STAR EbyE Fluctuations

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STAR Collaboration
QM2001

EbyE Fluctuations - Outline

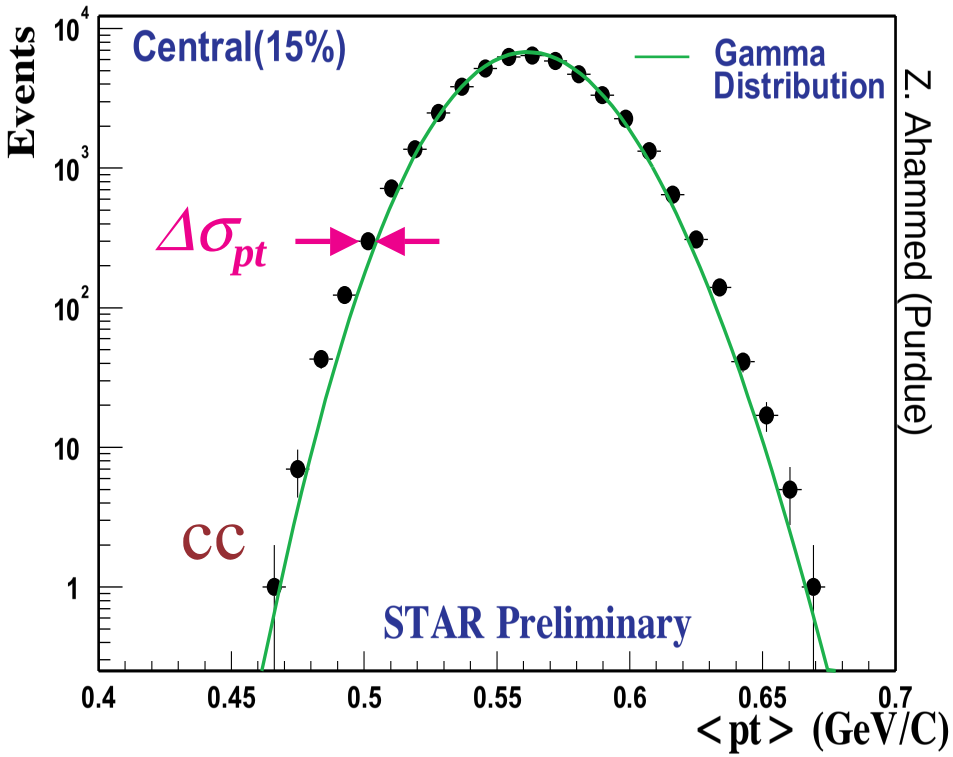
Fluctuation & correlation studies in *transverse* phase space

- Fluctuation measures, two-point correlations and references
- Physics Topics
  - $<p_t>$ fluctuations
  - $m_t \times m_t$ correlations
  - N_+, N_- fluctuations
- Fluctuation summary

Fluctuations, Correlations and References

- Fluctuations
  - variances and covariances
  - covariance matrix
- Correlations
  - two-point densities
  - same/mixed-event pair-density *ratios*
- Fluctuation-Correlation Connection
  - Variance comparisons and *net* two-point correlations are closely related
- Precision references are a key element of correlation analysis in heavy-ion collisions

