

# $\Upsilon$ measurements in $pPb$ and $pp$ with the CMS detector

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*ERC grant "QuarkGluonPlasmaCMS"*

For the SaporeGravis Workshop 2013 – Nantes  
'Cold Nuclear Matter session'

# Outline

## CMS DETECTOR

Total weight : 14,000 tonnes  
Overall diameter : 15.0 m  
Overall length : 28.7 m  
Magnetic field : 3.8 T

### STEEL RETURN YOKE

12,500 tonnes

### SILICON TRACKERS

Pixel ( $100 \times 150 \mu\text{m}$ )  $\sim 16\text{m}^2 \sim 66\text{M}$  channels  
Microstrips ( $80 \times 180 \mu\text{m}$ )  $\sim 200\text{m}^2 \sim 9.6\text{M}$  channels

### SUPERCONDUCTING SOLENOID

Niobium titanium coil carrying  $\sim 18,000\text{A}$

### MUON CHAMBERS

Barrel: 250 Drift Tube, 480 Resistive Plate Chambers  
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

### PRESHOWER

Silicon strips  $\sim 16\text{m}^2 \sim 137,000$  channels

### FORWARD CALORIMETER

Steel + Quartz fibres  $\sim 2,000$  Channels

CRYSTAL  
ELECTROMAGNETIC  
CALORIMETER (ECAL)  
 $\sim 76,000$  scintillating  $\text{PbWO}_4$  crystals

HADRON CALORIMETER (HCAL)  
Brass + Plastic scintillator  $\sim 7,000$  channels  
12/04/13

Cold nuclear matter effects  
on quarkonium production

The CMS detector  
as used for  $\Upsilon$  in pPb

Event-activity dependence  
of  $\Upsilon(nS)$  production  
in pPb and pp

CMS in pPb - Status - N.F.

# Introductory remarks

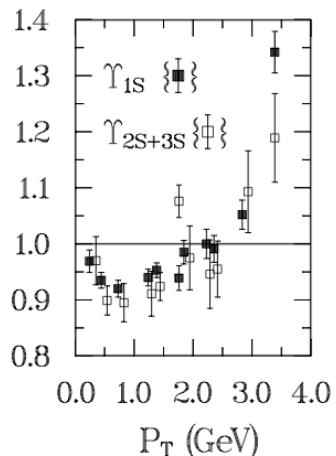
Quarkonia : long known probes of hot and dense medium formation in AA collisions.

For  $\Upsilon$ , suppression has been seen in AA at LHC and RHIC.

Several effects sum up to contribute to the modification of measured quarkonium states.

One needs a proper reference (pp), and a baseline for nuclear matter 'absorption' (pA)

Historically, A-dependence of quarkonium production in 'welterweight' collisions ( $\alpha=1$  DY, 0.96  $\Upsilon$ , 0.92  $J/\psi$ )

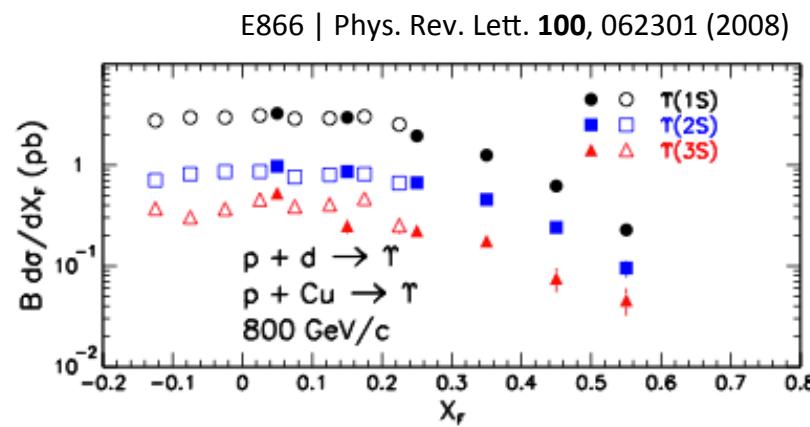
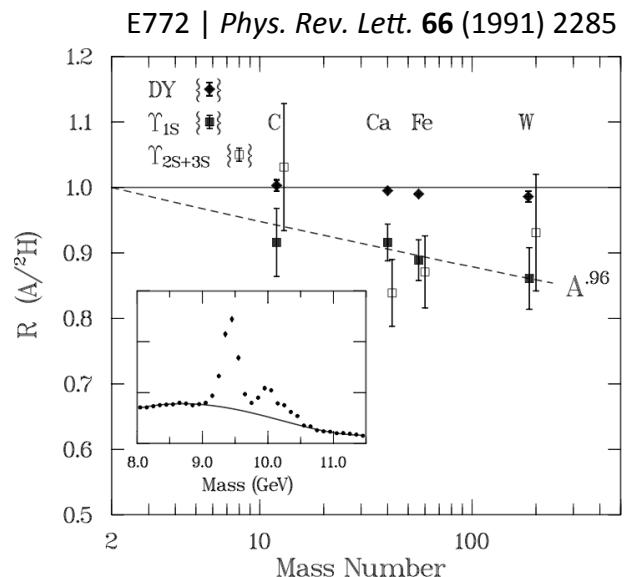


$$\sigma_A = \sigma_N \times A^\alpha$$

*From these measurements,  
 $\alpha$  has  $p_T$ ,  $x_F$  dependence*

E772 | Phys. Rev. Lett. **66** (1991) 2285

12/04/13



CMS in pPb - Status - N.F.

# Introductory remarks

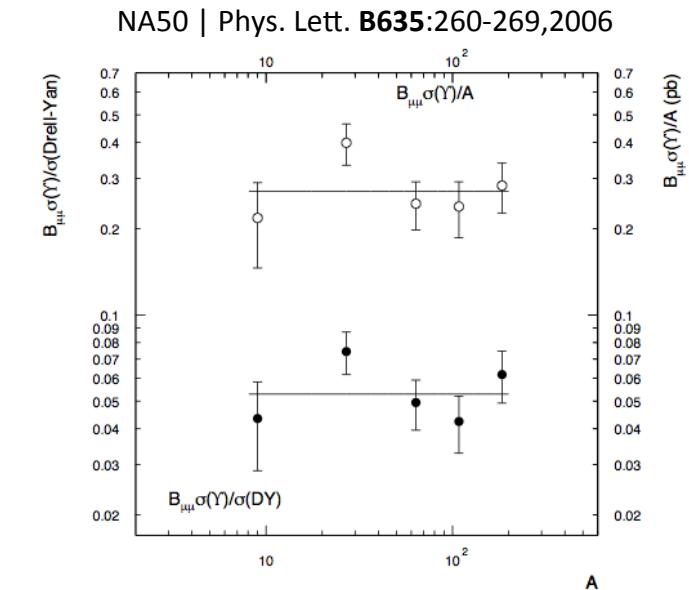
More recently,

NA50's  $\gamma$  cross section at midrapidity, and nuclear absorption in agreement with previous measurements at fixed-target energies:

$$\alpha = 0.98 \pm 0.02 \text{ (DY)}$$

$\alpha = 0.98 \pm 0.08 \text{ (\gamma), also consistent with 1.}$

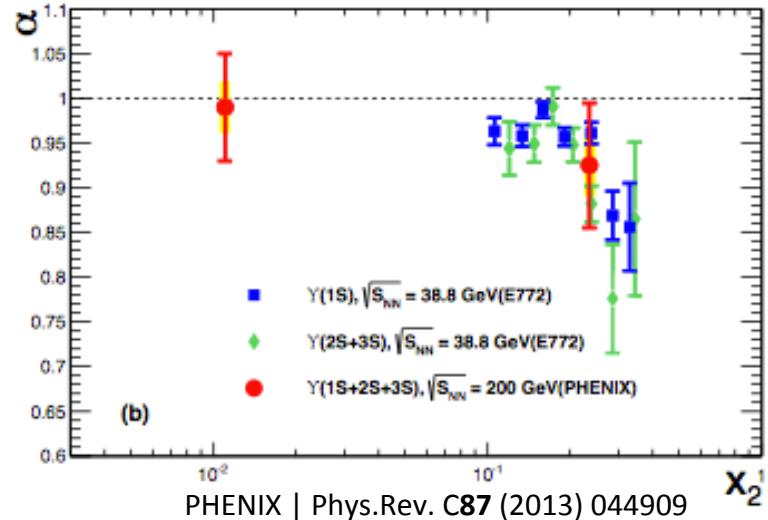
PHENIX measures rapidity dependence in dAu, consistent with E772...



