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Prospects for Quarkonium measurements in p-A and A-A collisions at the LHC

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Trento

Outline

1) Detector acceptances and collision systems

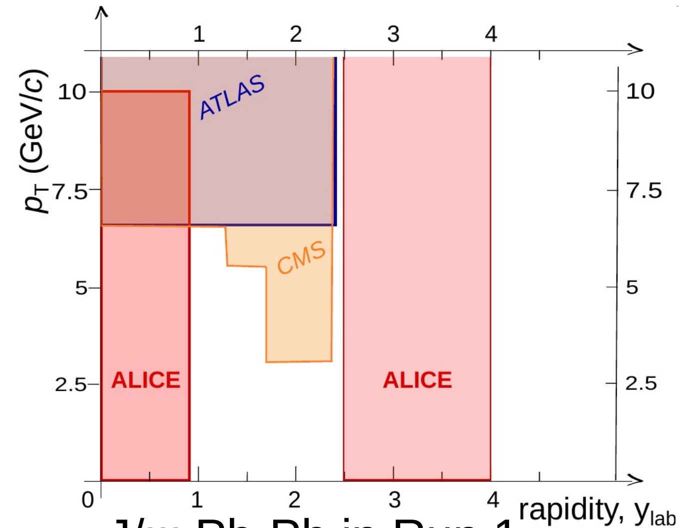
2) Expected quarkonium measurements in 2015-2022

- 2015
- 2016 p-Pb, 2018 Pb-Pb
- Run 3 (2020-2022)

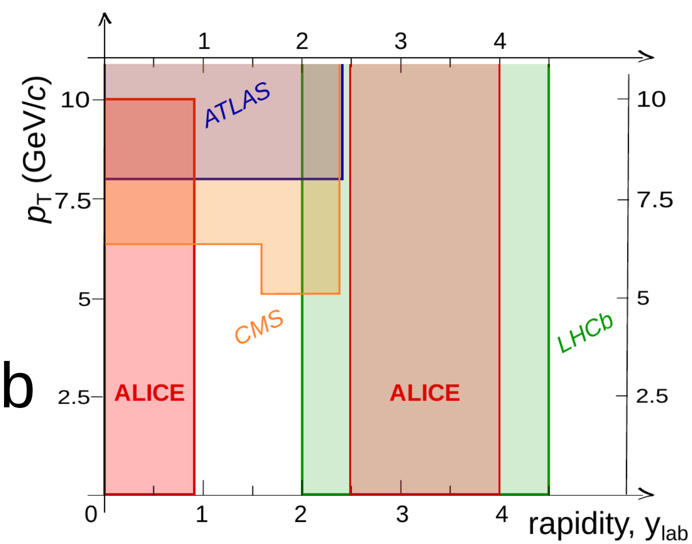
3) Some remarks

Acceptance for charmonium so far

- Muon trigger systems:
  - → statistics reach limited by delivered luminosity
- ALICE central barrel
  - → analysis so far based on minimum bias/centr. triggers
  - → statistics limited by read-out
- LHCb occupancy limitation:
  - → estimate: up to 40-50 % centrality in Pb-Pb
- ATLAS/CMS acceptance:
  - → with looser selection down to p_T= 1/0 GeV/c at y≈2, large background in A-A



