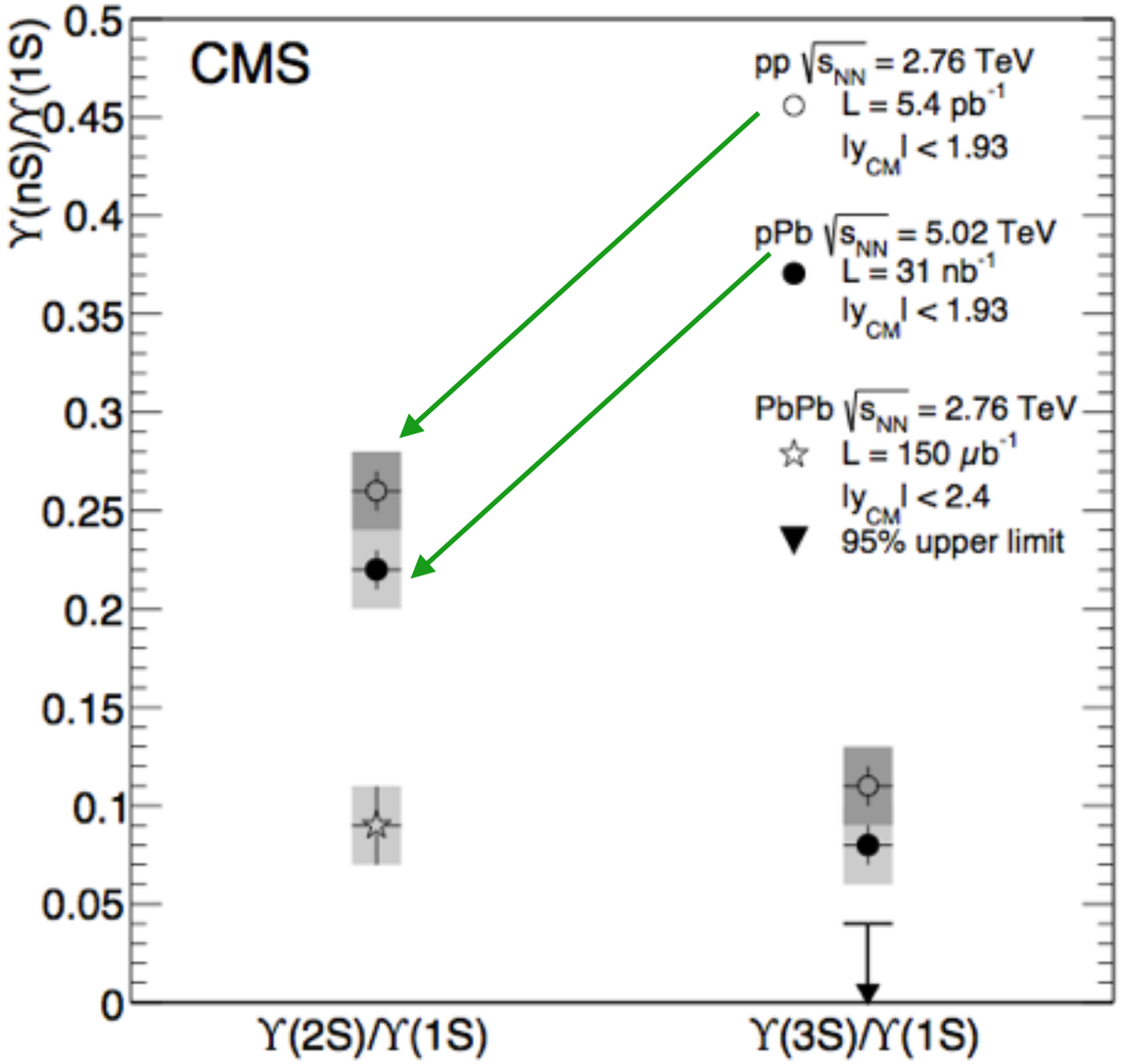
2S/1S ratio comparisons:

pp: Y(2S)/Y(1S) = 0.26 ± 0.01± 0.01± 0.02

pPb: Y(2S)/Y(1S) = 0.22 ± 0.01± 0.01± 0.02



ϒ *in* pPb

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2S/1S ratio comparisons:

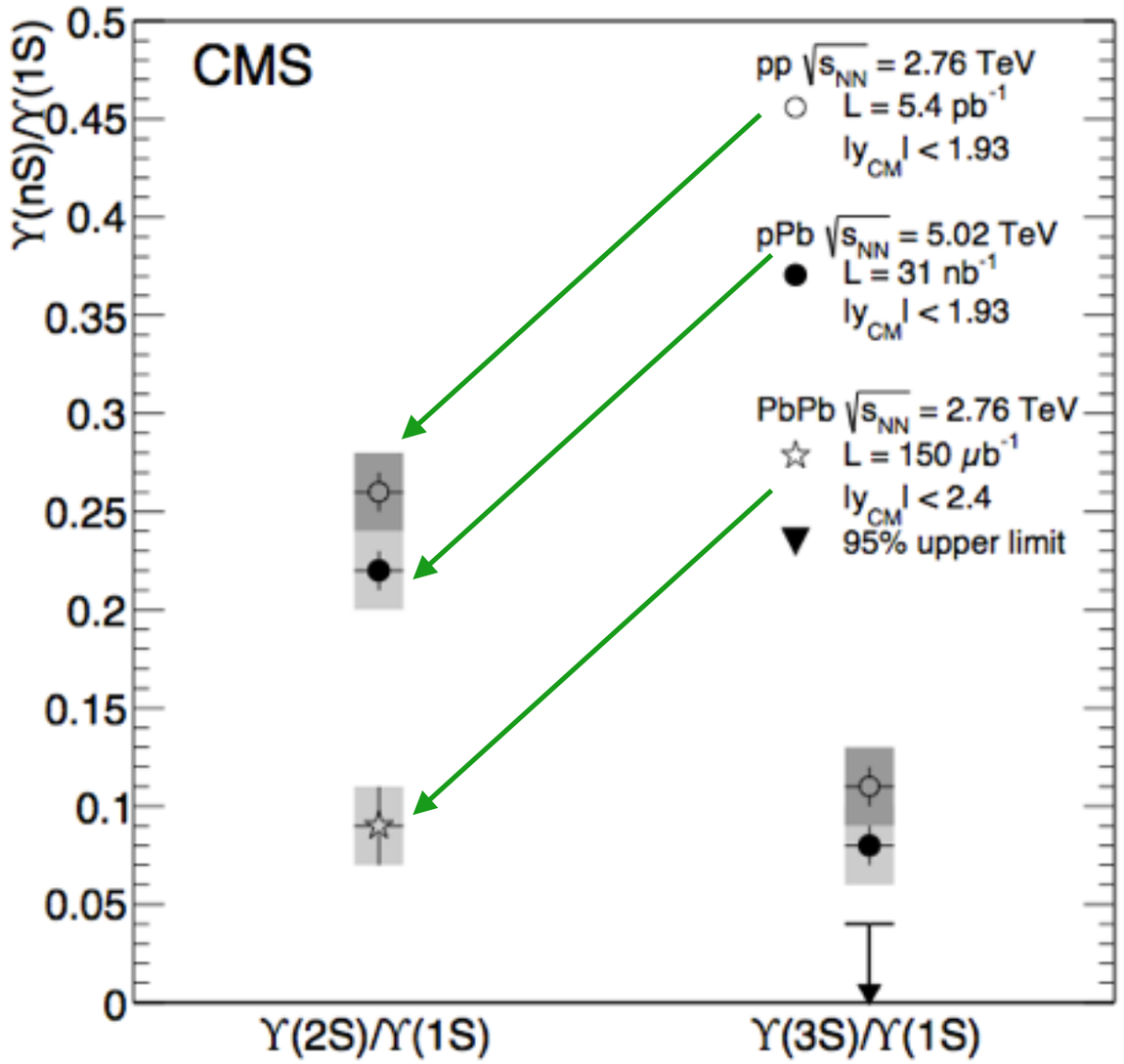
pp: Y(2S)/Y(1S) = 0.26 ± 0.01± 0.01

pPb: Y(2S)/Y(1S) = 0.22 ± 0.01± 0.01

PbPb: Y(2S)/Y(1S) = 0.09 ± 0.02± 0.02

→ Can compute **double ratios**
(equivalent to ratio of R_{pA} or R_{AA})

(Same procedure can be applied to Y(3S))



