Beauty spectrum measurements based on Quark Matter 2022

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Outline

- Heavy flavors in heavy ion collisions
- J/ψ production in jets in p+p collisions at $\sqrt{s}$ = 500 GeV
- Summary

Heavy flavors in heavy ion collisions

Qipeng Hu' talk

Introduction

- Open heavy flavors (HF) quarks — ***c, b*** — are *produced early* in the collision; *masses above QGP temperature*
- HF in heavy ion collisions are sensitive probe to **energy loss mechanisms** and QGP transport property
- HF pair angular correlation have additional sensitivity to QGP-induced angular deflection

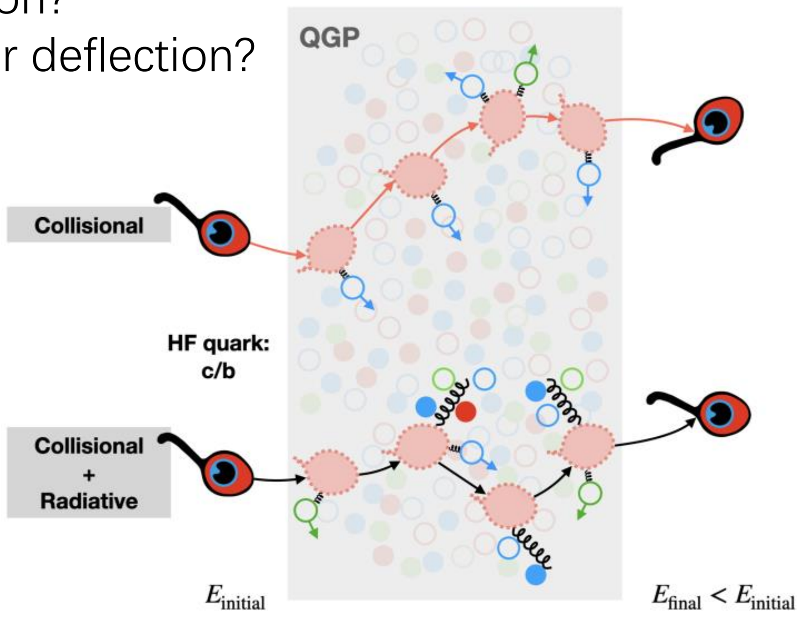
What is the temperature at LHC ?

Open heavy flavors?

Why are sensitive probe?

pair angular correlation?
QGP-induced angular deflection?

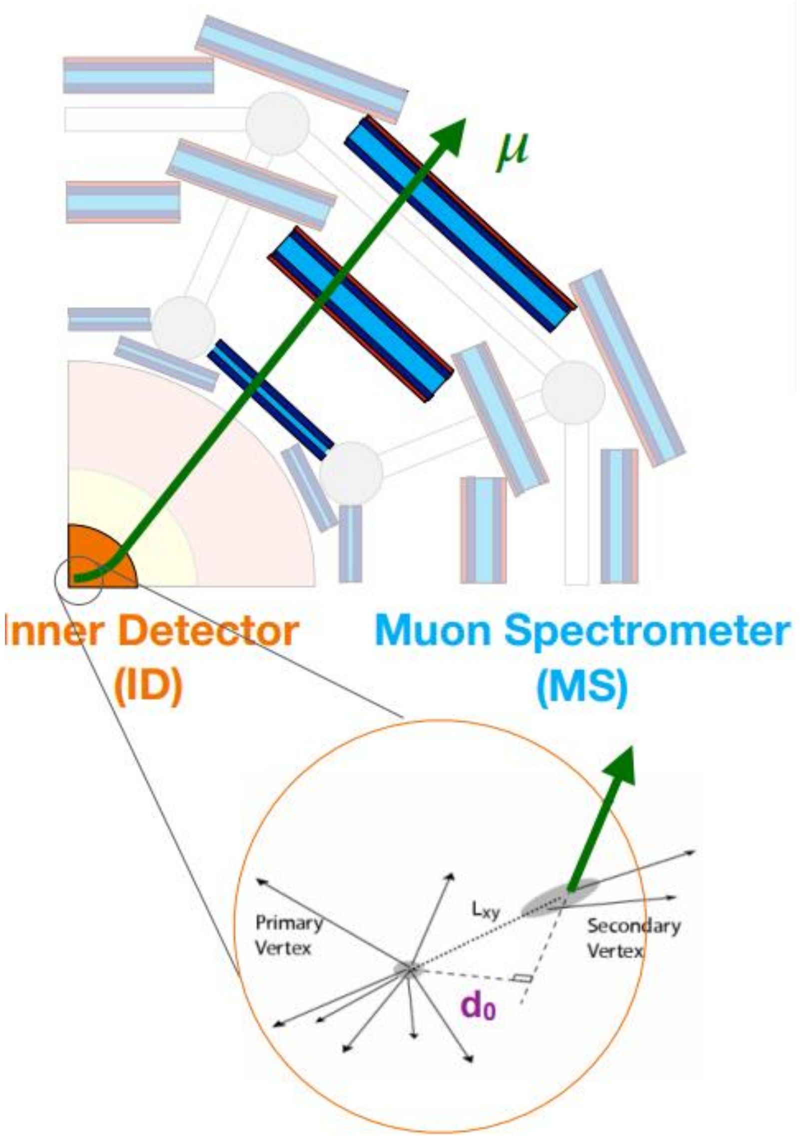
what is the different of open and solid circles?



Weakly interaction picture

2

ATLAS HF muon programs: Detectors



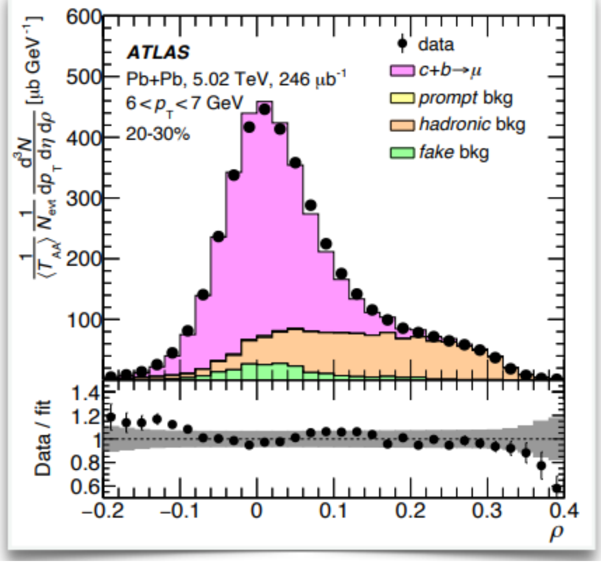
ATLAS HF program focuses on semi-leptonic decay to **muons**

ATLAS HF muon programs: Methods

Background removed using **ID-MS** momentum difference:

$$\rho = (p_T^{ID} - p_T^{MS})/p_T^{ID}$$

select c+b → μ

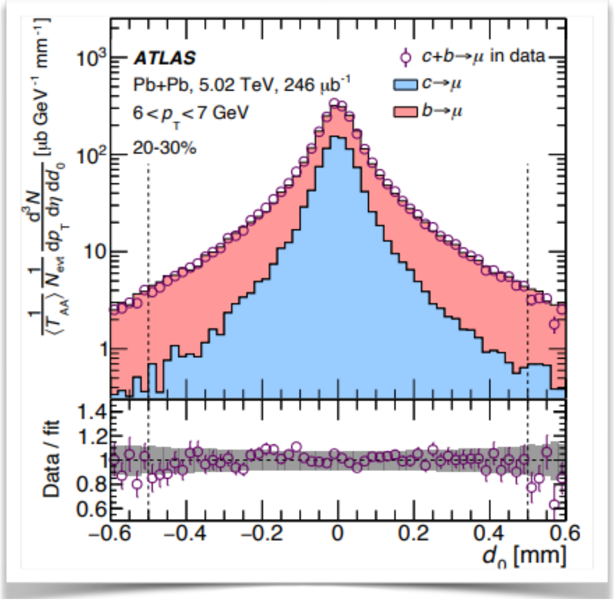


why the pT in ID and MS are different?

How to get the pT by MS detector ?

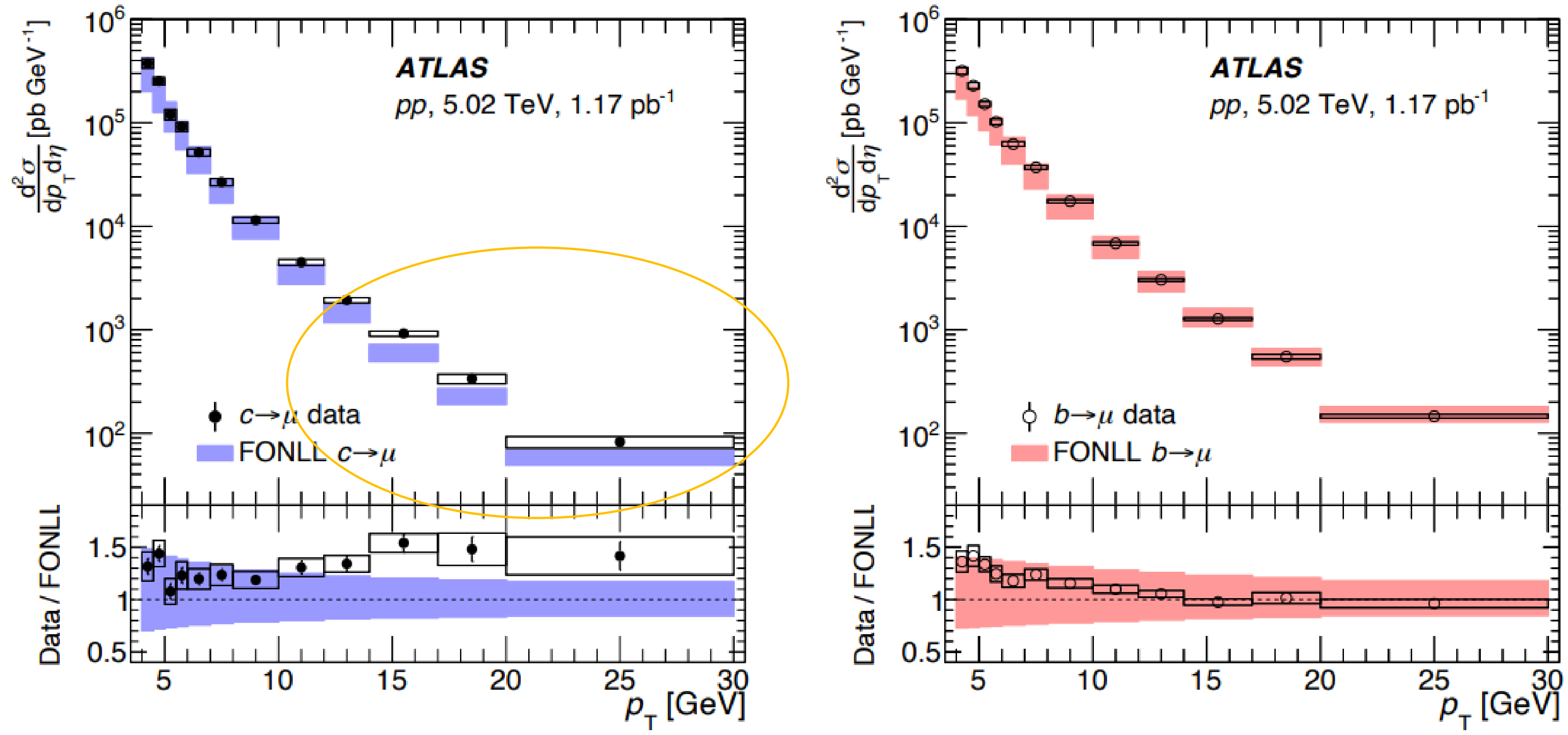
Charm / **bottom** separated via ID impact parameter (DCA): d_0

separated c → μ and b → μ



How to separate the Charm/bottom to muon by d0?

