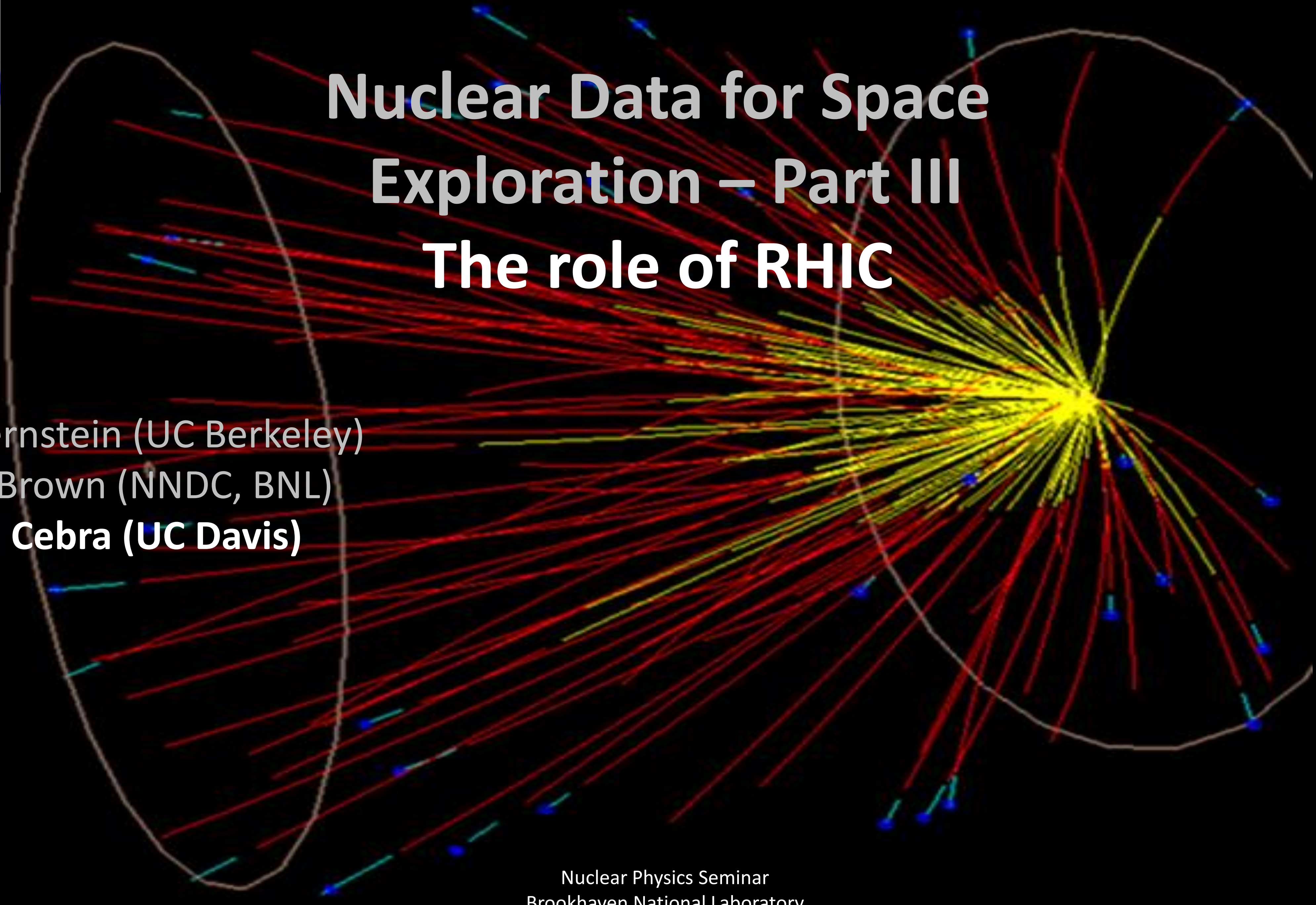
Nuclear Data for Space Exploration – Part III

The role of RHIC



Lee Bernstein (UC Berkeley)
David Brown (NNDC, BNL)
Daniel Cebra (UC Davis)

Nuclear Physics Seminar
Brookhaven National Laboratory

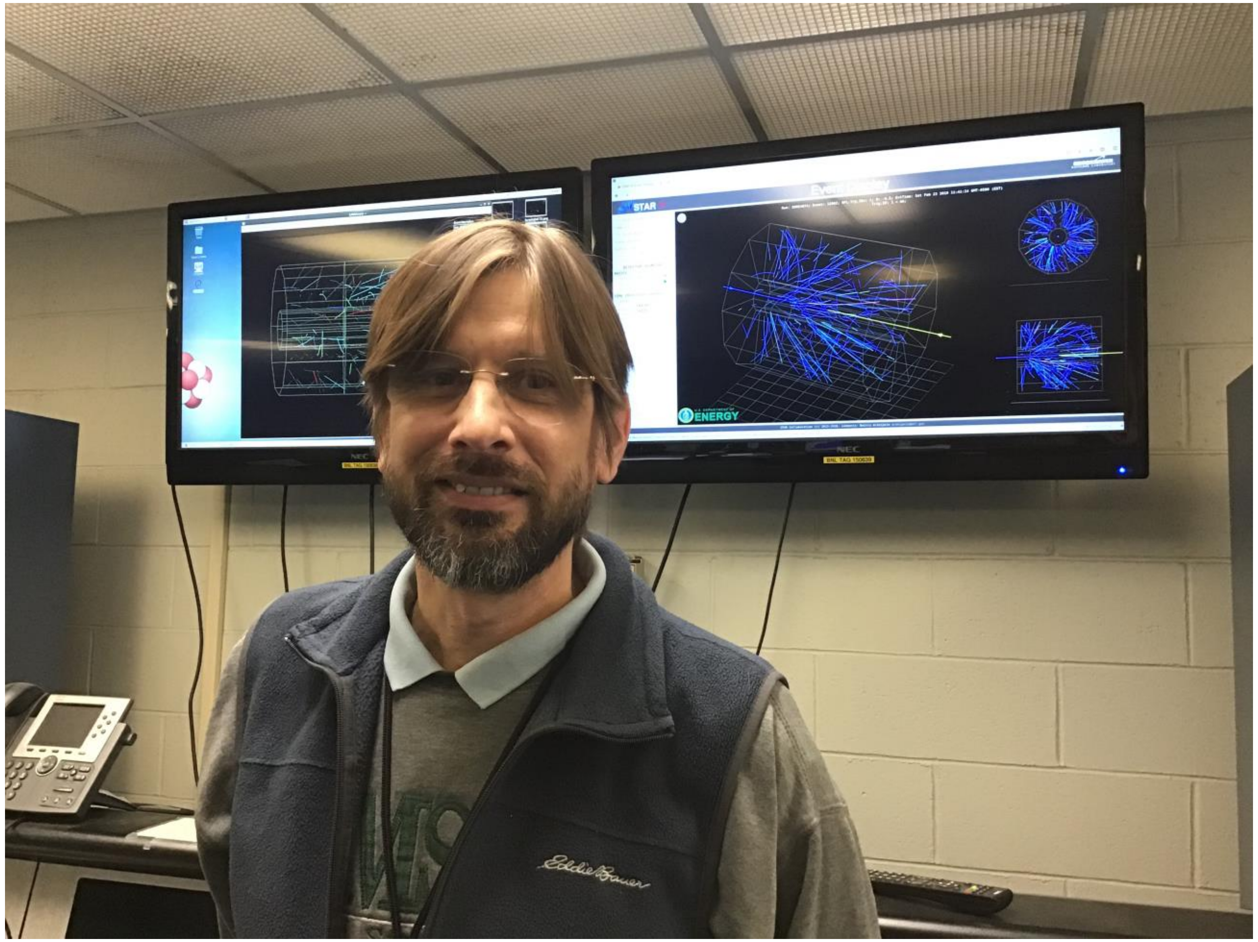
About me

- Michigan State University Ph.D. (1990)

- LBNL Post-Doc (1990-1992)
  - Part of the original Letter of Intent for STAR
  - Contributed to Revised Letter of Intent
  - Contributed to Conceptual Design Report
  - First visited BNL in 1991

- University of California – Davis, Faculty (1992-Present)
  - Principle Author: Beam Energy Scan Proposal (2009)
  - Principle Author: BES-II Proposal (2015)
  - Principle Author: **Fixed-Target Program** (2017)
  - Deputy Project Manager: iTPC upgrade (2017-2019)

And… a frequent visitor at Brookhaven Lab
  - Sabbatical Leave (1990)
  - Sabbatical Leave (AY 2018/2019)
  - Many summers
  - Shifts at RHIC every year



Why I am her:
The RHIC/STAR Fixed-Target program may be able to meet some of the Nuclear Data needs identified in Lee's and David's presentations.