Υ *in* pPb

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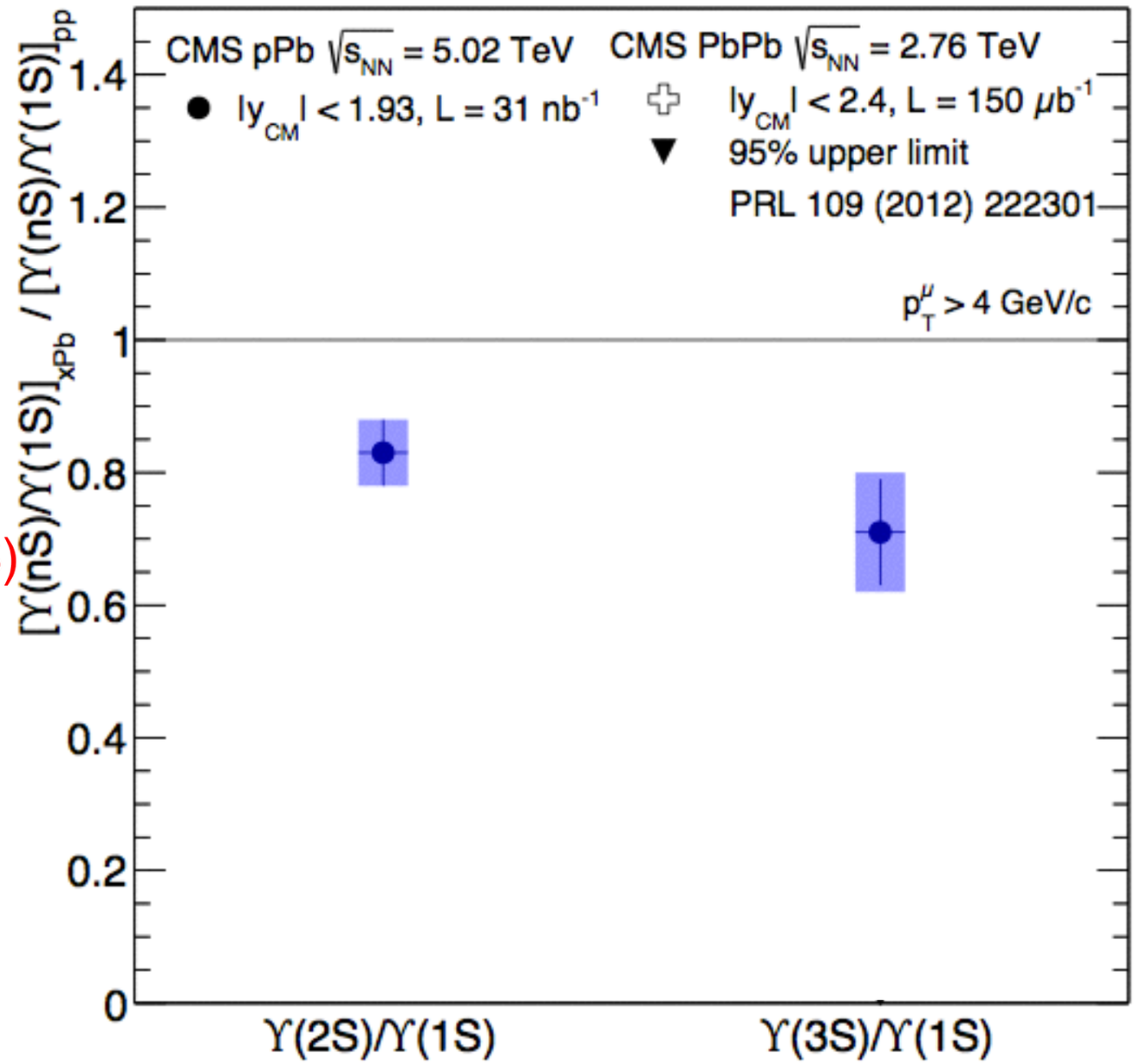
X: **Double ratios** pPb/pp

$X_2 = 0.83 \pm 0.05 \pm 0.05$

$X_3 = 0.71 \pm 0.08 \pm 0.09$

Excited states more affected than Y(1S)
Suggesting presence of final-state suppression in pPb vs. pp

'Event-activity integrated': can split the data in bins of $N_{trk}^{|\eta|<2.4}$ and $E_T^{|\eta|>4}$



Single ratios vs. event activity

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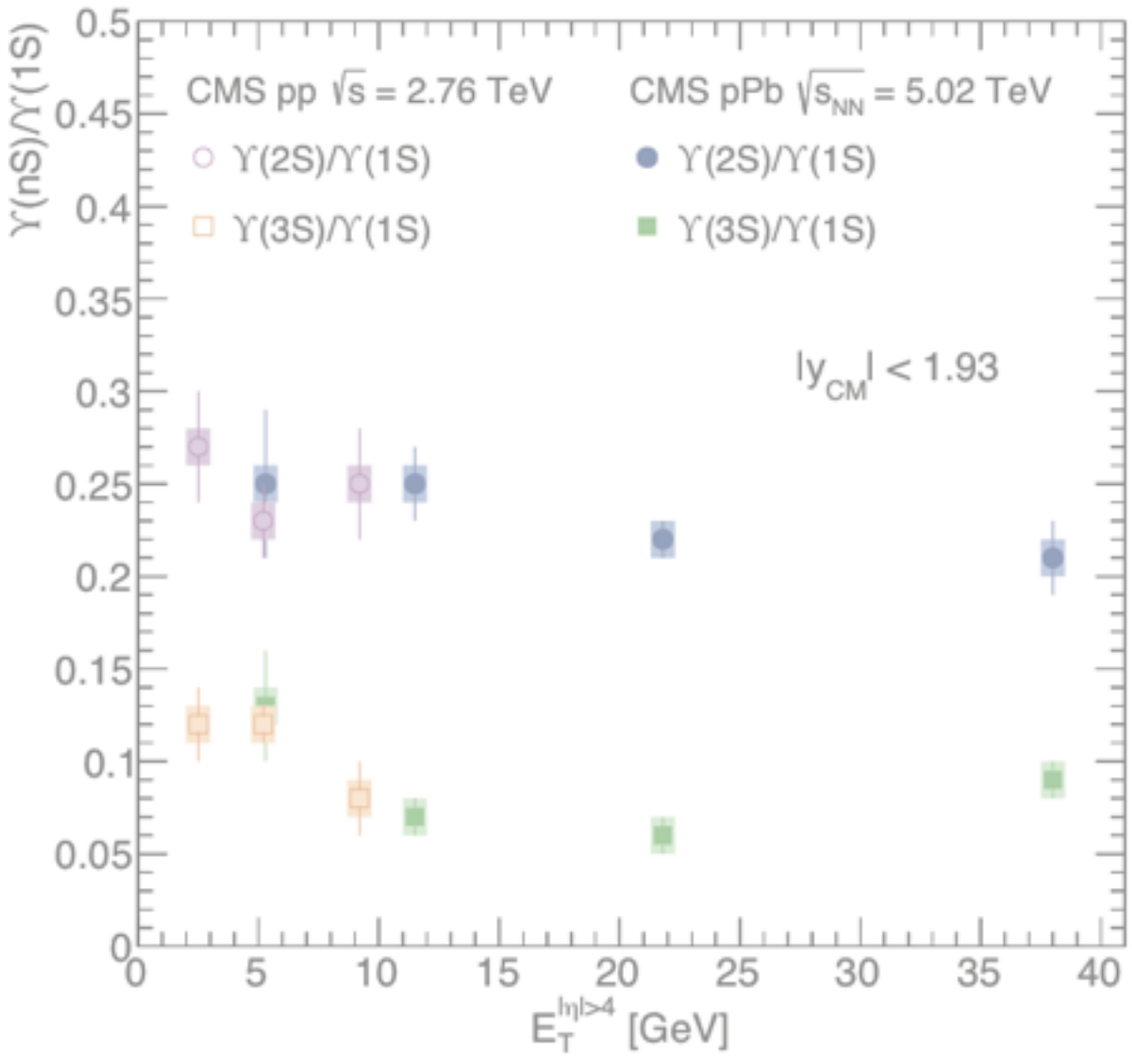