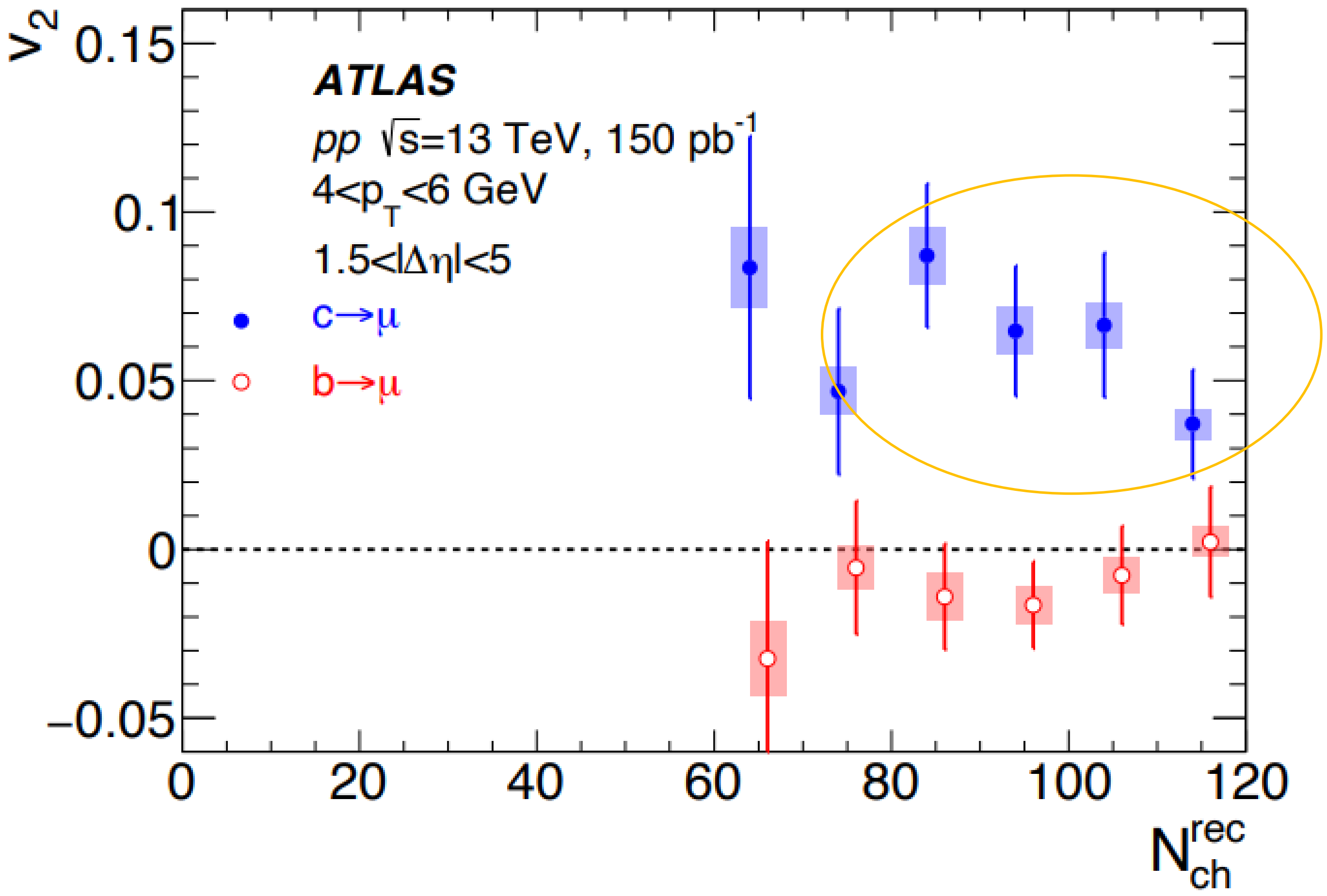
HF production in pp collisions



Charm muon **Bottom muon**

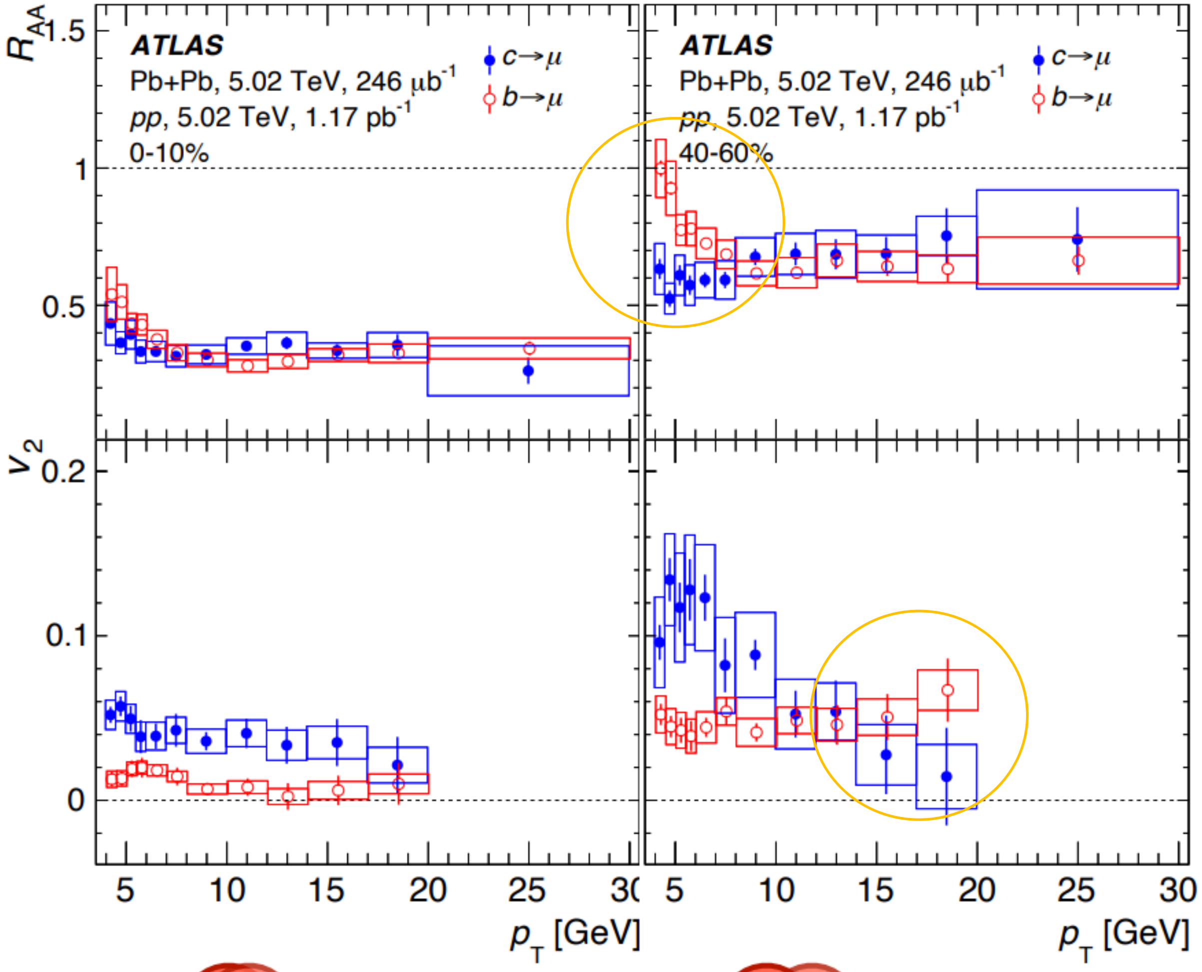
- Charm muon: data lay at the upper boundary of FONLL uncertainty
- Bottom muon: data agree with FONLL

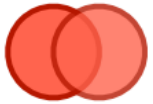
HF azimuthal anisotropy in pp collisions



- Significant azimuthal anisotropy for charm muon in high multiplicity *pp* events
- v_2(b) ~0. Charm and bottom difference is significant

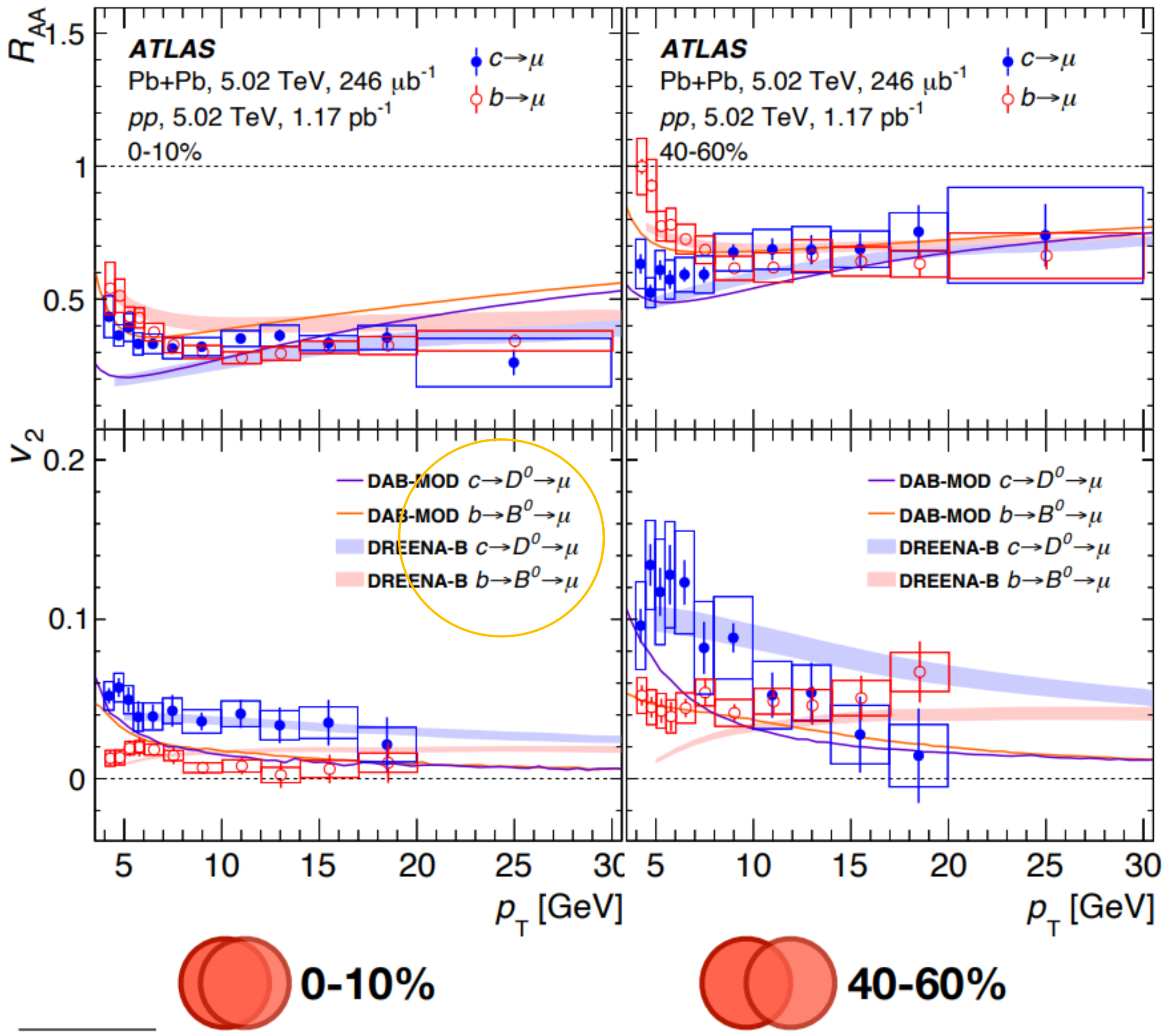
Charm and bottom muon R_{AA} vs v_2





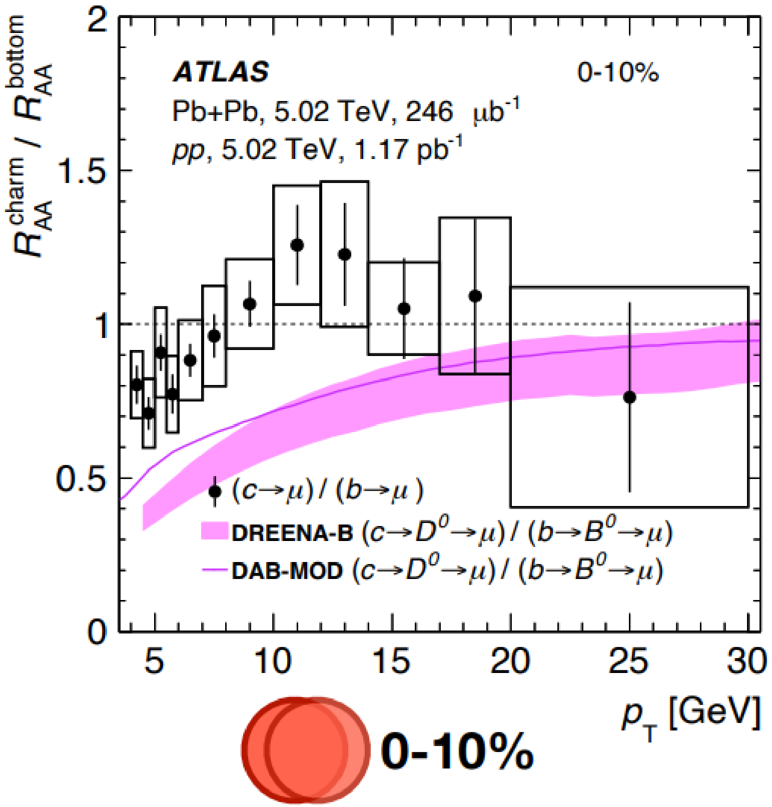
- $R_{AA}(c) < R_{AA}(b)$ at low p_T, insignificant difference above 10 GeV
- $v_2(c) > v_2(b)$
- Strong centrality dependence for R_{AA} and v_2

Charm and bottom muon R_{AA} vs v_2



- **DAB-MOD** Langevin
- **DREENA-B** dynamical radiative + collisional E_{loss}

Charm to bottom double ratio



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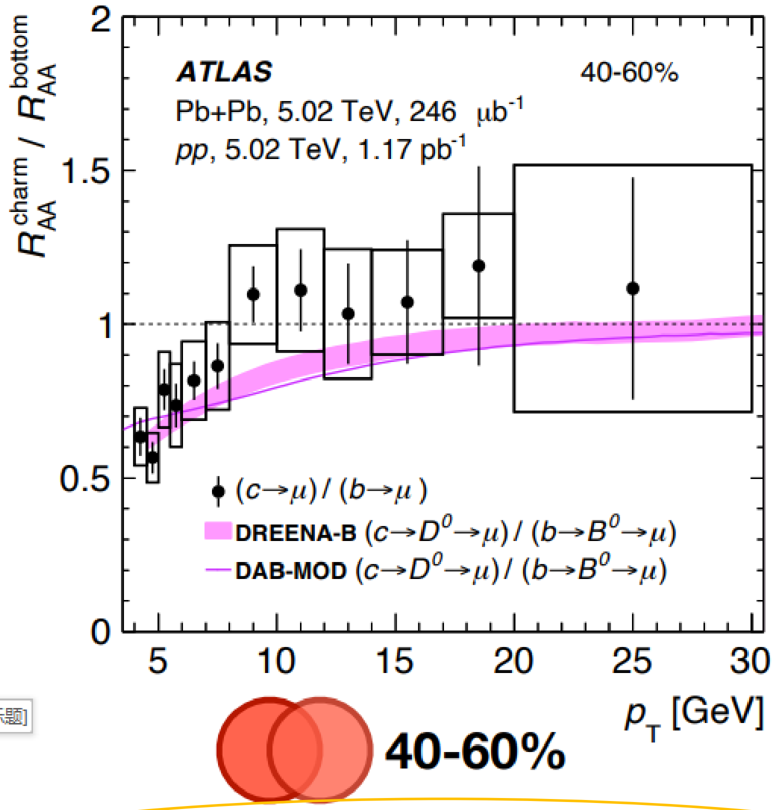
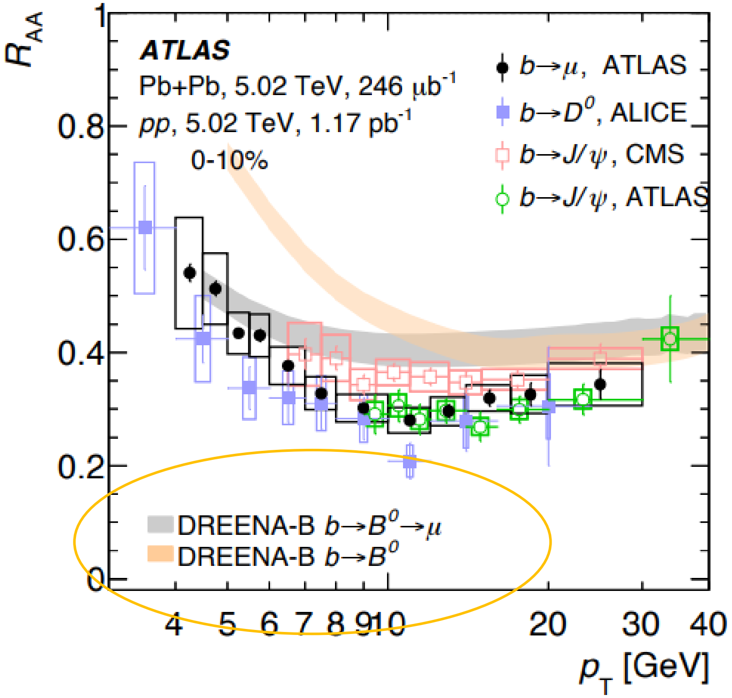
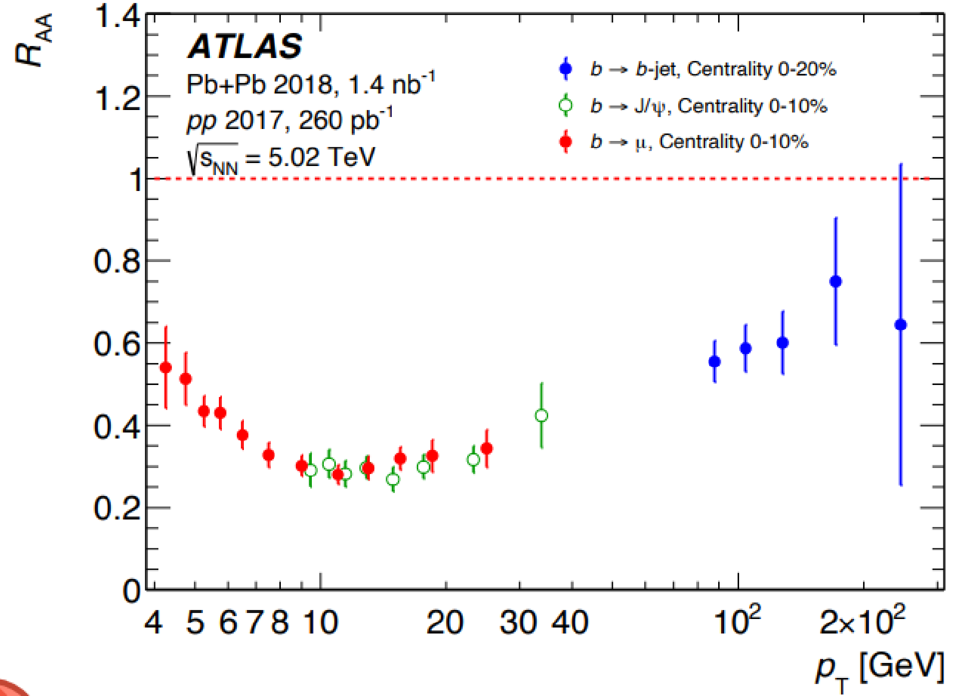


