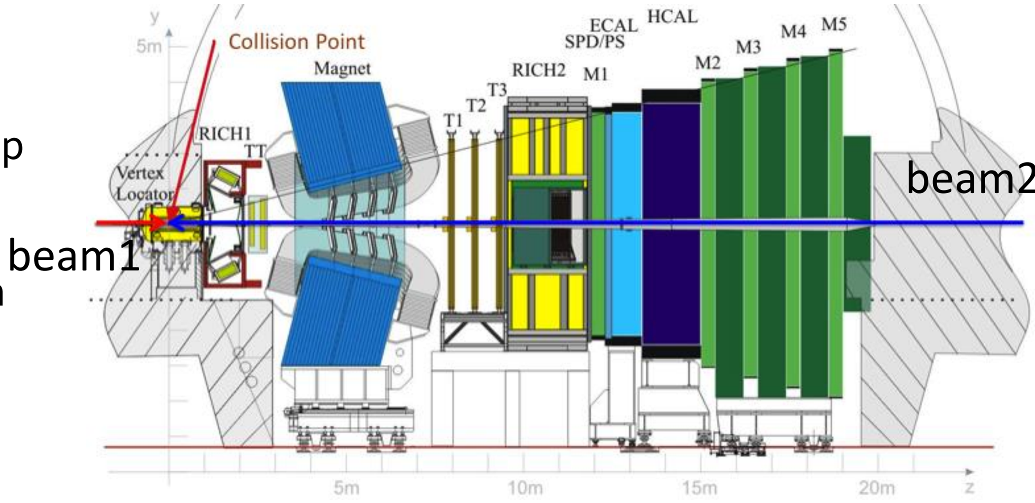
Fixed-target physics with LHCb

Patrick Robbe, IJCLab Orsay, 8 Oct 2021

LHCb up to 2018

- Physics core program: search for New Physics through heavy flavor decays
  - Study *CP* violation
  - Rare *B* decays
- Optimized acceptance: $1.6 < \eta < 4.9$
- Good particle ID: e, μ, p, K, π, γ identification up to p=100 GeV
- Good vertex and proper-time resolution: Interaction point resolution better than 80 μm
- Good mass and low momentum resolution
- Efficient trigger for lepton and hadron channels: 1 MHz readout rate up to 2018 – main improvement point for first upgrade.
- LHCb became a more general detector in the forward region

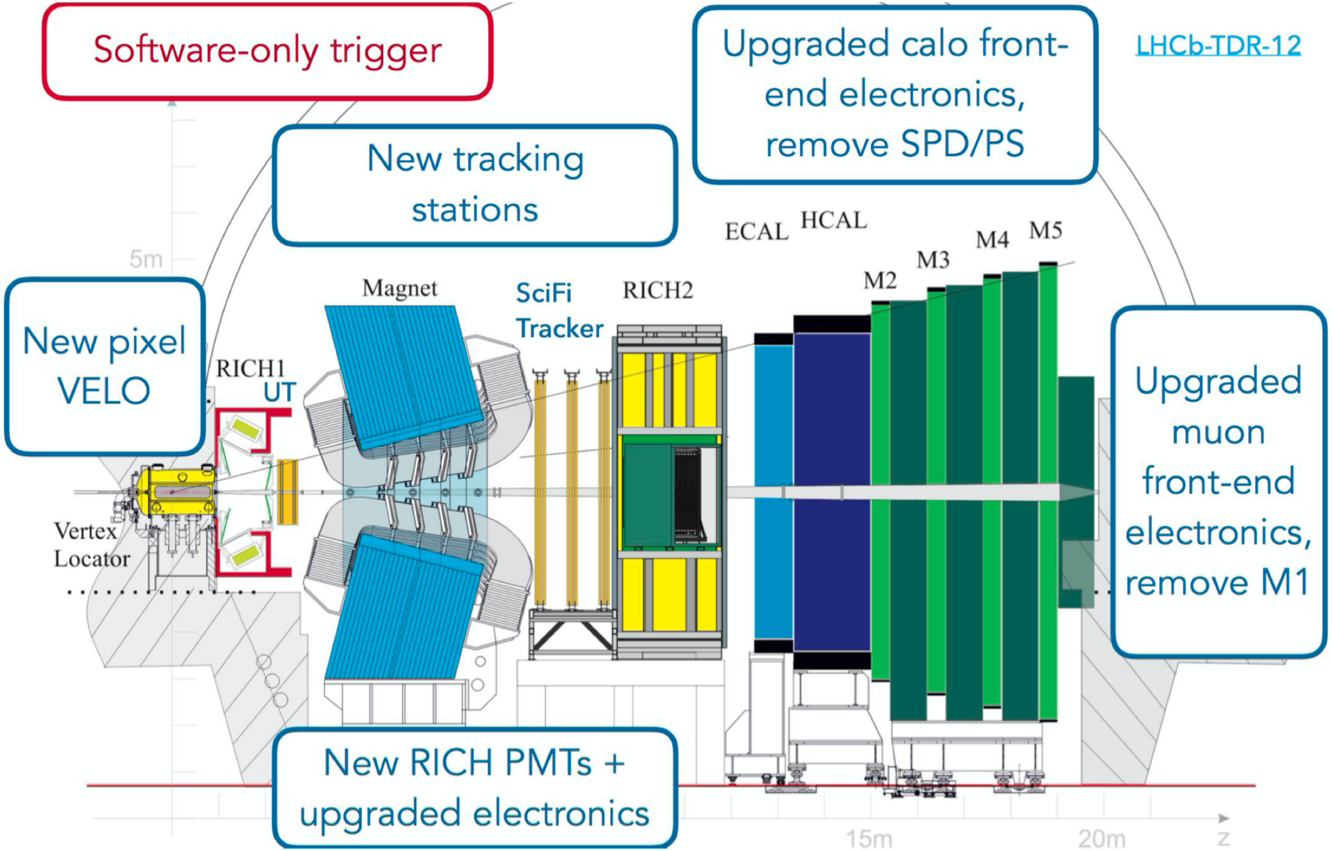
[*JINST* 3 (2008) S08005]



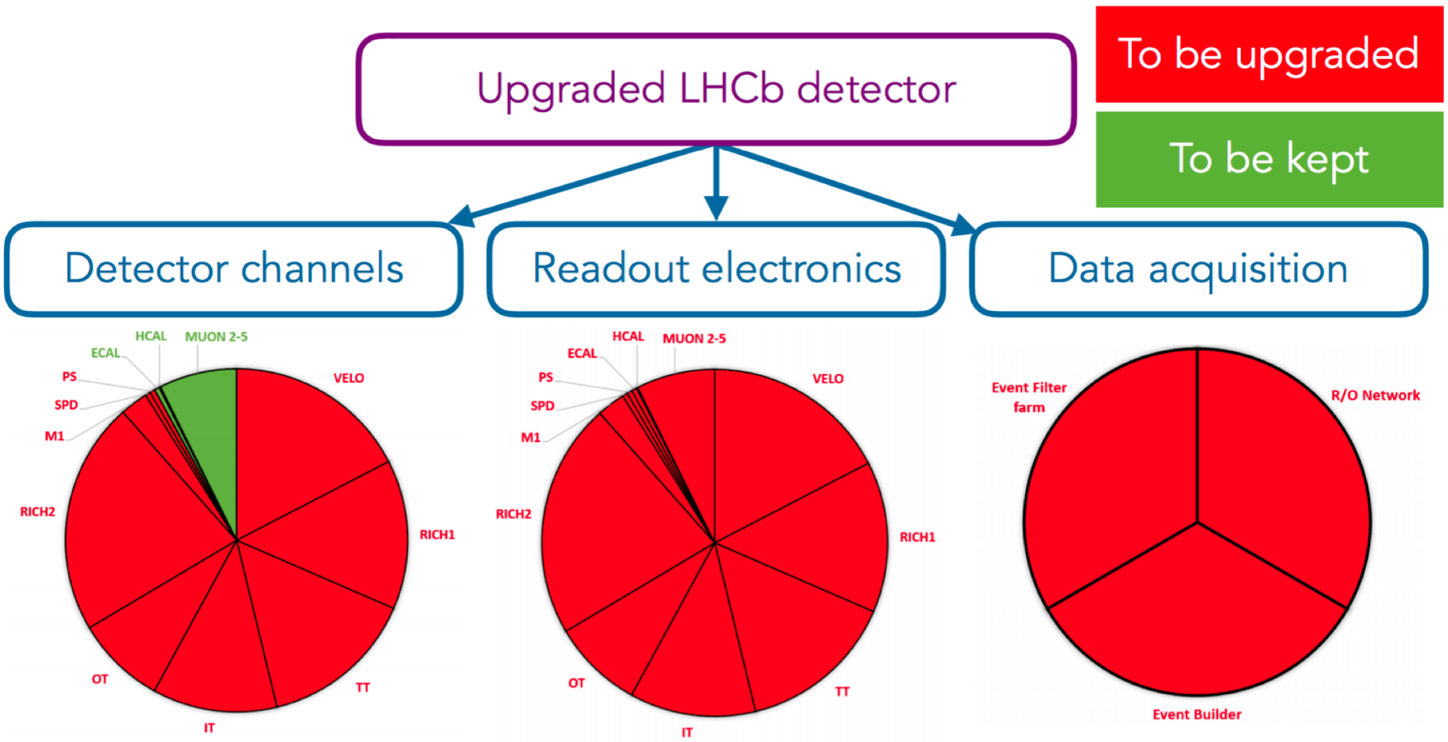
LHCb upgrades

NB: Run 3 and following steps shifted by 1 year due to COVID19

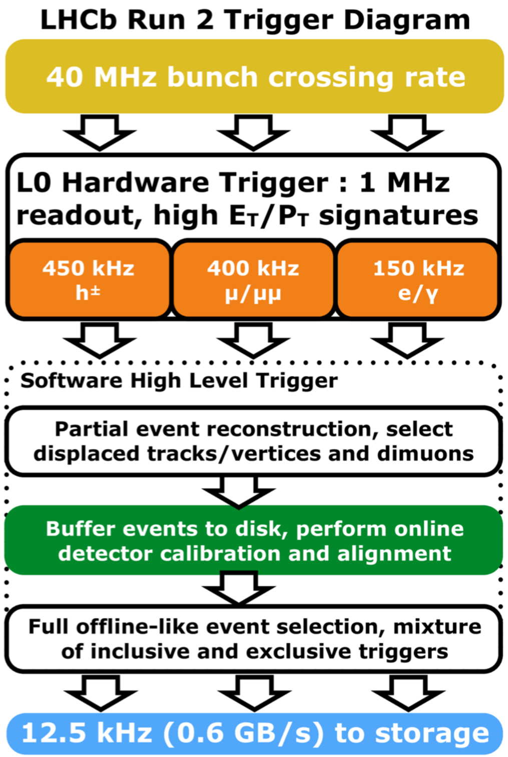
LHCb Upgrade Phase I

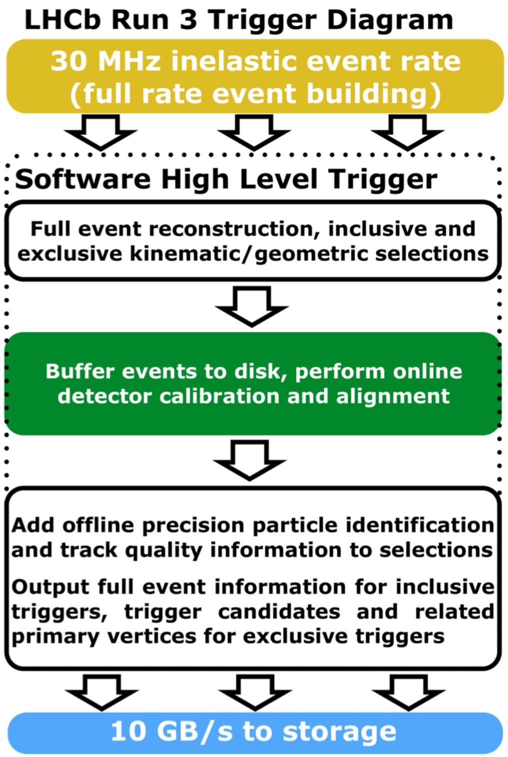


LHCb Upgrade Phase I



Full Software Trigger



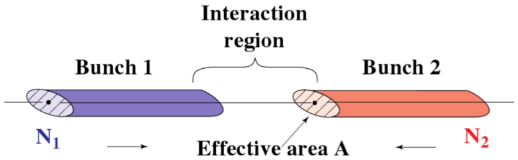


Luminosity measurement at LHCb

- Fixed-target physics started with luminosity measurements for LHCb: precise luminosity measurement is an important ingredient for many LHCb publications: cross-sections of J/ψ, $\Upsilon(1S)$, charm, beauty, ...
- Need to calibrate the luminosity measurements:
  - Using well-know processes, like $pp \to Z^0(\to\mu\mu)\,X$ but this has not good enough precision
  - Using dedicated LHC fills to measure directly the luminosity, L (per bunch):

$$L = \frac{N_1 N_2 f}{A_{eff}} = N_1 N_2 f \iint \rho_1(x,y)\,\rho_2(x,y)\,dxdy$$

