

Forward Upgrade Physics in Heavy Ion Collisions

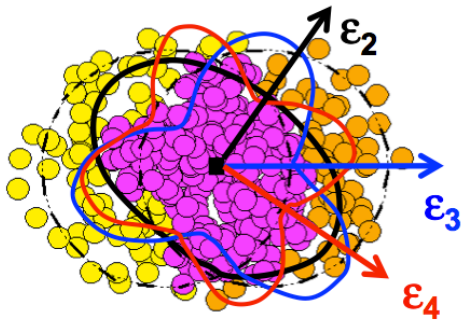
Lijuan Ruan (Brookhaven National Laboratory)

Science:

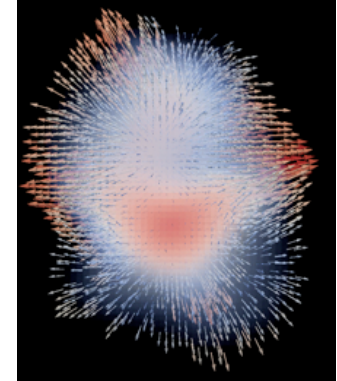
To enhance our understanding of QGP at 200 GeV and help complete the mission of the RHIC heavy-ion program in the flow sector

To constrain the temperature dependence of the QGP properties

Azimuthal anisotropy v_n



pressure



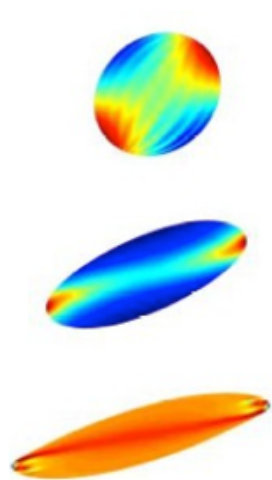
$$\frac{dN}{d\phi} \propto 1 + 2 \sum_n v_n \cos n(\phi - \Phi_n)$$

Initial anisotropy in spatial coordinate + pressure gradient = final-state anisotropy observed in momentum space

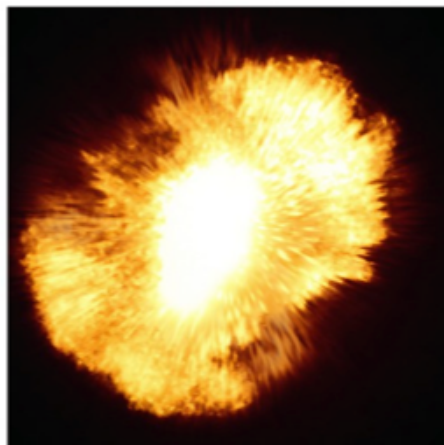
v_n : n th harmonic of the azimuthal distribution with respect to the event-plane angle

Viscosity

Shear viscosity:
resistance to deformation



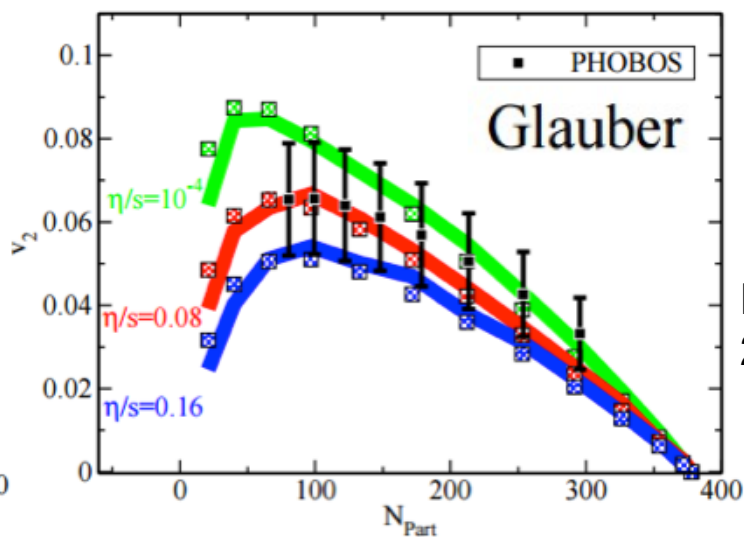
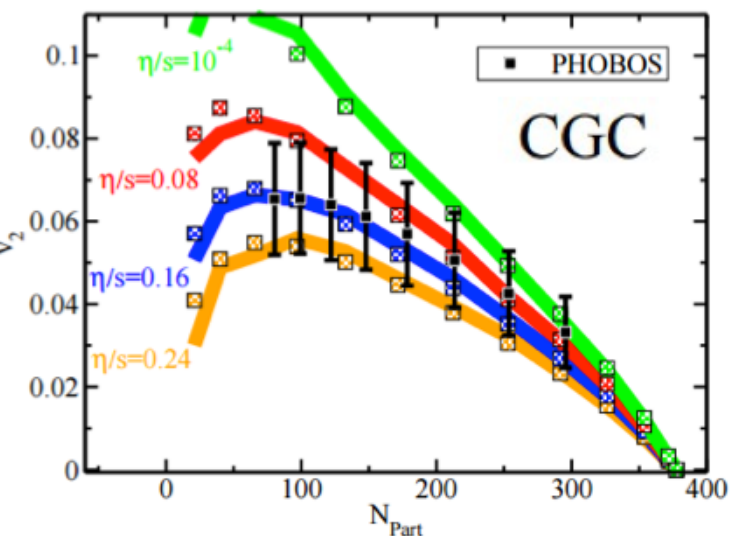
Bulk viscosity:
resistance to expansion



In 2015, “perfect liquid”
discovery at RHIC announced
by BNL.

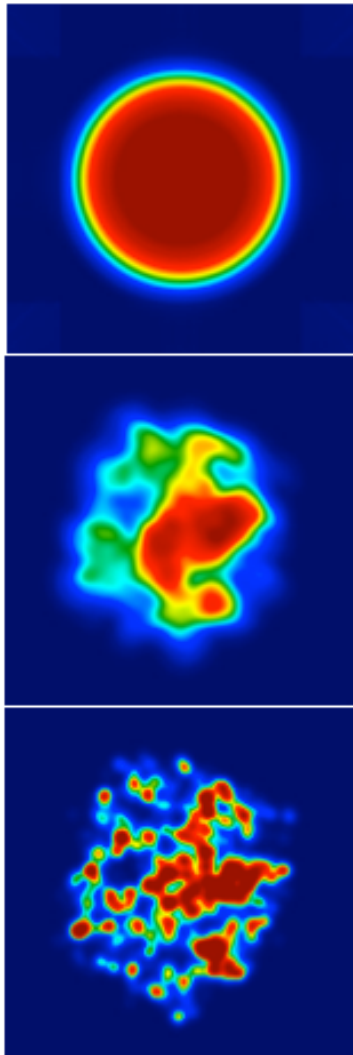
**Different Initial states give
different shear viscosity/entropy
values.**

