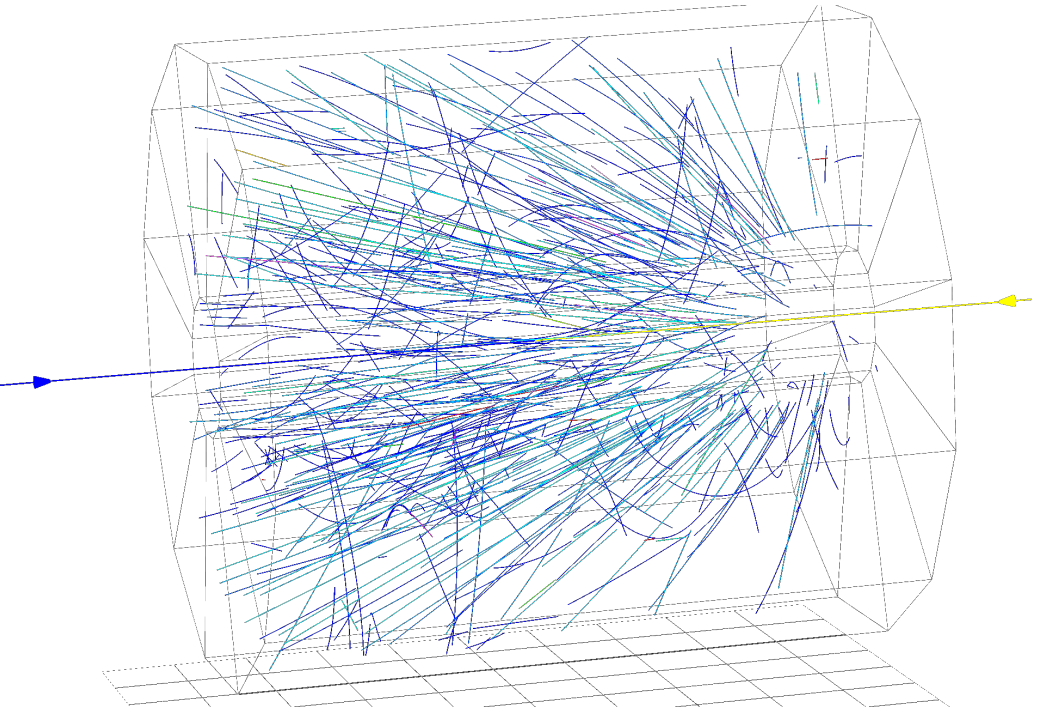

Proton-Cumulant Analyses in an Energy Scan of the STAR Fixed-Target Program at $\sqrt{s_{NN}}$ = 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.2,and 7.7 GeV

Zachary Sweger
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For the STAR Collaboration

Supported in part by

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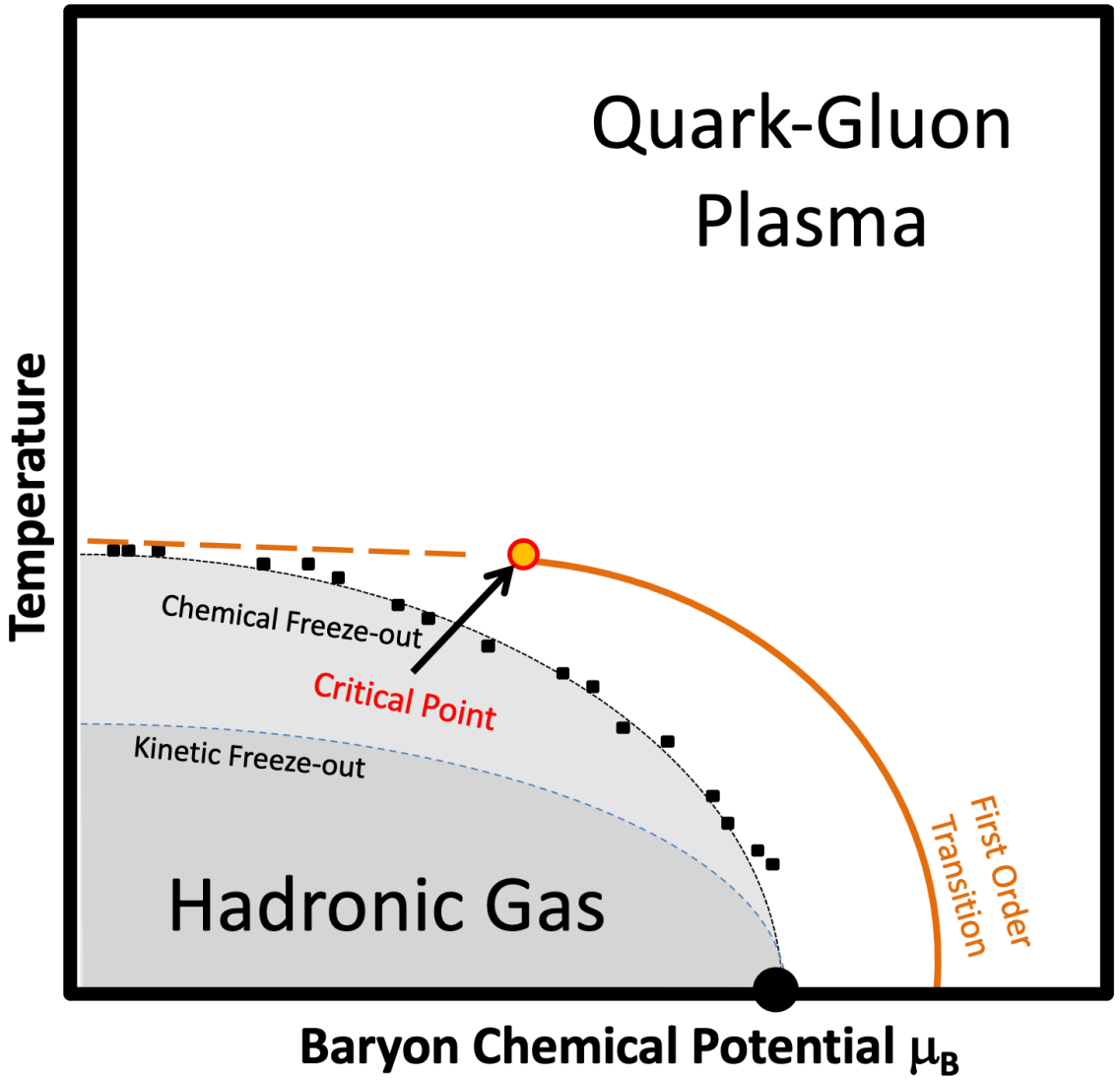
Phases of QCD Matter

QCD Phase Diagram

- Quarks and gluons experience confinement at low temperatures and densities.
- At high temperatures and densities, there is a deconfined phase, a quark-gluon plasma.

