Latest results of open and hidden heavy-flavour production in heavy-ion collisions from LHCb

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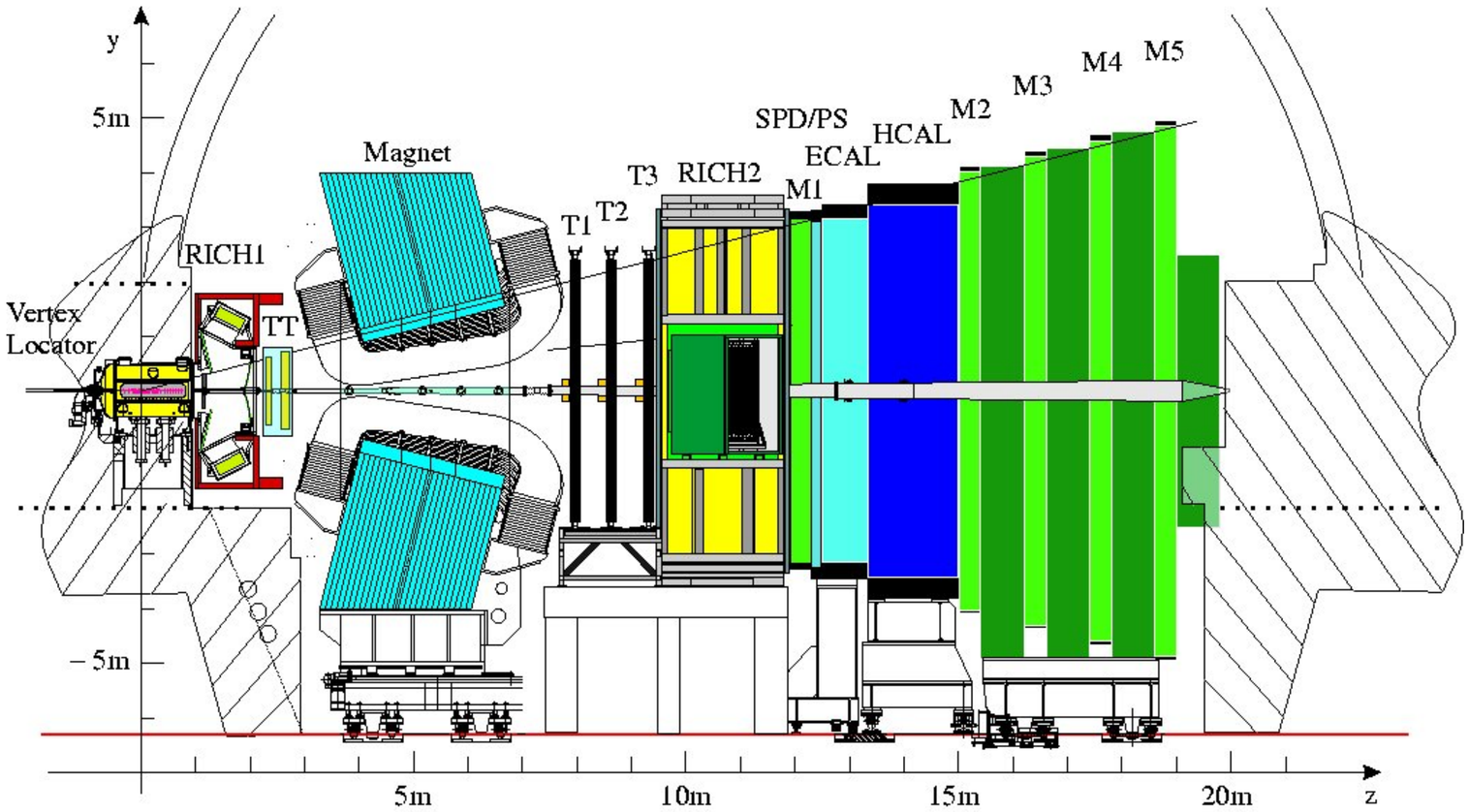
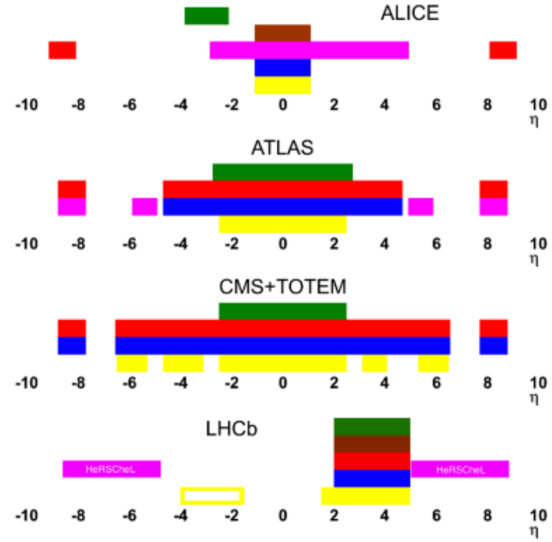
The LHCb detector

The LHCb detector

10.1142/S0217751X15300227

LHCb : **single arm spectrometer fully instrumented** in pseudo-rapidity range $2 < \eta < 5$



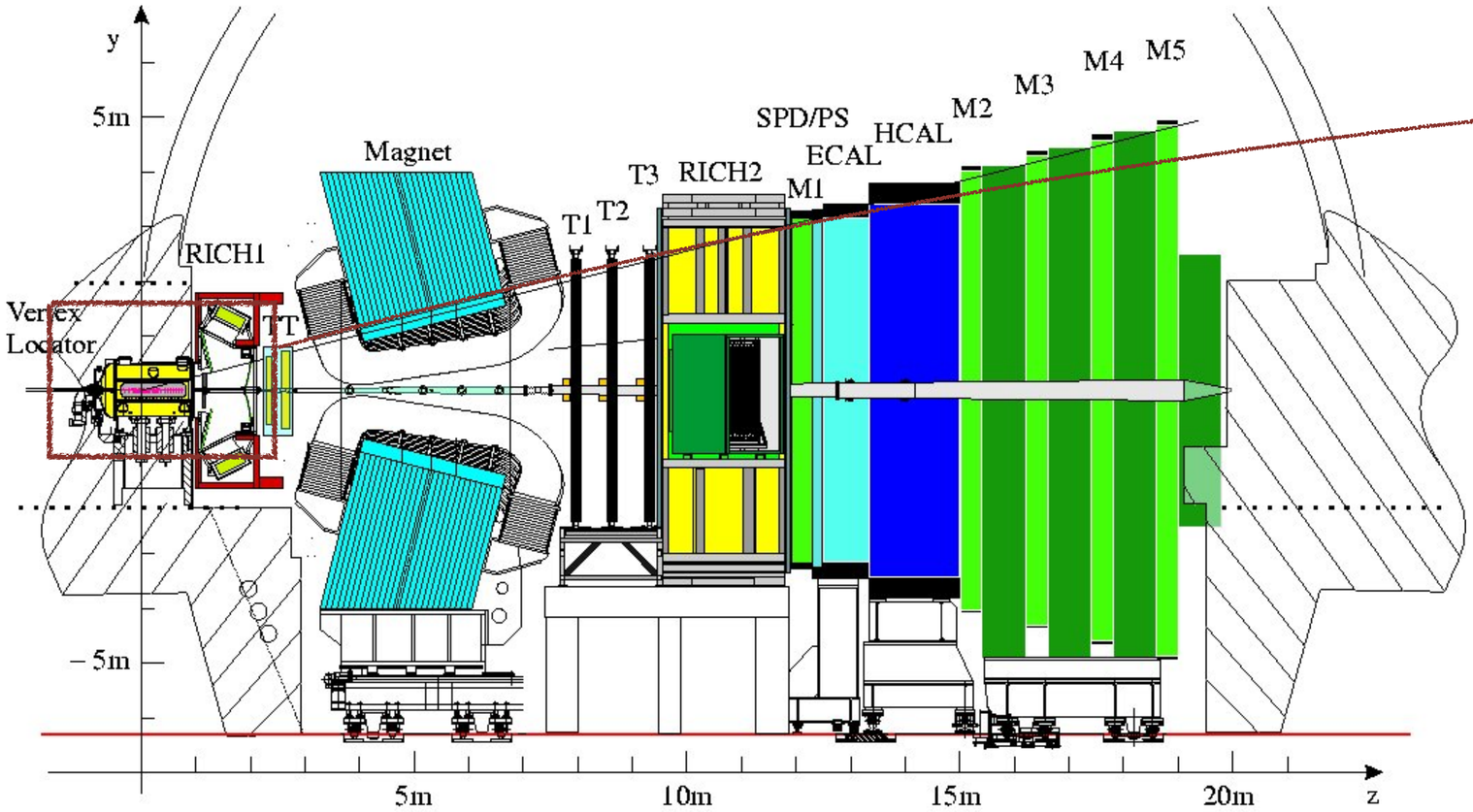


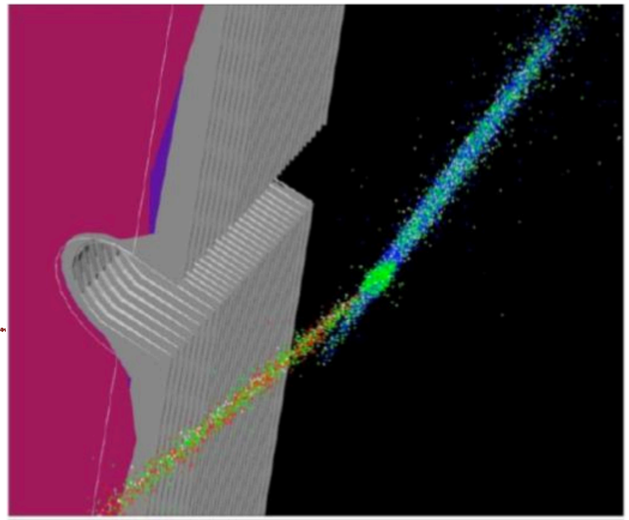
- Track reconstruction **down to $p_T = 0$.**
- Excellent **p_T and mass resolution.**
- Excellent **particle identification.**
- Precision **vertex reconstruction.**

The LHCb detector

10.1142/S0217751X15300227

Can operate both in pp/pPb/PbPb and fixed-target !





Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.

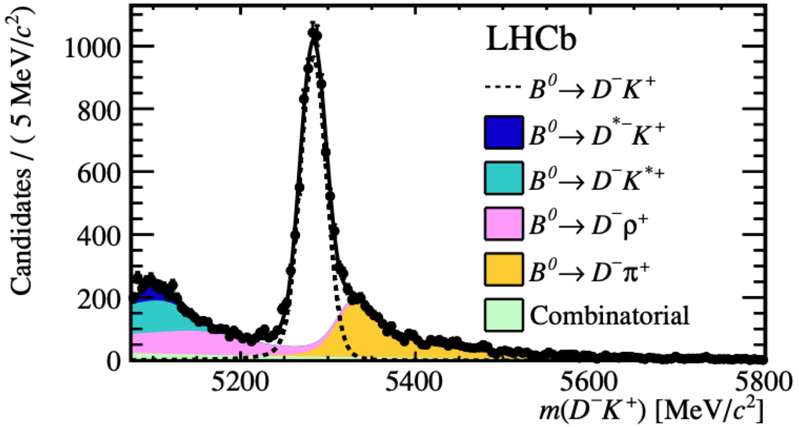
Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

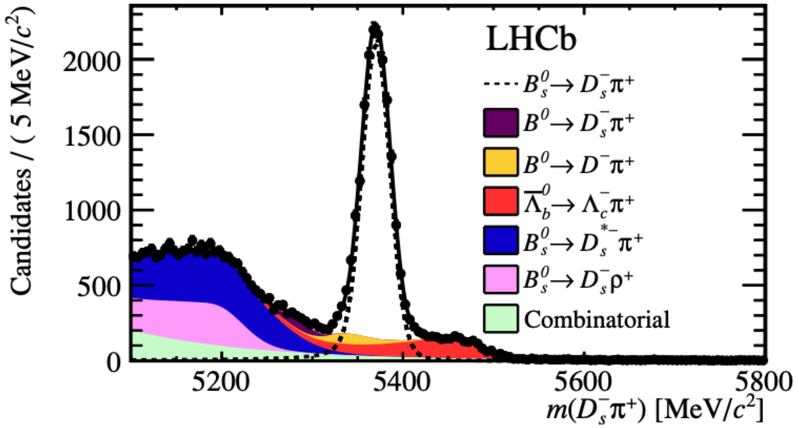
Fixed-target mode: **unique at LHC !**

- Injecting gas in the LHCb VErtex LOcator (VELO) tank.
- **Noble gas only** : He, Ne, Ar
- Gas pressure : 10^{-7} to 10^{-6} mbar

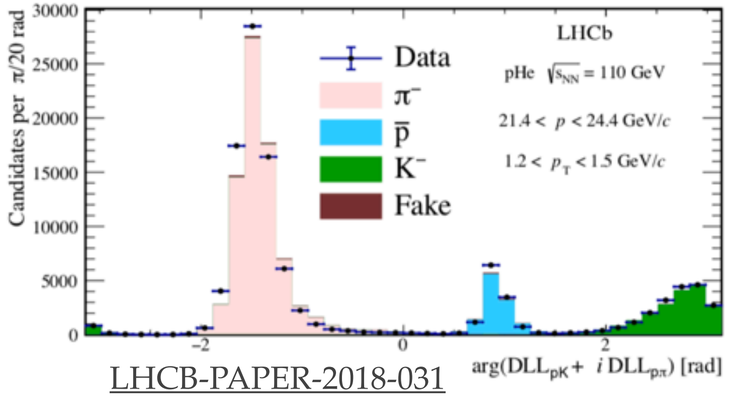
Illustration of LHCb performances

Excellent mass resolution



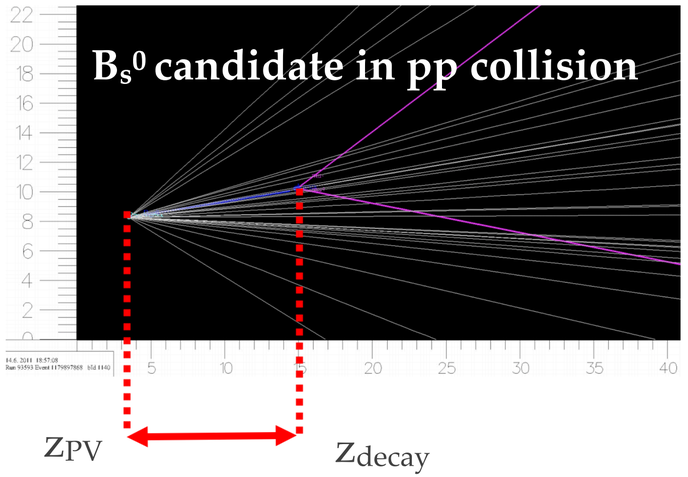


Good particle identification



LHCB-PAPER-2018-031

Excellent vertex reconstruction



- Same feature and performances for all the « small systems » (pp, pPb, p-gas). See later slides for status in PbPb.

List of (some) LHCb results

TITLE	DOCUMENT NUMBER	JOURNAL	SUBMITTED ON	CITED
Measurement of the nuclear modification factor and prompt charged particle production in pPb and pp collisions at $\sqrt{s_{\rm NN}} = 5$TeV	PAPER-2021-015 arXiv:2108.13115 [PDF]	PLB	30 Aug 2021	
Study of J/ψ photo-production in lead-lead peripheral collisions at $\sqrt{s_{NN}} = 5.02$ TeV	PAPER-2020-043 arXiv:2108.02681 [PDF]	PRL	05 Aug 2021	2
Study of coherent J/ψ production in lead-lead collisions at $\sqrt{s_{NN}} = 5$ TeV	PAPER-2021-013 arXiv:2107.03223 [PDF]	JHEP	07 Jul 2021	1
Measurement of prompt-production cross-section ratio $\sigma(\chi_{c2})/\sigma(\chi_{c1})$ in pPb collisions at $\sqrt{s_{NN}}$ = 8.16 TeV	PAPER-2020-048 arXiv:2103.07349 [PDF]	Phys. Rev. C103 (2021) 064905	12 Mar 2021	
Observation of multiplicity-dependent prompt $\chi_{c1}(3872)$ and $\psi(2S)$ production in pp collisions	PAPER-2020-023 arXiv:2009.06619 [PDF]	Phys. Rev. Lett. 126 (2021) 092001	14 Sep 2020	14
Observation of enhanced double parton scattering in proton-lead collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV	PAPER-2020-010 arXiv:2007.06945 [PDF]	Phys. Rev. Lett. 125 (2020) 212001	14 Jul 2020	5
Measurement of B^+, B^0 and Λ_b^0 production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV	PAPER-2018-048 arXiv:1902.05599 [PDF]	Phys. Rev. D99 052011 (2019)	14 Feb 2019	37
First Measurement of Charm Production in its Fixed-Target Configuration at the LHC	PAPER-2018-023 arXiv:1810.07907 [PDF]	Phys. Rev. Lett. 122 (2019) 132002	18 Oct 2018	59
Study of Υ production in pPb collisions at $\sqrt{s_{NN}} = 8.16$ TeV	PAPER-2018-035 arXiv:1810.07655 [PDF]	JHEP 11 (2018) 194	17 Oct 2018	42
Prompt Λ_c^+ production in pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV	PAPER-2018-021 arXiv:1809.01404 [PDF]	JHEP 02 (2019) 102	05 Sep 2018	43
Measurement of antiproton production in pHe collisions at $\sqrt{s_{NN}} = 110$ GeV	PAPER-2018-031 arXiv:1808.06127 [PDF]	Phys. Rev. Lett. 121 (2018) 222001	18 Aug 2018	56
Study of prompt D^0 meson production in pPb collisions at $\sqrt{s}$=5 TeV	PAPER-2017-015 arXiv:1707.02750 [PDF]	JHEP 10 (2017) 090	10 Jul 2017	101
Prompt and nonprompt J/ψ production and nuclear modification in pPb collisions at $\sqrt{s_{\rm NN}} = 8.16$ TeV	PAPER-2017-014 arXiv:1706.07122 [PDF]	Phys. Lett. B774 (2017) 159	21 Jun 2017	82
Study of $\psi(2S)$ production and cold nuclear matter effects in pPb collisions at $\sqrt{s_{NN}} = 5$ TeV	PAPER-2015-058 arXiv:1601.07878 [PDF]	JHEP 03 (2016) 133	28 Jan 2016	59
Measurements of long-range near-side angular correlations in $\sqrt{s_{\rm NN}} = 5$TeV proton-lead collisions in the forward region	PAPER-2015-040 arXiv:1512.00439 [PDF]	Phys. Lett. B762 (2016) 473	01 Dec 2015	90
Observation of Z production in proton-lead collisions at LHCb	PAPER-2014-022 arXiv:1406.2885 [PDF]	JHEP 09 (2014) 030	11 Jun 2014	61
Study of Υ production and cold nuclear matter effects in pPb collisions at $\sqrt{s_{NN}} = 5$TeV	PAPER-2014-015 arXiv:1405.5152 [PDF]	JHEP 07 (2014) 094	20 May 2014	88
Study of J/ψ production and cold nuclear matter effects in pPb collisions at $\sqrt{s_{NN}}$ = 5 TeV	PAPER-2013-052 arXiv:1308.6729 [PDF]	JHEP 02 (2014) 72	30 Aug 2013	191

