Bottomonium production
in pp, pPb and PbPb collisions at 5.02 TeV with the CMS detector

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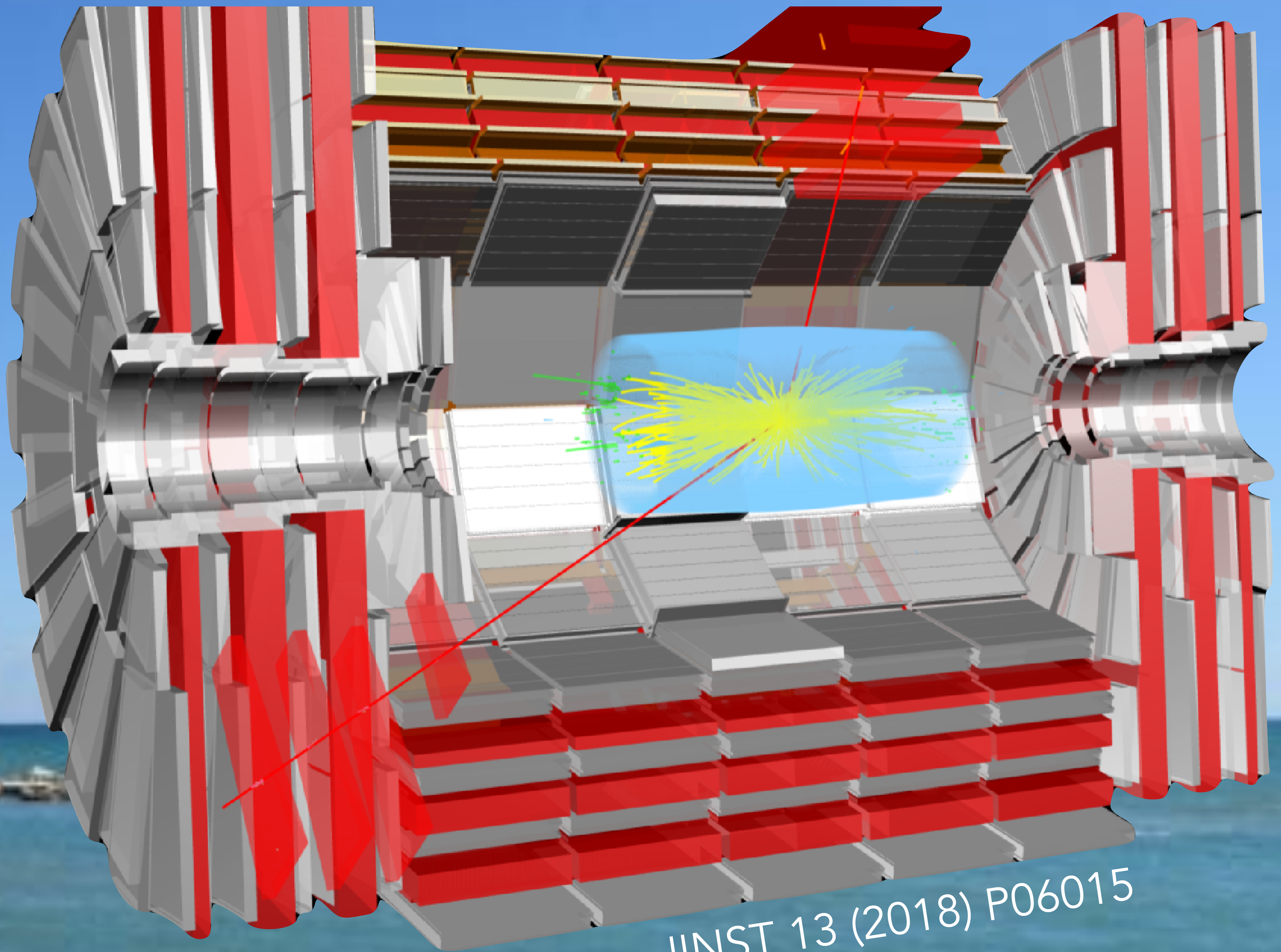
on behalf of the CMS Collaboration

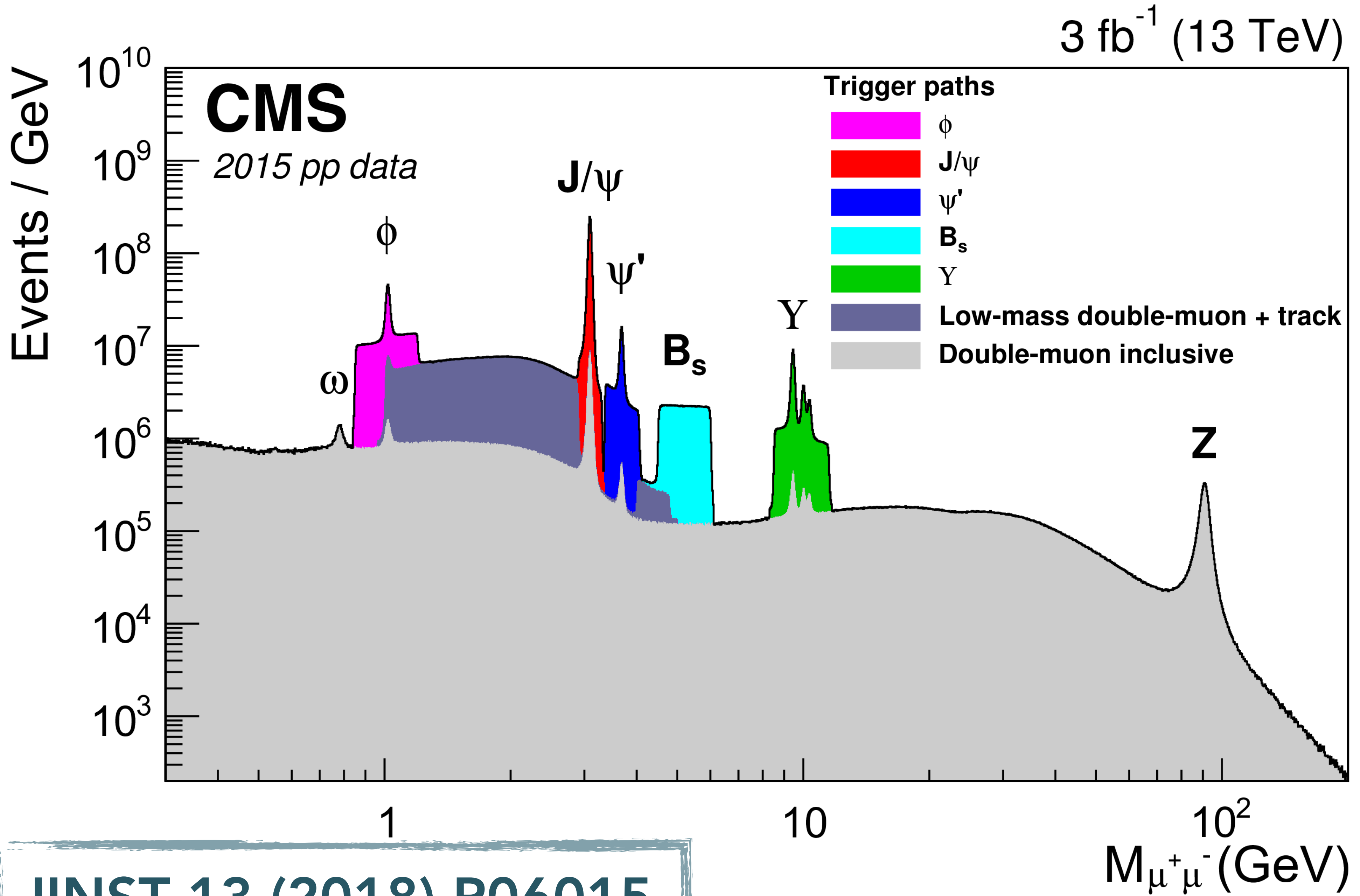
SQM2019:
Strangeness in Quark Matter Conference 2019
10-15 Jun 2019, Bari



JINST 13 (2018) P06015

Bottomonium at CMS

- The CMS is an ideal experiment to reconstruct **Υ(nS)** states ($b\bar{b}$) in their decays into $\mu^+\mu^-$
  - Large detector acceptance for muons $|\eta|<2.4$
  - Very good dimuon resolution let sets apart the **3 Υ(nS)** states
  - Many high precision results produced in pp collisions



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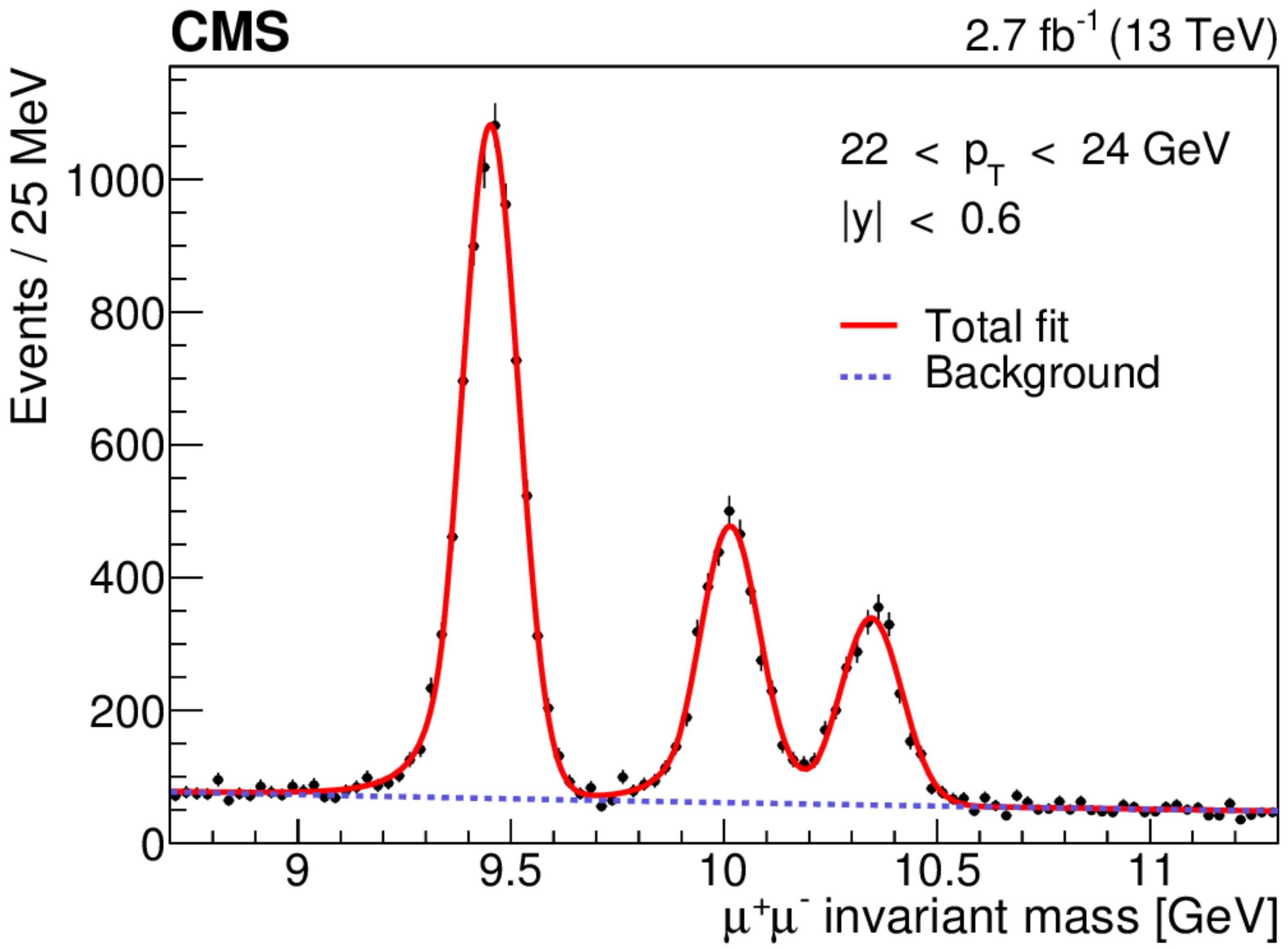
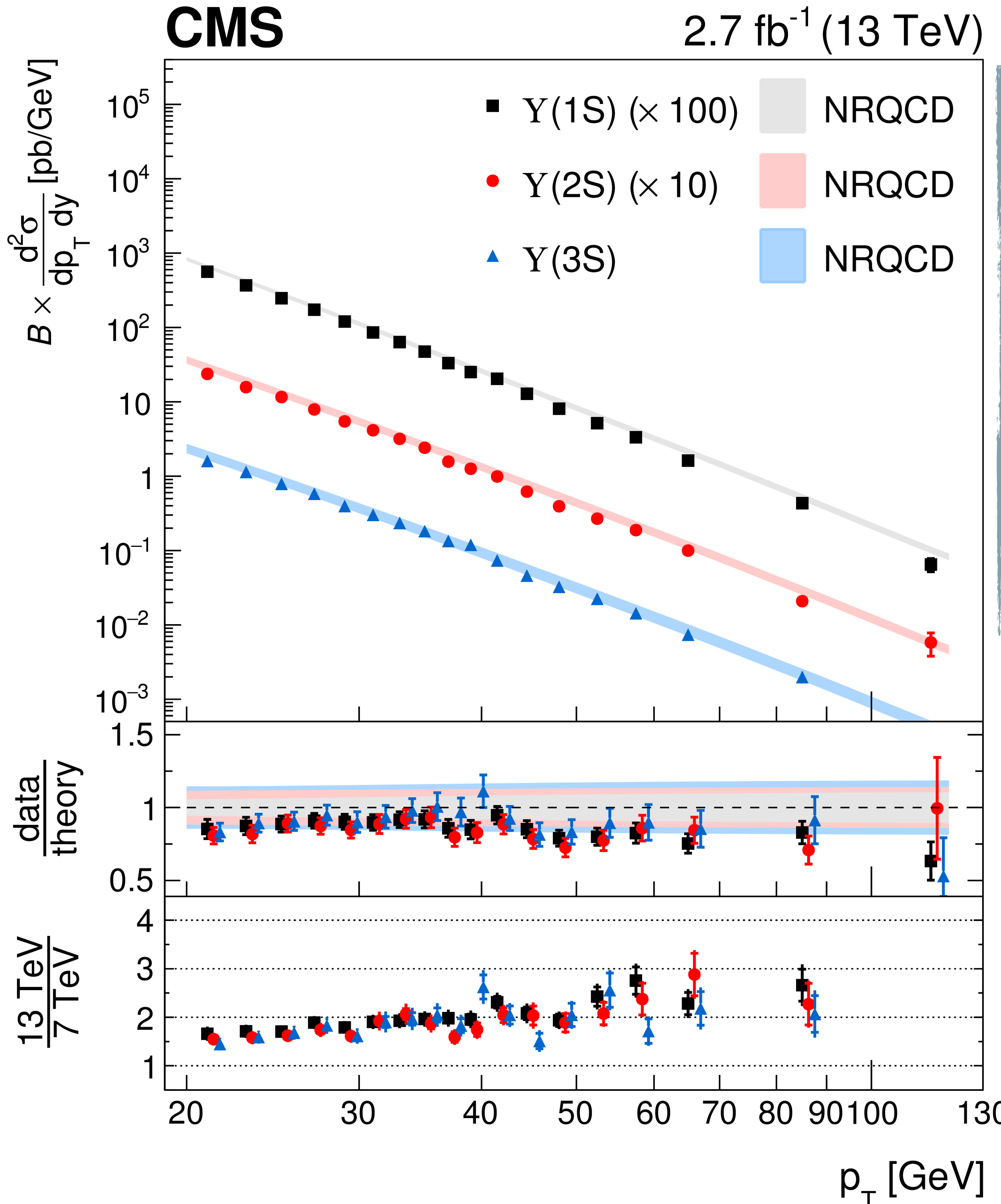


