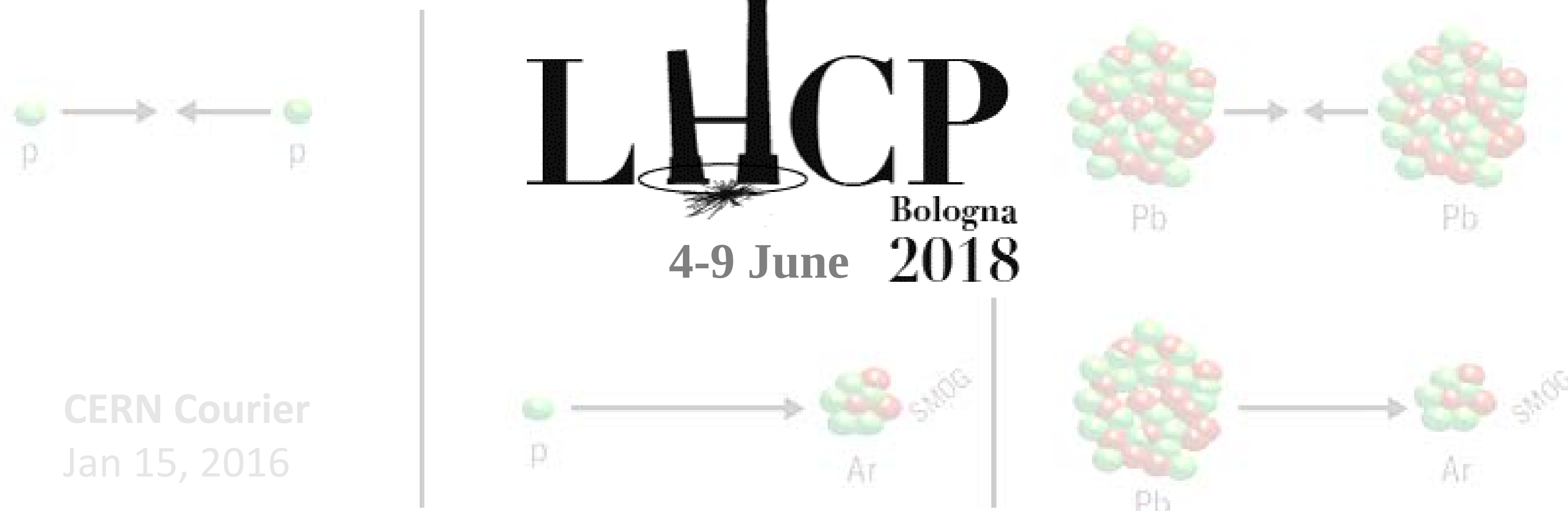
Fixed-target opportunities at LHCb

F. Martínez Vidal, IFIC-Valencia
On behalf of the LHCb Collaboration



LHCP Bologna
4-9 June 2018

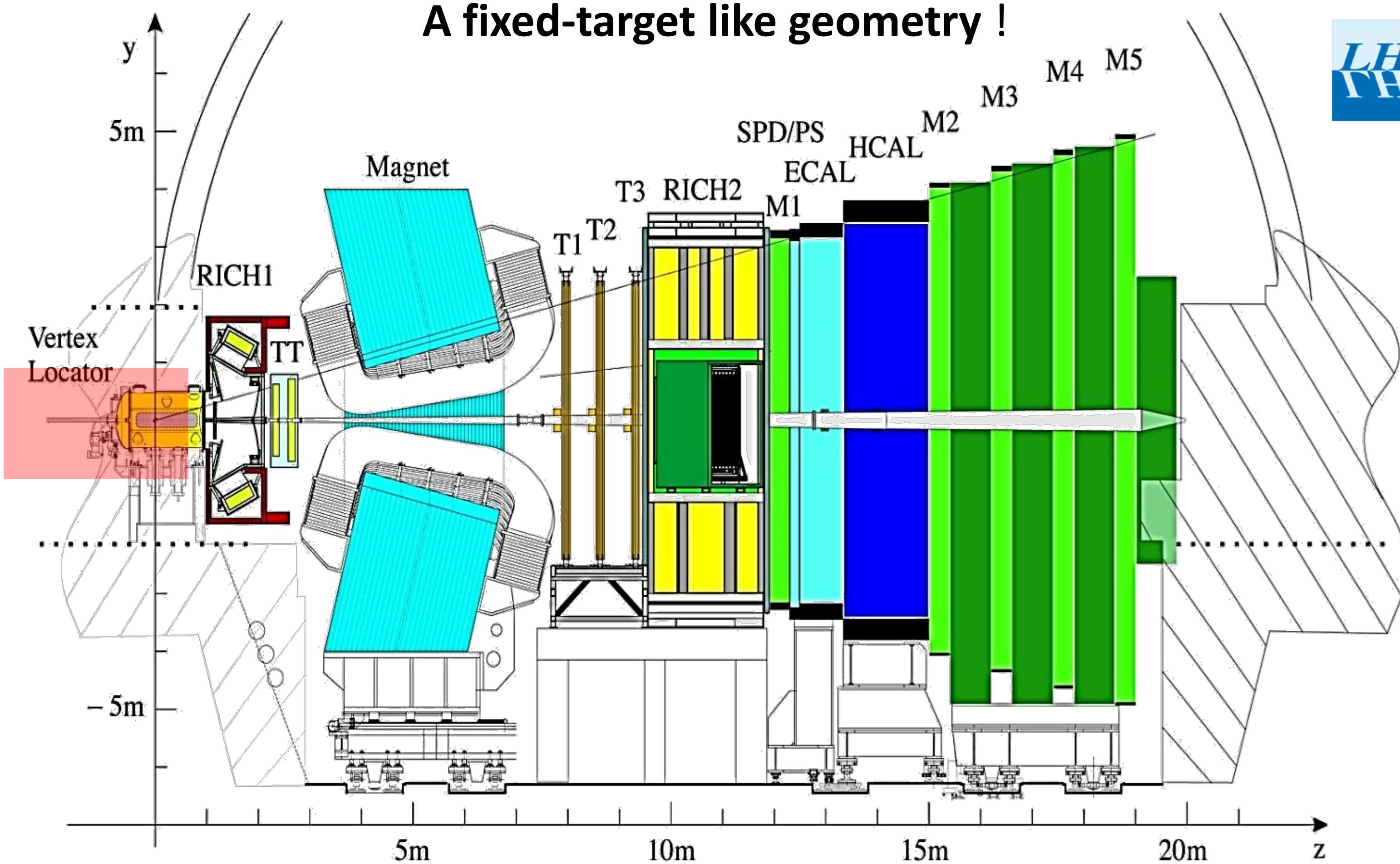
EXCELENCIA SEVERO OCHOA
IFIC INSTITUT DE FISICA CORPUSCULAR
CSIC
VNIVERSITAT DE VALÈNCIA

