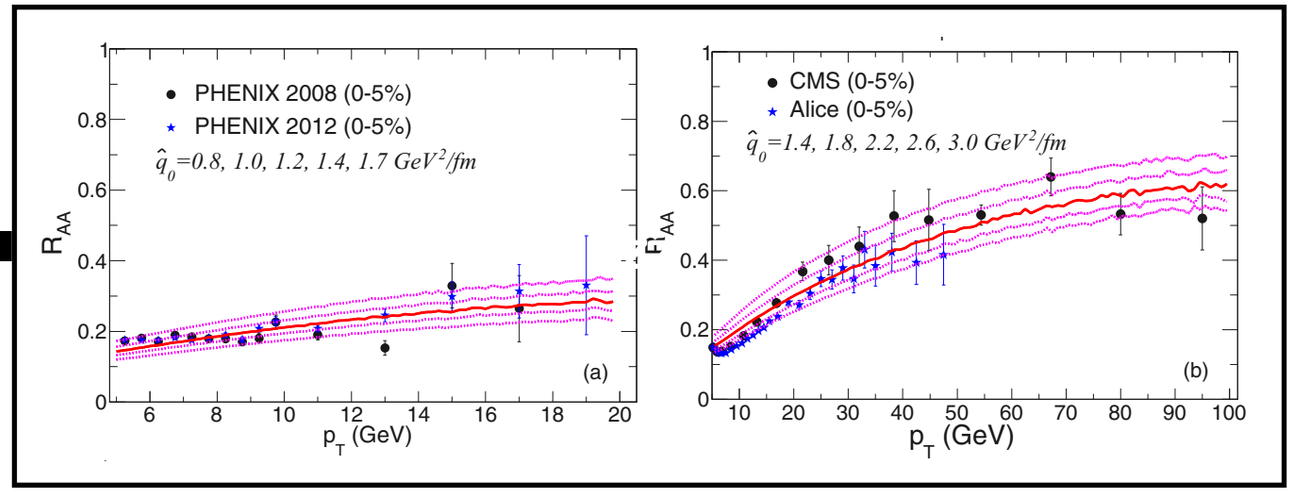
Bayesian extraction of $\hat{q}$ with a multi-stage jet evolution approach

Ron Soltz, Wayne State University, LLNL
for the JETSCAPE Collaboration

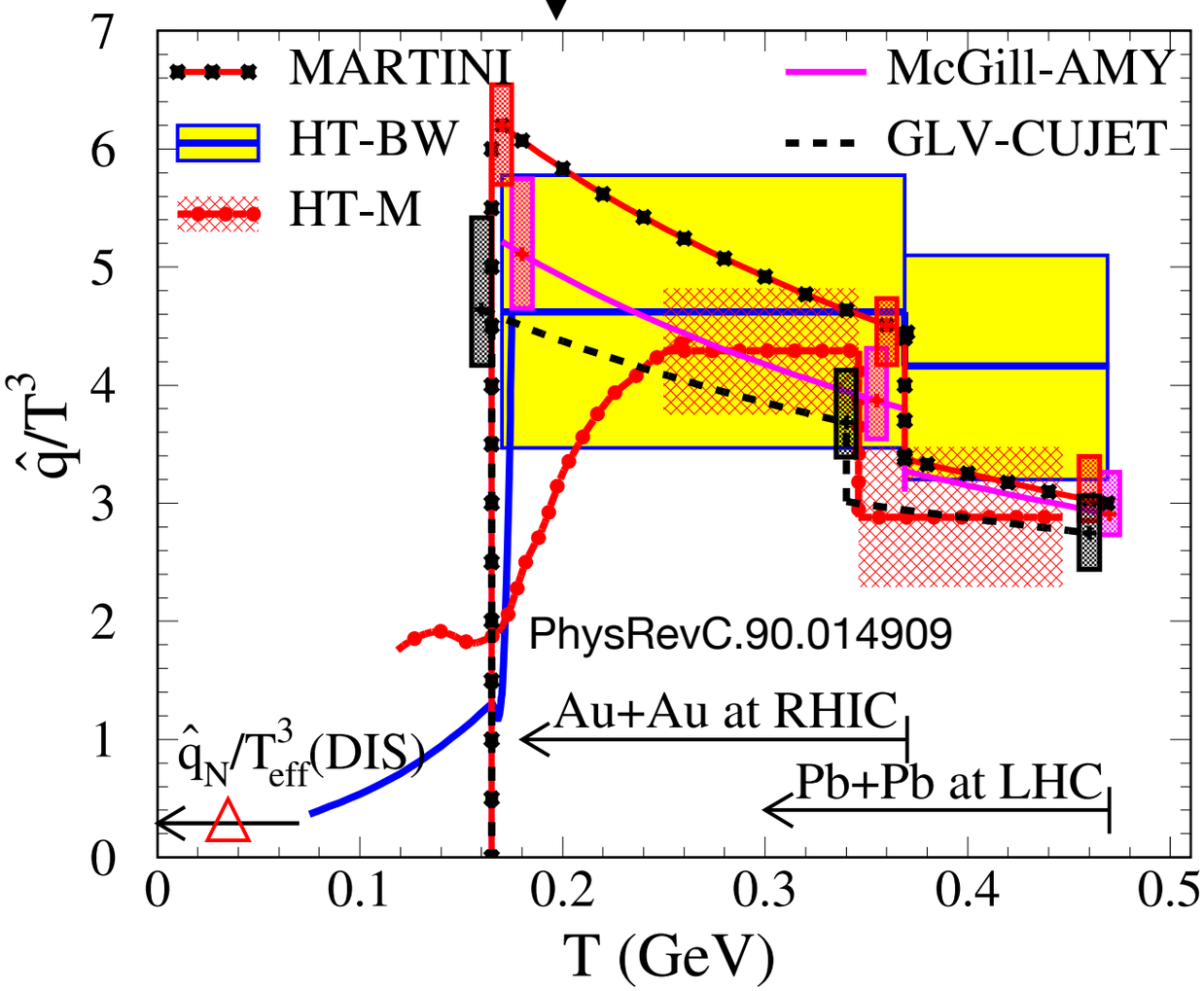
JETSCAPE Talks/Posters:

Y. Tachibana - Jet Substructure (Wed 12:05)
C. Park - Jet/hadron R_{AA} and jet v_2 (Thu 12:05)
J. Puschke - JETSCAPE 1.0 Framework (Poster)
R. Fries - p-p physics with JETSCAPE (Poster)

Motivation

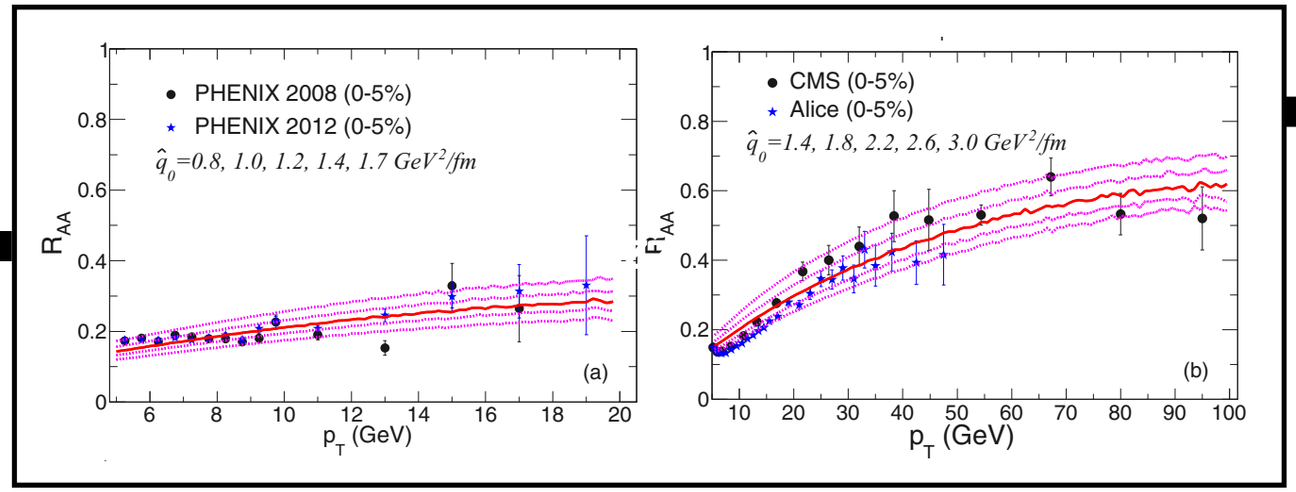


$\mathcal{X}_2$



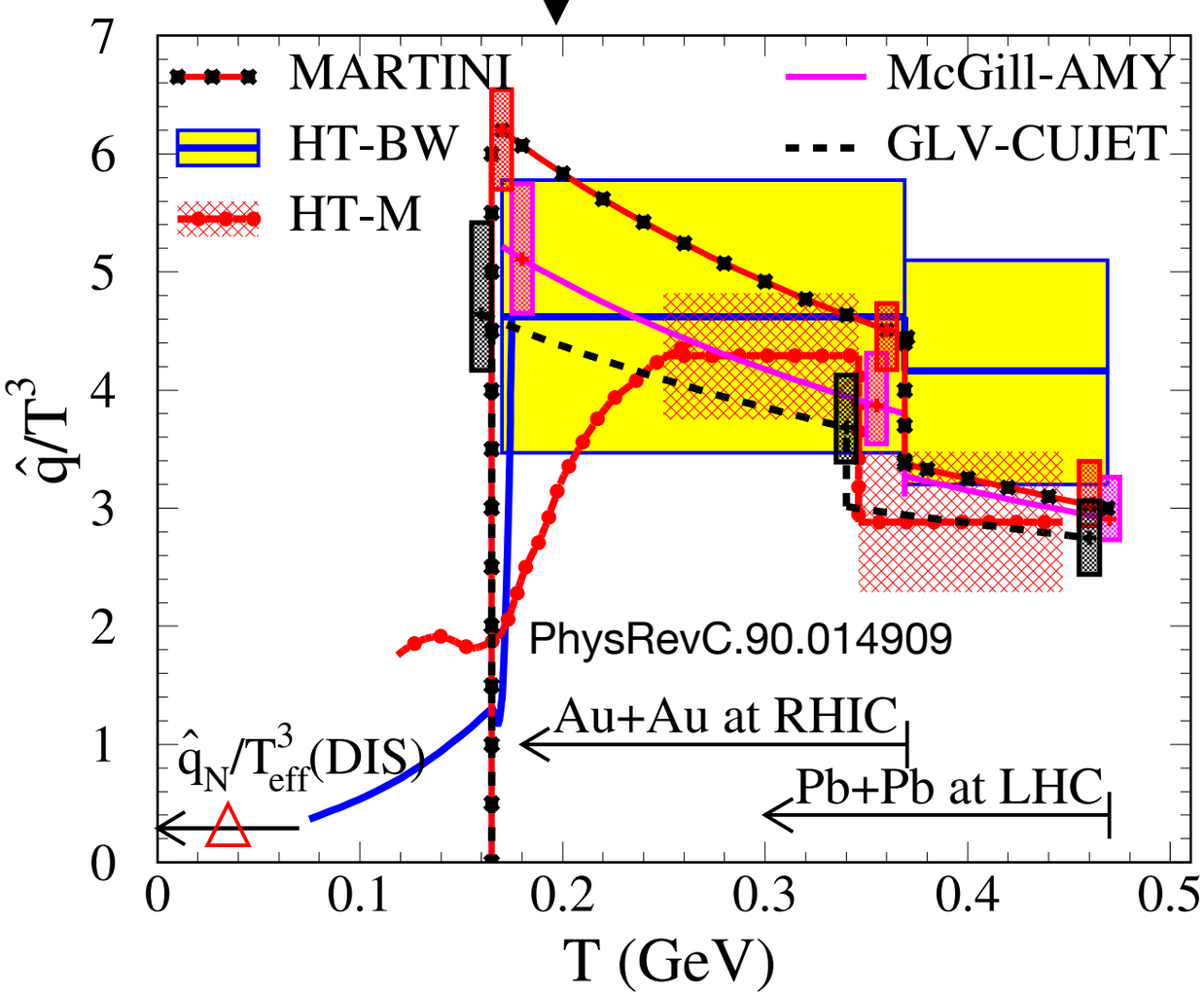
- Jet Collab. determined $\hat{q}=\langle p_T^2\rangle/L$ for 5-models fit to central RHIC/LHC hadron R_{AA}

