Extracting Bulk QGP Properties from Experiment

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MaDAI Collaboration
Models and Data Analysis Initiative

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Will be funded by NSF CDI program (Cyber-Enabled Discovery Initiative)

Lessons from RHIC (bulk properties)

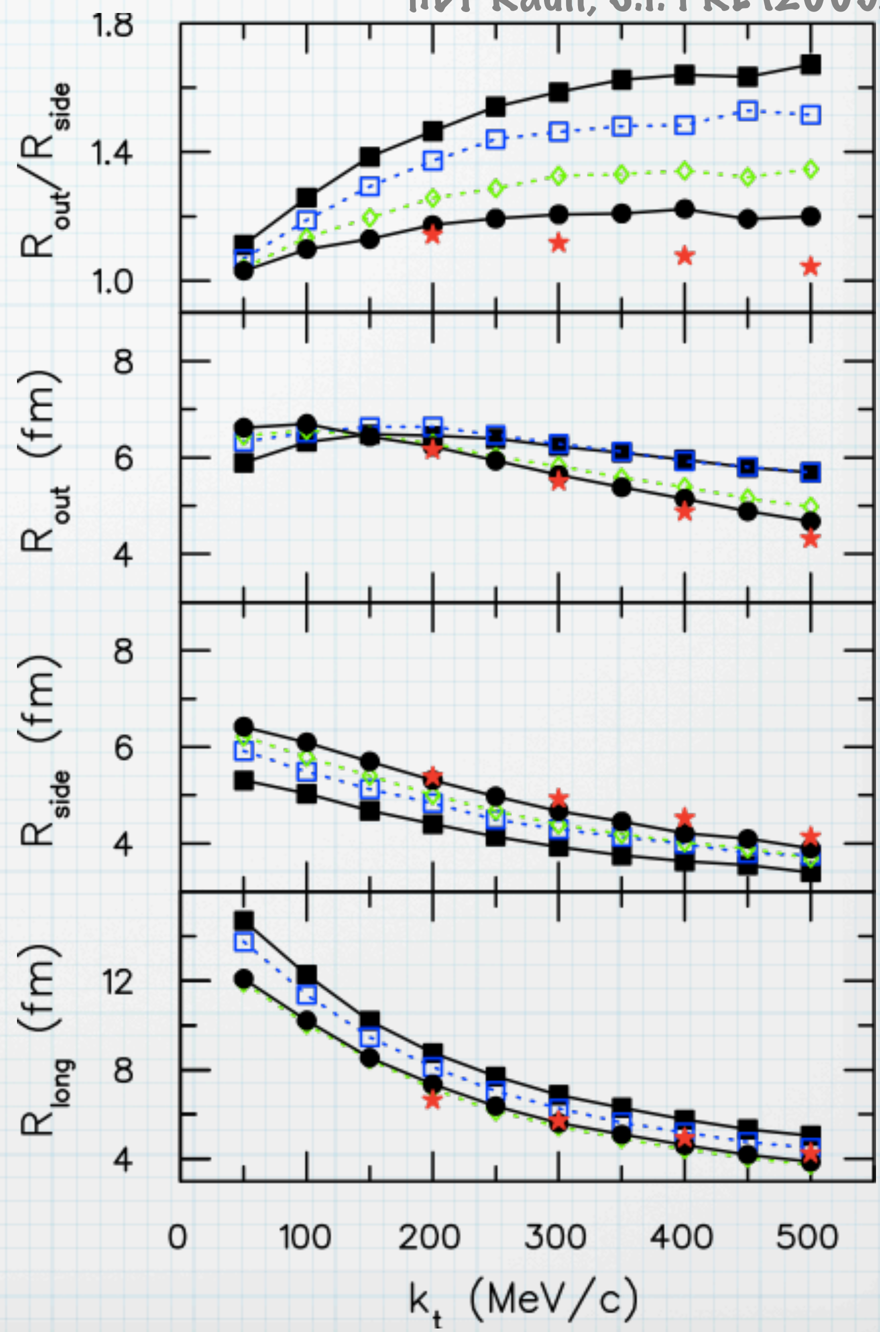
- Matter is rather stiff:
  (no large latent heat,
  but softer than π gas)