LHCb detector

JINST 3 (2008) S08005
Int. J. Mod. Phys. A30 (2015) 1530022

Single-arm forward spectrometer, optimized for b- and c-hadron physics.
The only LHC experiment fully instrumented at large η (2<η<5)

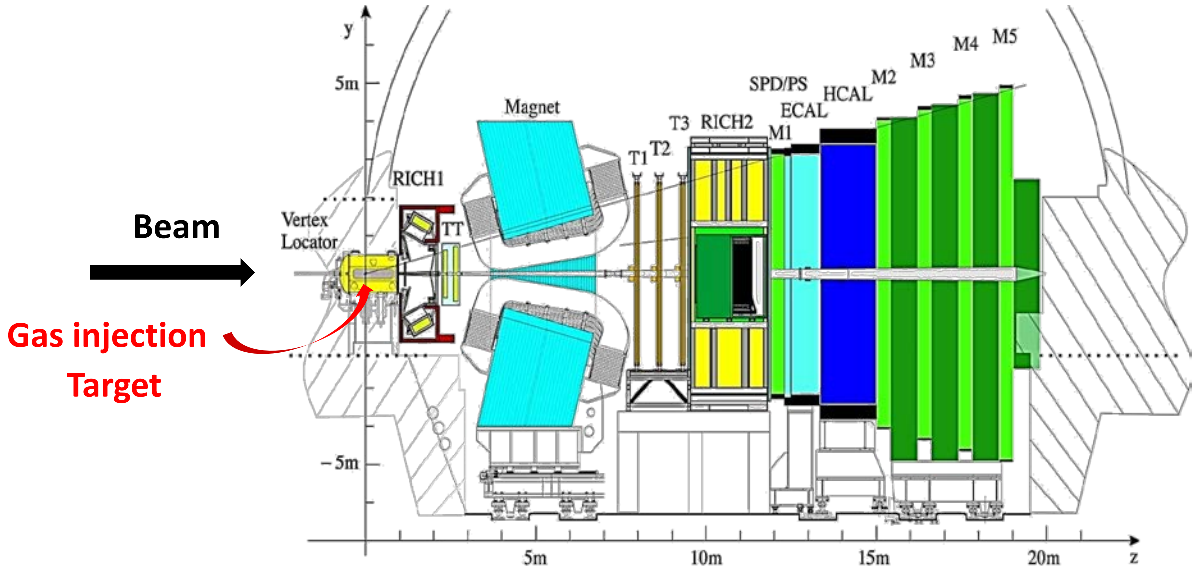
A fixed-target like geometry !



SMOG comes…

JINST 9 (2014) P12005

- Inject gas in the VELO tank, primarily done to perform luminosity measurement by measuring the beam images with beam-gas vertices (1.2% precision)



Noble gas only
(very low chemical reactivity)

	He	Ne	Ar
A =	4	20	40

Gas pressure:
From nominal 10^{-9} (LHC vacuum) to few×10^{-7} mbar (for beam safety)

Allows p-gas and ion-gas interactions

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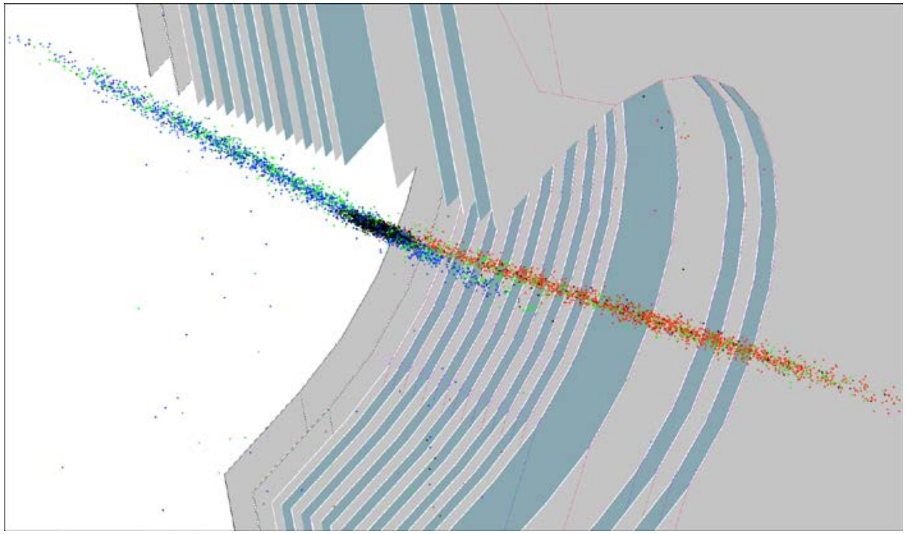


Reconstructed beam-gas vertices inside VELO

Noble gas only
(very low chemical reactivity)

	He	Ne	Ar
A =	4	20	40

Gas pressure:
From nominal 10^{-9} (LHC vacuum) to few×10^{-7} mbar (for beam safety)

Allows p-gas and ion-gas interactions

- Can be used as an internal gas system and operate in fixed-target mode
- Fixed-target physics at LHC via SMOG is already yielding results, e.g.

p He → $\bar{p}$ X @ $\sqrt{s_{NN}}$ = 110 GeV, important and well recognized input for cosmic rays physics

LHCb-CONF-2017-002

J/ψ and D^0 production cross-sections and yields in p He @ $\sqrt{s_{NN}}$ = 86.6 GeV and Ar @ 110 GeV