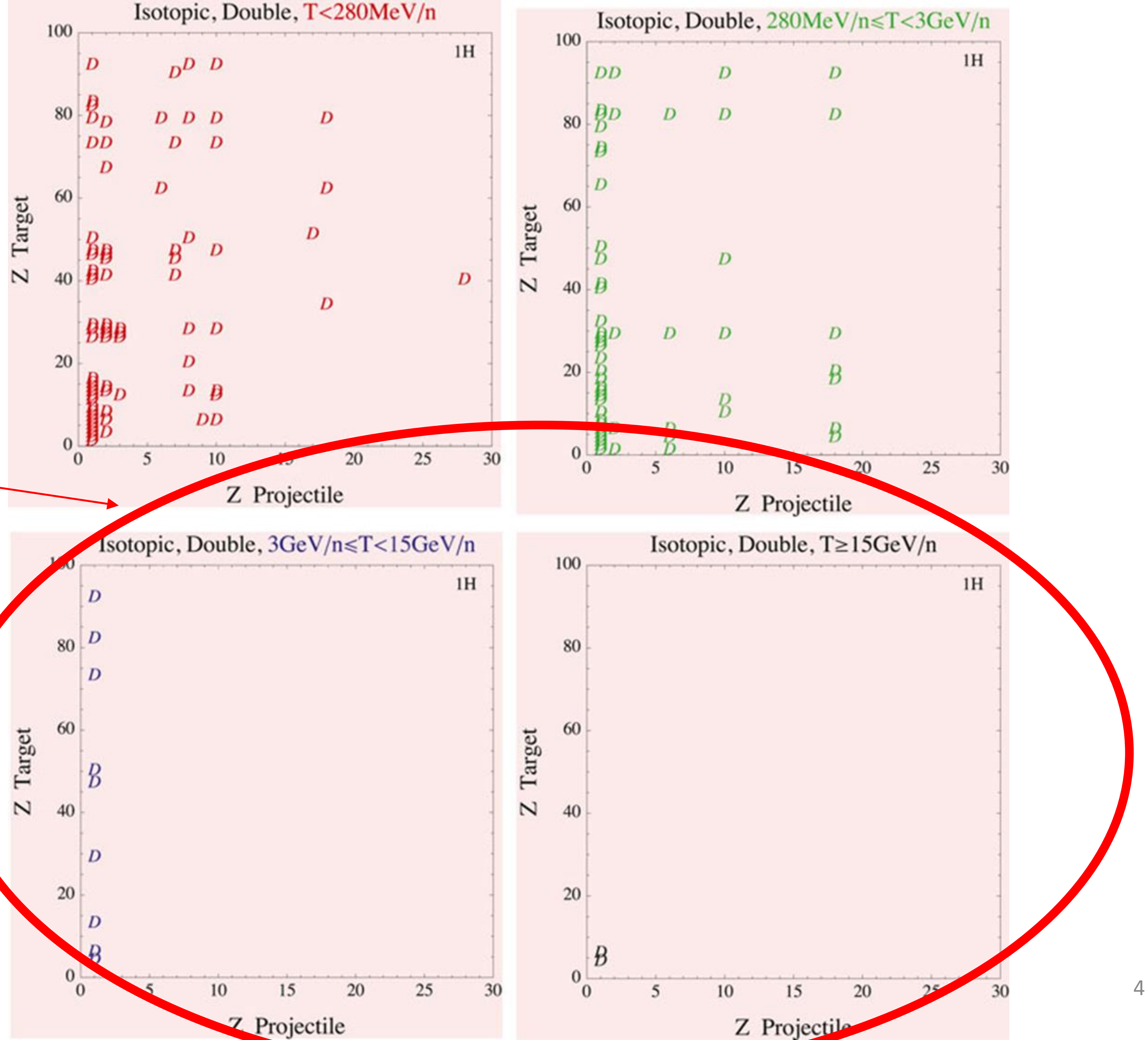
Justification: (Lee already provided the justification… but as a quick overview)

- Cosmic rays are a serious concern to astronauts, electronics, and spacecraft.
- The cosmic ray flux is composed of nuclei (90% protons, 9% He, and 1% nuclei up to Fe).
- The damage is proportional to Z^2, therefore the component due to ions is very important
- Damage from secondary production of p, d, t, ^{3}He, and ^{4}He is also significant.
- Extensive double differential measurements for light fragments production have been made for projectile energies below 3 GeV/n.
- No data exist for projectile energies from 3-50 GeV/n.
- The Space Radiation Protection community has identified this high energy regime as an area of need. https://doi.org/10.3389/fphy.2020.565954
- The STAR detector at RHIC has excellent light fragment capabilities.
- RHIC can deliver the ion beam species (He, C, Si, Fe) and energies (3-50 GeV/n) of need to the Space Radiation Community. STAR can install the targets of interest (C, Al, Fe).

Existing proton double differential measurements

(Dave already indicated a need for dN/dE’dΩ)

There are no data for beams from 3-50 GeV/n



- Identified as a key need for space radiation protection
- RHIC can supply the beam species and eneriges of interest
- STAR can make the double differential measurements

Opportunity for 2023-25

Light Fragment Yields from He, C, Si, and Fe on C, Al, and Fe Targets with beam energies from 3 to 50 GeV

Note: This “opportunity” was included in the STAR 2022-2025 Beam Use Request

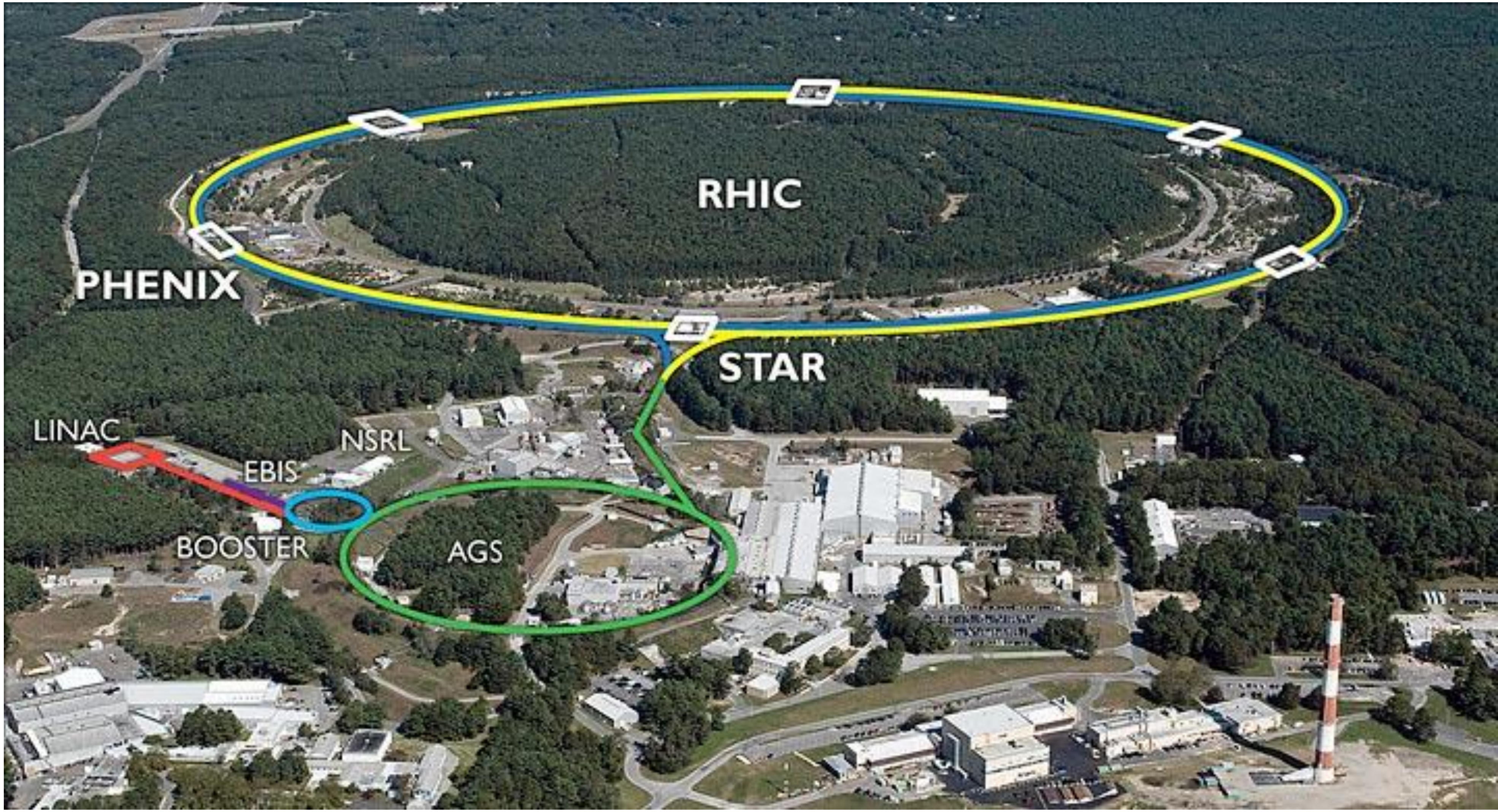
Note: 2022 is not possible as there is no opportunity to change targets

