STAR Future Scientific Program and Detector Upgrades

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Selected QCD Results from RHIC AA Program

sQGP Properties – QFT @ Strong Coupling Limit

QCD Phase Diagram

QCD Exotics

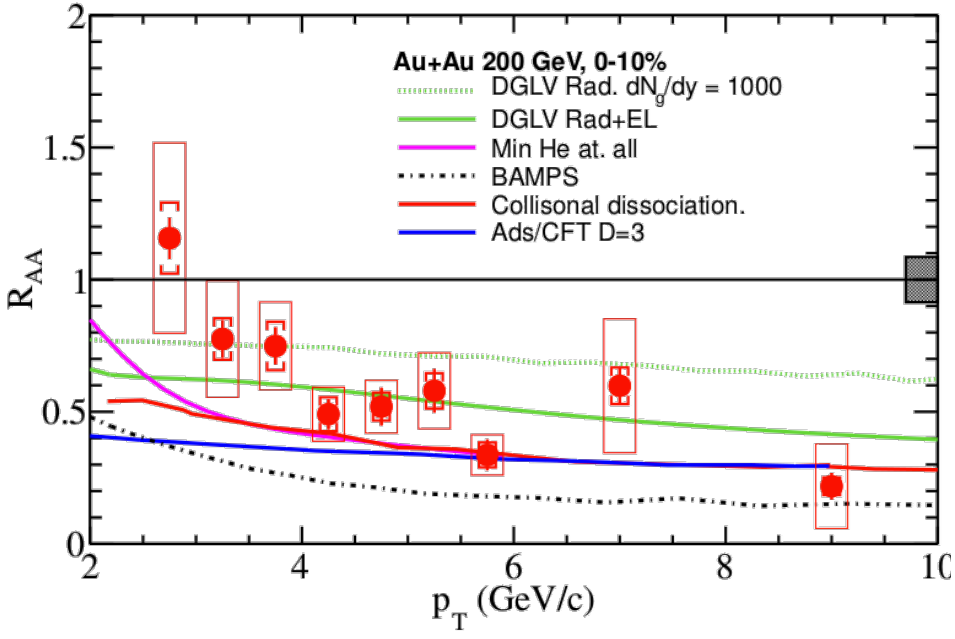
Towards Future QCD Studies @RHIC & Beyond

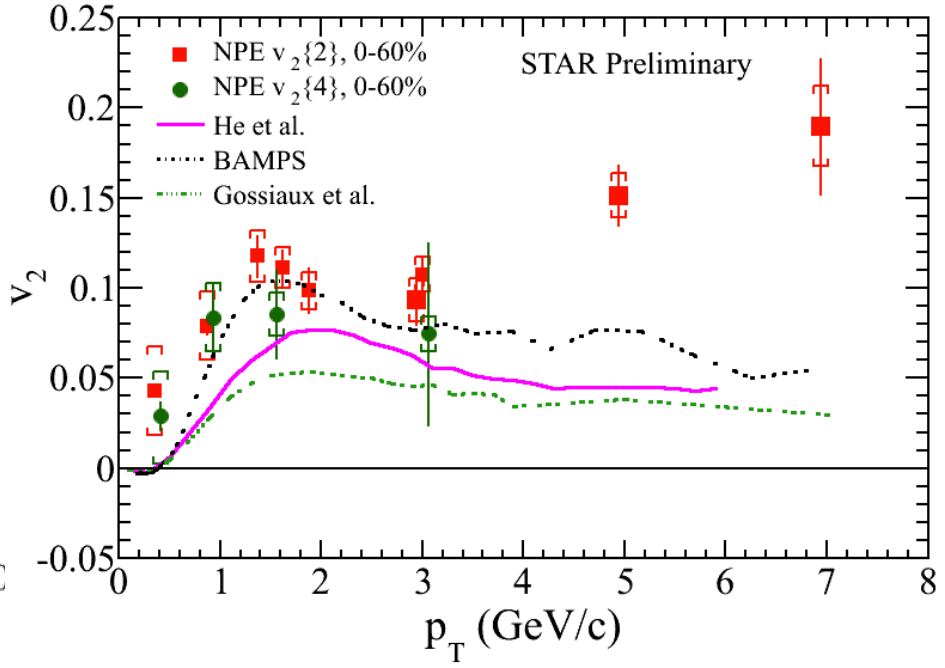
Heavy Quark Probe of sQGP properties

Heavy Quark – trace the evolution of collision

Simultaneous Measurements of R_{AA} and v_2

Electrons from heavy quark semi-leptonic decays



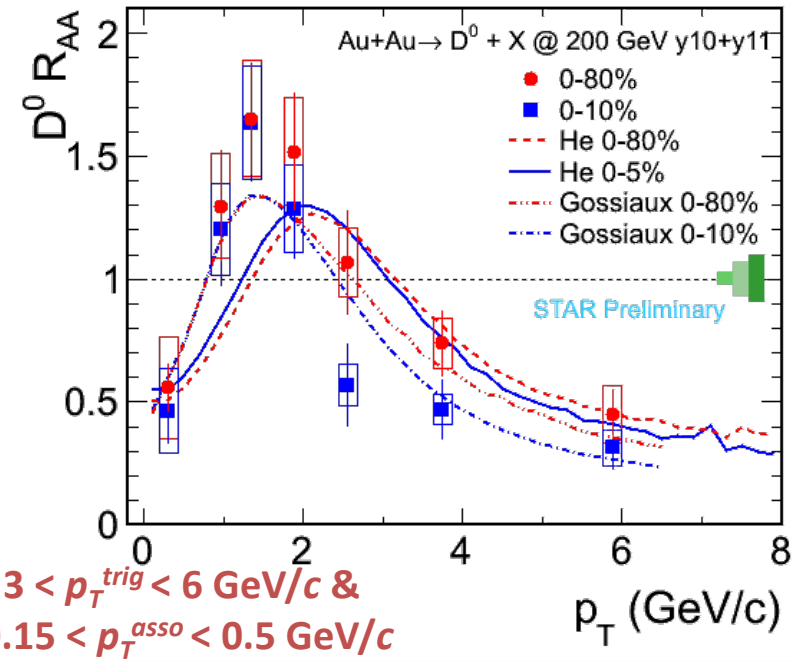


Better p+p reference data

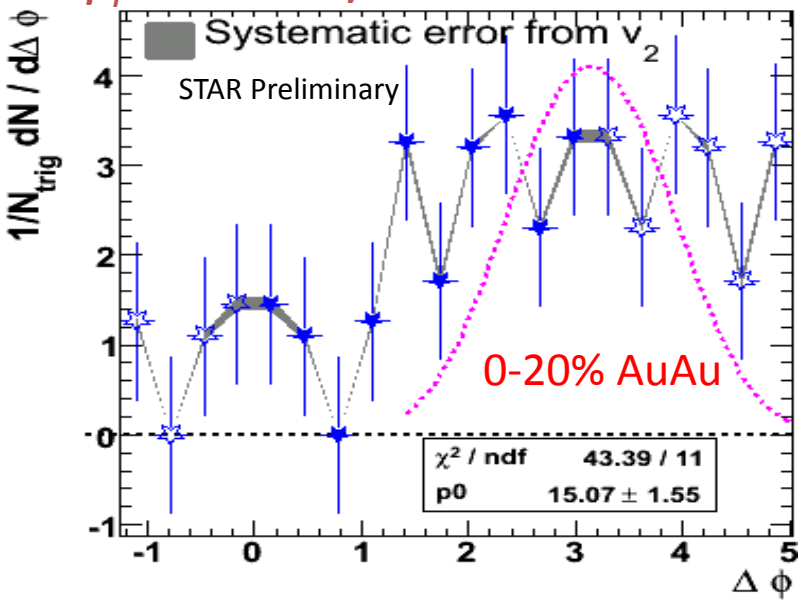
Nature of the measured v_2 value at high pT

Separation of B and D decay electrons !

Heavy Quark Collectivity – Next 2 years !



