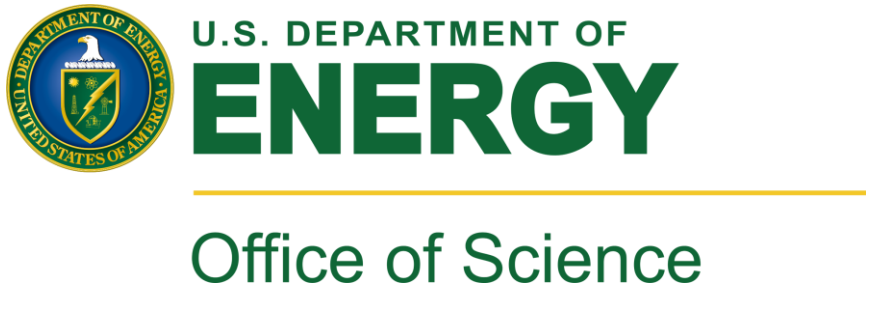
LHCb studies and plans in hadronic proton-nucleus collisions at the LHC

Cesar Luiz da Silva for the LHCb Collaboration
Los Alamos National Lab

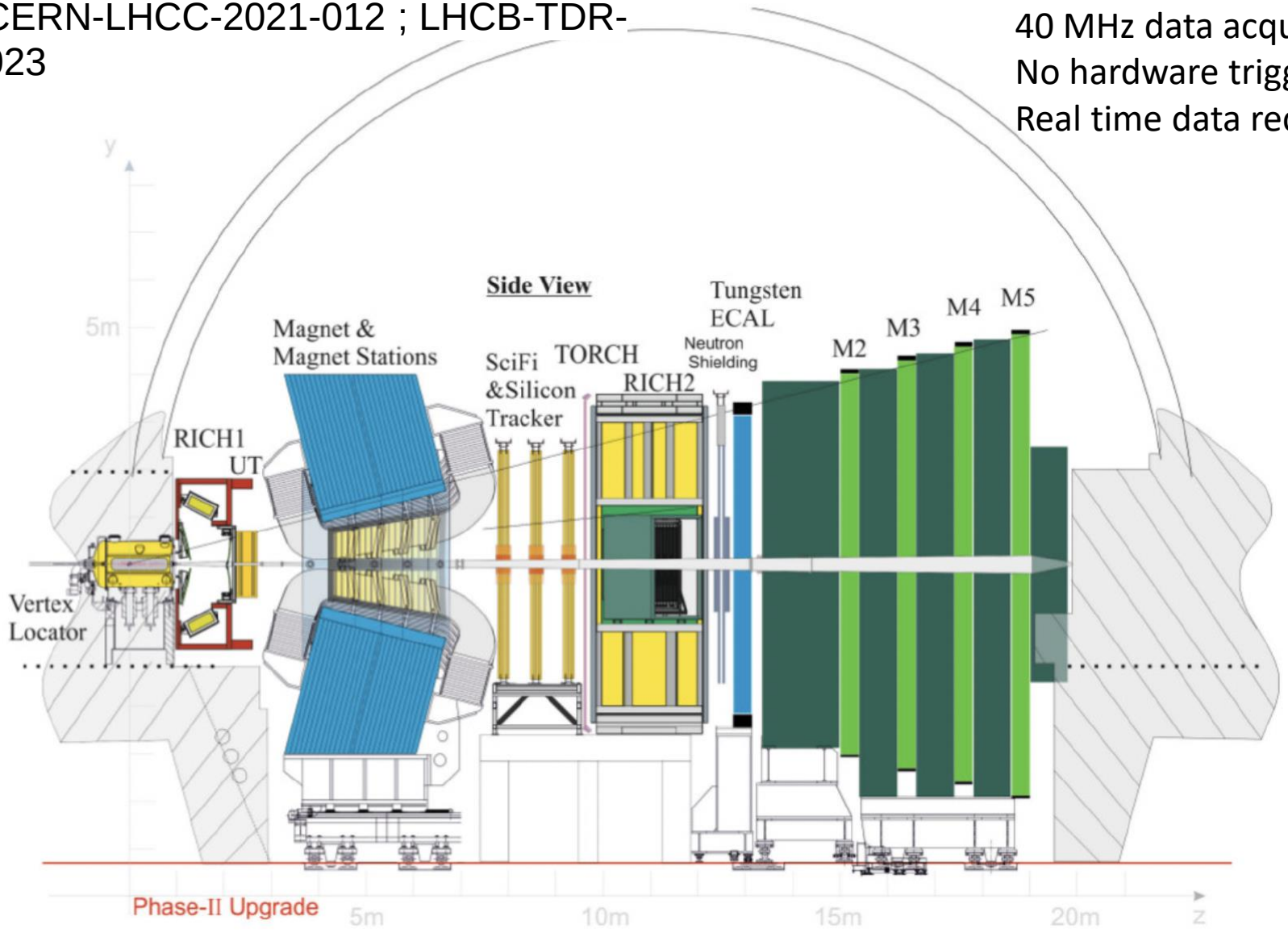
Physics with high-luminosity pA collisions at the LHC

