Benjamin Audurier - joint workshop on QCD - 31/05/2021

Highlights from fixed target at the LHC: SMOG results

I. LHCb: a general purpose detector.
II. Selected fixed-target results.
III. SMOG2@LHCb: prospects for Run 3.

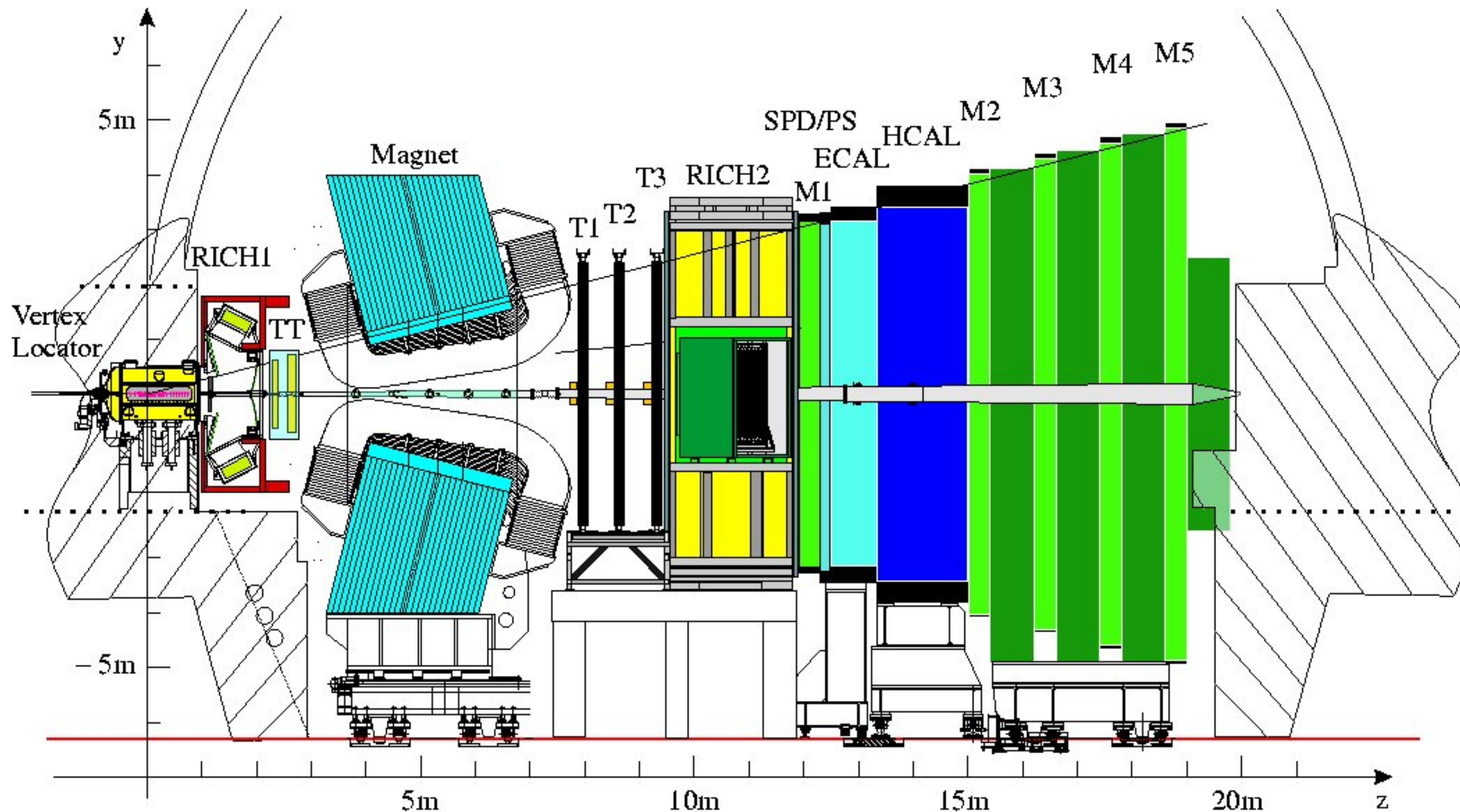*benjamin.audurier@cern.ch*

LHCb: a general purpose detector

The LHCb detector

LHCb : **single arm spectrometer** **fully instrumented** in pseudo-rapidity range **2 < η < 5**

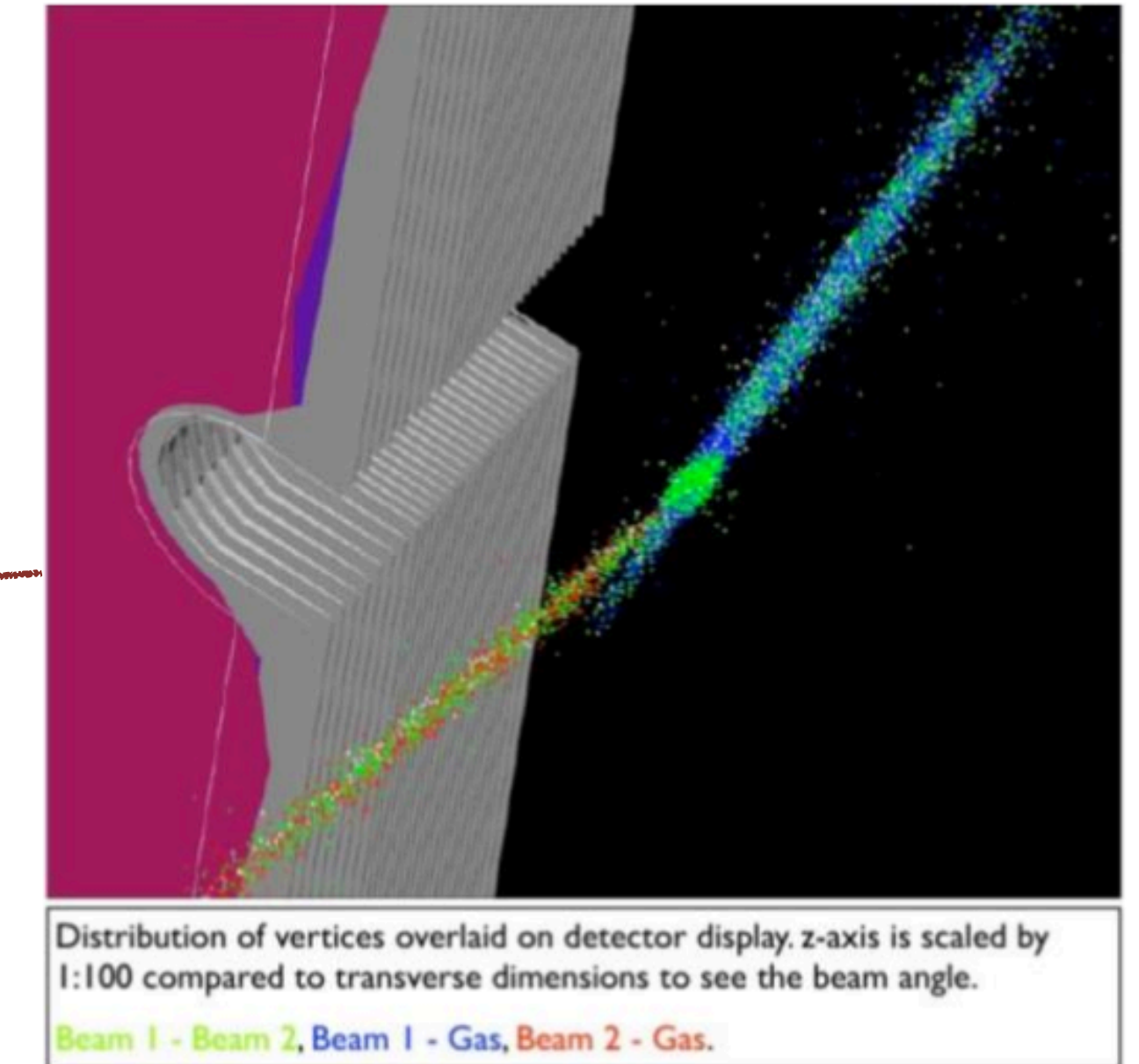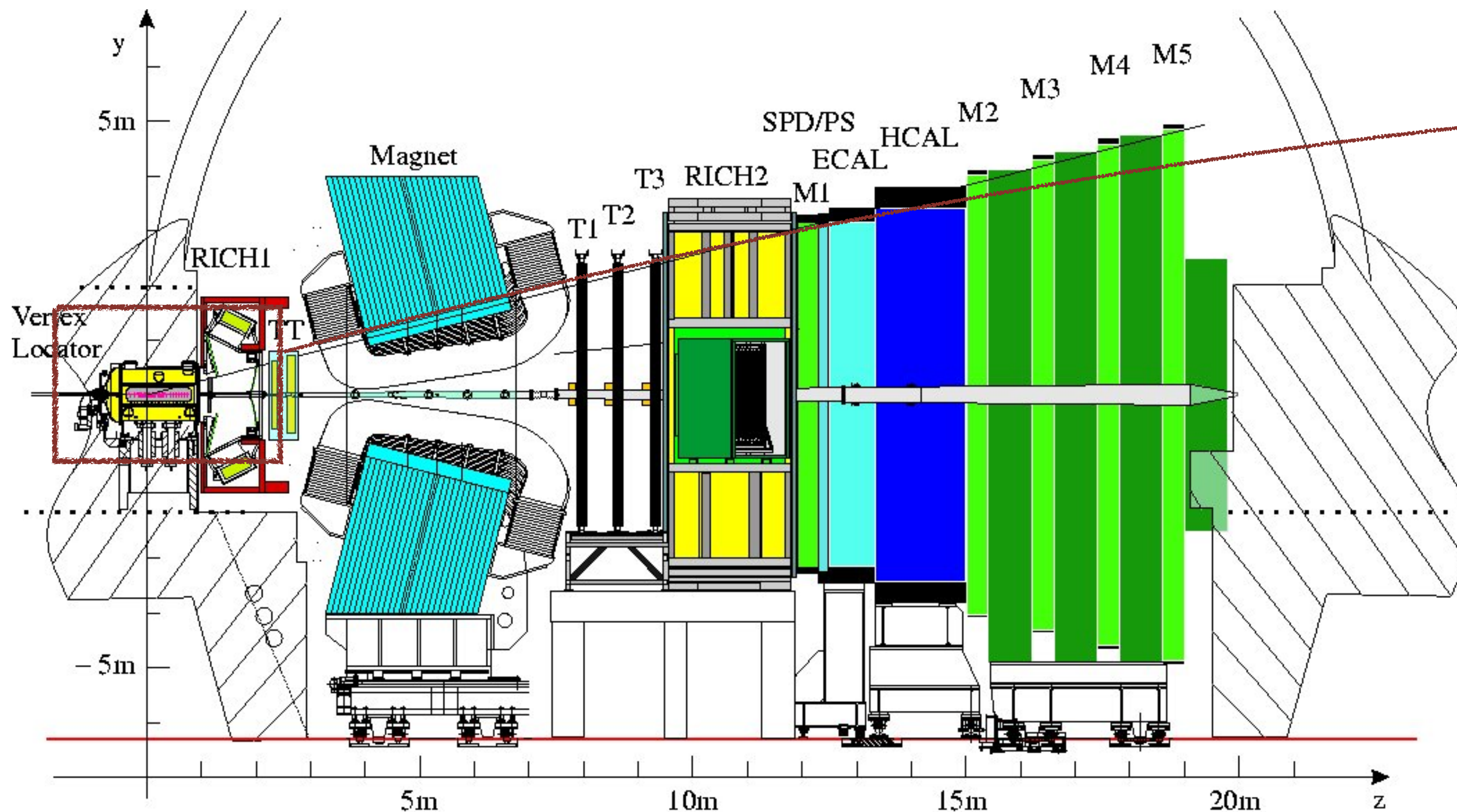hadron PID
muon system
lumi counters
HCAL
ECAL
tracking
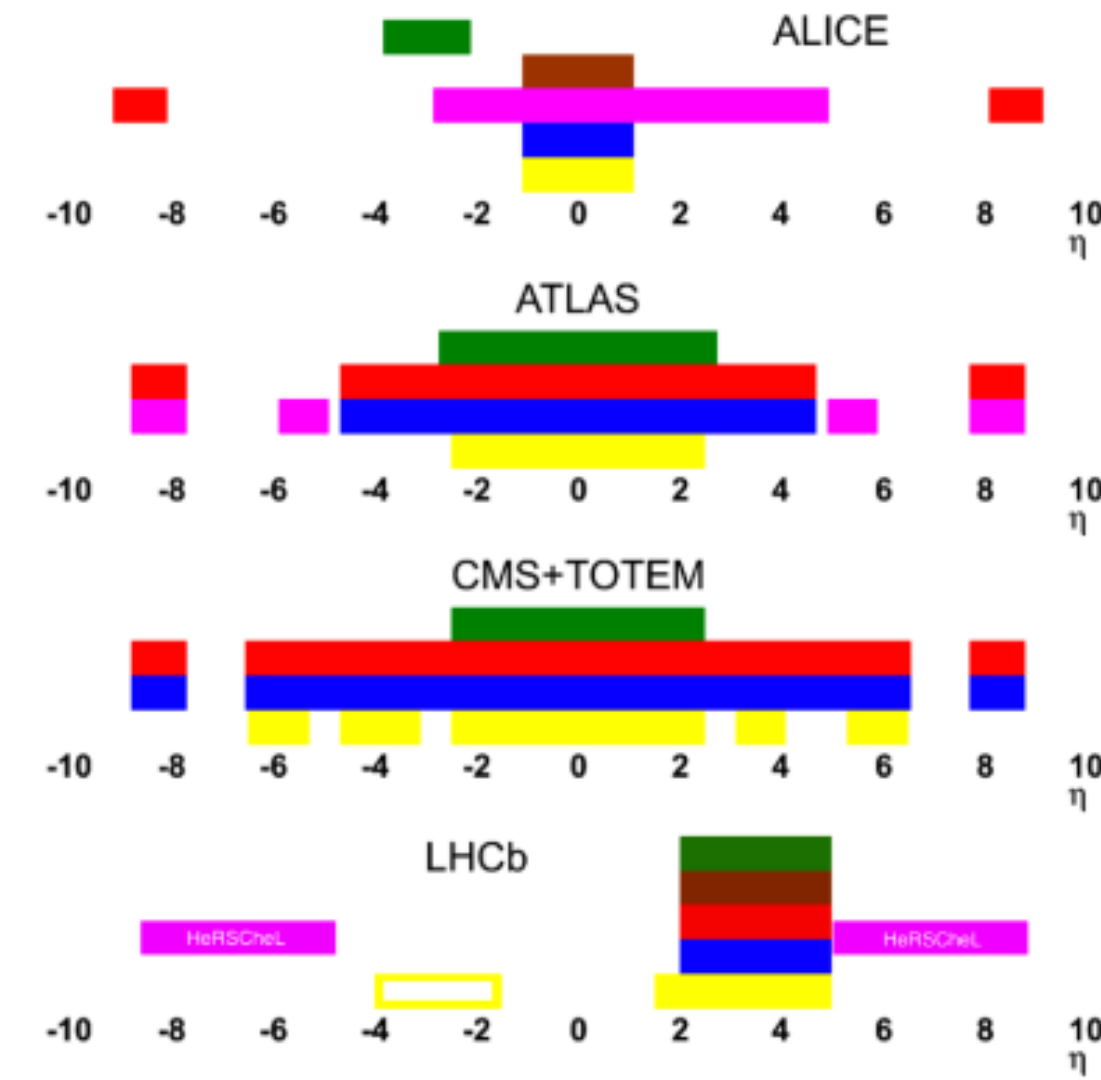
- ❖ Track reconstruction **down to $p_T = 0$**.

- ❖ Excellent **p_T and mass resolution.**

- ❖ Excellent **particle identification.**

- ❖ Precision **vertex reconstruction.**

The LHCb detector

Can operate both in pp/pPb/PbPb and fixed-target !

