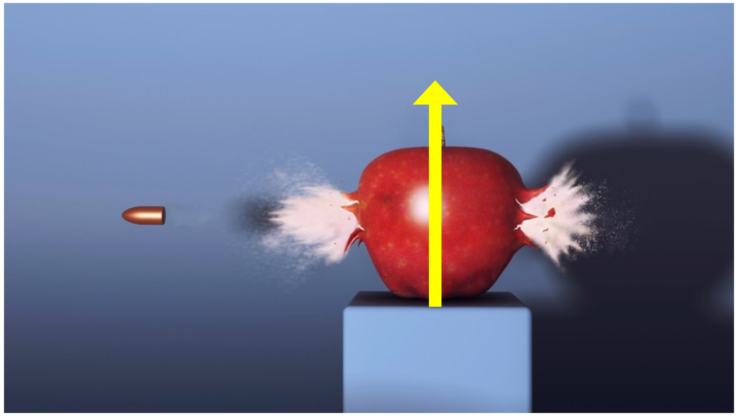
A proposal for a polarized target at LHCb

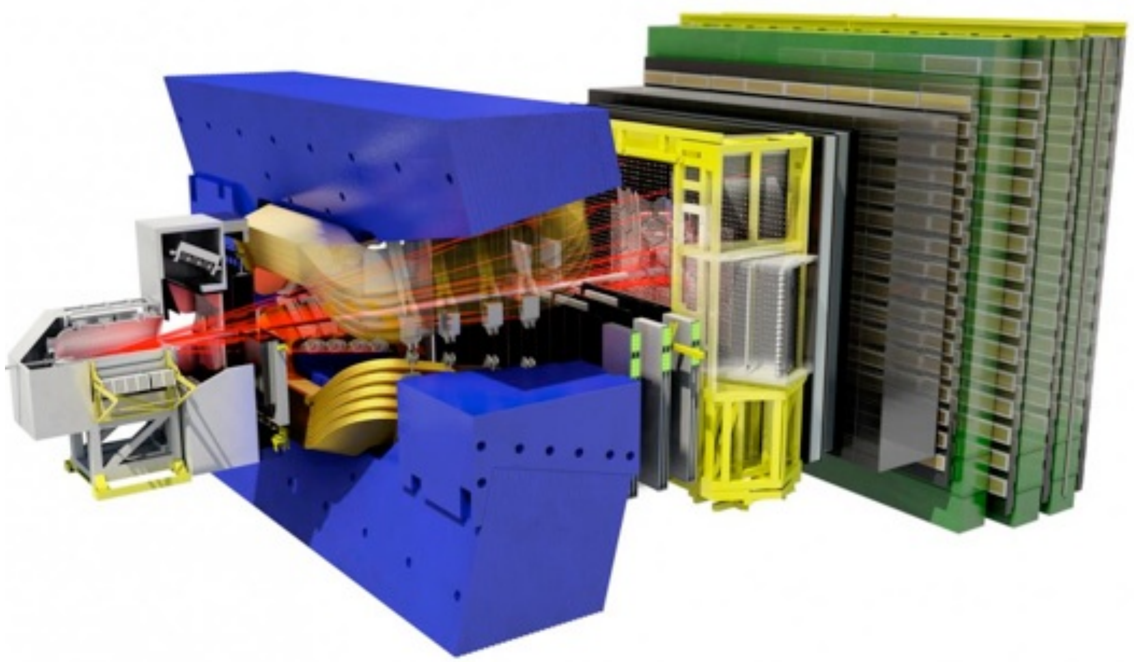


L. L. Pappalardo (for the LHCSpin group)

Transversity 2017
INFN-LNF - Frascati – December 11-15 2017

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.



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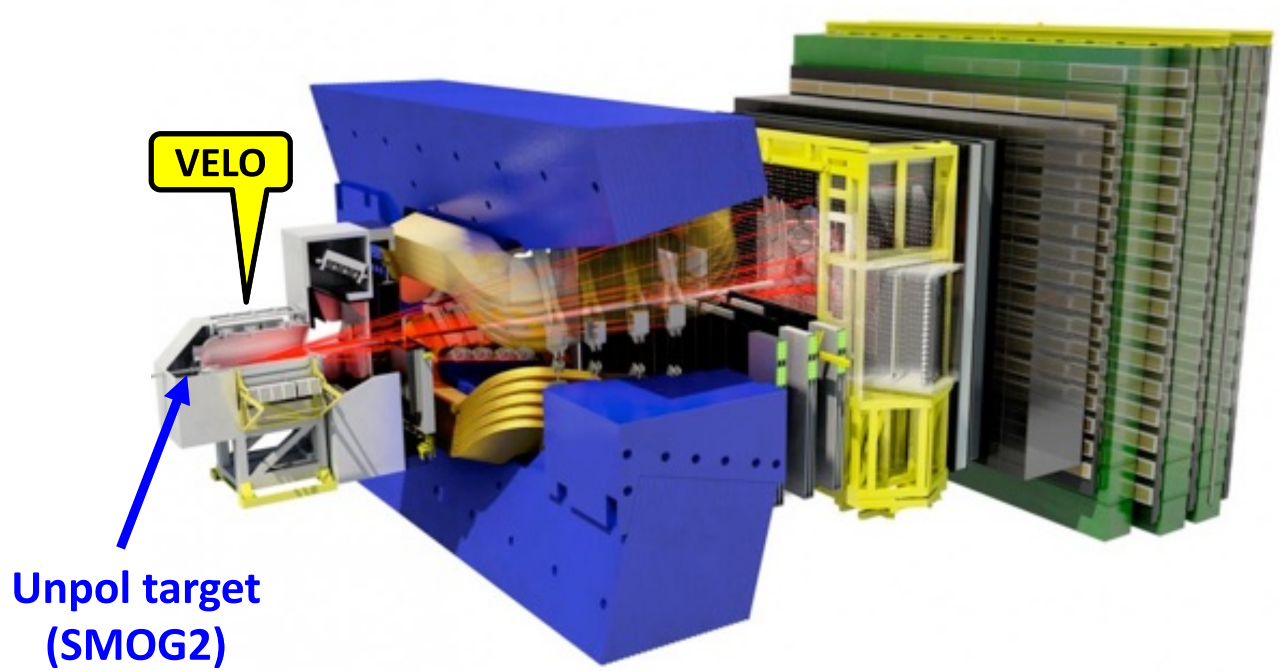
The project consists of **two phases**:

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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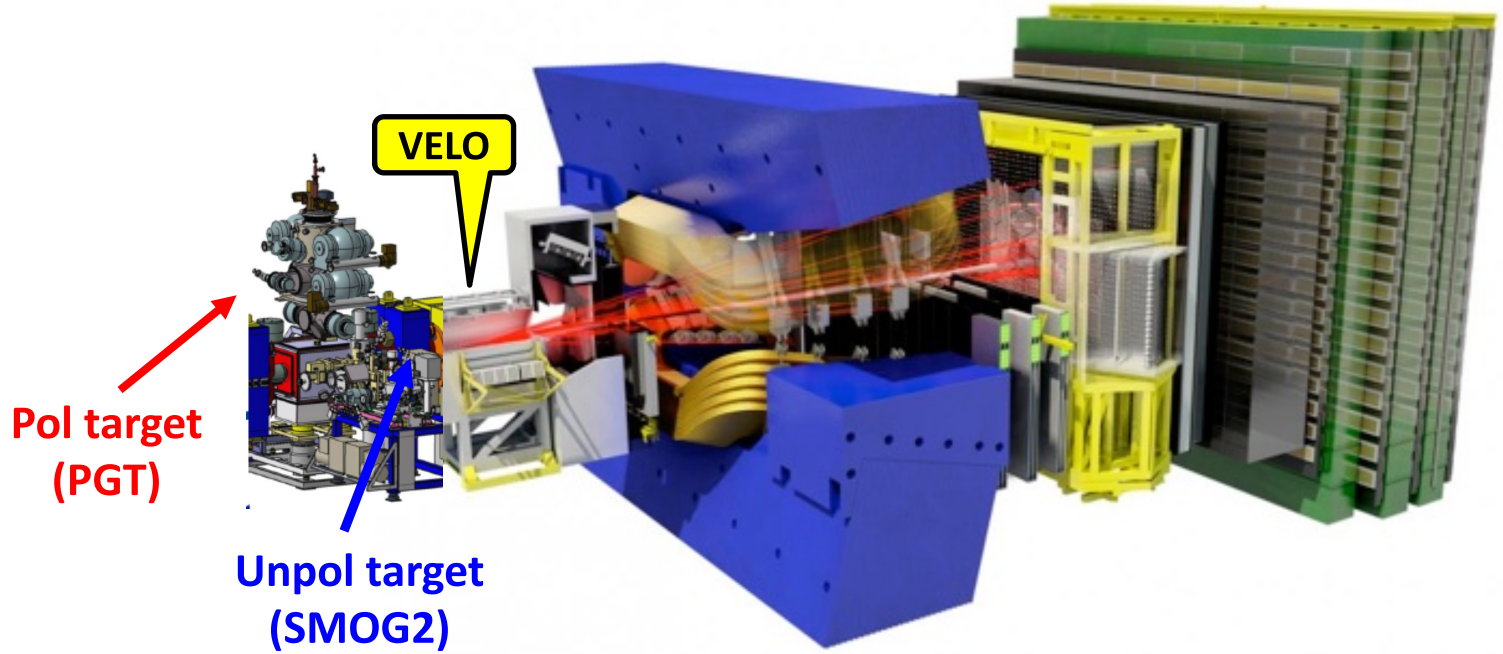
Phase II

Installation of a Hermes-like polarized gas target system (**PGT**) in front of LHCb



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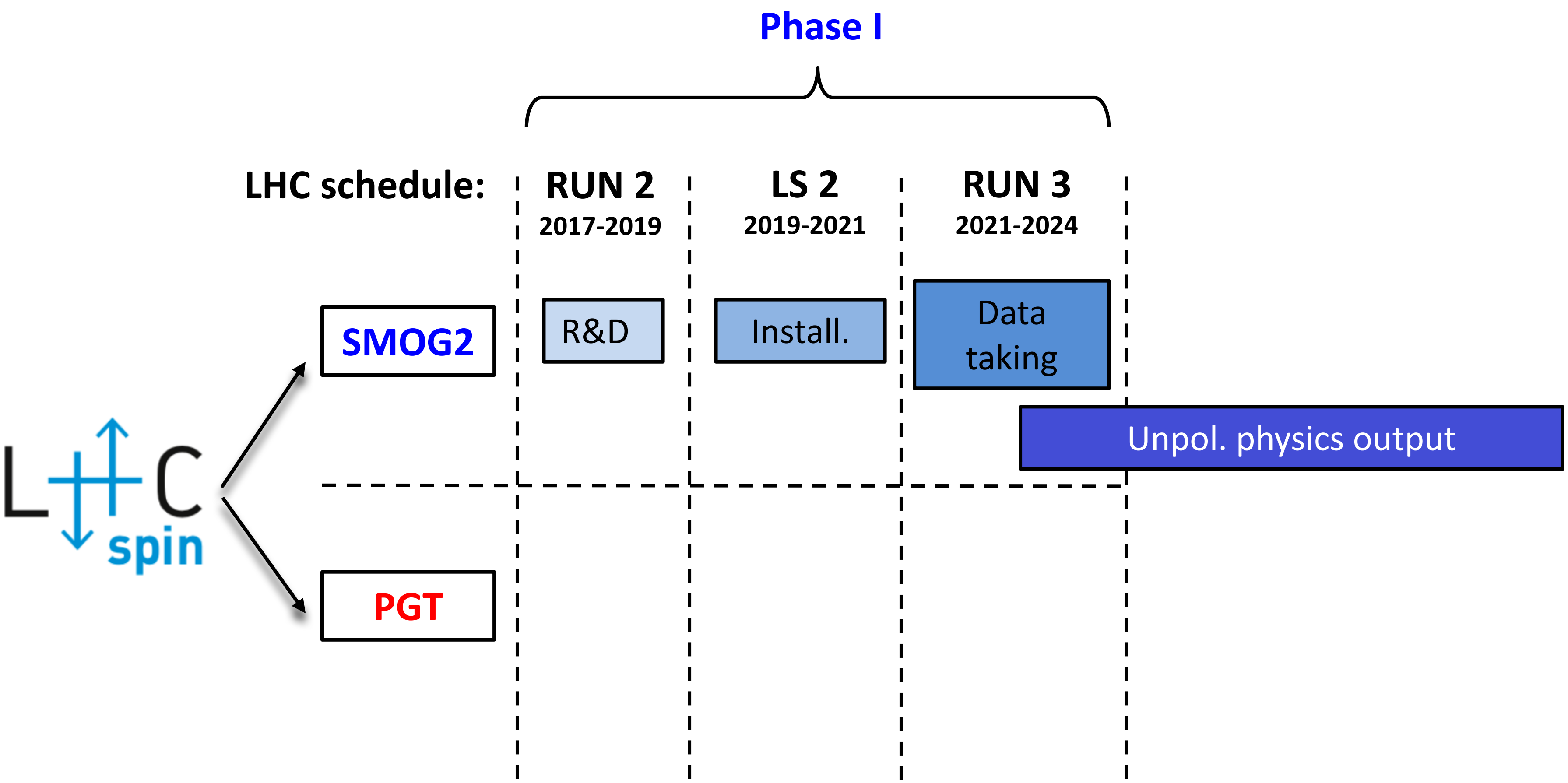
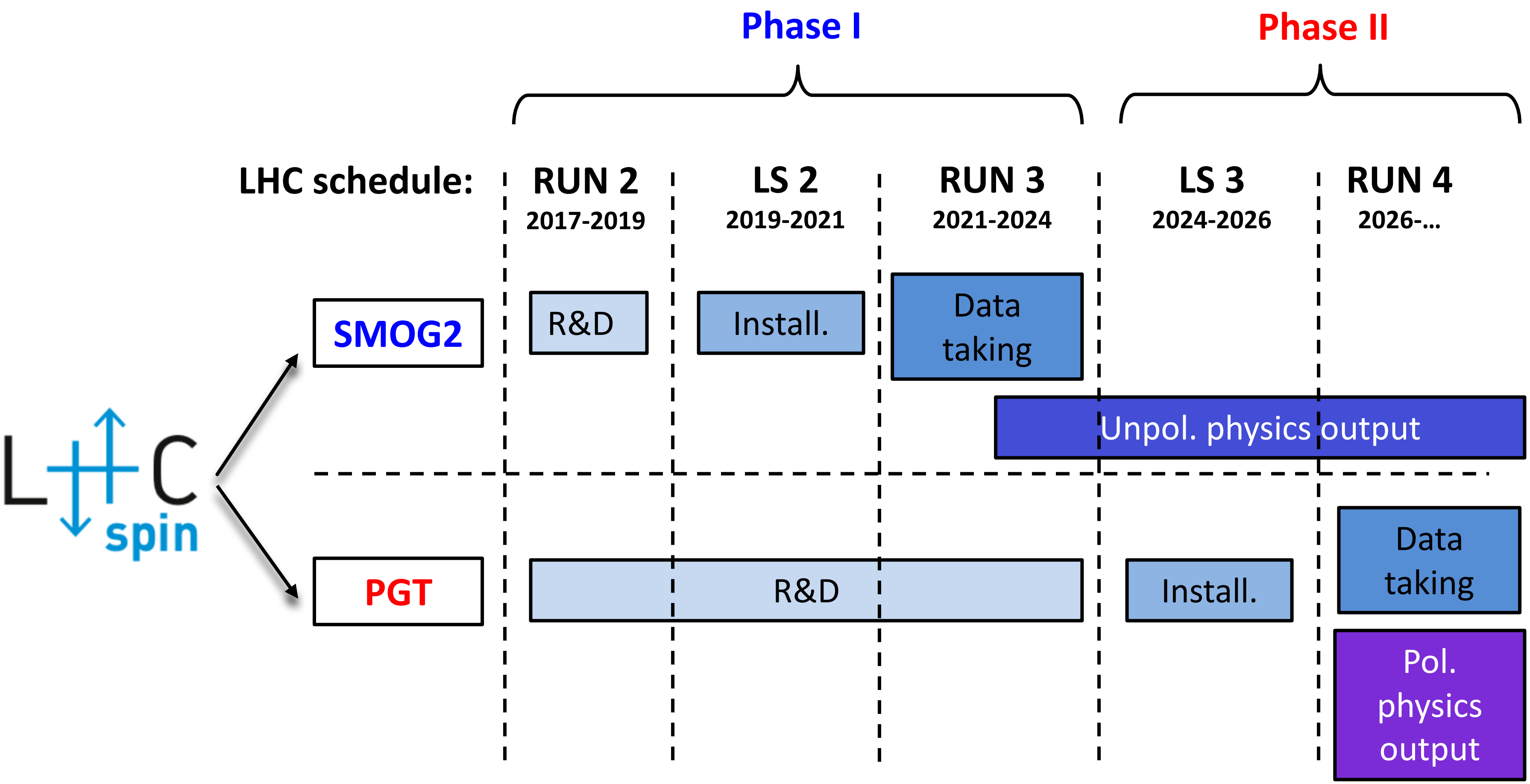


Find detailed time table in backup slides

The LHCSpin project



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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!