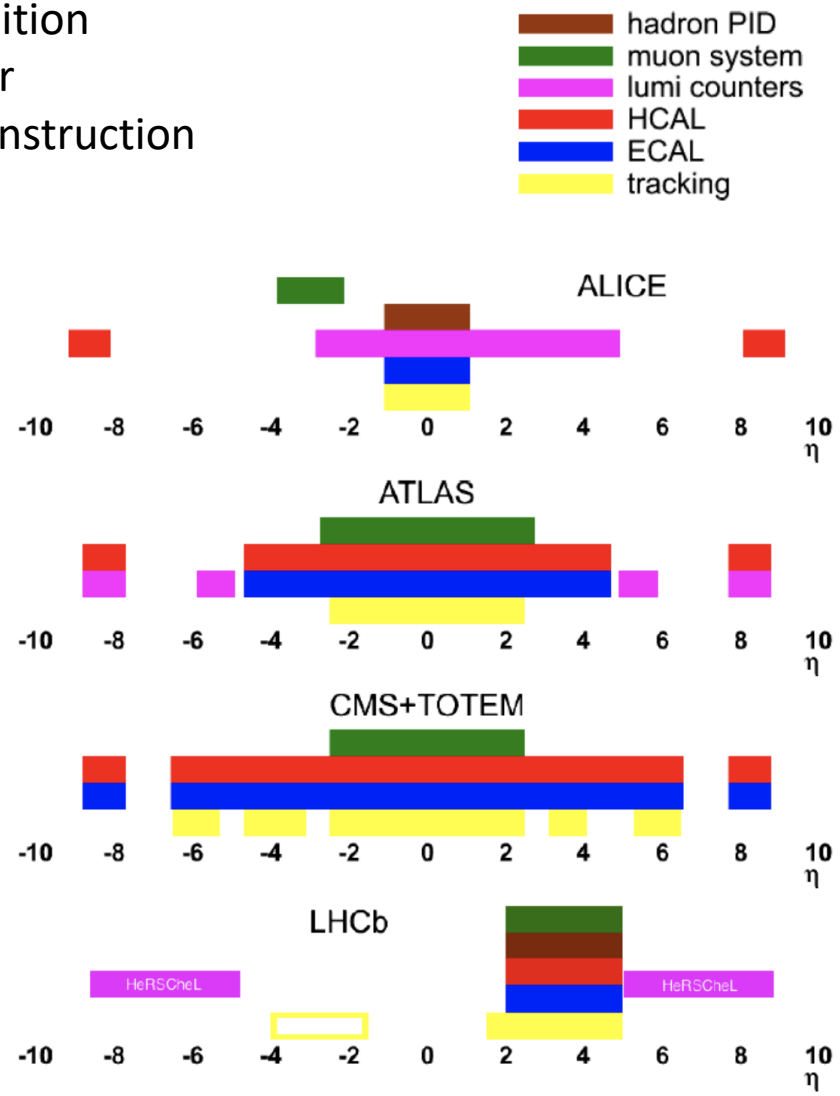


The LHCb Upgrade II Detector

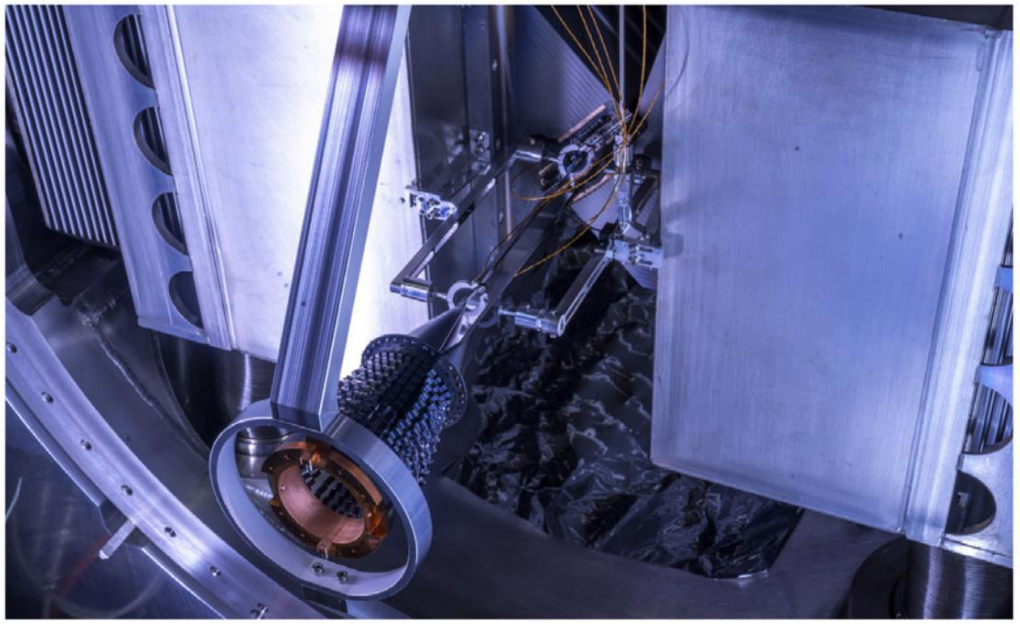
CERN-LHCC-2021-012 ; LHCB-TDR-023

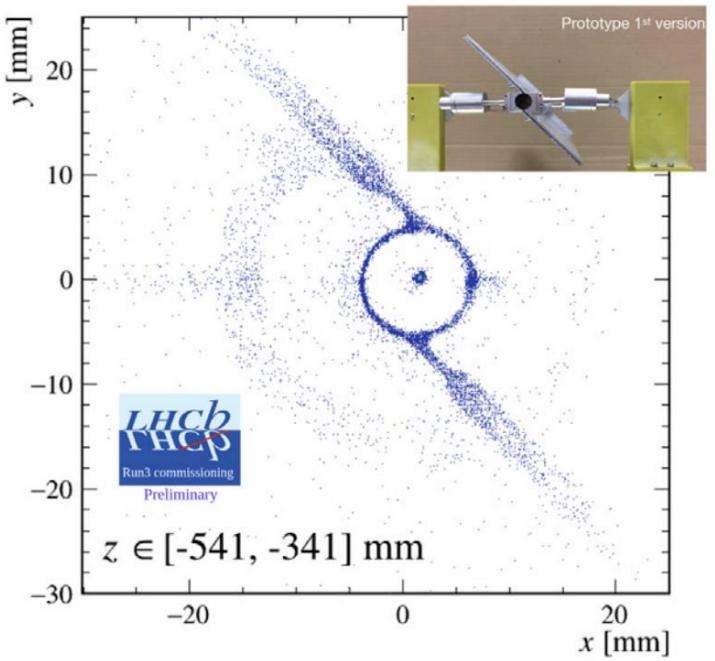
40 MHz data acquisition
No hardware trigger
Real time data reconstruction





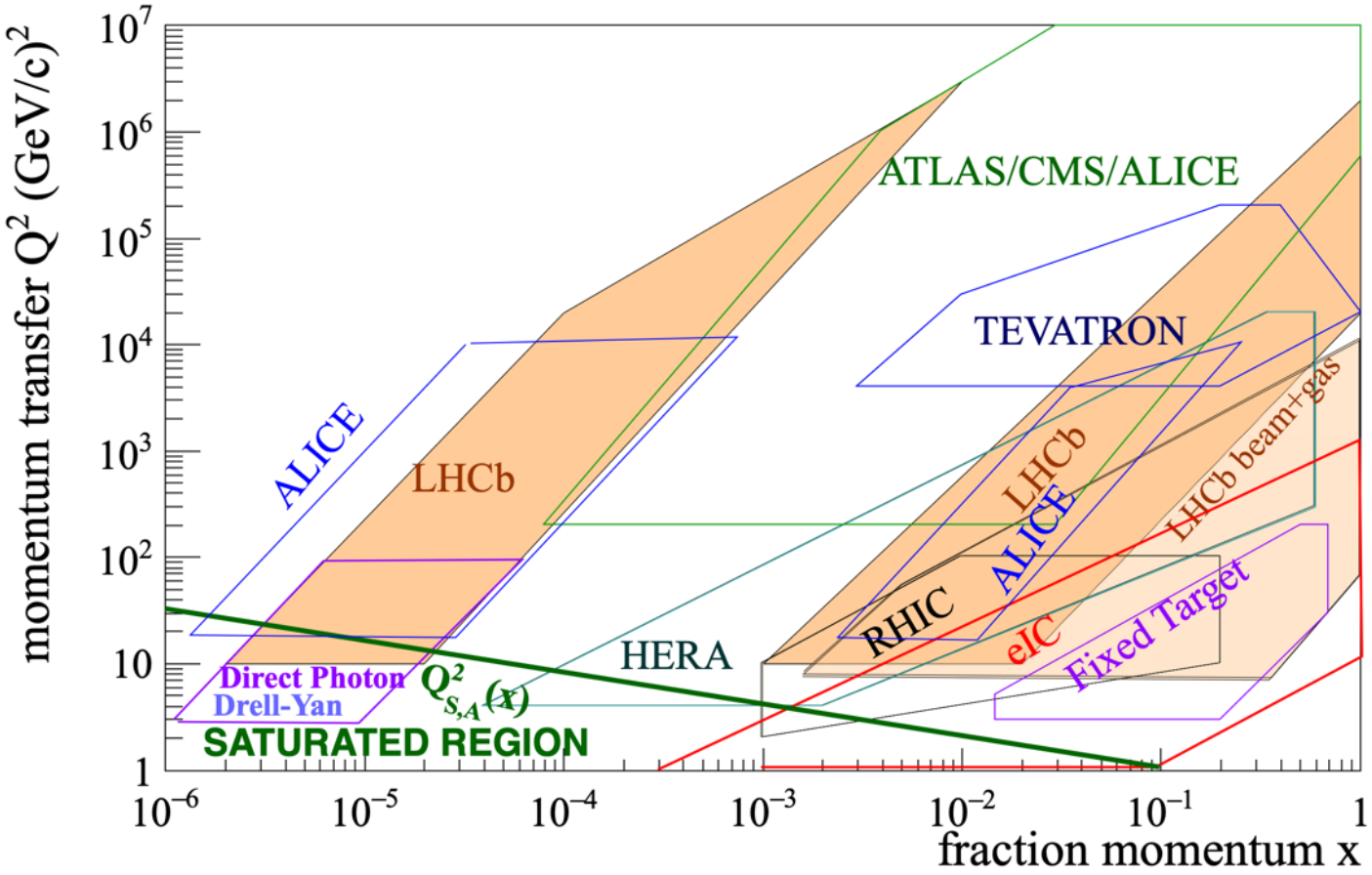
Ongoing High-lumi pA program of LHCb



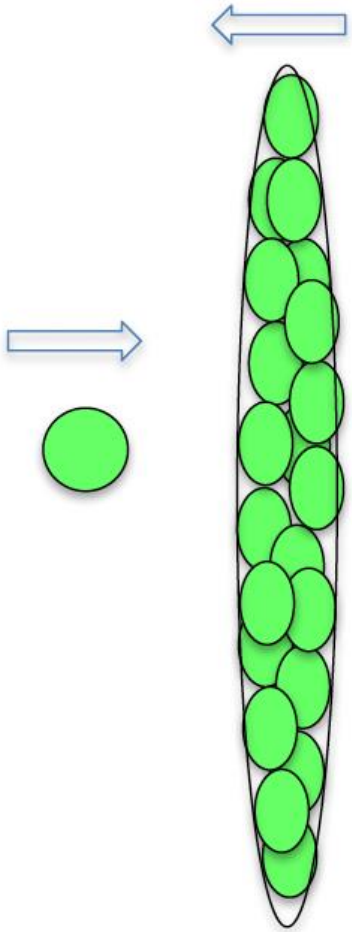


- LHCb has a constant pA program in fixed target mode at $\sqrt{s_{NN}}$=113 GeV
- High-lumi, high-energy pA program is still a need

Small-x Physics



- Unique coverage in the small-x region, where potential untested non-linear QCD takes places.
- Fundamental area for Quantum Field Theory.
- FCC will be predominantly in the gluon saturated regime, mandatory to study it in Run4.

