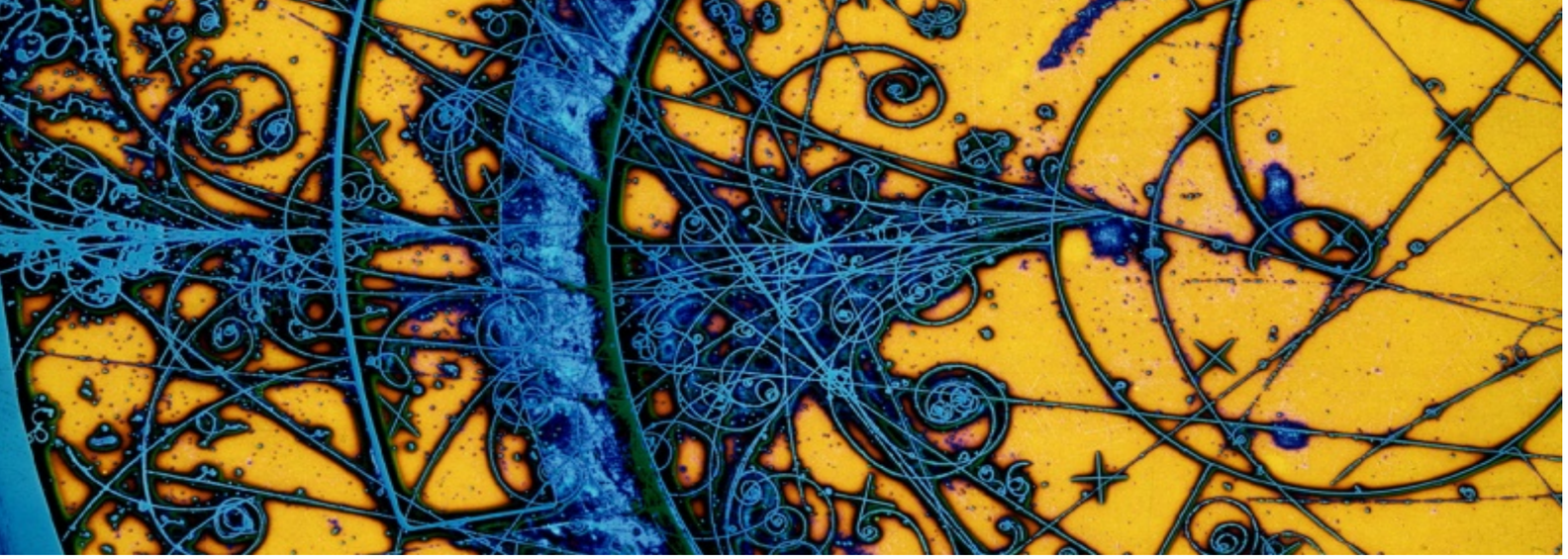


The L$\uparrow\uparrow$C project

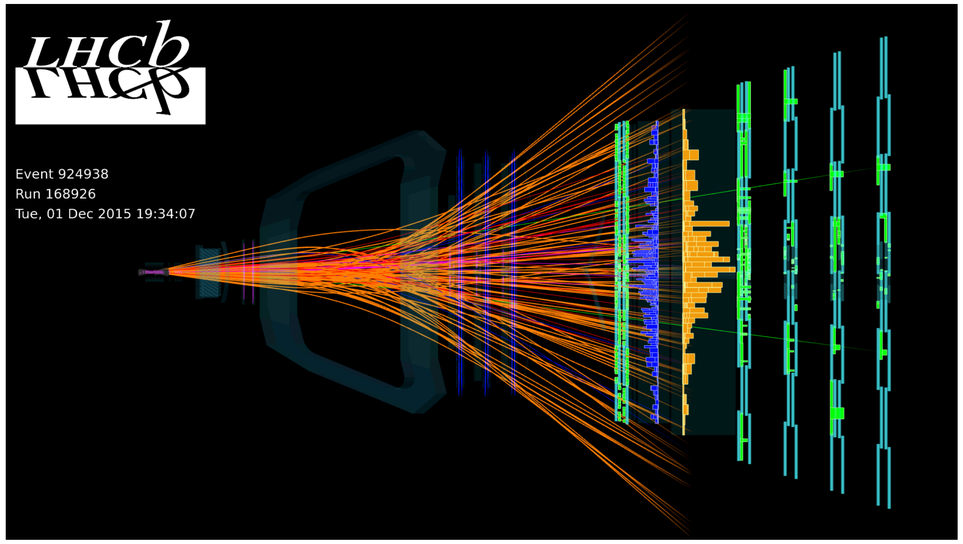
Marco Santimaria (INFN-LNF)

in collaboration with V.Carassiti, G.Ciullo, P. Di Nezza, P.Lenisa,
S.Mariani, L.Pappalardo, E.Steffens

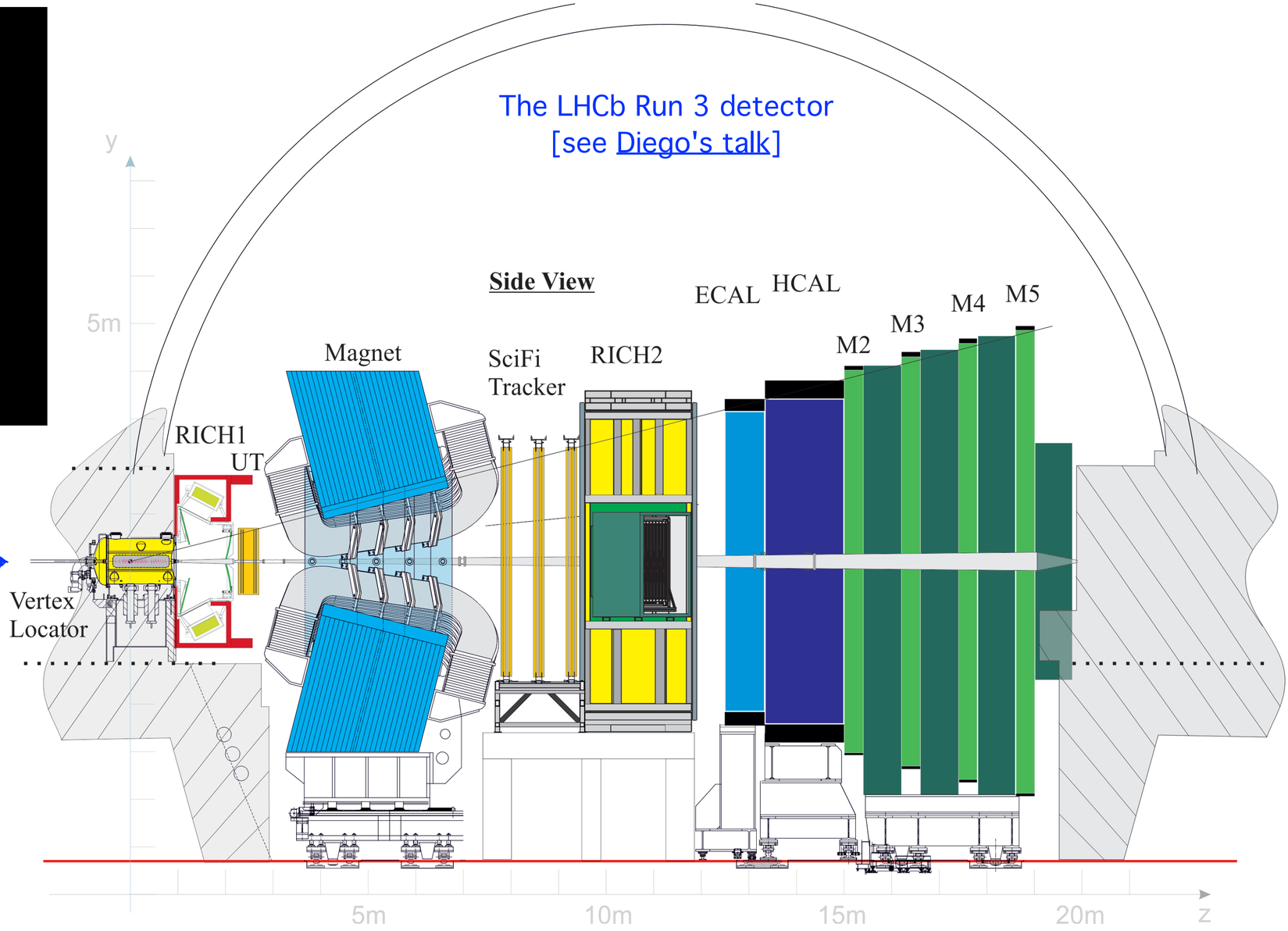
XXVIII International Workshop on Deep-Inelastic Scattering and Related Subjects
Stony Brook University, NY (Virtual), 14/04/2021

