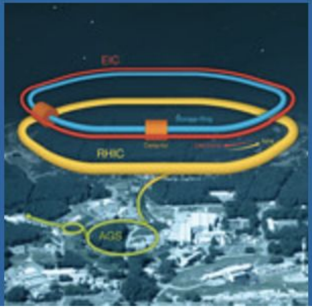


The 2025 CFNS-SURGE Summer Workshop on the Physics of the Electron-Ion Collider

Strange and Multi-strange Hadron Production in Heavy Ion Collisions

Iris Ponce
Yale University

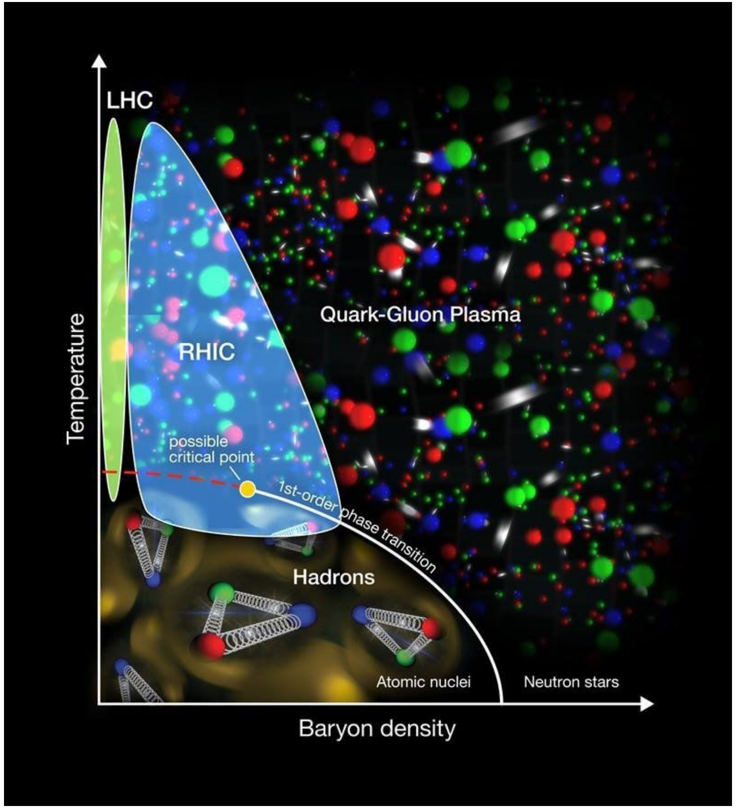
2025 CFNS-Surge Summer Workshop
June 2 - 13

Supported in part by:
U.S. DEPARTMENT OF ENERGY | Office of Science

Wright Lab

QCD and the QGP

- At high temperatures QCD matter becomes a new state of matter called the Quark-Gluon plasma (the QGP).
- It's existence was predicted in 1975 and experimentally discovered in the early 2000s.
- The QGP is predicted to have existed in the early universe
  - First μs after the Big Bang

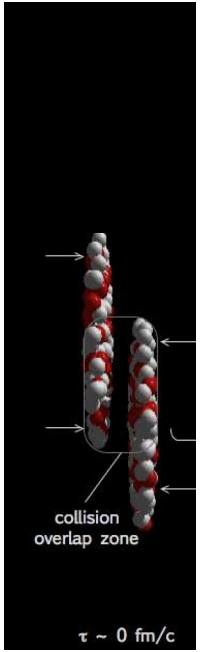


https://www.bnl.gov/newsroom/news.php?a=121072

Heavy Ion Collisions (HIC) and the QGP

The HIC recipe:

1) The nuclei are accelerated to speeds ~c.
2) The ions become Lorentz contracted into discs and collide.



https://indico.ihep.ac.cn/event/8853/contributions/104764/attachments/56128/64581/JhChen-HT-SCNU.pdf

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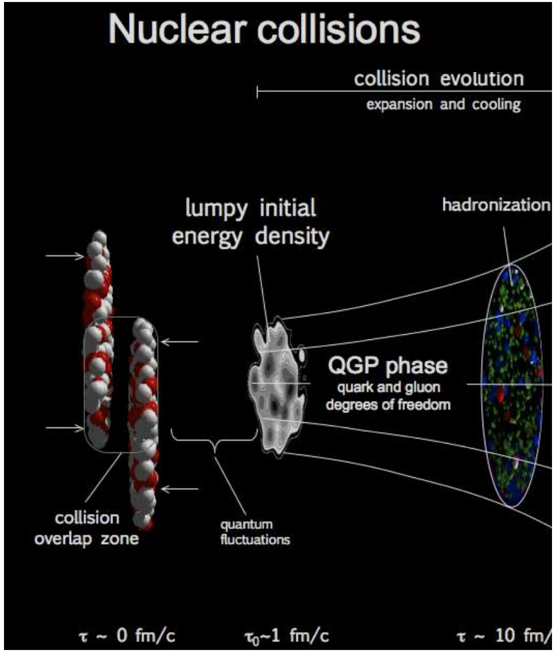
3) The QGP forms.
4) The QGP rapidly cools and expands.
5) The deconfined partons hadronize and become a system of interacting hadrons.
6) At the chemical freeze out temperature the hadron abundances become fixed.



