Internal gas target experiments at the LHC

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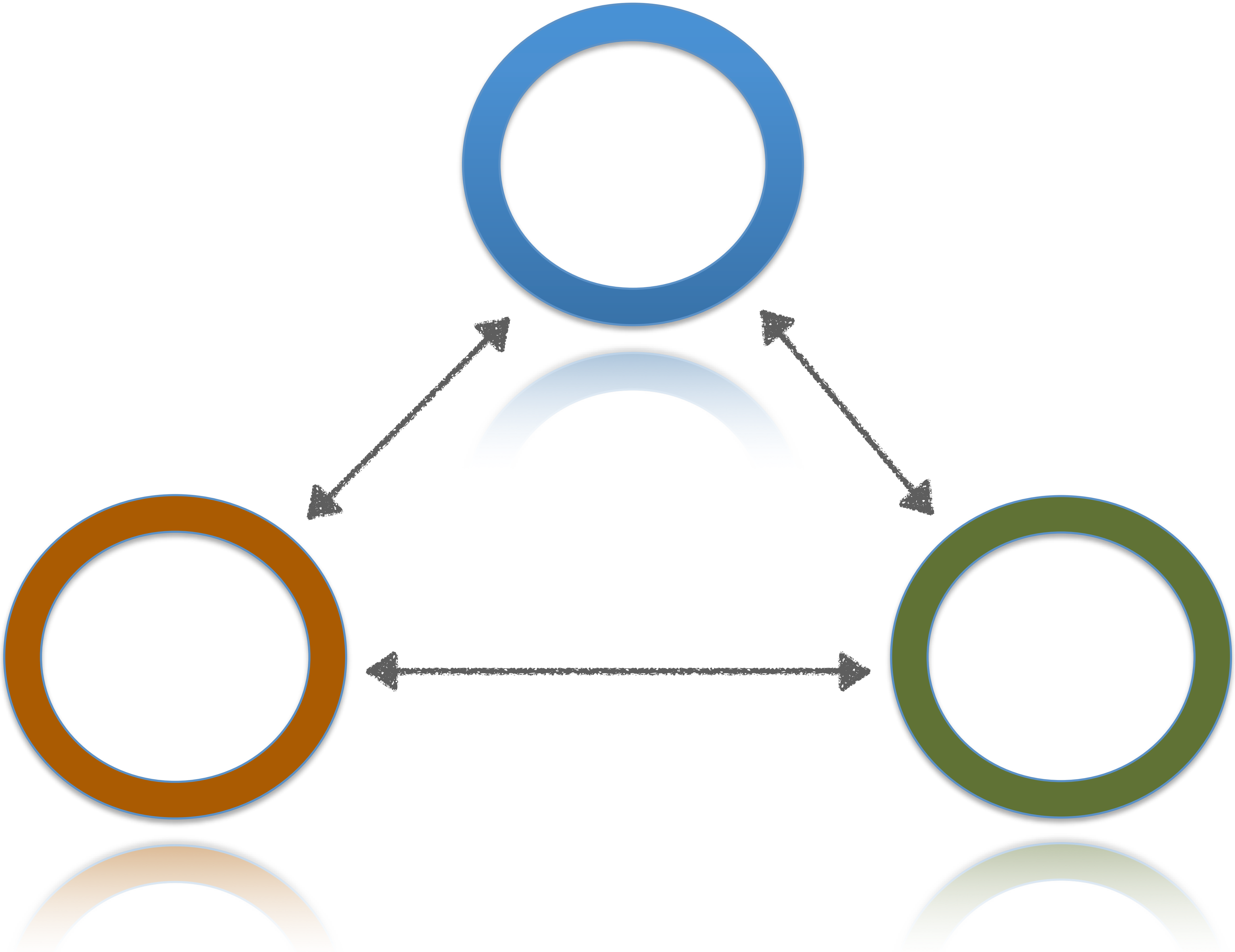
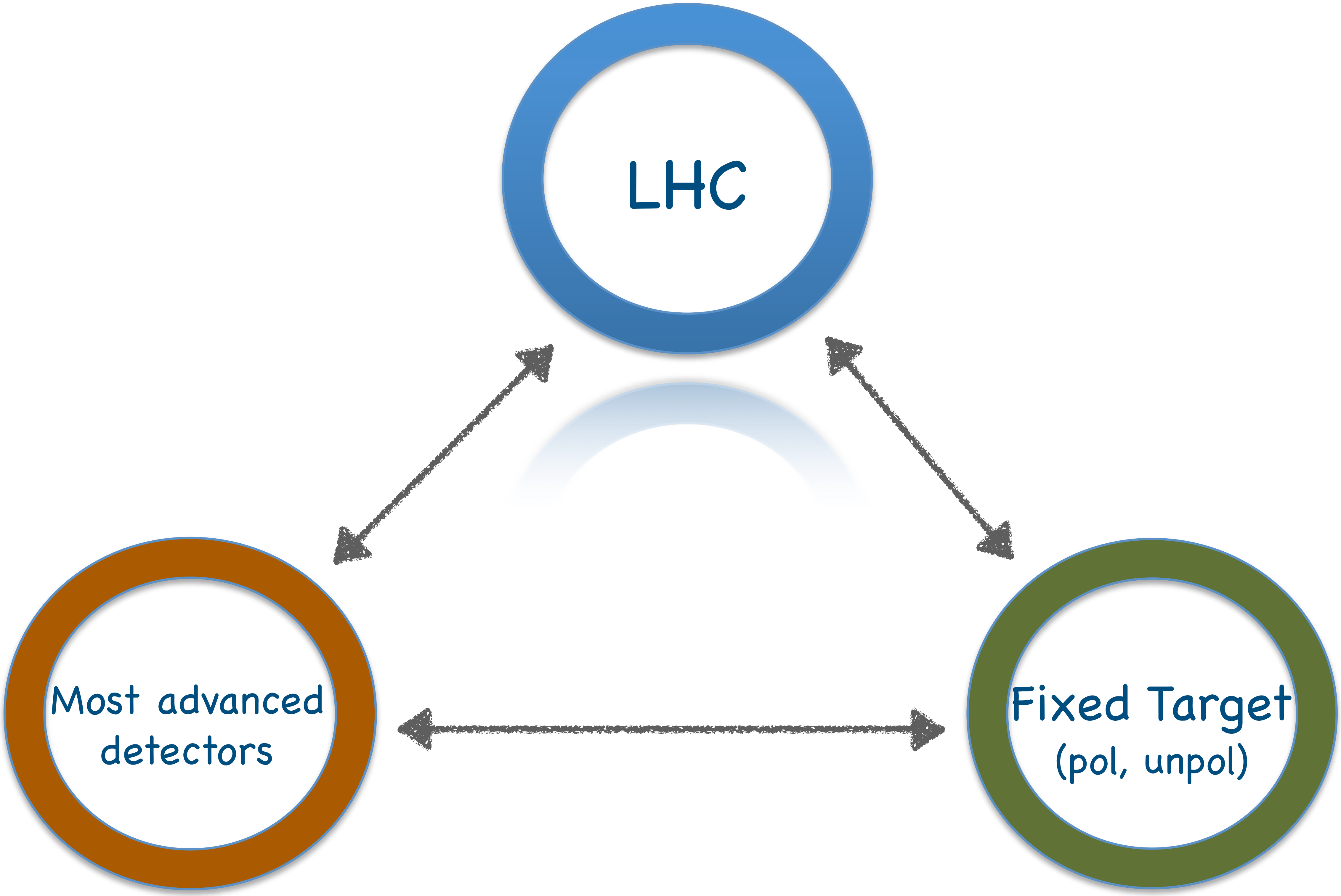
12/09/18

Spin 2018
23RD INTERNATIONAL SPIN SYMPOSIUM
FERRARA - ITALY

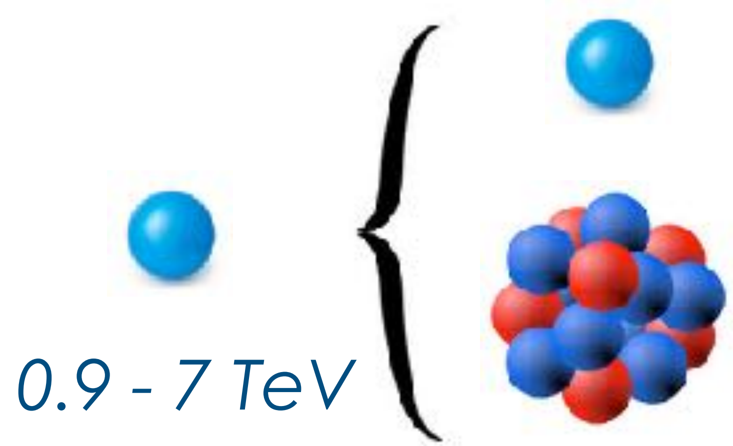
Merging 3 worlds



Merging 3 worlds



Kinematics

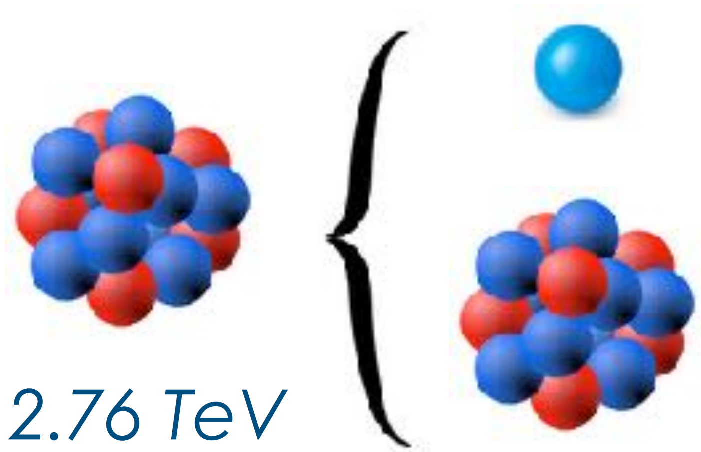


pp or pA collisions: 7 TeV beam on fix target

$$\sqrt{s} = \sqrt{2m_N E_p} \simeq 41 - 115\ GeV$$

$$y_{CMS} = 0 \ \rightarrow \ y_{lab} = 4.8$$

between SPS & RHIC

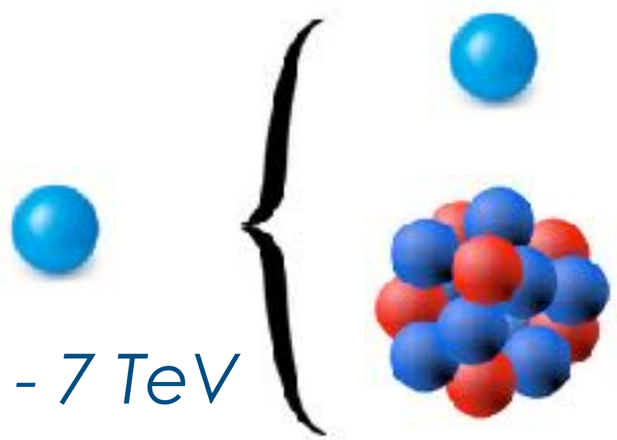


AA collisions: 2.76 TeV beam on fix target

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

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

Kinematics



0.9 - 7 TeV

pp or pA collisions: 7 TeV beam on fix target

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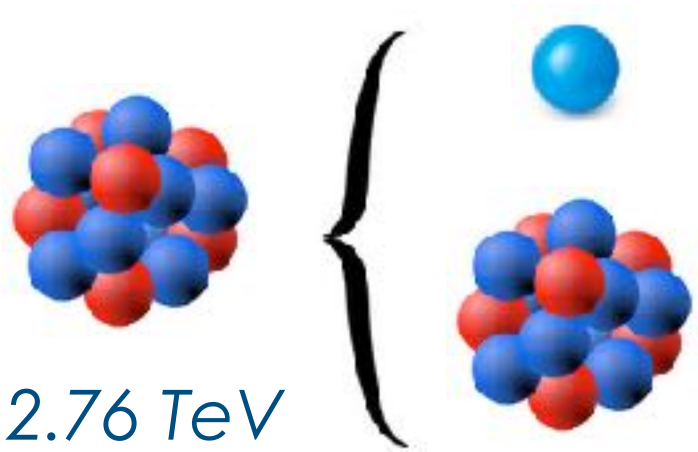


2.76 TeV

AA collisions: 2.76 TeV beam on fix target

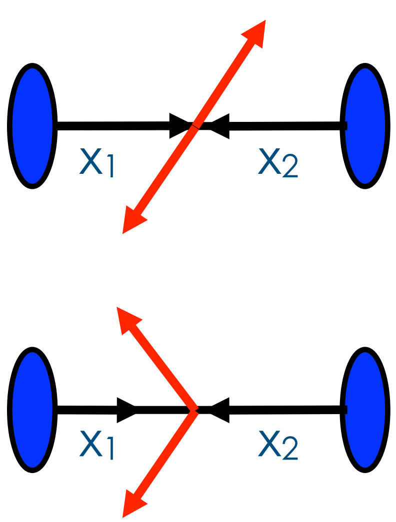
$$\sqrt{s_{NN}} \simeq 72\ GeV$$

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

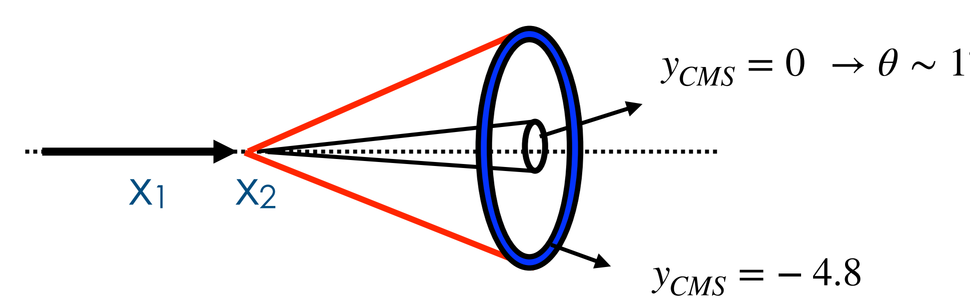
Boost effect → access to large x_2 physics (x_F<0)

$x_1 \sim x_2$

$x_1 << x_2$



CMS → **Target rest frame**



Why

- -Advance our understanding of the large-x gluon, antiquark and heavy quark content in nucleons and nuclei
- -Advance our understanding of the dynamics and spin distributions of gluons inside (un)polarised nucleons
- -Study heavy-ion collisions between SPS and RHIC energies at large rapidities

