Discerning Bulk Properties of the QGP from Experiment

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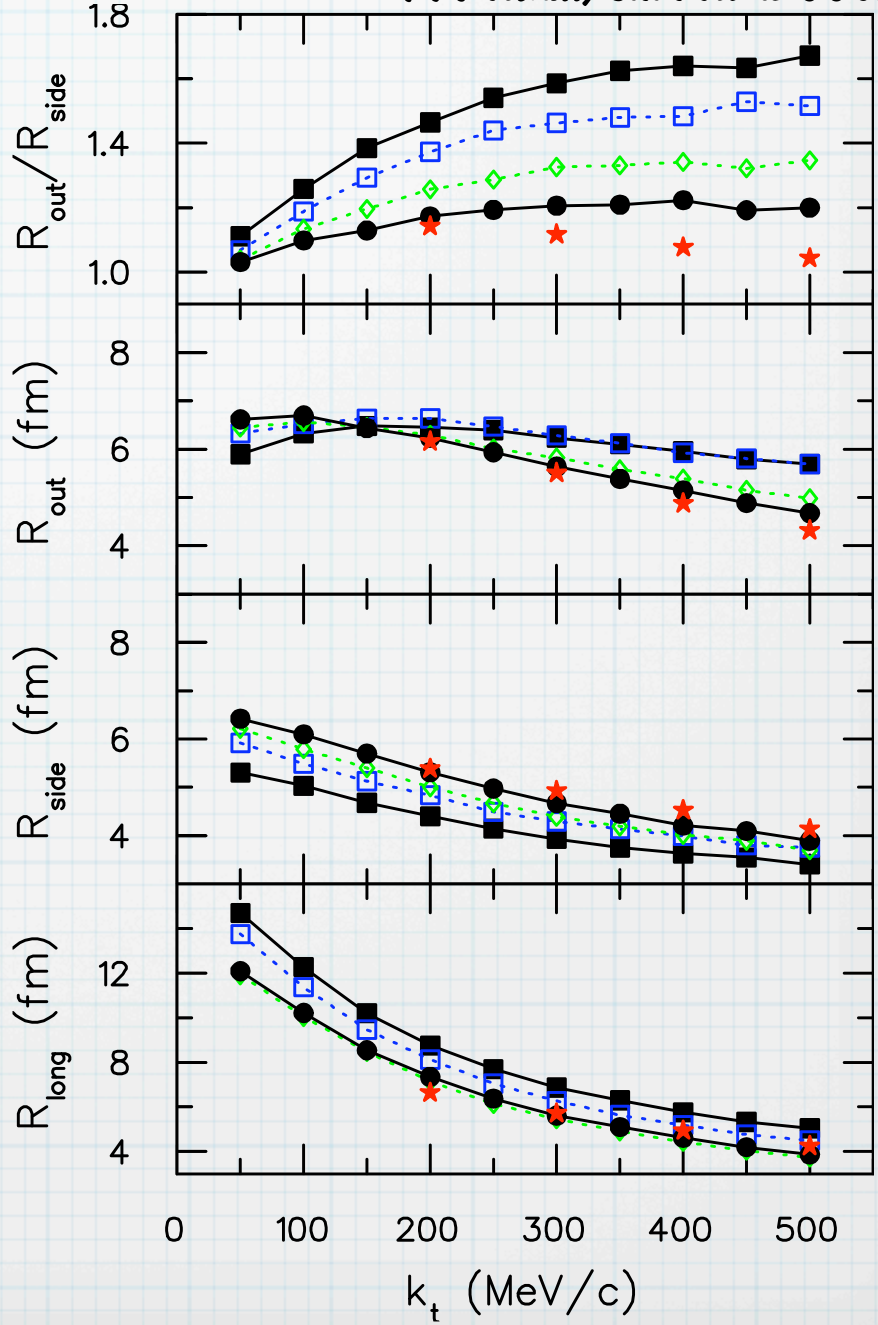
Lessons from RHIC (bulk properties)

- 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)