In this presentation,  
CMS brings its own piece to the story:

$\gamma(1S)$ ,  $\gamma(2S)$ ,  $\gamma(3S)$  in pPb at  $\sqrt{s_{NN}} = 5.02 \text{ TeV}$   
and in pp at  $\sqrt{s} = 2.76 \text{ TeV}$

<https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN13003>



PHENIX | Phys. Rev. C87 (2013) 044909

# Event activity in CMS

## CMS DETECTOR

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STEEL RETURN YOKE  
12,500 tonnes

### SILICON TRACKERS

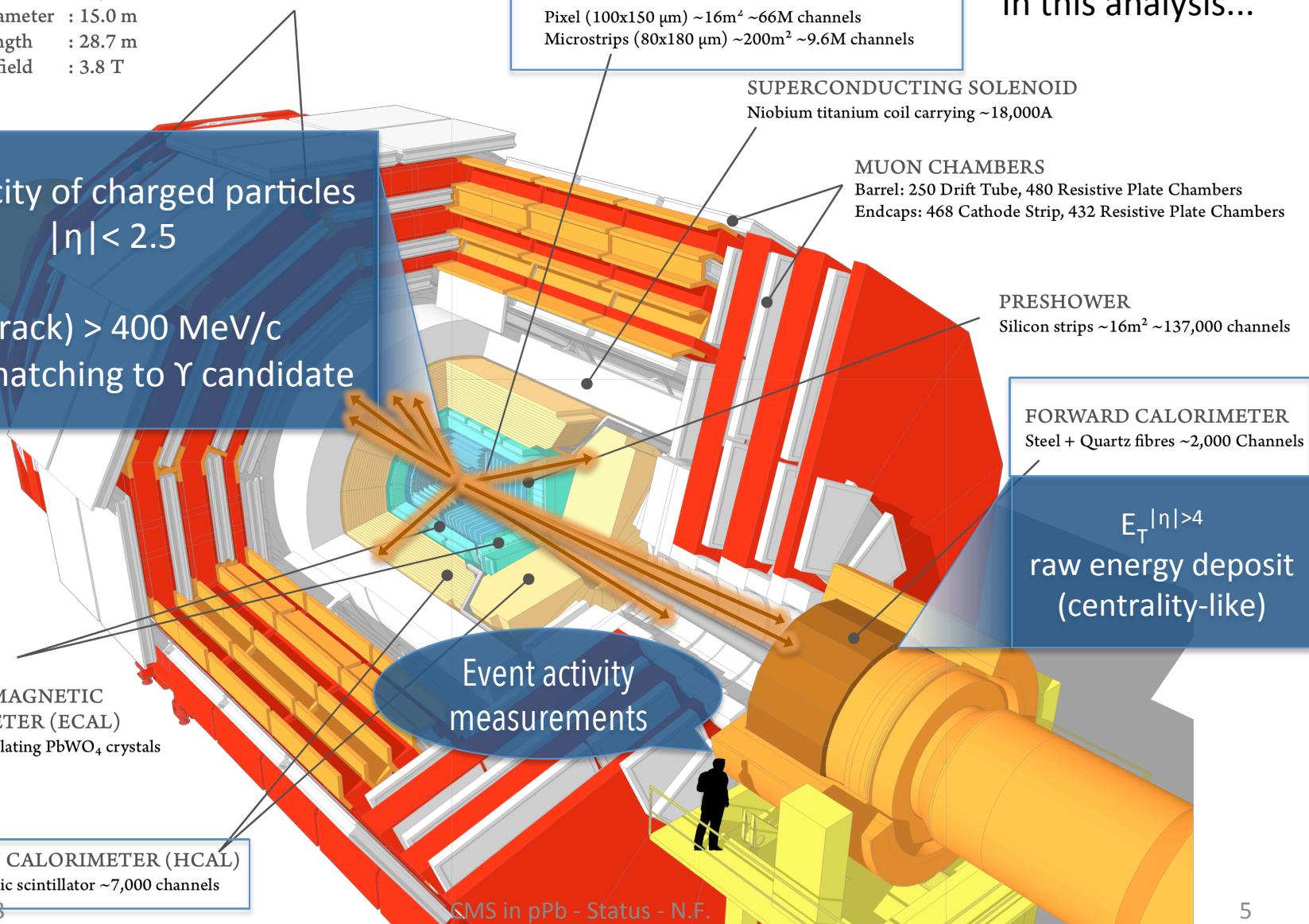
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Microstrips ( $80 \times 180 \mu\text{m}$ )  $\sim 200\text{m}^2 \sim 9.6\text{M}$  channels

In this analysis...

Multiplicity of charged particles  
 $|\eta| < 2.5$

$p_T(\text{track}) > 400 \text{ MeV}/c$   
Vertex matching to  $\gamma$  candidate

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)  
 $\sim 76,000$  scintillating  $\text{PbWO}_4$  crystals



12/04/13

CMS in pPb - Status - N.F.

# *di-muon events in CMS*

## CMS DETECTOR

Total weight : 14,000 tonnes

Overall diameter : 15.0 m

Overall length : 21.0 m

Magnetic field : 3.8 T

$\gamma \rightarrow \mu\mu$  down to  $p_T = 0$  GeV/c  
60 MeV/c<sup>2</sup> mass resolution ( $y=0$ )

