Recent updated results related to dimuons from CMS

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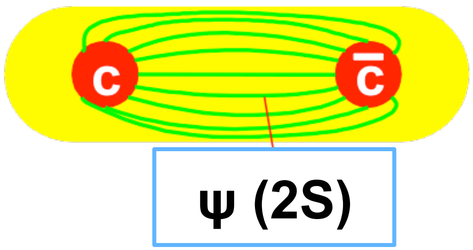
Contents

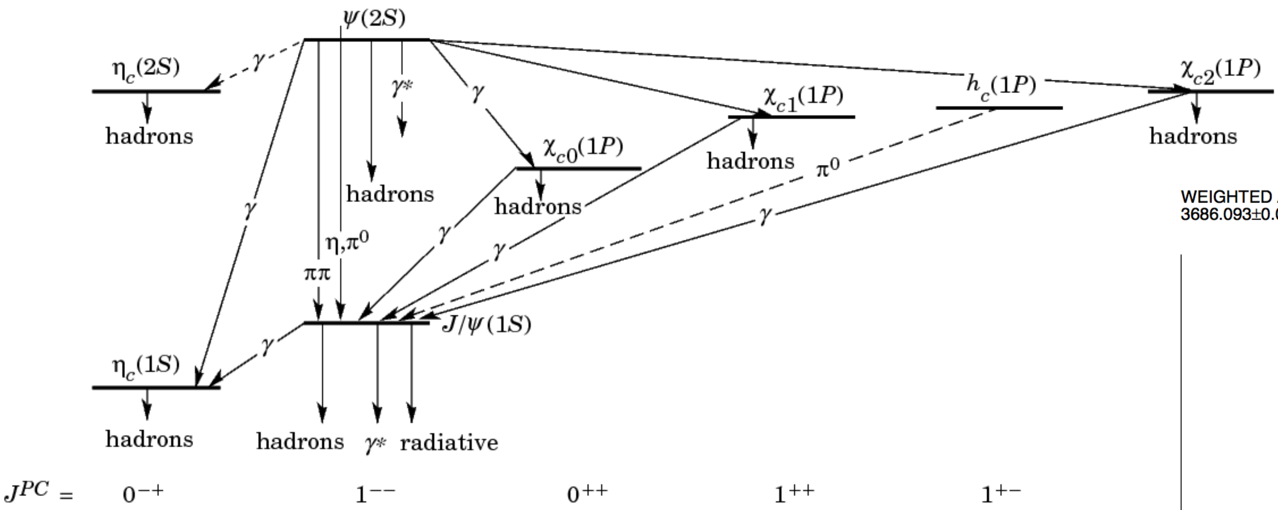
- Updated psi(2S) results in PbPb using new pp sample
- Z boson measurement in PbPb and pPb collisions
- Summary

Updated ψ(2S) in pp & PbPb collisions

ψ(2S) measurement

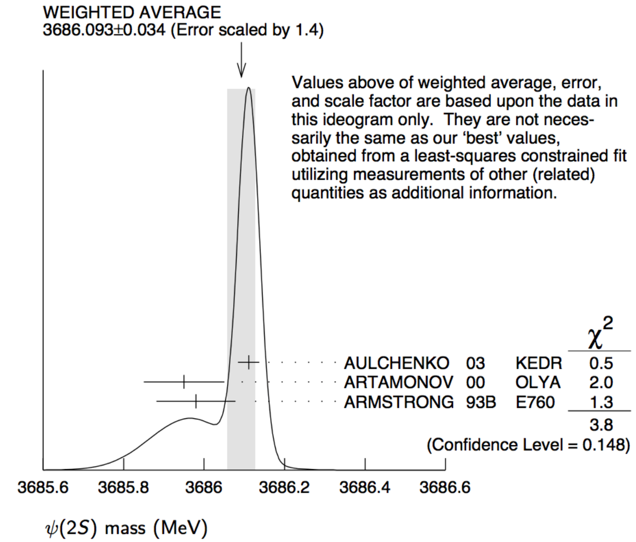
- One of ccbar bound state (2S)
- Mass : 3.686 GeV/c^2





ψ(2S) DECAY MODES

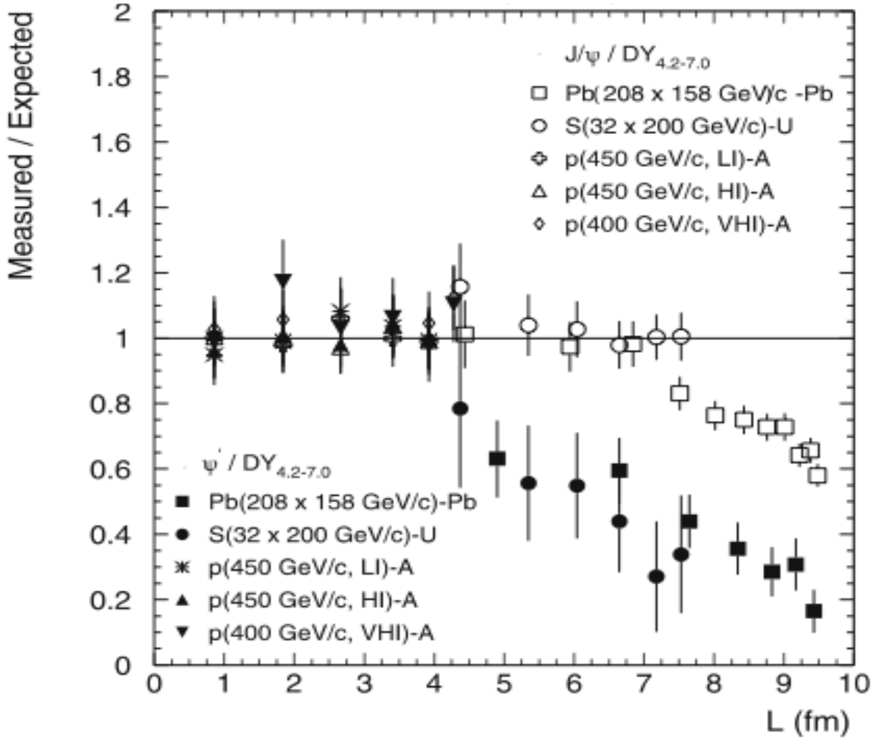
	Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level
Γ_1	hadrons	(97.85±0.13) %	
Γ_2	virtual $\gamma \to$ hadrons	(1.73±0.14) %	S=1.5
Γ_3	ggg	(10.6 ±1.6) %	
Γ_4	γgg	(1.03±0.29) %	
Γ_5	light hadrons	(15.4 ±1.5) %	
Γ_6	e^+e^-	(7.73±0.17) × 10^{-3}	
Γ_7	$\mu^+\mu^-$	(7.7 ±0.8) × 10^{-3}	
Γ_8	$\tau^+\tau^-$	(3.0 ±0.4) × 10^{-3}	



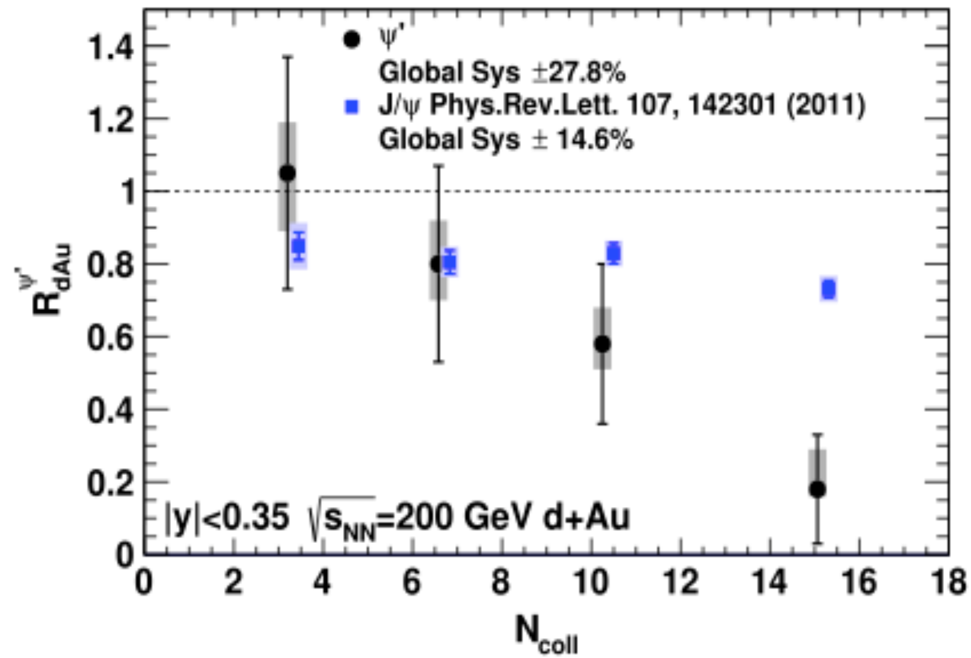
J/ψ feed down fractions	
Mechanism	**% ± Error**
Direct Production	41 ± 17
Ψ(2s) decay	8.1 ± 0.3 [133]
χ_{c1} decay	25 ± 5.0 [133]
b-hadron decay	8.1 ± 3.2 [134]

ψ(2S) Measurements in NN

EPJ C 49 (2007) 559



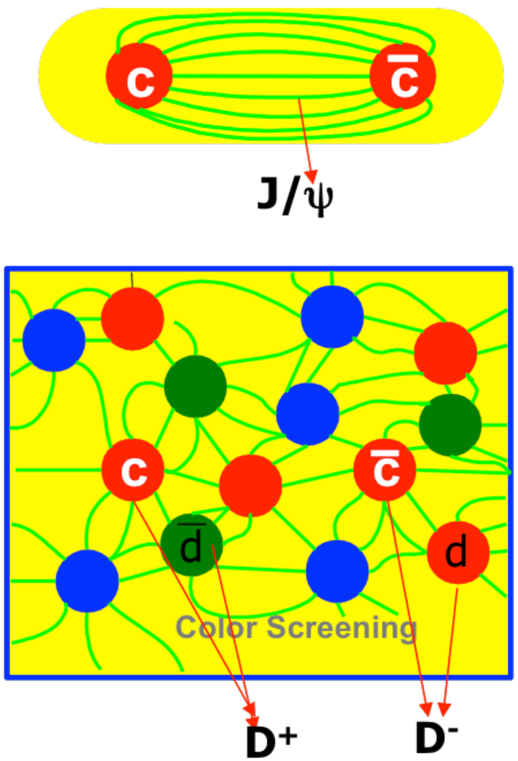
PRL 111 (2013) 202301

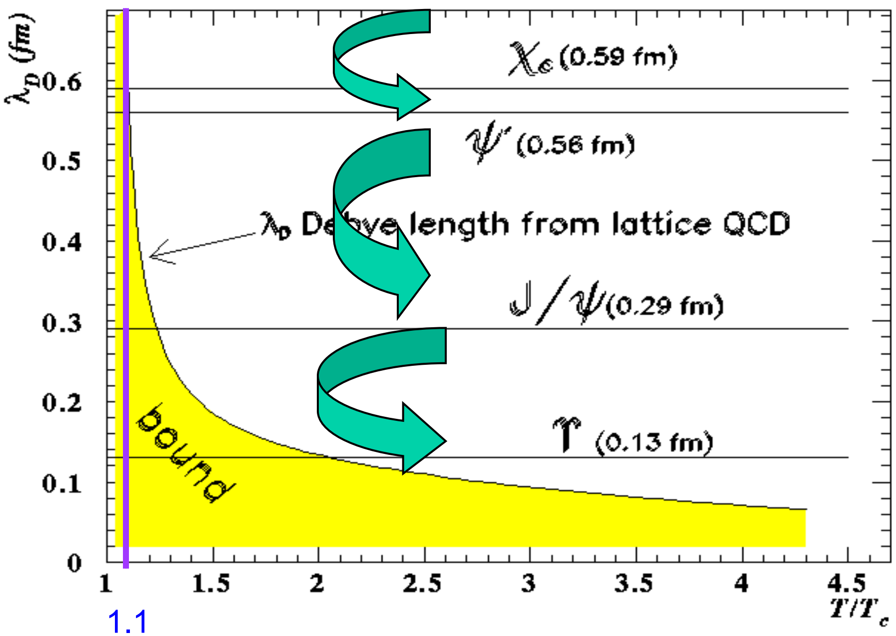


- NA50 (PbPb) : stronger suppression of ψ(2S) than J/ψ in central collisions
- Cold nuclear matter effect (dAu) : stronger suppression of ψ(2S) than J/ψ in central collisions
- (Re)generation : less generation of ψ(2S) than J/ψ (*X. Zhao and R. Rapp, Nucl. Phys. A 859(2011) 114*)

Quarkonia Suppression in Hot Medium

- One of striking signatures for Quark-Gluon-Plasma (QGP) formation
- Sequential melting : different binding energies → bound states are melt sequentially in hot medium





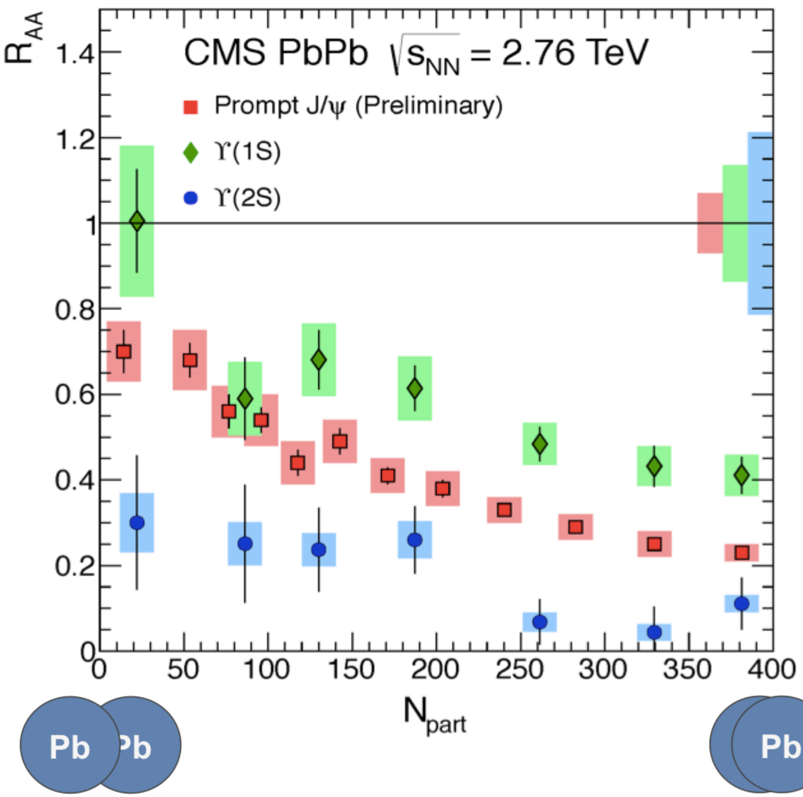
Sequential melting → a QGP thermometer

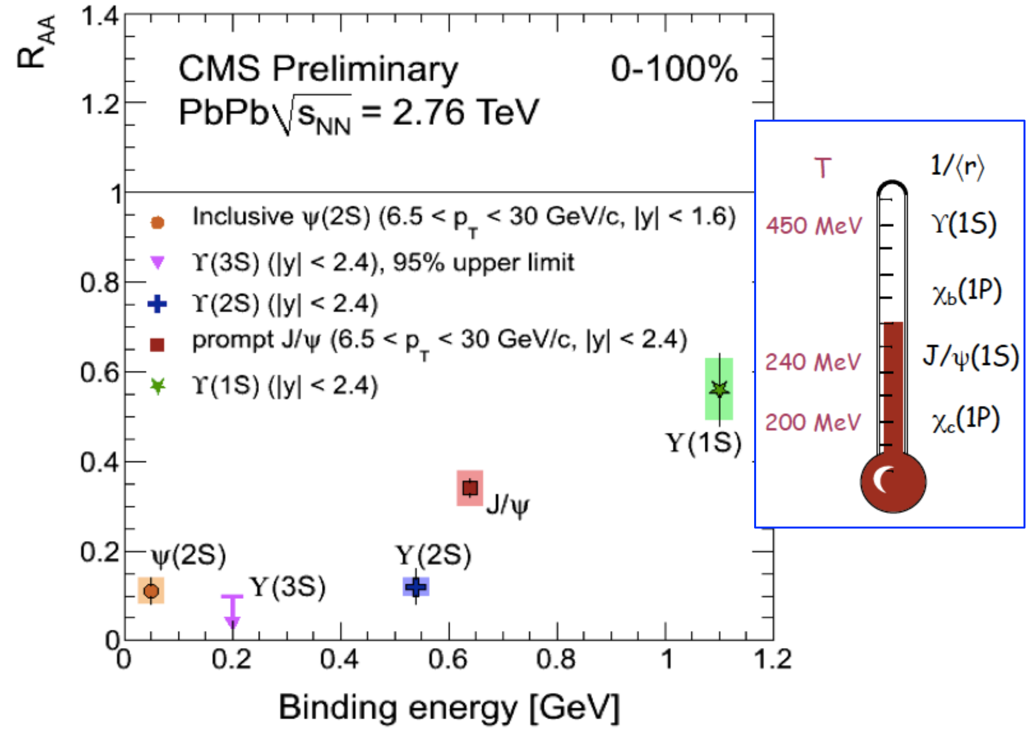
H. Satz, NPA 783 (2007) 249c.

2013 Heavy Flavor Measurements at RHIC and LHC (W. Xie)

- Quenched heavy quarks (energy loss): *A.Rothkopf,* ***PRL 108(2012) 162001***

Quarkonia Suppression in Hot Medium





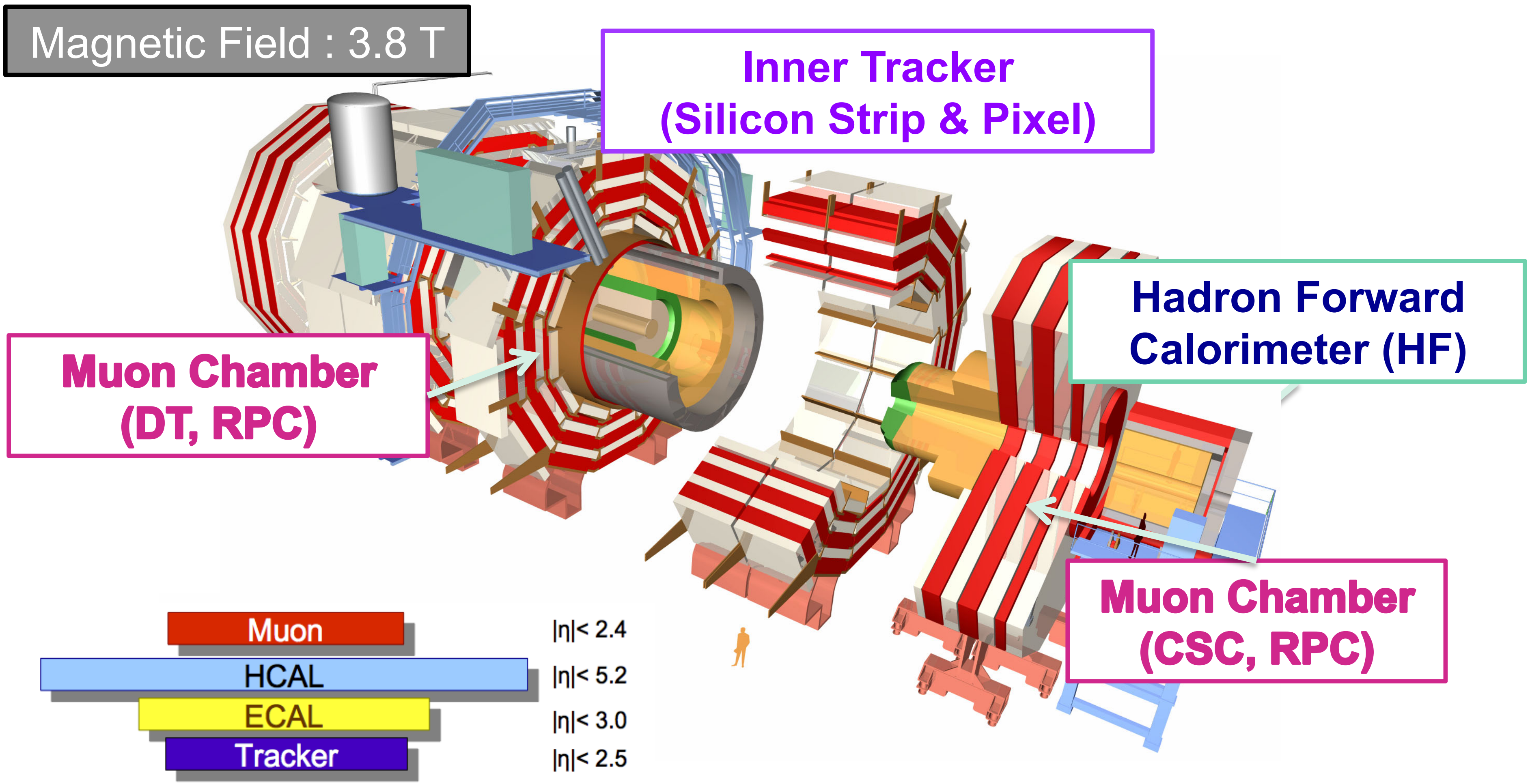
CMS-PAS-HIN-12-014
PRL 109 (2012) 222301

$$R_{AA} = \frac{\mathcal{L}_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}}{N_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}$$

