Production measurements in heavy ion and fixed target collisions at LHCb

Matt Durham, *Los Alamos National Lab*

for the LHCb Collaboration

Santa Fe Jets and Heavy Flavor Workshop 29-31 January 2018

Outline

- Studying the nuclear initial state
- The LHCb Detector – a unique facility for forward physics in heavy ion collisions
- Open charm measurements in *p*Pb: D^0 mesons
- Charmonia measurements in *p*Pb: $J/\psi, \psi'$
- A unique capability at LHC - fixed target running
- Summary

The nuclear PDF

Generic cross section for heavy quark production:

$$d\sigma(Q^2, \sqrt{s})_{pA\to a+X} = \sum_{i,j=q,\bar{q},g} f_i^p(x_1, Q^2) \otimes A f_i^A(x_2, Q^2) \otimes d\hat{\sigma}(Q^2, x_1, x_2)_{i,j\to a+X}$$

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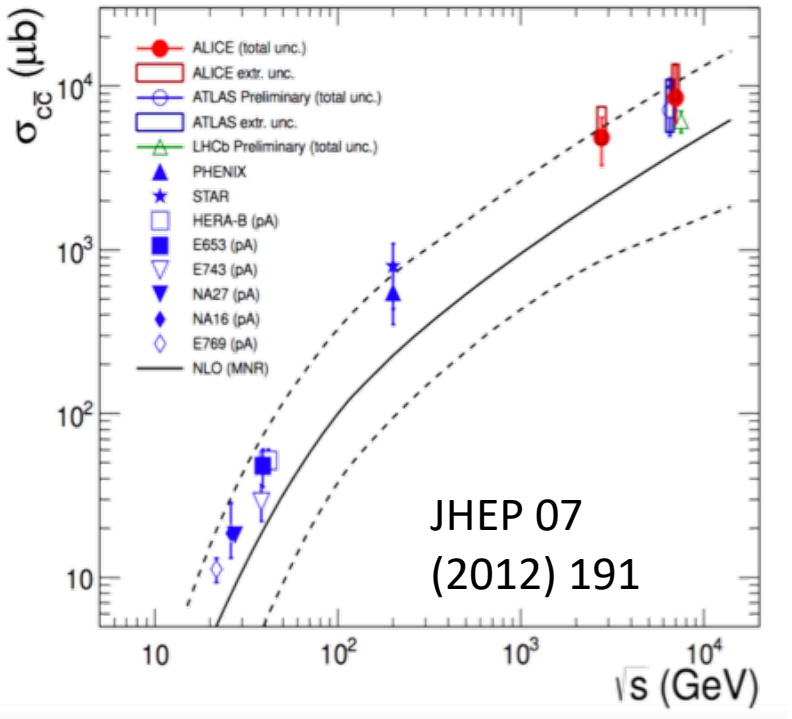

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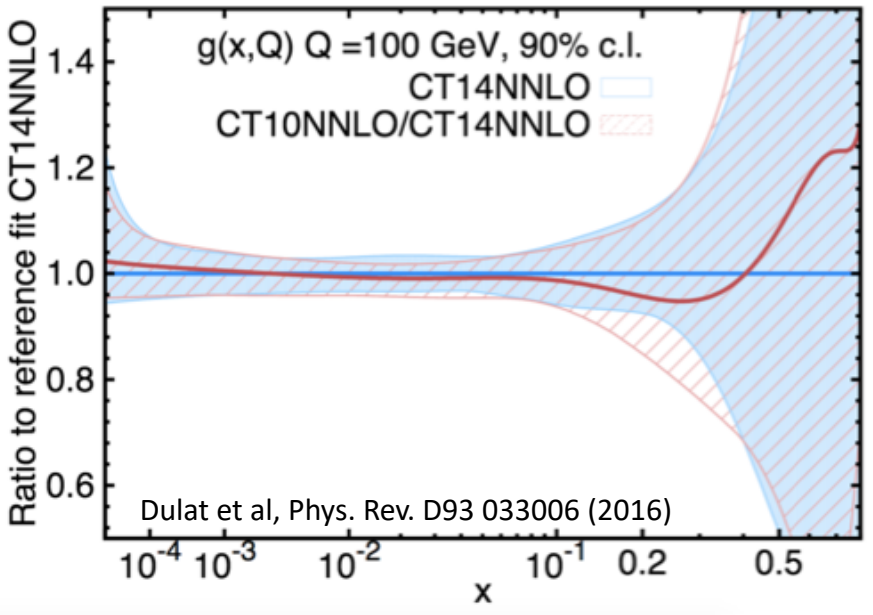
Due to incredible effort, proton PDF is reasonably well known

A sample of some recent work:
NNPDF3.1: EPJ C77 663 (2017)
CT14: Phys. Rev. D93 033006 (2016)
MMHT 2014: EPJ C75 204 (2015)
CJ15: Phys. Rev. D93, 114017 (2016)
ABMP16: Phys. Rev. D96, 014011 (2017)
Boughezal et al JHEP (2017) 130



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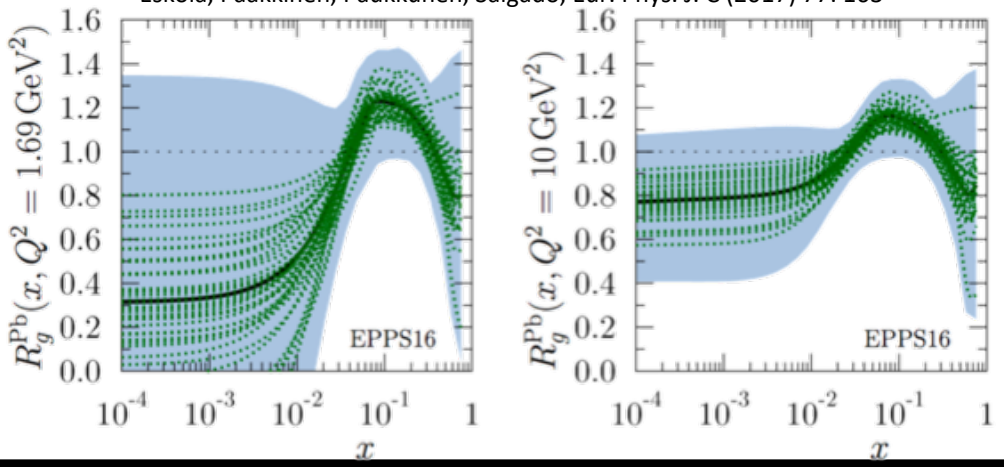
Despite incredible effort, nuclear PDF is not well constrained, esp gluons at low x

Eskola, Paakkinen, Paukkunen, Salgado, Eur. Phys. J. C (2017) 77: 163



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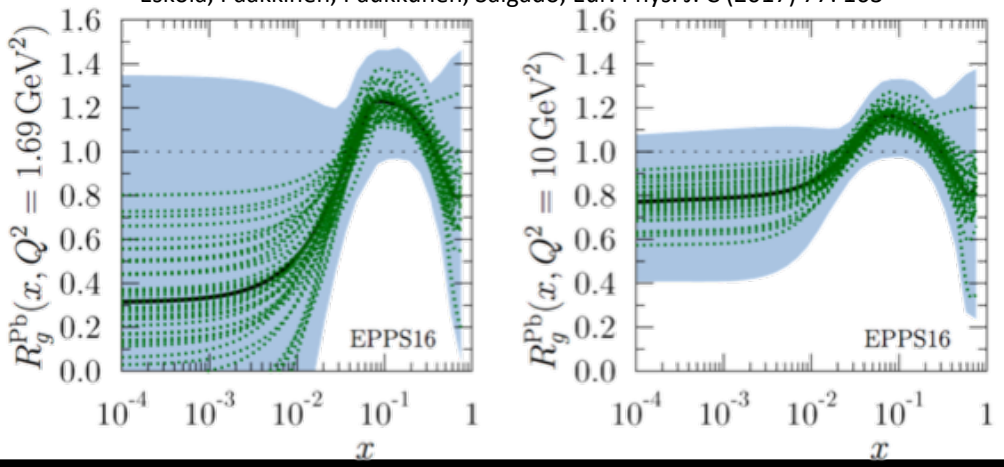

Solution: constrain fits with data at low x with probes that are sensitive to gluon distribution

->Heavy quarks at forward rapidity

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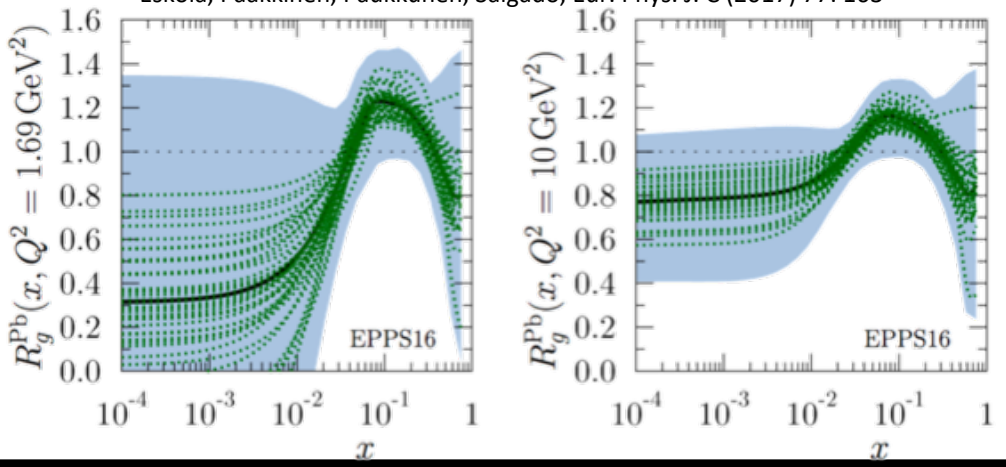

NB: Global fits of data include all possible effects

- **Parton modification (e. g. shadowing, CGC, etc)**
- **QCD energy loss**
- **k_T broadening**
- **charmonia "breakup"**
- **Hydrodynamics**
- **Any other effect**

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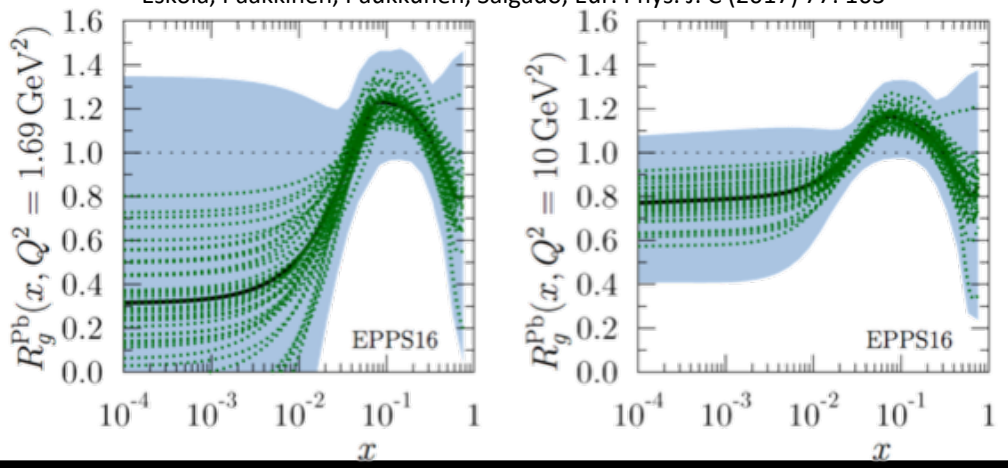

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To evaluate late stage effects, we need to measure multiple probes

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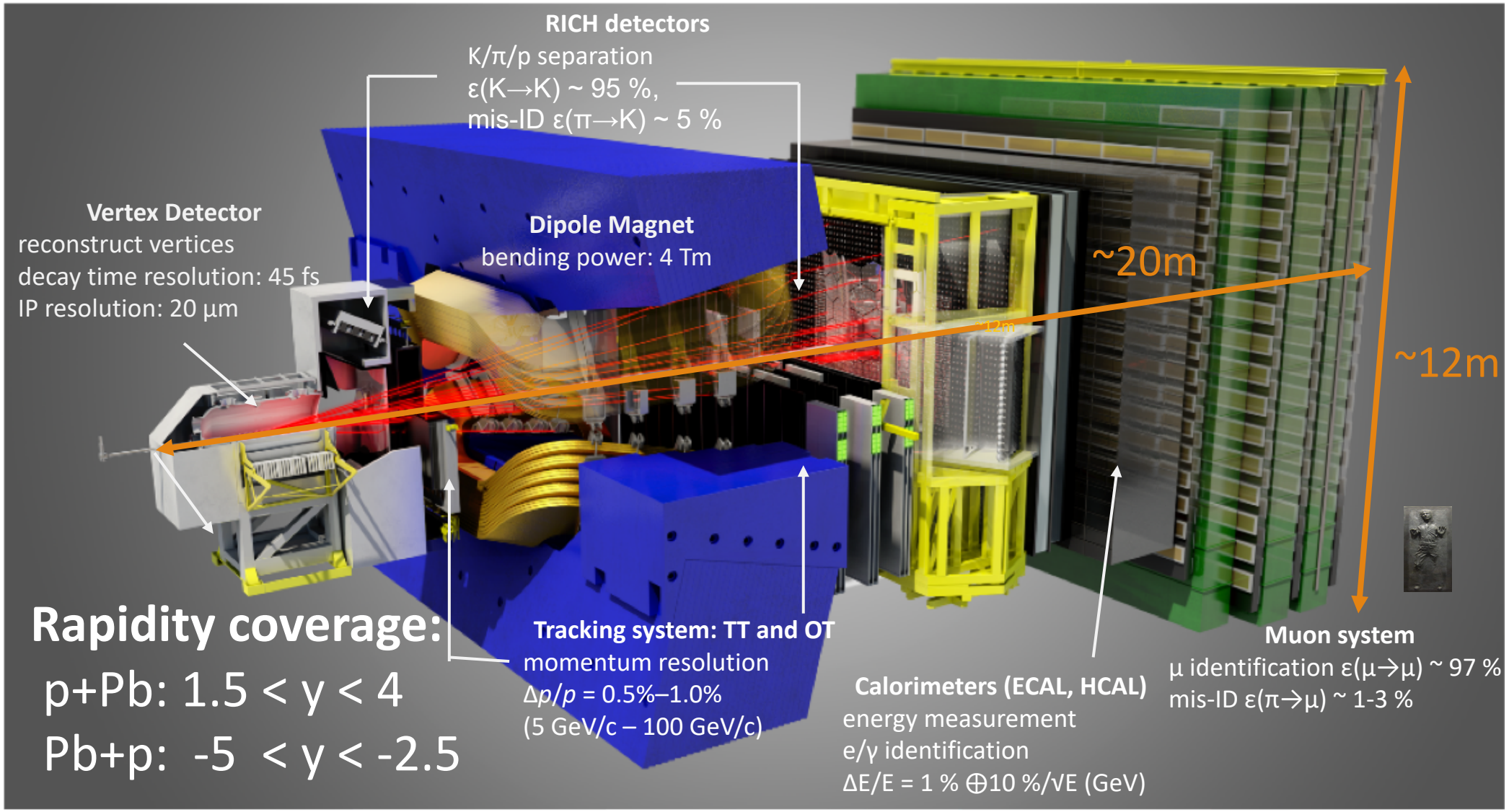
The LHCb Detector

