# Bottomonia results in pp, pPb and PbPb collisions at CMS

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*for*
*CMS Collaboration*

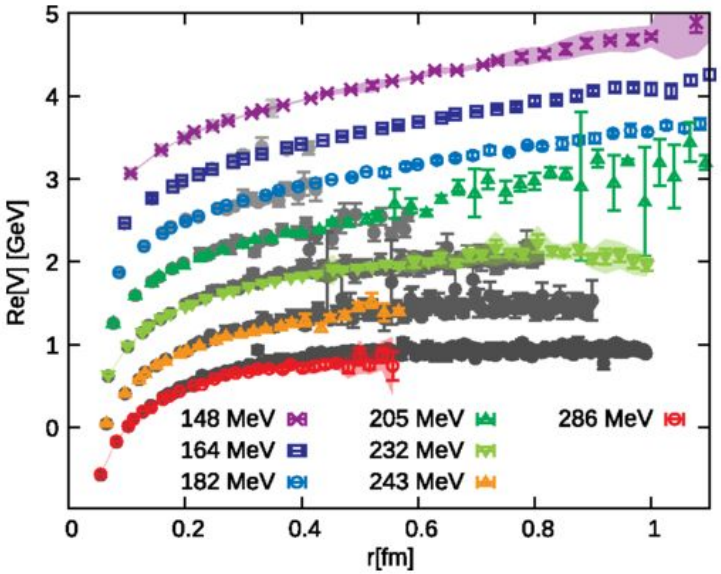
# Outline

- Motivation
- CMS and Collision Systems
- Upsilon pPb result
  - JHEP 04 2014:103
- Upsilon PbPb results
  - CMS-PAS-HIN-15-001
- Current/Future Work
  - Run 2 @ 5.02 TeV

# Motivation

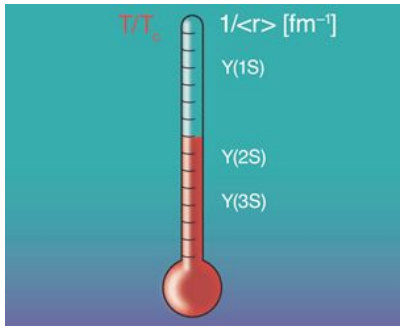
- Matsui and Satz proposed suppression of J/ψ in 1986
  - Suppression attributed to color screening in heavy ion collisions
  - This can be extended to other Heavy Quark systems like the Upsilon

Phys. Rev. Lett. 114, 082001




What are we probing?

- Hot Nuclear Matter (HNM)
  - Quark Gluon Plasma (QGP) formation
  - Quarkonia melting
    - Probe for temperature.
    - Recombination at LHC thought less than J/ψ. “clean”

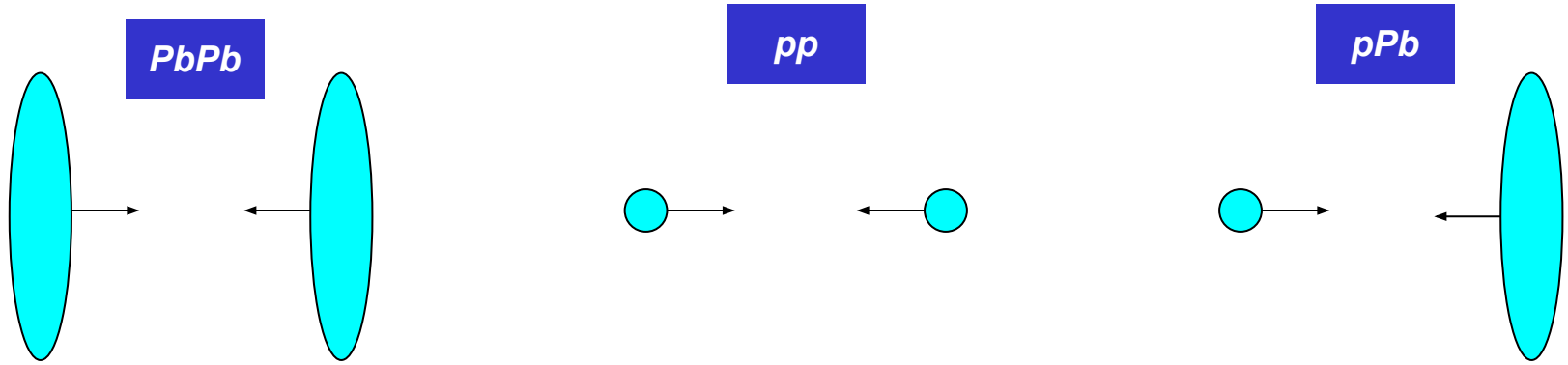



- Cold Nuclear Matter (CNM)
  - nPDF modification
  - Initial state energy loss
  - Absorption …

# Collision Systems

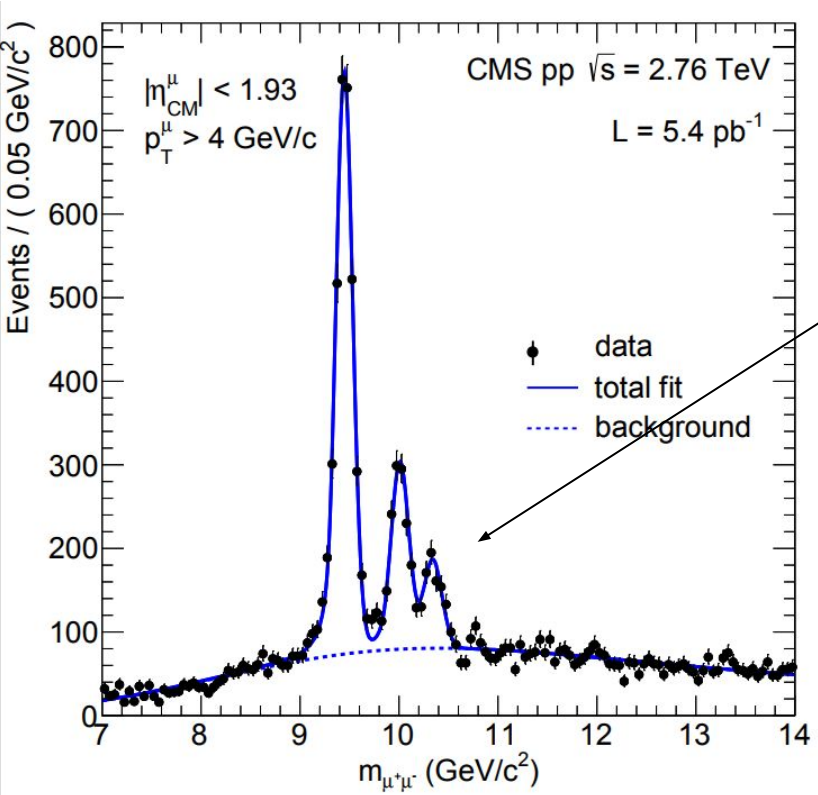
Goal: Understand Quark-Gluon Plasma in PbPb collisions

- PbPb collisions
  - Probe HNM and CNM
- pp collisions
  - Baseline reference
- pPb
  - Probe CNM effects