in pPb : use the same algorithms to  
reconstruct tracks as in pp

### STEEL RETURN YOKE

12,500 tonnes

### SILICON TRACKERS

Pixel (100x150  $\mu\text{m}$ ) ~16m<sup>2</sup> ~66M channels

Microstrips (80x180  $\mu\text{m}$ ) ~200m<sup>2</sup> ~9.6M channels

### SUPERCONDUCTING SOLENOID

Niobium titanium coil carrying ~18,000A

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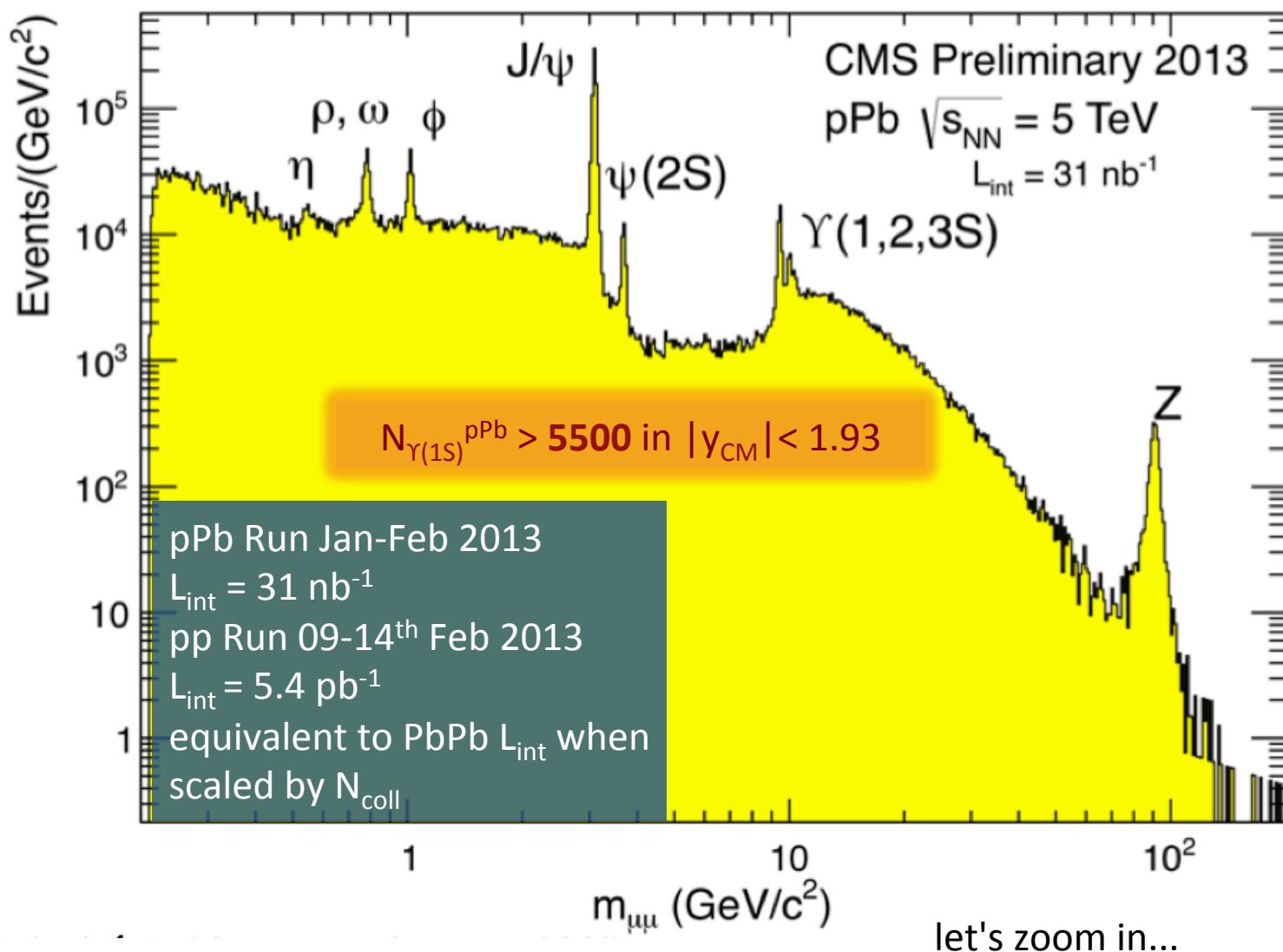
Steel + Quartz fibres ~2,000 Channels

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12/04/13

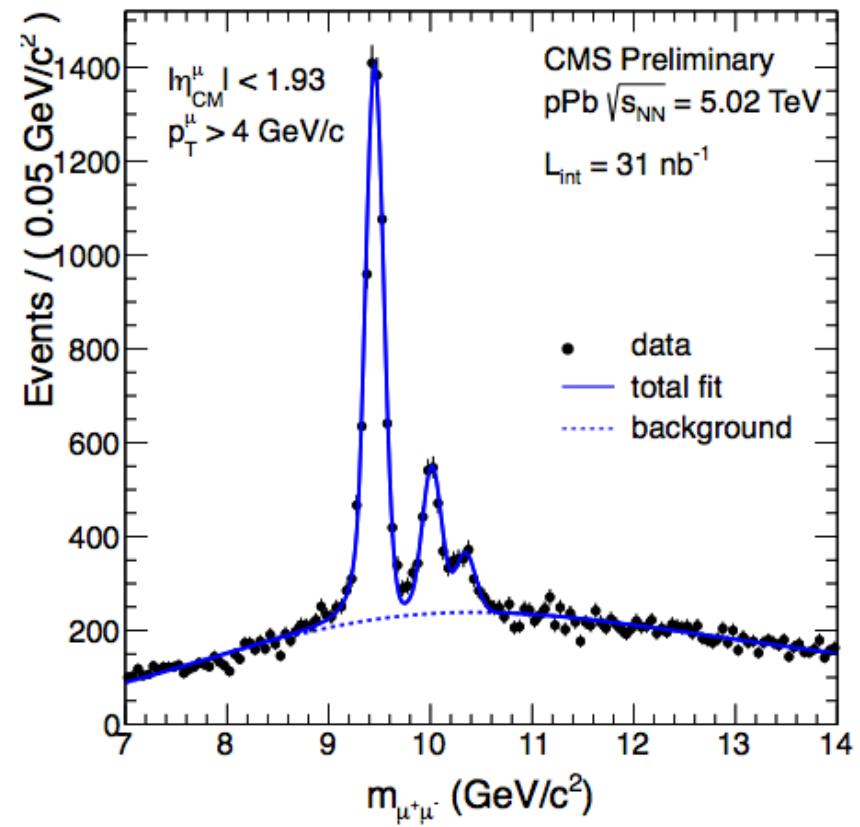
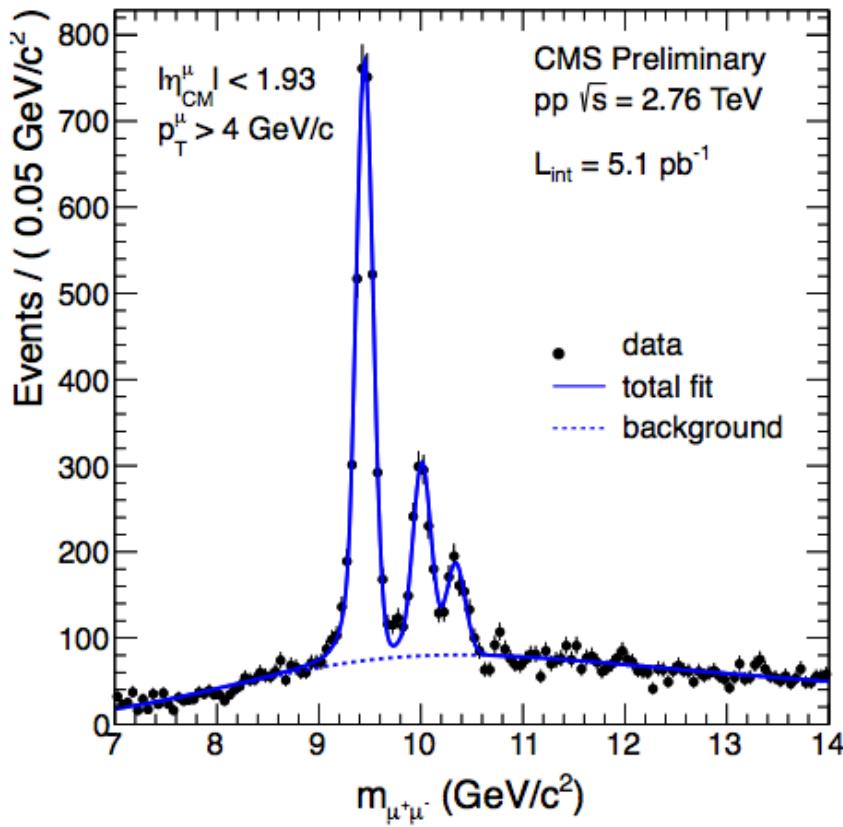
Muons,  
muons everywhere!