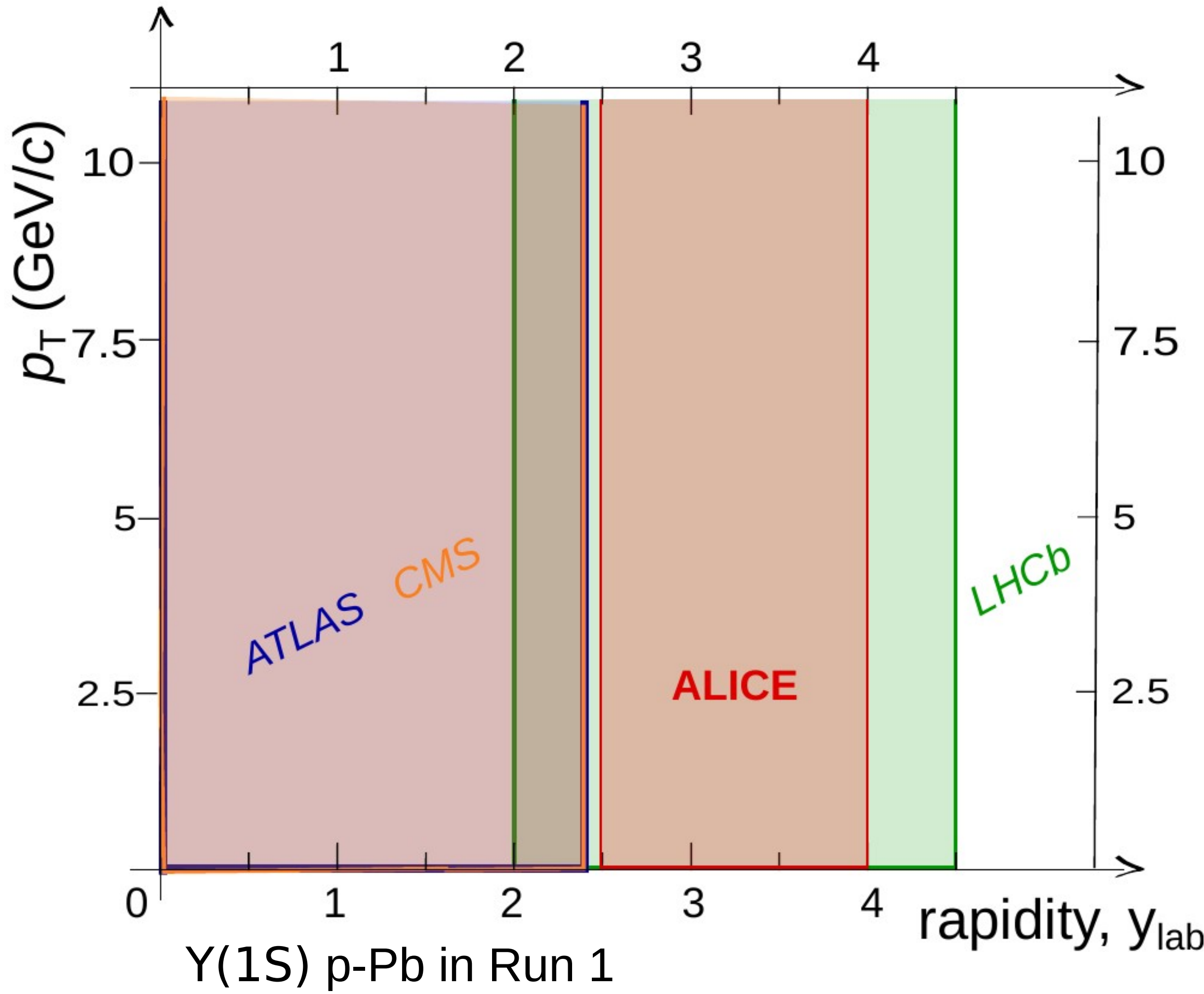
J/ψ Pb-Pb in Run 1



J/ψ p-Pb in Run 1

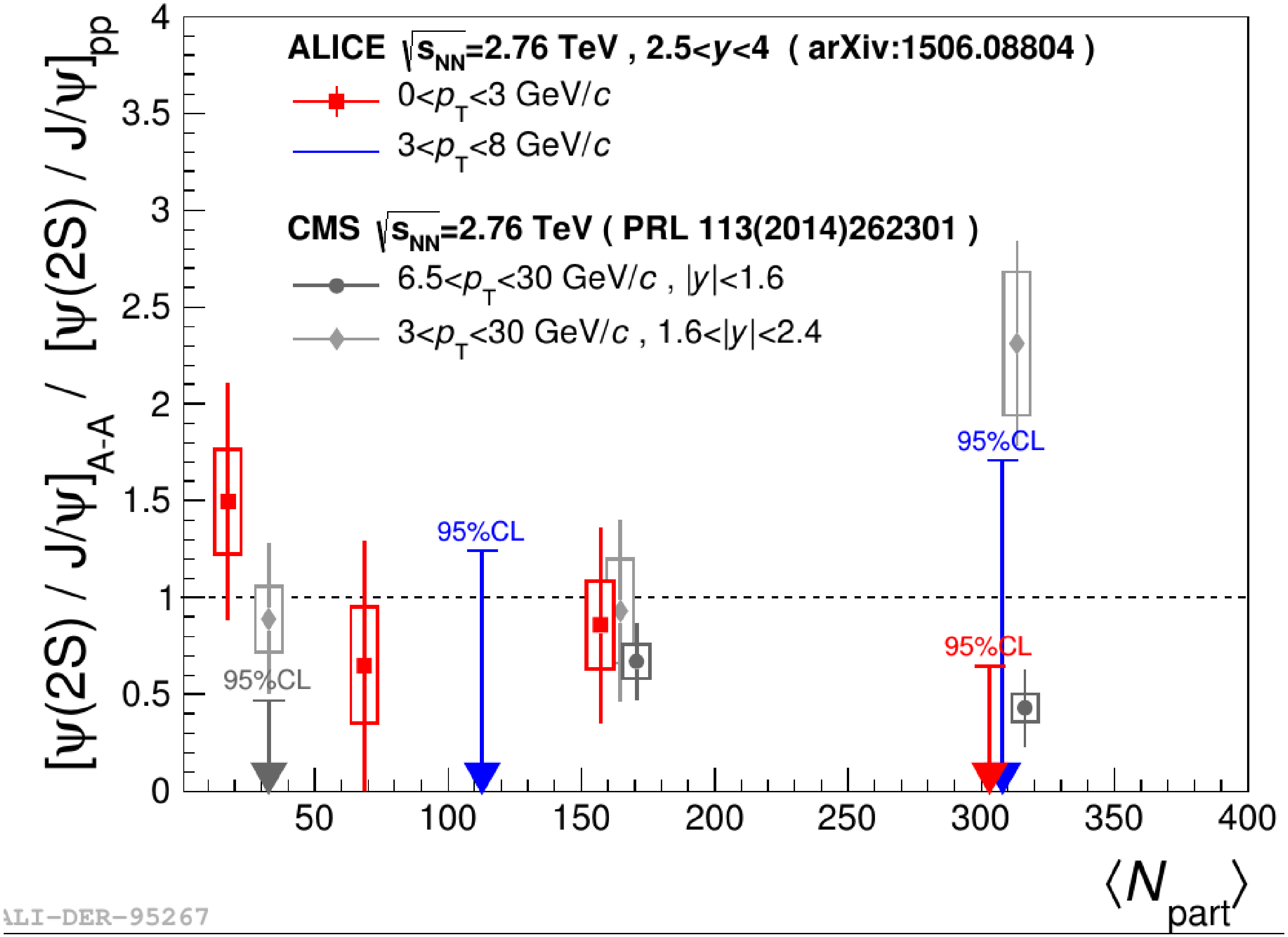
Acceptance for bottomonium so far

- All measurements based on muon trigger systems



Statistics in Run 1

- Observables statistically limited except of most single-differential J/ψ-measurements and Υ(1S)