Courtesy of G. Denicol



Luzum & Romatschke,
2008

Initial state fluctuates



Courtesy of G. Denicol

**Smooth Initial conditions
($v_2=0$ in central collisions)**



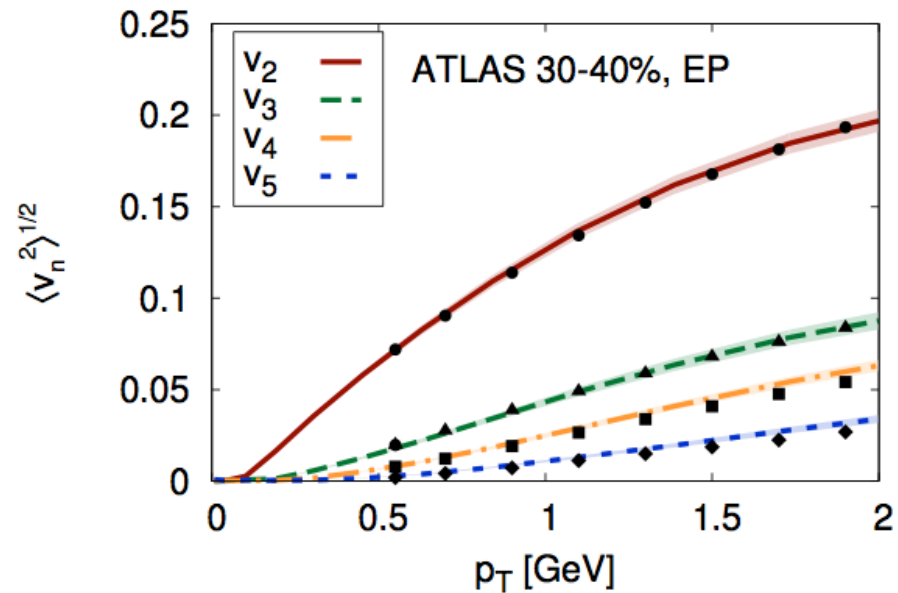
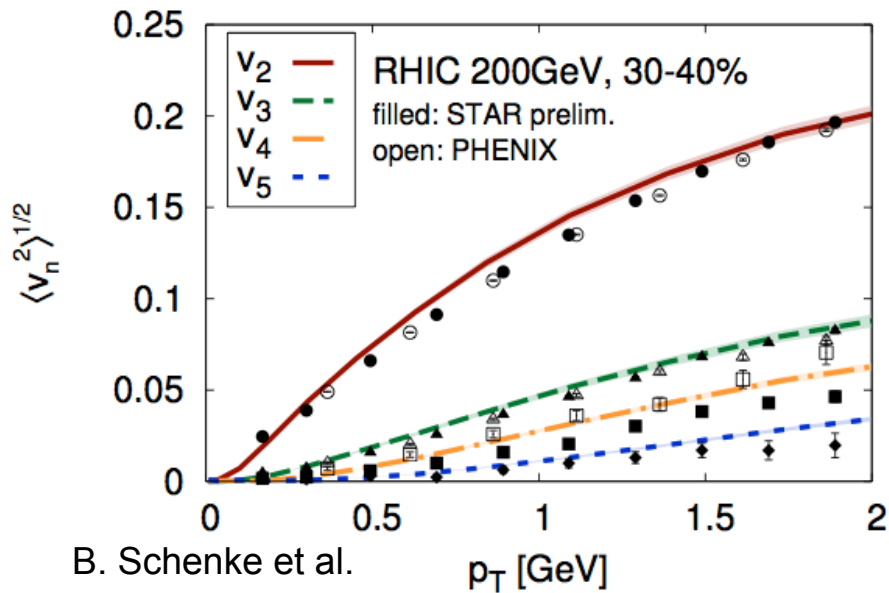
**Fluctuations in nucleon positions
(odd harmonics)**



**sub-fermionic fluctuations
(v_n distributions & correlations)**

Initial state fluctuates event-by-event!

What have we learnt

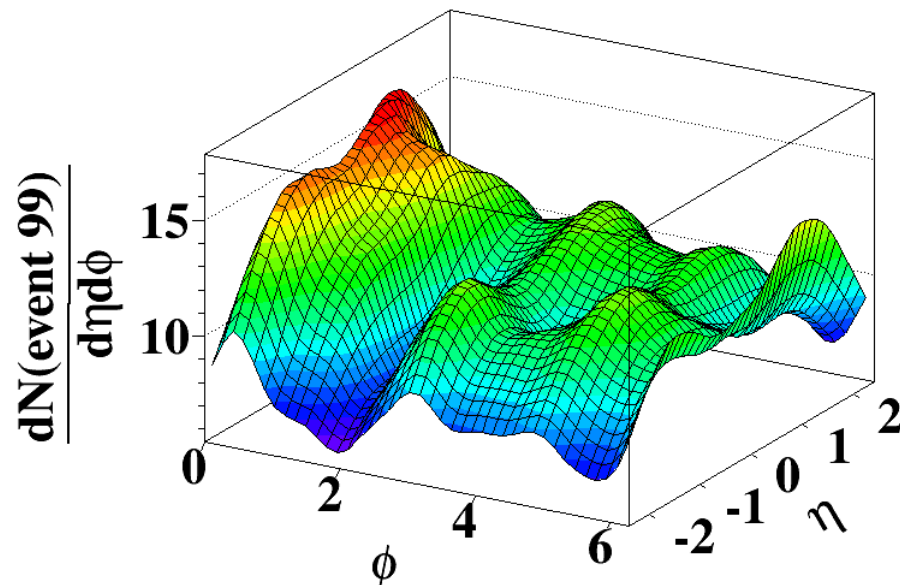


IP Glasma initial condition, subnucleonic color charge fluctuations, 3+1D hydro evolution: $\eta/s=0.12$ (0.2) at 0.2 (2.76) TeV

