LHC Run 3 and Run 4 prospects for heavy-ion physics with LHCb

Pasquale Di Nezza

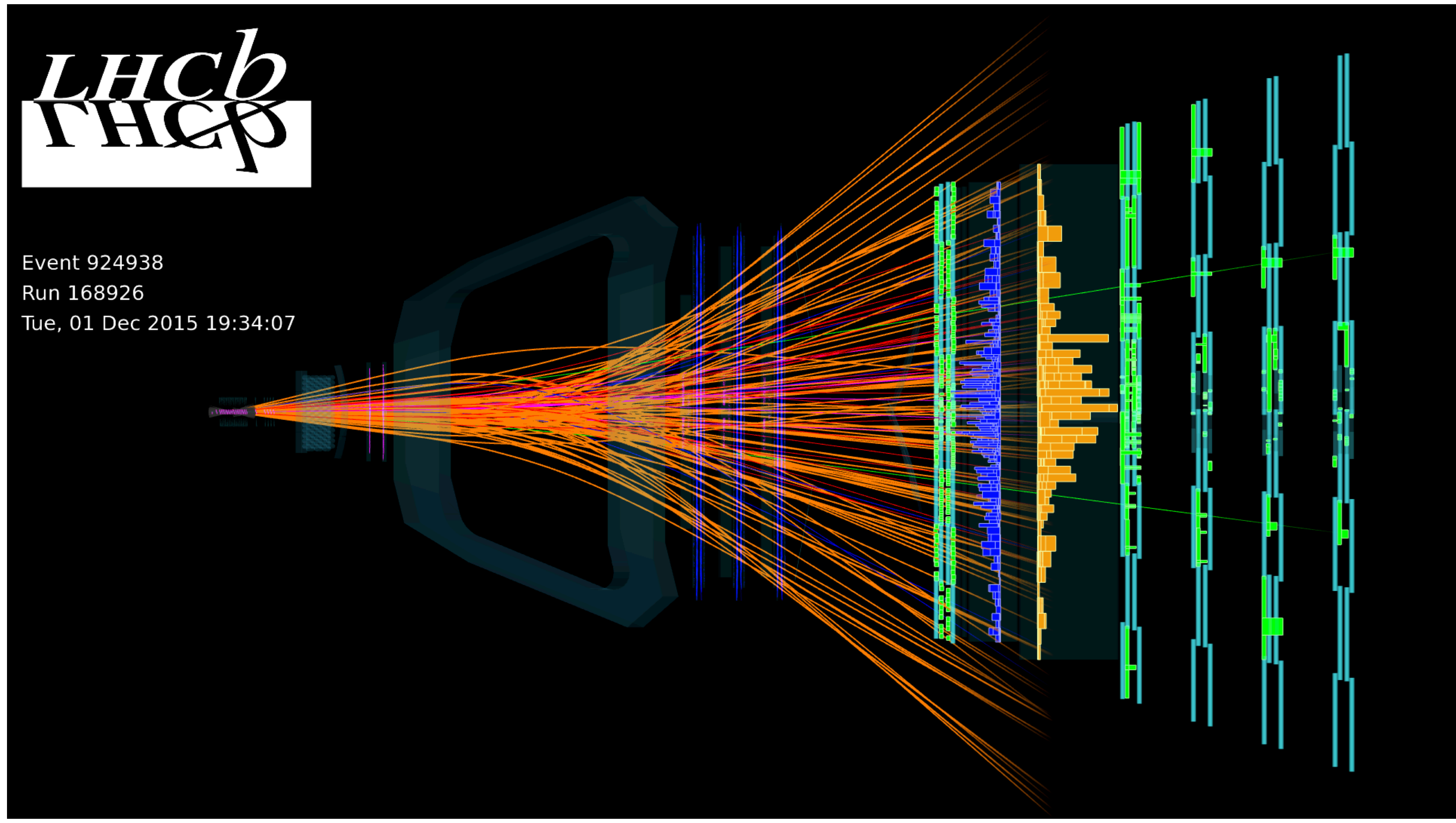
INFN LNF
Istituto Nazionale di Fisica Nucleare

on behalf of the LHCb *collaboration*

Wuhan, 05/11/19

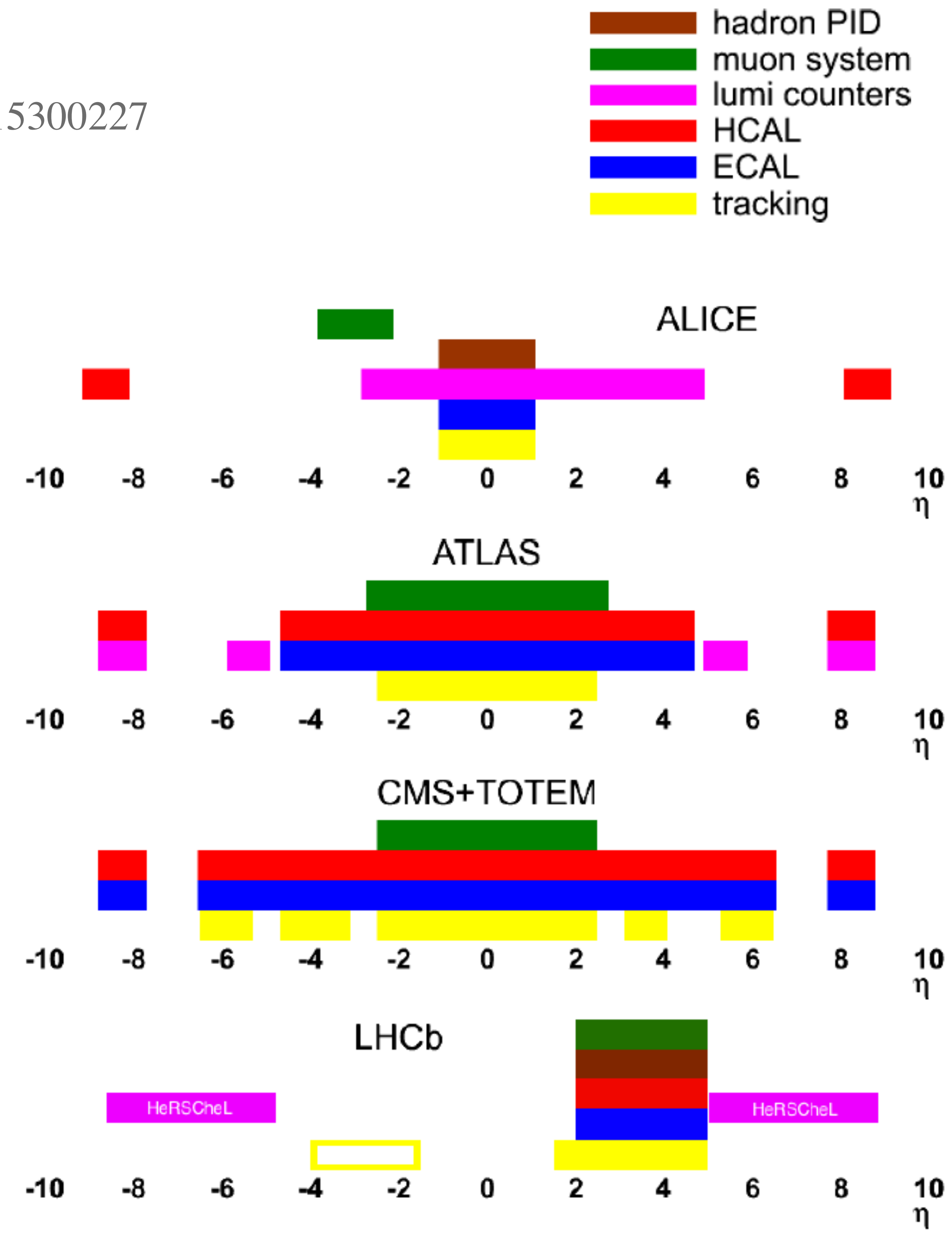
LHCb, specialized in heavy flavour precision physics, discovered its potentialities in HI in 2015:

- forward region $2<\eta<5$ fully instrumented
- precise vertexing: separation of prompt production from HF decay products
- precise tracking: reconstruction down to $p_T=0$
- particle identification: full reconstruction of hadronic decays of charm and beauty
- low pileup, ideal for recording high multiplicities



JINST 3 (2008) S08005
IJMPA 30 (2015) 1530022

DOI: 10.1142/S0217751X15300227



PbPb Data Sets:

- $\sqrt{s_{NN}}$ = 5 TeV in 2015: 10 μb^{-1}
- $\sqrt{s_{NN}}$ = 5 TeV in 2018: 210 μb^{-1}

pPb/Pbp Data Sets:

- $\sqrt{s_{NN}}$ = 5 TeV in 2015: 1.6 nb^{-1}
- $\sqrt{s_{NN}}$ = 8.16 TeV in 2018: 30 nb^{-1}

Published results

Title	Details	Reference
open beauty in p-Pb 8 TeV	PAPER-2018-048	Phys. Rev. D 99, 052011
Status and Prospects for Fixed Target Physics (PBC)	LHCB-PUB-2018-015	
SMOG2 Technical Design Report	LHCB-TDR-020	
Projections for pPb analyses in Run 3 and Run 4	LHCB-CONF-2018-005	
First measurements of charm production fixed-target configuration at the LHC	PAPER-2018-023	PRL 122 (2019) 132002
Study of Upsilon production in pPb collisions at √sNN=8 TeV	PAPER-2018-035	JHEP11(2018)194
Prompt Lc production in pPb collisions at √sNN=5.02 TeV	PAPER-2018-021	JHEP 02 (2019) 102
Measurement of antiproton production in pHe collisions at √sNN=110 GeV	PAPER-2018-031	PRL 121 (2018) 222001
Study of prompt D0 meson production in pPb collisions at √sNN=5 TeV	PAPER-2017-015	JHEP 10 (2017) 090
Prompt and nonprompt J/ψ production and nuclear modification in pPb collisions at √sNN=8.16 TeV	PAPER-2017-014	PLB 774 (2017) 159
Study of ψ(2S) production and cold nuclear matter effects in pPb collisions at 5 TeV	PAPER-2015-058	JHEP 03 (2016) 133
Measurements of long-range near-side angular correlations in sNN=5 TeV proton-lead collisions in the forward region	PAPER-2015-040	PLB 762 (2016) 473
Observation of Z production in proton-lead collisions at LHCb	PAPER-2014-022	JHEP 09 (2014) 030
Study of Y production and cold nuclear matter effects in pPb collisions at 5 TeV	PAPER-2014-015	JHEP 07 (2014) 094
Study of J/ψ production and cold nuclear matter effects in pPb collisions at 5 TeV	PAPER-2013-052	JHEP 02 (2014) 72

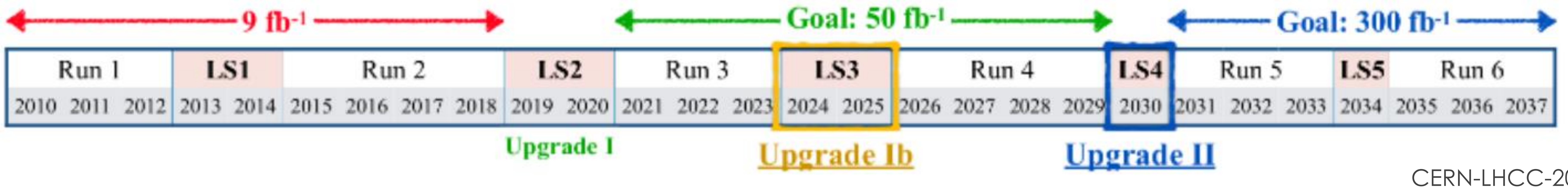
Ongoing analyses:

- Flow analysis
- Low/intermediate mass dileptons (thermal radiations) analysis
- Correlations: Double J/ψ, double-D, ...
- Drell-Yan
- ...

QM19

4 talks + 5 posters

LHCb upgrade schedule



CERN-LHCC-2012-007

Improvements in the phase I

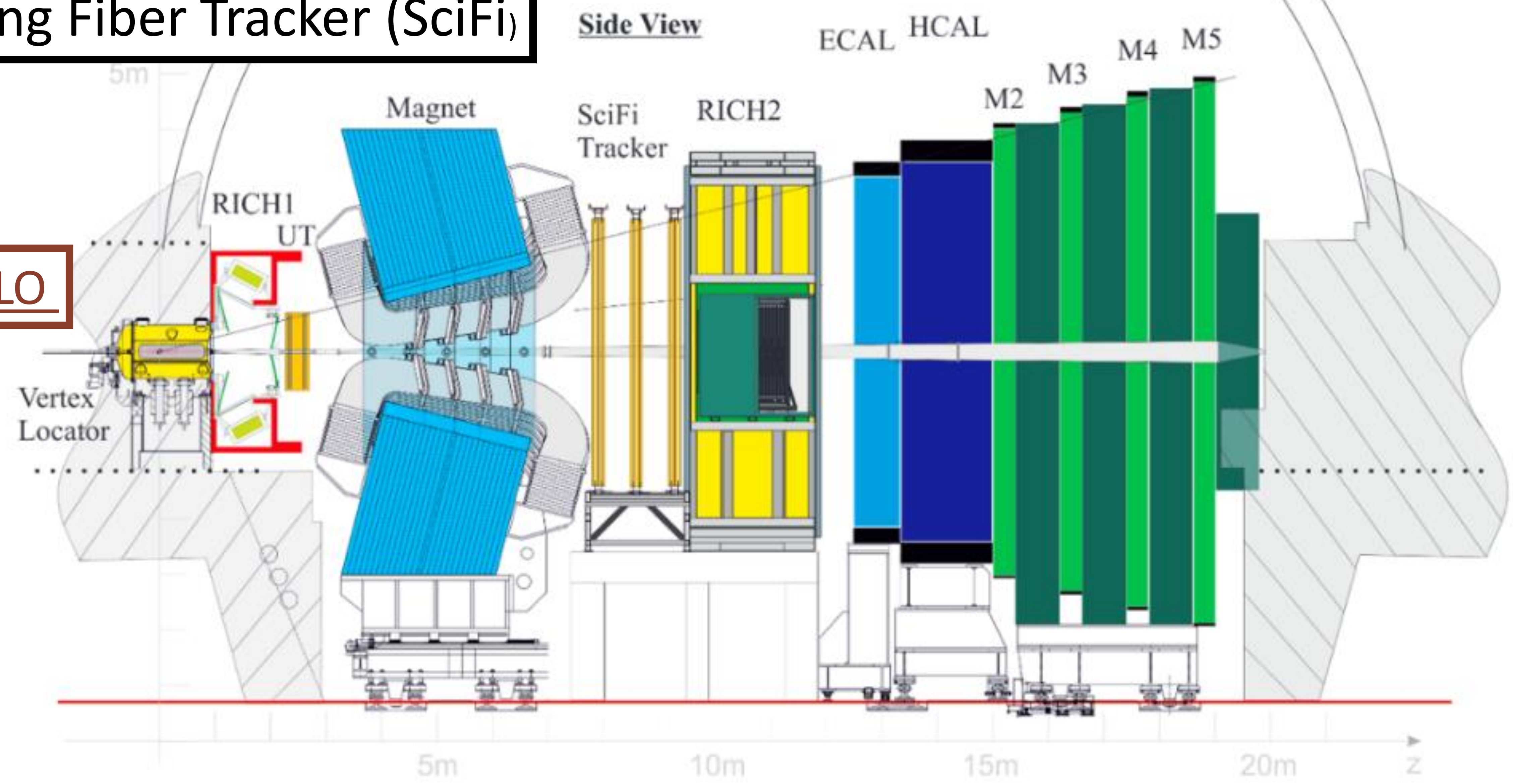
- Collision rate at 40 MHz
- Pile-up factor $\mu \approx 5$
- Remove L0 triggers (software trigger)
- Read out the full detector at 40 MHz
- Replace the entire tracking system

substantial improvements to HI, mainly for the possibility to reach more central PbPb collisions (up to 30%)

New Tracking system :
- Silicon upstream detector (UT)
- Scintillating Fiber Tracker (SciFi)