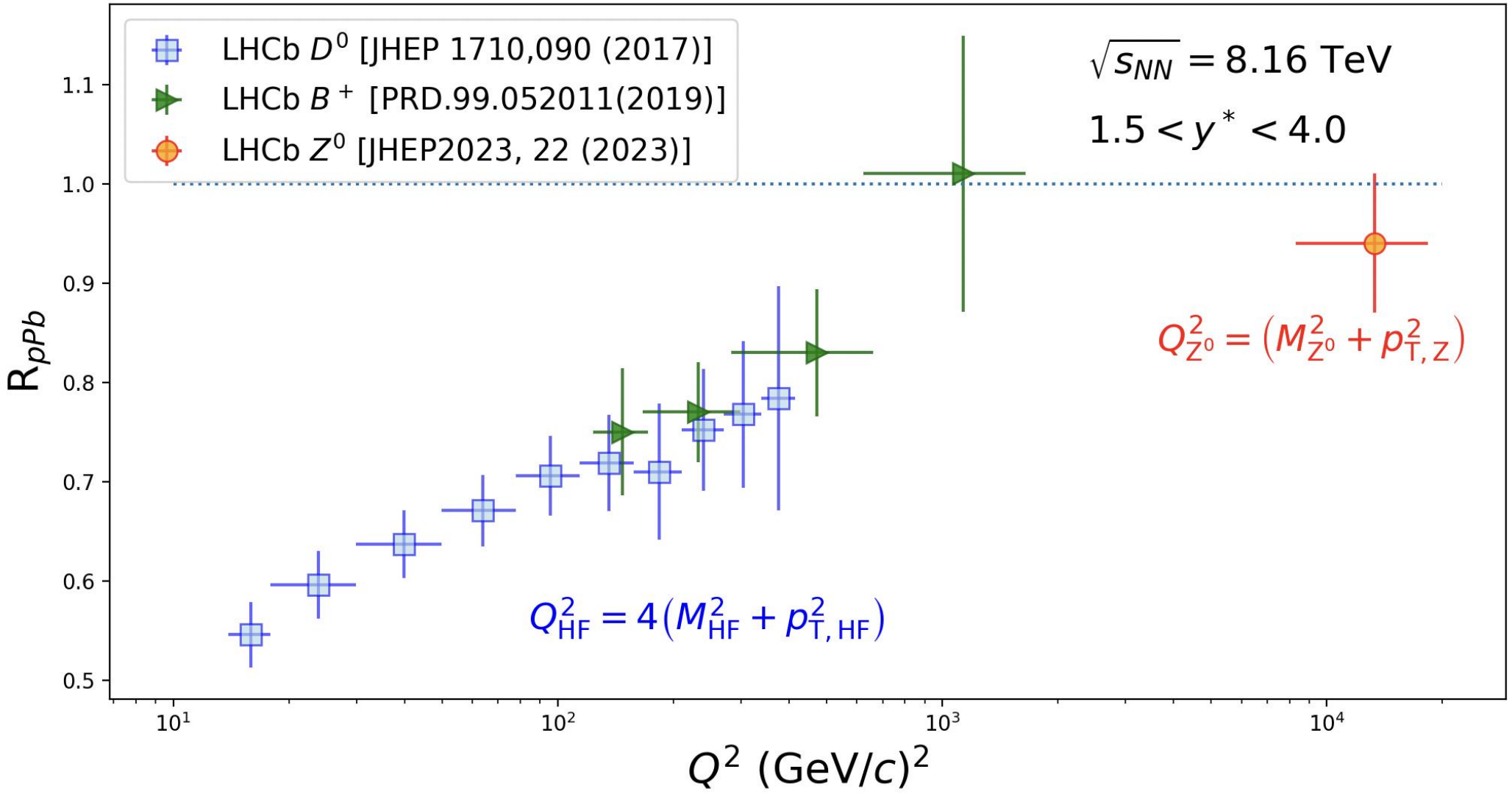


Gluon density is enhanced by the Lorentz contraction of the nucleus at the probe rest frame.

$$Q^2_{S,A} \propto A^{1/3} Q^2_{S,p}$$

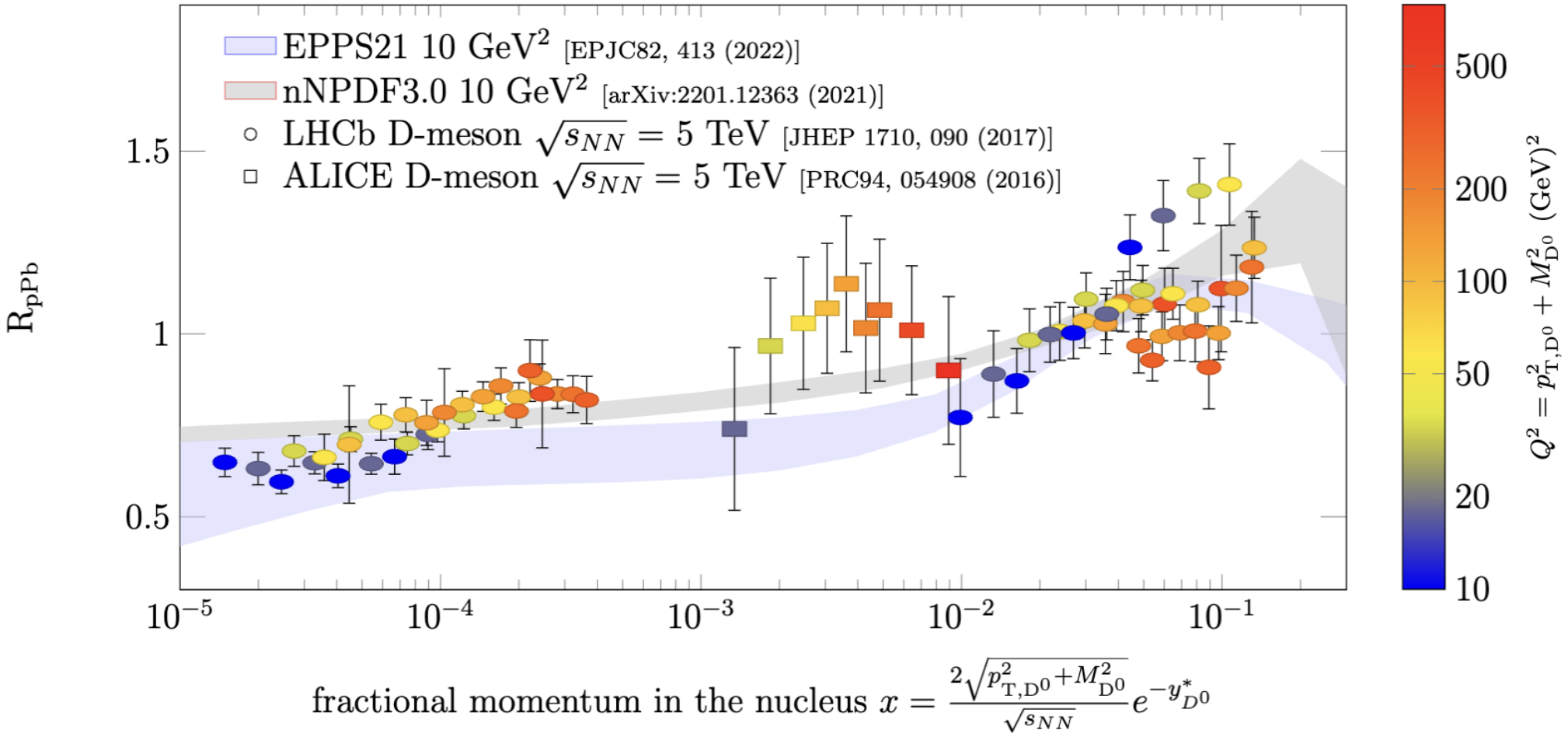
Saturation scale would be seen at a x and Q2 smaller than in pp collisions.

H. Kowalski, T. Lappi, and R. Venugopalan *PRL*100, 022303 (2008)



Consistent pattern of suppression of heavy flavor and Z yields.

Hot QCD White Paper arXiv:2303.17254

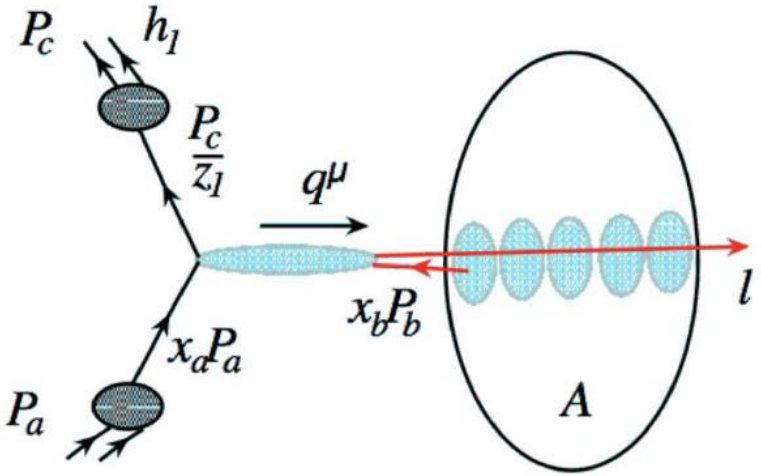


D^0 suppression observed by LHCb is a baseline for the latest nPDFs

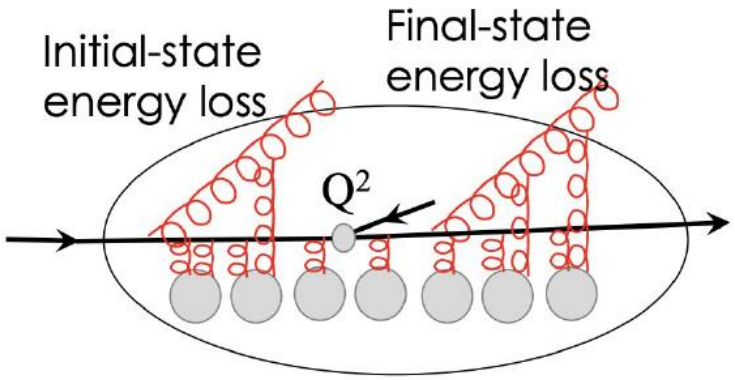
Expect to get a similar figure using direct photons and DY with 2016 data.

