Recent results from PHENIX and other experiments and future plan for sPHENIX upgrade

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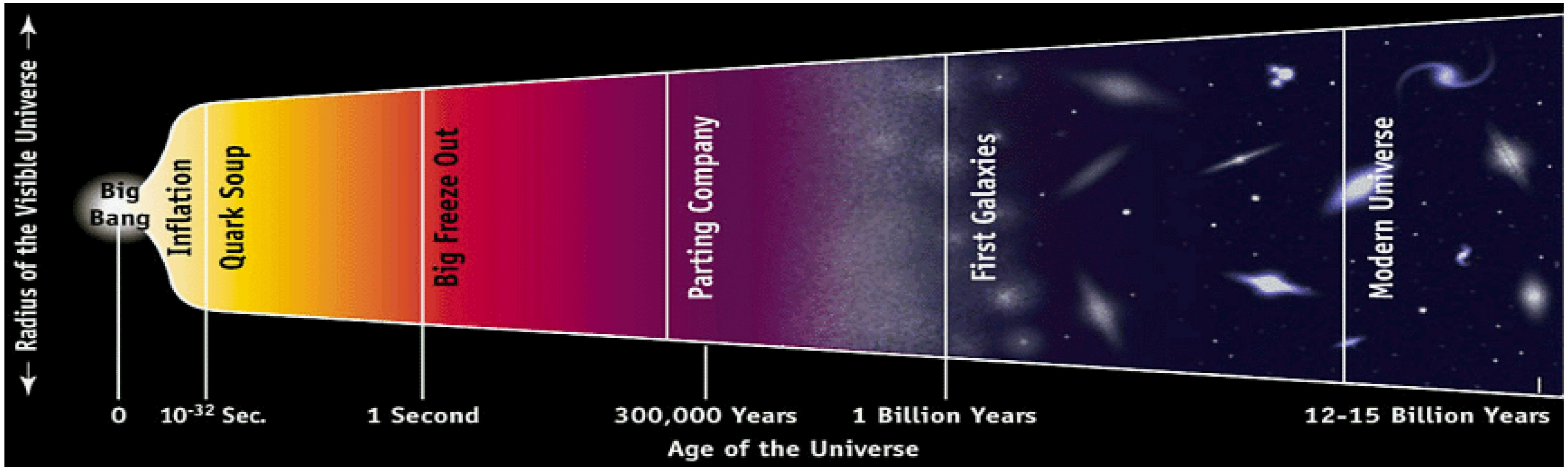
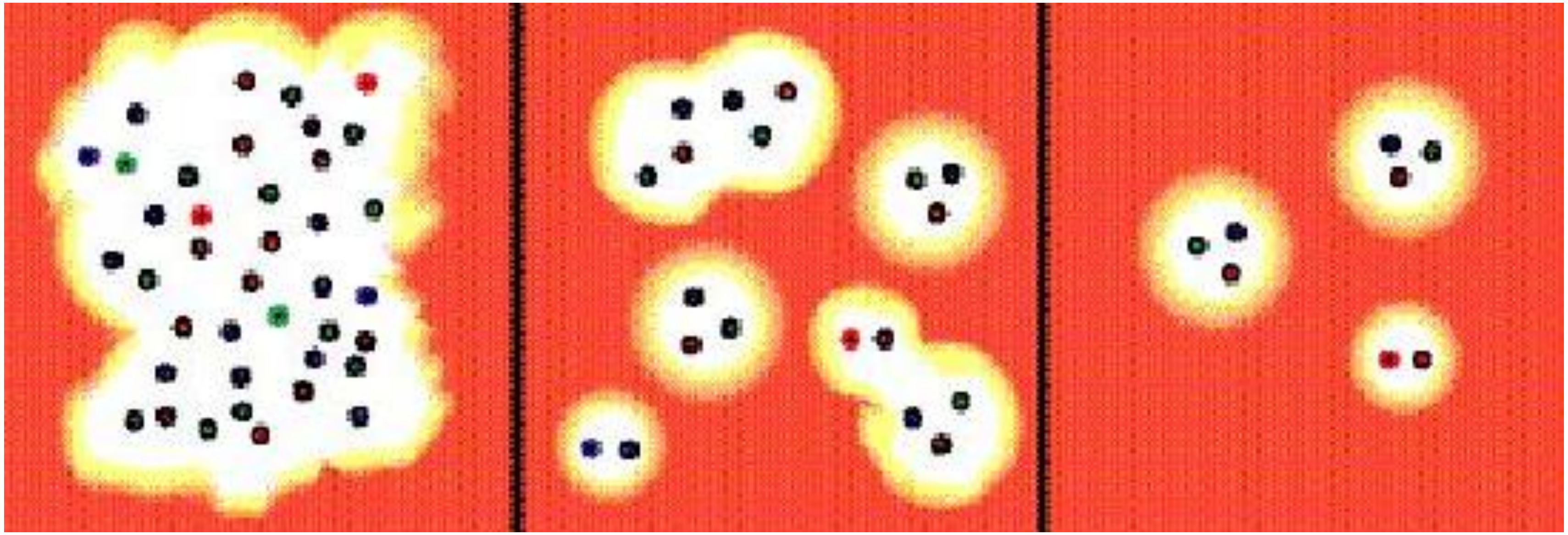
Contents

Quark Gluon Plasma (QGP)