LHCb-CONF-2017-001, paper in preparation

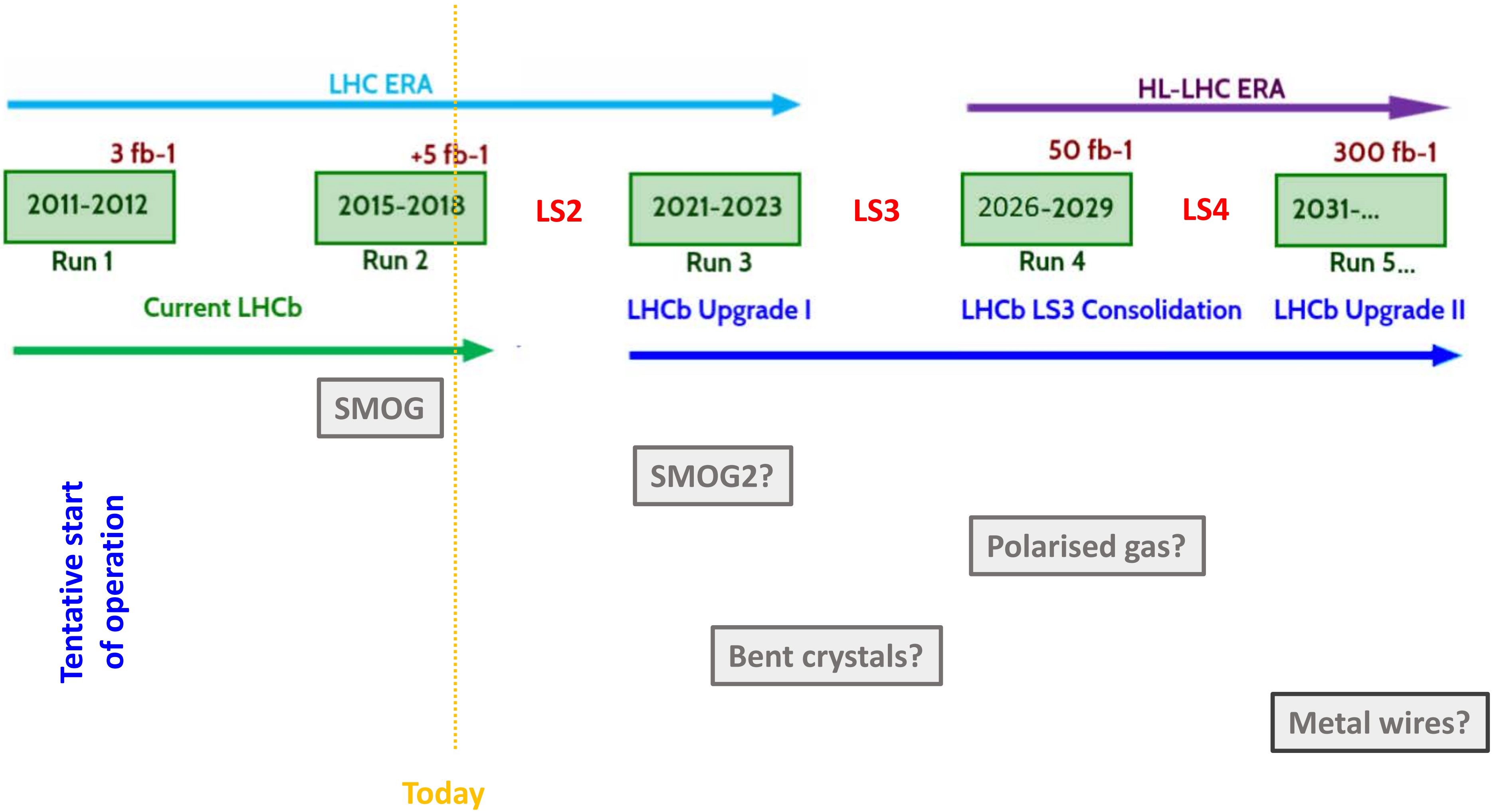
…and opens new horizons

- These results motivate continued exploitation of SMOG and upgrade of the current system with the introduction of a gas storage cell (SC) inside VELO tank (aka SMOG2)
- And other, more ambitious ideas…
  - ✓ Polarised gas target, to perform spin-physics measurements
  - ✓ Tungsten target paired to bent crystal to access magnetic (MDM) and electric (EDM) dipole moments of heavy flavoured baryons
  - ✓ Solid (metal) wire target, to extend SMOG2 heavy-ion program
- Discussions ongoing with LHC Collimation Project CERN, UA9 under CERN Physics Beyond Colliders

Disclaimer

- None of these proposals has been yet approved by LHCb.
- Moreover, they will have to be approved by relevant machine committees, as they rely on the LHC machine and/or could have some interference with it.

Tentative LHCb fixed-target program schedule



Fixed-target physics with LHC beams

High x (>0.5), including exotic x>1

Copious production (up to ~0.1 fb^{-1}/year) opens many novel possibilities

$\sqrt{s_{NN}} \approx$ 115 GeV (pA) and $\approx$ 72 GeV (PbA), intermediate between SPS ($\approx$20 GeV) and RHIC ($\approx$200 GeV)

- **Drell-Yan processes**
- **Heavy flavour states**
- **Jets**
- **Direct/isolated photons**
- **Z and W bosons, near threshold**

Wide Physics Goals

QCD and QGP

AFTER

Phys. Rep. 522 (2013) 239
Adv. High Energy Phys. 2015 (2015), SI

- **Nuclear partonic structure:** PDFs for gluons, antiquarks and heavy quarks (EMC effect, anti-shadowing, Fermi motion,…)
- **Particle production in soft QCD regime,** of particular relevance for cosmic-ray physics
- **Probes of QGP formation and deconfinement,** e.g. suppression of charmonium
- **TMD functions, nucleon spin puzzle,** Soft Collinear Effective Theory ($gg \to H$)
- **Ultra-peripheral and diffractive reactions**

~1 TeV secondary beams

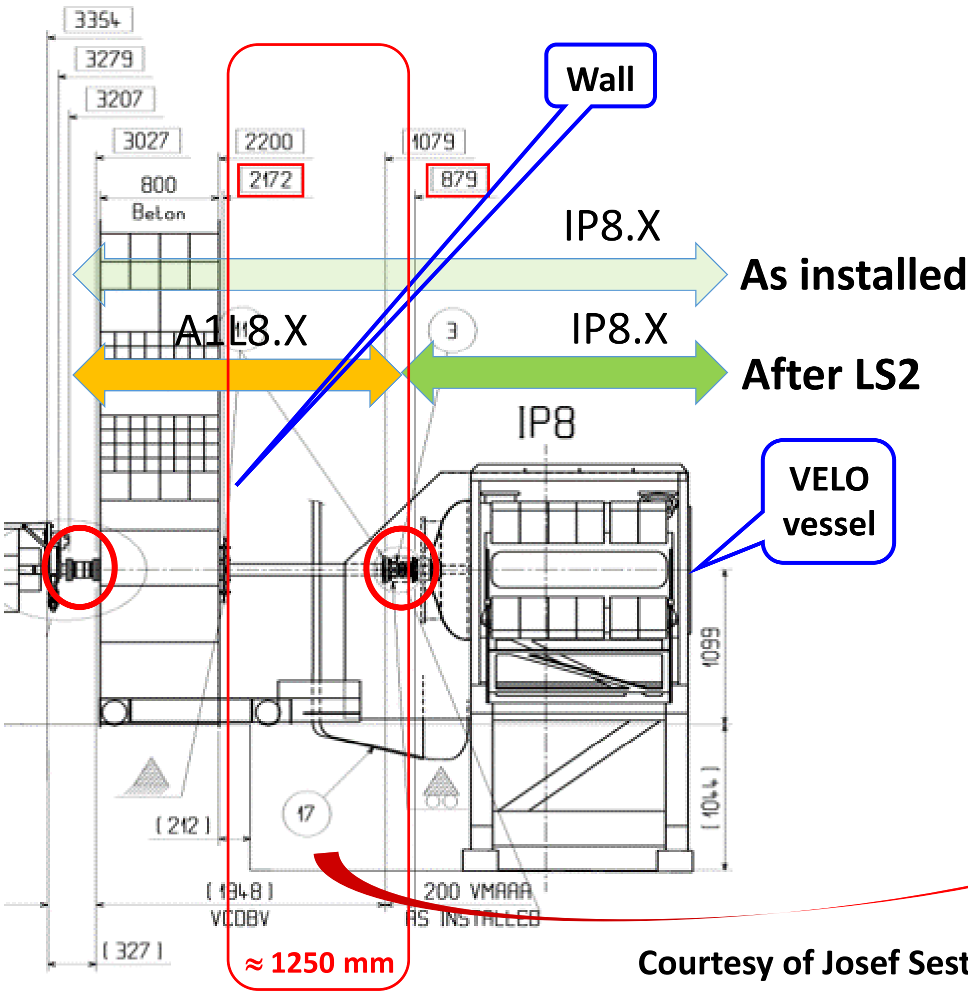
- **Heavy baryons,** e.g. Λ_c^+, to be channelled in a bent crystal for **magnetic and electric dipole moments**

