Initial State Parameterizations

Scott Pratt, Michigan State University

- **Role of IS parameterizations in global analysis**
- **Some parameterizations (smooth)**
- **PHENIX analysis of pp, pA, AA**
- **Some thoughts about this…**
- **Challenges of lumpy conditions**

14-parameter analysis of soft RHIC and LHC data

S.P., E.Sangaline, P.Sorensen and H.Wang, PRL 2015

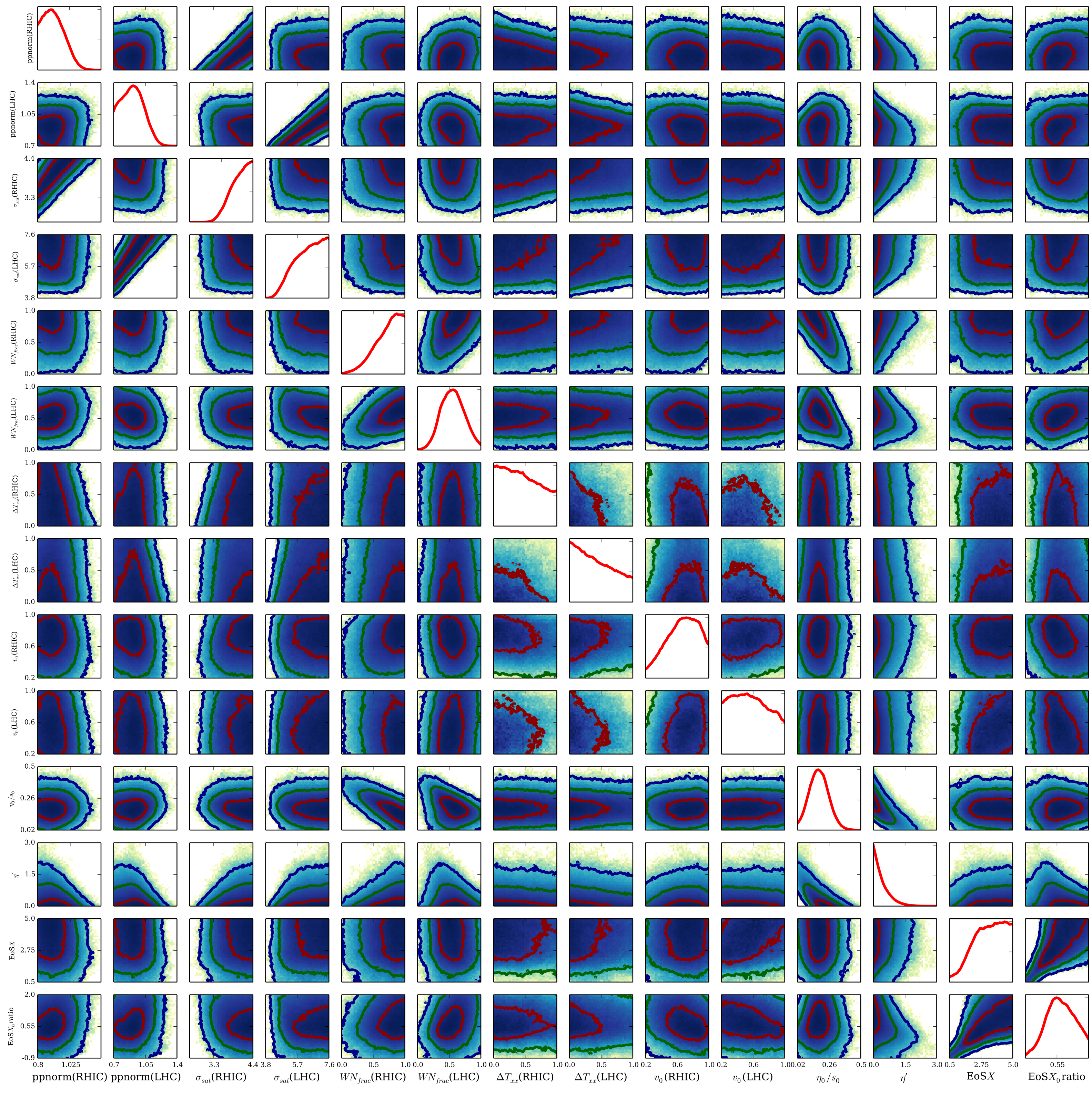
Observables:

- RHIC 100+100 GeV, Au+Au / LHC, Pb+Pb
- π-K-p spectra, v2, HBT radii
- 0-5% centrality & 20-30% centrality

MODEL:

- "standard" 2D viscous hydro+cascade
- 10 parameters describe IS
  (5 for RHIC, 5 for LHC)
- 2 parameters describe EoS
- 2 parameters describe η

