

Fixed-Target Proton–Nucleus at Intermediate Energies: Highlights, Lessons, and Next Steps

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Advancing Nuclear Physics: New Horizons with Fixed-Target Proton-Nucleus Experiments at Intermediate Energies

EIC is our main priority

Do we need a test beam facility?

Fermilab

LHC

GSI

?

What fits our needs?

EIC is our main priority

Interest in F-T open questions

Jlab

RHIC
STAR

GSI

AGS

Appreciating the past and looking into the future...

ePIC Beam Time Requirement Projections

- ePIC consists of (at least) 15 independent Detector Subsystem Collaborations (DSCs)
- Estimated beam time requirements (input for European Particle Physics Strategy Update EPPSU):
 - ✓ 2026: 31 weeks
 - ✓ 2027: 27 weeks
 - ✓ 2028: 28 weeks

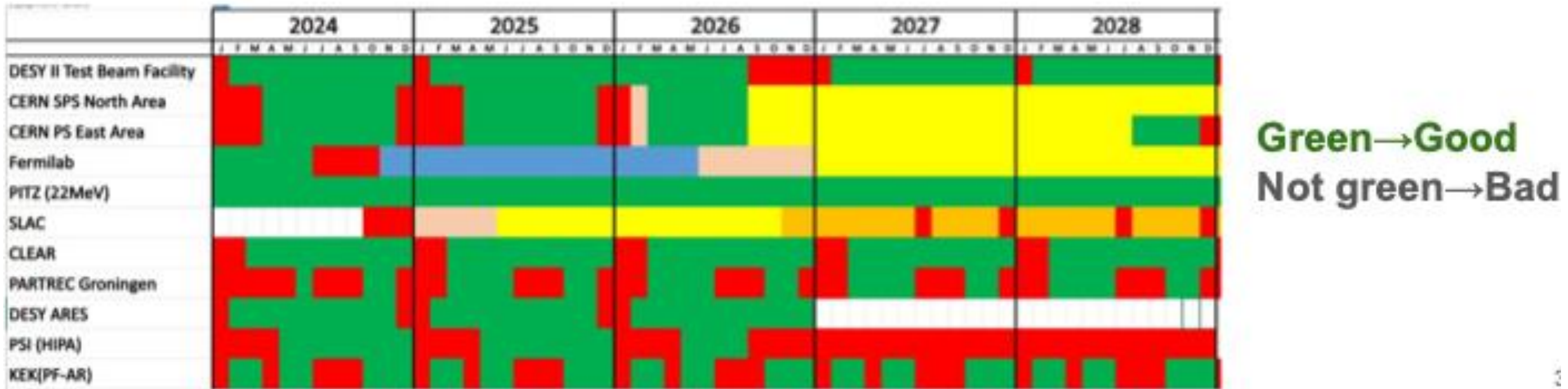
This is a small but significant fraction of available beam facilities in the world.

The Ideal Beam Test Facility - Beams

- Mixed hadrons: 1 GeV up to full AGS storage energy
 - ✓ Interesting for PID, calorimeters
 - ✓ Tracking detectors prefer the highest momentum to minimize multiple scattering
- Electron-enriched absorber configuration
- Muon configuration (beam stop)
 - ✓ Wide area muon beams are very useful for calorimeter calibration + parasitic running
- Variable beam focusing system
 - ✓ Including collimators for rate adjustment
- He/Vacuum tubes for precision low-energy beams?
- Support from beamline experts

Great Hadron Drought of 2026+

- We are entering a true drought in hadron beam facilities starting in 2026
- Even if all facilities come back on time, they will be seriously overbooked
- EPIC's estimate for the test beam needs is based on a survey of subsystems for the European Particle Physics Strategy Update: 86 weeks in 3 years



A (hadron) beam test facility at BNL would be a significant reduction of risk for ePIC