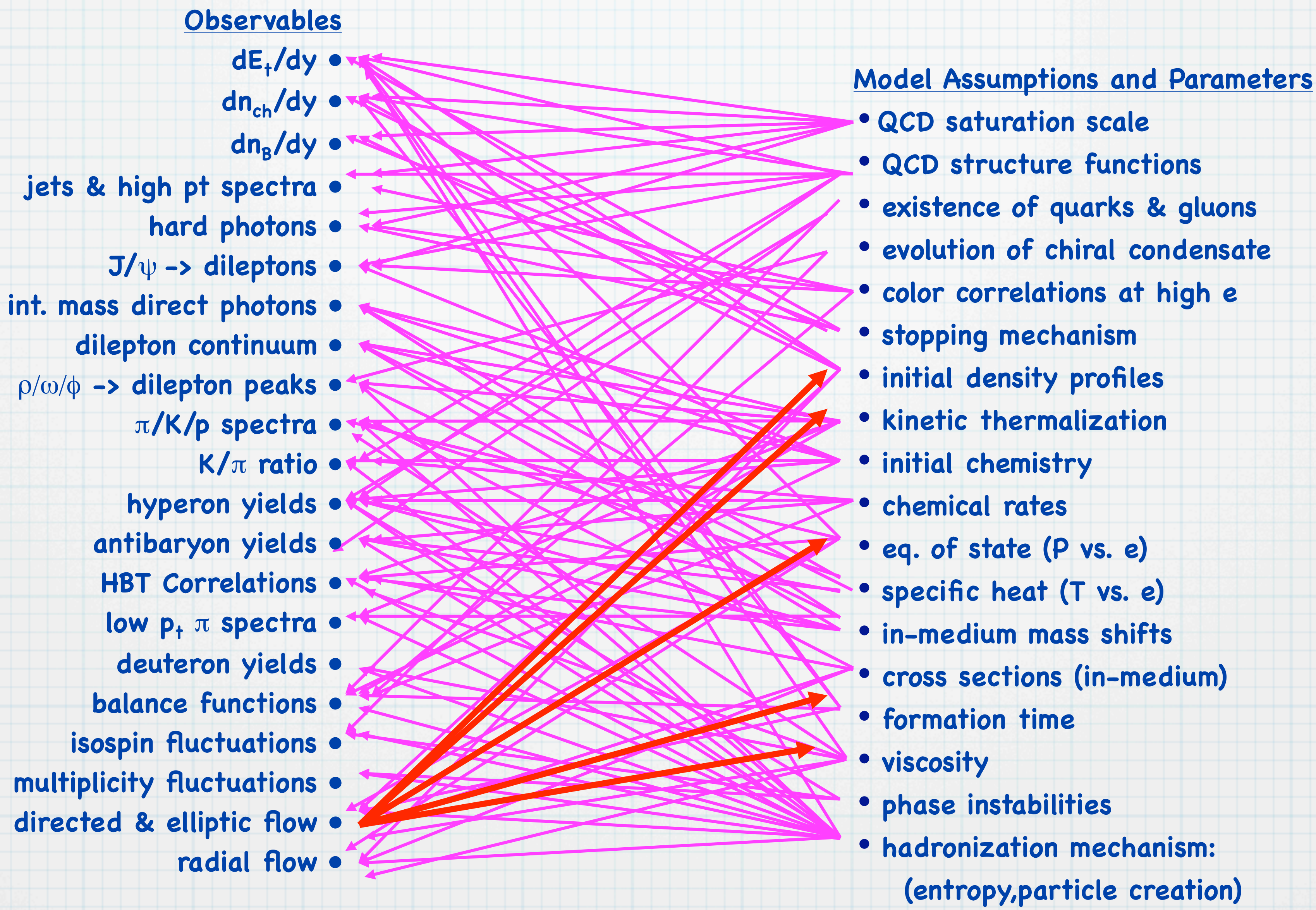


... but nothing is quantitative or rigorous

* 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

Properties are neither DETERMINED
nor VALIDATED rigorously

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!!!!