The LHCb detector for fixed target collisions

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



The LHCb Run 3 detector
[see Diego's talk]

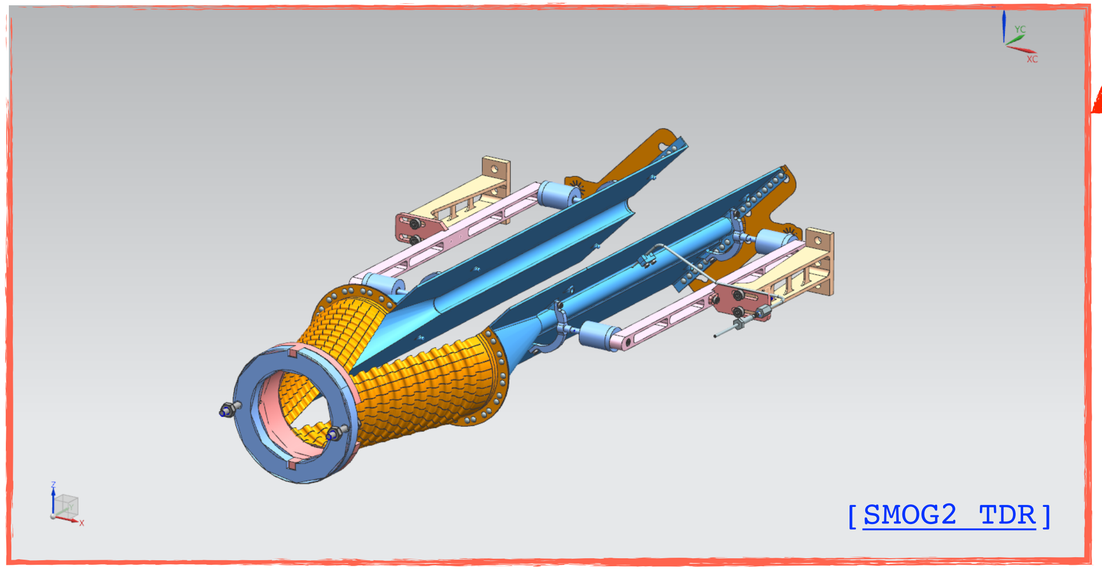


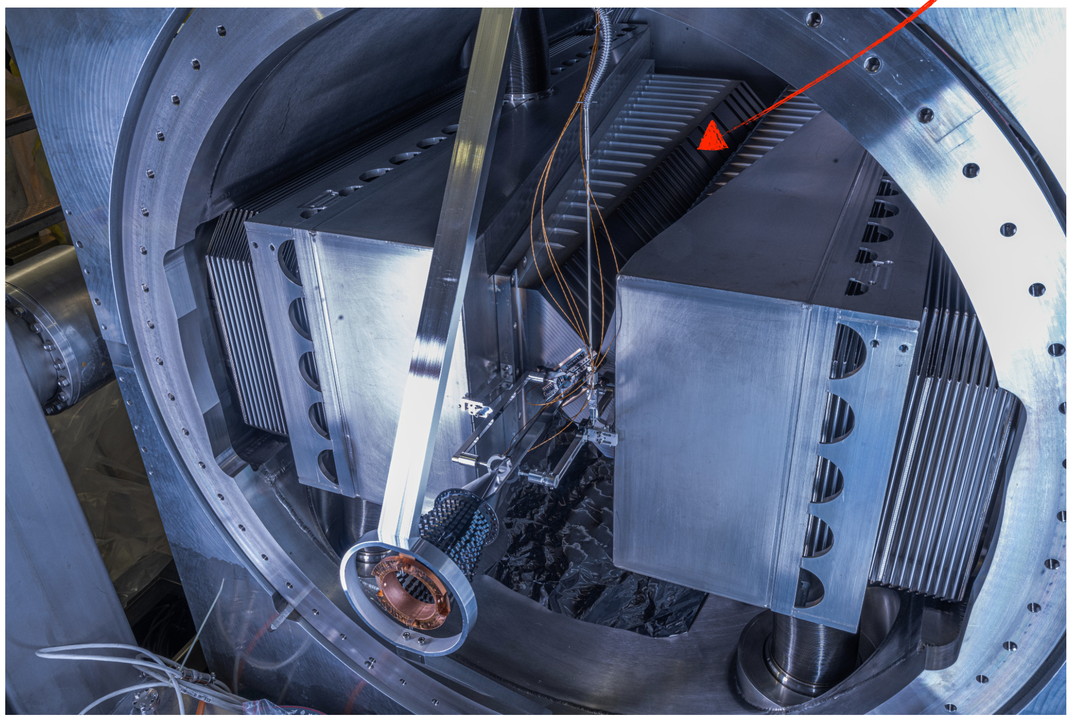
- LHCb is a general-purpose forward spectrometer, fully instrumented in $2 < \eta < 5$, and optimised for c and b detection
- Particle identification with RICH+CALO+MUON
- Excellent momentum resolution:

$$\sigma_p/p = 0.5 - 1.0\,\% \ (p \in [2{,}200]\ \text{GeV})$$

The SMOG2 gas storage cell

- Together with major hardware interventions, an unpolarised gas cell has been installed in 2020 next to the VELO



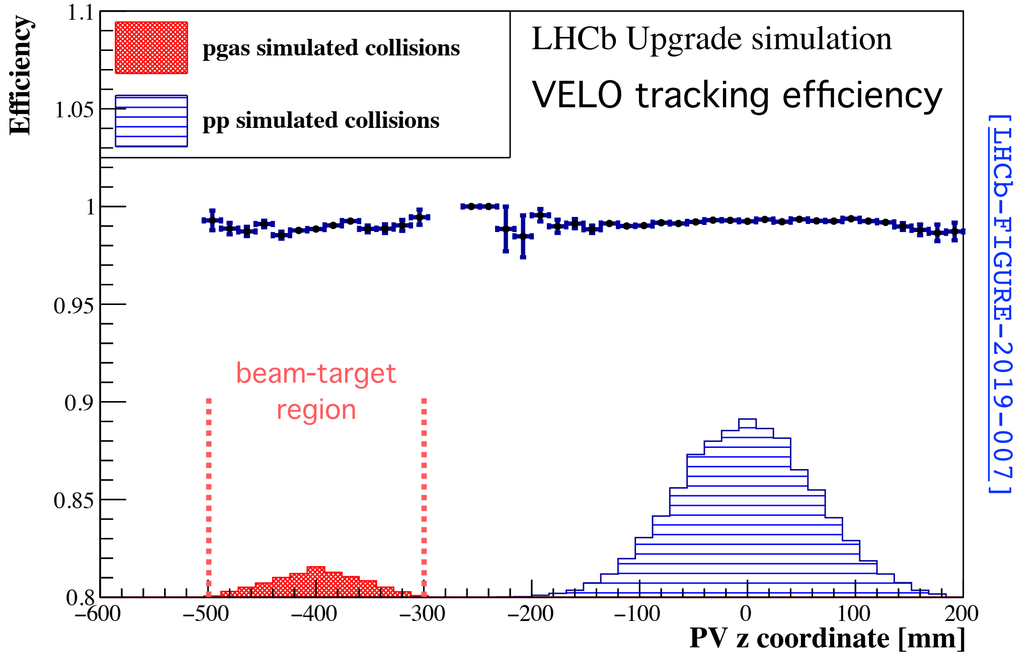


- Can be filled with $H_2, D_2, He, N_2, O_2, Ne, Ar, Kr, Xe$
- Negligible impact on the beam lifetime ($\tau_{beam-gas} \sim 2000$ days with hydrogen)

