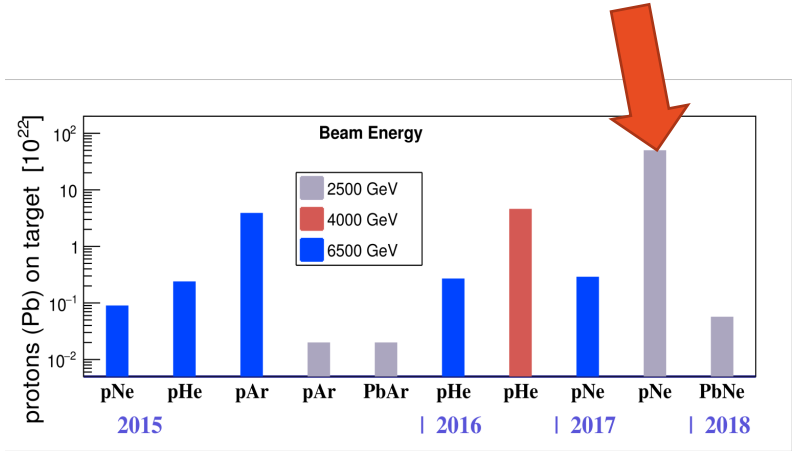
Measurement of charm baryons cross-section and production asymmetry in fixed-target collisions at LHCb

Elisabeth Maria Niel[1] Patrick Robbe [2] , Achille Stocchi [2]

Gabriel Ricart[6], Alberto Baldisseri [6], Michael Winn [6], Andrea Merli[3][4] , Daniele Marangotto [3][4], Nicola Neri [3][4]

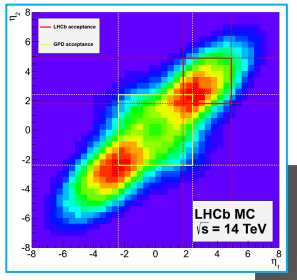
Emilie Maurice [5], Oscar Boente Garcia [5], Frédéric Fleuret [5], Kara Mattioli [5], Chenxi Gu[5]

(1) EPFL, Lausanne
(2) IJCLab - Laboratoire de Physique des 2 Infinis Irène Joliot Curie
(3) Università degli studi di Milano
(4) INFN - Insituto Nazionale di Fisica Nucleare, Sezione di Milano
(5) DPhN/CEA, LLR
(6) LLR

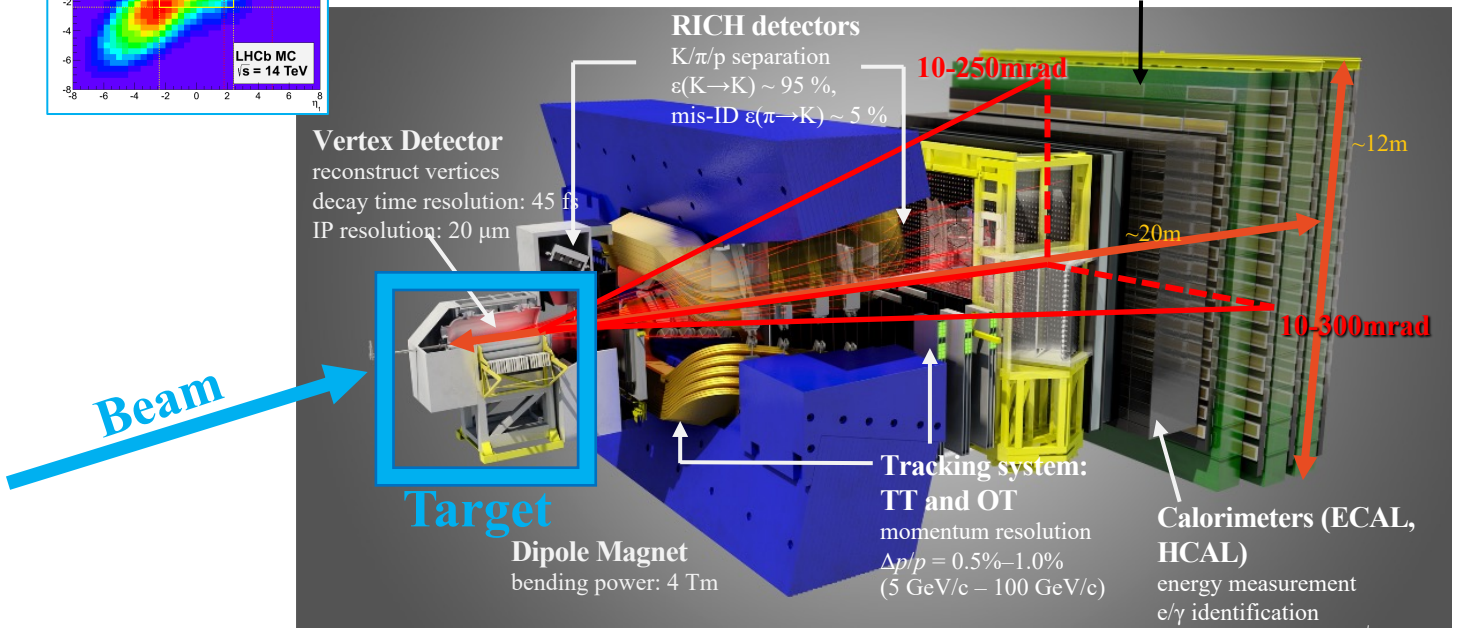


The LHCb detector

$b\bar{b}$ acceptance

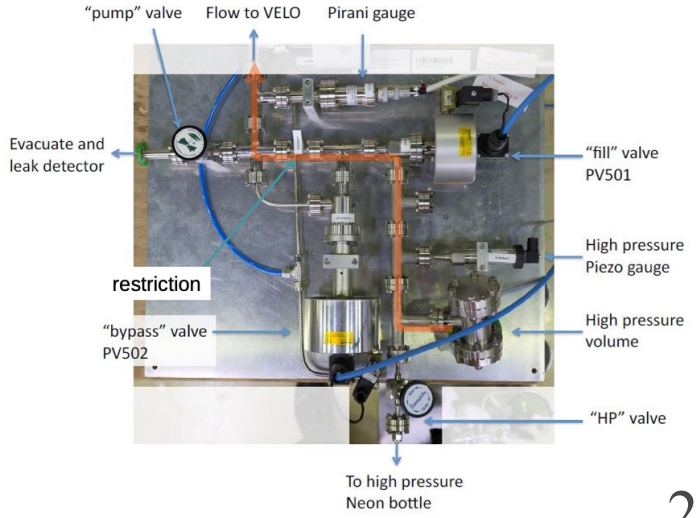


[IJMPA 30 (2015) 1530022]
[JINST 3 (2008) S08005]



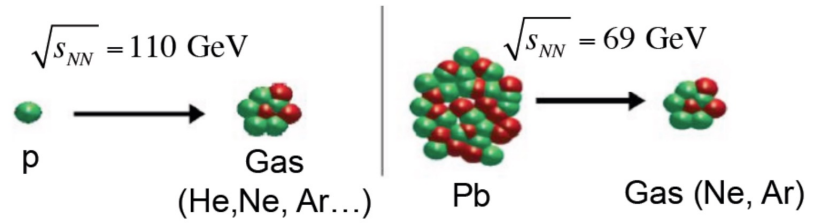
Single arm forward spectrometer with excellent vertexing, tracking, PID (acceptance $2 < \eta < 5$)

