Implementation and Performance of the Fixed Target System in STAR at RHIC

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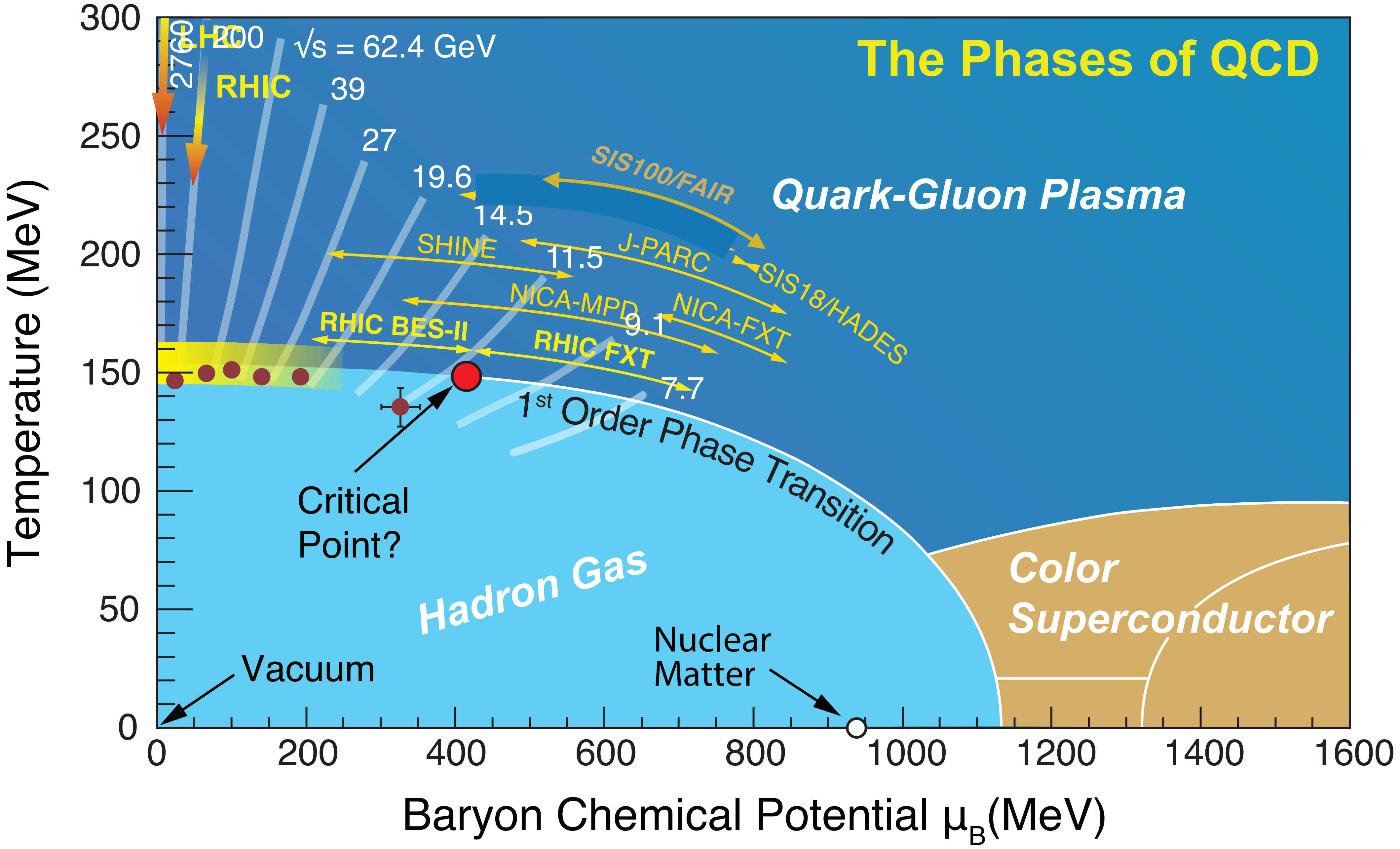
Fixed Target Experiments at LHC - strong2020 workshop

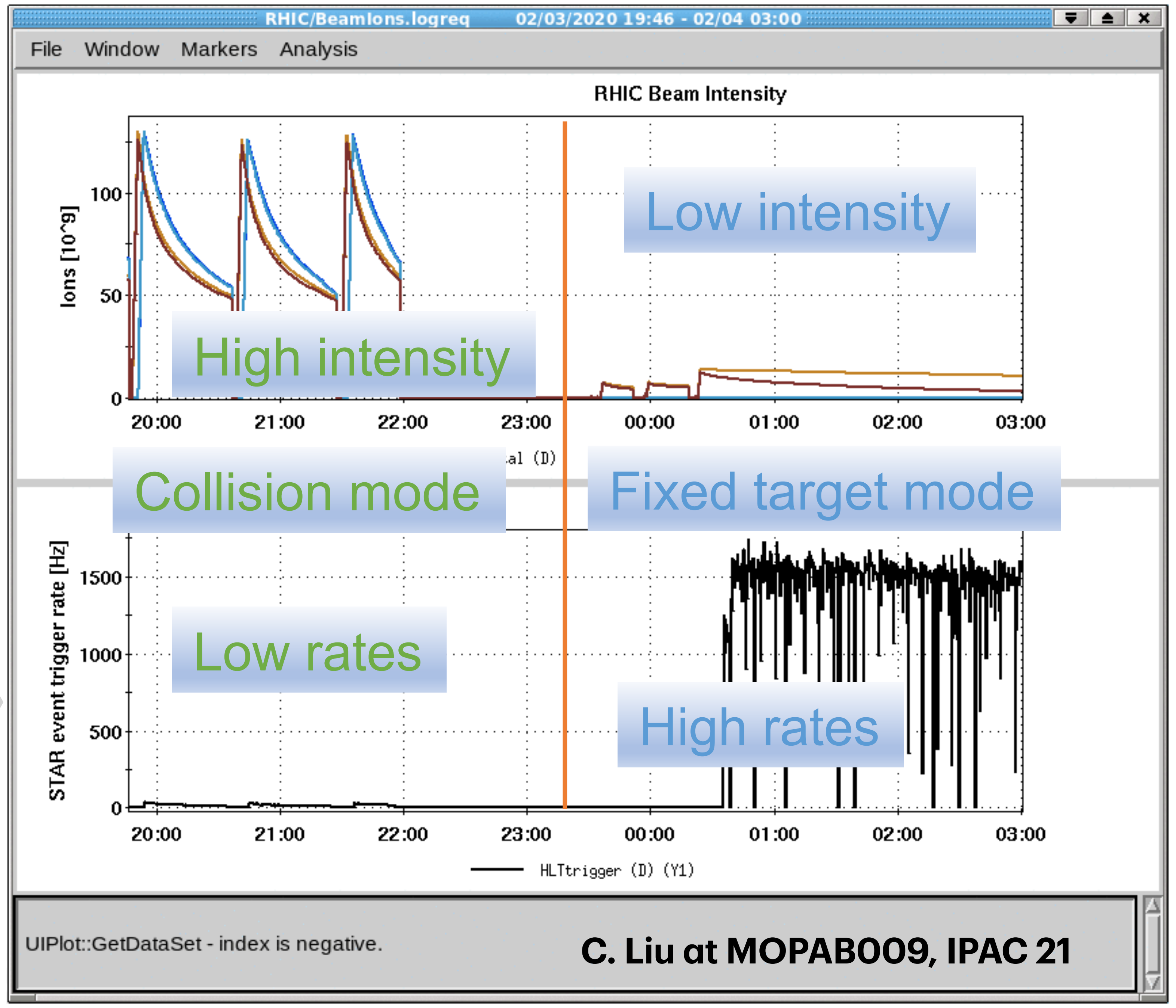
Why Fixed-target at RHIC?

- lowest collision energy accessible at RHIC (with adequate luminosity)
  - collider mode $\sqrt{s_{NN}} = 7.7\ \text{GeV}$
  - fixed-target mode $\sqrt{s_{NN}} = 3.0\ \text{GeV}$
  - expansion of RHIC Beam Energy Scan (BES-II) program



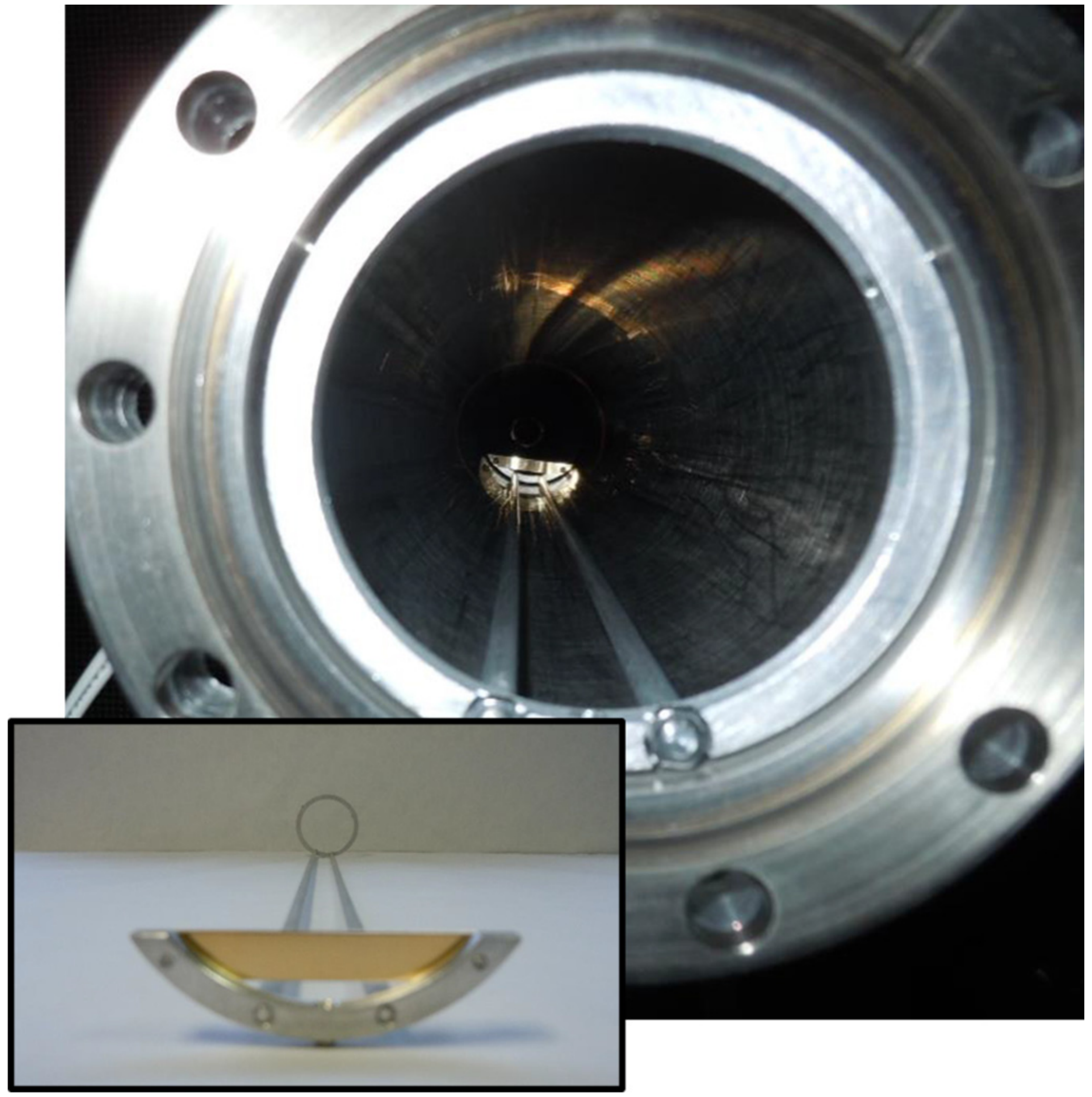
FXT Energy $\sqrt{s_{NN}}$	Single Beam E_T (GeV)	Single beam E_k (AGeV)	Center-of-mass Rapidity	Chemical Potential μ_B (MeV)	Year of Data Taking
3.0	3.85	**2.9**	1.05	721	2018
3.2	4.59	**3.6**	1.13	699	2019
3.5	5.75	**4.8**	1.25	666	2020
3.9	7.3	**6.3**	1.37	633	2020
4.5	9.8	**8.9**	1.52	589	2020
5.2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

