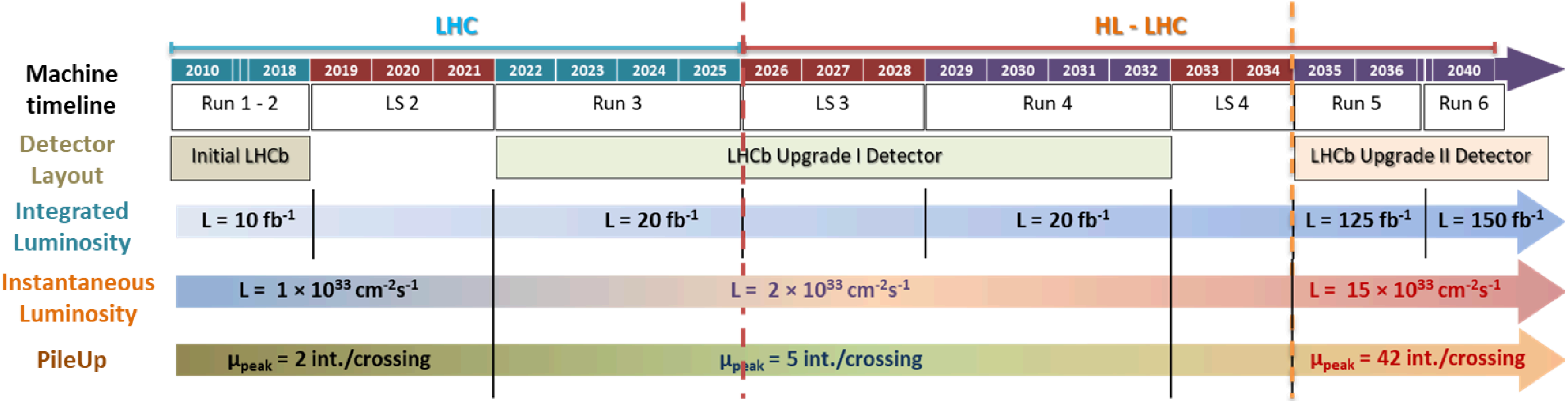
LHCb Upgrade II and heavy-ion physics

Samuel Belin on behalf of the LHCb Collaboration

Samuel Belin
samuel.belin@cern.ch

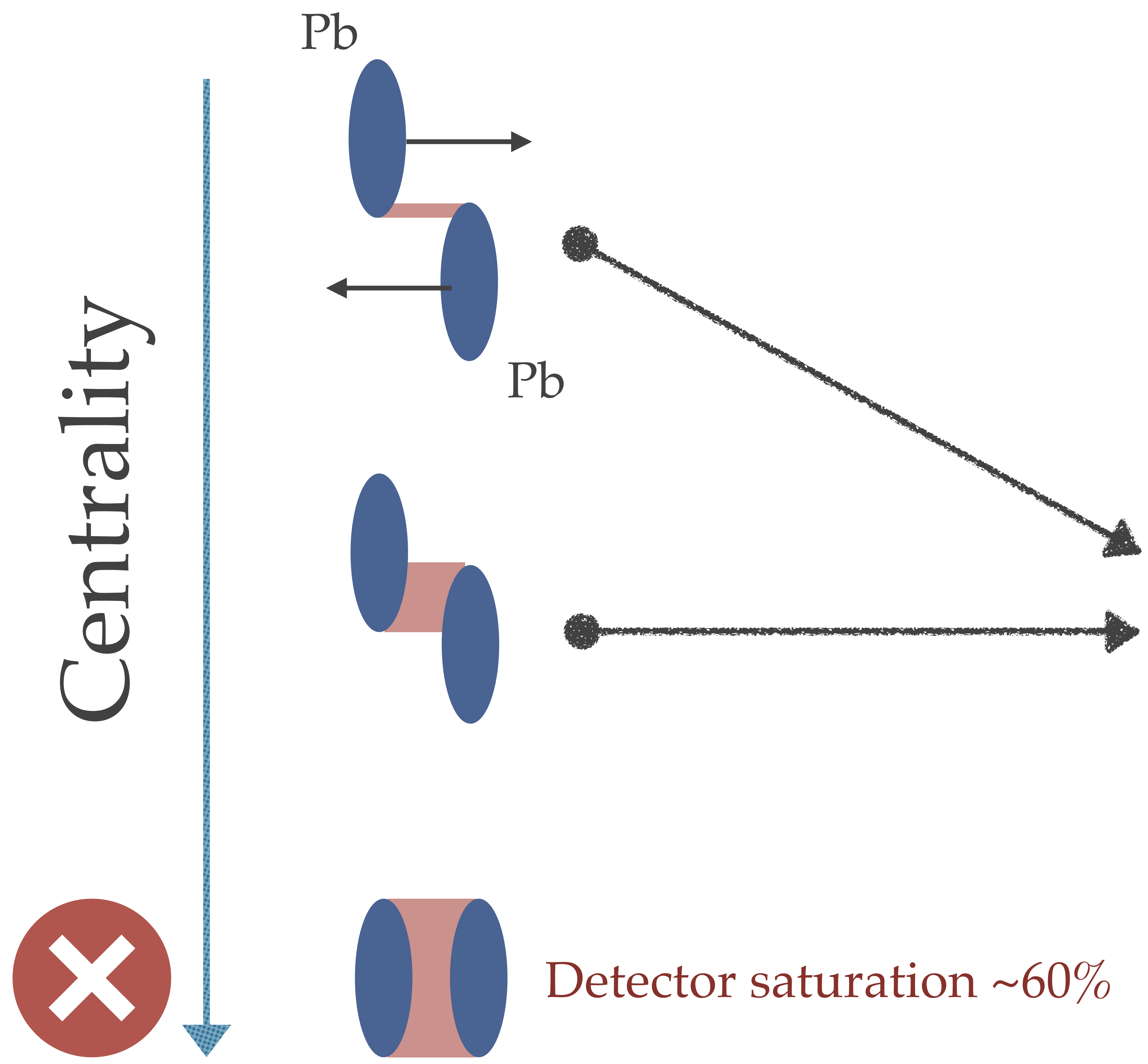
LHC-LHCb Schedule



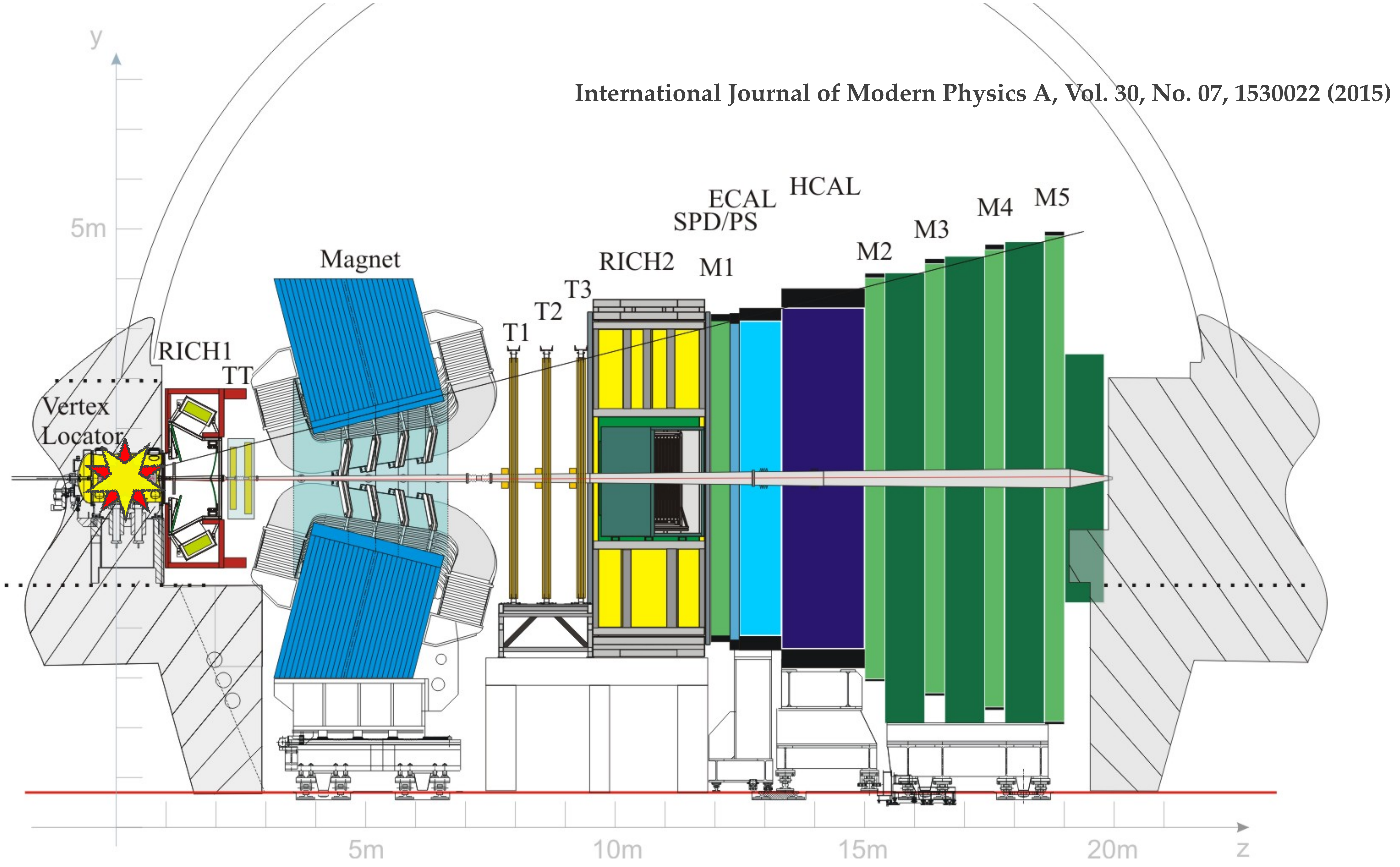
Goal of Upgrade I and II: keep up the performance with the increased instantaneous luminosity and pile-up

The LHCb detector run 2

Excellent tracking and PID performance in fixed target, *pp* and *p*Pb collisions, but…



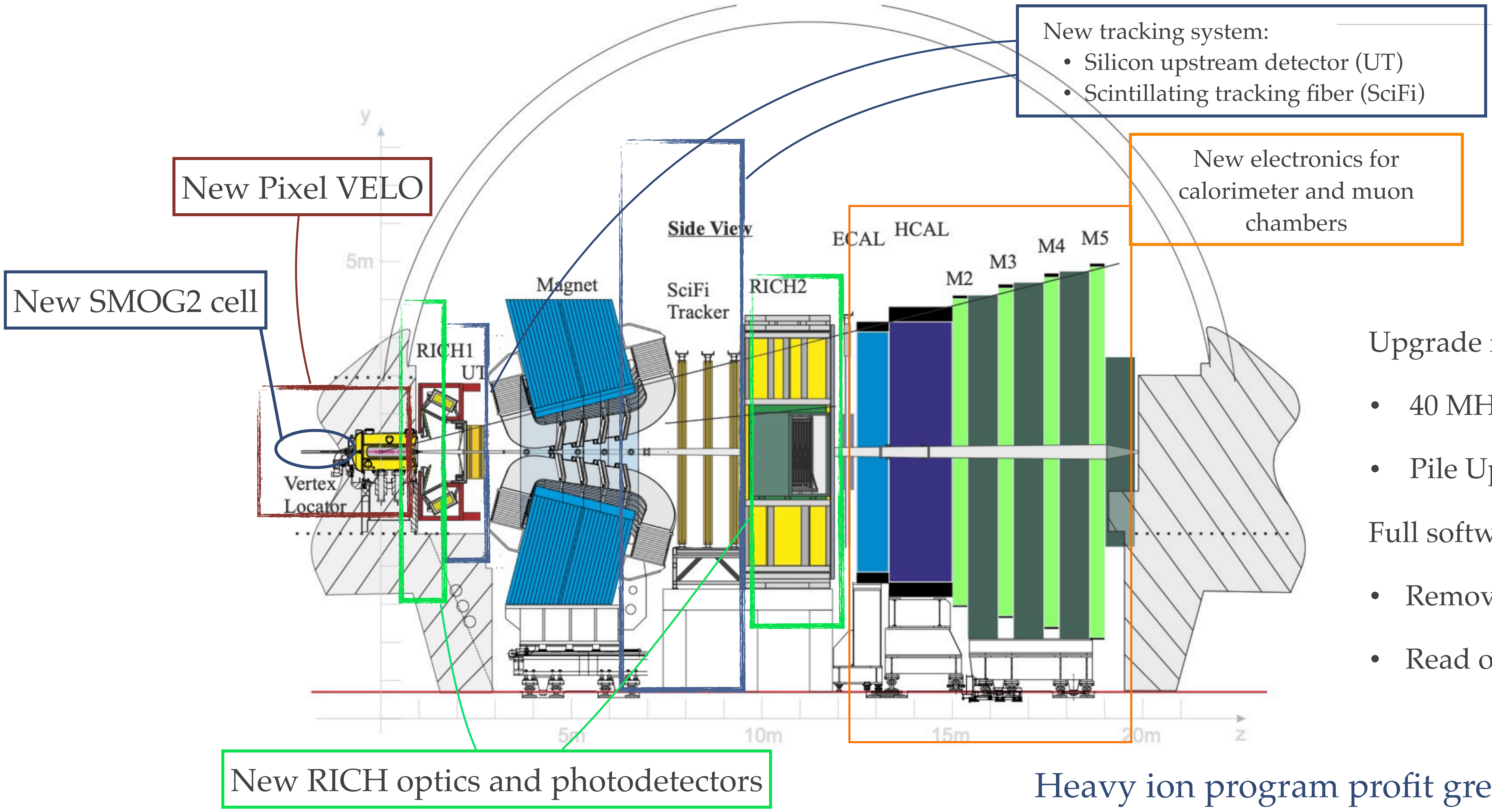
Detector saturation ~60%



Samuel Belin [*samuel.belin@cern.ch*](mailto:samuel.belin@cern.ch)

LHCb run 3

JINST 19 (2024) 05, P05065



Upgrade for pp requirement

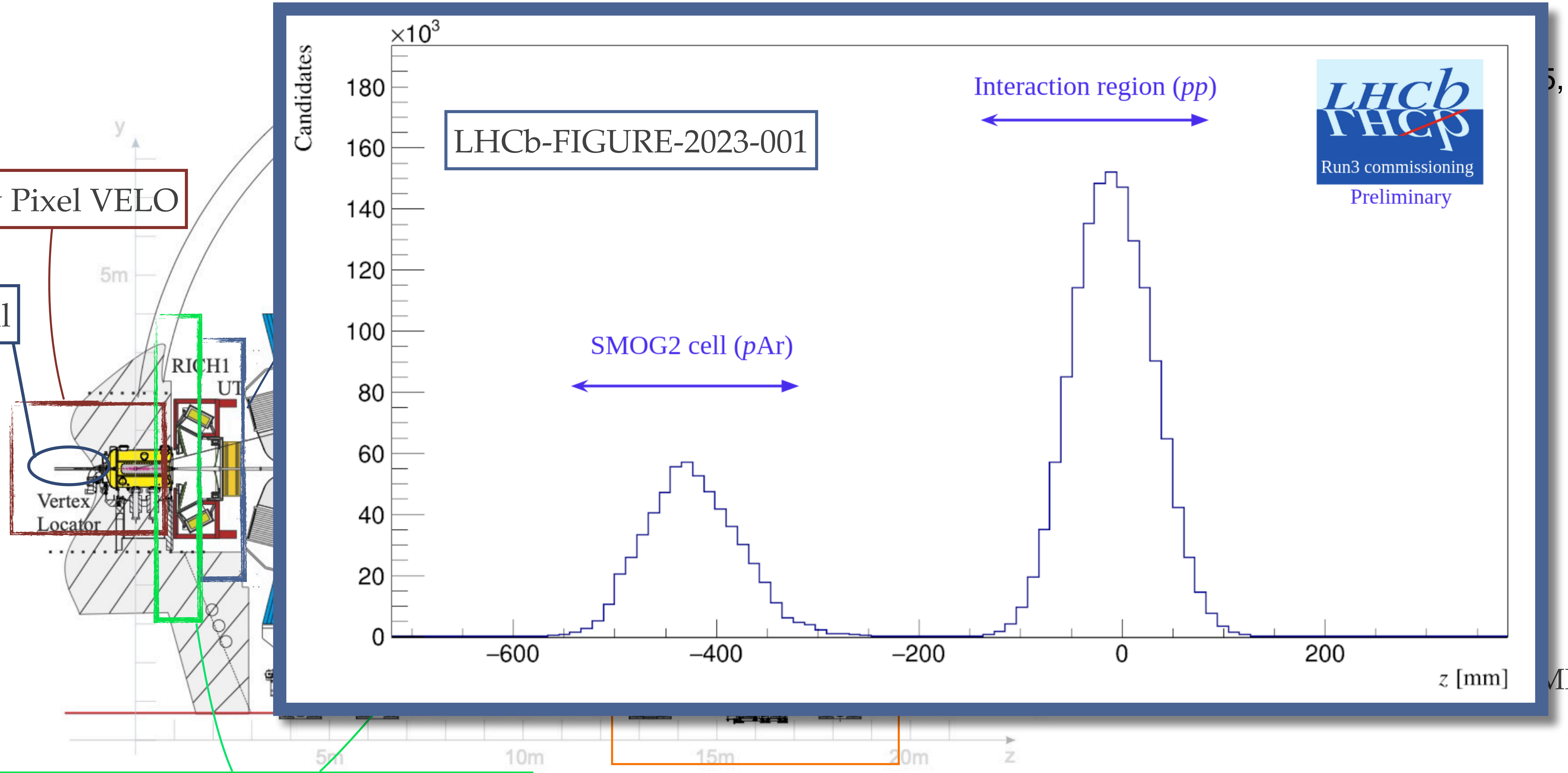
- 40 MHz collision rate
- Pile Up factor ~ 5

Full software trigger

- Remove L0 triggers.
- Read out full detector at 40 MHz.