- Excellent performances
- It is a "charm factory": for pp collisions,
  - $4 \times 10^{32}\ cm^{-2}s^{-1}$ luminostiy for Run 2: the rate of $c\bar{c}$ pairs is 0.96 MHz
  - rate of Λ_c^+ seen by the LHCb detector ~602 Hz
- Unique system to inject gas (SMOG) originally designed for luminosity measurements. Re-used to transform LHCb in a fixed-target experiment. [JINST 9 (2014) P12005]
- Injection valve:

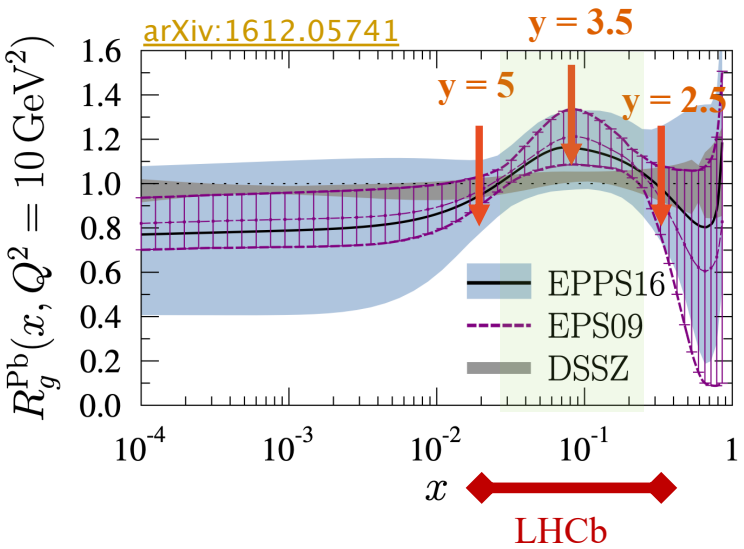


SMOG

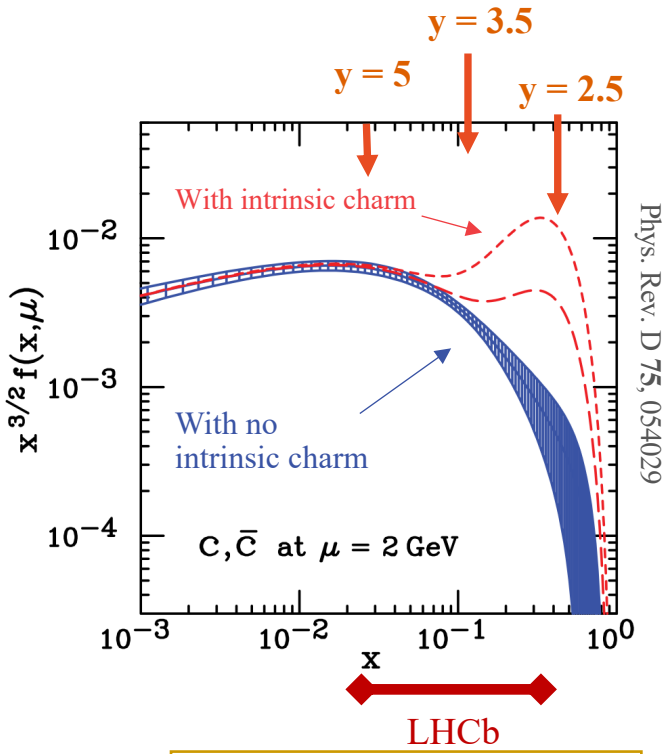
- SMOG: System for Measuring Overlap with Gas
- A noble gas (He, Ne, Ar) at $\sim 2 \times 10^{-7}$ mbar pressure injected into the LHC vacuum around the LHCb interaction region
- Energy between SPS and RHIC , $\sqrt{S_{NN}} \in [68.5\,, 110.4]$ GeV
- Rapidity: $-2.5 < y^* < 0.5$ (boost from 4.29 to 4.77) → backward and midrapidity range



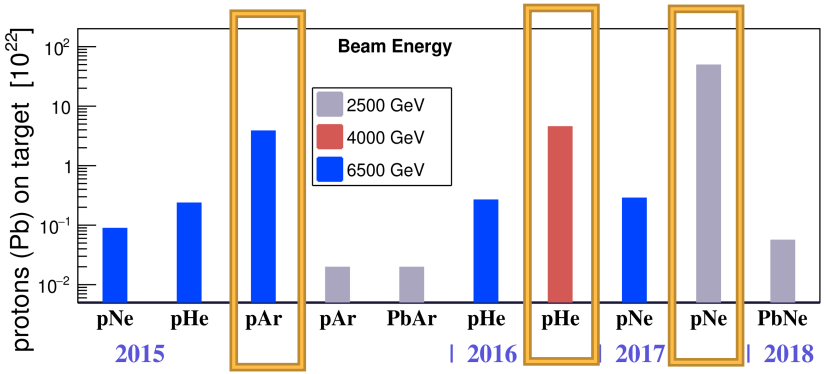
Bjorken x = fraction of nucleon momentum carried by a parton



$$\frac{PDF(Pb\ nucleus)}{PDF(single\ nucleon)}$$



Charm distributions

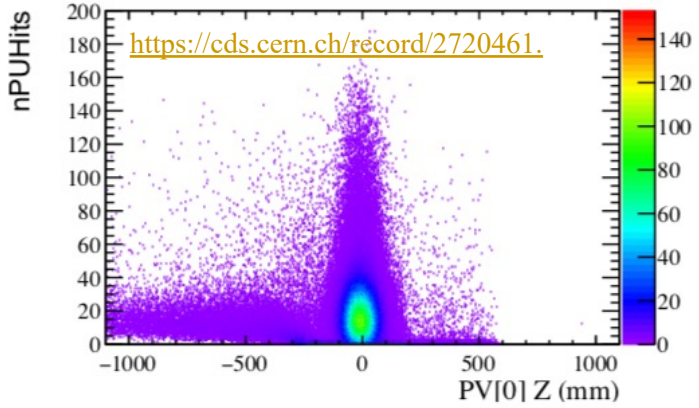


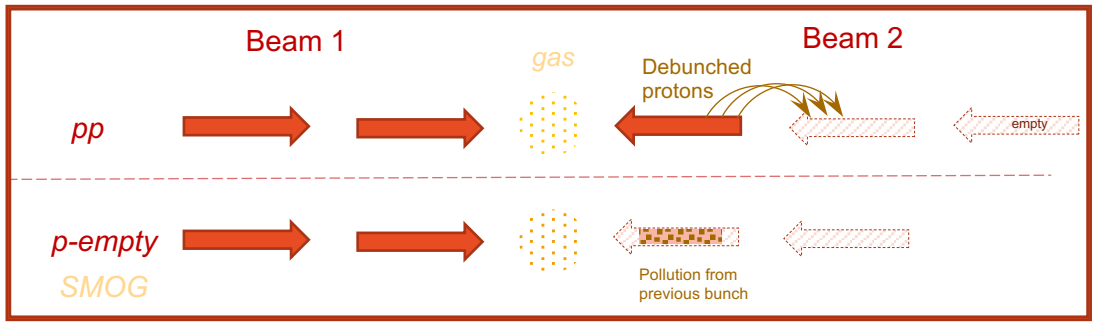
- Access nPDF anti-shadowing region
- Can probe intrinsic charm content of nucleon
- Important input for astrophysics measurements