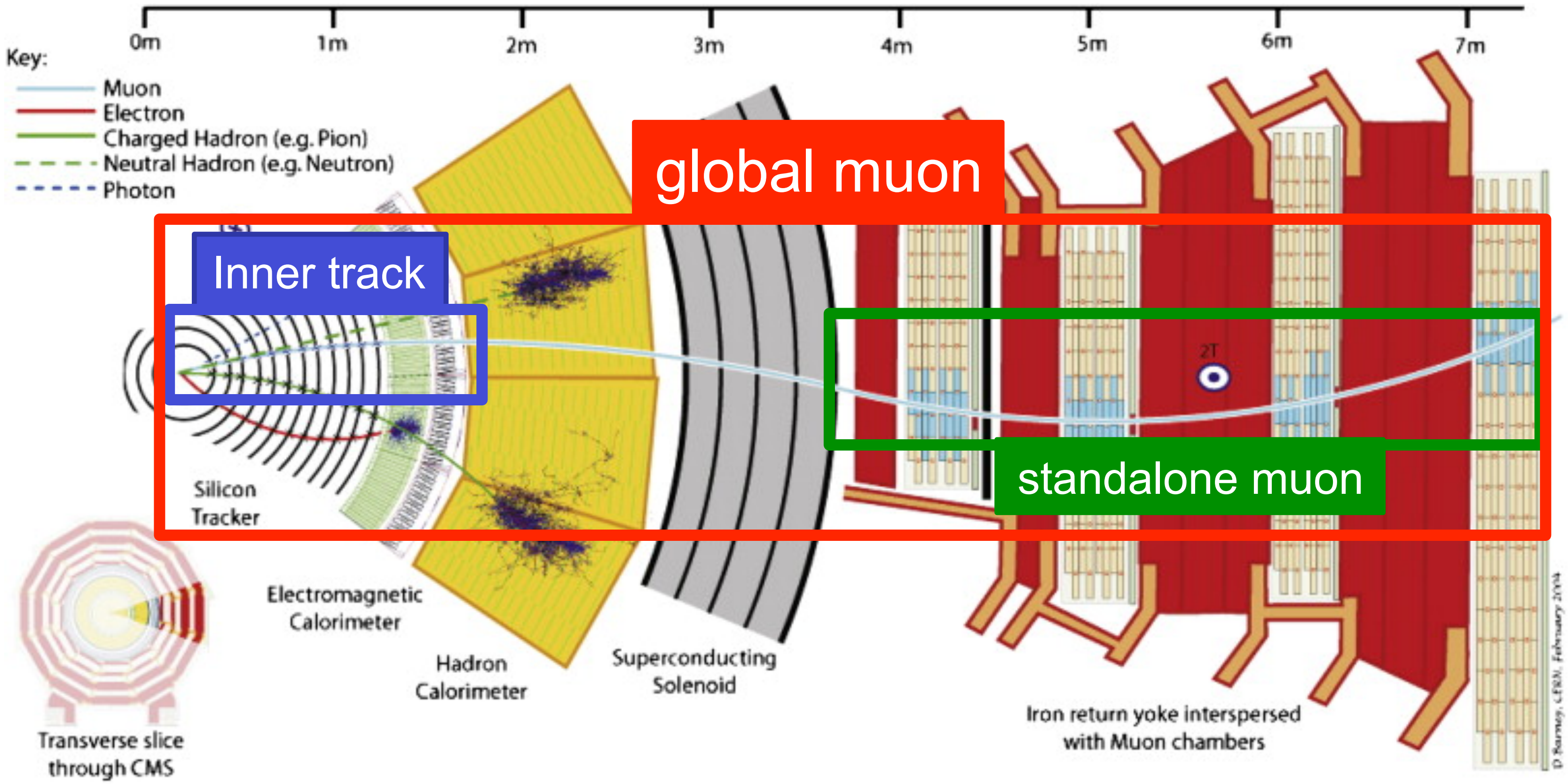
Observed

- Significant suppression of J/ψ and ϒ (1S, 2S, 3S) at PbPb collisions
- Expected hierarchy in the suppression of the states with different binding energy

CMS detector



Muon Reconstruction in CMS

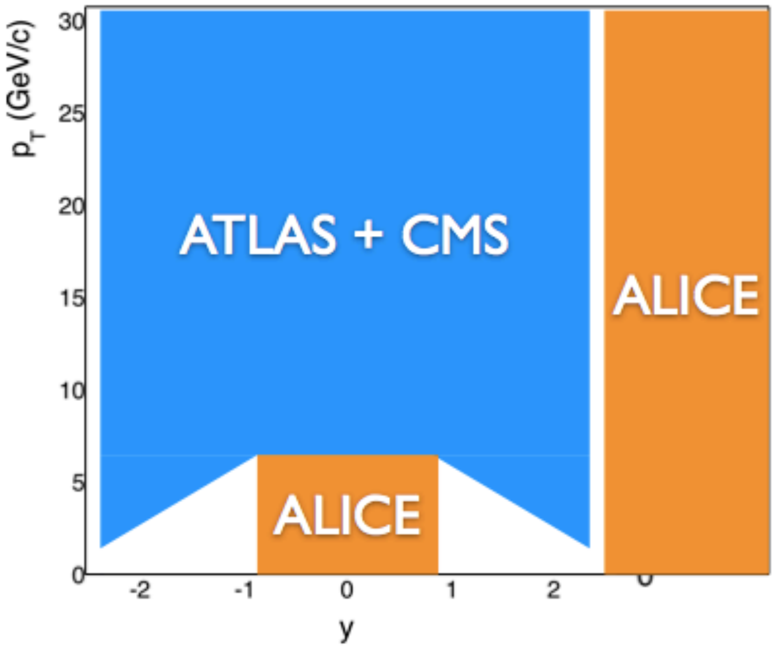


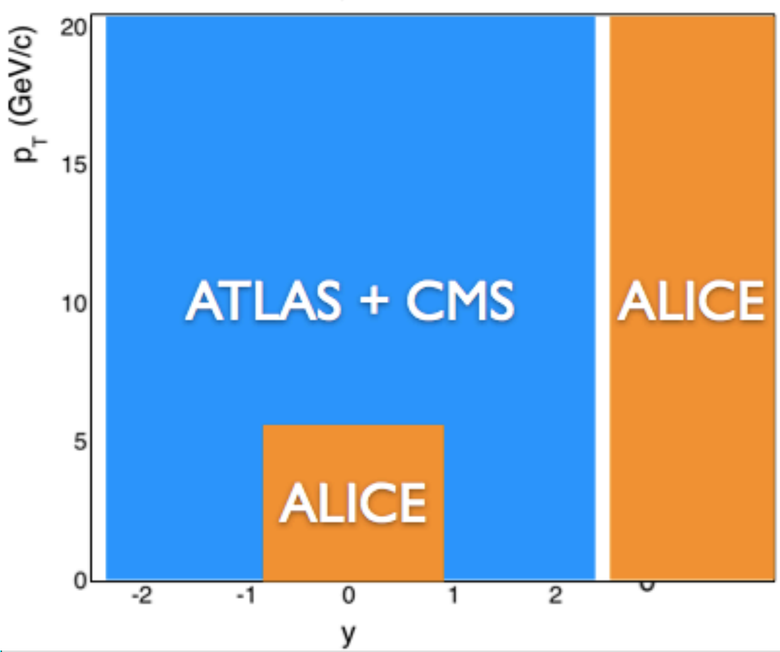
Muon Reconstruction

Muon tracks in muon chamber (or segments) + tracks in inner tracker
Excellent momentum resolution of tracking system.

✓ Overall resolution: 1~2 %

Quarkonia Acceptance



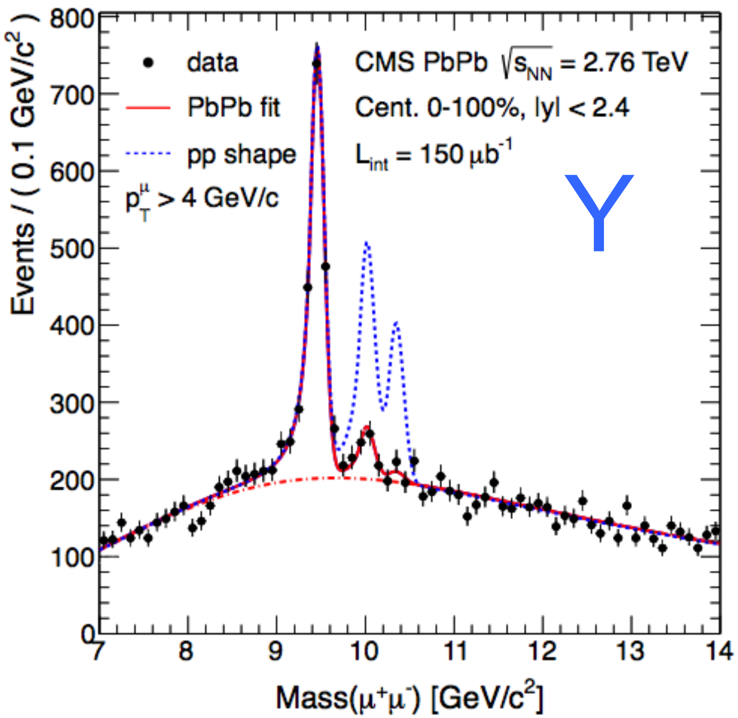


- ALICE: acceptance for $p_T > 0$
  - midrapidity: no absorber and low magnetic field
  - forward rapidity: longitudinal boost
- ATLAS and CMS: Muons need to overcome strong magnetic field and energy loss in the absorber
  - minimum total momentum p~3–5 GeV/c to reach the muon stations
  - Limits J/ψ acceptance:
    - mid-rapidity: $p_T > 6.5$ GeV/c
    - forward rapidity: $p_T > 3$ GeV/c
    - (values for CMS, but similar for ATLAS)
  - ϒ acceptance:
    - $p_T > 0$ GeV/c for all rapidity
- Complementary acceptances

Excited Quarkonia States in PbPb

Observed stronger suppression of excited states than ground state in bottomnia measurement. What about charmonia ?

PRL 109 222301 (2012)



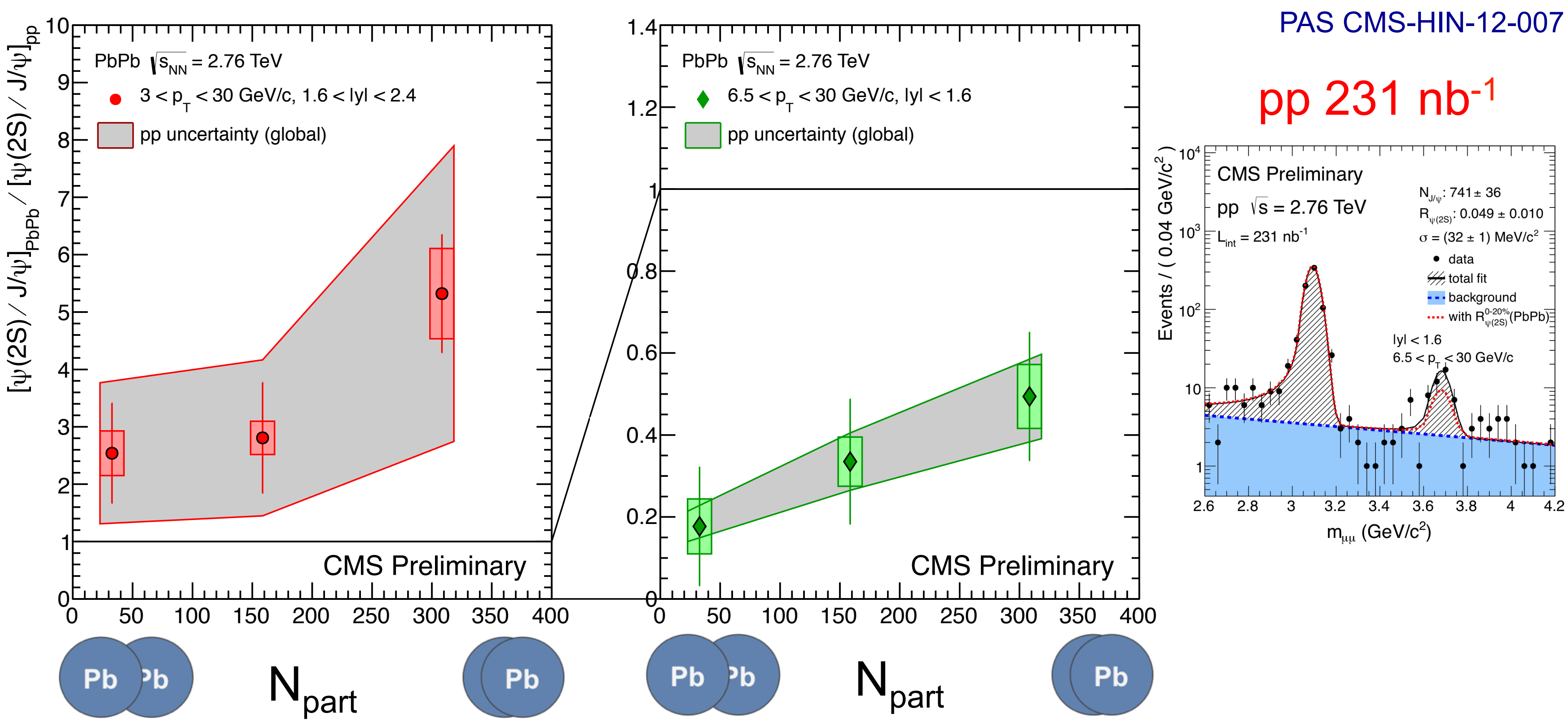
R_{AA} of Υ(1S)>Υ(2S)>Υ(3S)

Charmonia ?

Expectations:

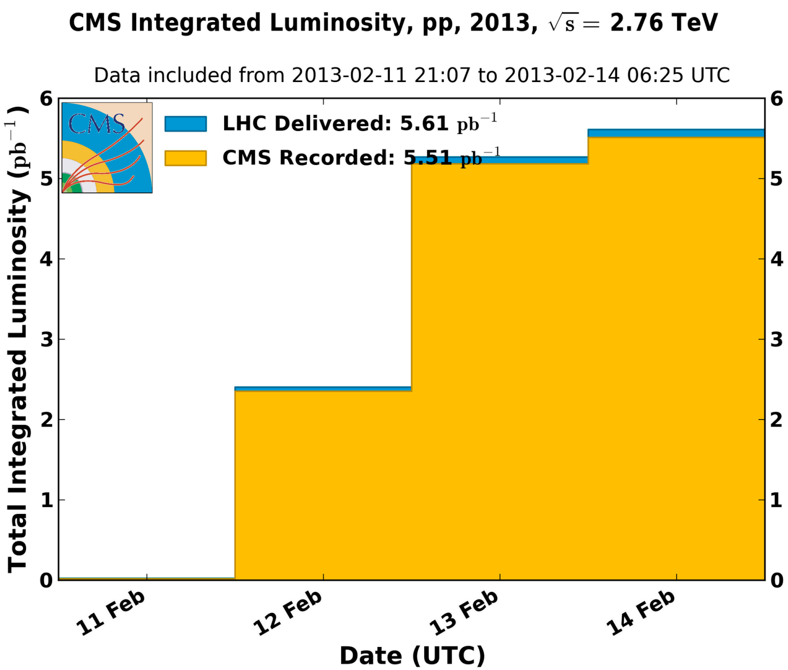
- Sequential melting: R_{AA} of (J/ψ)>ψ(2S)
- (Re)generation: R_{AA} of (J/ψ)>ψ(2S)

Previous results of ψ(2S) Measurements



- Double ratio of inclusive ψ(2S) to J/ψ
- Stronger suppression of ψ(2S) than J/ψ in mid-rapidity and high p_T (as predicted from sequential melting)
- Hint of ψ(2S) enhancement relative to J/ψ in central PbPb at low p_T and forward rapidity, however, severely limited by large pp uncertainty

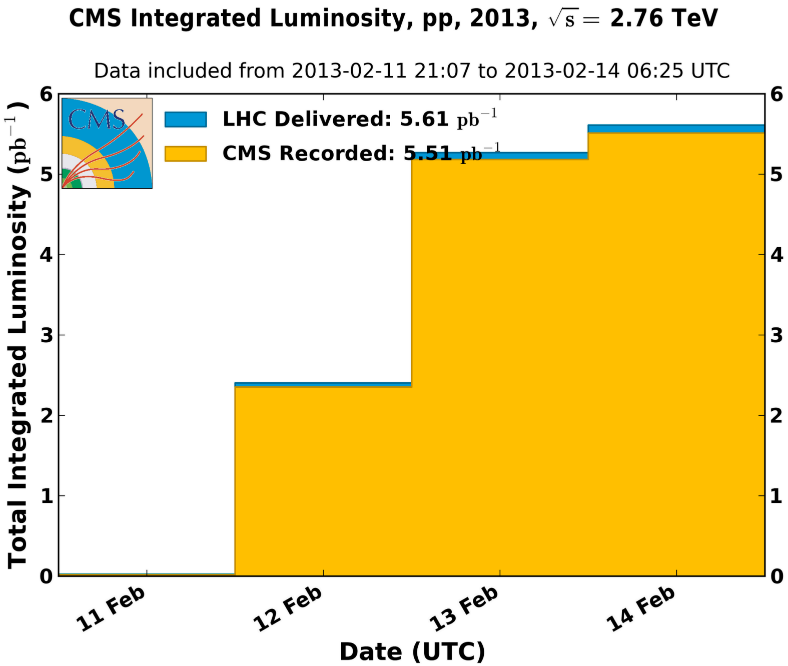
New ψ(2S) measurement in PbPb

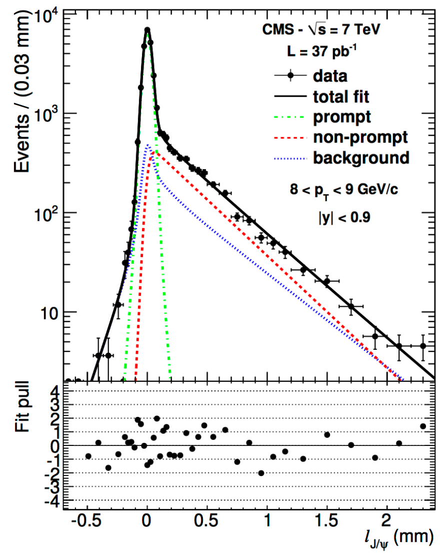


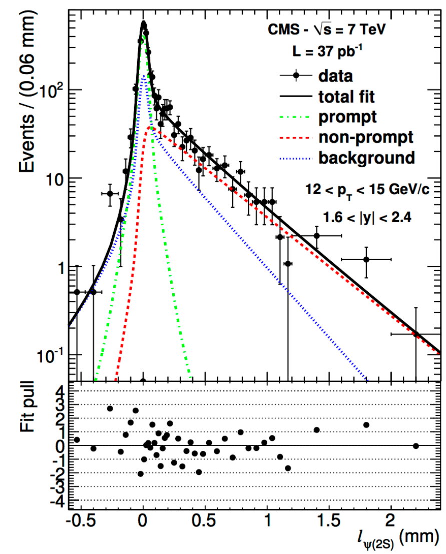
- Thanks to pp run in 2013: ~ 20 times larger data sample

New ψ(2S) measurement in PbPb

JHEP 02 (2012) 011







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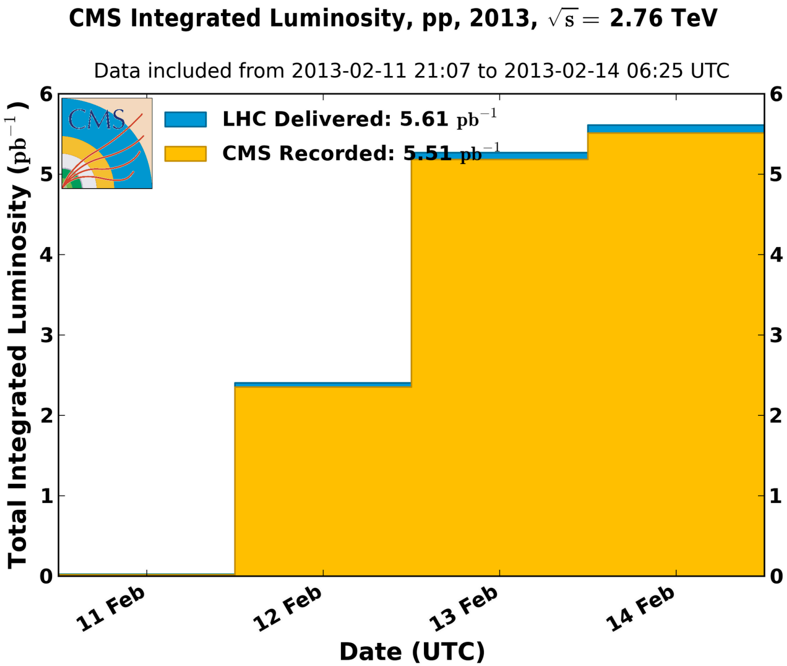
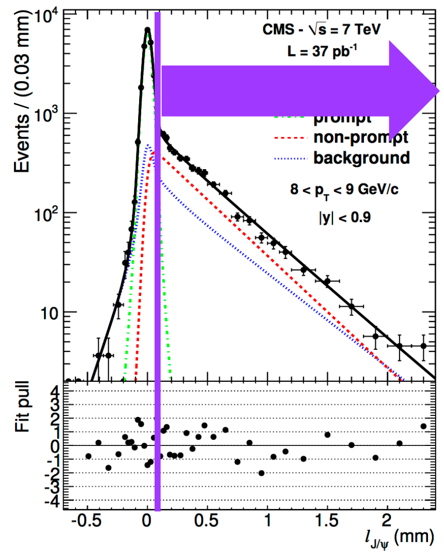
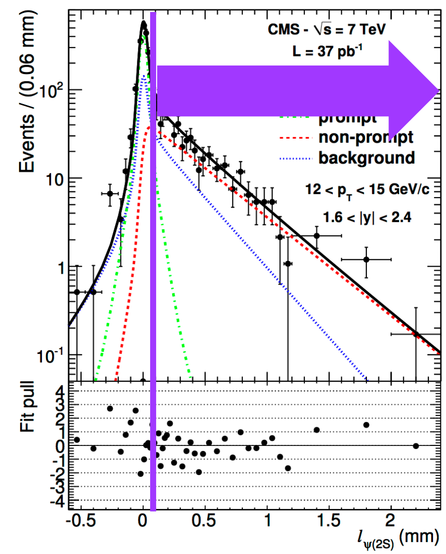
JHEP 02 (2012) 011