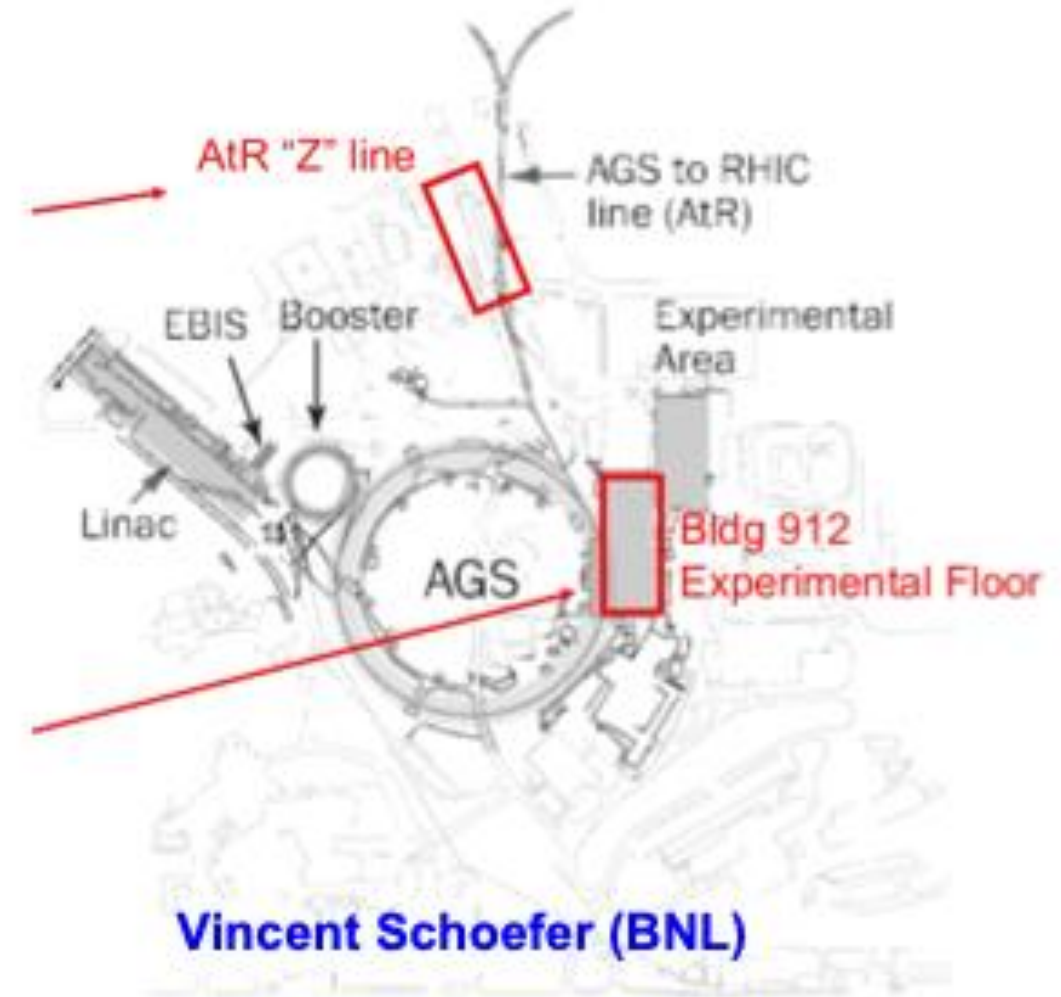
Oskar Hartbrich

Why AGS, Why Now?

- Unique energy range and time structure for the fixed-target program
- Natural test bench for EIC-era detector & polarized-beam R&D
- Two candidate target locations: AtR Z-line and Bldg. 912 floor

Z line: More limited options but faster and cheaper
Rapid beam only
Tight space

Building 912: Up to four beam lines and could be ideal, but requires more construction and more expensive



All facilities could run simultaneously

We need a test beam facility at the AGS to
mitigate risk and reduce contingency at
the EIC...