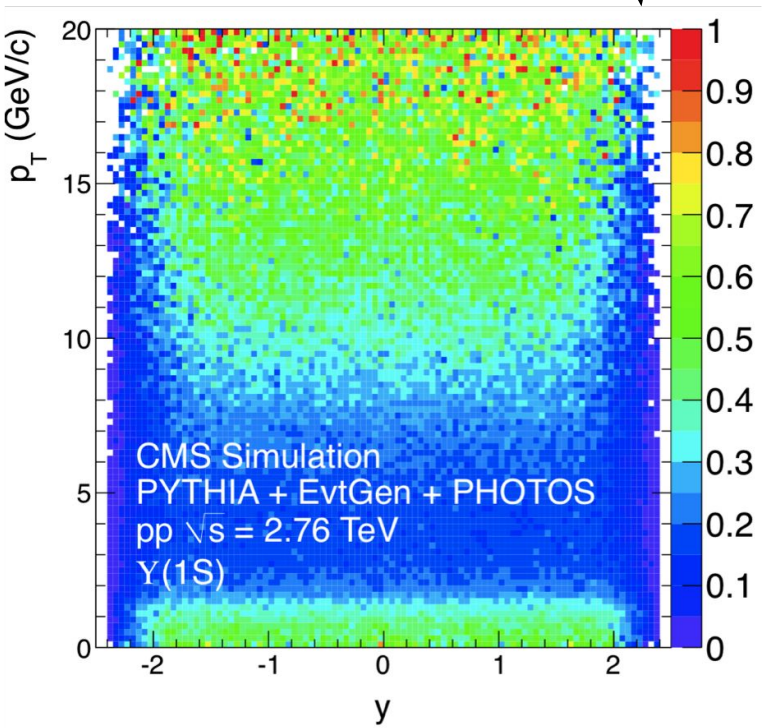
# CMS - Bottomonia

JHEP 04 2014:103

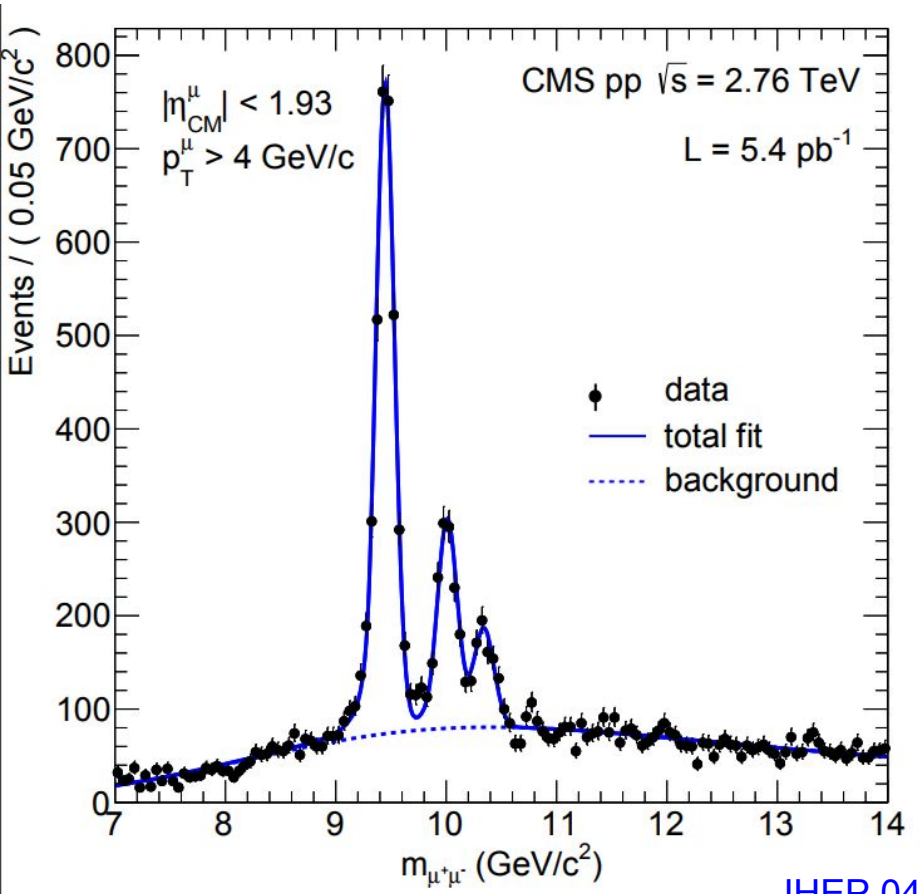


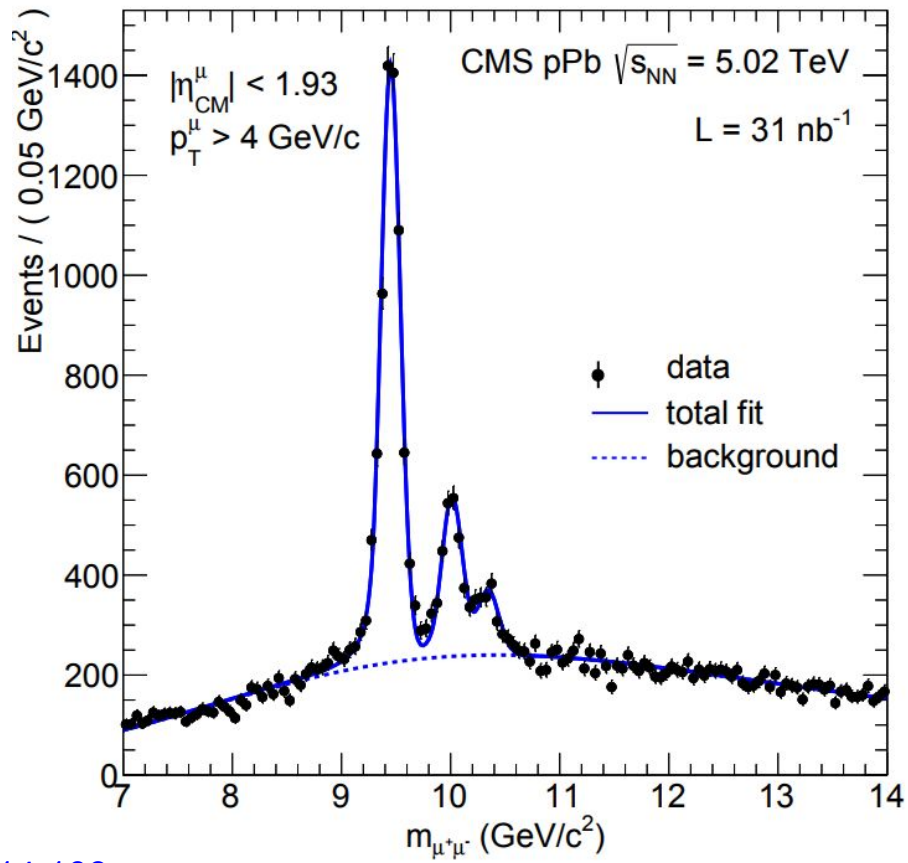

- *All yields are obtained with unbinned fits to dimuon invariant mass spectrum*

- Acceptance:
  - Single Muon $|\eta|<2.4$ $p_T > 4.0$ GeV/c
  - **Upsilons down to $p_T = 0$ GeV/c**
- Good momentum resolution
  - Clear separation of states



# Upsilons in pPb @ $\sqrt{s_{NN}}$= 5.02 TeV

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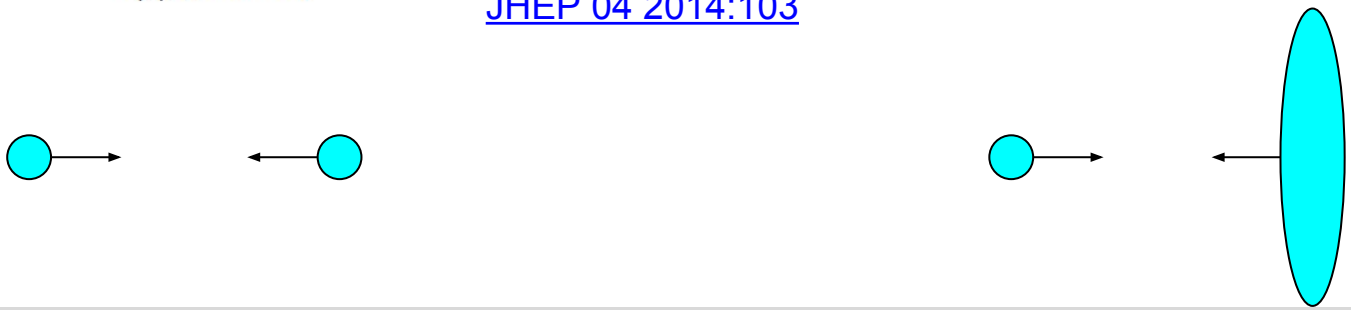

# Double Ratios

$$\frac{[\frac{\Upsilon(nS)}{\Upsilon(1S)}]_{pPb}}{[\frac{\Upsilon(nS)}{\Upsilon(1S)}]_{pp}} = \frac{R_{pPb}(\Upsilon(nS))}{R_{pPb}(\Upsilon(1S))}$$

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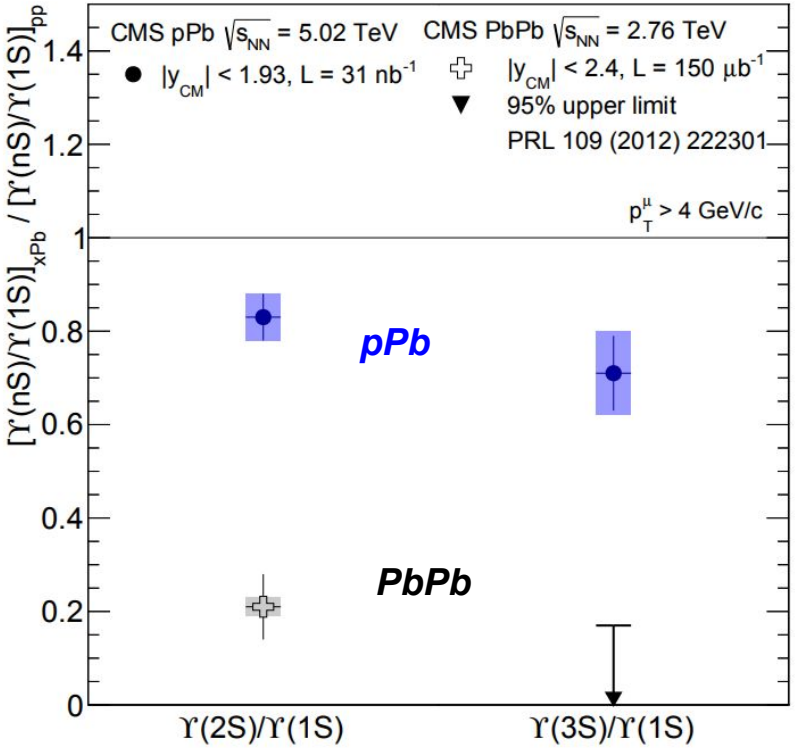


Double Ratio:

- Relative modification of the excited state compared to nuclear modification of the ground state
- Double ratio should cancel initial state effects like shadowing

- PbPb (Black Points)
  - pp normalization from 2011 run with less statistics

- pPb still has some suppression.
  - pp normalization from 2013 run pp @ 2.76 TeV. Single ratio not dep. On √s

# Single Ratios in pp and pPb

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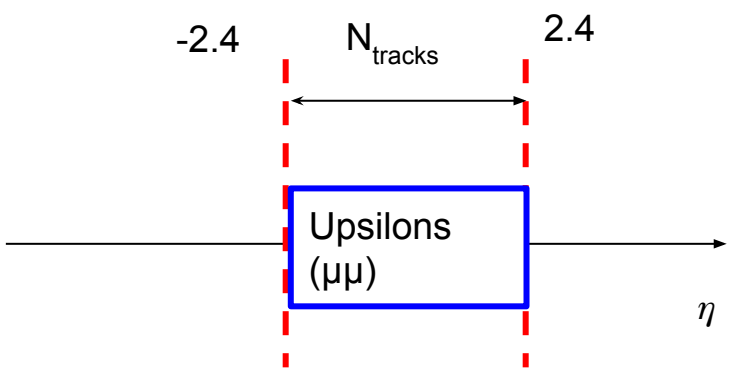
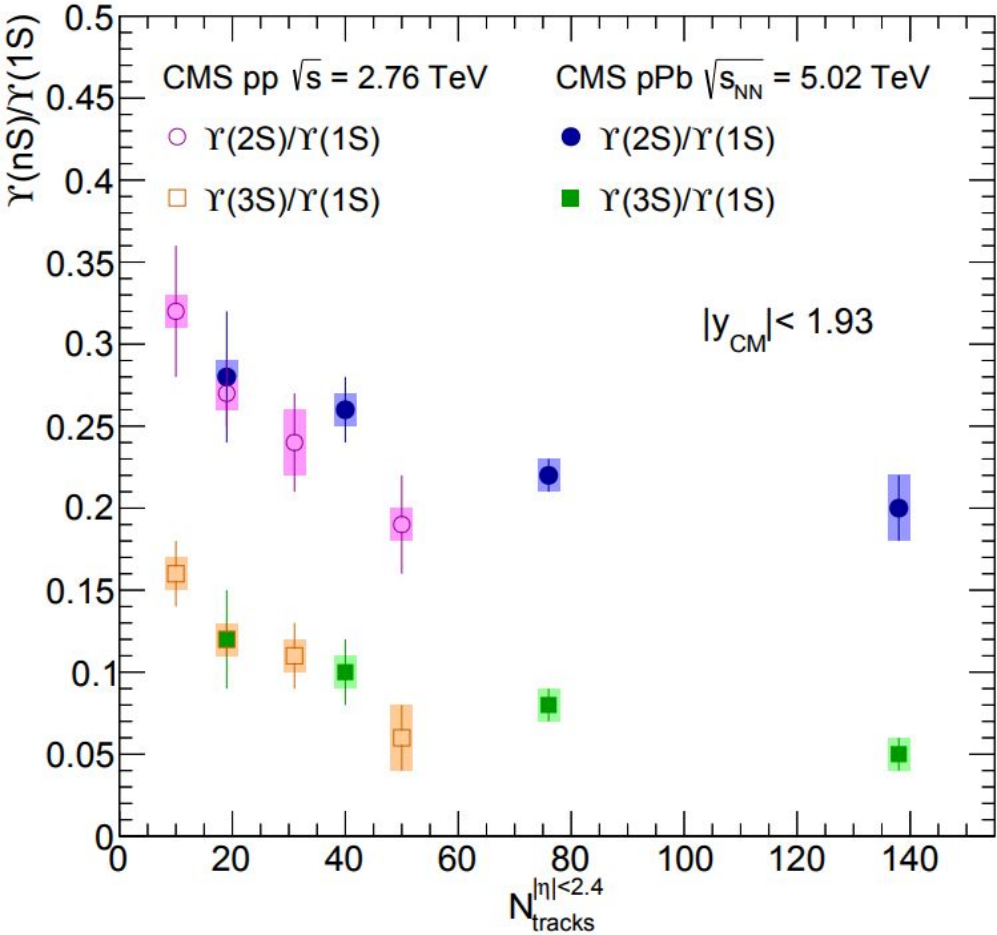
- pp and pPb dependent on multiplicity
  - Downward trend
  - Event activity in region of upsilon affects production?
  - Final state interactions in pp?




