Progress on Light-Flavour Hadron Production at Fixed-Target Energies with STAR

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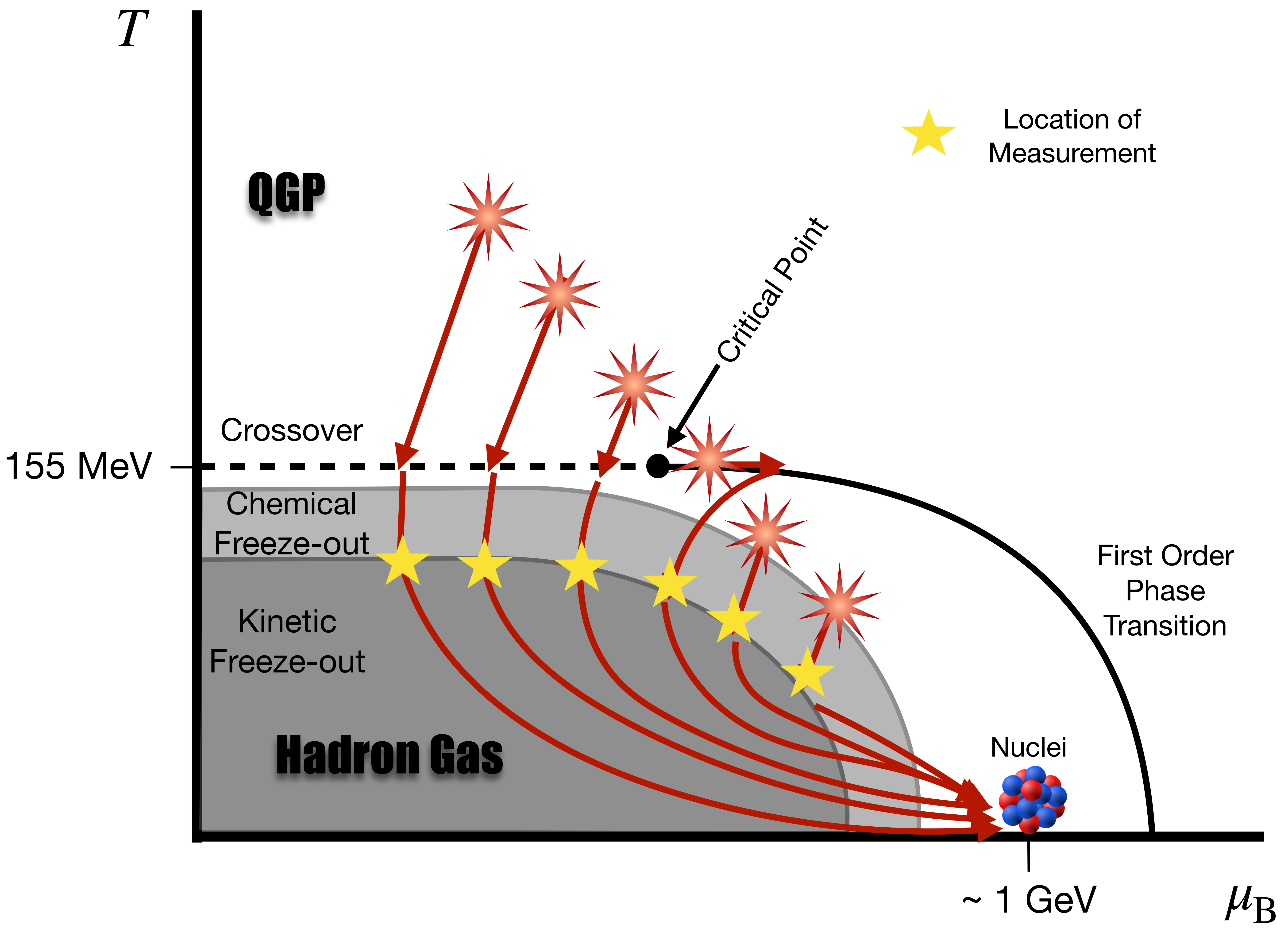
Supported in part by

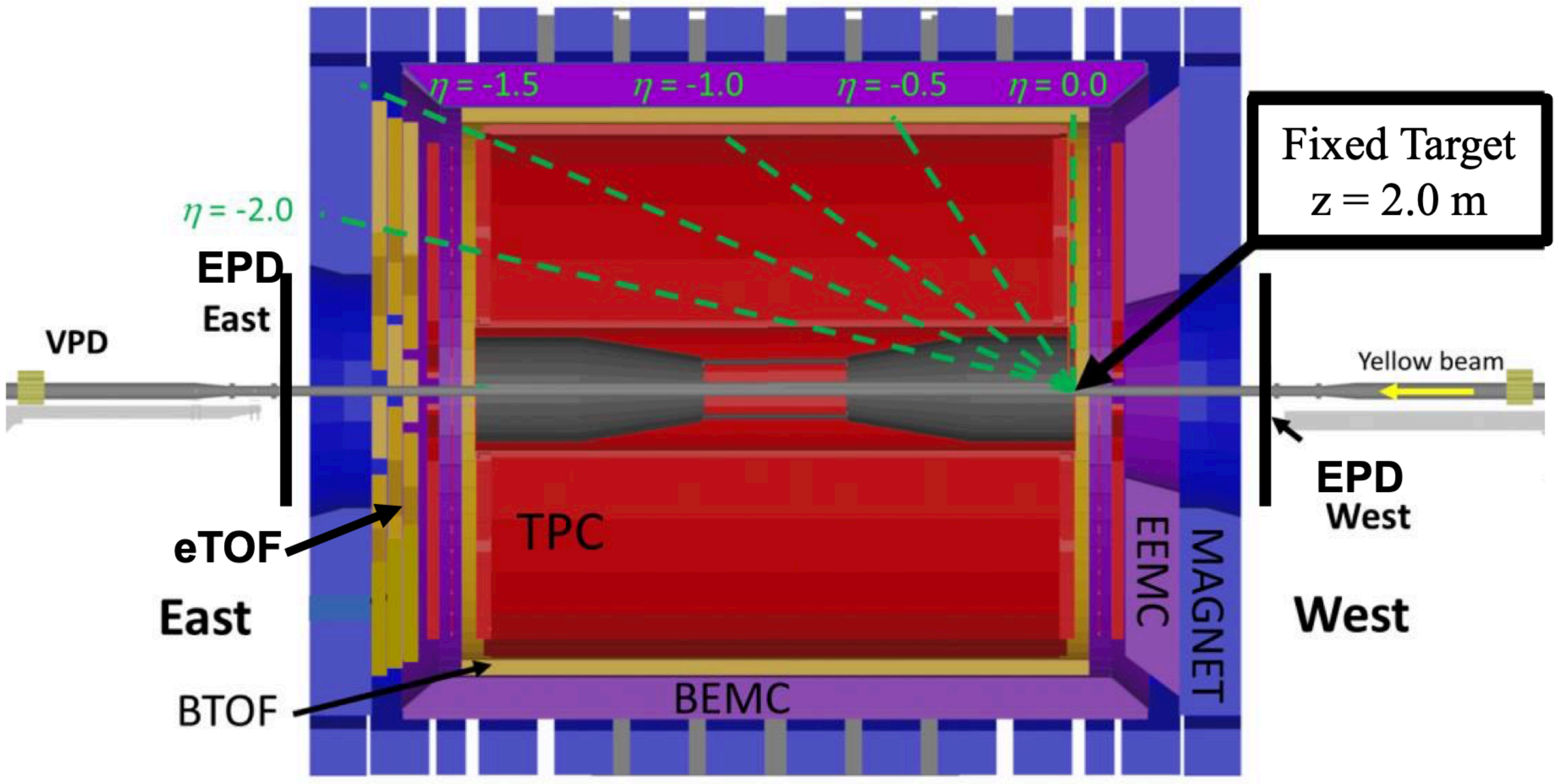
Beam Energy Scan at RHIC

- Designed to study the QCD phase diagram
- Search for 1st order and crossover phase transitions, and critical point
- BES-I energy range: $\sqrt{s_{NN}} = 7.7 - 62.4$ GeV
- BES-II extends the low end of the energy range to $\sqrt{s_{NN}} = 3.0$ GeV ($\mu_B \approx$ 720 MeV)