Why

-Advance our understanding of the large-x gluon, antiquark and heavy quark content in nucleons and nuclei

-Advance our understanding of the dynamics and spin distributions of gluons inside (un)polarised nucleons

-Study heavy-ion collisions between SPS and RHIC energies at large rapidities

- Unique and large kinematic coverage
- High luminosity and high resolution detectors → rare probes
- Proton or Heavy Ion Beam
- Large variety of atomic gas targets: $H_2, D_2, {}^{3,4}He, N_2, Ne, Ar, Kr, Xe$
- Polarised targets: $H^{\uparrow}, D^{\uparrow}$

Physics Motivations
(non exhaustive list)

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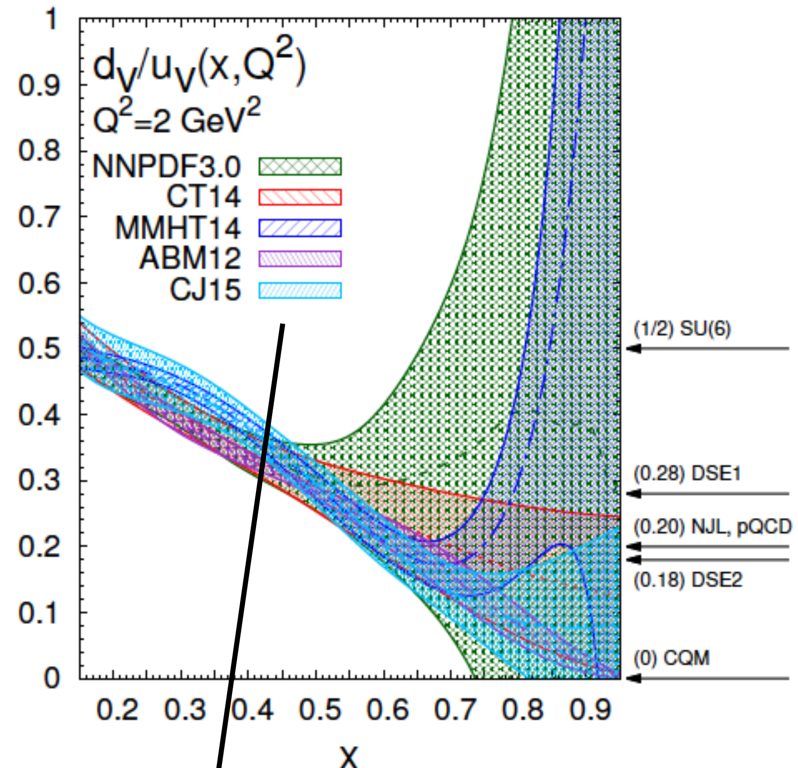
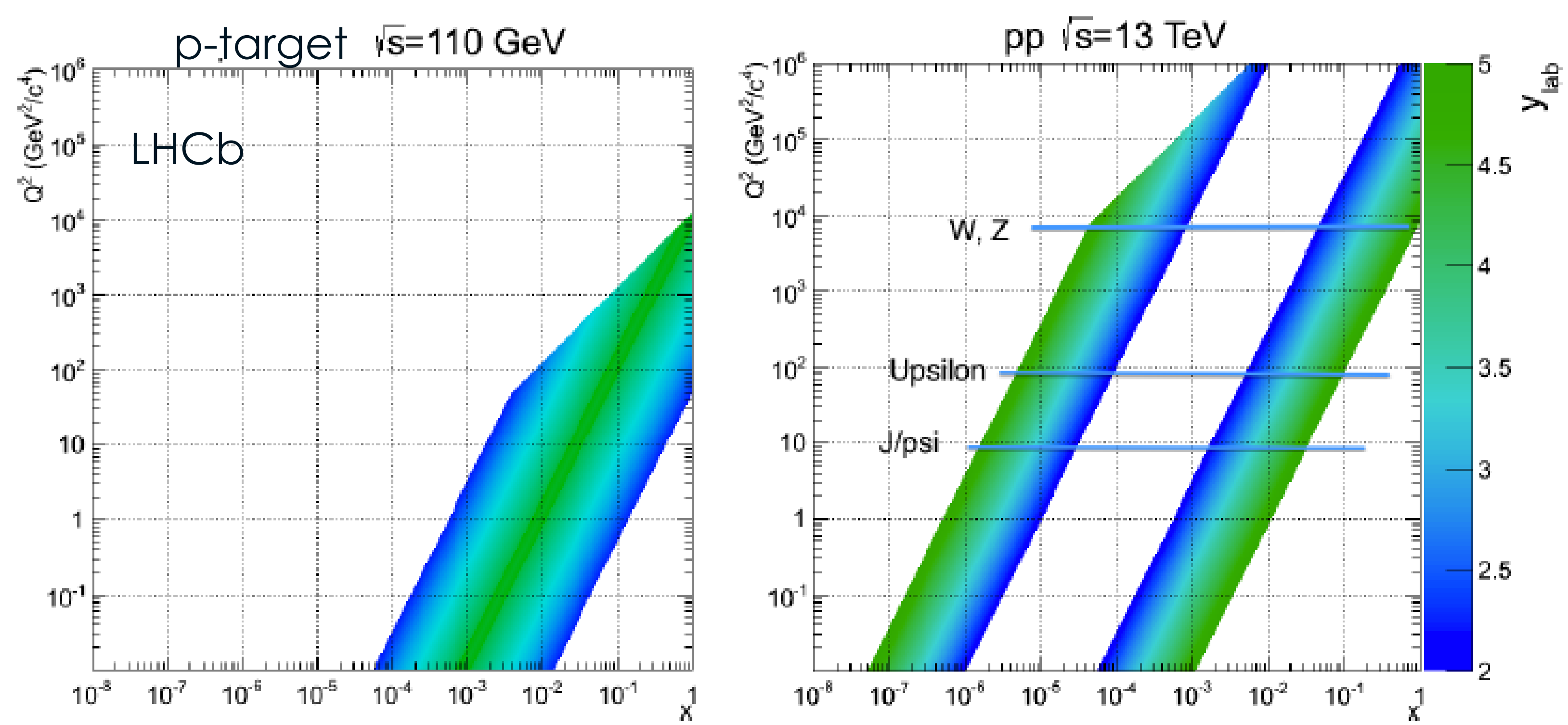
High-x physics

pp, pA, Pb-p and Pb-A collisions unique kinematic conditions at the energy scale √s=41-115 GeV, unexplored in most of the cases



predictions from non-perturbative models

PDFs parametrizations from global fits



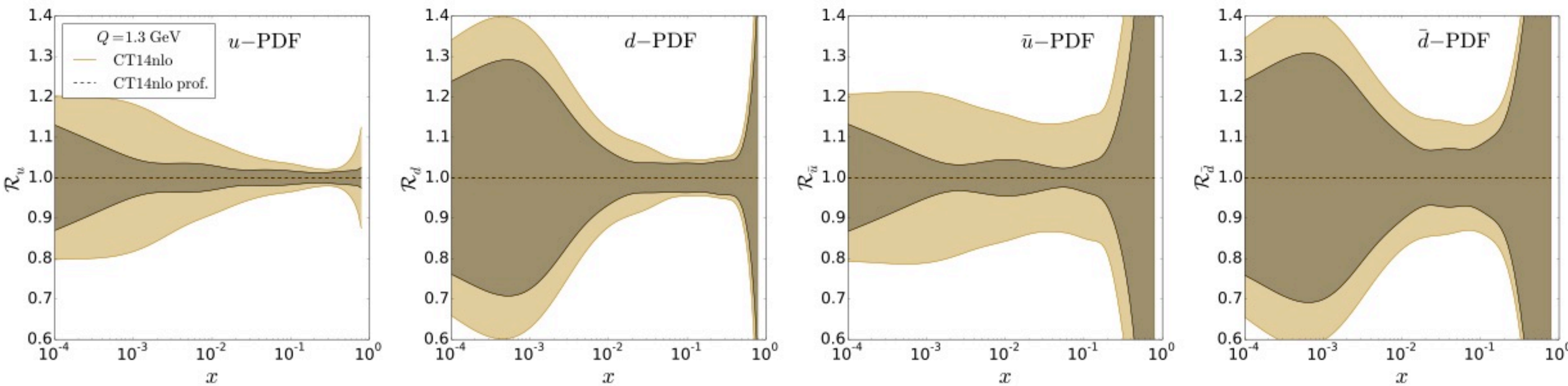
Fermi motion in the nucleus can allow to access the exotic $x > 1$ region, where parton dynamics depends on the interaction between the nucleons within the nucleus.

A bridge between QCD and nuclear physics

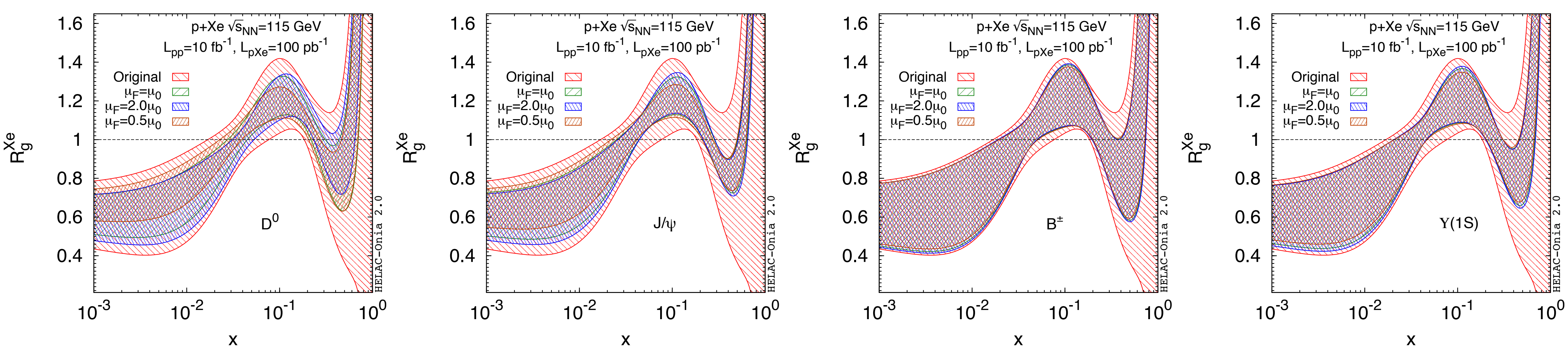
High-x physics

unpol

arXiv:1807.00603



PDF



nPDF (gluon)

Substantial improvement of the uncertainties

estimation with 10 fb^{-1}

unpol

- Intrinsic heavy-quark:

-recent global QCD analyses support the existence of non-perturbative intrinsic charm

-5-quark Fock state (uudQQ) of the proton may appear at high x

-charm PDFs at large x could be larger than obtained from conventional fits

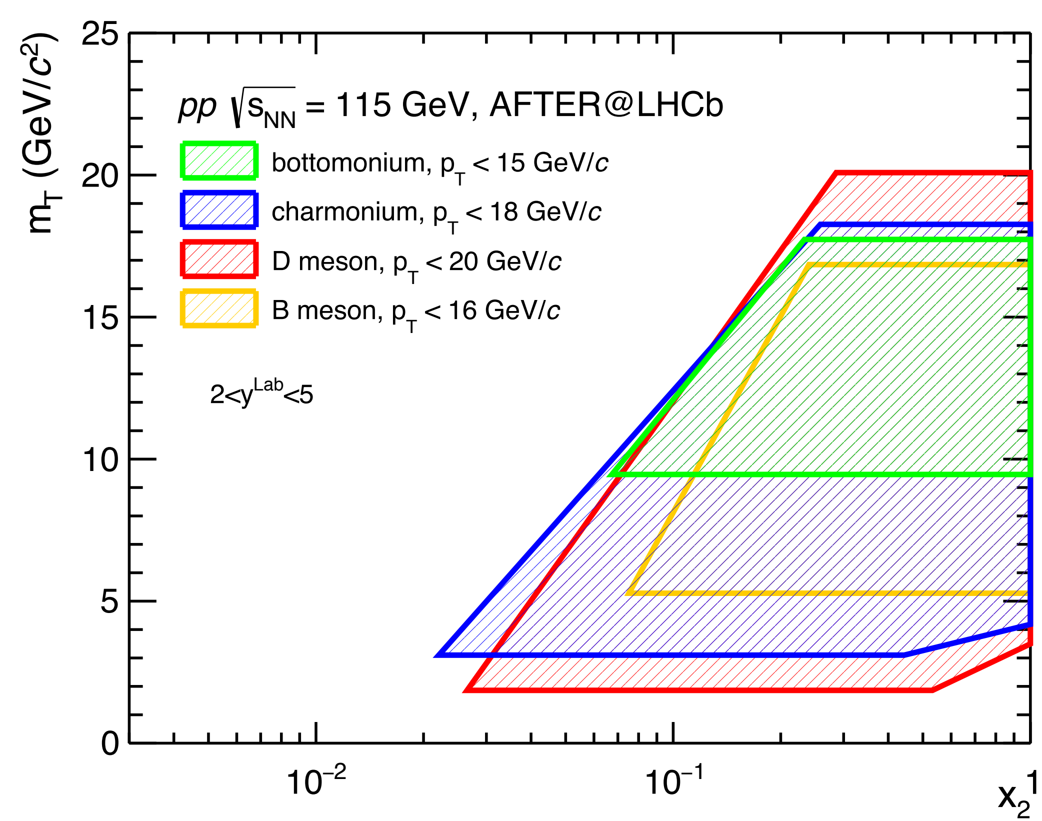
- $W^{\pm}$ boson production near threshold

-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 done at high energies

arXiv:1807.00603



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- pA collisions:

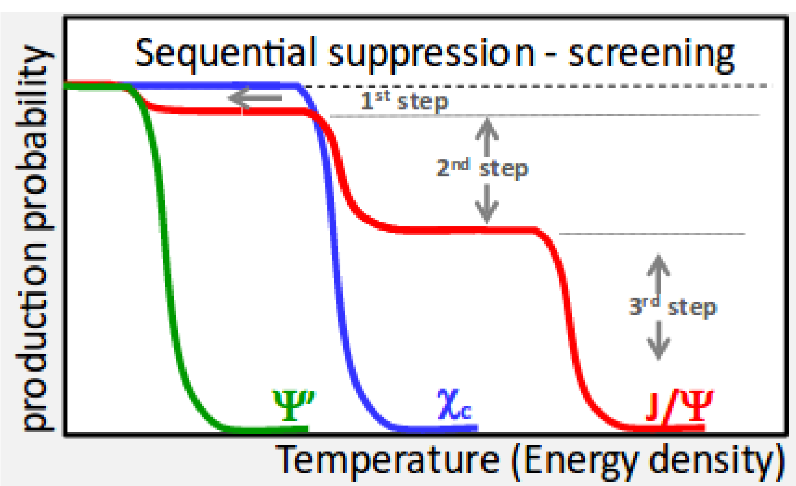
-nuclear matter effects on PDFs (special sensitivity to high-x, e.g. poorly known anti-shadowing)