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

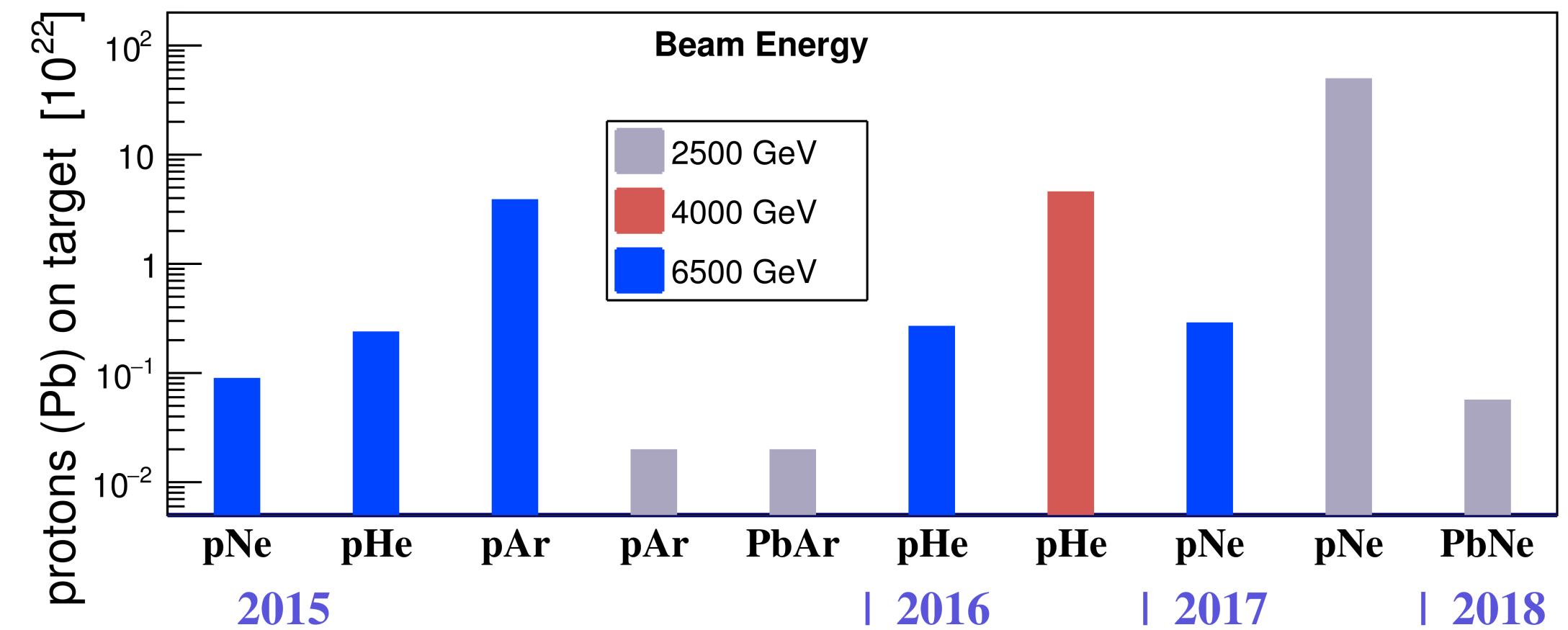Beam 1 - Beam 2, Beam 1 - Gas, Beam 2 - Gas.

Fixed-target mode: **unique at LHC !**
- **SMOG: System for Measuring Overlap with Gas**
- Injecting gas in the LHCb VErtex LOcator (VELO) tank.
- **Noble gas only** : He, Ne, Ar
- Gas pressure : 10^{-7} to 10^{-6} mbar

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LHCb fixed-target program

Fixed-target mode samples
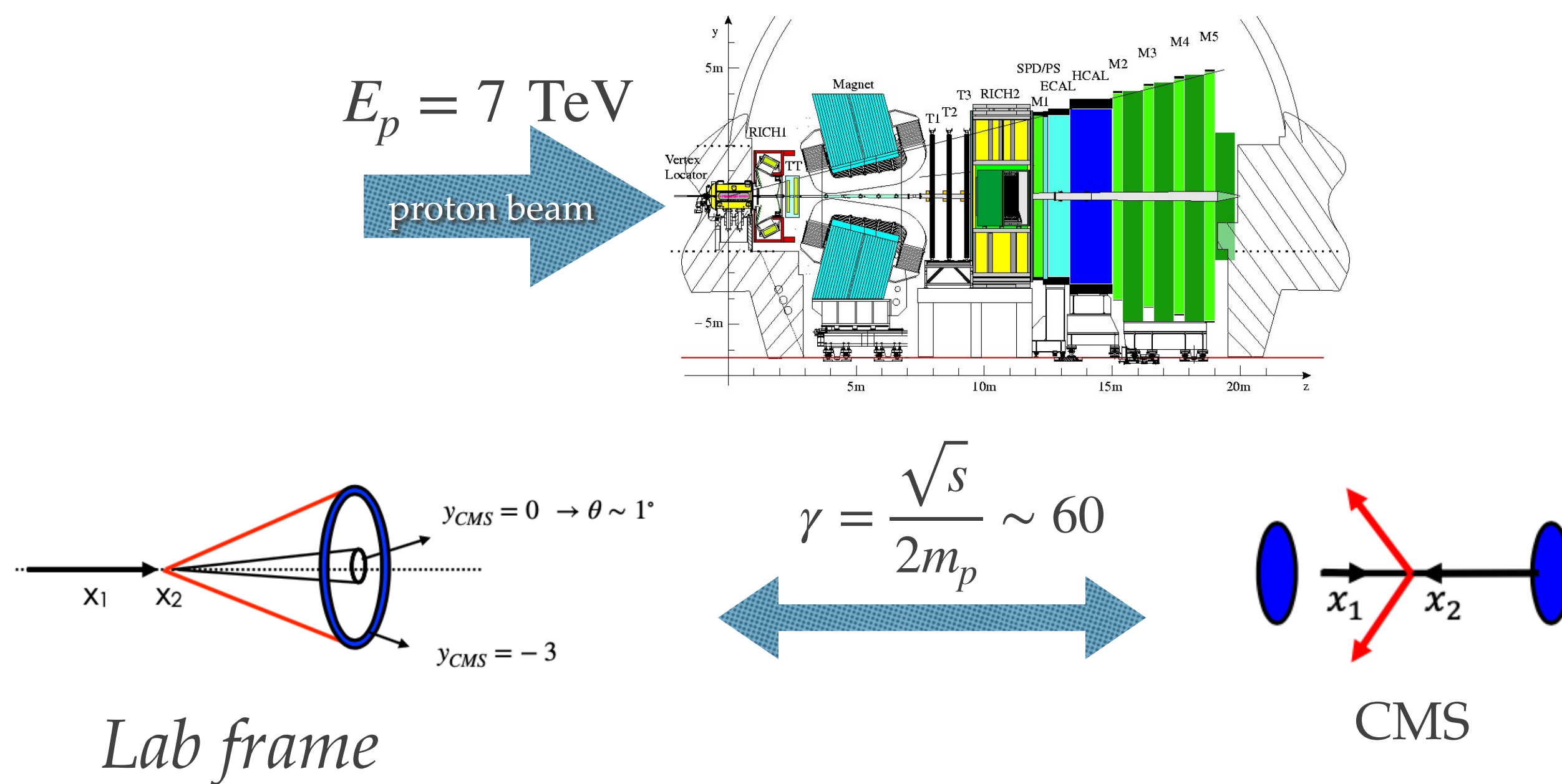

- ❖ Large variety of samples to study !

- ❖ 2 papers published on PRL:

 - ➡ Antiproton production in pHe collisions @ 110 GeV - PRL 121, 222001(2018)

  - ➡ First measurement of charm production in fixed-target configuration at the LHC - PRL 123, 239901

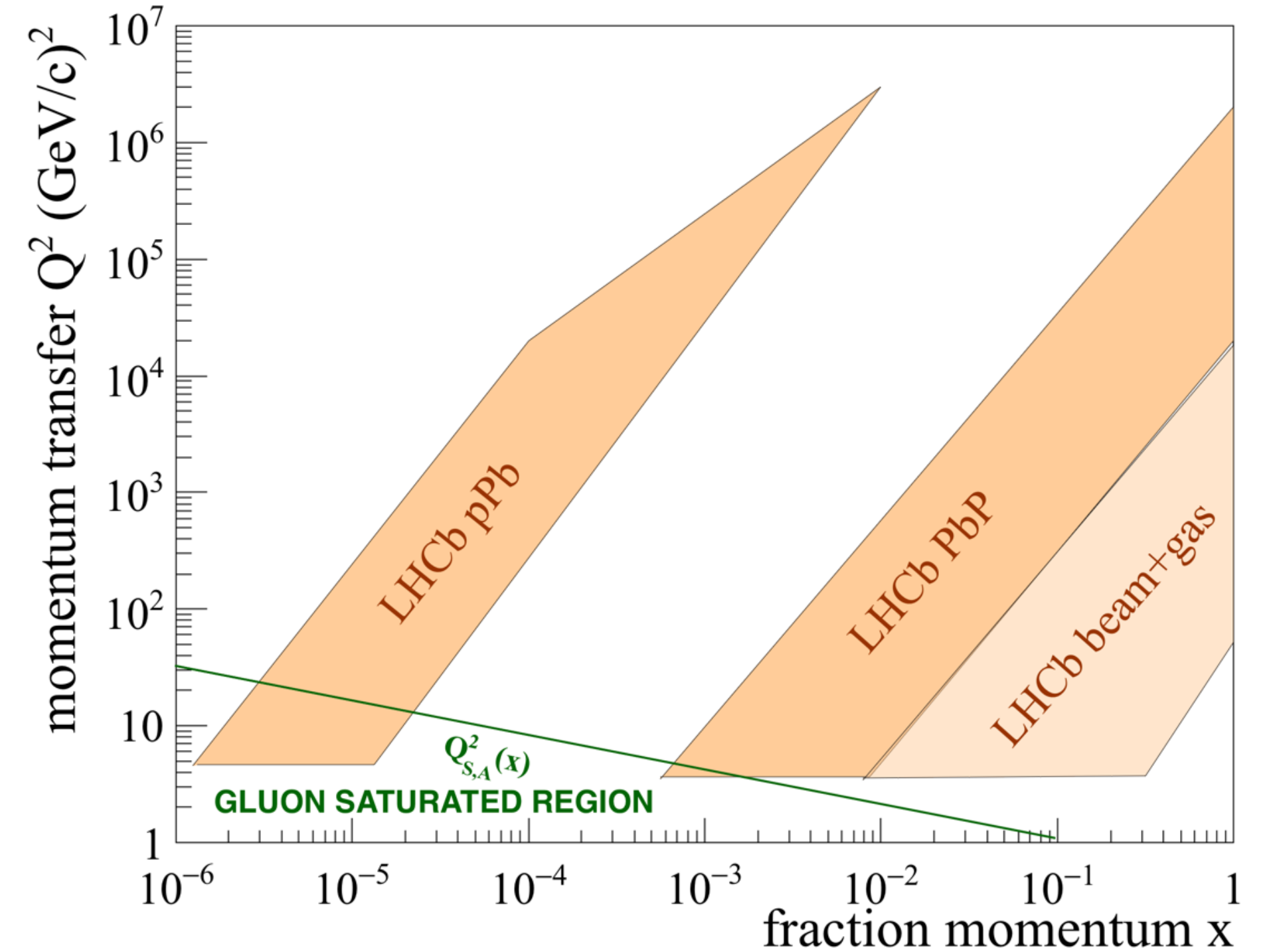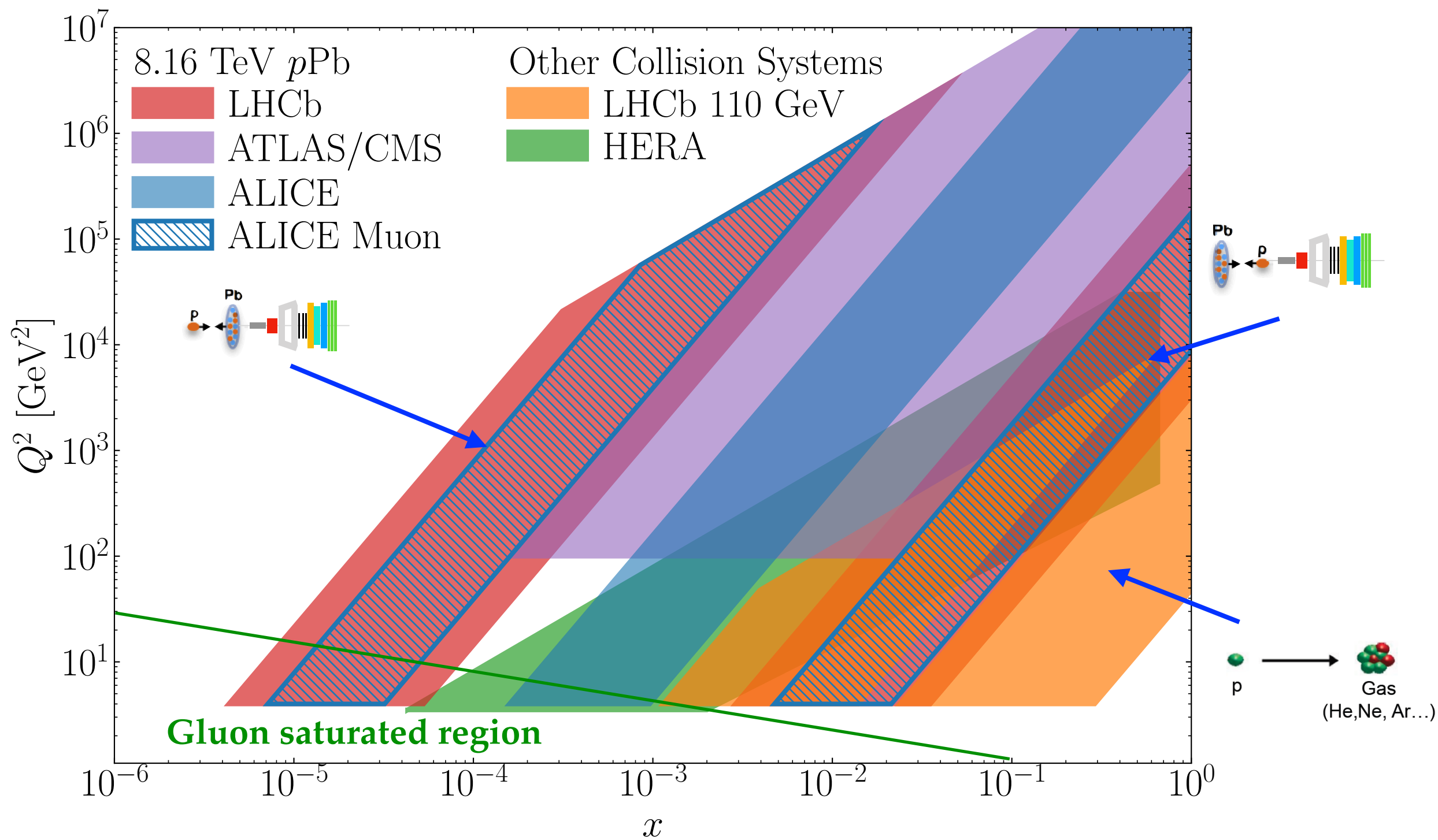- ❖ **New fixed-target samples** : PbNe at $\sqrt{s_{NN}} = 68.6$ GeV