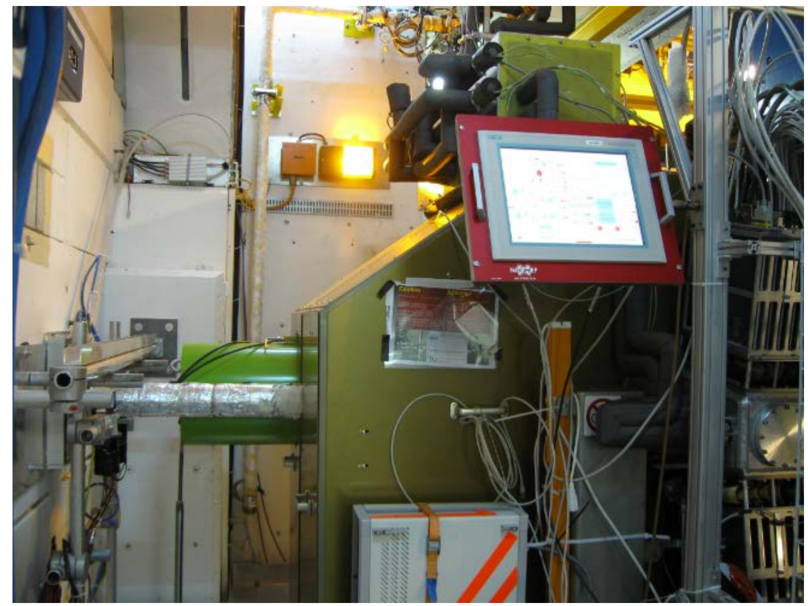
Phys. Lett. B 757 (2016) 426
CERN-SPSC-2016-030
Eur. Phys. J. C 77 (2017) 181
JHEP 1708 (2017)
Eur. Phys. J. C 77 (2017) 828

- **D^0 and B^0_s mesons,** e.g. for oscillations in matter (amorphous bent crystal)
- **Other flavour physics,** complementary to LHCb core physics program…

Additional vacuum sector upstream VELO

- In order to allow installation/maintenance of required instrumentation without breaking the VELO beam vacuum, a new vacuum valve will be installed in LS2



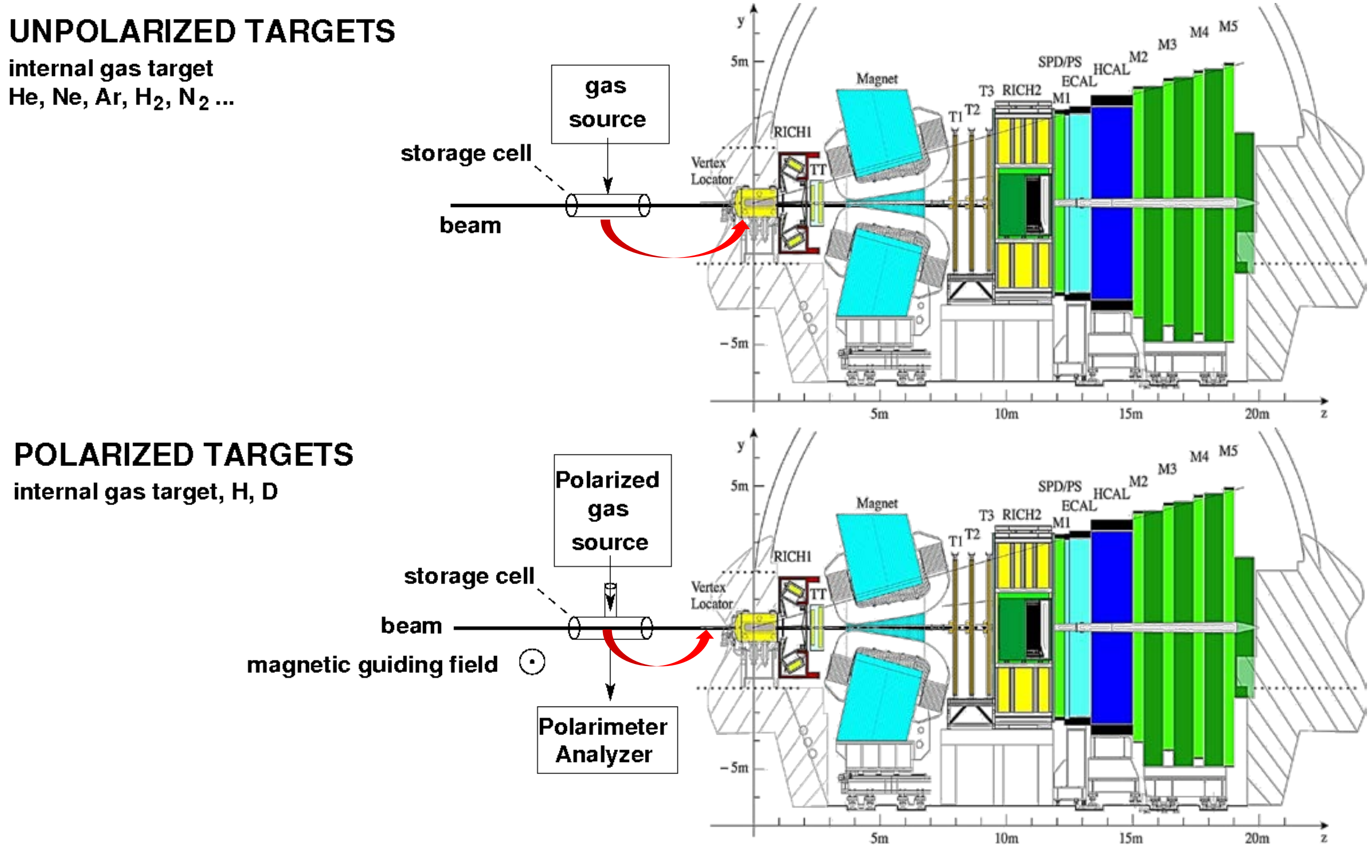


Courtesy of Josef Sestak, CERN

Principle of gas targets and storage cells (SC)