- Large uncertainties due to strong anti-correlation between charm and bottom
- **Charm is more suppressed than bottom** at low p_T; comparable at high p_T
- In radiation picture: mass hierarchy inline with “dead-cone” effect

Comparison (bottom R_{AA})

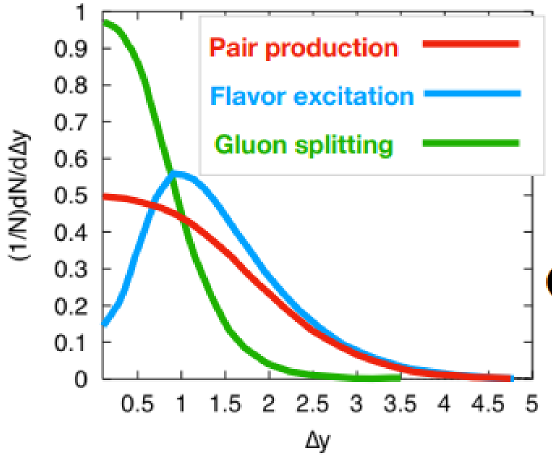




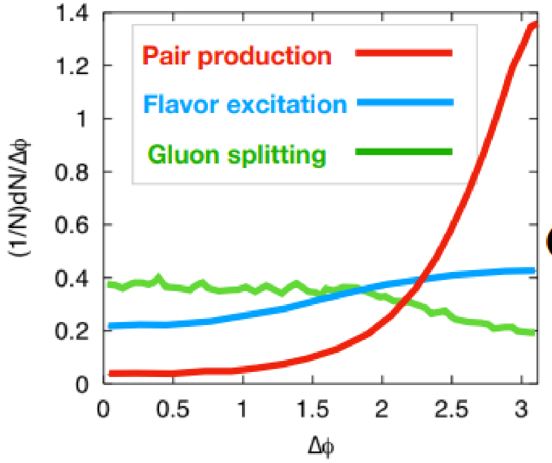
0-10%

- B-decay (muon, D^0, J/ψ) in 0-10% in comparison to **DREENA-B**
- B-decay and (muon-tagged) b-jet show smooth trend in wide p_T range

HF muon pair selection



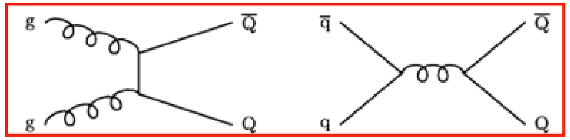
Rapidity Correlation



Azimuthal Correlation

$b - \bar{b}$ correlation at 2 TeV from **pQCD**

using $|\Delta\eta|$ and $\Delta\phi$ to select Pair production



Ideal probe for QGP induced angular broadening: **back-to-back** muon pairs from LO pair production processes

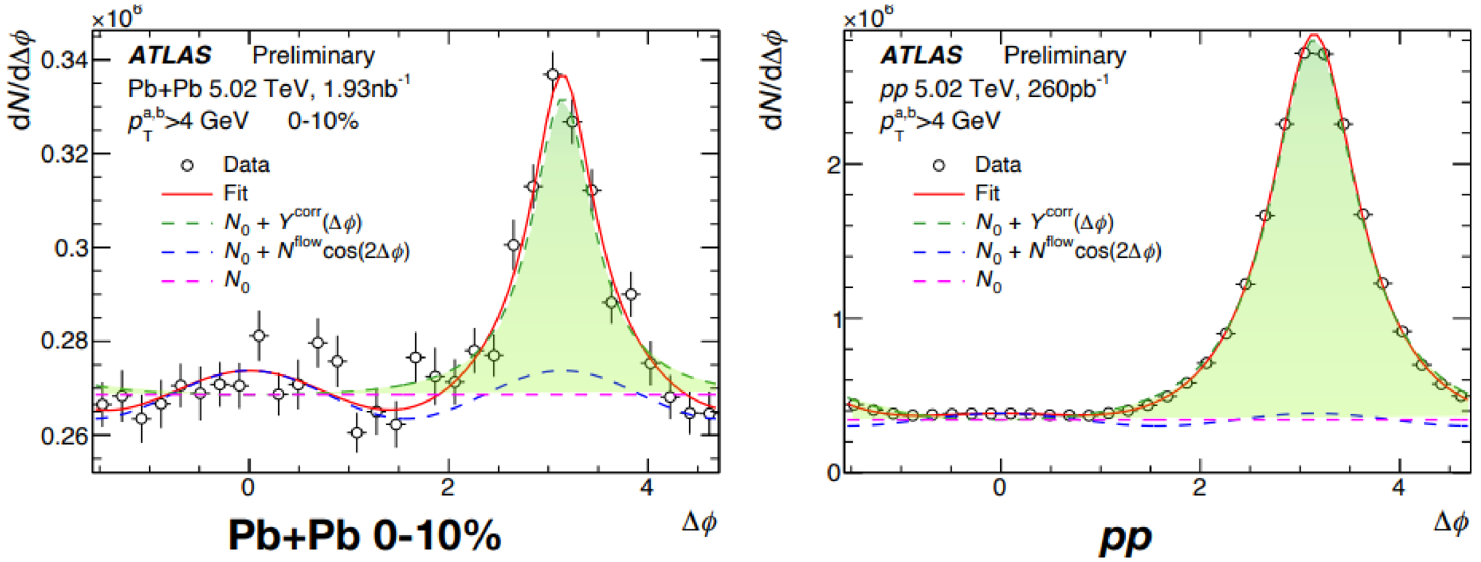
Rapidity gap between two muons: $|\Delta\eta| > 0.8$

- Suppress HF-bkg contribution from jets
- Suppress gluon splitting contribution

Azimuthal correlation at $\Delta\phi \sim \pi$:

- Back-to-back pair production
  - Contribution of flavor excitation
  - Small non-HF bkg contamination

Back-to-back yield extraction



存在QGP会怎么样？变宽？

$$dN/d\Delta\phi = N_0 + N^{\text{flow}}\cos(2\Delta\phi) + Y^{\text{corr}}(\Delta\phi)$$

Yields with no azimuthal correlation

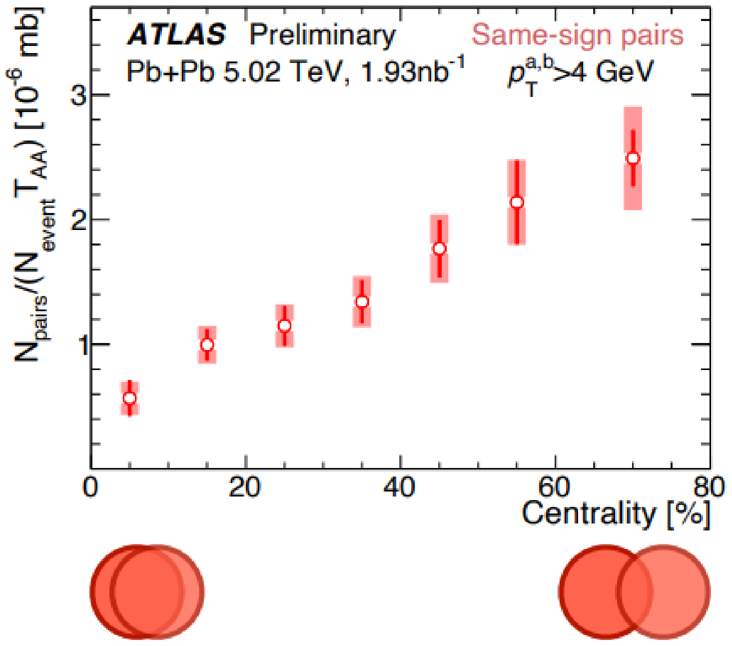
Collective flow modulation

Back-to-back correlation yields Lorentzian

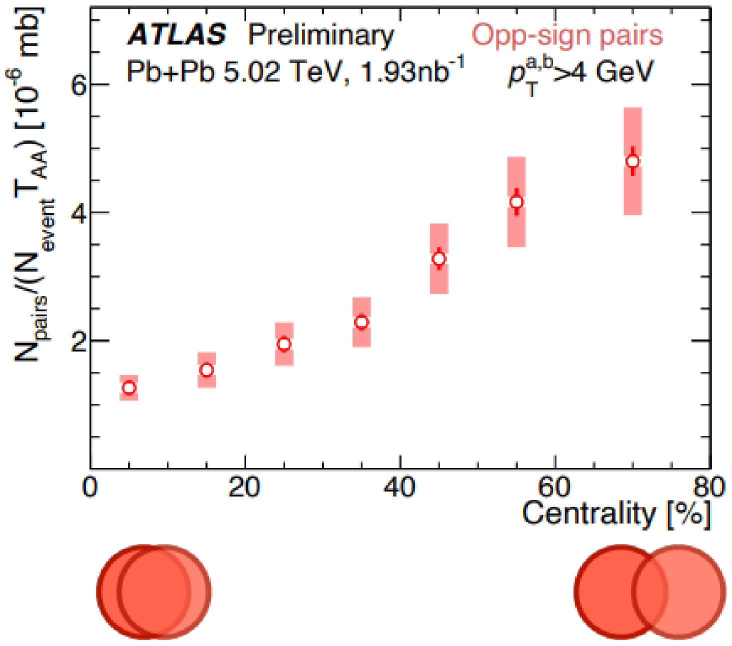
- Correlated yields and its width (std deviation) are extracted
- Separately for same-sign ($b\bar{b}$) and opposite-sign ($c\bar{c} + b\bar{b}$) HF pairs

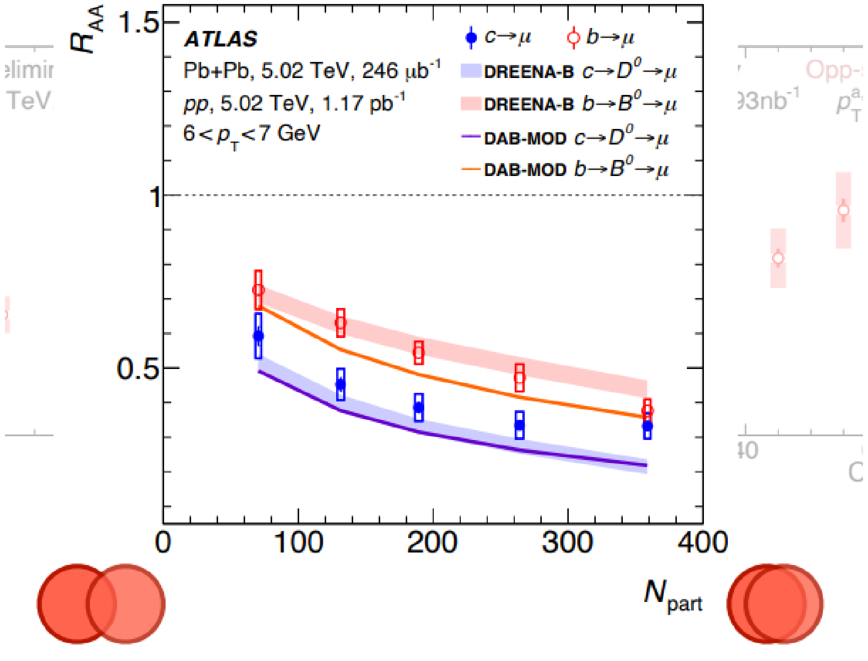
HF pair azimuthal correlation -- yields

Same-sign ($b\bar{b}$)