Overview of the Accelerator Facility

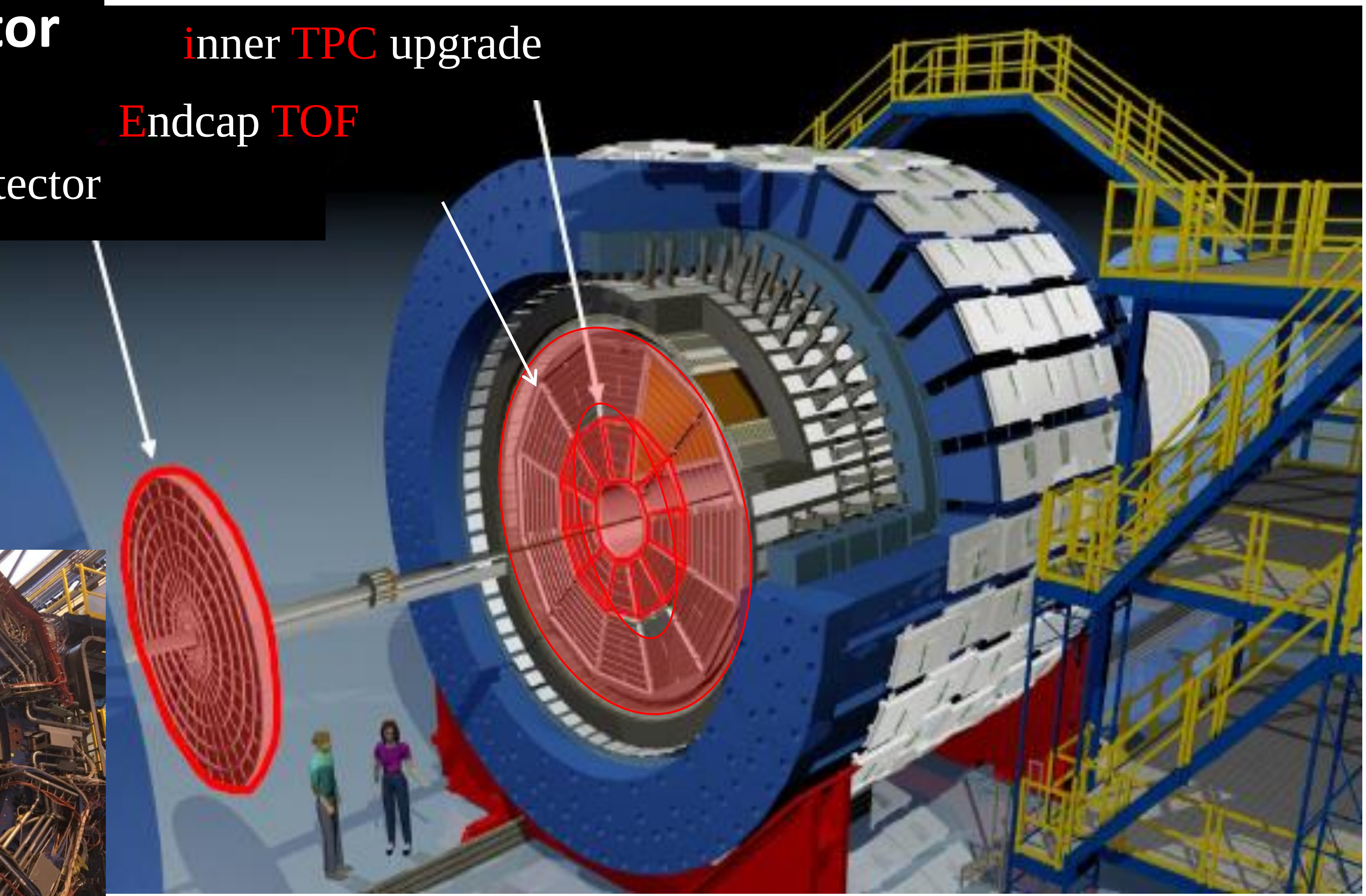
Ion Sources:
- LINAC
- EBIS
- Tandems

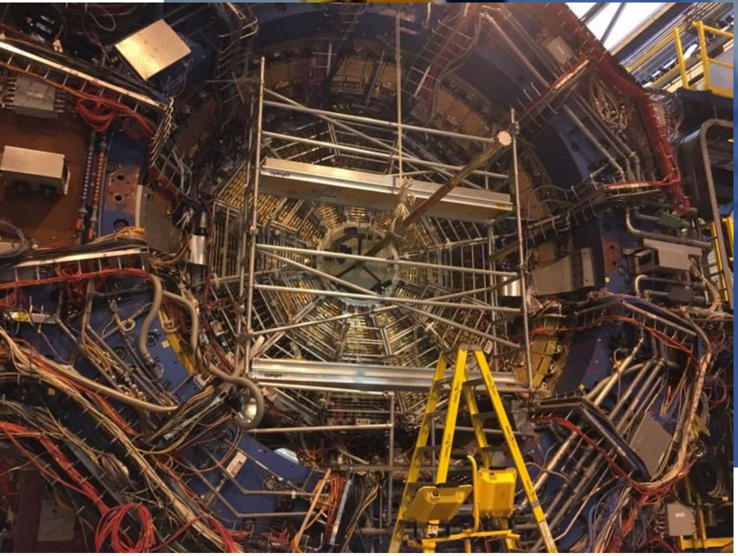
Synchrotrons:
- Booster
- AGS
- RHIC

Experimental Areas
- NSRL
- AGS Experimental hall
- RHIC: IP6, IP8



The STAR Detector





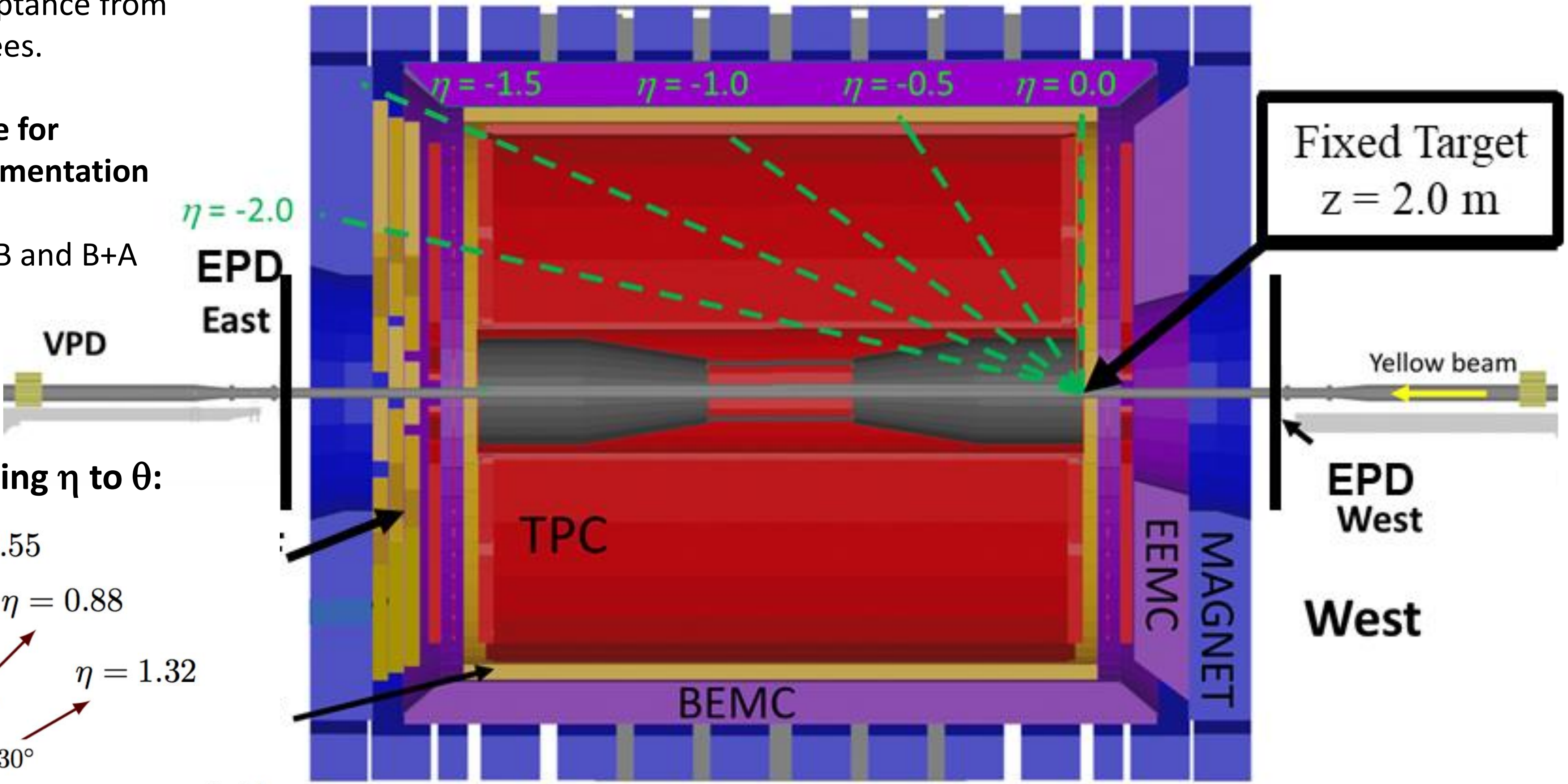
Detects Particles in the $0 < \eta < 2$ range
π, K, p, d, t, h, α through dE/dx and TOF
K^0_s, Λ, Ξ, Ω, ϕ, ${}^3_\Lambda H$, ${}^4_\Lambda H$ through invariant mass