Motivation



χ_2

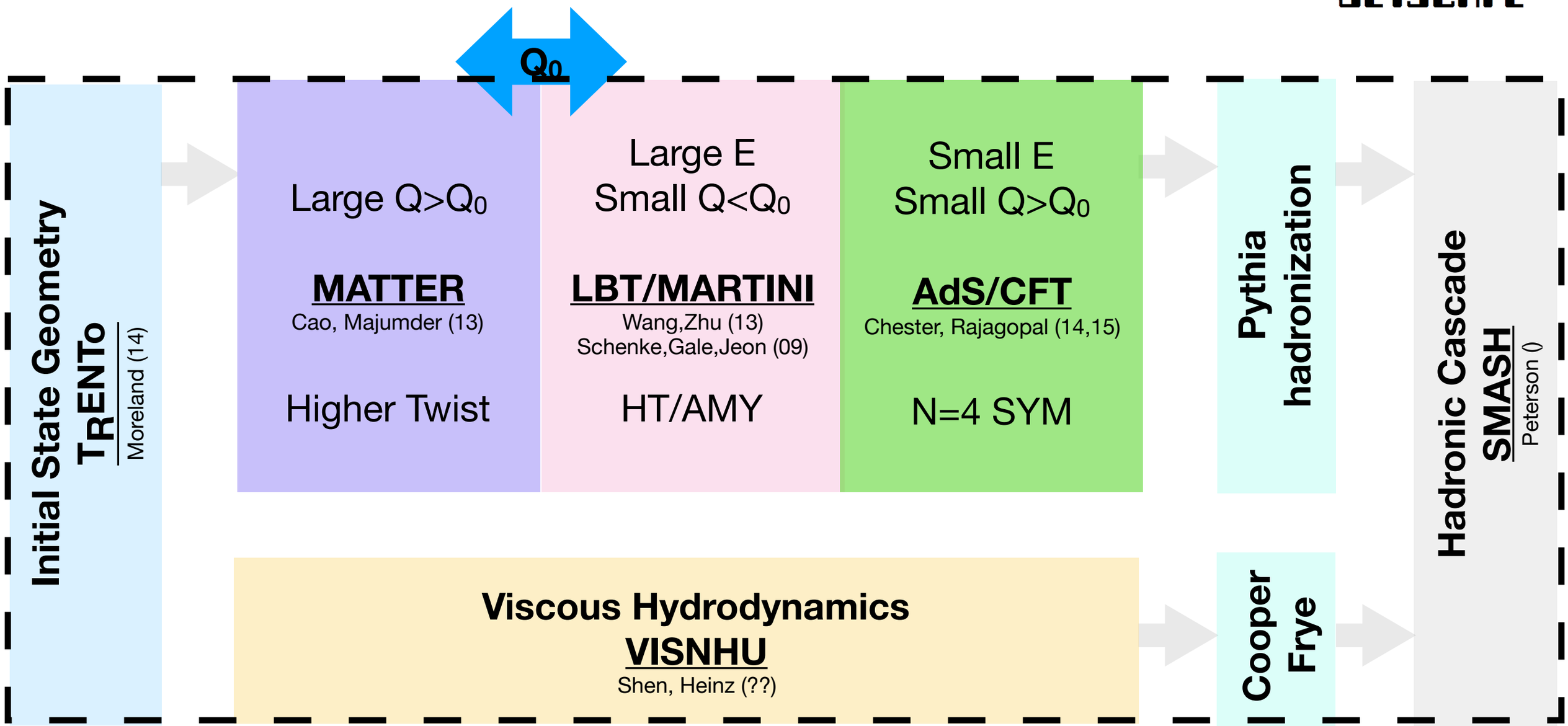
Bayesian



- Jet energy-loss mechanisms not mutually exclusive, apply to different E,Q scales
- Develop self-consistent, modular framework to evolve jet through decreasing E,Q regimes within hydrodynamic medium
- Apply Bayesian calibration methods, compare to non-central hadron R_{AA}
- Extract temperature-dependent q

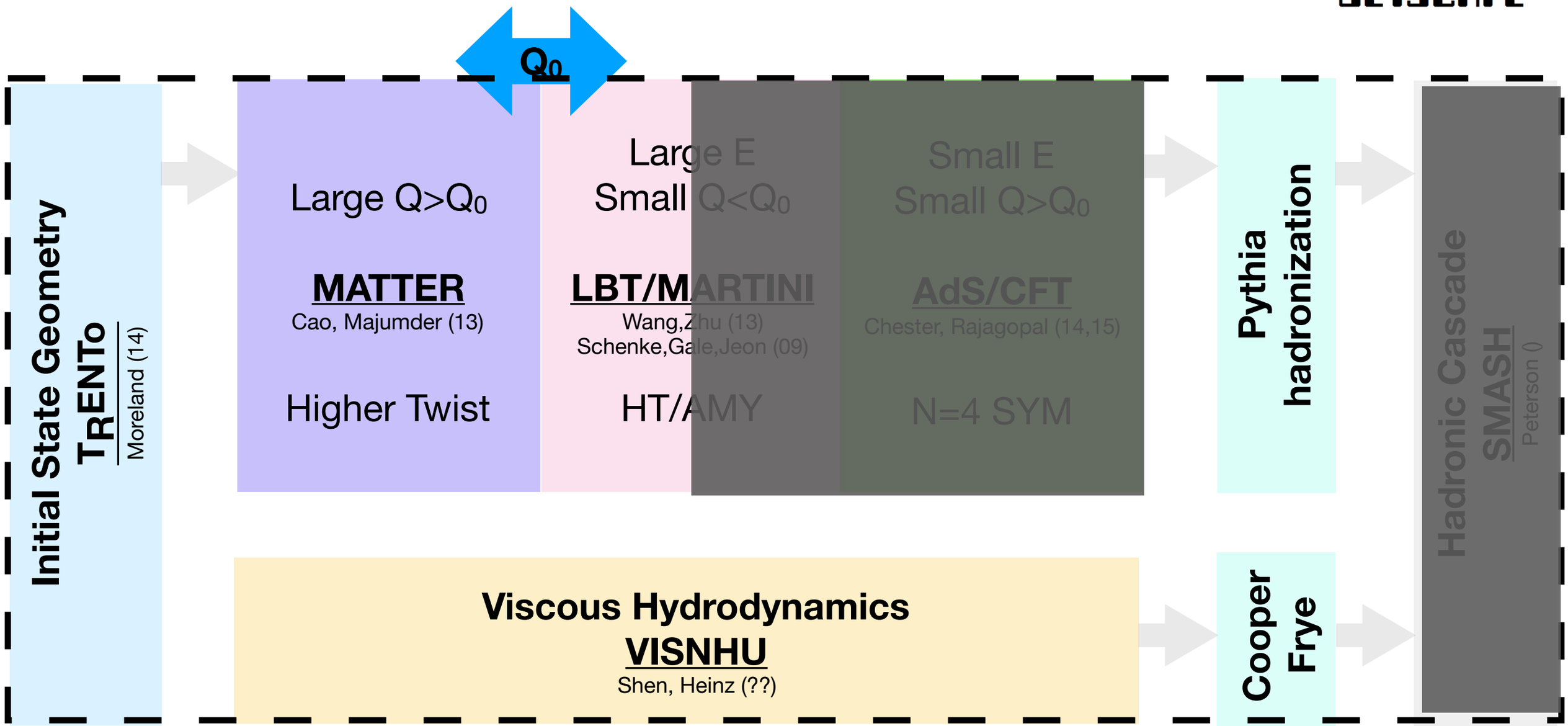
- Jet Collab. determined $\hat{q}=\langle p_T^2\rangle/L$ for 5-models fit to central RHIC/LHC hadron R_{AA}
- JetScape developing mult-stage approach to determine $\hat{q}(T)$ from multiple data sets

JETSCAPE Physics Package



- **Limit physics package to elements needed to study $\hat{q}$ and Q_0**

JETSCAPE Physics Package



- **Limit physics package to elements needed to study $\hat{q}$ and Q_0**

JETSCAPE Statistics Package

(figure adapted from Bass, Bernhard, Moreland 1704.0767)

Model Parameters - System Properties
- energy loss scale
- medium coupling constant

calculate events on Latin hypercube

Physics Package:
- MATTER + LBT
- VISHNU

Gaussian Process Emulator
- non-parametric interpolation
- fast surrogate to full Physics Model

Experimental Data
- RAA @ RHIC & LHC

MCMC
(Markov-Chain Monte-Carlo)
- random walk through parameter space weighted by posterior probability

after many steps, MCMC equilibrates to

Posterior Distribution
- **diagonals**: probability distribution of each parameter, integrating out all others
- **off-diagonals**: pairwise distributions showing dependence between parameters

Bayes' Theorem

posterior $\propto$ likelihood $\times$ prior

- **prior**: initial knowledge of parameters
- **likelihood:** probability of observing exp. data, given proposed parameters

Parameterizing $\hat{q}$

$$\frac{\hat{q}}{T^3} = 42 C_R \frac{\zeta(3)}{\pi} \left(\frac{4\pi}{9}\right)^2 \left\{ \frac{A\left[\ln\left(\frac{E}{\Lambda}\right) - \ln(B)\right]}{\left[\ln\left(\frac{E}{\Lambda}\right)\right]^2} + \frac{C\left[\ln\left(\frac{E}{T}\right) - \ln(D)\right]}{\left[\ln\left(\frac{ET}{\Lambda^2}\right)\right]^2} \right\}$$

Set range 0 < A,C < 1

Pure dependence on the scale of jet when Q >> T

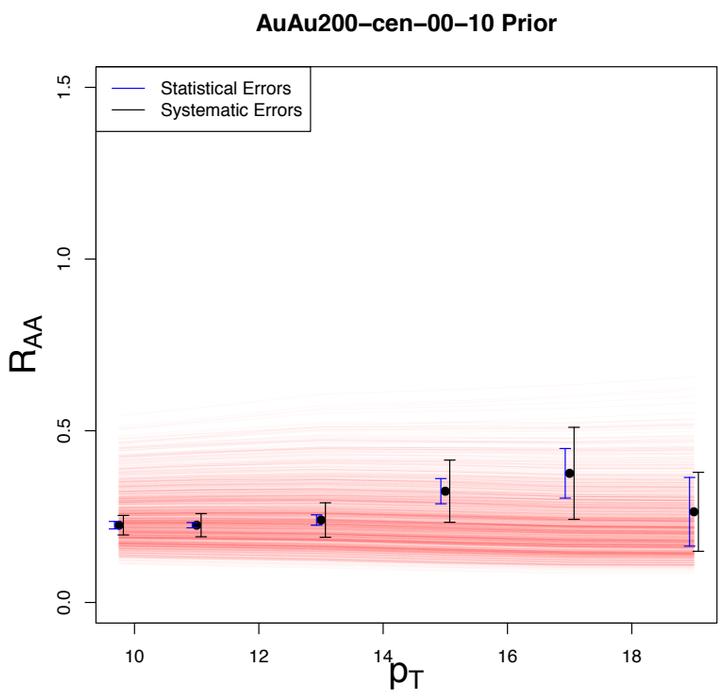
Perturbative scattering with quasi-particles from a thermal medium (*T*)

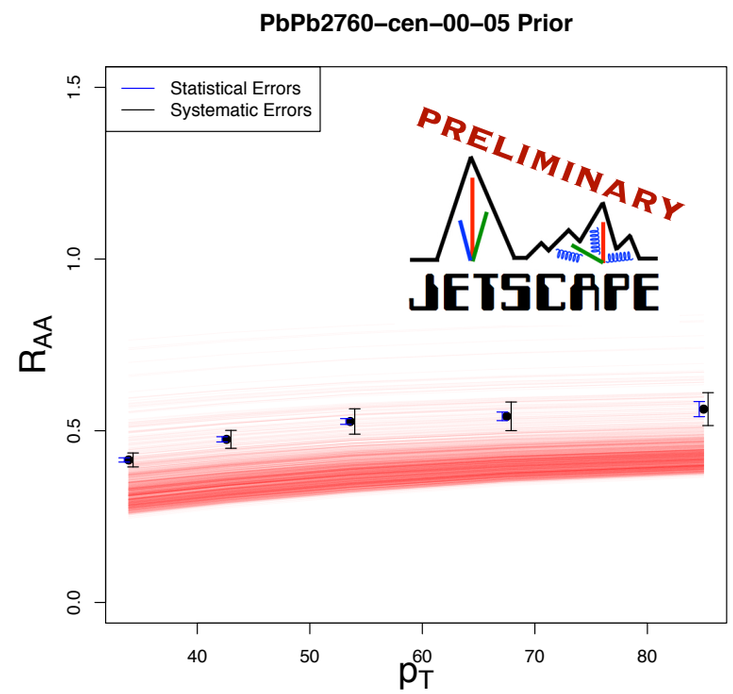
- Roadmap for Bayesian Extraction of $\hat{q}$
  1. Select physics-inspired parameterization for $\hat{q}(E,T)$
  2. Extract $\hat{q}$-parameters for MATTER and LBT independently
  3. Check that results are sensible
  4. Introduce Q_0 virtuality scale (switching parameter)
  5. Extract Q_0 and $\hat{q}$-parameters for combined MATTER+LBT