JINST 3 (2008) S08005
Int. J. Mod. Phys. A 30, 1530022 (2015)



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  -Forward (and backward) rapidity region completely instrumented
  allowing access to low-x region of nucleus

  -Reconstruction of open heavy flavor mesons down to p_T=0
  sensitive to gluon nPDF

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Tracking detector granularity designed for *pp* collisions is not optimal for measurements in central PbPb collisions

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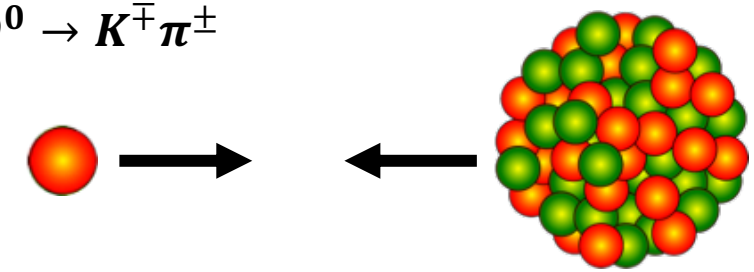
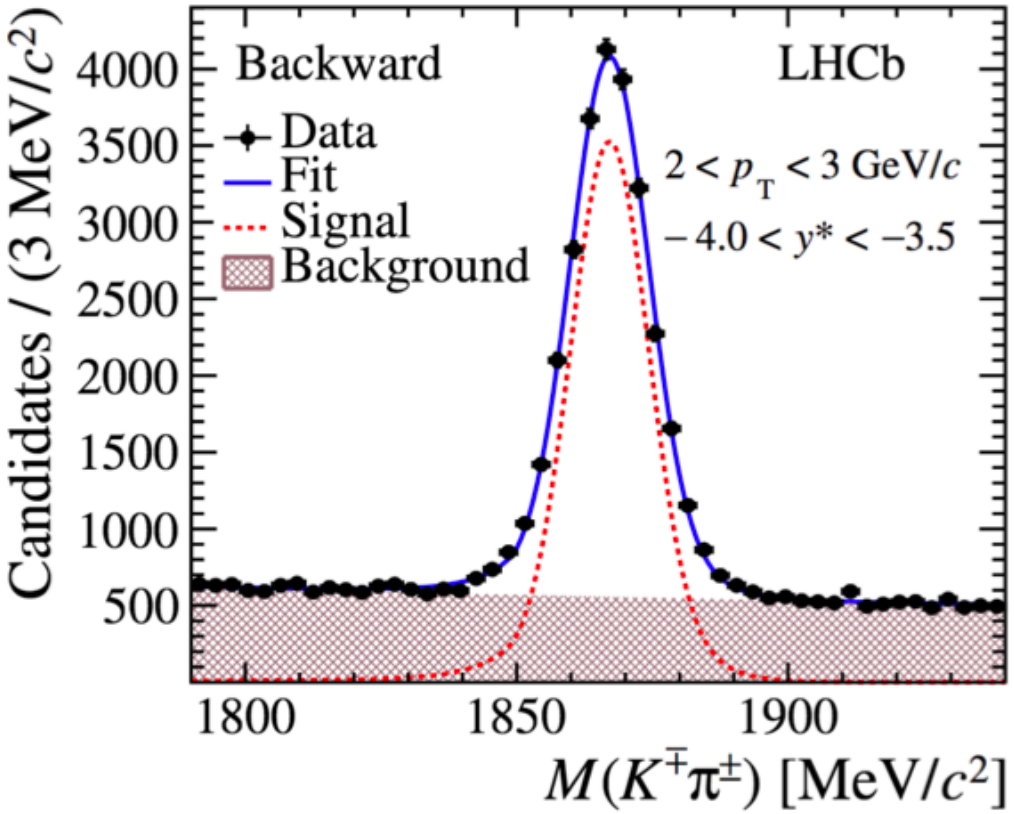
Open Charm Mesons in *p*Pb collisions: D^0

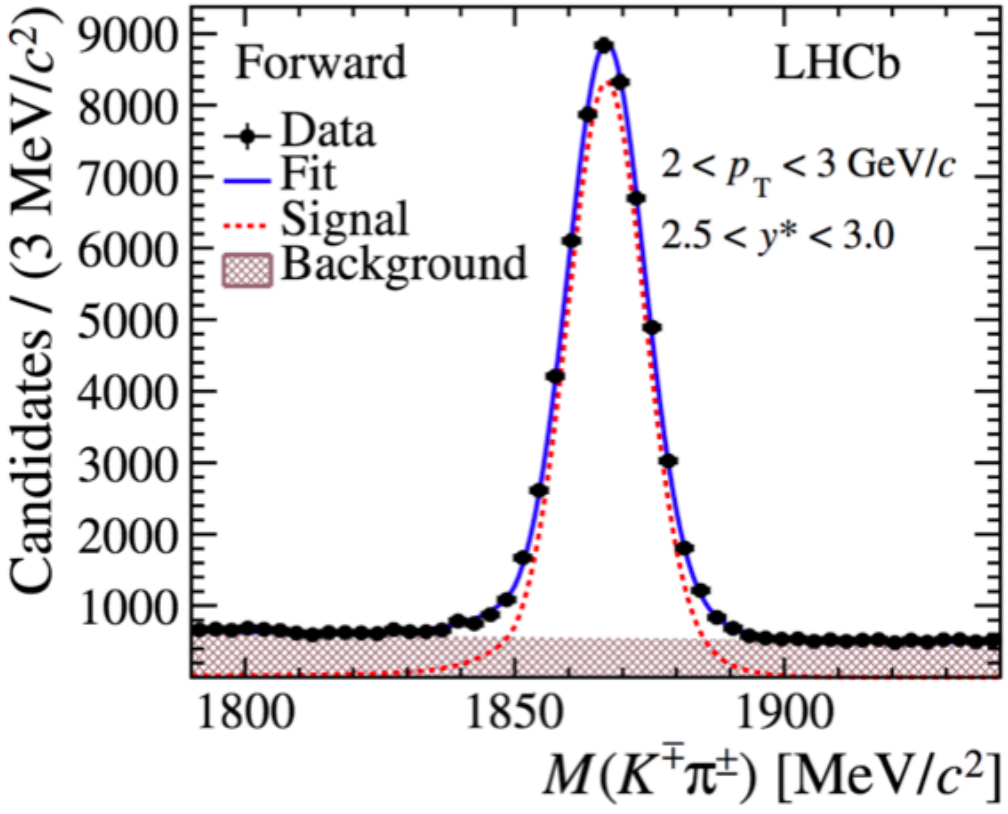
Fully reconstructed through decay channel $D^0 \to K^{\mp}\pi^{\pm}$

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

J. High Energ. Phys. 10 (2017) 90







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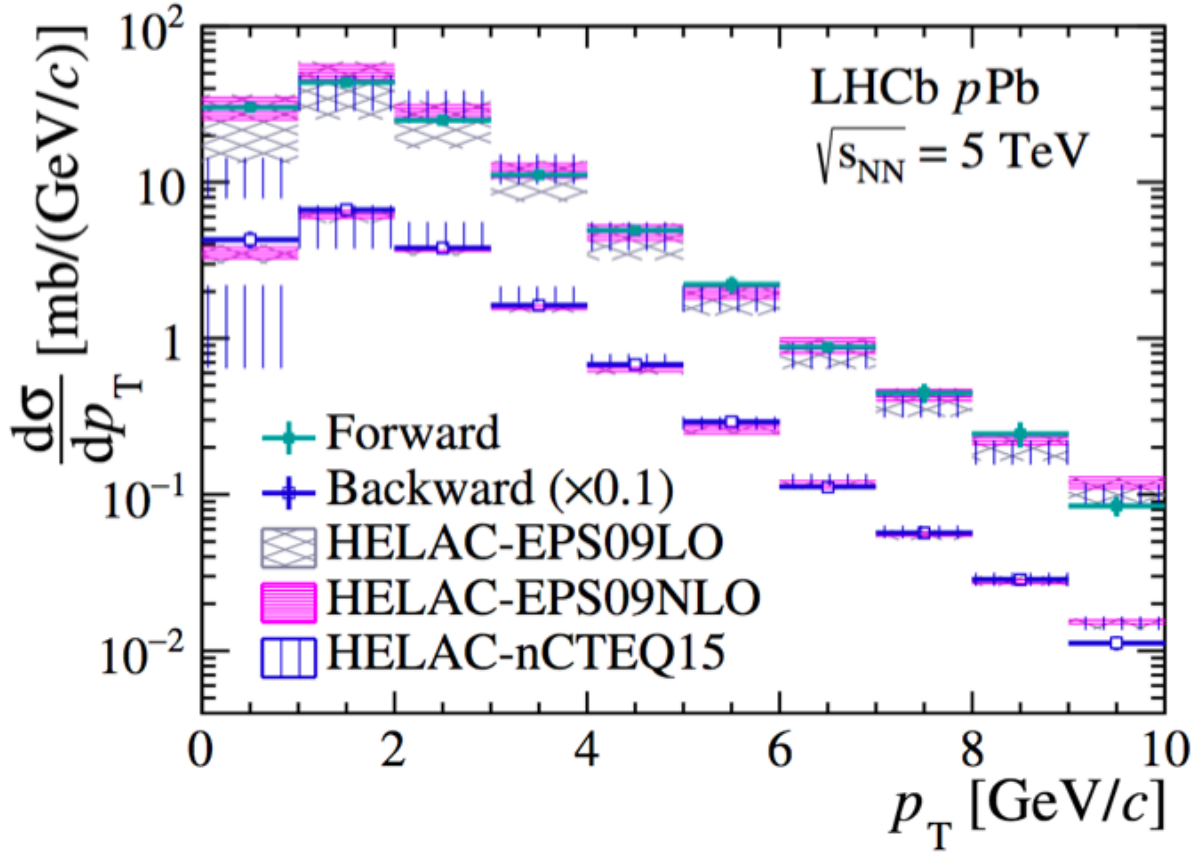

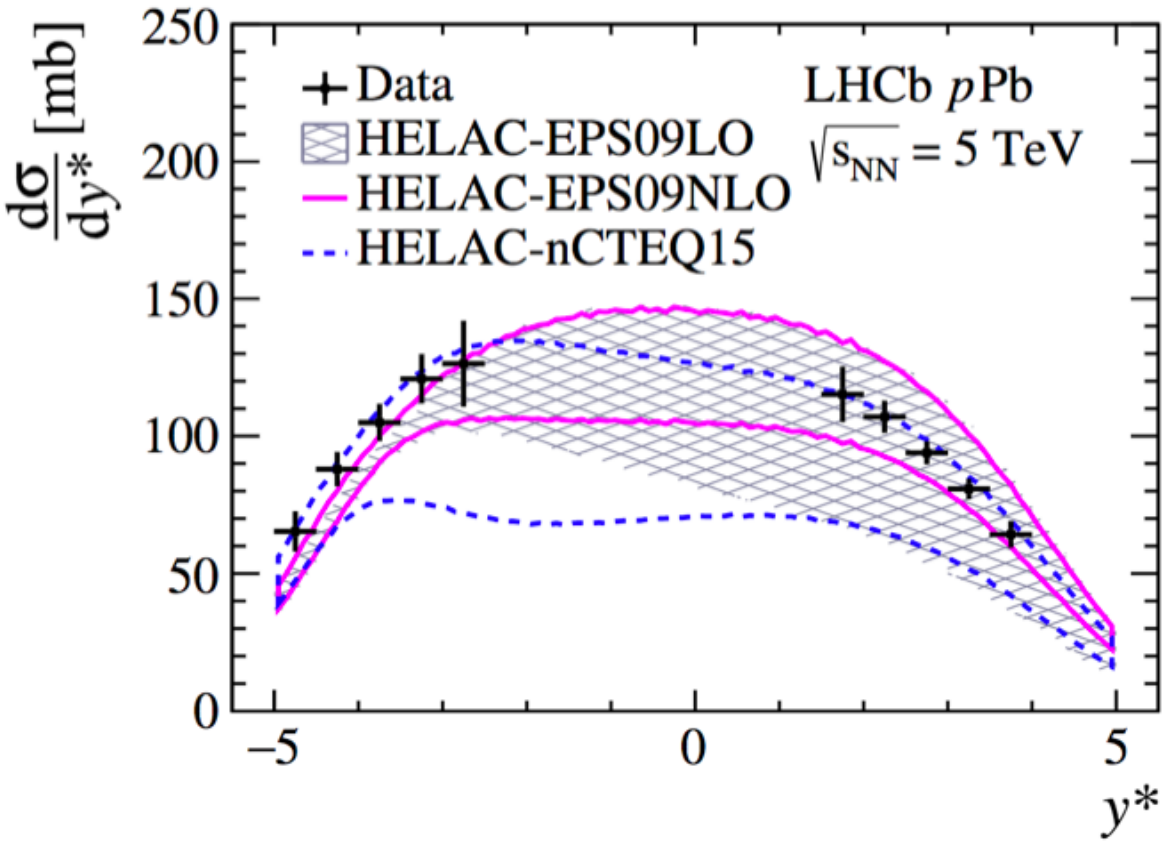

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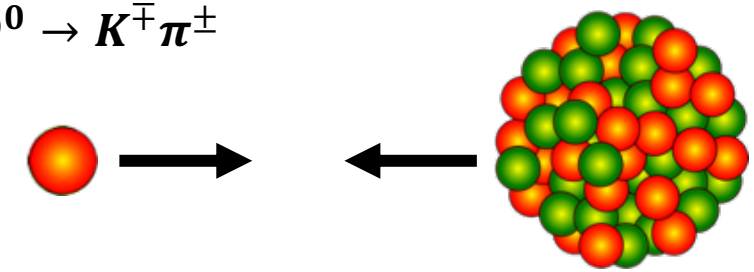