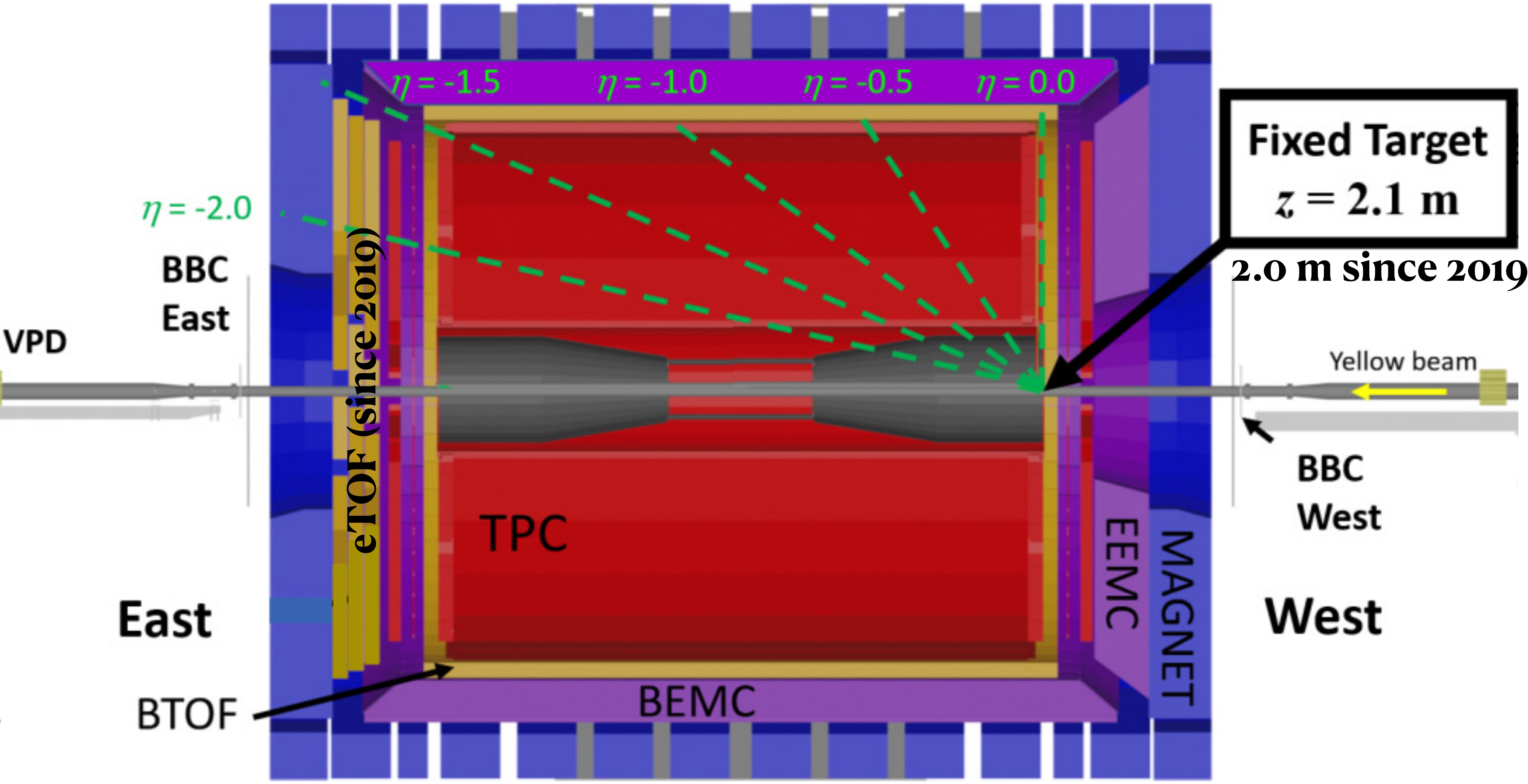
Example of STAR event trigger rate at Fixed-target mode vs in collision mode



Experimental Setup

- Au beam halo incident on a gold target of thickness 1.93 g/cm^2 (1 mm)
  - interaction probability = 4% (linear dependence on the thickness)
- Au target installed inside the beam pipe, 2cm below its center and 211 cm (later 200 cm) to the west of the center of the STAR detector
  - beam lowered by 1.8 cm so its halo grazed the top of the target