$3 < p_T^{trig} < 6$ GeV/c &
$0.15 < p_T^{asso} < 0.5$ GeV/c



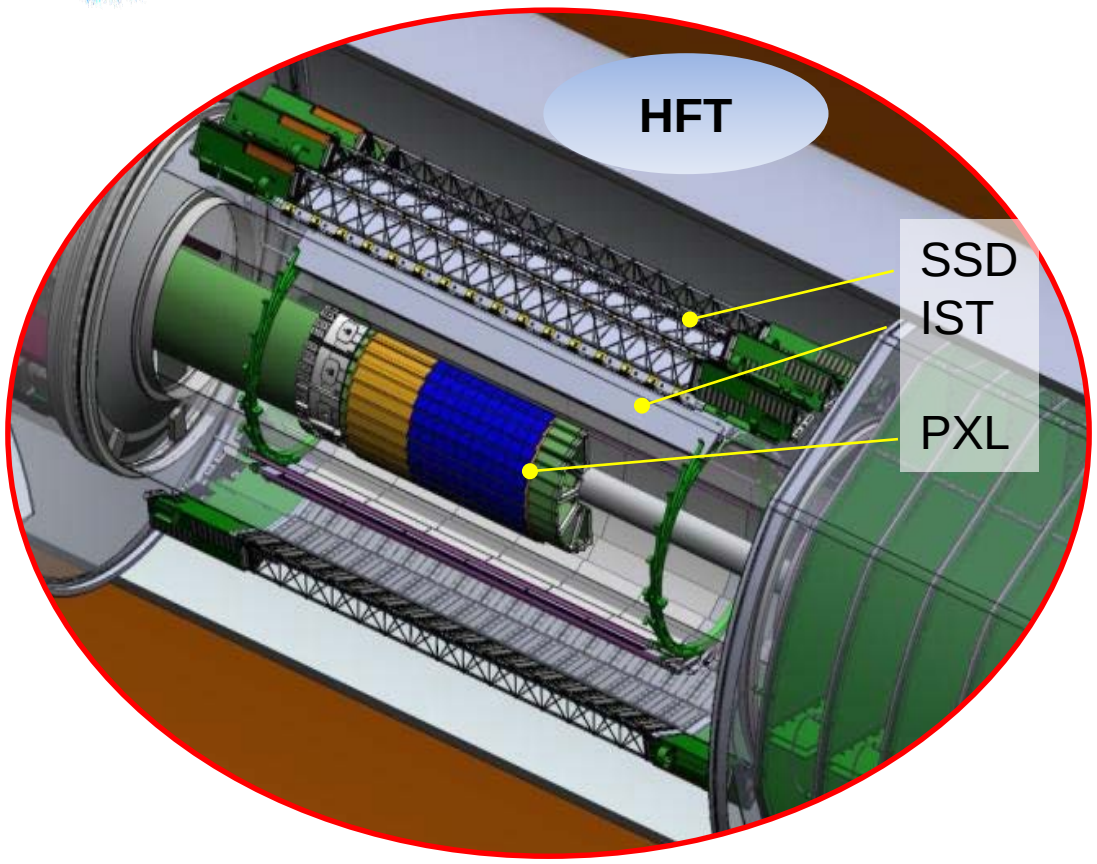
Elliptic Flow v_2 of D at low pT

NPE – Separation of B and D decays in Au+Au collisions

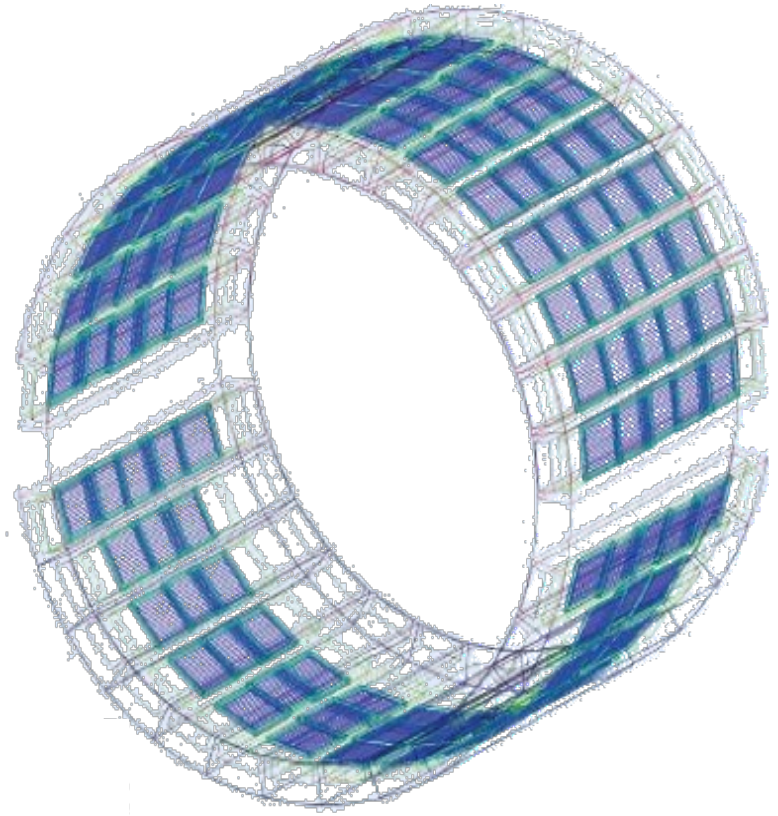
---- HFT Arrived

Heavy Quark Tagged Jet-Medium Interaction and Medium Response !

Status of HFT and MTD Upgrades



Heavy Flavor Tracker



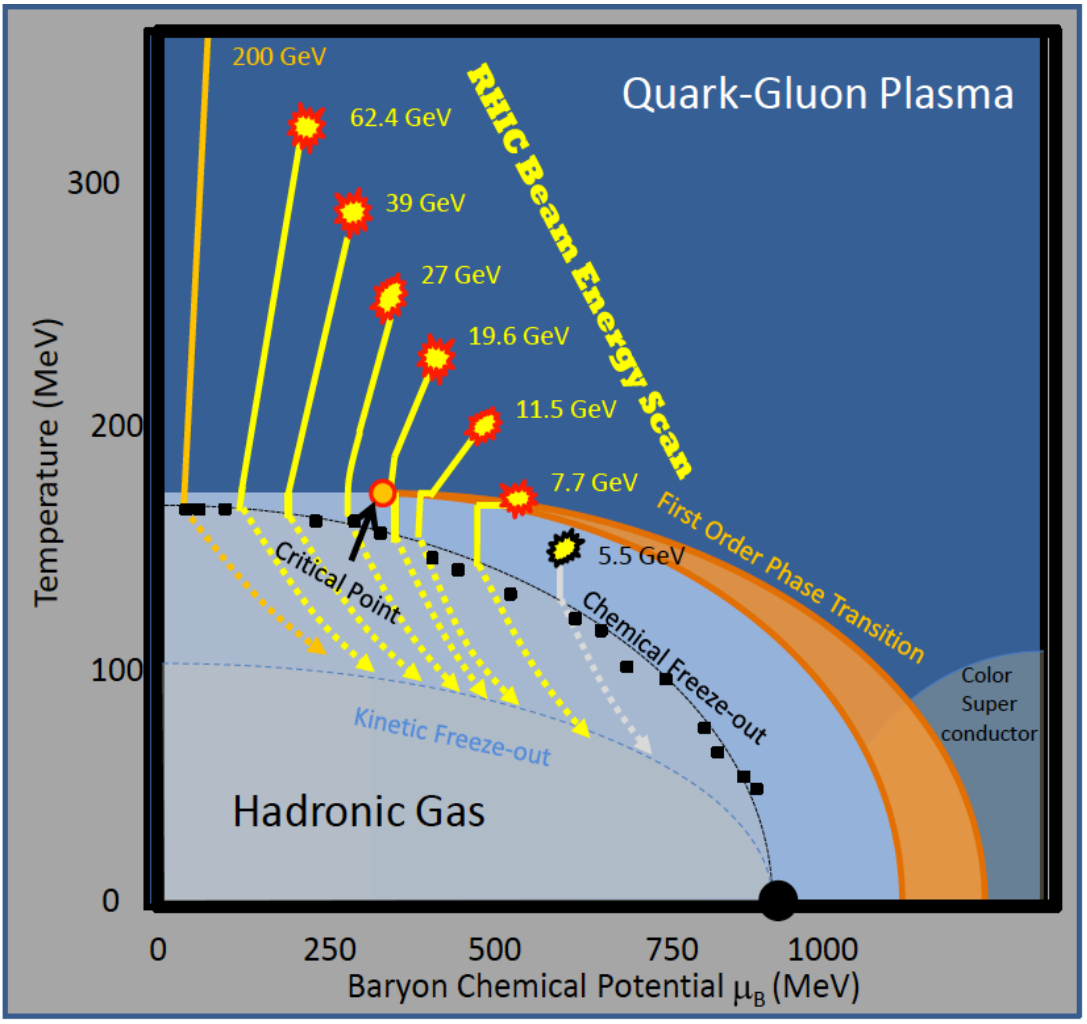
Muon Telescope Detector

Full Detector Commissioning and Physics Running in 2014

> 1 billion Au+Au Minimum Bias events !

Heavy Quark Collectivity, NPE B and D separation, Upsilon

QCD Phase Diagram and RHIC BES-I

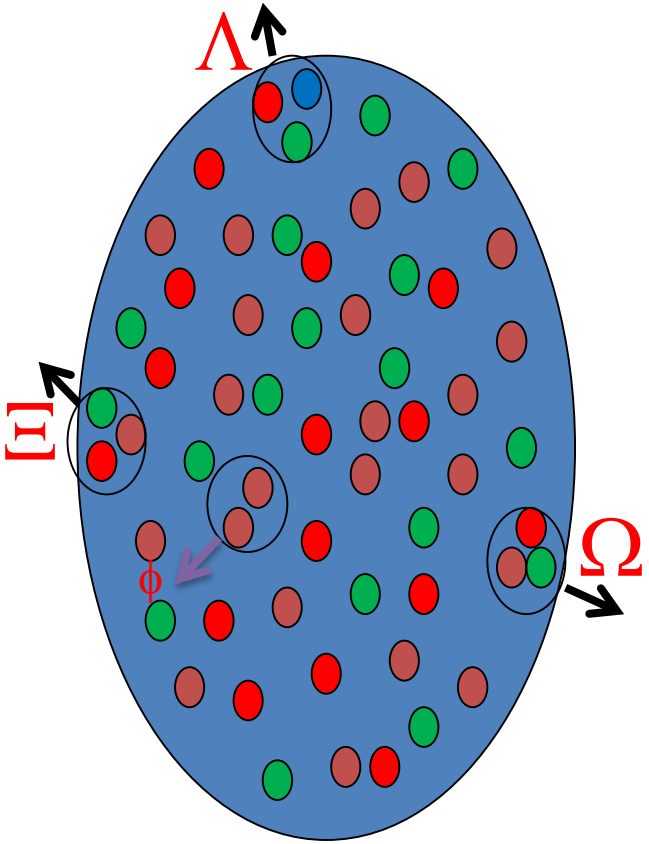


Year	En (GeV)	# Event (10^6)
2010	39	130
2010	11.5	12
2010	7.7	5
2011	27	70
2011	19.6	36
2014	14.6	150

RHIC can deliver low energy beams !

STAR: First glimpse of QCD bulk matter over a broad range of chemical potentials !