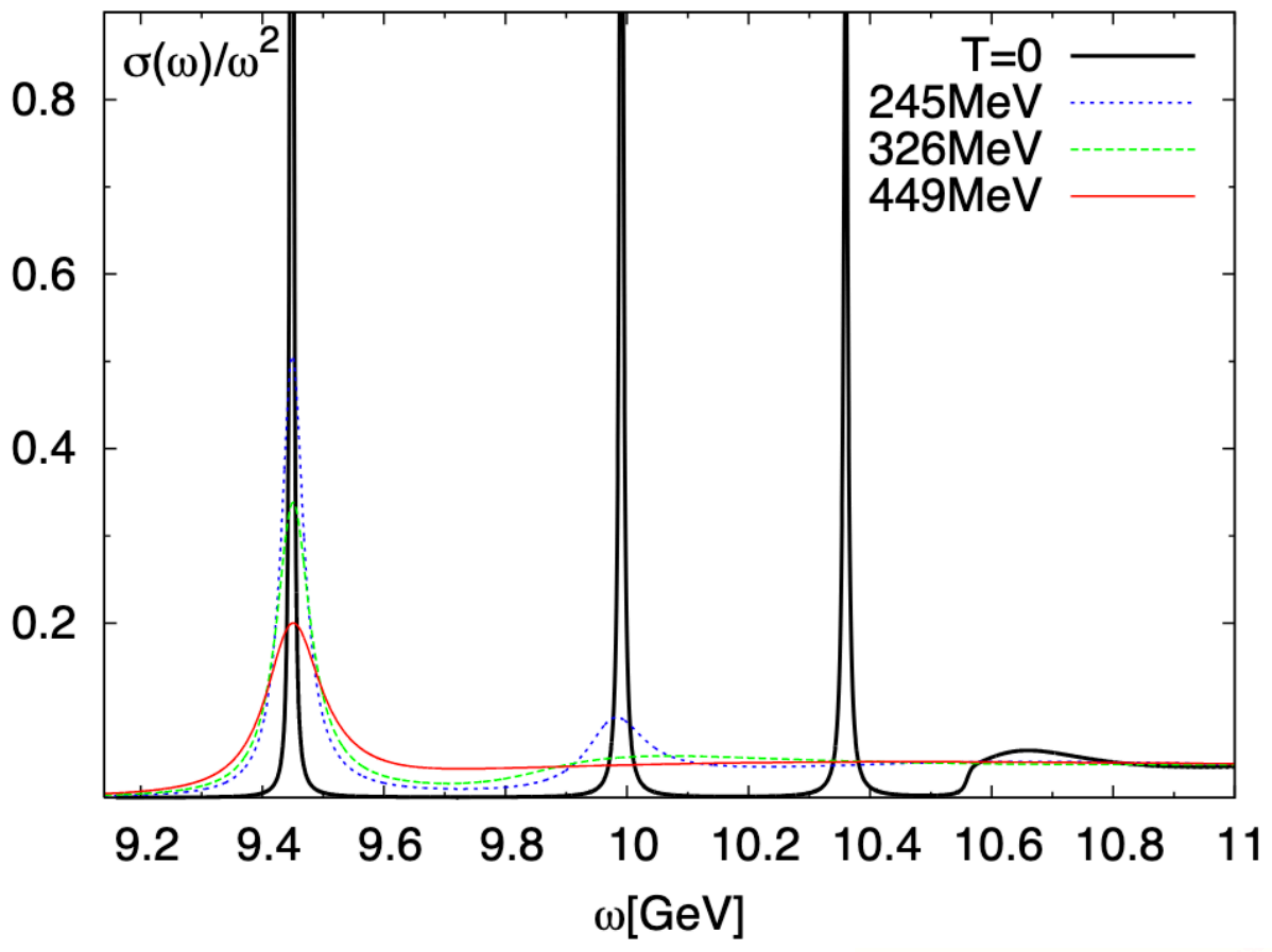


PLB 780 (2018) 251

Bottomonium in Heavy Ion Collisions

Υ(nS) production is an ideal probe for studying the Quark Gluon Plasma (QCD)

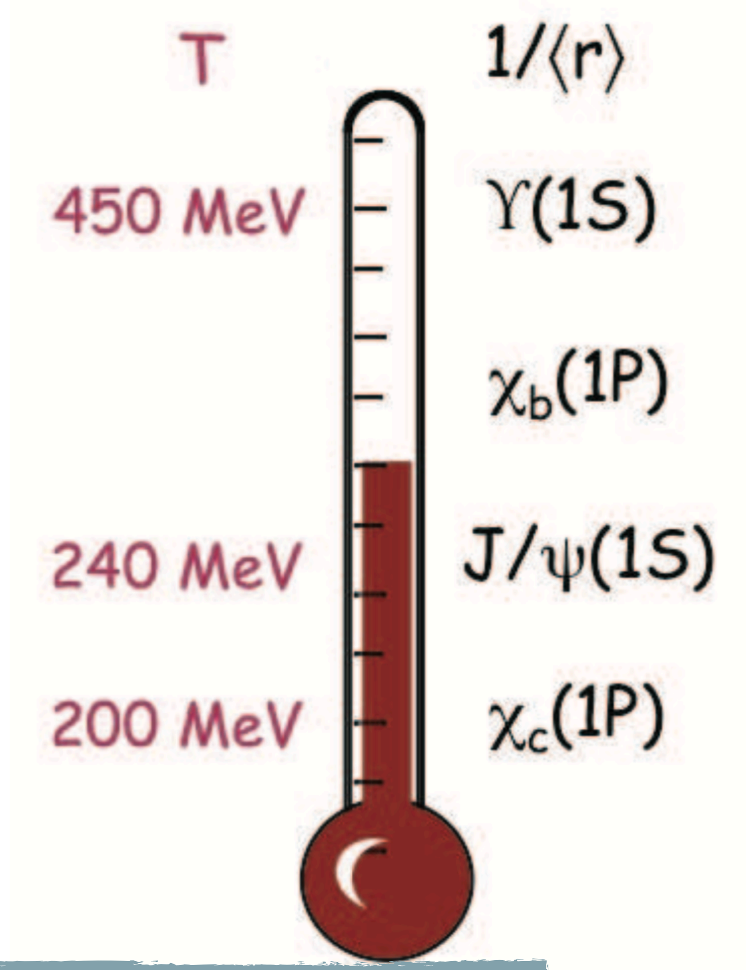
- Color Screening and thermal broadening of spectral functions:
  - Sequential suppression of Υ(nS) states
  - Υ(nS) as a probe of QGP temperature
- Color recombination of uncorrelated quark negligible in bottomonium w.r.t. charmonium



Nucl.Phys. A855 (2011)

Rich programme at LHC

- PbPb and pPb collision at different energies (5.02 and 2.76 TeV)
- pp runs at the same nucleon-nucleon energy of Heavy Ions runs



Eur.Phys.J. C61

Observables and definitions for PbPb studies

$$R_{AA}(\Upsilon(nS)) = \frac{\frac{\Upsilon(nS)_{PbPb}}{< N_{coll} >}}{\Upsilon(nS)_{pp}}$$

Nuclear Modification Factor

- Absolute modification from pp to AA

$$DR(\Upsilon(nS)) = \frac{\left(\frac{\Upsilon(nS)}{\Upsilon(1S)}\right)_{PbPb}}{\left(\frac{\Upsilon(nS)}{\Upsilon(1S)}\right)_{pp}} = \frac{R_{AA}(\Upsilon(nS))}{R_{AA}(\Upsilon(1S))}$$

Double Ratio of excited to ground state

- Cancellation of efficiency and acceptance corrections
- Cancellation of initial state effects, e.g. shadowing

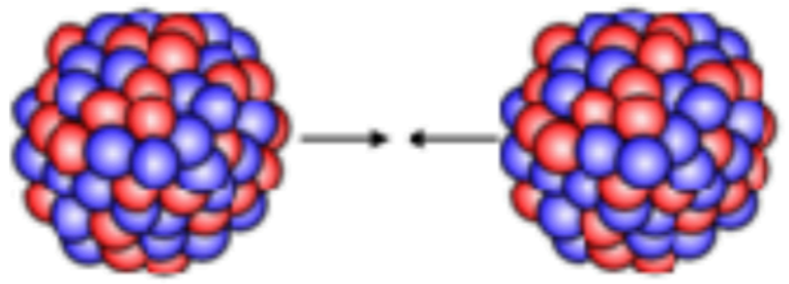
Centrality

- Degree of overlap between the two Heavy Ions Nuclei
- From 0% (largest overlap) to 100% (peripheral collisions)

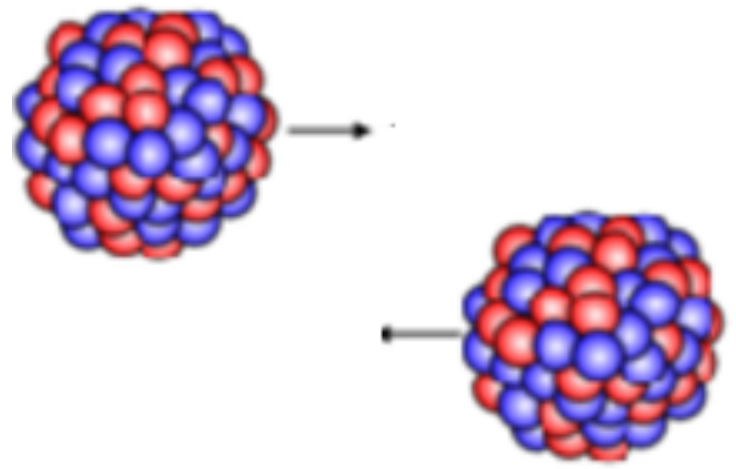
$<N_{part}>$

- Average Number of participating nucleons
- Quantification of centrality
- Obtained with a Glauber model MC simulation

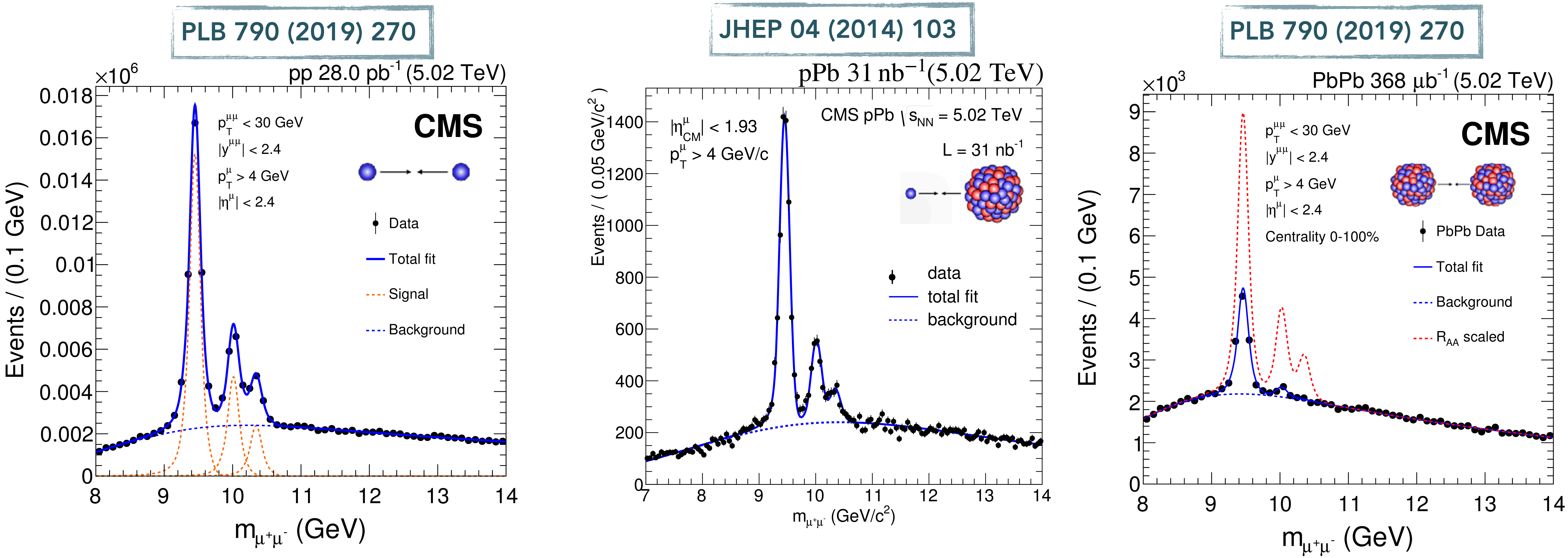
Centrality ~0%
High $<N_{part}>$



Large Centrality >90%
Low $<N_{part}>$



Υ(nS) in collisions at 5.02 TeV



- Raw yields in the $\mu^+\mu^-$ channel
- **Clear absolute suppression** from the raw yields of Υ(1S), Υ(2S) and Υ(3S) in PbPb
- No visible peak of Υ(3S) in PbPb collisions with given statistics

R_{AA} Υ(nS) vs Centrality at 5.02 TeV

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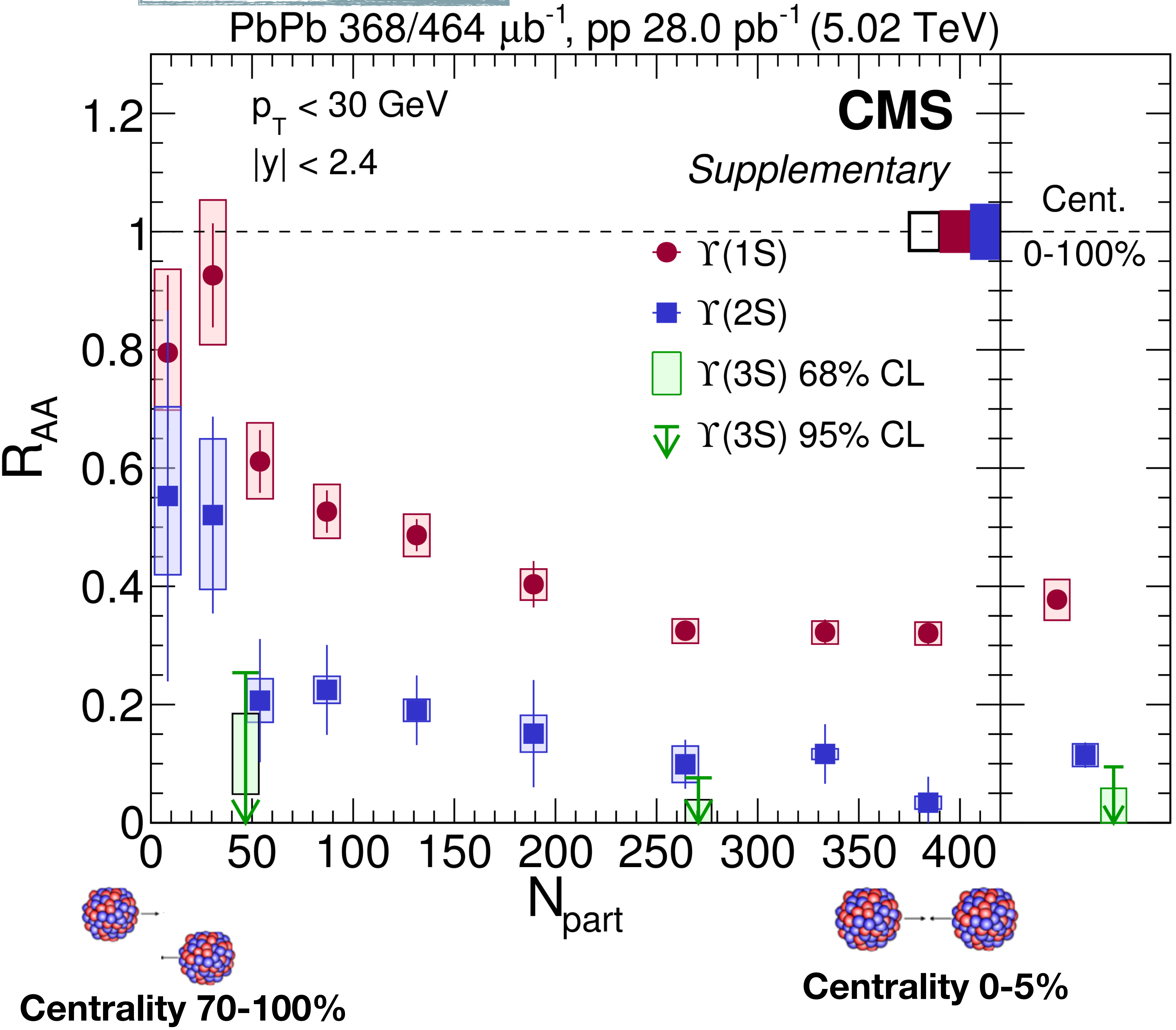