Goal: Determine posterior likelihood

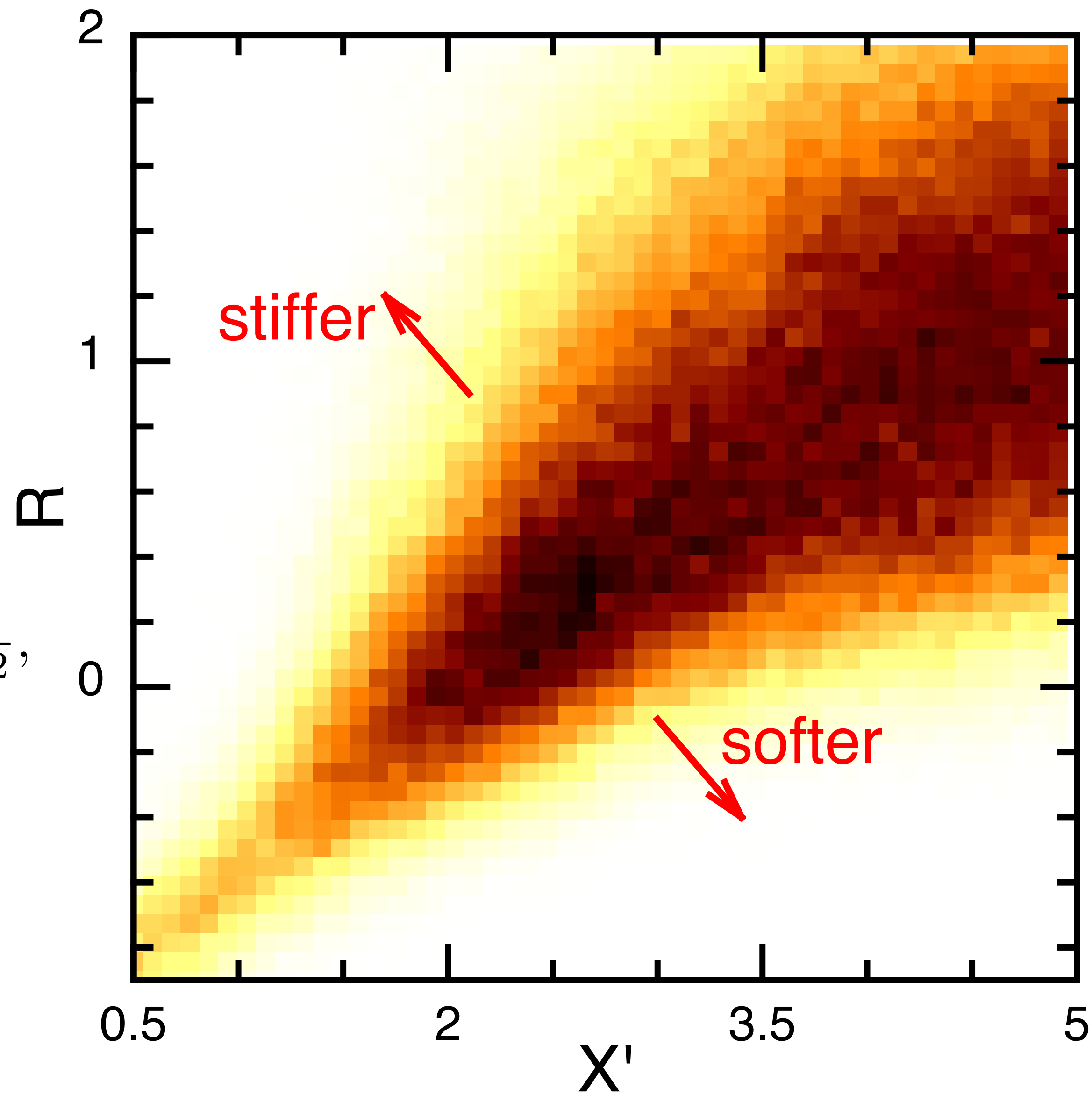


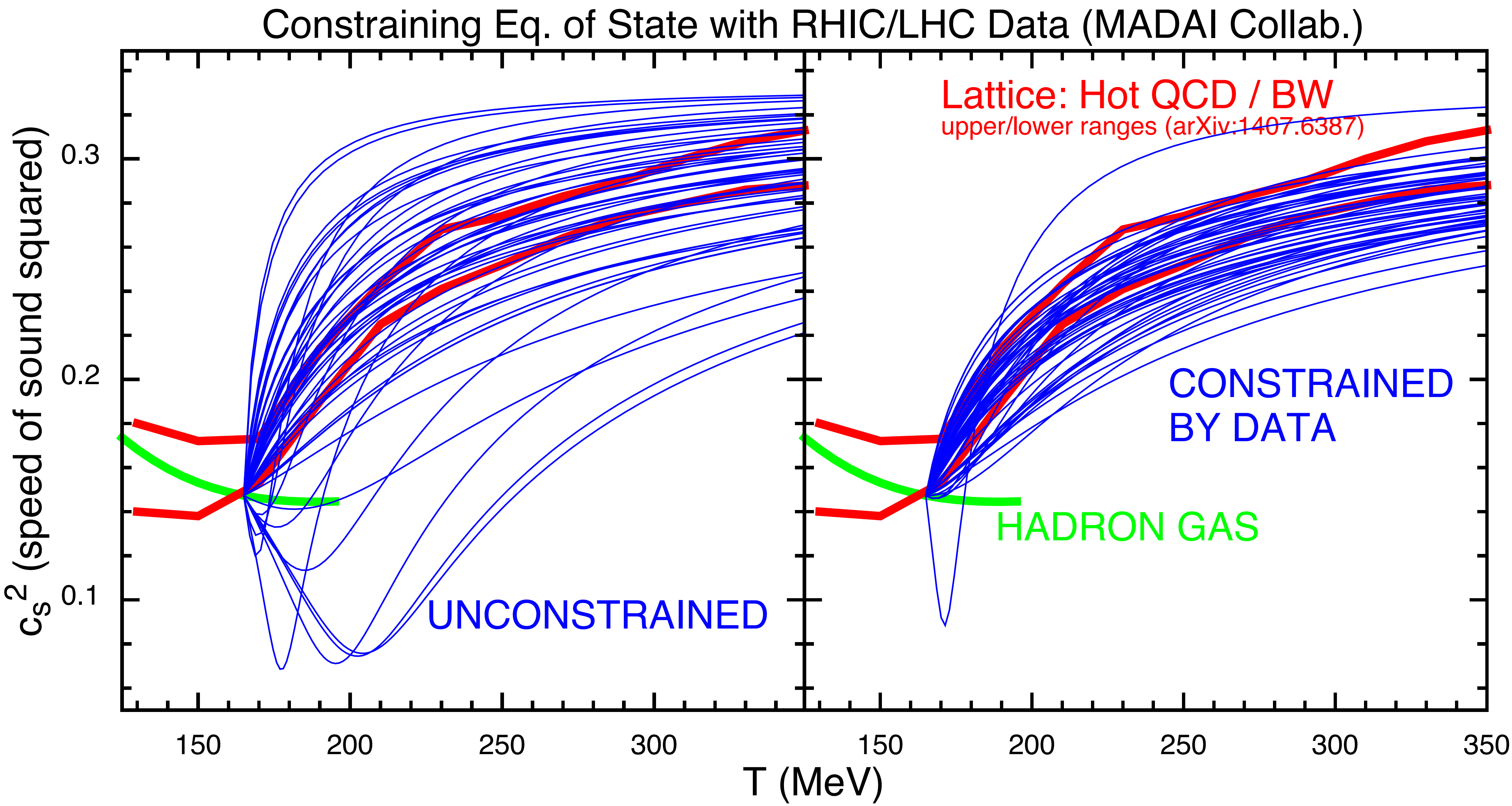
Eq. of State

$$c_s^2(\epsilon) = c_s^2(\epsilon_h) + \left(\frac{1}{3} - c_s^2(\epsilon_h)\right) \frac{X_0 x + x^2}{X_0 x + x^2 + X'^2},$$