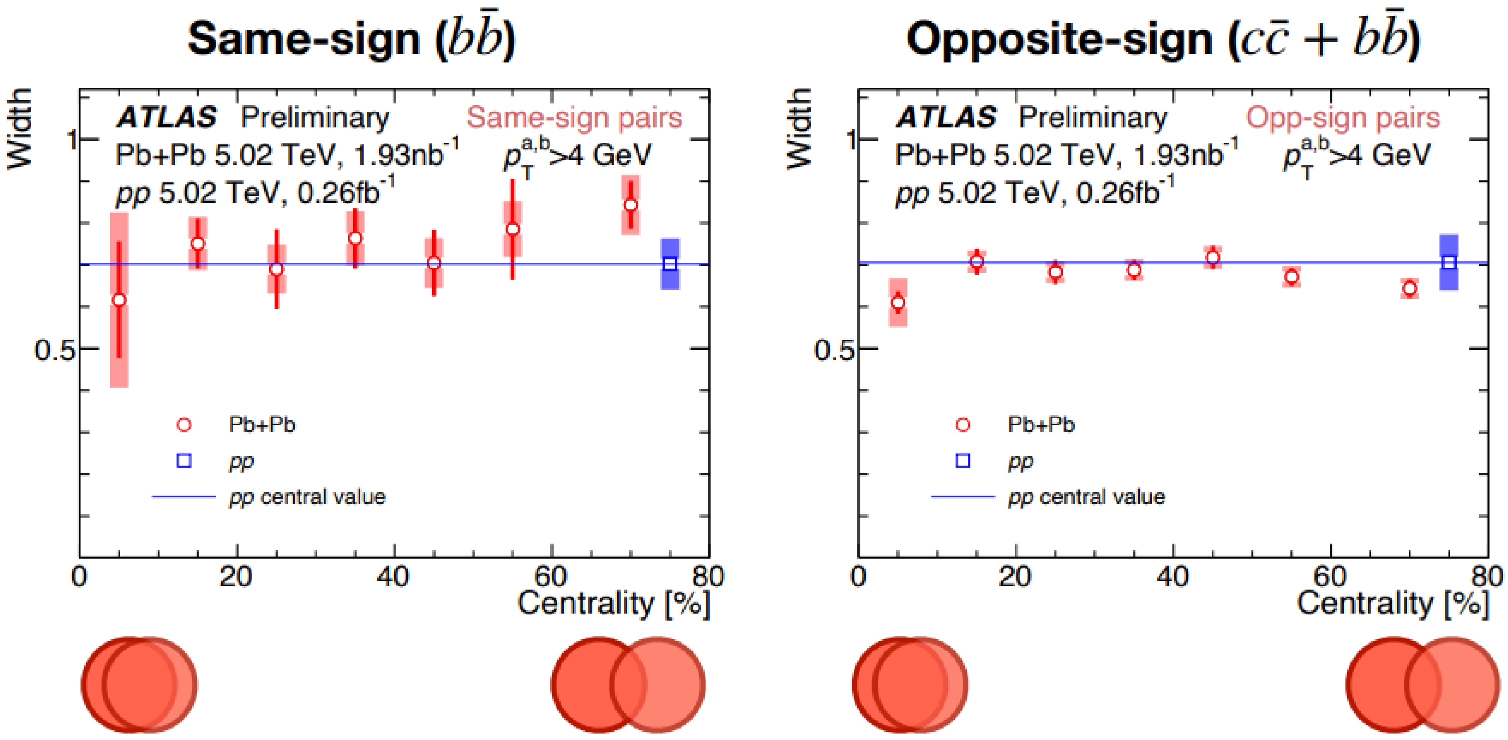
Opposite-sign ($c\bar{c}$ + $b\bar{b}$)





- Stronger suppression on back-to-back HF pair production in central wrt. peripheral
- Same-sign and Opposite-sign pairs have similar trend

HF pair azimuthal correlation -- width



- Comparable width between different centralities and between Pb+Pb and *pp*
- Centrality-independent width indicates small angular deflection. In weakly interaction picture: important role of radiative energy loss

Bottomonium in heavy ion collisions

Soohwan and Alexandre' talk

Introduction

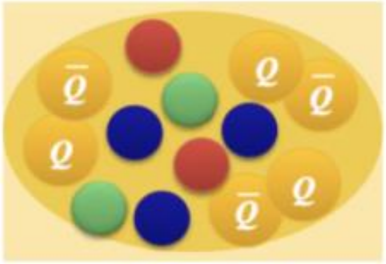
- Bottomonia are good probes to study the QGP

☑ Produced mostly from initial hard scattering

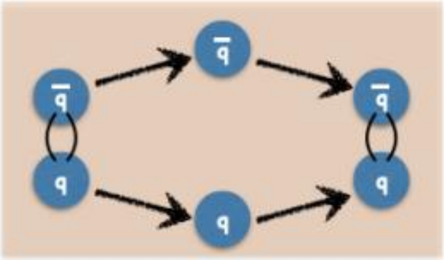
☑ In medium effects

(color screening, gluo-dissociation, recombination)

❖ Uncorrelated



❖ Correlated



QGP-like signatures have been observed in small systems, even in pp

- Event multiplicity dependencies

In nucleus-nucleus collisions:

- The three Υ states have similar kinematics, but different binding energies.
  -> QGP "thermometer" (sequential melting).
- Very different non-prompt fraction and regeneration compared to charmonia.

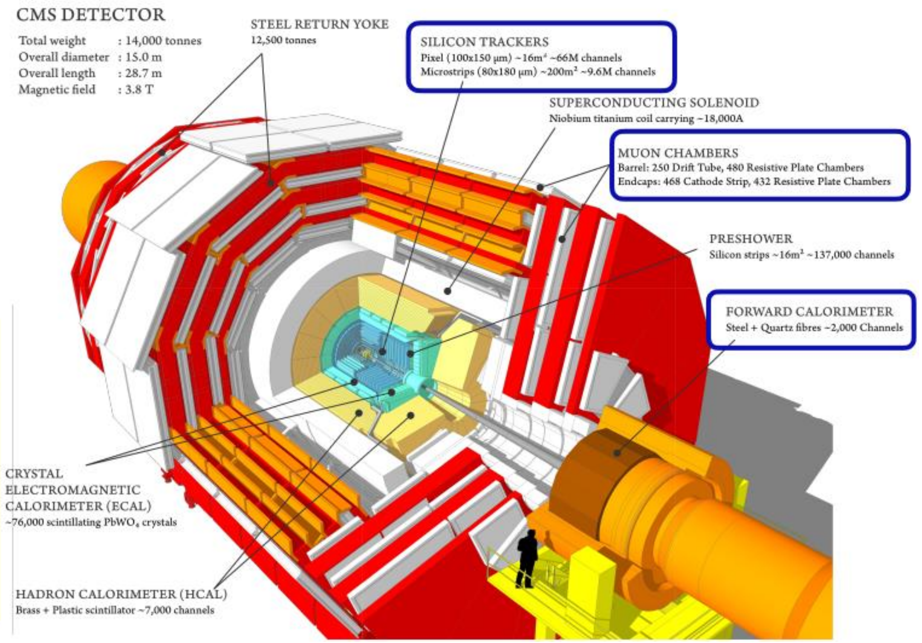
The CMS (Compact Muon Solenoid) detector

$$\Upsilon \rightarrow \mu^{+}\mu^{-}$$

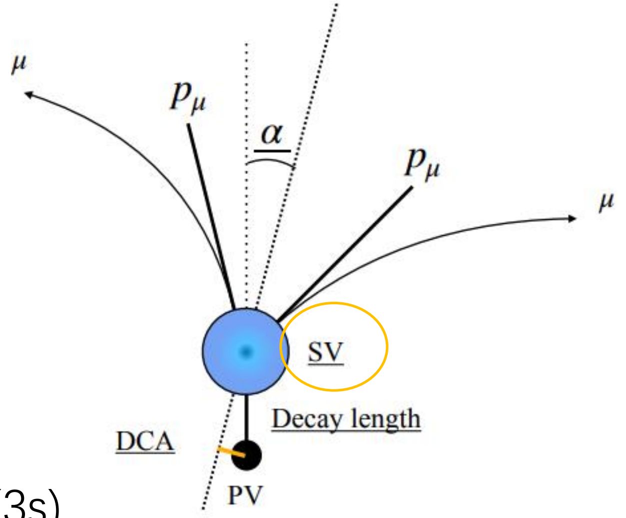
The CMS is the perfect detector for bottomonium measurement in HI collisions.

- Wide range of muon, ($> \mathcal{O}(100)$ GeV)
- Good momentum resolution
- Large cover of muon reconstruction ($0 < \phi < 2\pi$, $|\eta| < 2.4$)

The CMS detector



- Signal enhancement with MVA selection(BDT) for PbPb data
  - Signal(MC) and background (side band data) classification
    - Pointing angle α,
    - Distance to closest approach (DCA),
    - Vertex related information



Full width:

- J/ψ: 92.9 keV
- Υ: 54keV(1s)/32.0keV(2s)/20.3(3s)

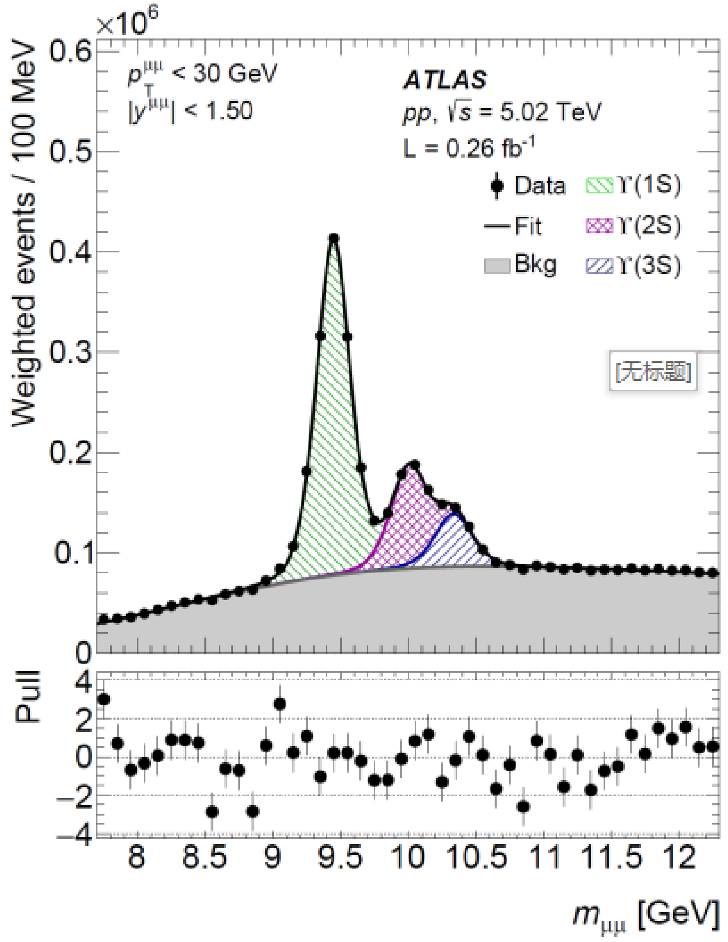
The ATLAS detector

Upsilons measured in di-muon channel at midrapidity

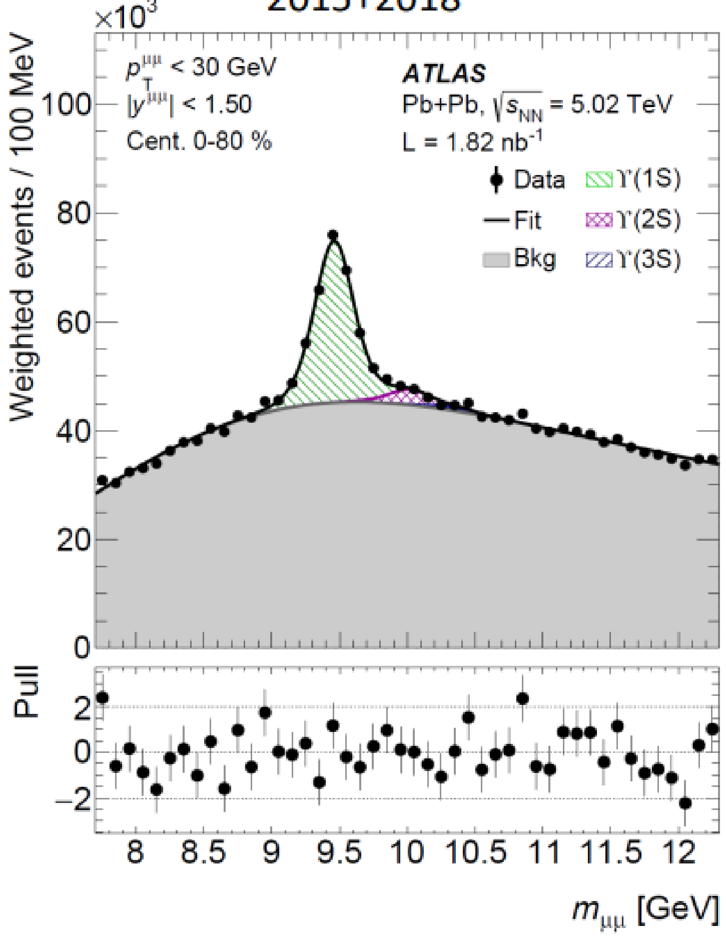
Υ kinematics:
p_T < 30 GeV
|y|<1.5
Centrality: 0-80%

Signal:
Crystal Ball + Gauss

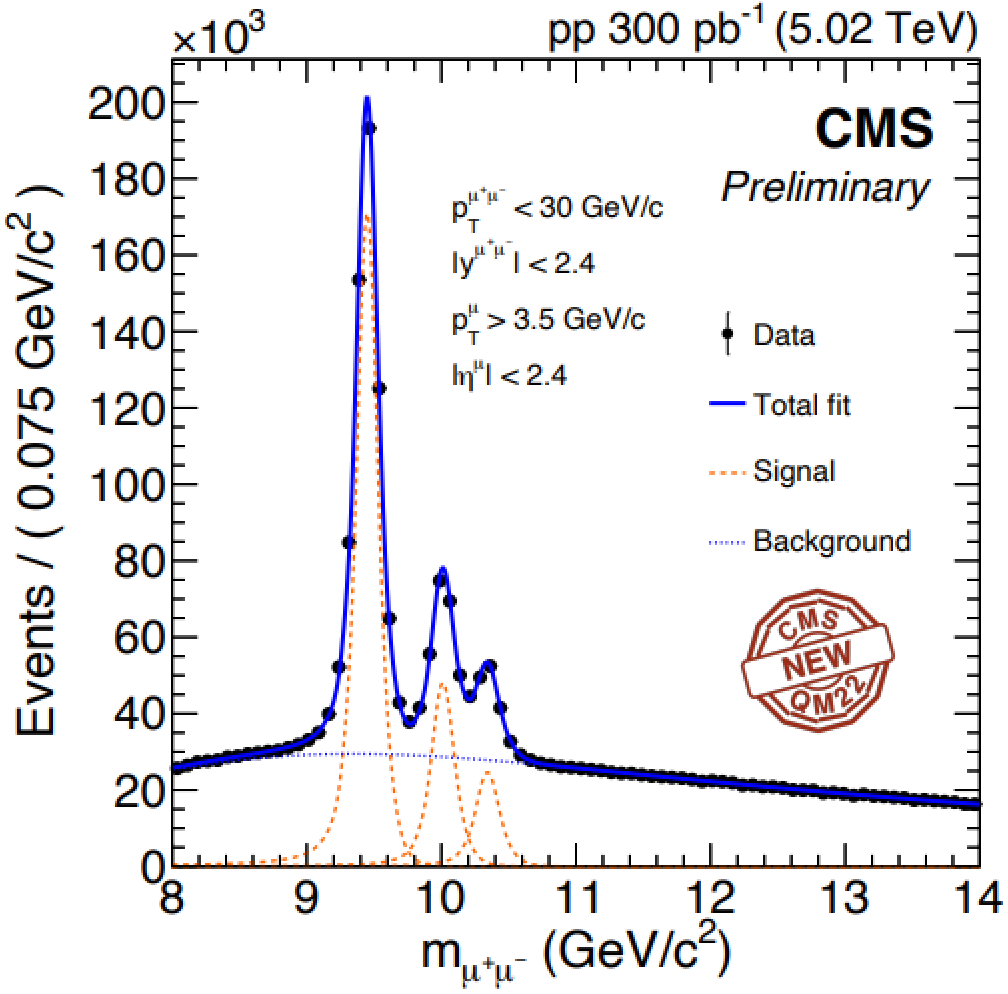
Background:
2nd order polynomial
or Erf*Exp