WHAT CAUSES GLUON SUPPRESSION IN NUCLEUS?

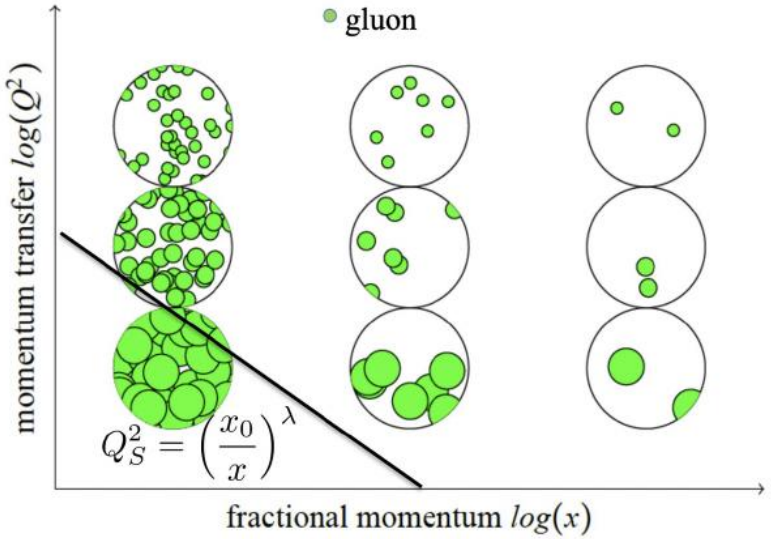
Multiple interactions



Energy Loss



Gluon Saturation



Suppression in nucleus caused by a shift in the gluon x

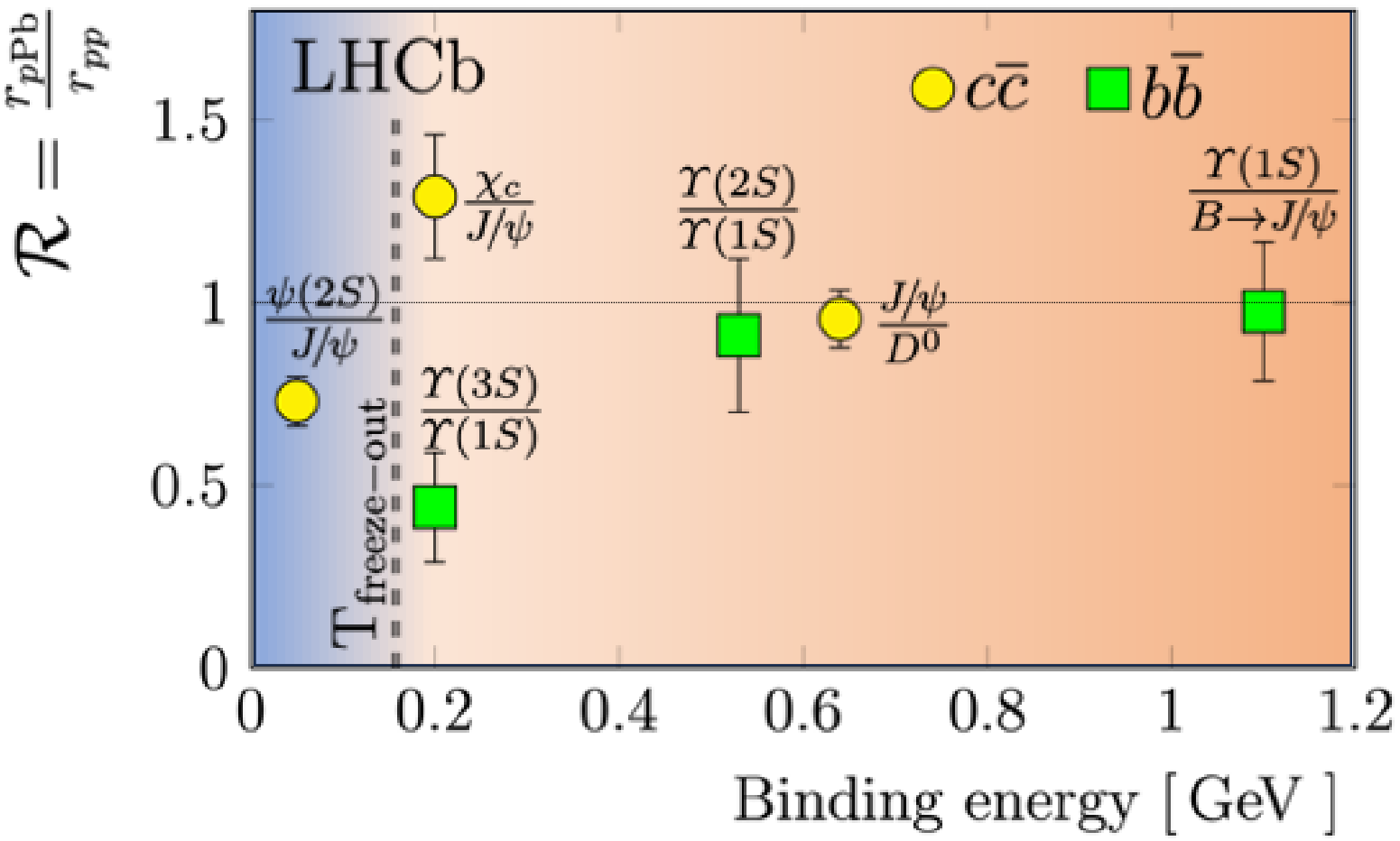
Suppression caused by non-increasing gluon density towards small-x in the nucleus

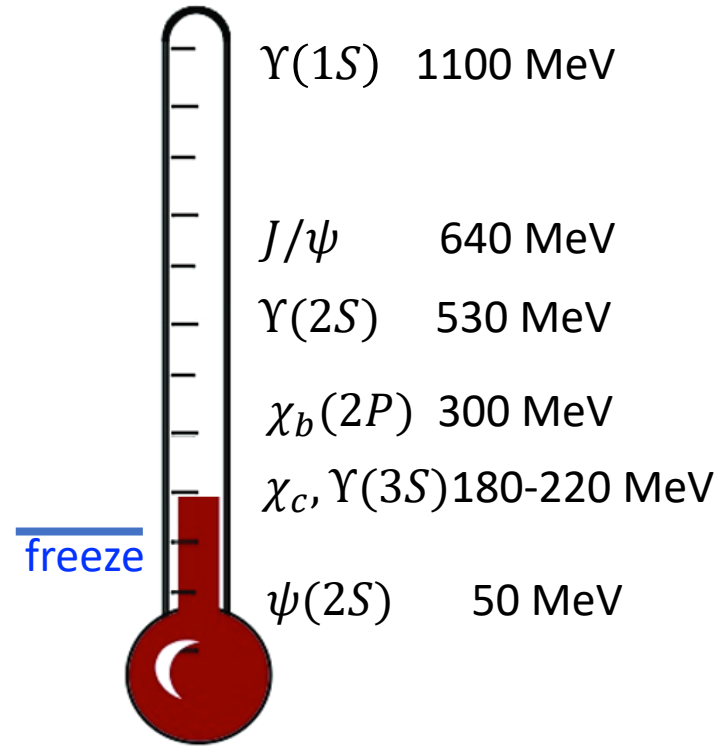
High statistics pA is mandatory to disentangle saturation and pQCD effects.
How partons would behave if DGLAP is broken ? Several probes may be needed.

Quarkonia

Quarkonium states in pPb collisions.