$$X_0 = X' R c_s(\epsilon)\sqrt{12},$$

$$x \equiv \ln \epsilon/\epsilon_h$$

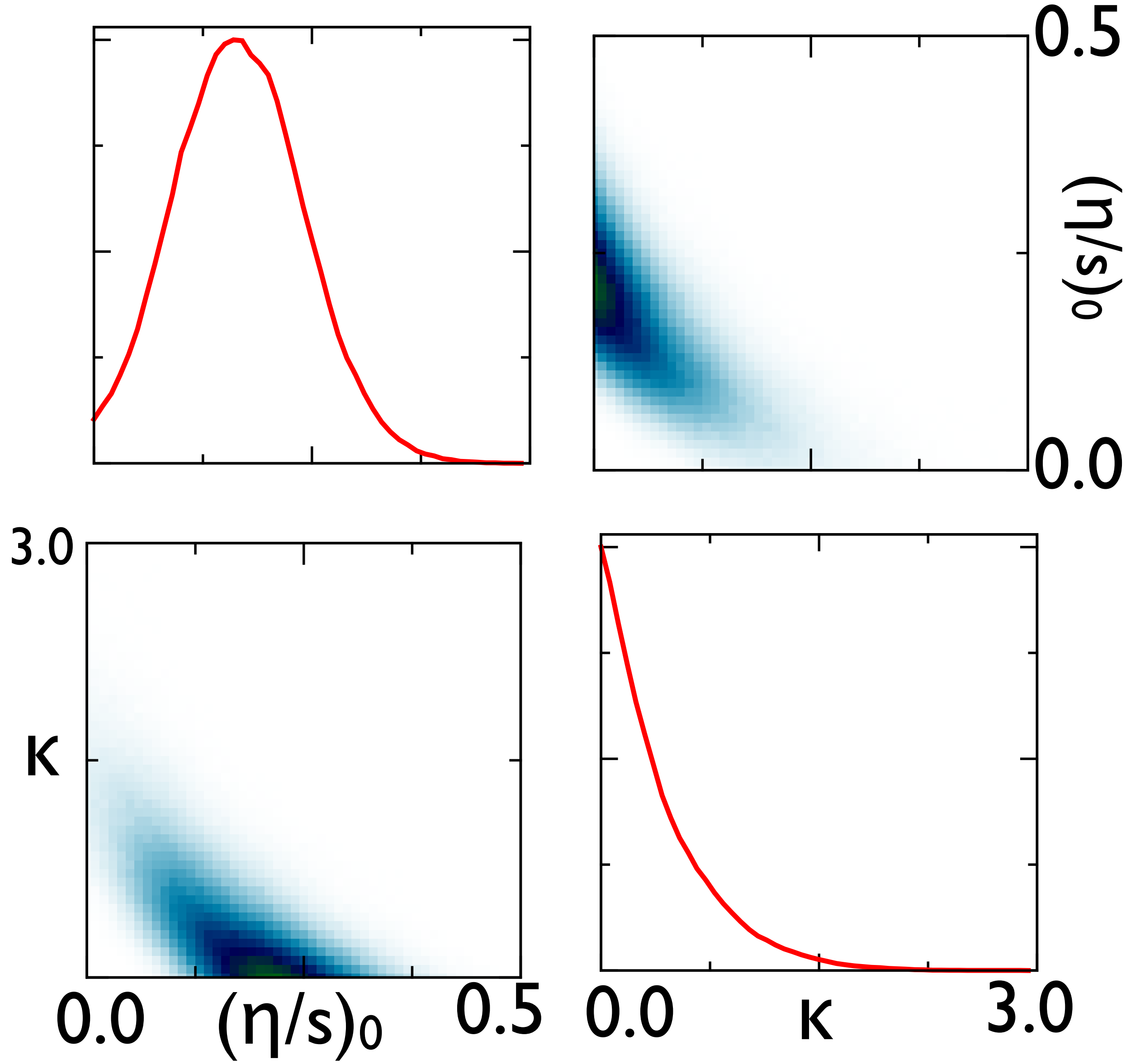




Constraining Eq. of State with RHIC/LHC Data (MADAI Collab.)
Lattice: Hot QCD / BW
upper/lower ranges (arXiv:1407.6387)
CONSTRAINED
BY DATA
HADRON GAS
UNCONSTRAINED
c_s^2 (speed of sound squared)
0.1
0.2
0.3
150
200
250
300
350
T (MeV)

Constraining η(T)

$$\eta/s = (\eta/s)_0 + \kappa \ln(T/165)$$



Constraining η(T)