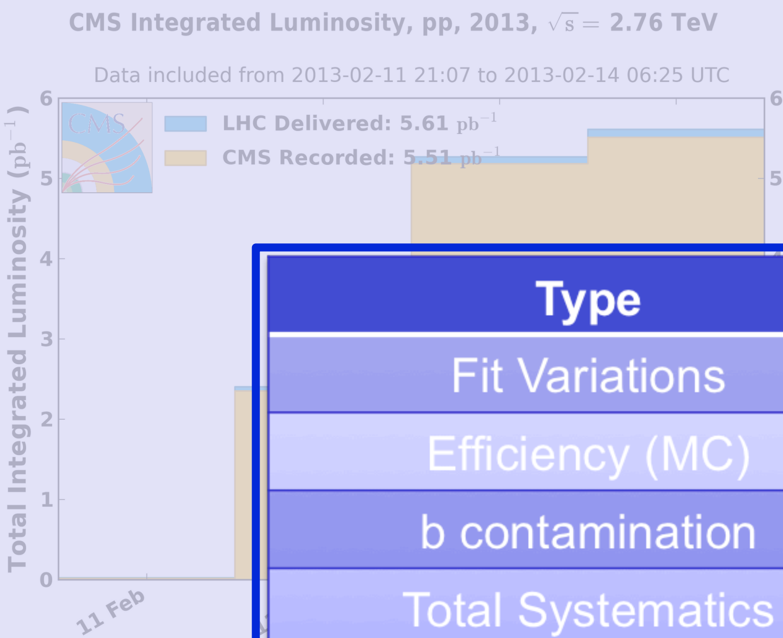


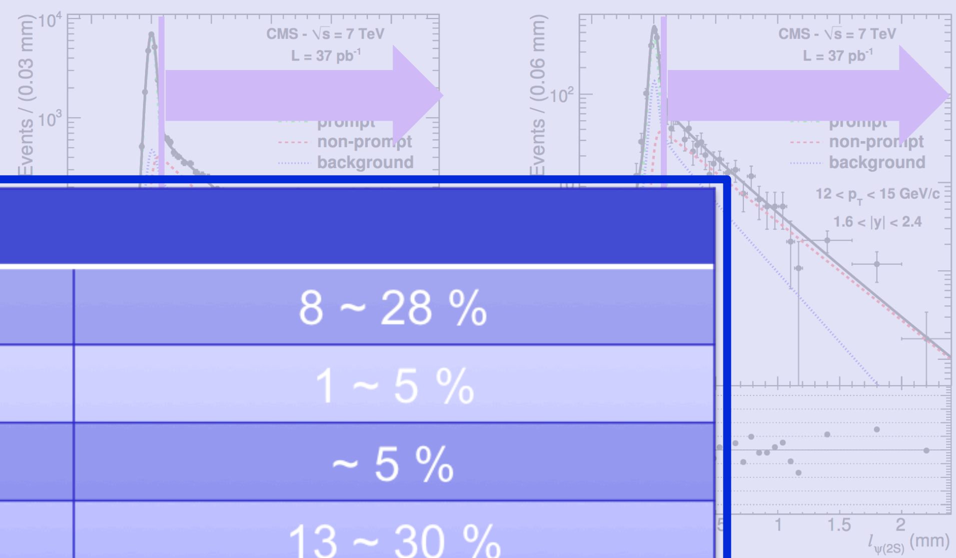


- Thanks to pp run in 2013: ~ 20 times larger data sample
- Reject non-prompt contribution by cut on pseudo-proper decay length
- Keep 90% of prompt charmonia: cancels in double ratio
- Non-prompt contamination ~5%: included in systematic uncertainties

New ψ(2S) measurement in PbPb

JHEP 02 (2012) 011



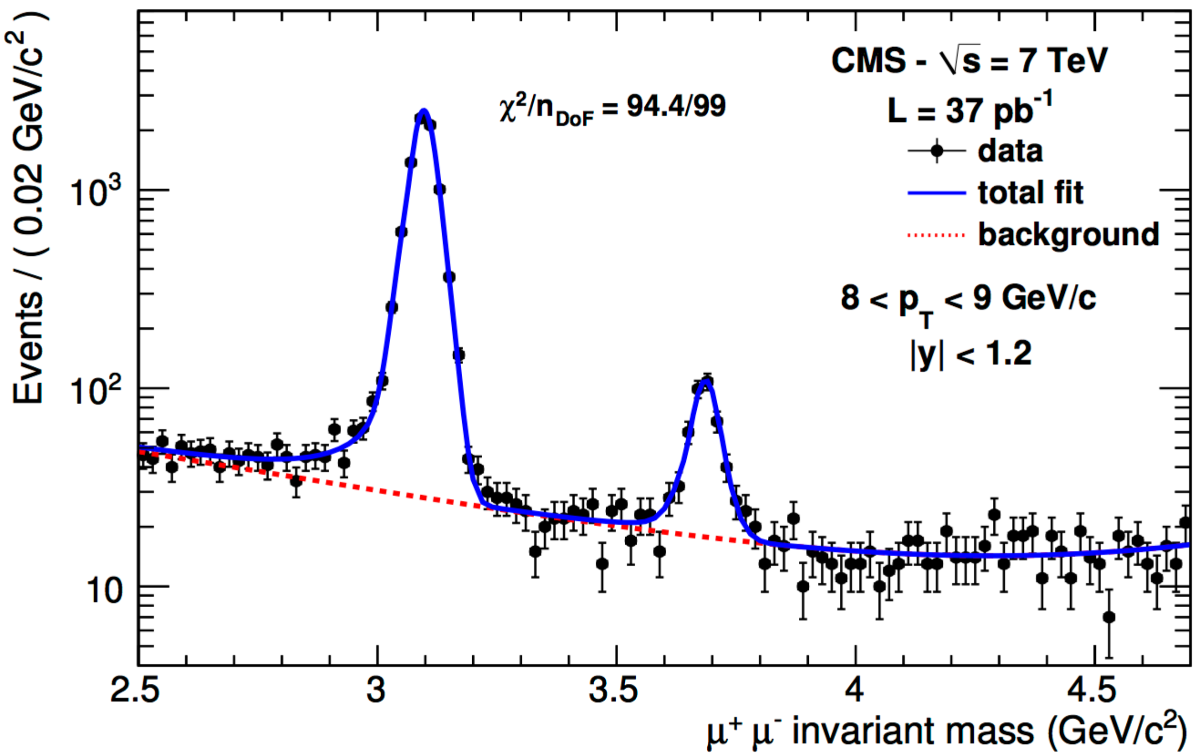


Type	
Fit Variations	8 ~ 28 %
Efficiency (MC)	1 ~ 5 %
b contamination	~ 5 %
Total Systematics	13 ~ 30 %
pp Statistics	≈ 6 %

- Thanks to pp run in 2013: ~ 20 times larger data sample
- Reject non-prompt contribution by cut on pseudo-proper decay length
- Keep 90% of prompt charmonia: cancels in double ratio
- Non-prompt contamination ~5%: included in systematic uncertainties

Signal Extraction of Prompt ψ(2S)

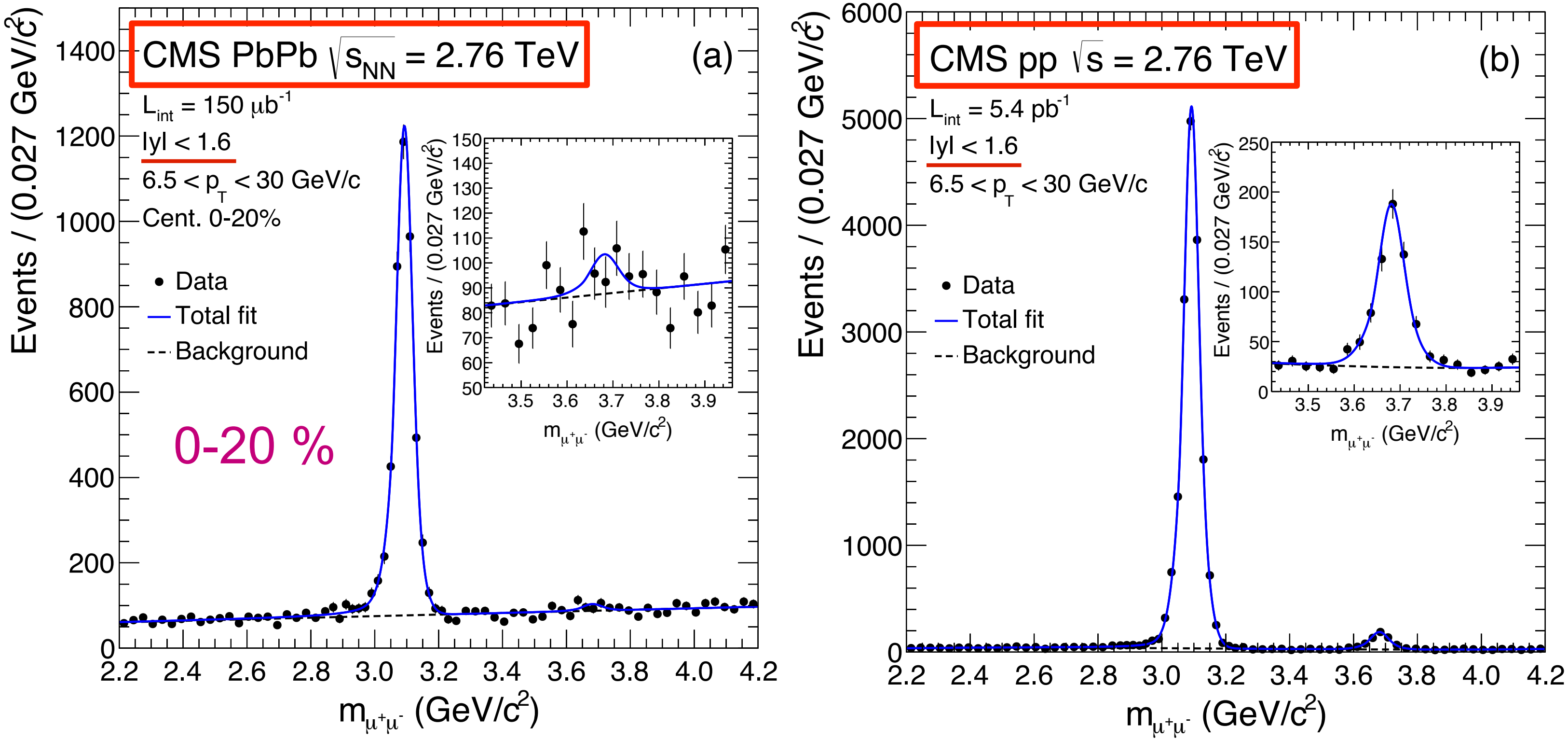
JHEP 02 (2012) 011



- Signal region : Gaussian + CrystalBall functions
- Background region : Chebyshev polynomials ($1 \leq N \leq 3$) for each analysis bins
- Several fit functions were tested for systematics (8% - 28%)

Prompt ψ(2S) in mid-rapidity (high p_T)

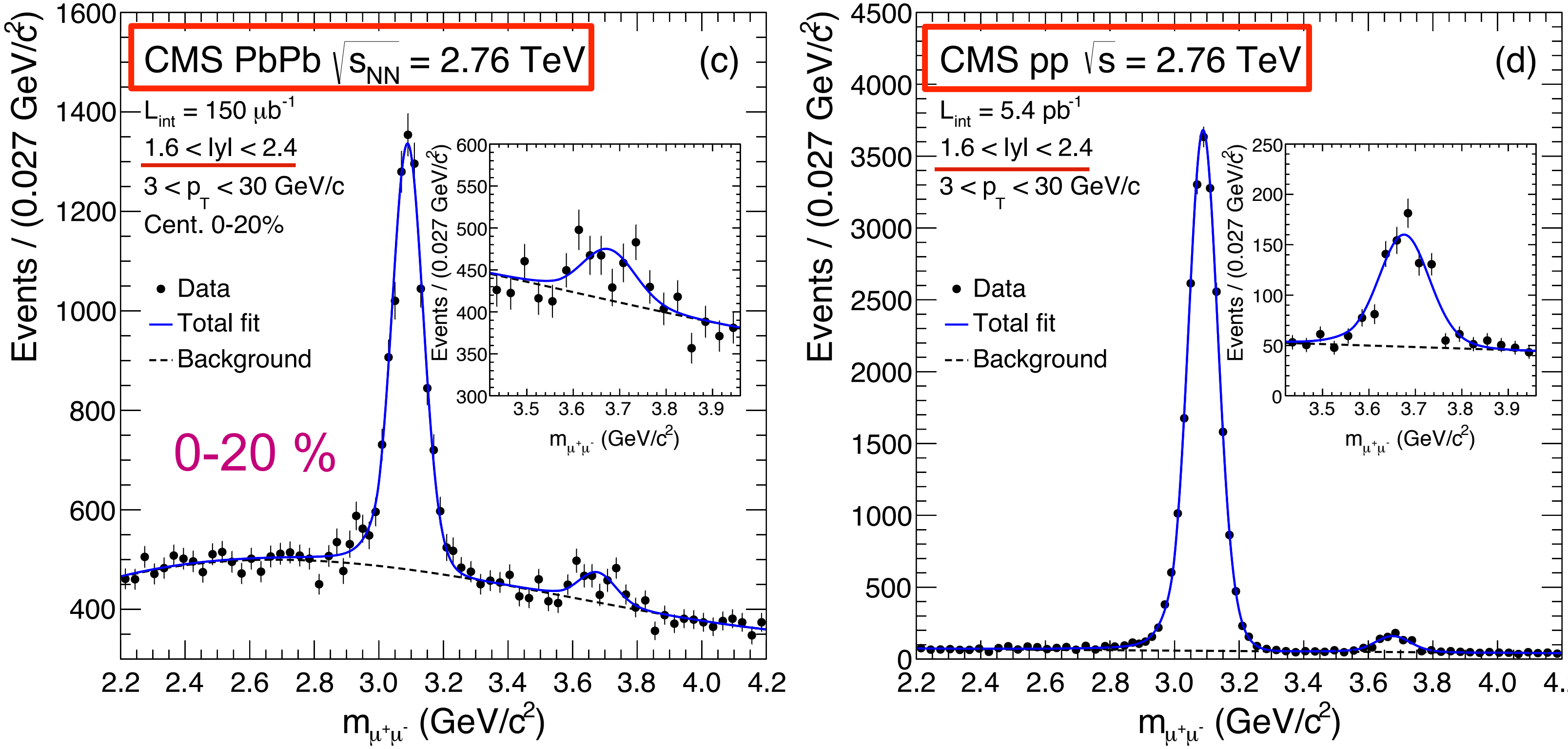
PRL 113 (2014) 262301



- In high p_T (mid-rapidity): ψ(2S) in PbPb is smaller than in pp with respect to the J/ψ as seen with 2010 pp data.

Prompt ψ(2S) in forward rapidity (low p_T)

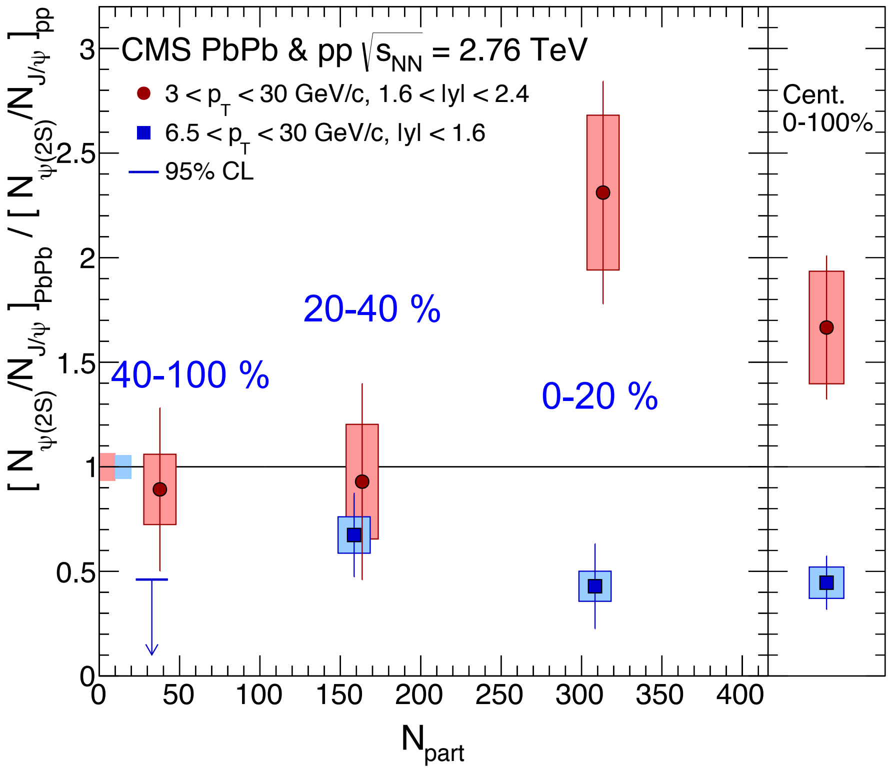
PRL 113 (2014) 262301



- In low p_T (forward-rapidity): ψ(2S) in PbPb is higher(or less) ?? than in pp with respect to J/ψ, yet.

