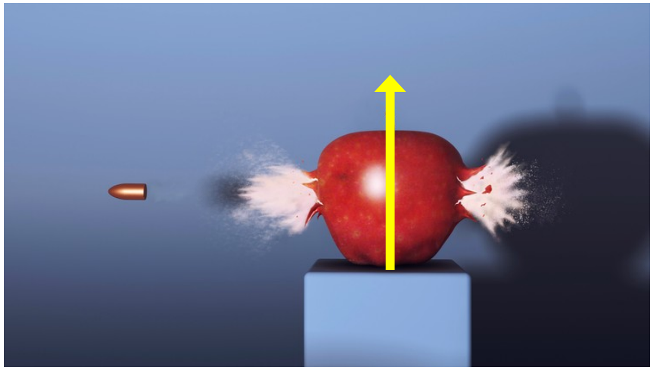
Future opportunities in Hadron Physics for the European Particle Physics Strategy
Mainz – November 20 2018

Hadron Physics with a fixed target at LHC



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Kinematic conditions for fixed-target collisions at LHC

$E_p = 7$ TeV $\Longrightarrow$ $\begin{cases} \sqrt{s} = 115\ GeV \\ \gamma = \sqrt{s}/2m_p \approx 60 \end{cases}$ $\Longrightarrow$ $\boxed{y_{CM} = y_{lab} - 4.8}$

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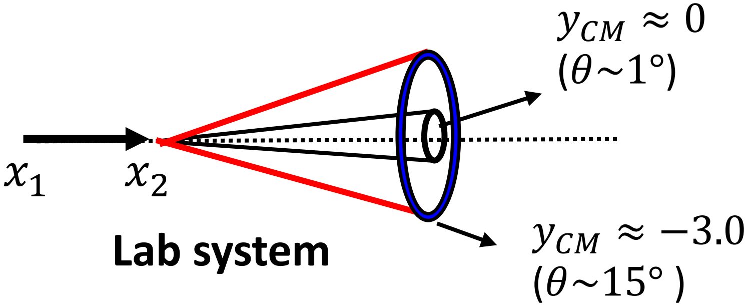
Backward CM rapidity region

$2 \lesssim y_{lab} \lesssim 5$
(LHCb acceptance) ⟹ $-3.0 \lesssim y_{CM} \lesssim 0$



A forward spectrometer at LHC can access the backward CM region with reaction products at measurable forward angles!

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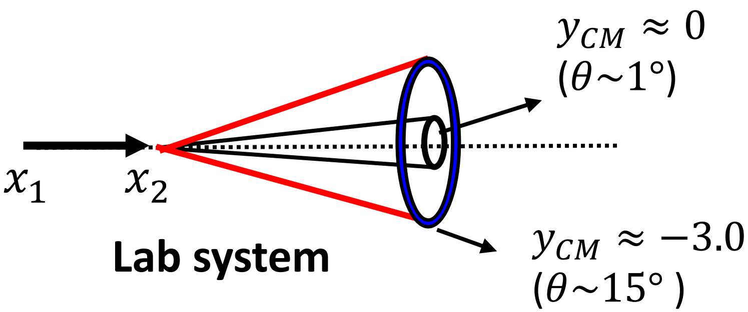

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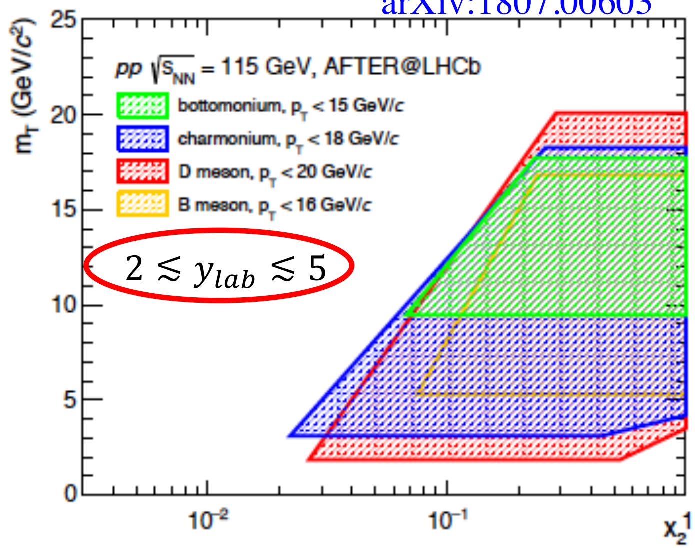
$$x_2 = \frac{m_T}{\sqrt{s}} e^{-y_{CM}}$$

$$m_T = \sqrt{E^2 - p_T^2}$$

arXiv:1807.00603



- **Sensitive to large Bjorken-x ($x_2 \to 1$)**
- **Access to target-fragmentation region ($x_F \to -1$)**

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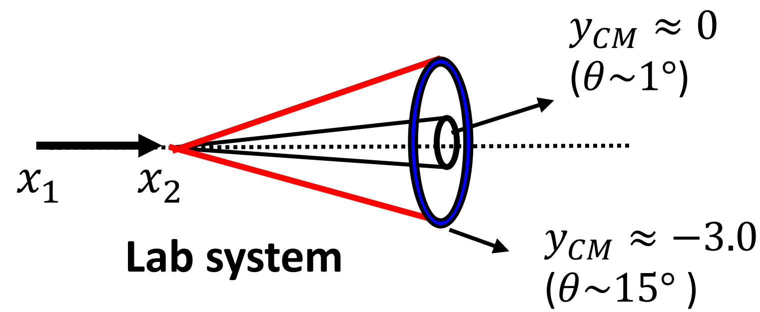

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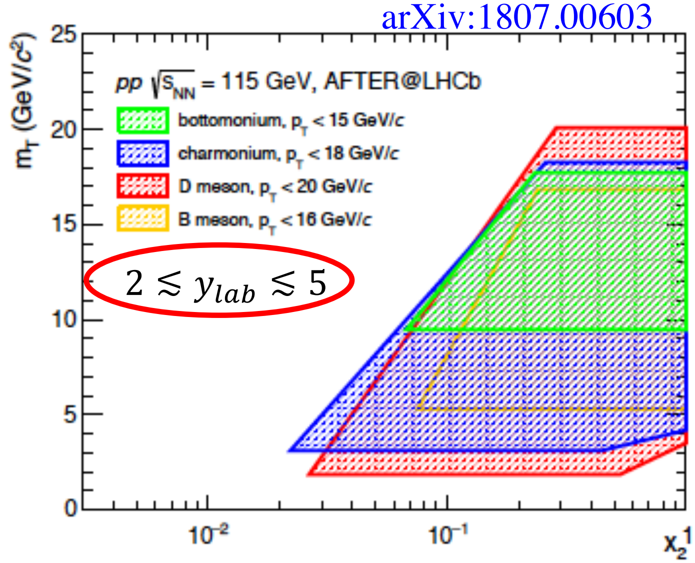
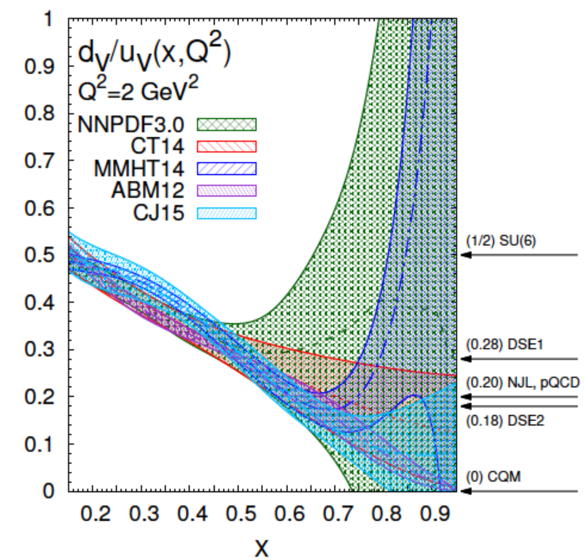
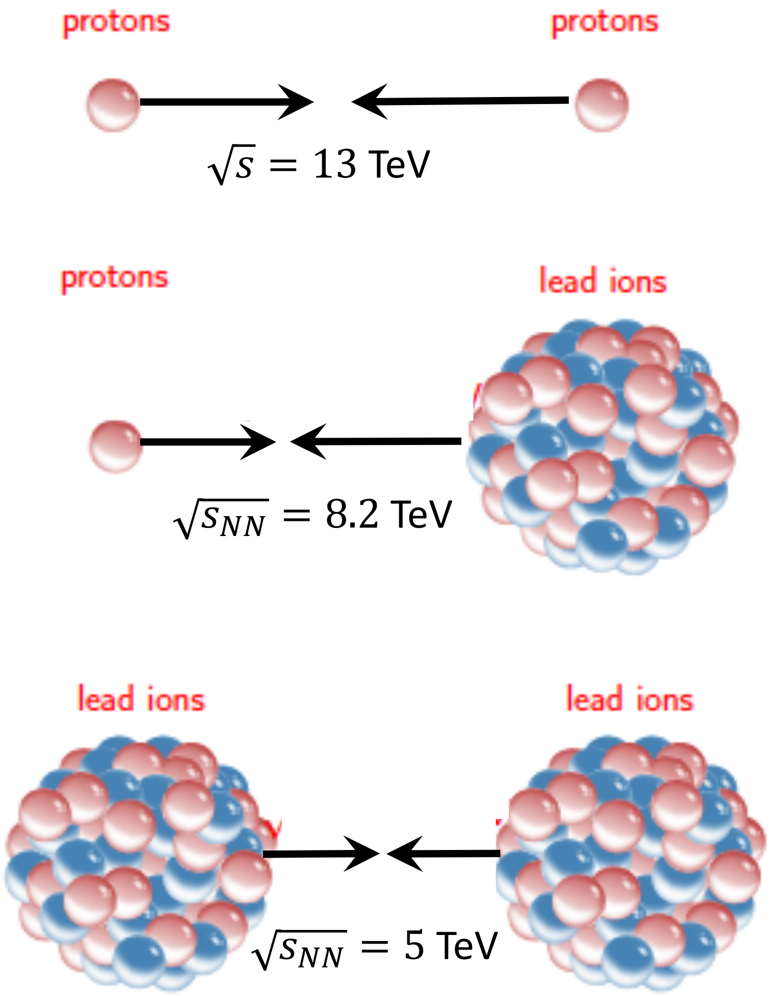


[R. D. Ball et al. Eur. Phys. J. C76 (2016) 383]



Types of collisions with a fixed-target experiment at LHC

Collider mode



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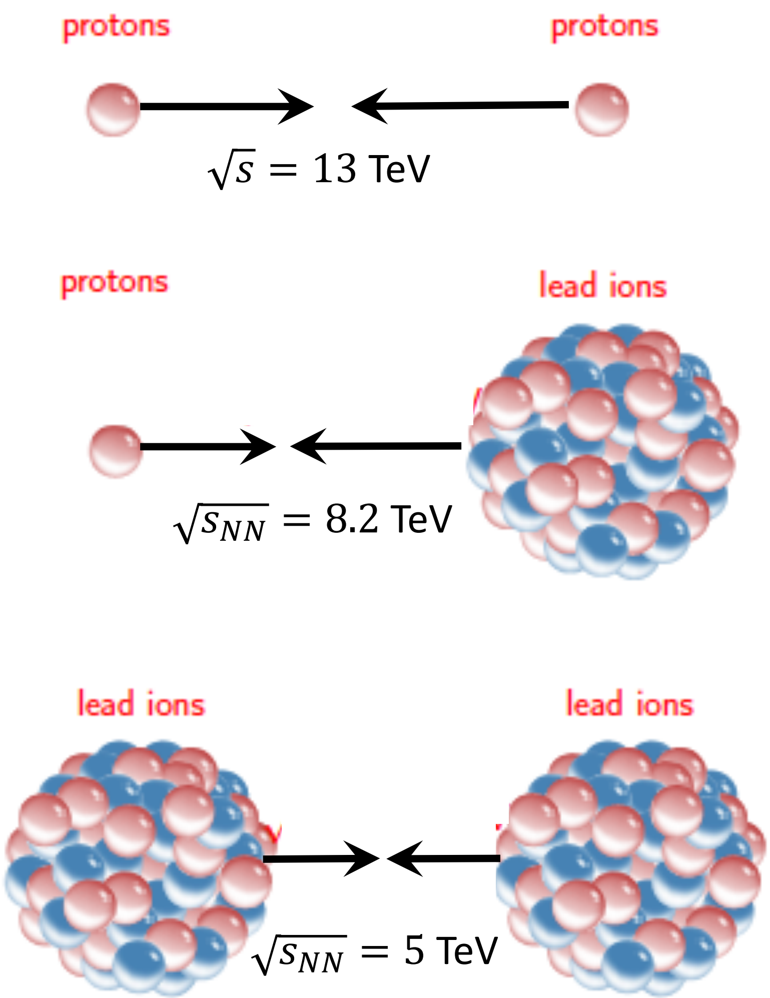

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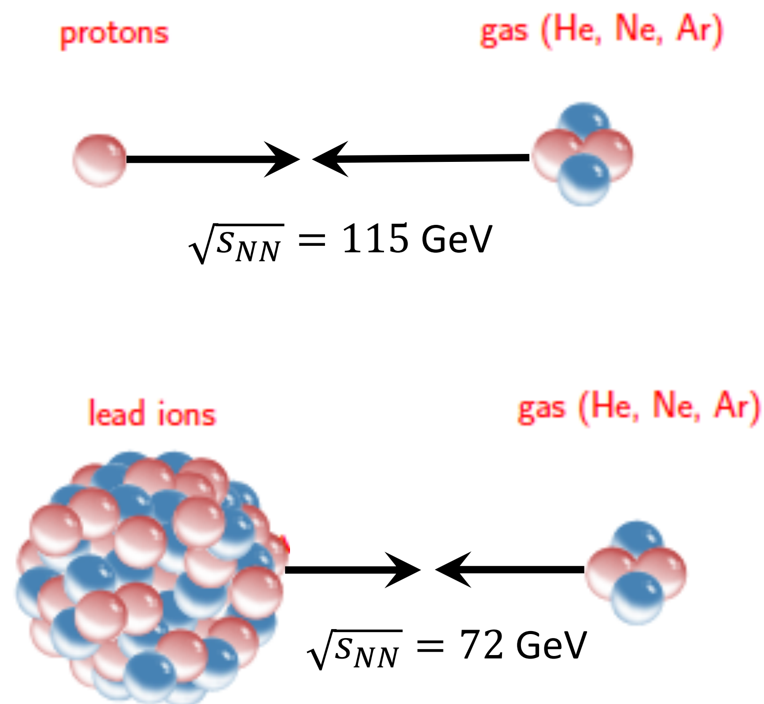

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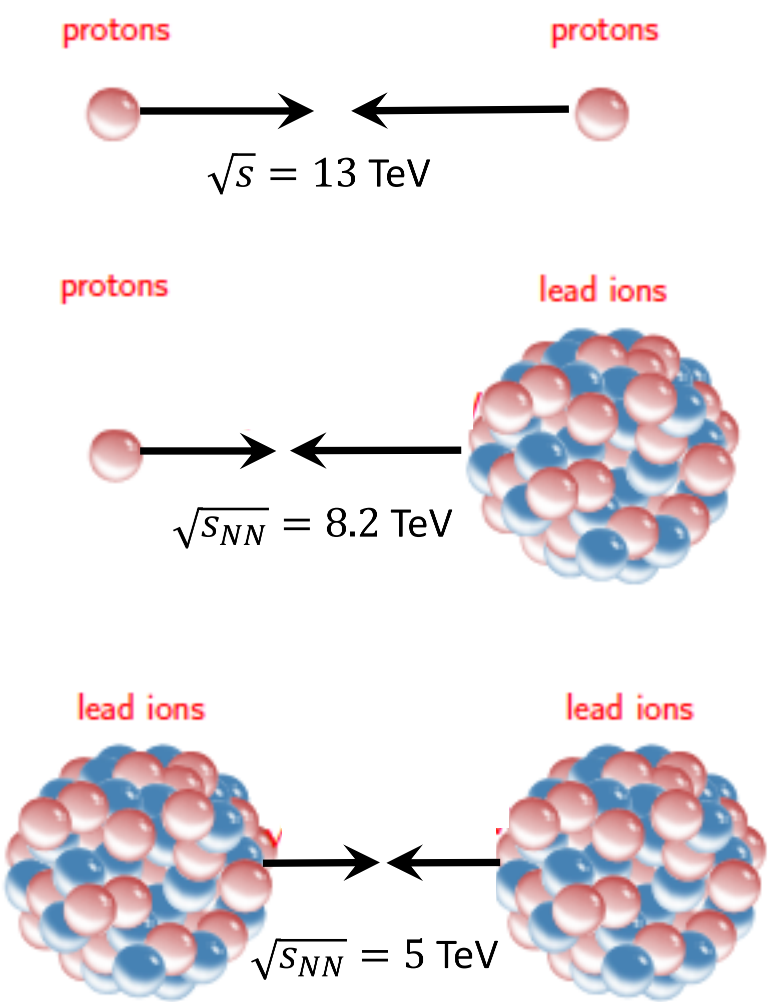

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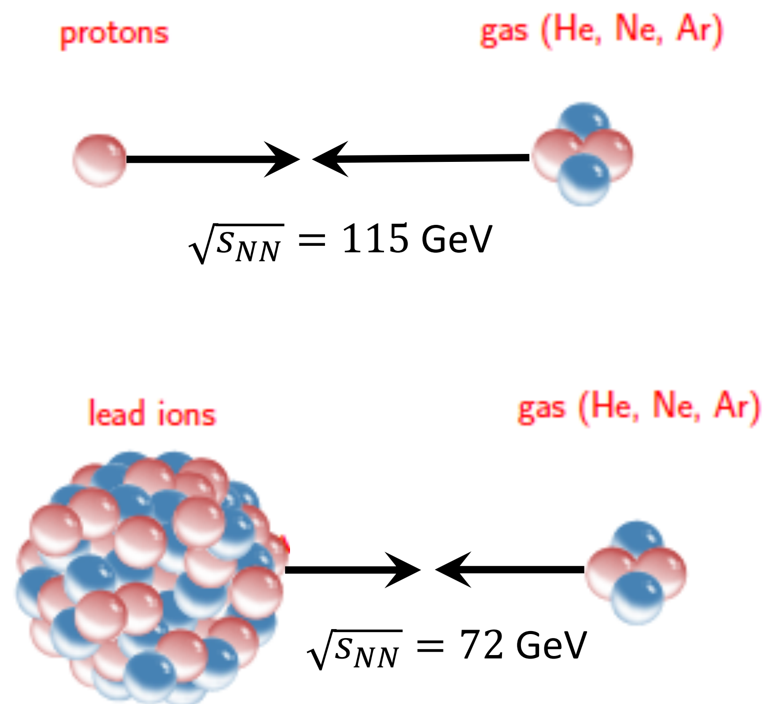

...but we can also consider the possibility of **polarized fixed-target collisions at LHC!**

Why a polarized fixed-target experiment at LHC?