Why LHCSpin?

✓ **Unique kinematic conditions**

- intermediate energies
- backward CM rapidity region
- sensitive also to poorly explored high x-Bjorken

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- 3D nucleon structure (quark and gluon TMDs)
- fundamental tests of QCD (universality, factorization, etc)
- effects of cold nuclear matter (EMC, jet-quenching, etc)
- QGP formation
- Intrinsic heavy quarks
- ... and much more!

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- ✓ **Polarized gas target technology well established (10 years @ HERMES)**
- ✓ **Very high performances ($P \sim 80\%$)**

Kinematics for a fixed target @ LHC

Kinematic conditions for a fixed target at LHC

7 TeV proton beam on a fixed target proton:

- $\sqrt{s} \approx 115\ \mathrm{GeV}$ **(between SPS & RHIC)**
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CM rapidity for parton-parton collisions

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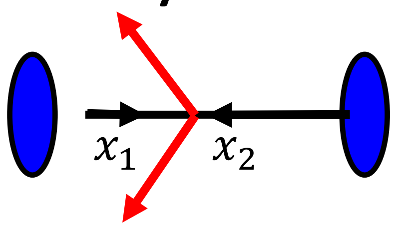
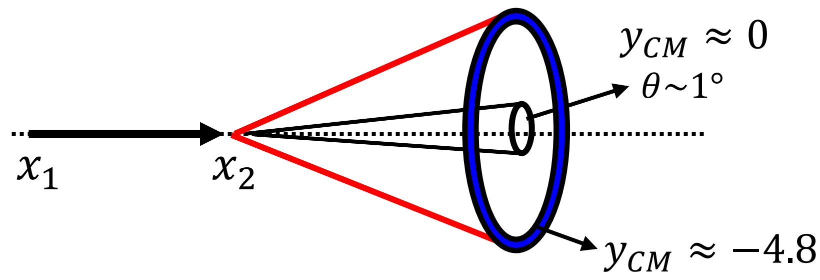
CM backward rapidity region
$(-4.8 < y_{CM} < 0)$

CM system



Target rest frame (Lab system)



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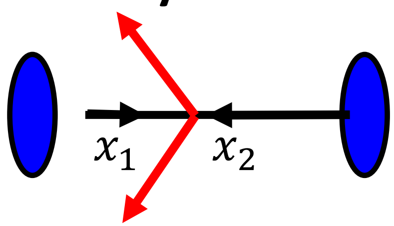

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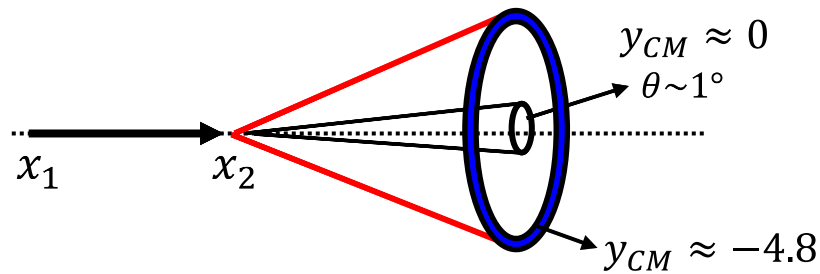

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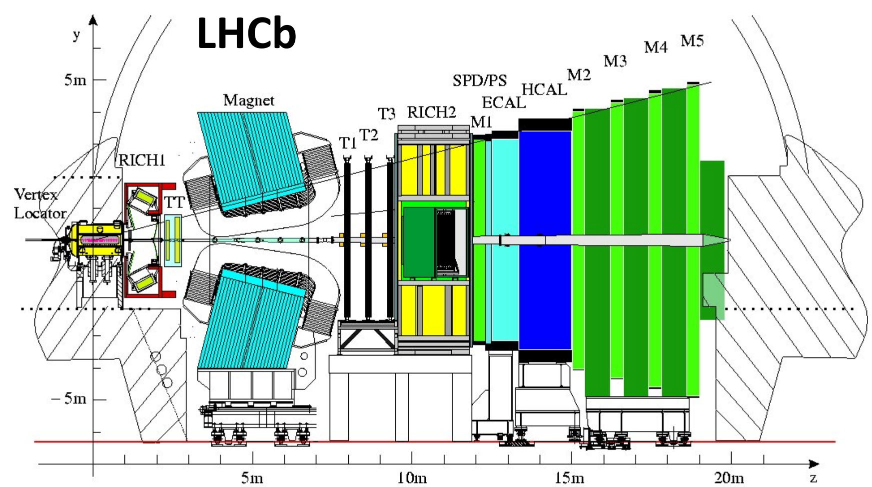

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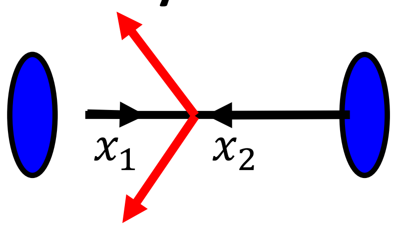

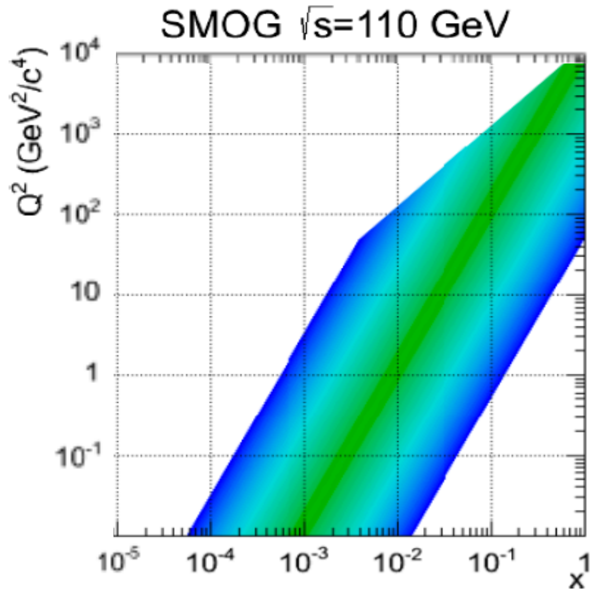

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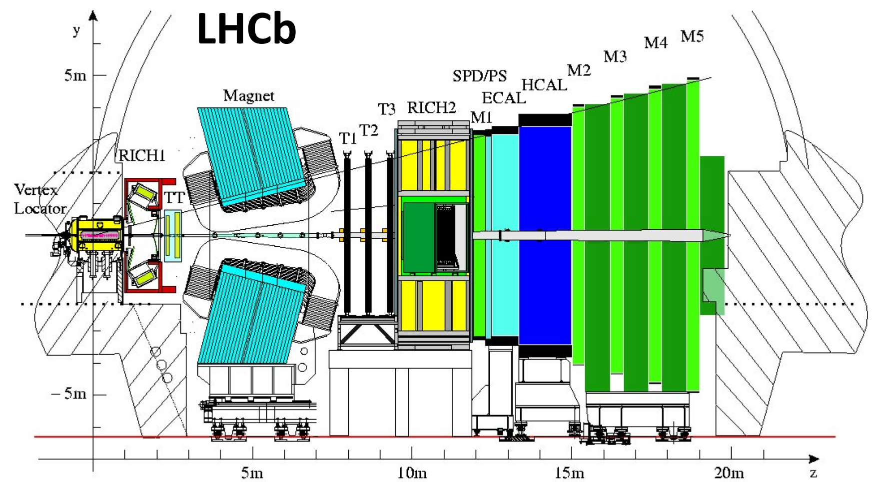

Selected physics opportunities with an **unpolarized target** @ LHCb (Phase I)

Probing the gluon PDFs

		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 $h_{1T}^{\perp}$

- **Very significant progress in the last 15 years!**
- Many experiments involved: HERMES, COMPASS, JLAB, RHIC, BELLE, BABAR,..
- First extractions from global analyses
- **Now entering precision era!**

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	Unpol	Circularly pol.	Linearly pol.
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Hadron L		g_1^g	$h_{1L}^{\perp g}$
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- Theory framework consolidated
- **…but experimental access still extremely limited!**

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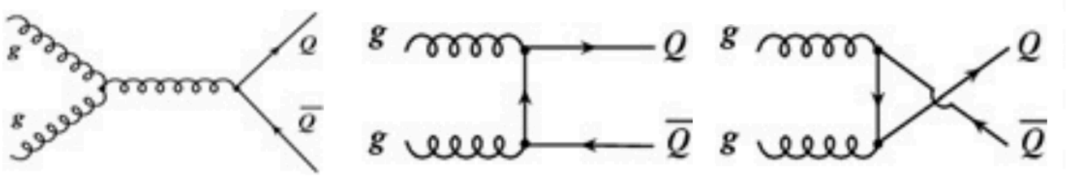
- **…but experimental access still extremely limited!**
- **LHCSpin can provide a significant contribution to the field, already from Phase I (unpol target)!**

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

Probing the gluon PDFs

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



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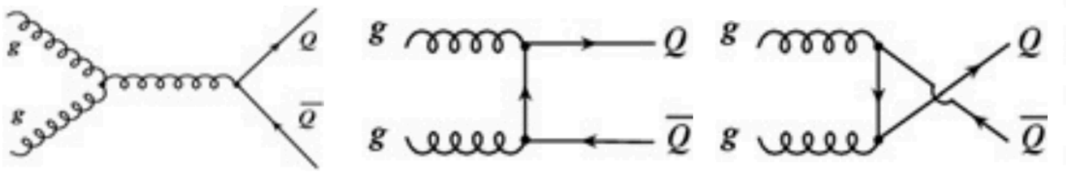

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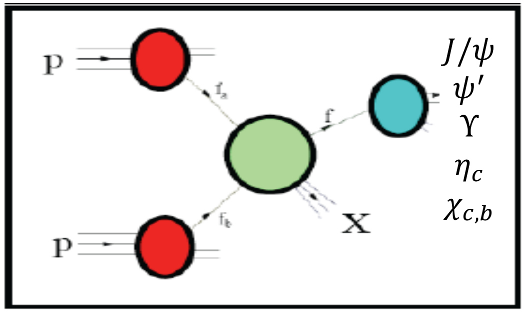
Inclusive quarkonia production in pp interaction turns out to be an ideal **gluon-sensitive observable!**



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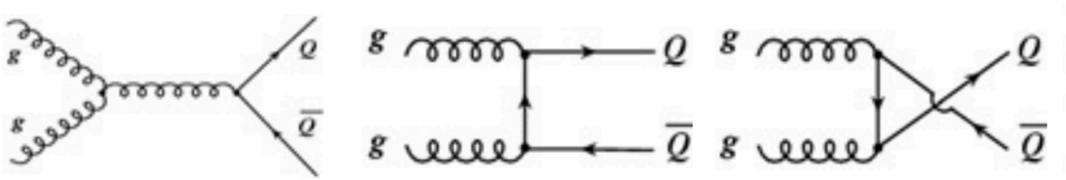

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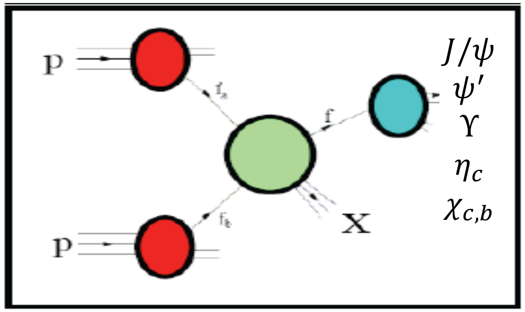


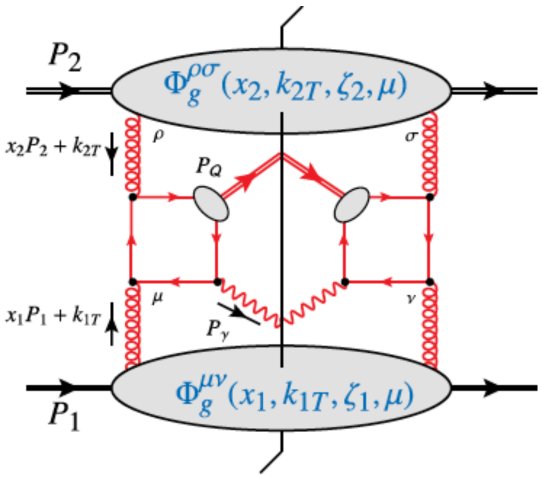
Caveat: TMD factorization requires $p_T(Q) \ll M_Q$. At LHC one can look at **back-to-back production of quarkonia and isolated photon or associate quarkonia production**, e.g.:

$$pp \to J/\psi + \gamma + X \qquad pp \to \Upsilon + \gamma + X \qquad pp \to J/\psi + J/\psi + X$$

where only the relative p_T has to be small. **Might not be necessary at fixed target kinematics!**

Probing the gluon PDFs

[Dunnen et al., PRL 112, 212001]



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Unpol. gluon distrib. funciton (→ f_1^g)

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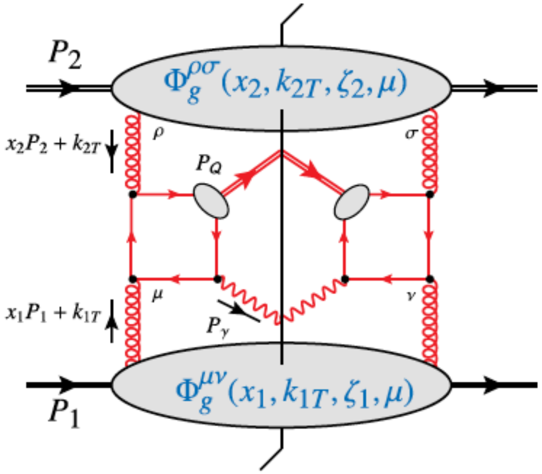

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Linearly pol. gluon distrib. function (requires non-zero gluon p_T)

$$\frac{d\sigma}{dQ\,dY\,d^2\boldsymbol{q}_T\,d\Omega} = \frac{C_0(Q^2 - M_Q^2)}{sQ^3D}\{F_1\mathcal{C}[f_1^g f_1^g] + F_3\cos(2\phi)\times\mathcal{C}[w_3 f_1^g h_1^{\perp g} + x_1\leftrightarrow x_2] + F_4\cos(4\phi)\times\mathcal{C}[w_4 h_1^{\perp g} h_1^{\perp g}]\} + \mathcal{O}\left(\frac{\boldsymbol{q}_T^2}{Q^2}\right)$$

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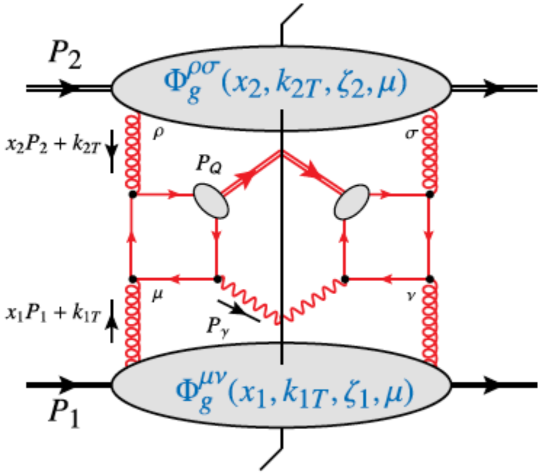