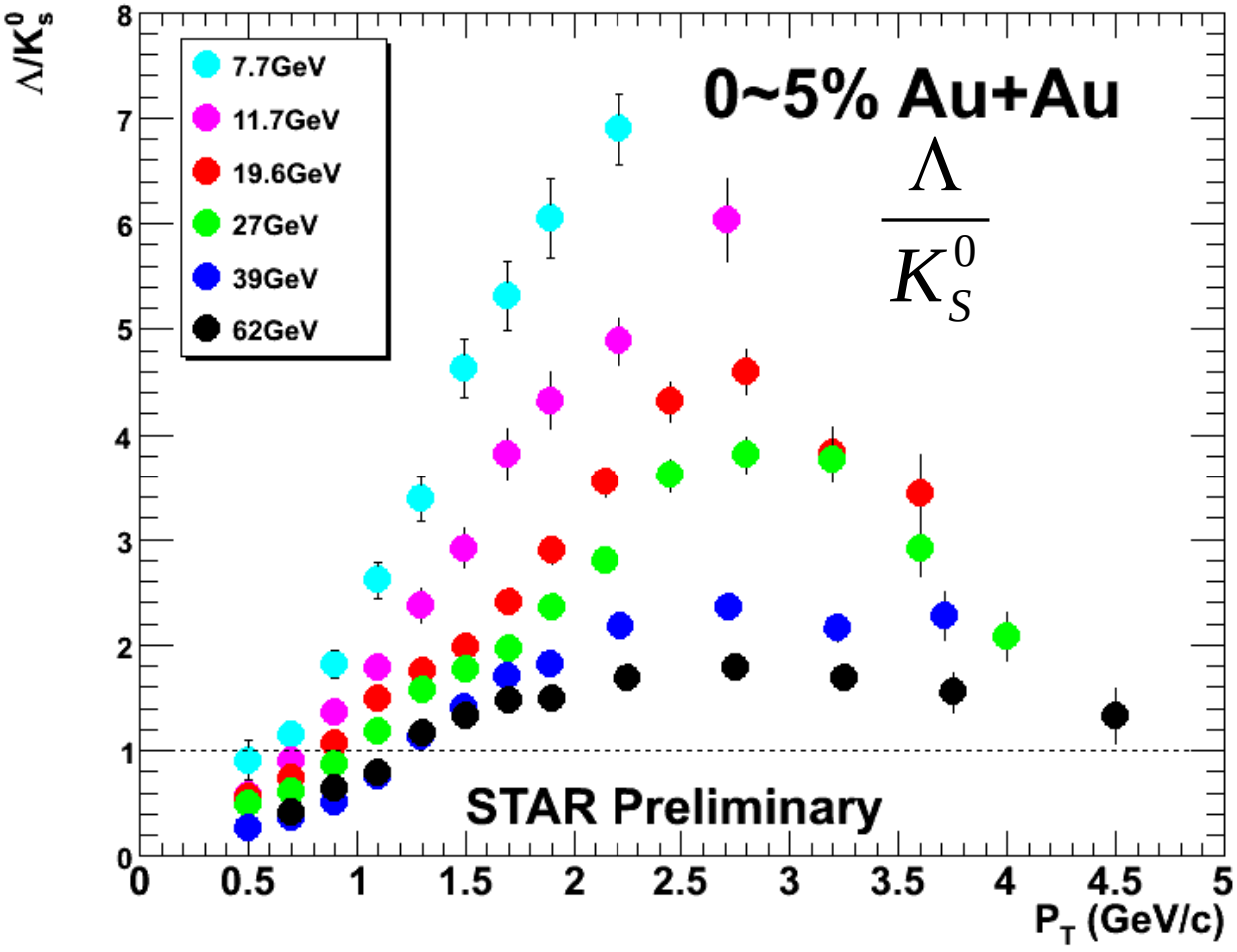
Coalescence and Cluster Formation



Hadron kinematics from sum of constituent partons instead of fragmentation of leading partons !

Increased Hyperon over Ks ratios

The formation probabilities of baryons and mesons depend on the environment – local parton density



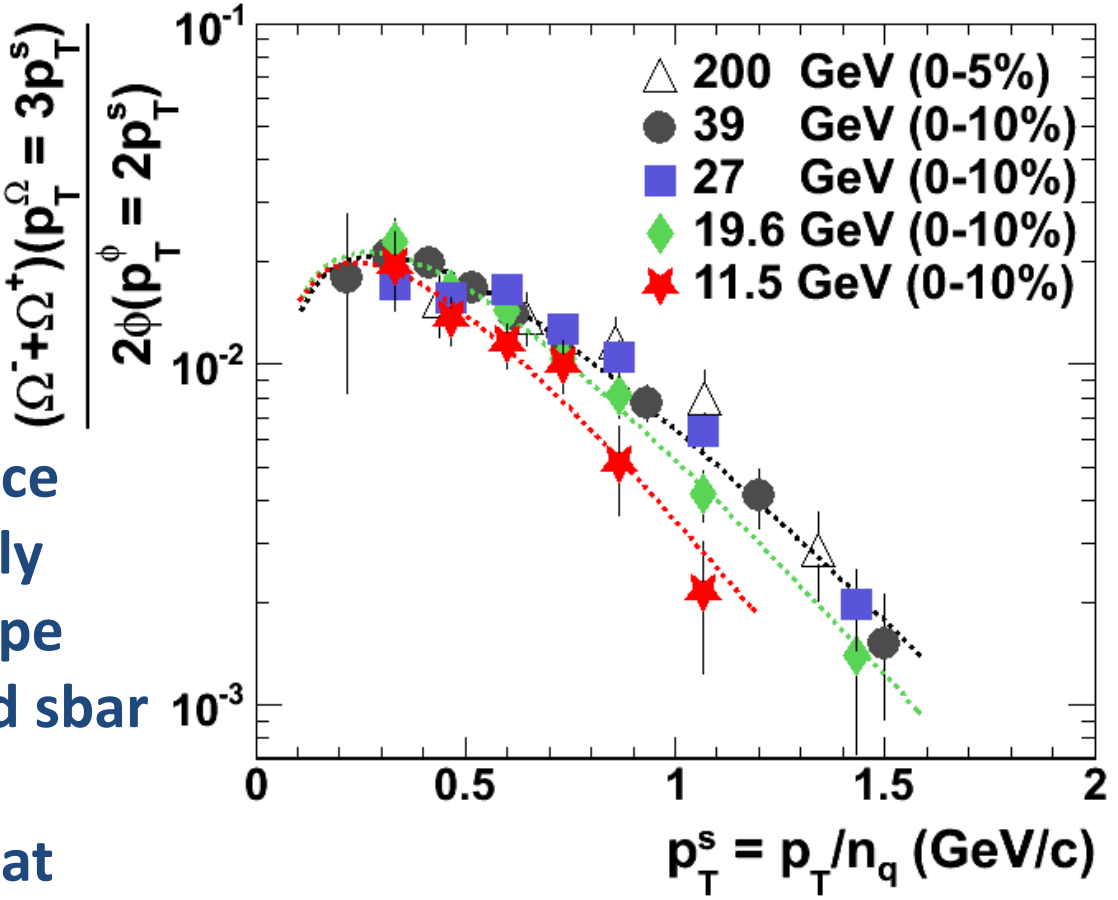
B/m ratios
-- measure of local parton density at hadronization !

Au+Au at 7.7 GeV
-- higher net baryon density !

In a broad pT region [1-4] GeV/c, much more hyperons than mesons produced !!
-- Coalescence

Strange quark analysis from Ω and ϕ using Coalescence Framework

- Ω(sss) and ϕ(s$\bar{s}$) formed at chemical freezeout from coalescence of 3 s quarks and s-sbar pairs.
- Assuming sudden coalescence of s quarks of approximately equal pT and the same shape of pT distributions for s and sbar quarks
- The s quark pT distribution at freeze-out ~ $\Omega(3p_T)/\phi(2p_T)$



IS there a difference in partonic dynamics between 11 and 20 GeV?

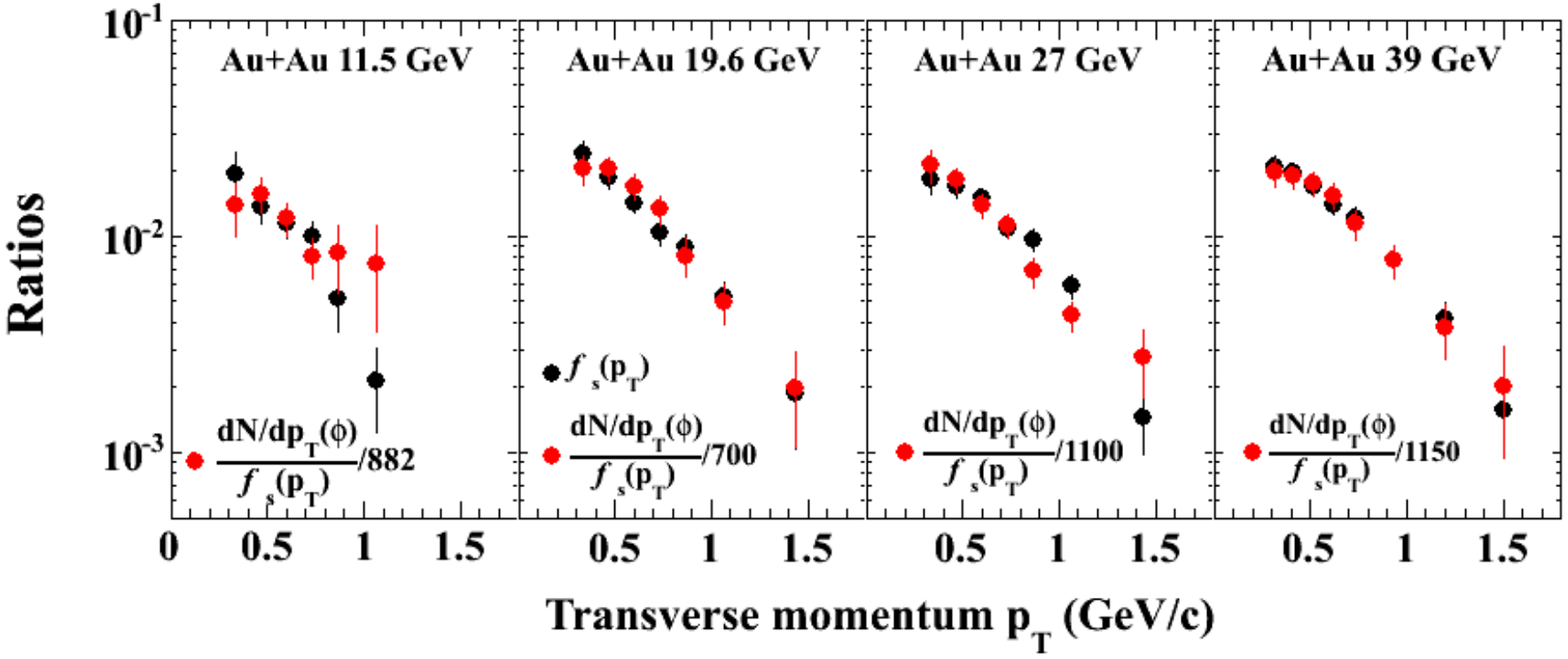
NEED more statistics (BES II) and a 15 GeV run !!