  - Where f is the collision frequence, N_1, N_2 are the bunch populations, ρ_1 and ρ_2 the beam profiles

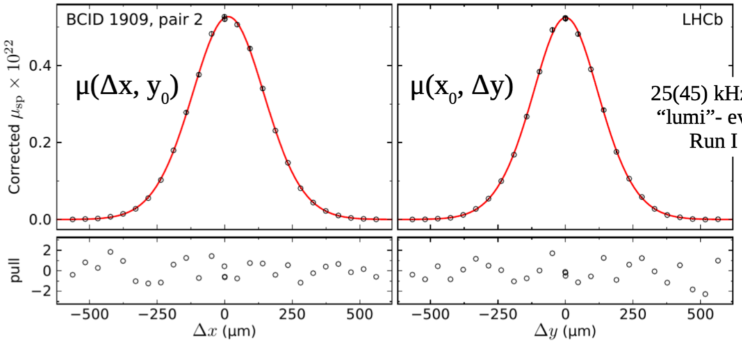


[JINST 9 P12005]

Luminosity measurement at LHCb

$$L=\frac{N_1 N_2 f}{A_{eff}}=N_1 N_2 f \iint \rho_1(x,y)\rho_2(x,y)\,dxdy$$

- N_1 and N_2 are measured by LHC beam monitors (DCCT and FBCT): more on background subtraction later
- Two methods to measure $\iint \rho_1(x,y)\rho_2(x,y)\,dxdy$
  - Traditional van der Meer scan
  - Beam gas imaging method with SMOG



25(45) kHz rate of "lumi"- events in Run I (II)

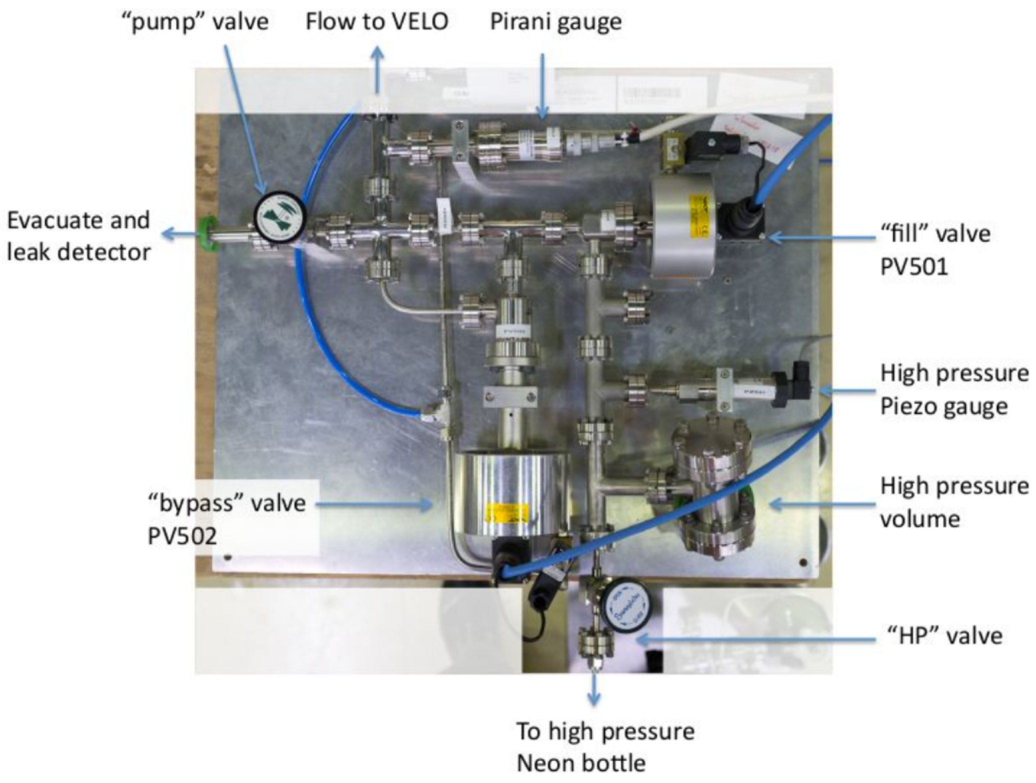
[JINST 9 P12005]

Beam Gas Imaging

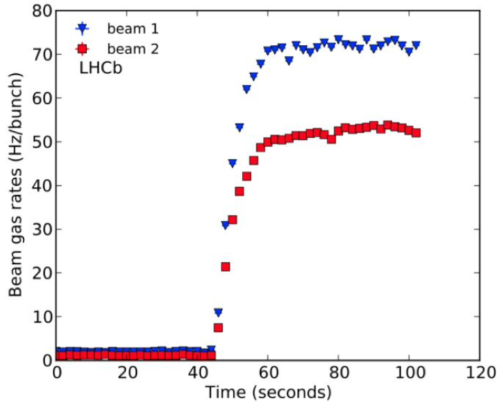
$$\iint \rho_1(x,y)\rho_2(x,y)\,dxdy$$

- Only done at LHCb: measure ρ_1 and ρ_2 from beam images reconstructed with beam-gas interactions
- First try in 2009, switch off vacuum pumps of the VELO to increase residual gas pressure at the interaction point
- From Nov 2011: inject in addition tiny amount of gas to increase statistics using a dedicated injection *System to Measure Overlap with Gas* (SMOG): x100 more interactions

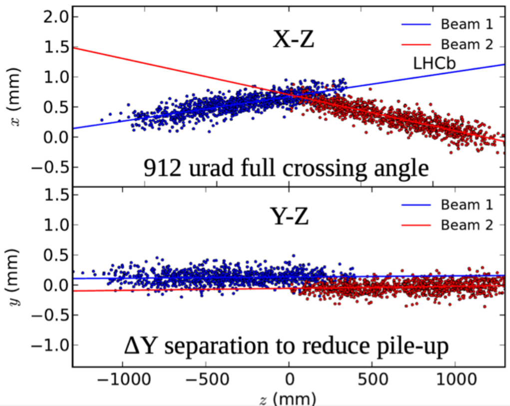
SMOG



"pump" valve
Flow to VELO
Pirani gauge
Evacuate and leak detector
"fill" valve PV501
High pressure Piezo gauge
"bypass" valve PV502
High pressure volume
"HP" valve
To high pressure Neon bottle



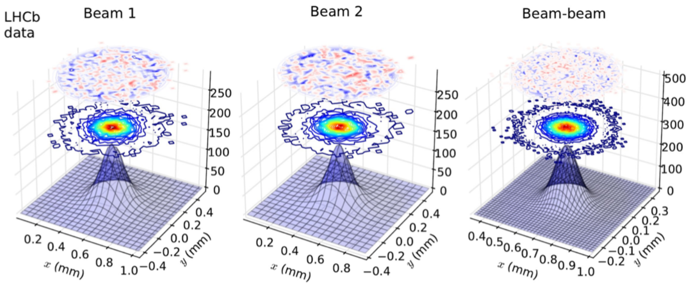
beam 1
beam 2
LHCb
Beam gas rates (Hz/bunch)
Time (seconds)
0
10
20
30
40
50
60
70
80
100
120



X-Z
Beam 1
Beam 2
LHCb
x (mm)
912 urad full crossing angle
Y-Z
y (mm)
ΔY separation to reduce pile-up
z (mm)
−1000
−500
0
500
1000

Beam Gas Imaging

- Beam profiles are folded with VELO spatial resolution, determined precisely from beam-beam collisions



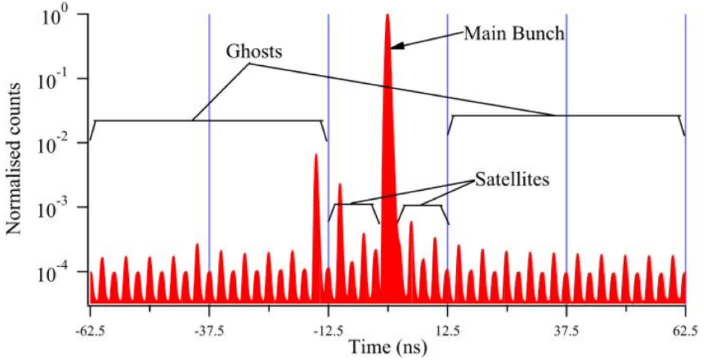
- With 8 TeV *pp* collisions, reached 1.4% precision on luminosity calibration (J. Instrum. 9 (2014) P12005)

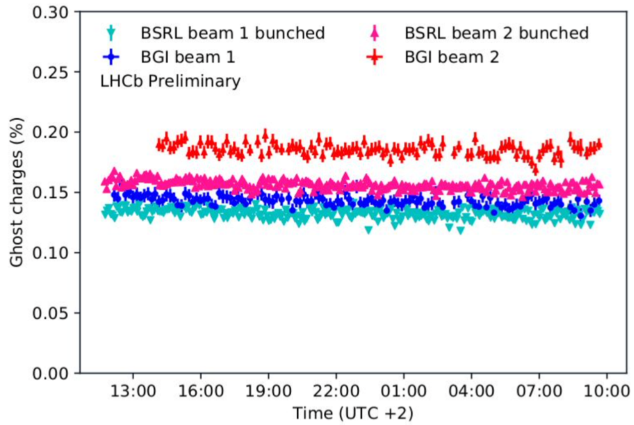
Method	σ_{vis} (mb)	Absolute calibration Weight	Uncertainty (correlated)	Relative calibration uncertainty	Total uncertainty
pp at $\sqrt{s} = 8$ TeV					
BGI	60.62 ± 0.87	0.50	1.43% (0.59%)		
VDM	60.63 ± 0.89	0.50	1.47% (0.65%)		
Average	60.62 ± 0.68		1.12%	0.31%	1.16%

[JINST 9 P12005]

Ghost-charge measurement

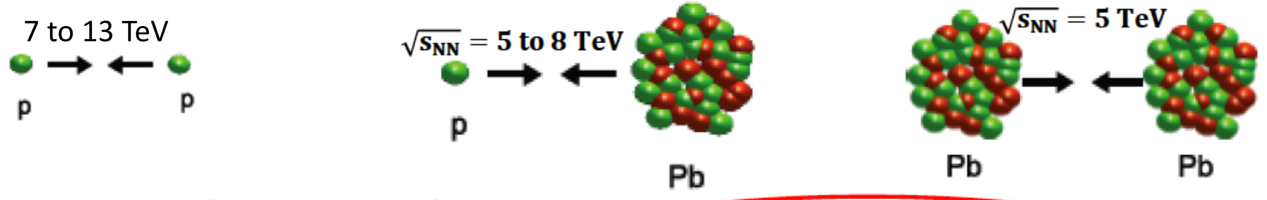
- Beam Gas Imaging is also used to measure ghost-charges during van der Meer scan sessions:
  - the results are used to subtract this background from the LHC beam monitors and used by the other LHC experiments to determine their luminosity precisely (this is one of the largest correction for them)
- Ghosts = protons in empty bunches
- Satellites: protons in filled bunches but in 2.5ns buckets ouside the main bunch (25 ns bucket)





