Recent LHCb results on charmonia in the QCD medium

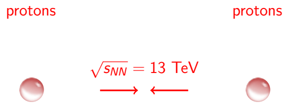
19^{th} International Conference on Hadron Spectroscopy and Structure
in memoriam Simon Eidelman

Albert Frithjof Bursche
on behalf of the LHCb collaboration

South China Normal University

30^{th} July 2021

available data sets



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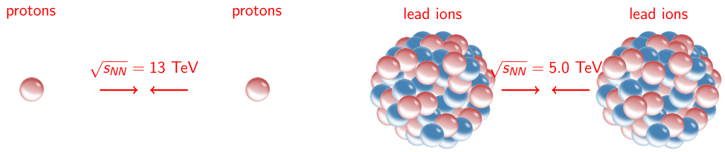

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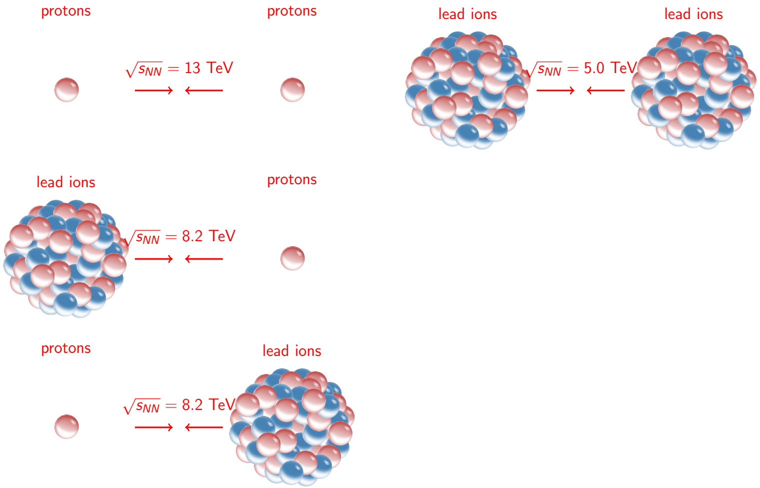

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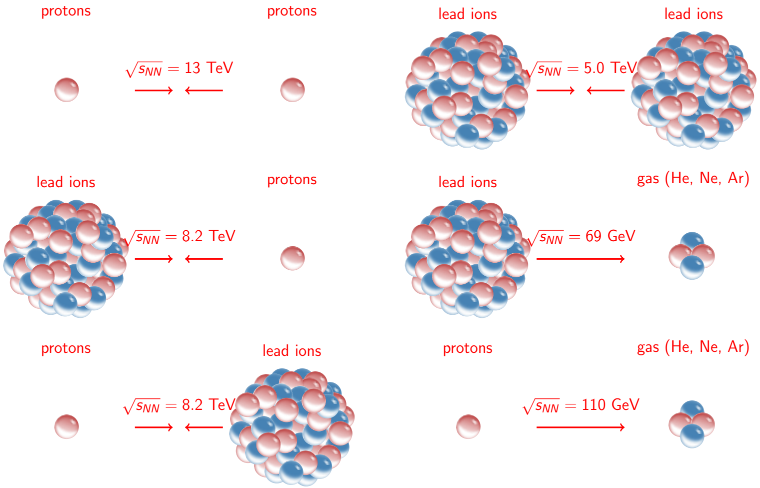
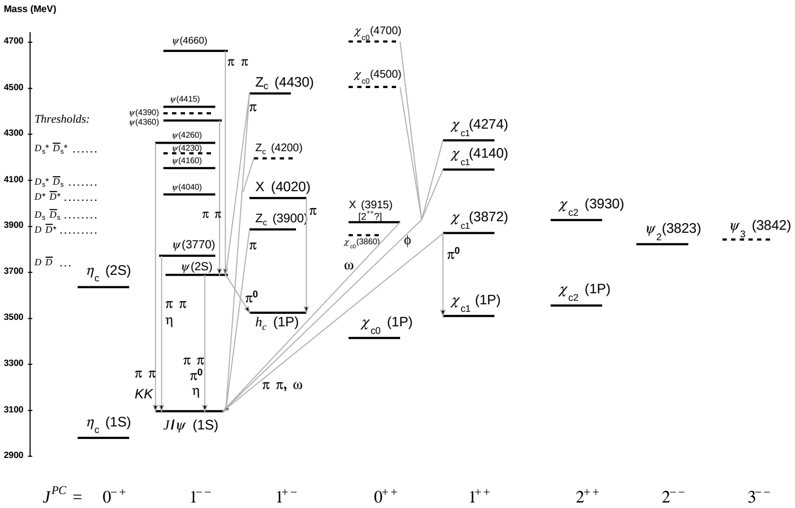