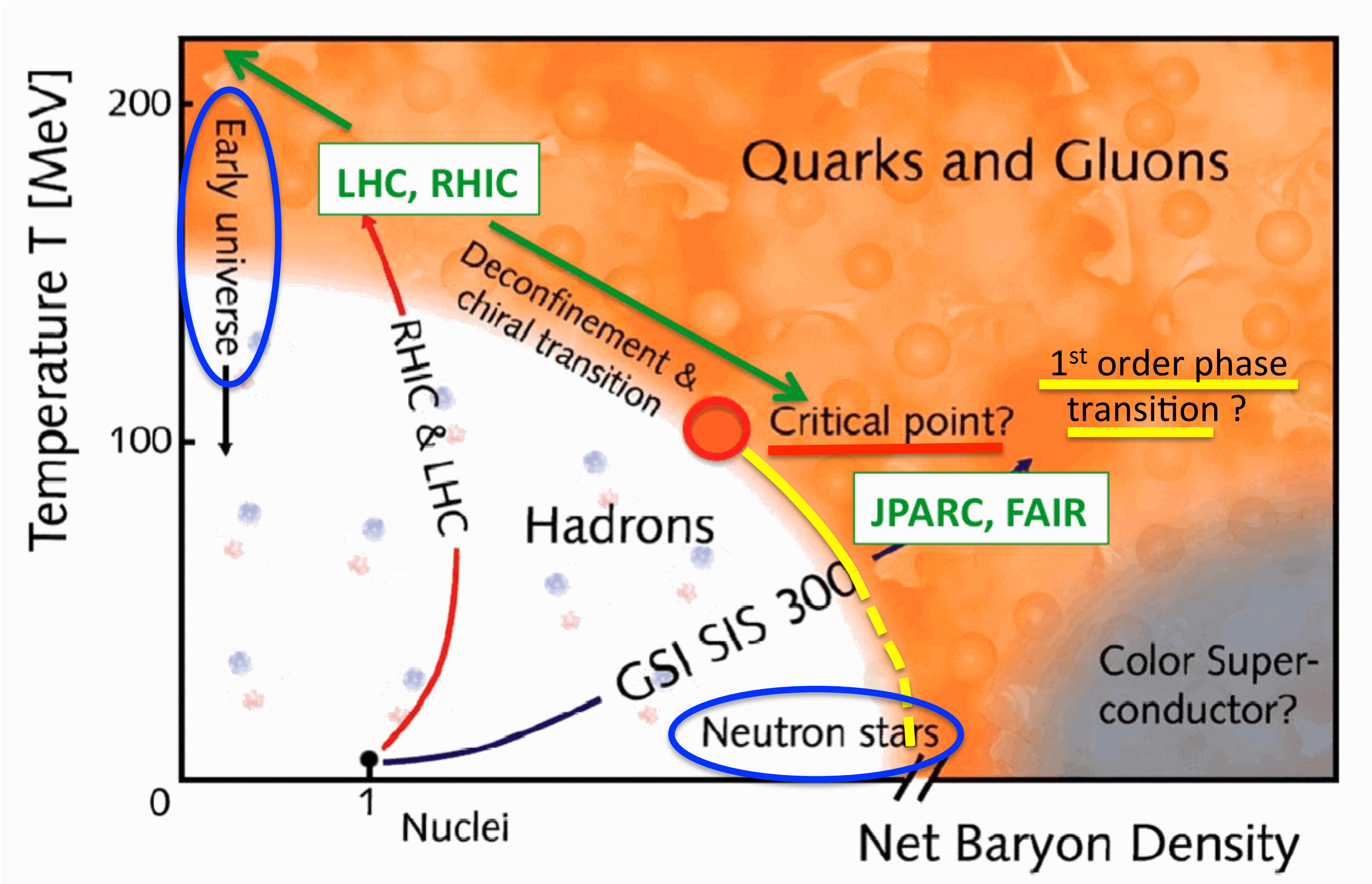




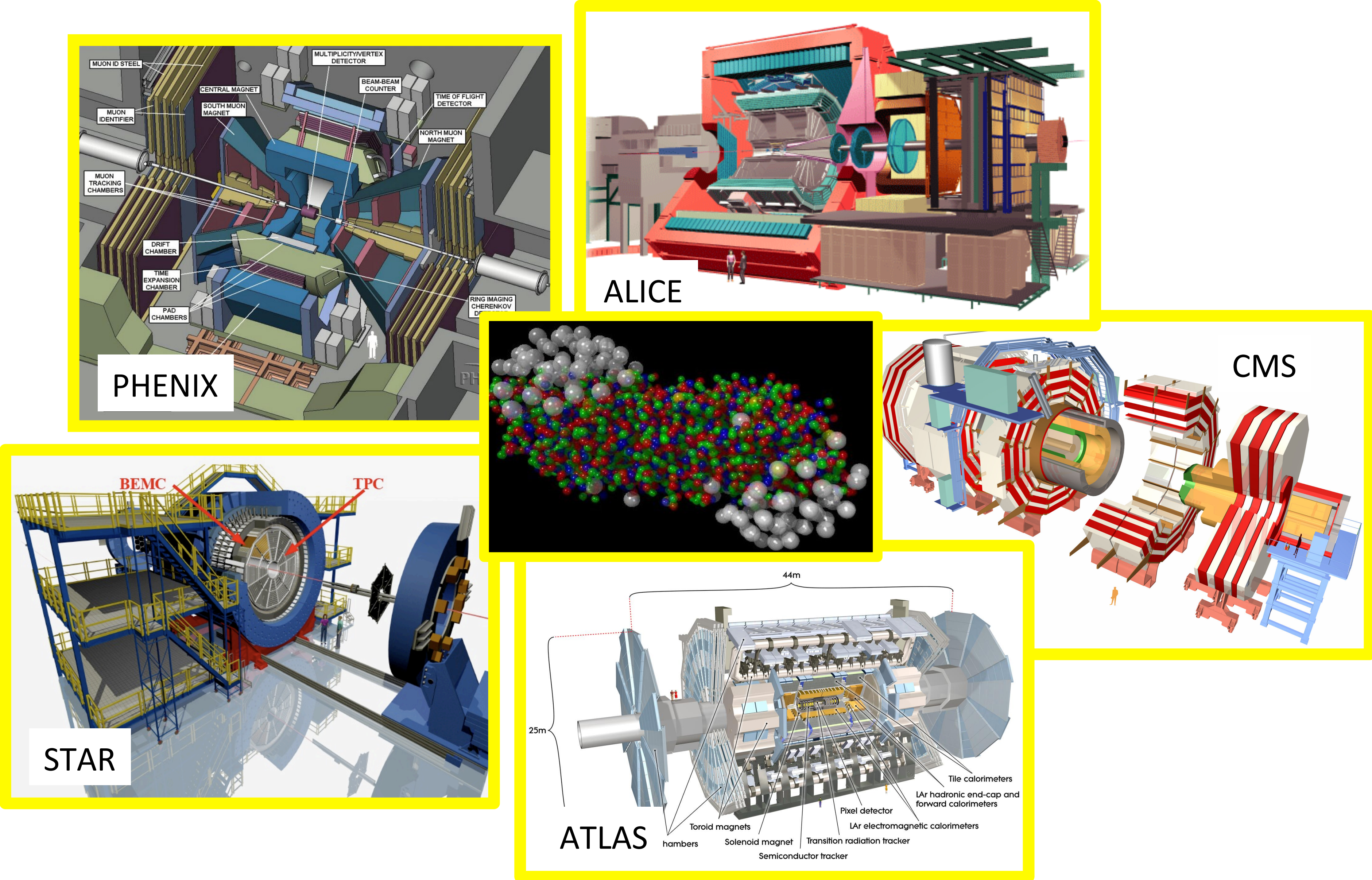
Quark Gluon Plasma   Hadrons

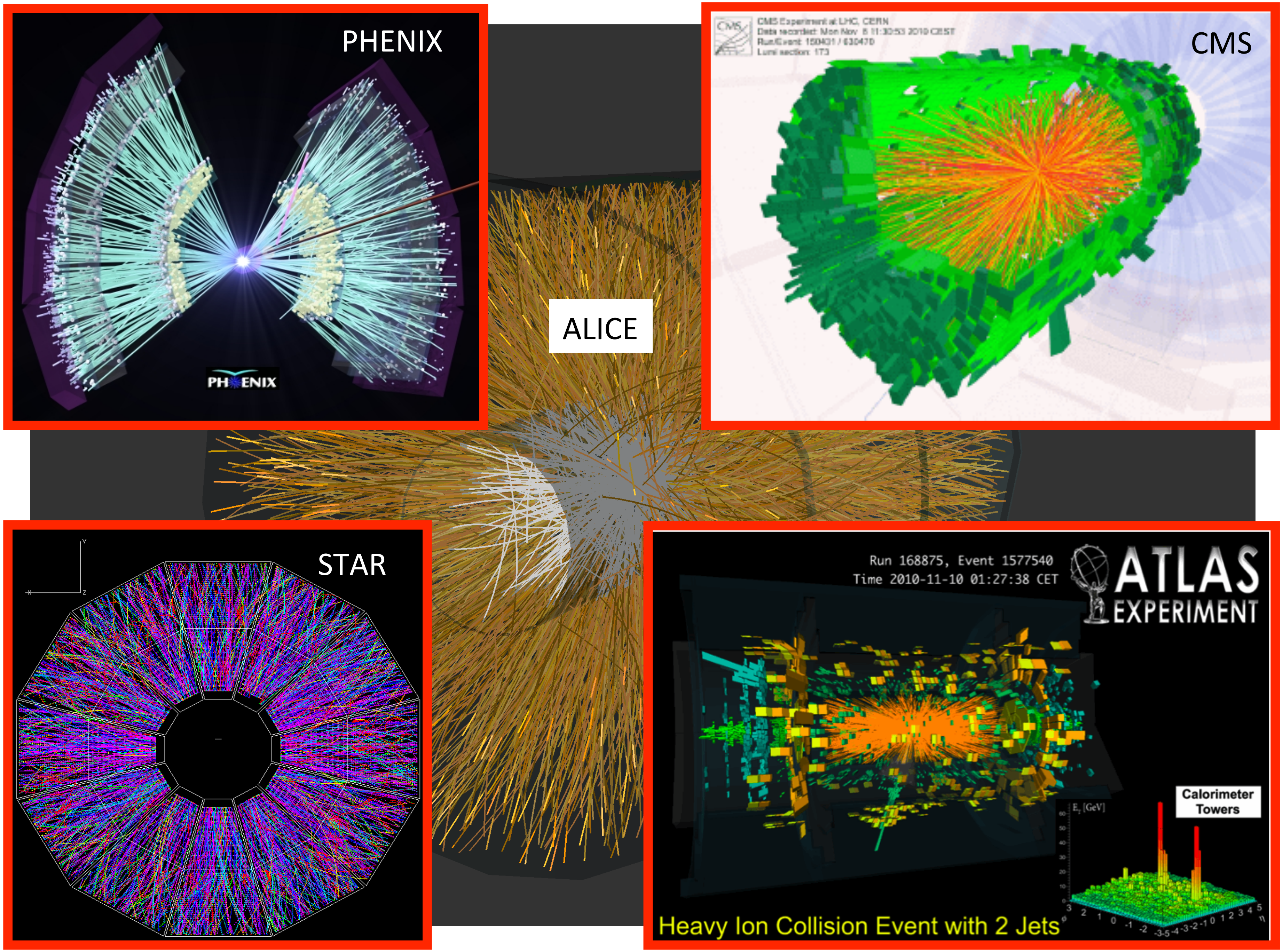
RHIC Beam Energy Scan program (BES)

to look for critical behaviors --- critical point and 1st order phase transition ---

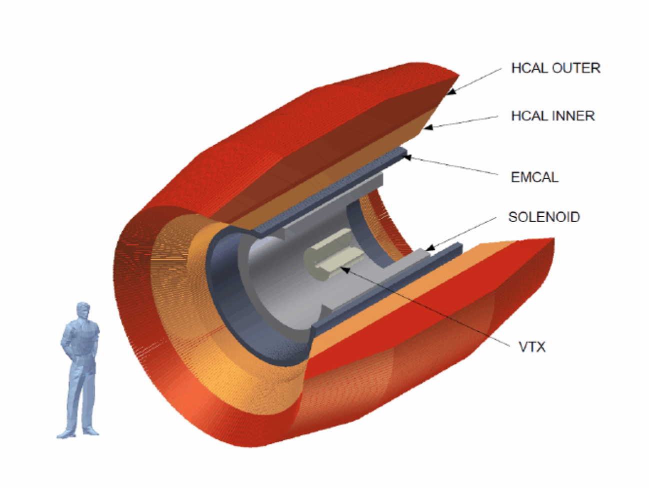


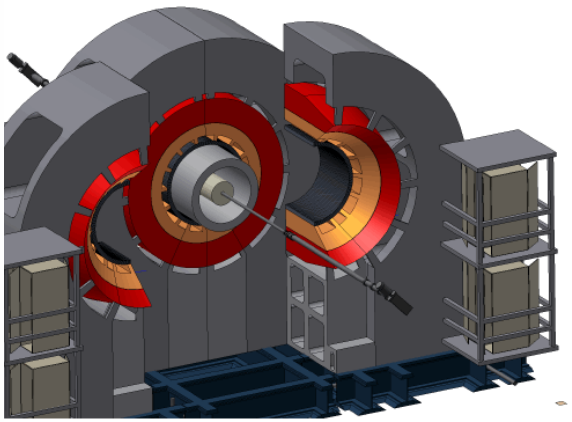
Relativistic Heavy-Ion Collider (RHIC) at BNL in New York
Large Hadron Collider (LHC) at CERN in Geneva

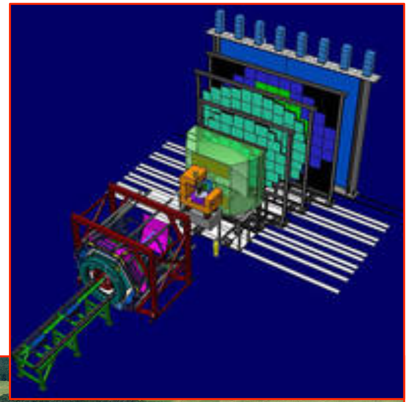



PHENIX
PHENIX
ALICE
CMS
STAR
ATLAS
EXPERIMENT
Run 168875, Event 1577540
Time 2010-11-10 01:27:38 CET
Calorimeter Towers
Heavy Ion Collision Event with 2 Jets

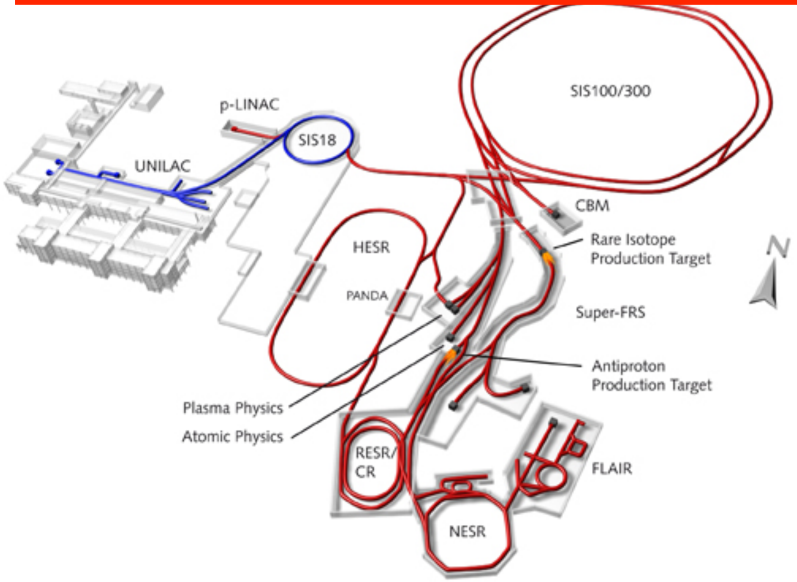
sPHENIX upgrade at RHIC, New York, USA





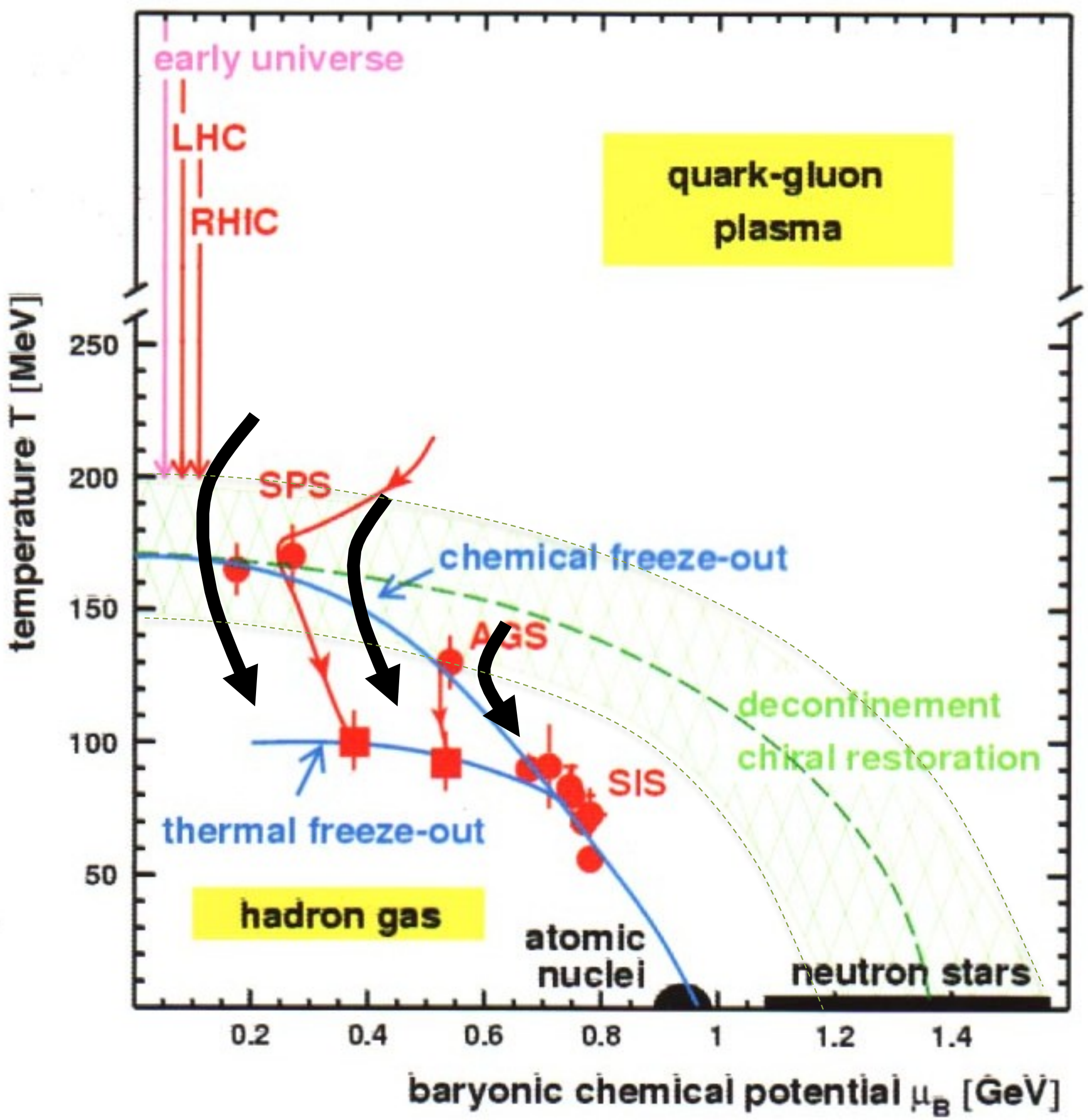


FAIR at GSI, Darmstadt, Germany



Heavy-Ion upgrade at J-parc, Tokai, Japan

Chemical and Thermal Freeze-out



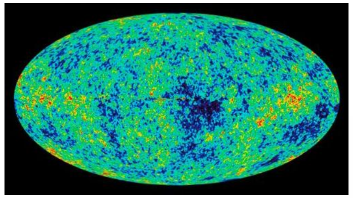
single particle p_T spectra, HBT measurements

- Thermal freeze-out
- $T_{fo}^{(Th)} \sim$ 100MeV
- end of elastic interaction among hadrons
- local thermalization
- Radial expansion, flow

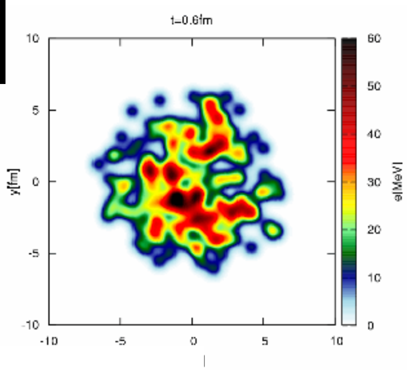
particle yield and ratio

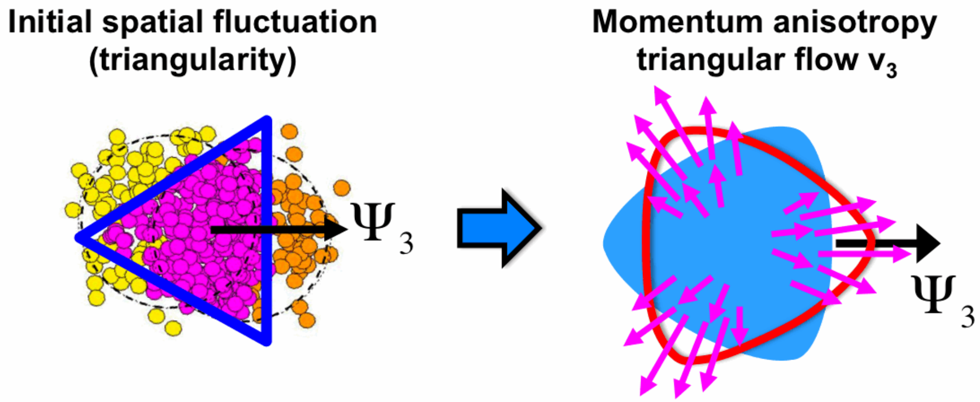
- Chemical freeze-out
- $T_{fo}^{(Ch)} \sim$ 170MeV
- end of inelastic interaction among hadrons
- close to the expected phase boundary

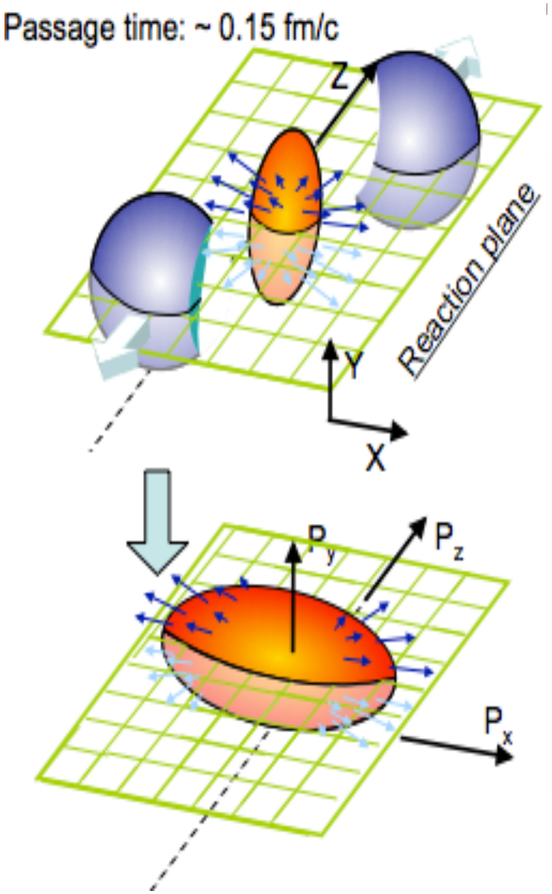
Initial Fluctuation and Higher Order Collective Flow