Side Cross Section of STAR

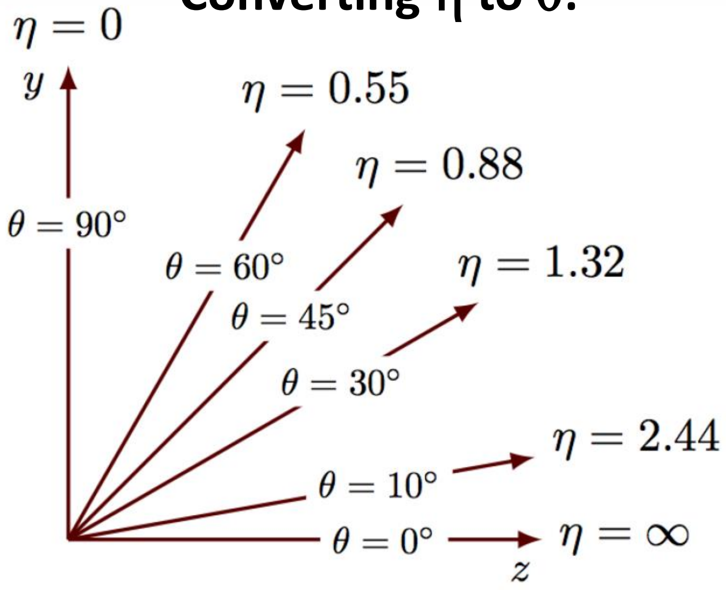
Using a collider detector as a fixed-target experiment

- STAR has acceptance from 90 to 12 degrees.
- **No acceptance for projectile fragmentation**

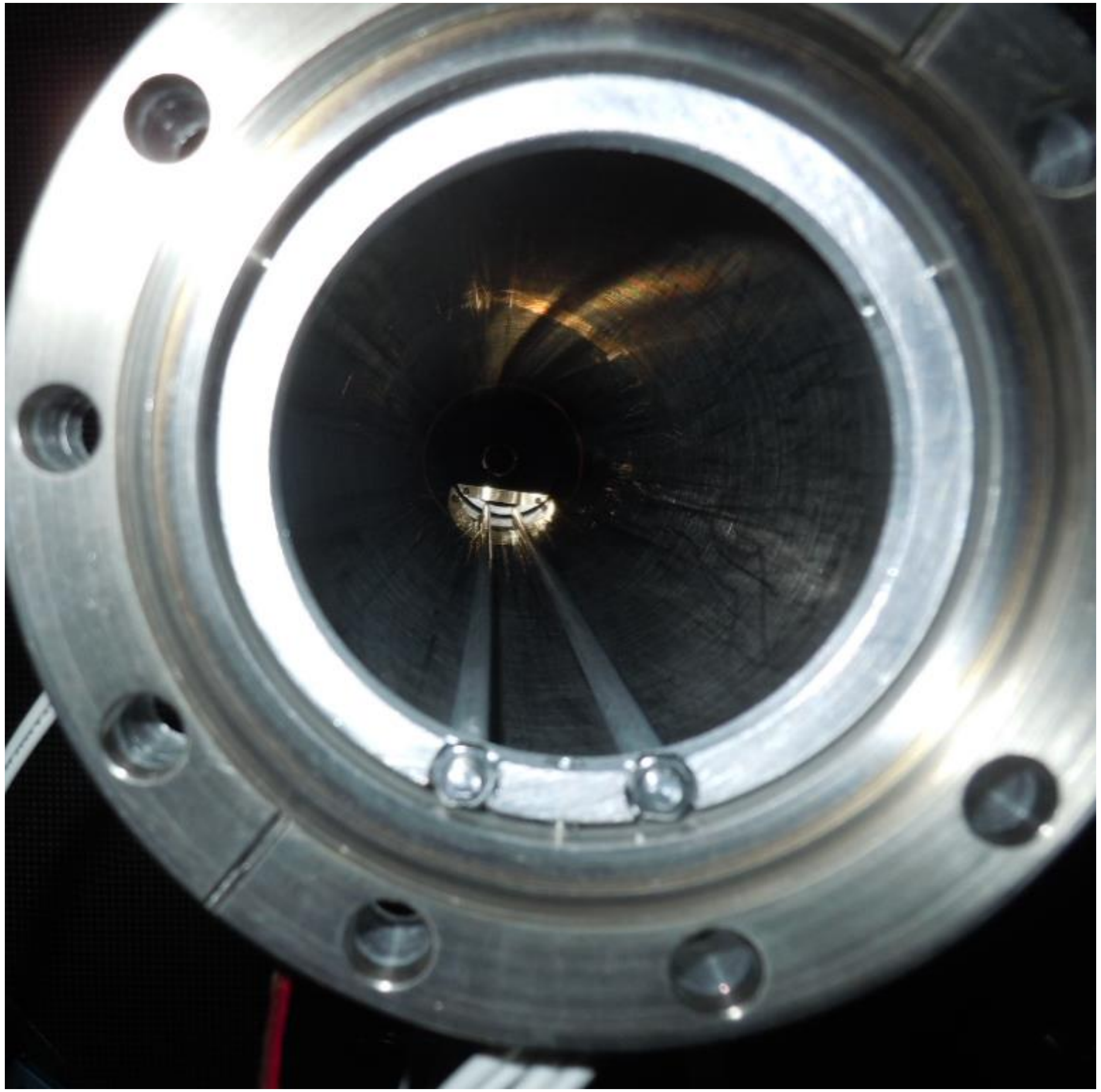
➔ Must have A+B and B+A



Converting η to θ:



Fixed-Target for STAR



Gold Target:

- 250 μm foil
- 2 cm below the nominal beam axis
- 2 m from the center of STAR
- Beam is steered to graze the edge of target
- Typically, 12 hours to develop a new beam

➔ **Can install Be, C, Al, Fe foils; no gas targets**

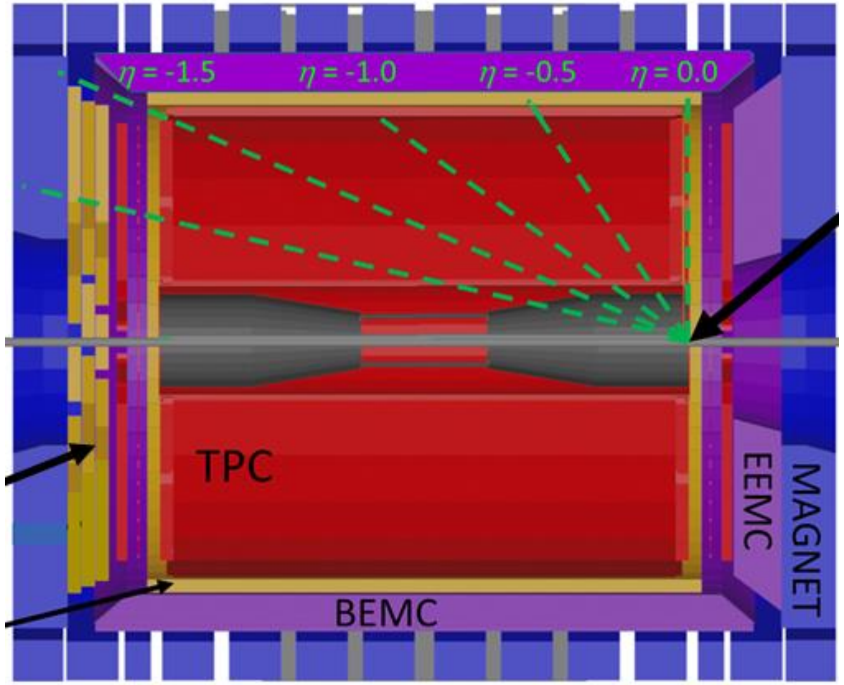
Acceptance for the FXT Program

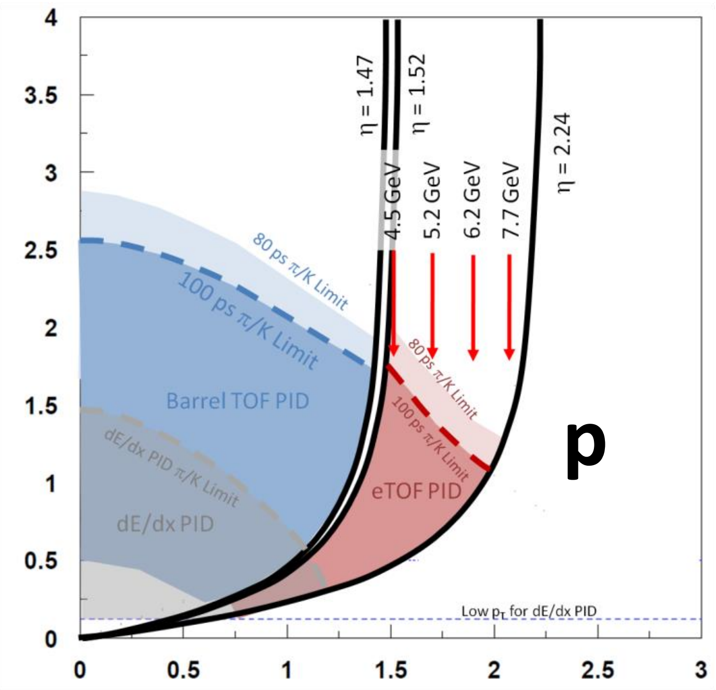
From 2018-2021, RHIC/STAR has beam running a fixed-target program performing an energy scan of gold beams on a gold target.

Note on energies: There a few different units to use to describe the collision energy.