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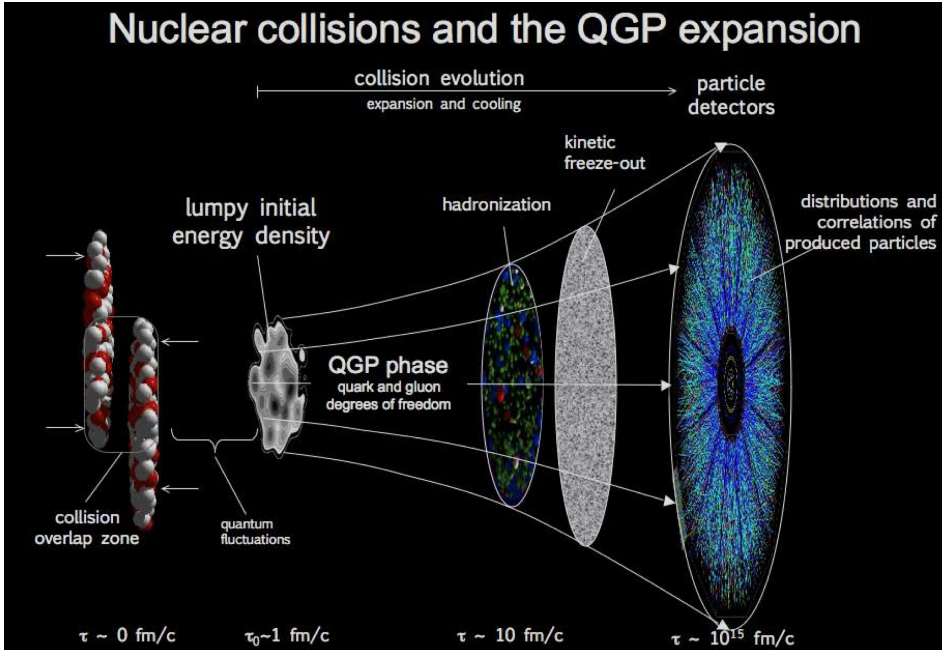
6) At the chemical freeze out temperature the hadron abundances become fixed.
7) At the kinetic freeze out temperature the particles’ momentum is fixed.
8) Particles are detected in the experiment.



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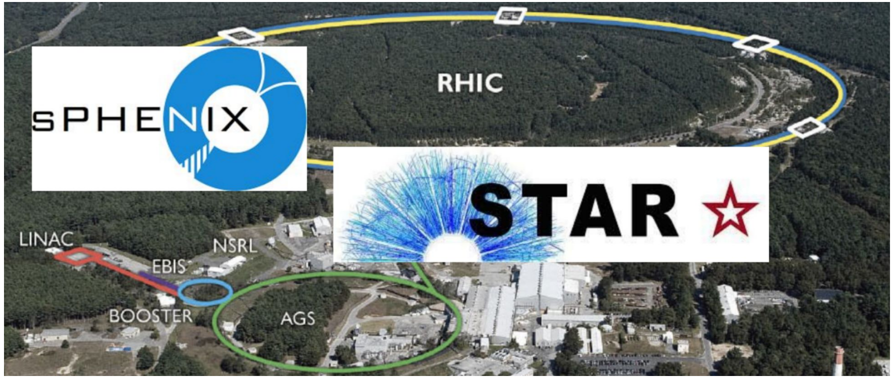
Existing Colliders

There are two existing facilities in the world that can recreate the conditions for QGP.

Credit: H. Bossi



Relativistic Heavy-Ion Collider (RHIC)

Top A+A energy: 200 GeV

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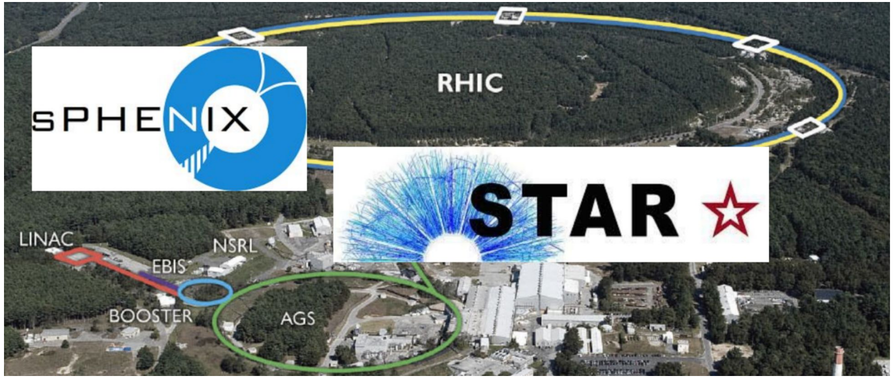


Relativistic Heavy-Ion Collider (RHIC)