Coalescence Picture !

Independent Empirical Check on Coalescence –

if $s(p_T) \sim \Omega(3p_T)/\phi(2p_T)$, then $\phi(2p_T)/s(p_T)$ is also $s(p_T)$

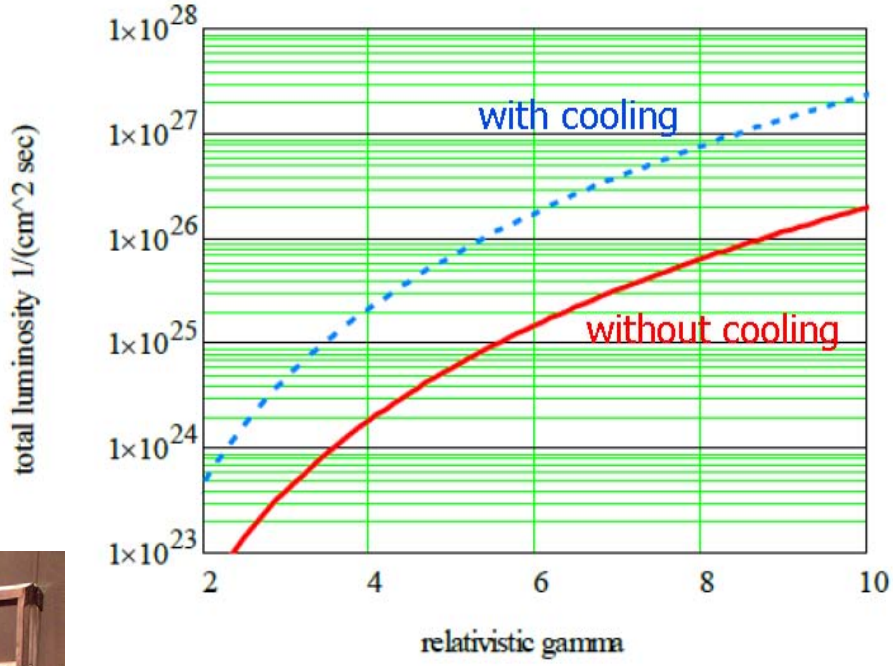
are these functions of similar shape?

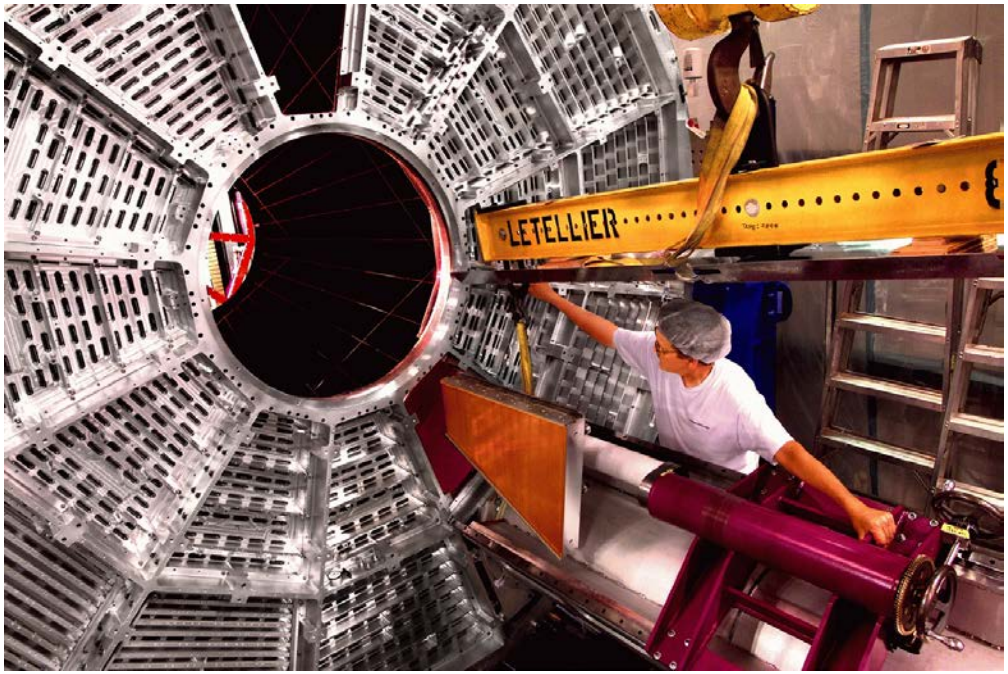


Probe Parton Distributions in QCD Drops at Hadronization !

Road to Beam Energy Scan II

1) Need electron cooling to be more efficient !



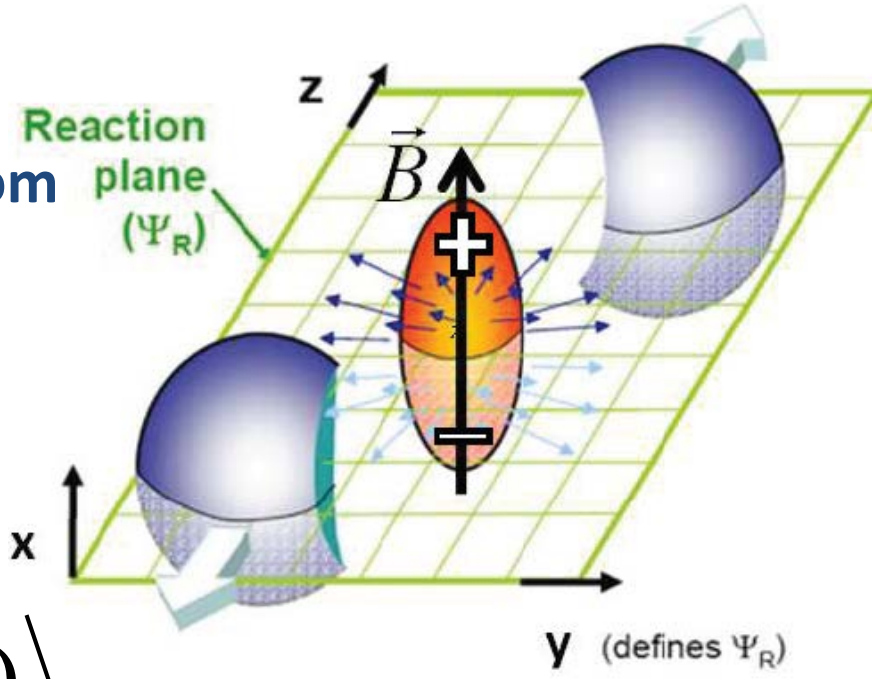


2) STAR TPC Inner Sector readout upgrade
-- enhance tracking and PID in η 1-1.7 region

BES II Starting 2018+

QCD Chiral Magnetic Effect

QCD Vacuum Sphaleron excitation coupled to strong magnetic field from spectator protons
-- charge separation across the reaction plane
parity violating in strong interaction



Kharzeev et al NP A803, 227 (2008)

$$\gamma = \left\langle \cos(\phi_\alpha + \phi_\beta - \psi_{RP}) \right\rangle$$

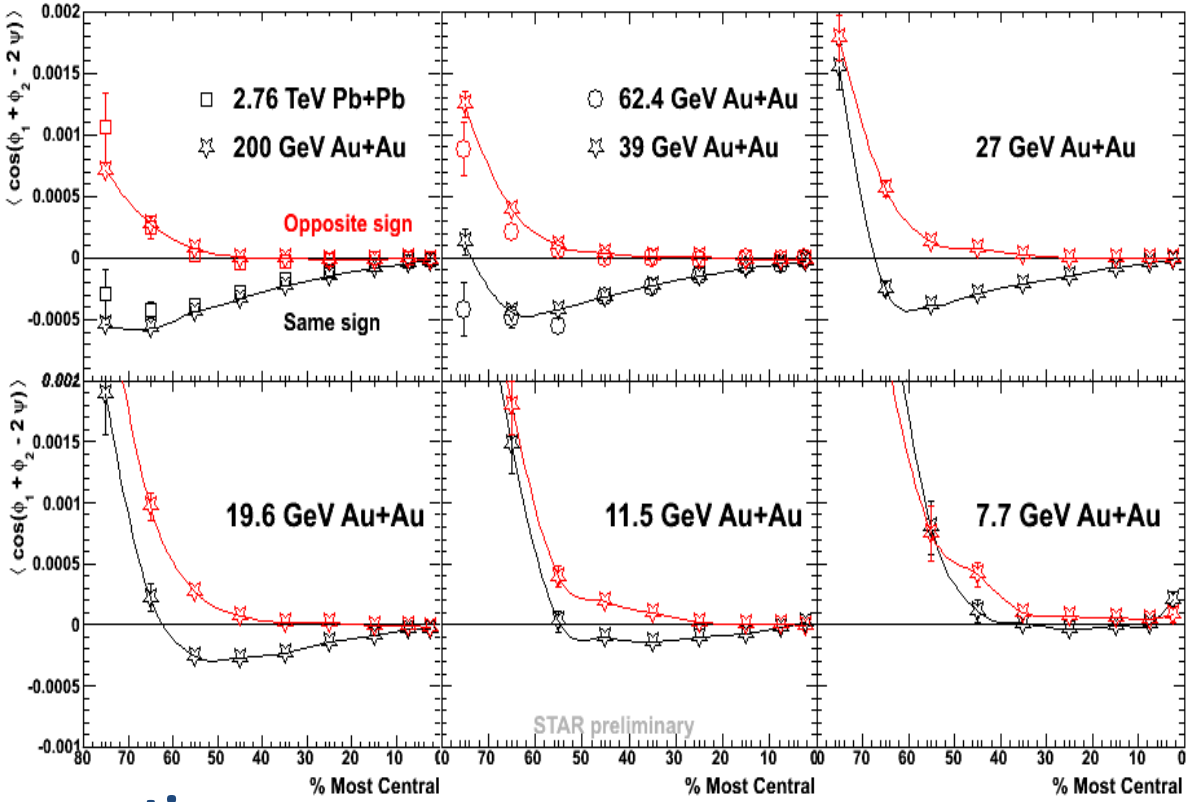
$$= \left[\left\langle v_{1,\alpha} v_{1,\beta} \right\rangle + B_{in} \right] - \left[\left\langle a_\alpha a_\beta \right\rangle + B_{out} \right]$$

