J/ψ Production and Suppression from pp to Pb-Pb Collisions at the CMS

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For the CMS Collaboration

Outline

- Quarkonia in heavy ion Collisions
- CMS detector
- Quarkonia measurement in CMS
- J/ψ and $\psi(2s)$ measurement in pp collisions
- J/ψ measurement in Pb+Pb collisions
- Summary

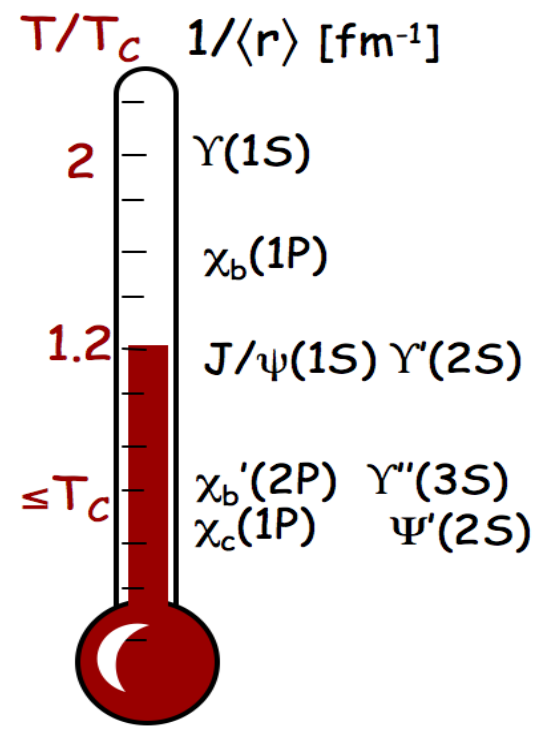
Quarkonia in Heavy Ion Collisions

- At large energy densities (large density and/or temperature), a new form of matter exists, in which the relevant degree of freedom are quarks and gluons known as Quark Gluon Plasma (QGP).
- Aim of Heavy Ion Collisions at high energies is to create, characterize and quantify the properties of QGP.
- Color screening in QGP is expected to prevent the formation of quarkonium states in deconfined matter.

- One of the most striking expected characteristic of QGP is suppression of quarkonium states J/ψ, ψ', χ_c, ϒ(1s,2s,2s).

- Different states are expected to dissociate at different temperatures, sequentially according to their binding energies.

- Measurement of a suppressed quarkonium yield may provide direct experimental sensitivity to the temperature of the medium created in high energy nuclear collisions.



arXiv:0811:0337

J/ψ Suppression at SPS and RHIC

- Similar suppression at SPS and RHIC energies

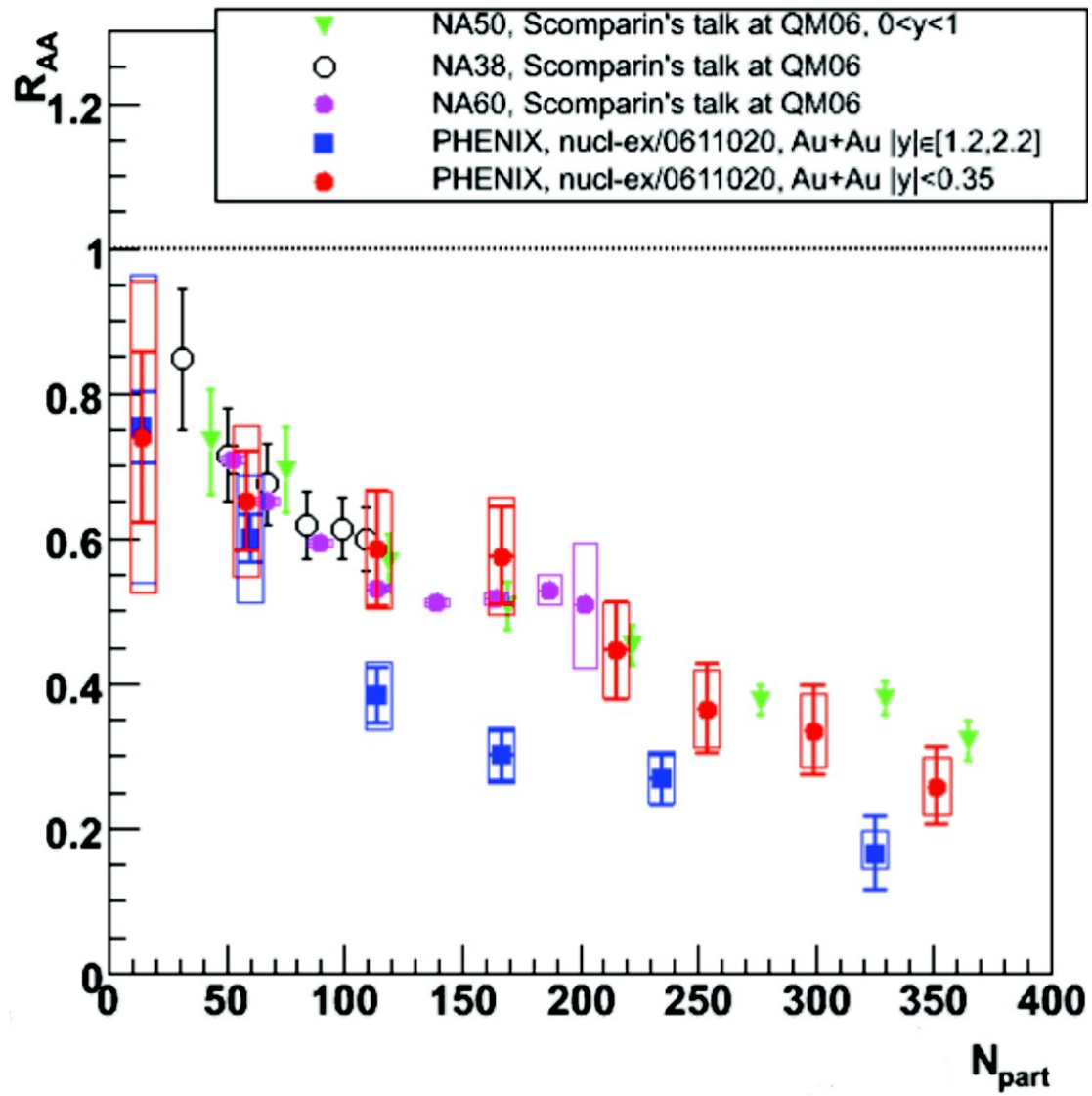
R_{AA} (RHIC, |y|<0.35) ≈ R_{AA} (SPS)

- New observation at RHIC: Suppression is more in forward rapidity region

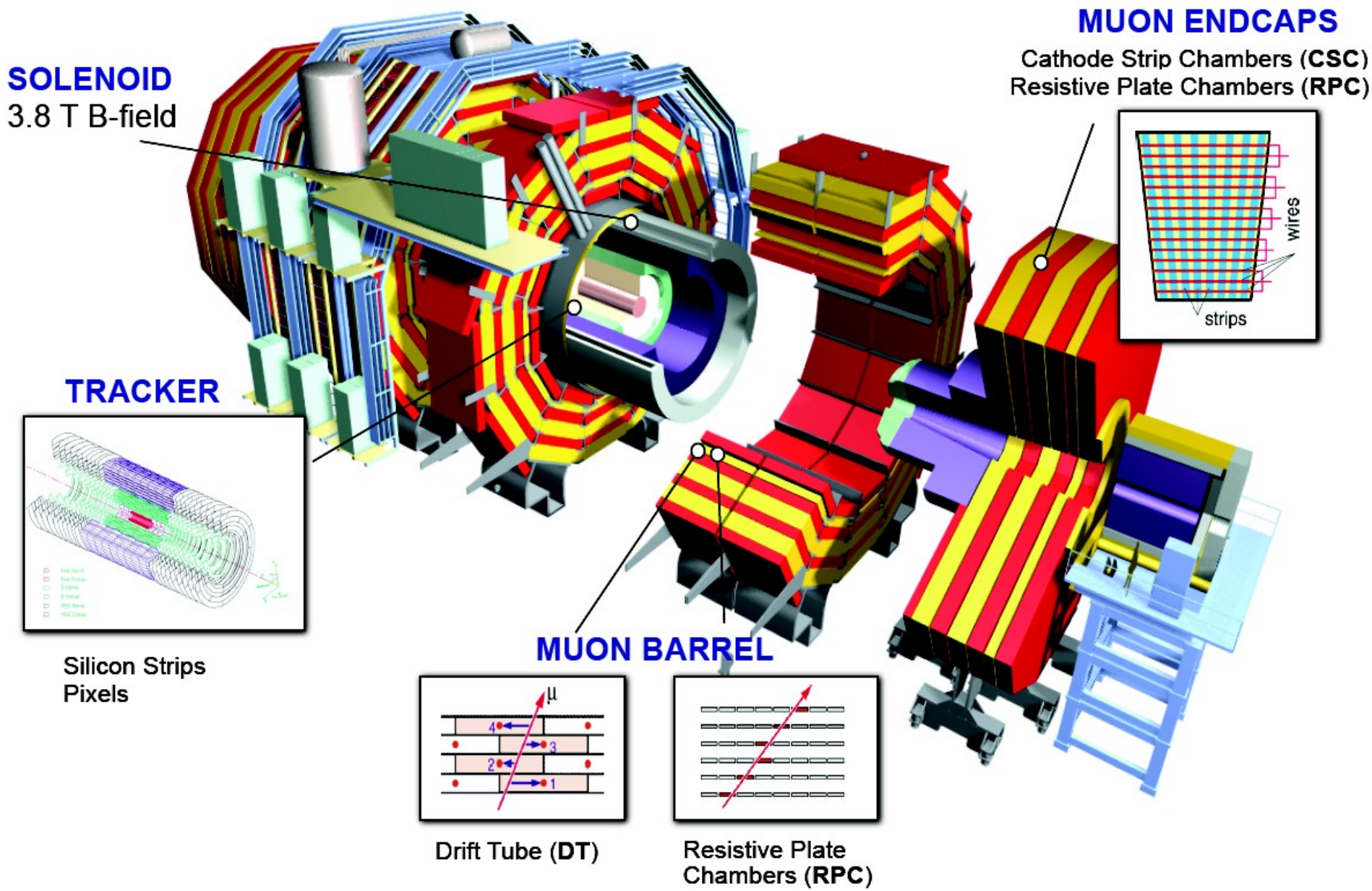
R_{AA} (|y|<0.35) > R_{AA} (1.2<|y|<2.2)

- Factors at work in nuclear collisions

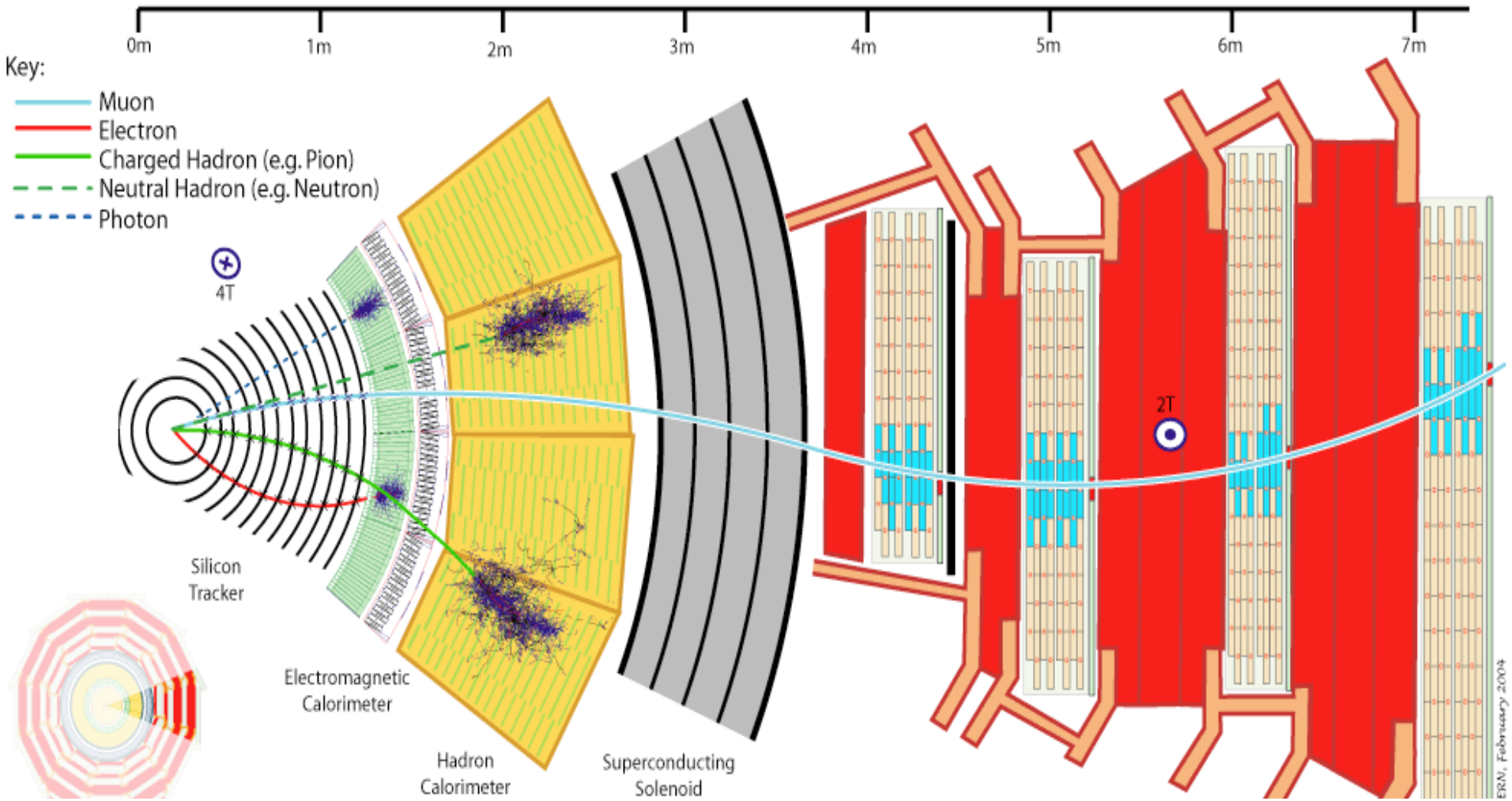
  - Shadowing/gluon saturation
  - Nuclear/comover interaction
  - Sequential melting
  - Regeneration
  - Some combination of all



CMS (Compact Muon Solenoid) Detector



Muon Reconstruction in CMS



Global Muons: match inner tracker track with track in muon station

Tracker Muons: match inner tracker track with signal in muon station

Quarkonia in CMS

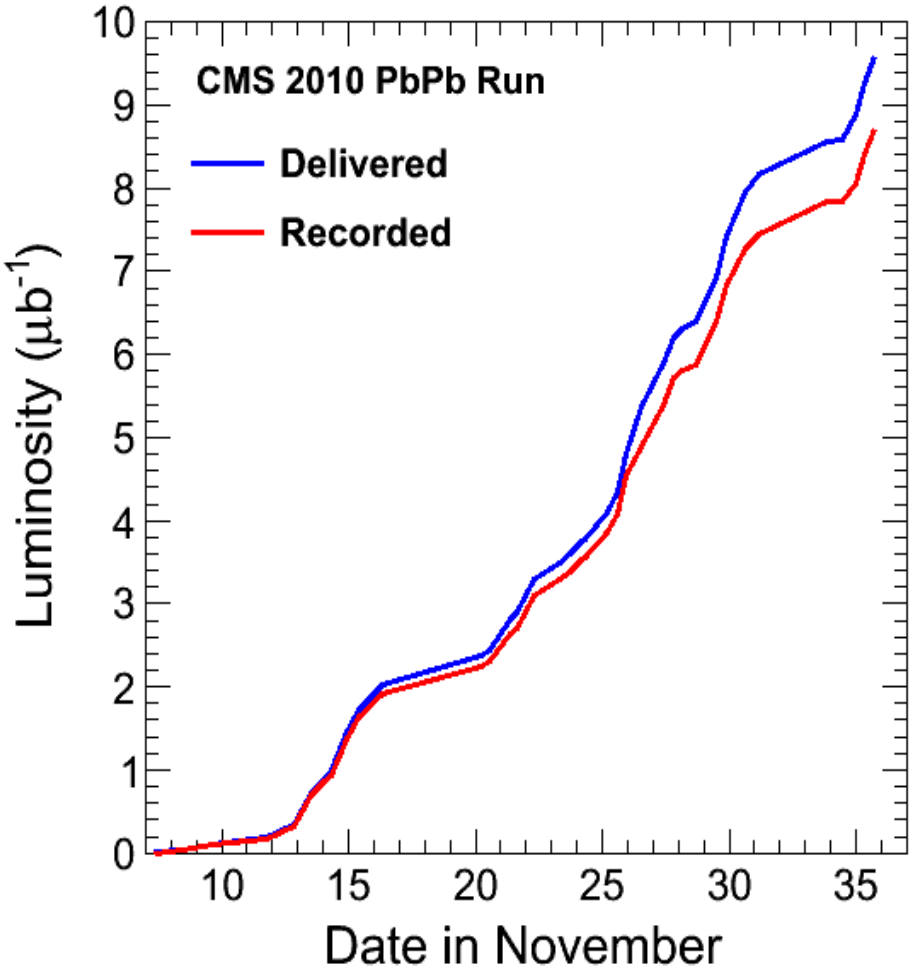
- Precision quarkonia physics

High statistics pp run $\sqrt{s}$=7 TeV
~ L_{int}= 2 fb^{-1}

- Quarkonia results for L_{int}=40 pb^{-1}
- Prompt and non prompt separation

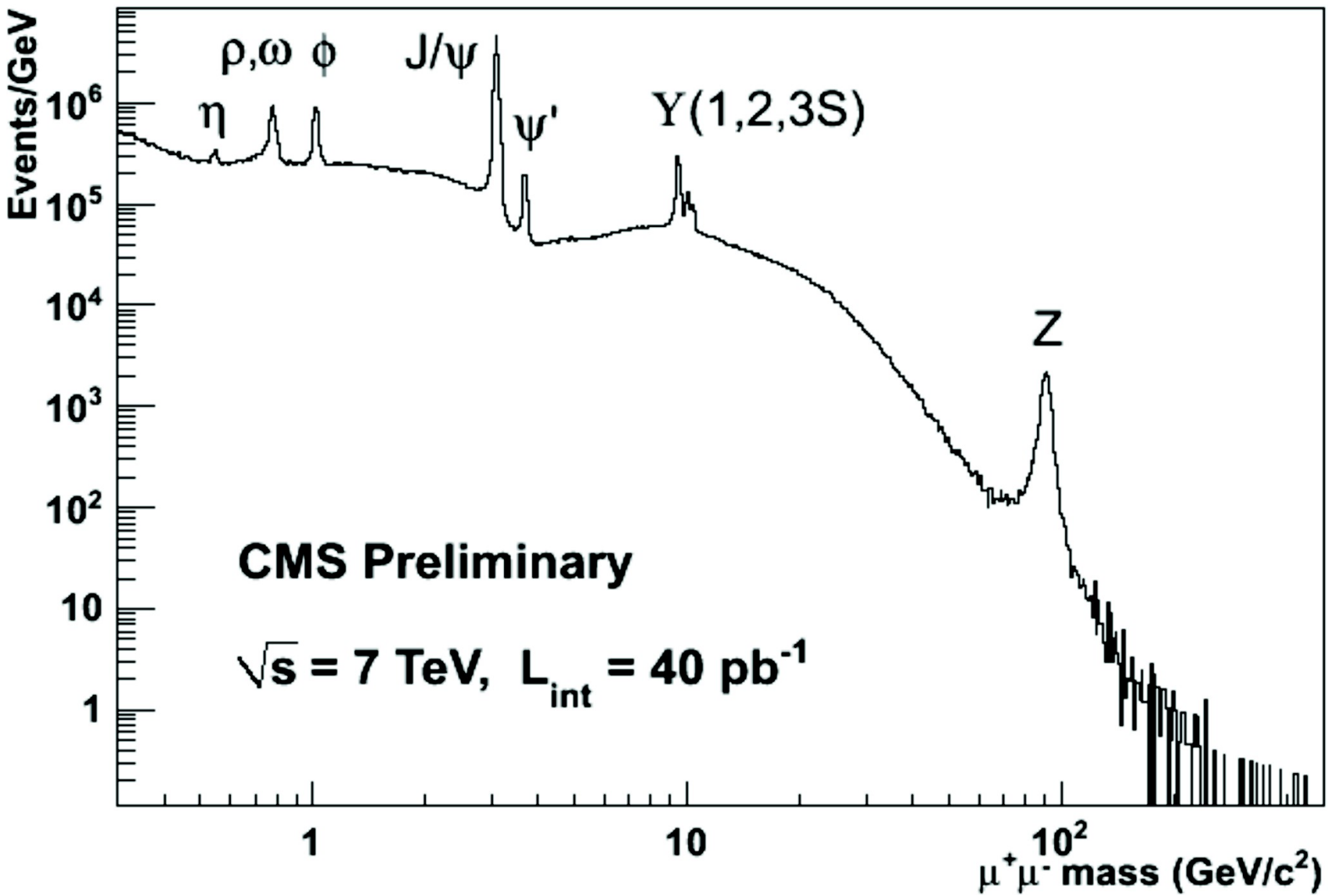
- Nuclear modification factor

- PbPb $\sqrt{s_{NN}}$=2.76 TeV L_{int}=7.28 μb^{-1}
- pp $\sqrt{s}$=2.76 TeV L_{int}=225 nb^{-1}
- Similar hard probes statistics
- Good reference
- Same reconstruction algorithm