Fixed-target program (FXT)

- Program was implemented to extend energy reach of BES-II
- Run STAR in fixed-target mode with a gold foil target at the entrance to the TPC
- New detector for fixed target configuration: endcap time of flight (eTOF)
- As energies increases, y_{cm} moves into eTOF



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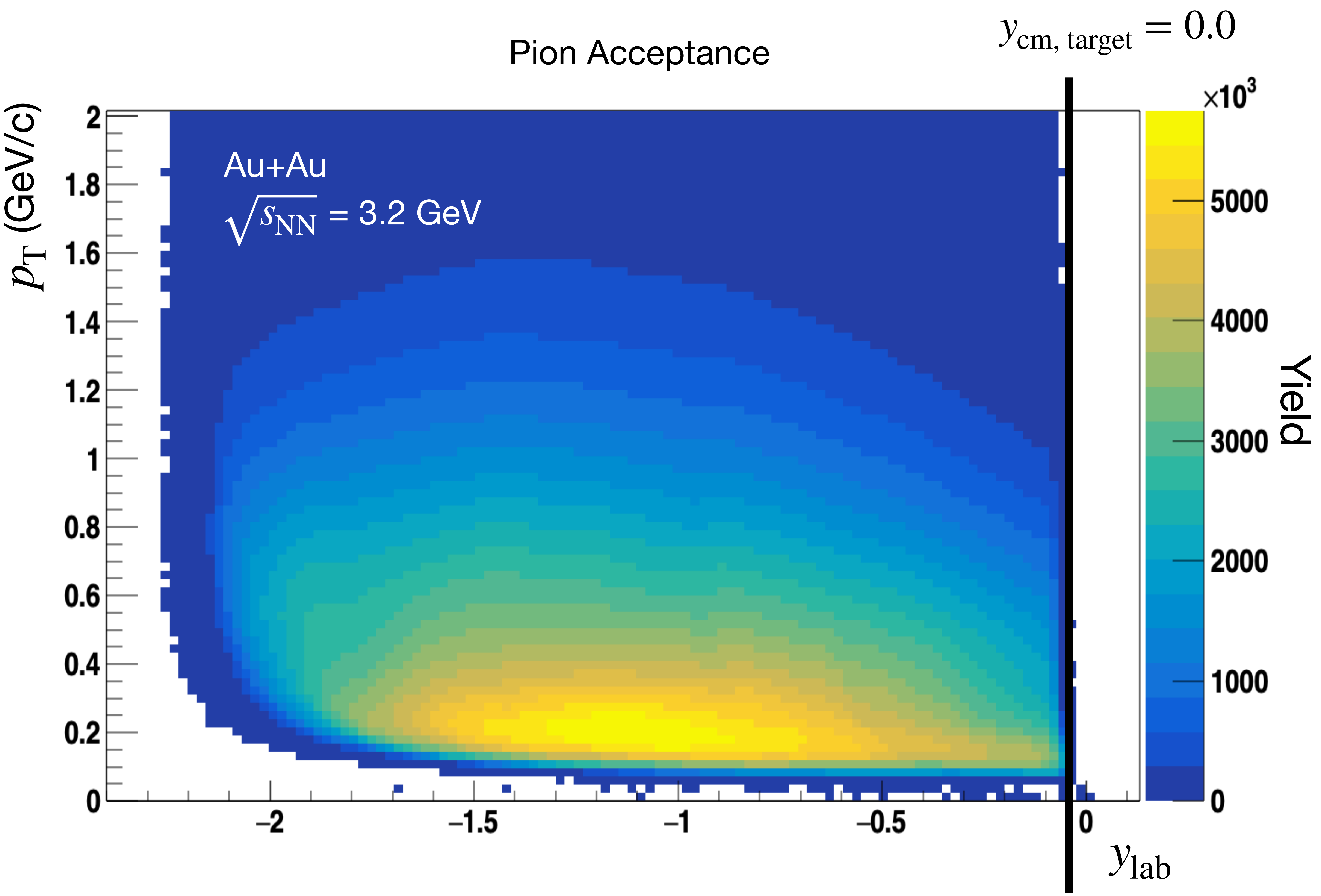
  FXT energies: $\sqrt{s_{\mathrm{NN}}}$ = 3.0 - 7.7 GeV
- $\mu_B \approx$ 276 - 721 MeV

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

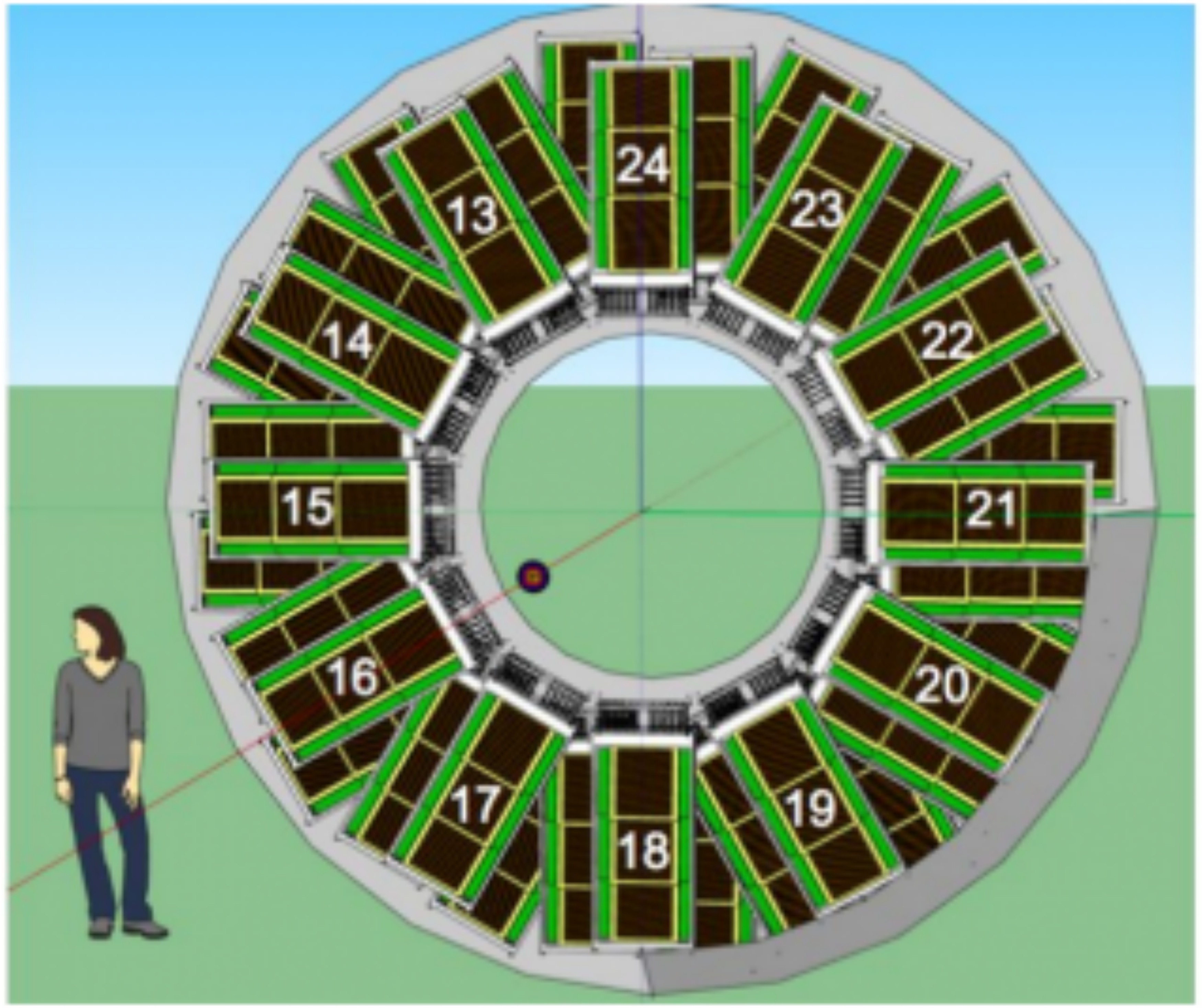
Time Projection Chamber (TPC)