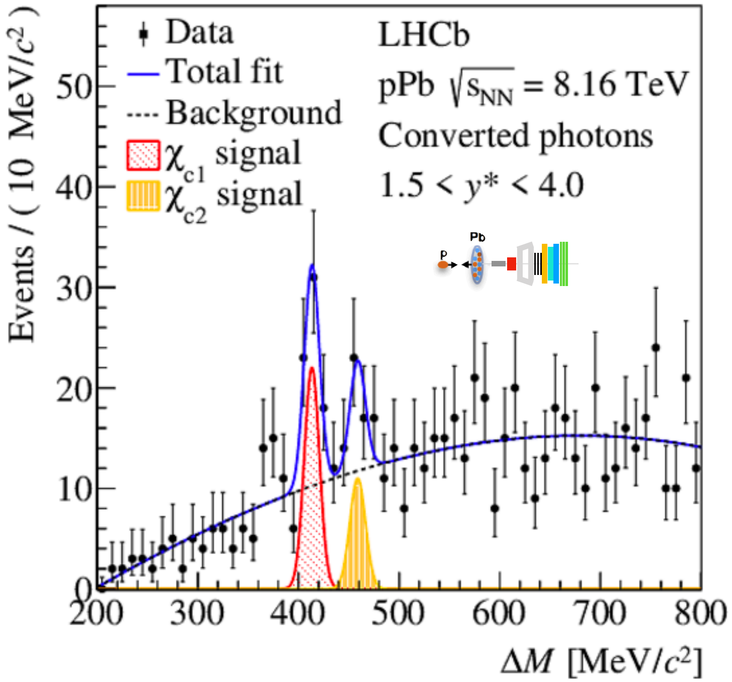
[All results can be found at the LHCb Public results]

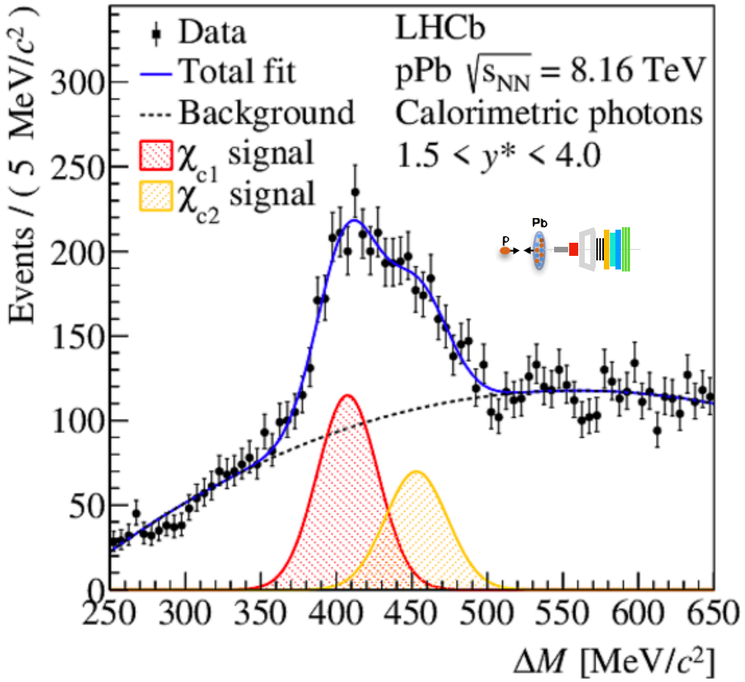
Selected results in pPb collisions

χ_{c2}/χ_{c1} production in pPb

Phys. Rev. C 103, 064905

- χ_c is a charmonium -> same physics motivation as for others $c\bar{c}$ states.
- In addition, feed-down from χ_c represents ~30% of the prompt J/ψ production.
- Experimentally, χ_c measurement is challenging ($\chi_c \to J/\psi(\to \mu^+\mu^-) + \gamma$)

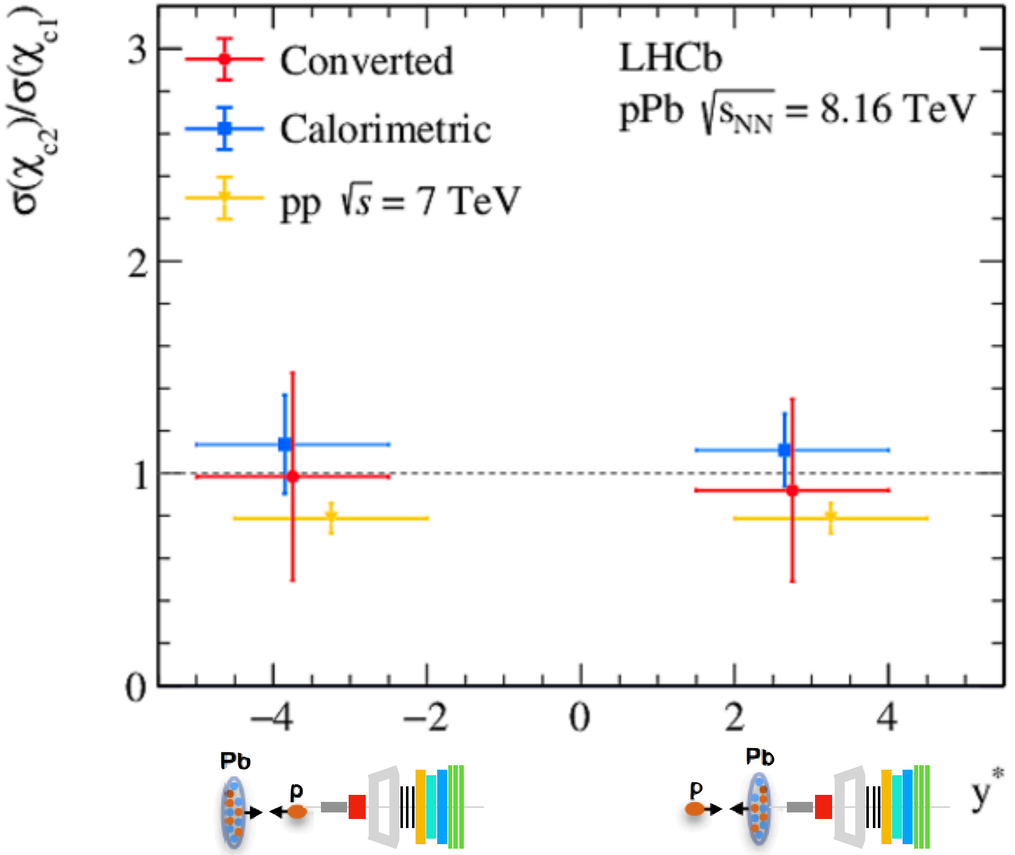




χ_{c2}/χ_{c1} production in pPb

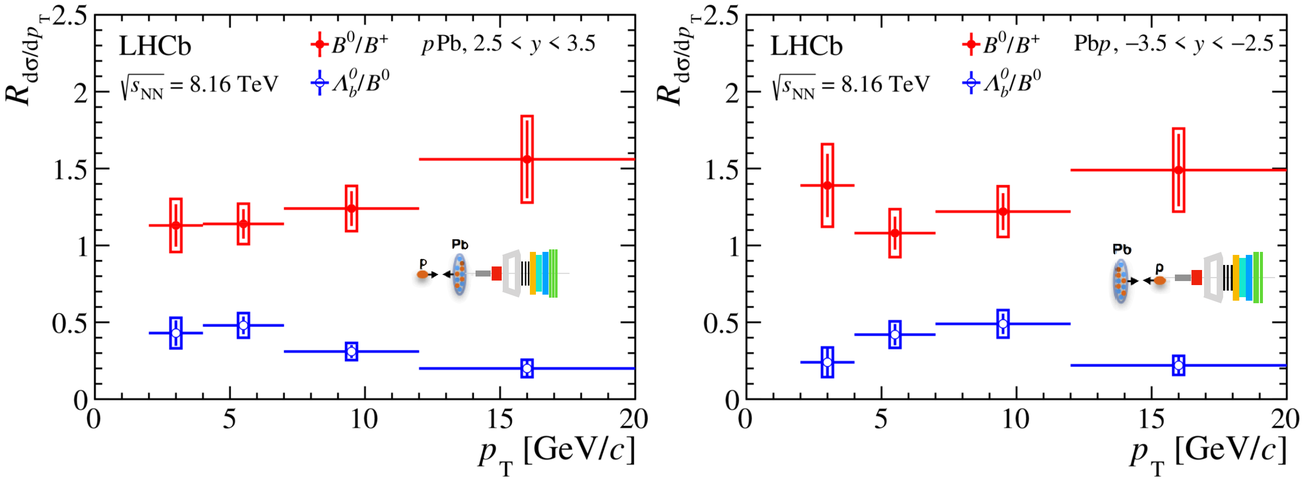
Phys. Rev. C 103, 064905

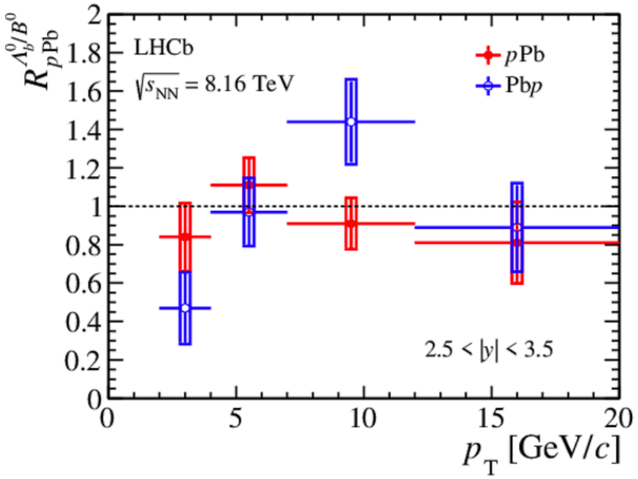
- **First χ_c measurements in heavy-ion data at the LHC.**
- χ_{c2}/χ_{c1} compatible with unity both in pPb and Pbp collisions with large statistical uncertainties.
- pPb results compatible with pp@7TeV results.