1. Transverse fluctuation essential to reproduce data
2. How about longitudinal dynamics? How much do we understand it?

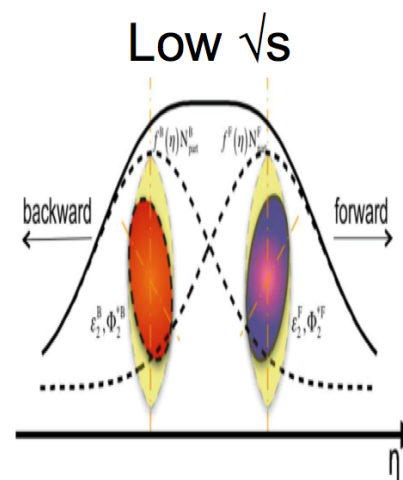
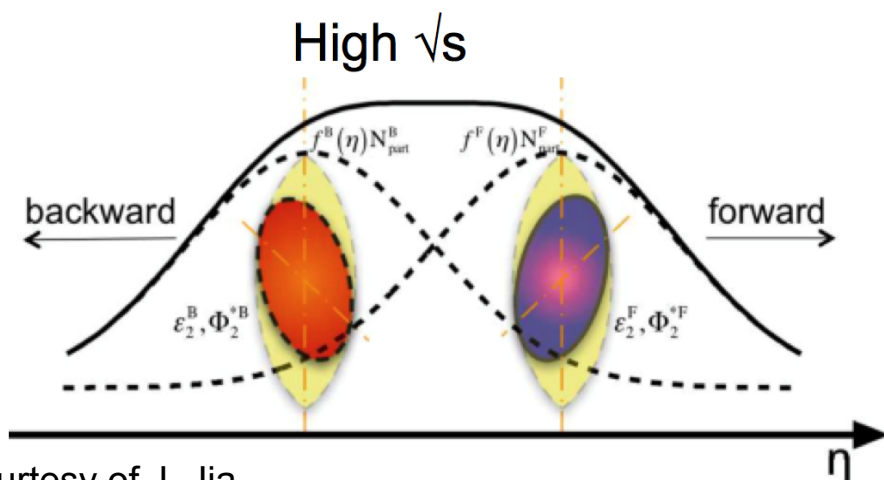
Longitudinal Fluctuations

Courtesy of L.Pang and X.N Wang, EbyE 3D hydro+AMPT condition



Significant transverse and **longitudinal** fluctuations!

Forward-backward asymmetry in N_{part} , eccentricity vector leads to **asymmetry** in multiplicity, transverse flow profile, and event plane.



