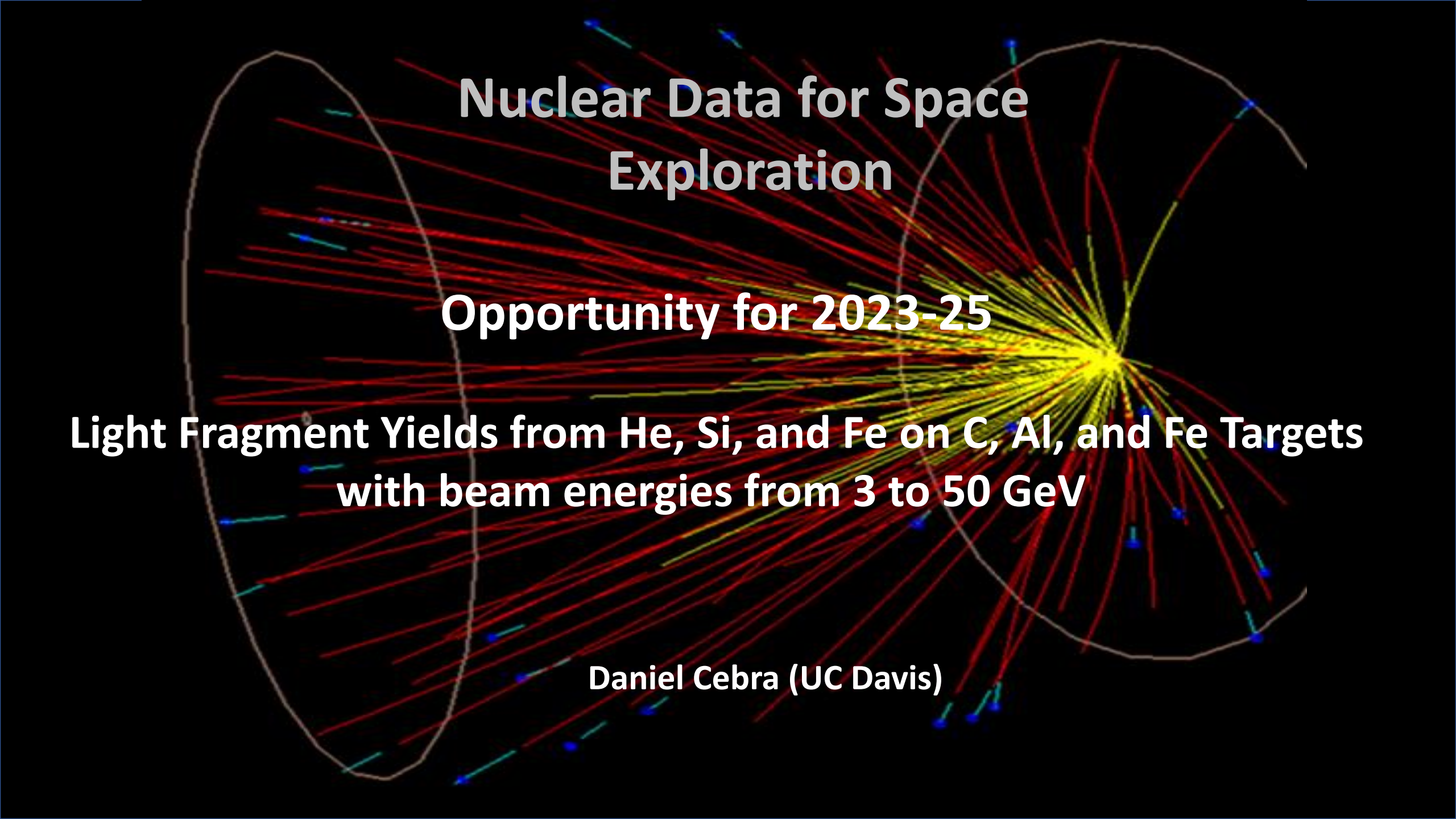


Nuclear Data for Space Exploration

Opportunity for 2023-25

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

Daniel Cebra (UC Davis)

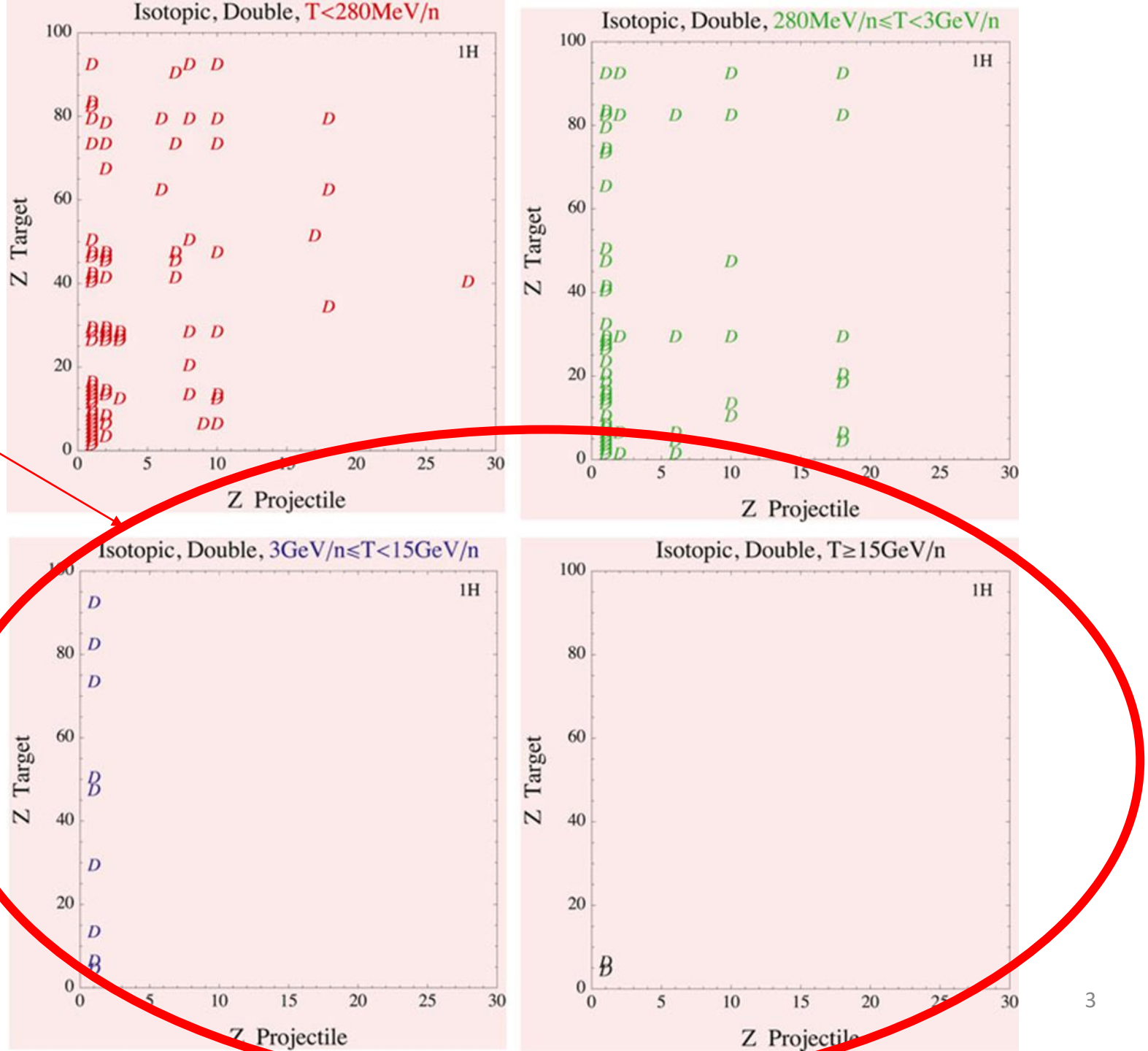
Justification:

