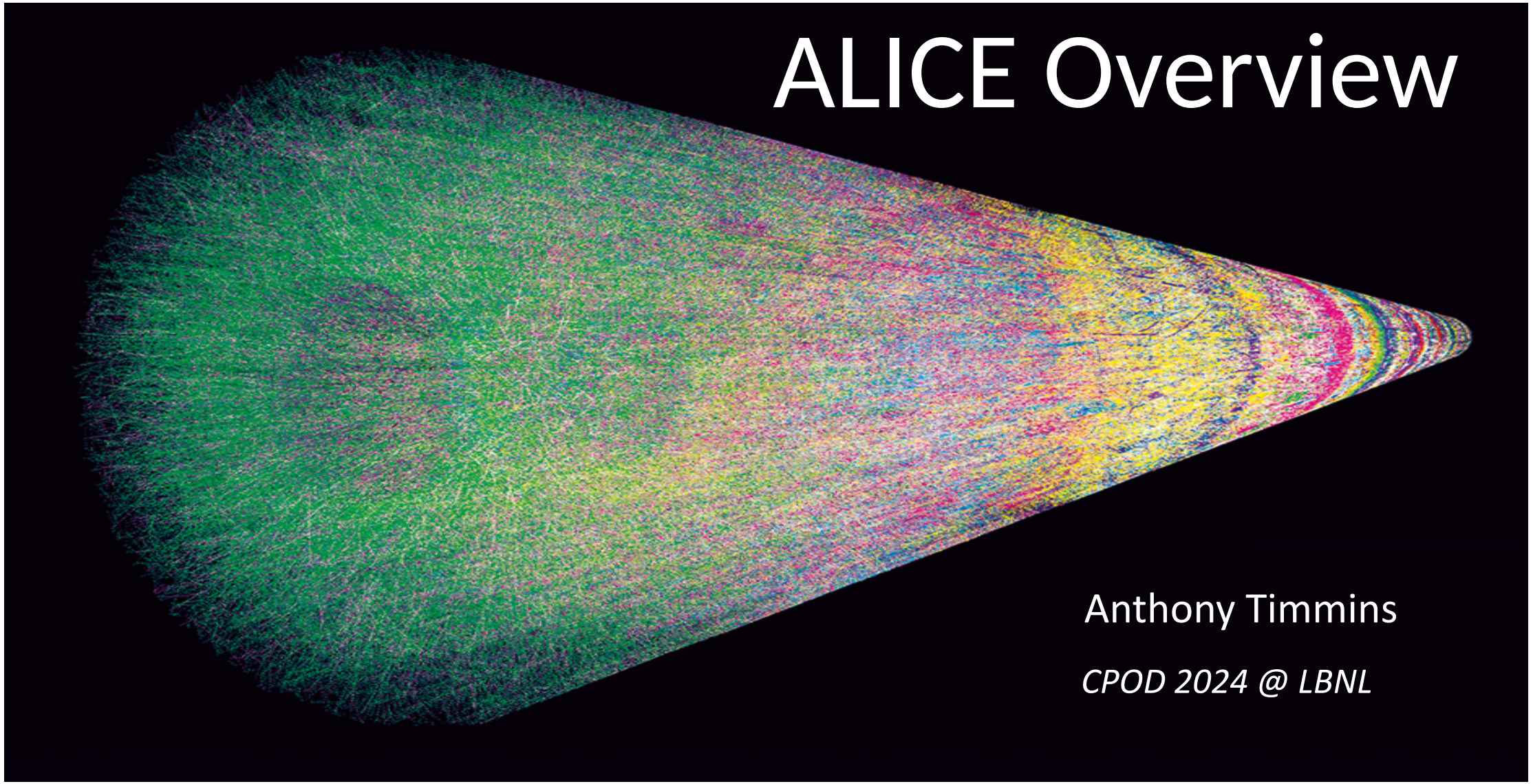
ALICE

ALICE Overview



Anthony Timmins

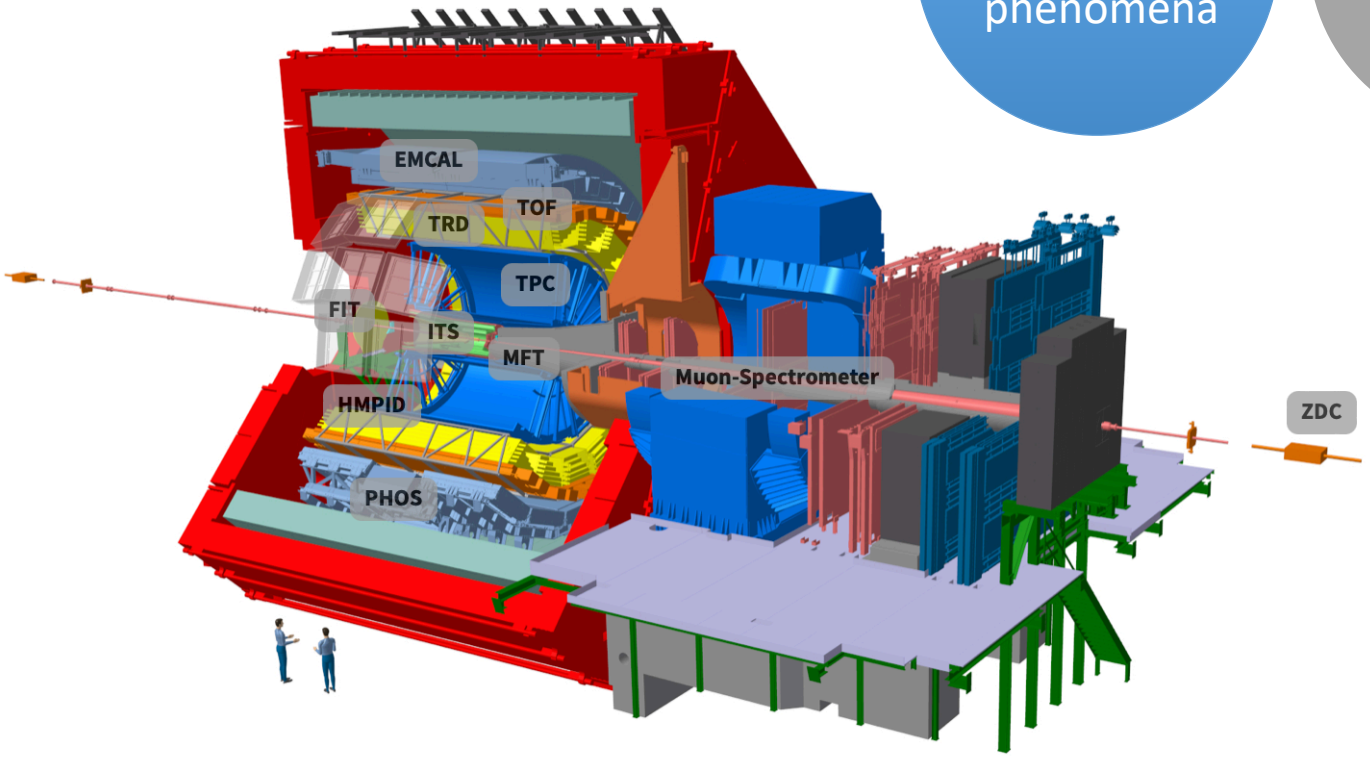
CPOD 2024 @ LBNL

UNIVERSITY OF HOUSTON

ALICE physics program

QGP properties

Thresholds of QGP formation



Stellar and interstellar phenomena

Few body QCD

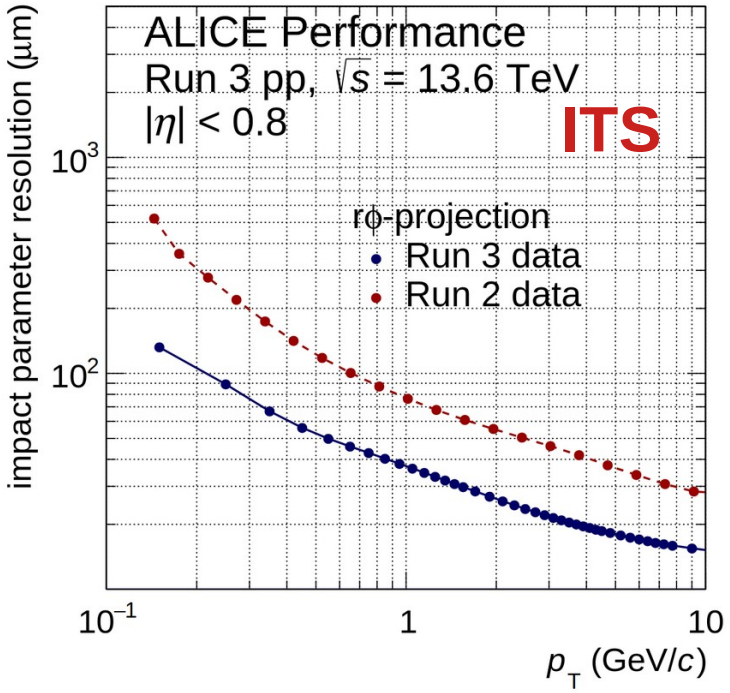
Rare hadron and nuclei interactions

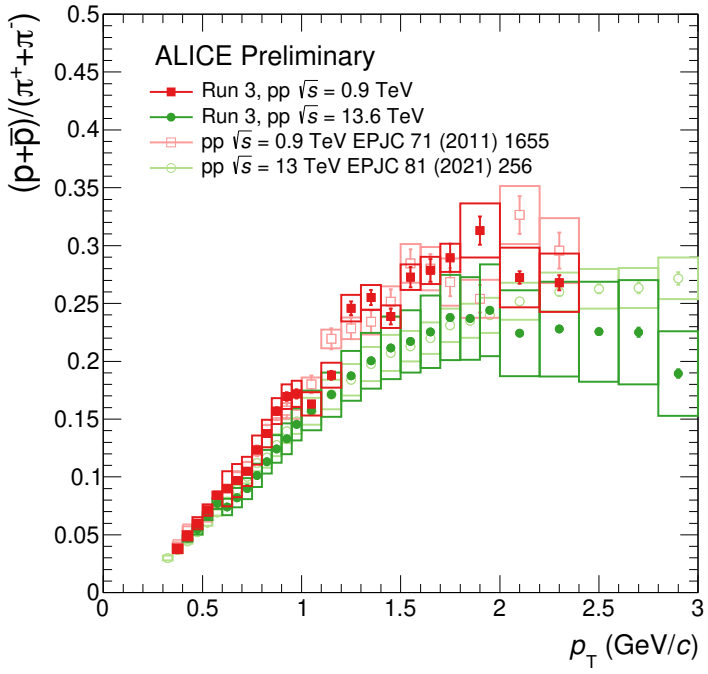
Interior probes of protons and nuclei

Large acceptance and **world leading particle identification** probes all aspects of **QGP behavior**

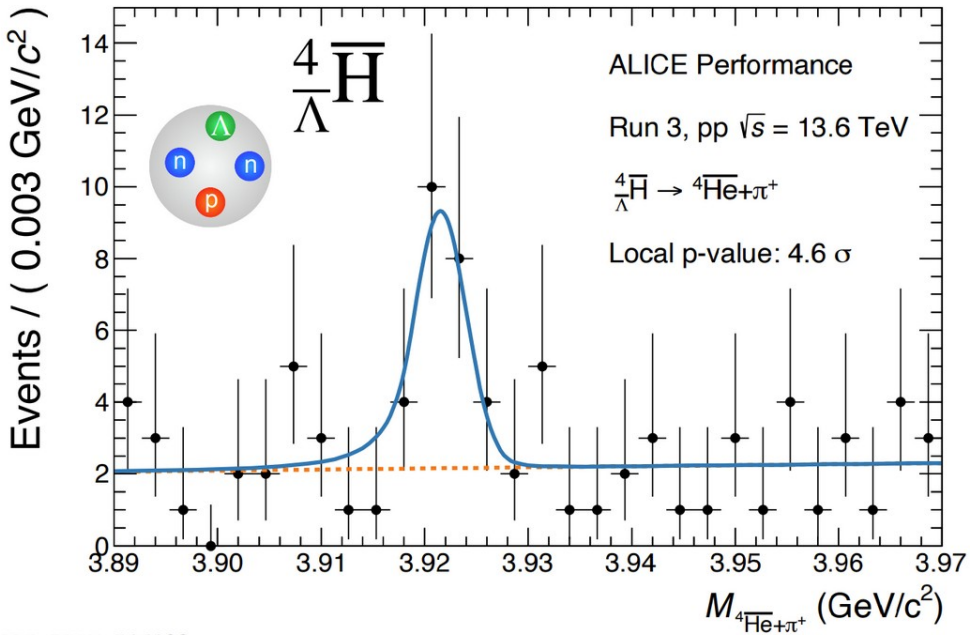
✓Broad physics program utilizing heavy-ion and pp collisions for hot and cold QCD

Status of pp data taking in Run 3





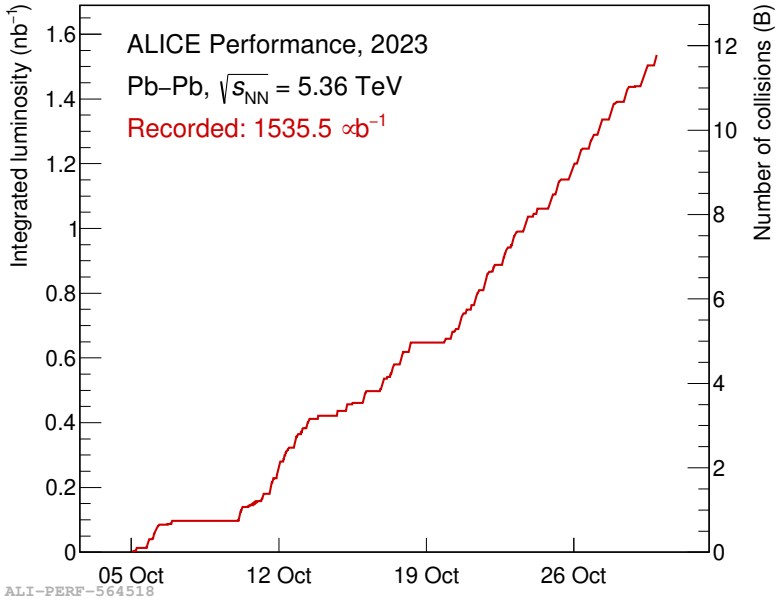
First signal!

