Understanding of QGP with soft probes

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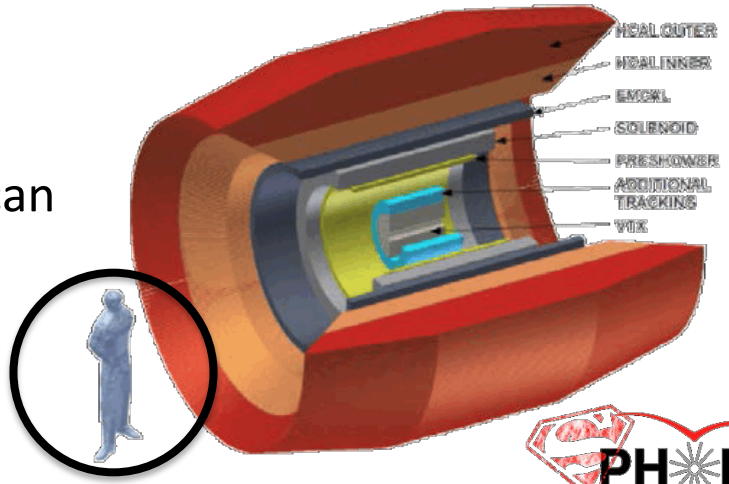
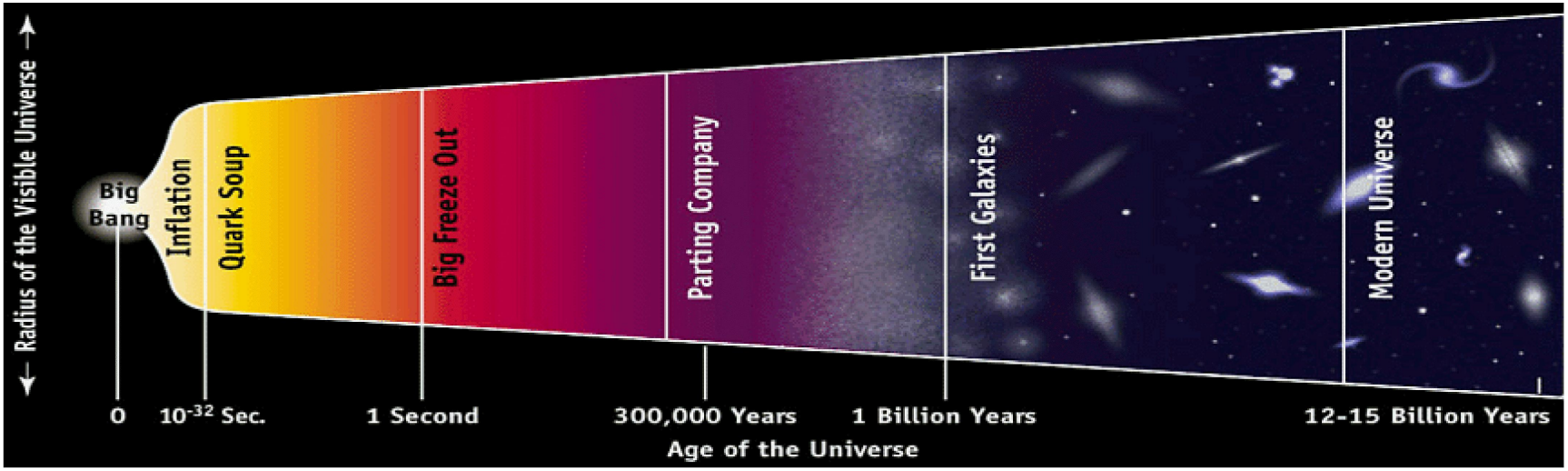
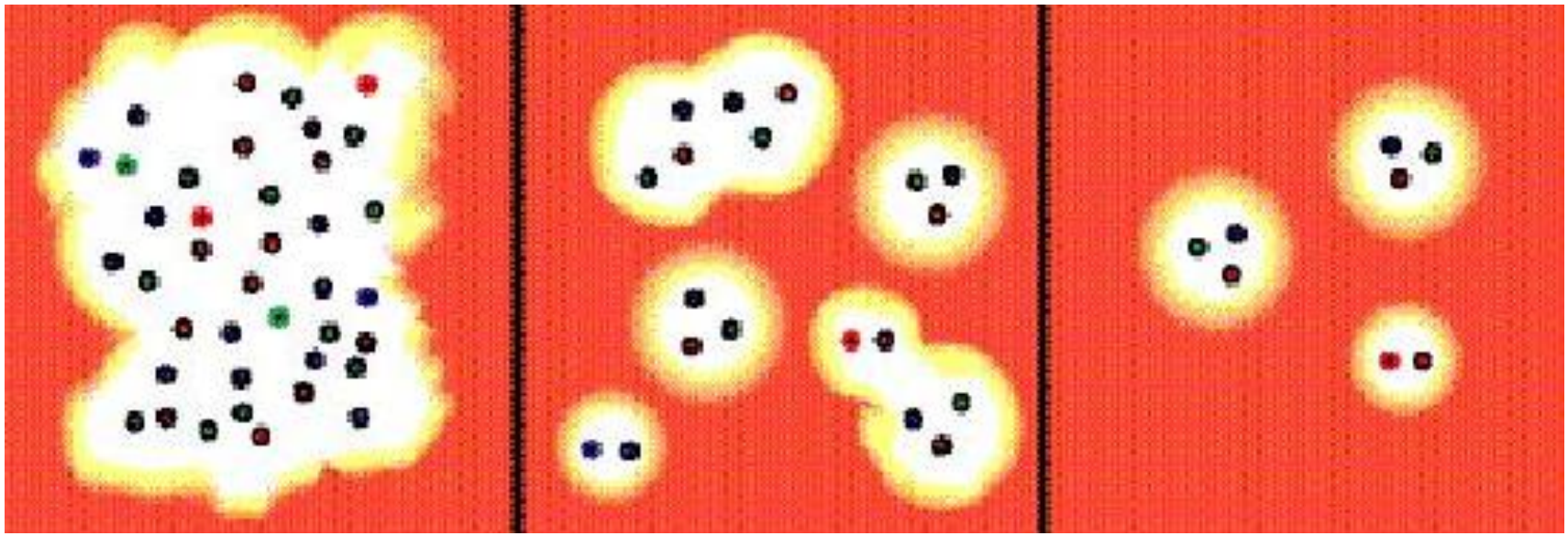
Initial and freeze-out temperature
Collective expansion
Partonic energy-loss
Hard-soft interaction
Critical point and energy scan
Future directions



at sPHENIX workfest in Japan

Quark Gluon Plasma (QGP)