$N_{tracks}$ in same region as Upsilon measurement



# Single Ratios in pp and pPb

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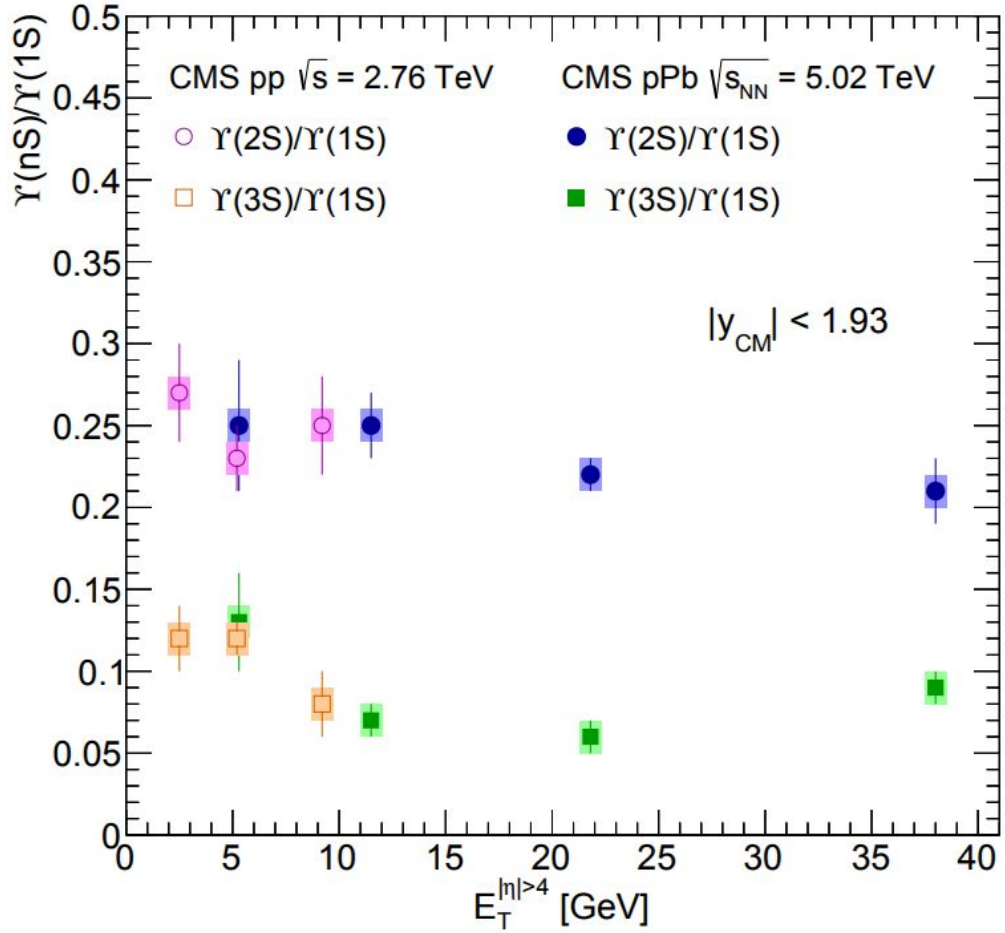
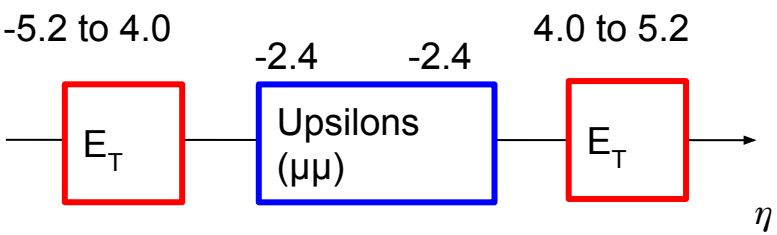
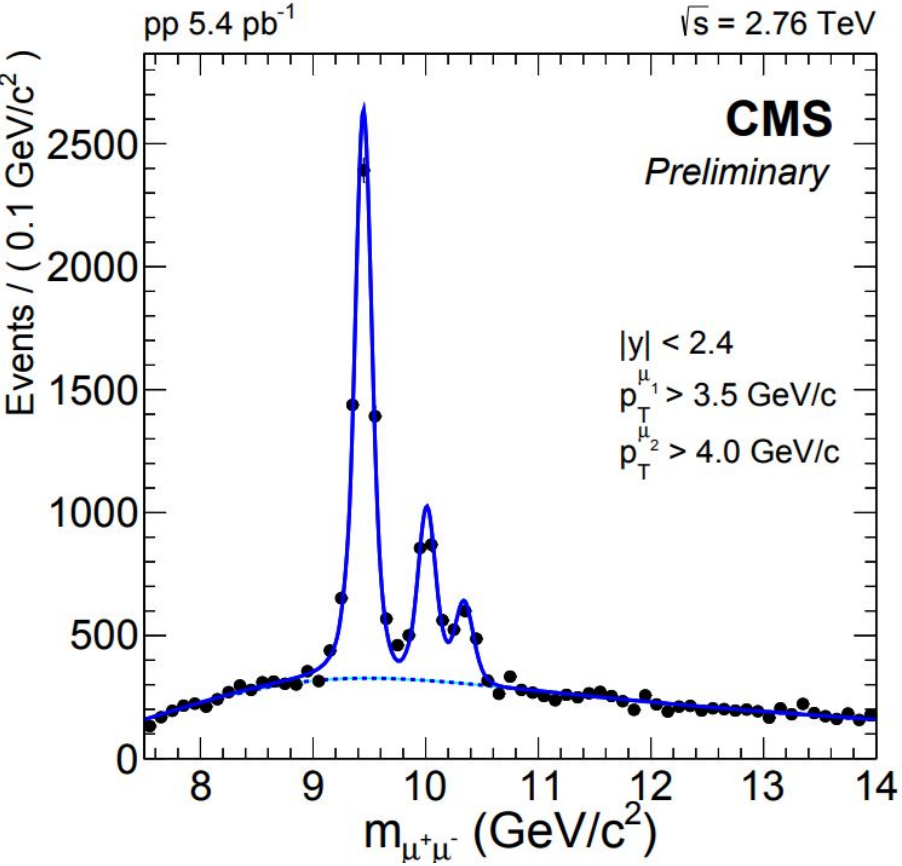
- Less dependence on $E_T$
  - Flatter dependence
  - $E_T$ and $N_{tracks}$ have different trends for single ratio

