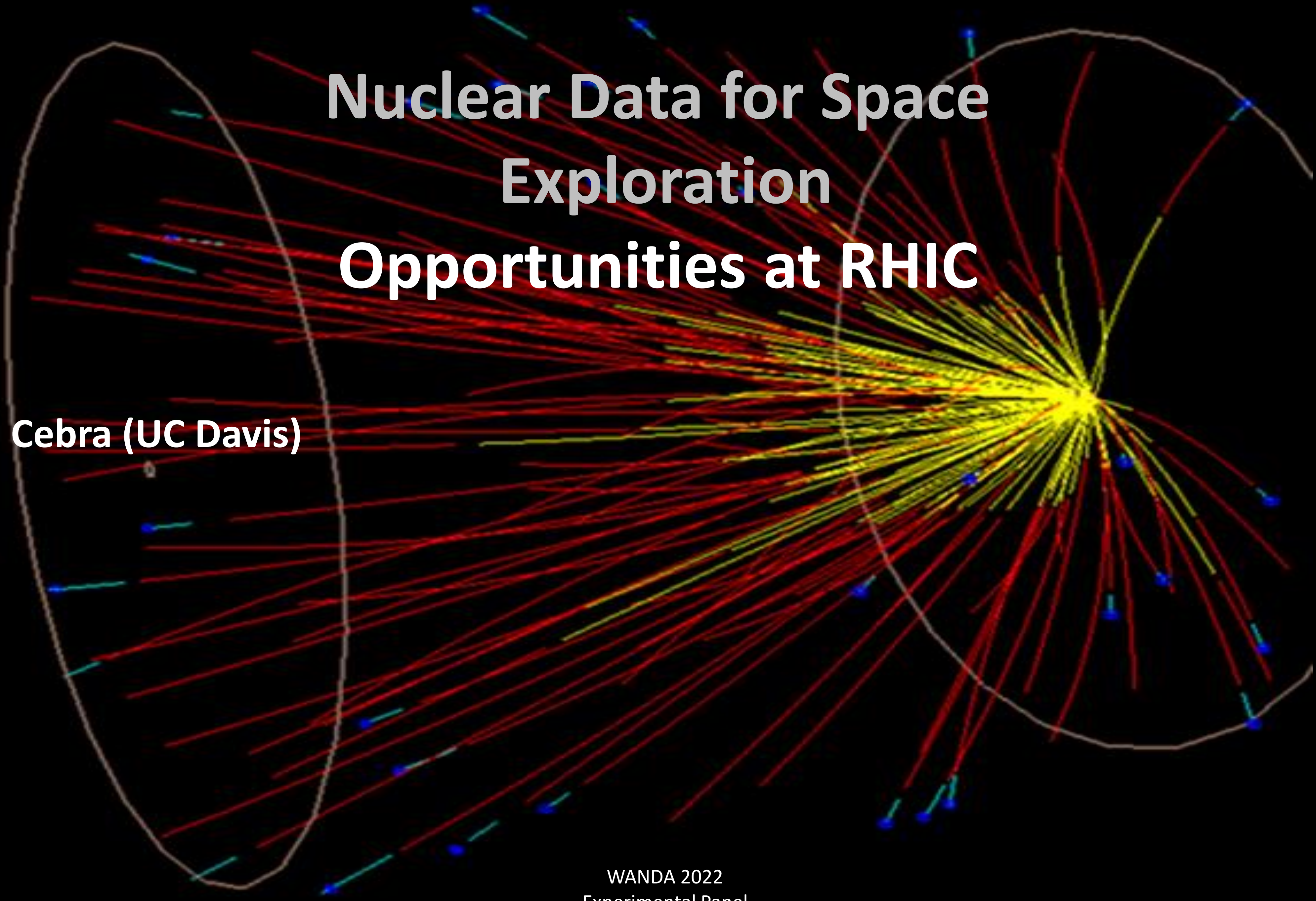


Nuclear Data for Space Exploration

Opportunities at RHIC

Daniel Cebra (UC Davis)

WANDA 2022
Experimental Panel

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

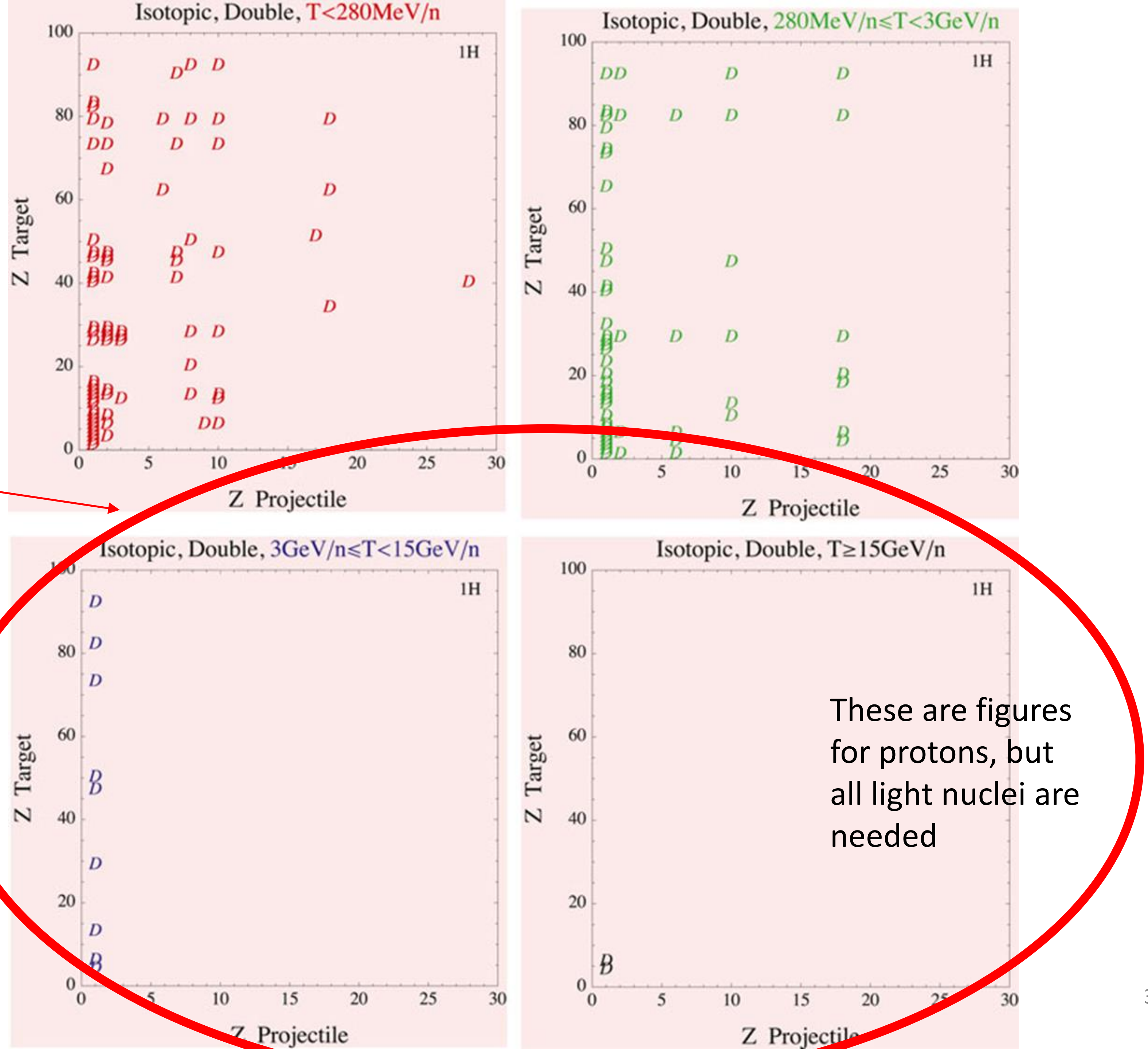
Note: This “opportunity” was included in the STAR 2022-2025 Beam Use Request

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

High Energy double differential measurements are needed

(See John Norbury's Monday presentations)