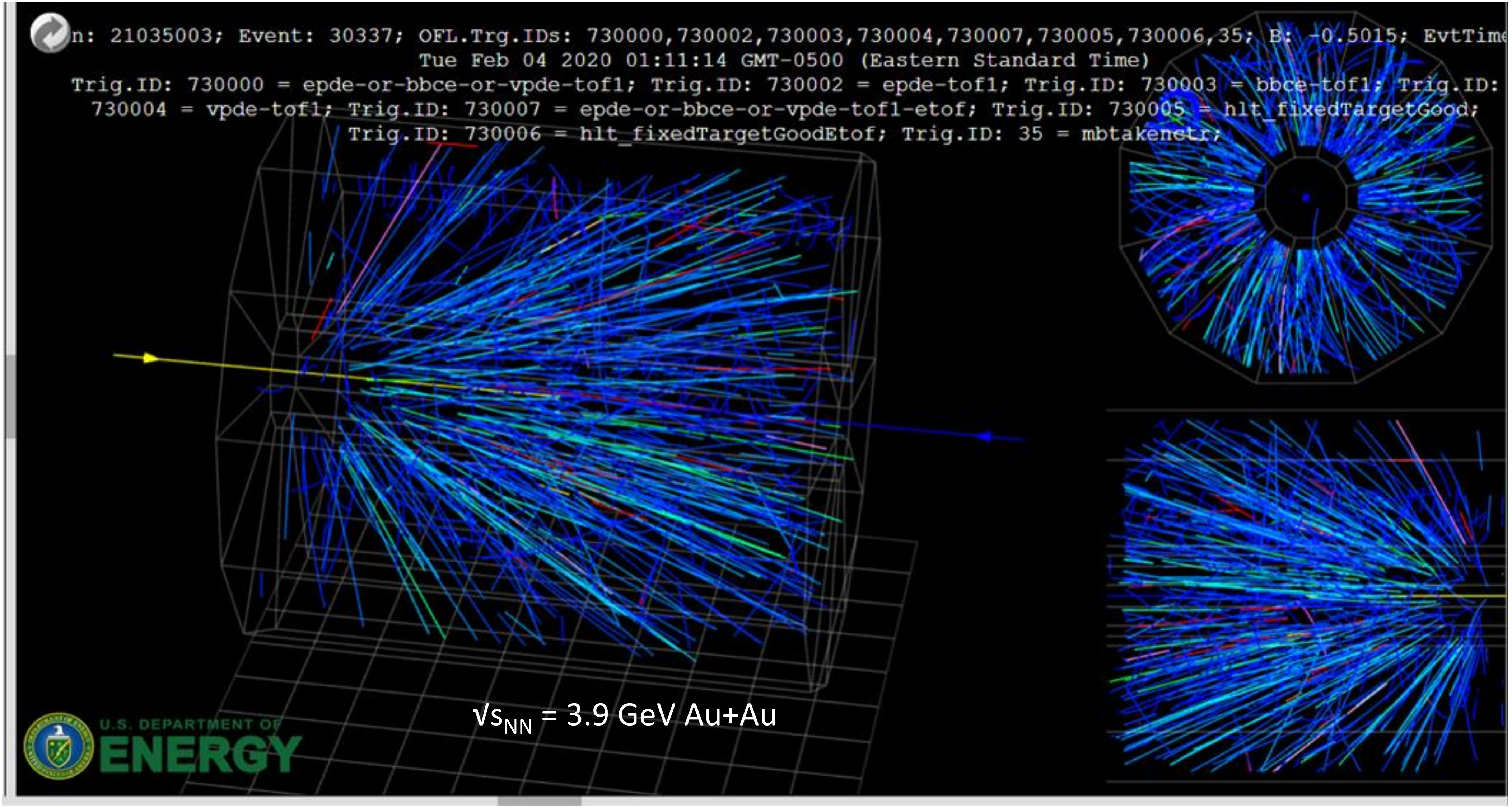
Note that acceptance is dependent on the collision energy

FXT Energy $\sqrt{s_{NN}}$	Single Beam E_T (GeV)	Single beam E_k (AGeV)	Center-of-mass Rapidity	Chemical Potential μ_B (MeV)	Year of Data Taking
3.0	3.85	**2.9**	1.05	721	2018
3.2	4.59	**3.6**	1.13	699	2019
3.5	5.75	**4.8**	1.25	666	2020
3.9	7.3	**6.3**	1.37	633	2020
4.5	9.8	**8.9**	1.52	589	2020
5.2	13.5	**12.6**	1.68	541	2020
6.2	19.5	**18.6**	1.87	487	2020
7.2	26.5	**25.6**	2.02	443	2018
7.7	31.2	**30.3**	2.10	420	2020
9.1	44.5	**43.6**	2.28	372	2021
11.5	70	**69.1**	2.51	316	2021
13.7	100	**99.1**	2.69	276	2021



