LHC Run 3 and Run 4 prospects for heavy-ion physics with LHCb

Samuel Belin, on behalf of the LHCb collaboration

Outline

1. LHCb run 2
2. LHCb Upgrade
3. Prospects
   - Fixed Target Studies
   - Heavy Ion Studies

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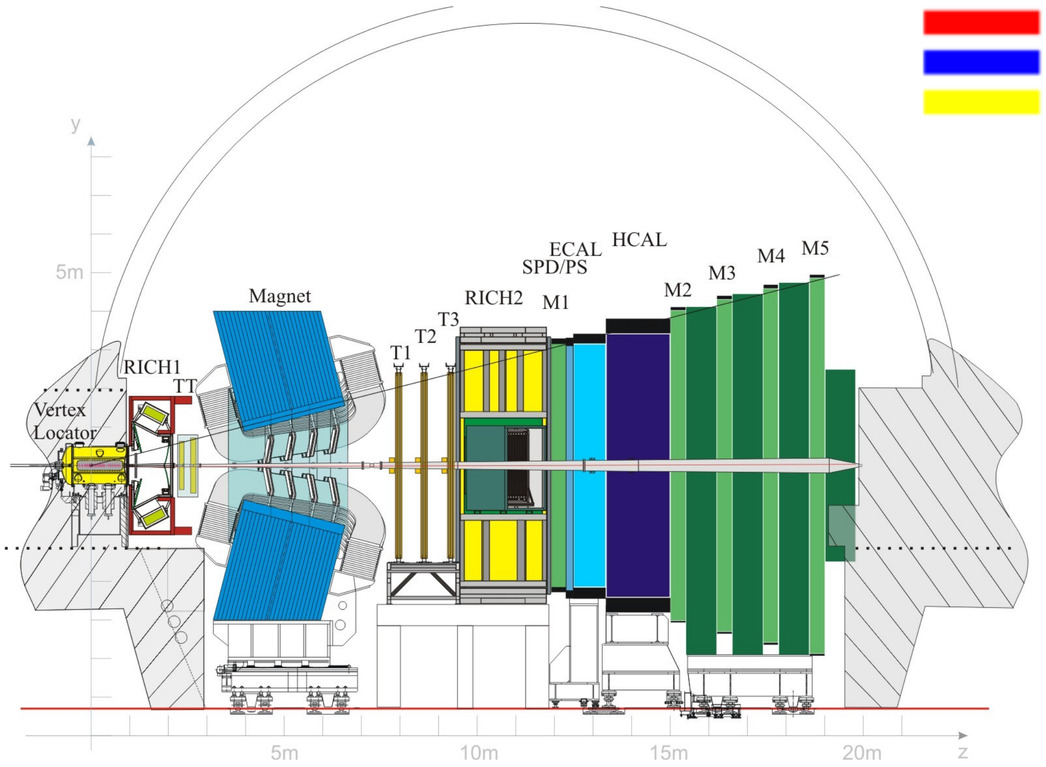
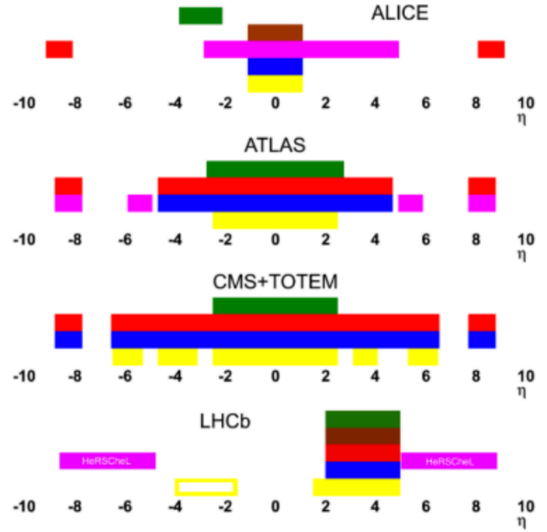
The LHCb detector

Single arm spectrometer fully instrumented in pseudorapidity range $2 < \eta < 5$

Unique in this range





- Excellent resolution down to p_T=0.
- Excellent particle identification.
- Excellent primary vertex determination.

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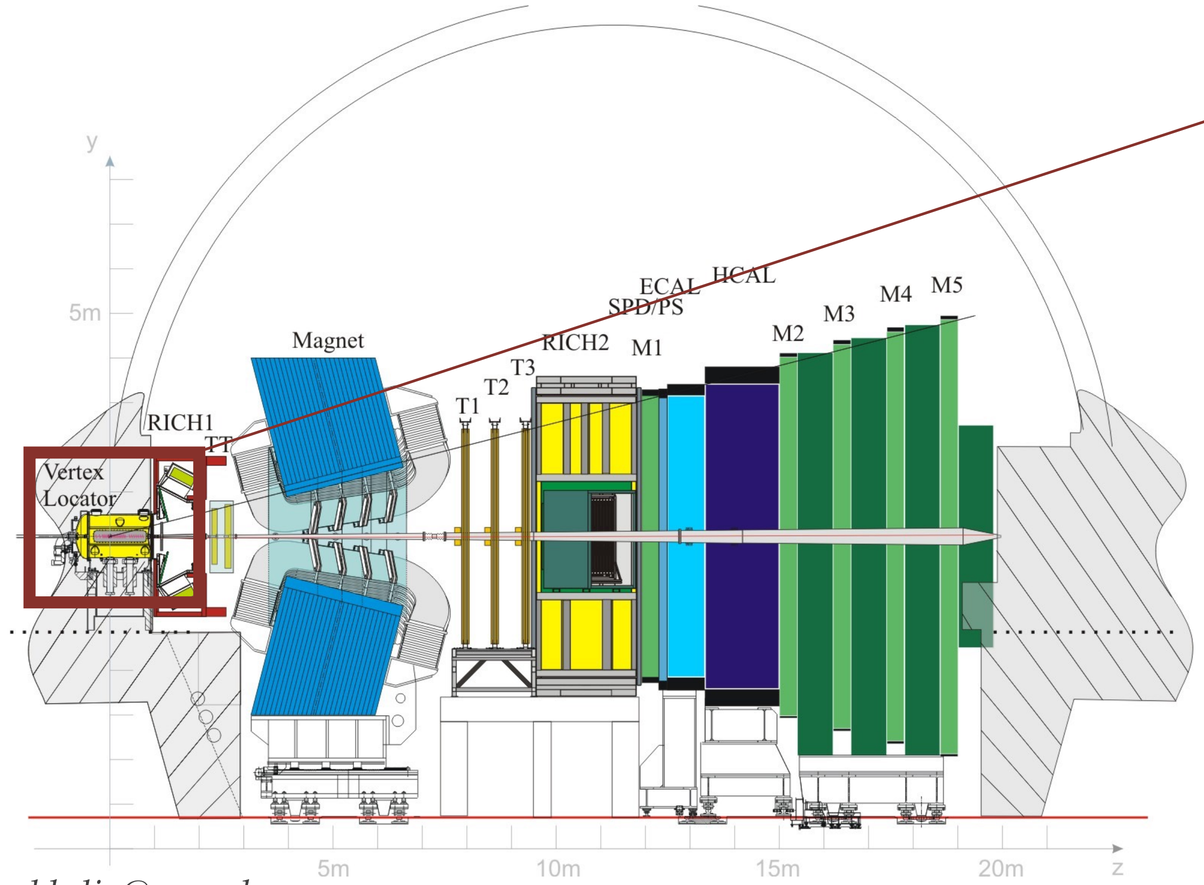
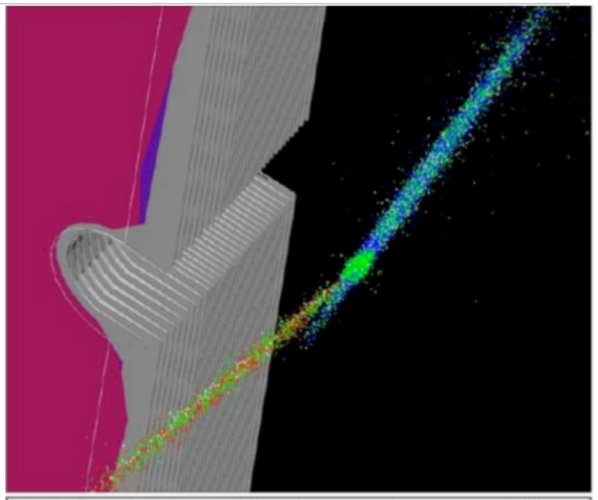
The LHCb detector