PRL 132, 102302 (2024)



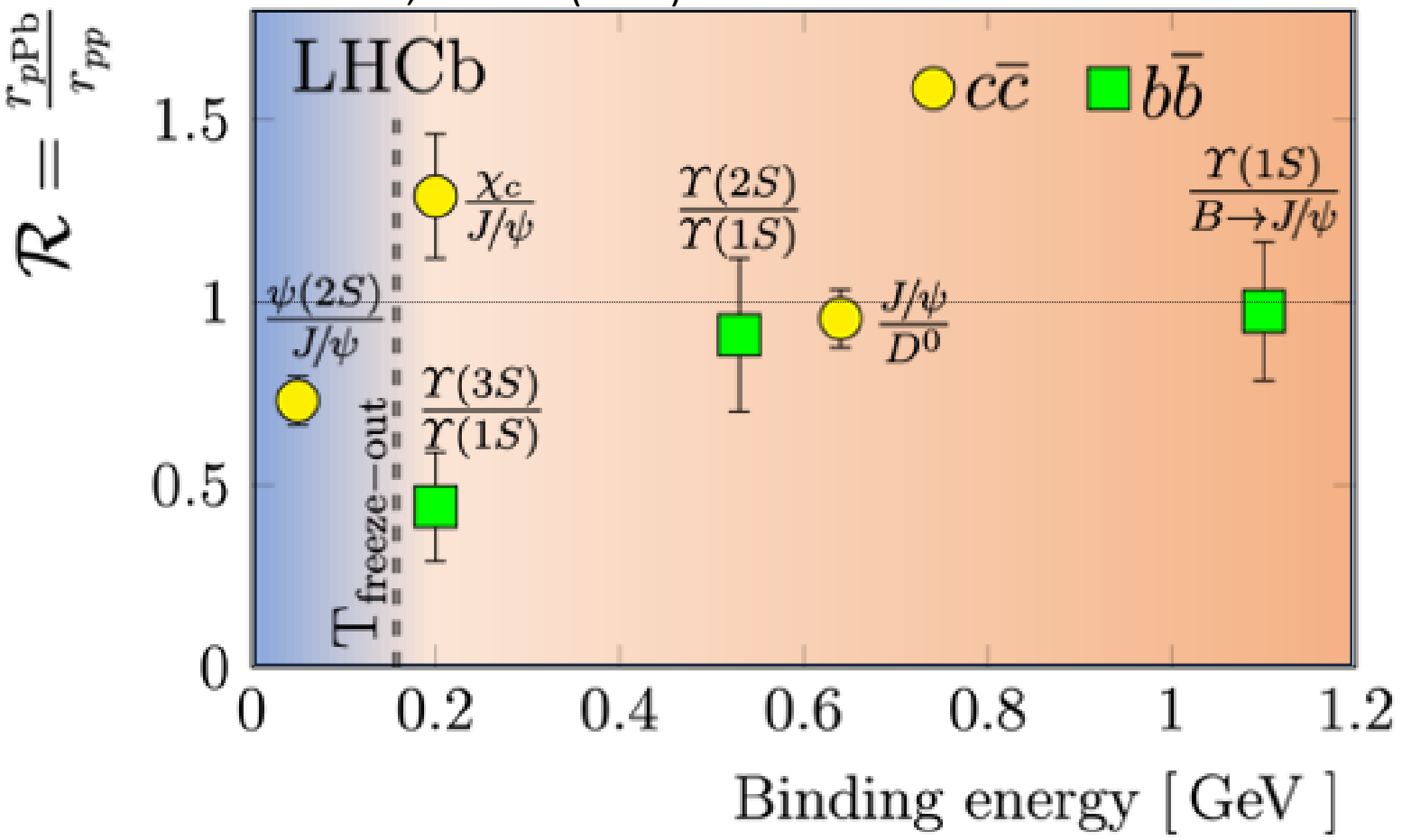


Doubled ratios btw. quarkonium states and corresponding HQ consistent with a hadronic medium in small system.

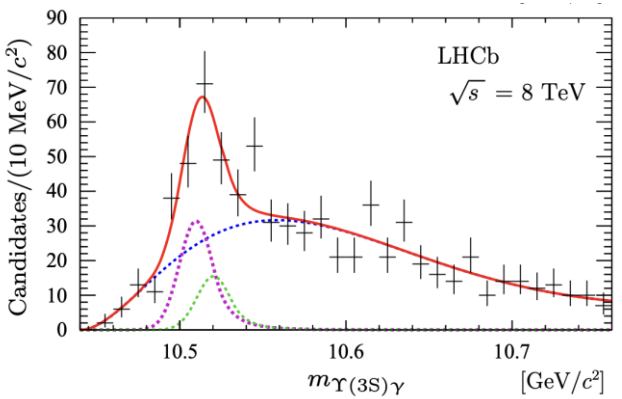
Except $\Upsilon(3S)$ state which seems to breaks in pPb collisions.

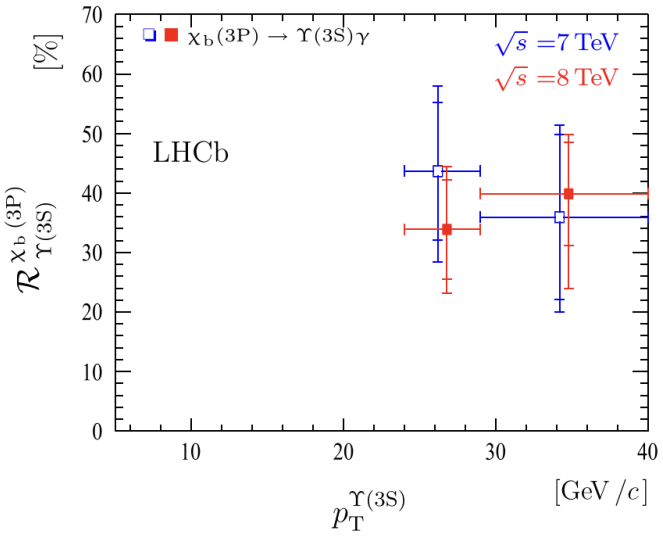
Quarkonium states in pPb collisions.

PRL 132, 102302 (2024)



Eur. Phys. J. C (2014) 74:3092





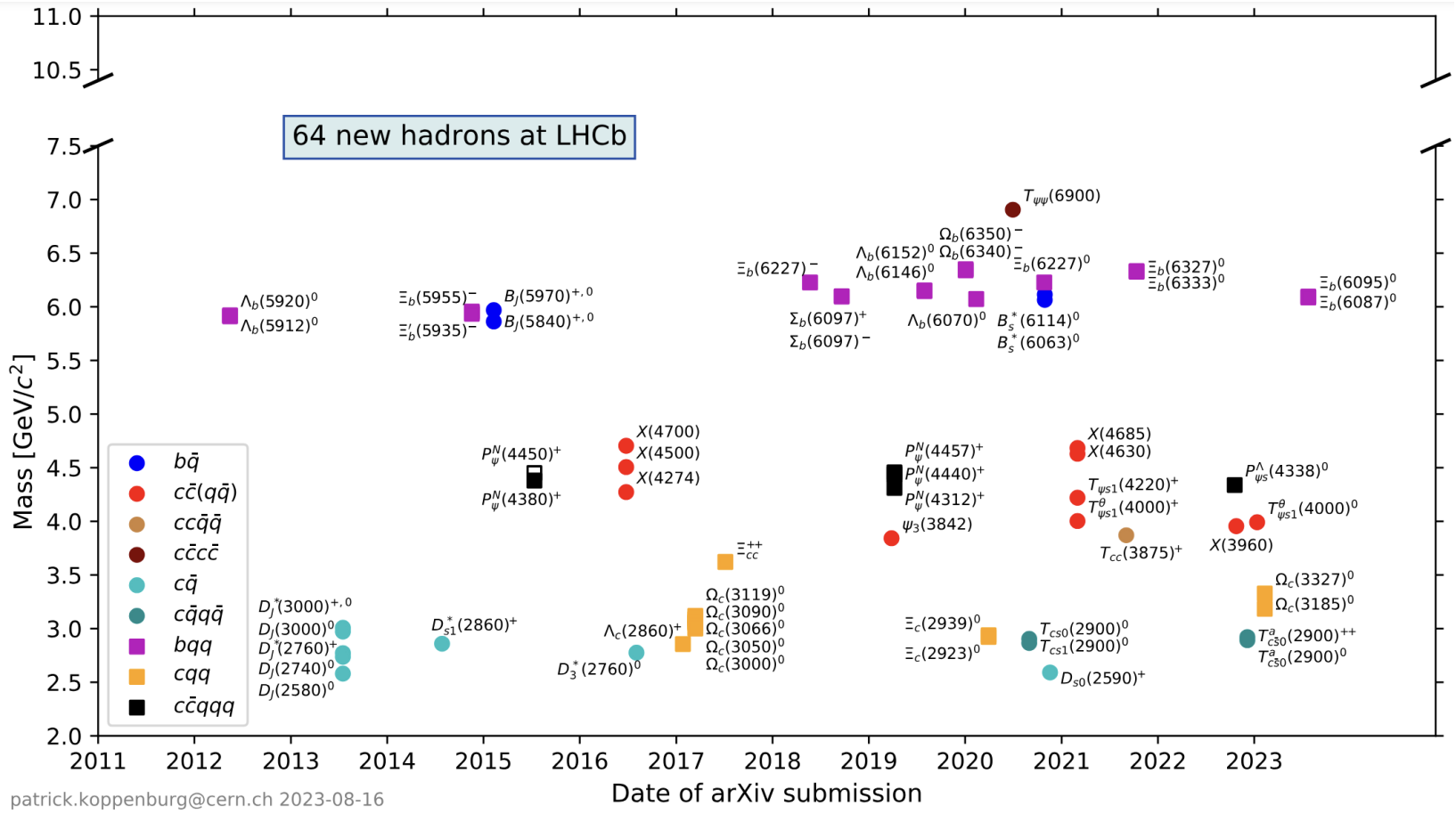
Υ states move slowly through comoving hadrons.