✓ **Unique kinematic conditions**

- $E_p = 7\ \text{TeV} \implies \sqrt{s} \approx 115\ \text{GeV}$ (fills the gap between between SPS & RHIC)
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- polarized: $\mathrm{pp}^{\uparrow}$, $\mathrm{pd}^{\uparrow}$
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- ✓ **Polarized gas target technology well established (10 years @ HERMES)**
- ✓ **Very high performances ($P \sim 80\ \%$)**

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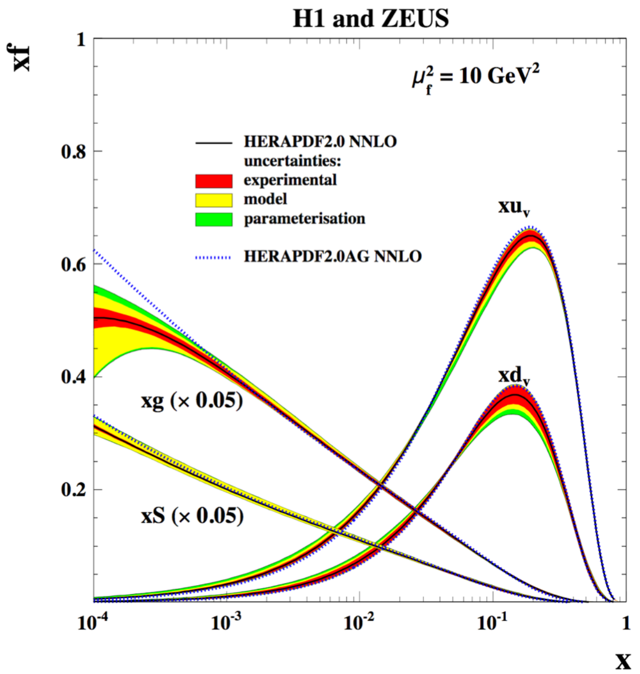
✓ **Broad and ambitious physics program**
- 3D mapping of the nucleon structure (quark and gluon PDFs)
- fundamental tests of QCD (universality, factorization, etc)
- study of cold nuclear matter effects
- search for intrinsic heavy quarks
- study of QGP formation

- ... and much more!

Accessing the nucleon structure

The present knowledge of the nucleon structure is dominated by **collinear (unpol.) PDFs**, measured with great precision in decades of DIS experiments



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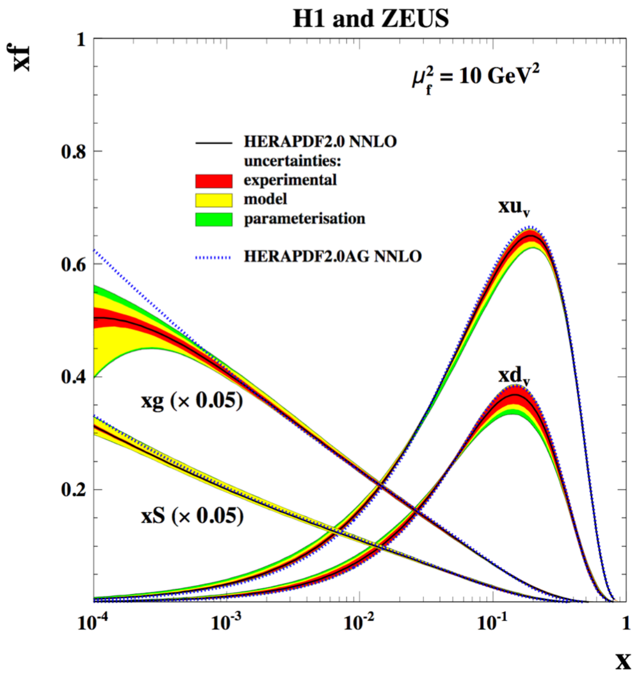
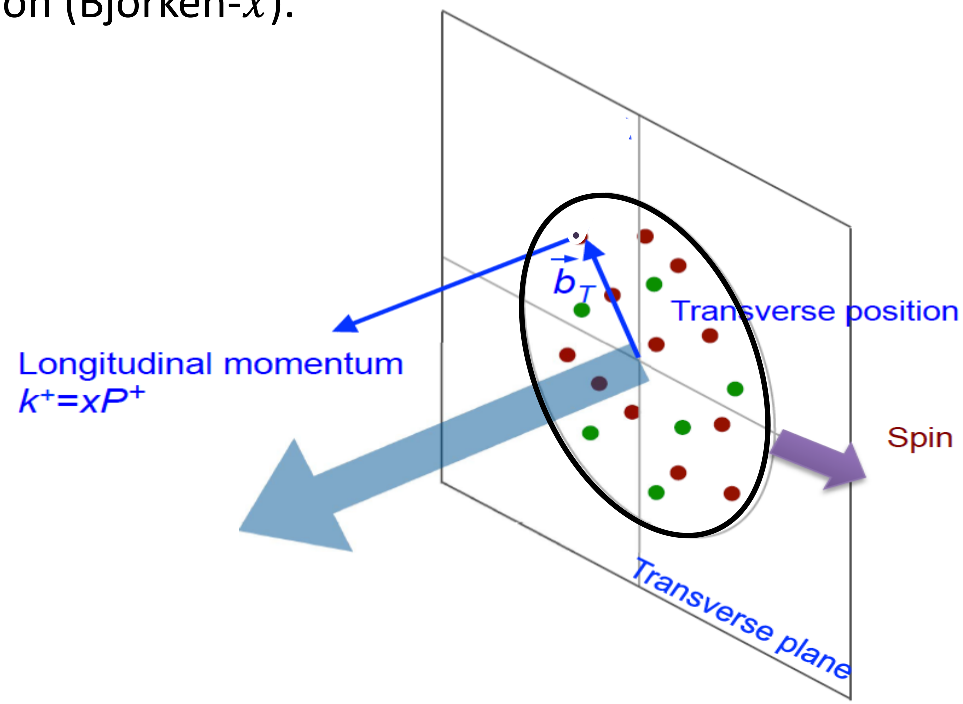


Despite the high level of accuracy, collinear PDFs provide only a 1-dim description of the nucleon structure, in terms of the parton long. momentum fraction (Bjorken-x).



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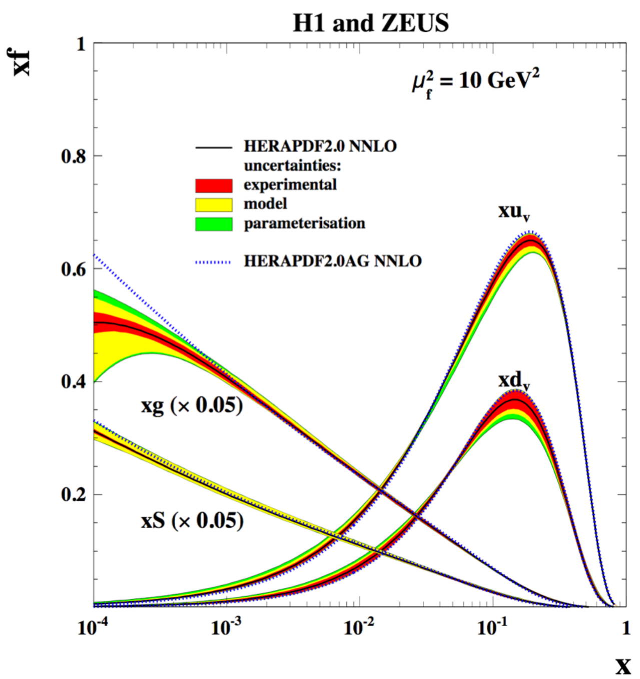

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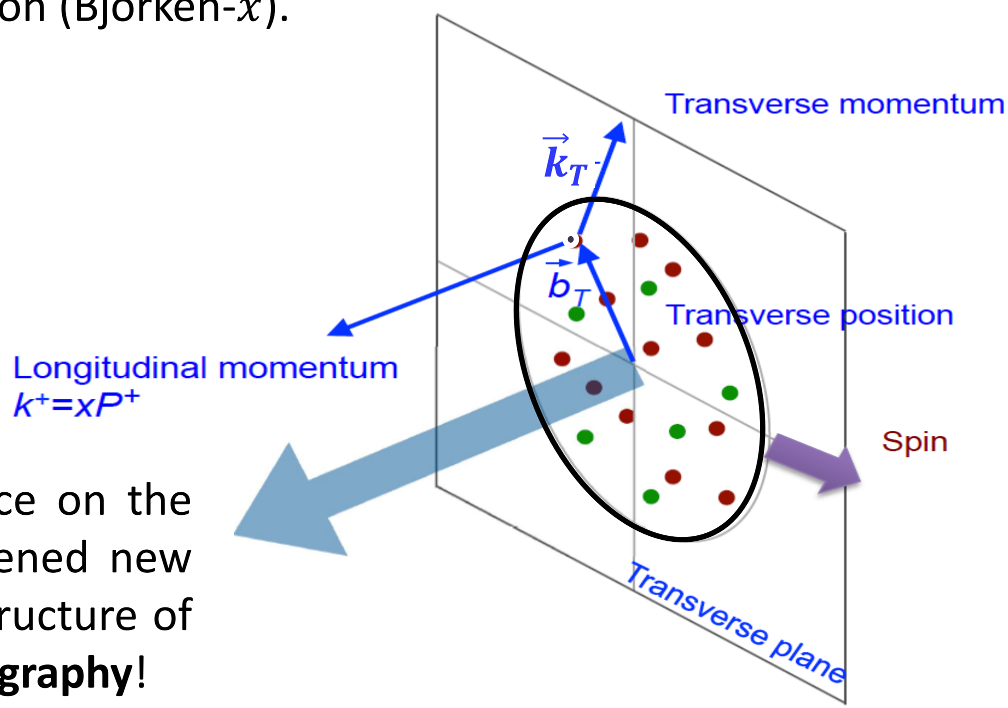

Considering also the explicit dependence on the parton transverse momenta k_T has opened new perspectives in the exploration of the structure of the nucleon! …**TMD PDFs**, **nucleon tomography**!

The quark TMDs

		Quark TMDs		
		U	L	T
Hadron	U	f_1		$h_1^\perp$
	L		g_1	$h_{1L}^\perp$
	T	$f_{1T}^\perp$	$g_{1T}^\perp$	h_1 $h_{1T}^\perp$

- **8 independent TMDs at twist-2**
- **Each with a probabilistic interpretation in terms of parton densities**
- **Significant experimental progress in the last 15 years!**
- First extractions from global analyses

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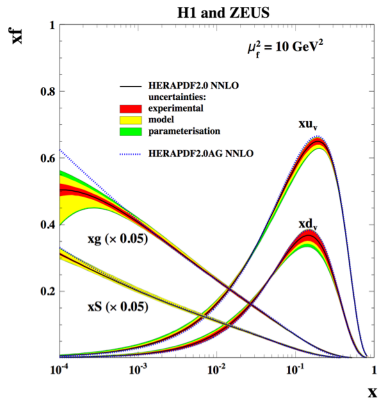
- So far, main results obtained in **SIDIS** measurements (HERMES, COMPASS, JLAB)
- **Drell-Yan** in hadron-hadron collisions represents a complementary approach
- Unique kinematic region with fixed-target collisions at LHC
- Comparison of results from SIDIS and DY will allow to set stringent tests on QCD: factorization, evolution, universality

Mapping the nucleon structure

Collinear PDFs

1D



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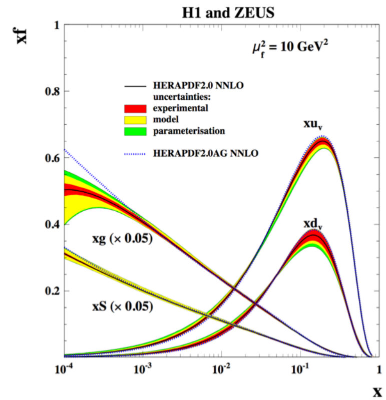
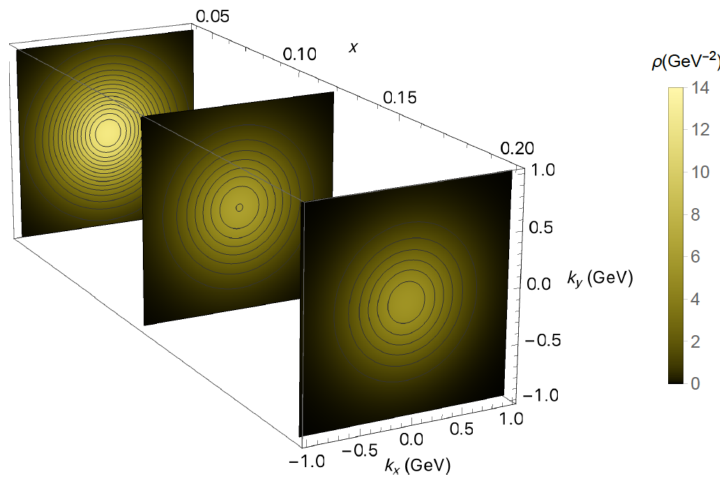


TMDs **3D**



(Courtesy of A. Bacchetta)

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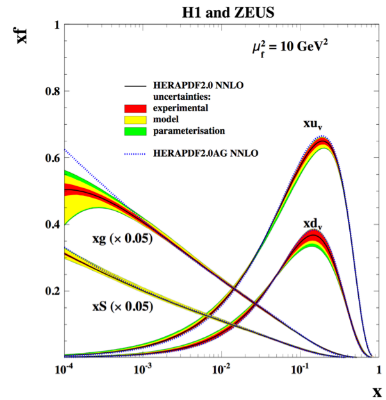

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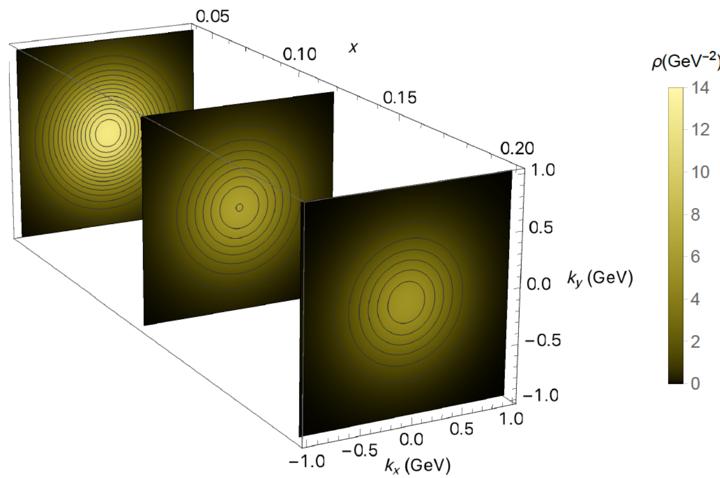

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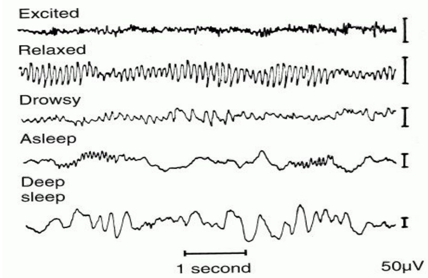
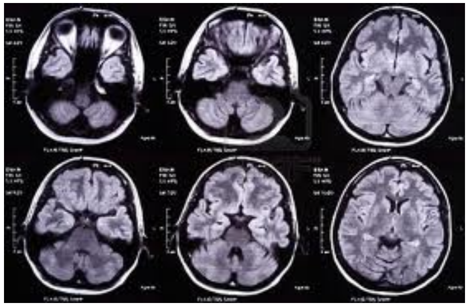
electroencephalograms

1D

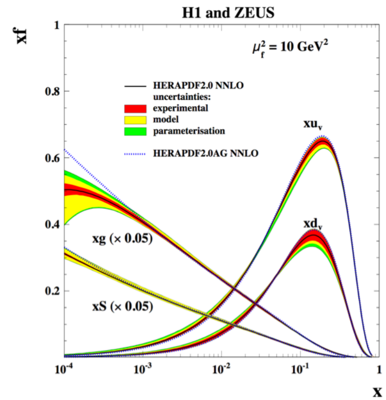


3D **NMR imaging**



Mapping the nucleon structure …and more

Collinear PDFs **1D**



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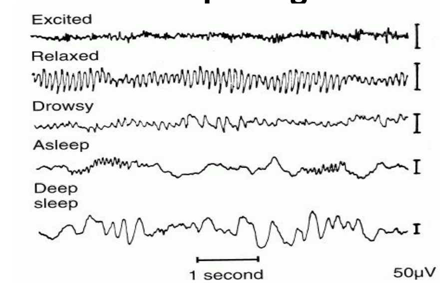

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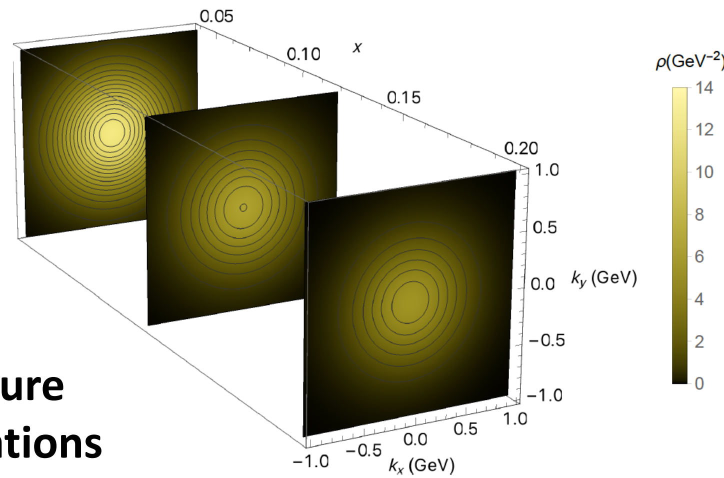

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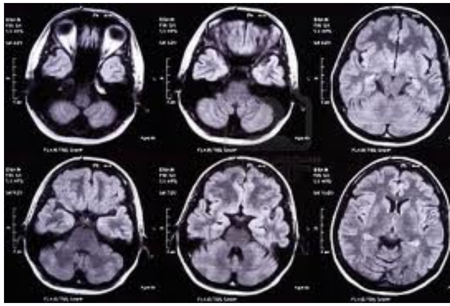
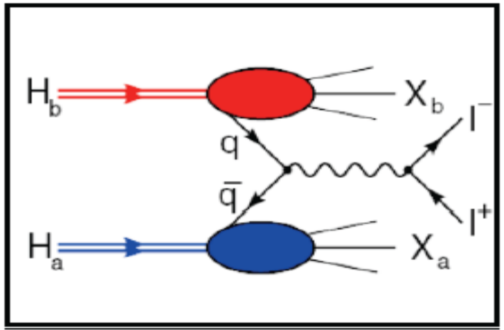


- **3D maps of nucleon structure**
- **Describe spin-orbit correlations**
- **Are sensitive to the parton OAM**
- **T-odd TMDs are process dependent**

(breaking of QCD universality! ..see details in backup slides**)**

Probing the quark TMDs with fixed-targets at LHC

Unpolarized Drell-Yan



- Clean process
- LHC experiments have excellent reconstruction capabilities for $\mu\mu$ channel!

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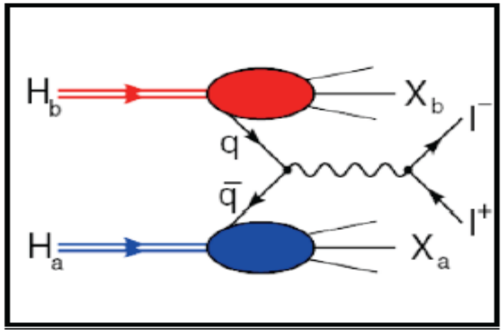

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$$\sigma_{UU} \quad \propto \quad f_1 f_1 + \cos 2\phi\, h_1^{\perp} h_1^{\perp}$$

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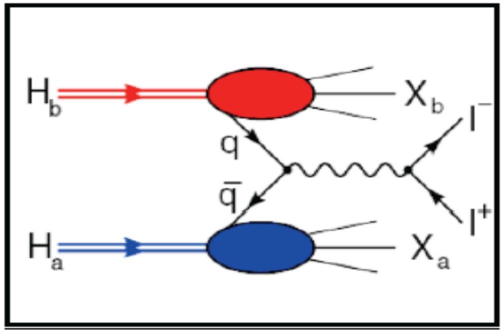

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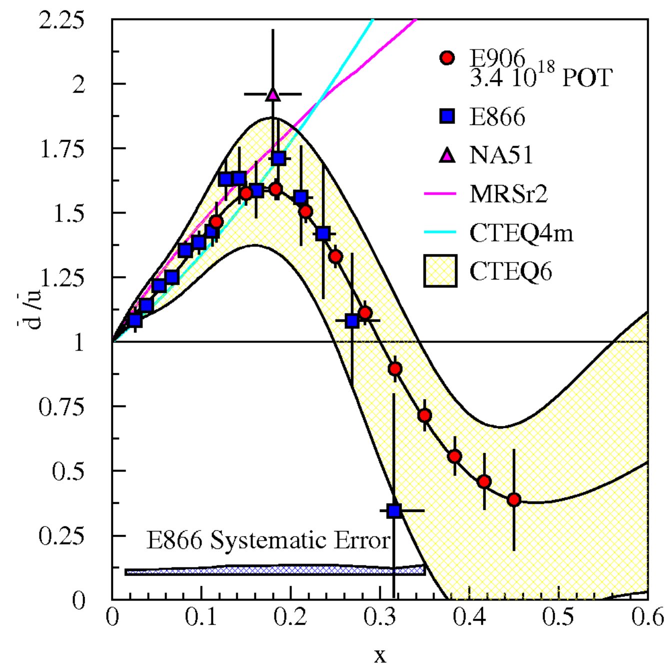
- Using fixed H and D targets allows to study the **antiquark content of the nucleon!**

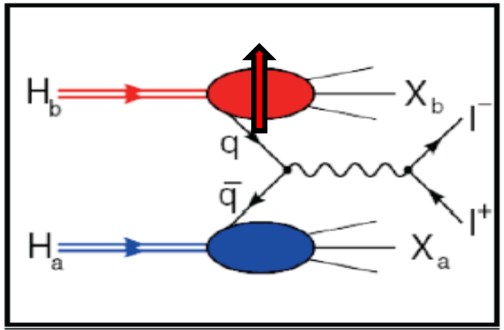


$\bar{d}(x) \neq \bar{u}(x)$!!