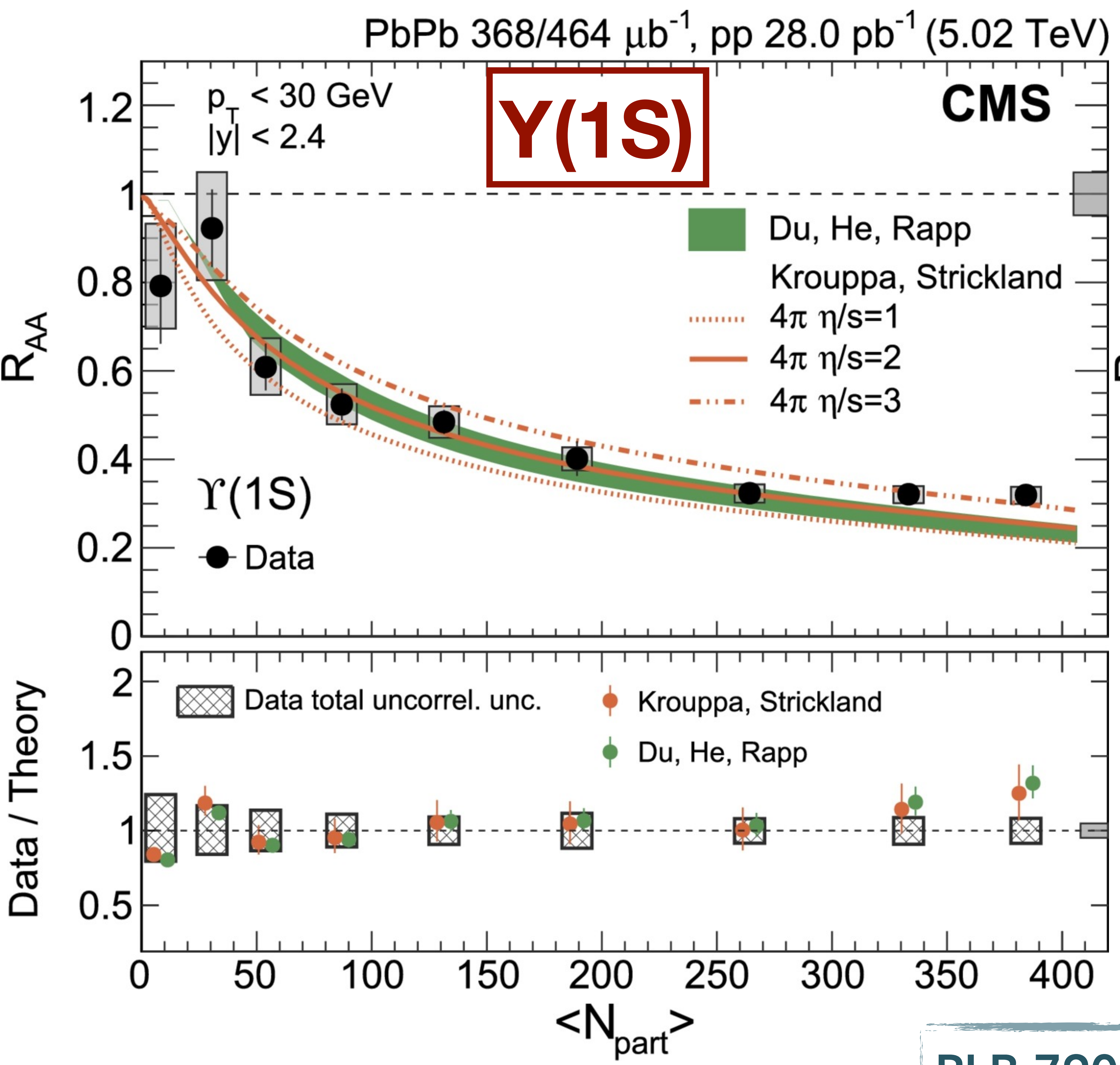
- Nuclear modification as a function of centrality for **all 3 states**
- Suppression of **Υ(1S)** and **Υ(2S)** have similar downward trend towards smaller centrality
- **Υ(3S) strongly suppressed**
- Sequential melting (integrated results):

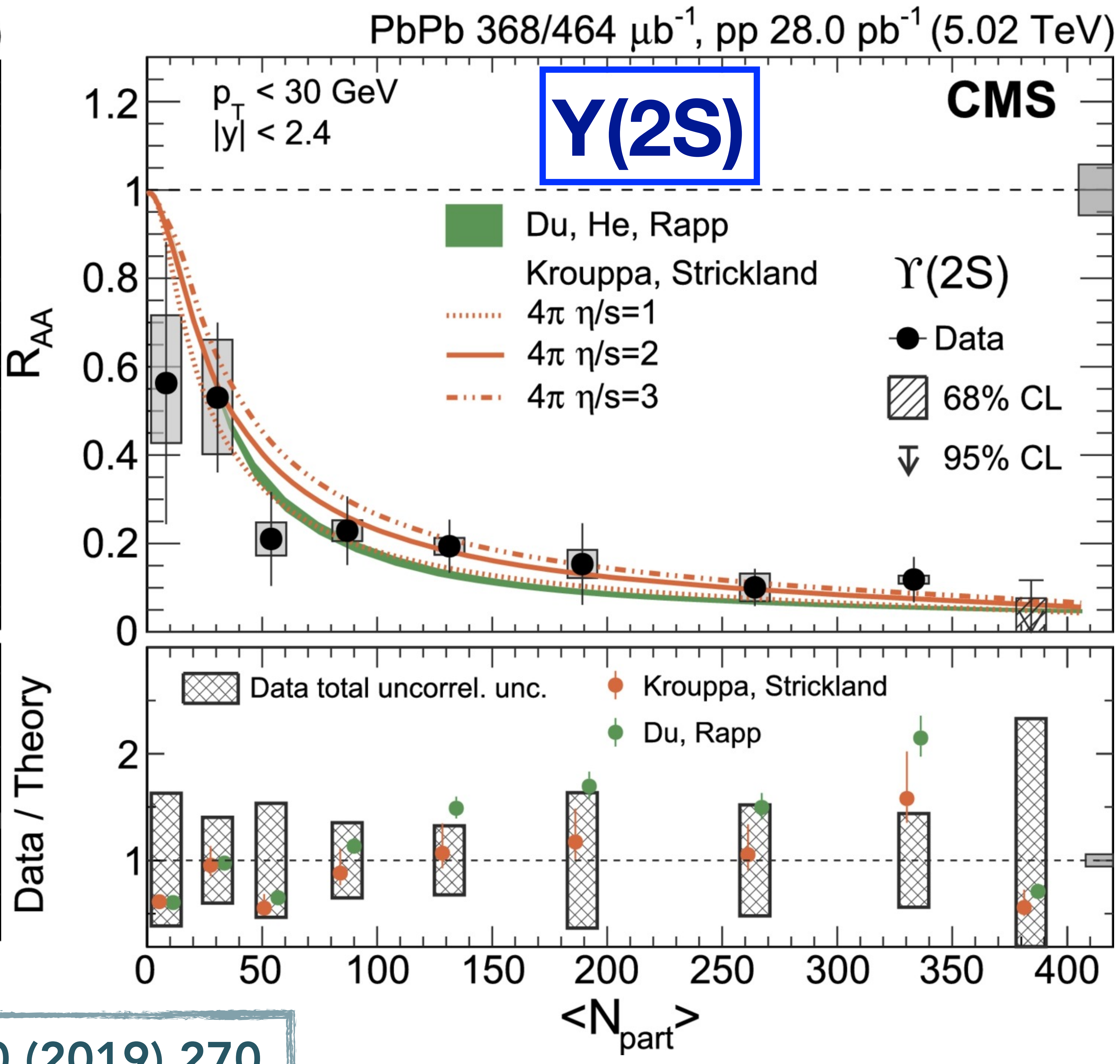
  R_{AA} Υ(1S) = **0.376** ± 0.013 ± 0.035

  R_{AA} Υ(2S) = **0.117** ± 0.022 ± 0.019

  R_{AA} Υ(3S) = **0.022** ± 0.038 ± 0.016

R_{AA} (nS) vs Predictions at 5.02 TeV





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Models:

Krouppa and Strickland model using anisotropic hydrodynamics evolution with different initial temperatures

