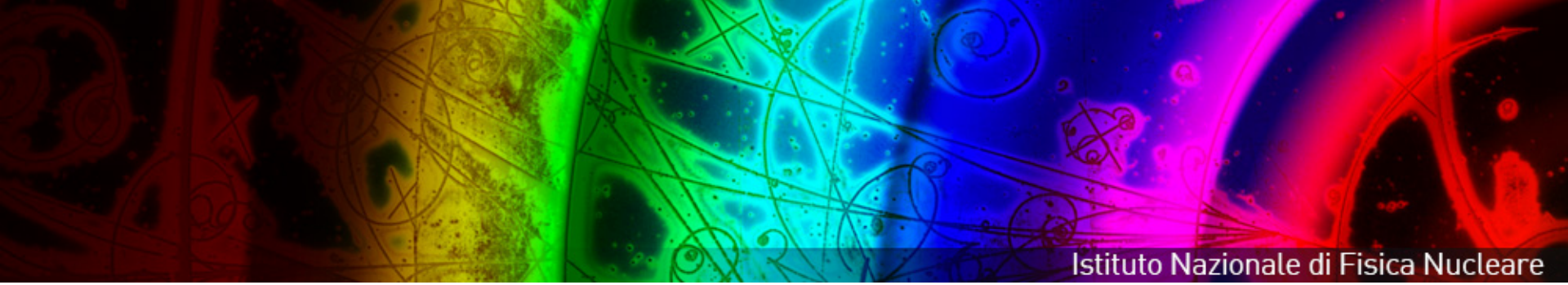


A polarised fix target @LHC

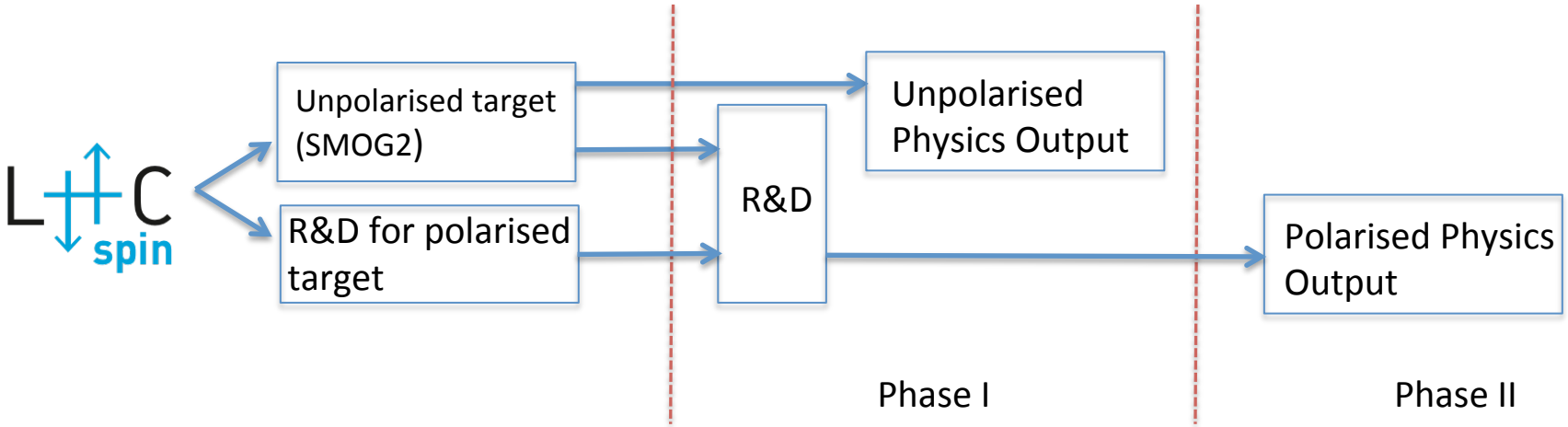
P. Di Nezza

In collaboration with:
C.Baumgarten (PSI), V.Carassiti (University of Ferrara and INFN), G.Ciullo (University of Ferrara and INFN), R.Engels (Juelich), K.Grygoriev (Gatchina), P.Lenisa (University of Ferrara and INFN), A.Nass (Juelich), L.Pappalardo (University of Ferrara and INFN), F.Rathmann (Juelich), D.Reggiani (PSI), M.Statera (INFN Milano), E.Steffens (University of Erlangen)

PBC - CERN, 21/11/17

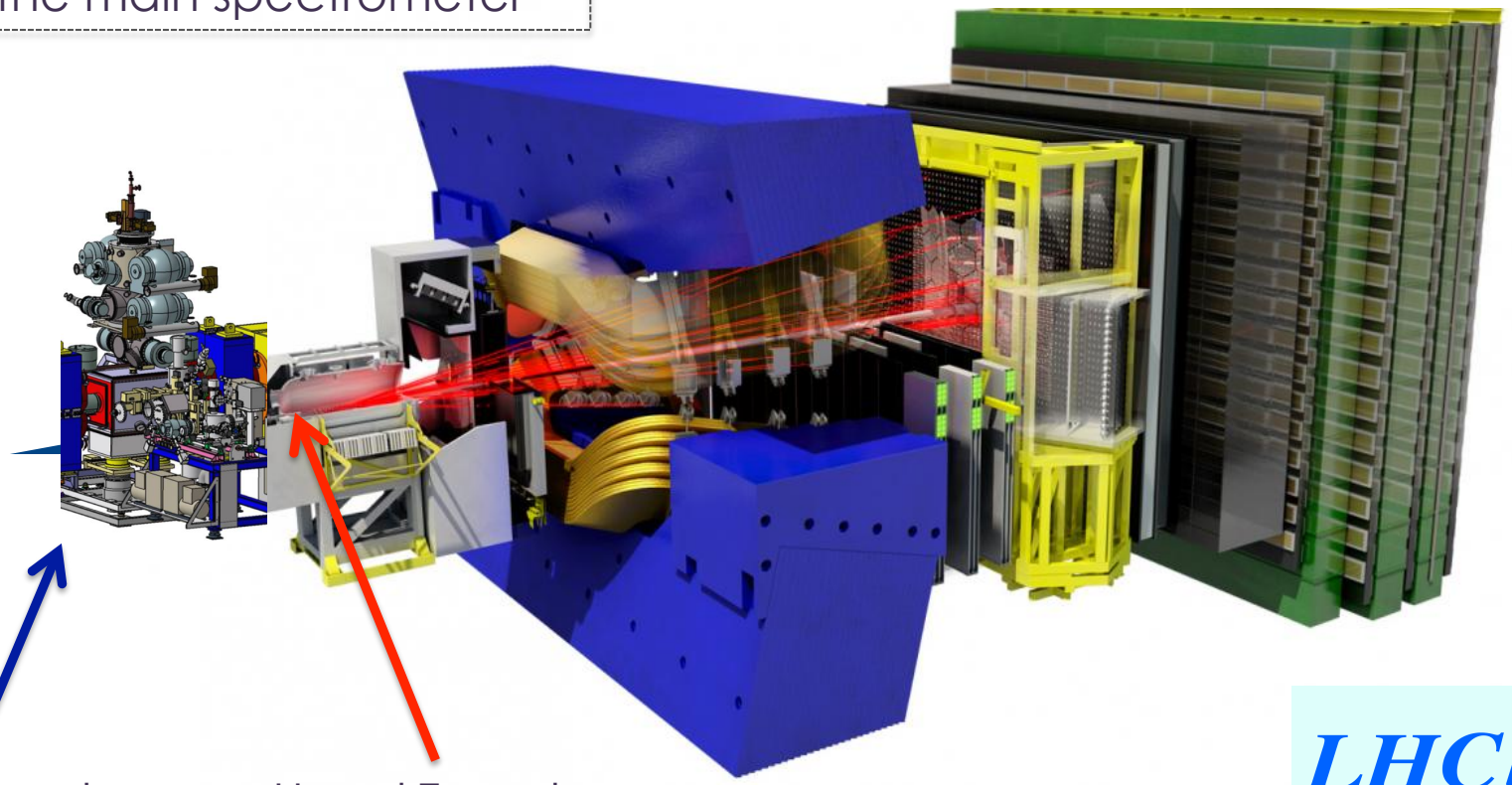
LHCSpin aims to bring un/polarized physics at the LHC as a new tool, using the existing, advanced and upgraded LHCb detector in parallel fixed-target and collider data taking