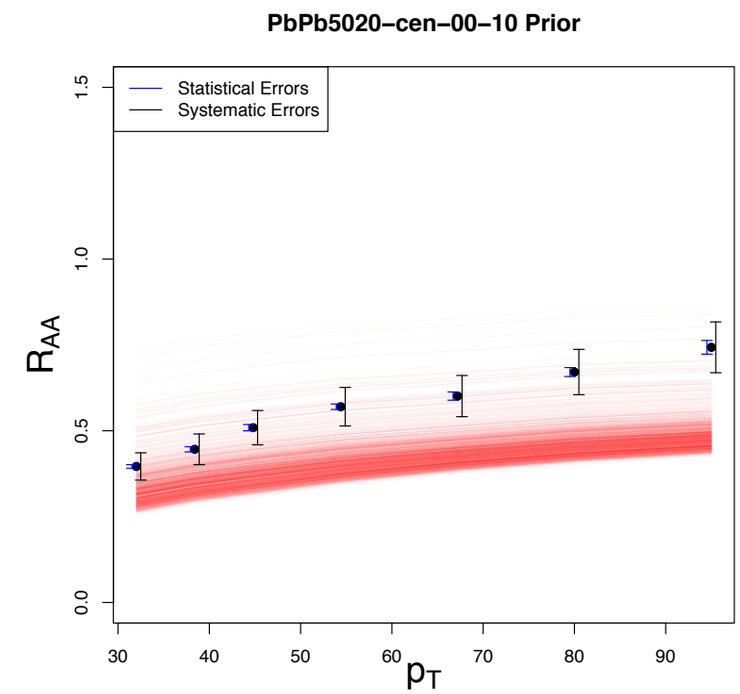
MATTER data calibration: prior

200 GeV Au+Au | **2.76 TeV Pb+Pb** | **5.02 TeV Pb+Pb**

Central







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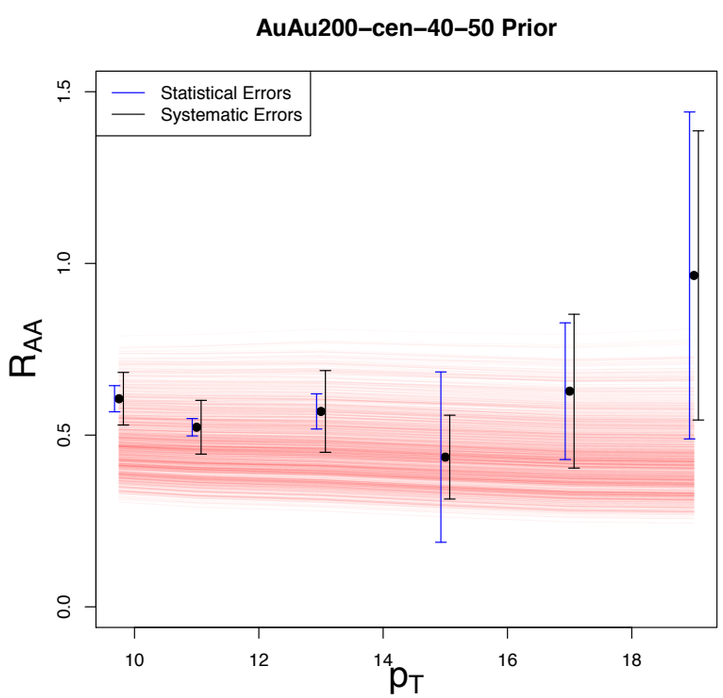
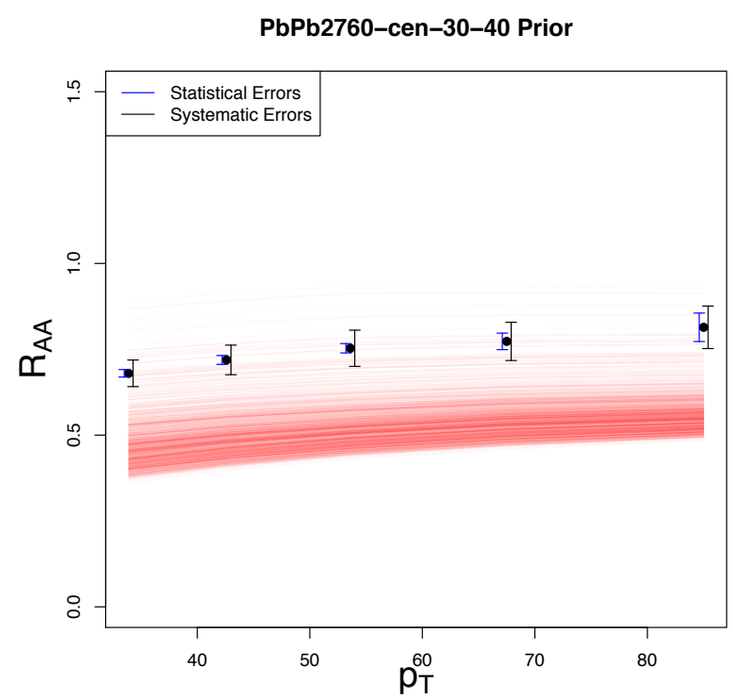
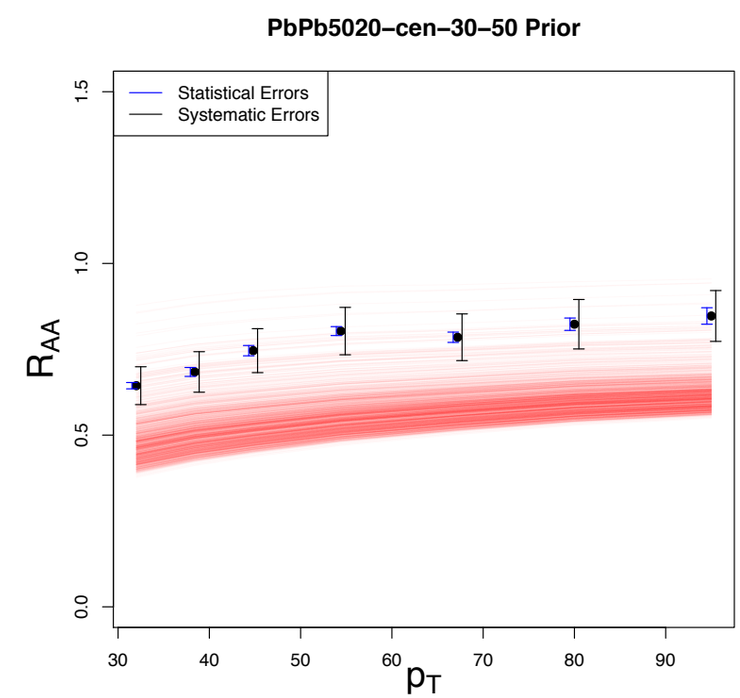


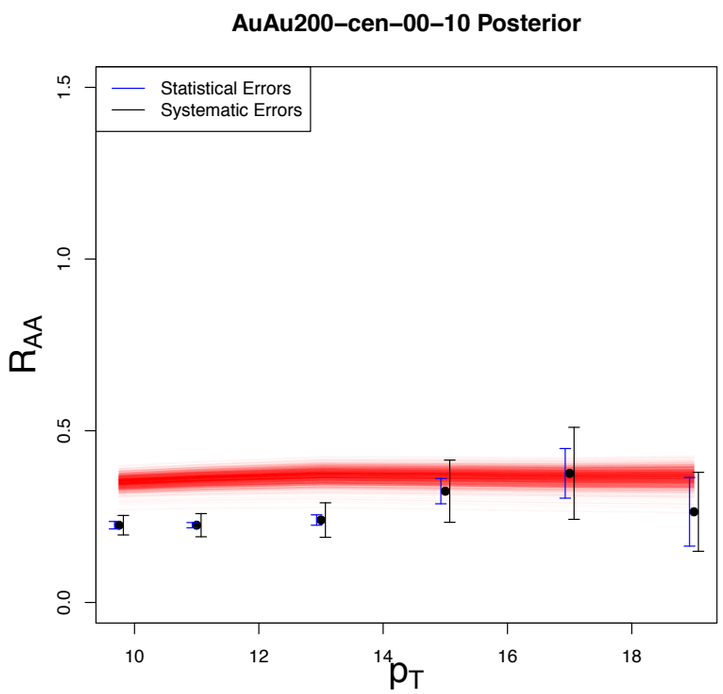


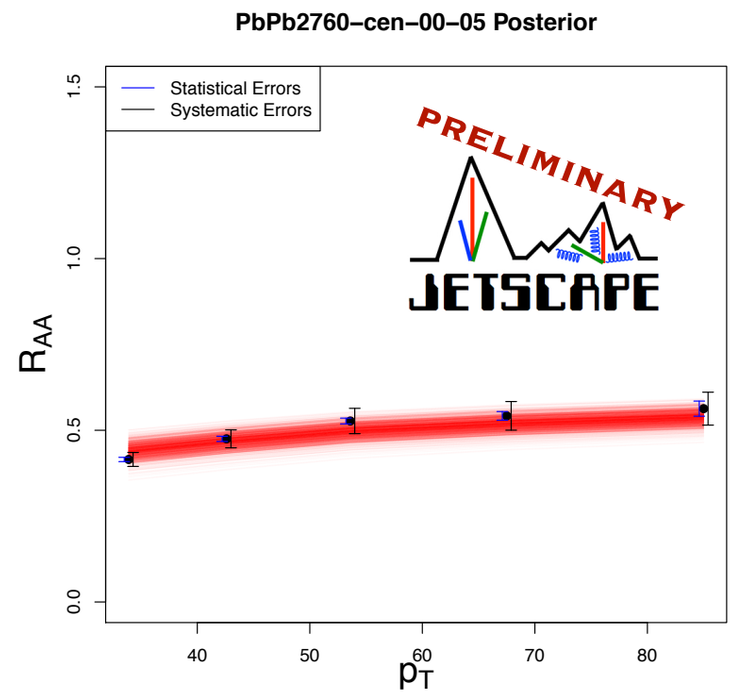


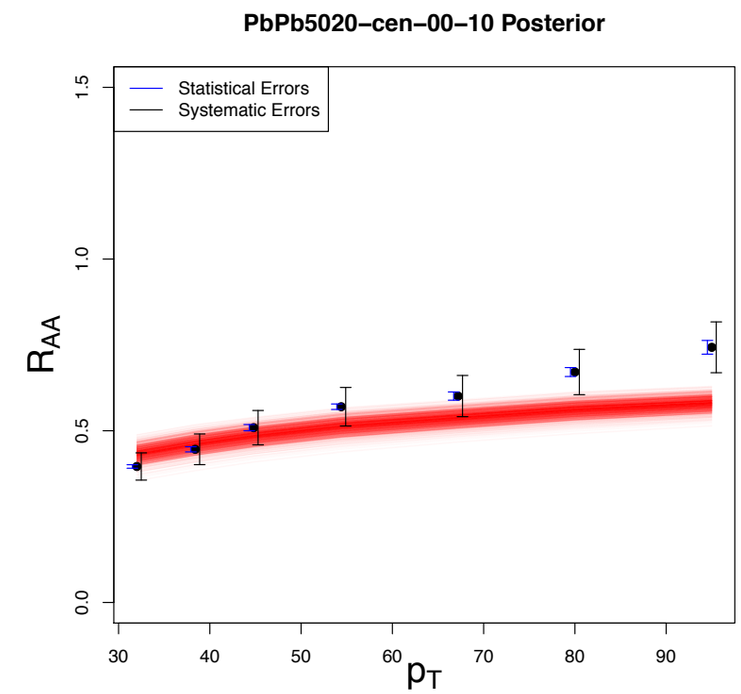
MATTER data calibration: posterior

200 GeV Au+Au | **2.76 TeV Pb+Pb** | **5.02 TeV Pb+Pb**

Central







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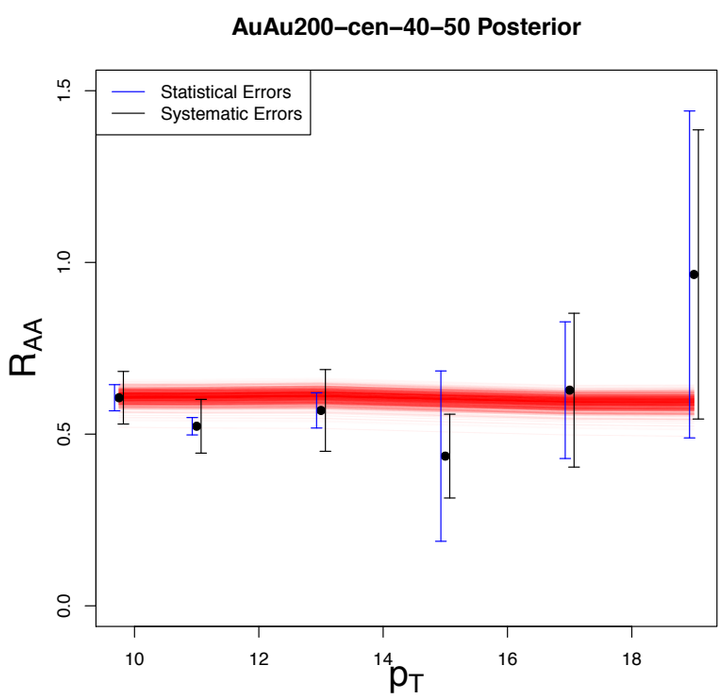
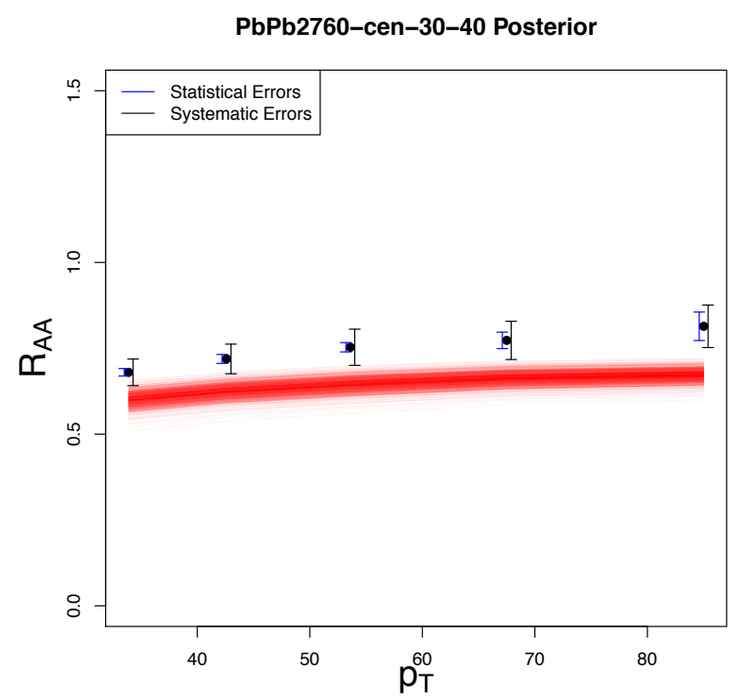
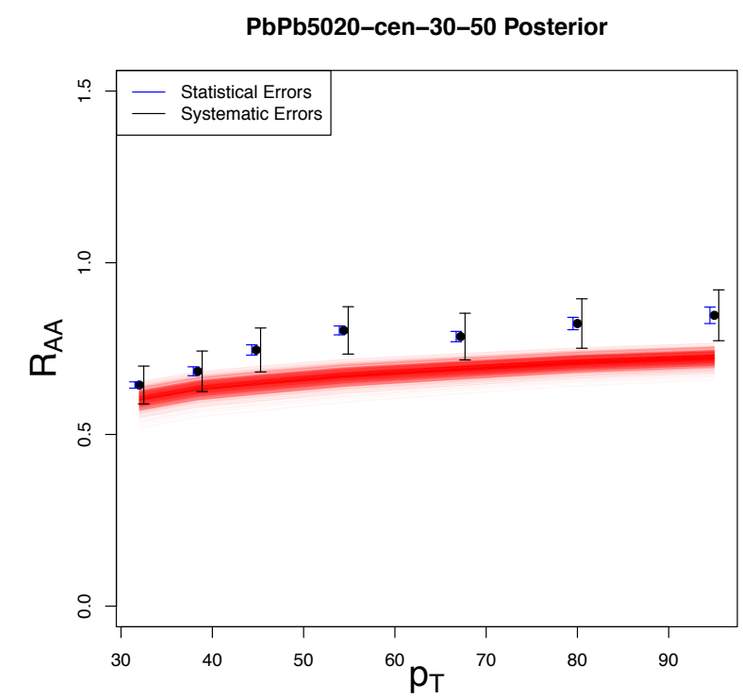