Beam Energy Scan (BES)

- BES program at the Relativistic Heavy-Ion Collider scans phase space of QCD matter by colliding gold ions at varying energies
- Seeking to map onset of deconfinement, and the predicted QCD critical point



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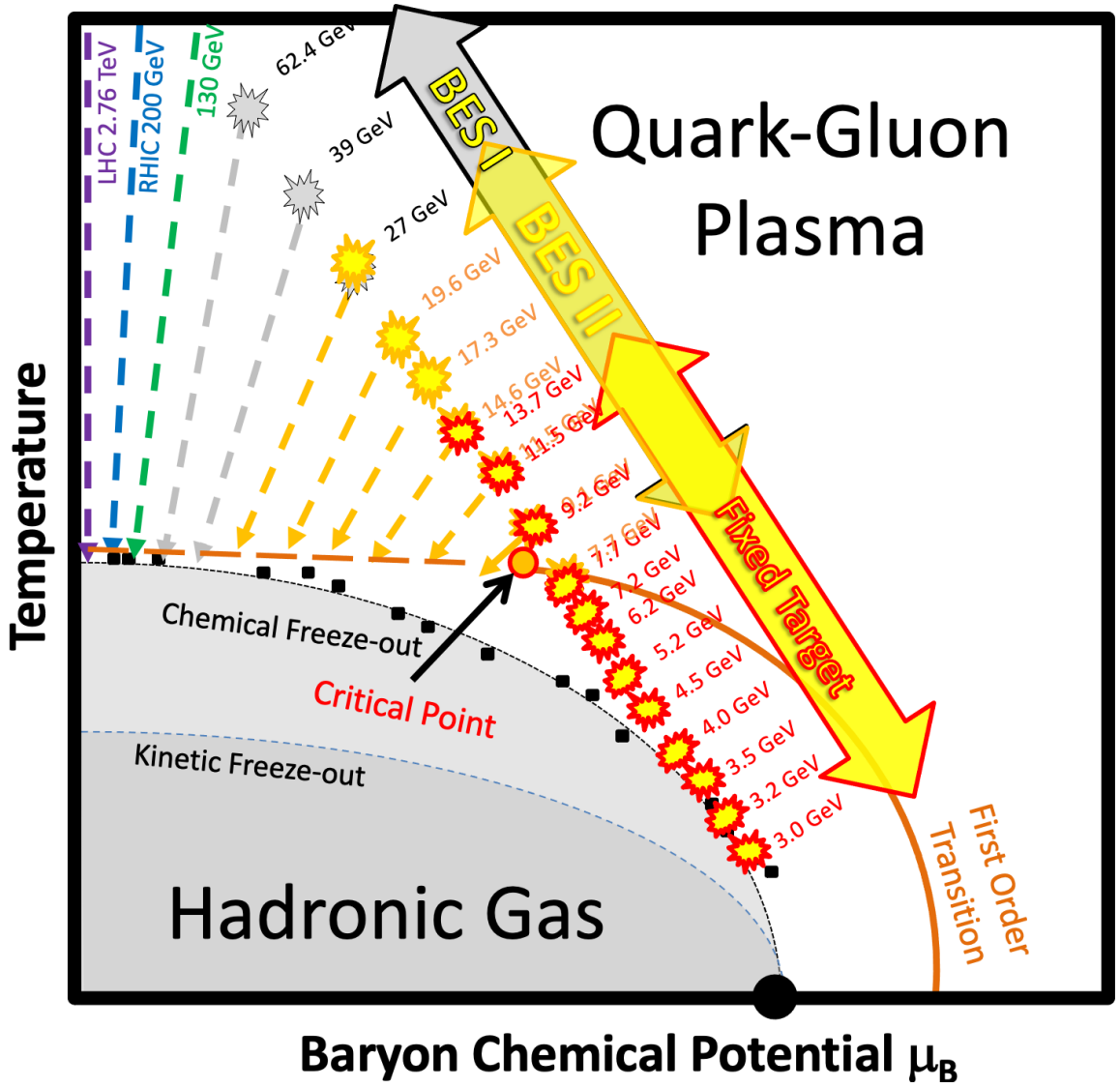
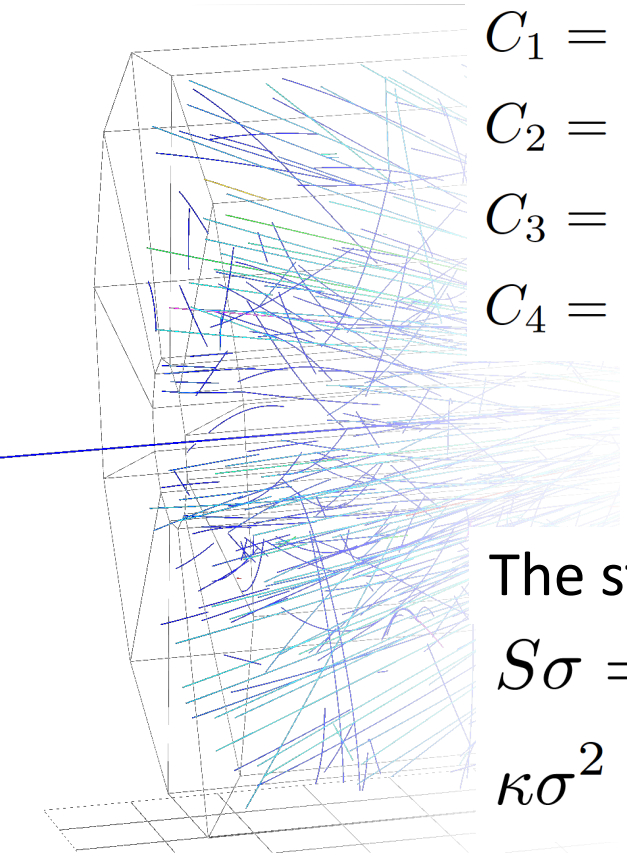


Cumulants and Moments



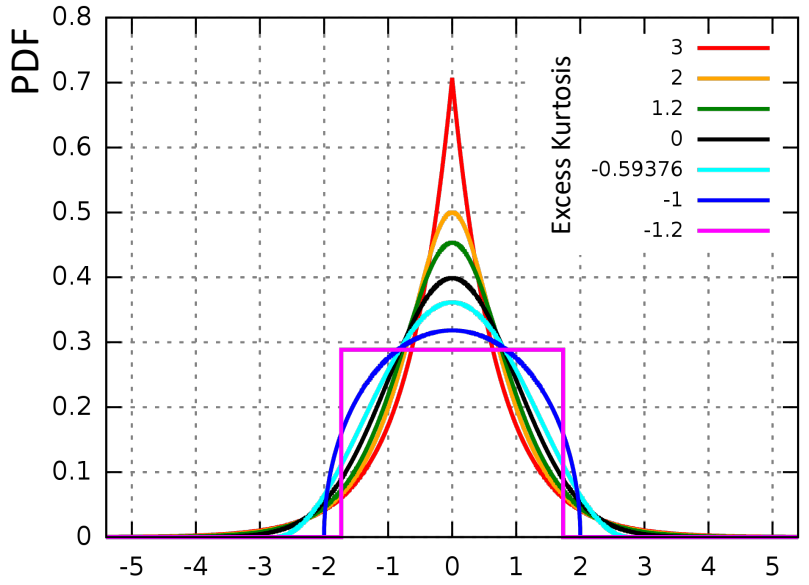
Cumulants of a distribution are defined as