The project will follow two paths:



Unpolarised+ Polarised Gas Target

N.B. No changes are requested to the main spectrometer



Pol Target

Unpol Target
SMOG2

Proton as a laboratory for QCD

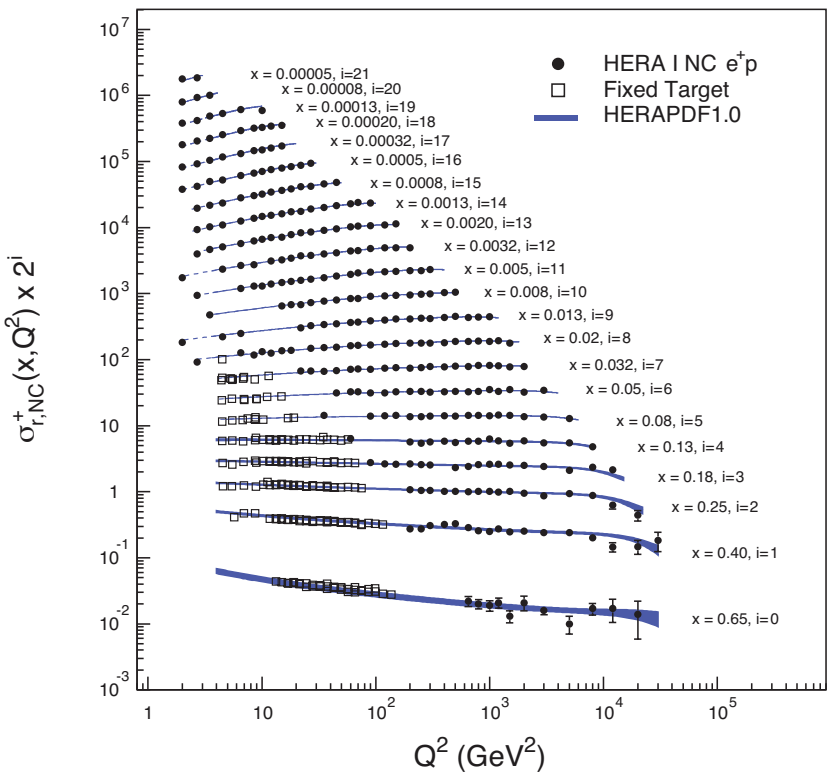
The knowledge on confinement and, more in general, on the dynamics of quarks and gluons in the non-perturbative regime of QCD is quite limited

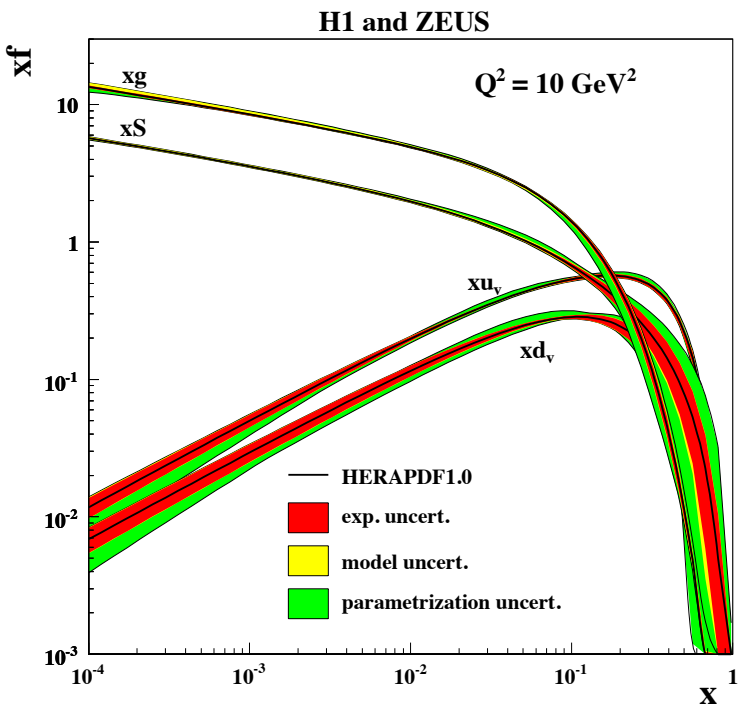
Proton as a laboratory for QCD

Our knowledge relies mainly on two types of physics quantities:

Fragmentation Functions: mechanism of hadronization

Parton Distribution Functions: longitudinal-momentum distributions of charge and current





Proton as a laboratory for QCD

Our knowledge relies mainly on two types of physics quantities:

Fragmentation Functions: mechanism of hadronization

Parton Distribution Functions: longitudinal-momentum distributions of charge and current

Unfortunately:

-FFs contain no dynamical information on the constituents (linear and angular momenta)

-PDFs provide no knowledge of spatial locations and transverse motion of the constituents

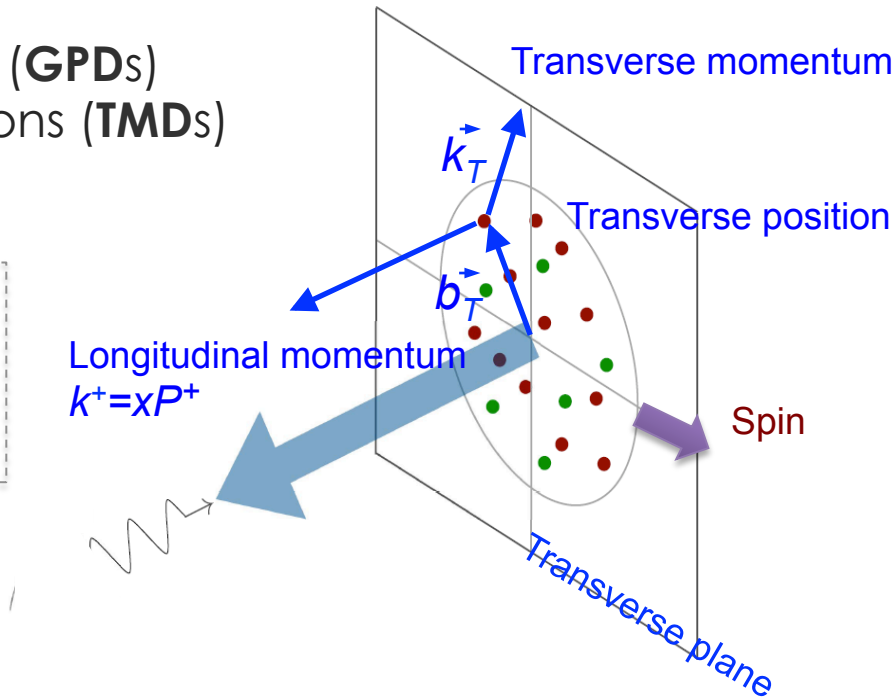
Wigner Distributions

(quantum-mechanical version of the classical phase space distributions)