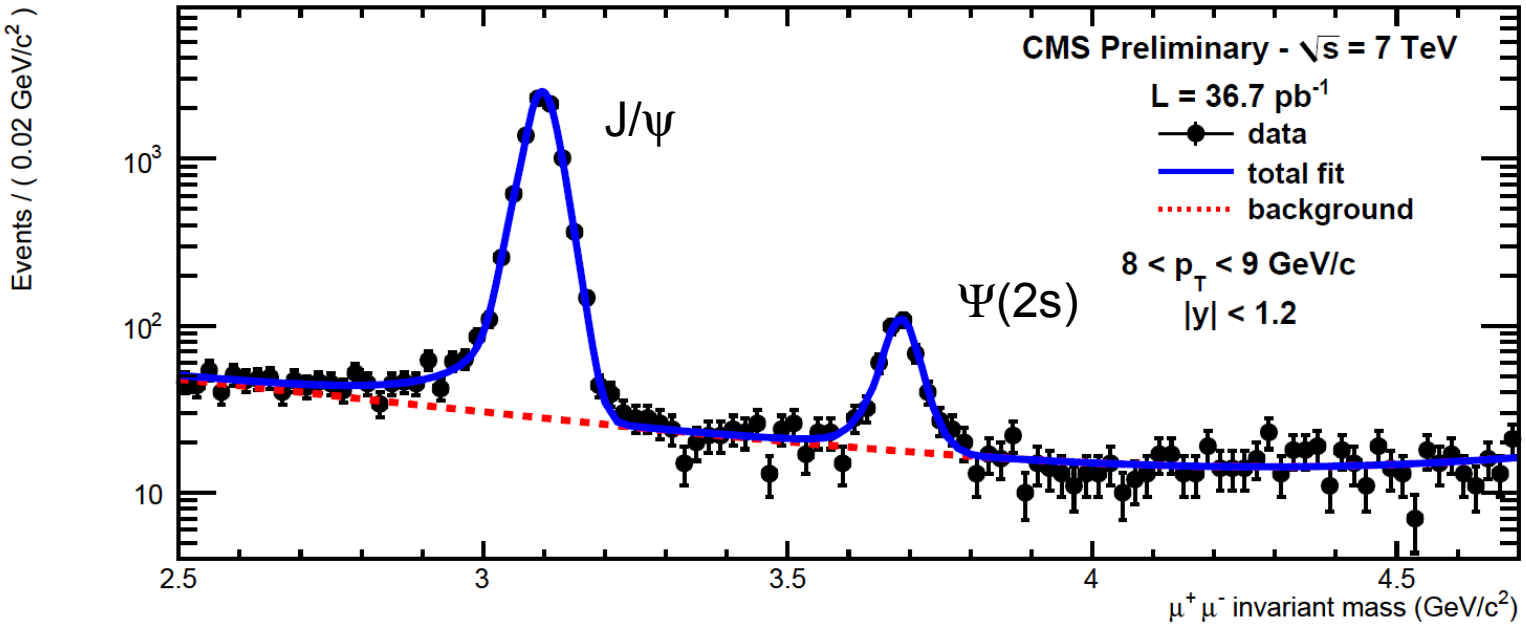


J/ψ in pp collisions with CMS

Dimuons by CMS in pp Collisions

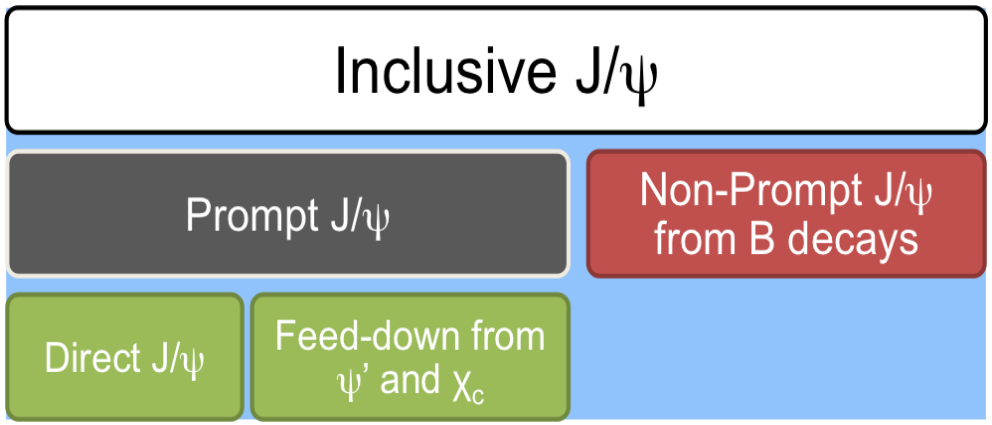


J/ψ and ψ (2s) Measurement by CMS in pp collisions

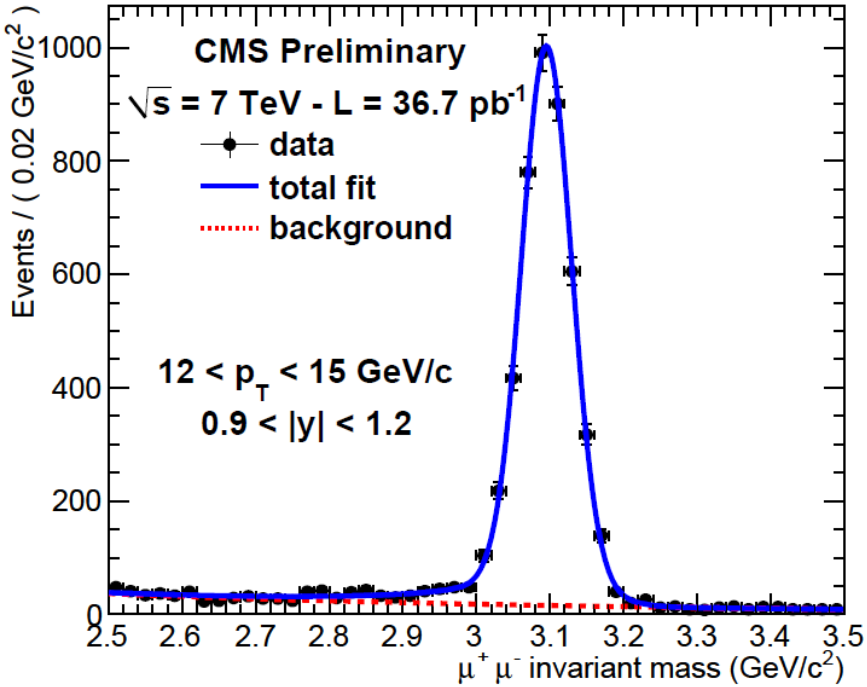


- Gaussian + Crystal Ball for signal
- Exponential for background.

CMS PAS BPH-10-14



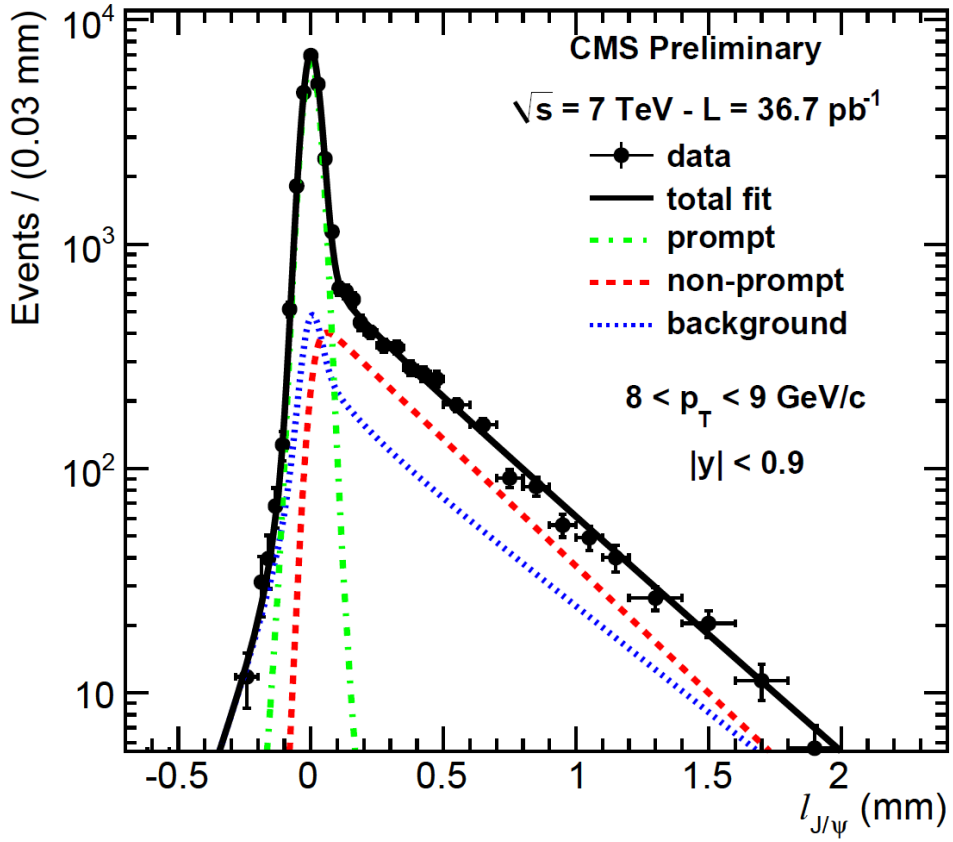
- Inclusive J/ψ : Production mechanism
- Non prompt J/ψ : b quark



Non prompt J/ψ and ψ(2s)

- Reconstruct dimuon vertex
- L_{xy} is distance of dimuon vertex from primary vertex in a plane orthogonal to beam direction.
- $l_{J/\psi}$ (Pseudo-proper decay length)

  $l_{J/\psi} = L_{xy} \cdot M_{J/\psi} / p_T$
- Simultaneous fit of Invariant mass and Pseudo-proper decay length



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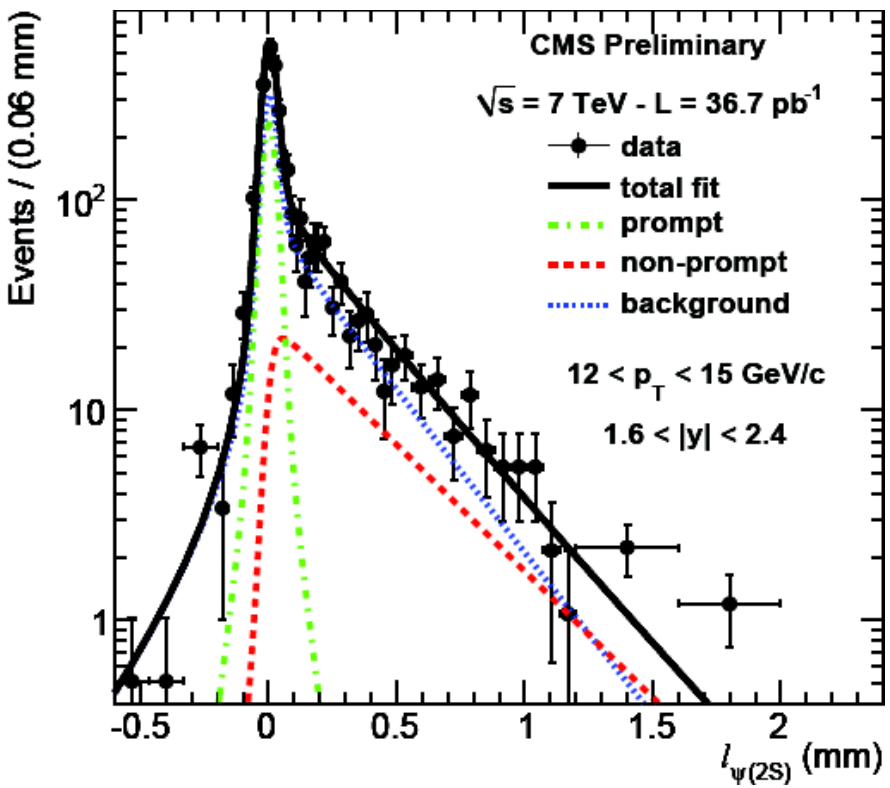
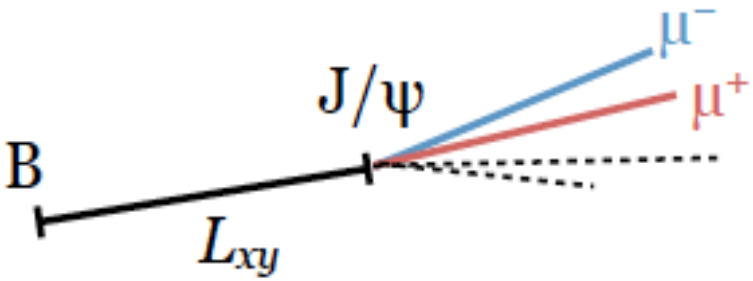
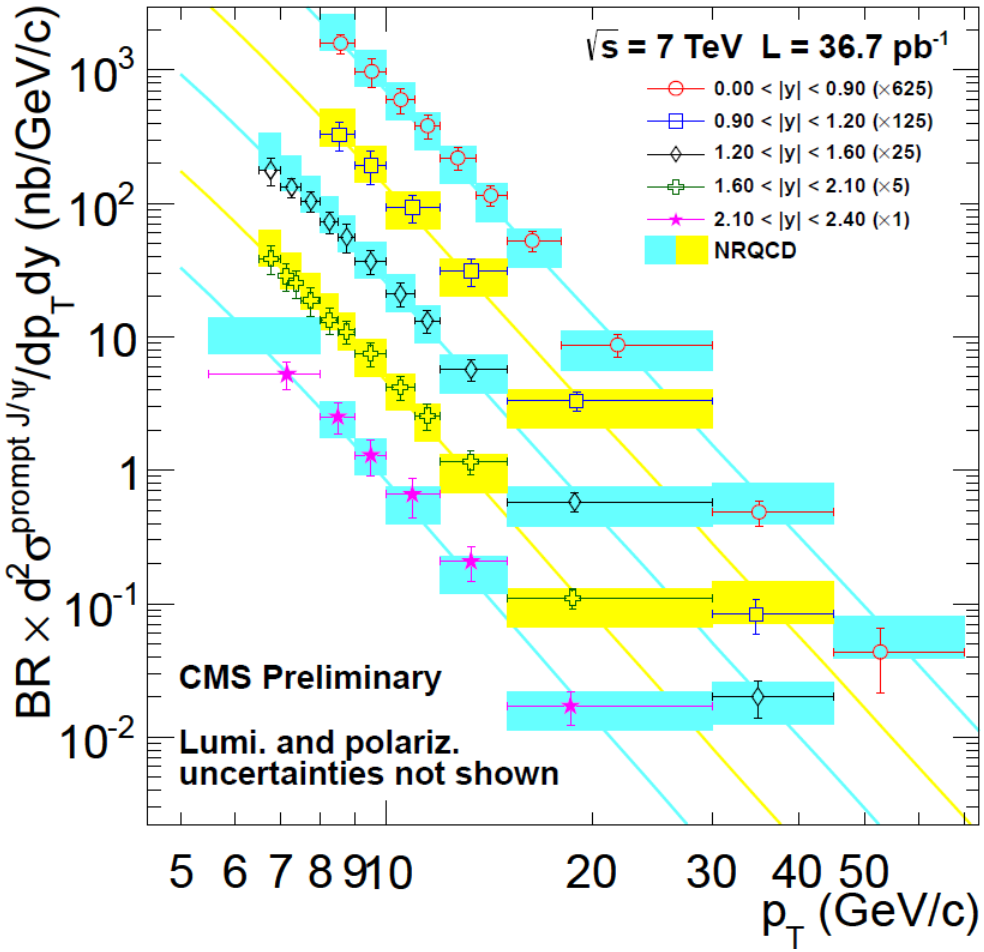
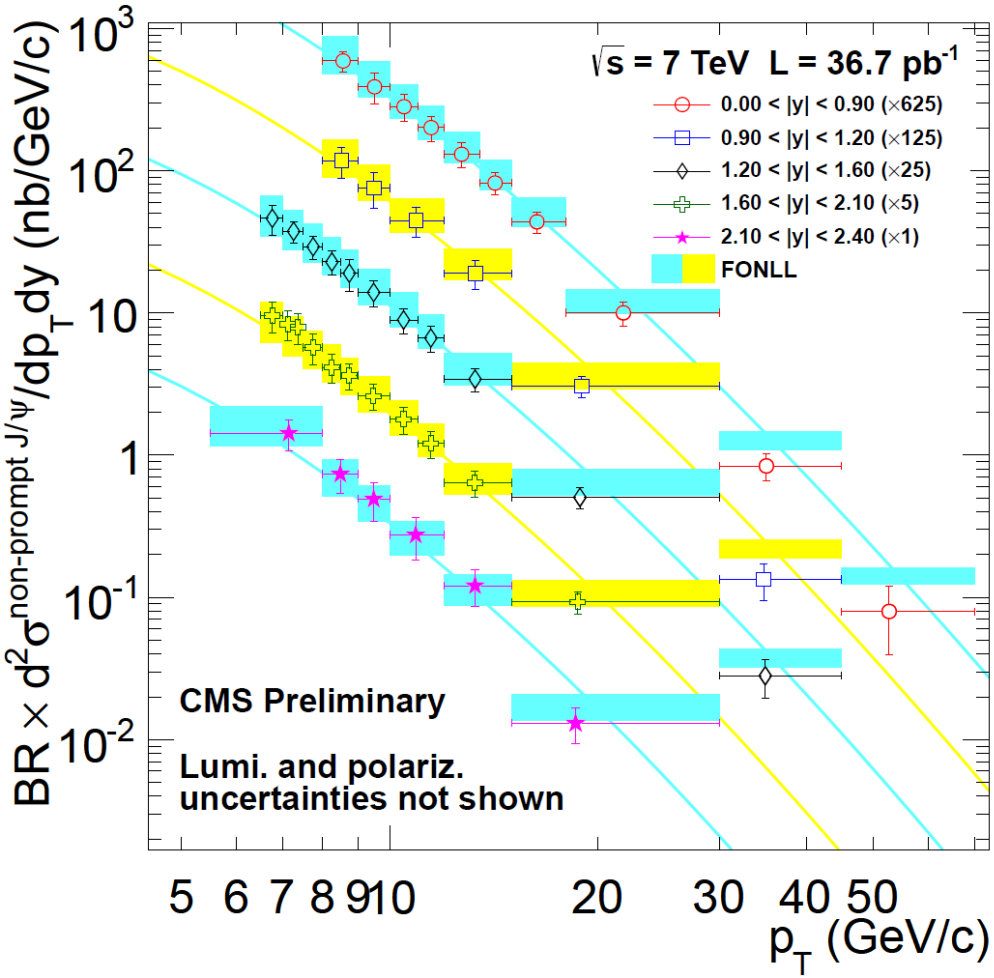