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



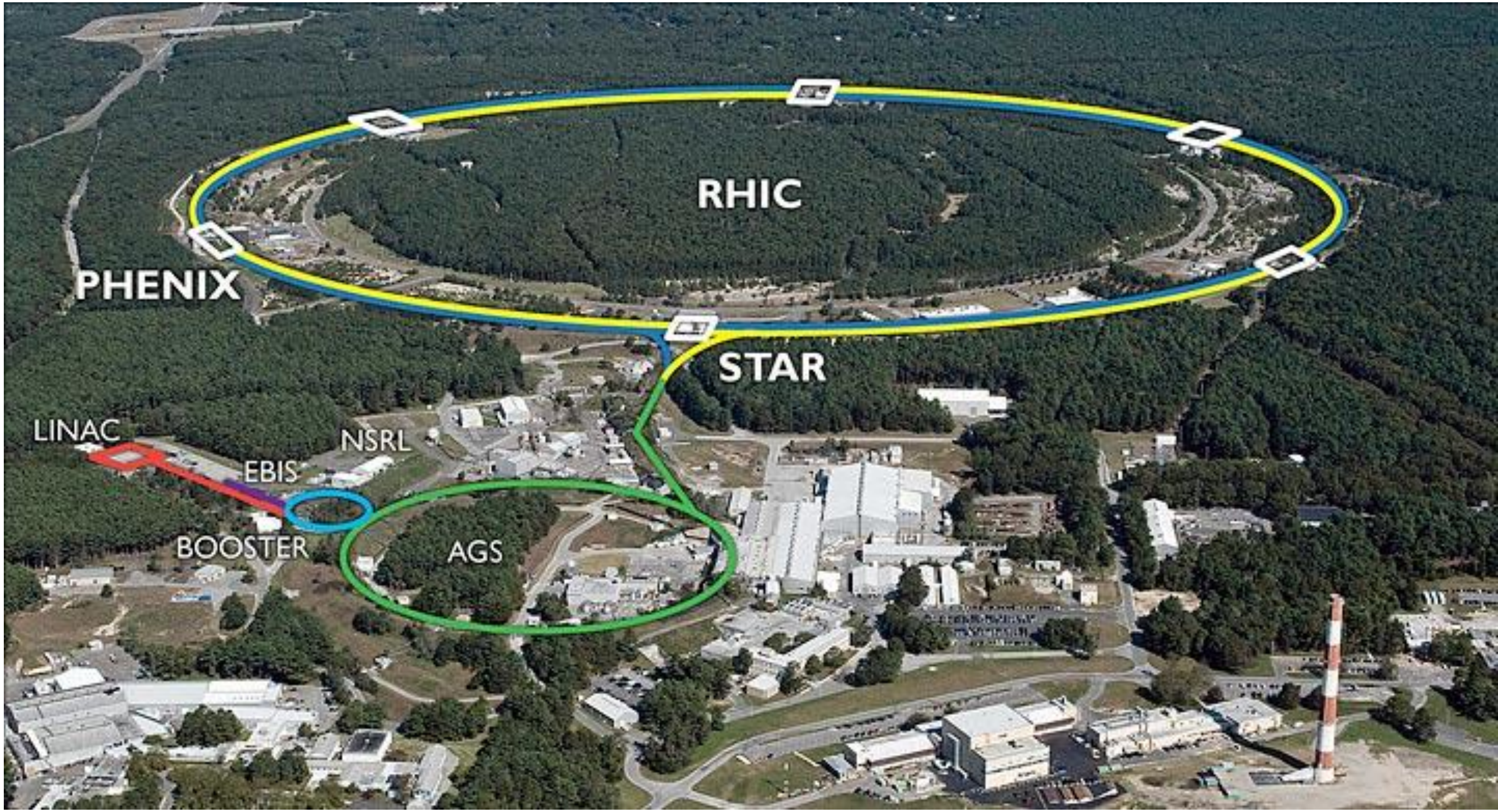
- Identified as a key need for space radiation protection
- RHIC can supply the beam species and energies of interest
- STAR can make the double differential measurements

Overview of the Accelerator Facility

Ion Sources:
- LINAC
- EBIS
- Tandems

Synchrotrons:
- Booster
- AGS
- RHIC

Experimental Areas
- NSRL
- RHIC IP6 (STAR)
- RHIC IP8 (PHENIX)



STAR has completed a fixed target energy scan using Au beams from 3-100 AGeV on Au targets.

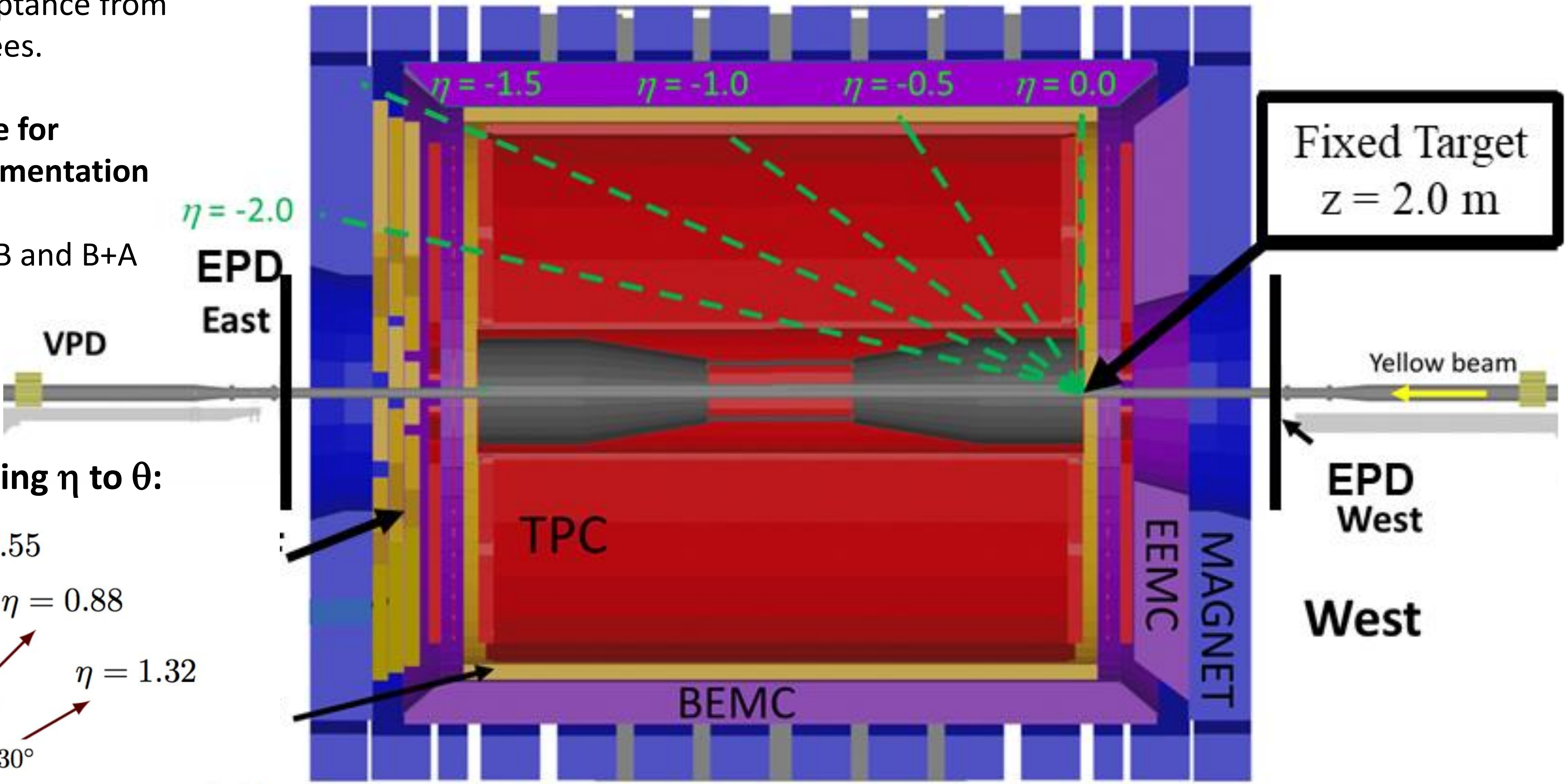
➔ **Could install other targets, and run other beams**