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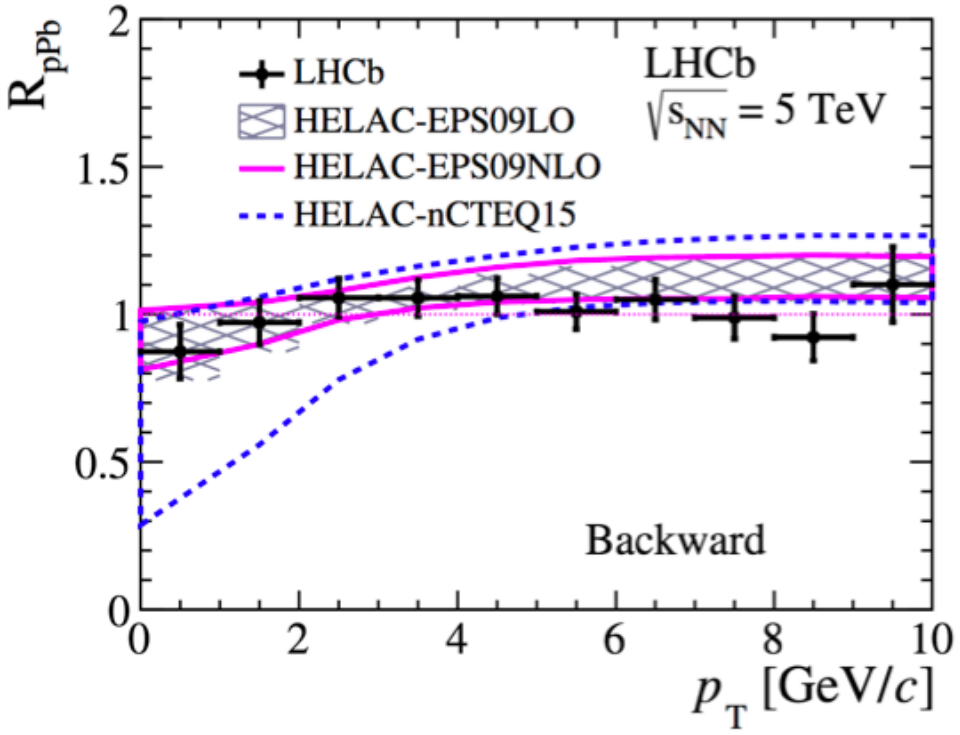

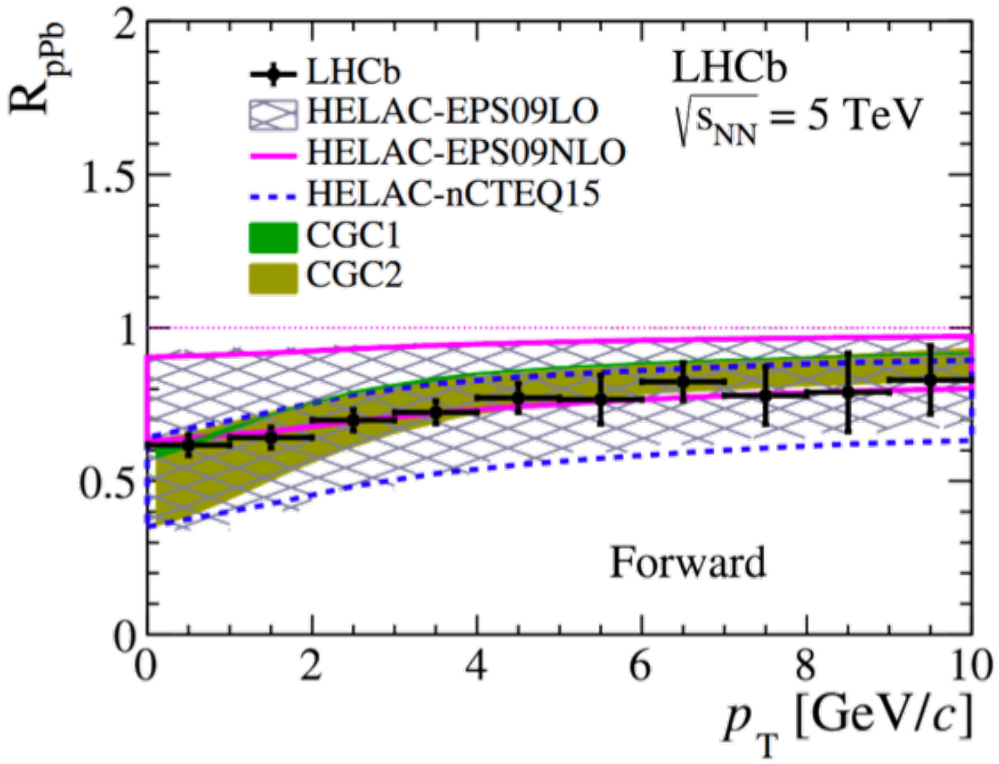

Error bars < calculation uncertainties

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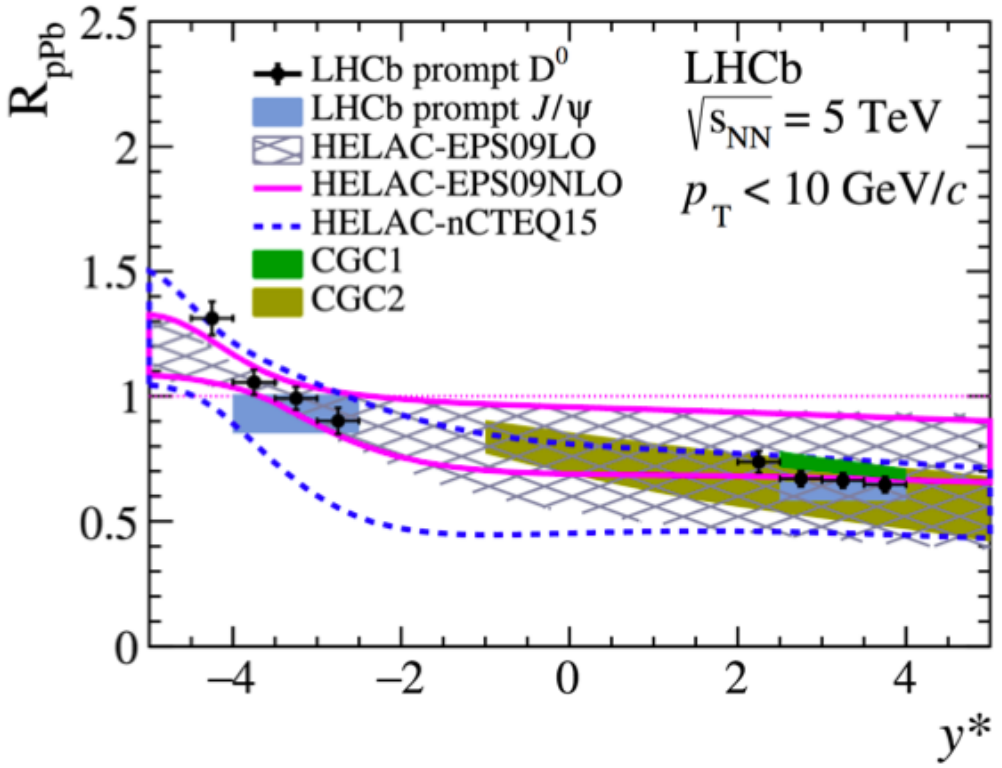

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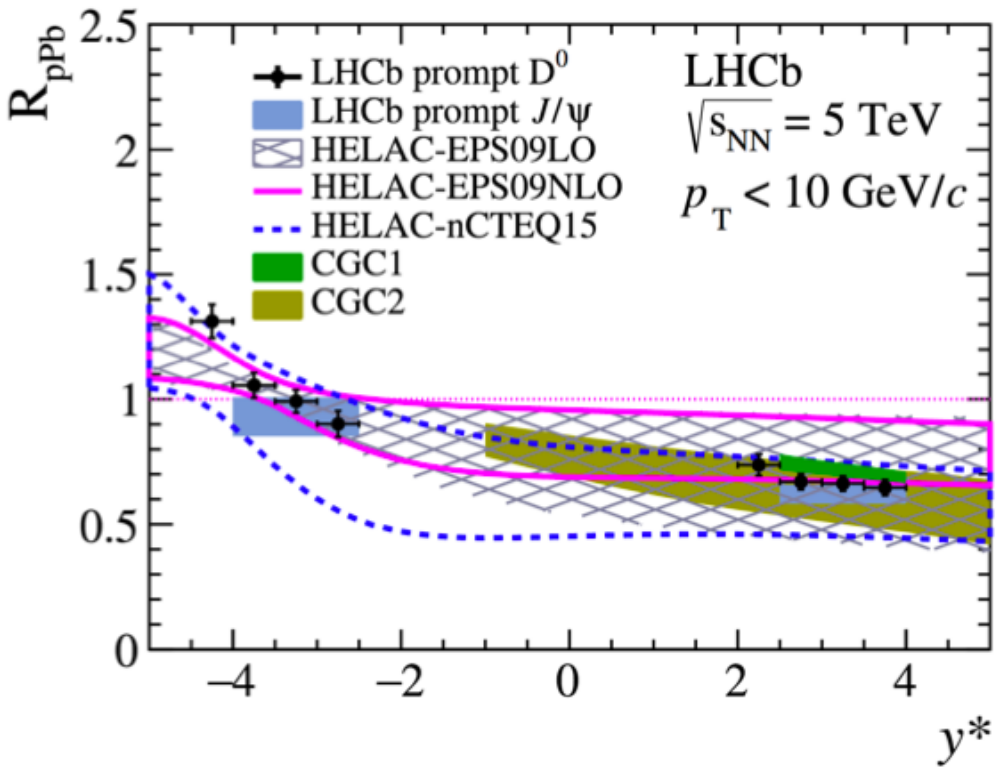

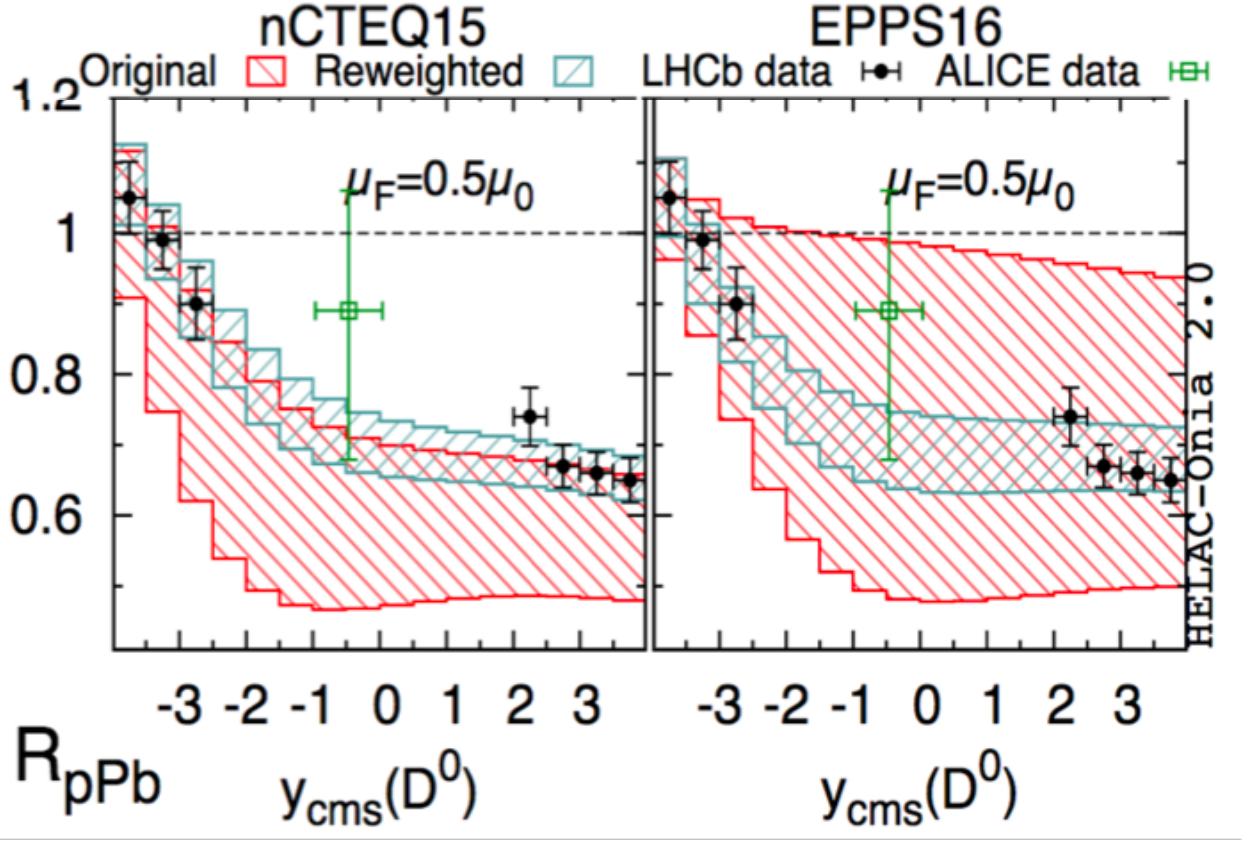

This data is already being used to constrain the gluon nPDF down to x~5x10^{-6}

Kusina, Lansberg, Schienbein, Shao, ***Gluon shadowing and antishadowing in heavy-flavor production at the LHC*** **arXiV: 1712.07024**