New electronics for muon and calorimeter systems

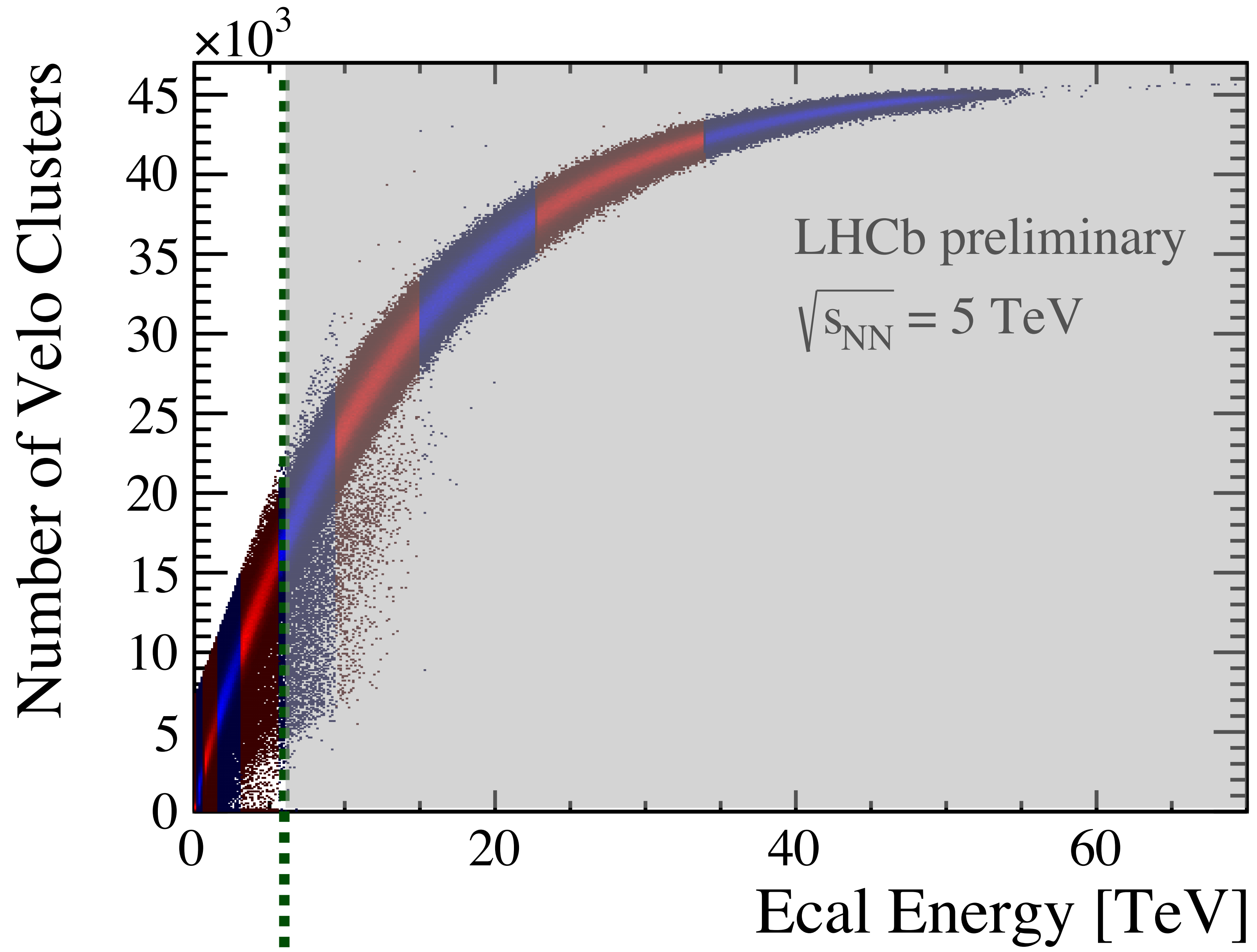
New pixel VELO



New RICH optics and photodetectors

LHCb upgrade schedule

Run 2

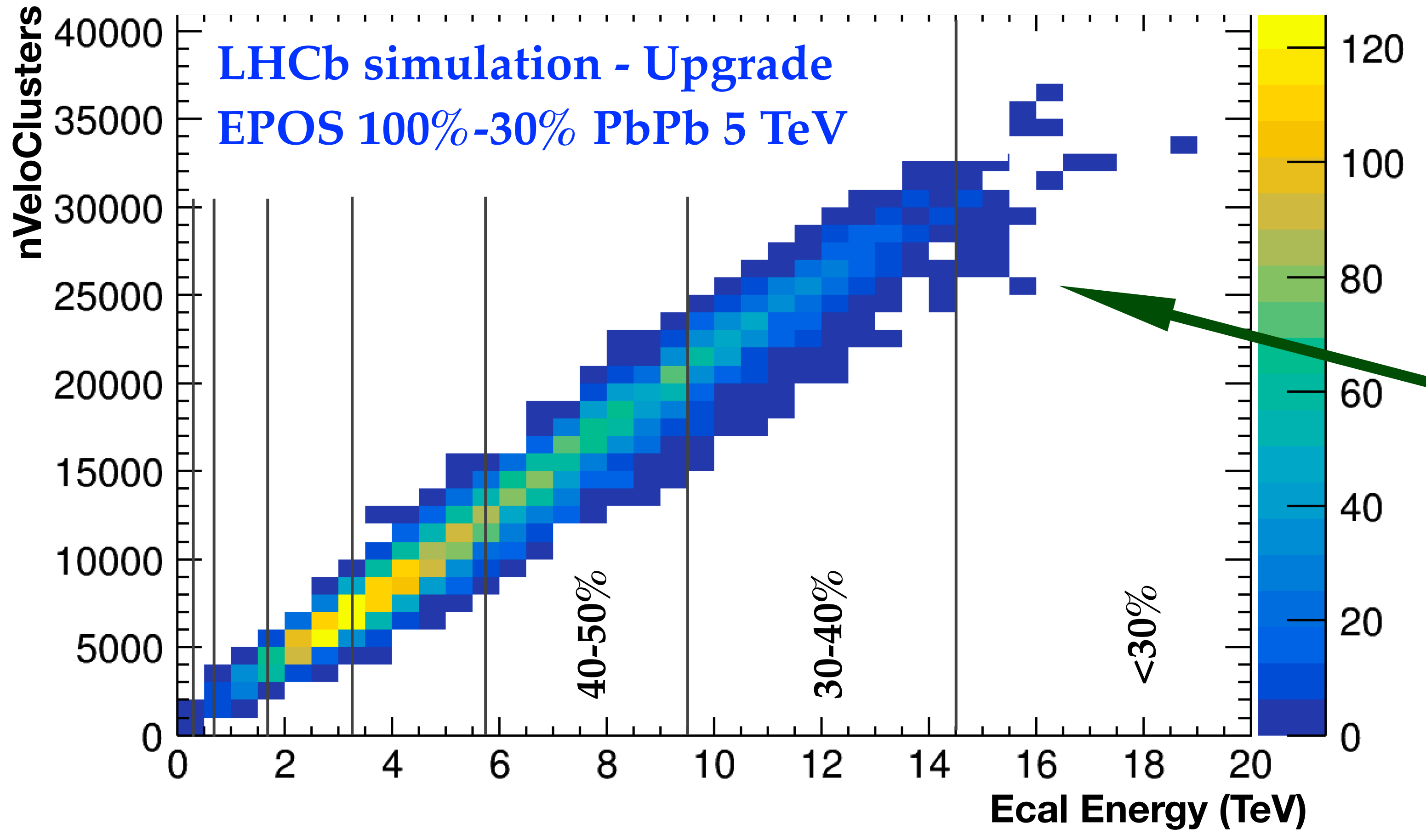


60% less central

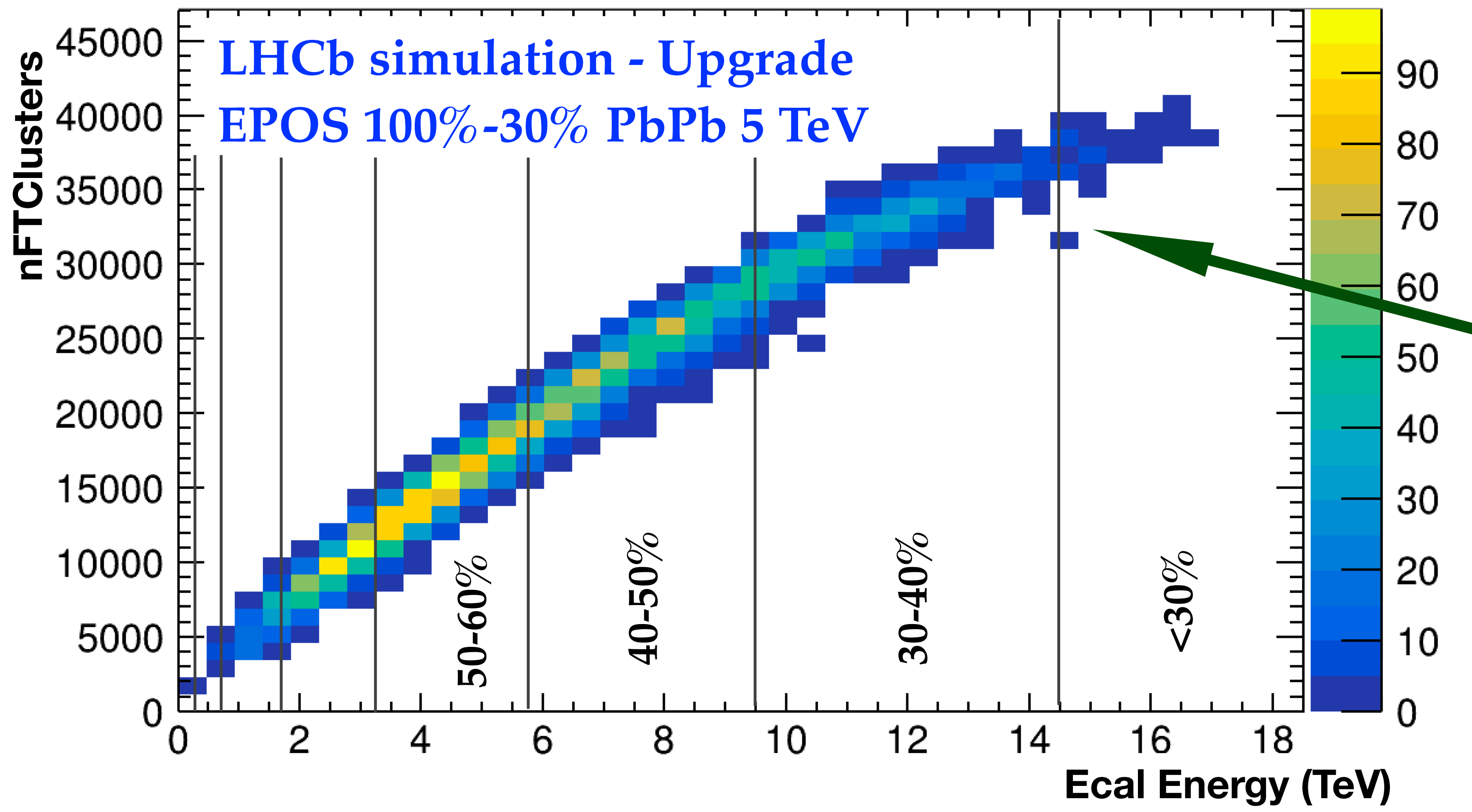
40% more central

Due to the VELO saturation, reconstruction limited to 60% less central

Run 3



New Vertex Locator does not saturate



Expect SciFi to saturate in most central collisions

LHCb upgrade schedule

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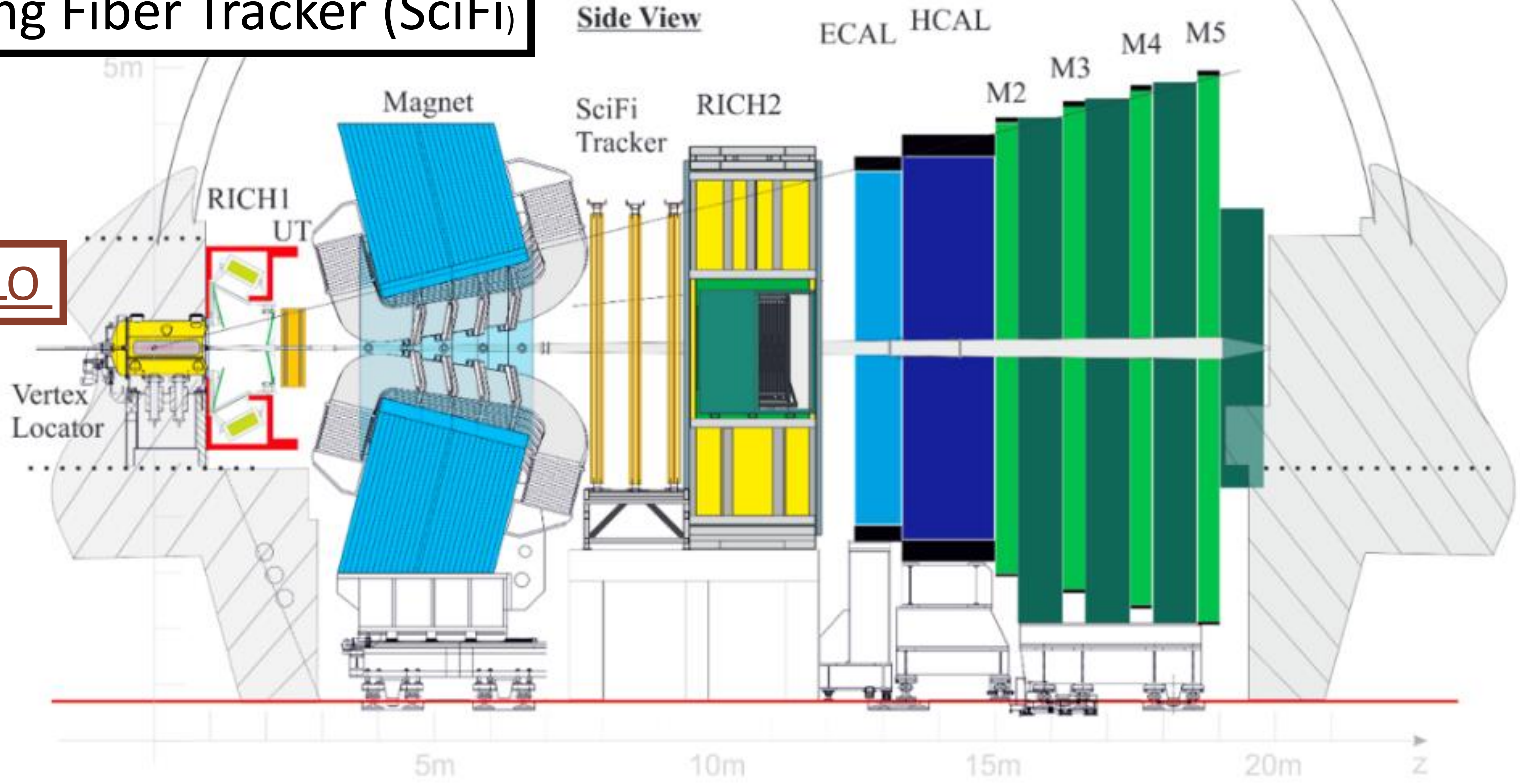

New RICH optics and photodetectors

- LS3 (2024 – 2026) Upgrade 1b for Run 4

  Proposal for a new tracker (stage 1): Inner tracker – 100 μm X 500 μm pixels or 0.1 mm X 100 mm strips
- LS4 (2030 – 2031) Upgrade 2 for Run 5, …

  Proposal for a new tracker (stage 2): Inner tracker + Middle tracker

no more limitations on the centrality

Possible LHC Run3 and Run4 schedule

LHC

HL-LHC

LS2 - LHCb upgrade Ia

Run3

LS3 - LHCb upgrade Ib

Run4

LS4 - LHCb upgrade 2

Run5

arXiv:1812.06772 - CERN-LPCC-2018-07

Year	Systems, $\sqrt{s_{\mathrm{NN}}}$	Time	L_{int}
2021	Pb–Pb 5.5 TeV	3 weeks	2.3 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2022	Pb–Pb 5.5 TeV	5 weeks	3.9 nb^{-1}
	O–O, p–O	1 week	500 $\mu\mathrm{b}^{-1}$ and 200 $\mu\mathrm{b}^{-1}$
2023	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2027	Pb–Pb 5.5 TeV	5 weeks	3.8 nb^{-1}
	pp 5.5 TeV	1 week	3 pb^{-1} (ALICE), 300 pb^{-1} (ATLAS, CMS), 25 pb^{-1} (LHCb)
2028	p–Pb 8.8 TeV	3 weeks	0.6 pb^{-1} (ATLAS, CMS), 0.3 pb^{-1} (ALICE, LHCb)
	pp 8.8 TeV	few days	1.5 pb^{-1} (ALICE), 100 pb^{-1} (ATLAS, CMS, LHCb)
2029	Pb–Pb 5.5 TeV	4 weeks	3 nb^{-1}
Run-5	Intermediate AA	11 weeks	e.g. Ar–Ar 3–9 pb^{-1} (optimal species to be defined)
	pp reference	1 week	

