Search for Hadronic Shore in High-Energy Nuclear Collisions

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Many Thanks to Organizers!

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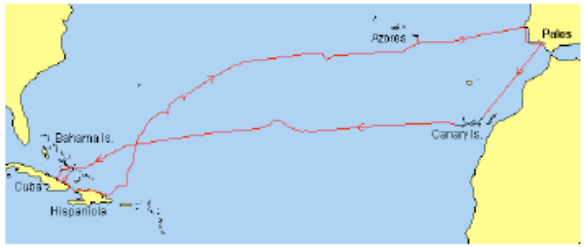
Columbus' discovery, HENC

Ed Shuryak: "One may have an absolutely correct theory and still make *accidental* discoveries…"

Columbus' Theory:
(1) world is not flat, $E_2 \Rightarrow S_3$
(2) if he goes west he should eventually come to India



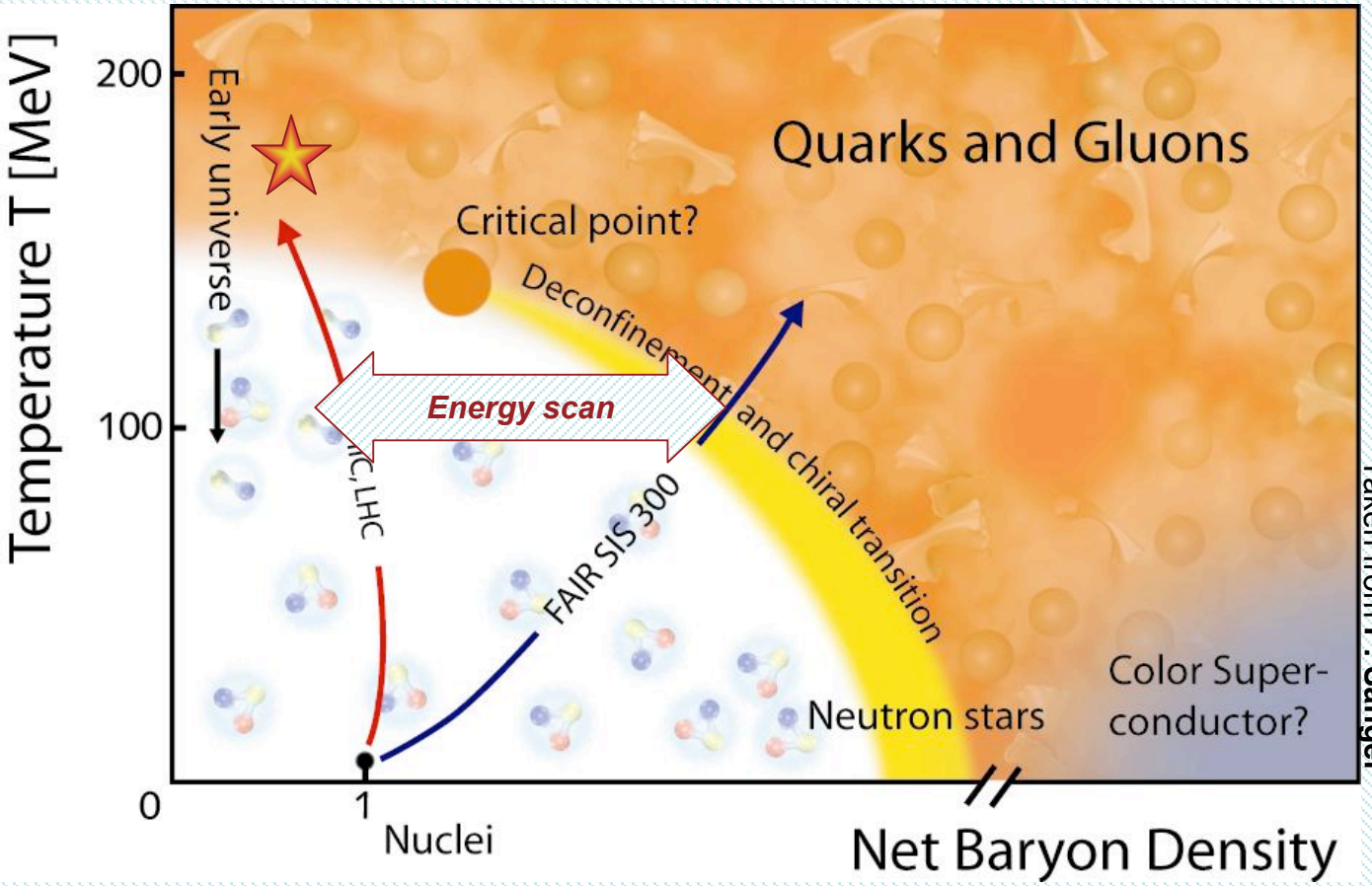
But he discovered something else was on the way…

We set out at RHIC we find wQGP. But 1000 experimentalists found something else on the way… the sQGP !

Gyulassy RBRC/BNL 12/16/04 8

Two unknowns:

(1) The properties of 'sQGP' and (2) the phase boundary



1) RHIC heavy-flavor program / LHC:
   - Study ***medium properties*** at RHIC
   - pQCD in hot and dense environment

2) RHIC energy scan / GSI program:
   - Search for the possible ***phase boundary***.
   - Chiral symmetry restoration

Outline

- What have we learned at 200 GeV?

- Why do we want to revisit the lower energy region?

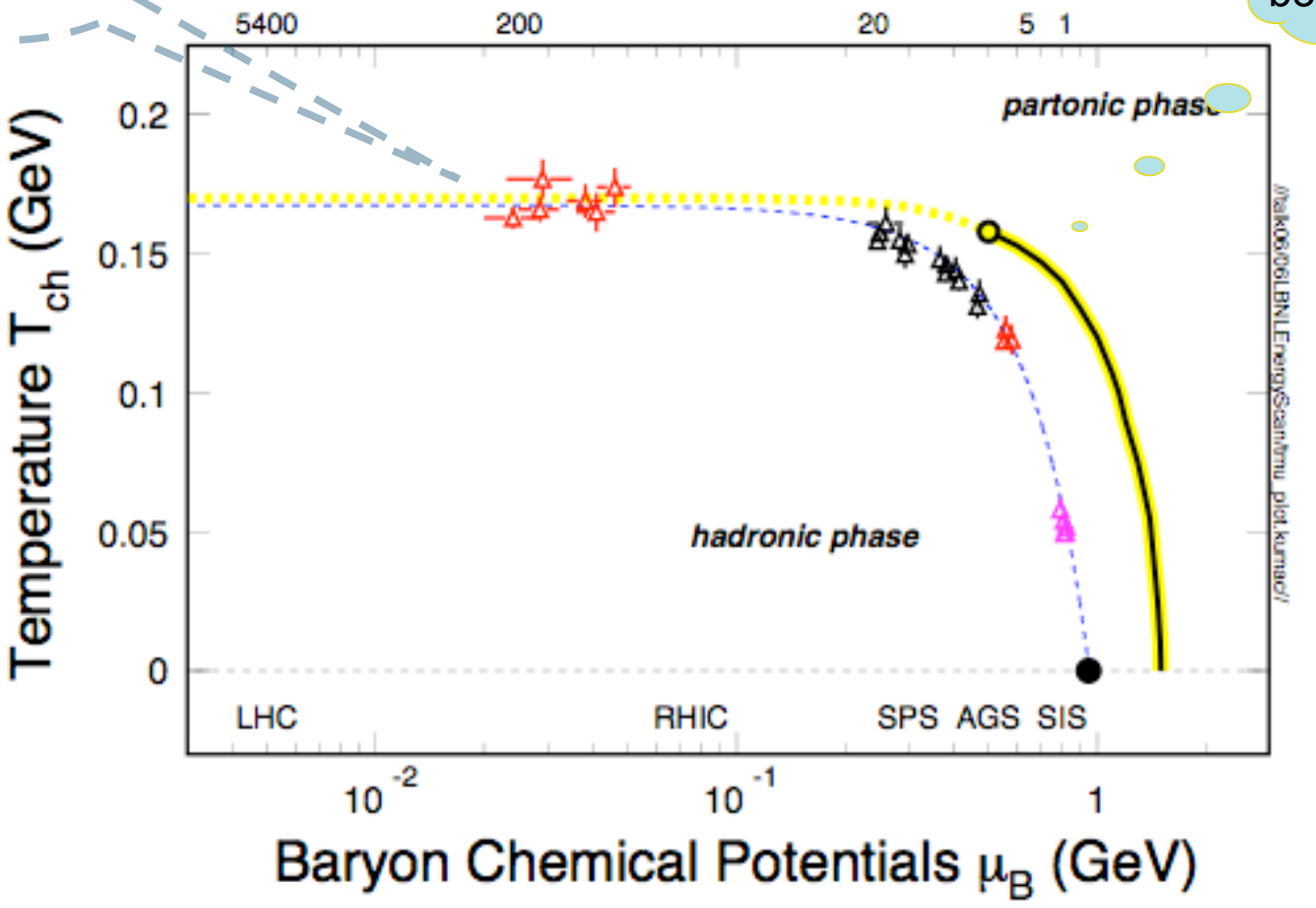
- Can we do better?