# Dimuon spectrum of $pPb$ at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$



# Signal extraction : yields, ratios

CMSPublic/PhysicsResultsHIN13003



Unbinned maximum log likelihood

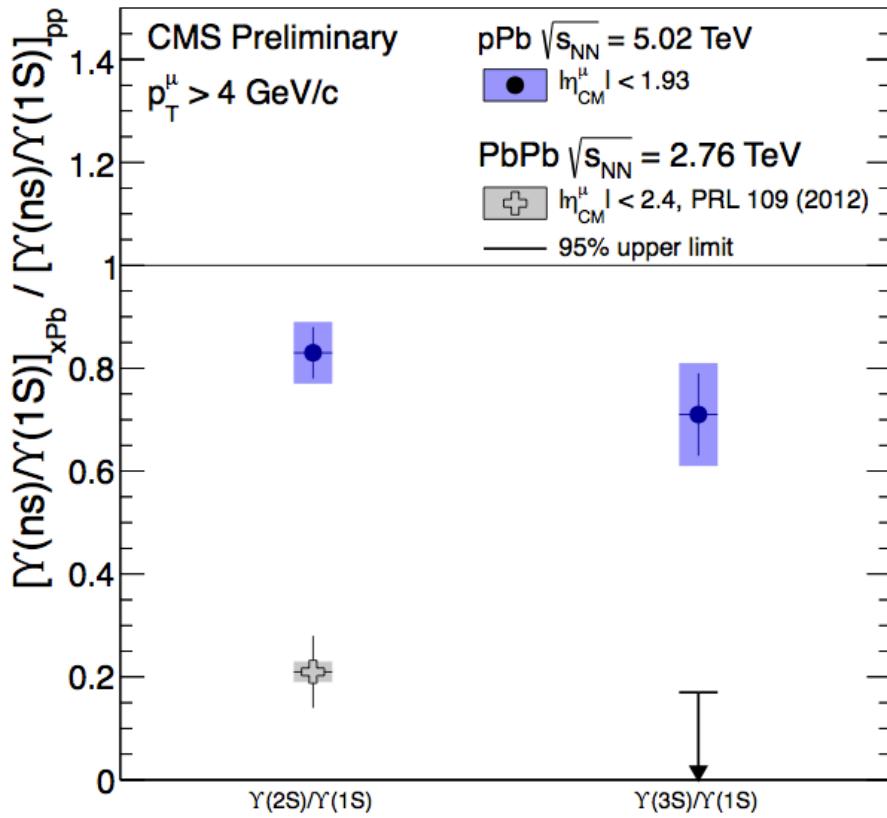
**Signal:** 3 Crystal-Ball functions (Gaussian with low-side tail replaced by a power-law)

**Background:** error function  $\times$  exponential

Checked with Tag&Probe, cancelling in excited-to-ground state pPb/pp ratios (a.k.a. double ratios)

# Double Ratios in pPb compared to PbPb !

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## PbPb vs pp from 2011 data:

Centrality integrated results, 2S significantly suppressed  
95% C.L. upper limit on 3S suppression

## pPb vs pp from new 2013 data:

initial state features are likely to cancel (should be the same for all states, and the double ratio **should = 1**)  
Excited states affected by a 20 % offset vs.  $\Upsilon(1S)$

## pPb vs PbPb:

**Much** larger double ratios in pPb than in PbPb  
Can help understanding (hot) final state effects on 2S and/or 3S, once an accurate extrapolation is given

**Applying the needed corrections, one gets  
single cross-section ratios**

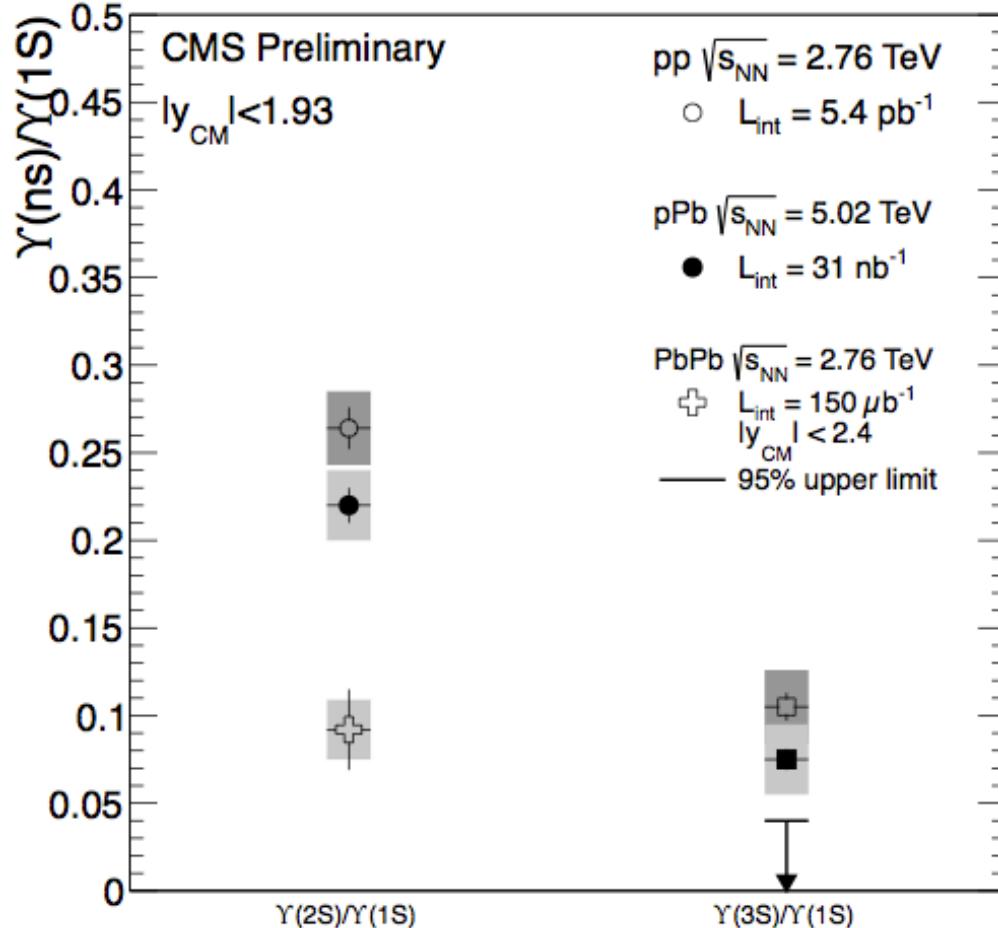
$$\frac{[\Upsilon(2S)/\Upsilon(1S)]_{\text{pPb}}}{[\Upsilon(2S)/\Upsilon(1S)]_{\text{pp}}} = 0.83 \pm 0.05(\text{stat}) \pm 0.05(\text{syst})$$

$$\frac{[\Upsilon(3S)/\Upsilon(1S)]_{\text{pPb}}}{[\Upsilon(3S)/\Upsilon(1S)]_{\text{pp}}} = 0.71 \pm 0.08(\text{stat}) \pm 0.09(\text{syst})$$

Our measurement:

# *From double to single ratios*

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**PbPb < pPb < pp:**

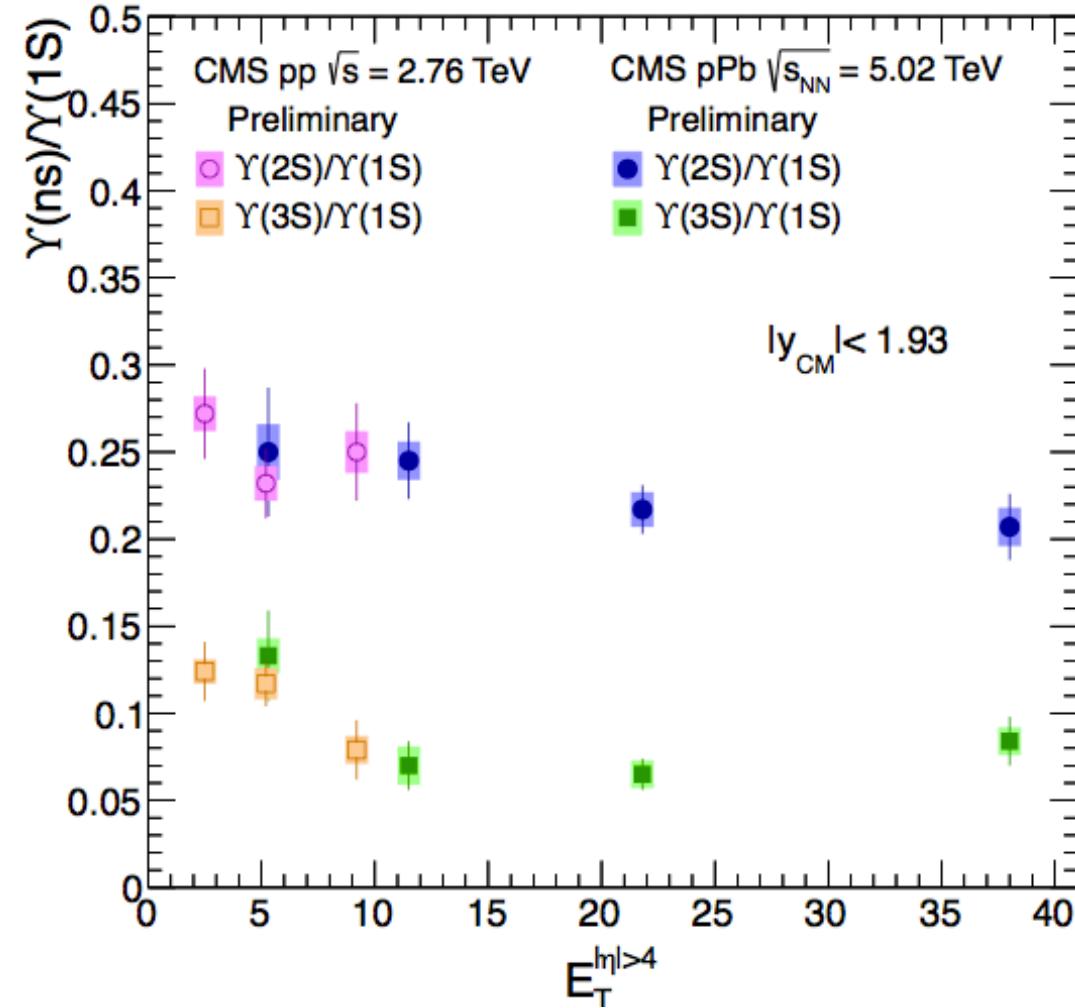
Expected to measure similar cross section ratios, while pPb is **not** sitting on top of pp

Centrality integrated results from PbPb still show significantly more suppression than pPb

Integrated over event activity. Split it!

# Event-activity variable : $E_T^{4<|\eta|<5.2}$

CMSPublic/PhysicsResultsHIN13003



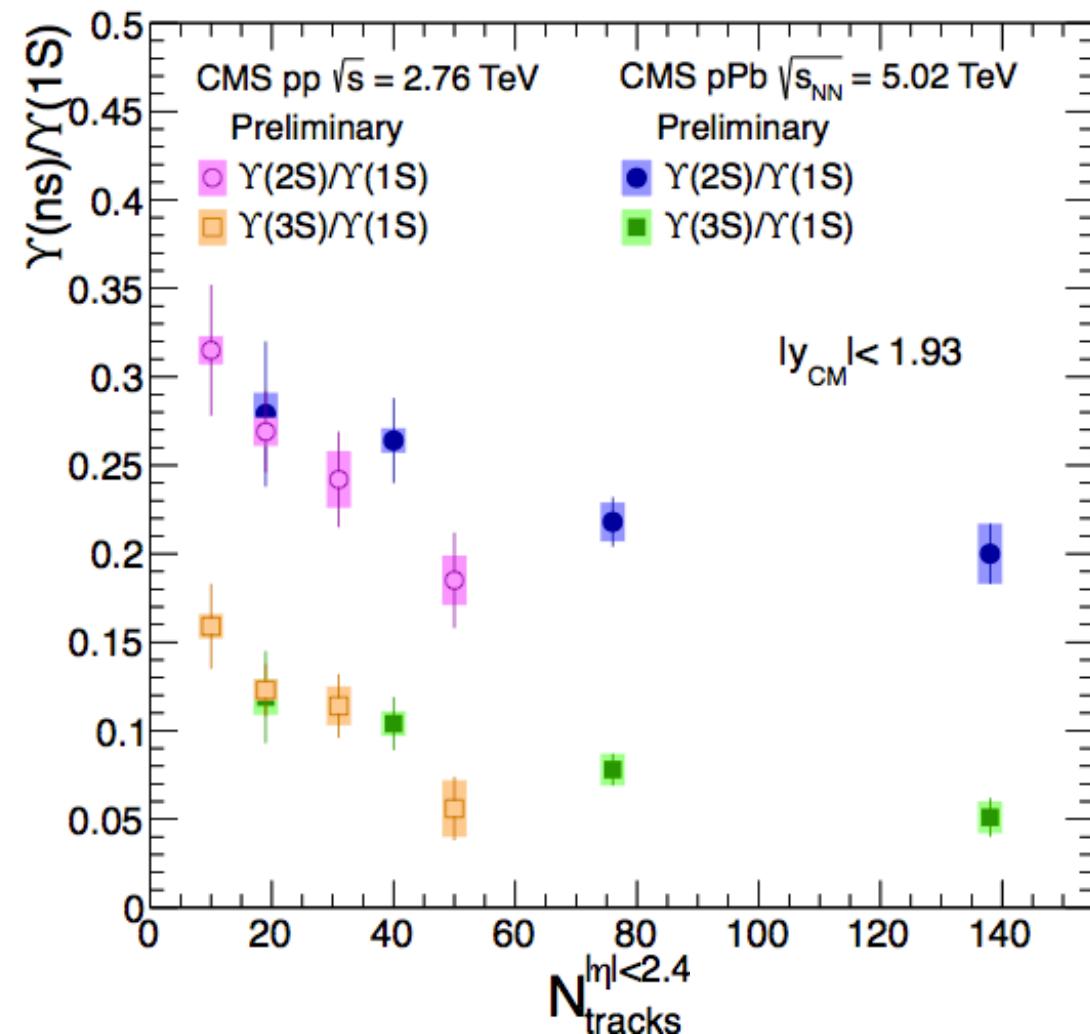
Production of excited states vs. ground state  
with respect to raw transverse energy  
deposit in the forward direction

$\langle E_T^{4<|\eta|<5.2} \rangle =$  3.5 GeV in pp,  
14.7 GeV in pPb,  
(765 GeV in PbPb)

When event activity is measured far from  $\Upsilon$ ,  
single ratios are consistent with being flat

(Single ratios)

# Event-activity variable : $N_{Trk}^{|\eta|<2.4}$



Production of excited states vs. ground state with respect to multiplicity

**pPb and pp from new 2013 data:**  
**Decreasing trend** of  $\Upsilon(nS)/\Upsilon(1S)$  with increasing multiplicity, both in pPb and pp!

$\langle N_{Trk}^{|\eta|<2.4} \rangle = 13$  in pp, 50 in pPb.

*About 2 extra tracks produced along  $\Upsilon(1S)$  events when compared to the  $\Upsilon(2S)$  and  $\Upsilon(3S)$  events seen in both pp, pPb samples*

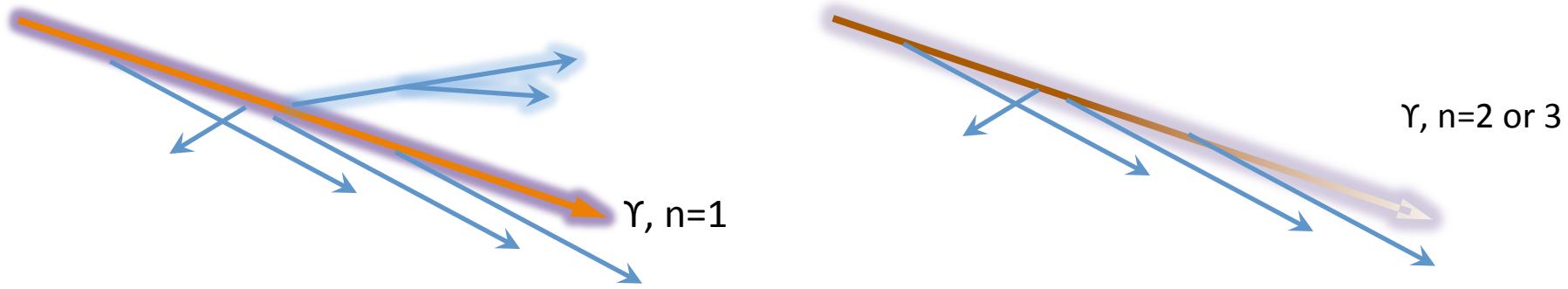
feed-down contributions  $\chi_b \rightarrow \Upsilon(nS)\gamma$  and  $\Upsilon(nS) \rightarrow \Upsilon(n-1S)\pi\pi$  are not fully responsible for this excess (we checked)... so what is this?