- hints that: $\bar{s}(x) \neq s\,(x)$
- **sea is not flavour symmetric!**
- **intrinsic sea quarks**?

Probing the quark TMDs with fixed-targets at LHC

Polarized Drell-Yan



Sensitive to quark TMDs up to high $x_2^{\uparrow}$ through TSSAs

$$A_{UT}^{\sin\phi_S} \sim \frac{f_1^q \otimes f_{1T}^{\perp q}}{f_1^q \otimes f_1^q} \qquad A_{UT}^{\sin(2\phi+\phi_S)} \sim \frac{h_1^{\perp q} \otimes h_{1T}^{\perp q}}{f_1^q \otimes f_1^q} \qquad A_{UT}^{\sin(2\phi-\phi_S)} \sim \frac{h_1^{\perp q} \otimes h_1^q}{f_1^q \otimes f_1^q}$$

(ϕ: azimuthal orientation of lepton pair in dilepton CM)

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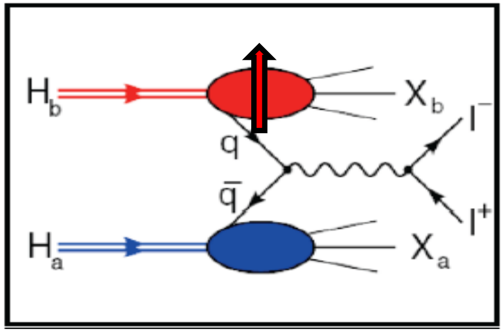

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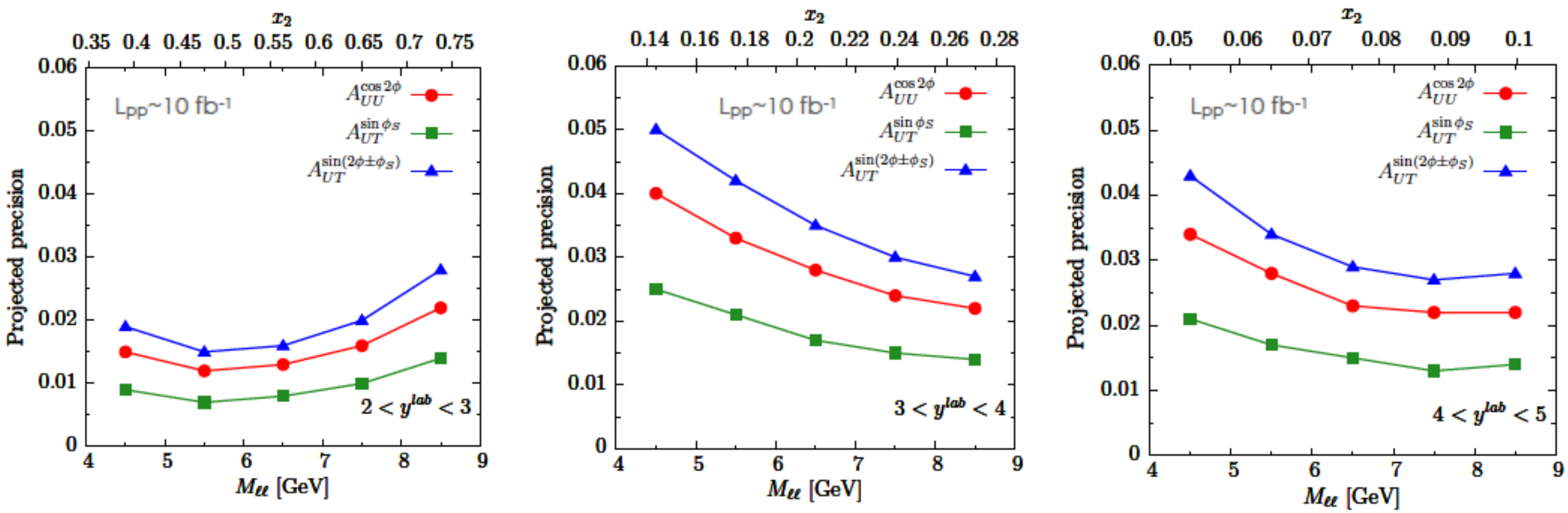

arXiv:1807.00603
and J.P.Lansberg, PBC CERN 2018

Probing the gluon TMDs with fixed-targets at LHC

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Theory framework consolidated

…but experimental access still extremely limited!

Note: gluons with non-zero p_T inside an unpolarized hadron can be linearly polarized!

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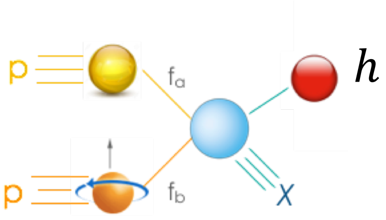
Gluon Sivers function:

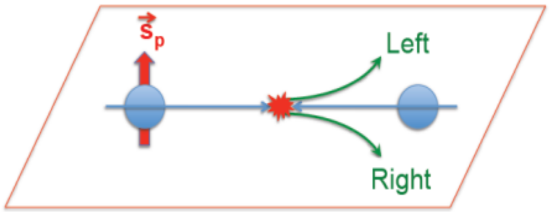
- first hints by RHIC and COMPASS, but still basically unknown!
- shed light on spin-orbit correlations of gluons inside the proton
- sensitive to gluon orbital angular momentum!

Probing the gluon TMDs with fixed-targets at LHC

Main observables in pol. hadron collisions: **Single Transverse Spin Asymmetries (TSSAs)**

Polarized inclusive hard scattering



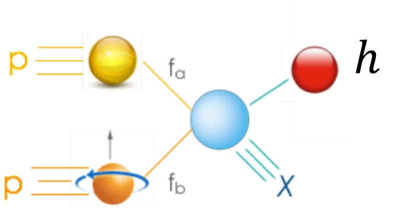


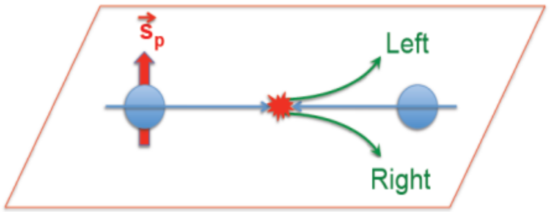
$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \sim \frac{1}{P}\frac{N_h^{\uparrow} - N_h^{\downarrow}}{N_h^{\uparrow} + N_h^{\downarrow}}$$

Probing the gluon TMDs with fixed-targets at LHC

Main observables in pol. hadron collisions: **Single Transverse Spin Asymmetries (TSSAs)**

Polarized inclusive hard scattering





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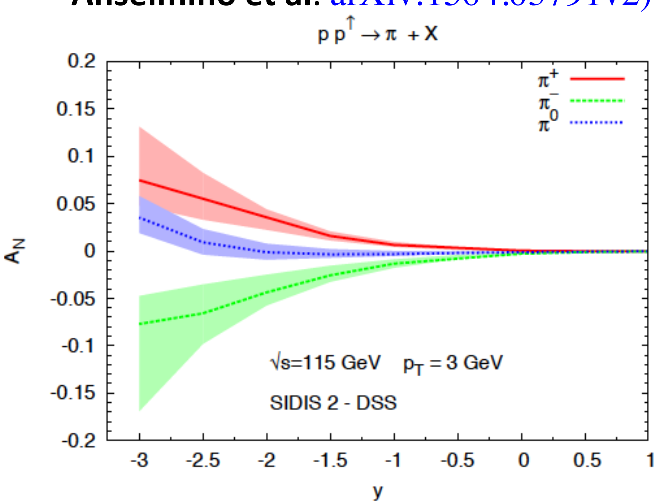
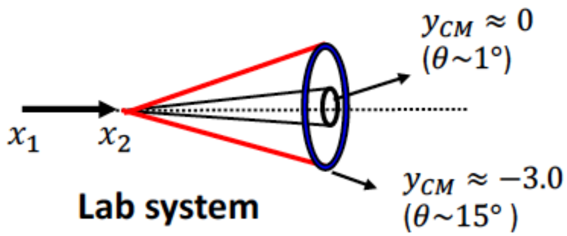
Anselmino et al. arXiv:1504.03791v2)



- **Asymmetries above 10 %! Big signature!!**
- The effect increases with more negative CM rapidity
- Nicely matches a forward spectrometer acceptance with fixed target at LHC



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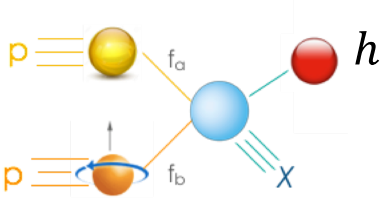

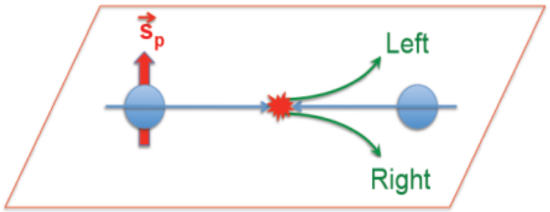

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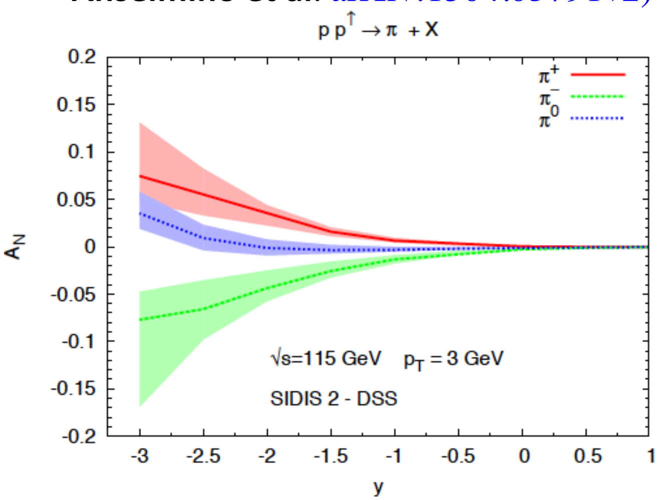

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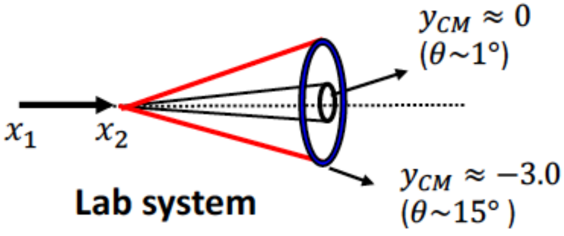
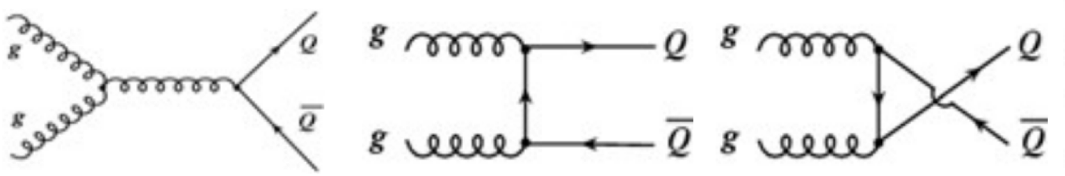


Inclusive pion production provides mainly sensitivity to the quark PDFs, but a fixed polarized target at LHC can also open the way to the **extraction of polarized gluon PDFs through heavy-flavour observables.**

Probing the gluon TMDs with fixed-targets at LHC

In high-energy hadron collisions Heavy quarks dominantly produced through gg interactions:



The most efficient way to access the gluon dynamics inside the proton at LHC is to **measure heavy-flavour observables**

Probing the gluon TMDs with fixed-targets at LHC

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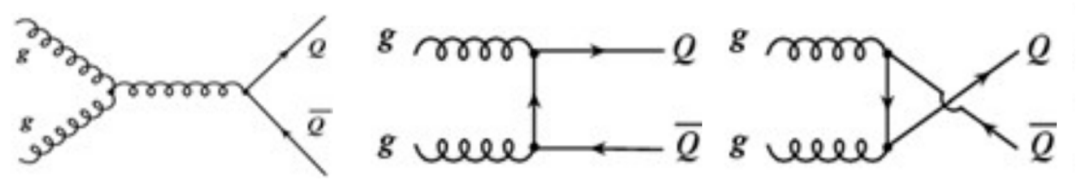
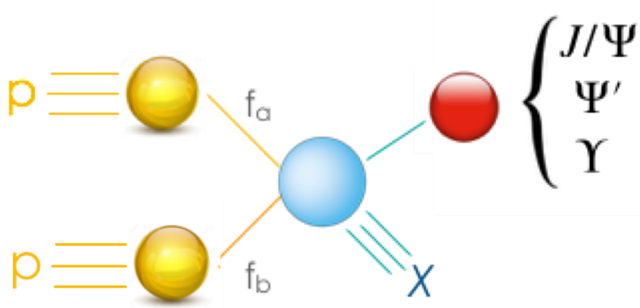


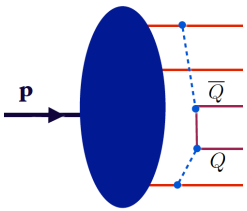
The most efficient way to access the gluon dynamics inside the proton at LHC is to **measure heavy-flavour observables**

Inclusive quarkonia production in pp interaction turns out to be an ideal **gluon-sensitive observable!**



More physics reach with an unpolarized fixed target

- **Intrinsic heavy-quark** **[S.J. Brodsky et al.,** Adv.High Energy Phys. 2015 (2015) 231547]
  - 5-quark Fock state of the proton may contribute at high x!
  - **charm PDFs** at large x could be larger than obtained from conventional fits



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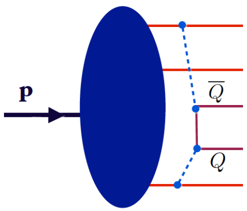

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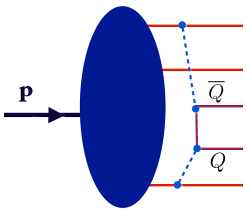

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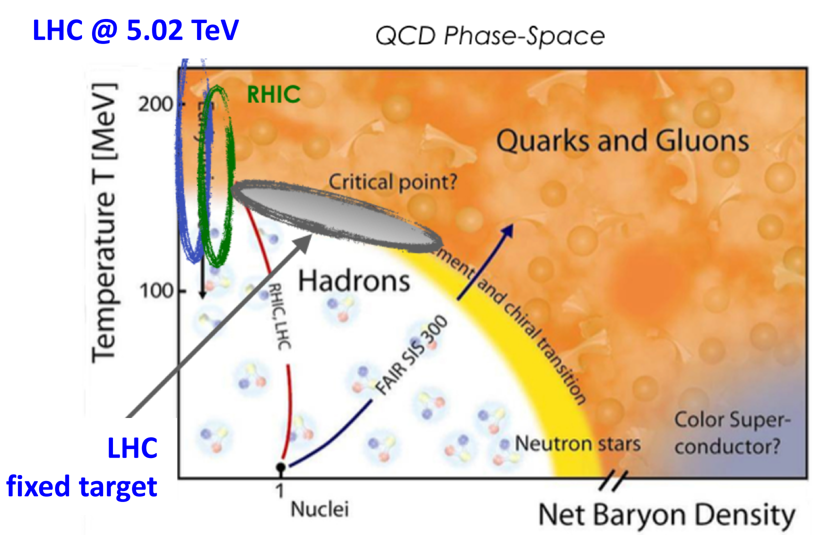
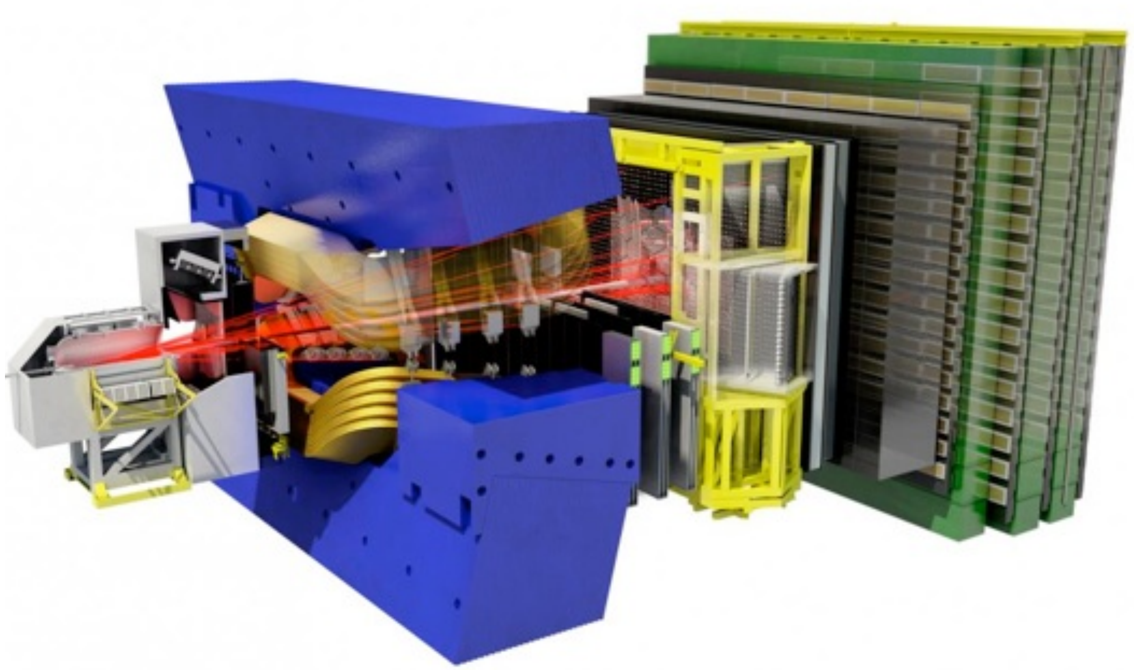
- **PbA collisions at $\sqrt{s_{NN}} \approx 72$ GeV** (using unpolarized gas: He, N, Ne, Ar, Kr, Xe)
  - Study of **QGP formation**



Experimental realizations

The LHCSpin project

The **LHCSpin** project aims to bring spin physics at the LHC through the implementation of a **polarized fixed target** in the **LHCb** spectrometer.