➢ Mapping the landscape of the QCD phase diagram and search for the native hadronic shore

QCD Phase Diagram

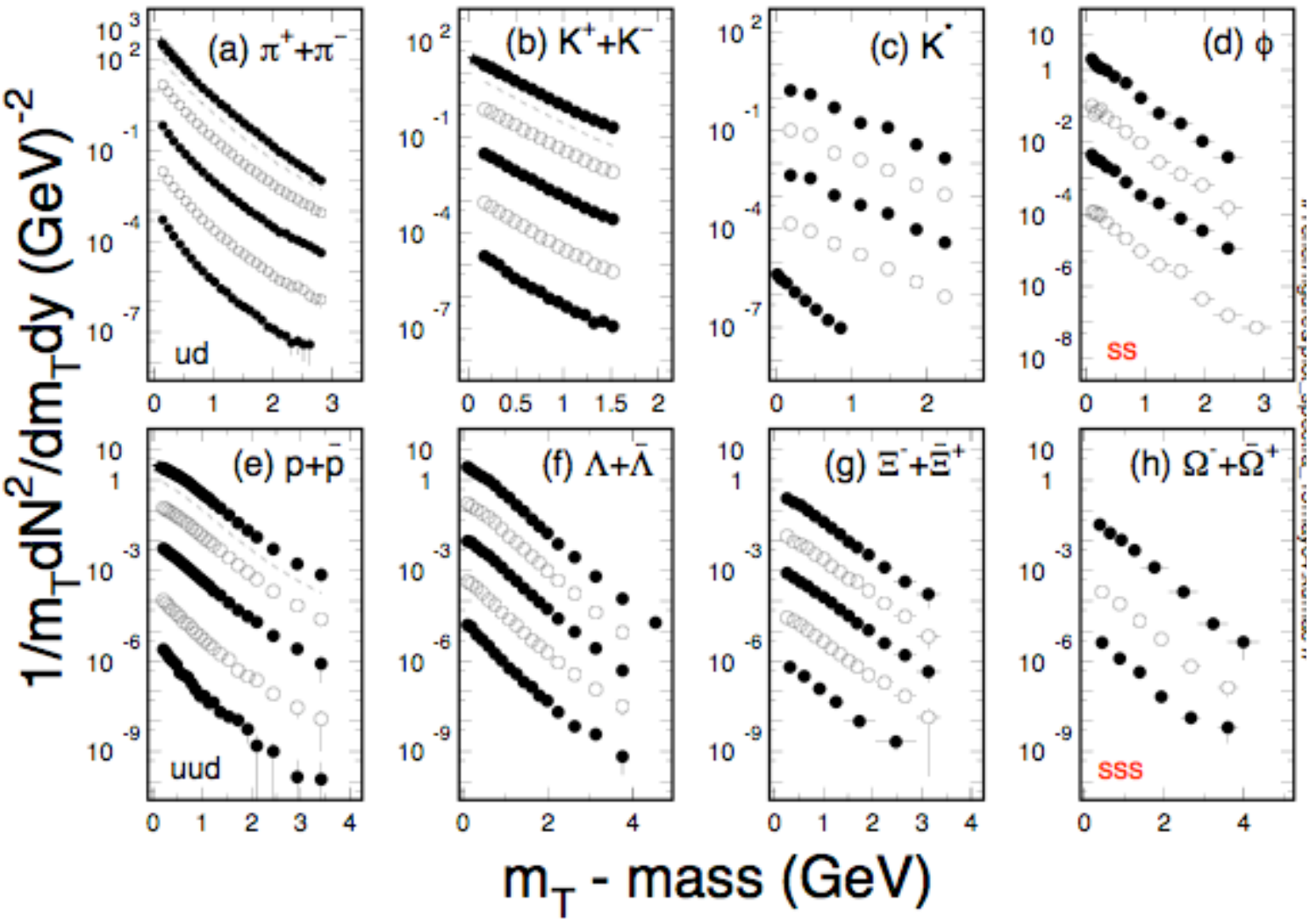
deep partonic ocean

phase boundary?



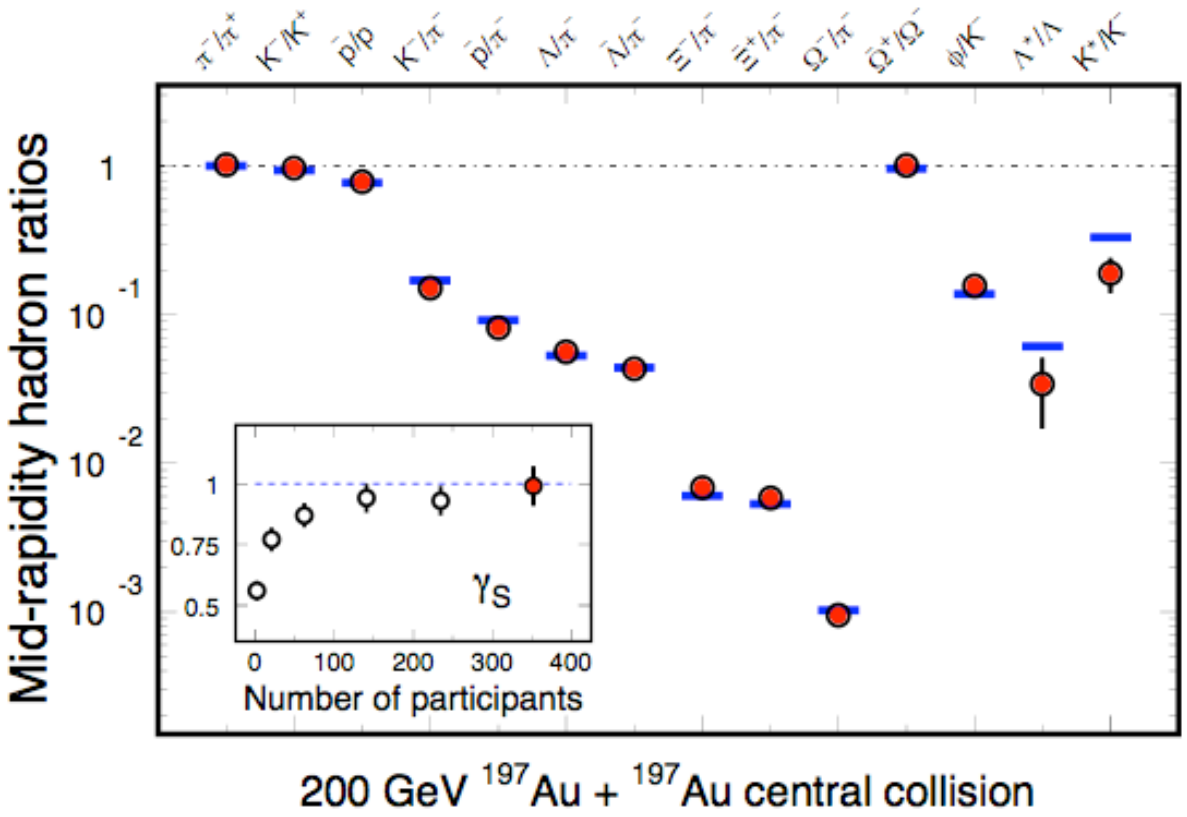
Hadron Spectra From RHIC

p+p and Au+Au collisions at 200 GeV



STAR white papers - Nucl. Phys. *A757*, 102(2005).