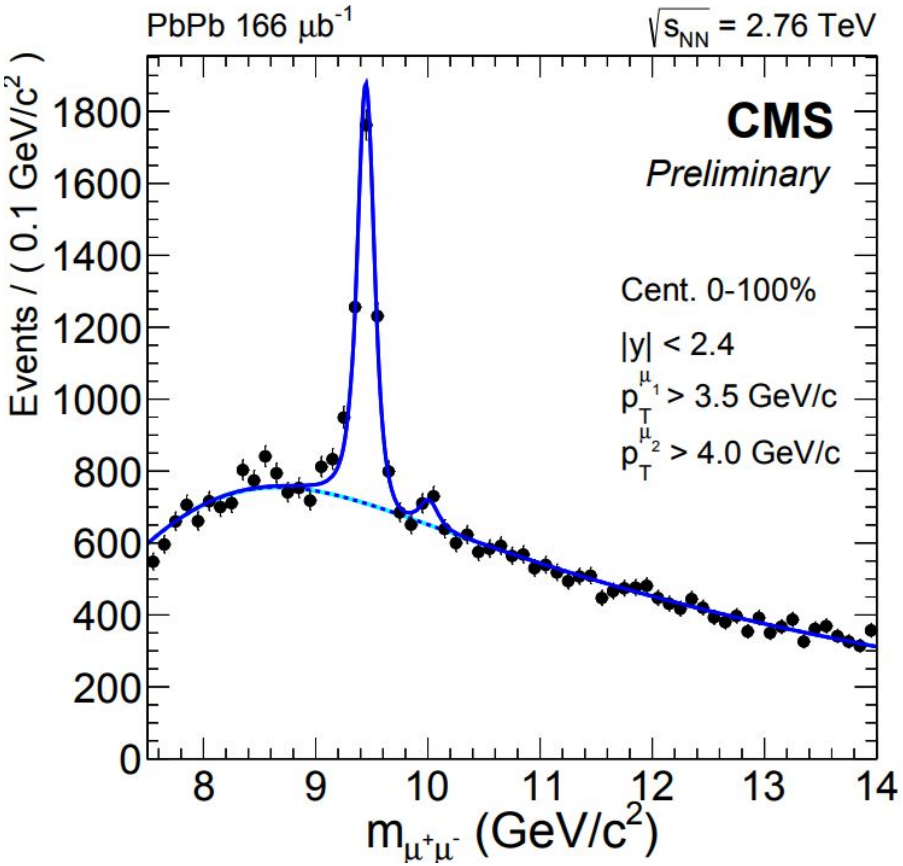


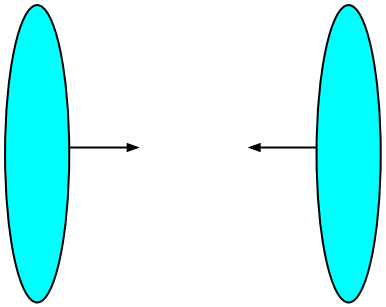

$E_T$(HF) in different region as Upsilon measurement

# Upsilons @ $\sqrt{s_{NN}}$ = 2.76 TeV




CMS-PAS-HIN-15-001



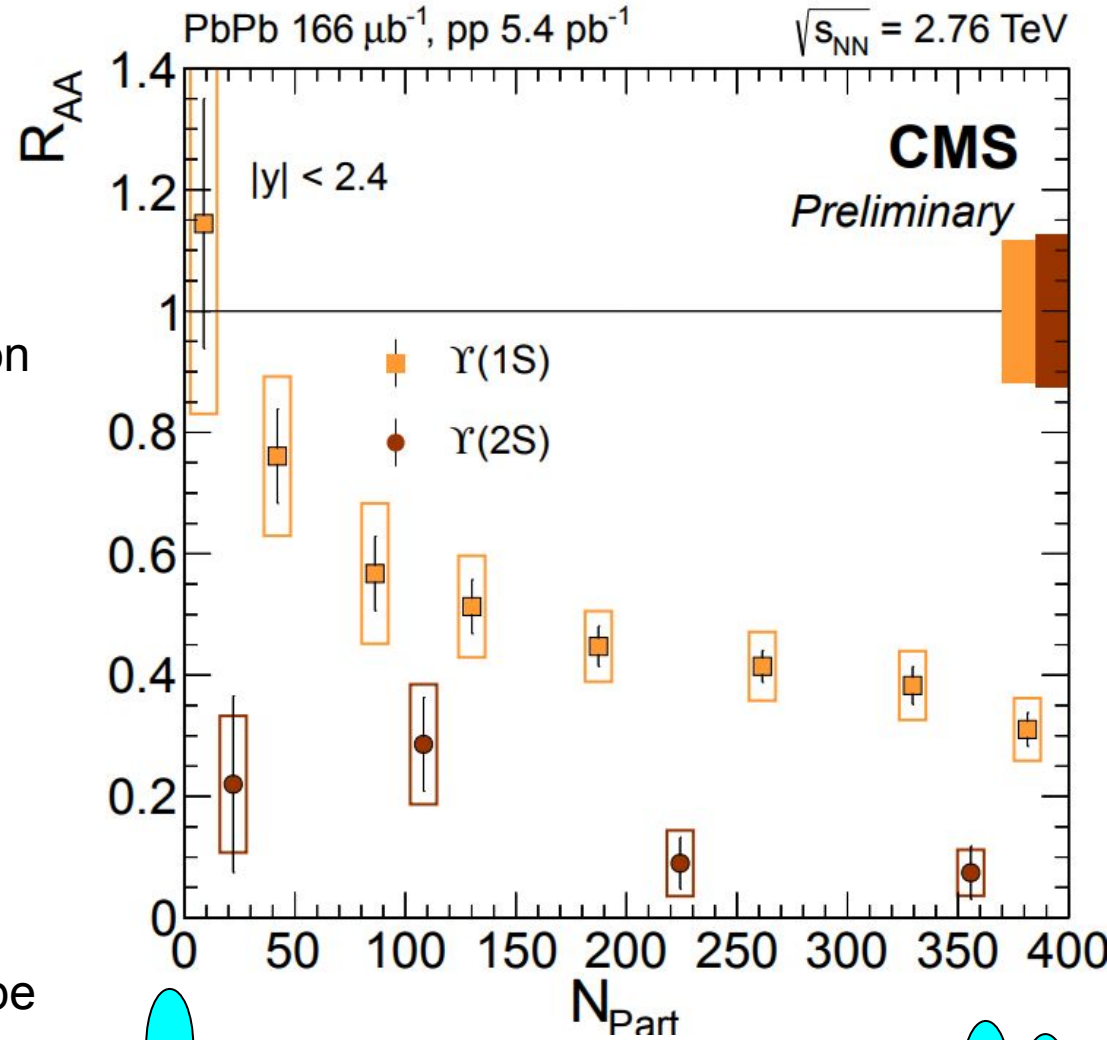
# Nuclear Modification - Centrality

$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}}{N_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

- Nuclear modification as a function of centrality
  - Suppression is largest most central

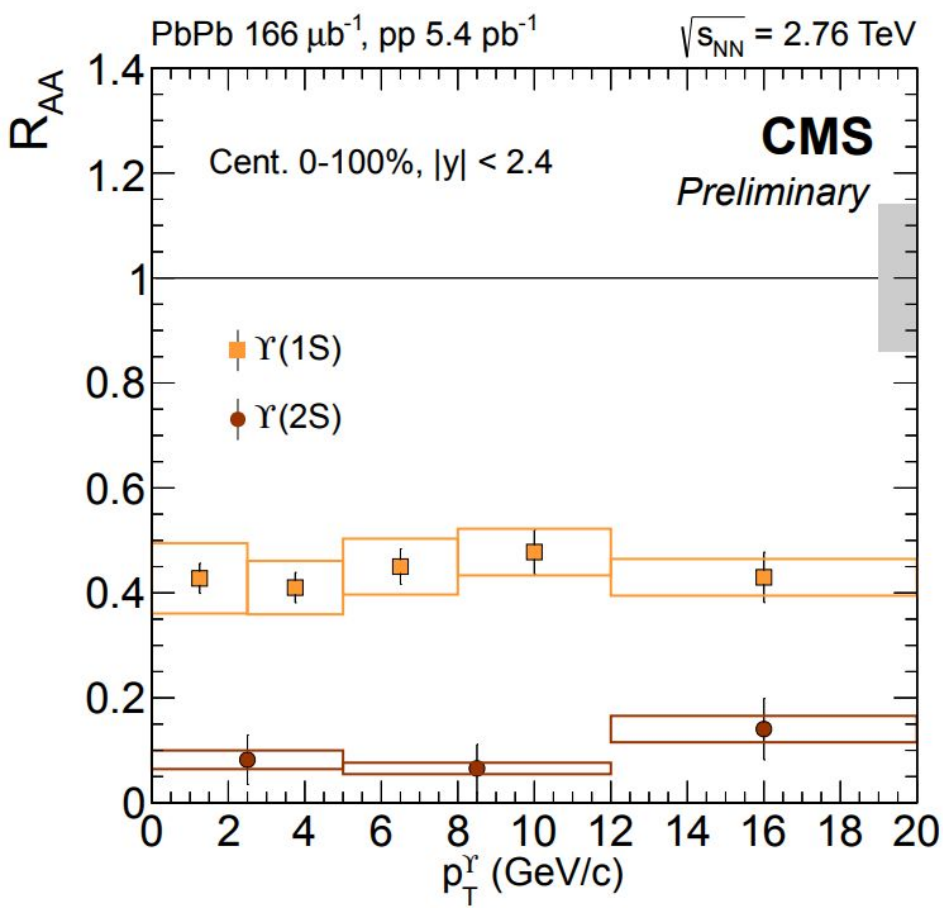
Integrated Result (0-100%):
$R_{AA}(\Upsilon(1S)) = 0.425 \pm 0.029 \pm 0.070$
$R_{AA}(\Upsilon(2S)) = 0.116 \pm 0.028 \pm 0.022$
$R_{AA}(\Upsilon(3S)) < 0.14$ at 95% CL

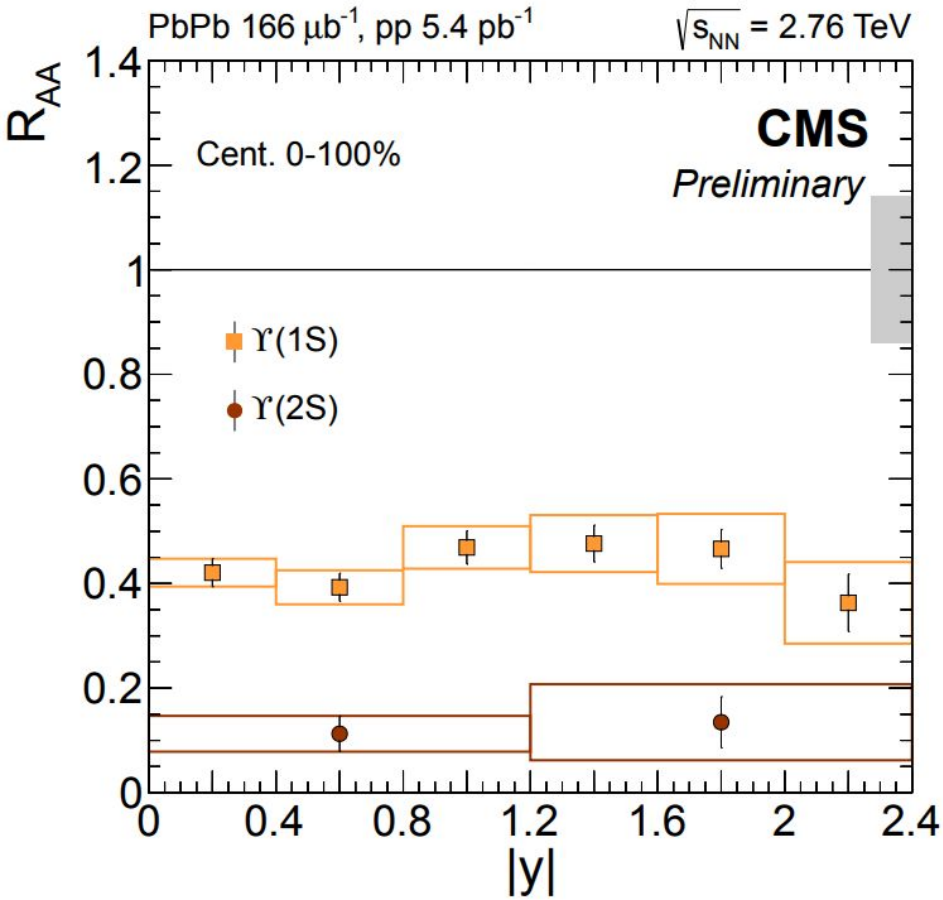
- Currently being updated and to be published soon
  - Data-driven efficiency and systematics




CMS-PAS-HIN-15-001

# Nuclear Modification - $p_T$ and |y|



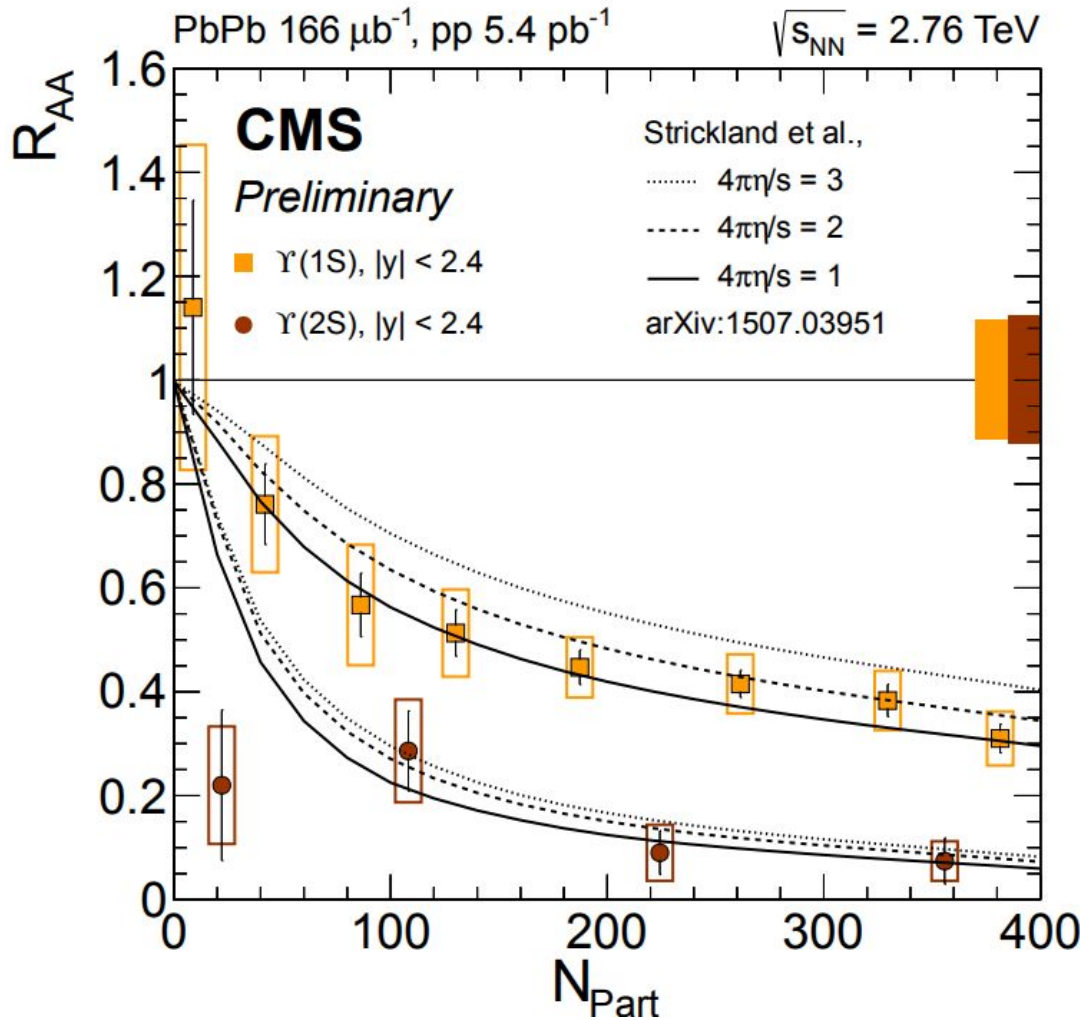

CMS-PAS-HIN-15-001

- Flat dependence as function of Upsilon kinematics.
- Currently being updated, to be published soon
  - Data-driven efficiency and systematics