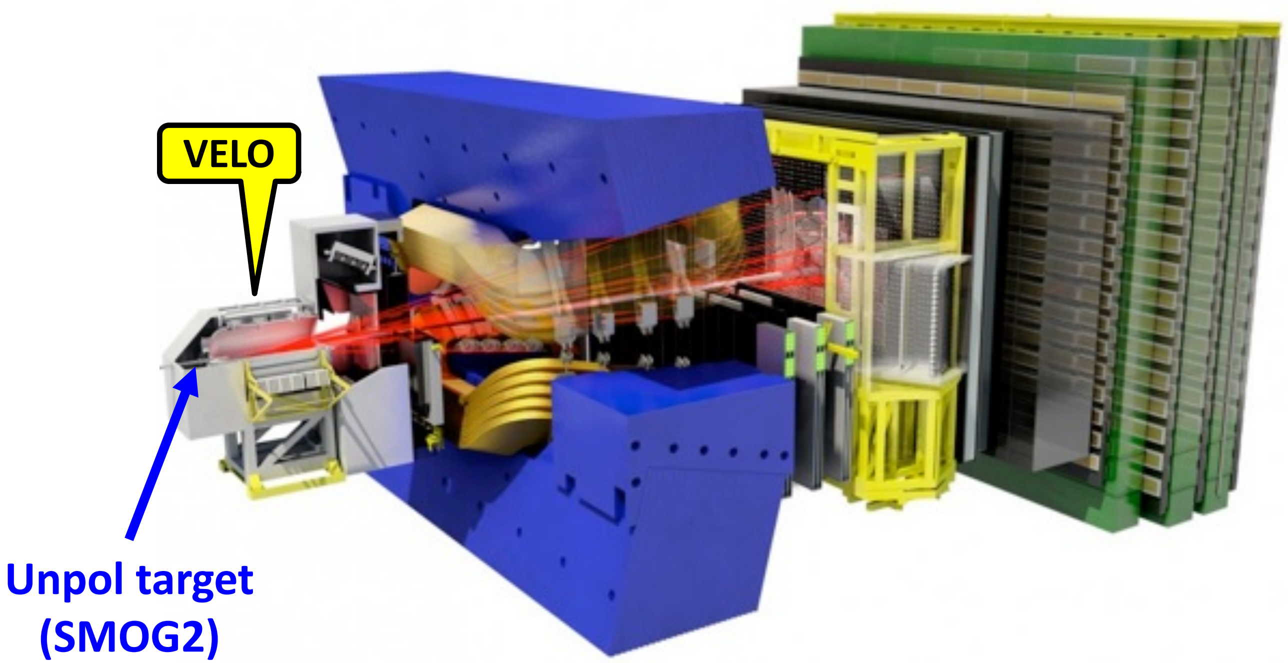


The LHCSpin project

The project consists of **two phases**:

Phase I

Upgrade the present LHCb unpol. fixed-target system (**SMOG**) with the installation of a storage cell in the LHC beam pipe upstream of the VELO tracker (→ **SMOG2**)



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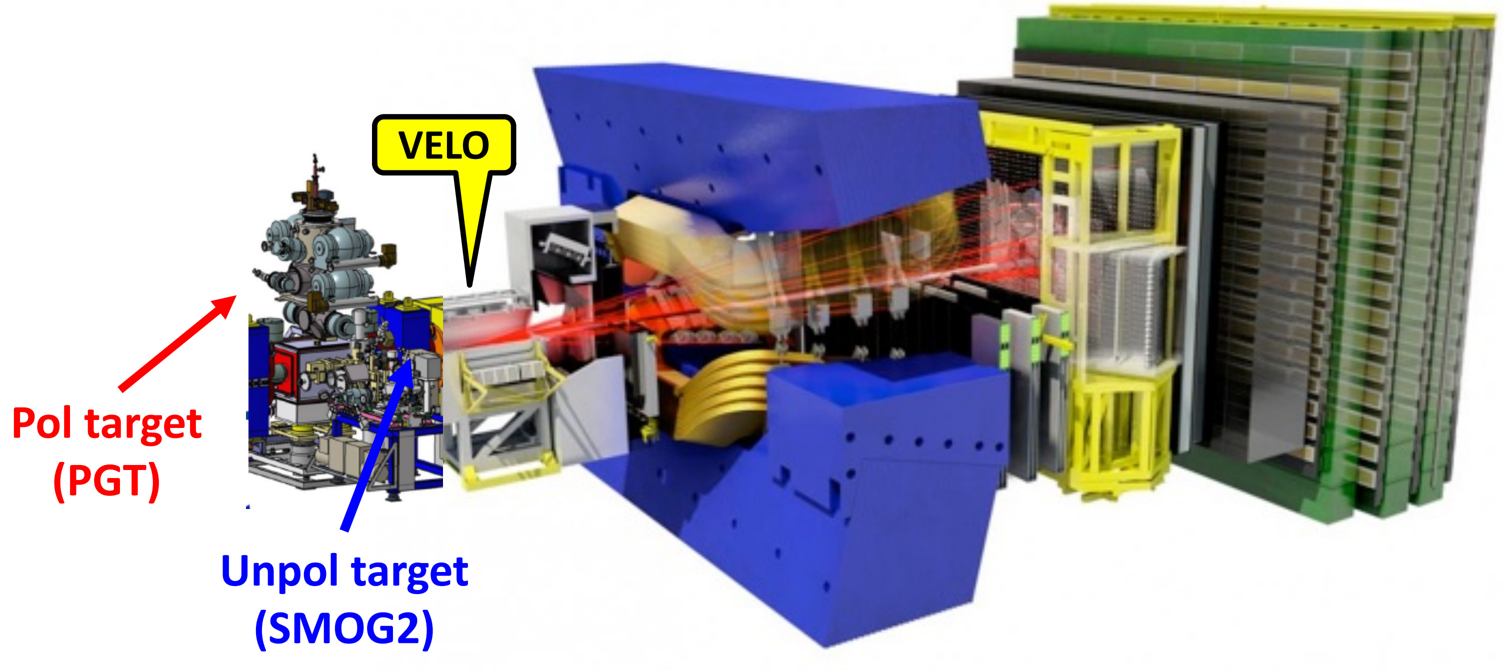
Phase II

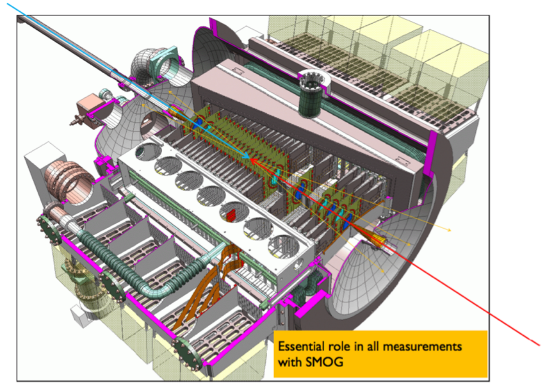
Installation of a HERMES-like Polarized Gas Target system (**PGT**) in front of LHCb

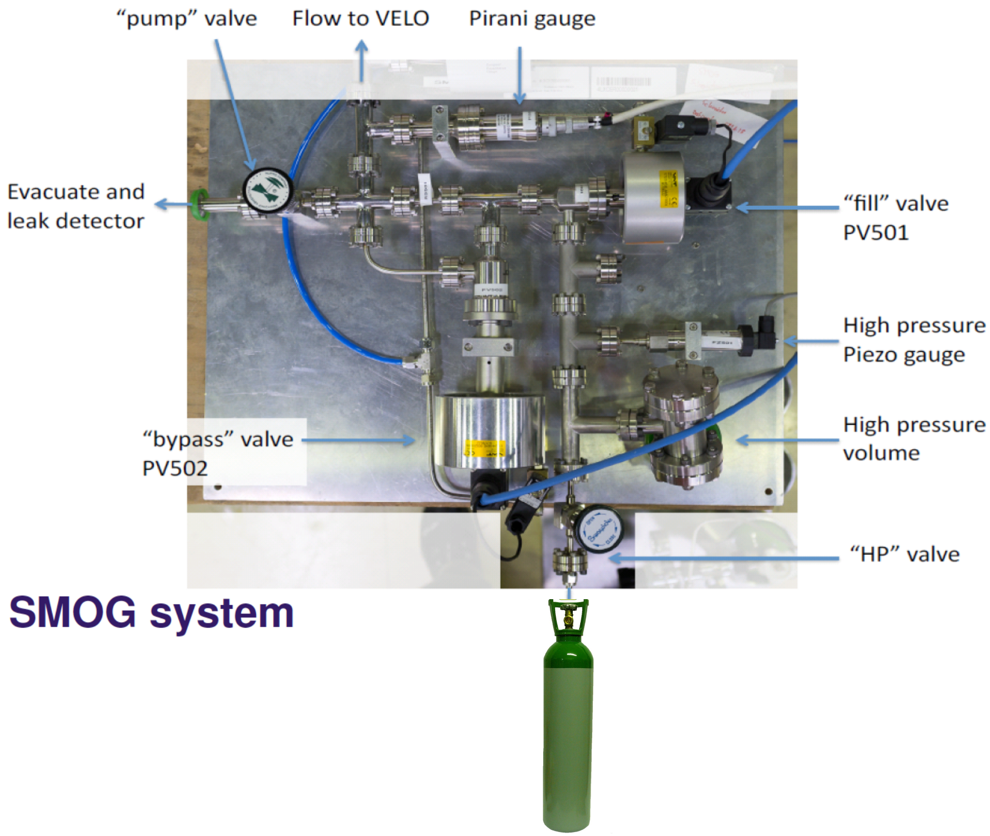


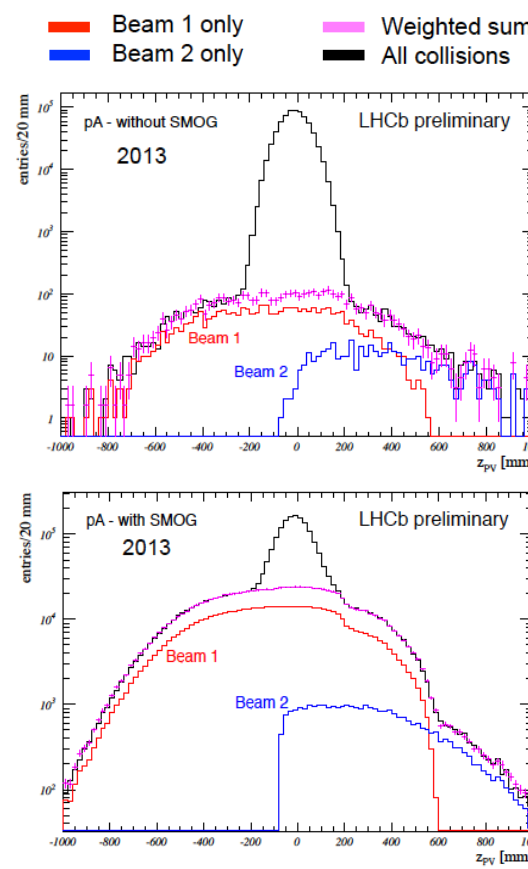
The LHCb fixed-target system

SMOG: System for Measuring Overlap with Gas:

- Low density noble gas injected in the VELO vessel ($\sim 10^{-7}$mbar)
- Gas pressure 2 orders of magnitude higher than LHC vacuum
- Beam-gas collision rate increased by 2 orders of magnitude







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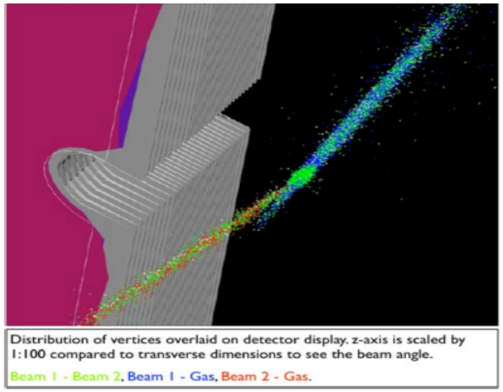

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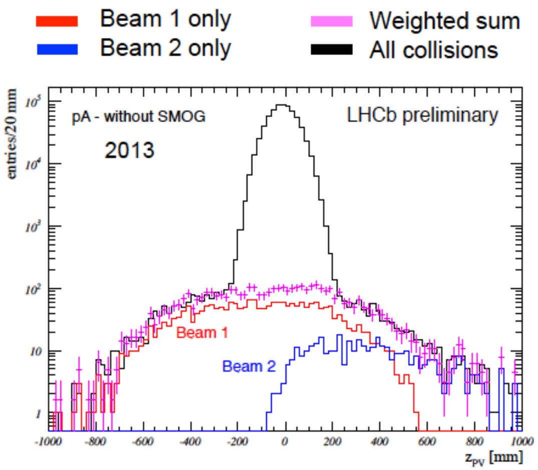
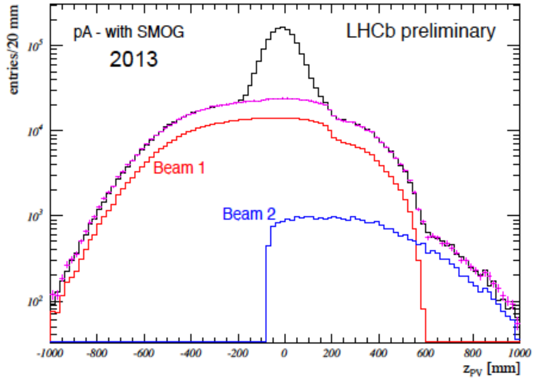
…but SMOG gives also the unique opportunity to operate an **LHC experiment in a fixed target mode** and to study pA and AA collisions on various targets!





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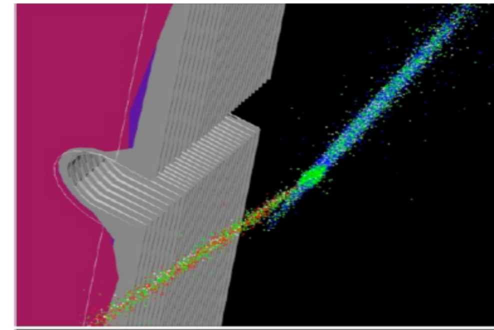

Distribution of vertices overlaid on detector display. z-axis is scaled by 1:100 compared to transverse dimensions to see the beam angle.
Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

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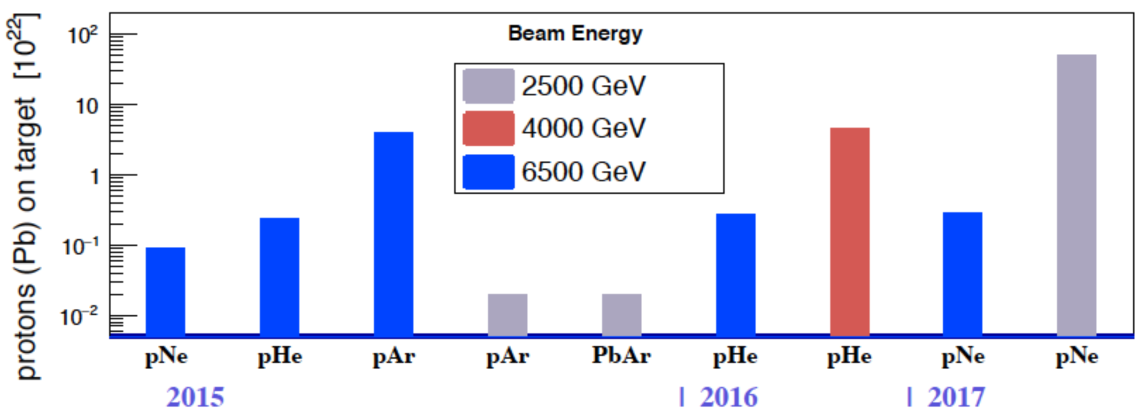
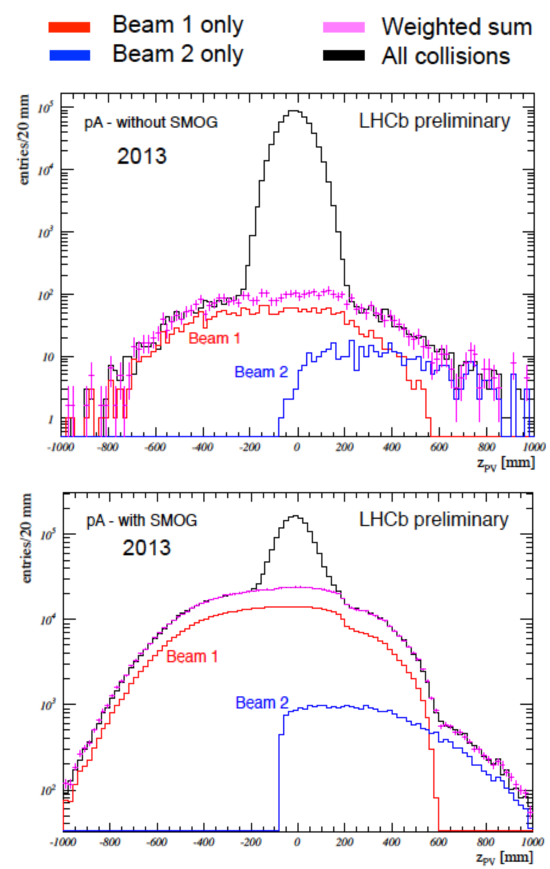


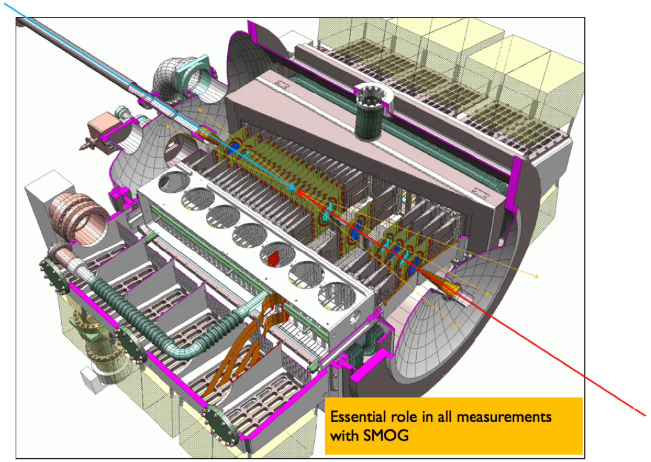


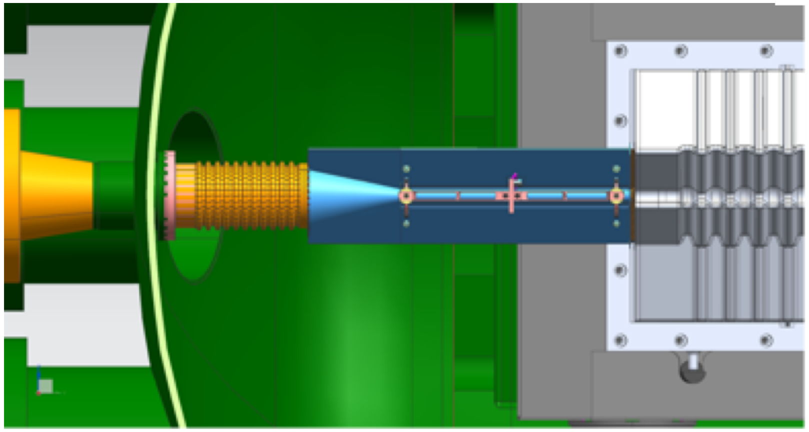
✓ First measurements of charm production in fixed-target configuration at the LHC, arXiv:1810.07907

✓ Measurement of antiproton production in pHe collisions at $\sqrt{s_{NN}} = 110$ GeV, arXiv:1808.06127