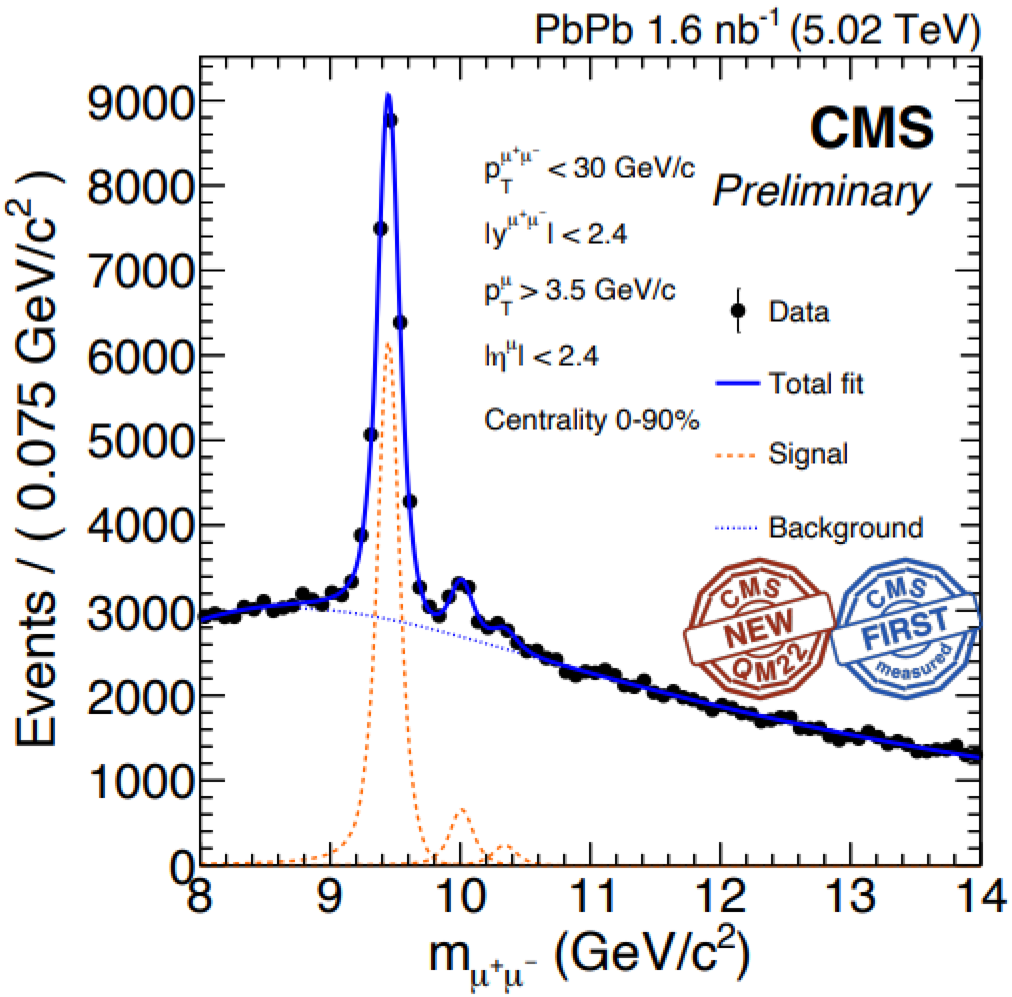


2015+2018



$\Upsilon(nS)$ signal extraction: CMS





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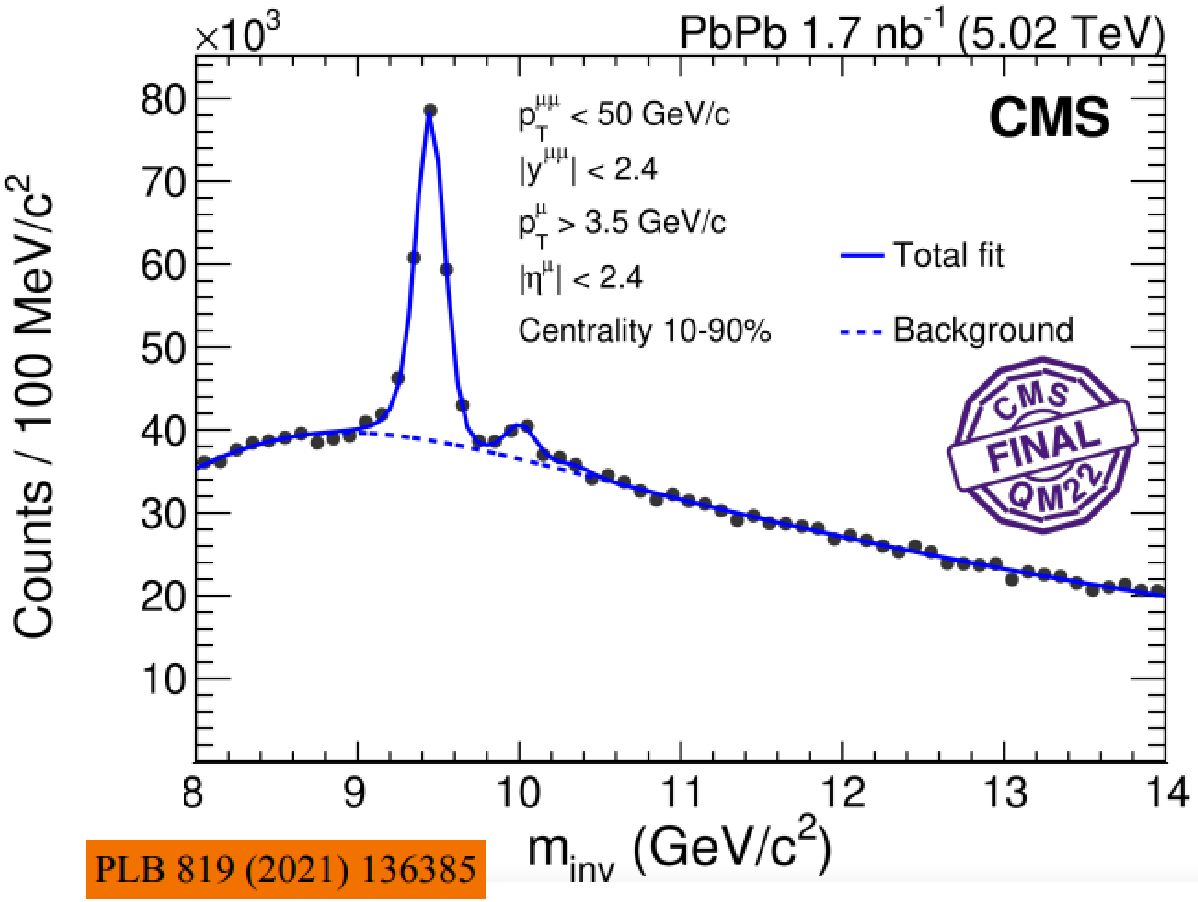
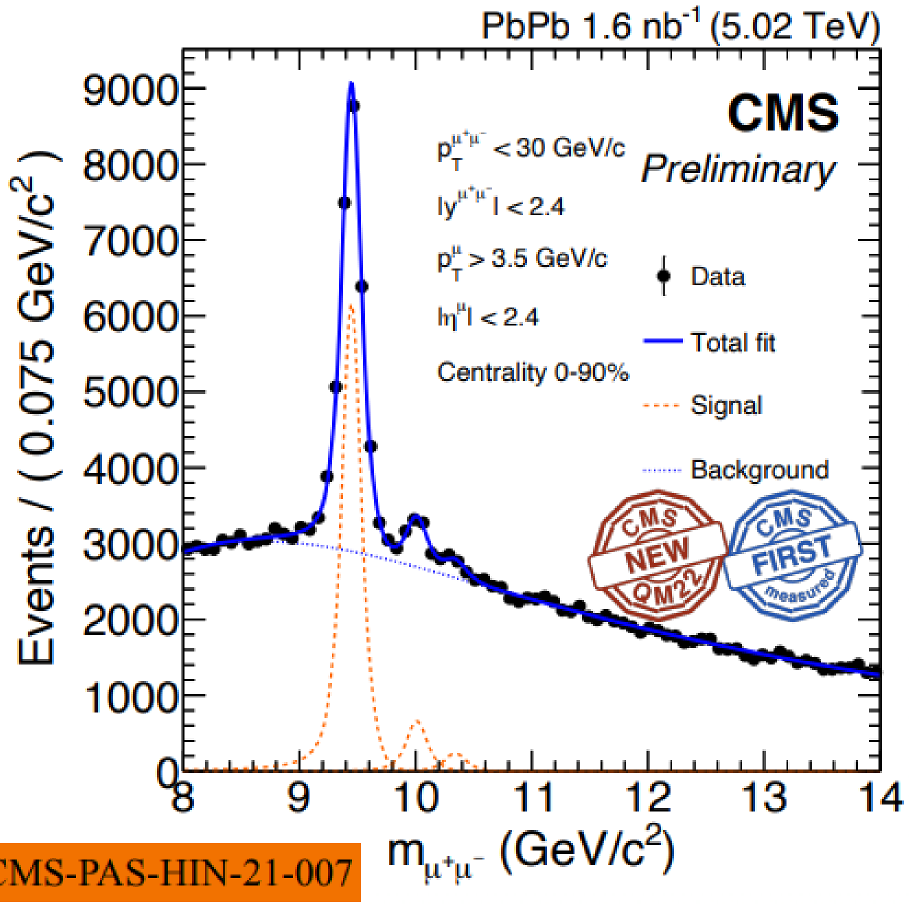
First Observation of Υ(3S) in AA collision($> 5\,\sigma$)!

