STAR Physics Program
- a status report

Nu Xu

Nuclear Science Division
Lawrence Berkeley National Laboratory

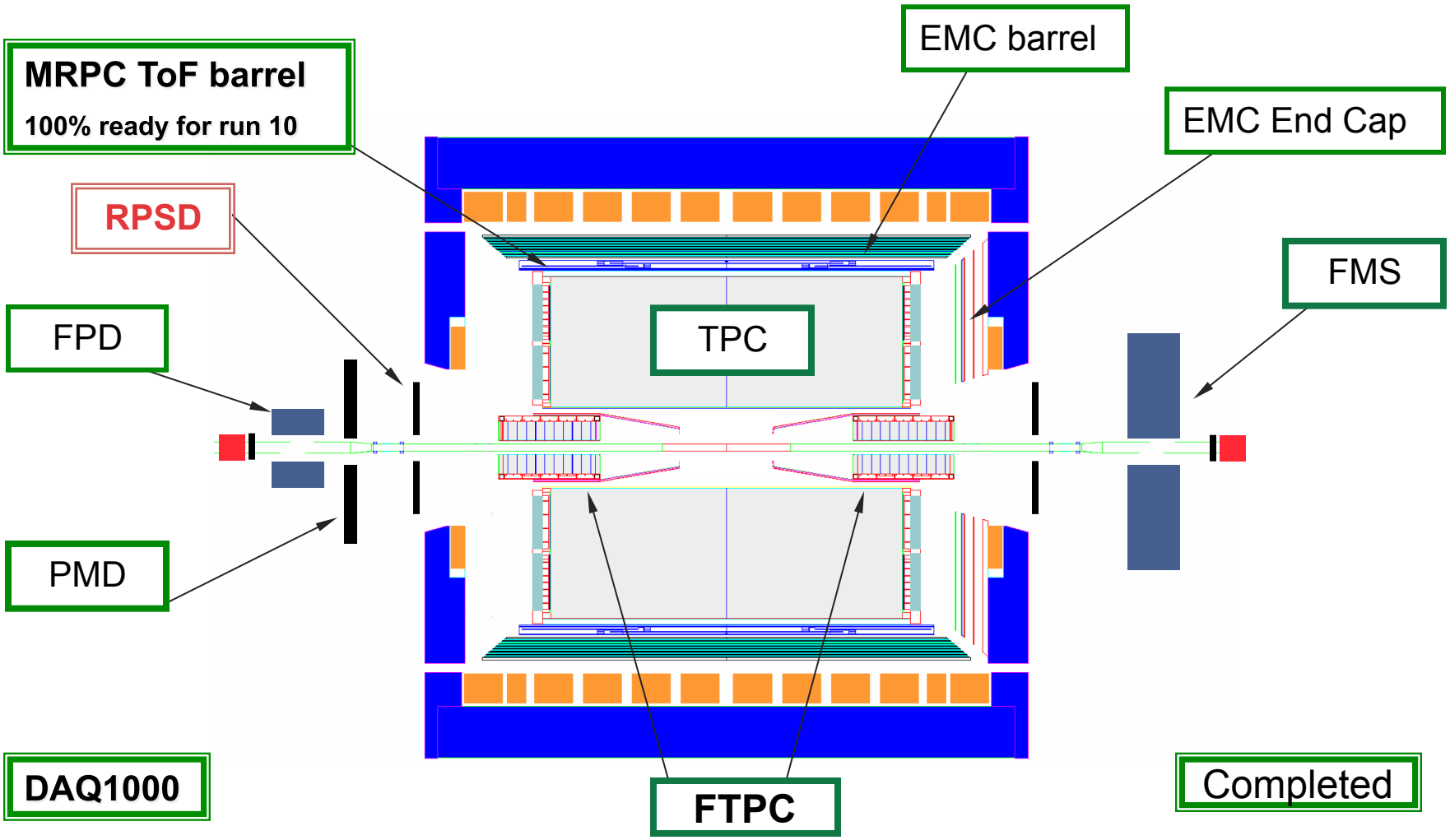
Many thanks to the organizers!

U.S. DEPARTMENT OF ENERGY

Office of Science
U.S. DEPARTMENT OF ENERGY

BERKELEY LAB

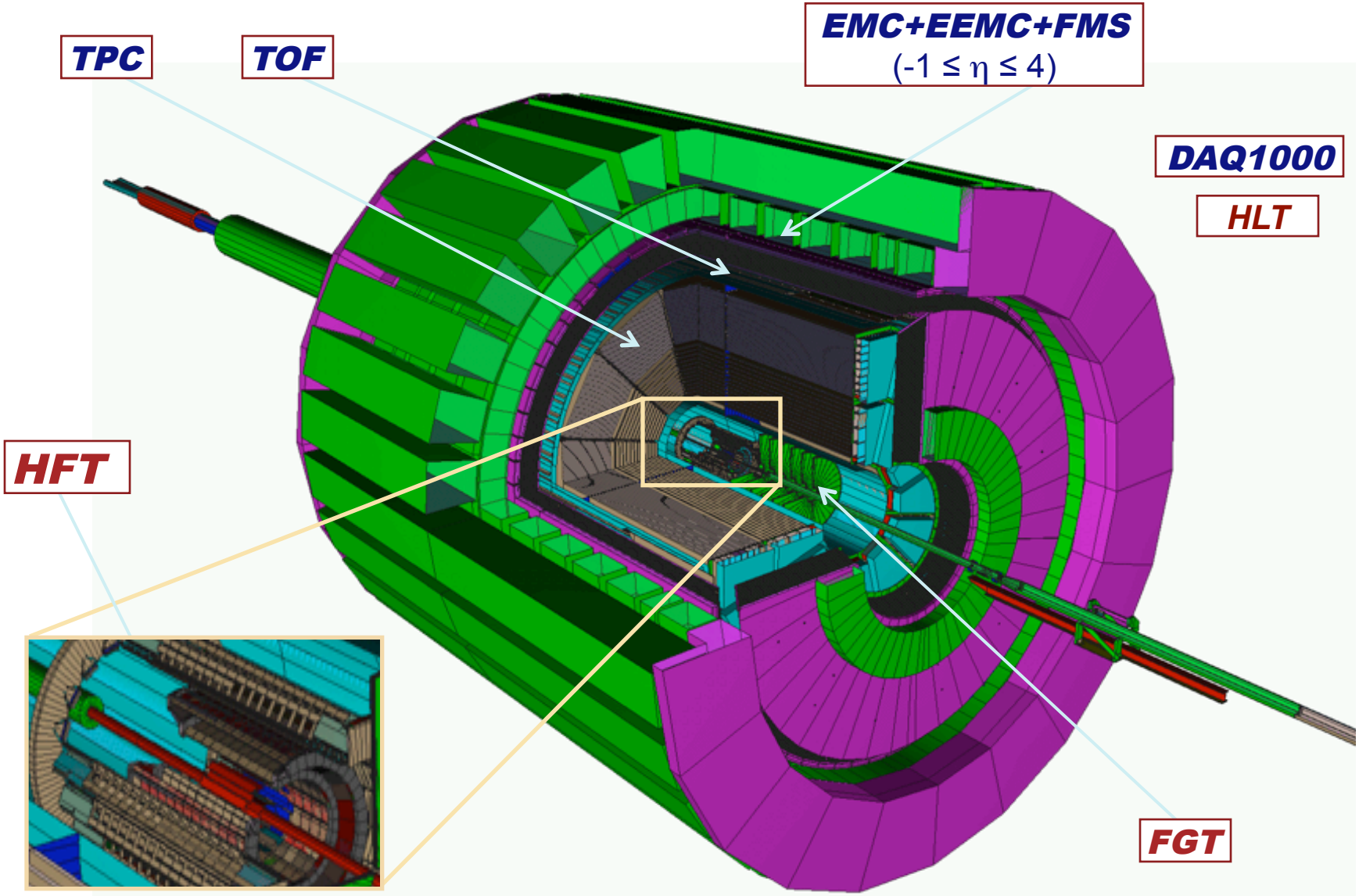
STAR Detector



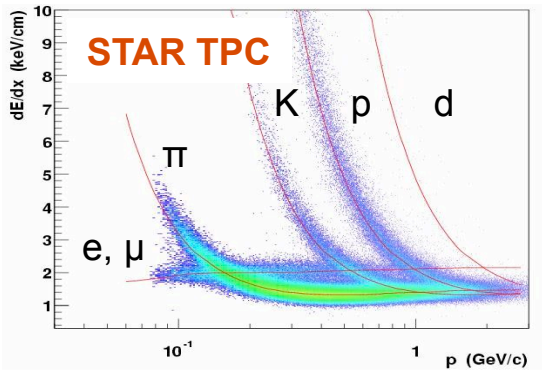
Full azimuthal particle identification!

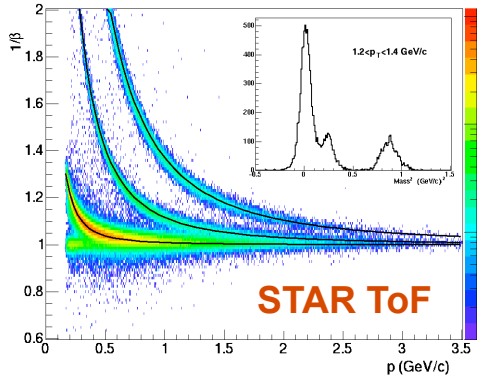
*γ, e, π, **ρ**, K, **K***, p, **φ**, Λ, Δ, Ξ, Ω, D, Λ_C, **J/ψ**, **Y** …*

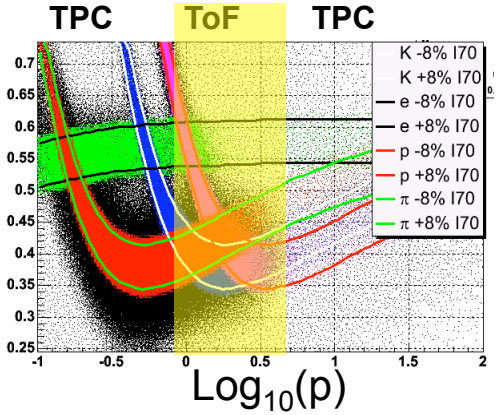
STAR Detectors: *Full 2π particle identification!*