-studies of parton energy-loss and jet-quenching in cold nuclear matter

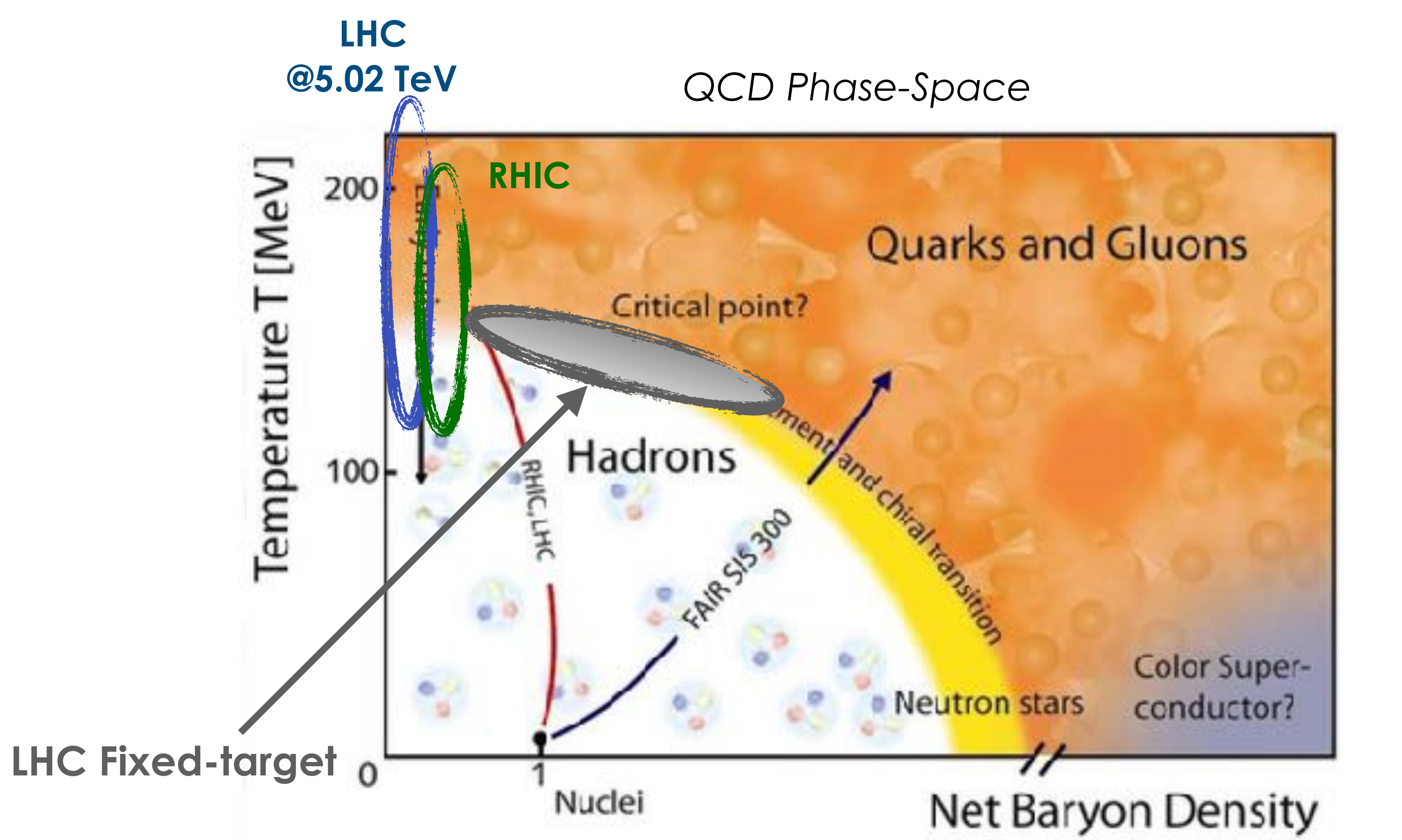
- PbA collisions at $\sqrt{s_{NN}} \approx 72$ GeV

-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)



cc bound states: J/ψ, χ_c , ψ', ...
different binding energy,
different dissociation
temperature



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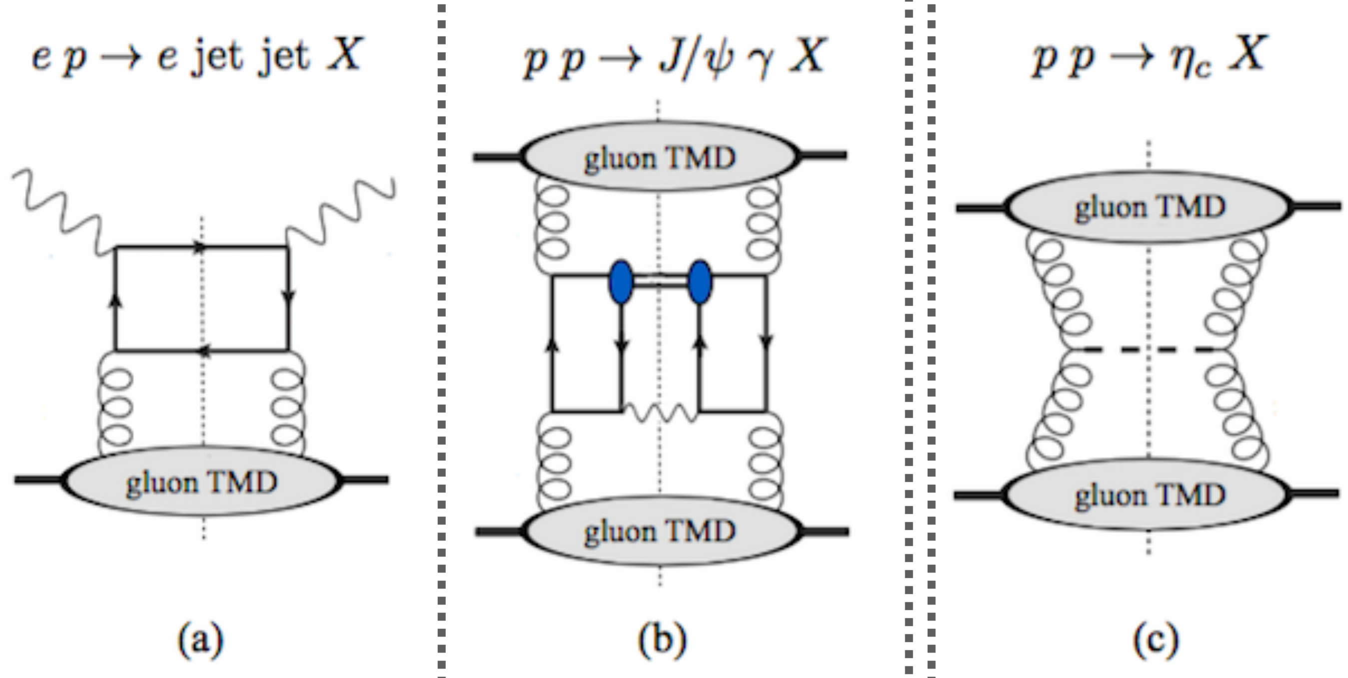
Transverse Momentum Distributions (TMDs)



Leading-order diagrams representing some of the processes relevant for the extraction of gluon TMDs.

Channels measured with high efficiency "also" at LHC+LHCb

Channels measured with high efficiency "only" at LHC+LHCb

Phys. Rev. Lett. 111, 032002 (2013)

TMDs effects can have a significant impact from the Higgs sector to the BSM physics, from the understanding of the J/Ψ polarisation to the quarkonia, …

Transverse Momentum Distributions (TMDs)

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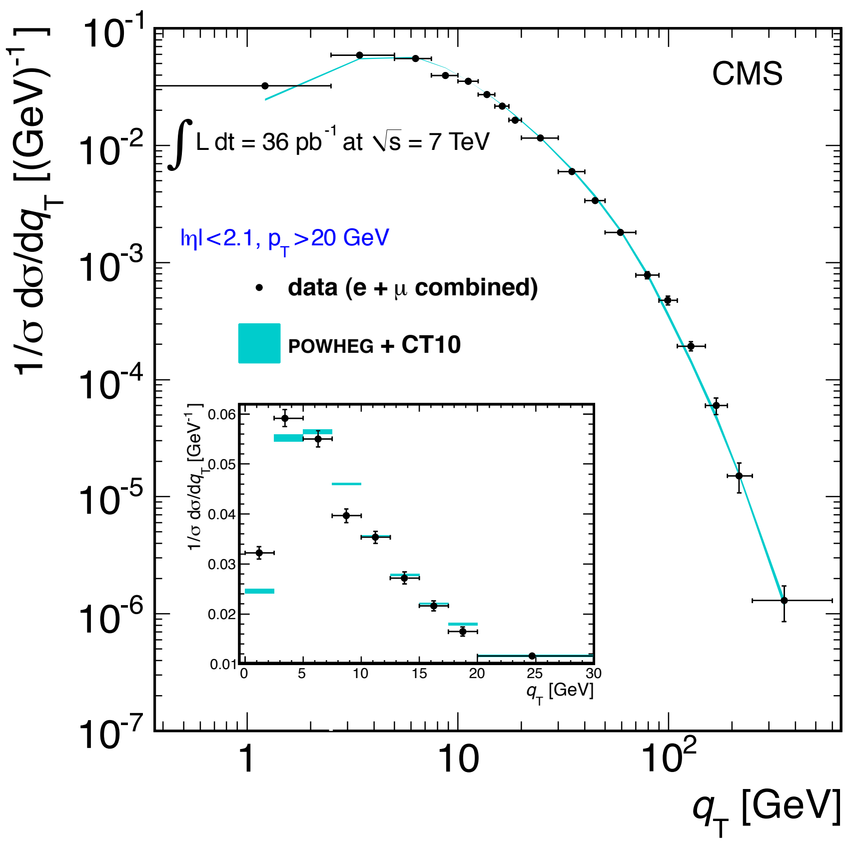
Z-boson transverse momentum q_T spectrum in pp by CMS



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

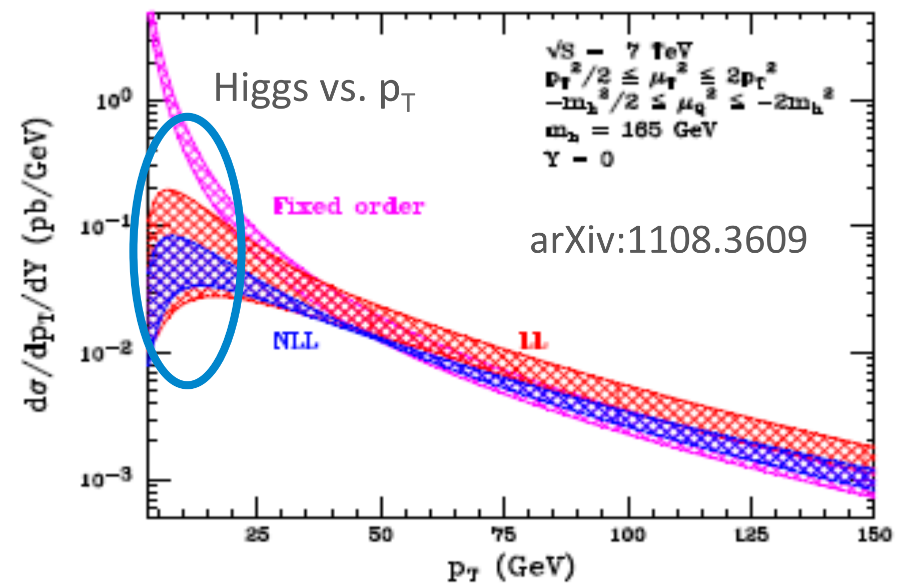
(Phys. Rev. D85 (2012) 032002)

... still unsolved

Effective field theories

Soft Collinear Effective Theory

p_T distribution for gg-Higgs



TRANSVERSE MOMENTUM DISTRIBUTIONS FROM EFFECTIVE FIELD THEORY

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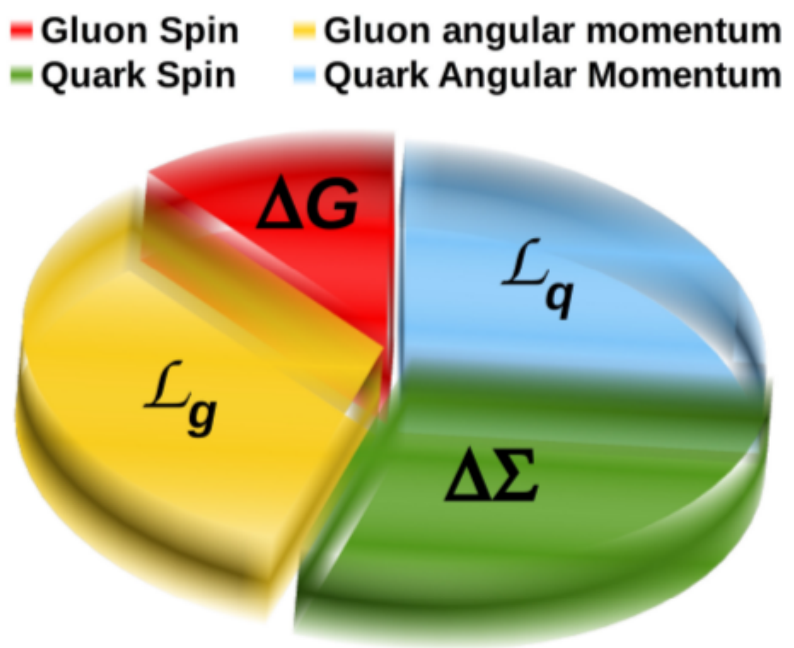
Effect of flavor-dependent partonic transverse momentum on the determination of the W mass
G.Bozzi's spin2018 talk, arXiv:1807.02101