Development of polarized sources and beams

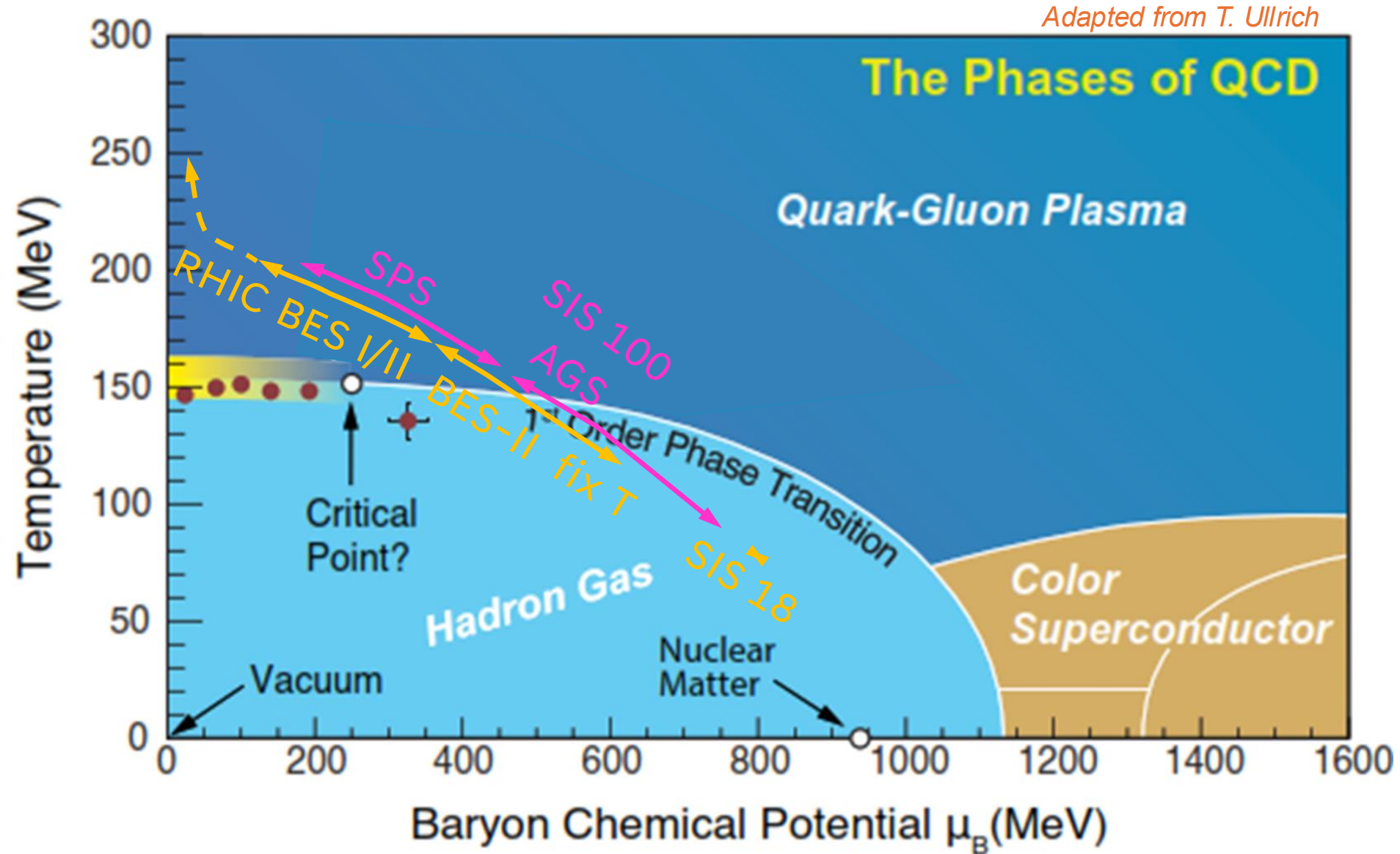
- We have had an order of a decade to develop the polarization technology that is essential for EIC science. This includes:
 - ✓ Polarized ion sources (^2H , ^3He , ^6Li and ^7Li)
 - ✓ Polarimeters
 - ✓ Spin manipulation in AGS and RHIC using solenoids and snakes
- We require maximum stable polarization and collision luminosity at the IP.
- The AGS is a local to EIC, is an integral element of the EIC accelerator, and should be made available after RHIC operations cease.

We need polarized beam development at
the AGS for the EIC...