$4\pi\ \eta/s = \{1,2,3\}$

T_0={641, 632, 629} MeV

Du et al. model containing a small component of regenerated bottomonia

$550 \leq T_0 \leq 800$ MeV

Results overlaps within the theoretical and experimental uncertainties

R_{AA} Y(nS) Comparison at 2.76 and 5.02 TeV

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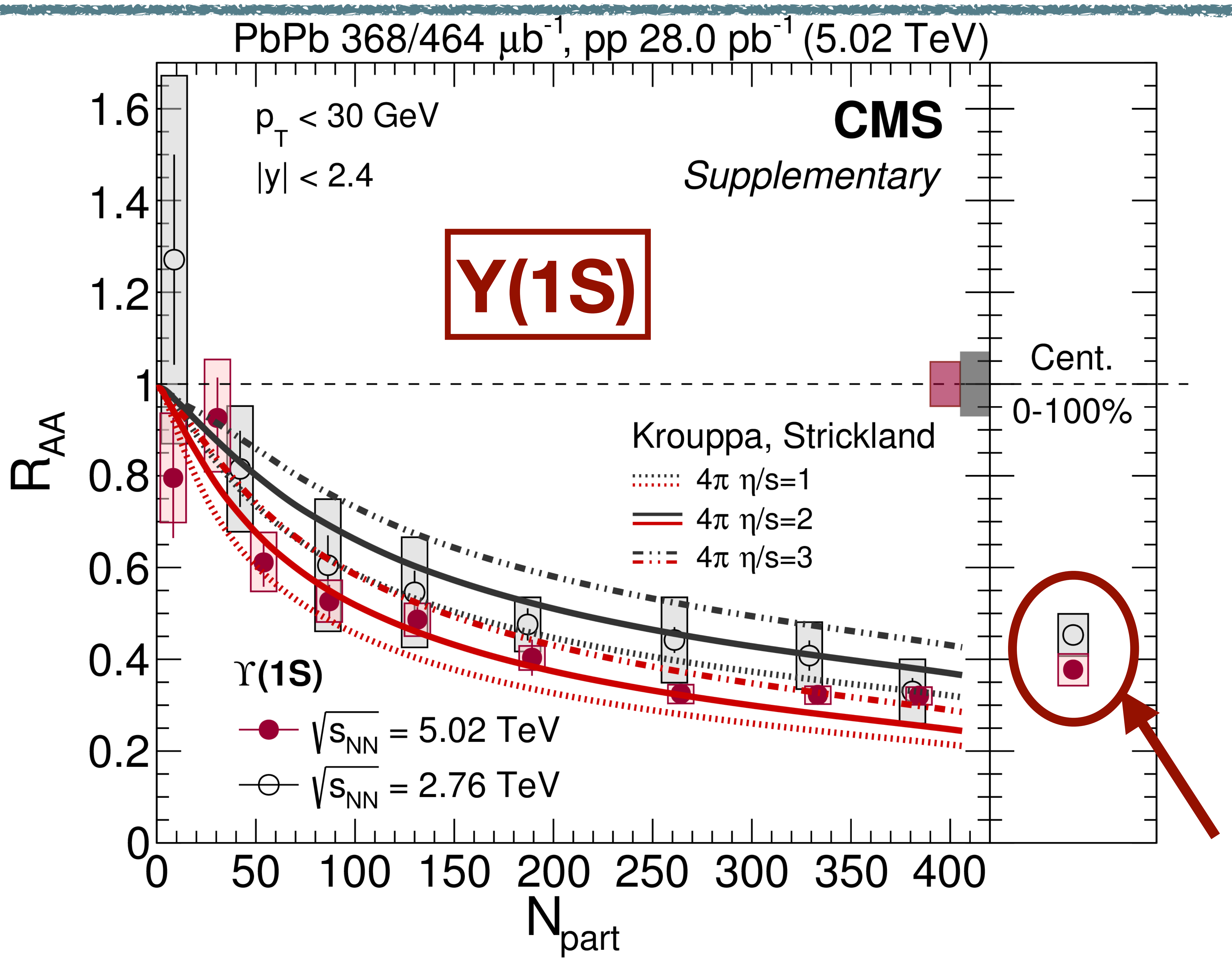
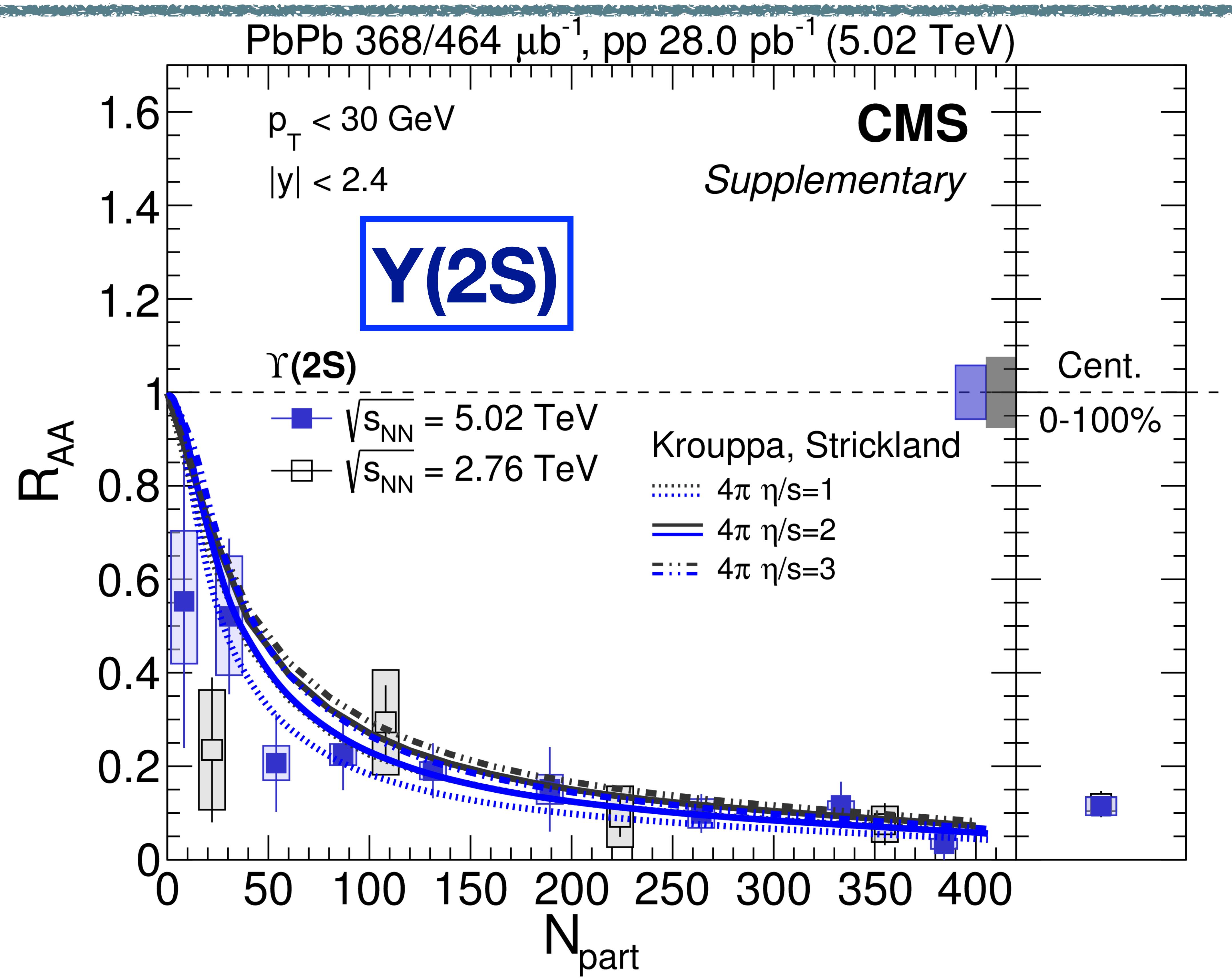
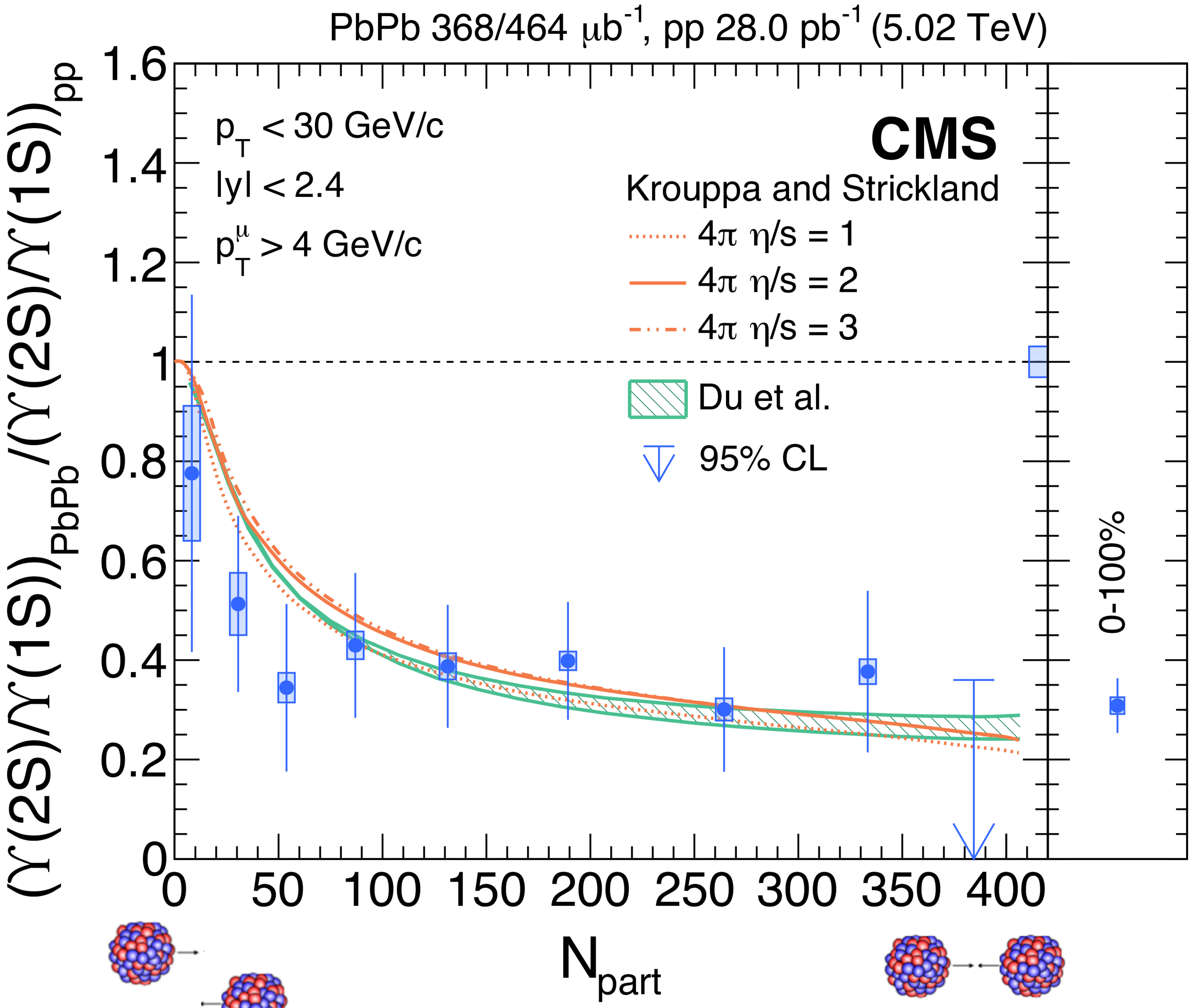




- Suppression is expected to be larger for higher QGP temperatures
    - R_{AA} at two different collision energies can provide information on the medium temperature
- **Indication of larger suppression at 5.02 TeV for the Y(1S)**
    - Still compatible within uncertainties

Y(2S) Double Ratio vs. Centrality

Phys. Rev. Lett. 120 (2018) 142301



Centrality 70-100%

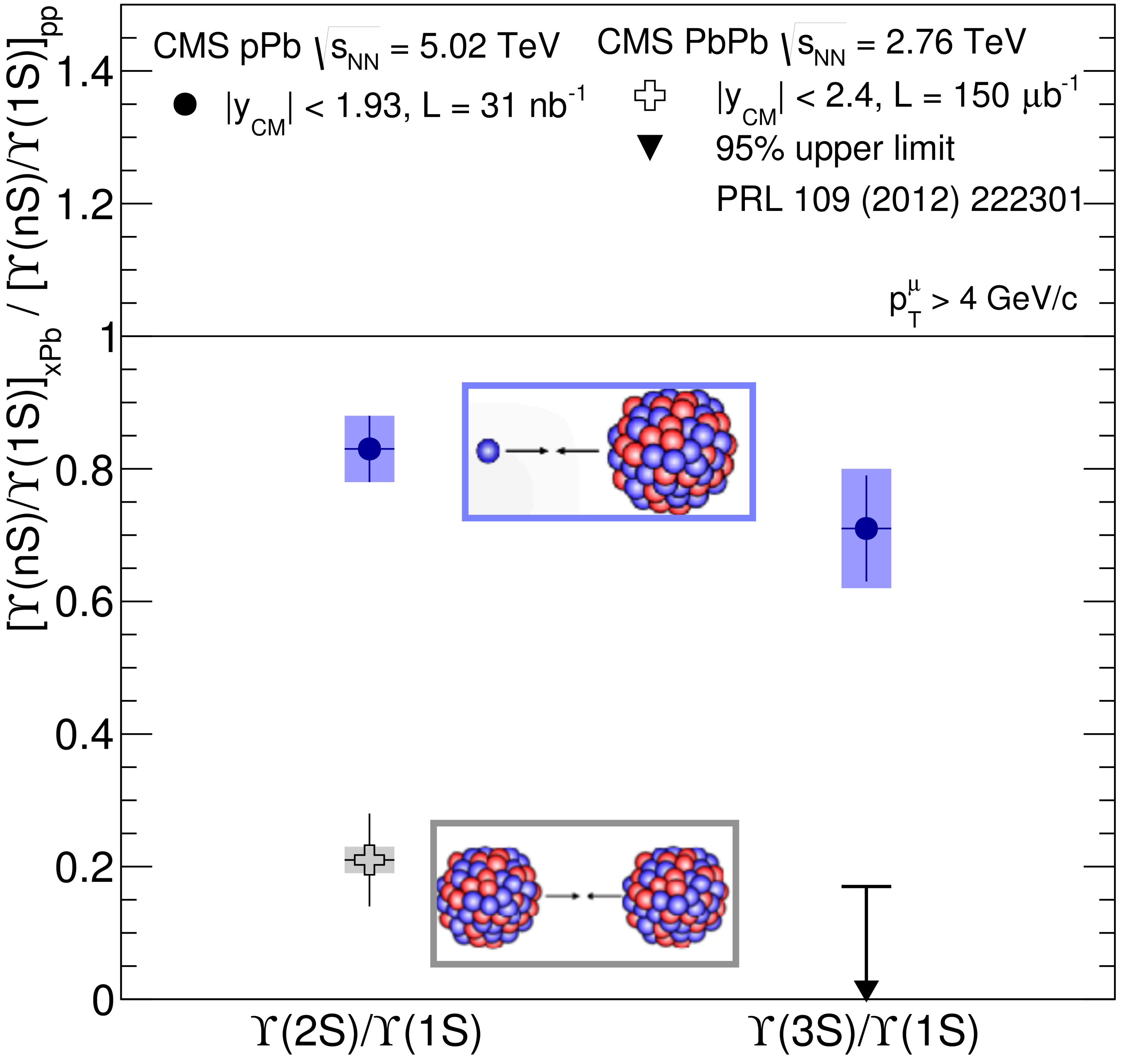
Centrality 0-5%

Ratio of the Y(2S)/Y(1S) R_{AA}

- Larger suppression toward more central events compatible with models
- Consistent with unity in most peripheral bin

Double Ratio in pPb Collisions

JHEP 04 (2014) 103



	DR Y(2S)	DR Y(3S)
pPb 5.02 TeV JHEP 04 (2014) 103	0.83±0.05 ±0.05	0.71±0.08 ±0.09
PbPb 5.02 TeV PLB 790 (2019) 270	0.308 ± 0.55 ± 0.019	<0.26 at 95% CL

Double Ratios are **smaller than unity in pPb** ….

…. **but much higher than** what measured in **PbPb** at 2.76 and 5.02 TeV

R_{AA} Υ(nS) vs p_T and Rapidity at 5.02 TeV

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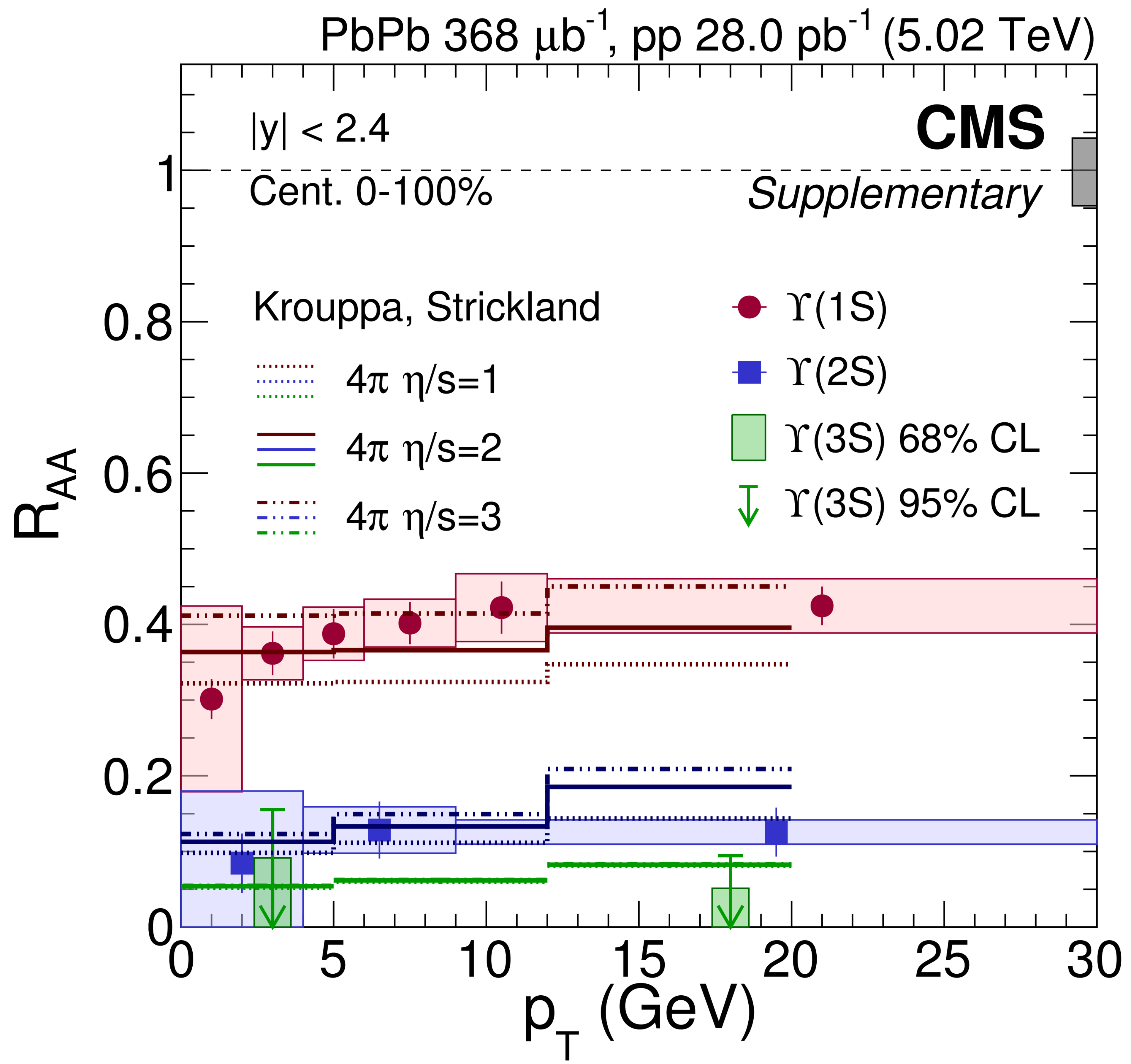
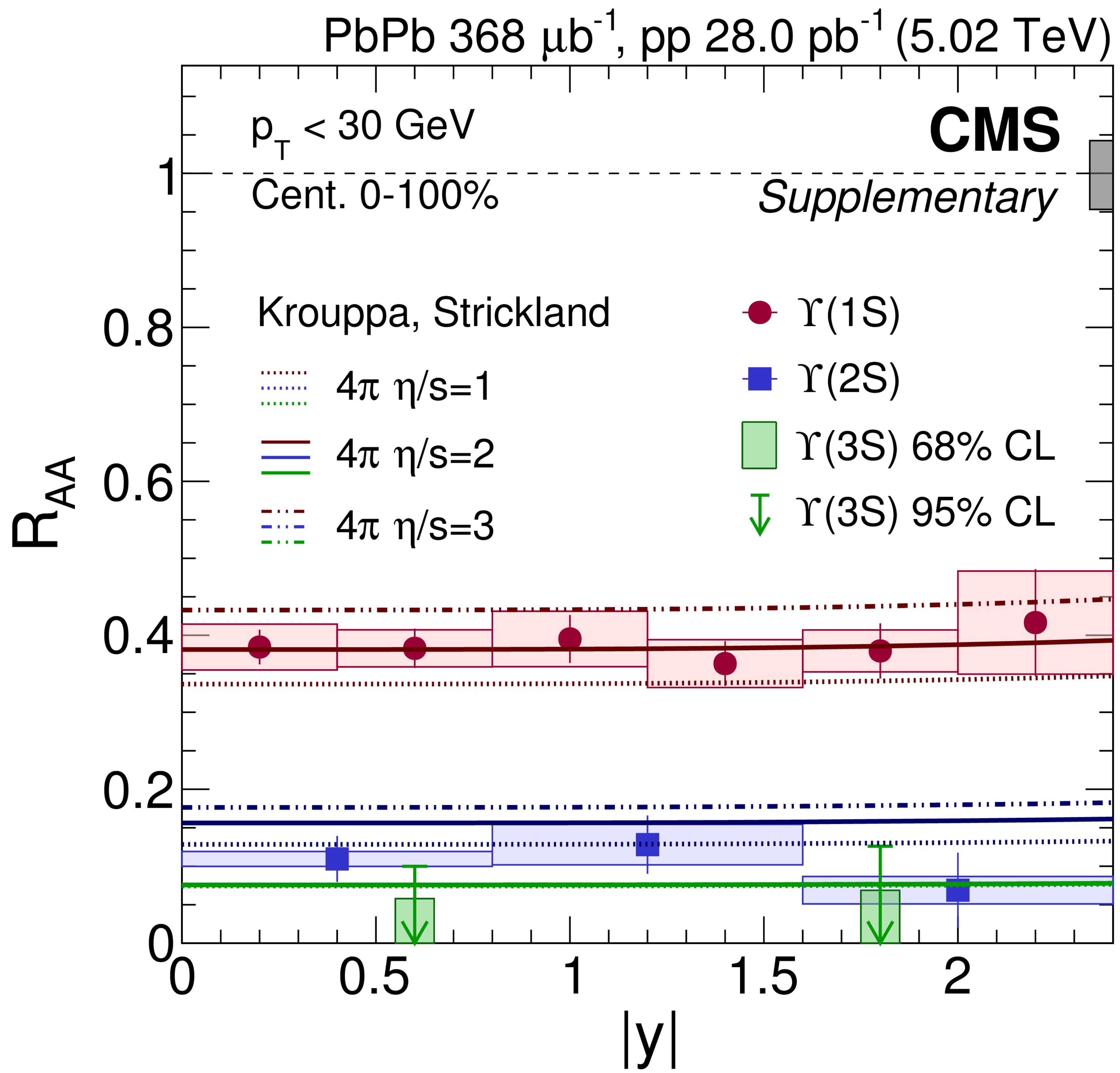