$<p_t>$ Fluctuations - Distribution

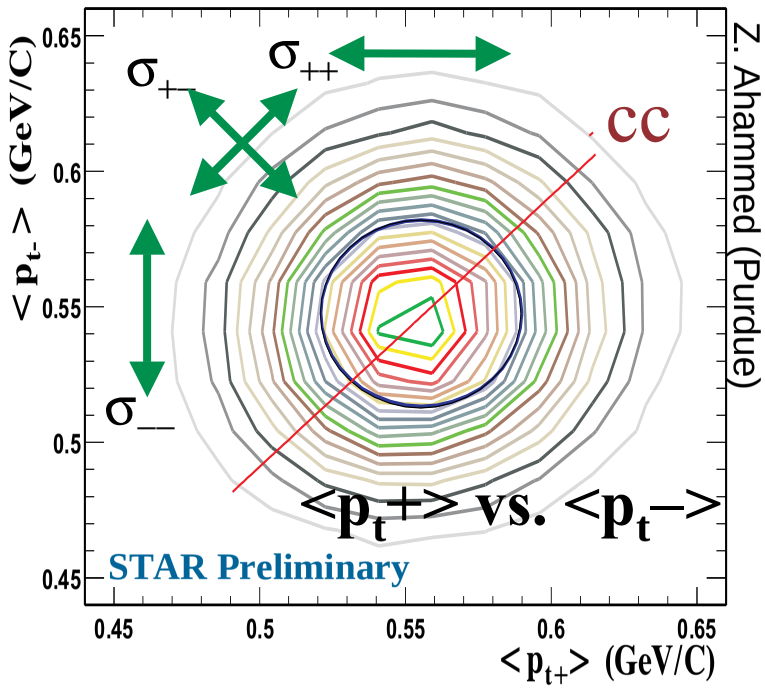


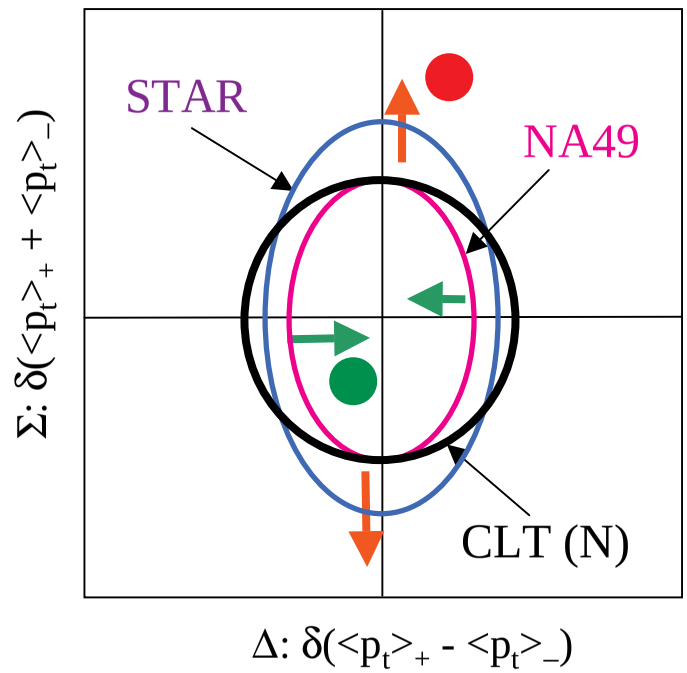
- $<p_t>$ *distribution* compared graphically with gamma-distribution* inclusive reference
- $<p_t>$ *variance* compared numerically with Central Limit Theorem (CLT) inclusive reference: *difference factors* $\Delta\sigma_{pt}$
- STAR data compared to gamma distribution or CLT indicate *substantial fluctuation excess* ($\Delta\sigma_{pt}$ ~ 35 MeV/c)

$$\overline{N}\sigma^2_{<p_t>} - \sigma^2_{p_t} \approx 2\sigma_{p_t}(\sqrt{\overline{N}}\sigma_{<p_t>} - \sigma_{p_t}) \equiv 2\sigma_{p_t}\Delta\sigma_{p_t}$$

* M.J. Tannenbaum, QM2001, poster session B: P107

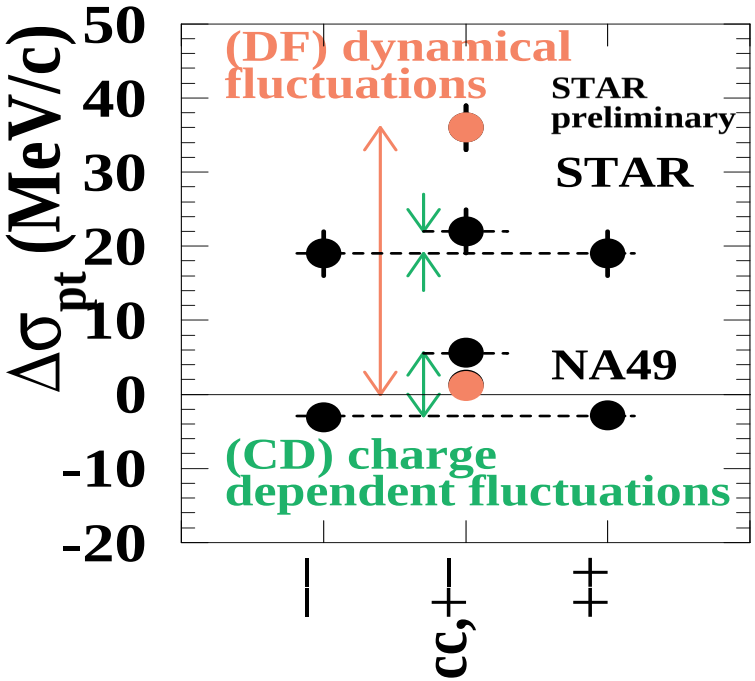
$\langle p_t \rangle$ Fluctuations - DF and CD