J/ψ Production cross section





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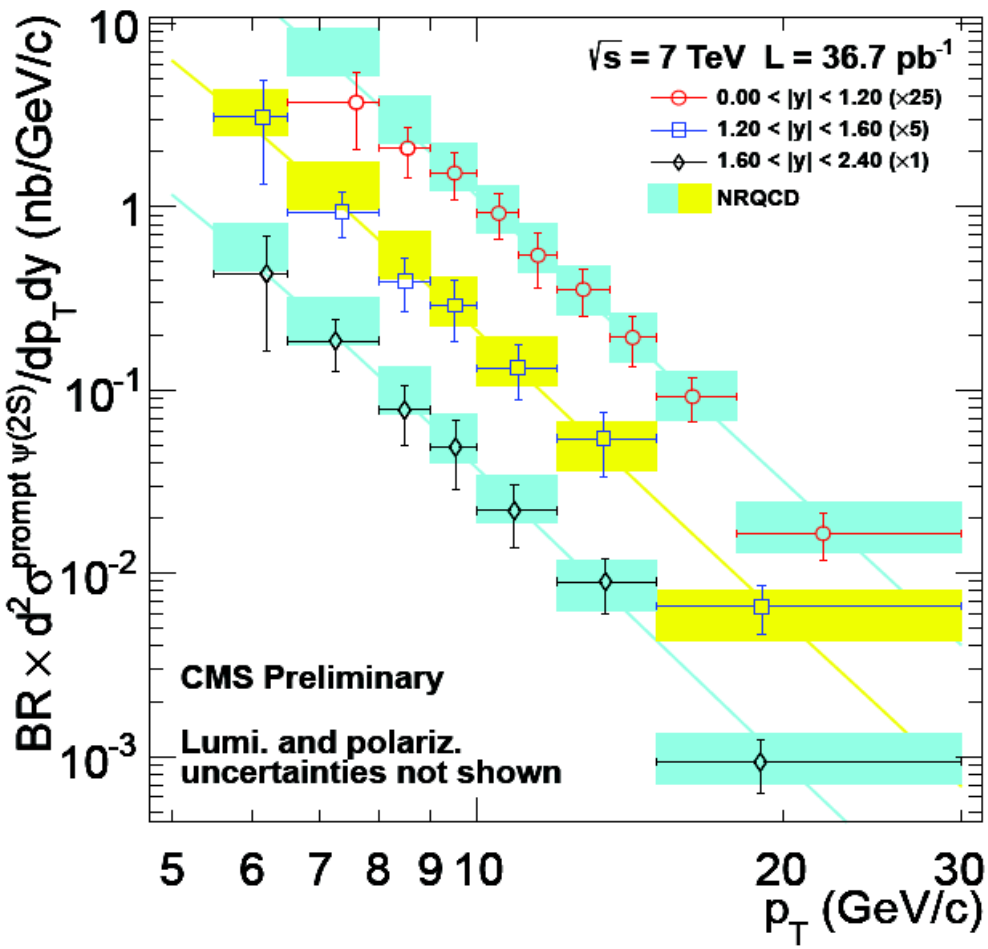
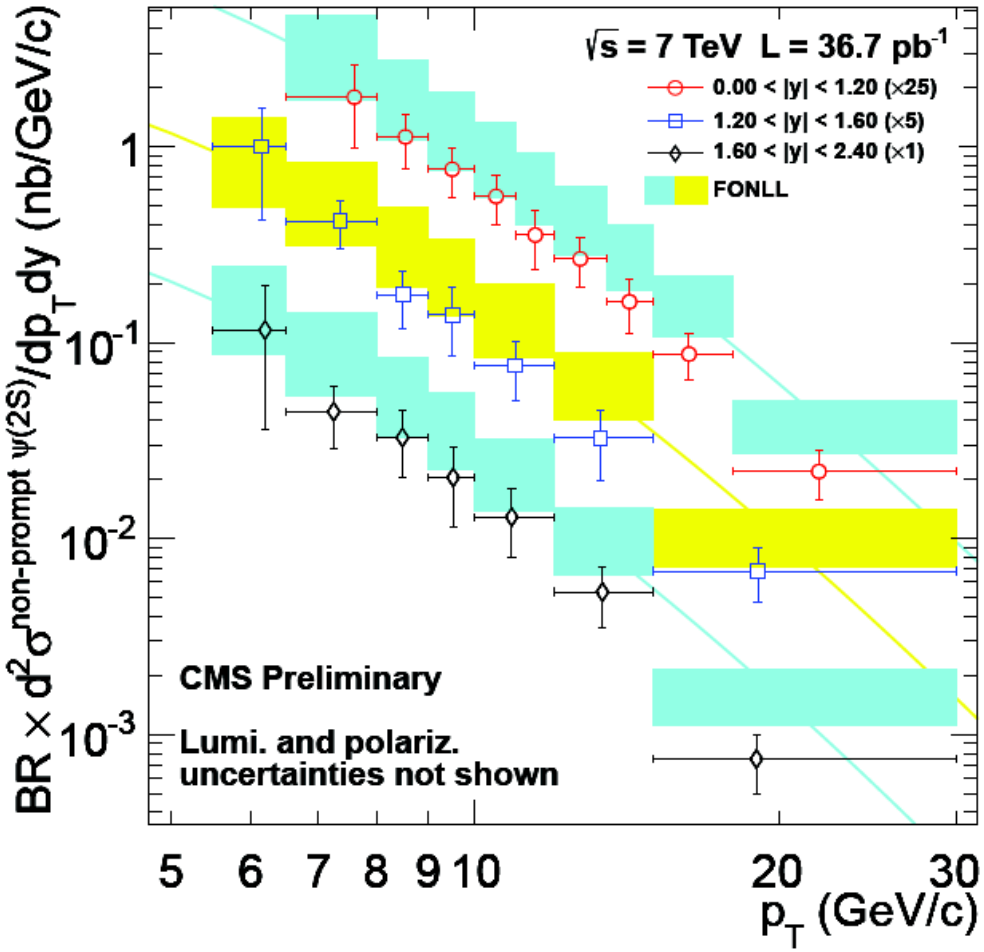
- Prompt and non J/ψ production cross section is measured at 7 TeV.
- Cross section is compared with NRQCD and FONLL predictions.
- Reasonable agreement except for non-prompt cross-sections at high p_T

ψ(2s) Production cross section





CMS PAS BPH-10-14

- Prompt and non ψ (2s)production cross section is measured at 7 TeV.
- Good agreement with NRQCD predictions.
- Observed cross section fall more rapidly than the FONLL calculations at high p_T.

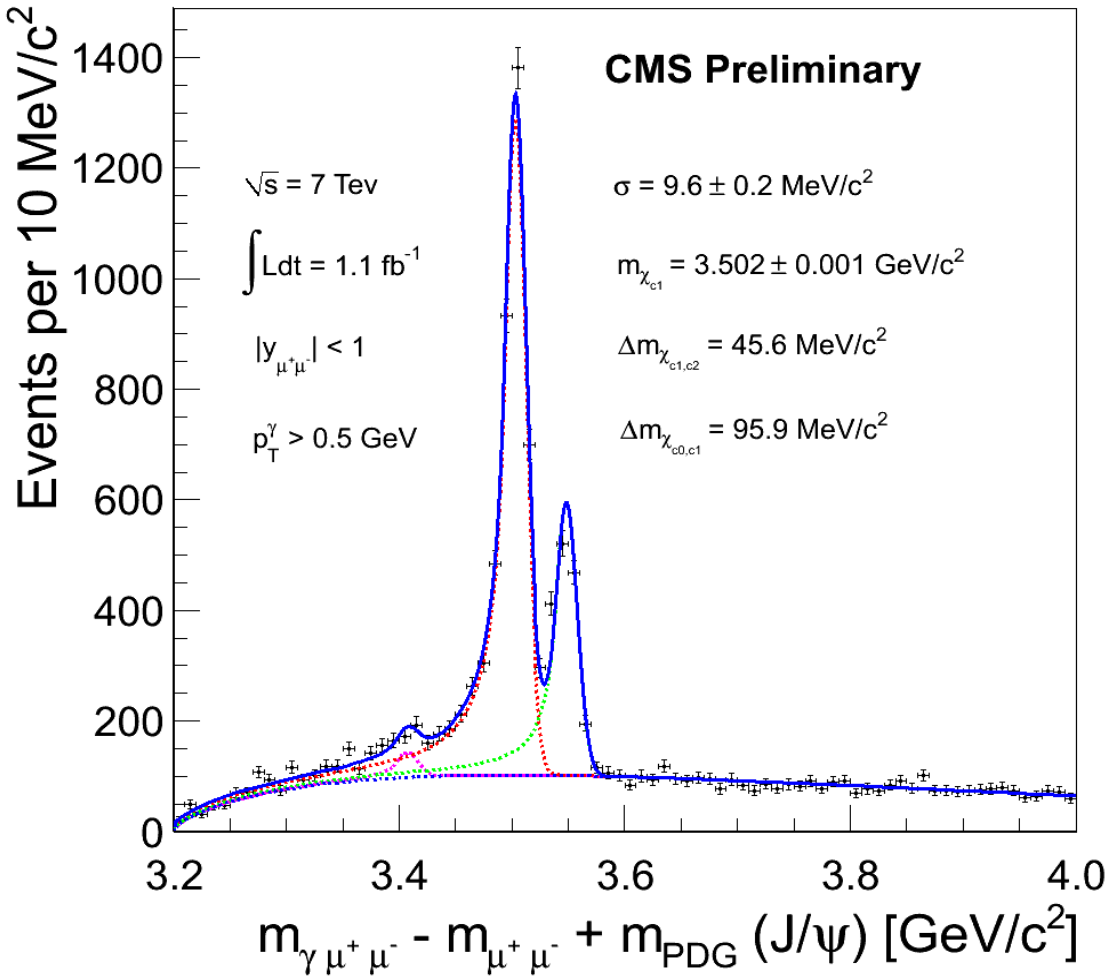
Excited charmonium states in pp colissions

- Measured radiative decay of:

$\chi_c \rightarrow J/\psi + \gamma$

- Reconstruct γ conversions.
- Excellent mass resolution

Separate $\chi_{c,1}$ and $\chi_{c,2}$



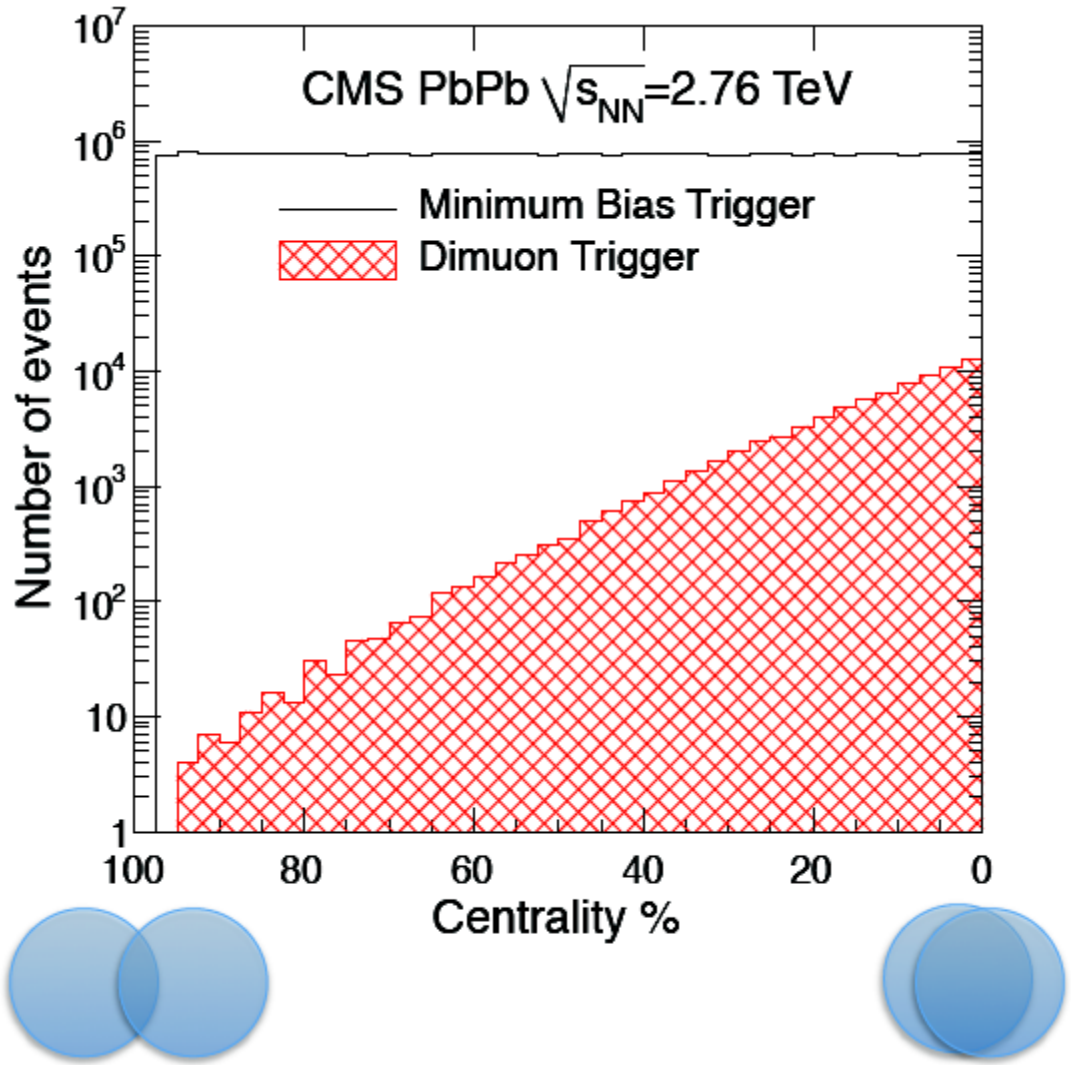
J/ψ in PbPb collisions with CMS

Event Selection

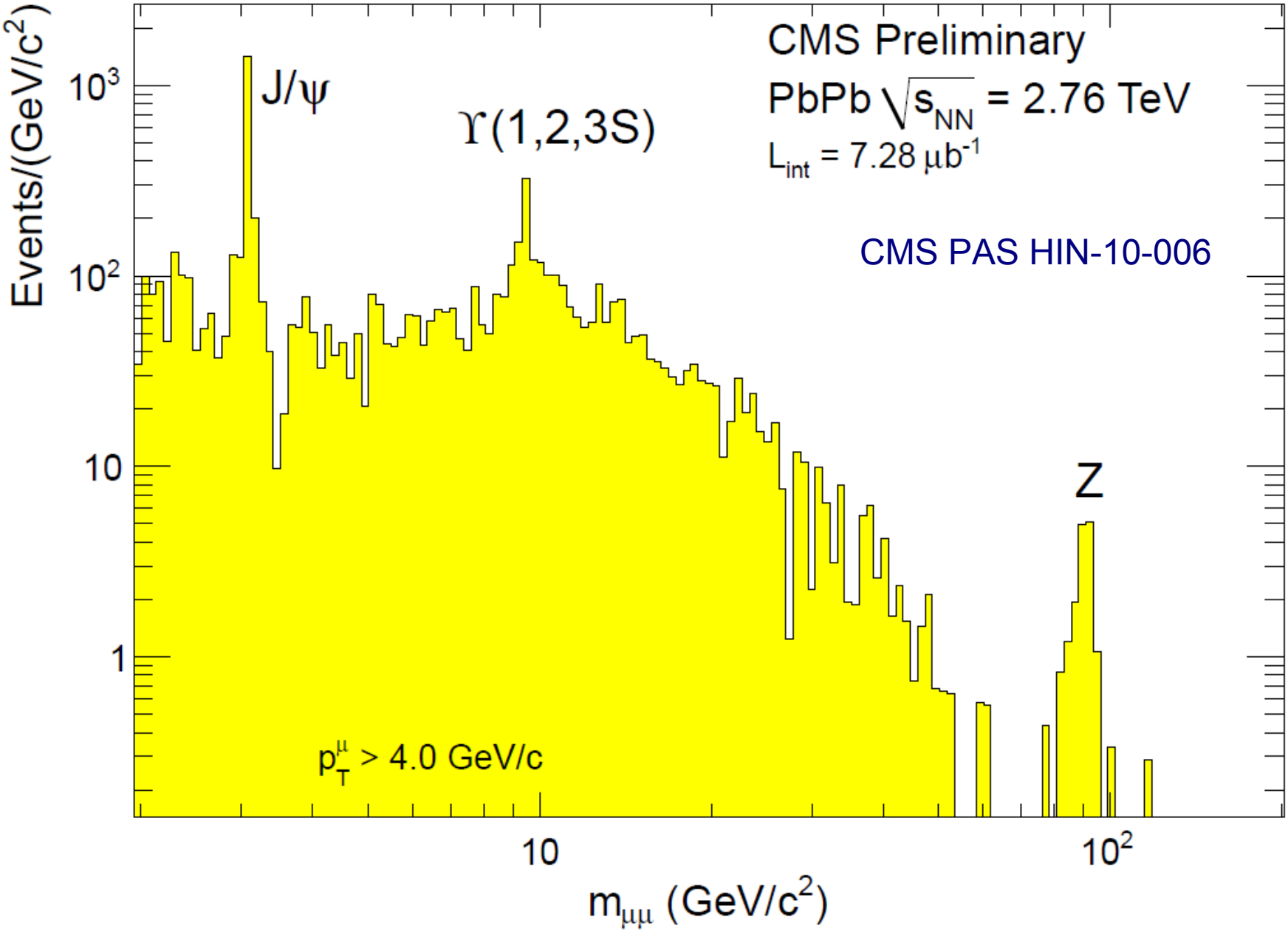
- Hadronic PbPb Collision Selection
  - Hits in both Beam Scintillator Counter Detectors and Forward Hadronic Calorimeters (HF)
  - Bunch crossing identified by the Beam Pick-up Timing Experiment Detectors (BPTX)

- Offline Selection
  - Coincidence of 3 HF towers above threshold
  - Selection of at least a two-track fitted vertex
  - Cluster-shape filter re-run offline