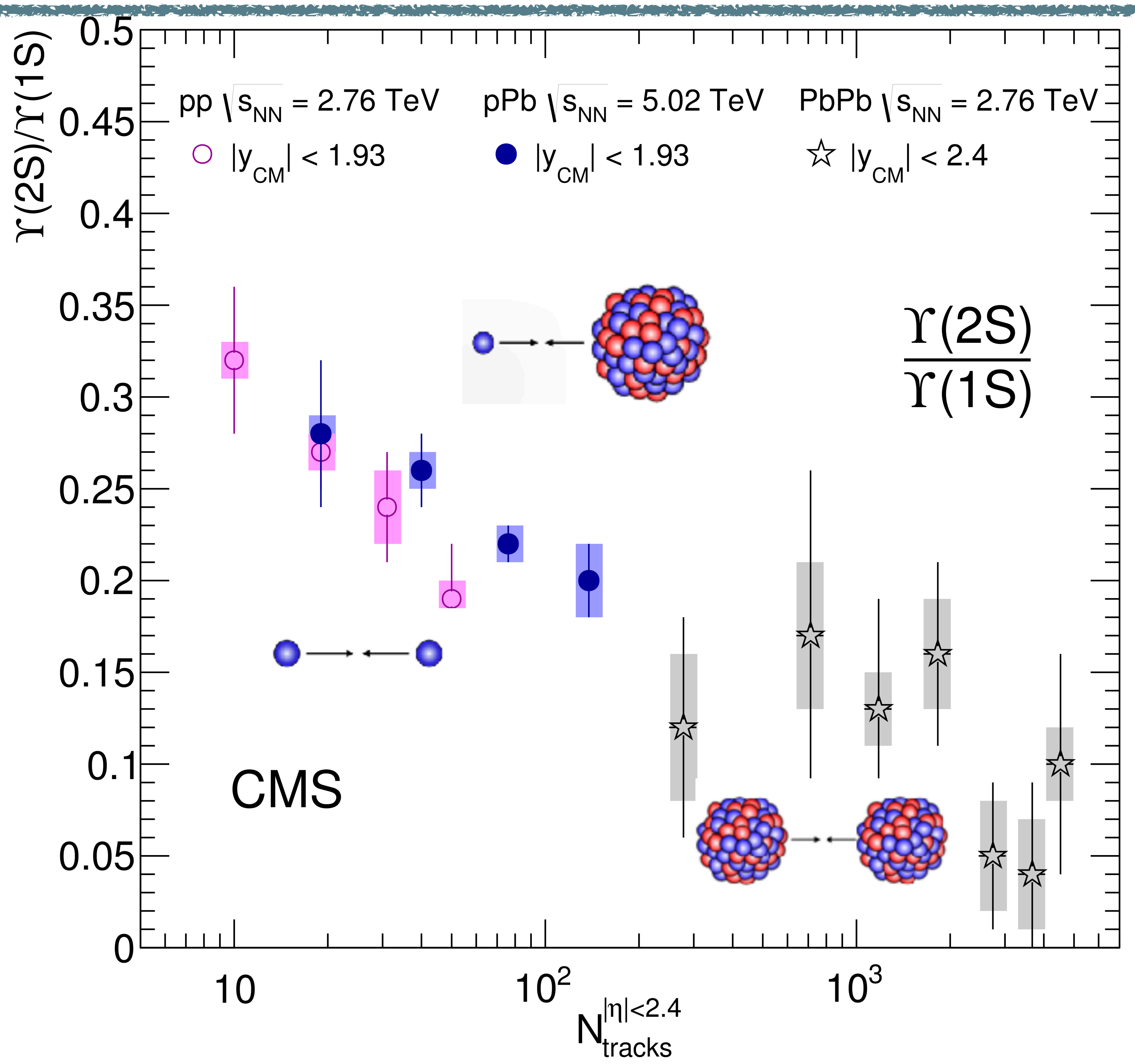


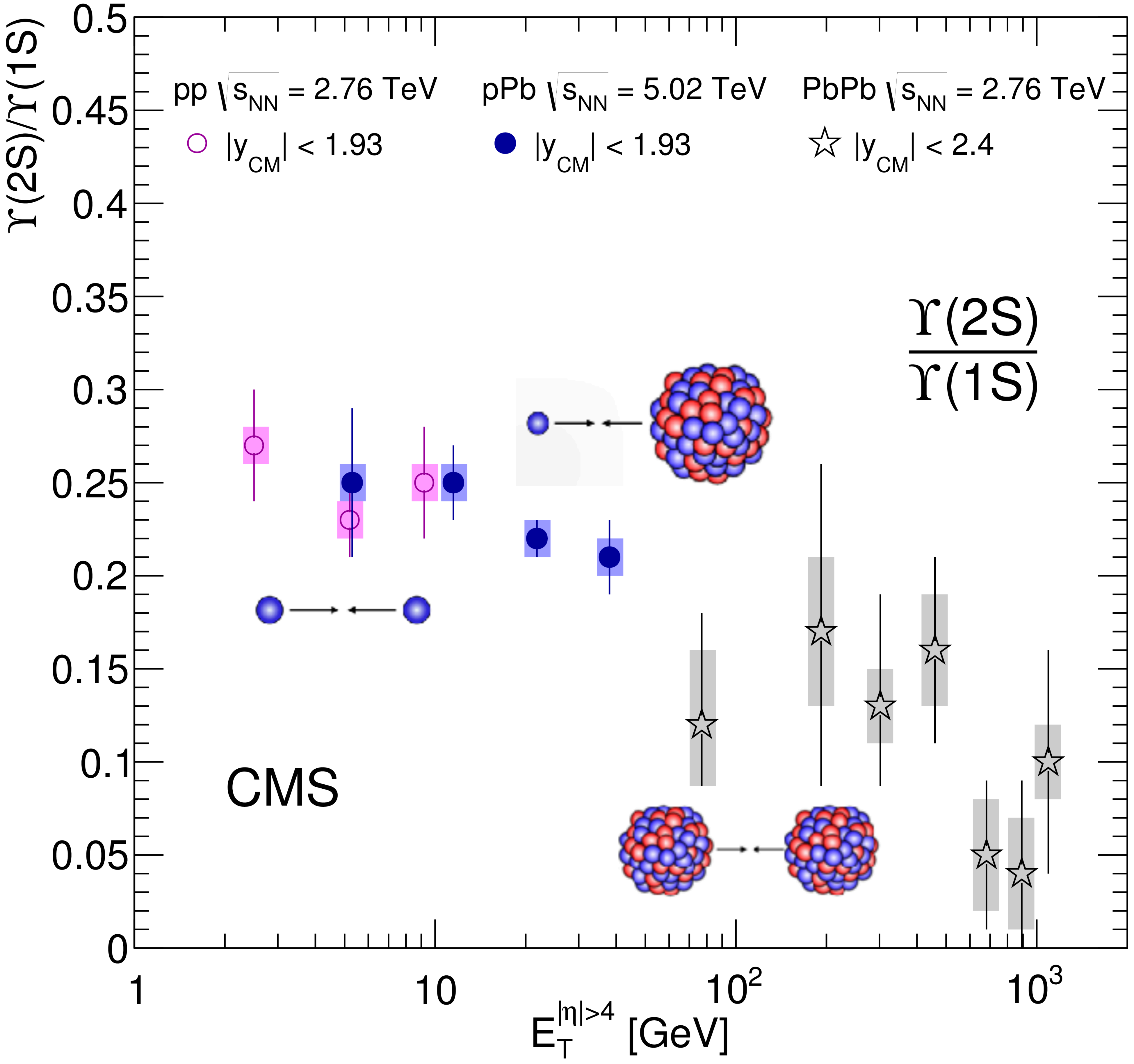
- Suppression slightly increasing in p_T for **Y(1S)**
- Constant suppression vs p_T for **Y(2S)** and **Y(3S)**
- Constant suppression vs |y|

Results compatible with the selected models

Event Activity dependence in pp, pPb and PbPb

JHEP 04 (2014) 103



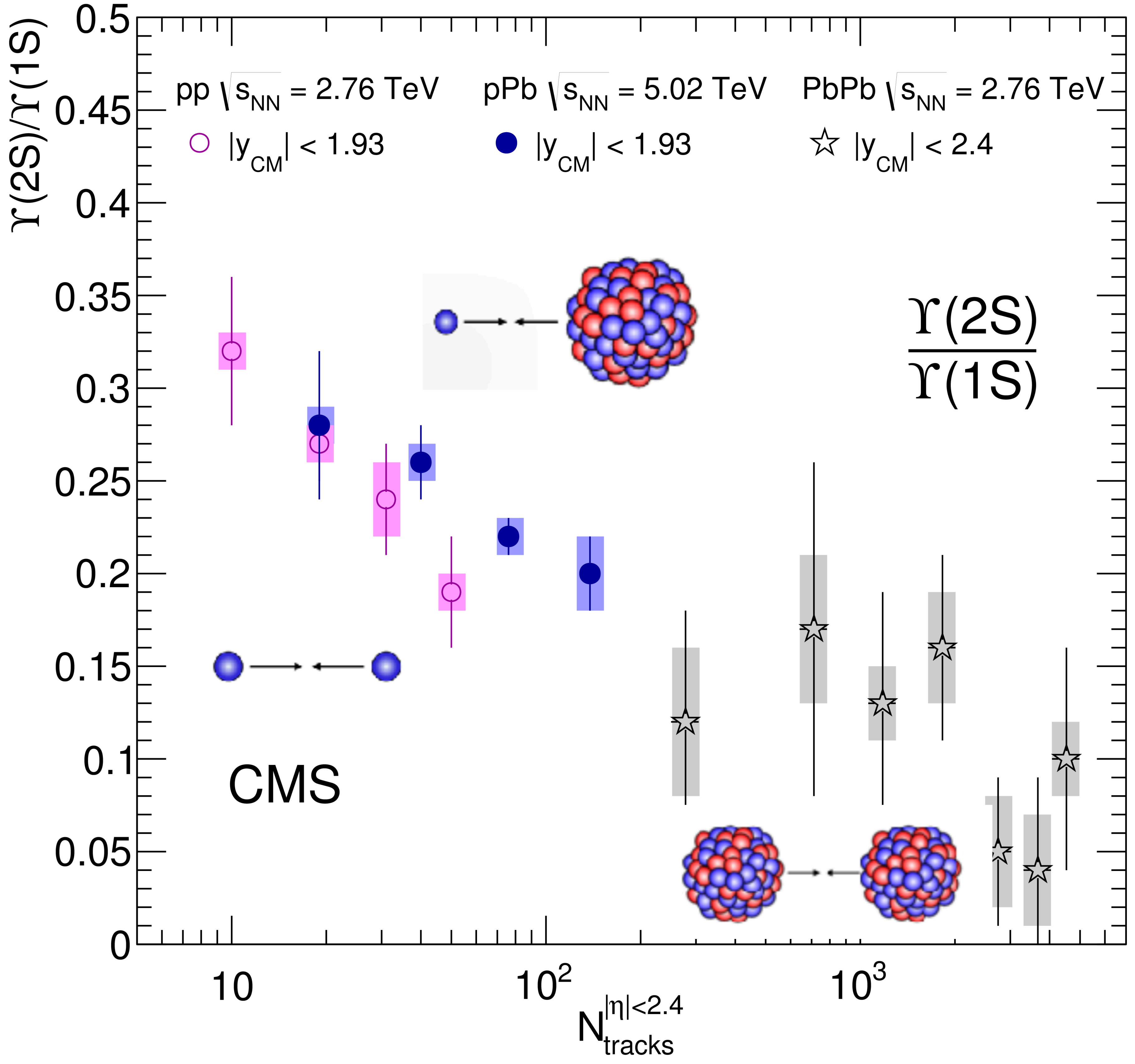


Excited-to-ground-states ratios found to decrease with increasing Event Activity

Unexpected dependence in pp and pPb with Multiplicity!