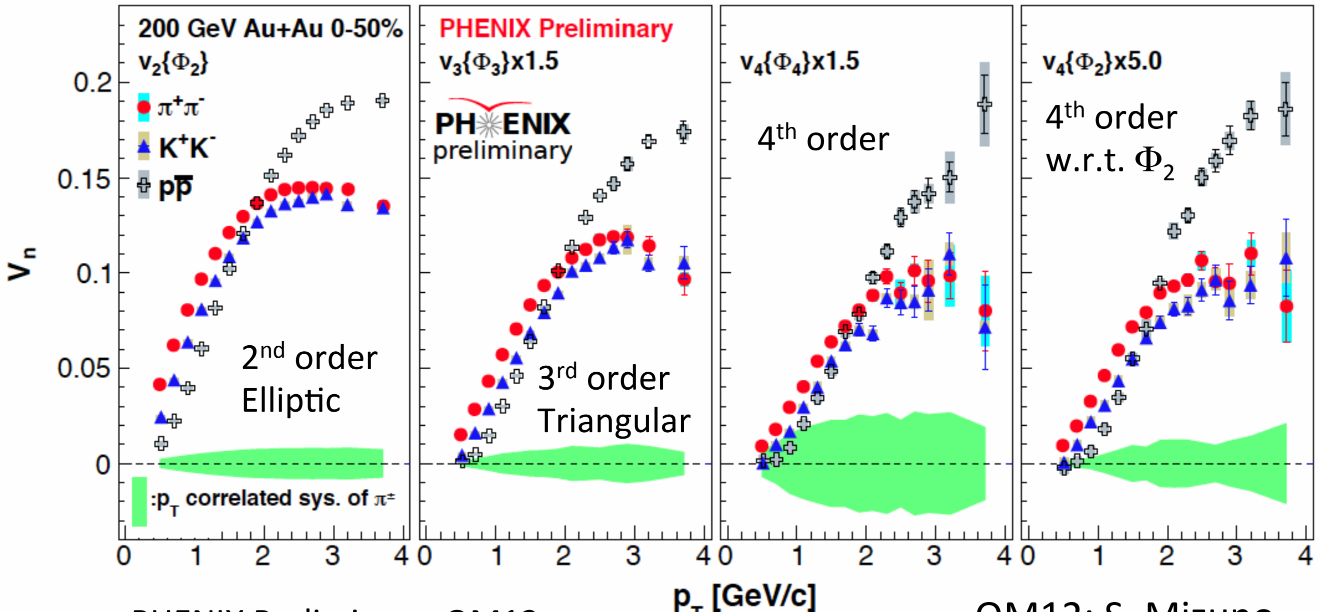


WMAP







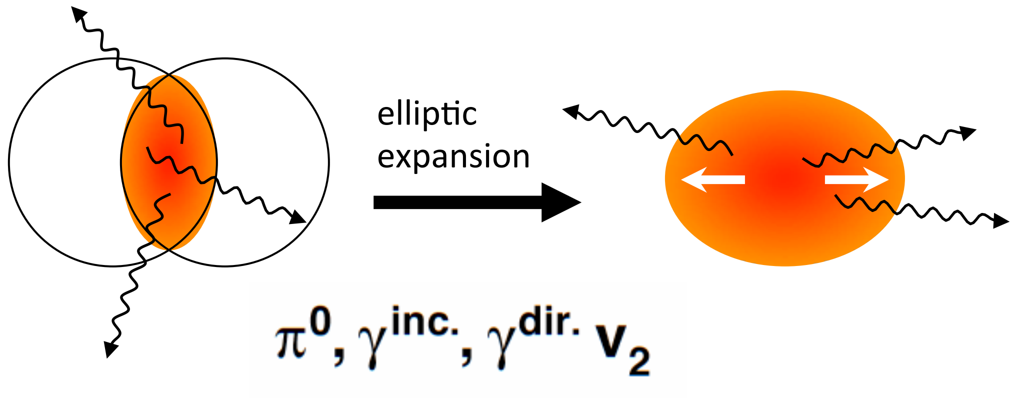


PHENIX Preliminary, QM12

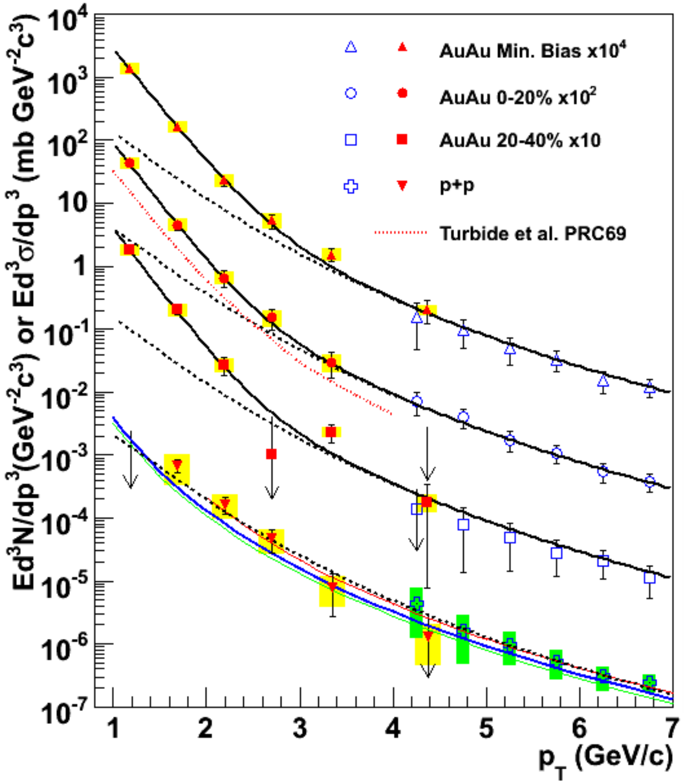
QM12: S. Mizuno

Thermal Photon Radiation and Collective Flow

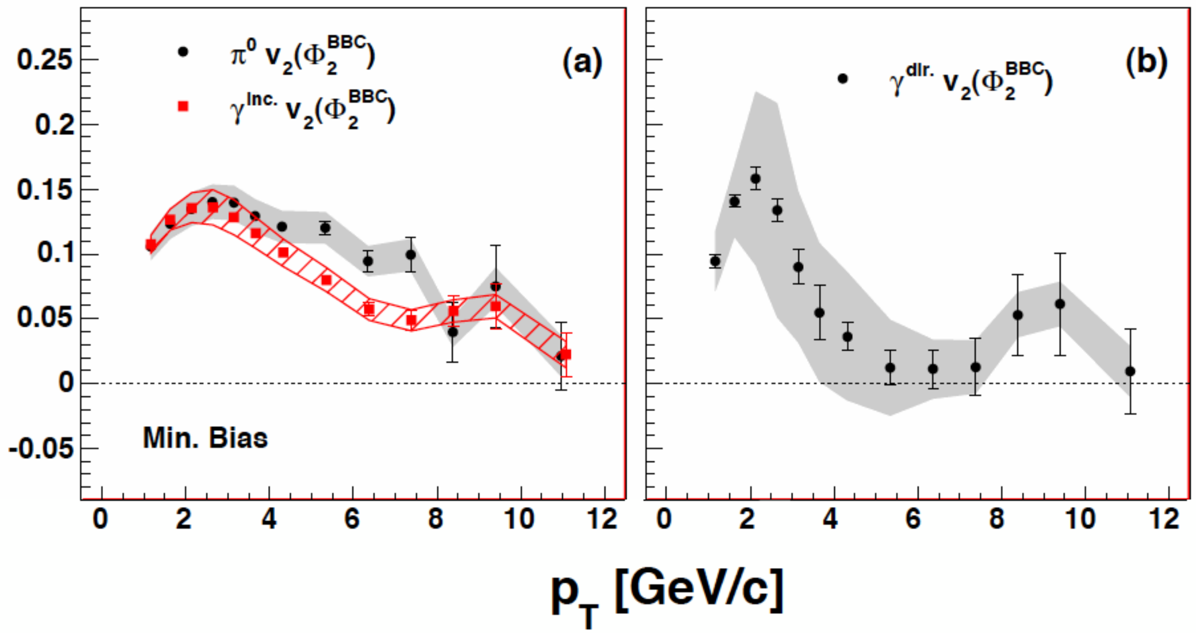
- significant low p_T photon excess with much higher temperature than T_f
- comparable v_2 with hadrons



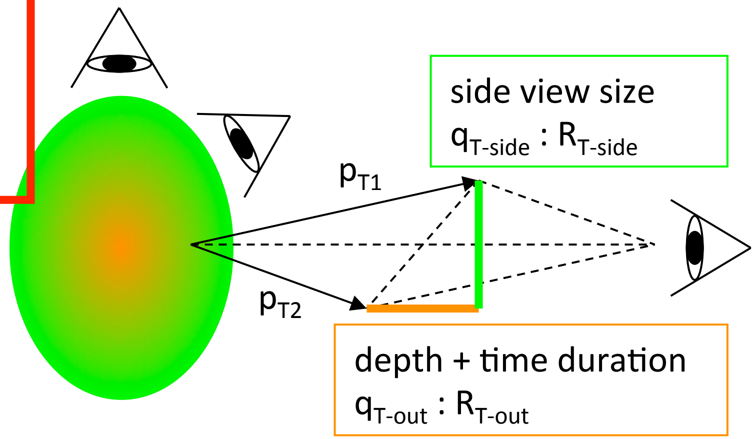
Phys. Rev. Lett. 104 (2010) 132301



Phys. Rev. Lett. 109 (2012) 122302

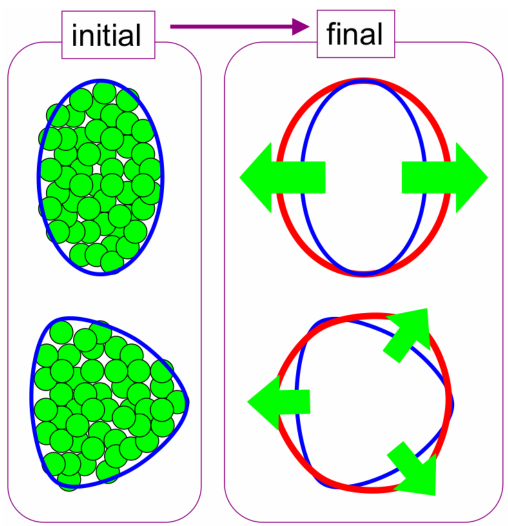


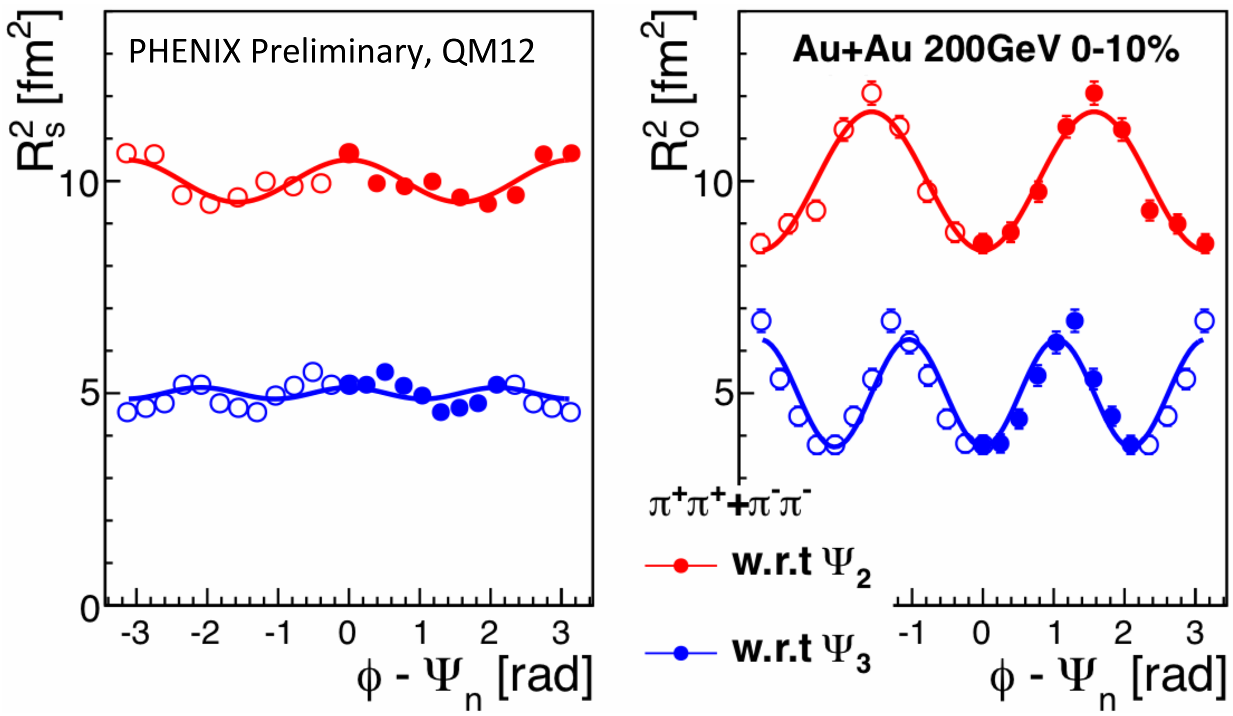
Geometrical Size and Shape at Freeze-out via Quantum Interferometry (multi-dimensional HBT) measurement



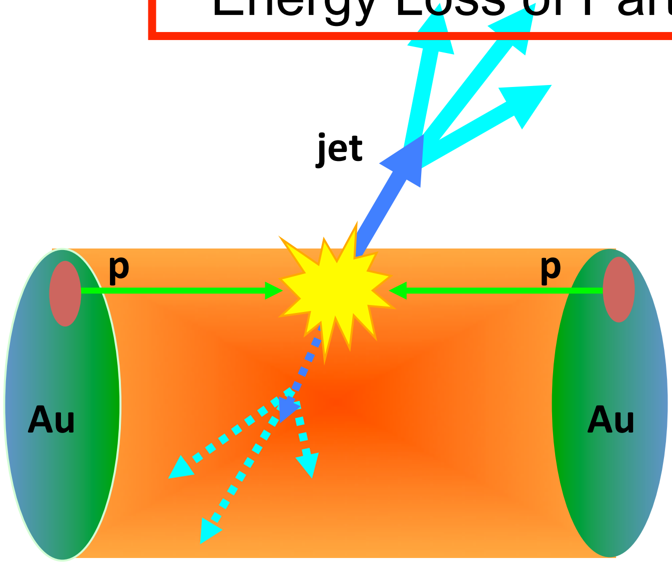
$R_{T\text{-side}}$, $R_{T\text{-out}}$ vs $(\phi-\Phi_2)$, $(\phi-\Phi_3)$
$R_{T\text{-side}}^{\text{oscill.}} < R_{T\text{-out}}^{\text{oscill.}}$ for n=2,3 (central)