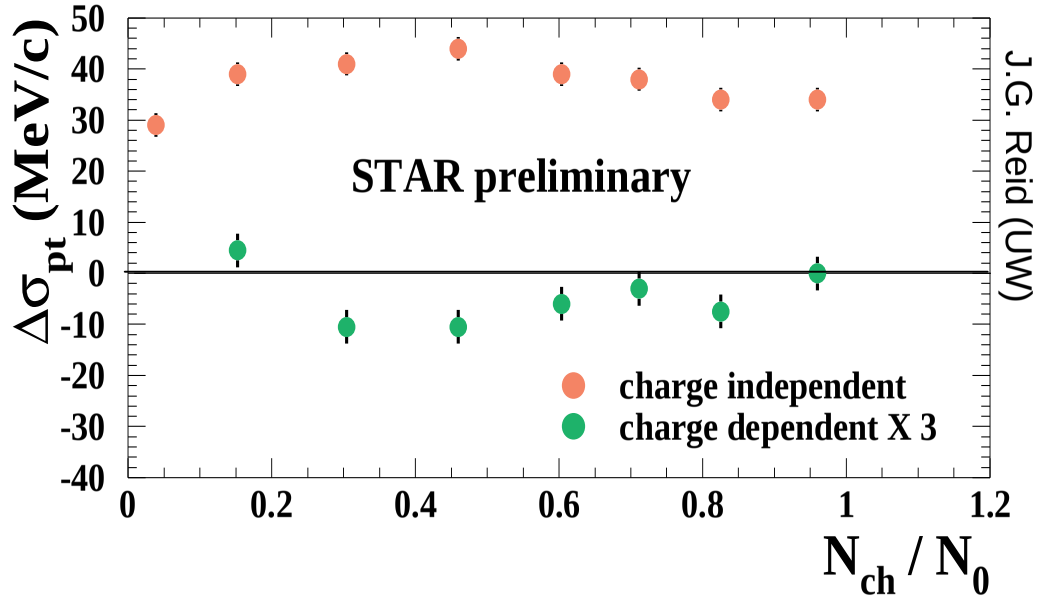




- Difference factor (Σ) measures dynamical or charge-independent fluctuations
  - $$N\Delta\sigma_{\Sigma}^{2} = N_{+}\Delta\sigma_{p_t+}^{2} + N_{-}\Delta\sigma_{p_t-}^{2} + 2\sqrt{N_{+}N_{-}}\Delta\sigma_{p_t+p_t-}^{2}$$
- Difference factor (Δ) between charge-pair types measure charge-dependent fluctuations
  - $$N\Delta\sigma_{\Delta}^{2} = N_{+}\Delta\sigma_{p_t+}^{2} + N_{-}\Delta\sigma_{p_t-}^{2} - 2\sqrt{N_{+}N_{-}}\Delta\sigma_{p_t+p_t-}^{2}$$

$\langle p_t \rangle$ Fluctuations - Centrality Dependence



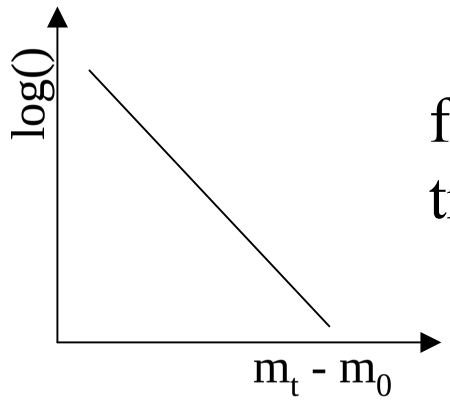


NA49 central: 1.1 MeV/c; –25.5 MeV/c

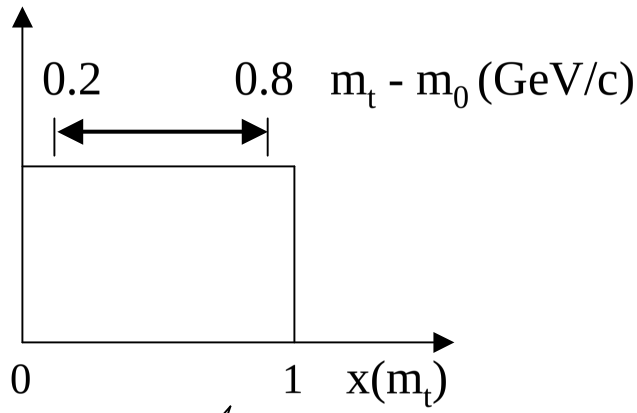
- STAR vs. NA49 differences
  - Rapidity: STAR ($|\eta|<1.0$) *vs* NA49 ($4<y_\pi<5.5$)
  - Multiplicity: STAR (525) *vs* NA49 (270)
  - see NA49 poster, session A:P082