- Early flow seems important:
  (otherwise difficult to fit HBT)

- Viscosity is low:
  (mostly from elliptic flow)

$$\frac{\eta}{s} \approx \left(\frac{1}{2} \text{ to } 3\right) \times \frac{\hbar}{4\pi}$$

HBT Radii, S.P. PRL (2009)

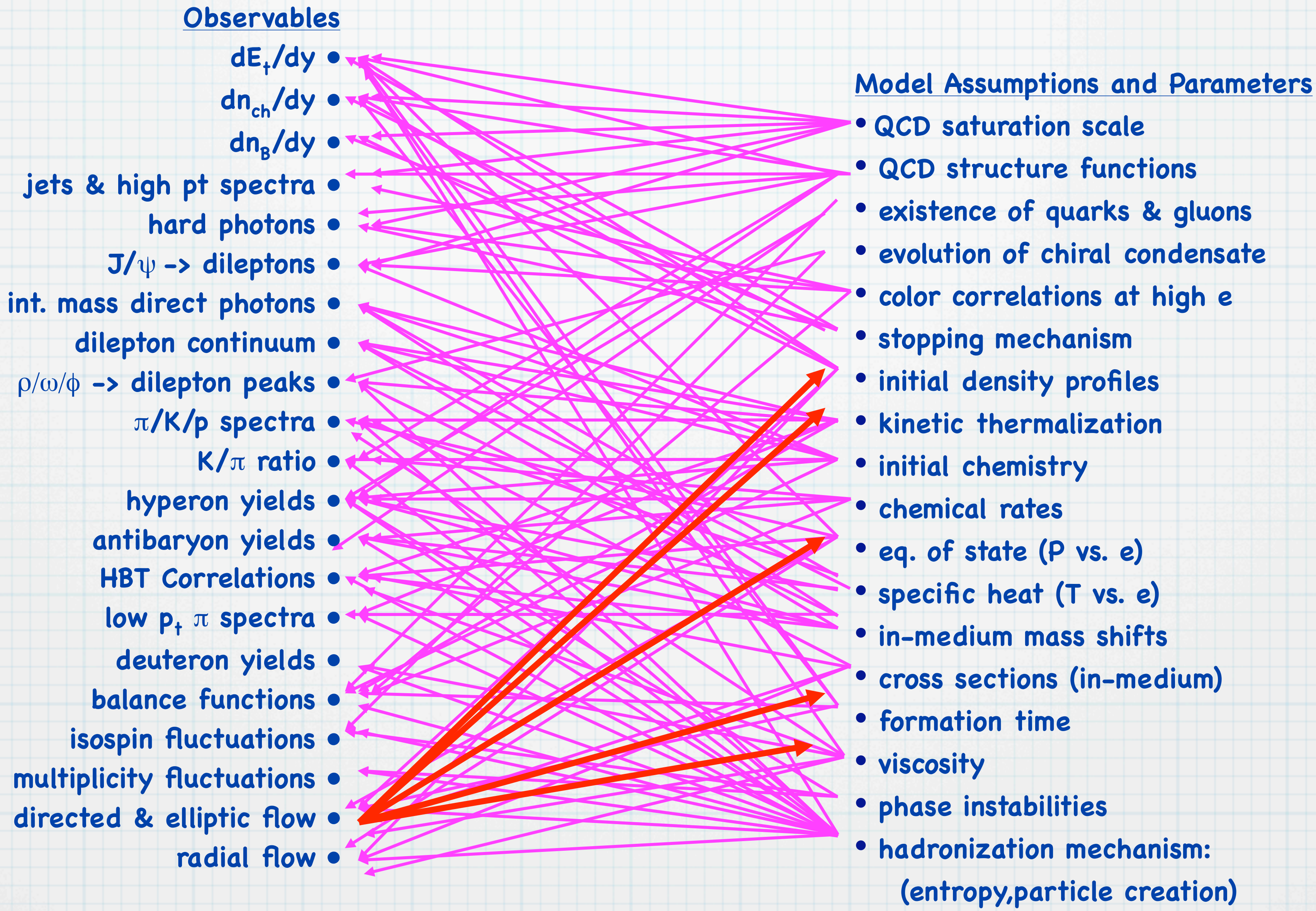


... but nothing is quantitative or rigorous

* EOS (min c_s^2, width of soft region, max c_s^2)
* ??? < η /s < ???   (energy dependence?)
* ε for τ < 0.5 fm/c uncertain by factor of 2