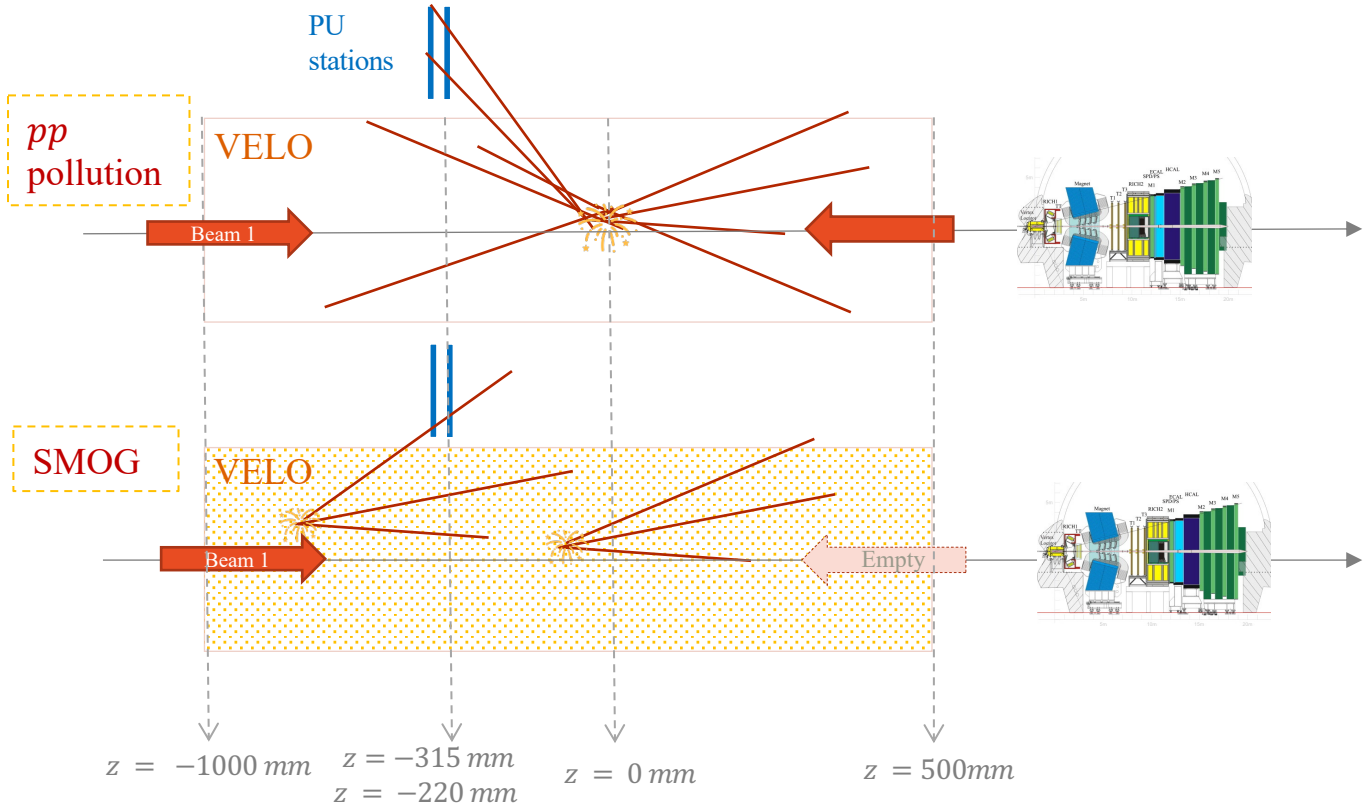
SMOG pollution

- Data are taken simultaneously with *pp* collisions at 5 TeV, no special runs pollution from *pp* collisions « ghost charges ».
  - ❖ pp and p-Gas data are taken at the same time alternating full and empty bunches.
  - ❖ Some debunched protons from the previous beam go to the following bunch which is supposed to be empty.

Cleaning using the event topology: Z-coordinate and number of hits pile-up stations







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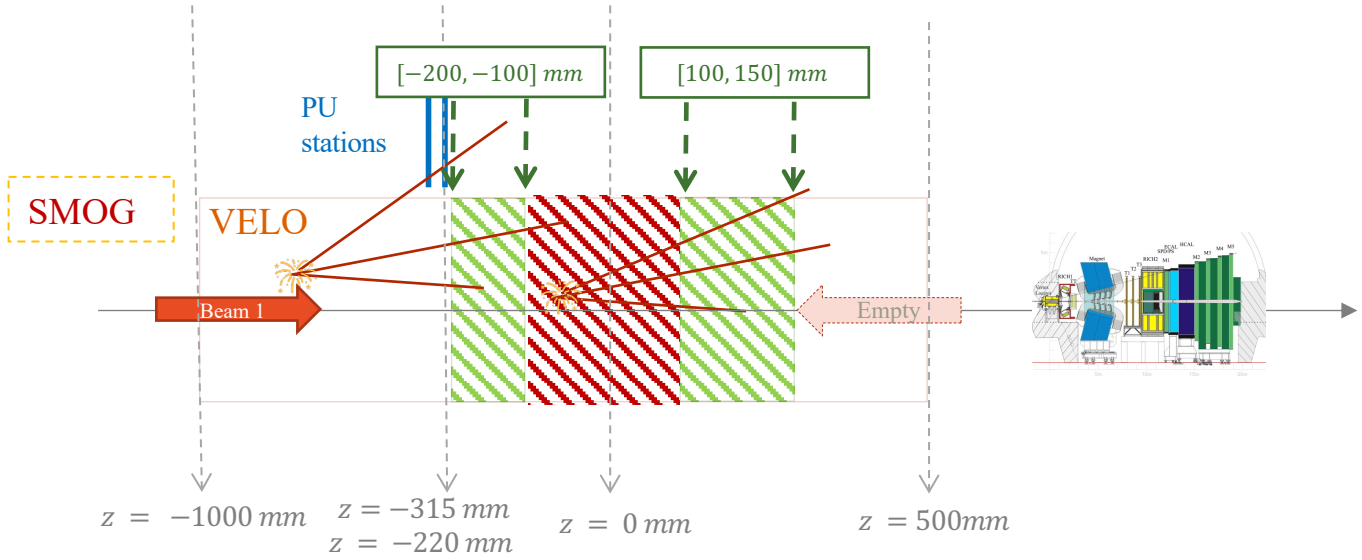
Cleaning using the event topology: Z-coordinate and number of hits pile-up stations