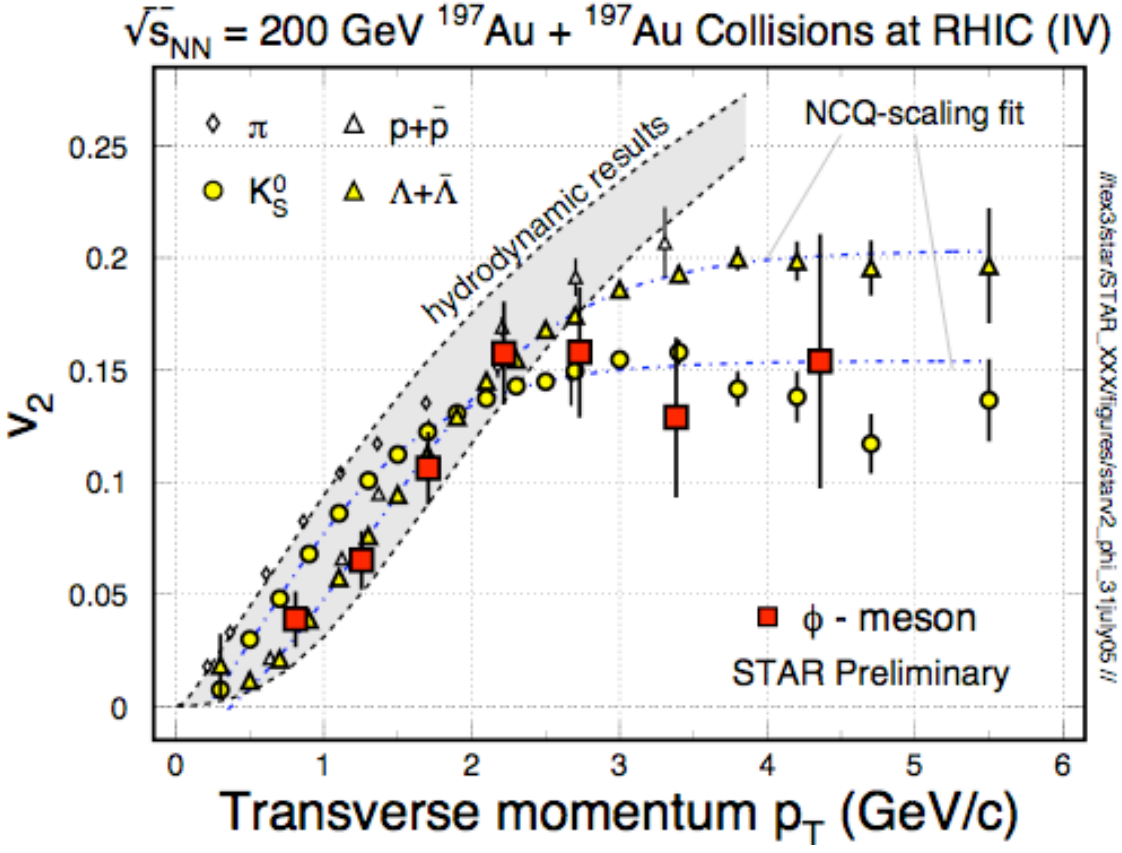
Yields ratio results



- In central collisions, thermal model fit well with $\gamma_S = 1$. **The system is thermalized at RHIC.**
- Short-lived resonances show deviations. **There is life after chemical freeze-out.**

RHIC white papers - 2005, Nucl. Phys. *A757*, STAR: p102; PHENIX: p184.

ϕ -mesons flow = partonic flow

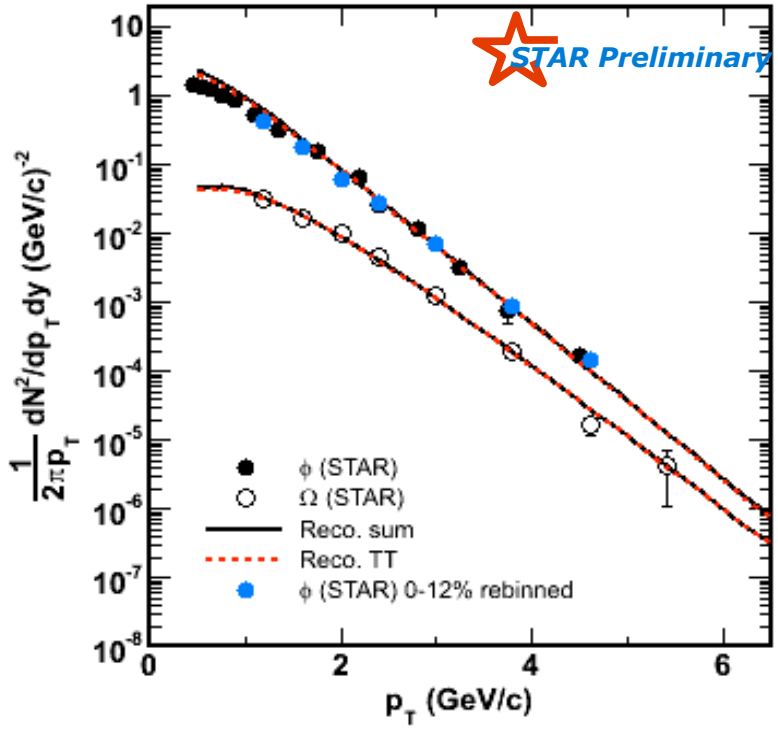


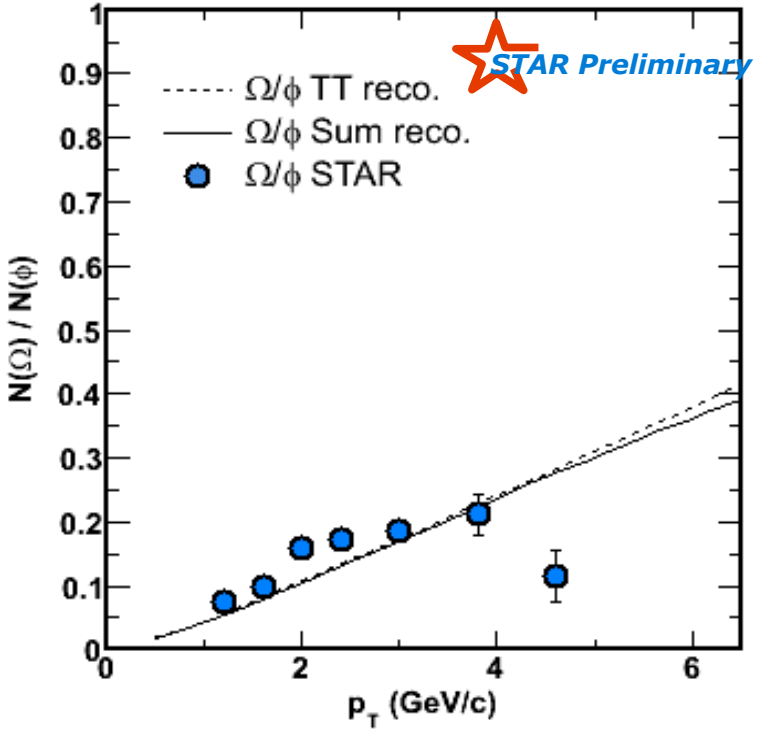
ϕ-mesons are very special:

1. they do not re-interact in hadronic environment
2. they are formed via coalescence with thermal s-quarks
3. they show strong collective flow