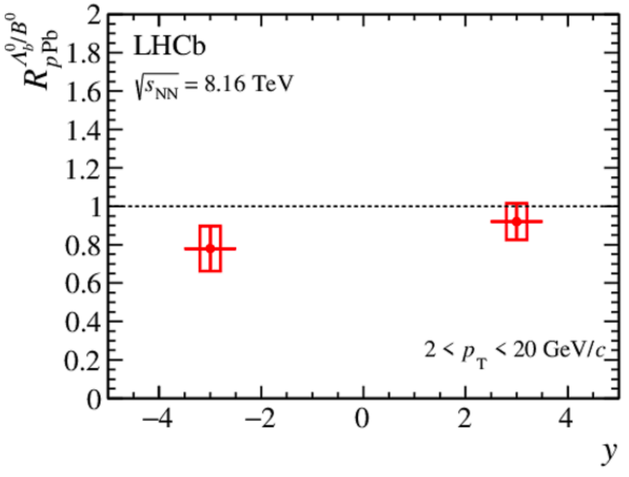


Baryon-to-meson ratio in pPb collisions

Phys. Rev. D 99, 052011



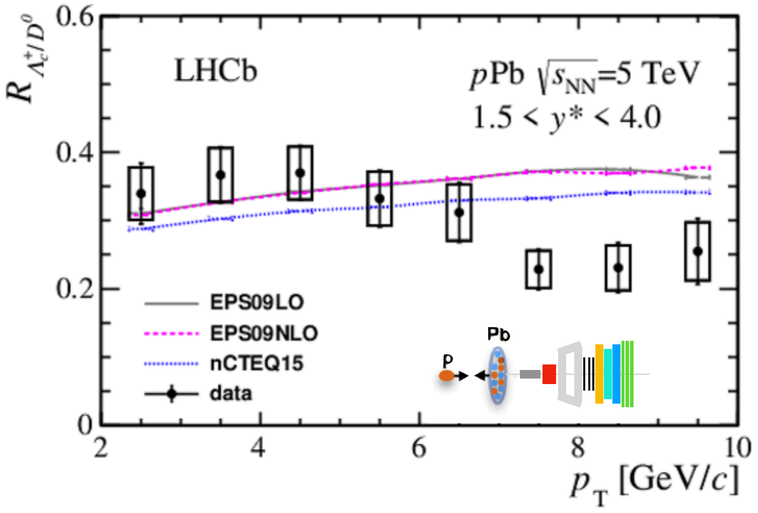


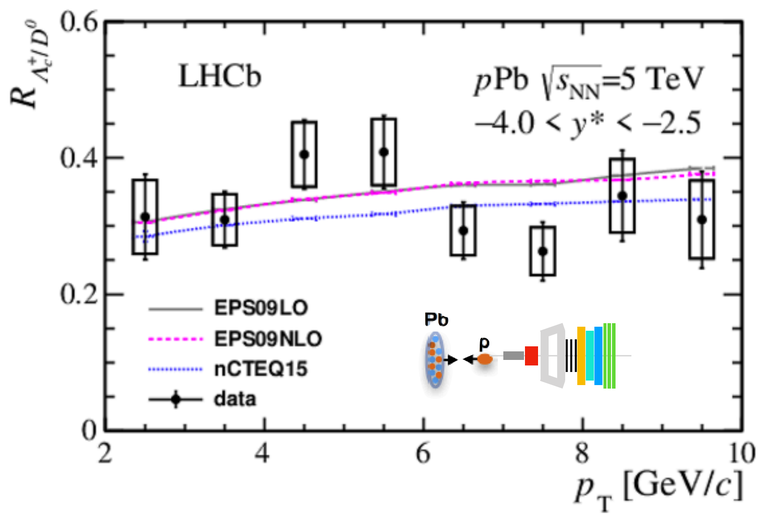


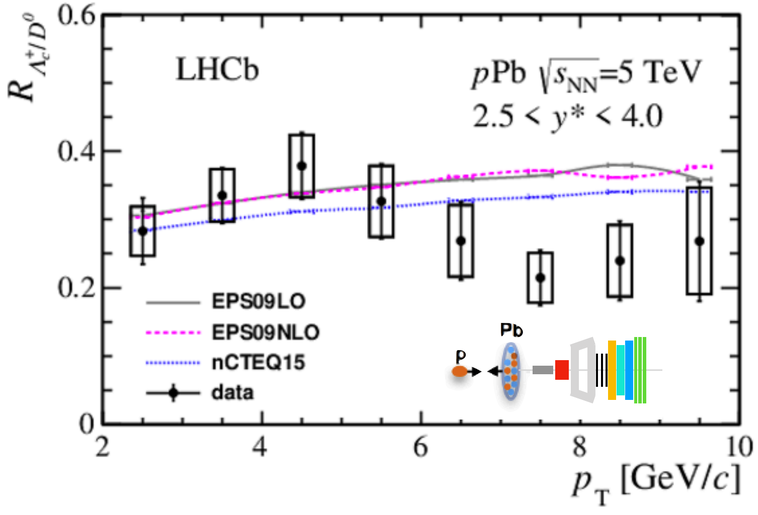
- **Beauty mesons and baryon measured in pPb/ Pbp** collisions at $\sqrt{s_{NN}}$ = 8 TeV.
  - Flat $\sigma(B^0)/\sigma(B^+)$ ratio versus p_T.
  - p_T dependance observed for the $\sigma(\Lambda^0_b)/\sigma(B^0)$ ratio.
  - Hint of a relative Λ^0_b/B^0 suppression in Pbp collisions compared to pp ?
- Extensive studies show **good agreement** between data and HELAC-onia predictions with several sets of nPDFs.