pp/Pbp/PbPb and fixed target mode





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.

- Injection of noble gas (He, Ne, Ar) in the VErtex LOcator tank
- Gas pressure: 10^{-7} to 10^{-6} mbar

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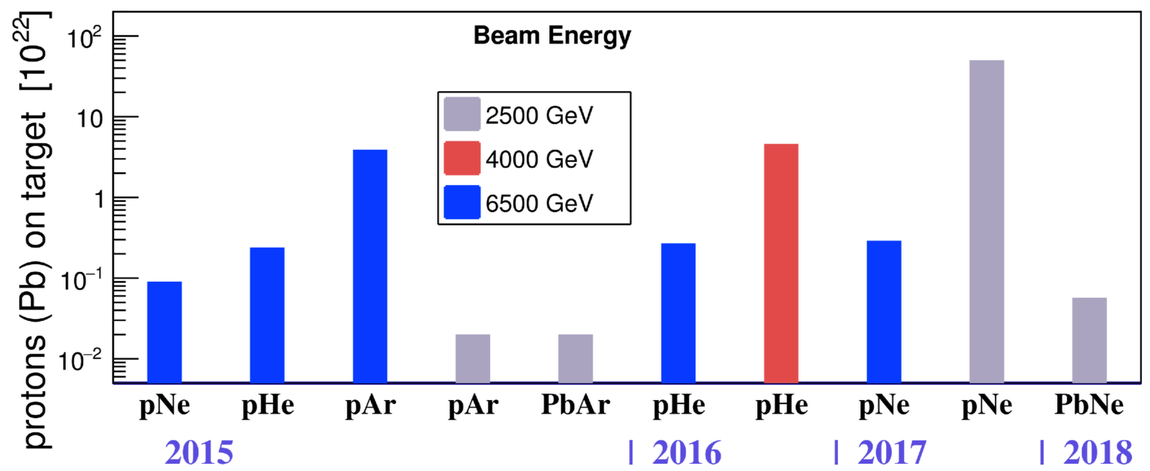
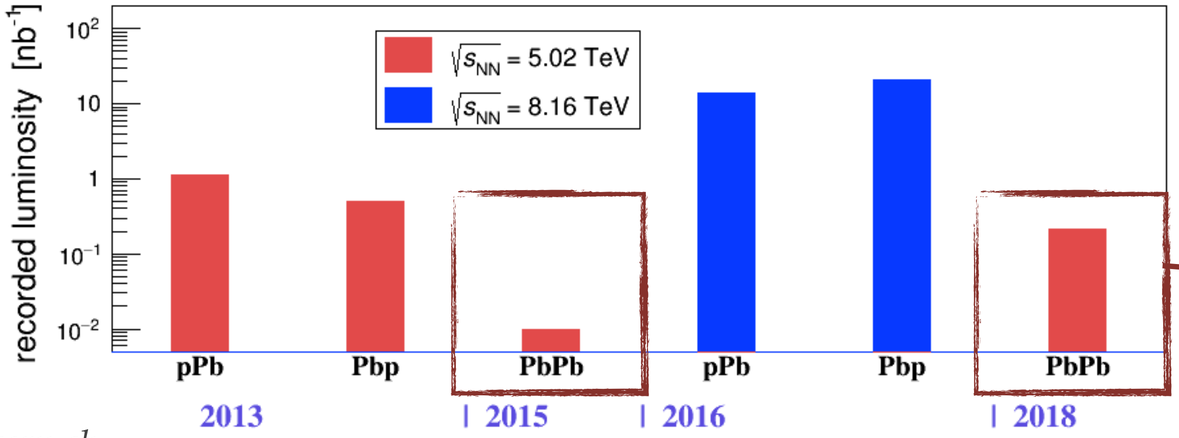
Available samples in Run 2

Fixed Target mode samples:



Collider mode samples:



Due to detector saturation, limited to 40% most peripheral

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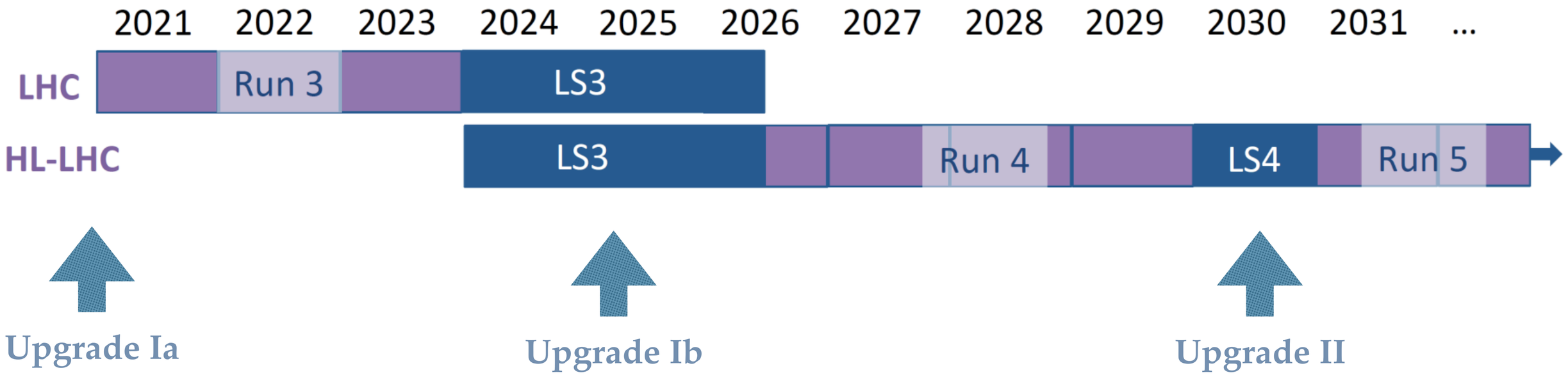
LHCb Upgrades

(to the best of our knowledge at present)