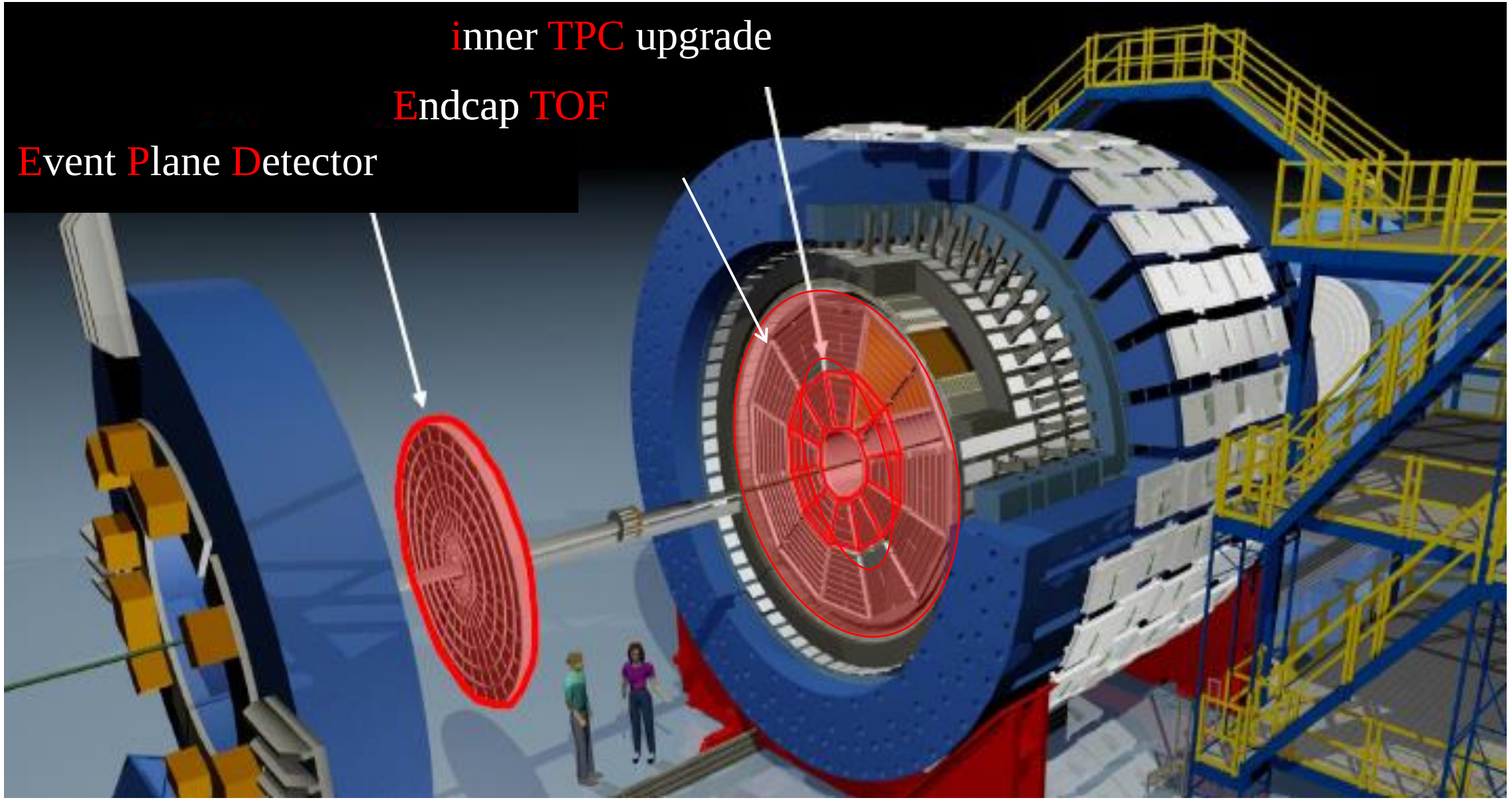
- **Cosmic rays are a serious concern to astronauts, electronics, and spacecraft.**
- **The cosmic ray flux is composed of nuclei (90% protons, 9% He, and 1% nuclei up to Fe.**
- **The damage is proportional to Z^2, therefore the component due to ions is very important**
- **Damage from secondary production 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. (At facilities like NRSL).**
- **No data exist for projectile energies from 3-50 GeV/n. *Energy range dominated by Galactic Cosmic Rays (GCR)***
- **The Space Radiation Protection community has identified this high energy regime as an area of need. https://doi.org/10.3389/fphy.2020.565954**
- **STAR has excellent light fragment capabilities.**
- **RHIC can deliver the ion beam species (He, 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

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

- Identified as a key need for space radiation protection
- Has support at the top level of DOE
- Has support from BNL administration
- Discussed at 2022 Workshop on the Applications of Nuclear Data and endorsed as a need of that community
- There are challenges for competing facilities