charmonia


Mass (MeV)
4700
4500
4300
4100
3900
3700
3500
3300
3100
2900
Thresholds:
Ds* D̄s* ……
Ds* D̄s ……
D* D̄* ……
Ds D̄s ……
D D̄* ……
D D̄ …
ψ(4660)
ψ(4415)
ψ(4390)
ψ(4360)
ψ(4260)
ψ(4230)
ψ(4160)
ψ(4040)
ψ(3770)
ψ(2S)
J/ψ (1S)
ηc (2S)
ηc (1S)
Zc (4430)
Zc (4200)
X (4020)
Zc (3900)
hc (1P)
χc0(4700)
χc0(4500)
X (3915) [2++?]
χc0(3860)
χc0 (1P)
χc1(4274)
χc1(4140)
χc1(3872)
χc1 (1P)
χc2 (3930)
χc2 (1P)
ψ2(3823)
ψ3 (3842)
π π
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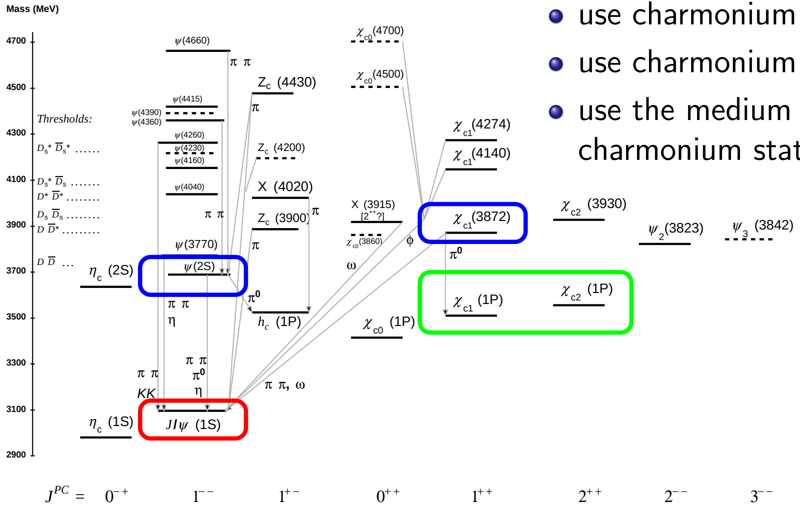
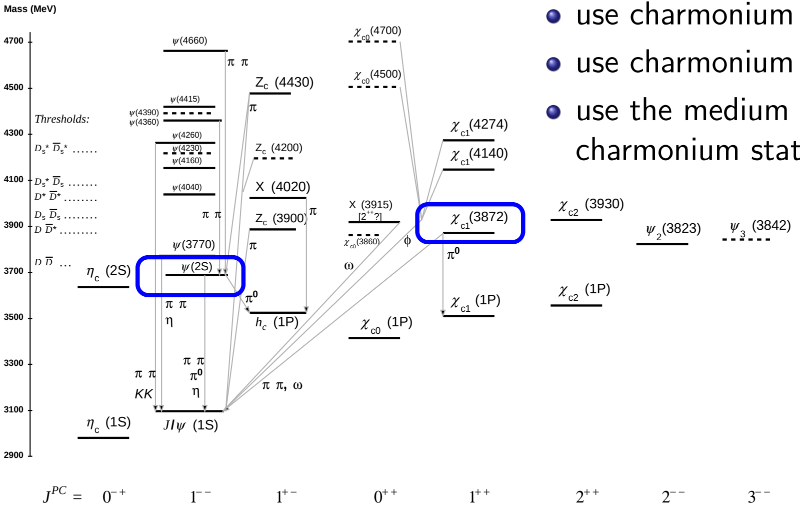
ω
φ
η
KK
π π, ω
JPC = 0−+ 1−− 1+− 0++ 1++ 2++ 2−− 3−−