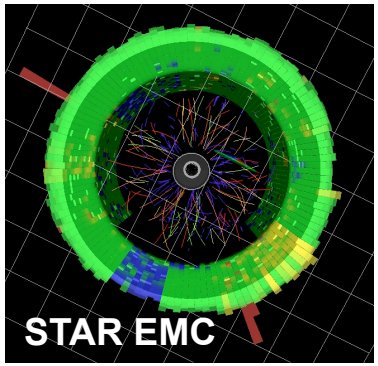


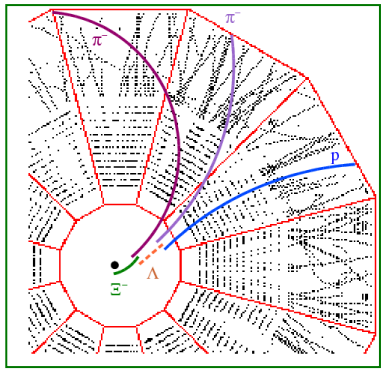
Particle Identification at STAR

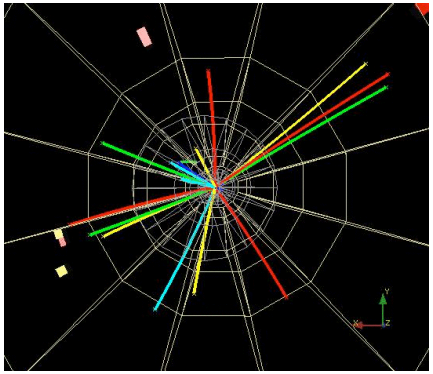


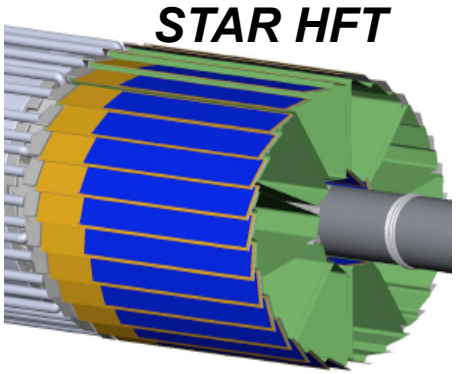








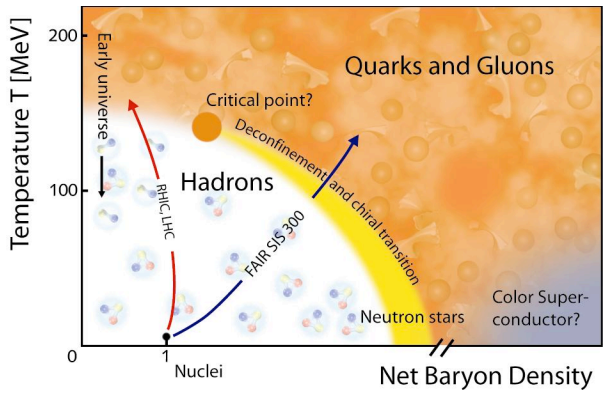




Neutral particles **Strange hyperons** **Jets** **Heavy Quark Hadrons**

Multiple-fold correlations among the identified particles!

STAR Physics Focus

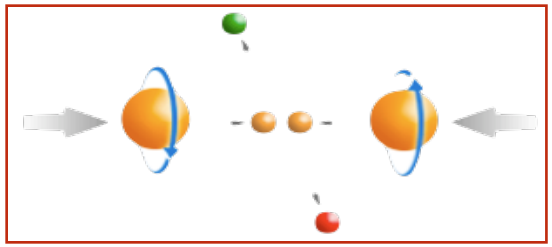


1) At 200 GeV top energy

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

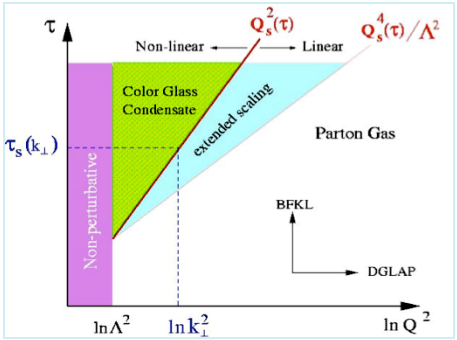
2) RHIC beam energy scan

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



Polarized spin program

- Study ***proton intrinsic properties***

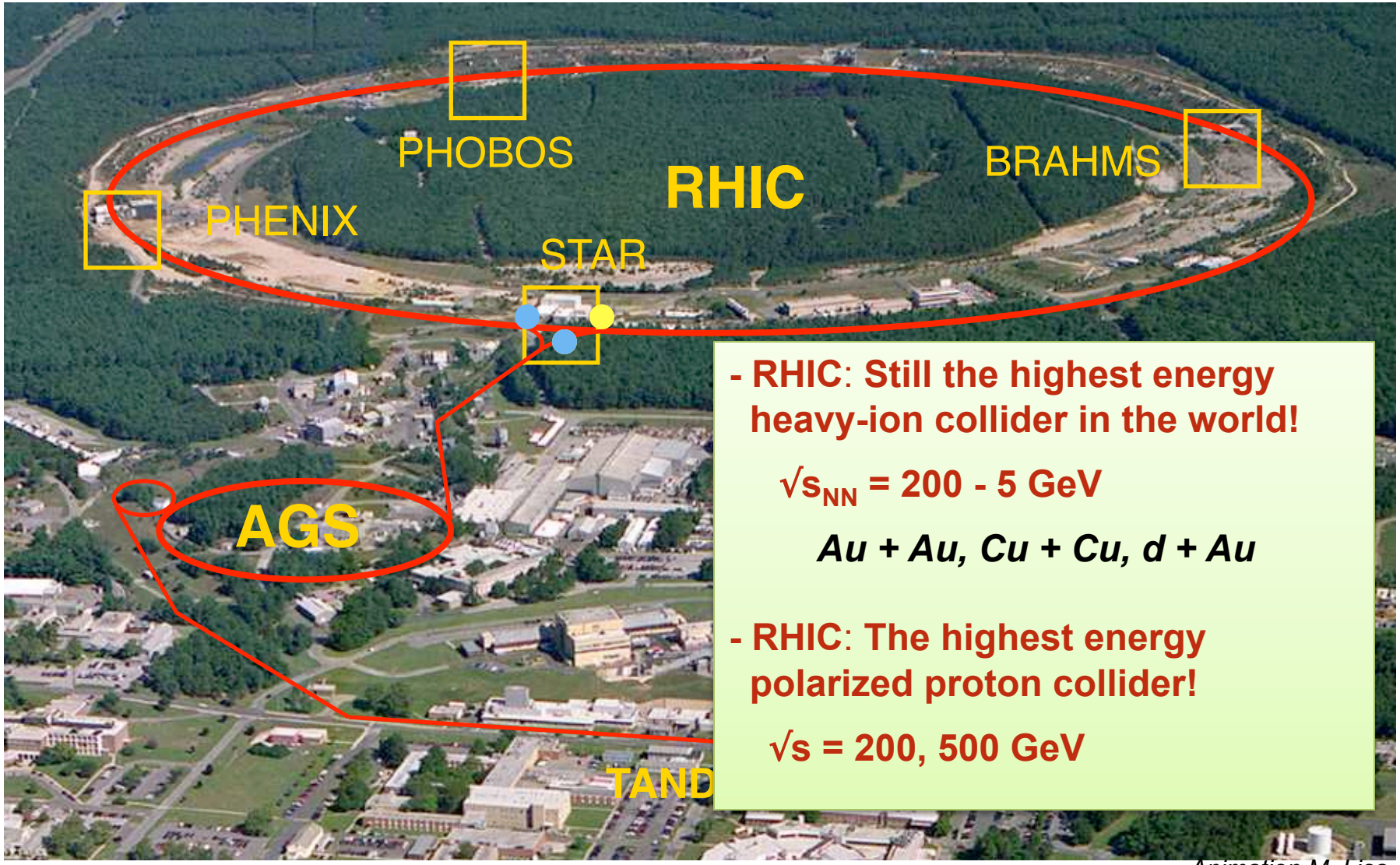


Forward program

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

Relativistic Heavy Ion Collider (RHIC)

Brookhaven National Laboratory (BNL), Upton, NY



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

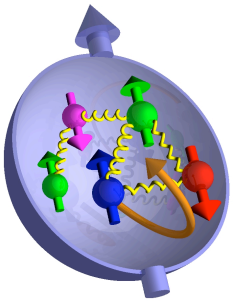
  $\sqrt{s_{NN}}$ = 200 - 5 GeV

  Au + Au, Cu + Cu, d + Au

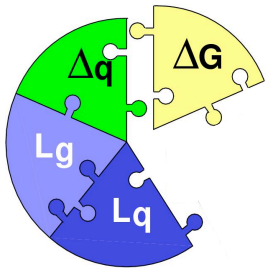
- RHIC: The highest energy polarized proton collider!