1. Can parameters be stated rigorously? (with uncertainties)
2. Can important links be identified? (e.g. be viscosity and v2)
3. Can prospects for future measurements be quantified?

RHIC Analysis Challenge



Individual elements cannot be isolated!!
complex, non-linear network

Uncertainties and Parameters

Initial State	6	Energy density, profile shape, rapidity width, pressure, anisotropy of T_{ij}, quark/gluon content
Hadronic Boltzmann	2-4	Mass changes
Eq. of State / Viscosity	3-8	Might be constrained by lattice, hadron gas
Chemical	3-6	Quark density, relaxation rates, hadronic scattering reduction
Jet Quenching	2-4	Dissipation rates
Systematic Experimental	?	Efficiencies, calibrations...

≈ 30 parameters

Some are unimportant

Some combinations are unimportant


Turn ALL the knobs!!!!
Input
Dyn
EQ filts
Aux
Pan
Ins in
Dyn in
EQ in
filts in
Pan to:
Func Select
Copy
Paste
cfg
LA1
MY1
PanF

Bayesian Analysis

WIKIPEDIA: Bayesian inference is statistical inference in which evidence or observations are used to update or to newly infer the probability that a hypothesis may be true. The name "Bayesian" comes from the frequent use of Bayes' theorem in the inference process.

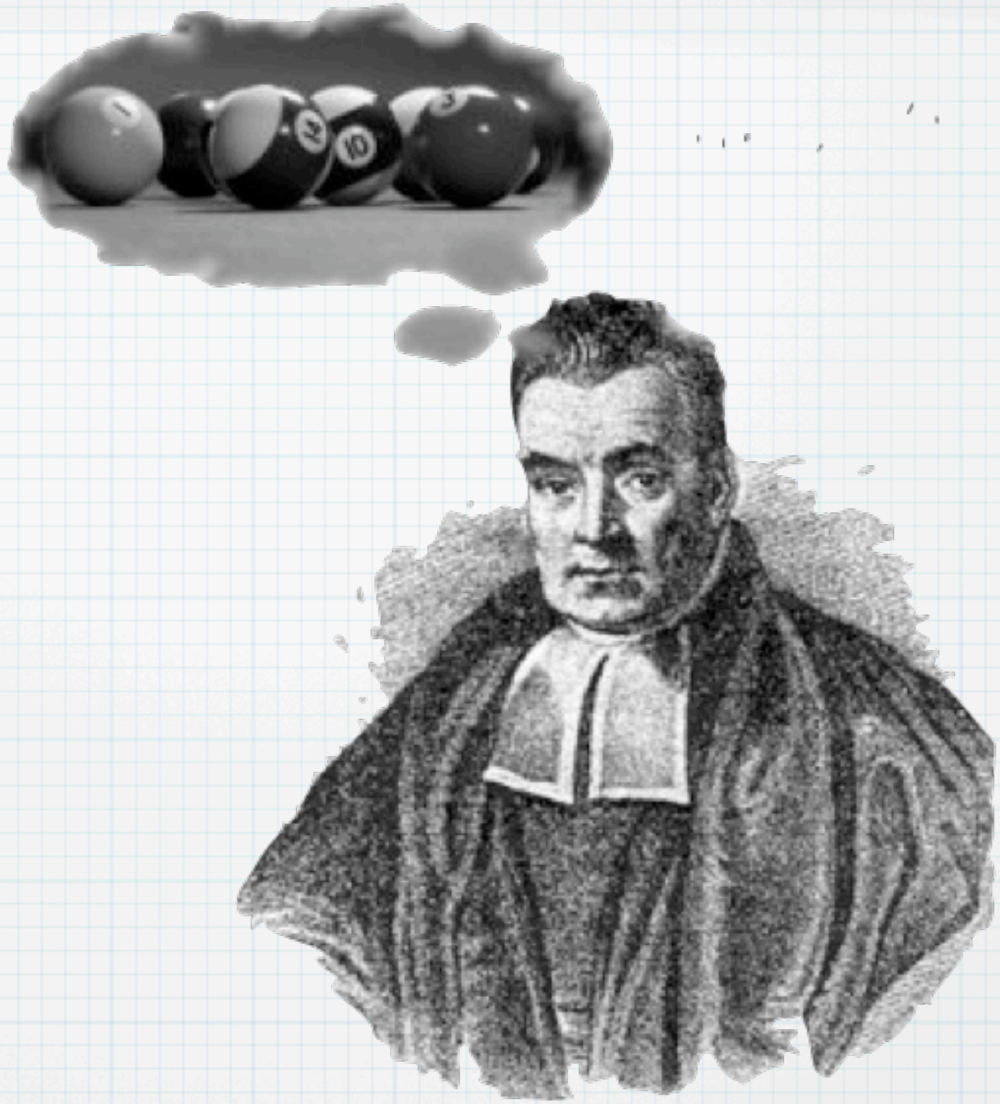
$$P(H \mid E) = \frac{P(E \mid H)P(H)}{P(E)}$$