Voloshin, PRC70, 057901 (2004)

charge dependent – same sign (++,--) and opposite sign(+-, -+) sensitive to charge separation

Recent STAR Results on the Charge Separation Measurement

STAR Collaboration, PRL 113, 052302 (2014)



Charge separation

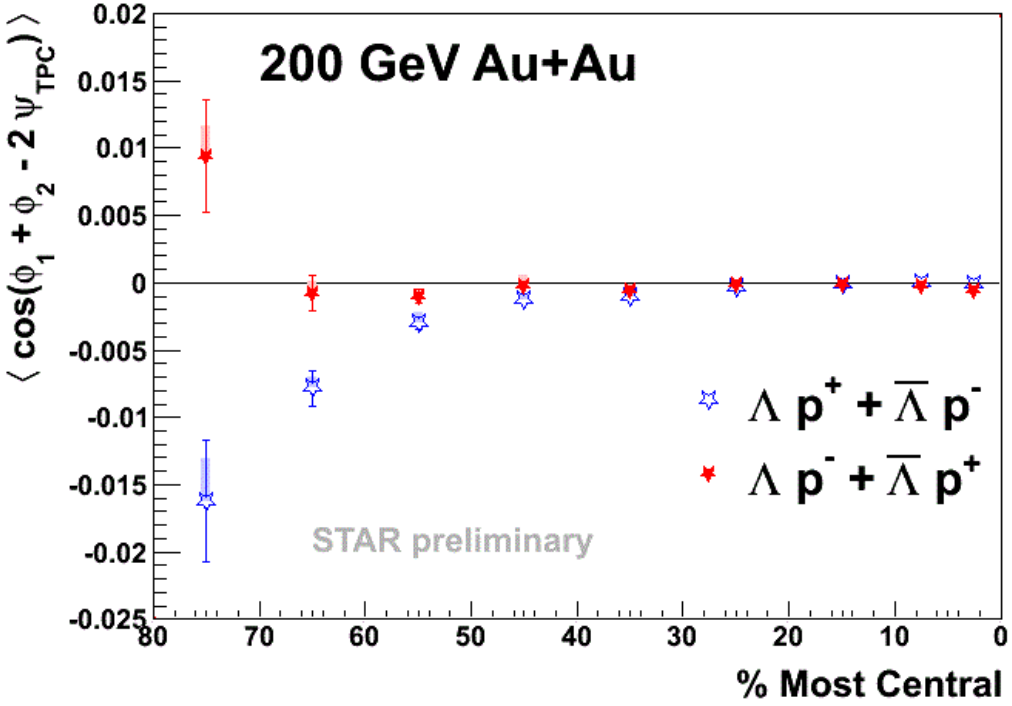
-- disappears at low energy where QGP presumably cannot be formed and/or cannot live long enough!

No QGP → No Local Parity Violation !

Is this the unique explanation ?

Chiral Vortical Effect

QCD – Gauge Fields → Topological Domain/Charge Formation (Parity Odd Bubbles) → Angular Momentum (Fluid Vorticity) → Chirl Vortical Effect (Baryon Number Correlations)



1) **The opposite baryon number (Λ-pbar or Λbar-p) correlations (OB) are similar**
2) **The same baryon number (Λ-p or Λbar-pbar) correlations (SB) are lower than that of the OB, *as expected from the CVE.***

D. Kharzeev, D.T. Son, PRL106, 062301(11)
D. Kharzeev. PLB633, 260 (06)
D. Kharzeev, et al. NPA803, 227(08)

What other sources could contribute to the correlations in baryon #s? CME and CVE – quantitative relations?

Intriguing, yet inconclusive !

Experimental measurements

-- consistent with some aspects of expectations from Chiral Magnetic Effect, Chiral Magnetic Wave and Chiral Vortical Effect

-- But we do not know for sure the magnitude of the background

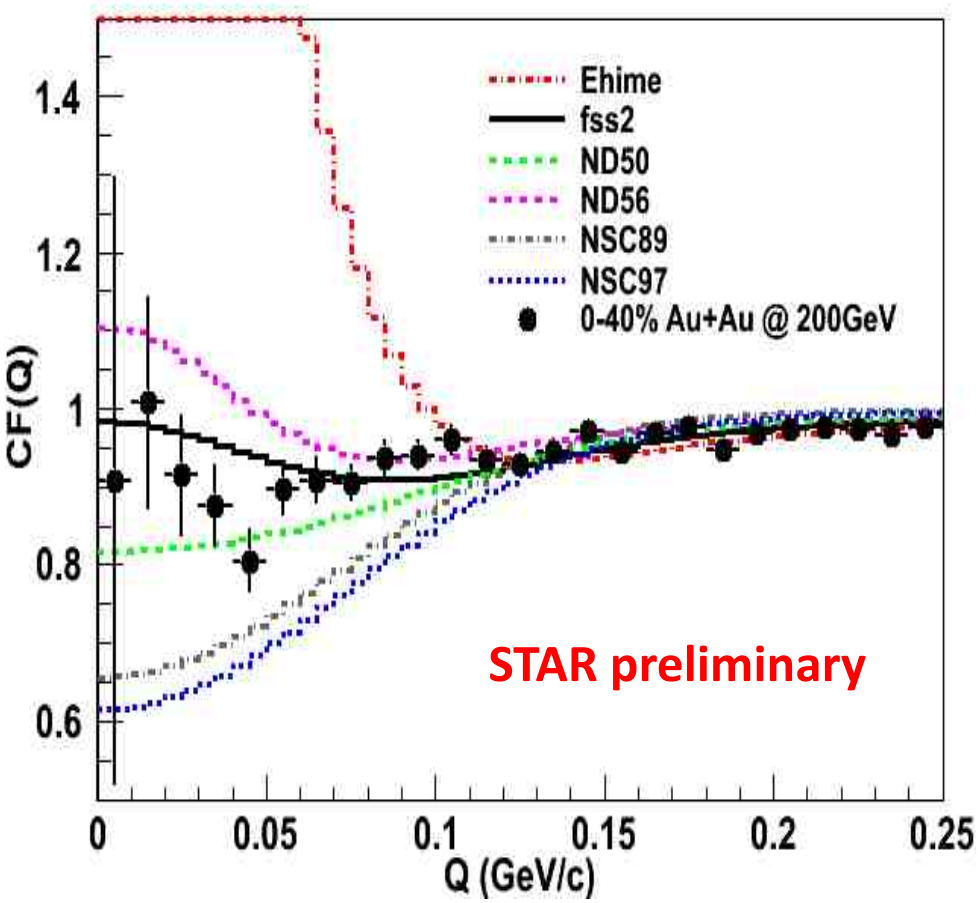
-- we are not sure of the nature of background for CMW, CVE.

We need more ideas and explorations !