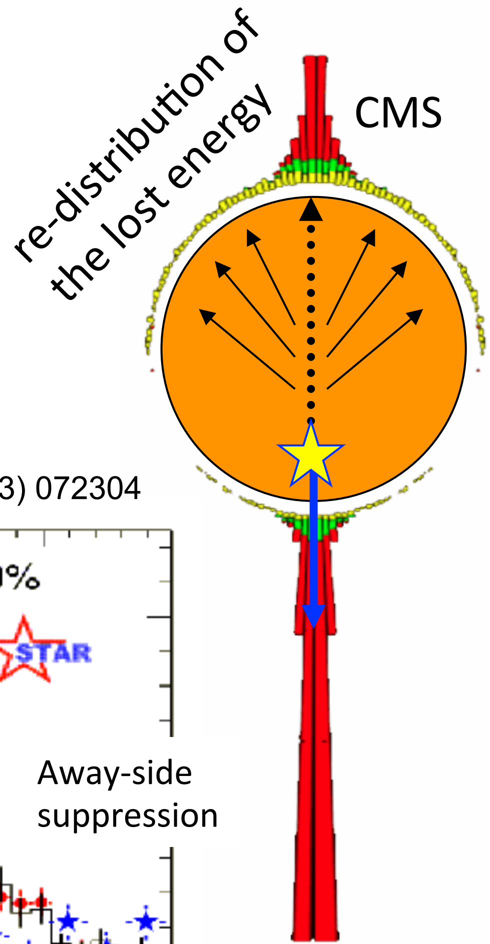
together with $v_n(p_T)^{PID}$ fitting with Blast Wave



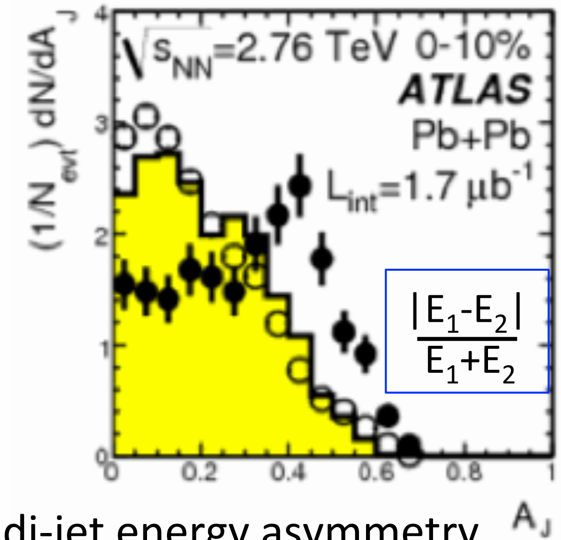


Energy Loss of Parton in QGP --- jet quenching ---

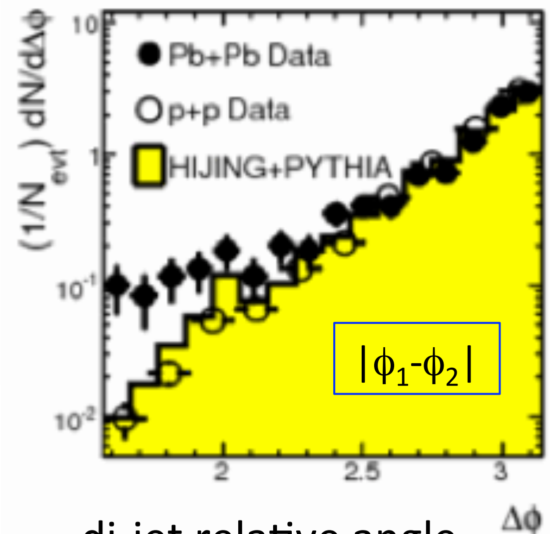




Phys. Rev. Lett. 105 (2010) 252303

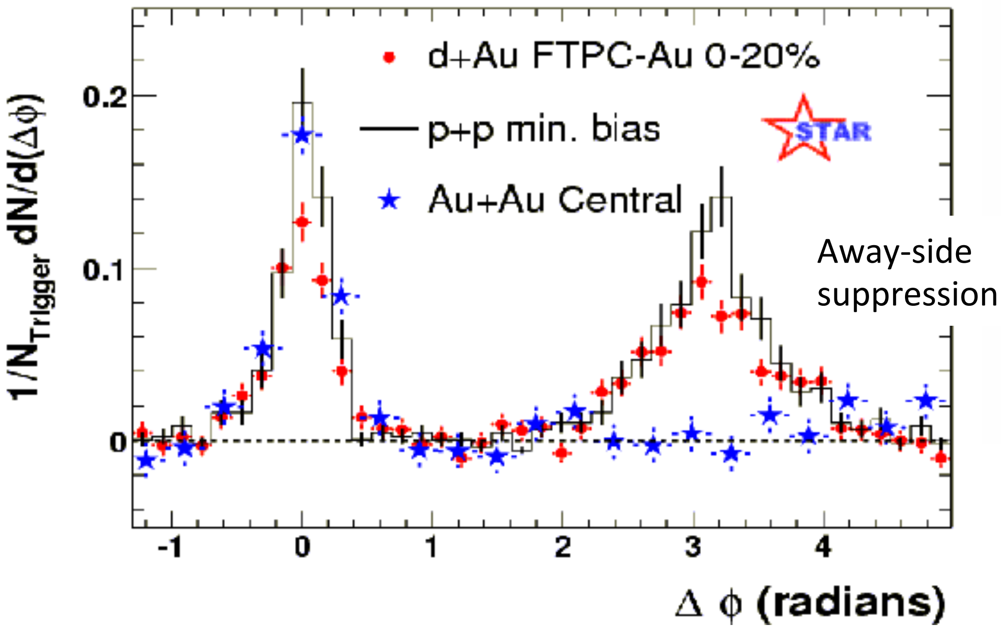


di-jet energy asymmetry

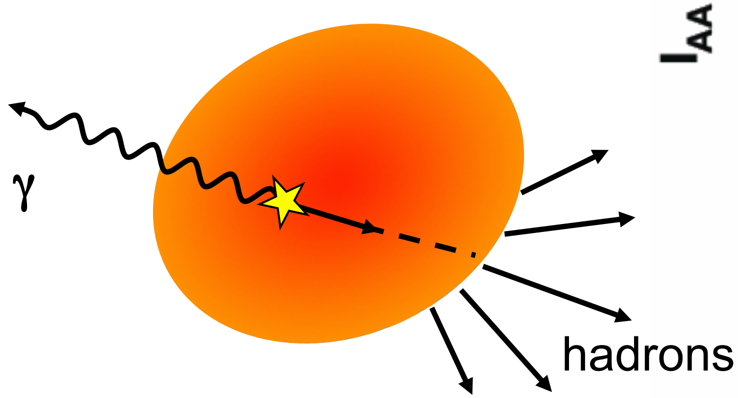


di-jet relative angle

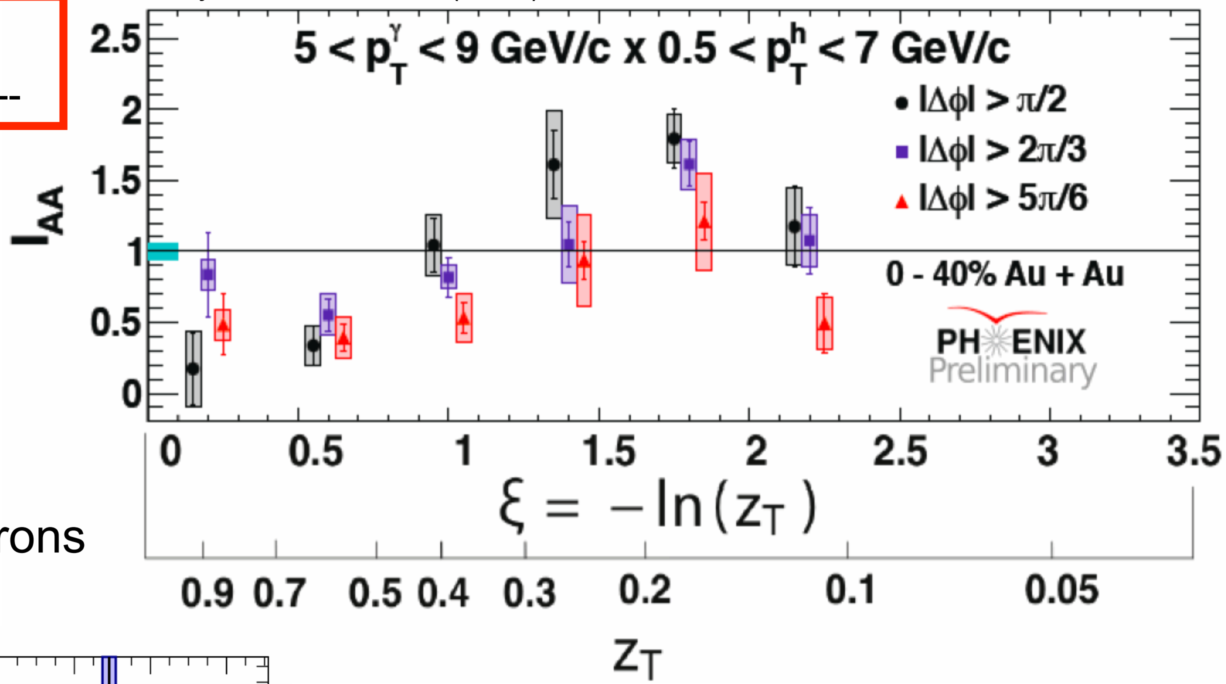
Phys. Rev. Lett. 91 (2003) 072304



γ-Hadron Correlation
--- golden probe for jet-quenching ---



Phys. Rev. Lett. 111 (2013) 32301



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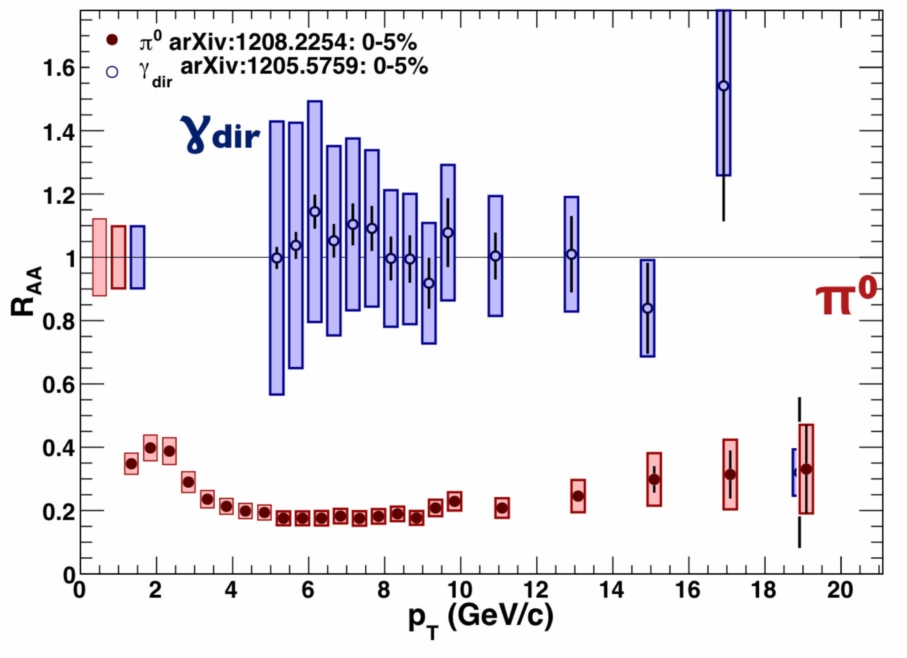
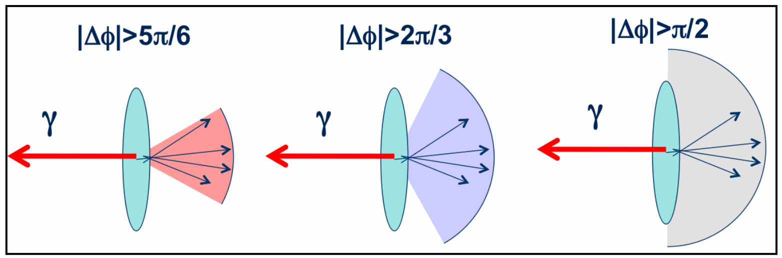


$$\xi \equiv -ln(z_T) \equiv -ln(p_T^{h^\pm} / p_T^{\gamma_{dir}})$$

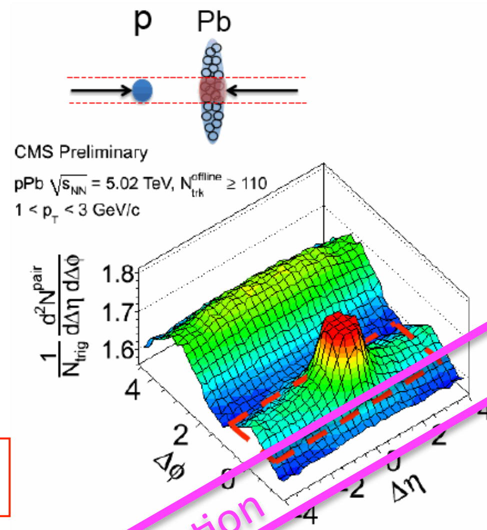
$$I_{AA} \equiv \frac{(1/N_{trig} dN/d\xi)_{AA}}{(1/N_{trig} dN/d\xi)_{pp}}$$