$$C_1 = \langle N \rangle \equiv \mu \ [\text{mean}]$$

$$C_2 = \langle (N-\mu)^2 \rangle \equiv \sigma^2 \ [\text{variance}]$$

$$C_3 = \langle (N-\mu)^3 \rangle$$

$$C_4 = \langle (N-\mu)^4 \rangle - 3\langle (N-\mu)^2 \rangle^2$$



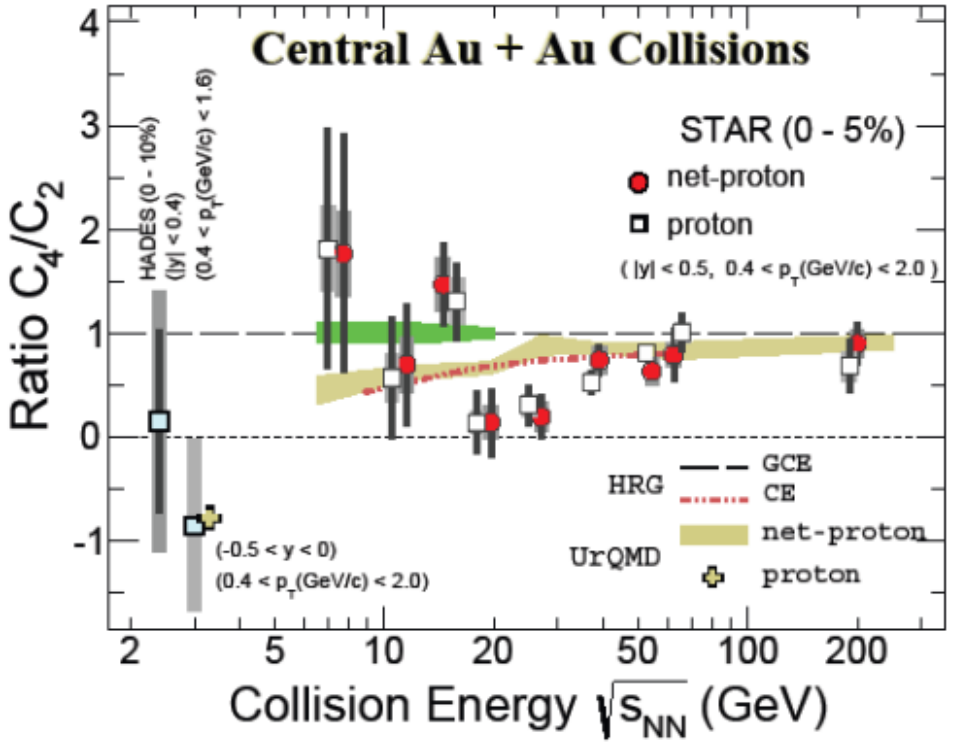
Kurtosis, Wikipedia (https://en.wikipedia.org/wiki/Kurtosis)

The standardized moments of a distribution are

$S\sigma = C_3/C_2 \ [\text{skewness}]$ measure of distribution's asymmetry

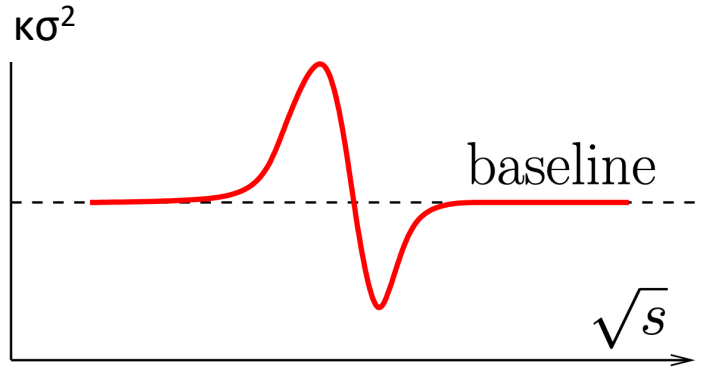
$\kappa\sigma^2 = C_4/C_2 \ [\text{excess kurtosis}]$ measure of distribution's tails

Current Status of Cumulants Analysis



STAR, Phys. Rev. Lett. 128, 202303 (2022) ; arXiv : 2209.11940.
Phys. Rev. Lett. 126, 092301 (2021); Phys. Rev. C 104, 024902 (2021)

Predicted Fluctuation in C_4/C_2 Near Critical Point



M. Stephanov. J. Physics G.: Nucl. Part. Phys. **38** (2011) 124147

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- Recent measurement at 3 GeV demonstrates a return to the UrQMD baseline.
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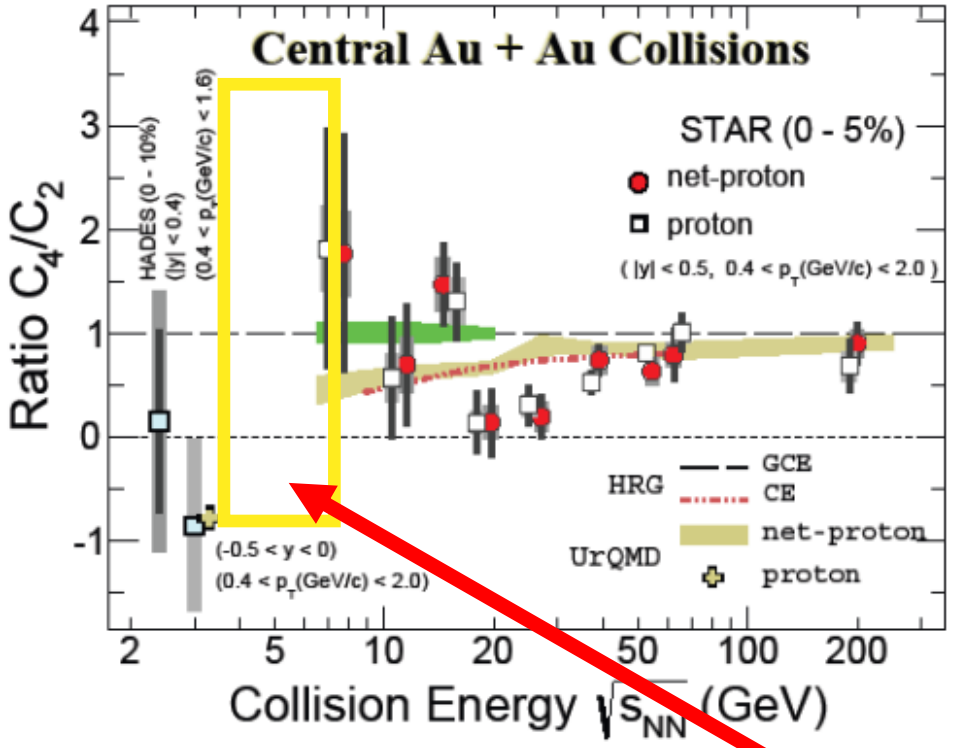