Heavy ion program profit greatly from this upgrade with now reaching 30% centrality

LHCb run 3



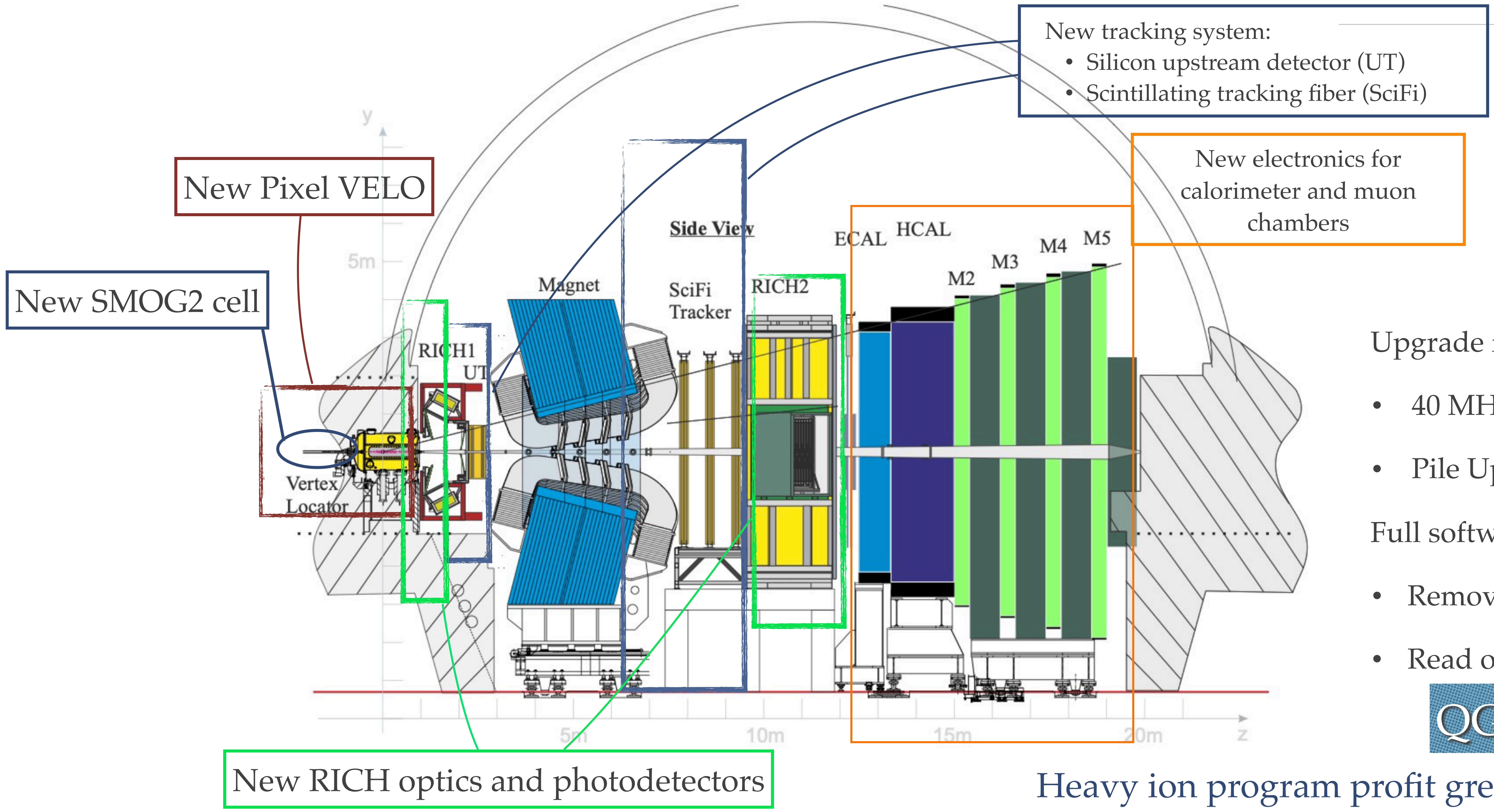
5, P05065

MHz.

Heavy ion program profit greatly from this upgrade with now reaching 30% centrality

LHCb run 3

JINST 19 (2024) 05, P05065



Upgrade for pp requirement

- 40 MHz collision rate
- Pile Up factor ~ 5

Full software trigger

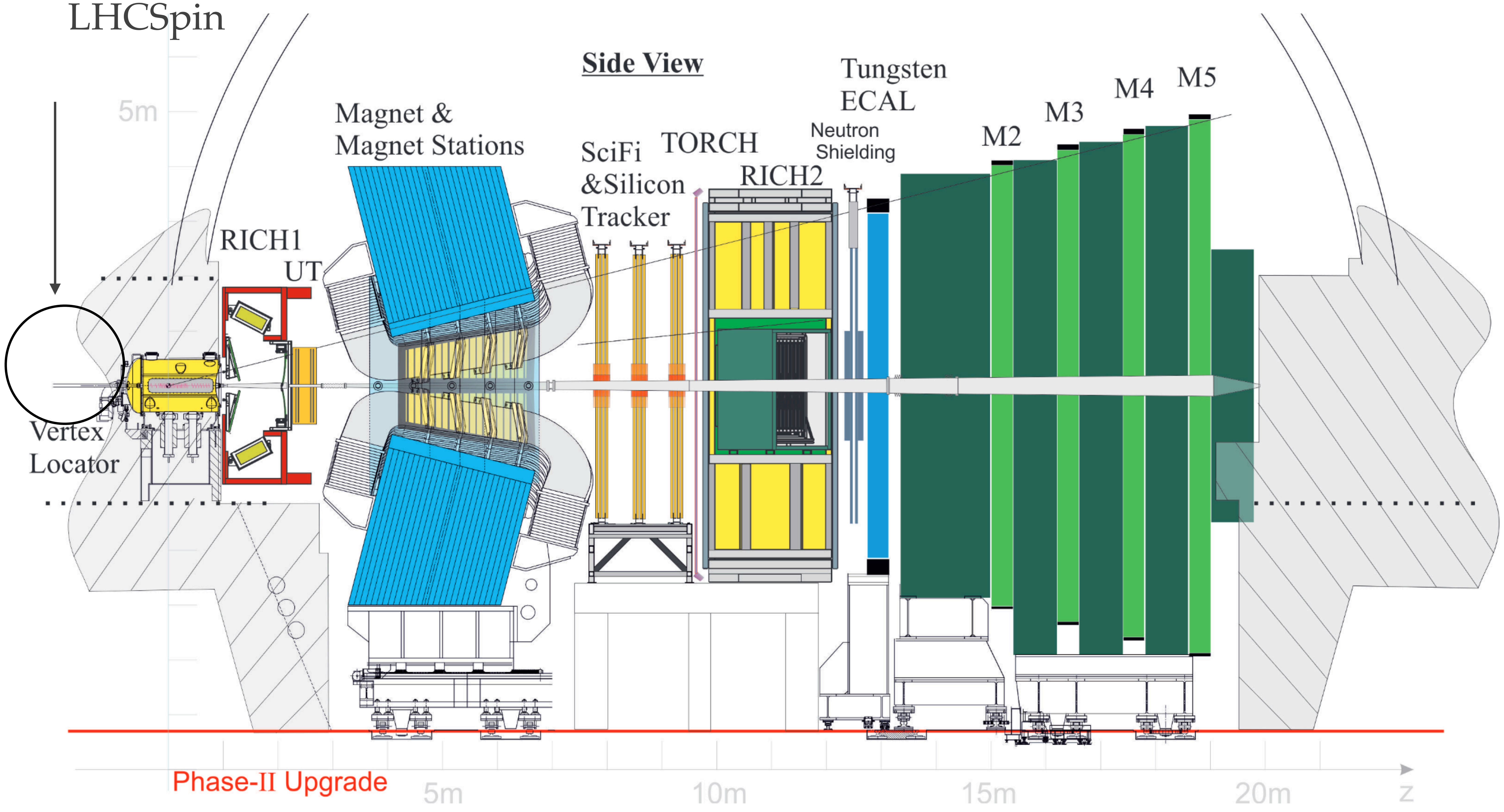
- Remove L0 triggers.
- Read out full detector at 40 MHz.

QGP PHYSICS!

Heavy ion program profit greatly from this upgrade with now reaching 30% centrality

LHCb Upgrade II

R&D polarized Target with LHCSpin



CERN-LHCC-2021-012

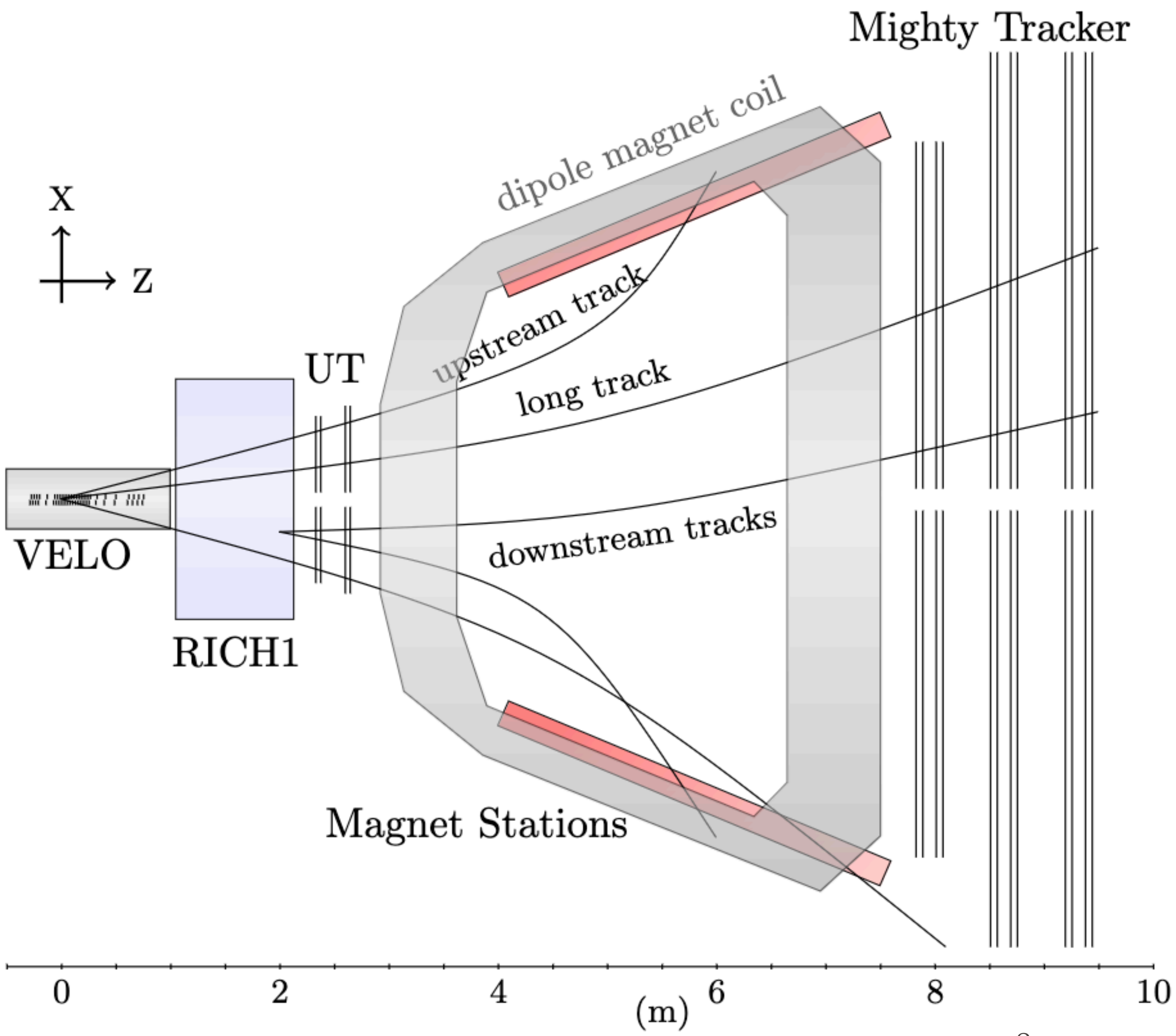
Upgrade for pp requirement

- Instanteneous luminosity $1.5 \times 10^{34} cm^{-2} s^{-1}$
- Pile Up factor ~ 42
- 1500 to 3500 charged particles produced per bunch crossing. Basically a PbPb collision!

Heavy ion program will profit greatly from this upgrade !