charmonia



- use charmonium to probe the medium
- use charmonium to probe initial state
- use the medium to learn about the charmonium state itself

charmonia



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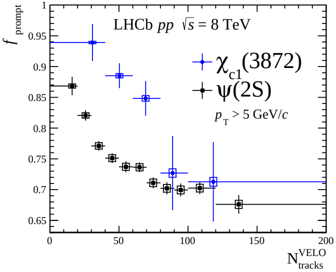
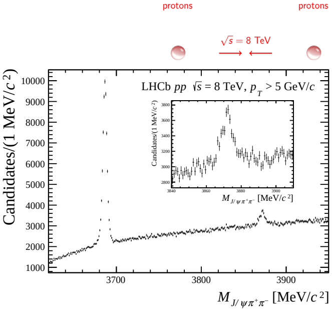
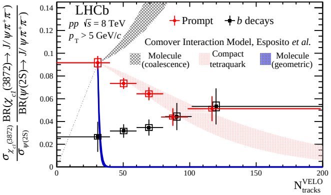
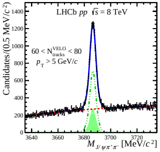
multiplicity-dependent χ_{c1} (3872) and $\psi(2S)$ production

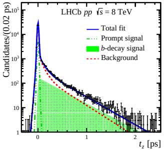
- χ_{c1} (3872) $\rightarrow J/\psi\,\pi^+\pi^-$
- $\psi(2S) \rightarrow J/\psi\,\pi^+\pi^-$
- corrected for b-feed-down
- differential in $n_{\text{VeLo tracks}}$
- χ_{c1} (3872) fraction lower at high multiplicity