Double Ratio of Prompt ψ(2S)

PRL 113 (2014) 262301



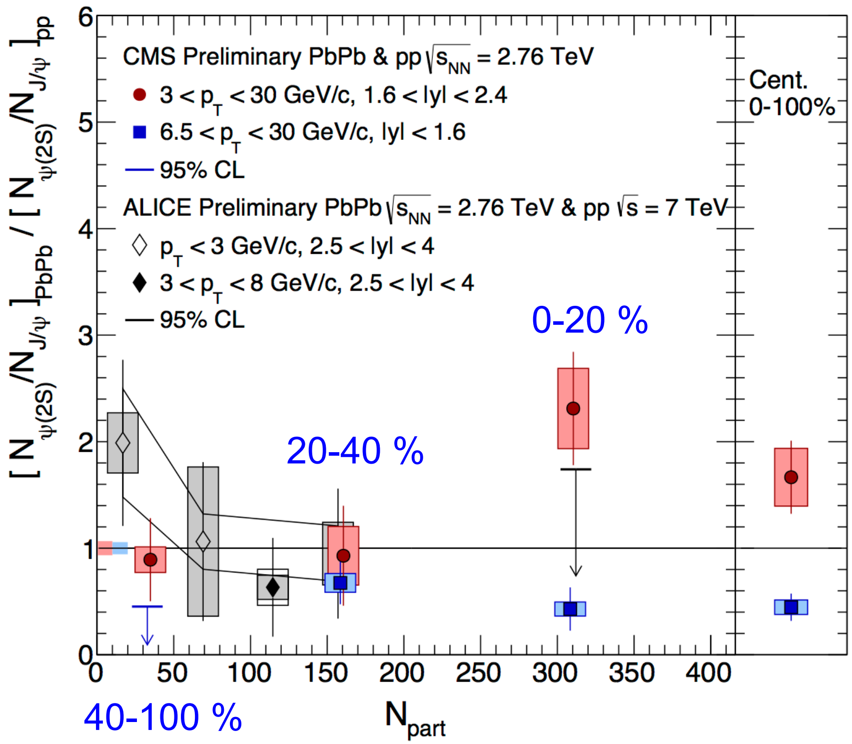
Double Ratio = Ratio of R_{AA}

$$\frac{[N_{\psi(2S)}/N_{J/\psi}]_{PbPb}}{[N_{\psi(2S)}/N_{J/\psi}]_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$$

- Observe a difference in ψ(2S) production for both central and minbias PbPb at high p_T (mid-rapidity) vs low p_T (forward-rapidity)
  - ➡ At high p_T and mid-rapidity ψ(2S) is more suppressed than J/ψ in PbPb collisions (as expected from sequential melting)
  - ➡ At low p_T and forward rapidity ψ(2S) is less suppressed than J/ψ at mid-rapidity and high p_T (contrary to expectations from sequential melting and/or regeneration)

Comparison of ALICE and CMS

PRL 113 (2014) 262301



Double Ratio = Ratio of R_{AA}

$$\frac{[N_{\psi(2S)}/N_{J/\psi}]_{PbPb}}{[N_{\psi(2S)}/N_{J/\psi}]_{pp}} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}$$

- Observe a difference in ψ(2S) production for both central and minbias PbPb at high p_T (mid-rapidity) vs low p_T (forward-rapidity)
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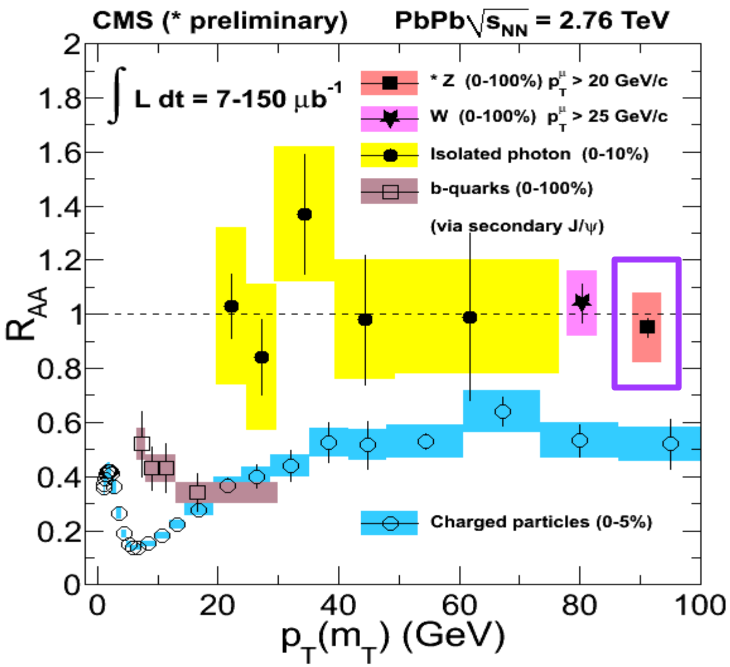
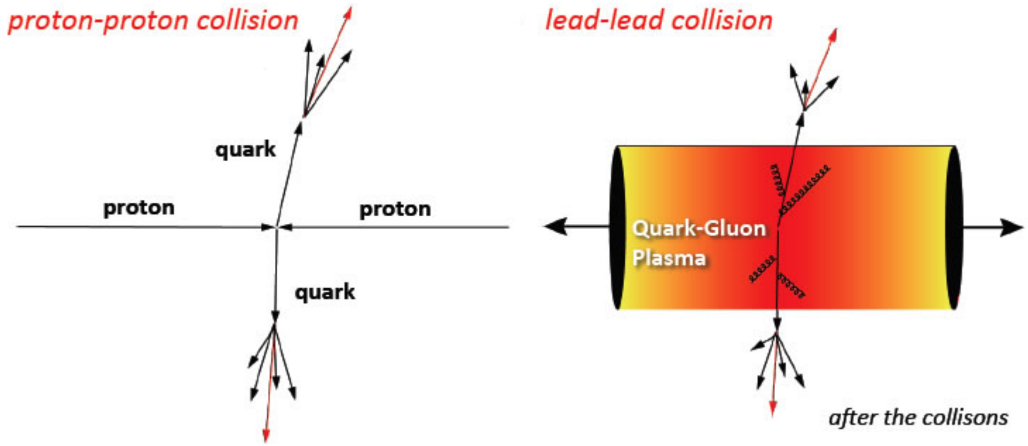
Z boson in pp & pPb & PbPb collisions

Z boson measurement

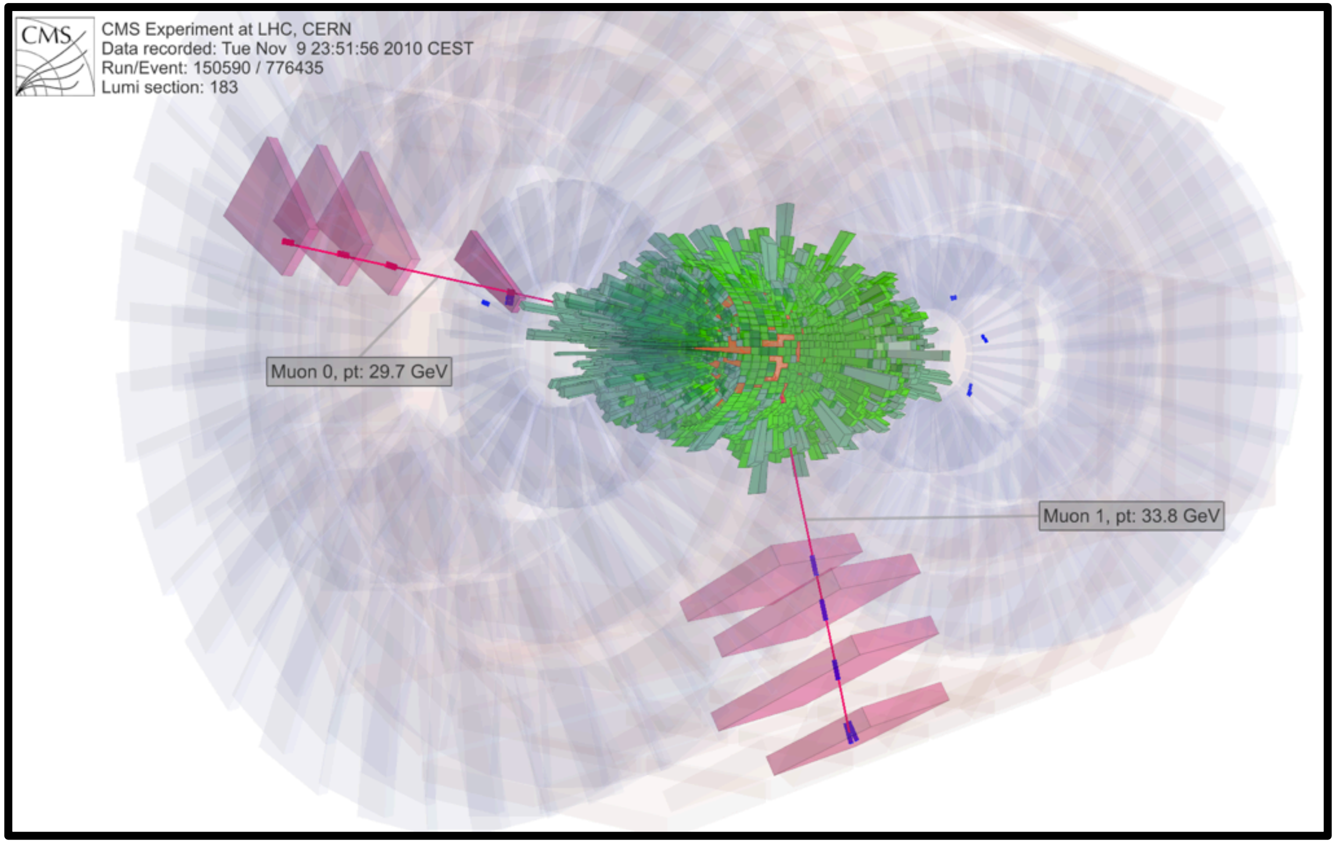




$$R_{AA} = \frac{\text{Yield}_{AA} / \langle N_{Coll} \rangle}{\text{Yield}_{pp}}$$

- Why we are interested in Z boson ?
  - Elector+weak interacting particles are expected not to be modified by QGP.
  - It should be used as the reference for modified objects (quarkonia, light hadrons … etc)
  - Ultimately can help to constrain initial state - standard candle of initial state.
- If the initial state effects would be influenced … by
  - Nuclear shadowing : nPDF can be modified (suppressed in low x region than pp): 10-20 %
  - Isospin effect : Proton and neutron have different quark constituent : ~3 %
  - Energy loss and multiple scattering of initial parton : ~3 %

Z boson measurement in PbPb

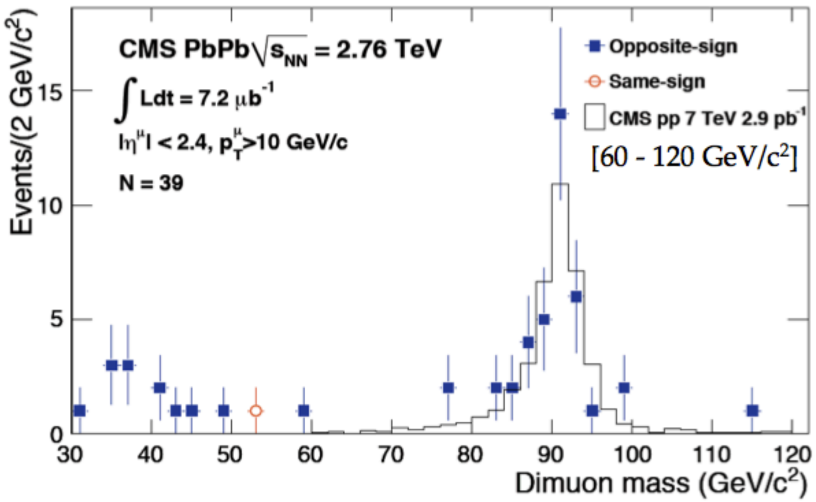


The first Z ➔ $\mu^-\mu^+$ candidate found in CMS heavy-ion collisions at 2010

Z boson measurement in PbPb

PRL 106 (2011) 212301

2010

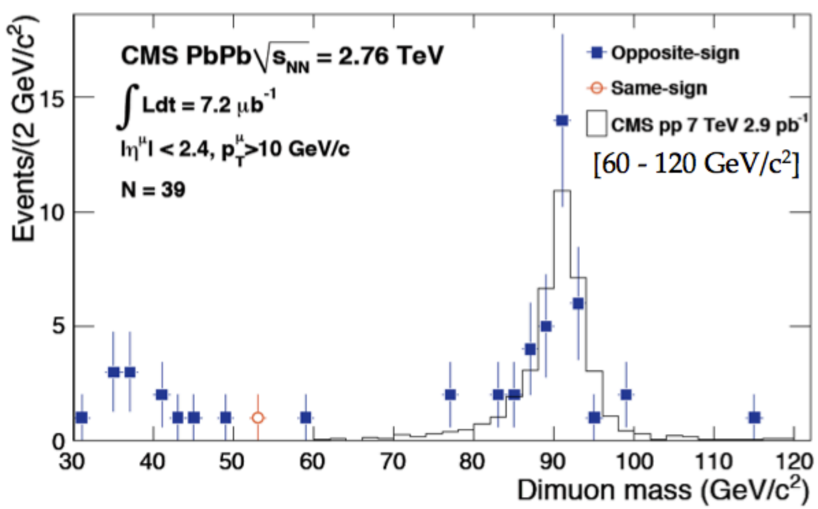


39 candidates

Z boson measurement in PbPb

PRL 106 (2011) 212301

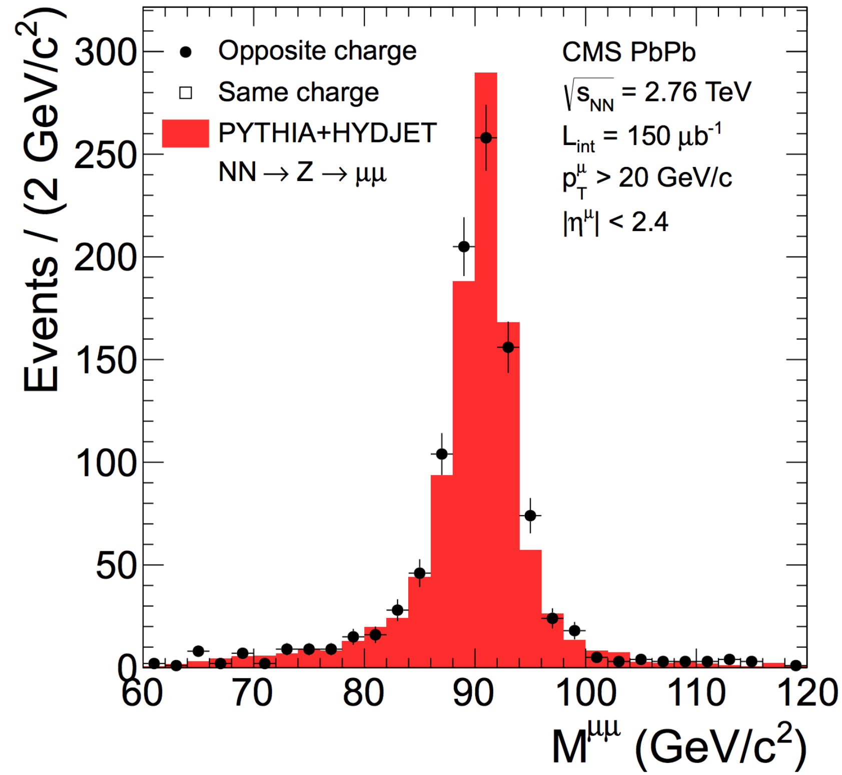
2010



39 candidates

2013

JHEP 03 (2015) 022

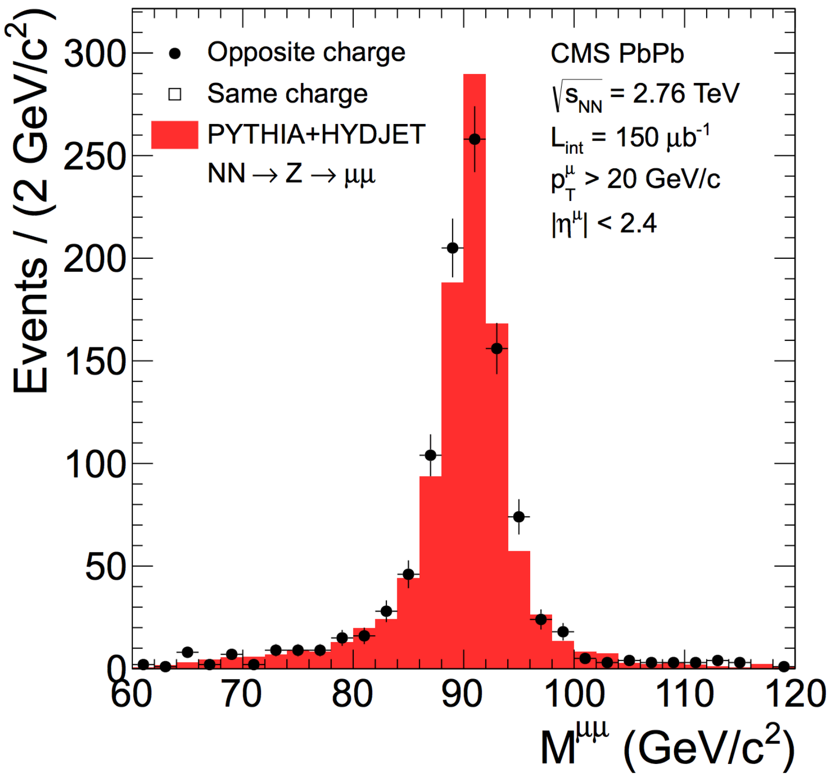


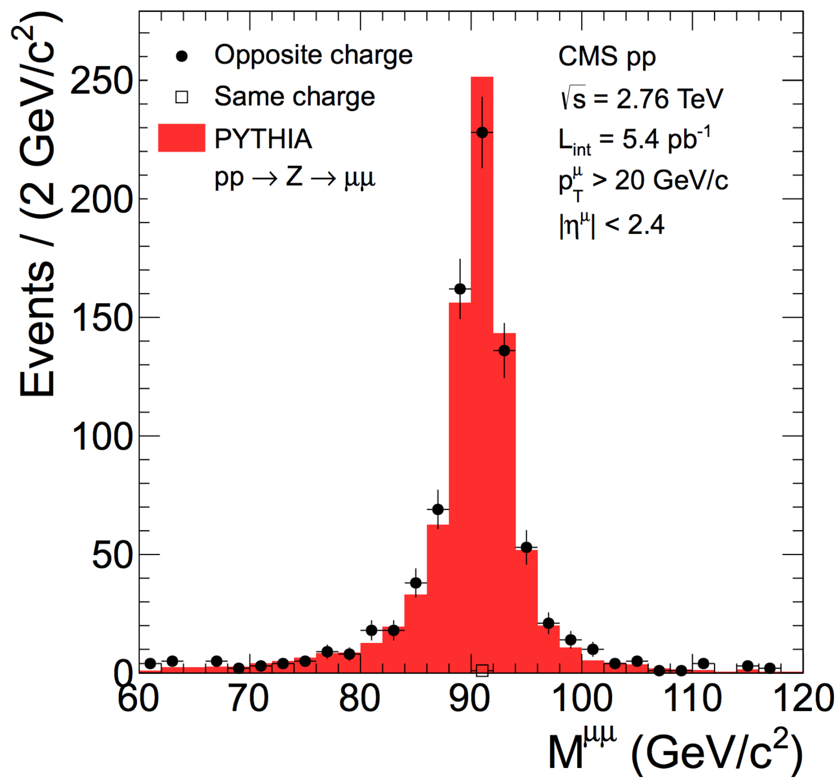
667 candidates

Z boson measurement in PbPb

2013

JHEP 03 (2015) 022





Z boson measurement in PbPb

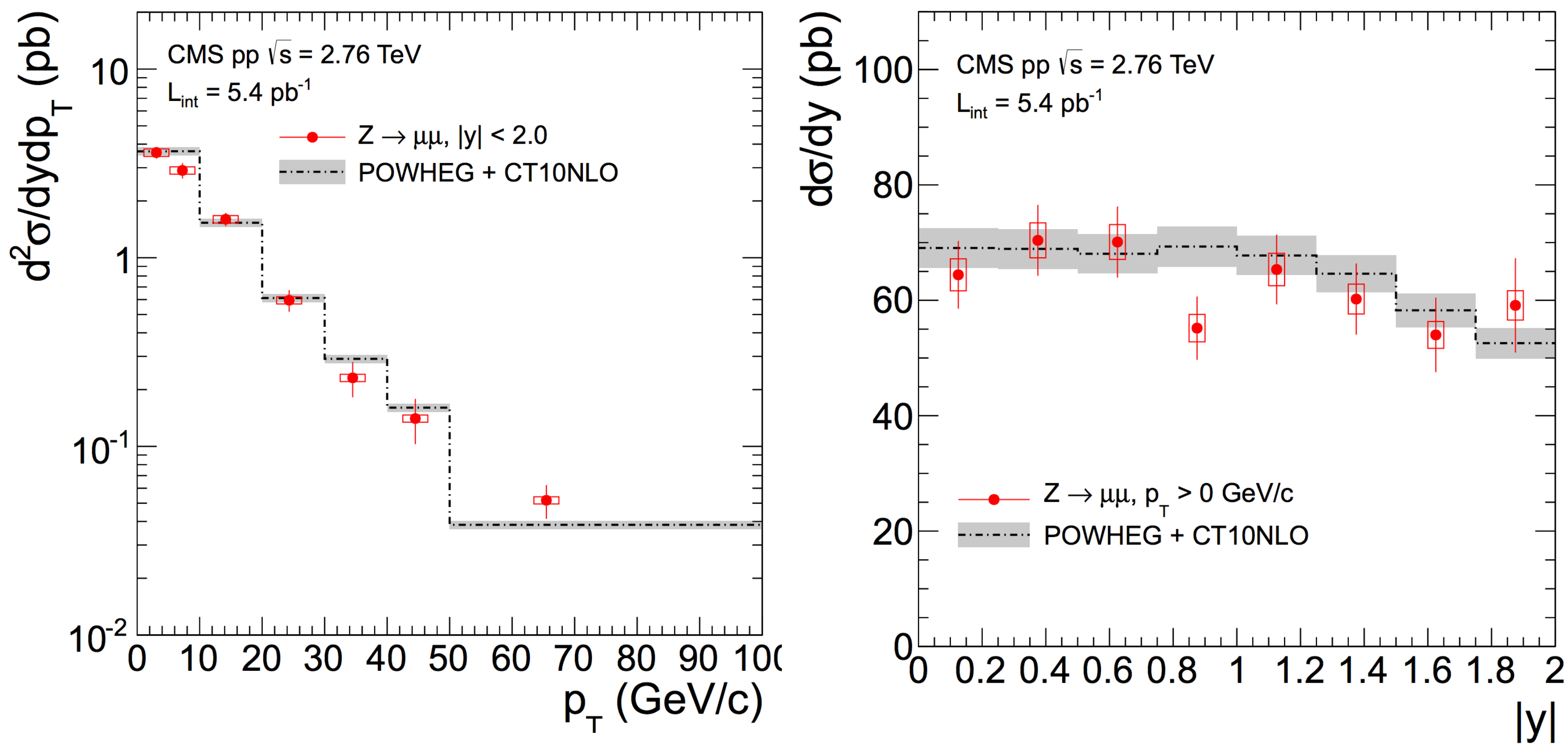
- Uncertainties

Source	$Z \to \mu^+\mu^-$	
	PbPb	pp
Combined efficiency	1.8%	1.9%
Acceptance	0.7%	0.7%
Background	0.5%	0.1%
N_{MB}	3.0%	–
T_{AA} (N_{MB} included)	6.2%	–
Integrated luminosity (L_{int})	–	3.7%
Overall (without T_{AA} or L_{int})	3.6%	2.0%
Overall	6.5%	4.2%