Unique potentialities in pPb/Pbp at forward rapidities:

- in pPb/Pbp: L ~ 30 nb^{-1} in Run2 (~1M J/ψ, ~8M D^0) — L~300 nb^{-1} in Run3 — 300 nb^{-1} in Run4

Great potentialities in PbPb at forward rapidity:

- will benefit from detector upgrade

Selection of few HI highlights for Run3+4

- Drell–Yan production in pPb collisions at low dimuon mass and at forward rapidity can probe the gluon nPDF at small Bjorken-x, where gluon saturation could be observed

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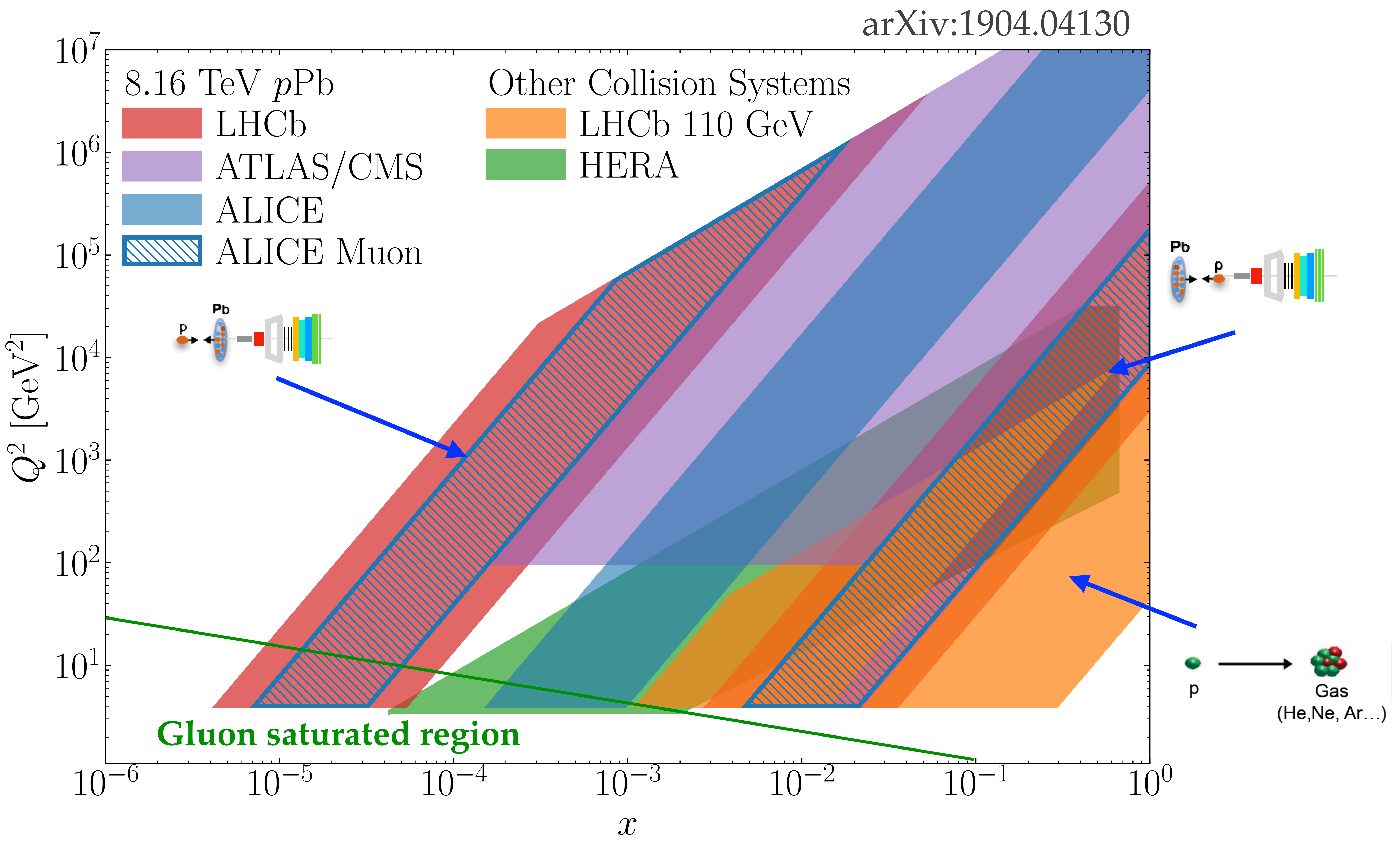
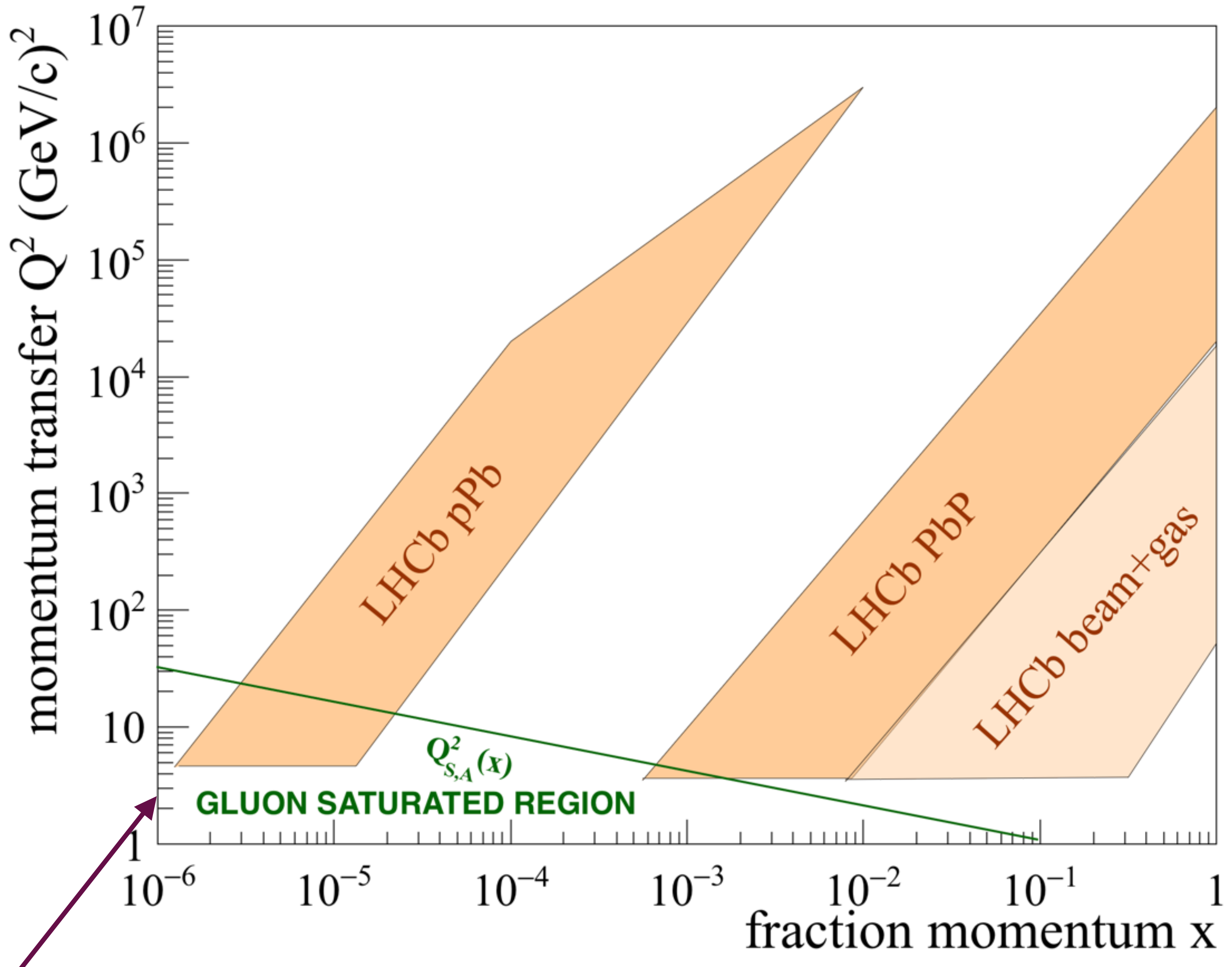


Large phase space coverage



can reach x~10^{-6} with the installation of the **Magnet Tracking Station** in Run4

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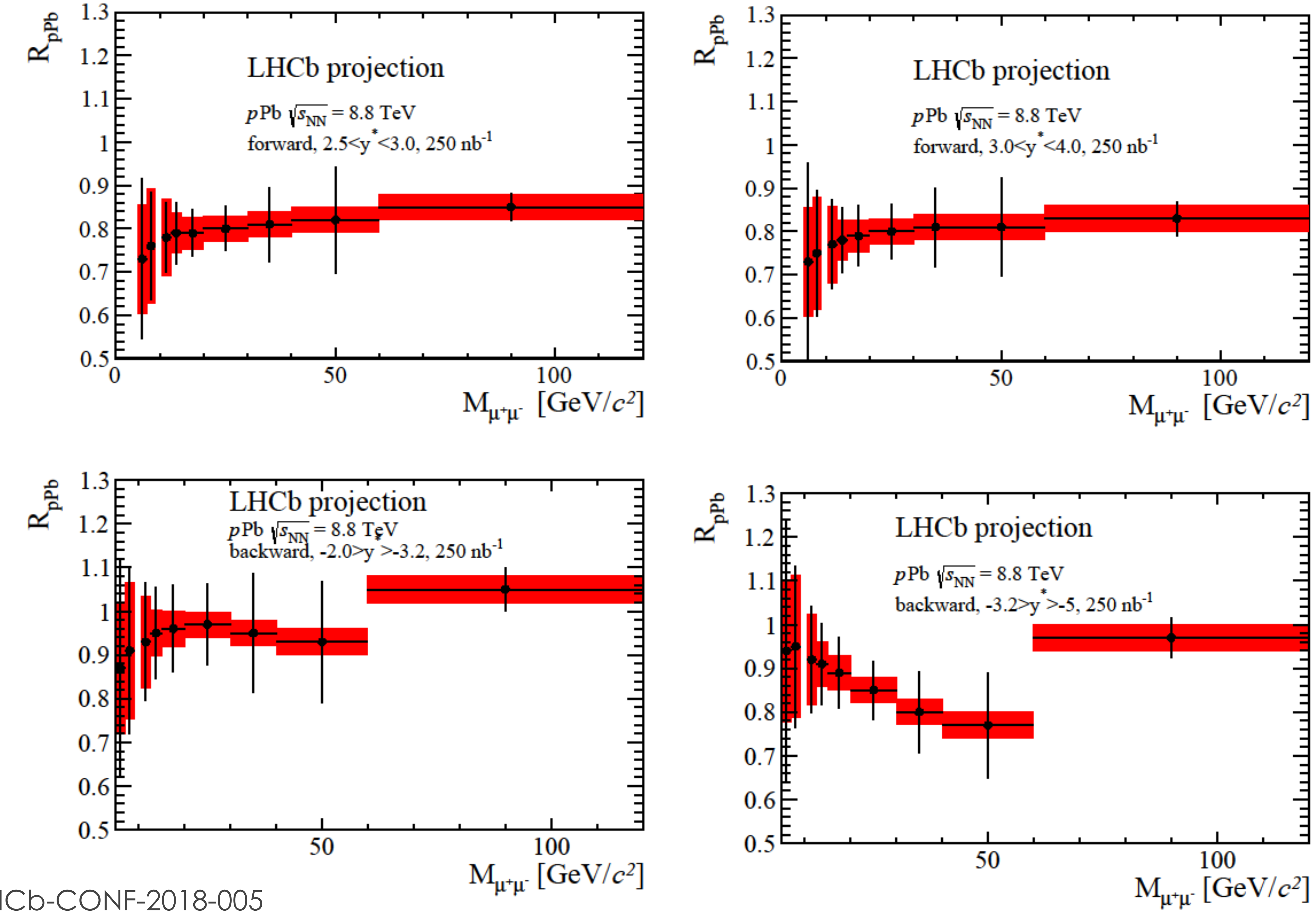
pPb: L_{total} = 500 nb^{-1} (4 weeks)

pp reference: L_{total} = 104 pb^{-1} (much shorter time)



LHCb-CONF-2018-005

EPPS16 nPDF prediction at NLO

At forward rapidity and low dimuon mass, a clear suppression is expected due to shadowing effect at low Bjorken-x

DY production in this region is indirectly sensitive to the gluon nPDF at low x, which is largely unconstrained by data except for heavy-flavour production, which might be affected by other nuclear effects

At backward rapidity, the EMC effect appears, whose origin remains an active field of research

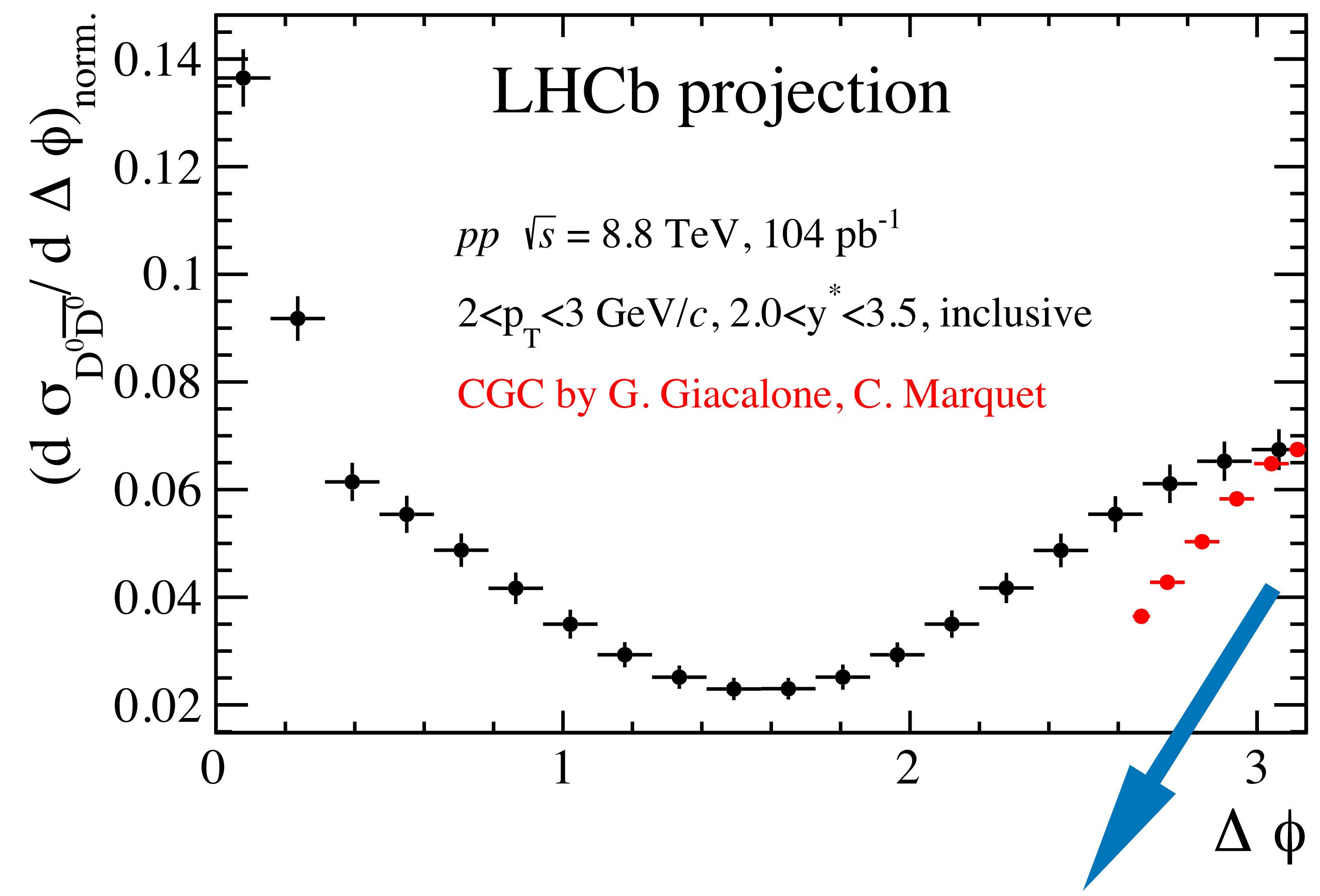
Already with a limited data taking period, these projections will provide valuable input for nPDF fits