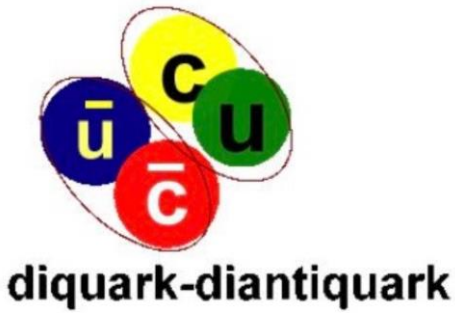
Υ(3S) relative suppression consistent with the $\chi_b(3P)$ breaking.

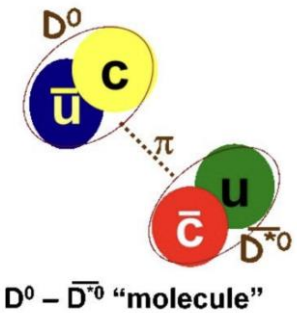
Needs high luminosity to understand the role of χ_b feed-down in the Υ(3S) suppression.

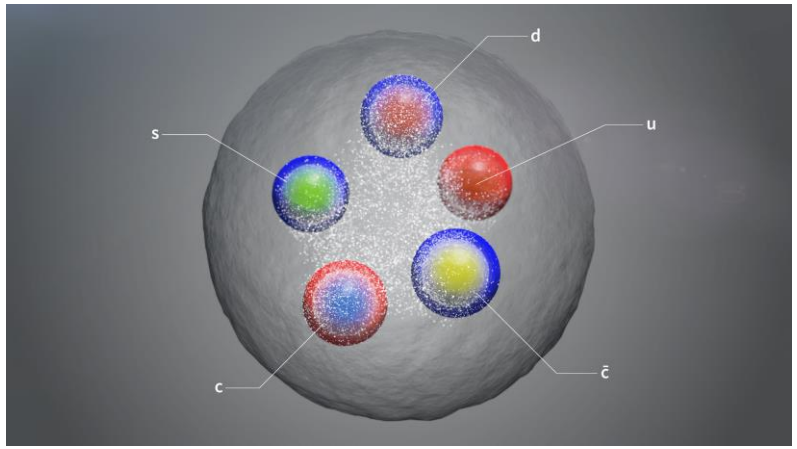
Exotica

The second particle revolution





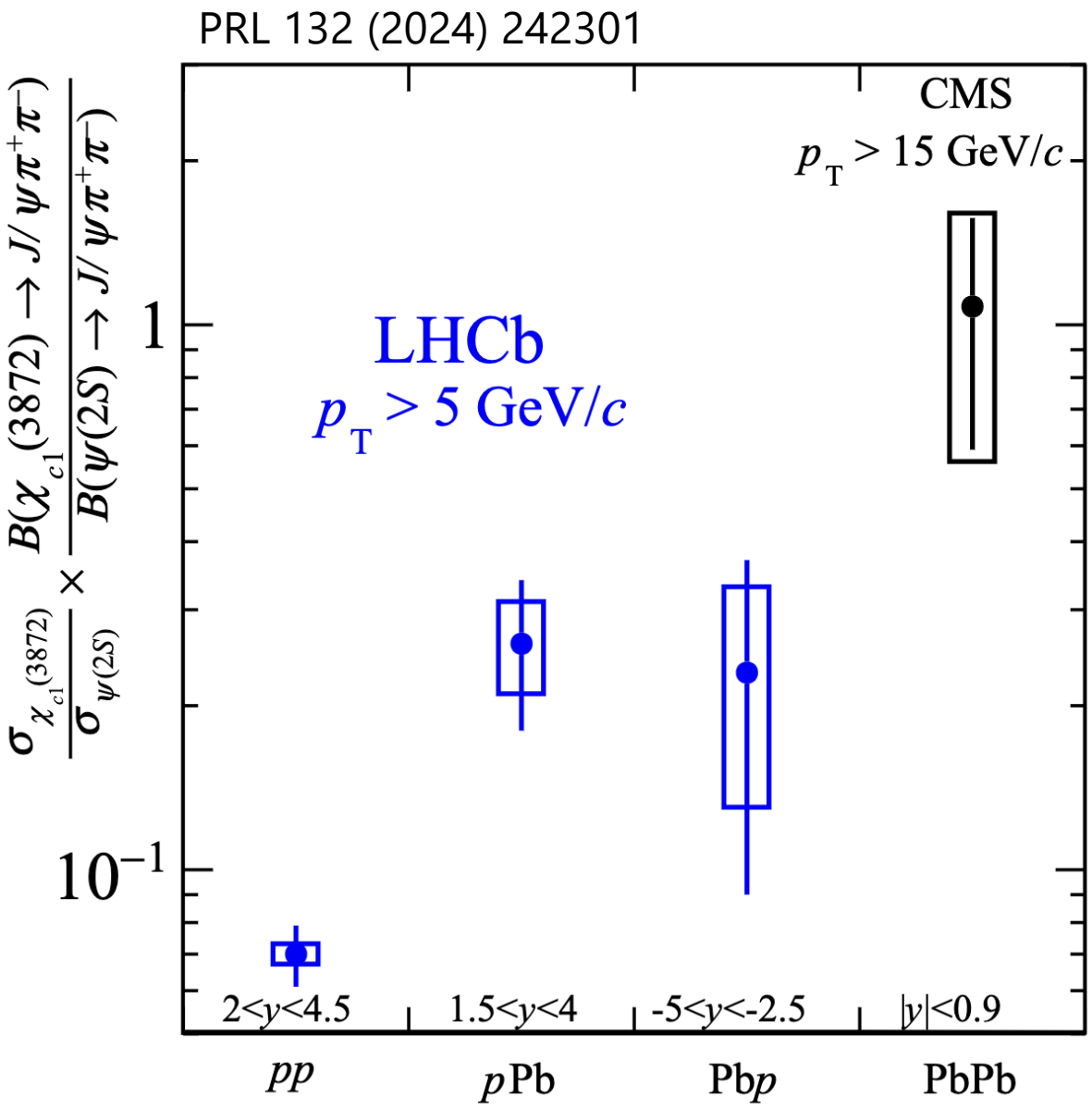




New mesons, baryons, tetraquarks and pentaquarks are discovered every 4-6 months.

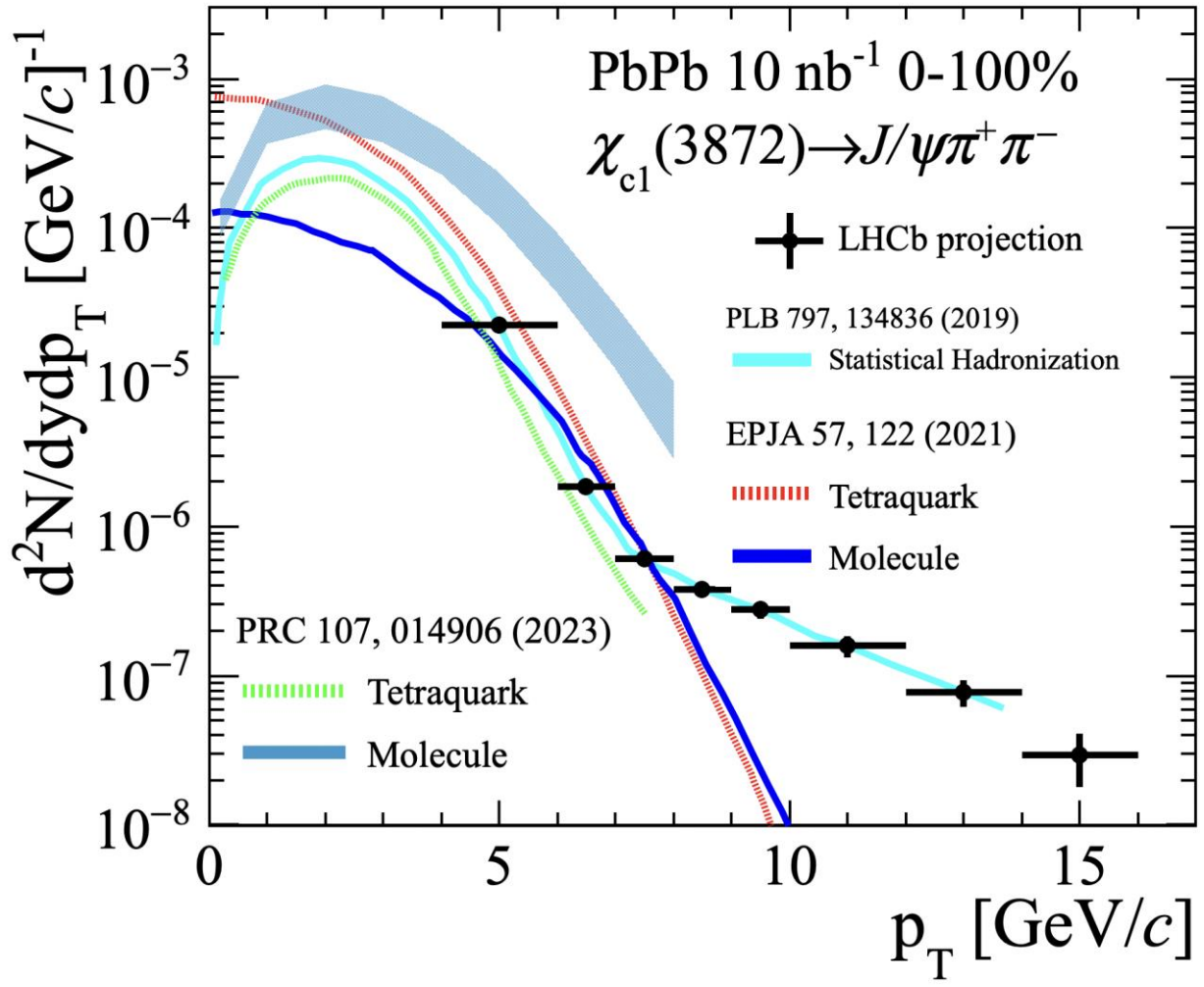
Understand how these new hadrons are formed and how they bind is a great laboratory on non-perturbative QCD and asymptotic freedom.