Kinematic conditions for fixed-target collisions at LHCb

$E_p = 7$ TeV

proton beam

$y_{CMS} = 0 \rightarrow \theta \sim 1°$

x_1 x_2

$y_{CMS} = -3$

Lab frame

$$\gamma = \frac{\sqrt{s}}{2m_p} \sim 60$$

x_1 x_2

CMS

❖ Centre-of-mass system strongly boosted in the lab frame.
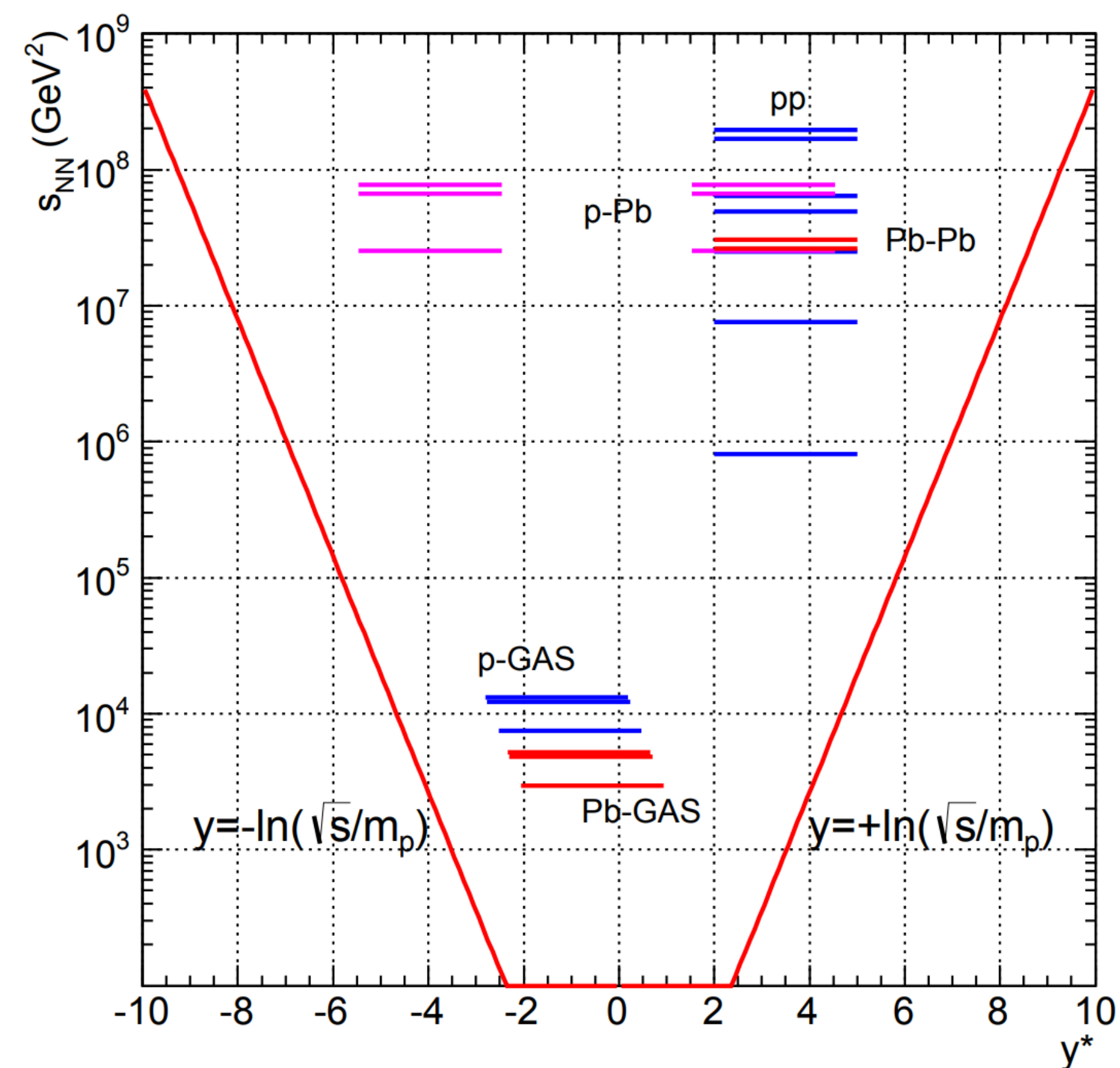
LHCb: Large phase space coverage

❖ SMOG program: unique access to the large-x region at the LHC.
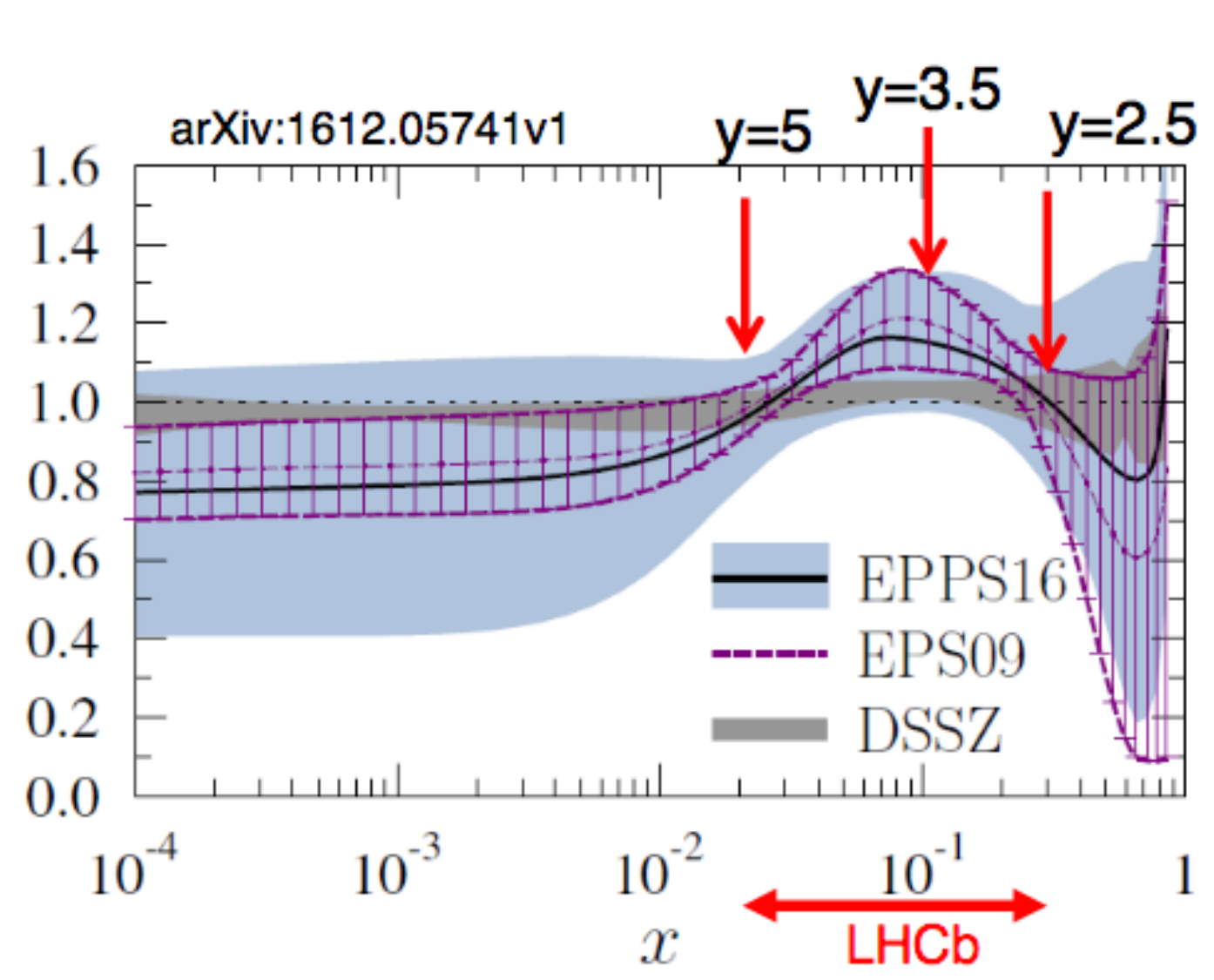
Selected fixed-target results

Other talk this topic this week:
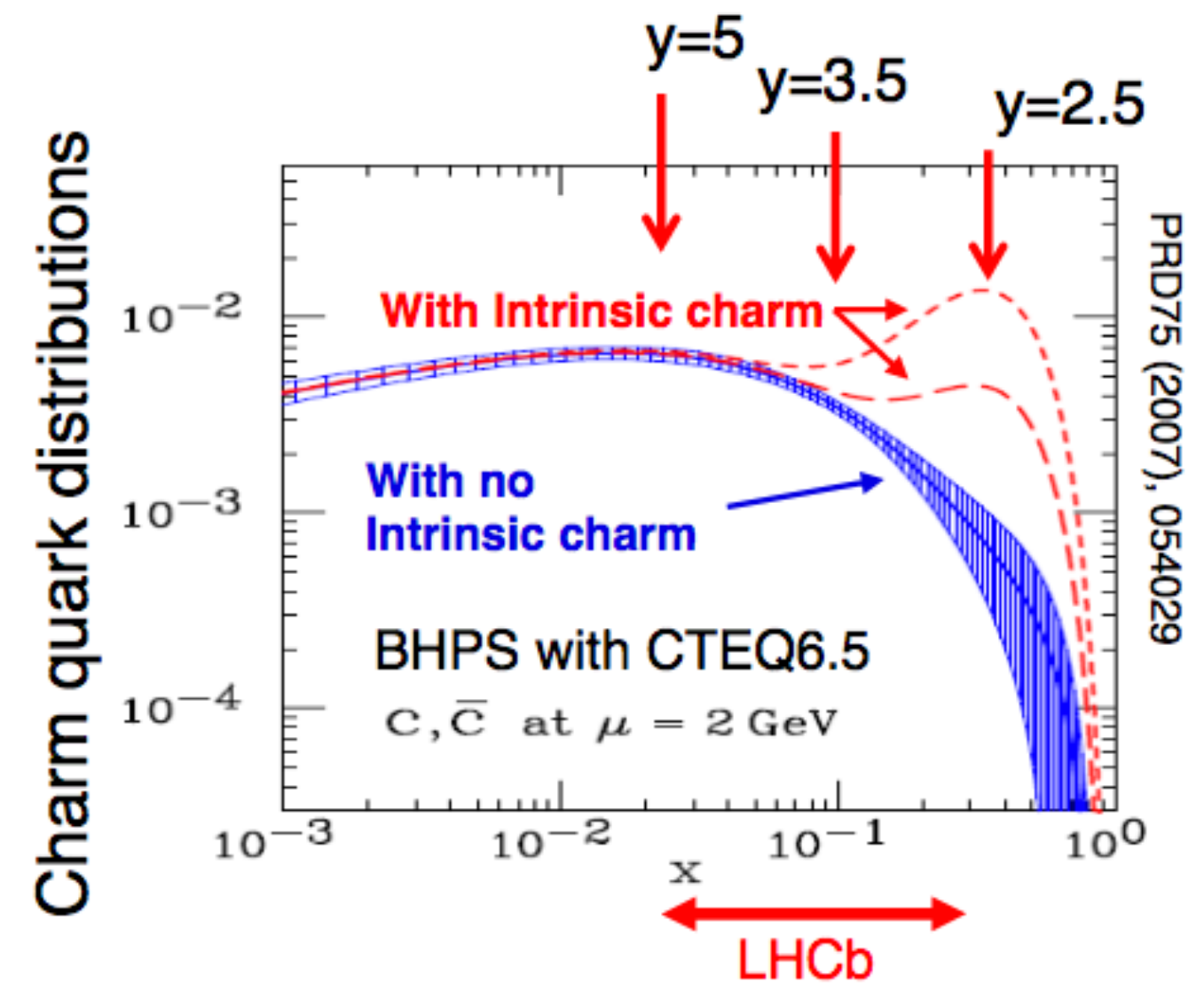- **Lambda_c polarisation with SMOG** - Elisabeth Niel - Thu. 03/06 12:30
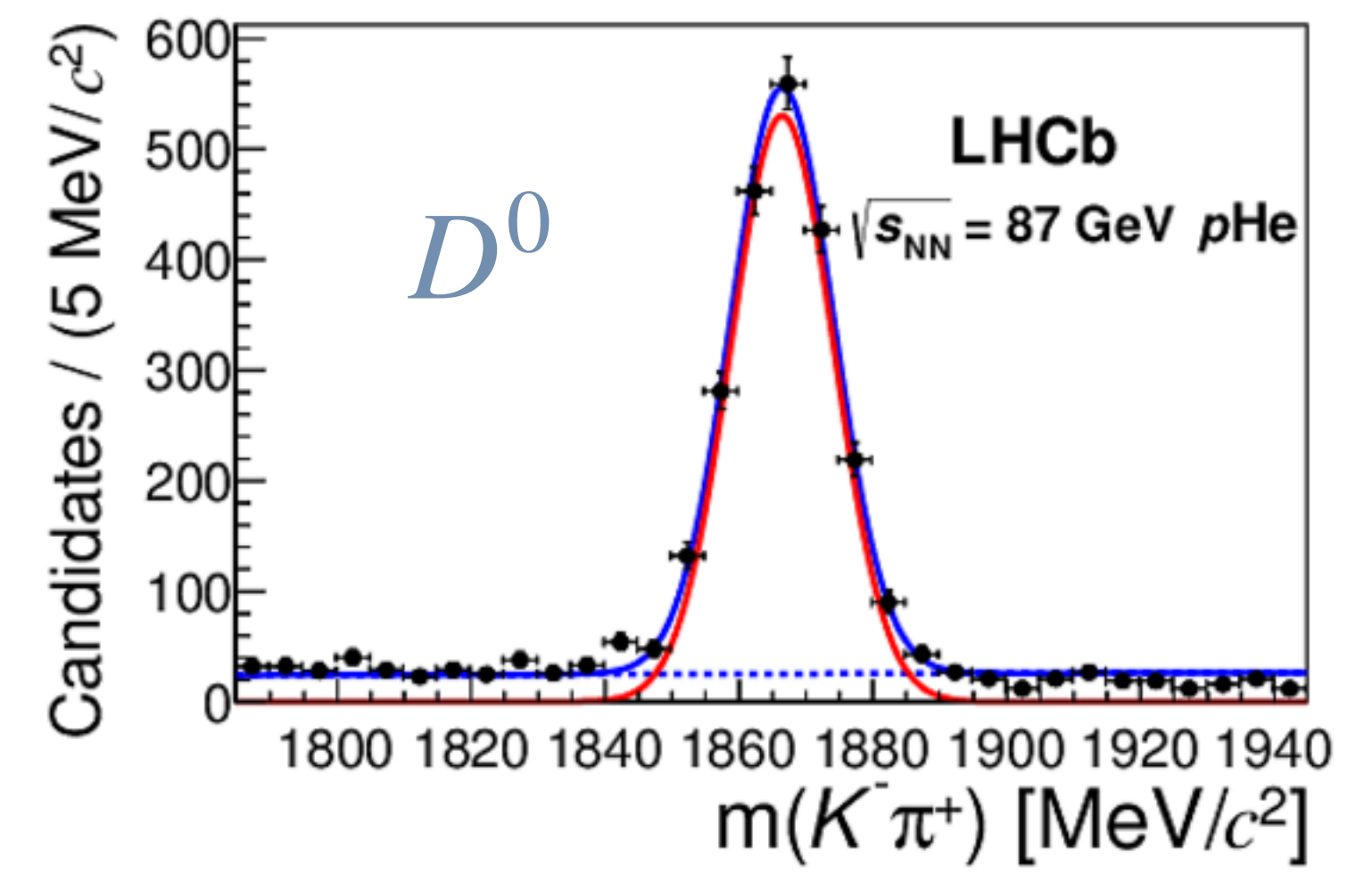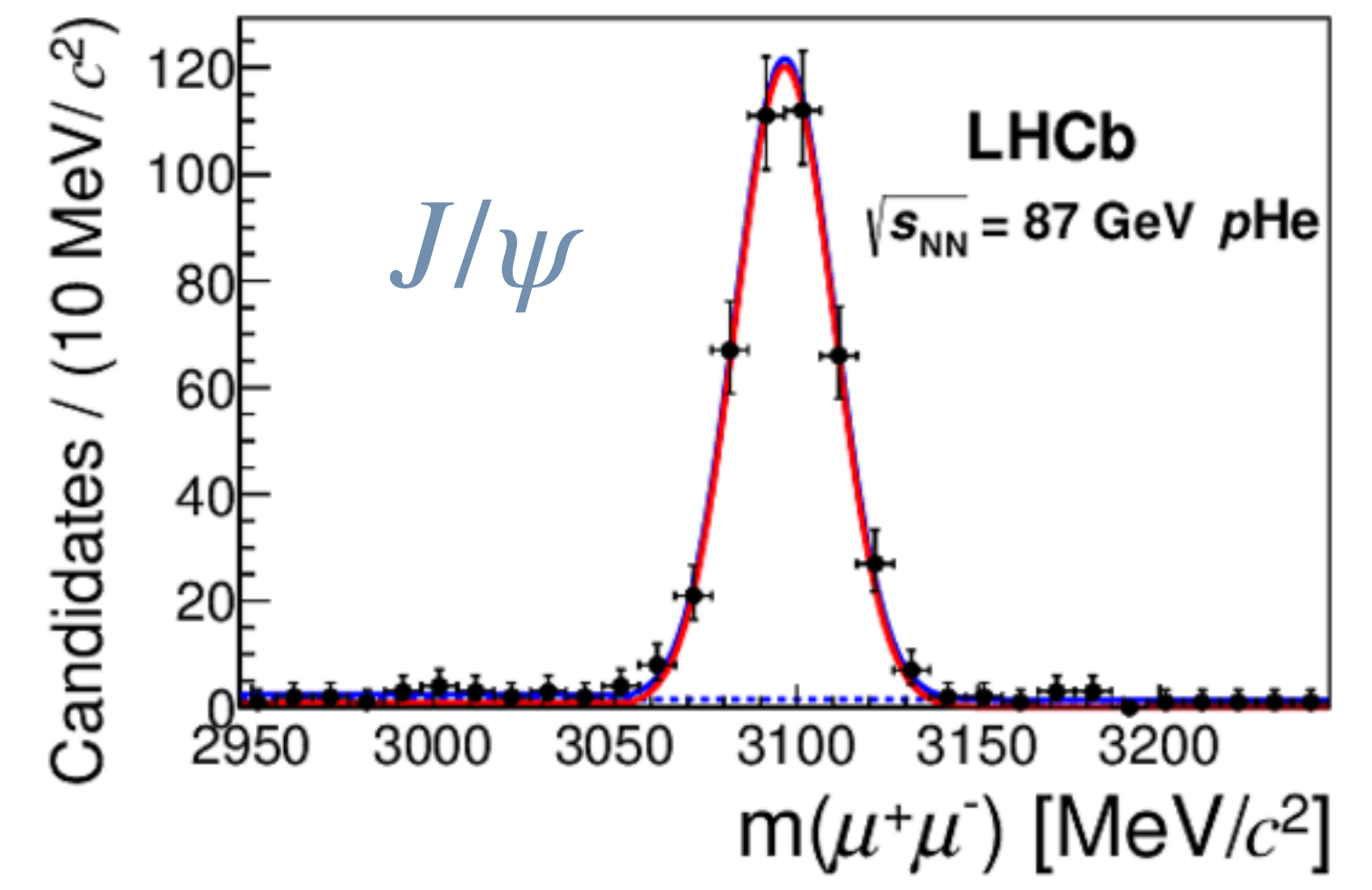
Charm production in Fixed-target