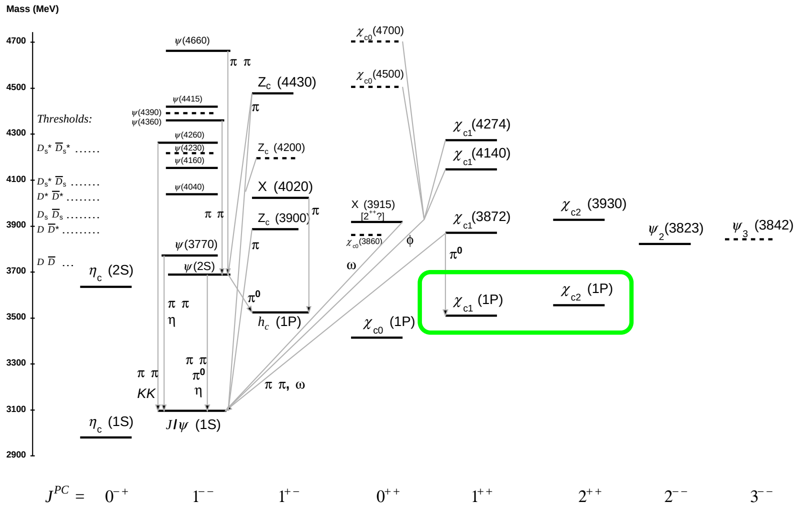




Theoretical interpretation from: Esposito et al arχiv:2006.15044

$\sqrt{s} = 8$ TeV *Phys. Rev. Lett. 126 (2021) 092001*

charmonia



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Thresholds:
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η_c (2S)
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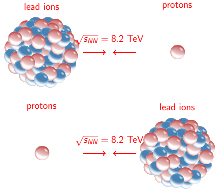
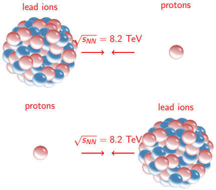
π π
π
π
π π
π
π π
η
π π
KK
π π
π^0
η
π^0
ω
ϕ
π^0
π π, ω
J^{PC} = 0^{-+} 1^{--} 1^{+-} 0^{++} 1^{++} 2^{++} 2^{--} 3^{--}

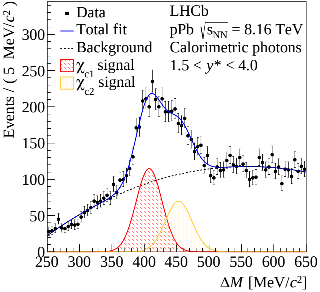


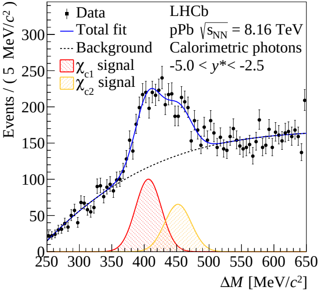
lead ions
protons
$\sqrt{s_{NN}}$ = 8.2 TeV
protons
lead ions
$\sqrt{s_{NN}}$ = 8.2 TeV

prompt production ratio $\sigma_{\chi_{c1}}/\sigma_{\chi_{c2}}$ in proton lead collisions



- $\chi_{c1}, \chi_{c2} \rightarrow J/\psi\ \gamma$
- promptly produced
- calorimetric photons and converted photons
- nuclear effects affect χ_{c1} and χ_{c2} in a similar magnitude





$\sqrt{s_{NN}} = 8.2$ TeV *Phys. Rev. C103 (2021) 064905 and JHEP 10 (2013) 115*

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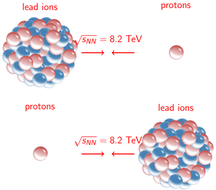

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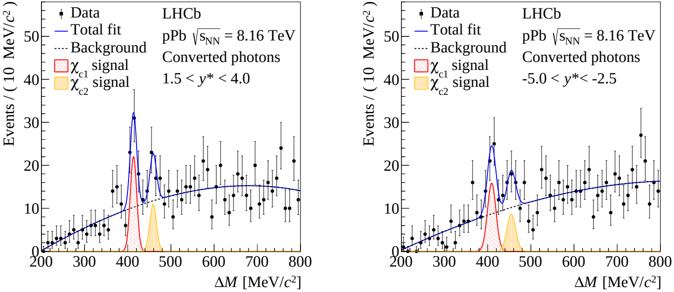

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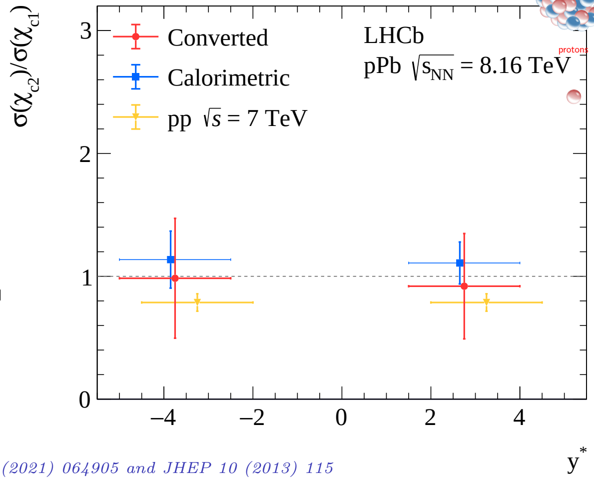