STAR: QM2005 / SQM 2006

Multi-strange Hadron Ratios

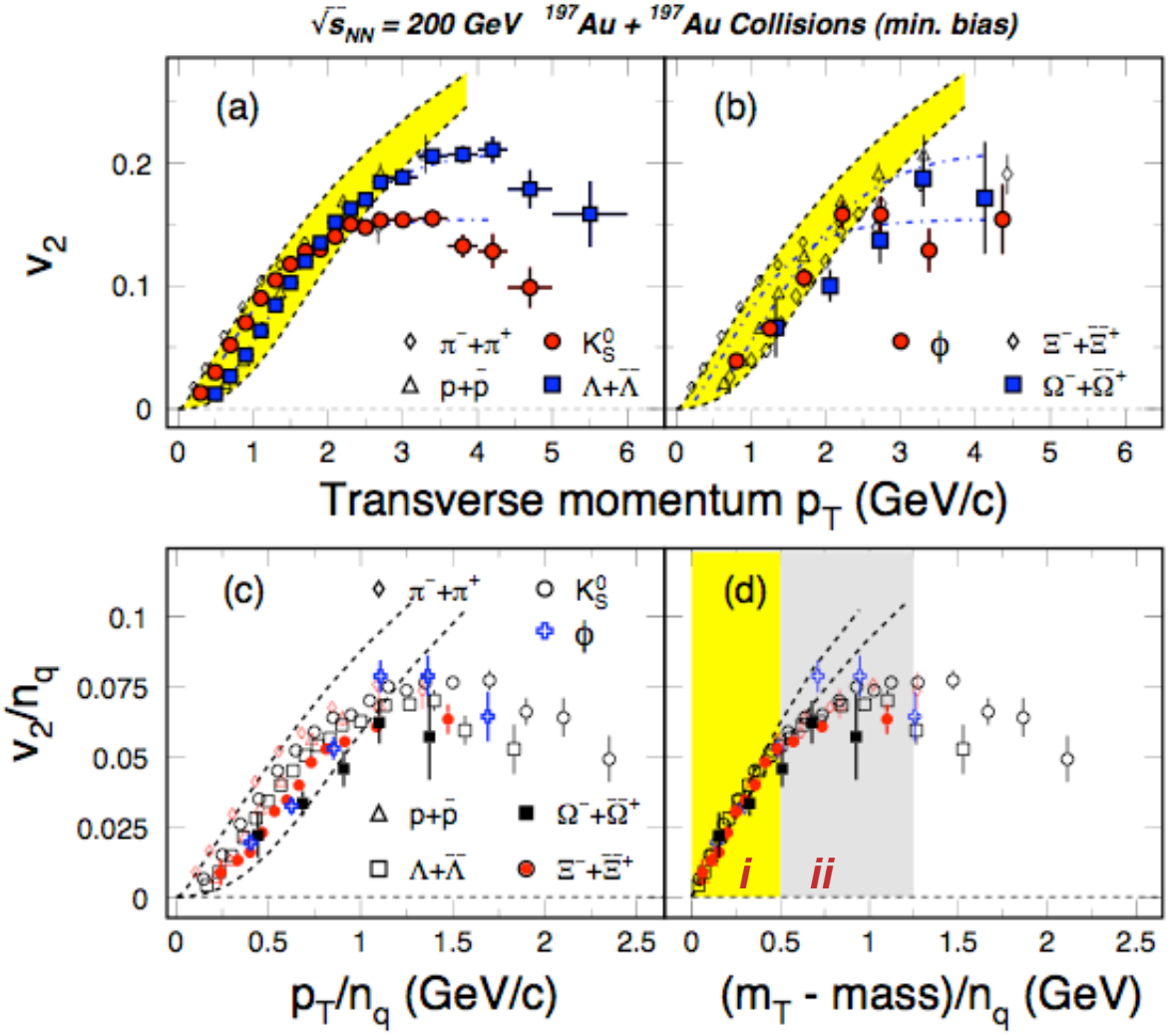




In heavy ion collisions at RHIC, up to p_T ~ 4 GeV/c, (*model predicts 8 GeV/c) the strangeness production is dominated by the thermal like processes.

Hwa and Yang, nucl-th/0602024; STAR data: QM05, SQM06

Collectivity, Deconfinement at RHIC



- v_2, spectra of light hadrons and multi-strange hadrons
- scaling by the number of quarks

At RHIC:

➪ **m_T - NQ scaling**

➪ **Partonic Collectivity**

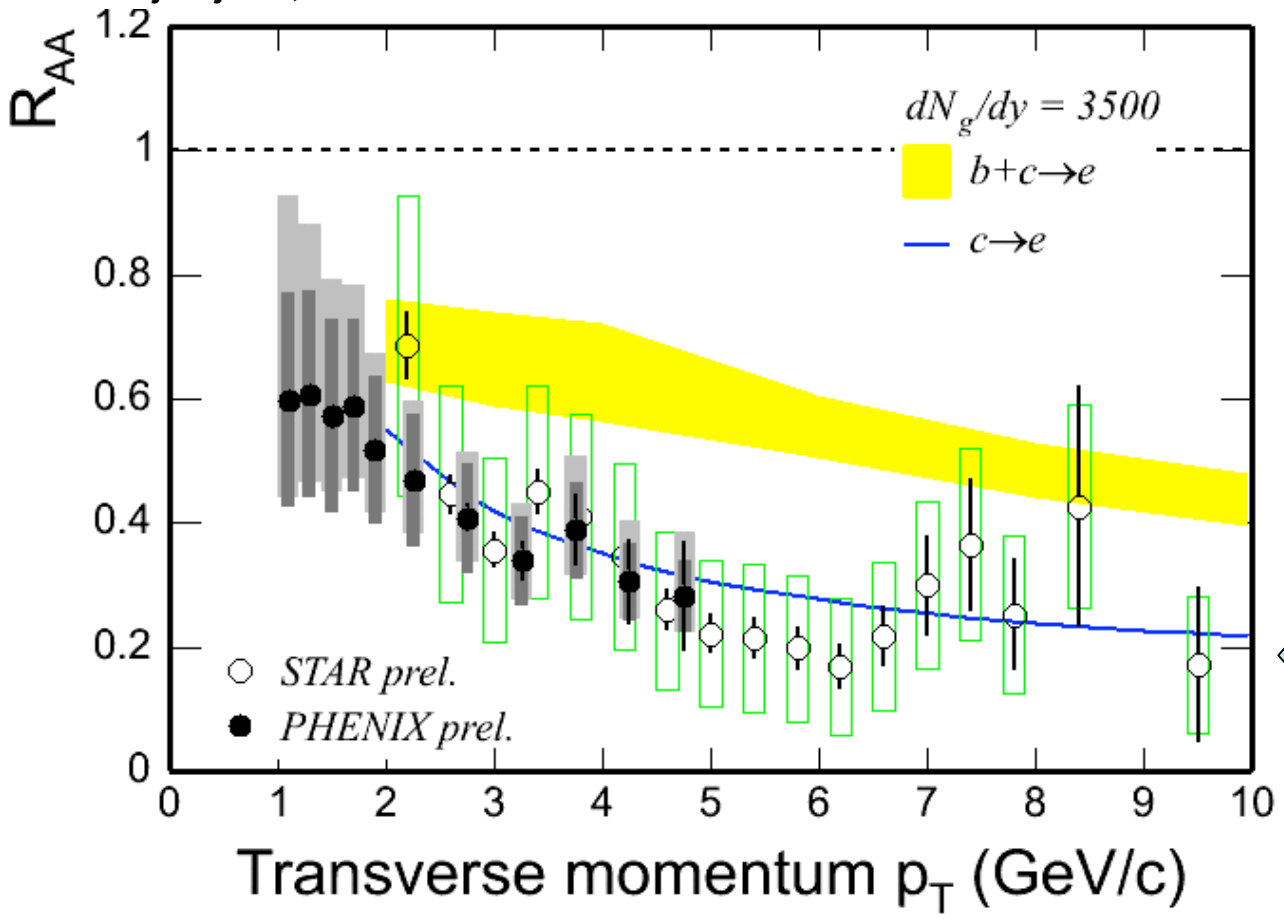
➪ **Deconfinement**

*PHENIX: PRL**91**, 182301(03)*
*STAR: PRL**92**, 052302(04), **95**, 122301(05)*
nucl-ex/0405022, QM05

S. Voloshin, NPA715, 379(03)
*Models: Greco et al, PR**C68**, 034904(03)*
Chen, Ko, nucl-th/0602025
*Nonaka et al. **PLB583**, 73(04)*
*X. Dong, et al., Phys. Lett. **B597**, 328(04).*
….