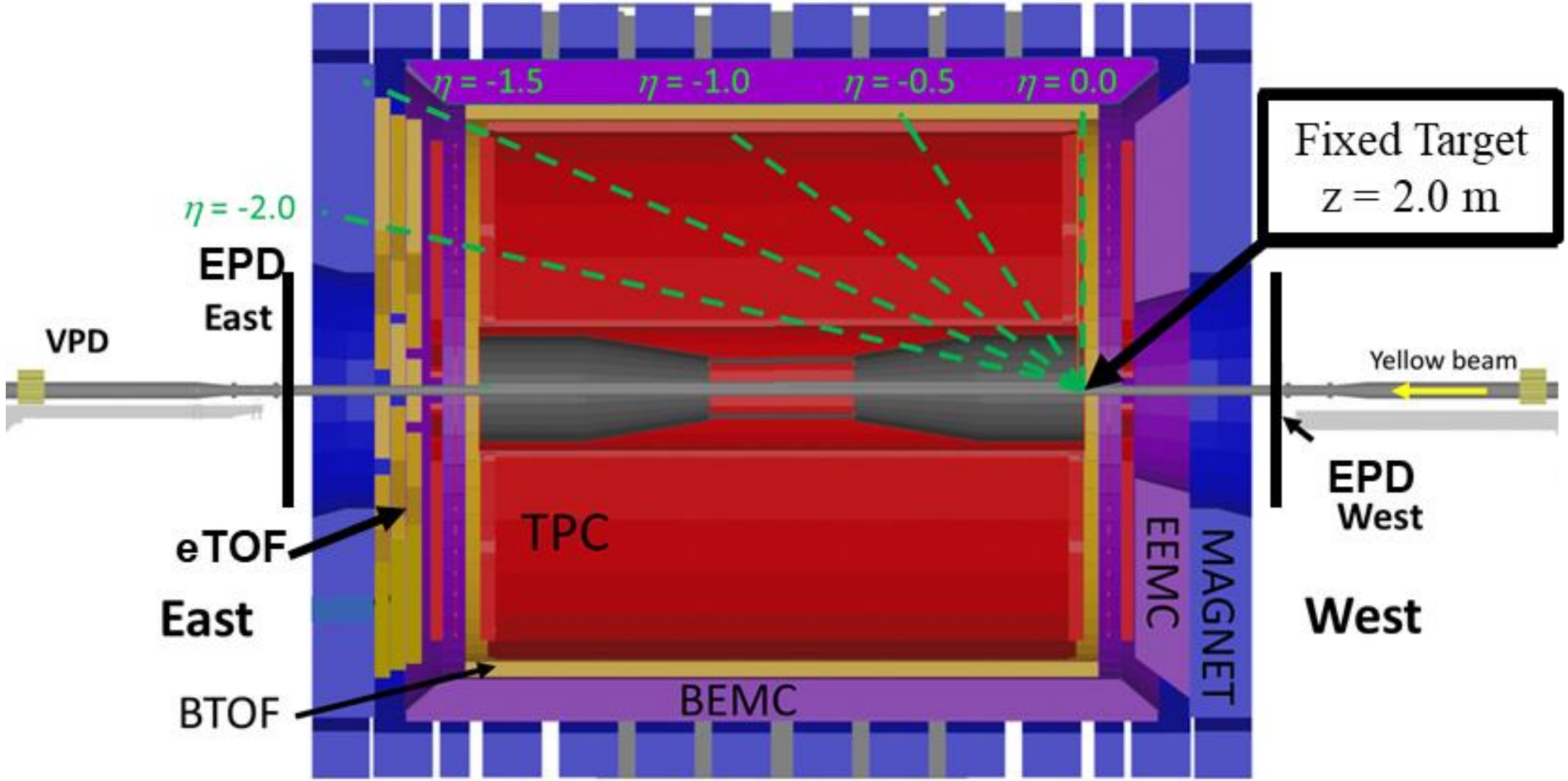


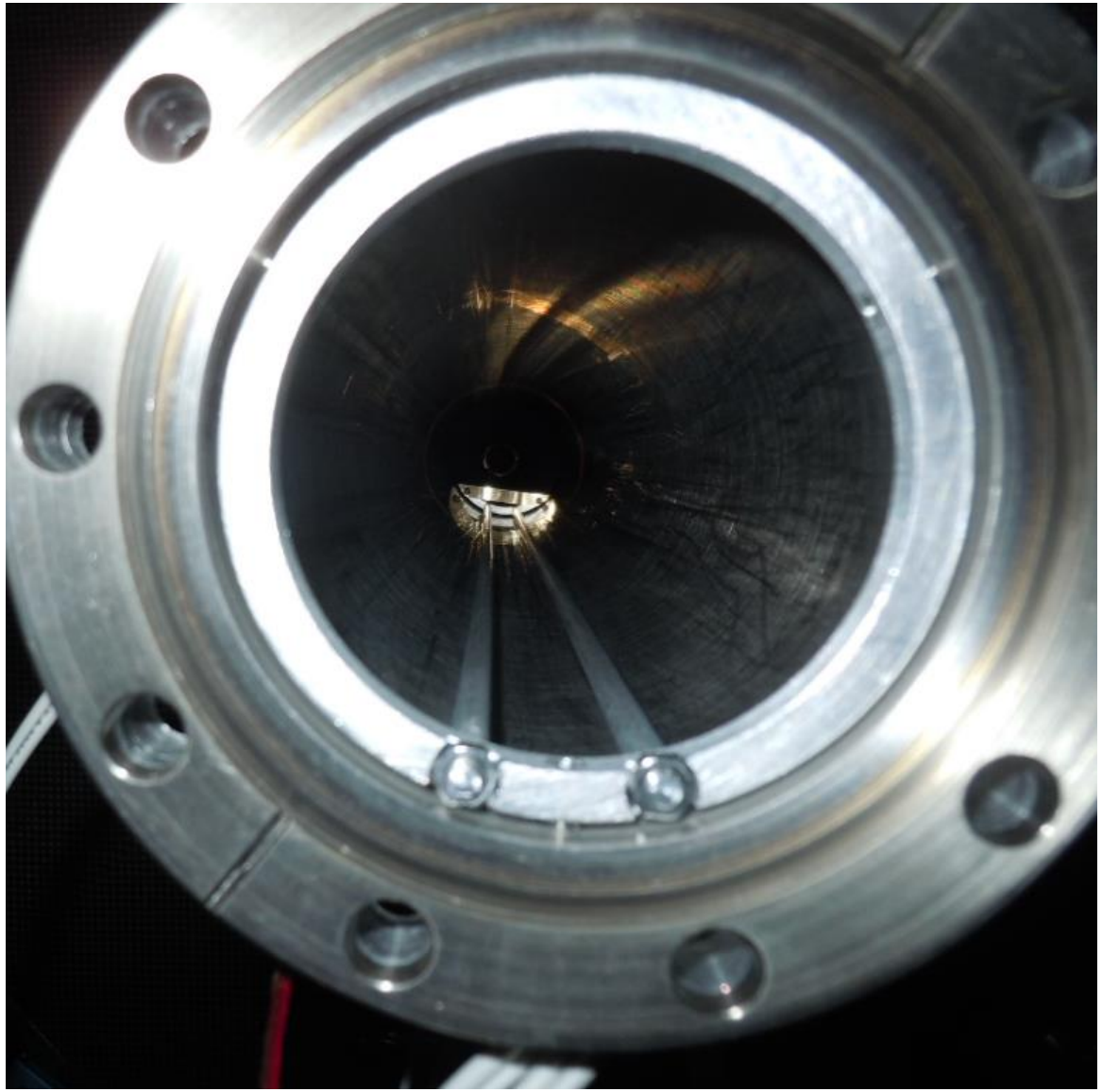


Detects Particles in the $0 < \eta < 2$ range

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

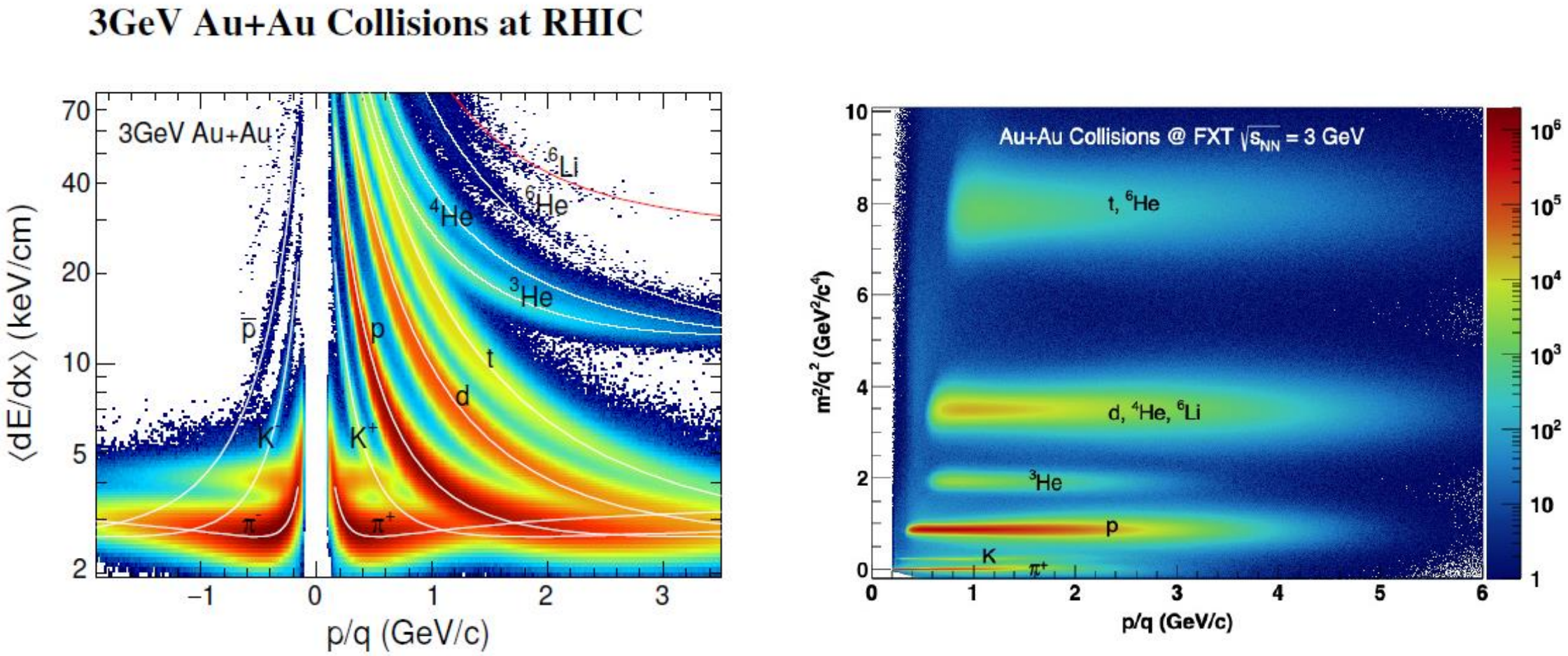

η = -1.5
η = -1.0
η = -0.5
η = 0.0
η = -2.0
EPD
East
VPD
Fixed Target
z = 2.0 m
Yellow beam
EPD
West
eTOF
East
TPC
EEMC
MAGNET
West
BTOF
BEMC



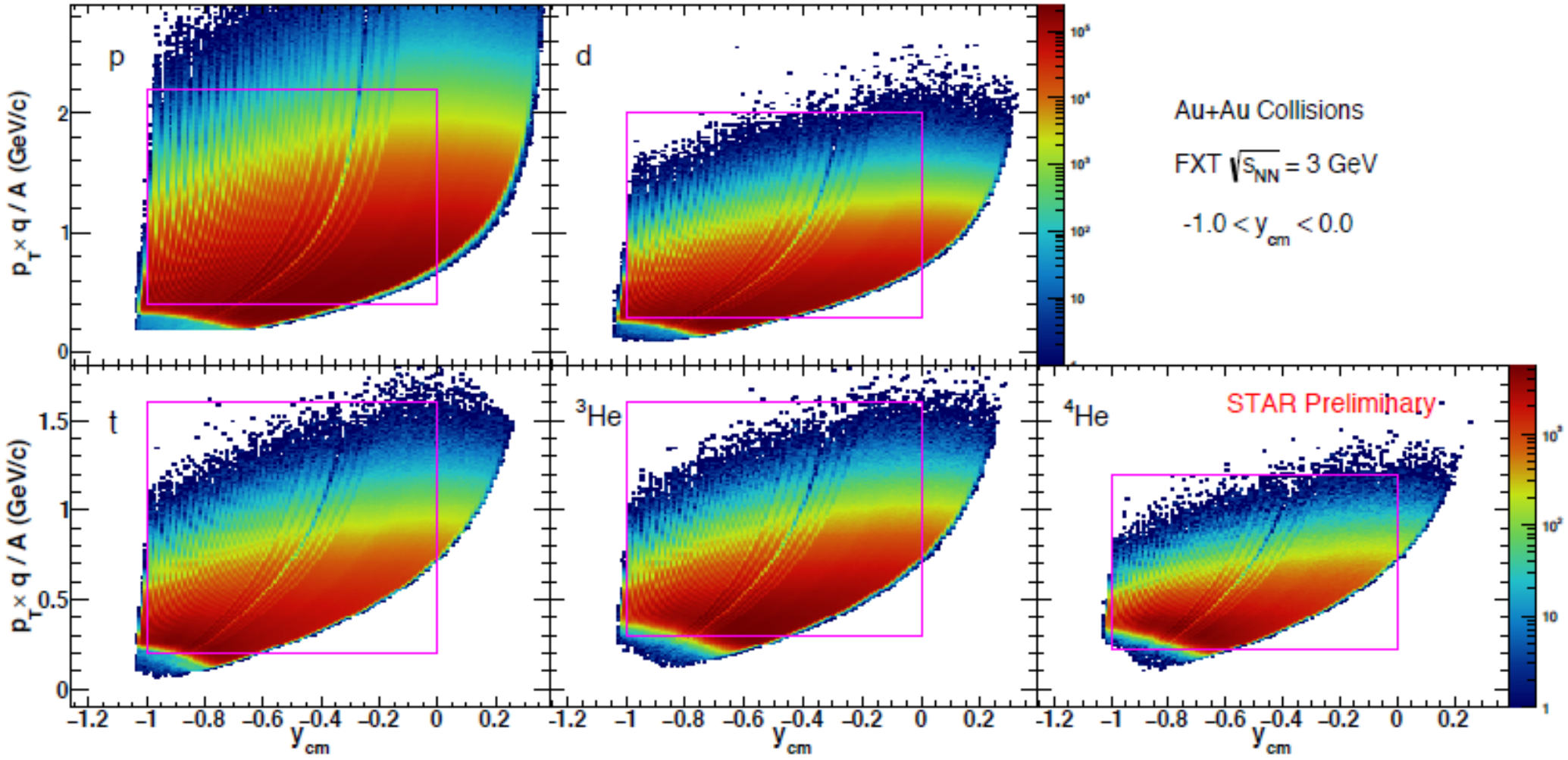
Targets:
Would need to modify the target holder to carry Carbon, Aluminum, and Iron foils.
➔ Adjust the thicknesses of the foils to have equal counts for each foil.

