Study QCD Phase Structure in High-Energy Nuclear Collisions

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Outline

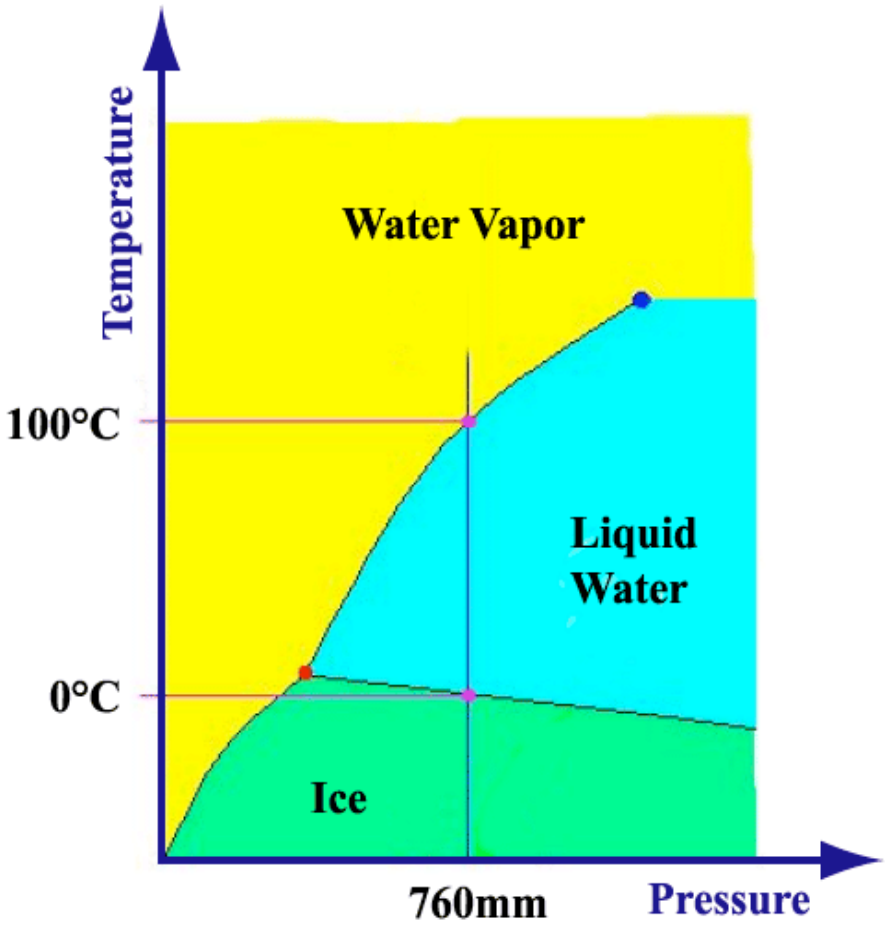
(1) Introduction

(2) Recent results on the formation of partonic matter at RHIC

(3) STAR physics program (BES)

(4) Summary

Phase Structure(s) of Matter



Phase Diagram: How matter organize itself under external conditions.

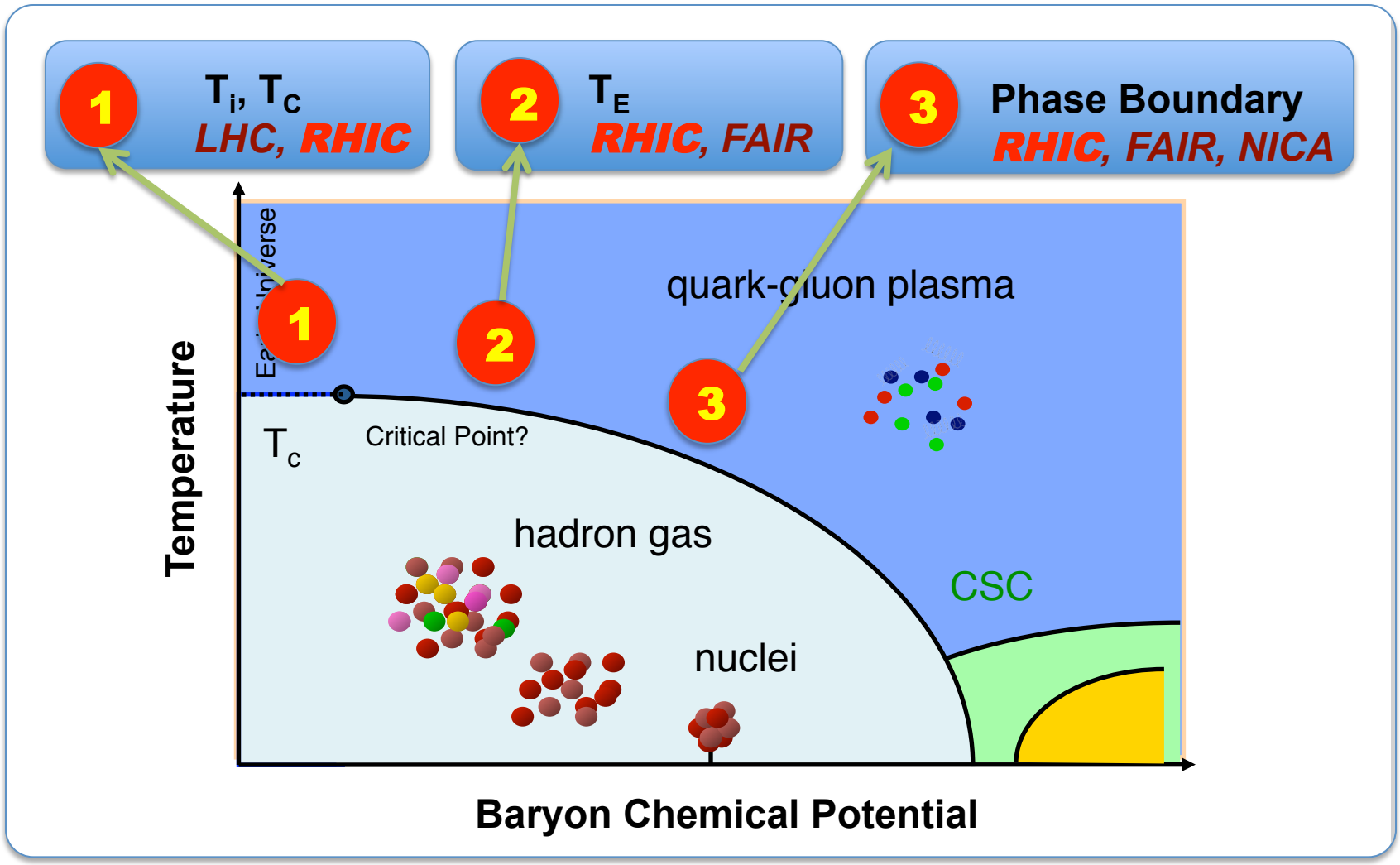
Water: EM interactions

How about strong interaction, ***matter*** with partonic degrees of freedom?