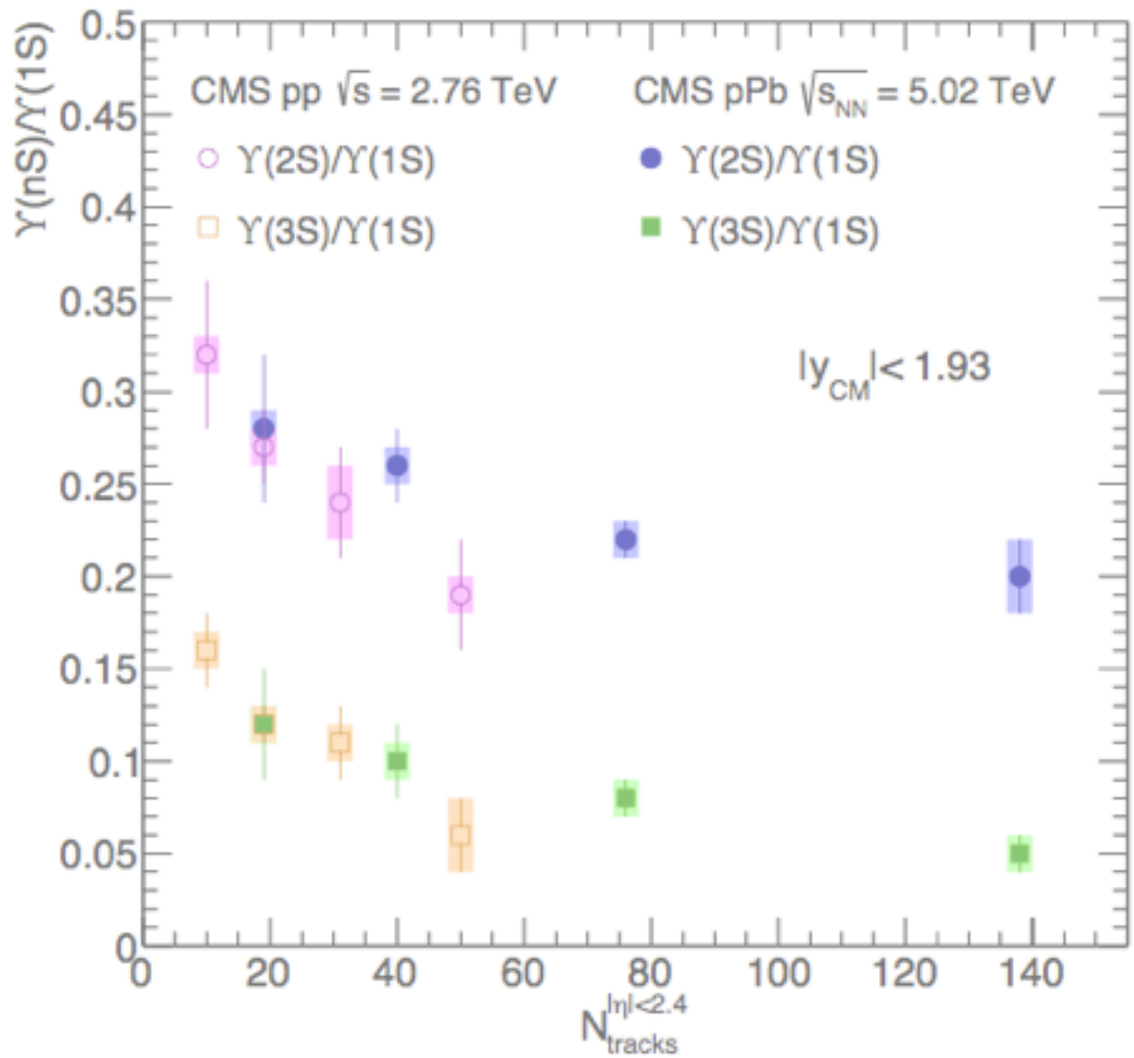

Single ratios vs. forward energy

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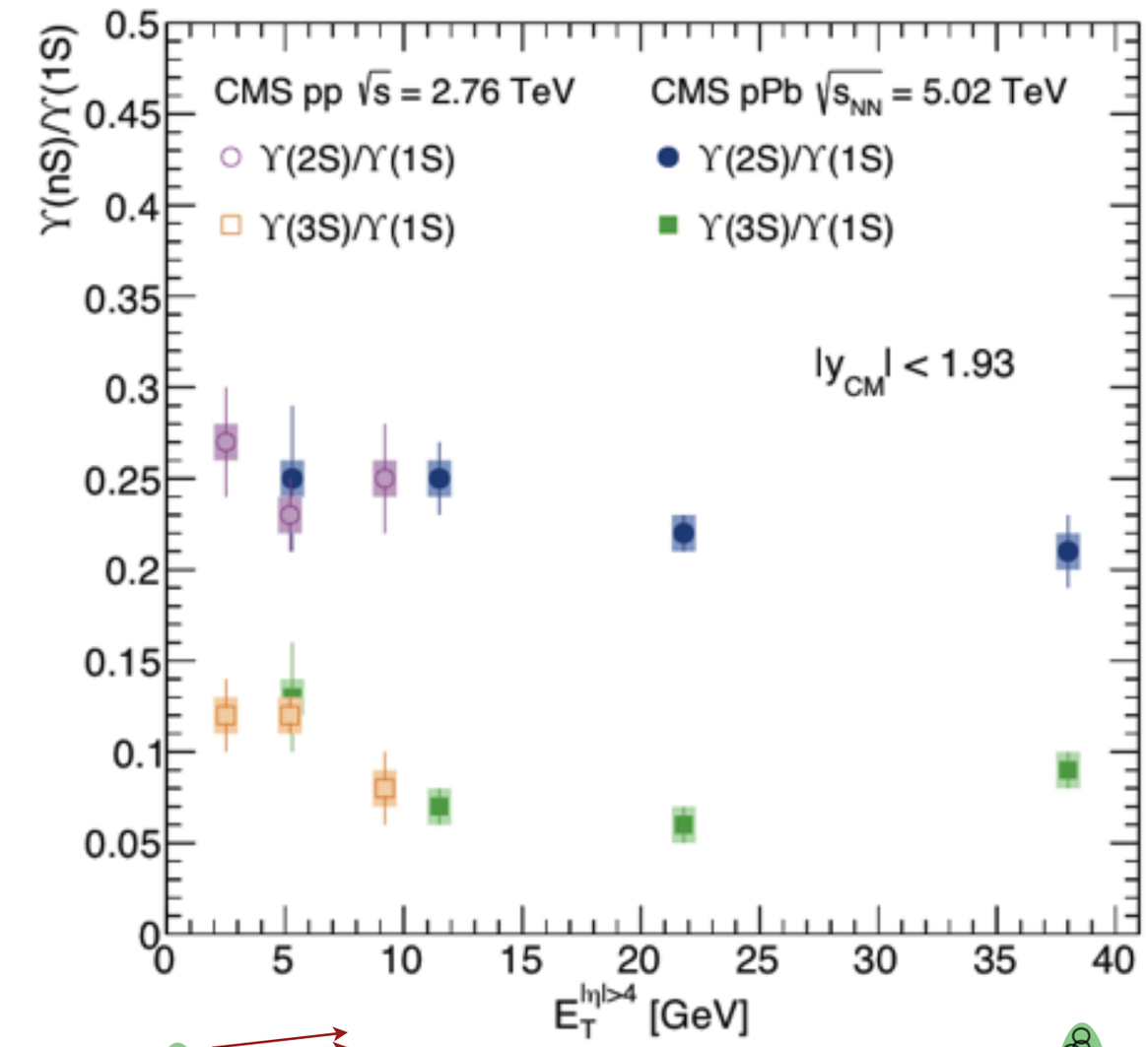
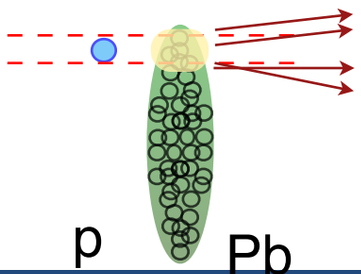
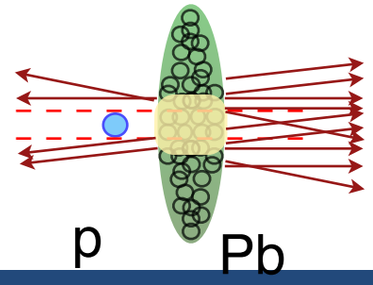
Single ratios Y(nS)/Y(1S) for pp, pPb systems w.r.t **forward transverse energy deposit**







No clear variation of the with $E_T^{|\eta|<4}$

Marginal overlap with the PbPb dataset (see below)

coll.	pp	pPb	PbPb (50-100%)
<E	3.5	15	77

-> Need more peripheral PbPb data !

Single ratios vs. multiplicity

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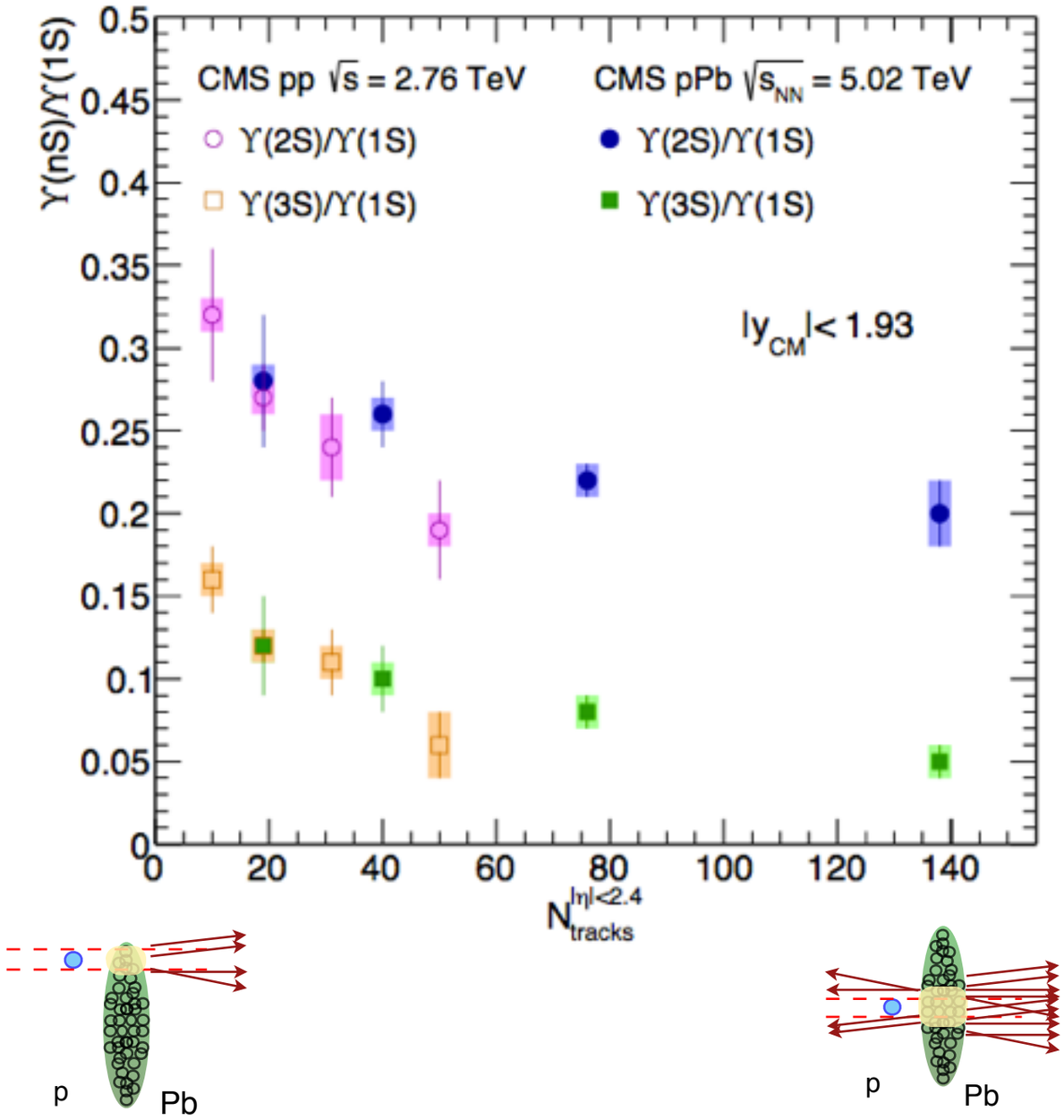
Single ratios Y(nS)/Y(1S) for pp, pPb systems w.r.t **charged particle multiplicity**



Sensible variation of **ratios** with $N_{trk}^{|\eta|<2.4}$ (unexpected) steeper slope in pp ratios

coll.	pp	pPb	PbPb (50-100%)
<	10	41	278

Multiplicity dependent ratios?