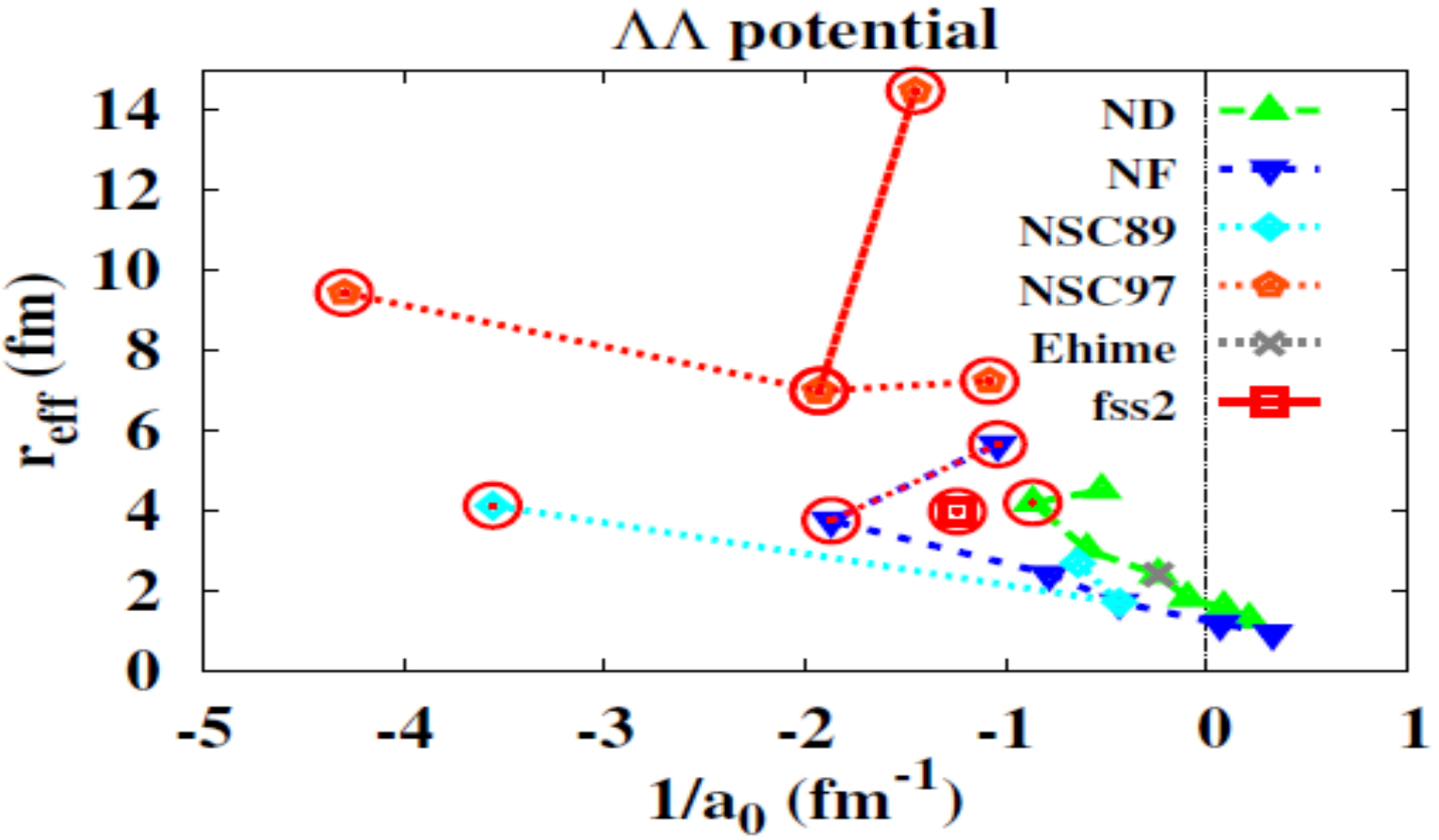
Searches for Exotic Particles

Λ-Λ Correlation
-- sensitive to ΛΛ interaction
H (uuddss) bound state
-- depletion of ΛΛ pairs

Theoretical models fit to STAR preliminary data:
ΛΛ – attractive interaction
no bound state !



Λ-Λ Correlation Function

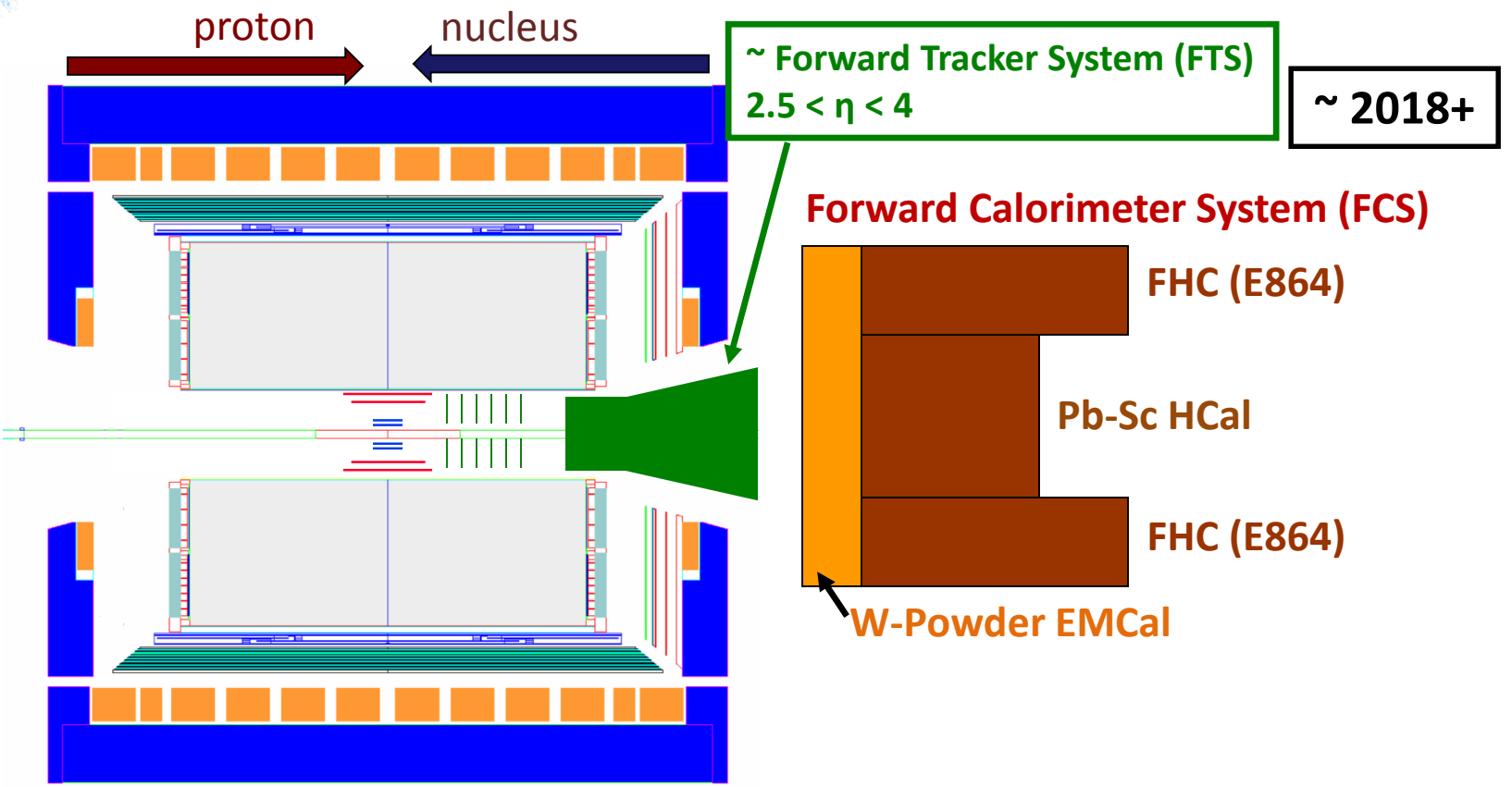


A. Ohnishi, HHI workshop proceedings 2012

- Scattering length (a_0) is negative in most fits
- Current fit from different potential models to data gives indication towards non-existence of bound H-dibaryon

Other exotic particles? ΞΞ, ΩΩ, NΩ, J/ψp, (bcs) …..

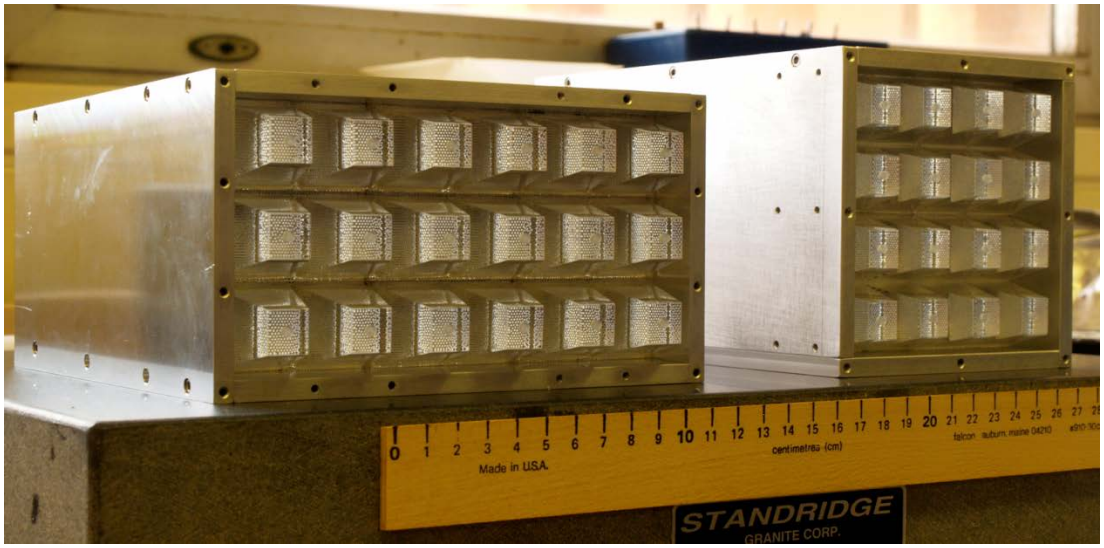
STAR Forward Upgrades: QCD at x and x



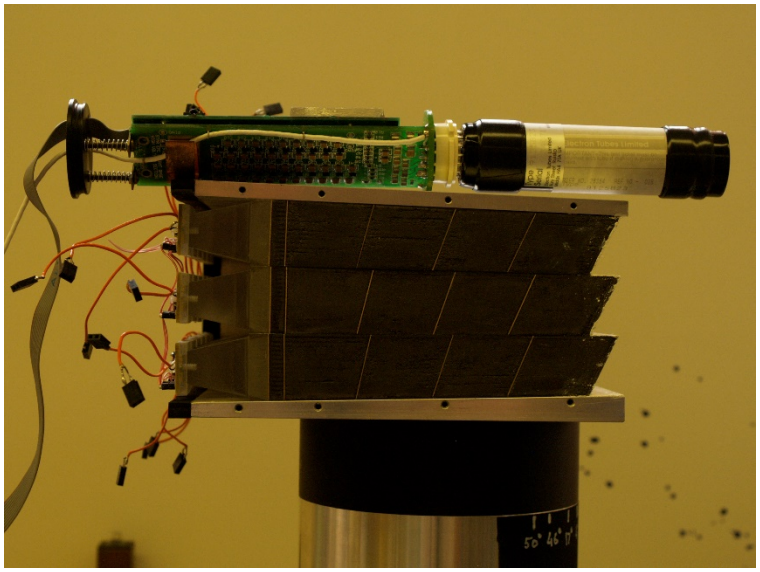
- **Forward instrumentation optimized for pp/pA and AA**
  - **Charged-particle tracking**
  - ***e/h* and γ/π^0 discrimination**
  - **Jet reconstruction**