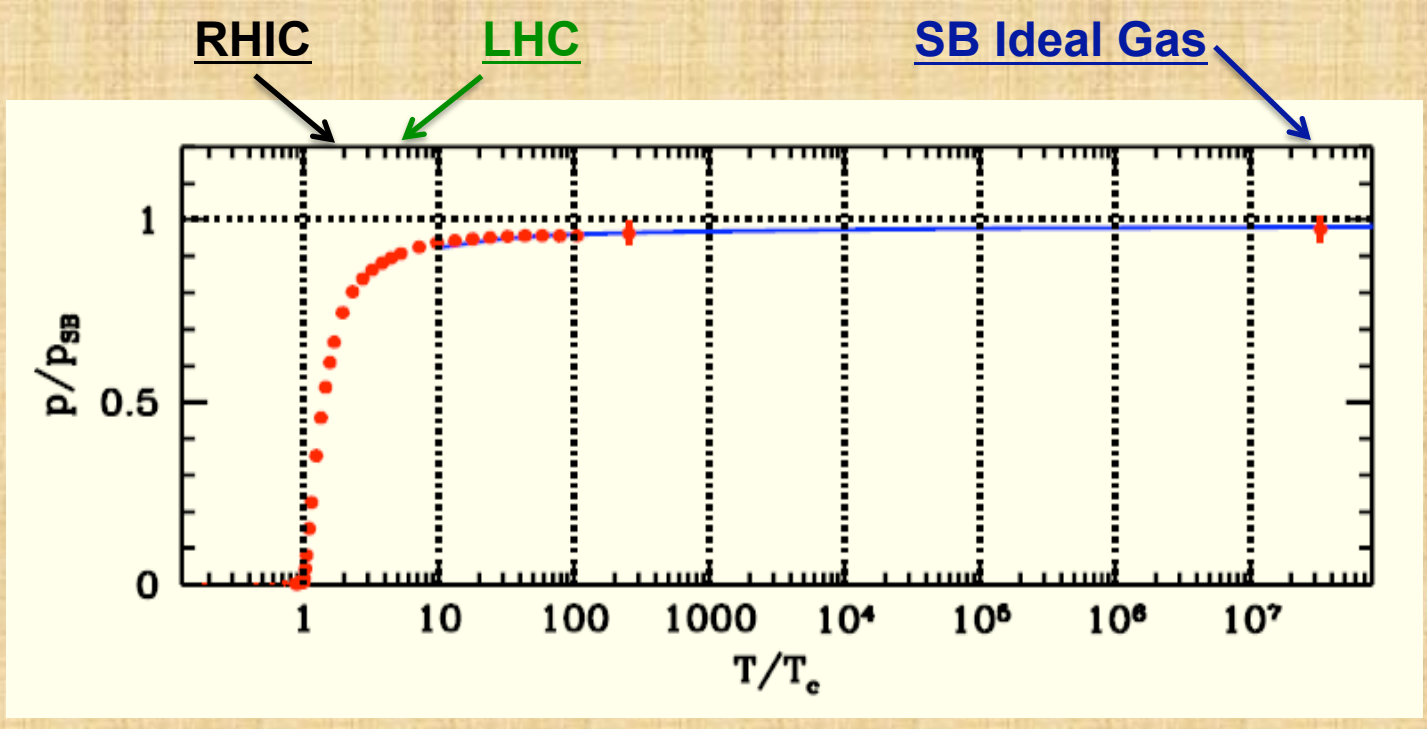
- ***Basic interactions***
- ***Structure, Organization***

http://serc.carleton.edu/research_education/equilibria/phaserule.html

The QCD Phase Diagram and High-Energy Nuclear Collisions



QCD Thermodynamics



1) At $\mu_B = 0$: cross over transition, $150 < T_c < 200$ MeV

2) The SB ideal gas limit: $T/T_c \sim 10^7$

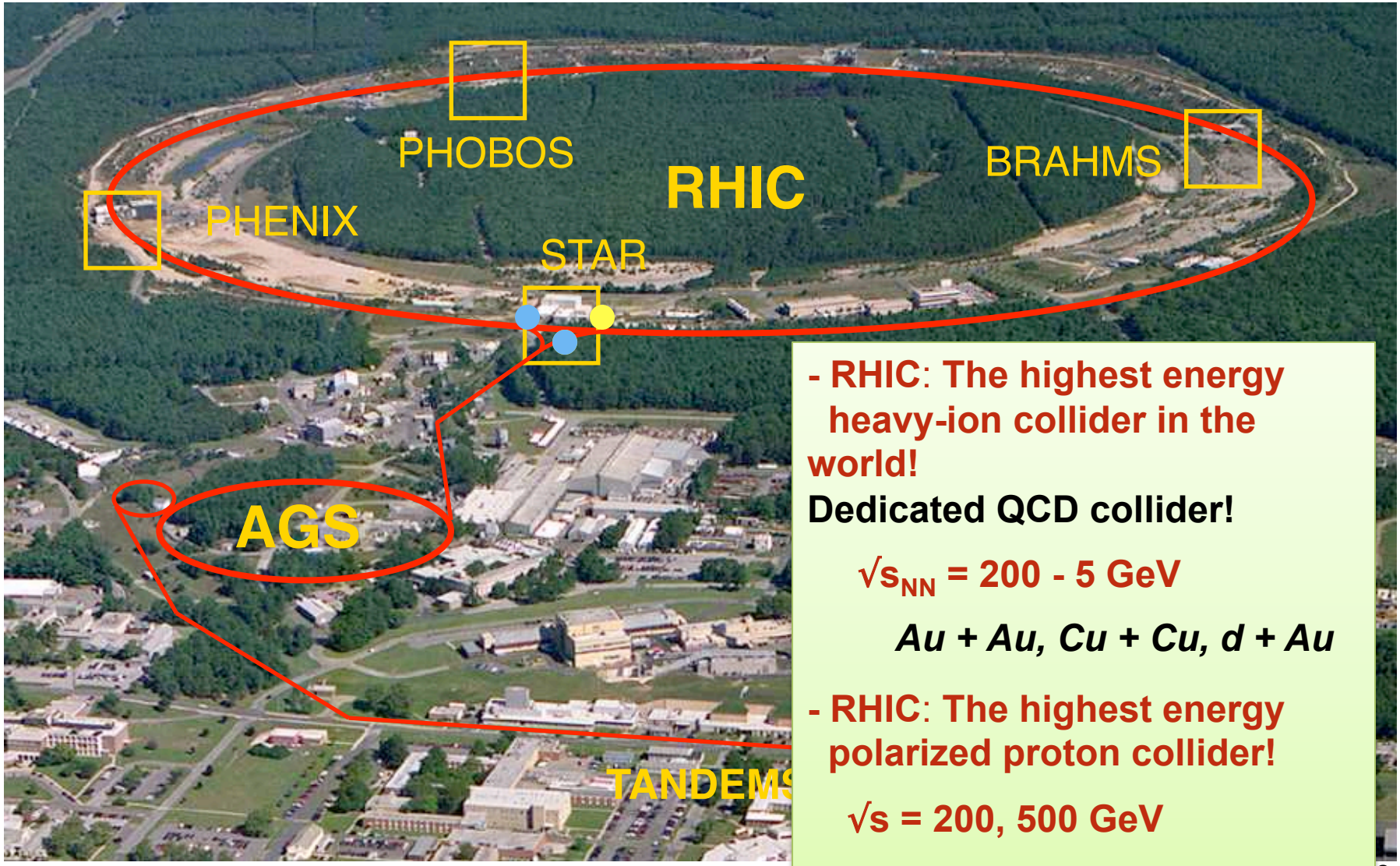
3) T_{ini} (LHC) ~ 2-3*T_{ini} (RHIC)

4) Thermodynamic evolutions are similar for RHIC and LHC

Zoltan Fodor, Lattice 2007

Relativistic Heavy Ion Collider (RHIC)

Brookhaven National Laboratory (BNL), Upton, NY



- RHIC: The highest energy heavy-ion collider in the world!

Dedicated QCD collider!