2015 instrumentation changes compared to Run 1

- LHCb joins A-A including a fixed-target program

- CMS/ATLAS muon system: additional redundancy at forward rapidity, may also help for muons from quarkonium in A-A

- ALICE central barrel:

  TRD completed: additional electron-id capabilities

  TPC operated with Ar instead of Ne and at higher gain: better e-ID

pp-reference from 2015

- pp run 2015 @ 5 TeV

  - ATLAS/CMS: about equivalent of Pb-Pb @ 5 TeV for hard probes

  - ALICE muon arm:

    → reference with similar precision as with interpolations in Run 1

  -ALICE central barrel: about 128 mio. MB events

    → reference with similar precision as with interpolations in Run 1

    second O(10) larger pp reference run under discussion with accelerator and other experiments

  - LHCb: about 0.3 times ATLAS/CMS luminosity

Pb-Pb data from 2015

- Pb-Pb run 2015

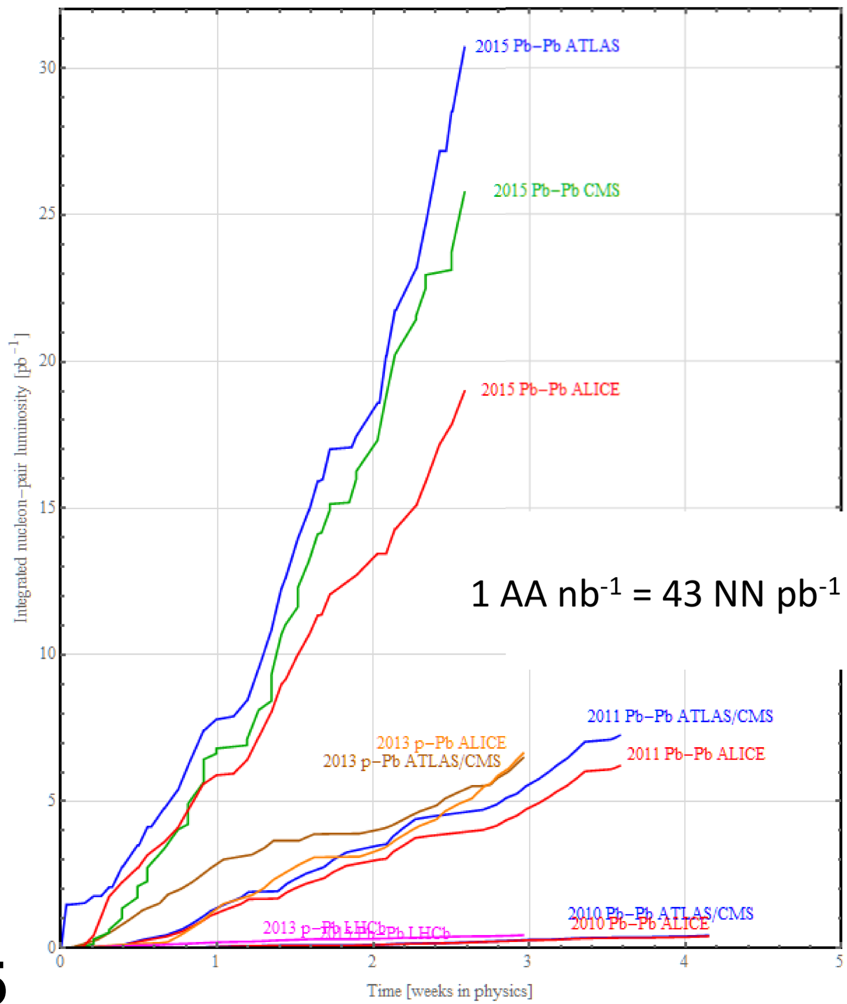
  - ATLAS/CMS:
    4 times more delivered lum. than at 2.76 TeV

  - ALICE muon arm:
    3 times more seen lum. than at 2.76 TeV

  - ALICE central barrel:
    about 25% less events for 0-10 %,
    4 times more in 10-40 %,
    10 times more in 40-100% than at 2.76 TeV

  total cc/bb cross section about 30 % (50 %)
  larger in pp-collisions at 5 TeV than at 2.76 TeV

  → **all Run 1 measurements can be repeated at 5 TeV with 2015 data with higher precision**