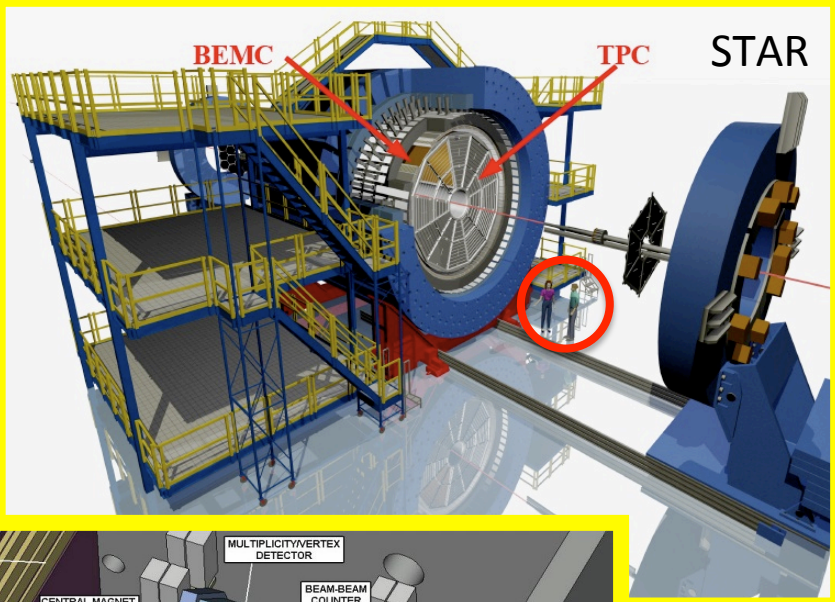


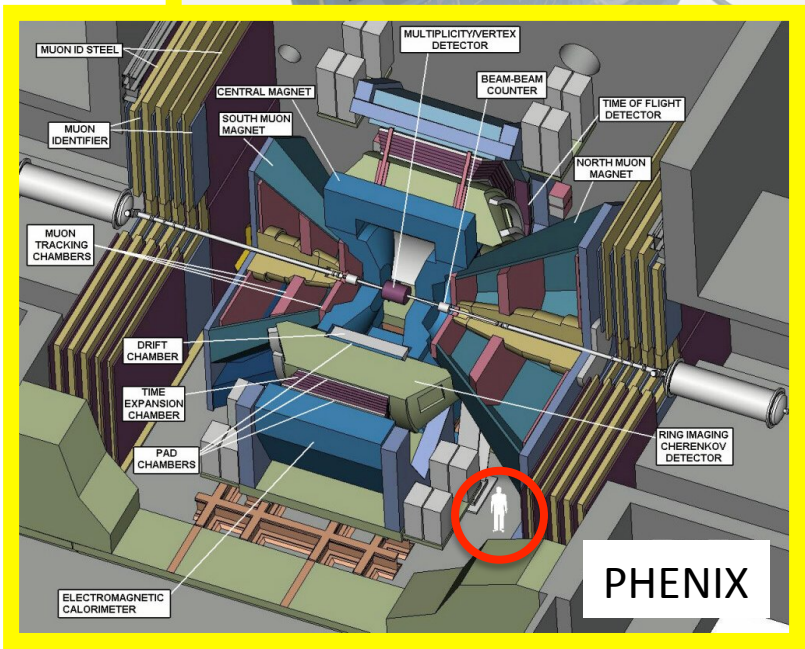


Quark Gluon Plasma

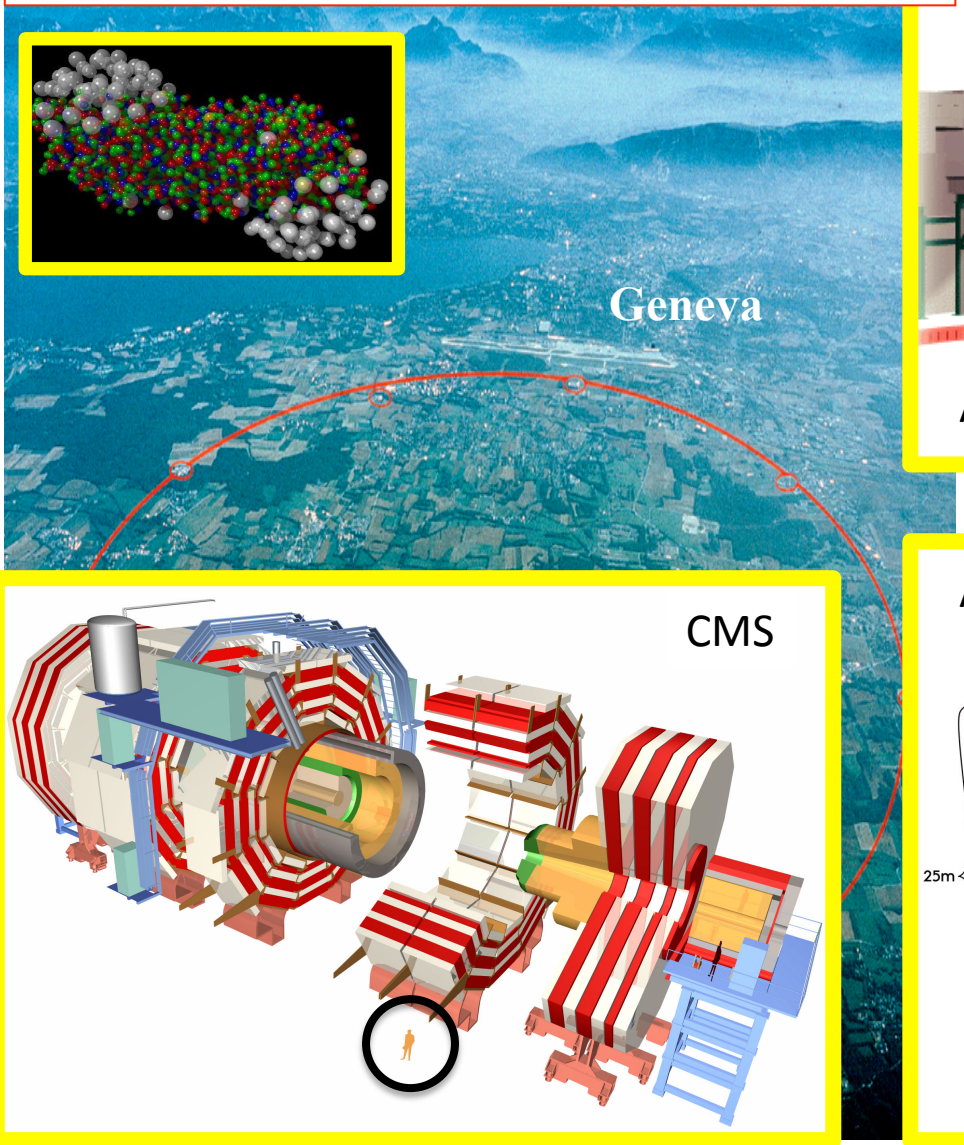
Hadrons

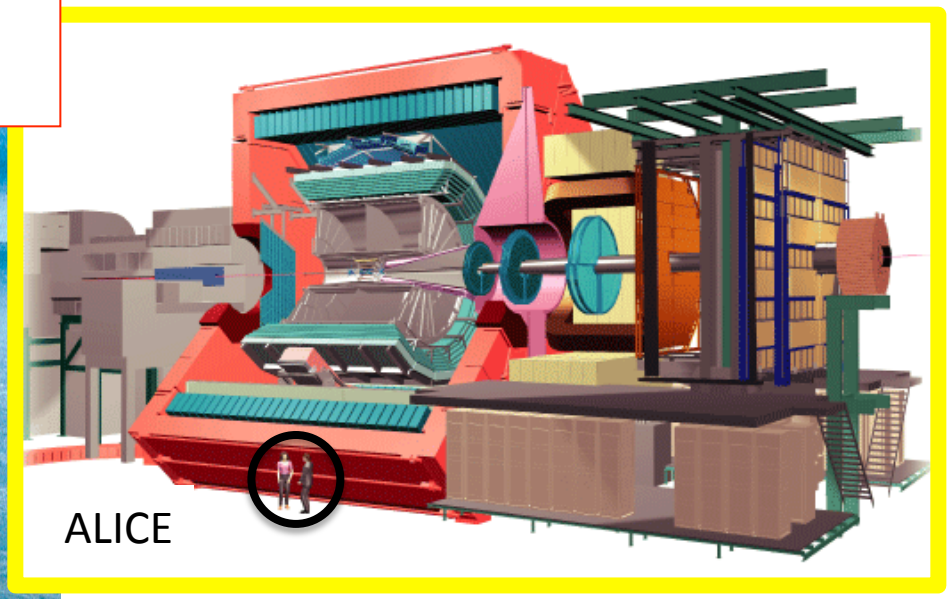
Relativistic Heavy-Ion Collider (RHIC) at Brookhaven National Laboratory (BNL) STAR and PHENIX experiments

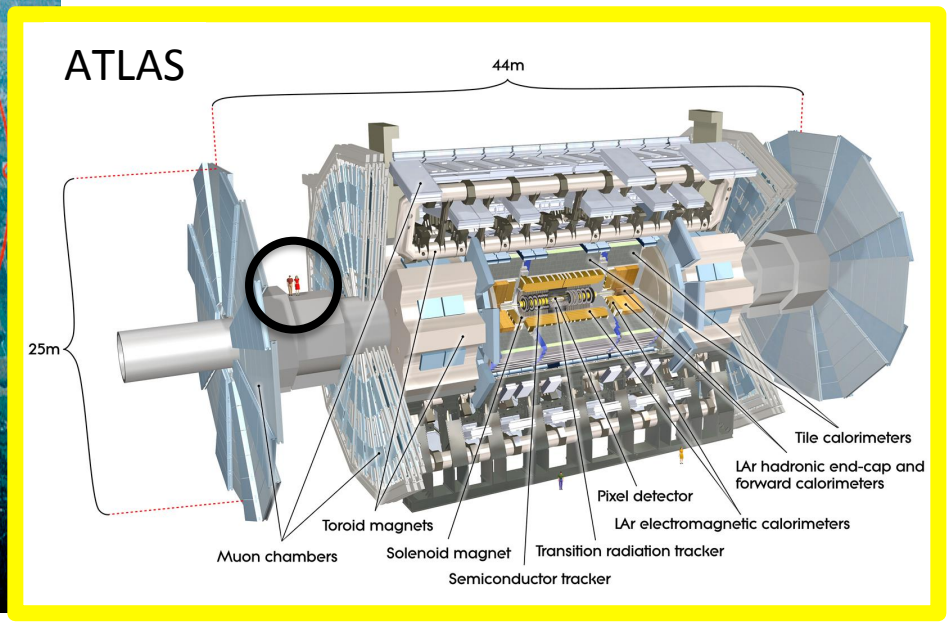


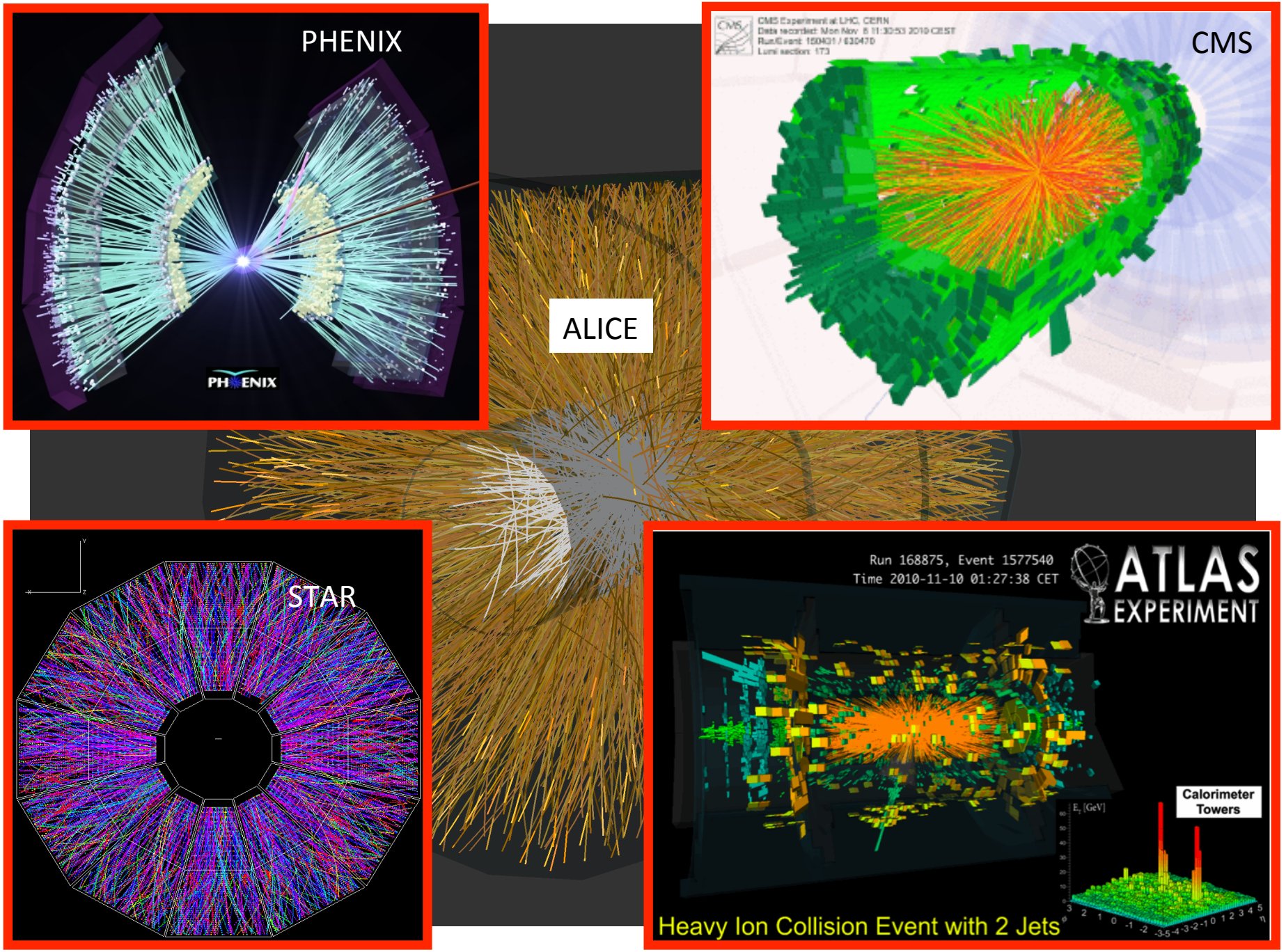


Large Hadron Collider (LHC) at European Organization for Nuclear Study（CERN）
ALICE, ATLAS and CMS experiments