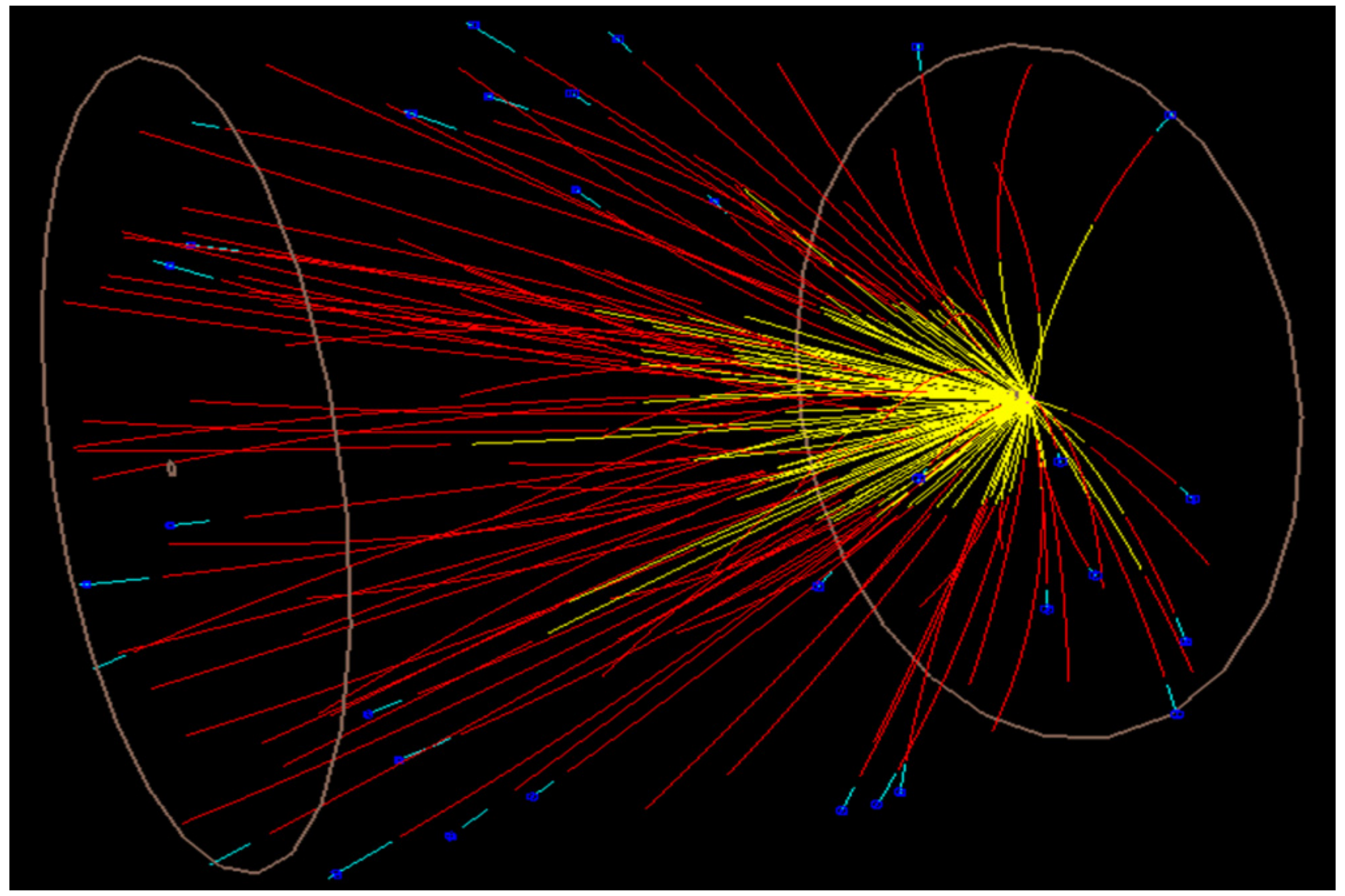


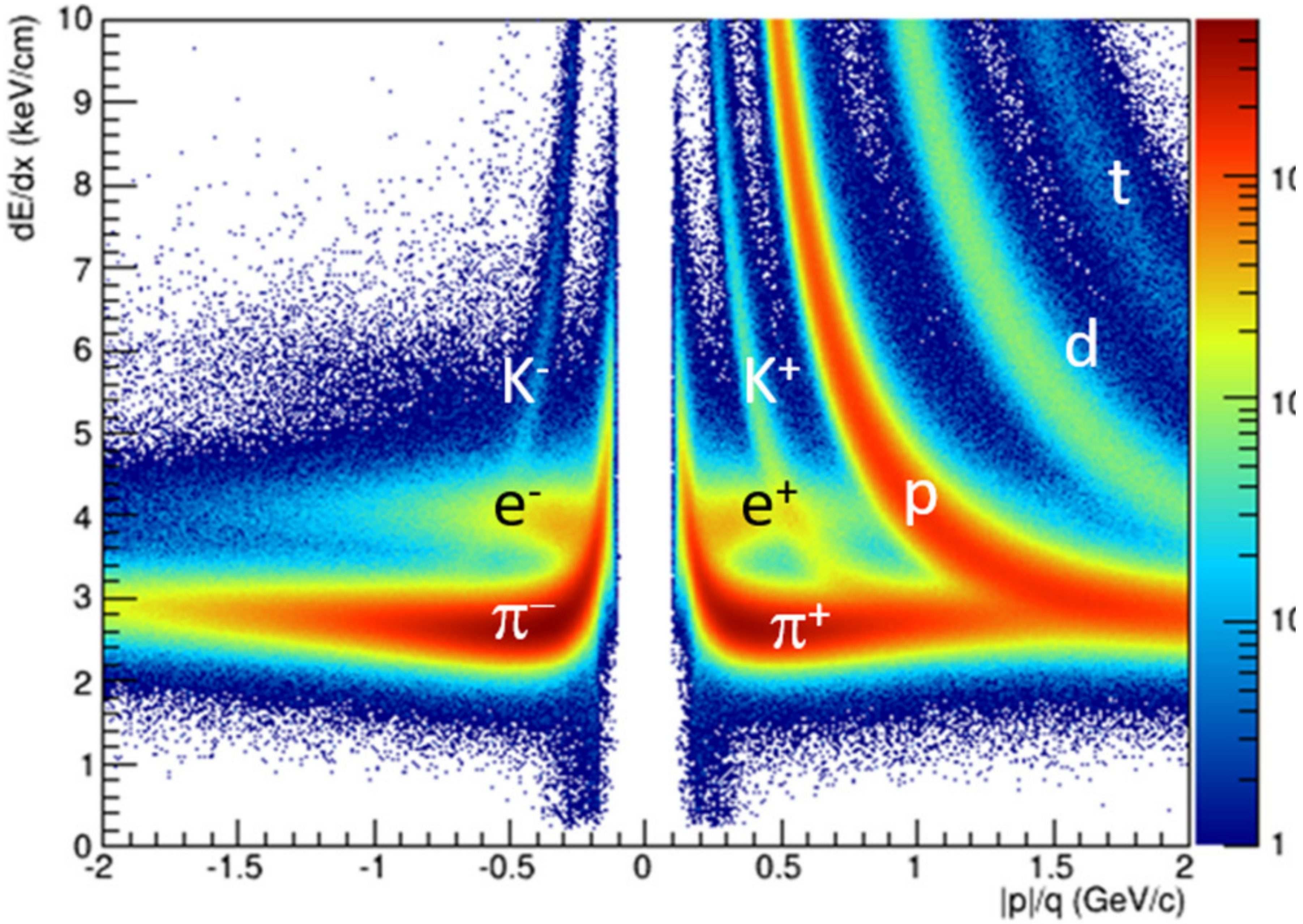


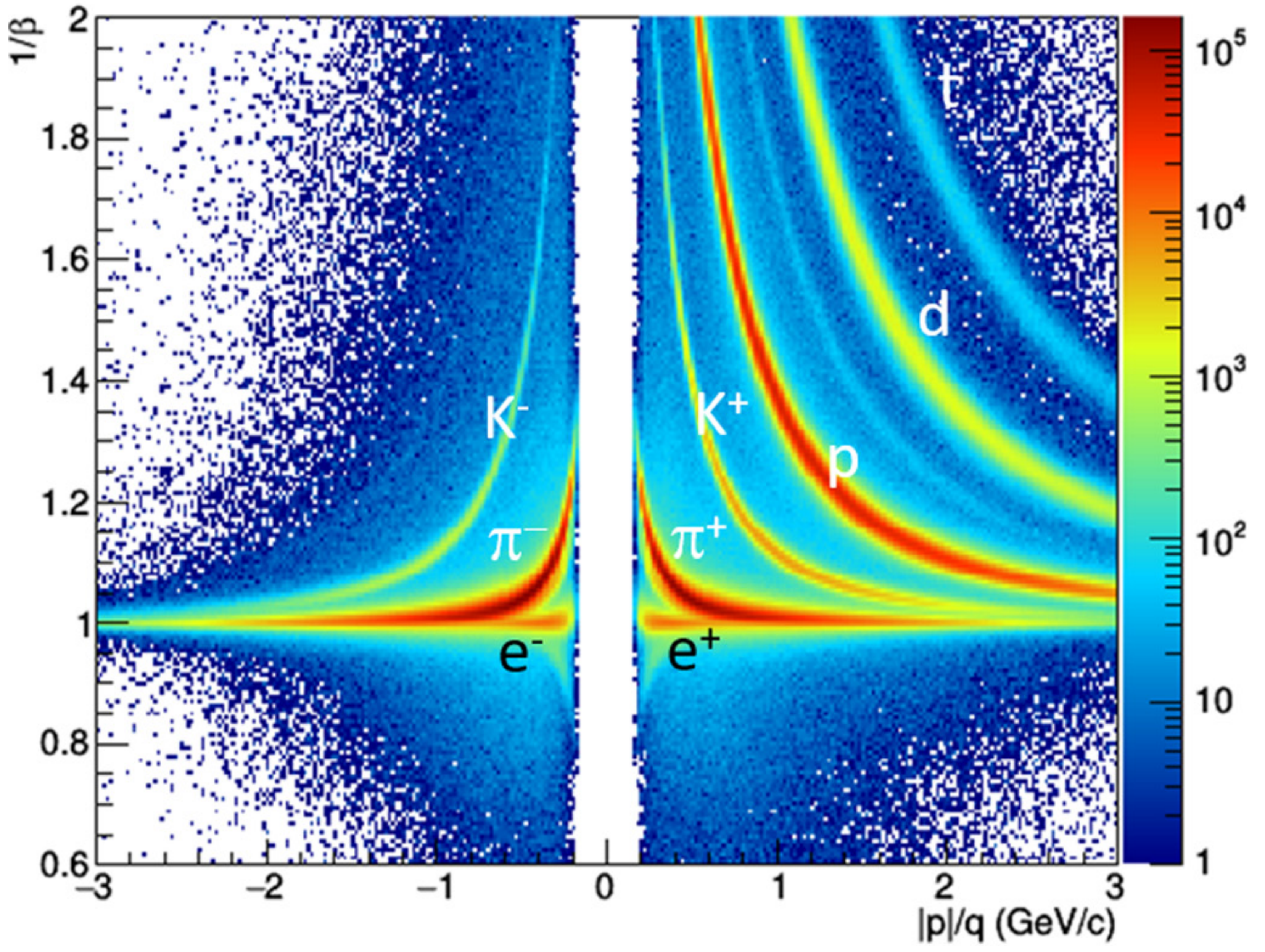
Test Run in 2015

Results are published in paper Phys. Rev. C 103, 034908 (2021)

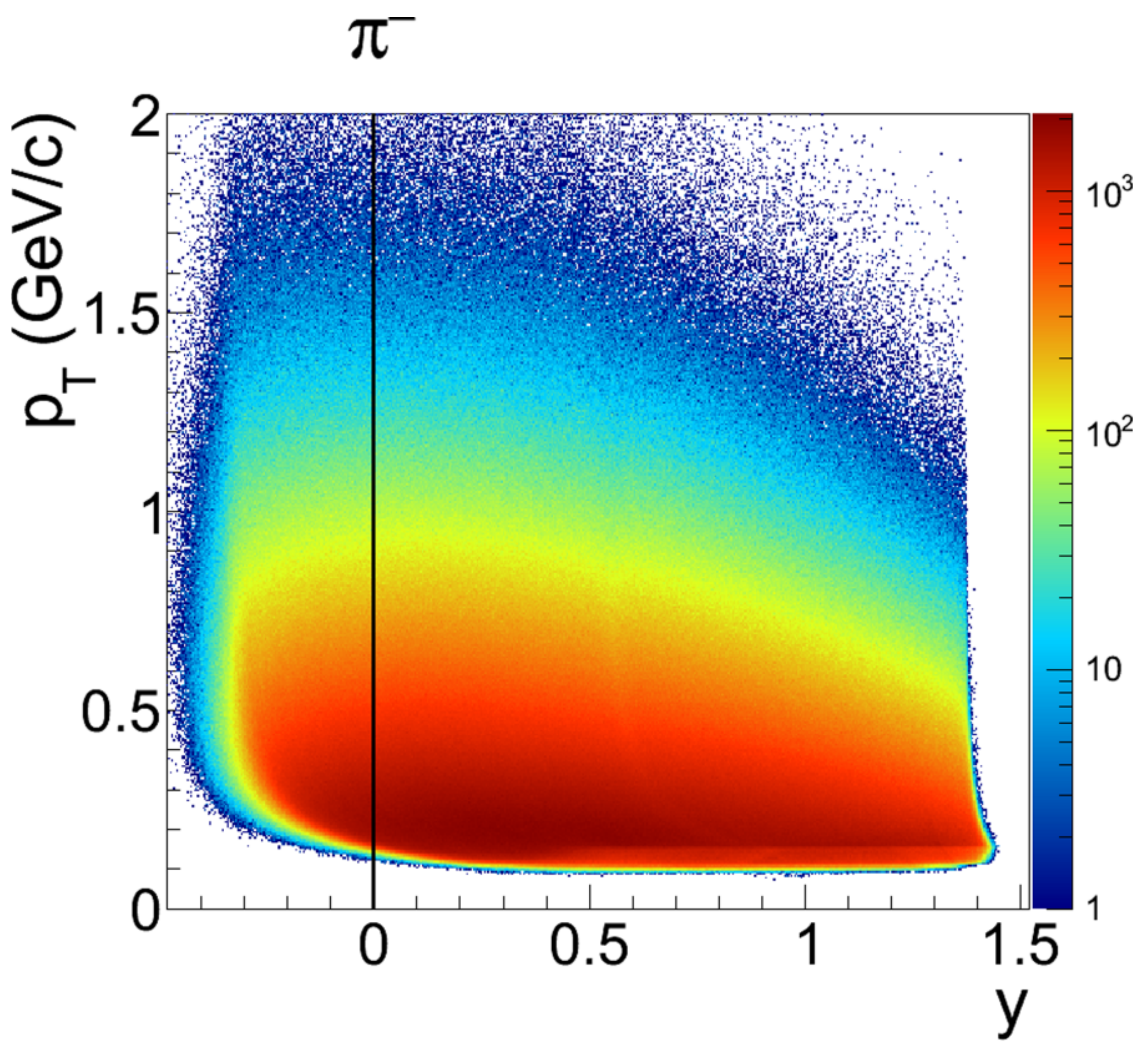
- beam consisted of 6 bunches of 3.4×10^9 Au ions passing the target at 500 kHz and trigger rate was 1 kHz, E_{total} = 9.8 GeV/nucl, $\sqrt{s_{NN}} = 4.5$ GeV
  - number of bunches selected to minimize pile-up
  - store held for 1 h, 1.3M events collected, no perceptible loss of beam intensity