- Dimuon Trigger
  - HLT HIL1DoubleMuOpen



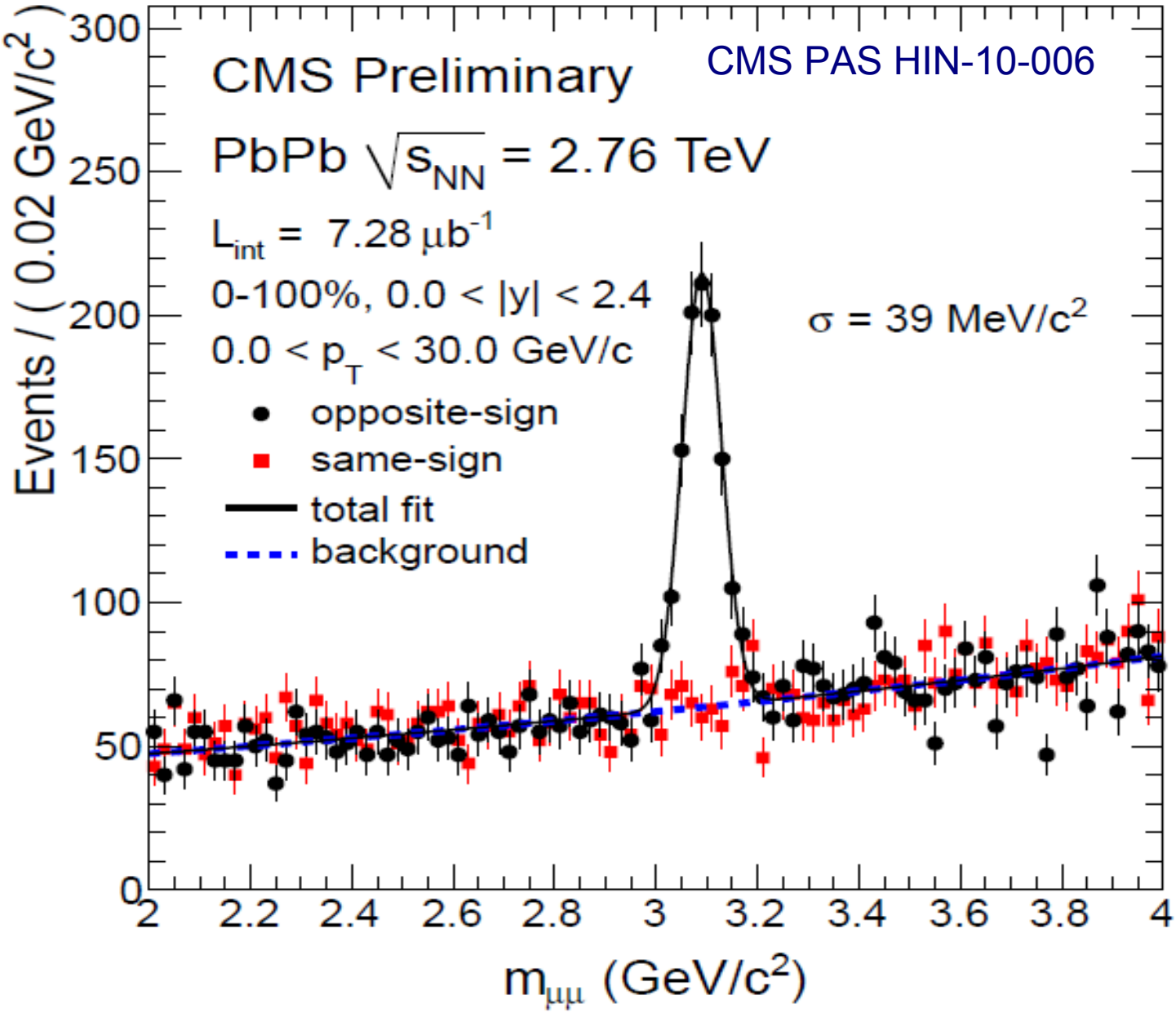
Muon Pairs in Pb Pb Collisions



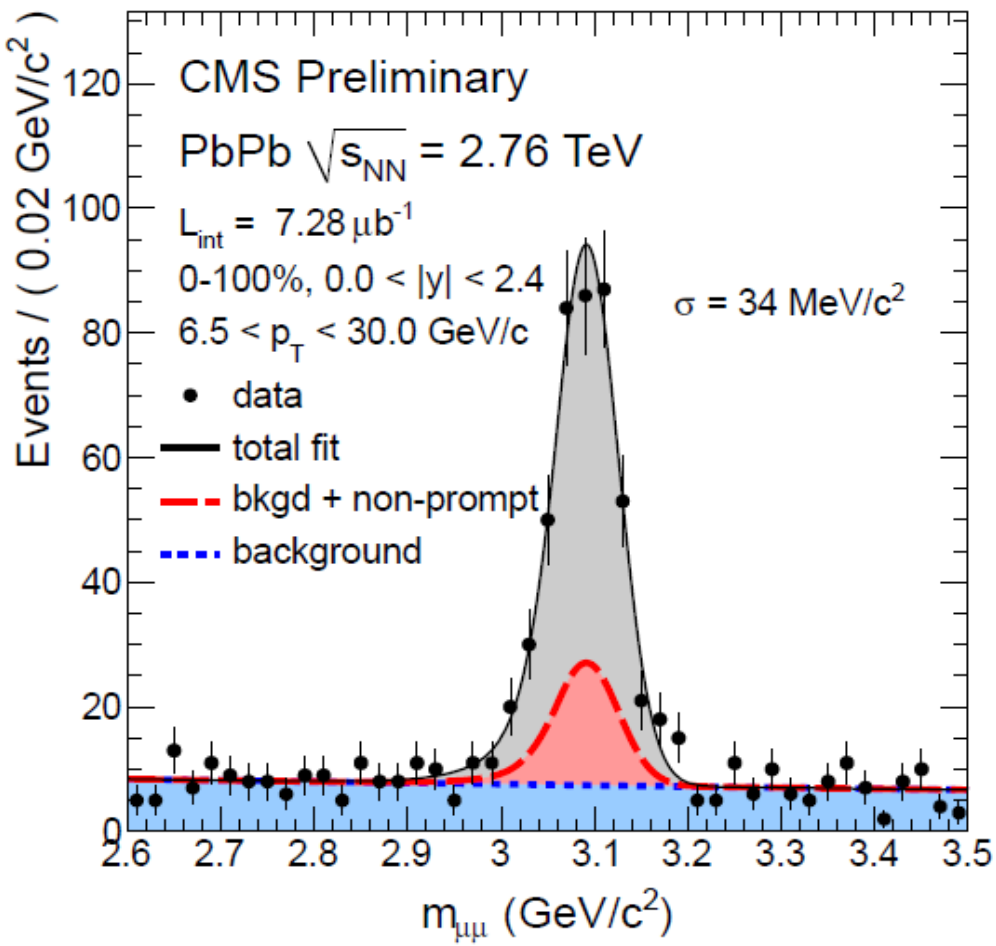
J/ψ in PbPb at $\sqrt{s_{NN}}$ = 2.76 TeV

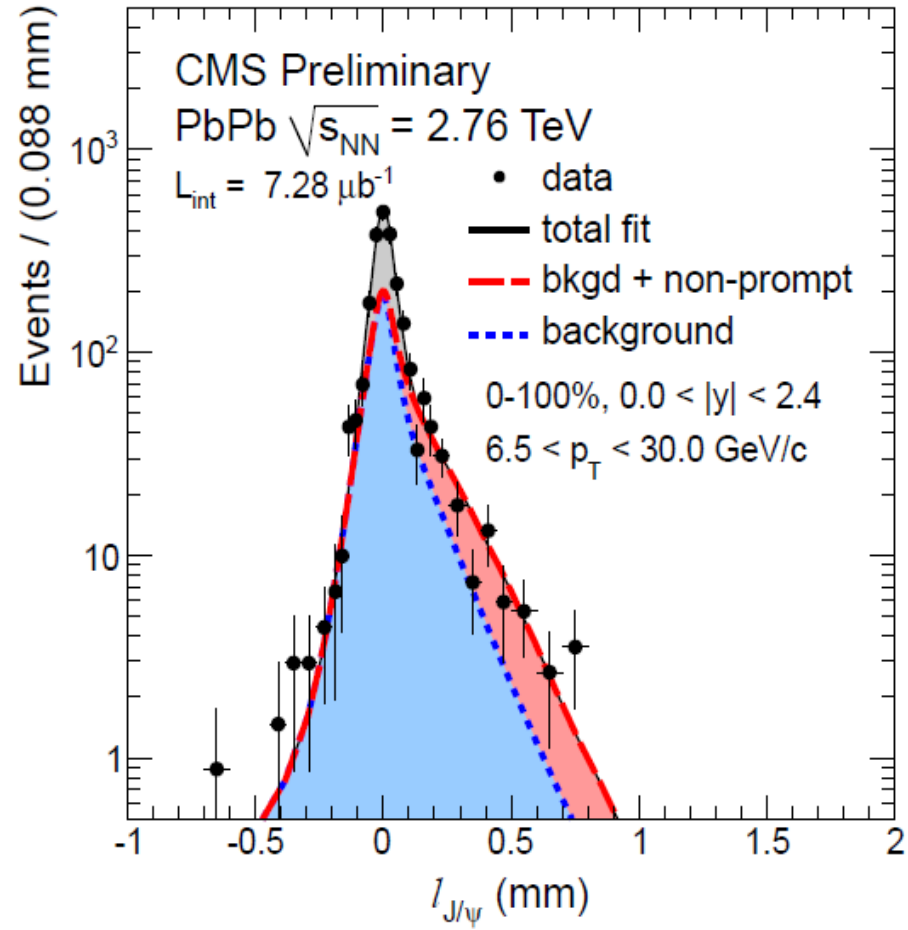
- Signal is fitted by Gaussian + Crystal Ball Function
- Background is constrained by exponential
- Similar resolution as in pp collisions
- Inclusive J/ψ yield

734 ± 54



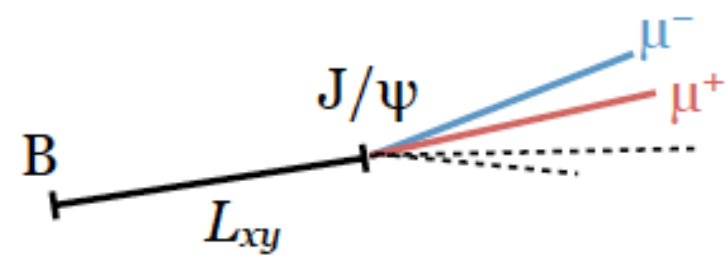
Non Prompt J/ψ



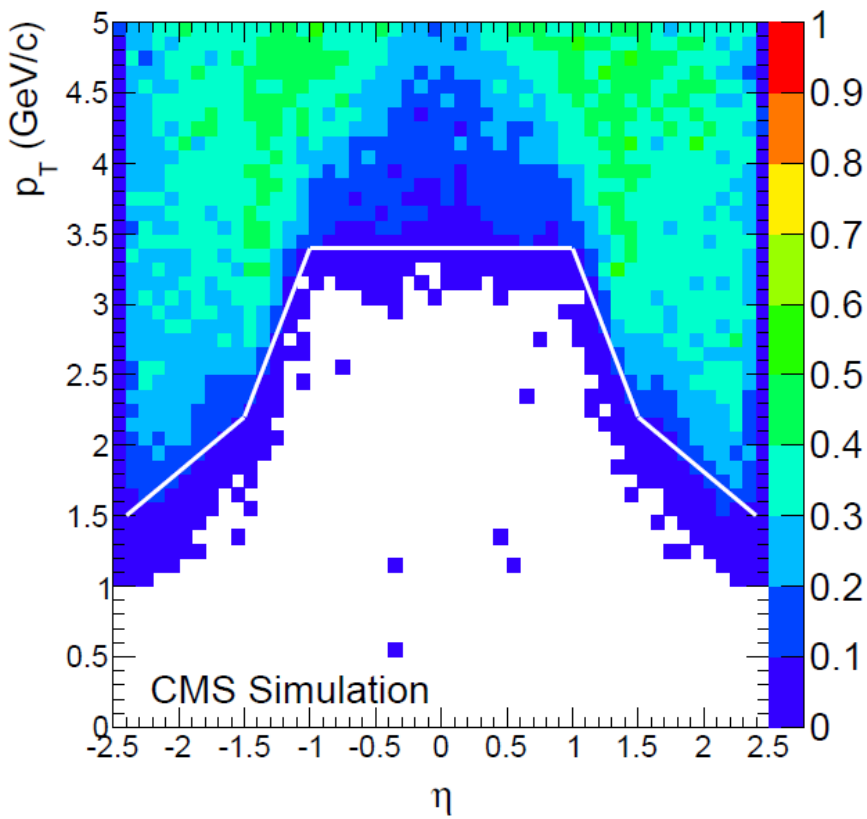


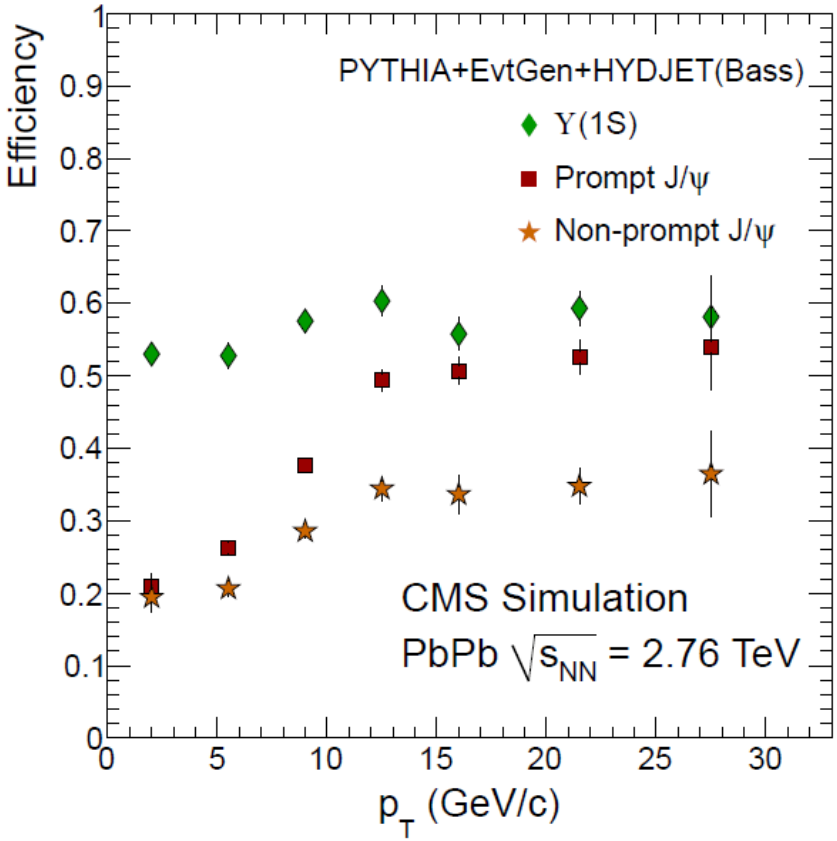
CMS PAS HIN-10-006

- First separation of Prompt and Non Prompt J/ψ in Heavy Ion Collisions
- 90 ±13 B → J/ψ b quark energy loss



Acceptance and Efficiency corrections





CMS PAS HIN-10-006

- Consider only muons in analysis which have a reconstruction efficiency > 10%
- Reconstruction efficiency from MC
  PYTHIA Signal + HYDJET
- Reconstruction efficiency Cross checked with data based Tag and Probe

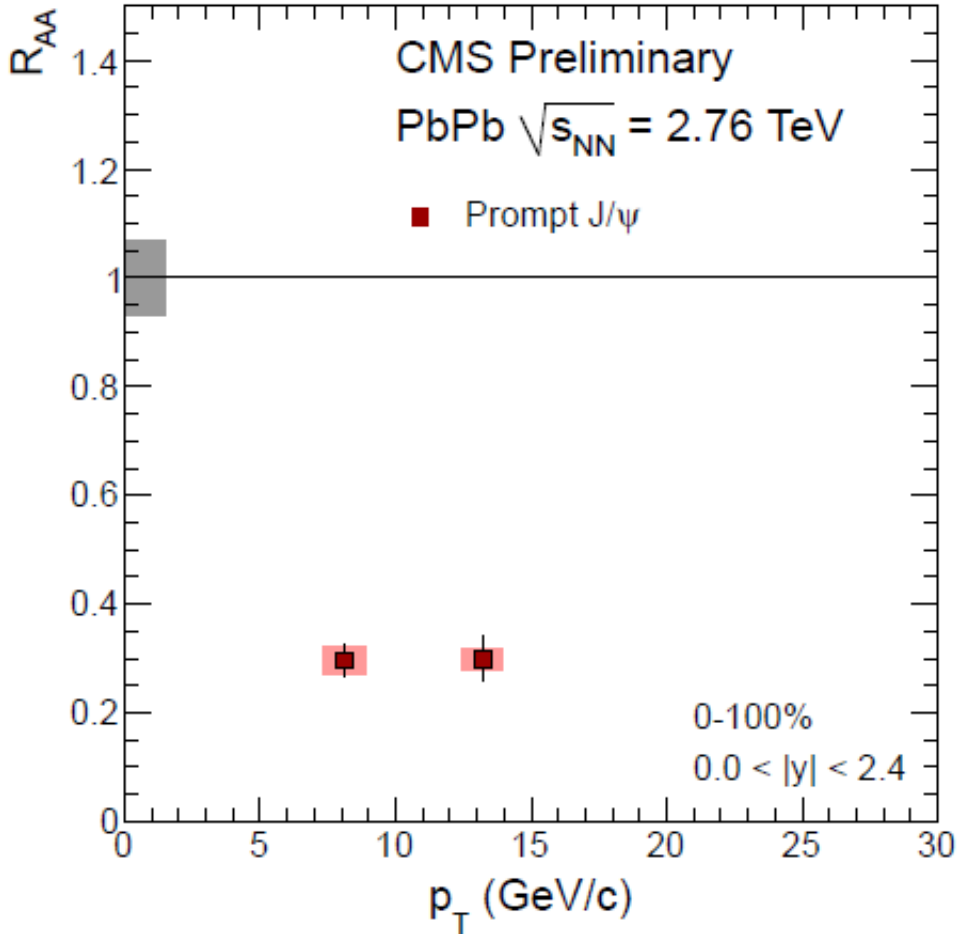
Nuclear Modification Factor (R_{AA})

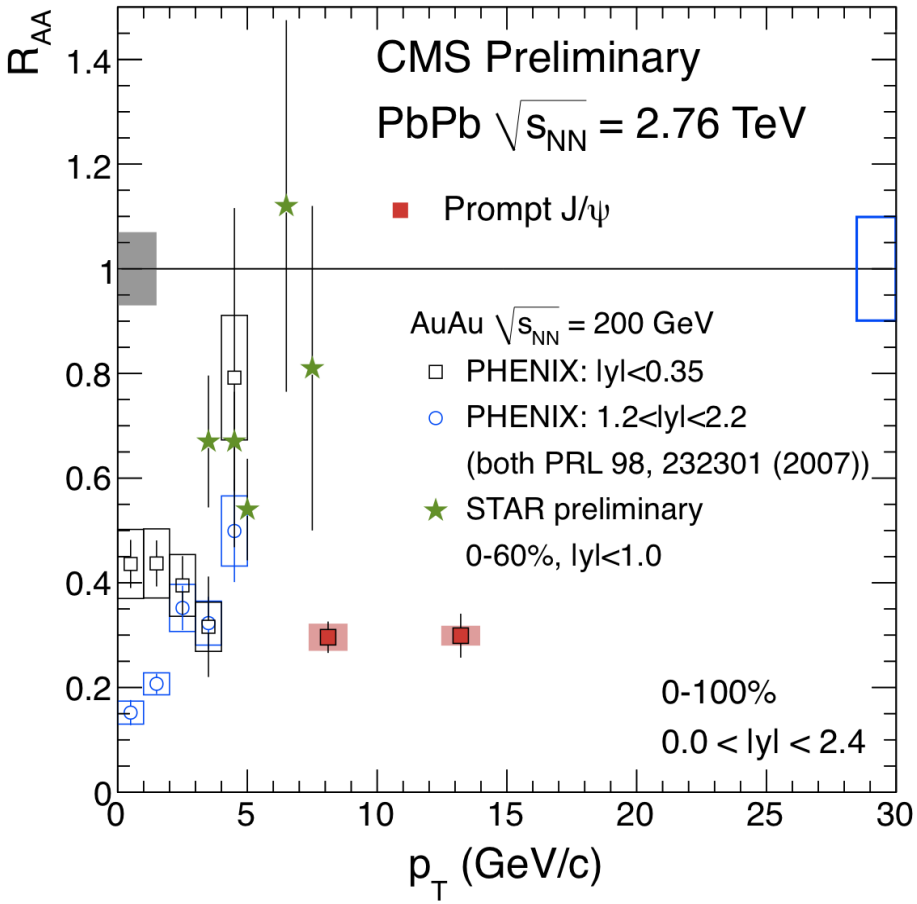
- LHC has pp run at 2.76 TeV in March 2011.
- $L_{Int} = 225\ nb^{-1}$
- pp data is reconstructed using heavy ion algorithm.
- For probes that follow binary scaling, the pp integrated luminosity is comparable to one of the PbPb sample.
- J/ψ is measured using the same procedure in pp data also.
- R_{AA} is defined as ratio of yield in AA collisions to yield in pp collisions scaled by no of binary collisions.