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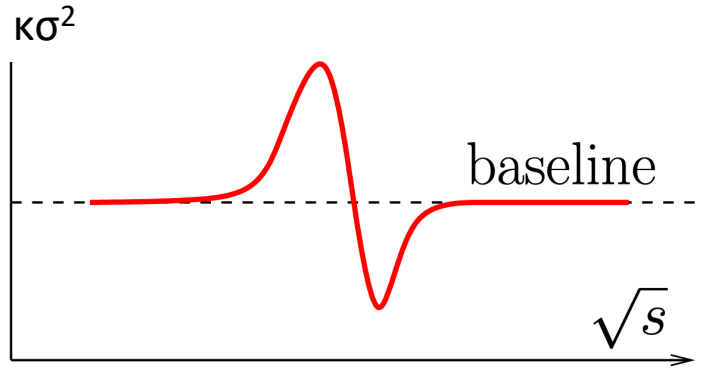

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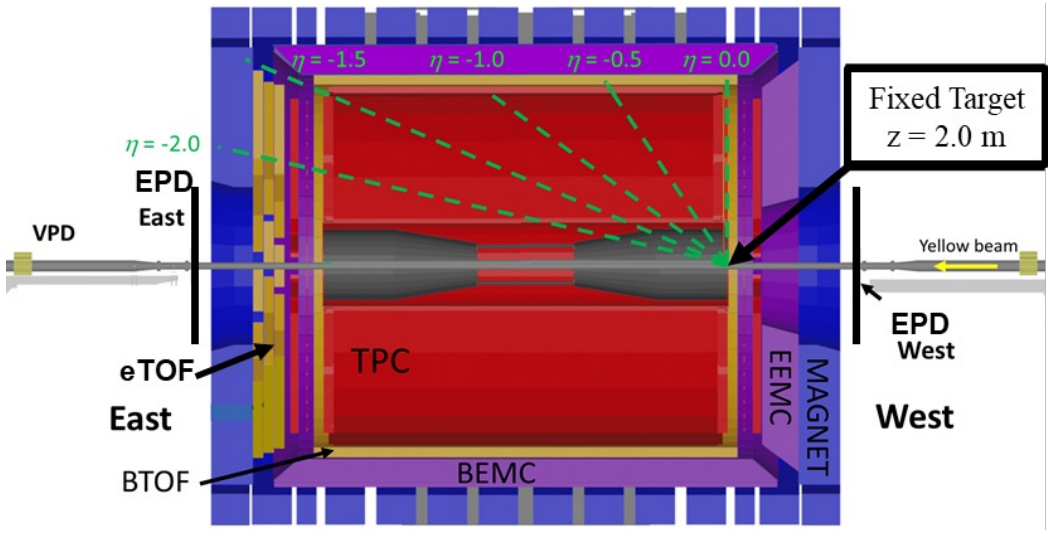
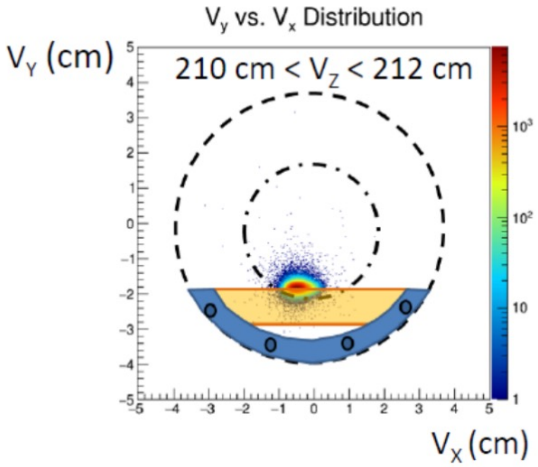
Fixed-Target (FXT) Program at STAR

- Test run with gold target in 2015
- First physics runs at $\sqrt{s_{NN}}$ = 3.0 GeV and 7.2 GeV in 2018
- Now have data at $\sqrt{s_{NN}}$ of 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.2, and 7.7 GeV



Challenges for FXT

- Shifting asymmetric acceptance wrt midrapidity
- At 7.7 GeV midrapidity moves to edge of Time Projection Chamber (TPC) acceptance
- Boost at higher energies shifts PID to rely more on TOF than TPC identification