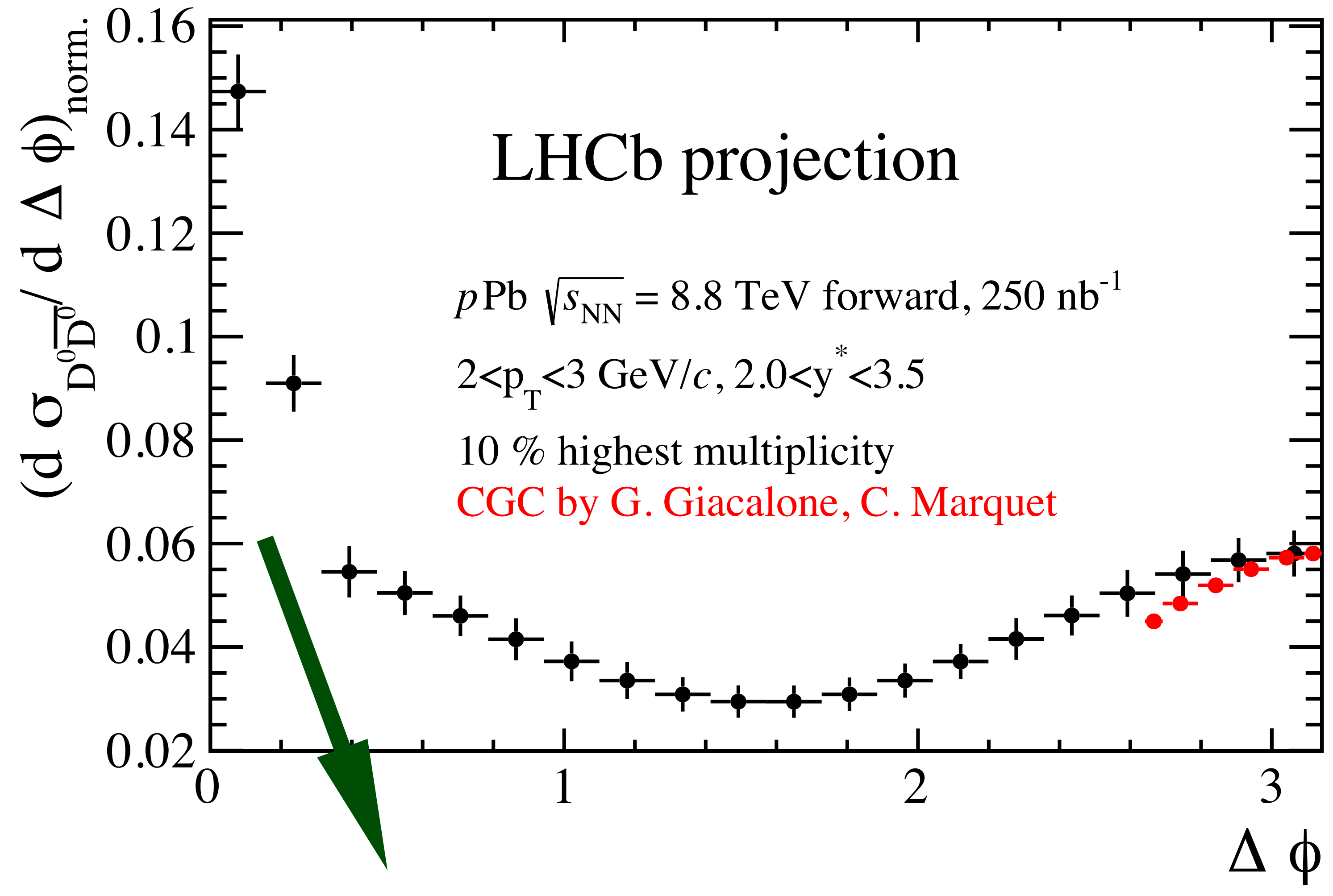
Selection of few HI highlights for Run3+4

- Drell–Yan production in pPb collisions at low dimuon mass and at forward rapidity can probe the gluon nPDF at small Bjorken-x, where gluon saturation could be observed
- Correlations between pairs of charm and beauty hadrons in pp and pPb. The angular distribution can be used to disentangle the contributions from different production mechanisms revealing intrinsic transverse momentum k_T, which may be related to the saturation scale

Projections for $\Delta\phi$ compared with theory calculations within the CGC framework with arbitrary normalisation

LHCb-CONF-2018-005





The shape of the away-side peak at $\Delta\phi = \pi$ provides k_T information, and is expected to be different in pPb and pp collisions

Near $\Delta\phi = 0$ the NLO production process via gluon splitting becomes dominant and is responsible for the peaking structure

The relative importance of these two contributions affects the initial momentum distribution of charm quarks, which is important for modelling charm thermalisation in nucleus-nucleus collisions

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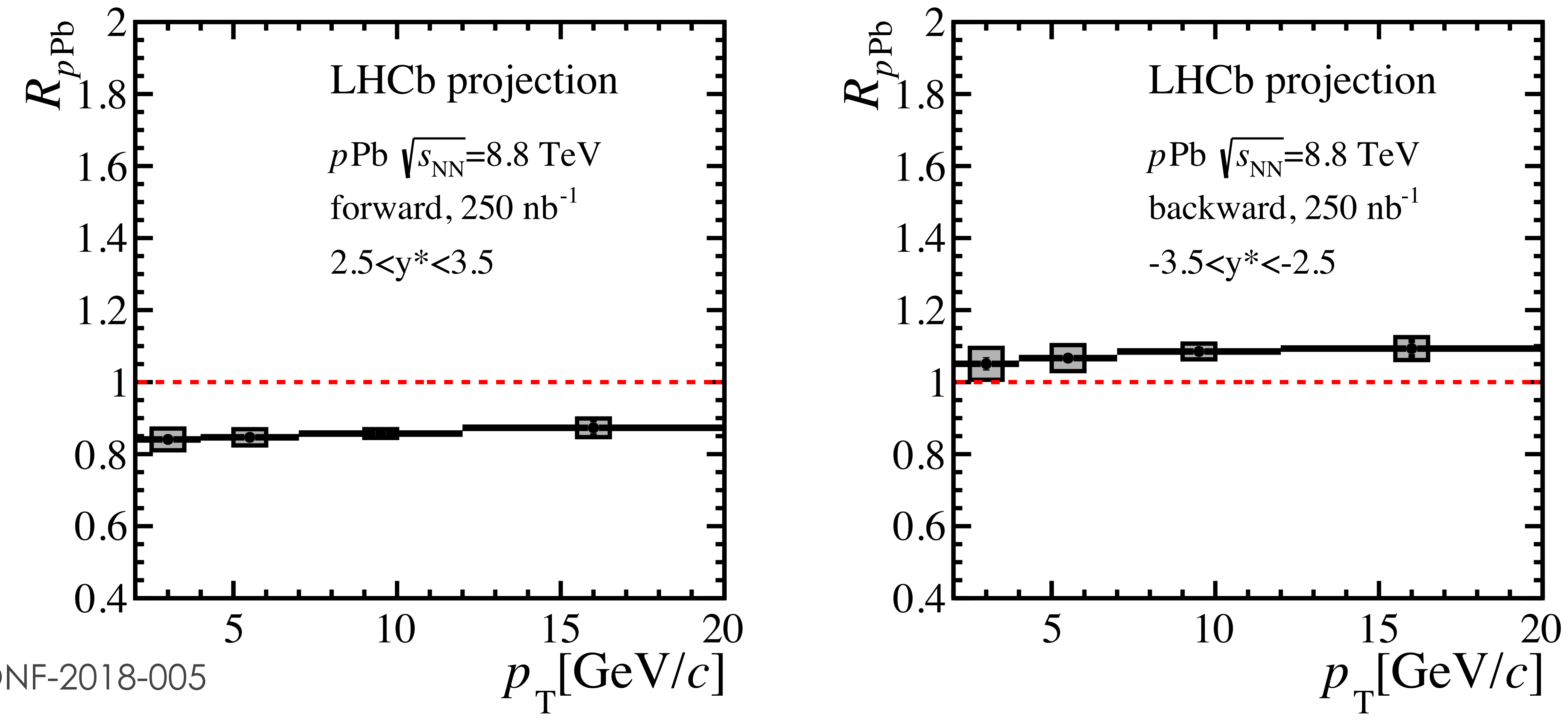
- Correlations between pairs of charm and beauty hadrons in pp and pPb. The angular distribution can be used to disentangle the contributions from different production mechanisms revealing intrinsic transverse momentum k_T, which may be related to the saturation scale
- Beauty hadron production has negligible high-order corrections wrt charm. The production mechanism in pPb collisions provides an important reference for the study of HI collisions



LHCb-CONF-2018-005

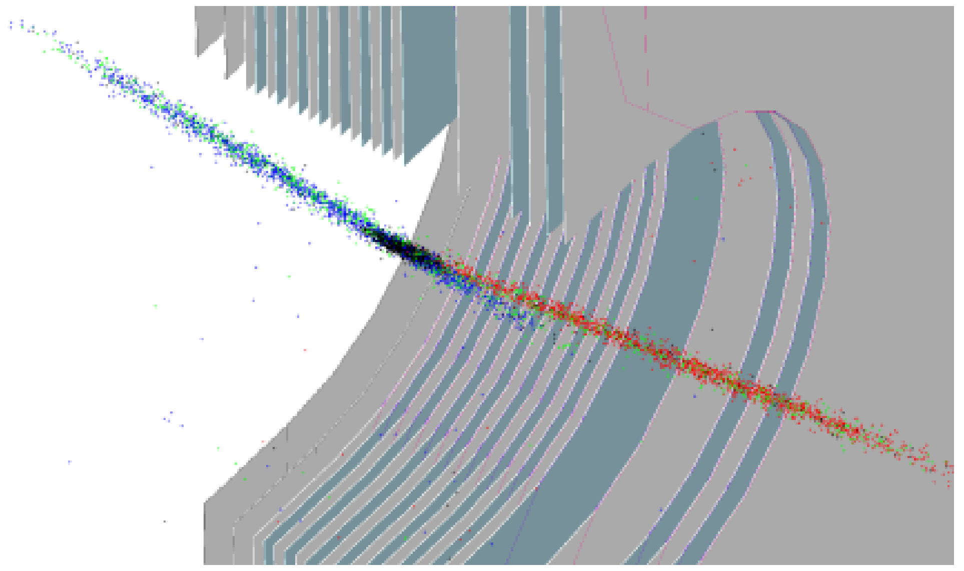
Precise measurements of nuclear modification in the beauty sector will potentially enable disentangling whether these effects are due to PDF modifications or other effects, such as coherent energy loss

The projected statistical uncertainty on the B^+ production cross-section is scaled using the inverse of the square root of the expected luminosity increase

The B^+ meson R_{pPb} projection is based on the B^+ production cross-section measurement in pPb collisions at 8.16 TeV. The production cross-section of B^+ mesons is measured using two decay channels: $B^+ \rightarrow J/\psi K^+$ and $B^+ \rightarrow D^0\pi^+$

The first fixed target at the LHC

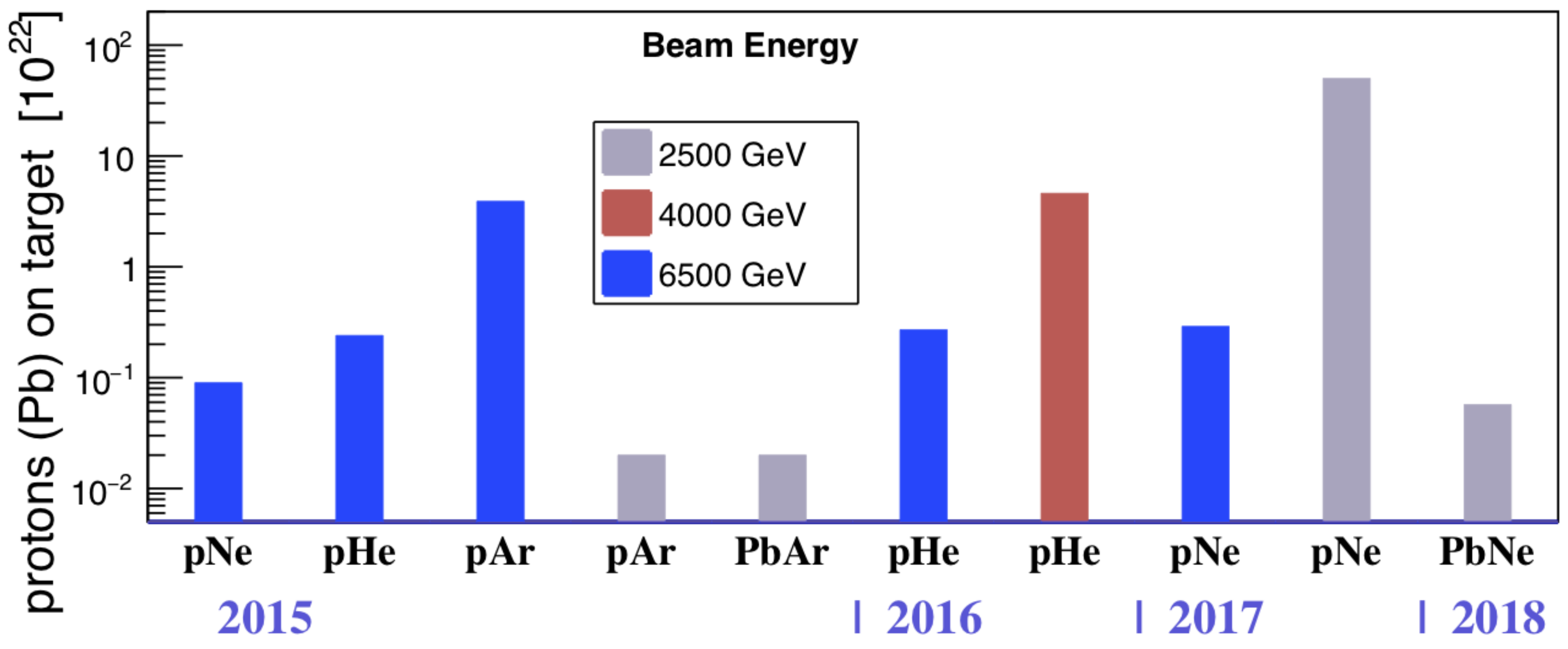
System for Measuring Overlap with Gas (SMOG) has been thought for precise luminosity measurements by beam gas imaging, but then it served as a “pseudo-target” producing interesting results



gas injection at the nominal IP

- Low intensity noble gas injected in the VELO vessel (~10^{-7} mbar)
- Gas pressure 2 orders or magnitude higher than LHC vacuum

Data taking SMOG 2015-2018



2 papers published on PRL + other released results:
-antiproton production in p-He collisions @ 110 GeV PRL121,222001(2018) (arXiv:1808.06127)
-First measurement of charm production in fixed-target configuration at the LHC - PRL122,132002(2019) (arXiv:1810.07907)