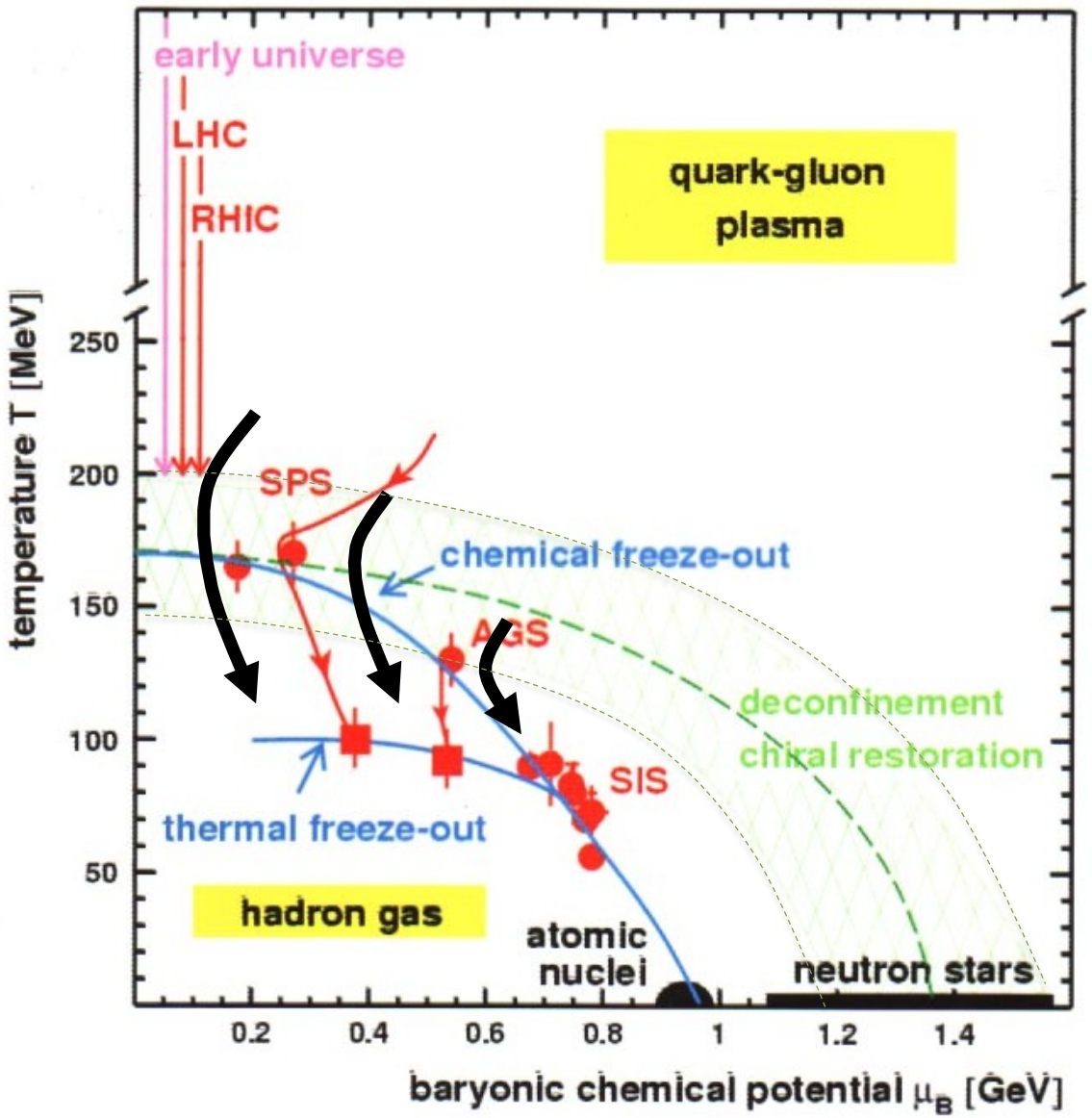







PHENIX
PHENIX
ALICE
CMS
CMS Experiment at LHC, CERN
Data recorded: Mon Nov 8 11:30:53 2010 CEST
Run/Event: 150431 / 630470
Lumi section: 173
STAR
Run 168875, Event 1577540
Time 2010-11-10 01:27:38 CET
ATLAS
EXPERIMENT
Calorimeter
Towers
Heavy Ion Collision Event with 2 Jets

Chemical and Thermal Freeze-out



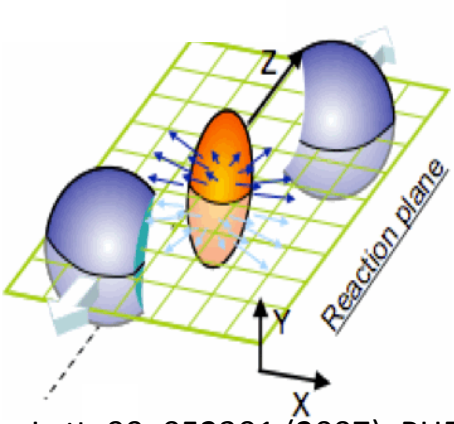
single particle p_T spectra, HBT measurements

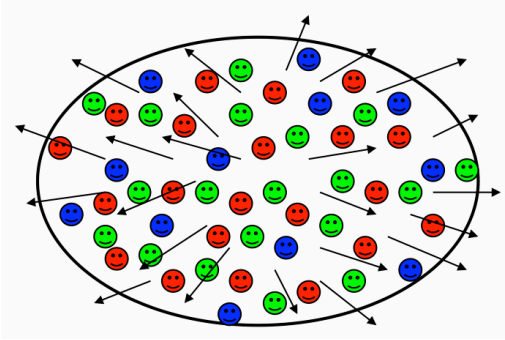
- Thermal freeze-out
- $T_{fo}^{(Th)} \sim 100$MeV
- end of elastic interaction among hadrons
- local thermalization
- Radial expansion, flow

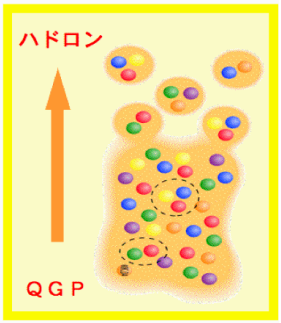
particle yield and ratio

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

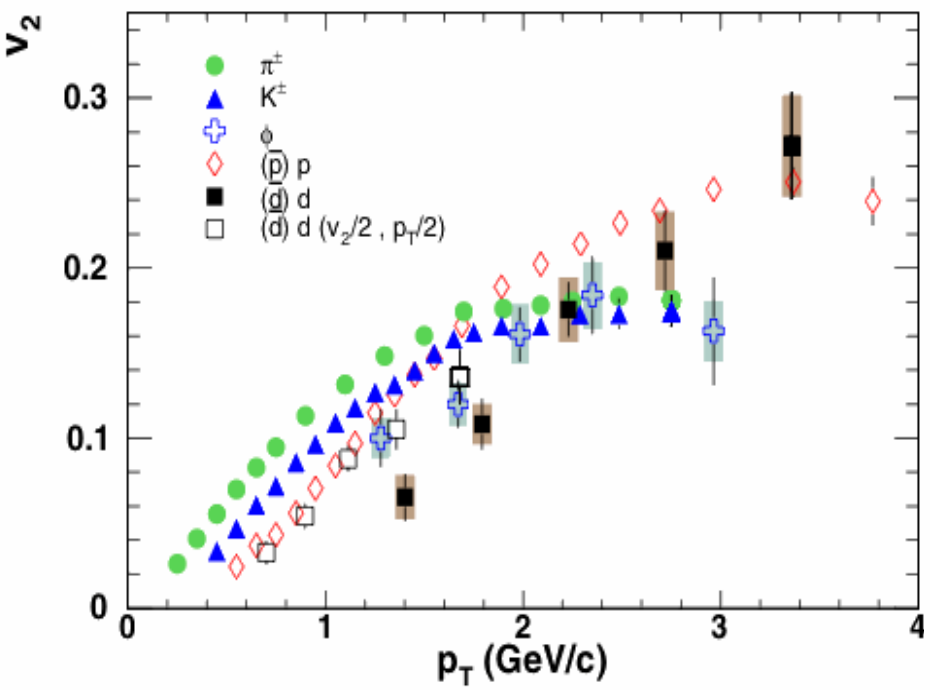
Elliptic expansion in pre-hadronic phase



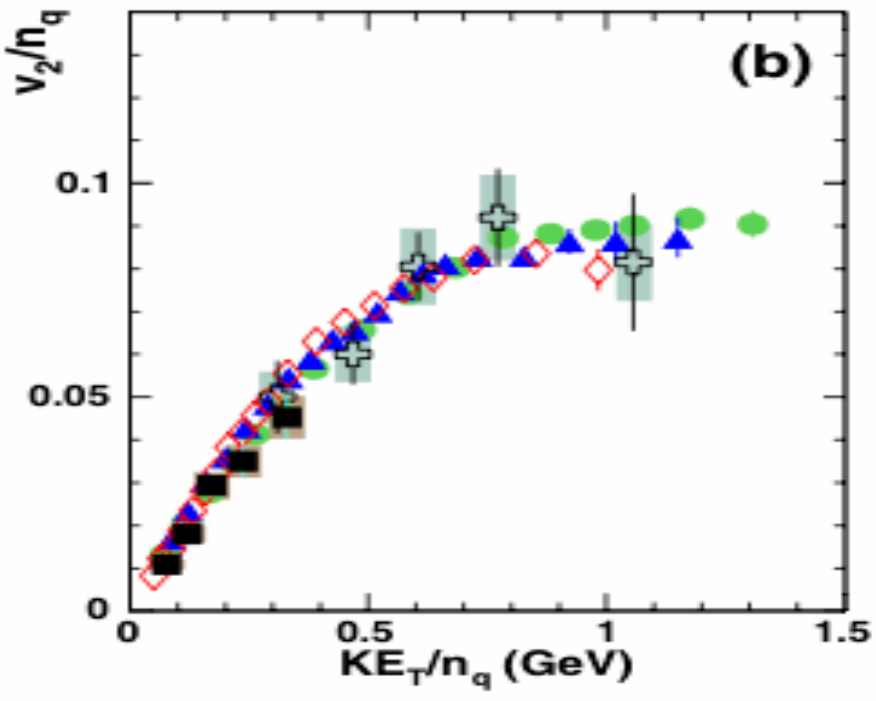




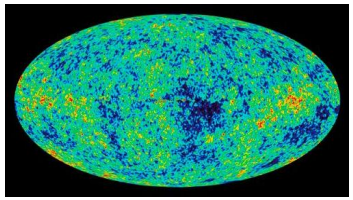
Phys. Rev. Lett. 99, 052301 (2007), PHENIX



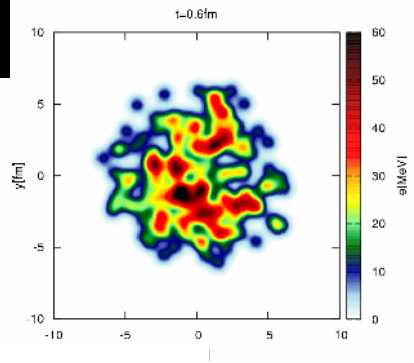
Phys. Rev. Lett. 99, 052301 (2007), PHENIX

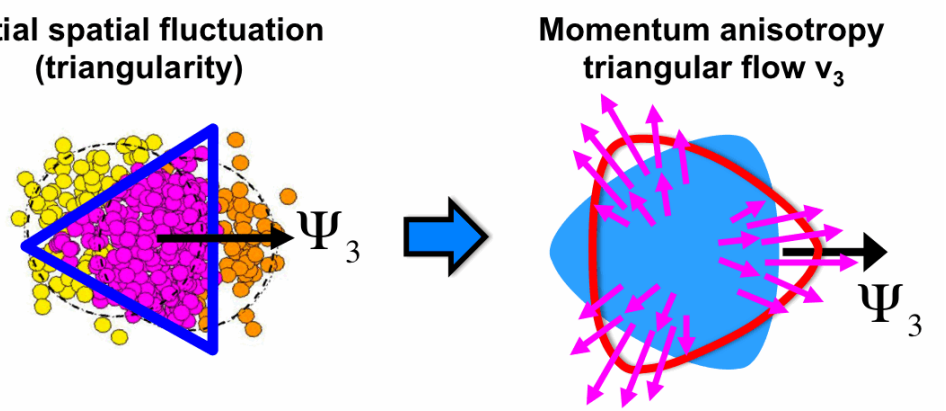


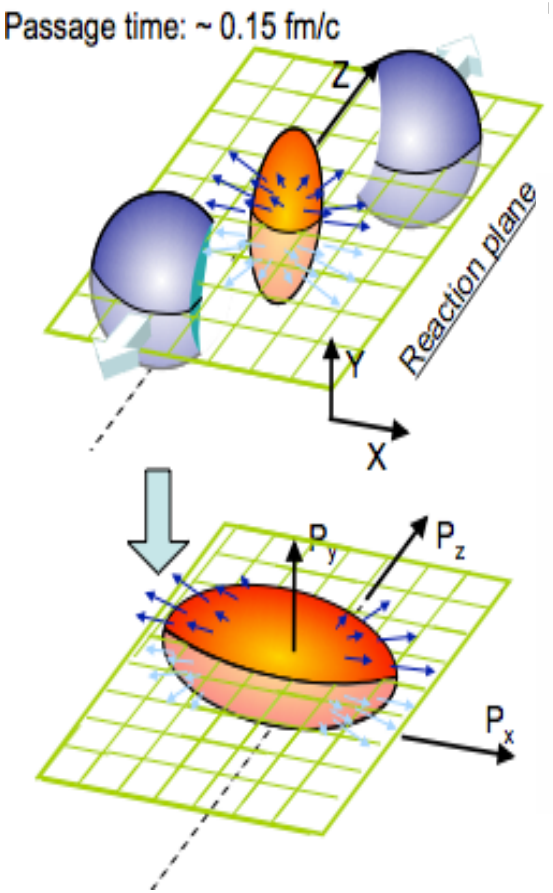
Higher harmonic order collective expansion of QGP