$\Upsilon(nS)$ signal extraction: CMS

No MVA selection



PLB 819 (2021) 136385

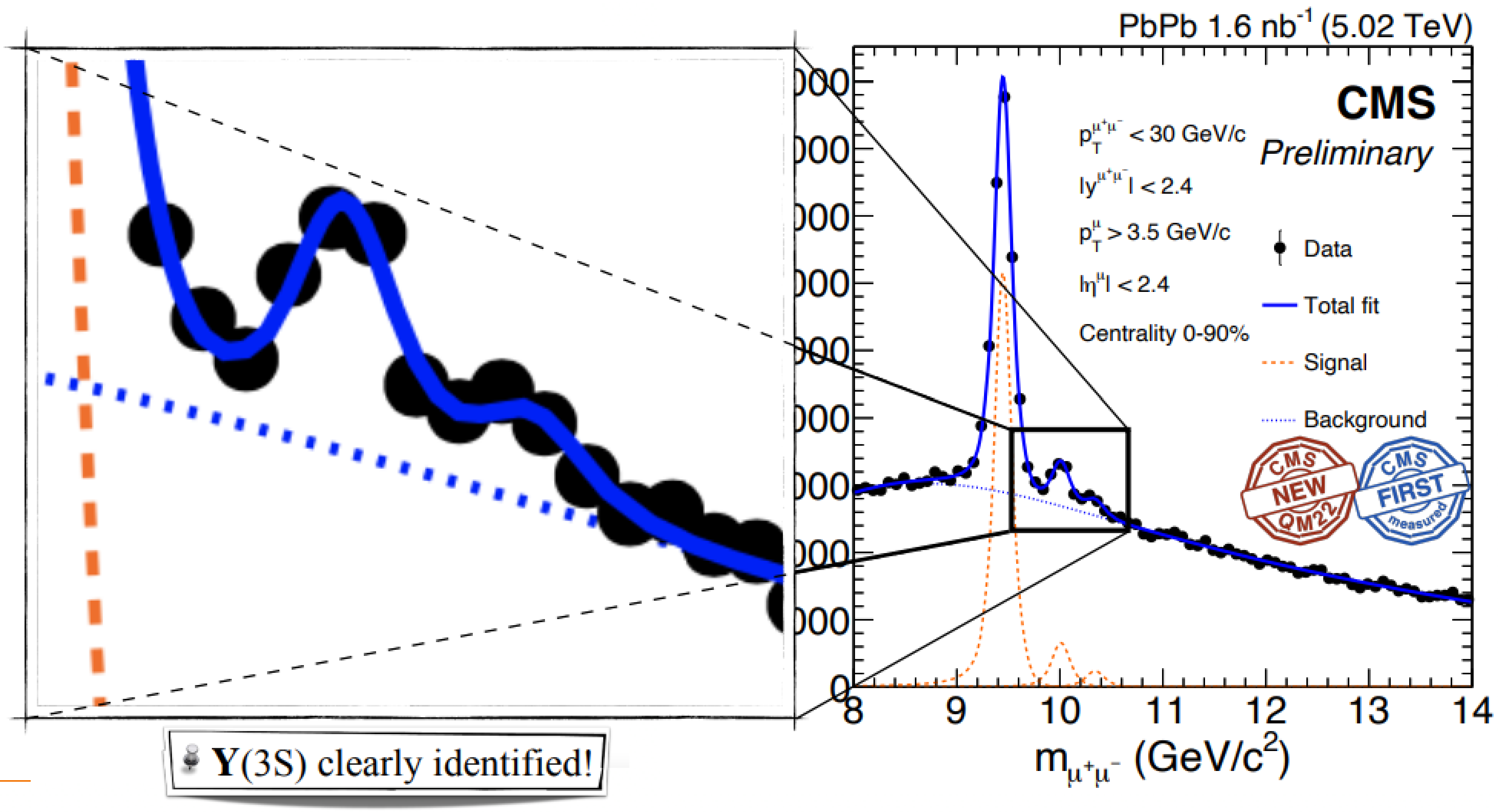


CMS-PAS-HIN-21-007

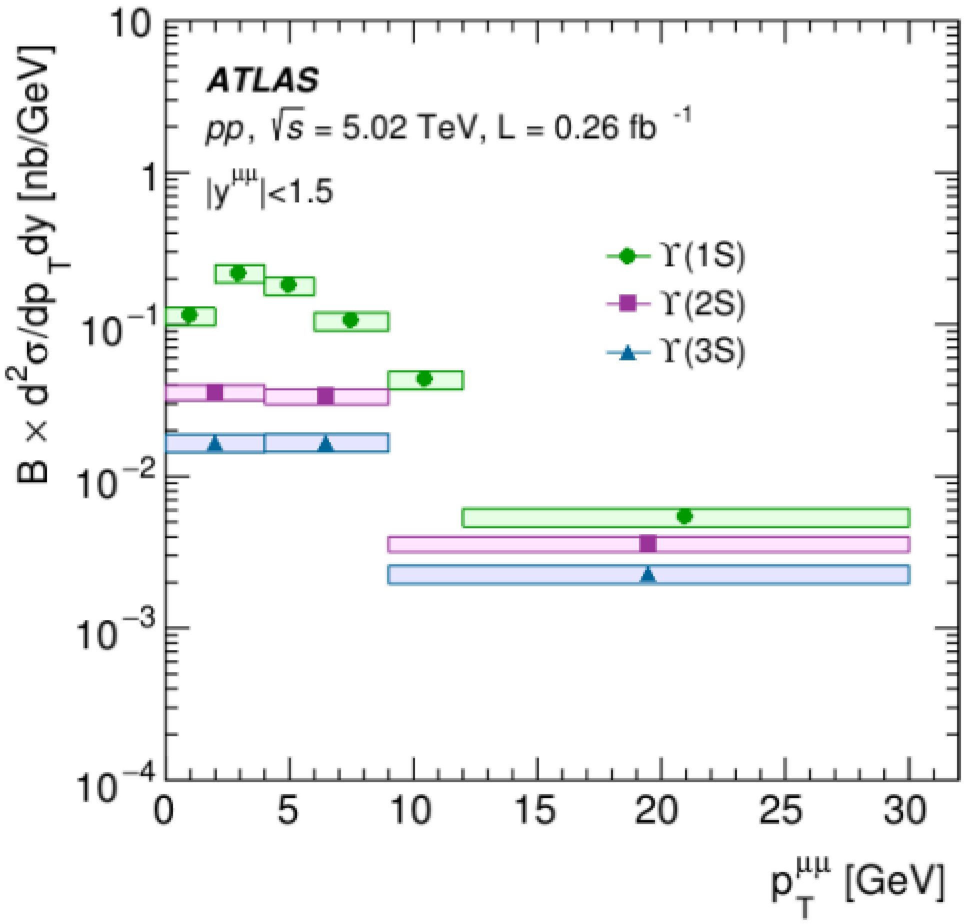
Huge improvement with BDT

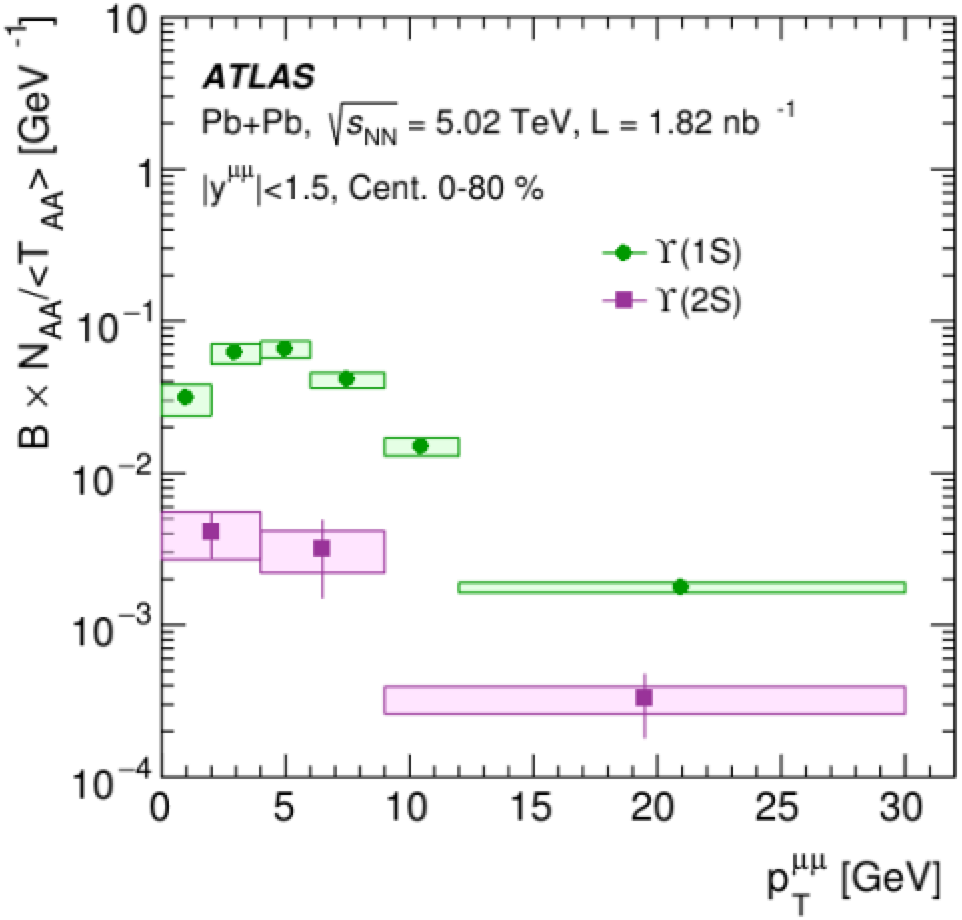
SV position in MVA selection?

$\Upsilon(nS)$ signal extraction: CMS



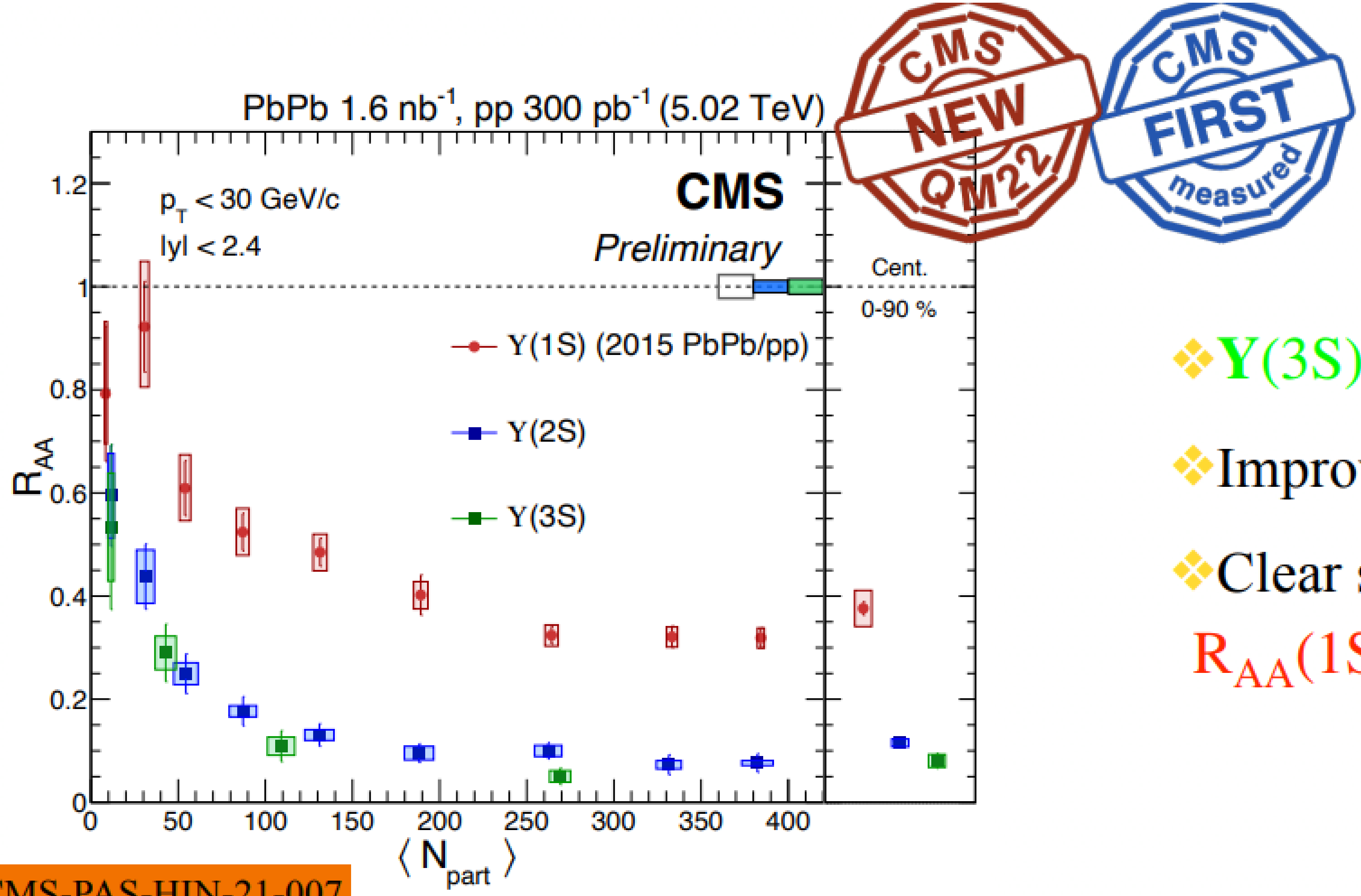
$\Upsilon(nS)$ signal extraction: ATLAS





Y(3S) not shown since peaks are not statistically significant.

$\Upsilon(nS)$ Nuclear modification factor: CMS

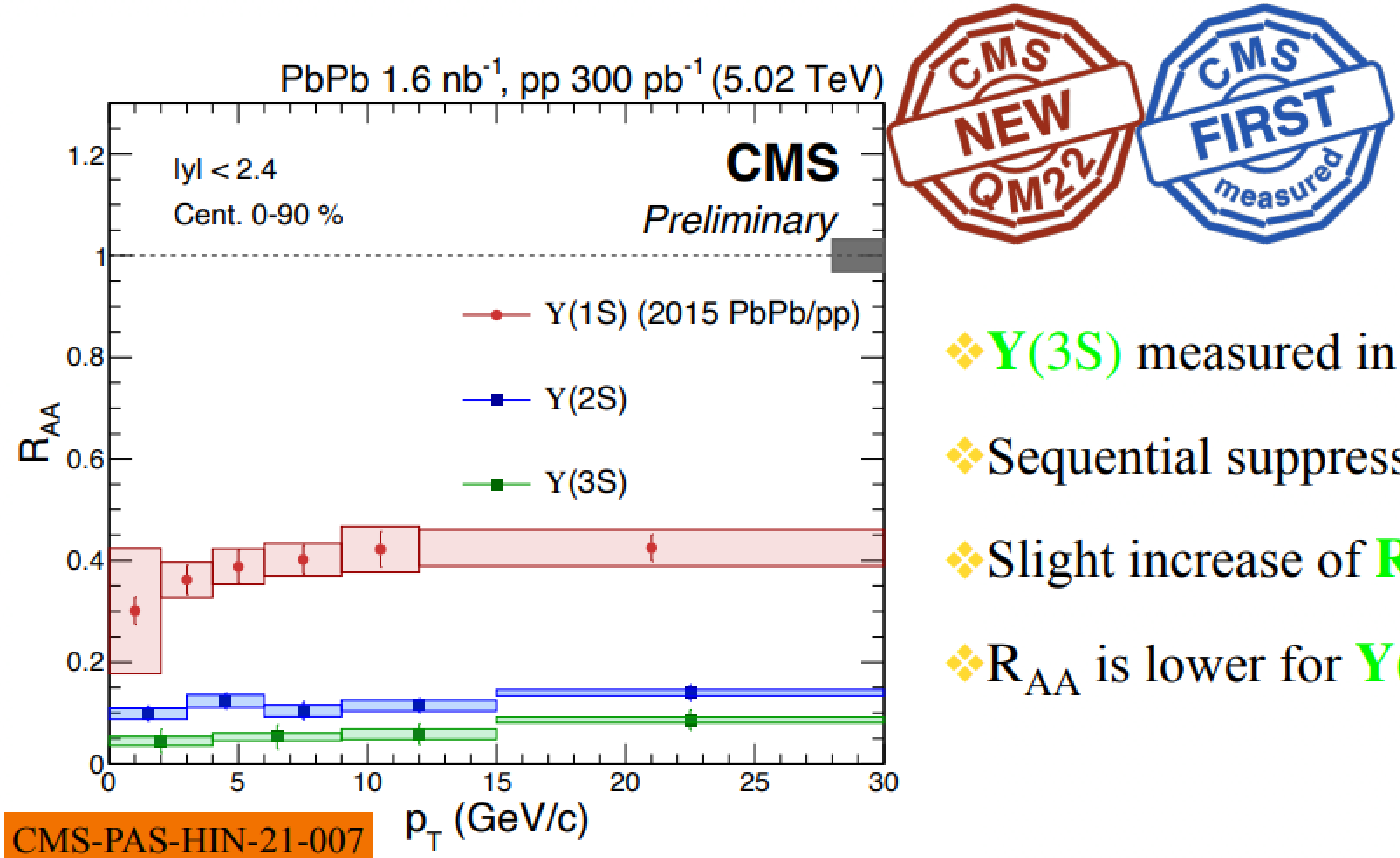


CMS-PAS-HIN-21-007

- ϒ(3S) measured in all centrality region
- Improved ϒ(2S)!
- Clear suppression

$R_{AA}(1S) > R_{AA}(2S) > R_{AA}(3S)$

$\Upsilon(nS)$ Nuclear modification factor: CMS

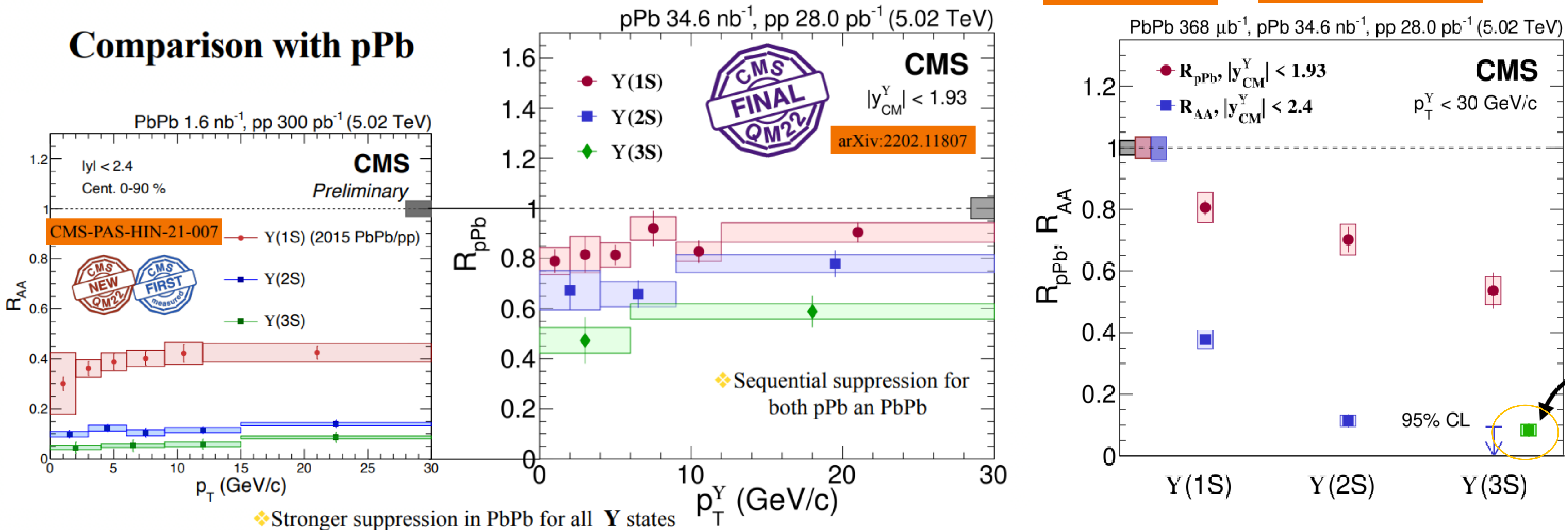


CMS-PAS-HIN-21-007

- $\Upsilon(3S)$ measured in all p_T intervals
- Sequential suppression in measured p_T range
- Slight increase of $R_{AA}(3S)$ vs. p_T
- R_{AA} is lower for $\Upsilon(3S)$ than $\Upsilon(2S)$ in all intervals