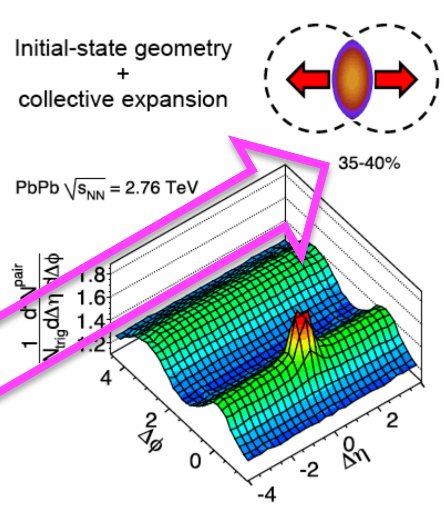
Ridge Structure (v_n) in Small System

High-temperature, High-density system might be created even in small system at high multiplicity event.
--- collective expansion ---
--- centrality/multiplicity dependence ---

High mult. p+A



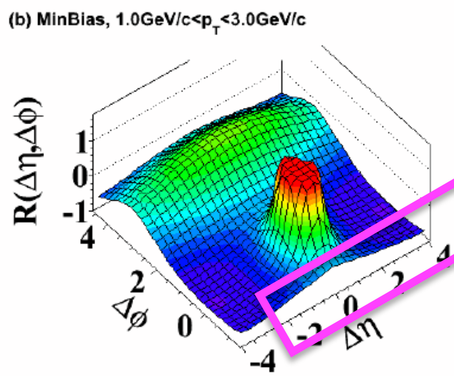
A+A



shape evolution

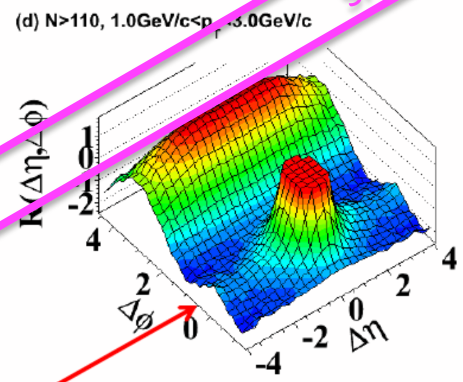
Min. bias p+p

Minimum Bias
no cut on multiplicity



High mult. p+p

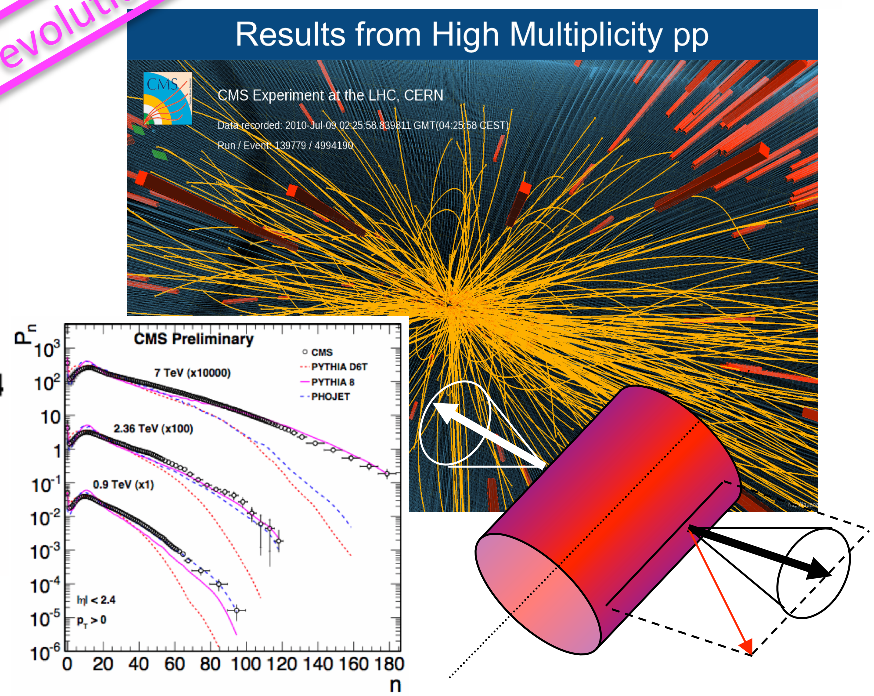
High multiplicity data set
and N>110



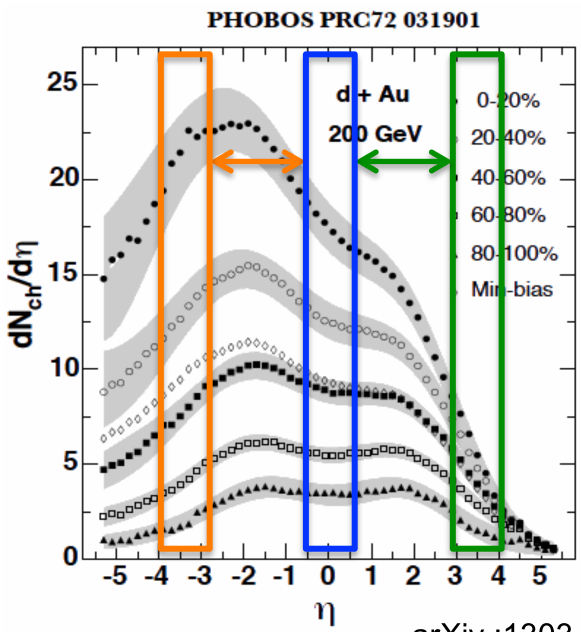
New "ridge-like" structure extending to large Δη at Δφ ~ 0

JHEP 09 (2010) 091, Eur. Phys. J. C 72 (2012) 2012
Phys. Lett. B 718 (2013) 795-814

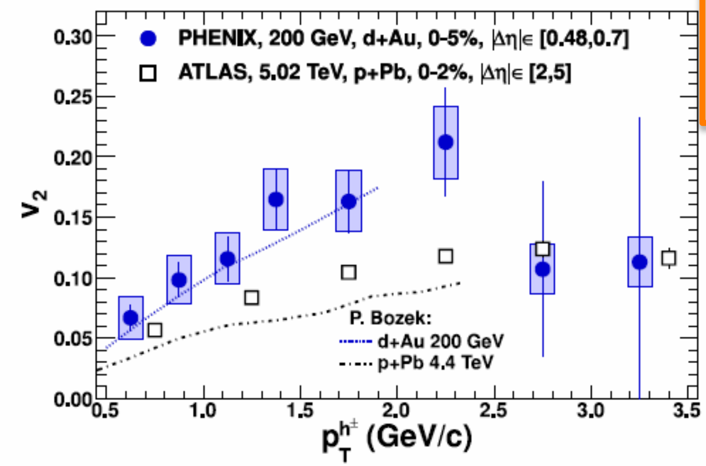
CMS

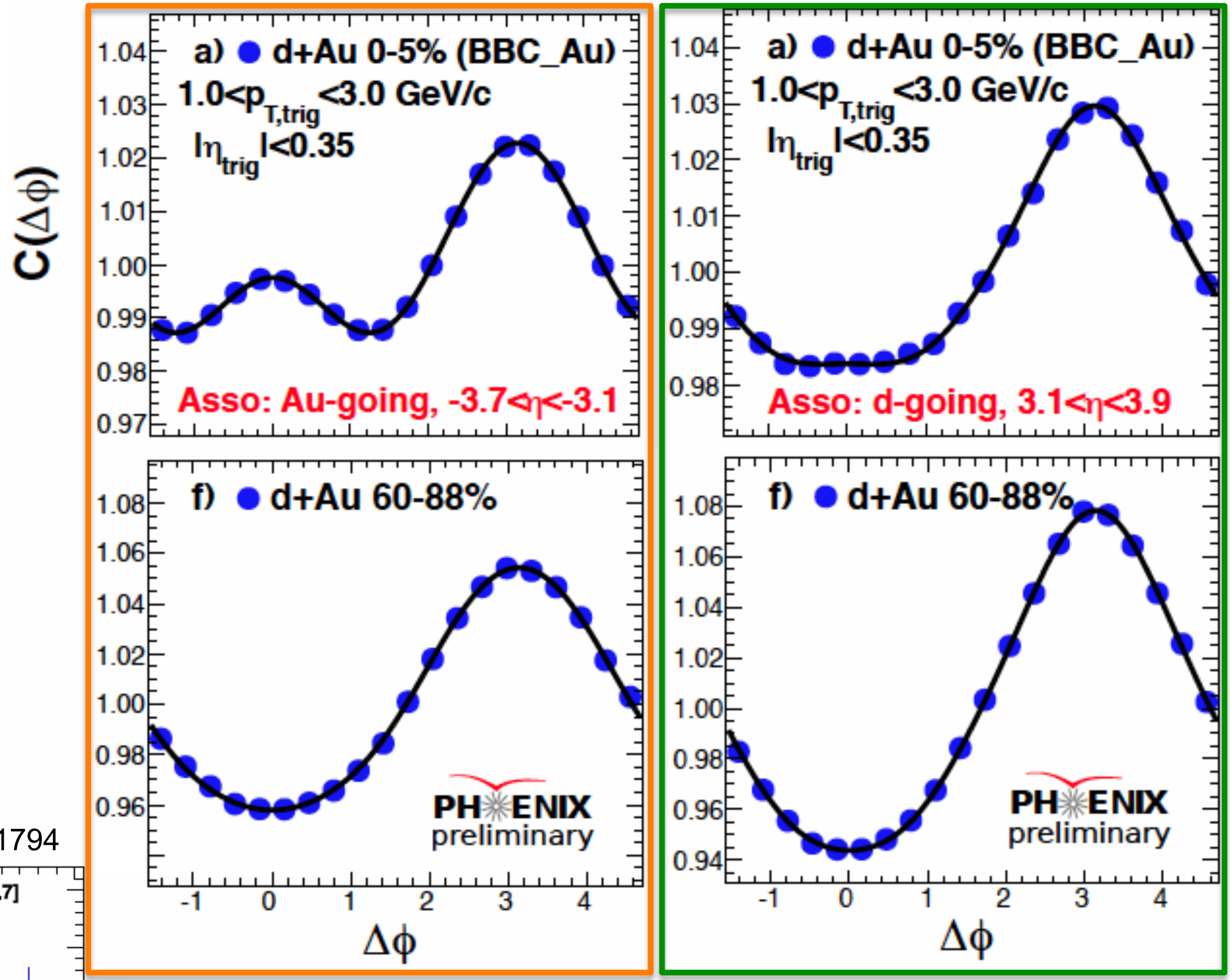


Ridge Structure (v_n) in d+Au at RHIC



arXiv :1303.1794



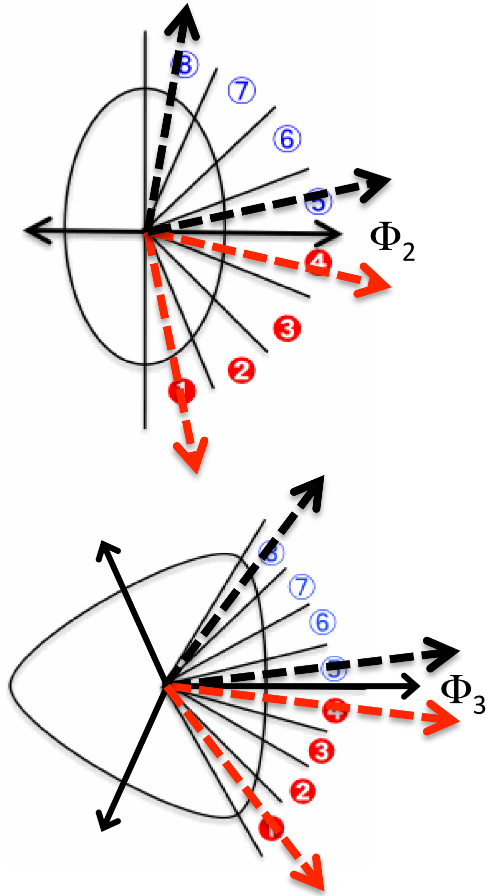


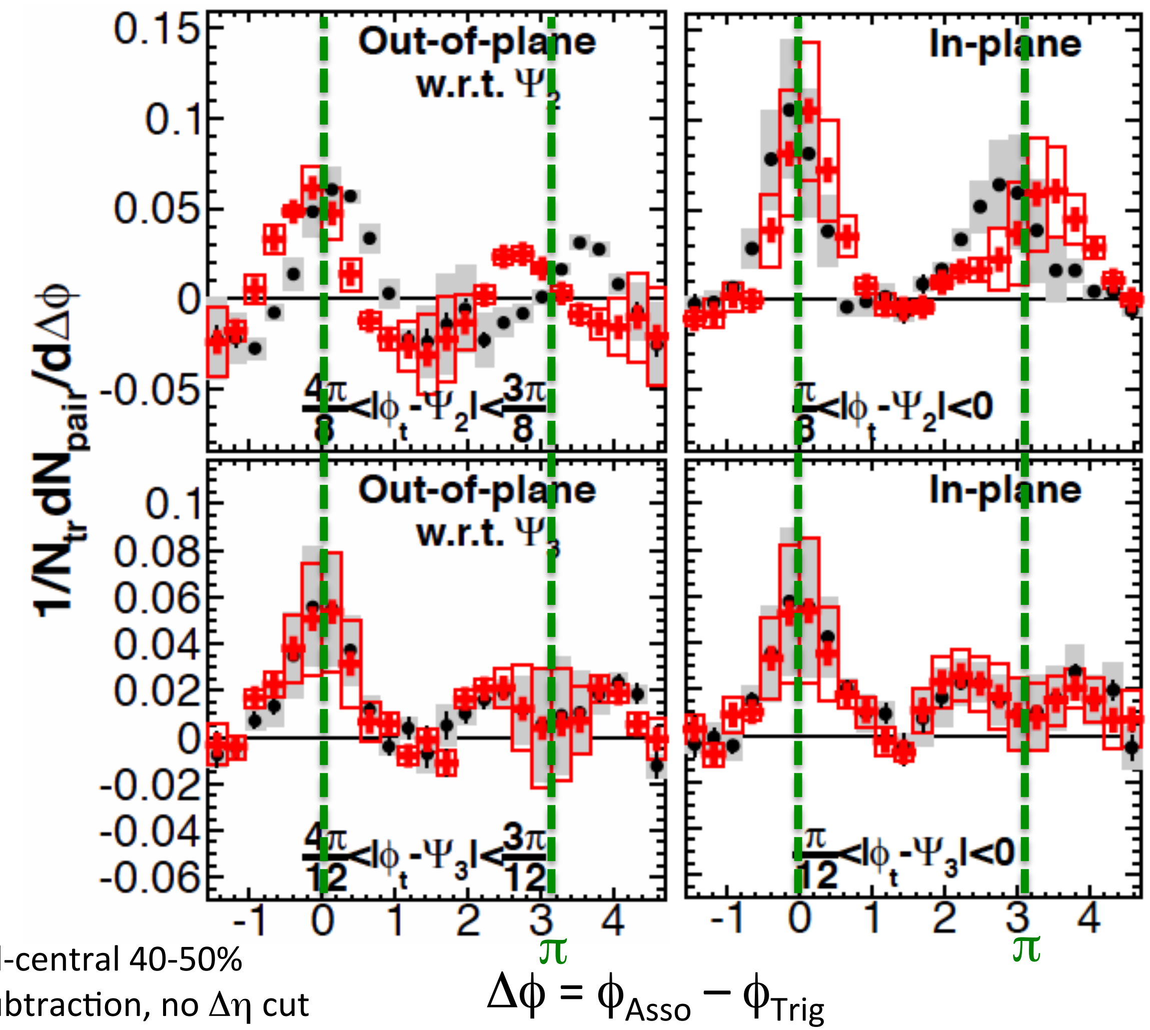
Backward-Central or Forward-Central

Two-particle correlations

Angular Dependence of Jet Shape --- hard-soft interplay ---

- strong Φ_2 dependence and left/right asymmetry (coupled with energy loss and collective flow)
- broader out-of-plane correlation than in-plane correlation (re-distribution of lost energy)
- some weak Φ_3 dependence