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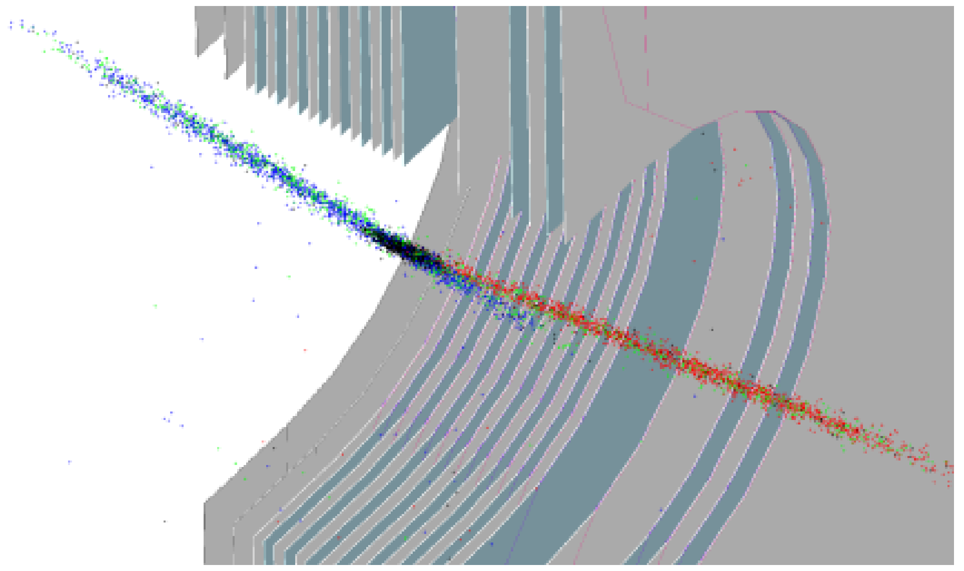

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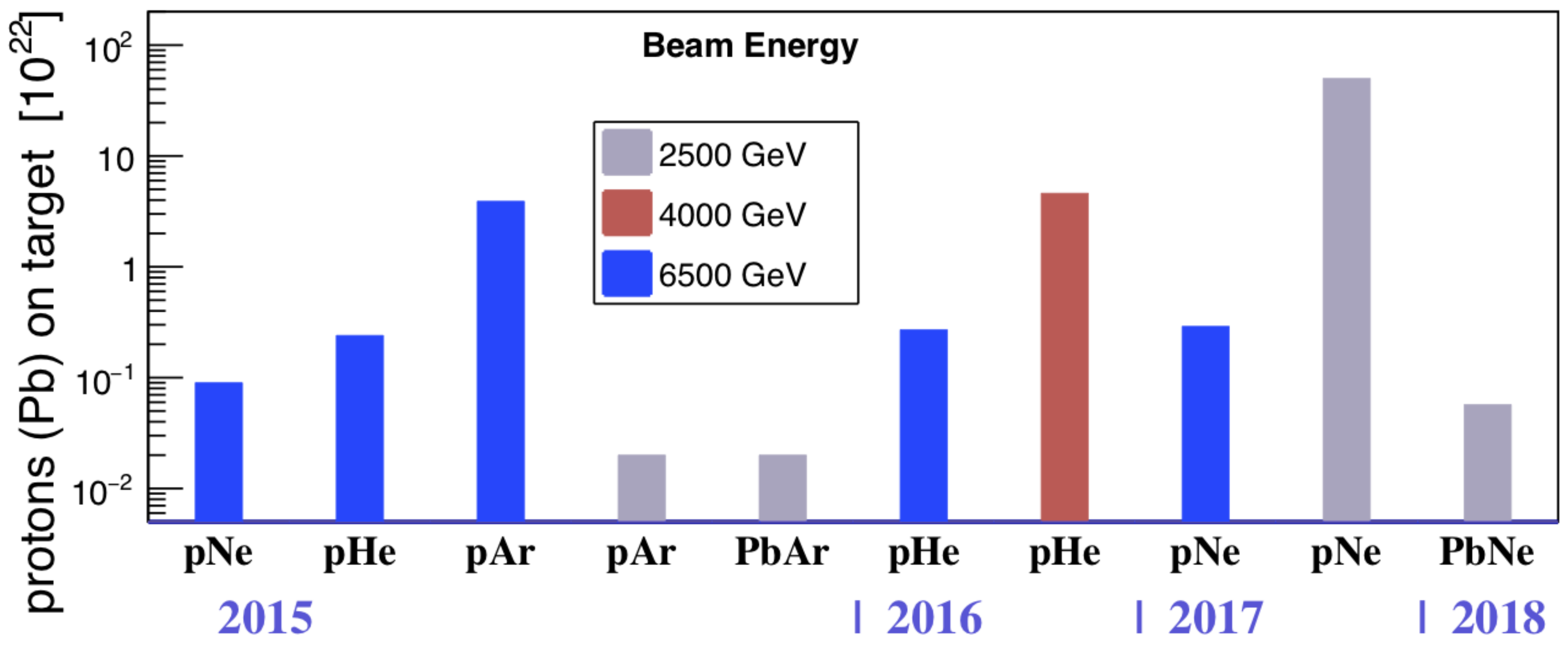

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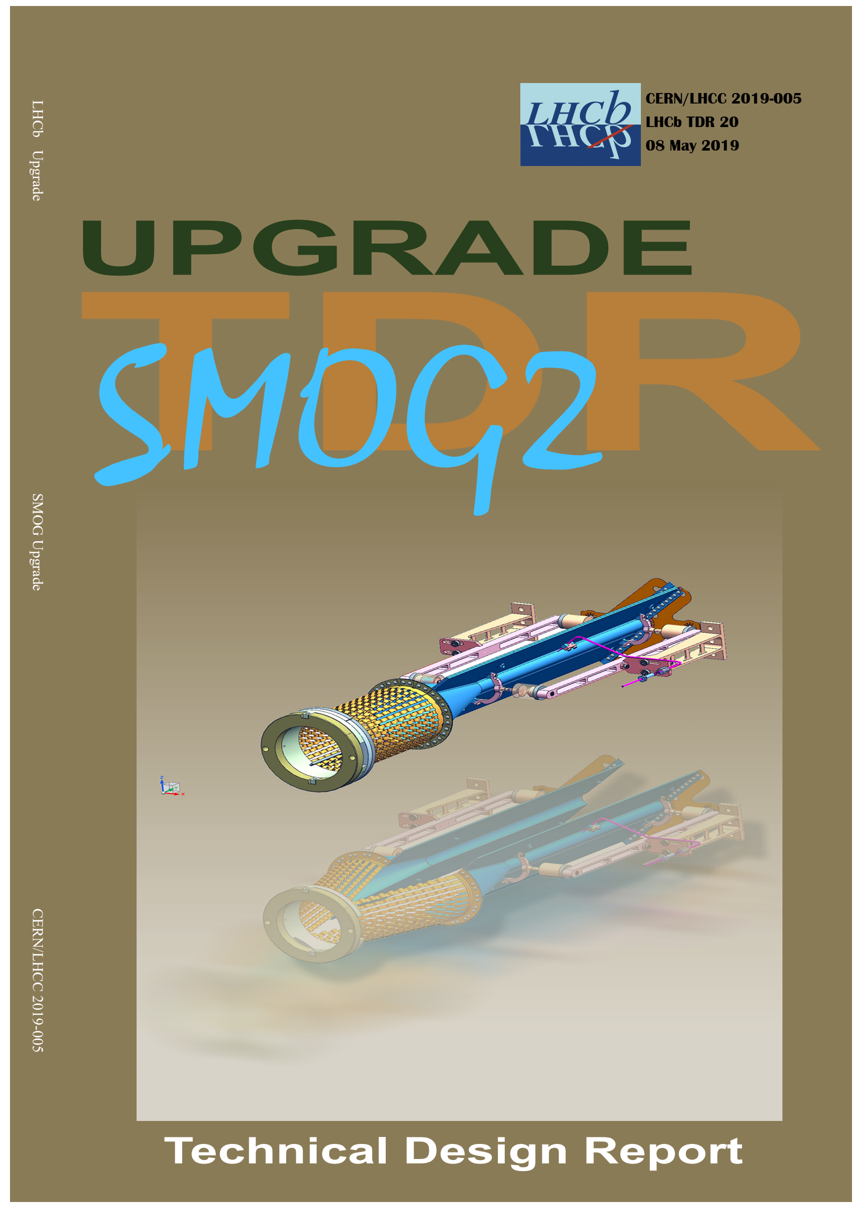
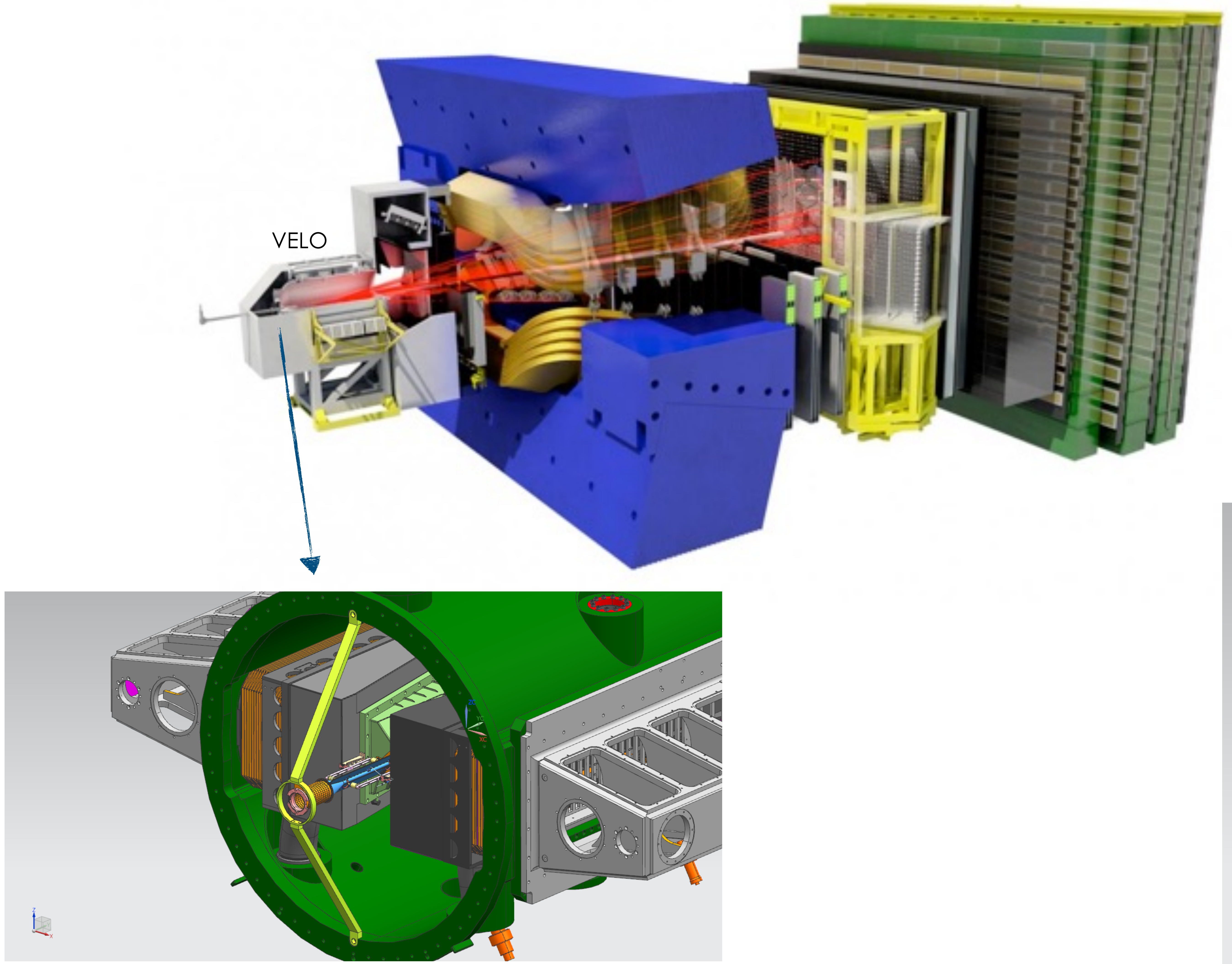
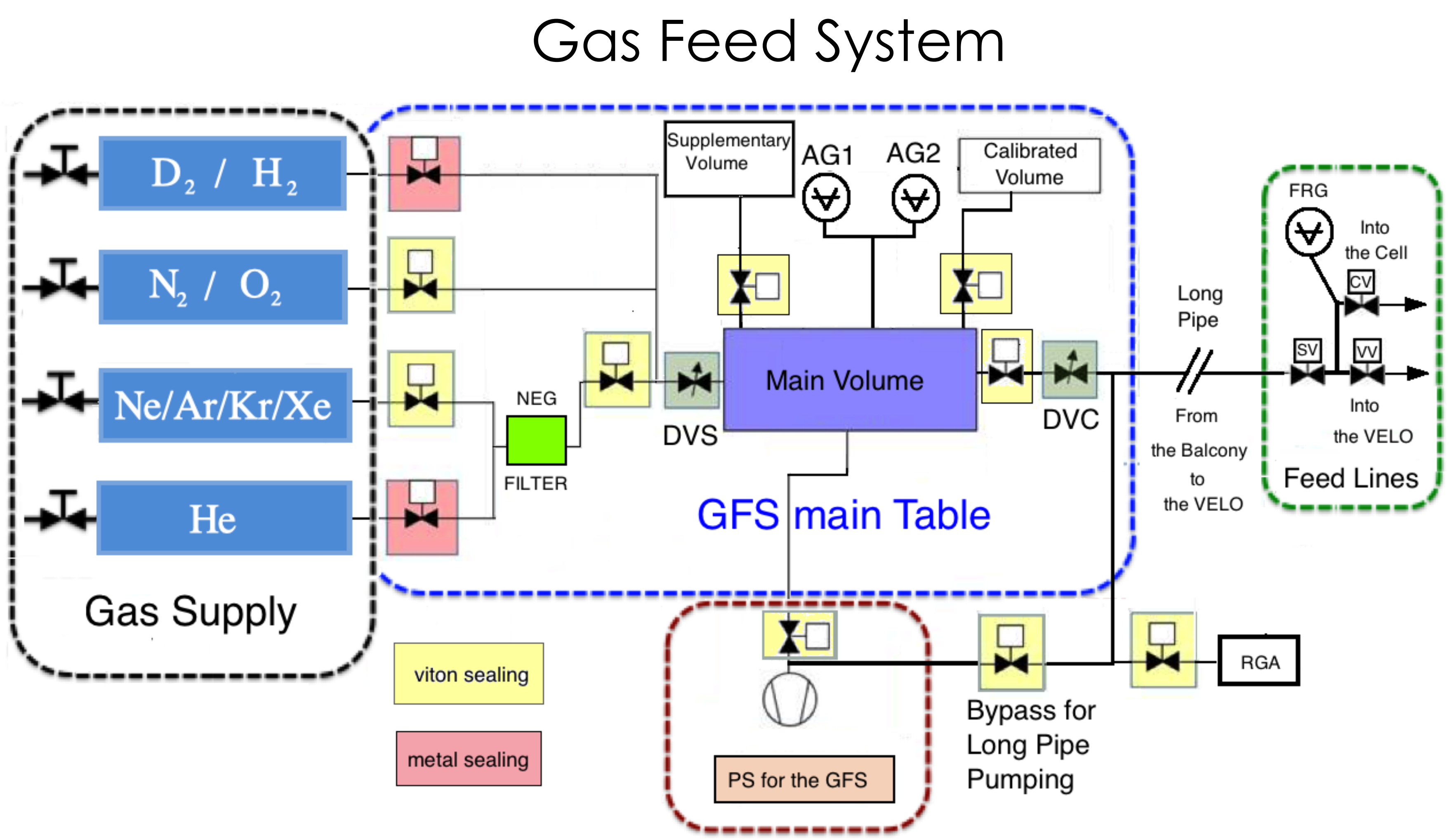
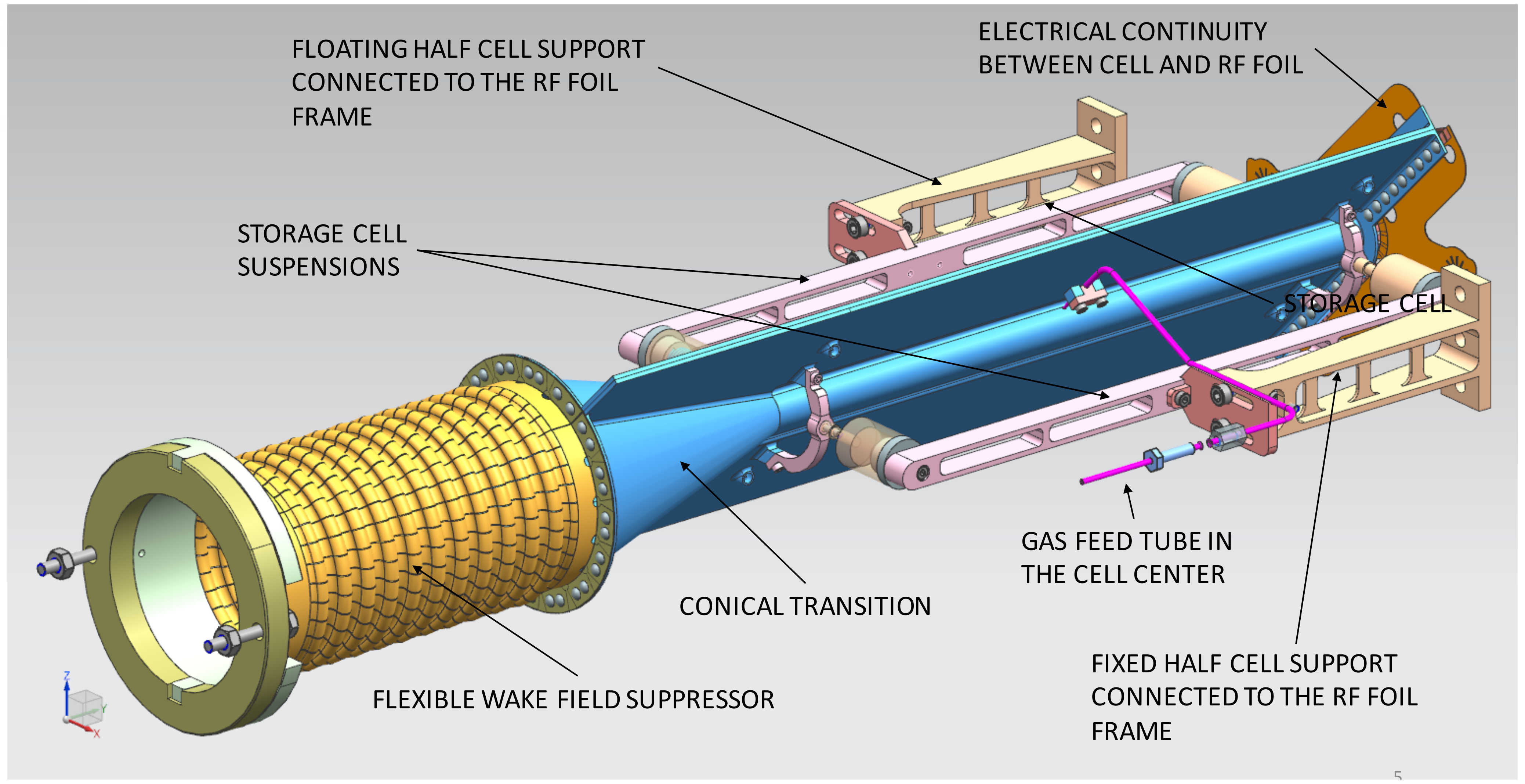
During the LS2 a real storage cell will be installed
Ready to take data from Run3