Side Cross Section of STAR

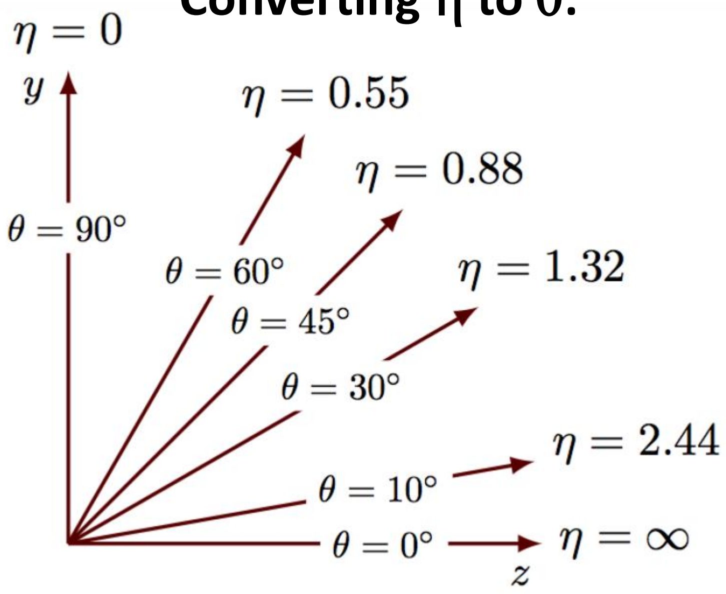
Using a collider detector as a fixed-target experiment

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

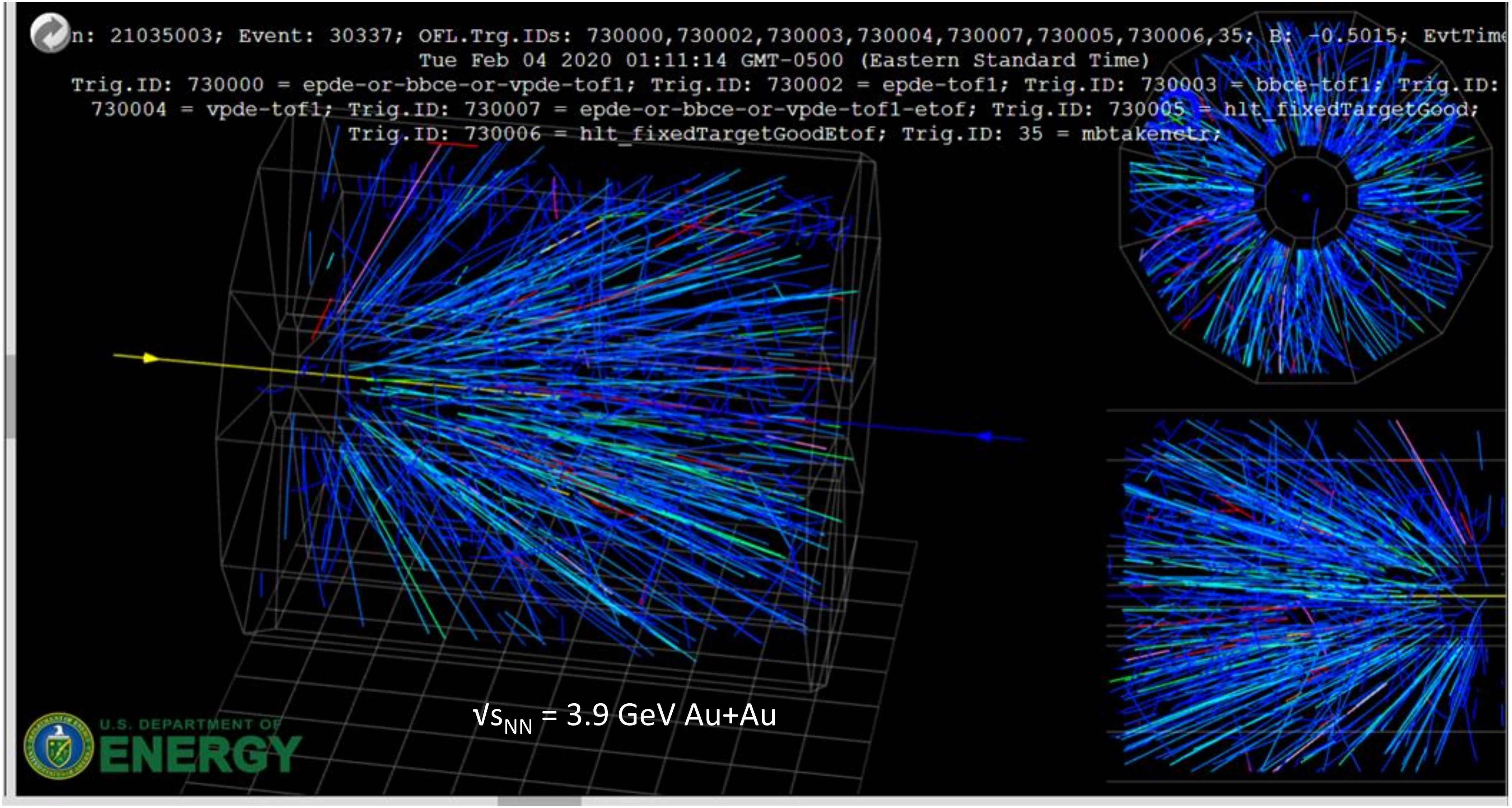
➔ Must have A+B and B+A



Converting η to θ:

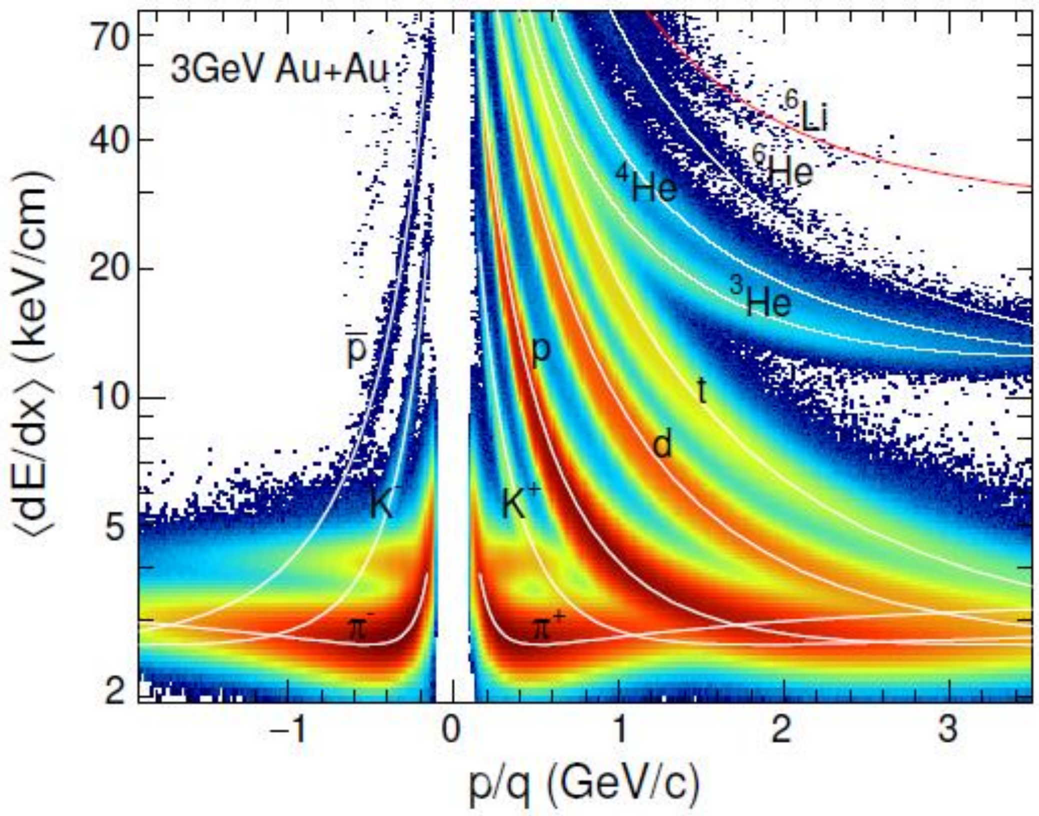


Online Event Display – FXT Event

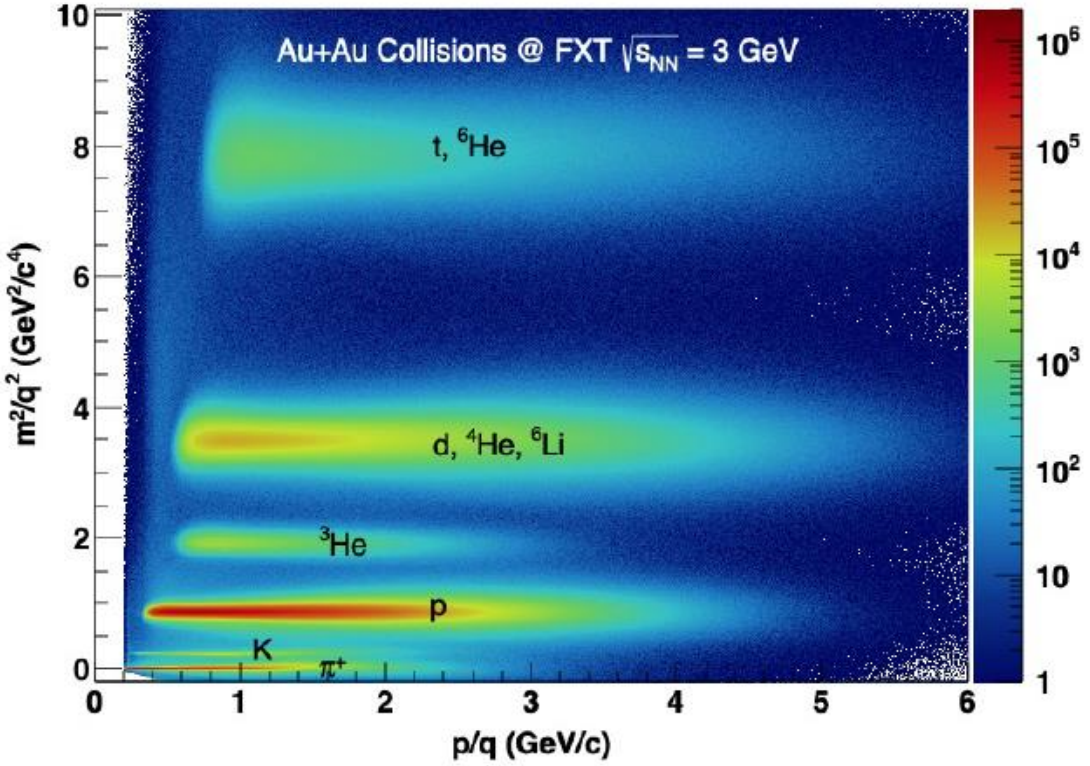


STAR light fragment particle identification

PID through dE/dx in the TPC gas

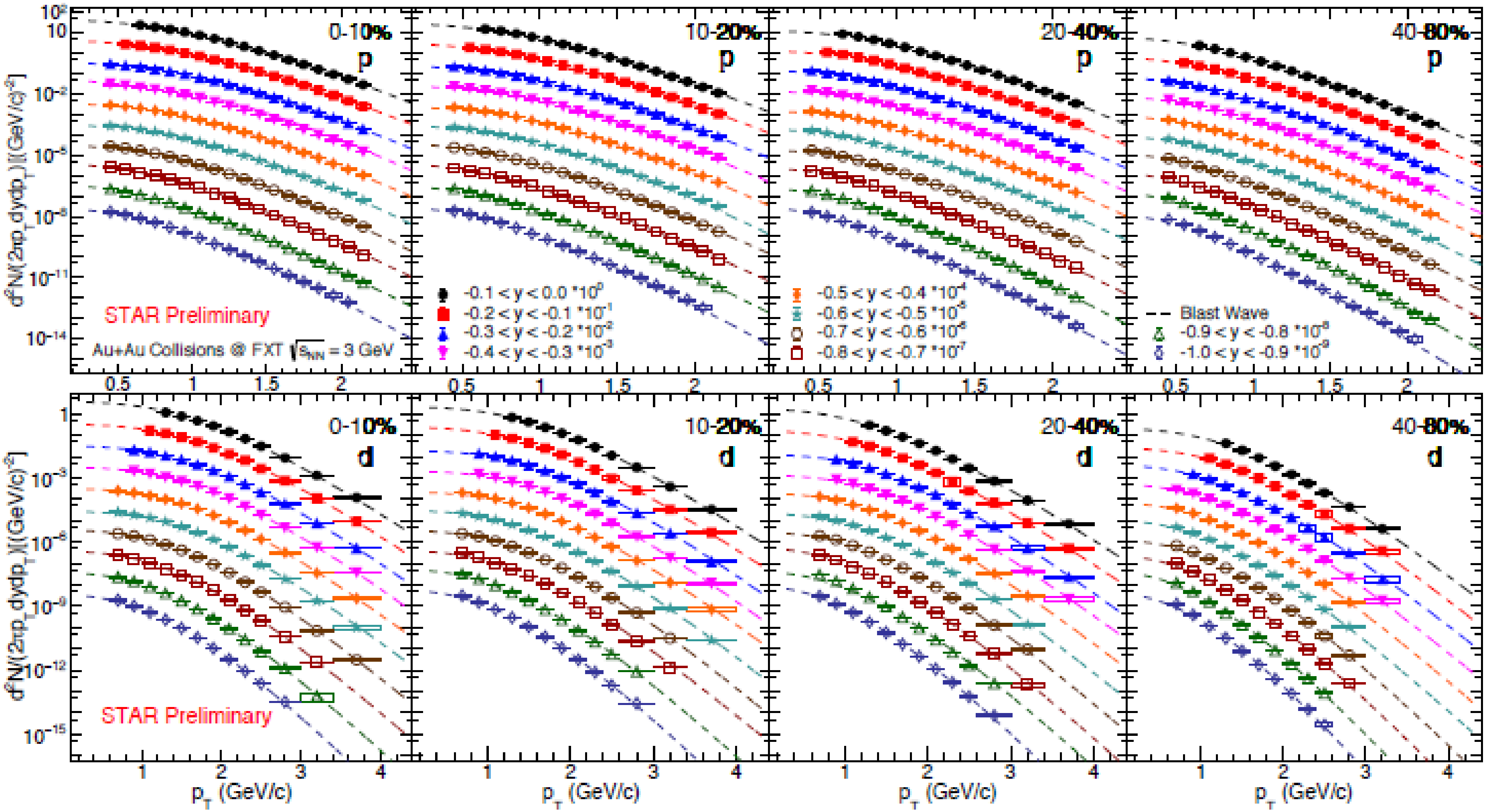


PID through Time-of-Flight



Spectra → Differential Cross Sections protons and deuterons

3 GeV Au+Au



Spectra – tritons, ^{3}He, and ^{4}He

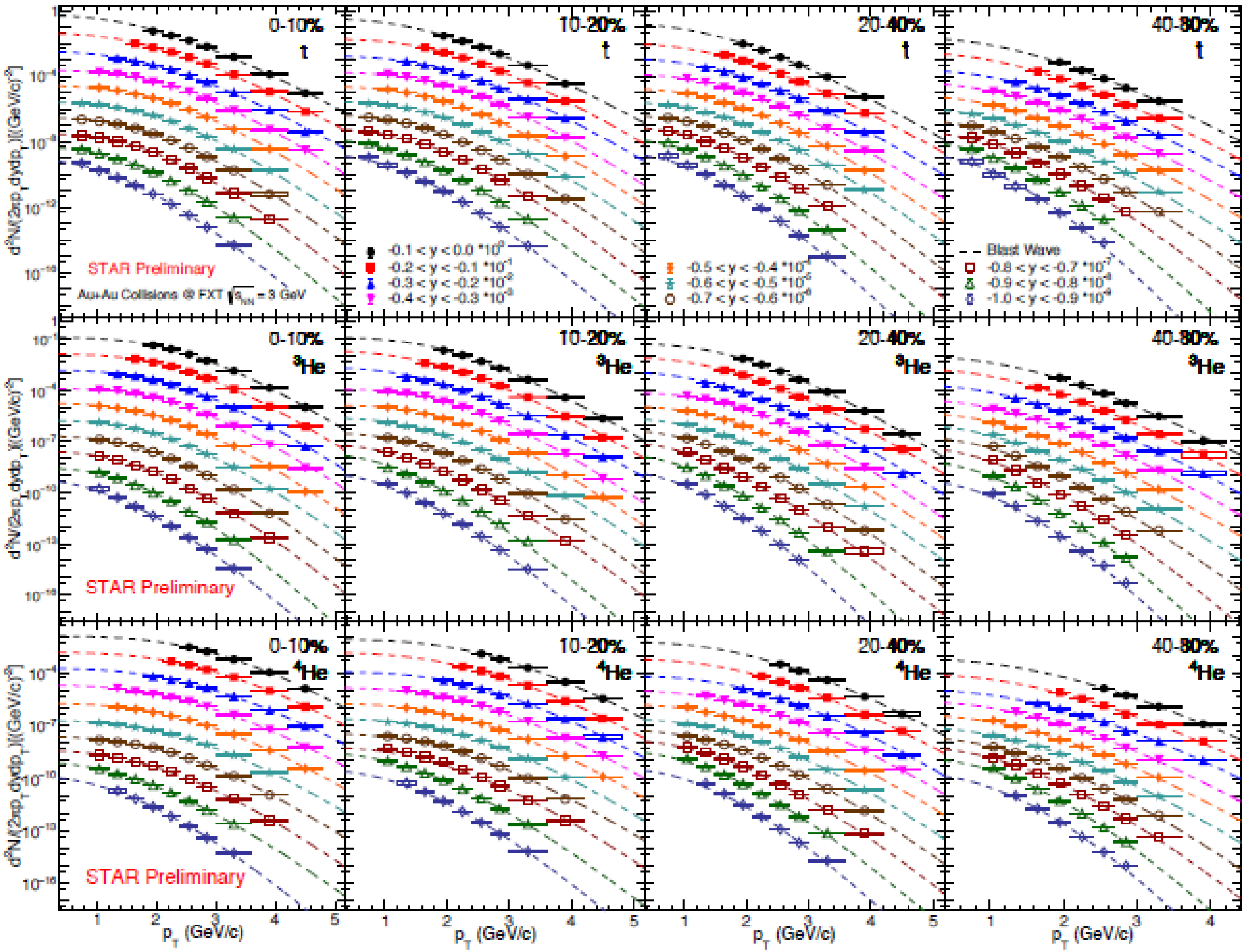
3 GeV Au+Au

Triton

^{3}He

^{4}He

Note, the low p_T thresholds could be a problems



Summary

- **Light fragment cross section data are needed for projectiles in the energy range 3-50 GeV.**

- **RHIC/STAR have capabilities that could contribution to filling that need.**