	$-200 < Z_{PV} < -100$	$-100 < Z_{PV} < +100$	$+100 < Z_{PV} < +200$
nPUHits=0 - GC	$(0.64 \pm 0.31)\%$	$(8.93 \pm 3.27)\%$	$(0.57 \pm 0.34)\%$
nPUHits=0 - SL	$(24.32 \pm 1.16)\%$	$(31.26 \pm 0.88)\%$	$(21.35 \pm 1.28)\%$
Correction factor	1.235 ± 0.012	1.195 ± 0.044	1.207 ± 0.013
nPUHits<3 - GC	$(2.25 \pm 0.47)\%$	$(29.44 \pm 4.77)\%$	$(1.84 \pm 0.56)\%$
nPUHits<3 - SL	$(14.86 \pm 0.91)\%$	$(24.32 \pm 0.77)\%$	$(14.23 \pm 1.04)\%$
correction factor	1.123 ± 0.010	0.877 ± 0.060	1.121 ± 0.012
nPUHits<5 - GC	$(4.69 \pm 0.62)\%$	$(49.08 \pm 5.35)\%$	$(3.76 \pm 0.78)\%$
nPUHits<5 - SL	$(11.91 \pm 0.81)\%$	$(21.79 \pm 0.73)\%$	$(12.17 \pm 0.96)\%$
correction factor	1.067 ± 0.010	0.620 ± 0.065	1.080 ± 0.013

Table 7: GC: Fraction of Ghost-Charge residual contamination after nPUHits cut; SL: fraction of fixed-target Signal Loss after nPUHits cut. Correction factor is given by $(1 - GC) \times (1 + SL)$

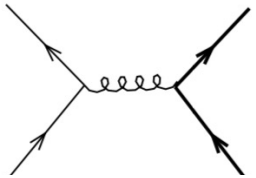


Cross section

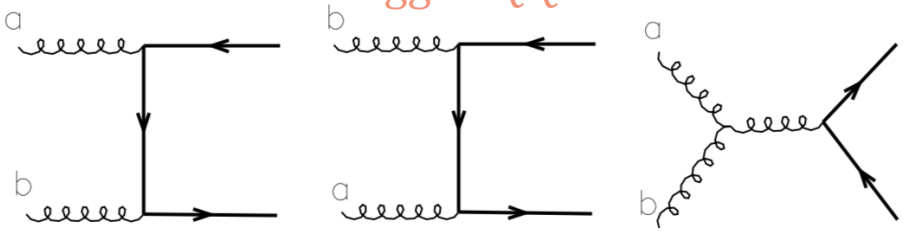
How does QCD describe the charm production? → perturbative calculations (see Quan Rojo's talk)

Two processes are responsible for heavy-quark hadro-production at the LO in perturbation theory:

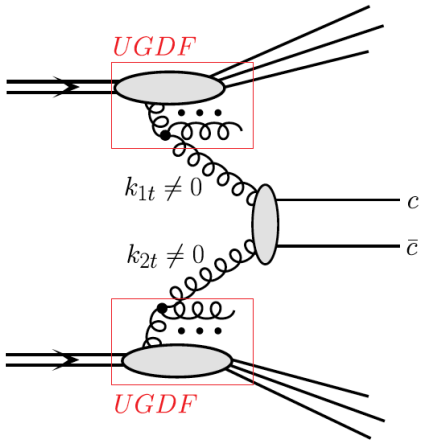
$q\bar{q} \to Q\bar{Q}$



$gg \to Q\bar{Q}$



dominant at the LHC (~ 85% at $\sqrt{s} = 14\,TeV$).



arXiv:2206.02750.pdf

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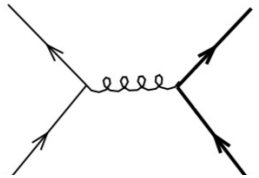

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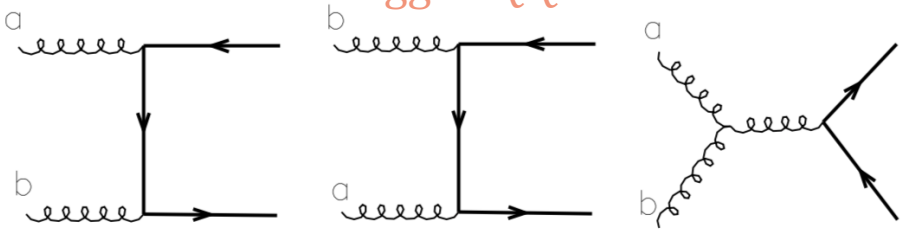

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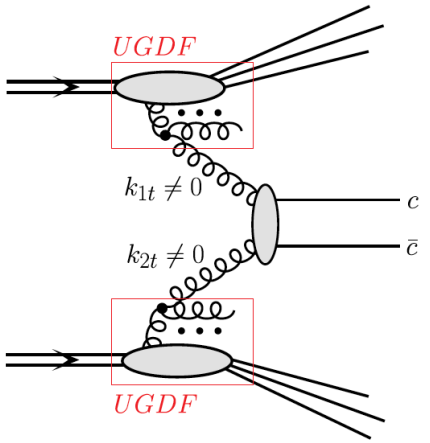
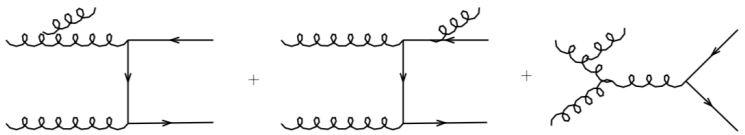
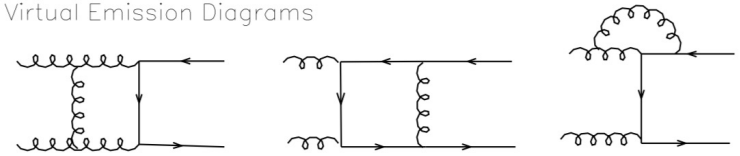


Next-to-leading-order (NLO) corrections come from two sources of $O(\alpha_S^3)$ diagrams:

Real Emission Diagrams



Virtual Emission Diagrams



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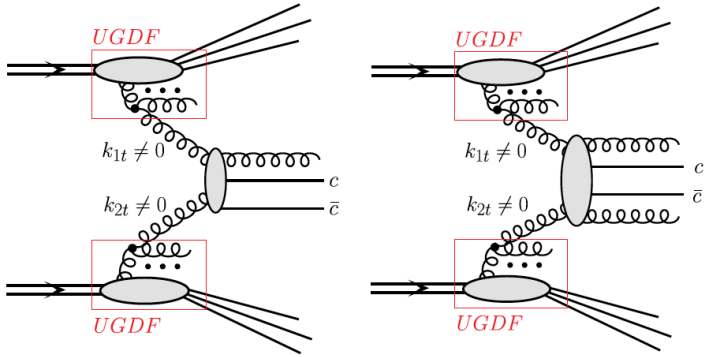

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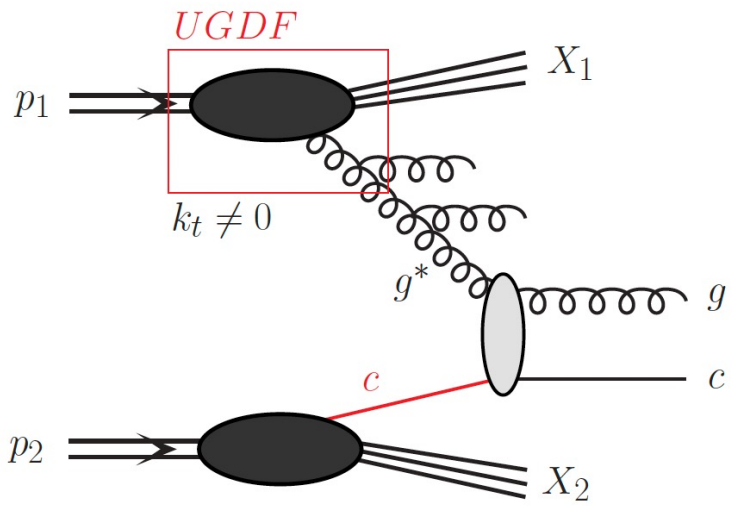
Other contributions to charm production