https://cds.cern.ch/record/2673690/files/LHCB-TDR-020.pdf, LHCb-PUB-2018-015, CERN-PBC-Notes-2018-007, https://cds.cern.ch/record/2651269, PoS(SPIN2018)011, https://pos.sissa.it/346/011/pdf, PoS(SPIN2018)098, https://pos.sissa.it/346/098/pdf, CERN-ESPP-Note-2018-111, arXiv:1901.08002



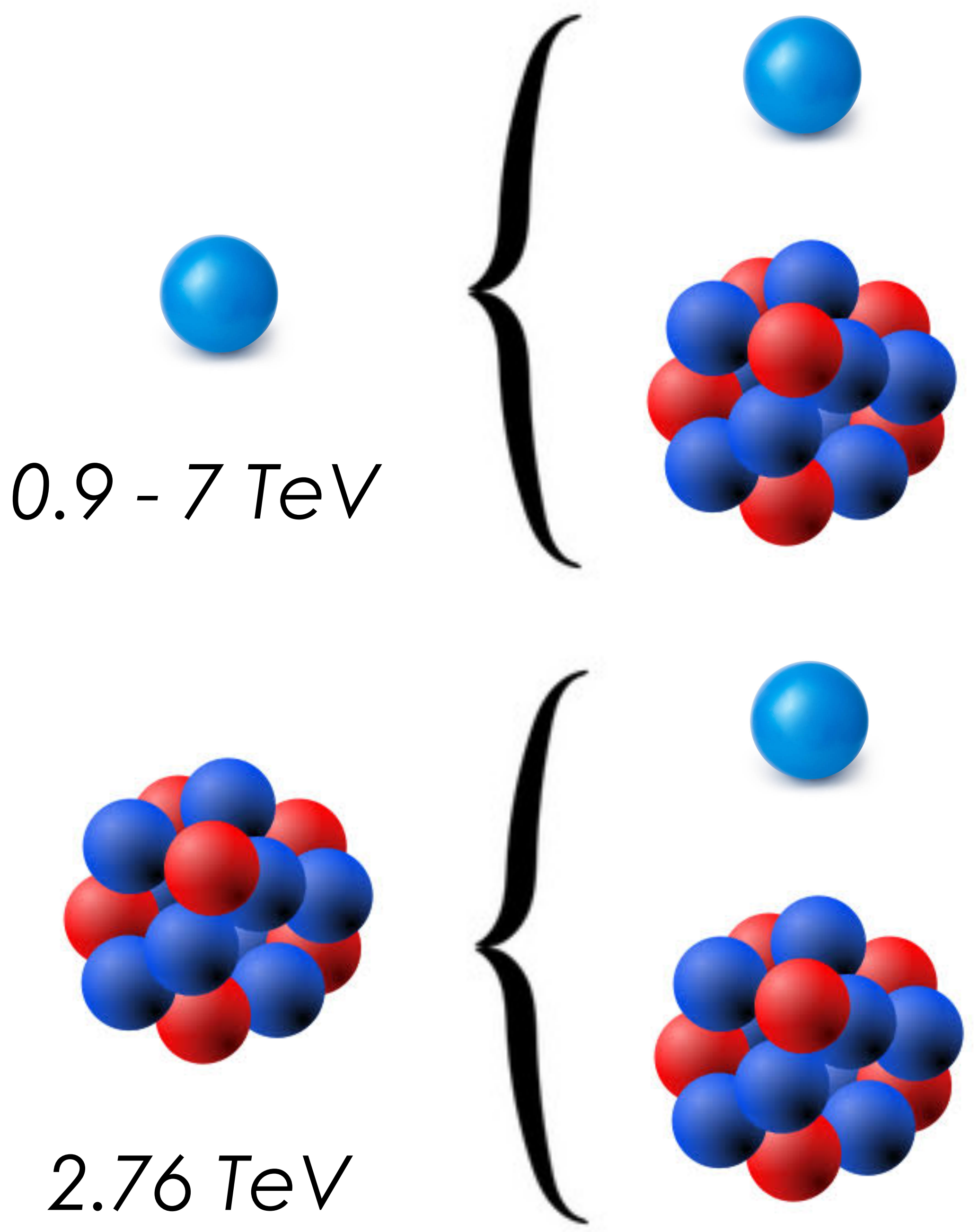




SMOG2 can potentially run in synergy with the pp physics at 13 TeV

Unique kinematic region

At the LHC fixed target pp, pA, Pb-p or Pb-A collisions one has unique kinematic conditions at the poorly explored energy of √s ~ 115 GeV



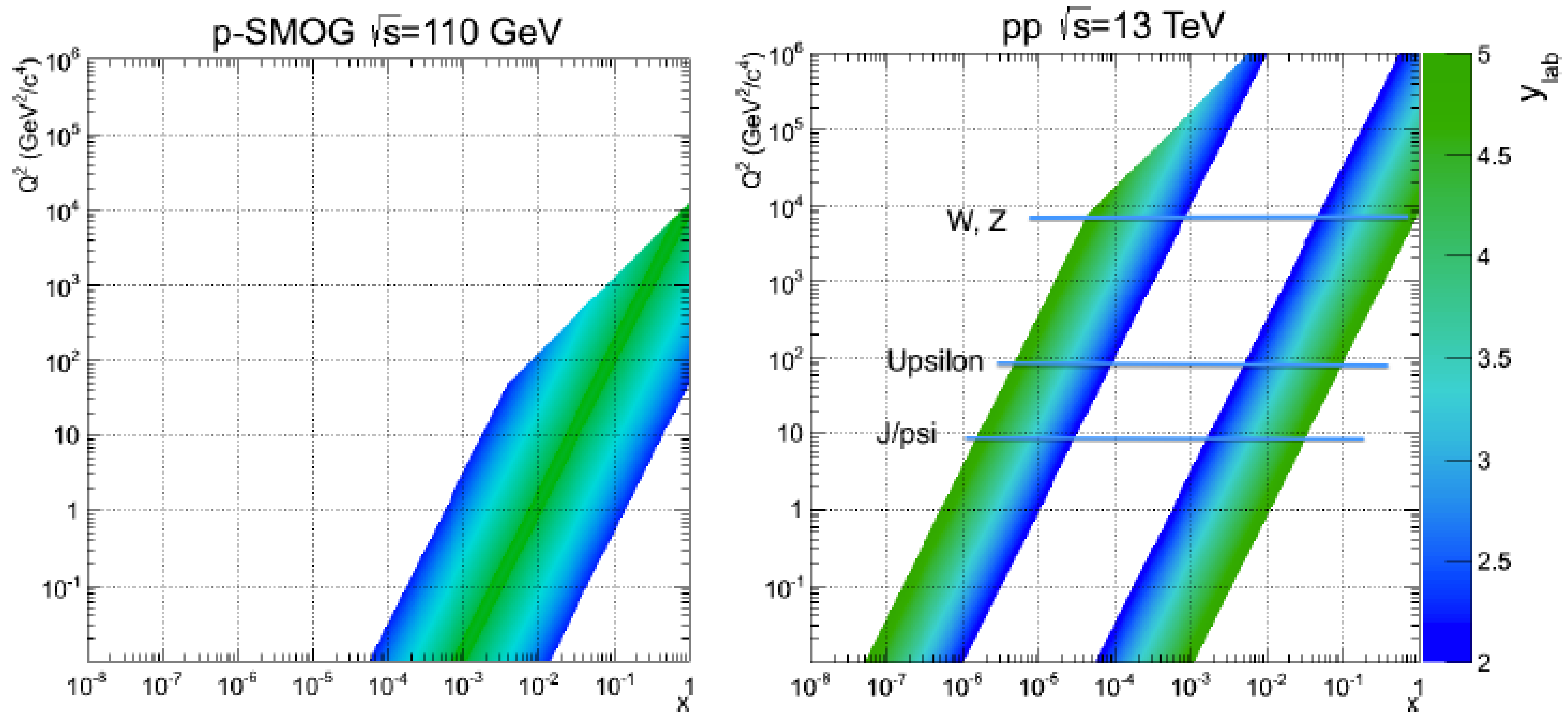
$$\sqrt{s} = \sqrt{2 m_N E_p} = 115\ GeV$$

$$-3.0 \le y_{CMS} \le 0 \ \rightarrow\ 2 \le y_{lab} \le 5$$

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

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

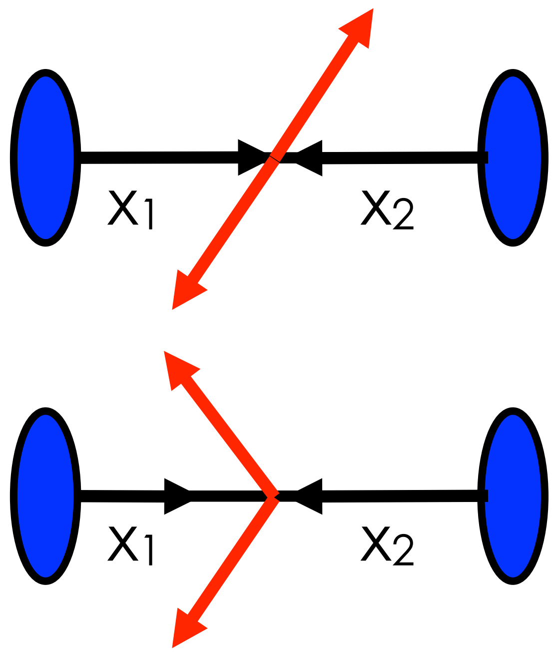
PRD 93, 114017 (2016)



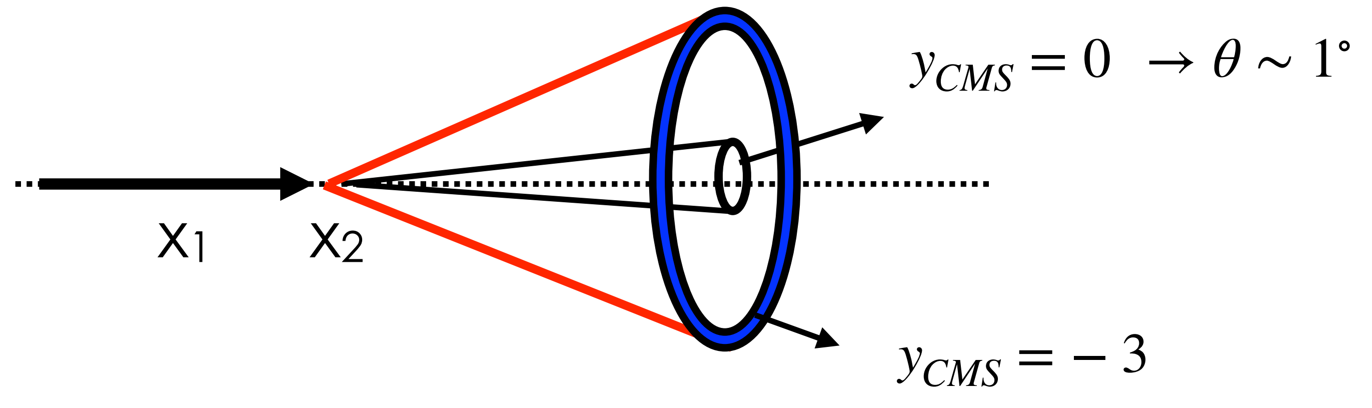
Boost effect $\gamma = \dfrac{\sqrt{s}}{2 m_p} \sim 60$ access to large x_2 physics (x_F<0)

$x_1 \sim x_2$

$x_1 << x_2$



CMS → **Target rest frame**



Statistics in full synergy mode (1 yr data taking)

LHCb-PUB-2018-015

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

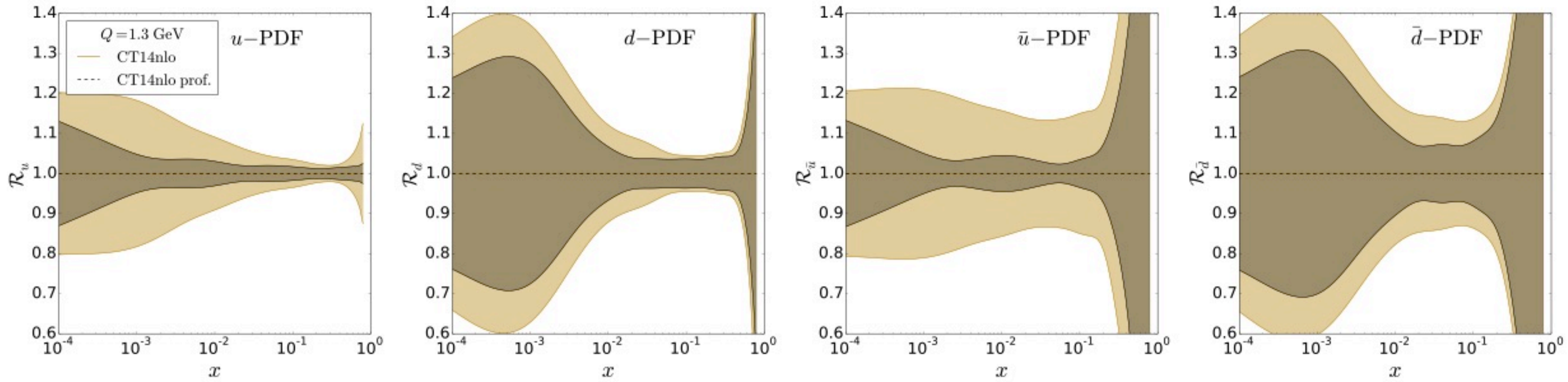
Int. Lumi.		80 pb^{-1}
Sys.error of J/Ψ xsection		~3%
J/Ψ	yield	28 M
D^0	yield	280 M
Λ_c	yield	2.8 M
Ψ'	yield	280 k
$\Upsilon(1S)$	yield	24 k
$DY\ \mu^+\mu^-$	yield	24 k