  ➔ As long as the detector acceptances are not prohibitive

- **We could run this program during the 2023-2025 running periods.**
  ➔ Scheduling beam time at RHIC is challenging, and a well considered proposal is necessary.

BACKUPS

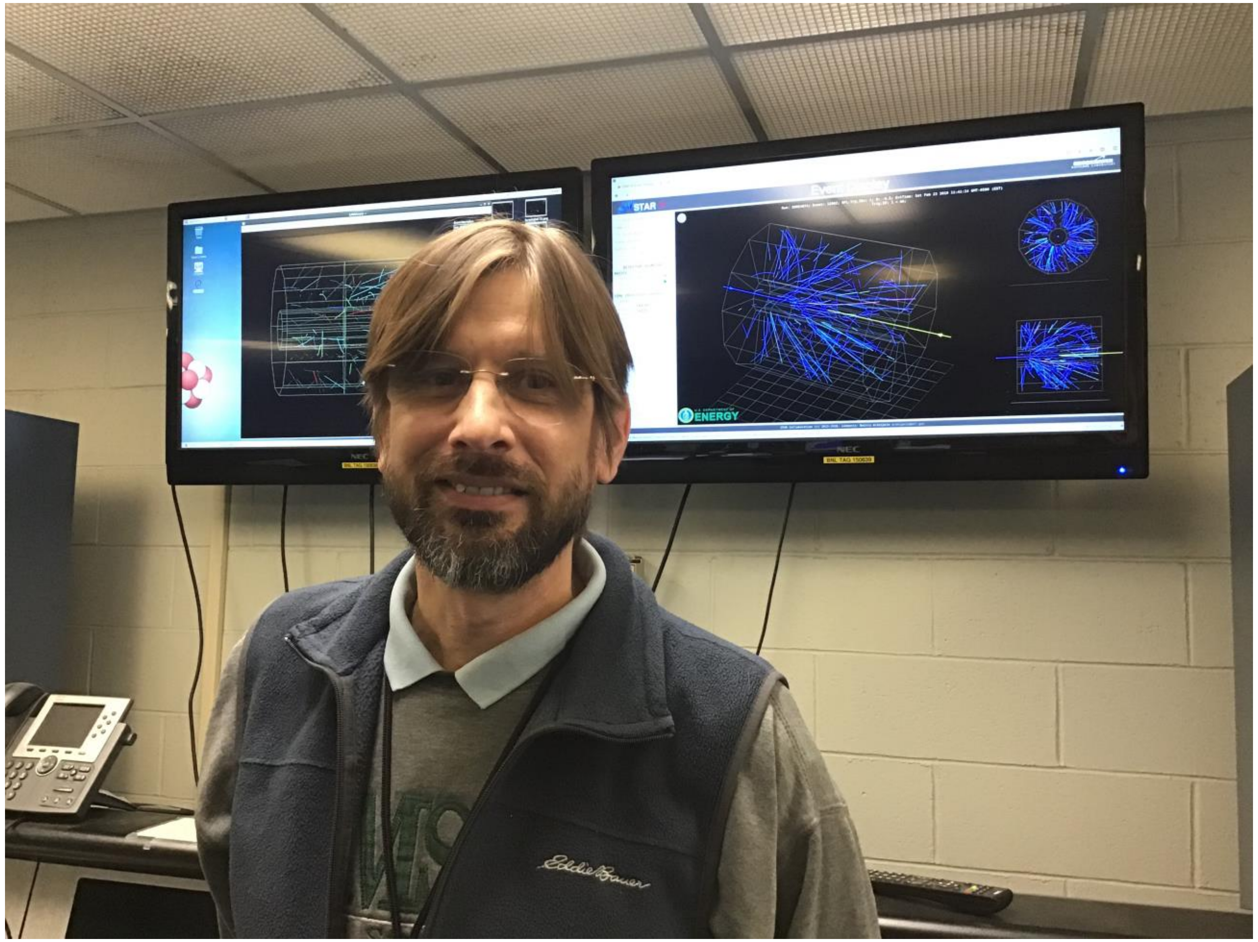
About me

- 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)
  - Principal Author: Beam Energy Scan Proposal (2009)
  - Principal Author: BES-II Proposal (2015)
  - Principal Author: **Fixed-Target Program** (2017)
  - Deputy Project Manager: iTPC upgrade (2017-2019)

And... a frequent visitor at Brookhaven Lab
  - Sabbatical Leave (1999)
  - Sabbatical Leave (AY 2018/2019)
  - Many summers
  - Shifts at RHIC every year