- Recently upgraded TPC (iTPC upgrade, 2019)
  - Replaced inner pad rows (higher density of pad rows than before)
- Better dE/dx and momentum resolution
- For FXT, -2.24 < η < 0
- With iTPC upgrade, a validation of the efficiency methodology is needed



Endcap Time-of-Flight (eTOF)

- New detector for BES-II, implemented in 2019
- Psuedorapidity coverage of: $-2.24 < \eta < -1.52$
- Extends PID coverage for STAR analyses
- When combined with collider data, will allow for large rapidity reach beyond center-of-mass rapidity, and extensive comparisons with collider data
- Center-of-mass rapidity moves into eTOF acceptance at higher FXT energies



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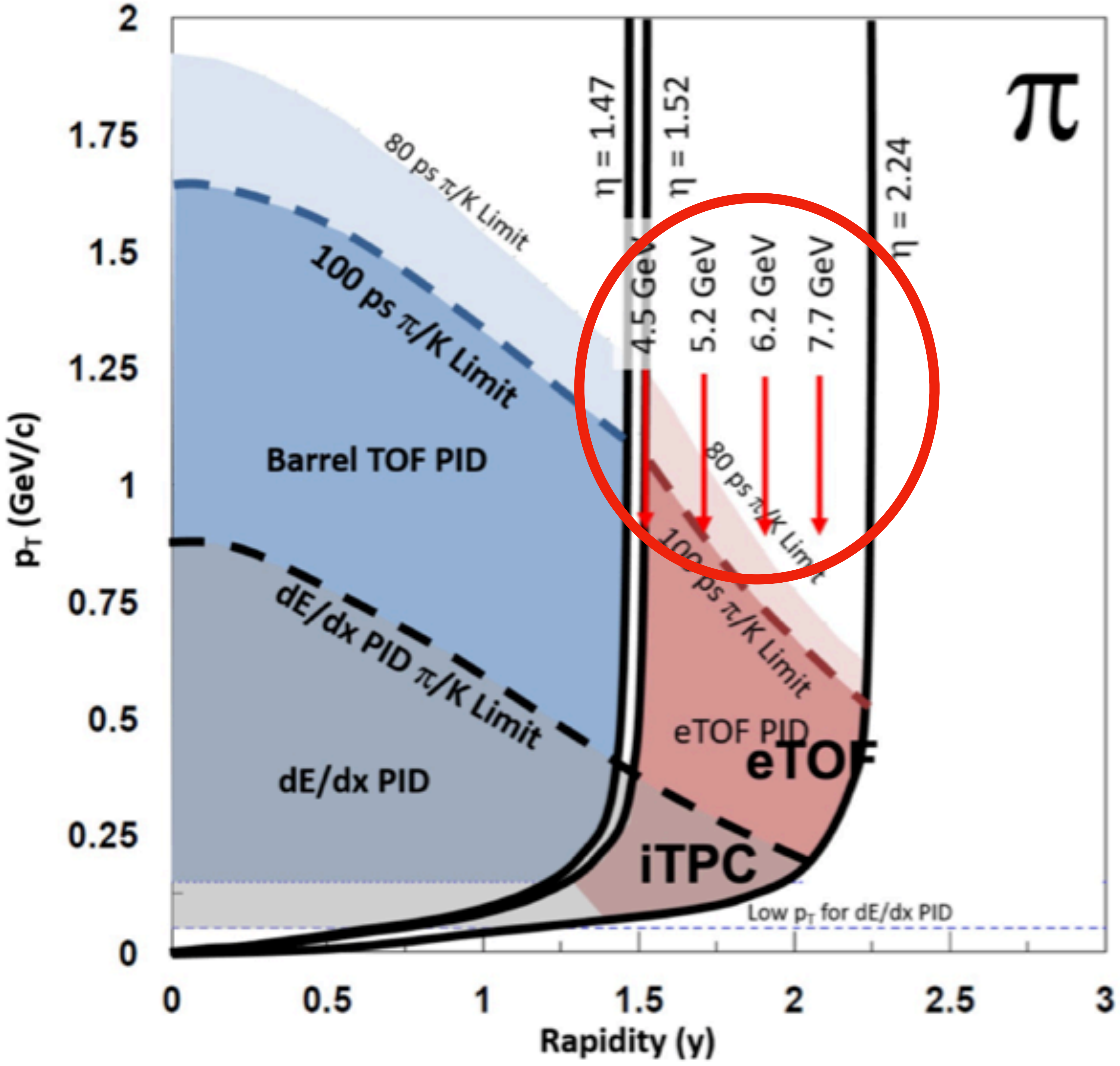
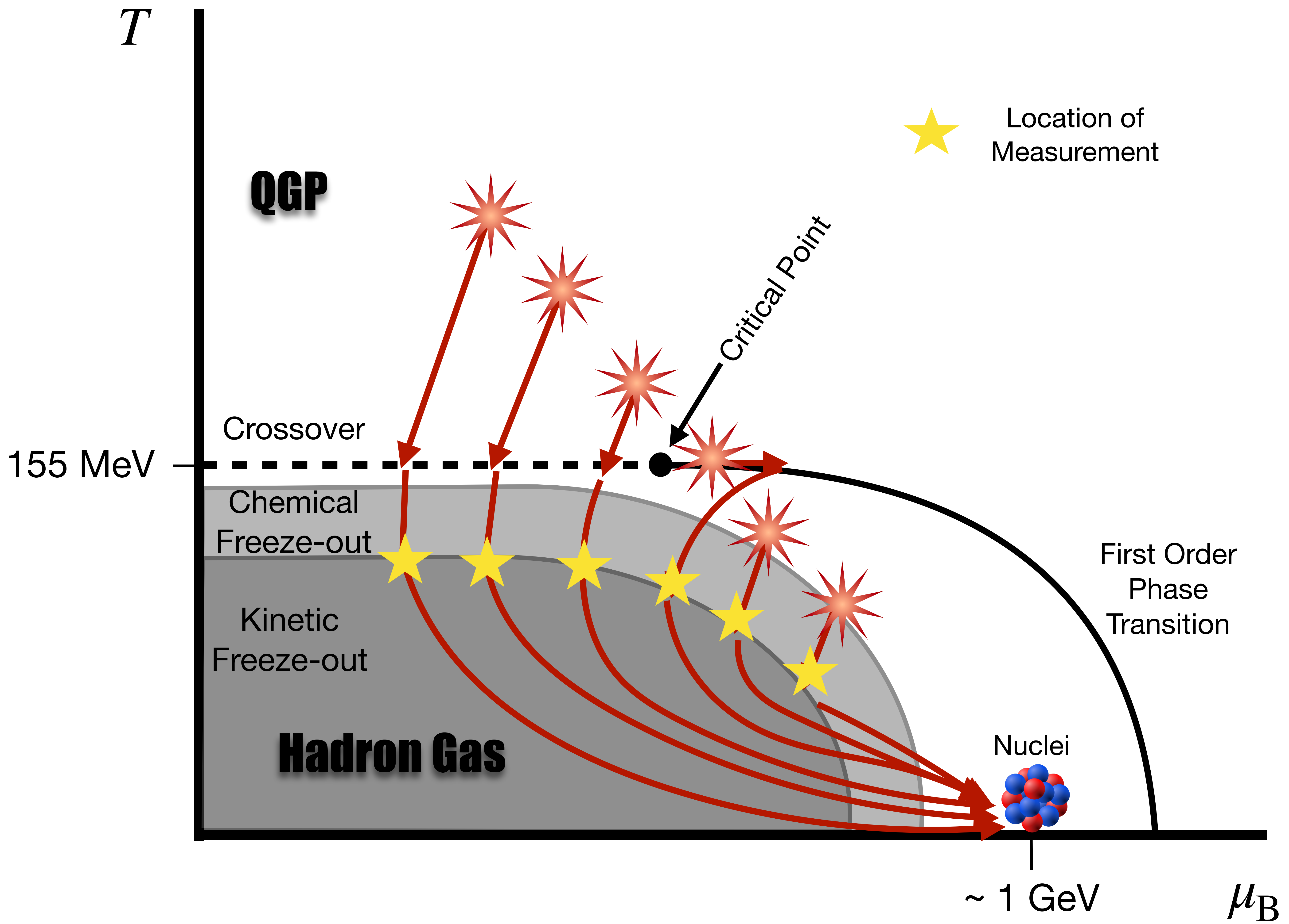