Z boson measurement in PbPb

JHEP 03 (2015) 022

pp differential cross section

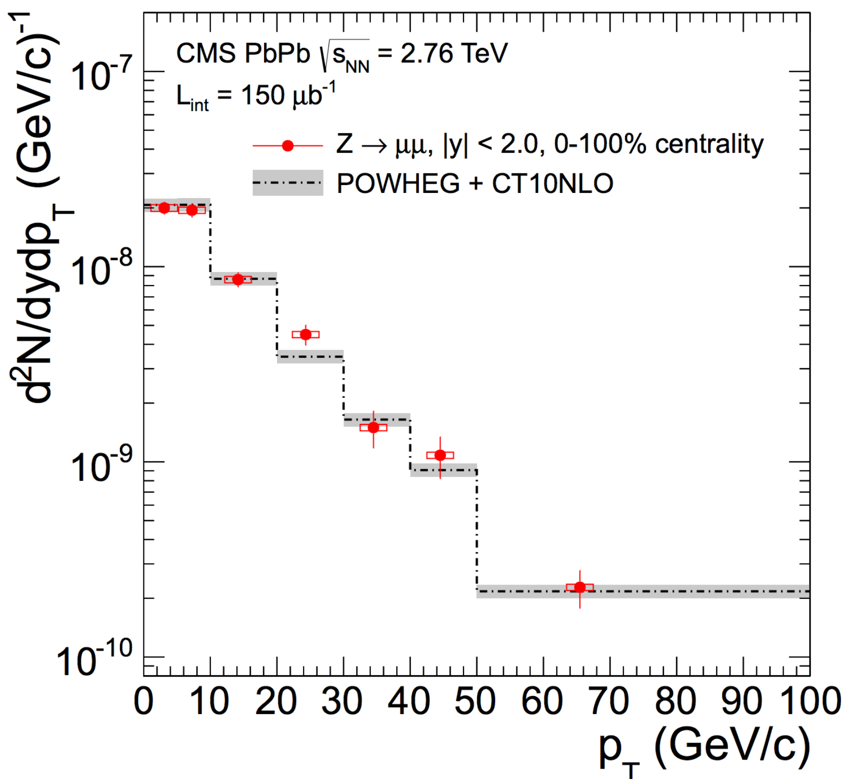


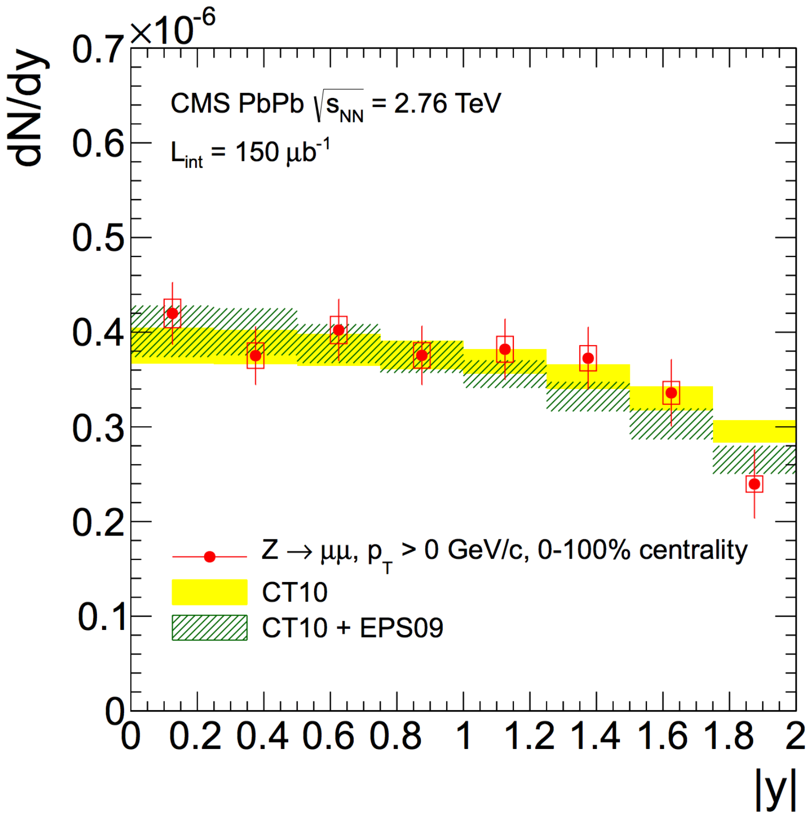
- Overall cross sections agree with the POWHEG theoretical prediction.
- Higher order correlation (~3%), Next-to-next-to-leading-order calculation (~3%) – grey band.

Z boson measurement in PbPb

JHEP 03 (2015) 022

PbPb differential cross section



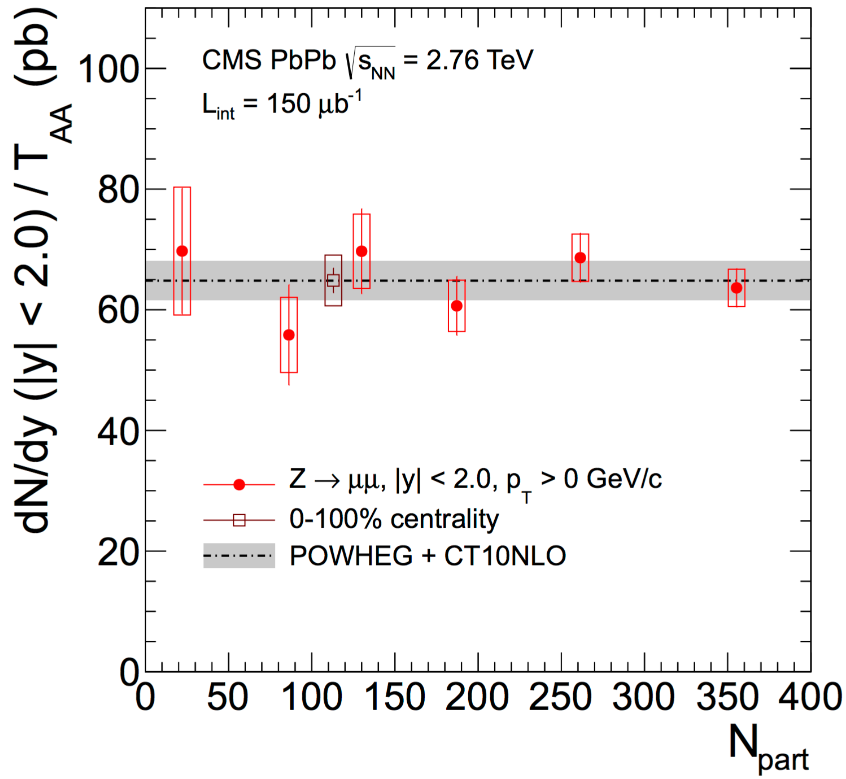


- p_T dependence : compatible to POWHEG theoretical prediction
- |y| dependence : compared to consideration of no nuclear effect (yellow band) or nuclear effect (green band)

Z boson measurement in PbPb

JHEP 03 (2015) 022

PbPb differential cross section

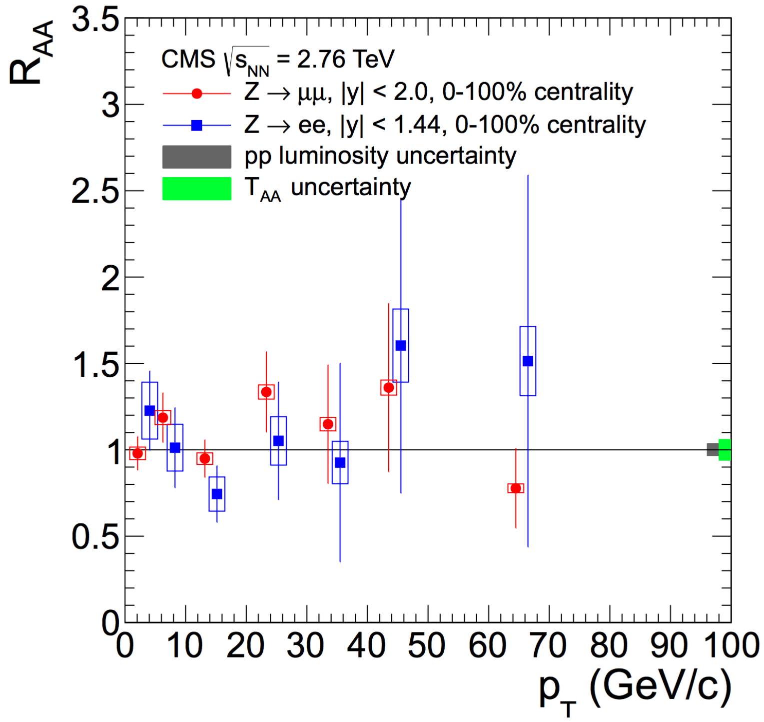


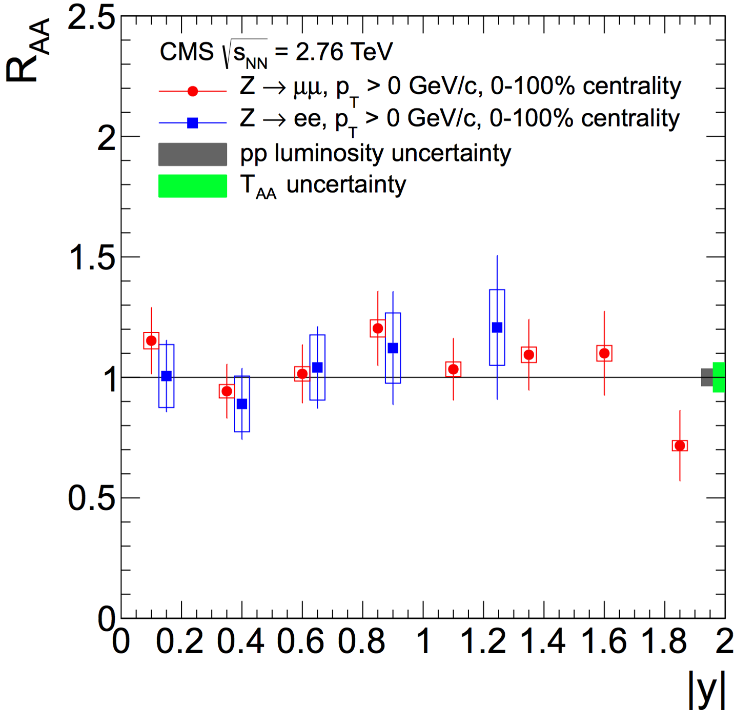
- Centrality dependence : no strong dependence observed. Compared to pythia pp cross section generated by POWHEG.

Z boson measurement in PbPb

JHEP 03 (2015) 022

$$R_{AA} = \frac{N^{Z}_{PbPb}}{T_{AA} \times \sigma^{Z}_{pp}} \equiv \frac{N^{Z}_{PbPb}}{N_{coll} \times N^{Z}_{pp}}$$



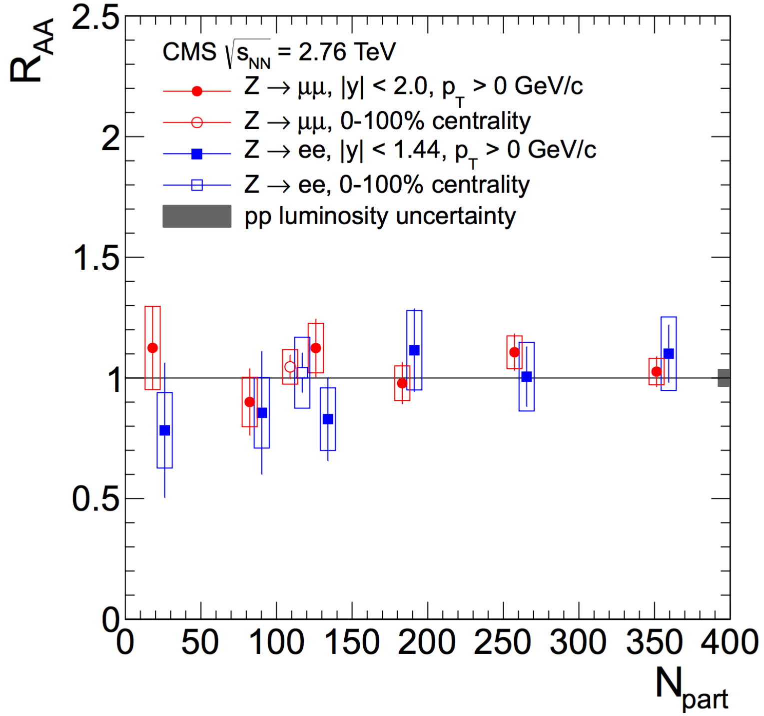


- No strong dependence on p_T and y as expected.
- R_{AA} is consistent with ~ 1 within uncertainties.

Z boson measurement in PbPb

JHEP 03 (2015) 022

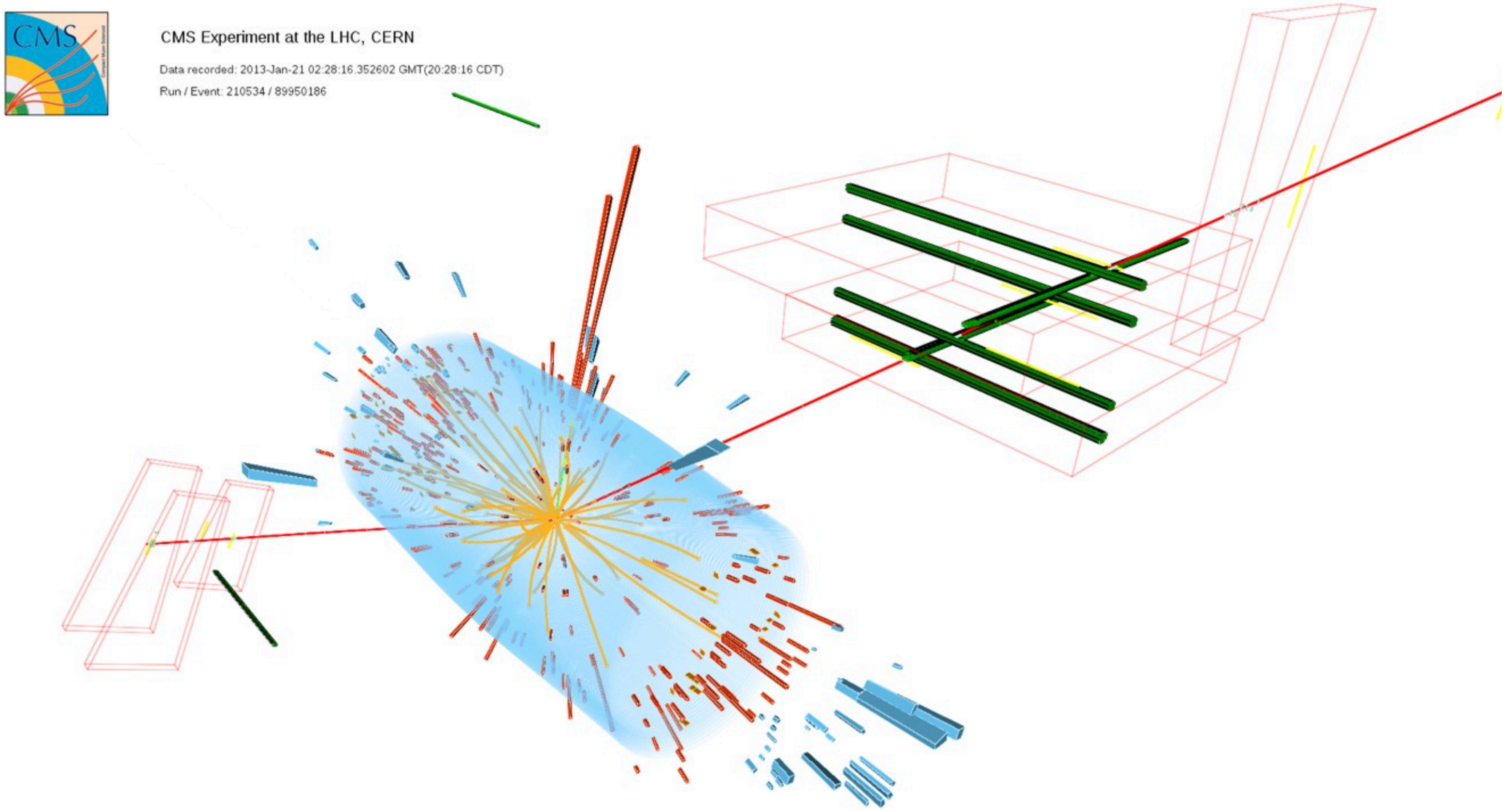
$$R_{AA} = \frac{N^{Z}_{PbPb}}{T_{AA} \times \sigma^{Z}_{pp}} \equiv \frac{N^{Z}_{PbPb}}{N_{coll} \times N^{Z}_{pp}}$$



R_{AA} = 1.06 ± 0.05 ± 0.11

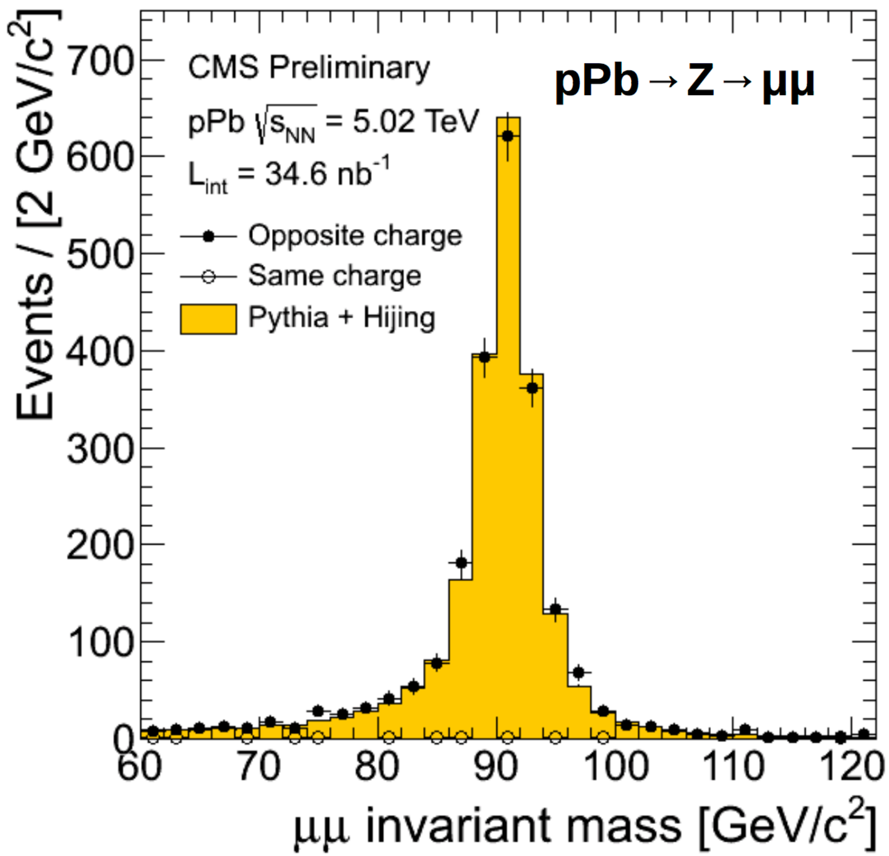
- No strong dependence on centrality as expected.
- R_{AA} is consistent with ~ 1 within uncertainties.

Z boson measurement in pPb

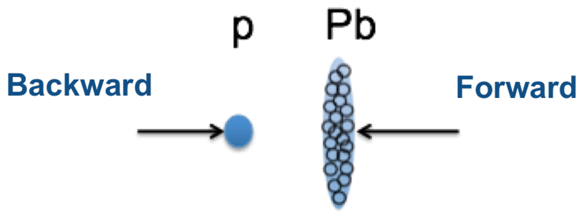


Z boson measurement in pPb

CMS-PAS-HIN-14-003



- L = 34.6 nb^{-1}, 5.02 TeV collision
- Selection condition
  - Muon : p_T > 20 GeV/c, $|\eta^{\mu}|$<2.4
- Asymmetric acceptance in rapidity due to the boost in center of mass frame



- 2183 Z candidates

Z boson measurement in pPb

CMS-PAS-HIN-14-003

- Inclusive cross section of Z production

$\sigma(pPb \rightarrow Z \rightarrow \mu\mu)$	Measured $\sigma \pm$ stat. $\pm$ syst. $\pm$ lumi.	$\sigma^{NLO\ POWHEG} \times A$
Full phase space	134.4 ± 2.9 ± 7.1 ± 4.7 nb	134 ± 7 nb
$-2.5 < y_{c.m.} < 1.5$	94.1 ± 2.1 ± 2.4 ± 3.3 nb	94.0 ± 4.7 nb

- Compared to NLO POWHEG calculation scaled by 208

- Results consistent with σ^{pp} x A (208)

Z boson measurement in pPb

CMS-PAS-HIN-14-003

- Inclusive cross section of Z production

Measured

NLO POWHEG

Table 1: Summary of the relative systematic uncertainties on the inclusive and differential cross sections.