…then the SPIN

3D mapping of the parton momentum: access to …

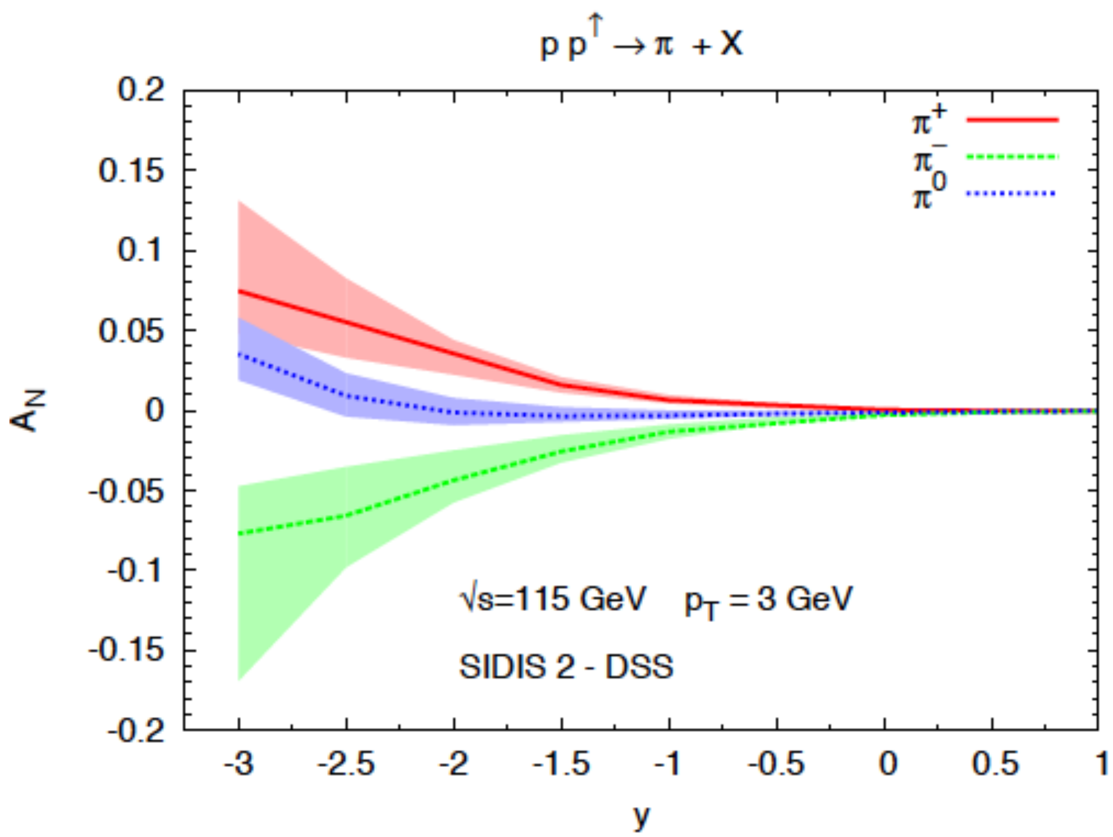
-quark and gluon orbital angular momentum L_q and L_g
-gluon transverse-momentum dependent PDF (TMDs)
-linearly polarised gluons in unpolarised protons
-…



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

pol

-involves TMD PDFs and FFs
-requires 2 scales (p_T<<Q), but is not supported by TMD factorization
-can be considered as an effective model description (Generalized Parton Model)
-SSAs arise mainly from Sivers effects



-Asymmetries above 10%! (for pions)

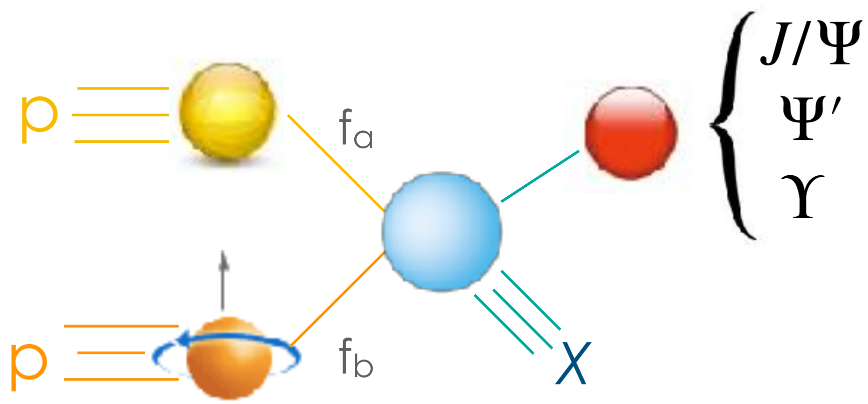
-The effect increases with more negative CM rapidity

Anselmino et al. arXiv:1504.03791v2

Probing the gluon PDFs

Inclusive pion production provides sensitivity to the quark PDFs, but a fixed polarised 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 is dominated by gluon fusion
- Heavy quarks and quarkonium production turns out to be an ideal gluon-sensitive observable



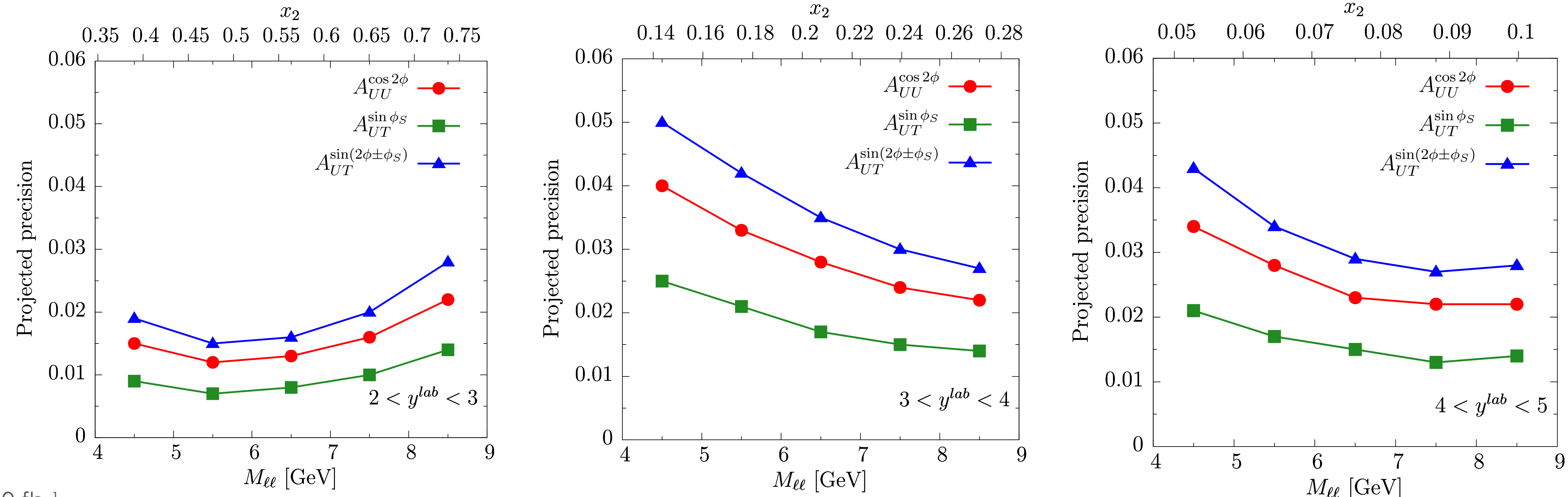
For instance, LHCb can measure nearly all quarkonia states (including C-even) with high precision!

The expected yields are much larger than previous fixed-target experiments

Mesons are unique observables, poorly accessible from other hadron-hadron experiments
[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 ($\mu^+\mu^-$)]

A golden channel like DY

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



L_{pp}~10 fb^{-1}

Expected statistical uncertainty on asymmetries in DY production at LHCb-like experiment

$$A_{UU}^{cos2\phi} \sim \frac{h_1^{\perp q} \otimes h_1^{\perp q}}{f_1^q \otimes f_1^q} \qquad A_{UT}^{sin\phi_S} \sim \frac{f_1^q \otimes f_{1T}^{\perp q}}{f_1^q \otimes f_1^q} \qquad A_{UT}^{sin(2\phi+\phi_S)} \sim \frac{h_1^{\perp q} \otimes h_{1T}^{\perp q}}{f_1^q \otimes f_1^q} \qquad A_{UT}^{sin(2\phi-\phi_S)} \sim \frac{h_1^{\perp q} \otimes h_1^q}{f_1^q \otimes f_1^q}$$

Excellent precision achievable for observables connected to (i.e.) the transversity, the Boer-Mulders function, the pretzelosity and the Sivers TMDs

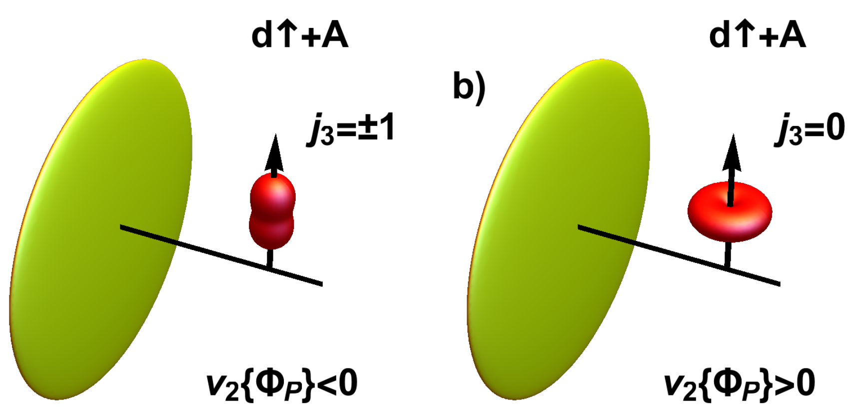
Elliptic flow in ultra-relativistic collisions with polarised deuterons

arXiv:1808.09840

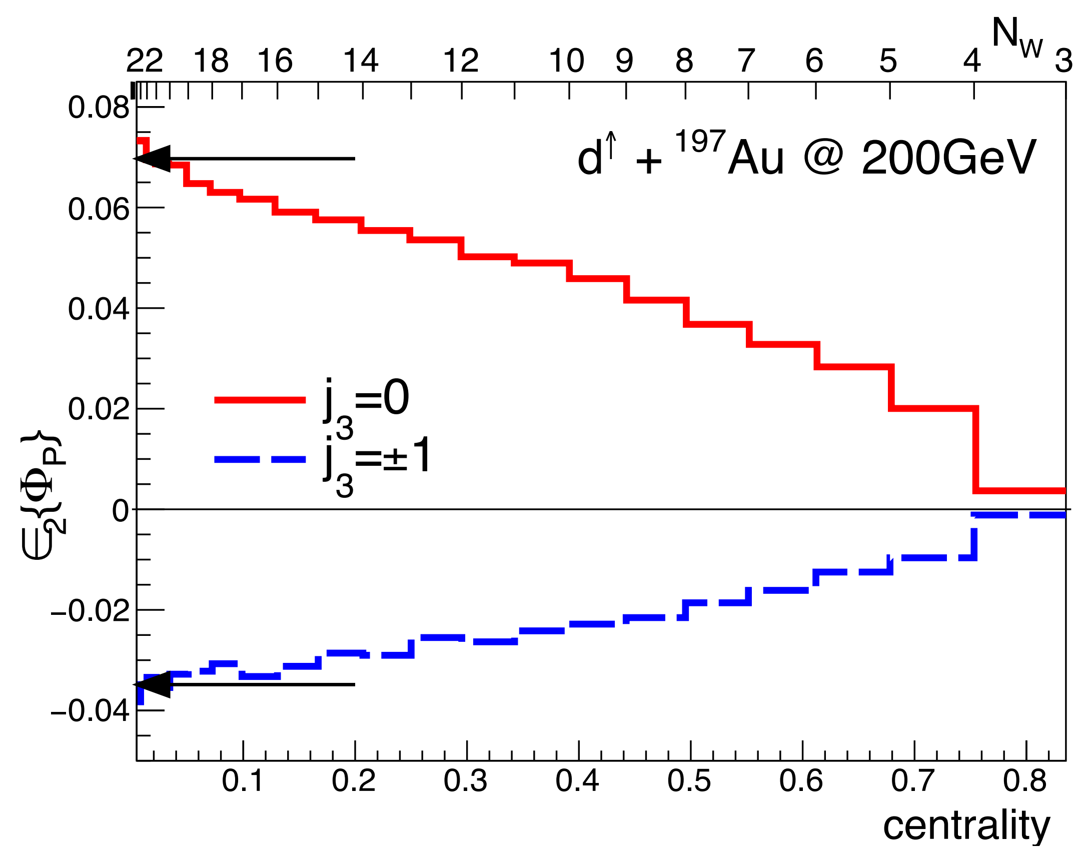
Ridge and flow measurements, connected to collectivity phenomena, are among the most interesting results achieved in the last years in the QGP physics.

We can put this in connection with spin clarifying the nature of dynamics in small systems

its experimental confirmation would prove the presence of the shape-flow transmutation mechanism, typical of hydrodynamic expansion, or rescattering in the later stages of the fireball evolution



ultra-relativistic d+A collision, where the deuteron is polarised along the axis ΦP perpendicular to the beam



Ellipticities of the fireball

A polarised D-beam at BNL will not come in a near future

A polarised target at LHC can easily provide Pb $D^{\uparrow}$ collisions

We are already on the road ...