Light-flavour hadron production at STAR

- Hadron production is a key measurement in the search for a change of the QCD equation of state

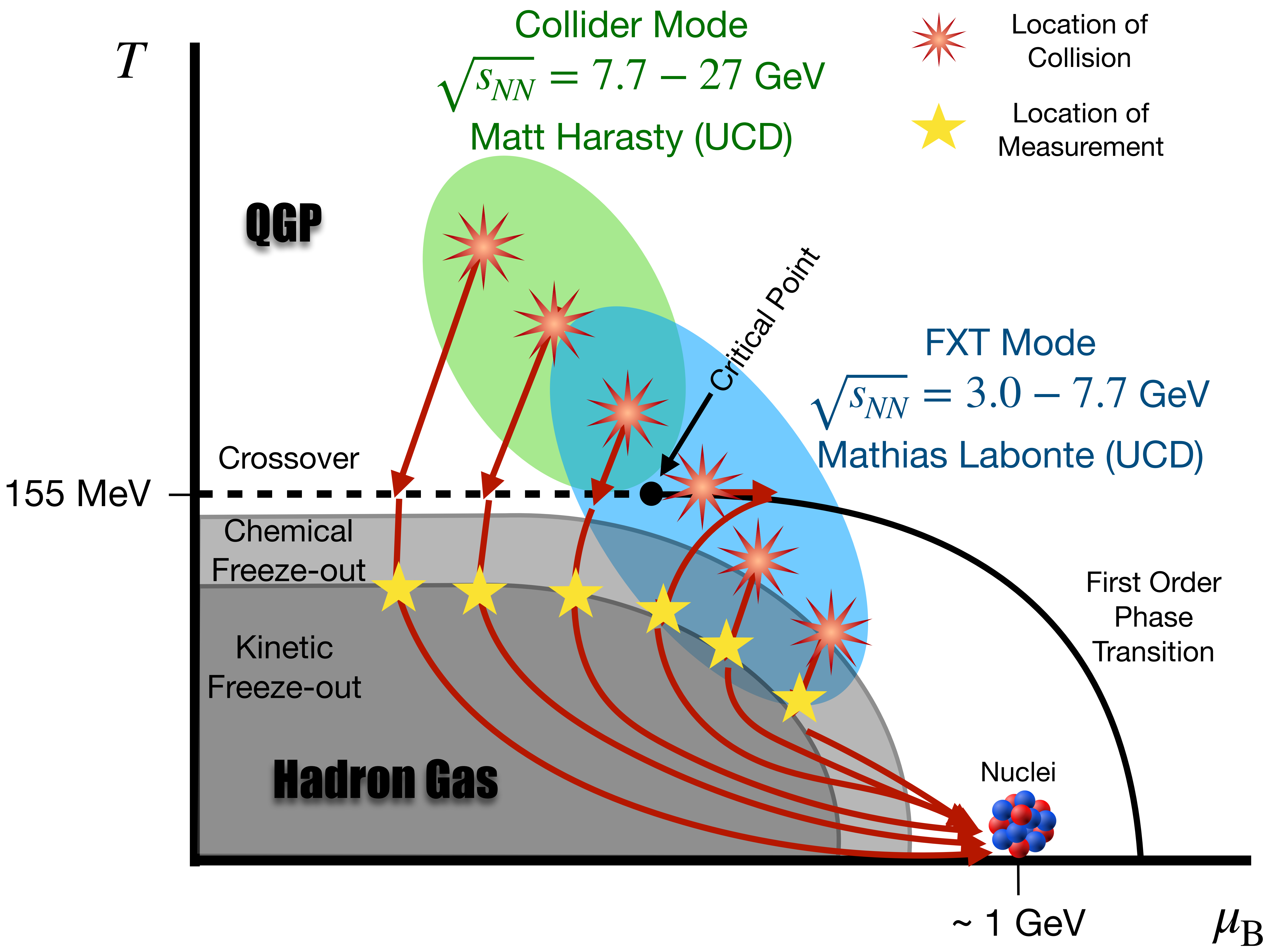
- Light-flavor hadron [π,K,p] production measurements yield insights into the bulk properties of the produced medium



Light-flavour hadron production at STAR

Measurements of the bulk properties

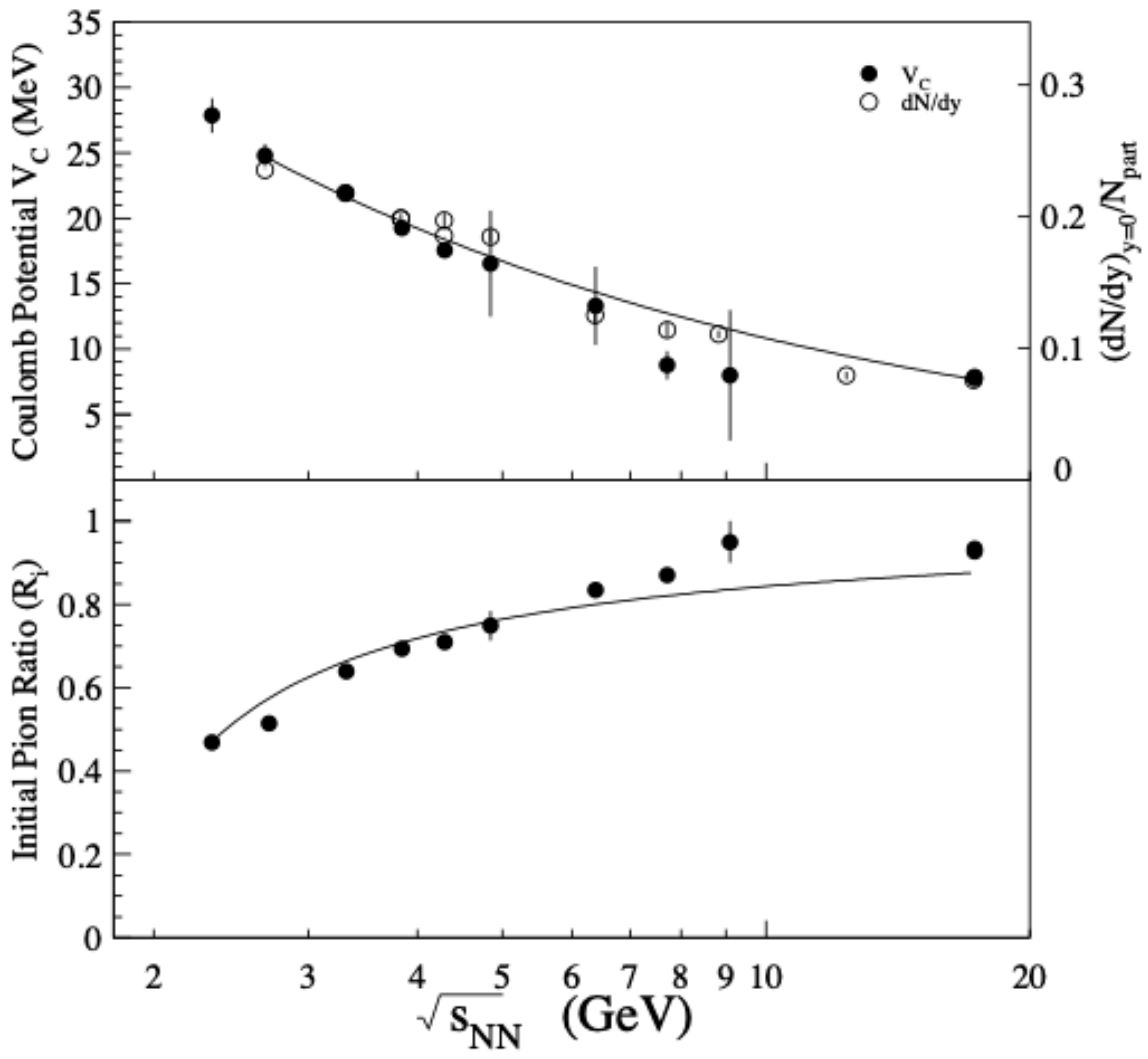
- Why hadron spectra?
  - π, K, p spectra allow us to constrain T, μ_S, μ_B at chemical and kinetic freeze-out through thermal modelling
  - By coupling these measurements to other observables, can 'map' the QCD phase diagram after chemical freeze-out!
  - Overlap energies provide cross-checks with collider configuration