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.

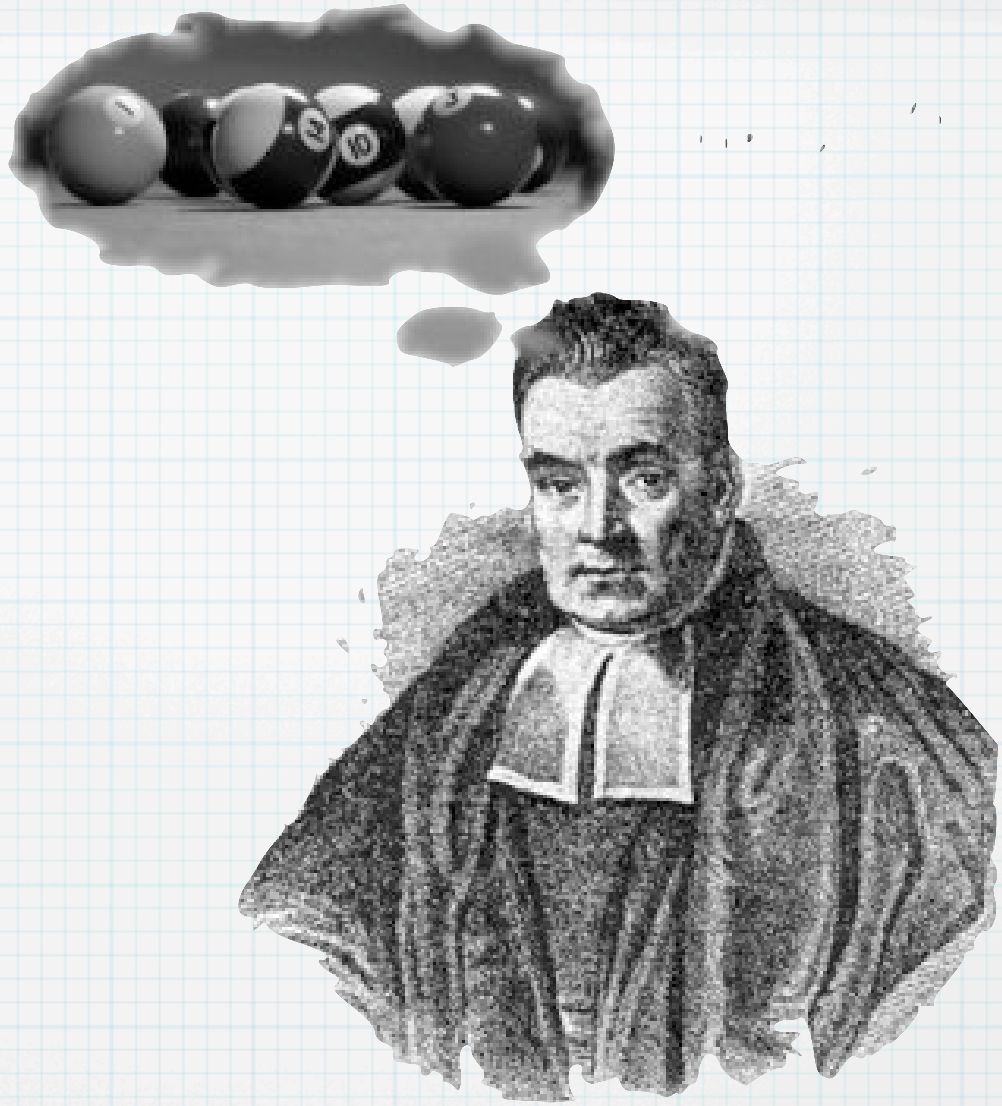
$$P(H \mid E) = \frac{P(E \mid H)P(H)}{P(E)}$$