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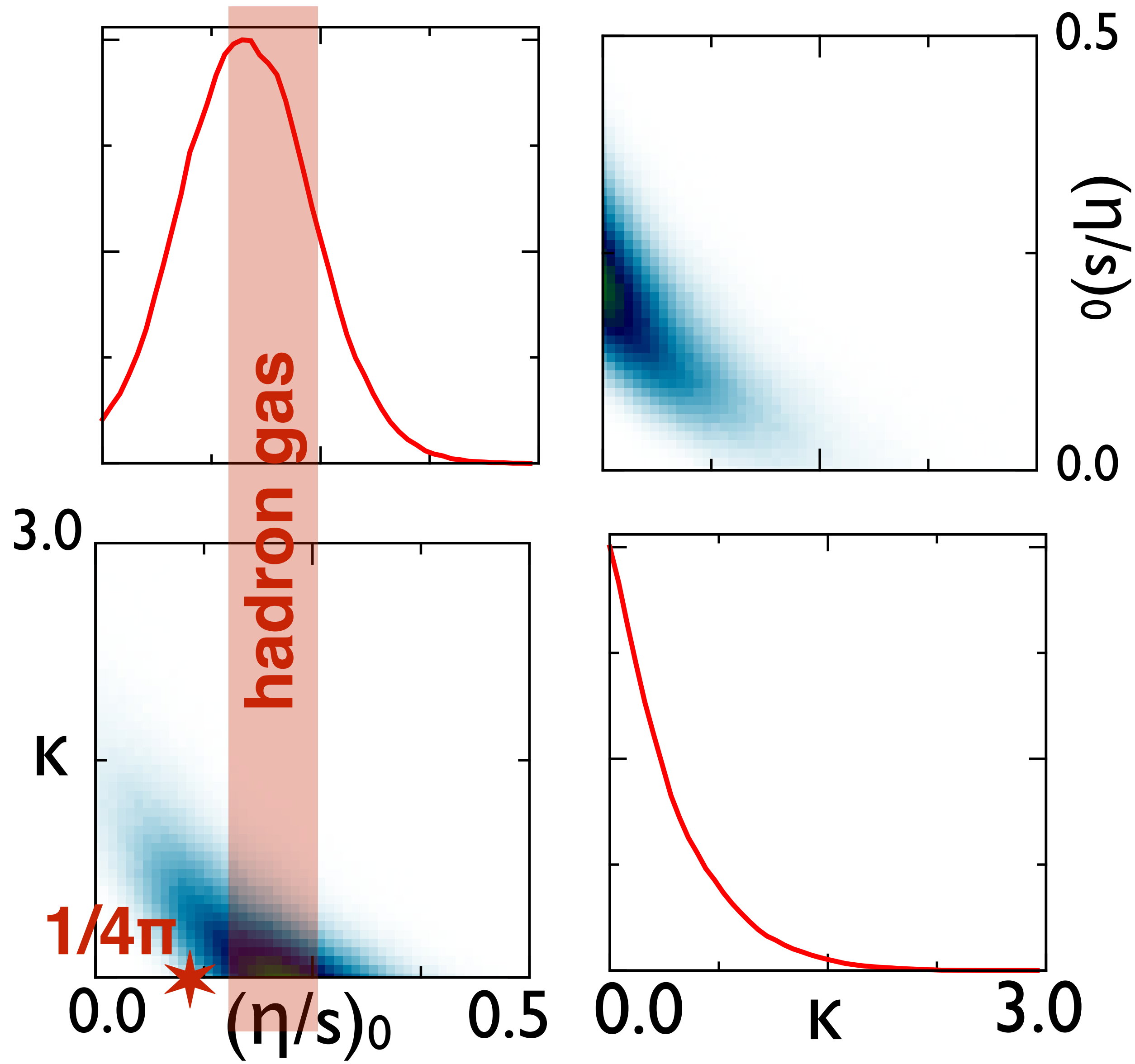
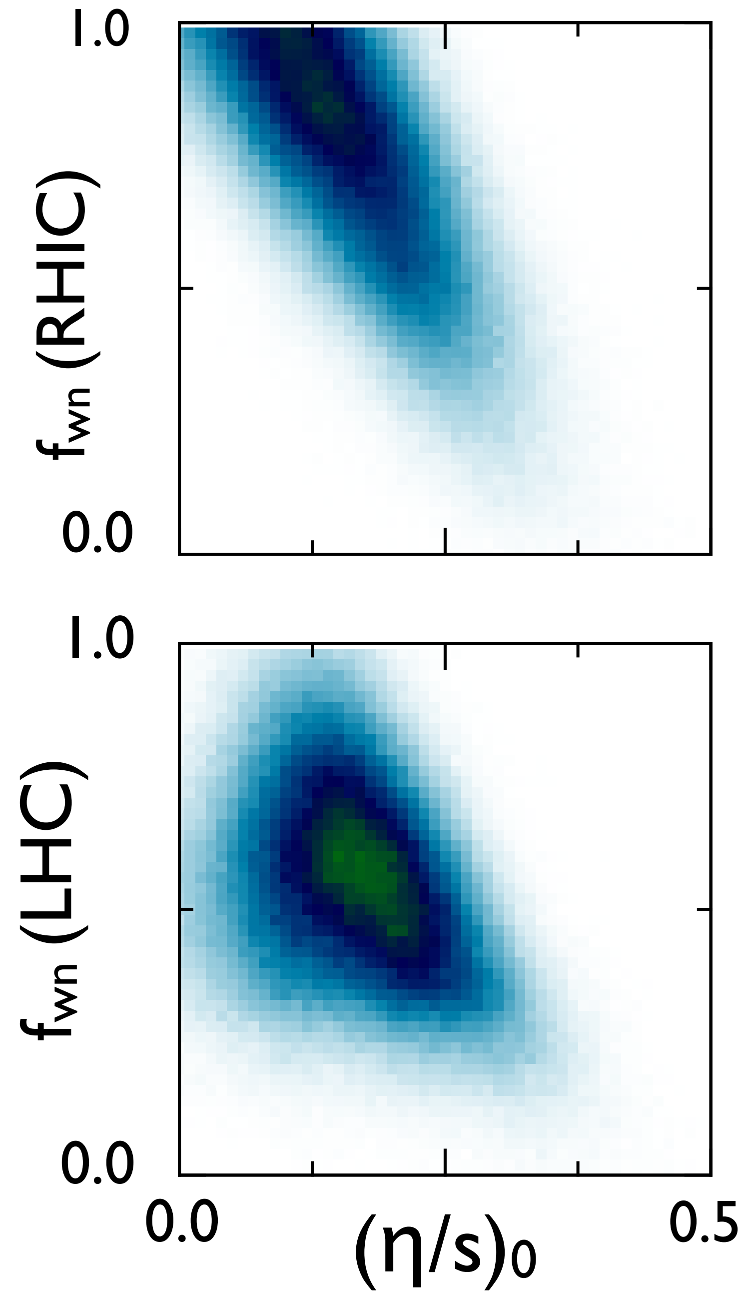
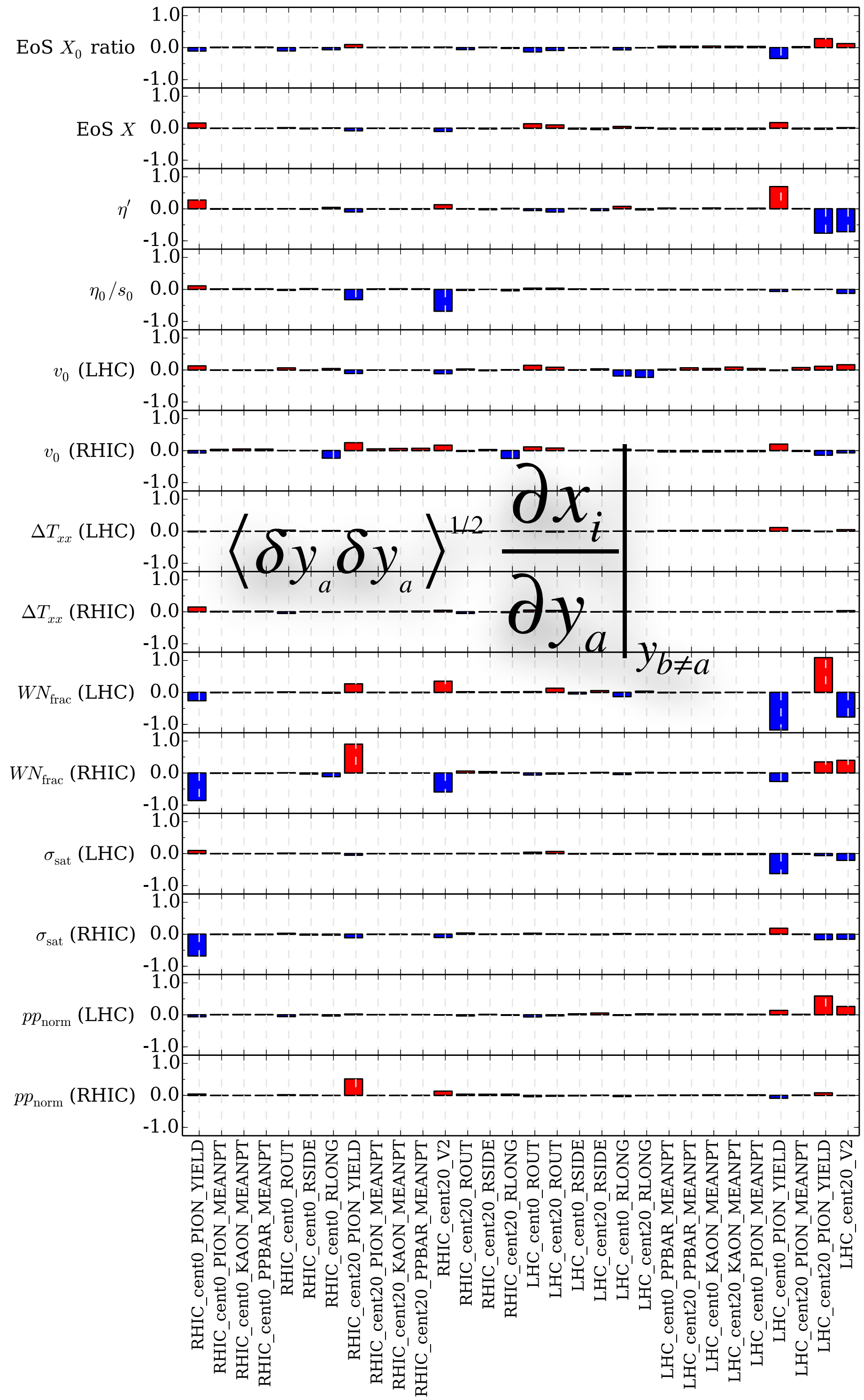