Light-flavour hadron production at STAR

Interesting physics from $\pi^{\pm}$ production

- Why hadron spectra?
  - $\pi^{\pm}$ production in FXT energies has significant contributions from Δ resonance decays
  - The coulomb potential of the fireball will repel positive particles, and attract negative pions
  - A ratio between the yields of charged pions will give us information about the coulomb potential of the fireball
  - Coulomb potential is related to the source size



Cebra, D., et al. "Coulomb effect in Au+ Au and Pb+ Pb collisions as a function of collision energy." *arXiv preprint arXiv:1408.1369* (2014).

Light-flavour hadron production at STAR

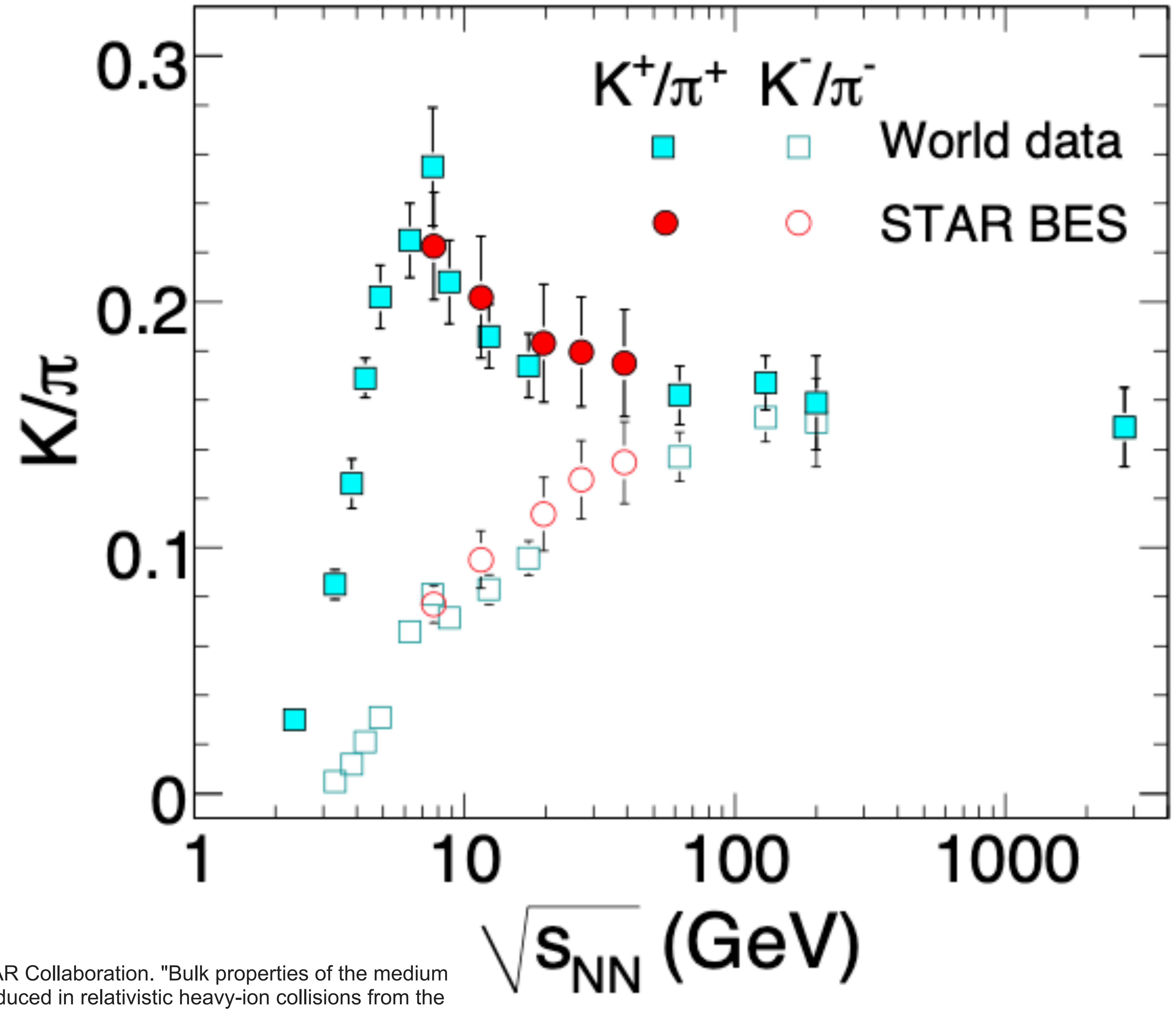
Interesting physics from $K^{\pm}$ production

- Strangeness production proposed as a signature of the onset of deconfinement

- Kaon production has significant contributions from associated production ($N + N \rightarrow \Lambda + K + N$)

- Classic 'horn' may also be related to increased baryon stopping and a change in the production mechanisms for kaons and pions at low energies (Busza, Wit, and Alfred S. Goldhaber. "Nuclear stopping power." *Physics Letters B* 139.4 (1984): 235-238.)