STAR has completed a Au+Au fixed-target program; energies from 3-100 GeV/n

STAR light fragment particle identification

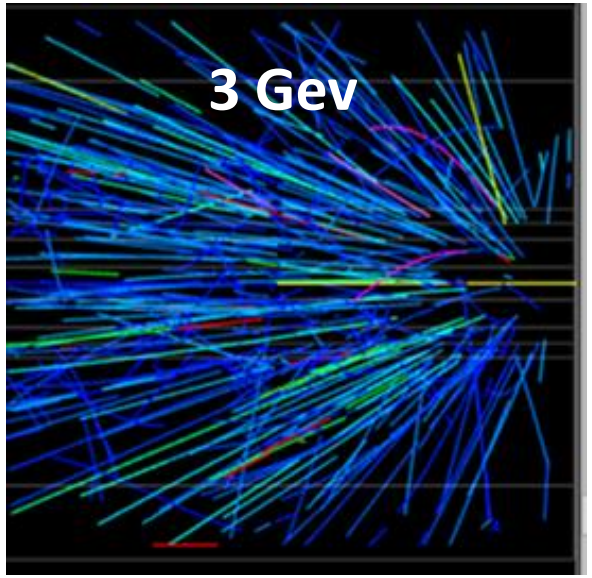


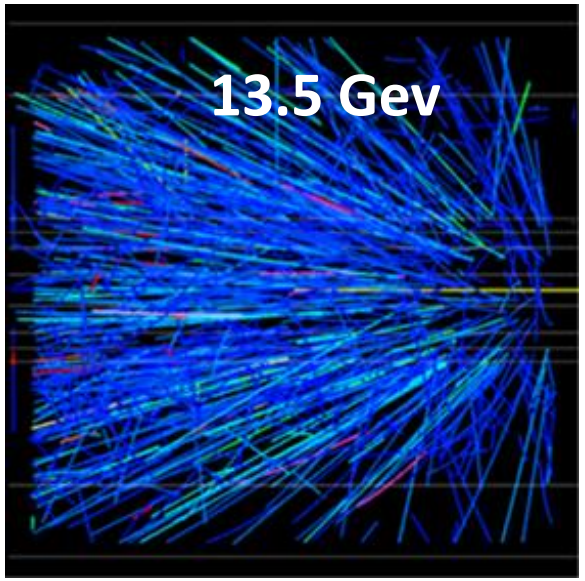
STAR light fragment acceptance

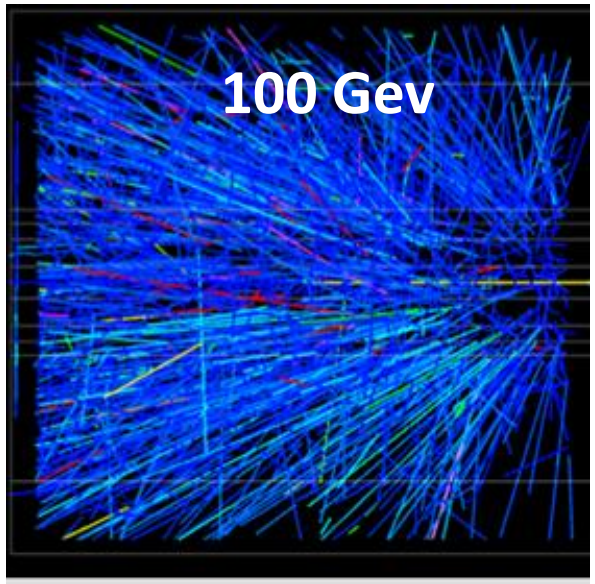


Performance with Beam Energy

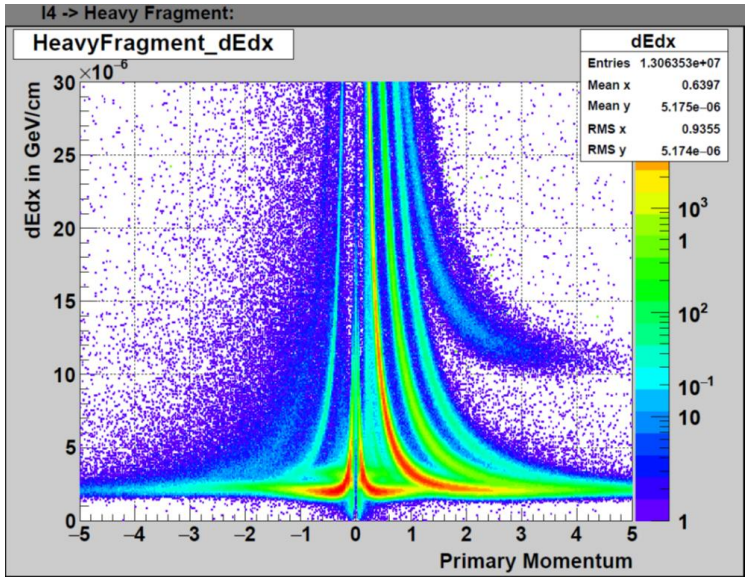
Fewer tracks, more helium nuclei

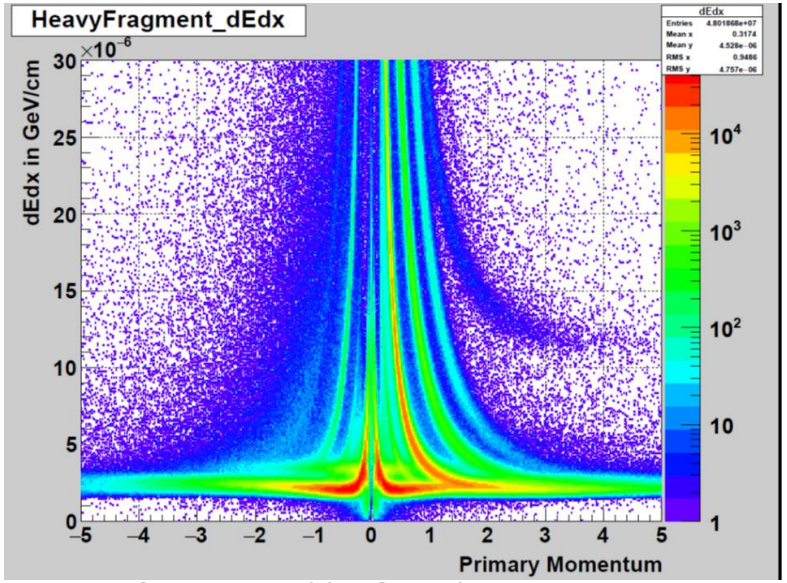


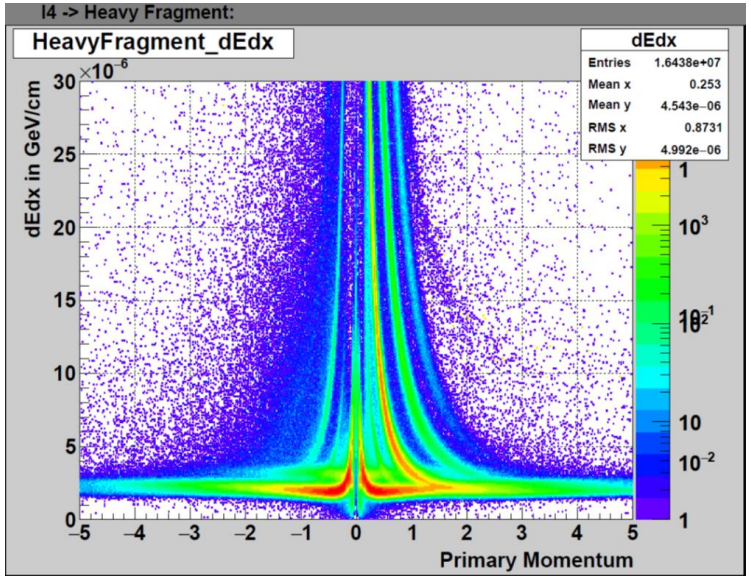




More tracks, fewer helium nuclei







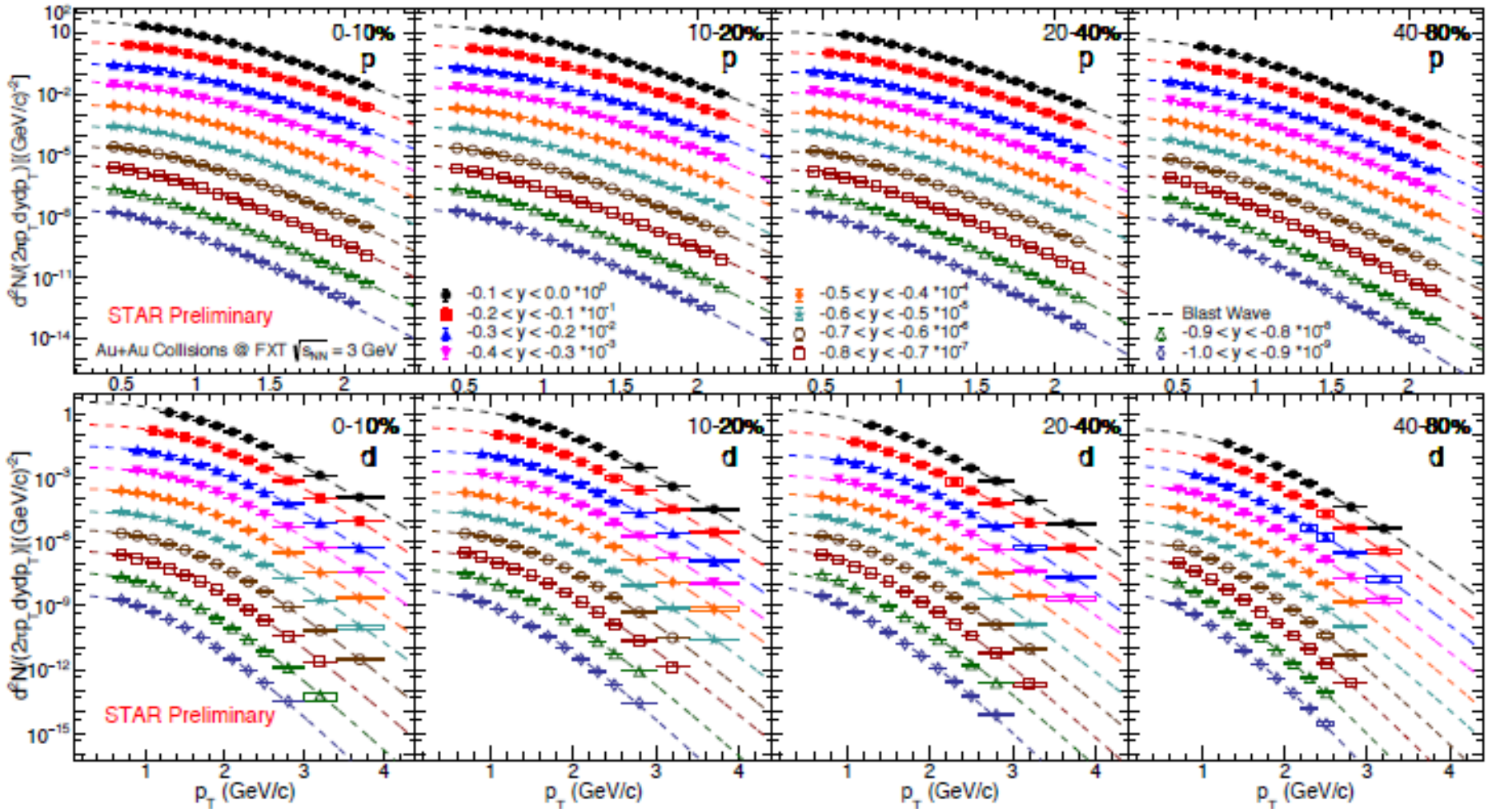
Proposal:

Three Beam Energies: 3.0 GeV, 15 GeV, and 50 GeV
Three Beam Species: Carbon, Aluminum, and Iron
➔ Total of nine energy X beam species combinations

➔ For each beam, 12 hours of beam development, 36 hours of data
➔ ~50 Million events for each beam X target X energy combination
➔ Total of 18 days of RHIC operations over three years

Summary

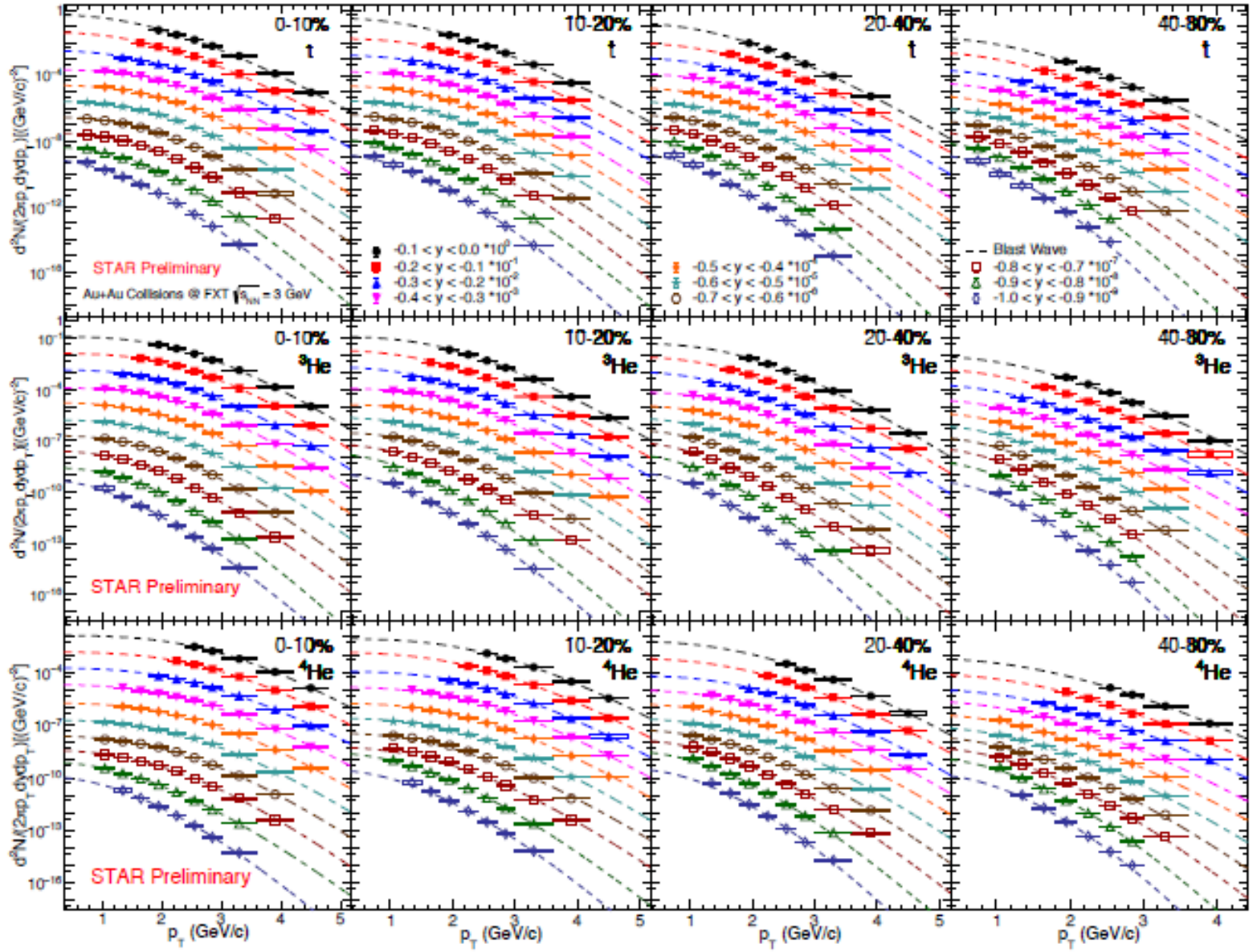
- **Light fragment cross section data are needed for projectiles in the energy range 3-50 GeV.**
- **RHIC/STAR have capabilities that can fill that need.**
- **We can run this program during the 2023-2025 running periods.**