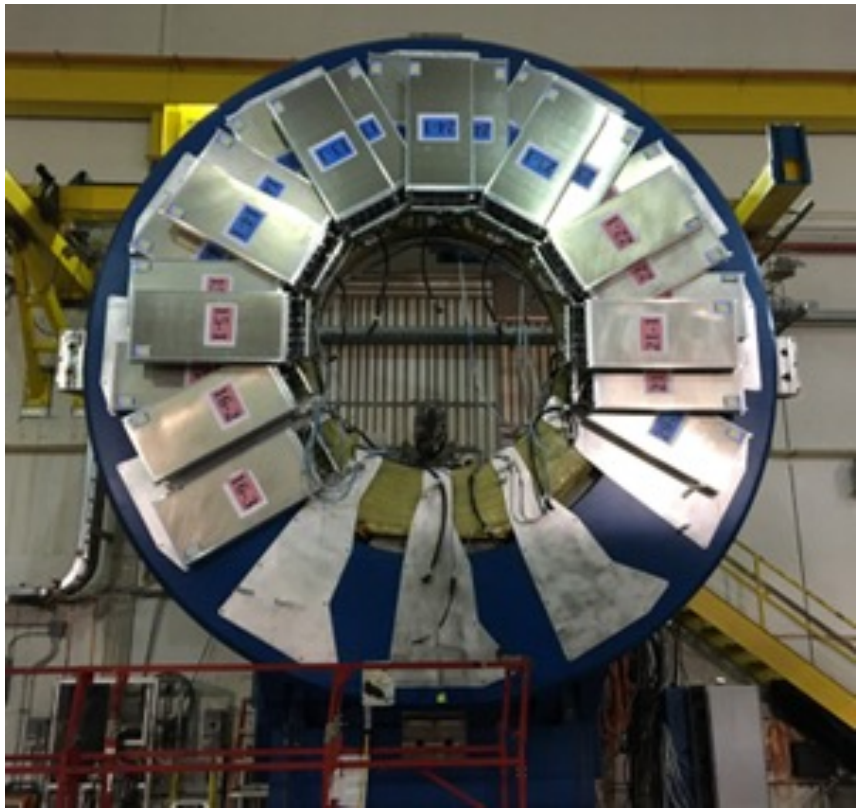


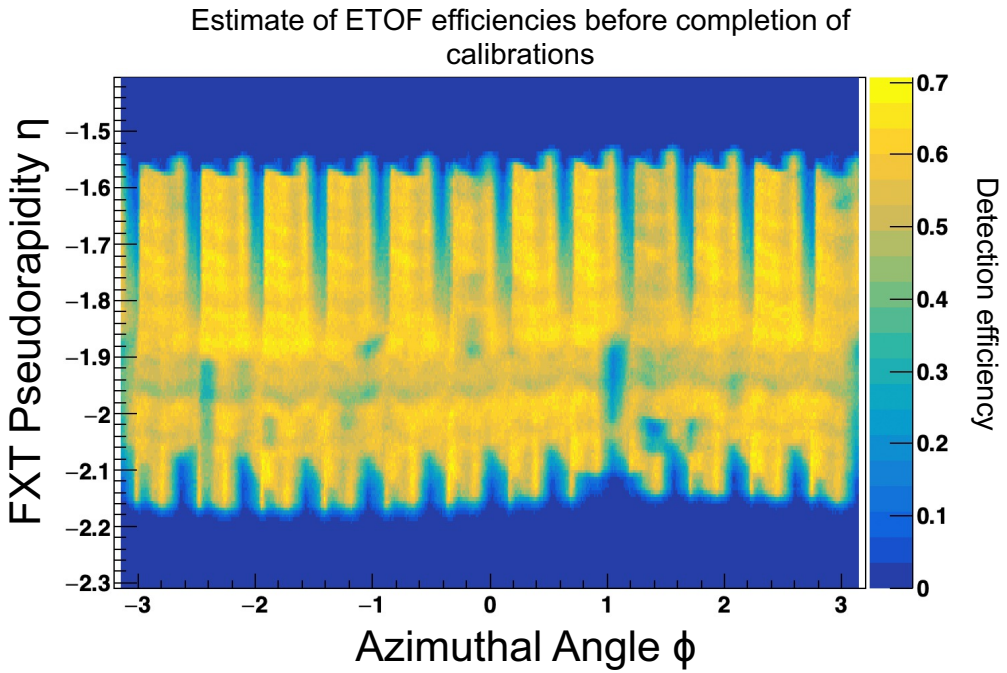
Data from the Fixed-Target Program

Nominal √s (GeV)	Chemical Potential μ_B	Year	Number of Good events	Precise y_{cm}	Status of Production	ETOF Calibration Status	Efficiency Calibration Status	Bad Runs Analysis
3.2	0.697	2019	200.6M	1.139	Produced	Not needed	Pending	Completed
3.5	0.666	2020	115.6M	1.254	Produced	Pending	Pending	Completed
3.9	0.632	2020	117M	1.375	Produced	Pending	Pending	Completed
4.5	0.589	2020	108M	1.522	Produced	Pending	Pending	Completed
5.2	0.541	2020	103M	1.683	Produced	Pending	Pending	Completed
6.2	0.487	2020	118M	1.867	Produced	Pending	Pending	Completed
7.2	0.443	2020	316.9M	2.021	Not yet Produced	Pending	Pending	Pending
7.7	0.420	2020	112.5M	2.102	Produced	Pending	Pending	Completed

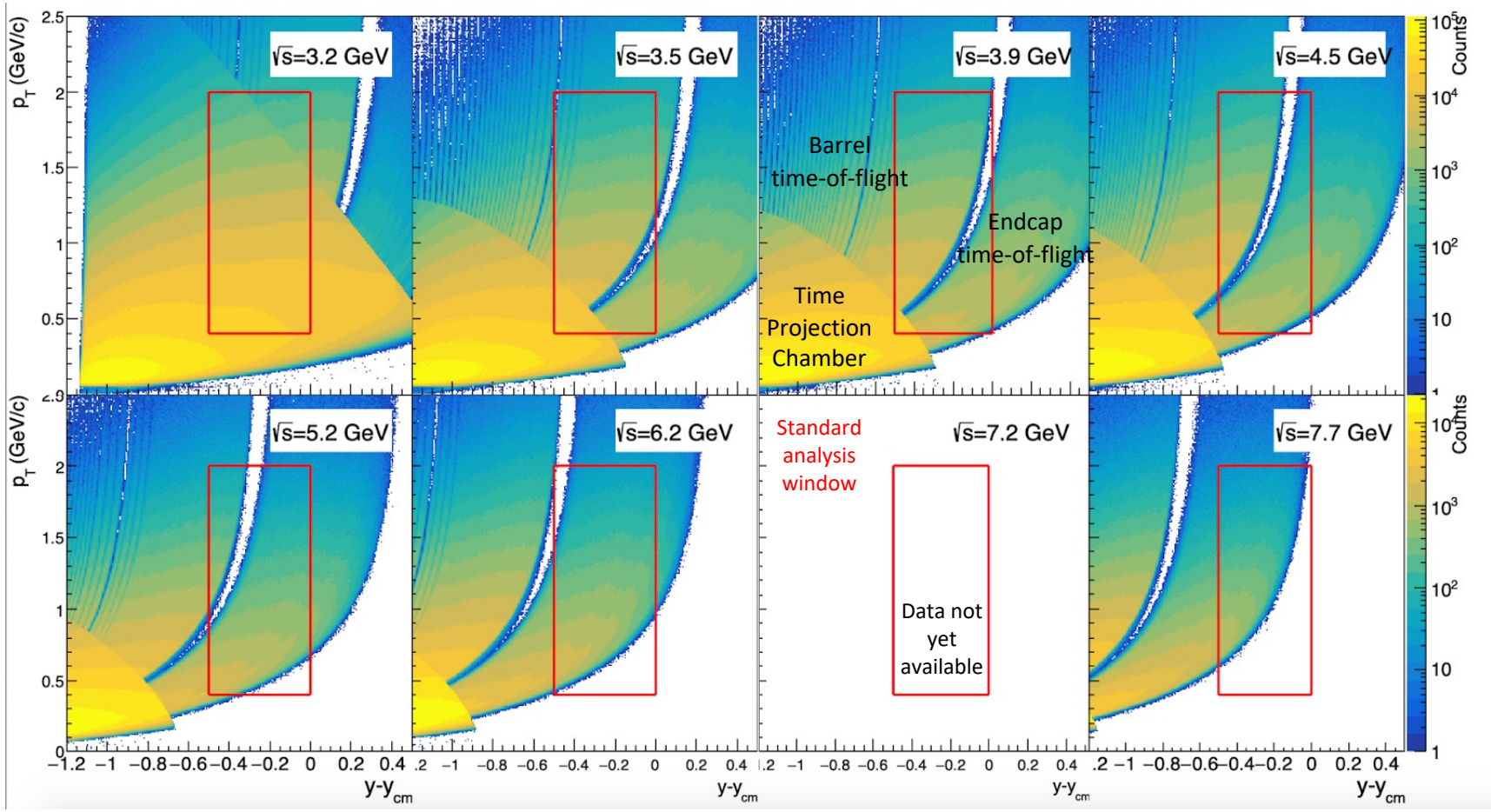
ETOF Details

- CBM-TOF group provided ETOF system
- Provides particle identification over $1.55<\eta<2.2$
- Collected data for the Fixed-Target Program
- Calibrations still in progress.