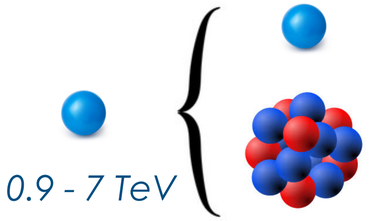
- SMOG2 boosts the LHCb fixed-target programme for the Run 3 of LHC (starting next year)
- Will set the basis for the development of a polarized gas target (PGT), that we aim to install during LS3 (2025-2027)
- LHCspin to take data from Run 4 ⟶[The LHCspin project]

An excellent starting point

- A trigger for simultaneous p-p ($\sqrt{s} = 14$ TeV) and p-gas ($\sqrt{s} = 115$ GeV) data-taking is already in place for SMOG2
- $1 - 3\,\%$ throughput decrease when adding p-gas to the LHCb event reconstruction sequence
- LHCb is the only experiment able to run in collider- and fixed-target mode simultaneously!



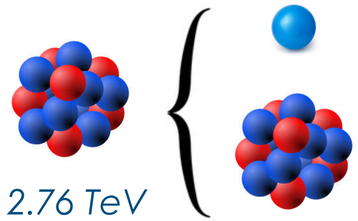
kinematics of fixed target collisions:



pp/pA collisions, 7 TeV beam:

$$\sqrt{s} = \sqrt{2 m_N E_p} = 115 \text{ GeV}$$

$$-3.0 \le y_{CMS} \le 0 \;\rightarrow\; 2 \le y_{lab} \le 5$$



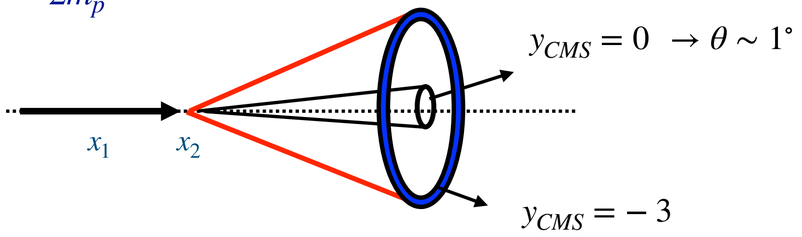
AA collisions, 2.76 TeV beam:

$$\sqrt{s_{NN}} \simeq 72 \text{ GeV}$$

$$y_{CMS} = 0 \;\rightarrow\; y_{lab} = 4.3$$

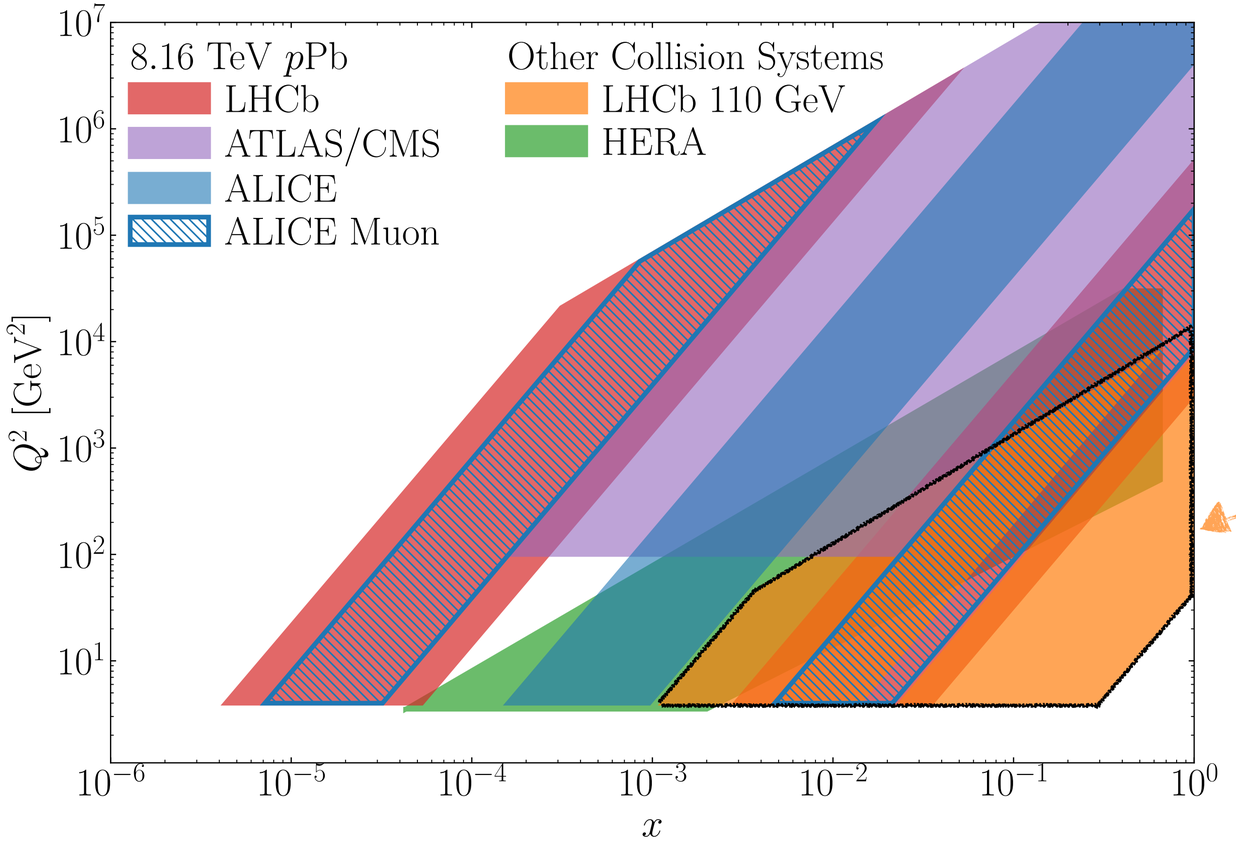
Large boost : access to large x_2 values ($x_F < 0$)

$$\gamma = \frac{\sqrt{s}}{2 m_p} \sim 60$$



A lot of possibilities!

- Bring (un) polarised physics at the LHC for the first time exploiting one of the most advanced particle detector



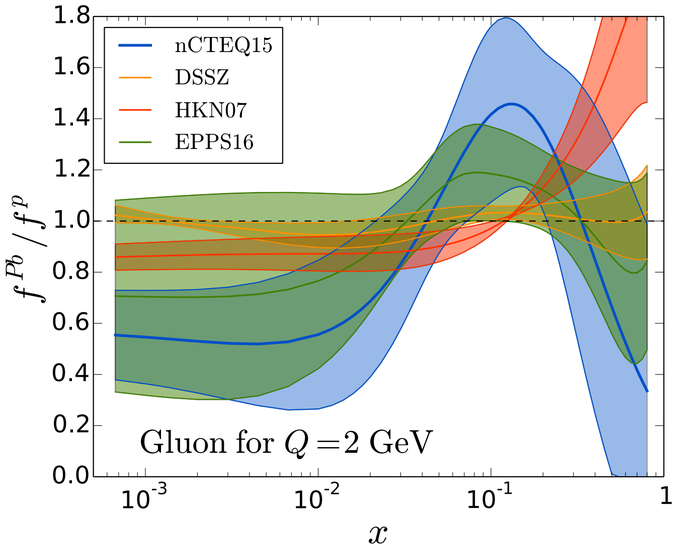
- Unique obserables:
  - Large x content of g, $\bar{q}$ and heavy quarks in nucleons and nuclei
  - Spin distributions of gluons inside unpolarised and polarised nucleons
  - Heavy Ion FT collisions at an energy in between SPS and RHIC (at large rapidities)
- Unique features:
  - broad and unexplored kinematic range
  - high luminosity, high resolution detectors
  - proton and heavy ions beams
  - large variety of gas targets: $H_2, D_2, He, N_2, O_2, Ne, Ar, Kr, Xe$
  - polarised targets: $H^{\uparrow}, D^{\uparrow}$