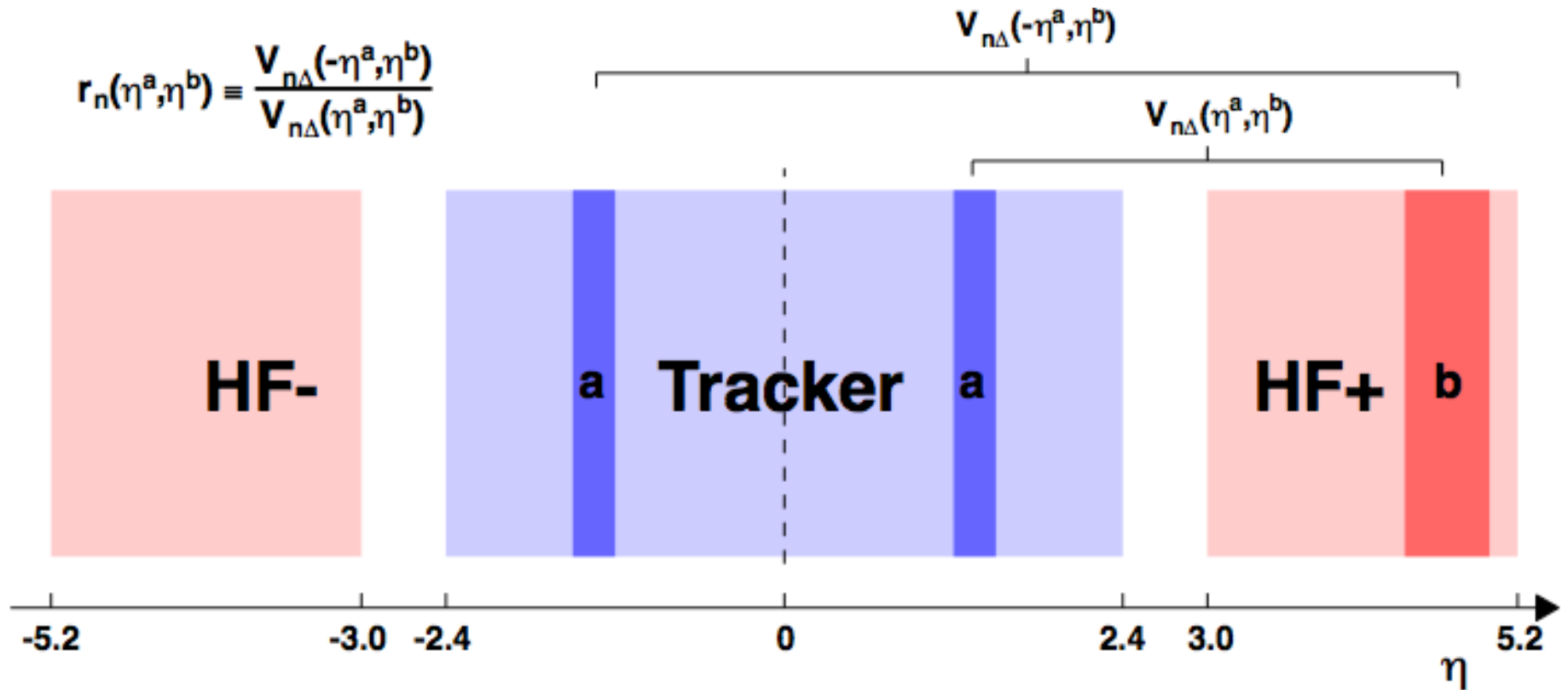
Courtesy of J. Jia

9/22/15

Lijuan Ruan, Physics Department, BNL

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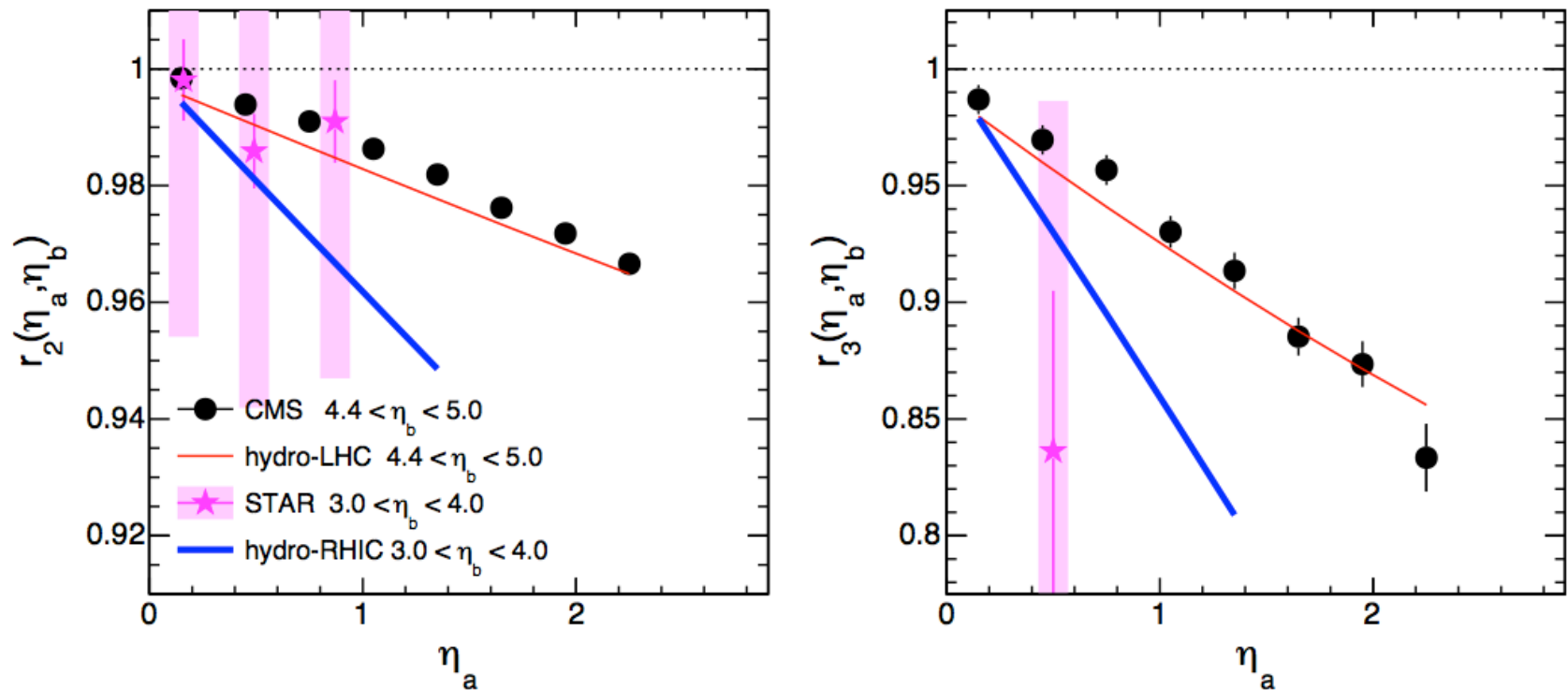
Longitudinal decorrelation



$$r_n(\eta^a, \eta^b) = \frac{\langle v_n(-\eta^a) v_n(\eta^b) \cos [\Psi_n(-\eta^a) - \Psi_n(\eta^b)] \rangle}{\langle v_n(\eta^a) v_n(\eta^b) \cos [\Psi_n(\eta^a) - \Psi_n(\eta^b)] \rangle}.$$

Measure **relative event-plane angle fluctuations** in η for planes separated by $|\eta_a + \eta_b|$ and $|\eta_a - \eta_b|$

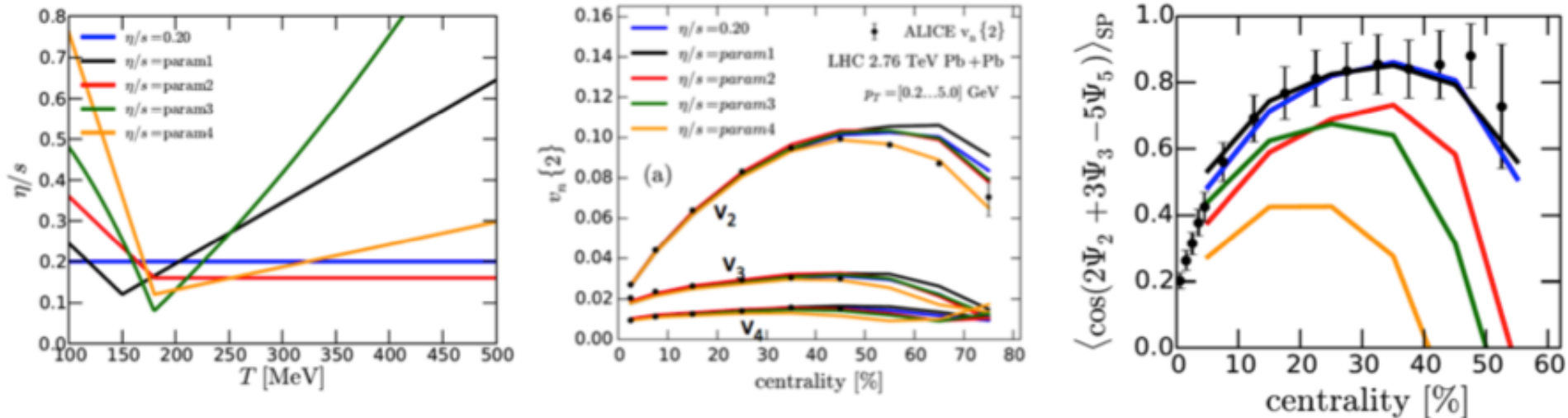
Longitudinal decorrelation



Longitudinal decorrelation observed by CMS. Models predict larger effect at RHIC.

Need forward upgrades with more uniform acceptance and finer granularity to create enough rapidity gap. Critical to constrain 3+1D viscous hydro models, gain more understanding of multiple-source contributions.

Event-plane correlator measurements

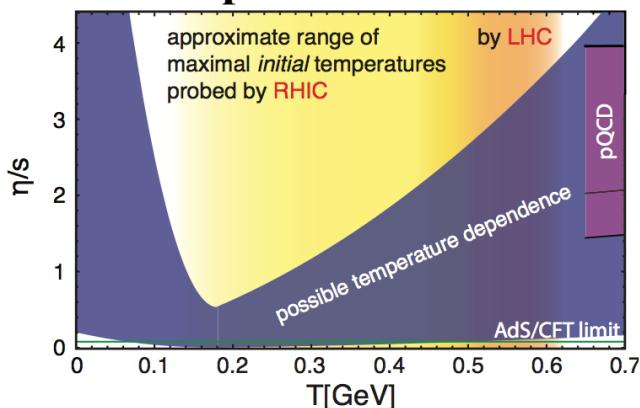


Inclusive v_n measured in one energy is **not sensitive to the temperature dependence of η/s**