Bjorken-x = fraction of the nucleon momentum carried by a parton

❖ **Fixed-target@LHCb** : access to **anti-shadowing** and **intrinsic charm** content in the nucleons.
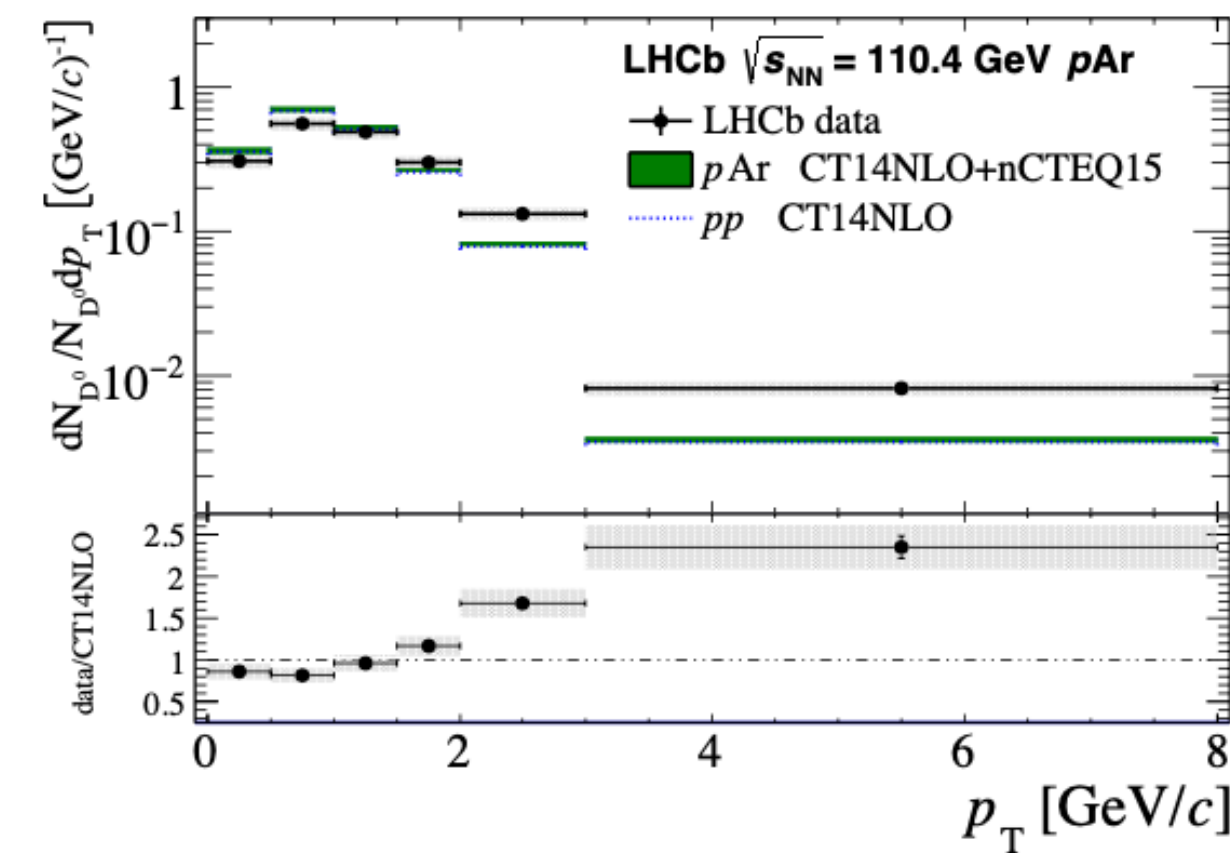
  ➡ probed via charm-production.

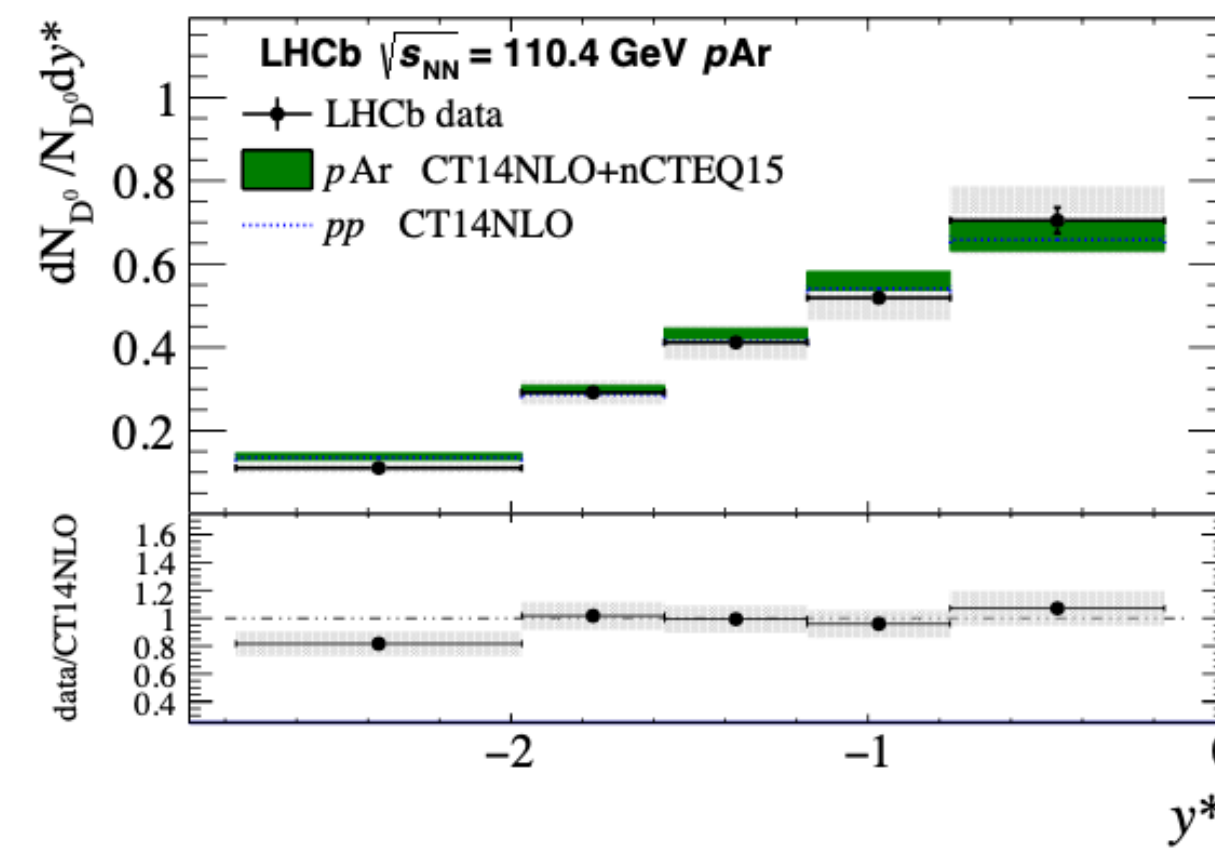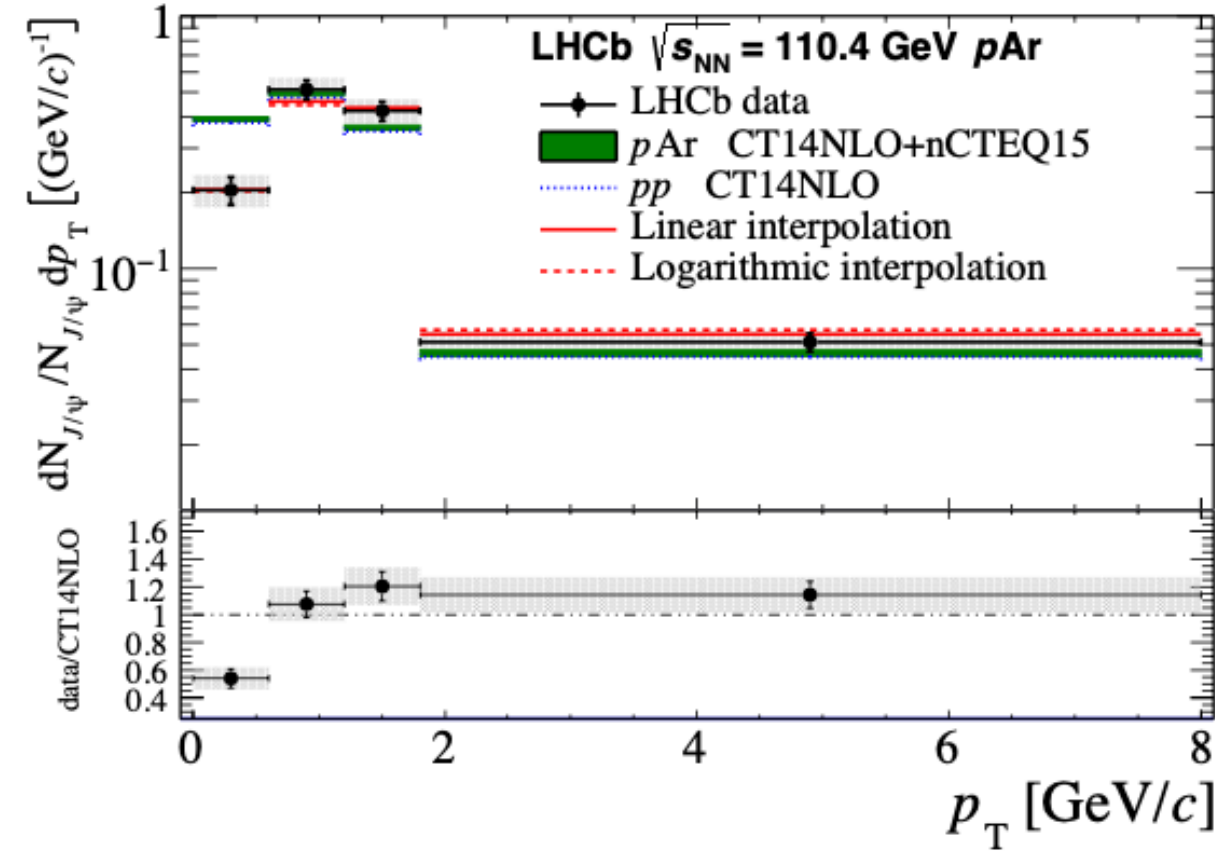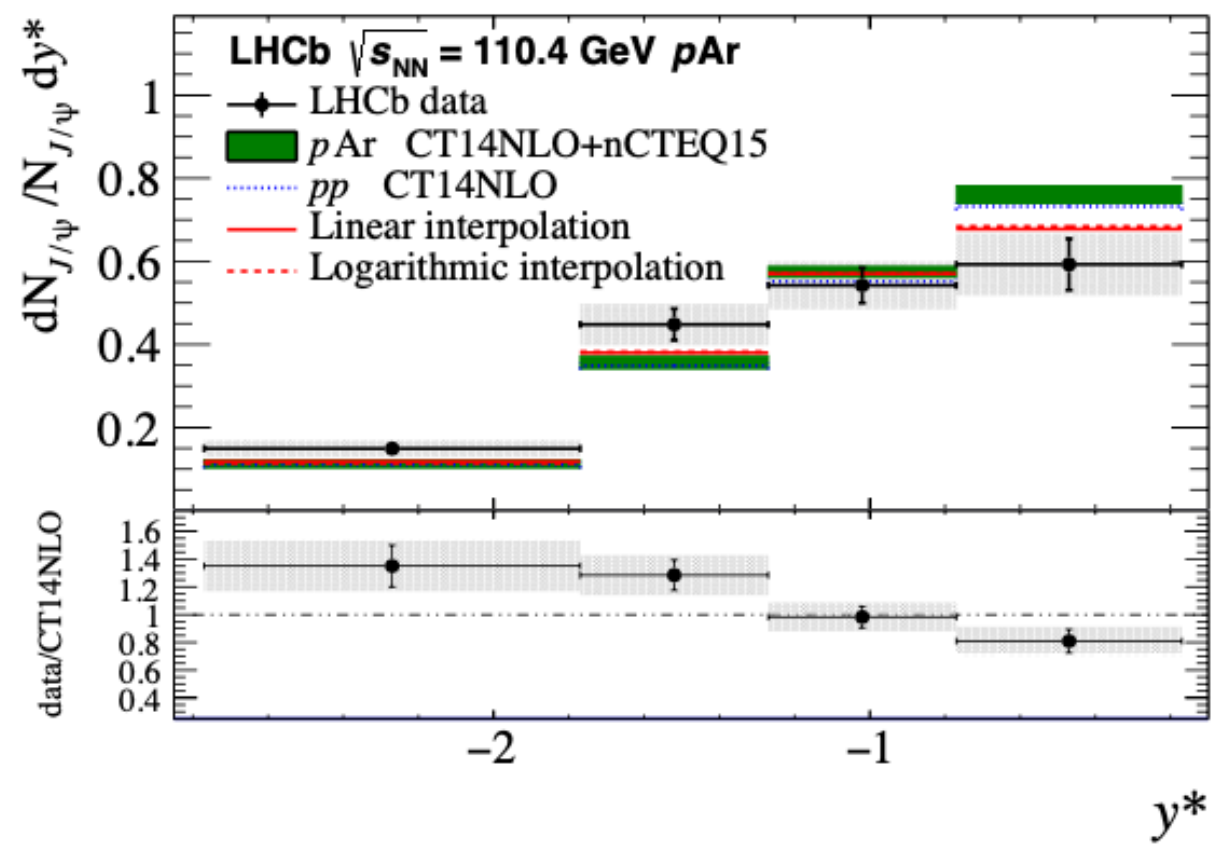# Results in pAr@110 TeV: J/ψ and D⁰
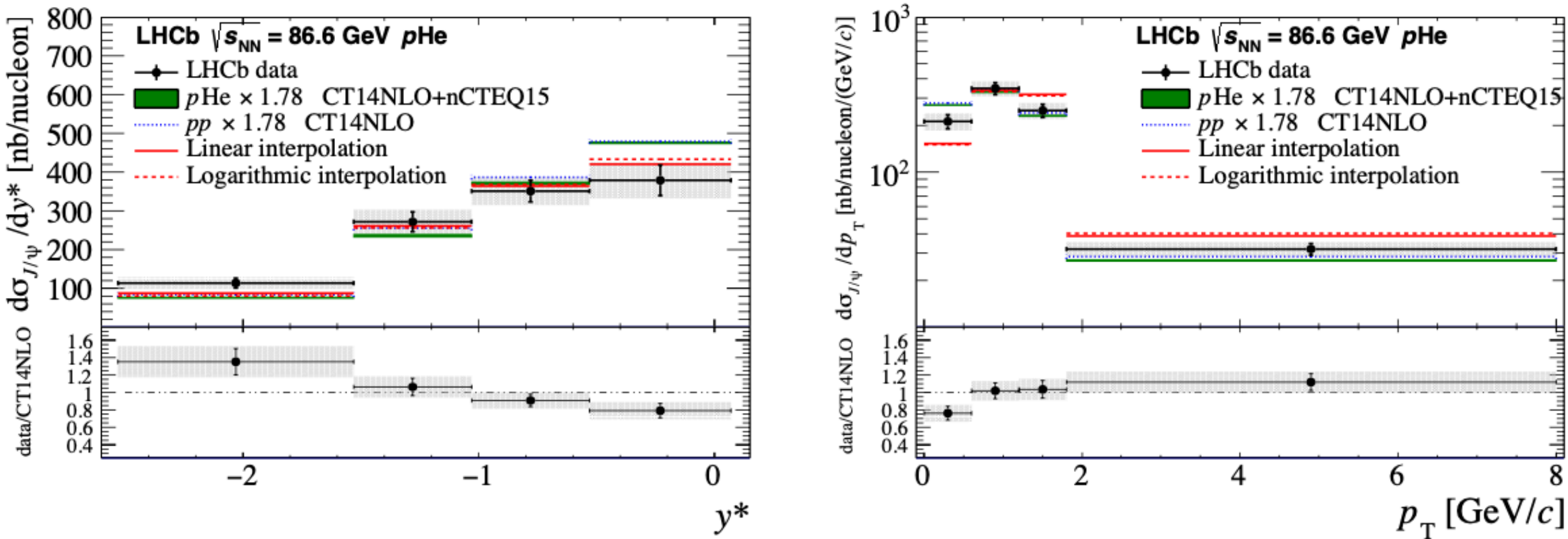
J/ψ production yield

D⁰ production yield

- ❖ No luminosity measurement for this dataset. Data and theory yields are compared after normalisation to unity.

