# STAR TPC Inner Sector Upgrade (iTPC)

## The STAR Collaboration

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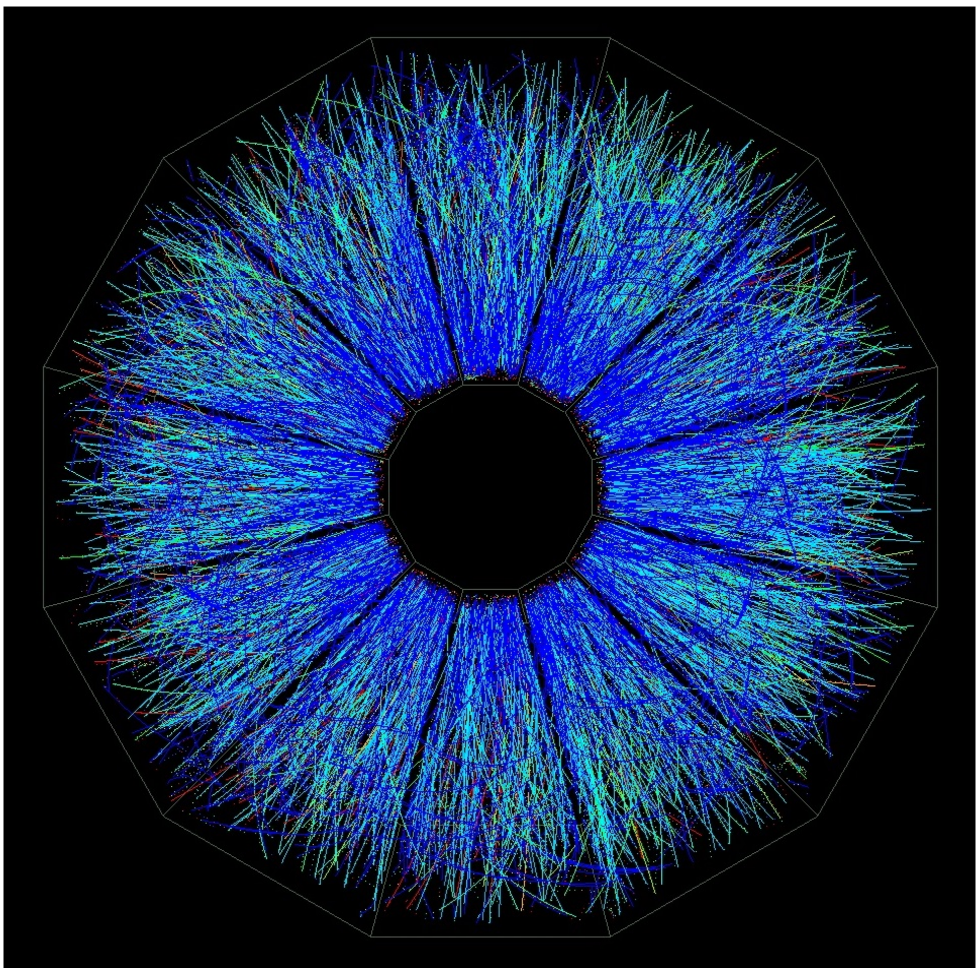

# STAR TPC Inner Sector Upgrade (iTPC)
## A Brief Summary of the Project

## by The STAR Collaboration

We propose to upgrade the inner sectors of the STAR TPC to increase the segmentation on the inner padplane and to renew the inner sector wire chambers. These two improvements will extend the capabilities of the TPC in many ways. Most significantly, the enhanced tracking at small angles relative to the beamline will expand the TPC's acceptance out to pseudo-rapidity $|\eta| \leq 1.5$, compared to the current limitation of $|\eta| \leq 1$. Furthermore, the detector will have better acceptance for tracks with low momentum, as well as better resolution in both momentum and dE/dx for tracks of all momenta. These changes will enable the collection of data that is critical to the physics mission for Phase-II of the Beam Energy Scan (BES-II). In addition, the improved dE/dx and momentum resolution, as well as tracking at higher pseudorapidity, provide the foundation for another proposed upgrade - the endcap time of flight project (endcap-TOF) by the STAR/CBM collaboration.

The enhanced performance resulting from the iTPC project will be critical for making the measurements needed to fully address the physics questions which form the basis for the BES-II program. This brief summary will discuss only two topics: (*i*) using net-proton kurtosis measurements in the search for a critical point in the QCD phase diagram, and (*ii*) using low mass dielectron pairs to explore the modification of vector mesons in connection with the approach to chiral symmetry restoration in a dense medium. The critical point, if it exists, will provide a landmark in the phase diagram of nuclear matter and guide further experimental and theoretical studies of QCD over a wide range of conditions. The discovery of a QCD critical point would constitute a significant scientific achievement in heavy ion physics. In addition, characterization of how the system approaches chiral symmetry restoration in dense systems will greatly enhance our understanding of QCD in these environments. As detailed in the STAR BES-II White Paper, the QCD Town Meeting Summary Report, and the Hot QCD White Paper, results from Phase-I of the beam energy scan show provocative results calling for further investigation with greater statistics and increased rapidity coverage.