- Can be further investigated with BES-II data

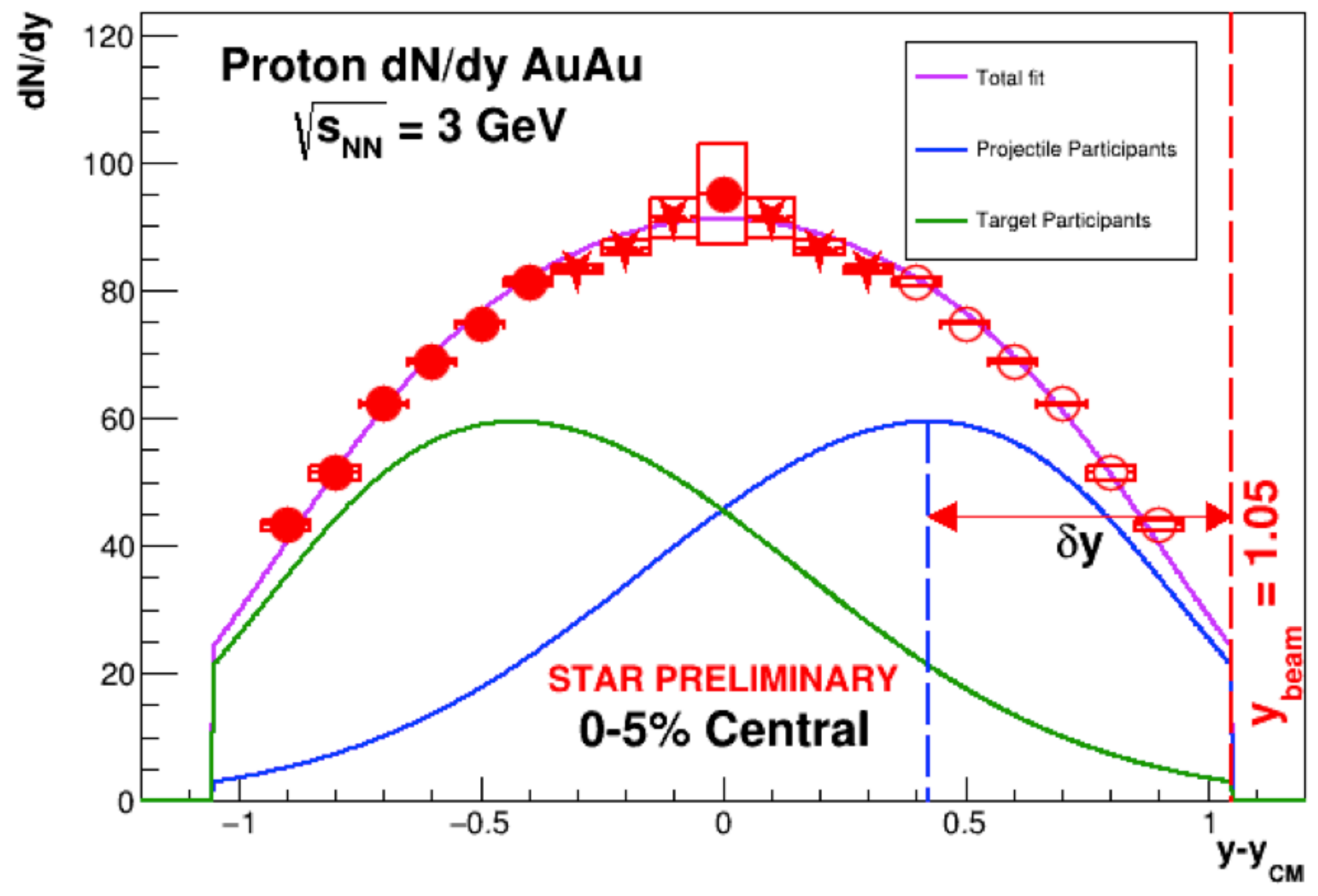


STAR Collaboration. "Bulk properties of the medium produced in relativistic heavy-ion collisions from the beam energy scan program." *Physical Review C* 96.4 (2017): 044904.

Light-flavour hadron production at STAR

Interesting physics from *p* production

- Baryon stopping - Stopped baryons are pushed away from beam rapidity. Studying the stopped protons could indicate the order of the phase transition (Ivanov, Yu B. "Alternative scenarios of relativistic heavy-ion collisions. I. Baryon stopping." *Physical Review C* 87.6 (2013): 064904.)



Ben Kimmelman Ph.D. Dissertation. "Baryon Stopping and Charged Hadron Production in Au+Au Fixed-Target Collisions at $\sqrt{s_{NN}}$ = 3.0 GeV at STAR ". 2022

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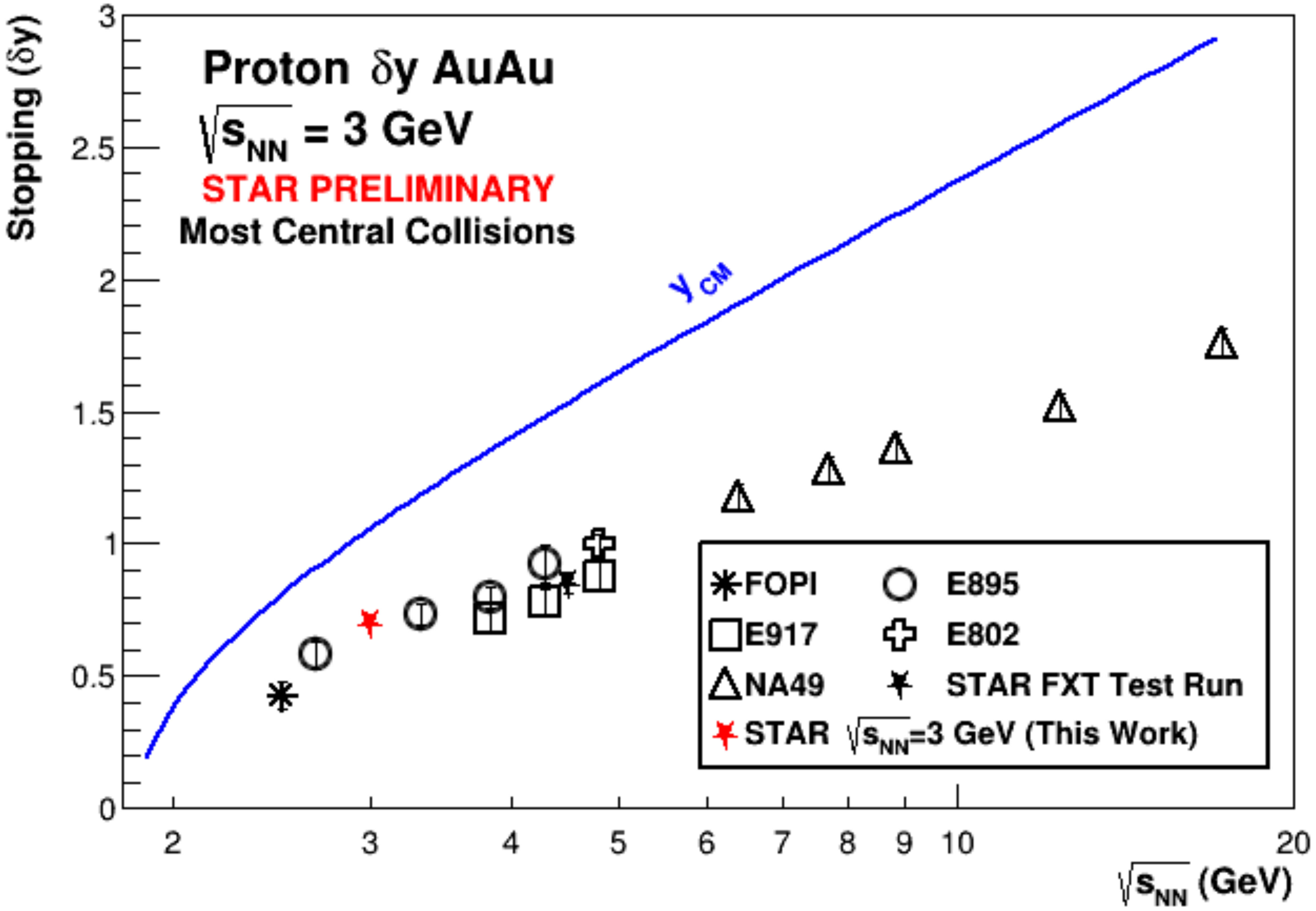
  (Ivanov, Yu B. "Alternative scenarios of relativistic heavy-ion collisions. I. Baryon stopping." *Physical Review C* 87.6 (2013): 064904.)

- Can investigate discrepancy in measurements between 4-6 GeV - indication of a first order phase transition?