No saturation of the detector and excellent efficiency to 0% centrality PbPb

Tracking system

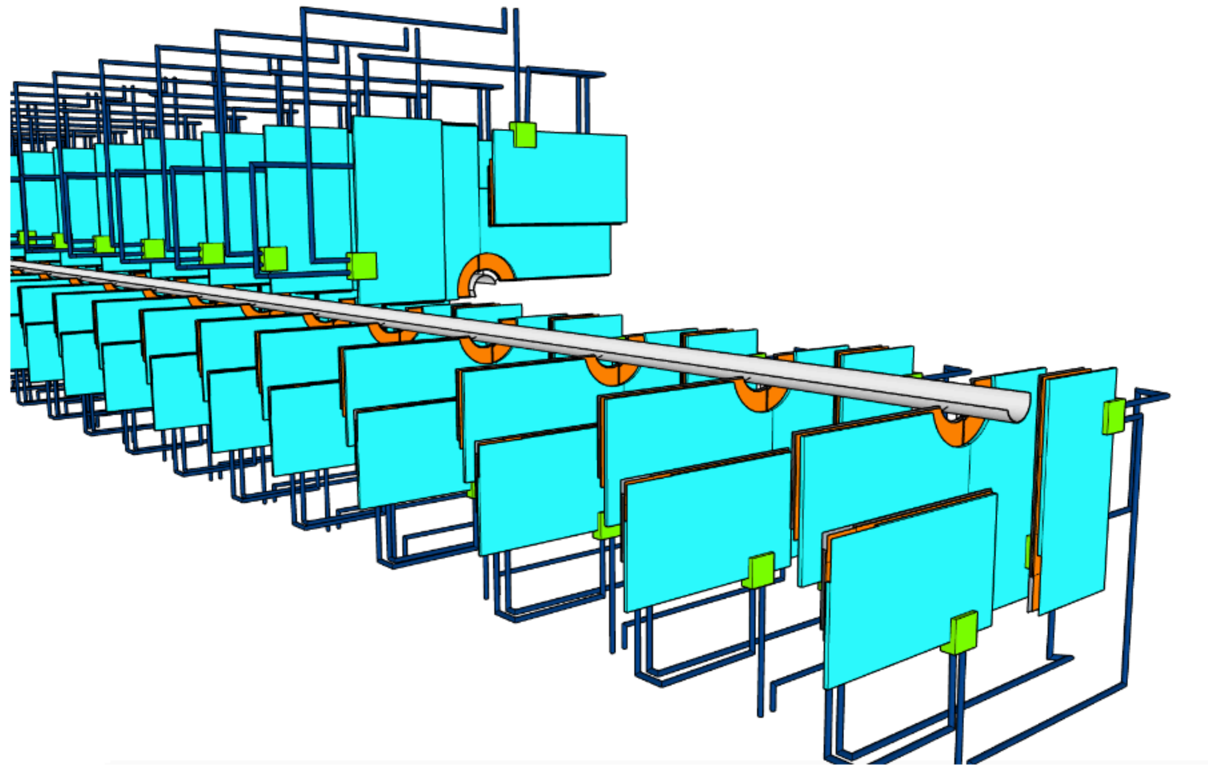


CERN-LHCC-2021-012

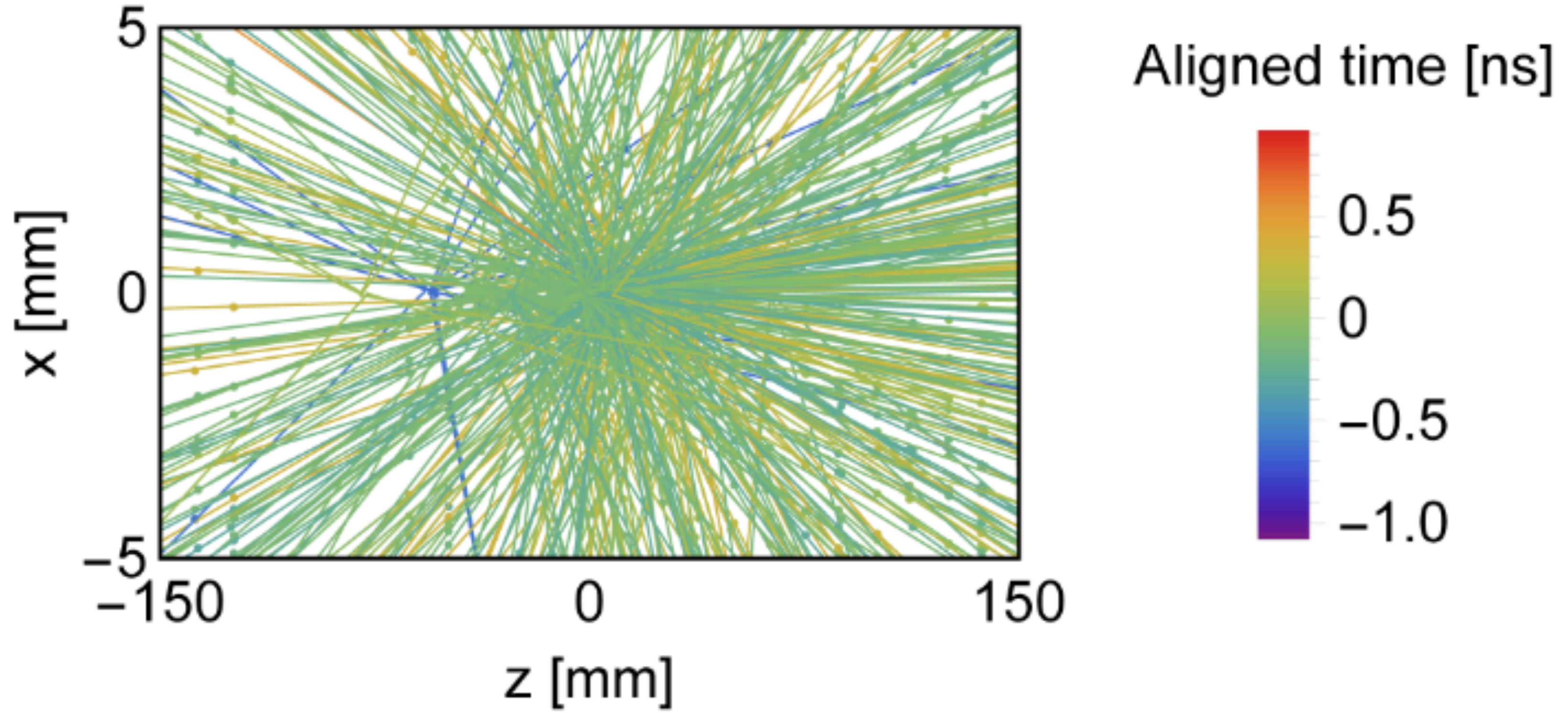
- The tracking system will be improved a lot
- New VELO
- Upgraded SciFi with silicon pixel Mighty Tracker in the inner part
- Upgraded Sci-Fi
- Addition of Magnet stations for low momentum charged particle

New VELO Design

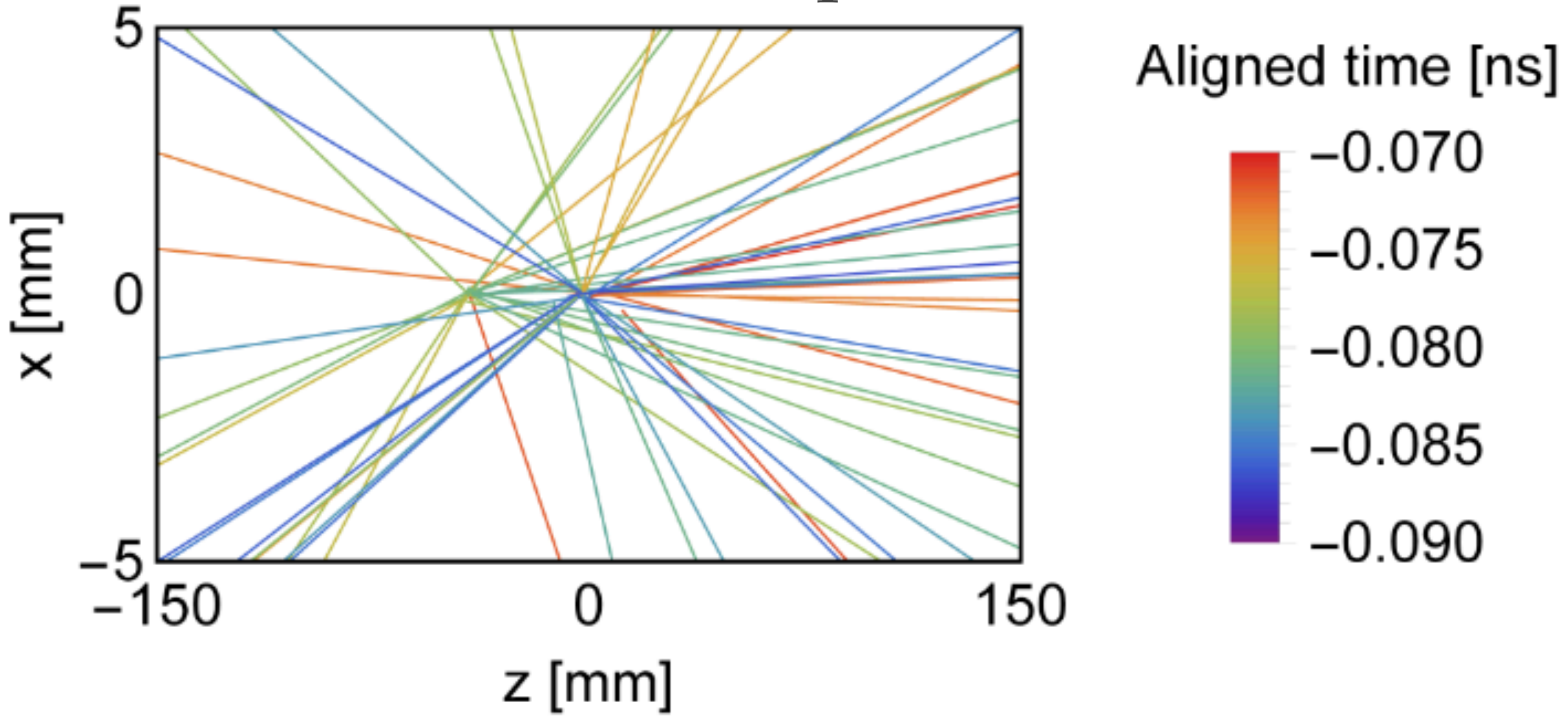
CERN-LHCC-2021-012



42 collisions in 1ns window

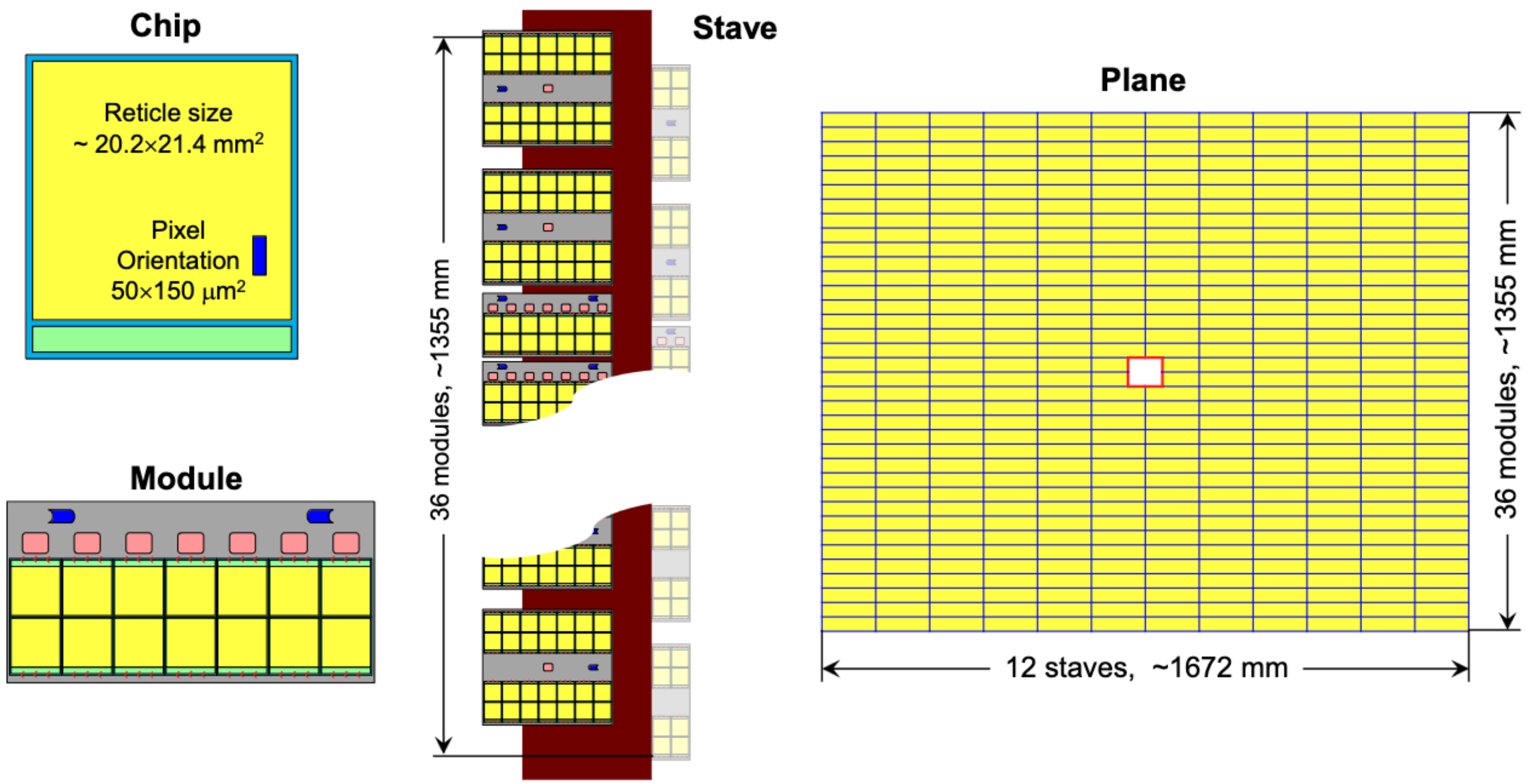


Same but with 20ps



- Design improved from last VELO. Smaller pixel size, reduced sensor silicon thickness. Better shielding for radiation hardness.
- Excellent timing to assign each track to the correct primary vertex (PV). Below 20 ps time resolution.
- Overall better granularity of the detector will benefit the heavy-ion program.

Upstream Tracker (UT)