While the increased data sample provided by BES-II will improve upon the quality of current measurements, only the enhanced capabilities provided by the iTPC upgrade will allow a full study of observables which are sensitive to changes in correlation length near the critical point. For example, in the vicinity of a critical point, the net-proton kurtosis is expected to rise as the fourth power of the size of the rapidity window but then saturate as the window becomes comparable to, or larger than, the correlation length in the system. Existing BES-I data exhibit interesting energy trends that suffer from limited statistics and the signal only appears near the edge of the current STAR rapidity acceptance ($\Delta$y). The iTPC improvements will allow the fullest possible coverage of the collision region to establish the existence of a rapid rise in the kurtosis signal and, if found, to more fully map out its properties.

In the area of low mass dielectron measurements, the iTPC upgrade improves the acceptance of the detector but also reduces the hadron contamination which is responsible for and is the dominant source of systematic uncertainties in previous measurements. The reduction in uncertainty made possible by the iTPC project will allow the full exploitation of the increased statistics to be collected during BES-II. Full characterization of any meson broadening, and distinguishing between competing theoretical interpretations for a quantitative assessment of how the system approaches chiral symmetry restoration, will only be possible with these improvements.

The costs for the upgrade project will be shared by the US DOE and the Chinese NSF. The DOE project costs are mainly for the design and fabrication of the new sectors, for the design and fabrication of compatible electronics, and for the design and fabrication of the installation tooling. The in-kind contributions from China will focus on the construction of the MWPCs which will be mated to the sector strongbacks in China. The iTPC project proposes to do conceptual design studies in FY2015, sector and MWPC production in FY2016-FY2018, with final installation in FY2018. Following this schedule, the iTPC would be ready to take data during RHIC Run-19. Current RHIC long-range planning calls for the STAR BES II program to take measurements during Run 19 and Run 20.

**Key Physics Observables: Net-proton Kurtosis and Low-mass Di-electron Spectra**

**Kurtosis:**

In the study of critical phenomena, we are interested in the overall size of the system and the dynamical correlation length related to genuine fluctuations near the critical point. The range of the correlations $y_{corr}$ is the crucial issue for the dependence of a fluctuation signal on the rapidity acceptance window ($\Delta y$). If $\Delta y$ is smaller than the correlation length ($y_{corr}$), then the critical point contribution to the *n*-th order cumulant of the fluctuations grows as $(\Delta y)^n$. When $\Delta y$ is much larger than $y_{corr}$, all cumulants grow linearly with $\Delta y$ since uncorrelated contributions are additive in a cumulant.

The following argument provides an estimate of what determines $y_{corr}$ in a boost-invariant scenario with a finite correlation length. Consider a comoving coordinate system near freezeout with correlation length $\xi$. This translates into a Bjorken rapidity correlation length $\Delta\eta_{corr} \approx \xi/\tau$. Or in other words, $\Delta\eta_{corr}$ is approximately 0.1-0.3 units wide: assuming $\xi$ ranges from 1 fm to 3 fm near the critical point and a Bjorken freeze-out time $\tau$ of about 10 *fm*. However, detectors do not measure the spatial (Bjorken) rapidity $\eta$ but, rather, they measure the kinematic rapidity (y) of the particles. Within the spatial correlation volume $\Delta\eta_{corr}$, the rapidity of the thermal particle distribution in the comoving frame ranges roughly from -1 to 1 and the observed rapidity of the particles from the correlated volume spreads over an interval $\Delta y_{corr} \approx 2$ units in rapidity due to the freeze-out smearing. Thus, $\Delta y_{corr}$ is much larger than $\Delta\eta_{corr}$ and the value of $\Delta y_{corr}$ is not sensitive to the value of $\xi$. (However, it is worth noting that larger values of $\xi$ mean more correlated particles in the observed $\Delta y_{corr}$ interval.) This means that the proposed iTPC rapidity window lies in the range of quartic growth for the magnitude of the kurtosis signal, transitioning to linear growth at the widest rapidity intervals. (For more details, see https://drupal.star.bnl.gov/STAR/starnotes/public/sn0619 by M. Stephanov.)

At present, we do not have any additional theoretical guidance for the exact amplitude of the net-proton Kurtosis in the presence of a critical point. This is an area being actively pursued by the theory community. But we do have guidance that emphasizes the importance of the widest possible rapidity window and actual measurements from BES I. The measured growth of the net-proton Kurtosis signal is shown in Fig. 1 as a function of the rapidity window ($\Delta y$). The figure also shows BES-II projections following an extrapolation from the central values of the BES-I data points.