Non-photonic Electron Spectra

M. Djordjevic, et. al. *nucl-th/0507019*



Charged hadrons

-Partonic energy loss - necessary for the plasma formation!

- Challenge to pQCD energy loss calculations!

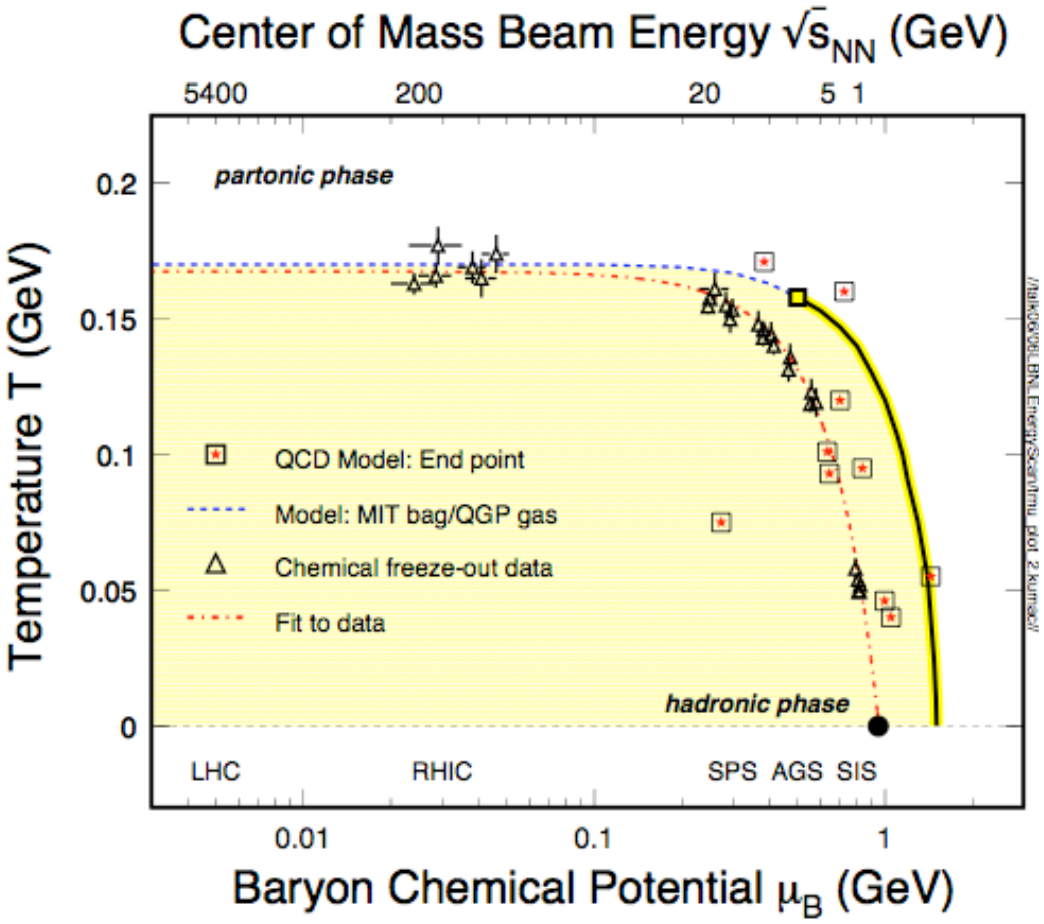
High-Energy Nuclear Collisions

Goals:

(1) Identify the bulk-matter (EOS) with partonic d.o.f
(2) Study the properties of the partonic matter

(3) *Demonstrate* the transition between partonic and hadronic worlds - the hadronic shore

QCD Phase Diagram



Model predictions:

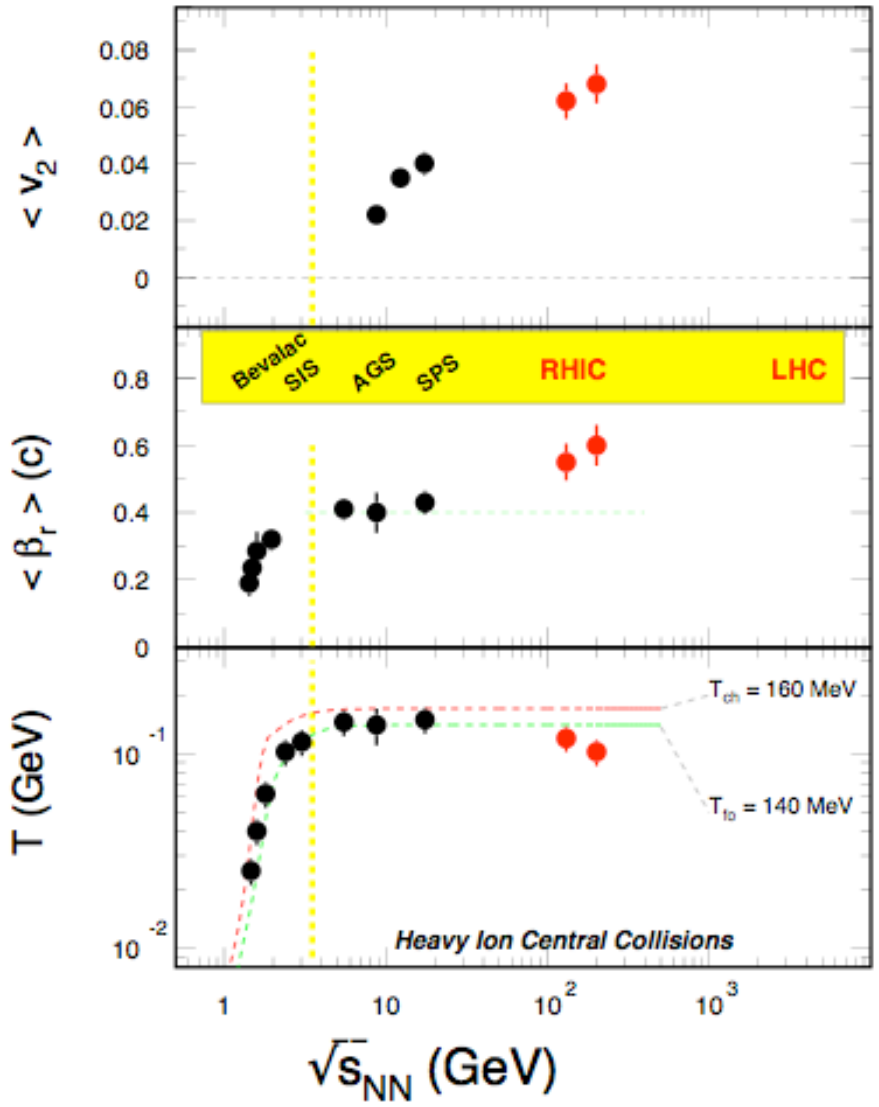
1) All 'end points' exist at $\mu_B > 0.1$GeV

2) Most 'end points' exist at $\mu_B < 0.95$GeV

3) Large uncertainties in the predictions. Data is important.

M.A Stephanov, Prog. Theor. Phys. Suppl. ***153****, 139(2004); Int. J. Mod. Phys.* ***A20****, 4387(05); hep-ph/0402115*