# Comparison with Predictions

Nuclear Modification as a function of Centrality

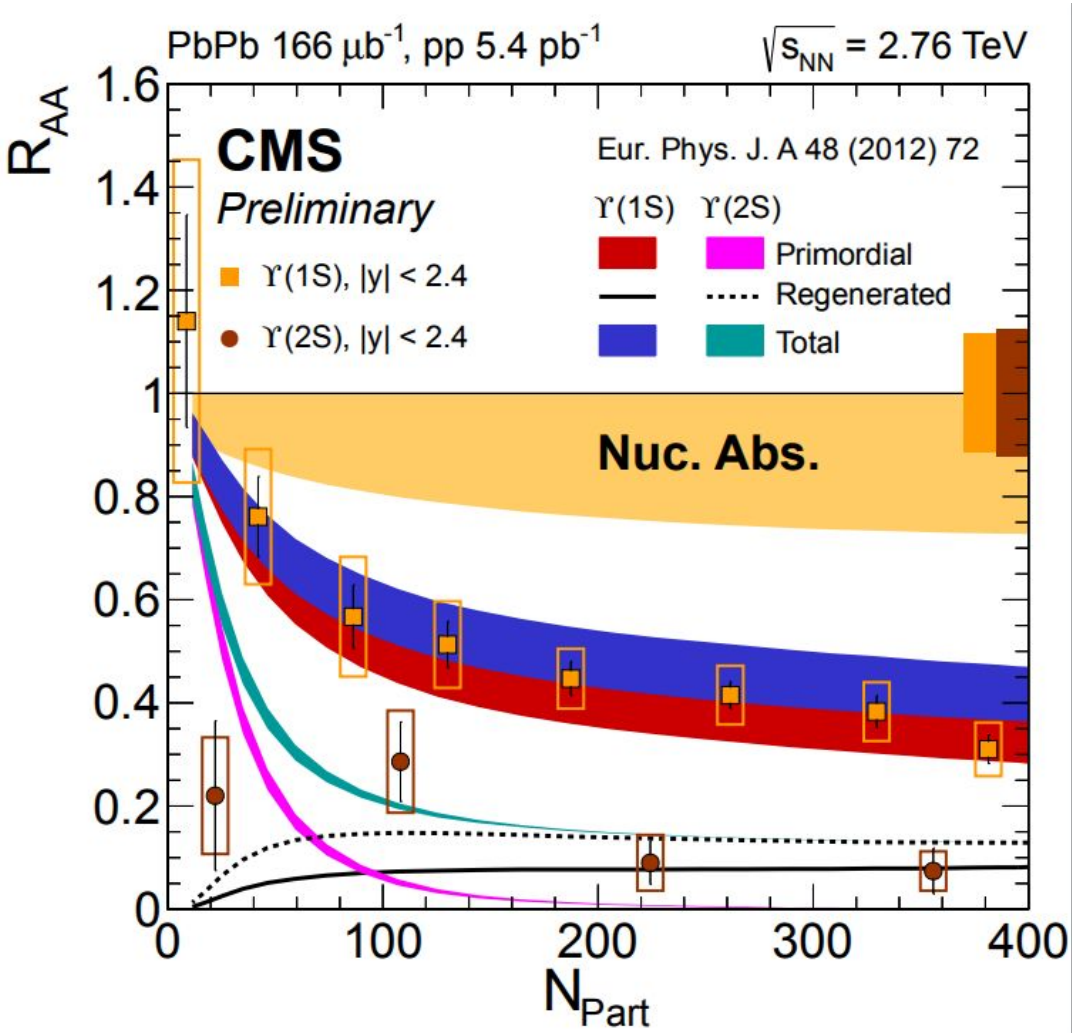
- Overlaid with thermal model from the Strickland and Bazow Model
  - Lattice based potentials
  - Sequential melting and feed down ~ 50%
  - Variation in $T_0$ and η/S
  - Data indicate
    - $539 < T_0 < 550$ MeV
  - In good agreement



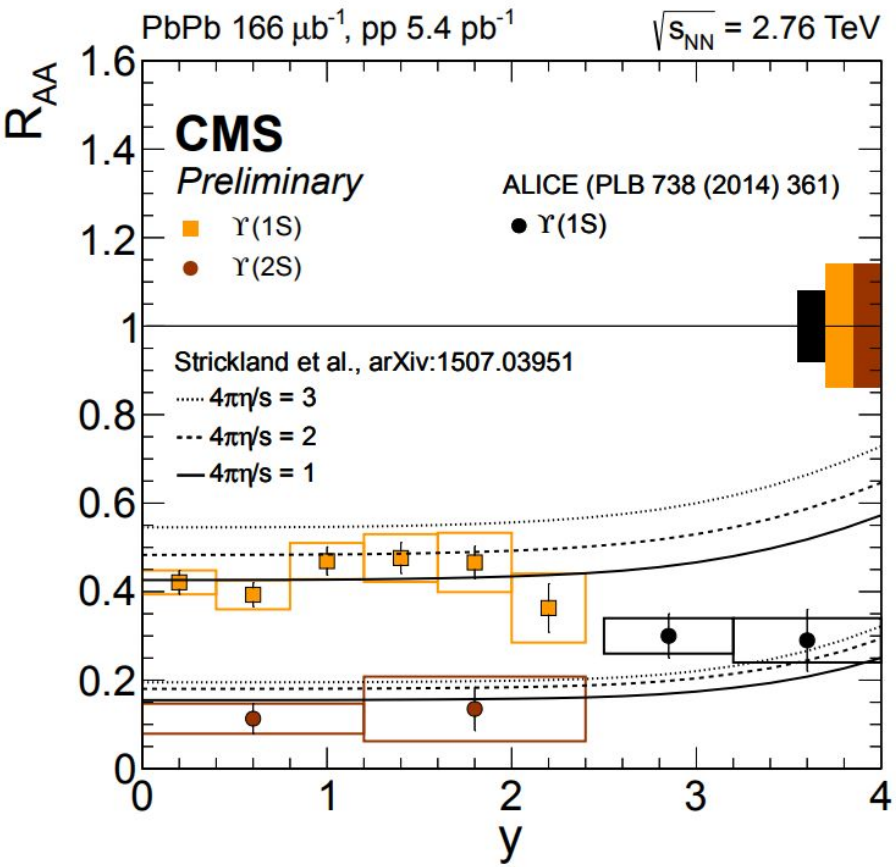
# Comparison with Predictions

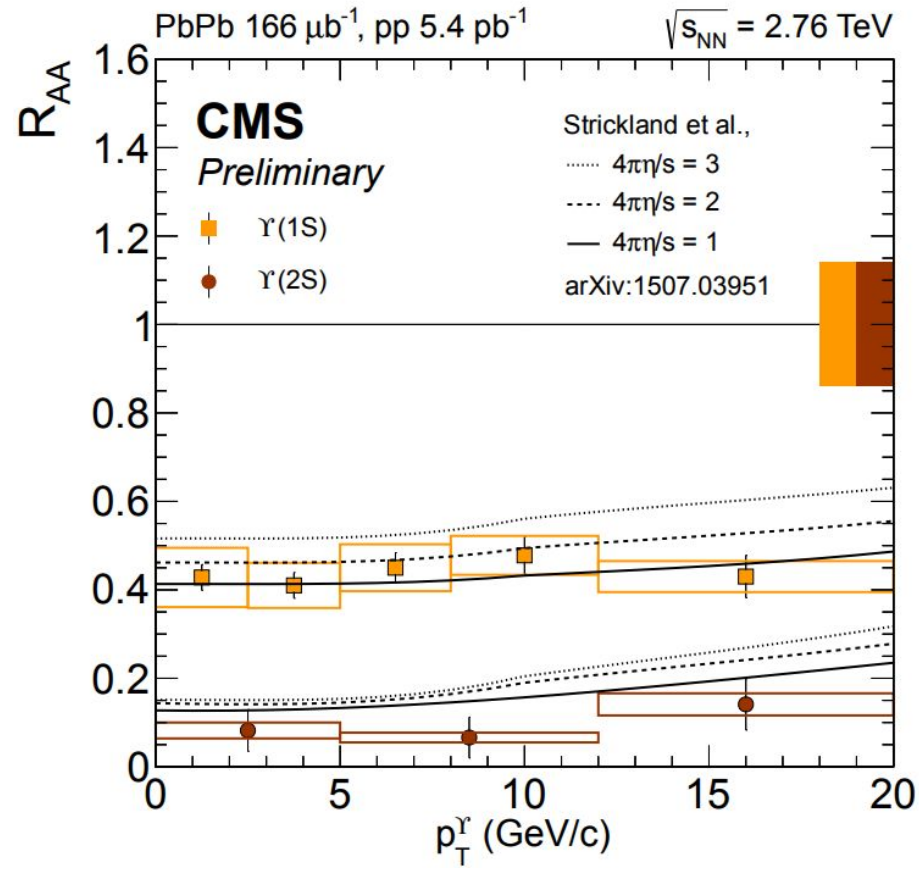
Nuclear Modification as a function of Centrality

- Overlaid with Kinetic Theory Model from Emerick, Zhao, Rapp
  - Dissociation + Regeneration
  - Fireball with T evolution
    - $T_0$ ~ 600 MeV