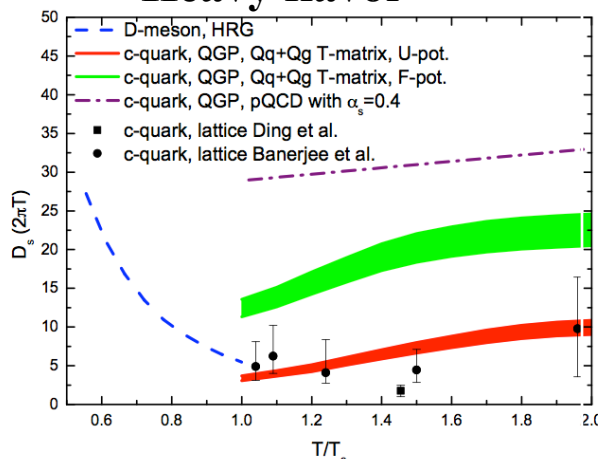
Event-plane correlator (correlations between multiple event planes of different orders) **is sensitive to the temperature dependent of η/s**

Transport coefficients

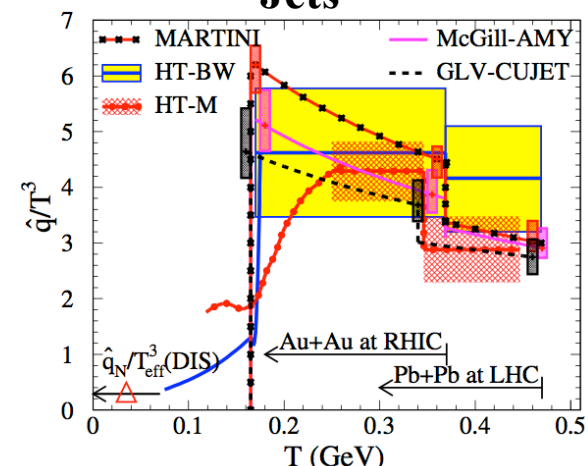
Flow and particle correlation



Heavy flavor



Jets



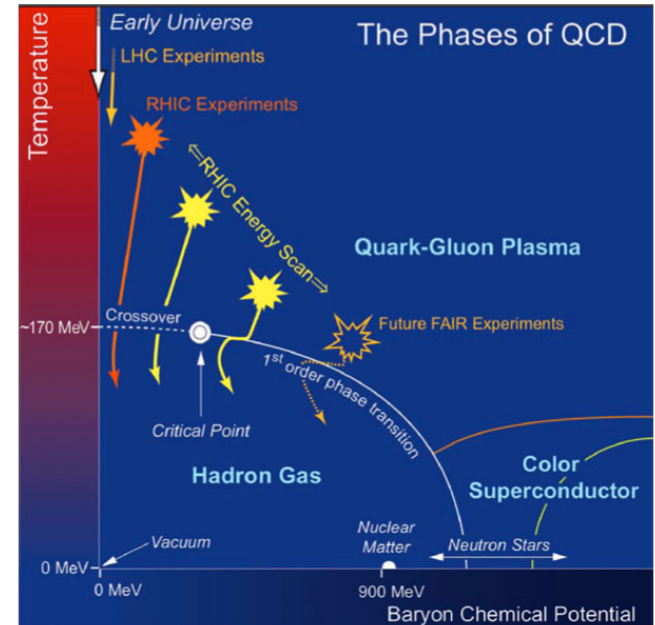
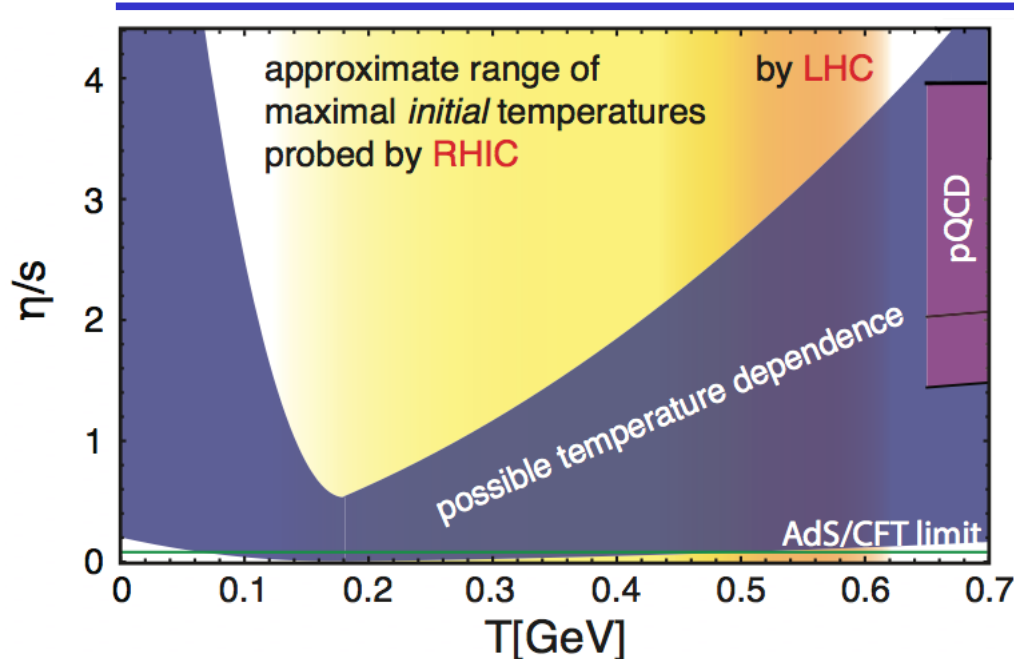
Currently η/s and 3+1D hydro are essentially constrained by bulk measurements.

Utilizing 3+1D viscous hydro evolution and the heavy flavor measurements, one can constrain heavy flavor diffusion coefficient.

Utilizing 3+1D viscous hydro evolution and the jet related measurements, one can obtain jet transport coefficients (the average squared transverse momentum broadening per unit length and longitudinal energy loss coefficient with the latter constrained by heavy flavor).

Direct constraints on the temperature dependence of η/s from bulk observables are essential to understand heavy flavor and jet physics.