- Cylindrical open-ended tube located around the beam

Rep. Prog. Phys. 66 (2003) 1887



- Gas injected in the middle of the tube, ≈ triangular density
- Enhanced target thickness as compared to gas injected directly in the beam pipe

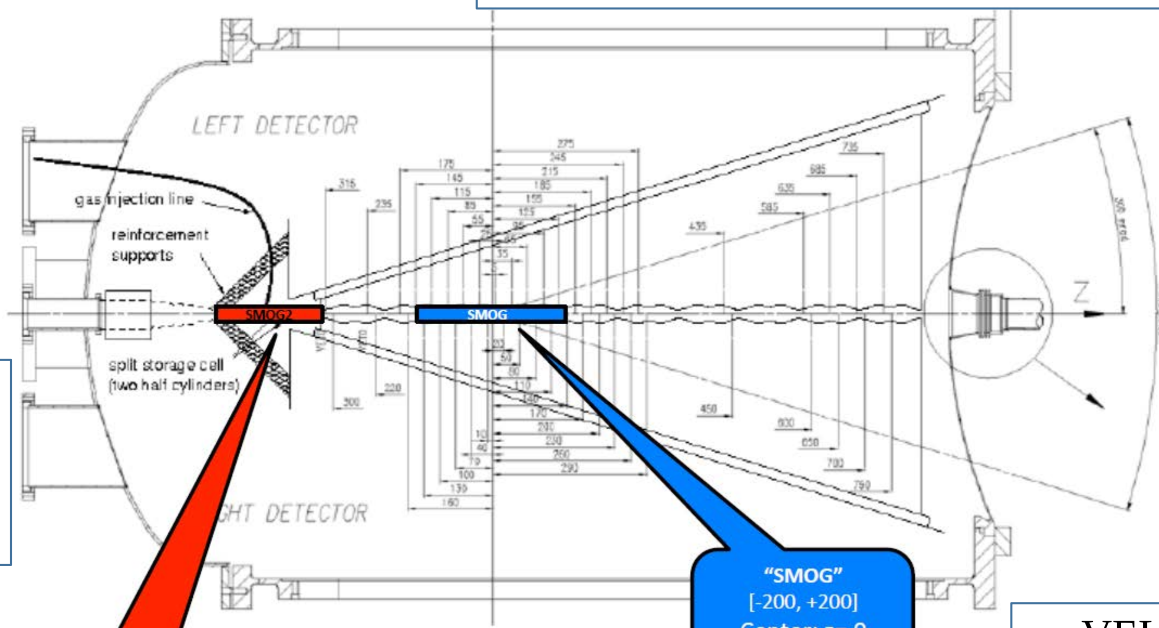
SMOG upgrade: SMOG2

- Install a gas SC inside VELO tank, upstream the sensors
- Many benefits:

Increase of target density up to two orders of magnitude for the same gas flow
(e.g. from ≈5×10^{9} He/cm^3 for ≈4×10^{15} He/s to ρ_{max}≈10^{12} He/cm^3)

Better known density (luminosity)

Goal to inject other gasses, eg. H_2, D_2, besides He, Ne, Ar,…



SMOG2 cell
[-500, -300]
Center: z=-400 mm
Length: 20 cm

"SMOG"
[-200, +200]
Center: z= 0
IP Region selected for SMOG analyses

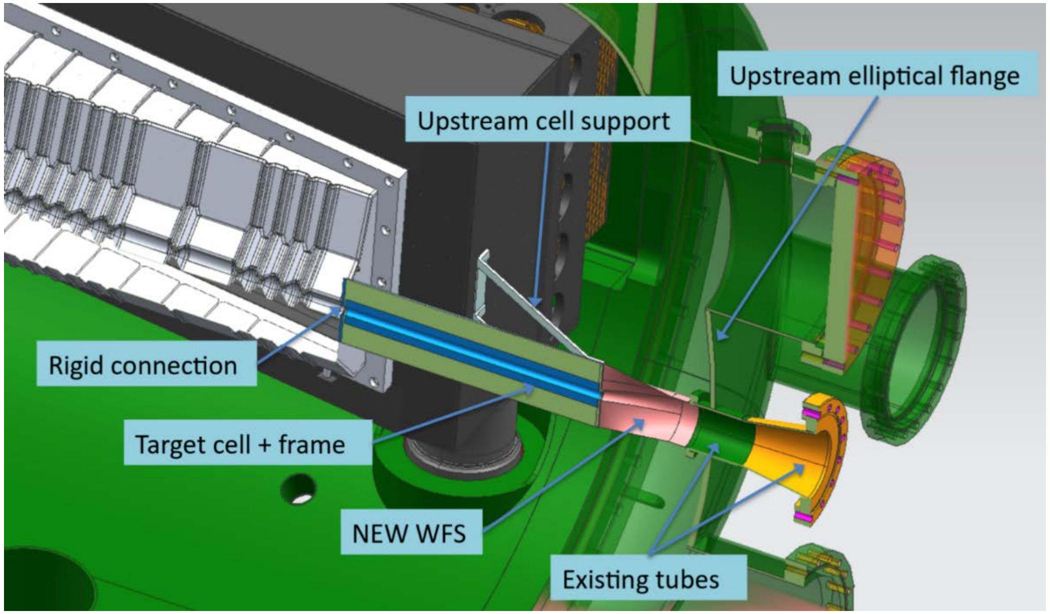
Update of Gas Feed System, HERMES-like: 1% or better gas flow uncertainty and remote control for gas change

VELO pump activated, lower residual gas pressure

Fixed-target IP upstream proton-proton IP

SMOG2

- No overlap with pp collisions: reduced backgrounds and possibility for parallel running with pp collisions
- Better acceptance at high η
- Lower PV reconstruction performances
  - ✓ Can be compensated by the higher (and better known) gas density
- First technical design of the SC: two halves, supported to VELO box and retractable along with sensors