A three-dimensional description of the nucleon through measurable quantities:

- Generalised Parton Distribution functions (**GPD**s)
- Transverse Momentum Distribution functions (**TMD**s)

*Correlation between momentum and spatial coordinates goes through the **spin** and how it arises from the nucleon's components*



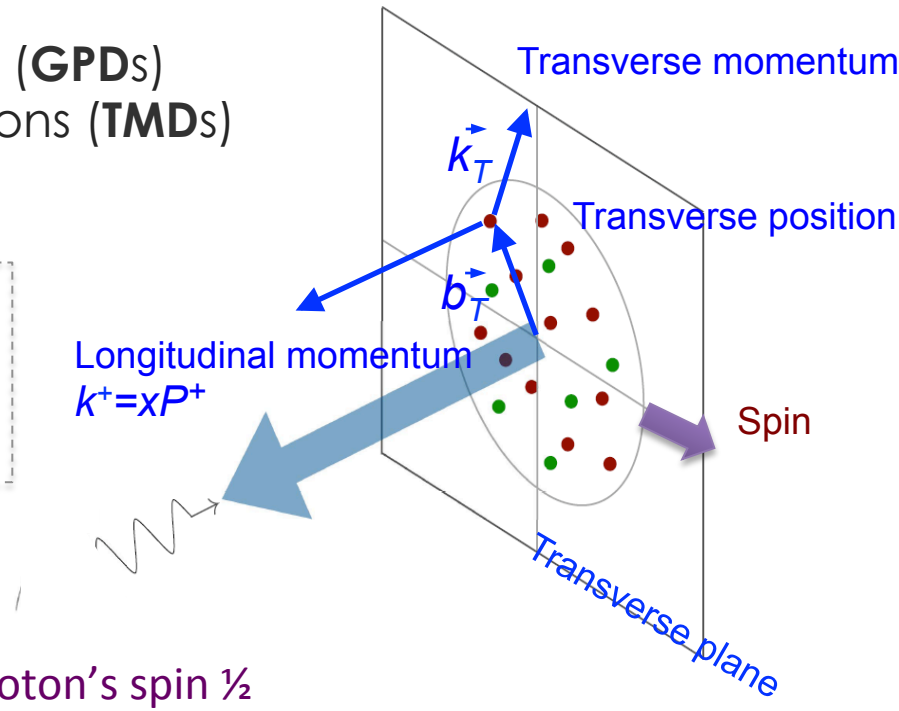
Wigner Distributions and the nucleon Spin puzzle

(quantum-mechanical version of the classical phase space distributions)

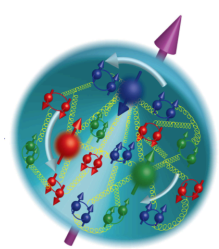
A three-dimensional description of the nucleon through measurable quantities:

- Generalised Parton Distribution functions (**GPD**s)
- Transverse Momentum Distribution functions (**TMD**s)

*Correlation between momentum and spatial coordinates goes through the **spin** and how it arises from the nucleon's components*



How quarks and gluons conspire to provide the proton's spin ½



$$\frac{1}{2}\hbar = \overbrace{\sum_q \frac{1}{2} S_q^z}^{\text{Total quark spin}} + \overbrace{S_g^z}^{\text{gluon spin}} + \overbrace{\sum_q L_q^z + L_g^z}^{\text{angular momentum}}$$

An interesting and fundamental physics case itself and a tool to study (TMDs, GPDs) the inner structure of composite systems

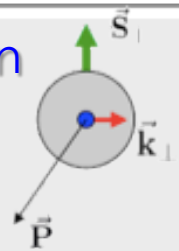
The 3-D Structure of the Nucleon *EPJ A (2016) 52*

Visualize Color interactions in QCD

Chiral-odd function

Sivers function

$\sin(\phi_h - \phi_s)$ modulation



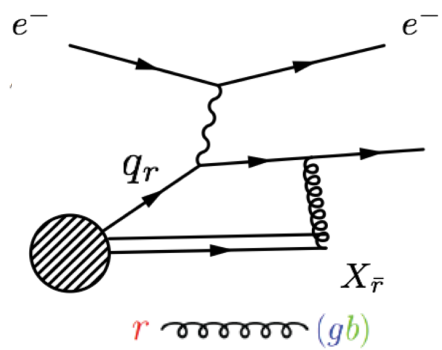
correlation of nucleon's transverse spin with the k_T of an unpolarized quark

- measures spin-orbit correlations
- link to parton orbital motion (through models)
- reveals non-trivial aspects of QCD color gauge invariance

T-odd function

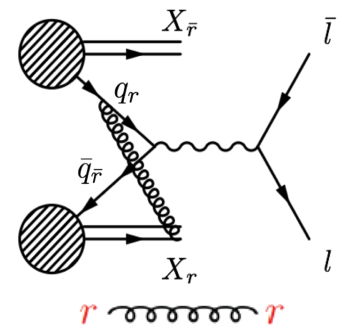
Measure non-universality of the Sivers-function

DIS: gq-scattering attractive FSI



attractive

pp: qqbar-anhilation repulsive ISI



repulsive

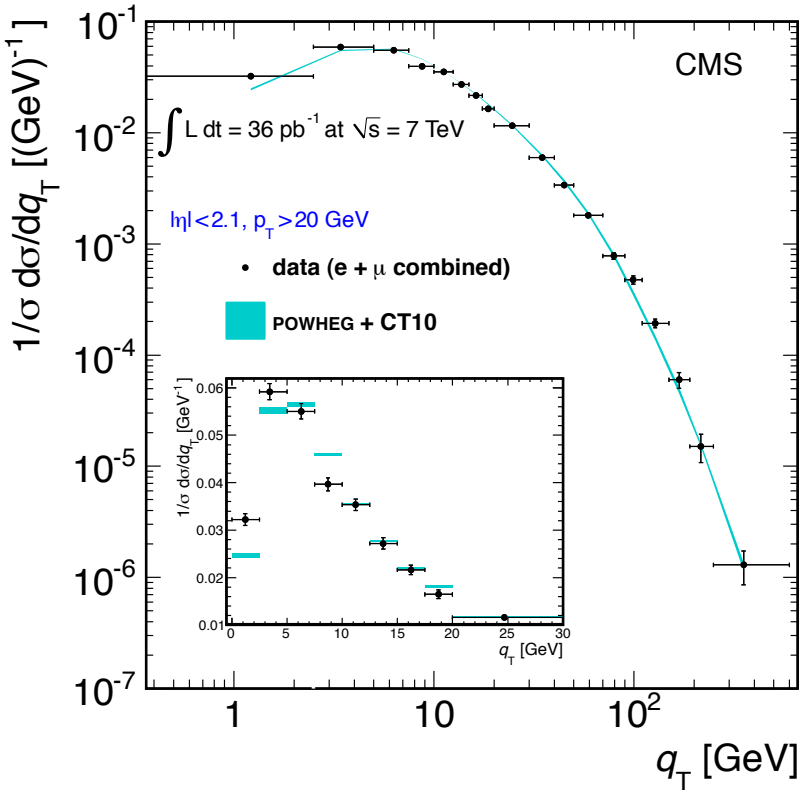
hep-ph/0604226
arXiv:1109.2521

$$f_{1T}^{\perp q}(x, k_T^2)\Big|_{\text{SIDIS}} = -f_{1T}^{\perp q}(x, k_T^2)\Big|_{\text{DY}}$$