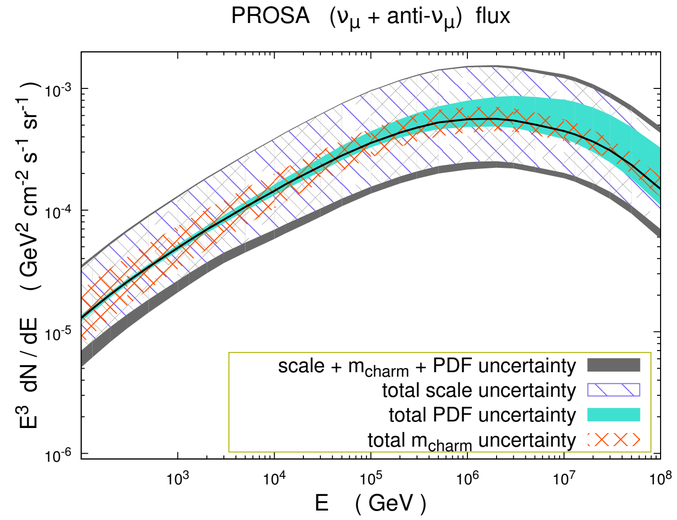
- A selection of physics cases from LHCspin is shown in the following

Physics case #1: PDFs

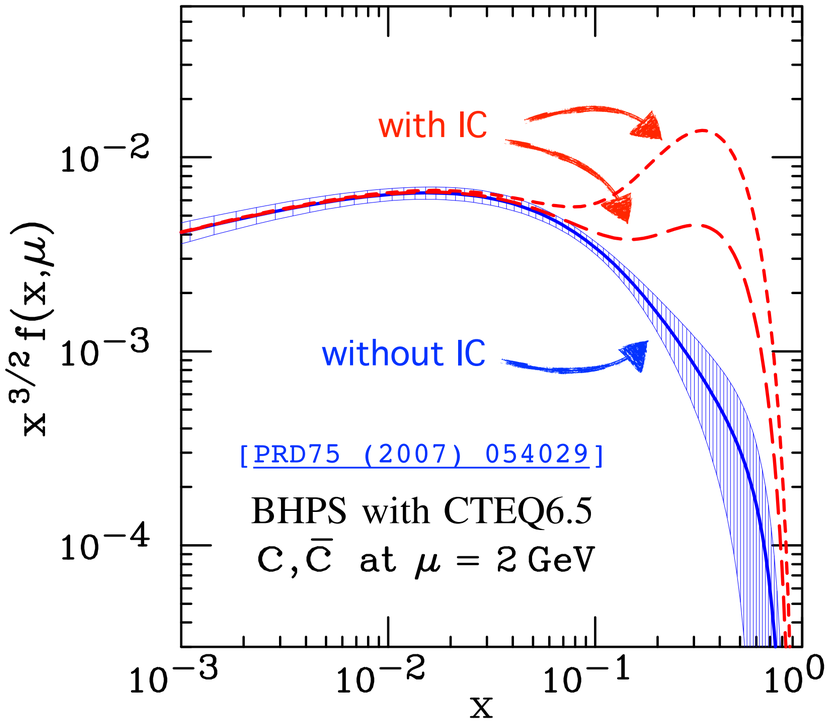
- Improved knowledge of gluons PDFs, a crucial ingredient for HEP computations and FCC

[ArXiv:1807.00603]





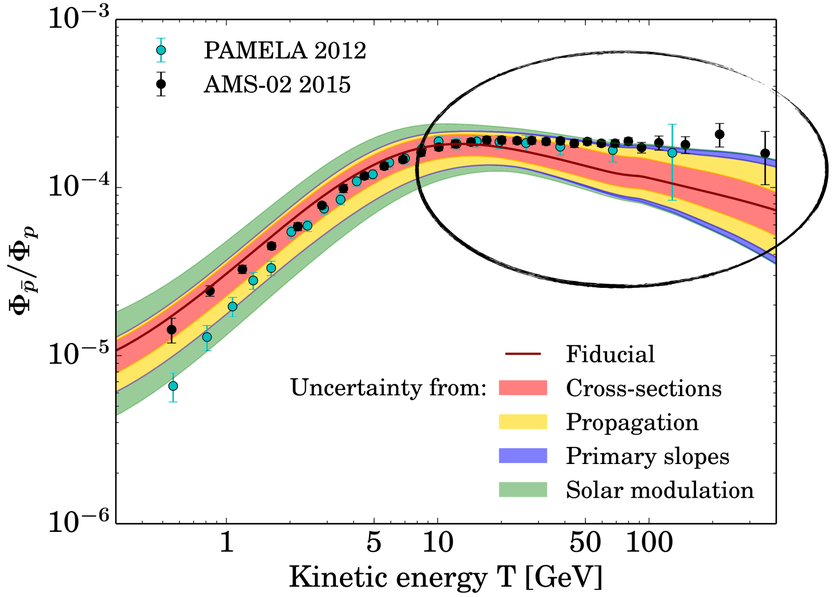
- Intrinsic charm component
- First search at LHCb FT [see Tom's talk]



- Improve the prompt ν_μ flux prediction via heavy-flavour hadroproduction measurements [JHEP 05 (2017) 004]

- Interpret DM annihilation with $\bar{p}$ production on pHe collisions

[PRL 121 (2018) 222001]



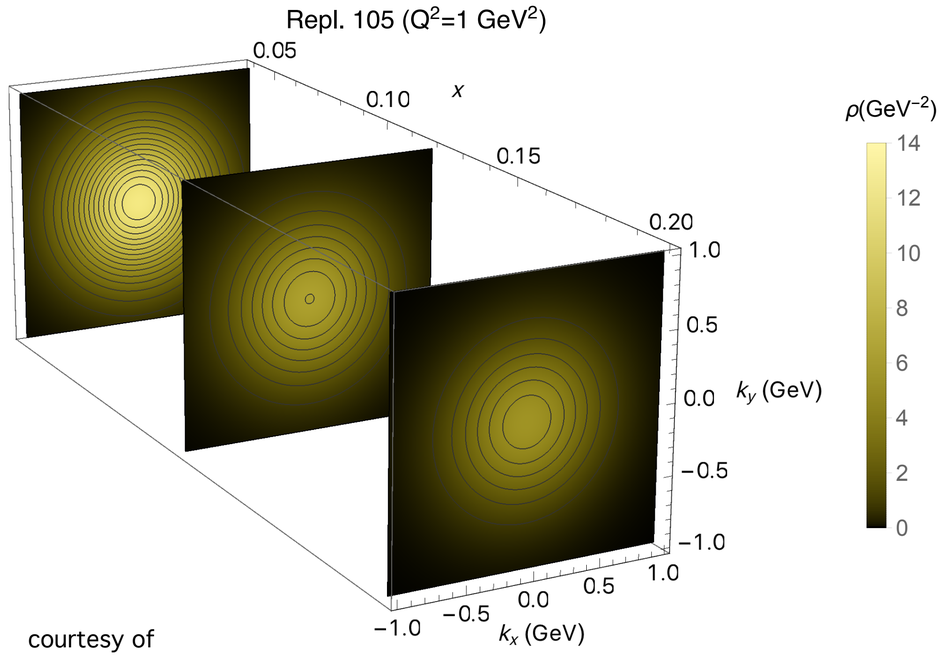
And more, for example:

- UHECR flux composition with pHe, pO, pN data
- More insight on EMC effect, nPDFs
- ^{16}O beam at LHC