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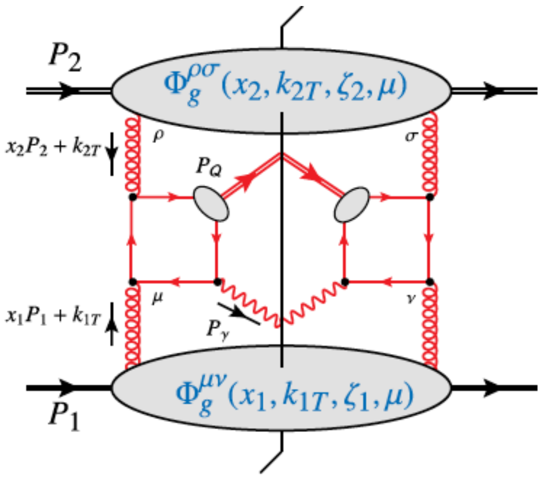

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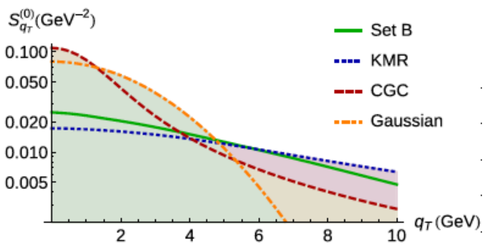
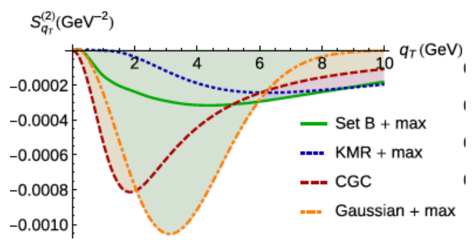
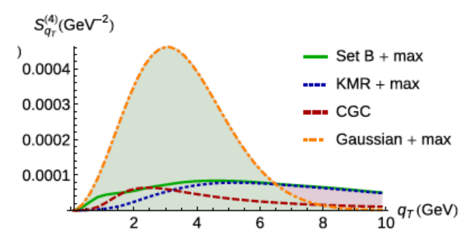
$$S_{q_T}^{(4)} = \frac{F_4\mathcal{C}[w_4 h_1^{\perp g} h_1^{\perp g}]}{2F_1\int d\boldsymbol{q}_T^2\,\mathcal{C}[f_1^g f_1^g]}$$





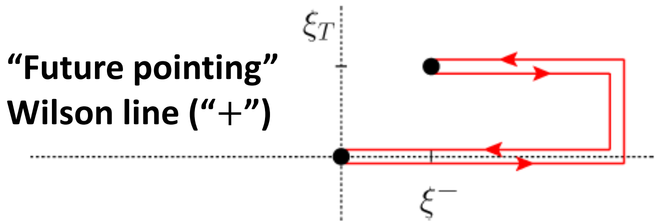


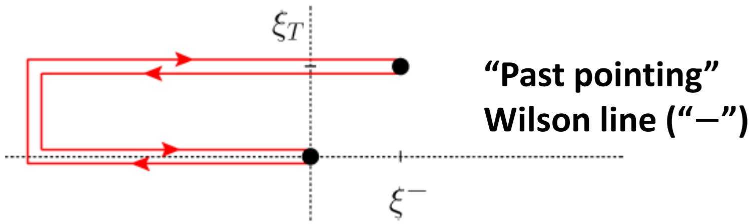
Probing the gluon PDFs

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]

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





Probing the gluon PDFs

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**.

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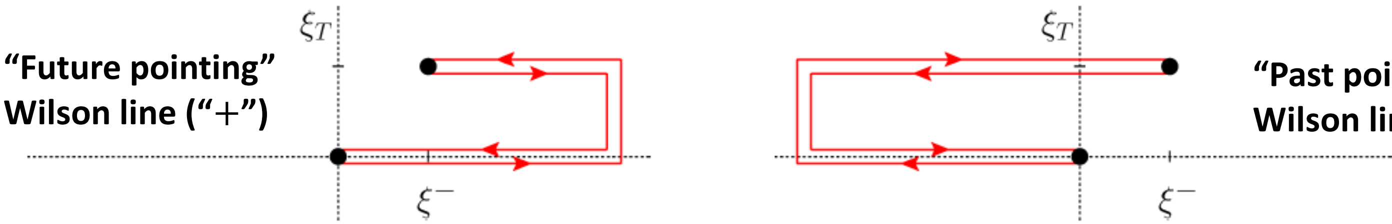
"Future pointing" Wilson line ("+")



"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**

Probing the gluon PDFs

[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)	×	√	×	×	×

(Pink box) Can be measured at the EIC

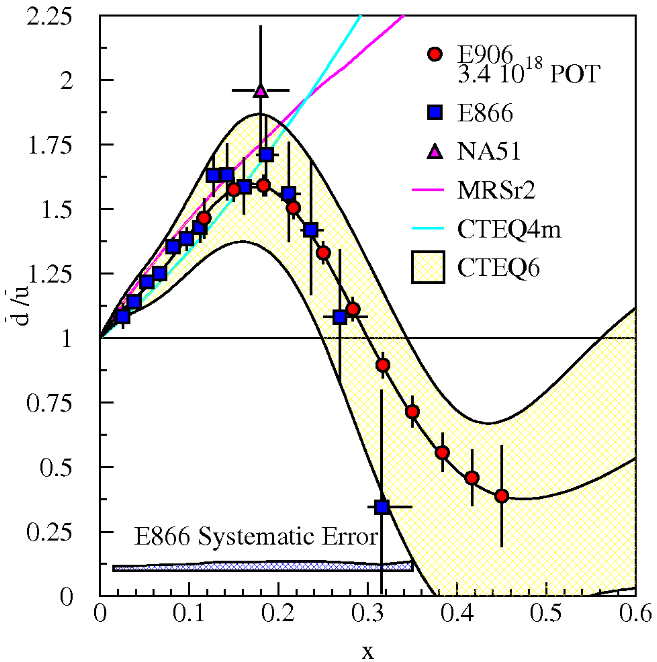
(Blue box) Can be measured at the LHC (and in particular at LHCb with SMOG2)

What about quark PDFs ?

- **Unpolarized Drell-Yan provides sensitivity to unpolarized and BM TMDs up to high x_2**

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

- Allows to study the **antiquark content of the nucleon!**



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

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

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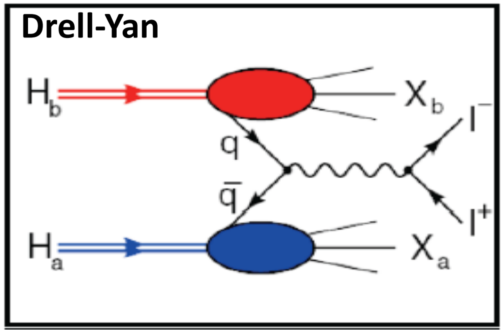
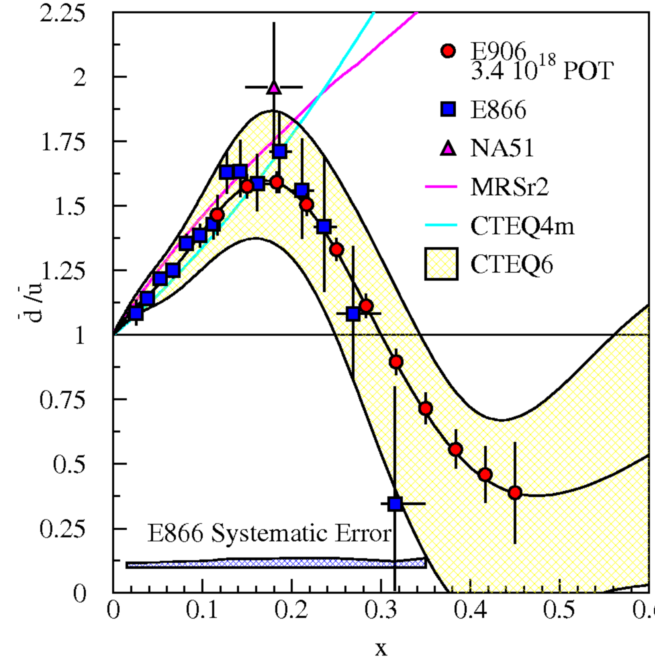


- Clean process
- LHCb has excellent reconstruction capabilities for $\mu\mu$ channel!



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- But also possible: $q(x_{beam}) + \bar{q}(x_{target}) \rightarrow \mu\mu$

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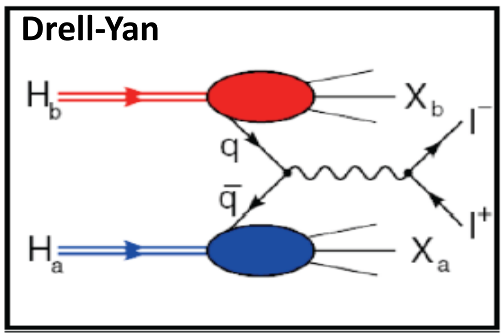

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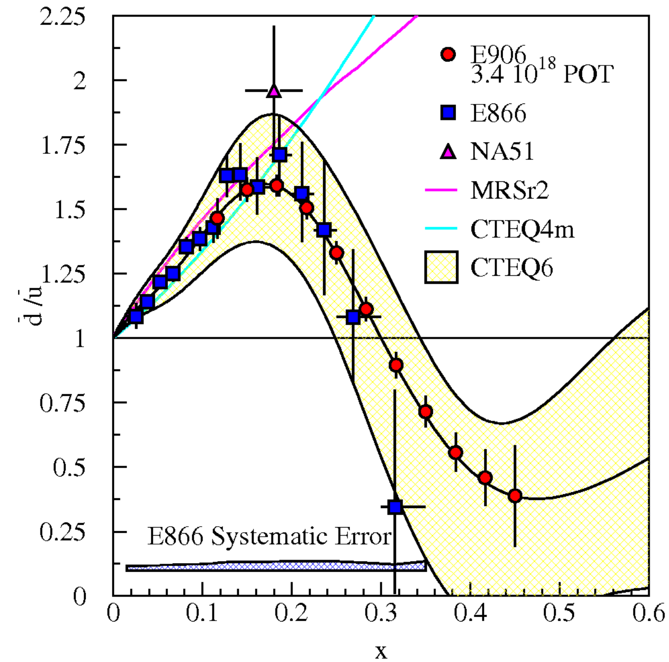

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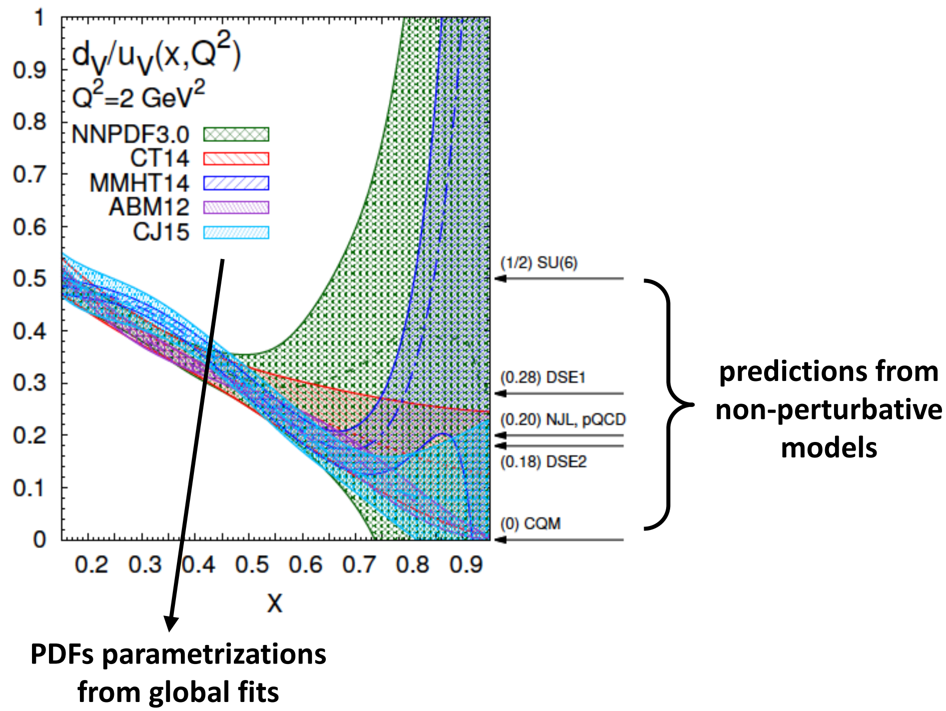
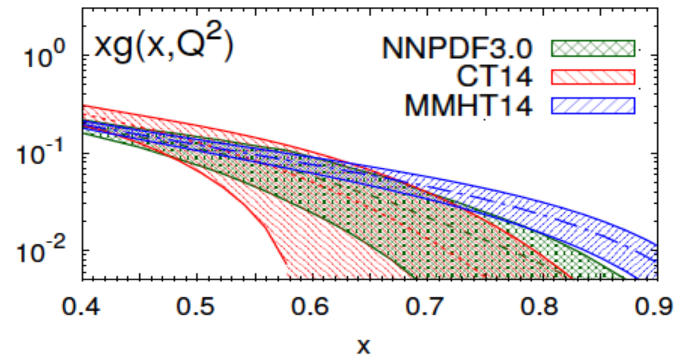
- But also possible: $q(x_{beam}) + \bar{q}(x_{target}) \rightarrow \mu\mu$

- Using fixed H and D targets one can access the **antiquark momentum distributions $\bar{u}(x)$ and $\bar{d}(x)$** (complementing E906 results) and possibly get access to observables sensitive to the BM function of quarks and antiquarks.

The high-x frontier

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





- Huge uncertainties at very large x
- **Quest for data in this x region**

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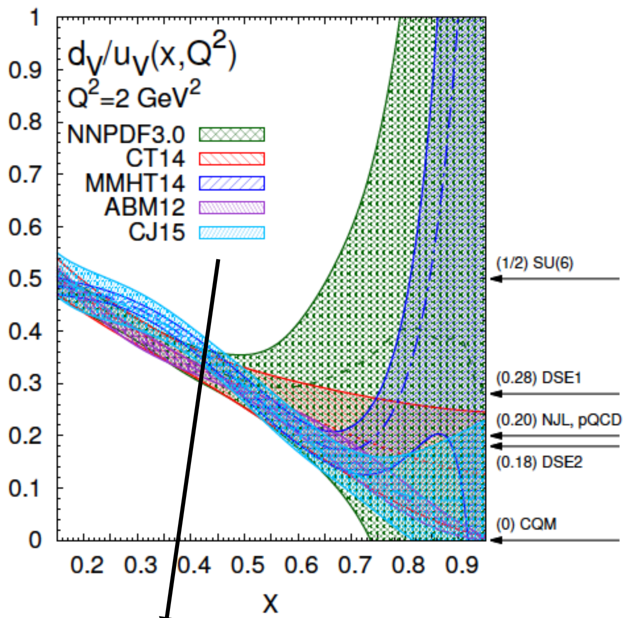
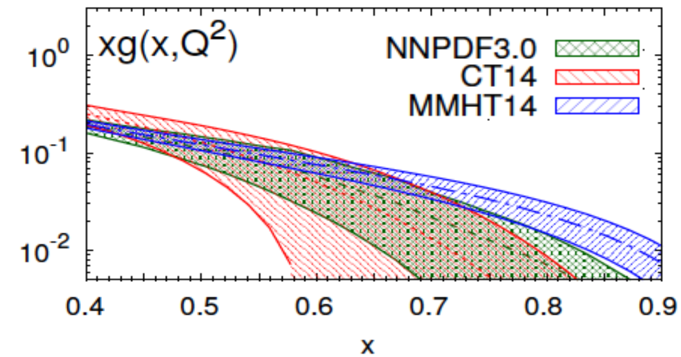
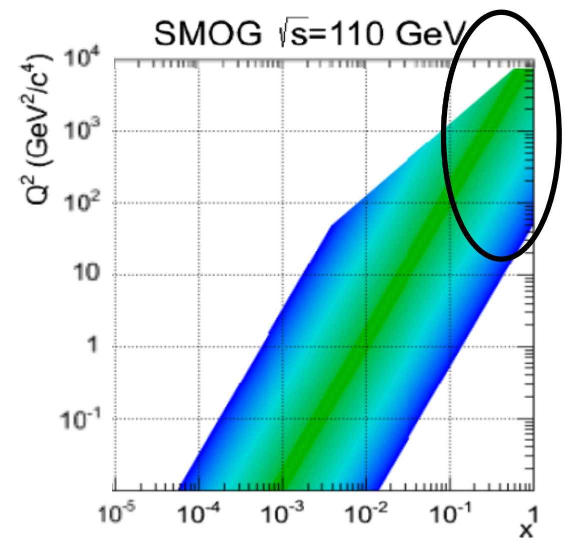


predictions from non-perturbative models

PDFs parametrizations from global fits



- Huge uncertainties at very large x
- **Quest for data in this x region**
- $q(x_{targ})$ **with H and D at SMOG2**