LHCb operation modes

– Collider mode



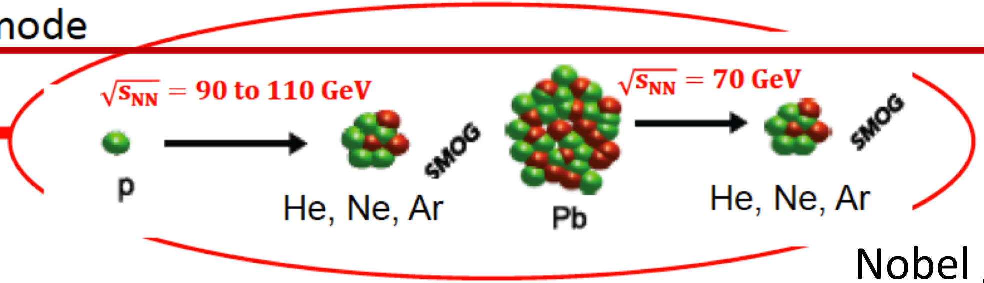
– Fixed-target mode

Unique to LHCb
Unique energies

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

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

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



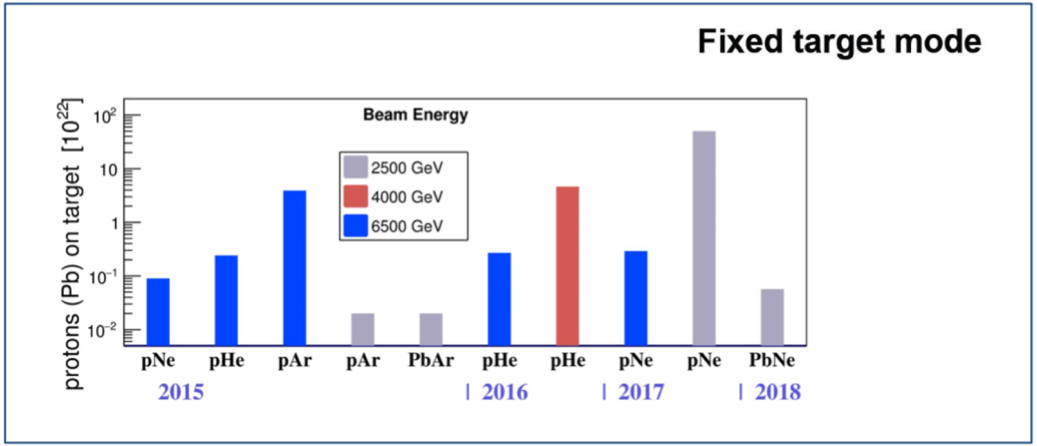
Nobel gases

LHCb rapidity 2.5 < yLHCb < 4.5 $\Rightarrow$ 7 TeV beam: $-2.3 < y^*_{LHCb} < -0.3$; 2.75 TeV beam: $-1.8 < y^*_{LHCb} < 0.2$

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

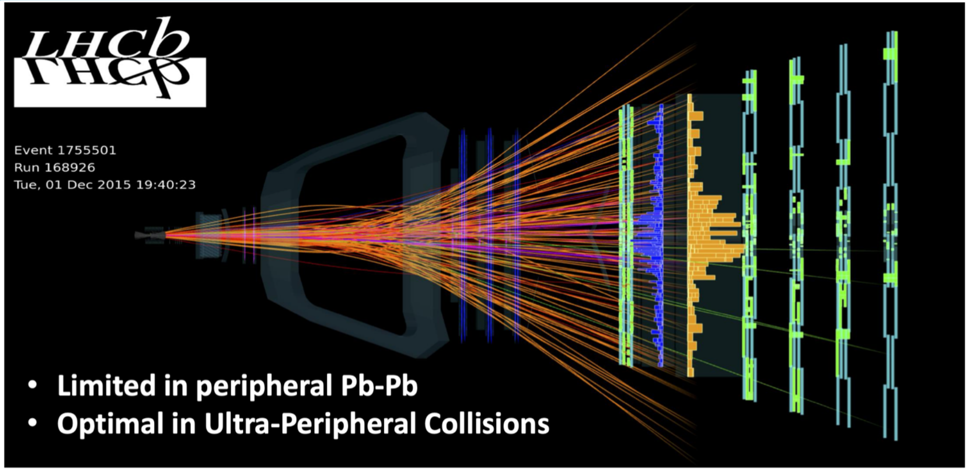
Fixed Target Physics With LHCb

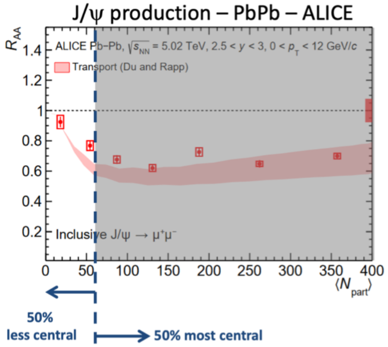
- Inject gas between 1 day and 2 weeks.
- The pressure is so low that it does not interfere with the running of the LHC and data can be collected also in parallel with *pp* collisions by LHCb.
- Operation in 2015 demonstrated that running with SMOG in completely transparent for the LHC: it is considered now as routine operation.
- During Heavy Ion runs, we also took data in parallel collisions/beam-gas.



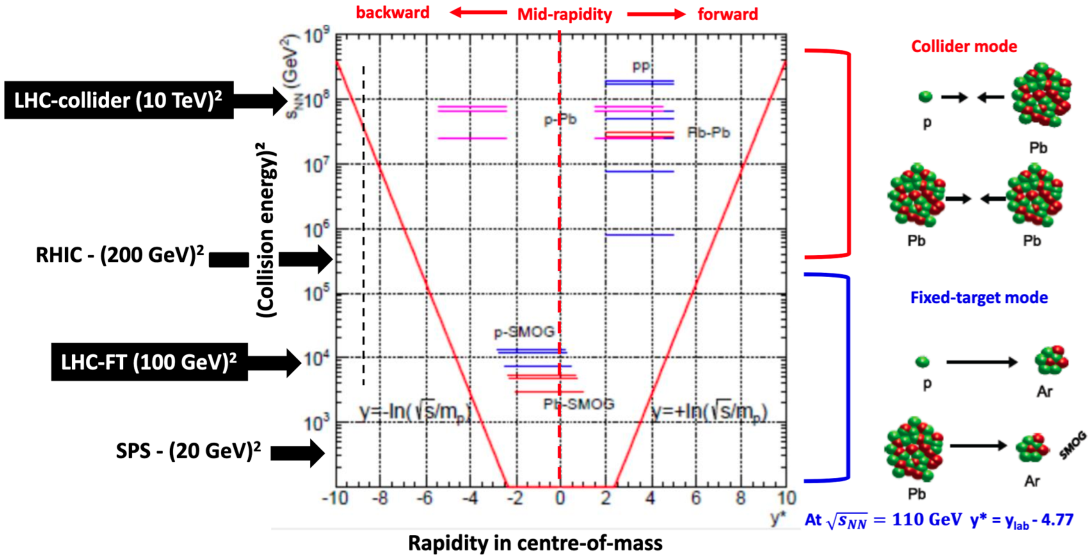
LHCb Heavy Ion Physics Program

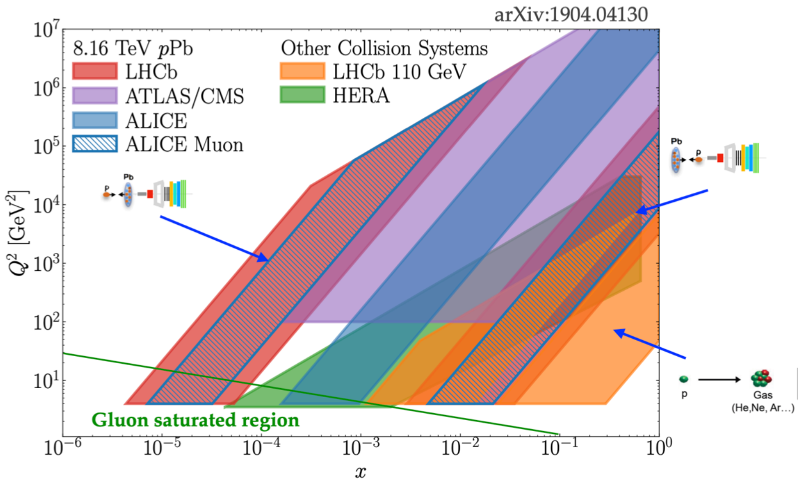
- The fixed-target is mainly connected to the LHCb QCD/Heavy Ion Physics Program.
- So far mostly concentrated on study of heavy-flavor production in *p*Pb collisions: well established performances and large statistics
- New areas emerging, that will be consolidated with the future upgrades of the detector:
  - Fixed target program (SMOG)
    - Limited for the moment by the small statistics available: fixed target data taking required dedicated time limited slots
  - PbPb collisions
    - Limited by the reach in centrality of the detector





LHCb Heavy Ion Physics Program

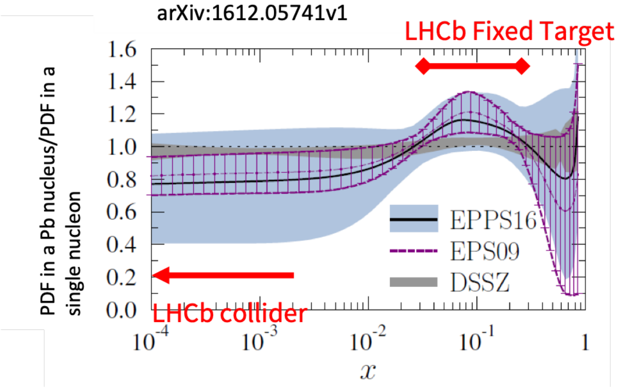




Large phase space coverage

Heavy Ion Physics with LHCb

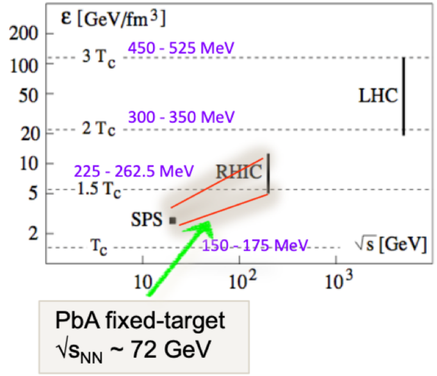
- Proton-nucleus collisions
  - Serve as a baseline for nucleus-nucleus collisions
  - Nuclear parton distribution function (nPDF), nuclear absorption, saturation, energy loss…
  - Unique capabilities with LHCb in the heavy flavor sector to constraint nPDF at very small (*p*Pb collisions – charm and beauty) and large (fixed target - charm) Bjorken-*x*