Freeze-out Systematic



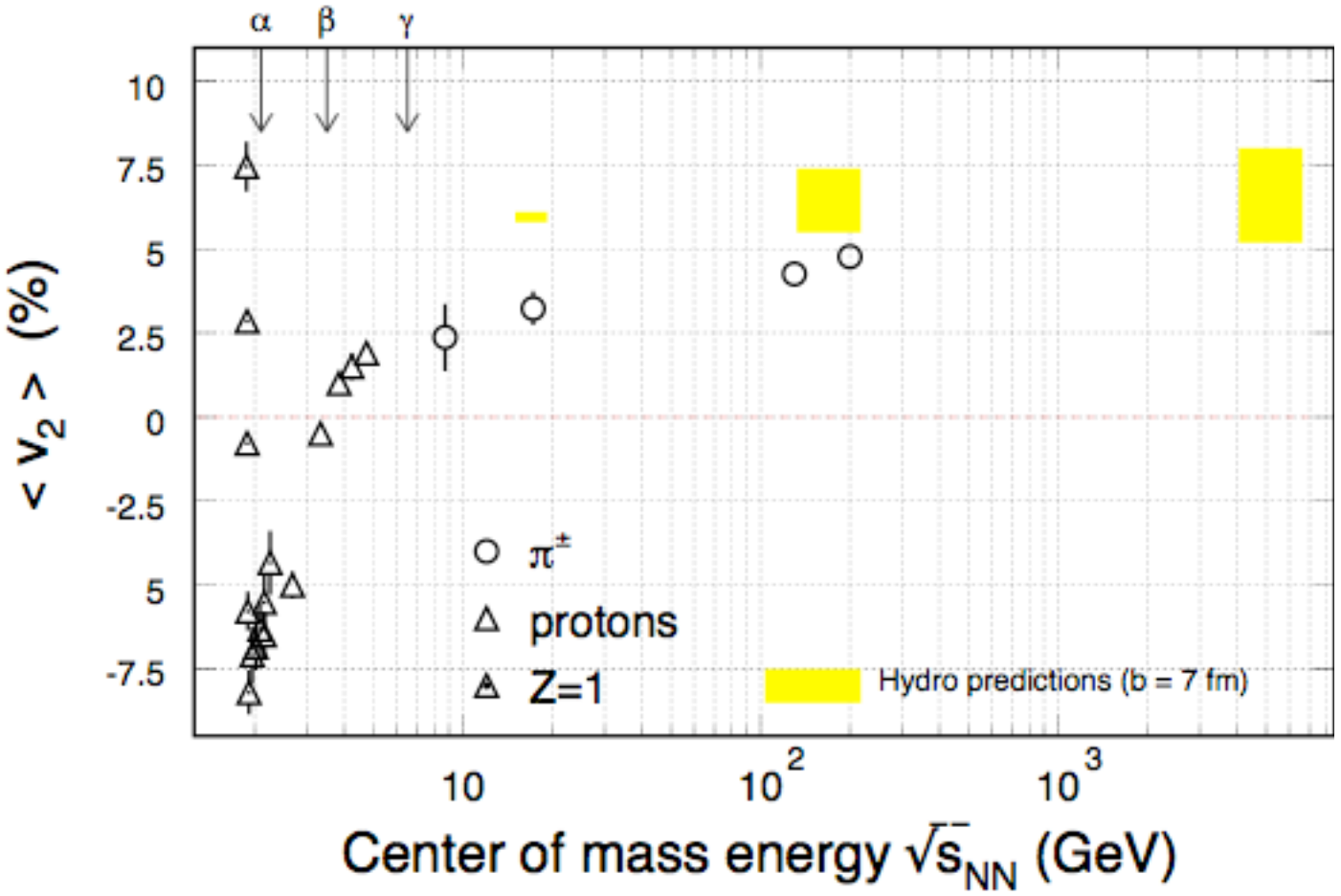
At freeze-out:

The 'temperature' parameters T_{fo} seem to be around 100 - 140 MeV.

v_2 continuously rise with beam energy. A clear increase in averaged velocity parameters β_r - increase of the 'pressure' in the system at RHIC.

When v_2 crosses zero, a plateau appears for T_{fo} and β_r at beam energy ~ 3-5 GeV.

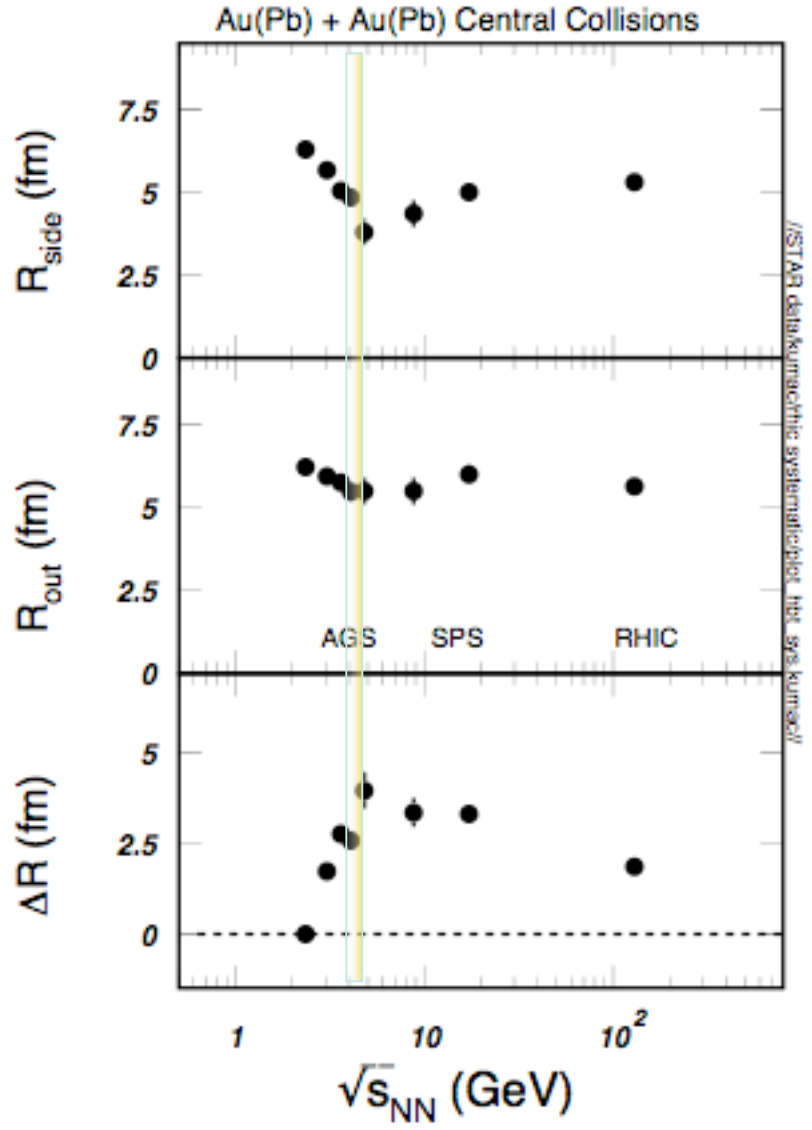
v_2 Excitation Function



1) α: v_2 ⇨ $v_2|_{minimum}$ (nucleon driven dynamics)
2) β: v_2 ⇨ 0 (E_{cm} ~3.5 GeV, collision geometry & passing time, EOS change)
3) γ: Δv_2 ⇨ 0 (pressure driven expansion)

Hydro model: Heinz & Kolb, nucl-th/0305084

HBT systematic

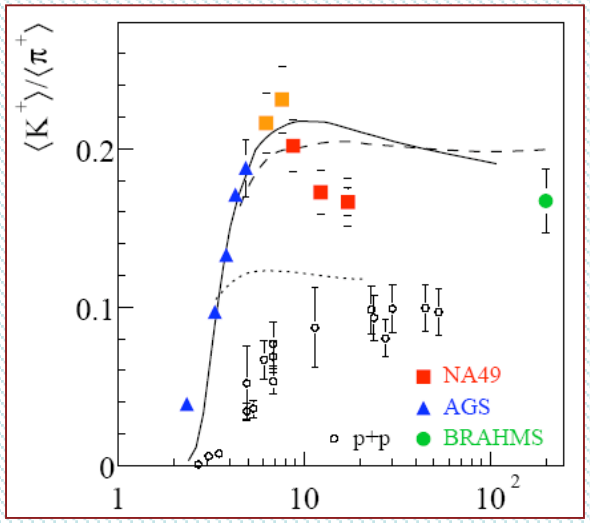


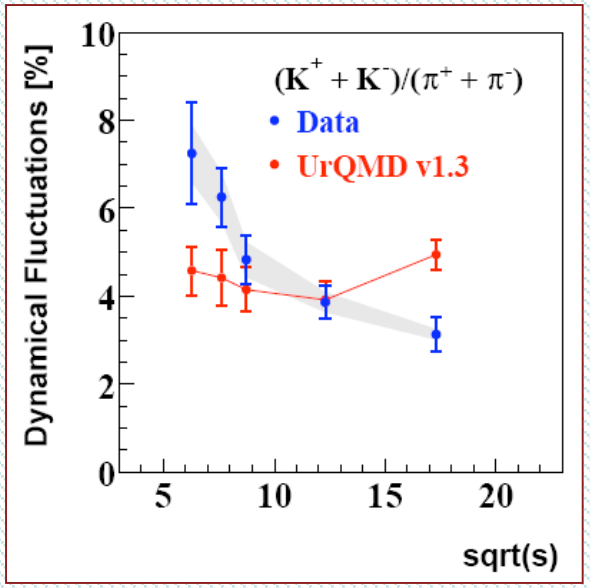
Again, a dramatic change in the HBT radius parameters occur at 5 GeV!