# Comparison with Predictions

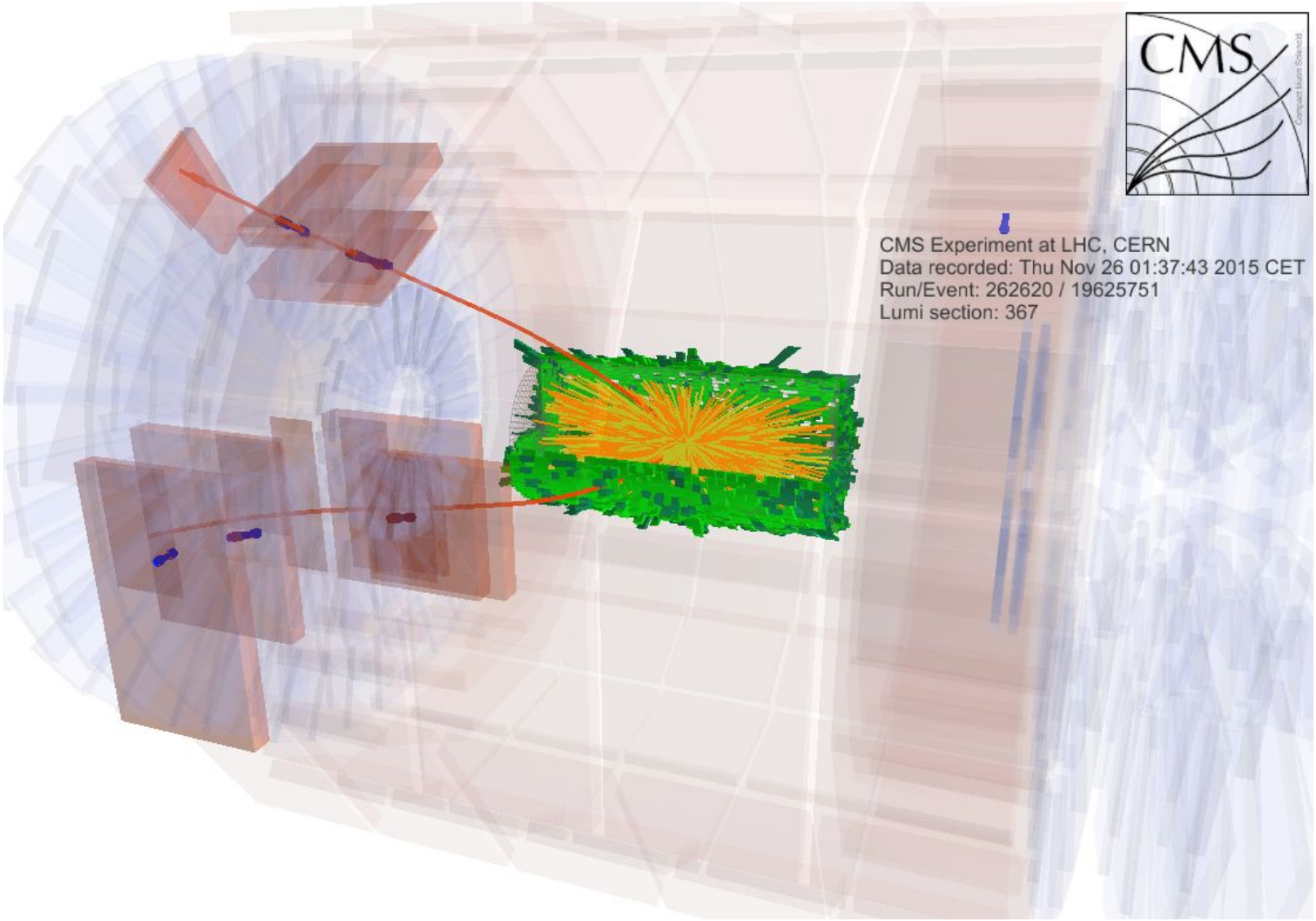



Nuclear Modification as a function of |y| and $p_T$

- Overlaid with thermal model from the Strickland and Bazow Model
  - In good agreement for $p_T$
  - As a function of |y| data seems to falls at forward instead of rise

# Upsilon Candidate - Run2

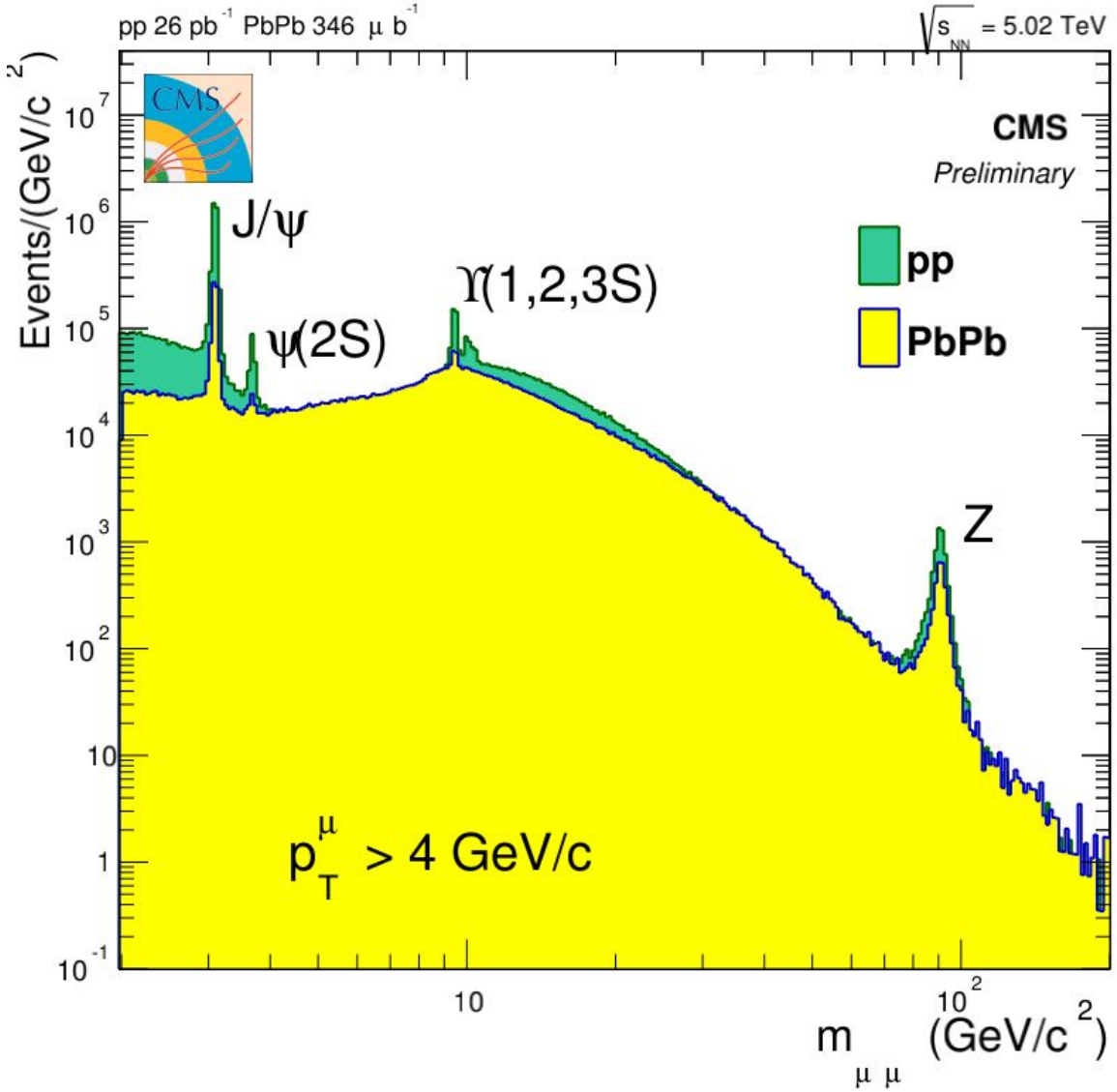


# Dimuon Invariant Mass in 5.02 TeV - Run2

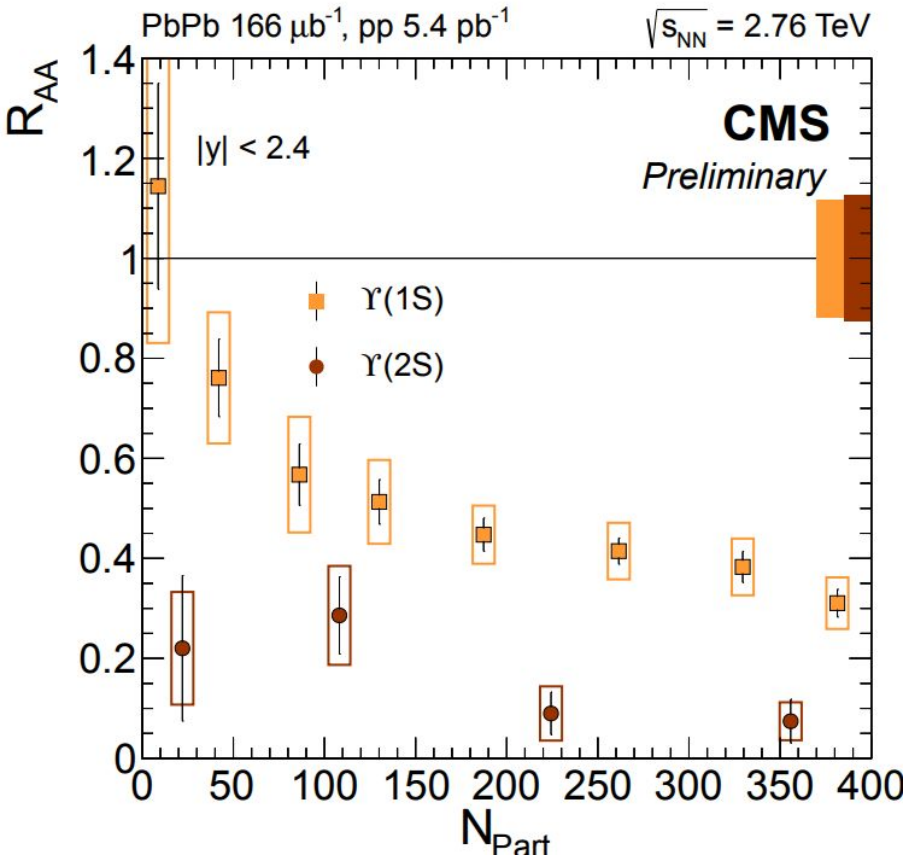
In CMS-PAS-HIN-15-001:
2013 pp data: $L_{int}$ = 5.4 $pb^{-1}$
2011 PbPb data: $L_{int}$ = 166 $\mu b^{-1}$

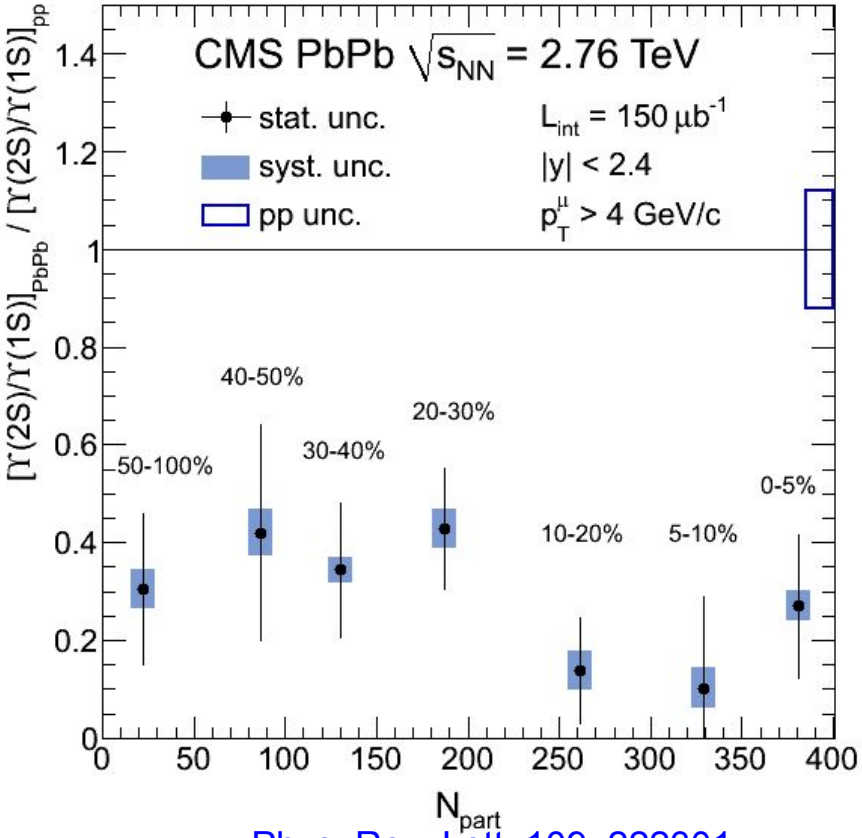
Current work:
2015 pp: $L_{int}$ = 26 $pb^{-1}$
2015 PbPb data: $L_{int}$ = 346 $\mu b^{-1}$

Have more beautiful data at higher energy!