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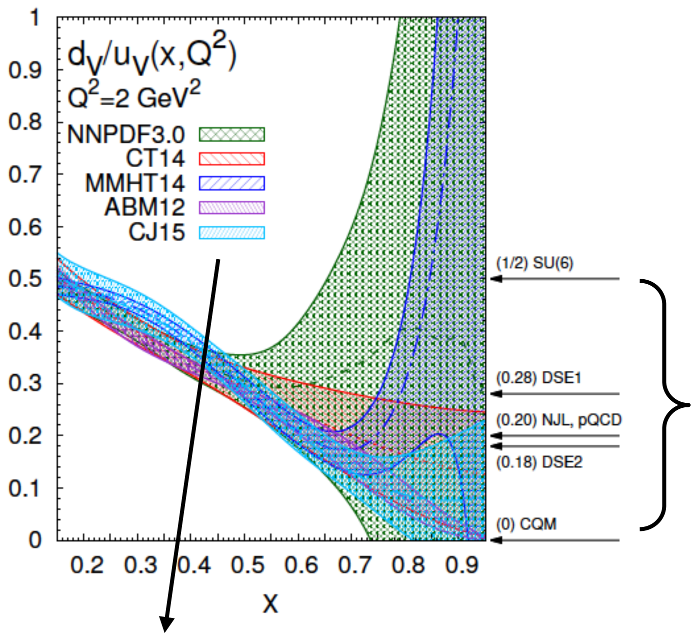

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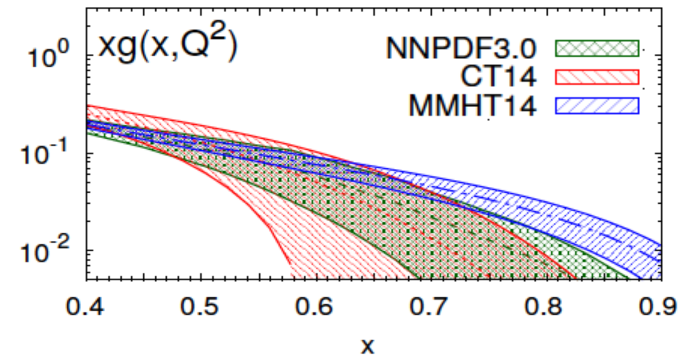
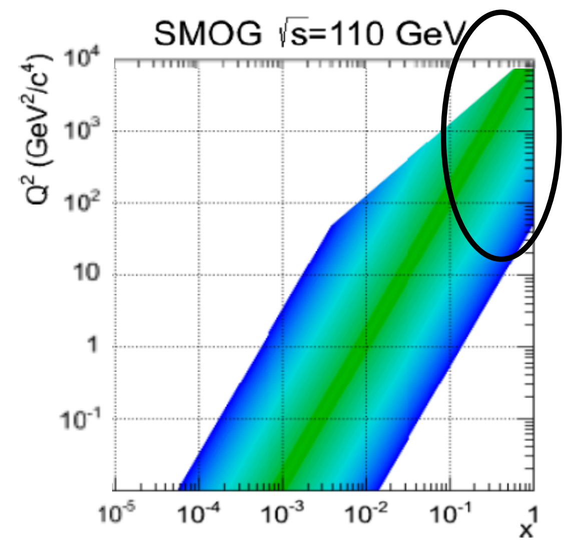


- Huge uncertainties at very large x
- **Quest for data in this x region**
- $q(x_{targ})$ **with H and D at SMOG2**

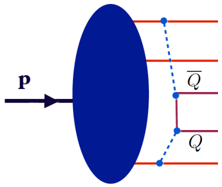
Fermi motion in the nucleus can allow to access the **exotic $x > 1$ region**, where parton dynamics depends on the interaction between the nucleons within the nucleus (**unexplored bridge between QCD and nuclear physics!**)

Can in principle be probed at LHCb with unpolarized nuclear targets (He, O, Ne, Ar, Kr, …)



More physics reach with an unpolarized fixed target

- **Intrinsic heavy-quark** **[S.J. Brodsky et al.,** Adv.High Energy Phys. 2015 (2015) 231547]
  - Recent global QCD analyses supports existence of non-perturbative intrinsic charm
  - 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



- **pA collisions** (using unpolarized noble gas: He, O, Ne, Ar, Kr, Xe)
  - nuclear matter effects on PDFs (**EMC effect**, antishadowing, nuclear shadowing, Fermi motion, etc)
  - studies of parton energy-loss and **jet-quenching** in cold nuclear matter

- **PbA collisions at** $\sqrt{s_{NN}} \approx 72$ **GeV** (using unpolarized noble gas: He, O, Ne, Ar, Kr, Xe)
  - Study of **QGP formation** (quarkonium suppression, jet-quenching in hot nuclear matter)
  - fixed target kinematics allows to study the nucleus remnants in its rest frame (after QGP formation)

- $W^{\pm}$ **boson production near threshold**
  - small cross-section, but yields strongly dependent on quark PDFs at large x
  - search for **heavy partners of the gauge bosons** (predicted by many extensions to SM)

- **Complementary D and B-physics (LHCb mainstream) at fixed target kinematics**

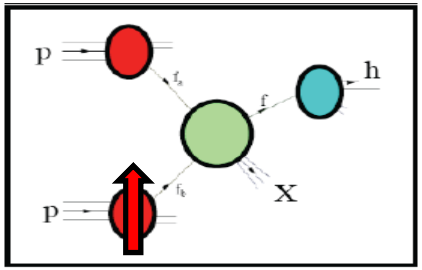
- …

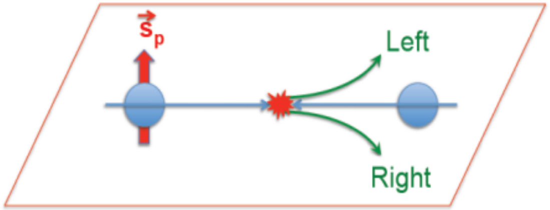
Selected physics opportunities with a **polarized target** @ LHCb (Phase II)

STSAs in pp collisions

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

Polarized inclusive hard scattering





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

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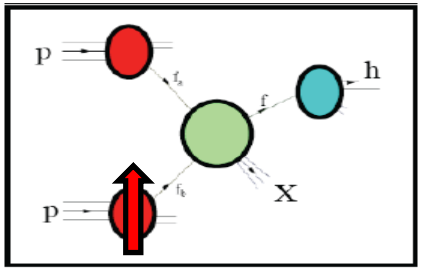
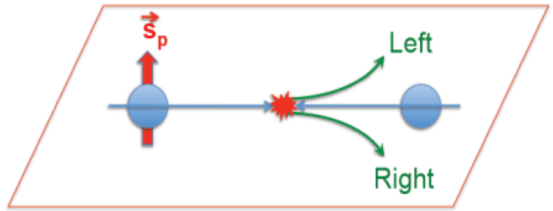
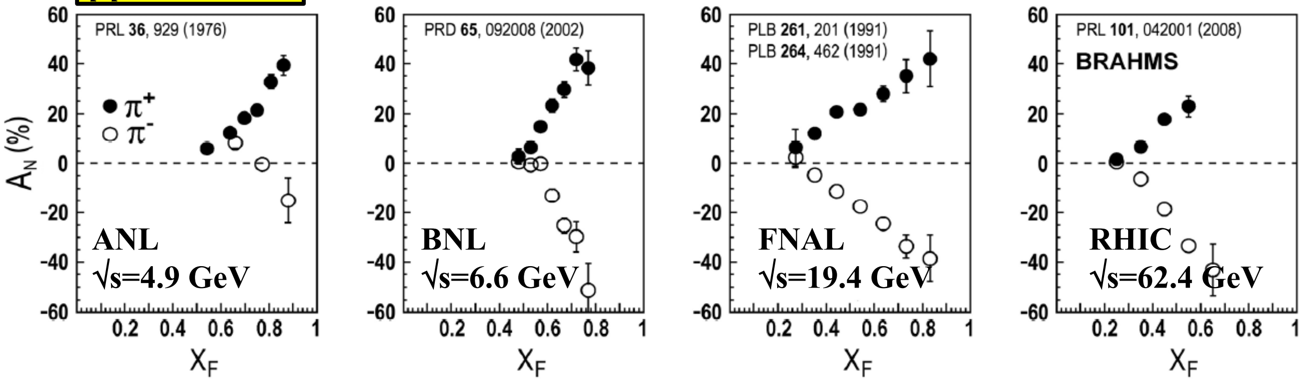


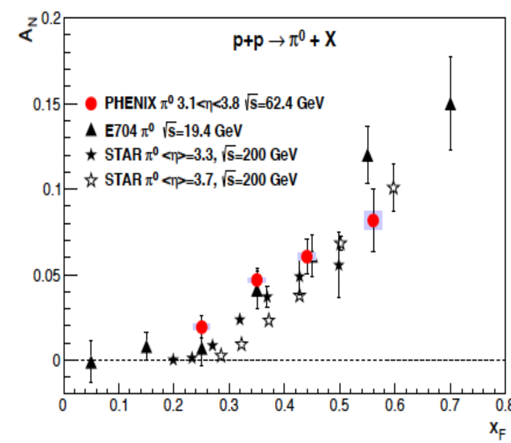


$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow}-\sigma^{\downarrow}}{\sigma^{\uparrow}+\sigma^{\downarrow}} \sim \frac{1}{P}\frac{N_h^{\uparrow}-N_h^{\downarrow}}{N_h^{\uparrow}+N_h^{\downarrow}}$$

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 also for π^0 at high-energies ($\sqrt{s} = 200$ GeV, $p_T > 2$ GeV), where the applicability of pQCD is well established.

STSAs in pp collisions

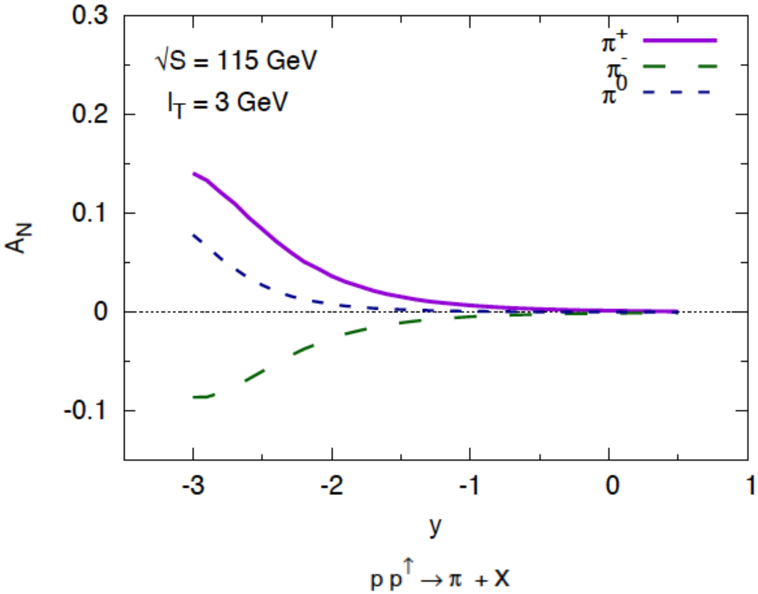
Collinear (twist-3) approach: (Efremov-Taryaev, Qiu-Sterman, Kanazawa-Koike)
- based on collinear QCD factorization (1 hard scale: works for $p_T, Q \gg \Lambda_{QCD}$)
- SSAs arise from interference between partonic amplitudes (3-parton correlators) generated by gluon exchange with IS or FS hadron

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)

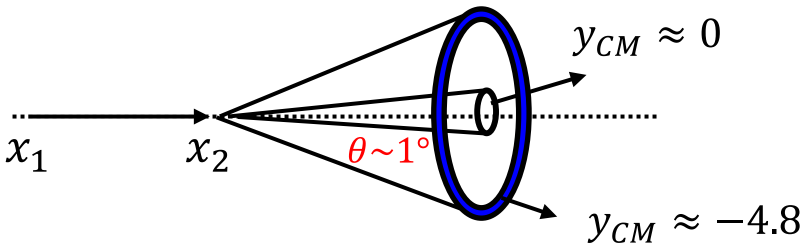
➢ …very little is presently known about **tri-gluon correlation functions** and **polarized gluon TMDs**.

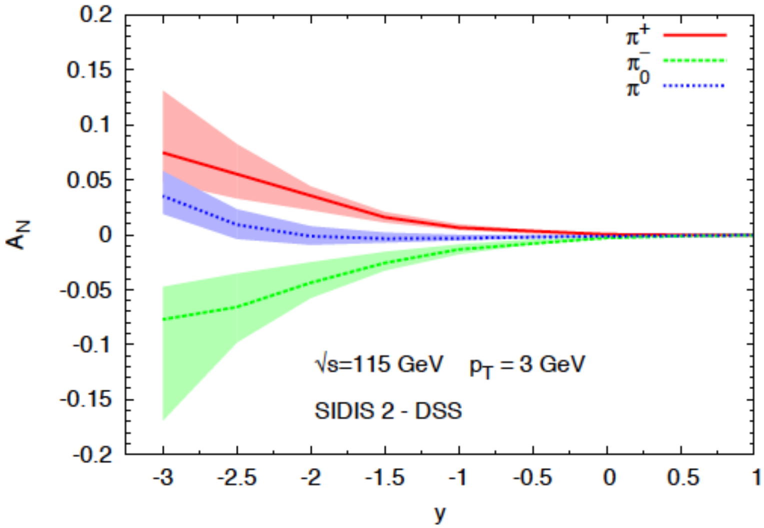
Physics potentiality with a polarized target @LHCb



Collinear (higher-twist) approach:
Kanazawa et al. arXiv:1502.04021v3

- Asymmetries above 10%! Big signature!!
- The effect increases with more negative CM rapidity
- Nicely matches LHCb acceptance with fixed target!



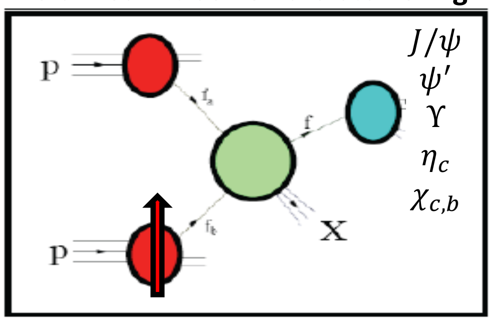


Non-collinear (leading twist) approach:
Anselmino et al. arXiv:1504.03791v2)

Probing the polarized gluon PDFs

Inclusive pion production provides 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:**

Polarized inclusive hard scattering



Hadron		Gluon TMDs		
		Unpol	Circularly pol.	Linearly pol.
Hadron	U	f_1^g		$h_1^{\perp g}$
	L		g_1^g	$h_{1L}^{\perp g}$
	T	$f_{1T}^{\perp g}$	$g_{1T}^{\perp g}$	h_{1T}^g $h_{1T}^{\perp g}$

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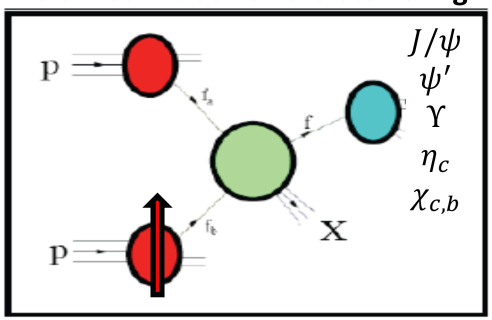

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	L		g_1^g	$h_{1L}^{\perp g}$
	T	$f_{1T}^{\perp g}$	$g_{1T}^{\perp g}$	h_{1T}^g $h_{1T}^{\perp g}$

One main achievement would be accessing the **gluon Sivers function through STSAs:**

- basically unknown!
- shed light on spin-orbit correlations of gluons inside the proton
- sensitive to gluon orbital angular momentum!