$$\Delta R = \sqrt{R_{out}^2 - R_{side}^2} \propto c\tau$$

- *$\sigma_{N\pi}$ dominants*
- *at higher energies, collective expansion is enhanced.*
- *long duration (?)*

Early SPS Results





NA49 Experiment:

(1) The "horn" structure in $\langle K^+\rangle/\langle \pi^+\rangle$ ratios observed

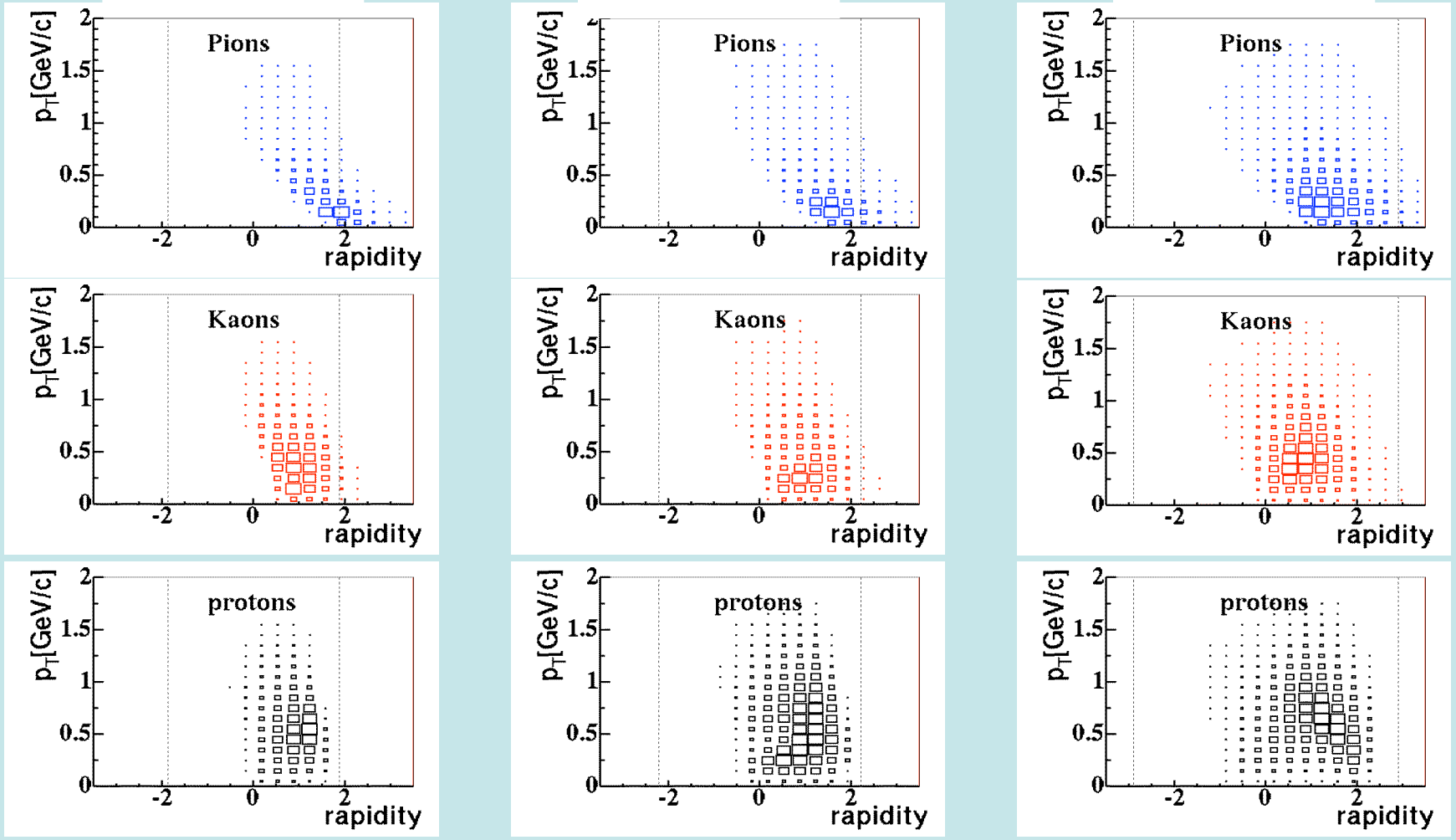
(2) Increased fluctuation signal at lower beam energies

$$\sigma^2_{dyn} = \sigma^2_{data} - \sigma^2_{mixed}$$

C. Blume (NA49), hep-ph/0505137

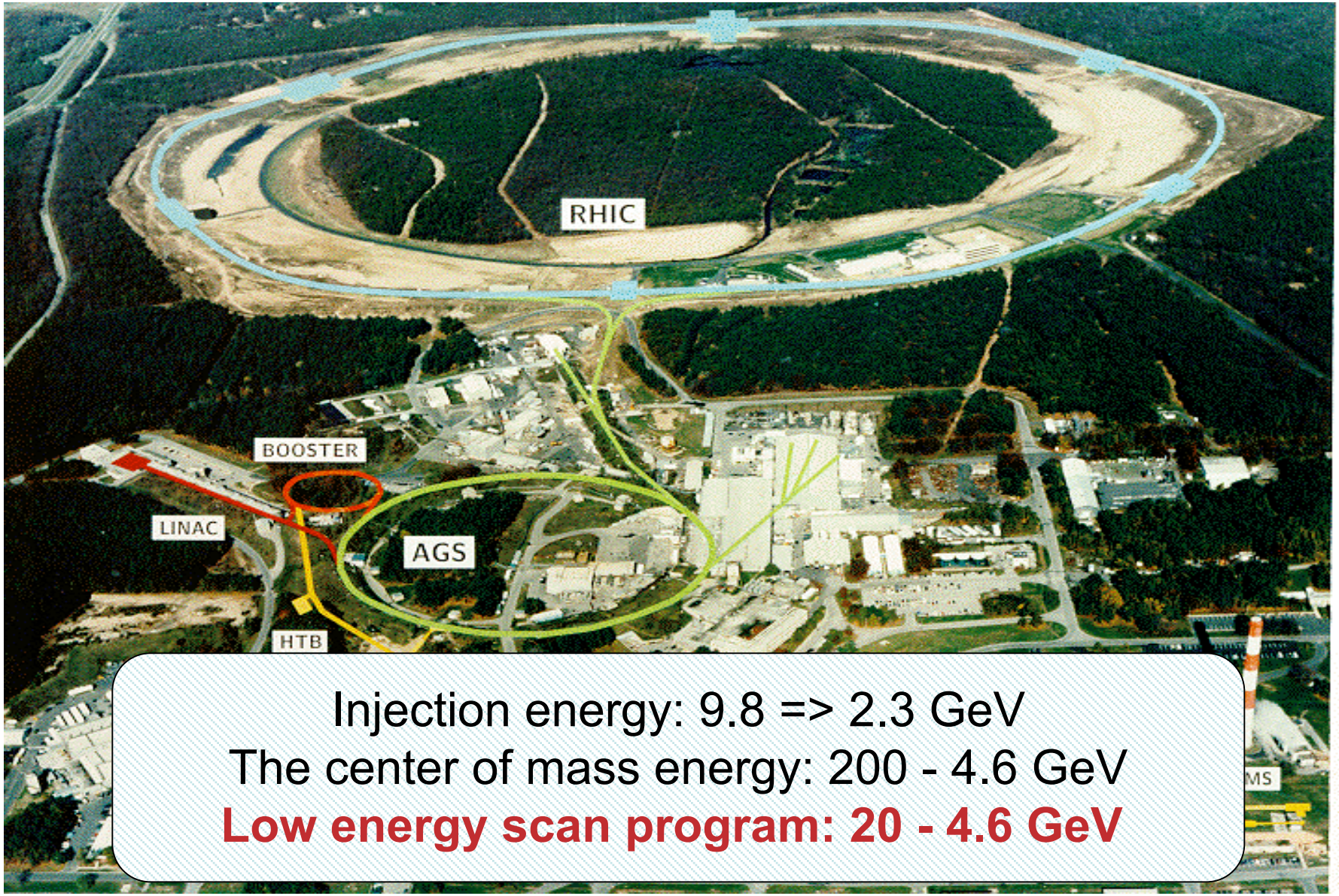
(3) Data suffer low statistics and large systematic uncertainties, due to acceptance and PID