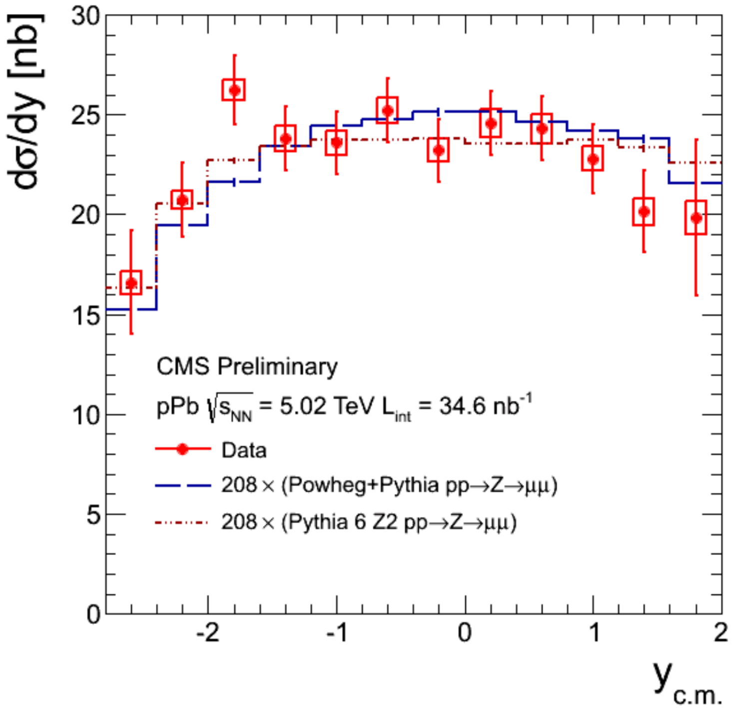
Source	σ(inclusive)	$\sigma(y_{\text{c.m.}} \in (-2.5, 1.5))$	$d\sigma/dp_T$	$d\sigma/dy_{\text{c.m.}}$
Acceptance	4.7%	0.9%	0.4% – 1.2%	0.1% – 1.1%
Efficiency from MC	0.2%	0.2%	0.1% – 0.3%	0.01% – 0.9%
Data/MC efficiencies	1.7%	1.7%	1.7%	1.7% – 3.4%
Background	1.7%	1.8%	0.3% – 5.4%	0.5% – 2.4%
Overall	5.3%	2.6%	2.1% – 6.3%	1.9% – 4.3%
Luminosity		3.5%		

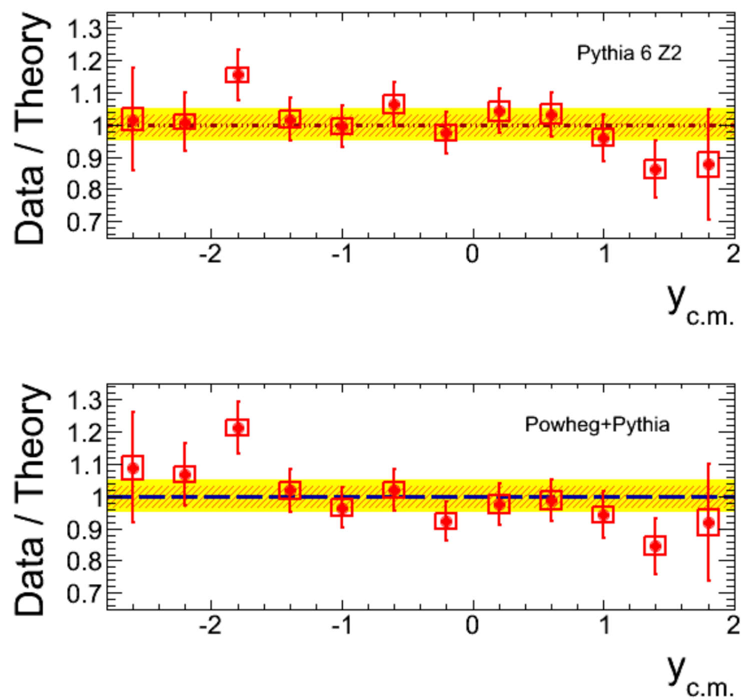
- Results consistent with σ^{pp} x A (208)

Z boson measurement in pPb

CMS-PAS-HIN-14-003

- Differential cross section of Z production vs y



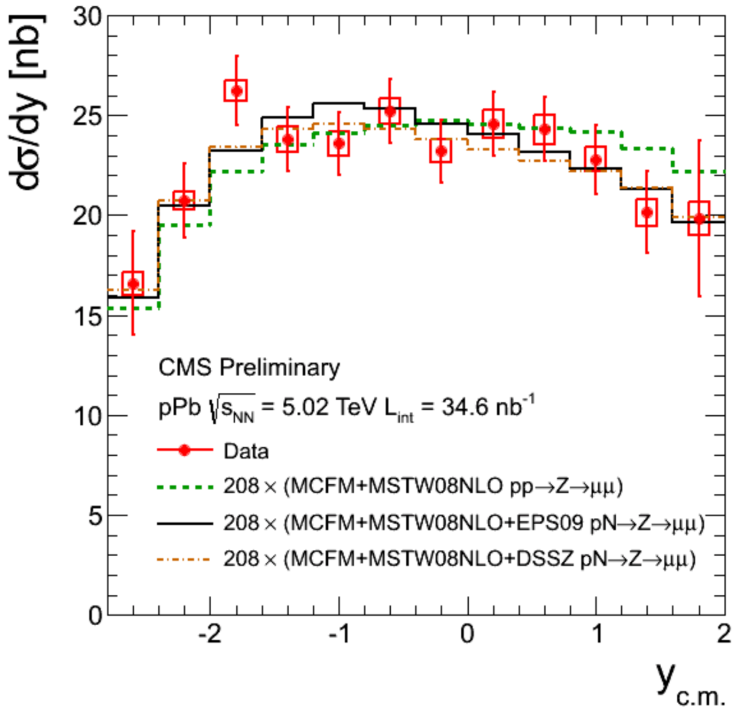


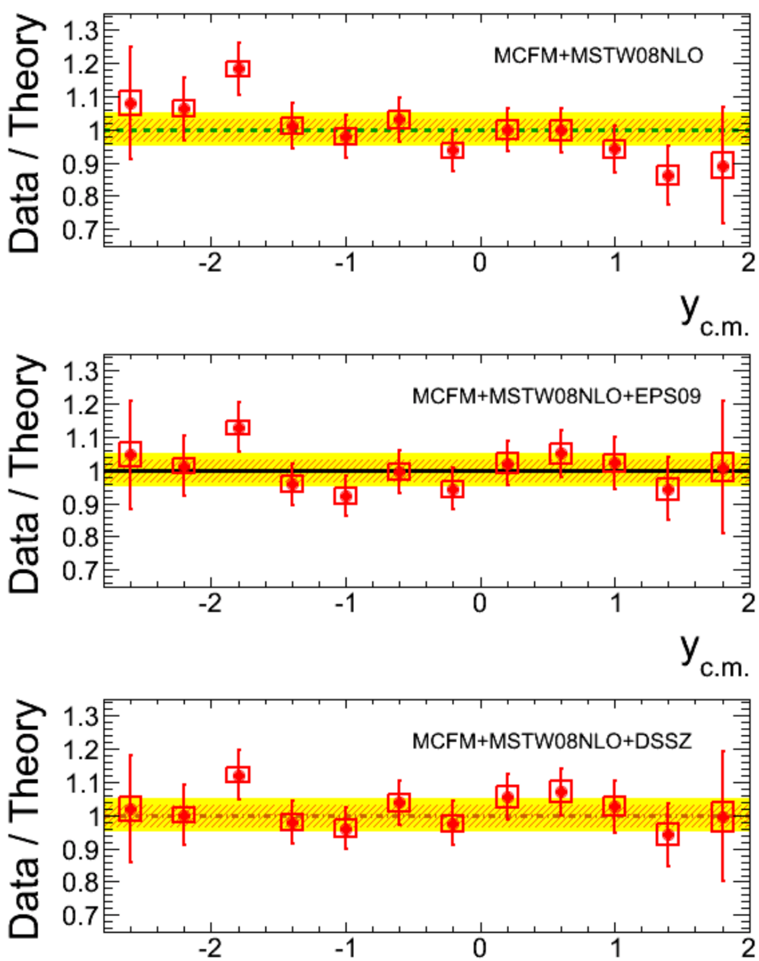
- dσ/dy shifted to center of mass frame
- Dominant uncertainty comes from statistics
- Consistent with pp prediction scaled by A

Z boson measurement in pPb

CMS-PAS-HIN-14-003

- Differential cross section of Z production vs y





- Nuclear effects expected in the forward and backward regions.

Z boson measurement in pPb

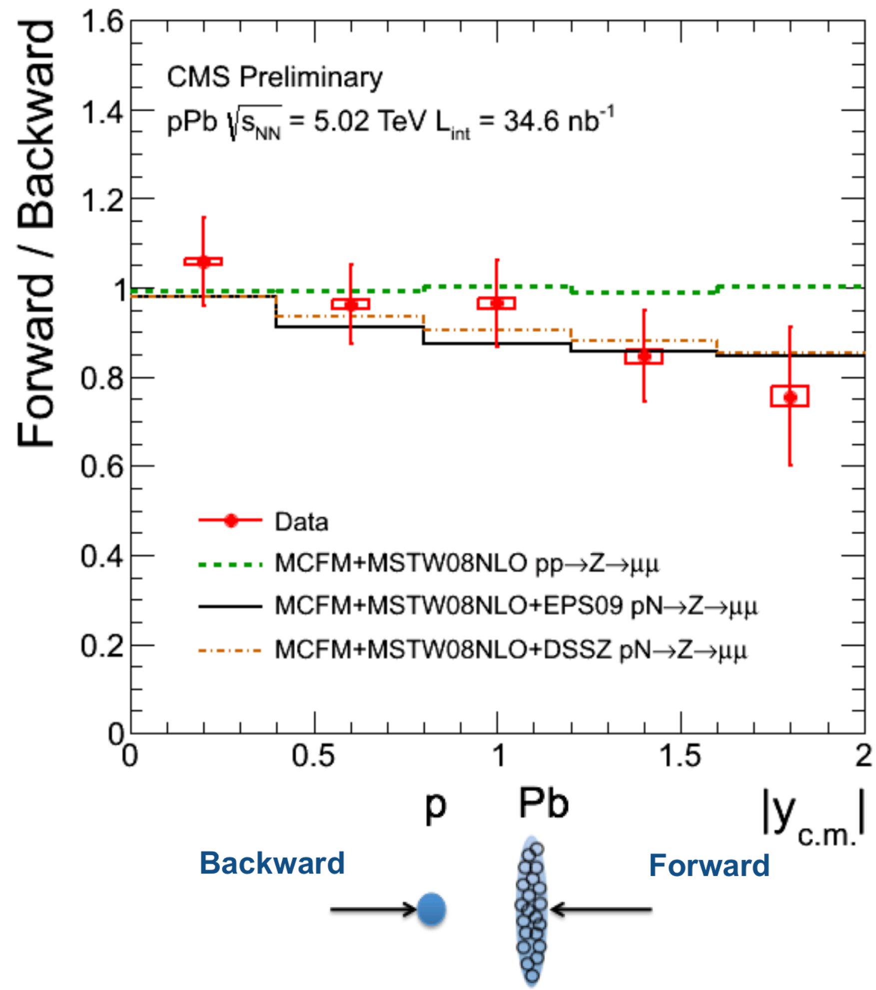
CMS-PAS-HIN-14-003

- Forward-backward ratio : expected to be more sensitive to nuclear effects

$$R_{FB} = \frac{d\sigma(+y_{\mathrm{c.m.}})/dy}{d\sigma(-y_{\mathrm{c.m.}})/dy}$$

- Hint of nuclear effect visible

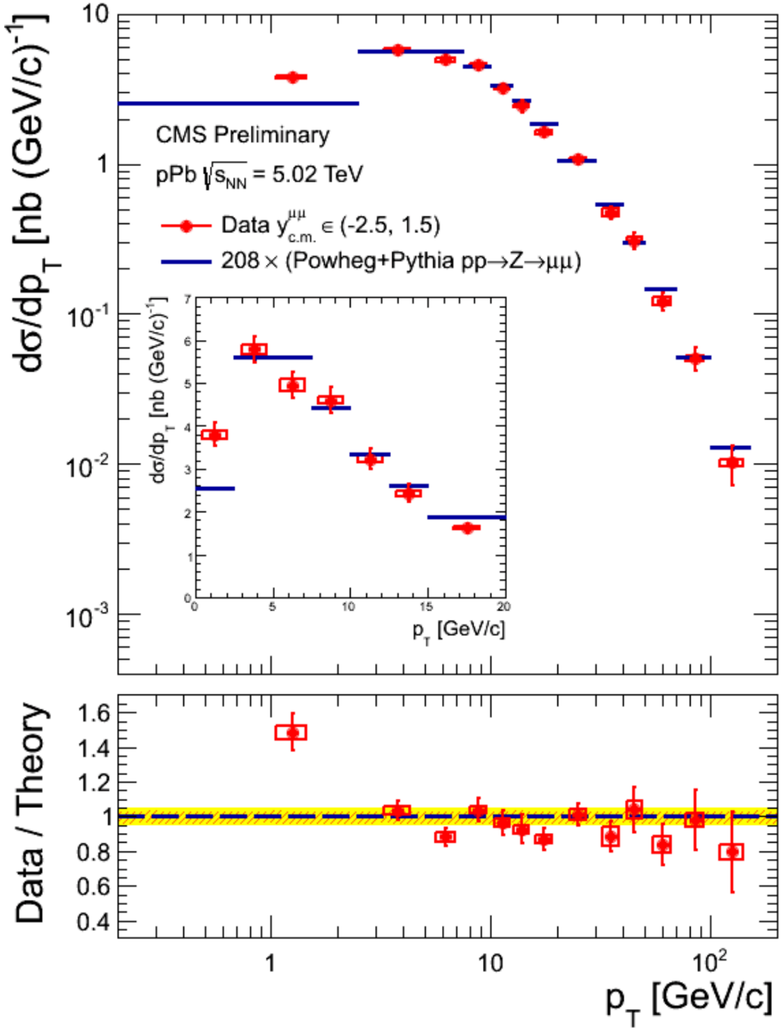
- Large statistical uncertainties in data



Z boson measurement in pPb

CMS-PAS-HIN-14-003

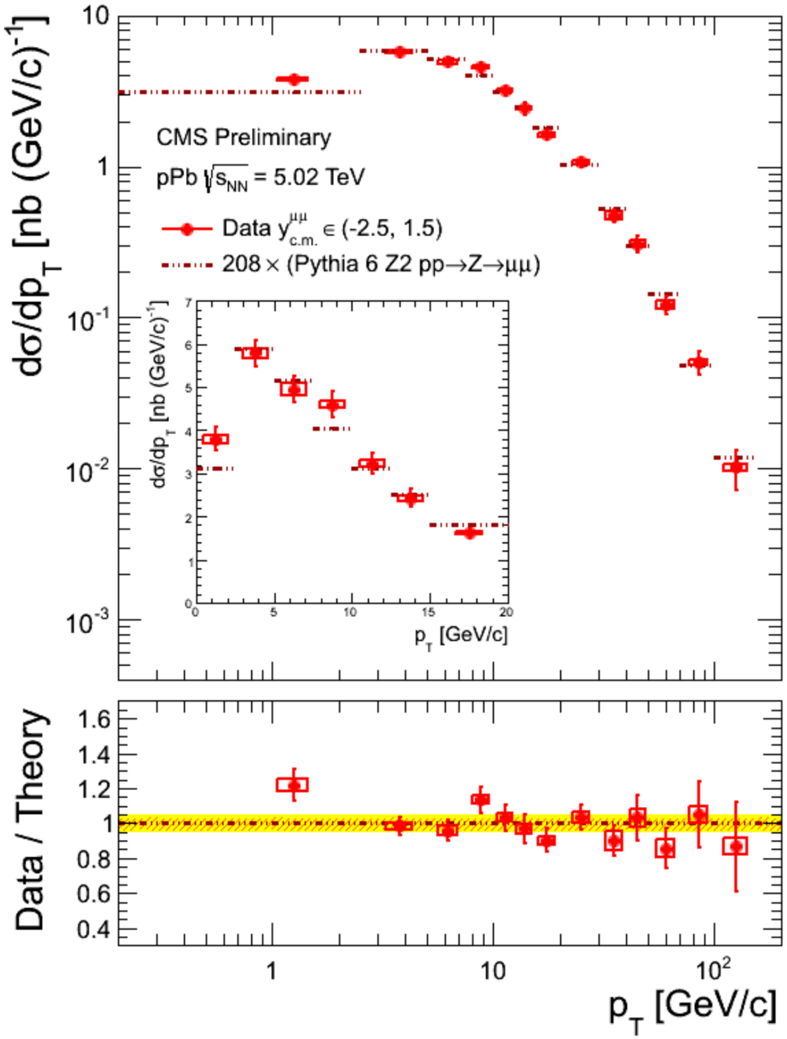
- Differential cross section vs p_T
  - Large covering p_T range [0, 150] GeV/c
- Expected nuclear effects are small
  - Comparing to only pp
- Compared to pythia and POWHEG



Z boson measurement in pPb

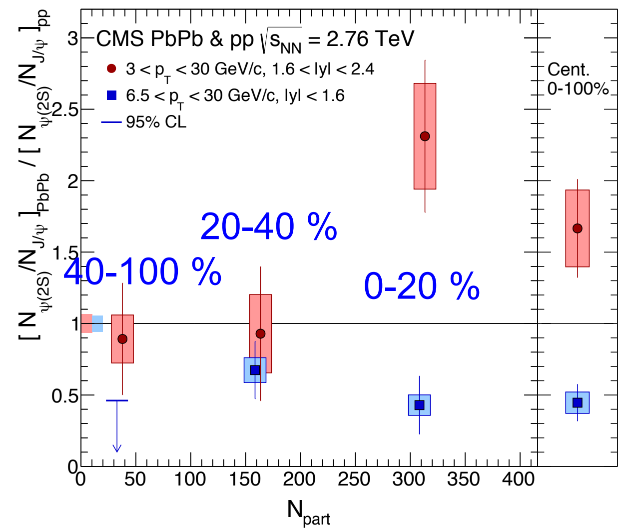
CMS-PAS-HIN-14-003

- Differential cross section vs p_T
  - Large covering p_T range [0, 150] GeV/c
- Expected nuclear effects are small
  - Comparing to only pp
- Compared to pythia only : better agreement in low p_T region.

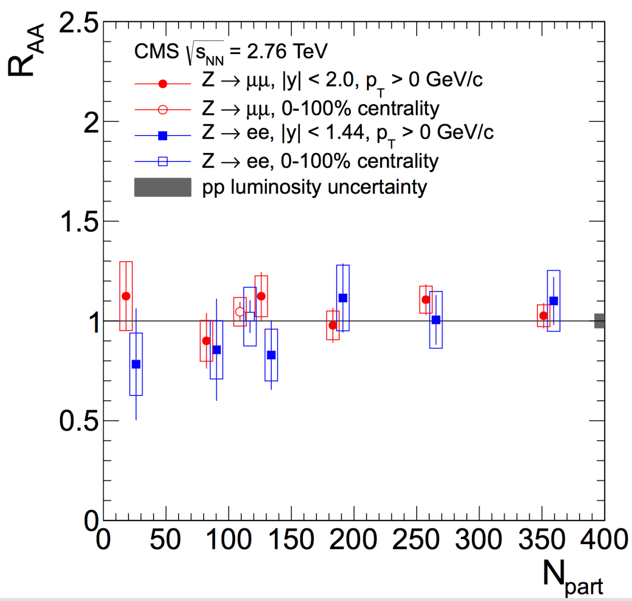


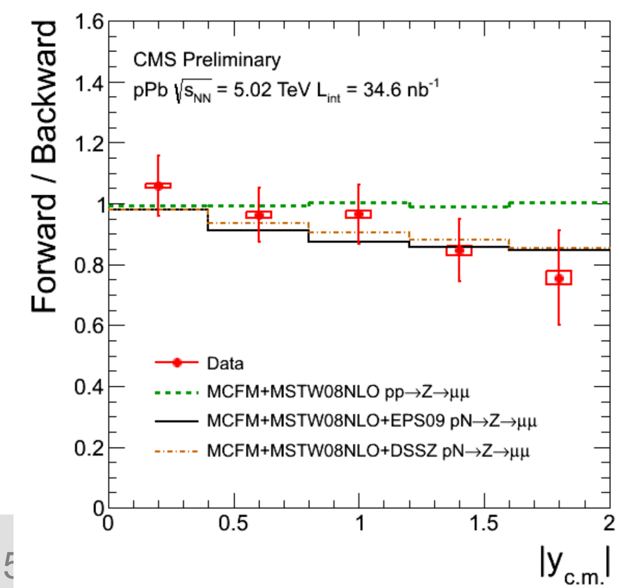
Summary

- Double ratio of prompt ψ(2S) in PbPb
  - Observed clear difference mid-rapidity (high p_T) and forward rapidity (low p_T)
  - Need more statistics



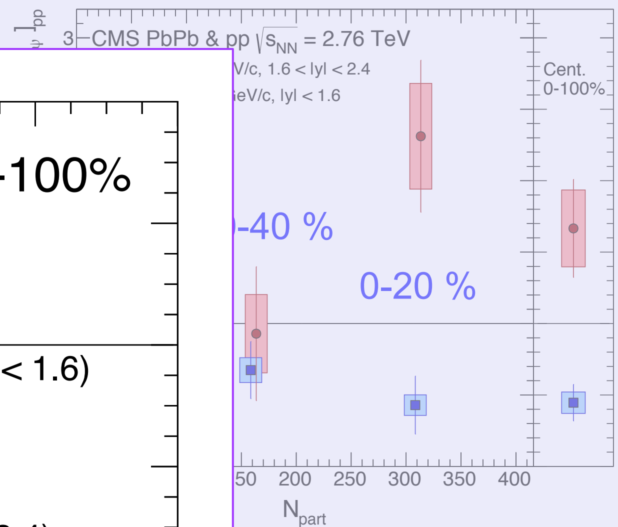
- Z boson in pp, pPb and PbPb
  - Observed no modification in PbPb
  - Observed hint of nuclear effect visible in pPb