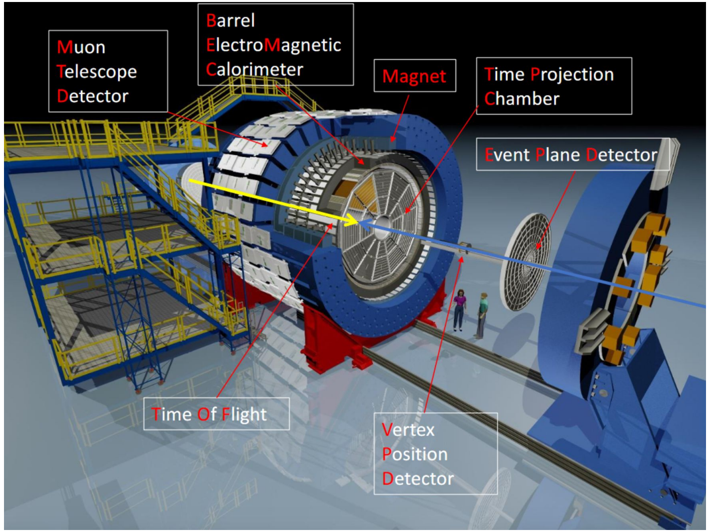
Top A+A energy: 200 GeV

Large Hadron Collider (LHC)

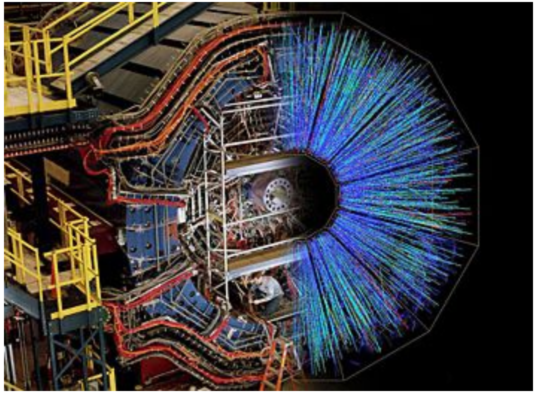
Top A+A energy: 5.36 TeV

STAR

- The Solenoidal Tracker at RHIC (STAR) has been operating since 2000.
- Time Projection Chamber (TPC) consists of a methane-argon mix.
  - Reconstructs charged tracks
- Time of Flight (TOF)
  - Used for particle identification for charged particles and pileup rejection