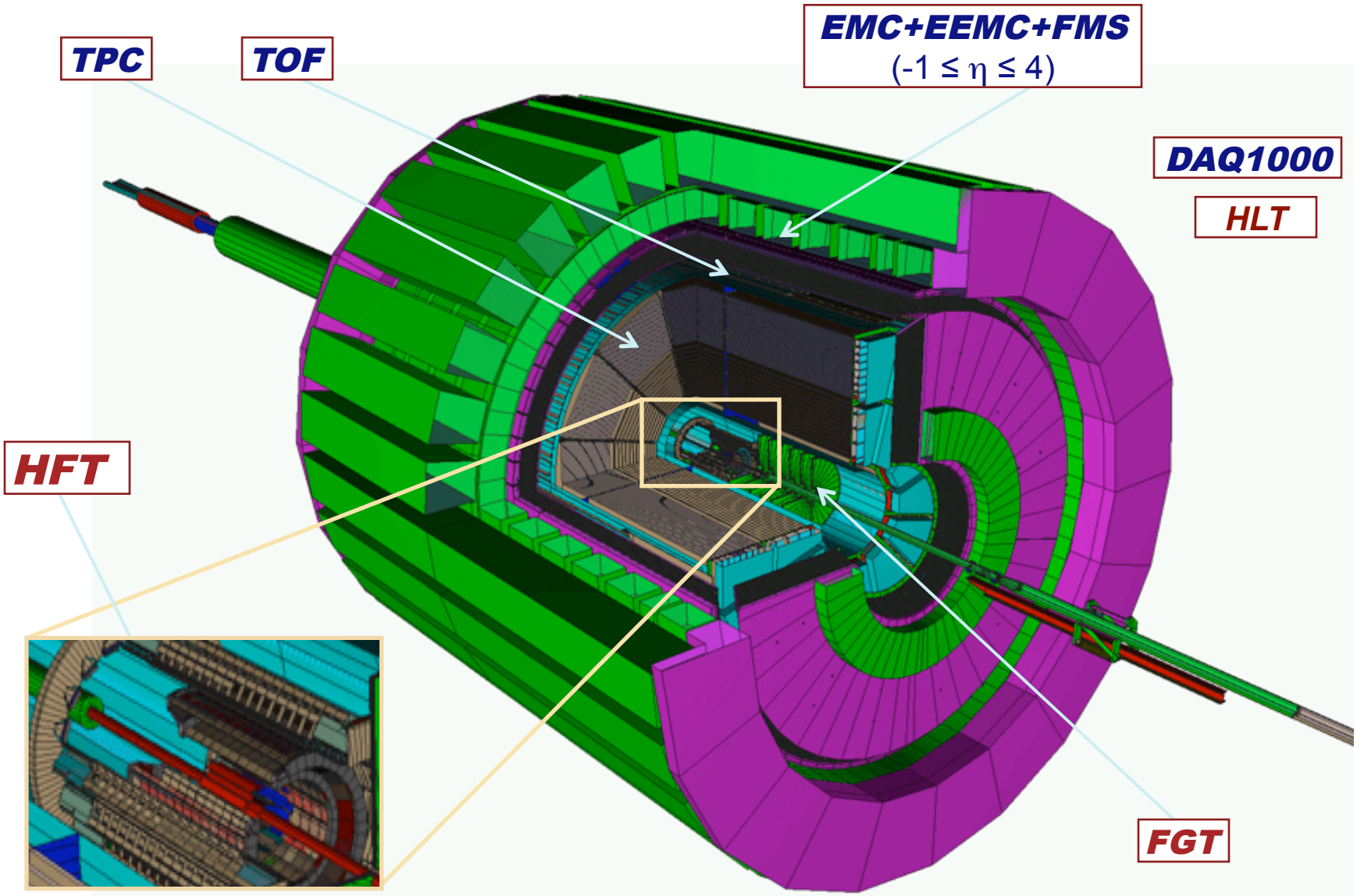
$\sqrt{s_{NN}}$ = 200 - 5 GeV

Au + Au, Cu + Cu, d + Au

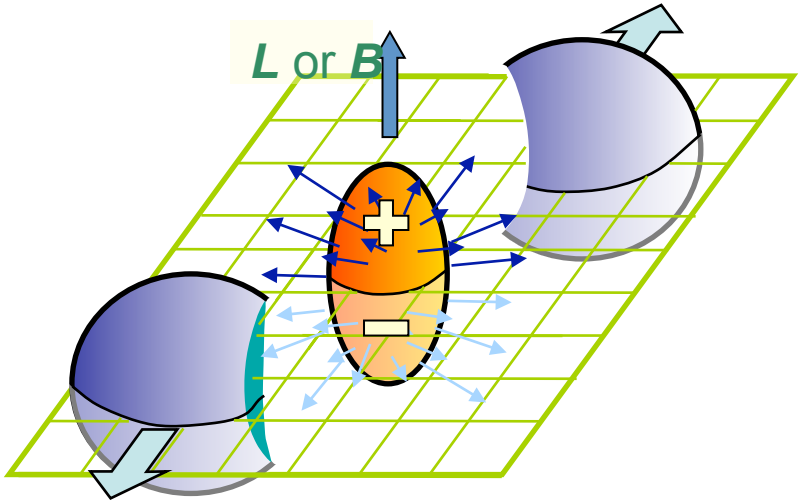
- RHIC: The highest energy polarized proton collider!

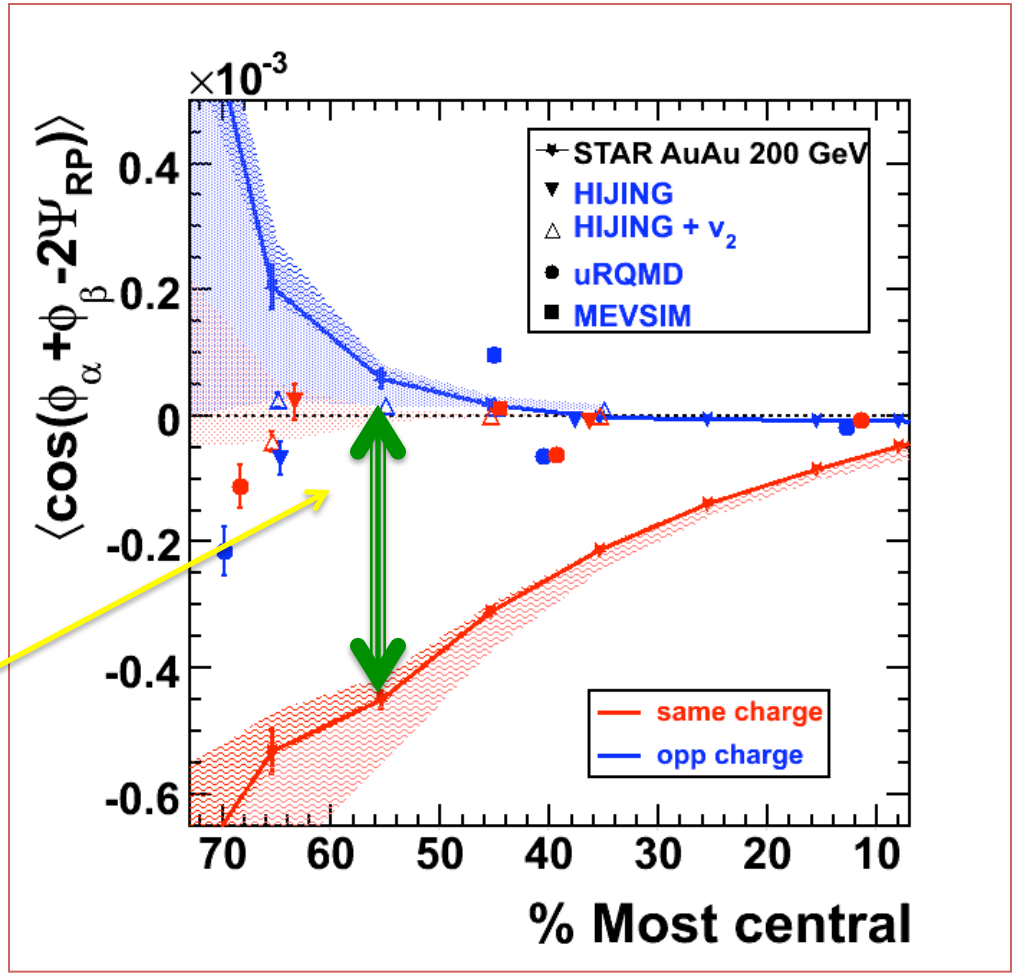
$\sqrt{s}$ = 200, 500 GeV

STAR Detectors: *Full 2π particle identification!*



Search for Local Parity Violation





The separation between the same-charge and opposite-charge correlations.

- Strong EM fields
- De-confinement and Chiral symmetry restoration

Voloshin, PR C62, 044901(00).

STAR; arXiv: 0909.1739 (PRL); 0909.1717 (PRC).