- ❖ Tensions between **HELAC-ONIA** and data distributions, **more important versus p_T**.

- ❖ **Good** shape agreement with **phenomenological predictions based on data interpolation** for J/ψ.

Results in pHe@86.6 TeV: J/ψ and D⁰

J/ψ cross-section

D⁰ cross-section
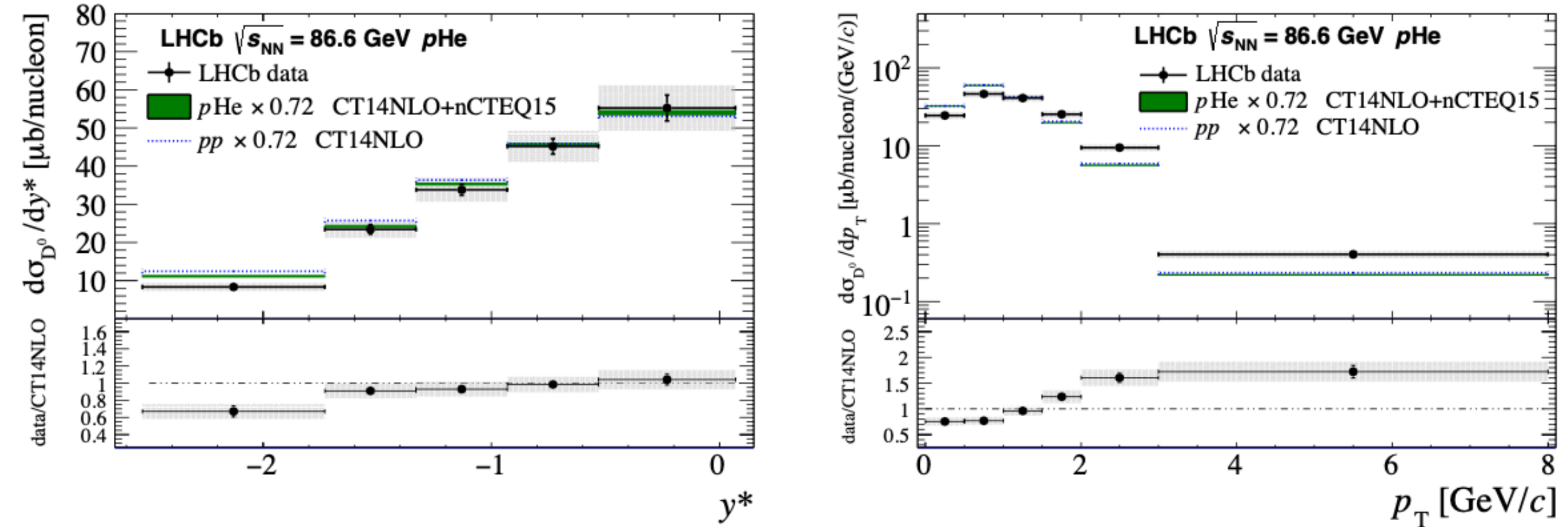
$$\sigma_{J/\psi} = 652 \pm 33 \,(\text{stat}) \pm 42 \,(\text{syst}) \,\text{nb/nucleon},$$
$$\sigma_{D^0} = 80.8 \pm 2.4 \,(\text{stat}) \pm 6.3 \,(\text{syst}) \,\mu\text{b/nucleon}.$$

$y \in [2.0, 4.6]$

❖ **Precise** J/ψ and D⁰ measurements in p-He.

❖ **HELAC-ONIA** predictions **under-estimate** J/ψ (D⁰) cross section (pHe) by a factor of 1.78 (0.72).
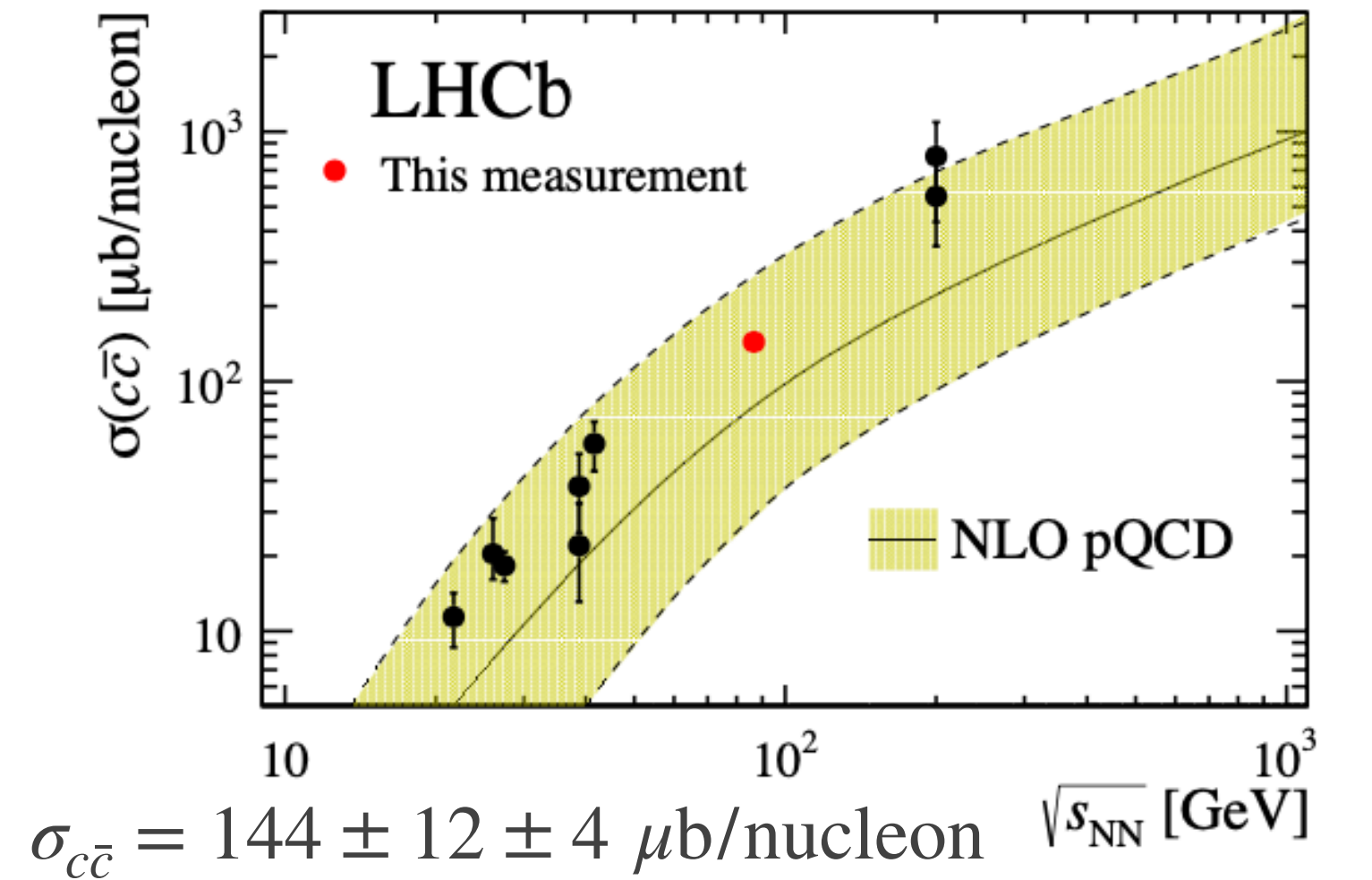
$\sigma_{c\bar{c}} = 144 \pm 12 \pm 4 \ \mu\text{b/nucleon}$

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What about the intrinsic charm then ?
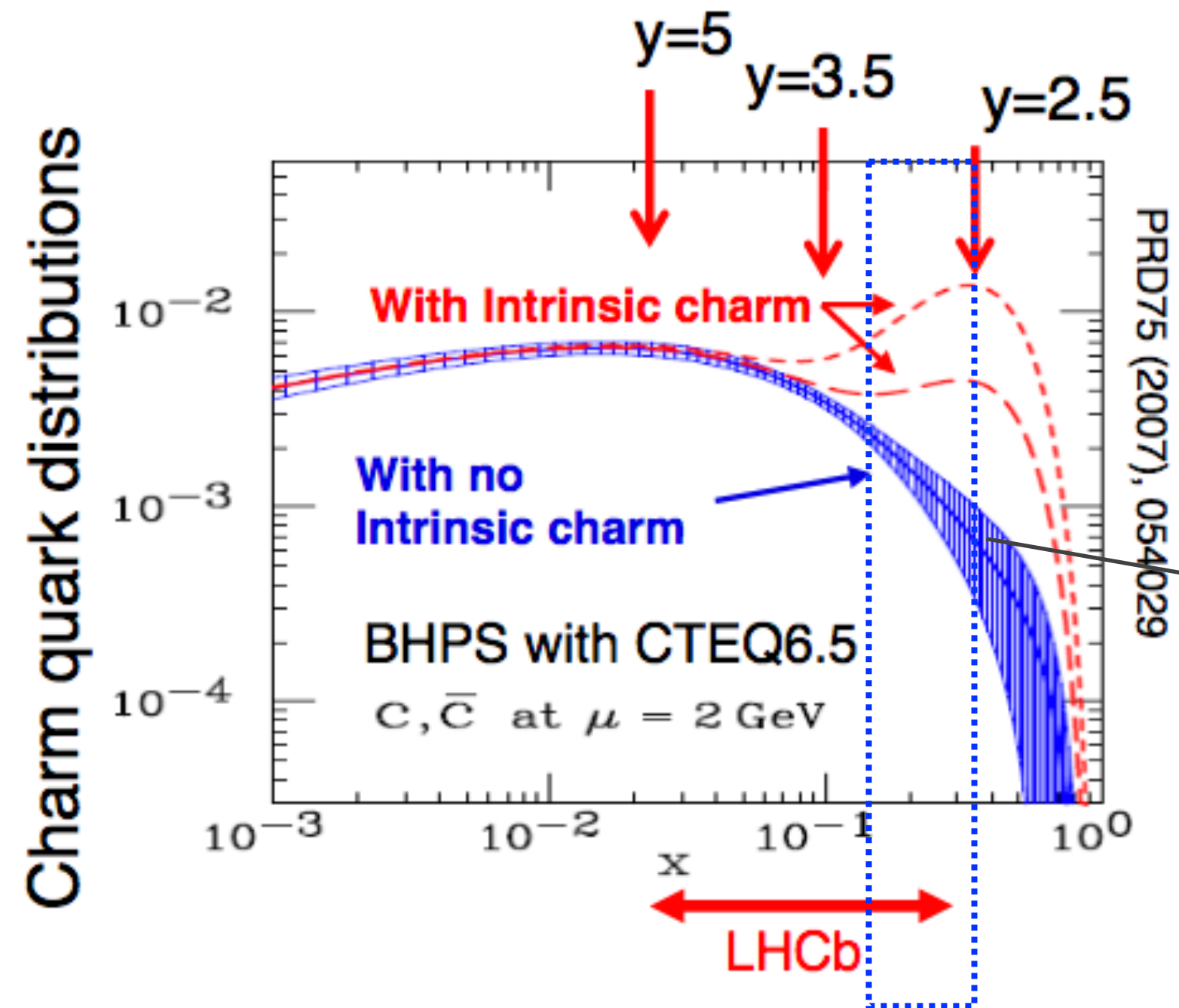
$$x \simeq \frac{2m_c}{\sqrt{s_{NN}}} \exp(-y)$$
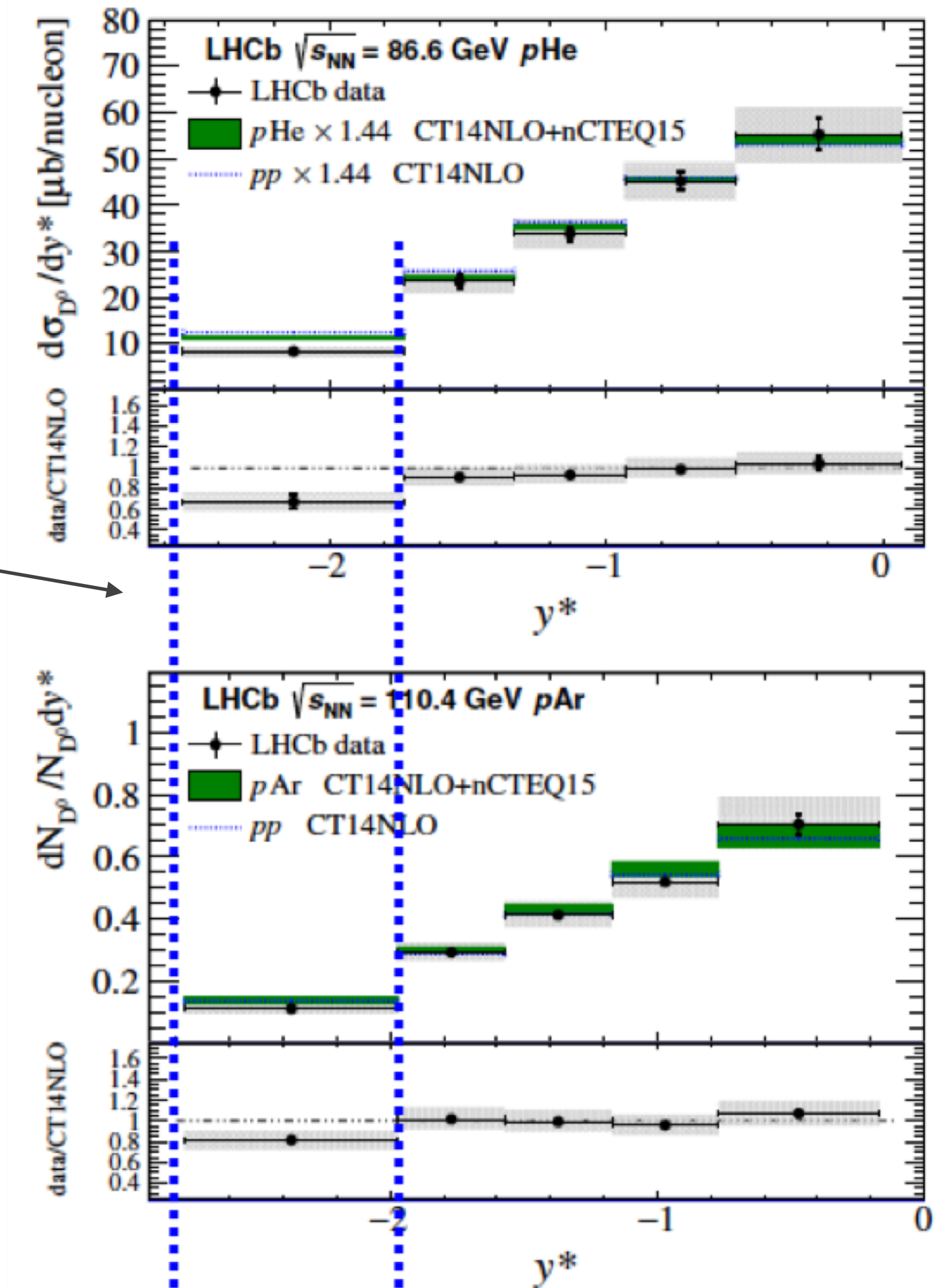
- ❖ In this range intrinsic charm is expected to contribute substantially.