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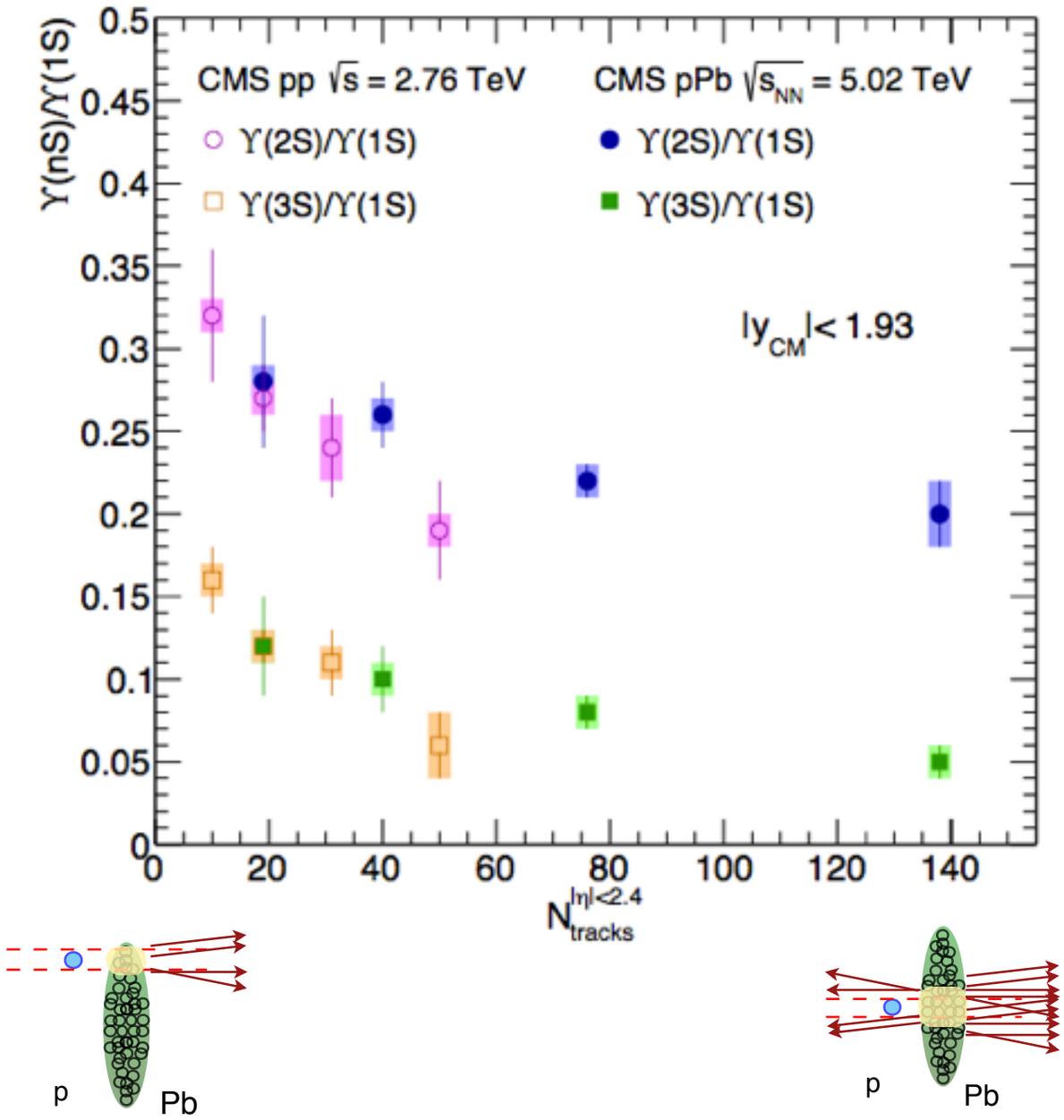
Single ratios Υ(nS)/Υ(1S) for pp, pPb systems w.r.t **charged particle multiplicity**



Sensible variation of ratios with $N_{trk}^{|\eta|<2.4}$

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Multiplicity dependent ratios?

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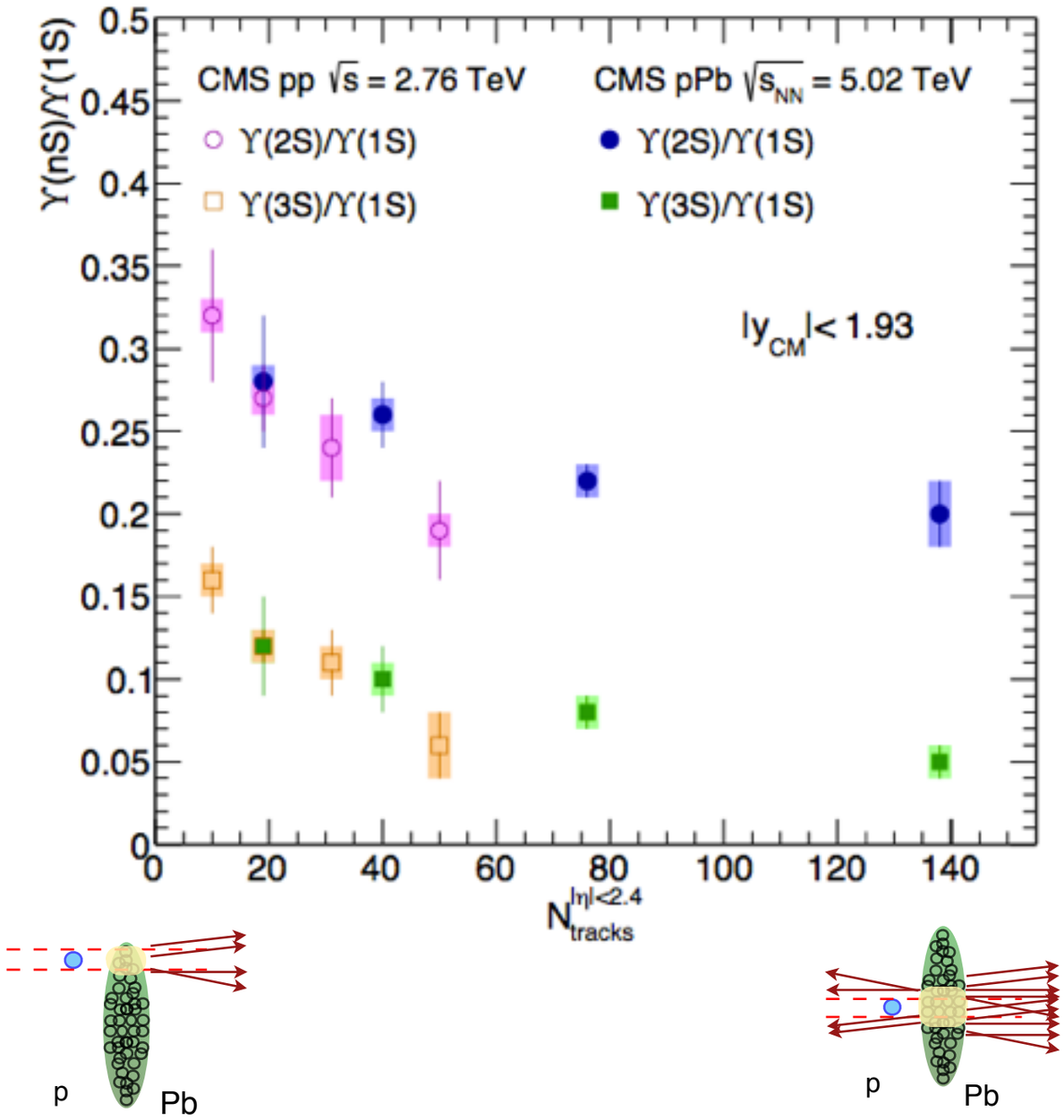

Sensible variation of ratios with $N_{trk}^{|\eta|<2.4}$

(unexpected) steeper slope in pp ratios

What is causing the slopes?

Υ *in* pPb: *single ratios vs.* $N_{trk}^{|\eta|<2.4}$

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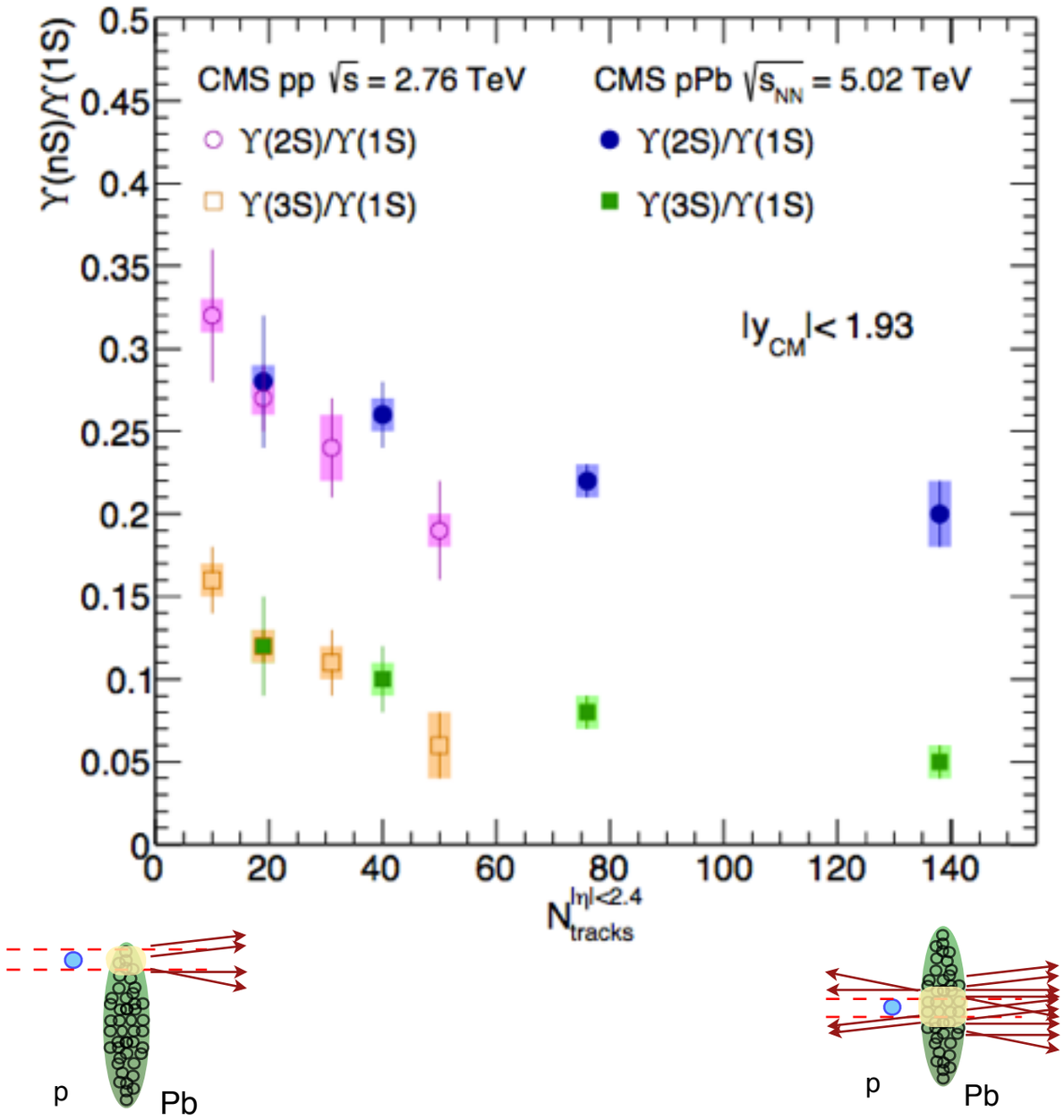
Single ratios Y(nS)/Y(1S) for pp, pPb systems w.r.t **charged particle multiplicity**



Sensible variation of ratios with $N_{trk}^{|\eta|<2.4}$
(unexpected) steeper slope in pp ratios

What is causing the slopes?