First Observation of $^{3}_{\Lambda}\overline{H} \rightarrow {}^{3}\overline{He} + \pi^{+}$

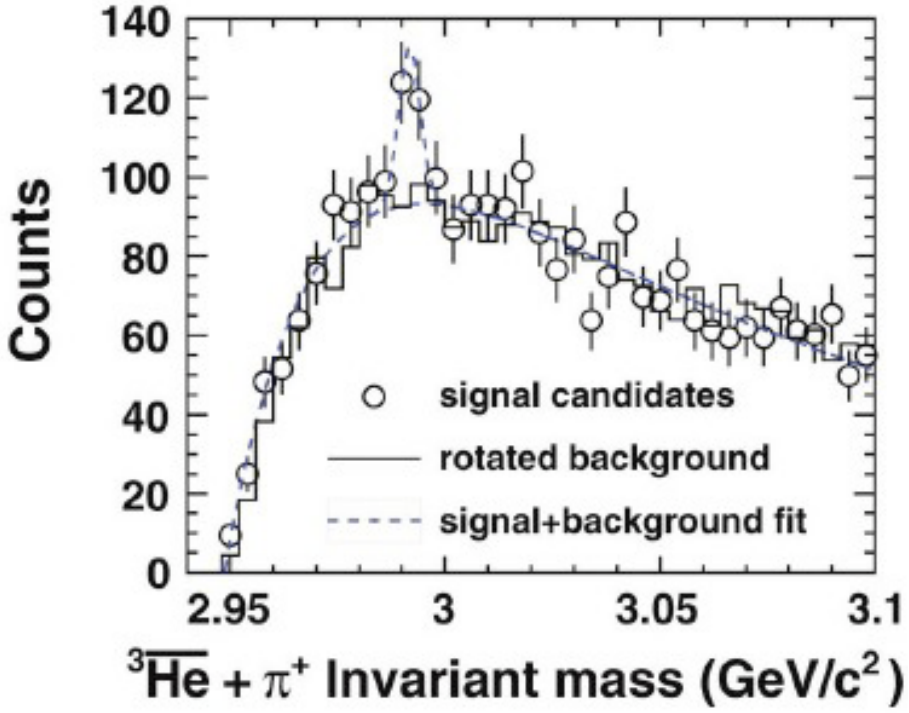
Sciencexpress Research Article

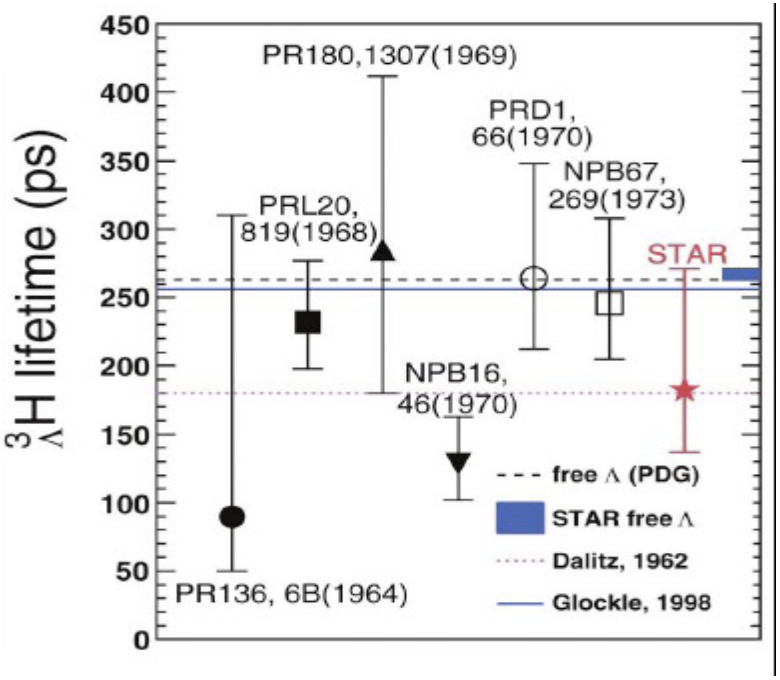
Observation of an Antimatter Hypernucleus

The STAR Collaboration*†

200 GeV Au+Au collisions at RHIC

- Equilibrium of s-quarks
- Thermal models (Stachel *et al*.)