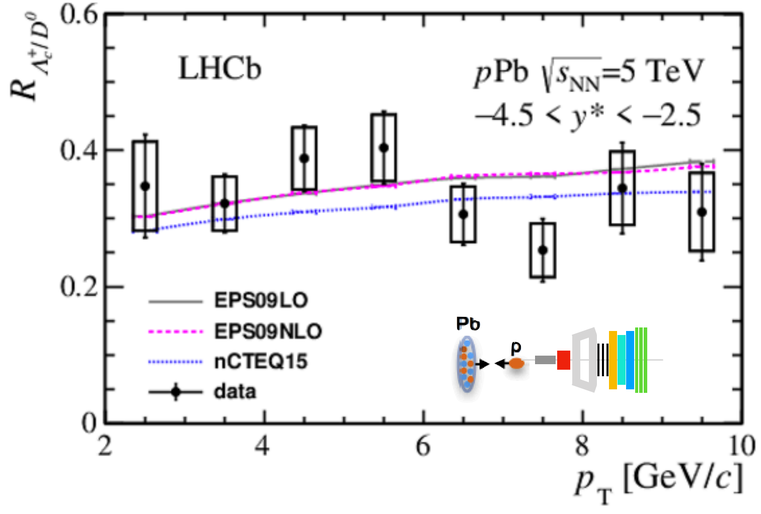
Baryon-to-meson ratio in pPb collisions

JHEP 02 (2019) 102



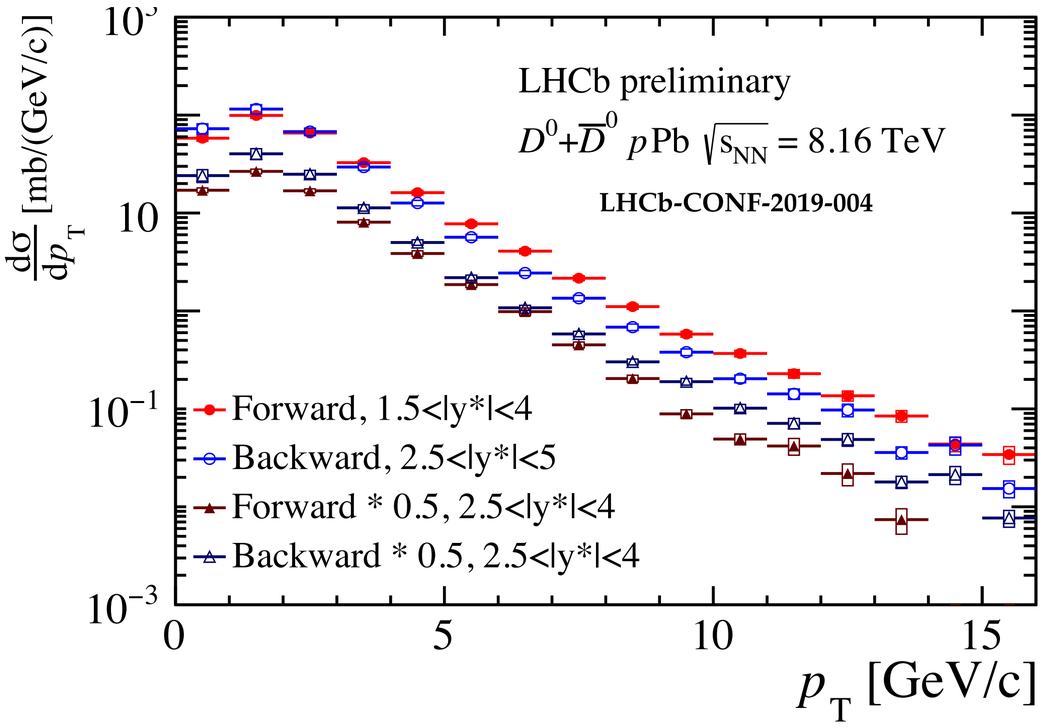


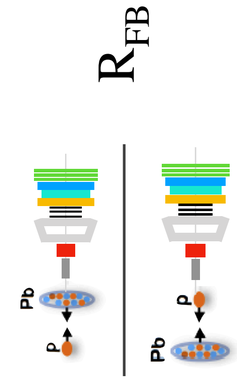




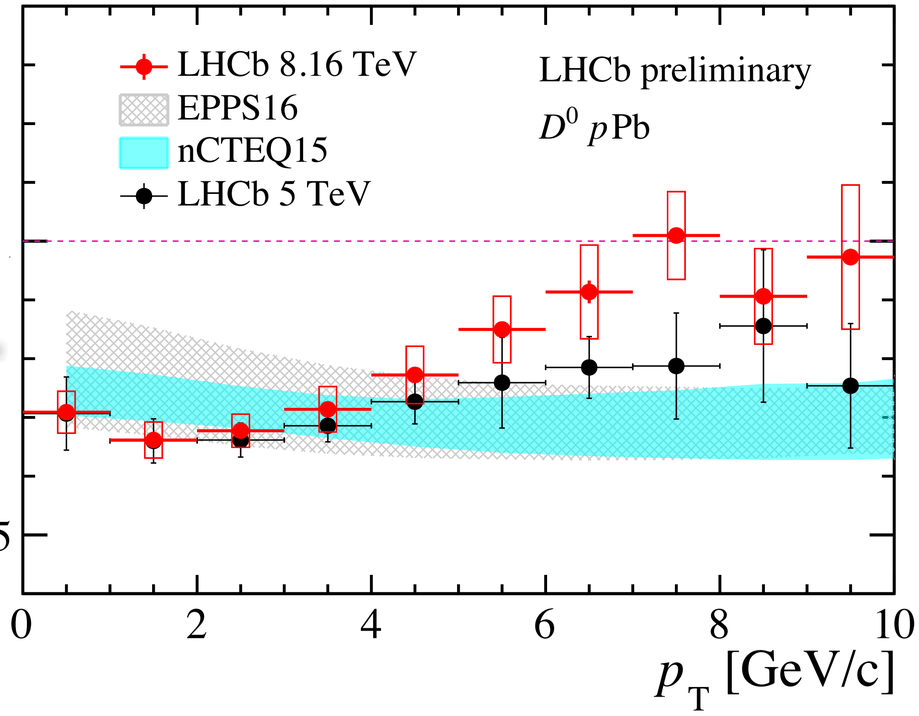
- **Charm mesons and baryon measured in pPb/Pbp** collisions at $\sqrt{s_{NN}}$ = 8 TeV.
- No strong dependance of the relative Λ_c^+/D^0 ratio is observed versus p_T and rapidity.
  - **Decreasing trend versus p_T** in pPb.
- **Good description of the nuclear modification factors and forward-to-backward ratios** with various nPDFs sets.
  - within large model uncertainties …
- **Tensions between models and data** at higher p_T in pPb collisions.
  - Data fluctuation ?
  - Additional effect ?

Open-charm production in pPb collisions



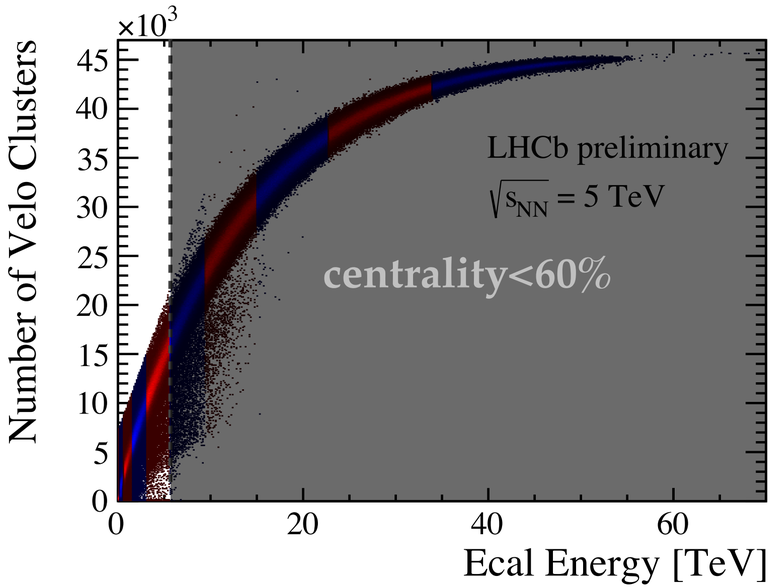


Analysis ongoing



- **Preliminary results for D^0 cross-section** in pPb / Pbp collisions at $\sqrt{s_{NN}}$ = 8 TeV **up to p_T = 16 GeV/*c***.
- **Improved statistics** by factor 20 compared to previous LHCb results.
- **Tension between data and nPDFs predictions. Additional effects required.**
- **Analysis ongoing for other open-charm stats !**

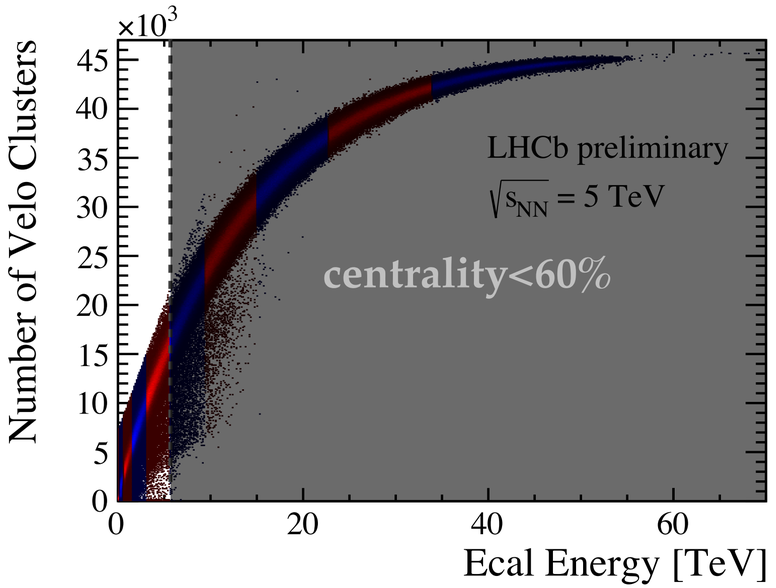
Status in nucleus-nucleus collisions



VELO saturation → loss of tracking efficiency

Status in nucleus-nucleus collisions

Studies in PbPb limited to 60% less central collisions.



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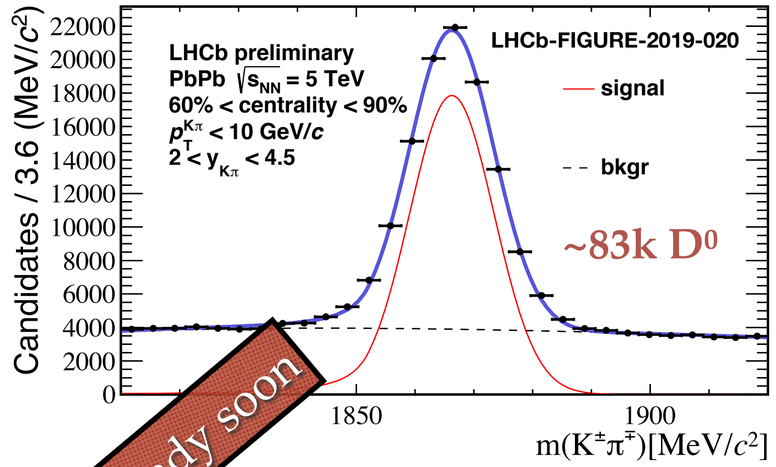
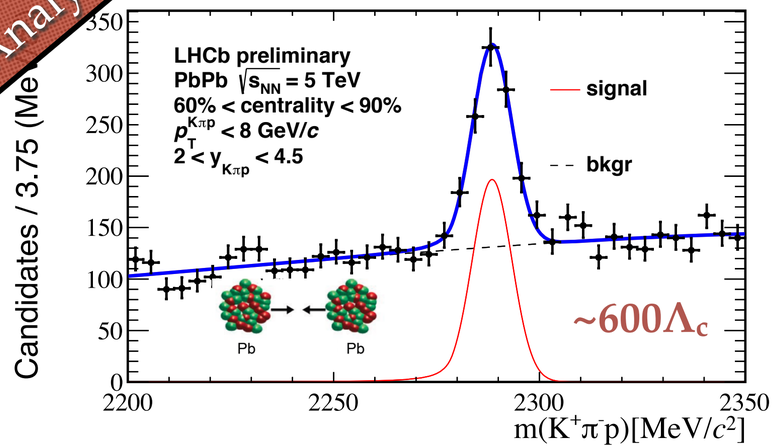