[ARNPS 61 (2011) 467-489]

Physics case #2: hadron structure

- Ultimate goal: a 3D tomography of hadrons



courtesy of
A. Bacchetta

- Accessing quark TMDs via TSSAs at high $x^{\uparrow}$

$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

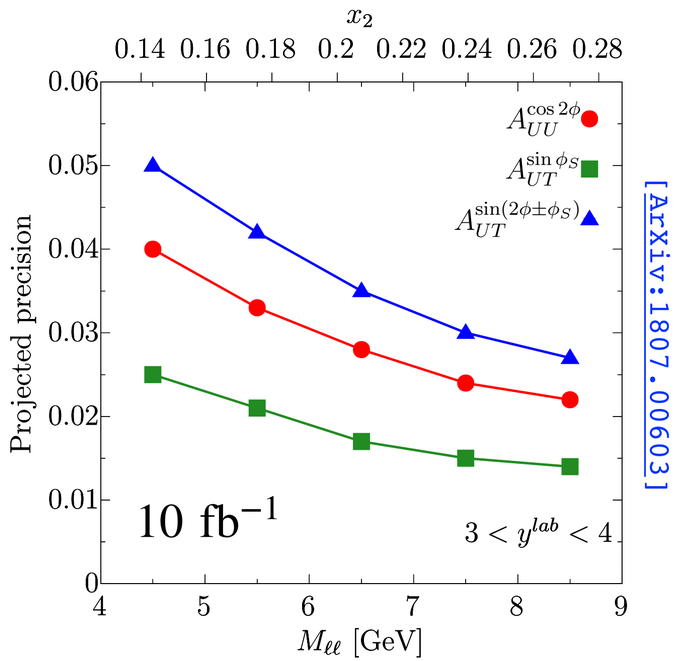
$$A_{UU}^{cos2\phi} \sim \frac{h_1^{\perp q}(x_1, k_{1T}^2) \otimes h_1^{\perp \bar{q}}(x_2, k_{2T}^2)}{f_1^{q}(x_1, k_{1T}^2) \otimes f_1^{\bar{q}}(x_2, k_{2T}^2)},$$

$$A_{UT}^{sin\phi_S} \sim \frac{f_1^{q}(x_1, k_{1T}^2) \otimes f_{1T}^{\perp \bar{q}}(x_2, k_{2T}^2)}{f_1^{q}(x_1, k_{1T}^2) \otimes f_1^{\bar{q}}(x_2, k_{2T}^2)},$$

$$A_{UT}^{sin(2\phi+\phi_S)} \sim \frac{h_1^{\perp q}(x_1, k_{1T}^2) \otimes h_{1T}^{\perp \bar{q}}(x_2, k_{2T}^2)}{f_1^{q}(x_1, k_{1T}^2) \otimes f_1^{\bar{q}}(x_2, k_{2T}^2)},$$

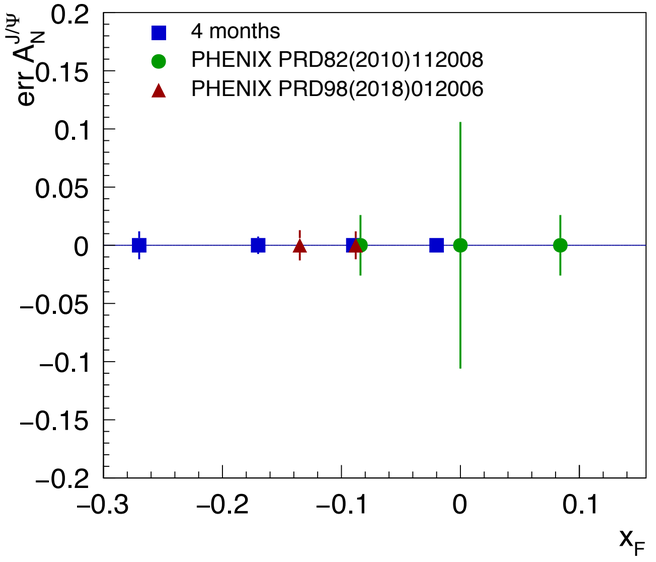
$$A_{UT}^{sin(2\phi-\phi_S)} \sim \frac{h_1^{\perp q}(x_1, k_{1T}^2) \otimes h_1^{\bar{q}}(x_2, k_{2T}^2)}{f_1^{q}(x_1, k_{1T}^2) \otimes f_1^{\bar{q}}(x_2, k_{2T}^2)},$$

- Polarised DY



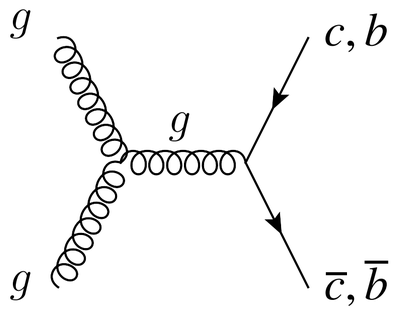
[ArXiv:1807.00603]

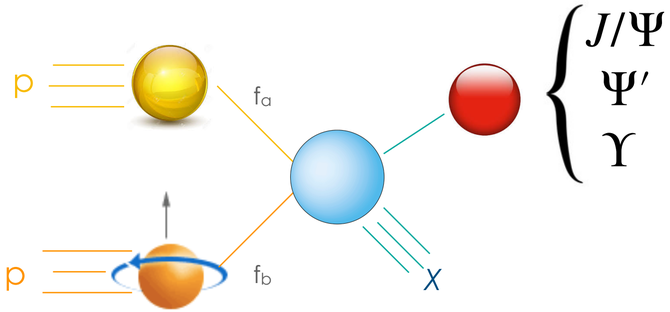
- Heavy Quark probes e.g. J/ψ , di-J/ψ



Physics case #2: hadron structure

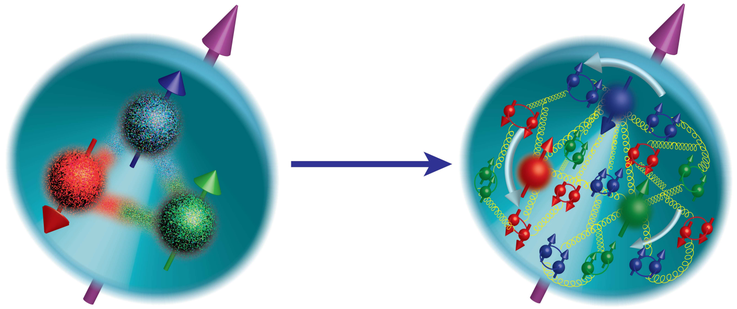
- Heavy Flavours mainly produced in via gg at LHC:





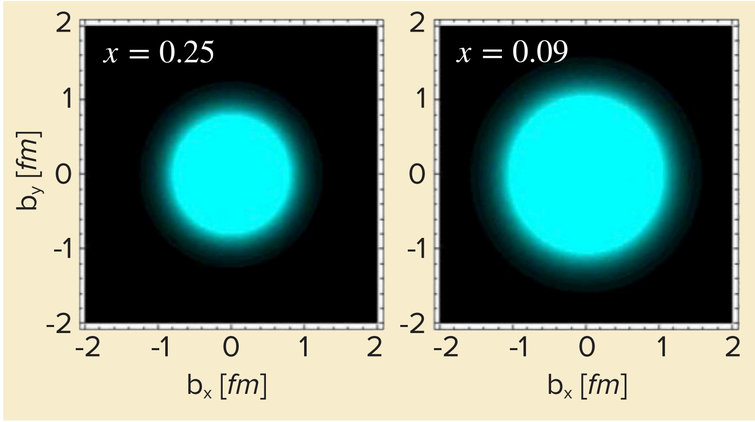
- LHCb can reconstruct large sample of quarkonia states with high resolution
- η, η_c, $\eta_c(2s)$, $\chi_{c,b}$, J/ψ, $\Upsilon(nS)$, D, $B\ldots$
- poorly accessible from other hadron-hadron experiments