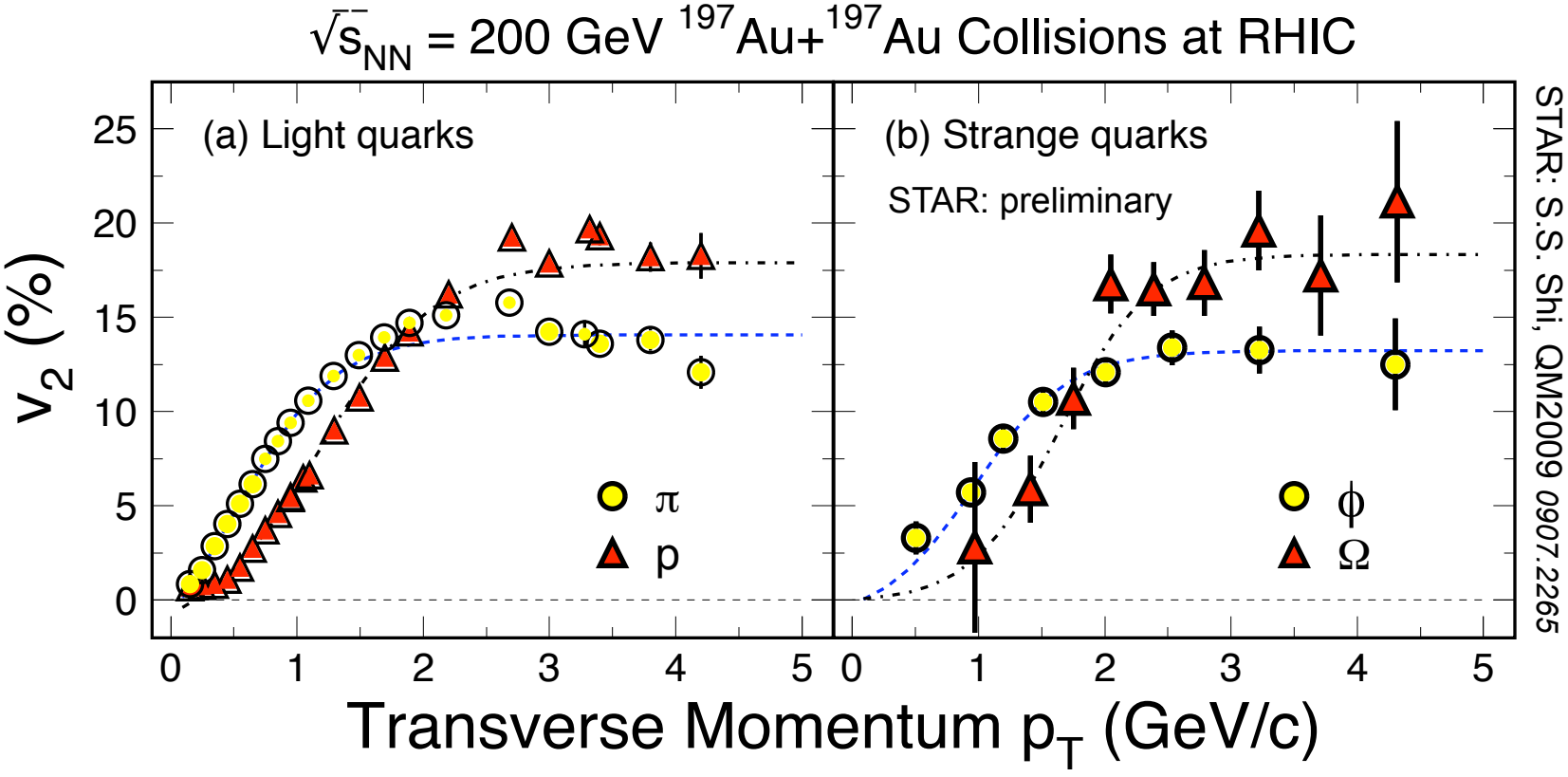




First observation of **the anti-hypernucleus**

STAR Collaboration, see Zhangbu Xu's talk

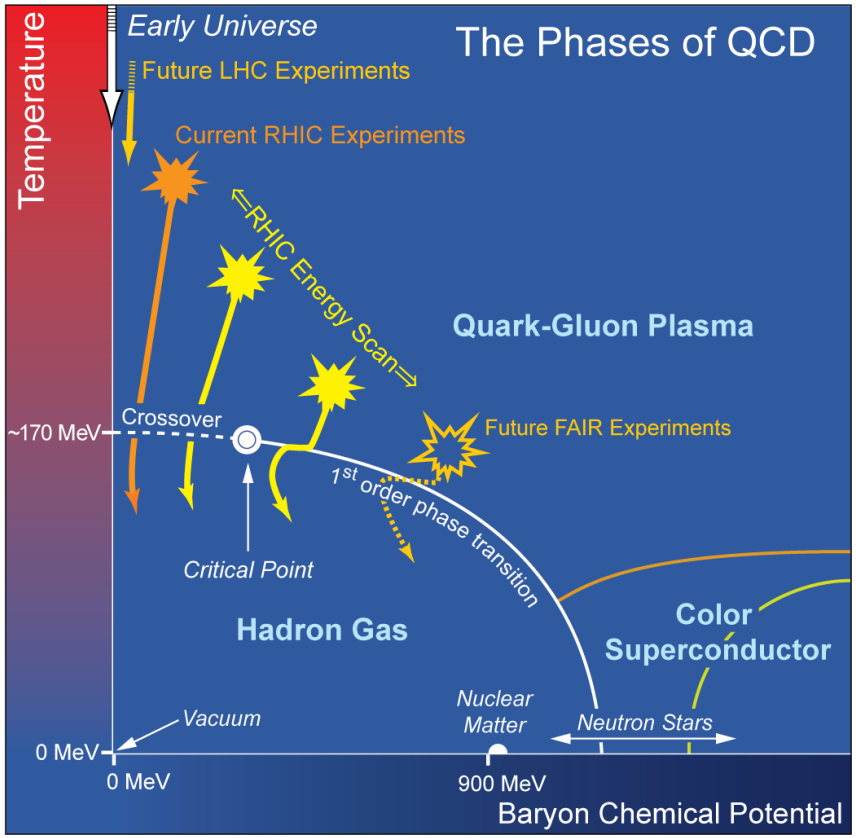
Partonic Collectivity at RHIC



Low p_T (≤ 2 GeV/c): hydrodynamic mass ordering
High p_T (> 2 GeV/c): number of quarks ordering
s-quark hadron: smaller interaction strength in hadronic medium
light- and s-quark hadrons: similar v_2 pattern

=> Collectivity developed at partonic stage!

The QCD Critical Point



RHIC (200) & LHC: Determine the temperature T_{ini}, T_C

BES: Explore the QCD phase diagram T_E and the location *phase boundary*

- LGT prediction on the transition temperature T_C is robust.

- LGT calculation, universality, and models hinted the existence of the critical point on the QCD phase diagram* at finite baryon chemical potential.

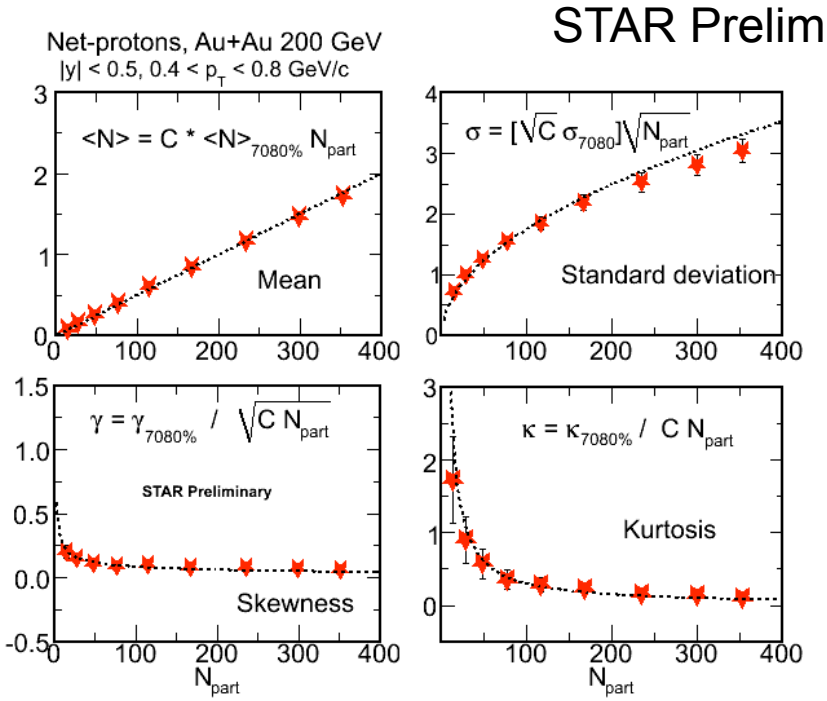
- Experimental evidence for either the critical point or 1st order transition is important for our knowledge of the QCD phase diagram*.

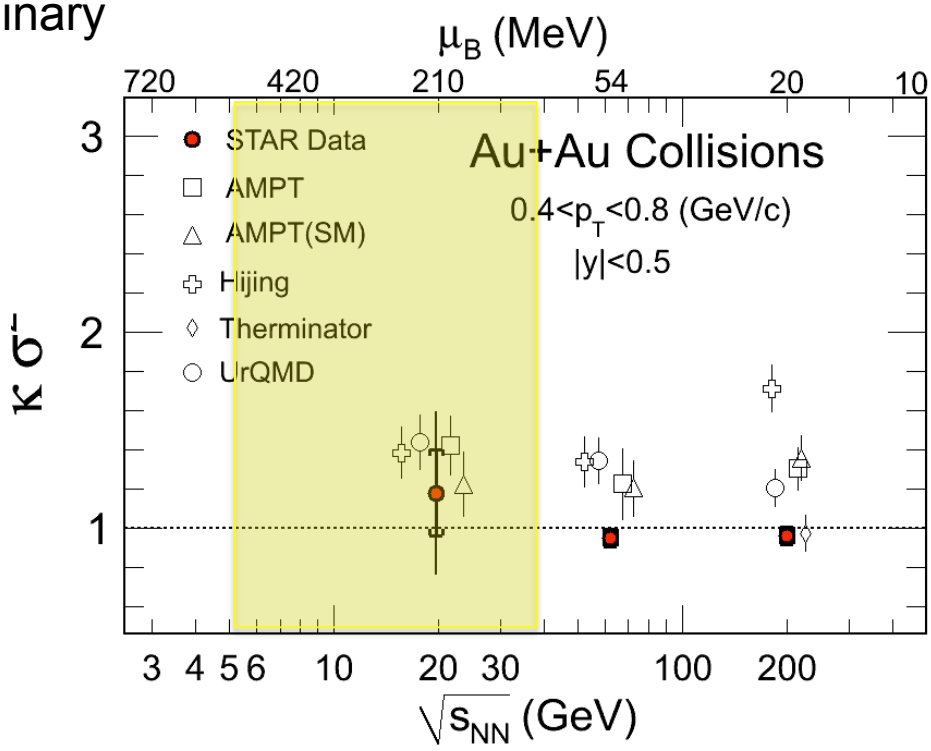
** Thermalization has been assumed*

*M. Stephanov, K. Rajagopal, and E. Shuryak, PRL **81**, 4816(98); K. Rajagopal, PR **D61**, 105017 (00)*

http://www.er.doe.gov/np/nsac/docs/Nuclear-Science.Low-Res.pdf

High Moment Analysis (BES)