- ❖ **No strong intrinsic charm** contribution is observed.

Antiproton production in pHe@110GeV

❖ <u>The antiproton fraction in cosmic rays</u>: indirect probe for exotic astrophysical sources of antimatter, such as Dark Matter.

❖ AMS experiment has measured proton-anti-proton production ratio in cosmic ray.

❖ An excess of antiprotons over current predictions was observed, limited by the precision on $p + He \rightarrow \bar{p} + X$ cross-section.

❖ For more detail, see Martin's talk today at 10:30.

Giesen et al., JCAP 1509, 023
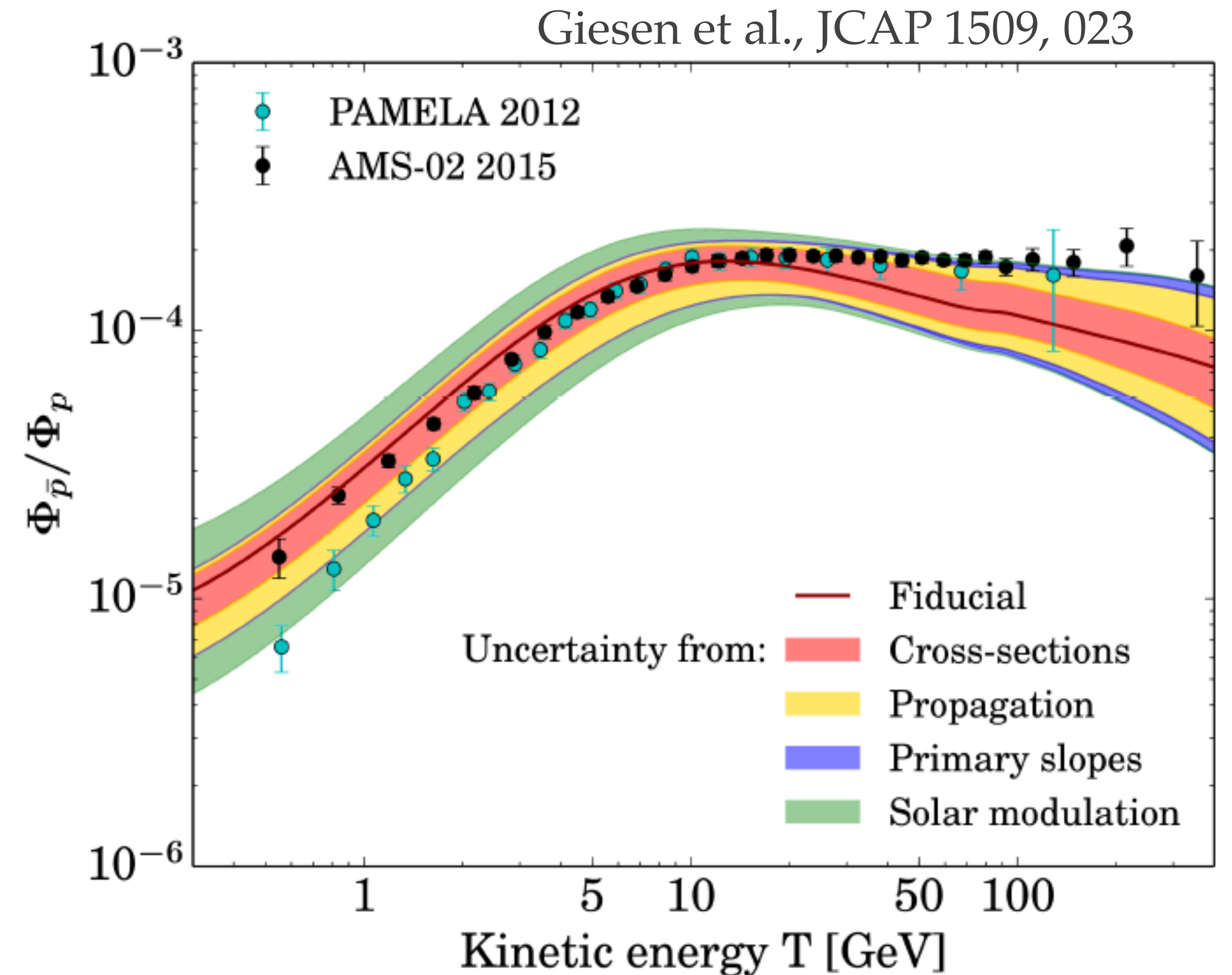
Antiproton production in pHe@110GeV

Clear pick of antiproton identified by the two RICH detectors
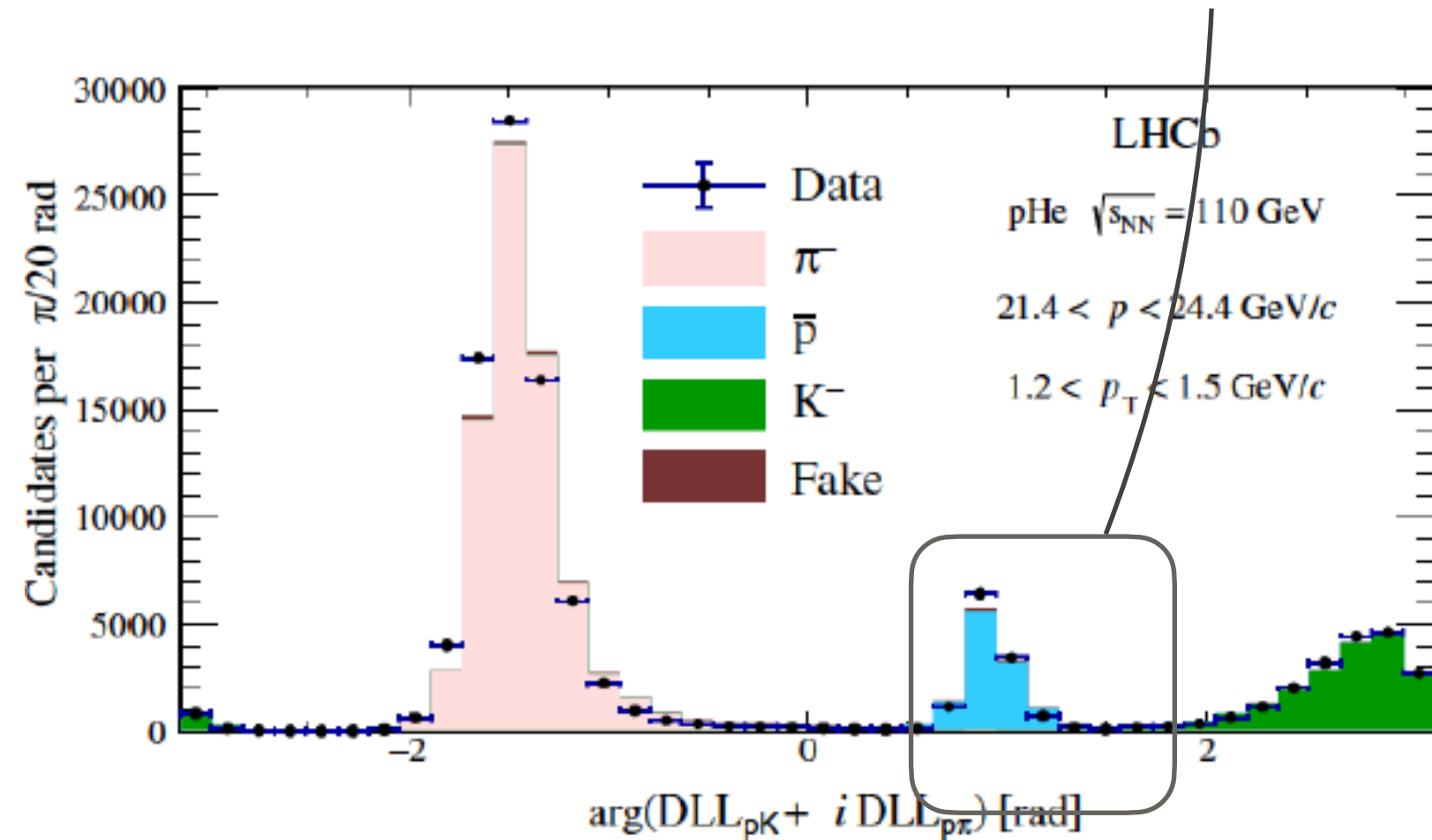
- ❖ <u>Antiproton cross-sections in pHe</u> : key to constrain dark matter search in cosmic flux.

  ➡ **Very precise data !**

  ➡ Data constrain extrapolations from pp to pHe cross-sections.

  ➡ Data constrain empirical parameterisation for scaling violation of cross-sections.

LHCb
pHe → p X $0.7 < p_T < 1.2$ GeV/c
$s_{NN} = 110$ GeV

LHCb
pHe → p̄ X $1.2 < p_T < 2.8$ GeV/c
$\sqrt{s_{NN}} = 110$ GeV

- DATA
- EPOS LHC
- EPOS 1.99
- QGSJETII-04
- QGSJETII-04m
- HIJING 1.38
- PYTHIA 6.4

(a)

Boudad et al., arXiv:1906.07119

$+$ AMS-02 (σ_{tot})
— Baseline prediction
▨ Total uncertainties
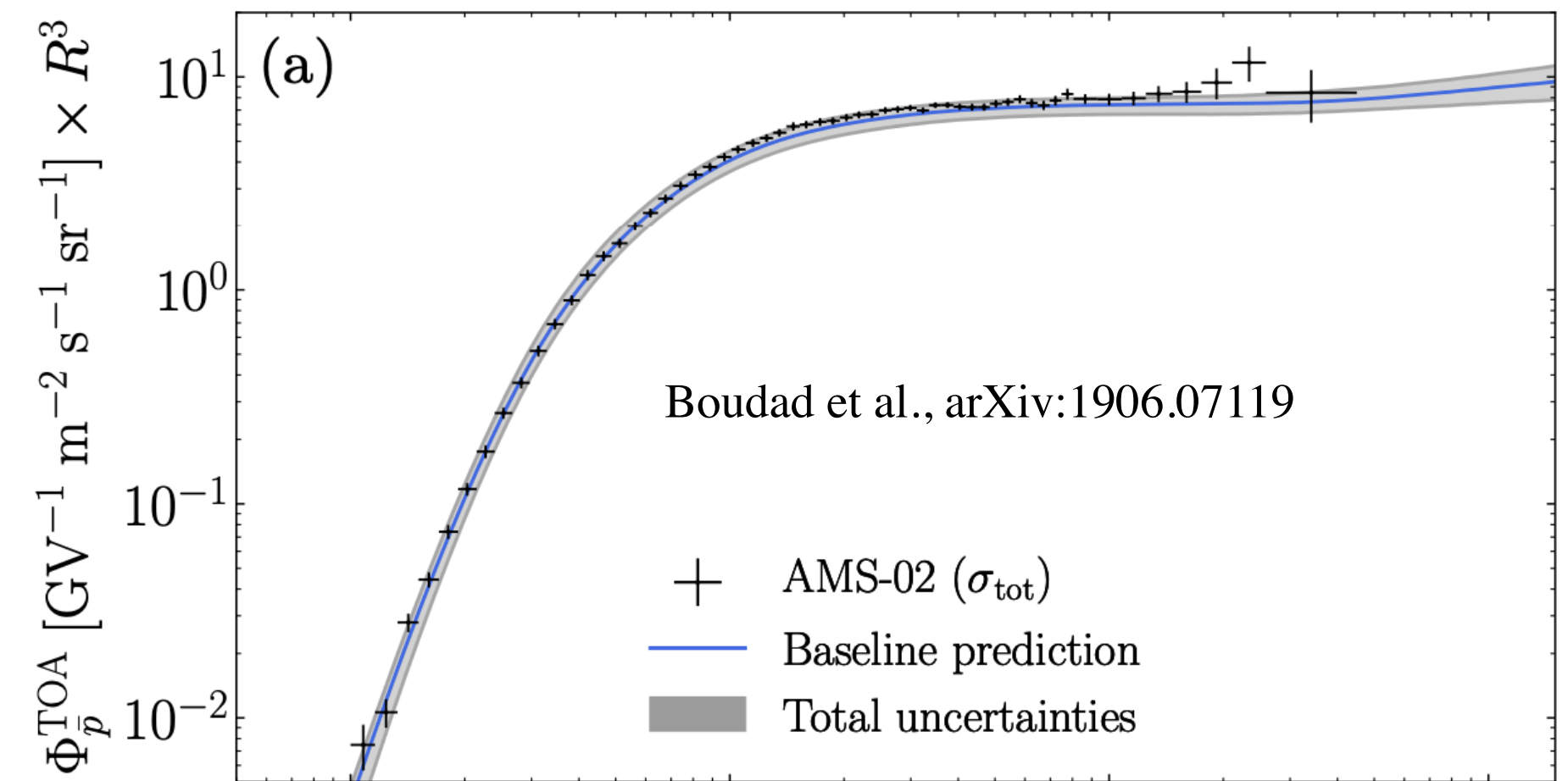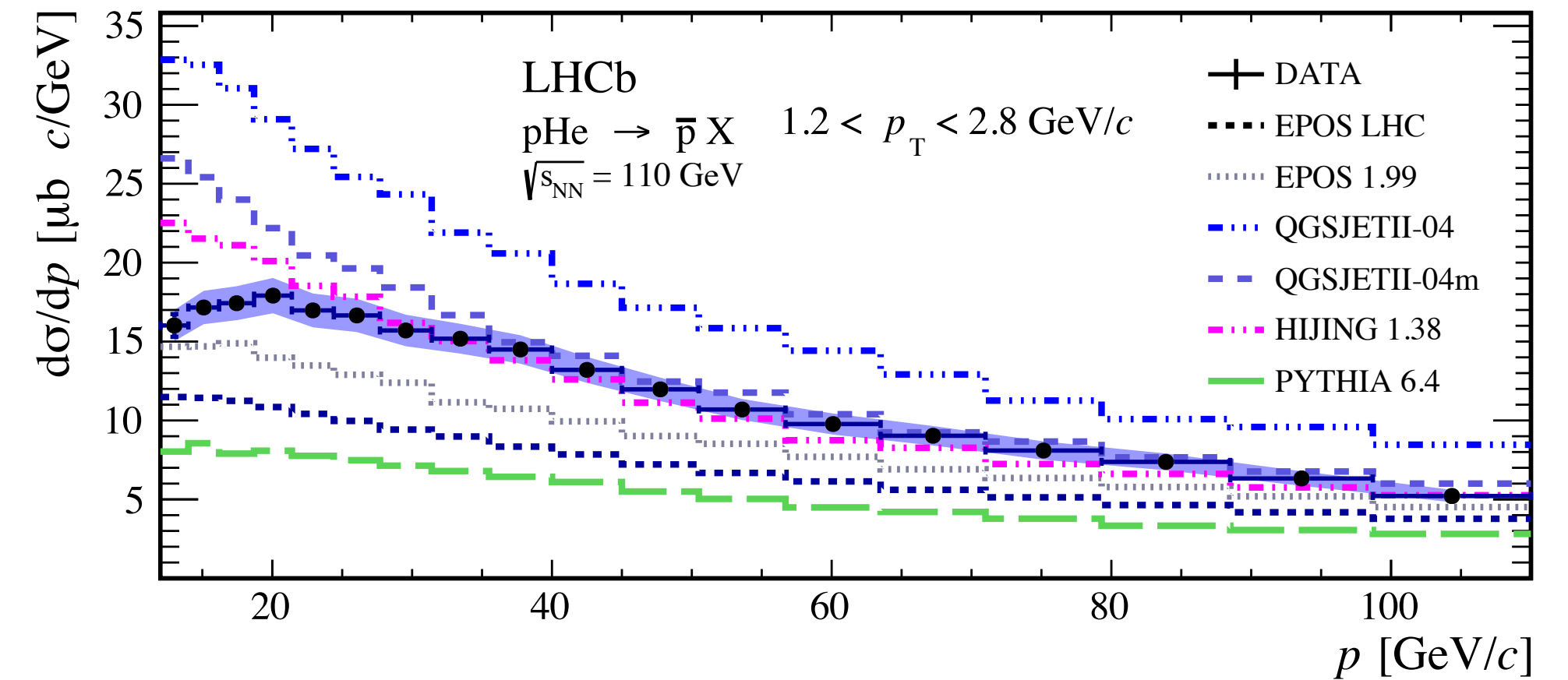
New predictions after LHCb's paper