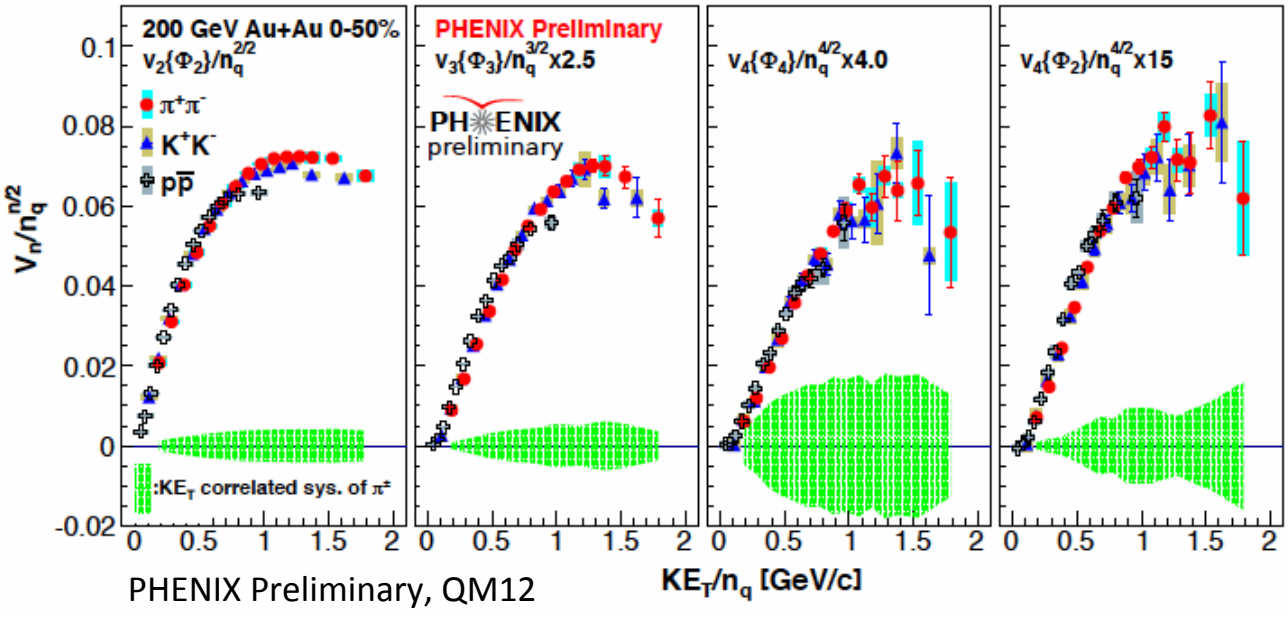


WMAP



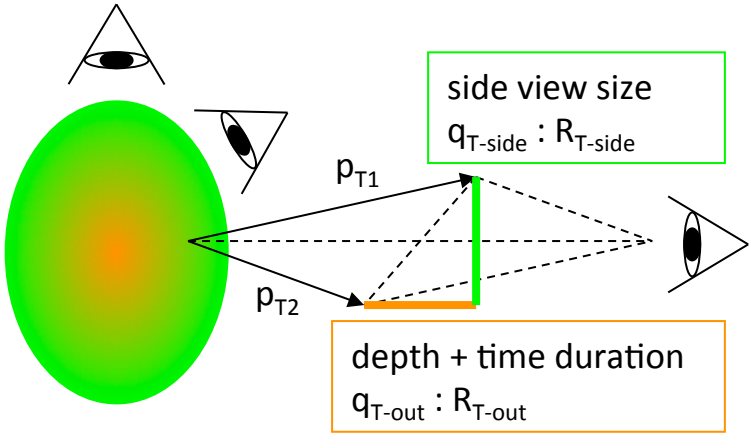




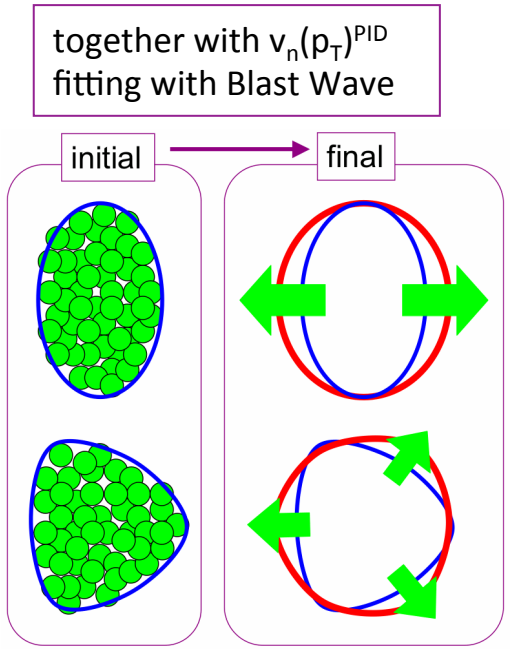


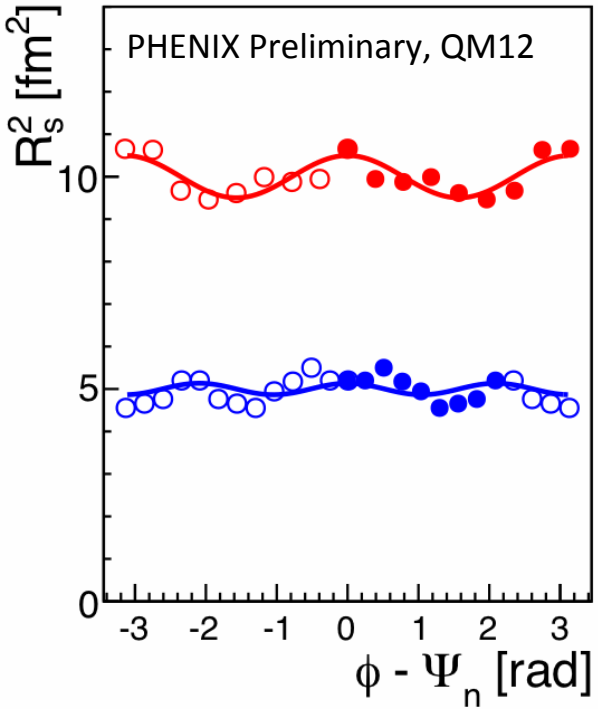
PHENIX Preliminary, QM12

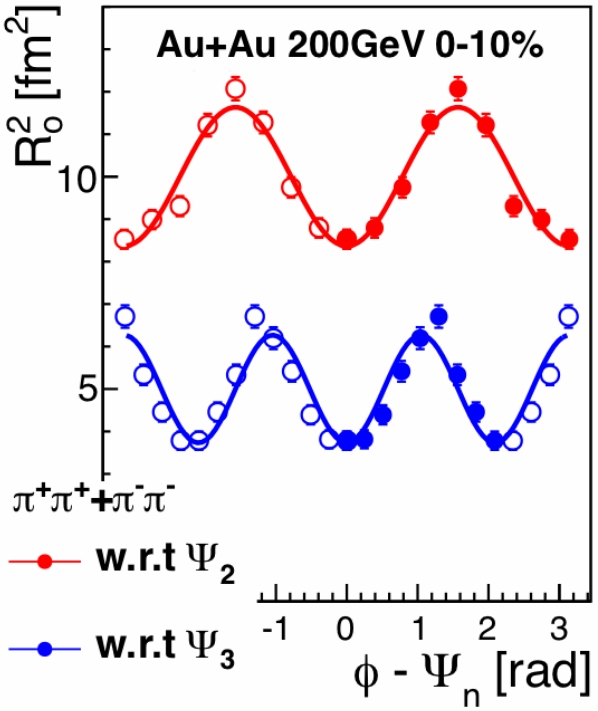
Source geometry (size, shape and time duration) at the end of freeze-out via two particle quantum interferometry (HBT measurement)



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

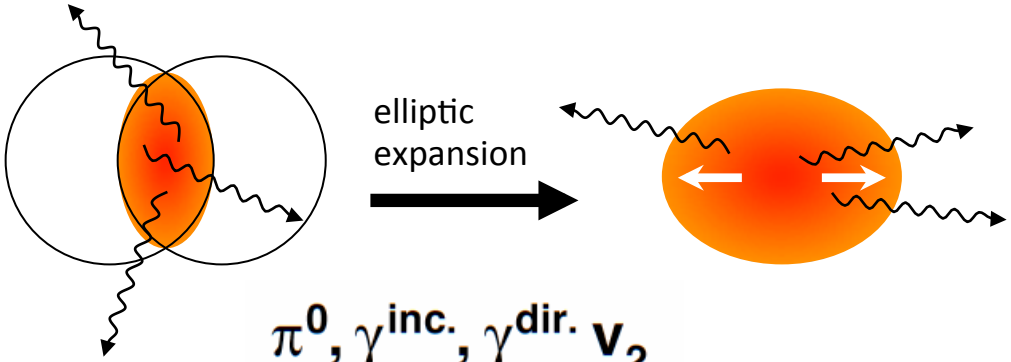






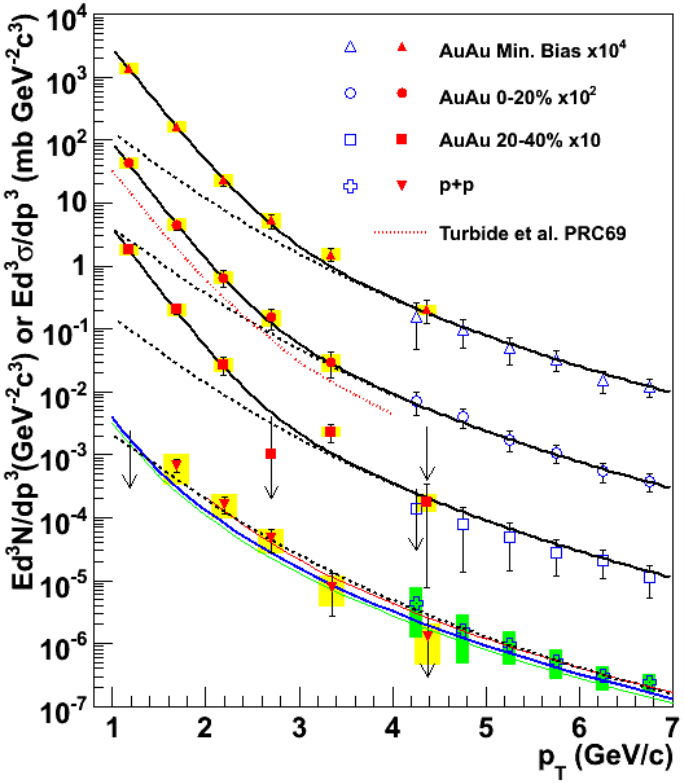
Thermal photon radiation and collective flow