$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{\mathrm{MB}}} \frac{N_{\mathrm{PbPb}}(\mathrm{Q}\overline{\mathrm{Q}})}{N_{pp}(\mathrm{Q}\overline{\mathrm{Q}})} \cdot \frac{\varepsilon_{pp}}{\varepsilon_{\mathrm{PbPb}}}$$

- $R_{AA} > 1$ enhancement
- $R_{AA} = 1$ no medium effect
- $R_{AA} < 1$ suppression

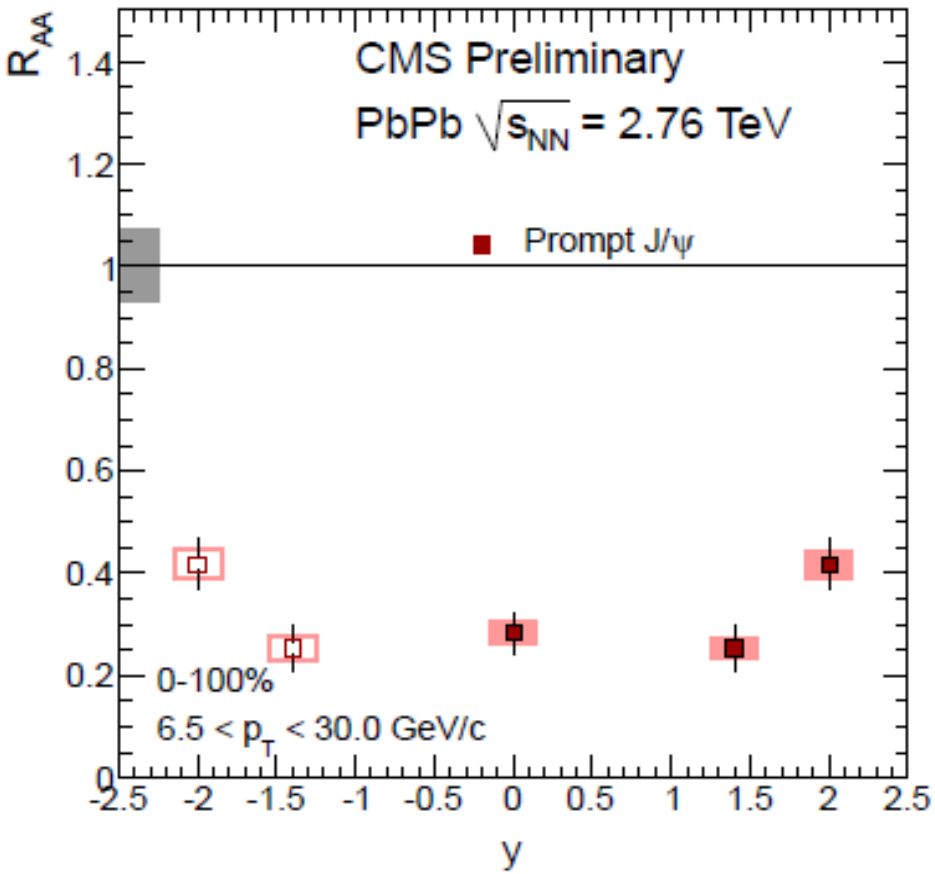
Prompt J/ψ R_{AA} vs p_T

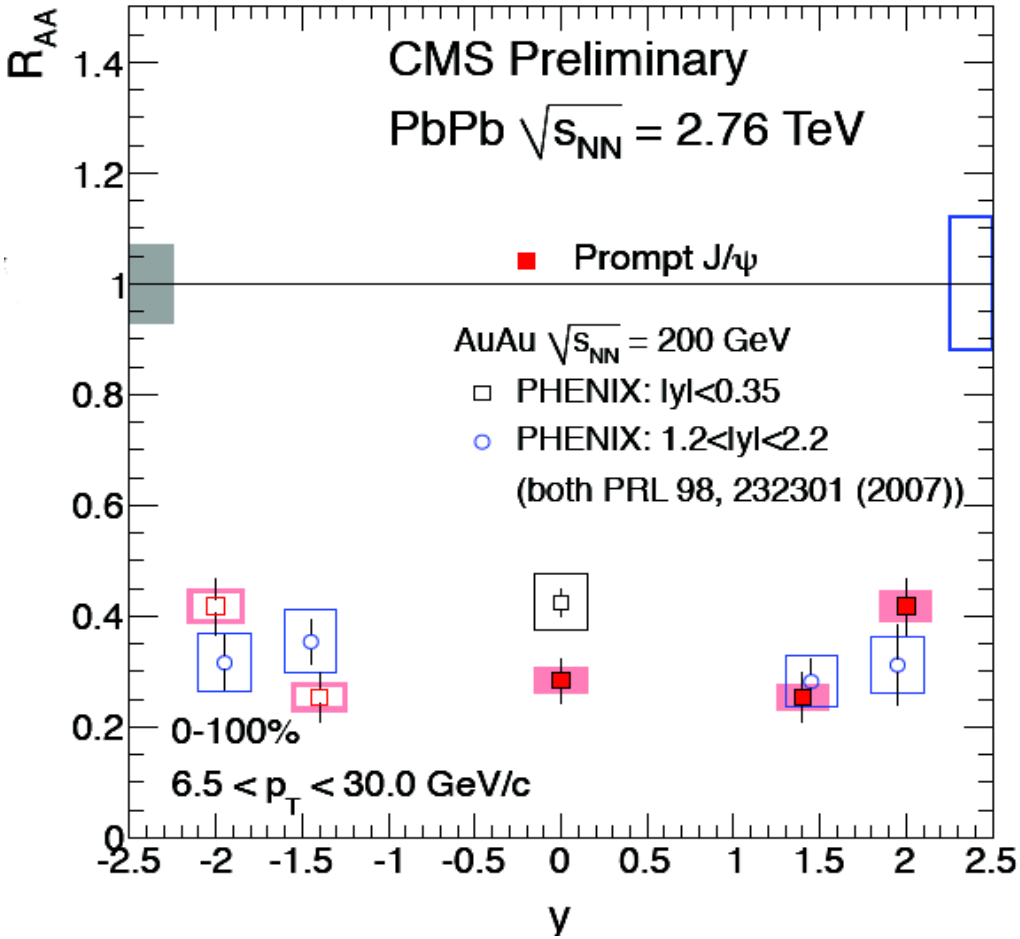




- Factor 3 suppression for pT > 6.5 GeV in CMS
- STAR p_T < 8 GeV PHENIX small p_T
- High p_T J/ψ 's tendency to survive at RHIC (SPS) is not seen at LHC

Prompt J/ψ R_{AA} vs rapidity





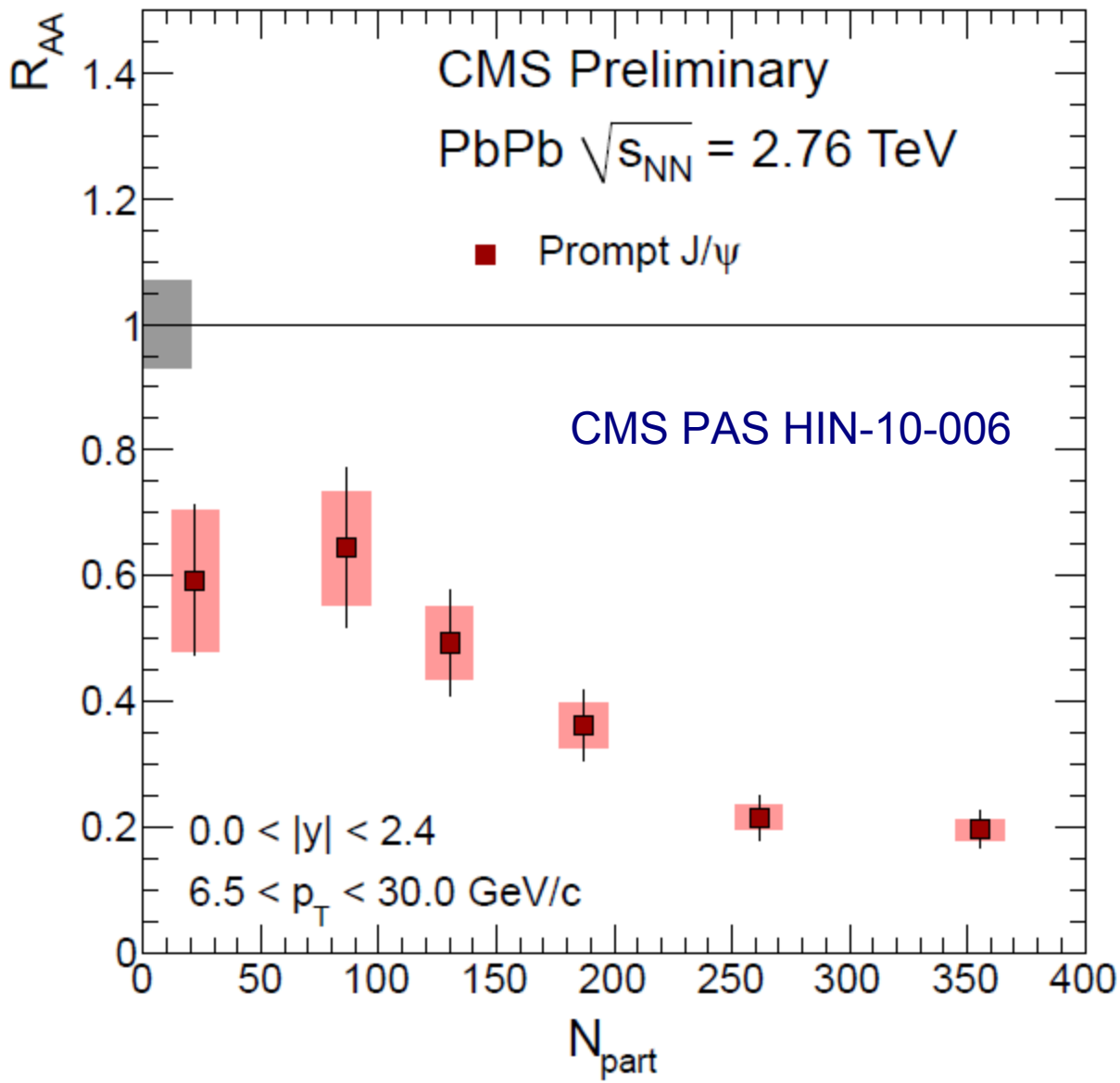
CMS PAS HIN-10-006

- Less suppression at forward rapidity
- Opposite trend than PHENIX
- Different p_T cuts Or Antishadowing

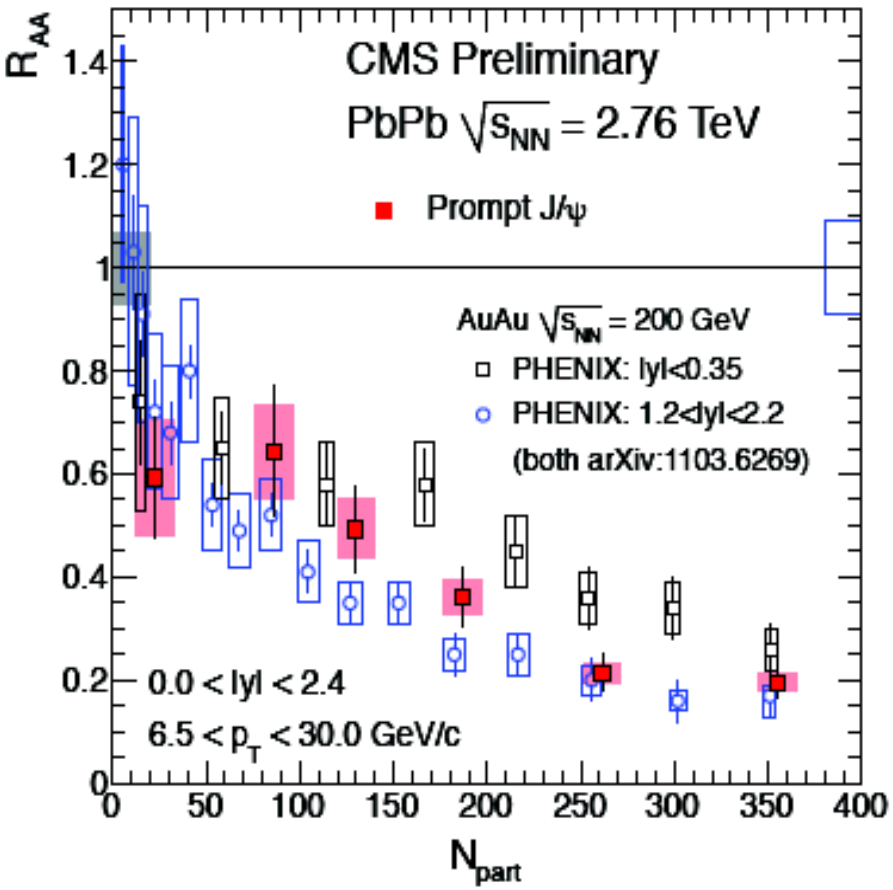
Prompt J/ψ R_{AA} vs centrality of collission

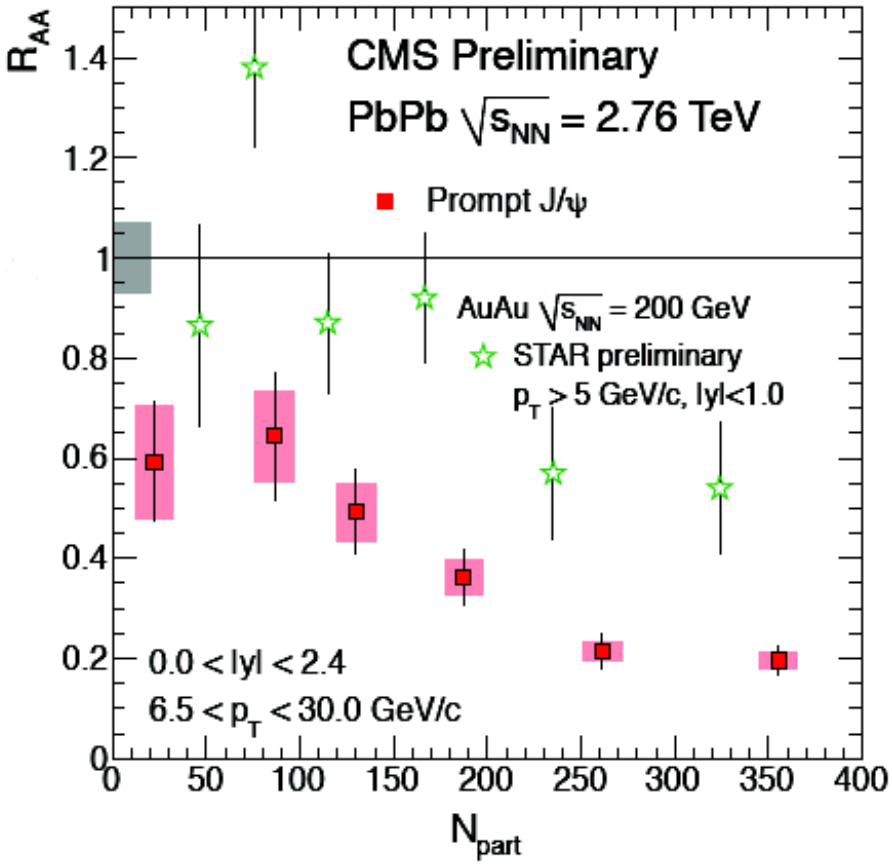
Prompt J/ψ:

- 0-10% suppressed by factor 5 with respect to pp
- 50-100% suppressed by factor ~ 1.6
- Suppression even in most peripheral bin



Prompt J/ψ R_{AA} vs centrality of collission

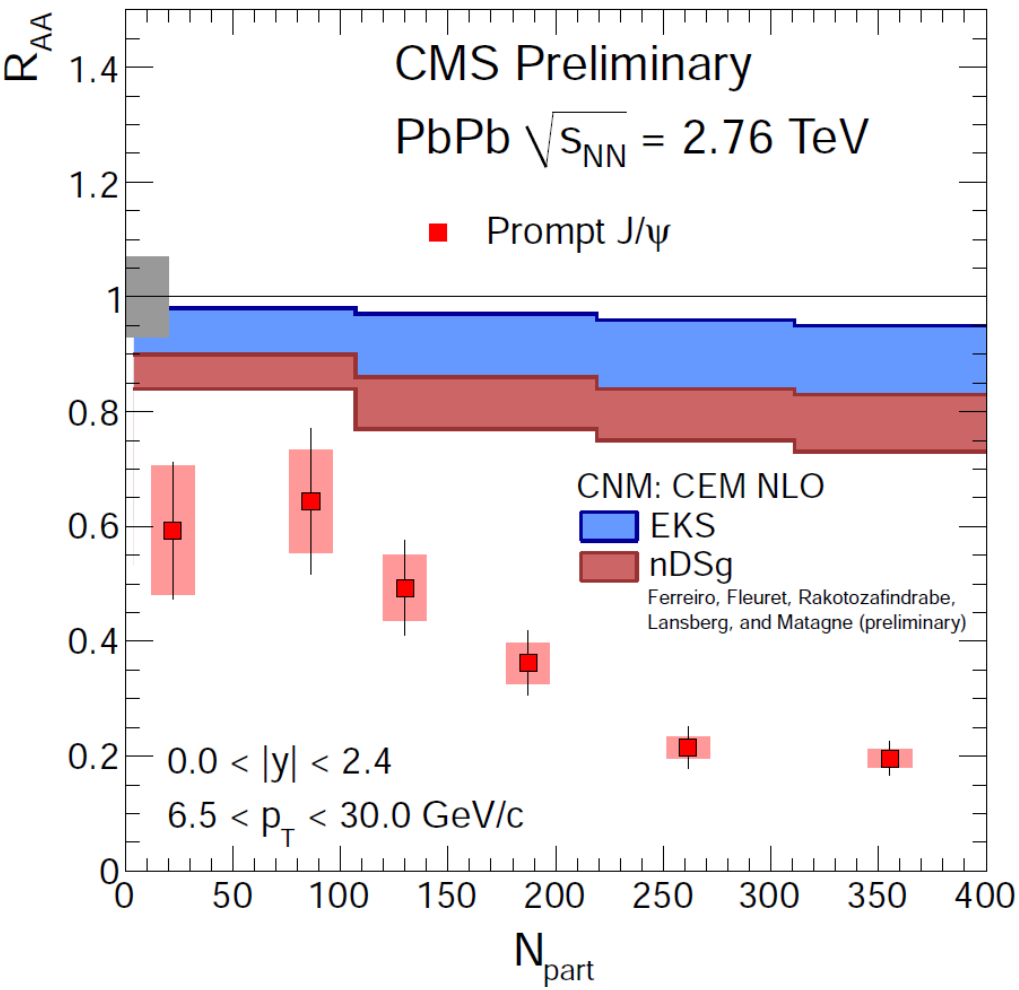


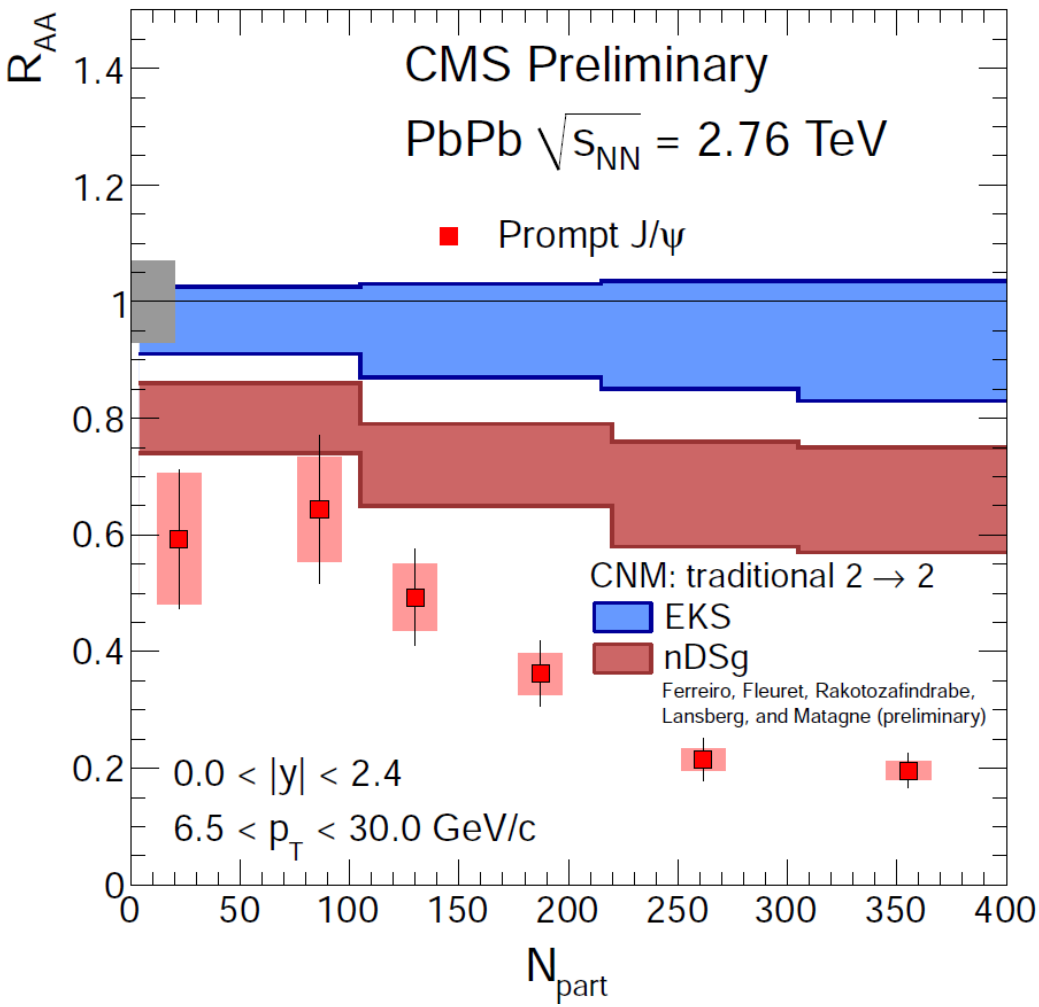


- Surprising qualitative agreement in centrality dependance with PHENIX.
- More suppression than STAR