The measured STSAs can be related (GPM) to the convolution of the gluon Sivers function for the target proton and the unpolarized gluon pdf for the beam proton:

$$A_N = \frac{1}{P}\frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \sim \frac{1}{P}\frac{N_h^{\uparrow} - N_h^{\downarrow}}{N_h^{\uparrow} + N_h^{\downarrow}} \propto \left[f_{1T}^{\perp g}(x_a, k_{\perp a}) \otimes f_g(x_b, k_{\perp b}) \otimes d\sigma_{gg \to QQg} \right] \sin\phi_S + \cdots$$

Process dependence of the GSF

Two independent gluon Sivers functions can be defined from the different combinations of Wilson lines in the gluon correlator:

$f_{1T}^{\perp g[+,+]}$ (Weizsacker-Williams type or "**f-type**") → antisymmetric colour structures

$f_{1T}^{\perp g[+,-]}$ (Dipole s type or "**d-type**") → symmetric colour structures

Can differ in magnitude and width (!)

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Can be probed by different processes:

[D. Boer: arXiv:1611.06089, D. Boer et al. HEPJ 08 2016 001]

	DY	SIDIS	$p^\uparrow A \to h X$	$p^\uparrow A \to \gamma^{(*)}$ 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)	√	√	√	√	×	×

Can be measured at the EIC

Can be measured at the LHCb with a PGT

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$f_{1T}^{\perp g\,[+,+]}$ (WW)	×	×	×	×	√	√
$f_{1T}^{\perp g\,[+,-]}$ (DP)	√	√	√	√	×	×

Can be measured at the EIC

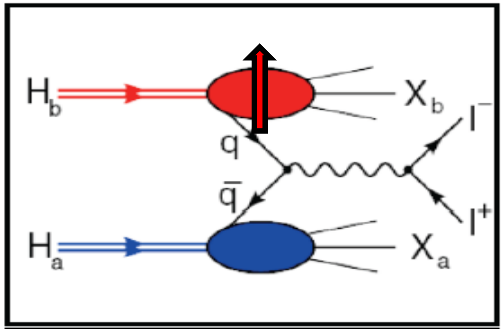
Can be measured at the LHCb with a PGT

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

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

What about quark TMDs ?

Polarized Drell-Yan



- **Sensitive to 5 quark TMDs up to high $x_2^{\uparrow}$!**
  (ϕ: azimuthal orientation of lepton pair in dilepton CM)

$$\sigma_{TU} \propto f_{1T}^{\perp} f_1 + \sin 2\phi \, h_1 h_1^{\perp} + \sin 2\phi \, h_{1T}^{\perp} h_1^{\perp}$$

Sivers function

Momentum distribution

Boer-Mulders function

Transversity function

"pretzelosity" function

Main reactions or interest

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

☛ **Pol and unpol gluon PDFs**

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

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

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

☛ **TMDs of valence and sea quarks**

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

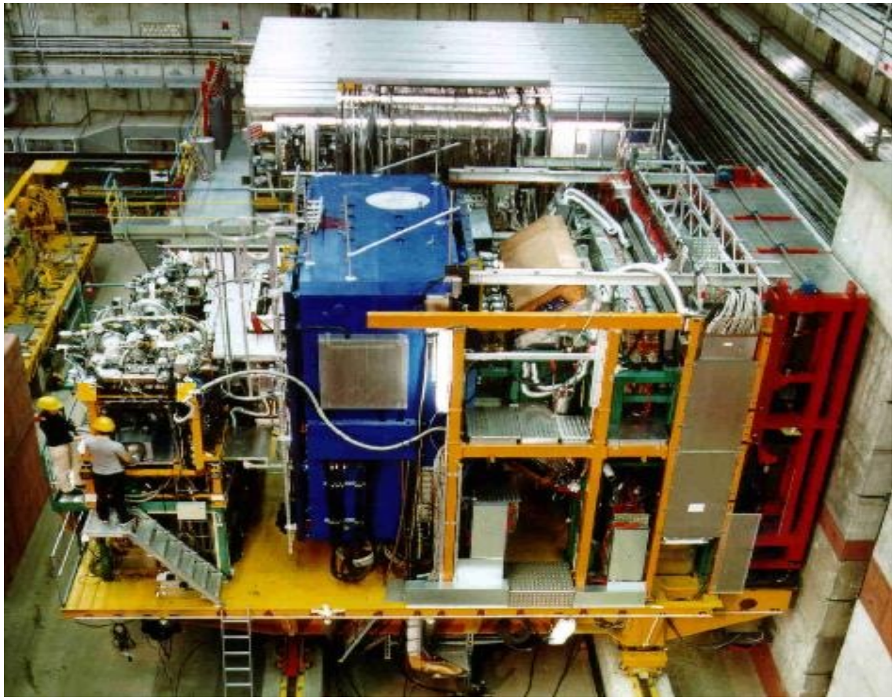
☛ **Nuclear matter effects, QGP, etc**

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

The polarized target Setup

The Hermes target

HERMES

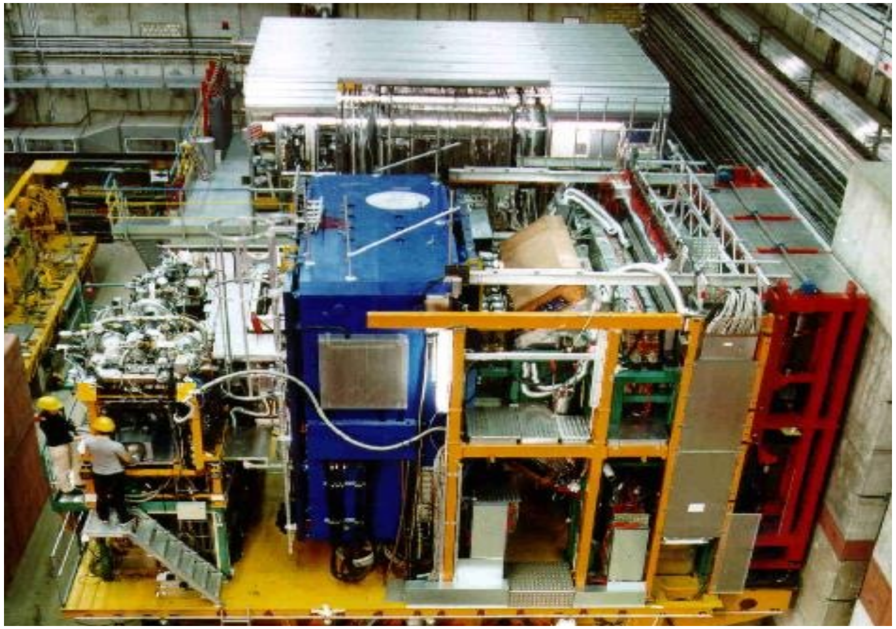


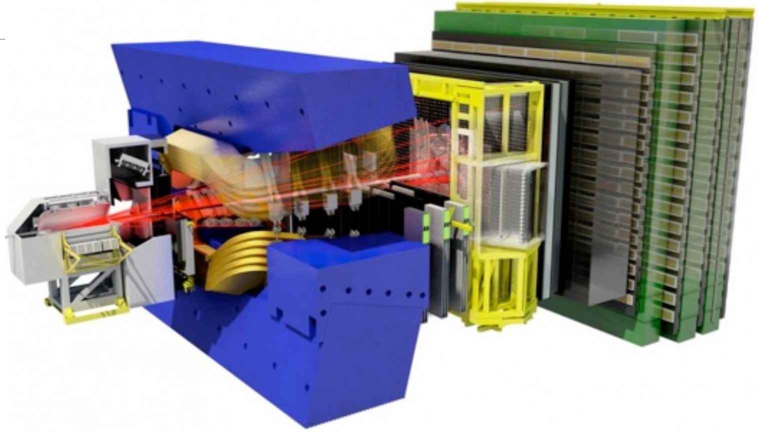
A conventional fixed target **forward spectrometer** at HERA:

- -Gas target
- -Silicon vertex
- -Tracking chambers
- -Dipole
- -Tracking chambers
- -RICH
- -Tracking chambers
- -Preshower
- -Calorimeter
- -Muon tracker

The Hermes target

HERMES





A conventional fixed target **forward spectrometer** at HERA:

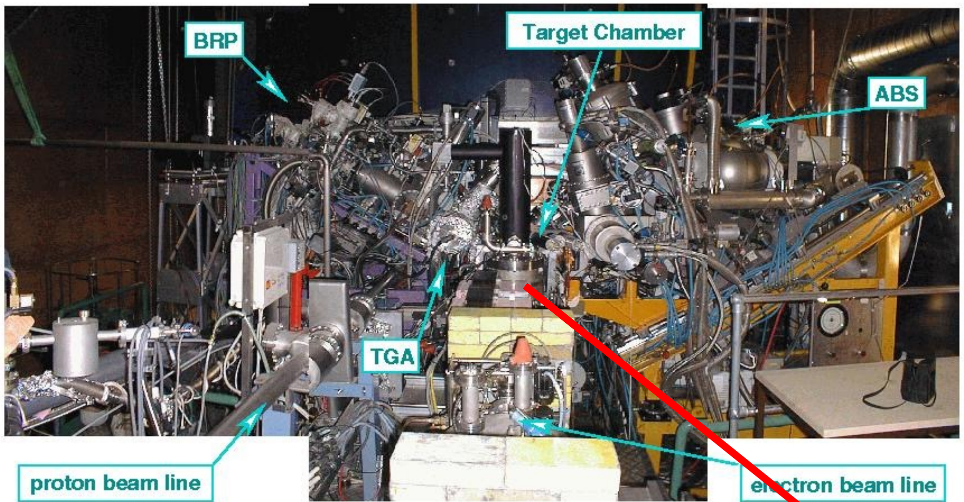
- -Gas target
- -Silicon vertex
- -Tracking chambers
- -Dipole
- -Tracking chambers
- -RICH
- -Tracking chambers
- -Preshower
- -Calorimeter
- -Muon tracker

... a mini LHCb

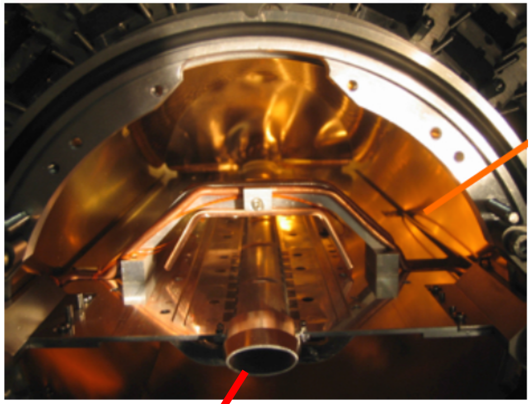
The Hermes target

Polarimeter

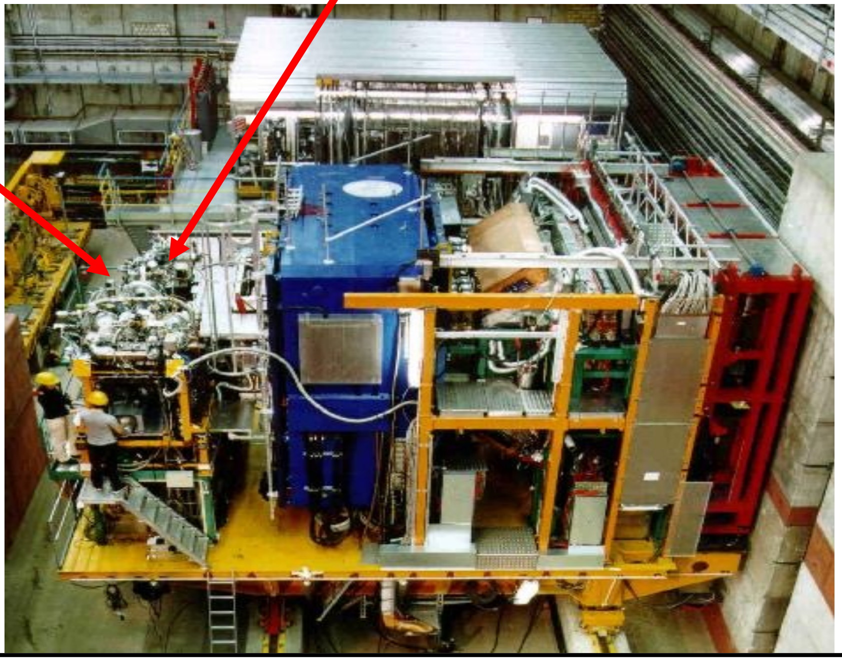
Atomic Source

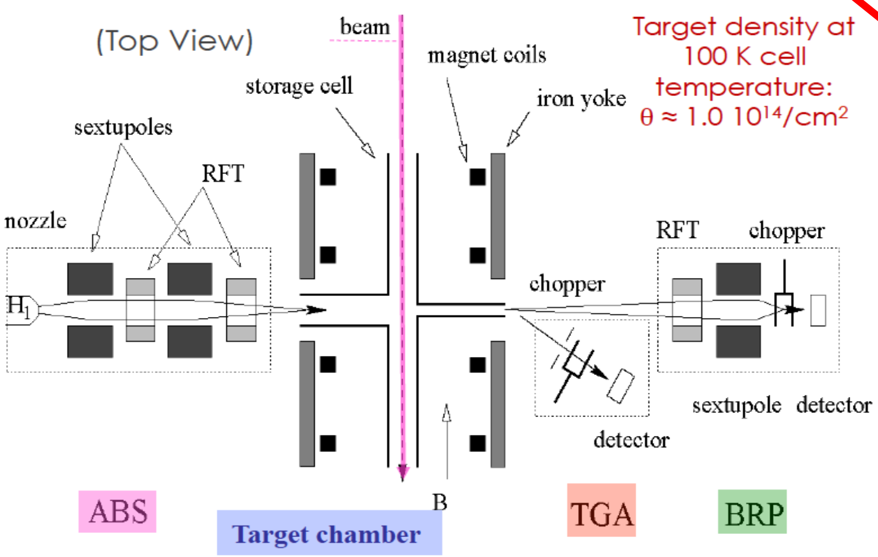


storage cell



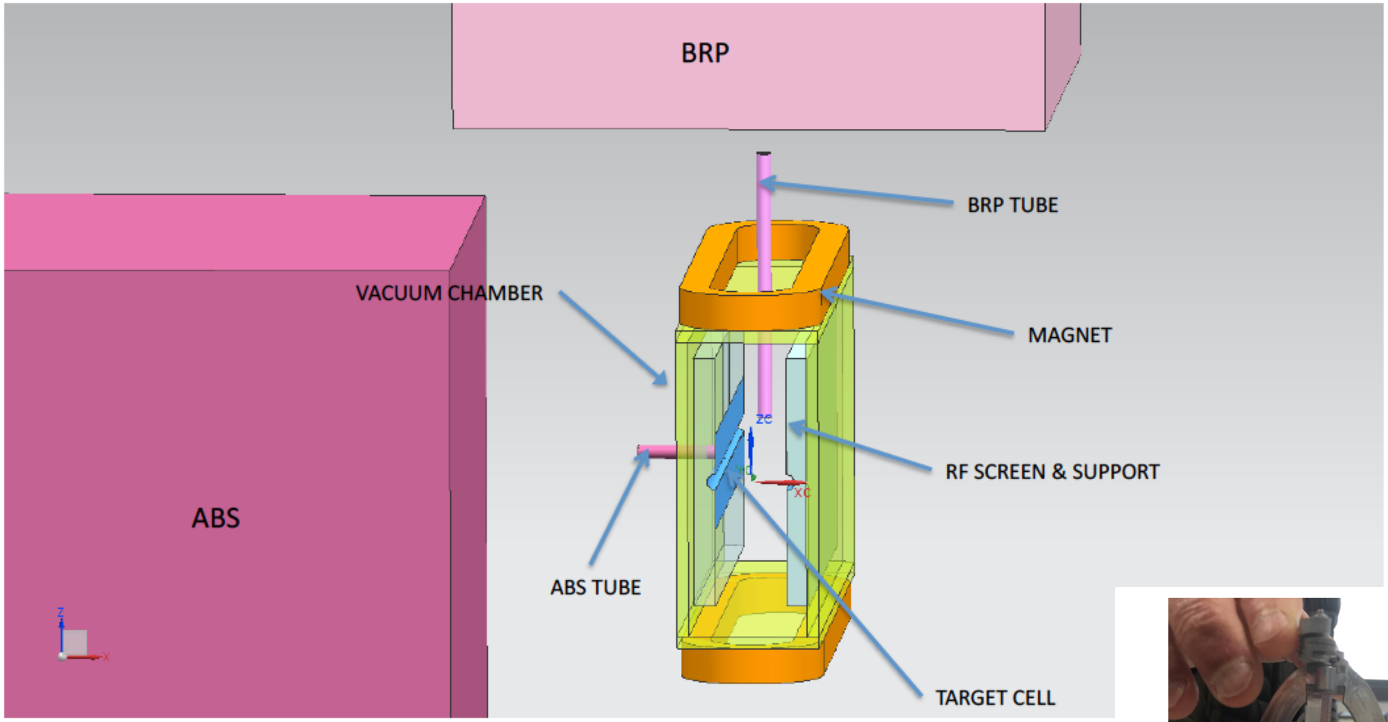
HERMES (HERA)