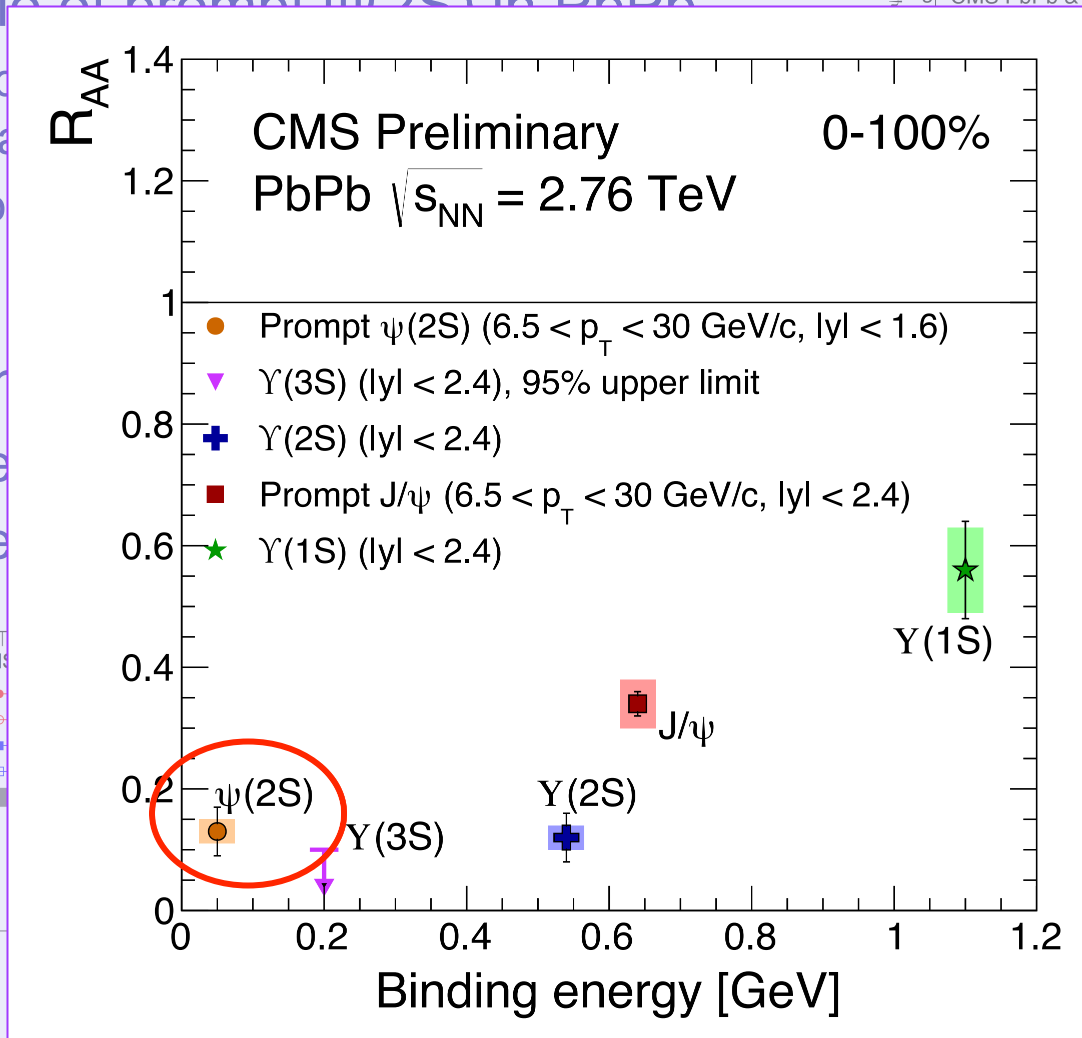


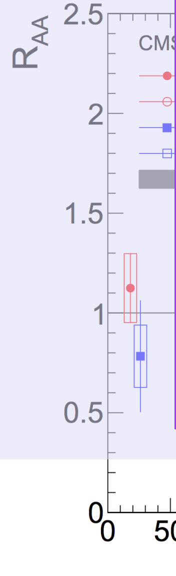


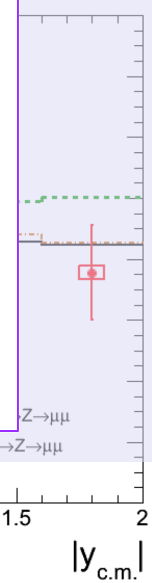
Summary

- Double ratio of prompt ψ(2S) in PbPb
  - Observed … and forwa…
  - Need mo…
- Z boson i…
  - Observe…
  - Observe…



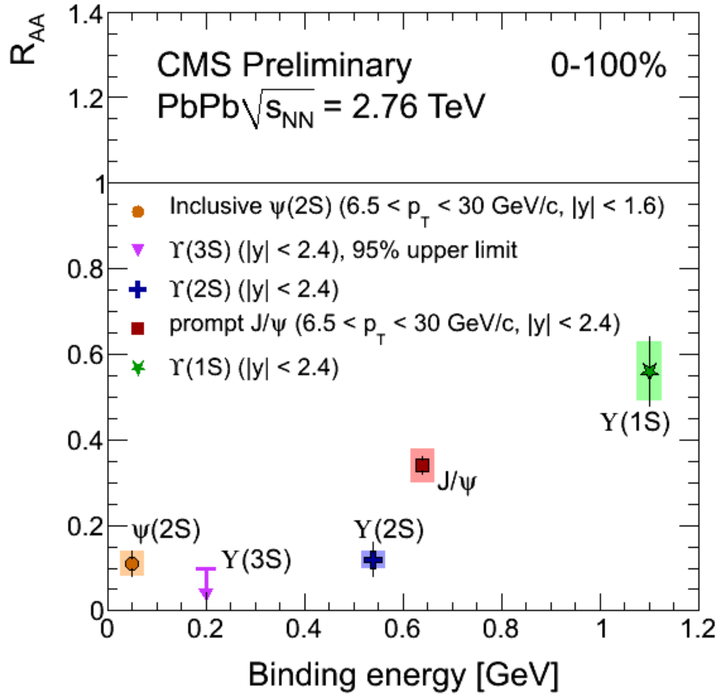






Back up

R_{AA} vs binding energy



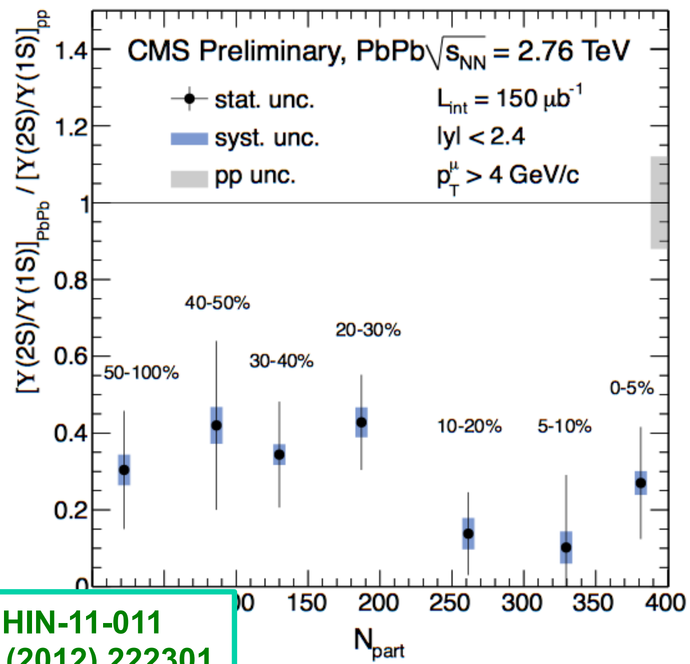
state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
r_0 [fm]	0.50	0.72	0.90	0.28	0.44	0.56	0.68	0.78

Table 3: Quarkonium Spectroscop

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIN12014

Results from PbPb Collisions

Double Ratio



CMS HIN-11-011
PRL 109 (2012) 222301

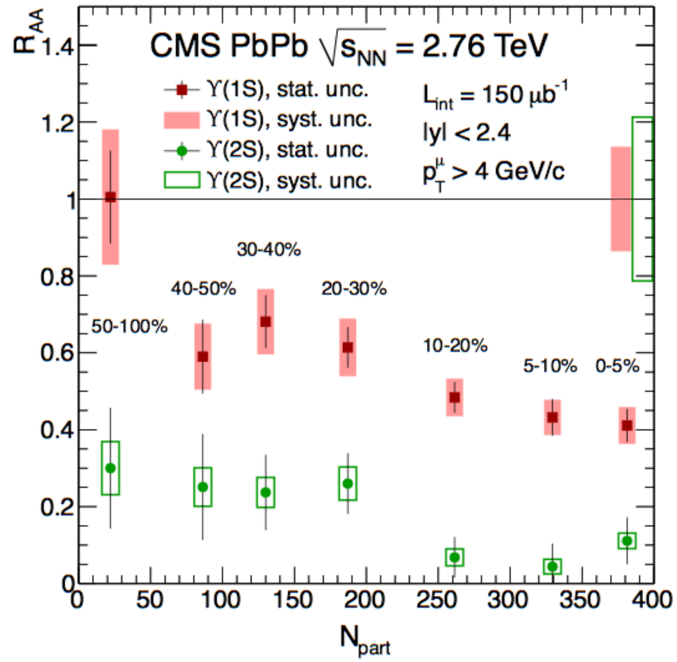
$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{\text{PbPb}}}{\Upsilon(2S)/\Upsilon(1S)|_{pp}} = 0.21 \pm 0.07(\text{stat}) \pm 0.02(\text{syst}),$$

$$\frac{\Upsilon(3S)/\Upsilon(1S)|_{\text{PbPb}}}{\Upsilon(3S)/\Upsilon(1S)|_{pp}} = 0.06 \pm 0.06(\text{stat}) \pm 0.06(\text{syst})$$

$$< 0.17(95\%\text{CL}).$$

Y(2S) and Y(3S) are more suppressed than Y(1S)

R_{AA}

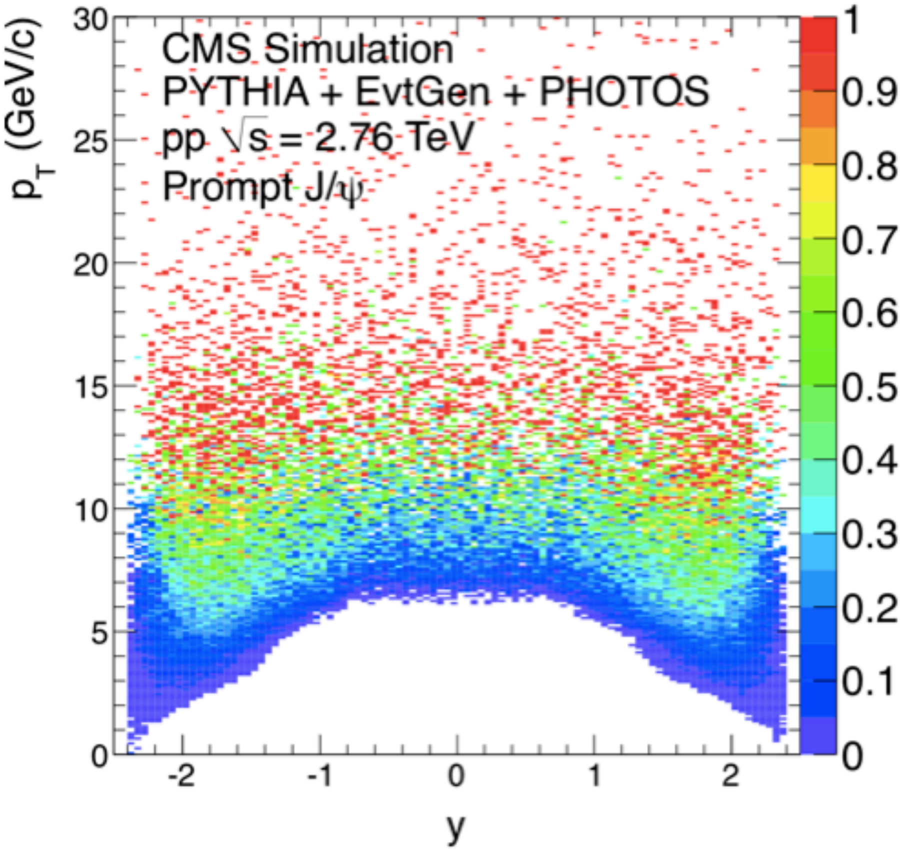


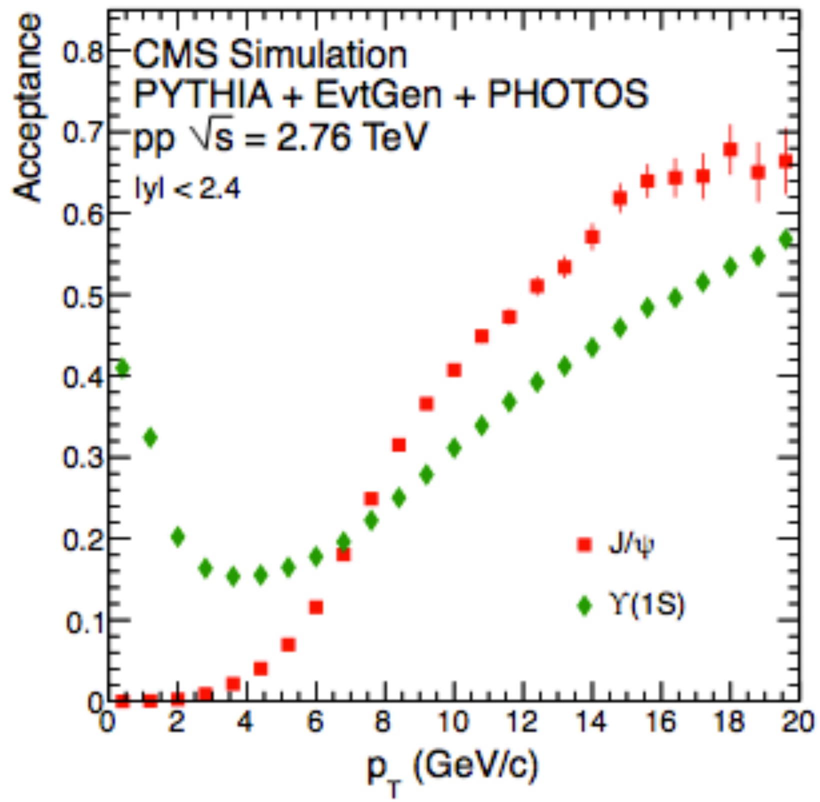
$$R_{AA}(\Upsilon(1S)) = 0.56 \pm 0.08(\text{stat}) \pm 0.07(\text{syst}),$$
$$R_{AA}(\Upsilon(2S)) = 0.12 \pm 0.04(\text{stat}) \pm 0.02(\text{syst}),$$
$$R_{AA}(\Upsilon(3S)) = 0.03 \pm 0.04(\text{stat}) \pm 0.01(\text{syst})$$
$$< 0.10(95\%\text{CL}).$$

Y(3S) are more suppressed than Y(2S).

Ordering: R_{AA}(Y(3S)) < R_{AA}(Y(2S)) < R_{AA}(Y(1S))

Muon Pair Acceptance



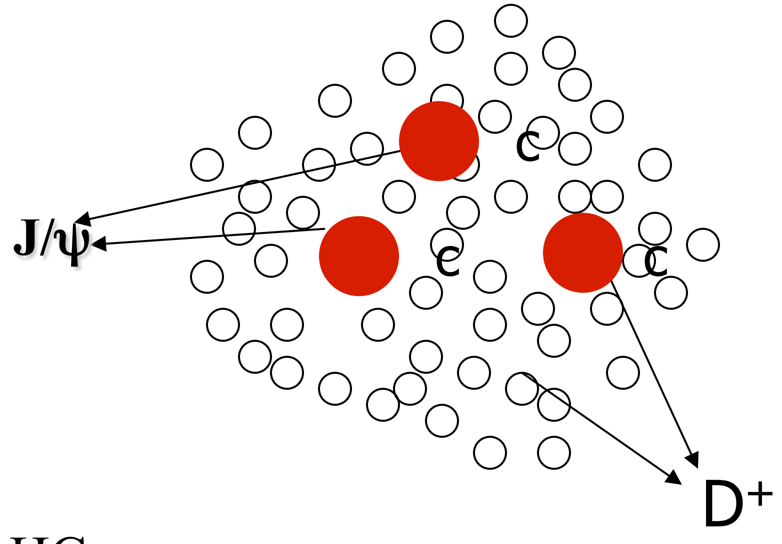


The life of Quarkonia in the Medium can be Complicated

- Observed J/ψ is a mixture of direct production+feeddown (R. Vogt: Phys. Rep. 310, 197 (1999)).
  - All J/ψ ~ 0.6J/ψ(Direct) + ~0.3 χ_c + ~0.1ψ'
  - B meson feed down.
    - Important to disentangle different component

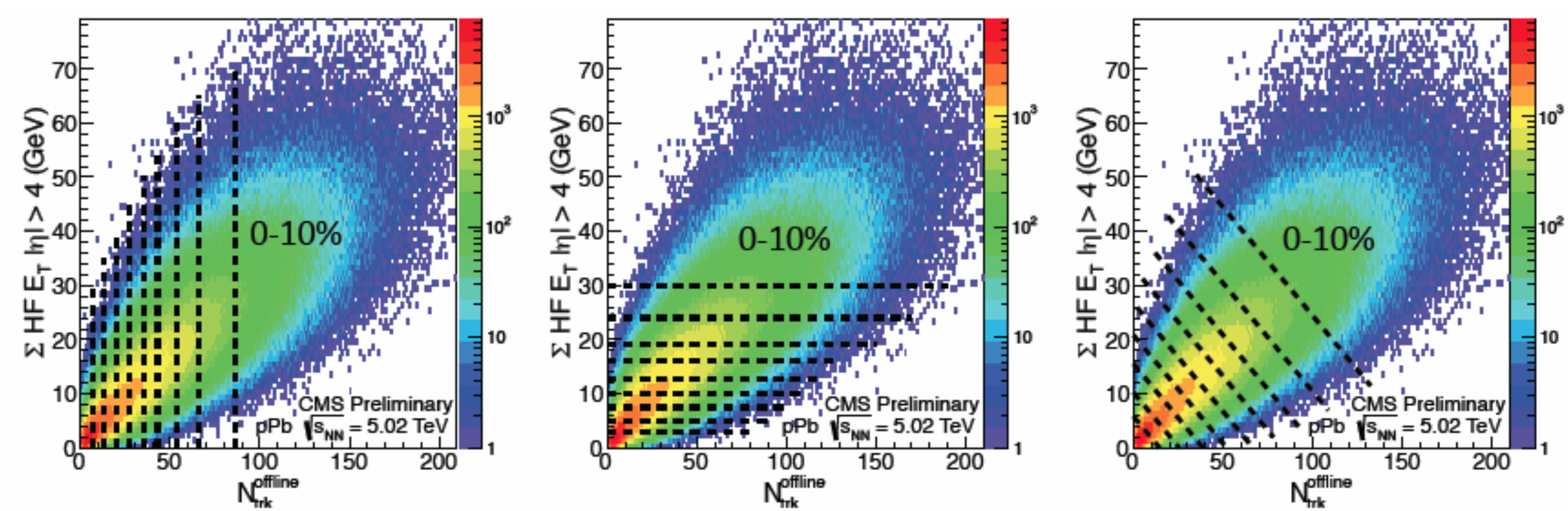
- Suppression and enhancement in the "cold" nuclear medium
  - Nuclear Absorption, Gluon shadowing, initial state energy loss, Cronin effect and gluon saturation (CGC)
  - Study p+A collisions

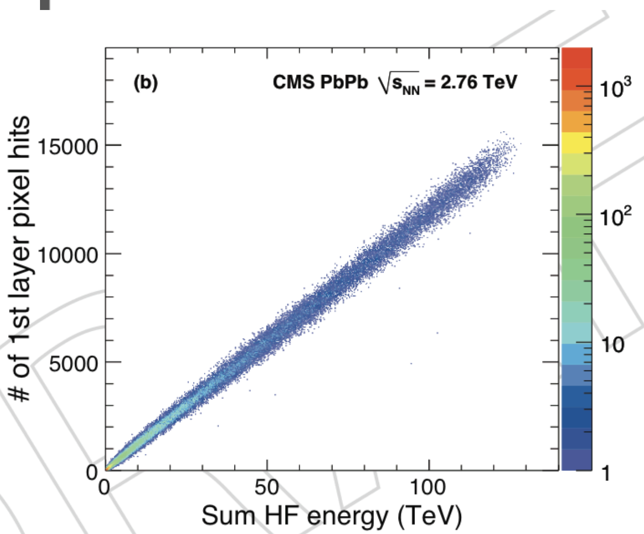
- Hot/dense medium effect
  - J/ψ, ϒ dissociation, i.e. suppression
  - Recombination, i.e. enhancement
  - Study different species, e.g. J/psi, ϒ
  - Study at different energy, i.e. RHIC, LHC



$<N_{coll}>$ from different methods agree well

Defining centrality from different methods:

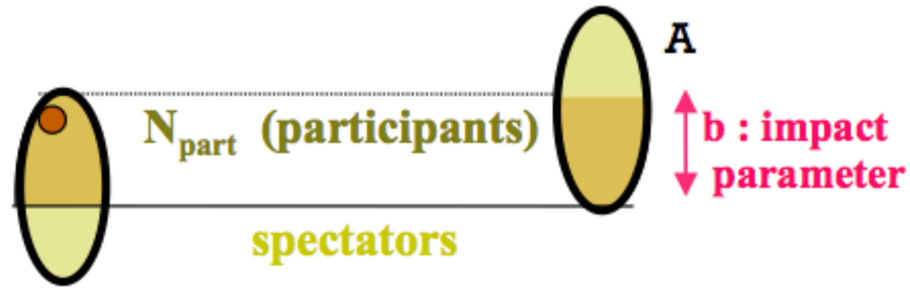




nd ΣHF E_T |η|>4 means selecting very
;. 0-10% in the plots), but $<N_{coll}>$ are the same
of centrality determination are about how to
real data (which η range to use?) for an
ossible biases

+ How do we quantify medium effects ?