The experimental studies are limited by practical considerations such as acceptance, efficiency and kinematic cuts. Fig. 1 shows that there is a rapidity width dependence for the measured net-proton kurtosis signal scaled by the variance ($\kappa*\sigma^2$) at 7.7 and 19.6 GeV. The magnitude of the net-proton correlation function is expected to increase rapidly with rapidity as discussed in the previous paragraphs. The BES-I data indicate that STAR's current TPC acceptance is at the lower bound of the sensitivity that is useful for theoretical analysis. Clearly we need wider rapidity acceptance; for example, see the extrapolated results shown in Fig. 1. This is a crucial step in the search for the QCD critical point in the BES-II program. The iTPC expansion in pseudorapidity from $|\eta < 1.0$ to $|\eta| < 1.5$ extends the size of the available window in proton "real" rapidity difference from $|\Delta y| < 1.0$ out to $|\Delta y| < 1.6$, thereby greatly enhancing our ability to explore finite volume scaling effects.

The amplitude of the projection shown in Fig. 1 is driven by the central values of the BES-I data points. Without the iTPC upgrade, one could imagine that the measured value from BES-II at large rapidity (maximum $\Delta y = 1$) might be close to unity and still lie within the allowed BES-I uncertainty ($2\sigma$) producing an inconclusive result. With the iTPC extension as illustrated in Fig.1, the multiple data points from BES-II covering the crucial rapidity range between 1 and 1.6 will provide datasets for a convincing assessment of the sensitivity of the net-proton Kurtosis measurement to the QCD criticality. Results from the AMPT with string melting (SM) are also shown in the figure to illustrate the cases without a critical point but with finite baryon number conservation.

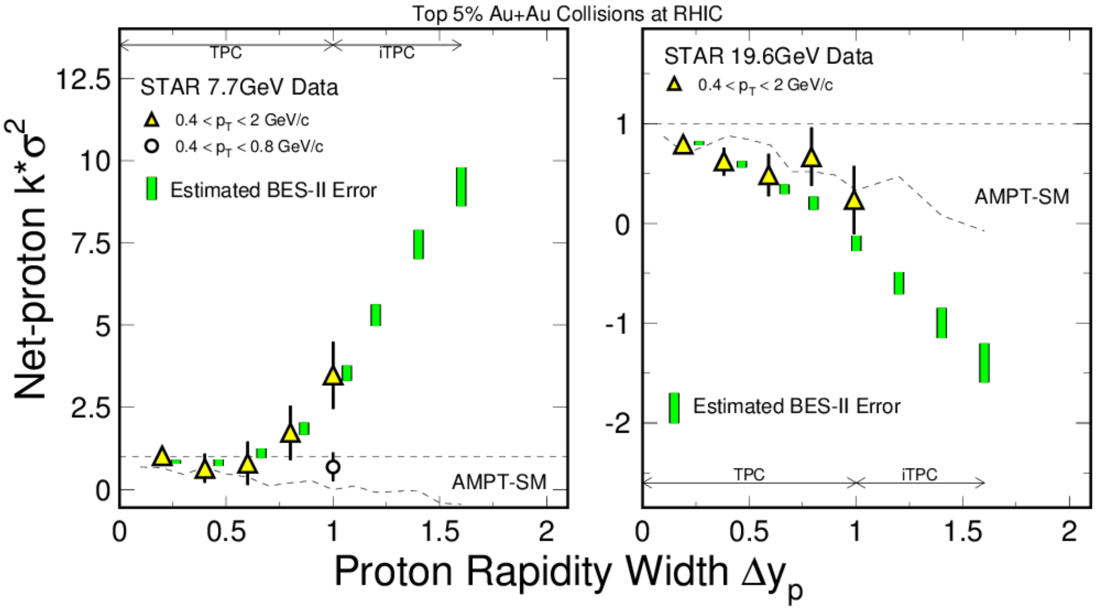


Figure 1: The observed net-proton kurtosis ($\kappa*\sigma^2$) as a function of rapidity window from BES I (yellow triangles). The preliminary data are for central (5%) Au+Au collisions at 7.7 GeV (left panel) and 19.6 GeV (right panel). The green bars are the estimated statistical uncertainties with the iTPC for BES-II, for 7.7 GeV and 19.6 GeV. In the extended region covered by the iTPC upgrade ($1.0 < |\Delta y| < 1.6$), the error bars were estimated assuming that the variances increase linearly with rapidity width. The locations of the projected error bars illustrate one possible rapidity-window dependence of the net-proton Kurtosis signal. Also shown are AMPT simulations with string melting and without a critical point (dashed lines).