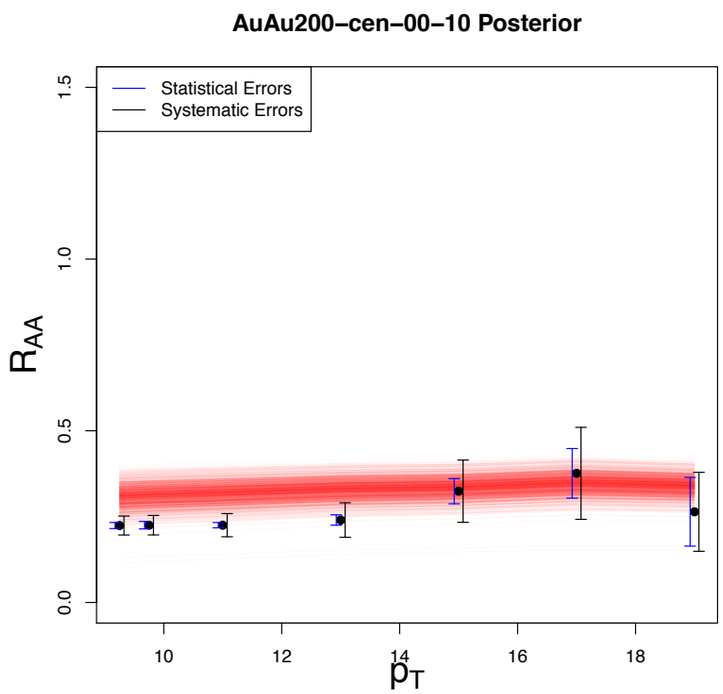


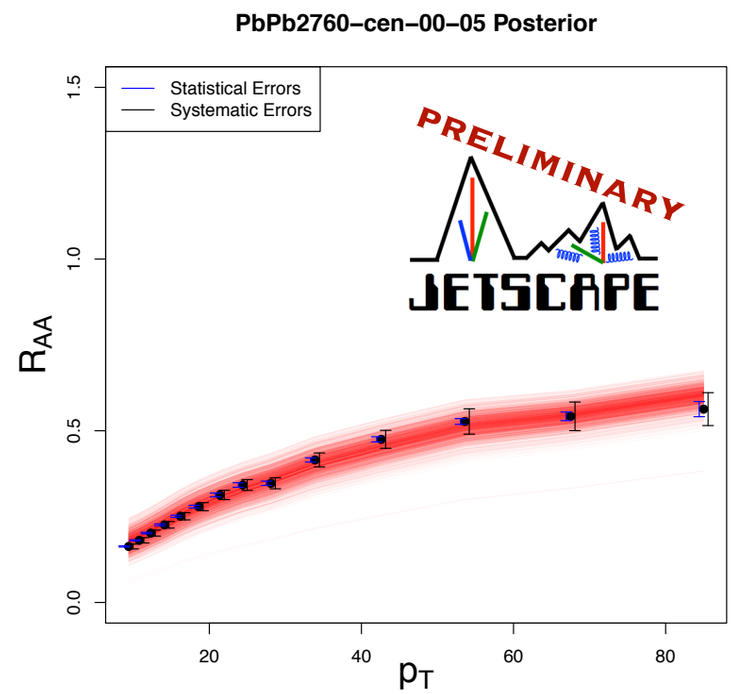


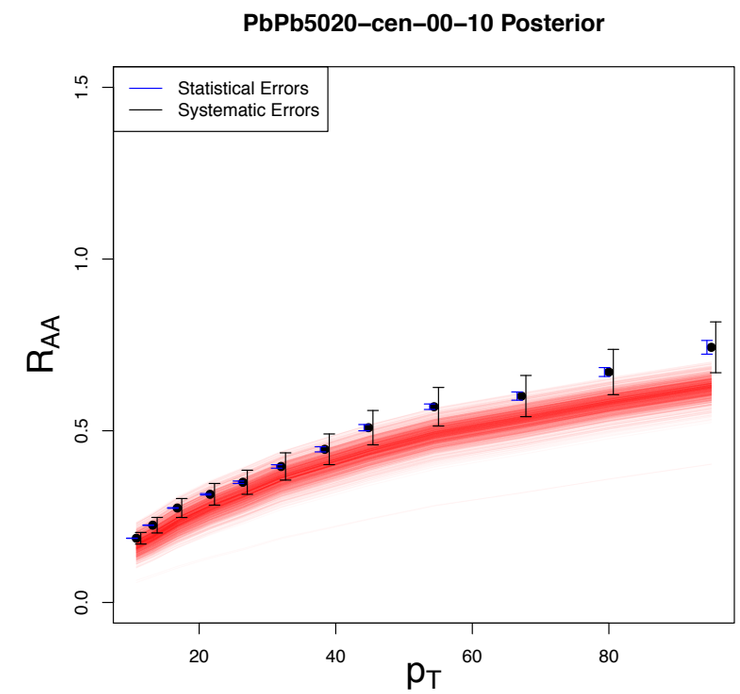
LBT data calibration: posterior

200 GeV Au+Au | **2.76 TeV Pb+Pb** | **5.02 TeV Pb+Pb**

Central







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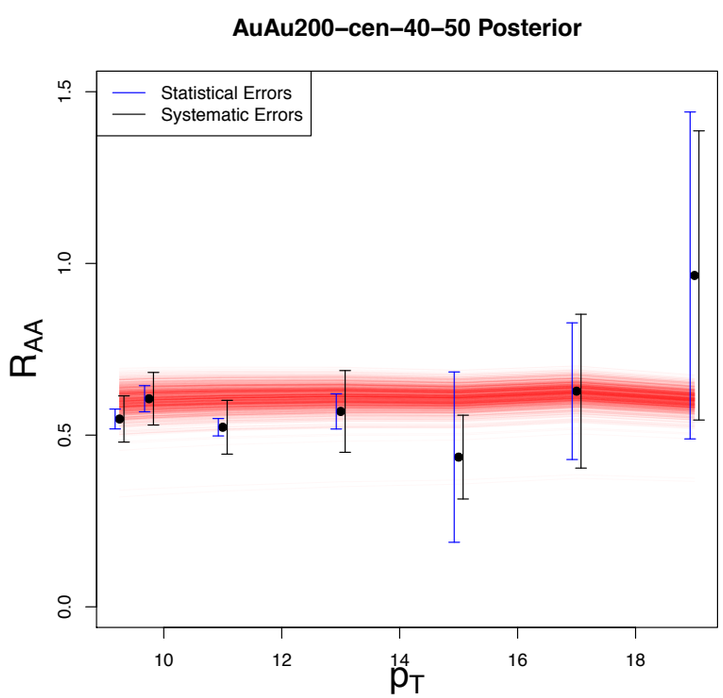
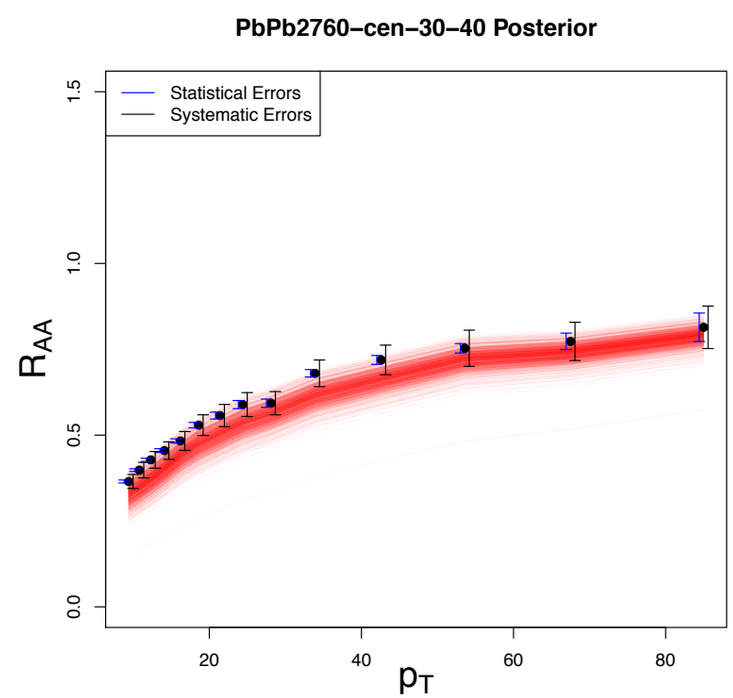
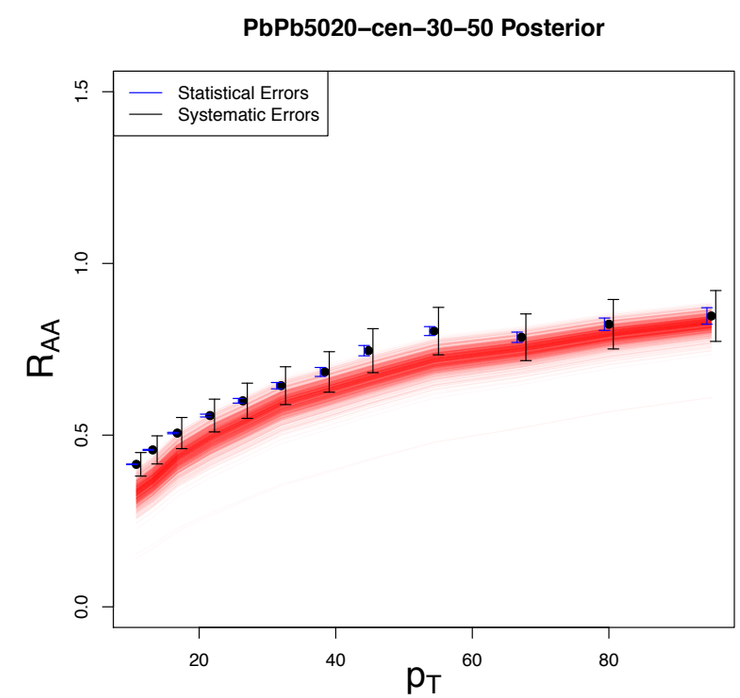
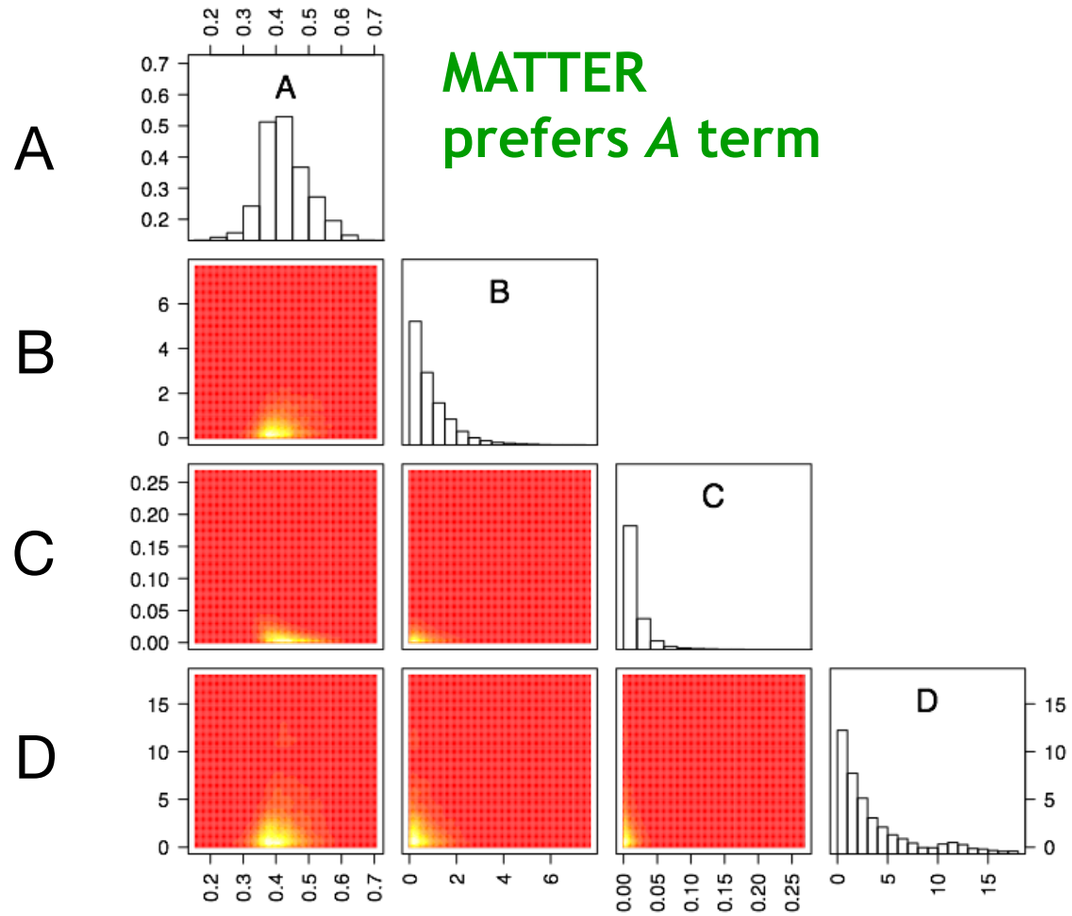