Constrain $\eta/s(T)$



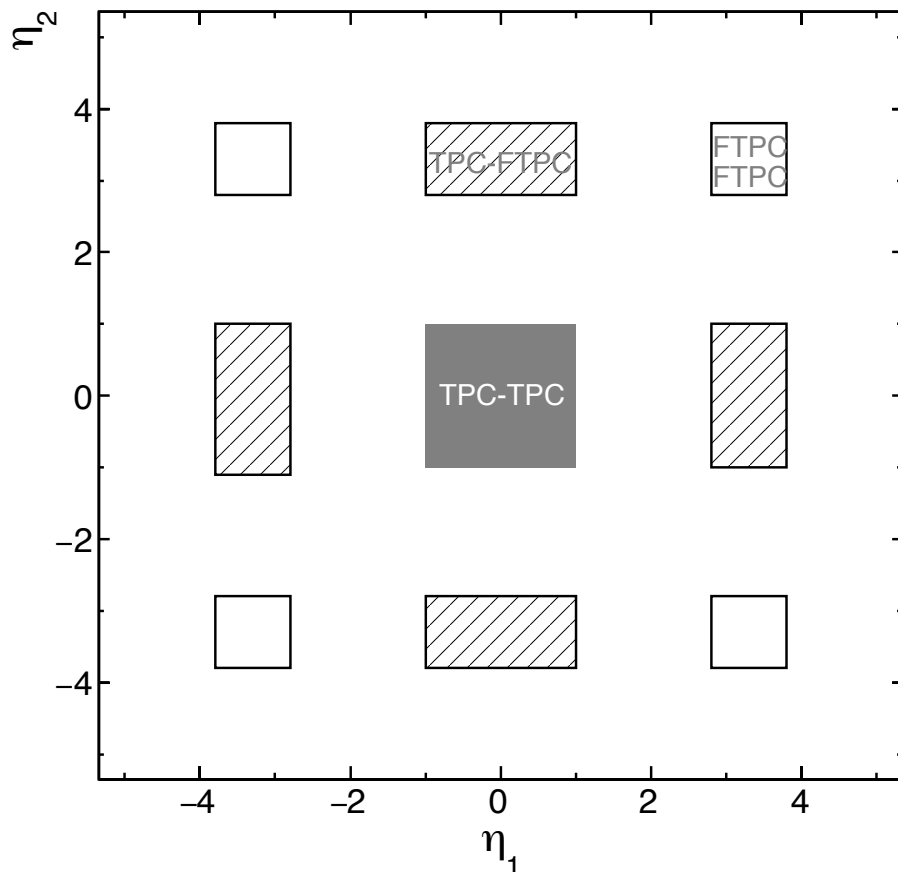
Further constrain $\eta/s(T)$ with better understanding on 3+1D hydro from longitudinal decorrelation:

RHIC and LHC v_n , sensitive to average value of η/s at RHIC and LHC energies.

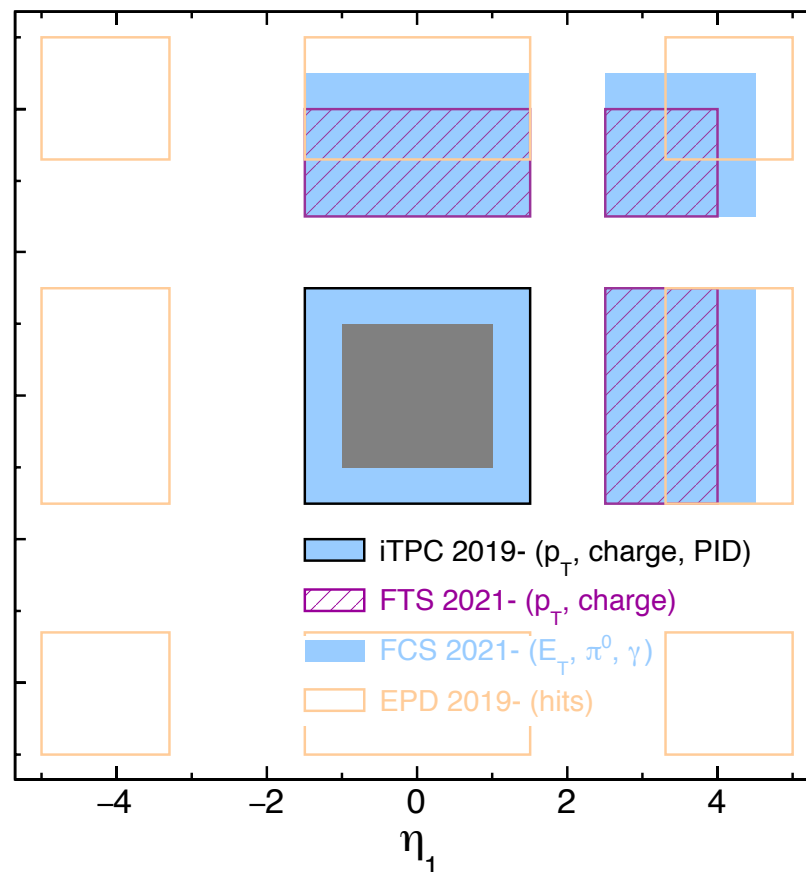
multiple event-plane correlation, sensitive to temperature evolution of η/s in QGP space-time dynamics in each collision energy

$v_n(p_t, y)$, sensitive to temperature and μ_b evolution of η/s in QGP space-time dynamics in each collision energy

TPC+fTPC (2001-2012)