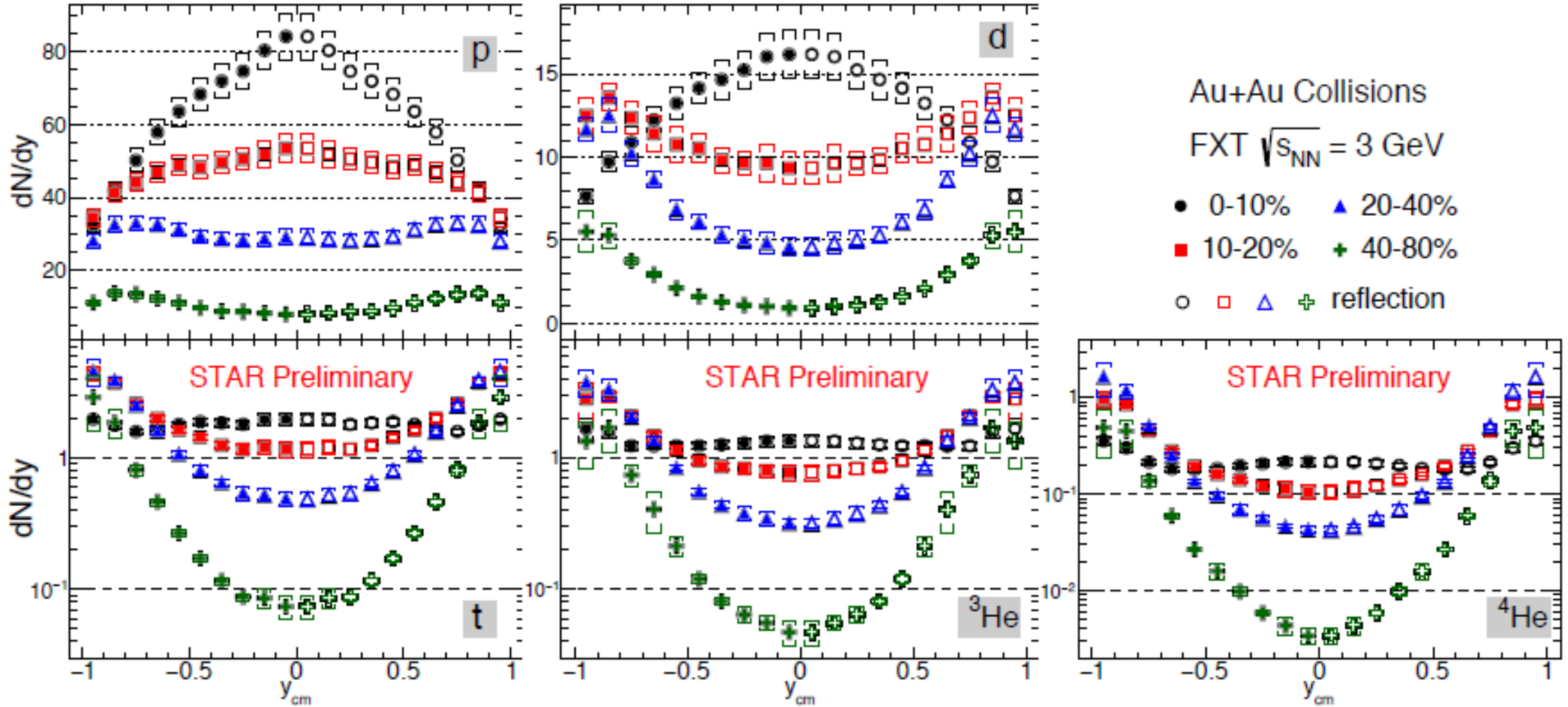

0-10%
p
10-20%
p
20-40%
p
40-80%
p
STAR Preliminary
Au+Au Collisions @ FXT $\sqrt{s_{NN}}$ = 3 GeV
-0.1 < y < 0.0 *10^0
-0.2 < y < -0.1 *10^-1
-0.3 < y < -0.2 *10^-2
-0.4 < y < -0.3 *10^-3
-0.5 < y < -0.4 *10^-4
-0.6 < y < -0.5 *10^-5
-0.7 < y < -0.6 *10^-6
-0.8 < y < -0.7 *10^-7
Blast Wave
-0.9 < y < -0.8 *10^-8
-1.0 < y < -0.9 *10^-9
$d^2N/(2\pi p_T dy dp_T)$ [(GeV/c)$^{-2}$]
0-10%
d
10-20%
d
20-40%
d
40-80%
d
STAR Preliminary
p_T (GeV/c)
p_T (GeV/c)
p_T (GeV/c)
p_T (GeV/c)

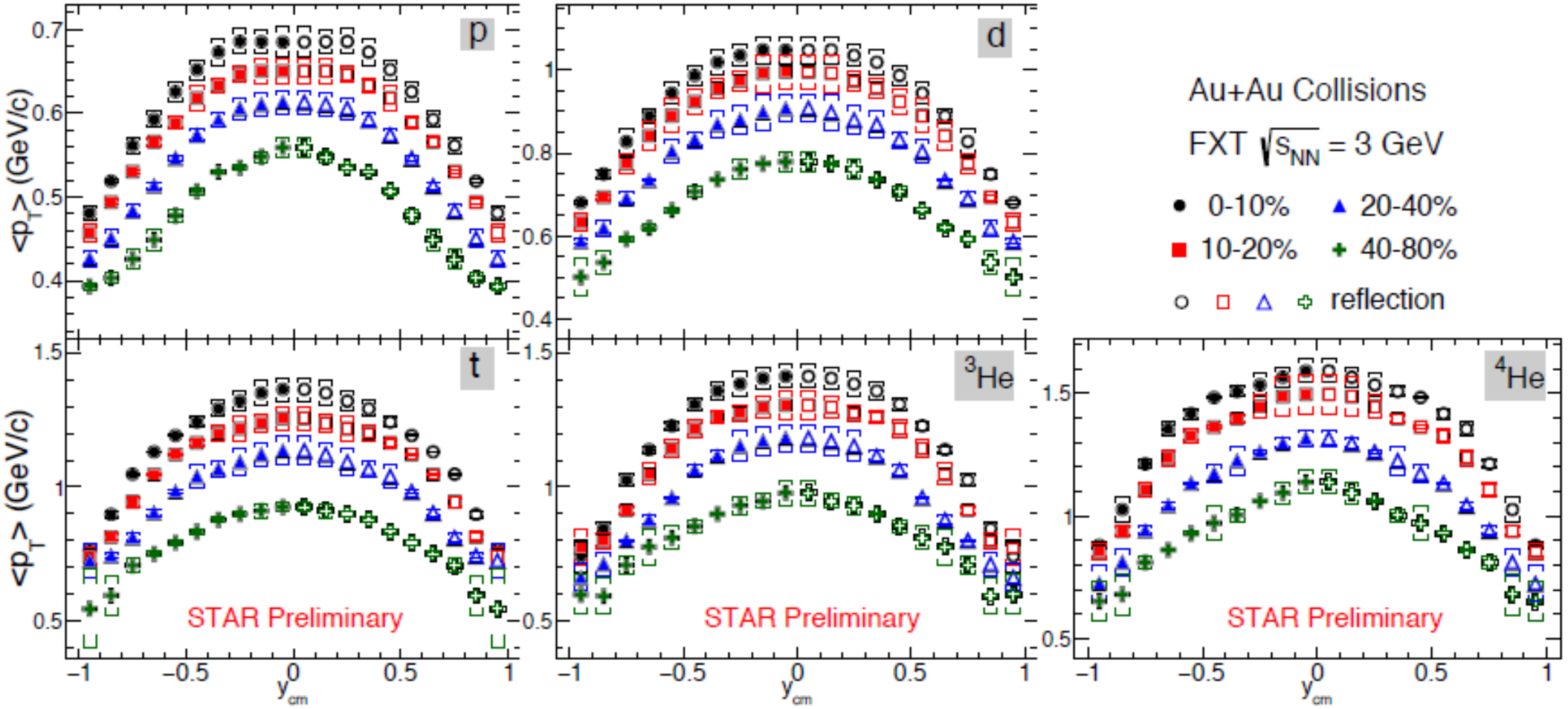
Triton

^{3}He

^{4}He




p
d
t
^{3}He
^{4}He
STAR Preliminary
STAR Preliminary
STAR Preliminary
dN/dy
dN/dy
y_{cm}
y_{cm}
y_{cm}
Au+Au Collisions
FXT $\sqrt{s_{NN}}$ = 3 GeV
0-10%
20-40%
10-20%
40-80%
reflection


p
d
t
^{3}He
^{4}He
Au+Au Collisions
FXT $\sqrt{s_{NN}}$ = 3 GeV
0-10%
20-40%
10-20%
40-80%
reflection
STAR Preliminary
STAR Preliminary
STAR Preliminary
$\langle p_T \rangle$ (GeV/c)
y_{cm}