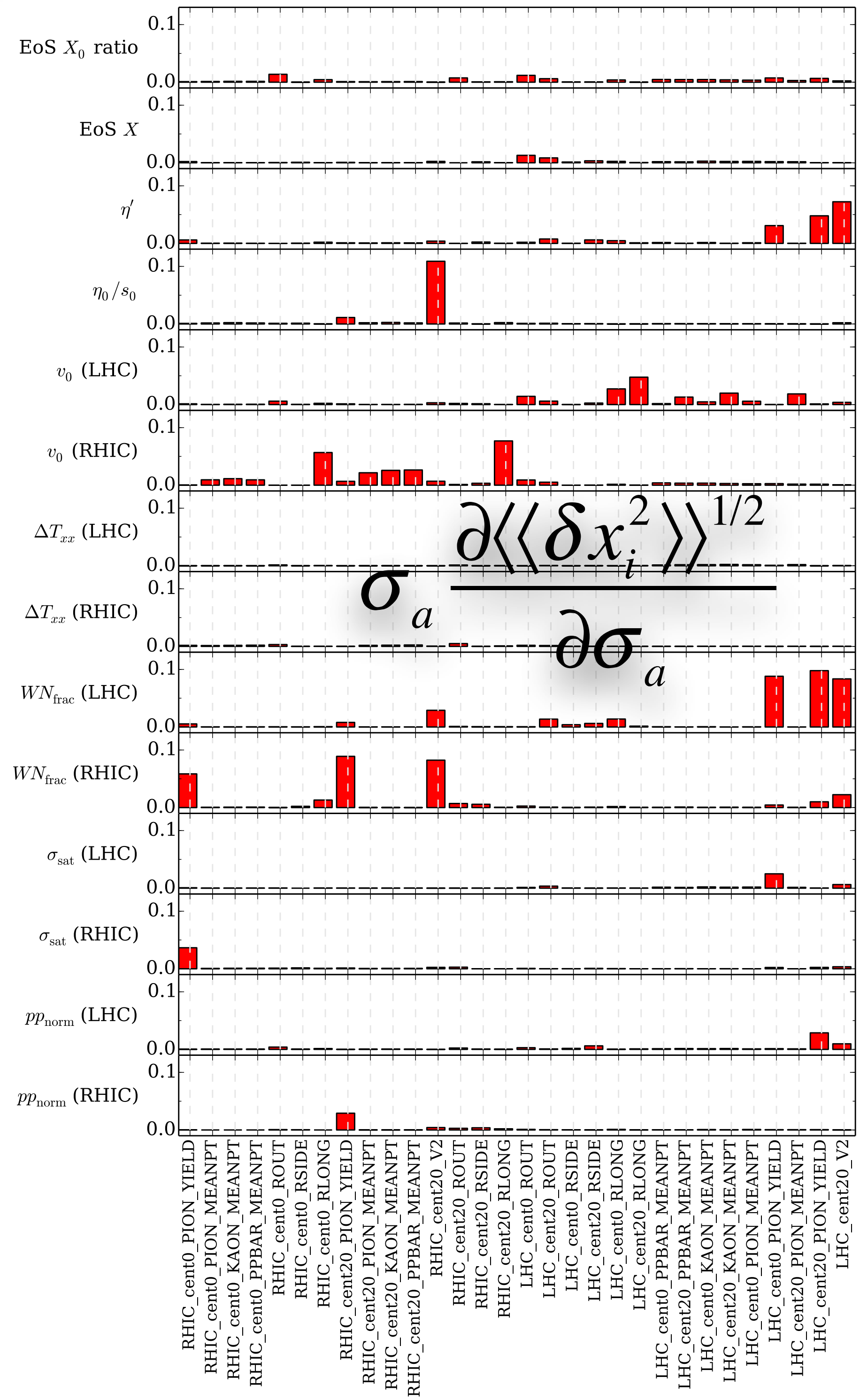
η/s vs saturation picture

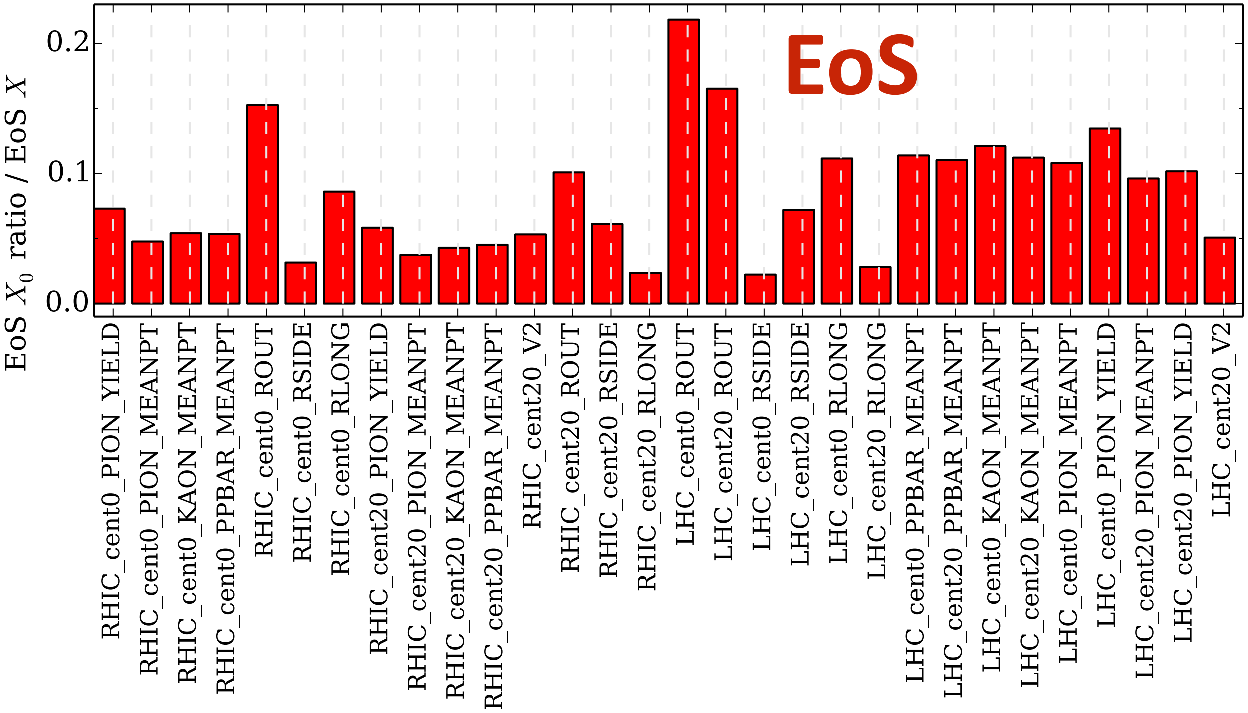


See Drescher, Dumitru, Gombeaud and Ollitrault
PRC 2007

Sensitivity Analysis

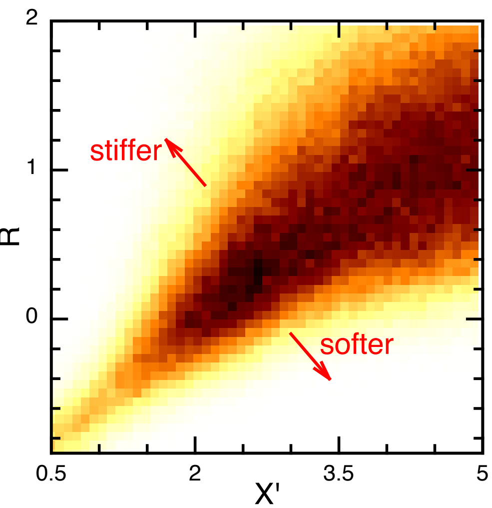


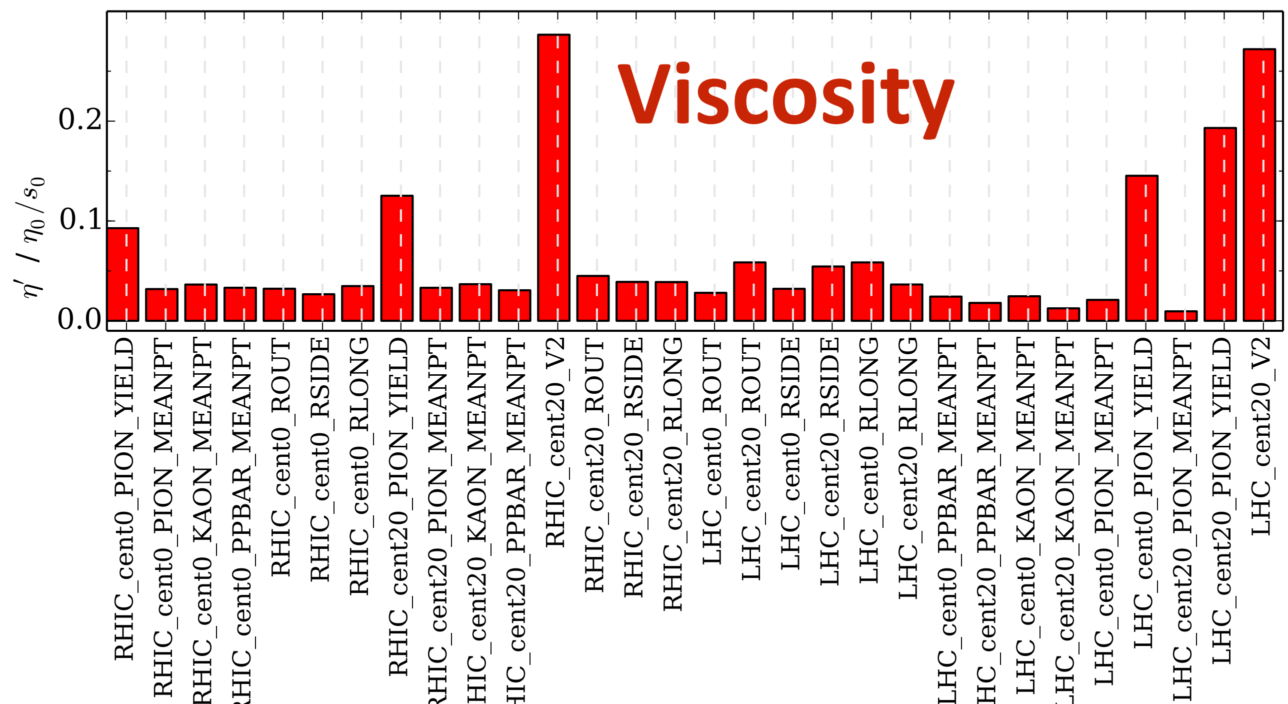




2-parameter Sensitivity

$$\frac{d}{d\sigma_y}\sqrt{\left|\begin{matrix}\langle\langle\delta x_1\delta x_1\rangle\rangle & \langle\langle\delta x_1\delta x_2\rangle\rangle \\ \langle\langle\delta x_1\delta x_2\rangle\rangle & \langle\langle\delta x_2\delta x_2\rangle\rangle\end{matrix}\right|}\,\langle\delta y\delta y\rangle^{1/2}$$





5 IS parameters

$$\epsilon(\tau = 0.8\mathrm{fm}/c) = f_{\mathrm{wn}}\epsilon_{\mathrm{wn}} + (1 - f_{\mathrm{wn}})\epsilon_{\mathrm{cgc}},$$

$$\epsilon_{\mathrm{wn}} = \epsilon_0 T_A \frac{\sigma_{\mathrm{nn}}}{2\sigma_{\mathrm{sat}}}\{1 - \exp\left(-\sigma_{\mathrm{sat}} T_B\right)\} + (A \leftrightarrow B)$$

$$\epsilon_{\mathrm{cgc}} = \epsilon_0 T_{\mathrm{min}} \frac{\sigma_{\mathrm{nn}}}{\sigma_{\mathrm{sat}}}\{1 - \exp\left(-\sigma_{\mathrm{sat}} T_{\mathrm{max}}\right)\}$$