SMOG2@LHCb: prospects for Run 3
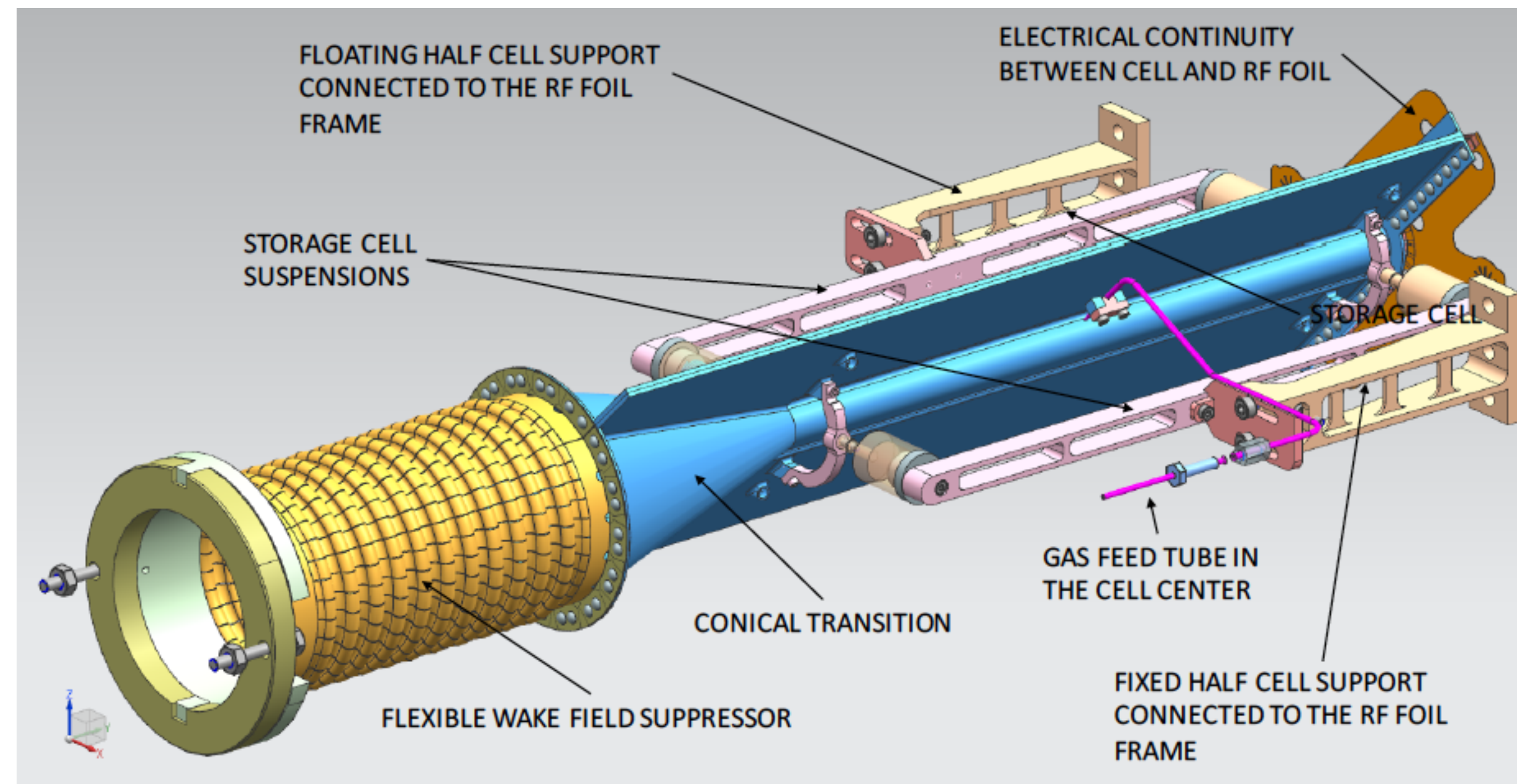
Other talk this topic this week:

- **Tracking with LHCb Phase II** - Felipe Garcia - Tue. 01/06 10:40
- **SMOG2** - Pasquale Di Nezza - Wed. 02/06 15:00
- **Study of cold nuclear matter with SMOG2** - Edoardo Franzoso - Thu. 03/06 - 10:00

SMOG2 versus SMOG1

"pump" valve   Flow to VELO   Pirani gauge

Evacuate and
leak detector

"fill" valve
PV501

High pressure
Piezo gauge

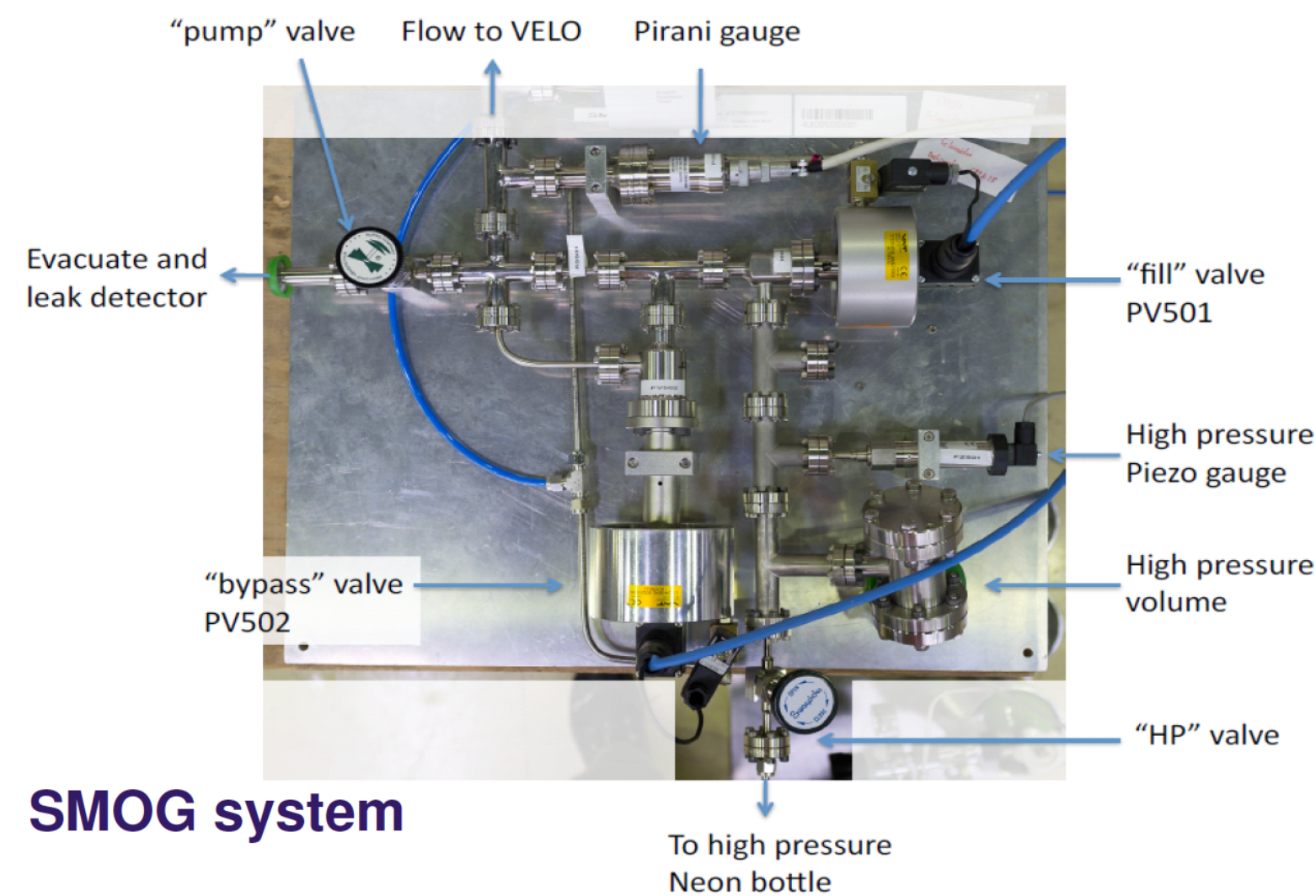"bypass" valve
PV502

High pressure
volume

"HP" valve

SMOG system

To high pressure
Neon bottle

SMOG2 cell

❖ **SMOG2** ([TDR](#)) : Standalone gas storage cell covering z ϵ [-500;-300] mm :

➡ Well defined interaction region.

➡ **Increase of target density (luminosity)** by up to 2 orders of magnitude using the same gas load of SMOG.

➡ Gas feed system measures the **gas density with few % accuracy**.

➡ Possibility to inject more gas species: H, D, He, N, O… (SMOG: He, Ne, Ar).

➡ **More sophisticated Gas Feed System**: will allow to measure the target density (and luminosity) with much higher precision.

➡ **Possibility to run in parallel of pp collisions and inject non noble Gaz.**

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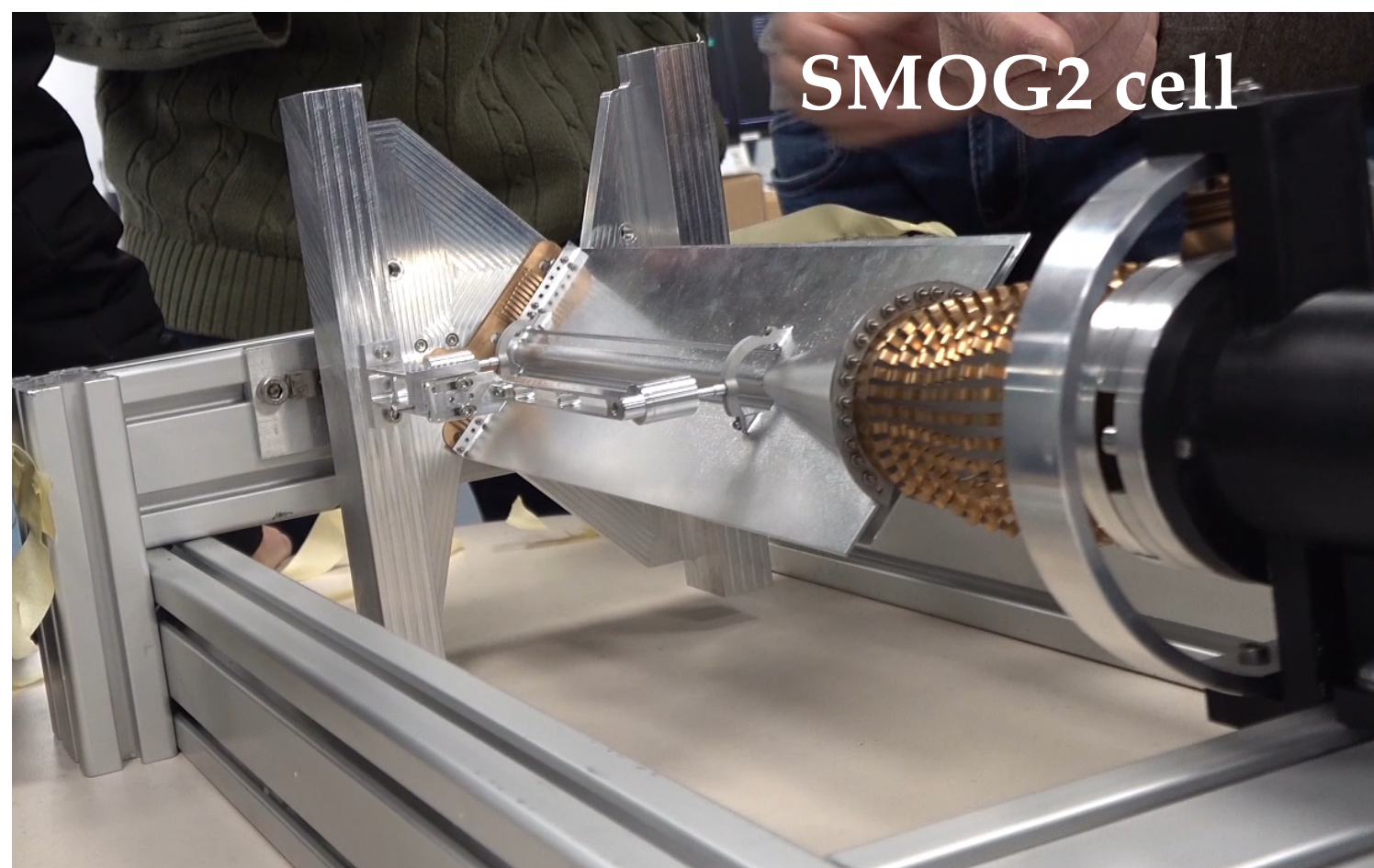
Status of SMOG2