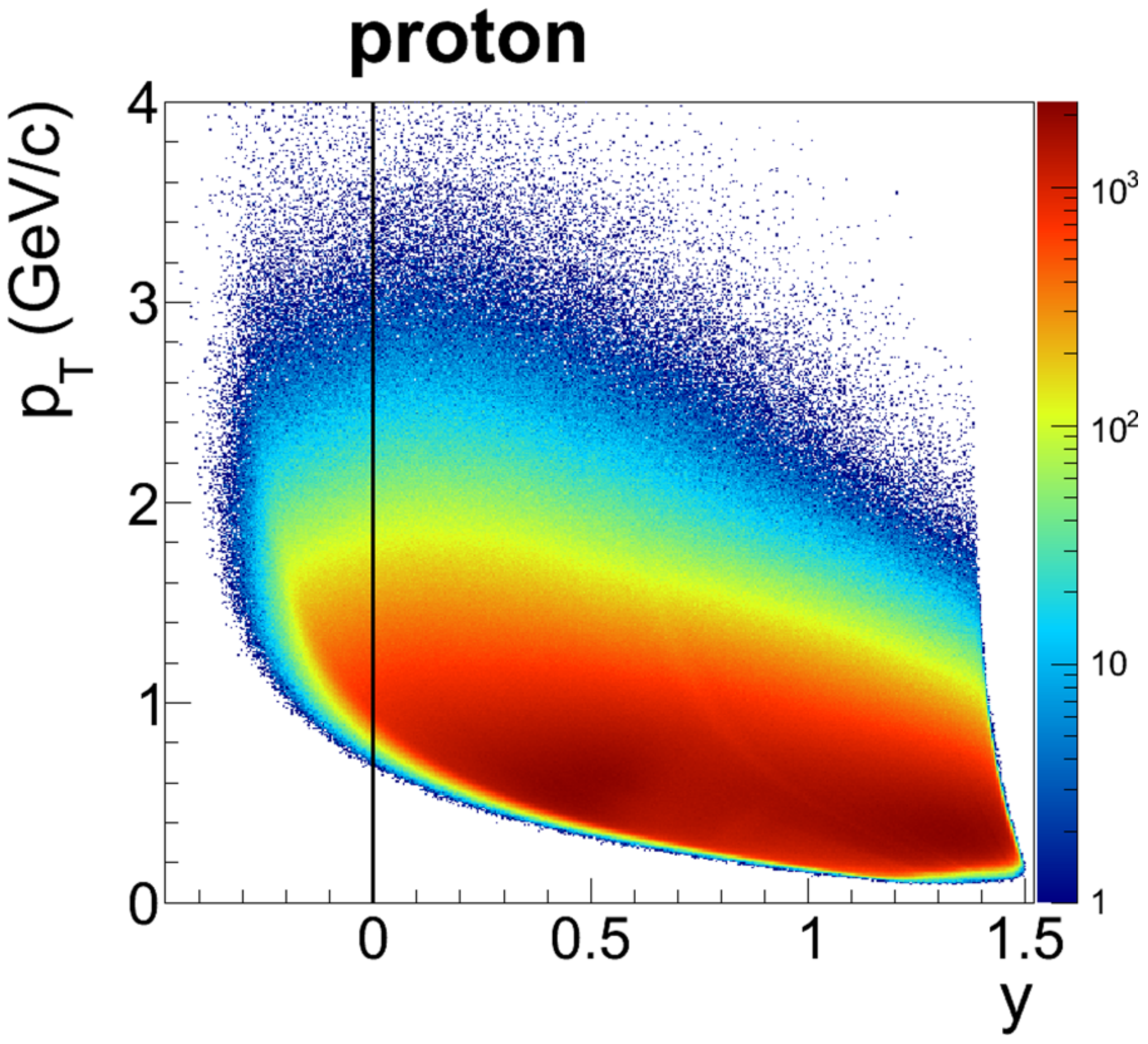


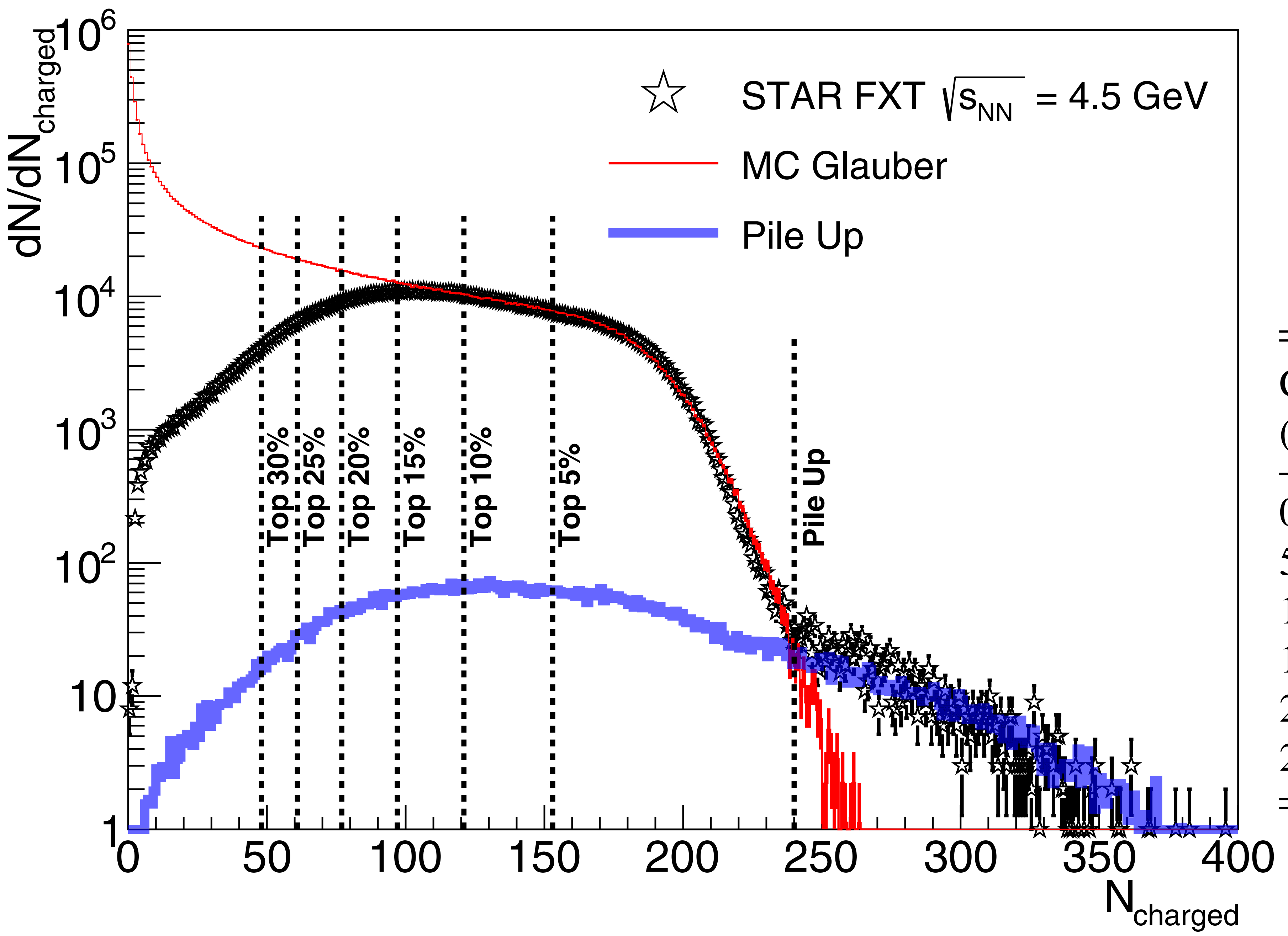


Test Run in 2015 - Acceptance and Centrality



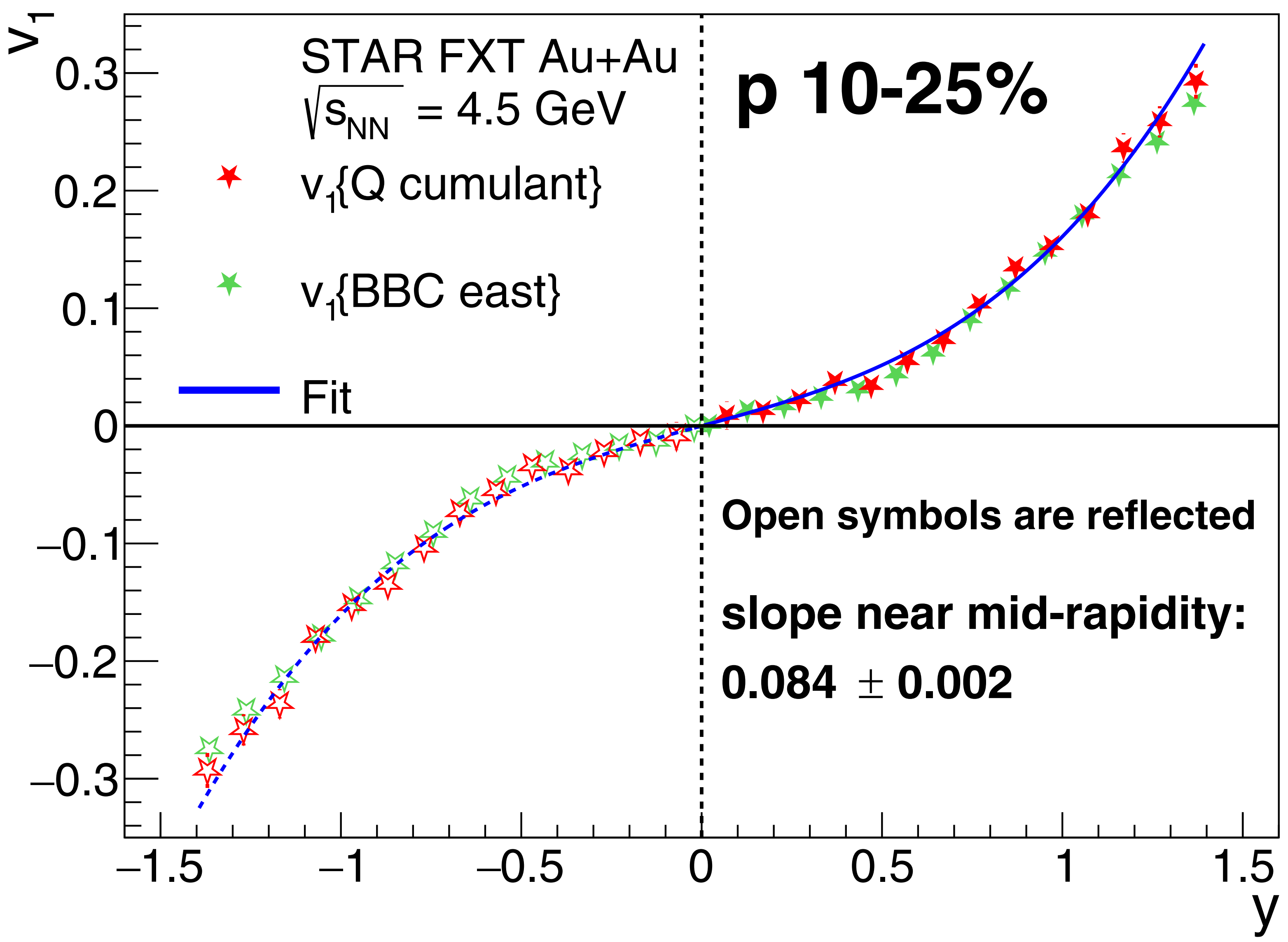
- Negative pion and proton relative yield versus rapidity and transverse momentum
- The black line indicates the location of mid-rapidity. The target (beam) rapidity in the center of mass frame is at +1.52 (–1.52).