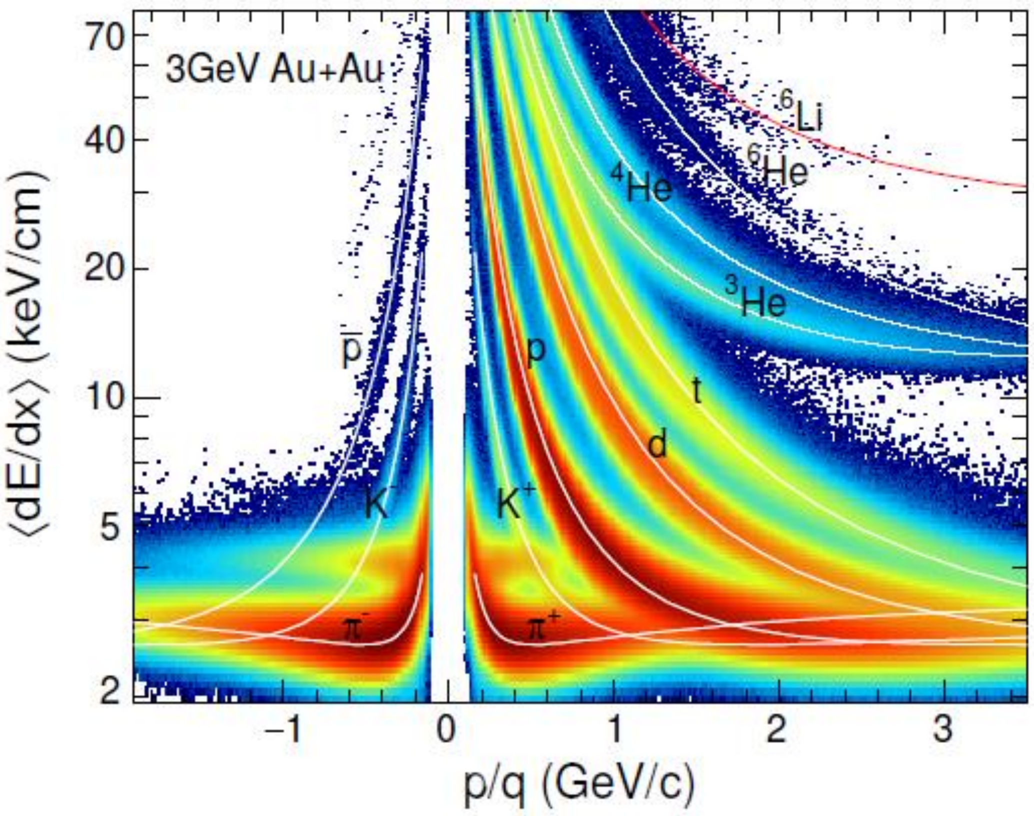


Online Event Display – FXT Event

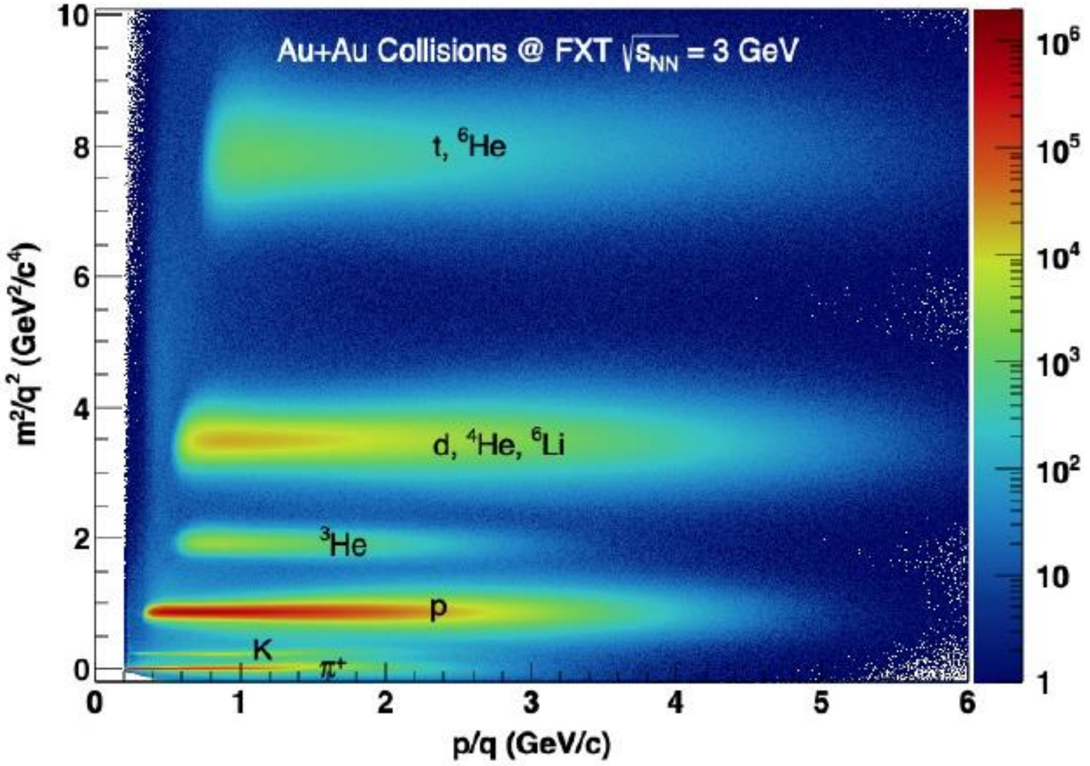


STAR light fragment particle identification

PID through dE/dx in the TPC gas

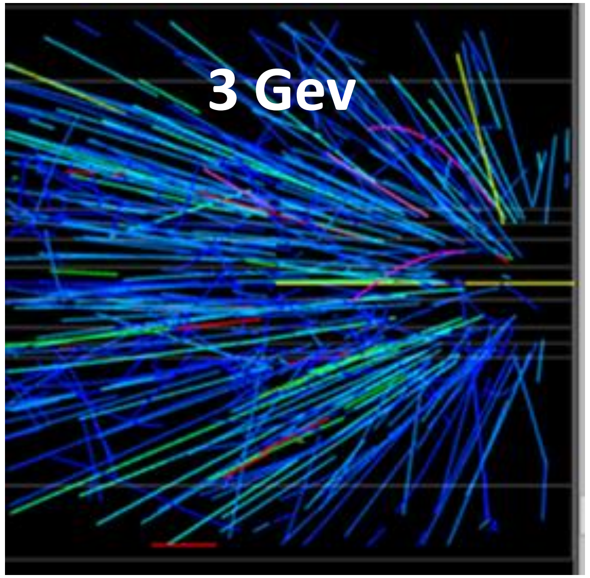


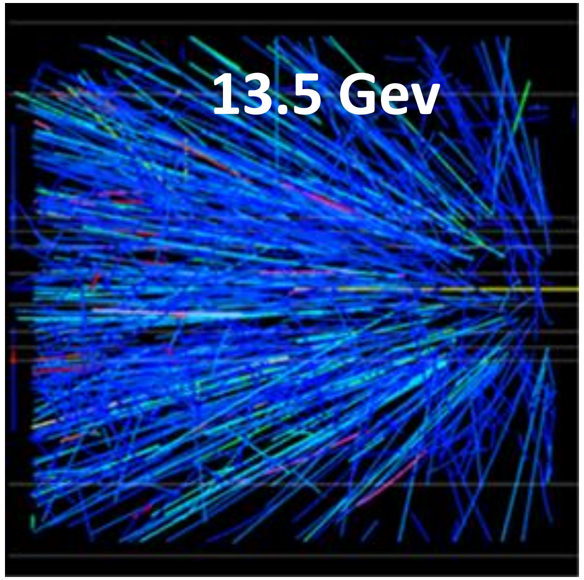
PID through Time-of-Flight

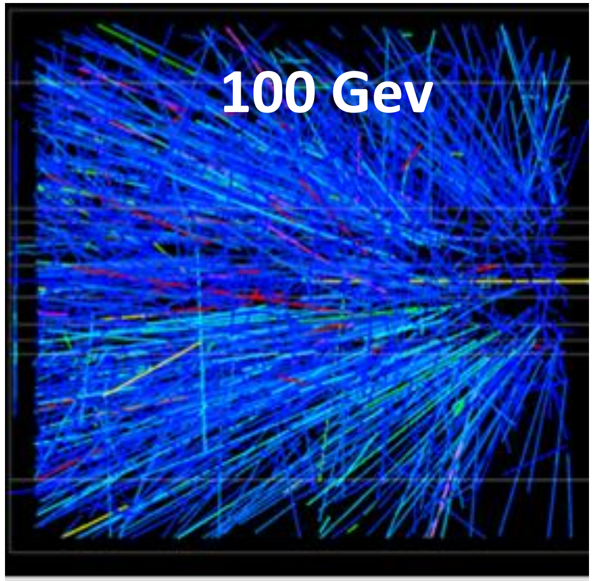


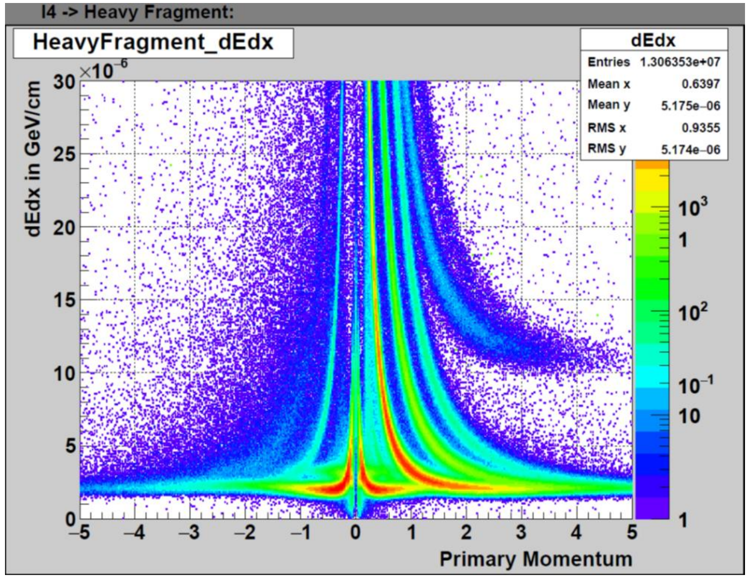