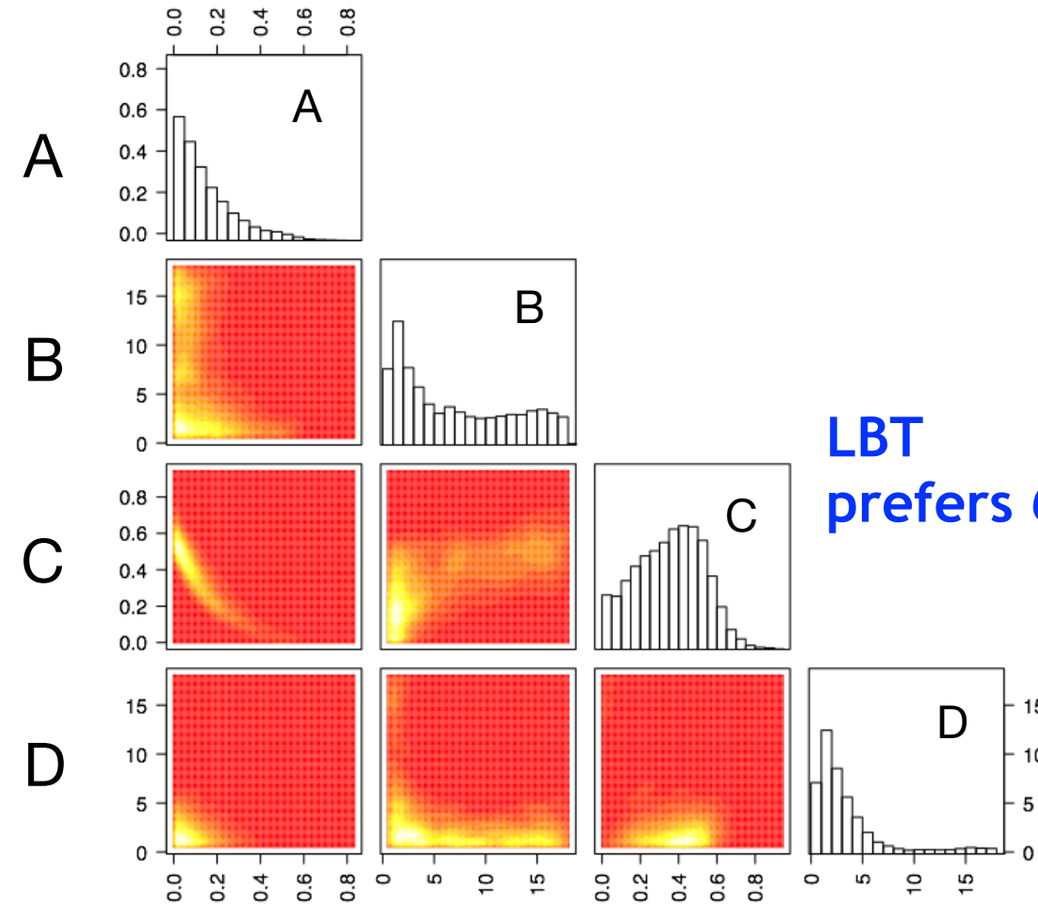


Independent $\hat{q}$ Extraction: MATTER and LBT

$$\frac{\hat{q}}{T^3} = 42 C_R \frac{\zeta(3)}{\pi} \left(\frac{4\pi}{9}\right)^2 \left\{ \frac{A\left[\ln\left(\frac{E}{\Lambda}\right) - \ln(B)\right]}{\left[\ln\left(\frac{E}{\Lambda}\right)\right]^2} + \frac{C\left[\ln\left(\frac{E}{T}\right) - \ln(D)\right]}{\left[\ln\left(\frac{ET}{\Lambda^2}\right)\right]^2} \right\}$$



MATTER prefers *A* term



LBT prefers *C* term

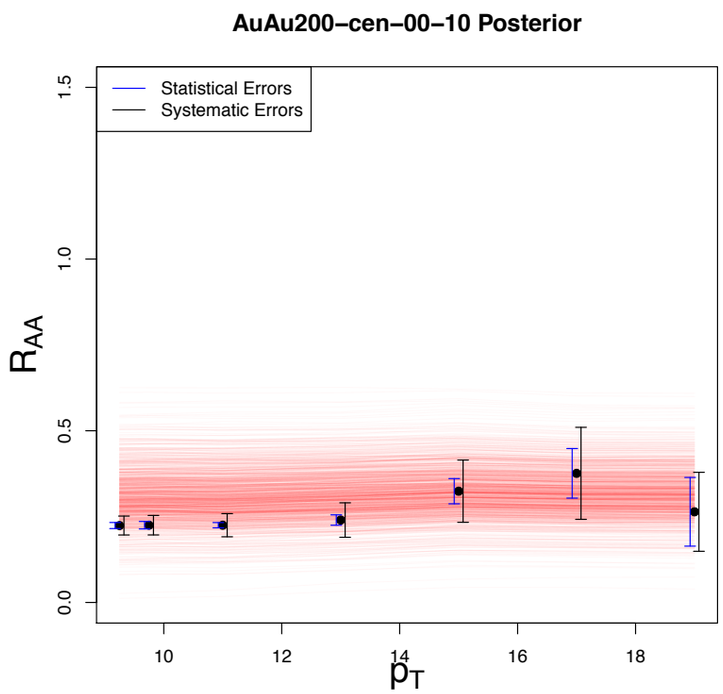
- **Independent $\hat{q}$-extraction results for MATTER and LBT are self-consistent**
- **Next: Introduce Q_0 virtuality scale and run with MATTER+LBT physics model**

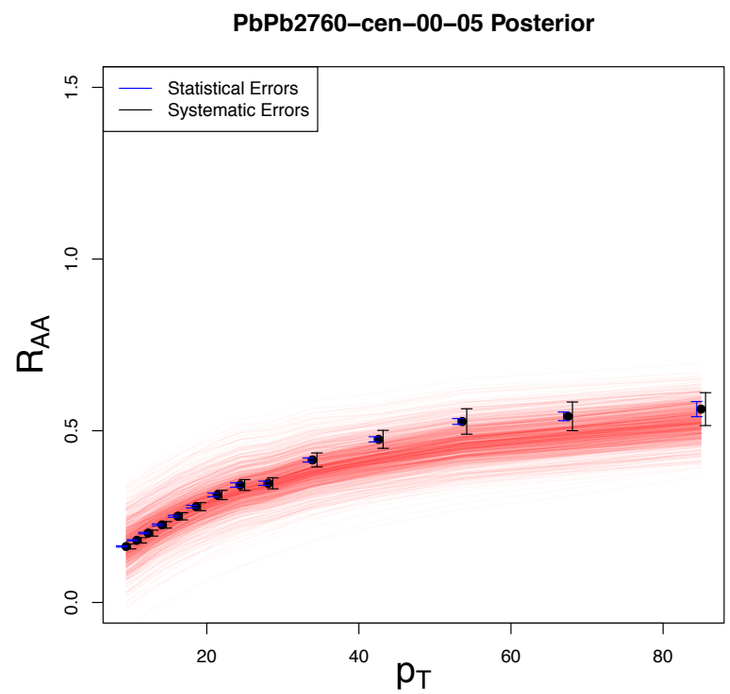
MATTER + LBT data calibration: posterior