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

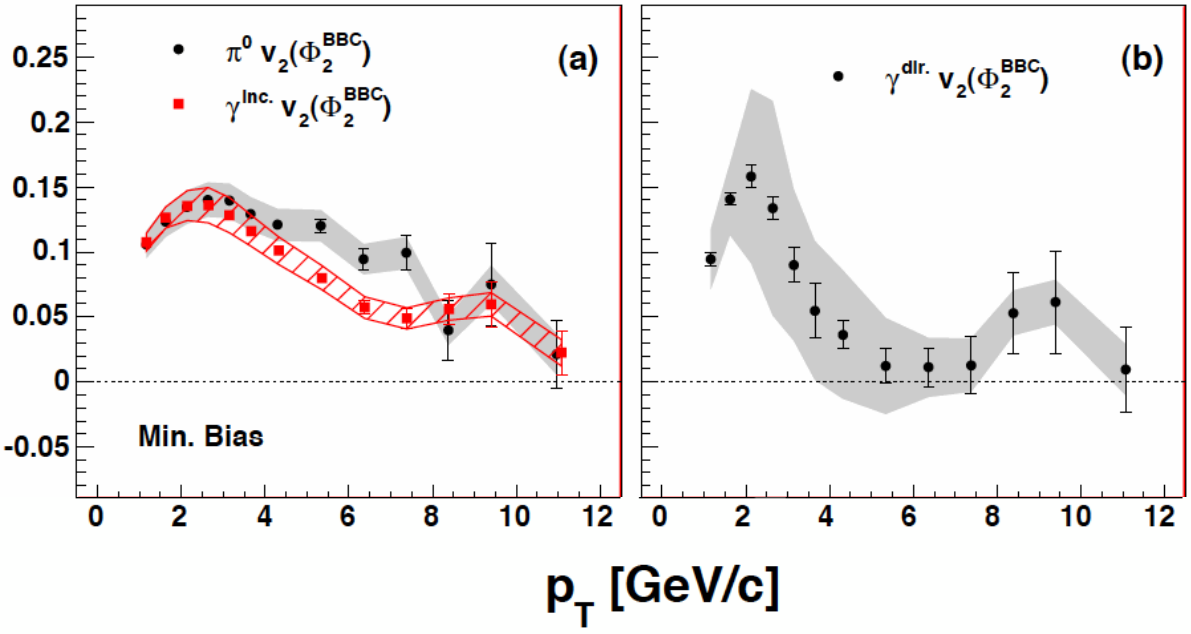


$\pi^0, \gamma^{inc.}, \gamma^{dir.}$ v_2

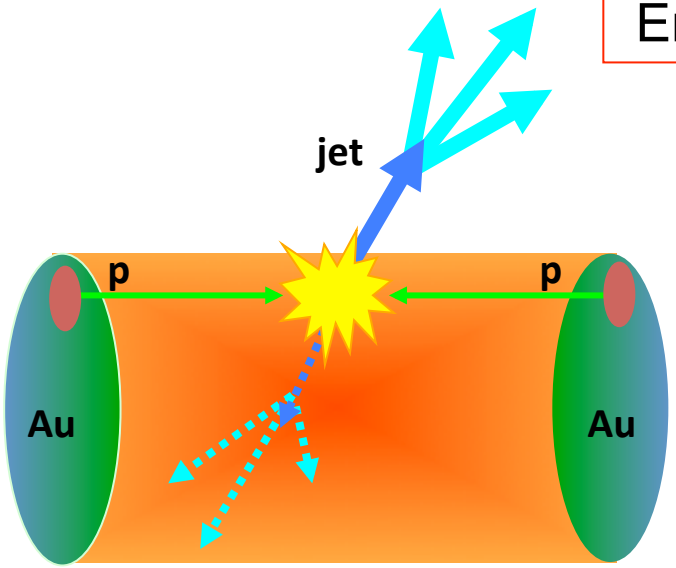
Phys. Rev. Lett. 104, 132301 (2010)

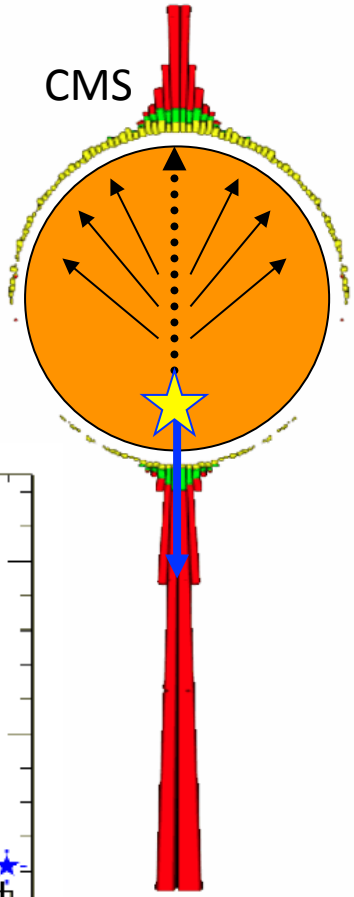


arXiv: 1105.4126
Phys. Rev. Lett. 109, 122302 (2012)

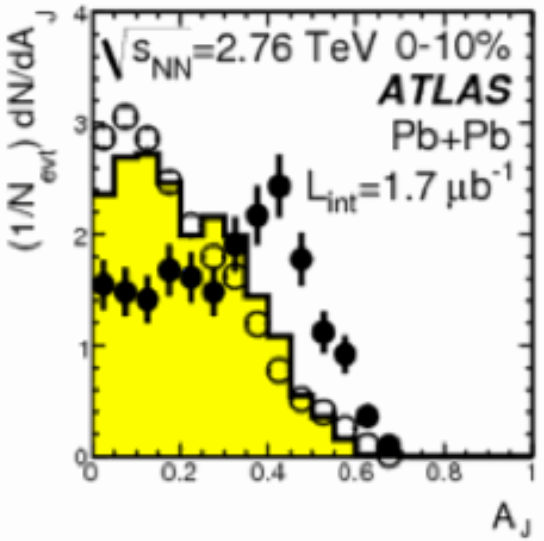


Energy loss (jet quenching)

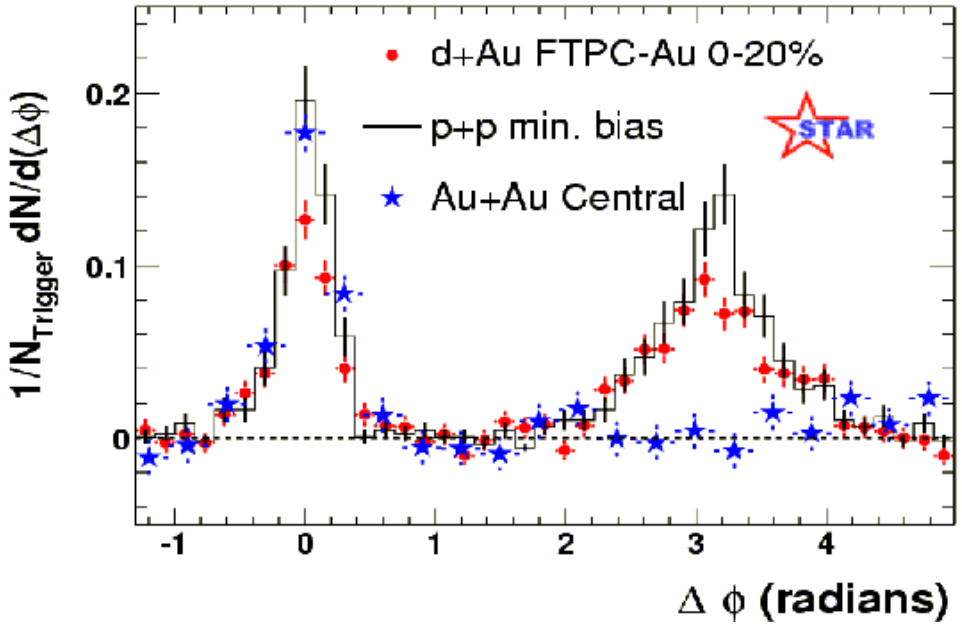


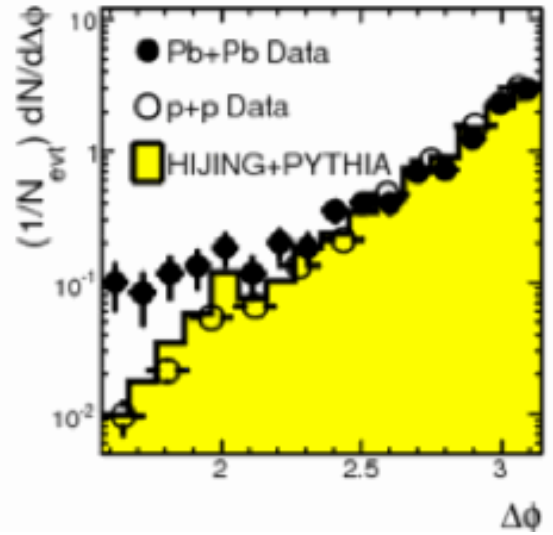


Phys. Rev. Lett. 105, 252303 (2010)



Phys. Rev. Lett. 91, 072304 (2003)



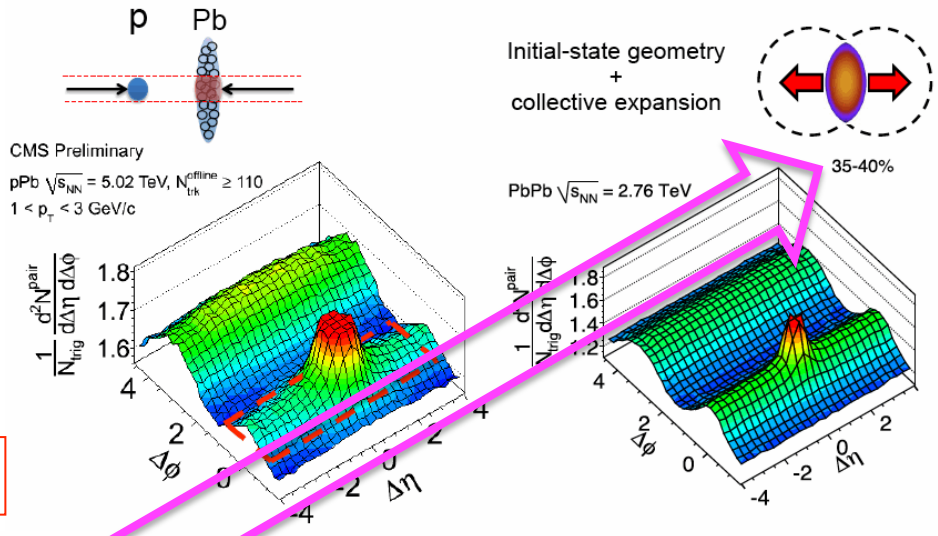


Ridge structure

A small but high-temperature/density system might be created in high multiplicity pp and pA collisions…
Are they collective/expanding?