Performance with Beam Energy

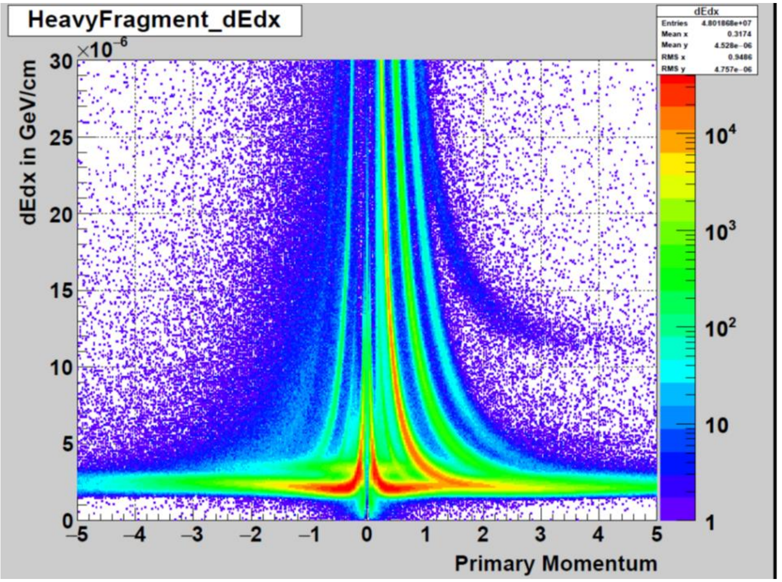
Fewer tracks, more helium nuclei

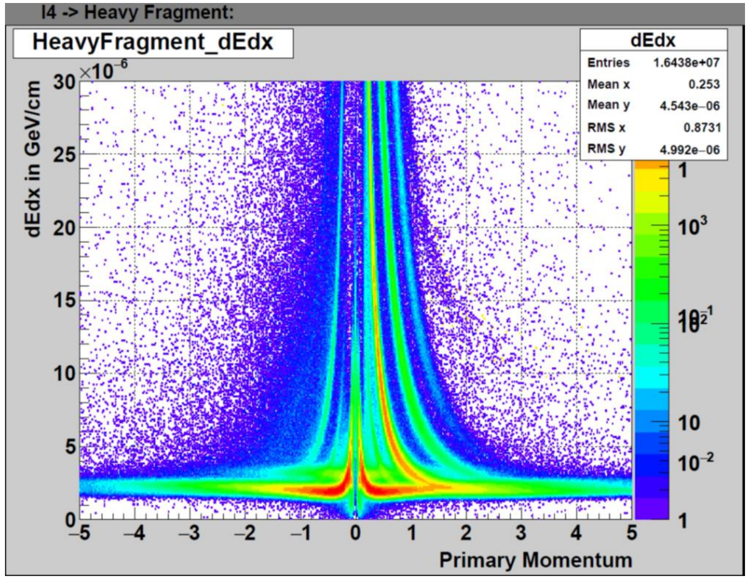








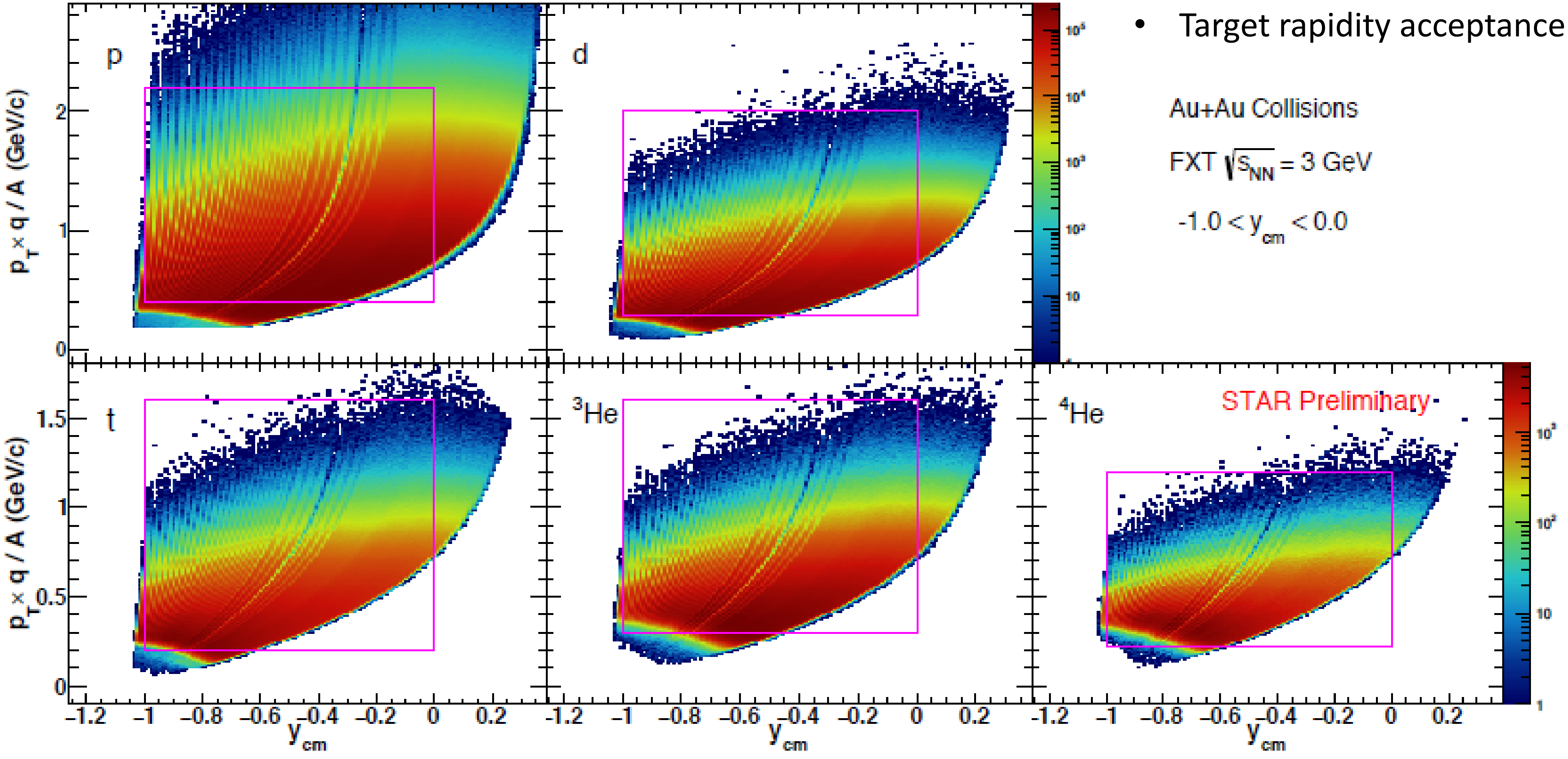




More tracks, fewer helium nuclei

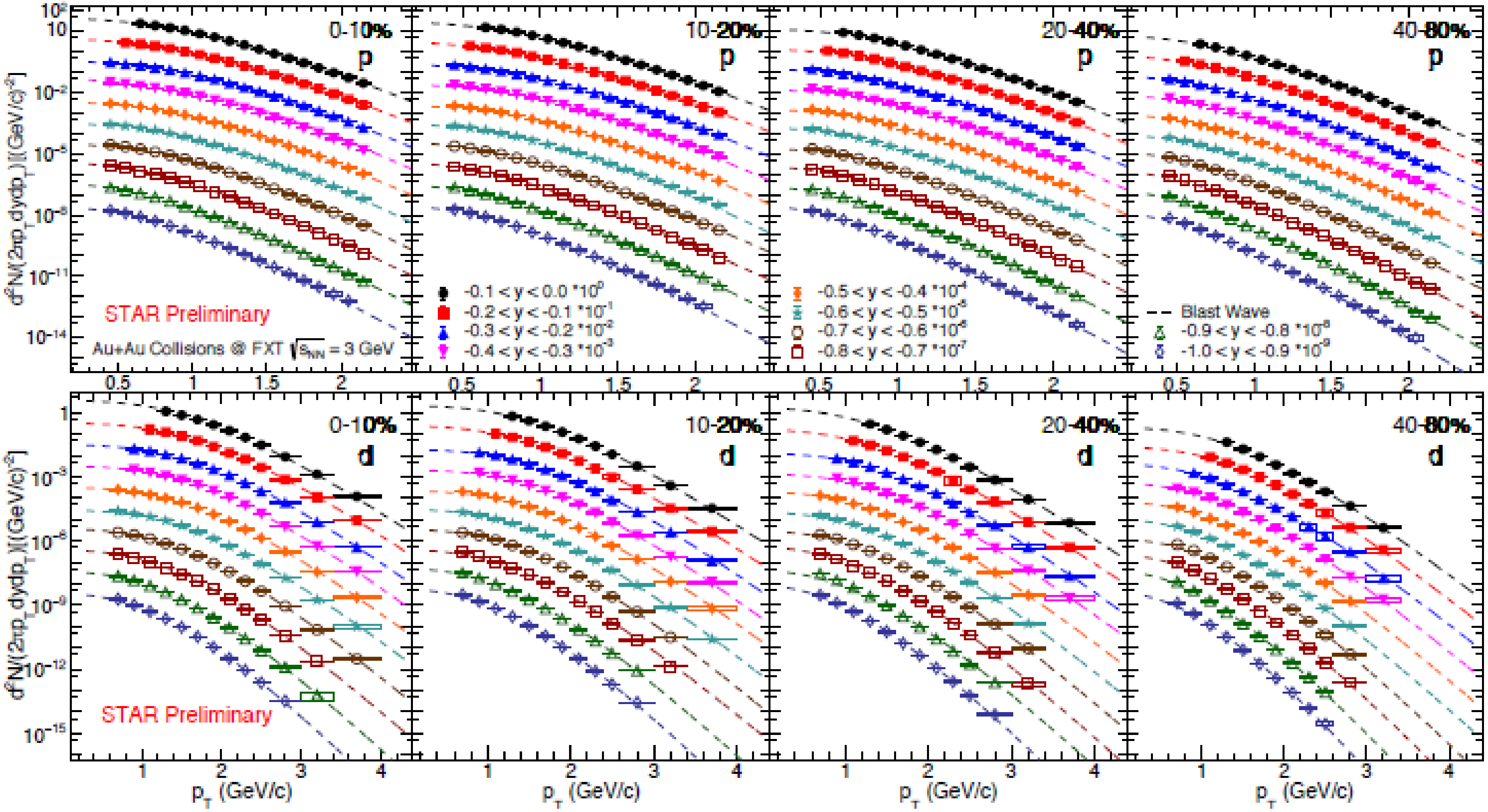
STAR light fragment acceptance

- Acceptance in 2018, now better
- Low p_T cut-in may be a challenge
- Target rapidity acceptance can be fixed