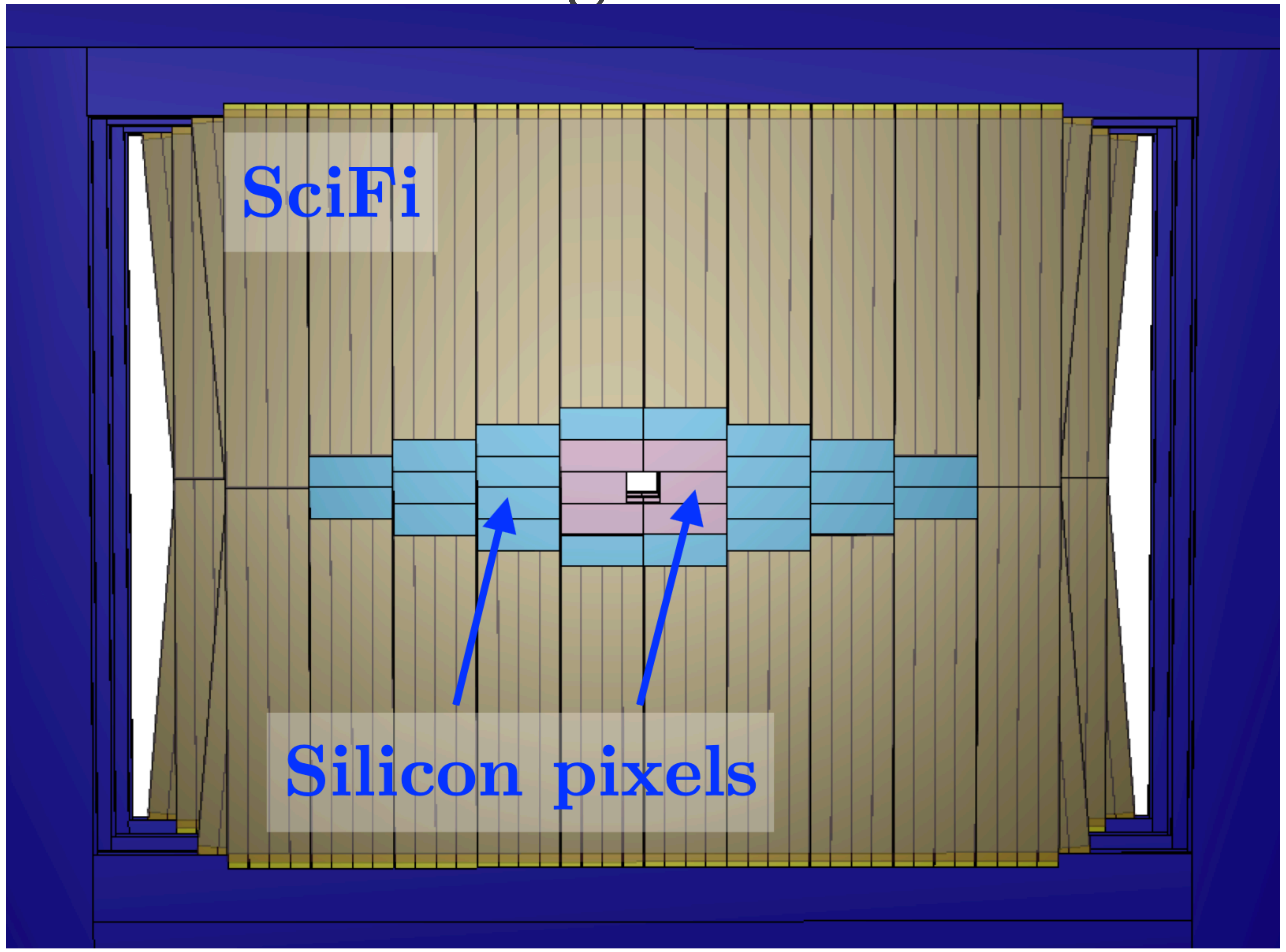
CERN-LHCC-2021-012

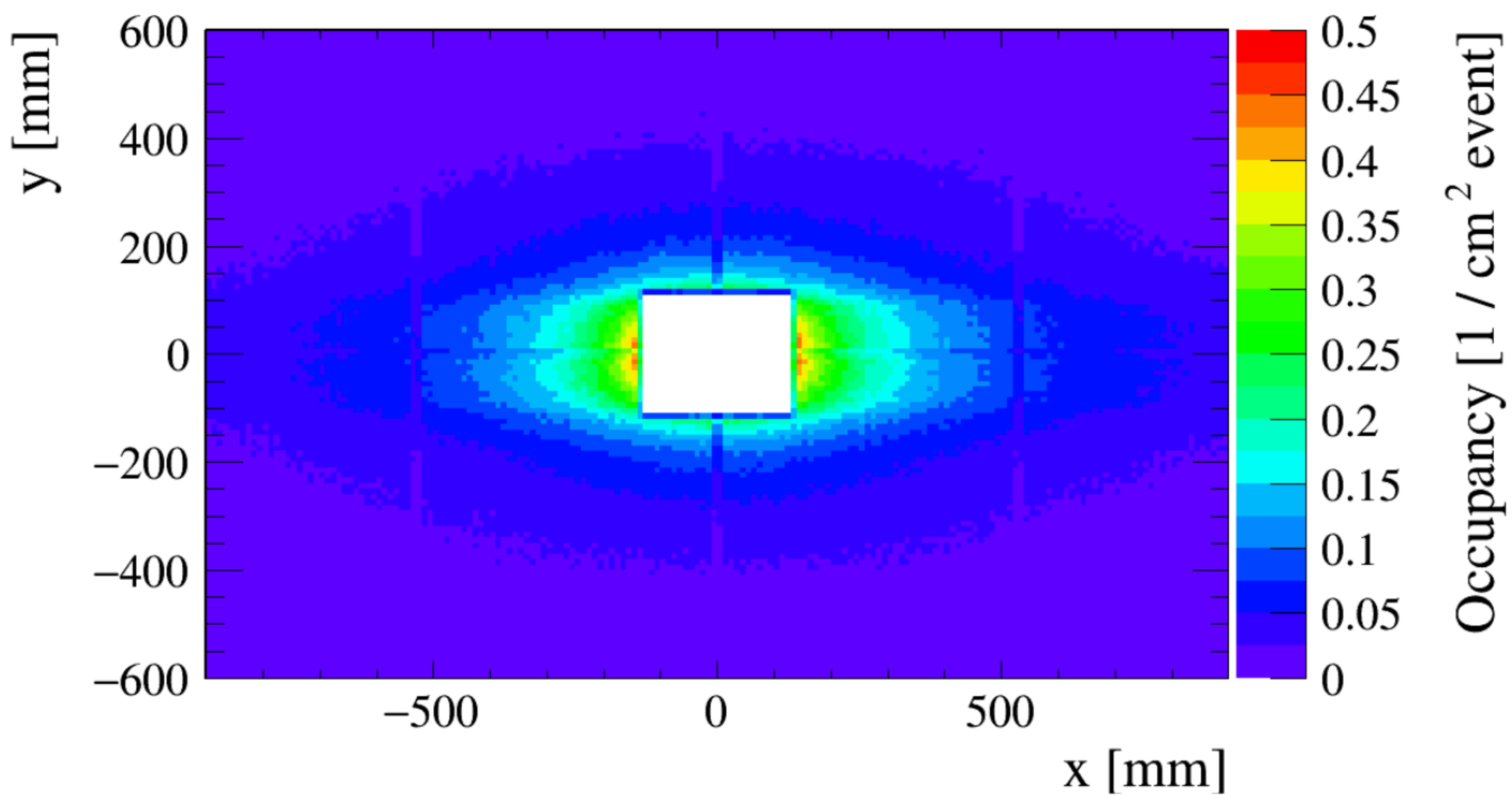
- Detector based on CMOS MAPs (Monolithic Active Pixel Sensors)
- Improves track matching between VELO and Forward Tracker
- Reduces a lot the ghost rate

Mighty Tracker

- Scintillating Fiber and CMOS MAPs close to the beam
- Better tracking for central PbPb collisions