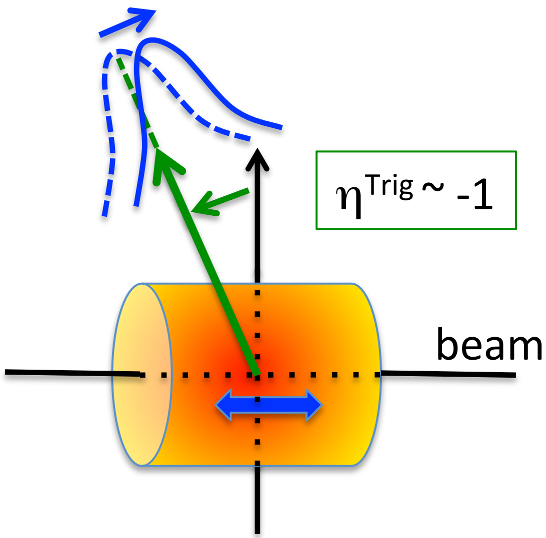


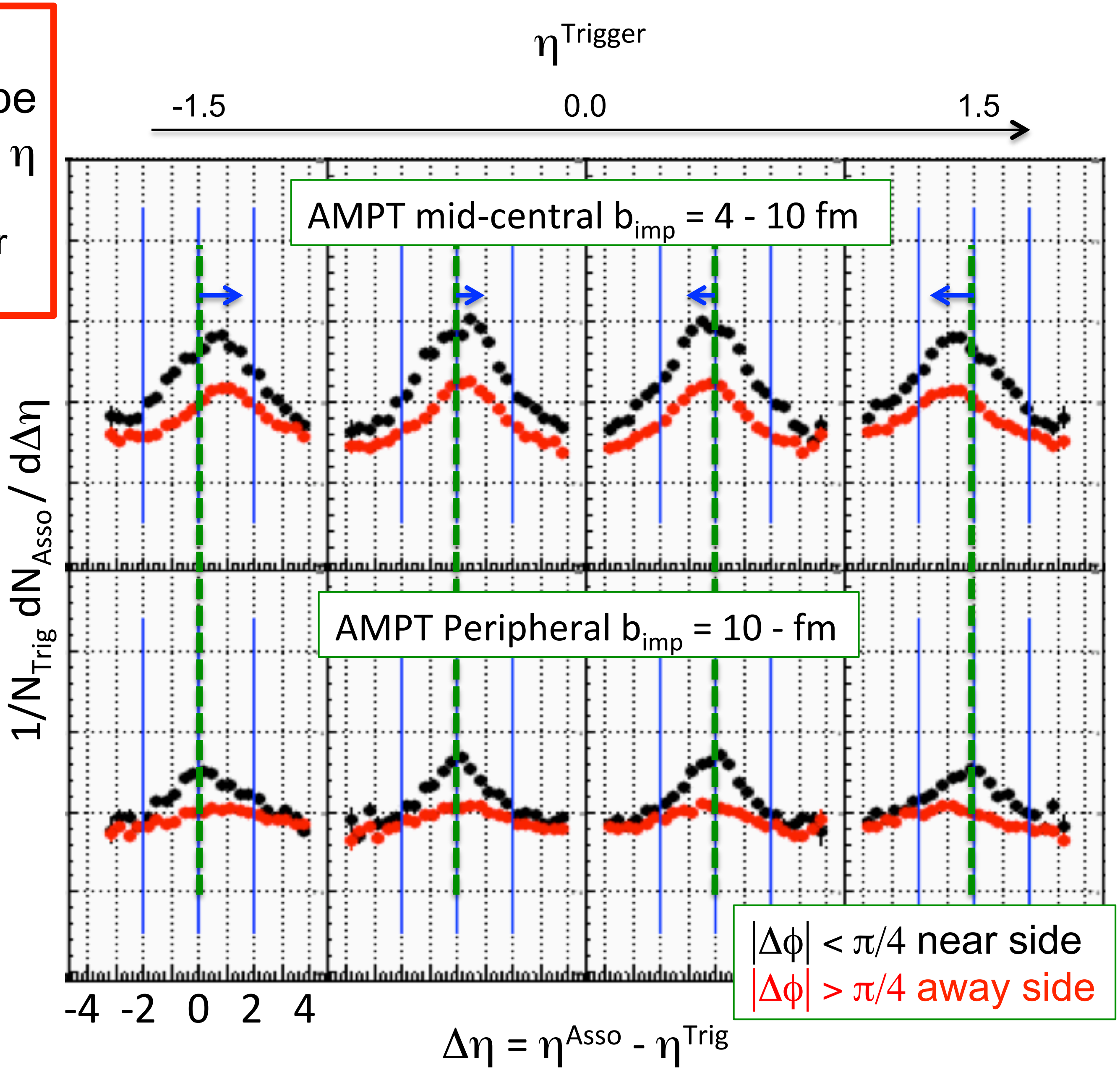
PHENIX Preliminary, QM12
Au+Au 200GeV, hadron-hadron, mid-central 40-50%
p_T : $(2\sim4)_{Trig}$ x $(1\sim2)_{Asso}$ (GeV/c), vn subtraction, no $\Delta\eta$ cut

Forward-Backward Asymmetry in $\Delta\eta$ Shape with respect to Trigger η

(associate yield per trigger with AMPT simulation)

Forward-backward asymmetry is visible in AMPT simulation. Near side $\Delta\eta$ peak is backward shifted w.r.t. trigger η direction.



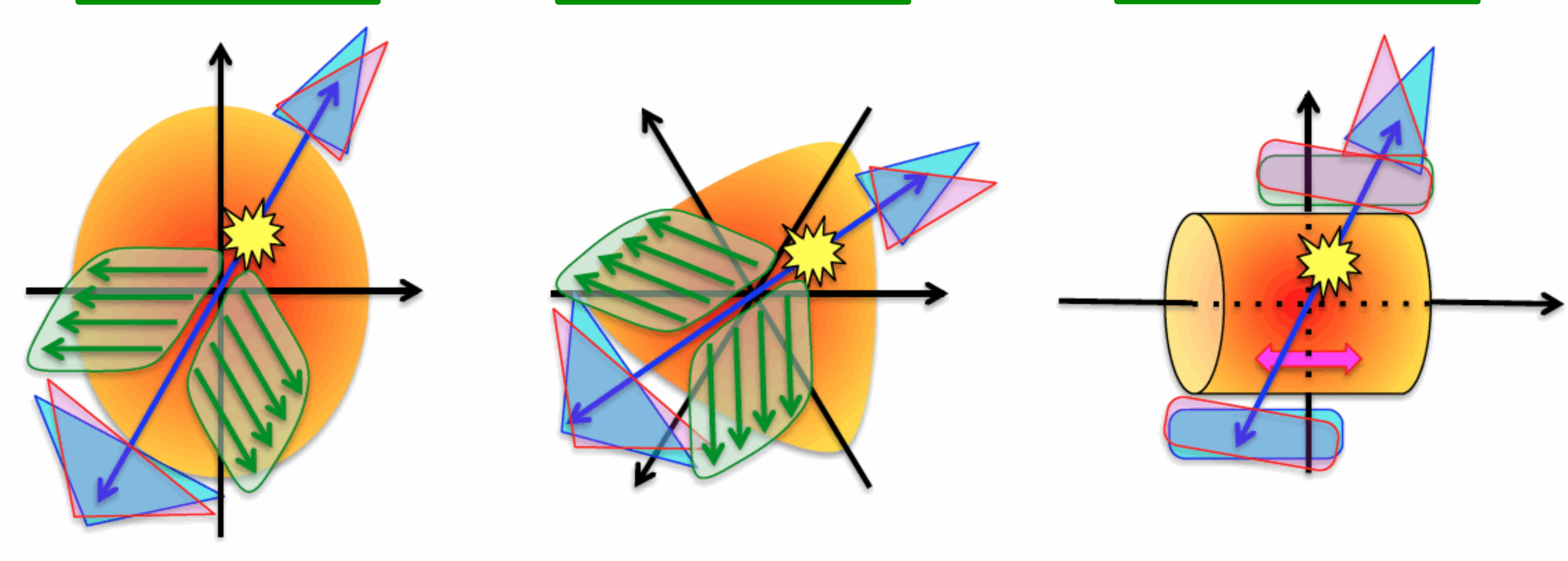


Jet Fragmentation (multi-particle correlation) and Di-jet Analysis with respect to Bulk Geometry and/or Collectivity

with respect to Elliptic plane Φ_2

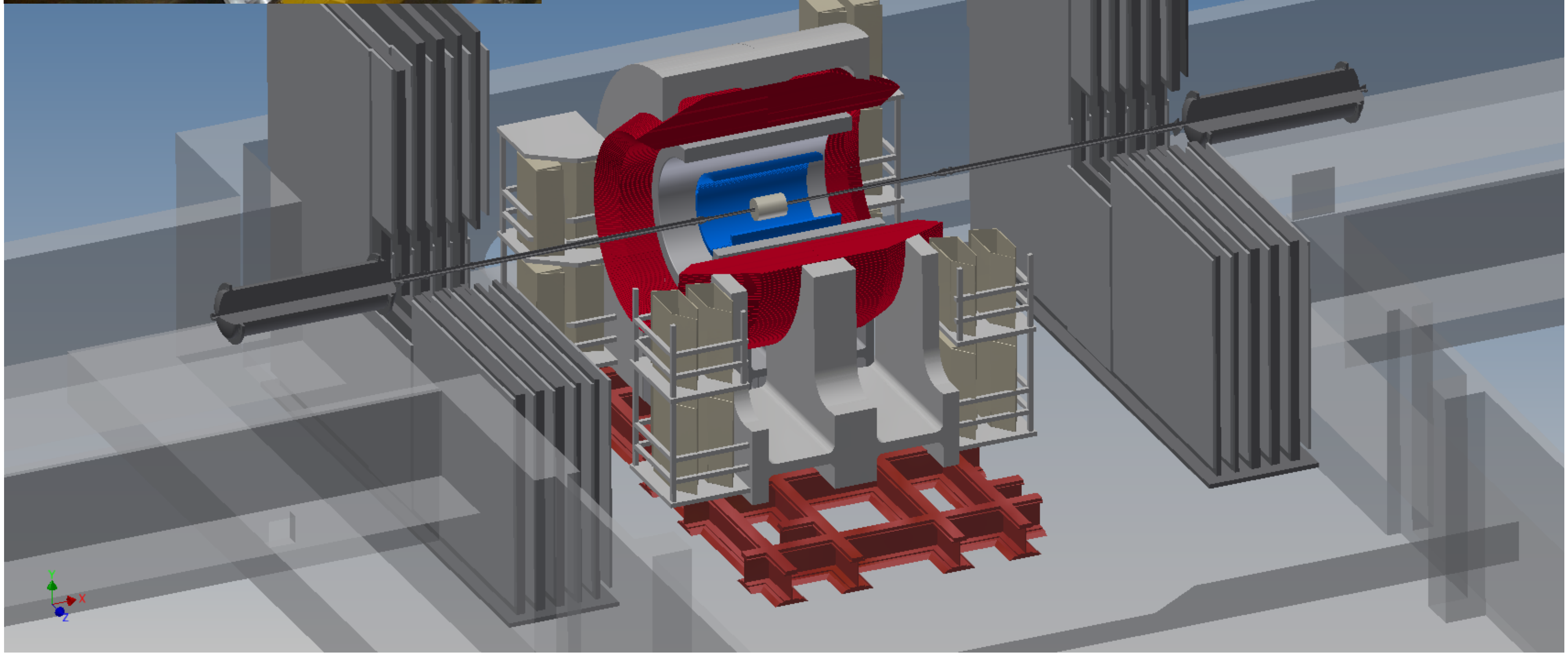
with respect to Triangular plane Φ_3

with respect to Longitudinal angle η



Not only to study the effects on the jet (hard) probes,
But also to study the effect on the bulk (soft) probes