Bjorken-*x* = fraction of the nucleon momentum carried by a parton

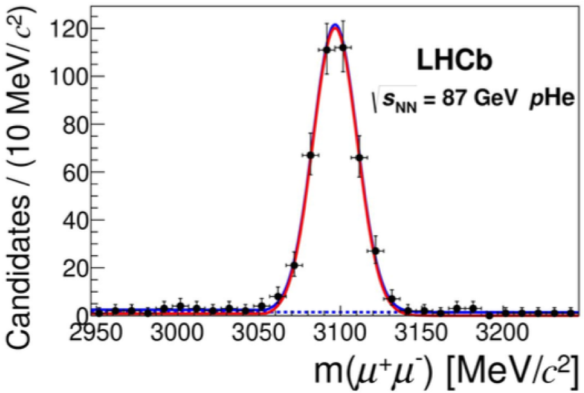
- Nucleus-nucleus collisions in FT mode
  - 2.75 TeV Pb beam on fixed target: $\sqrt{s_{NN}}$~71 GeV (close to the 17 GeV regime reached at SPS)
    - Investigate the color screening
    - Thanks to unique capabilities, LHCb offers new opportunities in the charm sector: J/ψ, ψ', χ_c, D^0, $D^{+/-}$, D^*, Λ_c… (in the 90's the NA50/SPS experiment measured only J/ψ and ψ' in PbPb @ 17 GeV)
  - Accessing similar energy density regime than SPS: operate PbAr@71 GeV, lower multiplicity than PbPb collisions, central events should be accessible

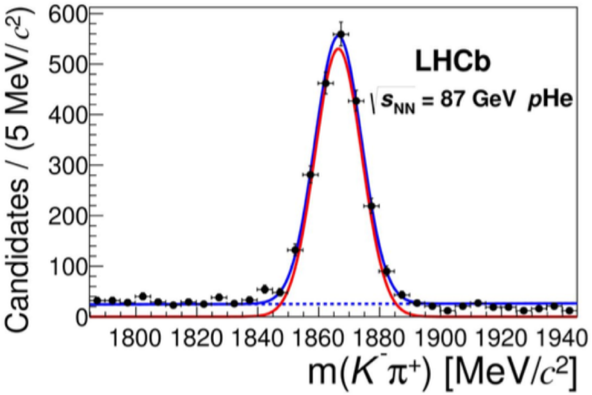
Satz, J. Phys. G32 (2006) R25



Production of charm in fixed target

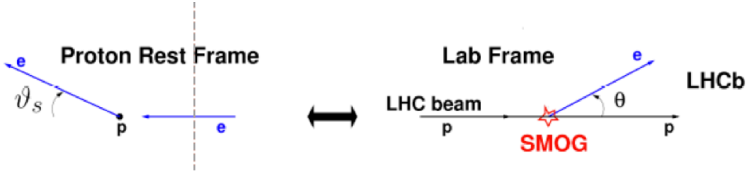
- Use two of the data samples: *p*He (4 TeV beam, 86 GeV) and *p*Ar (6.5 TeV beam, 110 GeV)
- Largest sample is *p*He, 7.6 ± 0.5 nb
- Measurement of prompt production of J/ψ ($\rightarrow\mu^+\mu^-$) and D^0($\rightarrow K\pi$)

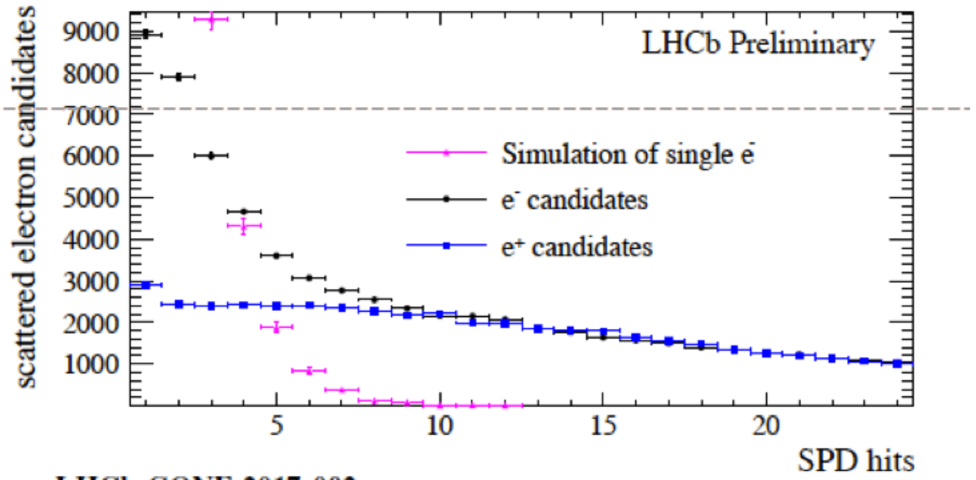




Fixed-target luminosity

- Use p-e- elastic scattering (Mott)
- Pro:
  - Only elastic regime in LHCb acceptance:
    - θ>10 mrad → θ_s< 29 mrad, Q^2<0.01 GeV^2
    - Cross-section very well-known
  - Clear event signature: single low p_T electron track and nothing else
  - Background comes mainly from conversions: it is charge-symmetric and can be estimated precisely from single positron events
- Cons:
  - Small cross-section (1000 less than hadronic cross-section)
  - Low momentum electrons = low acceptance and reconstruction efficiency

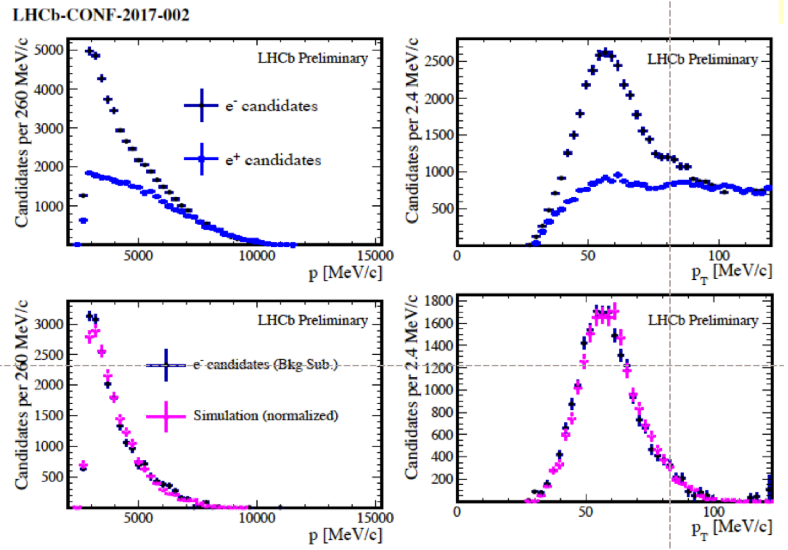




LHCb-CONF-2017-002

Fixed-target luminosity

- Electron spectra in very good agreement with simulation
- Data confirm charge symmetry of background
- Systematic from variations of selection cuts: largest dependency is on azimuthal angle



$$\mathcal{L} = 0.443 \pm 0.011 \pm 0.027\,\mathrm{nb}^{-1}$$

(*p*He at 110 GeV)

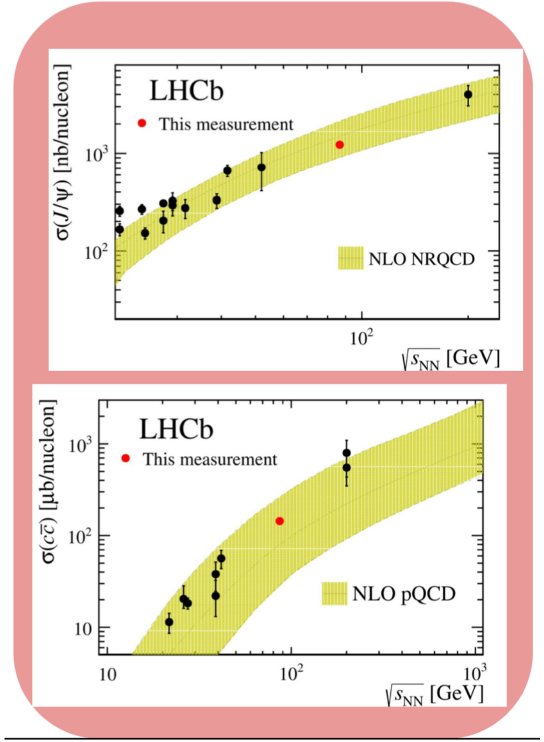
- Equivalent to gas pressure of $2.4\text{x}10^{-7}$ mbar, as expected

[PRL 122 (2019) 132002]

Production of charm in fixed target

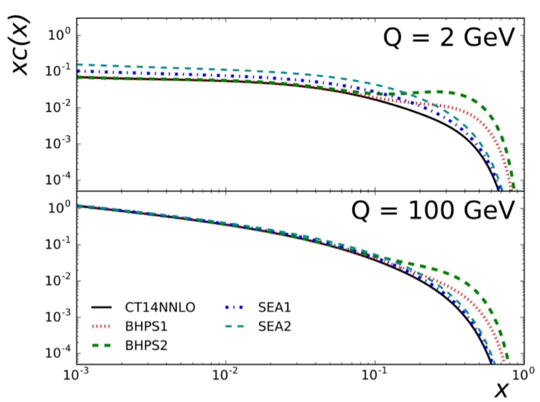
- Measured cross-sections are extrapolated to the full phase space (4π) and in the case of the D^0, to the full $c\bar{c}$ spectrum (using $f(c \to D^0)$ from external measurements)
- Compared to
  - Previous measurements at lower and higher energies
  - Predictions from NLO NRQCD for J/ψ [PLB 638 (2006) 202] and NLO pQCD for $c\bar{c}$ [NPB 373 (1992) 295]

$$\sigma_{J/\psi} = 652 \pm 33(\text{stat}) \pm 42(\text{syst})\ \text{nb/nucleon},$$
$$\sigma_{D^0} = 80.8 \pm 2.4(\text{stat}) \pm 6.3(\text{syst})\ \mu\text{b/nucleon}.$$

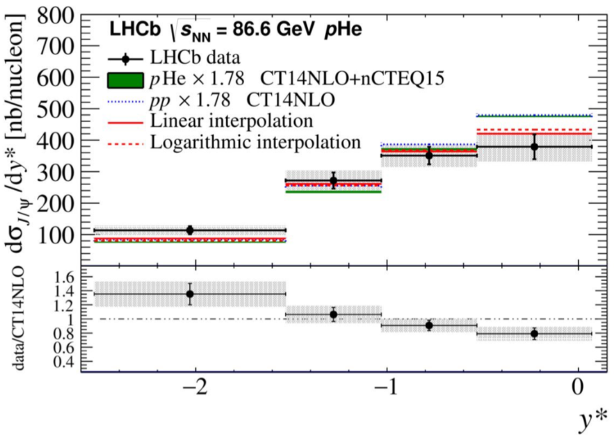


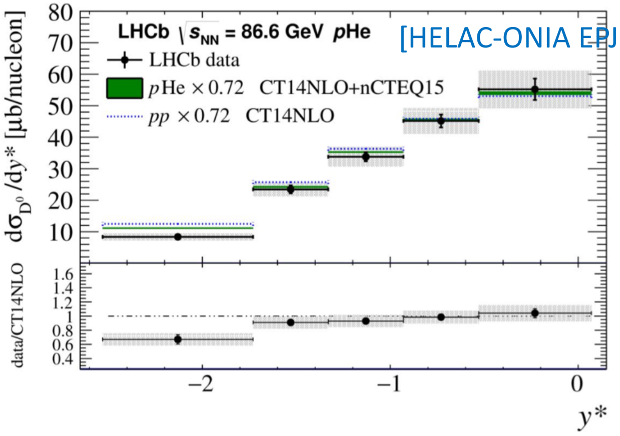
Production of charm in fixed target

- Cross-section as a function of rapidity (y^*) and p_T to test intrinsic charm content of proton (would be seen as increase of cross-section at negative rapidities compared to predictions)