# Outlook - Review



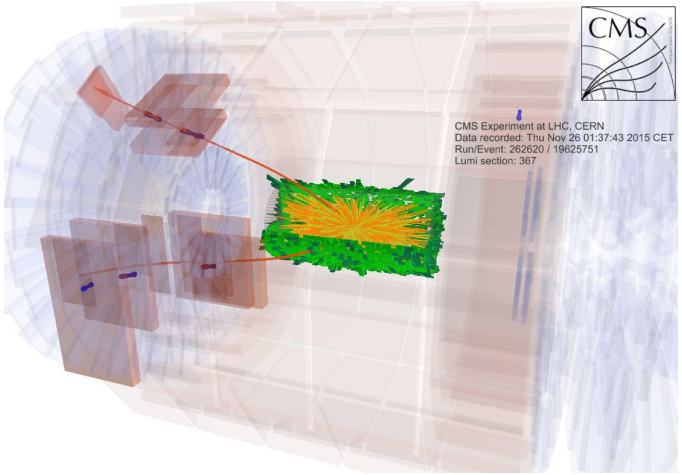

Phys. Rev. Lett. 109, 222301

- $R_{AA}$ measurement and Double Ratio have the same PbPb data but with differing pp samples
- Can we improve on these measurements with Run 2 data to better understand:
  - Double Ratio and $R_{AA}$ over centrality and more differentially?

# Conclusion

- CMS has extensively measured Upsilon production and nuclear modification.
  - PbPb
    - Suppression is dependent on event activity
    - Suppression is independent of Upsilon kinematics in $p_T$ and |y|
      - Rapidity dependence does not show forward rise as theory
    - Temperatures from model predictions tells us early onset temperatures
  - pPb
    - Final state effects present in Double Ratio.
    - Single Ratio for pp and pPb show decline vs. $N_{tracks}$

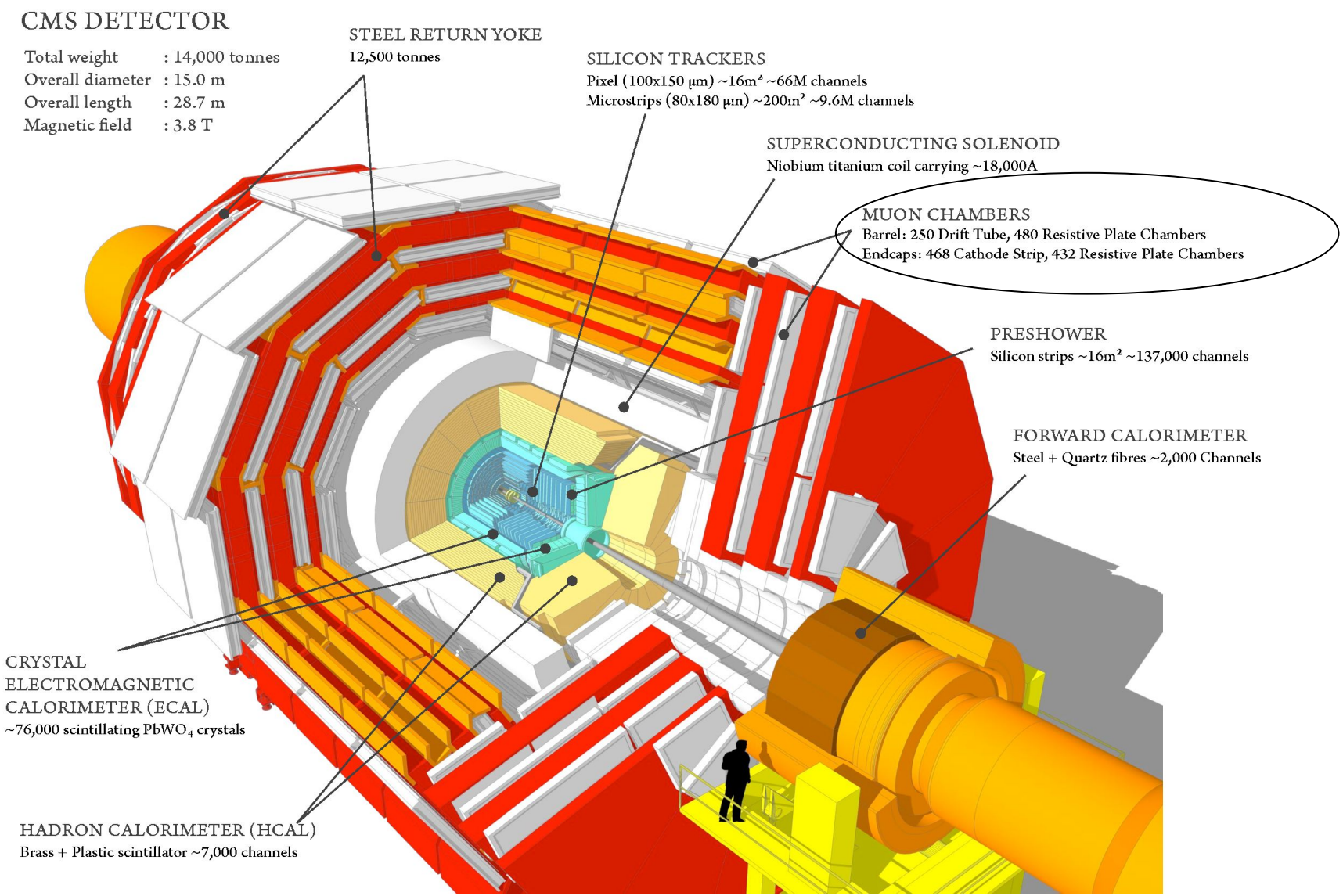
- CMS has collected a substantial amount of data in Run2.
  - Full results shall be coming soon!!!



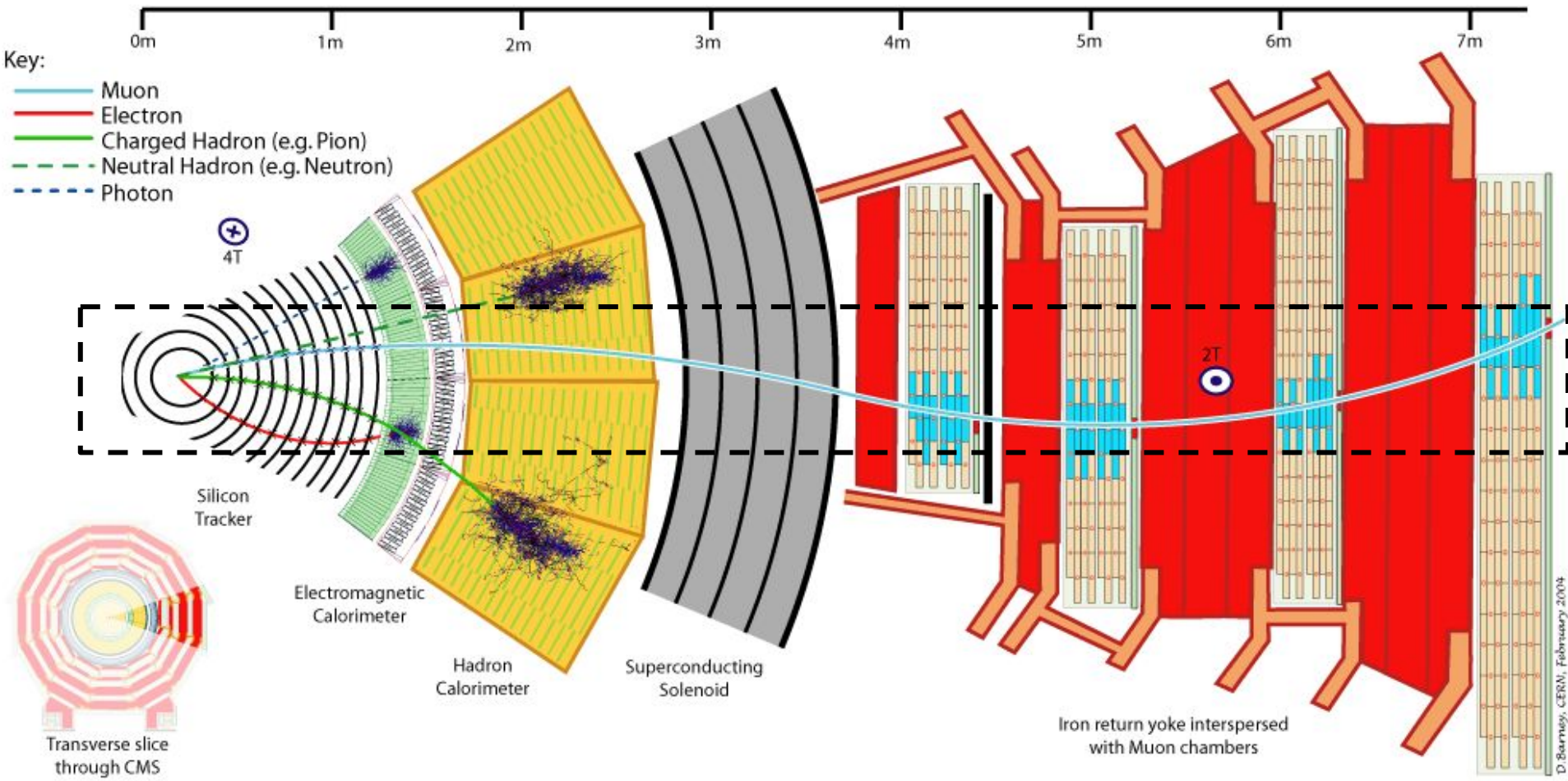
# THANK YOU!