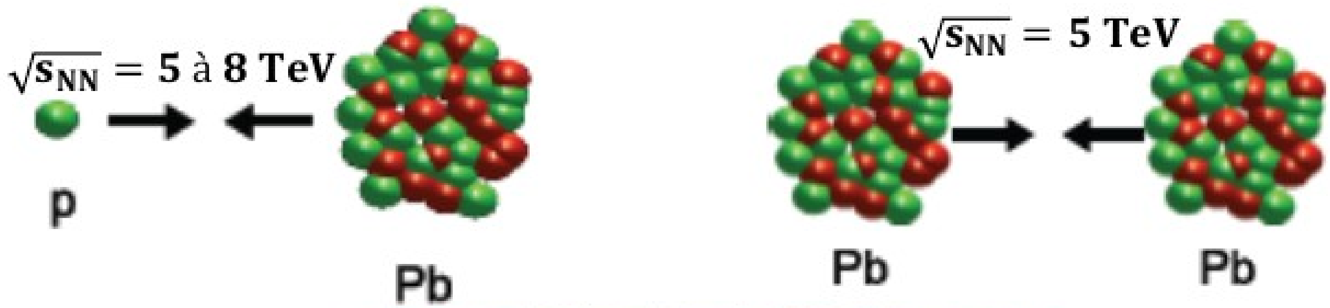
John Jowitt, Chamonix link

  - LHCb: similar than ALICE in Pb-Pb 2010

  → **unique potential in peripheral collisions: better resolution, χ_c and complementary open charm measurements**

- **LHCb fonctionnera en deux modes**
  - Mode collisionneur

Frédéric Fleuret, Etretat 2015, link

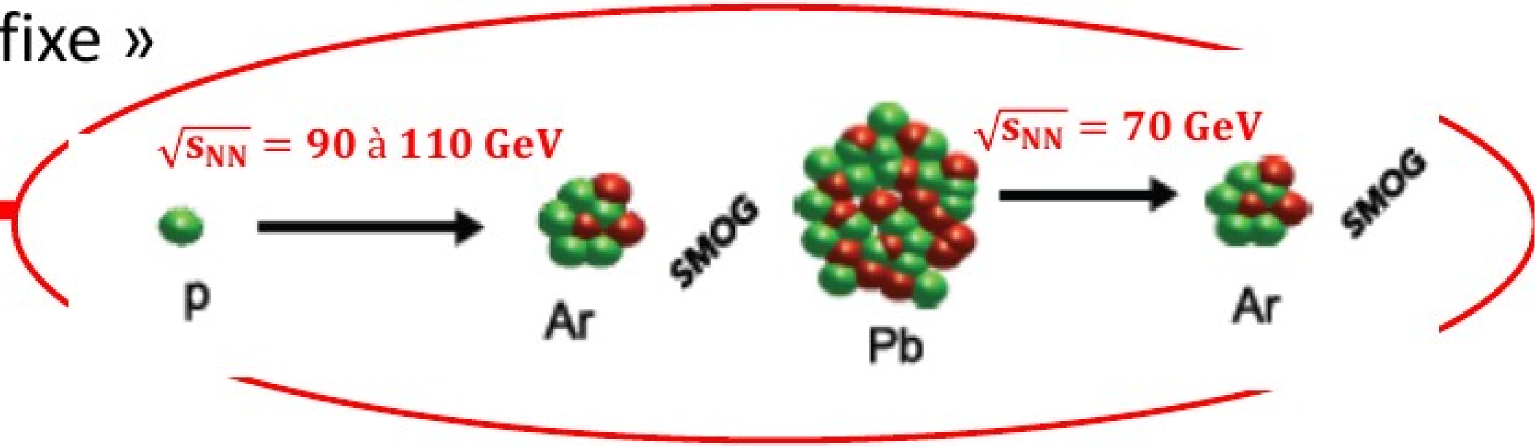


  - Mode « cible fixe »

$\sqrt{s_{NN}^{SPS}}$ ~ 20 GeV

$\sqrt{s_{NN}^{RHIC}}$ = 200 GeV

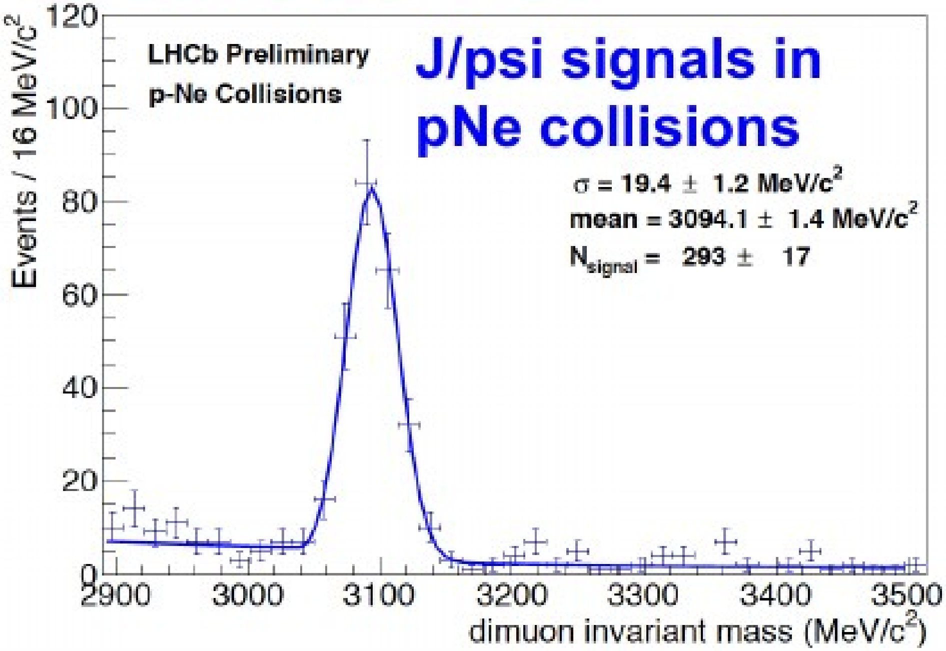
$\sqrt{s_{NN}^{LHC}}$ = 5 TeV



LHCb rapidity 2.5 < yLHCb < 4.5 $\Rightarrow \begin{cases} \text{7 TeV beam:} & -2.3 < y^{*}_{\mathrm{LHCb}} < -0.3 \\ \text{2.75 TeV beam:} & -1.8 < y^{*}_{\mathrm{LHCb}} < 0.2 \end{cases}$