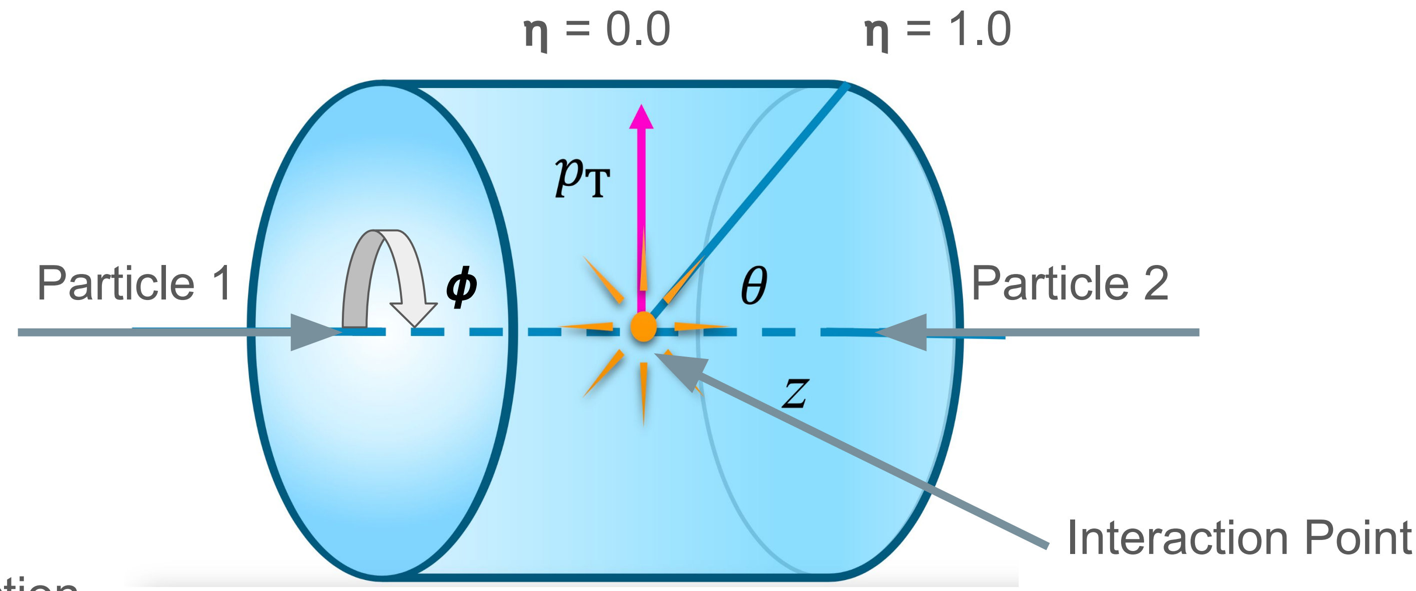


https://www.nature.com/articles/nature23004



https://phys.org/news/2018-10-star-detector.html#google_vignette

Useful Coordinates



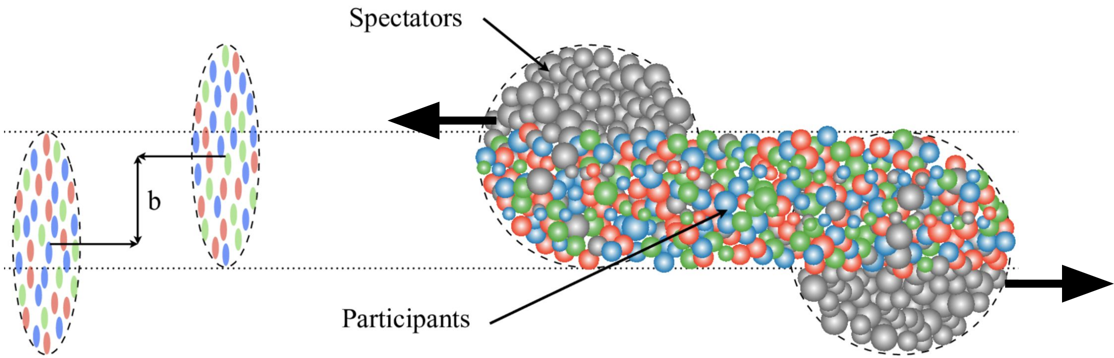
Credit: C. Beattie

z : Beam Direction
p_T: transverse momentum
Pseudorapidity (η) = $-ln[\tan(\theta/2)]$
ϕ: Azimuthal angle.

Centrality and Multiplicity in HIC

- The distance between the centers of the nuclei in heavy-ion collisions is called the “impact parameter” (b).

- Collisions are then split into different centralities
  - Proxy for impact parameter



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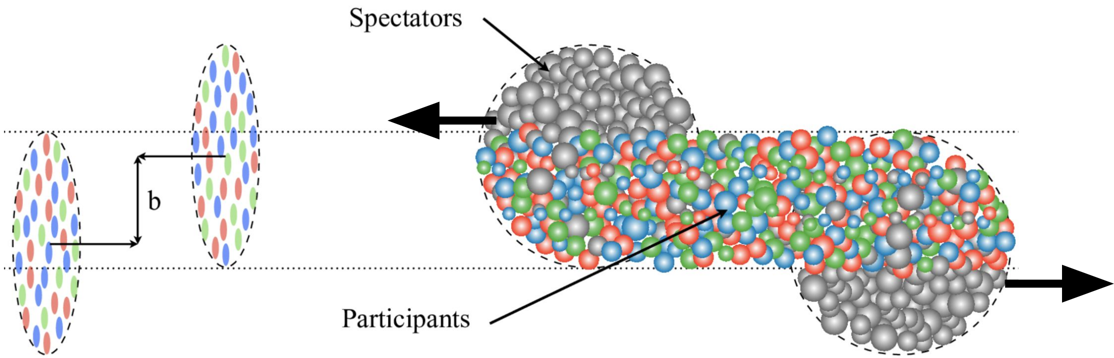
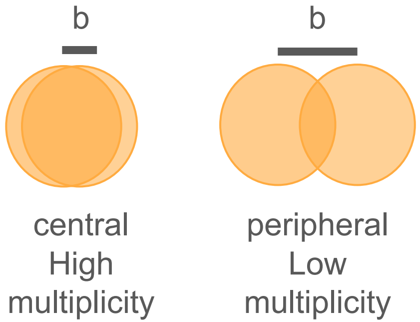
- Smaller impact parameter (b) correspond to more head on collisions
  - 0-10% Centrality

- Larger impact parameter (b) correspond to peripheral collisions.
  - 40-60% centrality

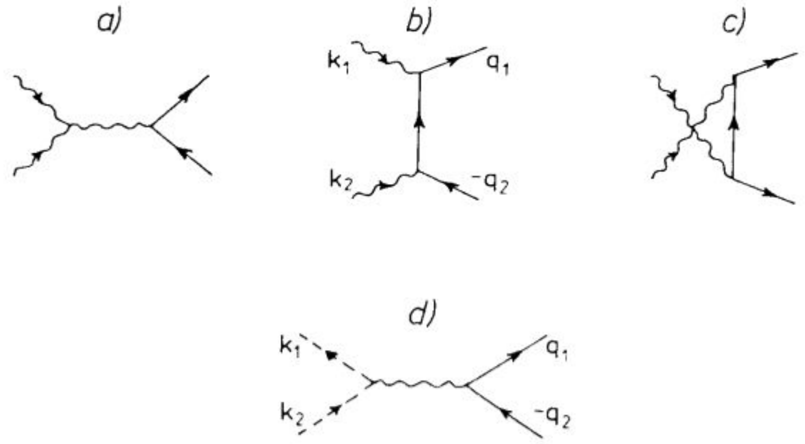




R. Snellings. Collective Expansion at the LHC: Selected ALICE Anisotropic Flow Measurements. J. Phys. G: Nucl. Part. Phys. 41 (2019), 124007.