**Di-electron Spectra:**

The iTPC will also enable STAR to make better measurements of the dielectron invariant mass spectra during BES-II and improve our fundamental understanding of hot QCD matter. High-statistics datasets from the SPS fixed target program (NA60) have established that in-medium broadening of vector mesons is a possible indication of Chiral Symmetry Restoration, but only with one energy (17.3 GeV) and with smaller colliding system (In+In). To date, the results from RHIC top energy and BES-I show that models incorporating temperature dependence of hadron structure and thermal radiation are consistent with our data. However, with limited statistics and large systematic uncertainties, we are neither able to test the baryon-density dependence nor able to distinguish between and constrain different model implementations. In BES-II, we will be able to quantitatively assess the evolution of hadron structure toward chiral symmetry restoration at high baryon density (low beam energies) using higher statistics data sets. However, only the reduced uncertainties resulting from the improved particle identification and improved acceptance at low momentum using the iTPC upgrade will allow a full exploitation of these larger data samples.

The iTPC upgrade will also reduce the systematic uncertainties due to hadron contamination, efficiency corrections, acceptance differences between unlike-sign and like-sign pairs, and cocktail subtraction. These improvements will result in a factor of 2 improvement in the systematic uncertainties for the dielectron excess yield. In addition, the iTPC will extend the acceptance for low-momentum electrons from $p_T > 0.2$ to

$p_T > 0.1$ GeV/c. This improves the acceptance for dielectron measurement by more than a factor of 2 in the low mass region (0.4 < mass < 0.7 GeV), and lowers the statistical uncertainties as well. Only with these improvements will we be able to distinguish models with different ρ-meson broadening mechanisms; for example, the Parton-Hadron String Dynamic (PHSD) transport model versus Rapp's microscopic many-body model with macroscopic medium evolution. Knowing the mechanism that causes in-medium ρ broadening and its temperature and baryon-density dependence is fundamental to our understanding and assessment of chiral symmetry restoration in hot QCD matter. The right panel of Fig. 2 shows the projected BES II measurements from STAR, with the iTPC, together with data already taken at higher beam energies and compared to recent model calculations. STAR detectors in the BES-II era will cover a unique energy range because the excitation function above 20 GeV for the low mass region (LMR) depends strongly on initial temperature, while the LMR excess below 20 GeV depends more strongly on baryon density.

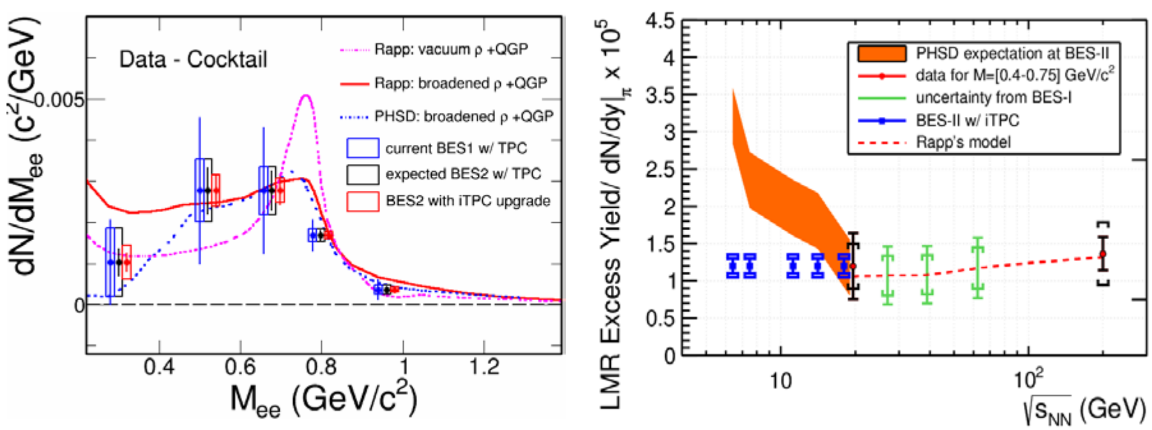


Figure 2: (left panel) Dielectron invariant mass spectrum in the STAR acceptance ($|y_{ee}| < 1$, $0.2 < p_T < 1.4$ GeV/c, $|\eta| < 1$) after efficiency corrections, in Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV. Theoretical calculations of a broadened ρ spectral function are shown up to 1.5 GeV/$c^2$ for comparison. The expected dielectron excess invariant mass spectra in Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV is shown for BES-II with and without the iTPC upgrade. Comparisons to PHSD and Rapp's model calculations are also shown (right panel). The Beam Energy dependence for the Low-Mass dielectron excess from published data at 19.6 and 200GeV, model expectation from PHSD for energy below 20GeV and Rapp's model above 20 GeV. Also shown are projected sys. and stat. errors from preliminary results at 27, 39 and 62.4GeV, and projections for BES-II with the iTPC. Projections without the iTPC for these energies would have x2 (√2) bigger sys. (stat.) errors.