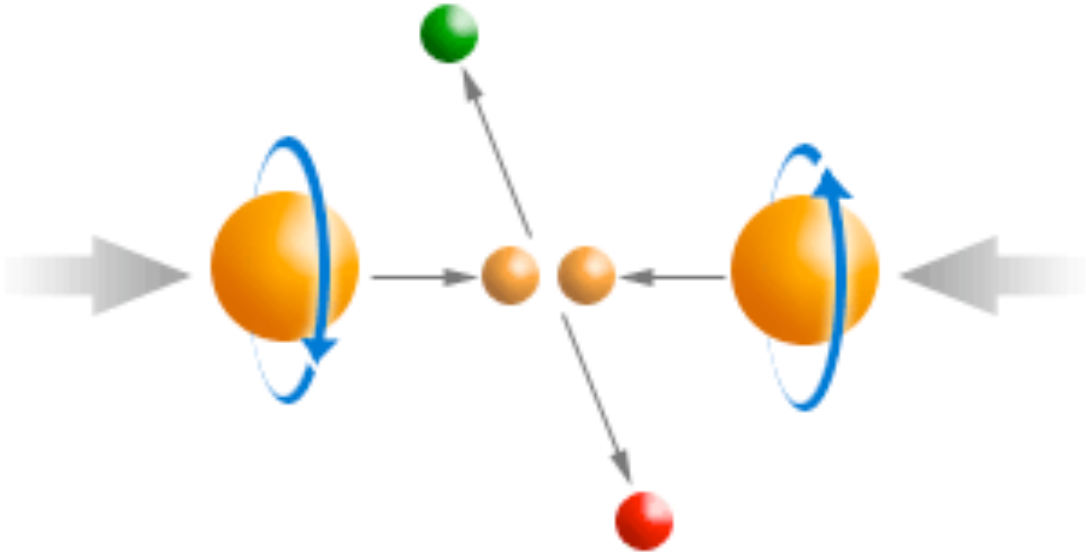
  $\sqrt{s}$ = 200, 500 GeV

Animation M. Lisa

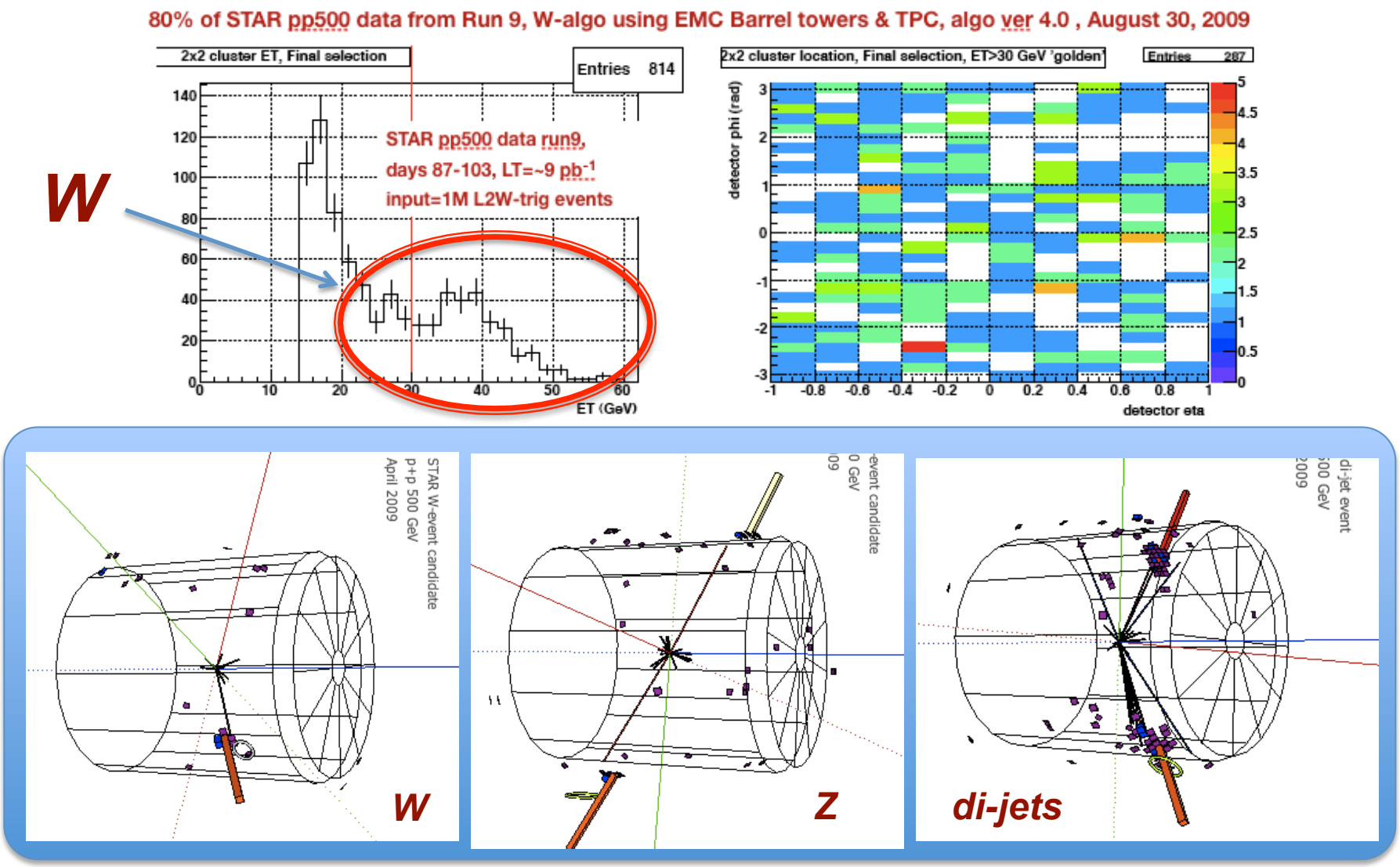


Proton Spin Physics

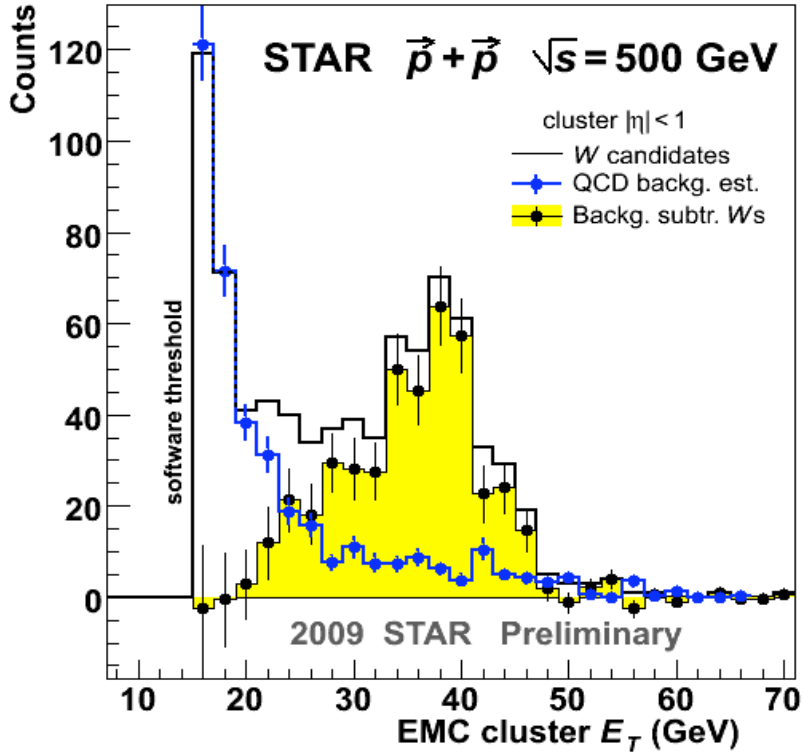


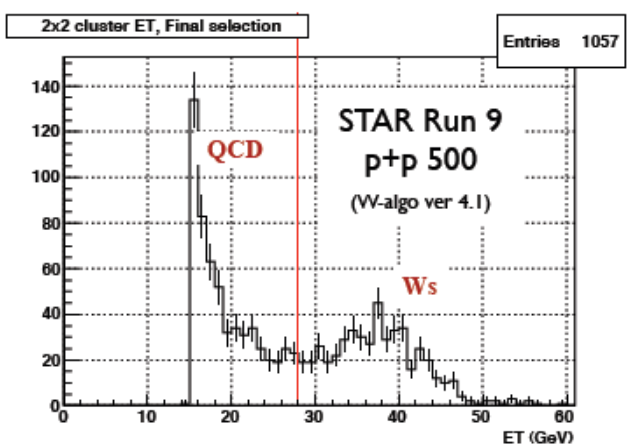


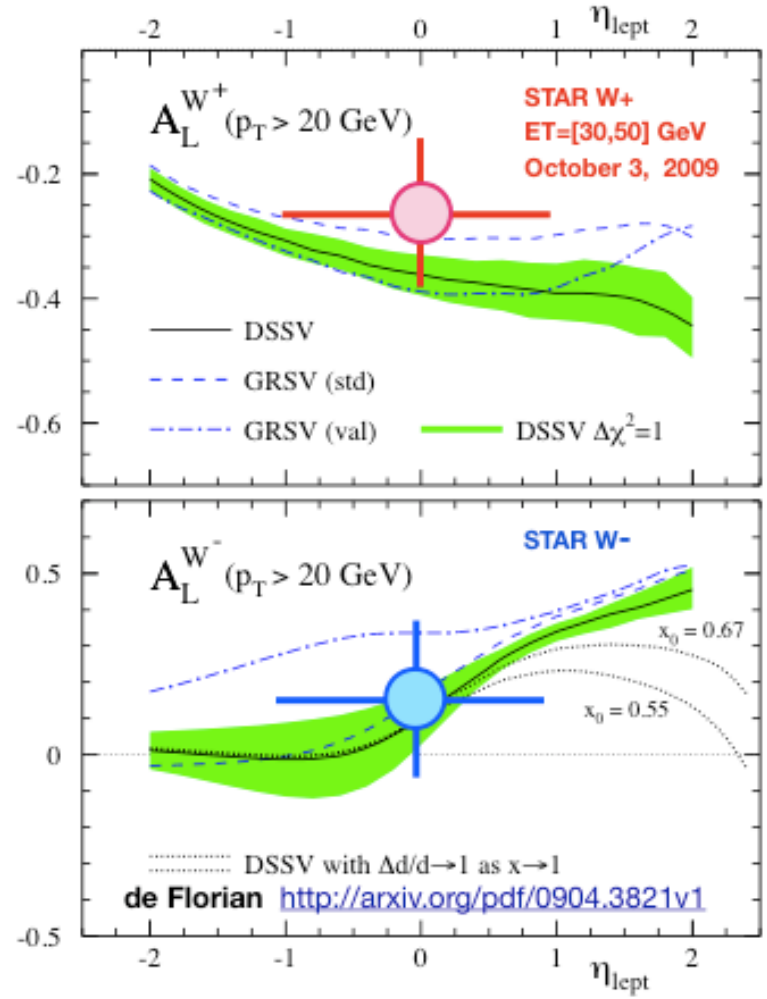
500 GeV p+p collisions



500 GeV pp Results (run9)



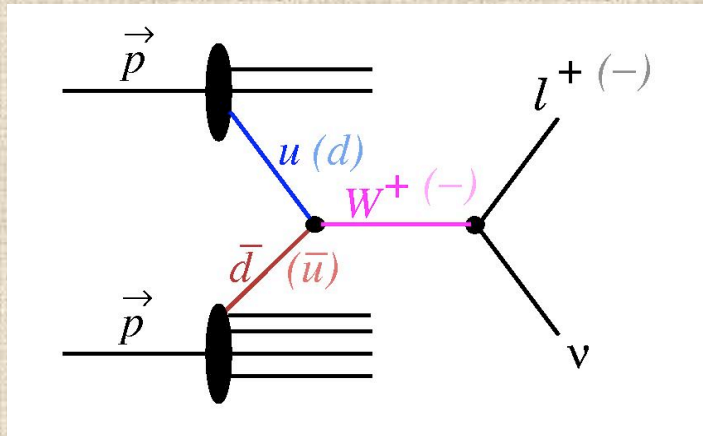




Victory of pQCD!