- 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

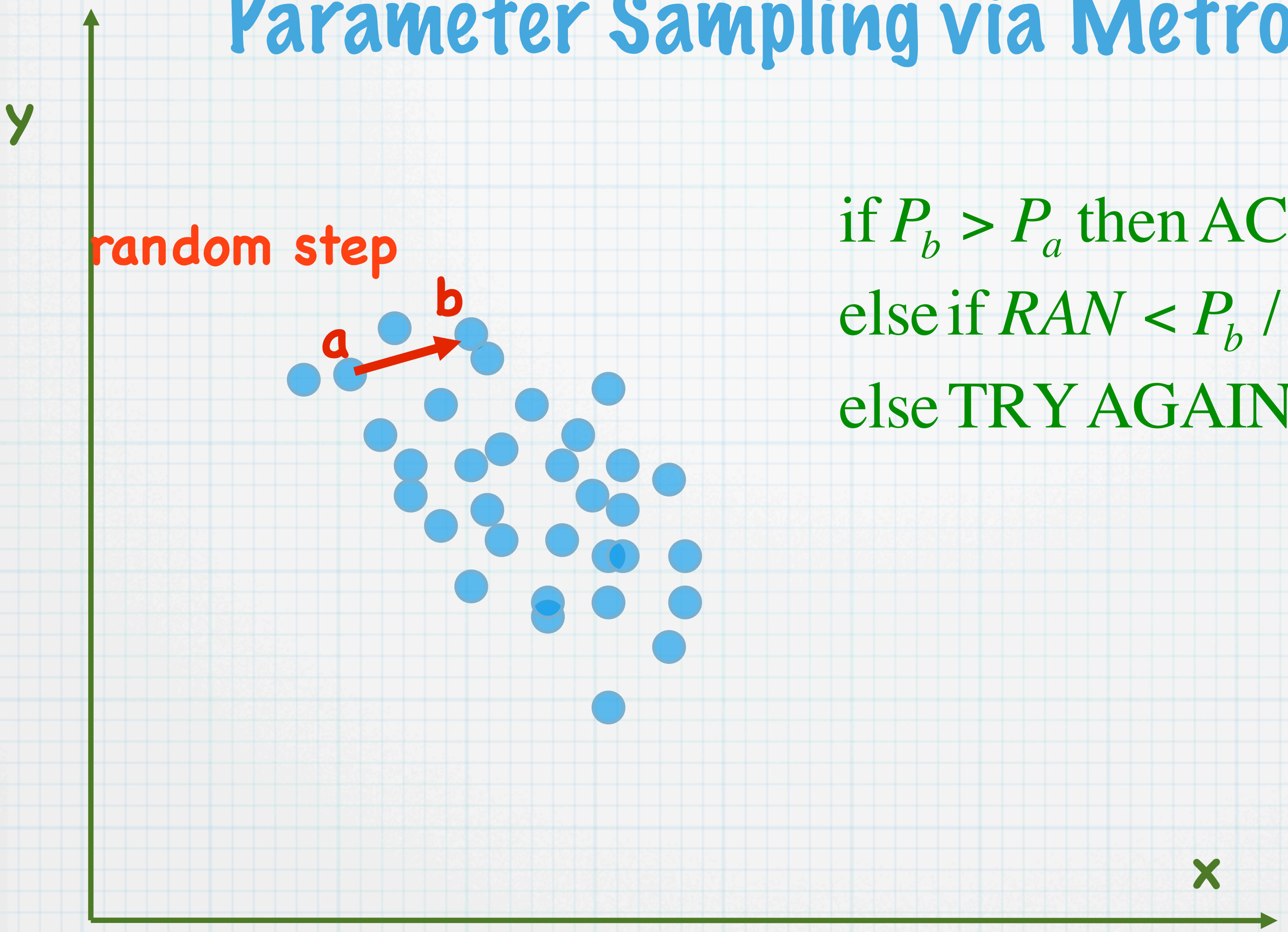
Bayes' Theorem



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

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

Parameter Sampling via Metropolis



if $P_b > P_a$ then ACCEPT

else if $RAN < P_b / P_a$ ACCEPT

else TRY AGAIN

Can find disjoint regions

No problem with undeterminable parameters

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

Brute Force:

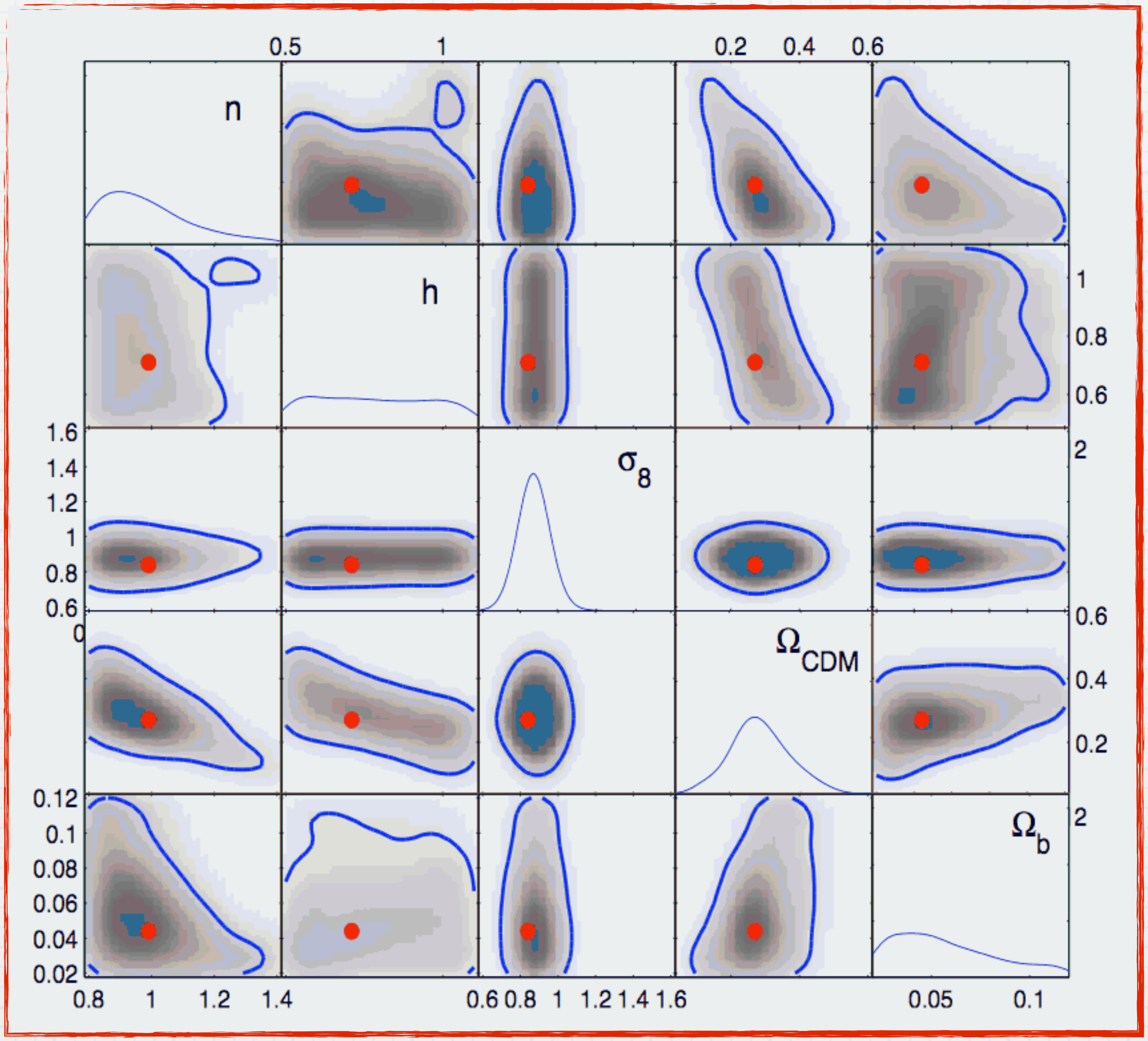
- Sampling requires millions of runs
- Each run requires 1 work-station day

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

Other fields can do it....



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