EM Calorimeters Prototypes

EIC Barrel Prototype



STAR Prototype

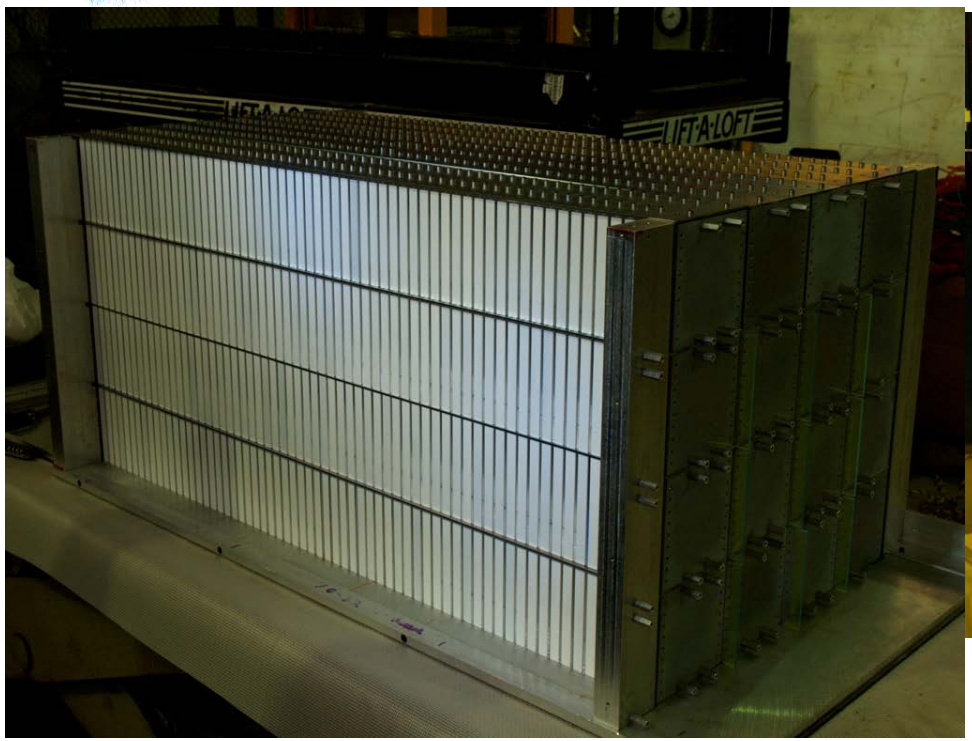


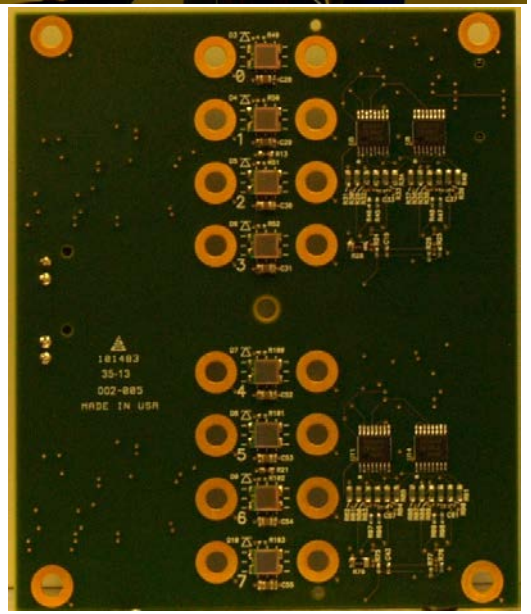
EIC BEMC: Tapered towers (for inner radius of EMCal of 120 cm). 18 towers, each 18Xo deep. Dimensions of tower at the outer radius is 2.5 x 2.5 cm. Fibers SCSF78M, diameter 0.5 mm. Initial reflector at the front end of the fibers.

STAR EMCal: 16 straight towers. 23Xo deep. Dimensions of single tower 2.5 x 2.5 cm. Fibers SCSF78, diameter 0.47 mm. Reflector at the back end of the fibers Bicron BS620.

SiPM MPPC read-out scheme

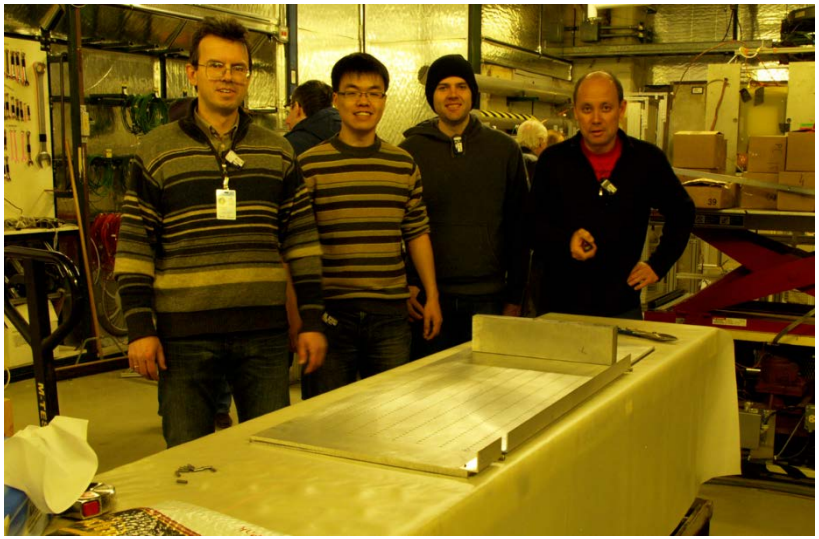
Hadronic Calorimeter Prototype at FNAL

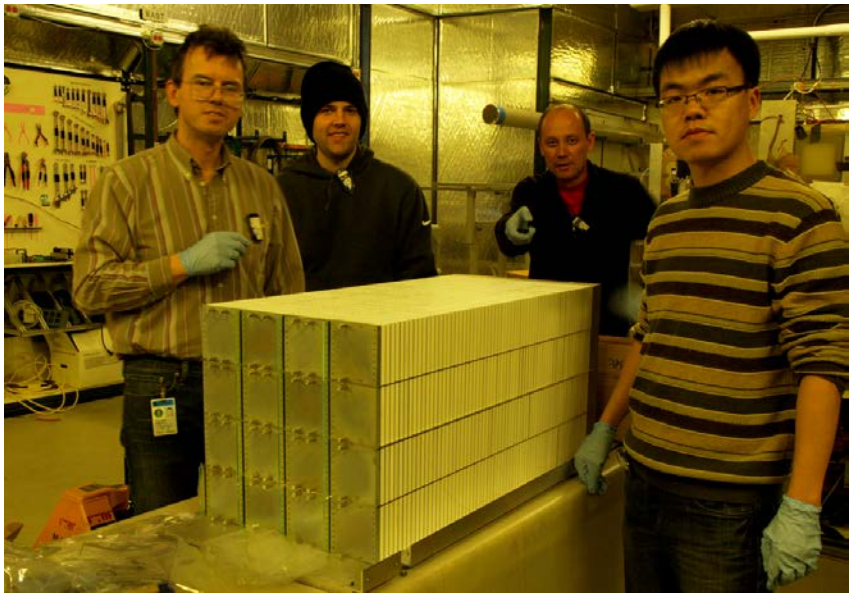




- HCal is ~4 interaction lengths Pb/scintillator.
- Readout is from Hamamatsu S10931-025p SiPMs attached to wavelength shifting plates which run the length of the detector.
- 16 individual towers.
- Total Volume 0.4 m x 0.4 m x 0.8 m

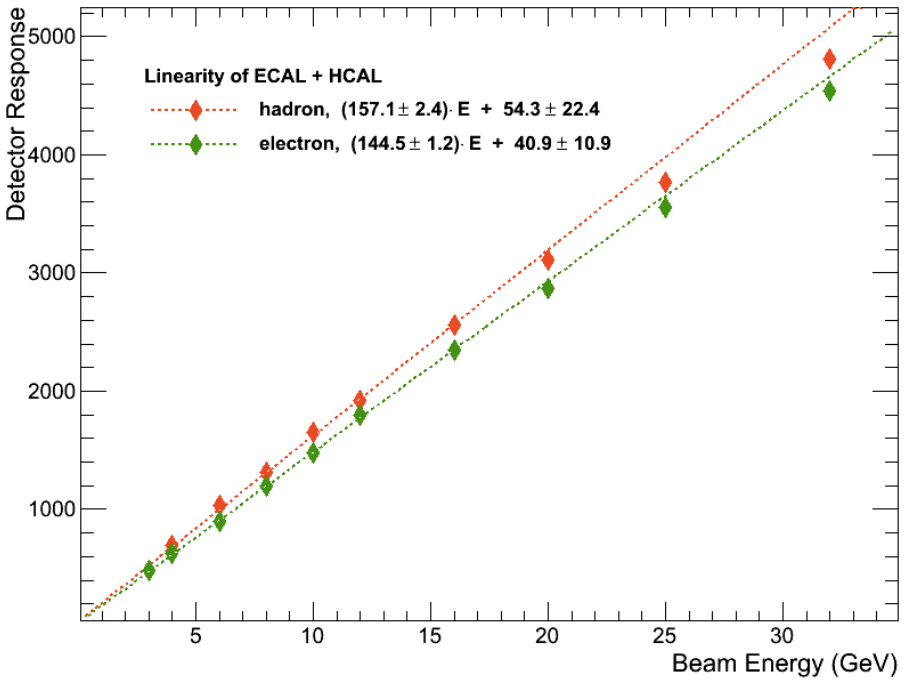
Assembling HCal Onsite -- Feb 26, 2014 @FNAL

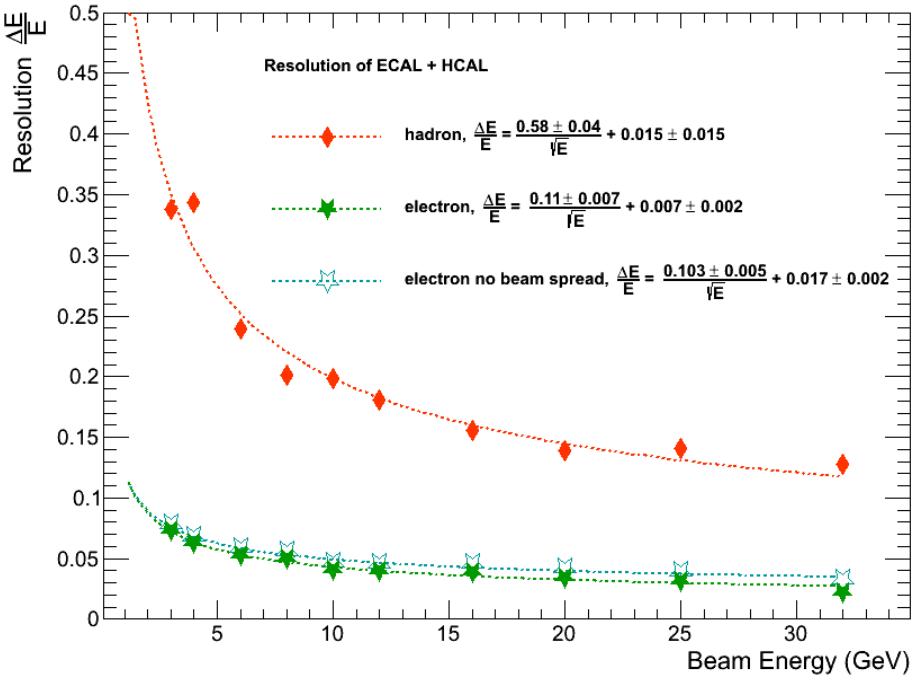




After two hours first layer done.