$$T_{\mathrm{min}} \equiv \frac{T_A T_B}{T_A + T_B},$$

$$T_{\mathrm{max}} \equiv T_A + T_B,$$

$$u_\perp = \alpha\tau \frac{\partial T_{00}}{2T_{00}}$$

$$T_{zz} = \gamma P$$

- ϵ_{cgc} **similar to Dumitru et al**

Wounded Nucleon++

$$\epsilon_{\rm wn} = \epsilon_0 T_A \frac{\sigma_{NN}}{2\sigma_{\rm sat}}\left(1 - e^{-\sigma_{\rm sat} T_B}\right) + (A \leftrightarrow B)$$

- ε_0 = dE/dy at τ_0
- Roughly participant scaling
- If $\sigma_{sat}=\sigma_{NN}$ ➙ one-and-done
- For $T_A>>T_B$, proportional to T_A
- One can add rapidity dependence

$$\epsilon'_{\rm wn} = \epsilon_0 T_A \frac{\sigma_{NN}}{\sigma_{\rm sat}}\left(1 - e^{-\sigma_{\rm sat} T_B}\right) \frac{|y - y_B|}{|y_A - y_B|} + (A \leftrightarrow B)$$

P. Bozek, PRC 2010

More Forms PHENIX, ArXiv:1312.667

Wounded Nucleon (WN): Angelis et al, PLB 84

- participant scaling, one-and-done

Number of Constituent Quarks (NQP): Eremin and Voloshin PRC 2003

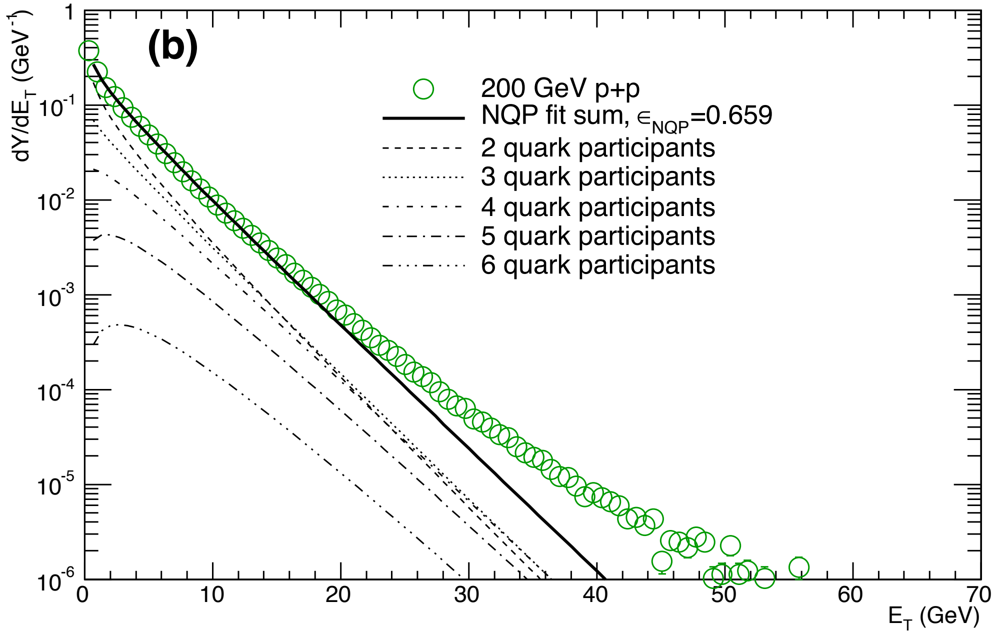
- three and done (but smaller individual sources)