Beam-gas collisions

- Exploiting the SMOG system with different noble gases: Ar, He, Ne
- Physics motivations:
  - Input to the understanding of nucleus-nucleus collisions
  - Sensitive probes of nuclear structure
  - Measurement of σ(pHe→p̄X). the largest uncertainty in the AMS results showing antiproton excess is due to the theoretical precision of the production σ(pHe→p̄X) [AMS-02 Coll., CERN 15.04.2015]
  - Probe quark gluon plasma (QGP)
  - Reference sample for heavy ion collisions



	√s	Date in 2015	Data sample
pNe	110.4GeV	25-26 Aug.	2 fills (~13h)
pHe	110.4GeV	8 Sept.	1 fill (~8 h)
pAr	110.4GeV	15-18 Oct.	7 fills(~29 h)

1 fill with p-Ar with 2.5 TeV beam for 10 h

'Hot' evident observables in 2015 data

- R_{aa} 5 TeV vs. 2.76 TeV for J/ψ at low-p_T: increase vs. 2.76 TeV?
- ψ(2S) R_{aa} with more precision
- Y-states suppression with CMS
- v_2 of J/ψ at high-p_T, maybe also at low-p_T at midrapidity and at forward rapidity: signal?

- non-prompt/prompt separation J/ψ semi-central/peripheral at forward rapidity by LHCb
- χ_c in peripheral Pb-Pb and in Pb-Ar collisions by LHCb
- Open charm with D-mesons down to 0 p_T by LHCb

Run 2 p-Pb campaign 2016

- Requests:

  1) 5 TeV requested by ALICE at levelled interaction rate for central barrel

  → 6 times 2013 minimum bias p-Pb statistics for the central barrel

  2) 8 TeV requested by ATLAS and CMS

  → similar statistics as in 2013 at 5 TeV can be expected

- to be decided what exactly

IP1&5	Ebeam (TeV)	Peak Lumi (cm-2s-1)	Integrated Fill Lumi (ub-1)	Integrated Run Lumi (nb-1)
PbPb	6.37Z	2.7e27	35	1
pPb	4Z	2e29	2600	77 = 2.5 L_{int} x 2013 Run 1 for ATLAS/CMS
pPb	6.5Z	3e29	3900	116 = 4 L_{int} x 2013 Run 1 for ATLAS/CMS

Machine estimates for 2016 for only 1 set-up, LHCC 2.3.2016 link

Second Run 2 Pb-Pb campaign

- ALICE central barrel read-out faster by factor 2 compared to 2015 thanks to TPC read-out upgrade

  → about 400 Hz read-out of 0-10 % most central collisions possible

  → foreseen to trigger mainly on most central collisions

  → personal estimate → factor 5-10 more 0-10 % evts. than 2011

- CMS with pixel upgrade („equivalent“ to IBL) in winter 2016/2017

- ATLAS/CMS sampling full luminosity for dimuons in trigger acceptance

  → statistics compared to 2015 increase depends on machine

Heavy-ion Run 3 upgrades (2020+)

- Planned to deliver 10 nb^{-1} to ALICE (50 kHz Pb-Pb interaction rate)

  about 35% in hand in terms of machine performance link
- ALICE muon arm upgrade with silicon vertex detector
- ALICE central barrel upgrade:

  → 7 layer silicon tracker with less mat-budget & more granularity

  → TPC upgrade: continuous read-out of all delivered collisions
- LHCb

  tracker upgrade: higher granularity allowing to measure more central collisions in A-A collisions
- ATLAS/CMS

  complete new inner trackers for ATLAS/CMS in LS3 (data 2025+)

Run 3 PbPb Projections

CMS-PAS-FTR-13-025

Table 3: Quarkonia yield estimates for $L_{\text{int}} = 10\ \text{nb}^{-1}$ at $\sqrt{s_{NN}} = 5.5$ TeV. Bottomonia are inclusive in p_{T}, charmonia have $p_{\text{T}} > 6.5\ \text{GeV}/c$.

$\sqrt{s_{NN}}$	2.76 TeV	5.5 TeV						
L_{int}	150 μb^{-1}	10 nb^{-1}						
Centrality(%)	0-100	0-100	50-100	60-100	70-100	80-100	90-100	0-100
Signal	p_{T}-inclusive raw yields							($p_{\text{T}} > 30$ GeV)
$\text{B} \to \text{J}/\psi$	2 250	300 000	12 400	6 150	2 350	810	215	5500
Prompt J/ψ	9 000	1 200 000	49 500	24 500	9 420	3 240	860	4400
ψ(2S)	200	26 600	1 100	547	210	70	20	100
Υ(1S)	2 000	266 000	11 000	5 460	2 090	720	191	267
Υ(2S)	300	40 000	1650	820	314	108	29	80
Υ(3S)	50	6 700	275	137	52	18	5	20

Matt Nguyen
Sapore Gravis
December 11th, 2014

link

Heavy-ion Run 3 upgrades (2020+): ALICE

Table 1.1: Comparison of the physics reach, minimum accessible p_T and relative statistical uncertainty, for selected observables between the approved scenario (1 nb^{-1} of delivered integrated luminosity, out of which 0.1 nb^{-1} is used for minimum-bias data collection) and the proposed upgrade (10 nb^{-1} of integrated luminosity, fully exploited in minimum-bias data recording).