The cell is in place and ready for commissioning !
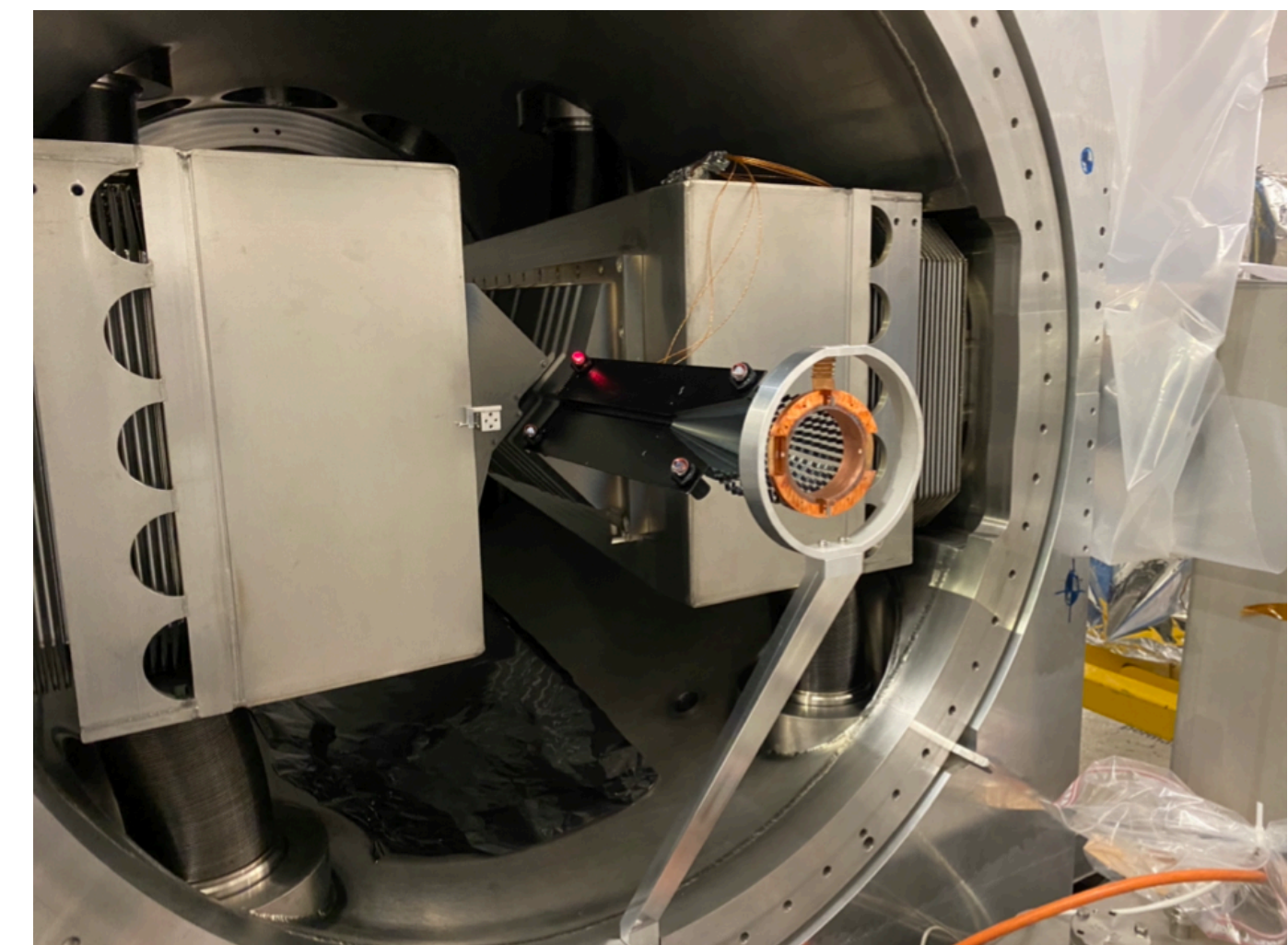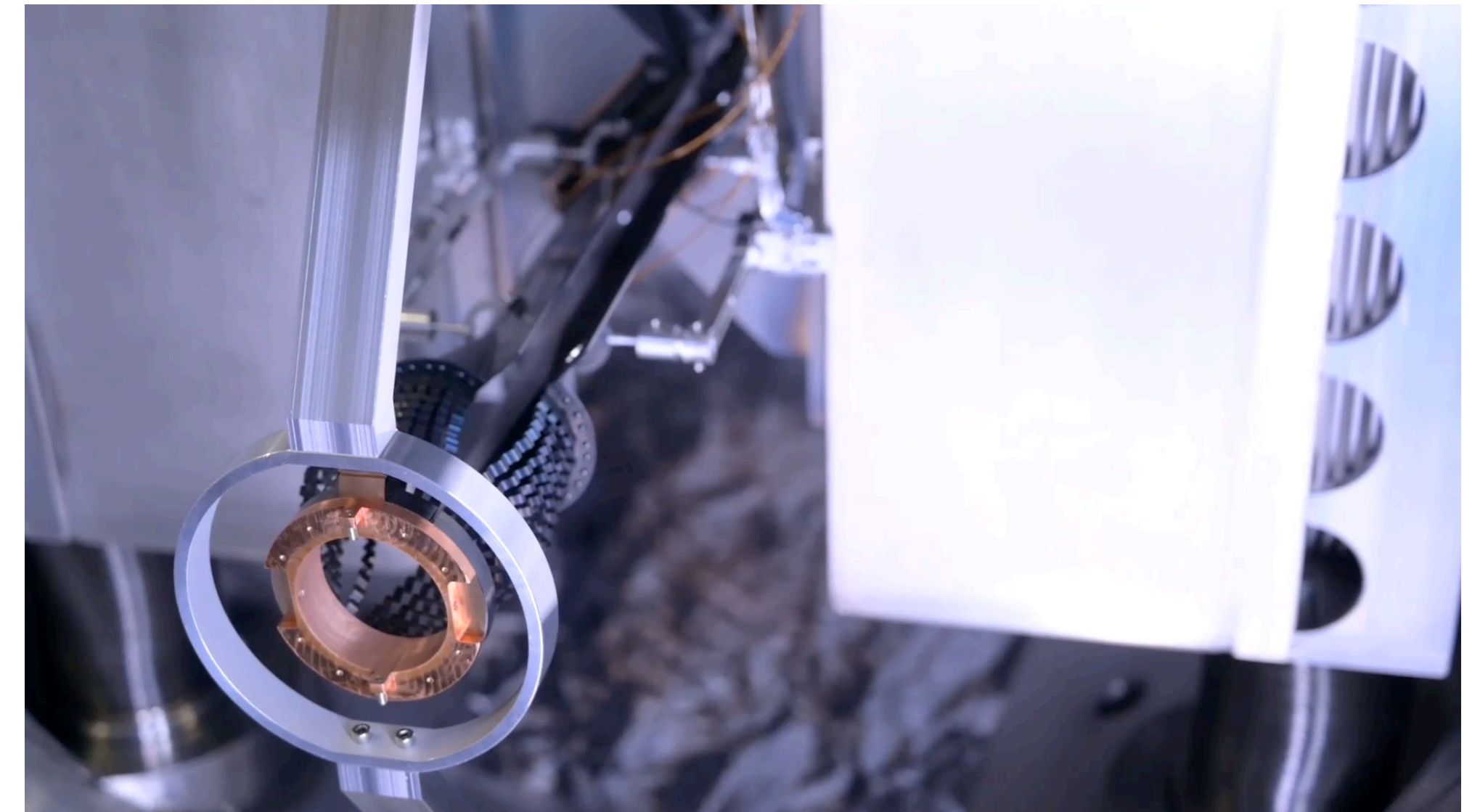
Operational opportunities for SMOG 2

Precise luminosity measurement

$$L_{ist} = \theta \; N_p \; f_{rev}$$

areal density

number of particles

$$N_{p/b} \cdot N_b$$

f_rev: beam revolution frequency
N_p/b: number of particles per bunch
N_b: number of bunches
ρ_0 : target density at the cell center
Φ: gas flow
θ : areal density
C= total conductance
D: cell diameter
L: cell length
T: temperature
M: molecular mass

$$\rho_0 \frac{L}{2} = \frac{\Phi}{C} \frac{L}{2}$$

$$C = 3.81 \sqrt{\frac{T}{M}} \frac{D^3}{L + \frac{4}{3}D}$$

❖ Depending on the gaz, one can expect a total uncertainty on luminosity of ~2%

Runtime in parallel of pp collisions

| 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

Projection of ~1 year data taking in parallel mode.

❖ Possibility to run in parallel of the usual pp program.

❖ Ongoing feasibility/performances studies are encouraging.

Run 3 prospects for SMOG2 with LHCb

Rapidity scan

Phys. Rev. C98 (2018) 034905
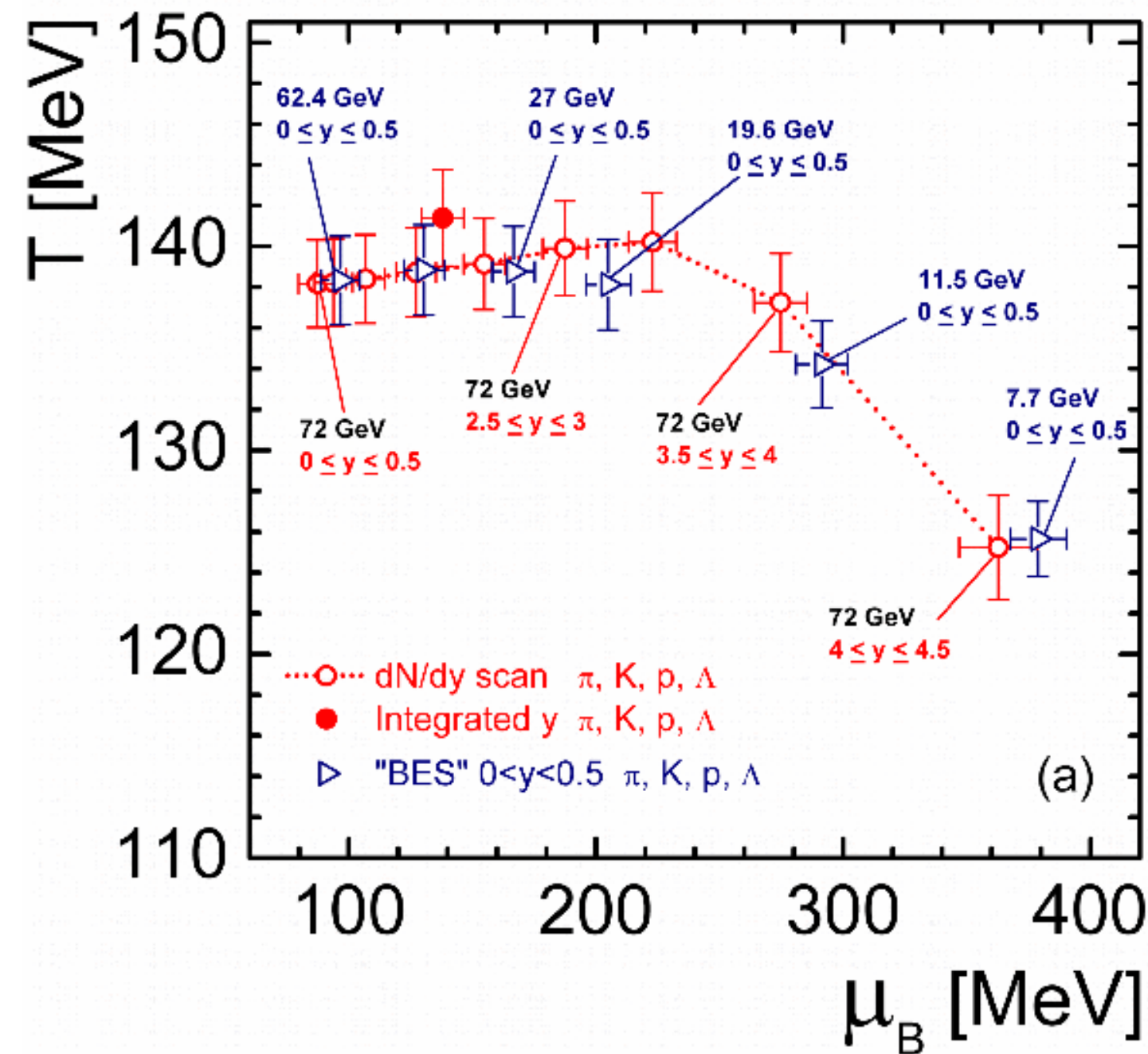
Deep in the hadronic structure
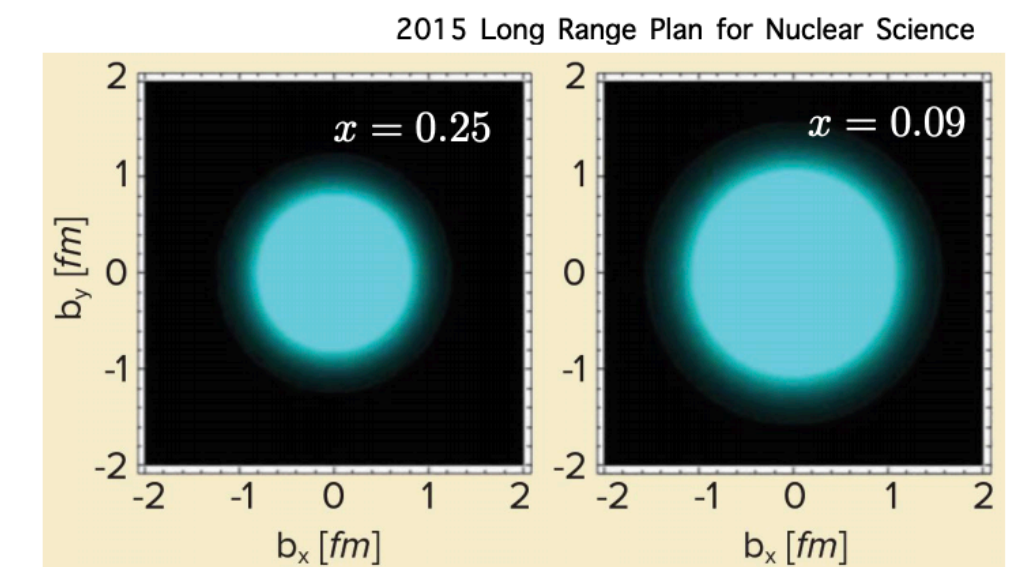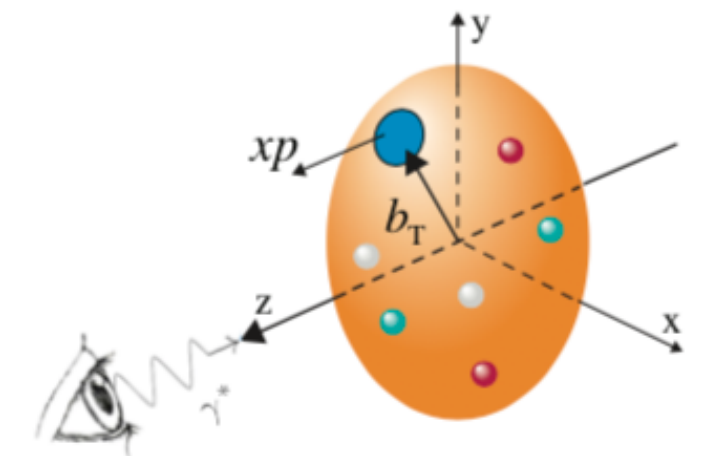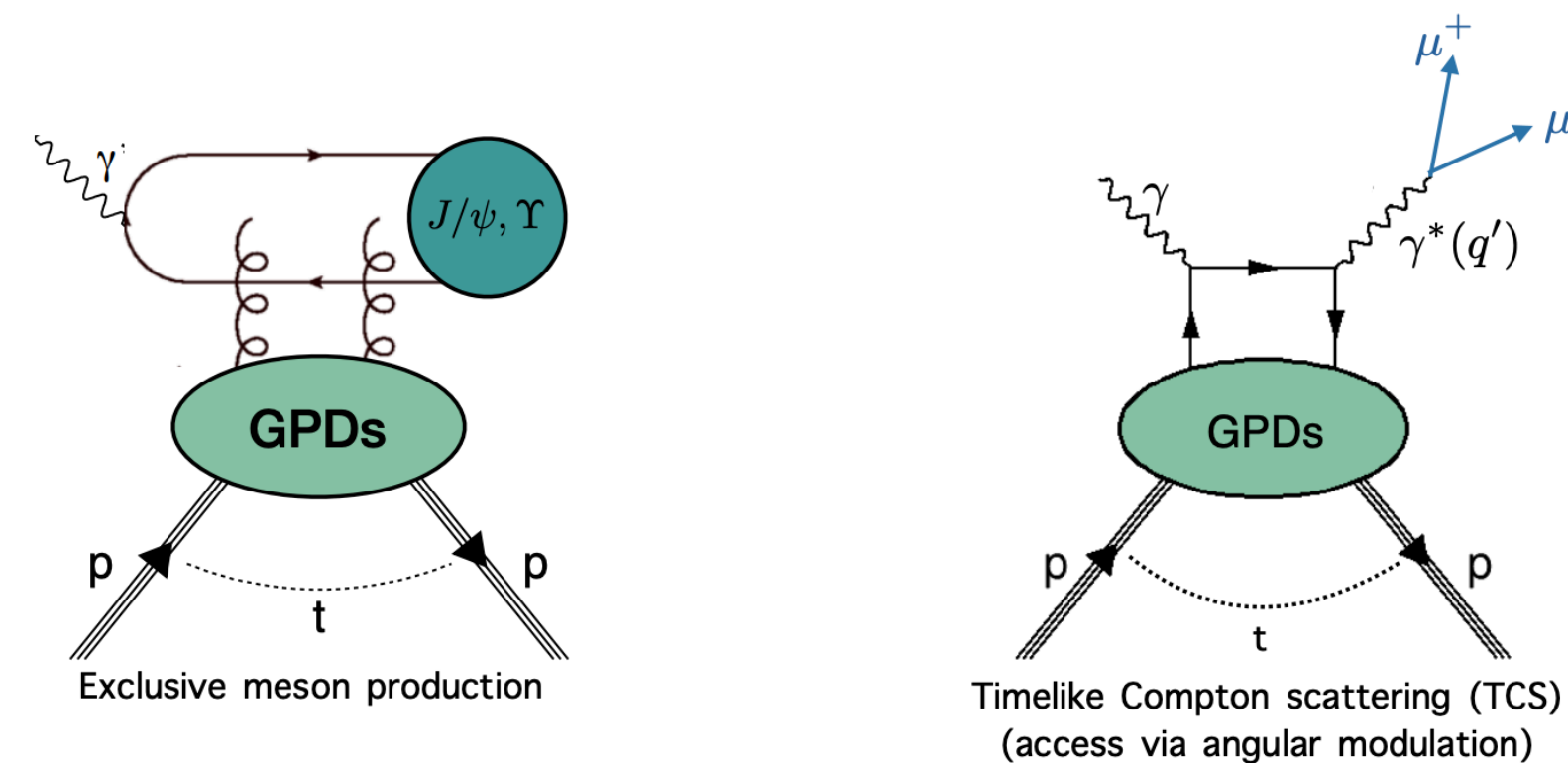
One of the objectives : 3D pictures
in impact parameter space

❖ **Rapidity scan** at $\sqrt{s_{NN}} = 72$ GeV with FT@LHCb **could complement the RHIC beam energy scan.**

❖ SMOG2@LHCb could probs **nuclear PDFs, TMDs, GPDs** at large Bjorken-x.

❖ **On GPDs, see Cédric's talk today at 9:30.**

Conclusion

❖ LHCb: unique results with the fixed-target program at LHC.

❖ The SMOG system has been successfully exploited for interesting fixed-target physics:

➡ prompt charm production in p-He and pAr collisions (cold nuclear-matter studies and intrinsic charm).

➡ antiproton production in p-He collisions (cosmic rays physics and DM search)

❖ Other analyses are ongoing

❖ **SMOG2** will significantly enhance the performances of fixed-target physics at LHCb.

❖ Extension of the fixed-target program = expansion of the physics program !

LHCb preliminary
$\sqrt{s_{NN}}$ = 69 GeV, PbNe