SMOG2 *and* LHCspin

We are already on the road …

SMOG2

Phase I
unpolarised target

and

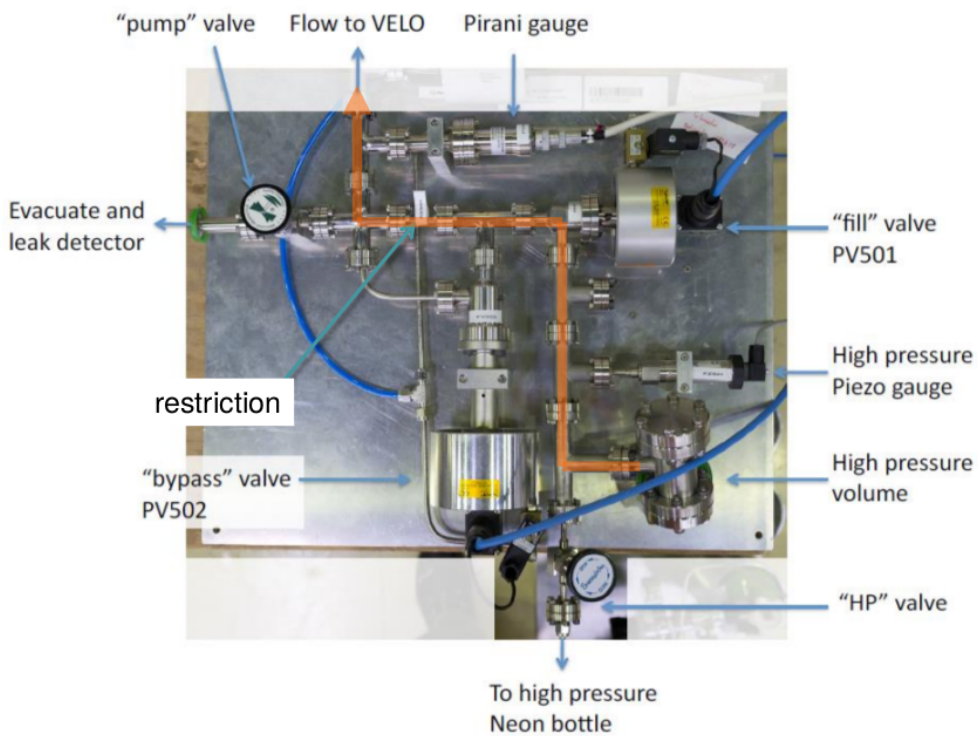
LHCspin

Phase II
transversely polarised H and D target

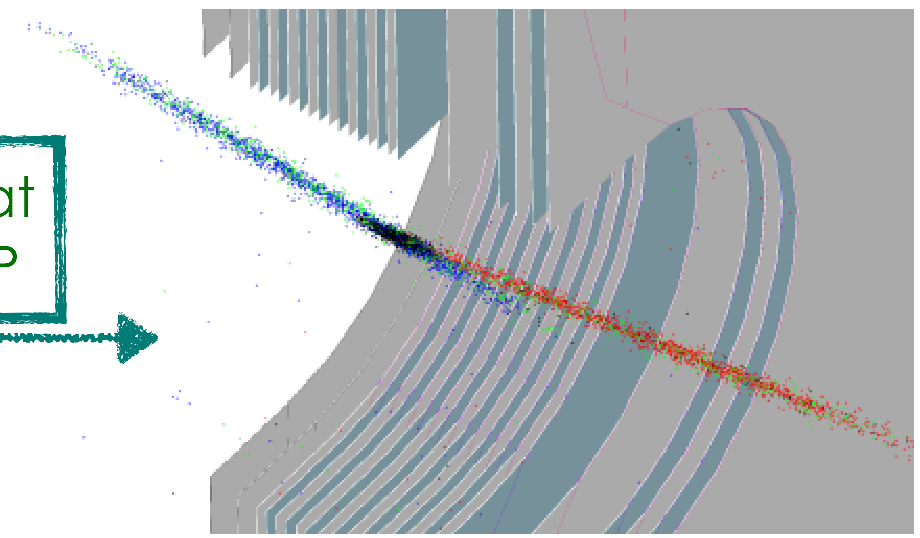
… at LHCb

SMOG, a successful idea and a pseudo-target

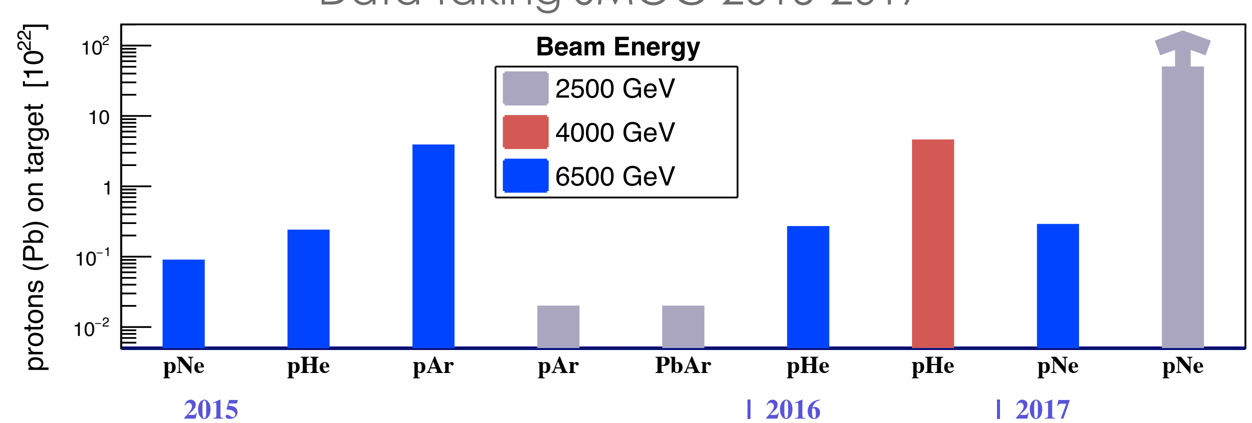
System for Measuring Overlap with Gas (SMOG) has been thought for precise luminosity measurements by beam gas imaging, but then it served as a "pseudo-target" producing interesting results



gas injection at the nominal IP



Data taking SMOG 2015-2017

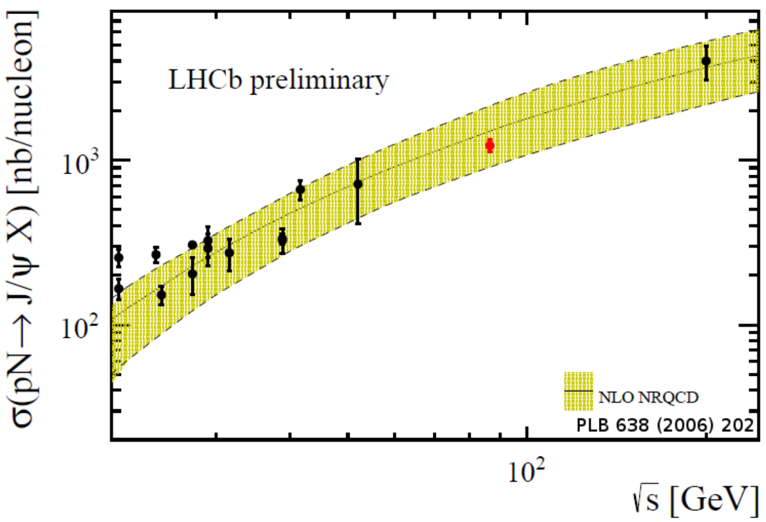


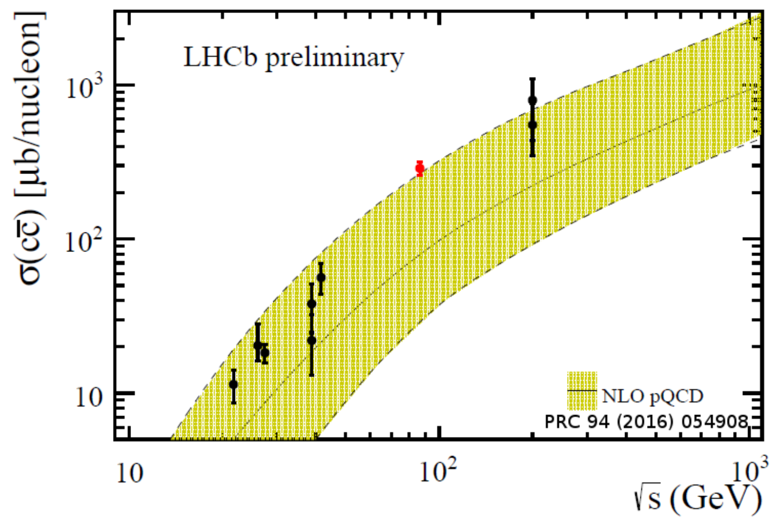
2 papers are going to be published on PRL:

- -antiproton production in p-He collisions @ 110 GeV — In print on PRL (arXiv:1808.06127)
- -charm (D^0 and J/ψ) production in p-Ar collisions @ 110 GeV — LHCb-CONF-2017-001

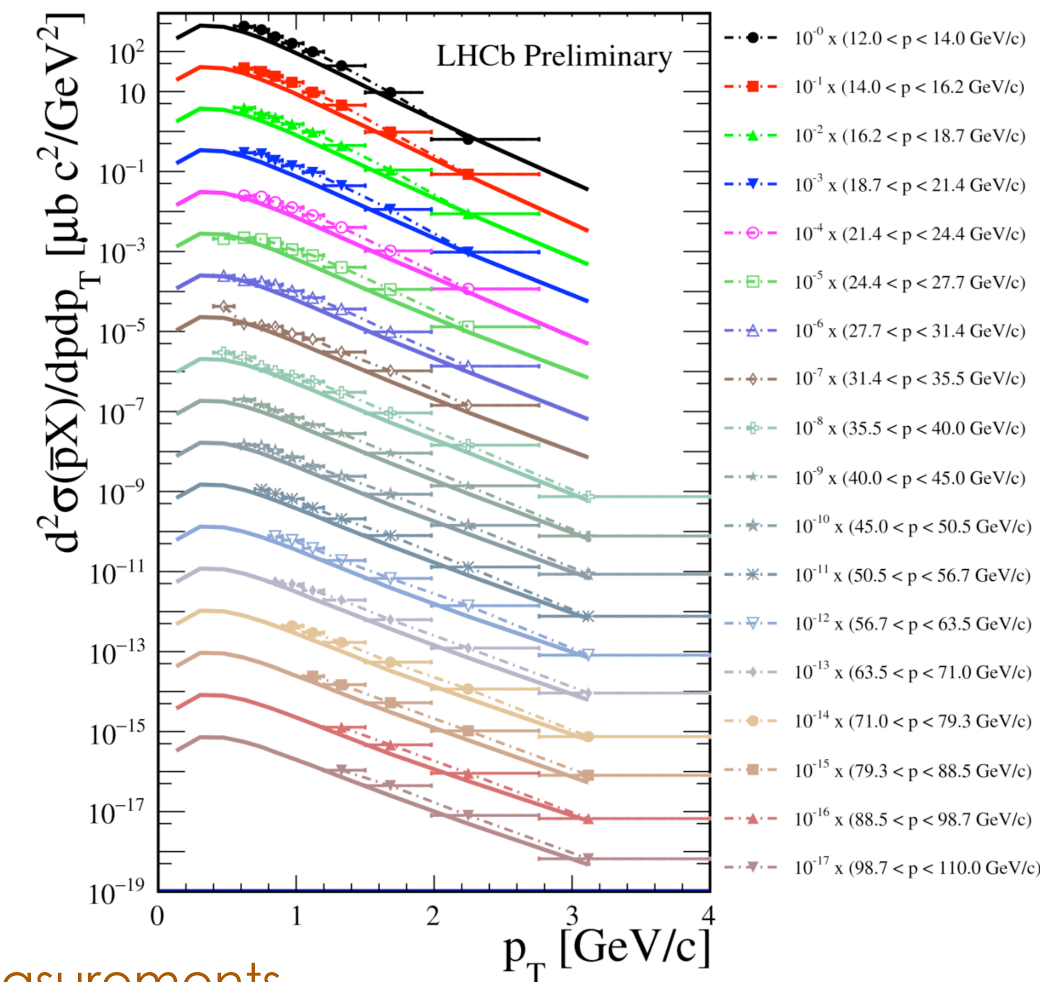
New perspectives in soft QCD for Cosmic Ray Physics