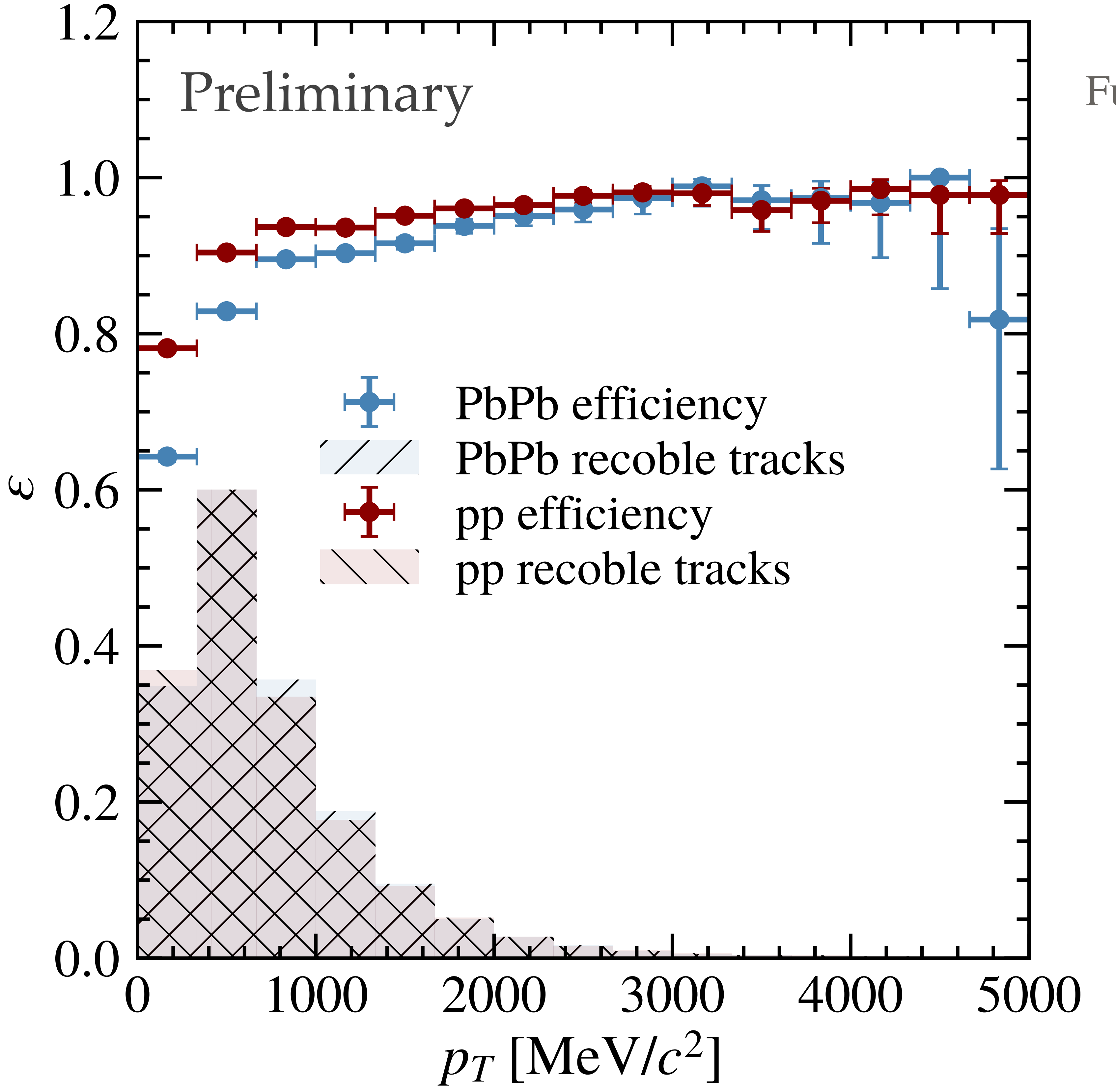
CERN-LHCC-2021-012



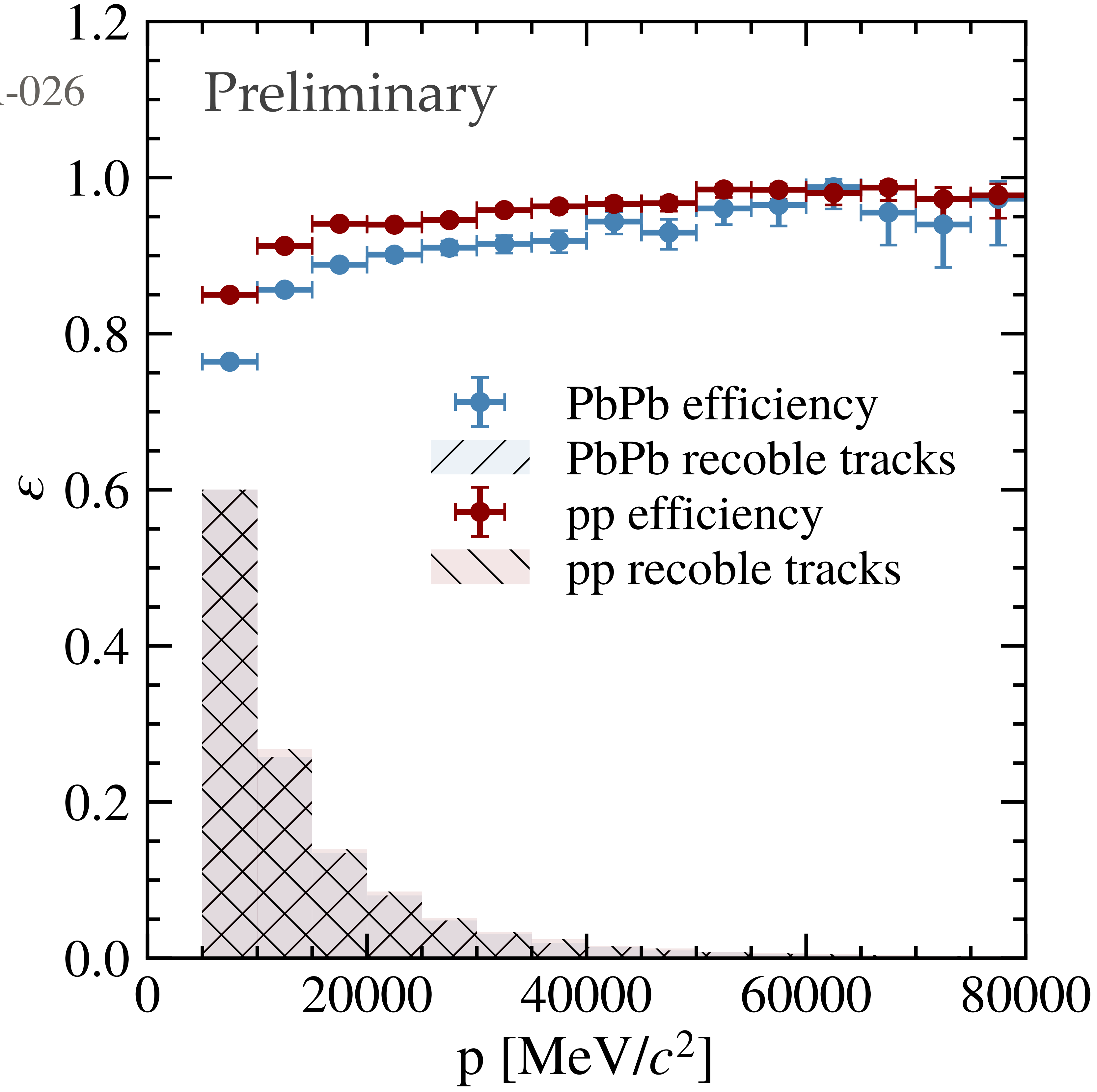


First estimation of detector performance

Tracking efficiency in pp collisions compared to PbPb 0-5% centrality



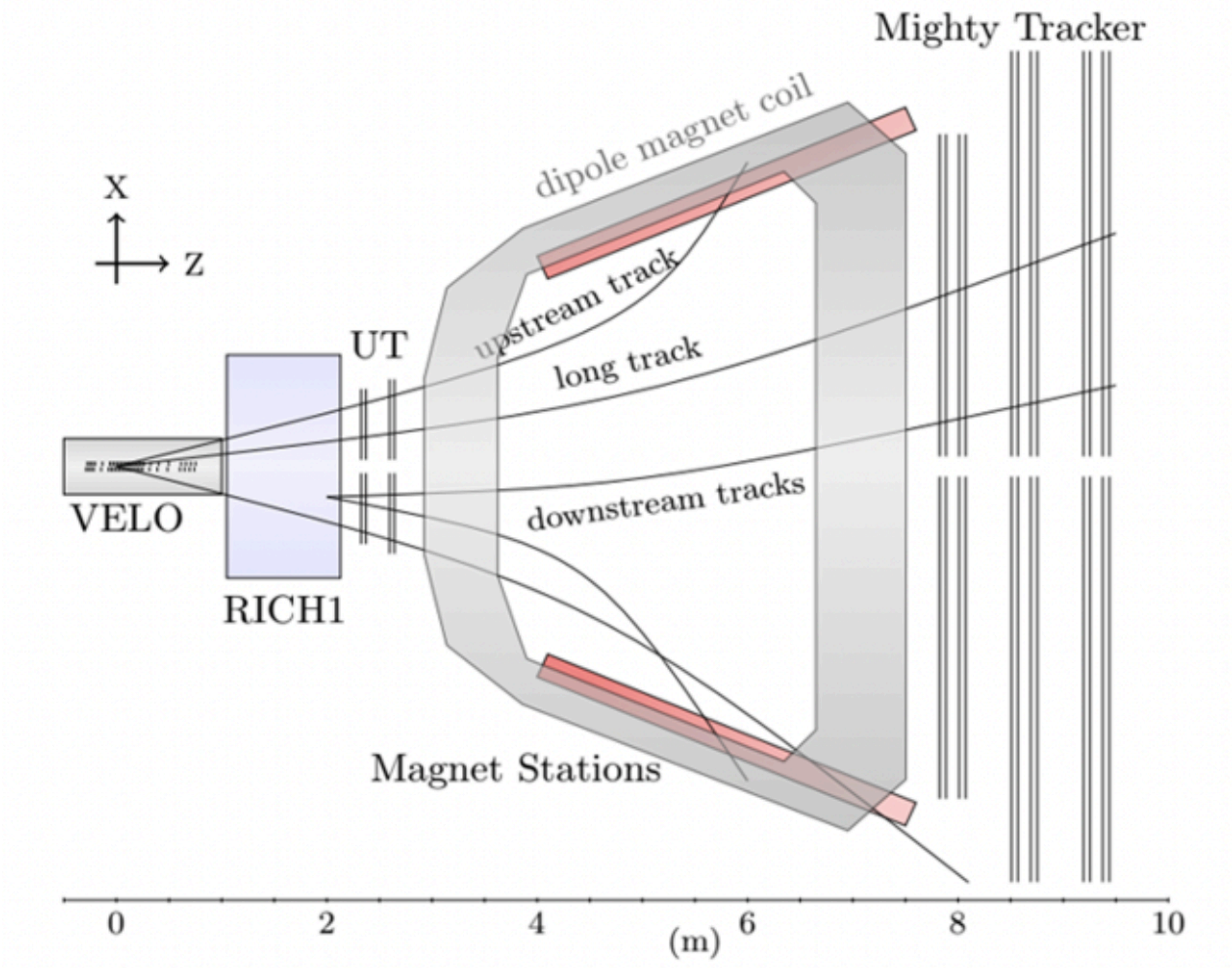
Future LHCB-TDR-026



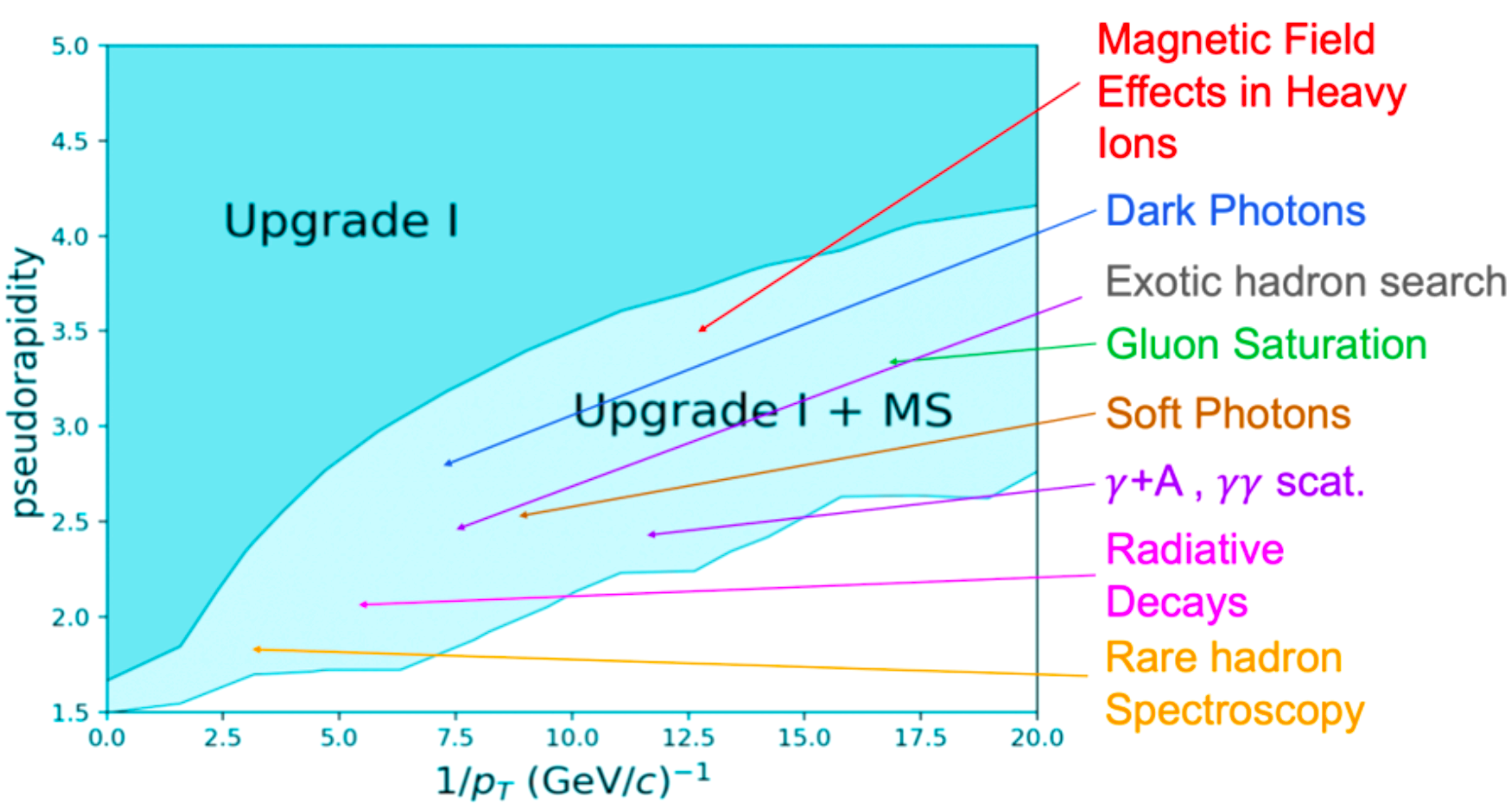
High precision for central collisions!

Design Magnet Stations

- Scintillators inside the magnet and photomultipliers outside
- Better acceptance and low-p_T reach



CERN-LHCC-2021-012

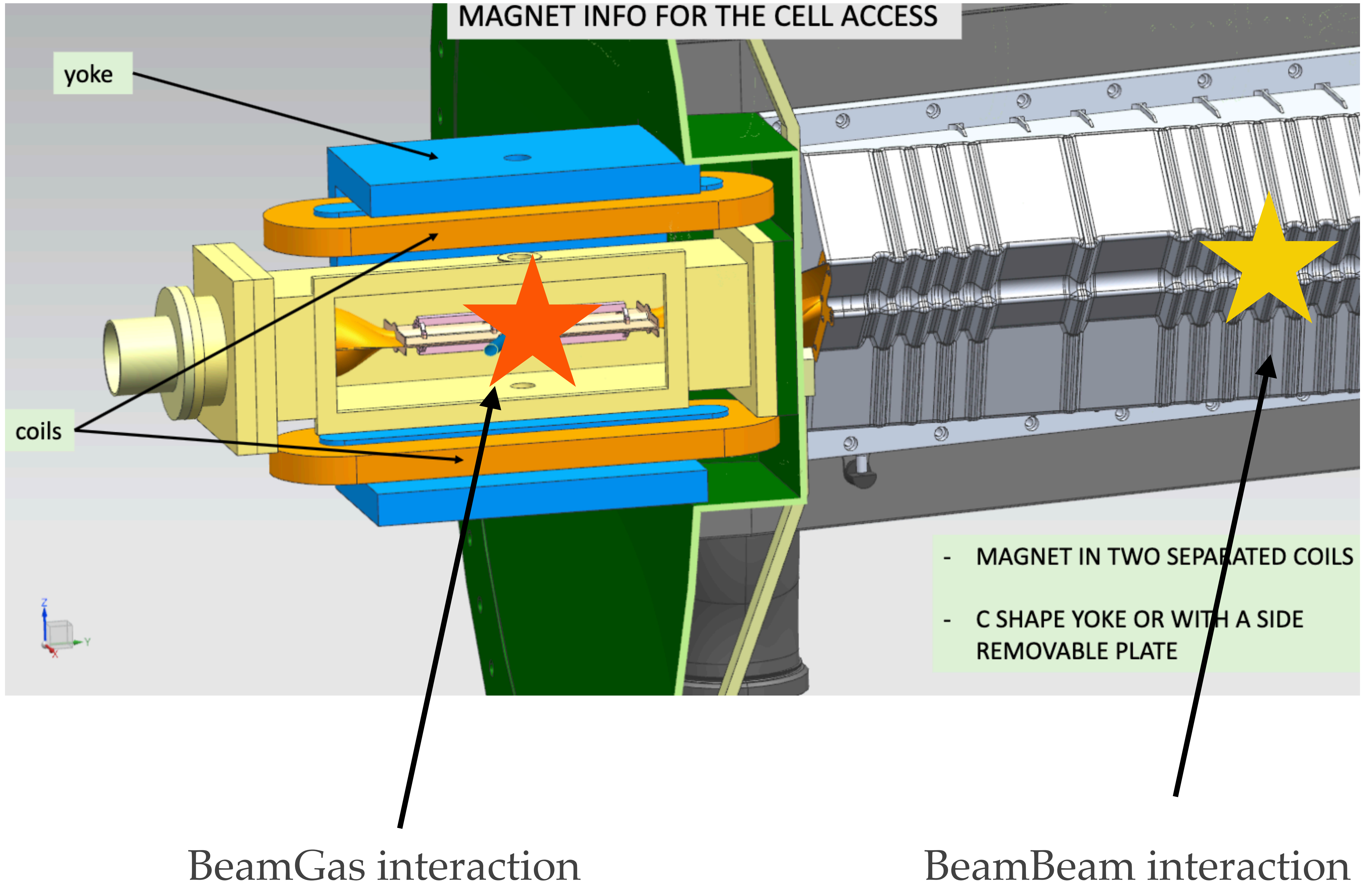


LHCSpin

R&D officially supported by LHCb, but not included in the UII plans yet

SciPost Phys. Proc. 8, 050 (2022)

- Improved SMOG2 system
- Can work with or without polarized target
- When polarized target only hydrogen and deuterium
- Work in parallel of the collider mode -> high statistic



What does it mean for the heavy-ion physics program?

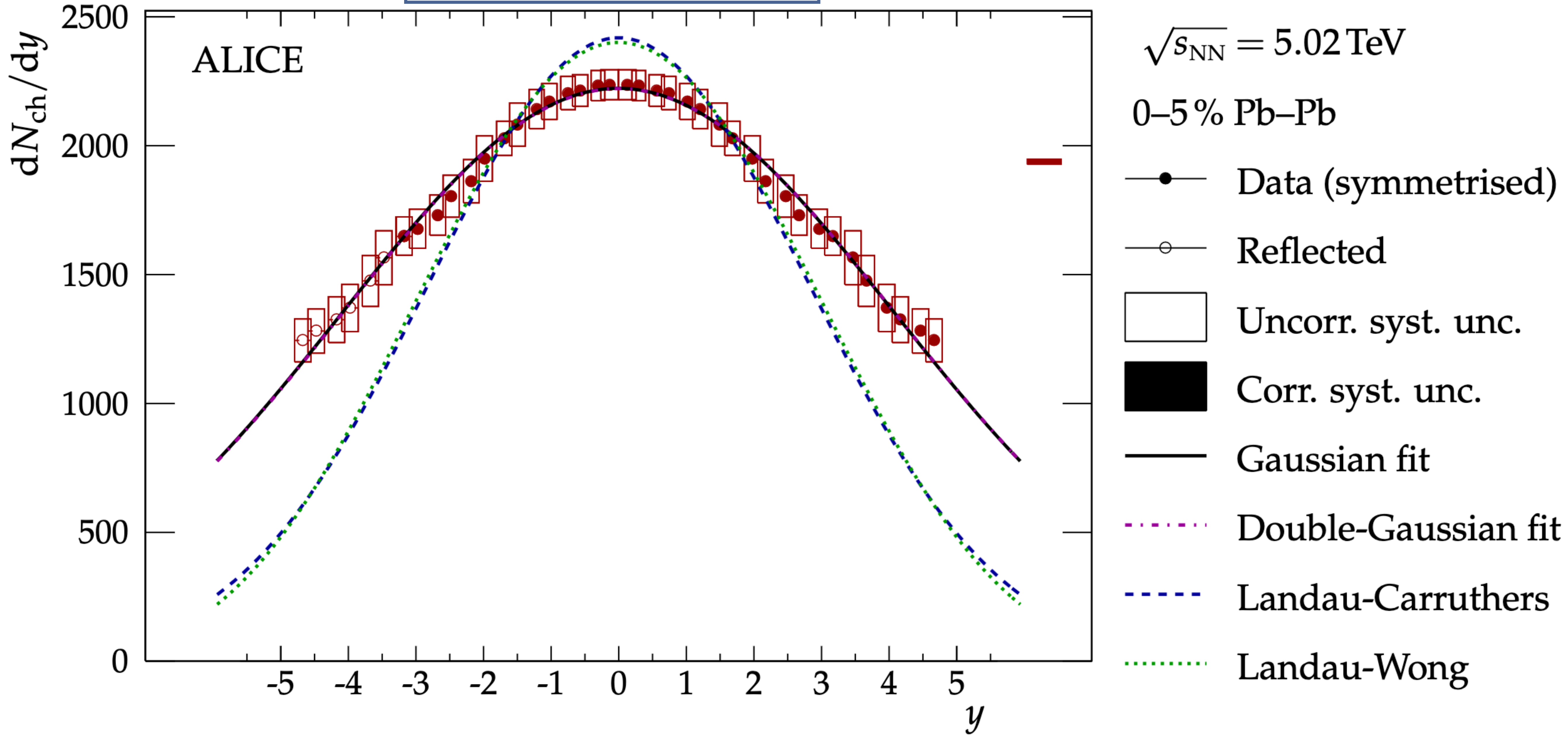
- After interesting discussion with the theory community during a *workshop*, we pinned down flagship measurements
- Most of them will take advantage of a fully operational detector for PbPb collisions in the forward region but obviously the improvement will benefit smaller system (lower p_{T} reach, better precision , pile-up in pA)
- We considered ~10 nb^{-1} luminosity for PbPb during run 5-6, so we expect a large production of c and b particles