Phase I: the SMOG2 setup

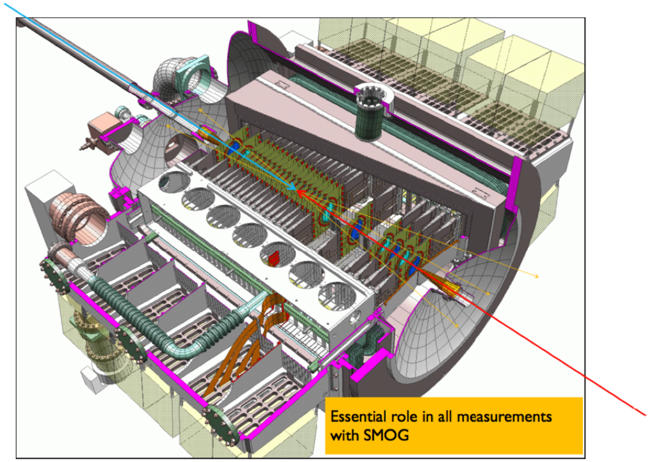
The proposed SMOG2 setup

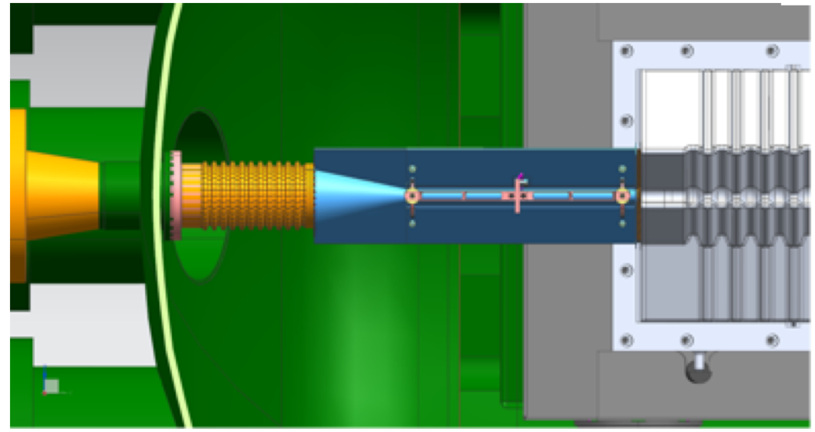




Internal side view

The proposed SMOG2 setup





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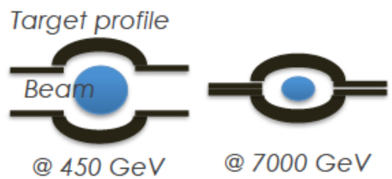
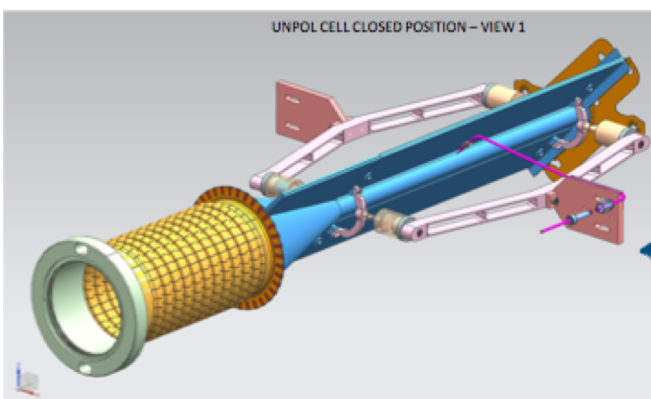
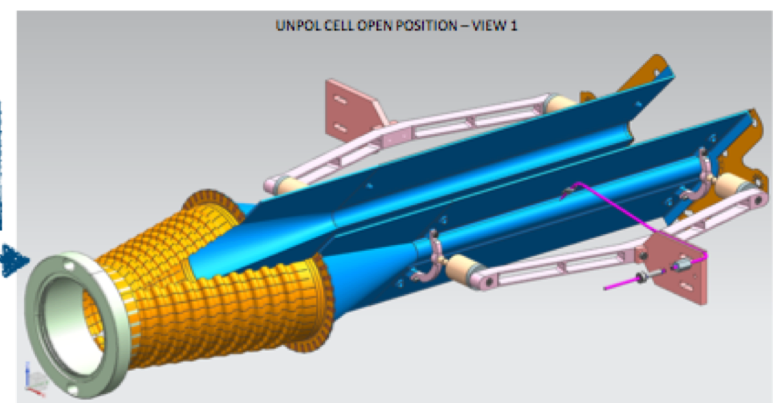




openable storage cell



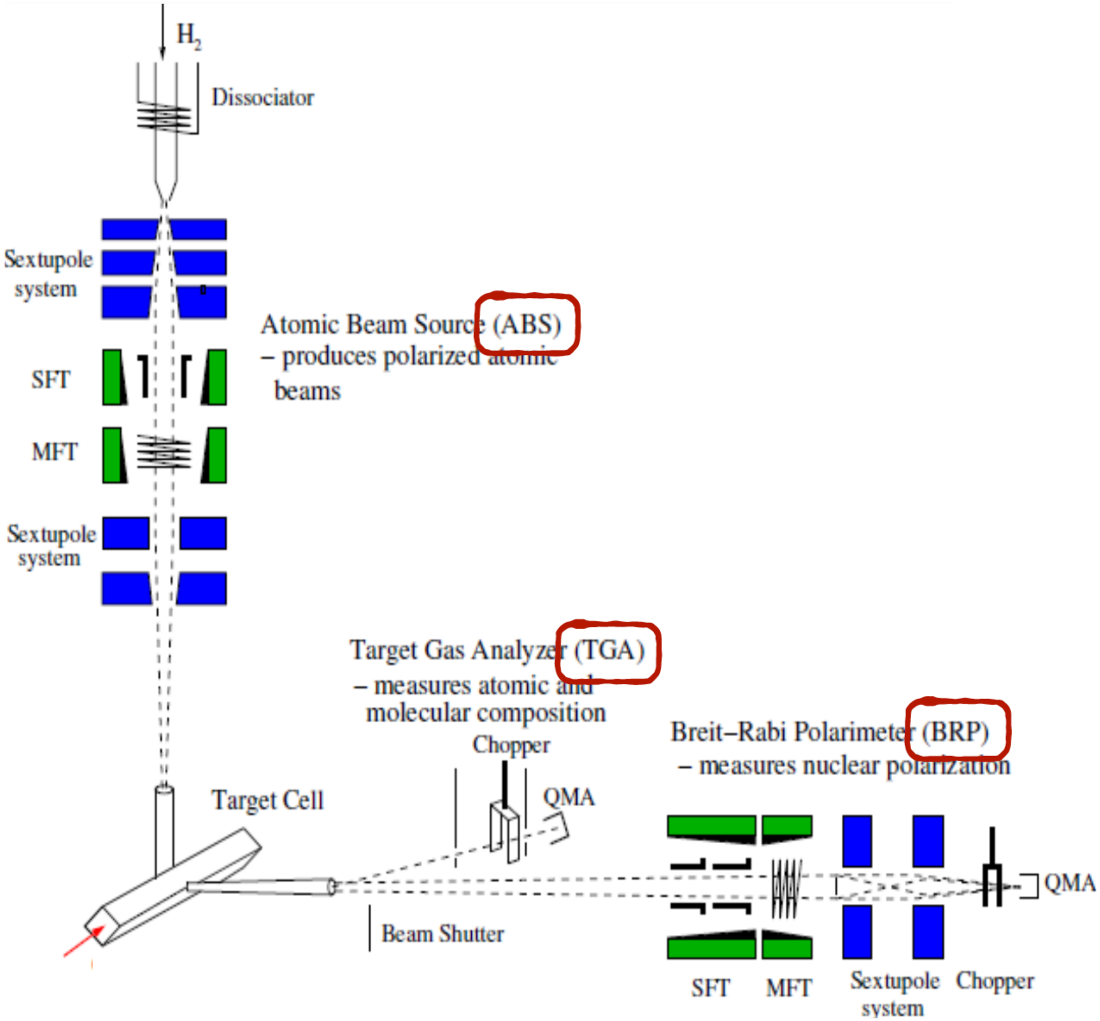
SMOG2 vs. SMOG

- ✓ **Increase of target density (luminosity)** by up to 2 orders of magnitude using the same gas load of SMOG ($\sim 10^{-7}$ mbar)
- ✓ Possibility to inject **more gas species**: H, D, He, N, Ne, Ar, Kr, Xe (SMOG: He, Ne, Ar)
- ✓ **More sophisticated Gas Feed System**: will allow to measure the target density with much higher precision (presently 50% uncertainty!)
- ✓ Well **defined interaction region** upstream of the IP@13 TeV (limited to cell length: 20 cm)
- ✓ SMOG2 can (in principle) **run in parallel with collider mode** (well displaced IP)

Phase II: the polarized target setup

A new design for a compact polarized gas target

Same principle of Hermes



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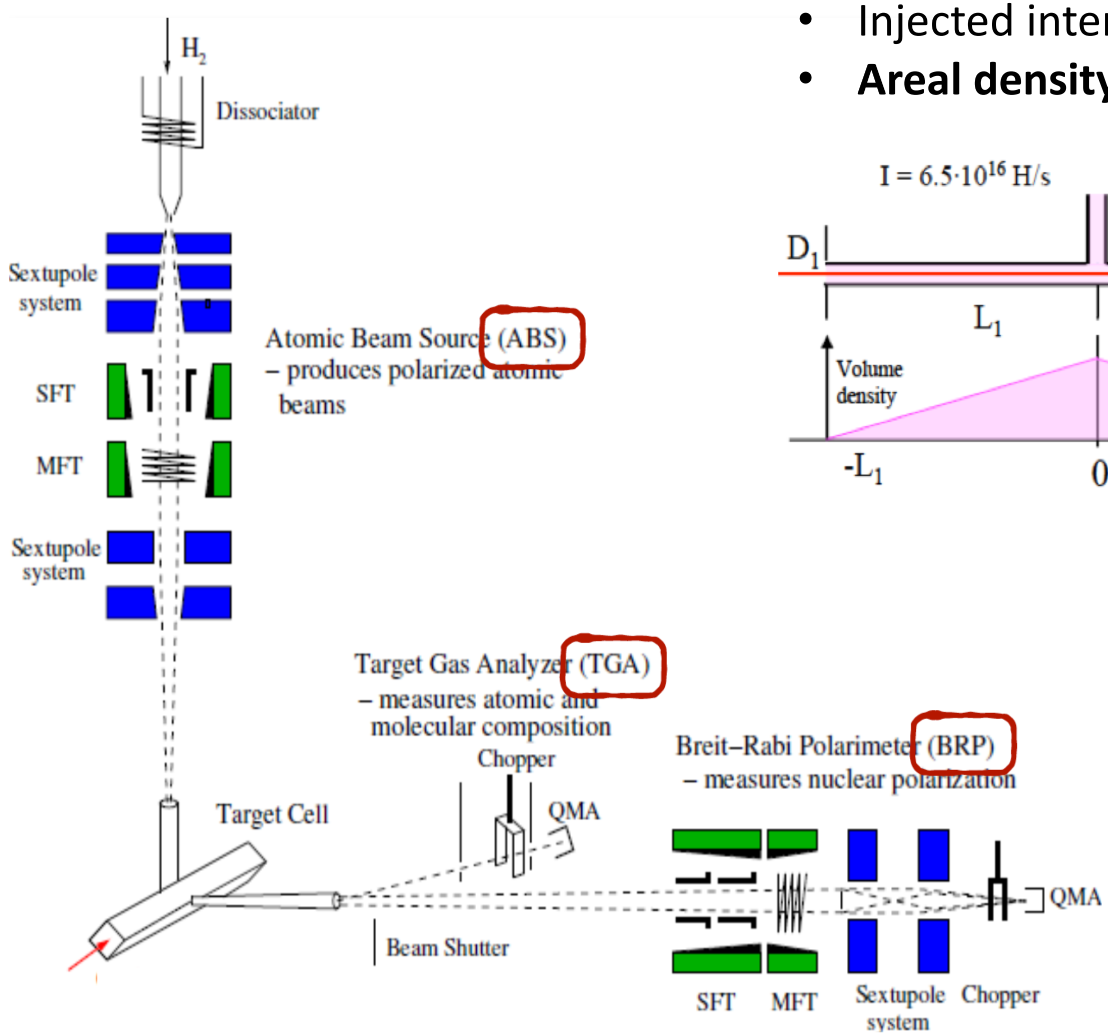
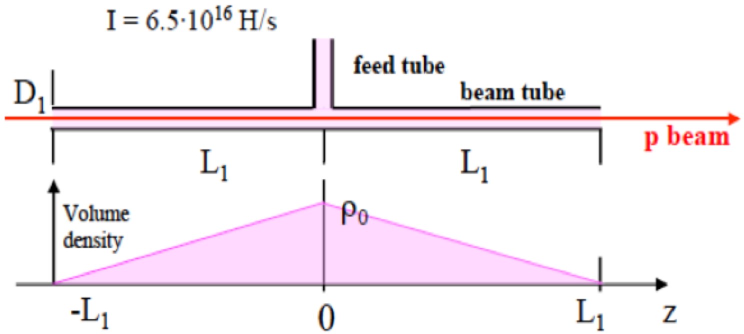


- Cell dimensions: 30 cm x 1 cm
- Injected intensity of H-atoms = $6.5 \cdot 10^{16}\ \mathrm{s}^{-1}$
- **Areal density** $\sim \mathbf{1.2 \cdot 10^{14}\ cm^{-2}}$



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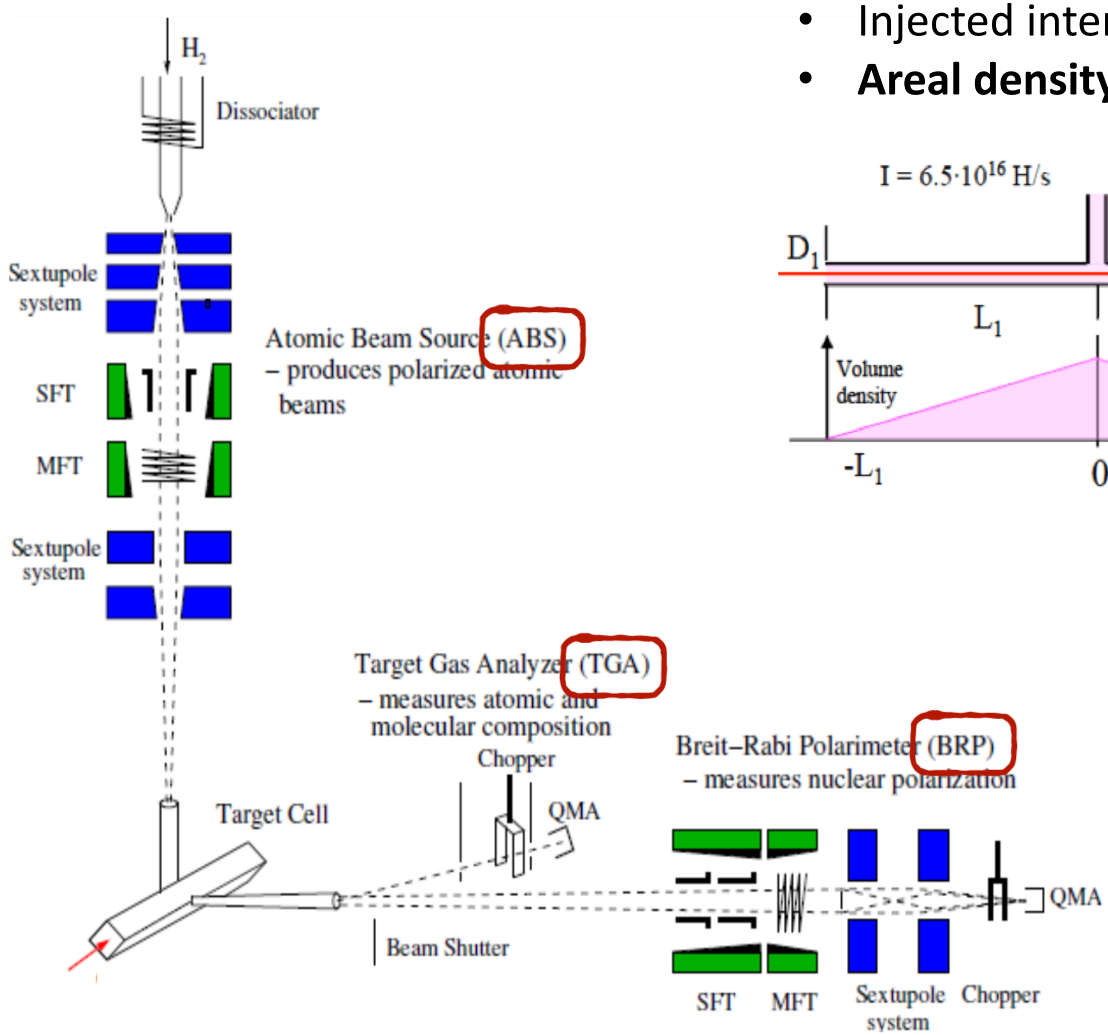

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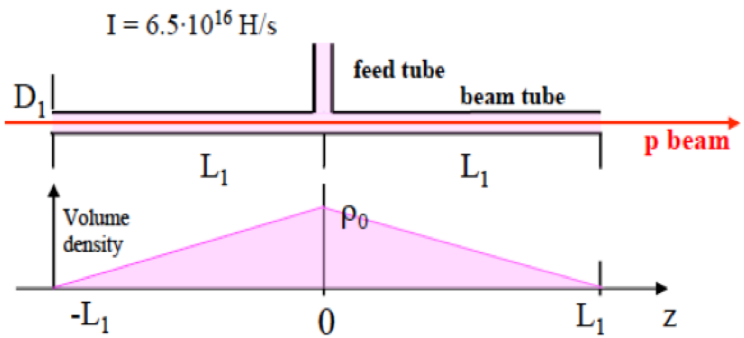
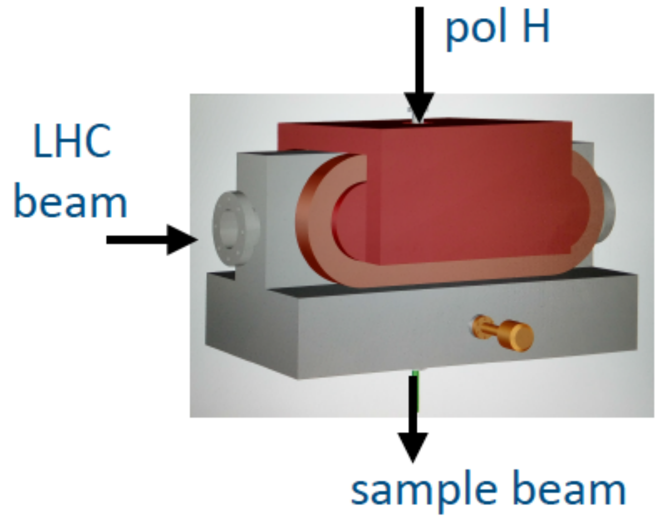
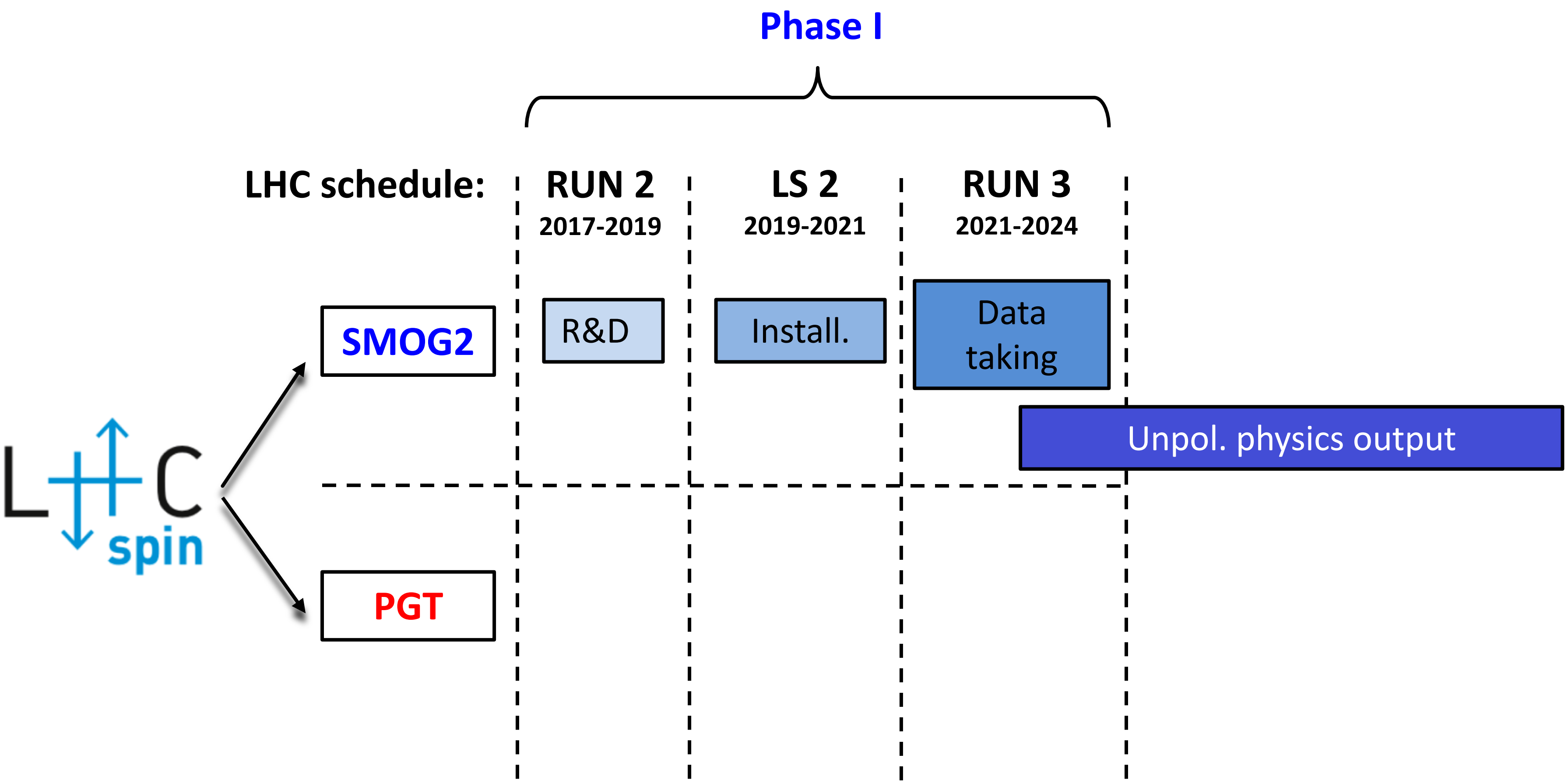