Exotic in pp, pA and AA collisions



- $\chi_{c1}(3872)$ yield seems to enhance in pA and AA collisions
- Requires large statistics of pA collisions to be able to measure event multiplicity dependency of $\chi_{c1}(3872)$ production to confirm the yield enhancement
- Multiplicity dependency measurement is essential to investigate the sources of the enhancement
- If the enhancement in pA is confirmed it would indicate that exotic particle production is favored in heavy ion collisions, making HI a exotic factory

Exotic in pp, pA and AA collisions



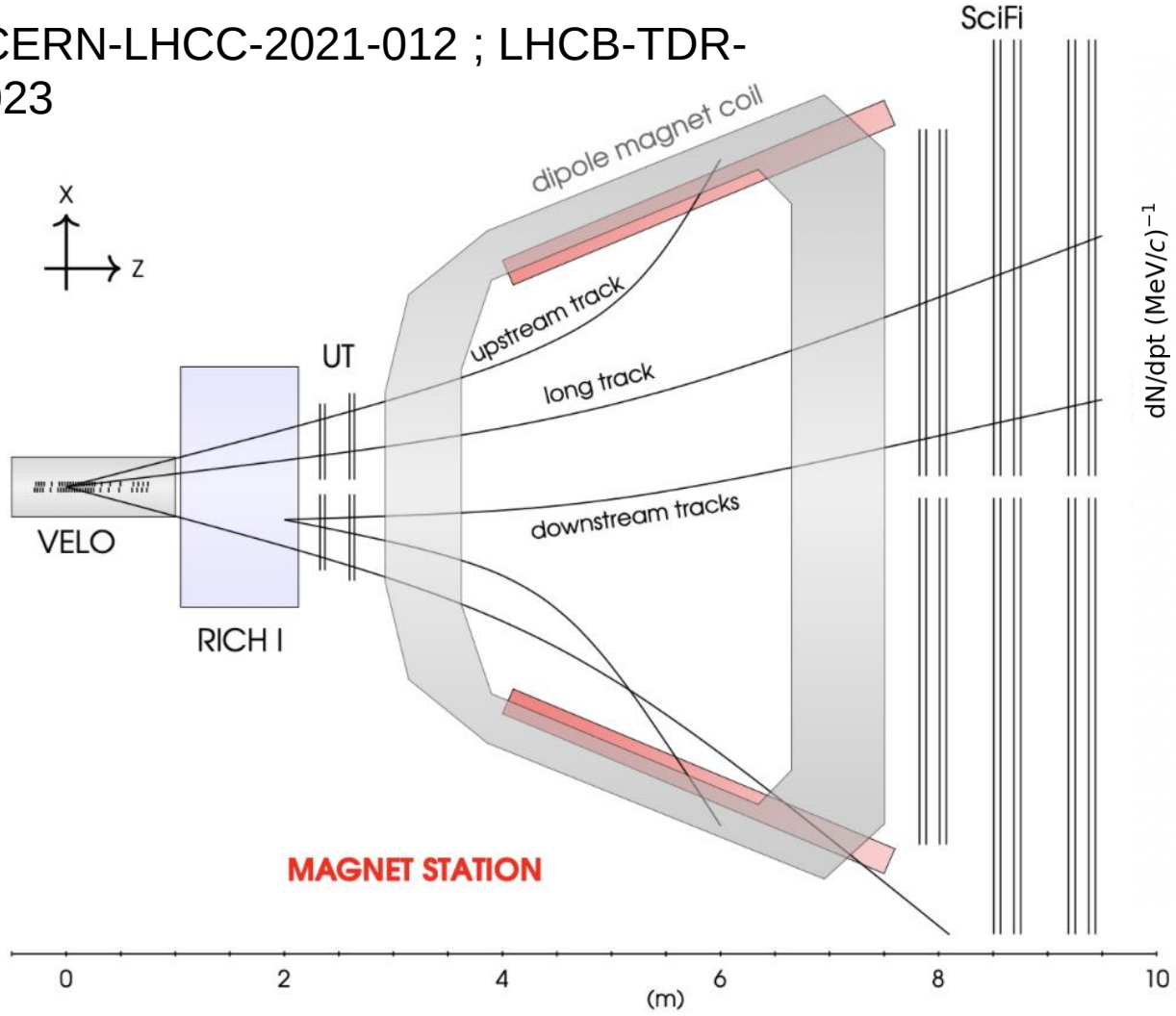
STATISTICAL HADRONIZATION MODEL
A. Andronic et al. Phys. Lett. B 797, 134836 (2019)

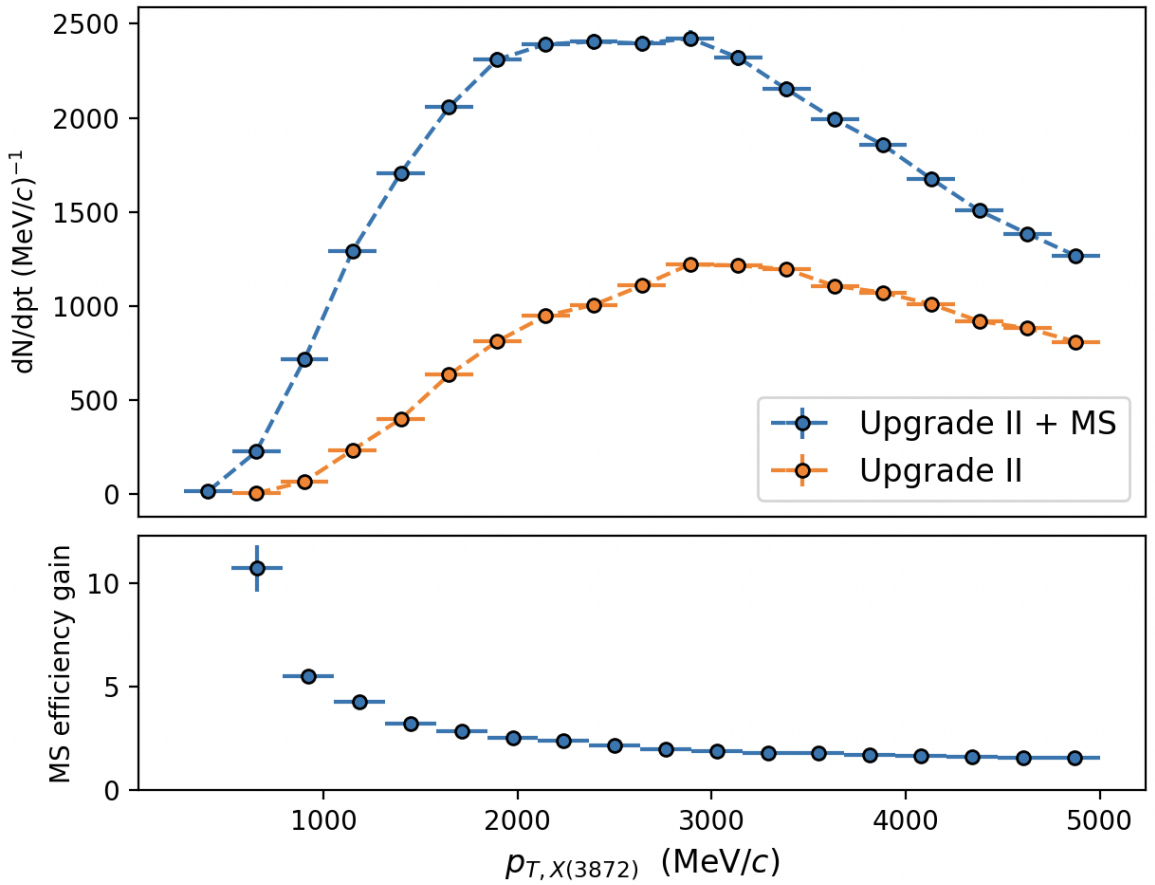
See Elena Ferrero's talk yesterday.