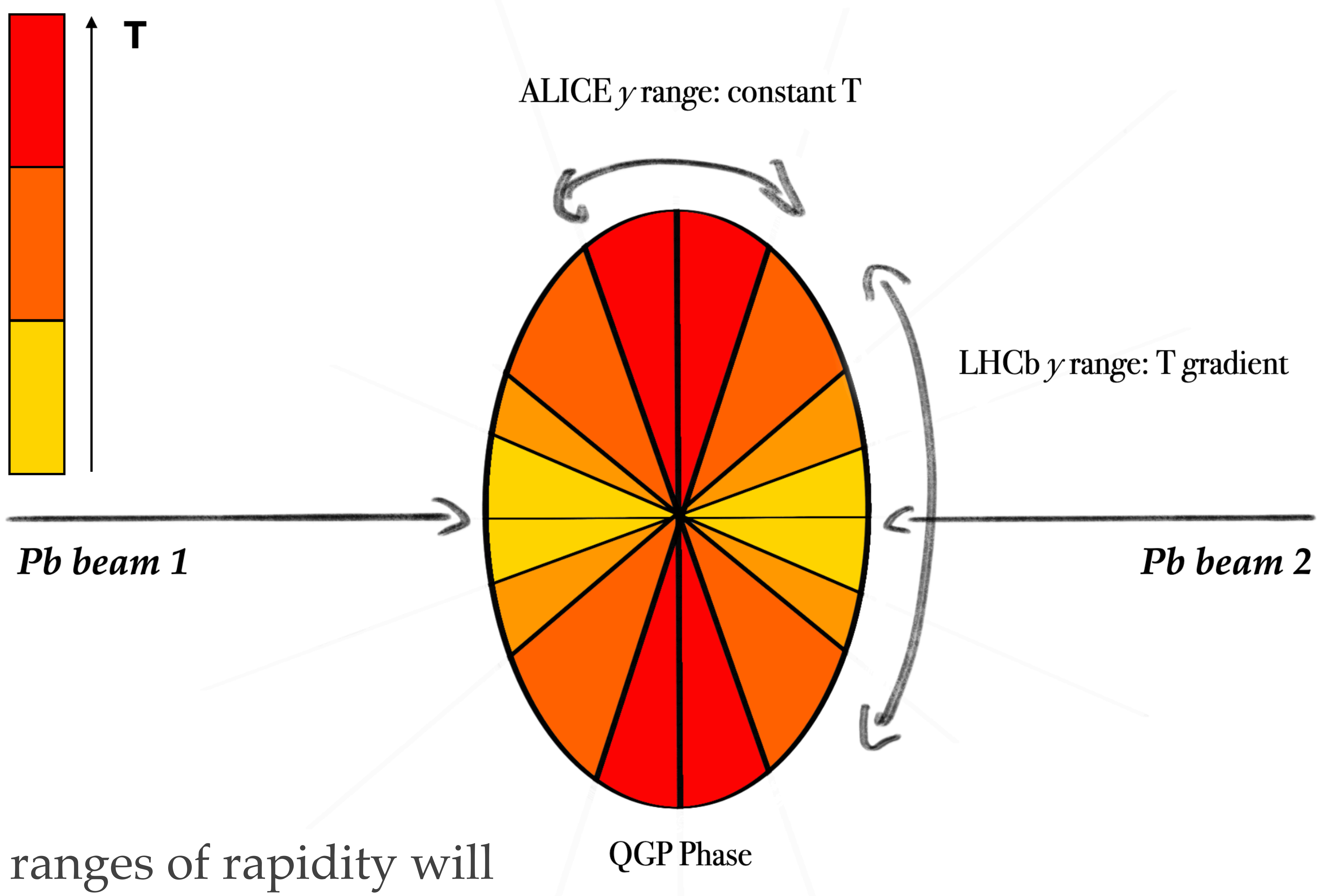
Equation of State of QGP

From relativistic hydrodynamic $dN_{ch}/dy \leftrightarrow Entropy\ density$

$< p_T >$ *of Charged particle* $\leftrightarrow\ T^{eff}$

Phys. Rev. D 90 (2014) 094503

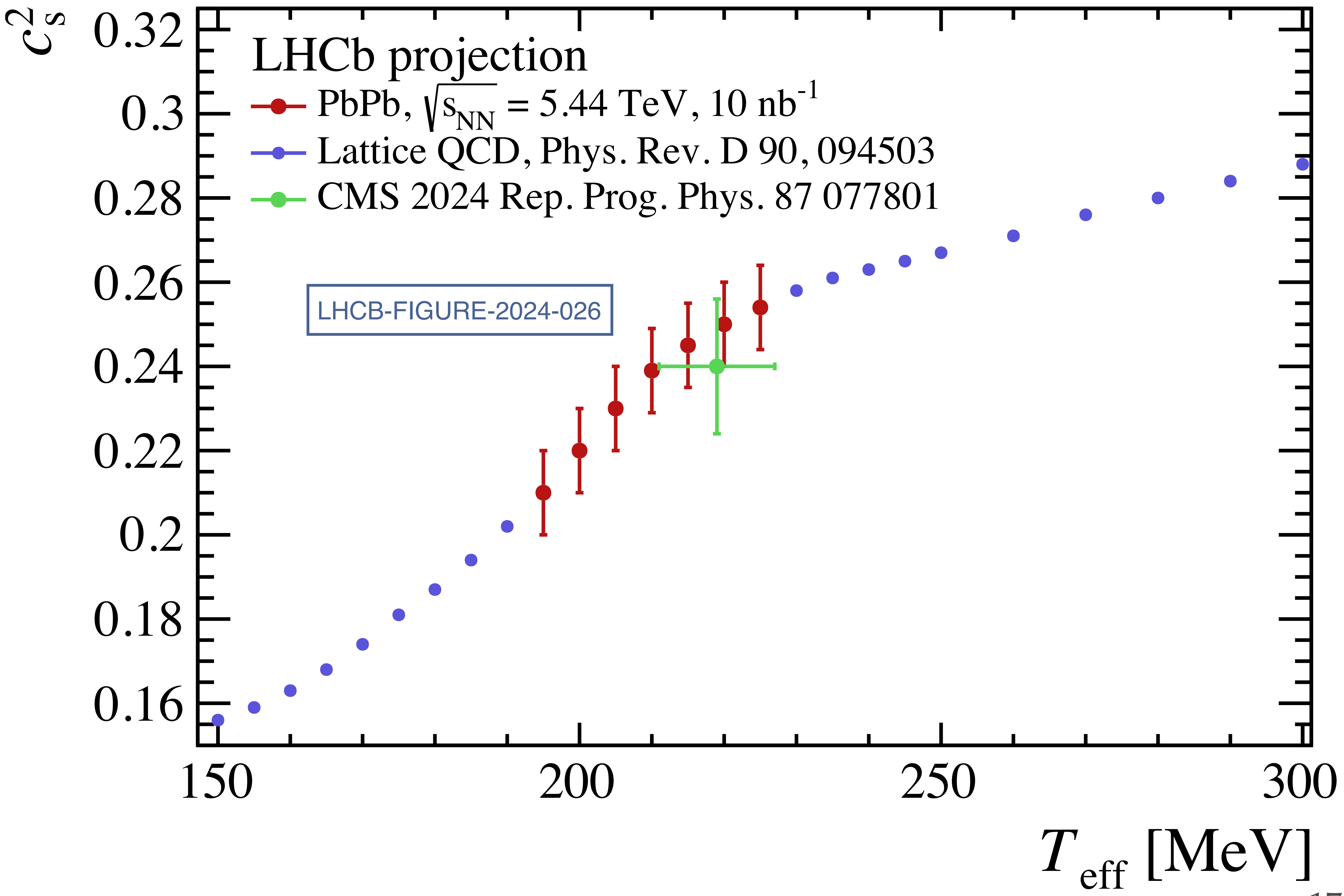




Measurement of $< p_T >$ for different ranges of rapidity will give an unprecedented description of the EoS

Equation of State of QGP

A LHCb projection on the speed of sound for different temperatures

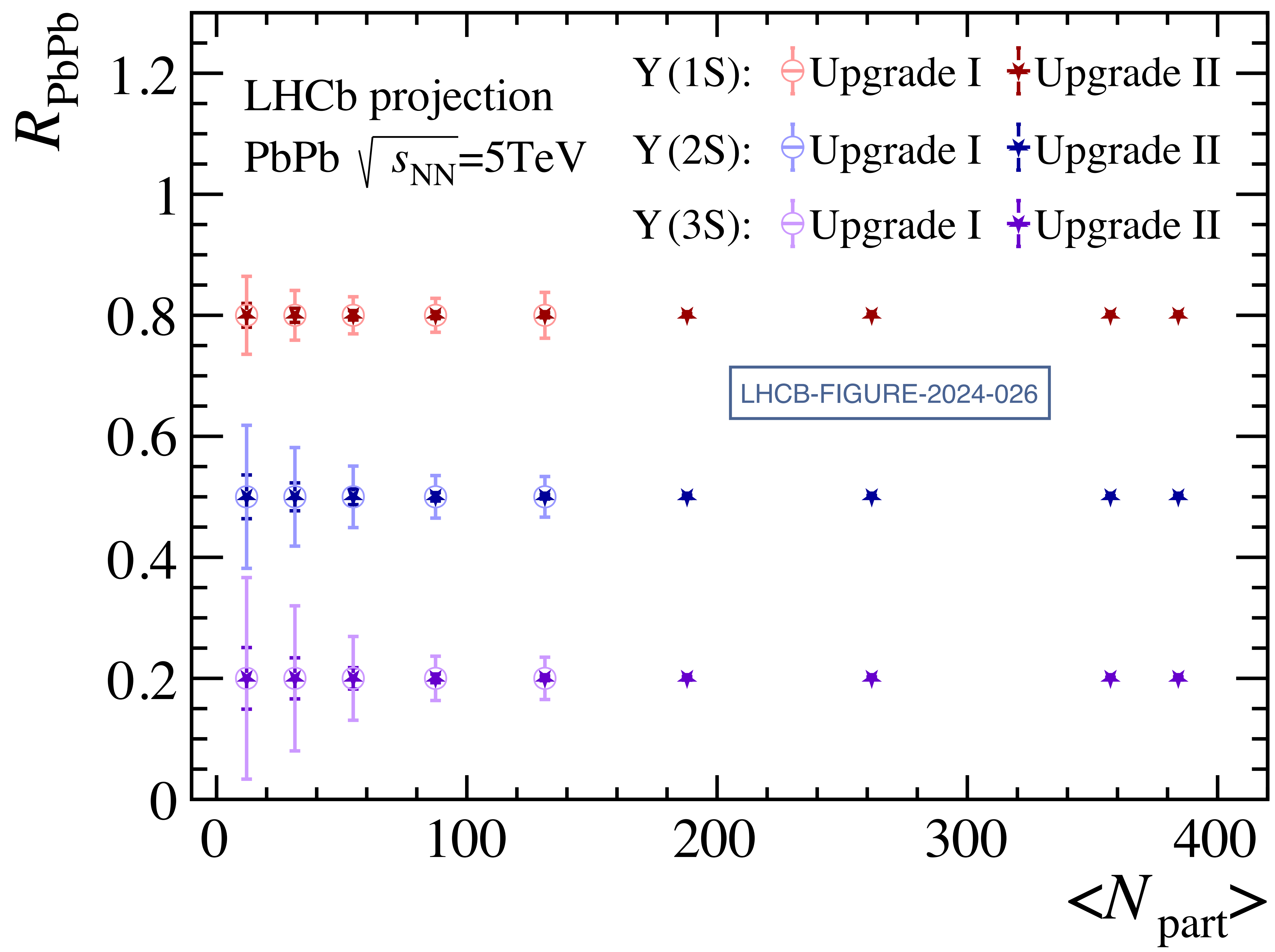


- Many study as a function of measured temperature!
  - Quarkonia suppression
  - Jet quenching
  - Link between temperature and hadronisation?

Quarkonia suppression

- Use bottomonia to study the QGP temperature through colour screening
- Much less recombination than for charmonia
- However, η_c, $\chi_{c,b}$ production might be better understood in the reference *pp* collisions.
- LHCb's robust PID and high statistic in PbPb collisions will make η_c, $\chi_{c,b}$ R_{PbPb} measurements possible!

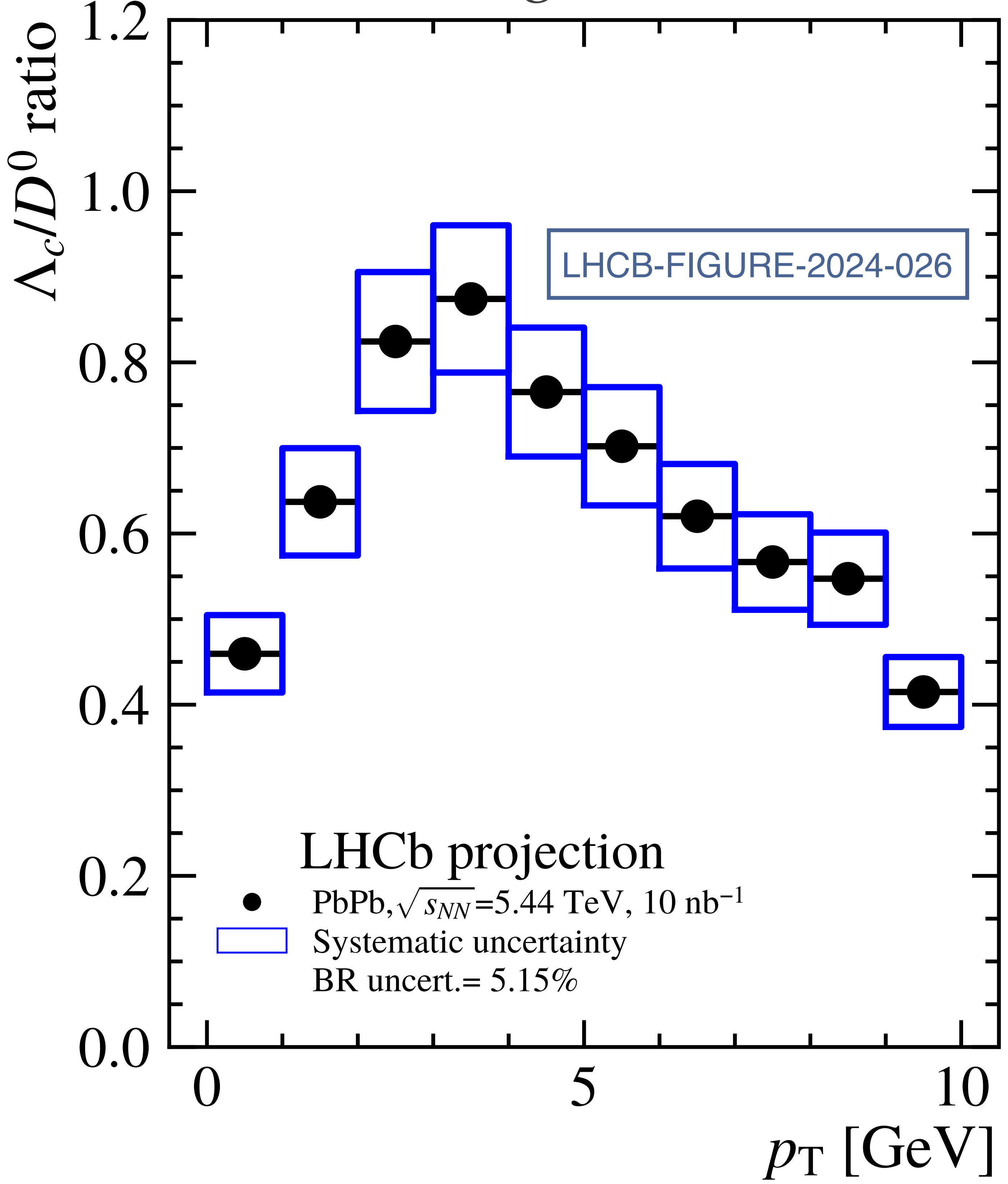
Excellent resolution, no overlap between states