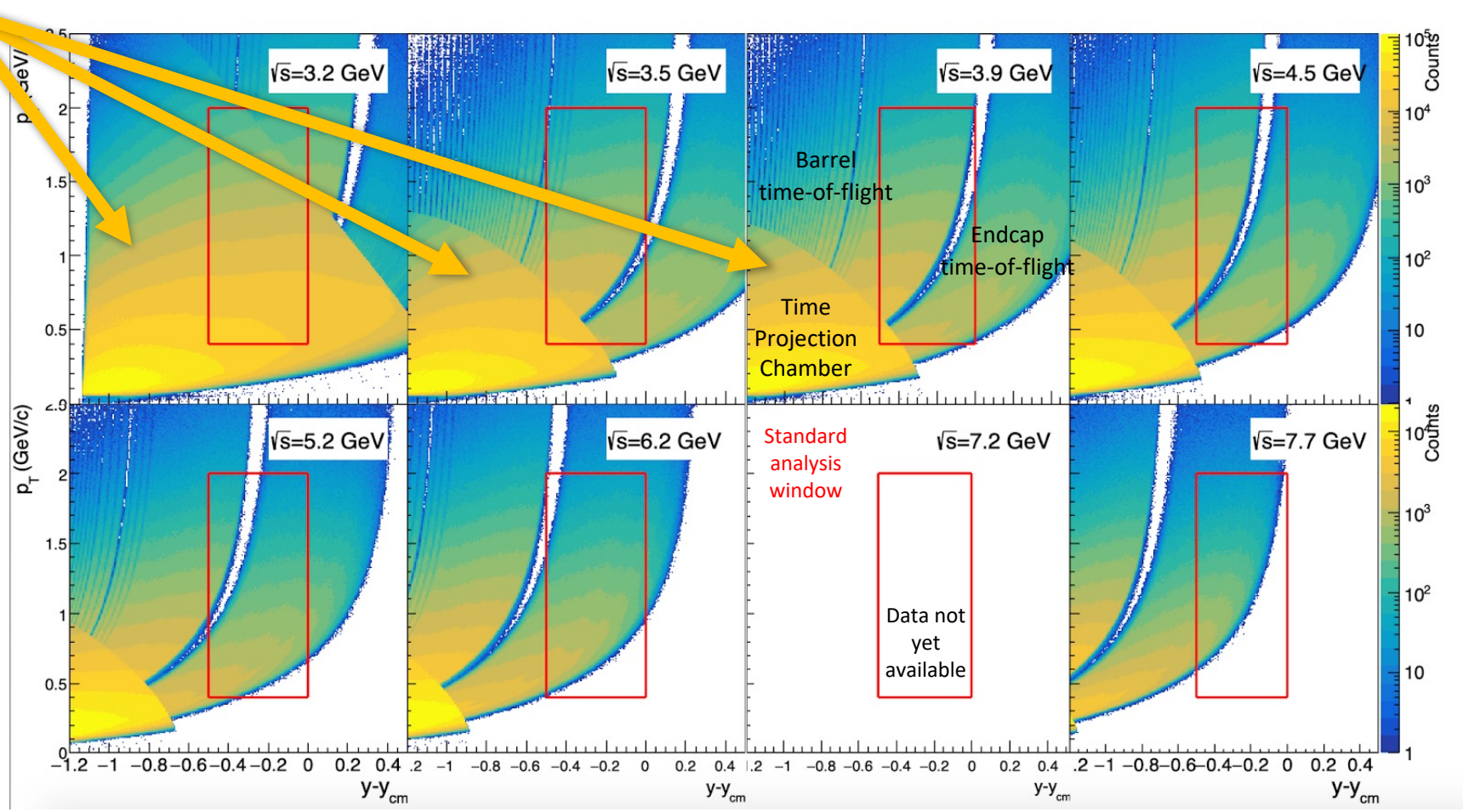


Detector Acceptances



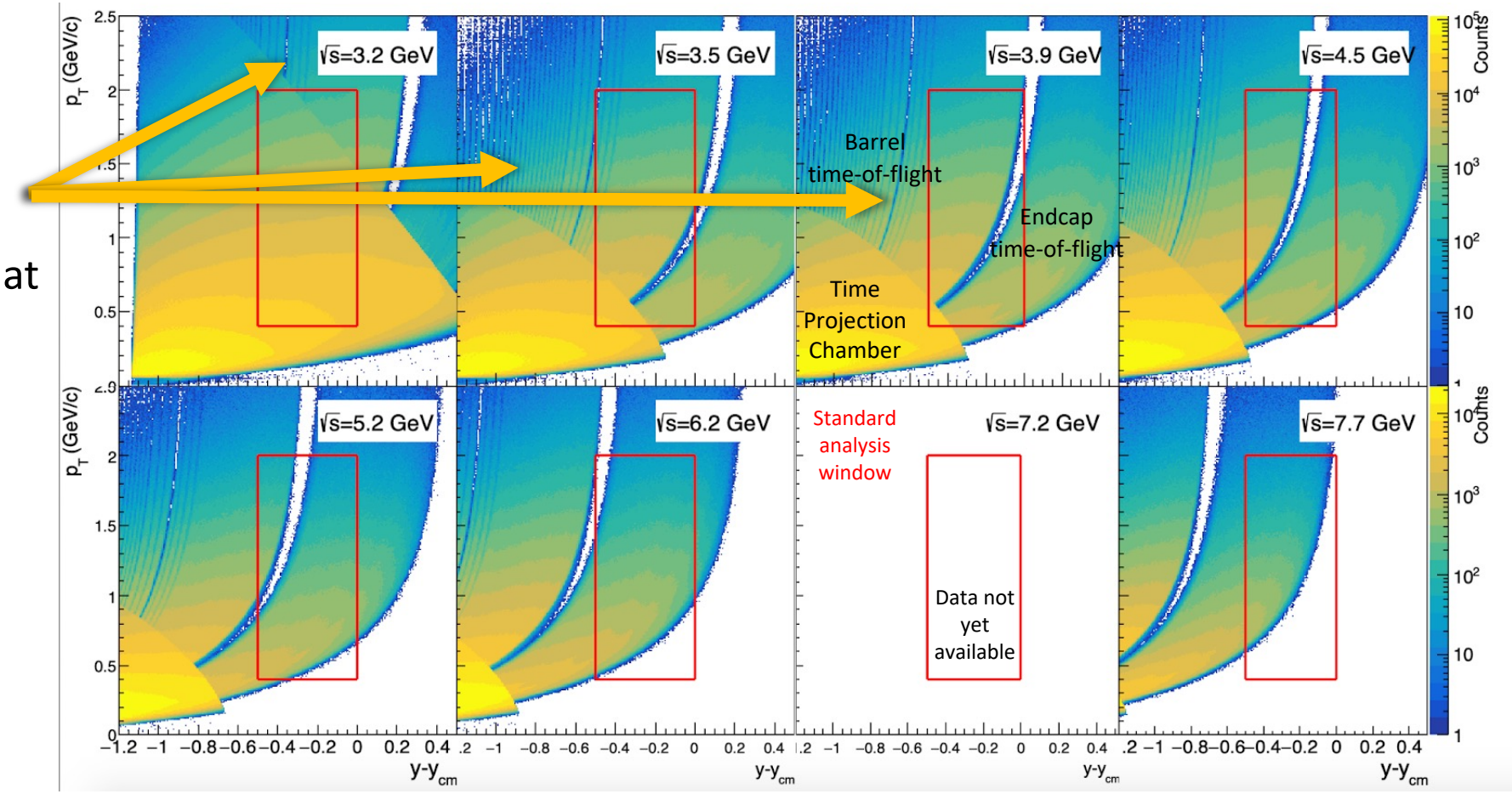
Detector Acceptances

- At low momenta and low rapidities, the time-projection chamber is used to identify protons
- Pion contamination starts to become significant as momentum increases.