J/ψ e cc cross section as a function of the c.m. energy

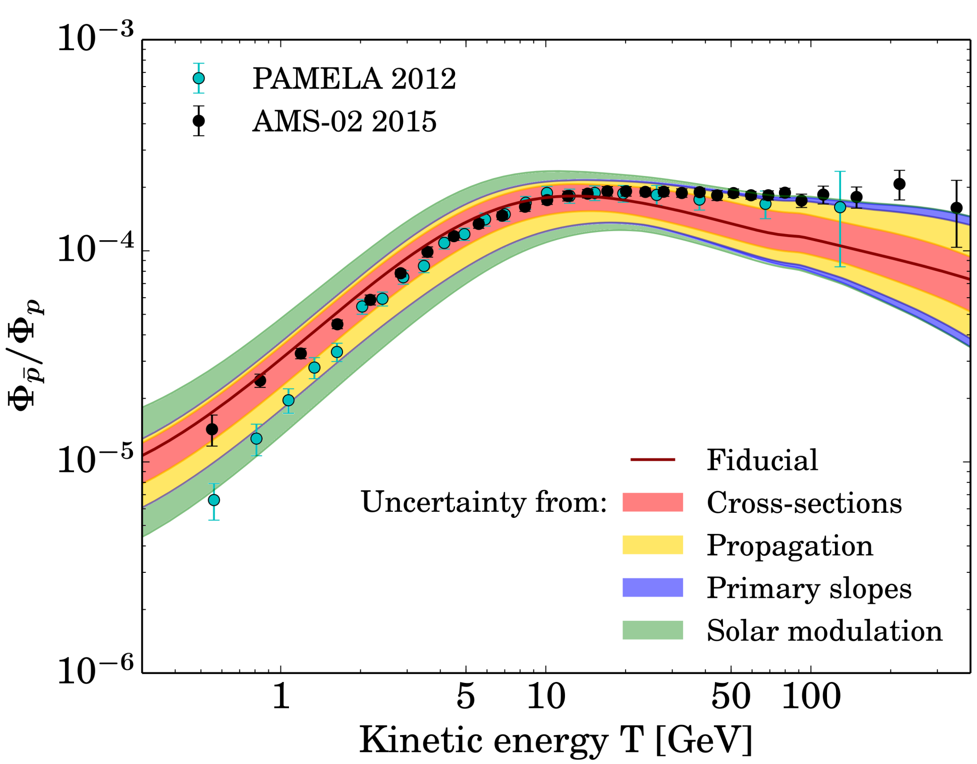


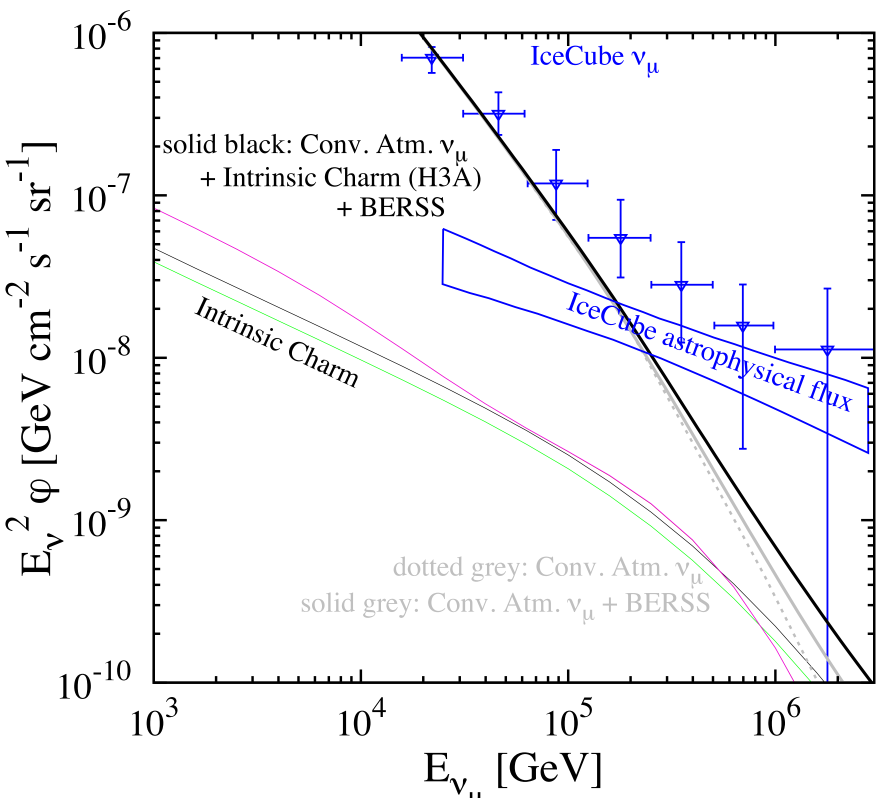


anti-p xsection



Large impact on the AMS (anti-p) and ICECUBE (open-charm) measurements



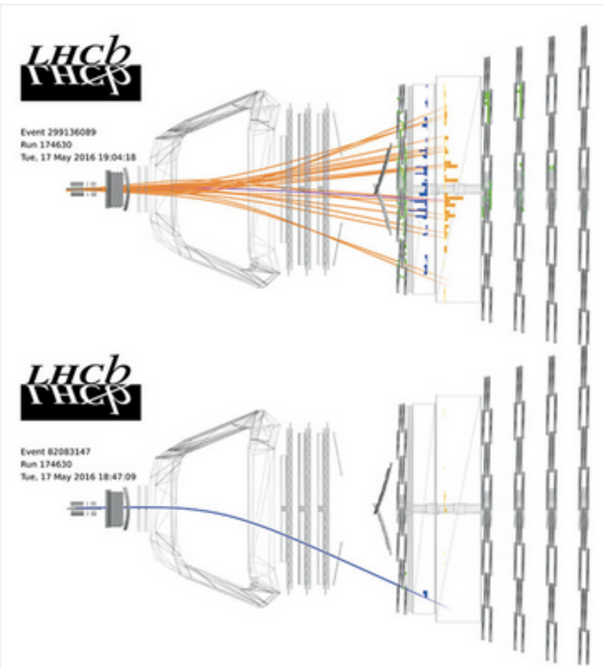


SMOG p-Neon data represent a valid model of the interaction in air. The energy corresponds to the 3rd-4th interaction for a 10^{10} GeV shower. Mid-rapidity measurements are useful for the lateral development of the showers

NEWS

LHCb brings cosmic collisions down to Earth

13 April 2017



Collision and scattering events (expand for full image)

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 cosmic rays outside of the Earth's atmosphere. By measuring the antimatter compon
can potentially unveil new high-e
notably a possible contribution fr
decay of dark-matter particles.

In the last few years, space-borne
study of cosmic rays have dramati
knowledge of the antimatter comp
Alpha Magnetic Spectrometer (AM

Cosmic collisions at the LHCb experiment

by *Stefania Pandolfi*

Posted by Stefania Pandolfi on 27 Mar 2017. Last updated 27 Mar 2017, 16.00.

Voir en français

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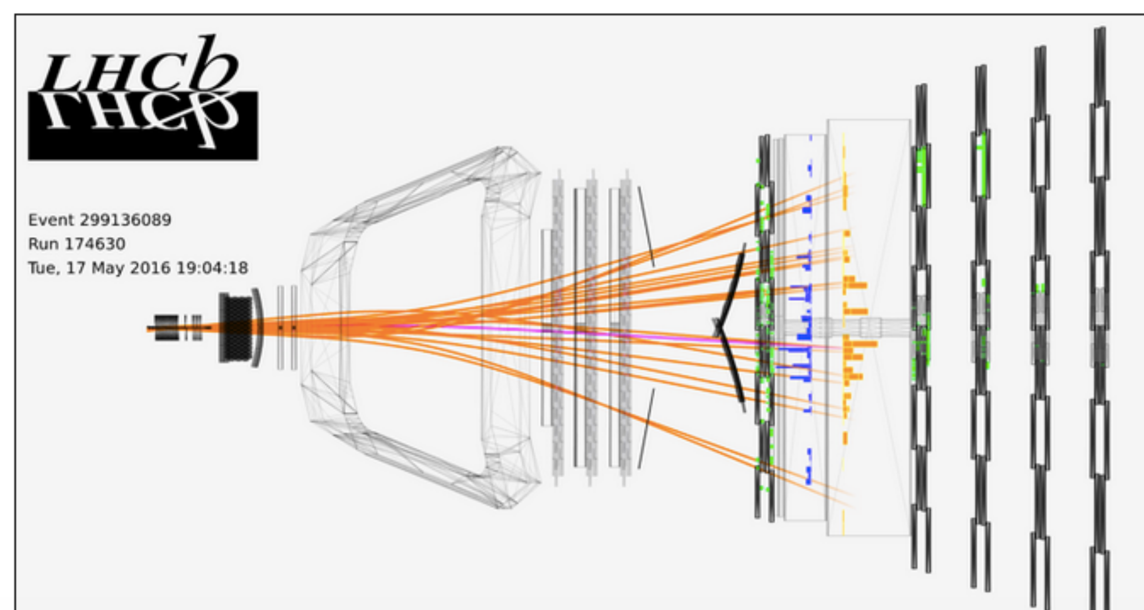


An example of a fully reconstructed proton-helium collision event in the LHCb detector. The particle

SMOG2 aims to built a real gas target (storage cell) in order to improve the SMOG performances and open the ground to the physics cases shown before

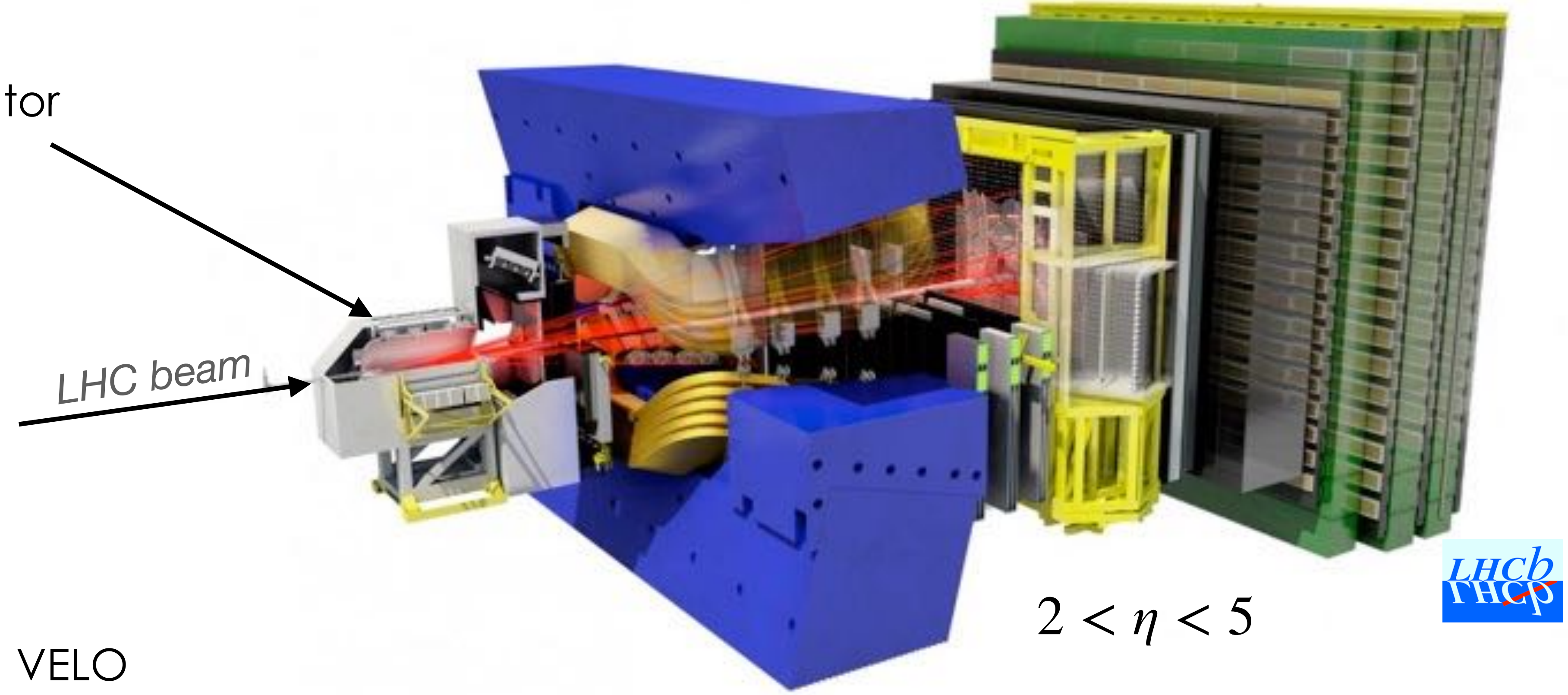
SMOG2 vs SMOG

- Increase of the luminosity by up to 2 orders of magnitude using the same gas load of SMOG
- Injection of $H_2, D_2, {}^{3,4}He, N_2, Ne, Ar, Kr, Xe$
- Multiple gas lines
- New Gas Feed System. Gas density measured with high precision
- Well defined interaction region upstream the IP@13TeV: strong background reduction, no mirror charges effect, possibility to use all the bunches

SMOG2 can run in synergy with the pp physics at 13 TeV

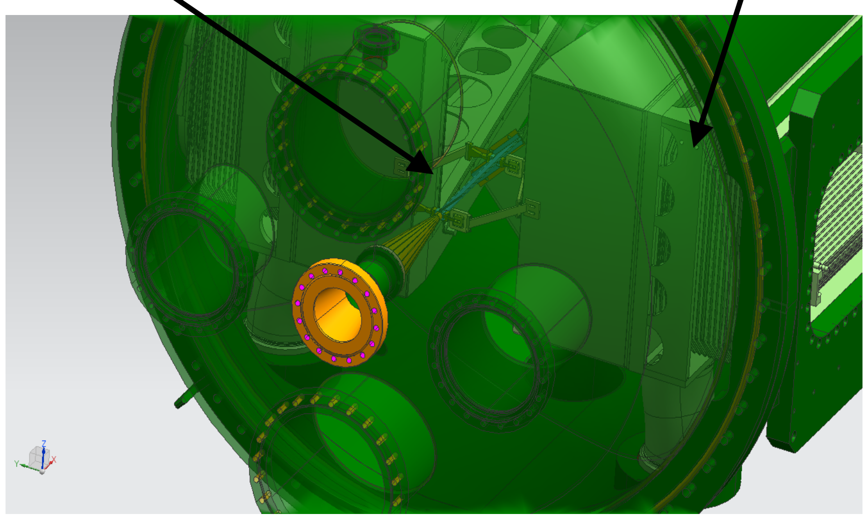
VELO
silicon VErtex LOcator

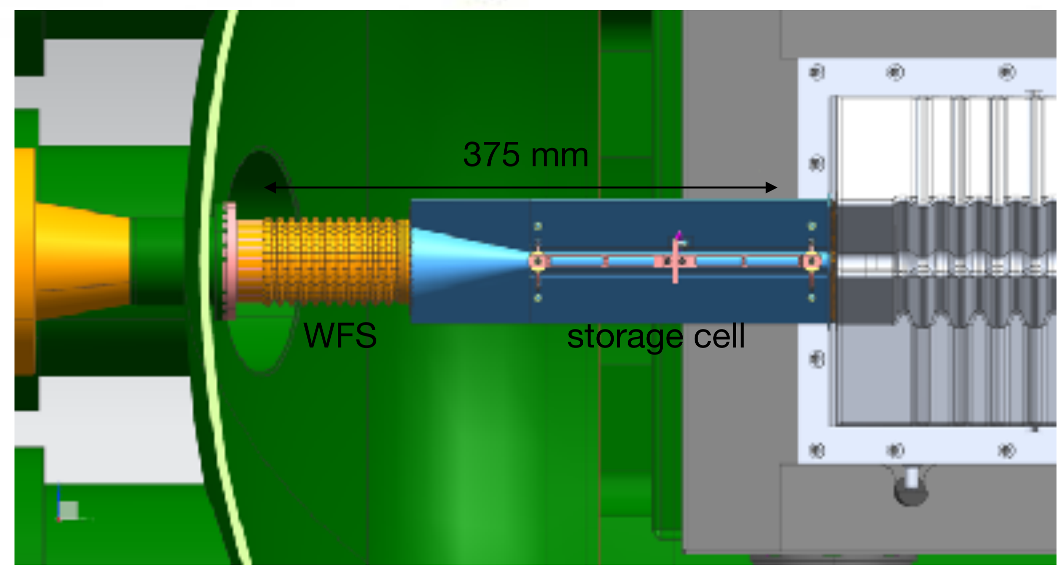
No changes are requested to the main spectrometer