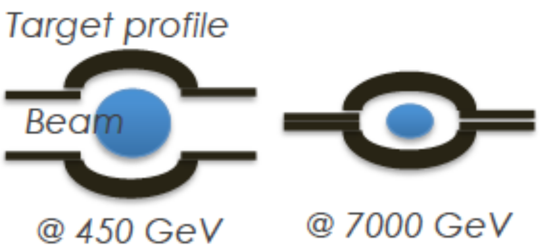


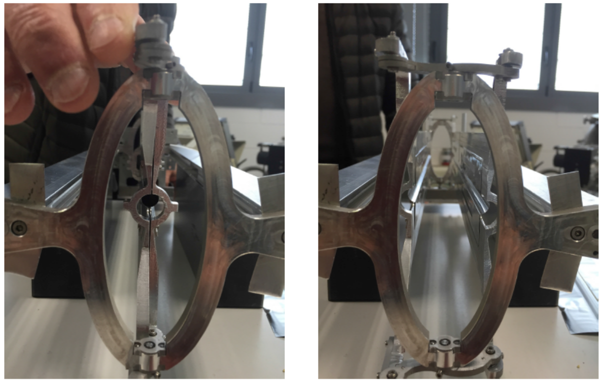


A new design for a compact polarized gas target

Draft-0 of the target 3D model

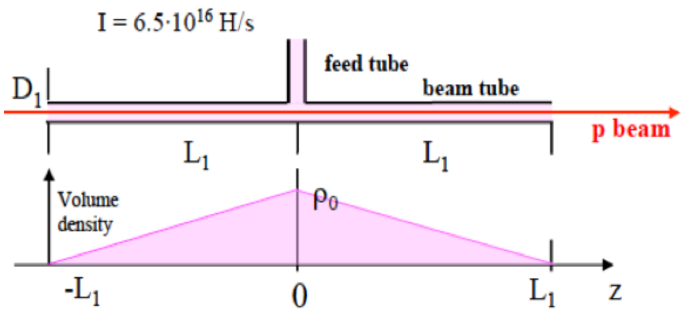






R&D already on going following the VELO drawings for the movement

Expected performance for the PGT



- T-shaped target cell: D=1cm, L=30cm
- Polarized beam of H(D)-atoms injected ballistic via Feed Tube into cell center
- Injected intensity I_0 of H-atoms = 6.5 10^{16} atoms/s
- Gas density in the cell has triangular shape
- Polarized atoms diffuse outwards to the 3 tube openings

- 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 liter/s $\sqrt{(T \cdot M)}$ D^3/ (L + 1.33D)

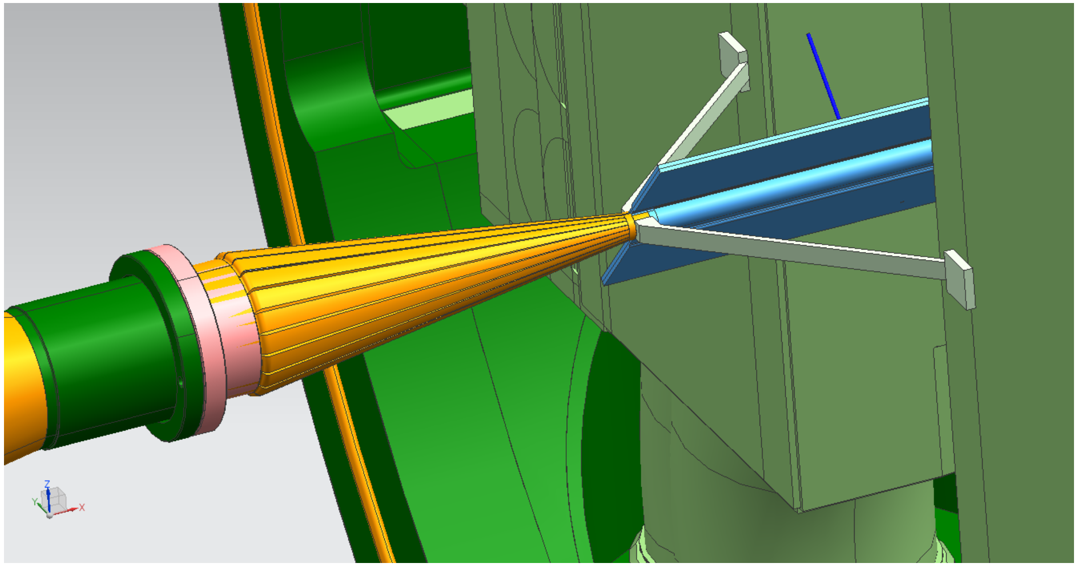
$$I_{beam} = N_{p/bunch} \cdot N_{bunch} \cdot f_{rev} = 1 \cdot 10^{11} \cdot 2800 \cdot 11245\ Hz = 3.15 \cdot 10^{18}\ s^{-1}$$

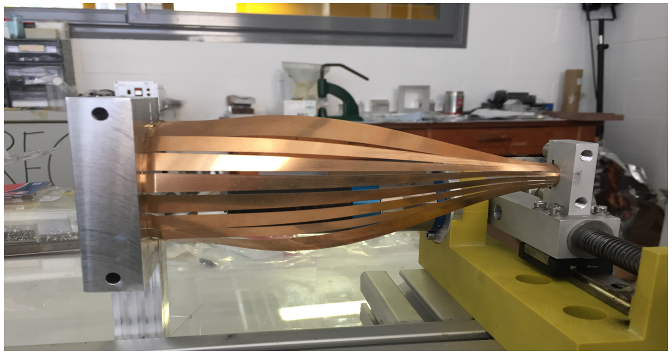
$I_0 = 6.5 \cdot 10^{16} s^{-1}$ **C_{tot} = 13.90 l/s** **ρ_0 = 4.68 ·10^{12}/cm³** **θ= 7.02 ·10^{13}/cm²**

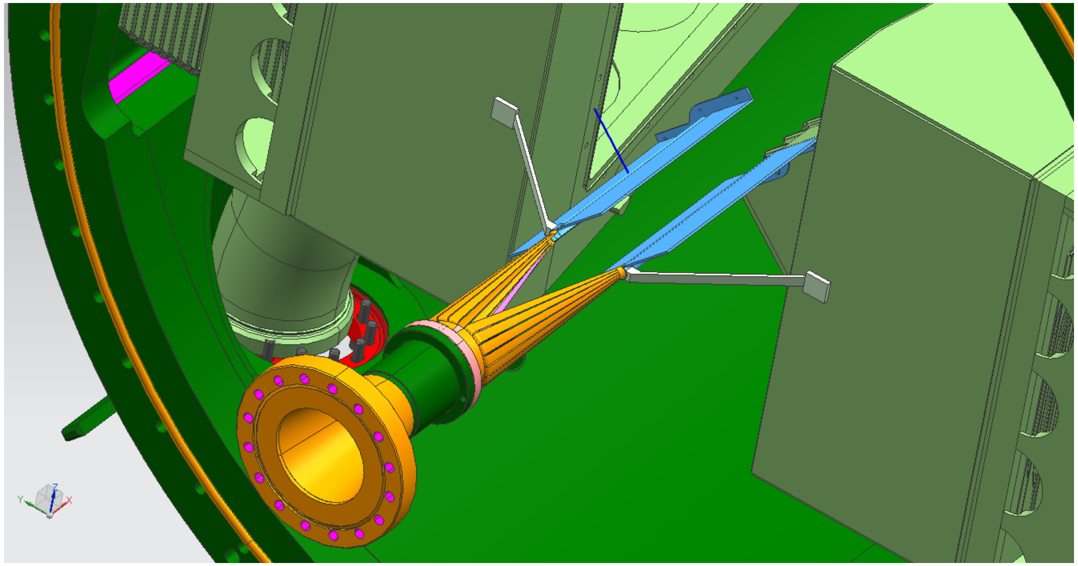
$$L(T_{cell} = 300K) = I_{beam} \cdot \theta = 3.15 \cdot 10^{18} s^{-1} \cdot 7.02 \cdot 10^{13} cm^{-2} = 2.2 \cdot 10^{32} cm^{-2} s^{-1}$$

- 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!

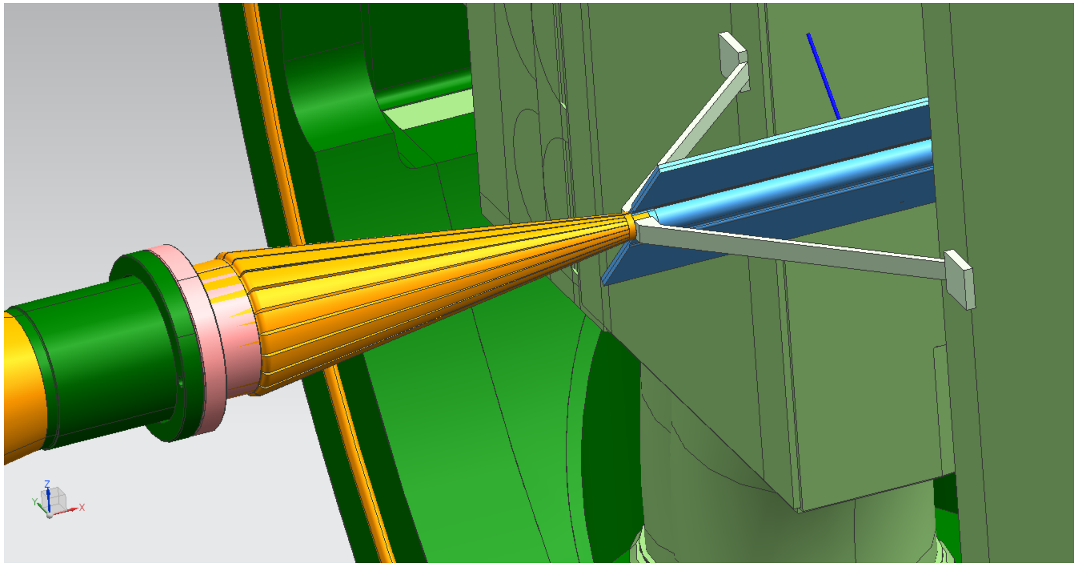
SMOG2 (design and construction in Ferrara)

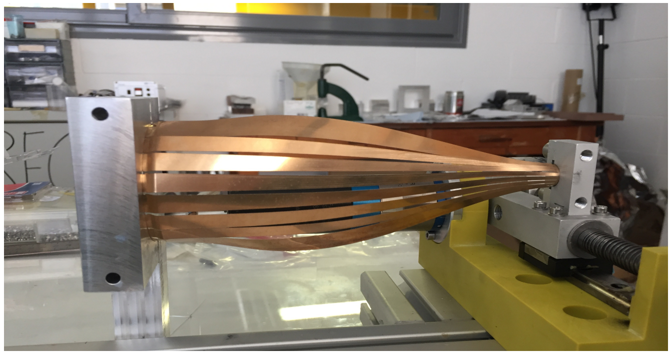


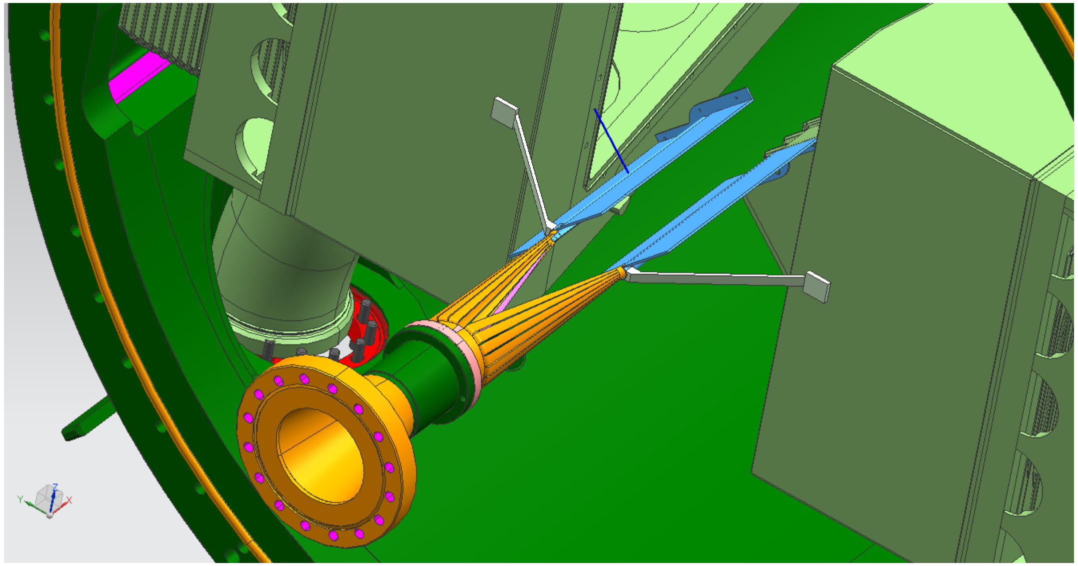




SMOG2 (design and construction in Ferrara)







- **Substantial increase of areal density** (w.r.t. SMOG) seen by the beam (at least 1 order of magnitude more!) keeping the same pressure in the VELO beam vacuum ($\sim 10^{-7}$ mbar)
- Preliminary MC simulations show **very similar reconstruction efficiencies** w.r.t SMOG!
- Even assuming slightly smaller efficiencies for SMOG2, this will be largely compensated by significant increase of the gas density resulting in a **significant overall increase of the performances of the LHCb unpol. fixed-target system**.

Conclusions

- A polarized fixed target at LHC will provide unique kinematic conditions for a broad and ambitious physics program!
- The **LHCb** spectrometer is perfectly suitable to host the target, ensuring high luminosity, excellent tracking and PID performances!
- The LHCSpin project is being taken into serious consideration by the LHCb Collaboration and LHC machine experts!
- A review process has been initiated inside the LHCb Collaboration
- Phase I of the project (SMOG2) is very likely to be approved in 2018!

Conclusions

- A polarized fixed target at LHC will provide unique kinematic conditions for a broad and ambitious physics program!
- The **LHCb** spectrometer is perfectly suitable to host the target, ensuring high luminosity, excellent tracking and PID performances!
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We are working to bring spin physics at the most powerful particle accelerator!

Anyone interested to contribute to this fascinating challenge is more than welcome!!