Phys Rev **D93** (2016) 074008

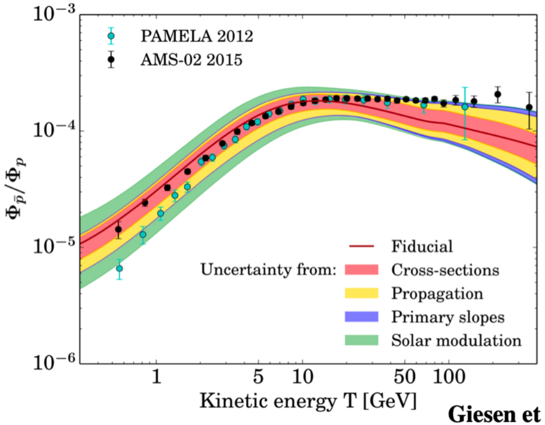




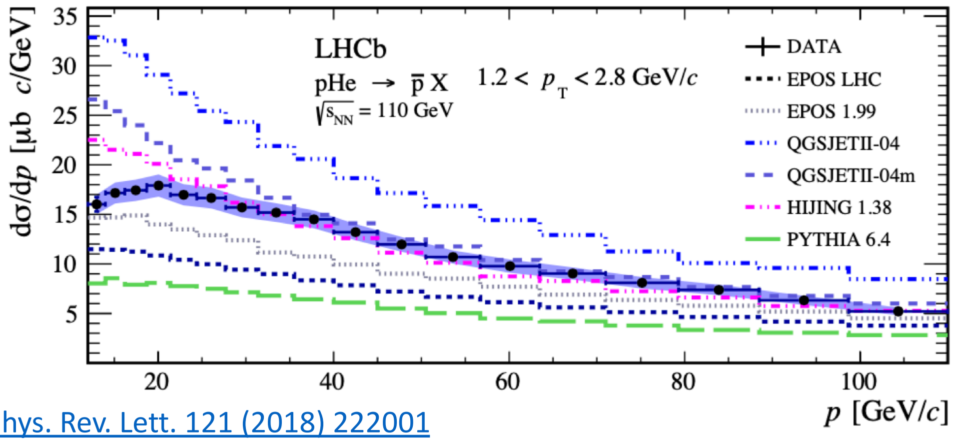
[HELAC-ONIA EPJC 77 (2017) 1]

SMOG: anti-protons in pHe collisions at 110 GeV

- Interesting to reduce uncertainties on anti-proton production in inter-stellar medium: $p\text{He} \rightarrow \bar{p}X$ is ~40% of secondary cosmic anti-proton



Giesen et al., JCAP 1509, 023



Phys. Rev. Lett. 121 (2018) 222001

EPOS LHC PRC92 (2015) 034906
EPOS 1.99 Nucl.Phys.Proc.Suppl. 196 (2009) 102
QGSJETII-04 PRD83 (2011) 014018
QGSJETII-04m Astr. J. 803 (2015) 54
HIJING 1.38 Comp. Phys. Comm. 83 307
PYTHIA 6.4 (2pp + 2pn) JHEP 05 (2005) 026

SMOG2

- SMOG proved that a fixed target physics program at LHCb works, but has limitations:
  - Fixed target data taking was mostly done during dedicated short runs, at maximum during 1 continous week: low statistics
  - The pressure of the injected gas is limited because the gas flow is not contained and goes into the LHC beam pipe
  - Changing types of gases is a long operation: requires an acces close to the VELO, i.e. stopping the LHC operation
  - The position of the interactions is distributed along a large area: strong variations of the detector efficiency as a function of that position
- To address all these difficulties: upgrade of SMOG system = SMOG2

European Strategy Briefing Document

- "The LHCb Upgrade II… will enable a wide range of flavour observables to be determined at HL-LHC with unprecedented precision”
- Including ion and fixed target program at LHCb
- “For heavy-ion studies, the proposed fixed-target experiments with LHCb and ALICE enable the exploration of new energy regimes…and the use of new physics probes…to test the factorisation of nuclear effects.”

LHC Heavy Ion Schedule

LHC: LS2 - LHCb upgrade Ia → Run3 → LS3 - LHCb upgrade Ib

HL-LHC: Run4 → LS4 - LHCb upgrade 2 → Run5

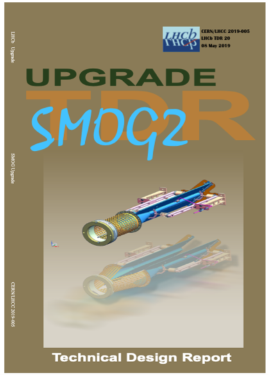
arXiv:1812.06772 - CERN-LPCC-2018-07

Year	Systems, $\sqrt{s_{NN}}$	Time	L_{int}
2021	Pb–Pb 5.5 TeV	3 weeks	2.3 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2022	Pb–Pb 5.5 TeV	5 weeks	3.9 nb^{-1}
	O–O, p–O	1 week	500 μb^{-1} and 200 μb^{-1}
2023	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2027	Pb–Pb 5.5 TeV	5 weeks	3.8 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2028	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2029	Pb–Pb 5.5 TeV	4 weeks	3 nb^{-1}
Run-5	Intermediate AA	11 weeks	e.g. Ar–Ar 3–9 pb^{-1} (optimal species to be defined)
	pp reference	1 week	

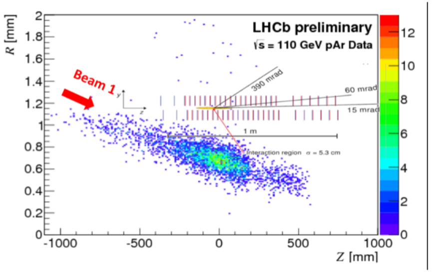
LHCb is very well placed to have a **decisive contribution** to Heavy Ion Physics **in LHC run 3 and HL-LHC**

- **Best placed in pp and pPb** at forward rapidity
  - In pPb/Pbp: $\mathcal{L}$ ~ 30 nb^{-1} in run 2 (~1M J/ψ, ~8M D^0) ➔ $\mathcal{L}$ ~ 300 nb^{-1} in run 3 + 300 nb^{-1} in run 4
- **Well placed** (less limited) **in PbPb** at forward rapidity
  - Will benefit from **detector upgrade**
- Start **full physics** program in **fixed-target** mode
  - Will benefit from target and detector upgrade

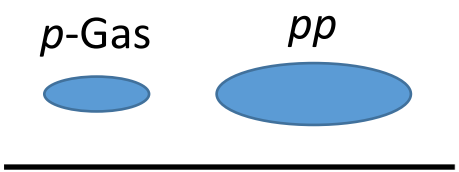
SMOG2



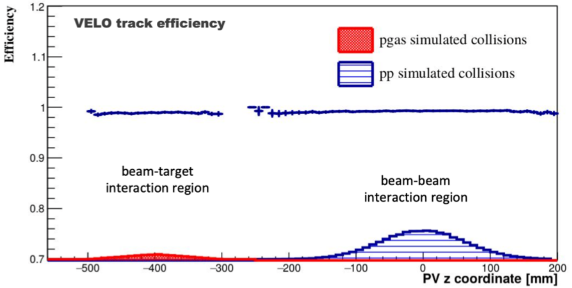
- New storage cell installed at LHCb to boost significantly the fixed target program
- Increase of the luminosity by up to 2 orders of magnitude using the same gas load as SMOG
- *Possibility to inject H2, D2, He, N2, O2, Ne, Ar, Kr, Xe* with multiple gas lines
- New Gas Feed System. Gas density (luminosity) measured with greatly improved precision (few %)
- Well defined interaction region upstream the nominal IP: strong background reduction, no mirror charges effect, possibility to use all the bunches. *pp* and *p*-Gas simultaneous data taking may be possible thanks to software trigger.
- In beam-beam slots:



SMOG



SMOG2



SMOG2

Gas species	He	Ne	Ar	Kr	Xe	H_2	D_2	N_2	O_2
SMOG2 areal density (10^{12} atoms/cm^2)	10	10	10	5	5	10	10	10	10
Intensity (10^{15} particles/s)	5.80	2.58	1.82	1.36	1.01	4.08	2.89	1.09	1.03
Flow rate (10^{-5} mbar $\cdot$ l/s)	21.4	9.6	6.8	4.68	3.75	15.02	10.07	4.05	3.83
SMOG areal density (10^{12} atoms/cm^2)	0.92	0.41	0.29	0.20	0.16	1.30	0.92	0.35	0.33
SMOG2/SMOG	10.9	24.4	34.5	25.0	31.3	7.7	10.9	28.6	30.3

- Noble gases He, Ne, Ar were already used with SMOG
- Need simulations to assess feasibility from LHC point of view to inject:
  - Kr, Xe: risk of accumulation at the warm-cold transitions, and outgasing at injection
  - H_2, D_2: degradation of NEG (non-evaporable getter) coating of LHC vacuum chambers
- Collision rates expected compared to *pp*:

$$\frac{R_{H_2}}{R_{pp}} = \frac{\sigma_{pH_2}(115\ GeV) \cdot L_{SMOG2}}{\sigma_{pp}(14\ TeV) \cdot L_{pp}} \simeq 1.3\%,$$

$$\frac{R_{Ar}}{R_{pp}} = \frac{\sigma_{pAr}(115\ GeV) \cdot L_{SMOG2}}{\sigma_{pp}(14\ TeV) \cdot L_{pp}} \simeq 10.6\%.$$

- Negligible impact on beam lifetime:

Beam	Target Gas	σ_{loss} (barn)	τ_{loss} (days)	Relative loss in 10 h
p	H	0.05	2060	0.02 %
p	Ar	1.04	97	0.4 %
Pb	Ar	4.63	22	1.9 %

SMOG2 statistics

- For 1 year of data taking during Run 3:
- Instantaneous luminosity measurement: precision of 2% expected on integrated luminosity

$$L_{ist} = \theta \; N_p \; f_{rev}$$

areal density

number of particles

$$N_{p/b} \cdot N_b$$

$$\rho_0 \frac{L}{2} = \frac{\Phi}{C} \frac{L}{2}$$

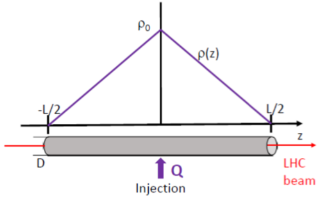
$$C = 3.81 \sqrt{\frac{T}{M}} \frac{D}{L + \frac{4}{3} D}$$

f_{rev}: beam revolution frequency
$N_{p/b}$: number of particles per bunch
N_b: number of bunches
ρ_0 : target density at the cell center
Φ: gas flow
θ : areal density
C= total conductance
D: cell diameter
L: cell length
T: temperature
M: molecular mass

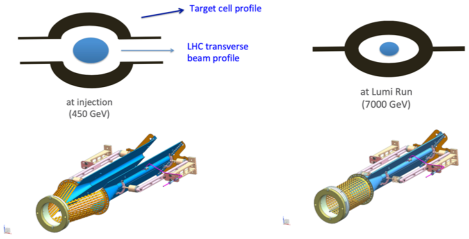
	pAr
J/Ψ	28 M
D^0	280 M
Λ_c^+	3 M
$\Psi(2S)$	5 M
$\Upsilon(1S)$	24 k
$DY_{low\ mass}$	24 k

SMOG2 storage cell

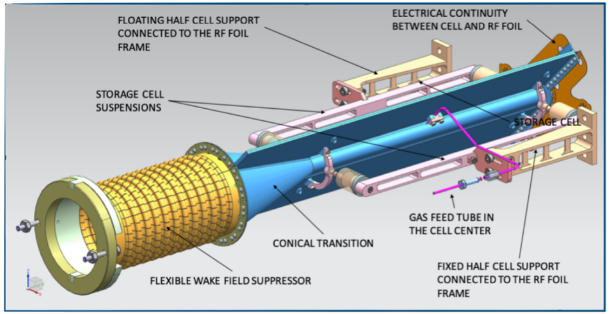
- The storage cell is a tube (20 cm length, 1 cm diameter) where the gas is injected at the center from a gas-feed system