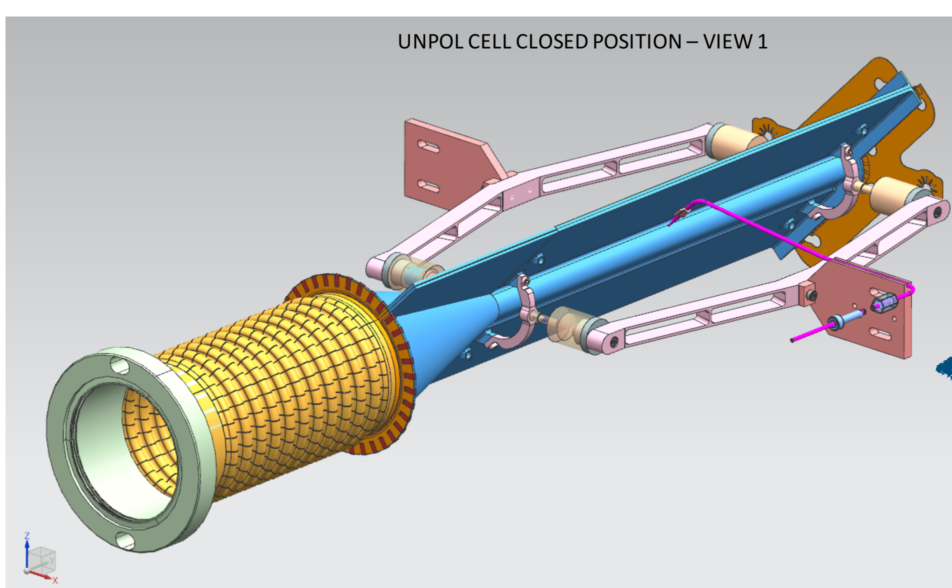
SMOG2

VELO

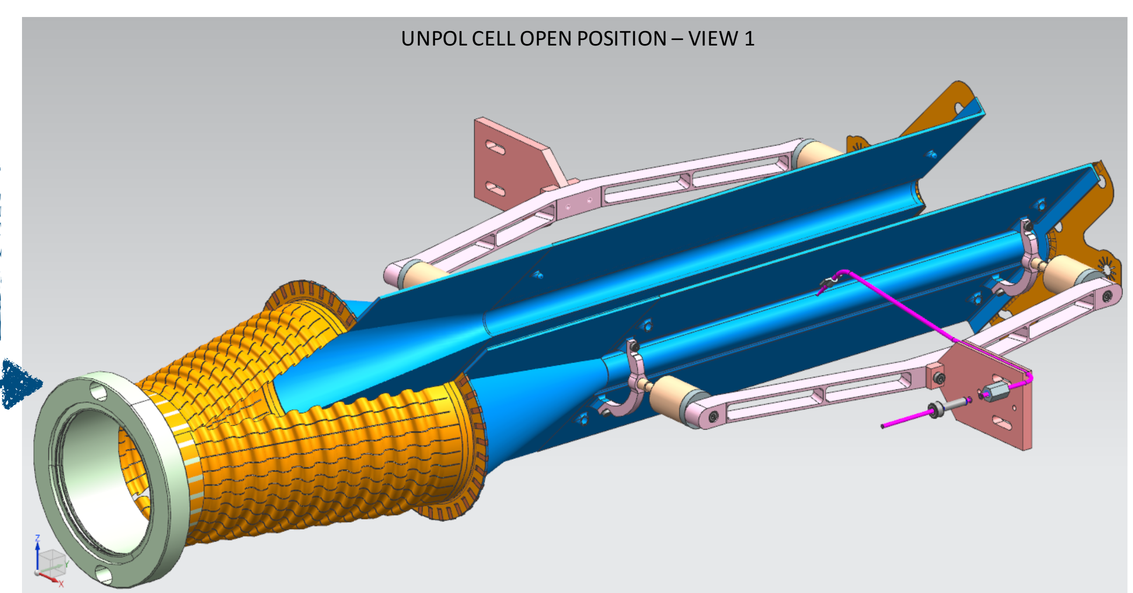




Internal side view



openable storage cell



Statistics in full synergy mode (1 yr data taking)

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

R&D basically completed

- *reconstruction efficiencies of major physics channels*
- *interaction with LHC:*
  - *-vacuum*
  - *-impedence*
  - *-aperture*
  - *-coating*
  - *-beam stability (SEY)*
- *target prototypes and tests*
- *induced heating and bake-out stress*
- *WFS prototypes and stress test*
- *Material budget and Background Induced on LHCb*

Informal green lights from both LHC and LHCb
Formal approval in Fall after EDR and LMC meetings

Installation foreseen during the LHC LS II (2019-2020)

R&D

SMOG2

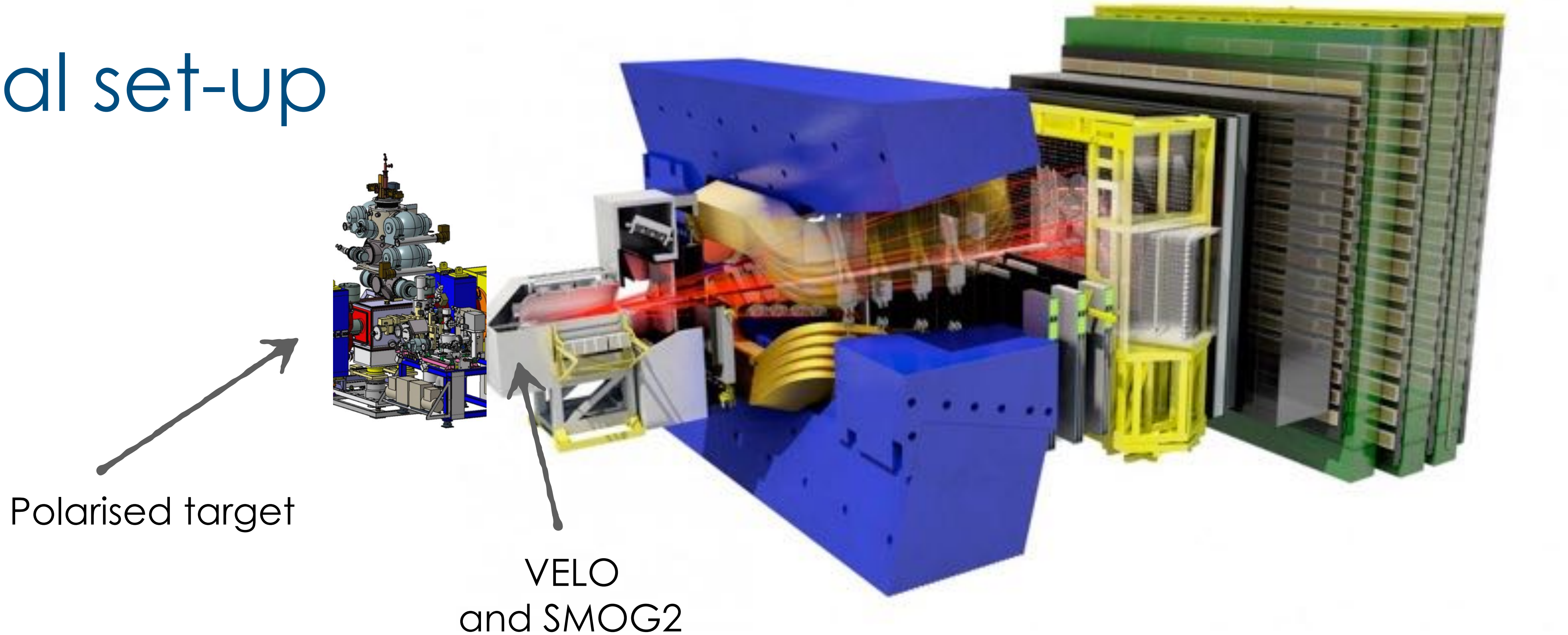
not only a project itself

LHCspin

Phase II transversely polarised H and D target

... at LHCb

Experimental set-up

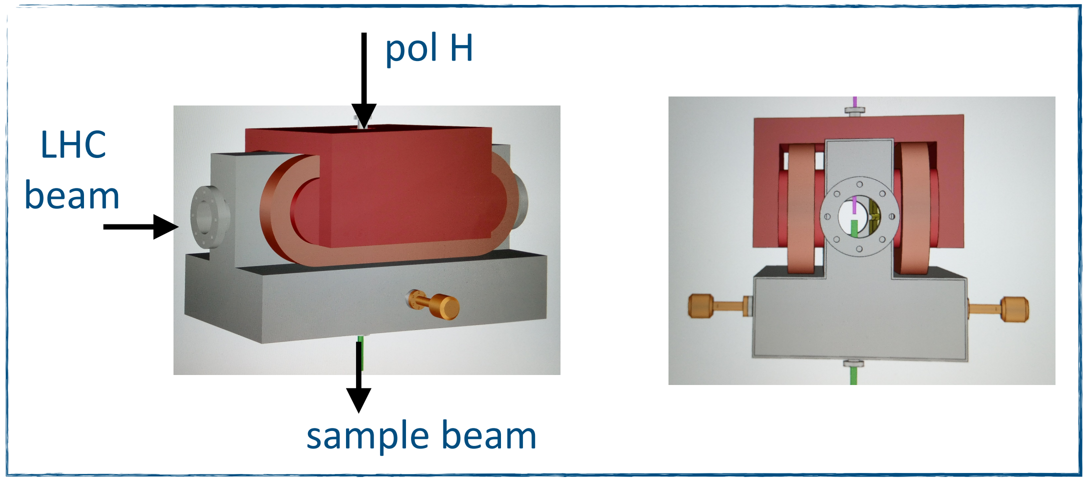


Well consolidated technique

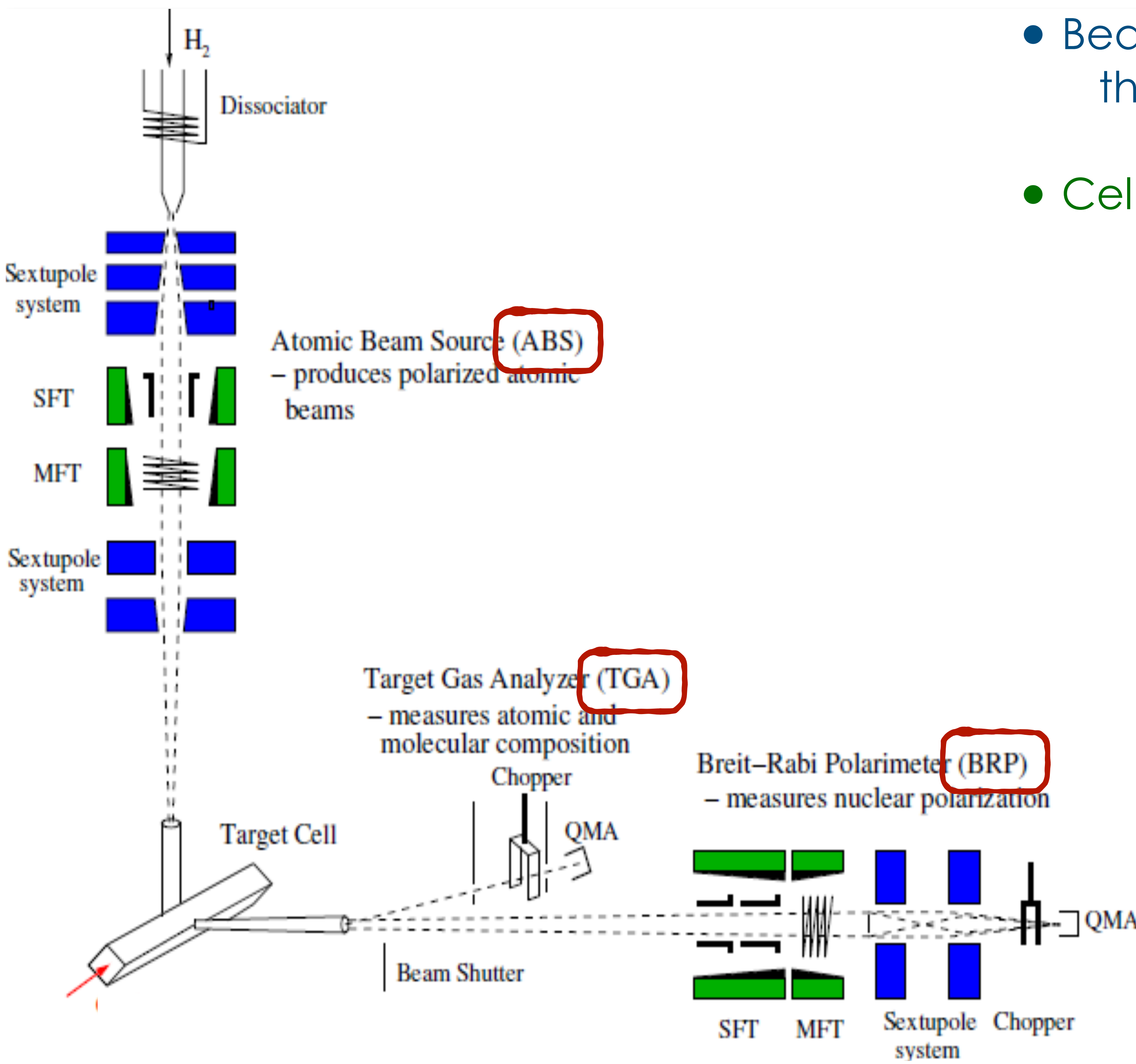
Design follows the successful HERMES Polarised Gas Target which ran at HERA 1996 – 2005, and the follow-up PAX target operational at COSY (FZ Jülich)

Important differences (i) HERA: multi-user facility (together with ZEUS, H1, HERA-B), but in case of problems usually access was granted quite timely; (ii) COSY: single-user, so access by decision of experimental group.
Requirements for LHC: (i) extreme reliability of all safety systems, in particular the vacuum interlock ABS-TC; (ii) very long running times without possibility of interventions

Completely different requirements for coating of surfaces



- Injected intensity of H-atoms = $6.5\ 10^{16}$/s
- Standard Feed Tube 1.0 cm i.d., 10 cm long
- Beam tube 30x1 cm
- Cell temperature T ~ 100K
- Areal Density $\approx 1.2 \cdot 10^{14}$ cm^2



- Beam Induced Depolarisation better in LHC than at HERA

- Cell coating: the proven Drifilm surface as a polymere is forbidden at the LHC. Carbon-type surfaces + ice layer seems the best solution for the target coating in order to prevent the atomic recombination

Small impact on the LHC beam life-time: reduction ~7%

The R&D is going on and it will speed up after the SMOG2 approval

We aim for the installation during the LHC LSIII(2024-…)

E.Steffens' talk
Design of a Polarized Gas Target (PGT) for the LHC
Monday 10/9, afternoon