<u>Critical test of factorization in QCD</u>

no sign change means rethink of QCD factorization

Z-boson transverse momentum q_T spectrum in pp by CMS

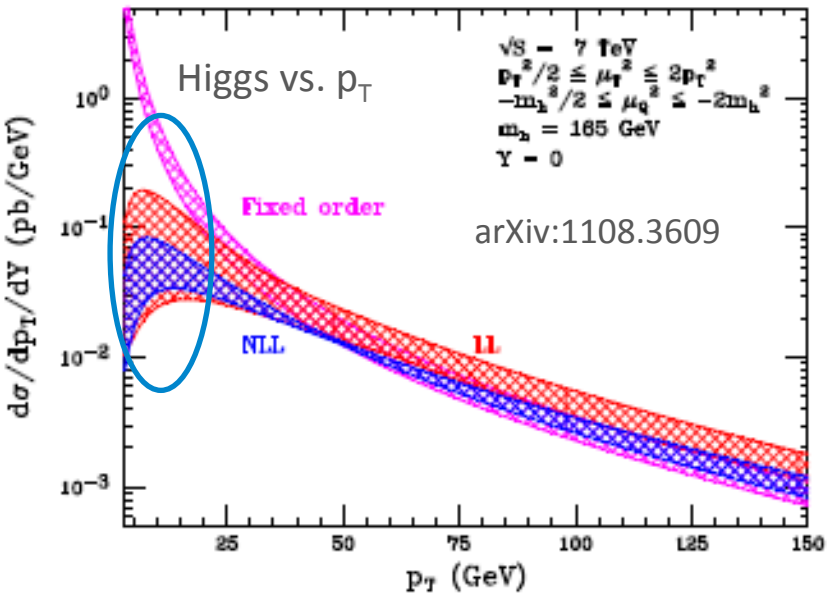


The small q_T region cannot be explained by usual collinear PDF factorization: needs TMD-PDFs

(Phys. Rev. D85 (2012) 032002)

Effective field theories

Soft Collinear Effective Theory – p_T distribution for gg→Higgs



TRANSVERSE MOMENTUM DISTRIBUTIONS FROM EFFECTIVE FIELD THEORY

Sonny Mantry*
University of Wisconsin at Madison
Madison, WI 53706, USA
mantry147@gmail.com

Frank Petriello
High Energy Physics Division, Argonne National Laboratory
Argonne, IL 60439, USA

Department of Physics & Astronomy, Northwestern University
Evanston, IL 60208, USA
f-petriello@northwestern.edu

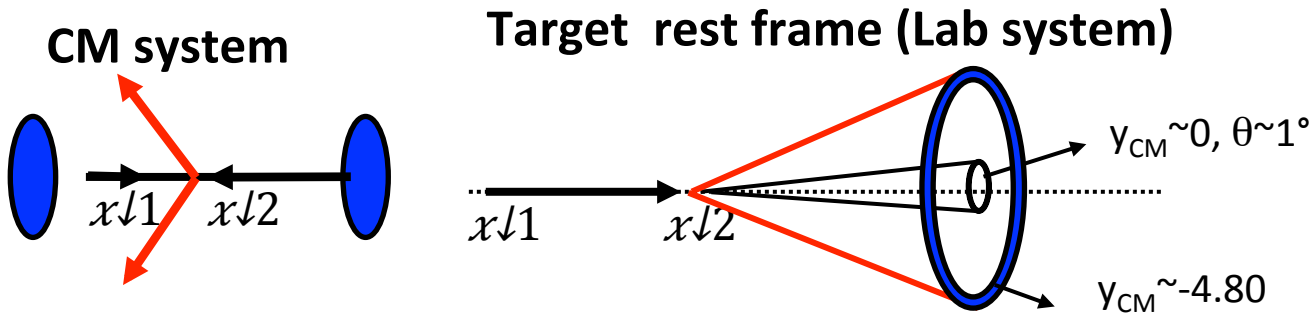
Kinematic conditions for a fixed target at the LHC

7 TeV proton beam on a fixed target proton:

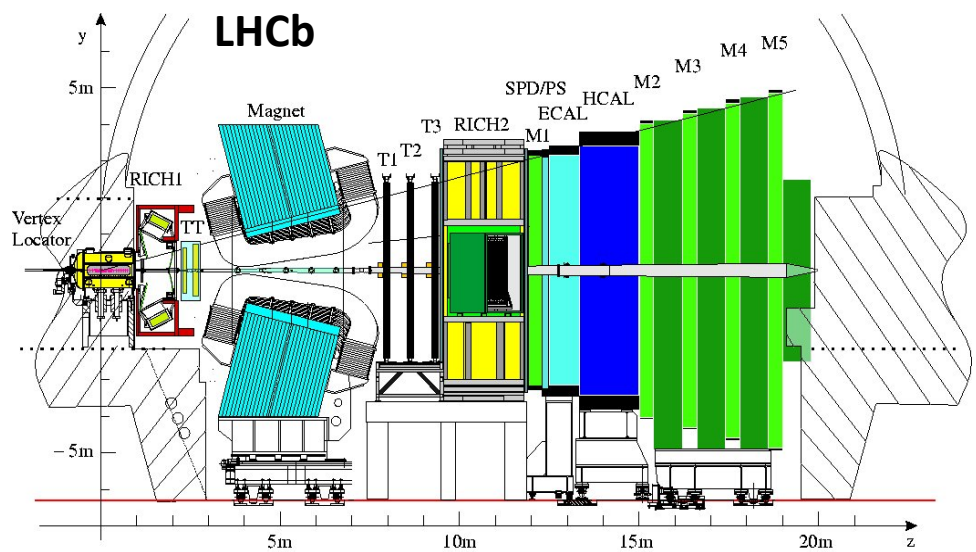
$\sqrt{s}$~115 GeV (between SPS & RHIC)

CM backward Rapidity Region

$-4.8<y_{CM}<0$



- Experimentally accessible: reaction products at large angles!
- LHCb acceptance and detector performance perfectly suitable!