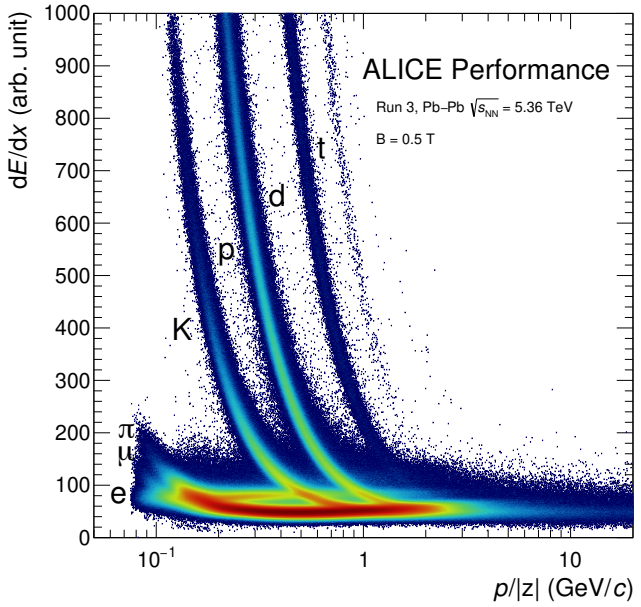


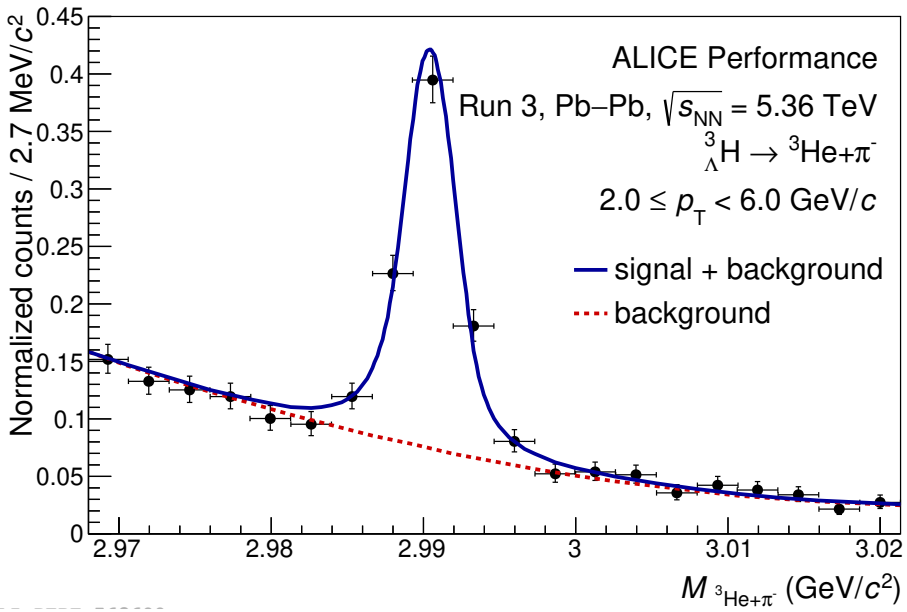
Taken ~30 pb of pp data in 2022-2023 → **500x times more than Runs 1&2**

✓Courtesy of new continuous readout TPC with greatly improved track resolution

Status of Pb-Pb data taking in Run 3





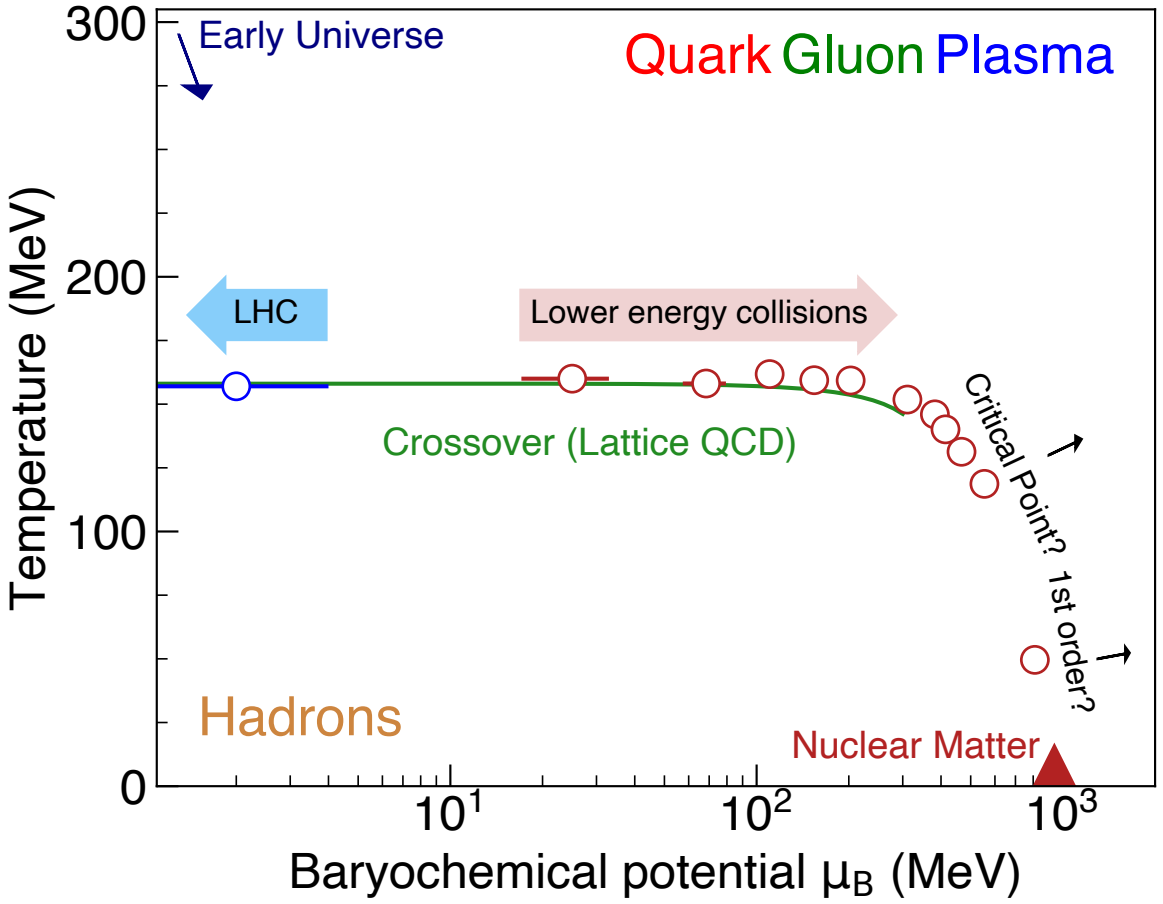


https://home.cern/news/news/experiments/alice-bags-about-twelve-billion-heavy-ion-collisions

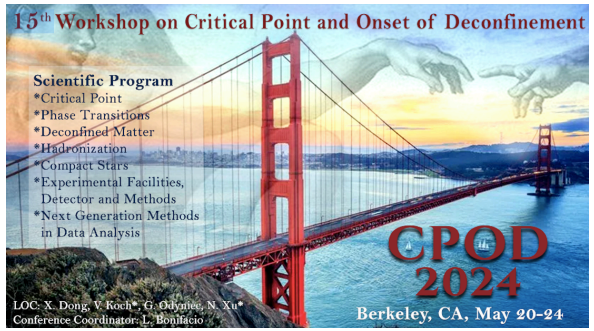
Hugely successful heavy-ion run in 2023 year → recorded 40x times data than Runs 1&2

✓First set of public physics results on Pb-Pb data released this summer!

What have we learned from ALICE at $\mu_B \sim 0$?



- Critical Point
- Phase transitions
- Deconfined Matter
- Hadronization
- Compact Stars
- Future experimental facilities and detectors



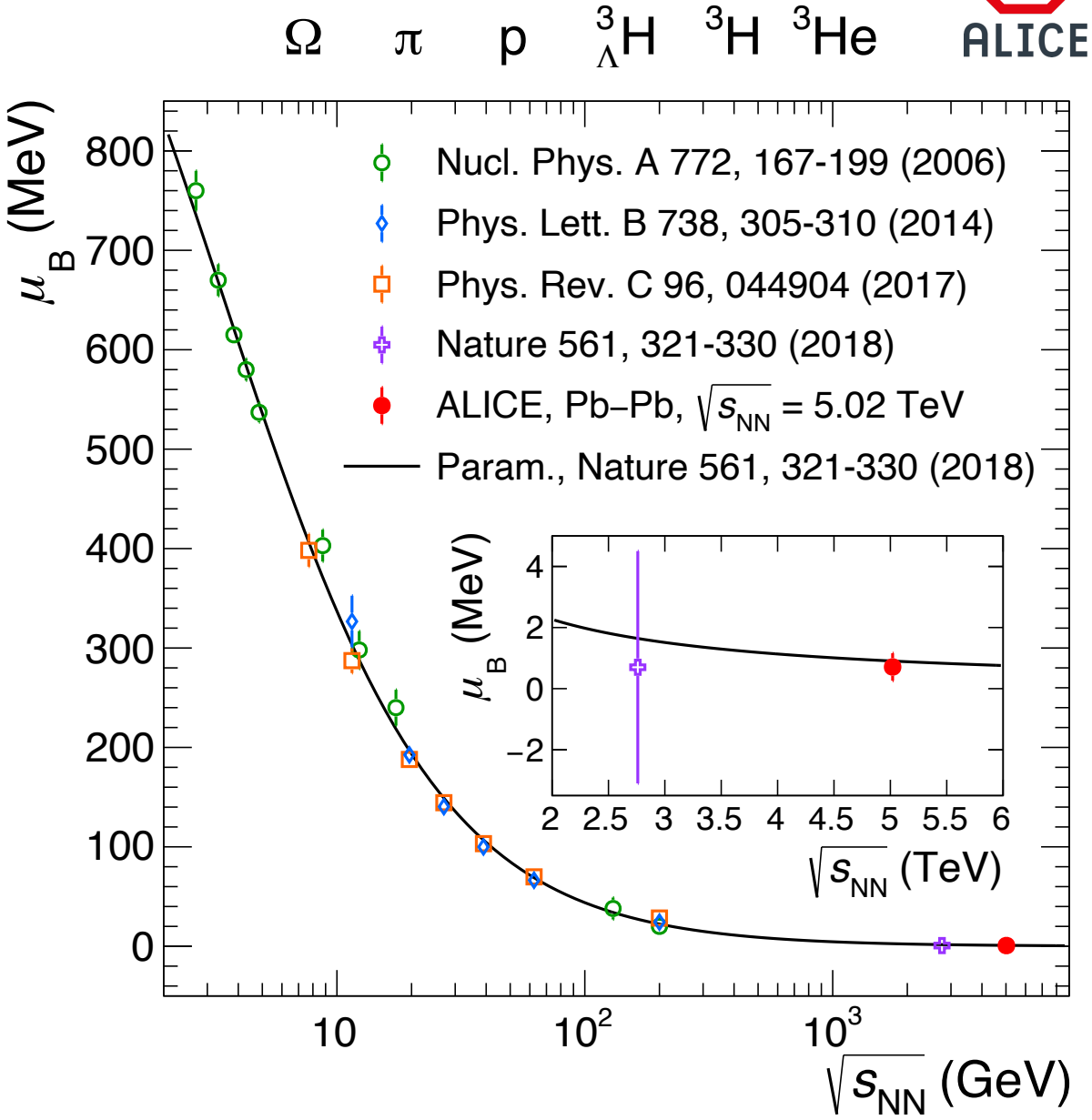
Is μ_B really 0 at the LHC?