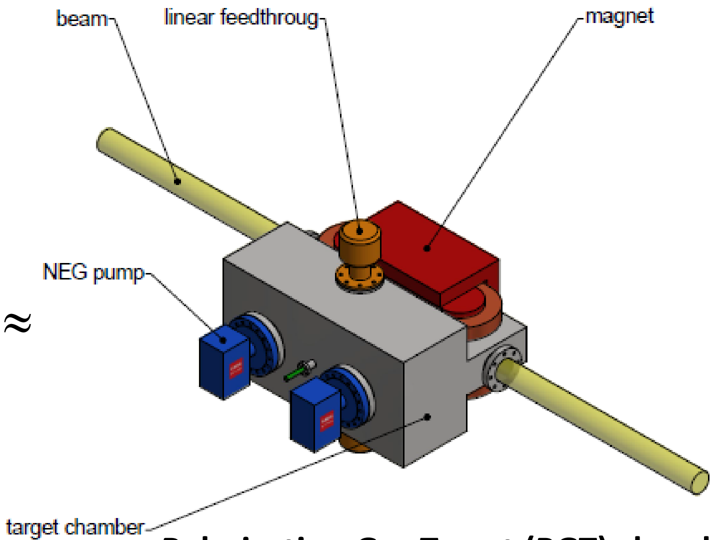
R&D on SC at NIKHEF, INFN-Ferrara, INFN-Frascati

- Further studies to assess the interaction of the SC with the beams (impedance and wakefields, dynamic vacuum,…) and impact of target density on detector performance

Polarised gas

- Polarised gas target similar to the one used in HERMES Nucl. Instr. Meth. A 540 (2005) 68
- Requires compact gas chamber, centered at –1.6 m from pp IP
- Acceptance and tracking in the upstream configuration worst but still acceptable
  - ✓ Could be improved adding detector layers
- Gas atoms or molecules undergo large number of wall collisions ⇒ depolarisation
  - ✓ R&D on coating materials compatible with both LHC and target requirements. Also interesting for FCC
- More studies needed to assess physics case, interaction with beams (magnetic fields, beam RF depolarisation,…) and detector performance

≈



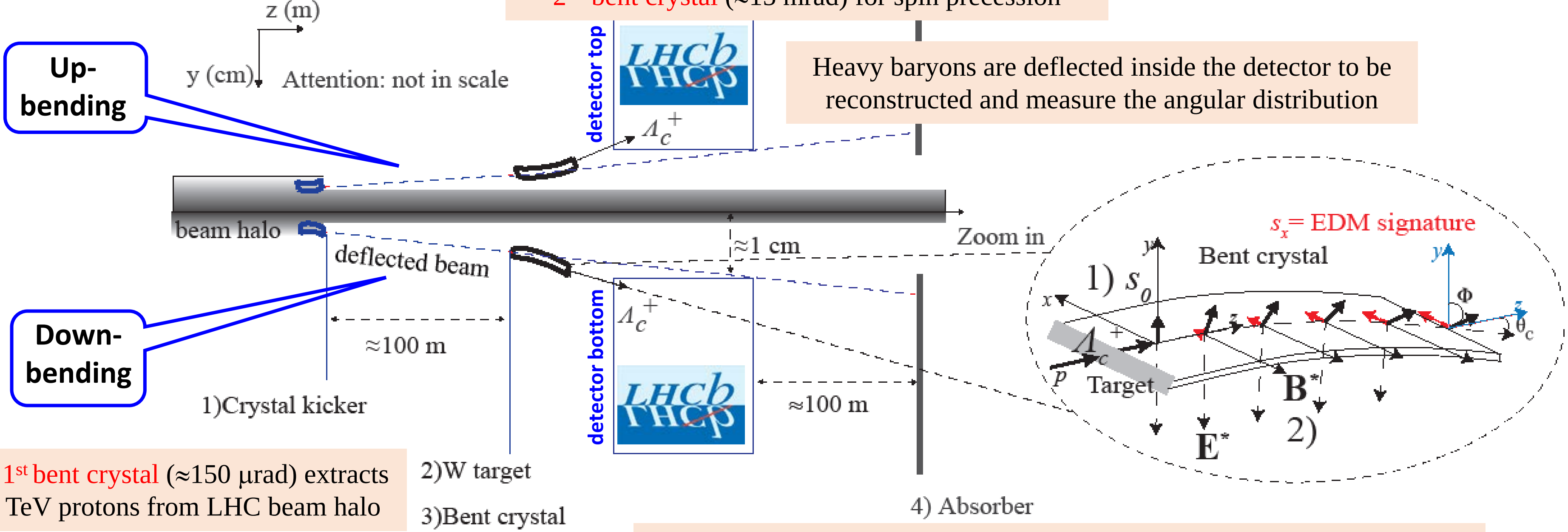
Polarisation Gas Target (PGT) chamber

Surface studies for FCC, INFN-Frascati

Principle of bent crystals target

Extracted p beam is directed on W target paired to a 2^{nd} bent crystal (≈15 mrad) for spin precession

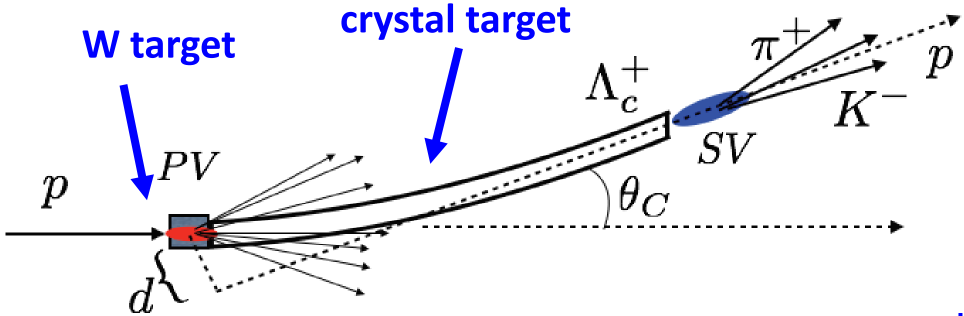
Heavy baryons are deflected inside the detector to be reconstructed and measure the angular distribution



A 1^{st} bent crystal (≈150 μrad) extracts 7 TeV protons from LHC beam halo

Non-interacting protons, non-channeling particles and most secondary interactions follow the beam pipe to be absorbed downstream the detector

- The high electric field between the crystallographic planes makes the heavy baryon spin precess, giving access to the MDM/EDM