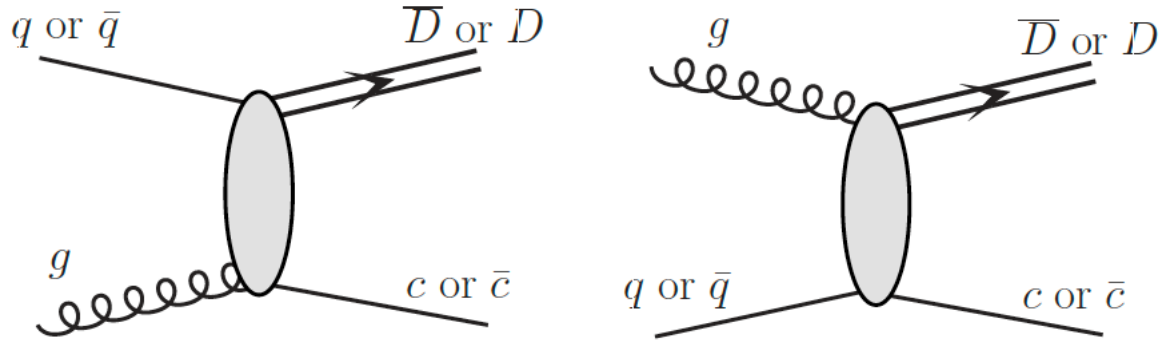
Intrinsic charm



$gc \rightarrow gc$

- LHCb fixed-target, backward rapidity→asymmetric configuration ($x_1 \ll x_2$)
- allows to probe both gluon and intrinsic charm PDF at different long. momentum fractions (gluon intermediate, charm large)

Recombination



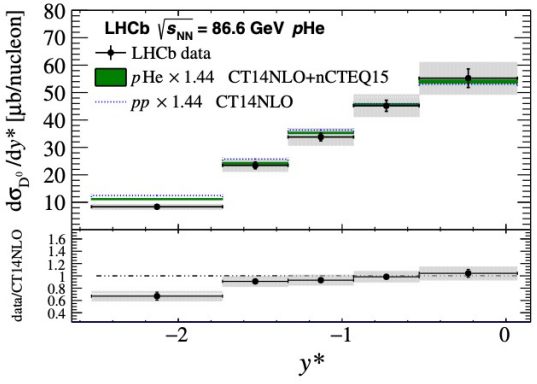
$gq \rightarrow Dc$

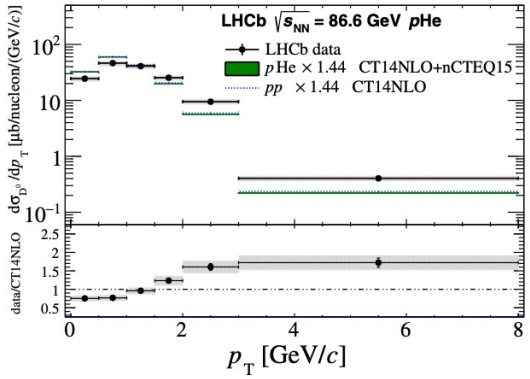
- Either direct production or from fragmentation of the c quark (which smaller rapidities)

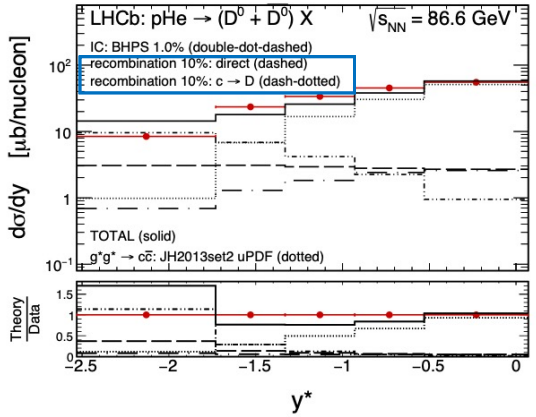
Comparison to LHCb data

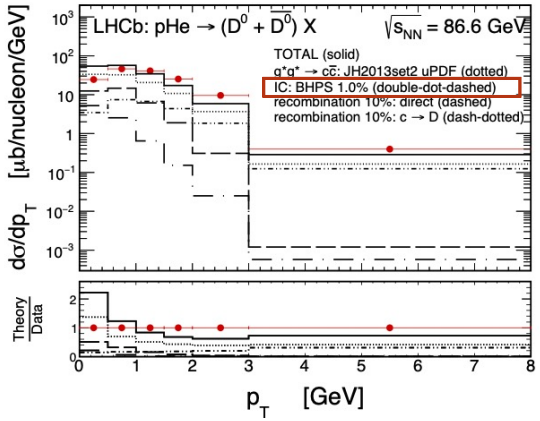
Cross-section relevant to investigate the nucleon content, especially regarding the intrinsic charm component.