Beam Test Results





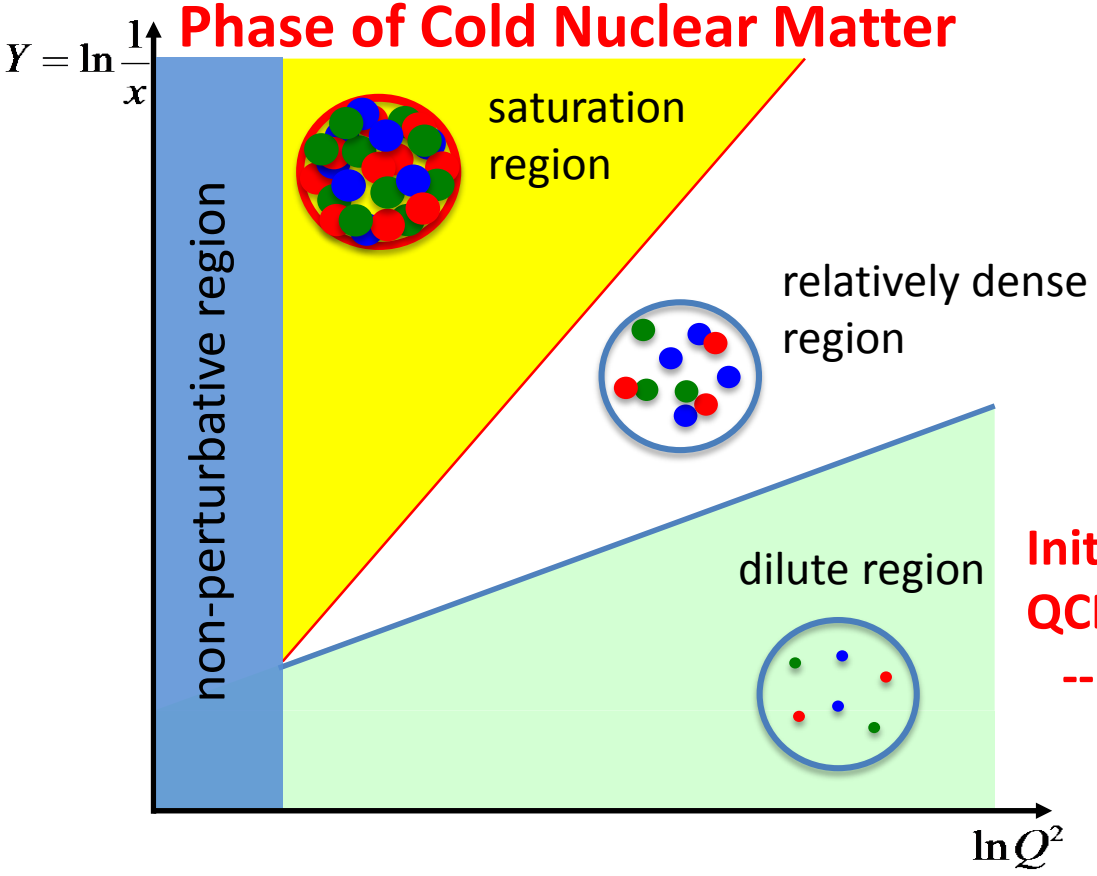
Measured the resolution of the combined ECal and HCal system for beam energies between 3 GeV and 32 GeV. Fits show hadron resolution of 58% which is close to expectations from simulation.

Non linearity above ~16 GeV is probably due to method of weighting fraction of the energy deposited in the EM section in the total sum.

Exact geometry of Test Beam setup put in place in stand alone GEANT4 and EIC MC Framework to tune/reproduce test beam data. Response to hadrons, shift from LHEP to FTFP physics list. Just Started.

Gluon Saturation in Nuclei

pA dynamics in the forward proton semi-sphere sensitive to details of the gluons in the nuclei



Forward direction kinematics favors parton scatterings of large x partons from p off small x partons from A !

Initial conditions for AA
QCD in high density non-linear regime
-- Color Glass Condensate

The quantum nature of the partons must manifest through saturations ! At what Q_S and x scales and to what extent?

RHIC – a Dedicated QCD Facility

QCD – Fundamental Corner Stone of the Standard Model !!

-Dynamics of QCD in bulk matter, vacuum structure and hadrons?

Condensed Matter Physics with Underlying QCD Interactions !

We are beyond the QGP discovery phase already !

LHC -- Energy/Temperature Frontier

RHIC – New Horizons in QCD Phase Structure, Vacuum Excitation, Initial State Color Charge Dynamics, Hadron Structure and Exotics

The Best of STAR is yet to Come

Heavy Flavor Physics – HFT/MTD: 2014-16

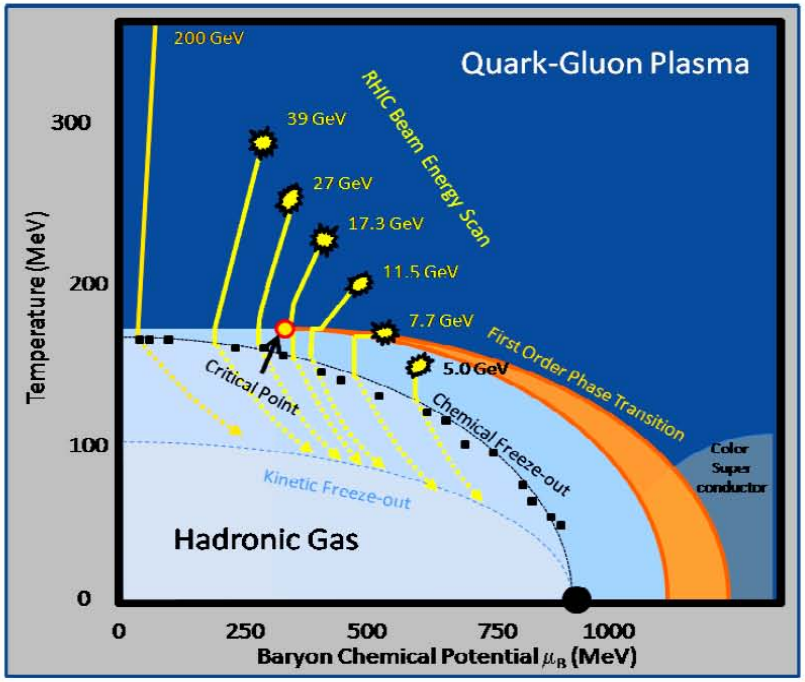
QCD Phase Diagram – BES Phase II: 2018-19+

Spin, Gluon Color Dynamics and AA – Towards eRHIC

Let us work together for a brighter future for Asian Countries in Coming QCD Endeavors !!

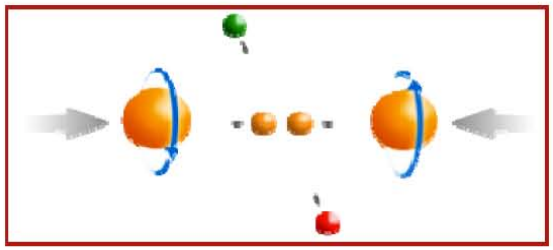
Outstanding Scientific Questions at RHIC in Coming Decade

Hot QCD Matter

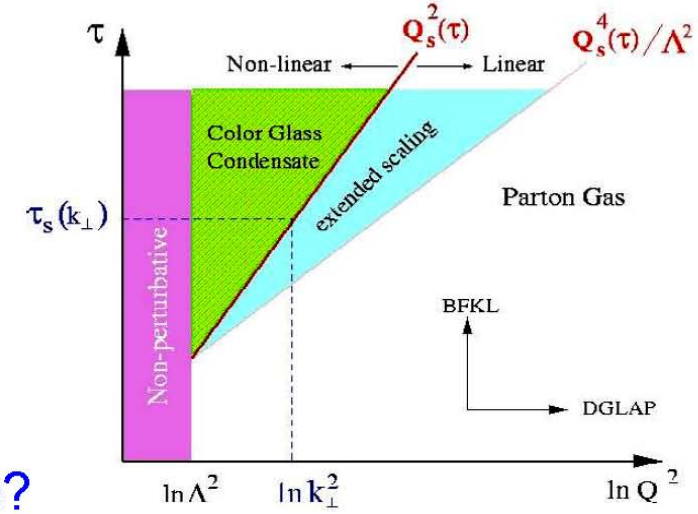


1: Properties of the sQGP
2: Mechanism of energy loss:
weak or strong coupling?
3: Is there a critical point, and if so, where?
4: Novel symmetry properties
5: Exotic particles

Partonic structure



6: Spin structure of the nucleon
7: How to go beyond leading twist and collinear factorization?



8: What are the properties of cold nuclear matter?

The End