- P(H) is probability (in absence of E) for parameter set H a.k.a. the "prior distribution"
- P(E|H) is probability of E given H, i.e,

$$P \sim \exp\left(-\sum \delta_i^2 / 2\sigma_i^2\right)$$

- P(E) is net probabiltiy of E, i.e., a normalization factor
- P(H|E) is probability of parameter set H given E

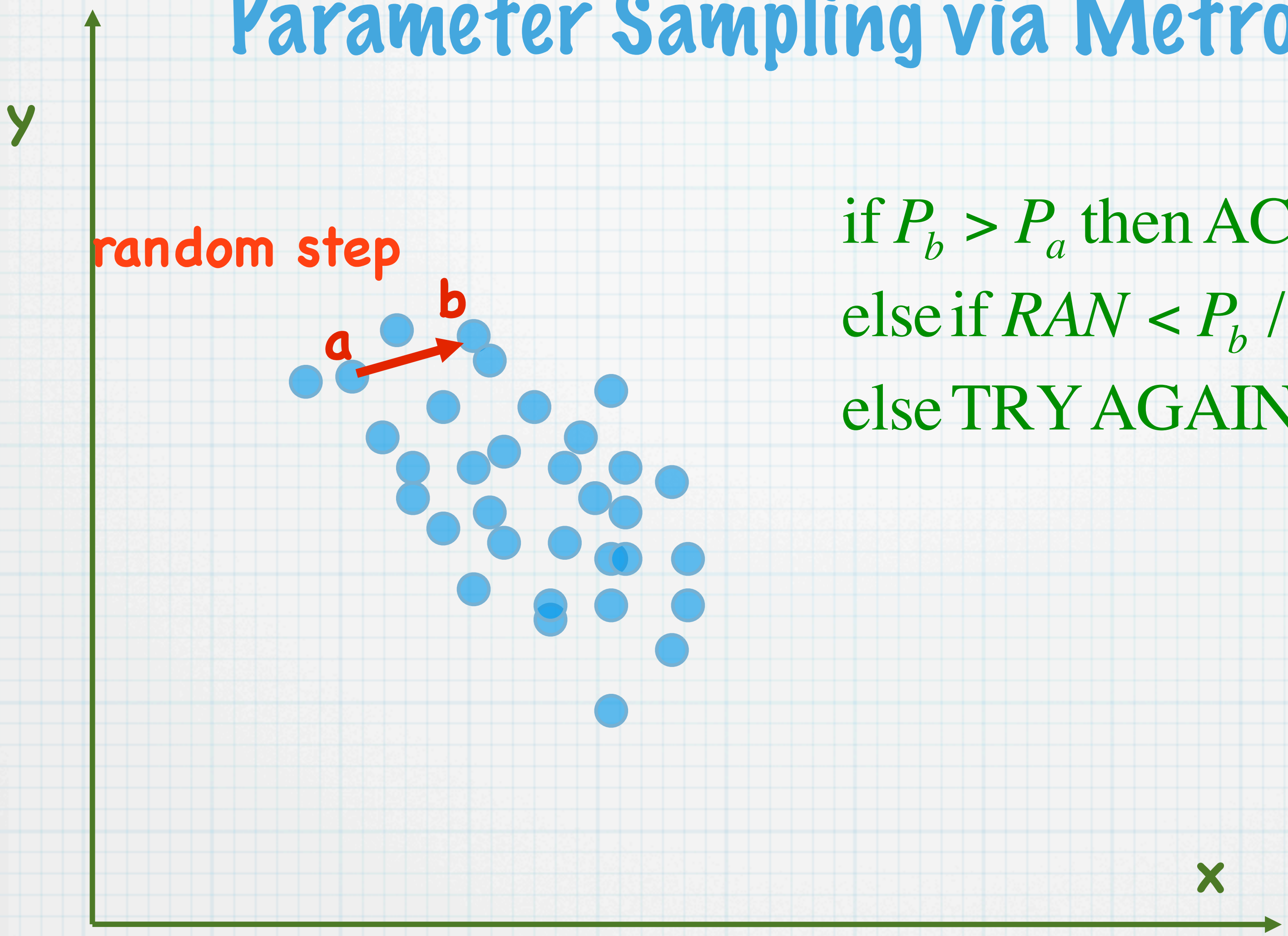
Bayes' Theorem



$$P(E \,\&\, H) = P(E \mid H) \cdot P(H) = P(H \mid E) \cdot P(E)$$

$$P(H \mid E) = \frac{P(E \mid H) \cdot P(H)}{P(E)}$$

Parameter Sampling via Metropolis



$$\text{if } P_b > P_a \text{ then ACCEPT}$$
$$\text{else if } RAN < P_b / P_a \text{ ACCEPT}$$
$$\text{else TRY AGAIN}$$

Can find disjoint regions
No problem with undeterminable parameters

Surrogate Models
(a.k.a. Emulators, Meta-Models)

Brute Force:

- Sampling requires millions of runs
- Each run requires 1 work-station day

Alternative:

- Run 10^2 - 10^3 times at various points
- "Interpolate" to find values at all other points
- Competing "interpolation" schemes:
  - Gaussian fields
  - Multi-dimensional splines

An Emerging Science

Identifying Key Links

Consider parameters θ_α and observables y_i

$$\sigma_{ij} \equiv \langle \delta y_i \delta y_j \rangle, \quad \sigma_{\alpha\beta} \equiv \langle \delta\theta_\alpha \delta\theta_\beta \rangle, \quad \sigma_{i\alpha} \equiv \langle \delta y_i \delta\theta_\alpha \rangle$$

Averages taken from MCMC sampling

Resolving Power is

$$\sigma^{-1}_{\alpha\beta} = \sum_{ij,\gamma\delta} \sigma^{-1}_{\alpha\gamma} \sigma_{\gamma i} \sigma^{-1}_{ij} \sigma_{j\delta} \sigma^{-1}_{\delta\beta}$$