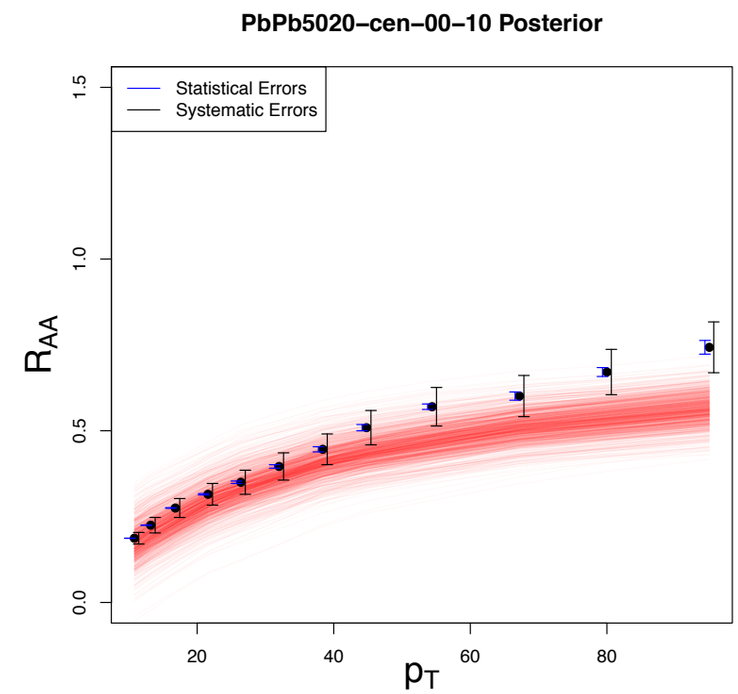
PRELIMINARY JETSCAPE

200 GeV Au+Au | 2.76 TeV Pb+Pb | 5.02 TeV Pb+Pb

Central







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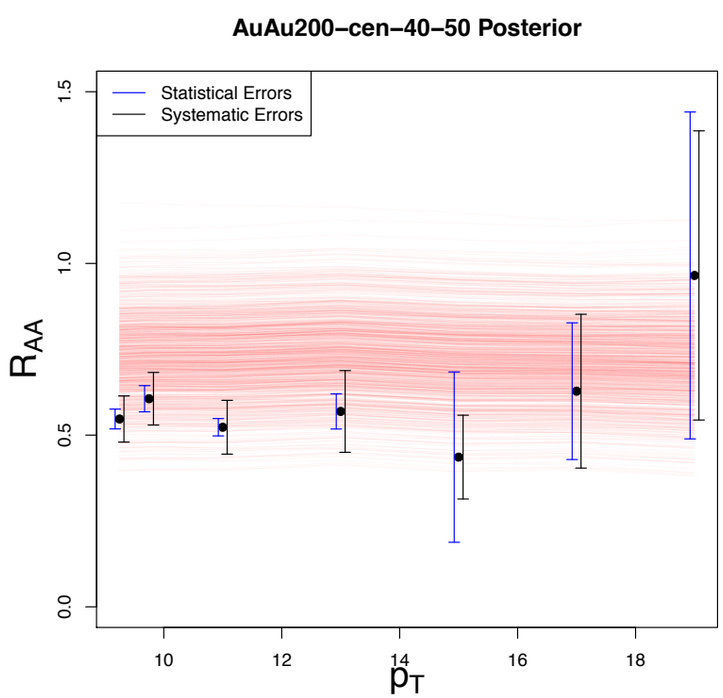
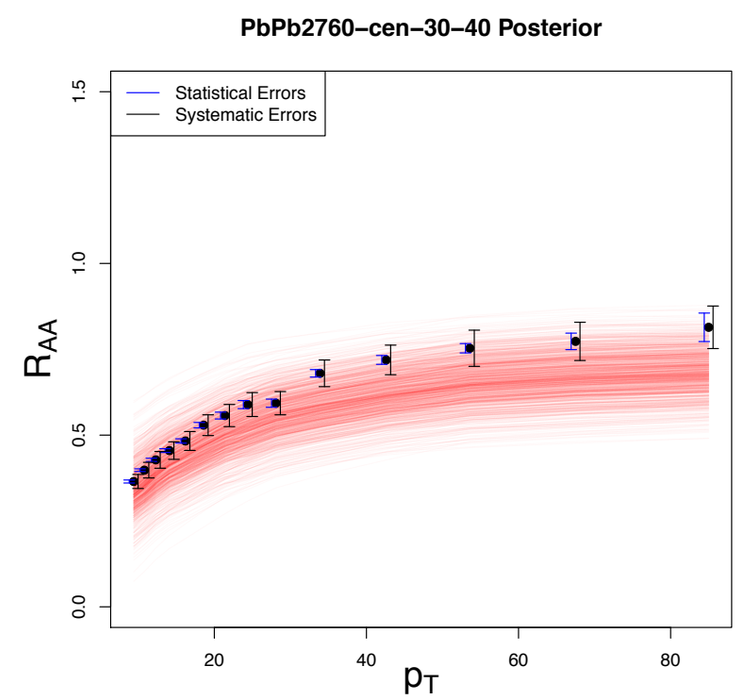
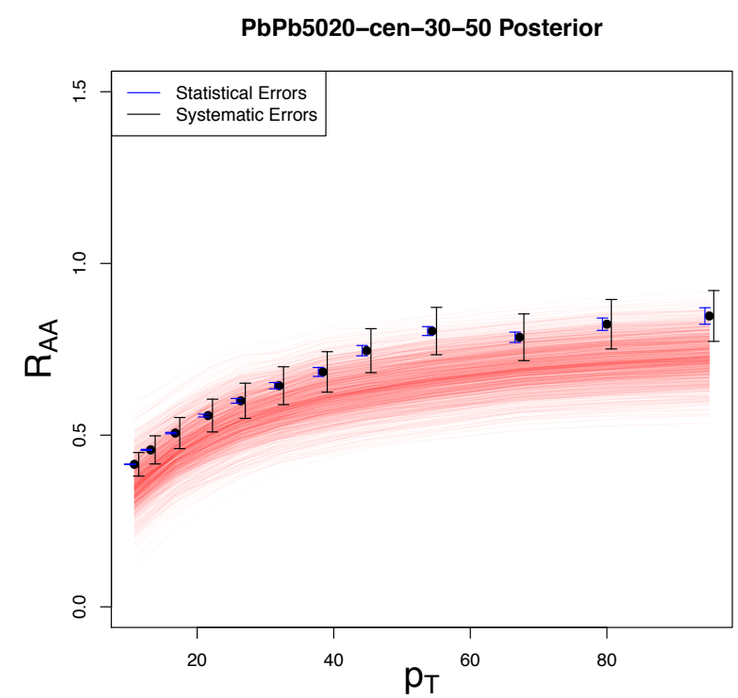
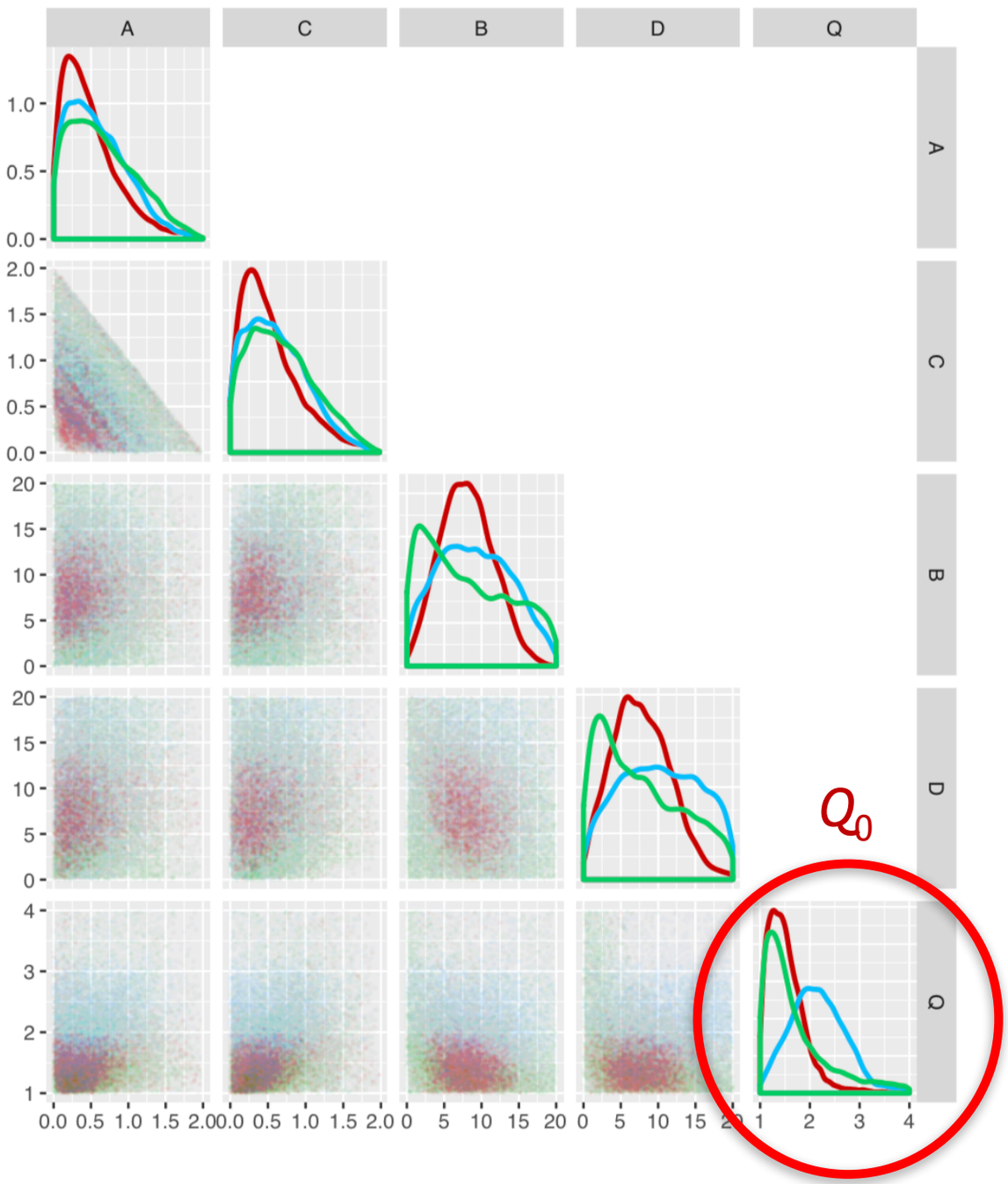






Q_0, $\hat{q}$-extraction: MATTER+LBT



- Larger constant Q_0 from LHC data calibration
- Smaller constant Q_0 from RHIC data calibration
- Combined RHIC+LHC data calibration for Q_0 around 1.5 GeV
- Motivate search for universal function $Q_0(E, T)$

Parameterizing $\hat{q}$ (again)

$$\frac{\hat{q}}{T^3} = 42 C_R \frac{\zeta(3)}{\pi} \left(\frac{4\pi}{9}\right)^2 \left\{ \frac{A\left[\ln\left(\frac{E}{\Lambda}\right) - \ln(B)\right]}{\left[\ln\left(\frac{E}{\Lambda}\right)\right]^2} + \frac{C\left[\ln\left(\frac{E}{T}\right) - \ln(D)\right]}{\left[\ln\left(\frac{ET}{\Lambda^2}\right)\right]^2} \right\}$$

Pure dependence on the scale of jet when Q >> T

Perturbative scattering with quasi-particles from a thermal medium (T)

$\Theta(Q-Q_0)$

$$\frac{\hat{q}}{T^3} = 42 C_R \frac{\zeta(3)}{\pi} \left(\frac{4\pi}{9}\right)^2 \left\{ \frac{A\left[\ln\left(\frac{Q}{\Lambda}\right) - \ln\left(\frac{Q_0}{\Lambda}\right)\right]}{\left[\ln\left(\frac{Q}{\Lambda}\right)\right]^2} + \frac{C\left[\ln\left(\frac{E}{T}\right) - \ln(D)\right]}{\left[\ln\left(\frac{ET}{\Lambda^2}\right)\right]^2} \right\}$$

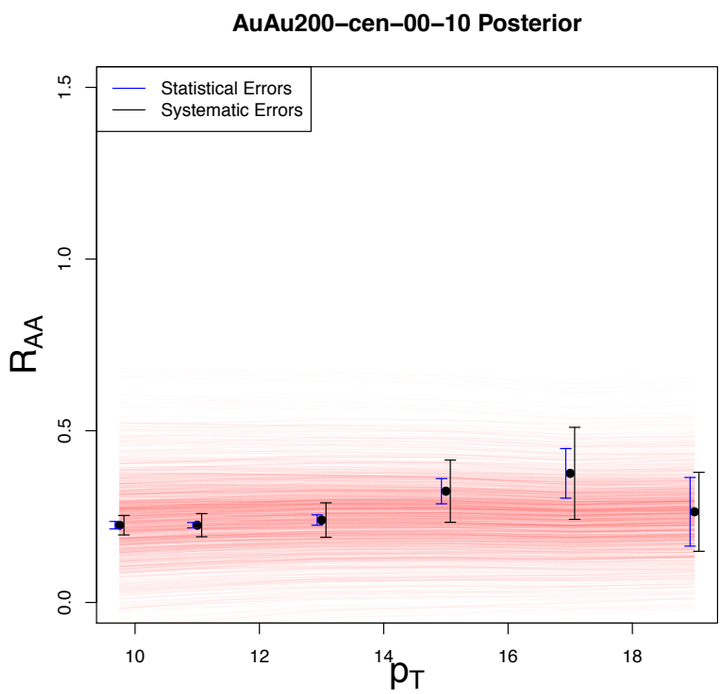
For $Q<Q_0$ (LBT-stage), only 2nd term contributes

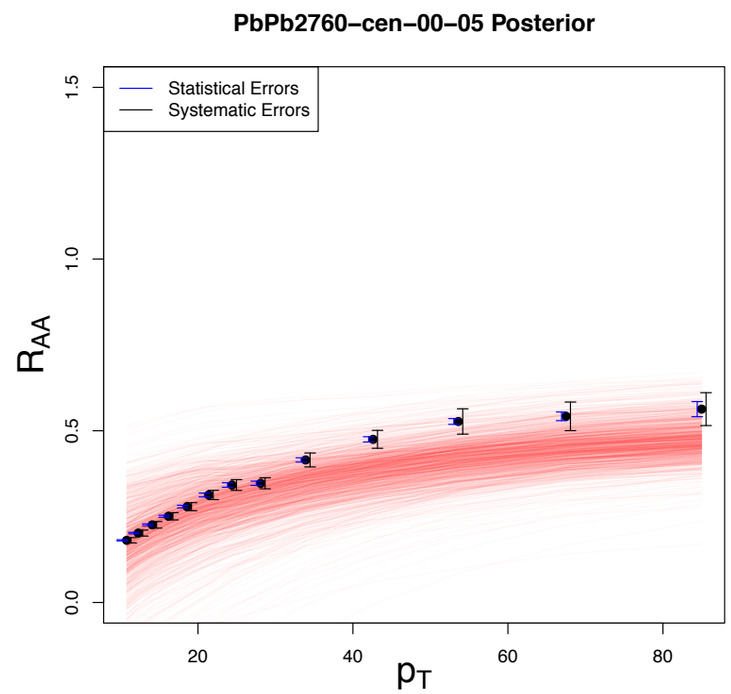
MATTER + LBT data calibration (Q_0,$\hat{q}$): posterior