Summary

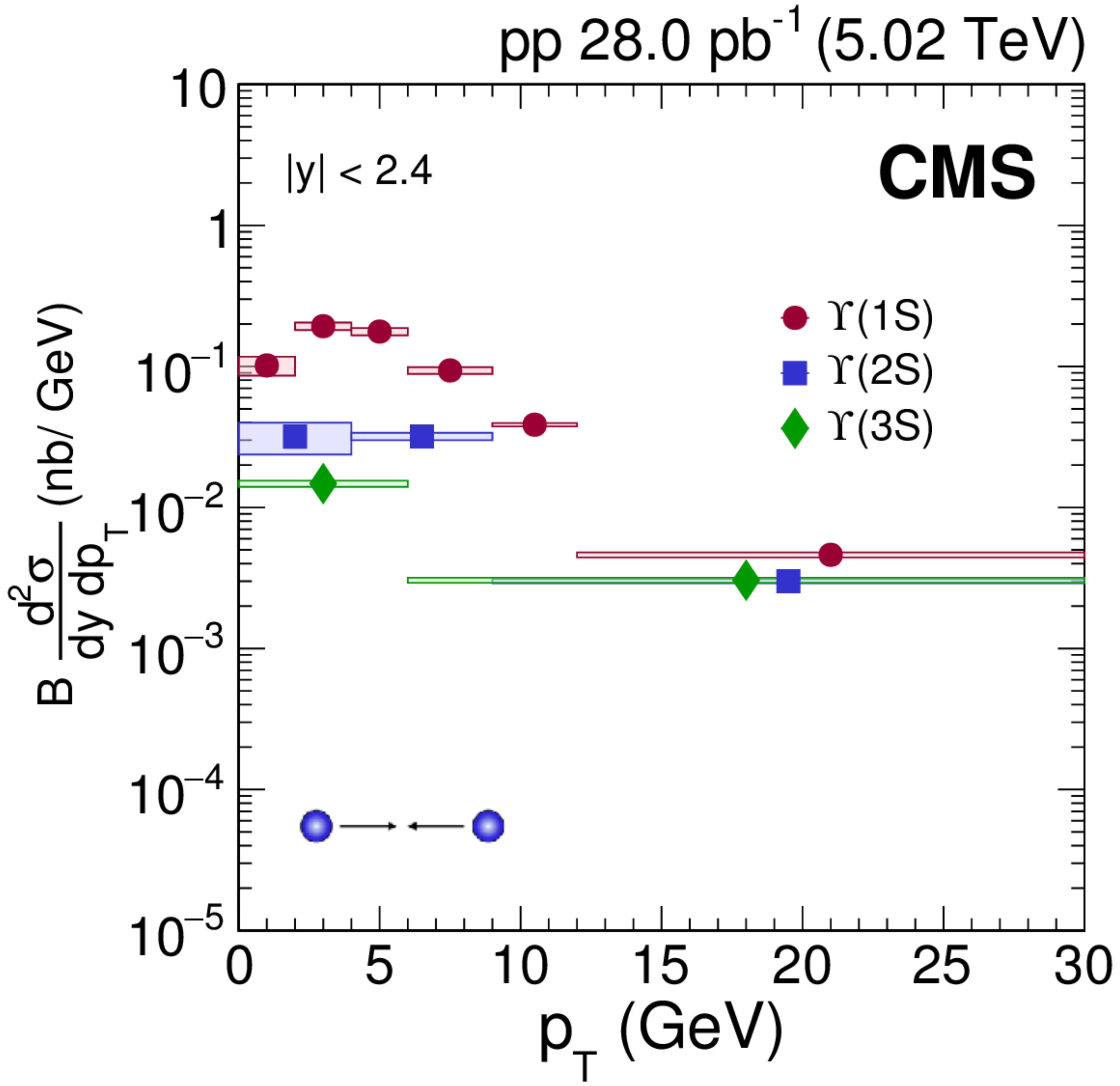
- CMS has a wide program for Υ(nS) production in pp, pPb and PbPb collision
- **In PbPb collision**:
  - Suppression is dependent on centrality.
  - Suppression is independent of Υ(nS) kinematics in p_T and |y|.
    - With exception of the Υ(1S) vs. p_T in 5.02 TeV where a small increase is observed.
  - Sequential melting picture consistent among different collision energies.

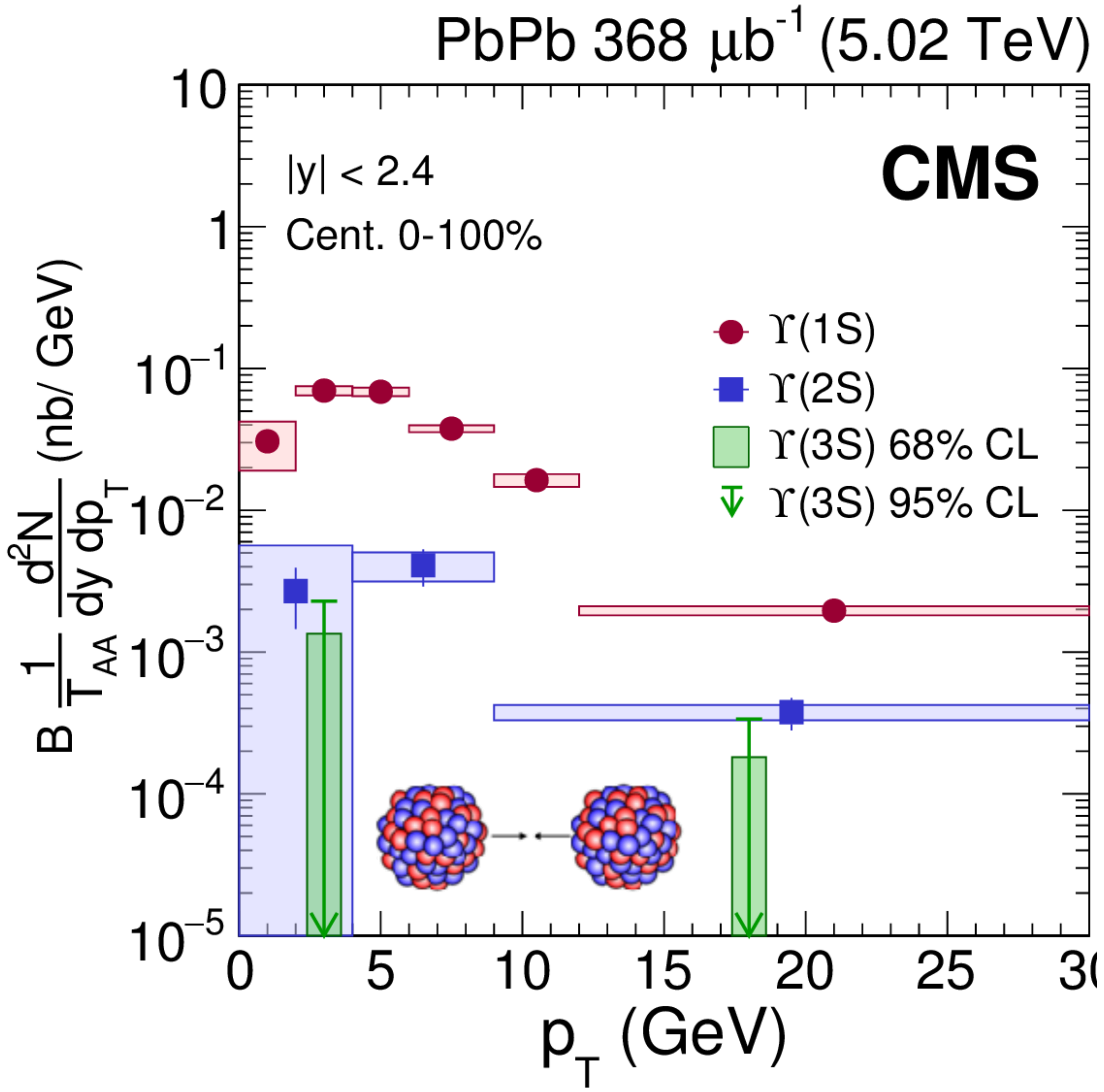


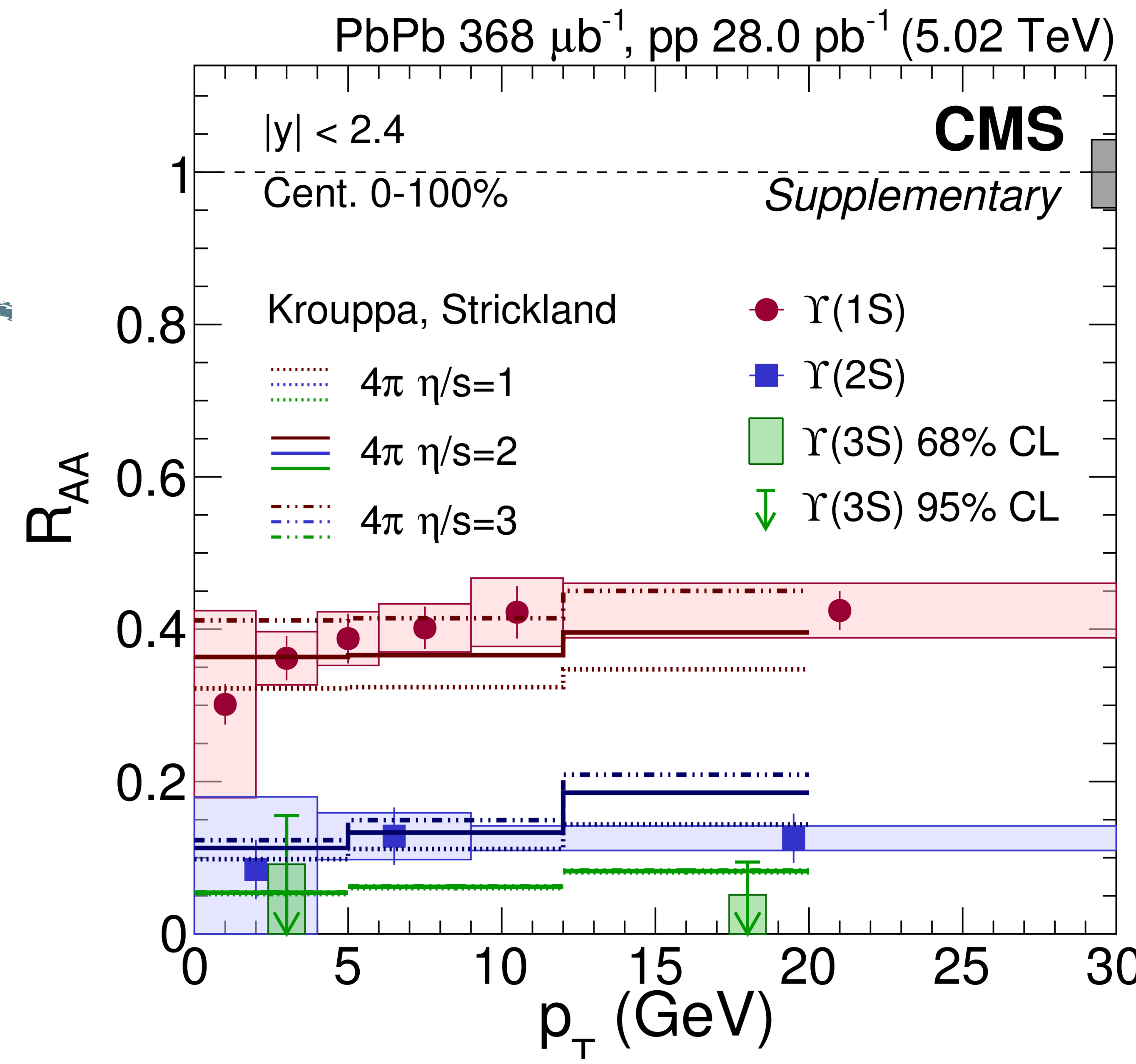
- **In small systems:**
  - Unexpected reduction of excited states over ground state observed for increasing event activity both in pp and pPb