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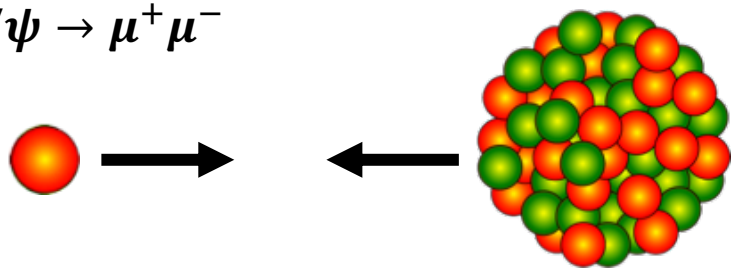
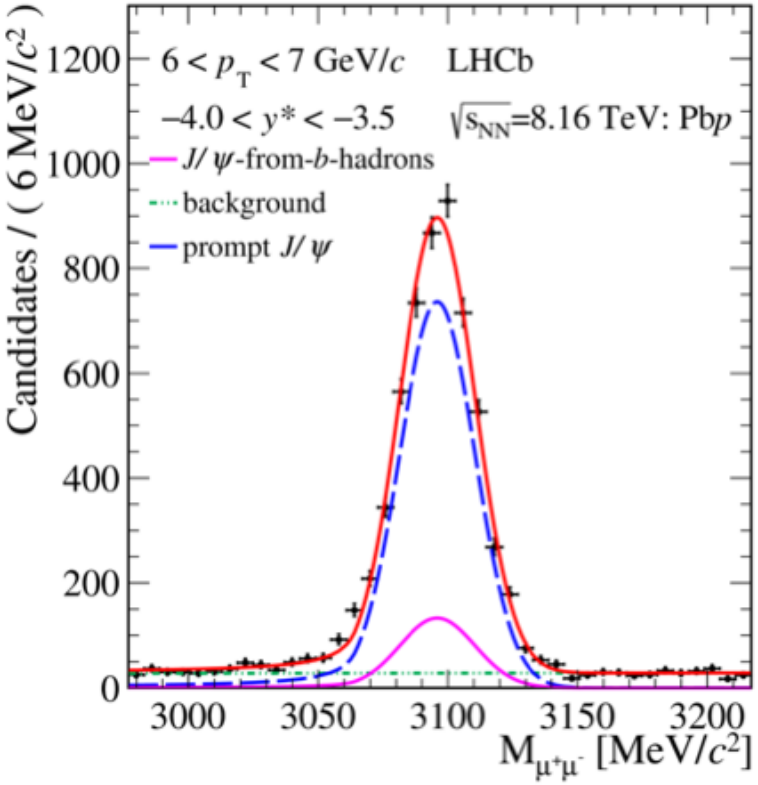
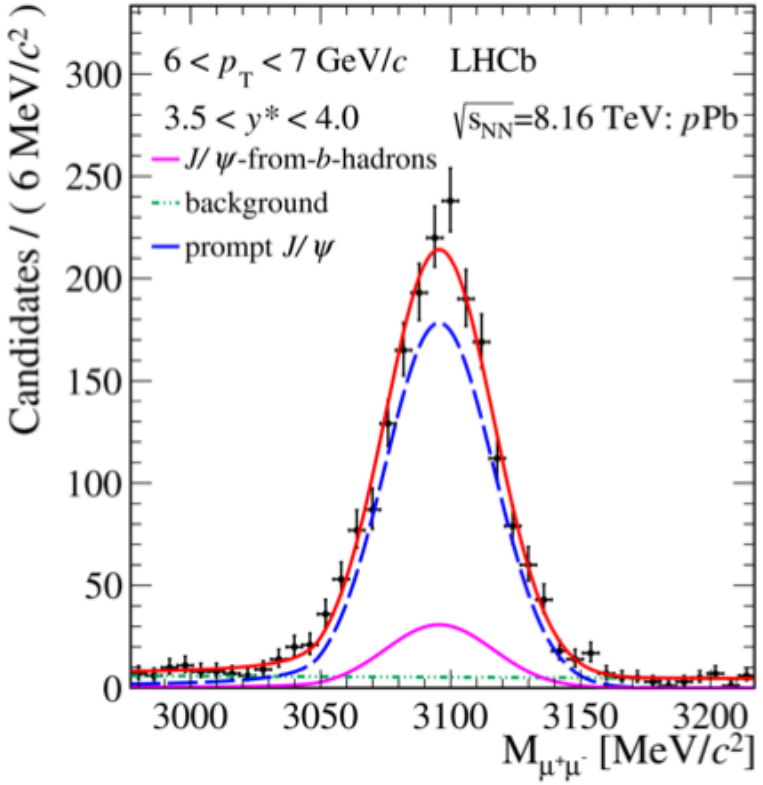
$\sqrt{s_{NN}}$ = 8.16 TeV

Phys. Lett. B 774 (2017)







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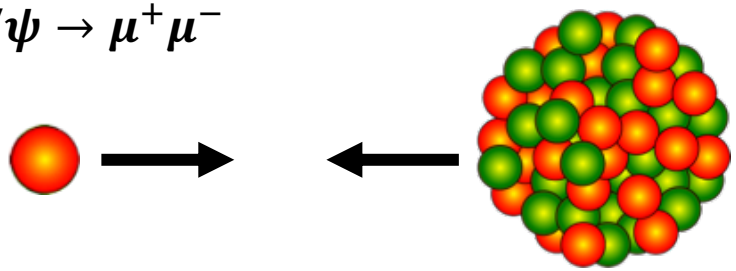

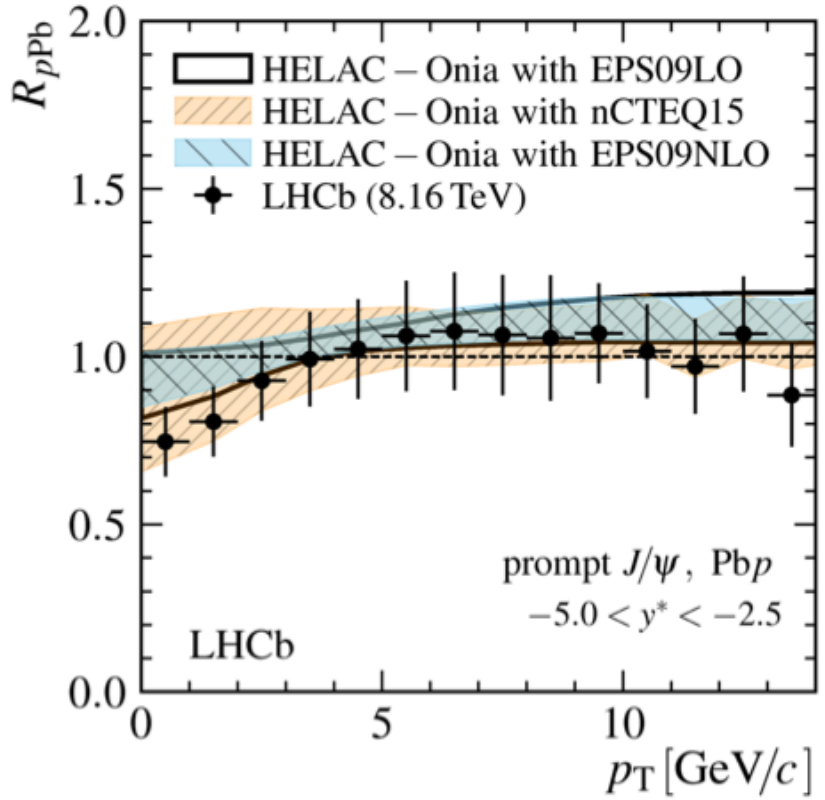

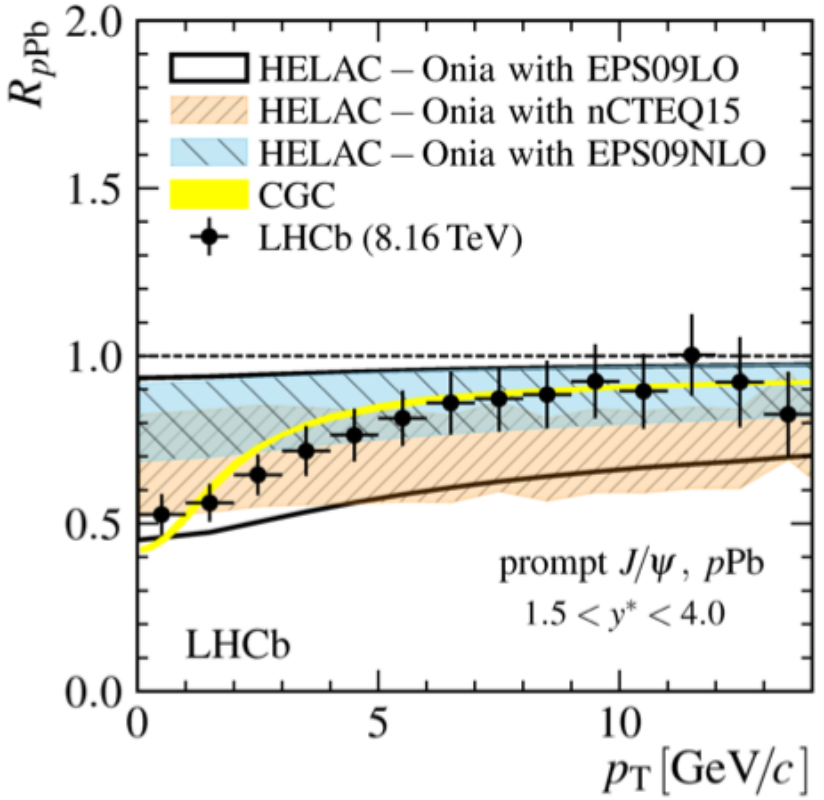

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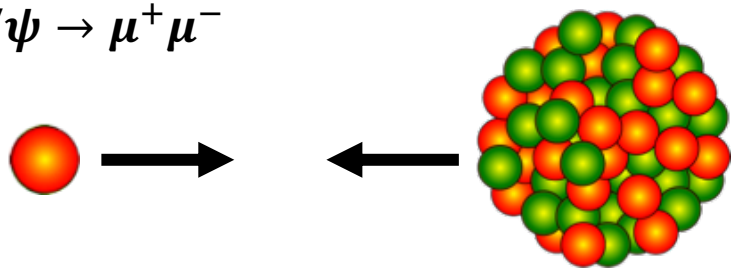

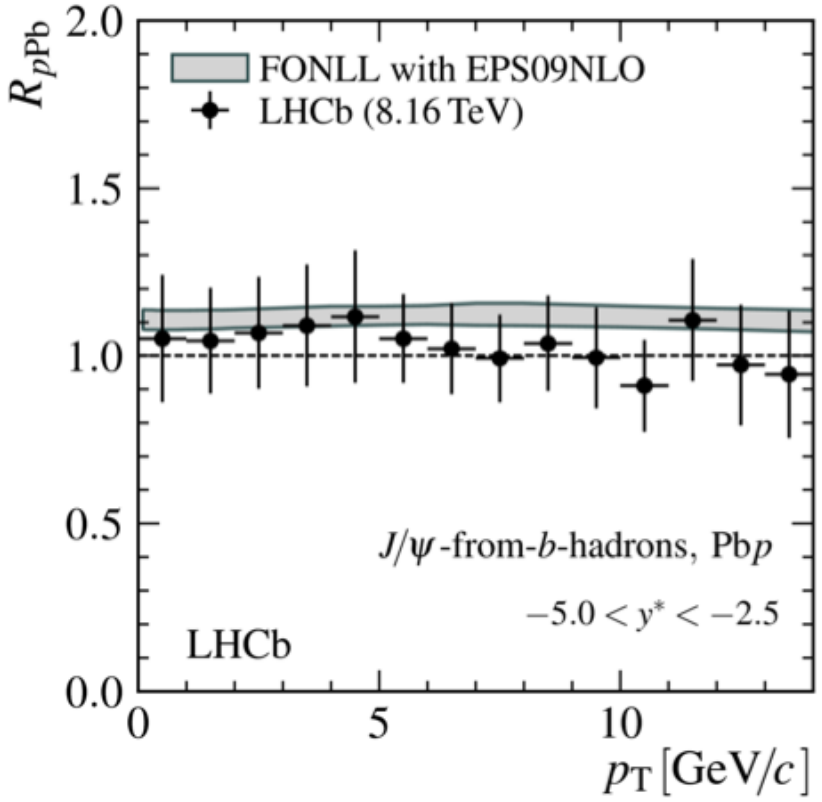

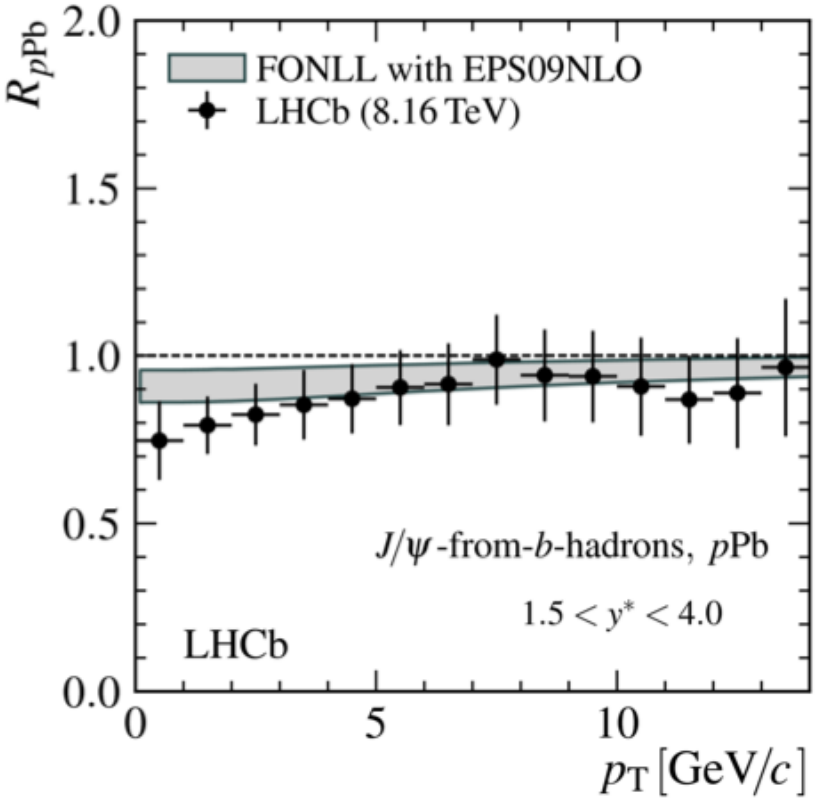

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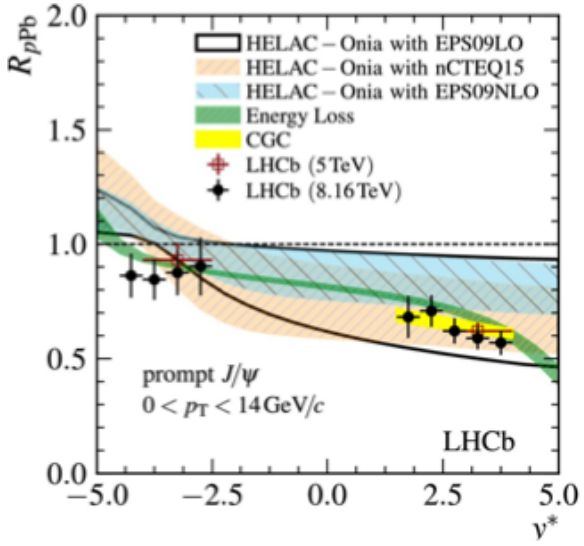