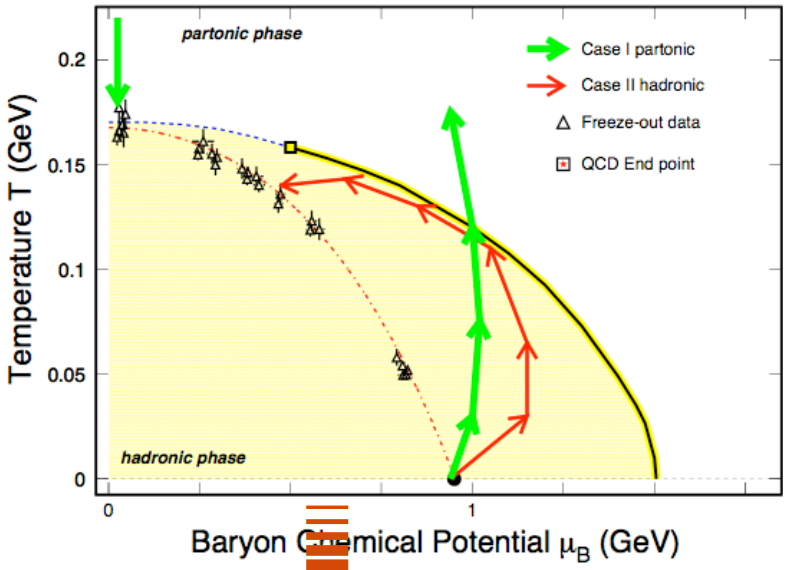


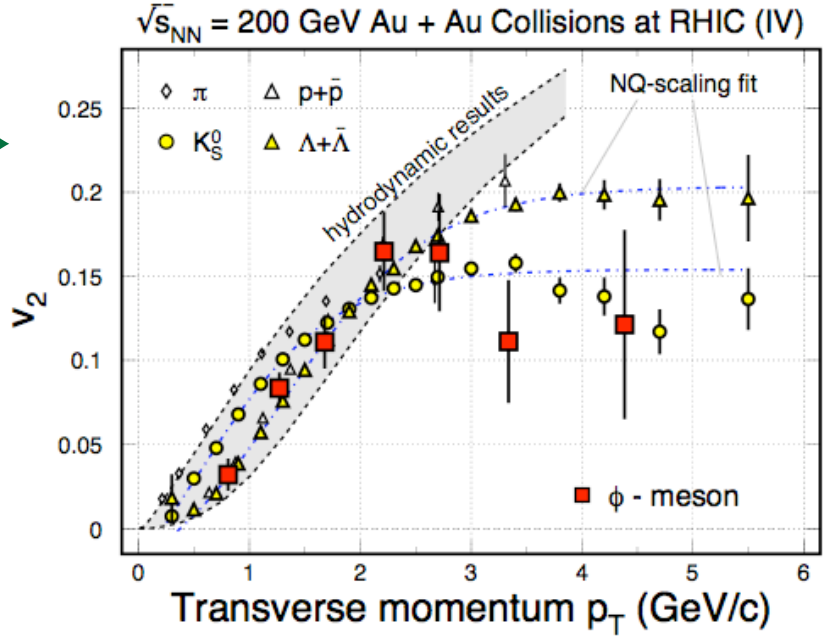
1) High moments are more **sensitive to critical point** related fluctuation.

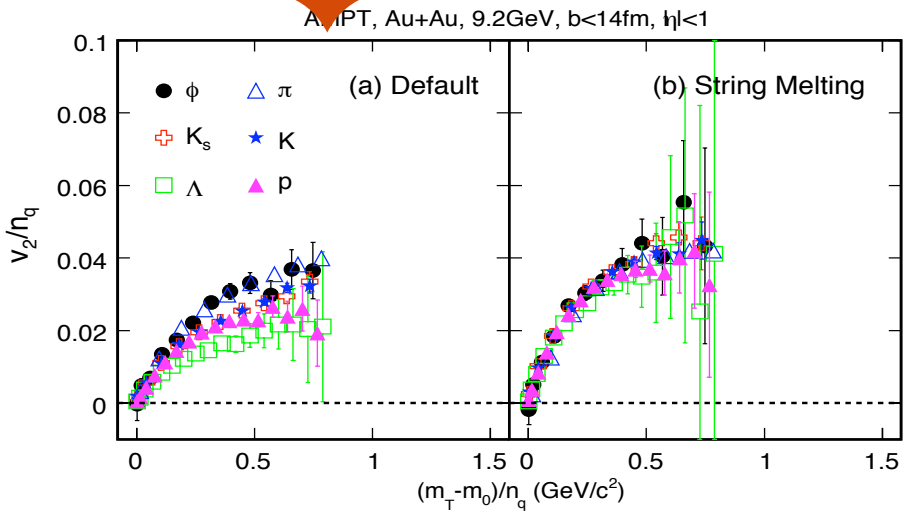
2) The 4th moment, Kurtosis, is **directly related to the corresponding thermodynamic quantity**: susceptibility for conserved quantum numbers such as Baryon number, charge, strangeness…

See HG Ritter's talk

Observable*: Quark Scaling in v_2







STAR Collaboration: F. Liu, S.S. Shi, K.J. Wu et al.

- $m_\phi \sim m_p \sim 1$ GeV
- ss ⇨ φ not K^+K^- ⇨ φ
- $\sigma_{\phi h} << \sigma_{p\pi,\ \pi\pi}$

In the hadronic case, no number of quark scaling and the value of v_2 of φ will be small.