Detector Acceptances

- At high momenta and low rapidities, the barrel TOF provides better proton ID, but at lower efficiency



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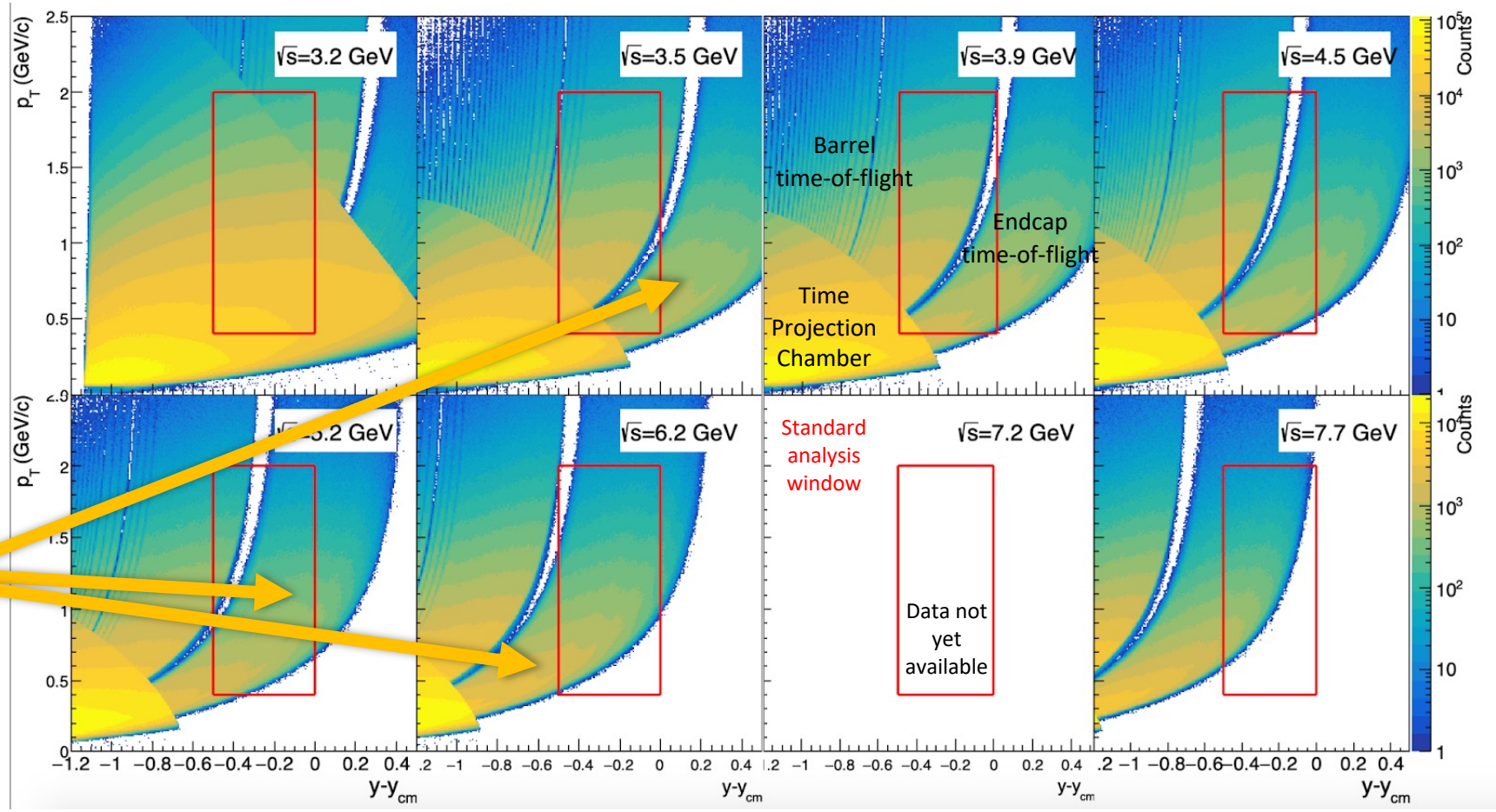
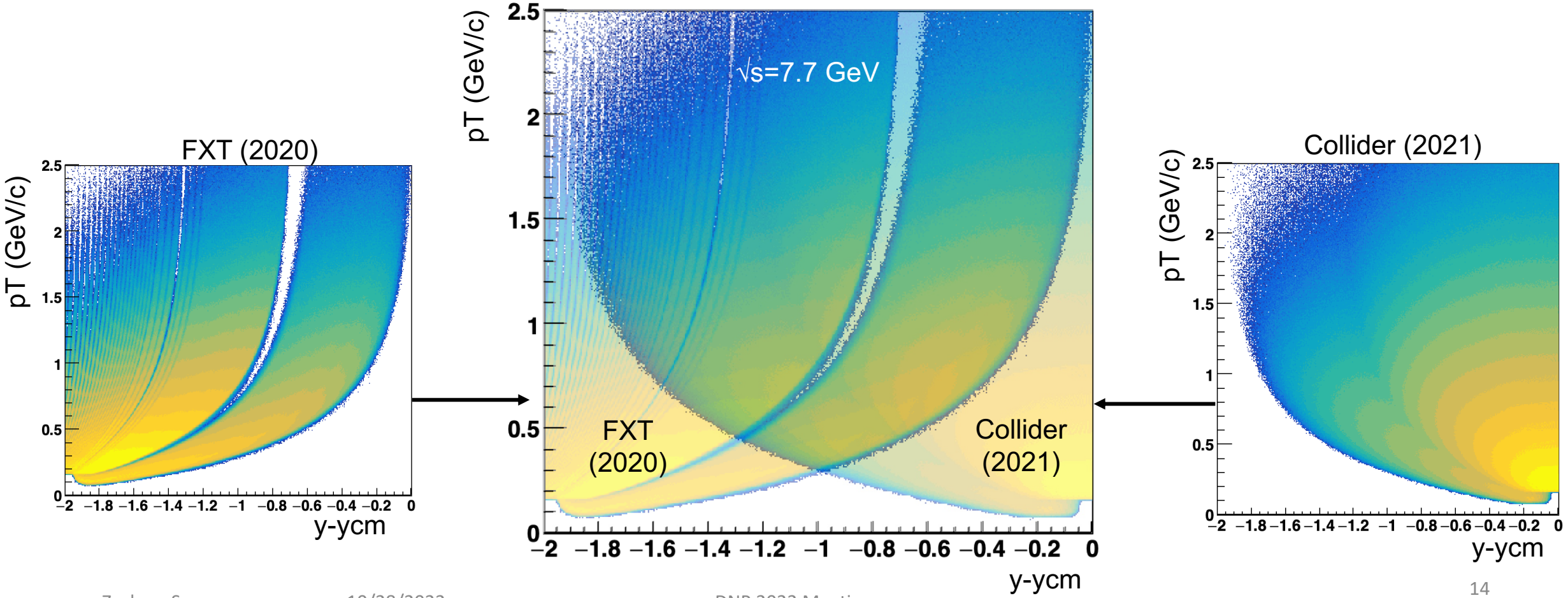


- At high momenta and high rapidities, the endcap TOF provides good resolution, with lower efficiency.
- New (2021) data at 3 GeV includes full acceptance