Fitting Grand Canonical SHM to ALICE antimatter/matter ratios

✓μ_B =0.71 ± 0.45 MeV

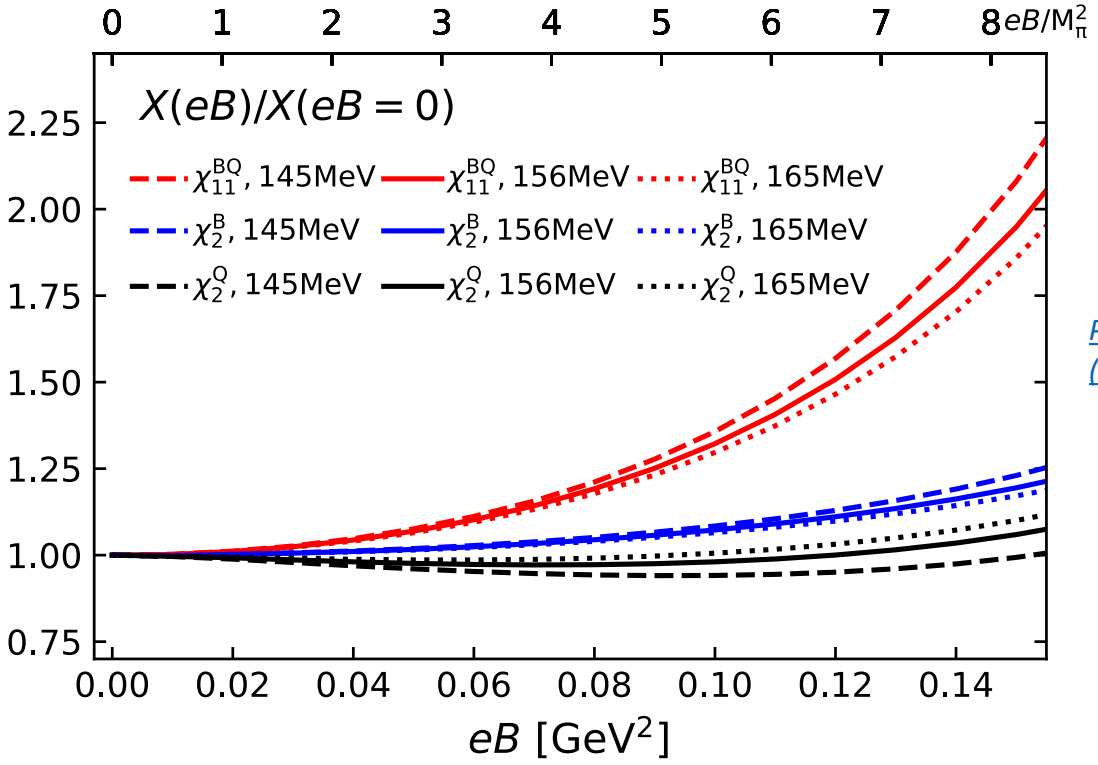
Order of magnitude increase in precision due to cancelation of correlated uncertainties in data

Medium created at top LHC energy really appears baryon-free…

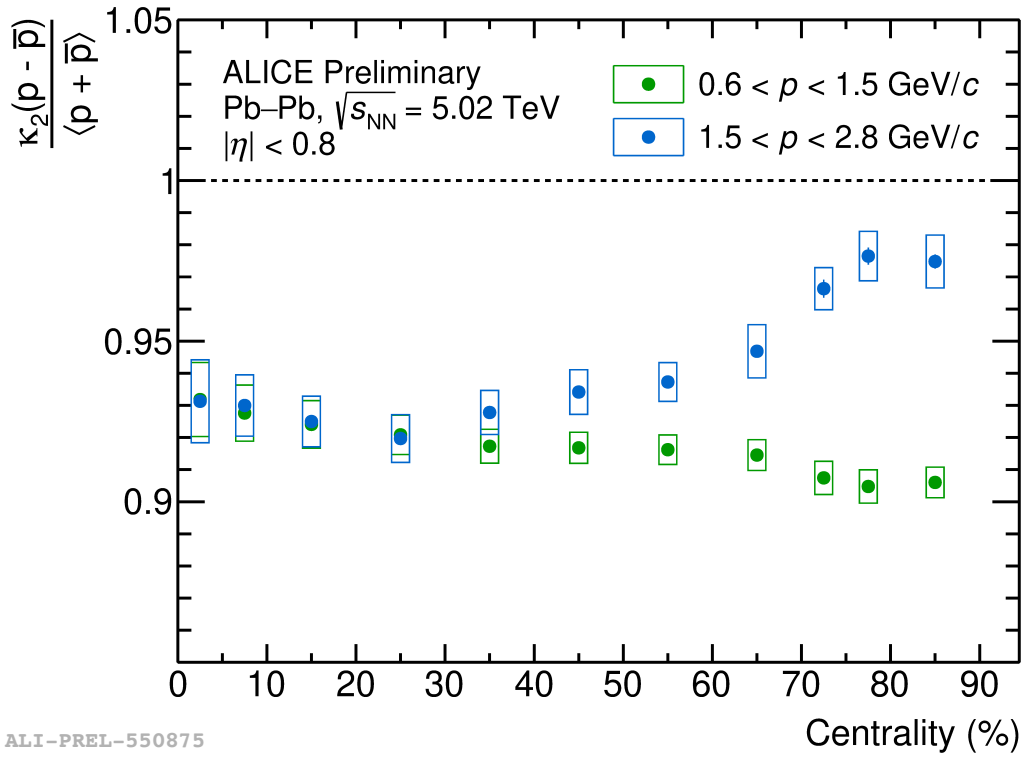


https://cerncourier.com/a/balancing-matter-and-antimatter-in-pb-pb-collisions/

Net-proton fluctuations & magnetic field



Phys. Rev. Lett. 132 (2024) 201903

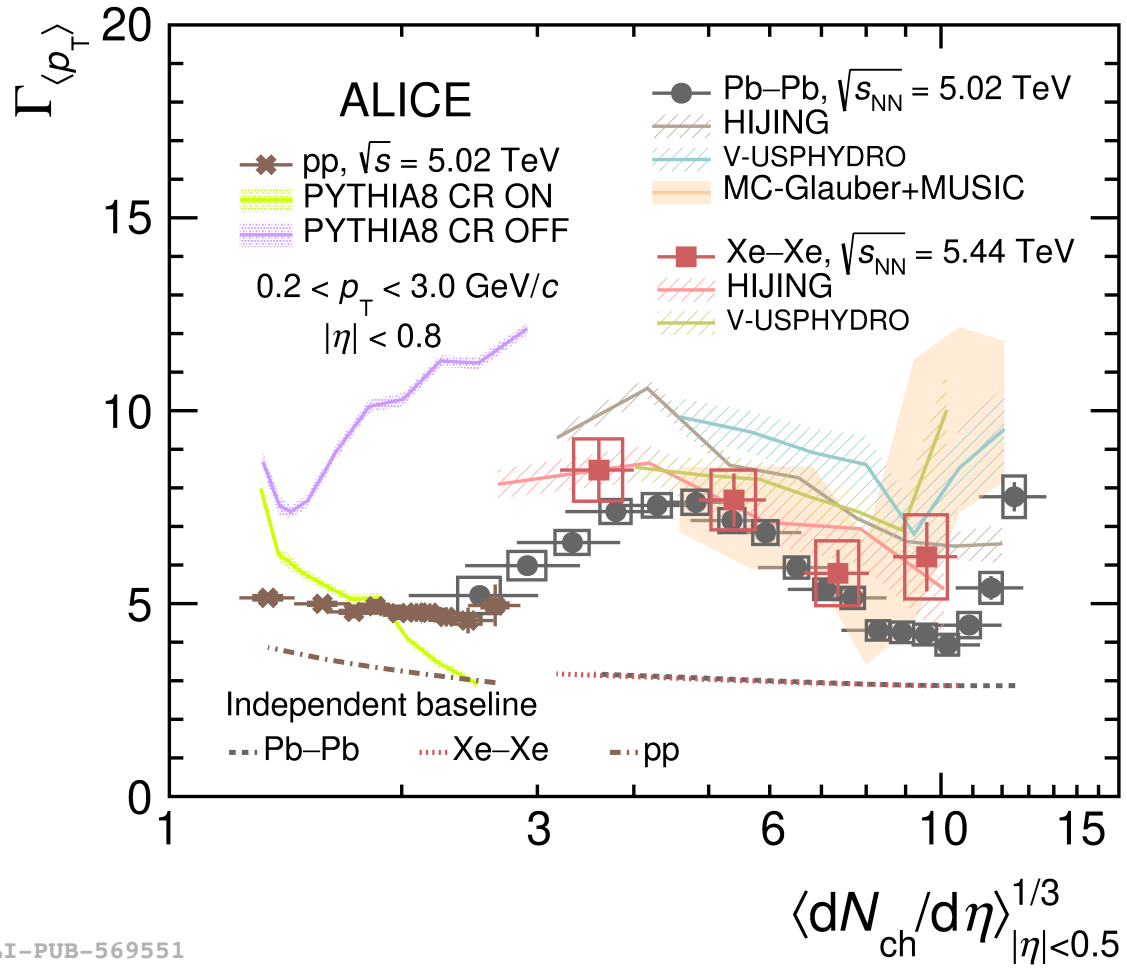


Lattice QCD predicts large magnetic fields increase proton fluctuations close to T_{pc}

✓Splitting for κ_2/κ_1 with momentum in peripheral collisions where B field largest…

→ M. Arslandok, Wed. at 11.00 am

Higher order p_T fluctuations



ALI-PUB-569551

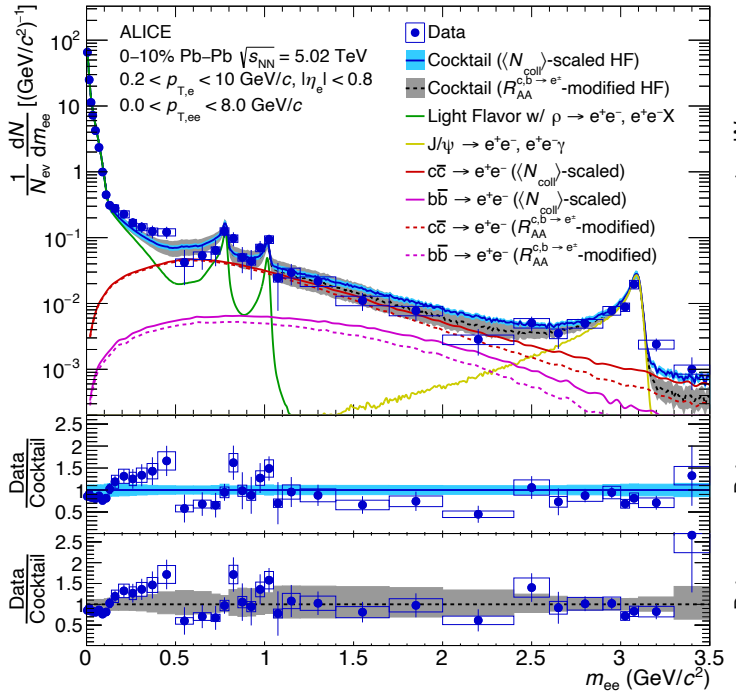
Measured for a variety of systems…

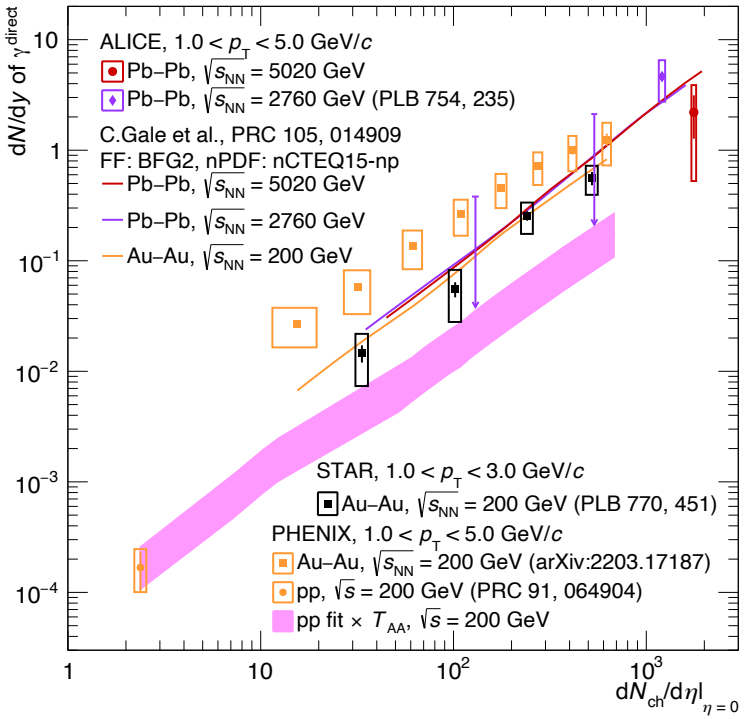
Skewness of mean p_T $h^{\pm}$ fluctuations can only be explained by **models invoking a QGP in central Pb-Pb**