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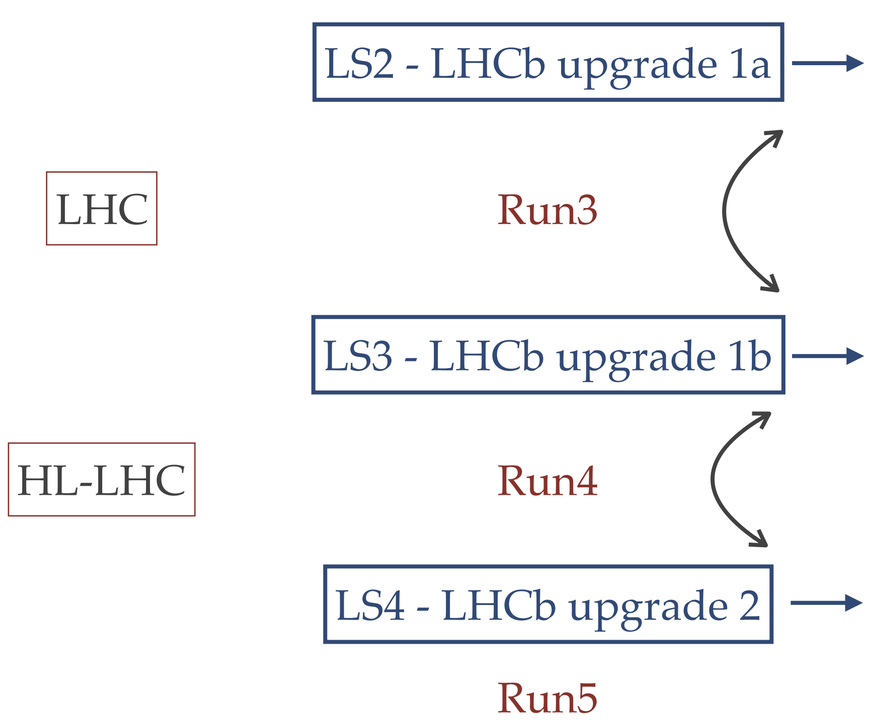
Possible schedule and future samples

Plan originally made in 2019, it will most likely be shifted…



arXiv:1812.06772 - CERN-LPCC-2018-07

Year	Systems, $\sqrt{s_{\mathrm{NN}}}$	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 $\mu\mathrm{b}^{-1}$ and 200 $\mu\mathrm{b}^{-1}$
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	

This table does not include the fixed target program

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LHCb upgrade run 3

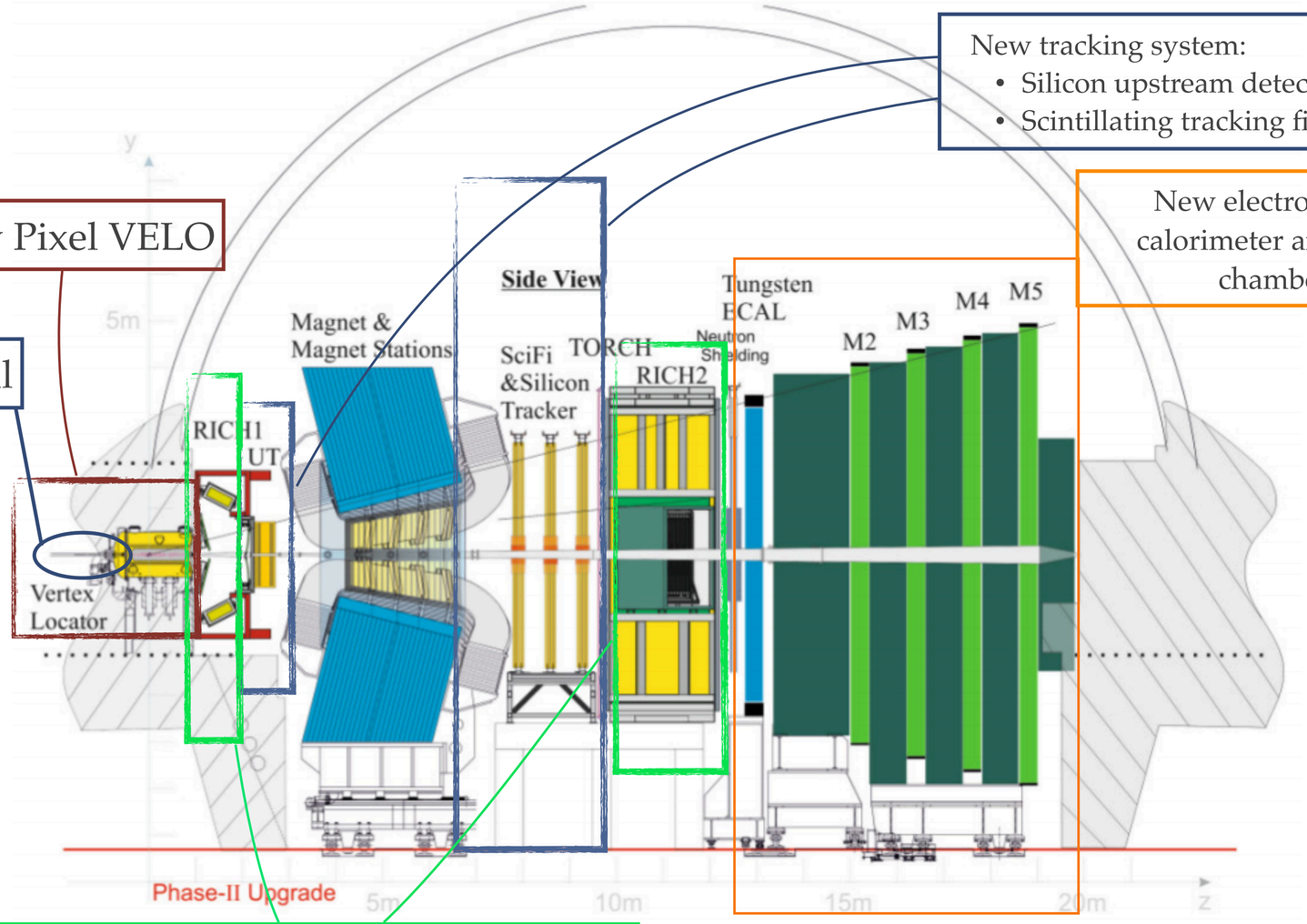
New tracking system:
- Silicon upstream detector (UT)
- Scintillating tracking fiber (SciFi)

[CERN-LHCC-2012-007]

New Pixel VELO

New electronics for calorimeter and muon chambers

New SMOG2 cell



New RICH optics and photodetectors

Upgrade for pp requirement

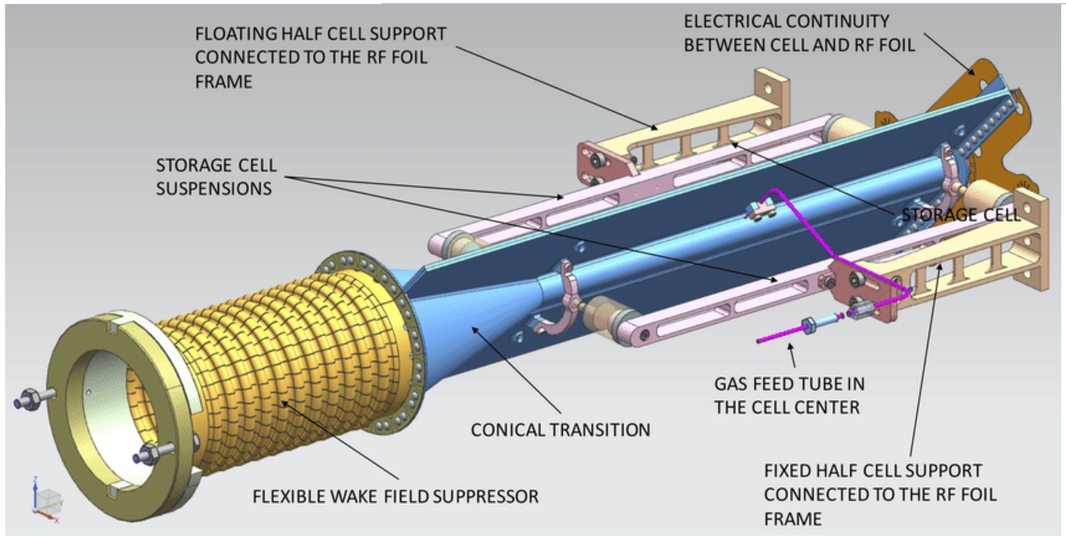
- 40 MHz collision rate
- Pile Up factor ~ 5