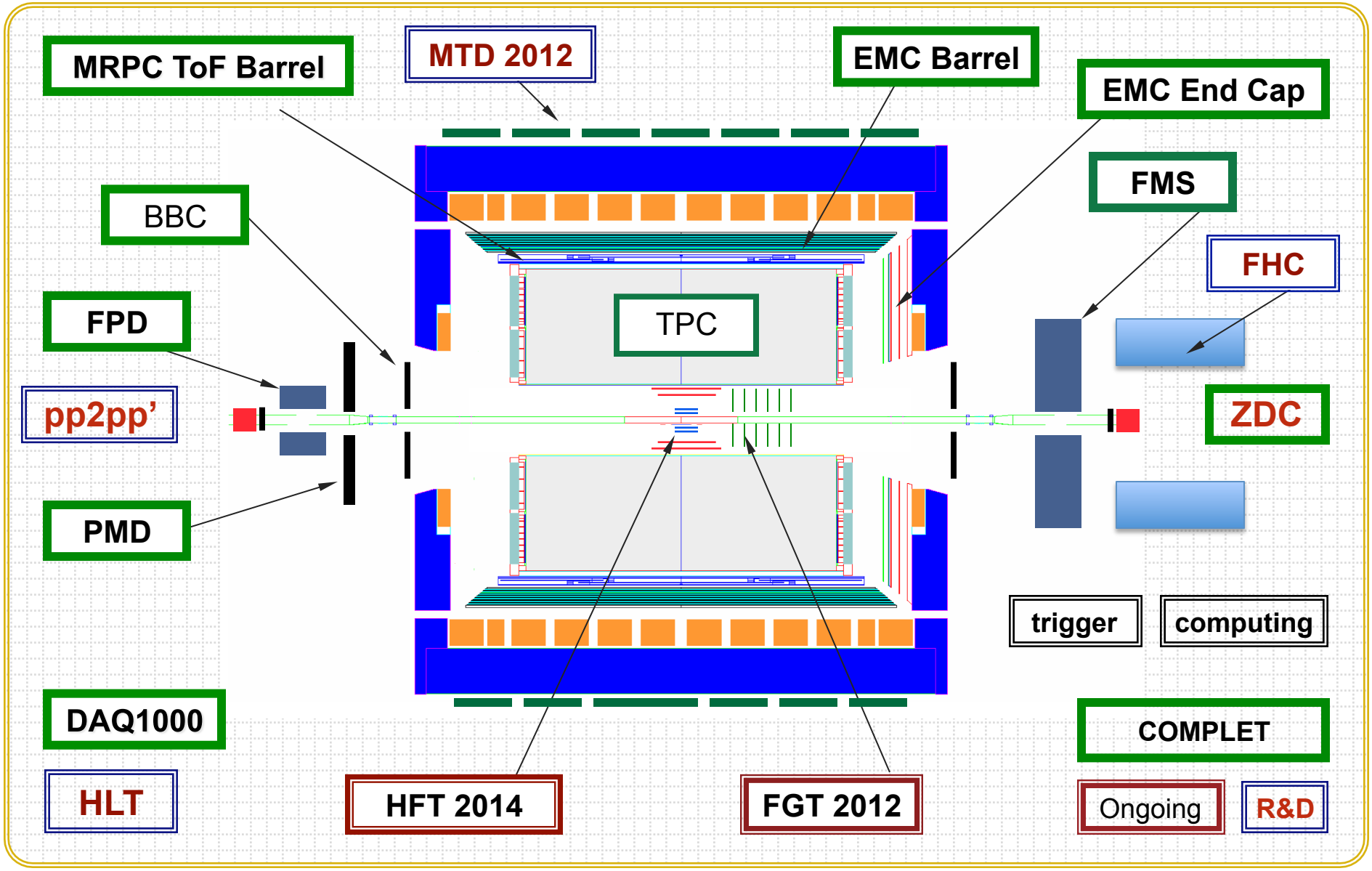
*** Thermalization is assumed!**

STAR Run10 Physics Programs

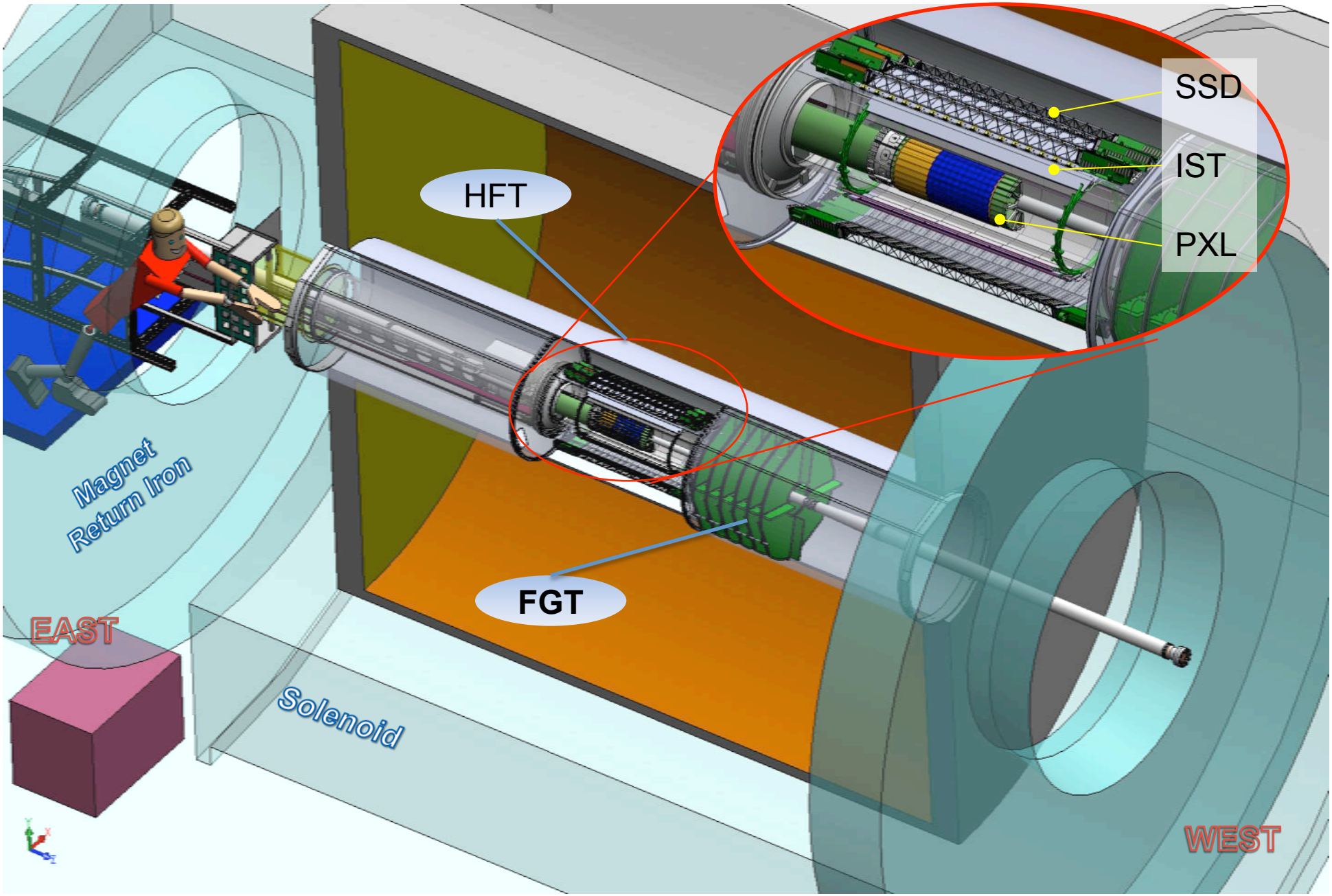
Beam Energy (GeV)	29 cryo-week	STAR BUR In days	Physics
200	11 1/2 - 3/18	56	
62.4	4 3/20 - 4/17	0	
39	1.5 4/8 – 4/21	5 (24M)	BES programs (1) QCD T_E (2) QCD phase boundary
27		15 (33M)	
18		16 (15M)	
11.5	2 **6/7 - 21**	19 (5M)	
7.7	4 4/21 – 5/31	56 (5M)	
5.5	0.5 6/2 - 5	5 (0.1M)	