Observable	Approved		Upgrade	
	p_T^{Amin} (GeV/c)	statistical uncertainty	p_T^{Umin} (GeV/c)	statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 % at p_T^{Amin}	0	0.3 % at p_T^{Amin}
D meson from B decays R_{AA}	3	30 % at p_T^{Amin}	2	1 % at p_T^{Amin}
D meson elliptic flow ($v_2 = 0.2$)	1	50 % at p_T^{Amin}	0	2.5 % at p_T^{Amin}
D from B elliptic flow ($v_2 = 0.1$)	not accessible		2	20 % at p_T^{Umin}
Charm baryon-to-meson ratio	not accessible		2	15 % at p_T^{Umin}
D_s meson R_{AA}	4	15 % at p_T^{Amin}	1	1 % at p_T^{Amin}
Charmonia				
J/ψ R_{AA} (forward rapidity)	0	1 % at 1 GeV/c	0	0.3 % at 1 GeV/c
J/ψ R_{AA} (mid-rapidity)	0	5 % at 1 GeV/c	0	0.5 % at 1 GeV/c
J/ψ elliptic flow ($v_2 = 0.1$)	0	15 % at 2 GeV/c	0	5 % at 2 GeV/c
ψ(2S) yield	0	30 %	0	10 %

LOI ALICE upgrade, link

Heavy-ion Run 3 upgrades (2020+): ALICE

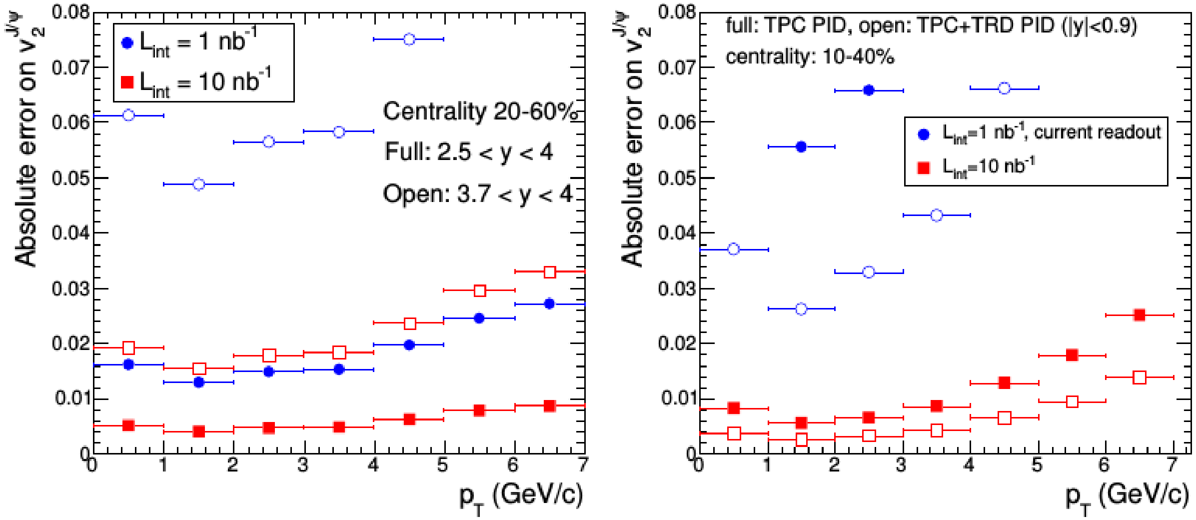
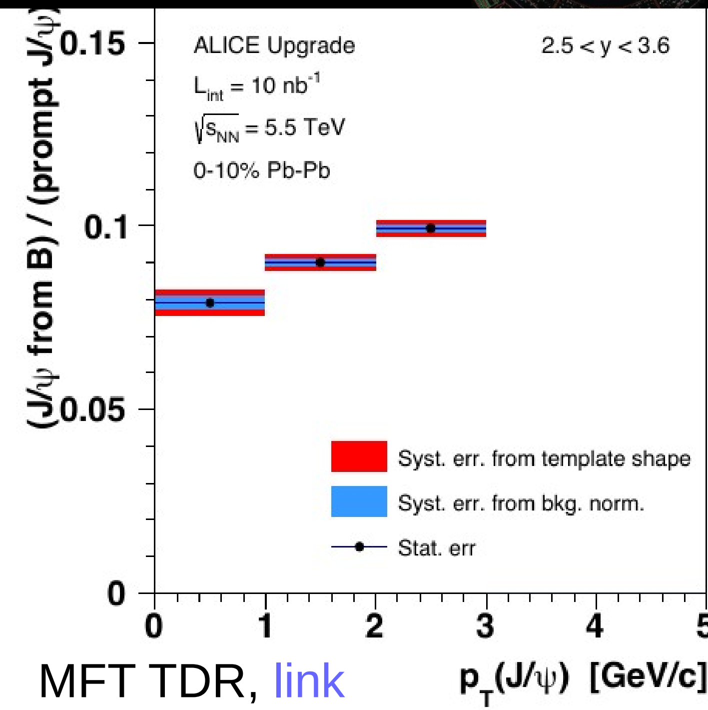
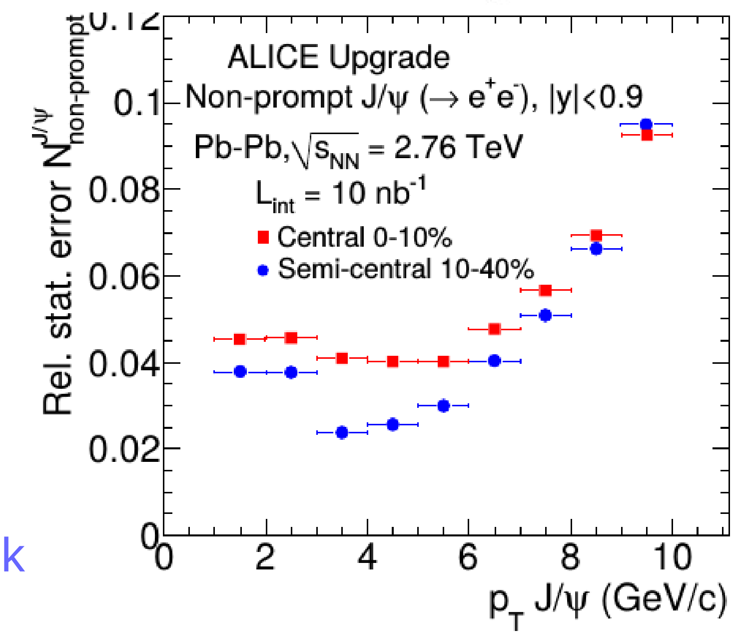