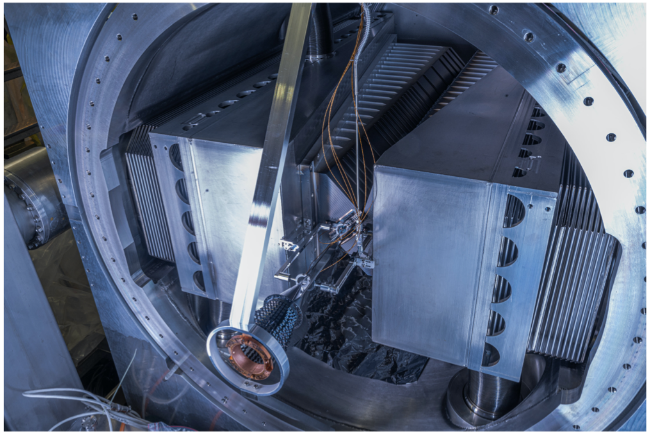
- Similarly to the VELO, the cell must be opened when the beam is not stable (at 3 cm)



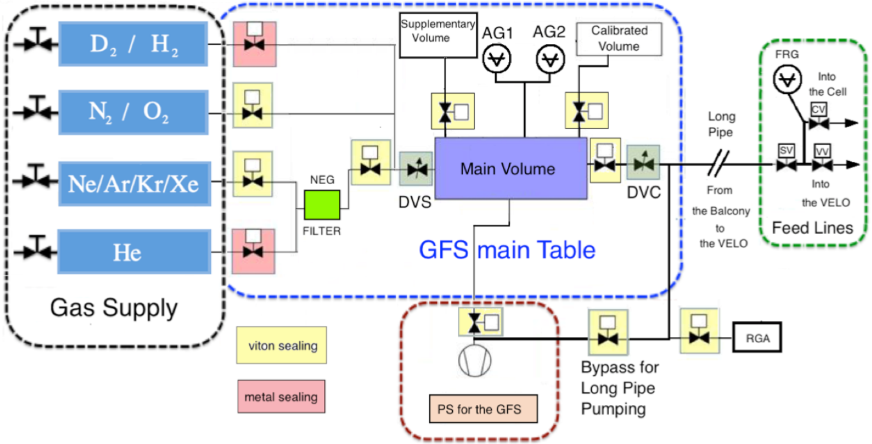
Solution adopted for SMOG2: L = 20 cm, R = 0.5 cm
for LHCspin: L = 30 cm, R = 0.5 cm



Installed in August 2020



Gas feed system for SMOG2



To be installed in 2022

Will give the possibility to change types of gas dynamically, and to measure the purity

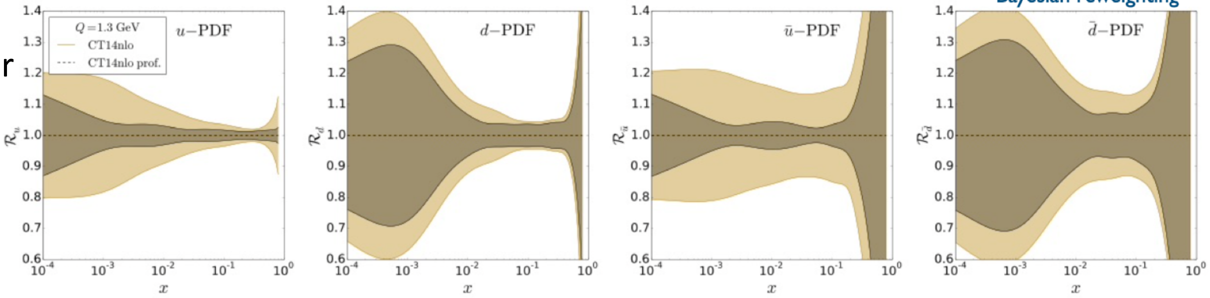
SMOG2: High x physics

Reduction of PDF uncertainties crucial for Beyond Standard Model searches

arXiv:1807.00603

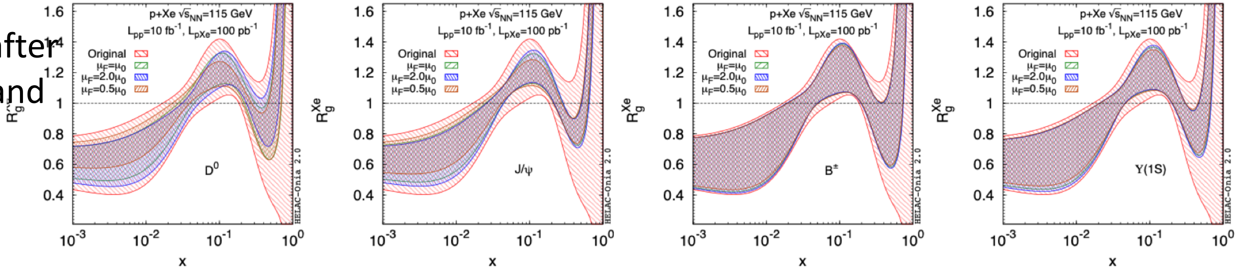
PDF uncertainties before and after including estimated Drell-Yan production SMOG2 data (Q= 1.3 GeV)

Bayesian reweighting



PDF

nPDF uncertainties before and after including estimated D^0, J/ψ, B^+ and $\Upsilon(1S)$ production SMOG2 data



nPDF (gluon)

Unique constraints on gluon nPDFs at high-x and low scales

SMOG2: Cosmic rays

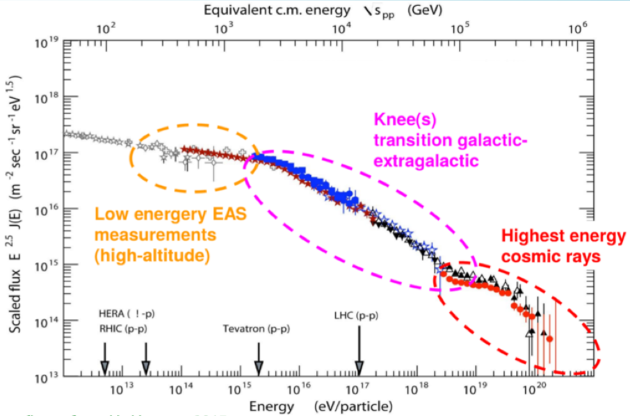


figure from H. Haungs, 2015

UHE CR composition (that unfortunately is inferred from comparison data/theory, instead of from just data) is still very uncertain!

Solving the **composition problem** would be important to understand the CR production mechanisms

All these find **crucial inputs from LHC data (FT)**:

-proton PDF fits (from pp collisions)

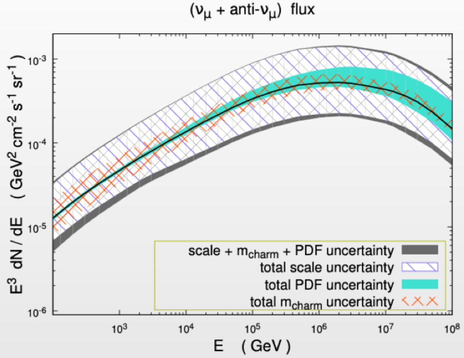
-validation of the theory used to describe charm hadroproduction

-cold and hot nuclear matter effects (in pA and AA collisions) 13

Primary interaction creates pions, kaons, nucleons, Λ, … which then propagate and interact with other nuclei of the atmosphere or decay

Heavier hadrons (D, …) are also created, but do not propagate significantly decaying immediately instead

PROSA prompt $(\nu_\mu + \bar{\nu}_\mu)$ flux:
QCD scale, mass and PDF uncertainties



from [arXiv:1611.03815]

M.V.Garzelli's talk

LHCb for CR
Antiproton production in p-He collisions @ 110 GeV, PRL121, 222001 (2018) (arXiv:1808.06127)

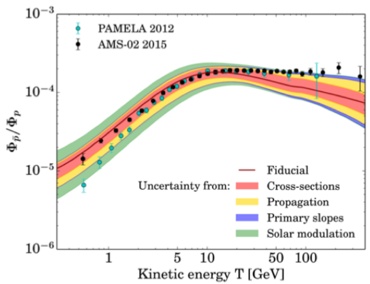
SMOG2: Cosmic rays

from Martin W. Winkler (Stockholm University) talk

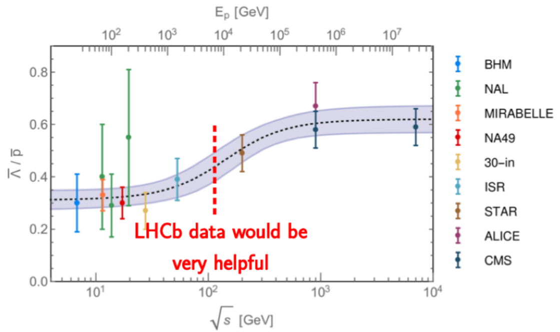
Antiproton issue: Dark Matter annihilation (primary), scatter on interstellar matter (secondary)

$$\sigma = \sigma^0_{\bar{p}} + \sigma^{\Lambda}_{\bar{p}} + \sigma^0_{\bar{n}} + \sigma^{\mathrm{Hep,pHe,HeHe}}$$

- $\sigma^0_{\bar{p}}$: measure + scaling
- $\sigma^{\Lambda}_{\bar{p}}$: ignored
- $\sigma^0_{\bar{n}}$: $= \sigma^0_{\bar{p}}$ assumed
- $\sigma^{\mathrm{Hep,pHe,HeHe}}$: MC or simple scaling factors

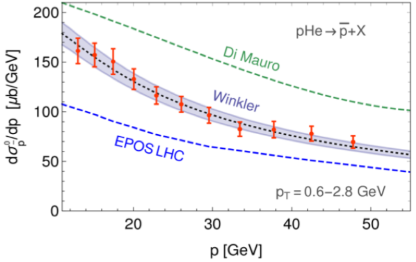


- increase of strangeness with collision energy



- first ever measurement by LHCb-SMOG

Phys.Rev.Lett. 121 (2018)



Wishlist for fixed target measurements at LHCb

1) p He $\rightarrow \bar{\Lambda}, \bar{\Sigma}$ from existing run
2) p p (H_2) $\rightarrow \bar{p}$ to test scaling violation in forward hemisphere
3) p d $\rightarrow \bar{p}$ to test isospin effects
4) p p, p He $\rightarrow \bar{d}, \bar{He}$ to determine coalescence momentum
5) p p, p He $\rightarrow \pi$, K to model positron source term