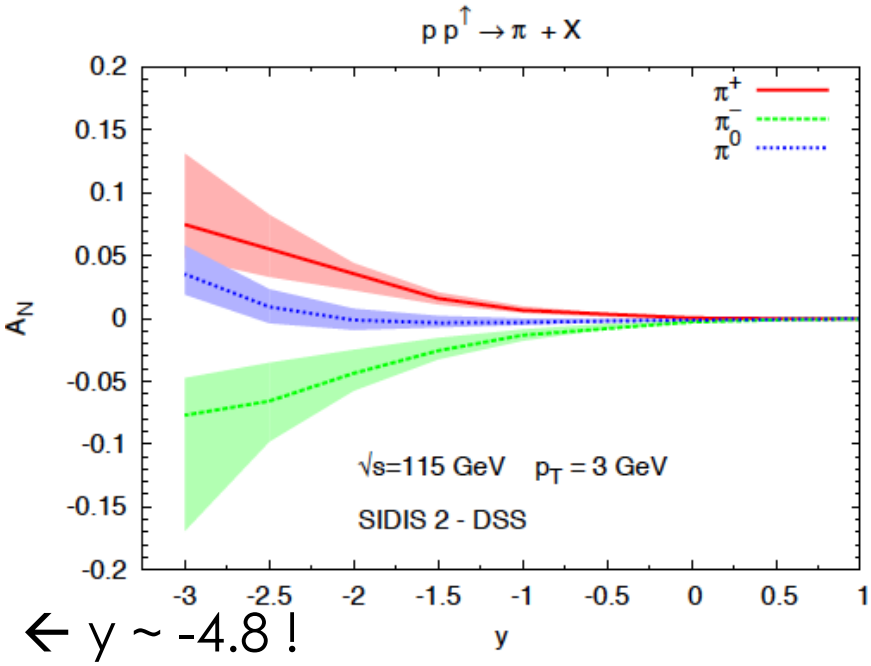


A couple of explicit examples

Single Spin Asymmetries: non-collinear (leading twist) approach

Anselmino et al. arXiv:1504.03791v2

- involves TMD PDFs and FFs
- works in the limit (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



← y ~ -4.8 !

- Asymmetries above 10%!
- The effect increases with more negative CM rapidity

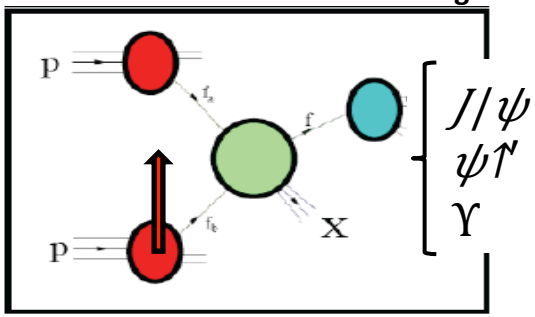
A couple of explicit examples

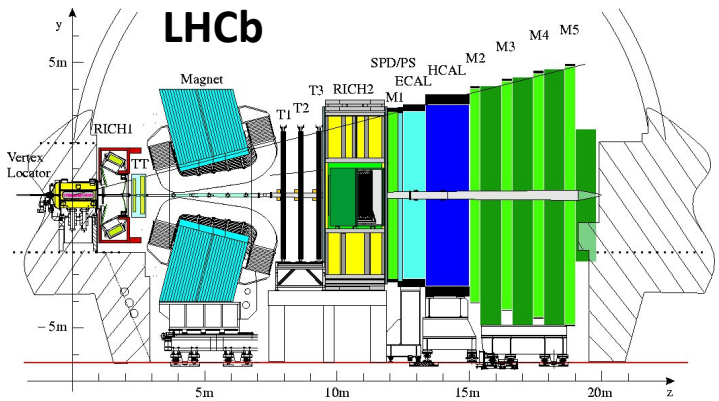
Probing the gluon PDFs

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 gluon PDFs!

- being heavy quarks dominantly produced through gluon-gluon interactions, one can probe the gluon dynamics within the proton by measuring **heavy-flavor** observables
- At LHC **quarkonia** production dominated by gluon fusion
- Heavy quarks and quarkonium production turns out to be an ideal gluon-sensitive observable!

Polarized inclusive hard scattering

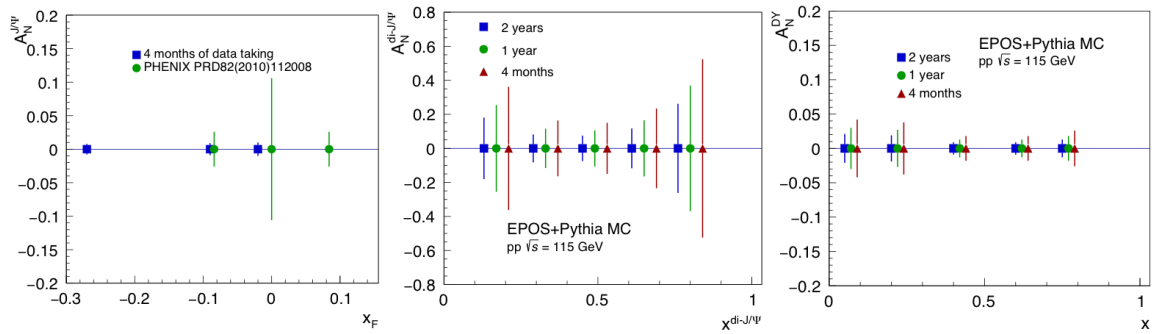


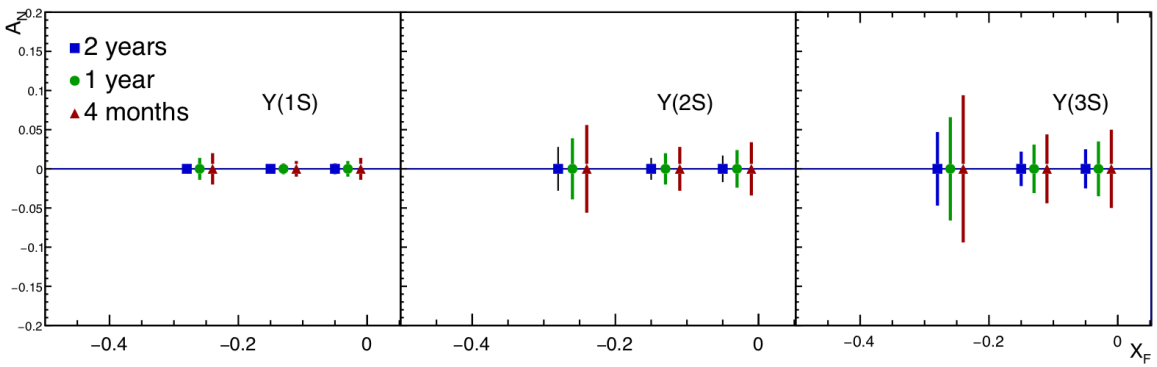


- LHCb can measure nearly all quarkonia states (including C-even) with high precision!
- Expected yields much larger than previous fixed-target experiments
- -mesons is a unique observable, poorly accessible from other hadron-hadron experiments

Statistical error projection for some of the possible channels (within the LHCb reconstruction framework)

Synergic pp / p-target data taking:
- 8 h per day
- 20 d per month
- 200 d per year





Disclaimer: these are not LHCb official MC results!