Figure 2.38: The absolute statistical error of the elliptic flow of J/ψ as a function of transverse momentum for the measurement with the Muon Spectrometer (left panel, centrality range 20-60%) and for the Central Barrel (right panel, centrality range 10-40%).

LOI ALICE upgrade, link



MFT TDR, link



ALICE ITS TDR, link

Some remarks

- total/open beauty/charm less 'complicated' observable than quarkonium

- cc cross section in A-A including baryons main goal of heavy-ion driven ALICE upgrade in Run 3

- measurements with D's and non-prompt J/ψ already in Run 2 down to low p_T

Some remarks

- Open/hidden heavy flavour comparison can also help in p-A respectively pp:

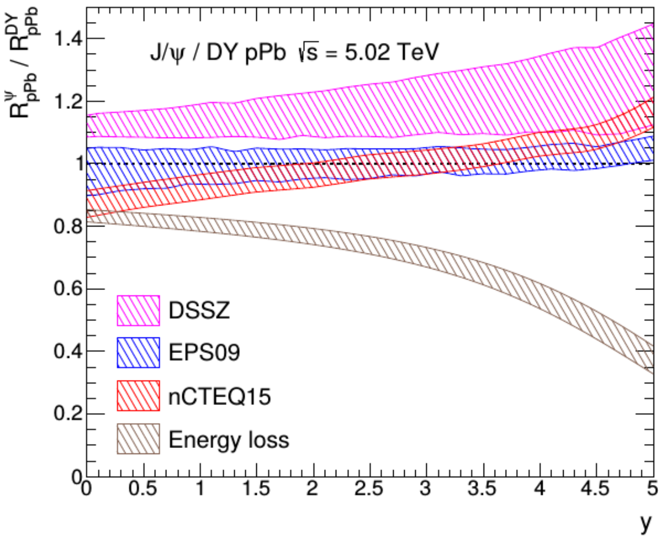
In [82], Ma and Venugopalan obtained a good description of the low-P_T J/ψ data over a wide range of energy by, on the one hand, using the LDMEs from [17] –our second set– and, on the other, a CGC-based computation of the low-P_T dependence. In reproducing the data, they found that the CS contribution is only 10% of the total yield. This 10% is reminiscent of the factor 10 between the CS and CO in our "collinear" study. From our viewpoint, it looks as if the specific ingredient of this CGC-based computation would correspond to an effective reduction of the two-gluon flux[15] by a factor of 10. It is therefore very interesting to find out new processes which would be sensitive to this physics.

Feng, Lansberg, Wang, arXiv:1504.00317

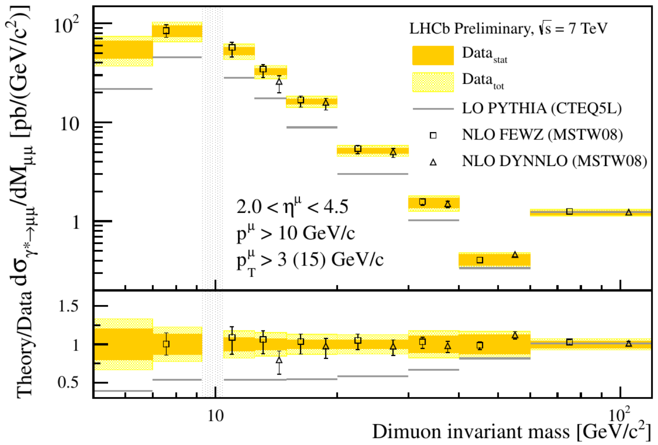
→ leverarm via open charm ratio in pp and in p-A

Some remarks

- Drell-Yan unreachable in A-A at low mass scales and rather sensitive to quarks than to gluons
  nevertheless:
  → uncoloured probe at same mass scale attractive
  to chose among different approaches in p-A and consequences for A-A



Arleo, Peigné, link



DY in LHCb with 37 pb^{-1} pp, link
→would require factor 6 more statistics for p-Pb than in 2013 for ATLAS/CMS assuming same S/B than in pp