Challenge: Changing Acceptance (NA49)



Slide from Christof Roland,
Correlations '05, MIT

RHIC

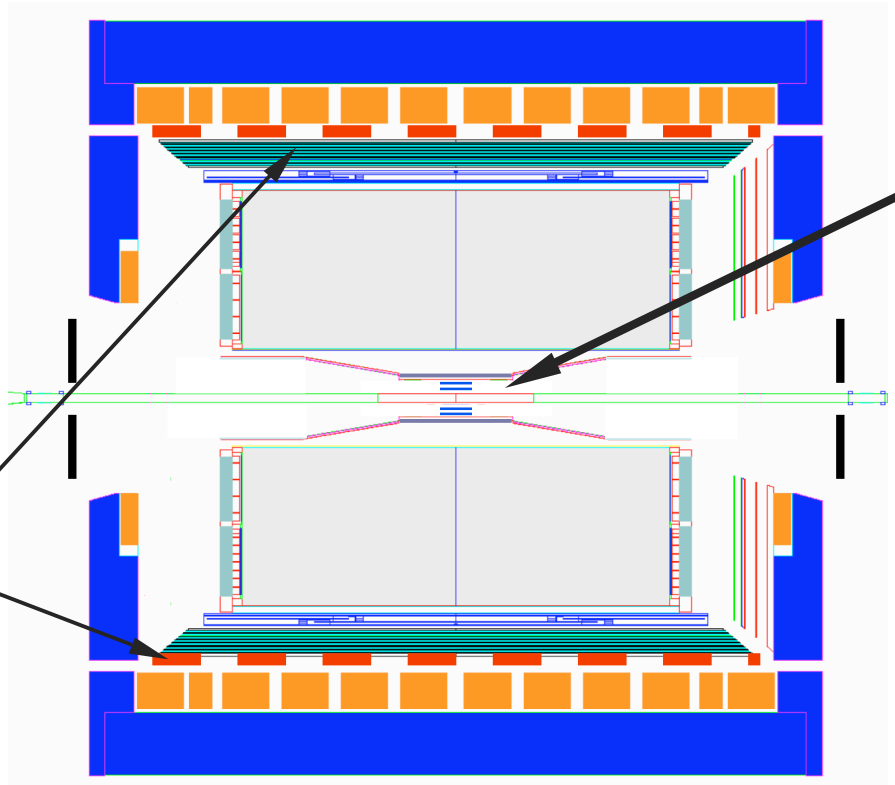


Injection energy: 9.8 => 2.3 GeV

The center of mass energy: 200 - 4.6 GeV

Low energy scan program: 20 - 4.6 GeV

STAR Upgrade Programs



HFT: 2 layers of Si at mid-y
Finish: 2010

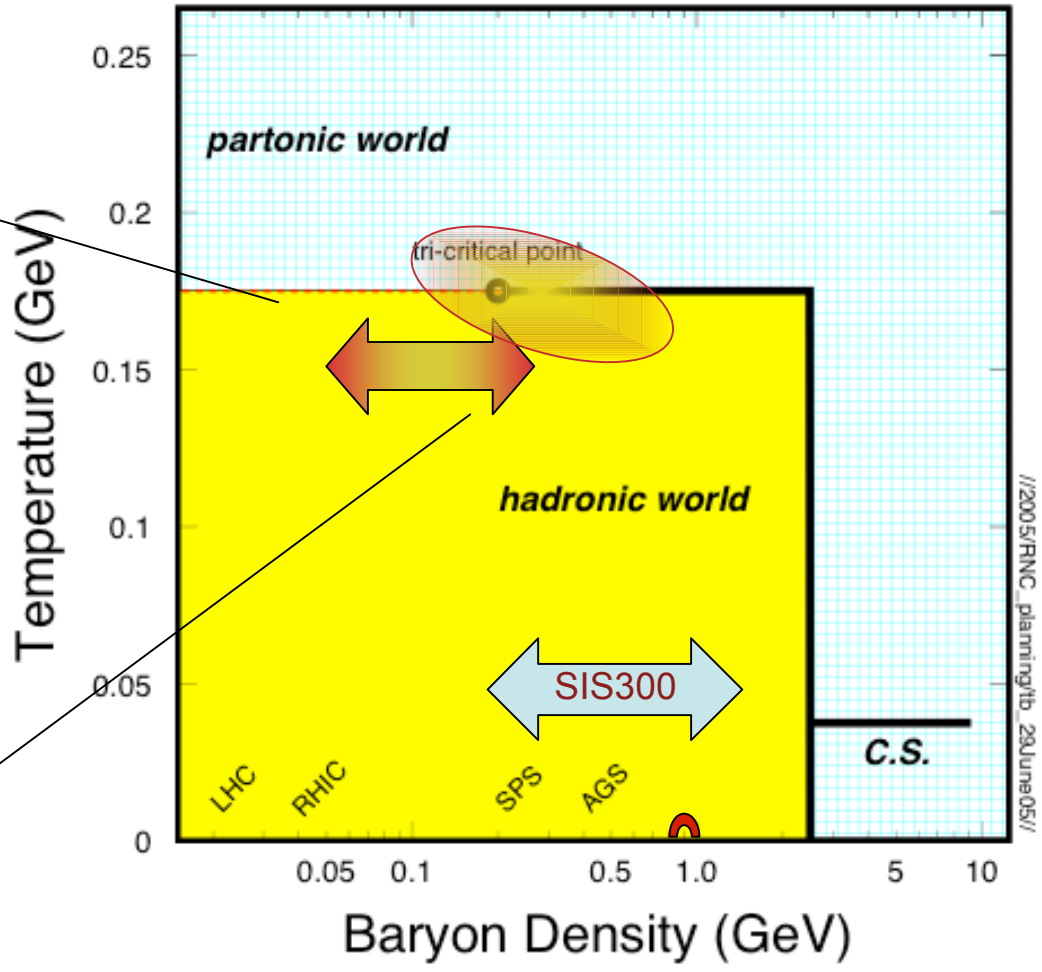
STAR MRPC ToF:
$\Delta\varphi=2\pi$ at mid-y
Finish: 2008

TOF: Large acceptance: 2π coverage at mid-y and low p_T
Good PID: K, π ID p_T ~ 1.8 GeV/c and p ID p_T ~ 4GeV/c

HFT: Allows to reconstruct conversions effectively.
Very important for di-lepton program

QCD Phase Diagram

High excitation
Partonic d.o.f. dominant
"Tsunami at deep ocean"
Null effect!!!



Energy scan:

Turn off partonic activities
- ϕ,Ω, D-meson $v_2 \Rightarrow 0$
- jet-quching disappear

Look for our
"Native hadronic shore"

Systematic study of correlation/fluctuations
Systematic of di-lepton signal

U+U collisions
Large acceptance !!!

Observables

- Spectra, v_2, and HBT of π, K, p, ϕ, Λ, Δ, Ξ, Ω, D, J/ψ
- Vector mesons: ρ, a_1, …

- Fluctuations: $\langle N(h^{\pm}) \rangle$, $\langle N(K)/N(\pi) \rangle$, $\langle N(p)/N(\pi) \rangle$, $\langle p_T \rangle$, σ_{dy}…

- Beam energy: RHIC **20 -- 4.6** GeV
  FAIR **8.2 -- 2.1** GeV

Step I: Disappearance of partonic activities

Step II: Fluctuation and vector meson production

Theoretical efforts, predictions, are essential!

QCD is great, we know!
Please give a (some) measurable prediction(s)!