Study the associated production with Υ states in more detail

Multiplicity effects on Υ

- **Observation:**
  Two or three additional charged tracks associated to Y(1S) compared to Y' or Y''
  Consistently in pp and pPb collisions

- **Additional tracks in the direction of the Y:**
  No additional tracks in cone around the direction of the Y(nS)

Multiplicity effects on Υ

- **Tracks at the same vertex:**
  two or three additional charged tracks associated to 1S compared to Y' or Y"
  consistently in pp and pPb collisions

- **Additional tracks in the vicinity of the Y:**
  no additional tracks in cone around the direction of the Y(nS)

- **Feed-down from P-states and excited states:**
  $\chi_b \longrightarrow Y(nS)\gamma$ but at low-pt, efficiency for electron pair from photon conversion < 1 %
  $Y(2S) \longrightarrow Y(1S)\pi^+\pi$ is not enough to account for the trend by itself

A difference in mass between 1S and 2S,3S could reflect itself
in the kinematics
in the associated particle multiplicity

About individual yields

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Goal: Quantify the cross-sections in bins of $E_T^{|\eta|<4}$ or $N_{trk}^{|\eta|<2.4}$ with **no multiplicity bias**!

Method: compare the cross-section in a given bin by the integrated result
⟶ Make normalised cross-sections

Example given in PbPb:

About cross sections

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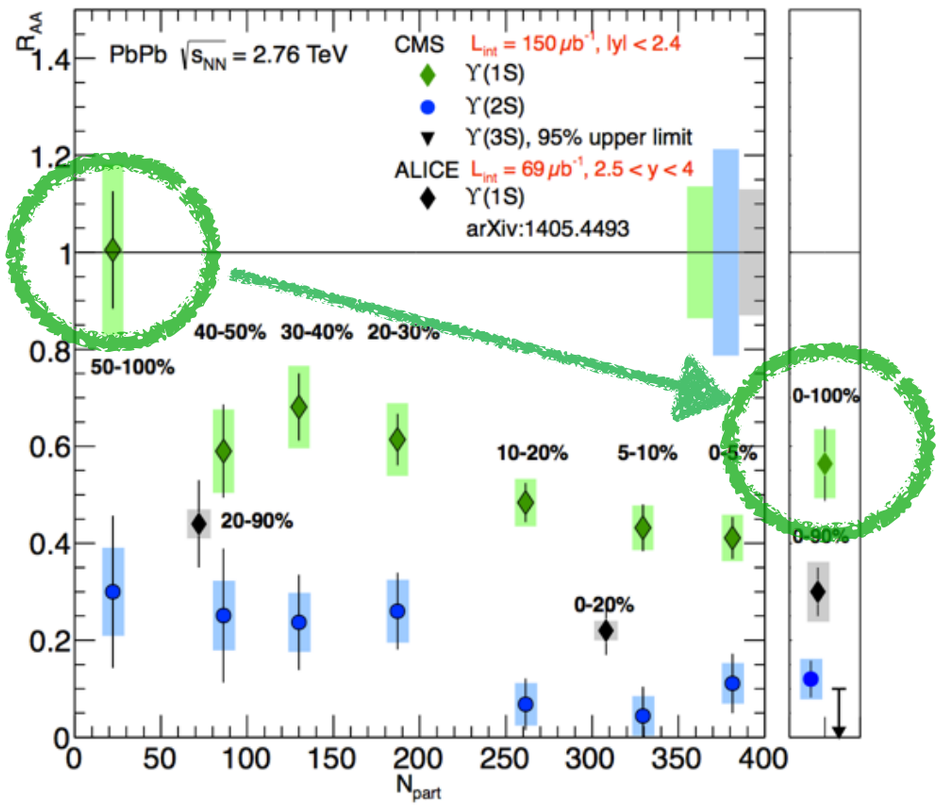
Goal: Quantify the cross sections in bins of $E_T^{|\eta|<4}$ or $N_{trk}^{|\eta|<2.4}$ with **no multiplicity bias**!

Method: compare the cross section in a given bin by the integrated result
⟶ Make normalised cross sections

Example given in PbPb:

Compare the R_{AA} of each centrality bin



with the minimum bias result

Caution!

1. absolute PbPb suppression gets ‘lost’
2. very different N_{track} range compared to pA,pp

About Υ(1S) *cross section*

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Goal: Quantify the cross-sections in bins of $E_T^{|\eta|<4}$ or $N_{trk}^{|\eta|<2.4}$ with **no multiplicity bias**!

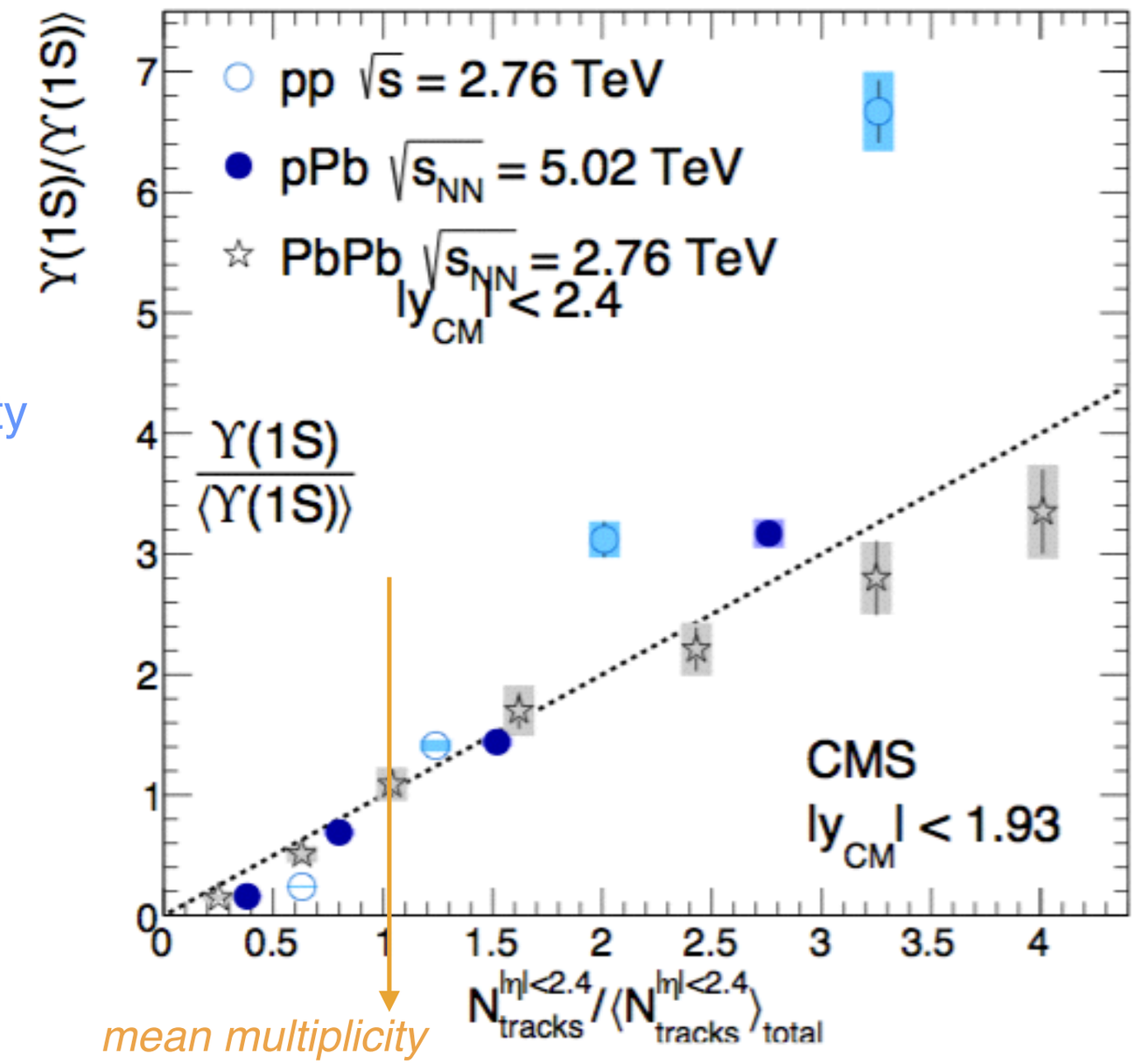
Method: compare the cross-section in a given bin by the integrated result
⟶ Make normalised cross-sections

Here, midrapidity multiplicity $\mathbf{N_{trk}^{|\eta|<2.4}}$
(simplified x-axis)

pp: Positive correlation of yield and activity
pPb: Slight offset from unity slope
PbPb: Anti-correlation from suppression

vs. $E_T^{|\eta|<4}$, all scale with slope=1

2S, 3S plots (back-up)



Summary

In HI collisions,

All Υ states are affected in PbPb, exhibiting ordered suppression

Υ(2S,3S) more affected than Υ(1S) in pPb

⟶ supporting the ordered picture

Meanwhile in proton-proton collisions

Positive correlation at mid-rapidity: more Υ in high-multiplicity!!

(Although not observed in forward region)

Summary

In HI collisions,

All Y states are affected in PbPb, exhibiting ordered suppression

Y(2S,3S) more affected than Y(1S) in pPb

⟶ supporting the ordered picture

Meanwhile in proton-proton collisions

Positive correlation at mid-rapidity: more Y in high-multiplicity!!