- Probe GPDs via UPC e.g. via DVCS or exclusive J/ψ production (gluon GPDs)
- Quantify gluon OAM via, e.g., the Ji Sum Rule



[PRD 85 (2012) 051502] [PRL 78 (1997) 610-613]

- Build a 3D picture of the proton in the IP space

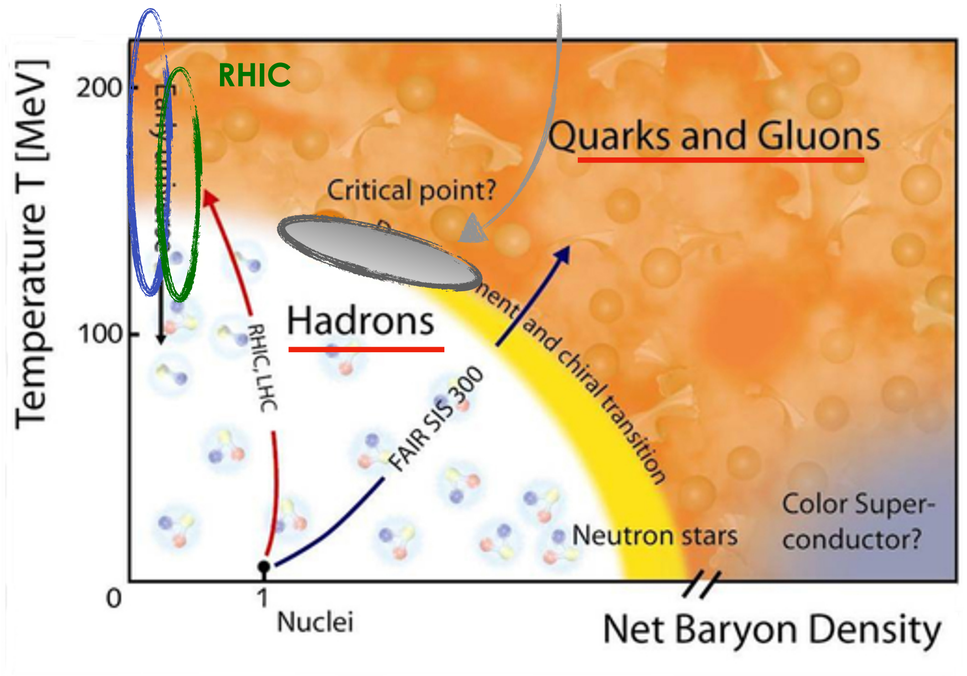


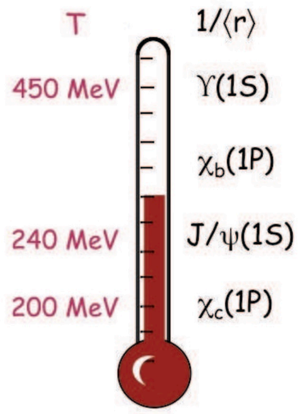
[The 2015 Long Range Plan for Nuclear Science]

Physics case #3: heavy ions

- QGP: complement the RHIC BES in the transition region via y scan [PRC 98 (2018) 034905]

LHC @5.02 TeV



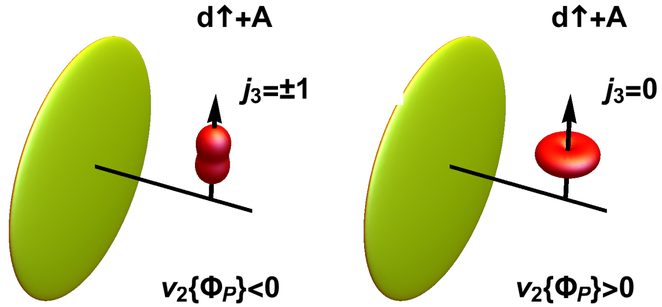


- Suppression of $c\bar{c}$ bound states as QGP thermometer
- Different binding energy → different dissociation temperature

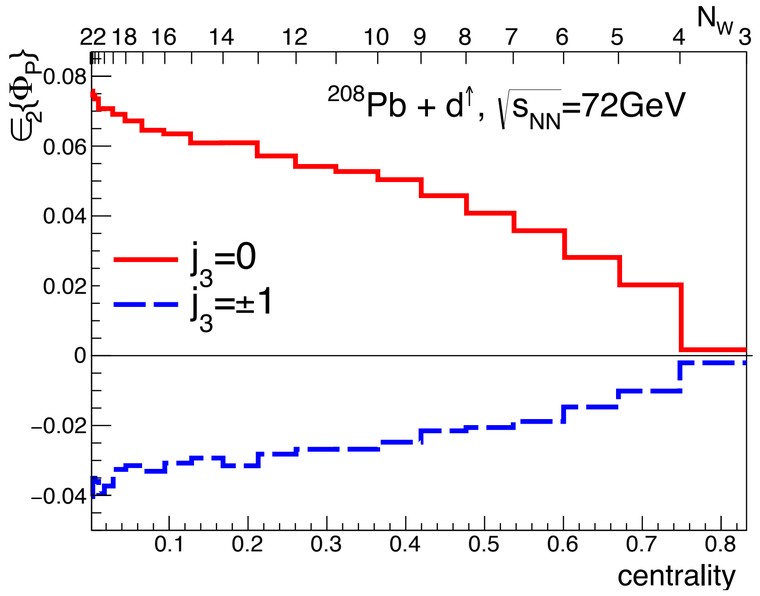
[IJMPA 28 (2013) 1340012]

- Ultra-relativistic collisions of heavy nuclei on T polarised deuterons to probe the dynamics of small systems
- Deformation of $D^{\uparrow}$ is reflected in the orientation of the created fireball in the transverse plane