Promising measurement at lower collision energies to establish when a QGP is formed…

Phys. Lett. B 850 (2024) 138541

EM probes and QGP temperature





https://cerncourier.com/a/dielectrons-take-the-temperature-of-pb-pb-collisions/

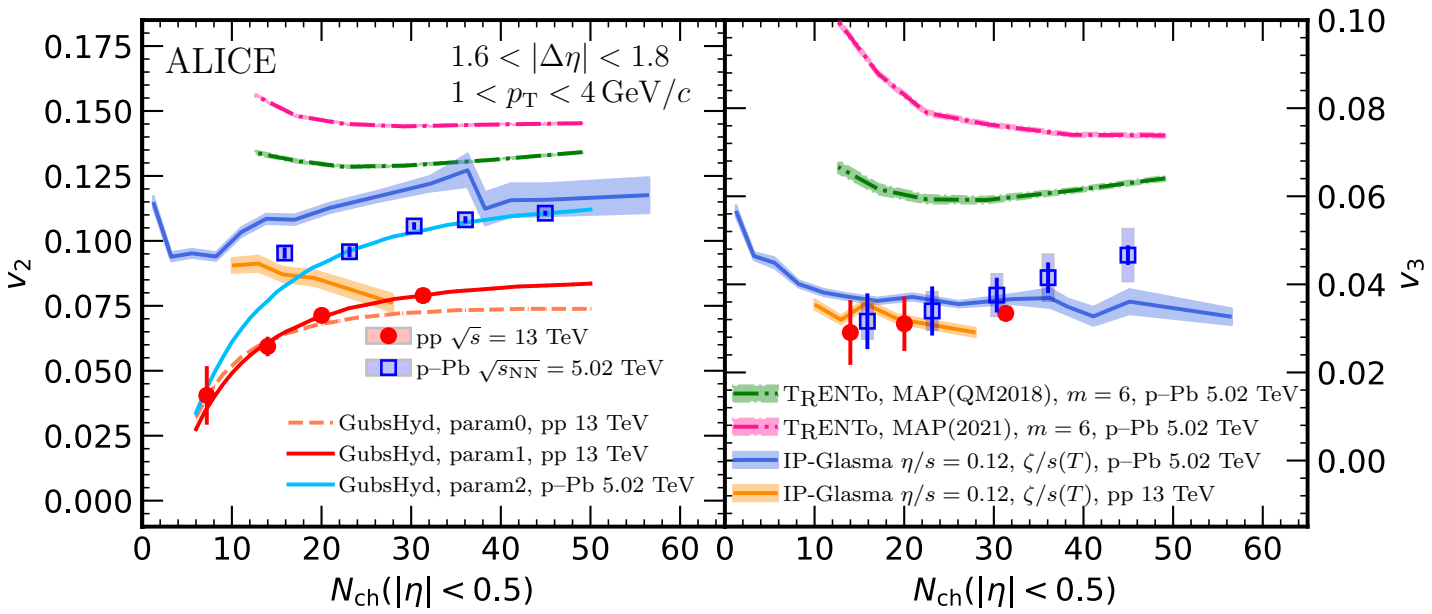
QGP temperatures can be obtained from **slope of intermediate di-electron mass** spectrum

✓Background from heavy flavor decays dominate in Run 2 data..

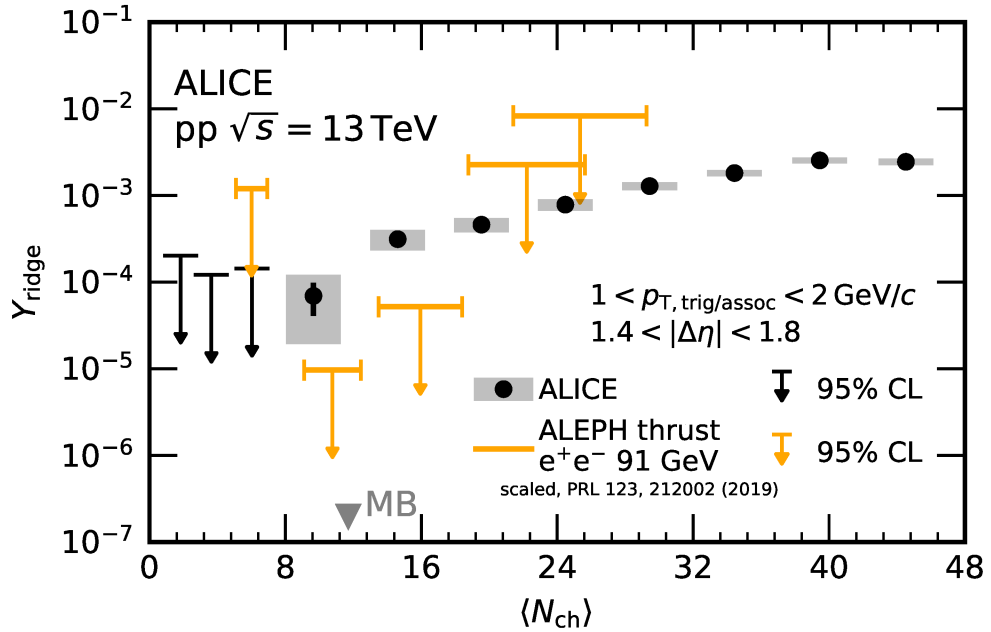
✓**Direct photon yield** consistent with **hydro expectations**

Thresholds of QGP formation

https://cerncourier.com/a/collectivity-in-small-systems-produced-at-the-lhc/



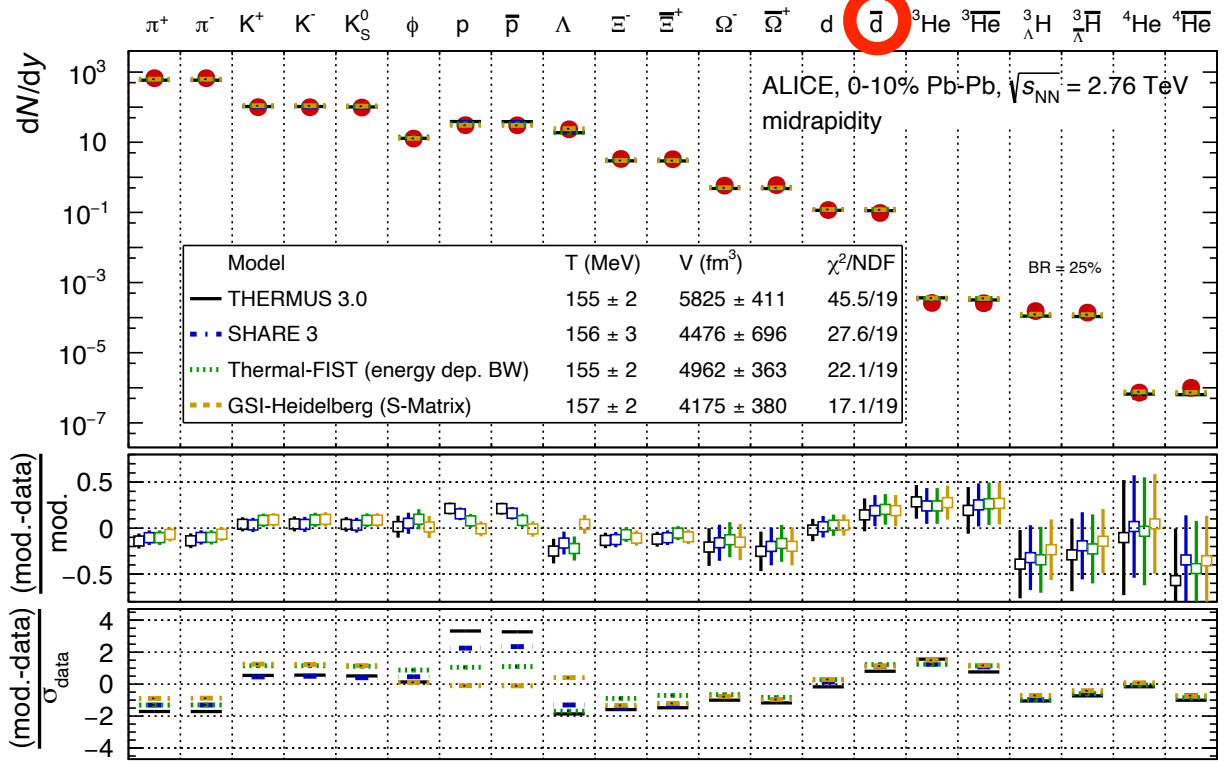
Phys. Rev. Lett. 132 (2024) 172302

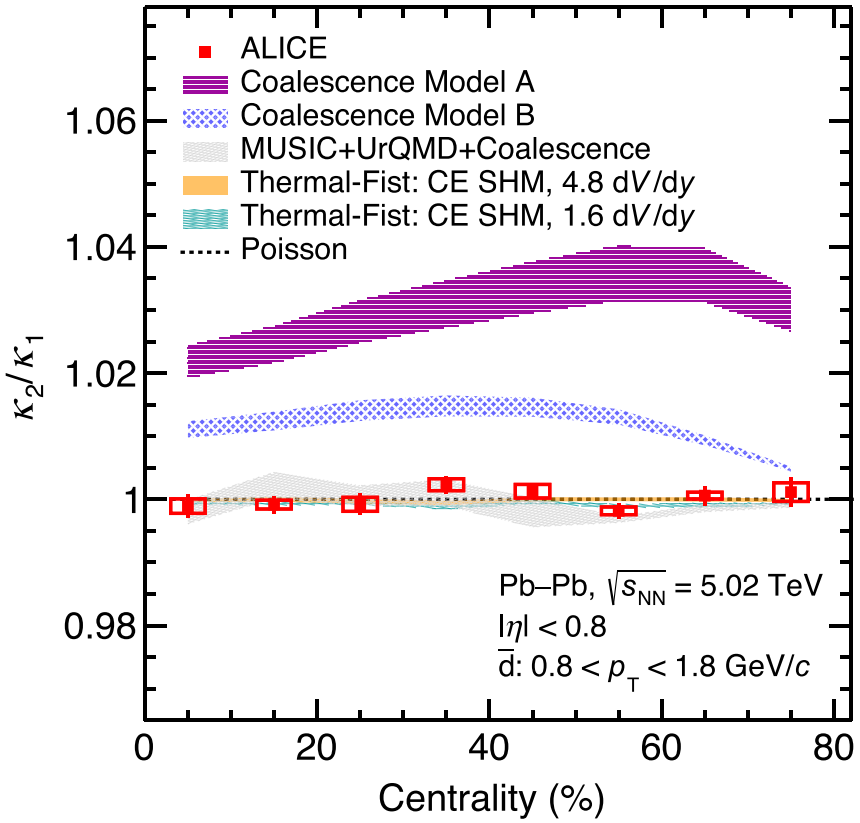


Discovery of **QGP-like effects in high multiplicity pp and p-Pb collisions** major finding at LHC