High mult. p+A

A+A

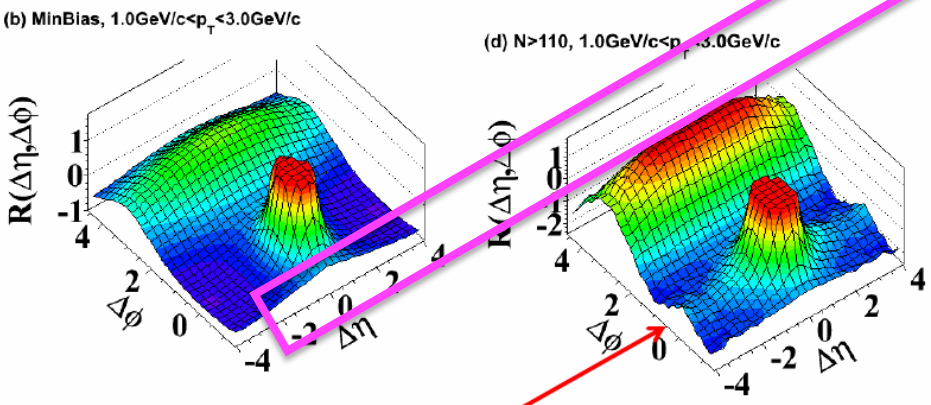


Min. bias p+p

Minimum Bias
no cut on multiplicity

High mult. p+p

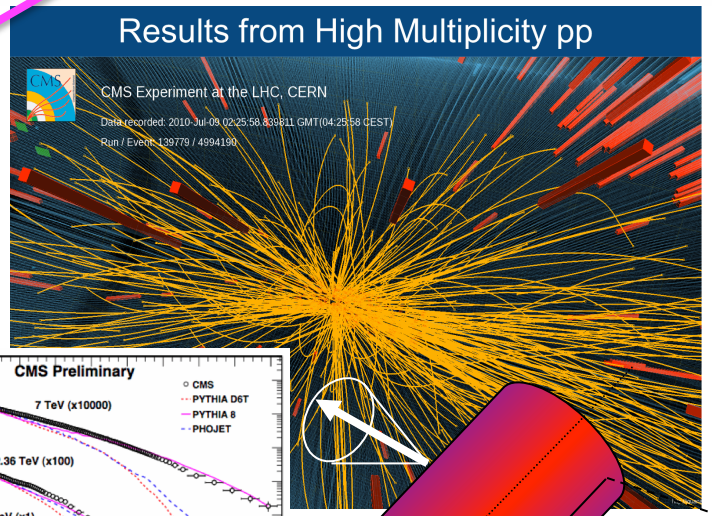
High multiplicity data set
and N>110

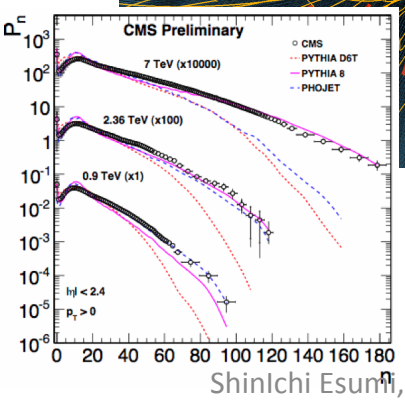


New "ridge-like" structure extending to large $\Delta\eta$ at $\Delta\phi \sim 0$

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

CMS





Left/right asymmetry of Ridge and Mach-cone

QM09: J. Konzer

STAR Preliminary

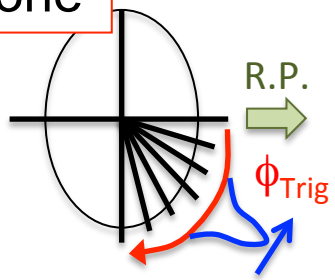
Au+Au 20-60%

$3<p_T^{Trig}<4$ GeV/c

$1<p_T^{Assoc}<1.5$ GeV/c

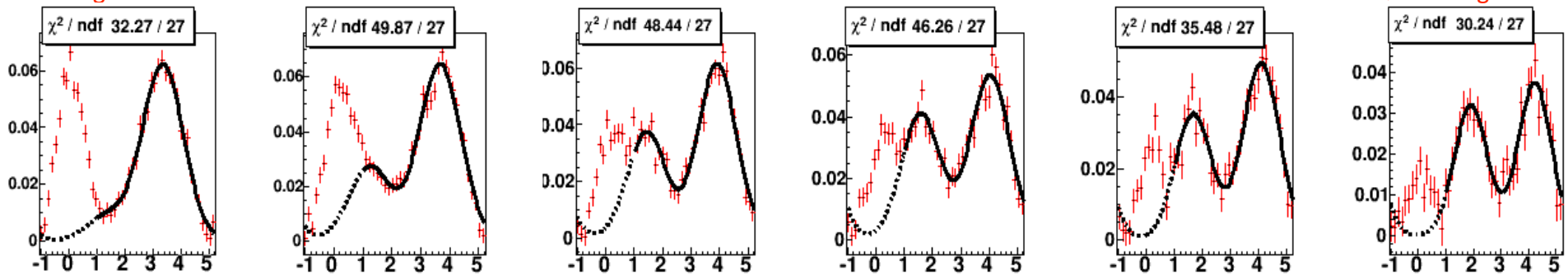
Y(|Δη|>0.7) = **Ridge** + away-side two-Gaussian

Jet = Y(|Δη|<0.7) – Acceptance*Y(|Δη|>0.7)

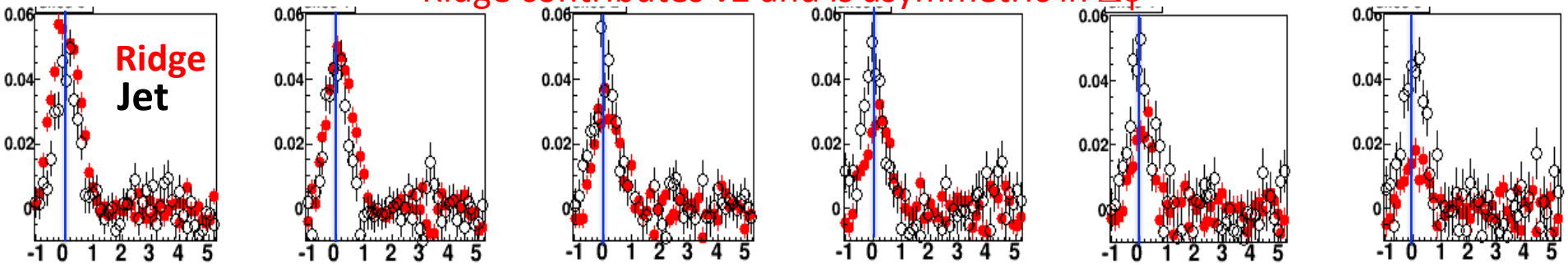


|Δη|>0.7

ϕ_{Trig}~0 → ϕ_{Trig}~90



Ridge contributes v2 and is asymmetric in Δφ

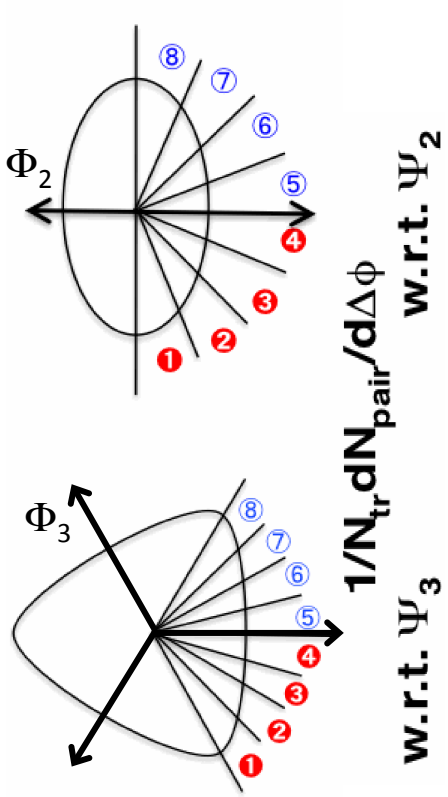


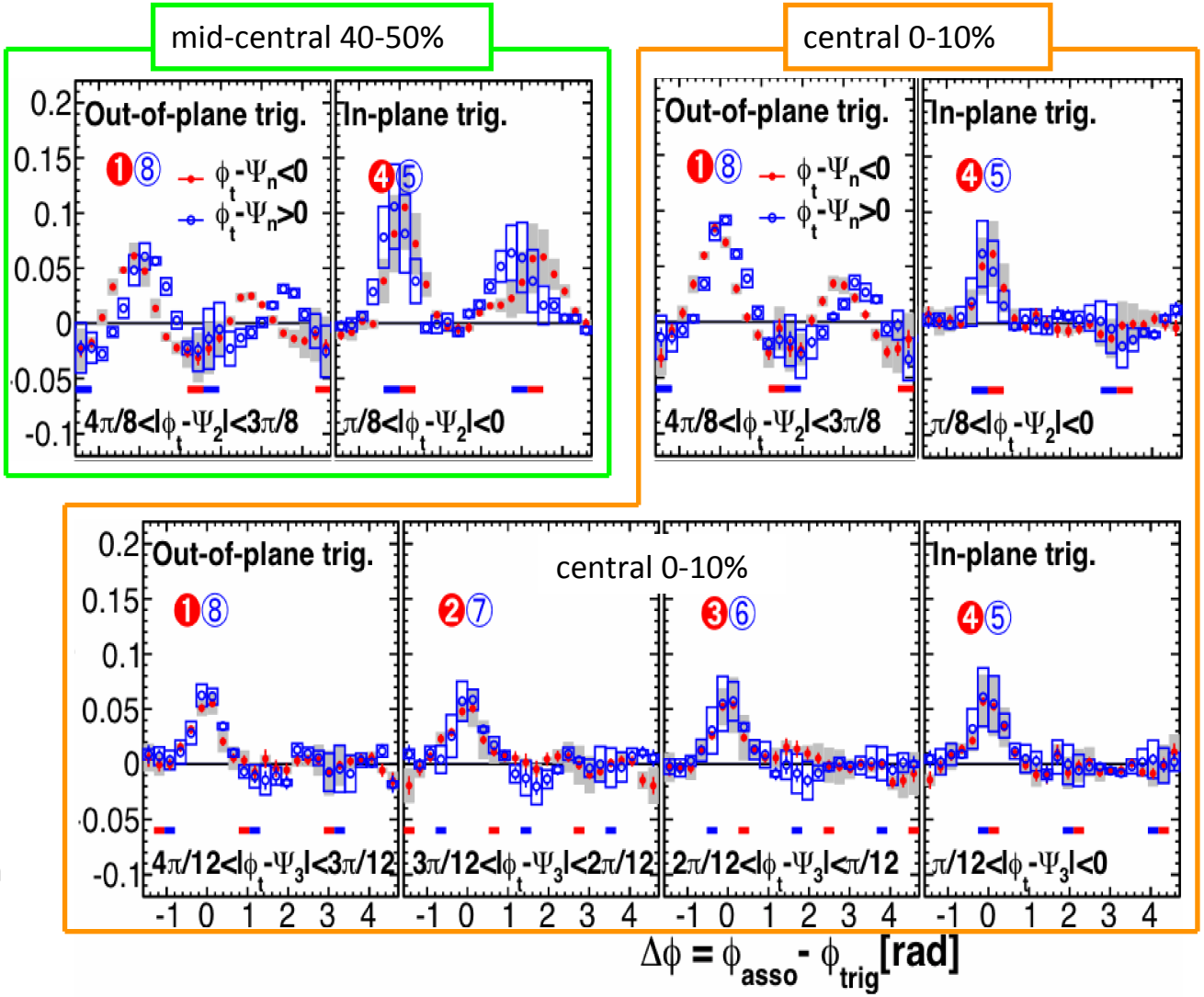
$\Delta\phi = \phi_{assoc} - \phi_{Trig}$

v2 subtraction

Hard-soft coupling via geometry and expansion

- strong Φ_2 dependence and left/right asymmetry (coupled with energy loss and flow)
- broad out-of-plane correlation enhanced more in central (redistribution and expansion)
- weak Φ_3 dependence