Fixed target experiments

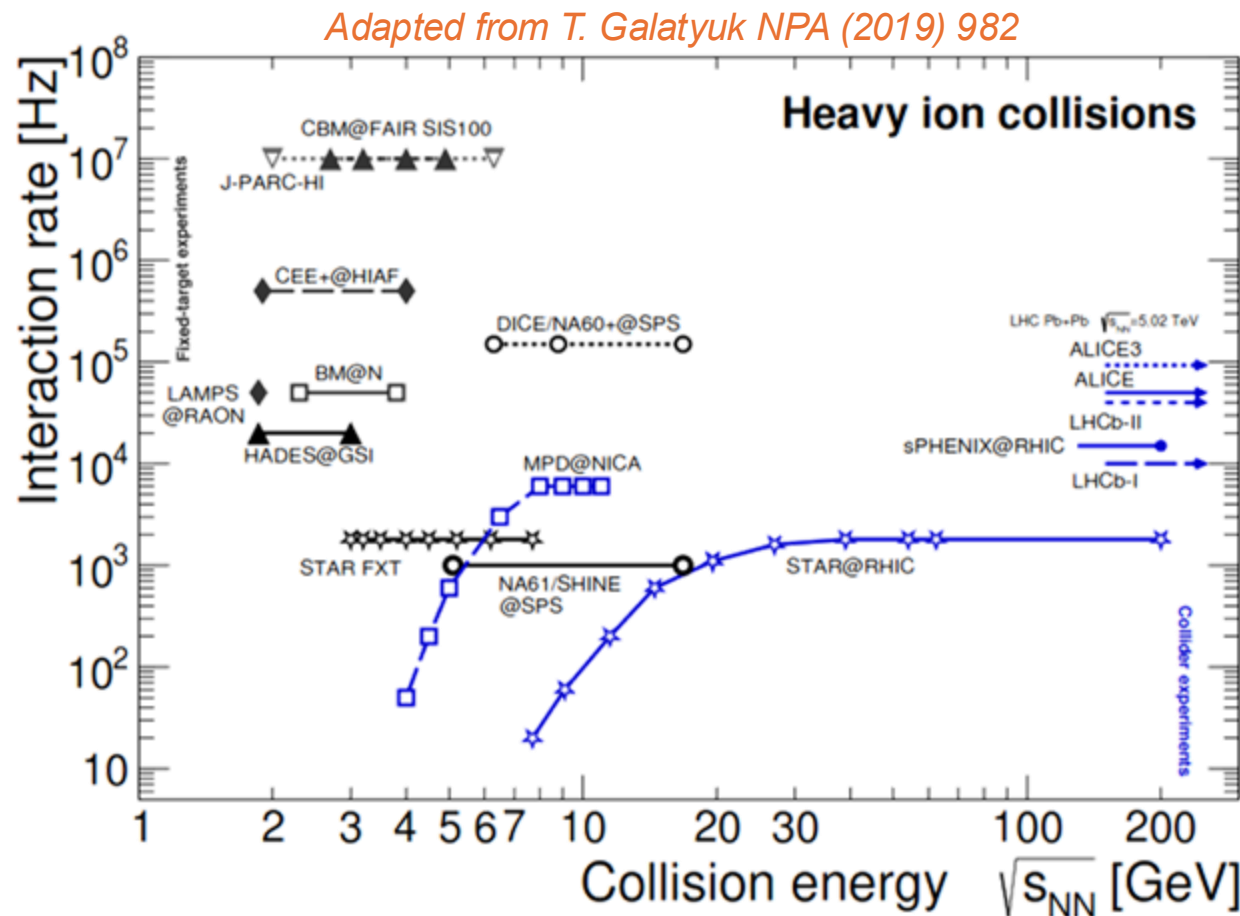
Yasuyuki: The easy measurements have been done. “If you want to do a new heavy ion experiment at the AGS energy, you need to promise new and very significant results that justify the cost and the effort.”

What is NOT Unique?



Phase Diagram of Nuclear Matter

What is NOT Unique?



New Generation HI Experiments @AGS:
complementary to CBM
and/or aggressive timeline

- **Fixed target machines**
 - Factor 100+ higher interaction rates
- **CBM at SIS 100 @ GSI**
 - Similar $\sqrt{s_{NN}}$ range as AGS
 - Similar interaction rate
 - Multipurpose experiment CBM
 - **Timeline:**
 - CBM installation to start 2026
 - SIS 100 commissioning at 2.7 GeV starts 2028
 - Full performance 2030+
- **DiCE at SPS @ CERN**
 - Higher $\sqrt{s_{NN}}$ range up to 17 GeV
 - Dedicated dimuon/charm experiment
 - **Timeline**
 - Proposal submitted 2025
 - Projected installation 2029
 - First physics 2030