and can be divided into contributions

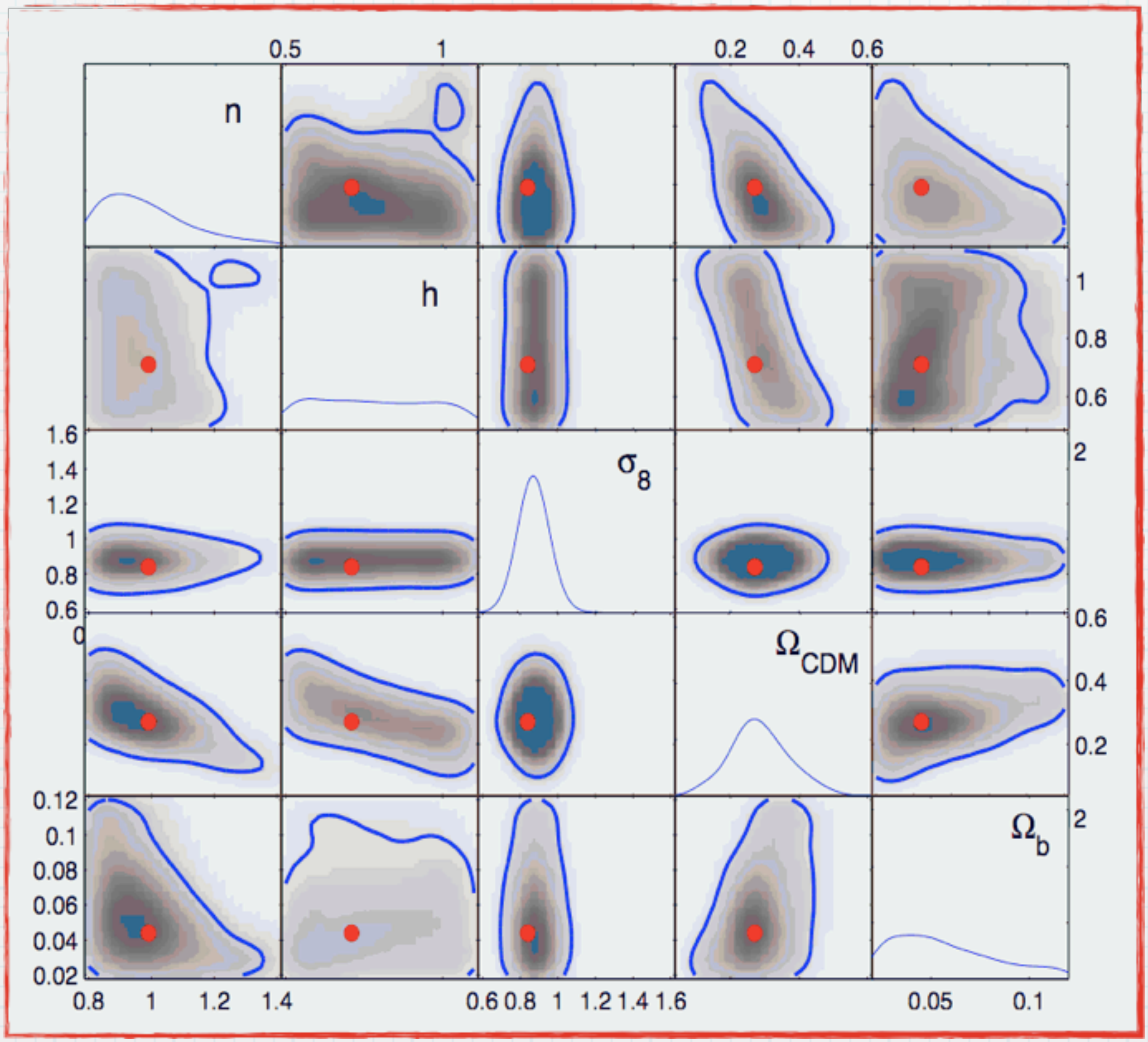
$$\sigma^{-1(s)}_{\alpha\beta} \equiv \sum_{ij\in s,\gamma\delta} \sigma^{-1}_{\alpha\gamma} \sigma_{\gamma i} \sigma^{-1}_{ij} \sigma_{j\delta} \sigma^{-1}_{\delta\beta}$$

"s" refers to subset of data, e.g. elliptic flow

Assessing Prospects for New Data

- Make Simulated Data
- Analyze Like Real Data
- Calculate Resolving Power of Subset

Other fields have done this ....