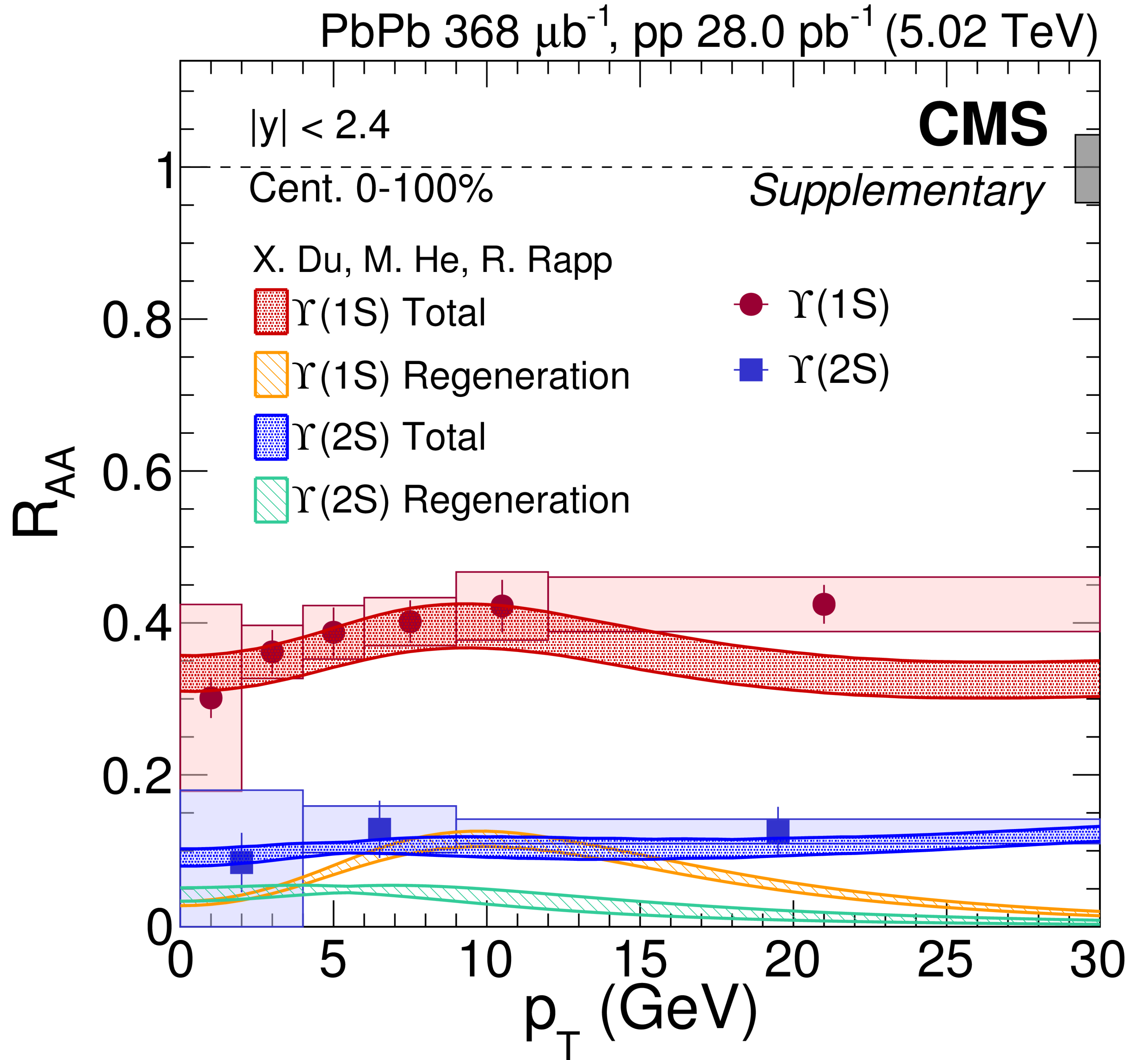
BACKUP

Cross Sections vs p_T



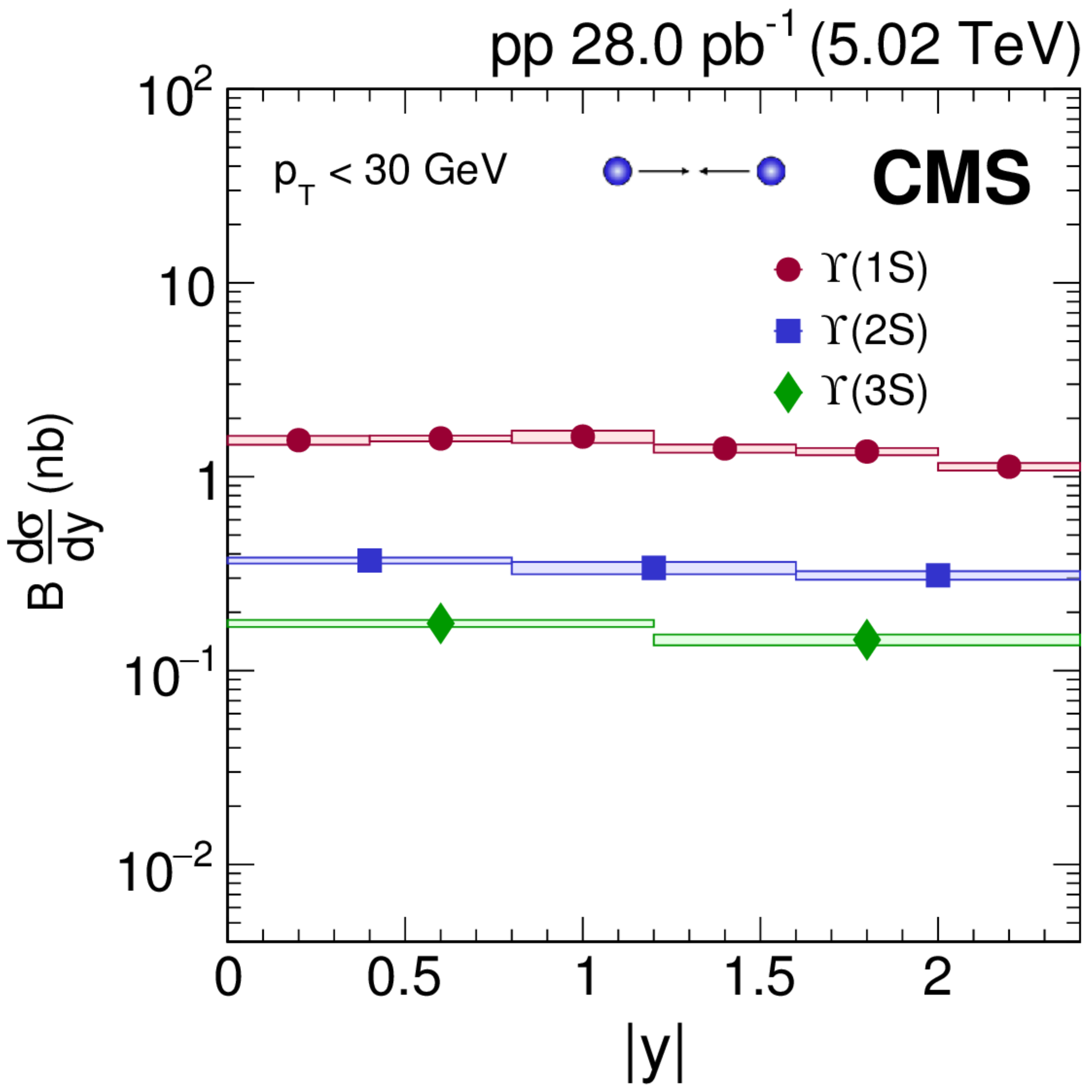


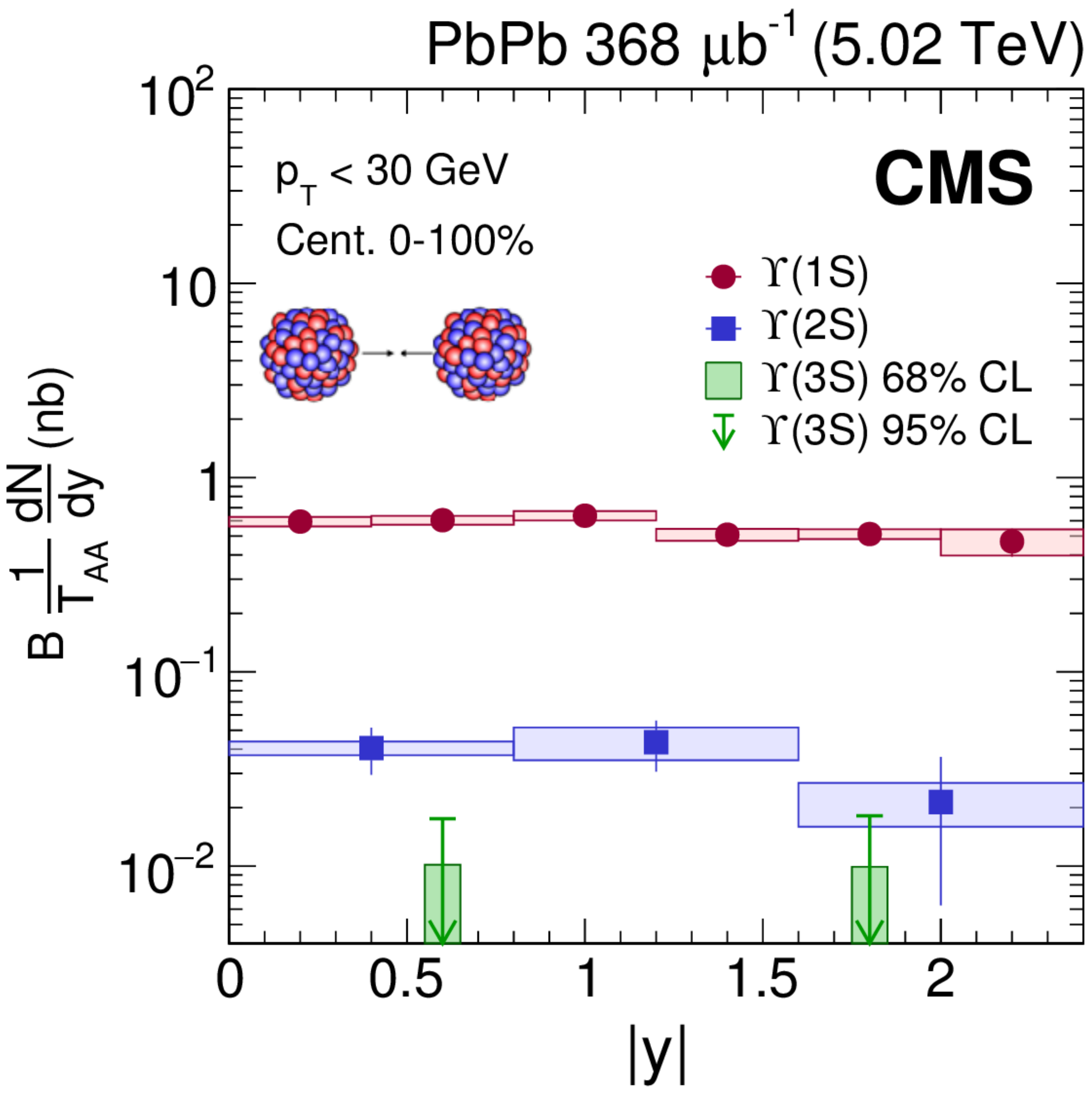


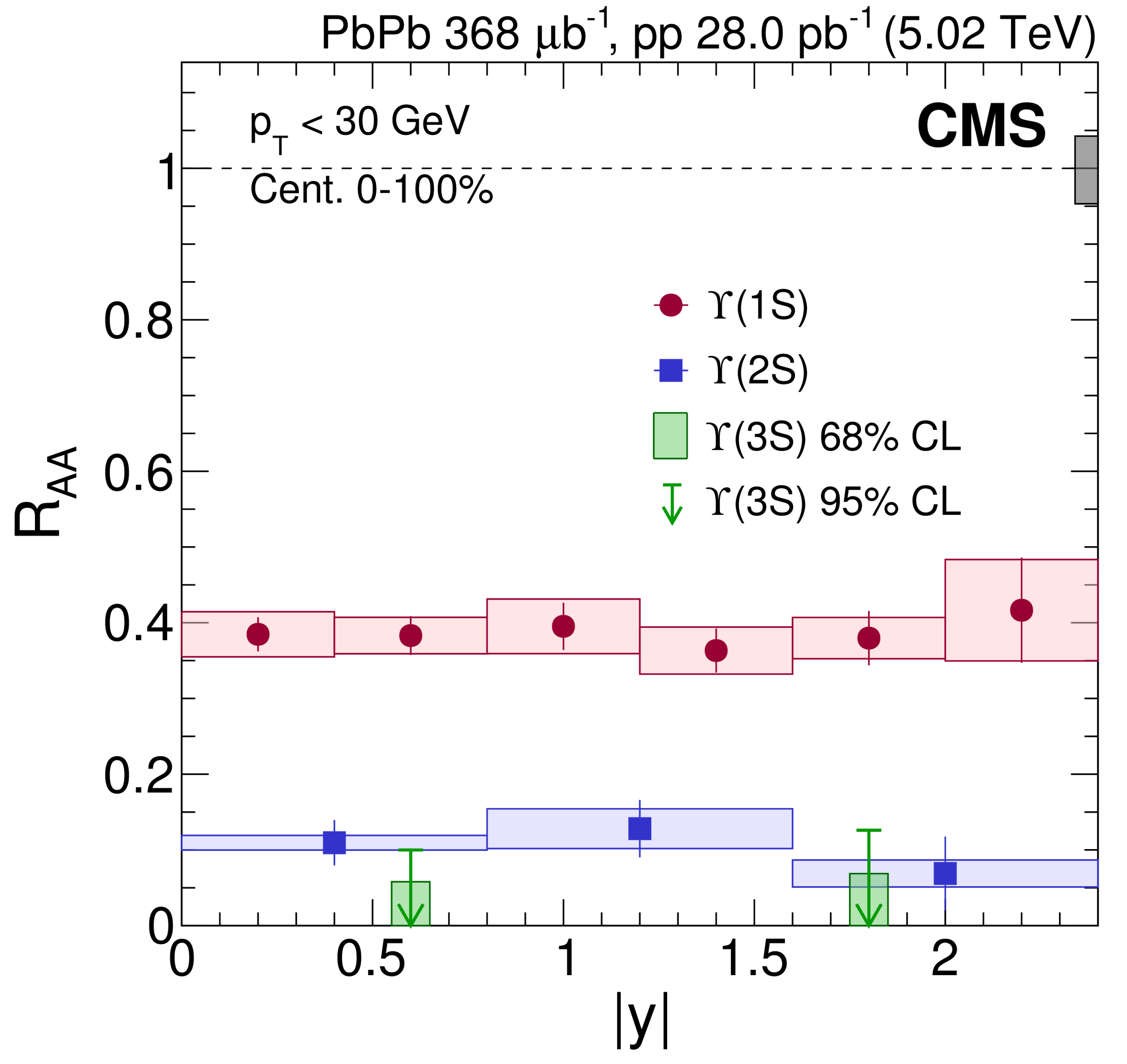


$$B\frac{d^2\sigma}{dp_T dy} = \frac{N_\Upsilon/(\mathcal{A}\,\varepsilon)}{\mathcal{L}_{\rm Int}\Delta p_T \Delta y}$$

Cross Sections vs |y|



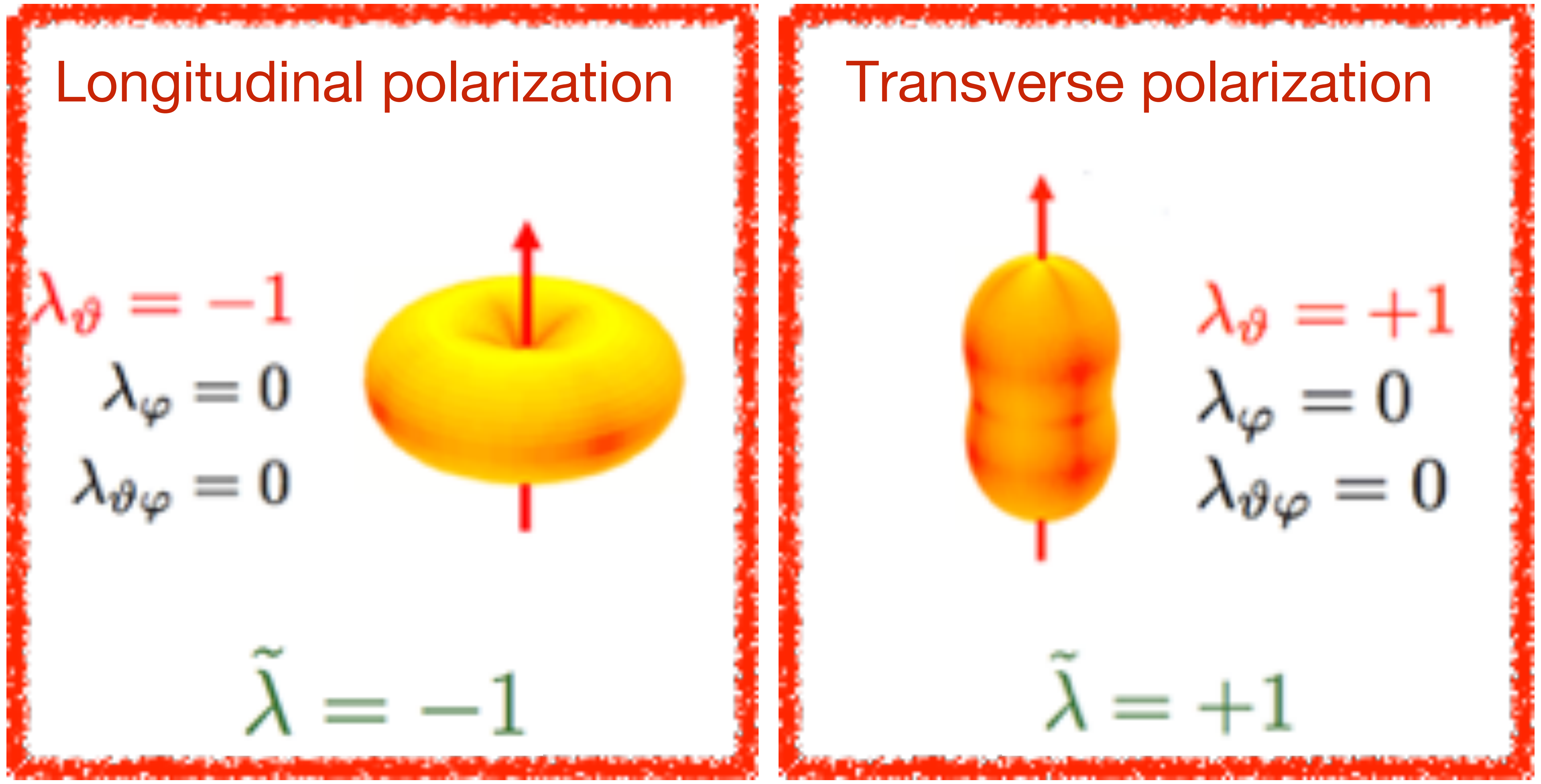




$$B\frac{d^2\sigma}{dp_T dy} = \frac{N_\Upsilon/(\mathcal{A}\,\varepsilon)}{\mathcal{L}_{Int}\Delta p_T \Delta y}$$