CMS J/ψ p_T > 6.5 GeV
STAR p_T between 5 and 8 GeV
PHENIX lower p_T

Prompt J/ψ R_{AA} : Cold Nuclear Matter Effects

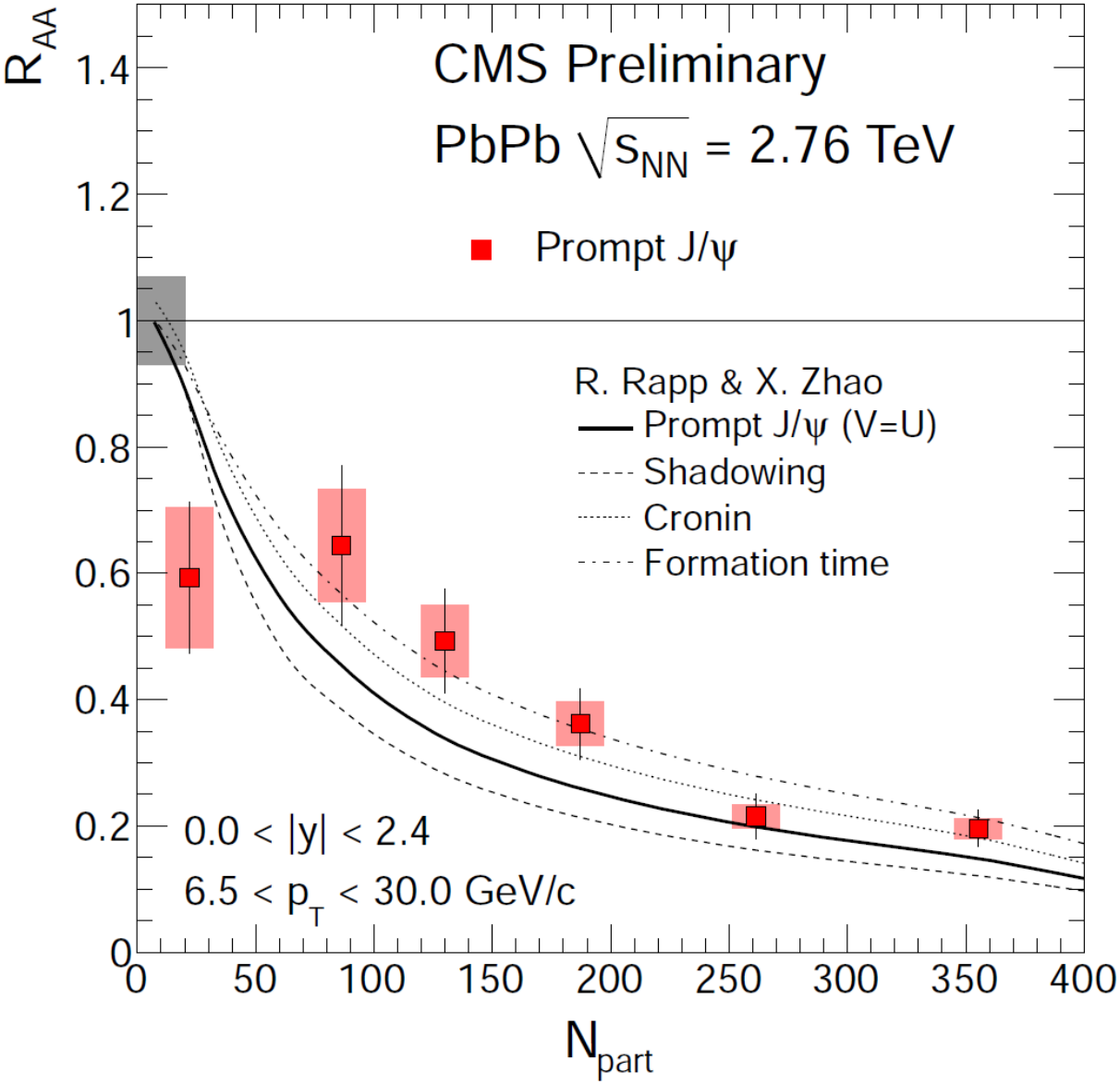




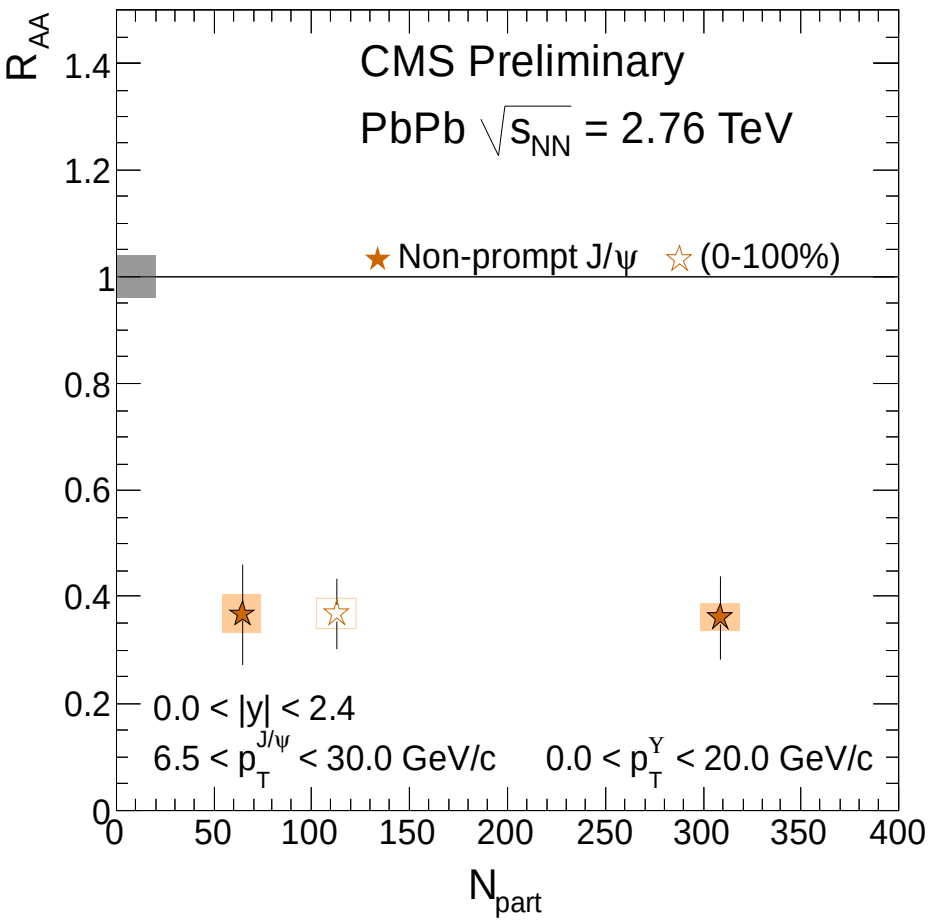
- Two different nuclear parton distribution functions.
- Traditional 2→ 2 calculations include kT smearing.
- Suppression beyond the reach of CNM effects.

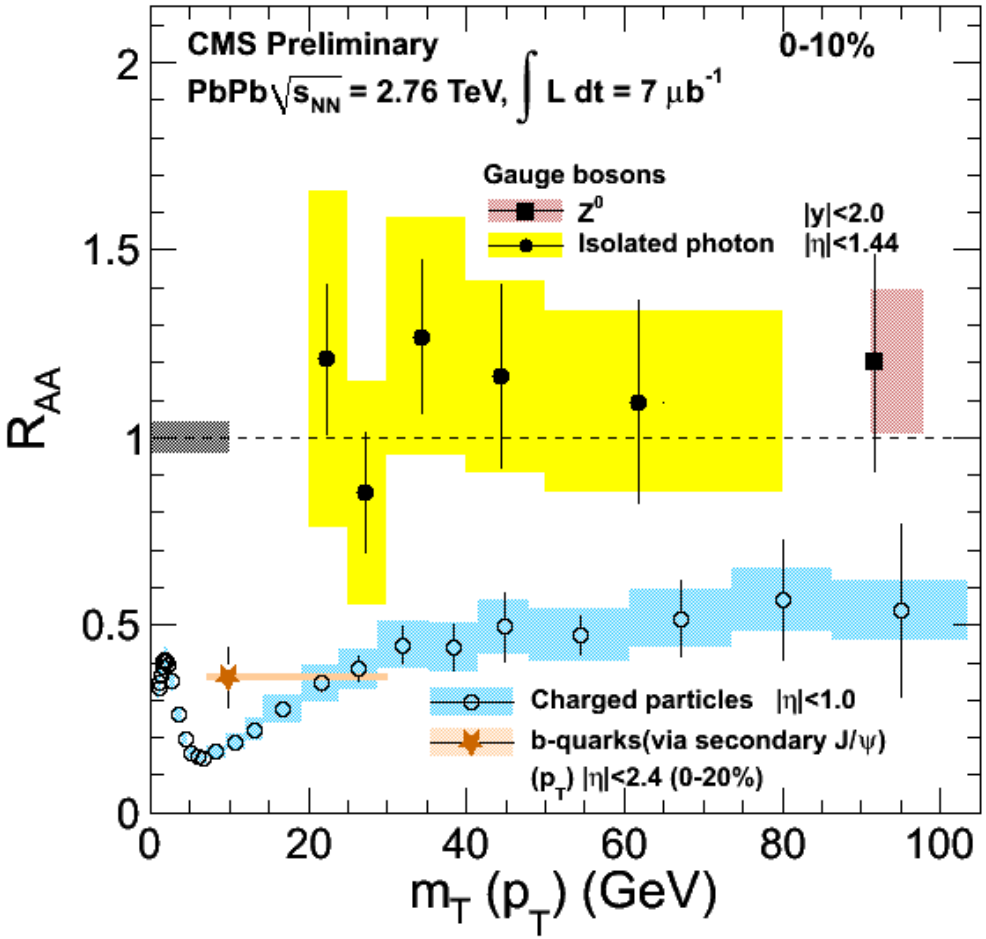
Prompt J/ψ R_{AA} : Kinetic Rate Equation Approch

- Incorporates various in-medium effects.
- Assuming strong binding scenario $T_D = 2\ T_C$
- Due to p_T cut regeneration contribution is essentially gone.
- Predict large suppression of primordial charmonia (~10 for central Pb-Pb collisions)



Non Prompt J/ψ R_{AA}





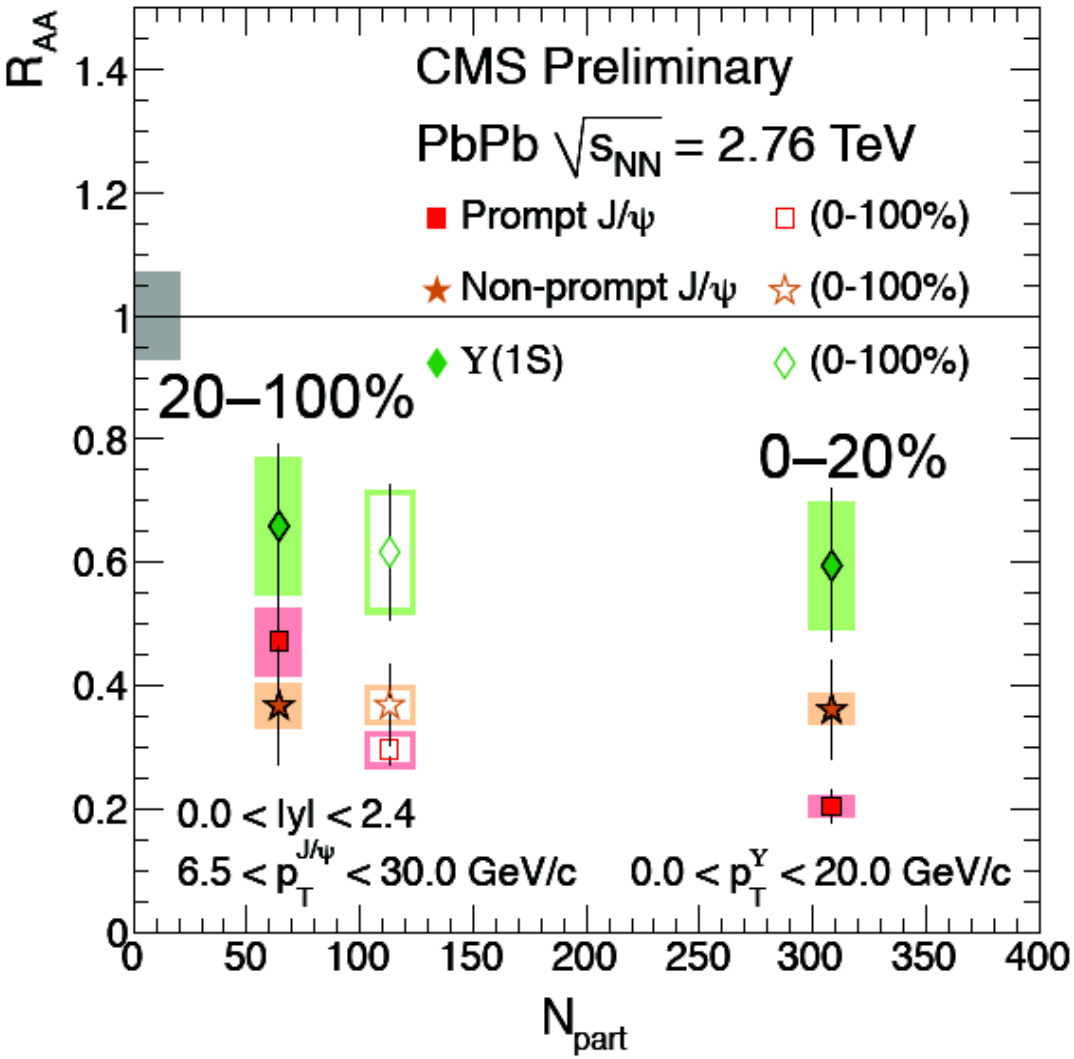
- Non prompt J/ψ (J/ψ from B decay) suppressed by a factor of 2.7
- Suppression same as charged hadrons

Summary

- First measurement of non prompt J/ψ in Heavy Ion Collissions

- Suppression of prompt and non-prompt J/ψ

- Prompt J/ψ suppress by a factor of 5 in most central collisions
- High p_T J/ψ 's tendency to survive at RHIC (SPS) is not seen at LHC.
- Surprising qualitative agreement in centrality dependence of suppression with PHENIX.
- Opposite trend in rapidity dependence of suppression.
- Non-prompt J/ψ suppressed equvilent to other charged particles



Back Up slides

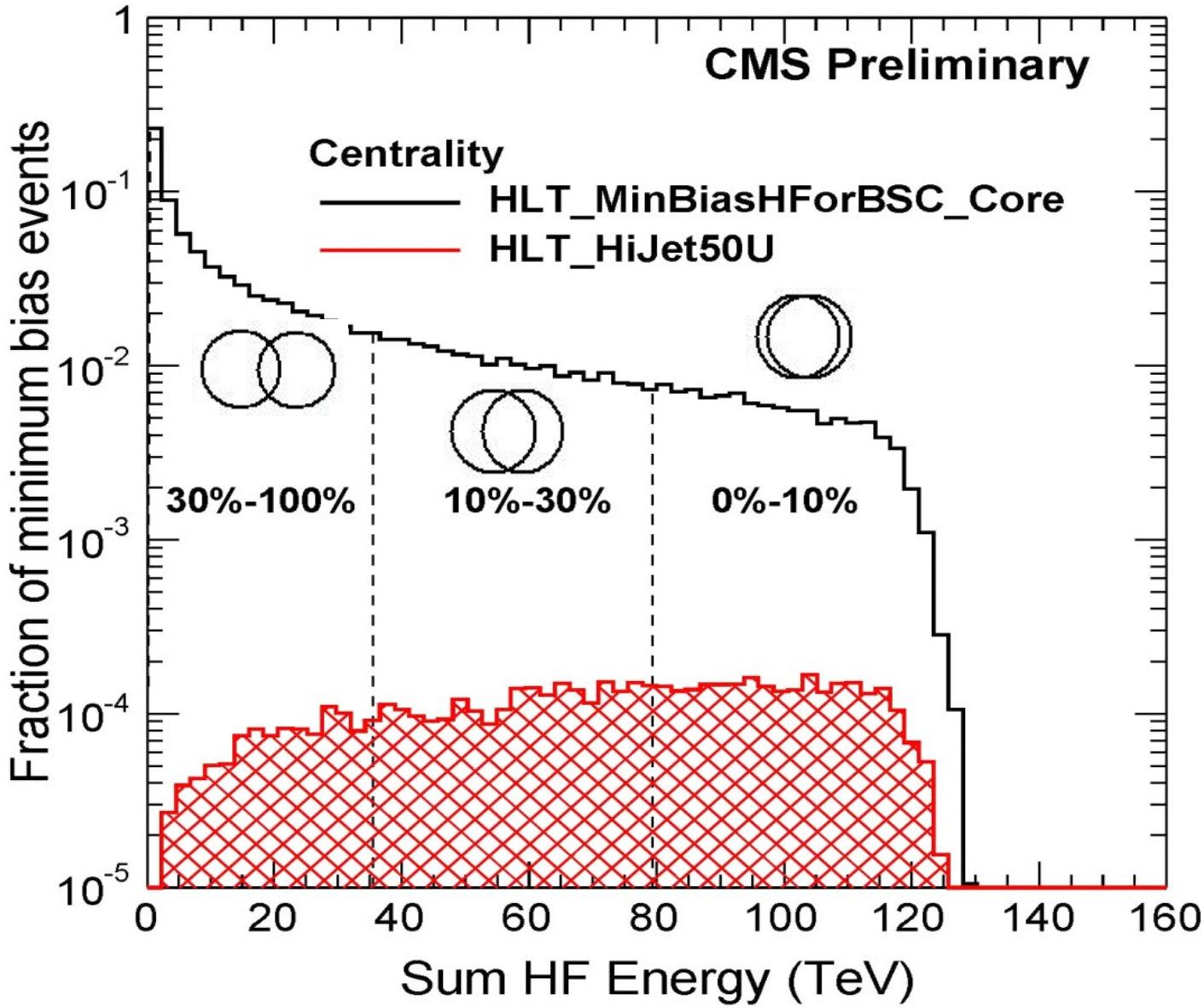
Muon quality cuts

- Extensive study to tune muon quality cuts using PYTHIA signal embedded in MB HYDJET background
- Final set of quality cuts

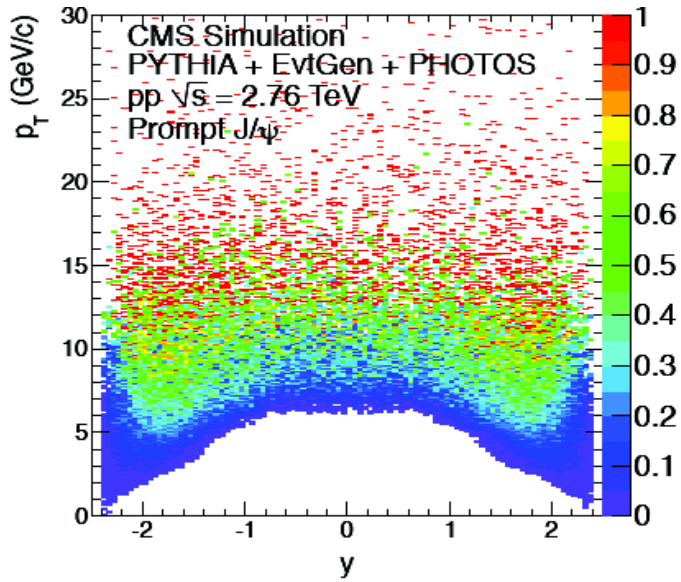
  - Is reconstructed as tracker muon as well as global muon
  - Tracker hits > 10
  - Hits in Pixel Layers > 0
  - Chi^2 / ndf for inner track fit < 4.0
  - Chi^2 / ndf for global fit < 20.0
  - $D_{xy} < 3$
  - $D_z < 15$
  - Probability of both tracks coming from common vertex is required to be better than 1%