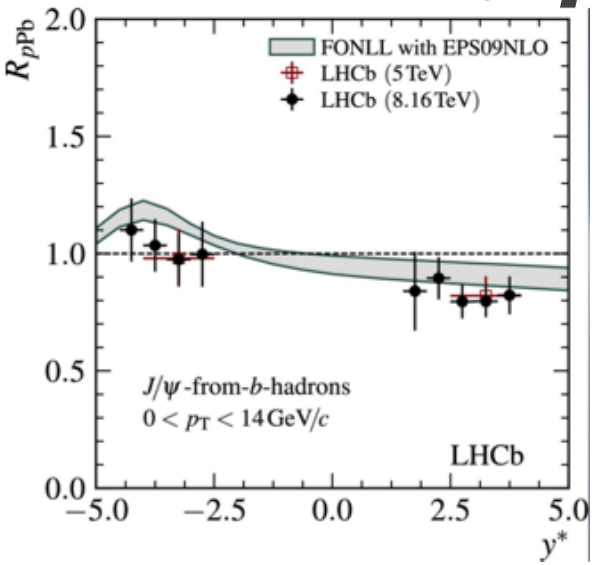

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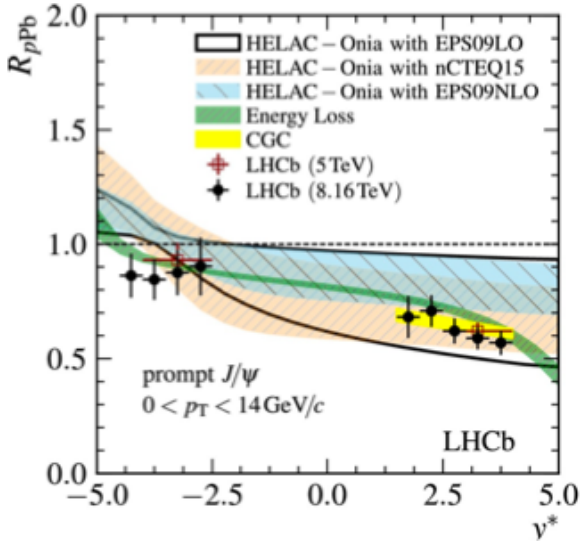

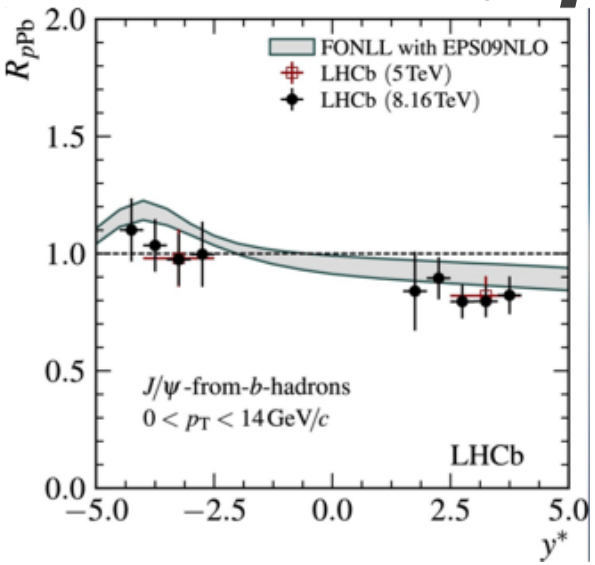

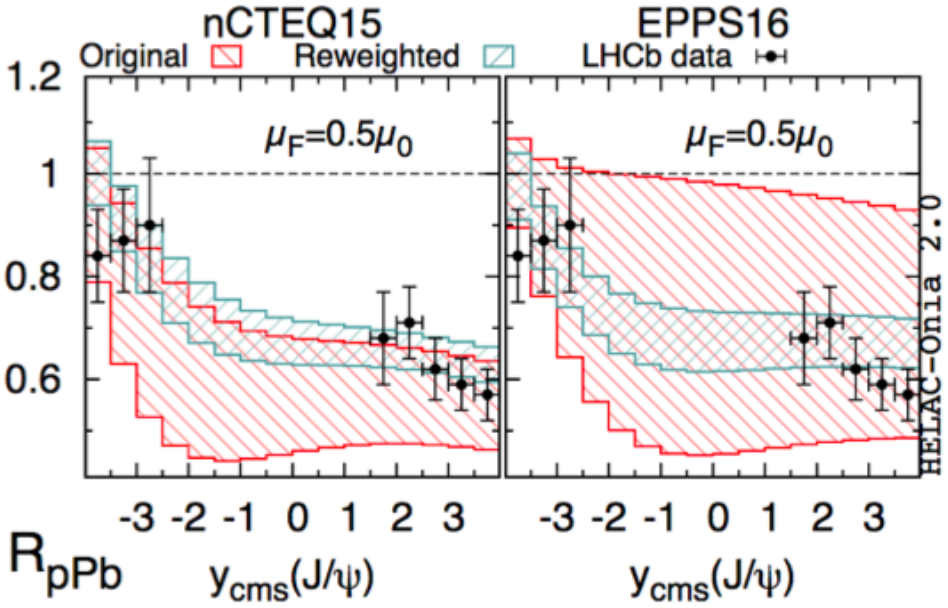

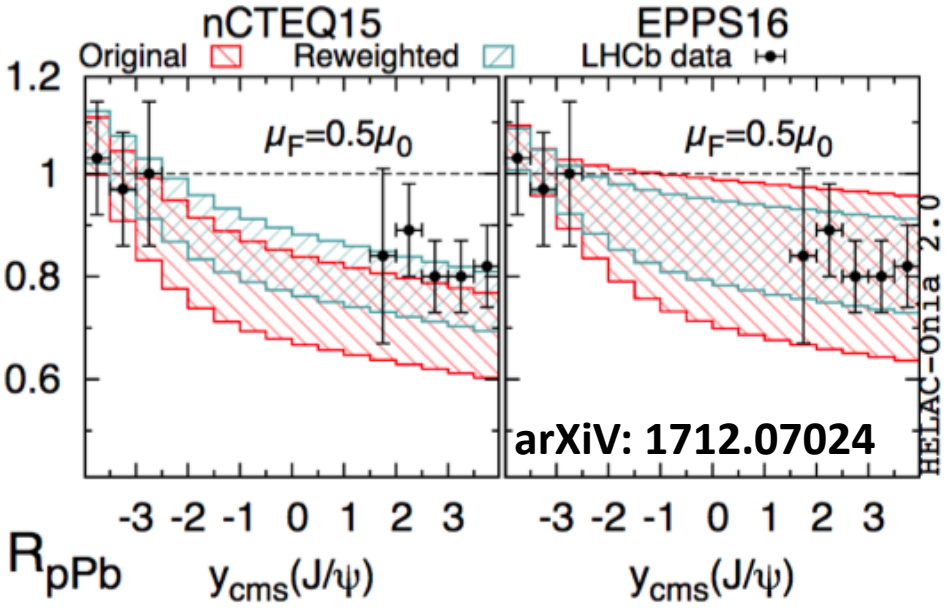

arXiV: 1712.07024

Charmonia in pPb collisions: ψ'

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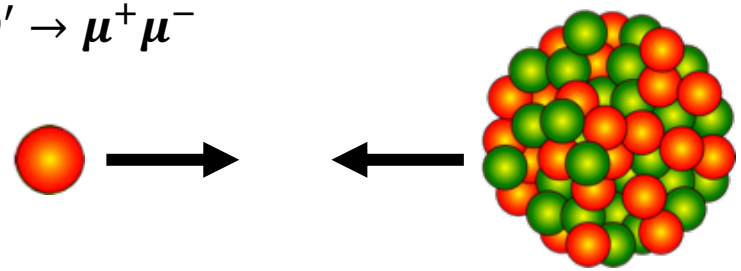
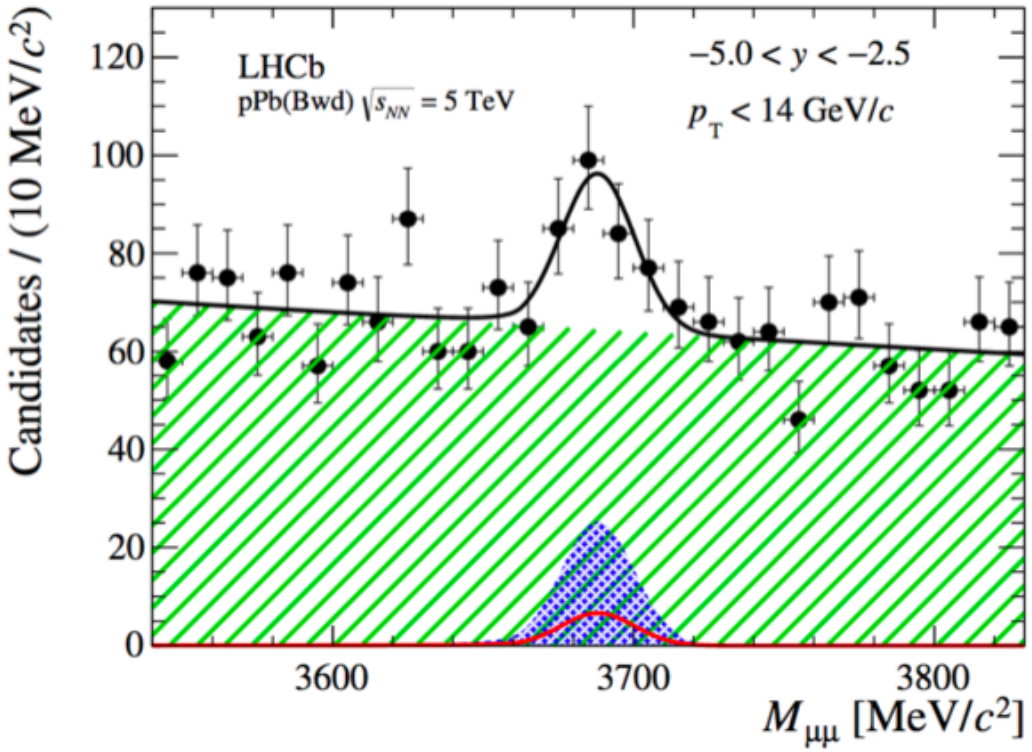
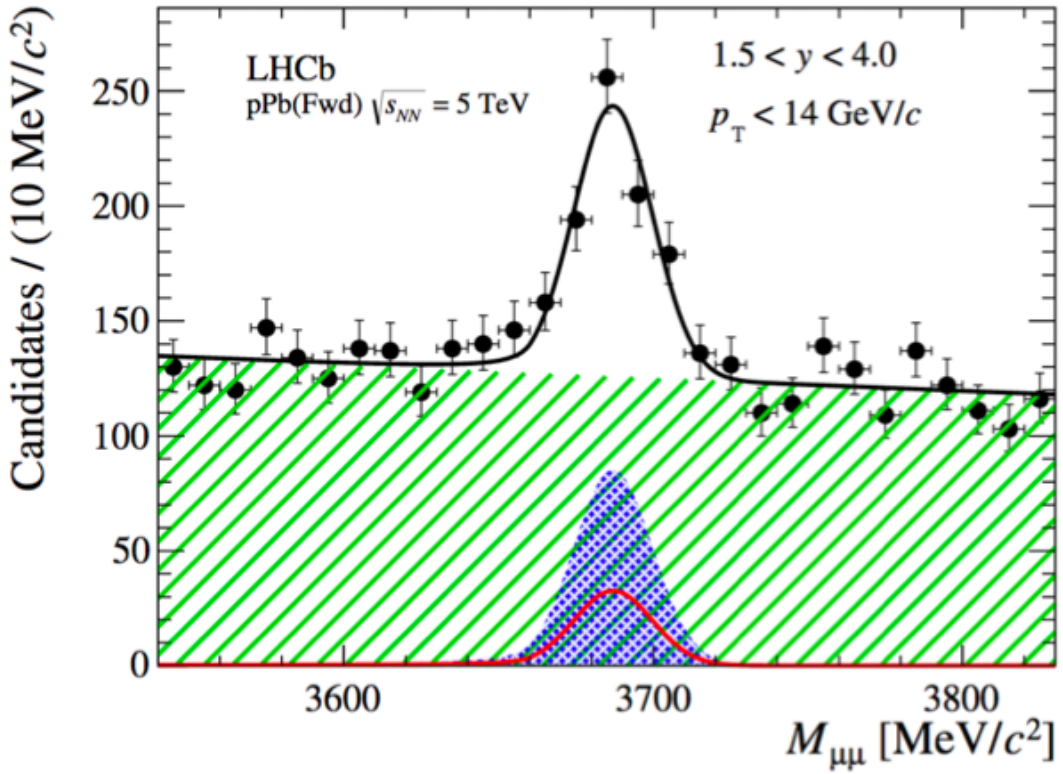
J. High Energ. Phys. 03 133 (2016)