Selection of few HI highlights for FT Run3+4

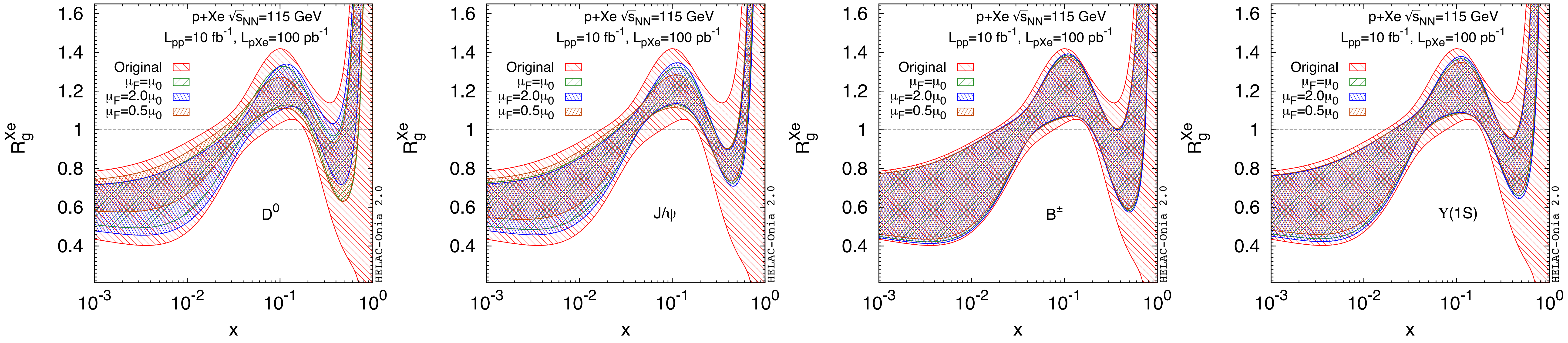
- To reduce the uncertainties on (n)PDFs goes beyond the "simple" knowledge. Among others, it is a crucial ingredient for HEP measurements and predictions of physics processes BSM (e.g. heavy partners of the gauge bosons), fundamental input to Cosmic Ray physics, etc…

arXiv:1807.00603

estimation with 10 fb^{-1}



PDF



nPDF (gluon)

Unique constraints on gluon nPDFs at high-x and low scales

Substantial improvement of the uncertainties

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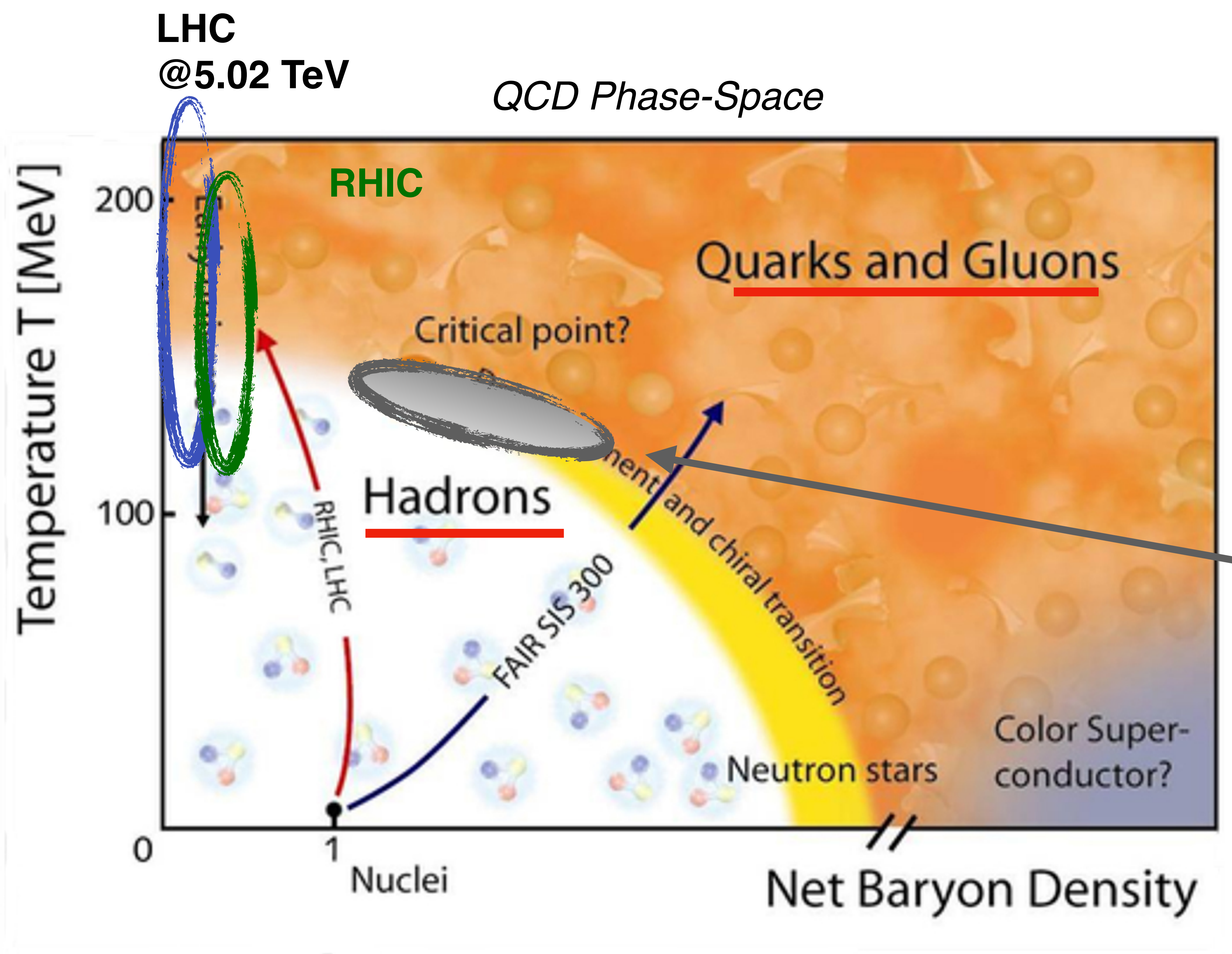
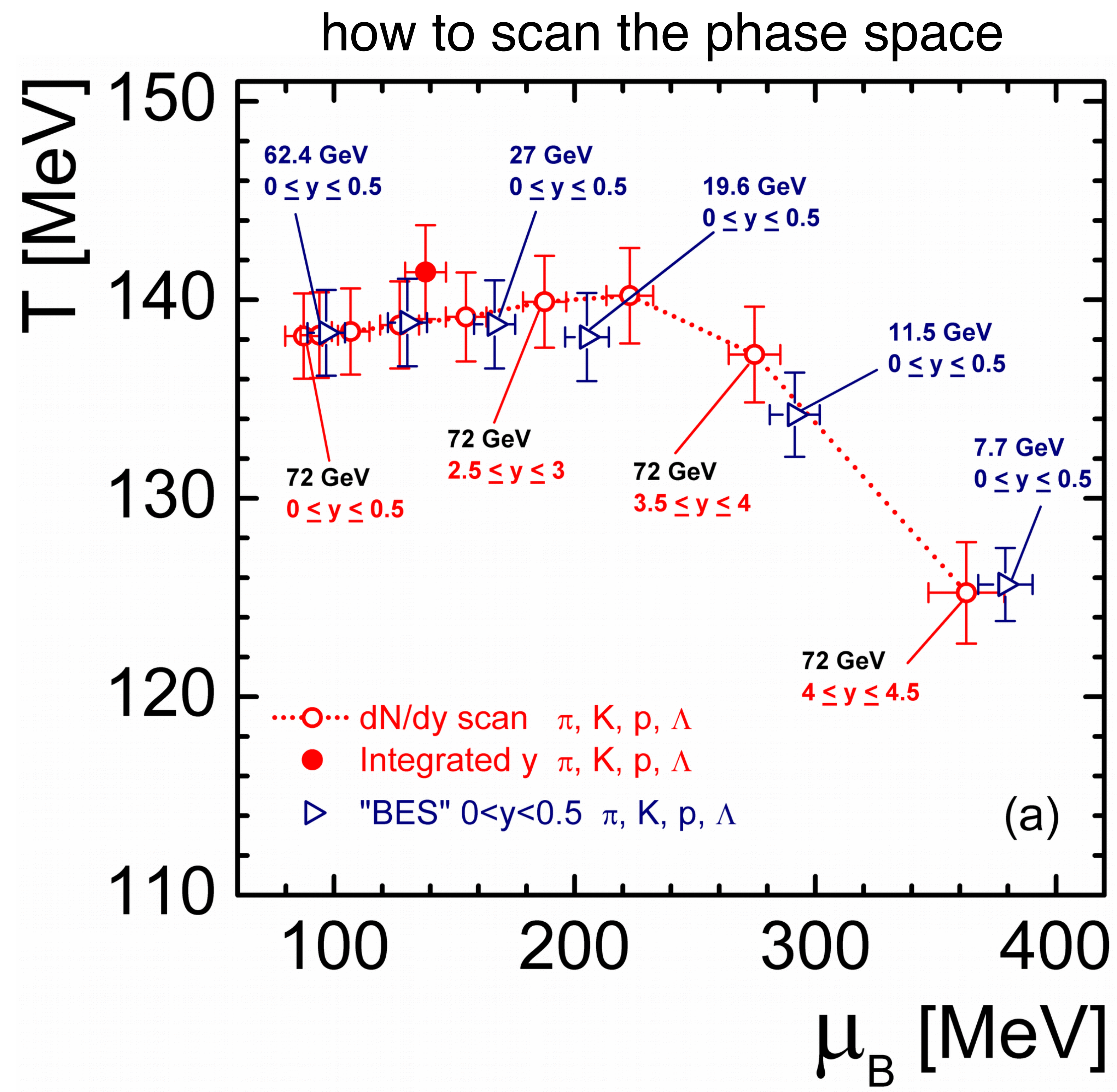
- QGP and phase transition



Region potentially covered by HI-FT collisions

Phys. Rev. C98 (2018) 034905



3 experimental degrees of freedom: rapidity scan, different colliding systems, centrality dependence
LHCb @72 GeV with FT can complement the RHIC beam energy scan

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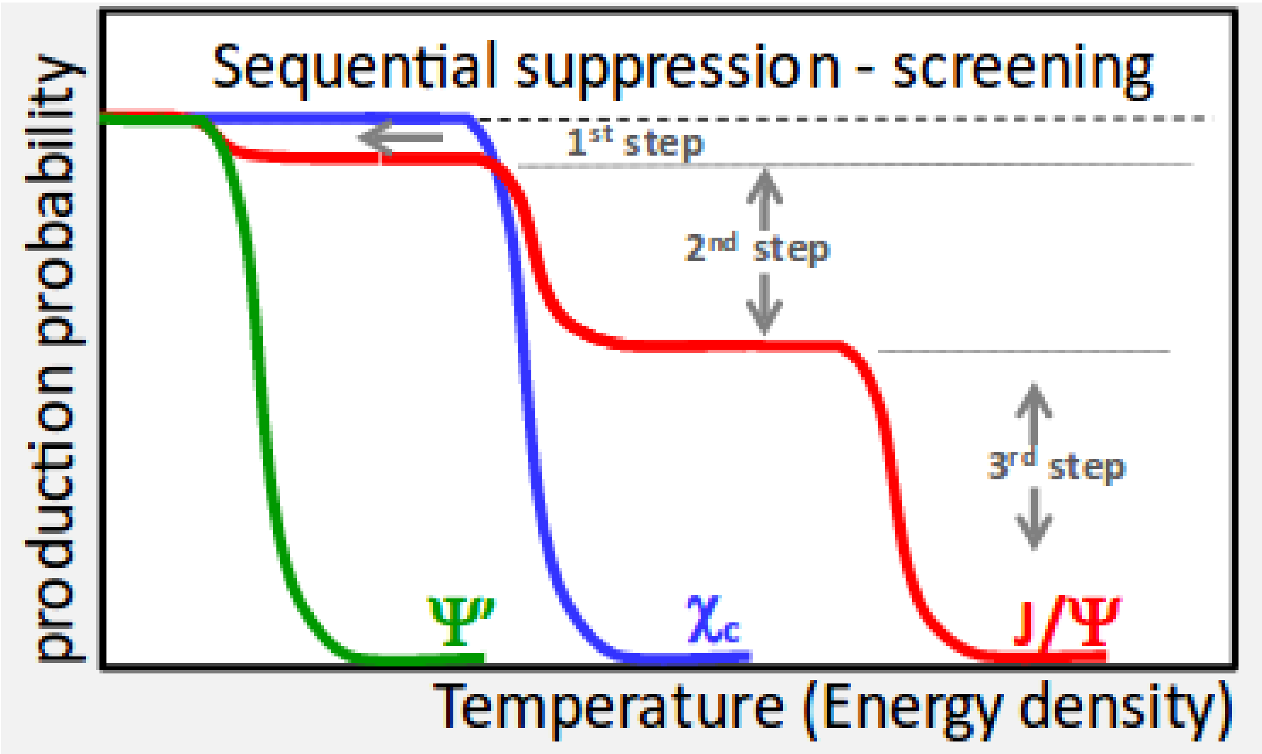
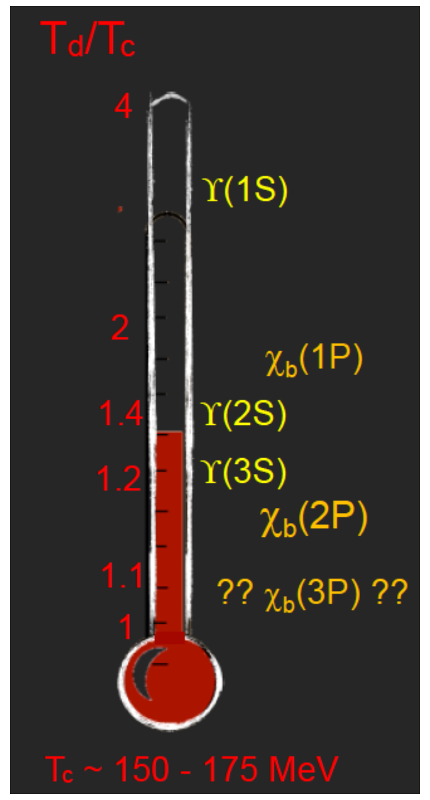
- QGP and phase transition
- Color screening, sequential suppression and QGP tomography



$c\bar{c}$ bound states: J/ψ, χ_C , ψ', … different binding energy, different dissociation temperature

sequential suppression pattern

Phys. A28(2013) 1340012



Dissociation temperature from lattice QCD (+hydro)

Probing:

-the longitudinal extension of the hot medium (high rapidities)

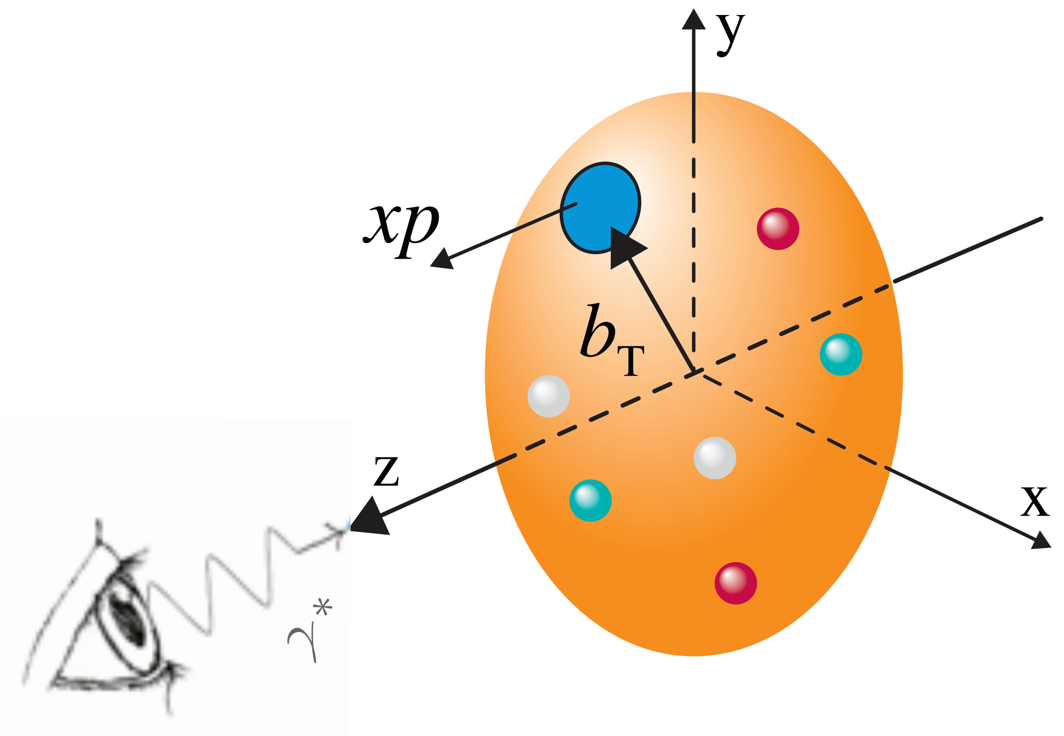
-the colliding systems of different sizes