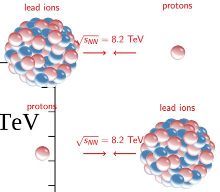

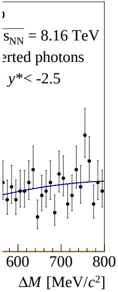

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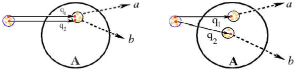
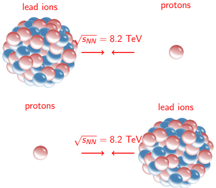
double charm production in proton lead collisions



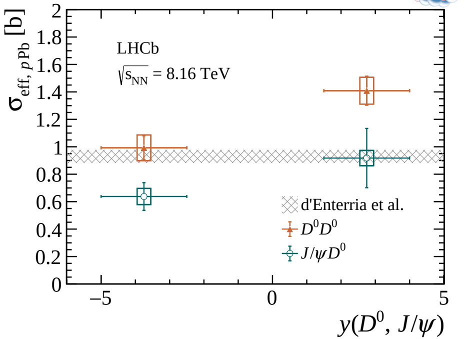


- select pairs of D^0, $\overline{D}^0$, D^+, D^-, D_s^+, D_s^- and J/ψ
- sort them into pair production and "DPS" categories

$$\sigma_{C_1,C_2} = \alpha \frac{\sigma_{C_1}\sigma_{C_2}}{\sigma_{\text{eff}}}$$

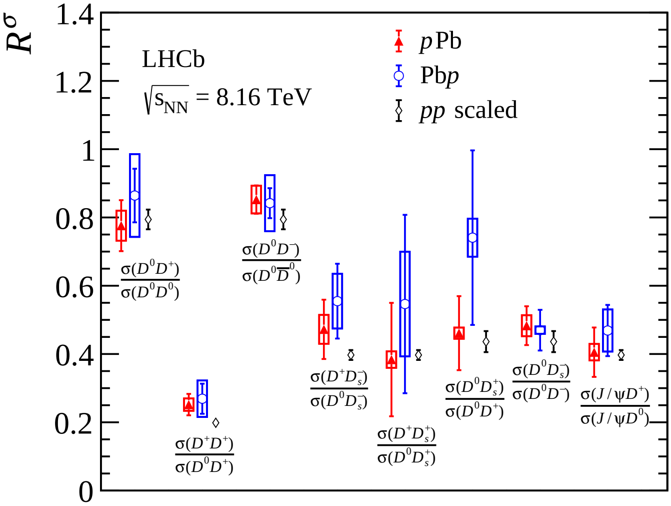
	$D^0 D^0$	$D^0 J/\psi$
pPb	$0.99 \pm 0.09 \pm 0.09$	$0.64 \pm 0.10 \pm 0.06$
Pbp	$1.4 \pm 0.11 \pm 0.14$	$0.92 \pm 0.22 \pm 0.06$
$pp_{\text{ex.pol.}}$	4.4 ± 0.5	3.1 ± 0.3

(all numbers in barn)



$\sqrt{s_{NN}} = 8.2$ TeV *Phys. Rev. Lett. 125 (2020) 212001*

- build the double production cross section ratios
- keep one state identical in nominator and denominator
- fragmentation similar to proton collisions

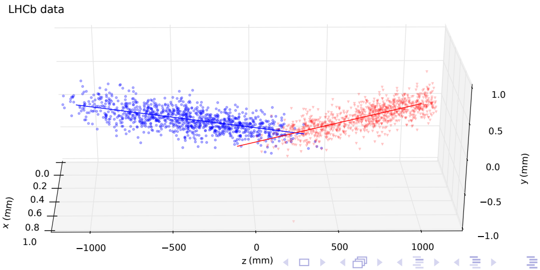


$\sqrt{s_{NN}} = 8.2$ TeV *Phys. Rev. Lett. 125 (2020) 212001*

SMOG System for Measuring Overlap with Gas

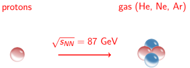
- Built for a Precise Measurement of the Beam Profiles (Luminosity)
- $\sqrt{s_{NN}} = \mathcal{O}(100\text{ GeV})$
- LHCb Acceptance becomes Central or Backward
- Injected Helium, Neon and Argon so far