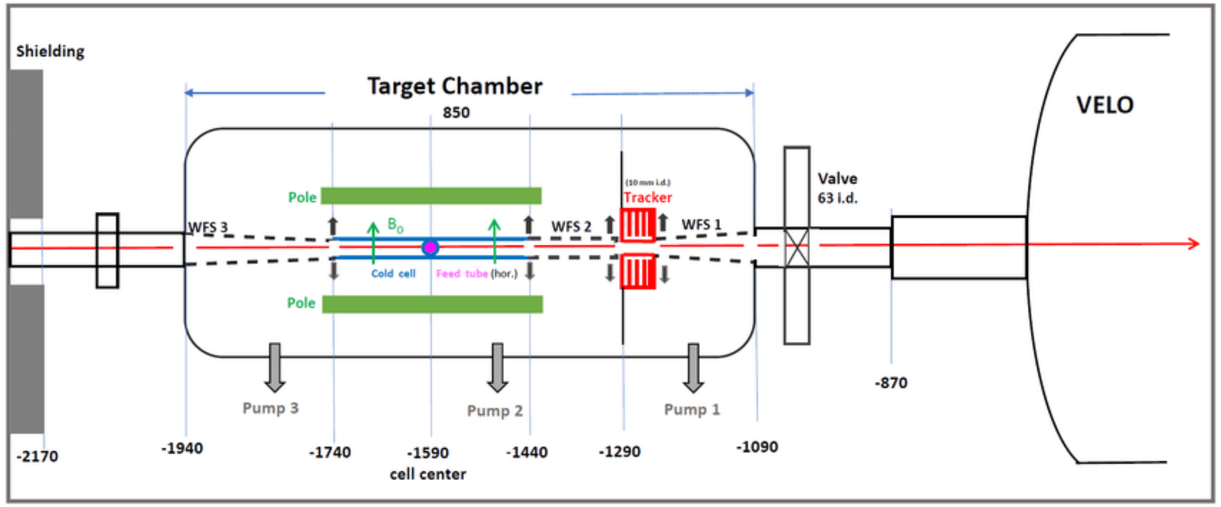
Full software trigger

- Remove L0 triggers.
- Read out full detector at 40 MHz.

Heavy ion program will profit from this upgrade !

Fixed Target: SMOG 2





CERN-LHCC-2019-005

- Higher density of the gas (up to 100 higher luminosity)
- Better control of the gas density (better luminosity determination)
- New gas H_2, D_2, O_2 in addition to all noble gases

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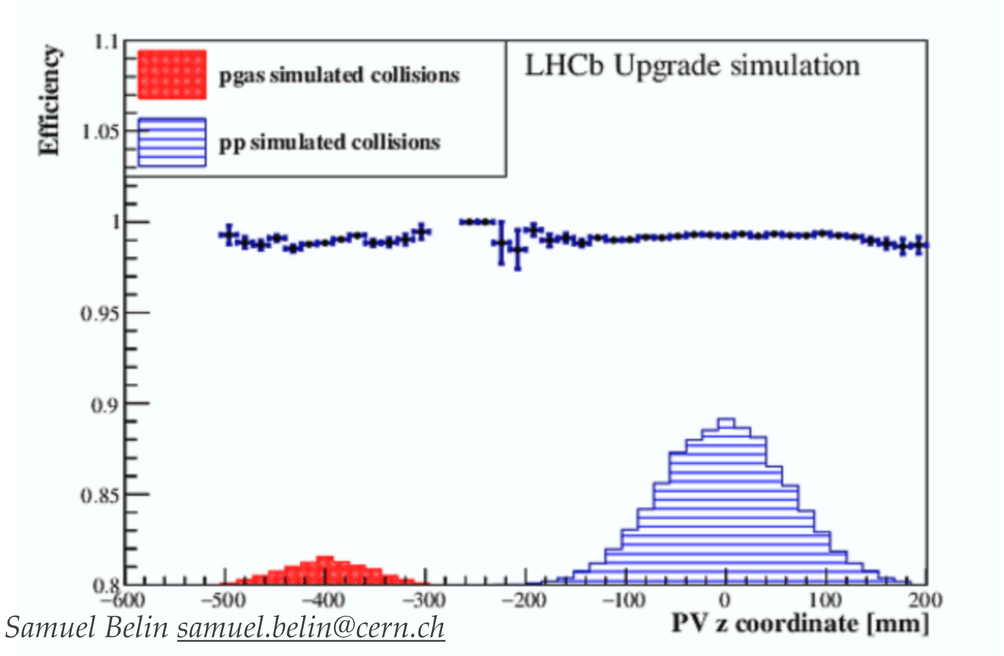
Fixed Target: SMOG 2

- The goal is to record SMOG collisions in parallel to the pp data-taking.
- First preliminary studies show minimal or no disturbance to the pp acquisition.
- Reconstruction efficiency is independent from the primary vertex position.



Example SMOG2 pAr at 115 GeV for one year

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

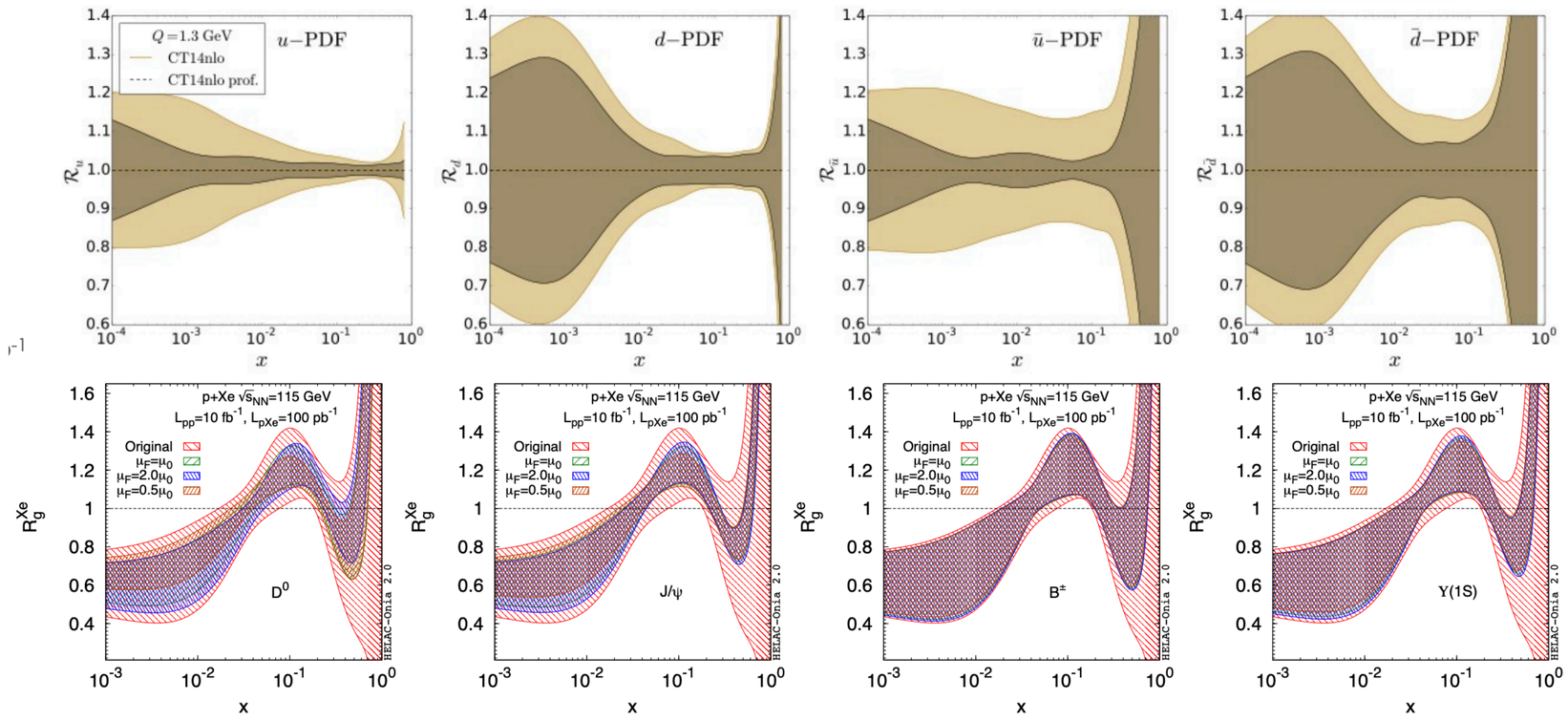
Potentially high statistics for the fixed target program !