✓**Flow** persists towards **lower multiplicities in pp collisions**

Formation of anti-deuteron in Pb-Pb collisions

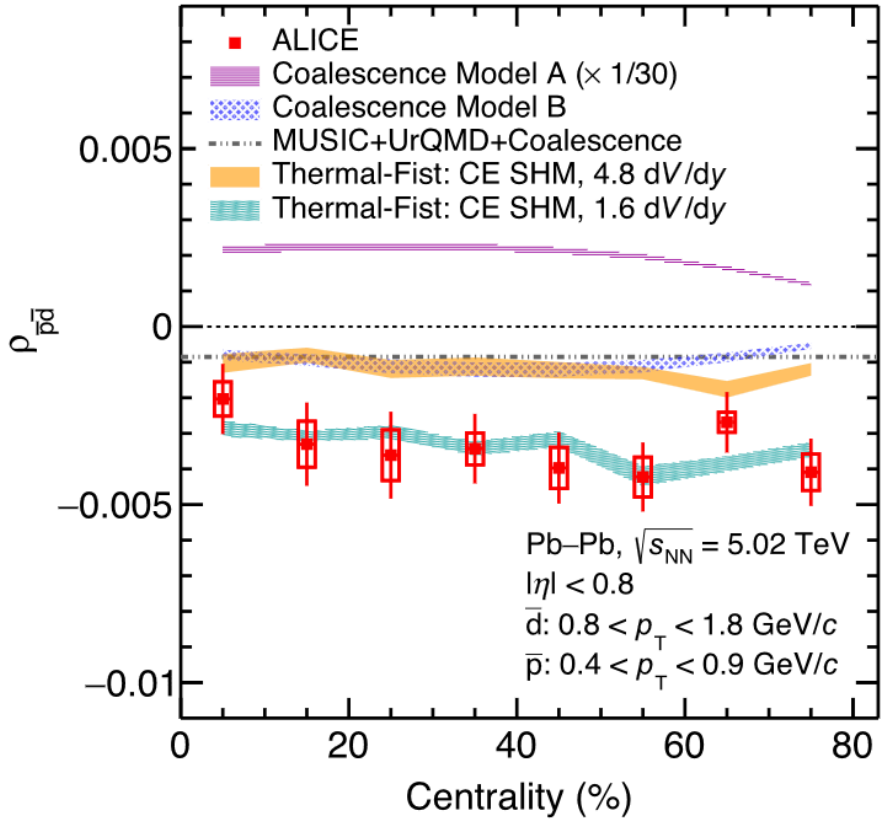


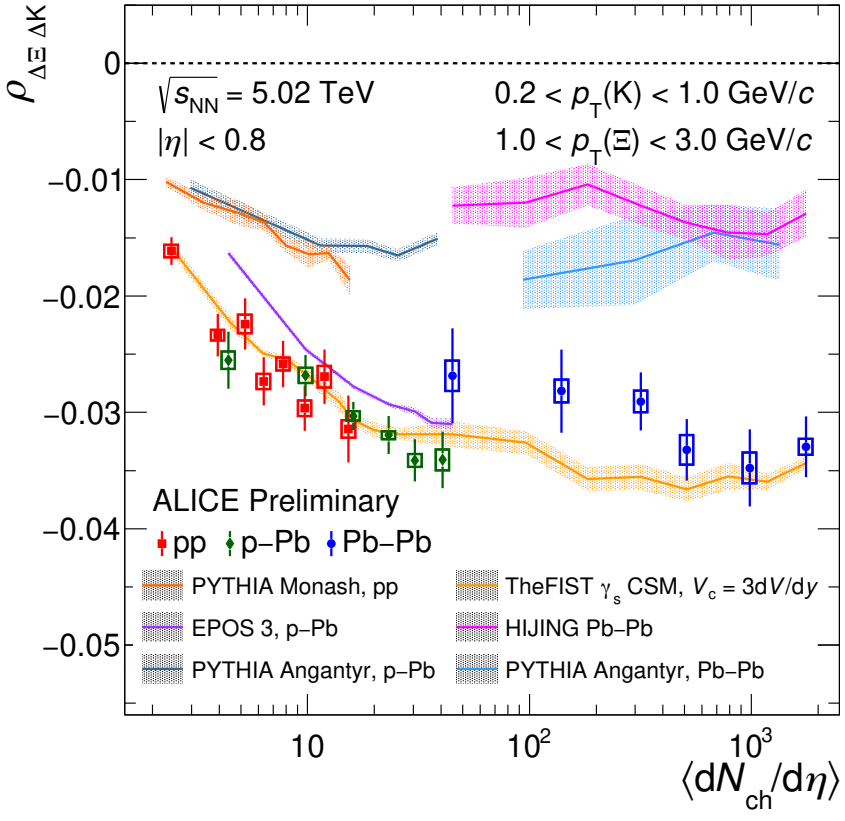


Snowball in hell appears to be thermally produced…

Phys. Rev. Lett. 131 (2023) 041901

Pinning down the correlation volume V_c





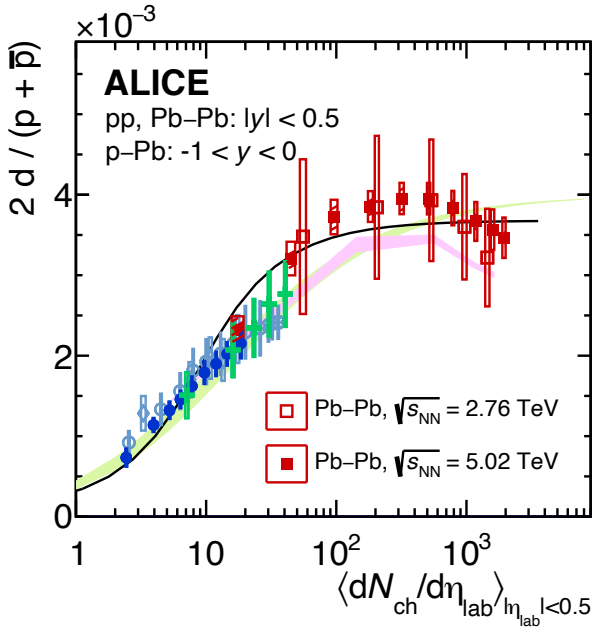
Event-by-event correlations of **anti-proton and anti-deuterons** indicate **1.6·dV/dy**

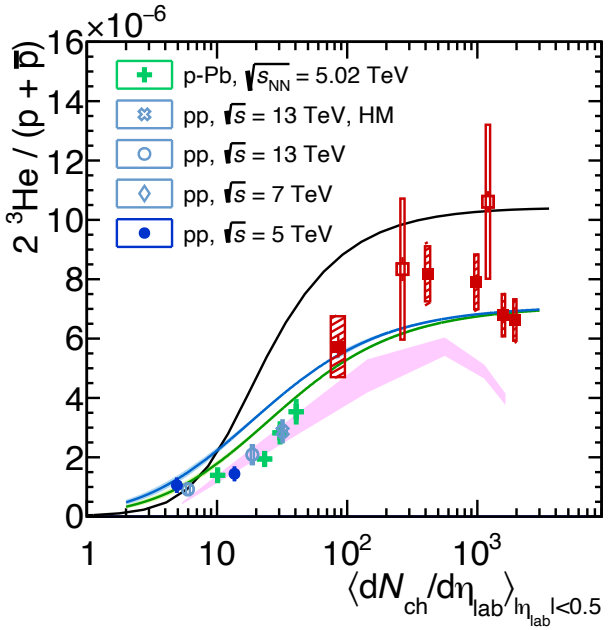
✓The same measurement in the **strange sector** requires **3·dV/dy**

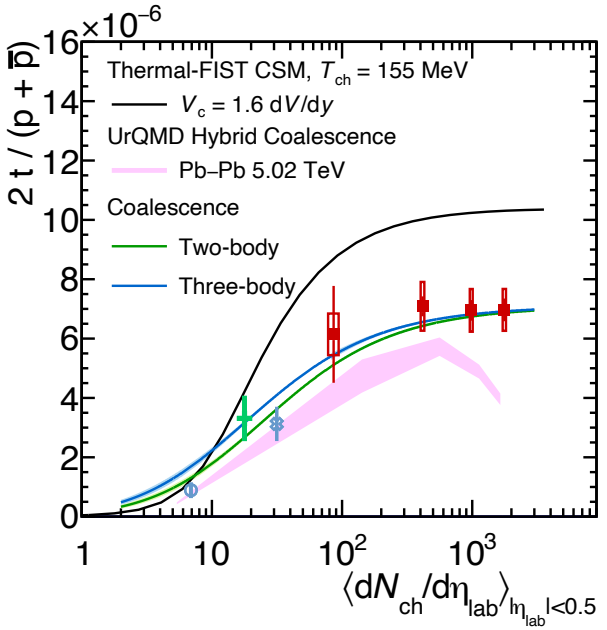
Limits of statistical production of light nuclei

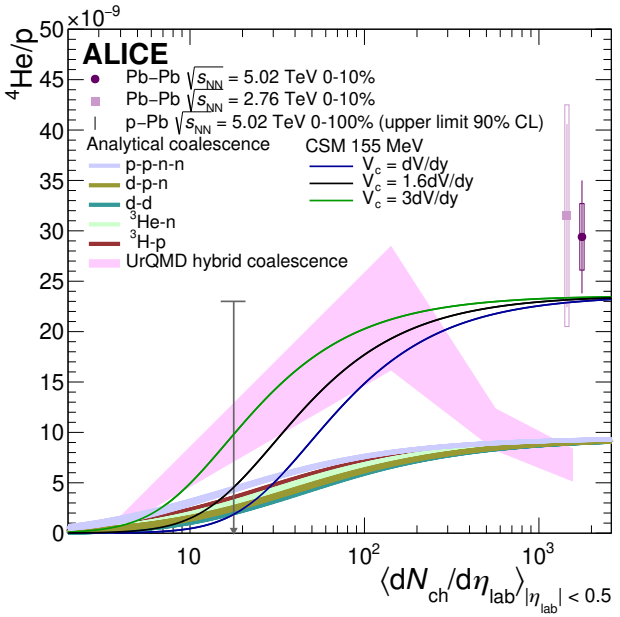
Phys. Rev. C 107 (2023) 064904

arXiv:2311.11758





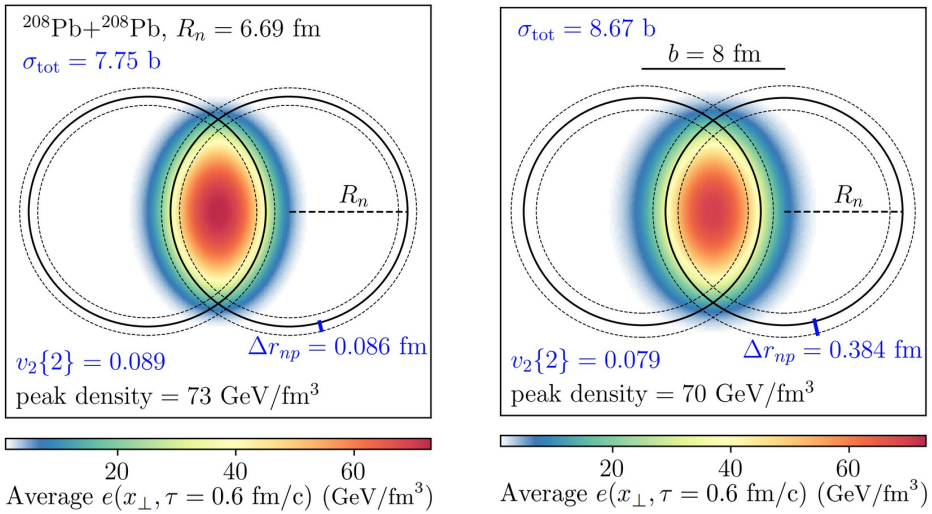




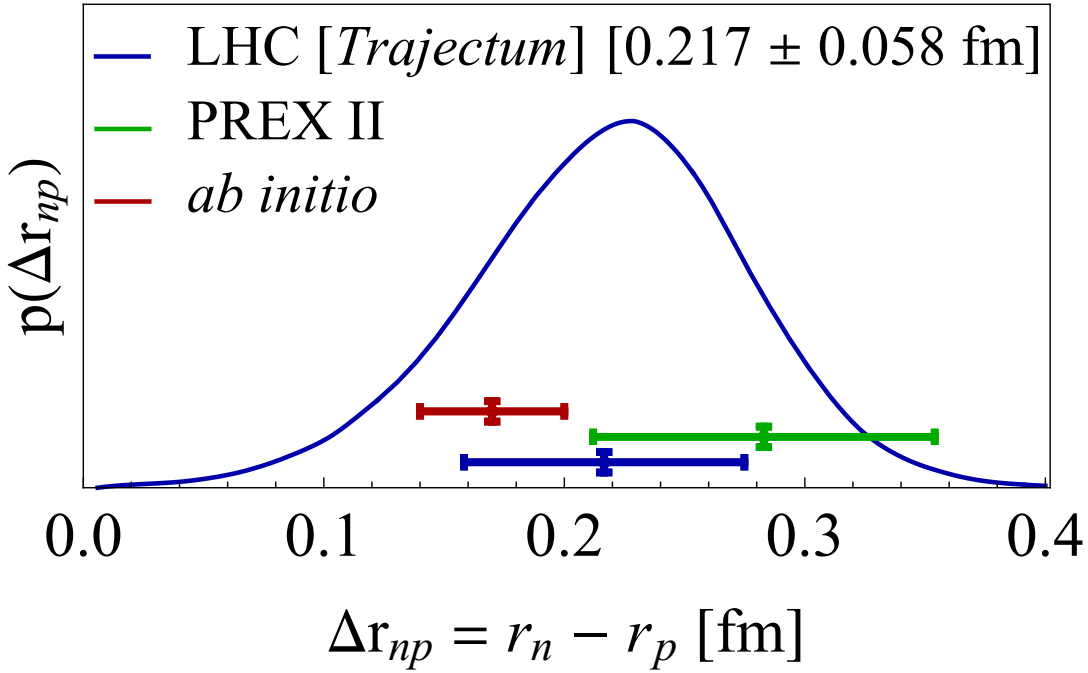
Improved accuracy of **A=3 data favor coalescence predictions**