Alice is investigating the possibility for a fixed target as well

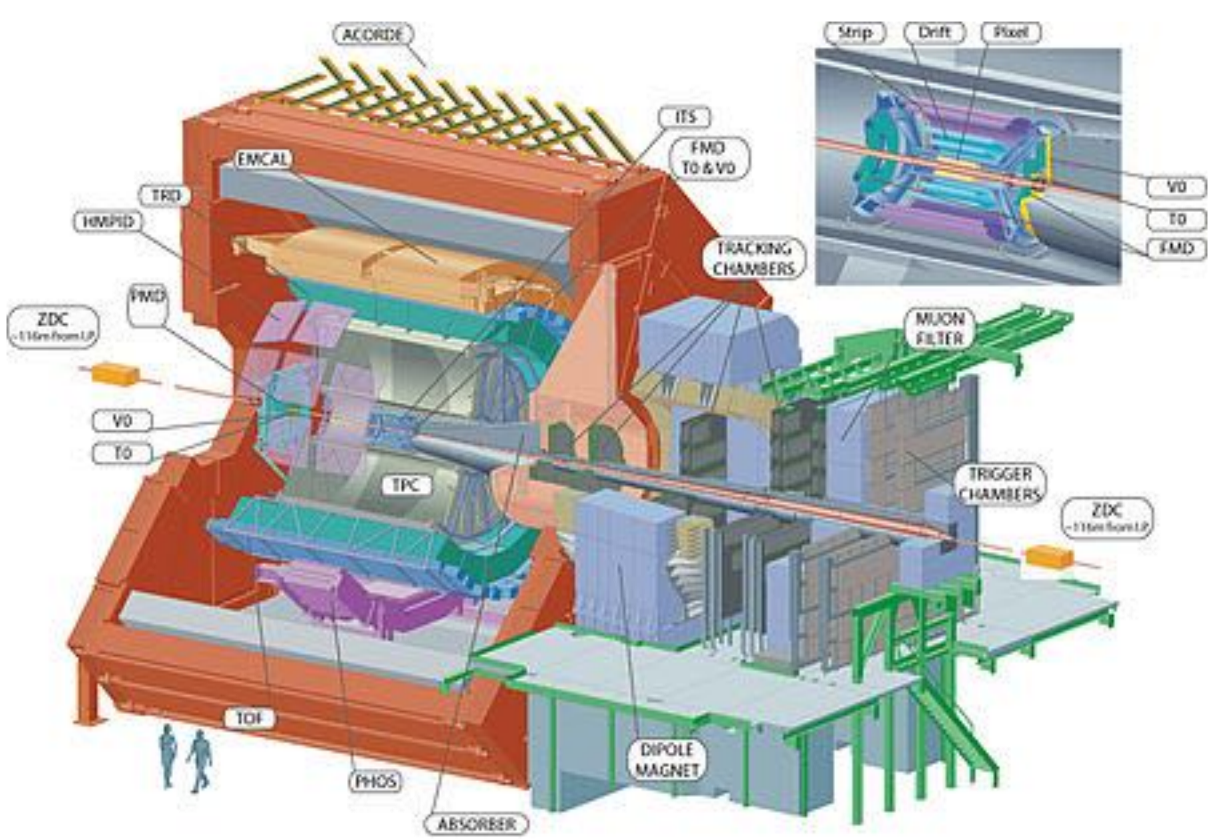
from L.Massacrier talk

- Feasibility of using an internal gas target at the LHC demonstrated by LHCb collaboration with the SMOG system. Limited running time (pumping system limited), no target polarisation, only low density noble gases, typical L_{int} ~ few to O(100) nb^{-1} in pA

- Storage Cell gas target (HERMES experiment like target) can permit to increase the gas density by several orders of magnitude. Gas densities reached with a storage cell already too large for ALICE data taking capabilities

- Gas jet option (H-jet polarimeter at RHIC like): already provides large gas densities compatible with ALICE setup

- Another way of making fixed target collisions compatible with the ALICE setup is to use an internal solid target (coupled to a bent crystal)



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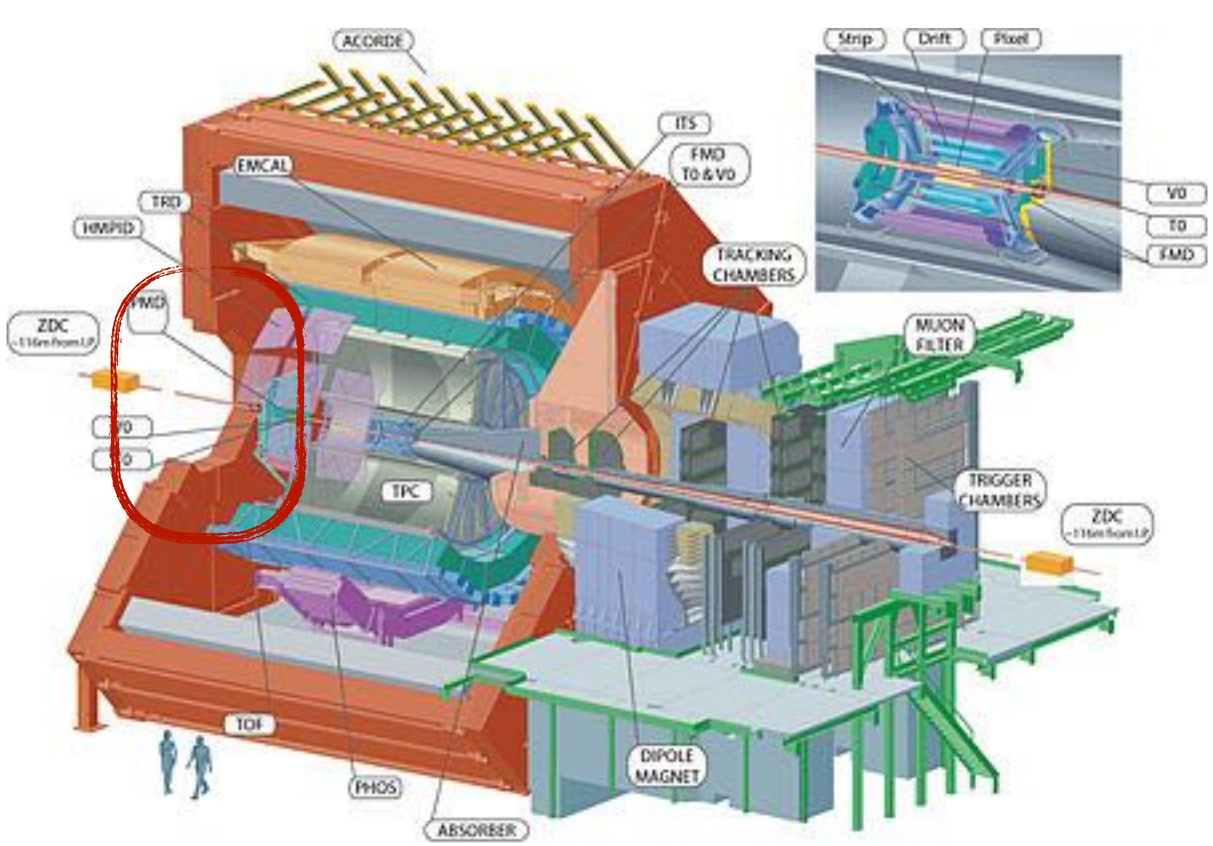

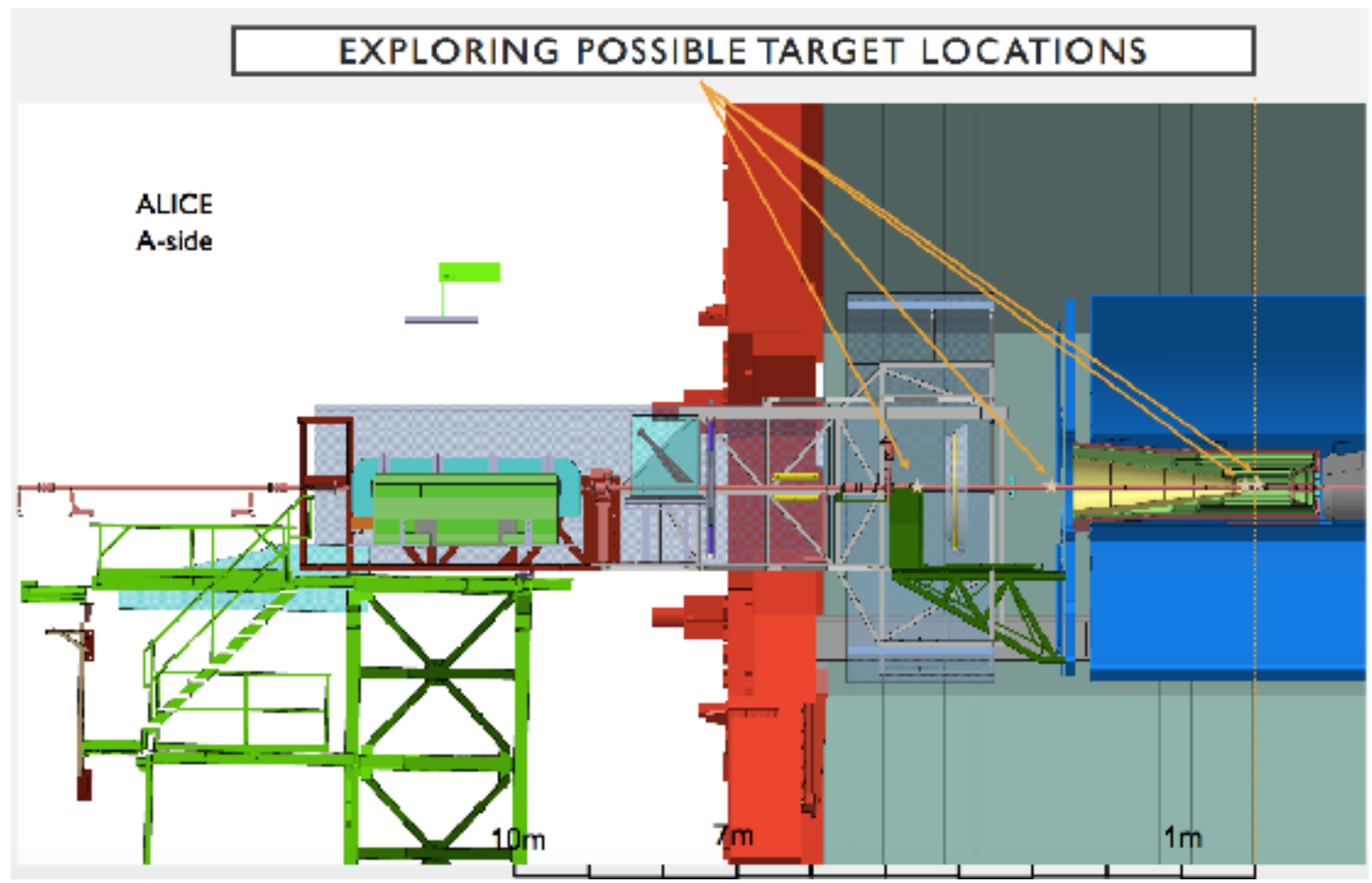

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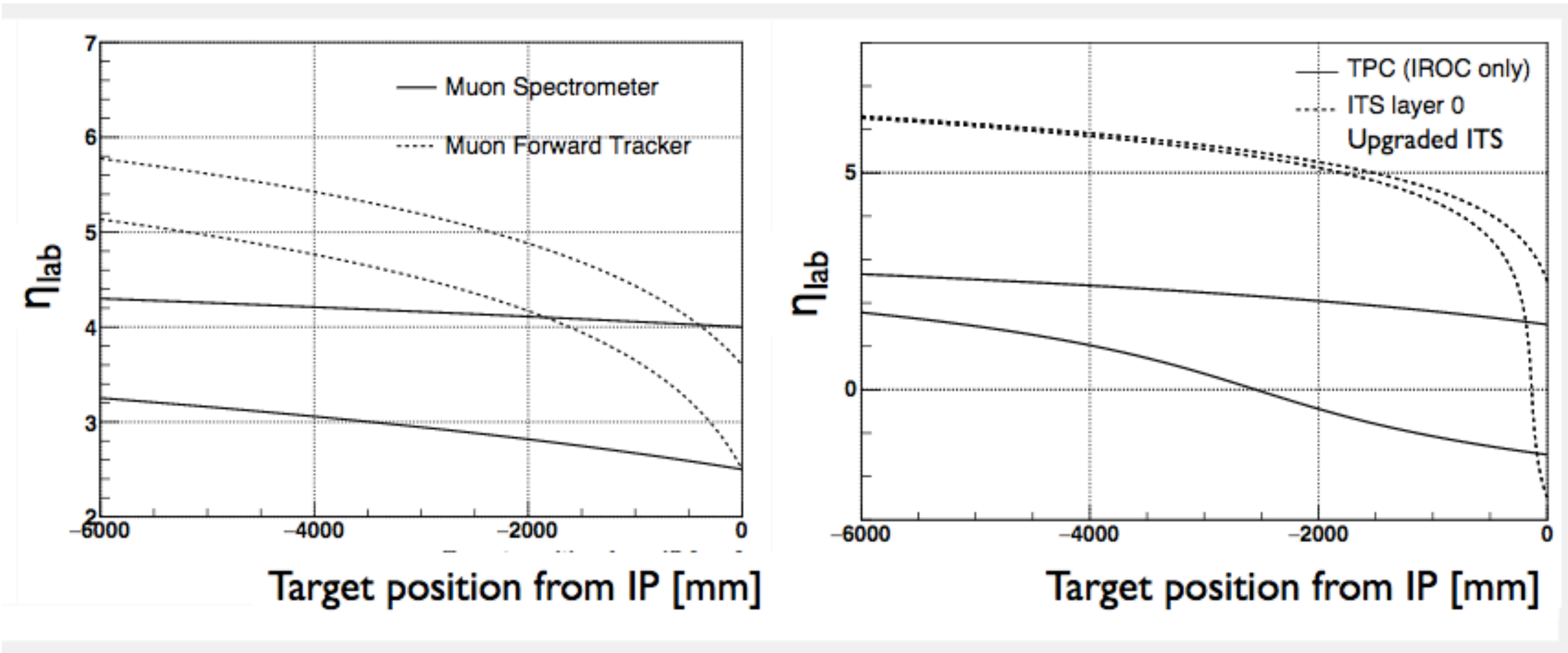

Caveats:
-disadvantaged by the cylindrical geometry of the main spectrometer
-muon arm (+absorber) poorly instrumented and far away from the IP
-there is no obvious place for the installation of an (un)polarised target

Conclusions

Fixed target collisions at the LHC represent an unique possibility for *a laboratory for QCD* in unexplored kinematic regions … in a realistic time schedule

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LHCb is very focussed on the project:

- SMOG2 is a reality and is foreseen to take data from 2021
- The R&D for LHCspin represents a fantastic challenge and is on its road

ALICE is investigating the possibility to install a fixed target

LHC spin informal meeting

to whom is interested

Tomorrow, Thursday, at 14.30 in the room MR1