Strangeness Enhancement and the QGP

- Strangeness enhancement was one of the first observables predicted as a signature of the QGP.



P. Koch, et Al, “Strangeness in Relativistic Heavy Ion Collisions,” Phys. Rep. 142, 167 (1986).

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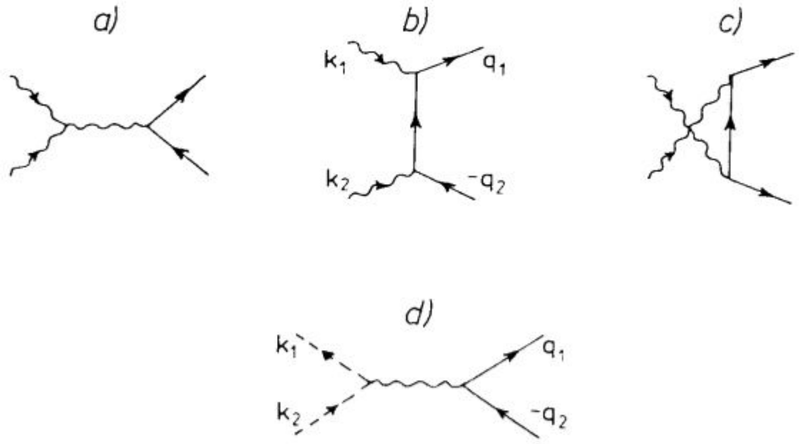
- The thermal production of s-$\bar{s}$ pairs is favorable in the QGP since the s-$\bar{s}$ masses are close to the QGP transition temperature ~156 MeV.
    - M_{ss} ~192 MeV
    - There are abundant thermal gluons in the QGP medium.

- Multi-strange ($\Xi^{\pm}$,$\Omega^{\pm}$) hadrons are more sensitive to the existence of QGP.



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Strangeness Enhancement and Multiplicity Dependence

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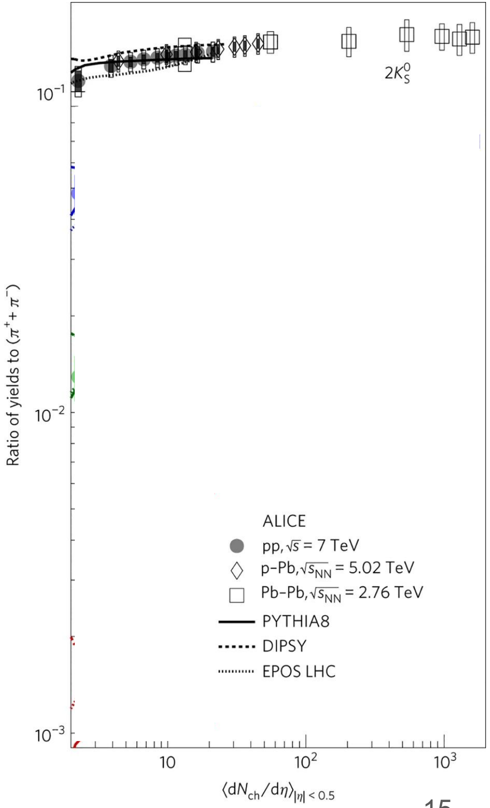

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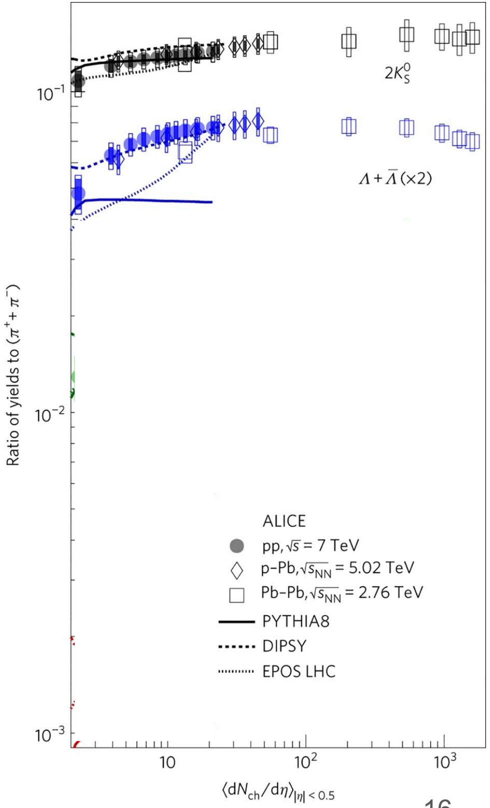