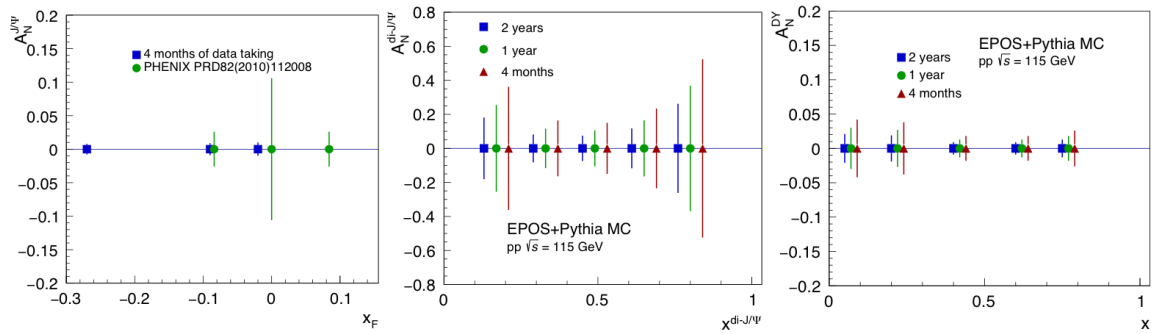
Unique channels:

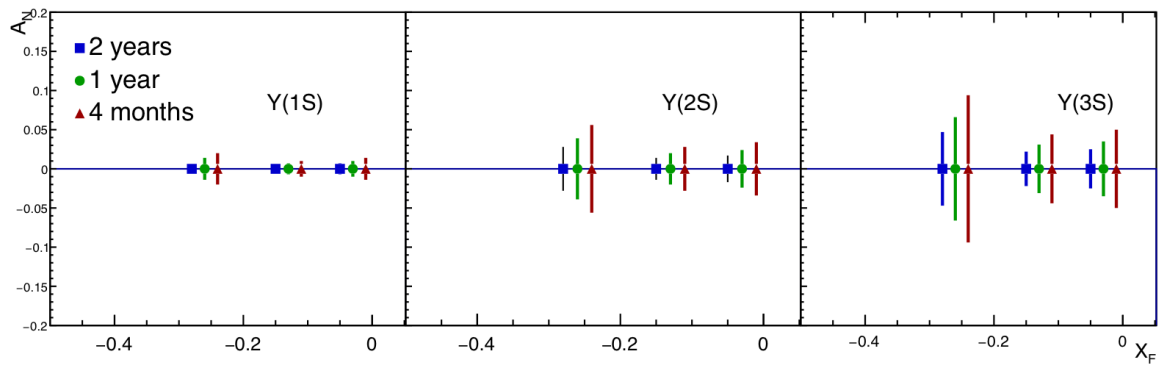
- Pseudoscalar quarkonia (η, η_c, $\eta_c(2S)$, $\chi_{c,b}$)
- Υ
- J/Ψ, Ψ', di–J/Ψ, $\Upsilon(1,2,3S)$
- D, B-mesons
- DY ($\mu^+\mu^-$)

arXiv:1504.03791
arXiv:1502.04021
arXiv:1203.5579
arXiv:1208.3642

Statistical error projection for some of the possible channels (within the LHCb reconstruction framework)

Synergic pp / p-target data taking:
- 8 h per day
- 20 d per month
- 200 d per year





Disclaimer: these are not LHCb official MC results!

LHC beam life time and synergic data taking

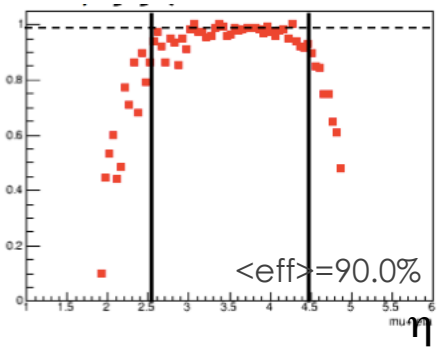
The Polarised Gas Target, at maximum intensity, will give a relative proton loss rate of $N/N_p = 1.6 \times 10^{-7}$/s, reducing the **1/e beam lifetime**, the inverse of the relative loss rate, of 6.4×10^{6} s, corresponding to **74 days** → negligible reduction for parallel data taking

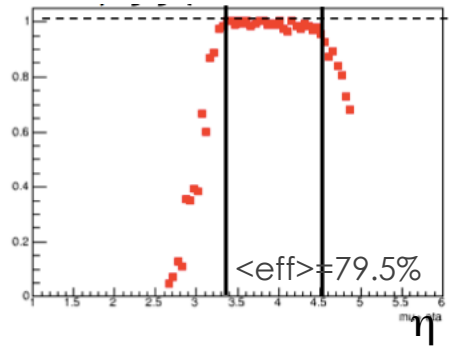
Simulations

MC by EPOS+Pythia at 7 TeV p-beam on fix target within the LHCb framework (GEANT4). In the following only the channel $J/\Psi \rightarrow \mu\mu$ is shown