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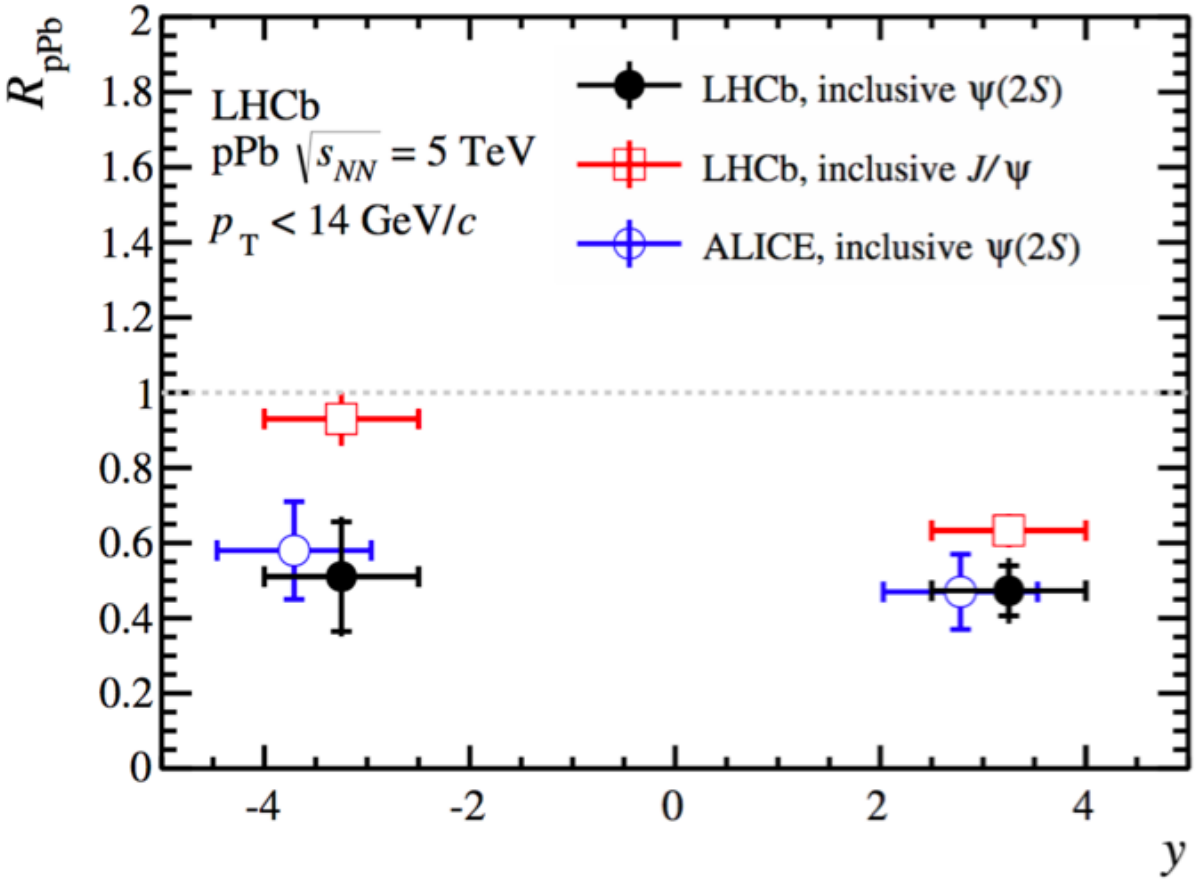
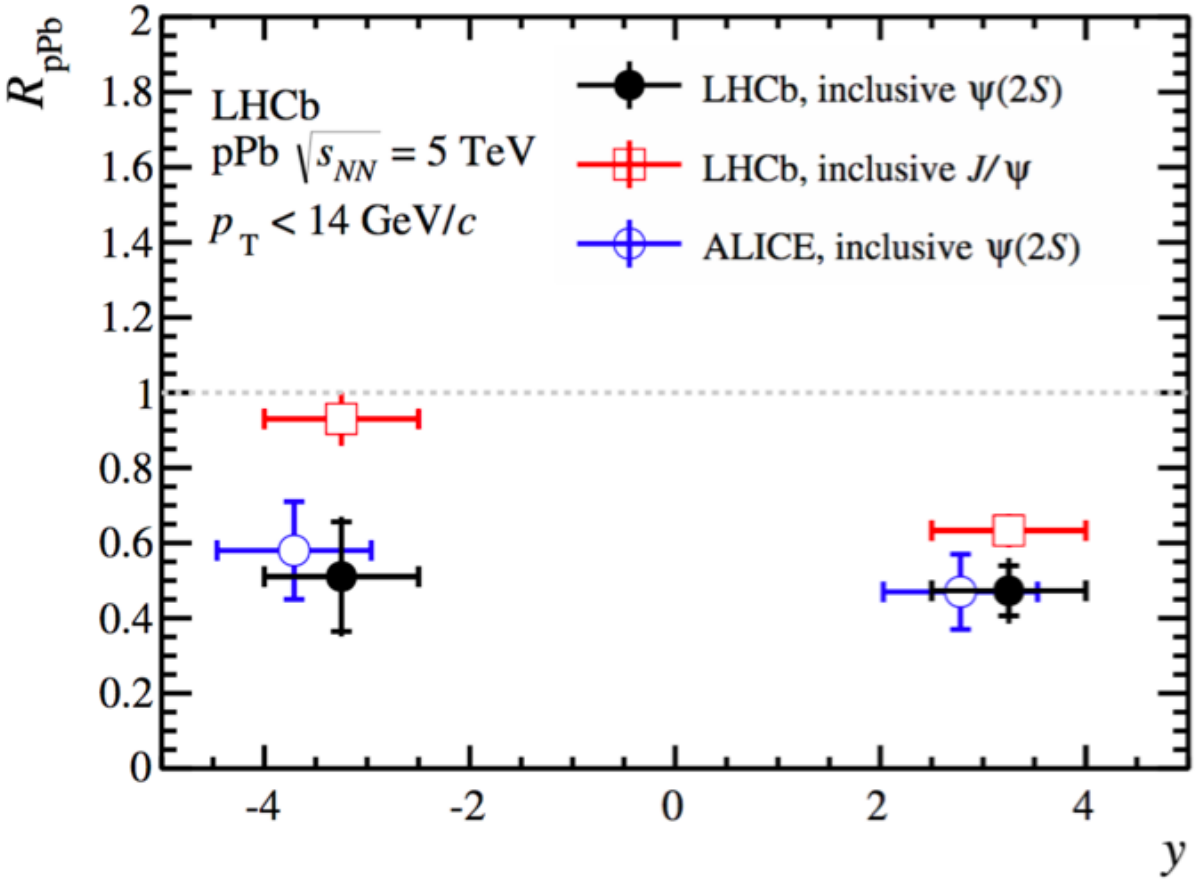


Absolute suppression is comparable between forward/backward rapidity

Charmonia in *p*Pb collisions: ψ'



Absolute suppression is comparable between forward/backward rapidity

J. High Energ. Phys. 03 133 (2016)

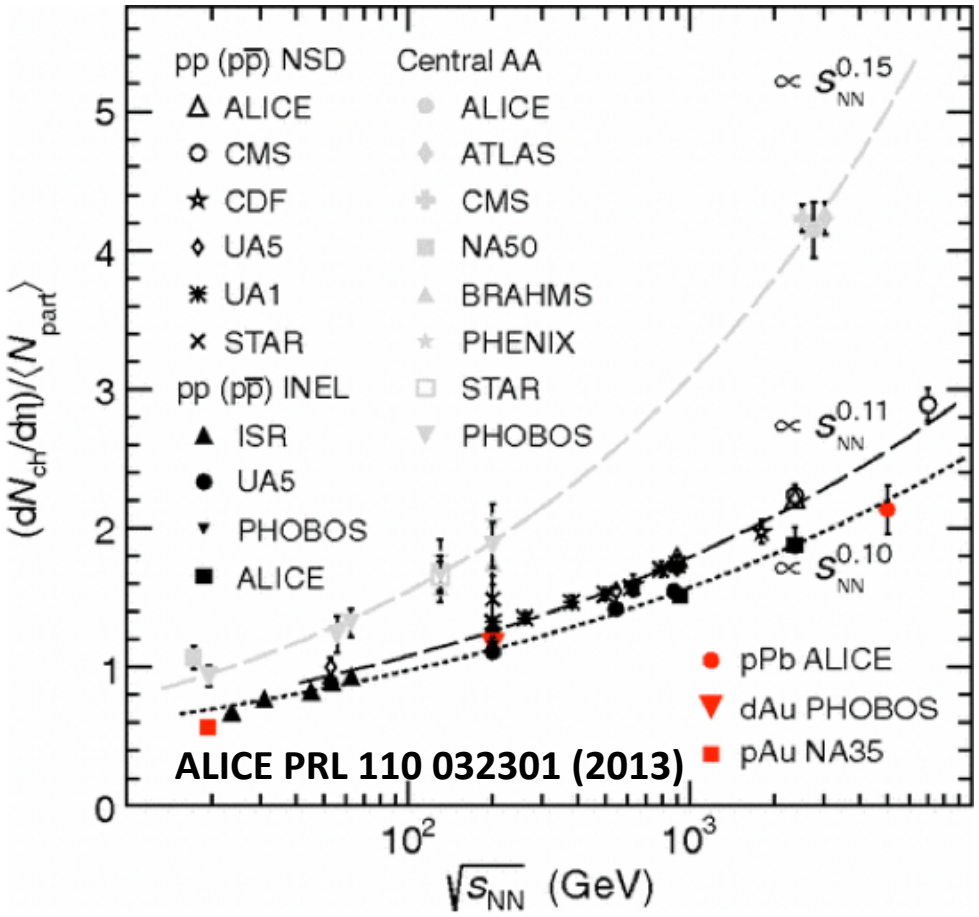
$$d\sigma(Q^2,\sqrt{s})_{pA\to a+X} = \sum_{i,j=q,\bar{q},g} f_i^p(x_1,Q^2) \otimes A f_i^A(x_2,Q^2) \otimes d\hat{\sigma}(Q^2,x_1,x_2)_{i,j\to a+X}$$

J/ ψ *versus* ψ'

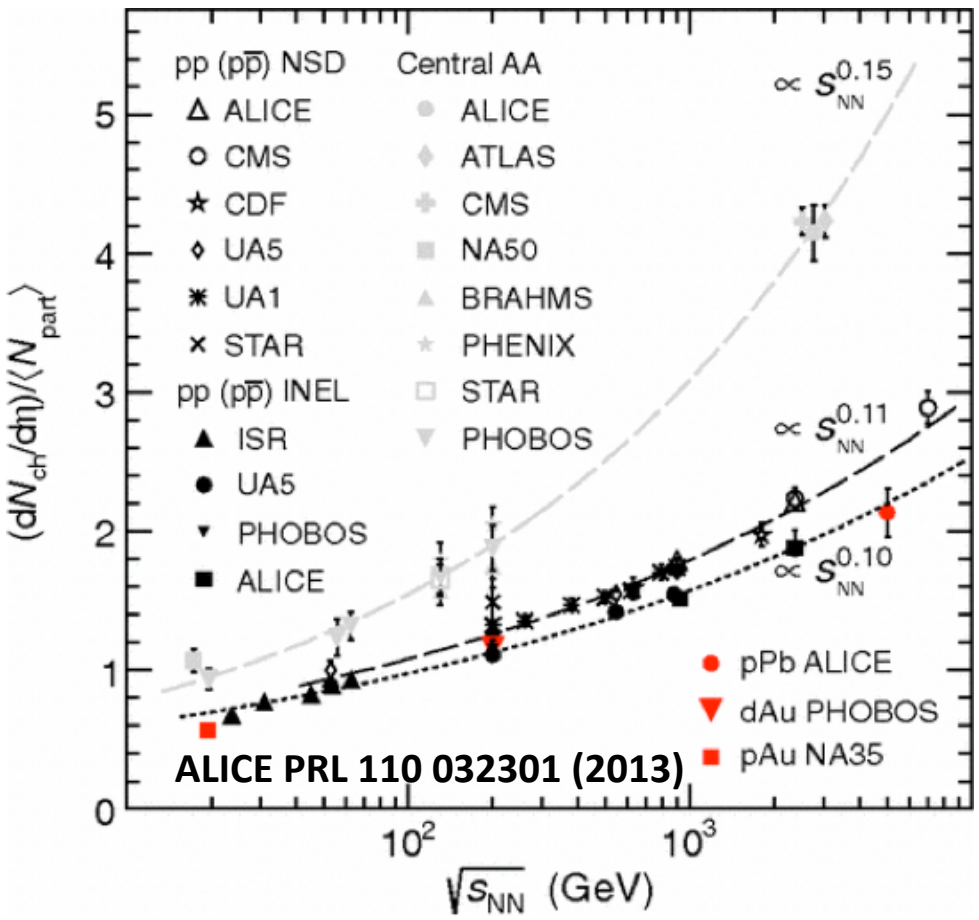
-Underlying $c\bar{c}$ production is identical
-Sample very similar phase space of proton and nucleus PDF
-Energy loss of $c\bar{c}$ identical inside nucleus
-At LHC energies, $c\bar{c}$ pairs project onto final state outside the nucleus