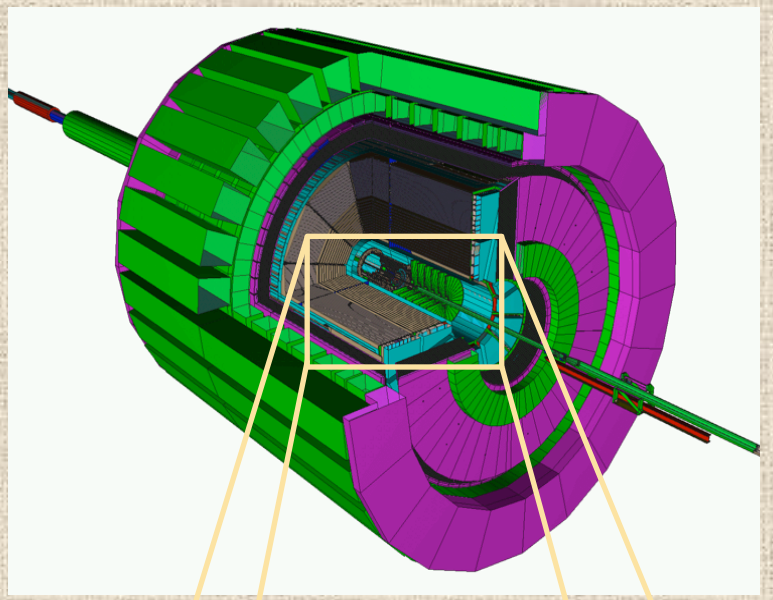
STAR: The *Sea-Quark* Program

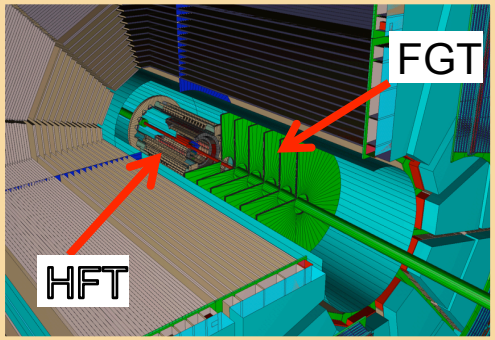
500 GeV p+p collisions



$$u + \bar{d} \rightarrow W^+ \rightarrow e^+ + \nu$$

$$\bar{u} + d \rightarrow W^- \rightarrow e^- + \bar{\nu}$$





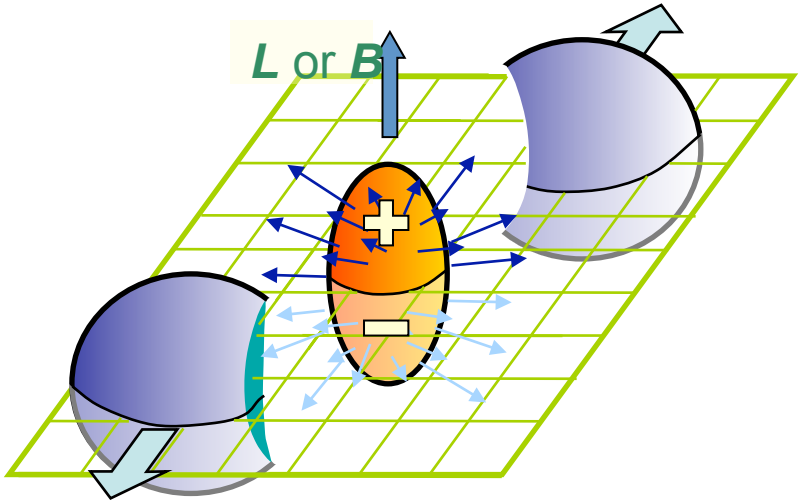
Forward GEM Tracker: FGT

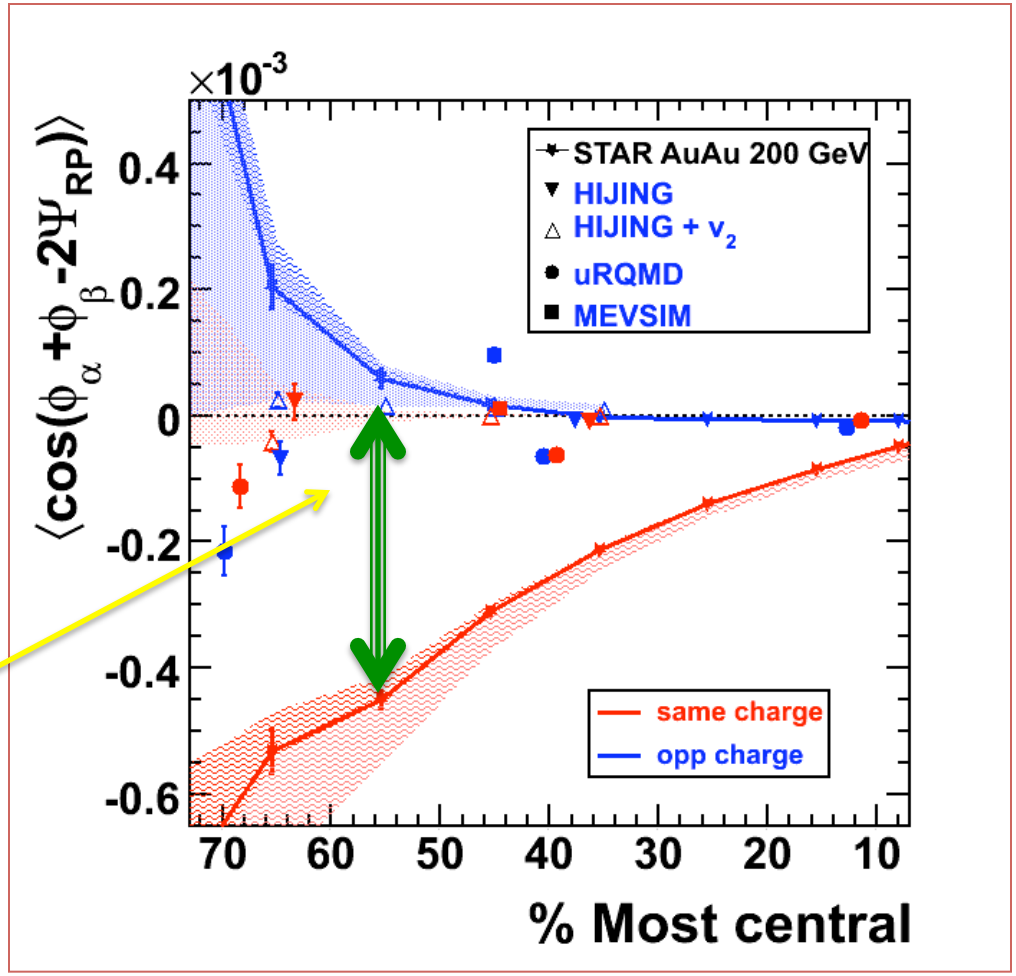
1) Charge sign identification for high momentum electrons from $W^{\pm}$ decay (Energy determined with EEMC)

2) Triple-GEM technology, Summer 2011 for Run12

High-Energy Nuclear Collisions

Search for Local Parity Violation …



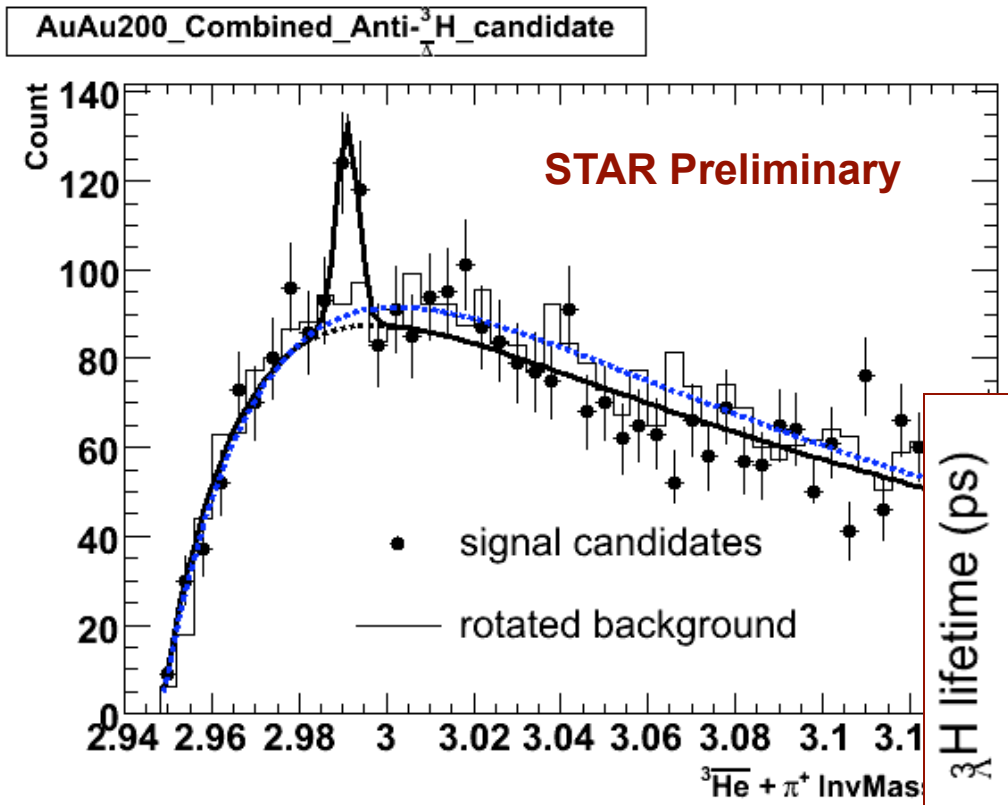


The separation between the same-charge and opposite-charge correlations.