Bent crystals

Phys. Rev. Lett. 69 (1992) 3286

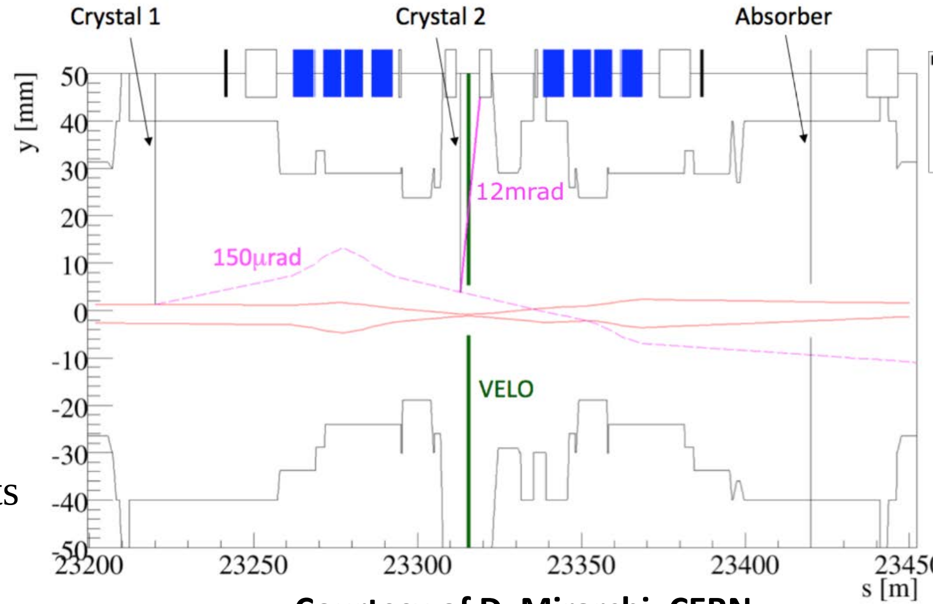
- Proof-of-principle by E761: MDM of Σ^+ from 800 GeV protons on Cu target
- Compatibility with LHC collimation scheme seems feasible according to preliminary studies, but detailed studies are required

Machine operation
(parasitic vs dedicated, primary/secondary/tertiary halos)

Achievable proton flux

Collimation system (absorber)
for disposal of the split beam and other products

All devices placed in available slots at IR8



Courtesy of D. Mirarchi, CERN

- Channeling with 6.5 TeV LHC protons demonstrated in 2016

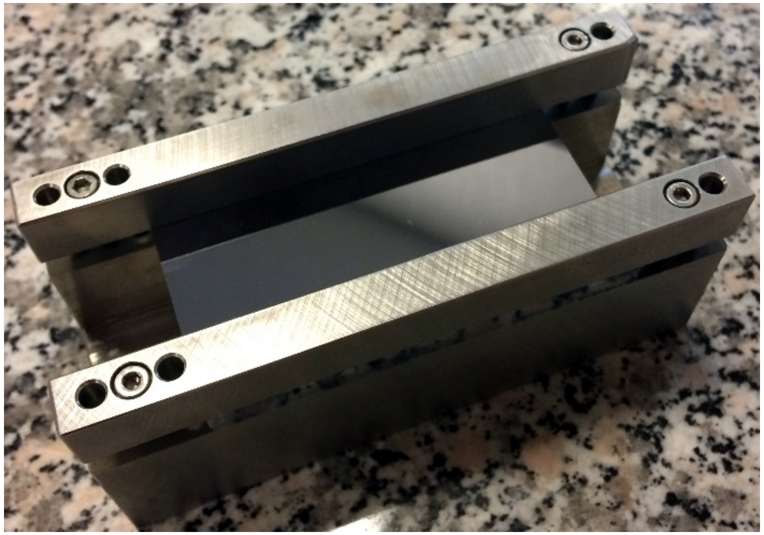
Phys. Lett. B758 (2016) 129

- First test of double-crystal scheme at SPS on 18 Sep 2017 very encouraging

Proceedings of IPAC2018, Vancouver
http://ipac2018.vrws.de/papers/tupaf043.pdf

Bent crystals

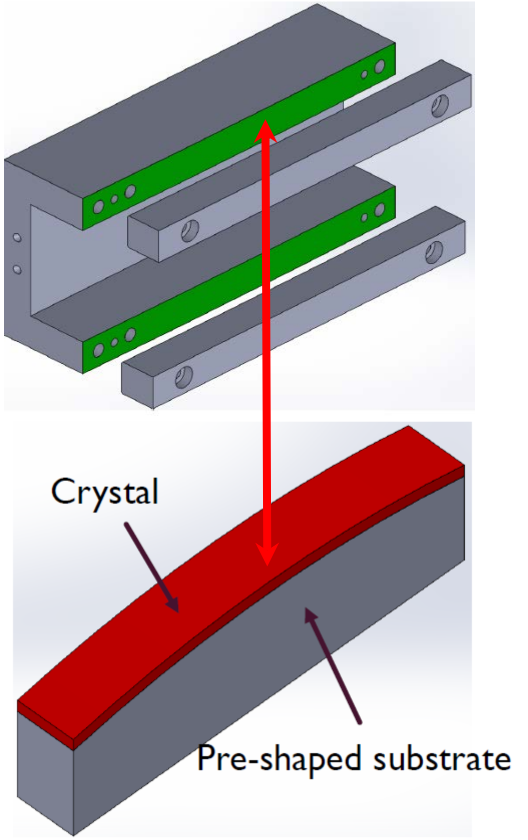
- R&D ongoing at INFN-Ferrara & PNPI/IHEP for large bending angle, ≈15 mrad (≈10 cm long), mainly determined by detector acceptance
  - ✓ Cannot use anticlastic deformation
  - ✓ Need special bending techniques with very precisely machined (~100 nm) holder to maintain uniform deformation
  - ✓ First prototypes produced. First test beam results will be available soon



Courtesy of A. Mazzolari, INFN-Ferrara

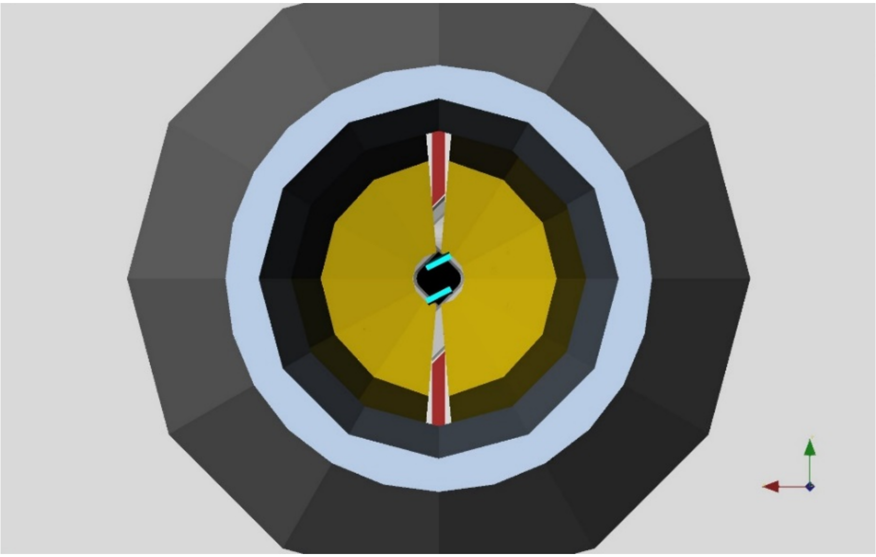
Sample tested on May 22, 2018 at H8 external line of the SPS in the frame of the UA9 Collaboration.