Spectra ➔ Differential Cross Sections protons and deuterons

3 GeV Au+Au



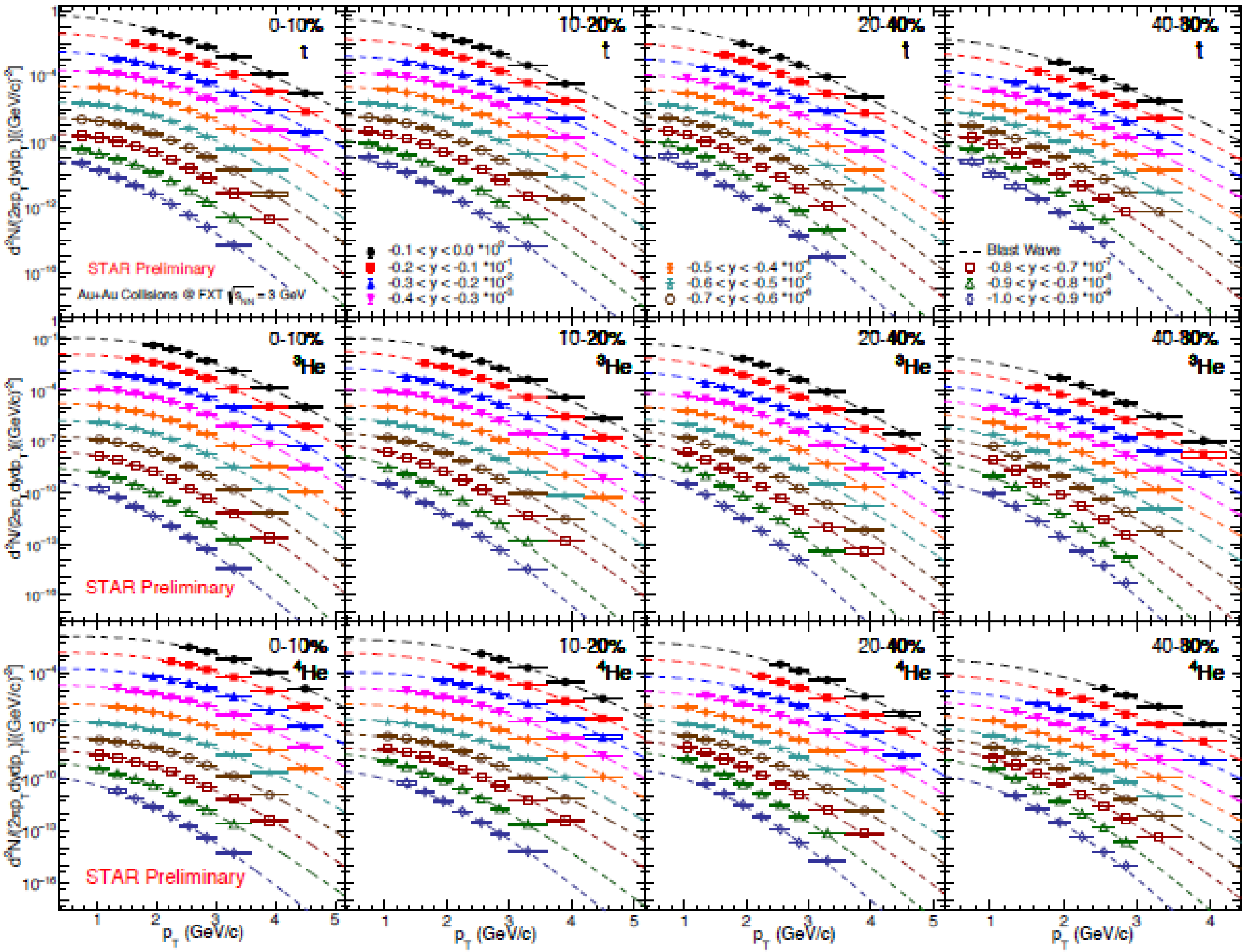
Spectra – tritons, ^{3}He, and ^{4}He

3 GeV Au+Au

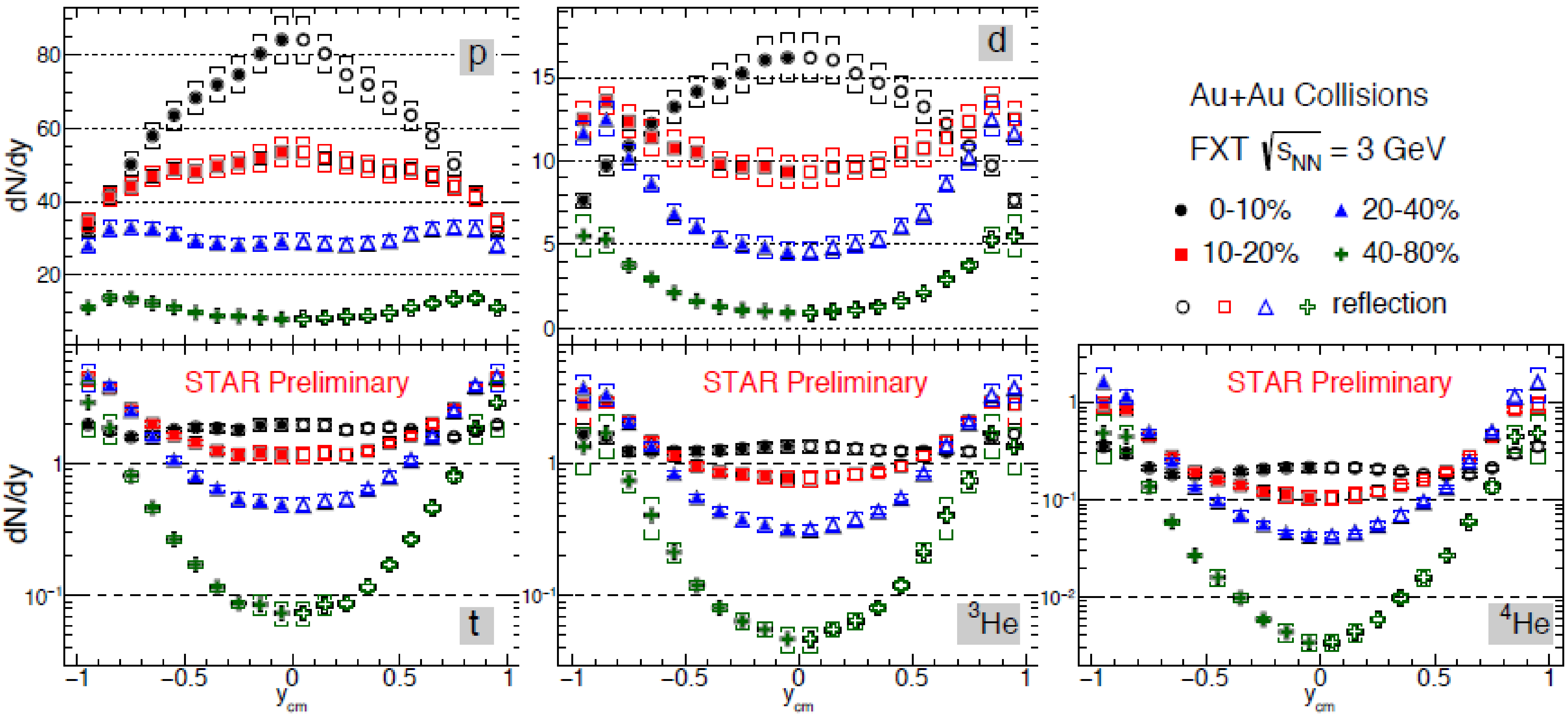
Triton

^{3}He

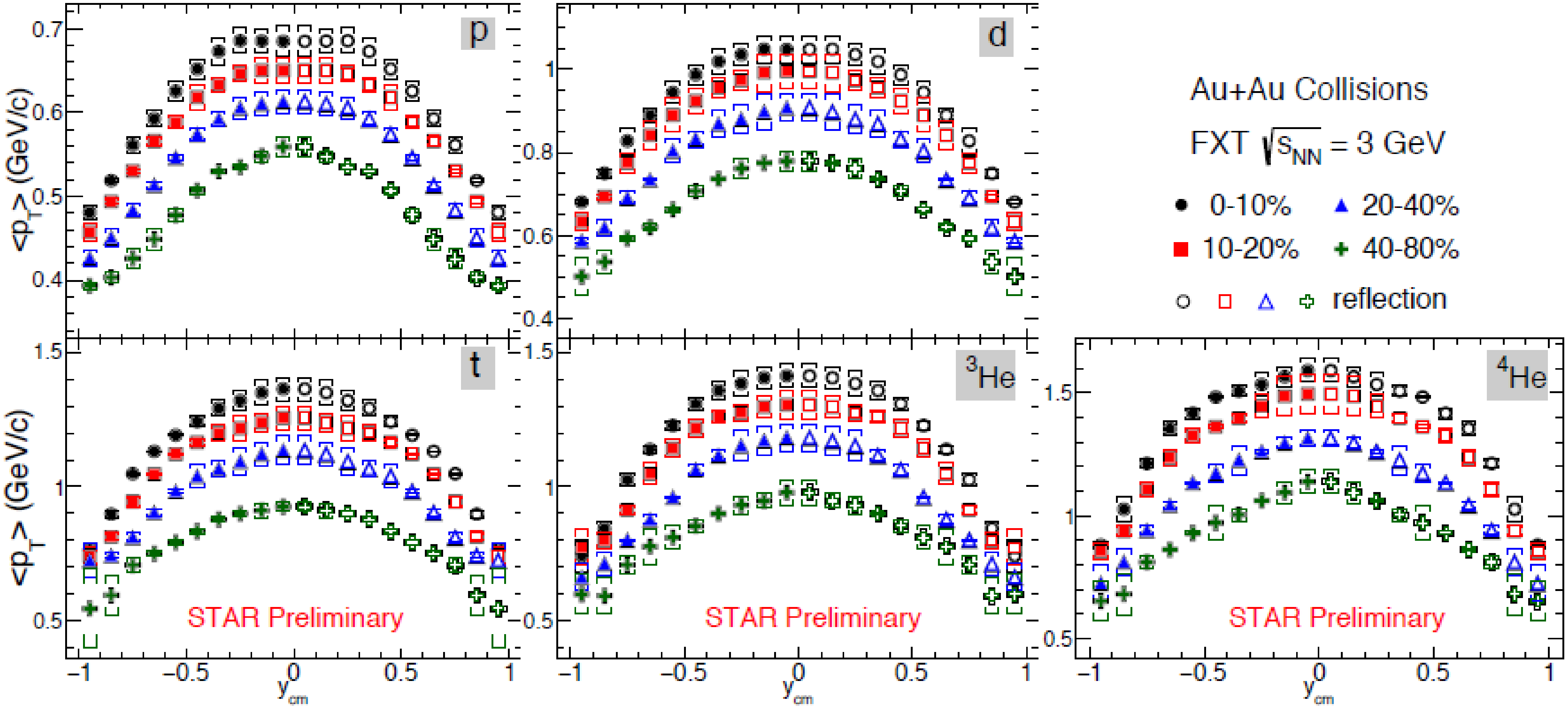
^{4}He



Yields of light nuclei



Average p_T for light nuclei



Summary

- **Light fragment cross section data are needed for projectiles in the energy range 3-50 GeV.**
- **RHIC/STAR have capabilities that can fill that need.**
- **We could run this program during the 2023-2025 running periods.**