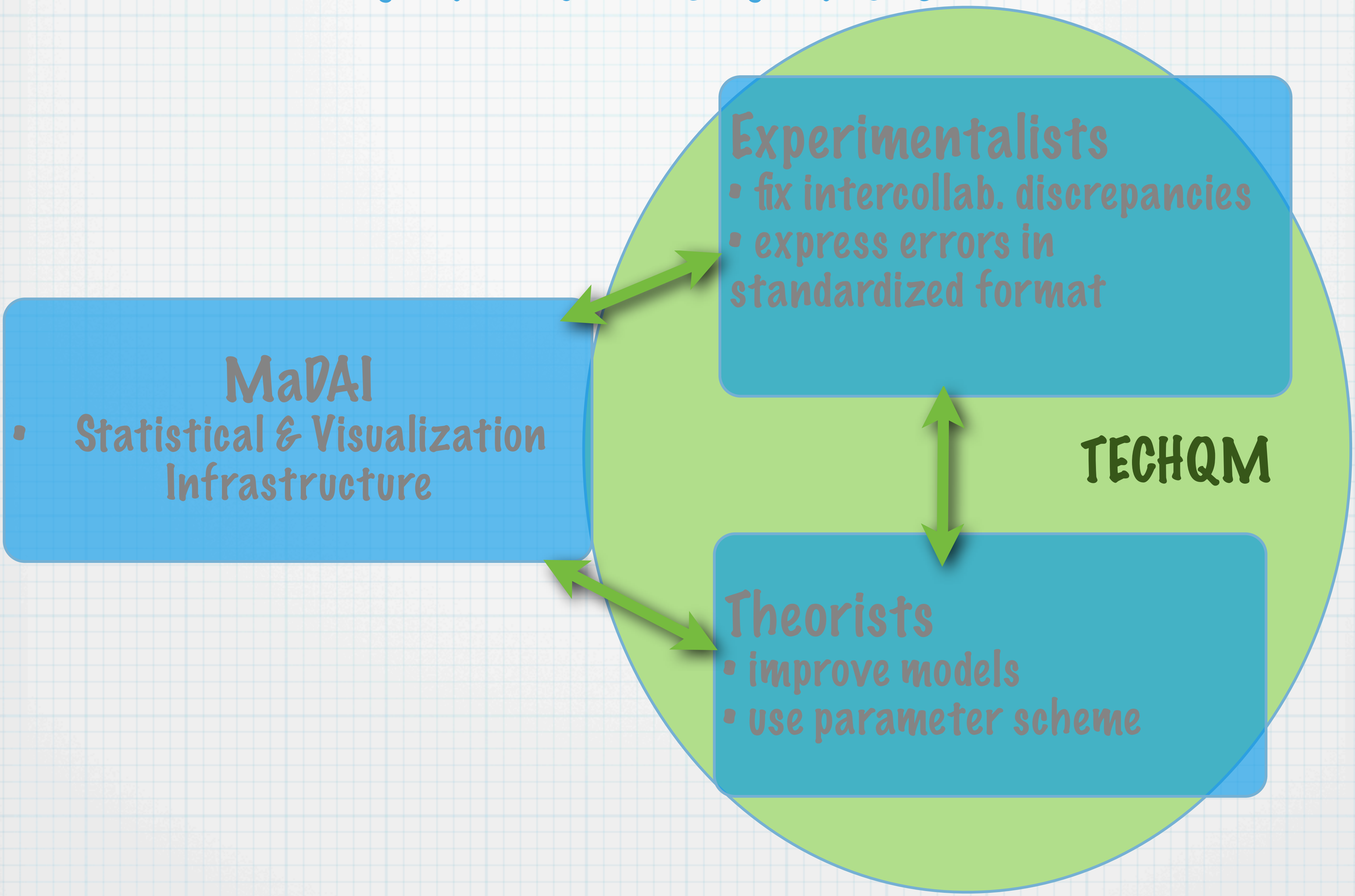


Cosmological parameters (Habib et al, astro-ph/0702348 1)

Can this work for RHIC?

* Must be amenable to parameterization
    * Model must contain basic truth
    * Not too many competing theories
    * First apply to soft observables (spectra, flow, HBT...)
    * Provide validated base for other calculations
* Must have well stated errors
    * Statistical & systematic for both theory and experiment
    * Cross correlated errors
    * May require re-expression of experimental results
    * Intimate theory/experimental discussions

Who Does What



Outcomes

- Rigorous Statement of Bulk Properties
- Validated Base for Calculating:
  Fluctuations, Jet Quenching, Heavy Flavors...