(Although not observed in forward region)

Next steps:

More multiplicity studies !

pp+PbPb kinematics

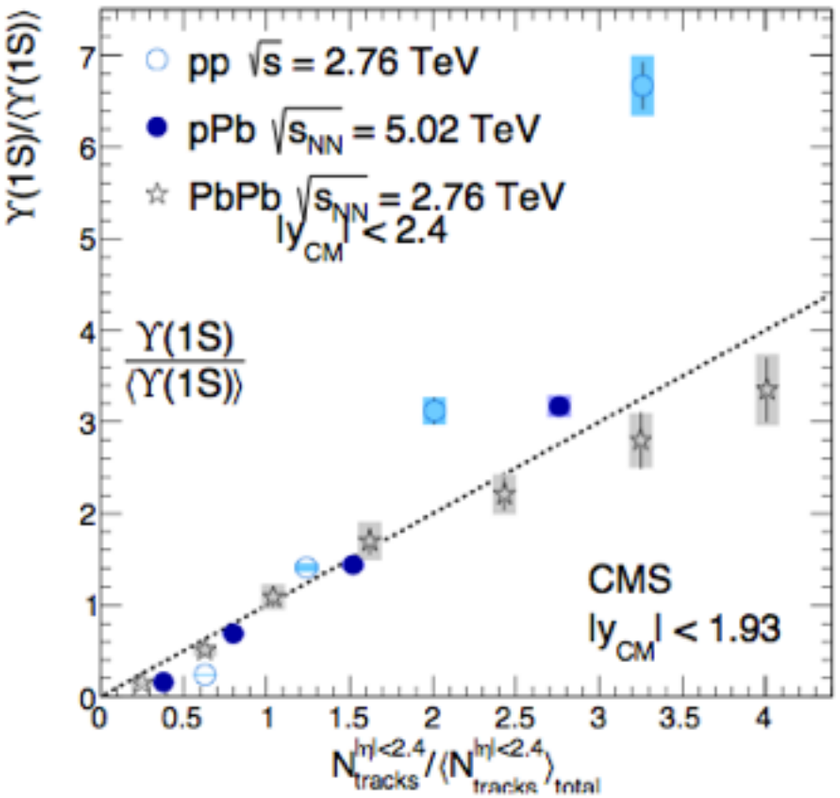
Y in peripheral PbPb

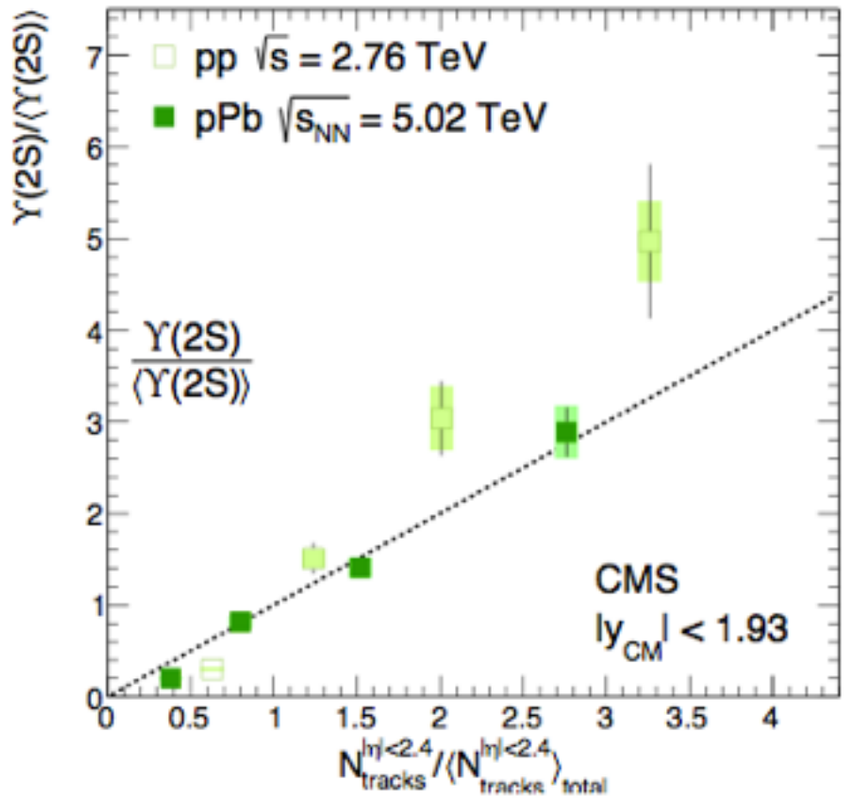
The end.

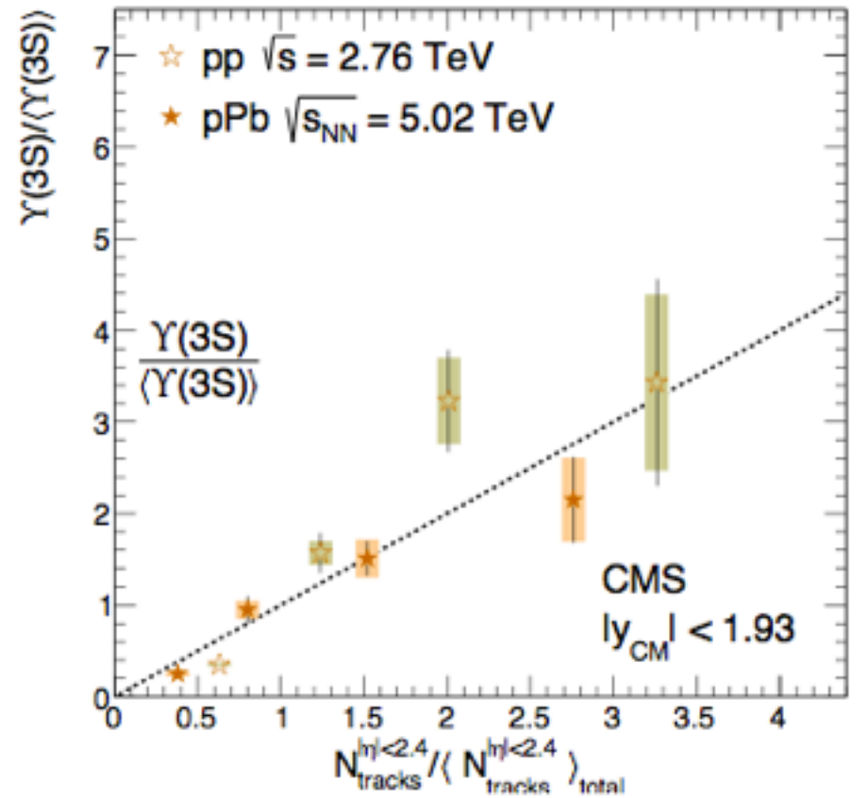
Thank you!!