Bending angle is ≈ 12 mrad



Bent crystals

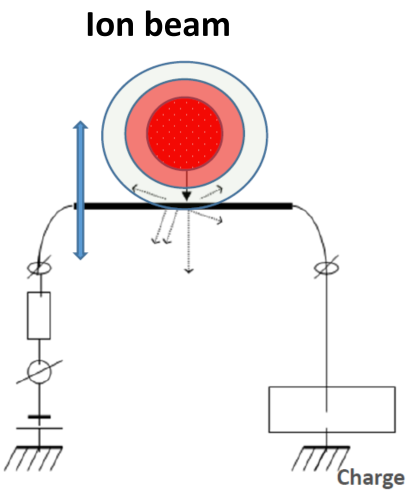
Downstream view of the up- and down-bent crystals



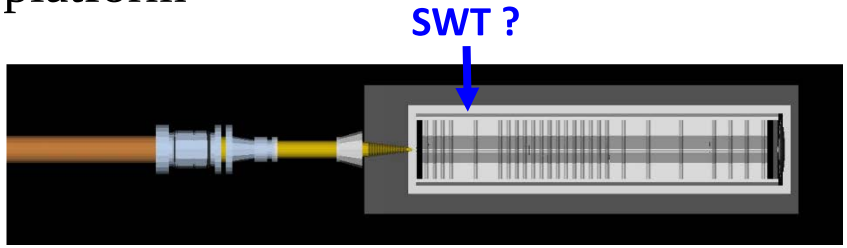
- Setup at ≈ 0.4 cm from beam center, installed on retractable goniometer (~20 μrad) upstream the VELO tank, ≈ –1.2 m from pp IP (W)
- Crystals rotated for optimal acceptance
- Clean signal signature mostly based on precise kinematical information, compensates low vertex resolution
- ≈ 2×10^{14} protons on 2.0 cm thick W target could be reached in 3 years of
  - ✓ parallel running with pp collisions (no overlap with pp), at maximum of ~10^{7} p/s
  - ✓ dedicated running, 2 weeks/year, at flux 10^{8} p/s
- ~10^{-3}-10^{-2} μ_N for charm MDM. Very valuable for low-energy QCD
- ~10^{-17} e cm for charm EDM. Improve indirect limits and sensitivity to new physics at EW scale. Also proof-of-principle for future experiments
- Setup can also be used as a standard fixed (gas) target

Solid wire target

- Wire metal target in the LHC ion beam halo
- Wires are target and sensors, vertices precisely located
- To avoid breaking the principle of magnet safety, current proposal uses super-thin wires (STW, ~1 μm) also in the beam core at low luminosity dedicated runs
- Installation inside VELO box mounted on a movable up & down platform



R&D on metal microstrip detector at KINR, Courtesy of V. Pugatch



- Can use many different materials

Nucl. Instr. Meth. A 446 (2000) 190
AIP Conf. Proc. 512, 359 (2000)

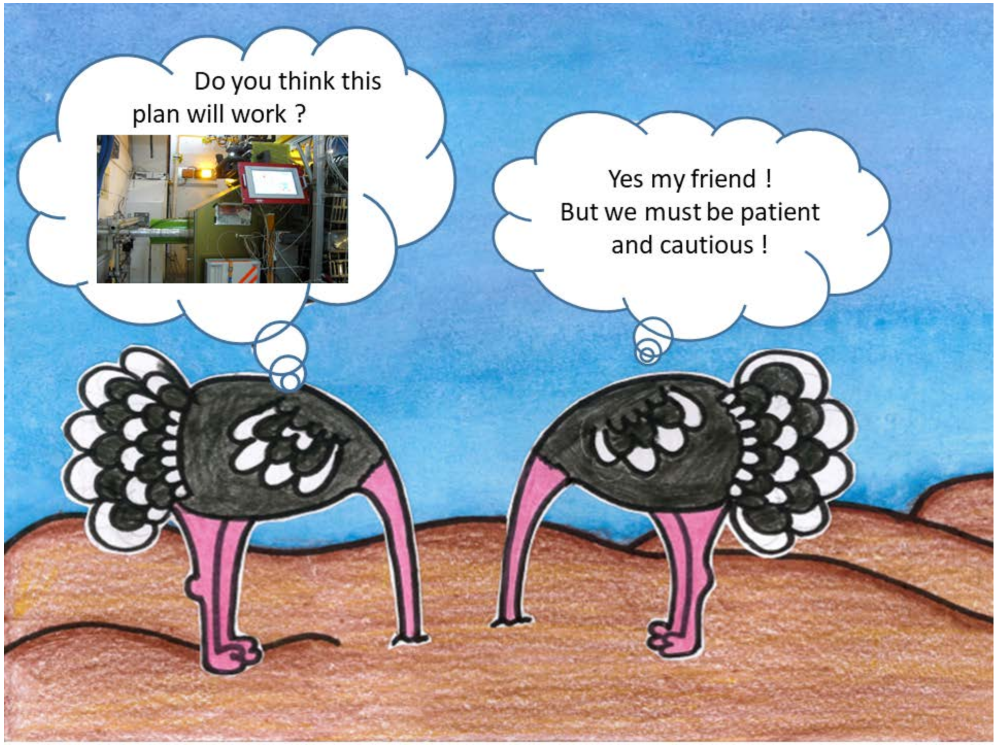
- Proof-of-principle at HERA-B, but LHC conditions are completely different
- Need to assess impact on detector & machine and physics reach wrt SMOG2

Conclusion

- LHCb success in Fixed Target (gas) has open new horizons

- New ideas, more ambitious, very challenging, but no showstoppers so far

- New realms that would expand the LHC physics potential



- Priority of the experiment is the **Upgrade I** and **Flavour Physics core program**, but significant R&D towards making these ideas a realm