# How to produce such a trend?

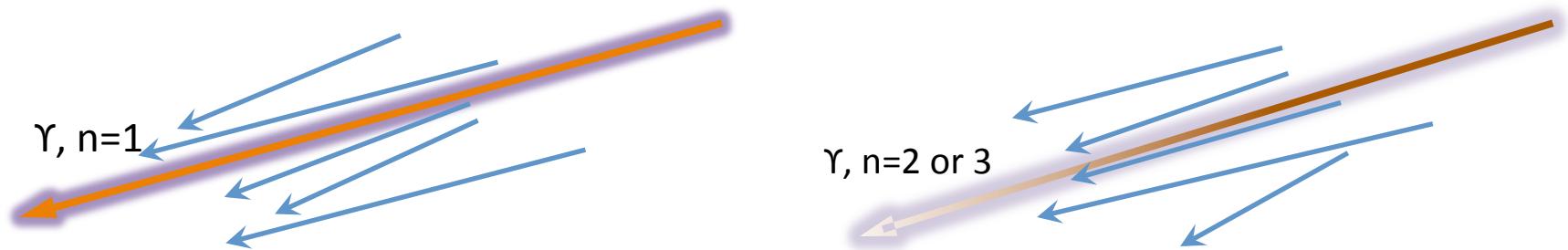
Two very different ways:

#1: The upsilon 1S and nS 'affect' the multiplicity – differently

A quarkonium emitting more partons than another will end in a different  $N_{TRK}$  class

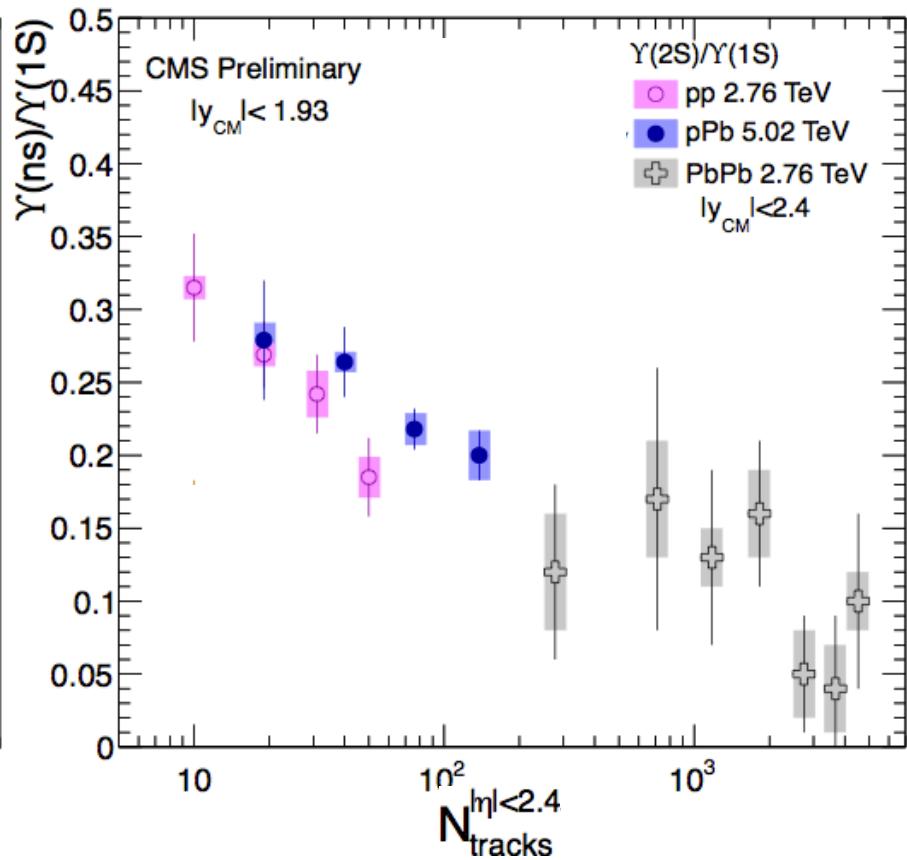
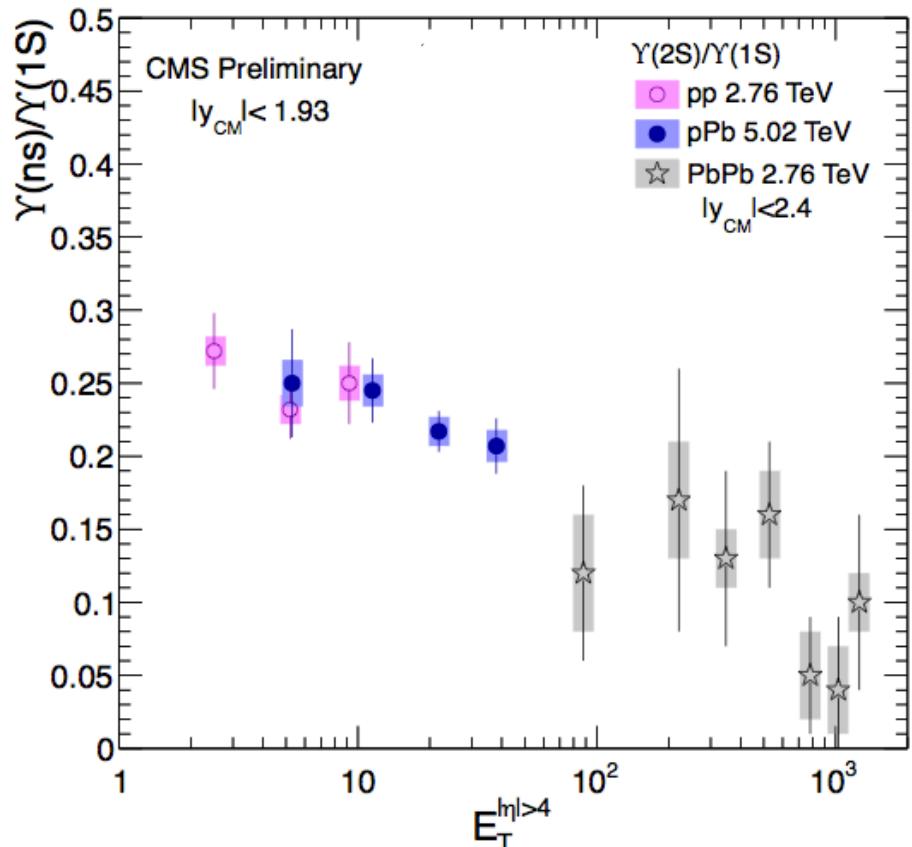


or, #2: The upsilon 1S and nS are affected by the multiplicity – somewhat differently too.