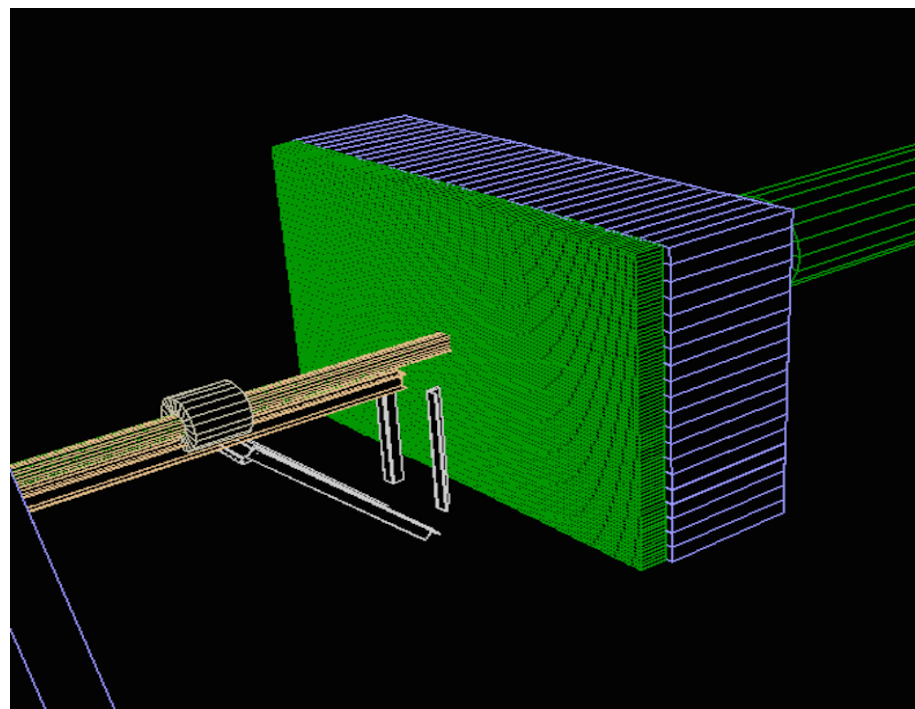
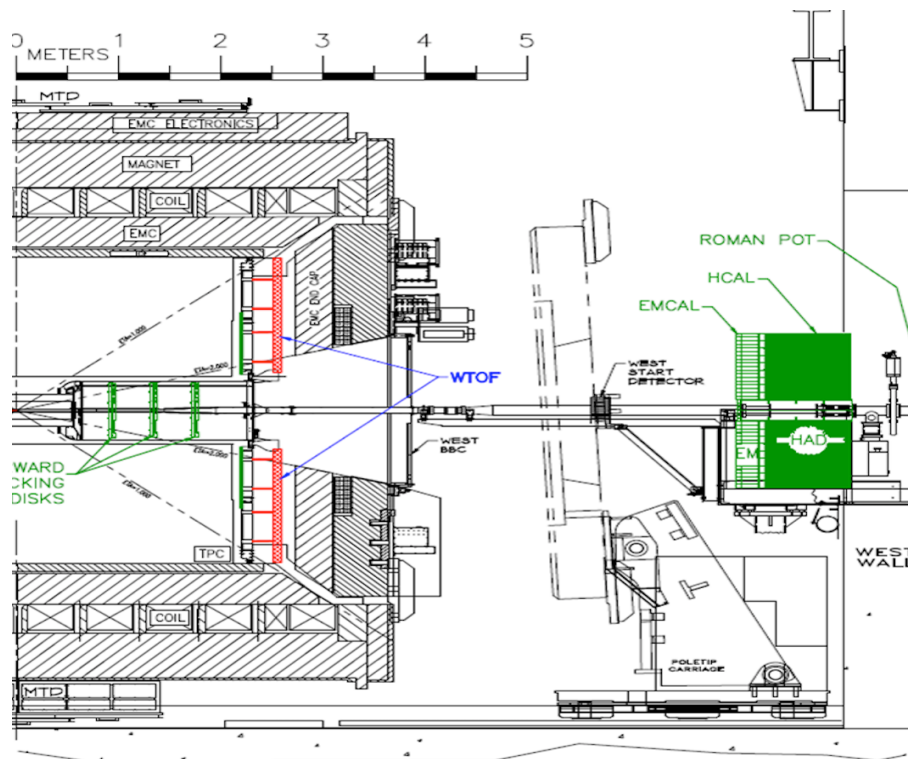
Future Capabilities



Understanding $\eta/s(T)$ is fundamental!

**The unique and important physics calls for forward upgrade:
Forward Calorimeter System+Forward Tracking System**

STAR Forward Upgrade



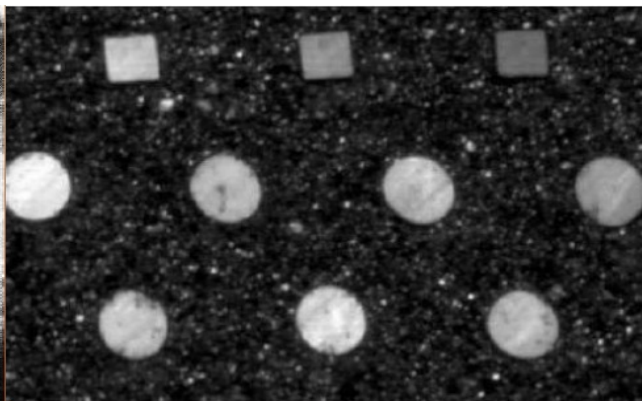
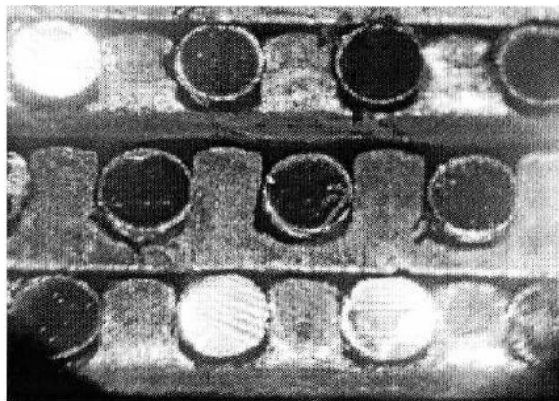
A Spaghetti EMCAL (SPACal) followed by a Lead and Scintillating Plate sampling HCAL:

SPACal made of Tungsten powder and scintillating fibers (Moliere Radius: 2.3 cm, size of each module: $2.5 \times 2.5 \times 17 \text{ cm}^3$, 23 X0 in length).

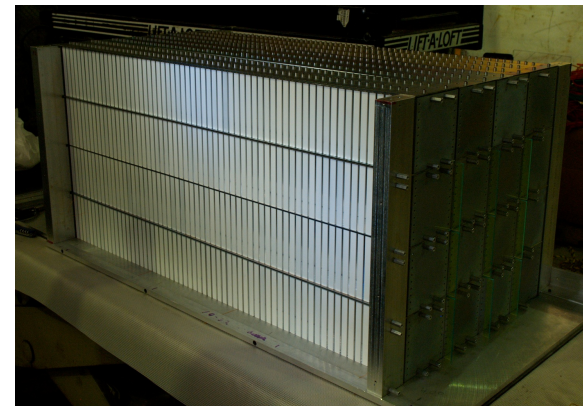
HCAL: Lead and Scintillator tiles with a tower size of $10 \times 10 \times 81 \text{ cm}^3$, 4 interaction lengths.

In total, 120×80 SPACal and 30×20 Hcal, covering an area of $3 \times 2 \text{ m}^2$.