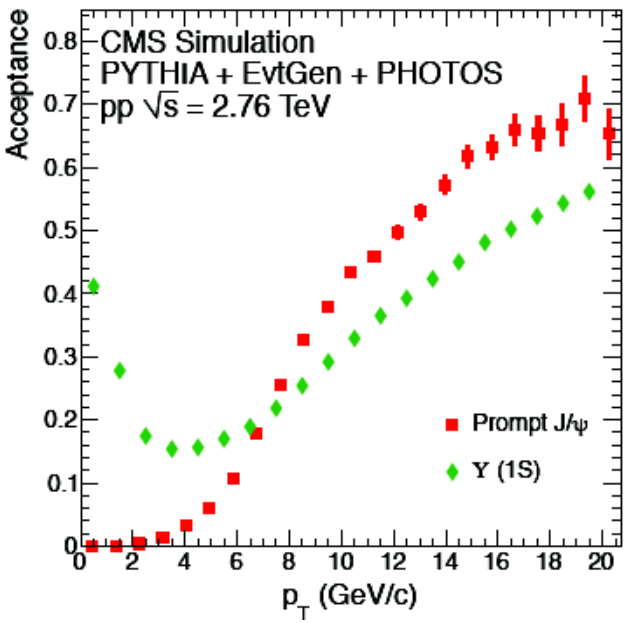
-

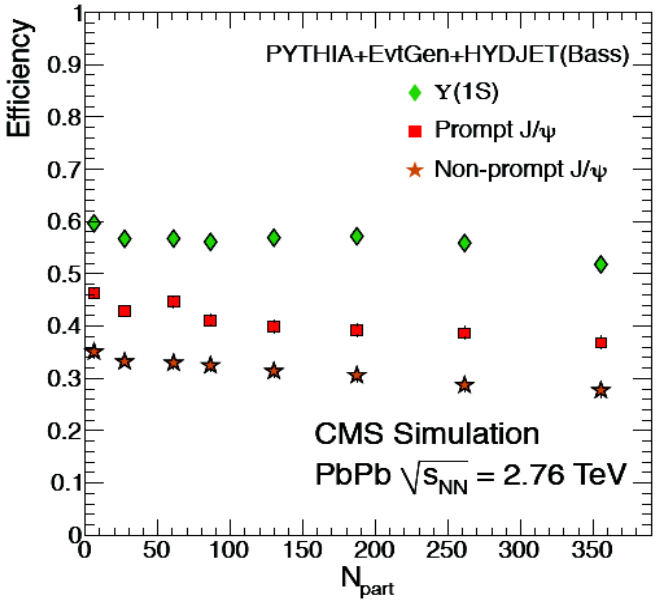
Centrality Determination

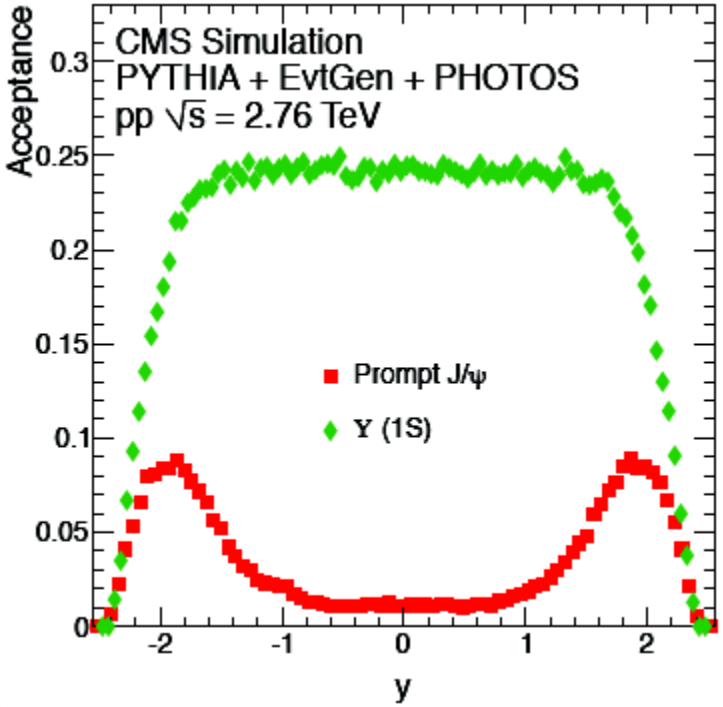


Acceptance of quarkonia in CMS

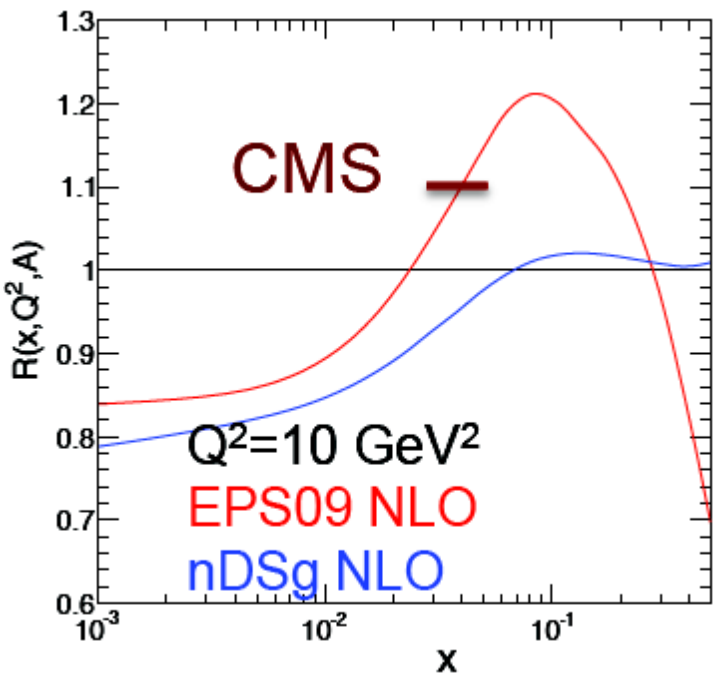


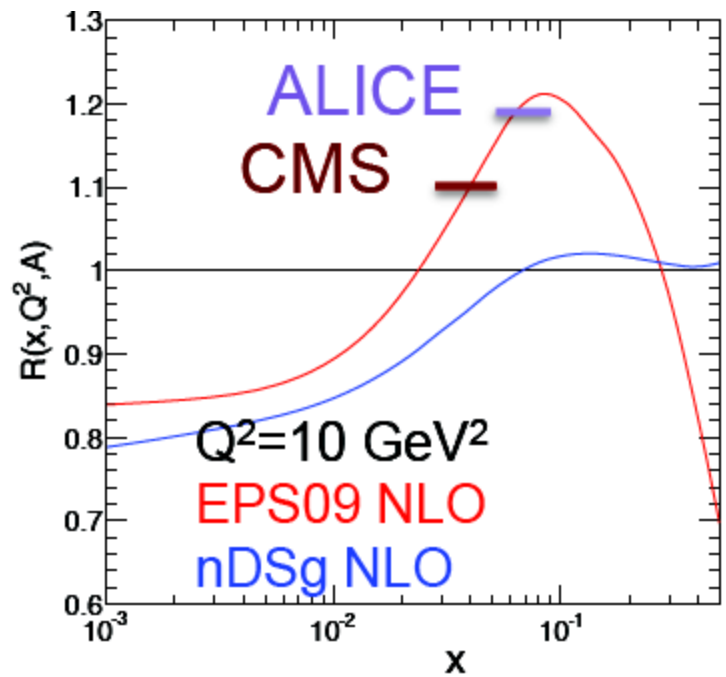






Antishadowing in LHC



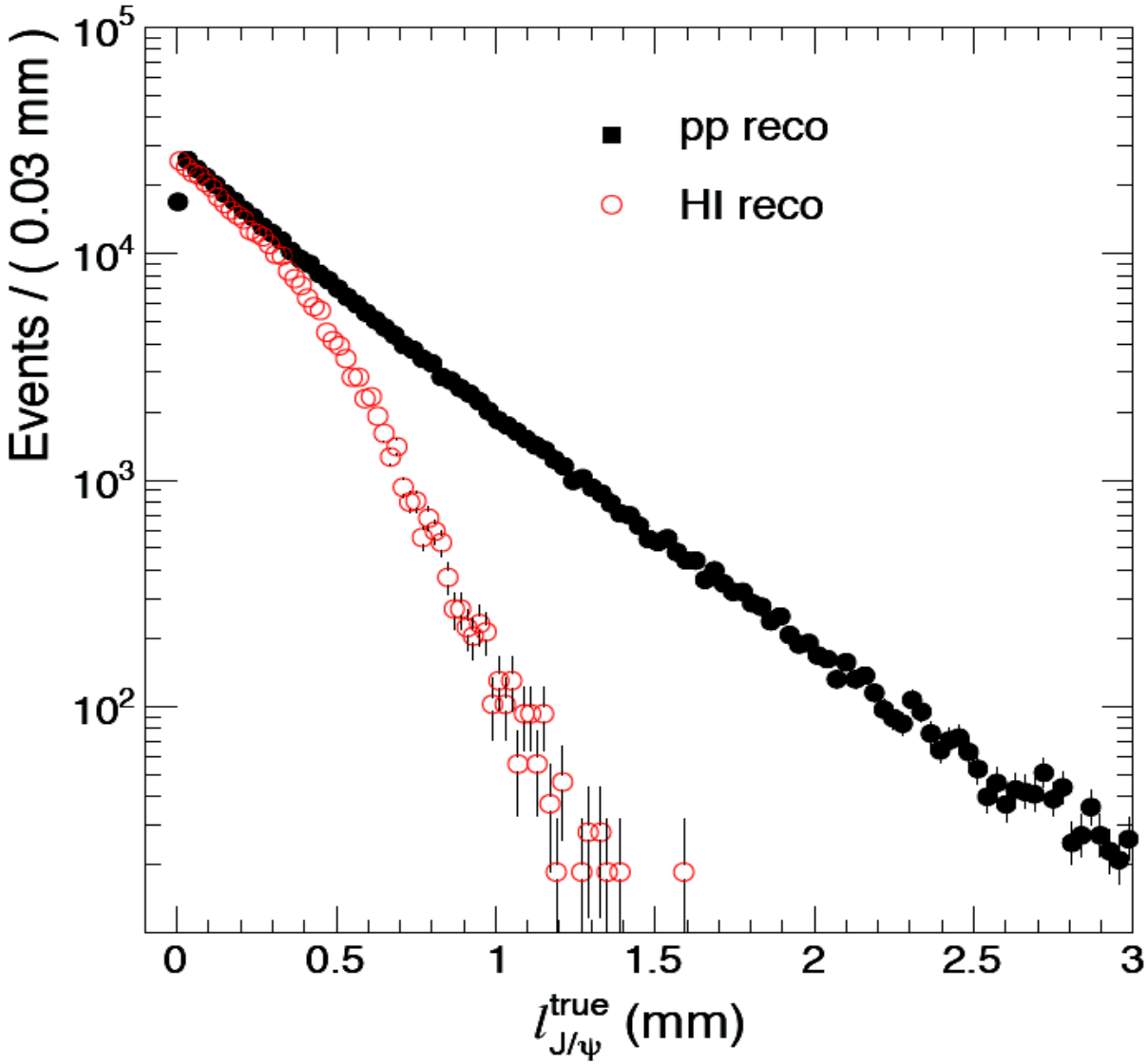


Watch out for anti-shadowing :

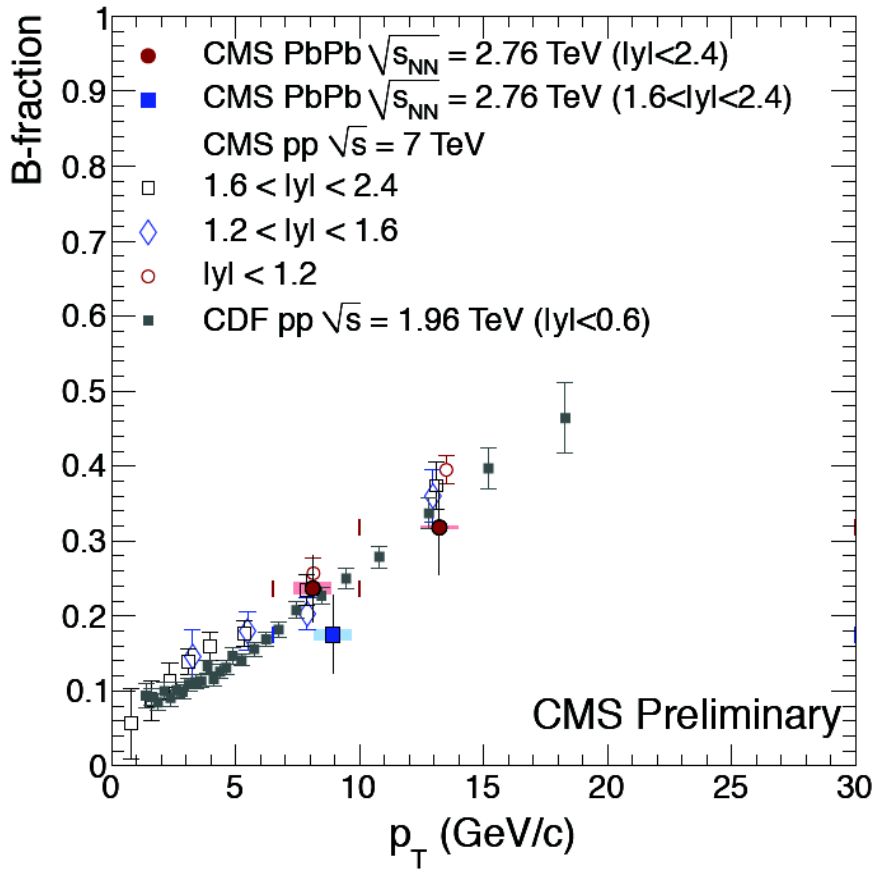
CMS@p_T=10 up to x_2~0.02 (x_1~5.10^{-4})

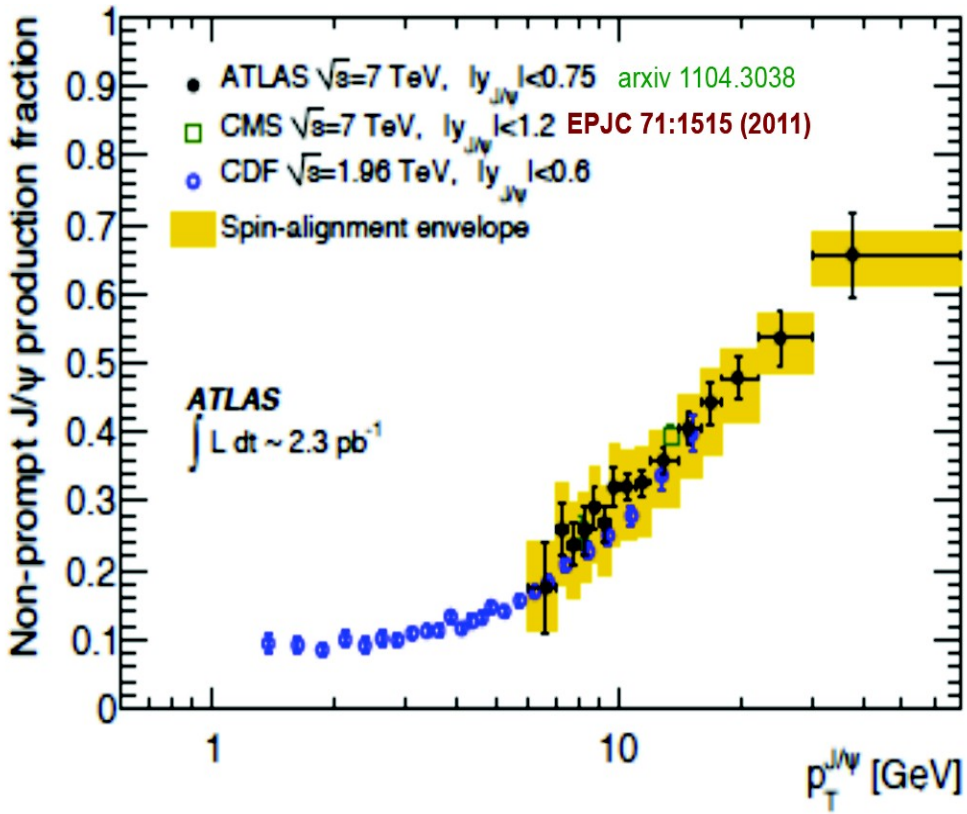
ALICE@p_T=0 up to x_2~0.06 (x_1~2.10^{-5})

HI Track reconstruction algorithm

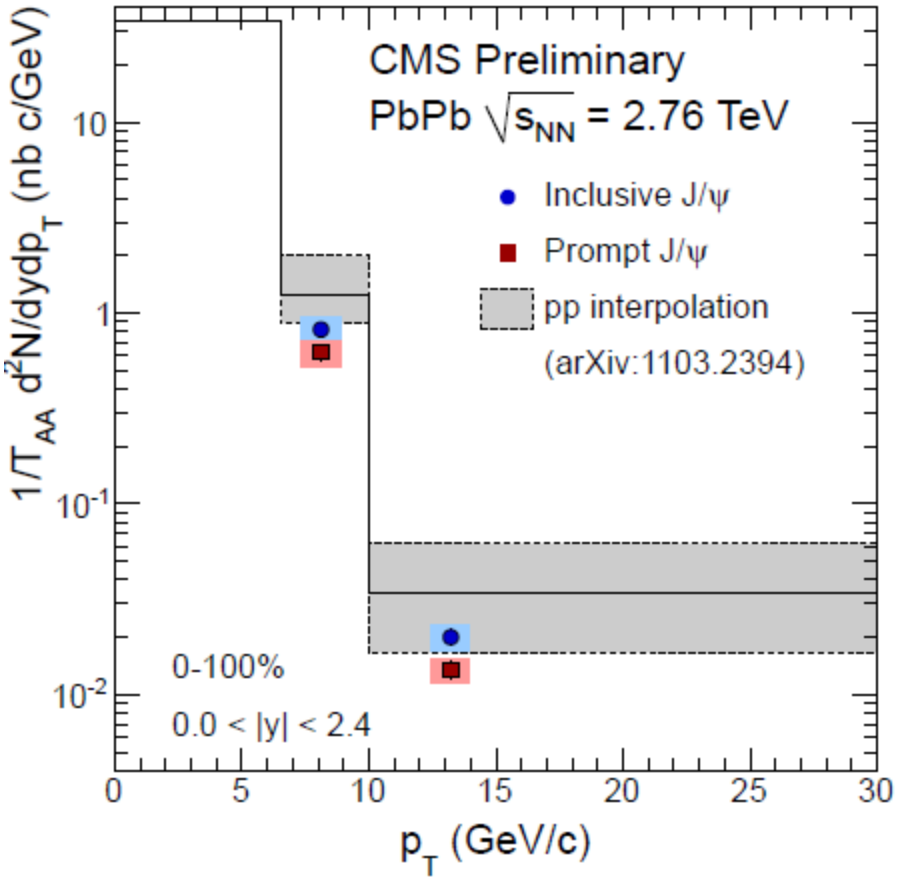


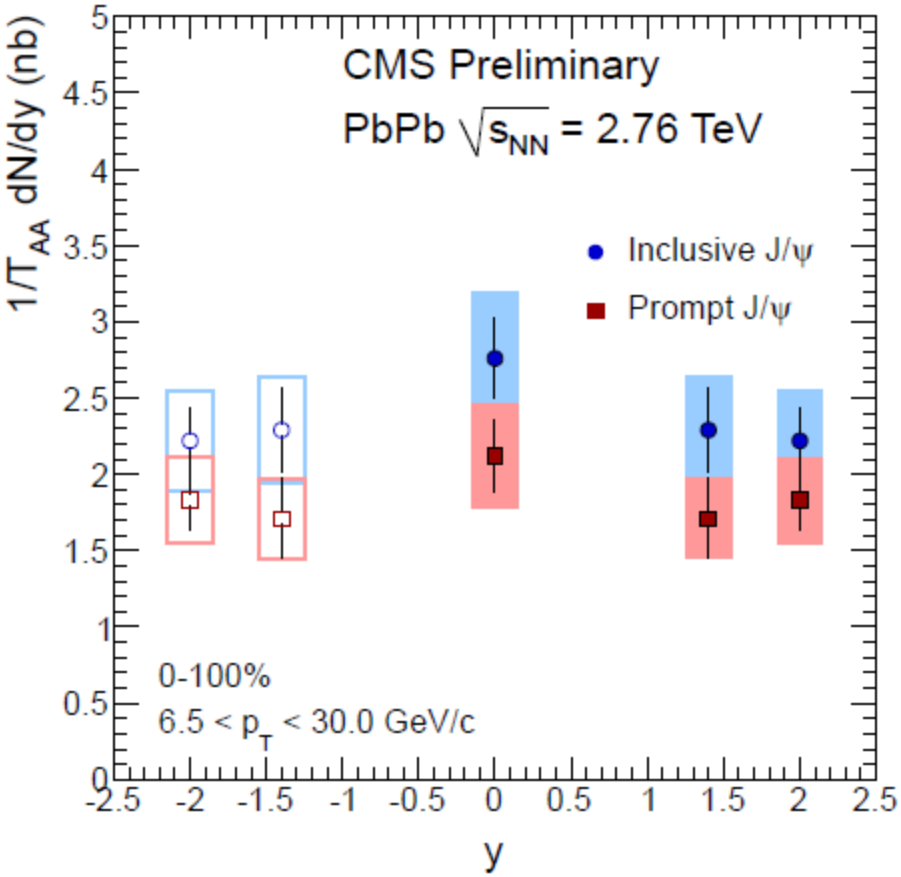
B Fraction


B-fraction
CMS PbPb $\sqrt{s_{NN}}$ = 2.76 TeV (|y|<2.4)
CMS PbPb $\sqrt{s_{NN}}$ = 2.76 TeV (1.6<|y|<2.4)
CMS pp $\sqrt{s}$ = 7 TeV
1.6 < |y| < 2.4
1.2 < |y| < 1.6
|y| < 1.2
CDF pp $\sqrt{s}$ = 1.96 TeV (|y|<0.6)
CMS Preliminary
p_T (GeV/c)