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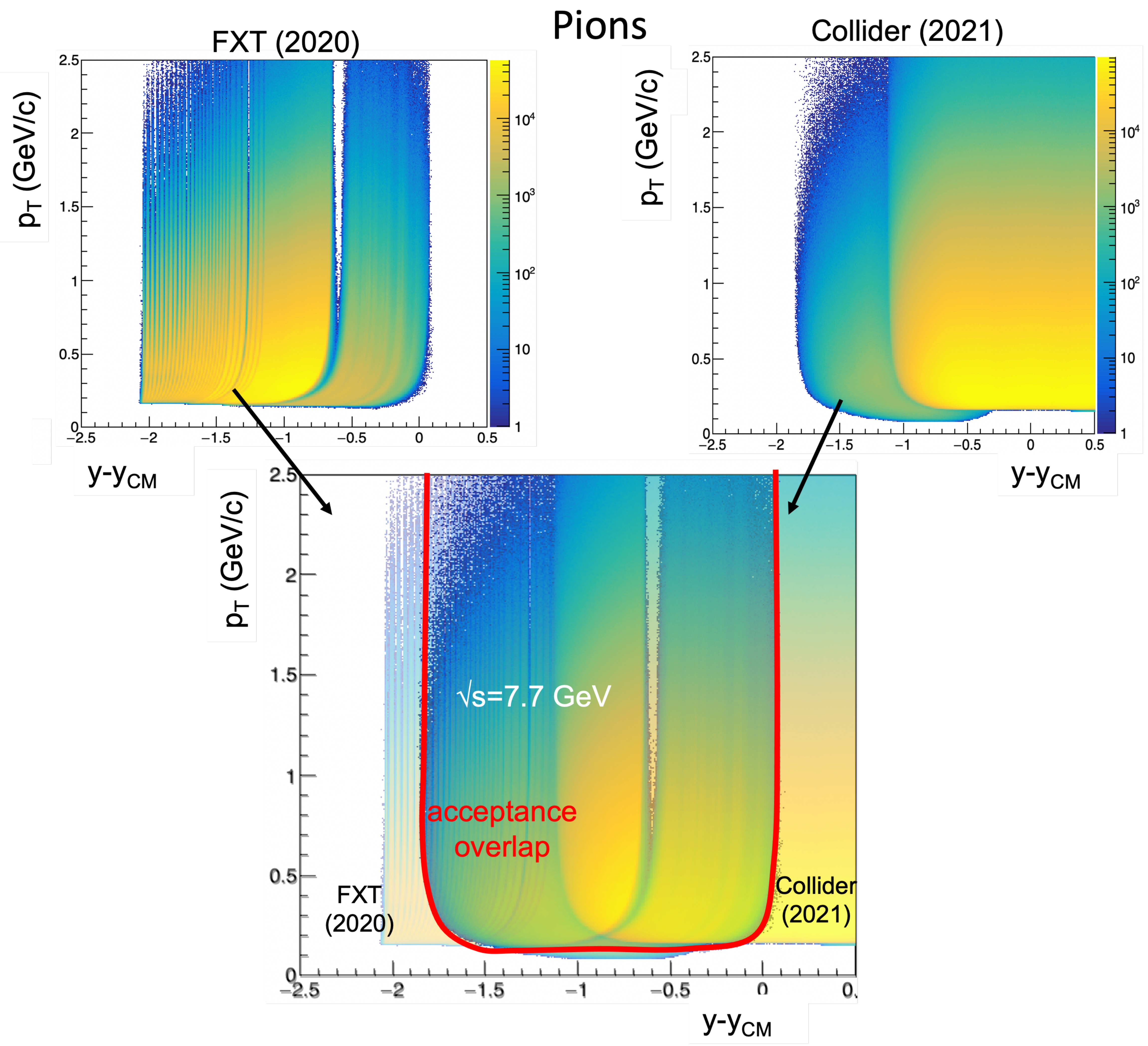
Cross-Checking with collider

- 7.7 GeV collisions were measured in collider and FXT modes
- Significant overlap in the phase space
- Allows for comparisons between collider and FXT configurations
- Allows us to assess the systematic error in the measurement



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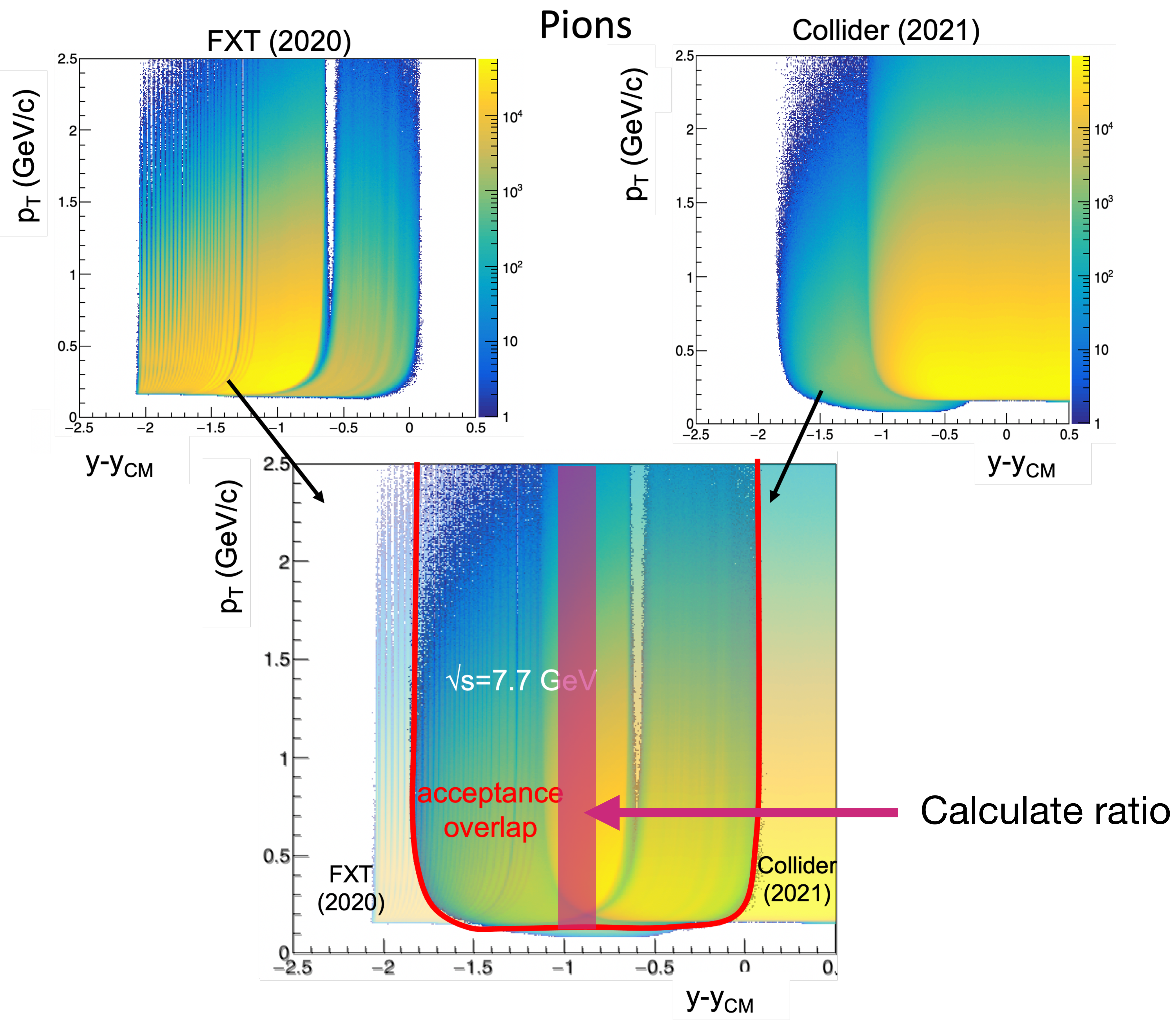
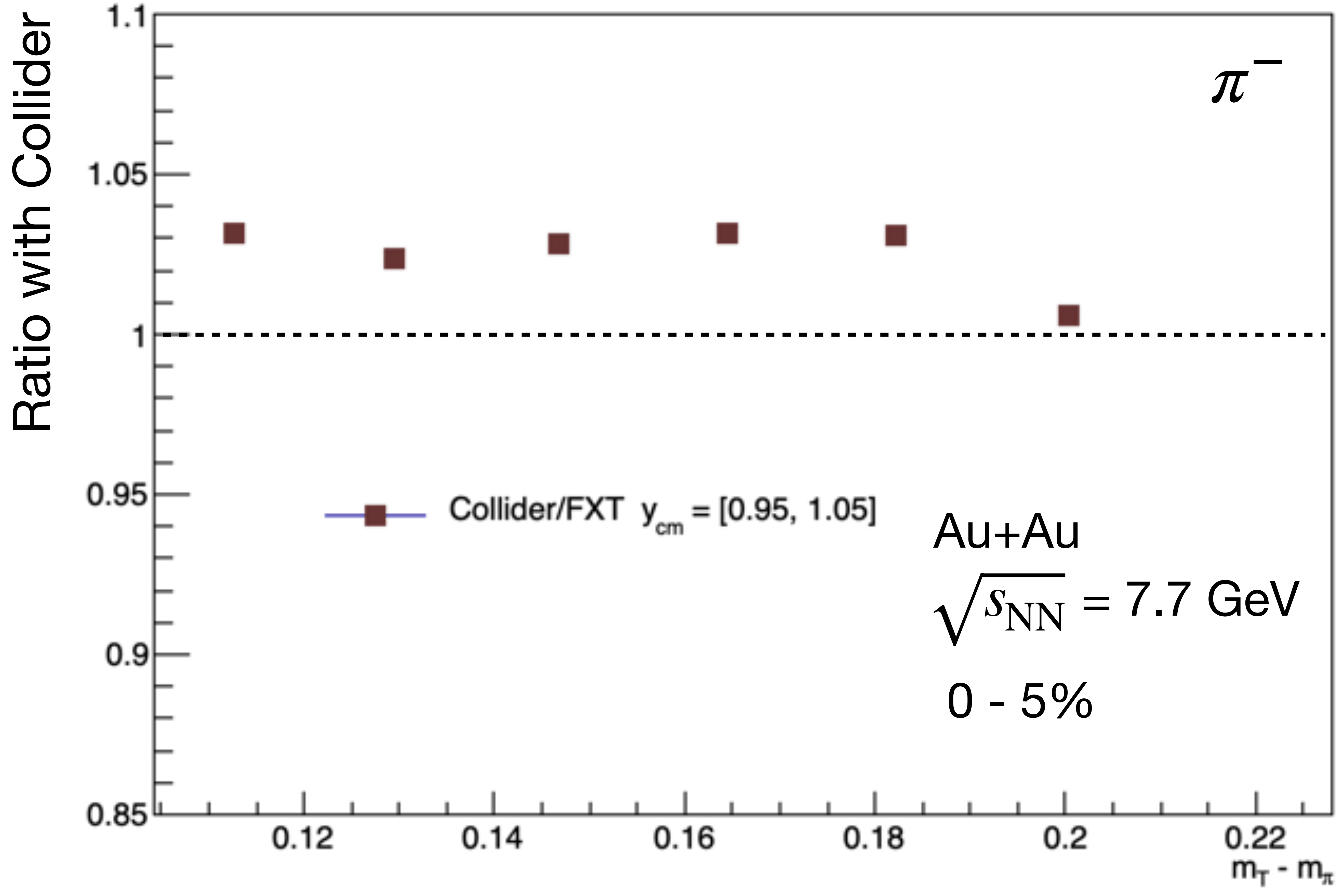