Fixed Target studies

- Access to large x-Bjorken and low scale Q^2.
- Possibility to reduce the uncertainty on the (n)PDFs, crucial input for HI physics as well as for other HEP measurements (BSM, Cosmic Ray physics…)

arXiv:1807.00603

Estimation with 10 fb^{-1}

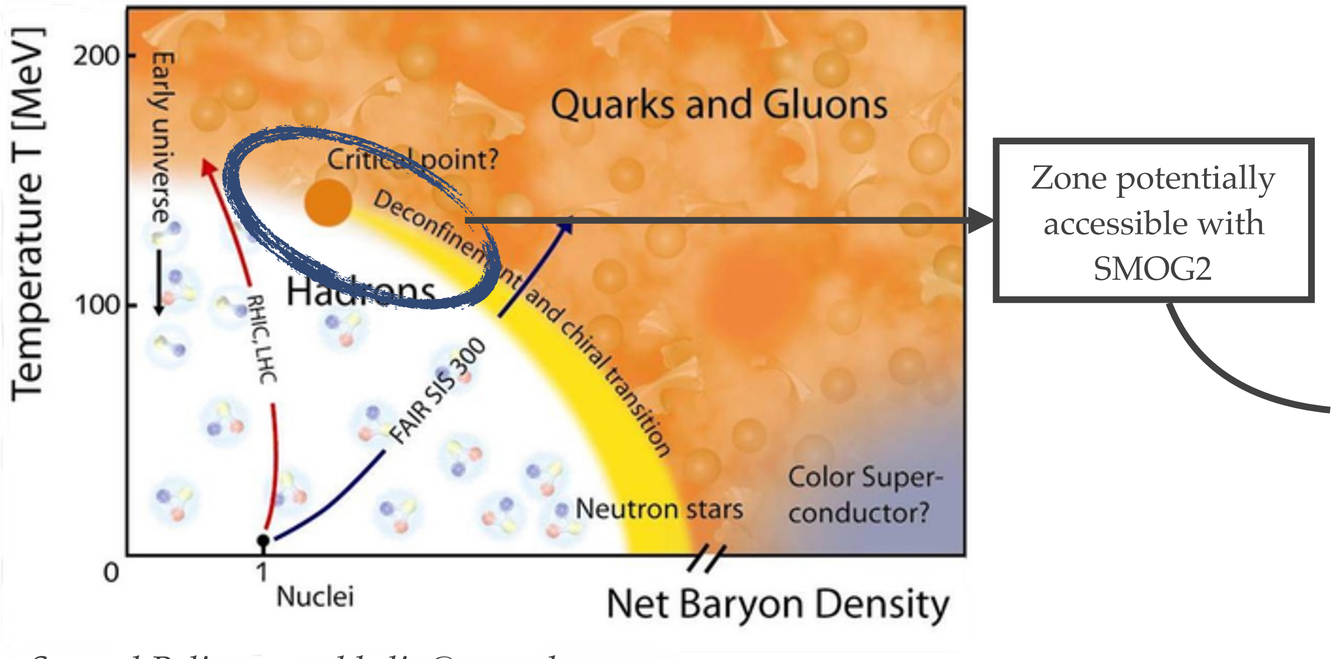


PDF

nPDF (gluon)

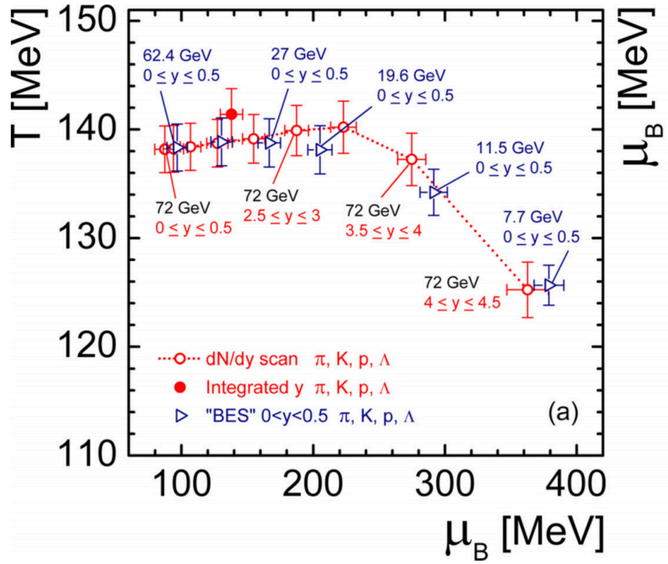
Fixed Target studies

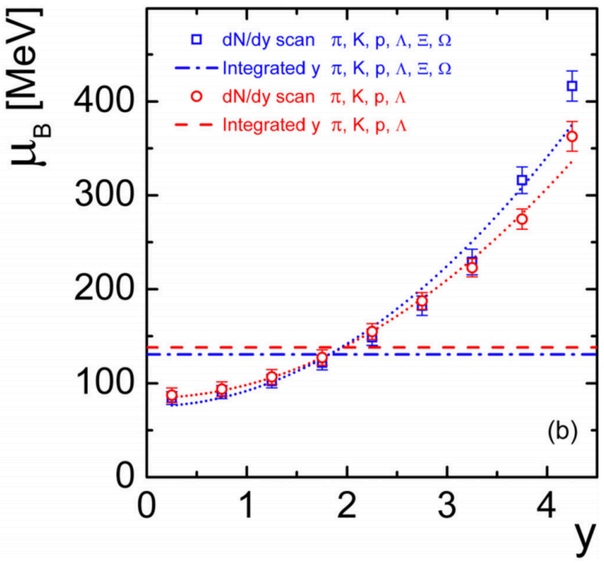
- Energy and rapidity scan possible with the variety of gas.
- Exploration of the phase diagram of hadronic matter (reach larger μ_B)!
- Complementary to the RHIC BES results