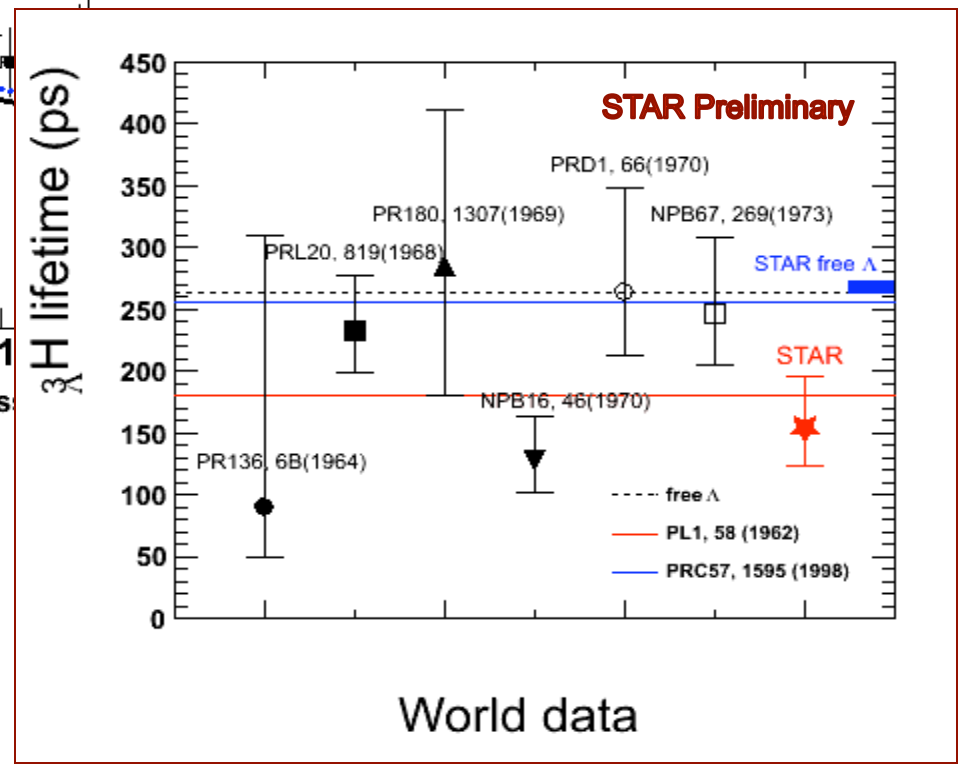
- Strong EM fields
- De-confinement and Chiral symmetry restoration

- **STAR**; *arXiv: 0909.1739 (**PRL**); 0909.1717 (PRC)*
- PID LPV analysis with TOF
- RHIC BES: disappearance

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



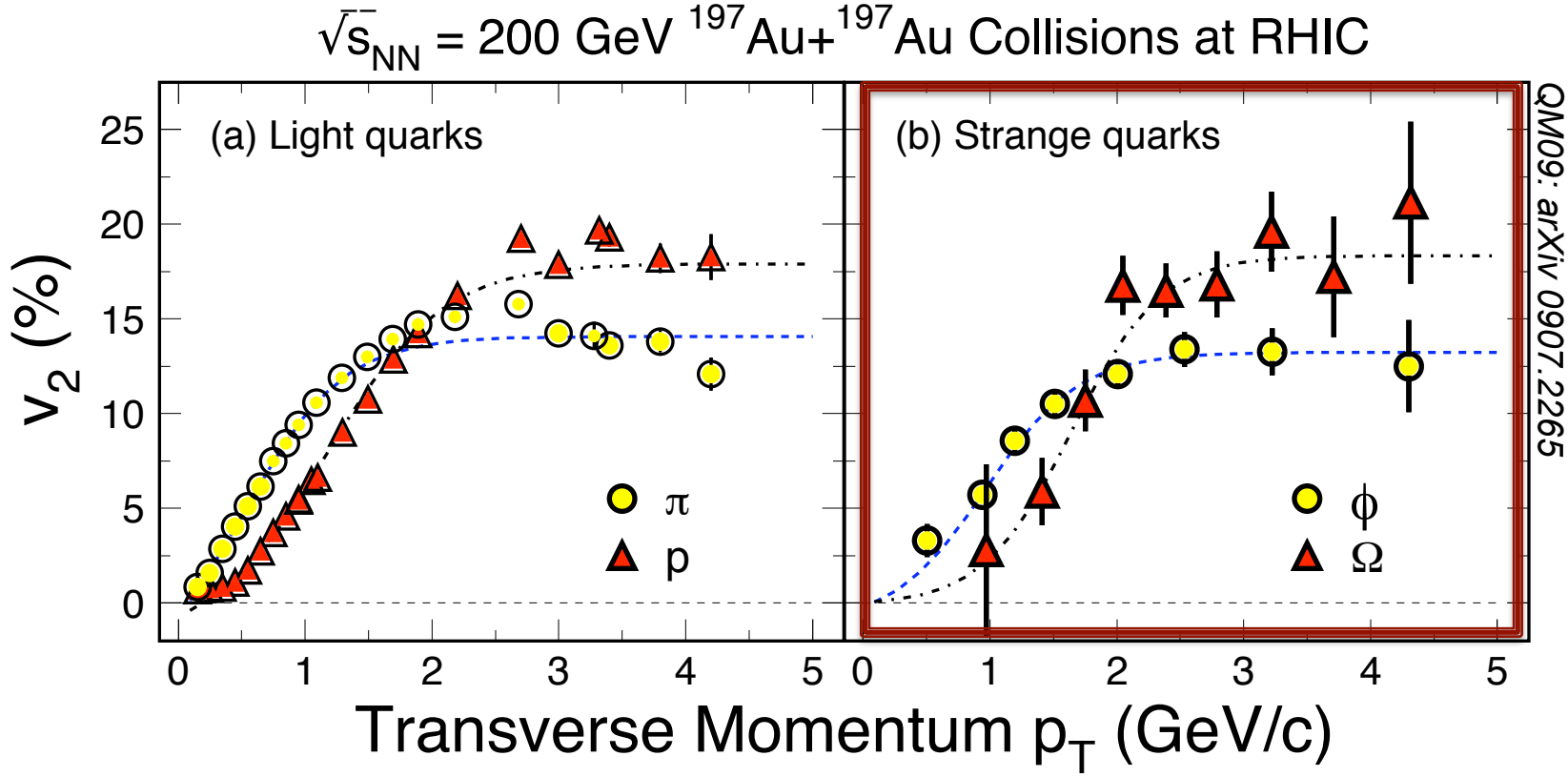
200 GeV Au+Au collisions at RHIC



First observation of
an anti-hypernucleus

Submitted to ***Science*** *Magazine*

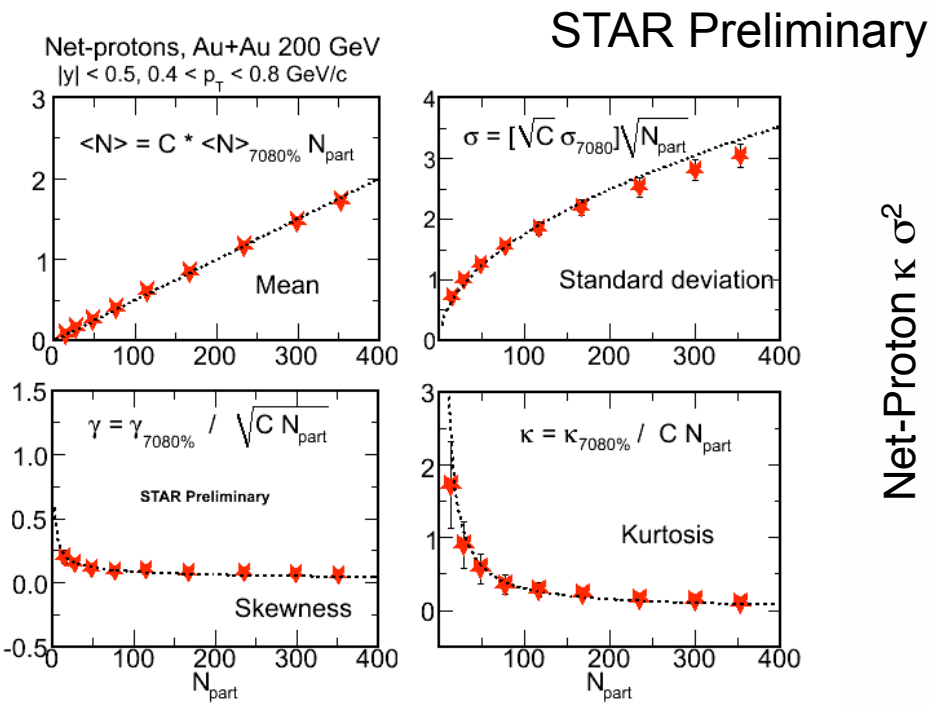
Partonic Collectivity at RHIC

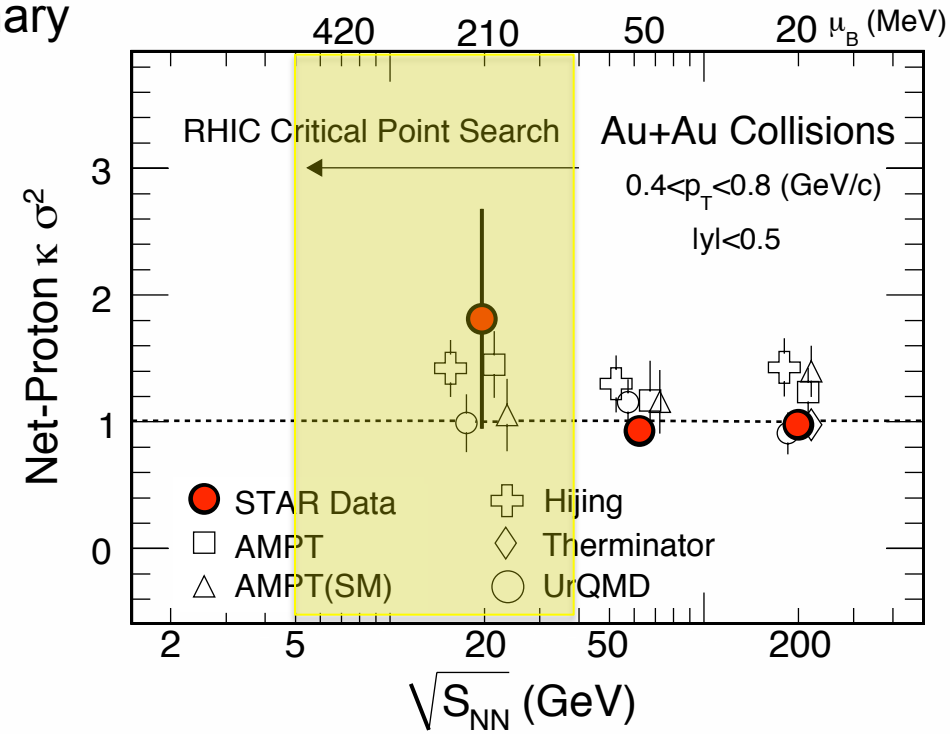


Low p_T (≤ 2 GeV/c): hydrodynamic mass ordering
High p_T (> 2 GeV/c): number of quarks ordering
s-quark hadron: smaller interaction strength in hadronic medium
light- and s-quark hadrons: similar v_2 pattern

=> Collectivity developed at partonic stage!