# Event-activity variables : $pp$ vs $pPb$ vs $PbPb$

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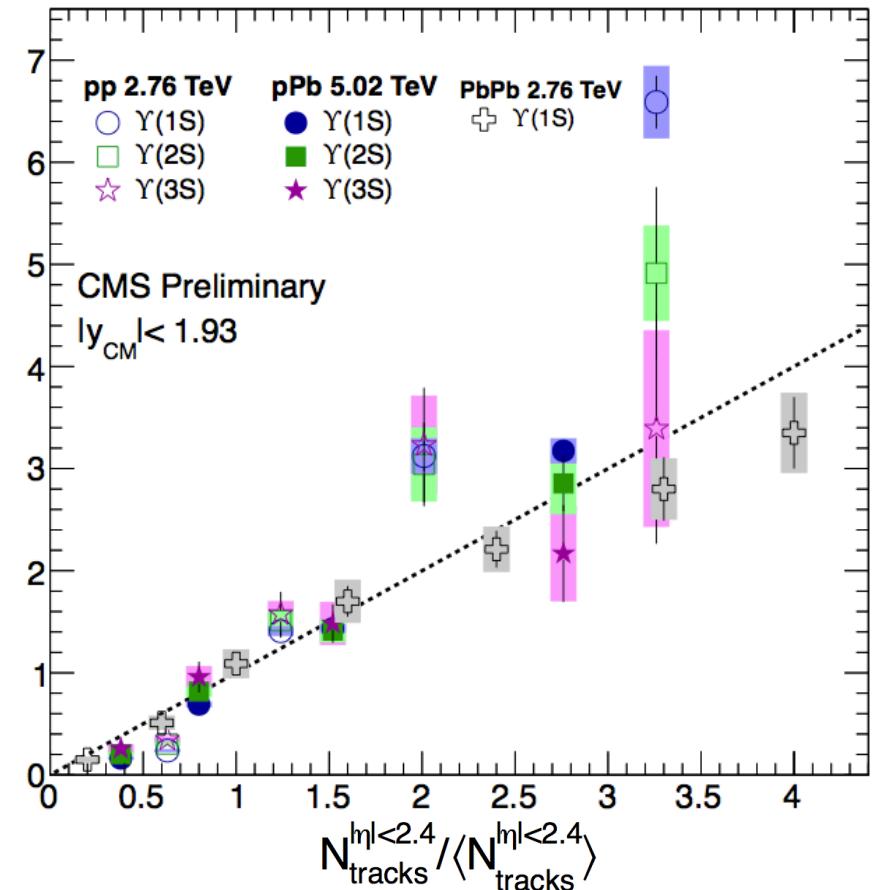
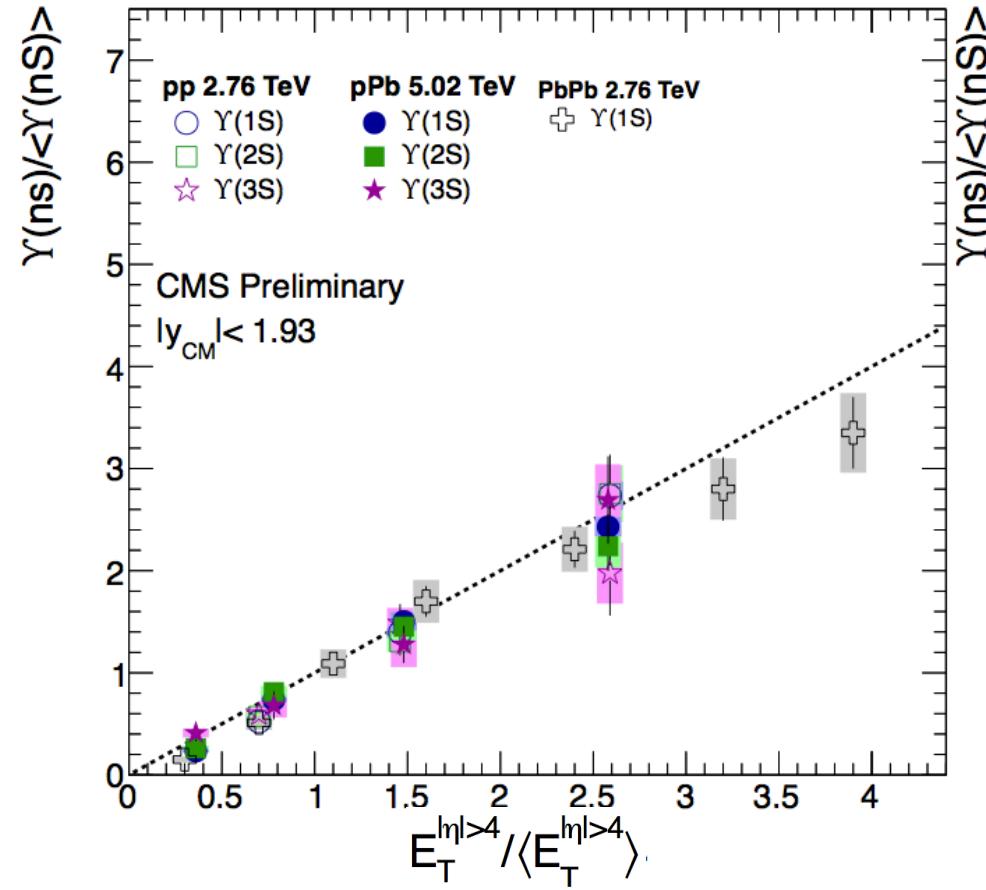


More PbPb peripheral events needed to reach overlapping ranges between pPb and PbPb  
 $pPb > PbPb \dots$  It has to be cautiously taken in consideration, as one needs to understand:

- What goes on in pp, and how does it extrapolate to pPb? (look at 7 TeV pp data?)
- How to extrapolate rigorously from pPb to PbPb?

# *Self-normalized cross-sections*

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vs  $E_T$ : For each of the three colliding systems, the slope is compatible with 1

Word of caution : large difference in mean values of each bin (as seen previously)

Where there are Pb ions involved,  $N_{\text{coll}}$  scaling approximately produces such a rising trend.

In pp, it suggests multi-parton interactions are at play (much more data available at higher energies)

# Conclusions

When integrated over event activity, the double ratios are:

$$\frac{Y(2S)/Y(1S)|_{pPb}}{Y(2S)/Y(1S)|_{pp}} = 0.83 \pm 0.05 \text{ (stat.)} \pm 0.05 \text{ (syst.)},$$

$$\frac{Y(3S)/Y(1S)|_{pPb}}{Y(3S)/Y(1S)|_{pp}} = 0.71 \pm 0.08 \text{ (stat.)} \pm 0.09 \text{ (syst.)}.$$

larger than the ones measured in PbPb collisions.

Multiplicity-dependence observed: single cross-section ratios pp > pPb  
slopes varying from 2S to 3S

$|E_T|$  shows no significant trend on the single ratios  
the multiplicity-dependent measurement isn't free of any bias.

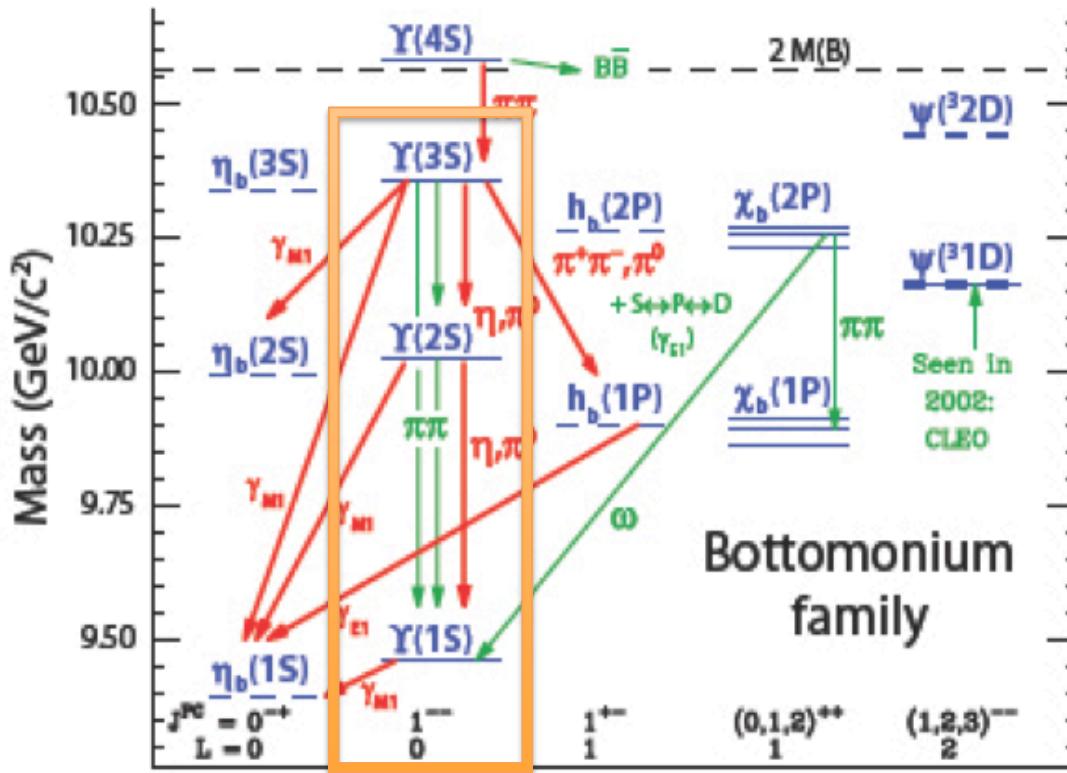
To understand pp, pPb and PbPb, need more activity-related study of the Y yields  
in pp collisions, as well as more PbPb data allowing finer investigation of the most  
peripheral events.