D polarised along Φ_p , perpendicular to the beam

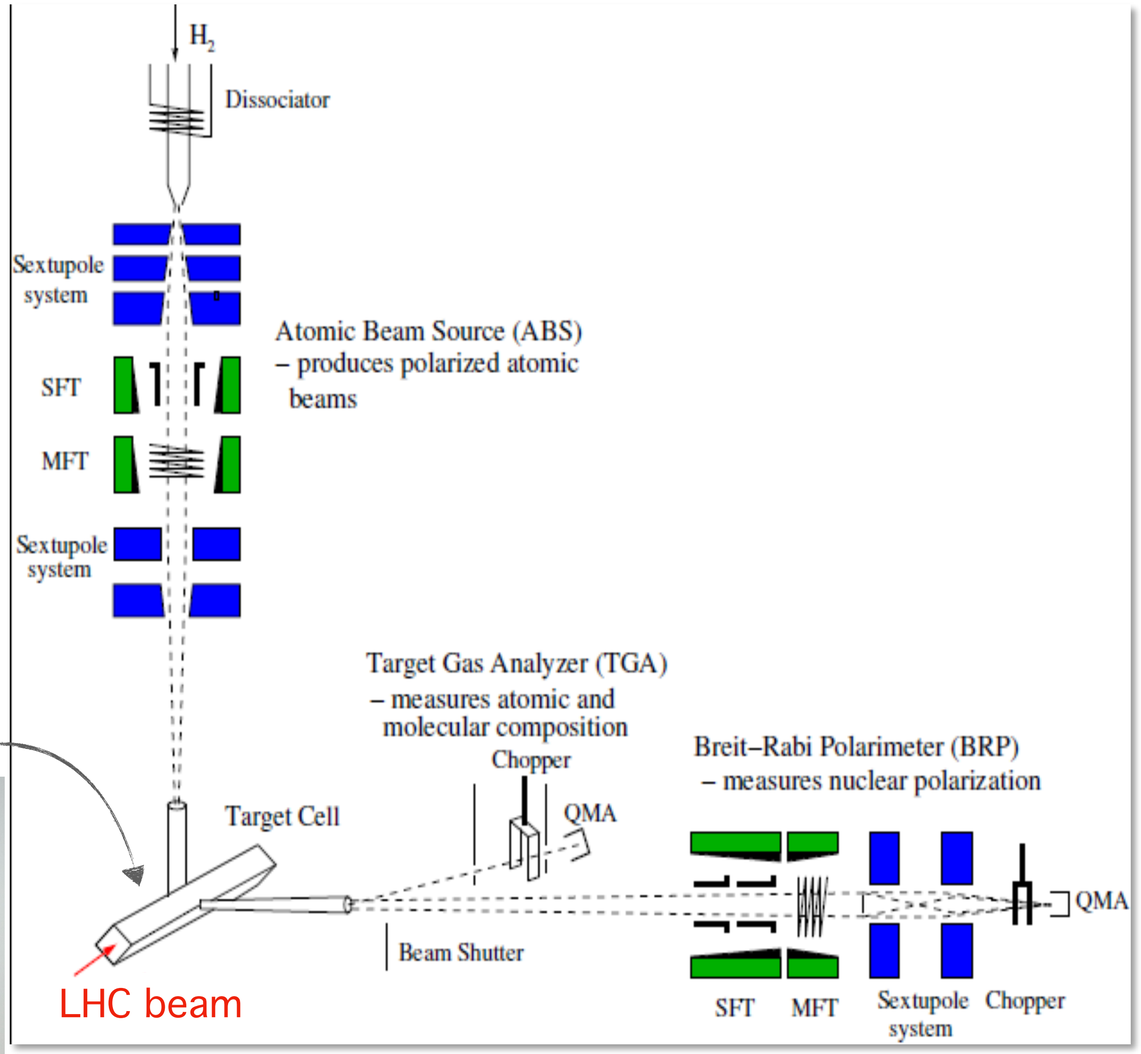


- Quantified by the ellipticity (ϵ_2 wrt Φ_p)

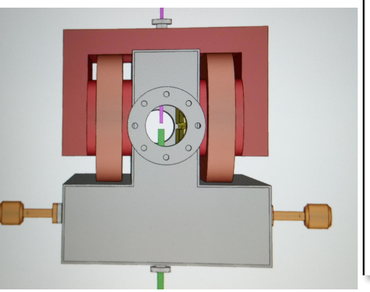


[PRC 101 (2020) 024901]

LHCspin setup



dipole



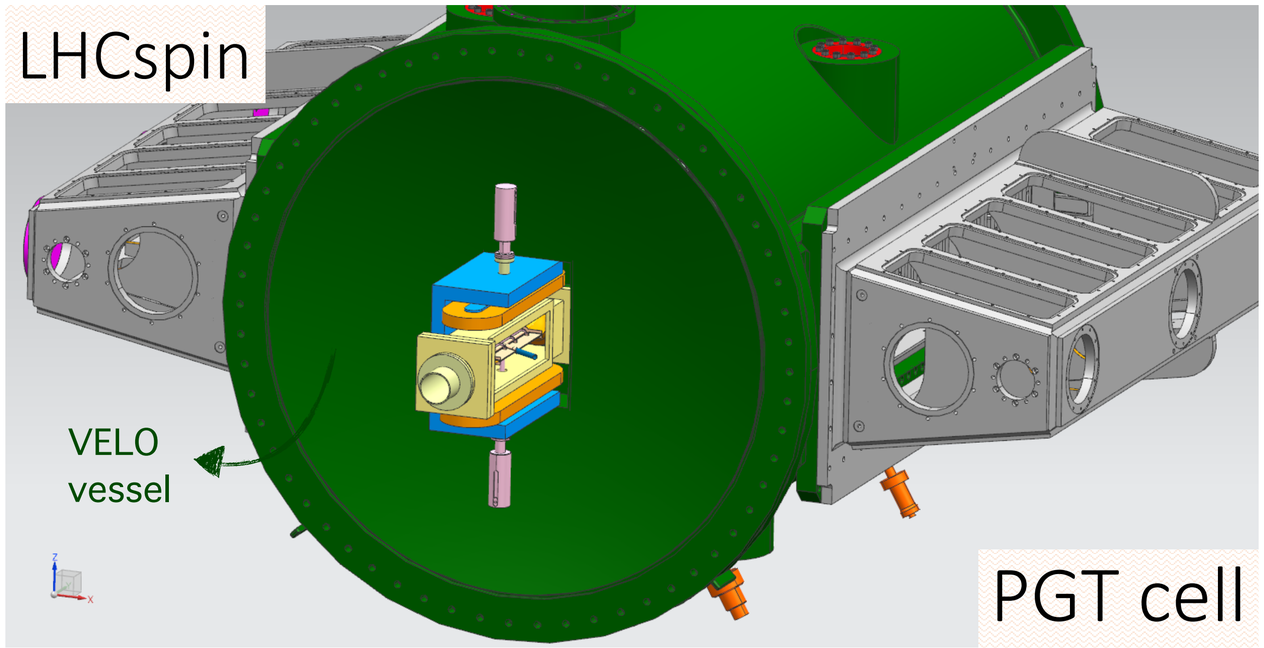
- The HERMES PGT [NIMA 540 (2005) 68–101]

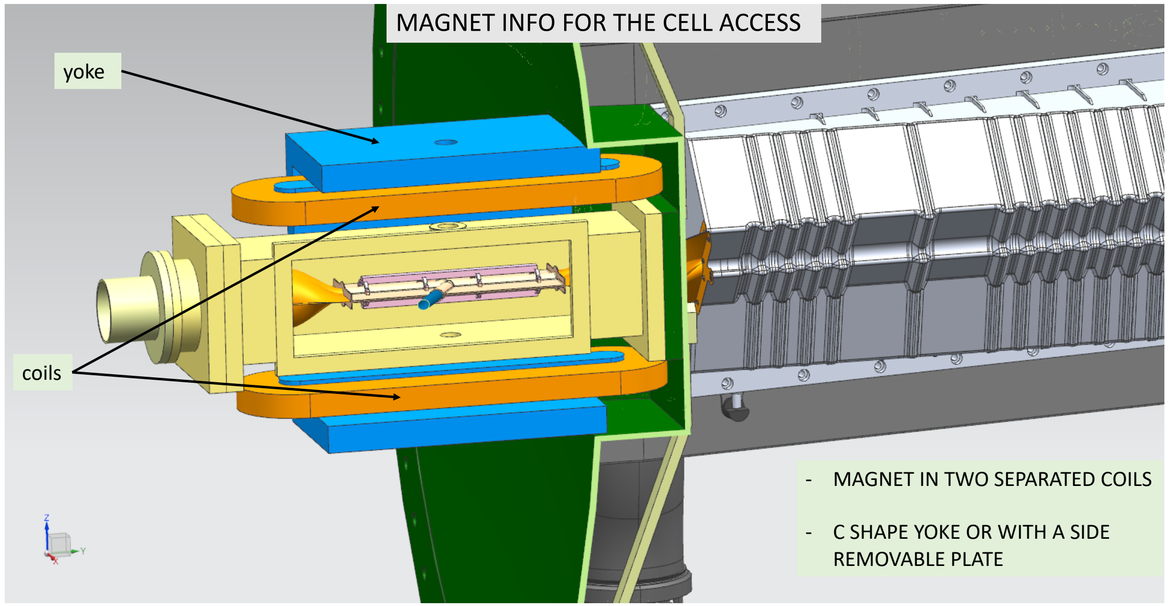
- Start from the well established HERMES setup...
- ... to create the next generation of fixed target polarisation techniques!