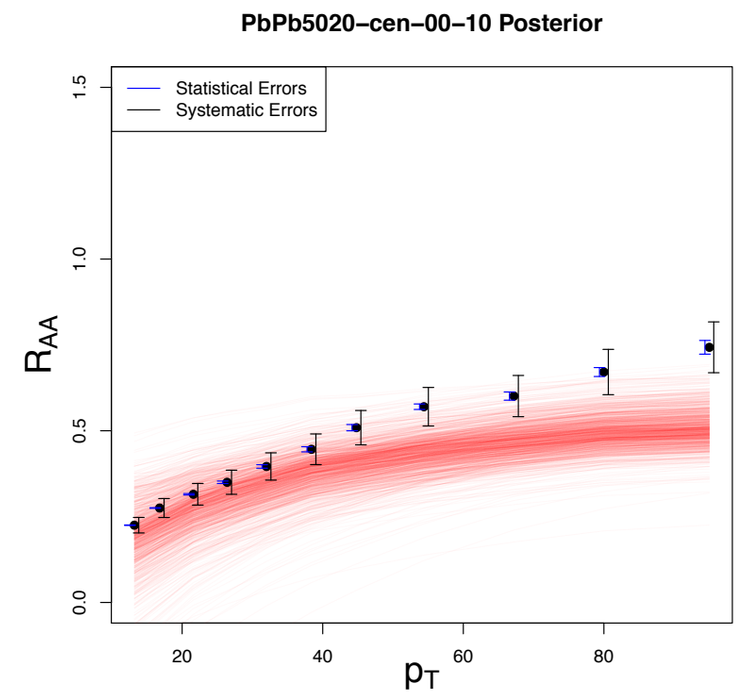
PRELIMINARY JETSCAPE

200 GeV Au+Au | **2.76 TeV Pb+Pb** | **5.02 TeV Pb+Pb**

Central







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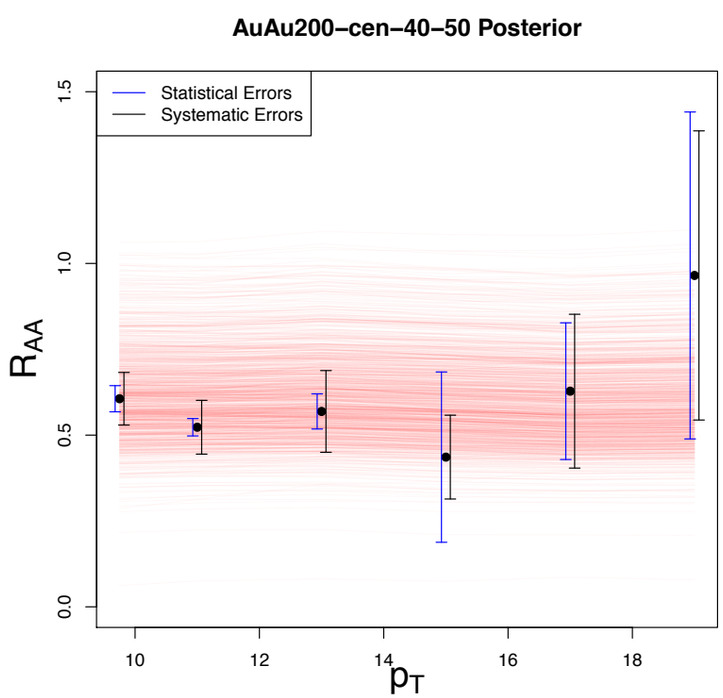
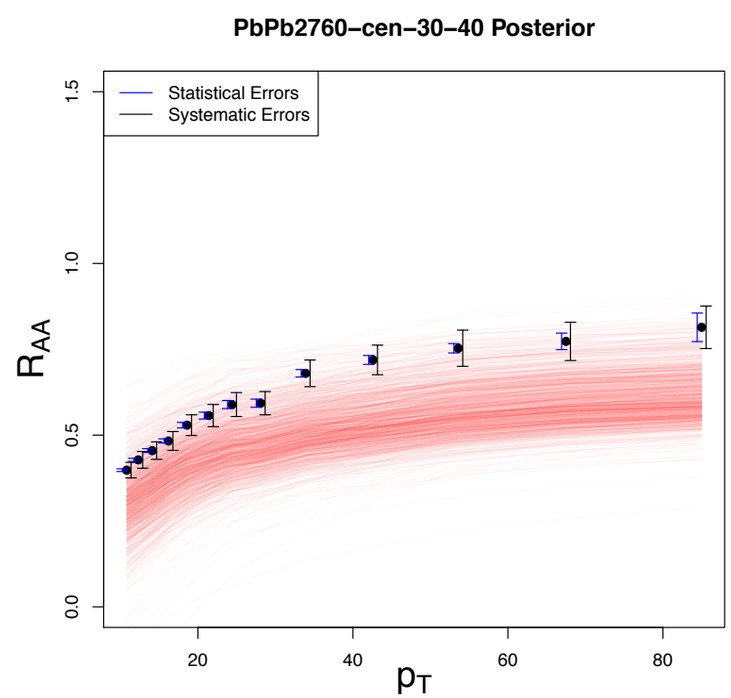
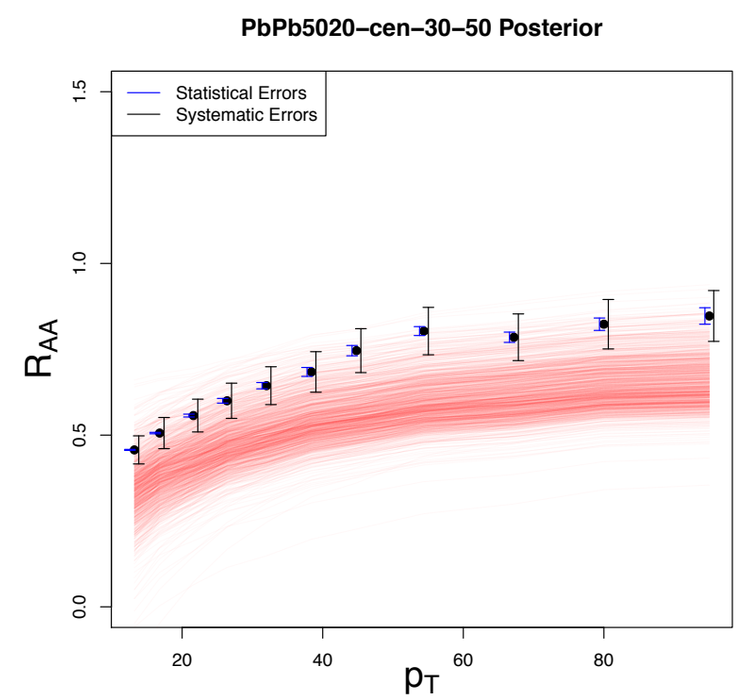
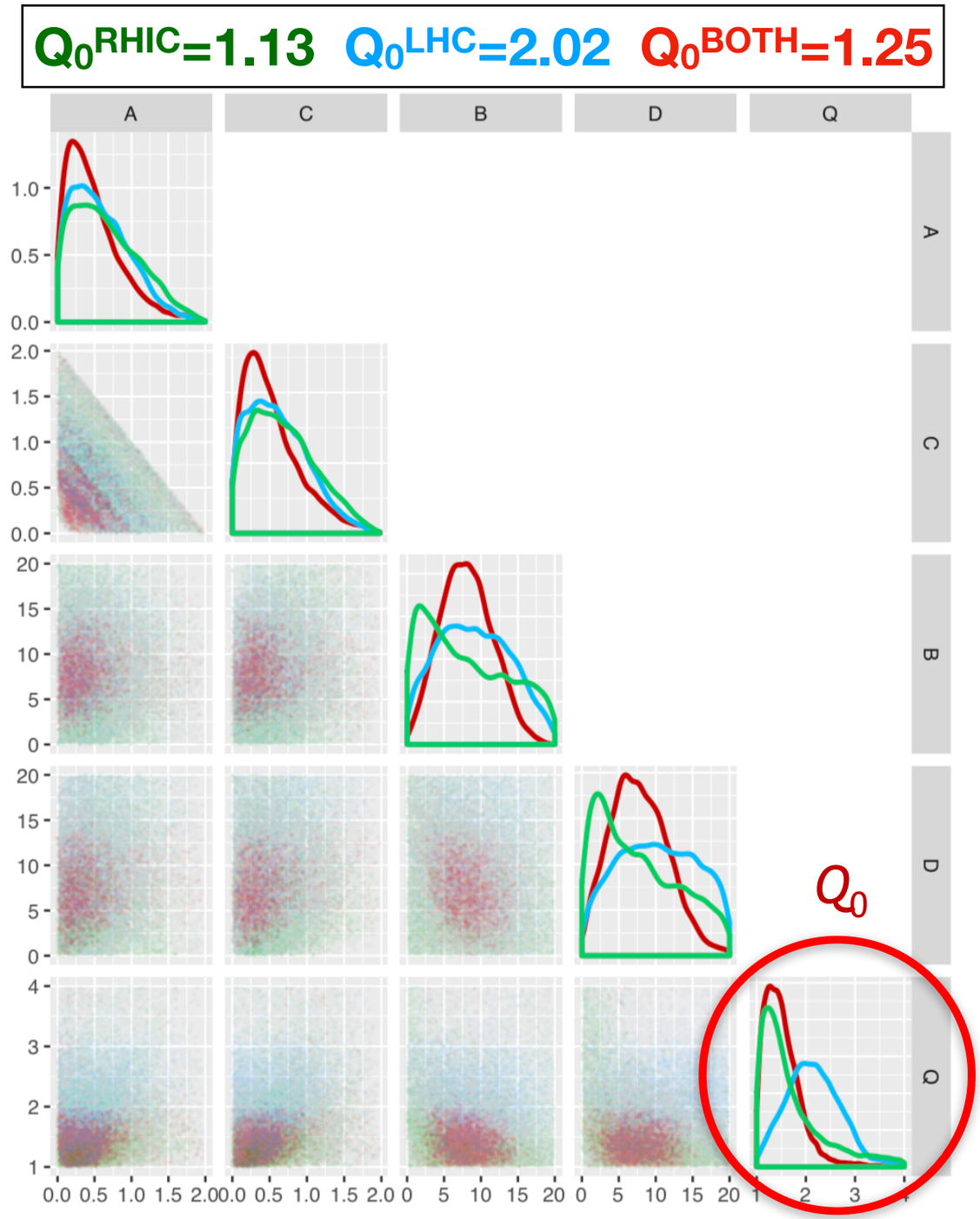
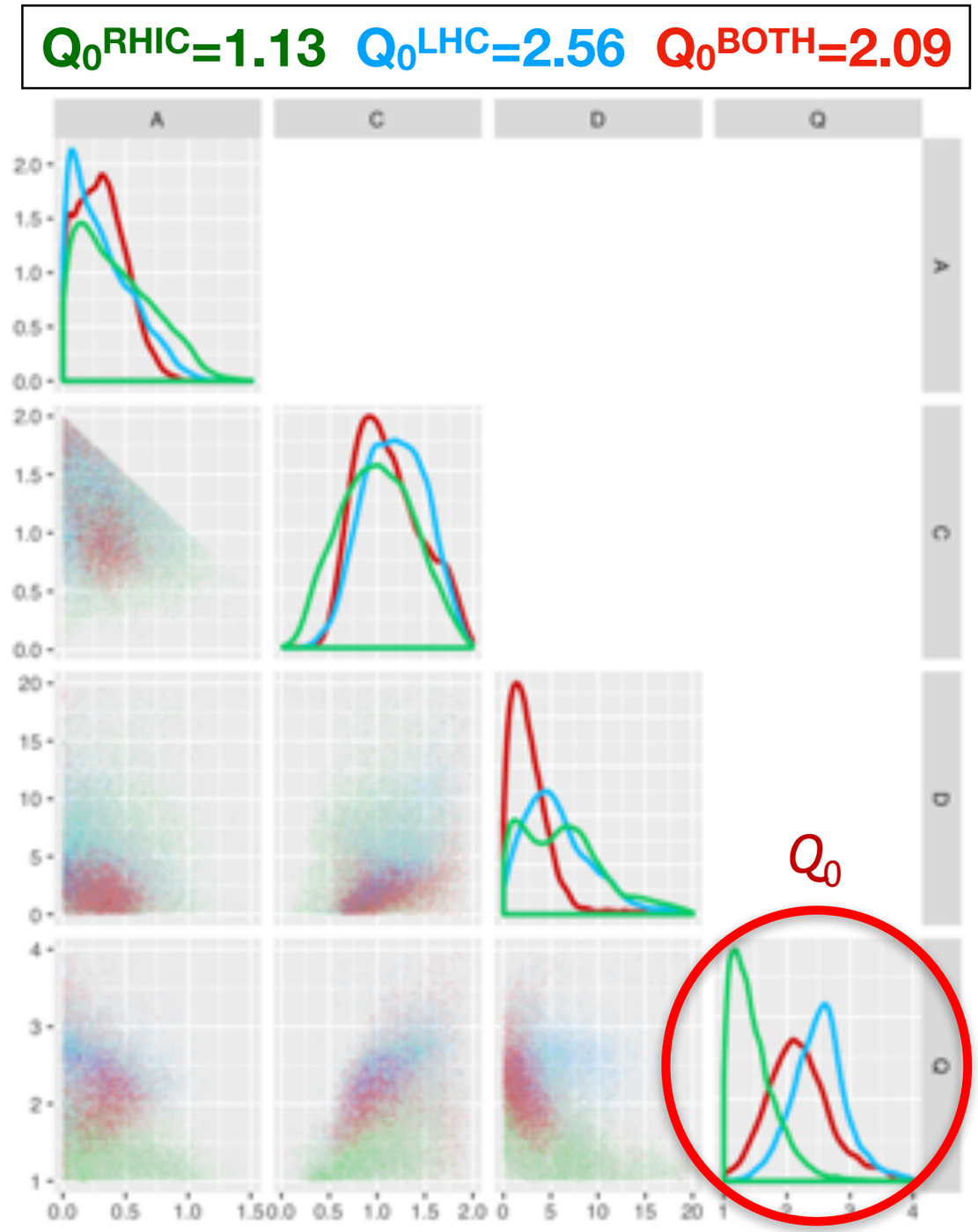






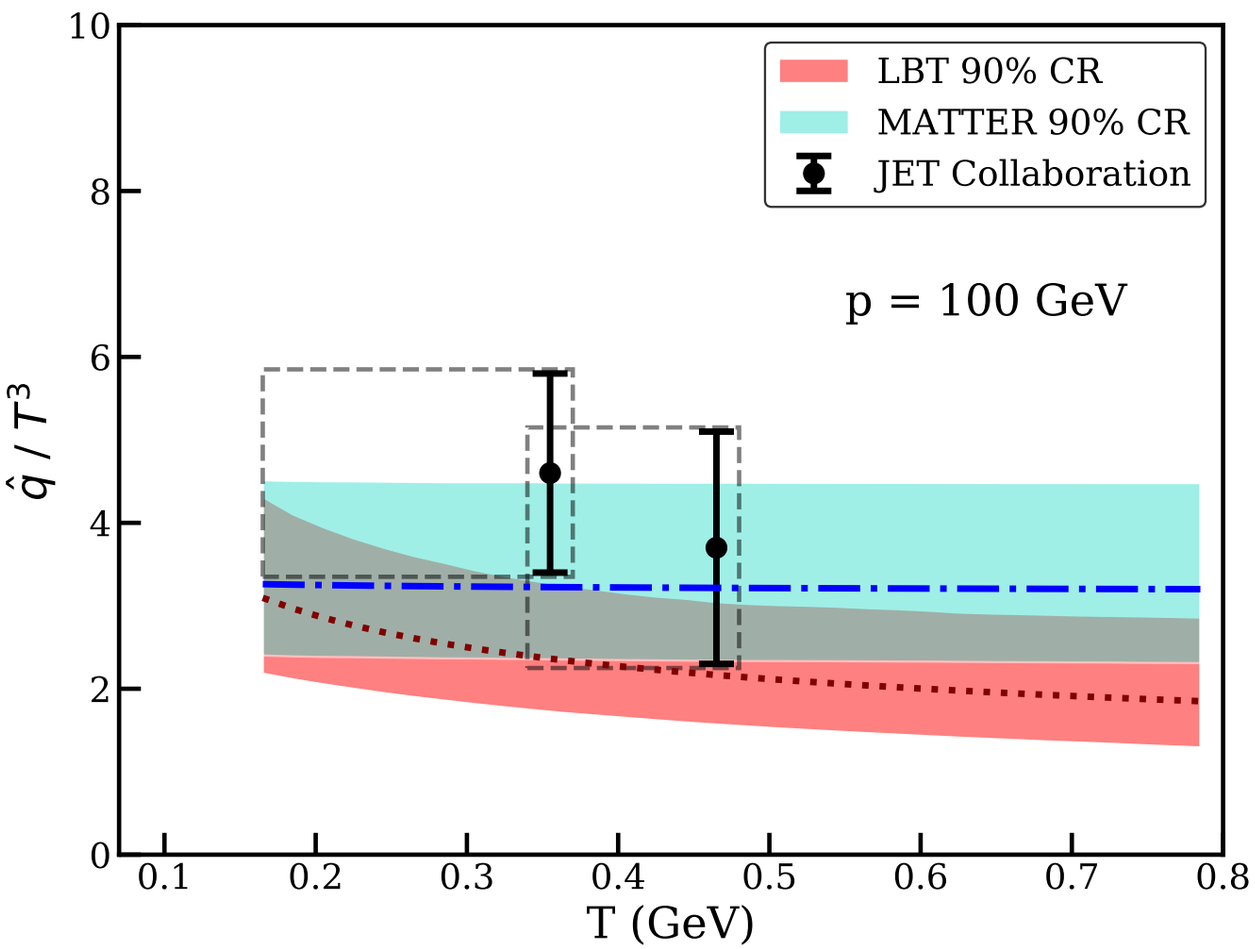
Parameter extraction comparison: MATTER+LBT