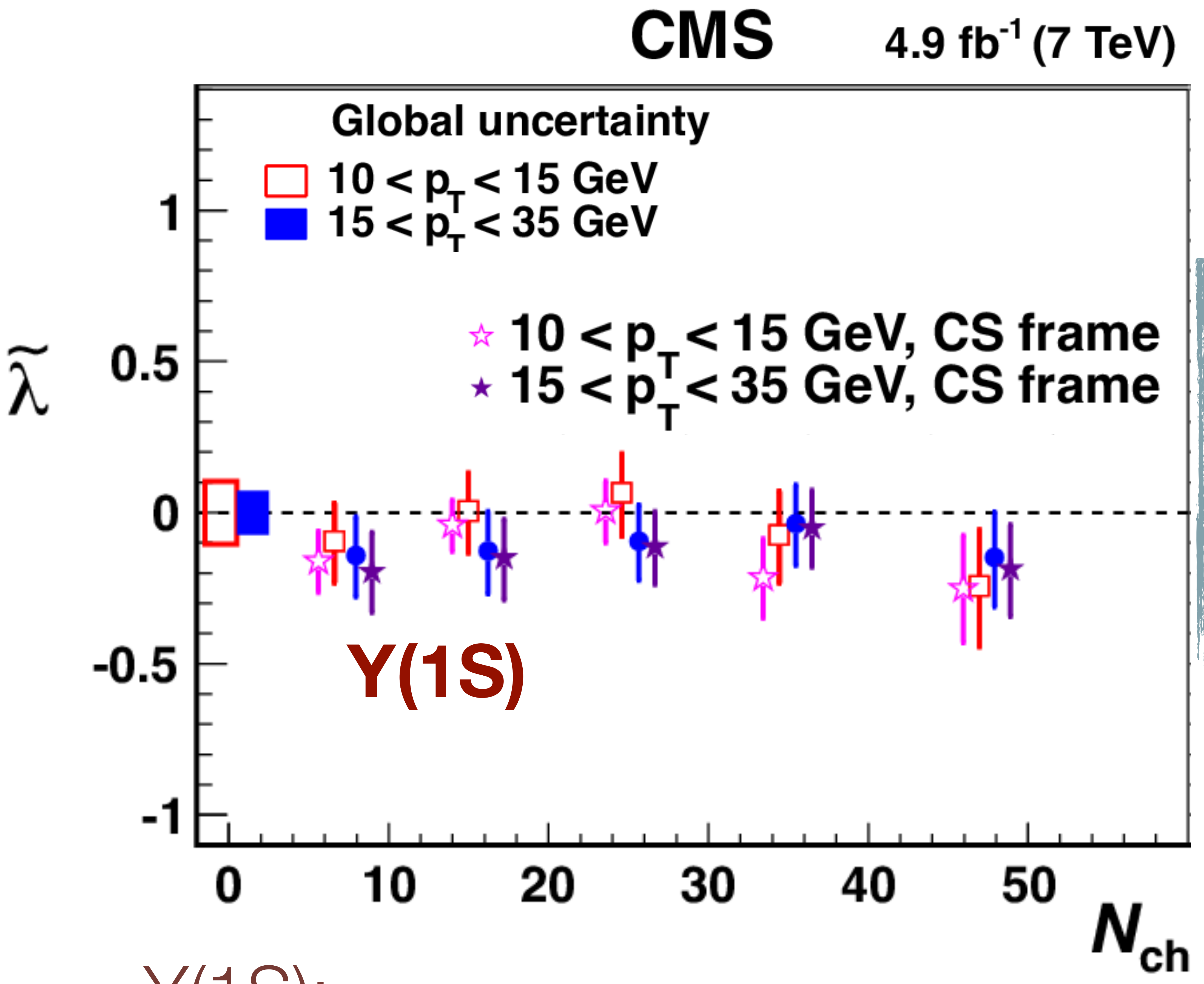
Υ(1S) polarization vs N_{ch} in pp collisions

Extreme decay distributions:



$$\tilde{\lambda} = \frac{\lambda_\vartheta + 3\,\lambda_\varphi}{1 - \lambda_\varphi}$$

The shape of the function is invariant and can be characterised in every frame by an invariant parameter.



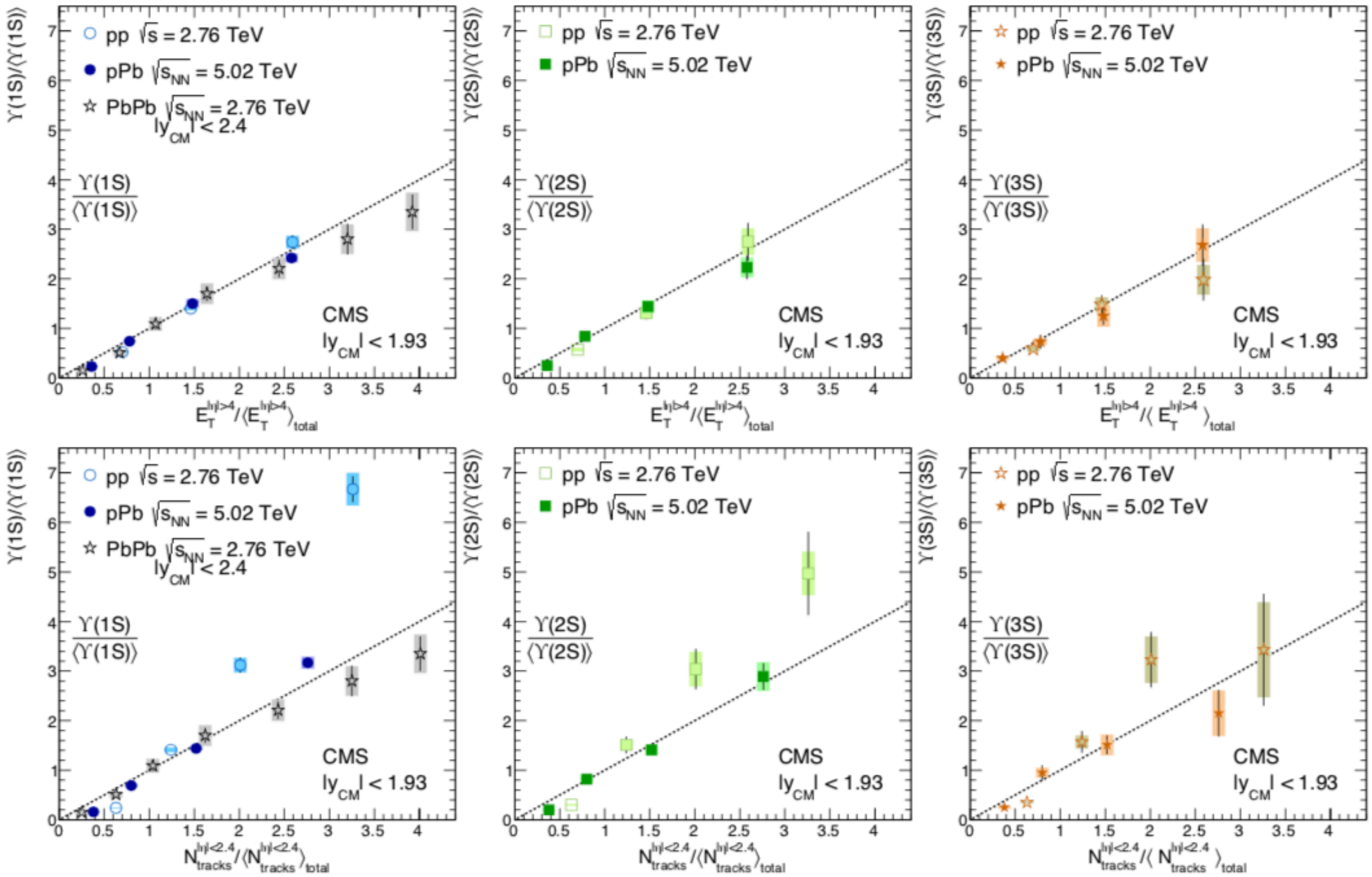
PLB 761 (2016) 31

Υ(1S):

- λ parameters close to 0
- Unpolarized production
- No dependence with N_{ch}

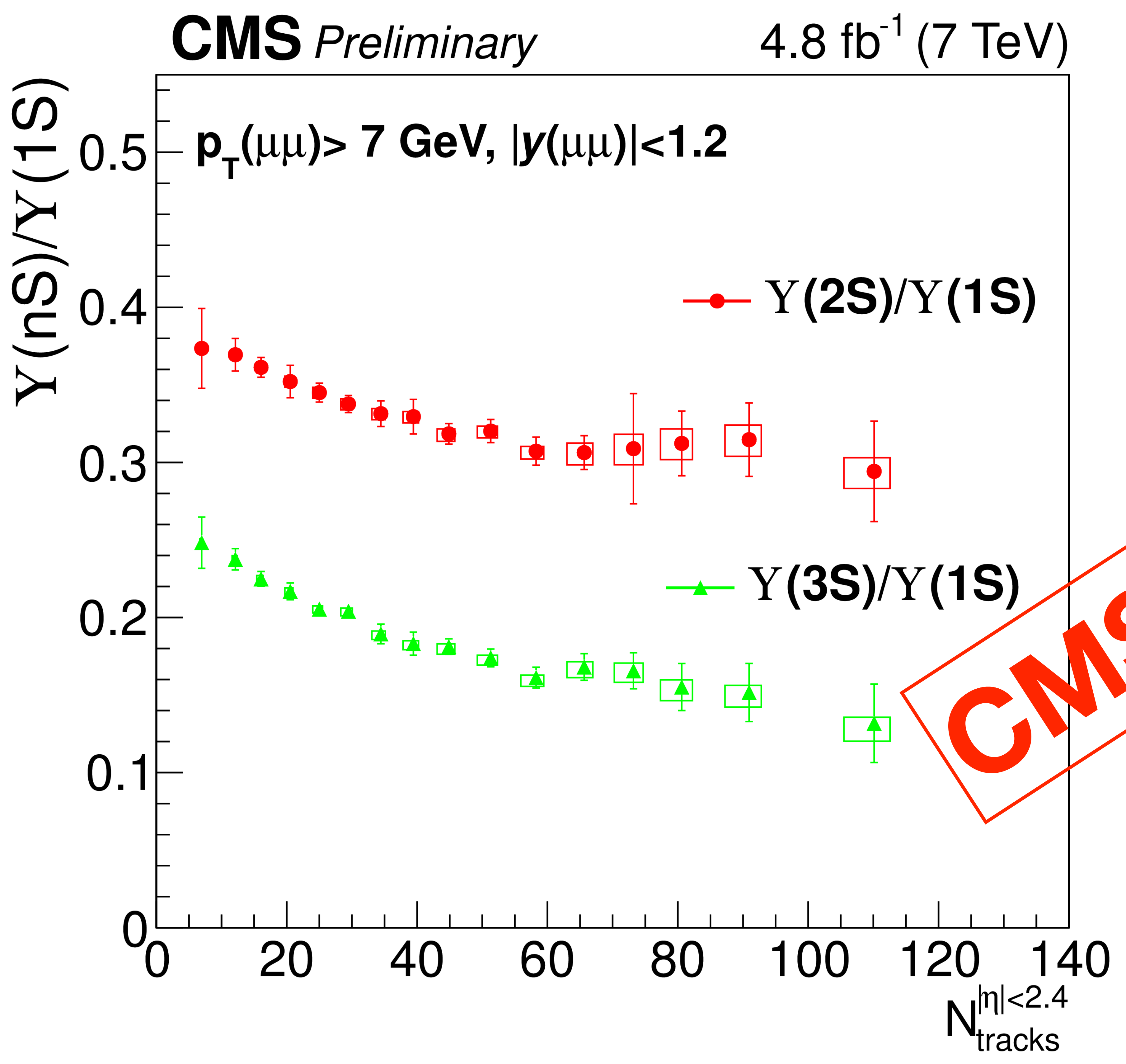
Event activity dependence of Υ(nS) production: self-normalised ratios

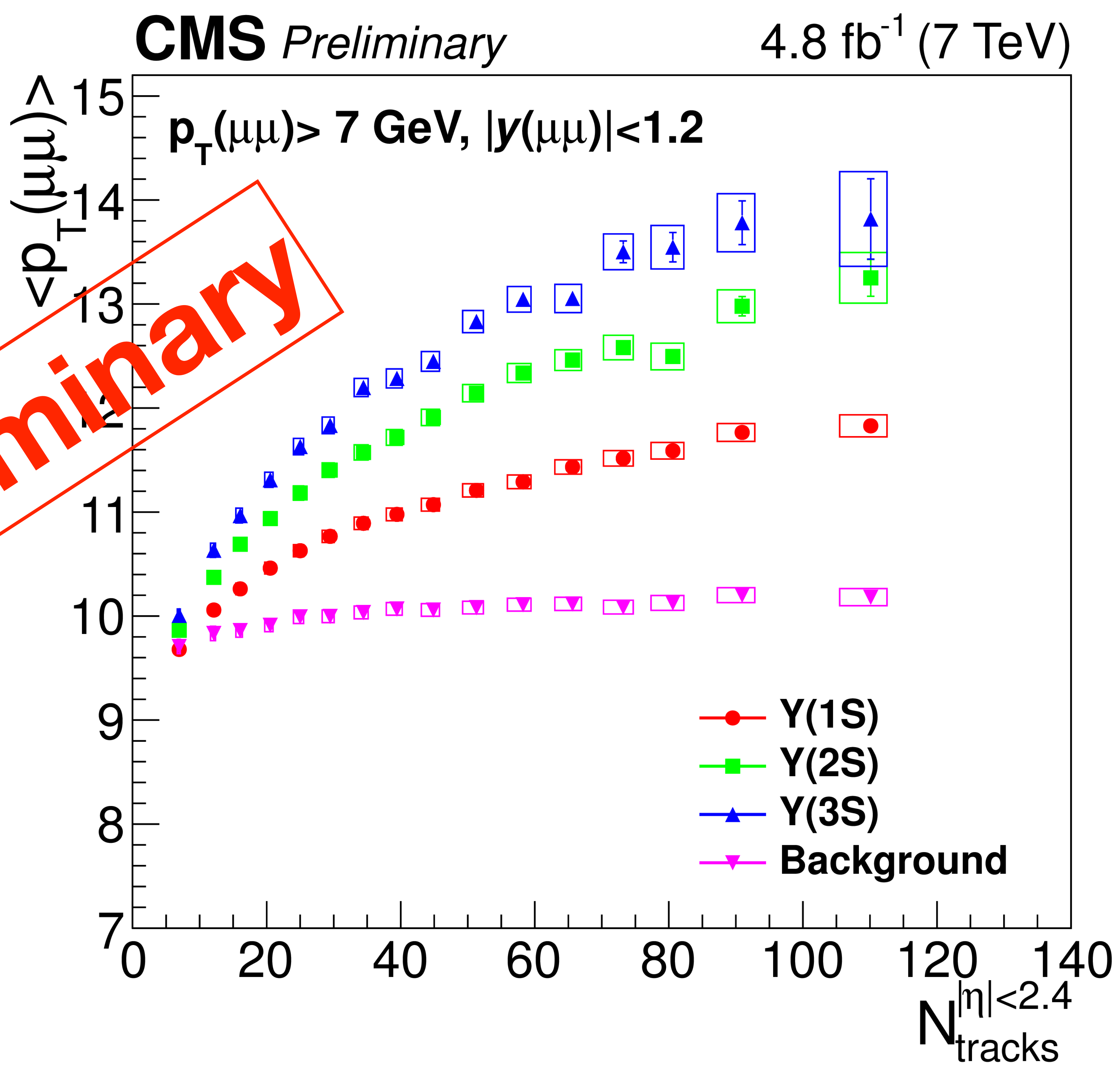
JHEP 04 (2014) 103



Multiplicity dependence of Single Ratios in pp at 7 TeV

CMS PAS BPH-14-009





- Full 2011 pp dataset at 7 TeV (with still low PileUp)
- Decrease of the excited-to-ground-states vs multiplicity is found, up to 45% for Υ(3S)/Υ(1S)
- Mean p_T increases with multiplicity
- Hierarchical structure as a function of mass observed also for pions, kaons and proton at LHC