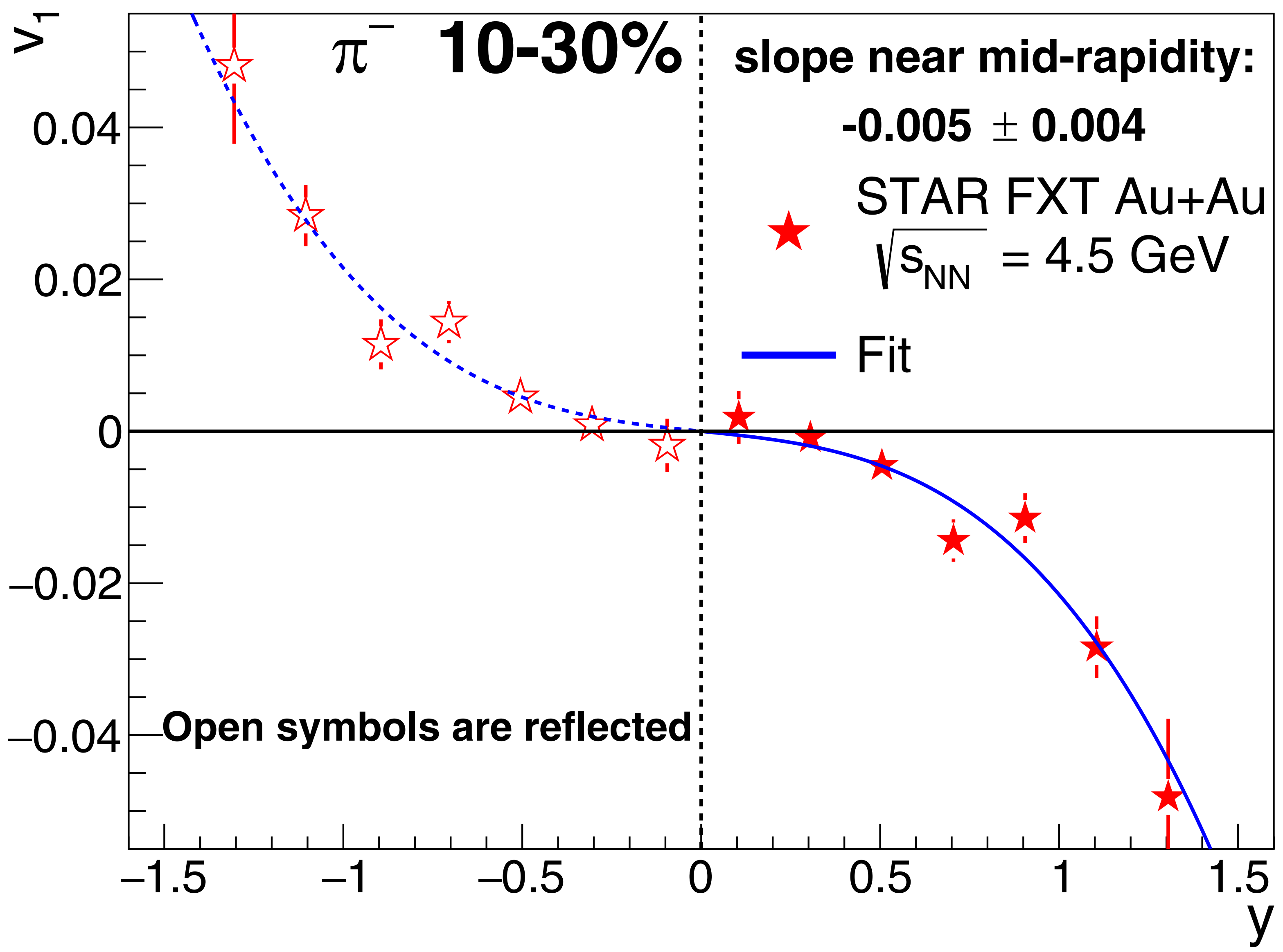


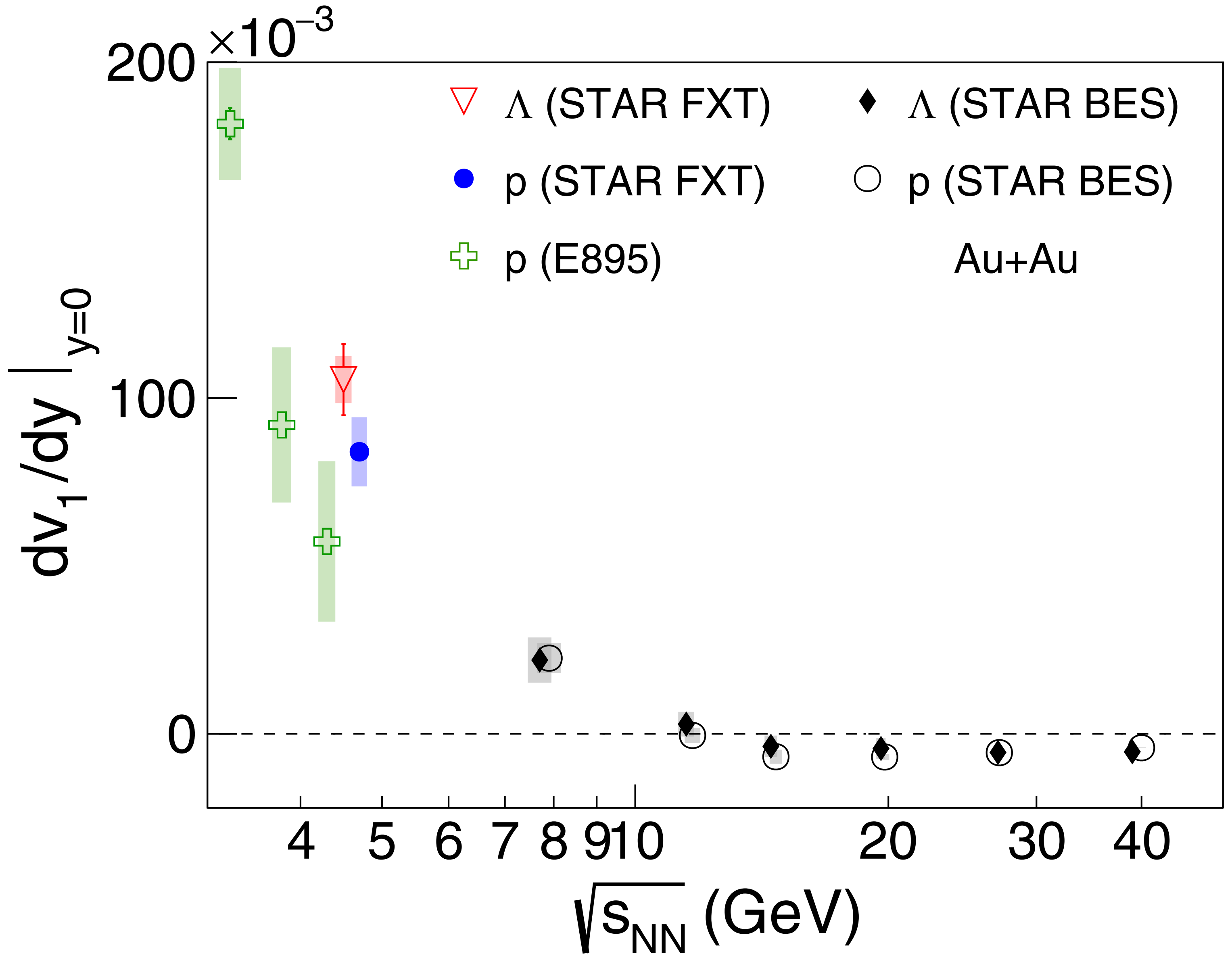


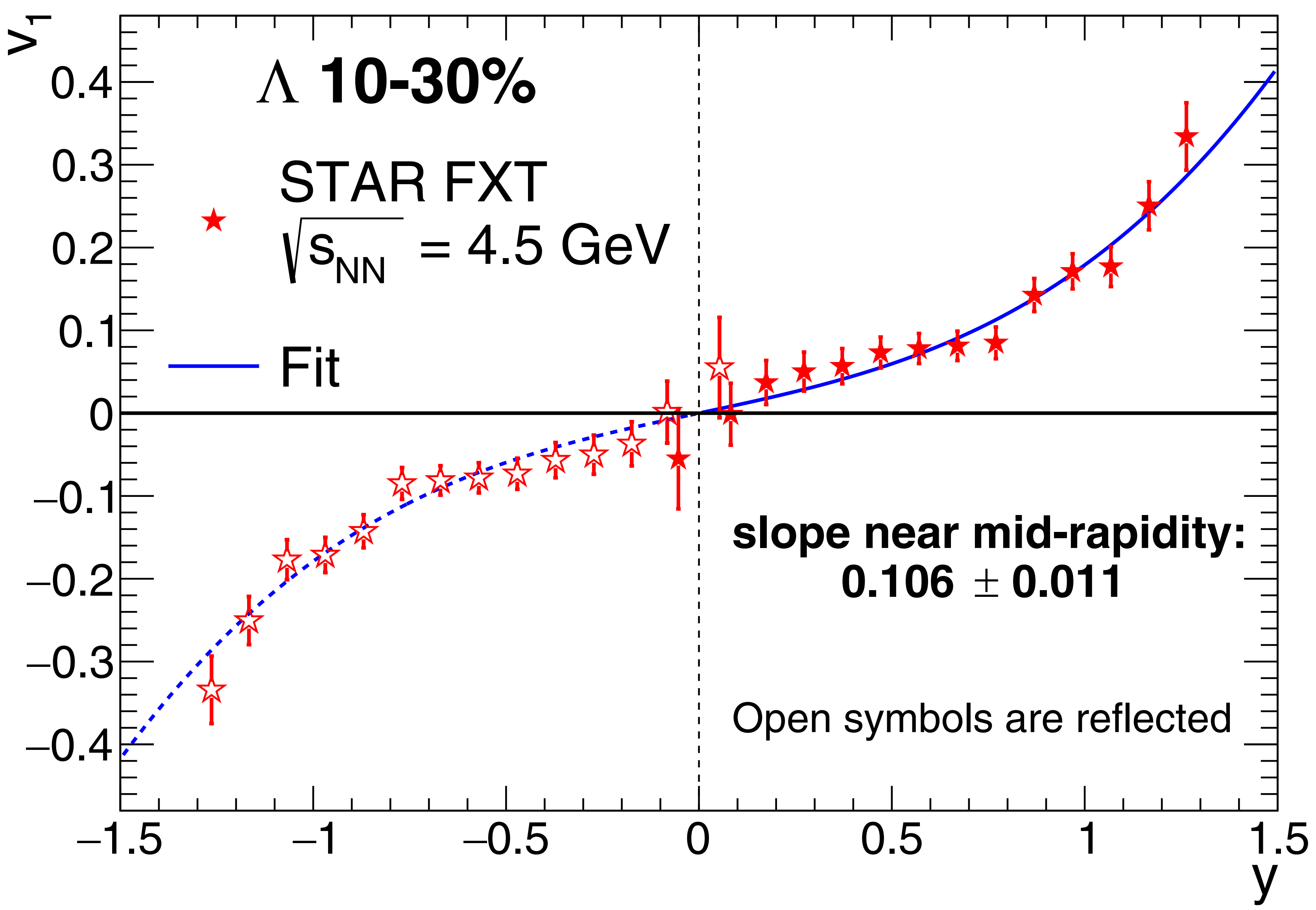
Centrality (% of σ_{total})	$\langle N_{part} \rangle$ (Estimated)	$\langle N_{part} \rangle$ (Min bias)	Pile-up (%)	Events
0–5	341 ± 5	336	1.35	266 694
5–10	289 ± 9	286	0.72	267 347
10–15	244 ± 8	242	0.58	258 854
15–20	210 ± 6	204	0.49	203 600
20–25	178 ± 5	170	0.44	125 539
25–30	154 ± 4	142	0.40	68 844