year	Beam 1	Beam 2	SMOG	$\sqrt{s_{NN}}$	amount
2012	p	p	Ne	87 GeV	$< 1h$
2013	Pb	p	Ne	54 GeV	$< 1h$
2015	p	p	He	110 GeV	$8h$
2015	p	p	Ne	110 GeV	$12h$
2015	p	p	Ar	110 GeV	$3d$
2015	Pb	p	Ar	69 GeV	few hours
2015	p	Pb	Ar	69 GeV	$1.5w$
2016	Pb	p	Ar	110 GeV	$2d$
2017	p	p	He	110 GeV	$10h$
2017	p	p	Ne	110 GeV	$20h$
2017	p	p	He	86.6 GeV	$170h$
2018	Pb	Pb	He	86.6 GeV	$170h$

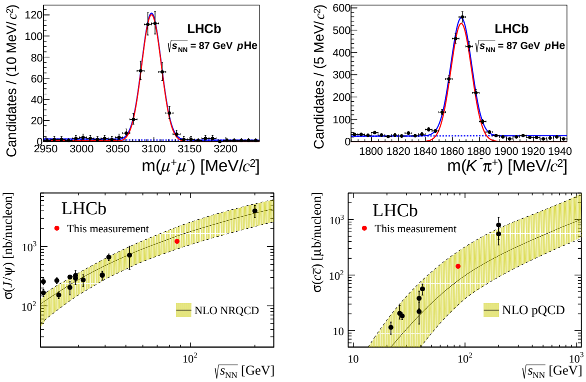


Colin Barschel, CERN-THESIS-2013-301

charm production in proton helium and proton argon



- first charm fixed target measurement at the LHC
- $J/\psi \rightarrow \mu^+\mu^-$, $D^0 \rightarrow K^-\pi^+$
- normalised data available for *p*Ar at 110 GeV
- shape is well described
- normalisation is not



$$\sigma_{J/\psi} = 652 \pm 33(stat) \pm 42(syst) nb/A$$

$$\sigma_{D^0} = 80.8 \pm 2.4(stat) \pm 6.3(syst) \mu b/A$$

$\sqrt{s} = 87$ GeV *Phys. Rev. Lett. 122 (2019) 132002*

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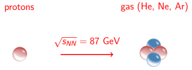

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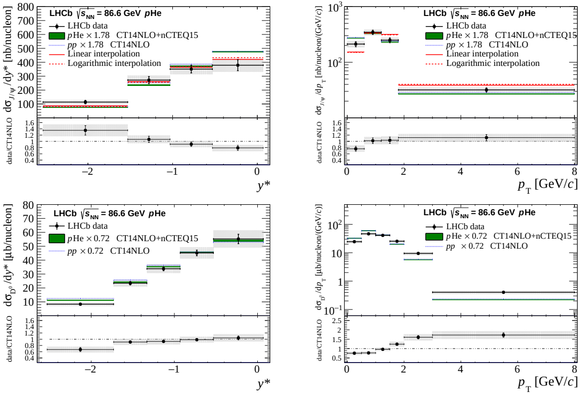
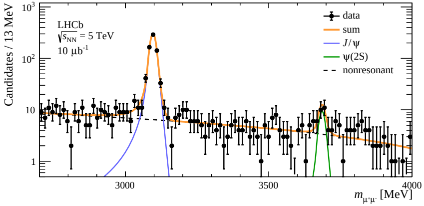


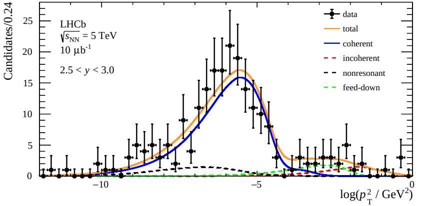
coherent photonuclear J/ψ production in ultra peripheral lead lead collisions