Time schedule of the project



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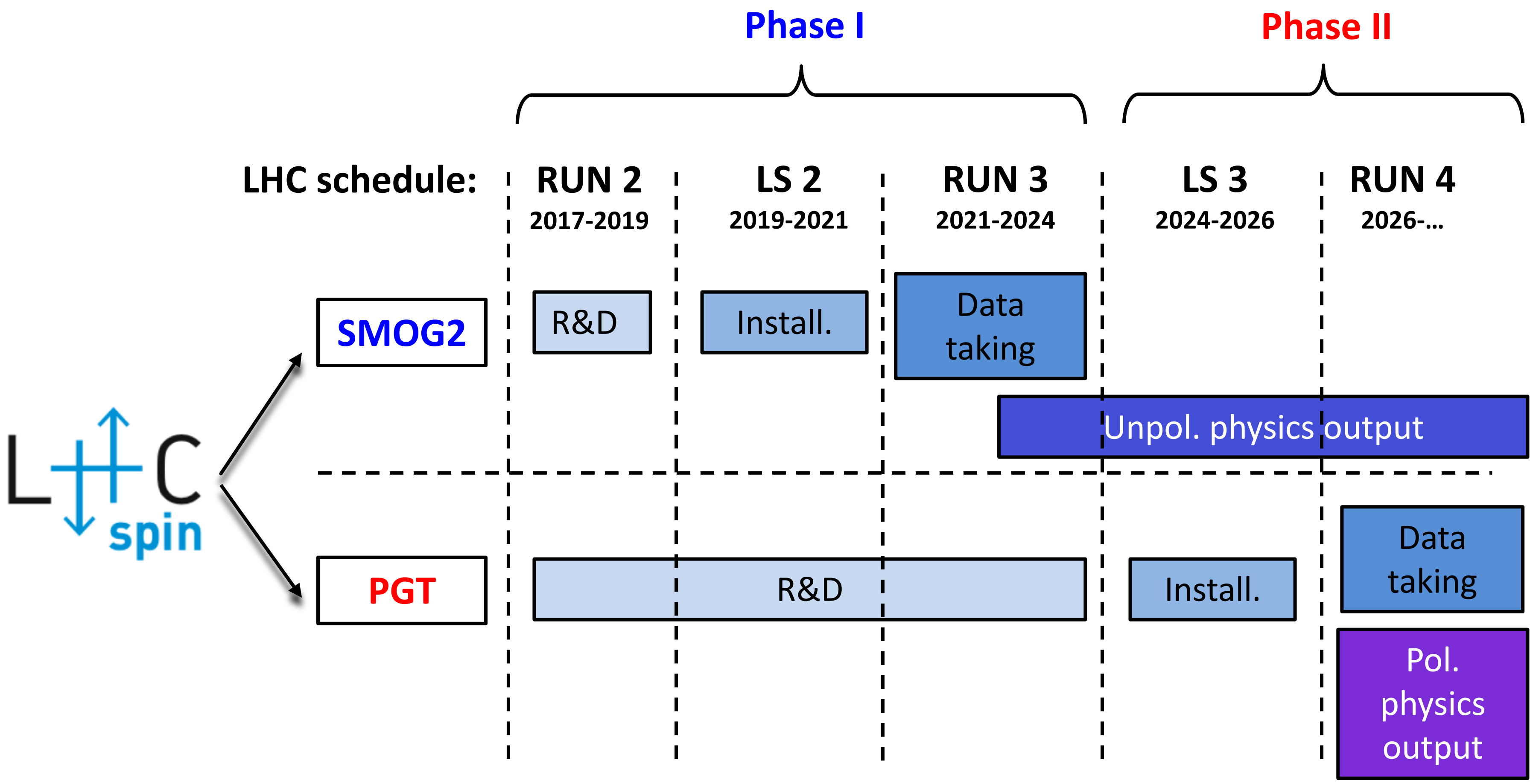

Fixed-target investigations in ALICE

Cynthia Hadjidakis
Hard Probes 2018
5 October 2018

- Central Barrel ($|\eta| < 0.9$) with full PID
- Muon Spectrometer ($2.5 < \eta < 4$)
- No limitation in high-multiplicity event reconstruction
- Upgrade LS2:
  - New Silicon Tracker
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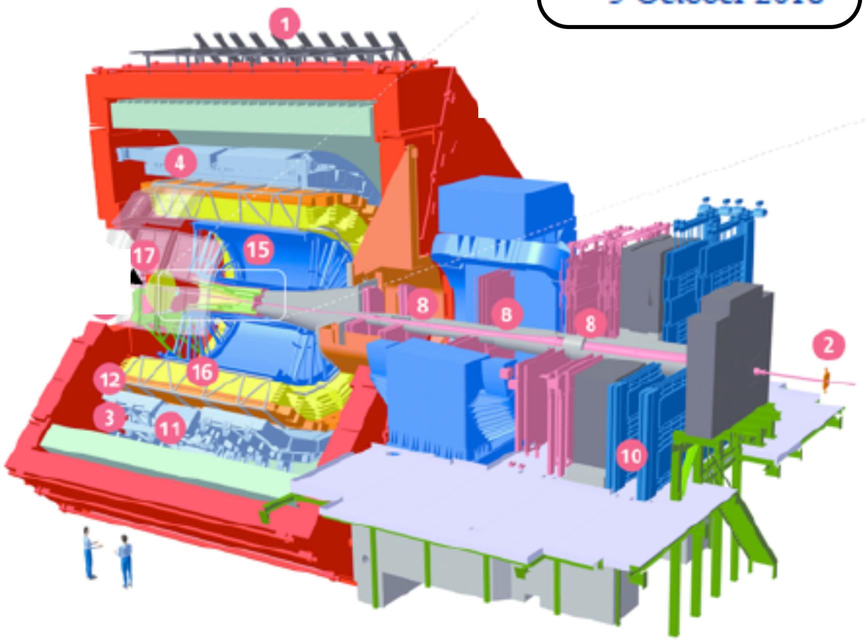

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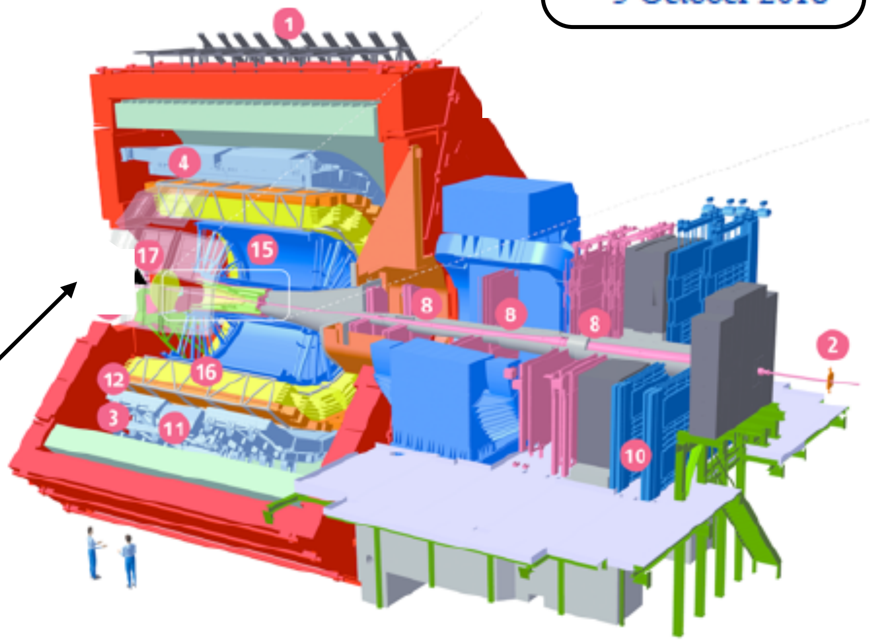
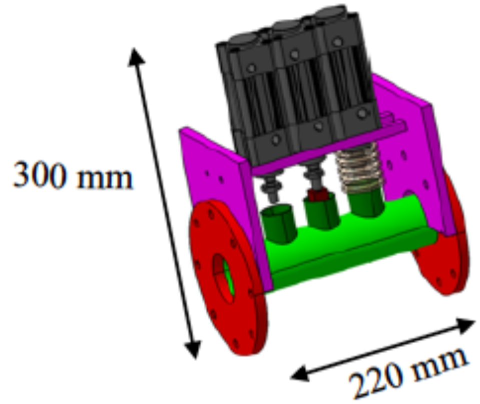


Current investigation:
- Beam splitting and internal solid target

Preliminary sketch of the target system:
- 3 target types (Be, C, Ti, W, …)
- Diameter ~ 5mm, thickness ~ 0.1-5 mm
- Pneumatic motion system with two positions: In/Out



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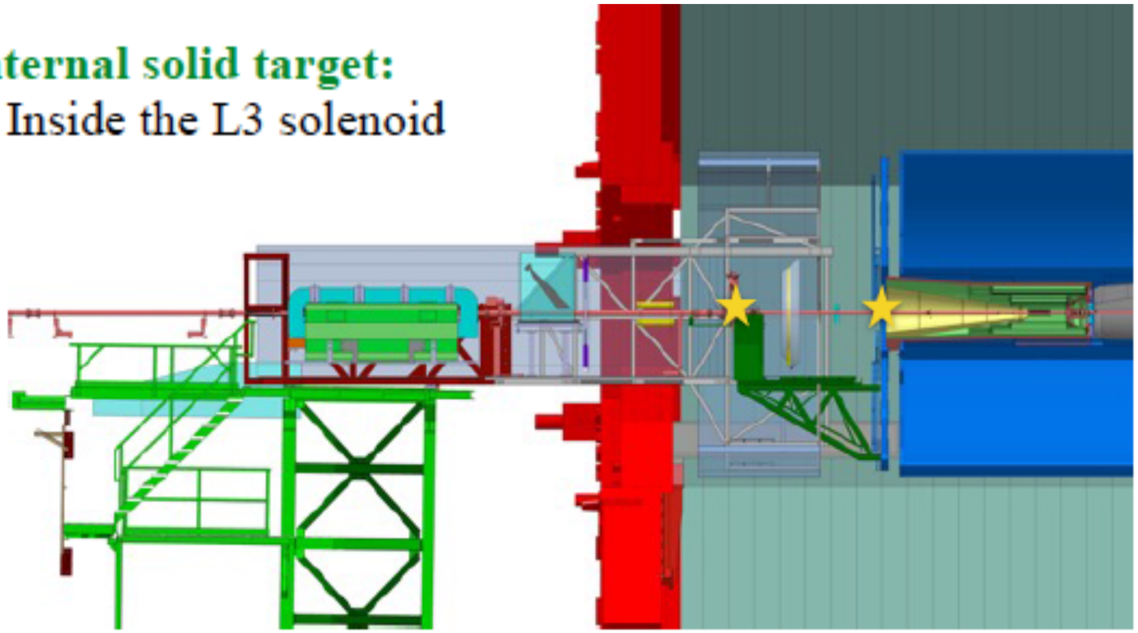
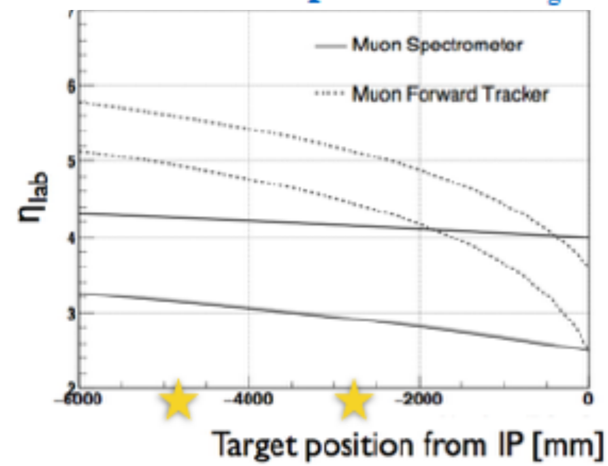
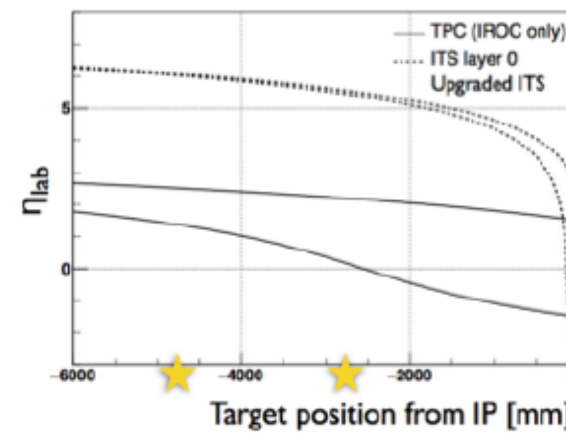
Internal solid target:
- Inside the L3 solenoid



Detector acceptance vs z_{target}





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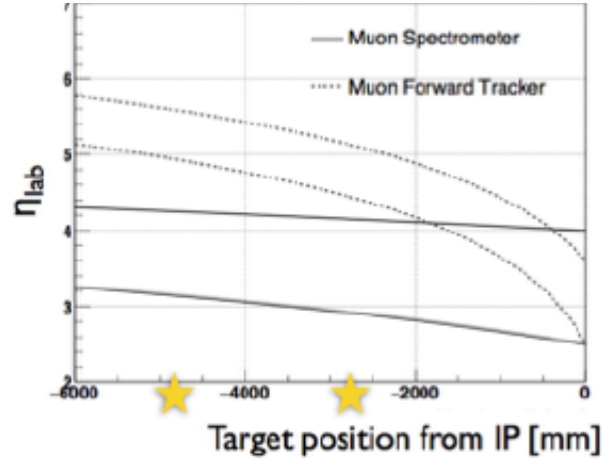
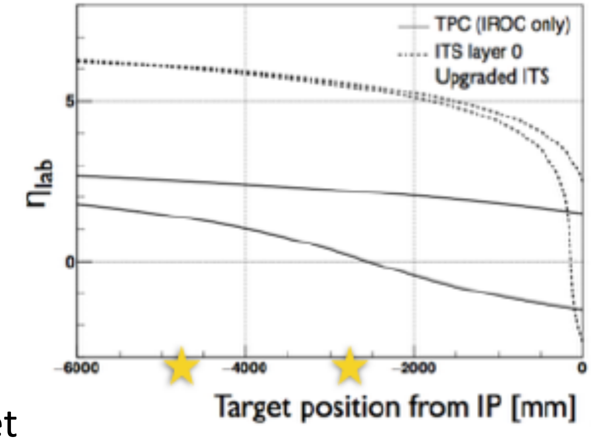




Caveats:
- Disadvanteged by the cylindrical geometry of the main detector
- muon arm (+absorber) poorly instrumented and far from the IP
- there is no obvious place for the installation of an (un)polarised target
- Compatibility of proposed target types (Be, C, Ti, W, …) with LHC conditions to be studied
- Compatibility of the target system with the operation of ALICE detectors to be verified

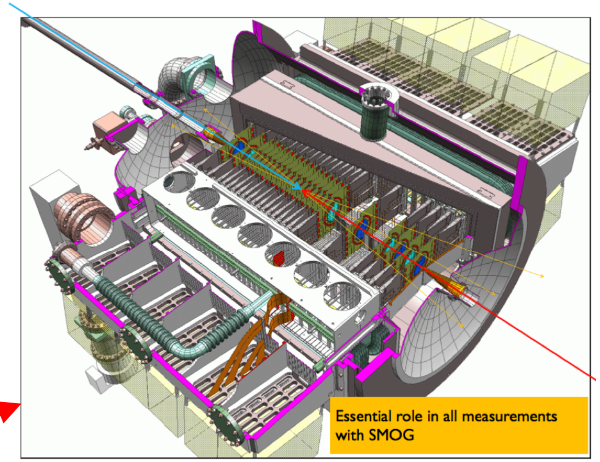
Conclusions

- A fixed-target experiment at the LHC will provide unique kinematic conditions for a broad and ambitious physics program!
- A fixed-target physics program is already ongoing at LHCb with SMOG
- The LHCSpin proposal for an upgrade of SMOG is in advanced stage of R&D and well endorsed by the Collaboration. A formal approval by LHCb/LHC/CERN is expected by the beginning of next year and full installation by 2020.
- The polarized target option is also taken into serious consideration by the LHCb Collaboration and LHC machine experts! A review process has been initiated.
- Investigations for a solid target at ALICE are ongoing