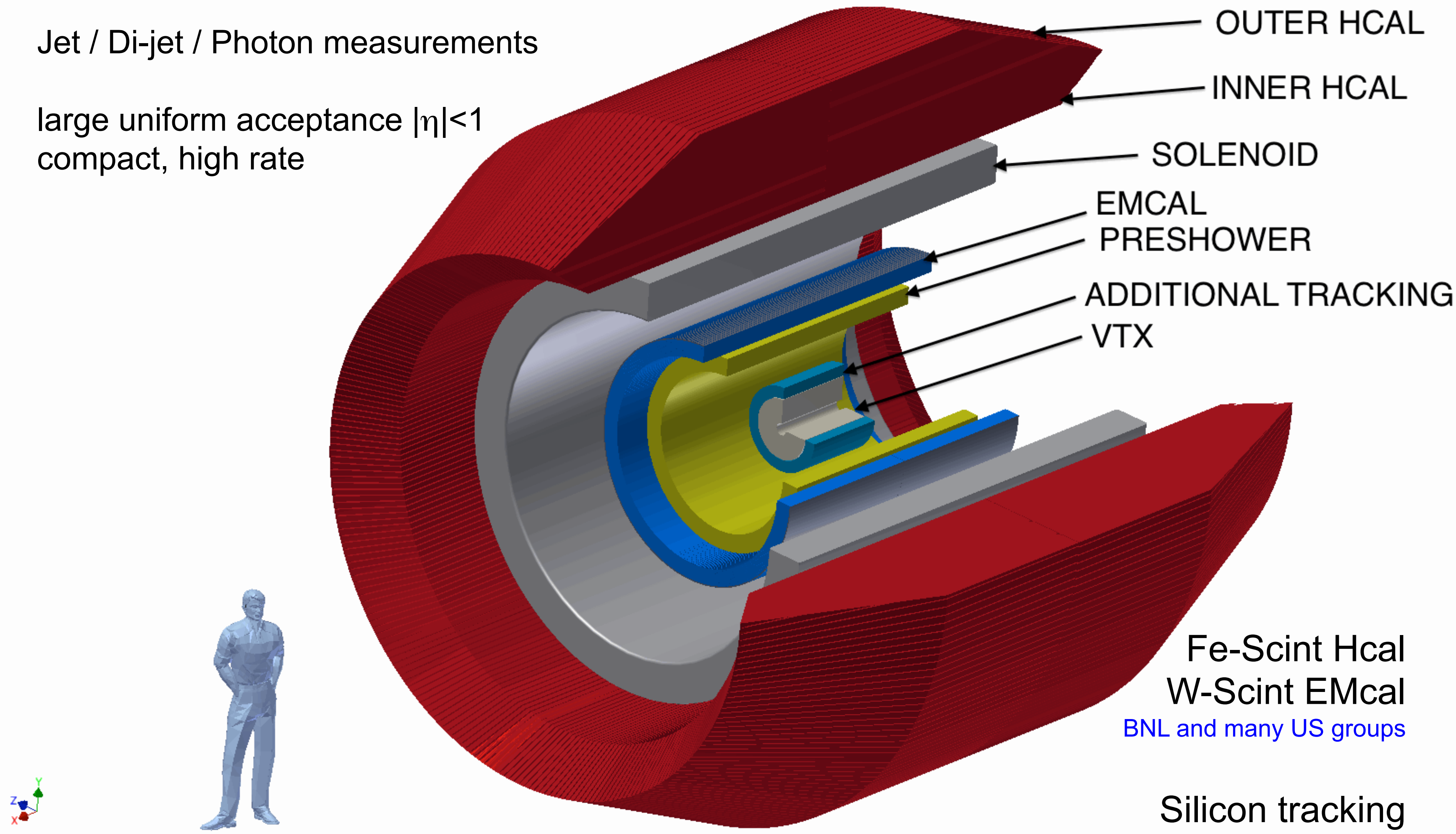
BaBar Magnet from SLAC : 1.5 T solenoid
Inner / outer radius / z-length : 140 / 173 / 385 cm



sPHENIX Central Barrel Detector

Jet / Di-jet / Photon measurements

large uniform acceptance $|\eta|<1$
compact, high rate



Fe-Scint Hcal
W-Scint EMcal
BNL and many US groups

Silicon tracking
Silicon-W pre-shower
RIKEN and US-J groups (Hiroshima, Tokyo, Tsukuba,,,)

Design, testing, R&D underway

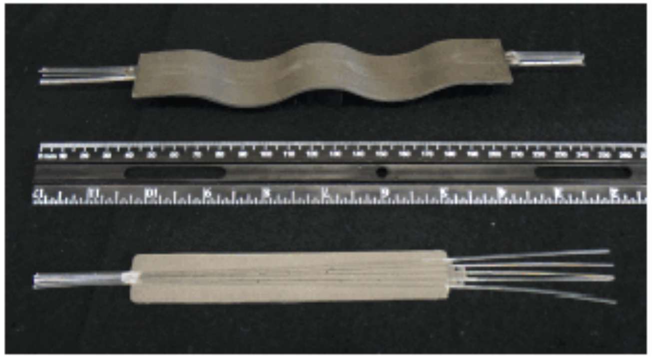


Figure 3.5: Samples of scintillating fiber embedded in a formed tungsten epoxy mixture. Produced by Tungsten Heavy Powder.

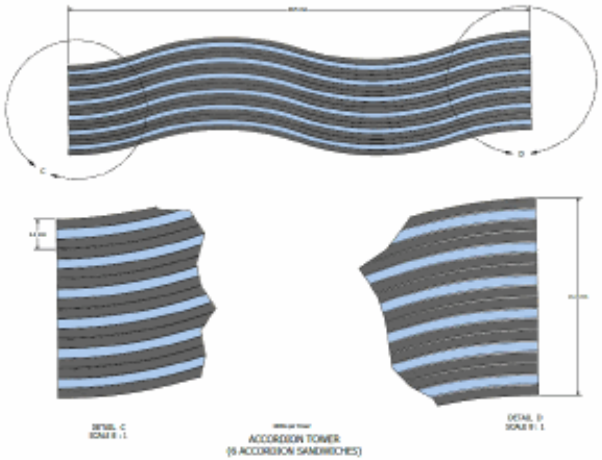


Figure 3.6: Cross section of the accordion calorimeter in the plane normal to the beam direction, showing how the single layers seen in Figure 3.4 are stacked. Scintillating fibers are embedded in tapered and undulating layers of tungsten and epoxy mixture and are approximately projective towards the interaction region, which has an extent of ± 30 cm along the beam direction.

Figure 3.32: HCal prototype under construction. The first layers of absorber are being stacked on the lift table for the beam test.

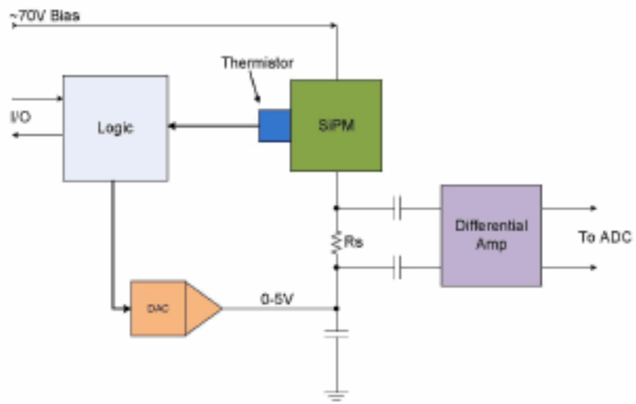
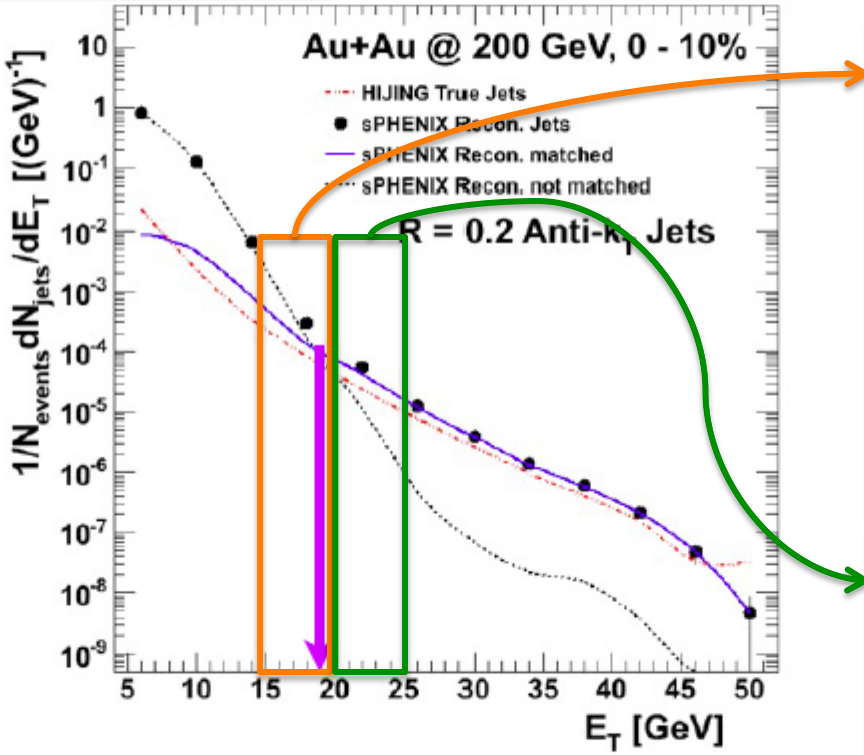
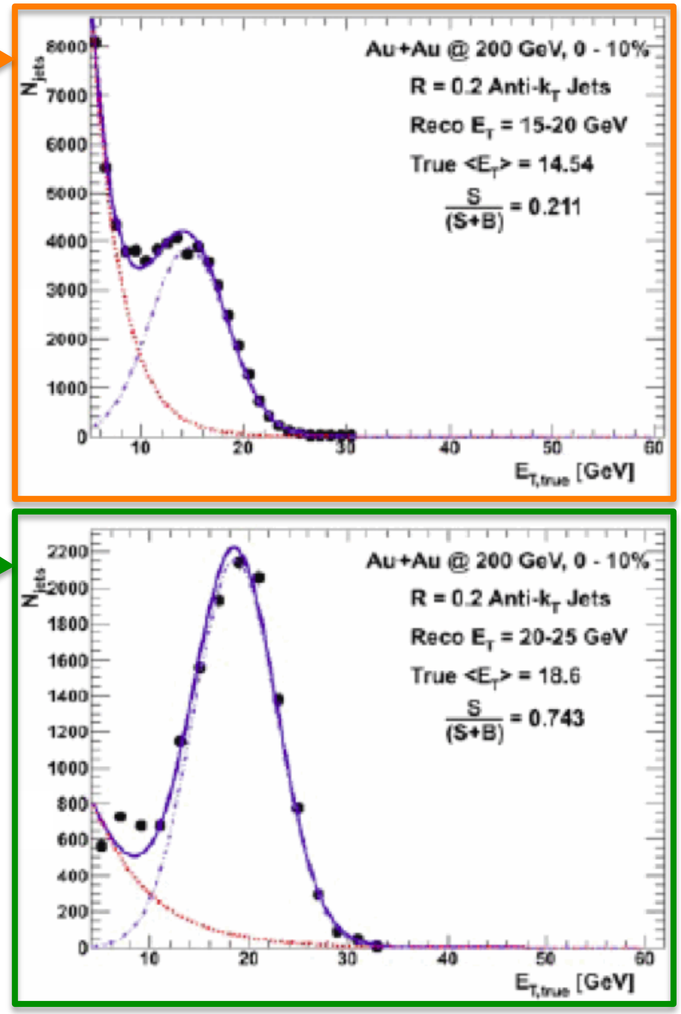


Figure 3.22: Block diagram of a temperature compensating circuit for SiPMs

matched jets:
within $\Delta R < 0.25$ of a HIJING truth jet (>5GeV)

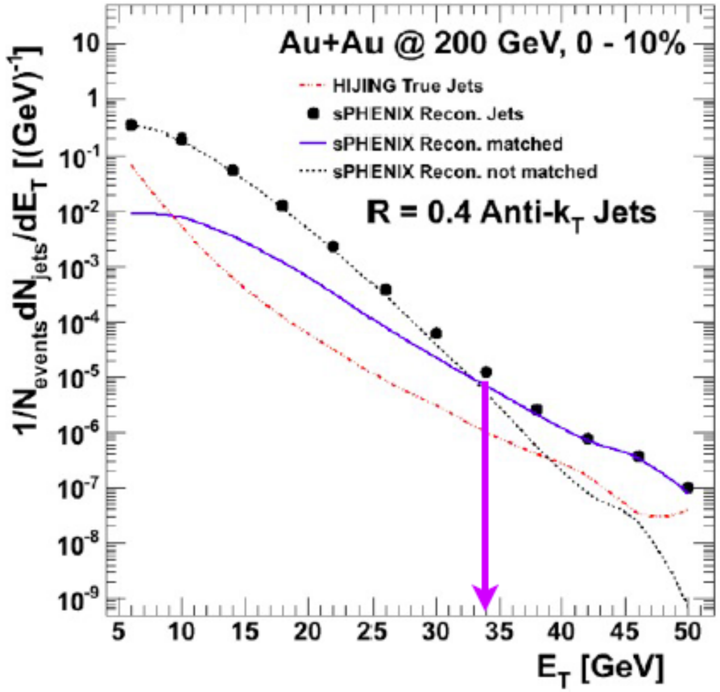
not matched jets:
no nearby HIJING jets
"fakes"

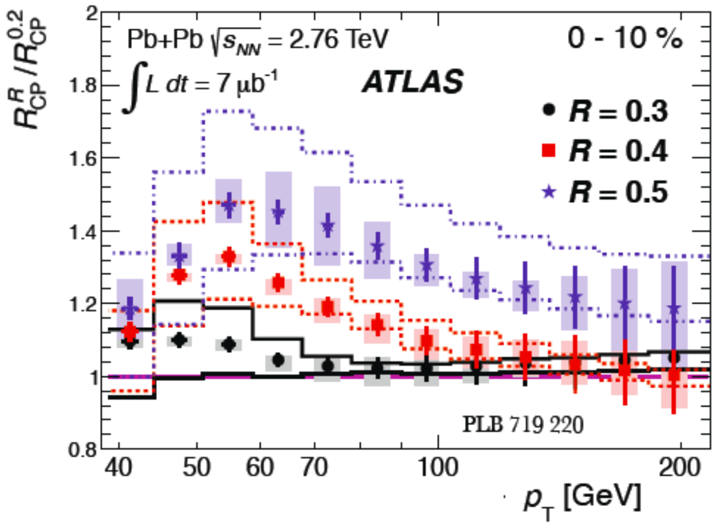




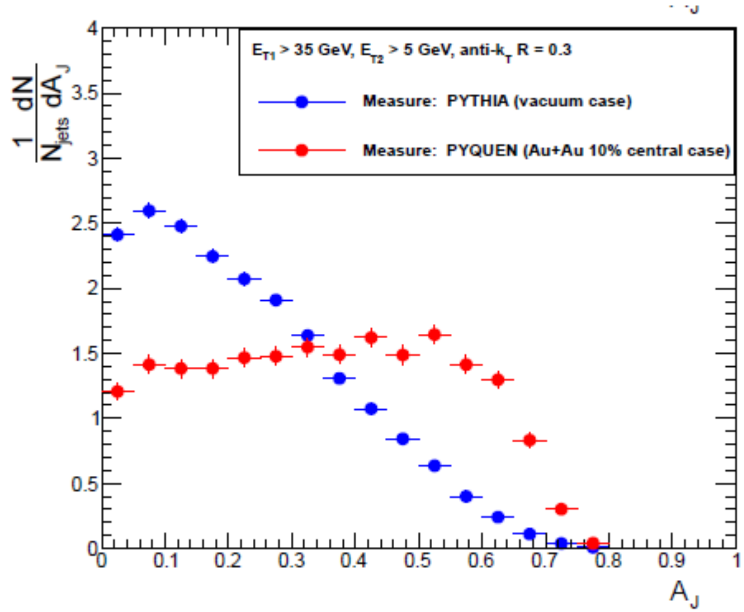
Jet Reconstruction down to Lower Energy in 200GeV Au+Au at RHIC