Analysis ready soon

2018 data



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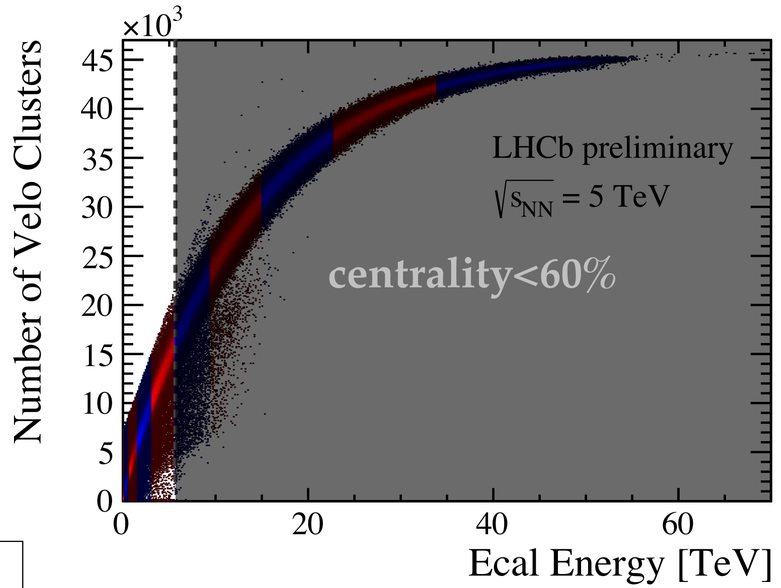
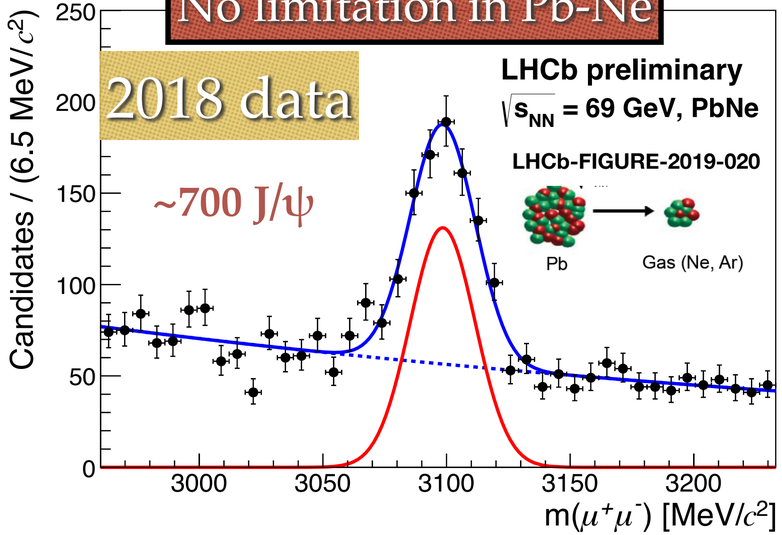


No limitation in Pb-Ne

2018 data



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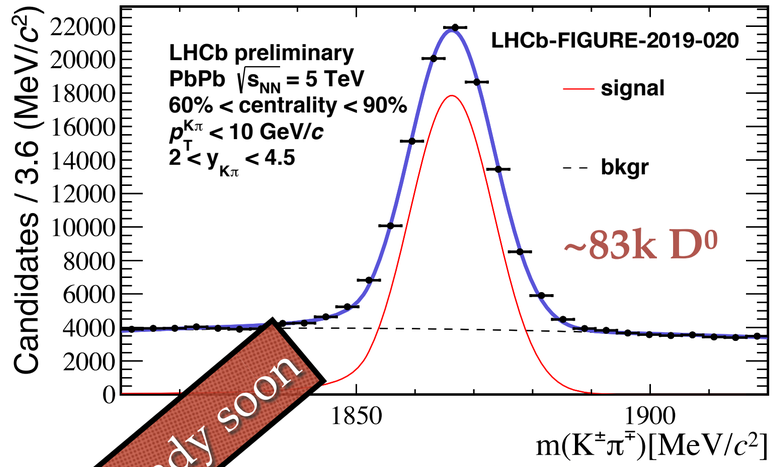

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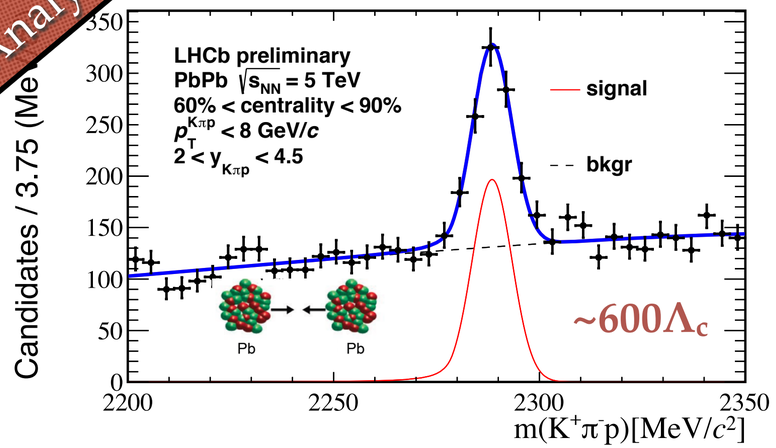
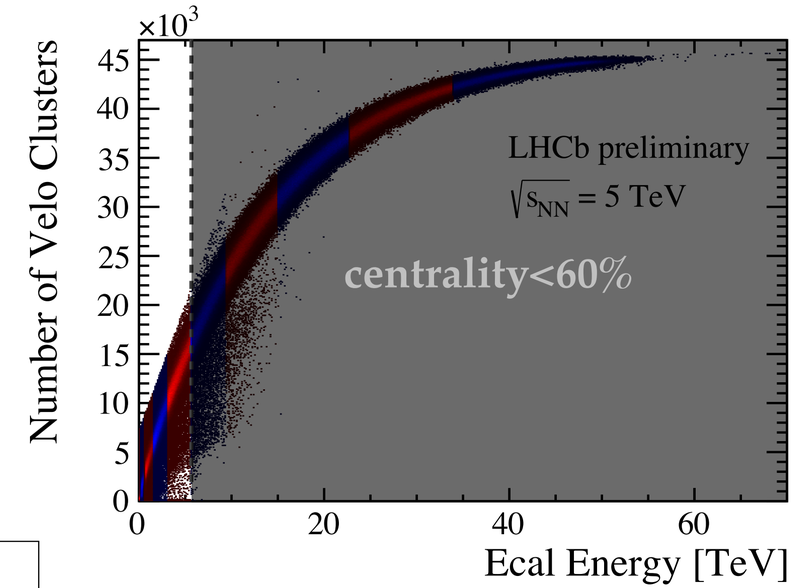


Studies in PbPb limited to 60% less central collisions.

Analysis ongoing, stay tuned !



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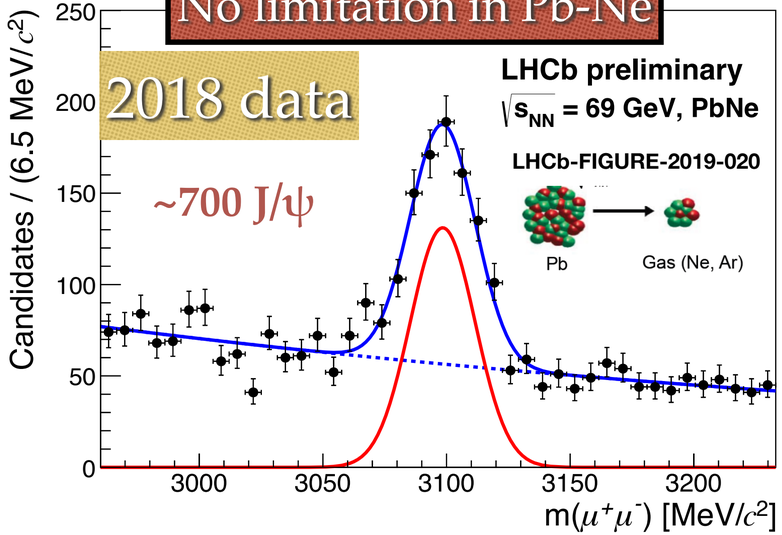