Physics Goals of the FXT Program

- The Onset of Deconfinement:
 - ✓ High p , suppression
 - ✓ NCQ scaling of Elliptic Flow
 - ✓ Strangeness Enhancement
- Compressibility → First Order Phase Transition
 - ✓ Directed flow
 - ✓ Tilt angle of the HBT source
 - ✓ The Volume of the HBT source
 - ✓ The width of the pion rapidity distributions
 - ✓ The zero crossing of the elliptic flow (~ 6 AGeV)
 - ✓ Volume measures from the Coulomb Potential
- Criticality:
 - ✓ Higher moments
 - ✓ Particle Ratio Fluctuations
 - ✓ Chirality:
 - ✓ Dilepton studies
- Hypernuclei: → Lifetime of the hypertriton

No measurements
in this energy
range

- What a STAR FXT Program will not do:
 - ✓ Omega's
 - ✓ Charm
 - ✓ Doubly Hyper nuclei
 - ✓ p+p scan
 - ✓ p+A scan
 - ✓ peripheral collisions
 - ✓ > 200 Million events per energy
 - ✓ $>$ two weeks of beam time

Can the AGS add
to that?

Physics Thoughts

Baryon Junction at AGS?

E941 (Spokesperson: Huan Z. Huang)

E941, PHYSICAL REVIEW C 65 014904 (2001, 2003)

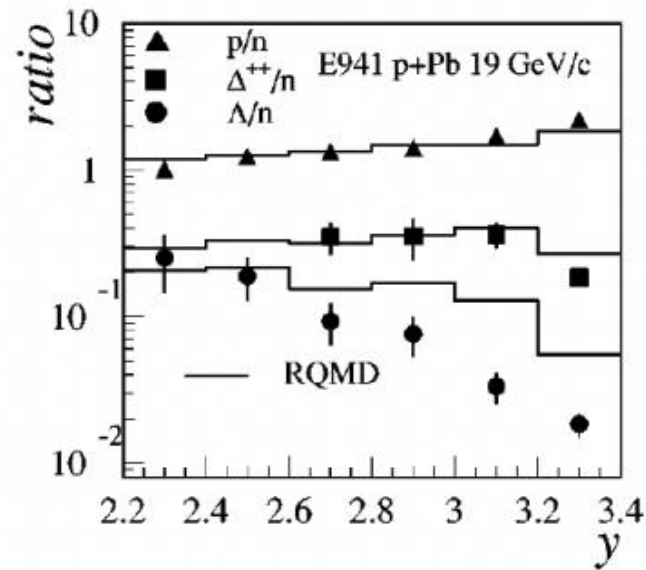
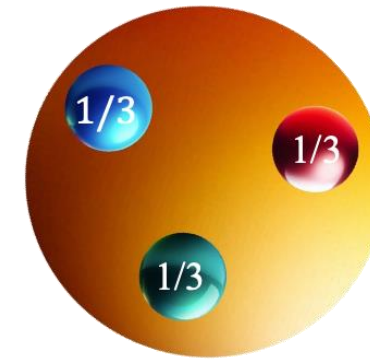
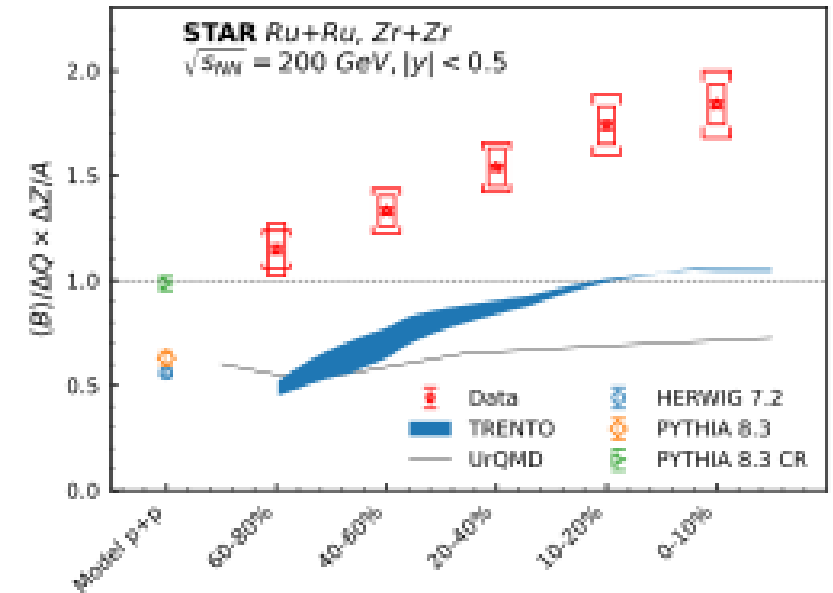
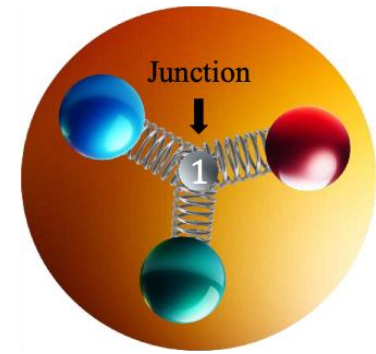