We look forward to see you in Ferrara next year!

http://spin2018.unife.it/home/

Backup

A couple of words on the proponents

Referent Persons

Physics Case
Pasquale Di Nezza
(LHCb Frascati)

Experimental Implementation
Paolo Lenisa
(INFN, Univ.Ferrara)

Study Group

- Polarised Target and Polarimeter

E.Steffens (Univ.Erlangen), A.Nass (Juelich), G.Ciullo (Ferrara)

- Target holding field and depolarisation studies

M.Statera (Milano), D.Reggiani (PSI)

- Openable storage cell design

V.Carassiti (Ferrara)

- MC Simulations

L.Pappalardo (Ferrara)

- Accelerator related issues

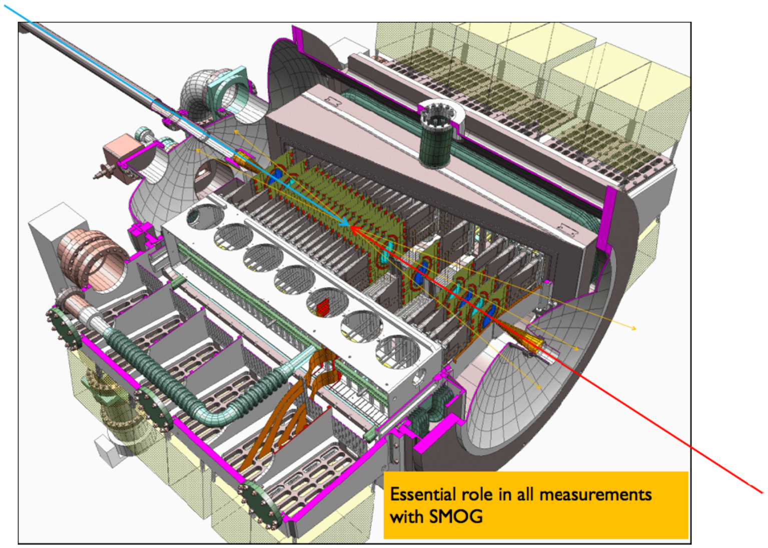
F.Rathmann (Juelich), B.Lorentz (Juelich)

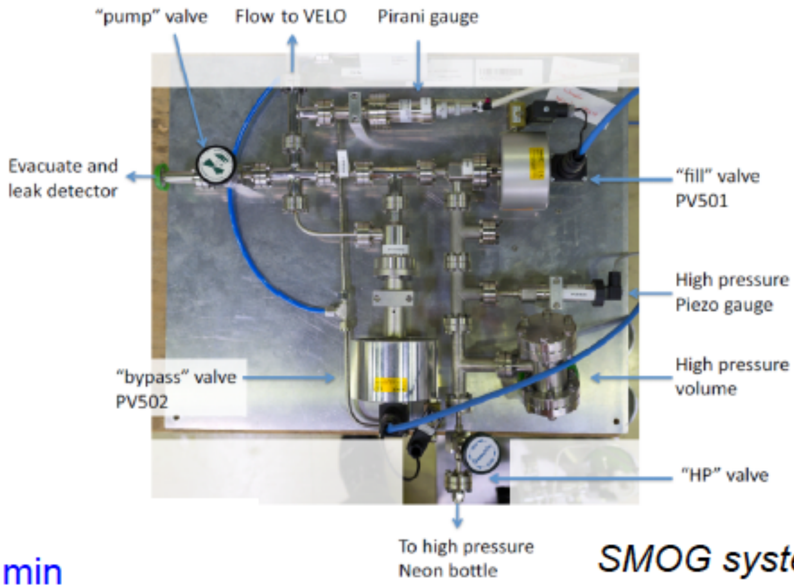
LHCSpin Time Schedule

TASKS	Periods			
	1st year	2nd year	3rd year	4th year
1.1 Design and construction of the openable cell				
1.2 Design and construction of the WFS				
1.3 Modification of the existing LHCb gas feed system				
1.4 Implementation of the unpol target into the LHC vacuum chamber				
1.5 Data collection and analysis				
2.1 Modification of existing ABS, BRP and TGA				
2.2 Design and construction of the PGT vacuum chamber				
2.3 R&D and cell coating				
2.4 Stand alone tests on polarisation and dissociation				
2.5 Beam tests at SPS				
3.1 Simulations for tracking reconstruction into LHCb				
3.2 Trigger development and implementation into LHCb software				
3.3 MC generation of the physics channels				
3.4 Slow Control and Data acquisition implementation				
	LHC Run 2	LHC Long Shutdown 2		LHC Run 3

SMOG: the present unpolarized fixed target experiment @ LHCb

→ SMOG: System for Measuring Overlap with Gas:
- Main use so far for precise **luminosity determination**
- Low density noble gas injected in the VELO, in the interaction region
- Only local temporary degradation of LHC vacuum





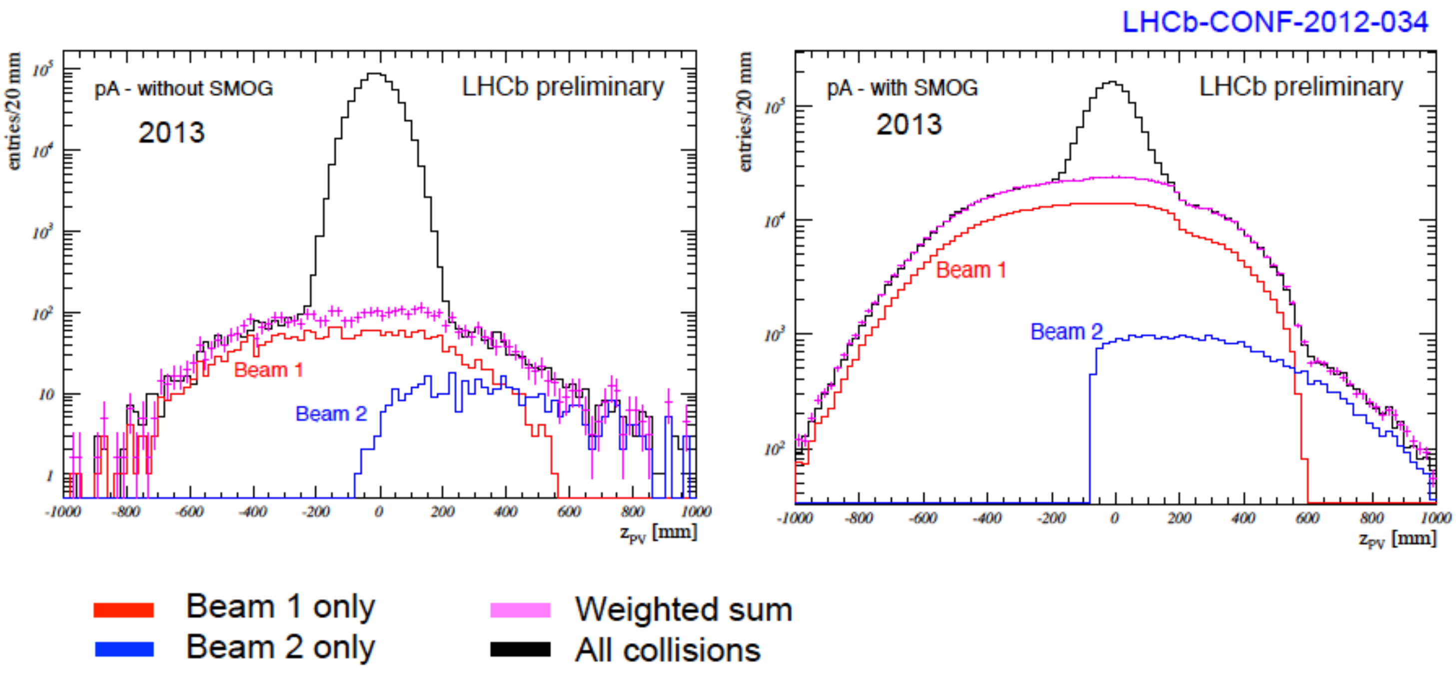
SMOG system

- pNe pilot run at $\sqrt{s_{NN}}$ = 87 GeV (2012) ~ 30 min
- PbNe pilot run at $\sqrt{s_{NN}}$ = 54 GeV (2013) ~ 30min
- pNe run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 12h
- pHe run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 8h
- pAr run at $\sqrt{s_{NN}}$ = 110 GeV (2015) ~ 3 days
- pAr run at $\sqrt{s_{NN}}$ = 69 GeV (2015) ~ few hours
- PbAr run at $\sqrt{s_{NN}}$ = 69 GeV (2015) ~ 1.5 week
- pHe run at $\sqrt{s_{NN}}$ = 110 GeV (2016) ~ 2 days

Preferred target Gas

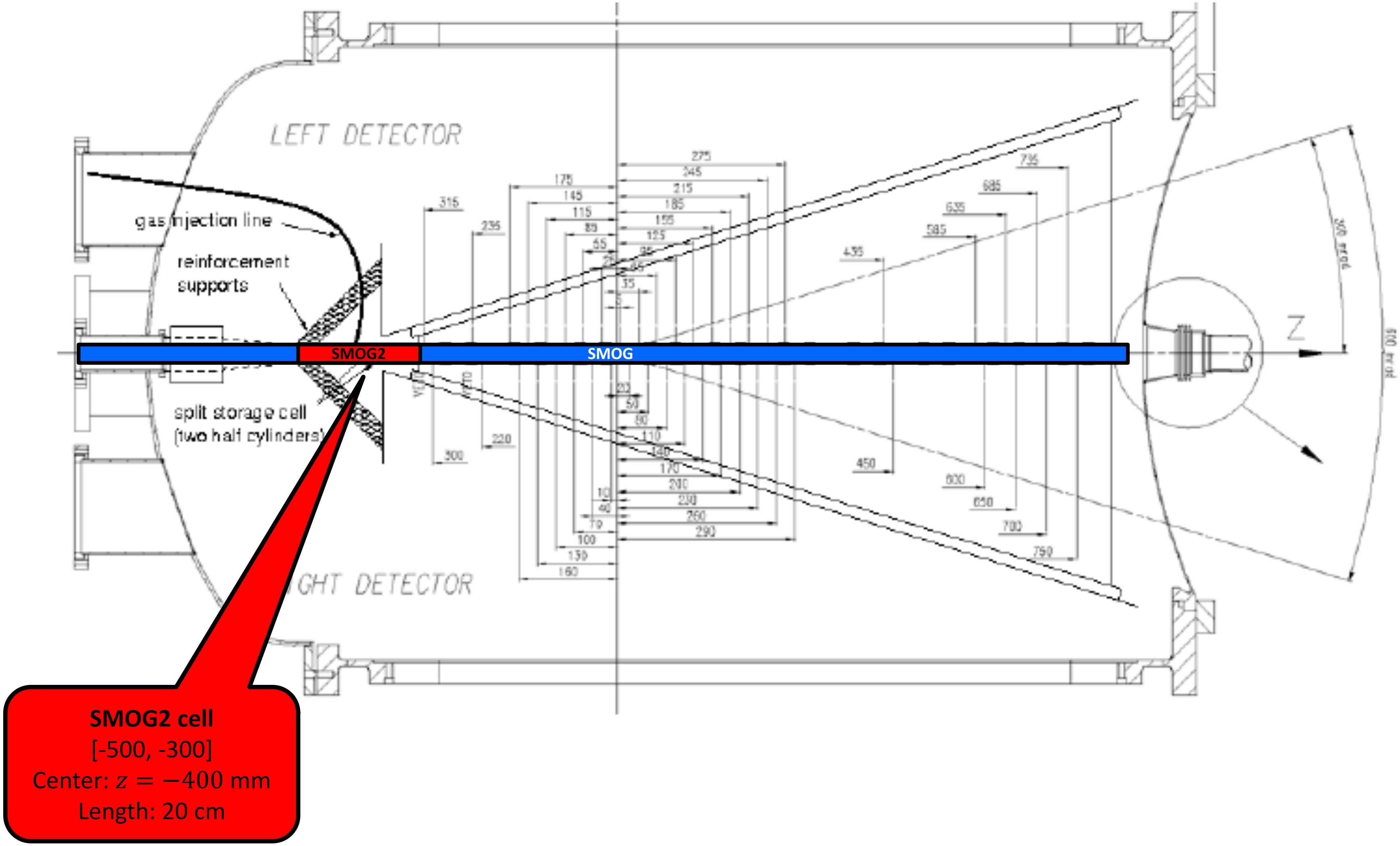
	He	Ne	Ar	Kr	Xe
A	4	20	40	84	131

SMOG: the present unpolarized fixed target experiment @ LHCb



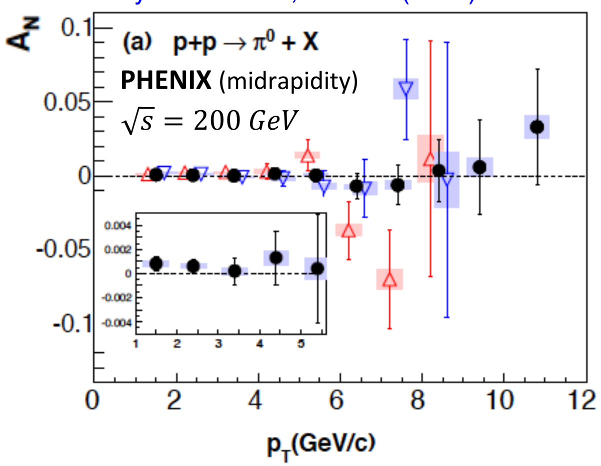
- Gas pressure ($\sim 10^{-7} mbar$) is 2 orders of magnitude larger than LHC vacuum pressure
- SMOG increases the beam-gas collision rate by 2 orders of magnitude
- Precise vertexing (and LHC filling scheme) allows to separate beam-beam and beam-gas contributions → **Fixed target collisions can be isolated from regular collider collisions**

SMOG2

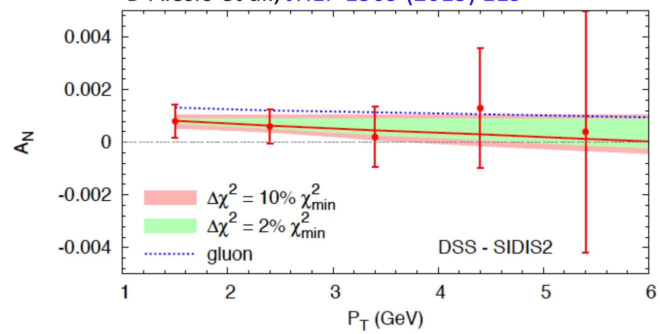

LEFT DETECTOR
gas injection line
reinforcement supports
SMOG2
SMOG
split storage cell (two half cylinders)
GHT DETECTOR
Z
SMOG2 cell
[-500, -300]
Center: $z = -400$ mm
Length: 20 cm

Probing the GSF (from RHIC data)

Phys. Rev. D 90, 012006 (2014)