Strong enhancement in pA expected, especially at low-p_T.

X(3872) with Magnet Station

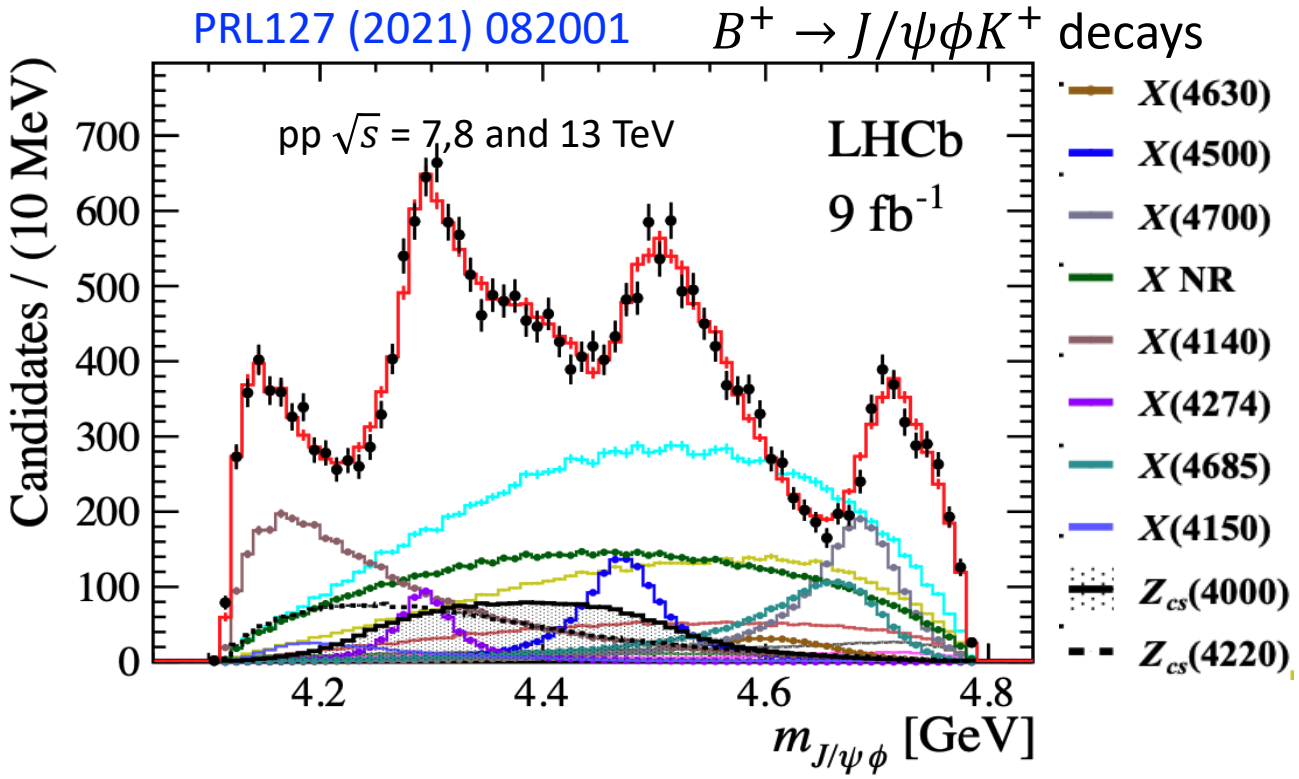
CERN-LHCC-2021-012 ; LHCB-TDR-023





Will enable low-p_T $\chi_{c1}(3872)$, other exotic states measurements where charm coalescence may be dominant.

Other exotic particles.



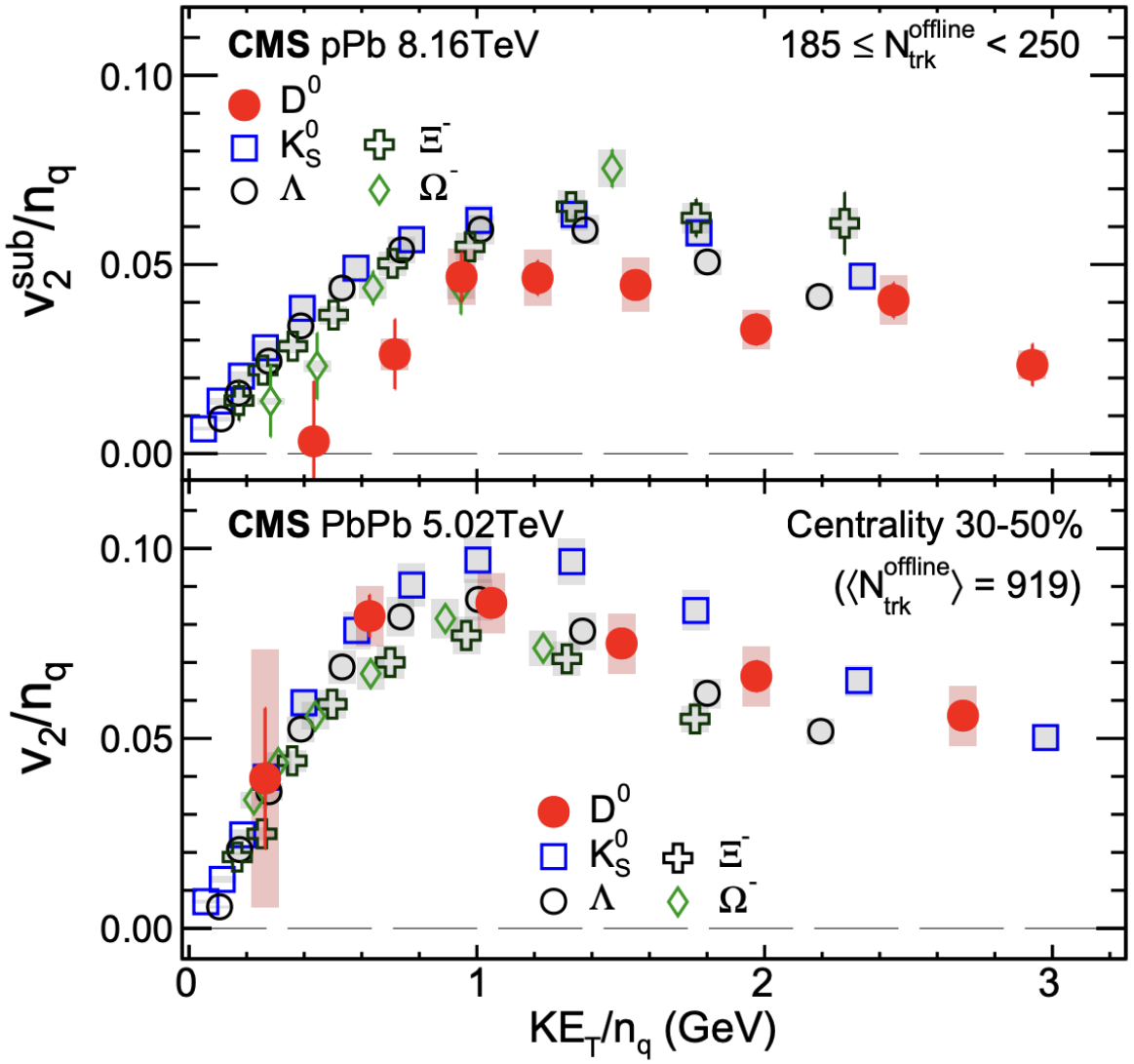
High luminosity pA would bring the possibility to study how other exotic states couple with nuclear medium. Multiplicity dependence may determine if

- the state is a molecule or a tightly bound state
- its binding energy

Essential to study non-perturbative QCD and how hadrons bind.

Search for low mass exotic hadrons

Phys. Rev. Lett. **121**, 082301



- Hadron elliptic flow (v_2) shows a scaling with number of valence quarks in AA and pA
- Thanks to its excellent PID and mass resolution, **LHCb** can measure several f_0, f_2 hadrons. Many of them with potential to be **tetraquark or glueball** states
- v_2 measurement of scalers and tensors can provide insight on their nature.
- Requires very high luminosities pA to measure v_2 of these rare hadrons in high multiplicity events
- pPb collisions are highly preferred because of the larger S/BG compared to PbPb collisions

Conclusions

- Shown just few examples on how a high luminosity pA run is essential for the heavy ion program of LHCb and the understanding of QCD on its limits
- Extensive physics program at low-x is essential for the future FCC program
- Full quarkonia spectroscopy vs. event multiplicities will be a unique opportunity to study the binding mechanisms of hadron formation
- Potential enhancement of exotic state yields in pA collisions could bring the possibility of exotic factories at LHC
- Cannot miss this opportunity during Run4-5 with Upgrade II LHCb configuration