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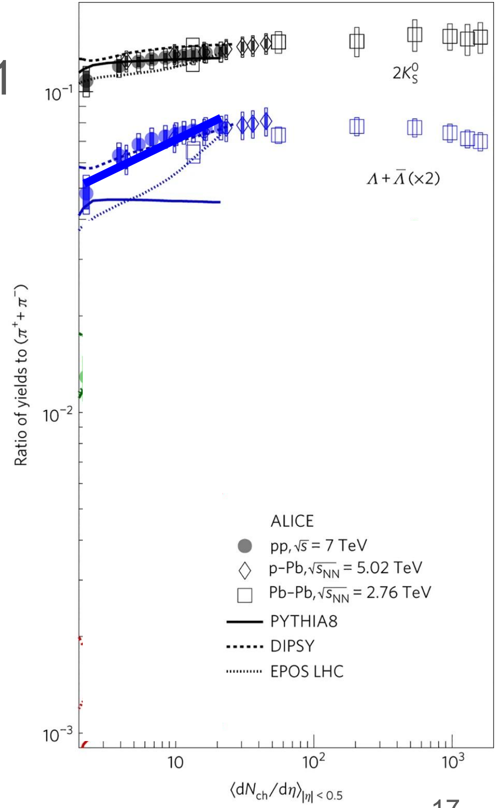

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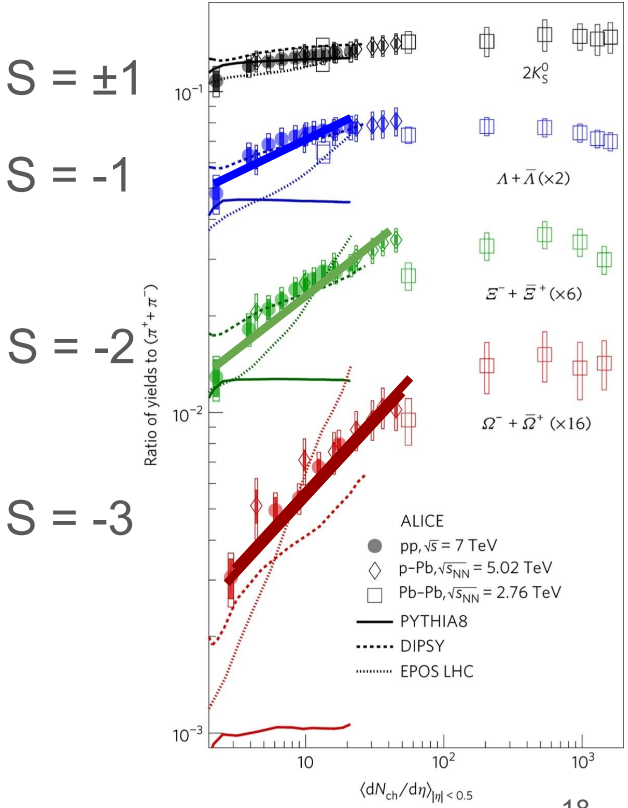

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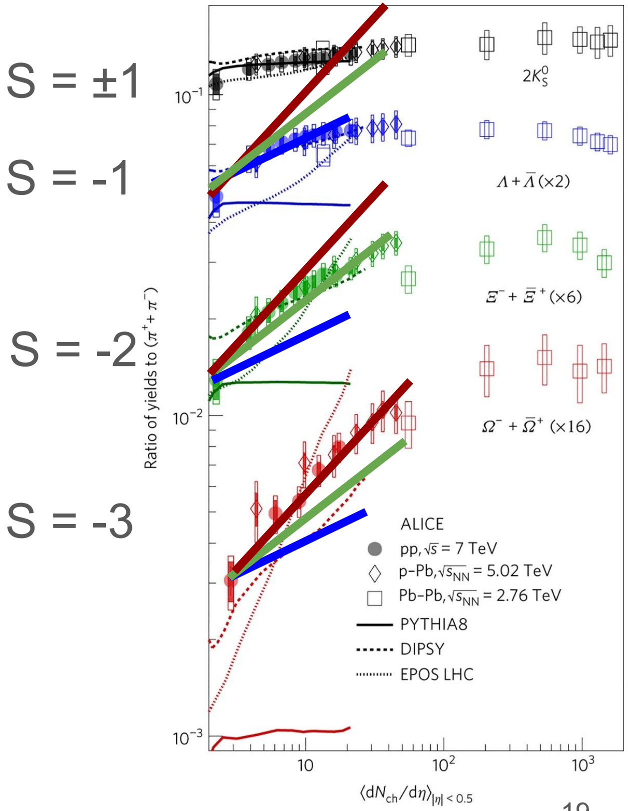