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…

sQGP and the QCD Phase Diagram

In 200 GeV Au+Au collisions at RHIC, strongly interacting matter formed:

- **Jet energy loss: R_{AA}**
- **Strong collectivity: v_0, v_1, v_2**
- **Hadronization via coalescence: n_q-scaling**

Questions:

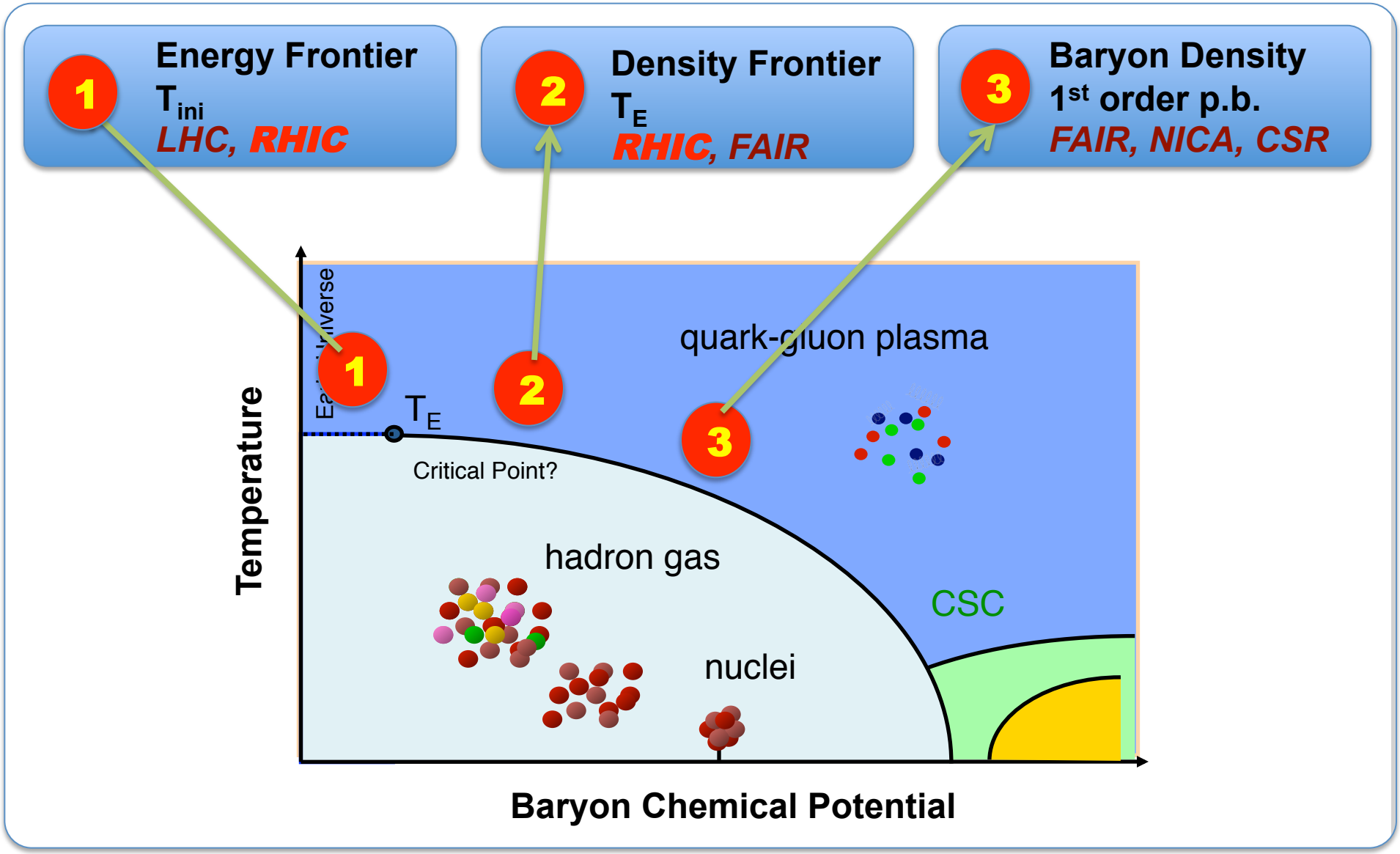
Is thermalization reached at RHIC?

- **Systematic analysis with dN/dp_T and dv_2/dp_T results…**
- ***Heavy quark and di-lepton measurements***

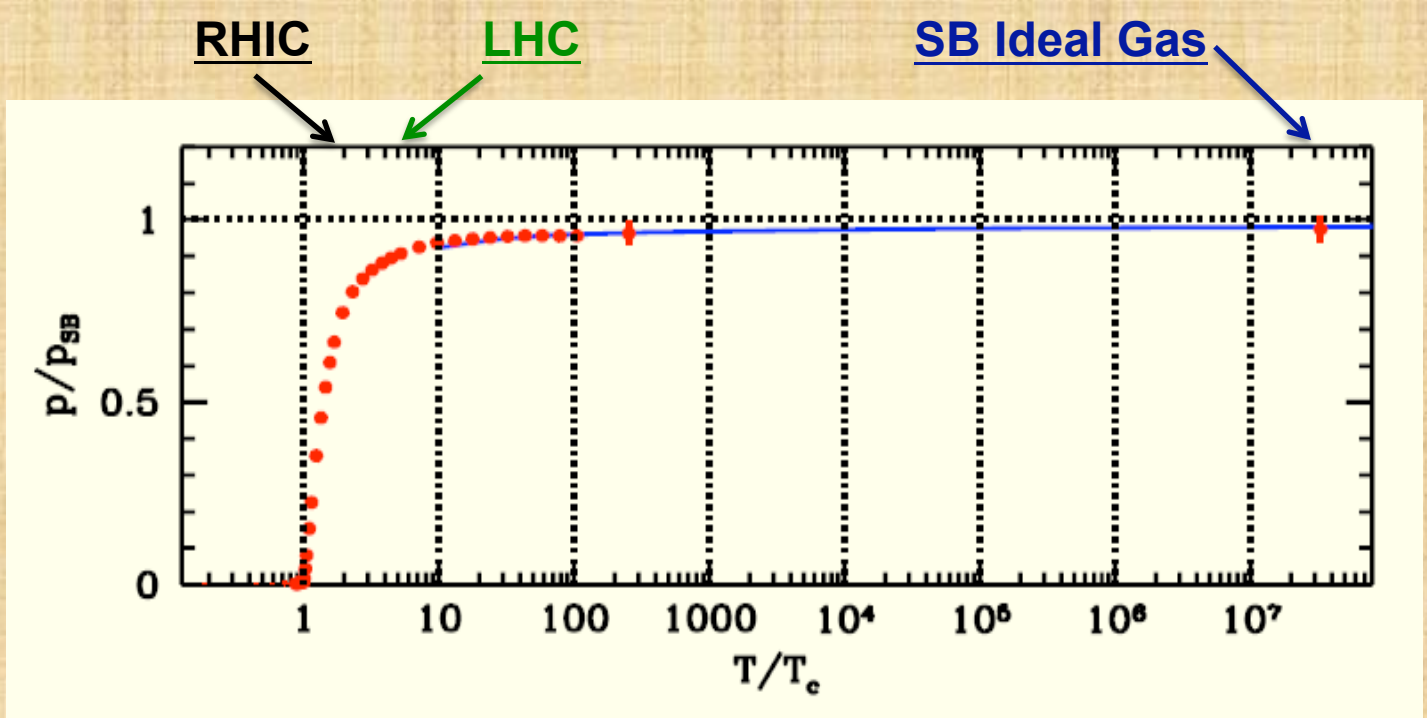
When (at which energy) does this transition happen?
What does the QCD phase diagram look like?