Additive Quark Model (AQM): Bialas et al, PRD 82

- similar to color-string model

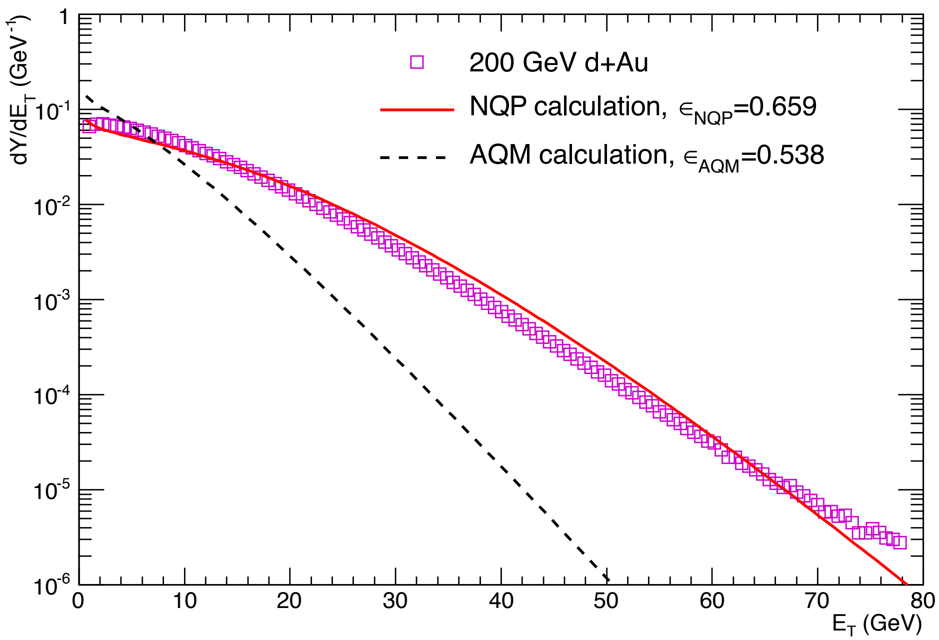
Wounded Nucleon Participant (WPNM): Ftaknik et al, PLB 87

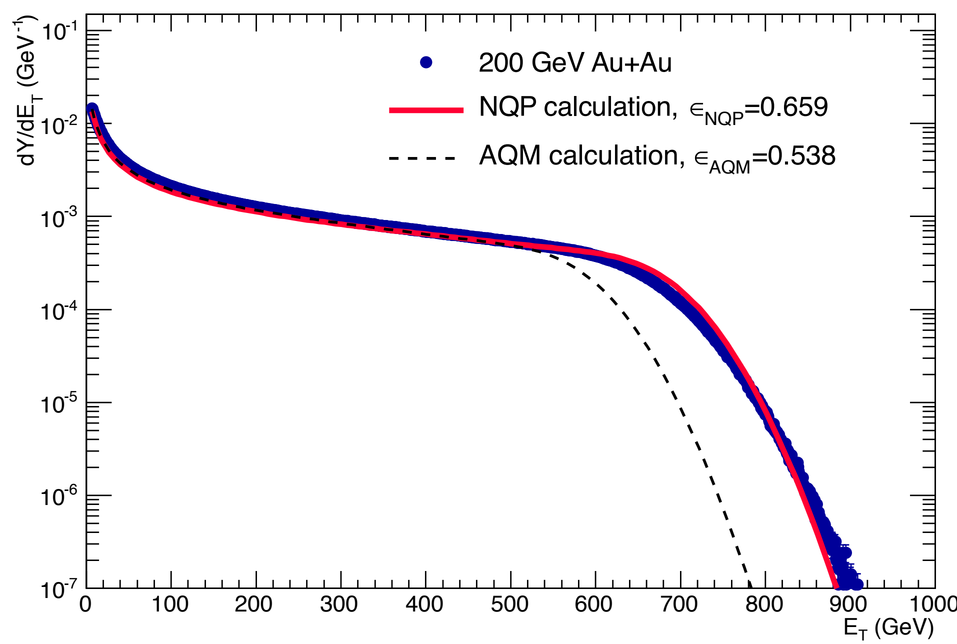
- scales *pA*



PHENIX data
(pp, dA, AA) ArXiv:1312.667

- prefers NQP
- better than N_{coll} scaling

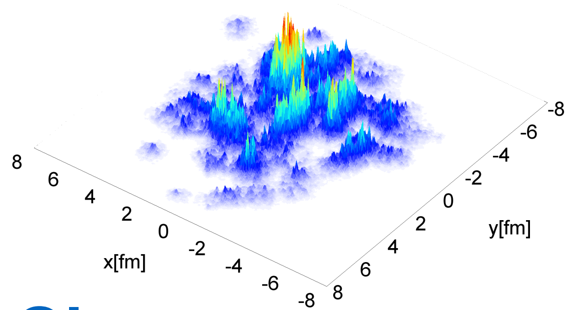




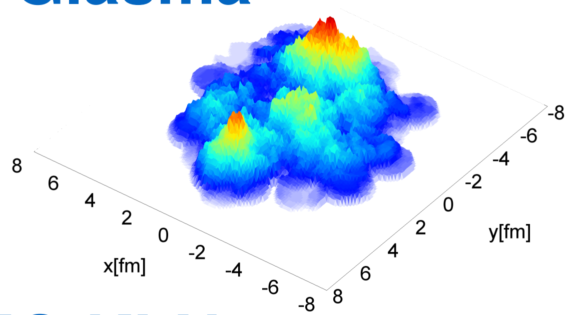
Intermediate thoughts

- All models have *saturation* in broad sense
- Must consider *pA* or *dA*
- Should also consider *dN/dy* **VS Y!**
  include full model
- LHC data?
- Haven't reconciled this with our *AA* analysis
- Entropy or energy?
- Discussion needs more physics