✓**A=4** on other hand described by **thermal models** → not affected by V_c in central collisions

Compact stars and the ^{208}Pb neutron skin



https://home.cern/news/news/physics/thick-skinned-using-heavy-ion-collisions-lhc-scientists-determine-thickness

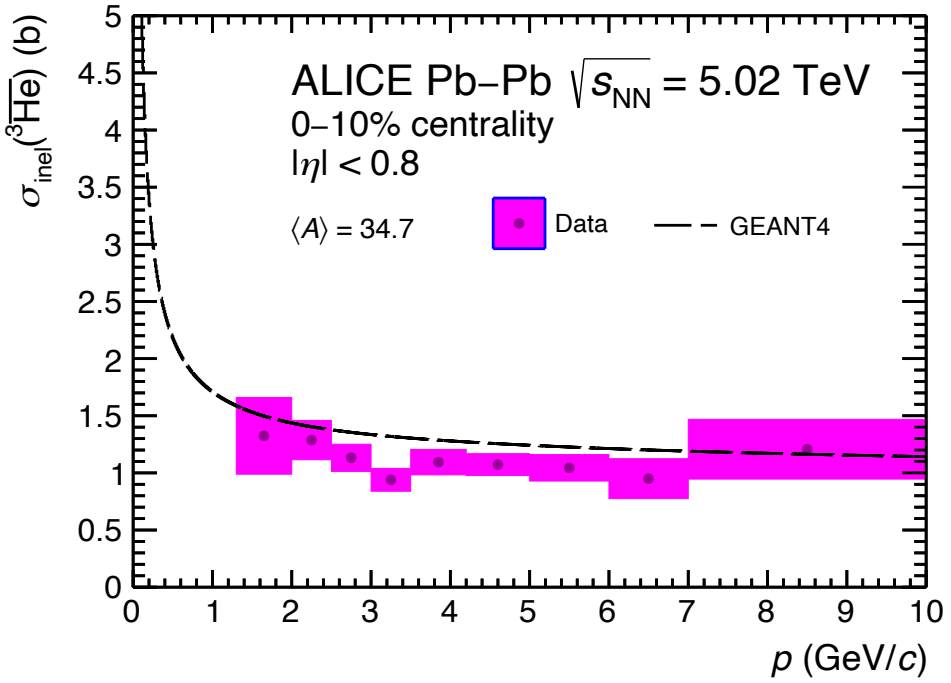


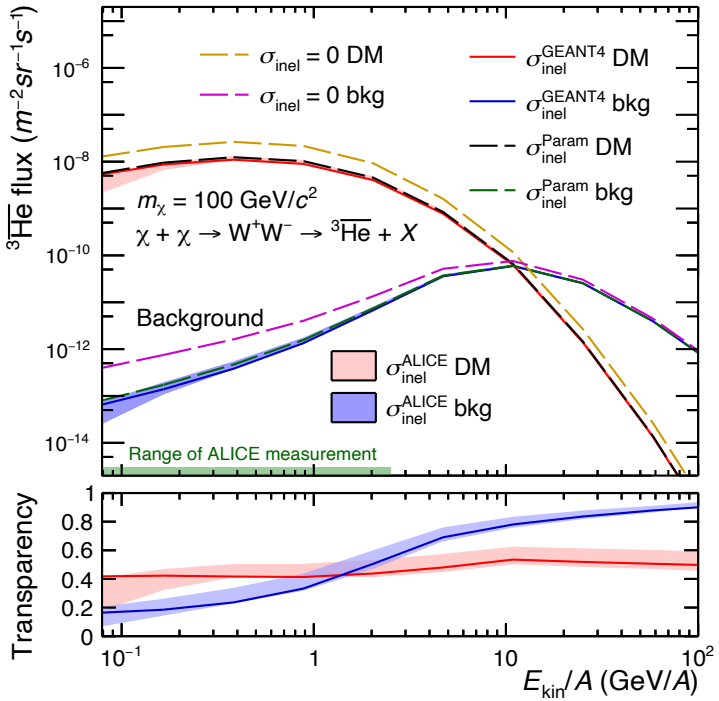
Large neutron skin Δr_{np} leads to more diffuse and spherical QGP → reduces QGP flow

✓Bayesian analysis of v_2 and $\langle p_{\rm T} \rangle$ ALICE flow data offers **competitive constraints on Δr_{np}(Pb)**

✓**Relevant for neutron star equation of state…**

Transparency of the milky way with ALICE





Nature Physics 19 (2023) 61–71

https://home.cern/news/news/physics/alice-estimates-how-transparent-milky-way-antimatter

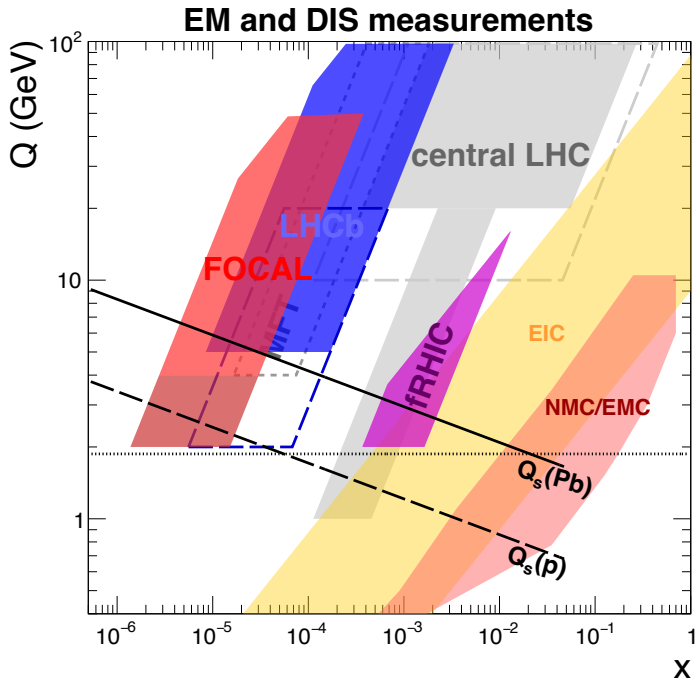
Novel approach uses ALICE detector as target to **measure anti-He³ cross section**

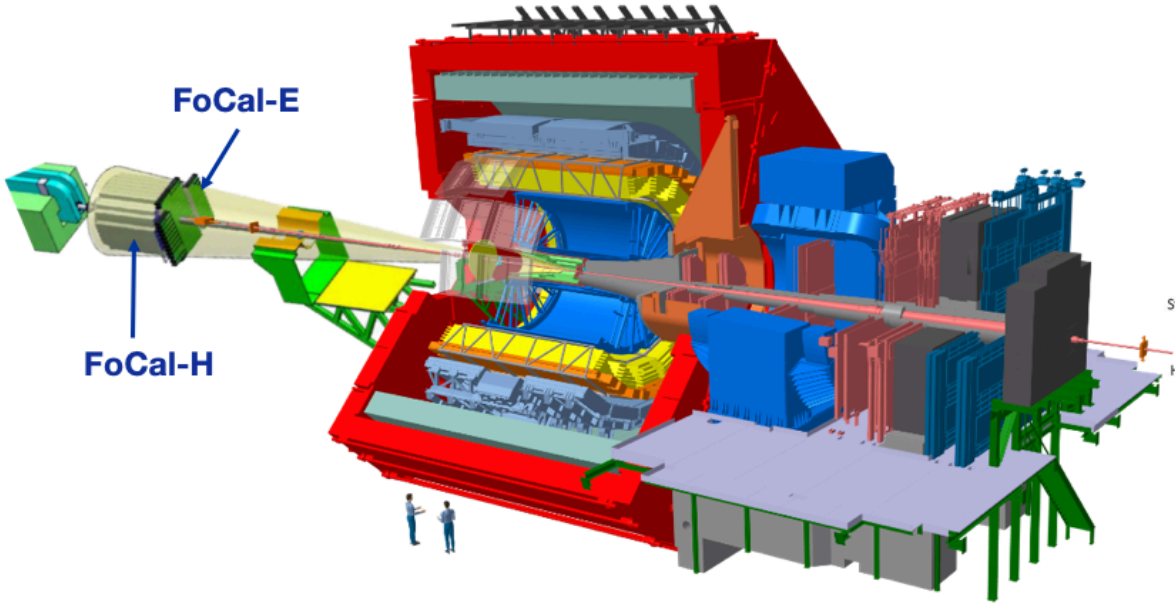
✓Sensitive to **dark-matter (DM) interactions** → specific DM profile implies **transparency ~50%**

ALICE in Run 4

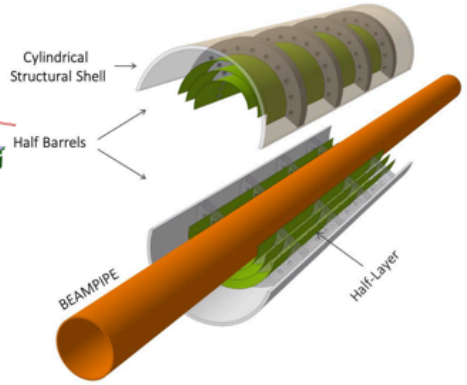
FoCal Letter of Intent (2020)
FoCal Physics (2023)
FoCal Physics Performance (2023)
TDR approved

https://home.cern/news/news/experiments/alice-gets-green-light-new-subdetectors





ITS3 Letter of Intent (2019)
TDR approved



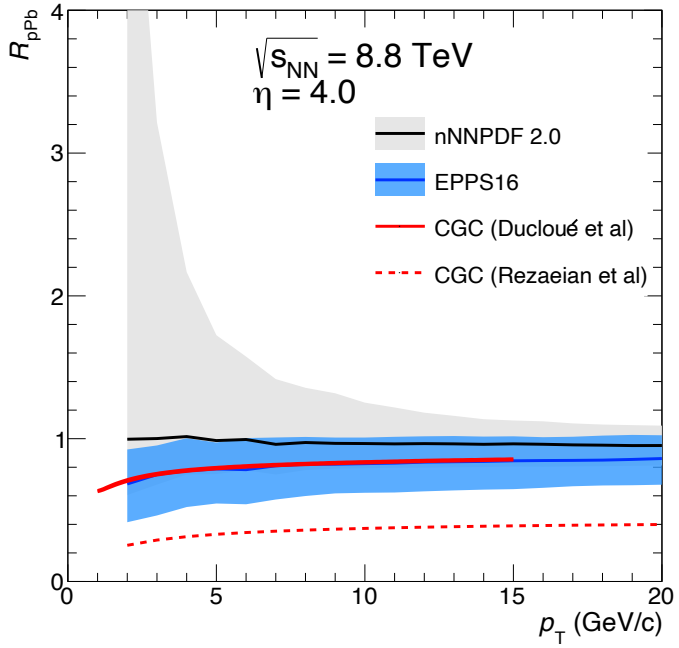
Forward Calorimeter (FoCal) and wafer-thin cylindrical **ITS3** to be installed

✓**ITS3** increases precision for heavy-flavor and electromagnetic probes in large & small systems

✓**FoCal** offers deepest explorations of **proton/nuclear structure** & complimentary to **future EIC studies**

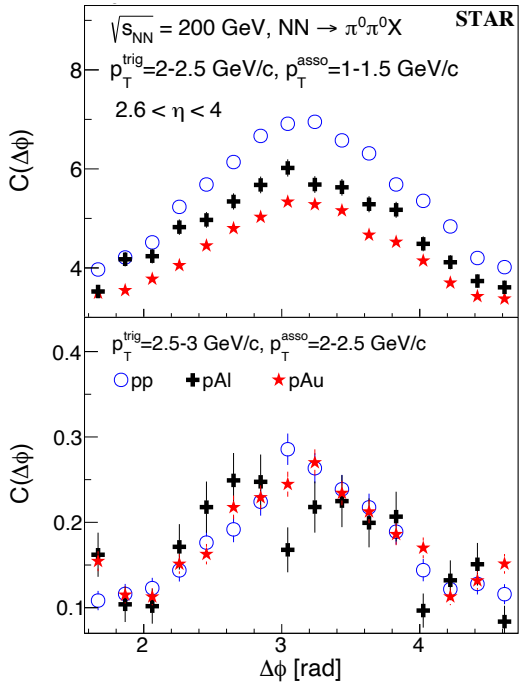
Gluon saturated state precedes QGP formation at the LHC?