Backup

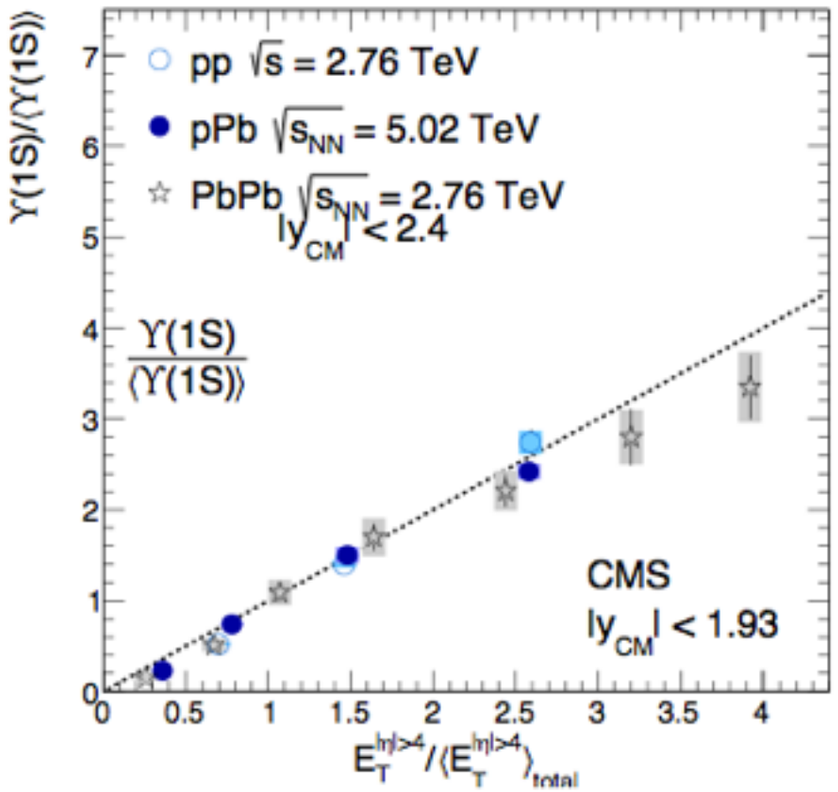
Self-normalised yields vs N_trk

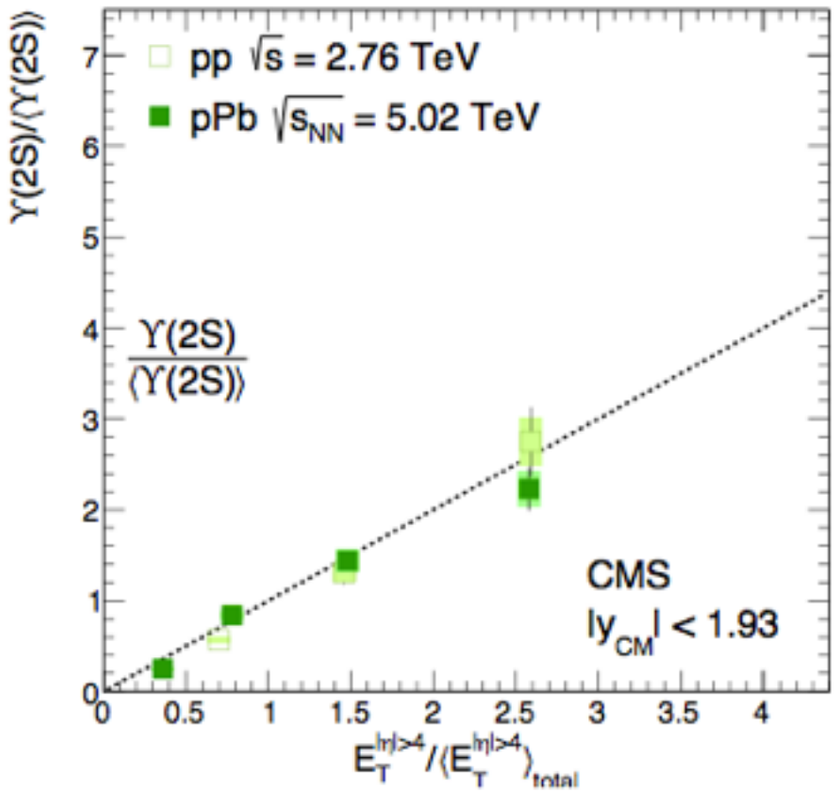


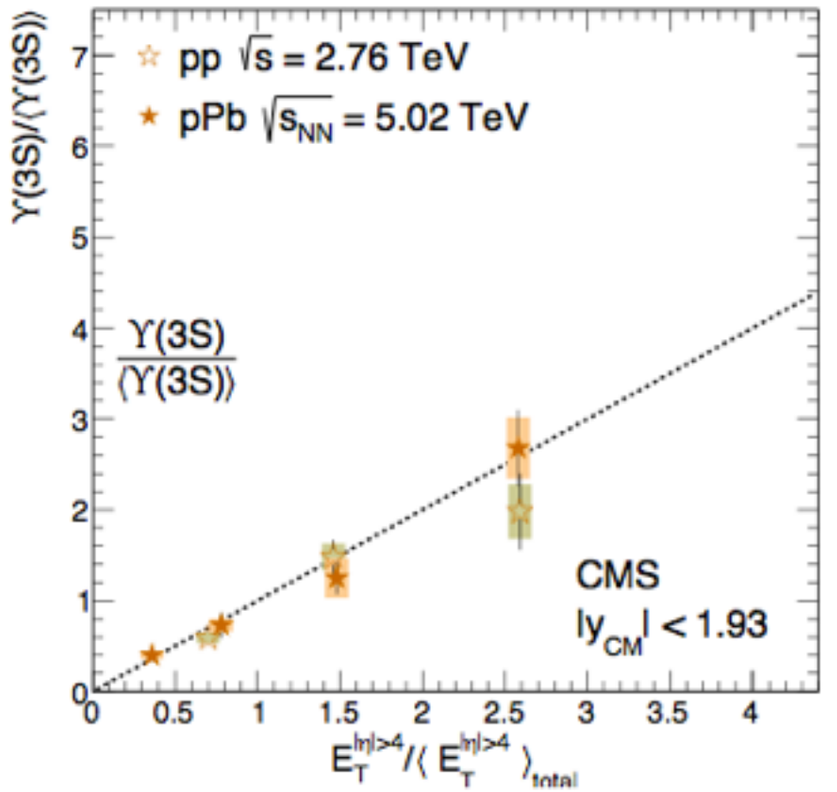




Self-normalised yields vs E_T







Ntrk / E_T tables

Left: multiplicity tables, Right: forward energy

	Bin	$N_{\text{tracks}}^{\lvert\eta\rvert<2.4}$				$E_{\text{T}}^{\lvert\eta\rvert>4}$			
		$[N_{\text{tracks}}^{\lvert\eta\rvert<2.4}]$ (raw)	$\langle N_{\text{tracks}}^{\lvert\eta\rvert<2.4}\rangle$	$\langle E_{\text{T}}^{\lvert\eta\rvert>4}\rangle$ [GeV]	Frac (%)	$[E_{\text{T}}^{\lvert\eta\rvert>4}]$ [GeV]	$\langle E_{\text{T}}^{\lvert\eta\rvert>4}\rangle$	$\langle N_{\text{tracks}}^{\lvert\eta\rvert<2.4}\rangle$	Frac (%)
pp	1	0–10	9.8 ± 0.4	3.3	64	0–3.5	2.5	9.6 ± 0.4	59
	2	11–20	19.4 ± 0.8	4.7	25	3.5–7.0	5.2	17.2 ± 0.7	32
	3	21–30	30.7 ± 1.2	5.9	8	≥7.0	9.2	25.8 ± 1.0	9
	4	≥31	49.9 ± 1.9	7.1	3				
pPb	1	0–21	19.1 ± 0.7	7.3	35	0–7.4	5.3	19.2 ± 0.7	30
	2	22–41	40.0 ± 1.6	13.0	24	7.4–14.7	11.5	40.2 ± 1.6	27
	3	42–82	75.9 ± 3.0	21.6	30	14.7–29.4	21.8	72.8 ± 2.8	33
	4	≥83	137.9 ± 5.4	34.4	11	≥29.4	38.0	118.0 ± 4.6	10

1st column - binning in raw number of tracks
2nd column - corrected mean number of tracks
3rd - corrected mean Et, quite correlated

1st column - binning in raw forward Et
2nd column - corrected mean forward energy
3rd - corrected mean multiplicity

Υ *in pPb*

JHEP 04 (2014) 103 Event activity dependence of Y(nS) production in $\sqrt{s_{NN}}$ = 5.02 TeV pPb and $\sqrt{s}$ = 2.76 TeV pp

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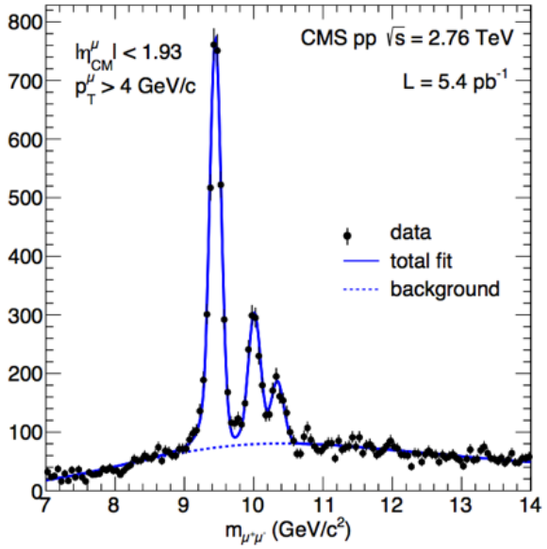
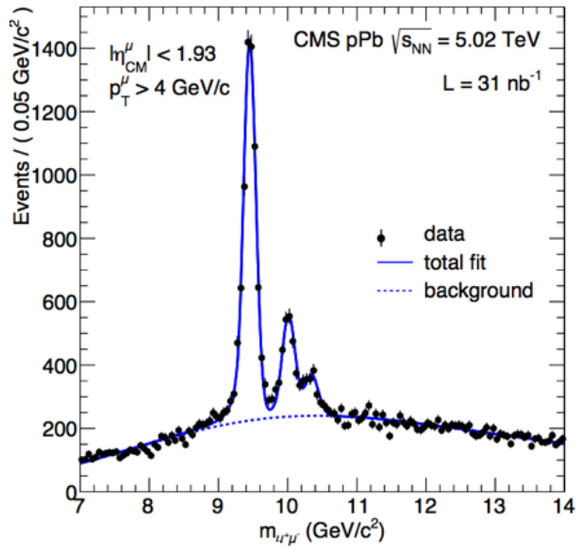
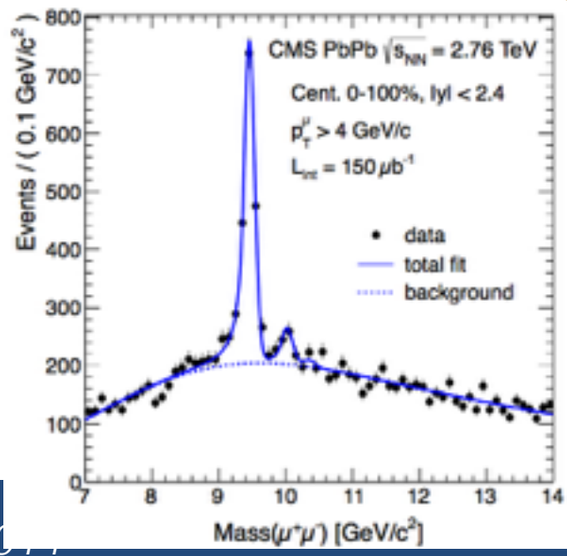
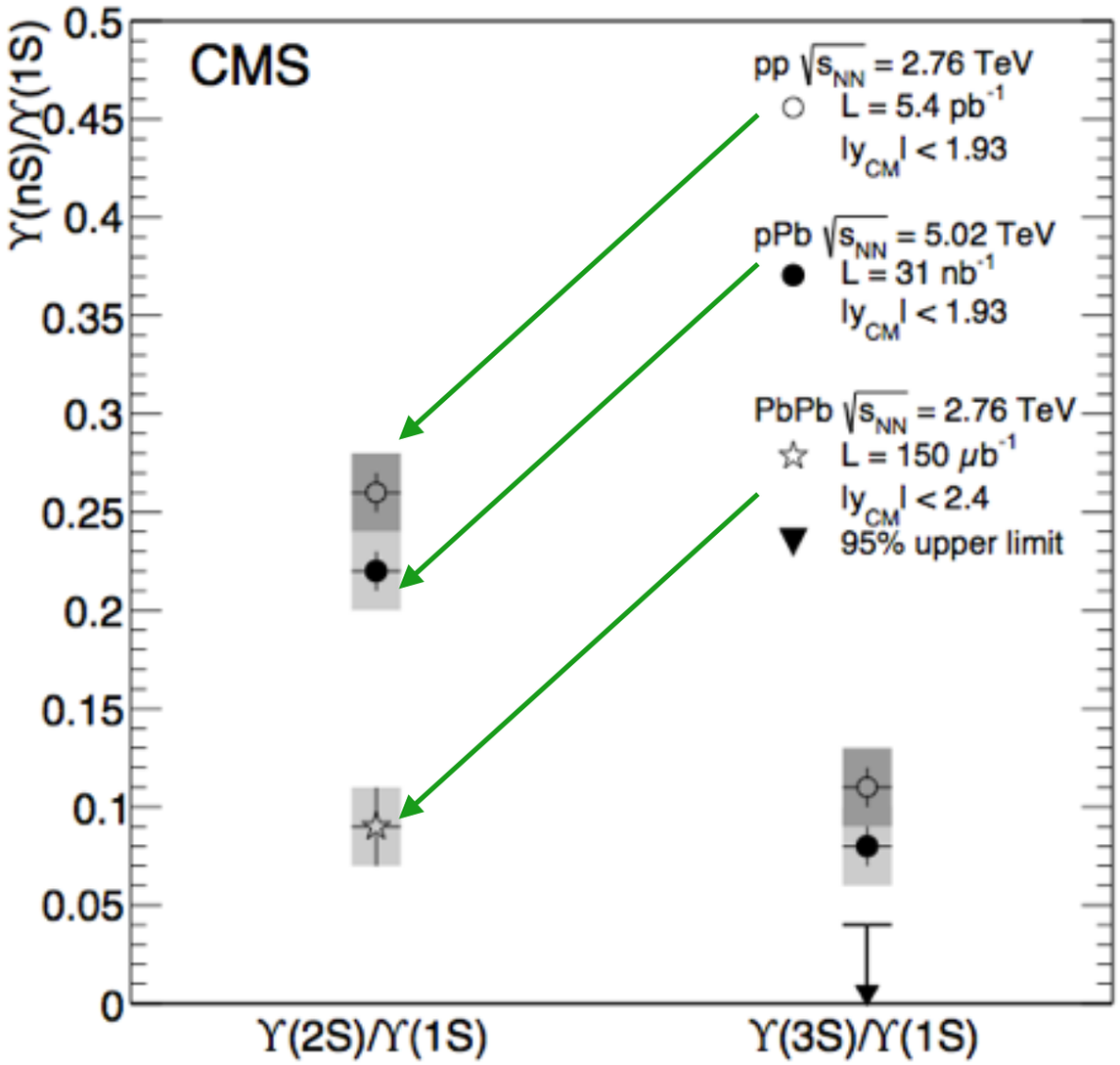