Non-prompt J/ψ production fraction
ATLAS $\sqrt{s}$=7 TeV, $|y_{J/\psi}|$<0.75 arxiv 1104.3038
CMS $\sqrt{s}$=7 TeV, $|y_{J/\psi}|$<1.2 EPJC 71:1515 (2011)
CDF $\sqrt{s}$=1.96 TeV, $|y_{J/\psi}|$<0.6
Spin-alignment envelope
ATLAS
$\int L\,dt \sim 2.3\ pb^{-1}$
$p_T^{J/\psi}$ [GeV]

Prompt J/ψ Yield with p_T and y





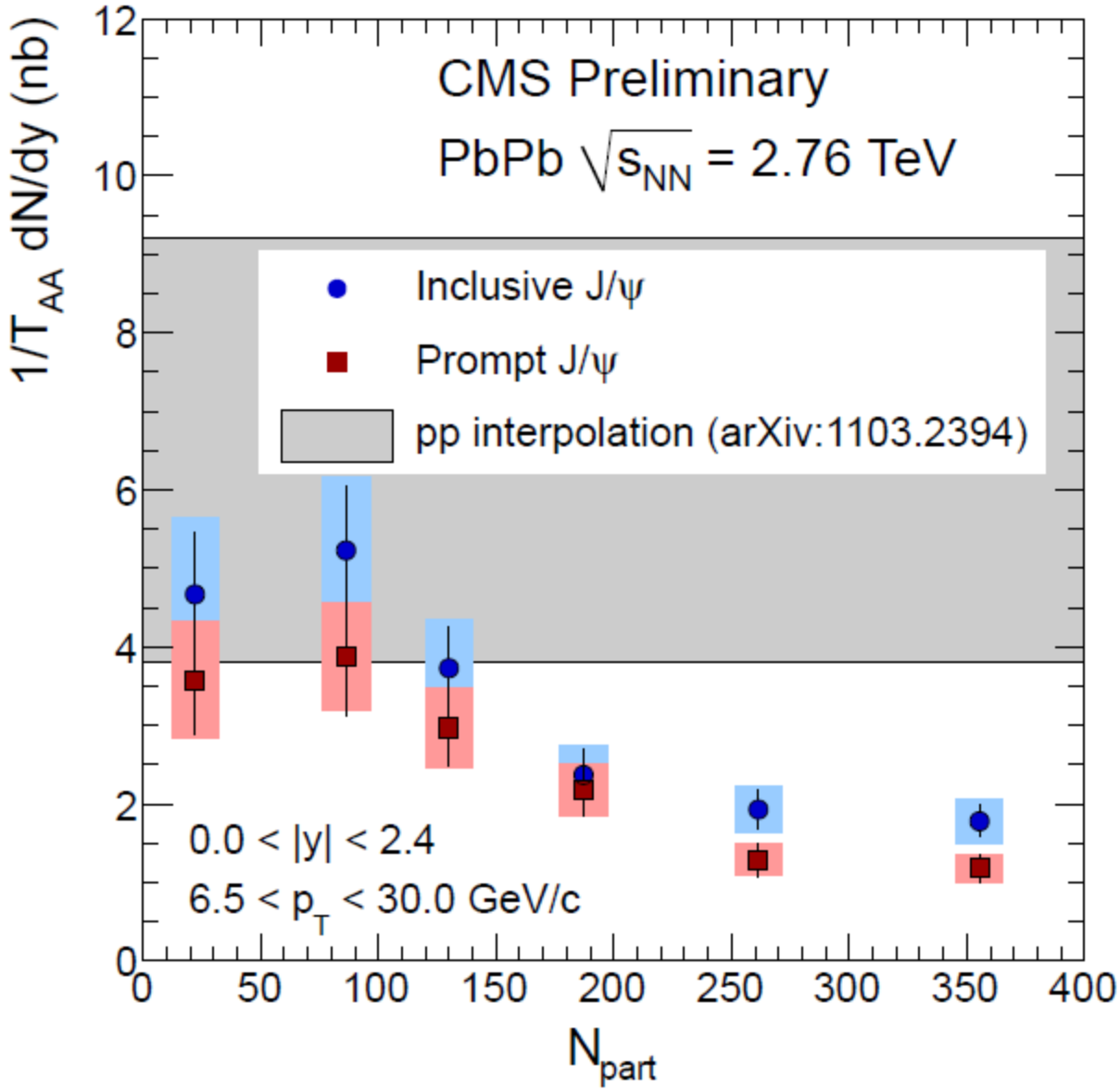
- T_{AA} : the nuclear overlap function (varies with the centrality of the collision and has units of mb^{-1})
- pp from interpolation of RHIC, Tevatron and LHC data.
- Large uncertainty on pp does not allow definite conclusion.

Prompt J/ψ Yield with N_{part}

- Large uncertainty on pp reference due to $p_T > 6.5$ GeV Cut.

- Prompt J/ψ:
  - Suppression by factor of 3 in central (0-10%) compared to peripheral (50-100%)

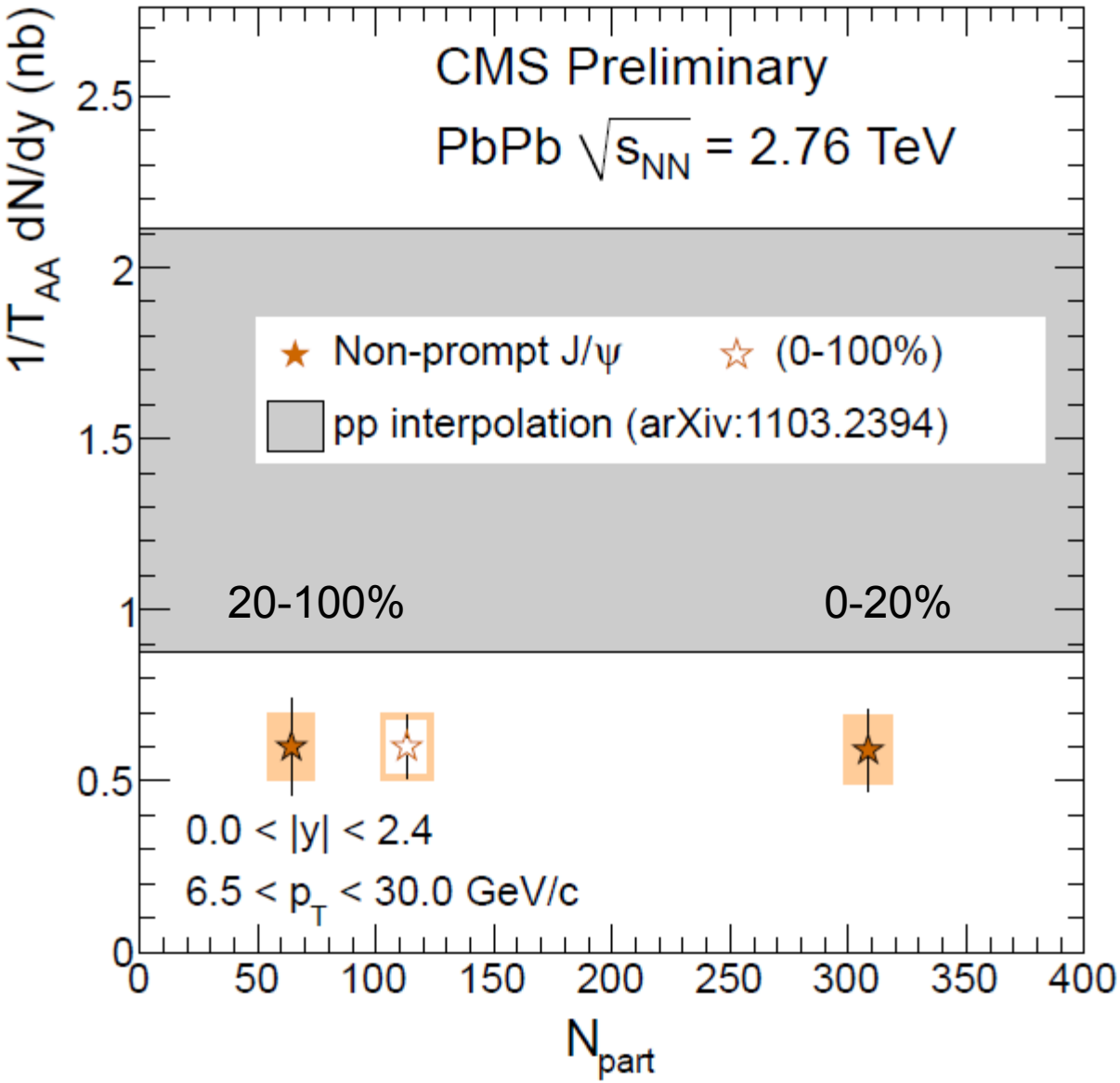
- Peripheral collisions in agreement with lower limit of interpolation



Non Prompt J/ψ Yield with N_{part}

- Scaled pp interpolation by measured B-fraction
- Non-prompt J/ψ: Suppression with respect to interpolation

Need a real pp reference!



Non prompt J/ψ (J/ψ from decay of B hadrons)

- Reconstruct dimuon vertex
- L_{xy} is distance of dimuon vertex from primary vertex in a plane orthogonal to beam direction.
- $l_{J/\psi}$ (Pseudo-proper decay length)

  $l_{J/\psi} = L_{xy} \cdot M_{J/\psi} / p_T$
- Simultaneous fit of Invariant mass and Pseudo-proper decay length

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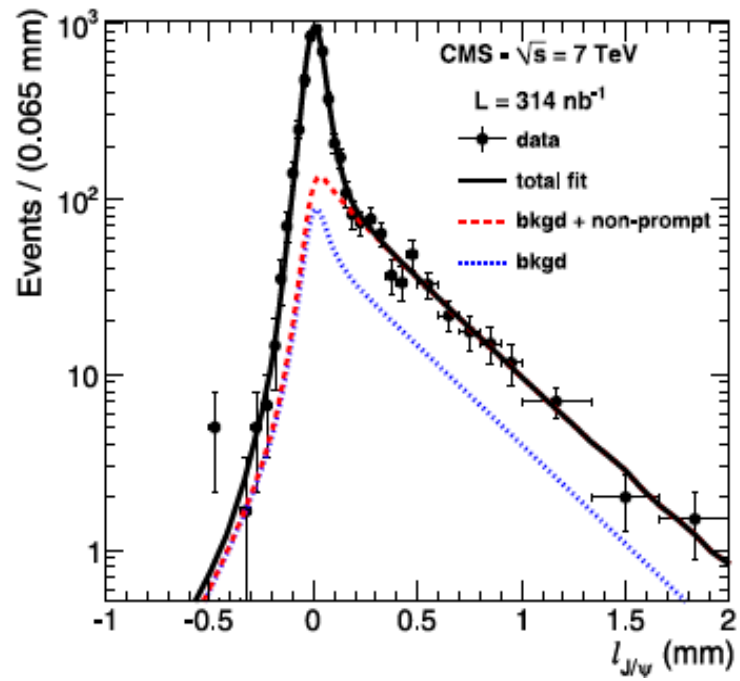
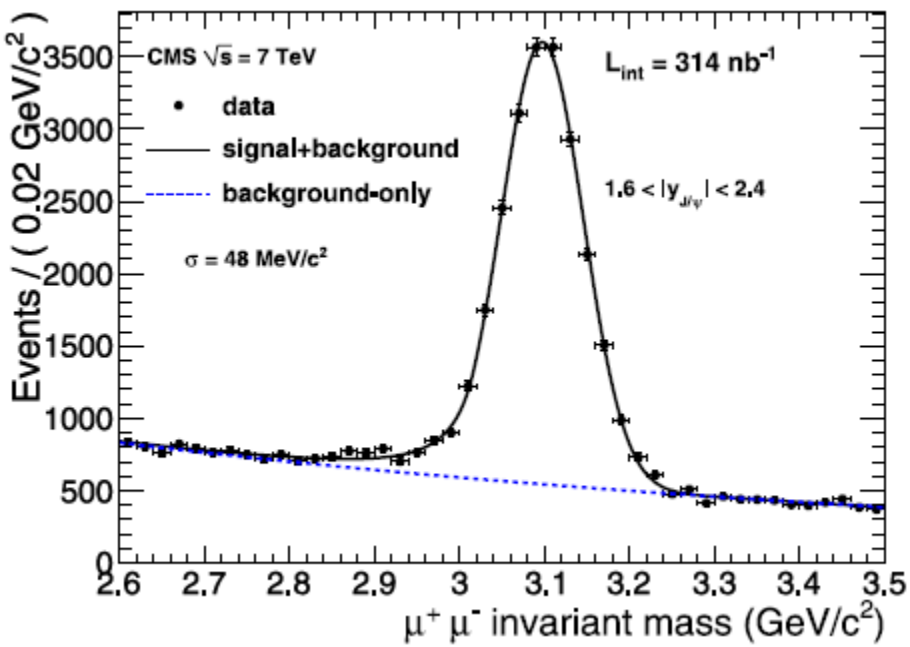
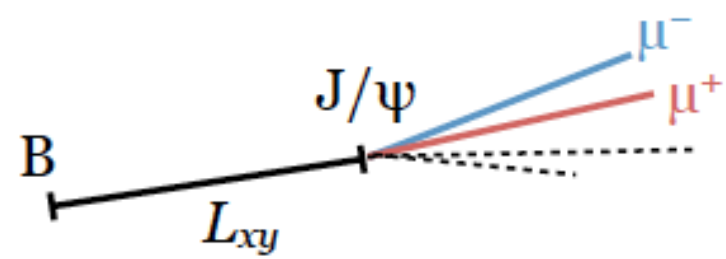
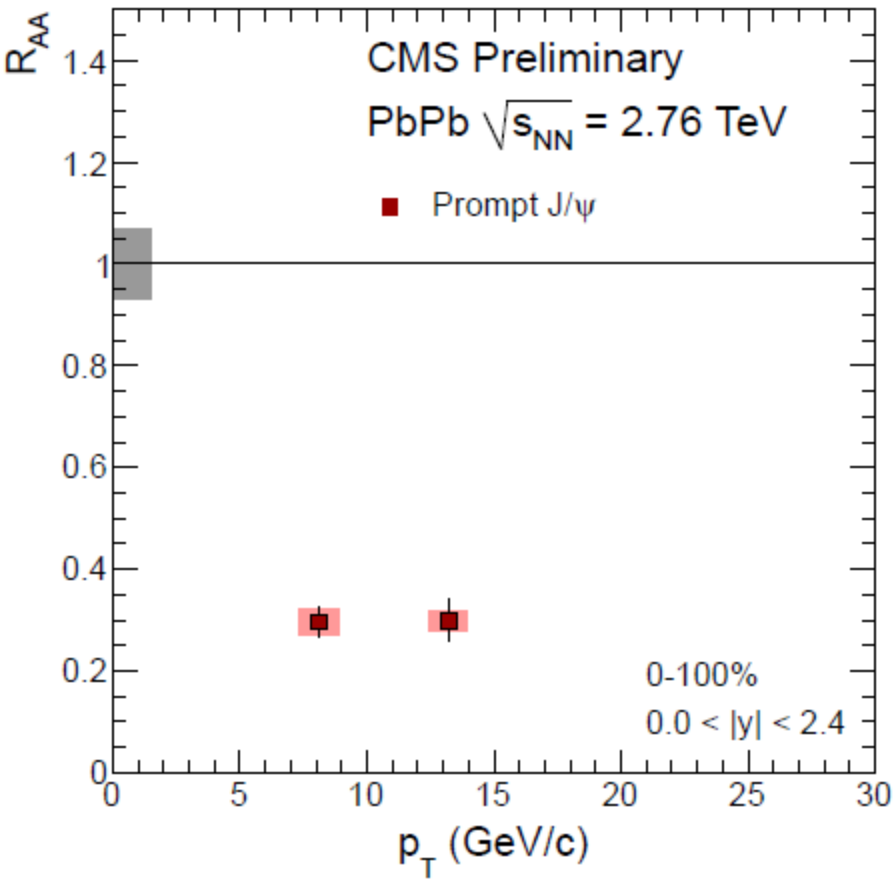
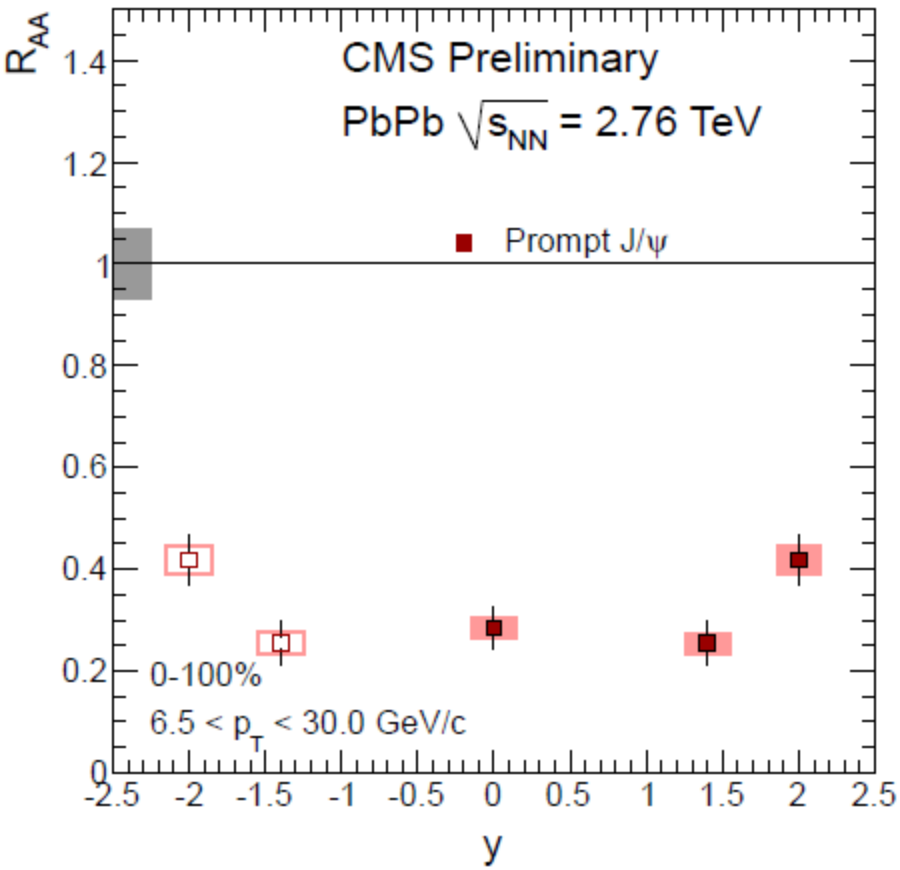






Prompt J/ψ R_{AA} vs p_T and y





CMS PAS HIN-10-006

- Factor 3 suppression for pT > 6.5 GeV and at y=0
- Trend to less suppression at forward rapidity