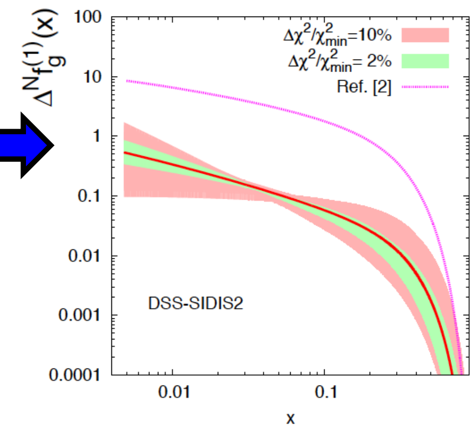


D'Alesio et al., JHEP 1509 (2015) 119

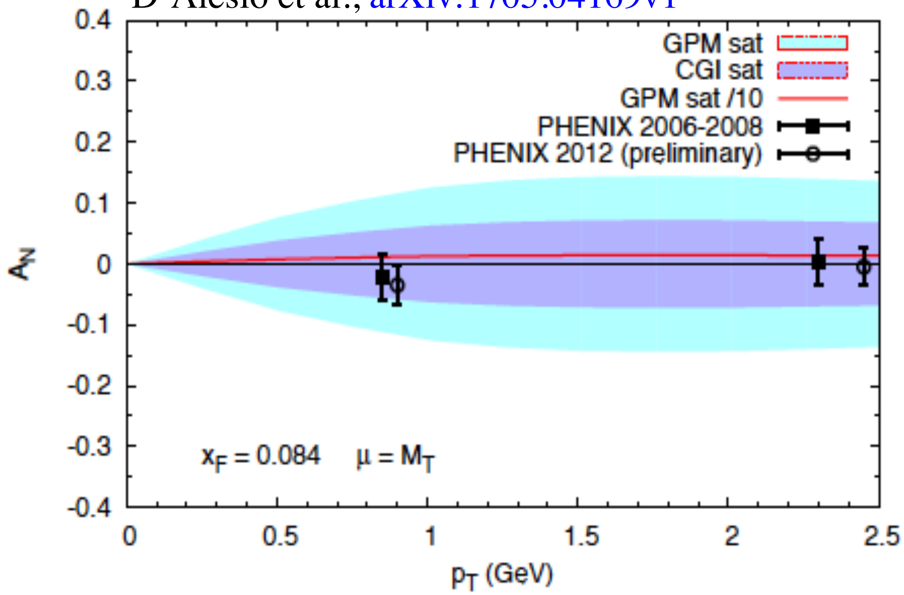


A_N estimate in the frame of GPM, based on param. from SIDIS data + FFs from DSS

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



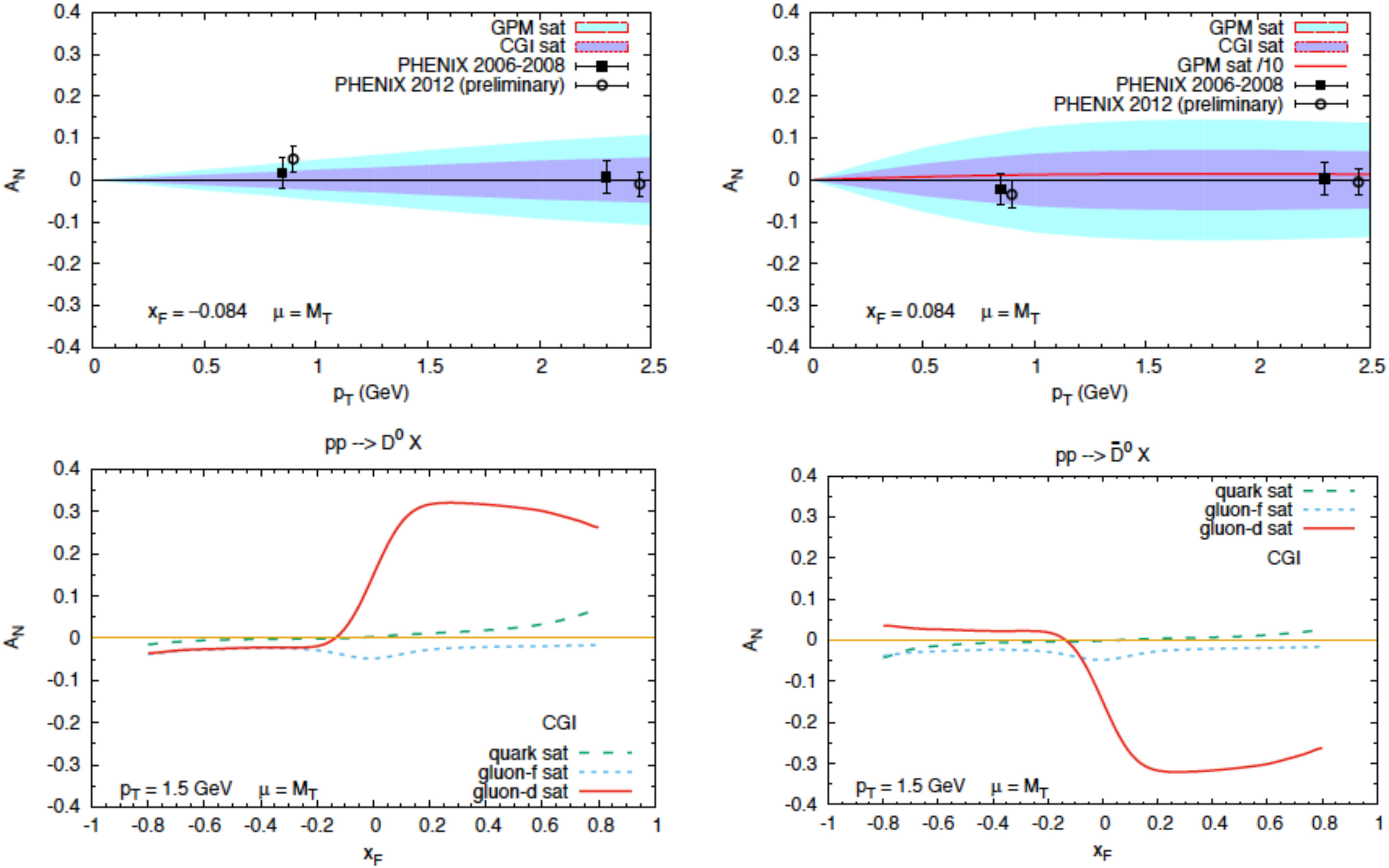
D'Alesio et al., arXiv:1705.04169v1



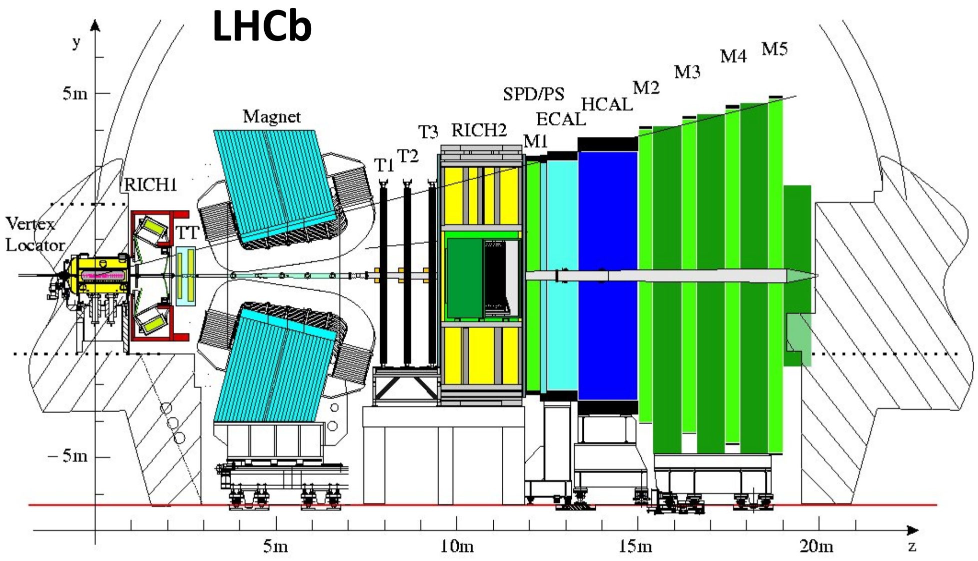
- **Existing quarkonia results only from PHENIX**
- First measurement of A_N for $pp^{\uparrow} \rightarrow J/\psi X$
- Sensitive to f-type gluon Sivers funciton
- A very recent prediction of A_N from Color-Gauge Invariant GPM **(CGI-GPM)**: takes into account the process dependence of the GSF

Probing the gluon PDFs (from RHIC data)

D'Alesio et al., arXiv:1705.04169v1

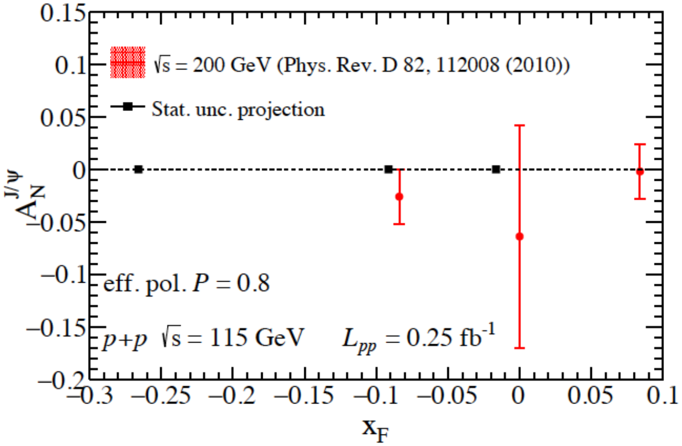


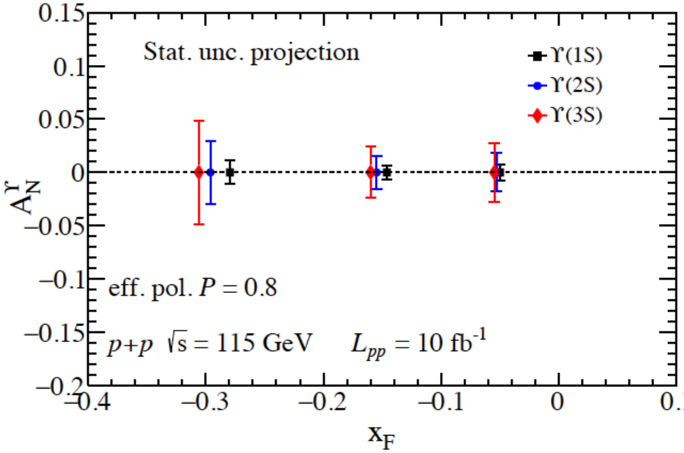
Probing the gluon PDFs at LHCb

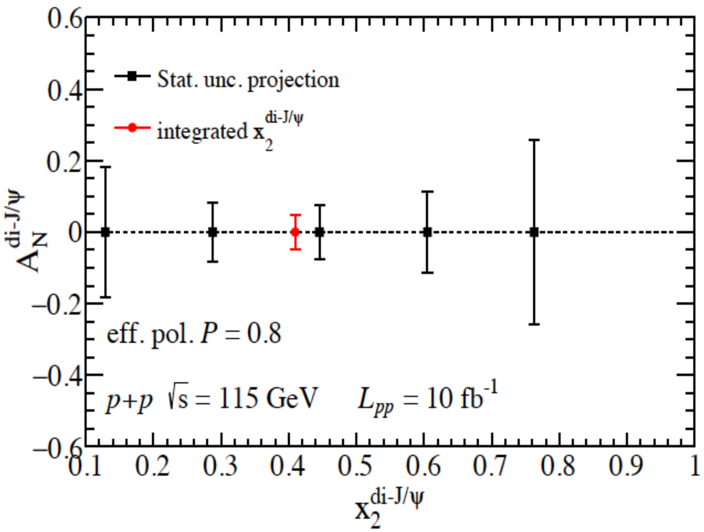


- LHCb can measure nearly all quarkonia states (including C-even η_c, χ_c, χ_b) and D mesons with high precision!
- Υ-mesons is a unique observable, poorly accessible from other hadron-hadron experiments

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







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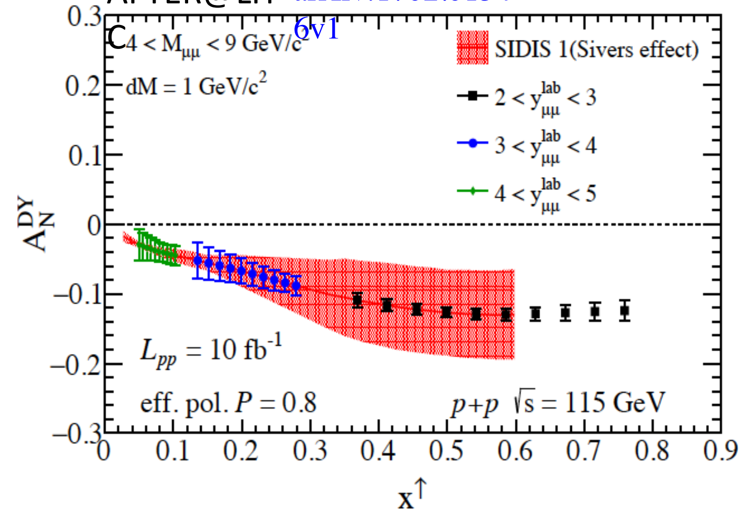
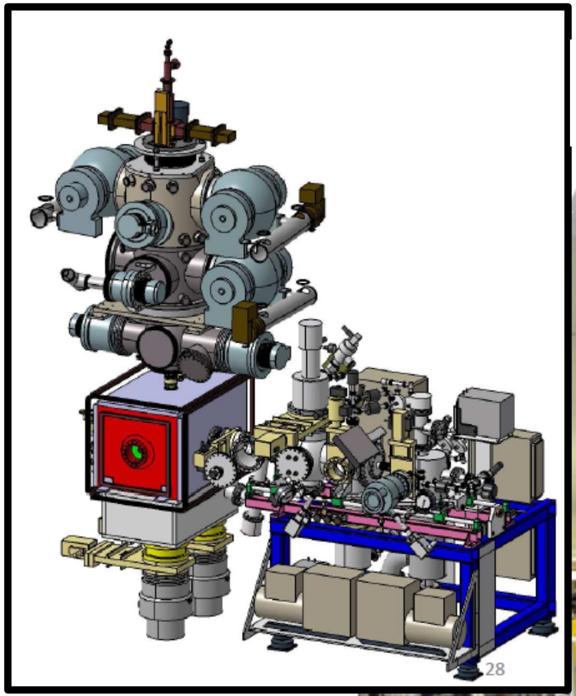
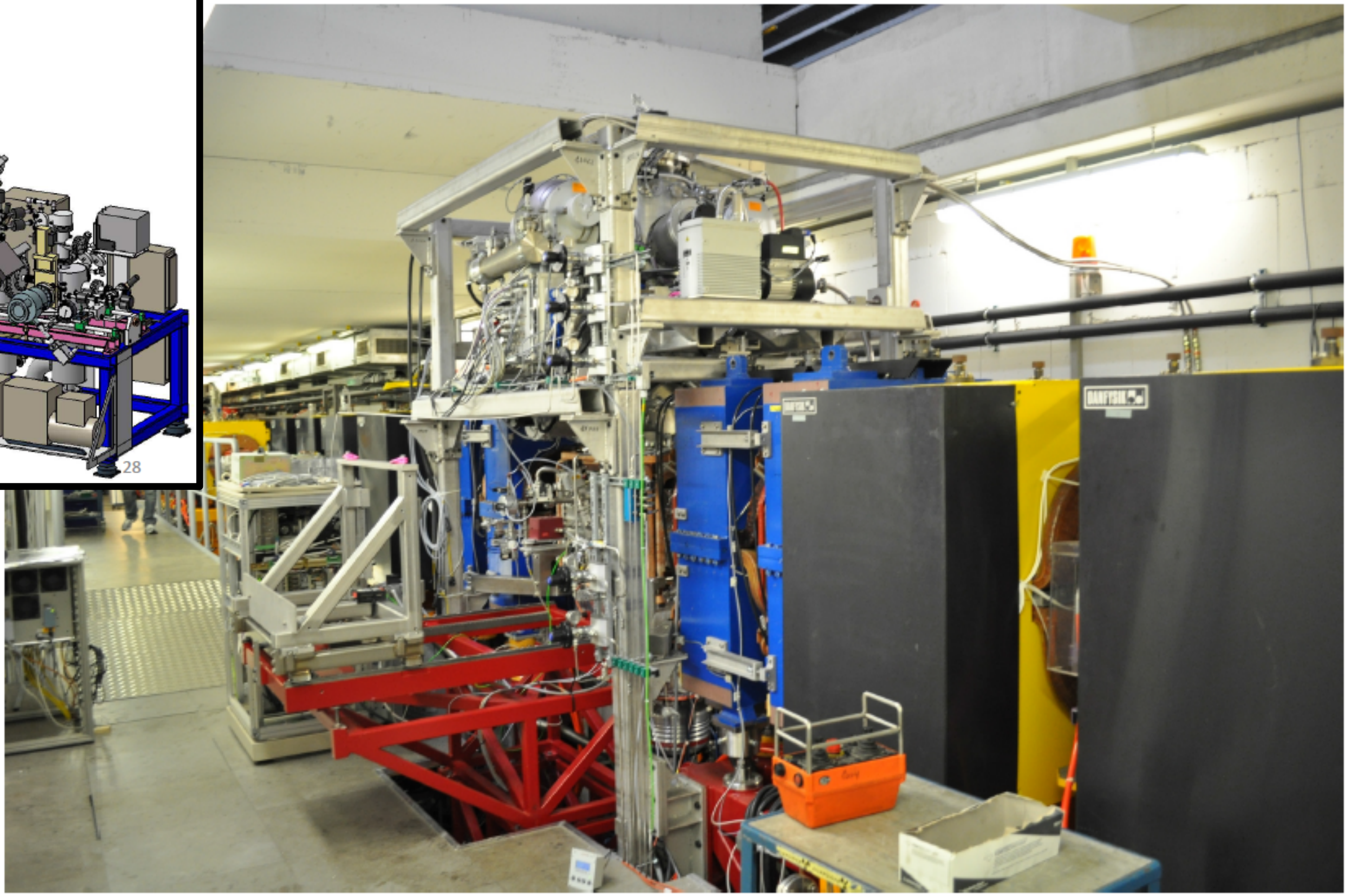


The second life of the HERMES target



PAX experiment @ COSY (Julich)



There is some room beyond the VELO…