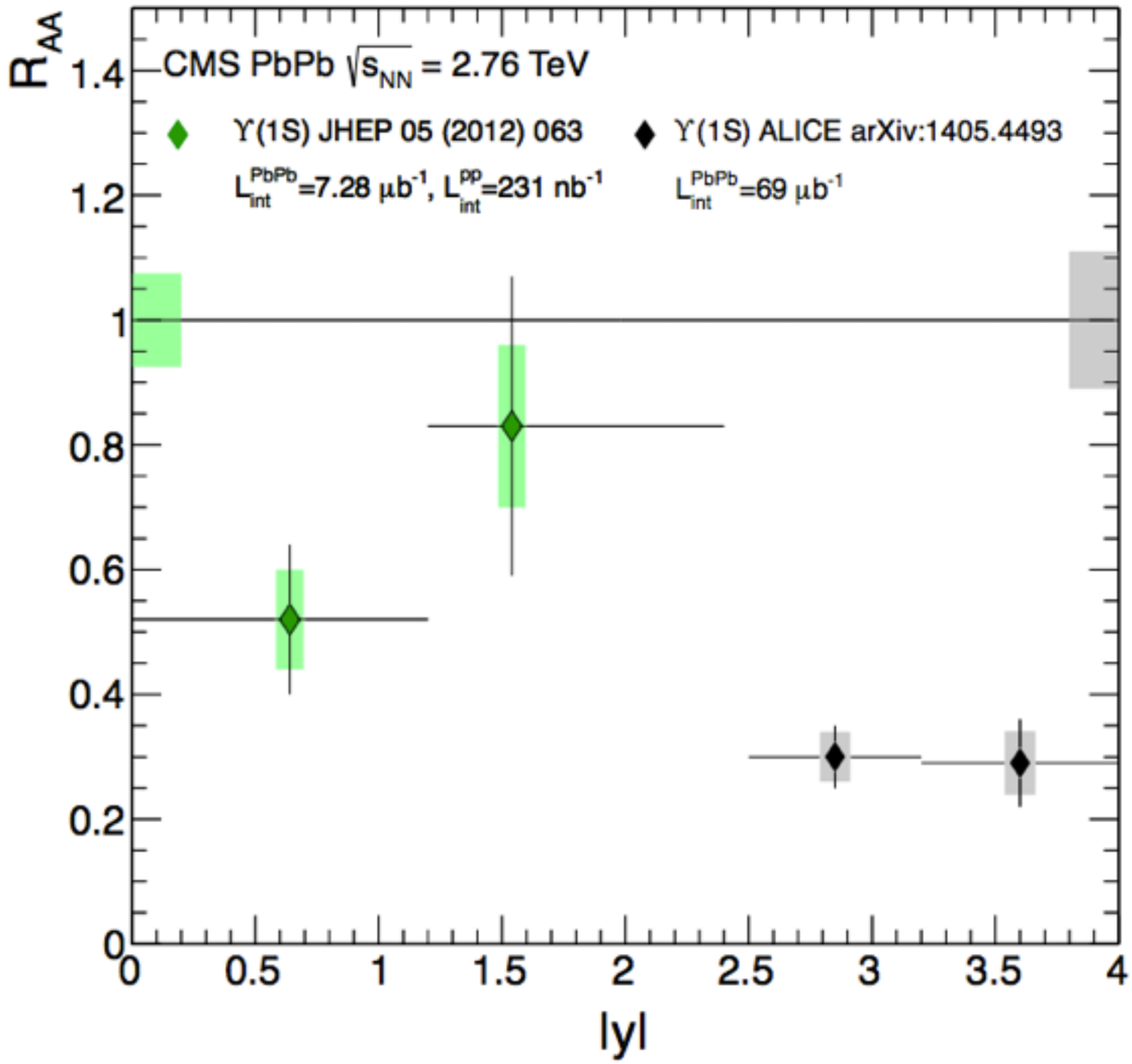
then compare with pp and PbPb ratios Y(nS)/Y(1S)



getting ready for kinematics

CMS points: ‘outdated’ datasets
20+ times more pp, PbPb now!

pp: cross-sections @ 2.76 TeV
PbPb: dependence of 1S suppression?



getting ready for kinematics

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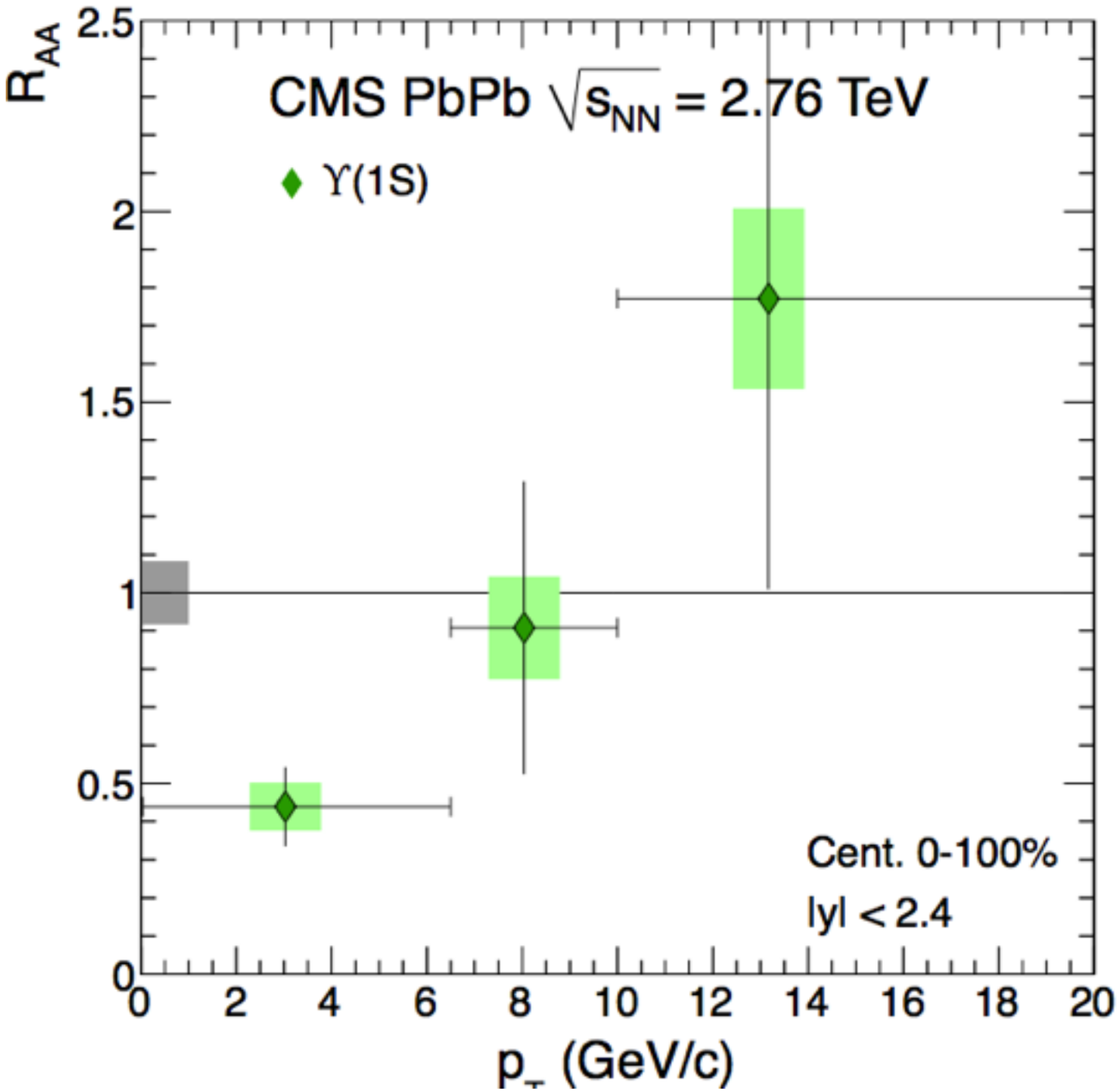

Longitudinal view of CMS