- ***RHIC beam energy scan***

High-Energy Nuclear Collisions



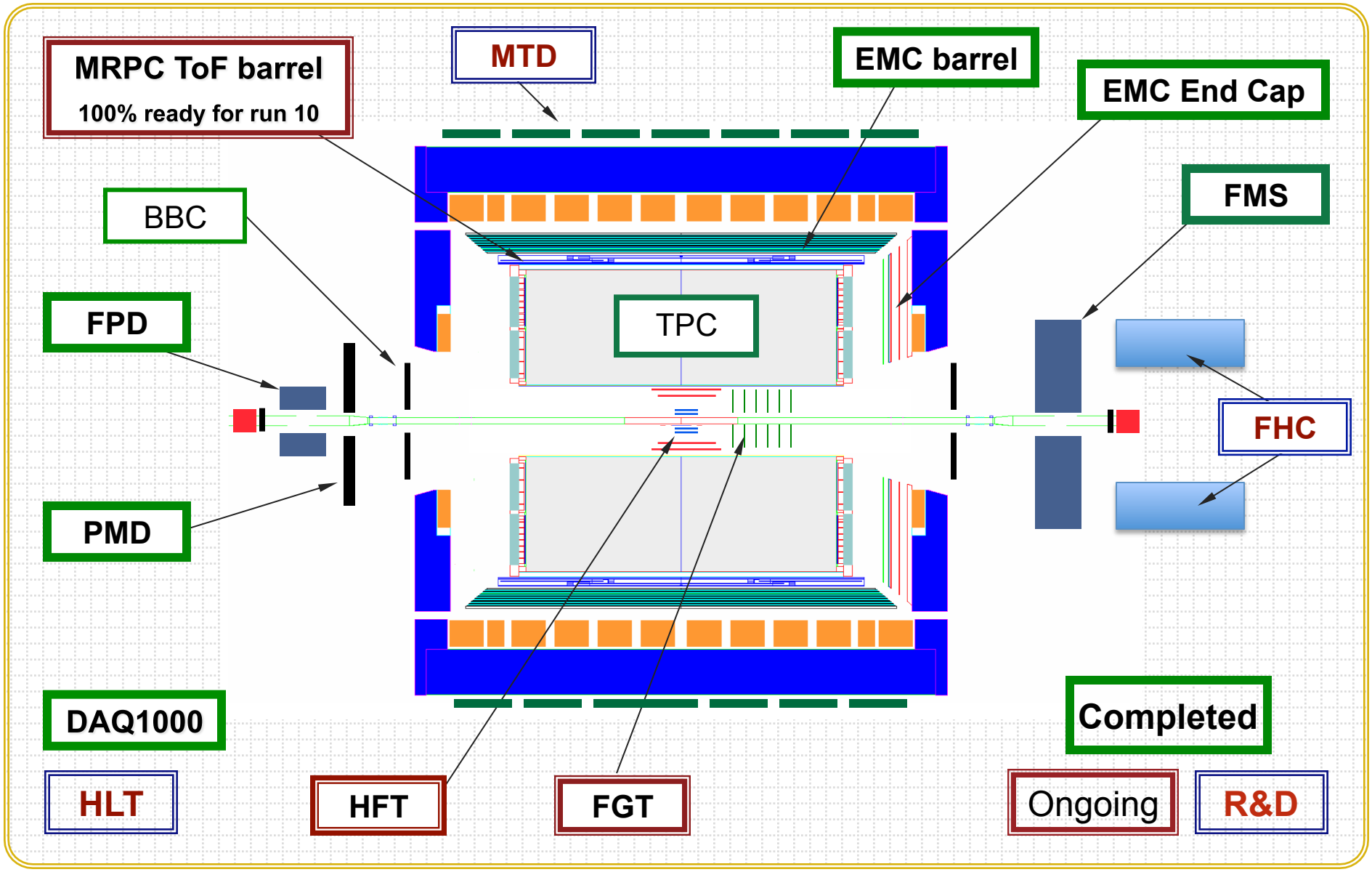
QCD Thermodynamics



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

STAR Detector



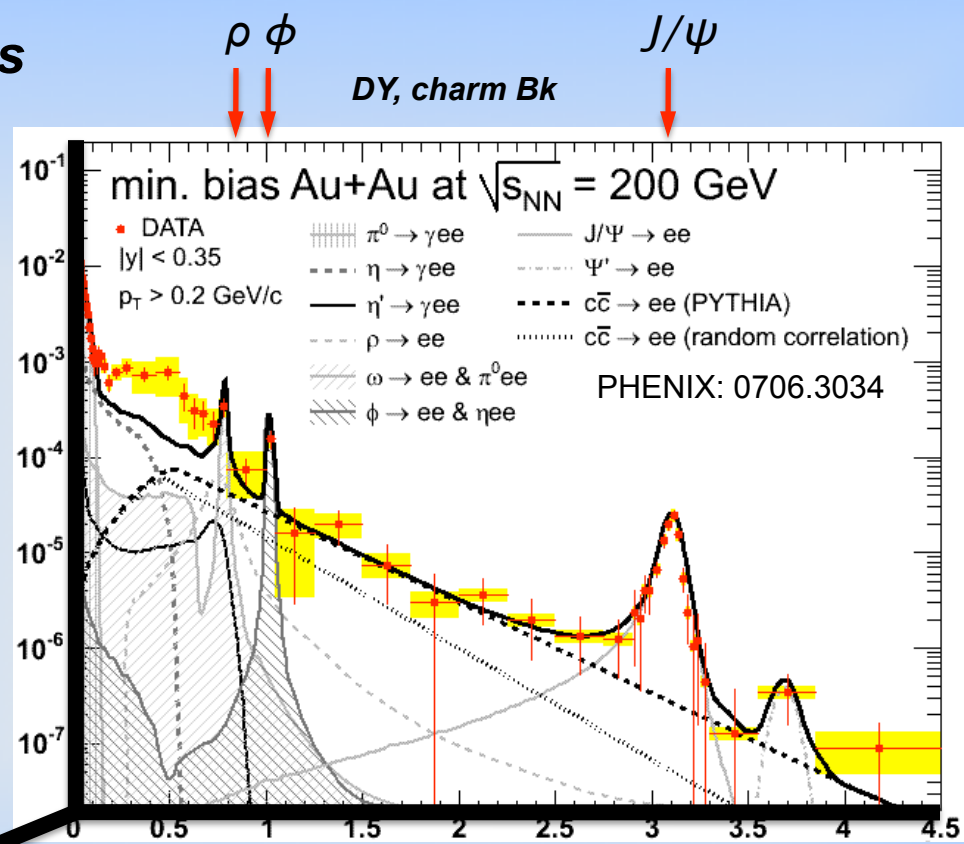
The di-Lepton Program at STAR

TOF + TPC + *HFT*

(1) *σ, mass*

(2) v_2

(3) R_{AA}



p_T (GeV/c)

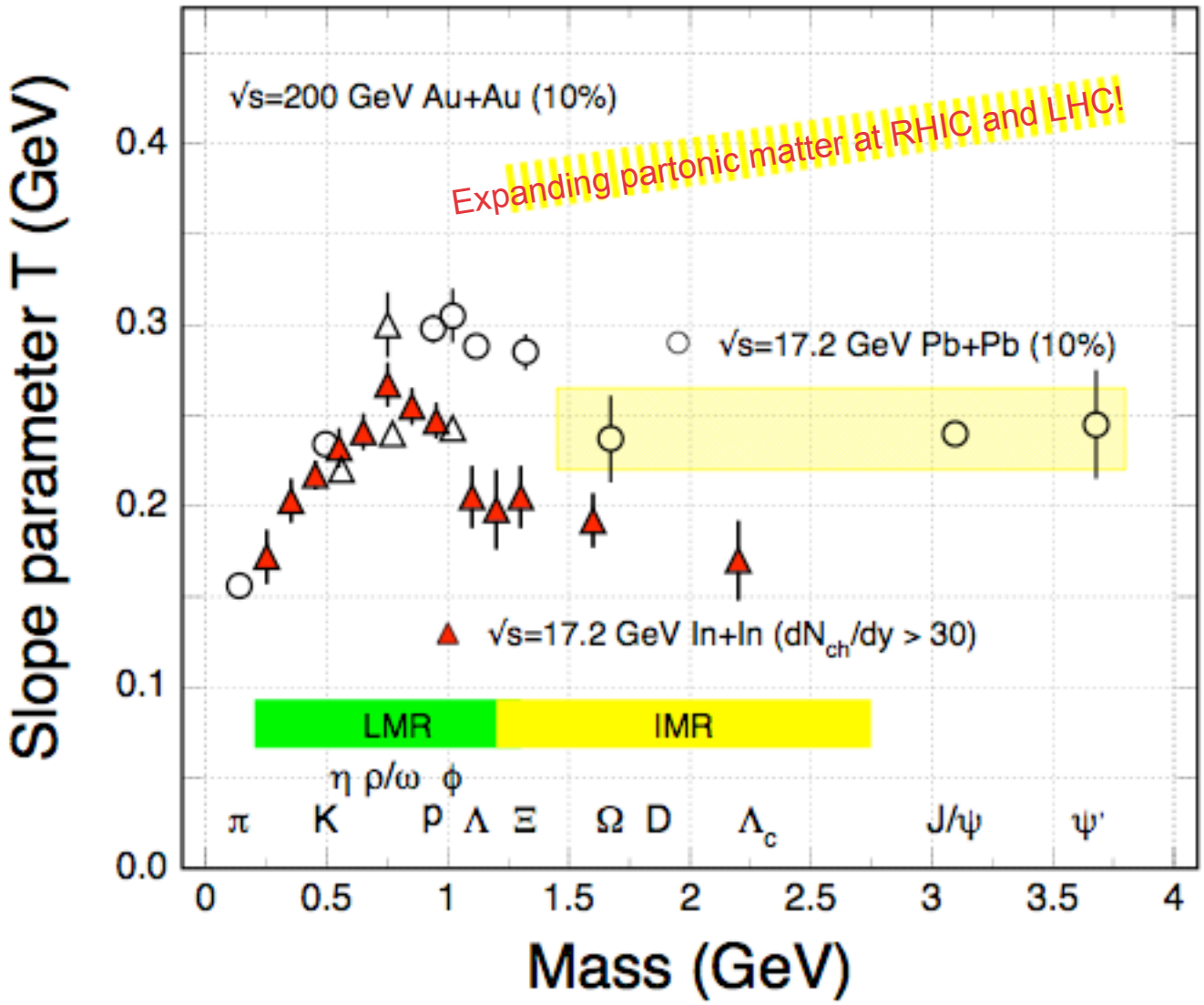
✓ **Direct radiation from the Hot/Dense Medium**

✓ **Chiral symmetry Restoration**

⇨ ***A robust di-lepton physics program extending STAR scientific reach***

HFT: removing irreducible correlated charm background!

Direct Radiation



Di-leptons allow us to measure the direct radiation from the matter with partonic degrees of freedom, no hadronization!

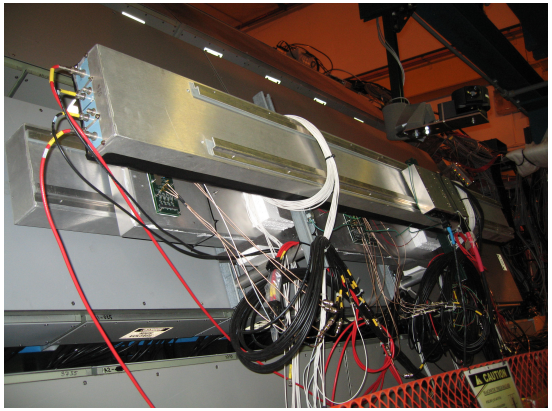
- Low mass region:
  $\rho, \omega, \phi \Rightarrow e^-e^+$
  $m_{inv} \Rightarrow e^-e^+$