m_t x m_t Correlations - Introduction

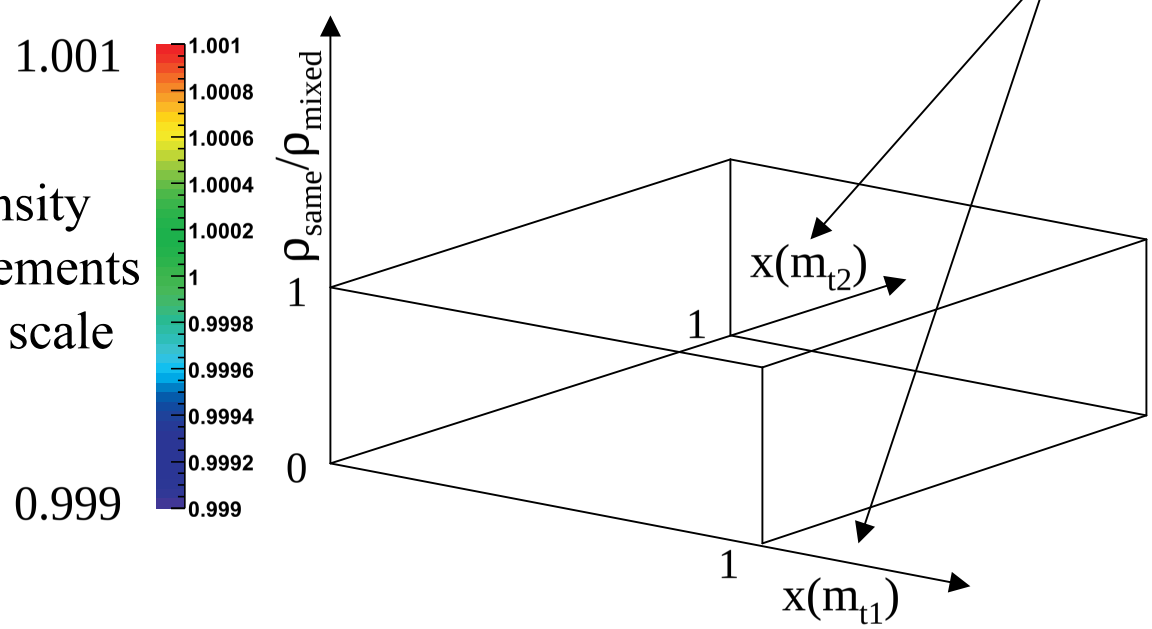
M-B distribution



flattening transformation



Precision density ratio measurements at the permil scale

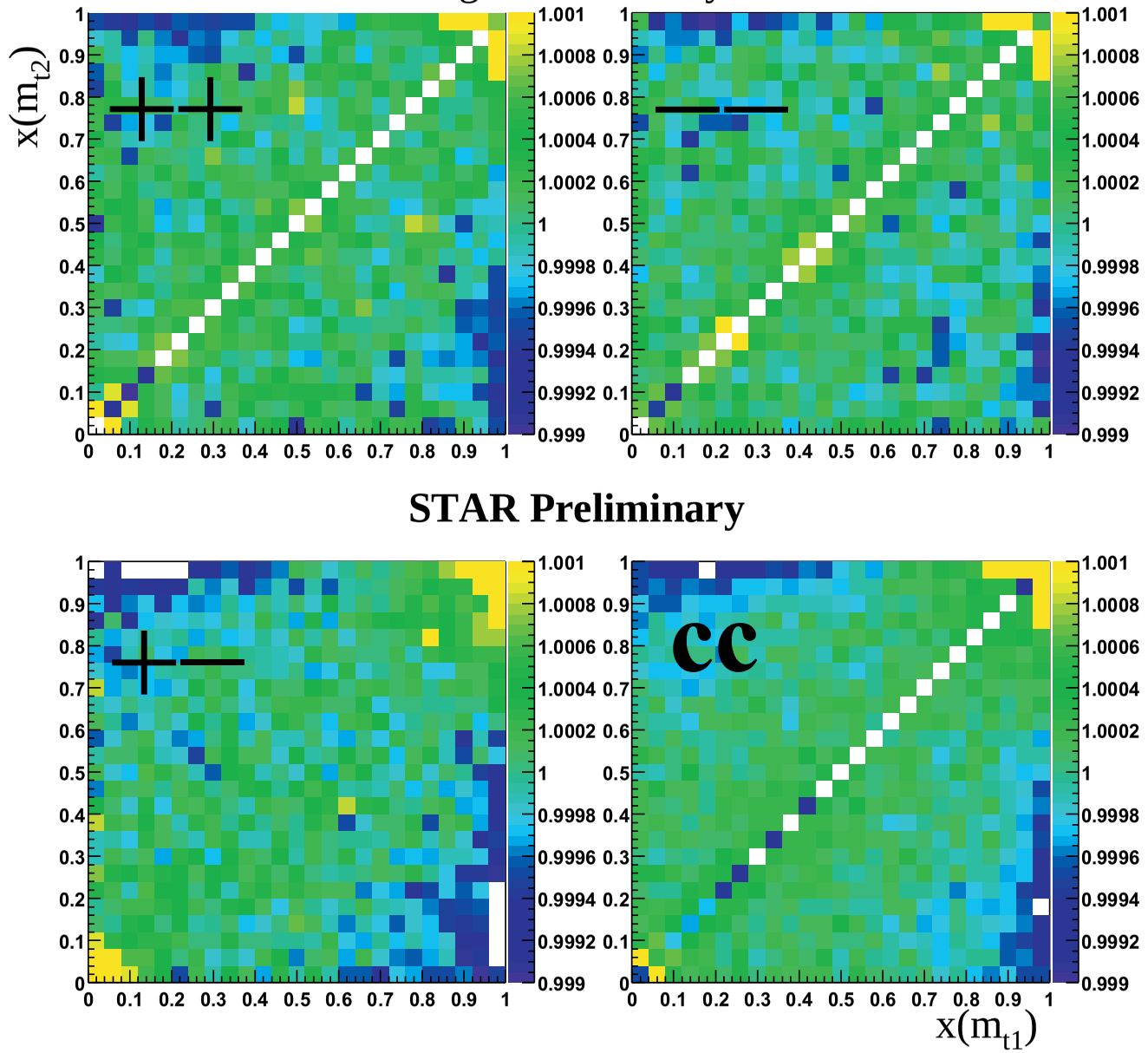


two-point density ratio:

same/mixed-pair densities

m_t x m_t Correlations - Charge Pairs

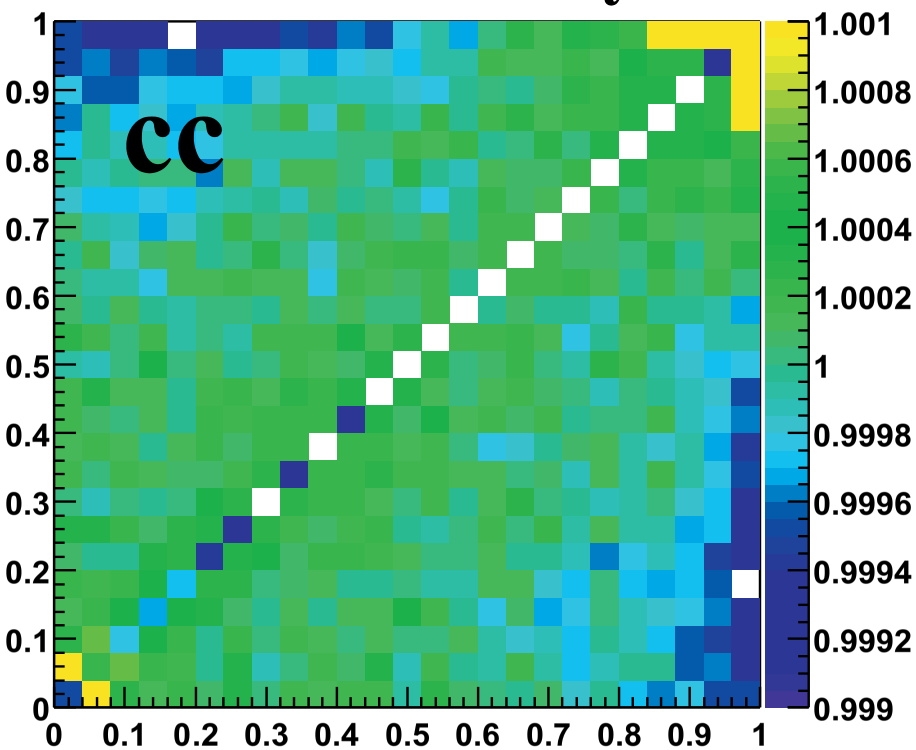
sibling/mixed density ratios



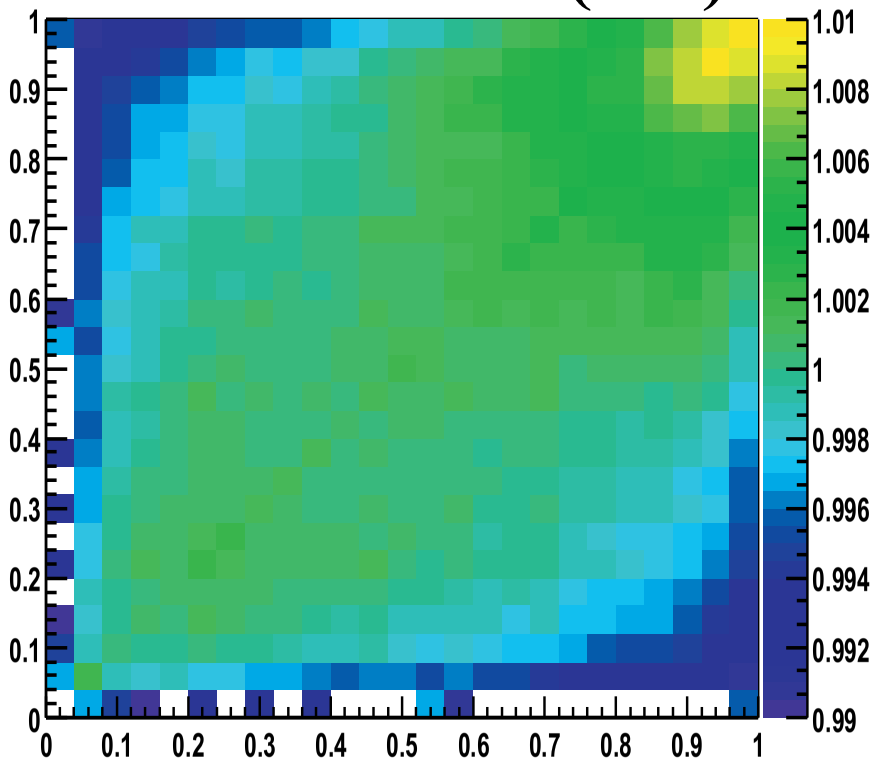
A. Ishihara (UTA), J. Seger (Creighton), J.G. Reid, Q.J. Liu (UW)