Zone potentially accessible with SMOG2

PHYSICAL REVIEW C 98, 034905 (2018)





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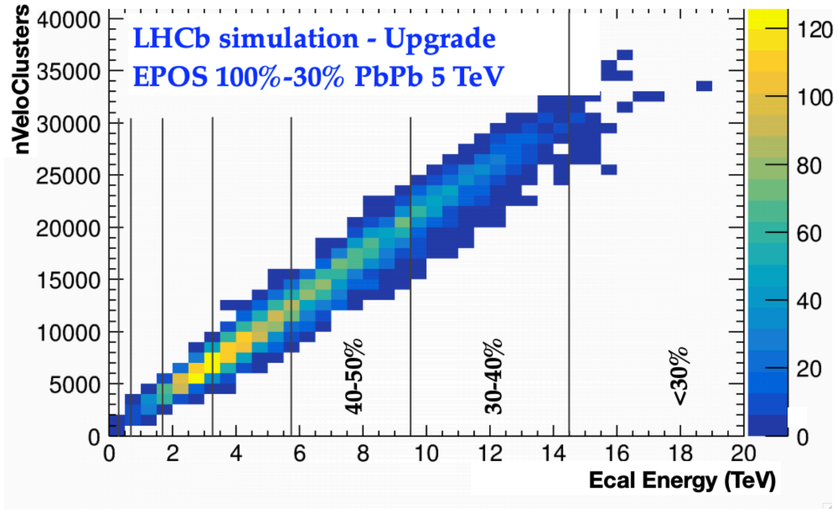
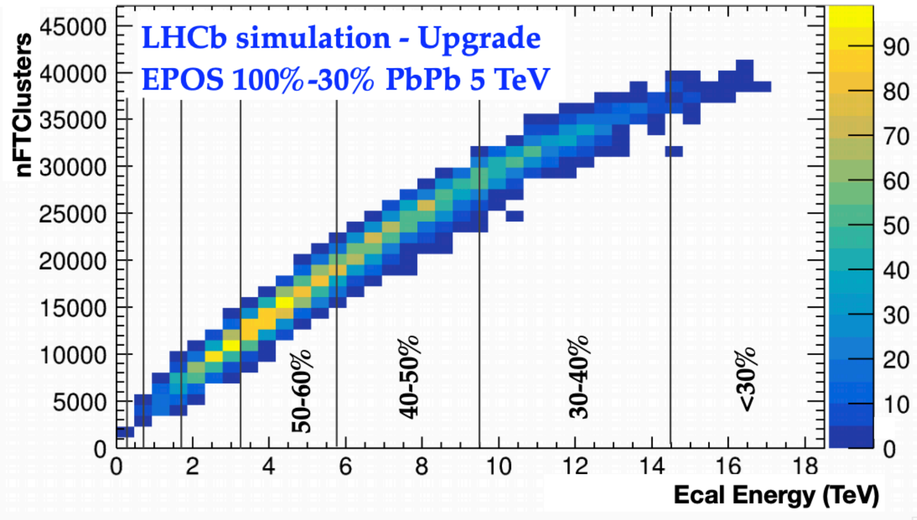
Performances Run 3 PbPb

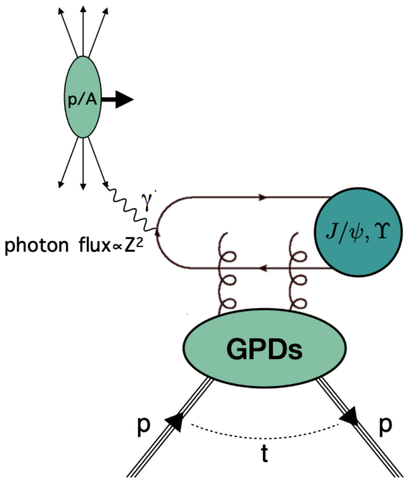
PbPb collisions

LHCB-FIGURE-2019-019





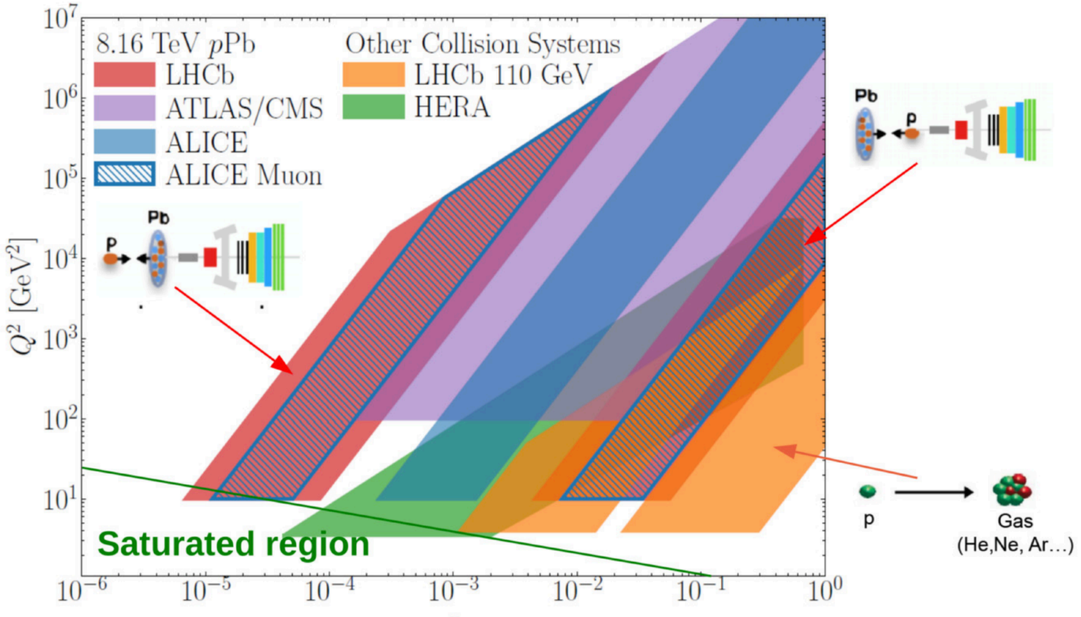
- No significant saturation for 70% most peripheral collisions (simulation for higher centralities are being produced), expect almost no saturation for Run4 (90% most peripheral) and no saturation for Run5.
- Semi-central PbPb collisions soon available : QGP studies for LHCb in run 3 !
- Increased statistics: improvement of UPC studies.