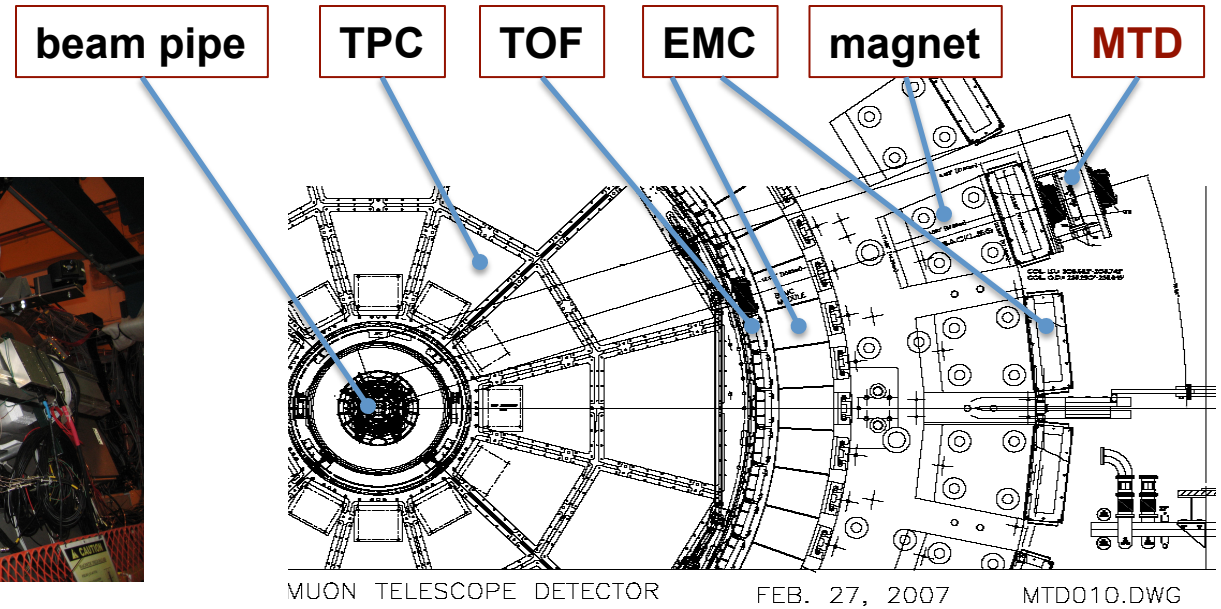
  medium effect
  Chiral symmetry

- High mass region:
  $J/\psi \Rightarrow e^-e^+$
  $m_{inv} \Rightarrow e^-e^+$

  Direct radiation

STAR: Muon Telescope Detector

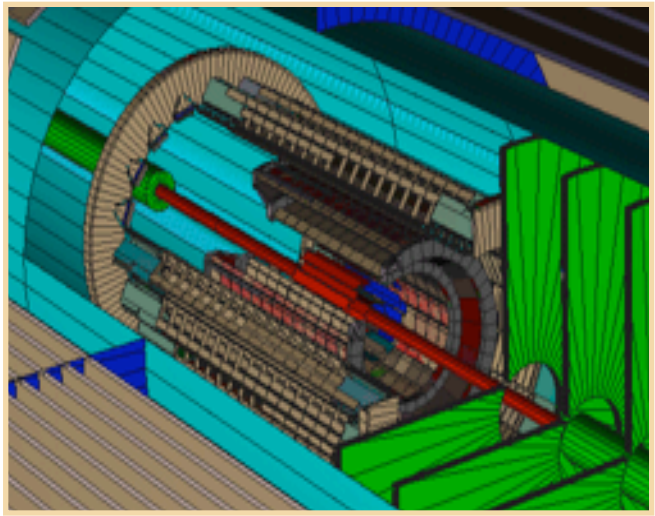


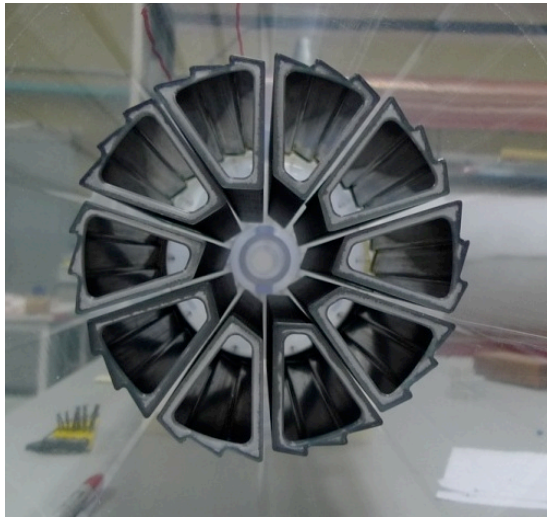


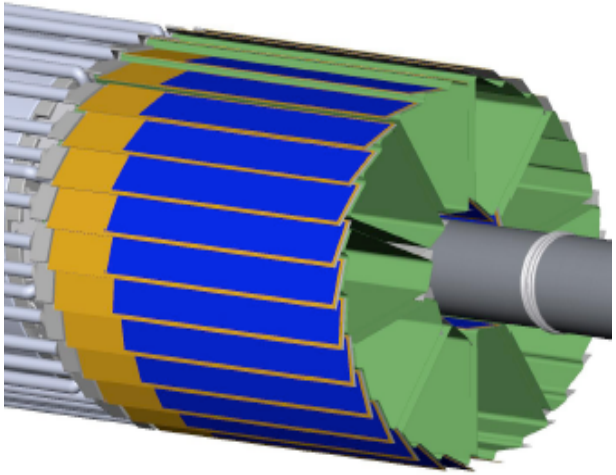
Muon Telescope Detector at STAR:

1) MRPC technology; μ_ε ~ 45%; cover ~60% azimuthally and |y| < 0.25
2) TPC+TOF+MTD: muon/hadron enhancement factor ~ $10^{2\text{-}3}$
3) For trigger and heavy quarkonium measurements
4) China-STAR collaboration: a proposal will be ready in mid-Sept.

STAR Heavy Flavor Tracker





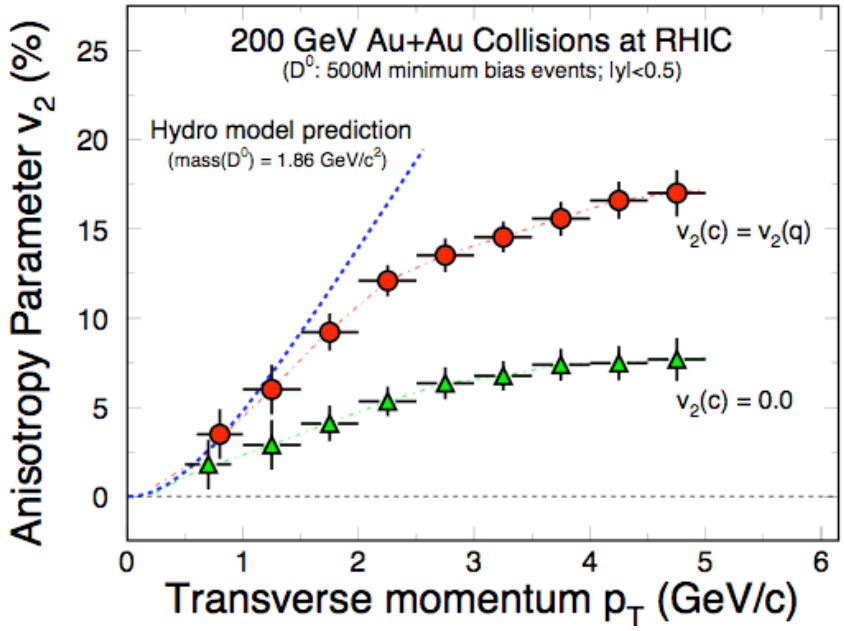


HFT: 2012-2014

1) 2-layer thin CMOS pixels; 1-layer strips; SSD
2) First layer at 2.5 cm close to the beam pipe, 2pi coverage

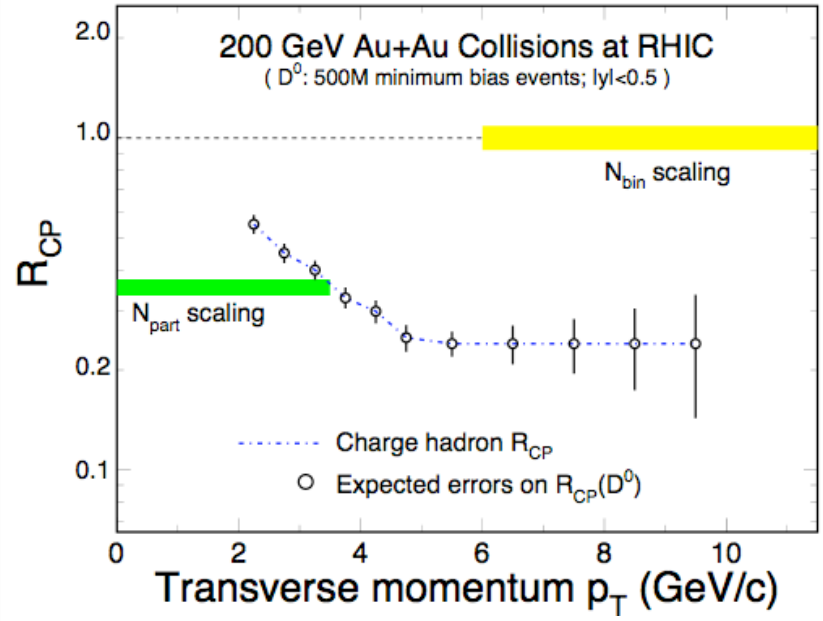
➔ Measure down to low p_T ~ 0.5 GeV/c for open charm hadrons

HFT: Charm Hadron v_2 and R_{AA}



- 200 GeV Au+Au m.b. collisions (500M events).
- Charm hadron collectivity ⇨ drag/diffusion constants ⇨

Medium properties!



- 200 GeV Au+Au m.b. collisions (|y|<0.5 500M events)
- Charm hadron R_{AA} ⇨

- Energy loss mechanism!
- QCD in dense medium!

Summary

STAR QCD physics program for next decade:

Spin Physics: (cold nucleon)

- 200 GeV: ***Δg*** inclusive and di-jets, γ-jet
- 500 GeV: ***sea quark*** helicity distributions
- 200/500 GeV: transverse spin phenomena

Low-x Physics: (cold nucleus)

- Study gluon-rich phenomena at RHIC
- Color glass condensate

Heavy Ion Physics: (hot nuclear matter)

- Thermalization at 200 GeV
- QCD phase boundary and critical point, starts in 2010
- In medium properties

STAR BES Physics Programs

Beam Energy (GeV)	μ_B (MeV)	STAR BUR (10)	PAC	27 week	25 week
200	25	**8**	10	**10**	**10**
62.4	50		4	**4**	**4**
39	110	**0.7**	0.5	**1.5**	**1.5**
27	160	**1.7**	0.5	**0**	**0**
18	260	**2.3**	1	**0**	**0**
*11.5**	*340*	***2.7***	*2*	***2***	***0***
7.7**	420	**8**	4	**4**	**4**
6.0	500				
5.0	550			0.5	0.5

* One collision site at RHIC

** *$N(K^+)/N(\pi^+)$* ratio peaks, maximum of the net-baryon density