one (new) question: Is the reference... the reference?

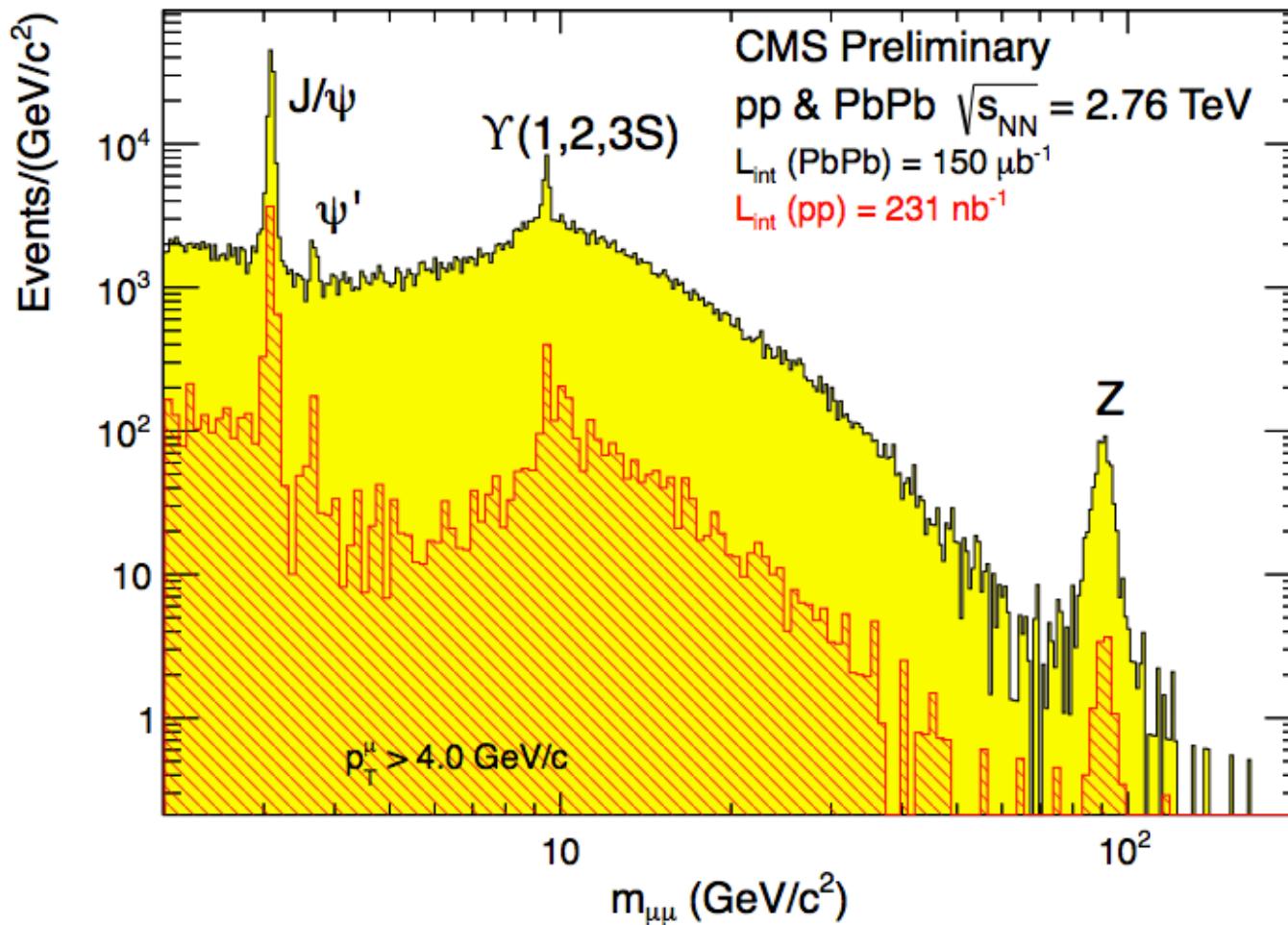
**Thank you !**

# backup

# backup



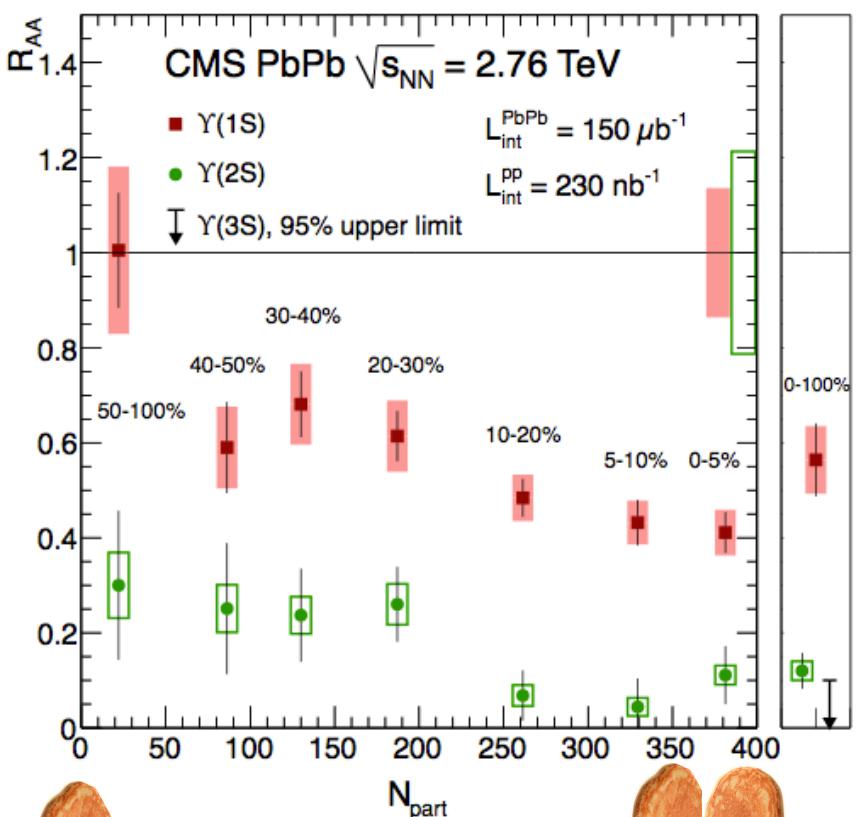
*Upsilon in PbPb*  
2011



Also, new pp data from 2013 (5.4 /pb)

# $\Upsilon(nS)$ suppression in $PbPb$ collisions at $\sqrt{s}_{NN} = 2.76$ TeV

PRL 109 (2012) 222301



$\Upsilon(1S)$ : clear modification  
 $\Upsilon(2S)$ : strong suppression  
 $\Upsilon(3S)$ , we can  
 (make a minimum bias  $R_{AA}$  upper limit)

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

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

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

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