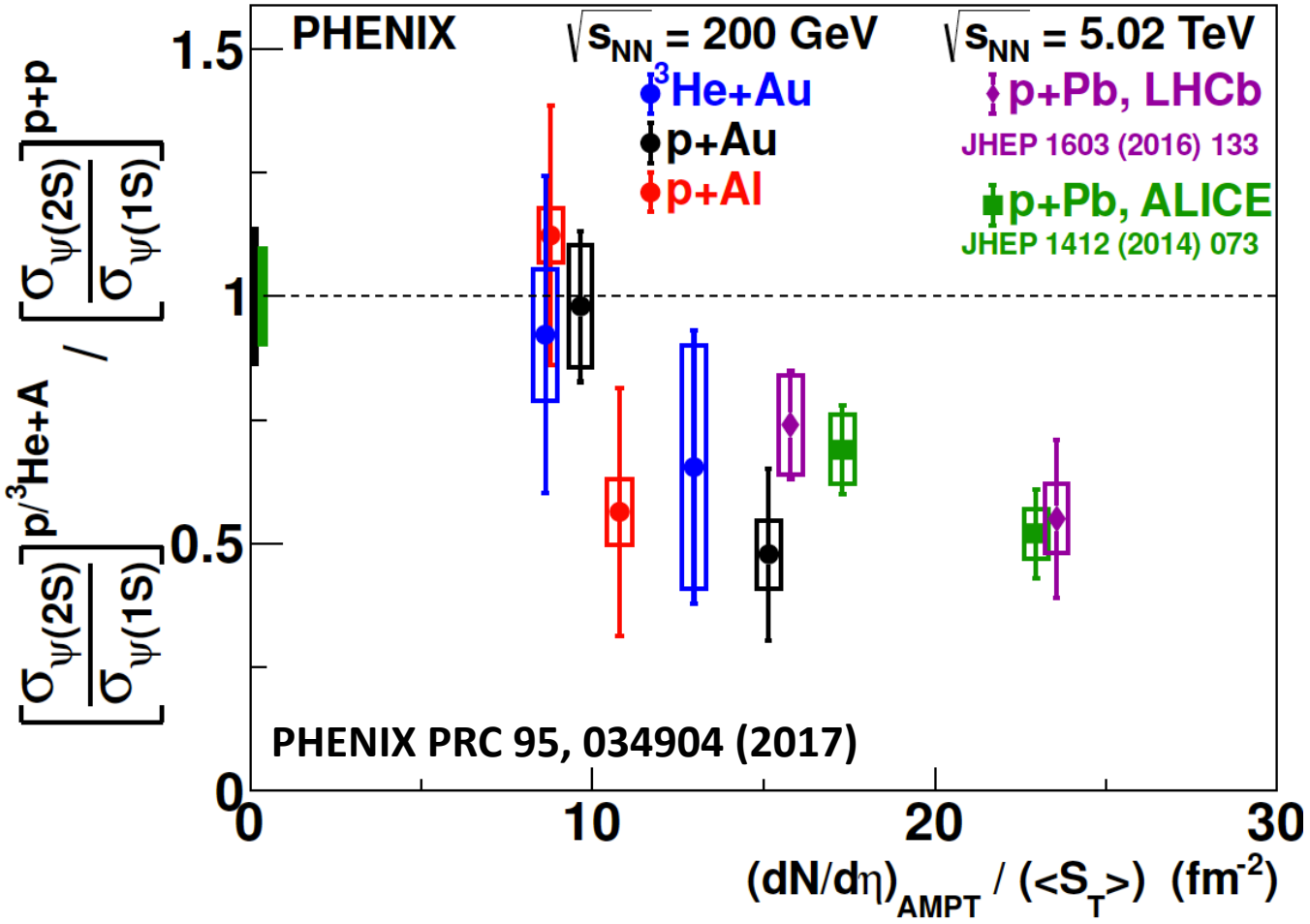
Suggests late stage effects that occur outside the nucleus are responsible for differences
->Plasma stage in pPb?
Du, Rapp Nucl. Phys. A 943 (2015)
->Interactions with co-moving particles?
Capella et al, PLB 393 (1997), Ferreiro, PLB 749 (2015), Ma et al 1707.07266

ψ' suppression via "comovers"



ψ' suppression via "comovers"





$$< S_T >= 4\pi\sqrt{< x^2 >< y^2 > - < xy >^2}$$

Comparison of open/hidden charm

$$d\sigma(Q^2,\sqrt{s})_{pA\to a+X} = \sum_{i,j=q,\bar{q},g} f_i^p(x_1,Q^2)\otimes Af_i^A(x_2,Q^2)\otimes d\hat{\sigma}(Q^2,x_1,x_2)_{i,}$$

Charmonia versus Open Charm

-Underlying $c\bar{c}$ production is similar

-Sample very similar phase space of proton and nucleus PDF

-Energy loss of $c\bar{c}$ identical inside nucleus

-At LHC energies, $c\bar{c}$ pairs project onto final state outside the nucleus

Qualitative interpretation:

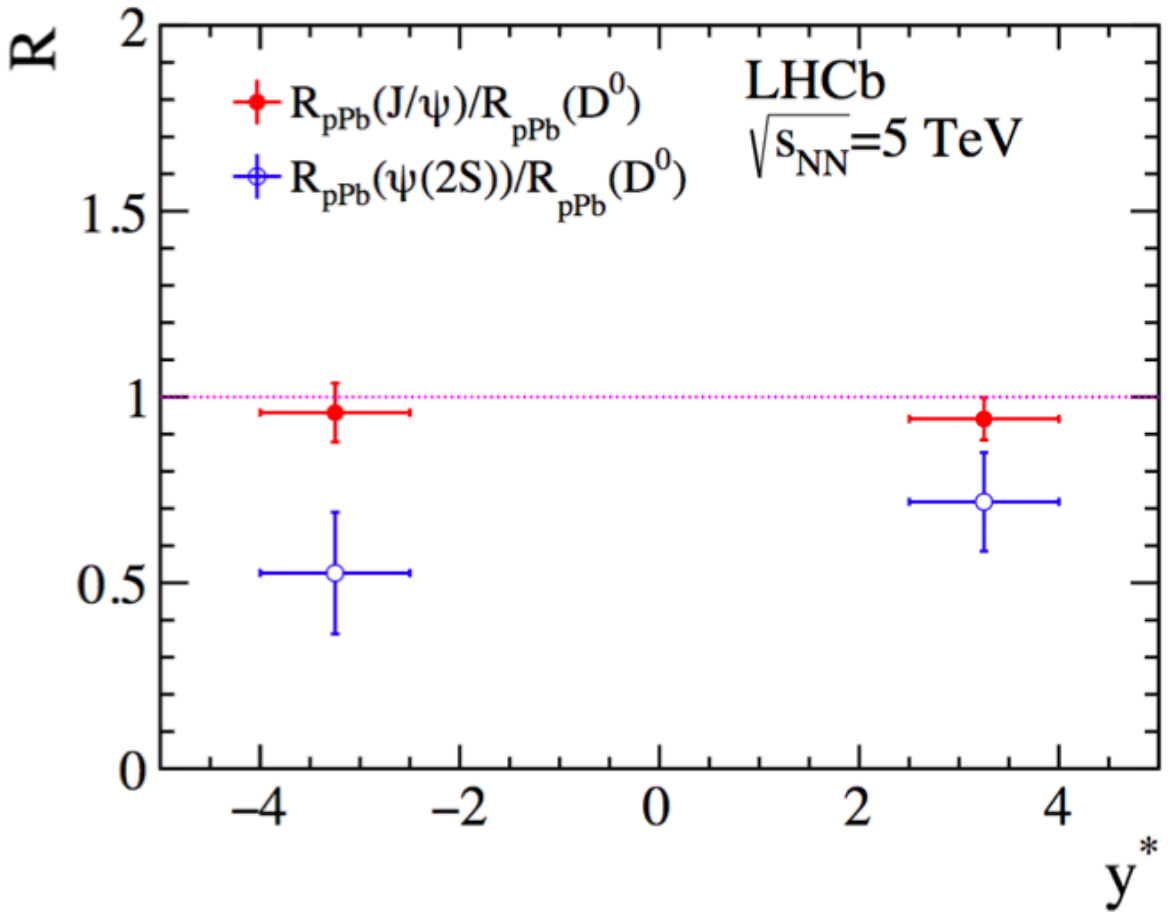
-Breakup of J/ψ seems relatively small

-Breakup of ψ' seems significant

state	η_c	J/ψ	χ_{c0}	χ_{c1}	χ_{c2}	ψ'
mass [GeV]	2.98	3.10	3.42	3.51	3.56	3.69
ΔE [GeV]	0.75	0.64	0.32	0.22	0.18	0.05

Satz, J. Phys. G32, R25 (2006)

J. High Energ. Phys. 10 (2017) 90

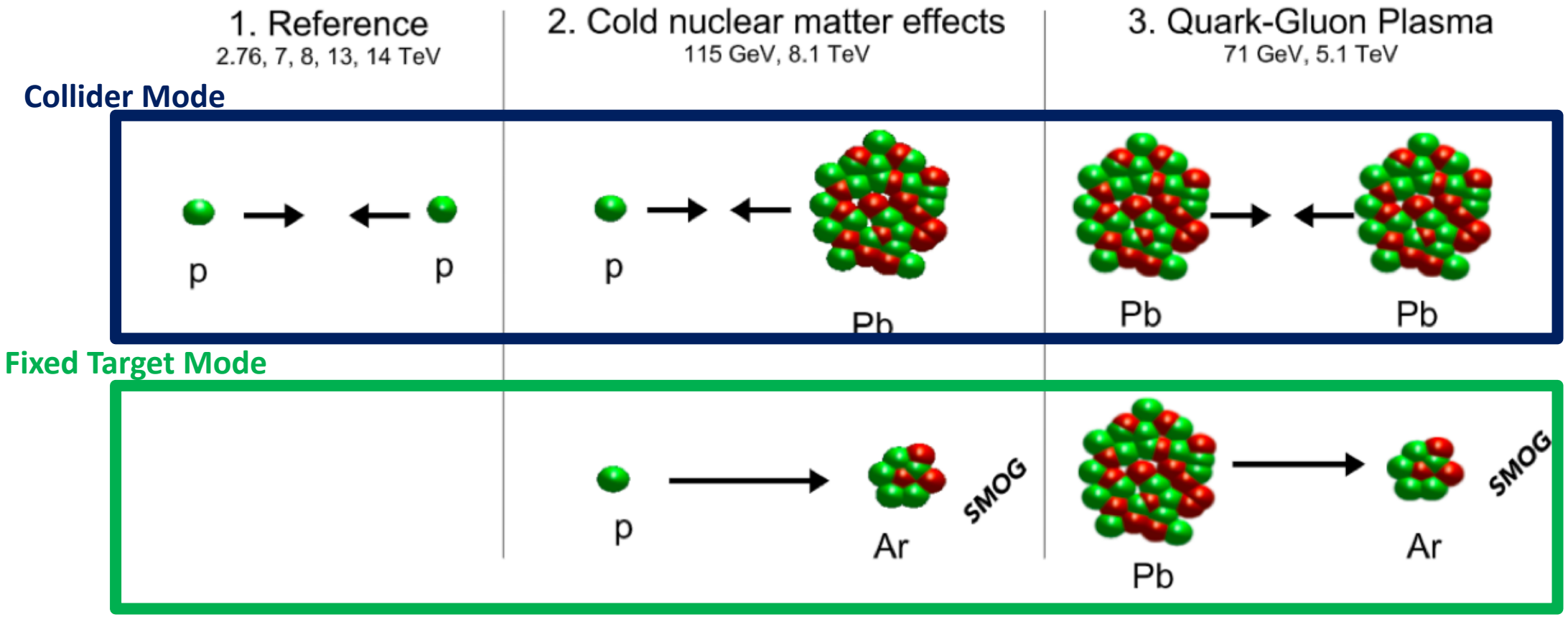


LHCb has 40x (10x) more data on tape for backward (forward) *p*Pb at 8 TeV, analysis ongoing.

Outline

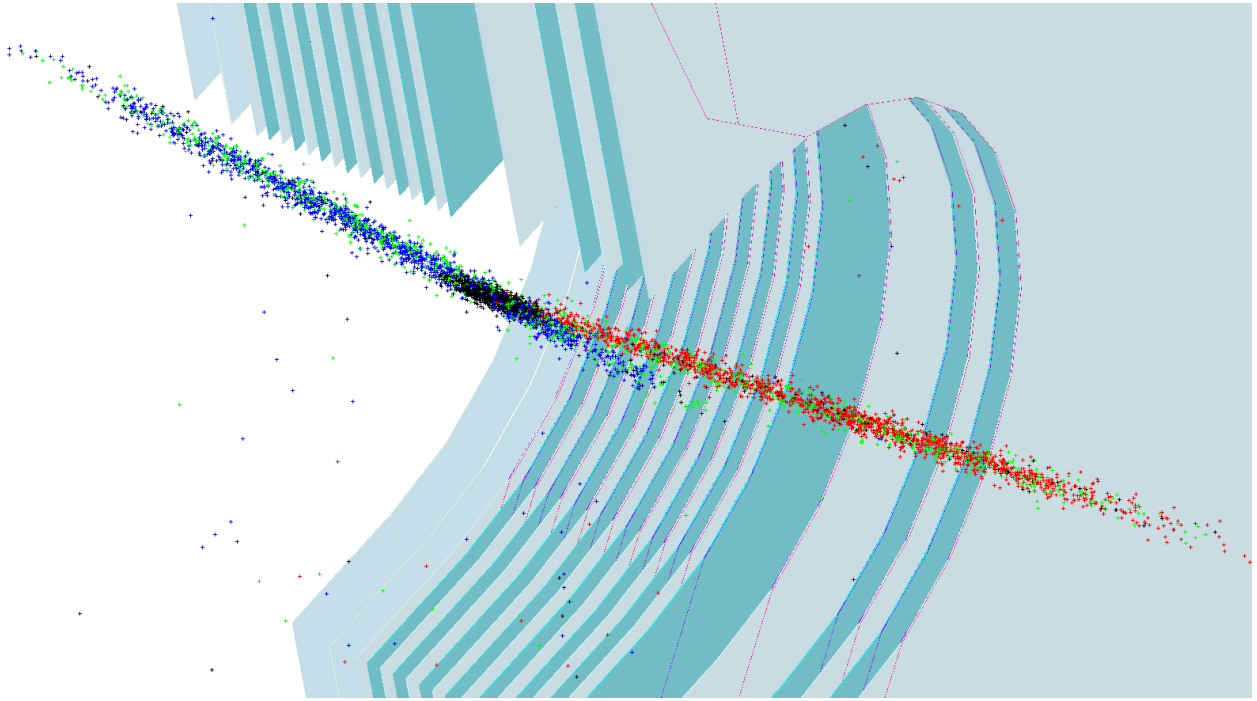
- Studying the nuclear initial state
- **The LHCb Detector – a unique facility for forward physics in heavy ion collisions**
- **Open charm measurements in *p*Pb: D^0 mesons**
- **Charmonia measurements in *p*Pb: J/ψ, ψ'**
- **A unique capability - fixed target running**
- Summary