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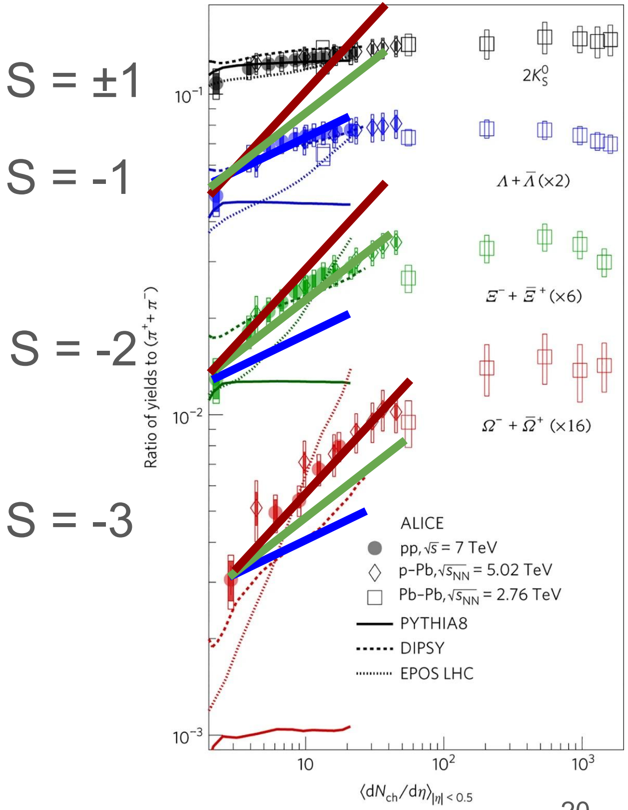
- Surprisingly there was no sudden jump for the onset of QGP.

- Models are not able to recreate the data.



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Motivation

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- Surprisingly there was no sudden jump for the onset of QGP.

However, there is a notable data gap in the low multiplicity region

STAR PRL. 98, 062301 (2007)
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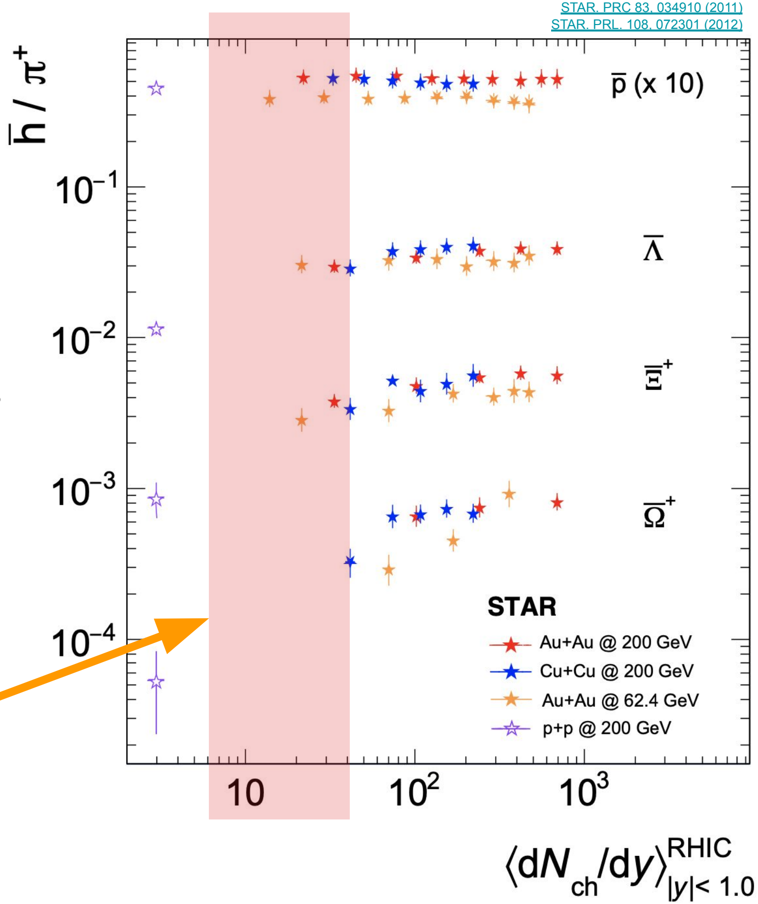
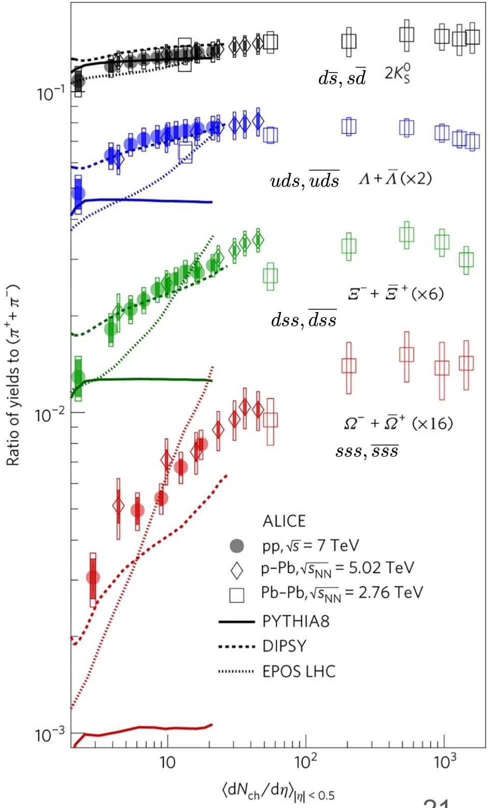