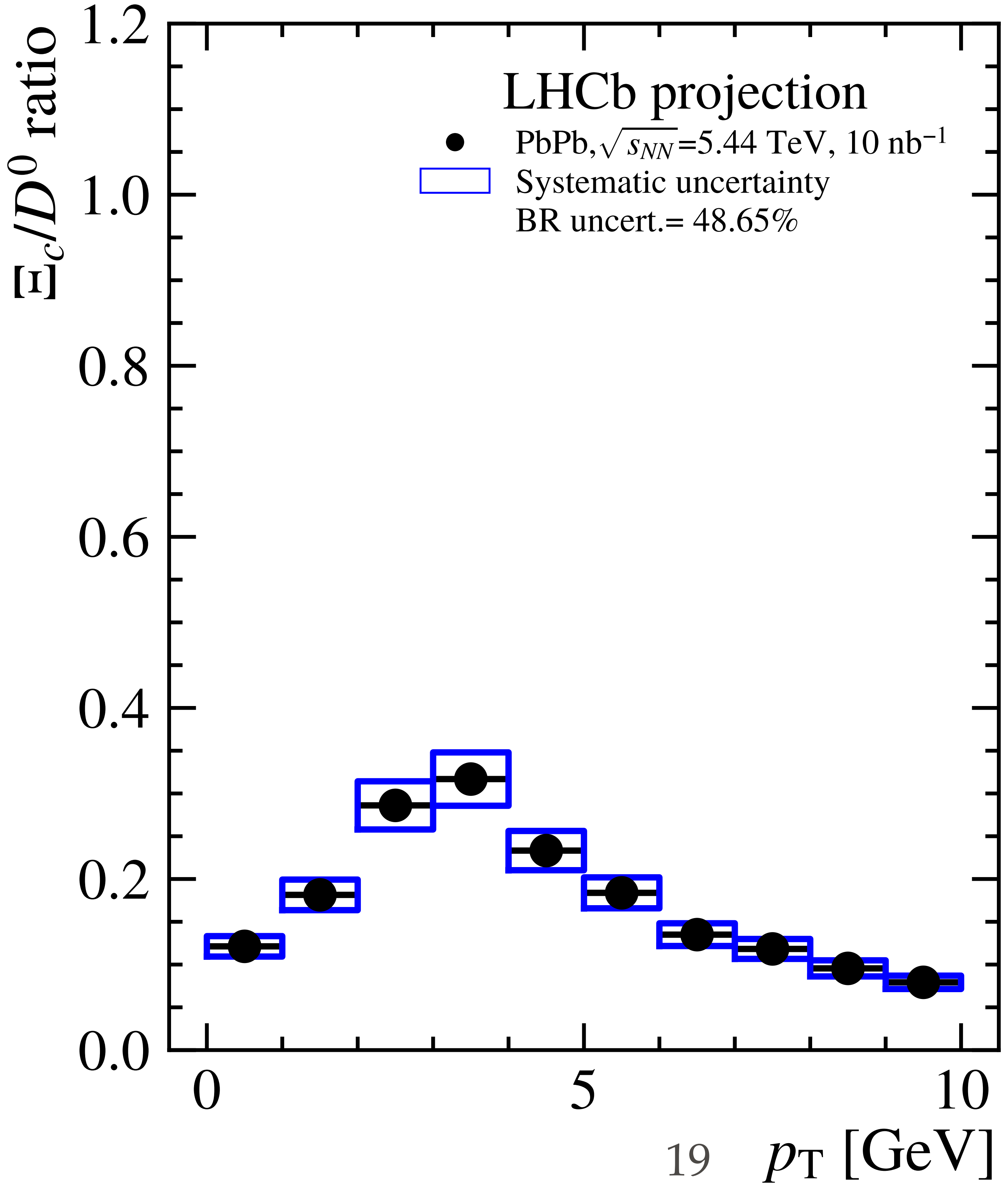


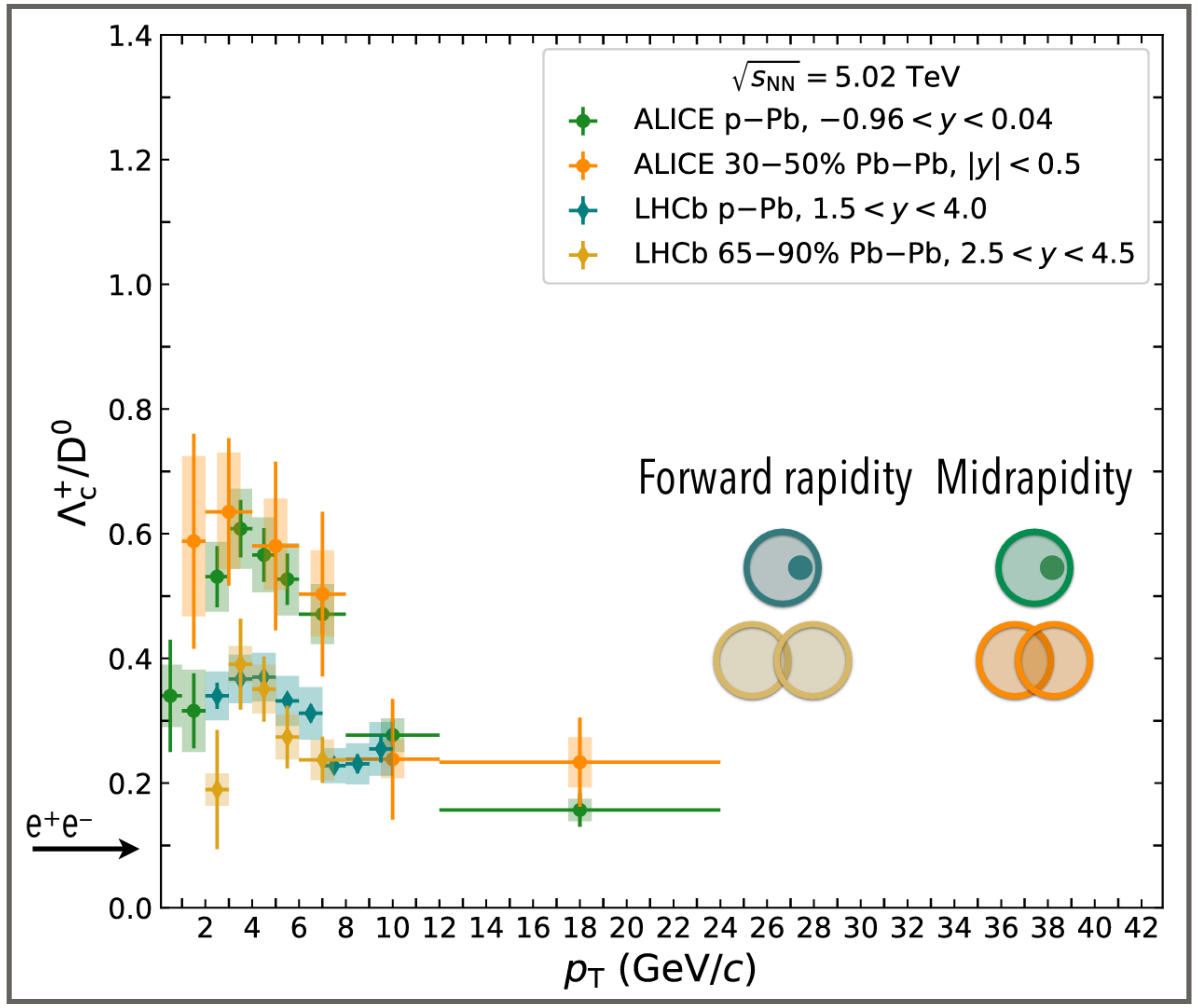
Heavy Flavor and Hadronisation

- Measurement of heavy flavor baryon-to-meson ratio to study hadronization mechanisms.
- The description of this mechanisms still at his beginning and more experimental results are needed as discrepancy in pPb and PbPb between ALICE and LHCb is not yet understood.

Enough stat. for double differential measurement!



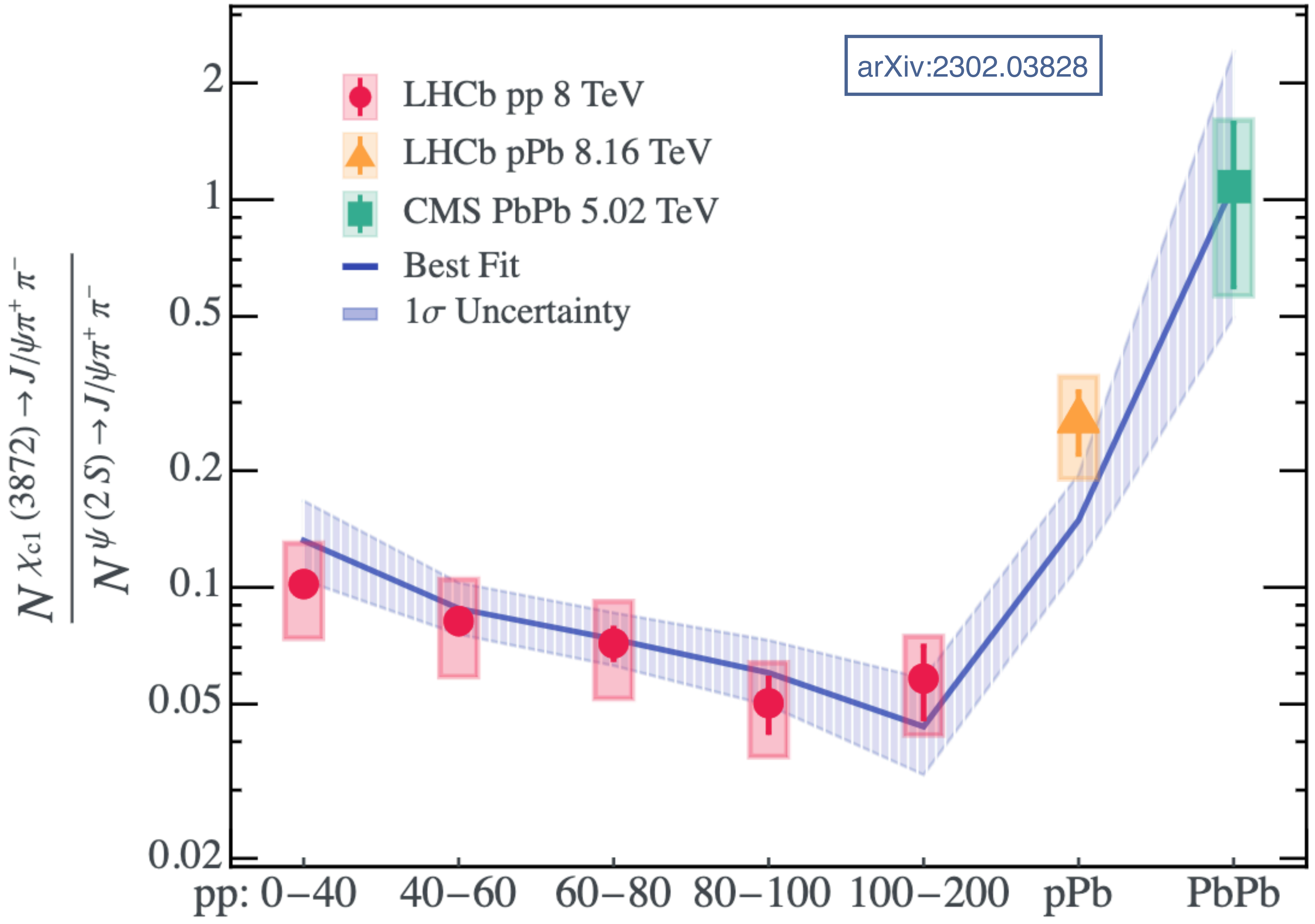




Exotica particles

- Thanks to its PID capabilities and b vertex identification, LHCb discovered many exotic states.
- Most of those states are considered to be made of 4 quarks wether in a compact or molecular form.
- Yield of $\chi_{c1}(3872)$ in a hot medium will depend on its hadronisation (increased yield if coalescence…)