Outlook: detector upgrade and futur performance

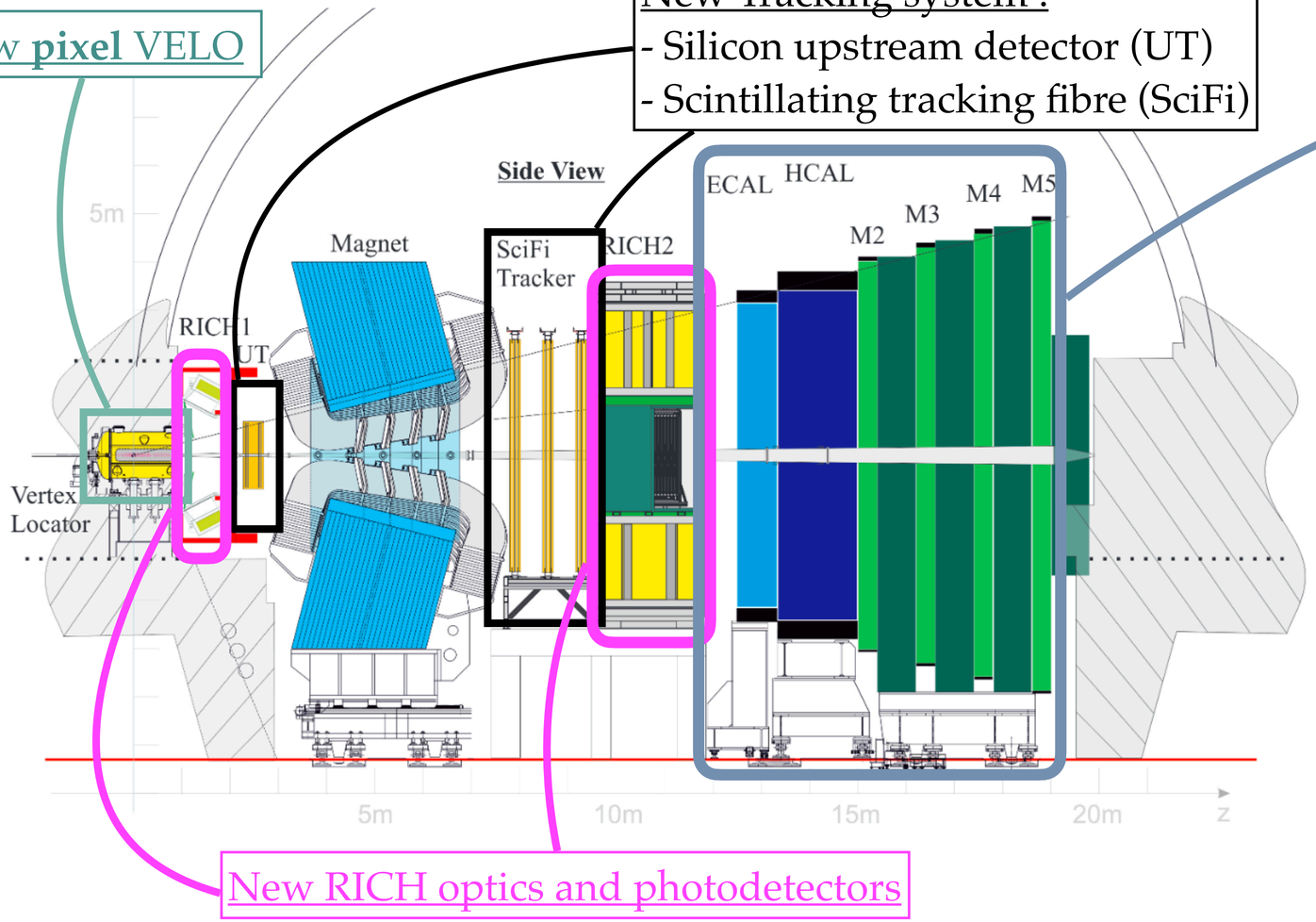
LHCb detector : season 3 (2022)

[CERN-LHCC-2012-007]

New **pixel** VELO

New Tracking system :
- Silicon upstream detector (UT)
- Scintillating tracking fibre (SciFi)

New electronics for muon and calorimeter systems

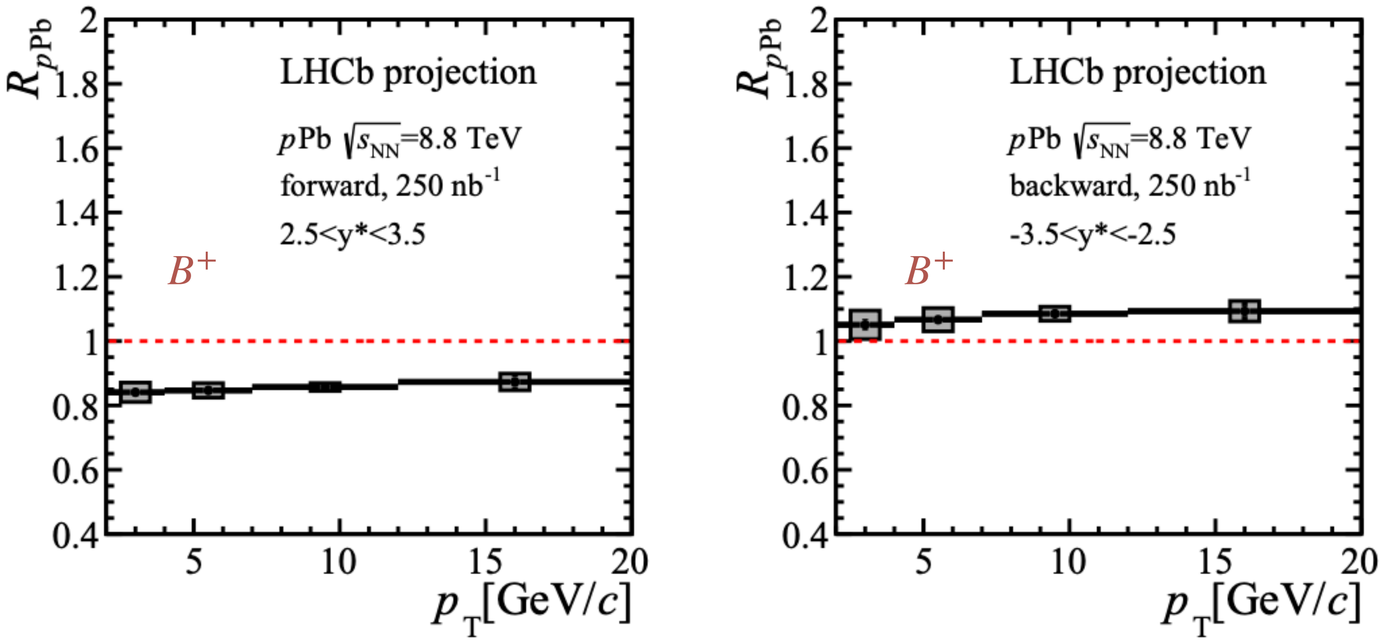


New RICH optics and photodetectors

- Upgrade based on pp collision requirements :
  - Collision rate at 40 MHz.
  - Pile-up factor $\mu \approx 5$
- **Replace the entire tracking system.**
- Full **software trigger.**
  - Remove L0 triggers.
  - Read out the full detector at 40 MHz.

Run 3 prospects for heavy-ion physics with LHCb

HELAC-Onia + EPPS16 nPDF predictions



Luminosity:
- pPb : 500 nb^{-1} (4 weeks)
- pp : 104 pb^{-1} (much shorter time)

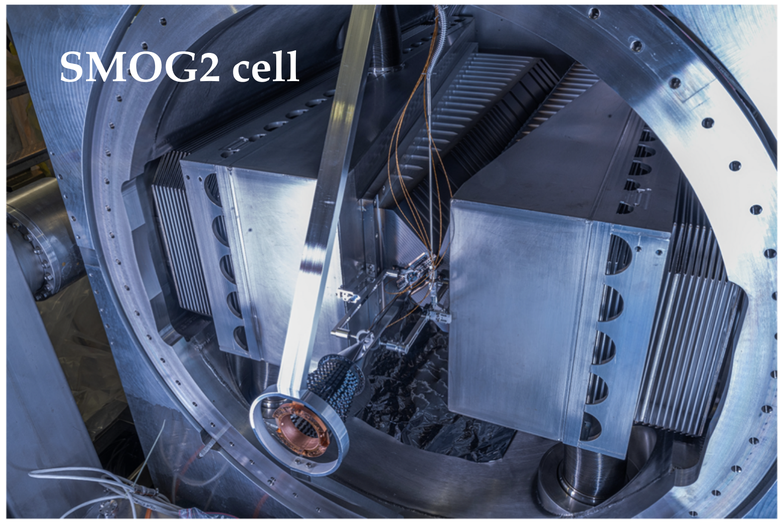
- Studies in this document :
  - D0-D0 correlations.
  - B+ meson productions.
  - Drell-Yan production
- Results obtained assuming similar systematics as in Run 2.
  - Dominated by tracking uncertainties and branching ratios in this scenario.
- **Projections show valuable inputs for nPDF fit with limited data taking periods.**

LHCb-CONF-2018-005

LHCb fixed-target program evolution

Projection of ~1 year data taking in parallel mode

Int. Lumi.		80 pb^{-1}
Sys.error of J/Ψ	xsection	~3%
J/Ψ	yield	28 M
D^0	yield	280 M
Λ_c	yield	2.8 M
Ψ'	yield	280 k
$\Upsilon(1S)$	yield	24 k
$DY\ \mu^+\mu^-$	yield	24 k



- **SMOG 2** (TDR) : Standalone gas storage cell covering z ϵ [-500;-300] mm :
  - **Up to x100 higher gas density** with same gas flow of current SMOG.
  - Gas feed system measures the **gas density with few % accuracy**.
  - **Possibility to run in parallel of pp collisions and inject non noble Gaz.**

SMOG2 installed and ready to go !

Summary

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- LHCb : a performant heavy-flavour detector **at forward rapidity :**
  - Large catalog of precise measurements in pp collisions.
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- Many analysis ongoing which should be ready soon
  - D mesons studies in pPb collisions at 8 TeV.
  - Λ_c^+/D^0 ratio in peripheral PbPb collisions.
  - J/ψ and D^0 measurements in PbNe fixed-target collisions.