*p*He results *PRL 122, 132002 (2019)*

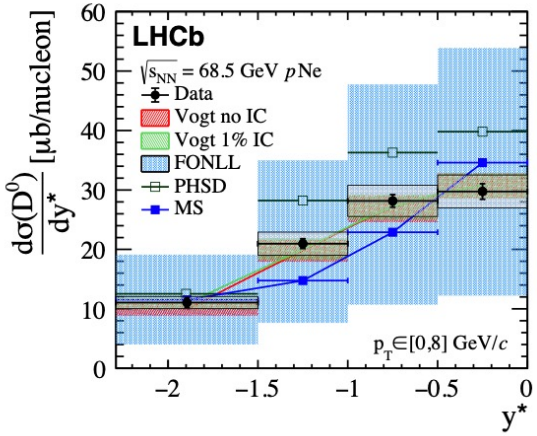


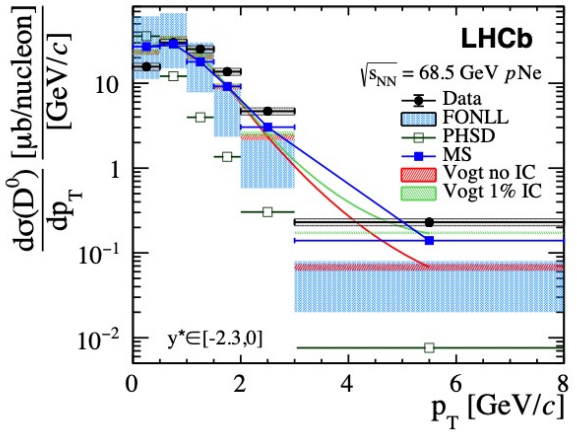


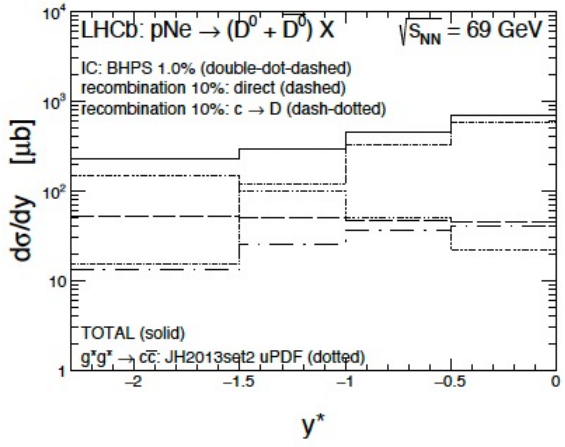


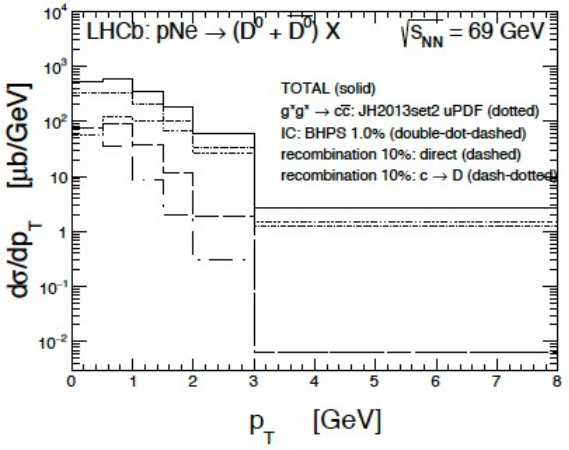


*p*Ne results *LHCb-PAPER-2022-015*

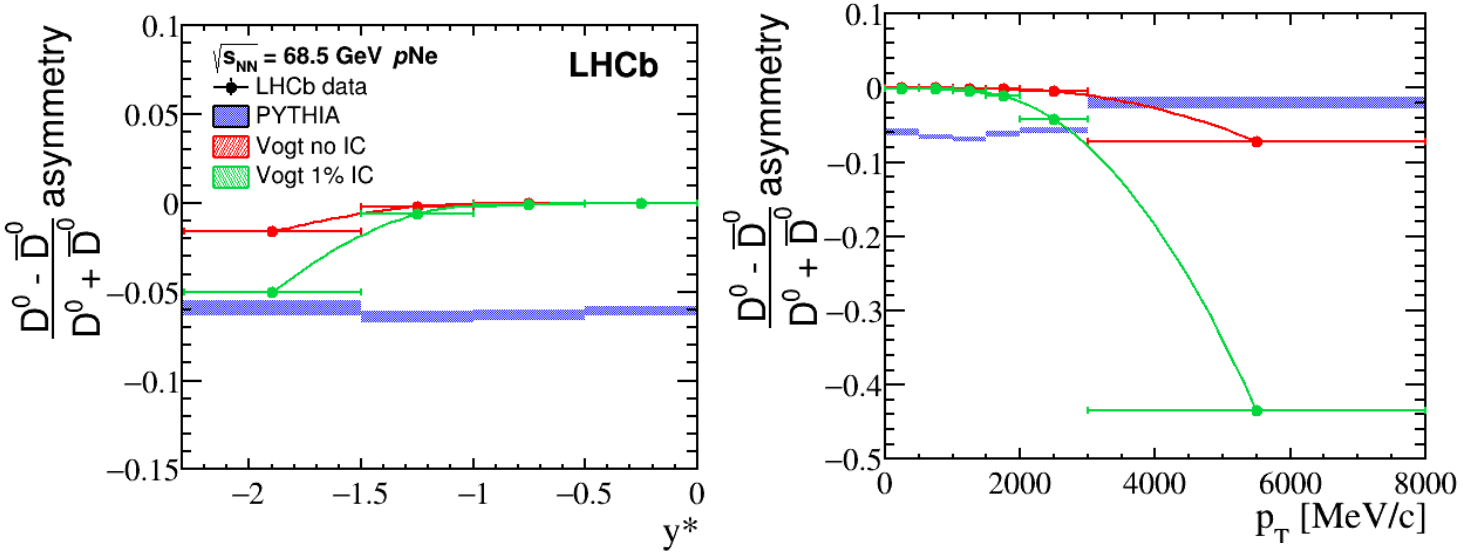


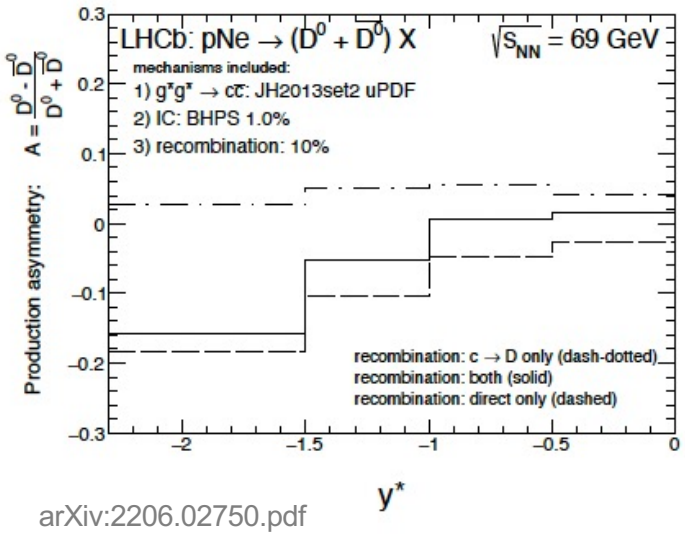


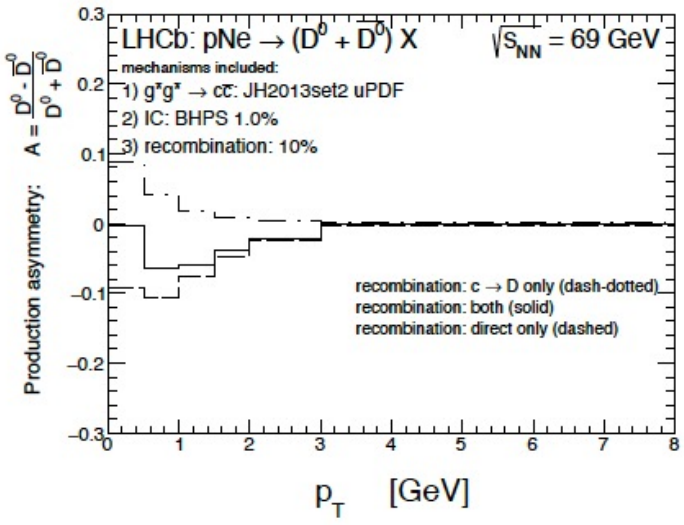




Production asymmetry D^0: predictions







arXiv:2206.02750.pdf

$$\mathcal{A}_X = \frac{N(X) - N(\bar{X})}{N(X) + N(\bar{X})}$$

- Pythia : flat prediction
- With 1 % of IC, expected negative asymmetry at backward rapidity and high p_T
- Recombination model: same behaviour as a function of rapidity but opposite for p_T