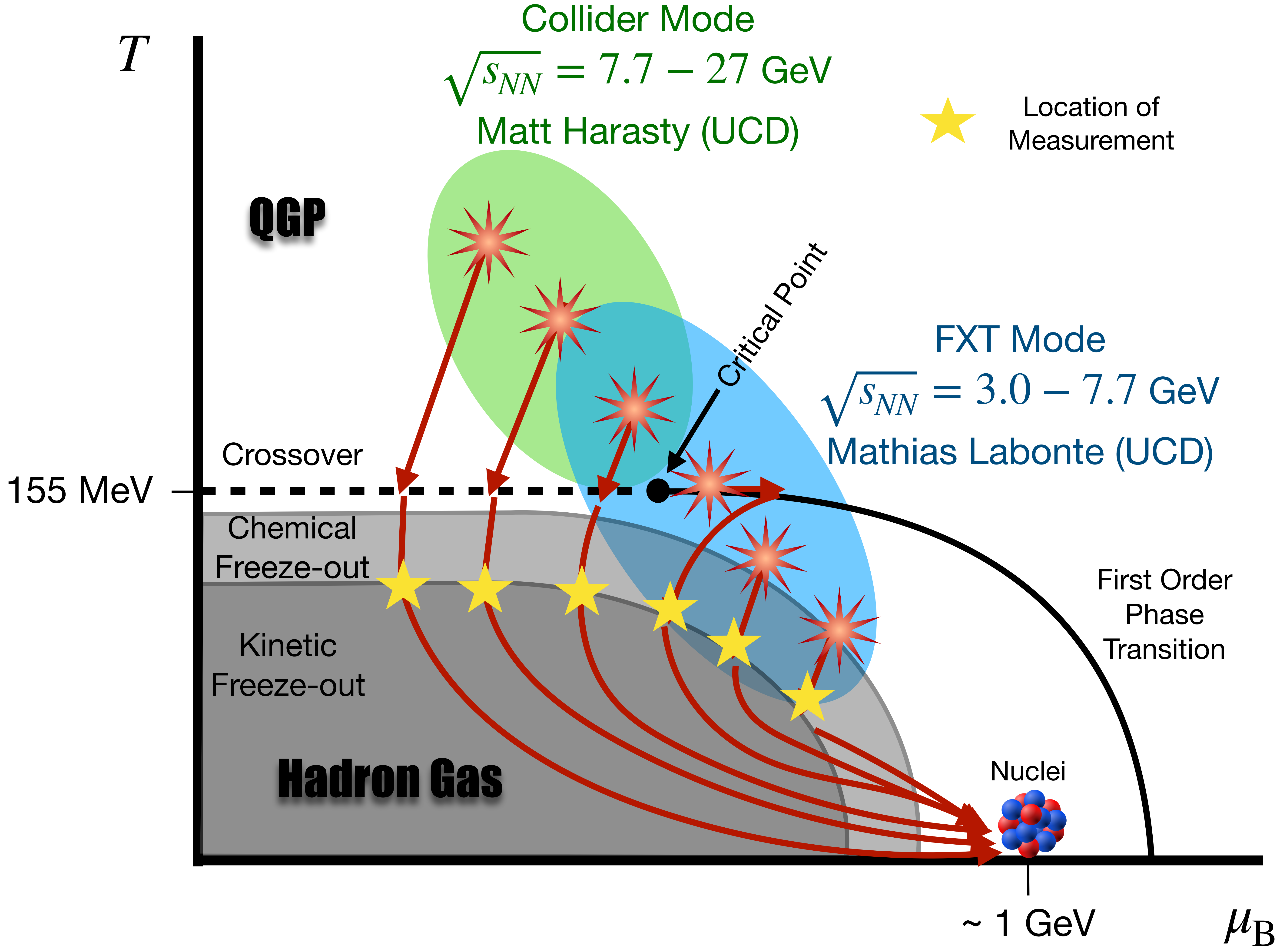
Cross-Checking with collider

- Allows us to assess the systematic error in the measurement
- Tracks measured by TPC only
- No systematic errors included
- Deviation in central value up to 3%
- Comes from systematic differences in efficiency correction



Summary

- FXT program extends the Beam-Energy Scan into an important region of the phase diagram
- Measurements of π, k, p spectra are ongoing for the fixed target energies: $\sqrt{s_{\mathrm{NN}}}$ = 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.2, 7.7 GeV
- Light flavour hadron production measurements provide valuable informations about the bulk properties of the system
- Lots of interesting physics to uncover:
  - Coulomb effect
  - Kaon horn
  - Baryon stopping
- Cross-checks between FXT and collider data at $\sqrt{s_{\mathrm{NN}}}$ = 7.7 GeV show a deviation in central value up to



Thank you