m_t x m_t - simulation comparison

STAR Preliminary Data



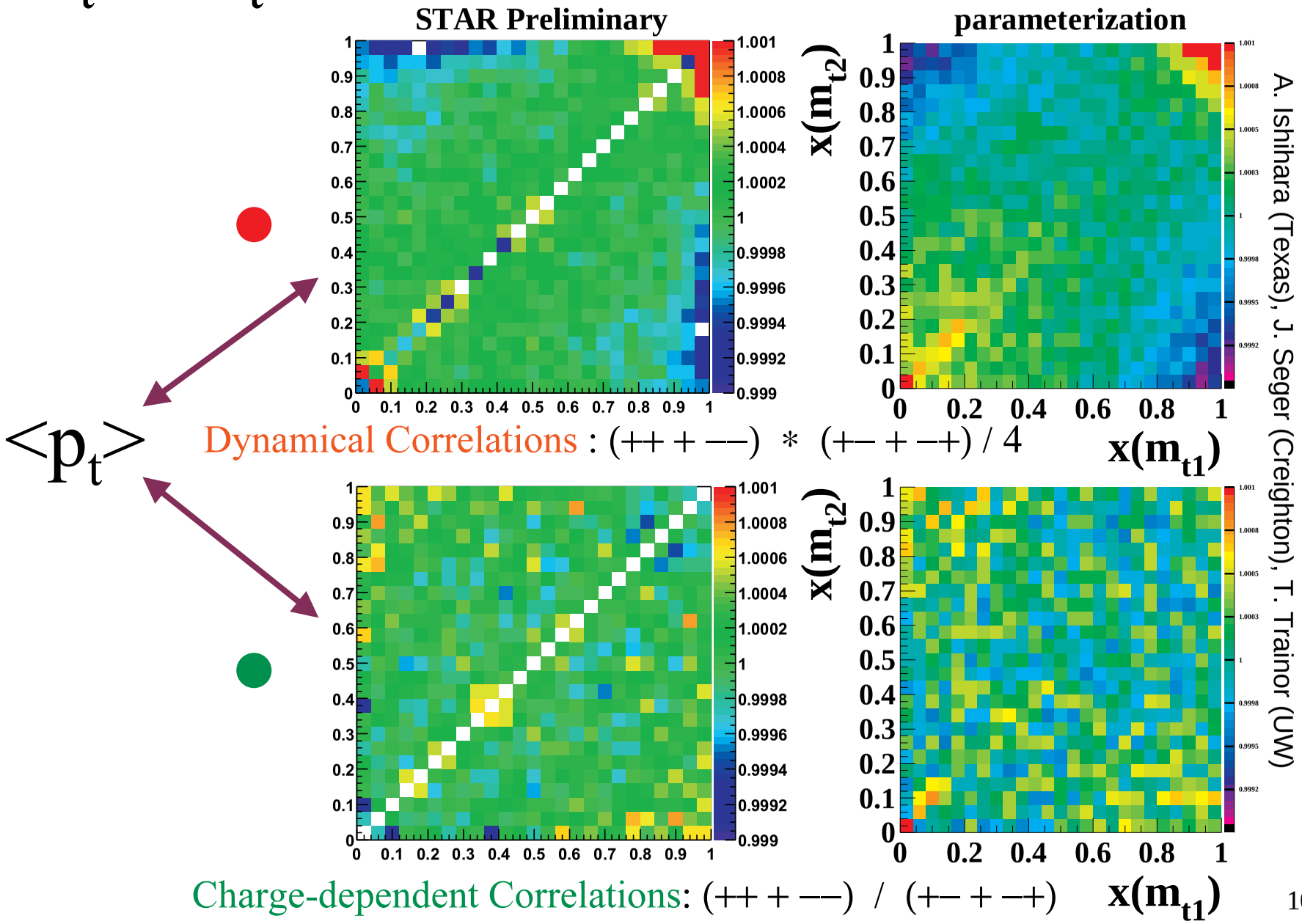
***mevsim** Monte Carlo: 1/T fluctuations (5%)**



- Data consistent with dynamical-fluctuations simulation

*L. Ray (UTA) and R. Longacre (BNL)