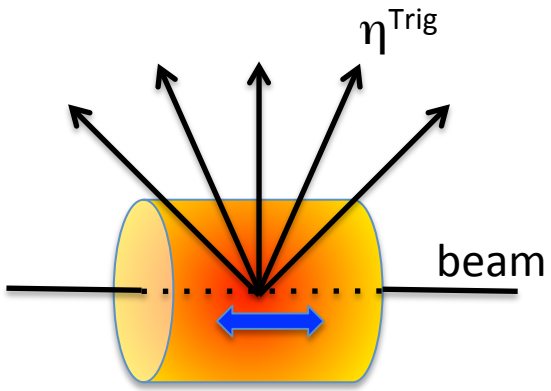




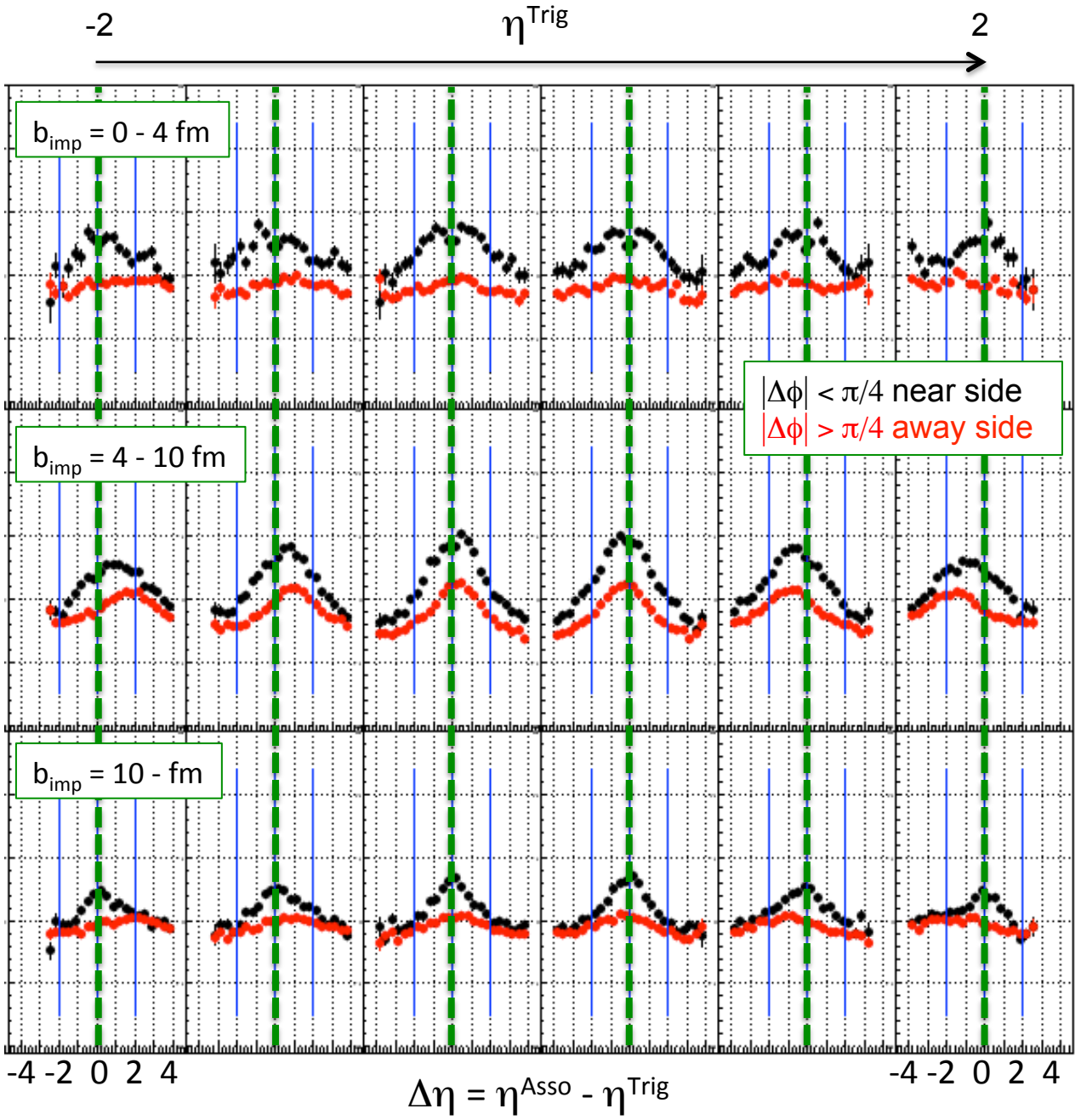
PHENIX Preliminary, QM12
Au+Au 200GeV, hadron-hadron
p_T : $(2\sim4)_{Trig}$ x $(1\sim2)_{Asso}$ (GeV/c)
vn subtraction, no $\Delta\eta$ cut

Trigger h dependence of $\Delta\eta$ distribution

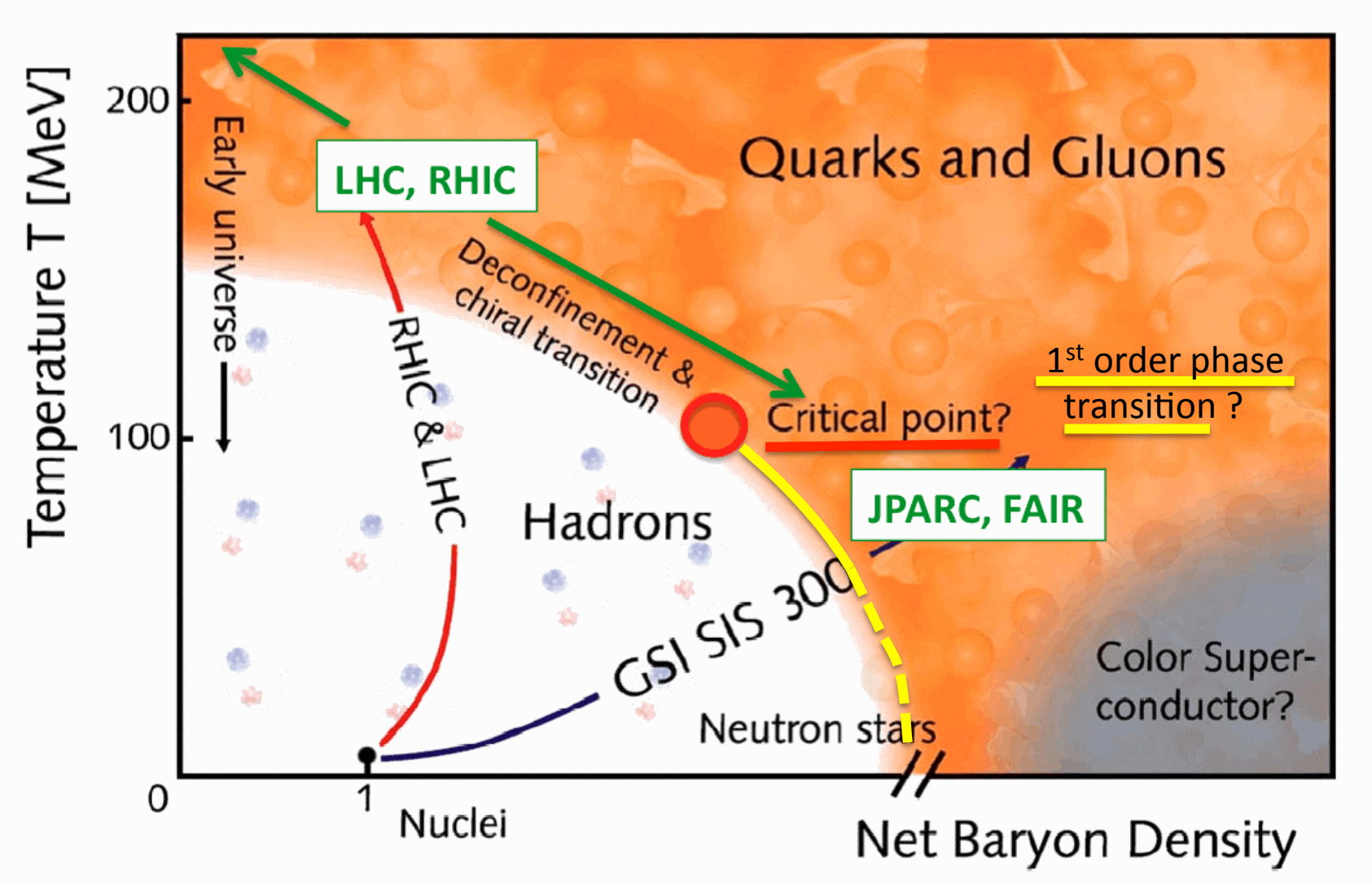
(associate yield per trigger with AMPT simulation)