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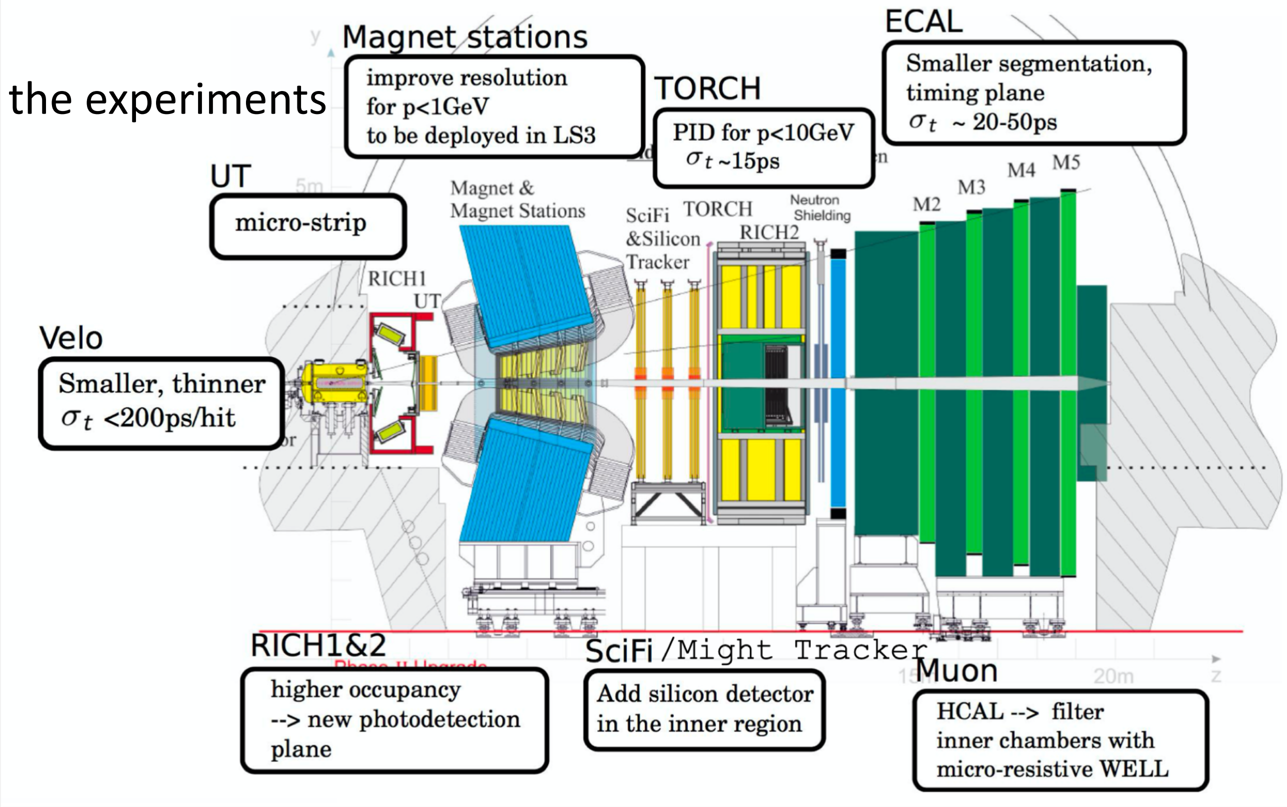
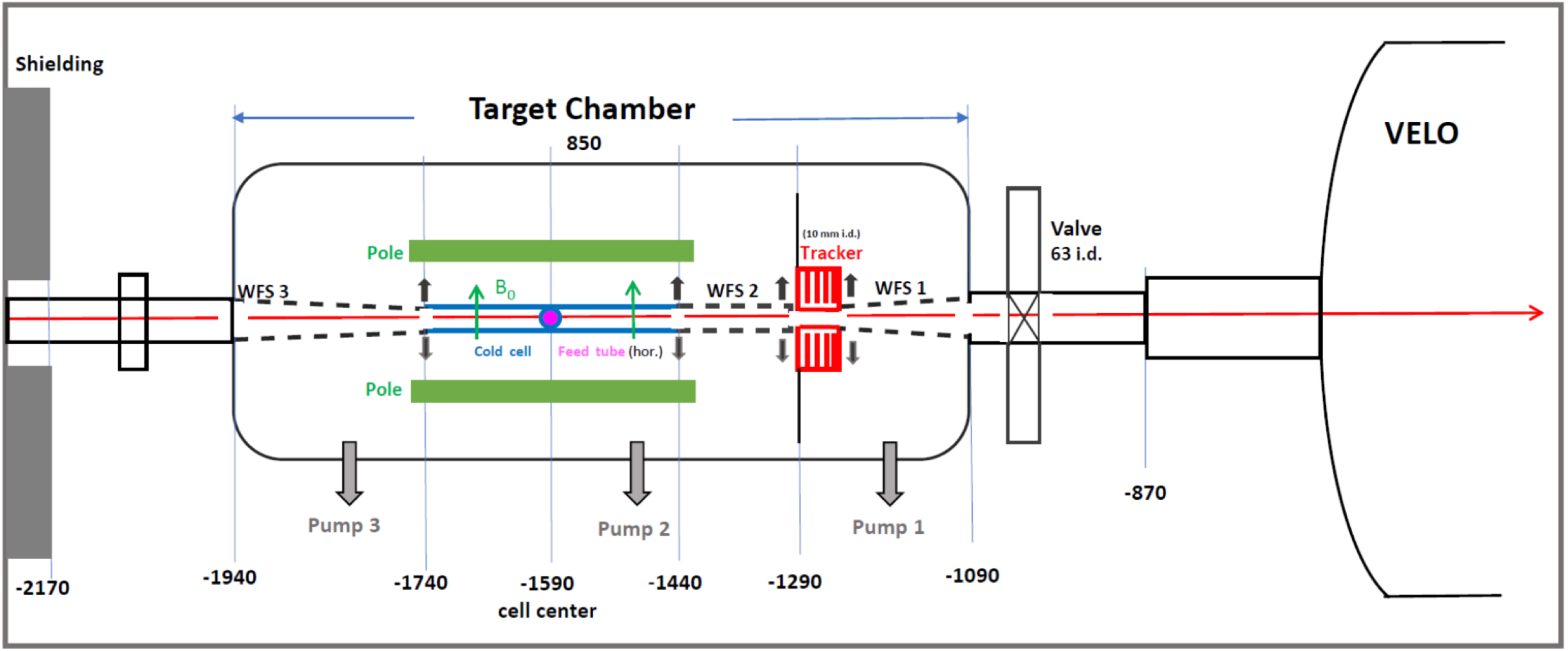
Upgrade Ib and II

Changes to all parts of the experiments



Polarized Gas Target Topology

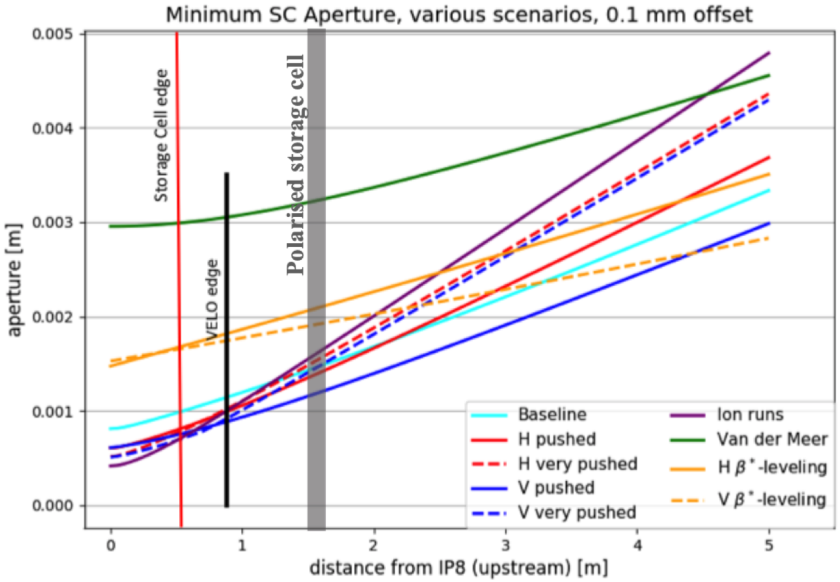


spin

Phase II transversely polarised H and D target

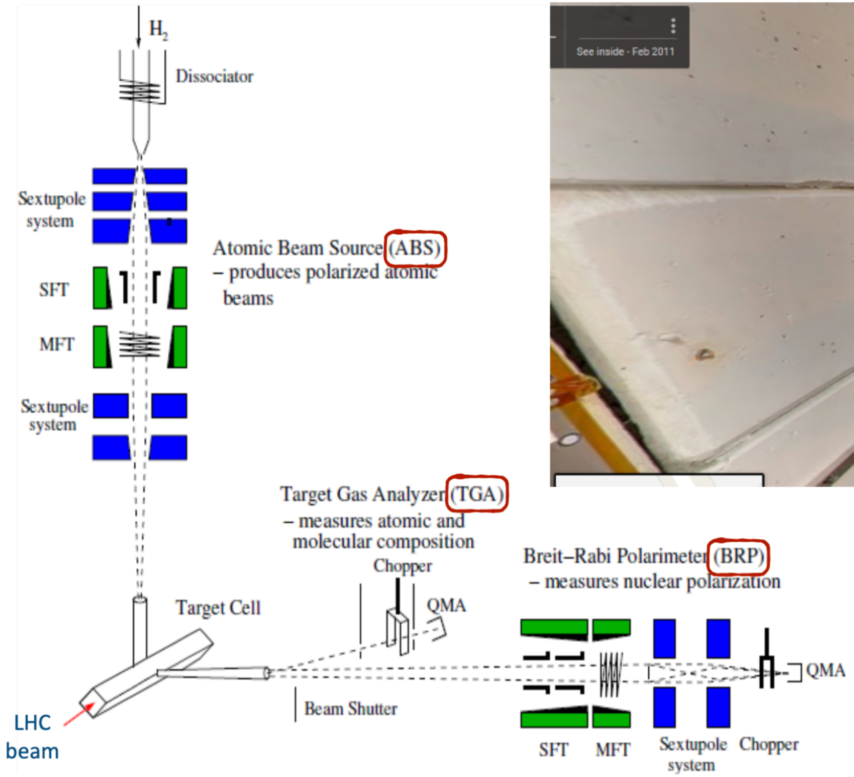
Polarized Gas Target: Luminosity

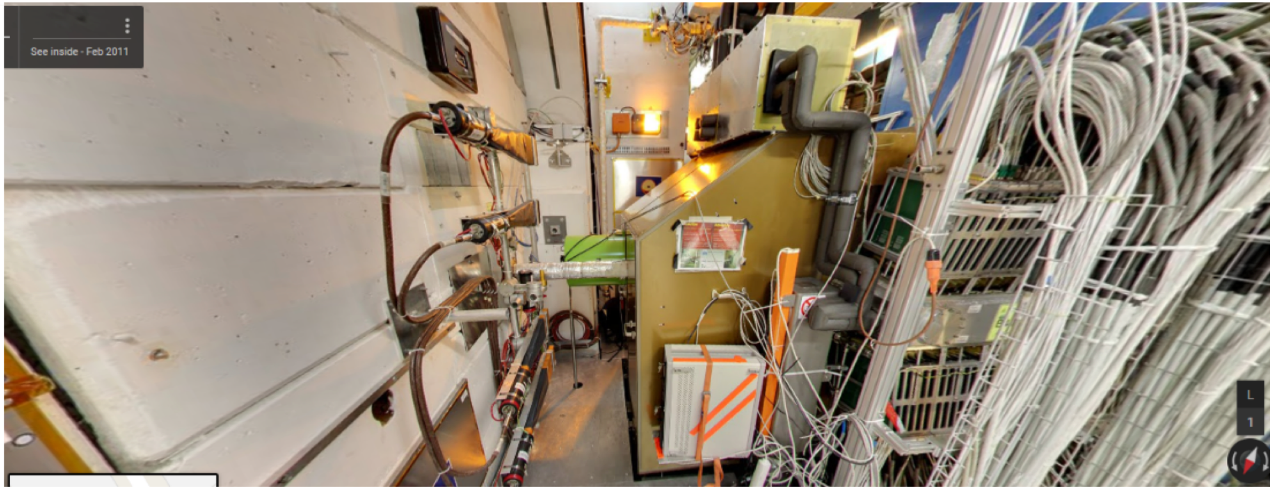
- Driven by aperture of the beam which limits the size of the target



- R = 0.5 cm, L = 30 cm means target density 1.2×10^{14} cm^{-2}
- At High Luminosity LHC, fixed target luminosity can reach $L=8.3\times10^{32}$ $cm^{-2}.s^{-1}$
- Impact on the LHC beam lifetime less than 1%