Fixed target configuration - SMOG

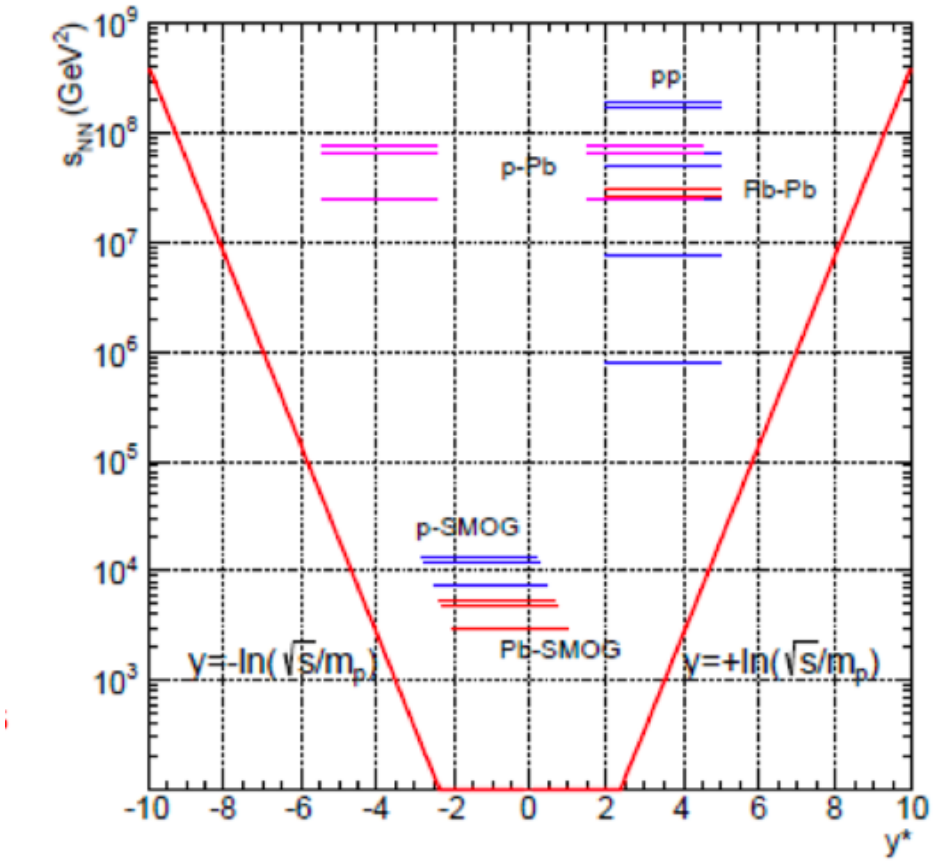


Fixed target configuration - SMOG

A unique capability at LHCb: inject noble gas into beampipe
P ~10^{-7} mbar



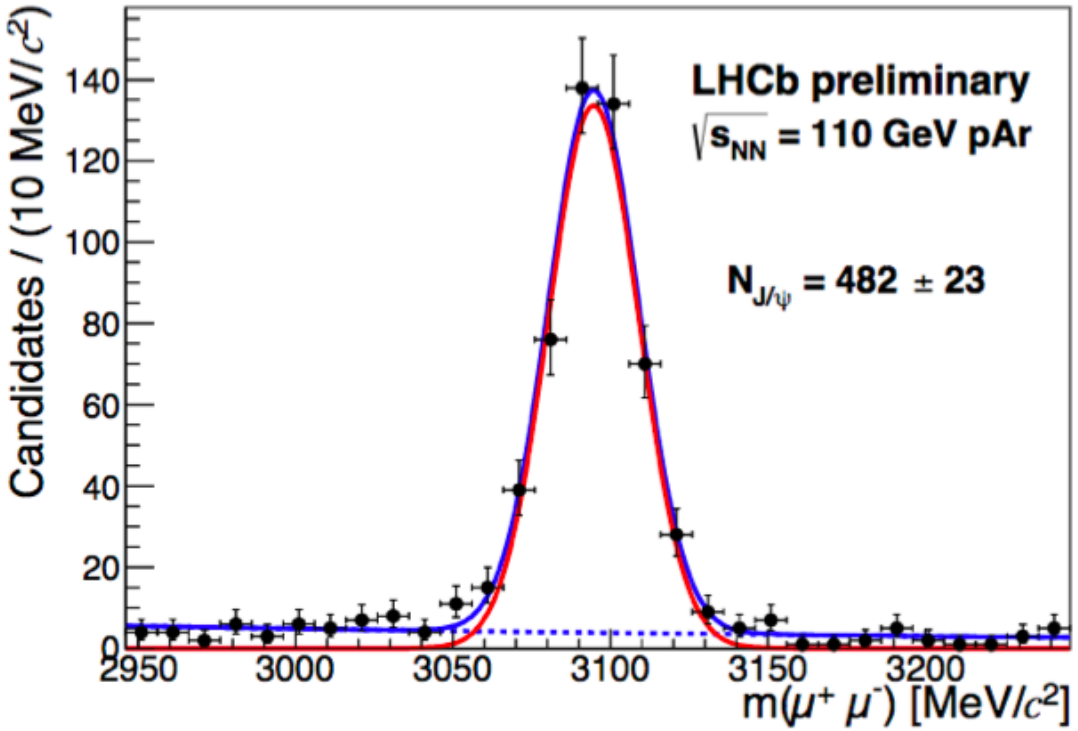
Reconstructed beam-gas vertices inside VELO

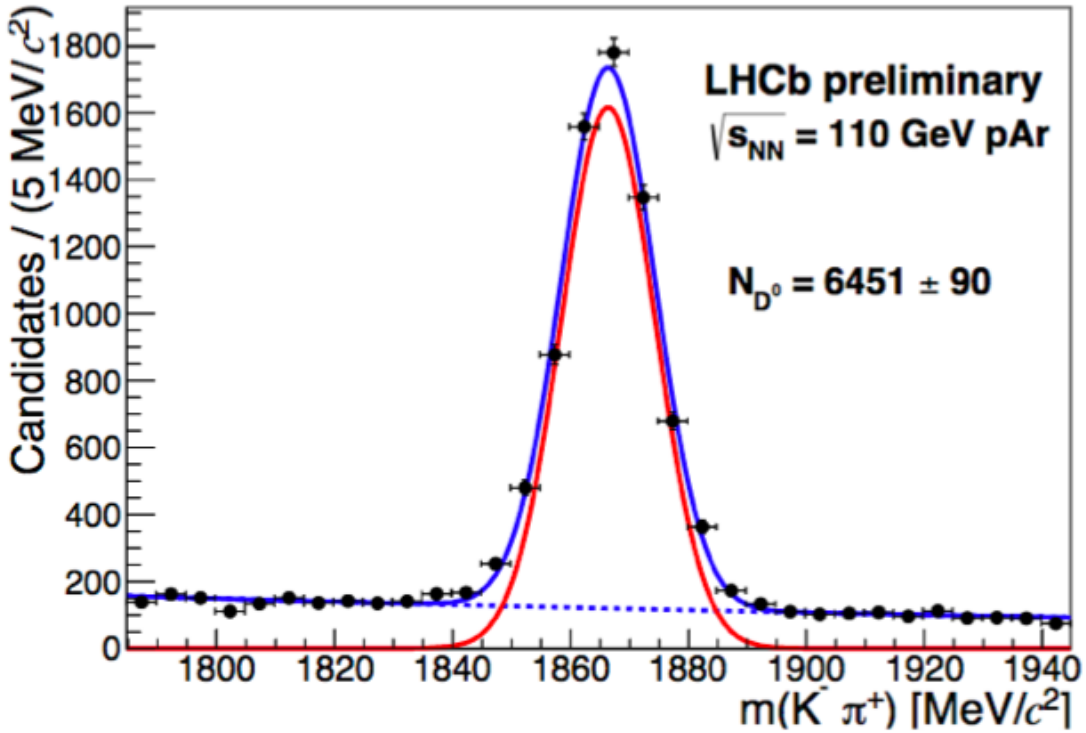


CM energy ~ 100 GeV/n

Fixed target configuration - SMOG

LHCB-CONF-2017-001
https://cds.cern.ch/record/2255650?ln=en



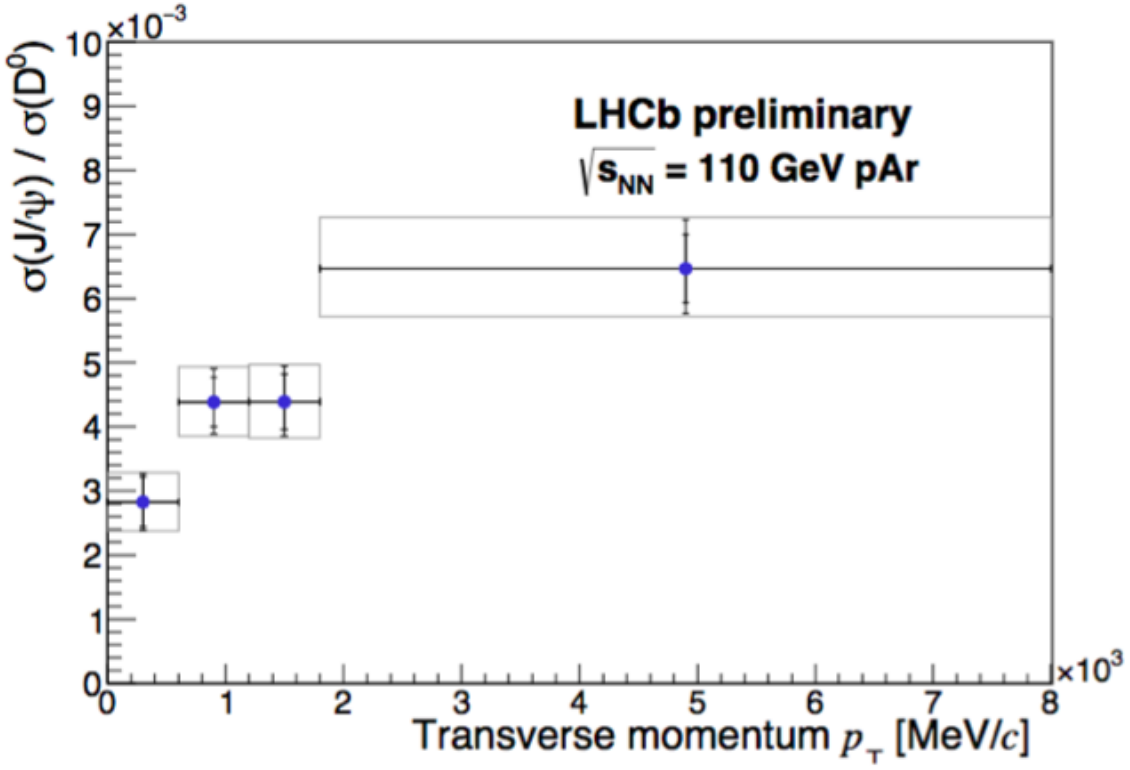


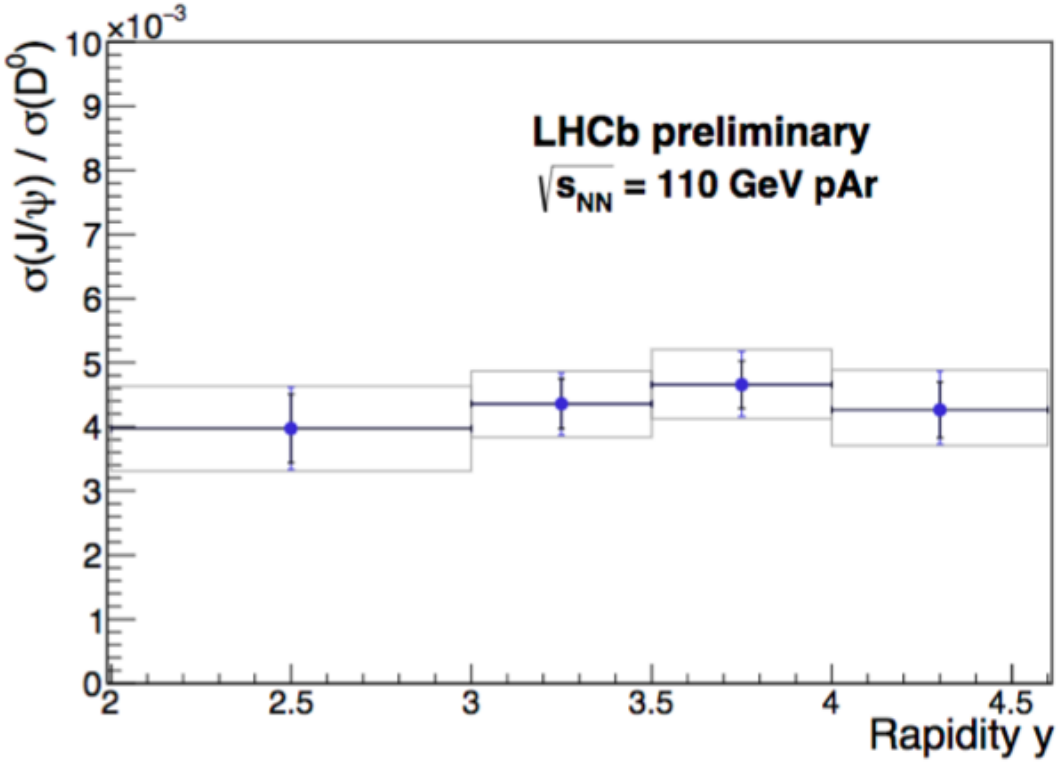
Data recorded in ~18 hours

Fixed target configuration - SMOG

Charmonia versus Open Charm
at very different x-range than collider mode

LHCB-CONF-2017-001
https://cds.cern.ch/record/2255650?ln=en





Summary

- **The LHCb Detector – a unique facility for forward physics in heavy ion collisions**
- **Impactful measurements – already being used in newest nPDF analyses**
- **Late stage effects on quarkonia (especially excited states) likely important**
- **We have only scratched the surface of LHCb capability in heavy ion physics**

BACKUPS

5 Tev vs 8 TeV comparison