# Back Up

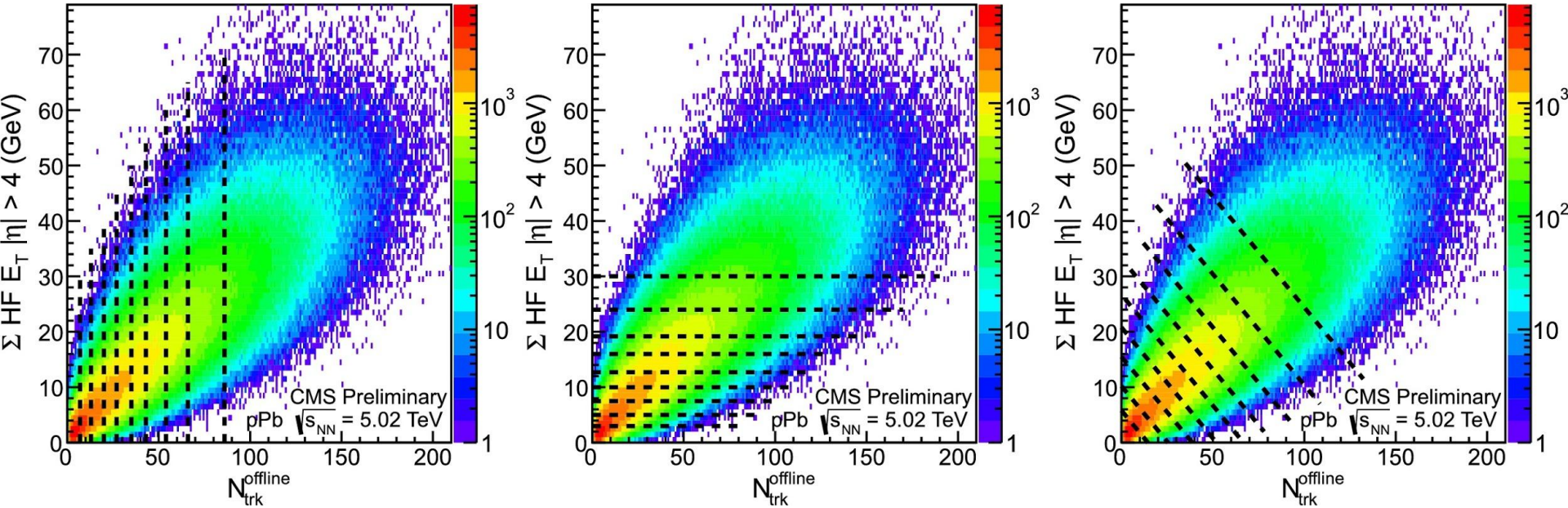
# CMS I


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 (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

# CMS II


0m
1m
2m
3m
4m
5m
6m
7m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
Transverse slice through CMS
D.Barney, CERN, February 2004

# $E_T$ and $N_{track}$




doi:10.1016/j.nuclphysa.2014.06.012

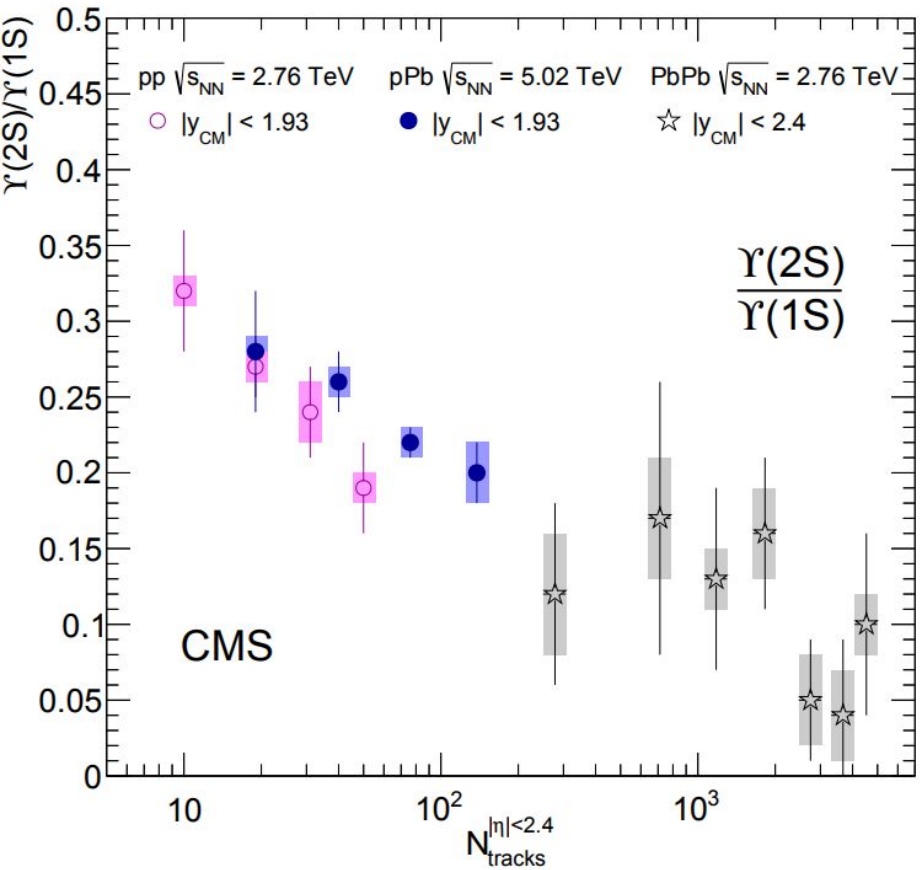
# Single Ratios in pp collisions

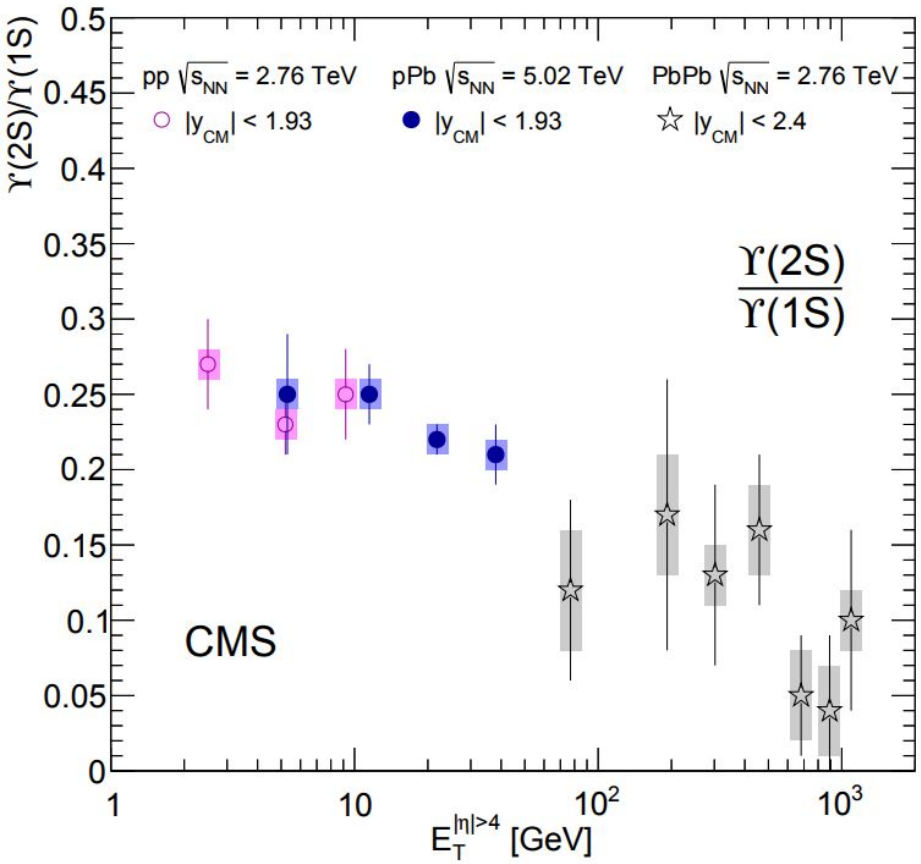
Table 1: The $\sqrt{s}$ dependence of the excited-to-ground-state cross section ratios, $\frac{\Upsilon(nS)}{\Upsilon(1S)}$, in pp and $p\bar{p}$ collisions. The total quoted uncertainties represent the quadratic sum of the statistical, systematic, and global uncertainties. Listed also are the Υ rapidity and transverse momentum ranges for which each measurement is reported.

| Data | $p_T$ [GeV/$c$] | Rapidity | $\frac{\Upsilon(2S)}{\Upsilon(1S)}$ total | $\frac{\Upsilon(3S)}{\Upsilon(1S)}$ total |
|---|---|---|---|---|
| CMS pp $\sqrt{s} = 2.76$ TeV | 0–40 | $\lvert y\rvert < 1.93$ | $0.26 \pm 0.02$ | $0.11 \pm 0.02$ |
| CMS pp $\sqrt{s} = 7$ TeV [33] | 0–38 | $\lvert y\rvert < 2.4$ | $0.26 \pm 0.03$ | $0.13 \pm 0.02$ |
| CDF $p\bar{p}$ $\sqrt{s} = 1.9$ TeV [34] | 1–10 | $\lvert y\rvert < 0.4$ | $0.28 \pm 0.05$ | $0.16 \pm 0.03$ |

- **Consistent in 3 energies from CDF to CMS**

# Single Ratios

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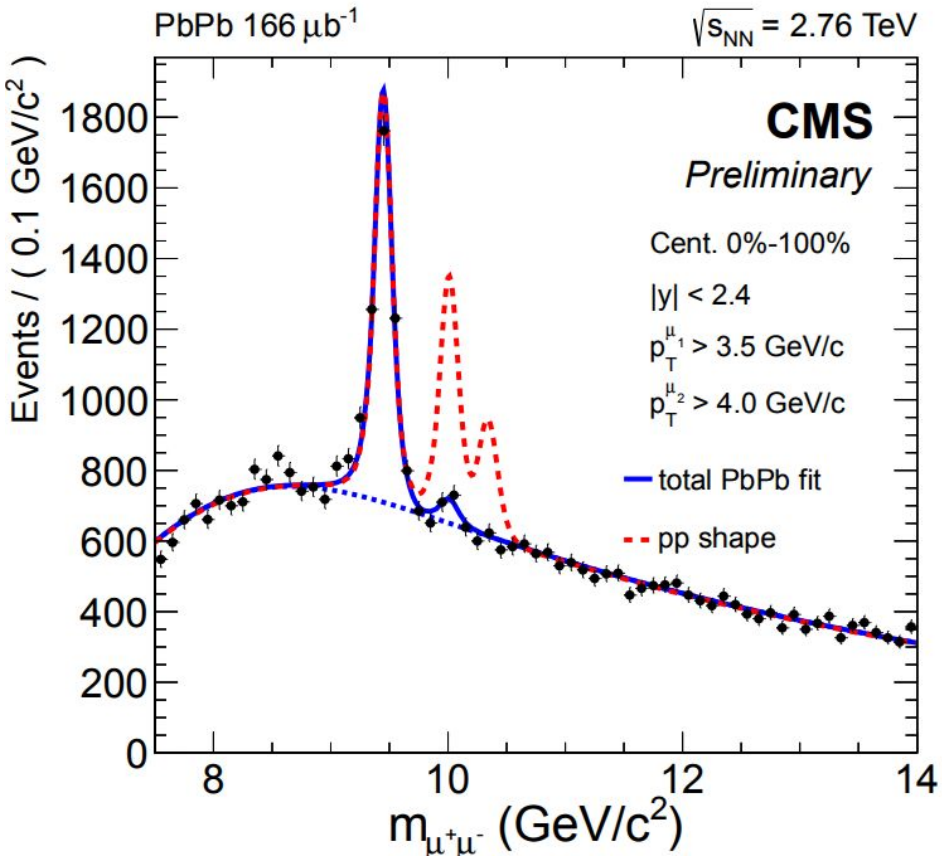
# Back Up


PbPb 166 μb-1
√sNN = 2.76 TeV
CMS
Preliminary
Cent. 0%-100%
|y| < 2.4
pT μ1 > 3.5 GeV/c
pT μ2 > 4.0 GeV/c
total PbPb fit
pp shape
Events / ( 0.1 GeV/c2 )
0
200
400
600
800
1000
1200
1400
1600
1800
8
10
12
14
mμ+μ- (GeV/c2)