$\Upsilon(nS)$ Nuclear modification factor: CMS

arXiv:2202.11807 + CMS-PAS-HIN-21-007

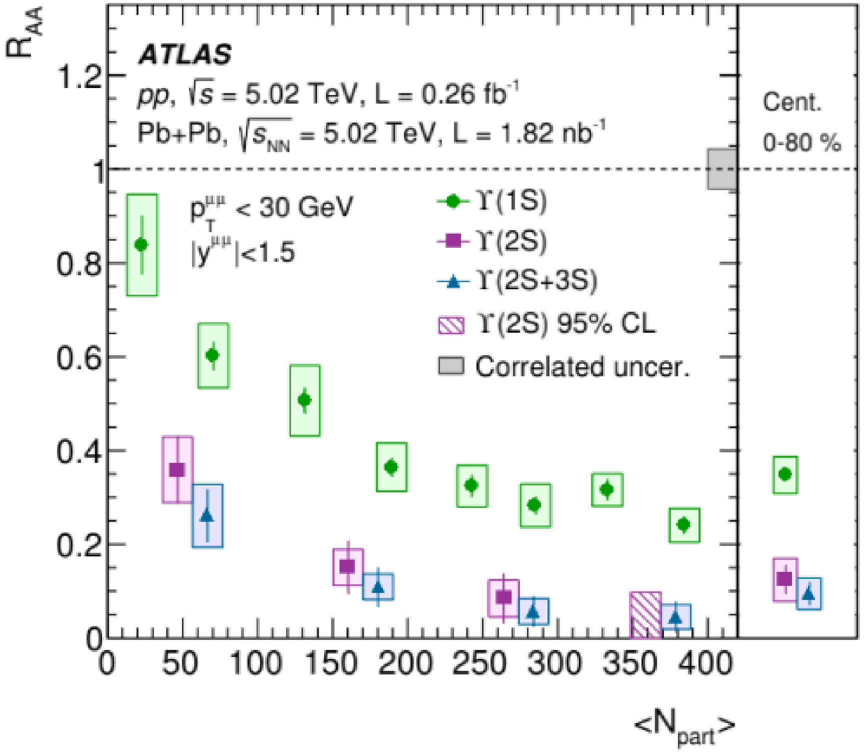


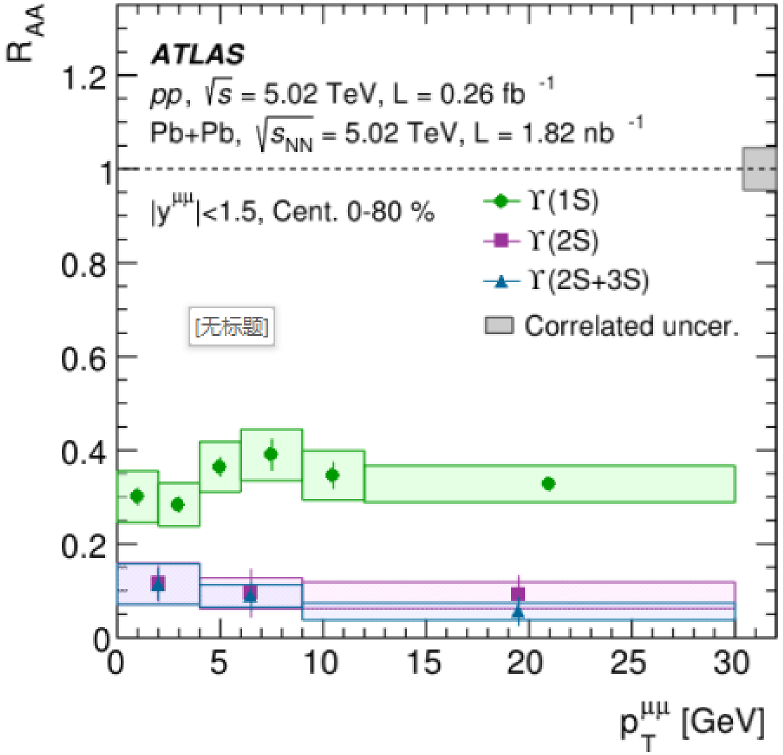
$\Upsilon(nS)$ Nuclear modification factor: ATLAS

Nuclear modification factor

$$R_{AA} = \frac{N_{AA}}{\langle T_{AA} \rangle \times \sigma^{pp}}$$

- Ordering in R_{AA}: Y(1S) > Y(2S) > Y(2S+3S)
- More suppression in more central collisions
- No strong p_T dependence.
- Y(2S+3S) is shown instead of Y(3S)

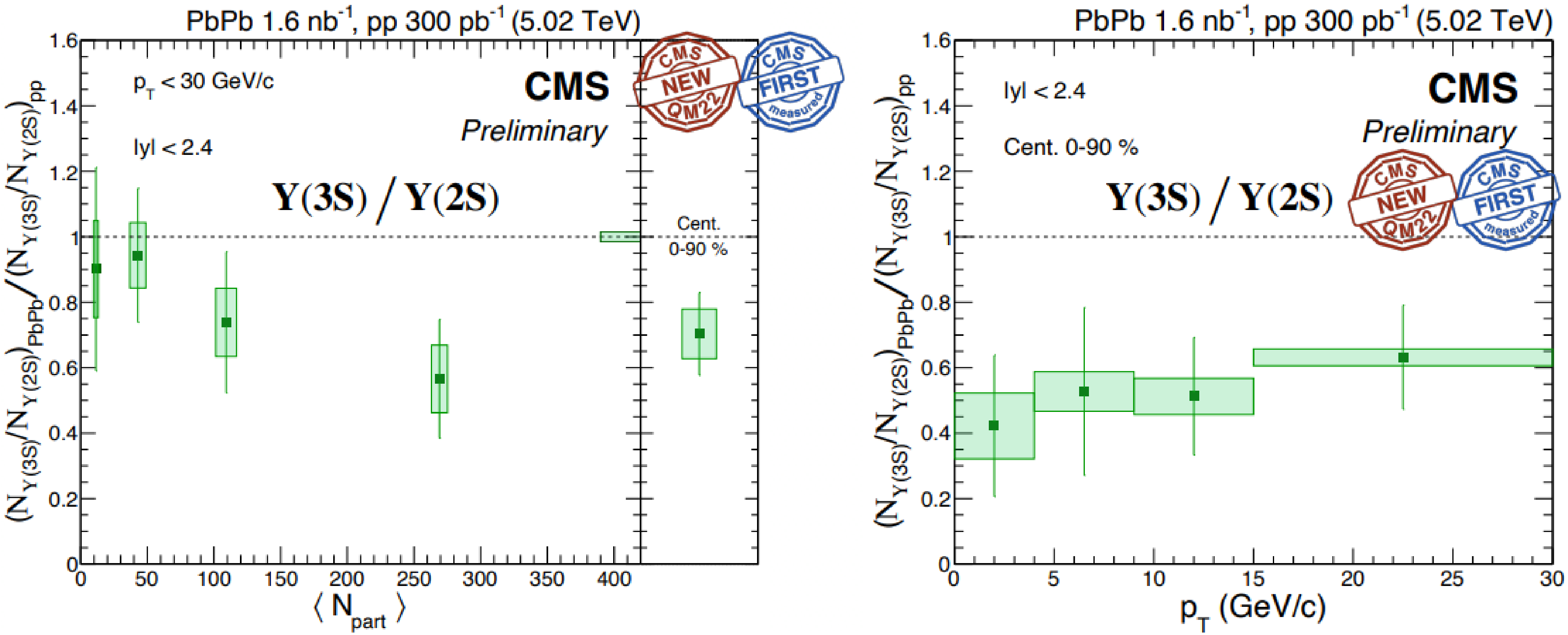




$\Upsilon(nS)$ Nuclear modification factor: CMS

Double ratio of Υ(3S) / Υ(2S)

CMS-PAS-HIN-21-007



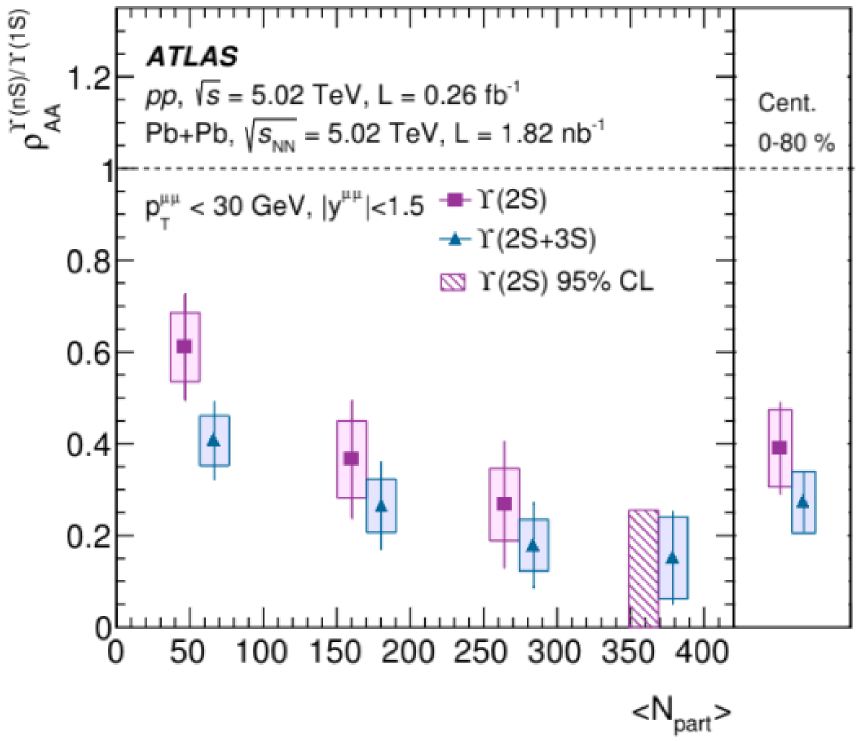
- Stronger suppression of Υ(3S) in central region
- Υ(3S) more suppressed than Υ(2S) in all p_T ranges
- No clear p_T dependance of double ratio Υ(3S) / Υ(2S)

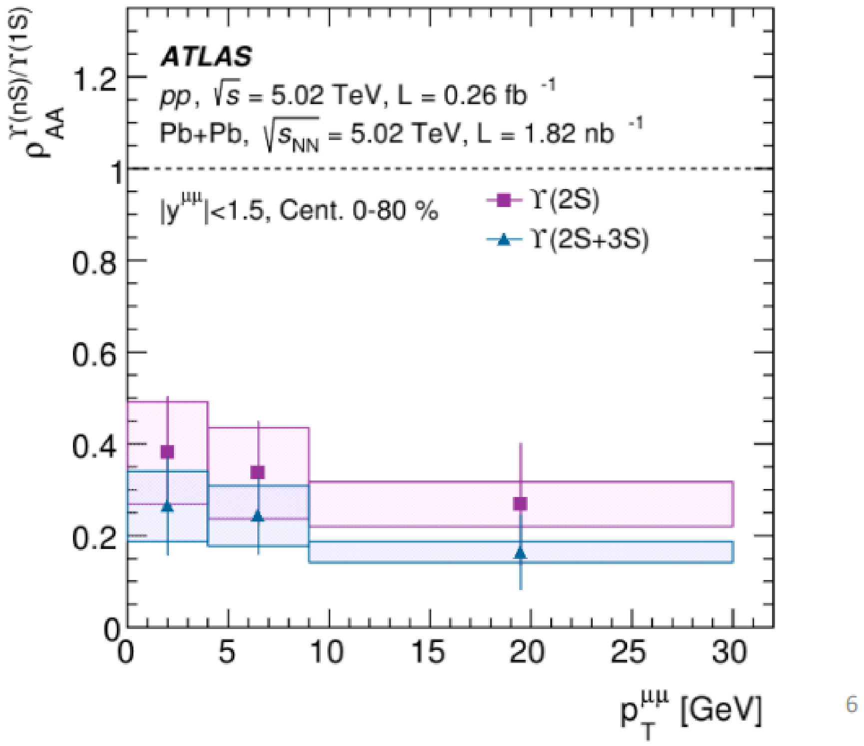
$\Upsilon(nS)$ Nuclear modification factor: CMS

Double ratios

$$\rho_{AA}^{\Upsilon(nS)/\Upsilon(1S)} = \frac{\sigma_{AA}^{\Upsilon(nS)}/\sigma_{AA}^{\Upsilon(1S)}}{\sigma_{pp}^{\Upsilon(nS)}/\sigma_{pp}^{\Upsilon(1S)}} = \frac{R_{AA}(\Upsilon(nS))}{R_{AA}(\Upsilon(1S))}$$

- Luminosity and $<T_{AA}>$ corrections cancel
- Acceptance and efficiency corrections partially cancel
- Consistent with sequential melting
- Y(2S+3S) systematically lower than Y(2S)