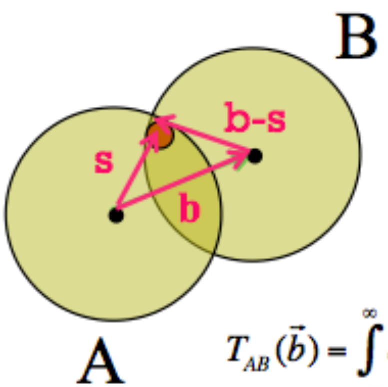
- N_{part} : number of nucleons which undergo at least one collision



- N_{coll} : number of n+n collisions taking place in A+B collision
- Modification nuclear factor $R_{AA} = \frac{1/N_{evnts} d^2N^Z/dydp_T}{<T_{AB}> d^2\sigma_{pp}/dydp_T}$

quantifies the effect of the medium on a particle production

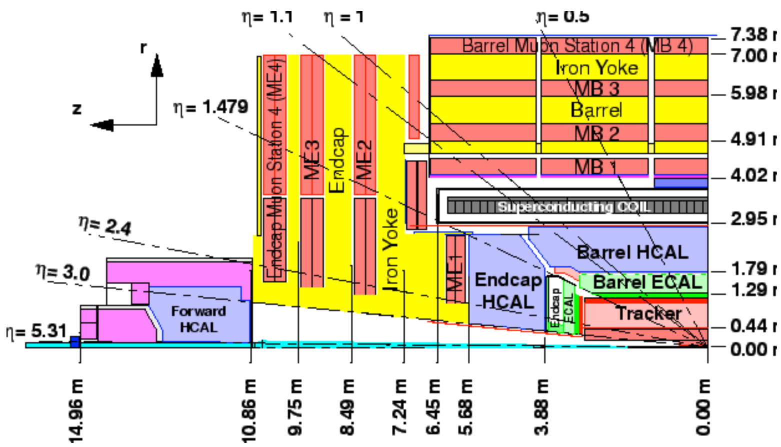
- To compare measured PbPb yields to theoretical pp cross sections, we need T_{AB} : nuclear overlap function
  - In absence of medium effects
    - $R_{AA} = 1$ for perturbative probes
  - T_{AB} is proportional to N_{coll}
    - 30-100% : $T_{AB} = 1.45 \pm 0.18\ mb^{-1}$
    - 10-30% : $T_{AB} = 16.6 \pm 0.7\ mb^{-1}$
    - 0-10% : $T_{AB} = 23.2 \pm 1.0\ mb^{-1}$

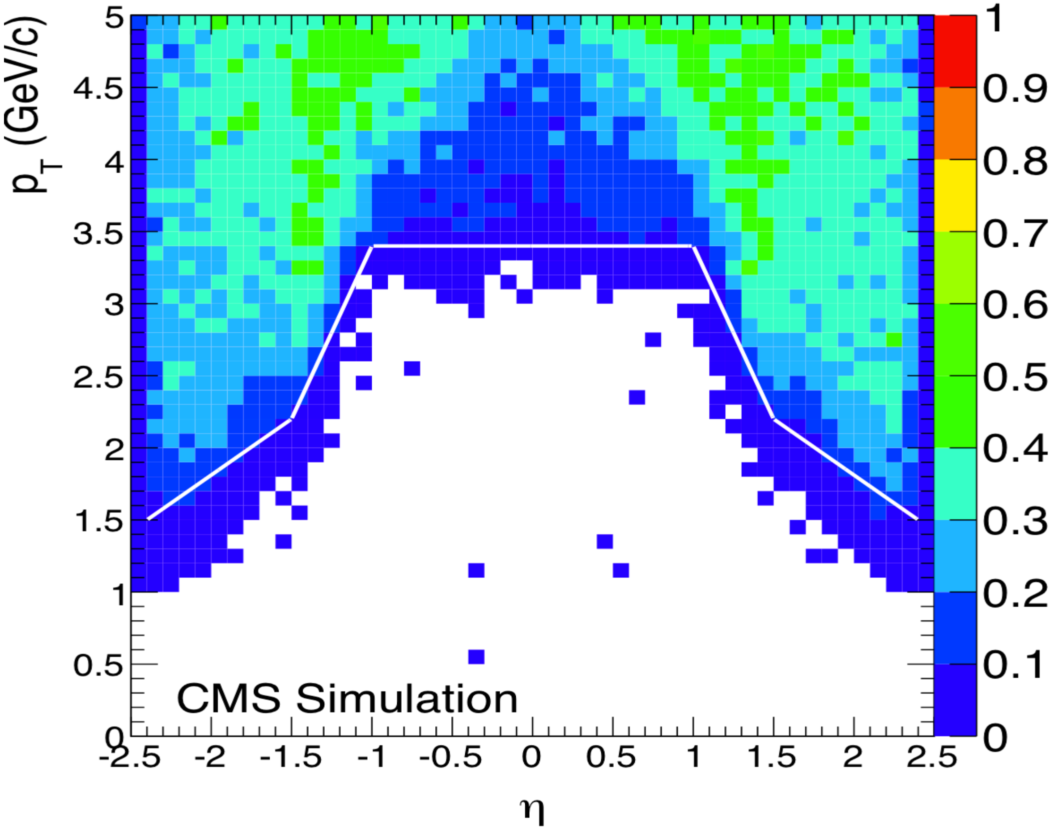


$$T_{AB}(\vec{b}) = \int_{-\infty}^{\infty} d\vec{s}\, T_A(\vec{s})\, T_B(\vec{b}-\vec{s})$$

Lamia, B. "Observation of Z Boson Production in Heavy Ion Collisions at CMS"
Moriond QCD and High Energy Interactions, 2011

Single Muon Acceptance





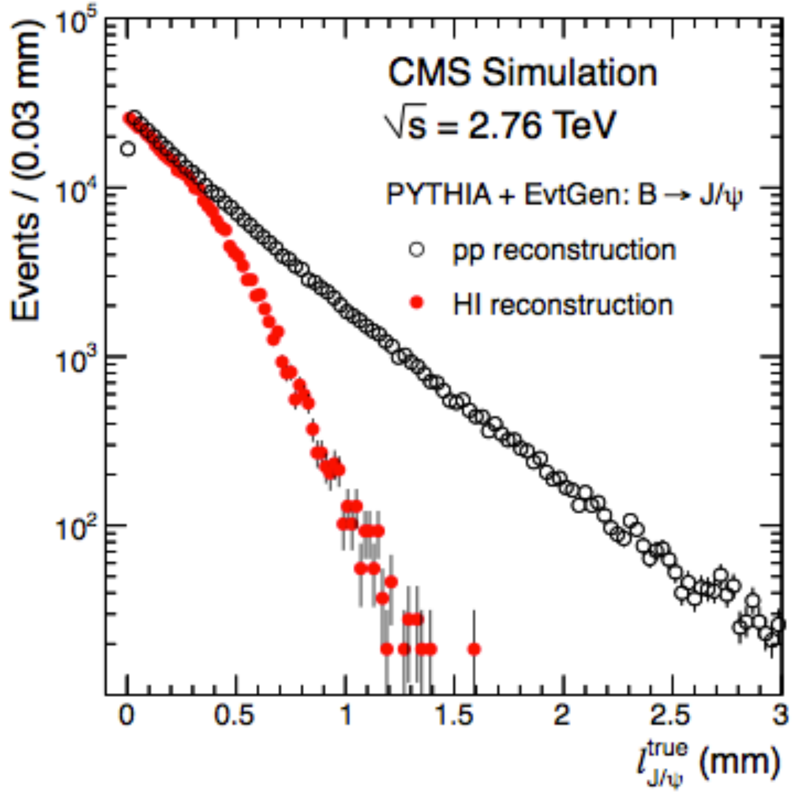
✔ Acceptance definition: Range of p_T and eta of reconstructable muon (RecoMu/GenMu ≥ 10%)

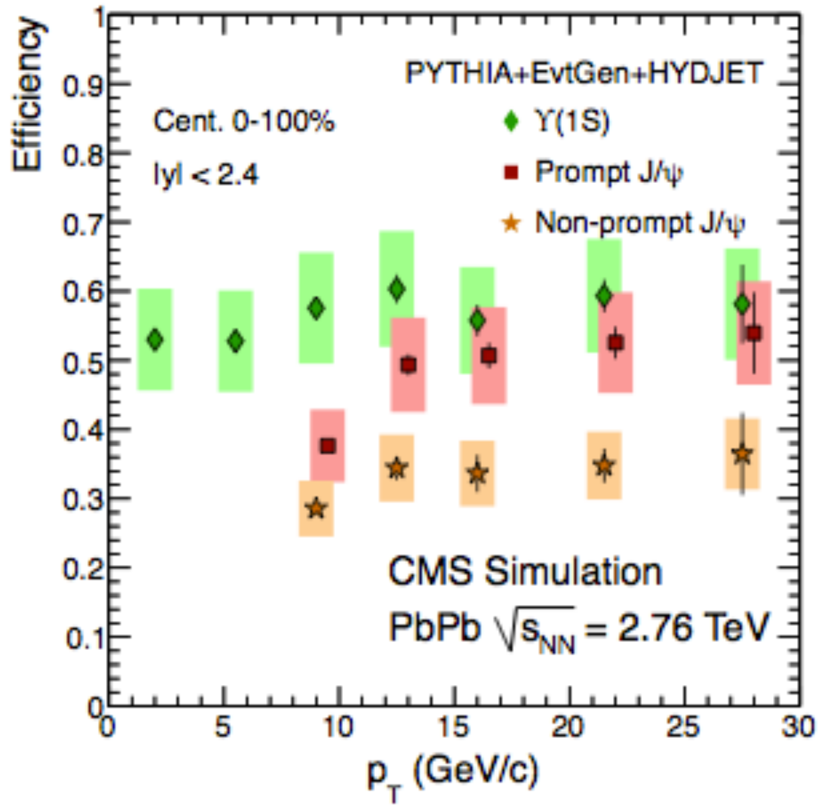
$$|\eta^{\mu}| < 1.0 \rightarrow p_T^{\mu} > 3.4 \text{ GeV}/c$$

$$1.0 \leq |\eta^{\mu}| < 1.6 \rightarrow p_T^{\mu} > 5.8 - 2.4 \times |\eta^{\mu}| \text{ GeV}/c$$

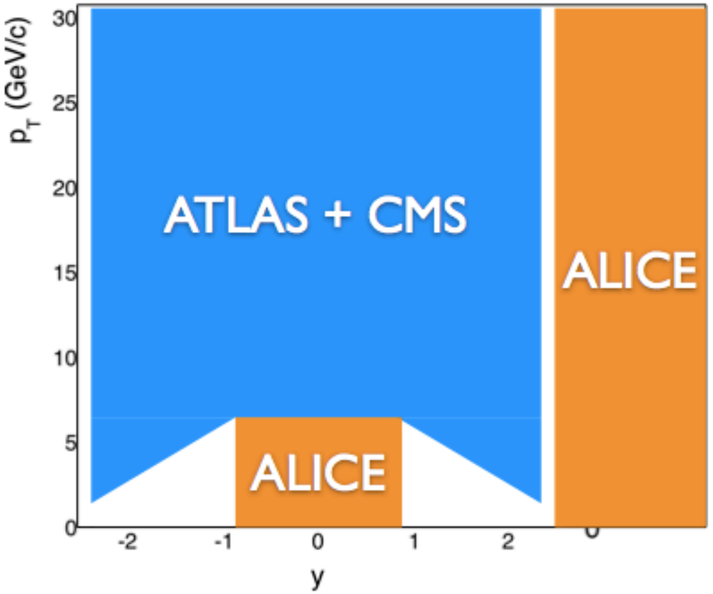
$$1.6 \leq |\eta^{\mu}| < 2.4 \rightarrow p_T^{\mu} > 3.3667 - 7/9 \times |\eta^{\mu}| \text{ GeV}/c$$

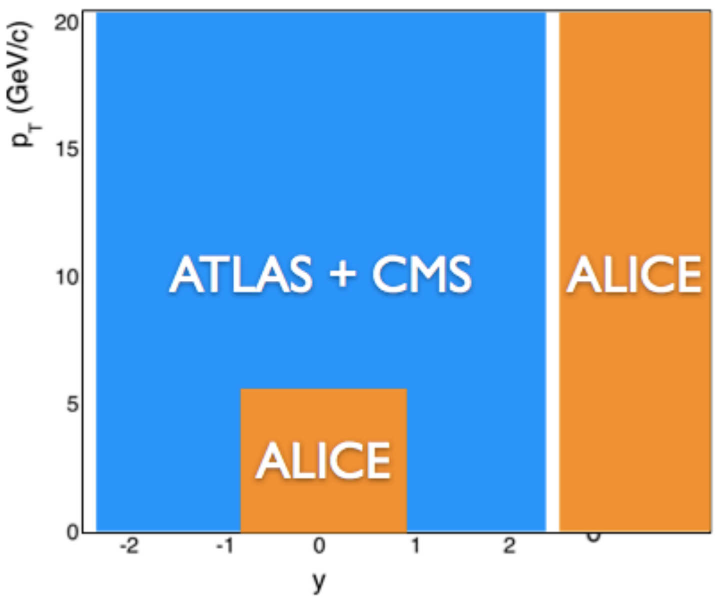
Reconstruction Efficiency





Quarkonia Acceptance





- ALICE: acceptance for $p_T > 0$
  - midrapidity: no absorber and low magnetic field
  - forward rapidity: longitudinal boost
- ATLAS and CMS: Muons need to overcome strong magnetic field and energy loss in the absorber
  - minimum total momentum p~3–5 GeV/c to reach the muon stations
  - Limits J/ψ acceptance:
    - mid-rapidity: $p_T > 6.5$ GeV/c
    - forward rapidity: $p_T > 3$ GeV/c
    - (values for CMS, but similar for ATLAS)
  - ϒ acceptance:
    - $p_T > 0$ GeV/c for all rapidity
- Complementary acceptances

Binding Energy of Quarkonia

state	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ_b'	Υ''
mass [GeV]	3.10	3.53	3.68	9.46	9.99	10.02	10.26	10.36
ΔE [GeV]	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
ΔM [GeV]	0.02	-0.03	0.03	0.06	-0.06	-0.06	-0.08	-0.07
radius [fm]	0.25	0.36	0.45	0.14	0.22	0.28	0.34	0.39

Heavy ion program timeline

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

LS1 ~0.3-1.5 nb^{-1} PbPb LS2 ~2-4 nb^{-1} PbPb LS3 ~10 nb^{-1} PbPb

CMS request

Also corresponding pp reference

PbPb	PbPb	pPb?
5.1TeV	5.1TeV	8.2TeV

Also corresponding pp reference

ArAr pPb PbPb
5-8 TeV

PbPb pp (?)
5.5 TeV

L1 trigger upgrade

Pixel detector upgrade

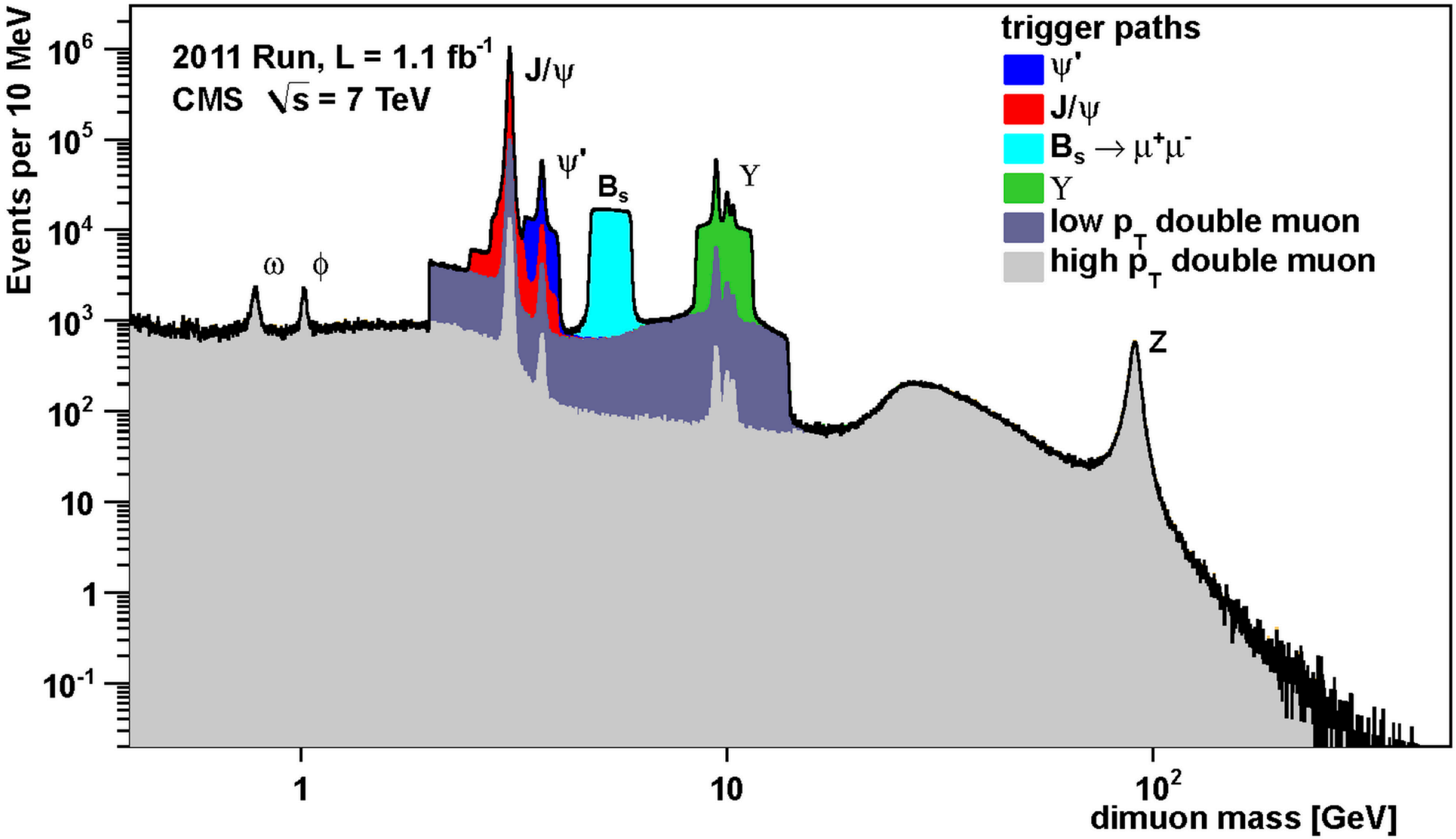
3 layers → 4 layers

Extended tracker coverage |η|<4 (?)

- PbPb statistics: 1.5nb^{-1} and 10nb^{-1} PbPb
- What is the expected pp statistics we should use?

pp DiMuon

•



2011 Run, L = 1.1 fb-1
CMS √s = 7 TeV
trigger paths
ψ'
J/ψ
Bs → μ+μ-
Υ
low pT double muon
high pT double muon
J/ψ
ψ'
Bs
Υ
ω
ϕ
Z
Events per 10 MeV
dimuon mass [GeV]

Z boson measurement in CMS

2013 JHEP 03 (2015) 022

Source	$Z \to \mu^+\mu^-$		$Z \to e^+e^-$	
	PbPb	pp	PbPb	pp
Combined efficiency	1.8%	1.9%	7.4%	7.7%
Acceptance	0.7%	0.7%	0.7%	0.7%
Background	0.5%	0.1%	2.0%	1.0%
N_{MB}	3.0%	–	3.0%	–
T_{AA} (N_{MB} included)	6.2%	–	6.2%	–
Integrated luminosity (L_{int})	–	3.7%	–	3.7%
Overall (without T_{AA} or L_{int})	3.6%	2.0%	8.3%	7.8%
Overall	6.5%	4.2%	9.9%	8.6%

Table 2. Summary of systematic uncertainties in the $Z \to \mu^+\mu^-$ and e^+e^- yields. PbPb values correspond to the full 0–100% centrality range. N_{MB} is the number of MB events corrected for the trigger efficiency.