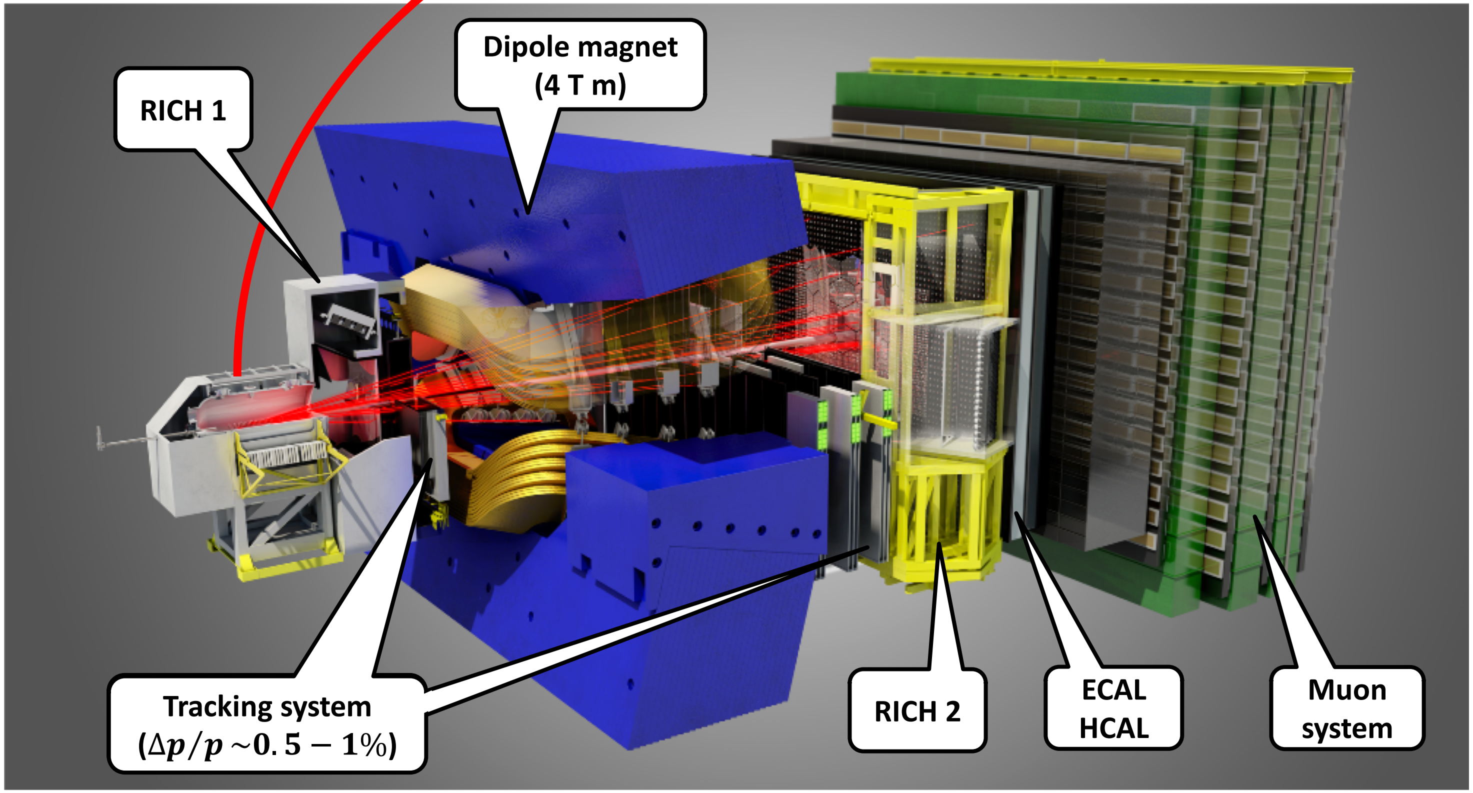
Backup

The LHCb detector

- A single-arm spectrometer designed for the study of particles containing c or b quarks
- **Forward acceptance:** $2 < \eta < 5$

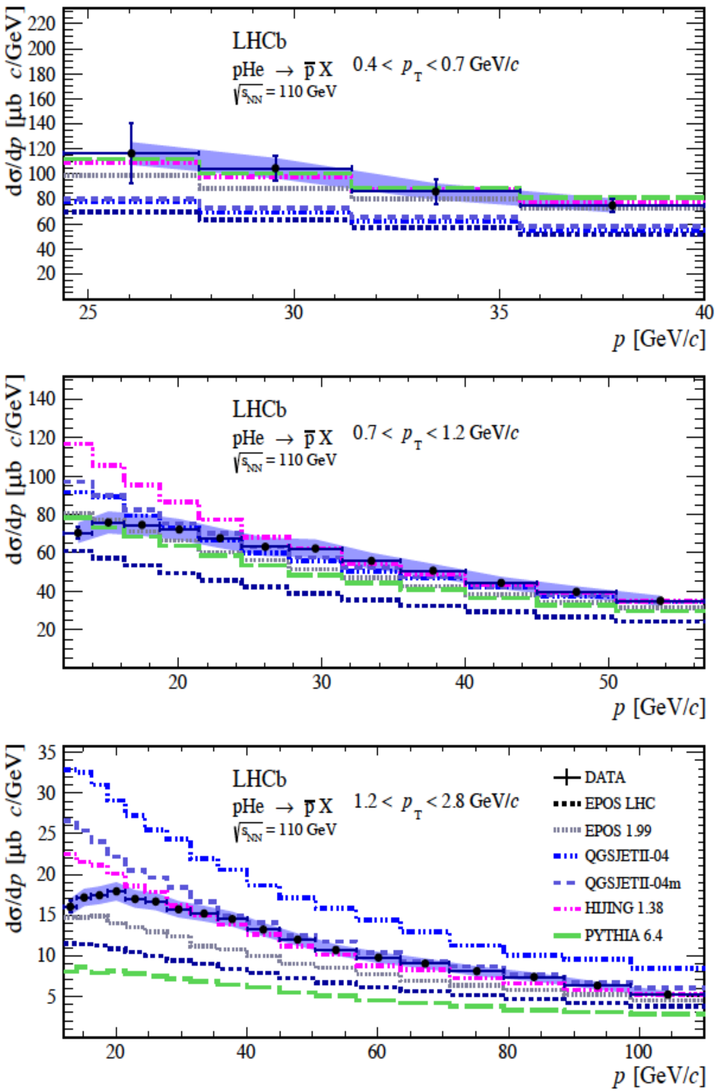


VELO (Vertex Locator)
- Vertex reconstruction
- IP resolution of 20 μm
- 21 stations of Si strip det.
- 2048 strips per sensor.

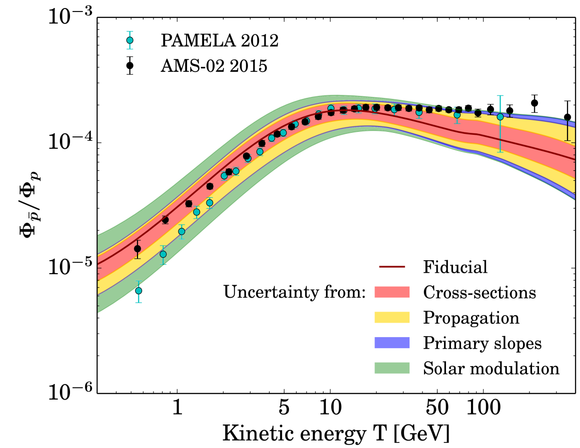


First physics results with SMOG

➢ **First measurement of $\bar{p}$ production in pHe collisions at $\sqrt{s_{NN}} = 110$ GeV** arXiv:1808.06127



Relevant for cosmic-rays/DM physics: predictions for $\bar{p}/p$ flux ratio from spallation of primary cosmic rays on interstellar medium (H and He) are presently limited by large uncertainties on $\bar{p}$ production cross sections (especially from He)



Unique analysis at LHC!

CERNCOURIER International journal of high-energy physics

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NEWS

LHCb brings cosmic collisions down to Earth

13 April 2017

In an effort to improve our understanding of cosmic rays, the LHCb collaboration has generated high-energy collisions between protons and helium nuclei similar to those that take place when cosmic rays strike the interstellar medium. Such collisions are expected to produce a certain number of antiprotons, and are currently one of the possible explanations for the small fraction of antiprotons (about one per 10,000 protons) observed in

CERNCOURIER

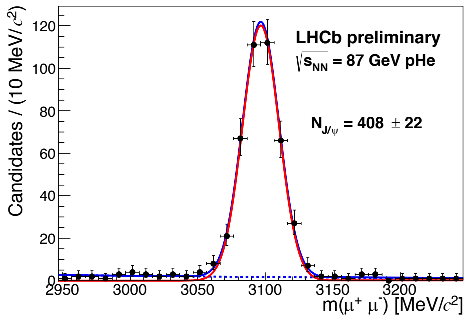
CERN Courier is evolving

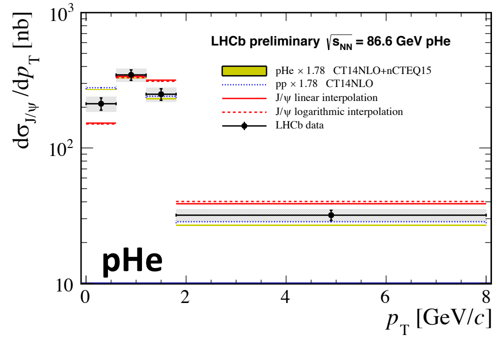
Click here to find out more

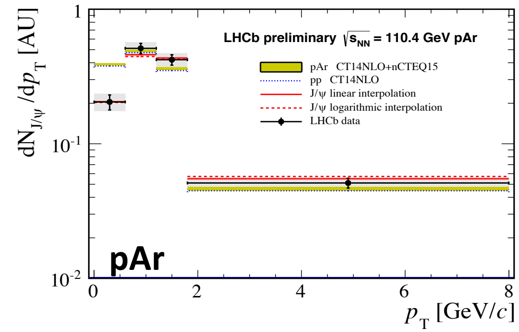
First physics results with SMOG

➢ **J/ψ and D^0 production in pAr and pHe collisions** LHCb-PAPER-2018-023 (in preparation)

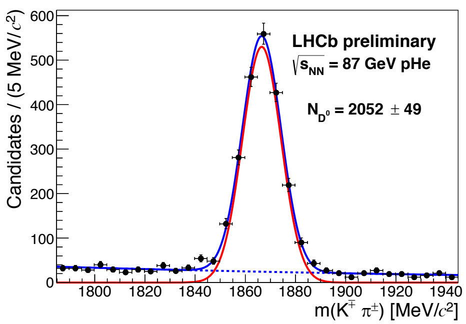
J/ψ

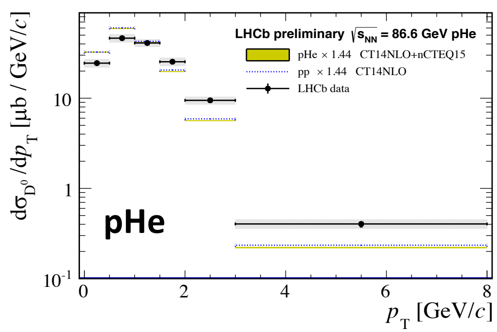


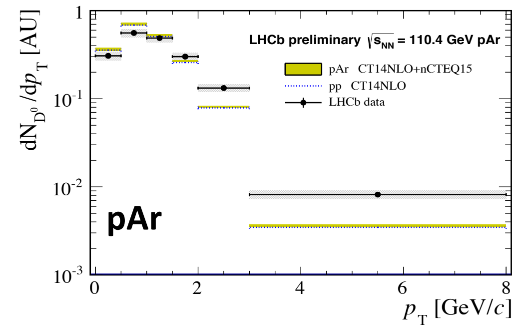




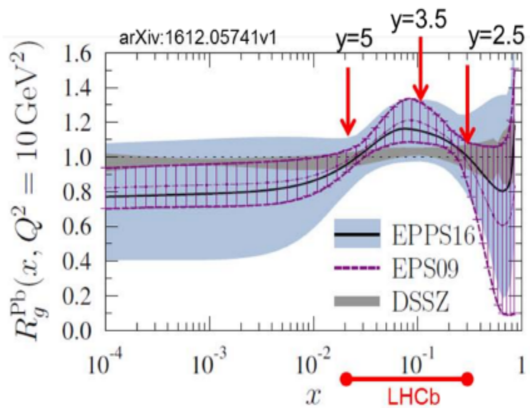
D^0

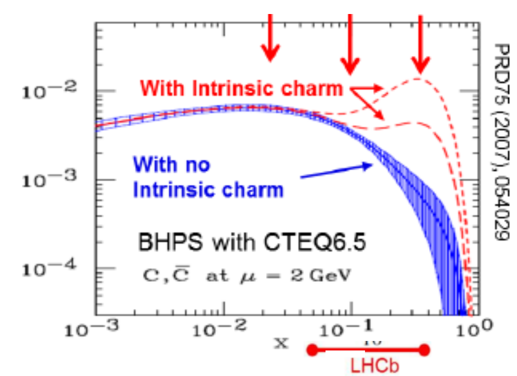






- Relevant for constraining nPDFs at high-x
- Can also help to pin-down possible contributions from intrinsic charm at high-x

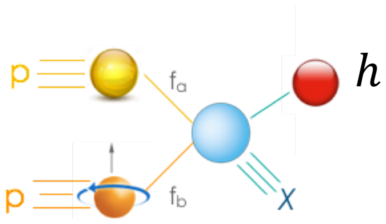


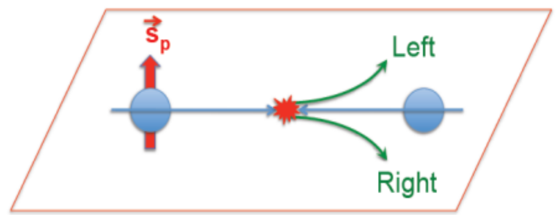


STSAs in pp collisions

Main observables in pol. hadron collisions: **Single Transverse Spin Asymmetries (STSAs)**

Polarized inclusive hard scattering

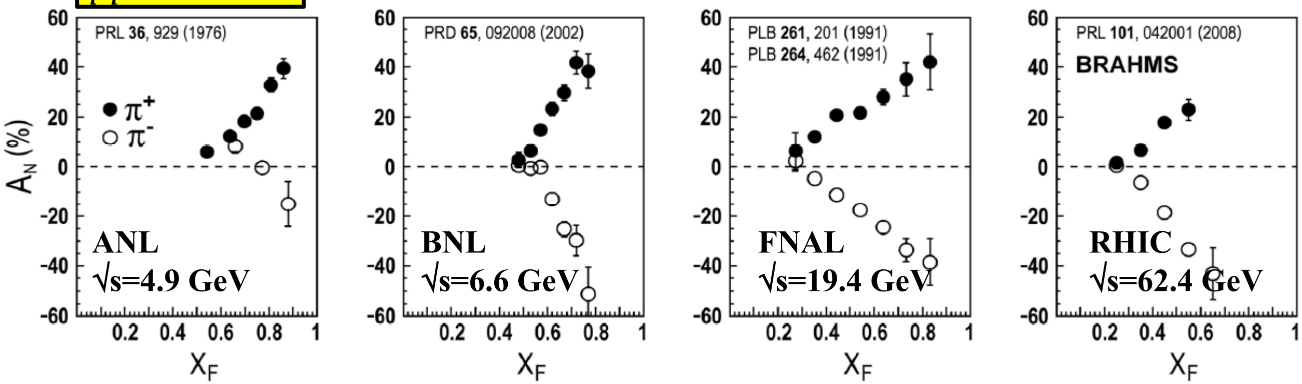


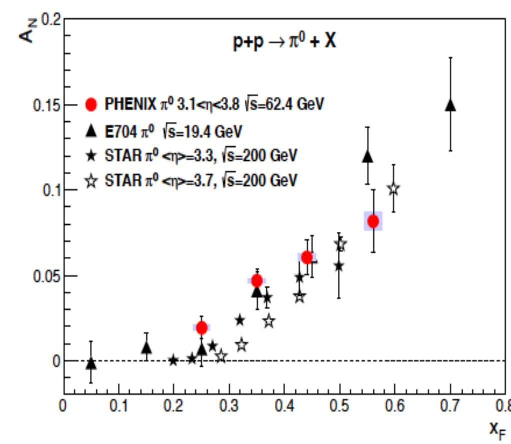


$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \sim \frac{1}{P}\frac{N_h^{\uparrow} - N_h^{\downarrow}}{N_h^{\uparrow} + N_h^{\downarrow}}$$

LO collinear pQCD predicts $A_N \sim O(10^{-4})$ but **asymmetries as large as 40%** have been measured!

$pp^{\uparrow} \rightarrow \pi + X$





- **Very large asymmetries persistent with energy !**
- Reproduced by various experiments over 40 years!
- Large asymmetries up to $\sqrt{s} = 500$ GeV, where the applicability of pQCD isestablished.

STSAs in pp collisions

Collinear (twist-3) approach: (Efremov-Taryaev, Qiu-Sterman, Kanazawa-Koike)

- based on collinear QCD factorization (1 hard scale: works for $p_T, Q \gg \Lambda_{QCD}$)
- SSAs arise from interference between partonic amplitudes (3-parton correlators) generated by gluon exchange with IS or FS hadron

Non-collinear (leading-twist) approach: (Anselmino, Boglione et al.)

- involves TMD PDFs and FFs
- works in the limit $p_T \ll$ Q (2 energy scales), but is not supported by TMD factorization
- can be considered as an effective model description (**Generalized Parton Model**)
- SSAs arise mainly from **Sivers effects**

➢ **The two approaches correspond exactly** in the overlap region $\Lambda_{QCD} \ll p_T \ll Q$ (proved for SSAs in Drell-Yan: Ji, Qiu, Vogelsang, Yuan, PRL, 2006)

➢ …very little is presently known about **tri-gluon correlation functions** and **polarized gluon TMDs!**

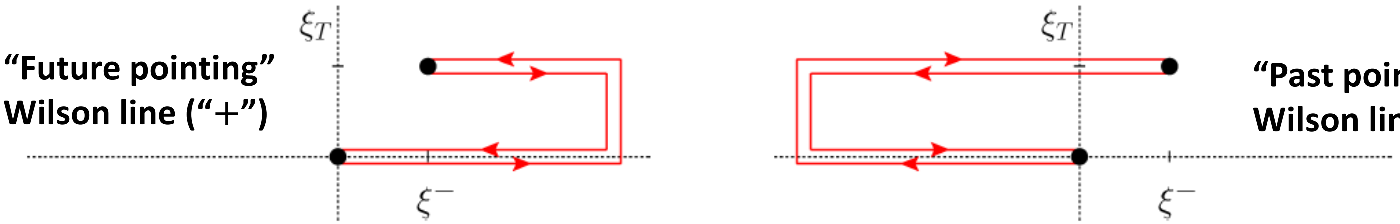
Process dependence

As for quark TMDs, also the gluon TMD phenomenology is enriched by the **process dependence** originating from ISI/FSI and encoded in the **gauge links**.

The gluon correlator depends on two path-dependent gauge links [D. Boer: arXiv:1611.06089]

$$\Gamma^{\mu\nu\,[\mathcal{U},\mathcal{U}']}(x,\boldsymbol{k}_T) \equiv \int \frac{d(\xi\cdot P)\,d^2\xi_T}{(P\cdot n)^2(2\pi)^3} e^{i(xP+k_T)\cdot\xi} \langle P|\mathrm{Tr}_c\left[F^{n\nu}(0)\,\mathcal{U}_{[0,\xi]}\,F^{n\mu}(\xi)\,\mathcal{U}'_{[\xi,0]}\right]|P\rangle$$

"Future pointing" Wilson line ("+")



"Past pointing" Wilson line ("−")

Both f_1^g and $h_1^{\perp g}$ are process dependent! Each of them can be of two types:

$[+\,+] = [-\,-]$ Weizsacker-Williams (WW) $[+\,-] = [-\,+]$ DiPole (DP)

- **can differ in magnitude and width (!)**
- **can be probed by different processes**

Process dependence

Can be measured at the EIC (pink shading)

Can be measured at the LHC with FT (blue shading)

[D. Boer: arXiv:1611.06089]

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

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

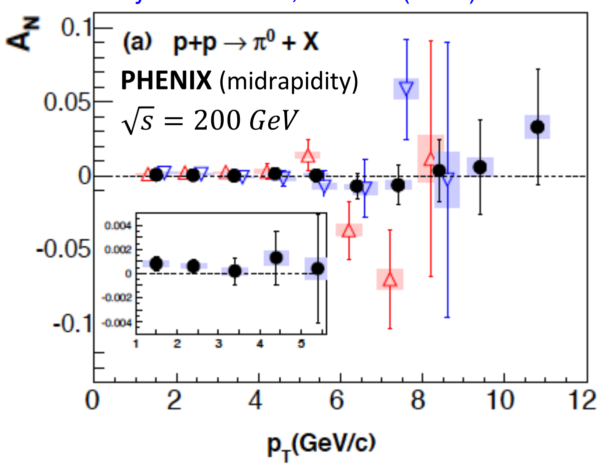
	DY	SIDIS	$p^\uparrow\,A \to h\,X$	$p^\uparrow A \to \gamma^{(*)}\,\text{jet}\,X$	$p^\uparrow p \to \gamma\,\gamma\,X$ $p^\uparrow p \to J/\psi\,\gamma\,X$ $p^\uparrow p \to J/\psi\,J/\psi\,X$	$e\,p^\uparrow \to e'\,Q\,\overline{Q}\,X$ $e\,p^\uparrow \to e'\,j_1\,j_2\,X$
$f_{1T}^{\perp\,g\,[+,+]}$ (WW)	×	×	×	×	√	√
$f_{1T}^{\perp\,g\,[+,-]}$ (DP)	√	√	√	√	×	×

$$[+,+] \quad f_{1T}^{\perp\,g[e\,p^\uparrow \to e'\,Q\bar{Q}\,X]}(x, p_T^2) = -f_{1T}^{\perp\,g[p^\uparrow\,p \to \gamma\,\gamma\,X]}(x, p_T^2) \quad [-,-]$$

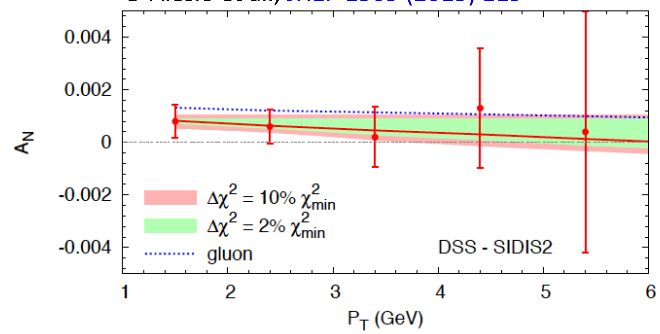
Same sign-change relation expected for the other T-odd gTMDs h_1^g and $h_{1T}^{\perp g}$!