m_t x m_t Correlations - DF and CD Fits

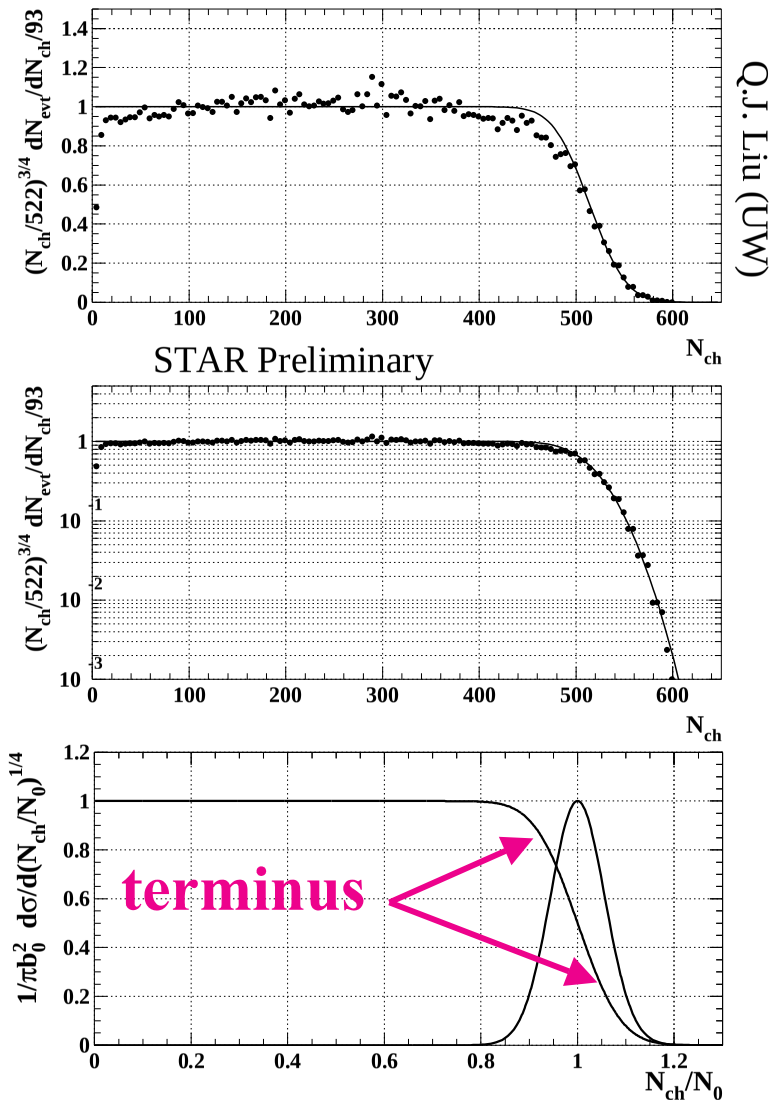


N_+, N_- Fluctuations and $d\sigma/dN_{ch}$

- $d\sigma/dN_{ch}$ distribution *transformed to* $N_{ch}^{1/4}$ has a simple structure with a **terminus** shape determined by fluctuations
- *erf* used to model the *terminus*
- σ^2_Σ, σ^2_+ and σ^2_- obtained from *erf*
- σ^2_Δ extracted from charge-ratio data
- Sum and difference variances are:

$$\sigma_\Sigma^2 = \sigma_+^2 + \sigma_-^2 + 2\sigma_{+-}^2$$

$$\sigma_\Delta^2 = \sigma_+^2 + \sigma_-^2 - 2\sigma_{+-}^2$$



N_+, N_- Fluctuations - Predictions

$$\sigma_\Sigma^2 = N_{ch} + \sigma_V^2 + \sigma_R^2 - \sigma_S^2$$

$$\sigma_\Delta^2 = N_{ch} - \sigma_R^2 - \sigma_S^2$$

$$\sigma_V^2 - 2\sigma_S^2 = \sigma_\Sigma^2 + \sigma_\Delta^2 - 2N_{ch}$$

$$\sigma_R^2 + \sigma_S^2 = N_{ch} - \sigma_\Delta^2$$

- *Volume/trigger* fluctuations (V)
  - *increase* Σ fluctuations
  - *don't change* Δ fluctuations
  - $\sigma^2_V = 0.85N$(BH), $0.40N$(DS)
- Resonance correlations (R)
  - *increase* Σ fluctuations
  - *decrease* Δ fluctuations
  - $\sigma^2_R = 0.3N(\mathrm{JK1} - \sigma^2_\Delta)$, $0.5N(\mathrm{SRS} - \sigma^2_\Sigma)$
- `QGP' fluctuation suppression (S)
  - suppress *all* fluctuations to some extent
  - $\sigma^2_S = 0.75N$(JK2), $0.5N$(AHM)

BH G. Baym, H. Heiselberg, nucl-th/9905022, Phys.. Lett., **B469** 5435 (1999)7-11