FIG. 6. Relative yields of protons, Δ^{++} 's, and Λ 's with respect to neutrons as a function of rapidity in $p+Pb$ collisions at 19 GeV/c compared with RQMD predictions.

(a) Valence quarks, $B=1/3$ and $Q \neq 0$



(b) Baryon Junction, $B=1$ and $Q=0$



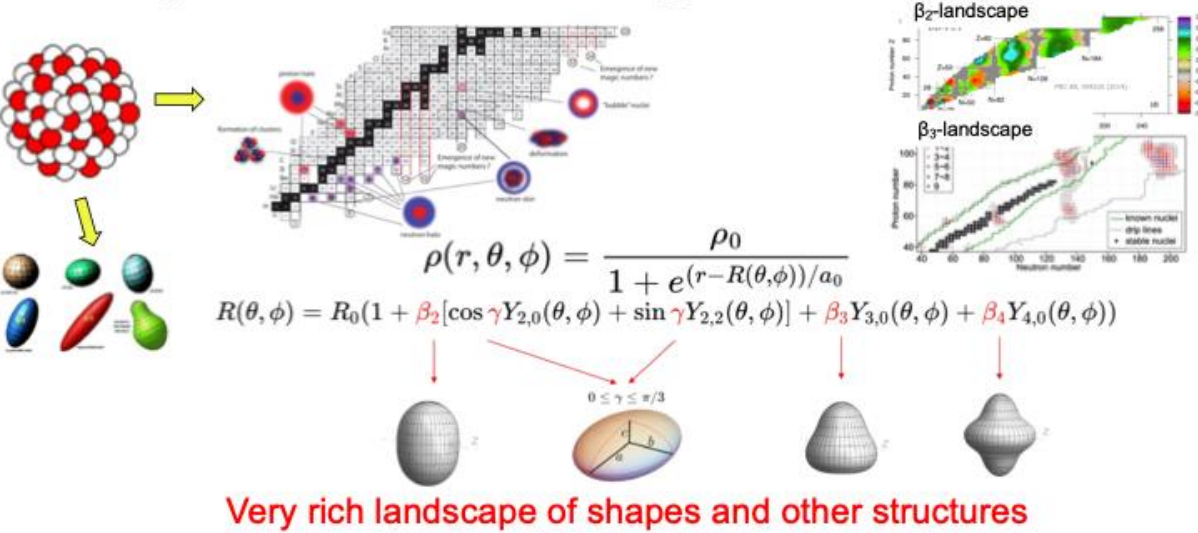
Zhangbu Xu

Physics Thoughts

Nuclear Structure via the Fixed-Target Experiment

Nuclear structure input

Many-body quantum systems, govern by short-range strong nuclear force
Emergent properties in between discrete nucleon and bulk nuclear matter.
Configuration is one that minimizes energy, often deformed



Very rich landscape of shapes and other structures

System scan at low energy?