Probing the GSF (from RHIC data)

Phys. Rev. D 90, 012006 (2014)

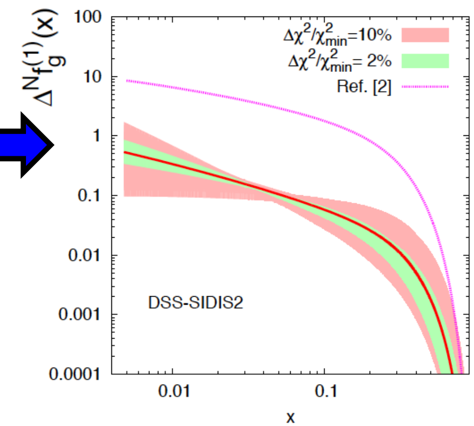


D'Alesio et al., JHEP 1509 (2015) 119

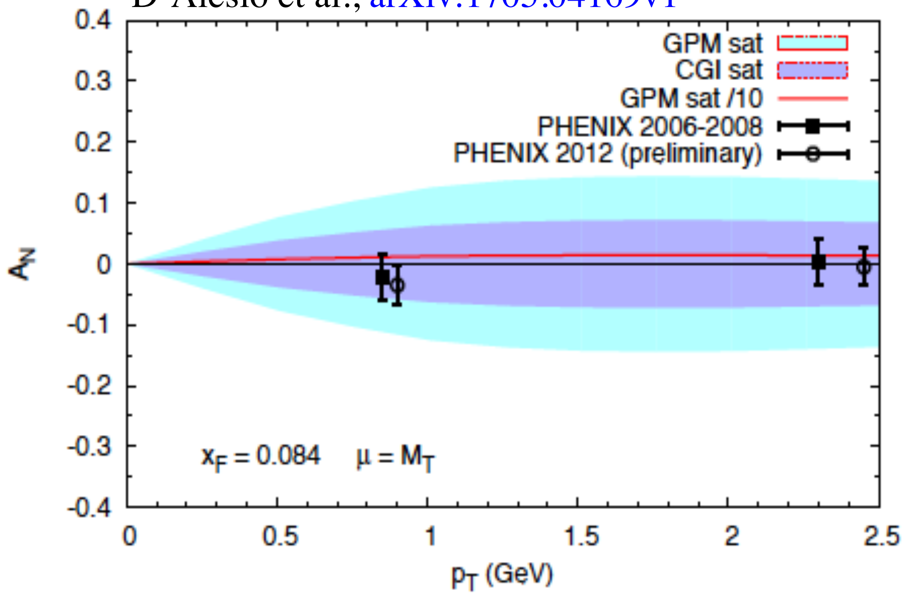


A_N estimate in the frame of GPM, based on param. from SIDIS data + FFs from DSS

First $k_\perp$-moment of the gluon Sivers function (small positive)

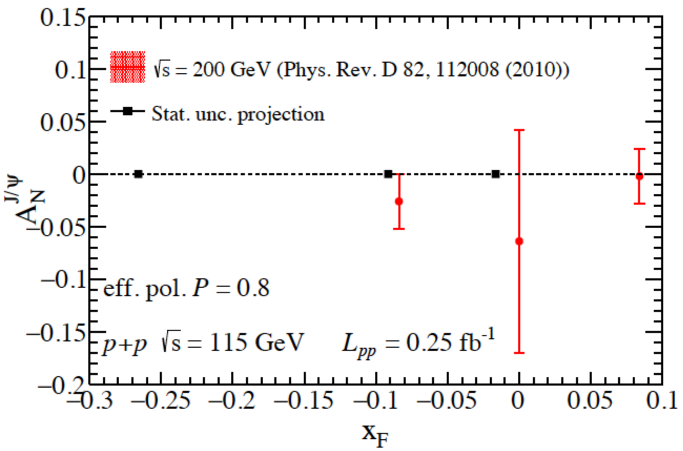


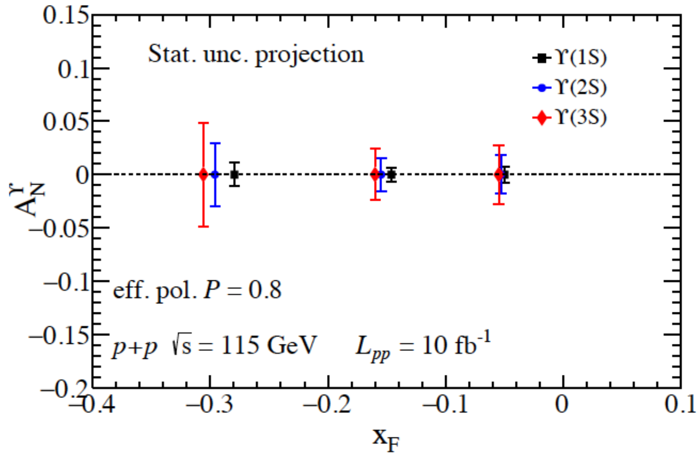
D'Alesio et al., arXiv:1705.04169v1

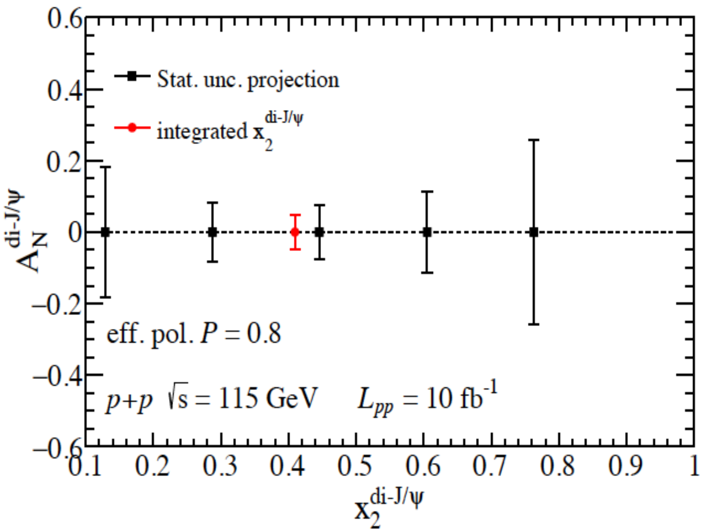


- **Existing quarkonia results only from PHENIX**
- First measurement of A_N for $pp^{\uparrow} \rightarrow J/\psi X$
- Sensitive to f-type gluon Sivers funciton
- A very recent prediction of A_N from Color-Gauge Invariant GPM **(CGI-GPM)**: takes into account the process dependence of the GSF

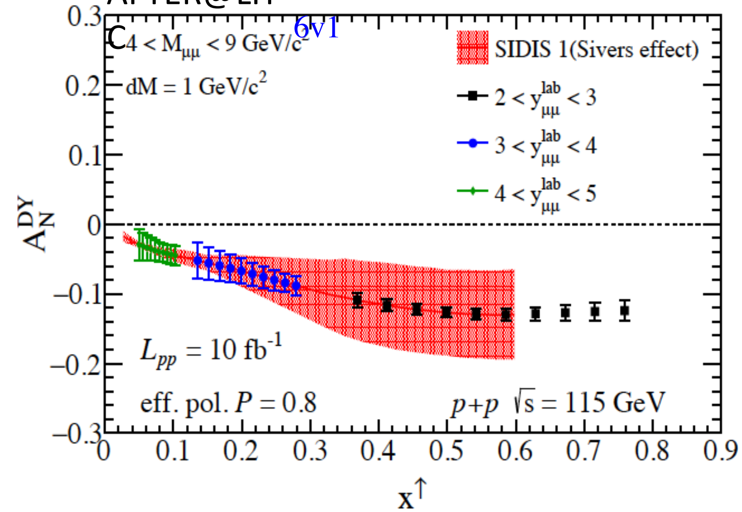
(projected results from **AFTER@LHC** arXiv:1702.01546v1)







AFTER@LHC arXiv:1702.01546v1



Main reactions of interest

- $pp^{(\uparrow)} \to \eta_c + X \quad (pp^{(\uparrow)} \to \chi_{c,b} + X)$
- $pp^{(\uparrow)} \to J/\psi + X$
- $pp^{(\uparrow)} \to \Upsilon + X$
- $pp^{(\uparrow)} \to J/\psi + J/\psi + X$
- $pp^{(\uparrow)} \to J/\psi + \gamma + X$
- $pp^{(\uparrow)} \to \Upsilon + \gamma + X$

☛ **Pol and unpol gluon PDFs**

- $pp \to \mu^+\mu^- + X \quad (pp \to e^+e^- + X)$
- $pd \to \mu^+\mu^- + X \quad (pd \to e^+e^- + X)$

☛ **momentum distrib. of sea quarks & unpolarized TMDs of valence and sea quarks**

- $pp^{\uparrow} \to \mu^+\mu^- + X \quad (pp^{\uparrow} \to e^+e^- + X)$
- $pd^{\uparrow} \to \mu^+\mu^- + X \quad (pd^{\uparrow} \to e^+e^- + X)$

☛ **TMDs of valence and sea quarks**

- pA, PbA $(A = He, Ne, Ar, Kr, \ldots)$

☛ **Nuclear matter effects, QGP, etc**

We warmly encourage our theory colleagues to propose new physics cases and new reactions of interest for LHCSpin!

SMOG2 vs. SMOG

Storage cell assumptions	gas type	gas flow (s^{-1})	peak density (cm^{-3})	areal density (cm^{-2})	time per year (s)	int. lum. (pb^{-1})
SMOG2 SC	He	1.1×10^{16}	10^{12}	10^{13}	3×10^{3}	0.1
	Ne	3.4×10^{15}	10^{12}	10^{13}	3×10^{3}	0.1
	Ar	2.4×10^{15}	10^{12}	10^{13}	2.5×10^{6}	80
	Kr	8.5×10^{14}	5×10^{11}	5×10^{12}	1.7×10^{6}	25
	Xe	6.8×10^{14}	5×10^{11}	5×10^{12}	1.7×10^{6}	25
	H_2	1.1×10^{16}	10^{12}	10^{13}	5×10^{6}	150
	D_2	7.8×10^{15}	10^{12}	10^{13}	3×10^{5}	10
	O_2	2.7×10^{15}	10^{12}	10^{13}	3×10^{3}	0.1
	N_2	3.4×10^{15}	10^{12}	10^{13}	3×10^{3}	0.1

SMOG2 example pAr @115 GeV

Int. Lumi.		80/pb
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

Expected performance for the PGT

- The LHC beam runs through the target cell and experiences an **Areal density**: $\theta = \frac{1}{2} \rho_0 L$
- **Volume density**: $\rho_0 = I_0/(2C_1 + C_2)$ where: $C = 3.81\sqrt{\frac{T(K)}{M}}\frac{D^3}{L+1.33D}\left(\frac{l}{s}\right)$

$I_0 = 6.5 \cdot 10^{16} s^{-1}$ $C_{tot} = 13.90$ l/s $\rho_0 = 4.68 \cdot 10^{12}/cm^3$ ⟹ $\boldsymbol{\theta = 7.02 \cdot 10^{13}/cm^2}$

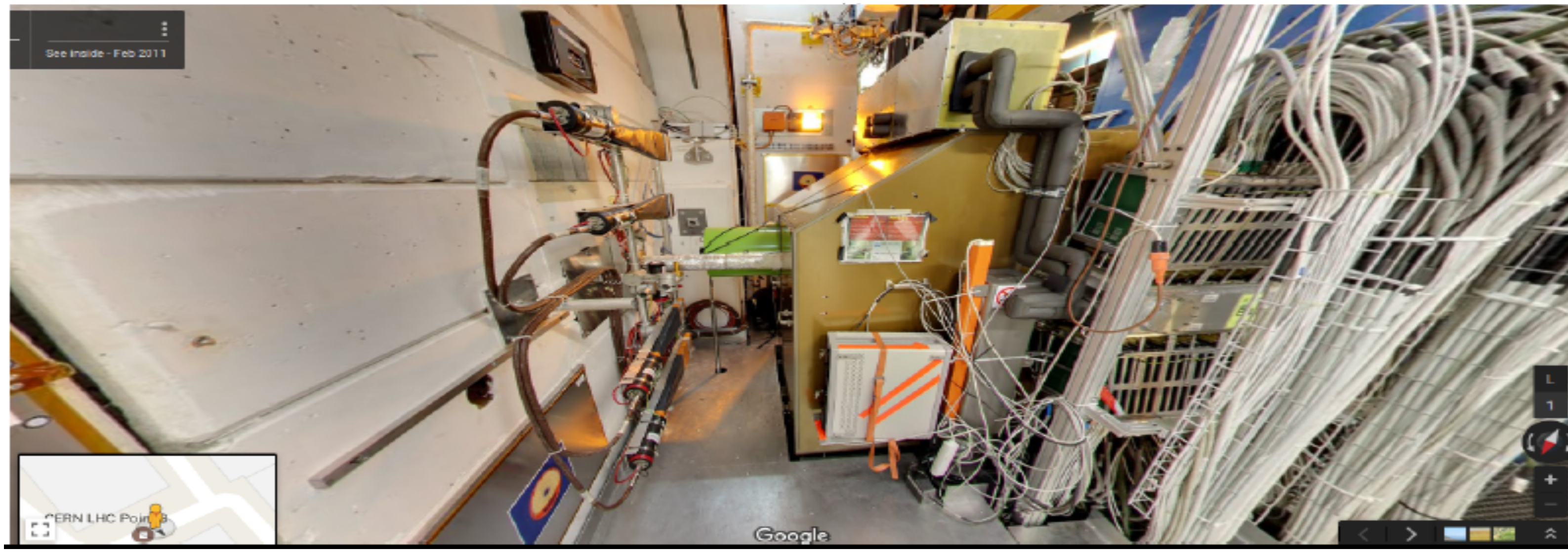
$$\begin{cases} N_{p/bunch} = 1.15 \cdot 10^{11} \\ N_{bunch} = 2800 \\ f_{rev} = 11245\ Hz \end{cases} \Longrightarrow \boldsymbol{I_{beam} = 3.6 \cdot 10^{18}\ s^{-1}}$$

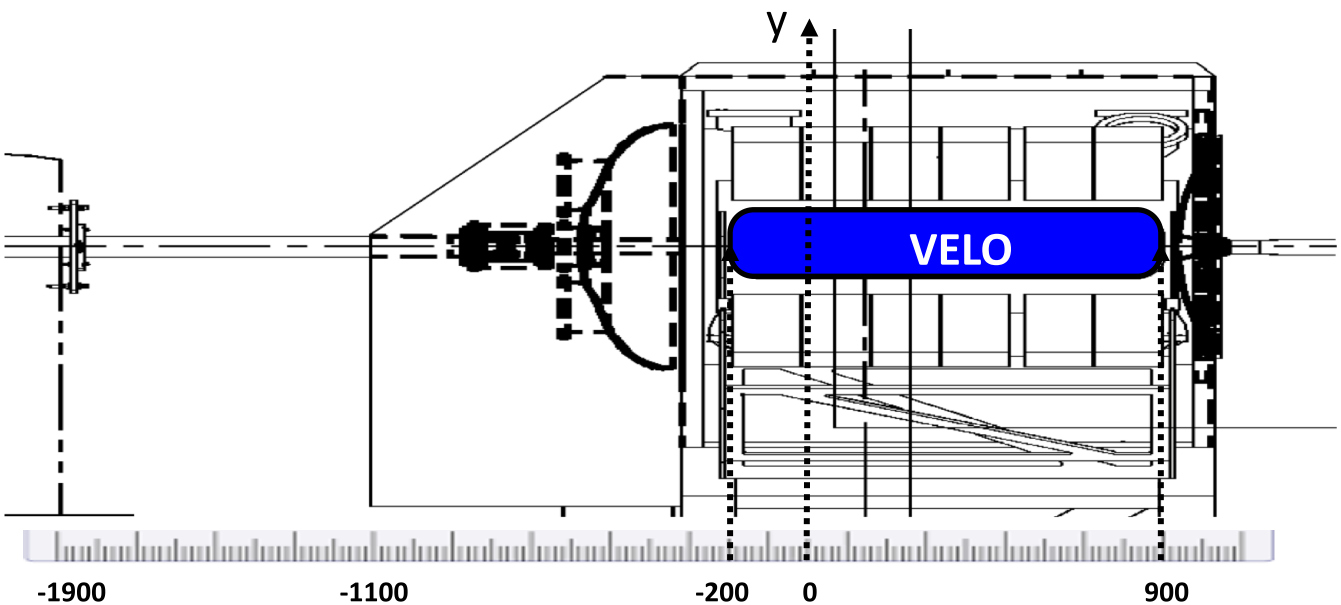
$$\boldsymbol{L(T_{cell} = 300\ K) = I_{beam} \cdot \theta = 2.5 \cdot 10^{32}\ \mathrm{cm^{-2}s^{-1}}}$$

$$\boldsymbol{L(T_{cell} = 100\ K) = \sqrt{3} \times L(T_{cell} = 300K) = 4.4 \cdot 10^{32}\ \mathrm{cm^{-2}s^{-1}}}$$

- The pressure in the LHC beam pipe outside the target region would be $\sim 10^{-7}$ mbar, one order of magnitude lower than the maximum pressure allowed by LHC
- Parallel operation will cause marginal reduction of beam half-life!

There is some room beyond the VELO…





The LHCSpin project

A growing motivated collaboration:

Christian Baumgarten	(PSI Zurich)
Vito Carassiti	(INFN and University of Ferrara)
Giuseppe Ciullo	(INFN and University of Ferrara)
Pasquale Di Nezza	(INFN Laboratori Nazionali di Frascati, LHCb)
Ralf Engels	(IKP - Forschungszentrum Jülich)
Kirill Grigoryev	(IKP - Forschungszentrum Jülich)
Paolo Lenisa	(INFN and University of Ferrara)
Emilie Maurice	(CNRS, Saclay, LHCb)
Alexander Nass	(IKP - Forschungszentrum Jülich)
Luciano Pappalardo	(INFN and University of Ferrara, LHCb)
Frank Rathmann	(IKP - Forschungszentrum Jülich)
Davide Reggiani	(PSI Zurich)
Marco Statera	(INFN and University of Milano)
Erhard Steffens	(University of Erlangen-Nürnberg)
Michael Winn	(CNRS, Saclay, LHCb)

Other groups from EU and US have informally expressed their interest in the project!