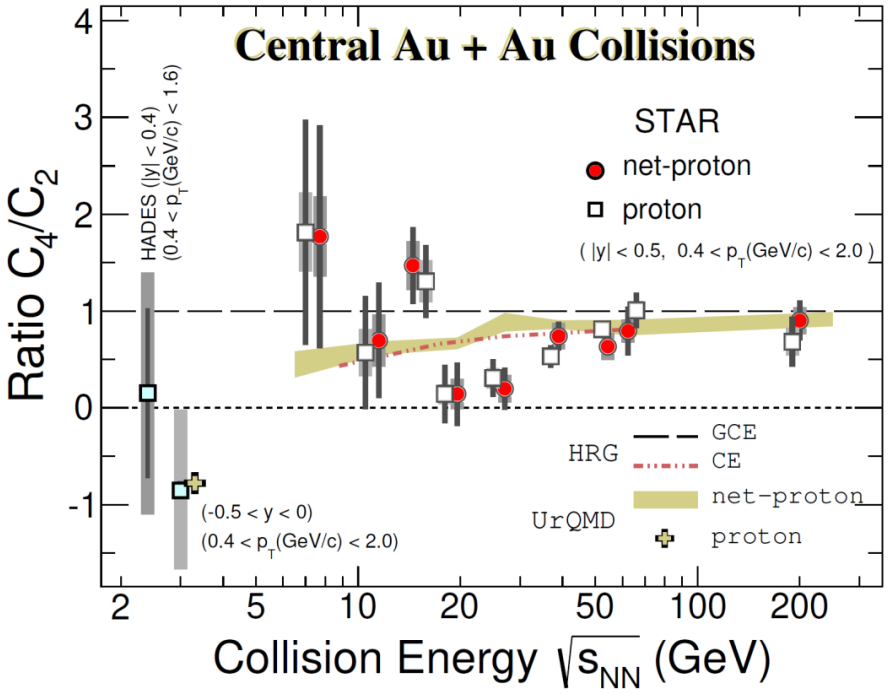
Important Check: FXT & Collider Overlap at 7.7 GeV

- Acceptance overlap at 7.7 GeV for FXT and collider data provides a unique opportunity to benchmark our understanding of FXT methodologies against collider data
- This will not be a standard fluctuation analysis window, and will not be a part of the cumulant energy scan, but is important for building confidence in comparisons between the fixed-target program and collider results



Projected Statistical Uncertainties

- Significance of C_4/C_2 goes as ~ $\langle N_p^3 \rangle$
- Proton yields from E895 with expected detector acceptances+efficiencies can be used to predict $\langle N_p \rangle$ for FXT



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Fixed Target

√s	Num Good events	Predicted $\langle N_p \rangle$ Eff. Uncorr
3.2	200.6M	32
3.5	115.6M	28
3.9	117M	24
4.5	108M	20
5.2	103M	16
6.2	118M	12
7.2	316.9M	8
7.7	112.5M	5

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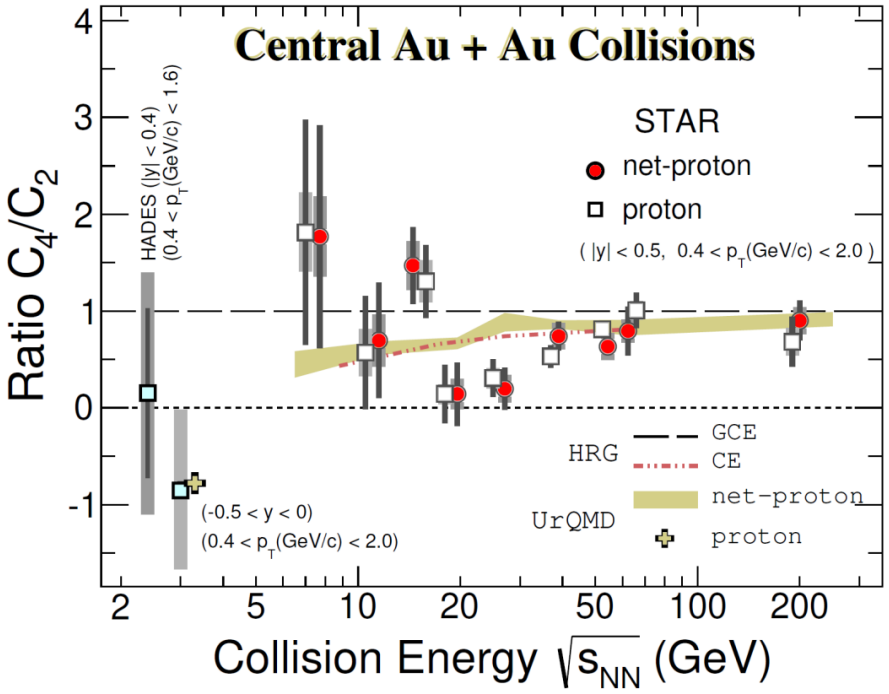

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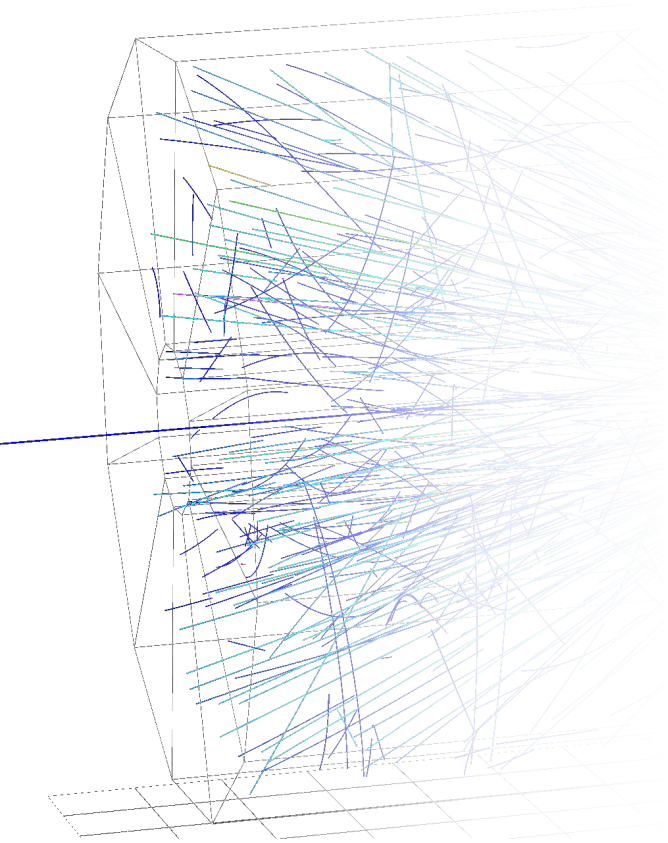
Conclusions and Outlook



- A main objective of the Beam Energy Scan II (both the collider and Fixed-Target Program) is to search for the critical point of the QCD phase diagram.
- Data taken in collider-mode show non-monotonic behavior of net-proton cumulant ratios which suggests proximity to the critical point.
- Recent data from the Fixed–Target Program will extend our knowledge of the (net-)proton cumulant ratios at low energies (3-7.7 GeV)