Polarized Gas Target

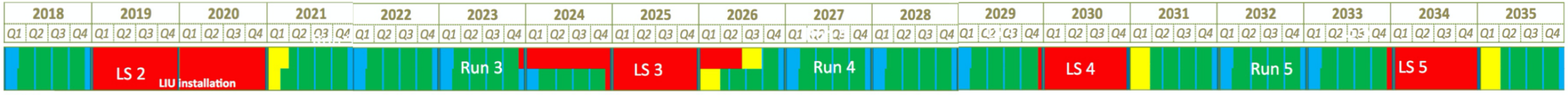




Space in front of LHCb ~1.5 m

Polarized Gas Target

- R&D already started at INFN Frascati, Ferrara, Erlangen, Julich, PNPI
- Groups interested in Italy, France (IJCLab, LLR, Saclay), Michigan, Los Alamos, MIT, PSI
- Budget: 2 – 4 MEuros



SMOG2

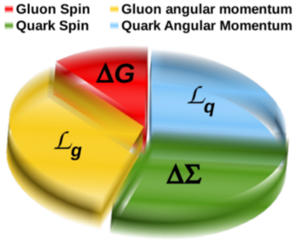
Polarized Gas Target

or

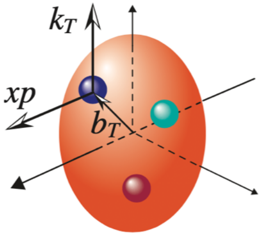
Vacuum chamber + ABS and diagnostic during YETS

Physics with polarized gas target

- Understand the spin of the proton and its content beyond PDFs



Composition



Tomography

(TMD: transverse momentum distribution)

[D. Boer: arXiv:1611.06089]

Weizsacker-Williams (WW) gluon distributions

dipole (DP) gluon distributions

Unpolarized gluon TMD

	DIS	DY	SIDIS	$pA \to \gamma \, \text{jet} \, X$	$e\,p \to e' \, Q\bar{Q}\, X$ $e\,p \to e' \, j_1 \, j_2 \, X$	$pp \to \eta_{c,b}\, X$ $pp \to H\, X$	$pp \to J/\psi\, \gamma\, X$ $pp \to \Upsilon\, \gamma\, X$
$f_1^{g\,[+,+]}$ (WW)	×	×	×	×	√	√	√
$f_1^{g\,[+,-]}$ (DP)	√	√	√	√	×	×	×

unpolarized gluon TMD

Polarized gluon TMD

	$pp \to \gamma\, \gamma\, X$	$pA \to \gamma^* \, \text{jet} \, X$	$e\,p \to e' \, Q\bar{Q}\, X$ $e\,p \to e' \, j_1 \, j_2 \, X$	$pp \to \eta_{c,b}\, X$ $pp \to H\, X$	$pp \to J/\psi\, \gamma\, X$ $pp \to \Upsilon\, \gamma\, X$
$h_1^{\perp\, g\,[+,+]}$ (WW)	√	×	√	√	√
$h_1^{\perp\, g\,[+,-]}$ (DP)	×	√	×	×	×

linearly polarized gluon TMD

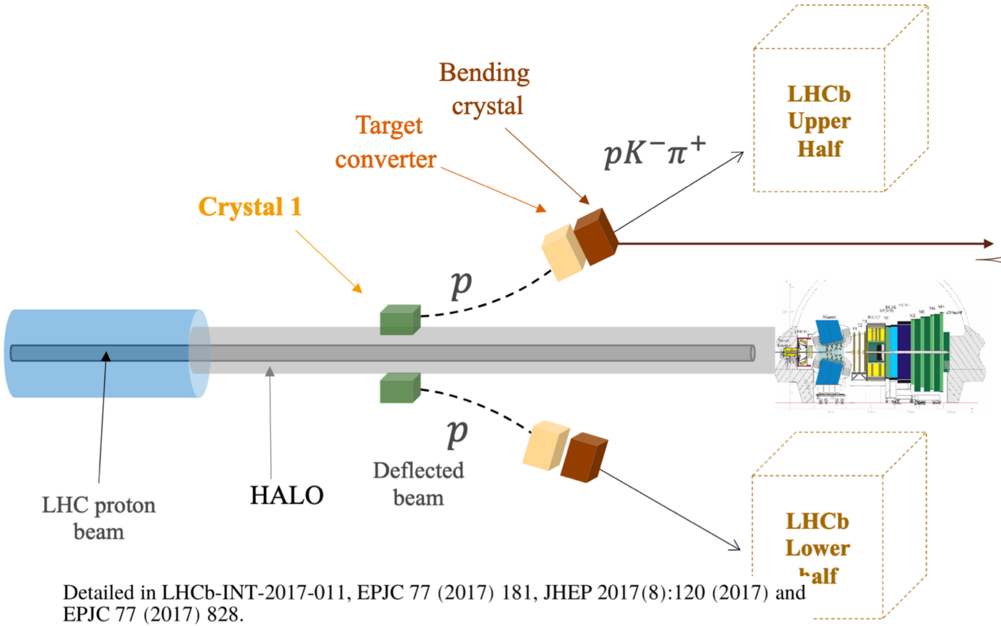
Can be measured at the Electron Ion-Collider (EIC)

Can be measured at the LHC, in particular at LHCb

[EPJC 77 (2017) 181]
[JHEP 8 (2017) 120]
[EPJC 77 (2017) 828]

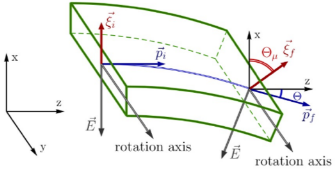
Target with crystals: SELDOM project

- Measurement of charm quark MDM and EDM via spin precession of Λ_c baryons produced in a fixed target, using crystals



Detailed in LHCb-INT-2017-011, EPJC 77 (2017) 181, JHEP 2017(8):120 (2017) and EPJC 77 (2017) 828.

$$\Theta_\mu \approx \gamma \left(\frac{g}{2} - 1\right) \Theta$$



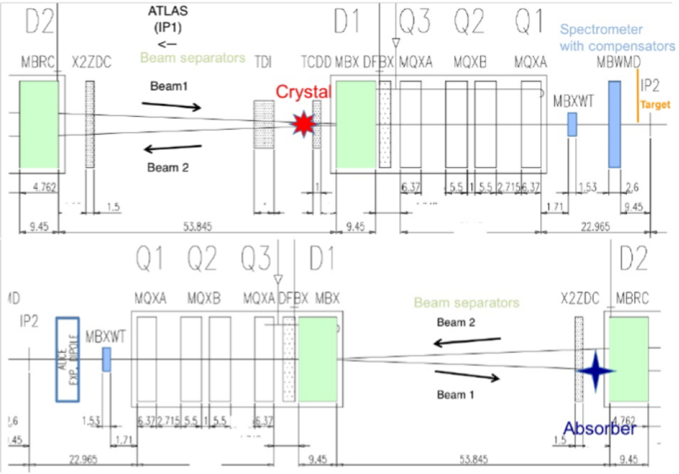
Need initial ($\overrightarrow{\xi_i}$) and final ($\overrightarrow{\xi_f}$) Λ_c^+ polarization

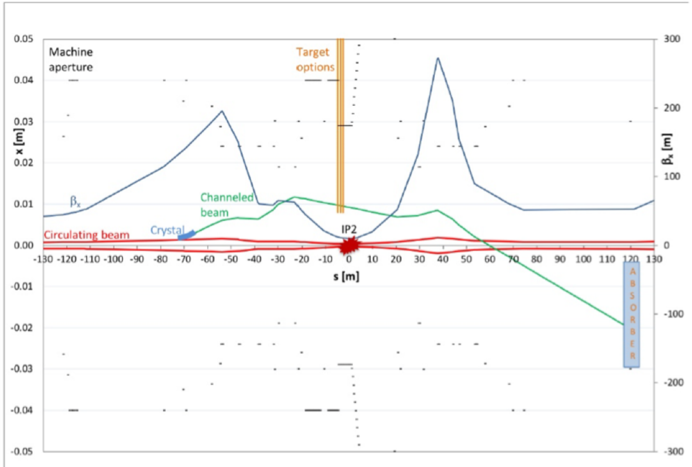
$\overrightarrow{\xi_i}$: Produce polarized baryons using a target-crystal before the bending crystal

$\overrightarrow{\xi_f}$: Measured using dedicated experiment or LHCb

Fixed target in ALICE

- Particles from beam halo + solid target inside ALICE:
  - Halo particles deflected by bent crystal (70m upstream of ALICE) sent on a solid target
  - Particles not interacting with the target need to be absorbed



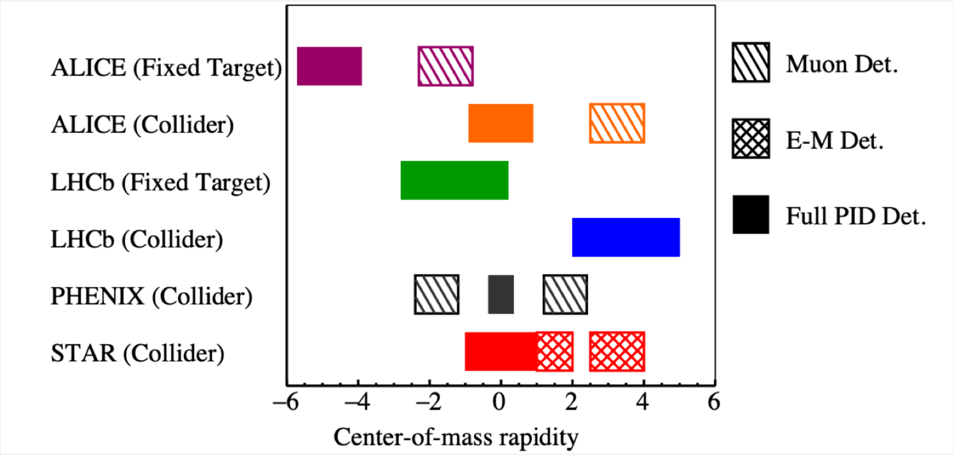


Simulation of the deflected beam at ALICE IP, F. Galluccio, W. Scandale UA9

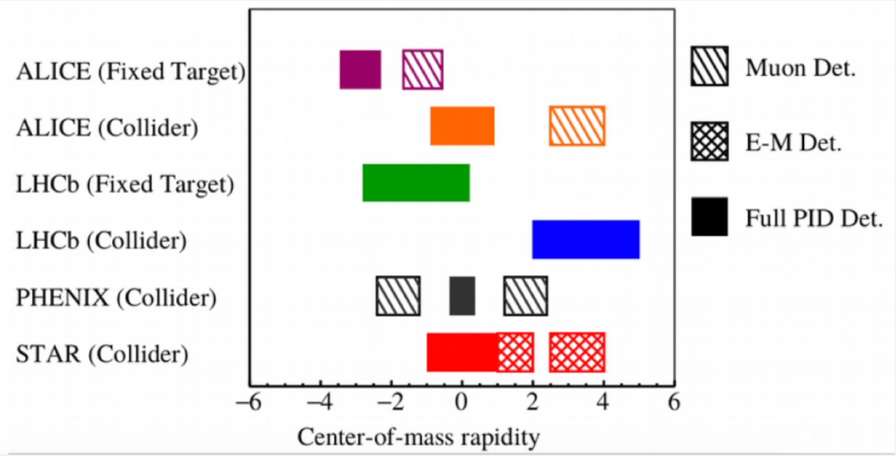
Fixed target in ALICE

- Physics program very similar to LHCb, with a different acceptance, with muon detector covering different acceptance than other parts of the detector

ALICE Z_{target} = 0 cm



ALICE Z_{target} = -4.7 m



Conclusions

- Fixed-target physics at LHCb/LHC feasibility established with SMOG during Run 2 of LHCb: limited by statistics

- Success of this first phase encouraged many new projects

- Installation of SMOG2 will boost significantly physics output

- New projects at LHCb and ALICE under design to explore new directions (polarized target, MDM-EDM, ...)