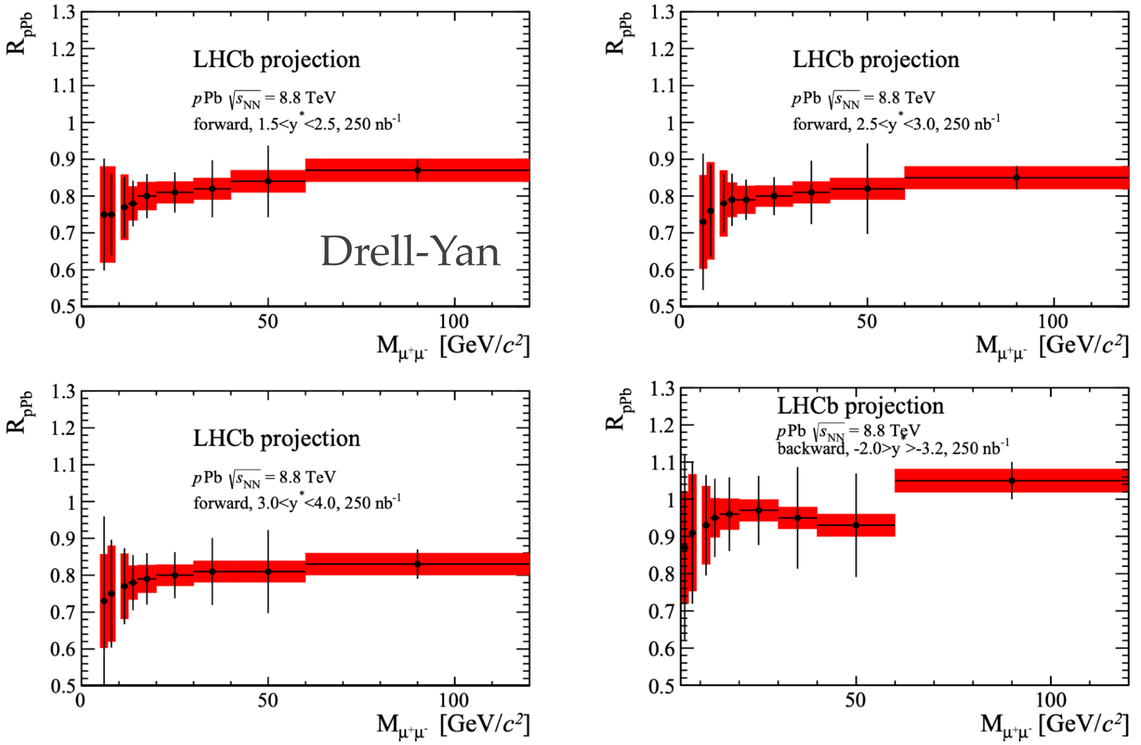
Exclusive meson production

Heavy Ion Studies

- Access to a low, medium and high region of x with Pbp and pPb samples
- Possibility to observe gluon saturation by studying the Drell-Yan process.
- The addition of a Magnet Tracking Station in Run4 will allow to reach even lower x region (~10^{-6}).



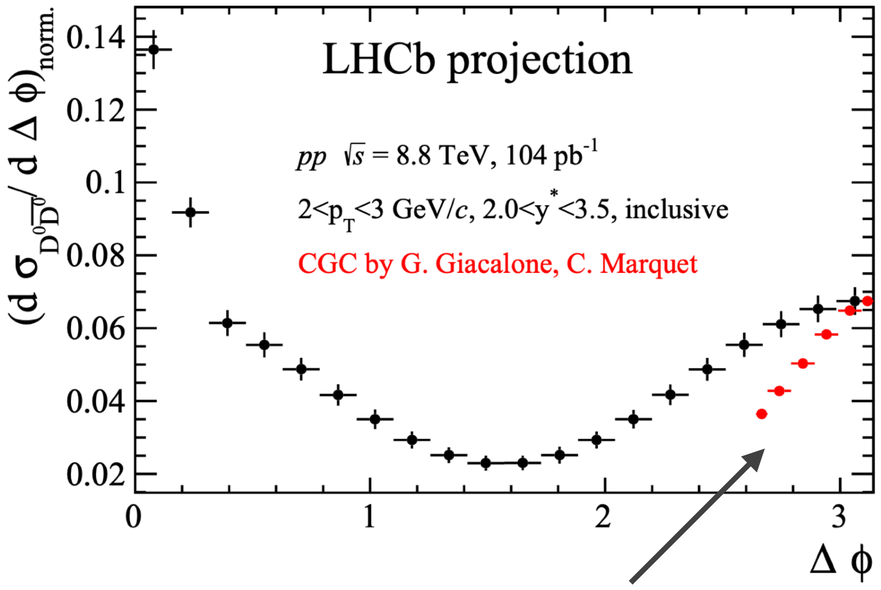
LHCb-CONF-2018-005



Heavy Ions Studies

- Charm and beauty pair correlations measurement both in pp and pPb collisions, the intrinsic transverse momentum k_T , carried by the incoming partons, may be sensitive to the saturation scale.

Projection with arbitrary normalisation



Shape at $\Delta\phi=\pi$ provides k_T information

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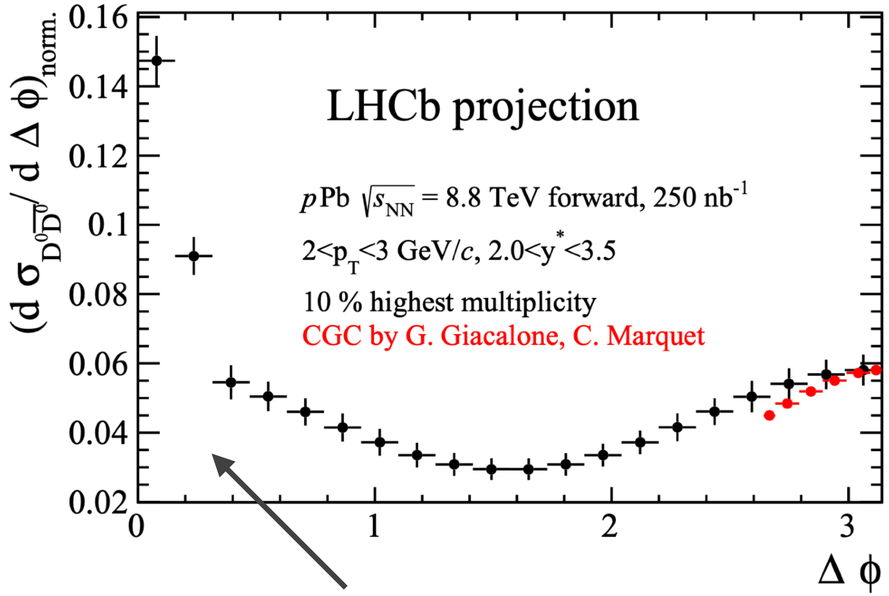

At $\Delta\phi=0$ the NLO production via gluon splitting becomes dominant

Recently measured by LHCb, see Jianqiao's talk [LINK]

Heavy Ions Studies

- B^+ meson production, nPDF modifications are supposed to be the dominant source of nuclear modifications. Beauty hadron production exhibits smaller uncertainty than charm mesons. Better input for constraining nPDFs.