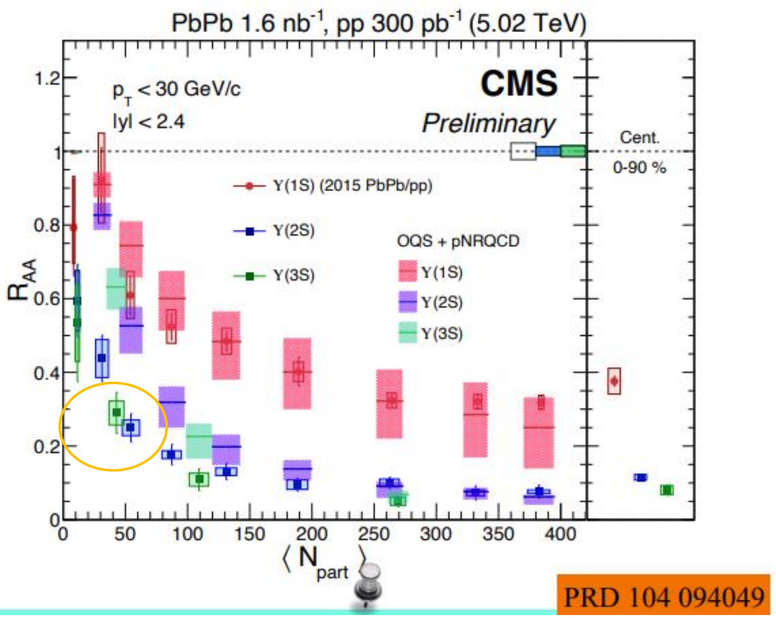


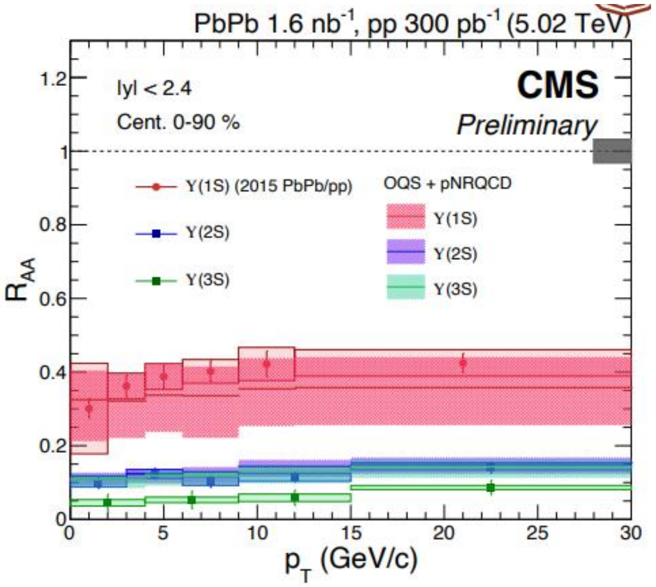


$\Upsilon(nS)$ Nuclear modification factor: Comparison with model

[1] N.Brambilla et al.,
Phys. Rev. D 104 (2021) 094049

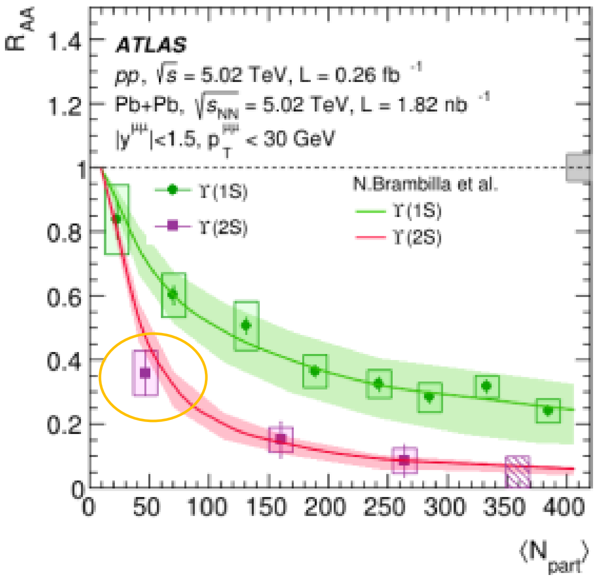
CMS

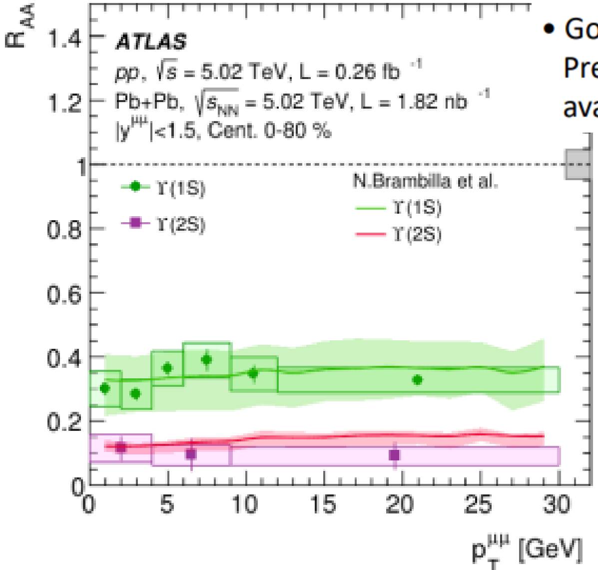




- Discrepancy of excited states in mid-peripheral collisions
- Overestimates $R_{AA}(3S)$ vs p_T

ATLAS



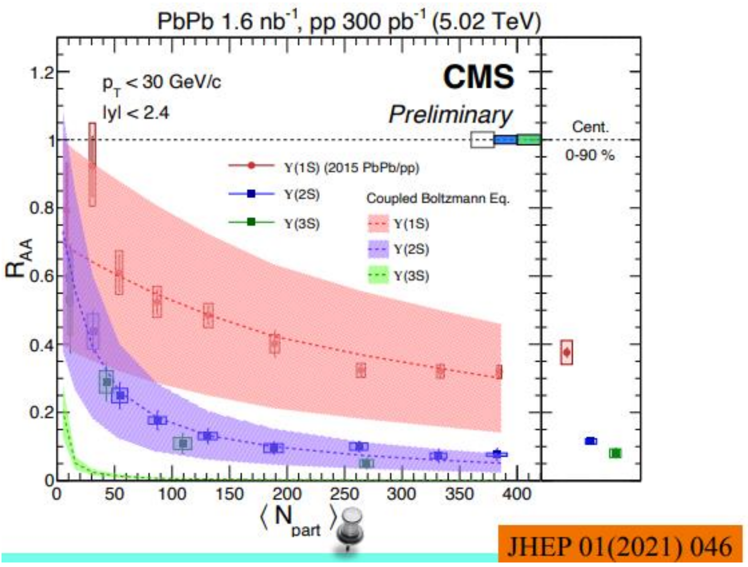


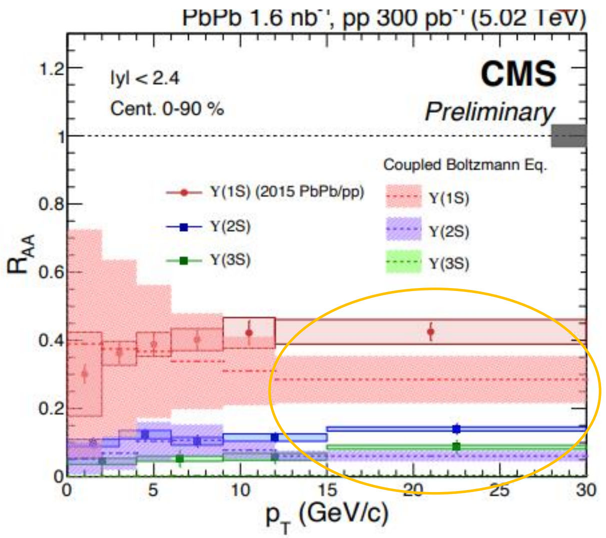
- Good agreement with the data
  Previous Υ suppression data available to authors.

$\Upsilon(nS)$ Nuclear modification factor: Comparison with model

[3] X. Yao et al.,
JHEP 2021 (2021) 46

CMS

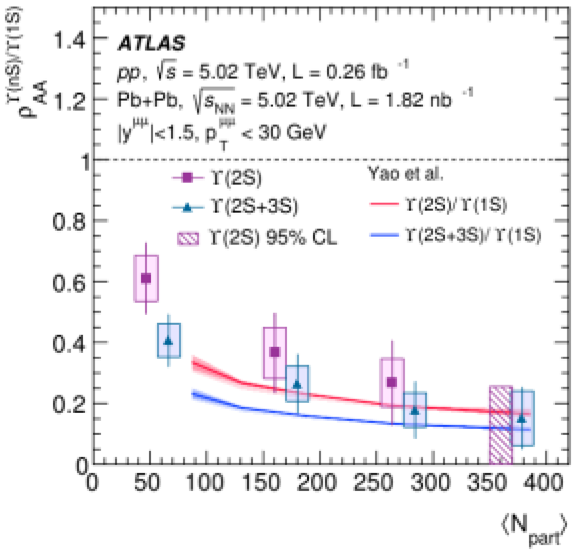


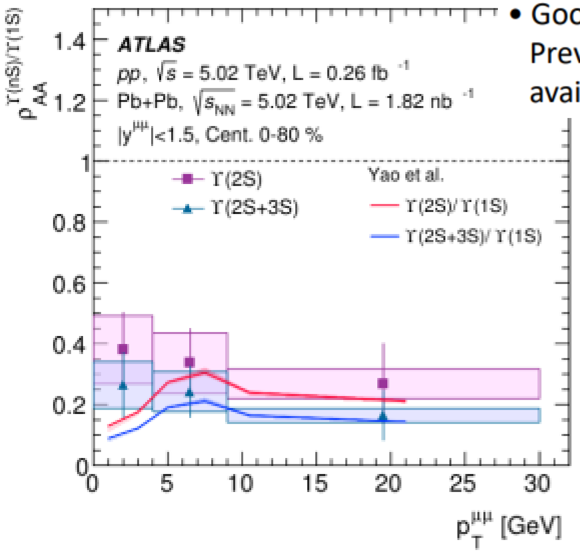


❖Predicts larger Υ(3S) suppression than data

❖Discrepancy at high p_T

ATLAS





- Good agreement with the data. Previous Υ suppression data available to authors.

Summary

Heavy flavors in heavy ion collisions

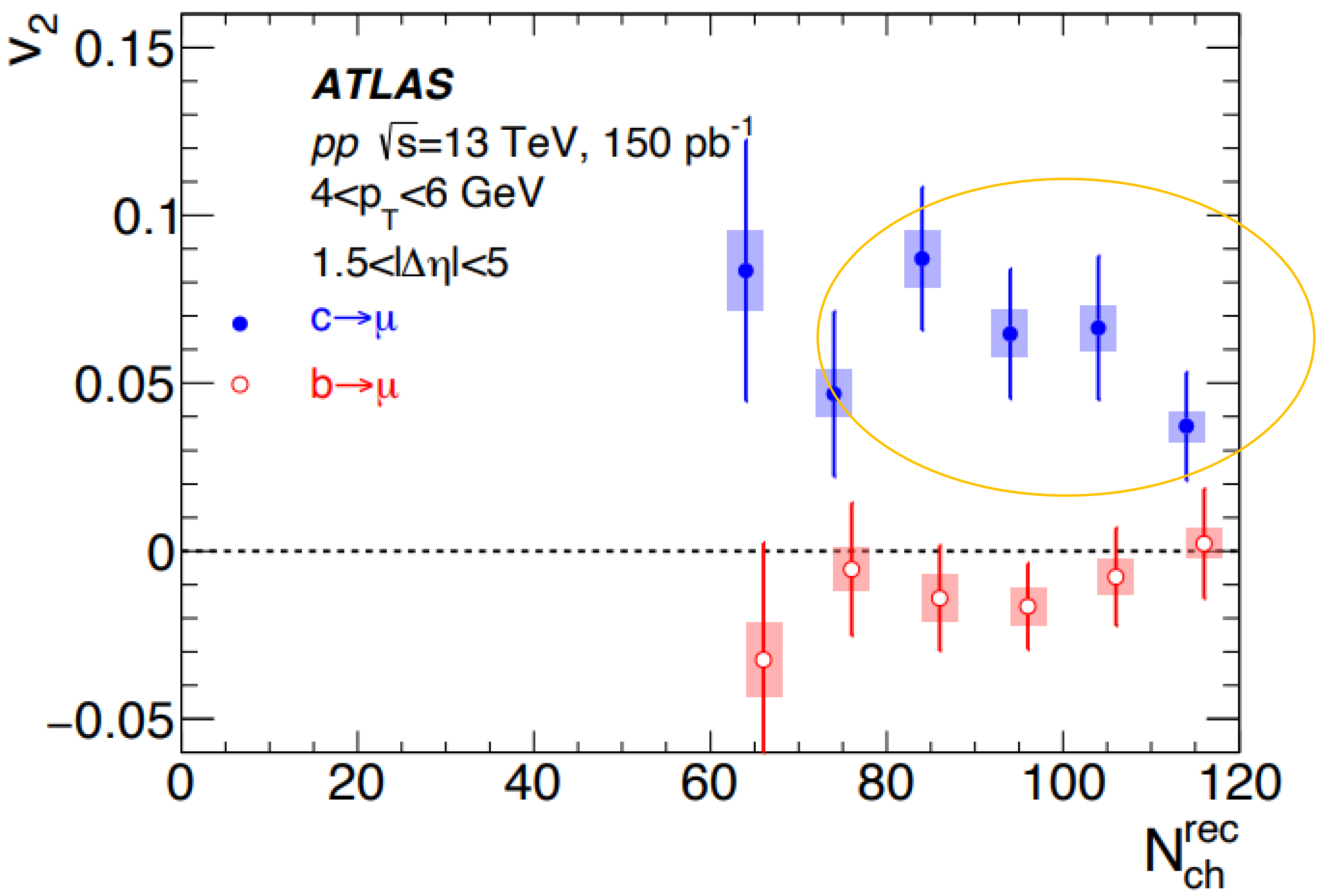
- Decay muons serve as powerful HF probes in HIC, especially for probing bottom quarks
- Detailed yield and azimuthal anisotropy measurements of HF muon in *pp* and Pb+Pb collisions are available in recent ATLAS publications
- HF pair azimuthal correlation measured with muon pairs. No significant azimuthal correlation broadening observed

Bottomonium in heavy ion collisions

- First observation of **Υ**(3S) in PbPb collisions!
- Sequential suppression of **Υ**(nS)
- Strong constraints on theoretical models
  - Need to carefully treat the theoretical ingredients

Back up

HF azimuthal anisotropy in pp collisions



如果在pp的high multiplicity的events里面有v2，且假设这个v2来自于QGP，那么v2随着multiplicity增加是不是应该上升？

现在实验室认为有可能的，造成pp里面有charm的v2？

这个v2是charm的还是测得muon？

- Significant azimuthal anisotropy for charm muon in high multiplicity *pp* events
- v_2(b) ~0. Charm and bottom difference is significant