Some remarks

Quarkonium
two „factorisation steps“ in pp
Deconfinement: redistribution in phase space and rate itself

open beauty/charm measurements
two „factorisation steps“ in pp
Deconfinement: redistribution in phase space and potentially hadronisation

'total' charm/beauty including baryons
one „factorisation step“ in pp,
conserved after initial encounters

Drell Yan
one „factorisation step“ in pp

'Easy' to measure
Theoretically most ambitious in A-A and in p-A as well

'Hard/impossible' to measure
Theoretically cleanest

→ the observable choice or the combination of the considered ones shifts problems from experiment to model or vice versa

→ **minimal 'total' uncertainty: evaluation of all assumptions for models and implications of underlying pictures for other observables**

Some remarks

- One example observable:

  $\Upsilon(nS)/(B \rightarrow J/\psi)$ ratios in pp, p-A, A-A integrated as much as possible over p_T

→ should cancel partially experimental uncertainties, i.e. on dimuon trigger level

→ uncertainties induced by feed-down, 'baryon-meson chemistry' and phase space cuts/thresholds on the model side

Conclusion

- Quarkonium measurements together with open flavour measurements in p-A and A-A collisions at the LHC with unprecedented precision in the upcoming years

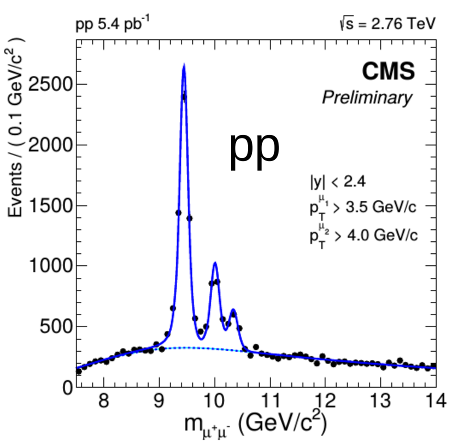
- Unique opportunity to progress in the understanding of quarkonium as:
  → probe of deconfinement
  → probe of low-x QCD

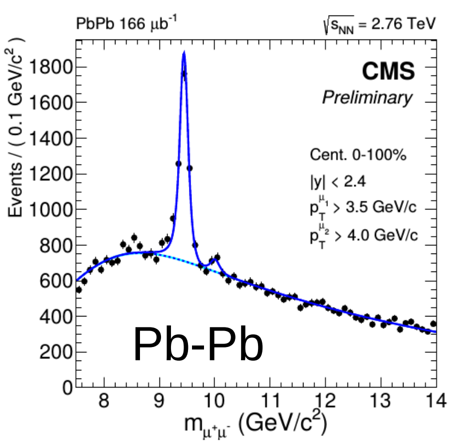
Conditions in Run 1

p-Pb: same performance as in pp-collisions, even cleaner than high luminosity running in CMS/ATLAS

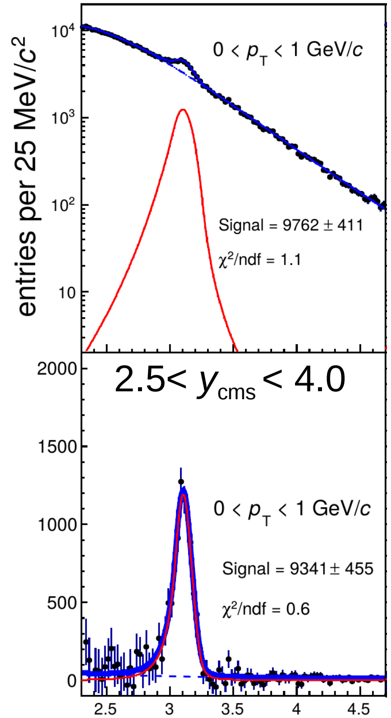
most central Pb-Pb: different environment at low p_T for charmonium

background conditions for high-p_T charmonium and for upsilon in CMS/ATLAS not that different than in pp for tight selections

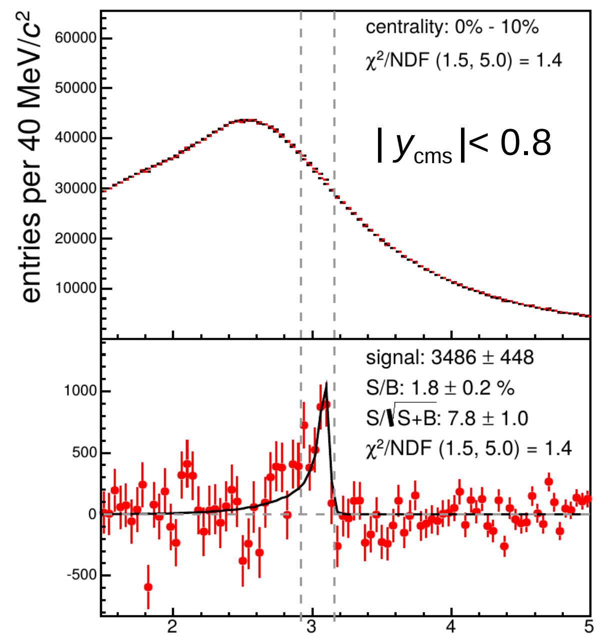




L_{int} = 166 μb⁻¹
0-100 %



L_{int} = 69 μb⁻¹ 0-90 %



L_{int} = 25.6 μb⁻¹
0-10 %