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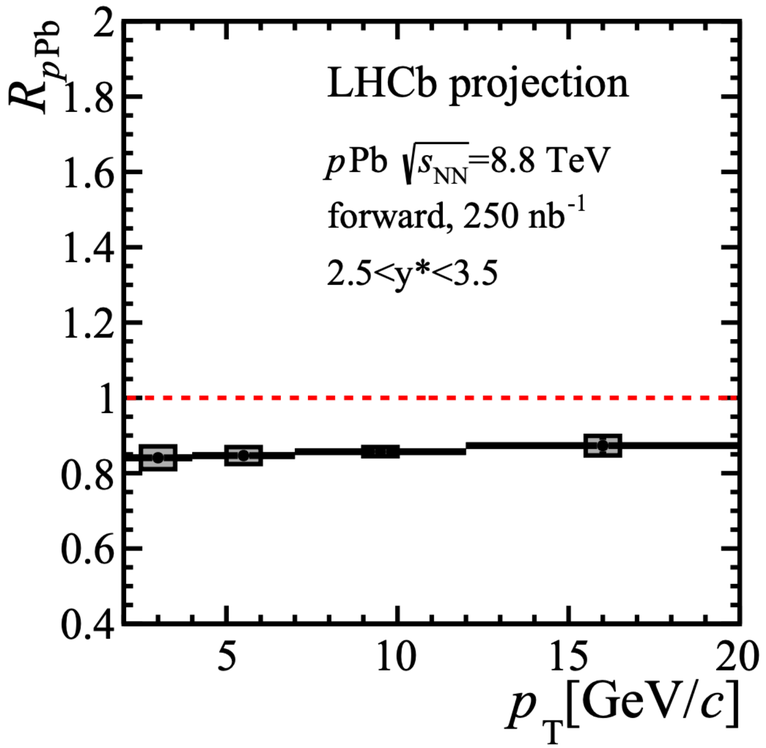

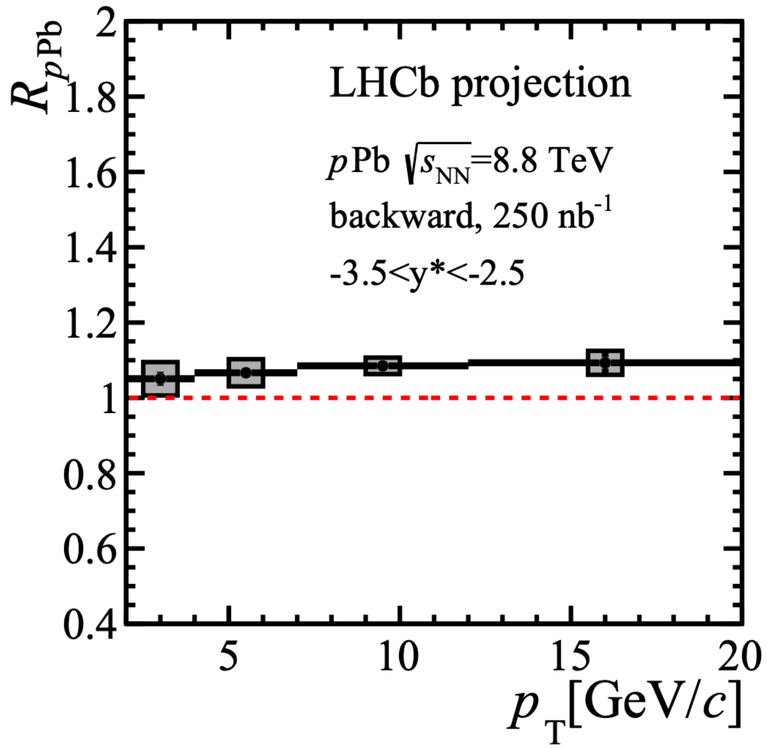

Nuclear modification factor for B mesons

Precise measurements of nuclear modification in the beauty sector will potentially enable disentangling whether these effects are due to PDF modifications or other effects such as coherent energy loss

Conclusions

- LHCb has a solid and complete Heavy Ion physics program, with unique capabilities.
- The Fixed Target program unlocks unexplored energies and kinematic conditions.
- The LHCb detector will soon be able to perform Quark Gluon Plasma studies with the improvements of the detector in high occupancy.

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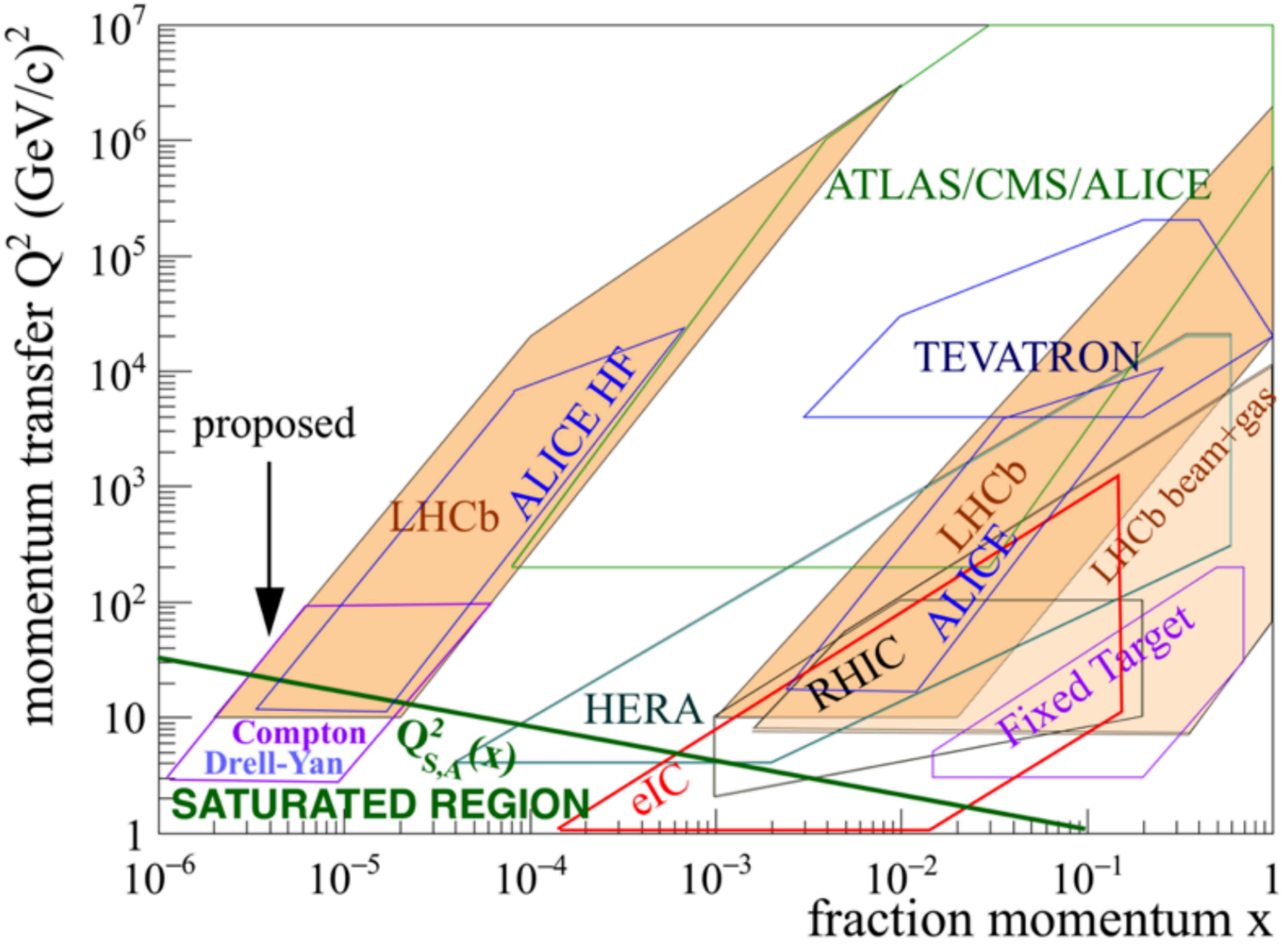
Backup


momentum transfer Q^2 (GeV/c)^2
10^7
10^6
10^5
10^4
10^3
10^2
10
1
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
fraction momentum x
proposed
LHCb
ALICE HF
ATLAS/CMS/ALICE
TEVATRON
LHCb
ALICE
LHCb beam+gas
RHIC
HERA
Fixed Target
eIC
Compton
Drell-Yan
$Q^2_{s,A}(x)$
SATURATED REGION