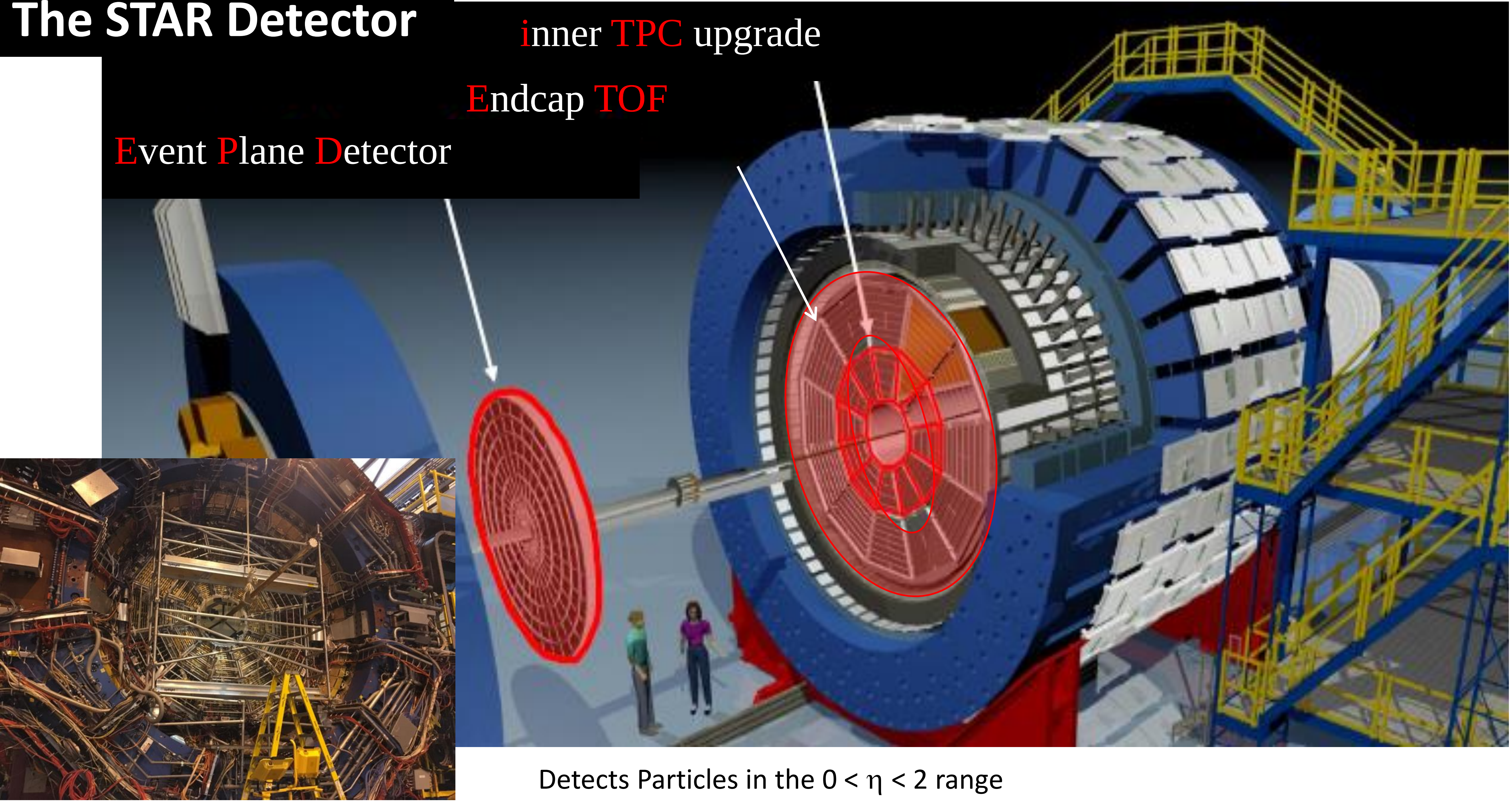


Why I am her:
The RHIC/STAR Fixed-Target program may be able to meet some of the Nuclear Data needs.

Justification: (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).

The STAR Detector

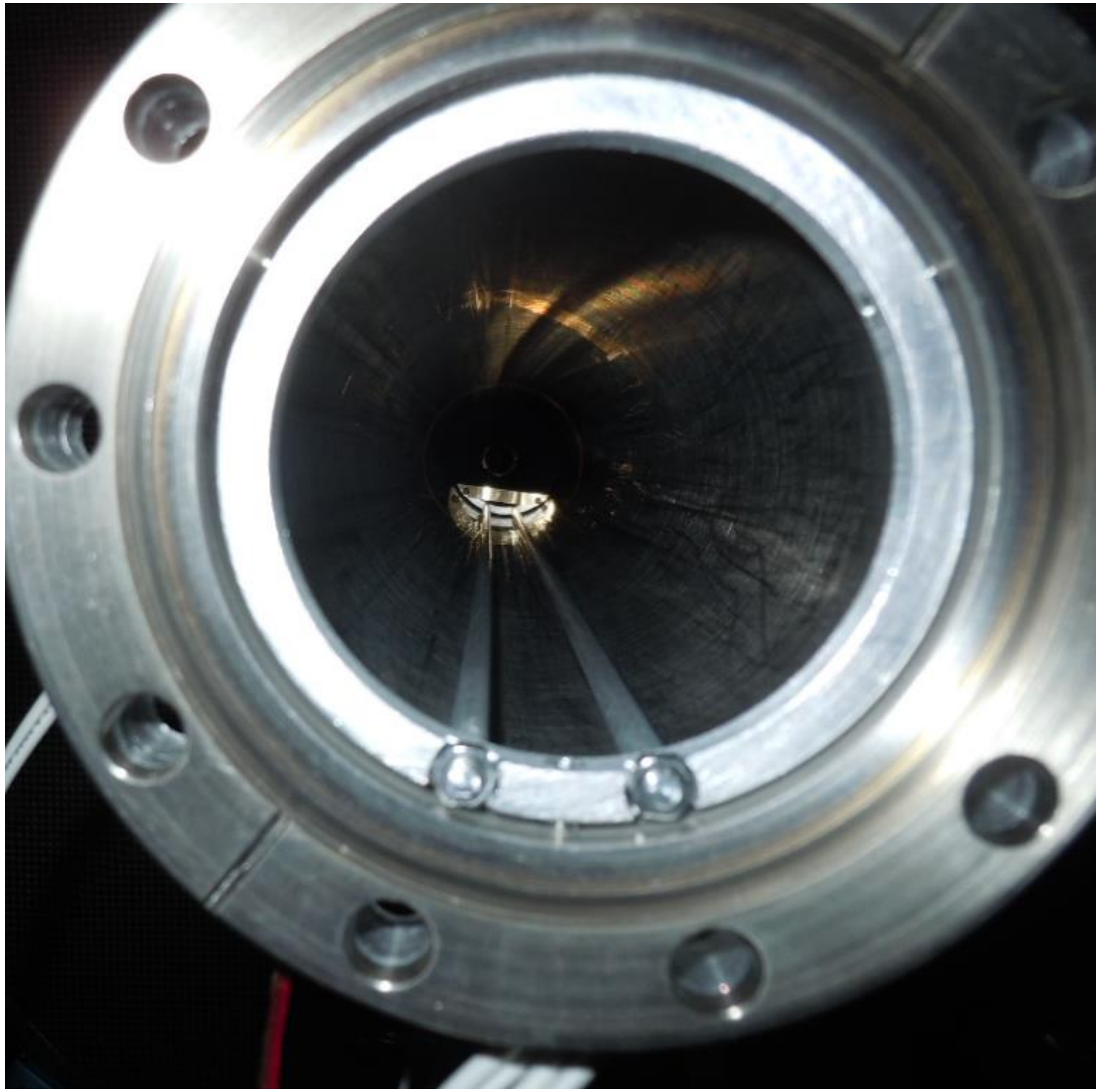


Detects Particles in the $0 < \eta < 2$ range
π, K, p, d, t, h, α through dE/dx and TOF
K^0_s, Λ, Ξ, Ω, ϕ, ${}^3_\Lambda H$, ${}^4_\Lambda H$ through invariant mass

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**



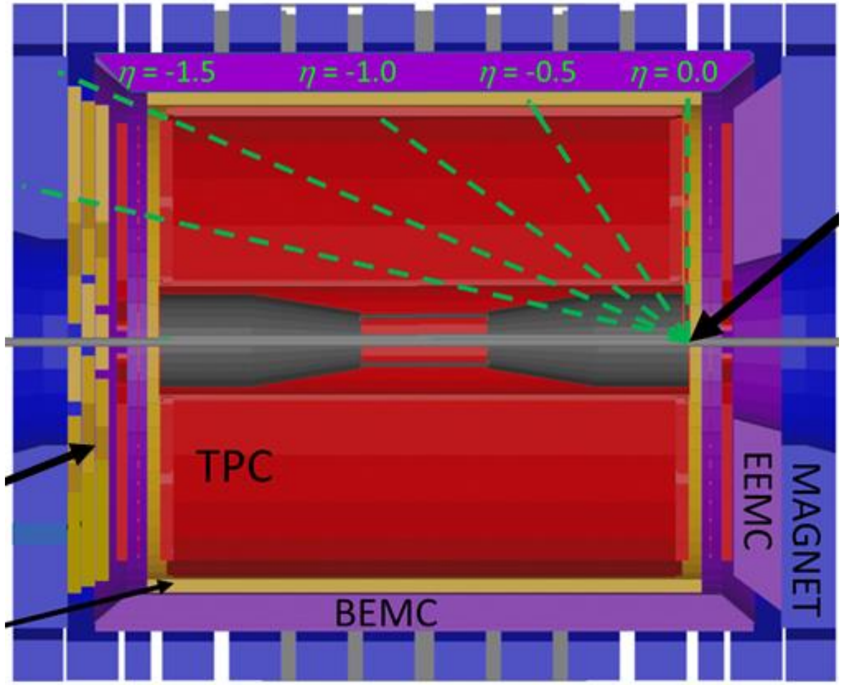
Acceptance for the FXT Program

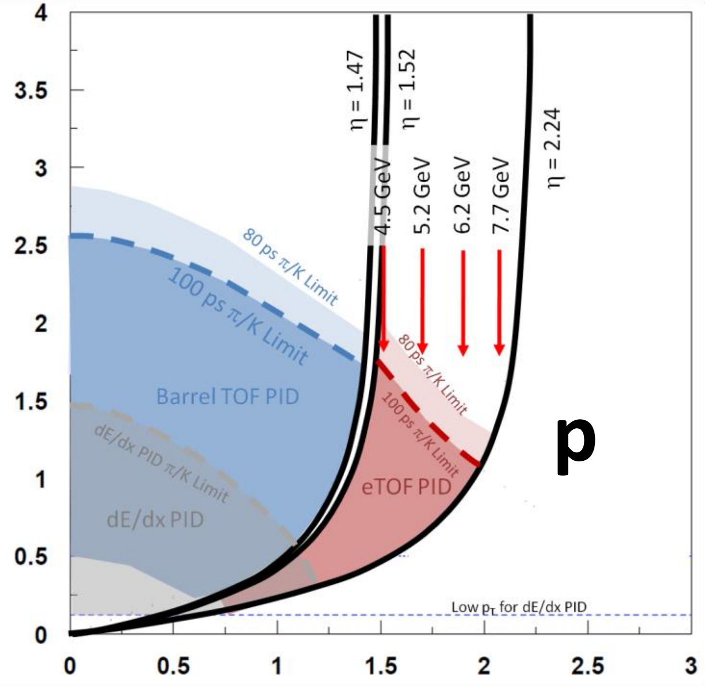
From 2018-2021, RHIC/STAR has beam running a fixed-target program performing an energy scan of gold beams on a gold target.