Study QGP ⇄ Study compact quark system

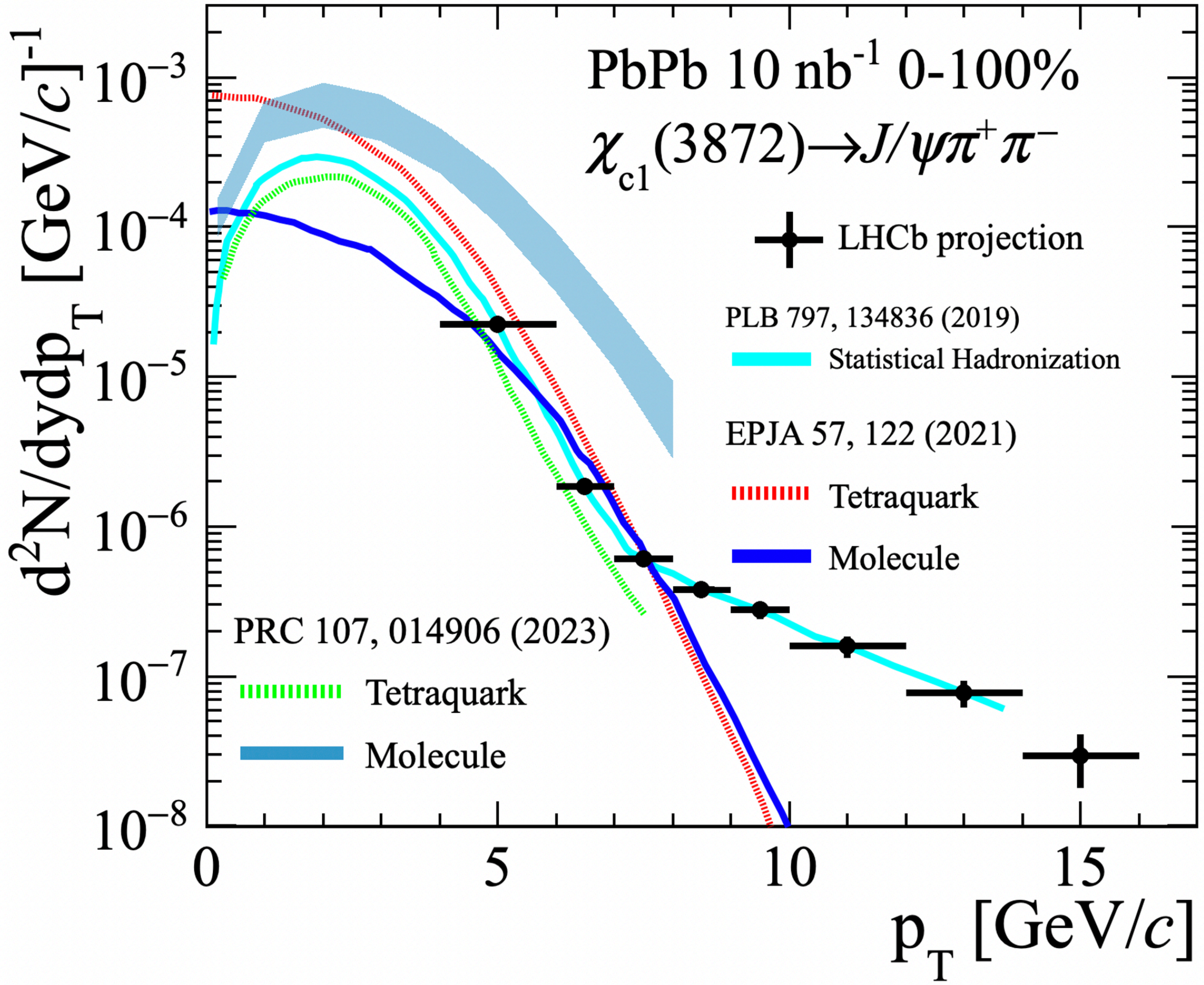


Projection done without the inclusion of the Magnet Station

Exotica particles

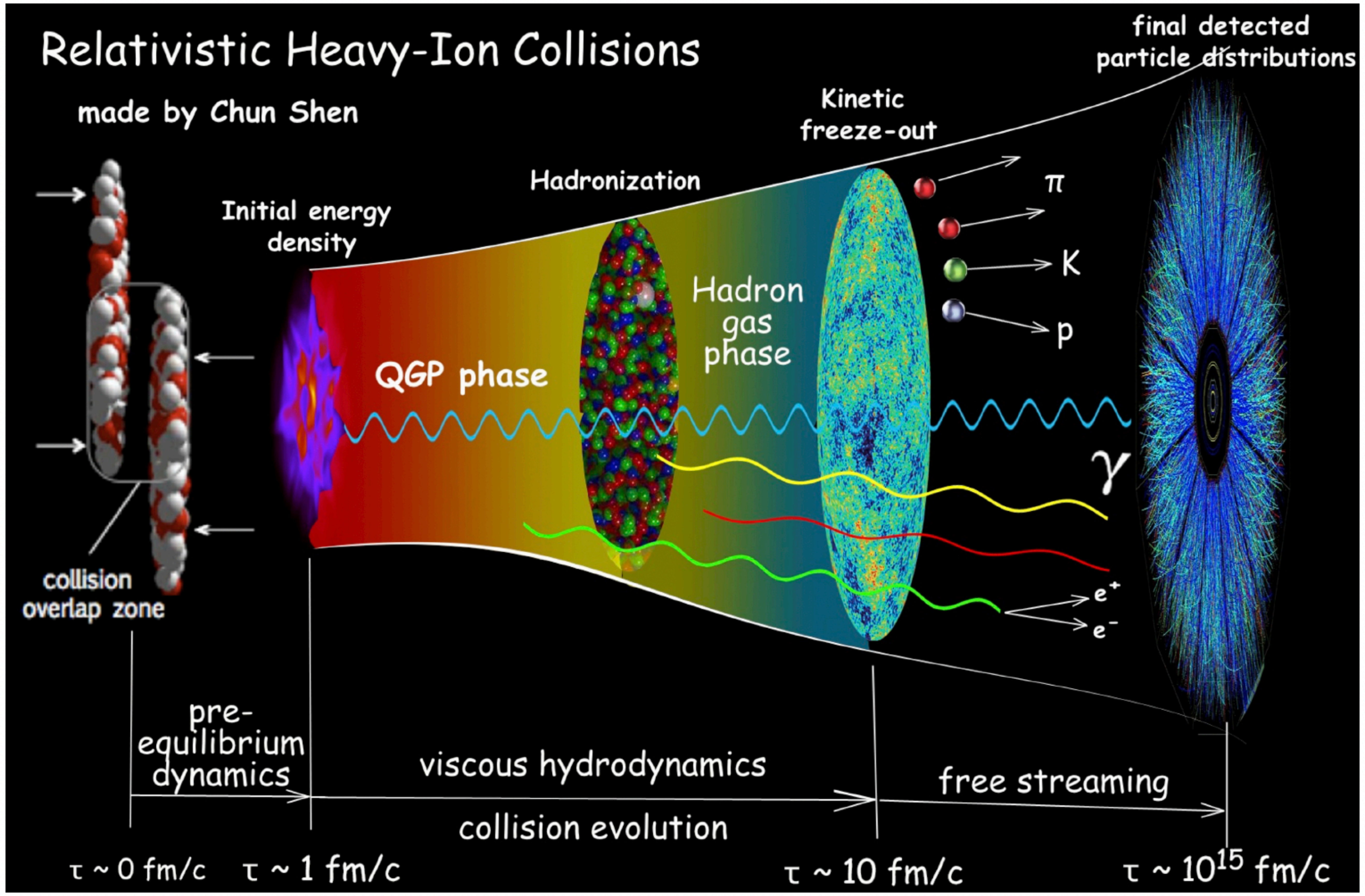
LHCB-FIGURE-2024-026

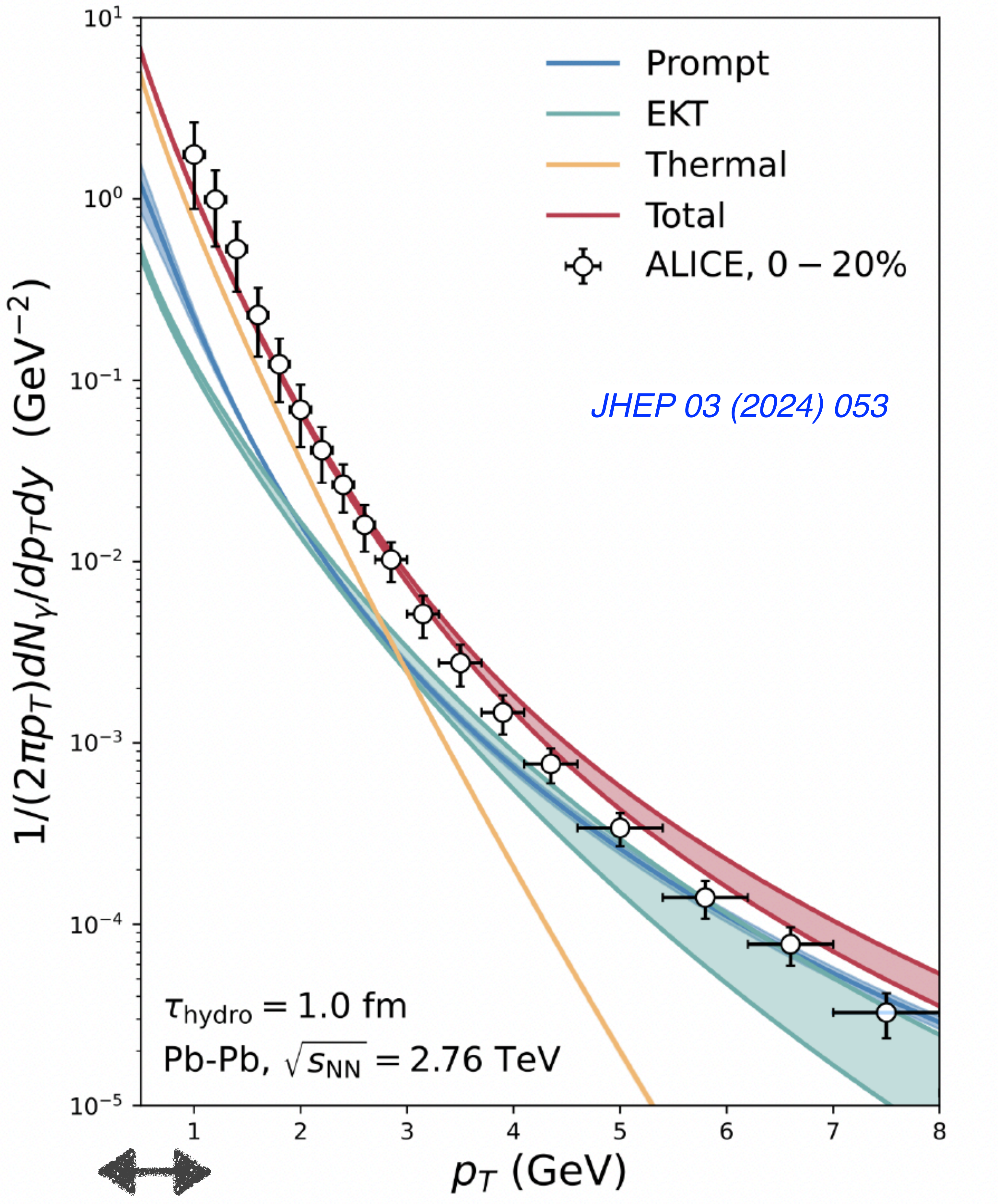
- Thanks to its PID capabilities and b vertex identification, LHCb discovered many exotic states.
- Most of those states are considered to be made of 4 quarks wether in a compact or molecular form.
- Yield of $\chi_{c1}(3872)$ in a hot medium will depend on its hadronisation (increased yield if coalescence…)



Projection done without the inclusion of the Magnet Station

Electromagnetic probes



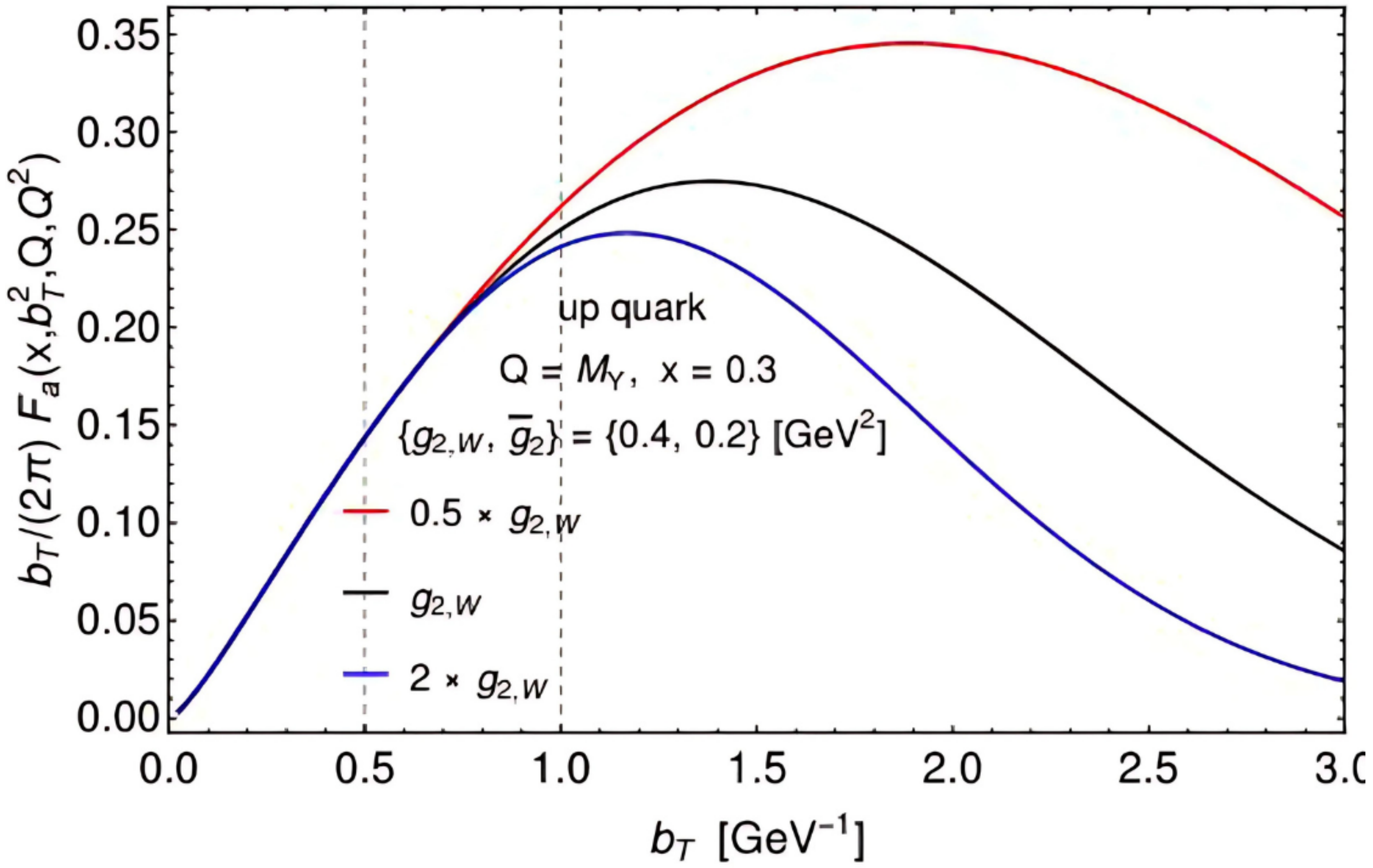


Reach low transverse momentum photon thanks to the Magnet Stations and photon conversion

LHCSpin

- Unique system complementary to future EIC
- Study non perturbative parameters in TMDs with Drell Yan and heavy quarks
- Measure η_c in different polarization configuration

At Mid Q and Large x



unpolarized

$$\frac{d\sigma_{UU}(\eta_Q)}{dy\, d^2\boldsymbol{q}_T} = \frac{2}{9}\frac{\pi^3\alpha_s^2}{M_h^3\, s}\langle 0|\mathcal{O}_1^{\eta_Q}(^1S_0)|0\rangle \left\{\mathcal{C}\left[f_1^g\, f_1^g\right] - \mathcal{C}\left[w_{UU}\, h_1^{\perp\, g}\, h_1^{\perp\, g}\right]\right\}$$

Unpolarized gluons

Longitudinally polarized gluons

Transversely polarized

$$\frac{d\sigma_{UT}(\eta_b)}{dyd^2\boldsymbol{q}_T} = \frac{2}{9}\frac{\pi^3\alpha_s^2}{M_h^3\, s}\langle 0|\mathcal{O}_1^{\eta_b}(^1S_0)|0\rangle\, |\boldsymbol{S}_{TB}|\, \sin\phi_S\ \times$$
$$\left\{\mathcal{C}\left[w_{UT}^{(A)}\ f_1^g\ f_{1T}^{\perp g}\right] - \mathcal{C}\left[w_{UT}^{(B)}\ h_1^{\perp g}\ h_1^g\right] - \mathcal{C}\left[w_{UT}^{(C)}\ h_1^{\perp g}\ h_{1T}^{\perp g}\right]\right\}$$

Sivers gluon TMD PDF

Longitudinally polarized

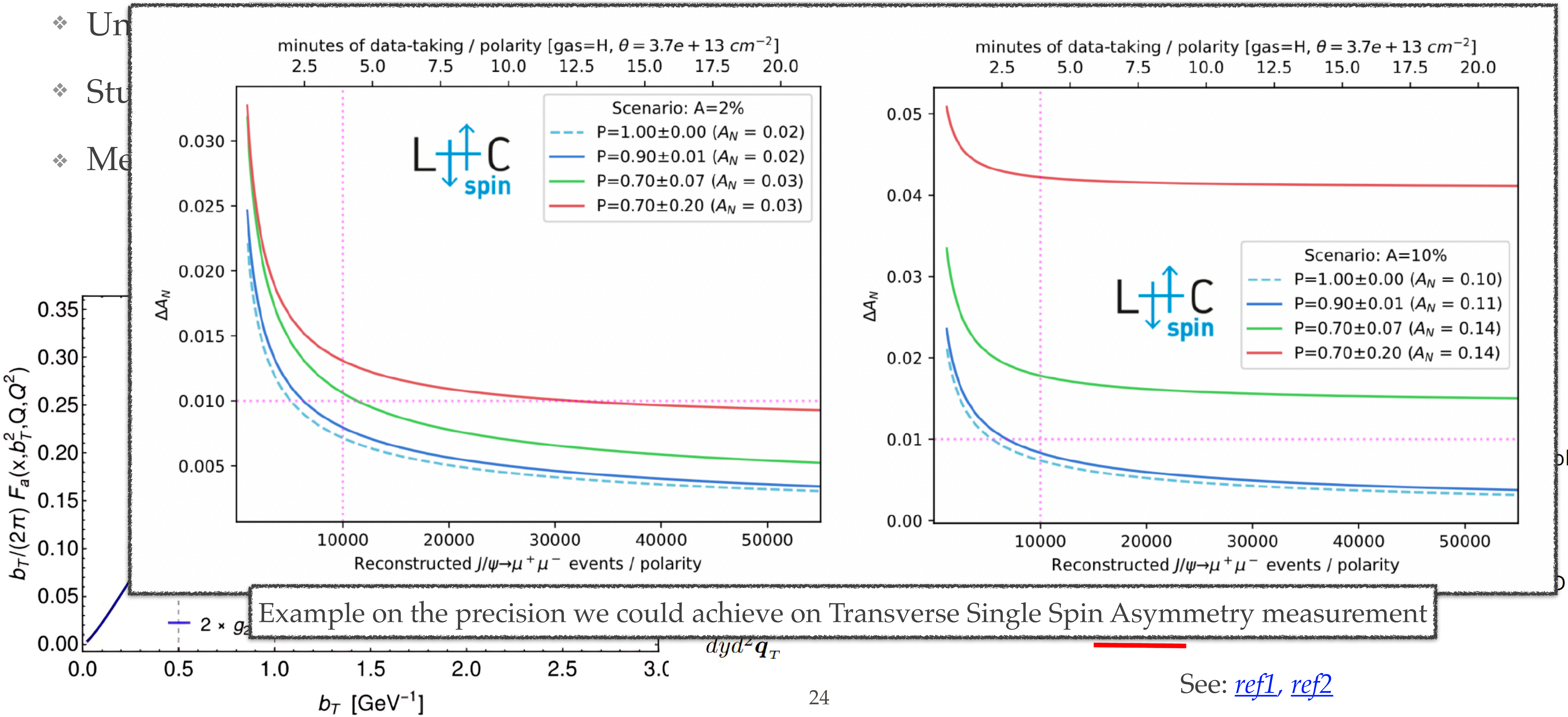
$$\frac{d\sigma_{UL}}{dyd^2\boldsymbol{q}_T} = 0$$

→ non-zero signal..? Twist 3 gluon TMDs

Credit to Andrea Signori: *talk*

LHCSpin

- Un
- Stu
- Me



olarized

D PDF

Example on the precision we could achieve on Transverse Single Spin Asymmetry measurement

$dyd^2\boldsymbol{q}_T$

See: ref1, ref2

Nuclei structure

- High statistic pA collisions will be also crucial to study saturation effect in the forward direction. In particular if the Upgrade II allows to have pile-up for pA collisions
- High statistic as well for exclusive measurement in pPb and PbPb
- Partonic distribution in small system collision thanks to low-p_T photon isolation measurement using the Magnet Station

Conclusion

- The upgrade II of the LHCb detector will unlock high precision heavy-ion physics in the forward direction, making it an unique detector to study mechanisms of saturation, thermalization, and hadronization.
- The addition of the LHCSpin will unlock many studies to understand nuclear structure distribution, showing great complementarities to the future EIC.
- A public note is being prepared