Production asymmetry D^0 : data

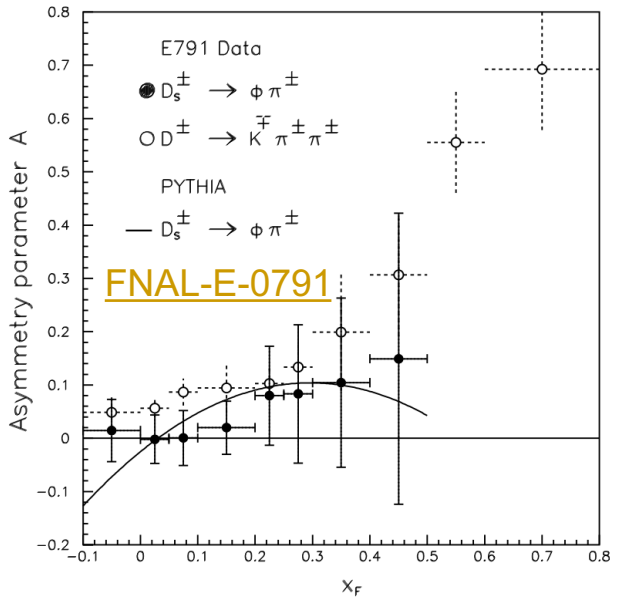
$$\mathcal{A}_X = \frac{N(X) - N(\bar{X})}{N(X) + N(\bar{X})}$$

- Pythia : flat prediction
- With 1 % of IC, expected negative asymmetry at backward rapidity and high p_T
- Recombination model: same behaviour as a function of rapidity but opposite for p_T
- Compare to **LHCb data**

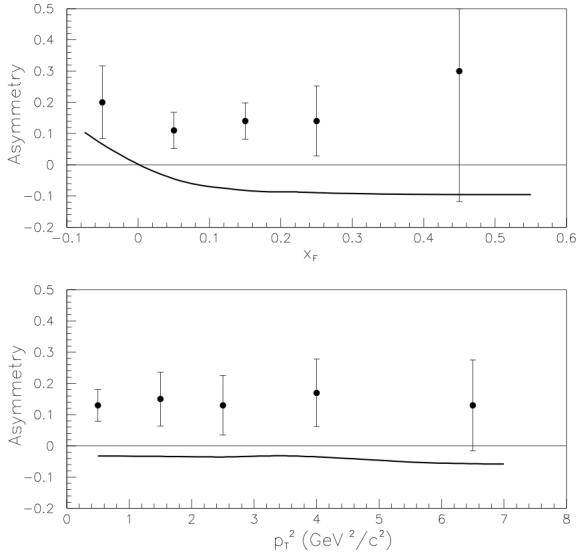
Paper: *LHCb-PAPER-2022-015*

What about charmed baryons?

- Questions we would like to answer after seeing a sizebale asymmetry for charm mesons:
  1. How is the $c/\bar{c}$ hadronization asymmetry changing for Λ_c^+(udc): same trend? Inverted trend?
  2. At y^* (very) negative, do we produce more Λ_c^+?
  3. Compare the different charm asymmetries in SMOG
  4. First measurement of baryon cross-section
- There is one (non conclusive) measurement from FermiLab (E791) for Λ_c^+ asymmetry, compatible with no asymmetry or with increasing at $x_F = 0$.
- Existing measurement from SELEX, with different beams



SMOG could largely improve this!



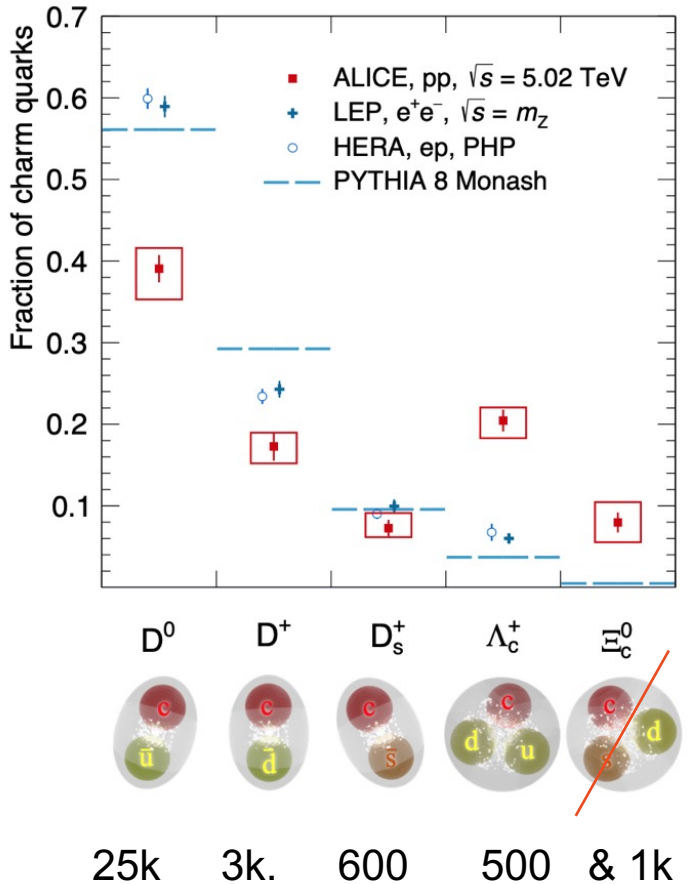
Phys.Lett.B495:42-48,2000

Experiment	Beam Momentum (GeV/c)	Beam Particle	Target Material
E690	800	p	LH_2
E771	800	p	Si
E866/NuSea, E789 and E772	800	p	LH_2, LD_2, C, Ca, Fe, W Ag, Au, and Cu dump
E769	250	$\pi^\pm, K^\pm$, and p	Be, Al, Cu, and W
E781/SELEX	600	Σ^- and π^-	C and Cu
	572	p	C and Cu
E791	500	π^-	C and Pt
E815/NuTeV	20 to 400	$\nu_\mu, \overline{\nu}_\mu$	Fe
E687	220	γ	Be
E831/FOCUS	170	γ	BeO and Si
WA89	340	Σ^- and π^-	C and Cu
WA82	340	π^-	Si, Cu, and W
	370	p	Si and W
WA92/Beatrice	350	π^-	Cu and W

What about charmed baryons?

In the target valence region :

Phys. Rev. D 105, L011103 (2022)

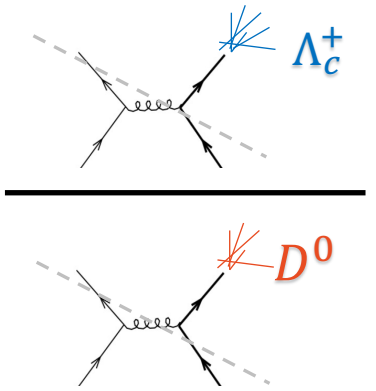


Transverse-momentum integrated production cross sections of charm meson/baryon normalised the D^0 (*pp* collisions 5.02 TeV)