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

Note that acceptance is dependent on the collision energy

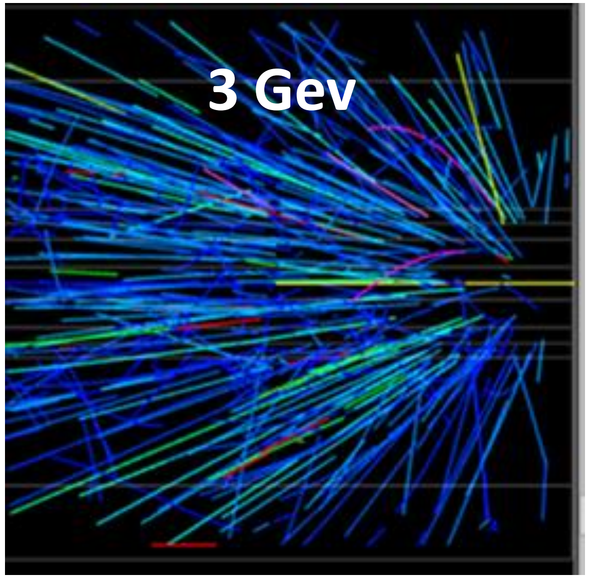
FXT Energy $\sqrt{s_{NN}}$	Single Beam E_T (GeV)	Single beam E_k (AGeV)	Center-of-mass Rapidity	Chemical Potential μ_B (MeV)	Year of Data Taking
3.0	3.85	**2.9**	1.05	721	2018
3.2	4.59	**3.6**	1.13	699	2019
3.5	5.75	**4.8**	1.25	666	2020
3.9	7.3	**6.3**	1.37	633	2020
4.5	9.8	**8.9**	1.52	589	2020
5.2	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