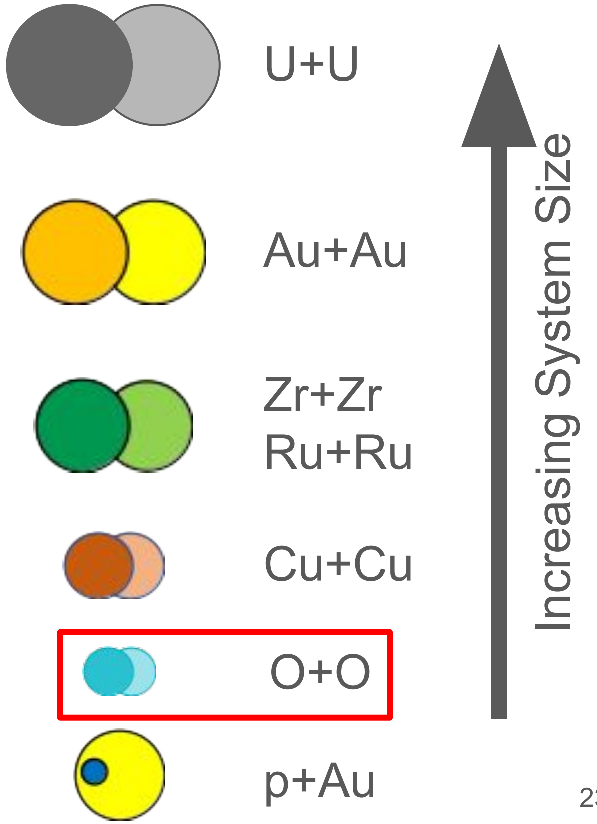
ALICE. Nat. Phys., 13, 535 (2017)

Where Do I Come In?

STAR Multiple Collision Systems

- Oxygen is one of the smallest ions used at RHIC.
    - Fill in the gap in the low multiplicity regions in the ratio of strange hadron production to the pion yield.
    - Allows a more straightforward geometry mapping with centrality than those asymmetric small system collisions like He+Au, or d+Au

Some of RHIC’s collision systems



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  - Allows a more straightforward geometry mapping with centrality than asymmetric small system collisions like He+Au, or d+Au
  - Fill in the hyperon to pion ratio in the low multiplicity gap

O+O's multiplicity can extend to this unexplored region

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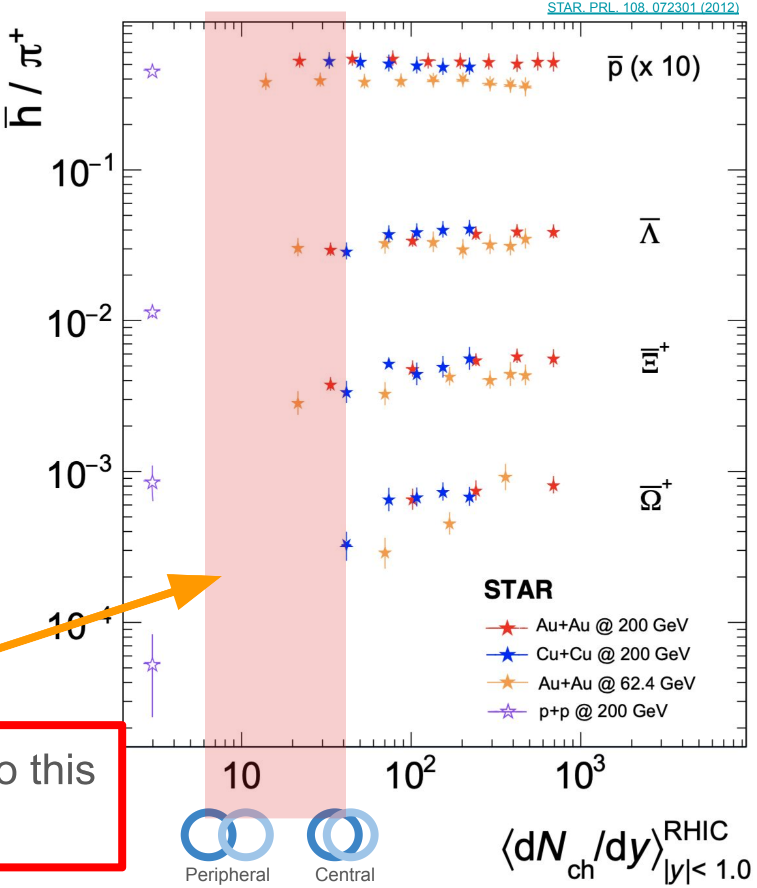

Conclusions

- The O+O dataset can fill in the gaps in the low-multiplicity regions of the ratio of strange hadron production to the pion yield for the STAR data.
- **We presented the first yield calculation for Λ's in the 0-10% centrality region for O+O. The O+O yield agrees with previous published STAR Λ yields at similar N_{part} values.**
- Additional O+O measurements were presented in QM2025 and **more to come!**
- With the LHC colliding O+O for their heavy run, there are many intriguing outcomes in the future!

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