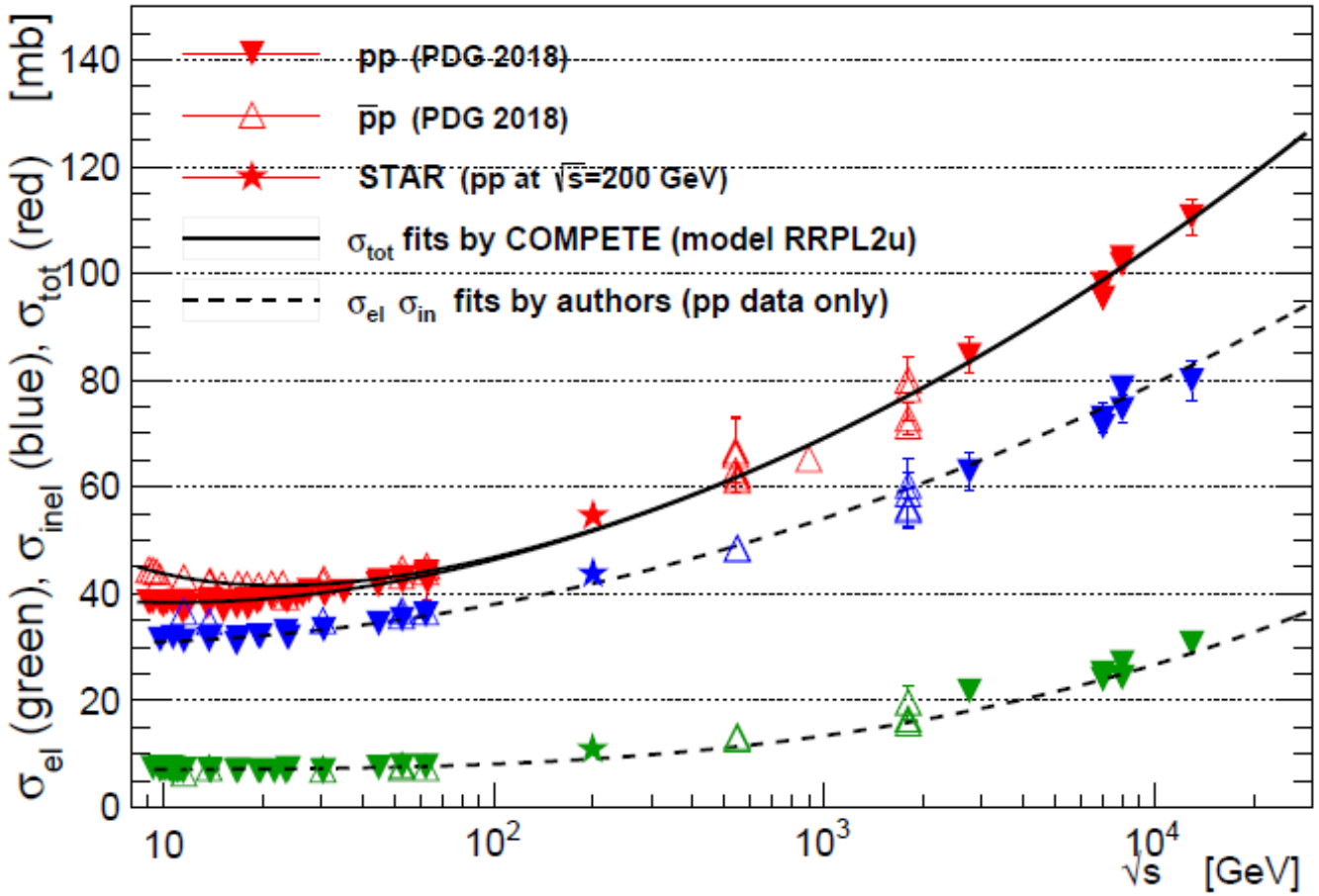
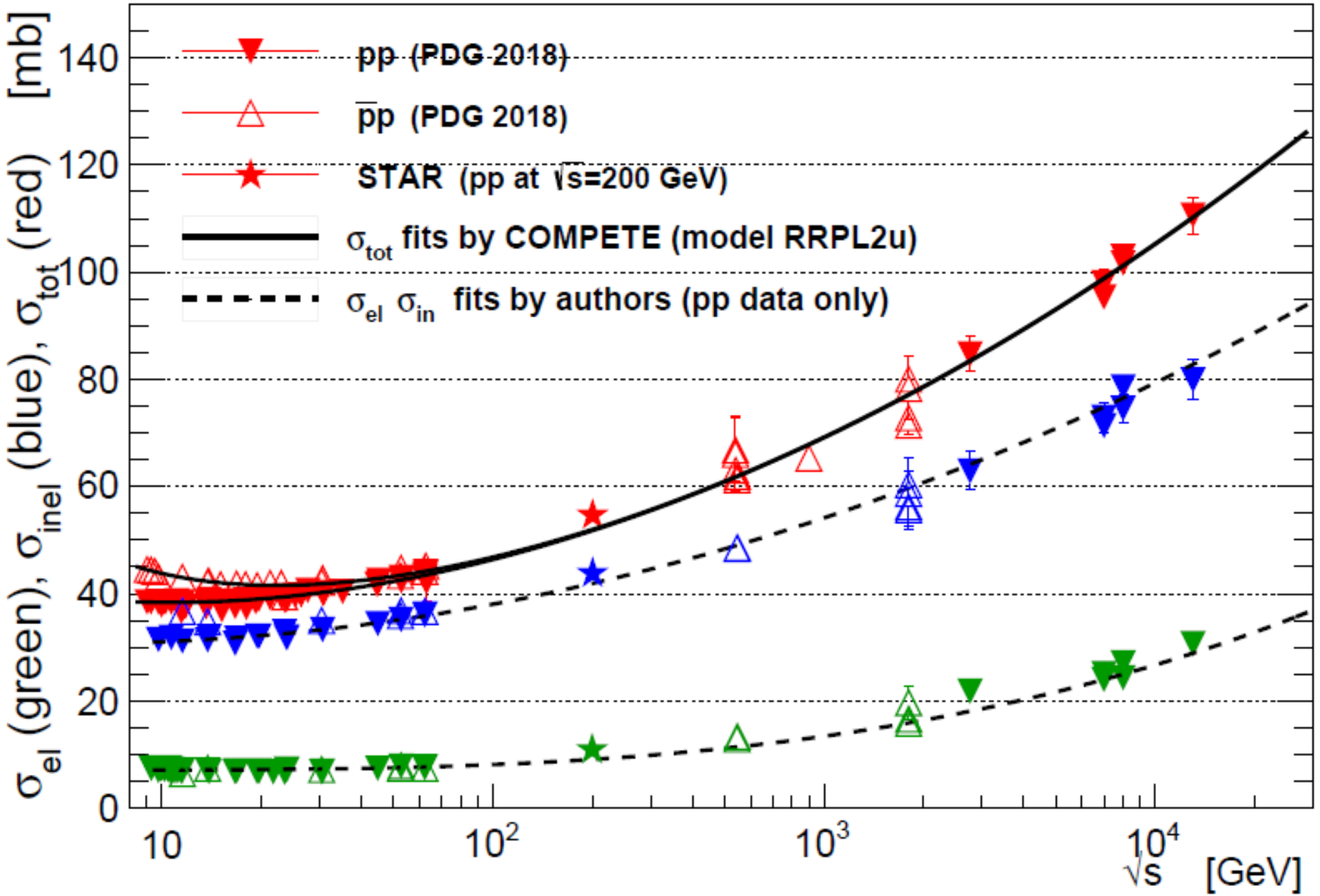
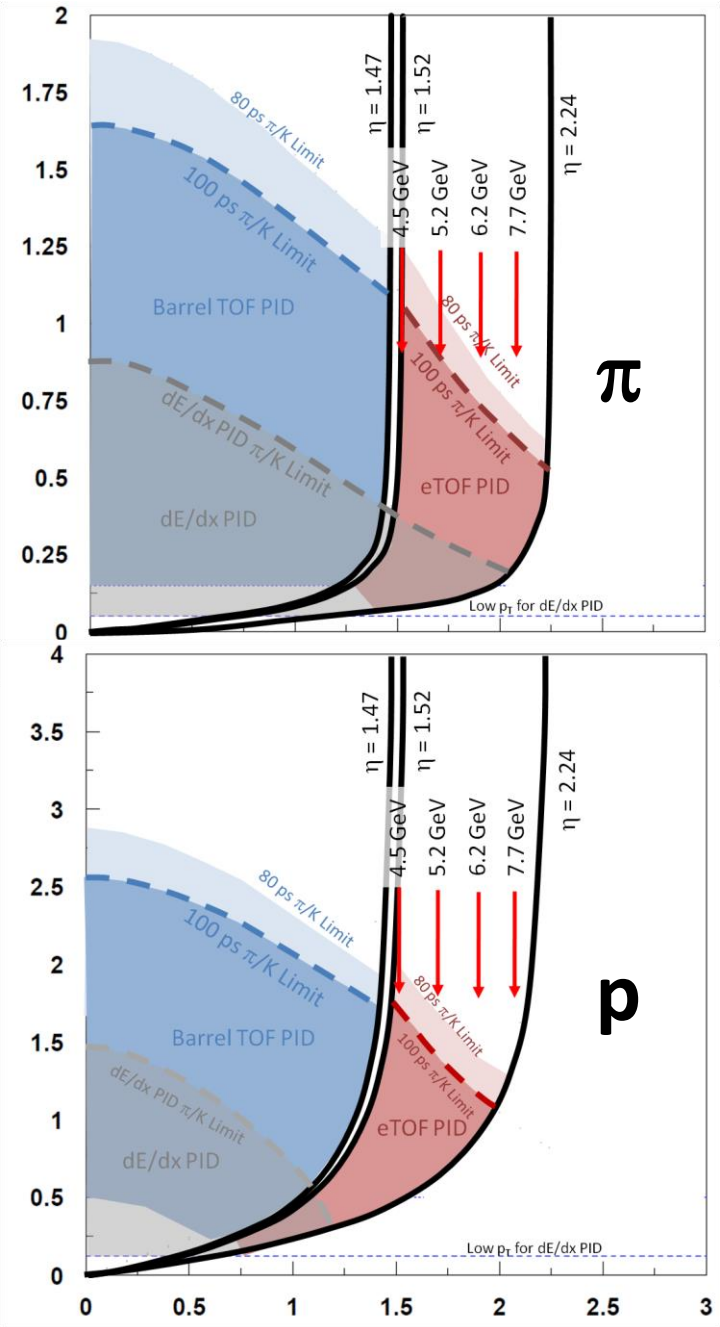


FIG. 7. Comparison of STAR results on σ_{tot}, σ_{inel} and σ_{el} with the world data for data below 1.8 TeV [22], the Tevatron [4–7] and the LHC experiments [1, 23–25, 27, 28]. The COMPETE prediction for σ_{tot} is also shown. The dashed curves, represent STAR fits to σ_{inel} and σ_{el} using the same function as used by COMPETE. STAR data points were not used in the fit.