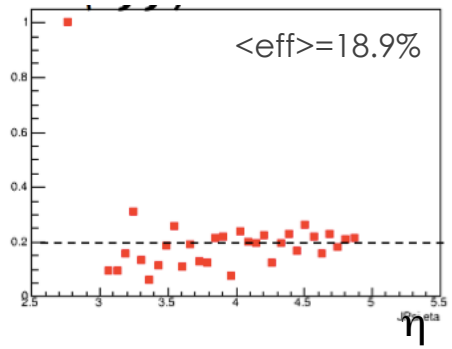
SMOG

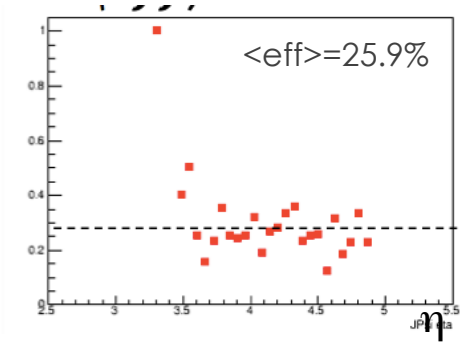
Upstream target



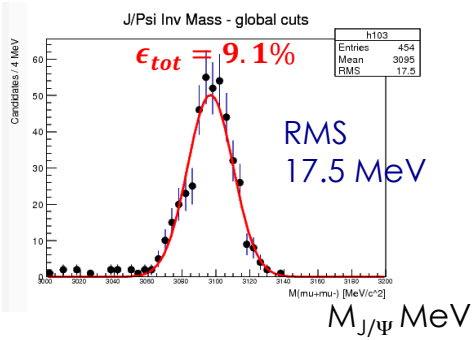


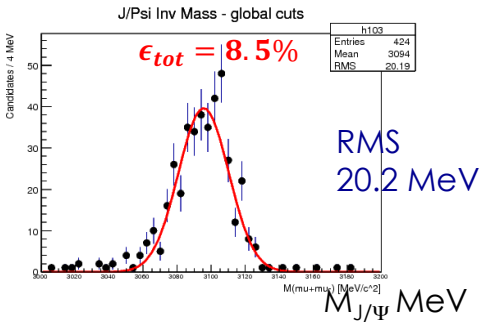
Single Track reconstruction





J/Ψ decay vertex reconstruction

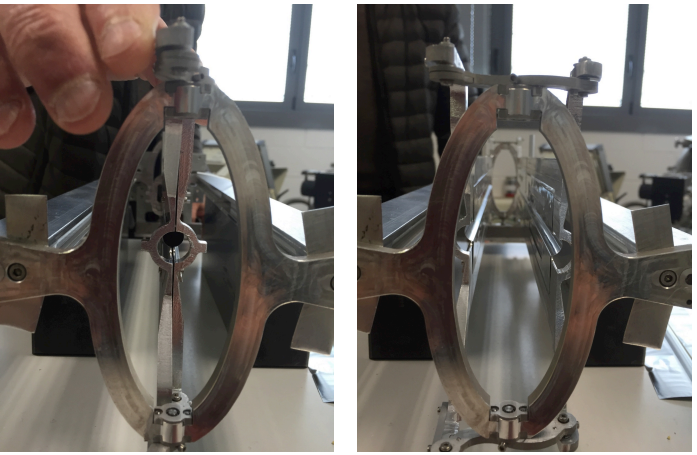




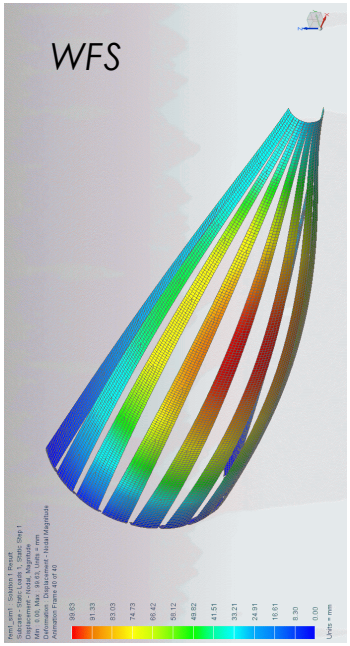
J/Ψ invariant mass reconstruction

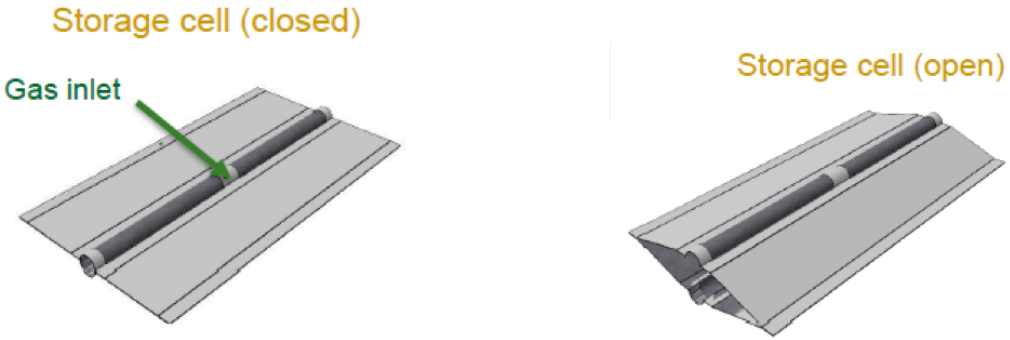
Disclaimer: these are not LHCb official MC results!

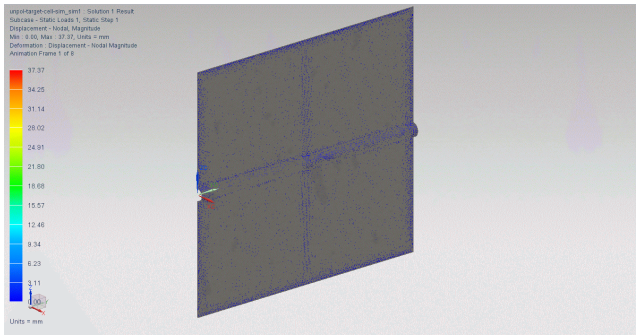
Quite advanced R&D



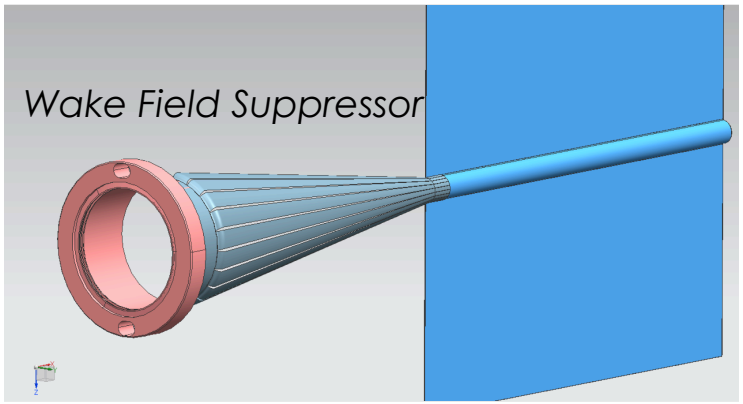
Openable storage cell







Stress test: http://www.lnf.infn.it/~dinezza/stress-sim.gif

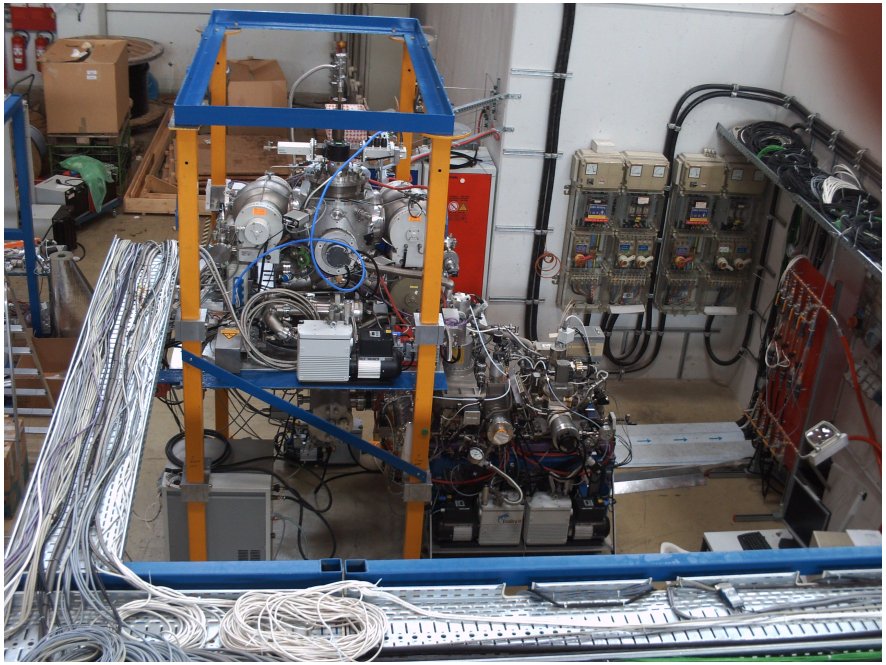


Stress test at: http://www.lnf.infn.it/~dinezza/stress-sim-wfs.gif

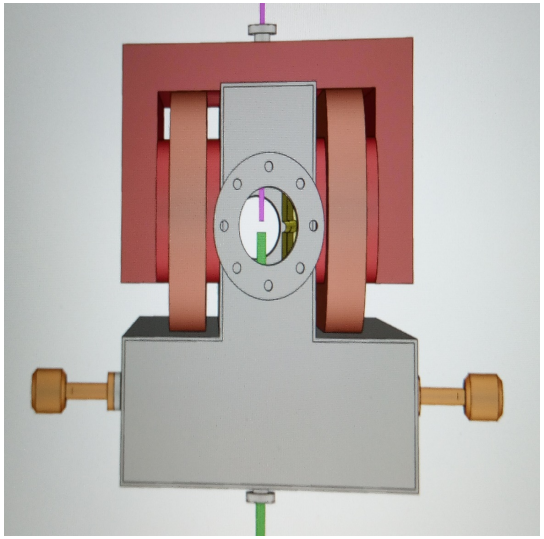
http://www.fe.infn.it/~vito/LHCb-target-cell/