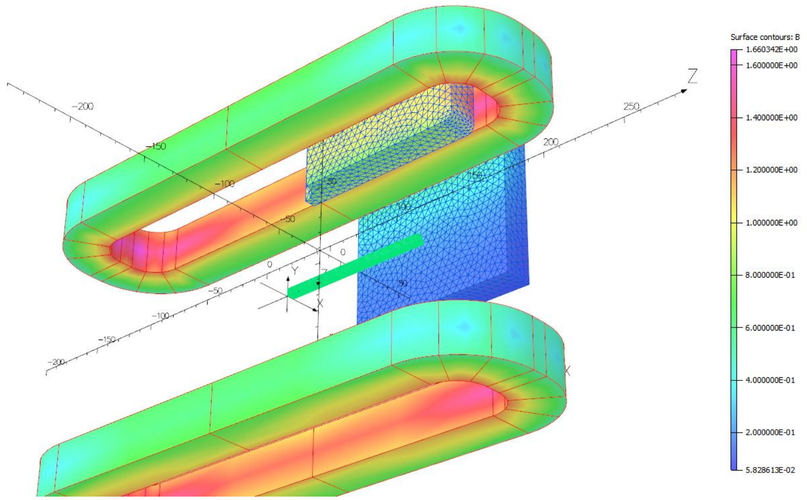
Cell and magnet R&D

- Same position of the SMOG2 cell ($30 \times 1\ \mathrm{cm}^2$), slightly larger volume
- Inject both polarised and unpolarised gas

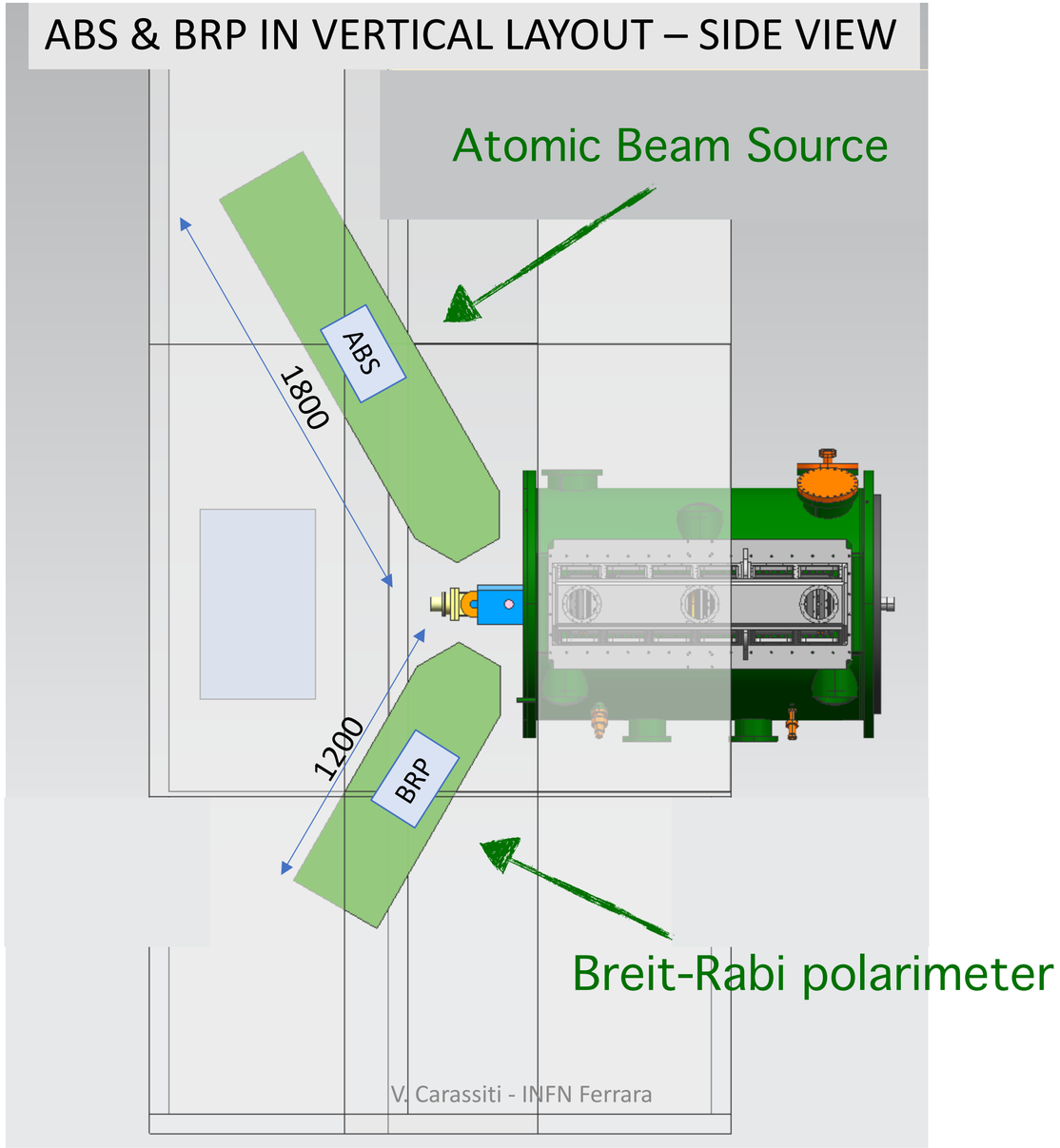
- Compact SC dipole magnet → static transverse field
- $B = 300\ \mathrm{mT}$
- polarity inversion
- $\Delta B/B \simeq 10\,\%$







ABS and BRP R&D

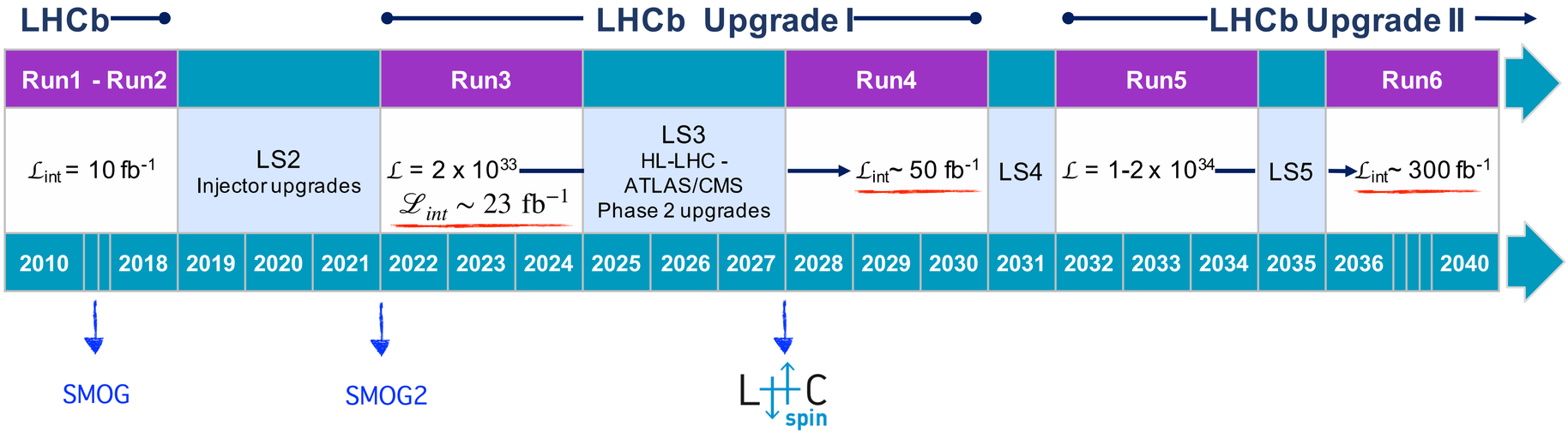


- Reduce the size of both ABS and BRP to fit into the available space in the LHCb cavern
- A challenging R&D!

Injected intensity of H-atoms:
$6.5 \times 10^{16}\ \mathrm{s}^{-1}$

Achievable Luminosity (HL-LHC):
$\sim 8 \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Conclusions



- The fixed target program at LHCb is active since Run 2, now greatly enriched with the SMOG2 cell for Run 3
- LHCspin: a step forward to bring spin-physics measurements for the first time at LHC, exploiting the well-suited LHCb detector
- The R&D calls for new generation of polarised gas targets: challenging but worth the effort!
- Extensive physics program, with new probes, and complementary to existing facilities and the future EIC