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- The futur LHC Run 3 will help us to improve the quality of the data:
  - Installation of the brand new detector with **improved performances** currently ongoing to cope with the **increase of the luminosity !**
  - The evolution of the fixed-target program will give unique possibilities to the LHCb physics program.
  - **Better performances expected** for Run 3 in high-multiplicity collisions.

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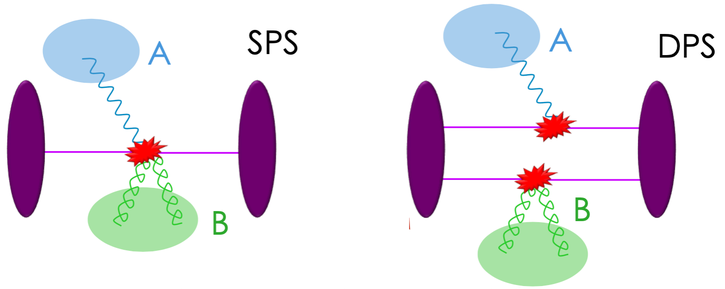
Extended capabilities of the detector = expansion of the physics program !

Back-up slides

Double charm production in pPb



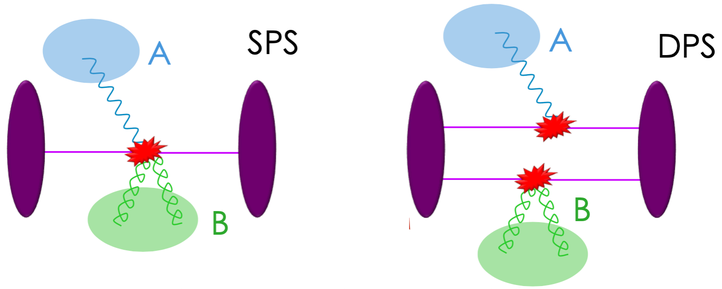
J. Gaunt, Quarkonia as Tools 2020 workshop

- Why Double Parton Scattering (DPS) ?
  - To study the underlying event.
  - To access Double Transverse Momentum Dependent Parton distributions (JHEP 1203 (2012) 089).
  - …
- DPS cross-section parametrisation, assuming two independent hard collisions :

$$\sigma_{\text{eff}} \propto \frac{\sigma^A \sigma^B}{\sigma^{AB}_{\text{DPS}}}$$

Related to the geometry of the collision and independent of the final state (?)

Double charm production in pPb



J. Gaunt, Quarkonia as Tools 2020 workshop

- Why Double Parton Scattering (DPS) ?
  - To study the underlying event.
  - To access Double Transverse Momentum Dependent Parton distributions (JHEP 1203 (2012) 089).
  - …
- DPS cross-section parametrisation, assuming two independent hard collisions :

$$\sigma_{\text{eff}} \propto \frac{\sigma^A \sigma^B}{\sigma^{AB}_{\text{DPS}}}$$

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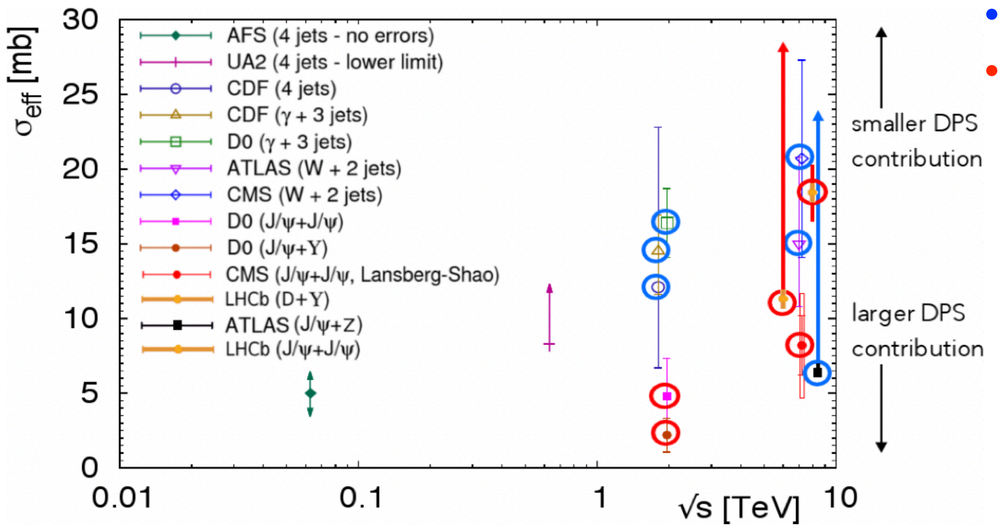
D.D'Enterria, Quarkonia as Tools 2020 workshop



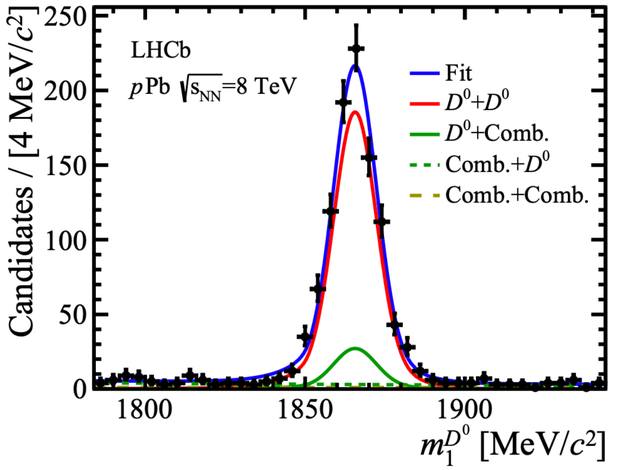
- q-q,g process
- g-g process

- σ_{eff} final state dependant ? (mind the large uncertainties).
- Is σ_{eff} interpretation correct ?
- σ_{eff} can also be measured in pA collisions and compared to pp collisions with simple scaling (arXiv:1708.07519).

Double charm production in pPb

PHYS. REV. LETT. 125 (2020) 212001

- LHCb has measured prompt double open-charm / open-charm + J/ψ production in pPb@8.16TeV.
  - Combined pairs from the same event and corrected from acceptance/efficiency.



Double charm production in pPb

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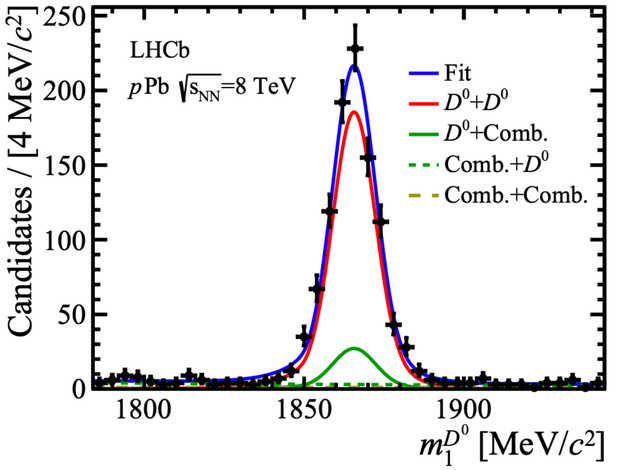

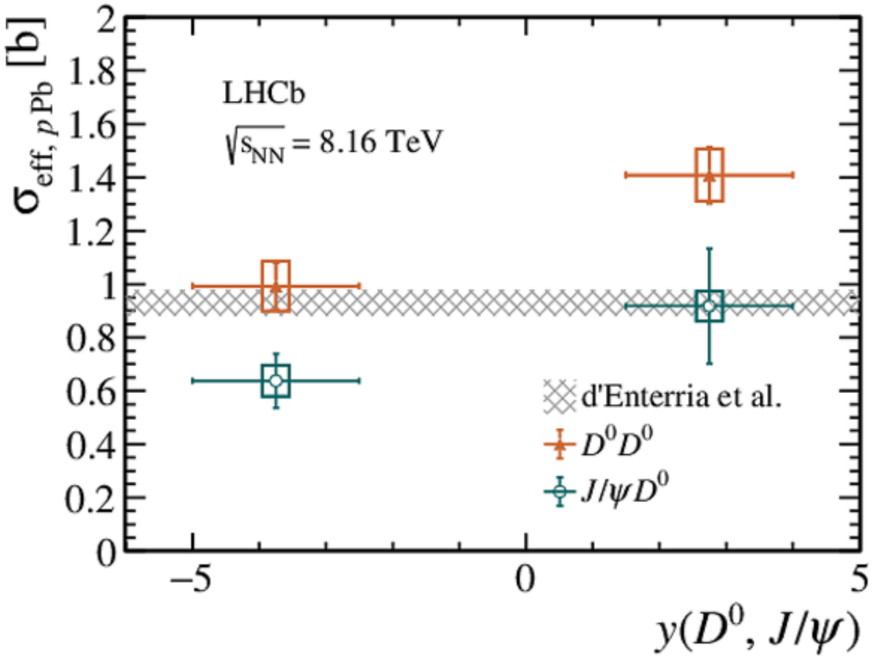

- $\sigma_{\mathrm{eff,pPb/Pbp}} = 0.9$ b : DPS/SPS enhanced by a factor of 3 compared to pp in agreement with the theory model.
- $\sigma_{\mathrm{eff,pPb/Pbp}}(J/\psi\text{-}D^0) < \sigma_{\mathrm{eff,pPb/Pbp}}(D^0\text{-}D^0)$: similar to pp case.
  - Can be due to DPS enhancement / SPS contamination.
- $\sigma_{\mathrm{eff,pPb}} > \sigma_{\mathrm{eff,Pbp}}$
  - Indication of enhanced DPS for charm production in Pbp compare to pPb.