ALICE FoCal has the answer!



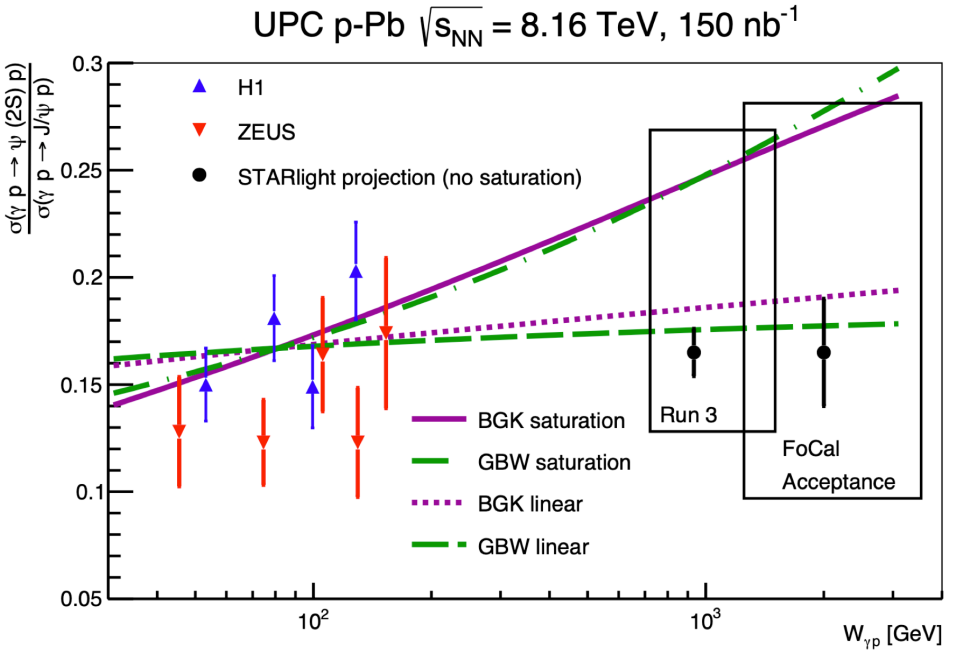
Direct photon R_{pPb}

Compton scattering provides clean probe of gluon nPDFs



$\pi^0(\gamma)$-π^0 correlations

Bjorken-x reach 2 orders magnitude smaller than RHIC



UPC vector meson production

Quarkonia ratios highly sensitive to proton saturation

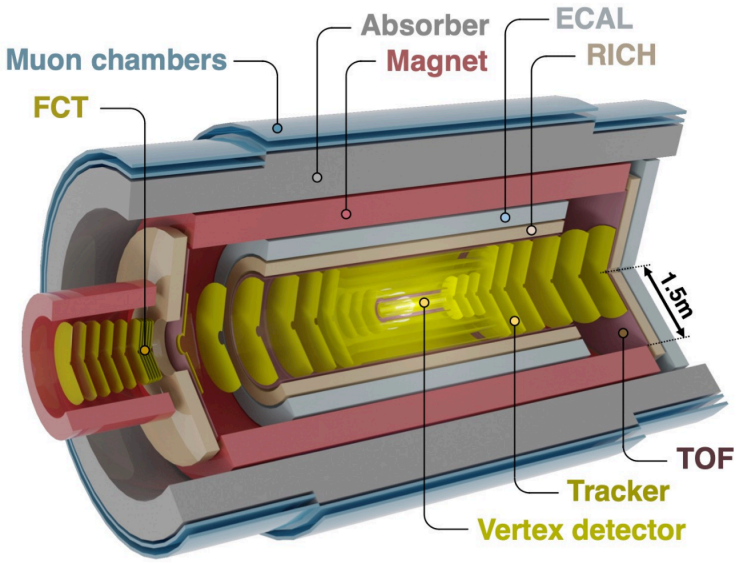
ALICE 3 - a next generation heavy-ion detector

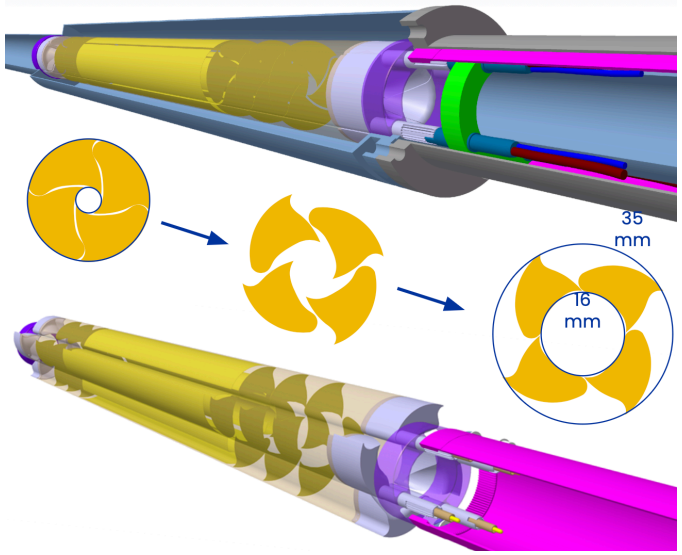
Compact all-silicon tracker with high-resolution vertex detector and **extremely low material budget** for **Run 5**

✓ $|\eta| < 4$ and p_T resolution 1-2% for **0.1 < p_T < 100 GeV/c**

Particle Identification over large acceptance: muons, electrons, hadrons, photons

Operates in continuous readout so **designed to measure everything!**





ALICE 3 physics program

arXiv:2211.04384

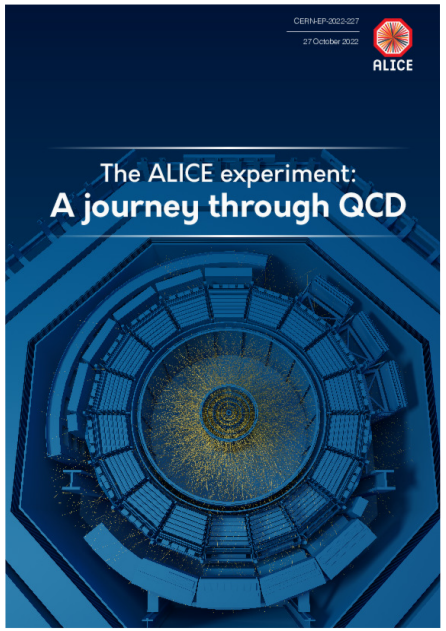
Key **QGP findings** from top RHIC energies and the LHC

✓Evolves as almost perfect fluid that quenches jets

✓Produces light hadrons in apparent thermal equilibrium

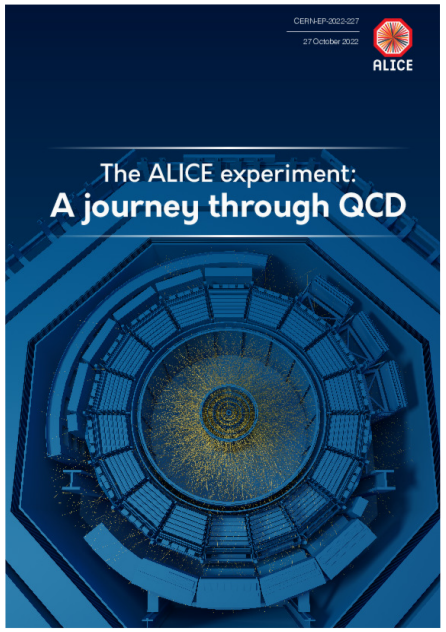
✓Readily couples with heavy quarks

✓Indications formed in small systems



ALICE 3 physics program

arXiv:2211.04384



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What is **ALICE 3** designed to discover and explore?

✓QGP temperature evolution and when equilibrium achieved

✓Limits and precision on heavy quark QGP diffusion

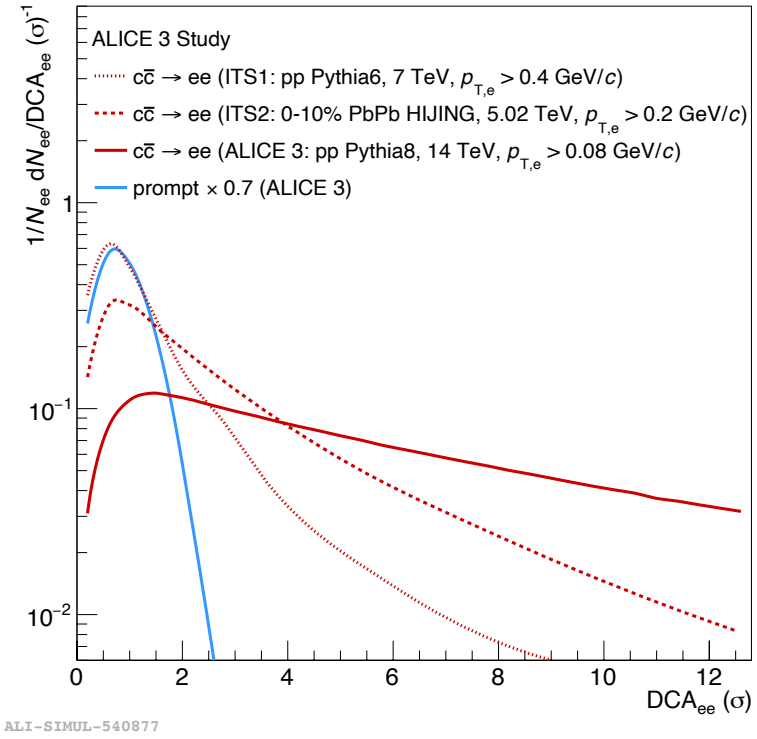
✓Nature of QCD phase transition at $\mu_b \sim 0$

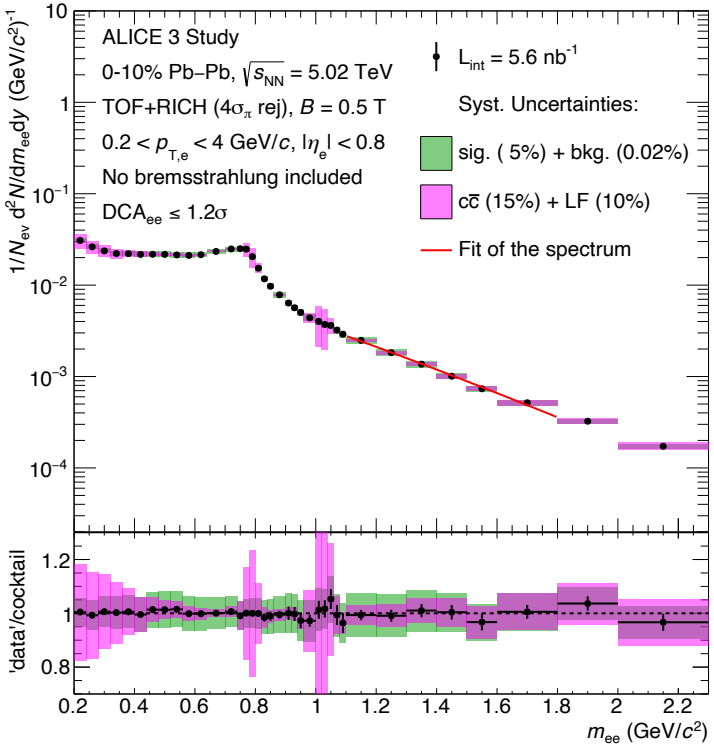
✓Exotic hadron production mechanisms and hadronic interactions