Test Run in 2015 - Selected Results - Directed Flow

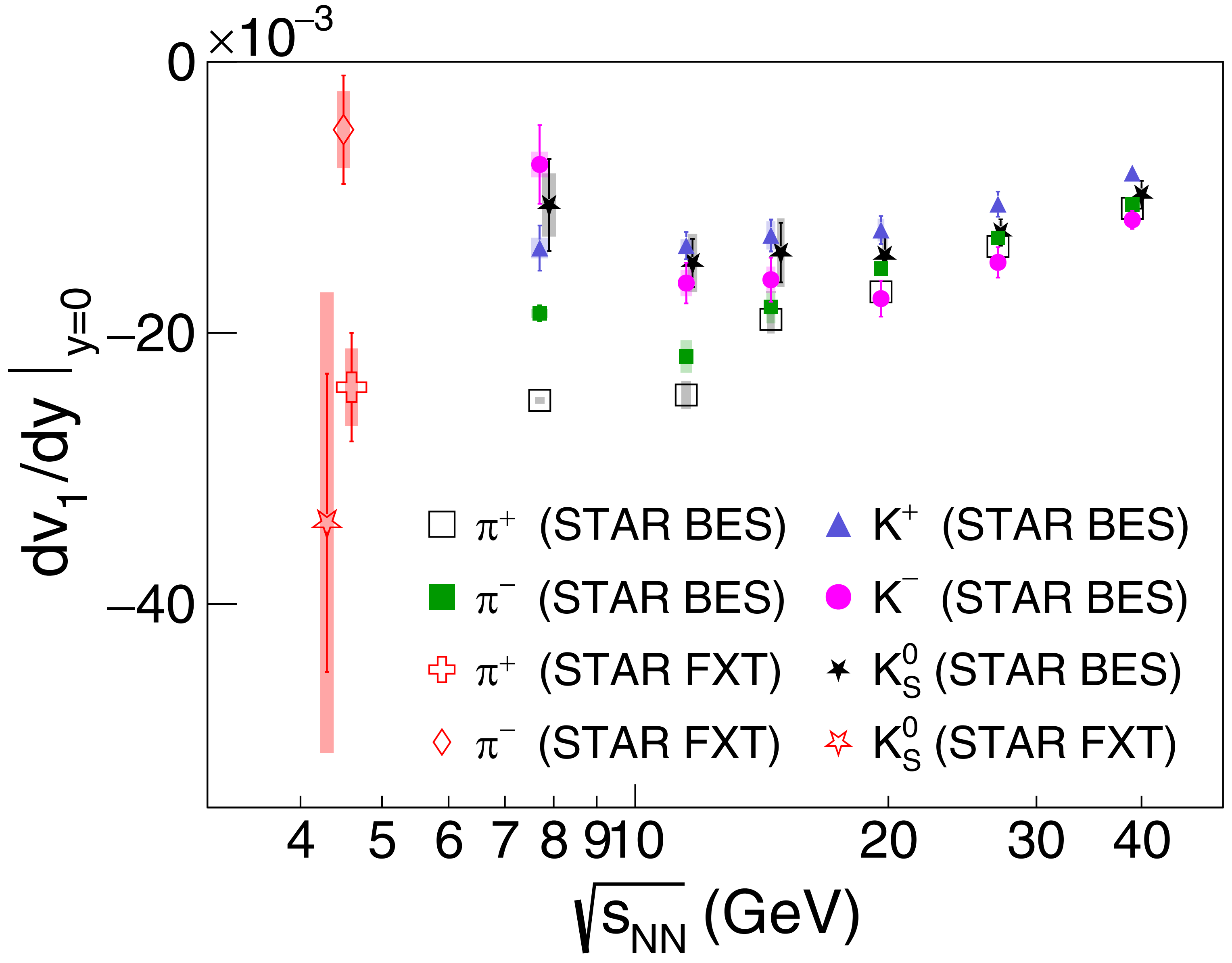




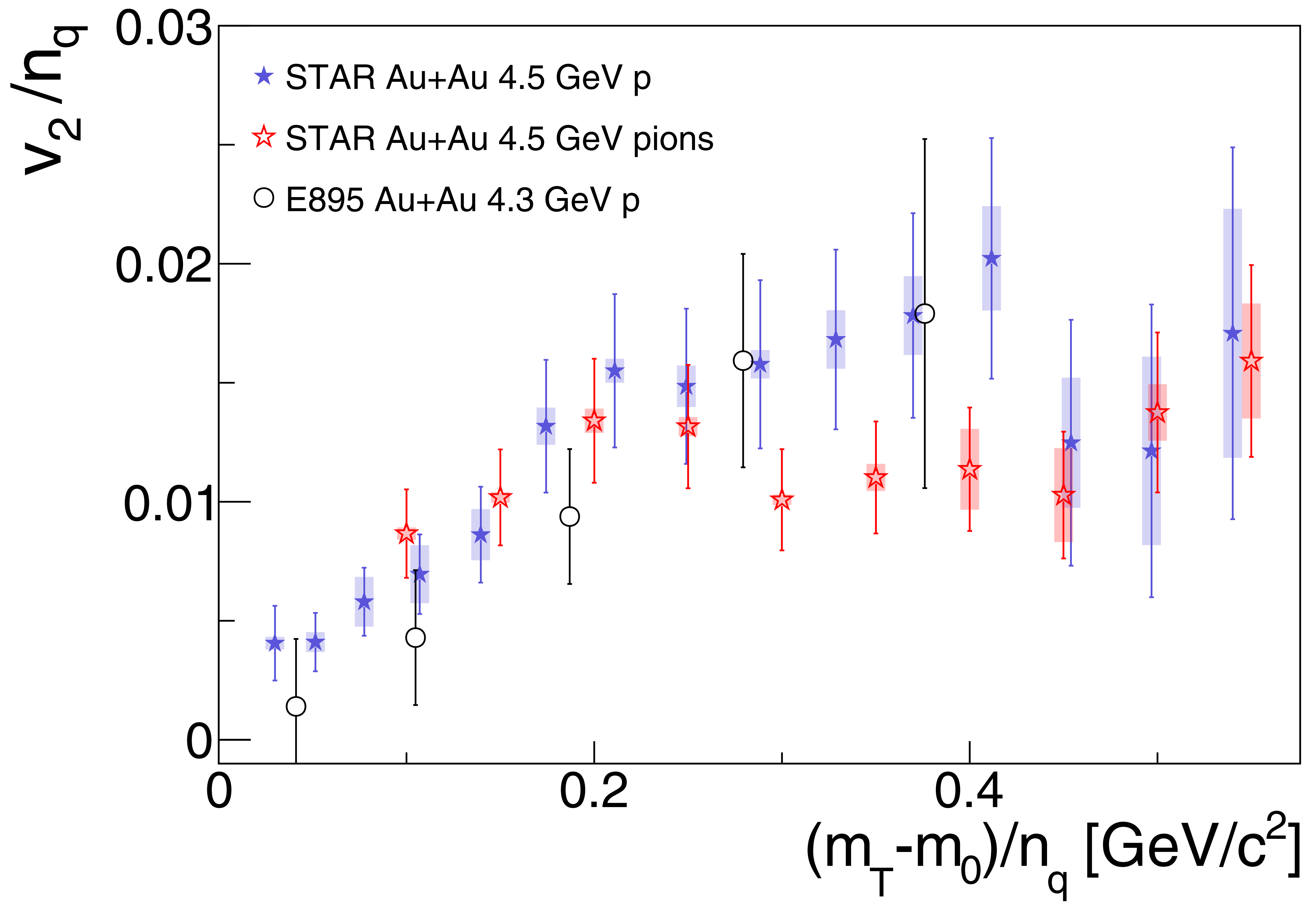


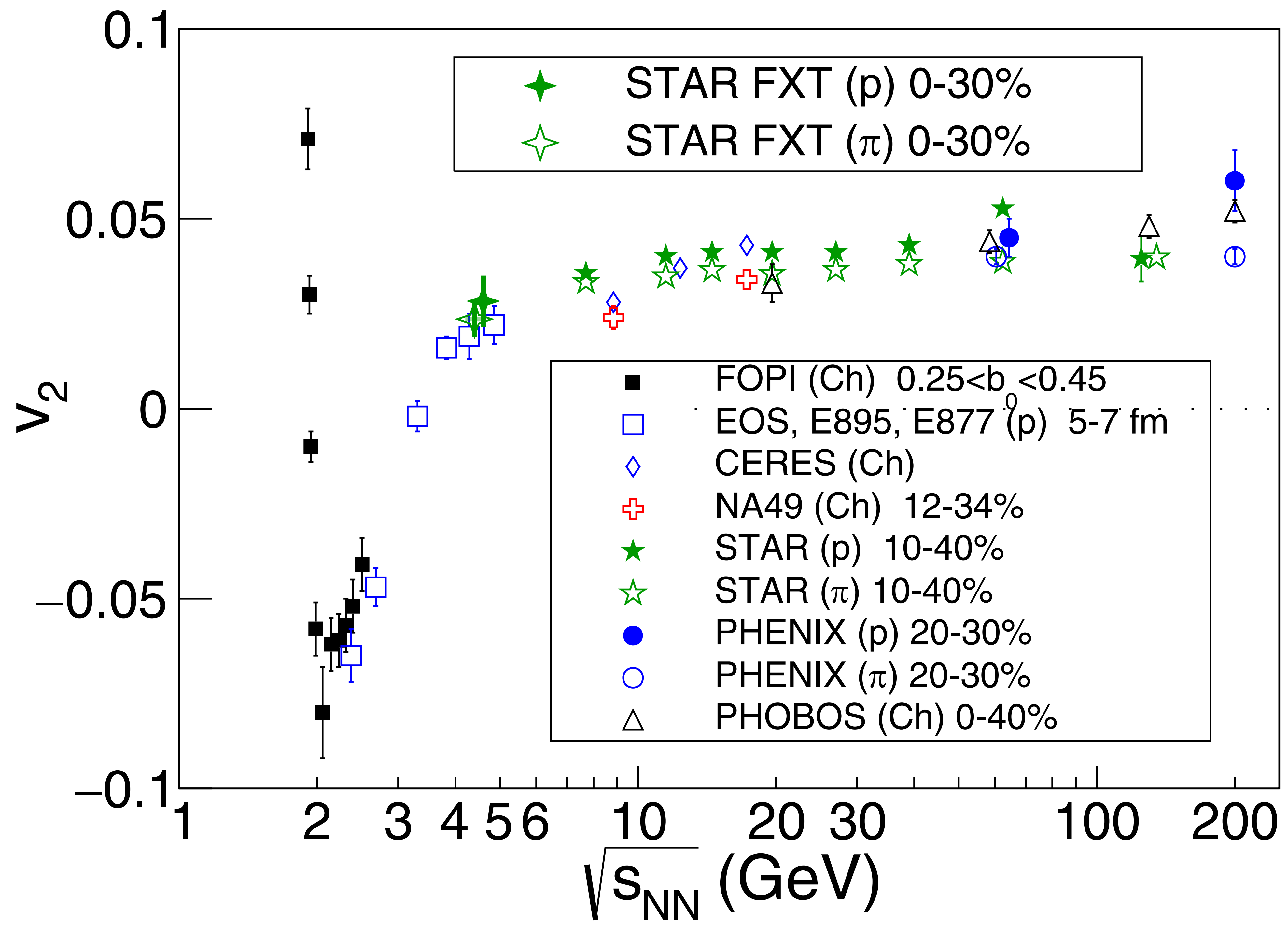


Expect a truck load of new results from the BES-II



Test Run in 2015 - Selected Results - Elliptic Flow



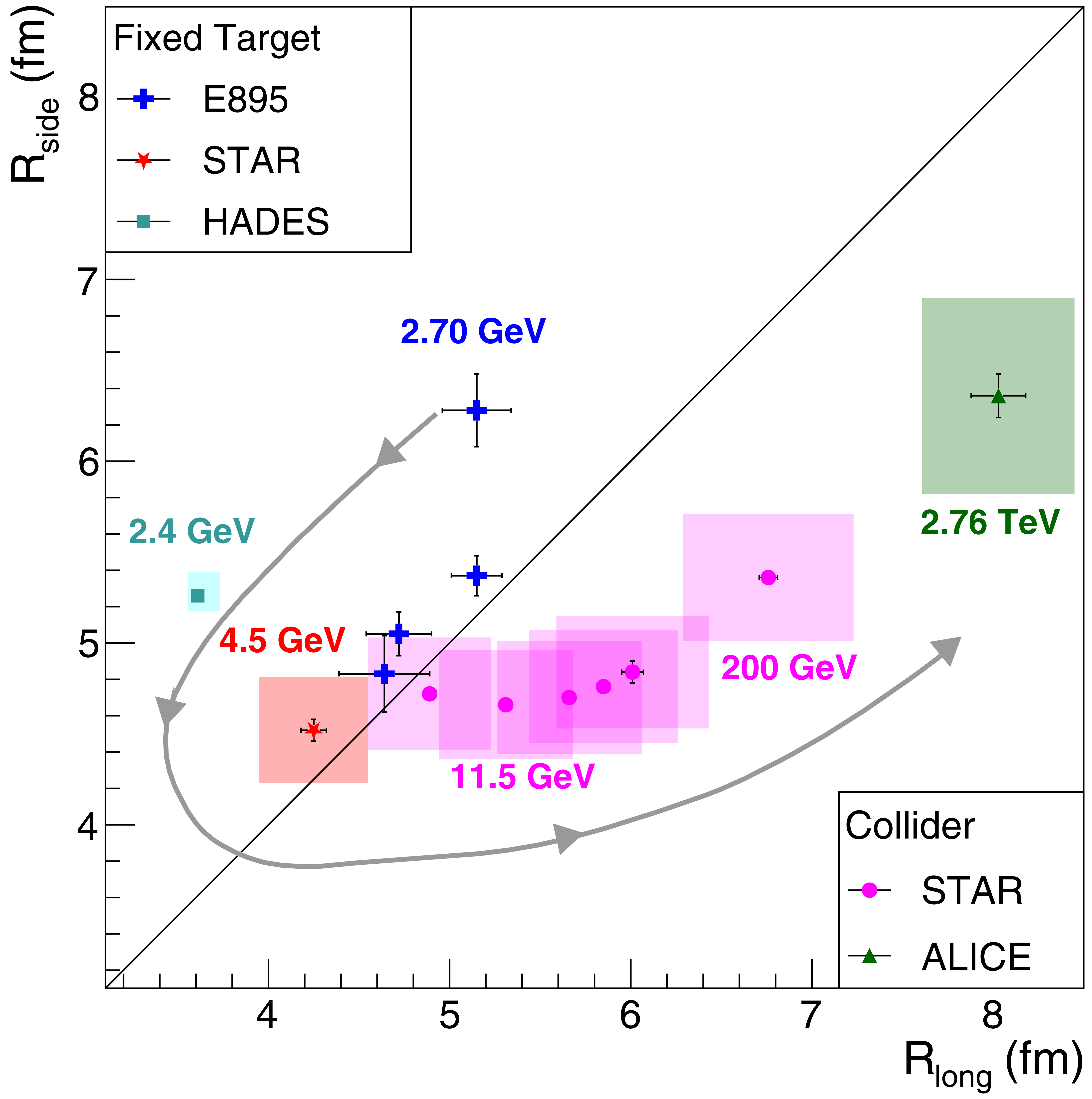


Expect a truck load of new results from the BES-II

Test Run in 2015 - Selected Results - Pion Femtoscopy

Evolution in the freeze out shape (hinted by the gray arrowed curve). Lower energy collisions generally produce more oblate systems, and the shape of the emission region tends to become more prolate with increased collision energy.

This trend reflects the evolution from stopping-dominated dynamics at low collision energies, to the approximately longitudinally-boost-invariant scenario at the highest energies. The STAR fixed-target point has $R_{side} \approx R_{long} \approx 4.5$ fm, indicating a source that is approximately round when viewed from the side, just at the transition point between oblate and prolate geometry.