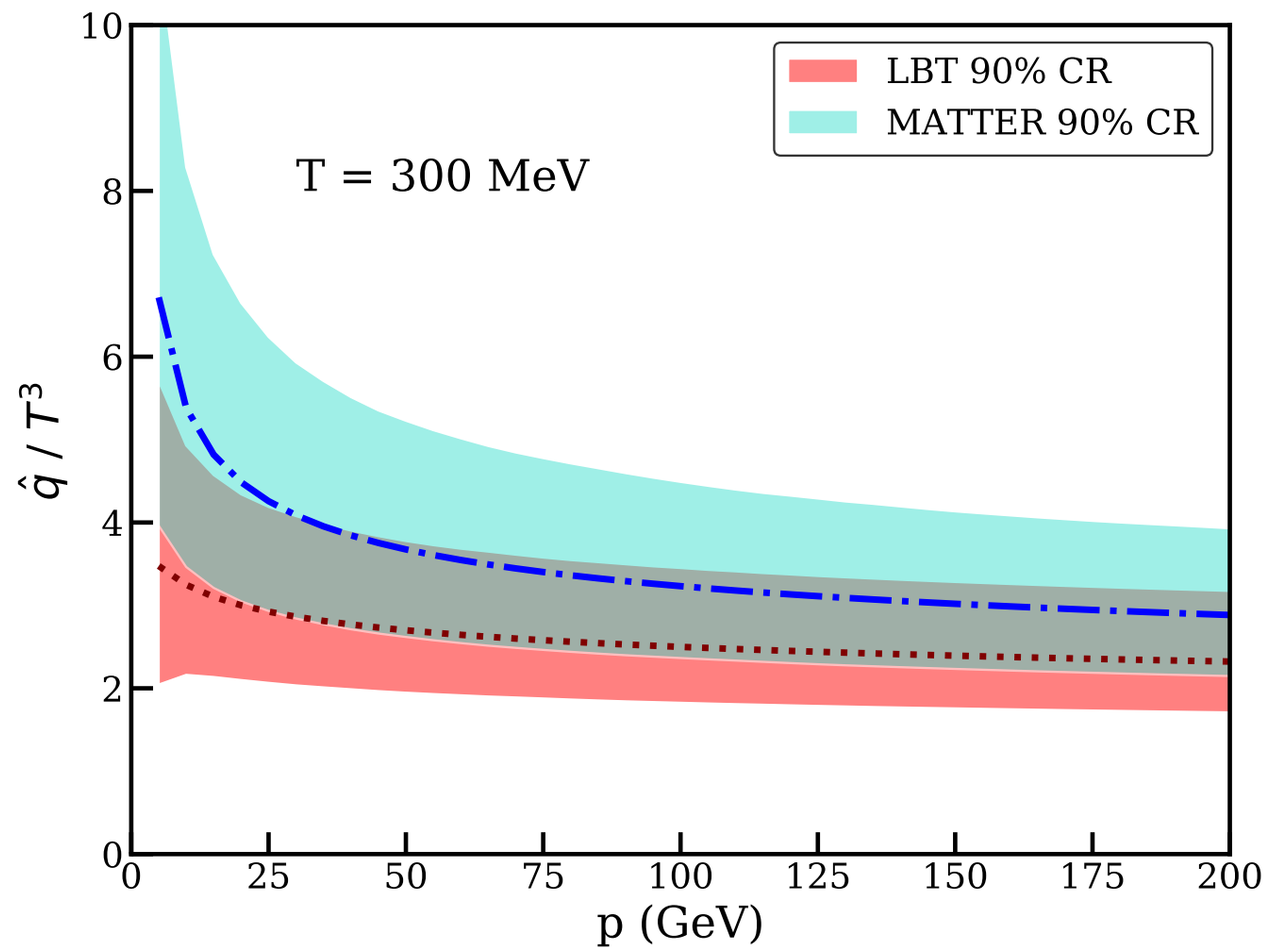




- **Alternate $\hat{q}$-parametrization yields larger Q_0, larger LHC-RHIC difference**

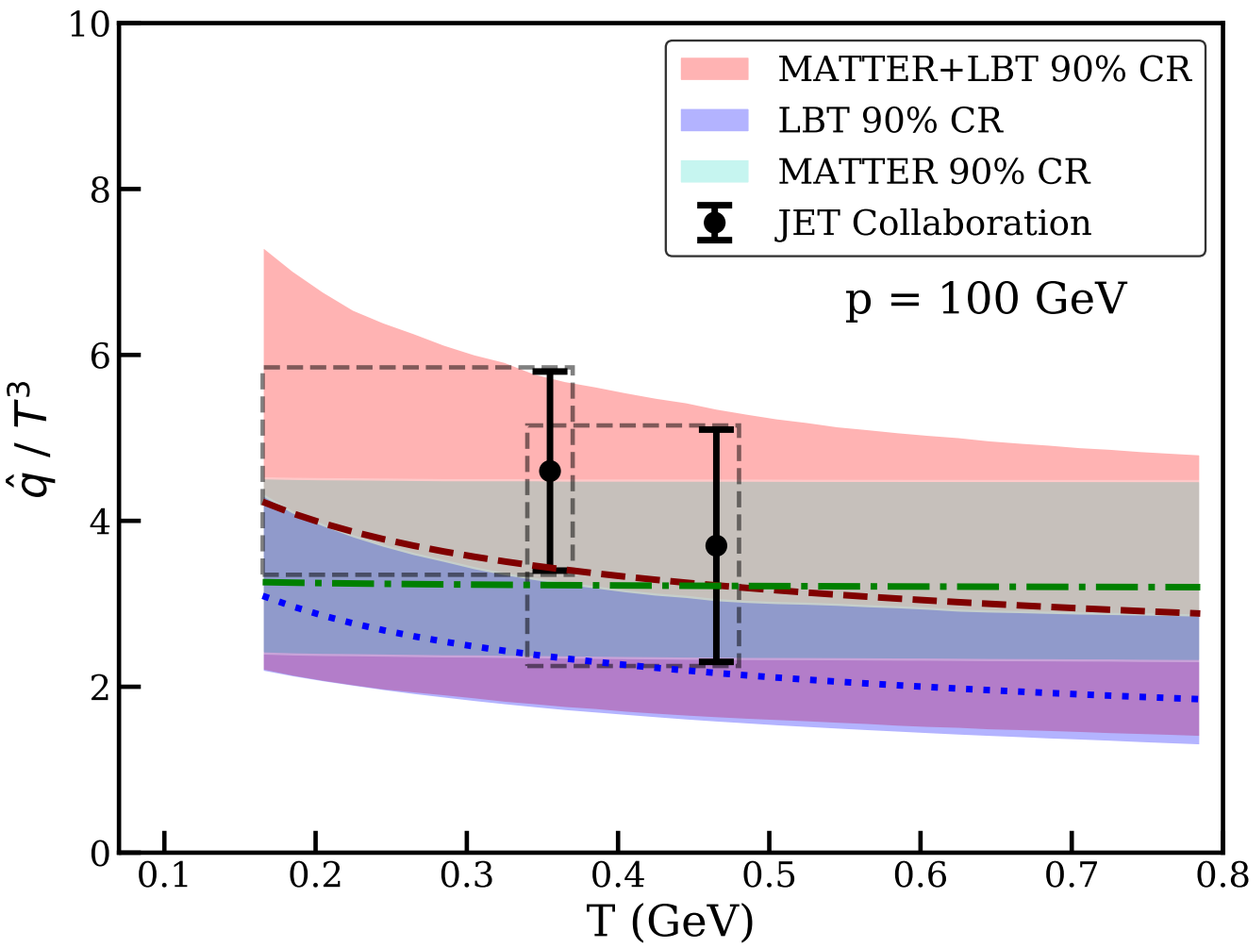
$\hat{q}$(T,p) dependence: Independent MATTER and LBT

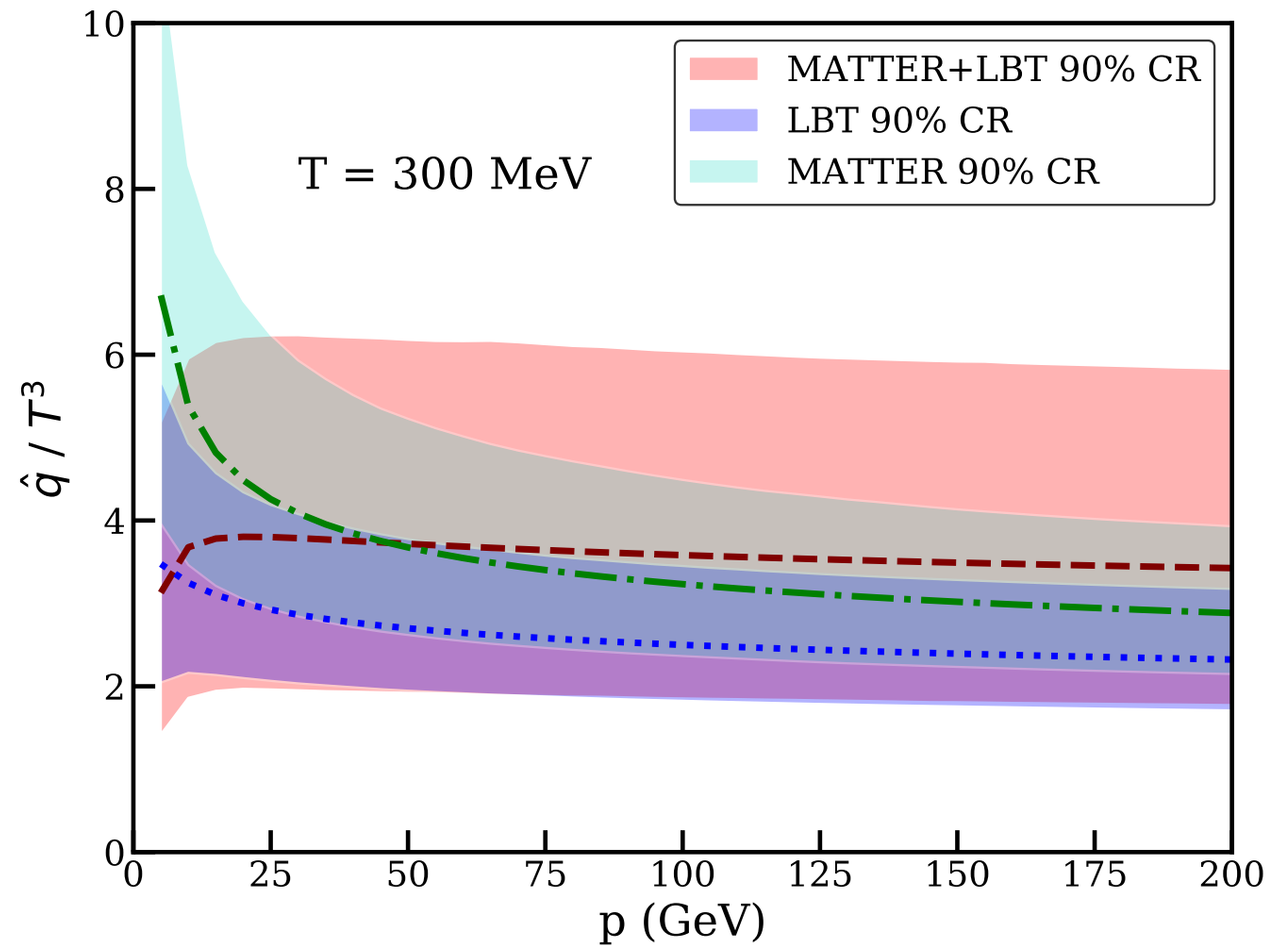




- **Independent $\hat{q}$-extraction for MATTER,LBT both consistent with JET results**

$\hat{q}$(T,p) dependence: Combined MATTER+LBT





- **Combined $\hat{q}$-extraction for MATTER+LBT consistent with JET results**

Conclusions & Outlook

- Conclusions
  - First Bayesian extraction of temperature dependent q with multi-stage model (JETSCAPE) consistent with JET Collaboration
  - Bayesian extraction of Q_0 virtuality scale (MATTER-LBT switching) is 1-2 GeV
- Outlook
  - Additional Improvements to JETSCAPE Physics Package Imminent
  - Vast expansion of data calibration sets to include jet R_{AA}, jet,hadron v_2, di-jet asymmetry, hadron correlations
  - Release of Statistics Package (JETSCAPE 2.0) scheduled for Fall 2019

Acknowledgements

special thanks

JETSCAPE

Collaboration

- National Science Foundation
- 1M core-hours

Open Science Grid

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Y. Tachibana - Jet Substructure (Wed 12:05)

C. Park - Jet/hadron R_{AA} and jet v_2 (Thu 12:05)

J. Puschke - JETSCAPE 1.0 Framework (Poster)

R. Fries - p-p physics with JETSCAPE (Poster)