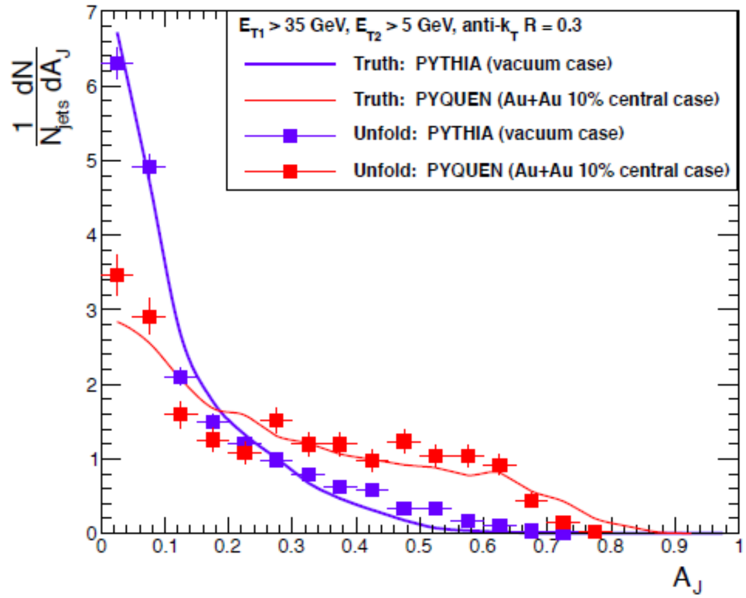
Larger Cone Jet Analysis : higher E_T cut



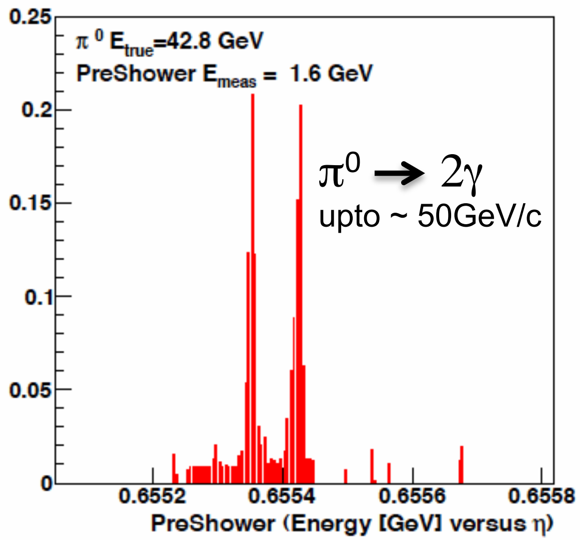


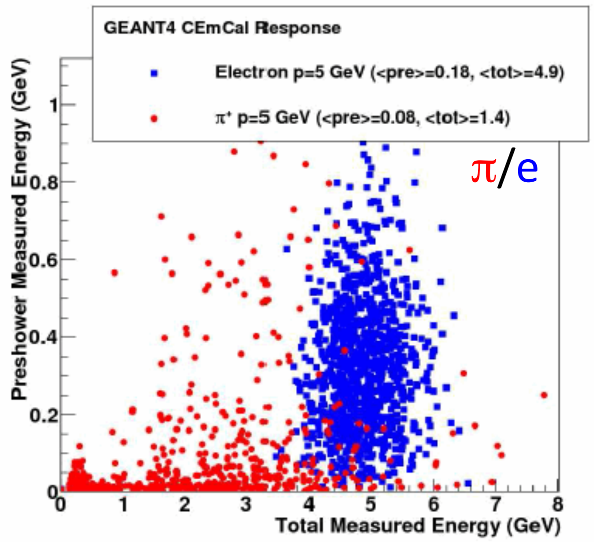
Unfolding of Jet Asymmetry : A_J





Pre-Shower and Additional Tracking for γ/π^0 and e/π Separation and Identification



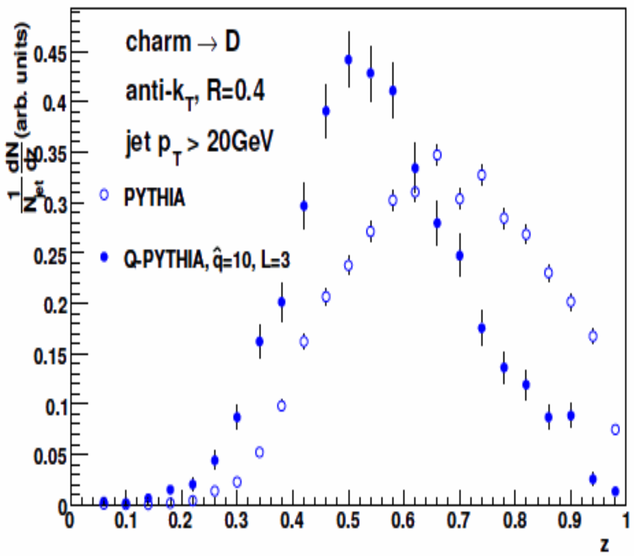


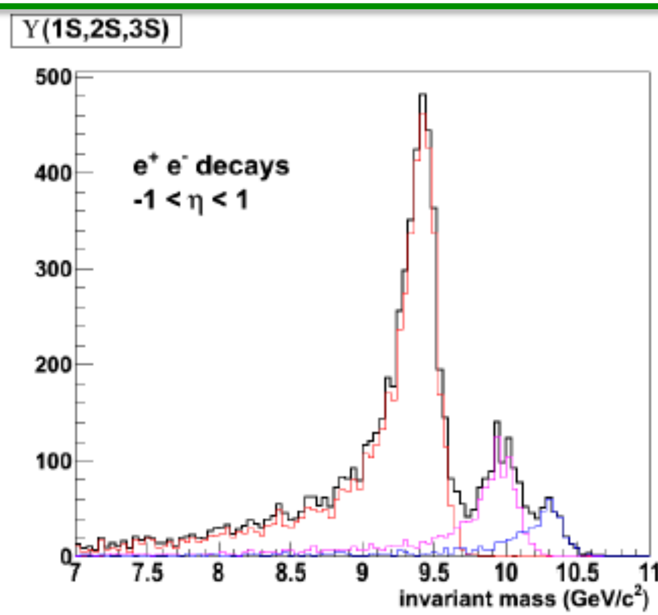
sPHENIX EMcal :
$\Delta\eta \times \Delta\phi = 0.024 \times 0.024$

Pre-shower :
2.3 radiation length
thickness of tungsten
backed by a silicon layer of
$\Delta\eta \times \Delta\phi = 0.0005 \times 0.1$

Tracking :
$\Delta p/p = 0.007+0.0015\times p$

Tagging of heavy flavor jets



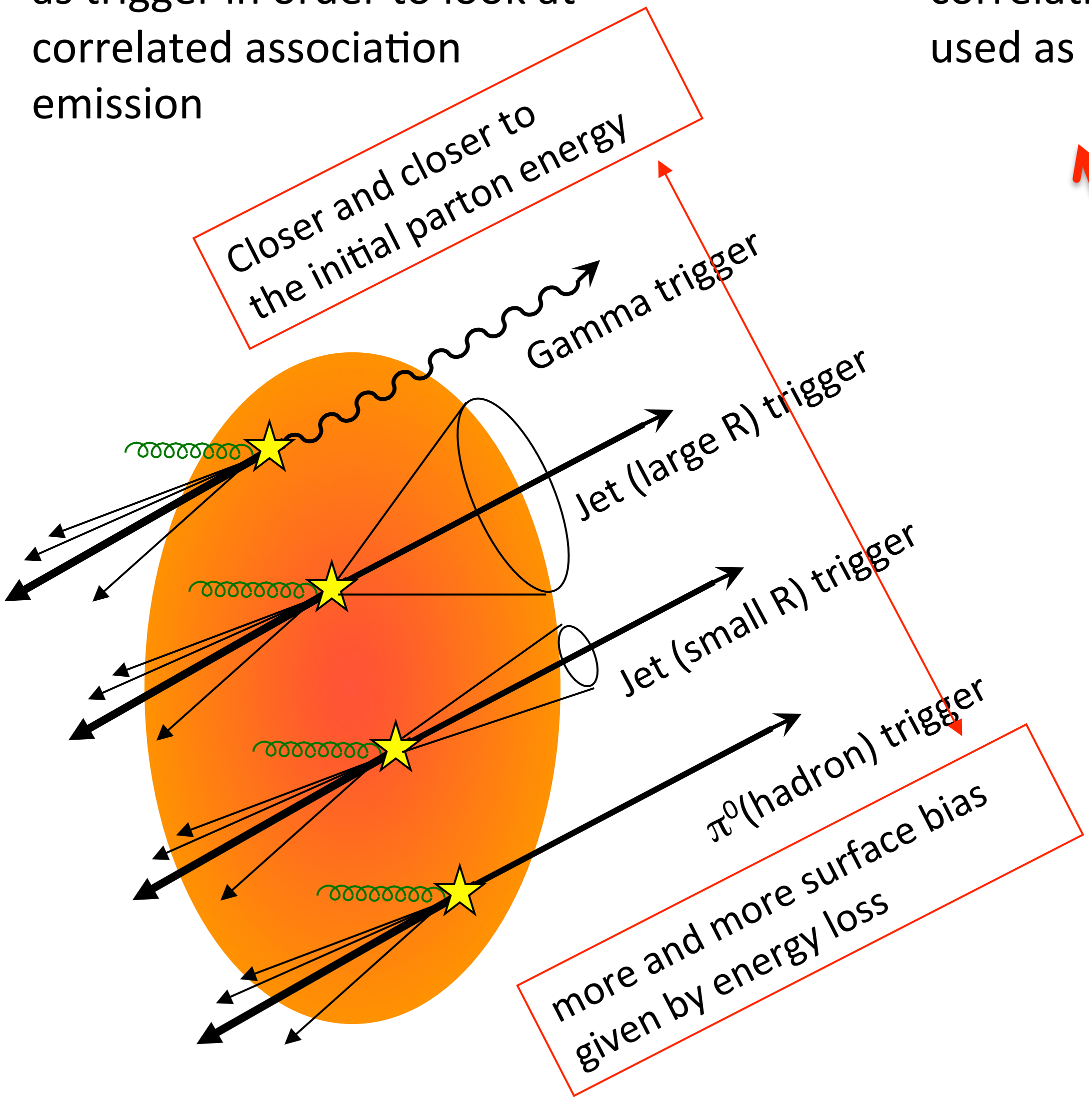


Plans at RHIC

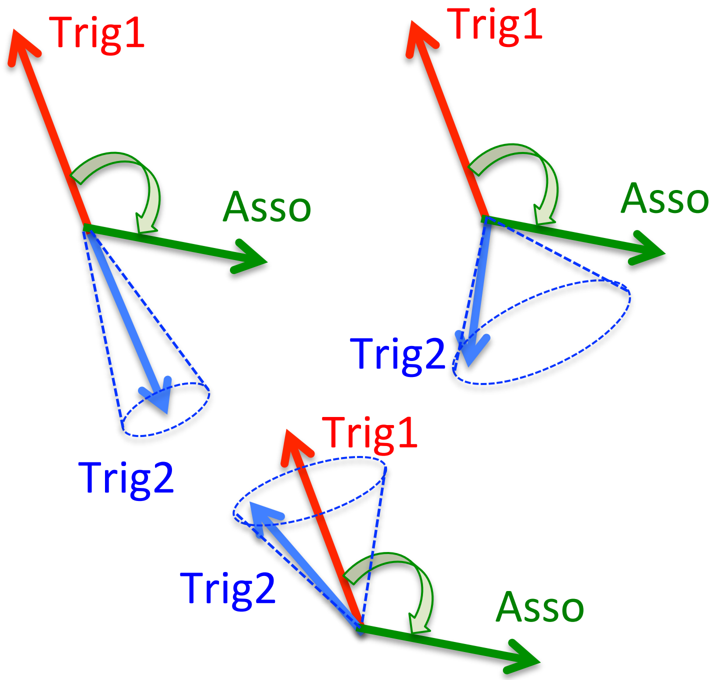
(From RHIC ALD Berndt Muller talk in June)

Years	Beam Species and Energies	Science Goals	New Systems Commissioned
2013	• 510 GeV pol p+p	• Sea quark and gluon polarization	• upgraded pol'd source • STAR HFT test
2014	• 200 GeV Au+Au • 15 GeV Au+Au	• Heavy flavor flow, energy loss, thermalization, etc. • Quarkonium studies • QCD critical point search	• Electron lenses • 56 MHz SRF • full STAR HFT • STAR MTD
2015-2016	• p+p at 200 GeV • p+Au, d+Au, ^{3}He+Au at 200 GeV • High statistics Au+Au	• Extract η/s(T) + constrain initial quantum fluctuations • More heavy flavor studies • Sphaleron tests	• PHENIX MPC-EX • Coherent electron cooling test
2017	• No Run		• Electron cooling upgrade
2018-2019	• 5-20 GeV Au+Au (BES-2)	Search for QCD critical point and deconfinement onset	• STAR ITPC upgrade
2020	• No Run		• sPHENIX installation
2021-2022	• Long 200 GeV Au+Au w/ upgraded detectors • p+p/d+Au at 200 GeV	• Jet, di-jet, γ-jet probes of parton transport and energy loss mechanism • Color screening for different QQ states	• sPHENIX
2023-24	• No Runs		Transition to eRHIC

Use photons, Jets, single hadrons as trigger in order to look at correlated association emission



Multi-particle correlation like 2+1 particle correlation analysis (Trig1, Trig2, Asso) can be used as largely modified jet and di-jet signal.



Use "Trig2 relative to Trig1" as jet trigger condition, and look at distribution : "Associate relative to Trig1" without jet-reconstruction bias

To be used for Φ_n and η_{Trig} dependent analysis

Summary

QGP and heavy ion experiments
Thermal and collective bulk (soft) measurements
Jet and correlation (hard) measurements
Interplay between hard and soft probes
Plans for sPHENIX