DS G.V. Danilov, E. Shuryak, nucl-th/9908027

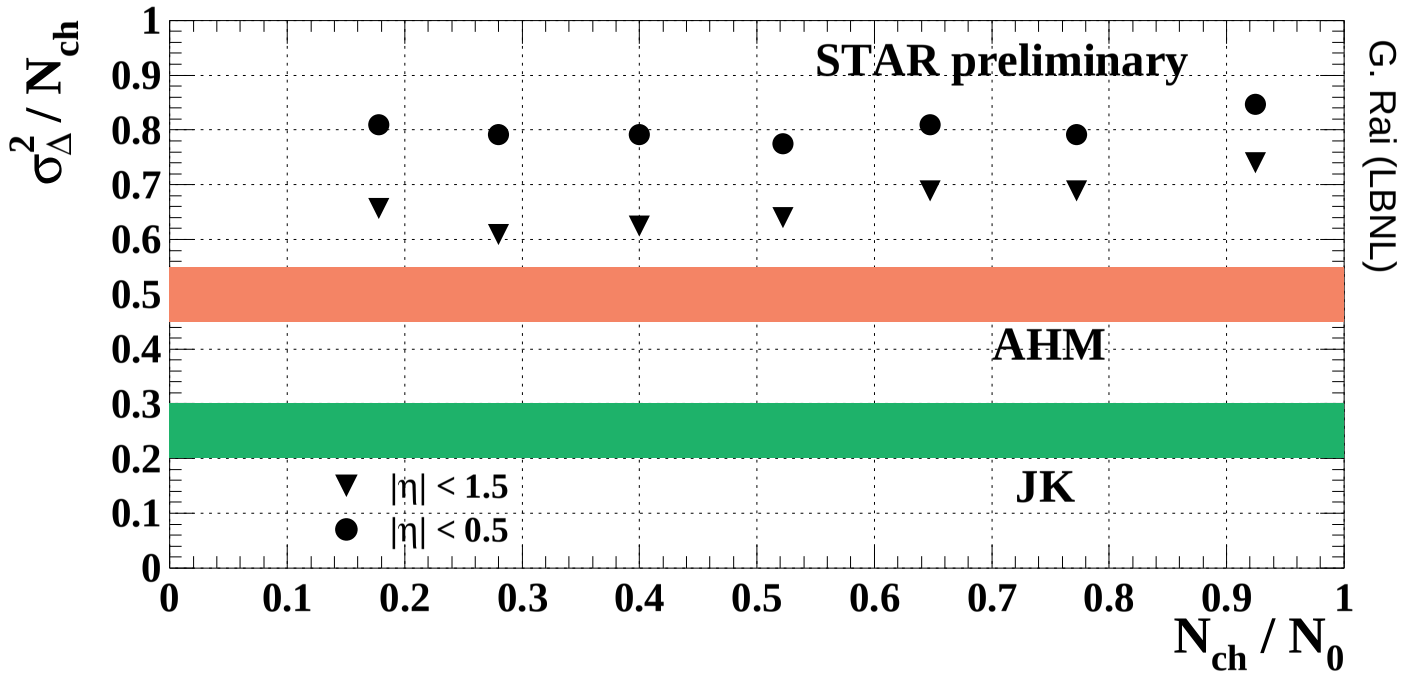
JK1 S. Jeon, V. Koch, nucl-th/9906074, Phys. Rev. Lett., **83** 5435 (1999)

SRS M. Stephanov, K. Rajagopal, E. Shuryak, hep-ph/9903292, Phys. Rev. **D60** 114028 (1999)

JK2 S. Jeon, V. Koch, Phys. Rev. Lett. **85** (2000) 2076-2079

AHM M. Asakawa, U. Heinz, B. Mueller, Phys. Rev. Lett. **85** (2000) 2072-2075

N_+, N_- Fluctuations - Centrality Dependence



- Charge-ratio studies provide σ^2_Δ for central events: 0.75-0.85 N_{ch}
- Small centrality dependence in minbias analysis
- Deviations from unity consistent with resonance correlations
- Expected dependence on η acceptance
- Multiplicity fluctuations: agreement between SPS* and RHIC

* NA49 EbyE Fluctuations poster - QM2001 session A: P082

N_+, N_- Fluctuations - Central Events

- $\sigma^2_+ = 1.50\ N_+$, $\sigma^2_- = 1.35\ N_-$, $\sigma^2_\Sigma = 2.09\ N_{ch}$ [terminus variance]
- $\sigma^2_\Delta \sim 0.75\ N_{ch}$ [charge-ratio]
- Experimental information is not determining
  - assume $\sigma^2_S = 0$ and compare σ^2_R and σ^2_V predictions to data OR
  - accept predictions for σ^2_R and σ^2_V and establish constraints on σ^2_S from data
- Using $\sigma^2_\Sigma = 2.09N_{ch}$ & $\sigma^2_\Delta = 0.75N_{ch}$
  - Volume/trigger fluctuations (V) : $\sigma^2_V = 0.83N_{ch} + 2\sigma^2_S$
    - theory: $\sigma^2_V = 0.40N_{ch}$, $0.85N_{ch}$
  - Resonance correlations (R) : $\sigma^2_R = 0.25N_{ch} - \sigma^2_S$
    - theory: $\sigma^2_R = 0.3N_{ch}$, $0.5N_{ch}$
  - QGP suppression (S) : $\sigma^2_S < 0.1N_{ch}$ (given σ^2_R, σ^2_V predictions)
    - theory: $\sigma^2_S = 0.25N_{ch}$, $0.5N_{ch}$

EbyE Fluctuations - Summary

- ***Transverse*** phase-space analysis
- Charge-independent and dependent $<p_t>$ fluctuations
- Charge-independent and dependent correlations in $m_t \times m_t$ distributions
  - consistent with $<p_t>$ results and model studies
  - *charge-dependent* correlations similar to NA49

- Multiplicity fluctuation results
  - agreement with NA49 (central)
  - N_+/N_- ratio fluctuation results consistent with hadronic resonances
  - No remarkable centrality dependence
  - No substantial evidence for predicted fluctuation suppression associated with rapid hadronization from a QGP

- Much more to come from EbyE:
  - ***Axial*** phase-space analysis
  - High-p_t correlations (minijets) [poster B:P162 (S. Chattopadhyay)]
  - QCD P,T violation [poster B:P167 (E. Finch)]
  - Flavor fluctuations (identified-particle EbyE)