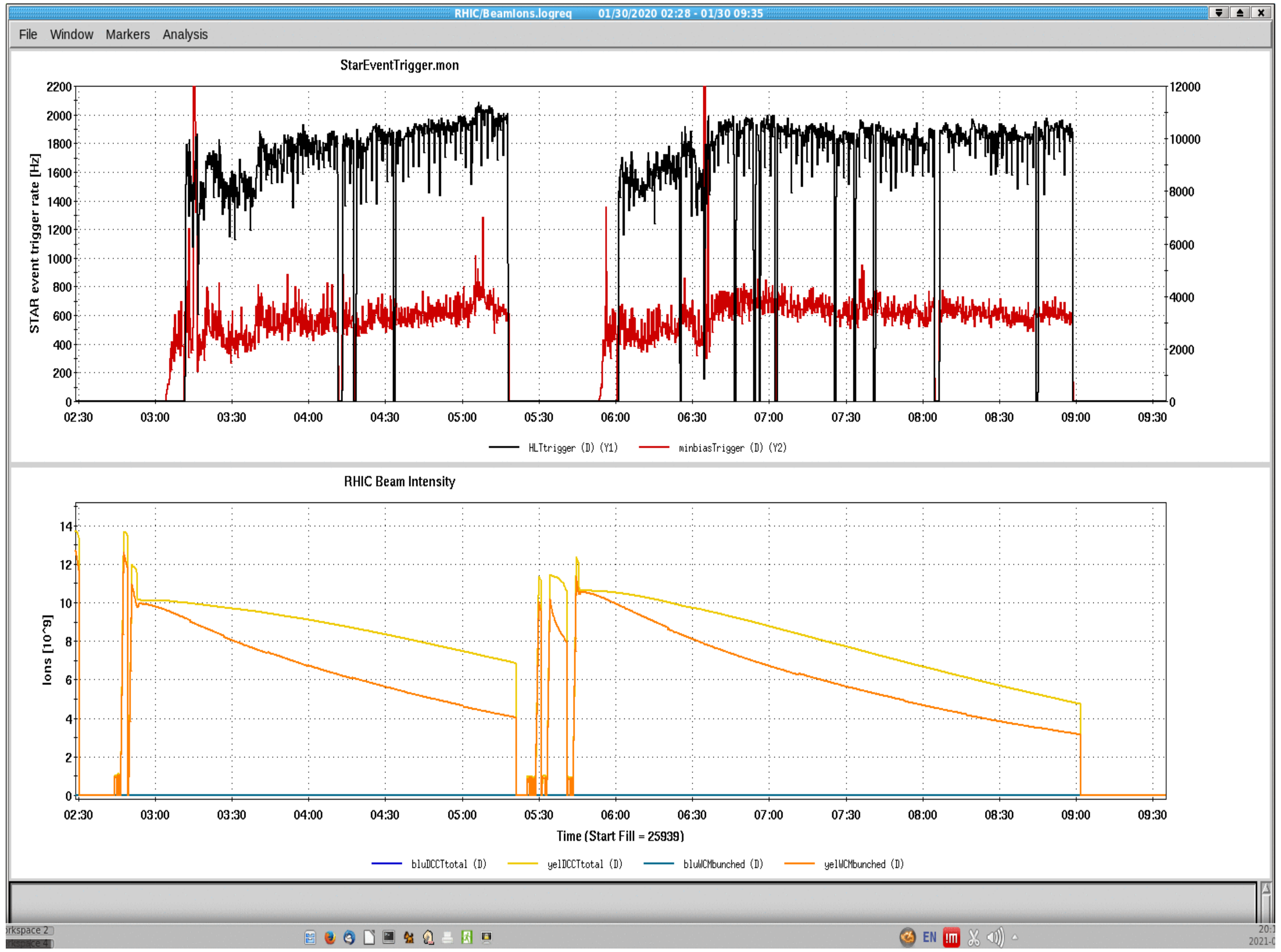
Ways to Control the Rate and Background

taken from C. Liu at MOPAB009, IPAC 21, Campinas, SP, Brazil

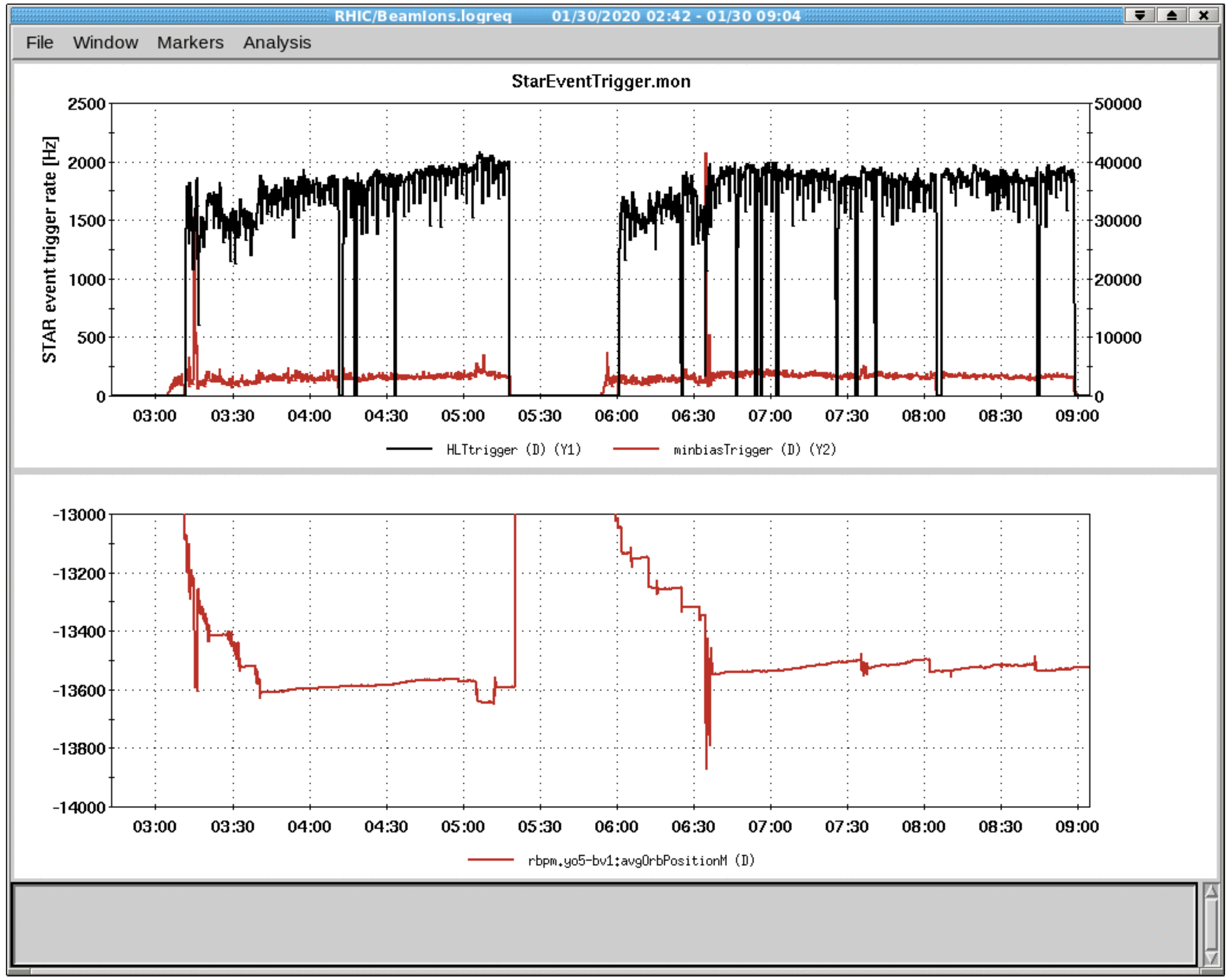
- relative large beam size at the fixed target
- small beam size at the final focusing magnet so the beam can be moved down vertically
- controlling procedure:
  - move orbit close the fixed target
  - fine tune vertical orbit to control rates
  - move in collimators to control background

Experimental Rates in Fixed Target Rate Mode

taken from C. Liu at MOPAB009, IPAC 21, Campinas, SP, Brazil



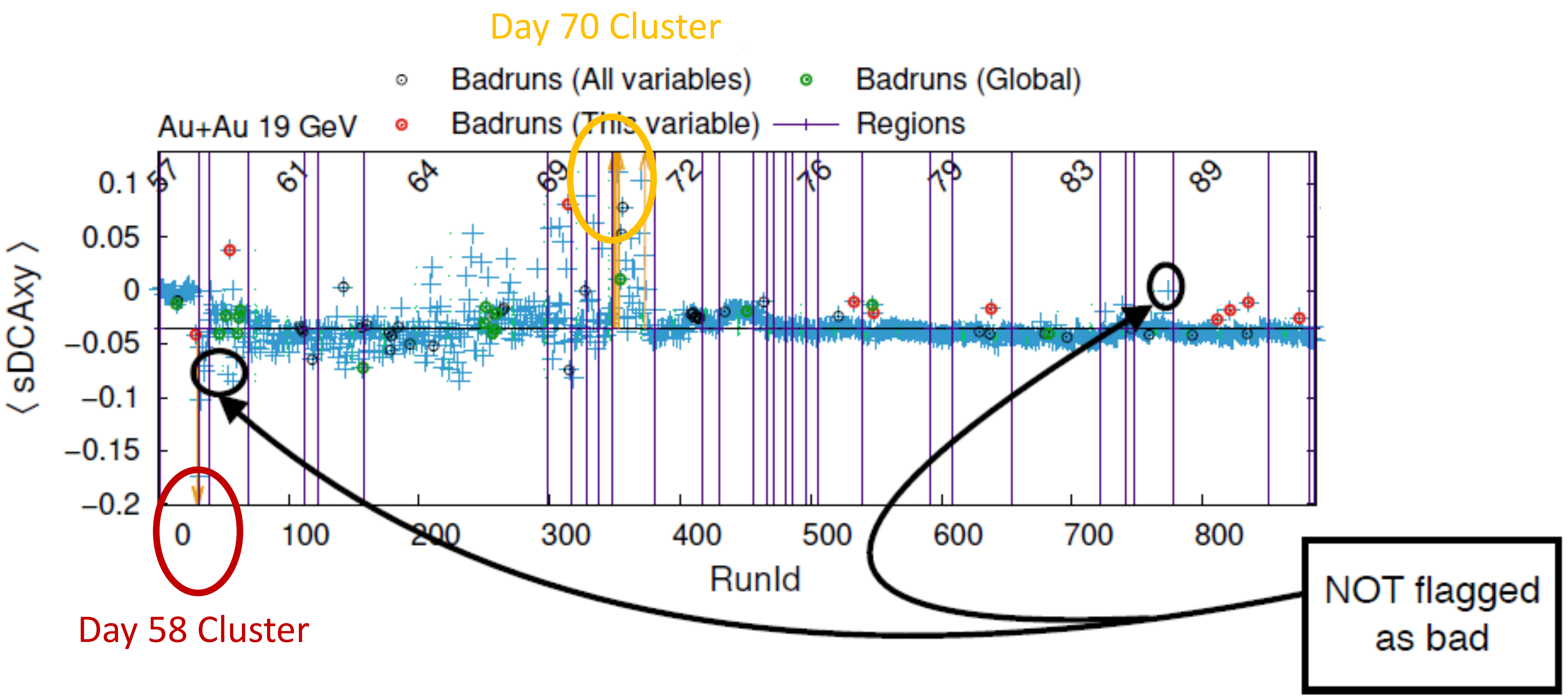
The upper plot shows the fixed target event rate (in black) and min-bias rate (in red) over the time period of two physics stores at 9.8 GeV. The lower plot shows the beam intensity evolution during the stores, total beam intensity in light yellow and bunched beam intensity in dark yellow.



Vertical orbit bump implemented during the fixed target stores to maintain the experimental rates.

A challenge to Opening The Beam Pipe

- STAR experienced poor vacuum for the first two weeks of the 2019 run
- This is due to molecules adhering to the wall of the pipe
- High Energy Colliders typically address this through beam “scrubbing”



Overall beam quality improved around day 71

Summary

- STAR experiment was designed to operate in collider mode, but it did not prevent successful implementation of Gold target, test run with enough data to publish Flow and Interferometry analysis at $\sqrt{s_{NN}} = 4.5$ GeV, and collect data at 12 energies as a part of BES-II program in years 2018-2021.
- Data are being produced and analyzed right now
- Stay tuned and expect publications within next 1-3 years

Thank you