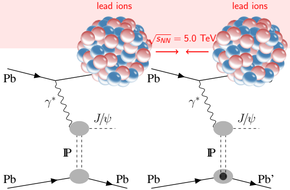
- first LHCb measurement in lead collisions
- $J/\psi \to \mu^+\mu^-$
- no extra tracks
- veto activity in HeRSCHeL
- mass fit for J/ψ yield
- $\log(p_T{}^2)$ for coherent yield

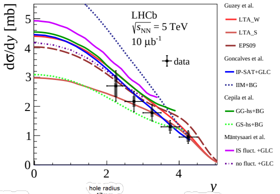
  templates from starlight

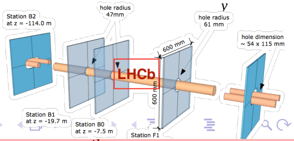
$\sqrt{s_{NN}} = 5$ GeV *arχiv:2107.03223*



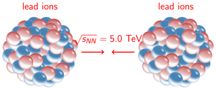




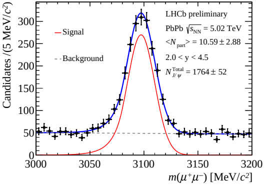


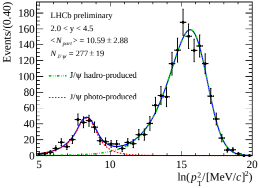


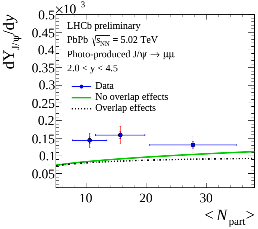
photonuclear J/ψ production peripheral collisions

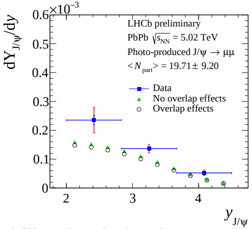


- select peripheral events $< n_{\text{part}} >= 19.7 \pm 9.2$
- similar technique
  photonuclear Double sided Crystal Ball function
  hadronic $\frac{p_T{}^{n_1}}{\left(1+\left(\frac{p_T}{p_0}\right)^{n_2}\right)^{n_3}}$
- normalised to min-bias
- *compared to W. Zha and S. R. Klein et. al Phys. Rev. C 97, 044910*



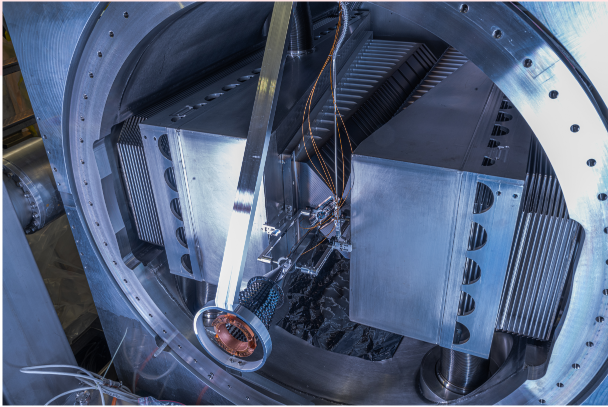






$\sqrt{s_{NN}} = 5$ GeV *LHCb-PAPER-2020-043 in preparation*

LHCb upgrade



- Many interesting upgrades are being installed
- Readout allows for better triggering on hadronic and neutral final states
- New SMOG2 allows for higher gas pressure and better knowledge of this pressure
- Improved granularity will allow tracking in lead lead collisions. The maximal centrality will be pushed from 60% to 30%.
- LHCb will be able to reconstruct oxygen oxygen collisions at full centrality

conclusion

- LHCb can analyse all data LHC can deliver
- Mapping out charmonium production requires large luminosity
- New SMOG2 will increase luminosity and determination thereof
- With the upgraded LHCb detector will be able to reconstruct events at higher centrality of about 60%

Thank you for your attention!