Perturb the initial condition and observe the final-state responses, potentially with a large lever arm to probe the dynamics at similar volume. **AGS is a unique facility for this**

Stopping and expansion dynamics depend on orientation

Isobar collisions, either switch beam or the target

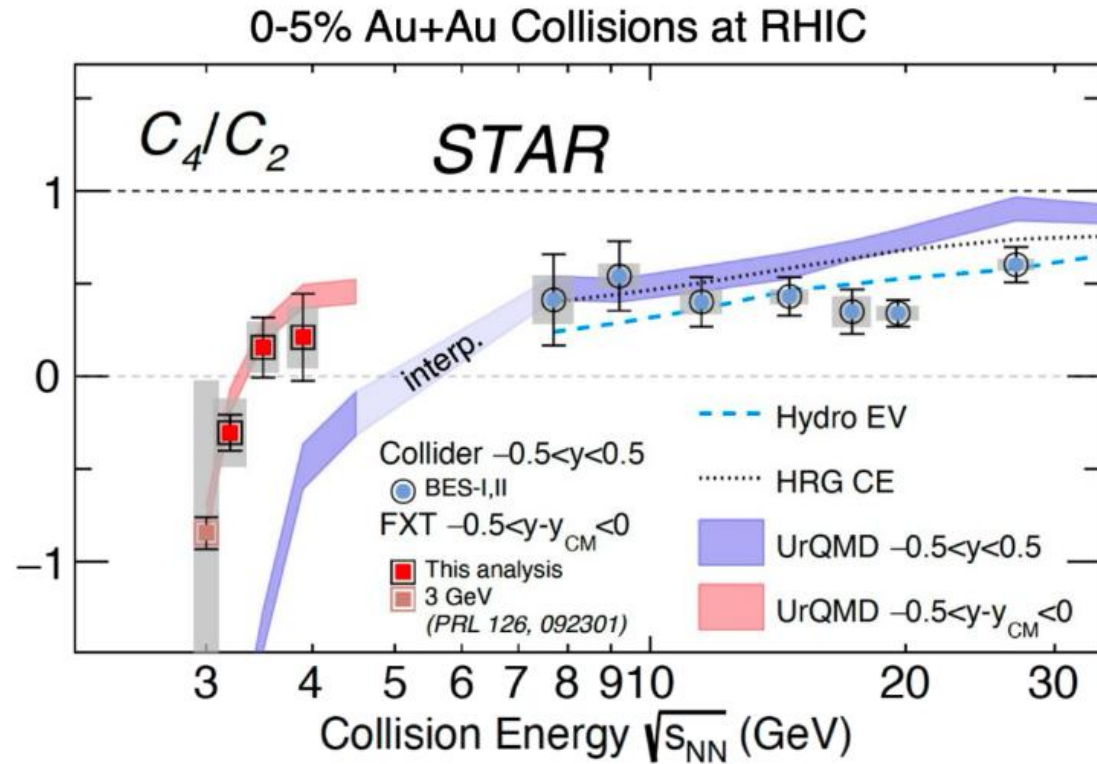
How structure lever-arm aid your favorite physics?

- Stopping/transport
- EOS
- CEP
- CSR
- QGP
- Polarization
- UPC
- Particle production
- ...

Dynamics is a strong function of \sqrt{s} , need collisions of the same isobar pairs at a few \sqrt{s}

Physics Thoughts

RESULTS: SEARCH FOR THE CRITICAL POINT



Zachary Sweger (STAR, QM2025)

STAR: arXiv:2504.00817

HRG CE: P. B. Munzinger et al, NPA 1008, 122141 (2021)

Hydro: V. Vovchenko et al, PRC 105, 014904 (2022)

New BES-II data (FXT mode)

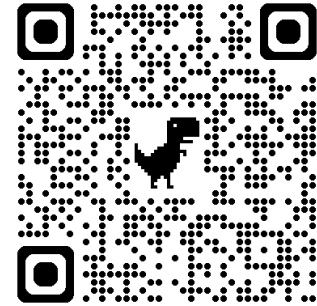
□ New FXT data at 3.2, 3.5, 3.9 GeV out.

□ Measurements done with half rapidity due to acceptance limitations

□ Consistent with hadronic transport model UrQMD

What is unique?

Flexibility in systems! Many proposals here.
Polarized beams!



Where do we go from here?

- Position paper
 - ✓ The case for a test beam “In progress, high priority”
- The case for a potential physics program
 - ✓ Discussion in progress