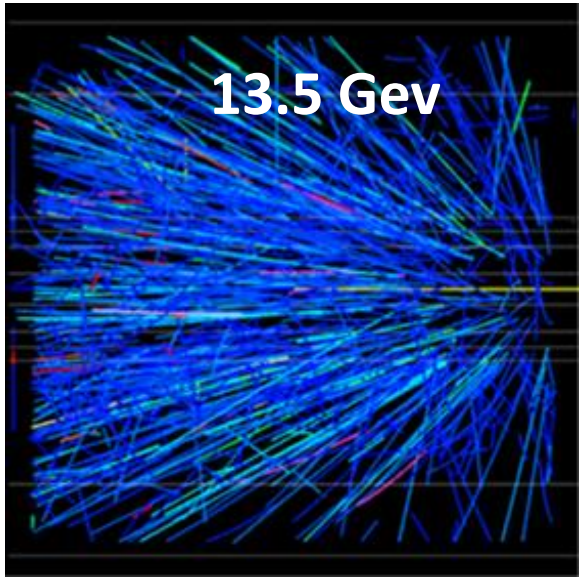


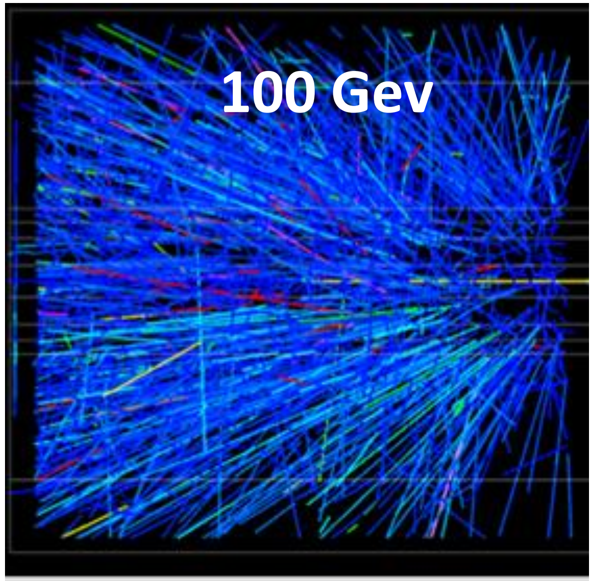


Performance with Beam Energy

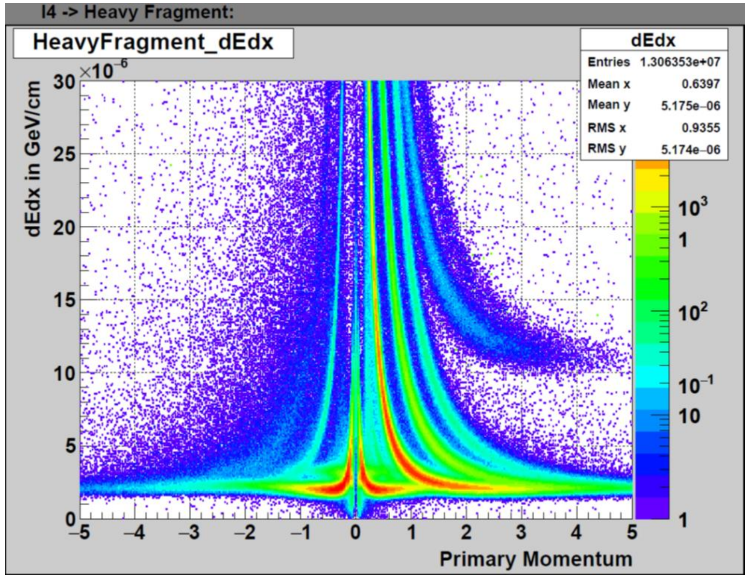
Fewer tracks, more helium nuclei

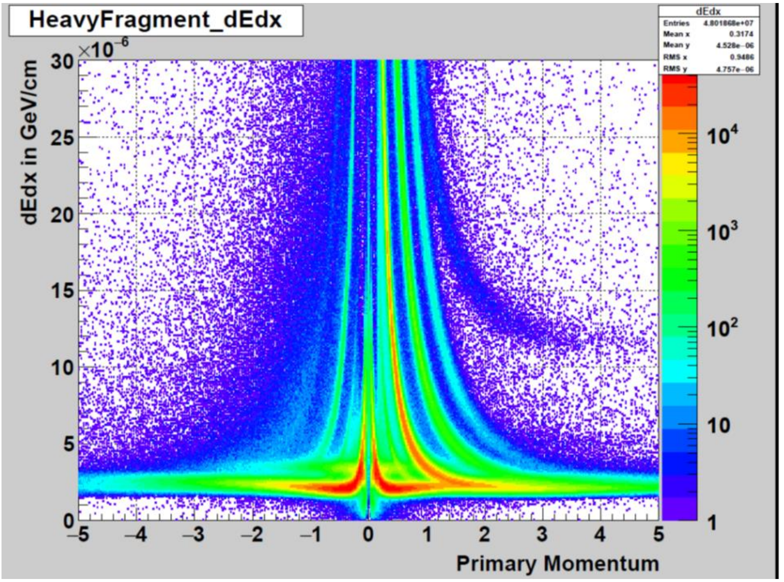


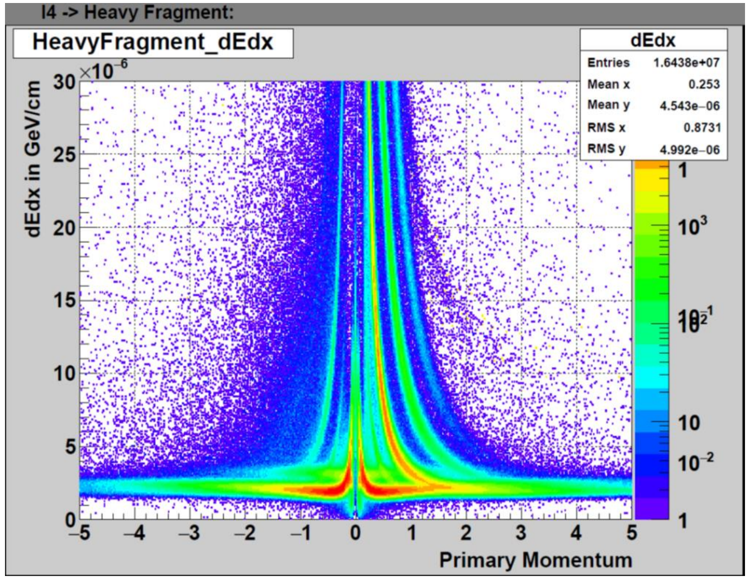




More tracks, fewer helium nuclei

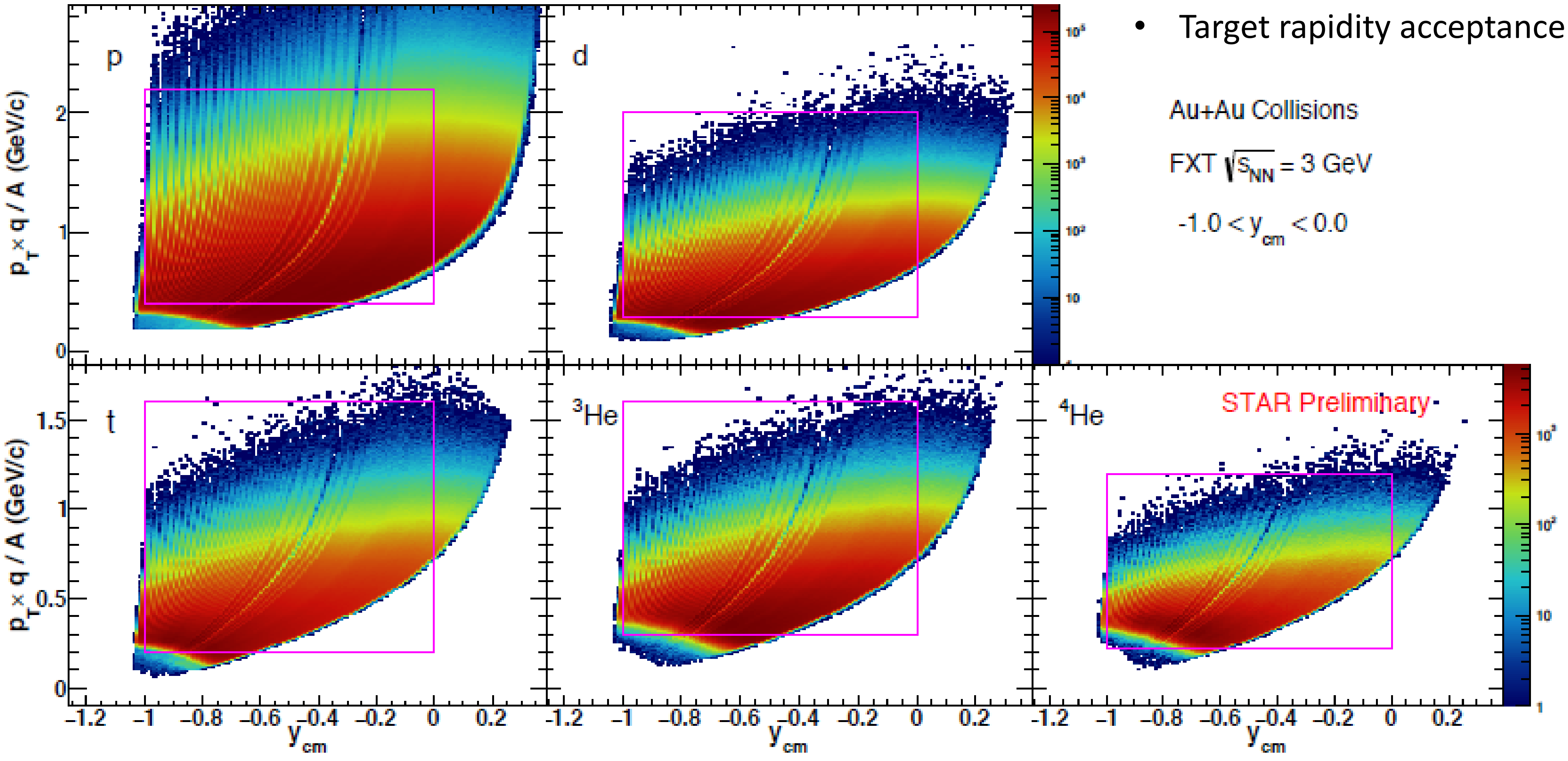




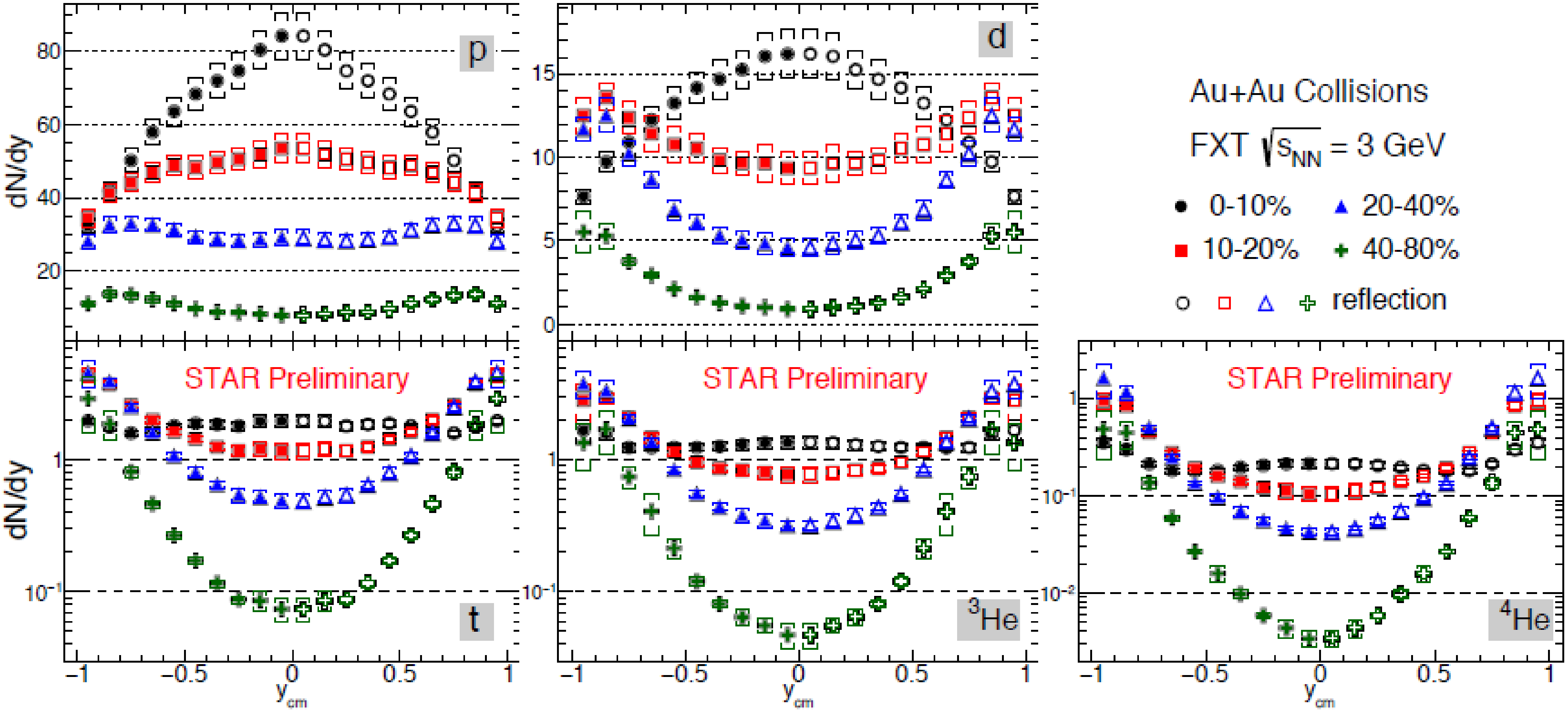


STAR light fragment acceptance

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



Yields of light nuclei



Average p_T for light nuclei