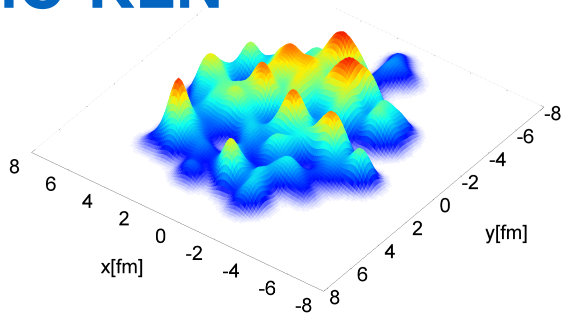
Lumpy Hydro



IP-Glasma

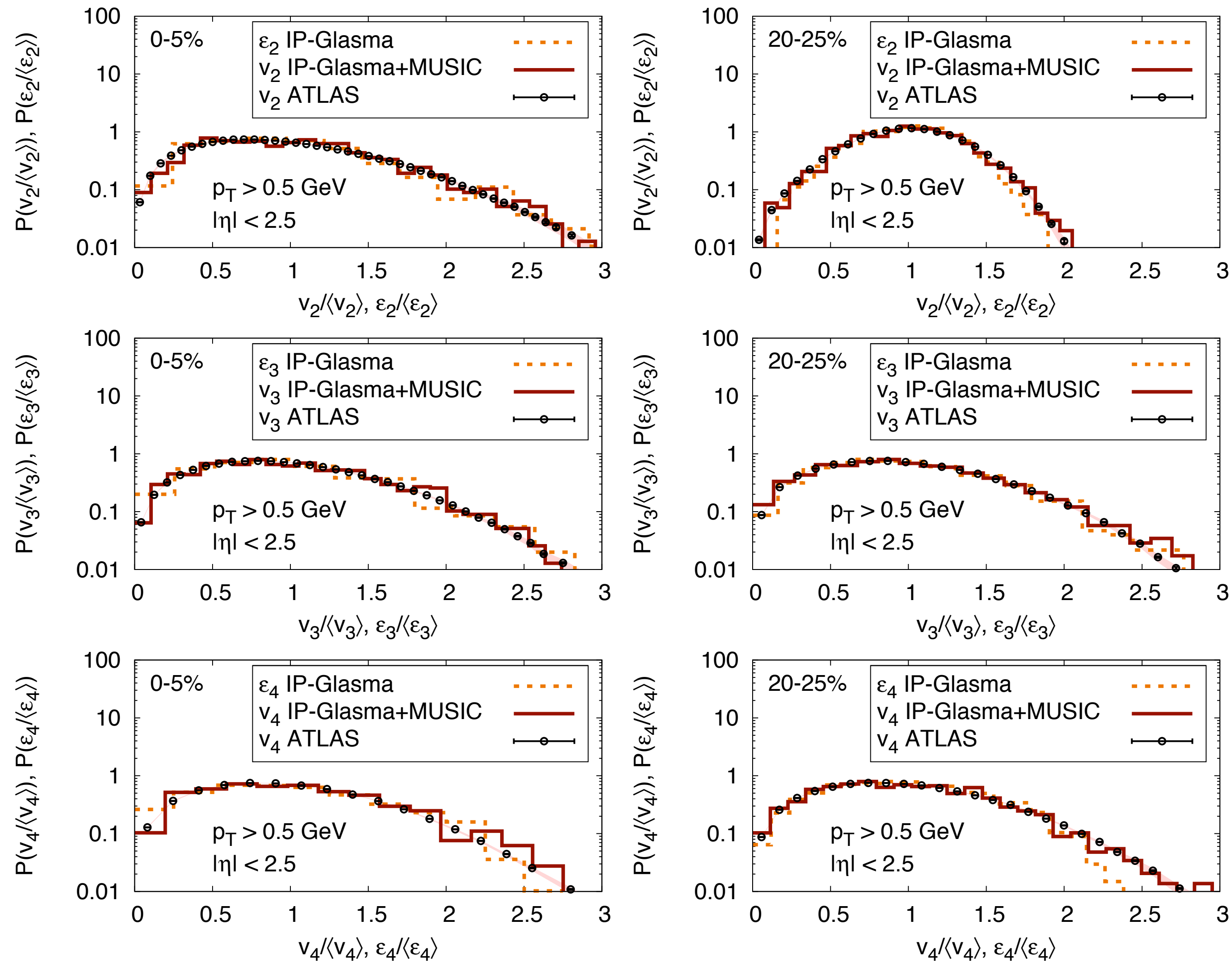


MC-KLN



MC-Glauber

IP-Glasma



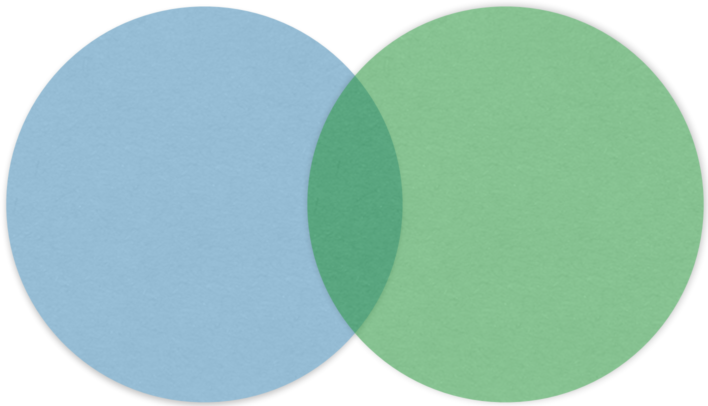
Gale, Jeon, Schenke, Tribidy & Venugopalan, 2014

Something's right! — But what?

FOOD FOR THOUGHT

- **Where does the energy/entropy go?**
- **How do you add initial flow?**
- **Nucleon-by-nucleon saturation?**
- Rematching pp, pA, AA
- Adding rapidity dependence
- **Can form be related to physics?**

Where does the energy/entropy go?



Should you emit from

a. overlap?
b. total area of participant?
c. saturation scale?
d. partonic participants?

Note:

area of nucleon overlap = 120 mb (b_{max}≈2 fm)

σ_{pp} at RHIC = 42 mb

What about initial flow?

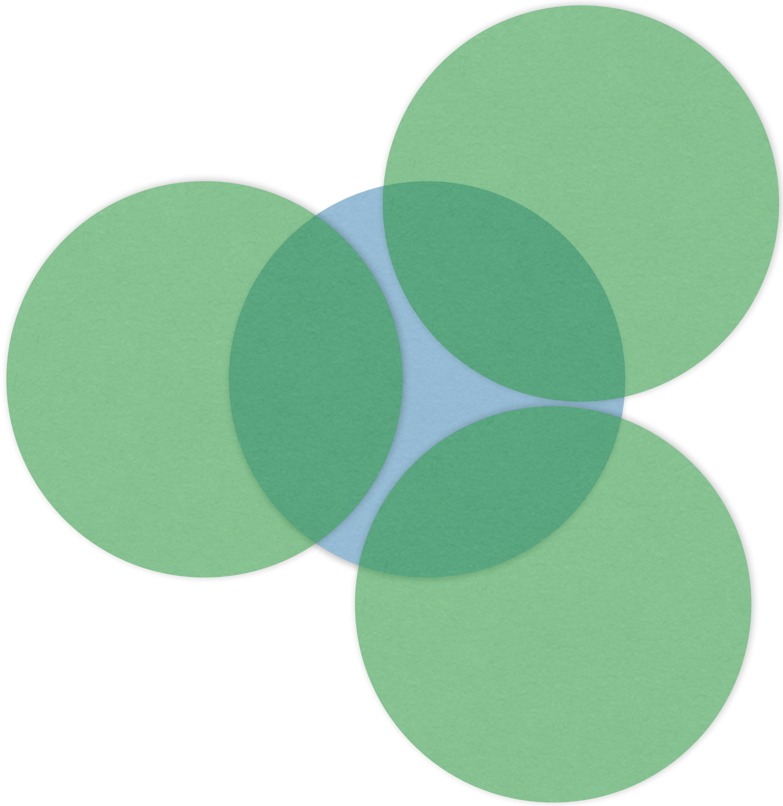
$$\frac{T_{0i}}{T_{00}} = -\frac{\partial_i T_{00}}{2T_{00}} t$$

S.P. and J.Vredevoogd, PRC 2009

- same “flow” for ideal hydro, Y.M. eq.s, free streaming…
- small times
- Bjorken
- traceless SE
- T_{zz}/ε independent of x,y

For small features, acceleration is LARGE !

Nucleon-by-Nucleon Saturation



What if blue nucleon can only produce one flux tube?
Should algorithm only depend on local T_a, T_b?

Can form be related to physics?

Important for:

- insight
- connecting to real models (e.g. IP Glasma)
- discard unphysical possibilities