-the centrality dependence

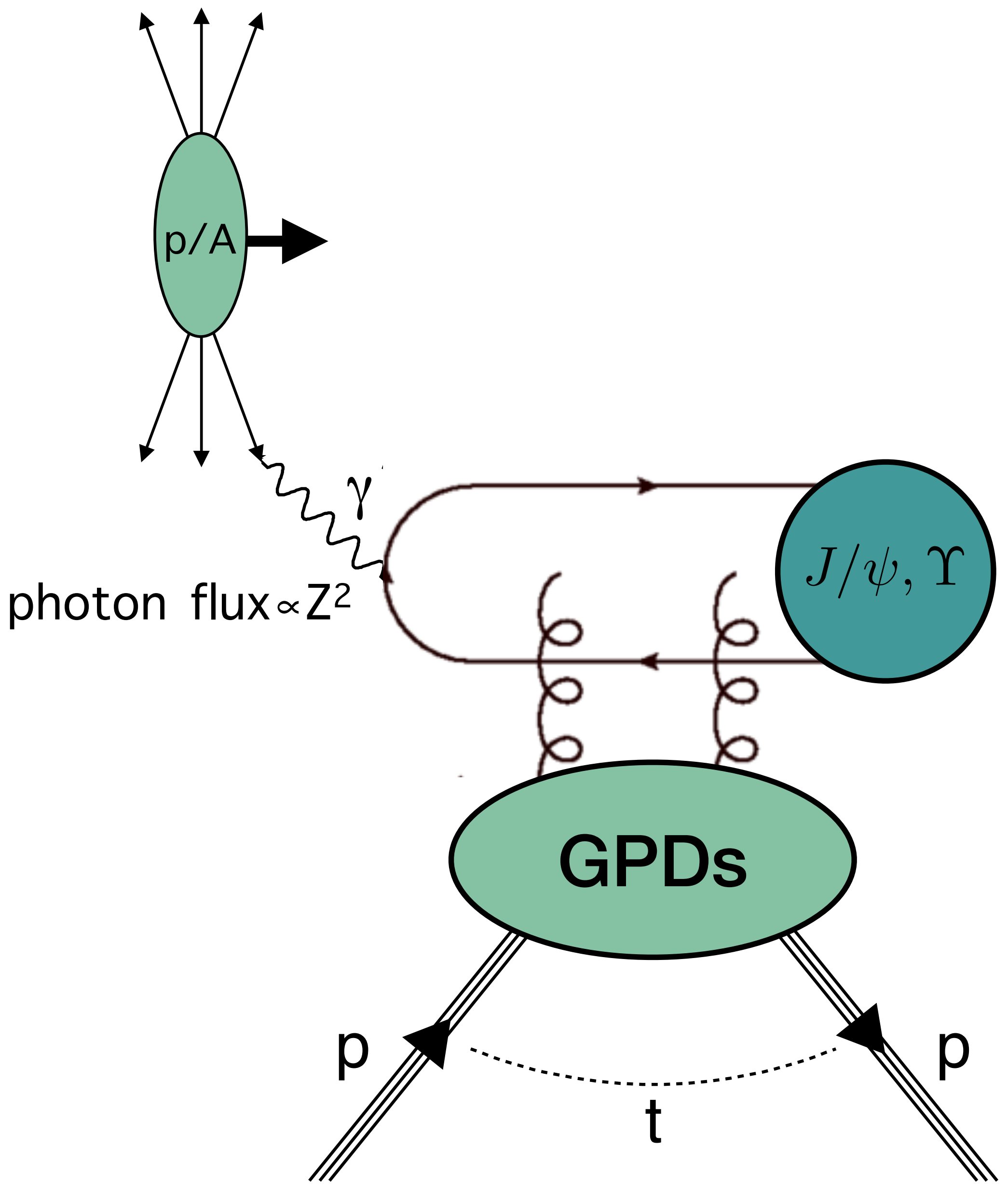
-with and w/o HF probes

T dependence of η/s by measuring the rapidity dependence of the anisotropic flow → 3D+1 viscous hydrodynamic calculations

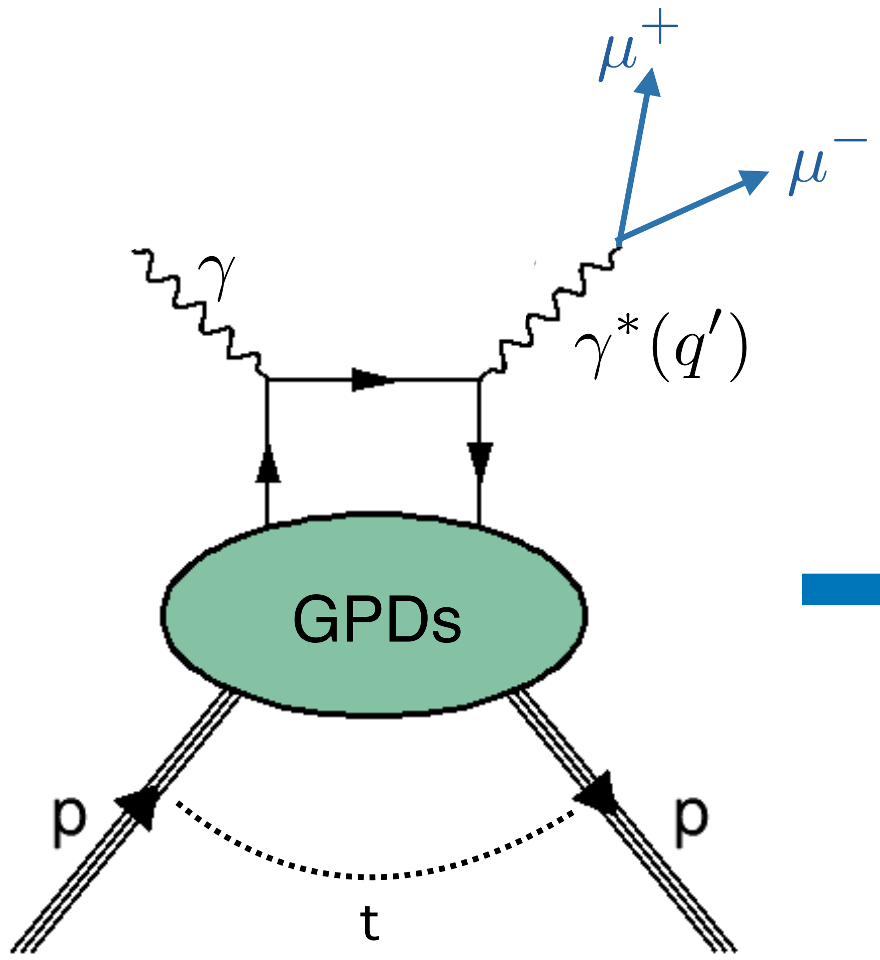
Deep in the hadronic structure



Exclusive physics via Ultra Peripheral Collisions



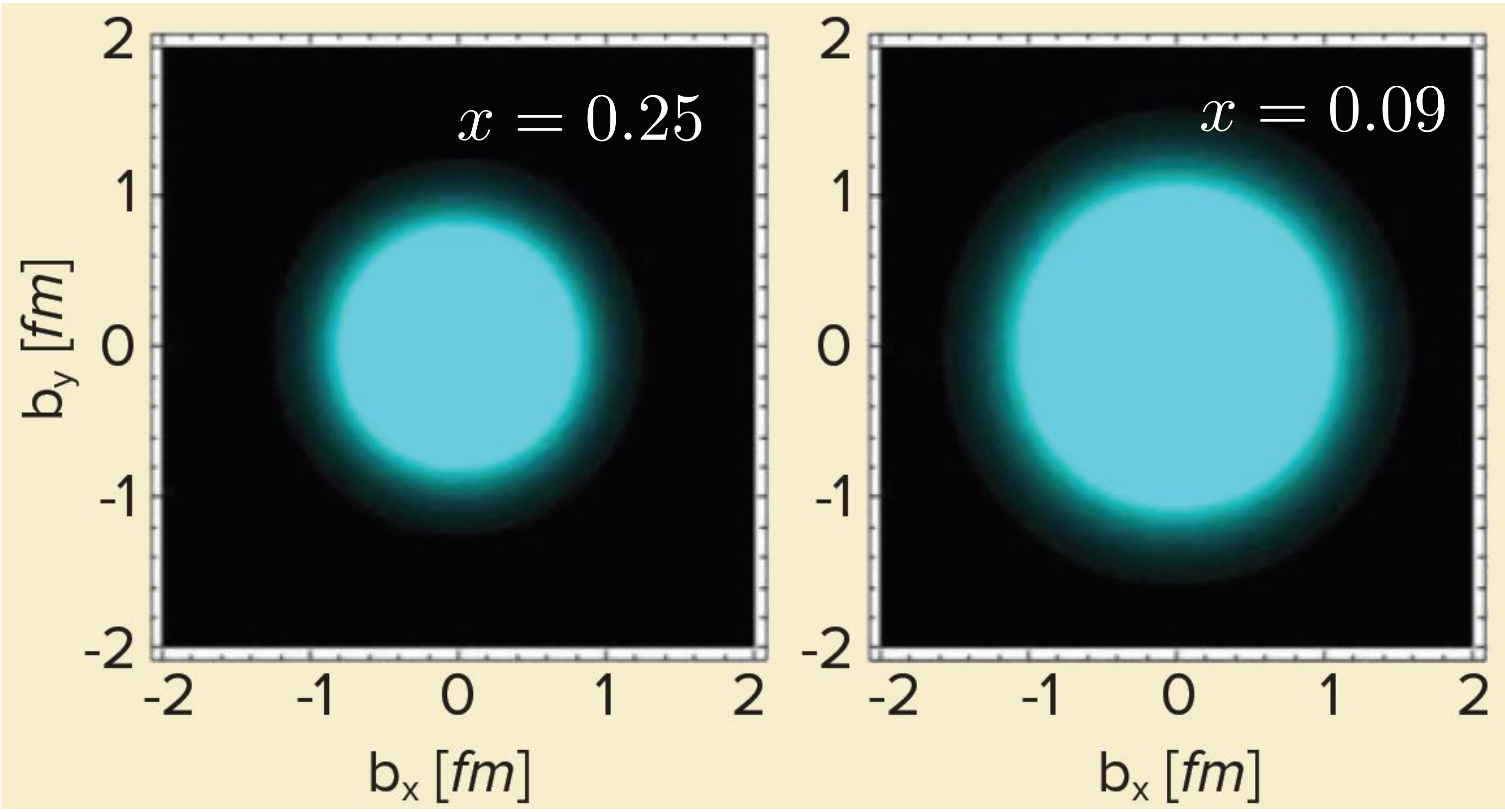
Exclusive meson production

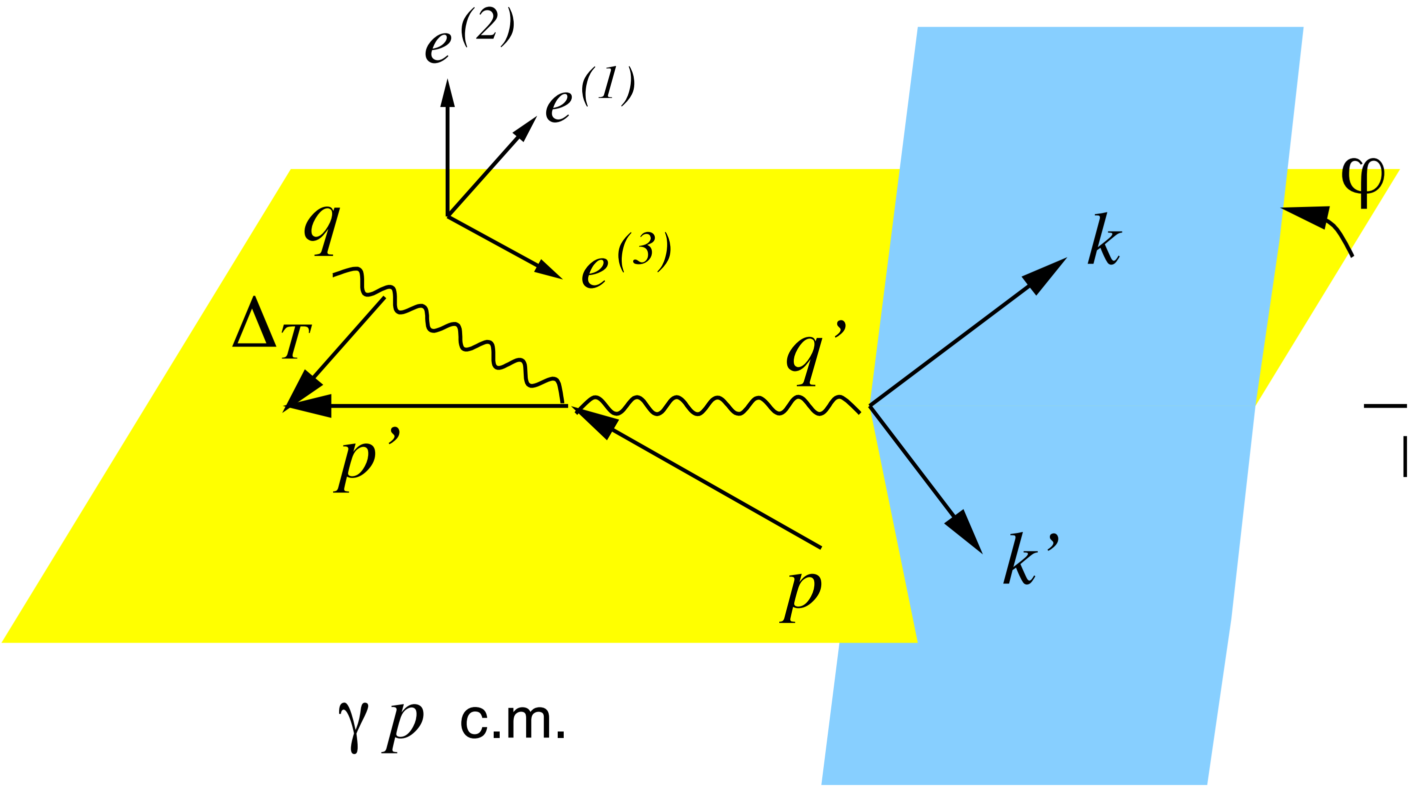


Timelike Compton scattering

One of the objectives:
3D pictures in coordinate (impact parameter) space

2015 Long Range Plan for Nuclear Science





$\gamma\, p$ c.m.

Already interesting results presented at this conference
With high statistics, new frontiers for the exclusive physics at LHC

Conclusions

- LHCb developed a lively and fast growing Heavy-Ion physics program, which benefits of the peculiar capabilities of the spectrometer

- Fixed target collisions represent a real laboratory for QCD and QGP, exploiting unexplored kinematic conditions provided by a TeV-scale beam and a fully instrumented forward spectrometer

Conclusions

- LHCb developed a lively and fast growing Heavy-Ion physics program, which benefits of the peculiar capabilities of the spectrometer

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In the realistic time schedule of Run3 and Run4, LHCb will give unique and groundbreaking insights on the intrinsic properties of the HI physics