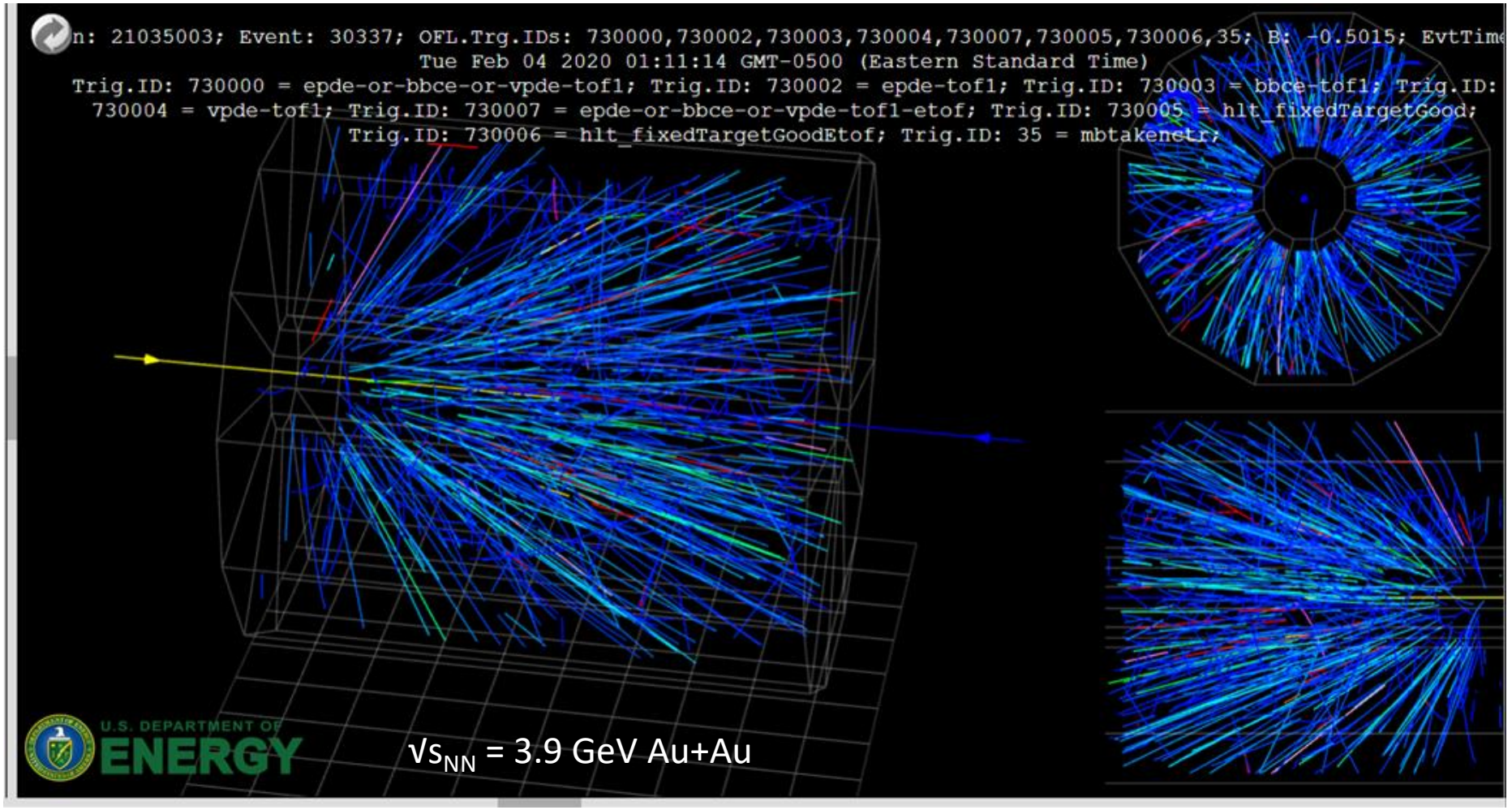

pp (PDG 2018)
$\bar{p}p$ (PDG 2018)
STAR (pp at $\sqrt{s}$=200 GeV)
σ_{tot} fits by COMPETE (model RRPL2u)
σ_{el} σ_{in} fits by authors (pp data only)
σ_{el} (green), σ_{inel} (blue), σ_{tot} (red) [mb]
0
20
40
60
80
100
120
140
10
10^2
10^3
10^4
$\sqrt{s}$ [GeV]

Acceptance for the FXT Program

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



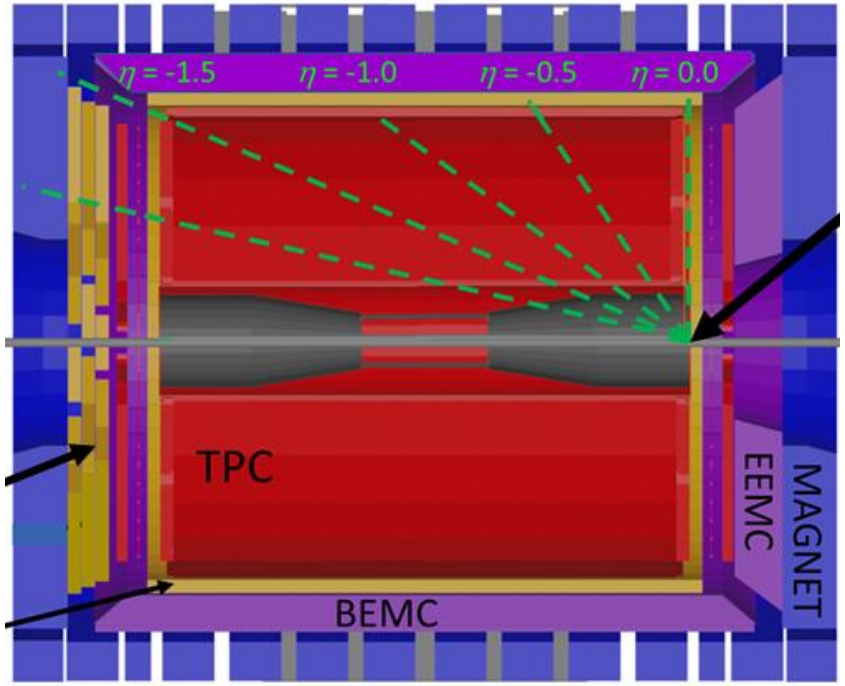
Acceptance for the FXT Program

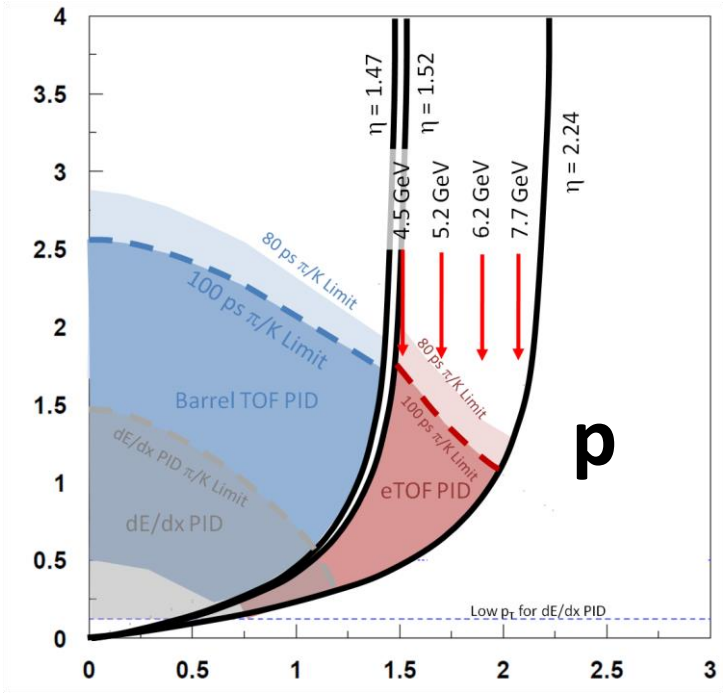
From 2018-2021, RHIC/STAR has beam running a fixed-target program performing an energy scan of gold beams on a gold target.

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





STAR light fragment acceptance

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