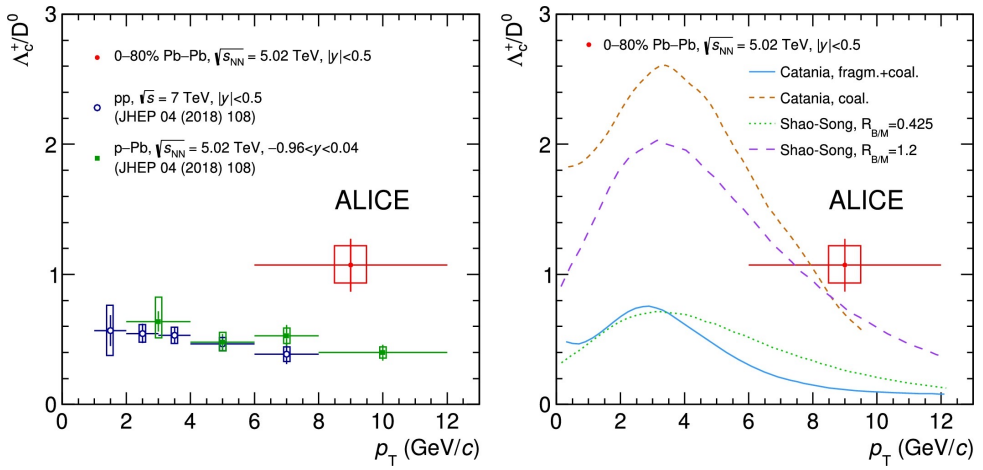
Ratios baryons/mesons

- Also interesting to study ratios of: Lc/D0, Lc/D+, Lc/Ds
- Heavy-flavour can be used to test pQCD,
  common part for baryons and mesons (production)→cancels in the ratio
- Ratios allows to study heavy quark **coalescence**
  if Colaescence happens, the $p_T^{\Lambda_c^+} \gg p_T^{D^0}$:
  → ratio should depend on rapidity
  → enhanced Λ_c^+ production (w.r.t. heavy quark fragmentation)
- ALICE measured that, LHCb measured smaller value, is there a multiplicity dependence?
- For SMOG: Different energy, multiplicity, we have more/less coalescence?

$$R(\Lambda_c^+ / D^0) = \frac{\Lambda_c^+}{D^0}$$



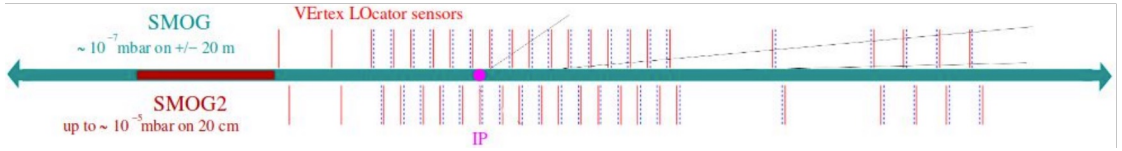
Physics Letters B 793, 2019

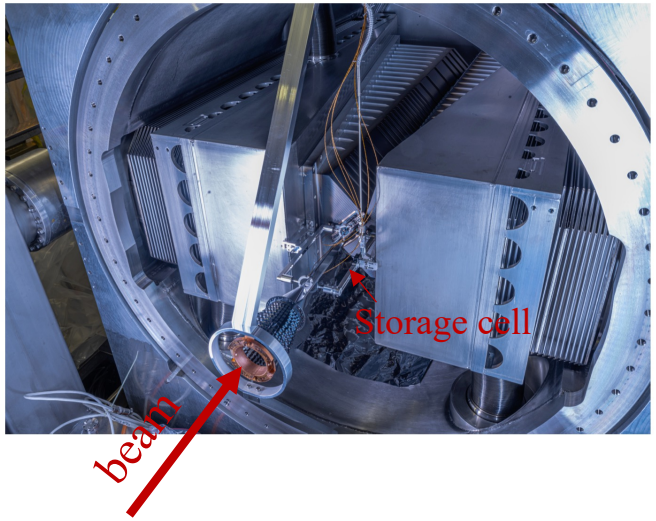


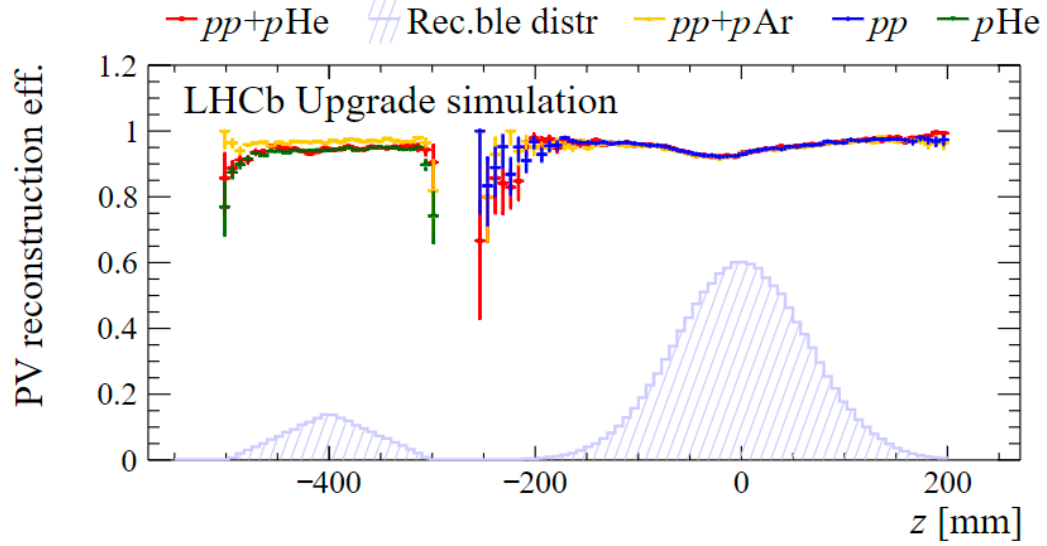
SMOG2

- Upgraded SMOG system with storage cell placed upstream nominal IP at z [-500,-300] mm, with dedicated Gas Feed System.
- Gas density increased of 2 orders of magnitude → higher luminosity
- Gas target possible: $H_2, D_2, He, N_2, O_2, Ne, Ar, Kr, Xe$
- Separated luminous region from *pp* allowing for simultaneous data-taking → more statistics
- First injections on May 25th (no beam), June 13th and 20th (with beam)

Reaction	DAQ time	Non coll. bunches	Lumi (nb^{-1})	Decays	SMOG yields	Scale factor	SMOG2 proj. yields
pAr	18 h	684	~ 2	$D^0 \to K^-\pi^+$	6450	62	400 *k*
				$D^+ \to K^-\pi^+\pi^+$	975		60 *k*
				$D_s^+ \to K^-K^+\pi^+$	131		8 *k*
				$D^{*+} \to D^0\pi^+$	2300		140 *k*
				$\Lambda_c^+ \to pK^-\pi^+$	50		3 *k*
				$J/\psi \to \mu^+\mu^-$	500		30 *k*
				$\psi(2S) \to \mu^+\mu^-$	20		1.2 *k*
pHe	84 h	648	7.6	$J/\psi \to \mu^+\mu^-$	500	19.6	10 *k*
				$\psi(2S) \to \mu^+\mu^-$	20		0.4 *k*







Conclusions

- SMOG data have produced unique results (See Patrick's talk) and more results are to come!
- Future: charm baryons (Λ_c^+ and Ξ_c^+) polarization, production cross-section and asymmetry
- Charm baryons measurement are an important input to understand charm production asymmetries seen in charm mesons production
- This is probably one of the last measurement with SMOG
- SMOG2 successfully installed, more open and hidden charm measurement to come!

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