Weekly planning info: *http://www.c-ad.bnl.gov/esfd/RMEM_10/rhic_planning.htm*

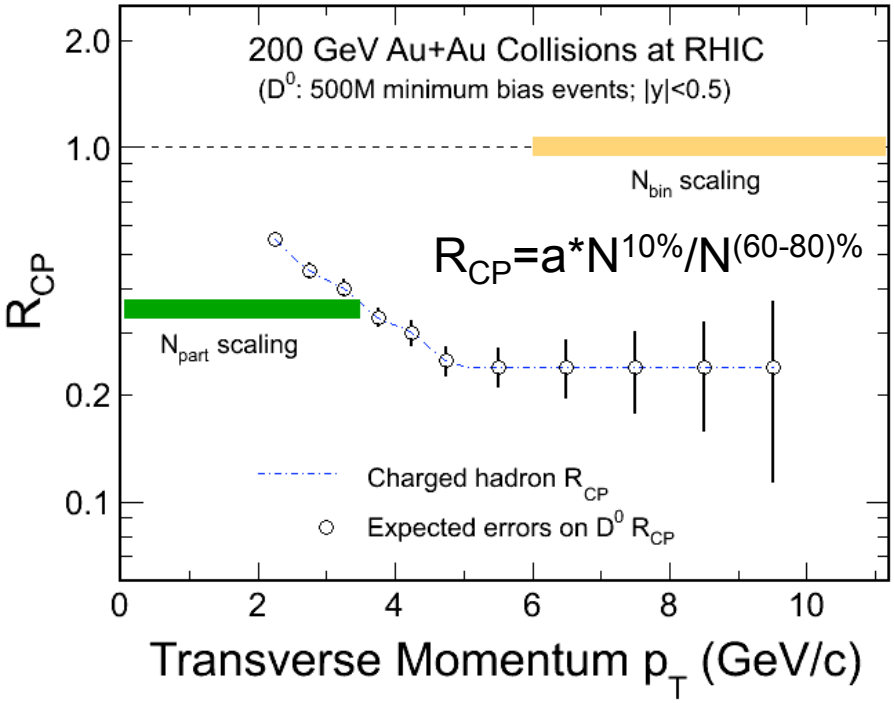
STAR Experiment

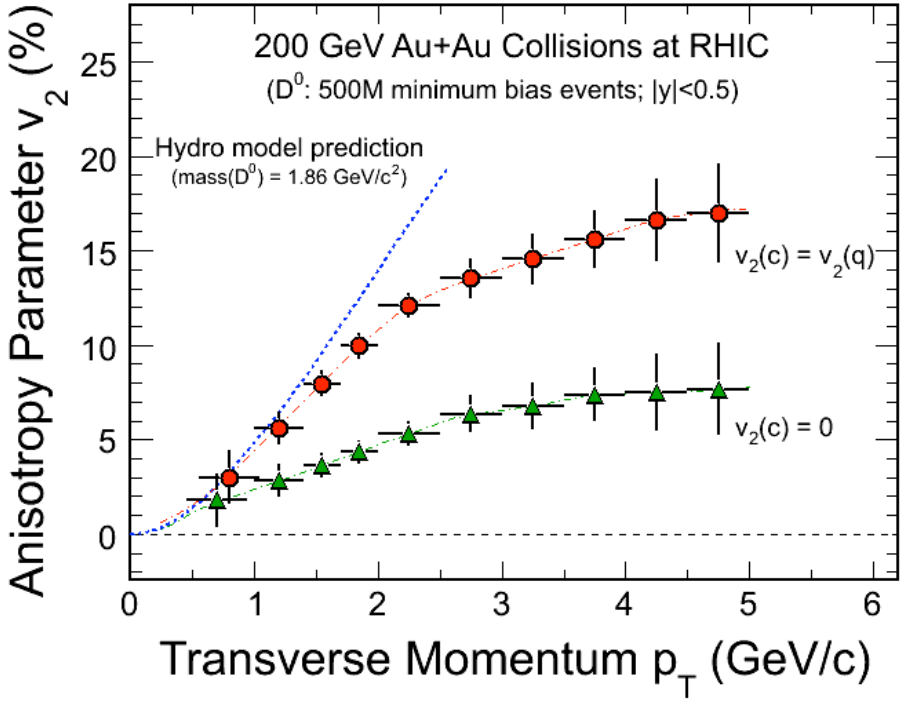


Heavy Flavor Tracker at STAR



HFT Key Measurements





Assuming D^0 R_{cp} distribution as $h^{\pm}$

500M Au+Au m.b. events at 200 GeV.

- Charm R_{AA} ⇨

Energy loss mechanism!
Interaction with QCD matter!

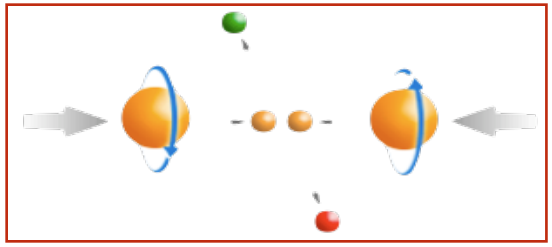
Assuming D^0 v_2 distribution from quark coalescence.

500M Au+Au m.b. events at 200 GeV.

- Charm v_2 ⇨

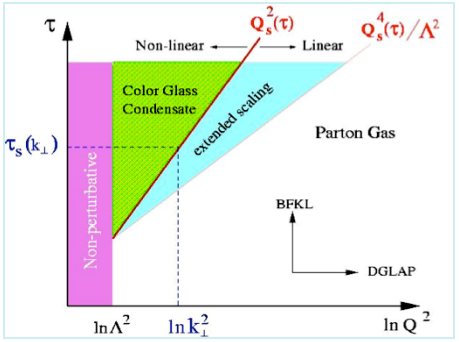
Thermalization of light-quarks!
Drag coefficients!

STAR Physics Focus



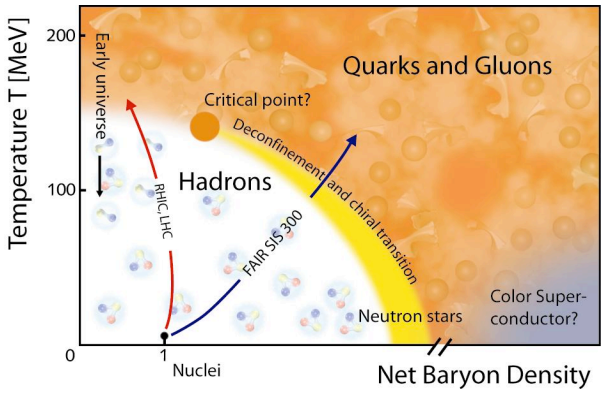
Polarized *p+p* program

- Study ***proton intrinsic properties***



Forward program

- Study low-x properties, search for ***CGC***
- Study elastic (inelastic) processes (pp2pp)
- Investigate ***gluonic exchanges***



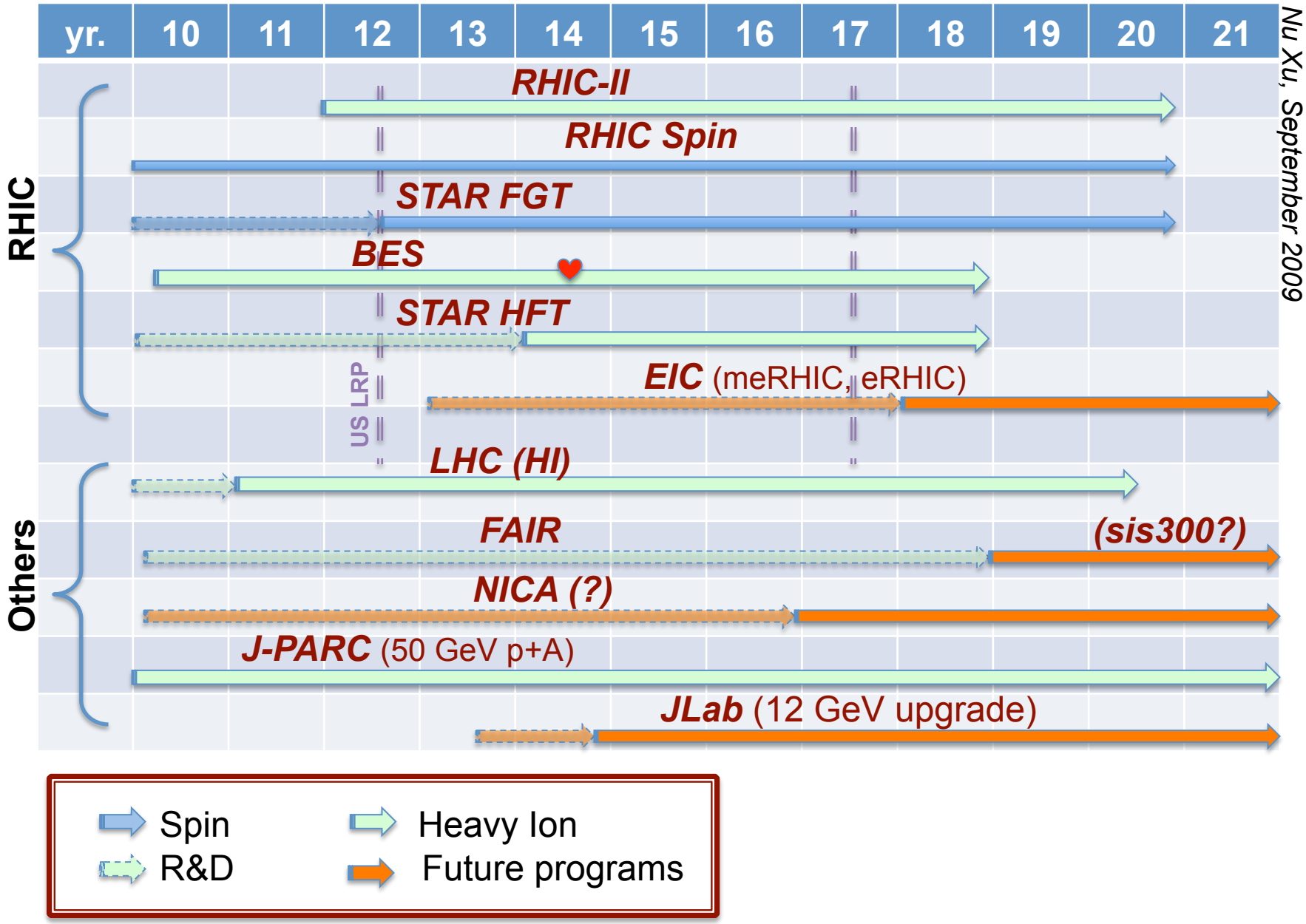
1) At 200 GeV top energy

- Study ***medium properties, EoS***
- pQCD in hot and dense medium

2) RHIC beam energy scan

- Search for the ***QCD critical point***
- Chiral symmetry restoration

Timeline of QCD and Heavy Ion Facilities



Summary

1) New form of **matter** with **partonic degrees of freedom**: evolution of the universe, QCD phase diagram, critical point, …
2) STAR at RHIC ($\sqrt{s_{NN}}$ = 200 – 5 GeV): search for phase boundary and the possible critical point.
3) CBM at FAiR ($\sqrt{s_{NN}}$ = 9 – 2 GeV): **new international endeavor** for the next **few decades'** QCD physics.

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