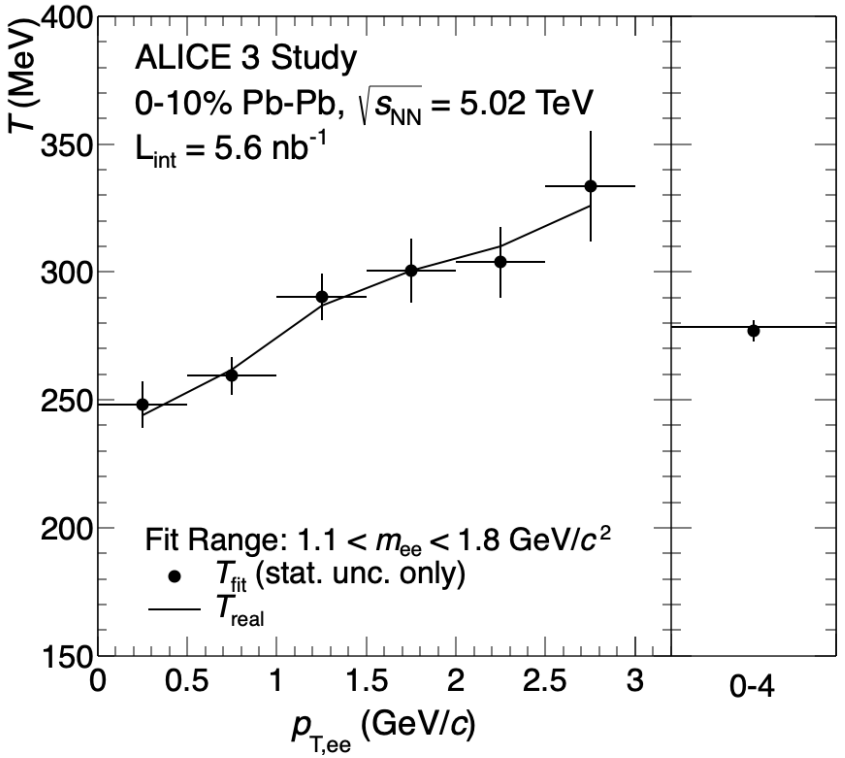
✓Beyond Standard Model searches…

arXiv:2211.02491

Thermal radiation from di-electrons in ALICE 3







Very clean **separation of prompt and heavy-flavor** electrons

✓ Extracting QGP temperature directly with di-electrons becomes accessible with high accuracy

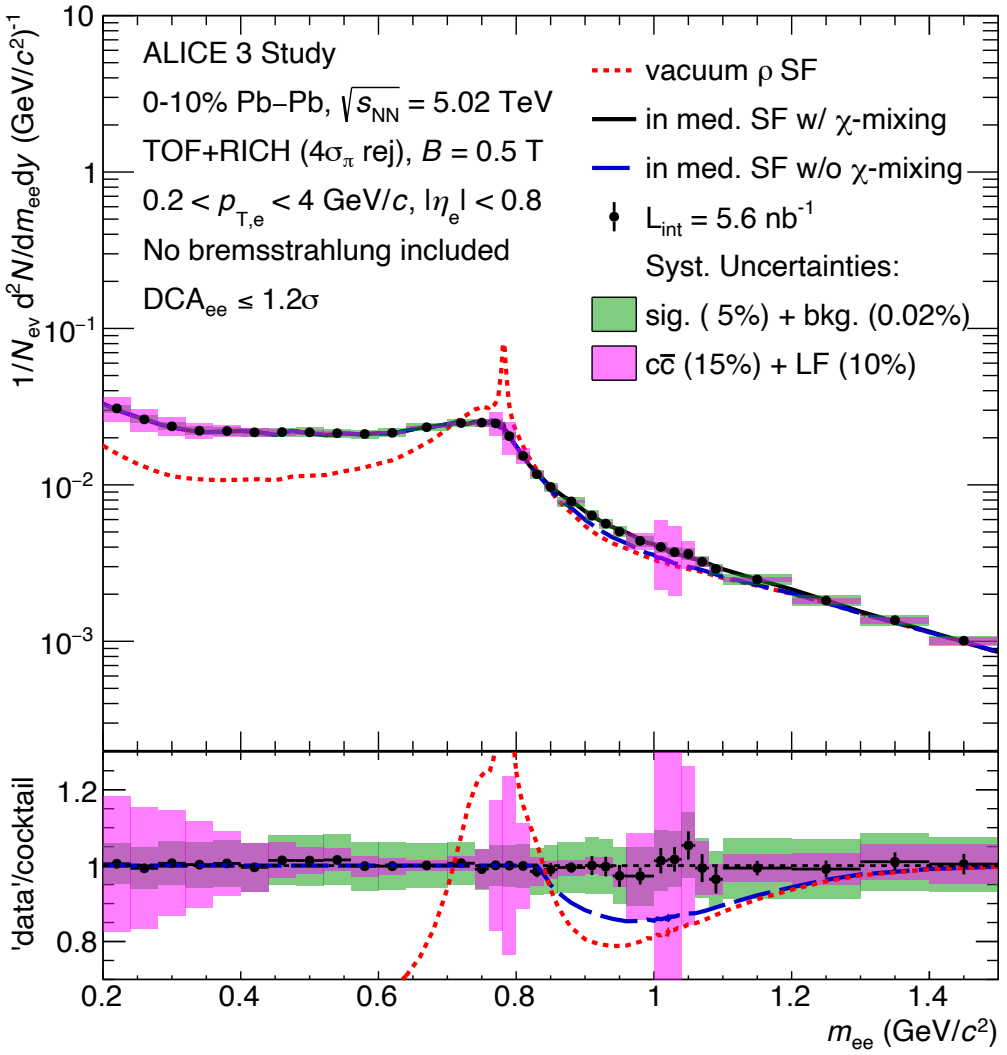
✓ Increasing di-electron p_{T} probes earlier times → **Evolution of QGP temperature**

Searches for Chiral Symmetry Restoration

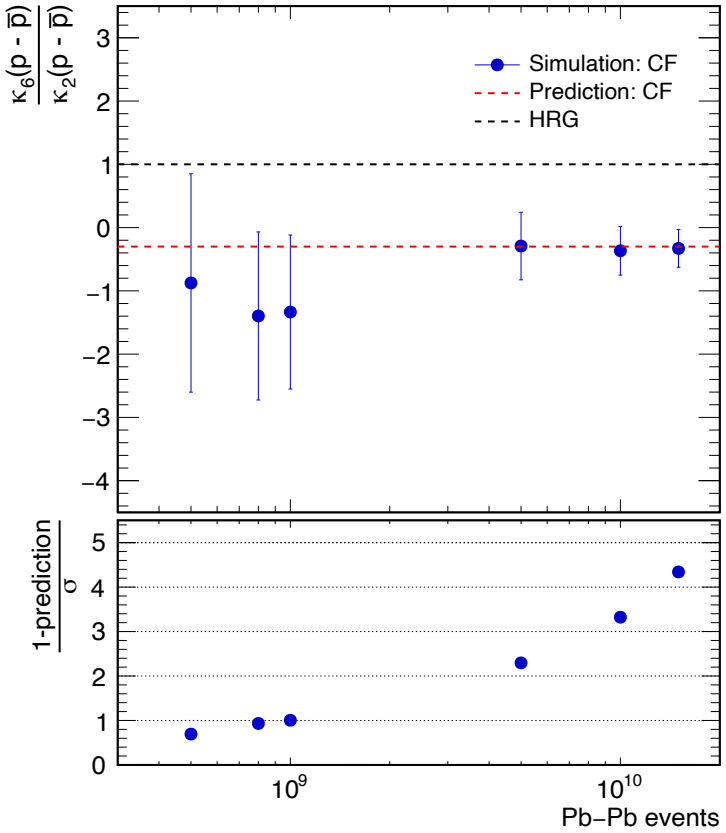
Fundamental feature of high-temperature **Lattice QCD**

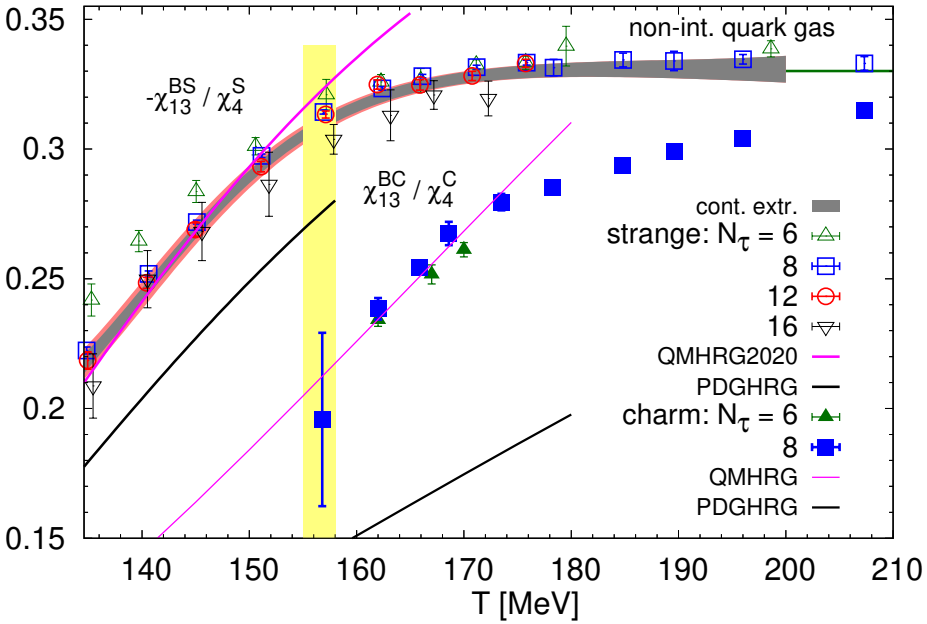
Direct sensitivity to QCD crossover transition signatures still lacking

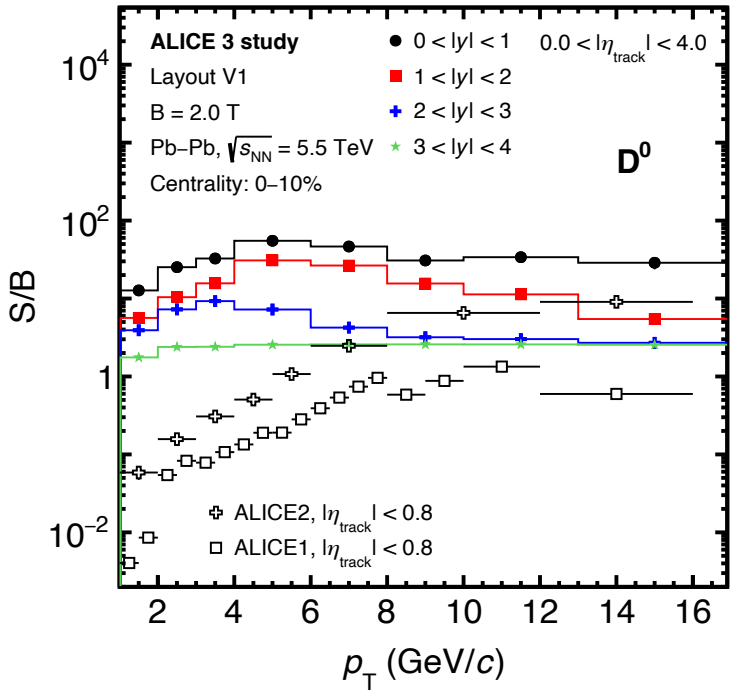
Enhancement at m_{ee} ~ 1 GeV/c² compared to vacuum production indicative of **Chiral Symmetry Restoration** via $\rho - a_1$ mixing



New tests of Lattice QCD during QGP transition







Measured **fluctuations of net-quantum numbers** explore **chiral features of cross-over transition**

✓ Increased precision of high order net baryon fluctuations and strangeness/charm being explored

Summary of ALICE endeavors at $\mu_B \sim 0$

Achievements

✓ Multiple measurements with ALICE show unique QGP behavior → can be performed at lower energies to probe the onset of deconfinement.

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Challenges

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Summary of ALICE endeavors at $\mu_B \sim 0$

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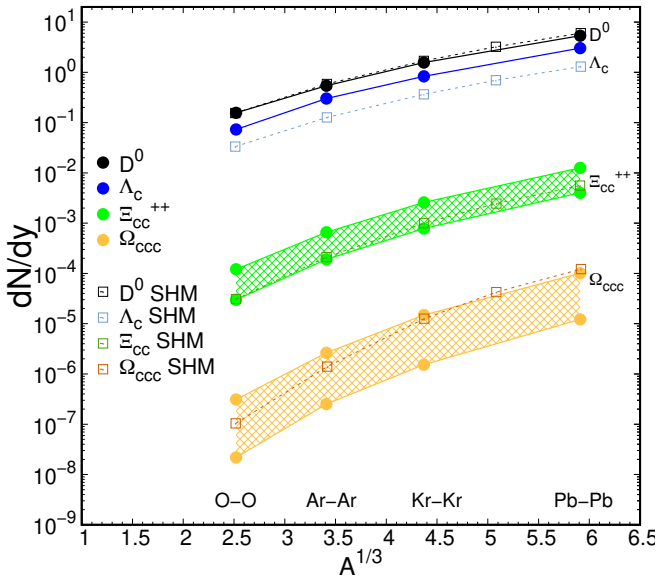

Opportunities

✓ ALICE 3 ideal detector to test the realization of QGP phase transition

✓ Unprecedented acceptance in momenta and particle identification will test much more e.g. thermalization of heavy quarks