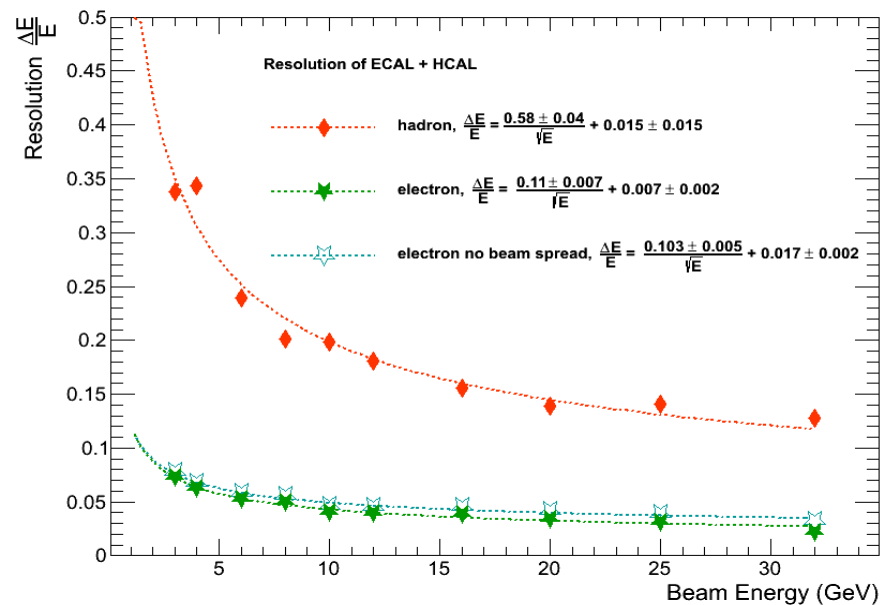
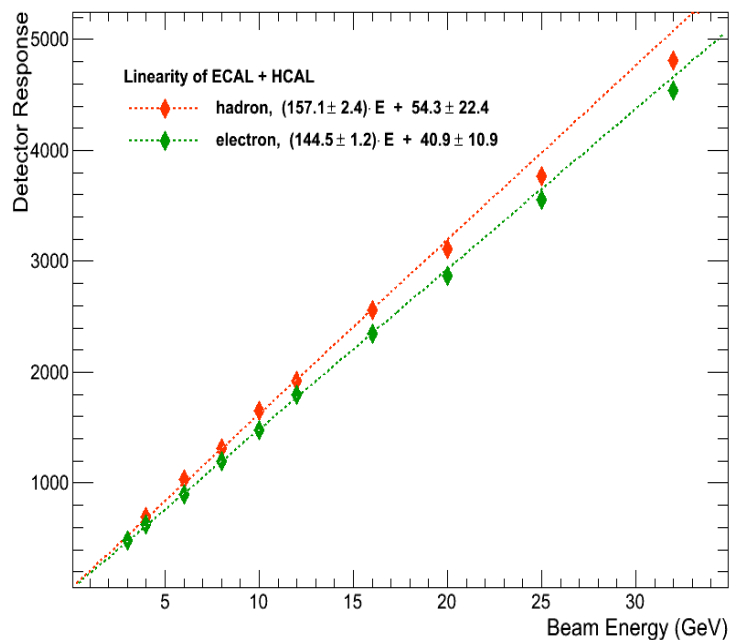
Performance from beam test



SPACal)



HCal



Realization of Forward Upgrade

The proposed FCS upgrade is expensive, about 10 million USD.

The realistic budget does not allow for this option. The consensus idea is to reuse PHENIX EMC (~0.6 M USD) and add new Hcal (~1.2 M USD) as a default option. The E864 Hcal option will be explored.

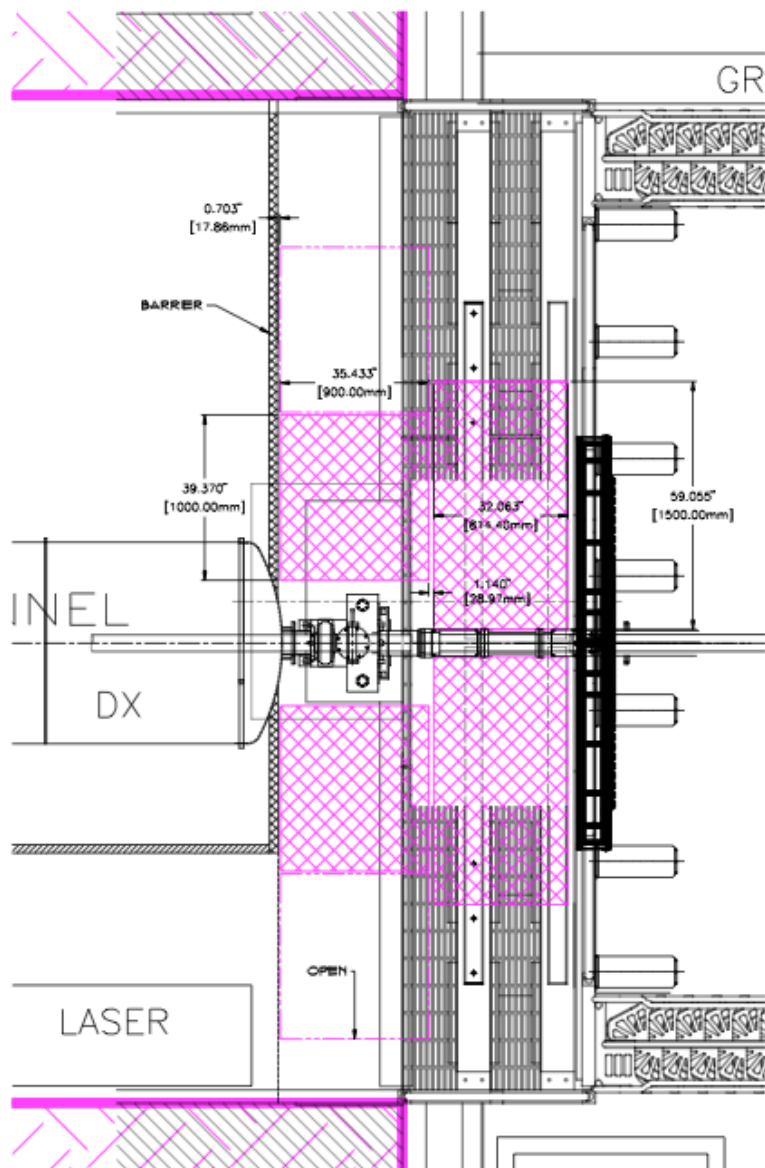
The FTS (Zhenyu will talk about) will be Si-based.

The total FCS+FTS is about 6 M USD.

Proposal need to be submitted to ALD in Jan., 2016 while Zhangbu would like to have an internal review after Oct., 2015.

Short document summarizing key physics need to be submitted to ALD in Sep., 2015.

Realization of Forward Upgrade



Readout for EMCal:APD or SiPM

HCal: SiPM

Summary

Measurements	Physics
Longitudinal decorrelation	Crucial to constrain full 3+1D viscous hydro dynamics, gain more insight to understand multiple source contributions.
$V_n(pt, y)$	temperature evolution of η/s in QGP space-time dynamics
Event-plane correlations	temperature evolution of η/s in QGP space-time dynamics
Correlation between mid-rapidity baryons and forward multiplicity	Sensitive to baryon stopping.
...	...