R&D for the Polarised Gas Target

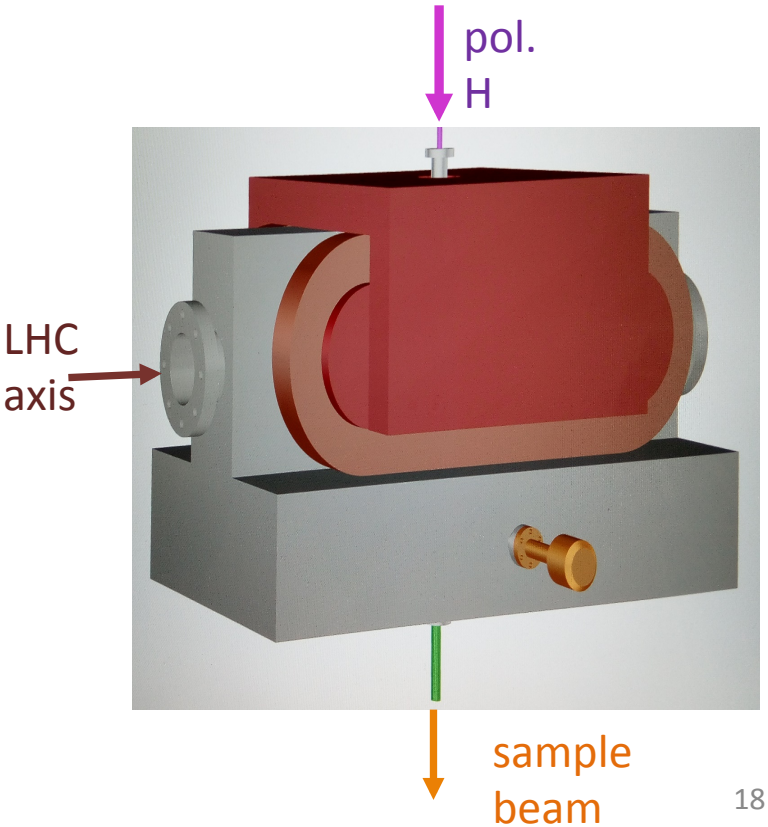
… a consolidated technology



Existing (Juelich lab) and available polarised target (Ferrara, Juelich resp.). Cell coating studies are ongoing



- Transverse magnet with C-shaped for providing a homogenous guide for the polarized gas of about 0.3 T, 0.5 m long
- Rectangular Target Chamber (TC)



R&D … various

Simulations for the **Beam Induced Depolarization** are in progress. Positive output. ✓

Implementation studies at LHC P8 have been planed. Drawings are in progress ✓

The installation of an LHC **vacuum valve** upstream LHCb will isolate a ~2 m long section allowing the target installation without venting any significant LHCb neither LHC component

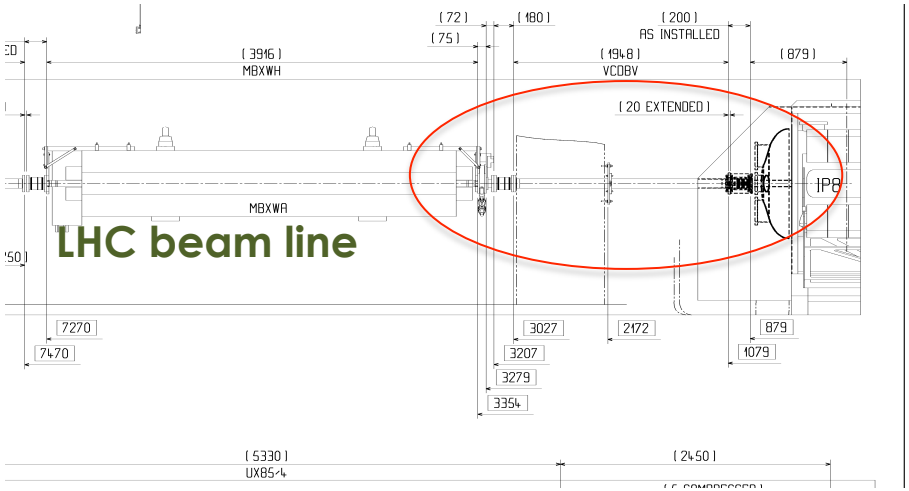


Figure of Merit

Considering the expected LHC beam intensity, the areal density of target nucleons, the polarization, the dilution factor and the beam intensity, this results in a Figure of Merit of:

- $1.57 \cdot 10^{30}$ $cm^{-2}s^{-1}$ for the UVa target and bent-crystal extracted beam
- $1.58 \cdot 10^{32}$ $cm^{-2}s^{-1}$ for the LHCSpin target.

We conclude that the polarized gas target for the LHC gives a FoM which is two orders of magnitude higher than for the Bent-Crystal scenario with UVa solid polarized target.

FITPAN

-LHCb has a dedicated panel which is following the progress of the project

-There are continuous interactions with LHC experts and <u>no show-stoppers</u> have been identified so far

LHCSpin Time Schedule

	TASKS	Periods						
		2018	2019	2020	2021	2022	2023	2024
SMOG2	1.1 Design and construction of the openable cell							
SMOG2	1.2 Design and construction of the WFS							
SMOG2	1.3 Modification of the existing LHCb gas feed system							
SMOG2	1.4 Implementation of the unpol target into the LHC vacuum chamber							
SMOG2	1.5 Data collection and analysis							
LHCSpin	2.1 Modification of existing ABS, BRP and TGA							
LHCSpin	2.2 Design and construction of the PGT vacuum chamber							
LHCSpin	2.3 R&D and cell coating							
LHCSpin	2.4 Stand alone tests on polarisation and dissociation							
LHCSpin	2.5 Beam tests at SPS							
LHCSpin	2.6 Assembly and installation of the polarised target in LHCb							
SMOG2 LHCSpin	3.1 Simulations for tracking reconstruction into LHCb							
SMOG2 LHCSpin	3.2 Trigger development and implementation into LHCb software							
SMOG2 LHCSpin	3.3 MC generation of the physics channels							
SMOG2 LHCSpin	3.4 Slow Control and Data acquisition implementation							
			LHC Long Shutdown 2		LHC Run 3			LHC LS3

Conclusions

L↑↓C spin will provide unique kinematic conditions for a broad and ambitious physics program!

The LHCb spectrometer is perfectly suitable to host the target and represents a unique opportunity:

high luminosity, excellent tracking and PID performances will allow to push, among other results, the STSAs for quarkonia to a precision era, opening the way to the extraction, among others, of the gluon PDFs

A group of experts for the various aspects of the project is already active.

A review process already started both inside the LHCb Collaboration and the LHC … with very positive feedback