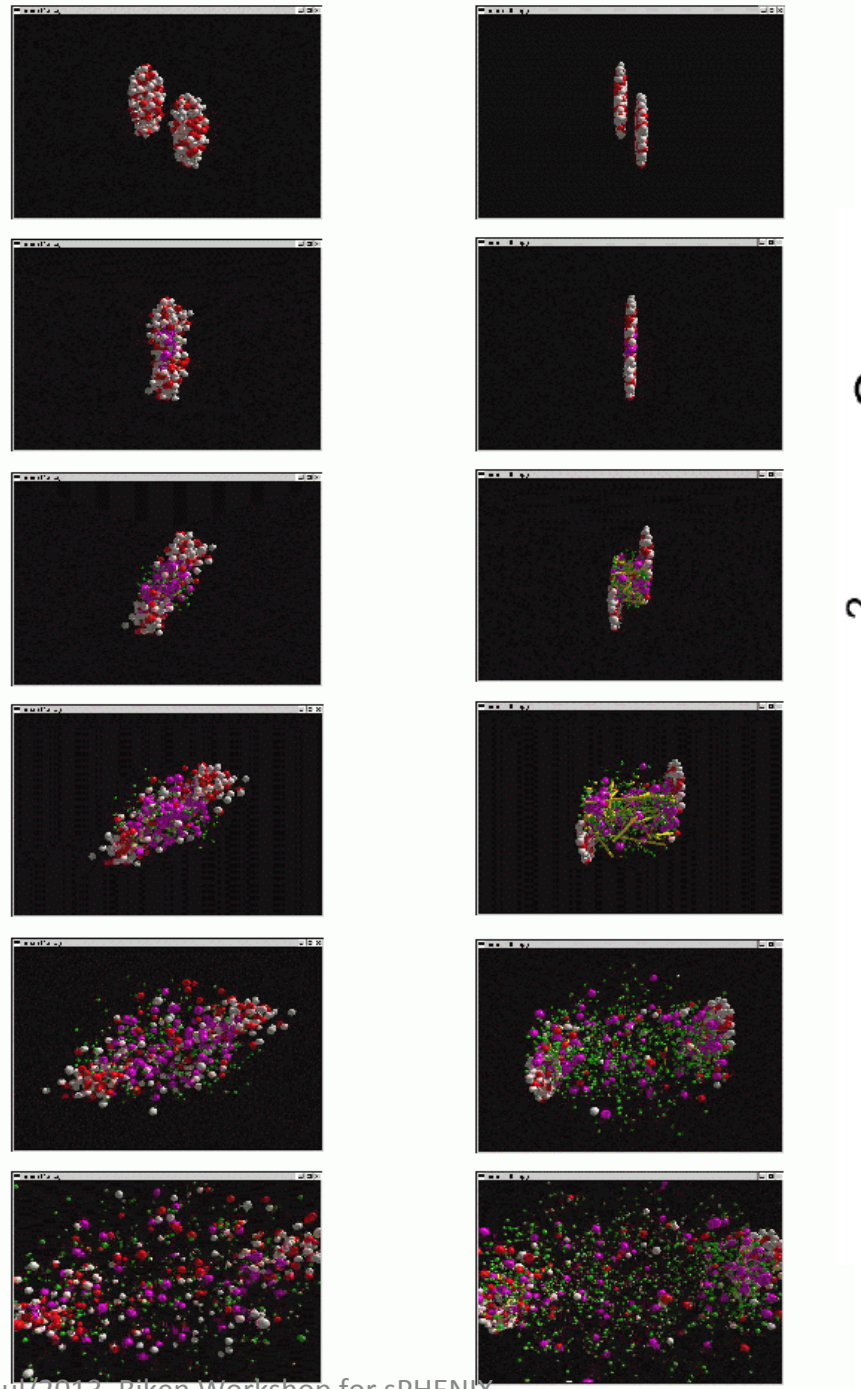


look at the asymmetry in $\Delta\eta = \eta^{Asso} - \eta^{Trig}$ (associate η distribution with respect to trigger η) in order to see the hard-soft coupling with longitudinal density profile and/or expansion

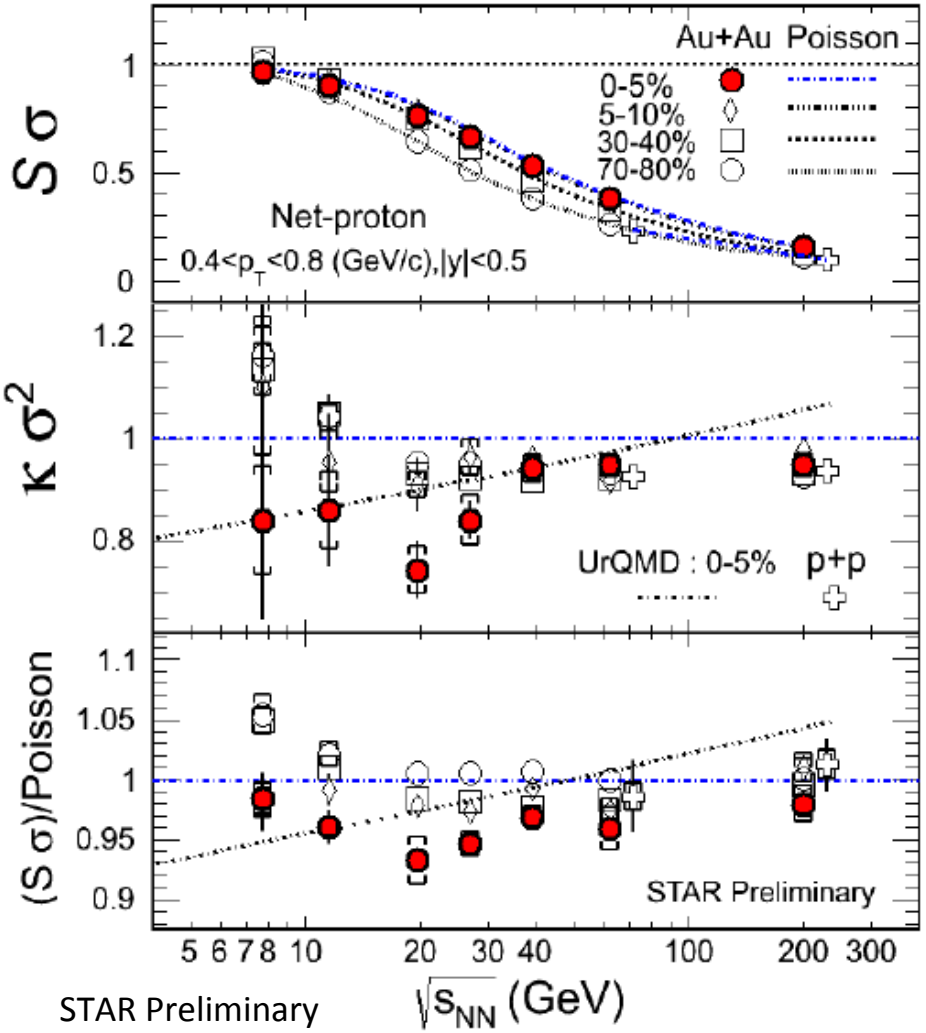


RHIC beam energy scan program
to look for critical behaviors --- critical point and 1st order phase transition ---

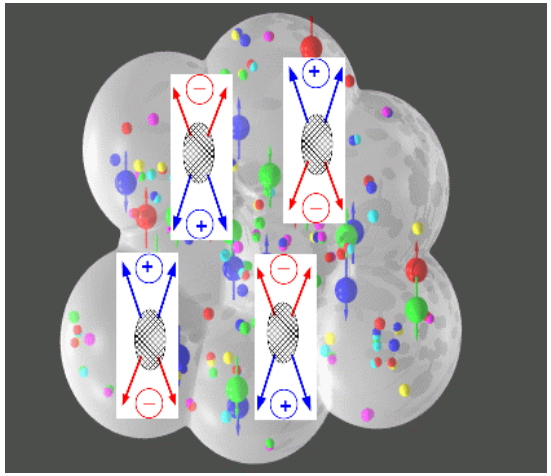


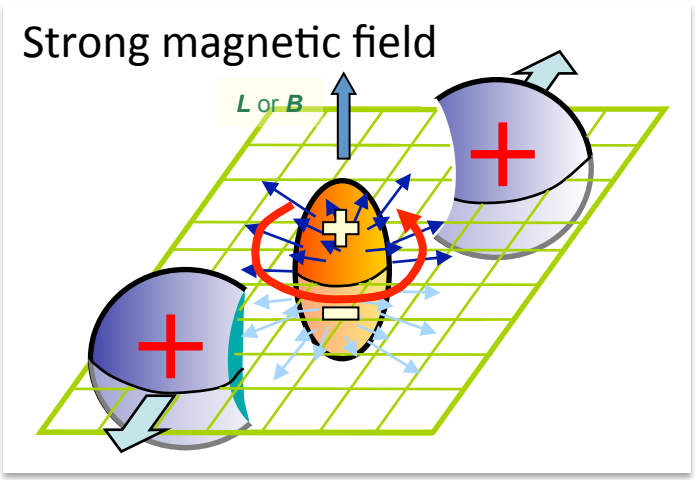


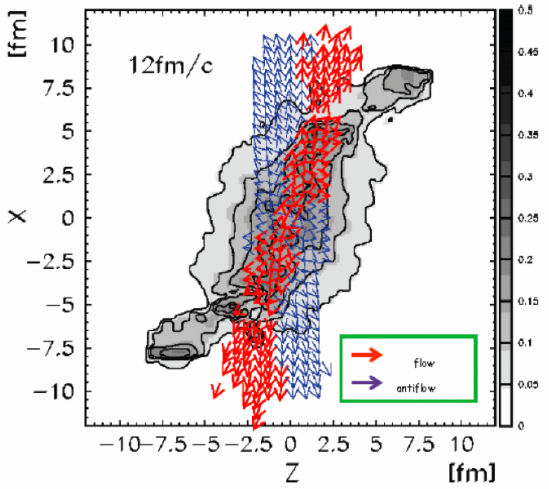
net-Baryon number fluctuation is expected to reflect the critical point as a non-monotonic behavior



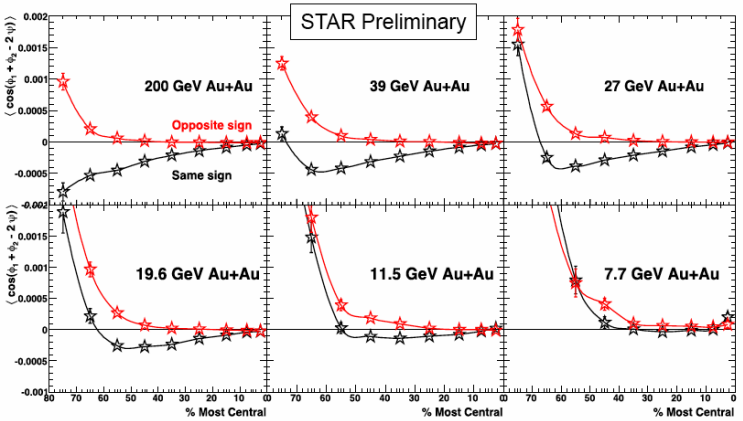
STAR Preliminary
QM12



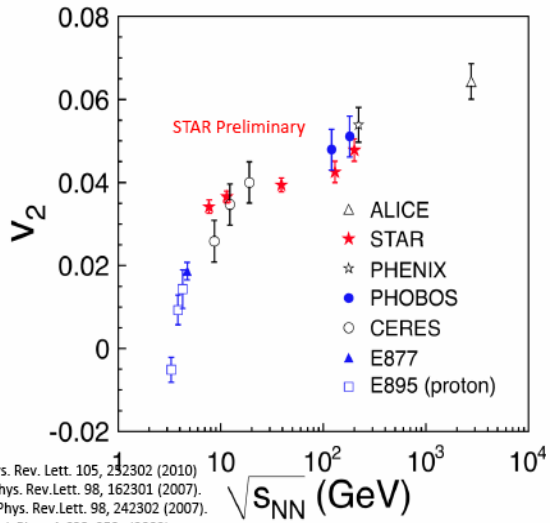




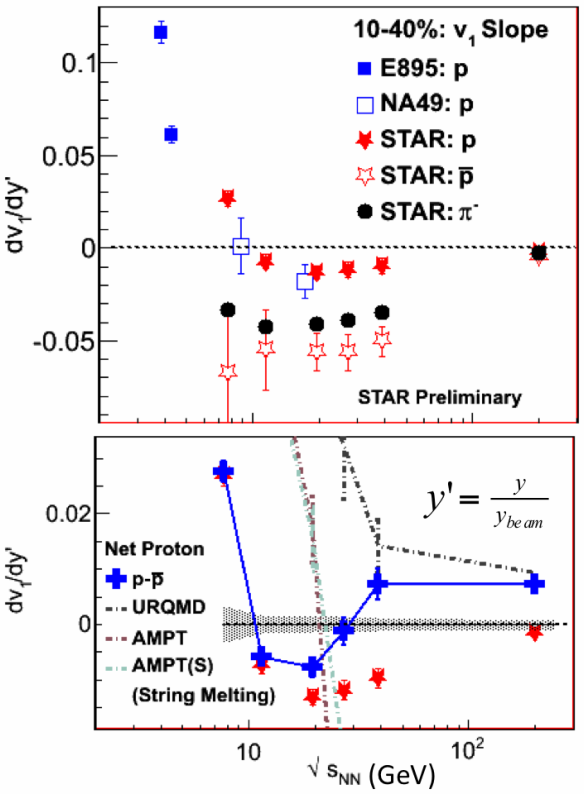
J. Brachmann et al., PRC 61, 24909 (2000).



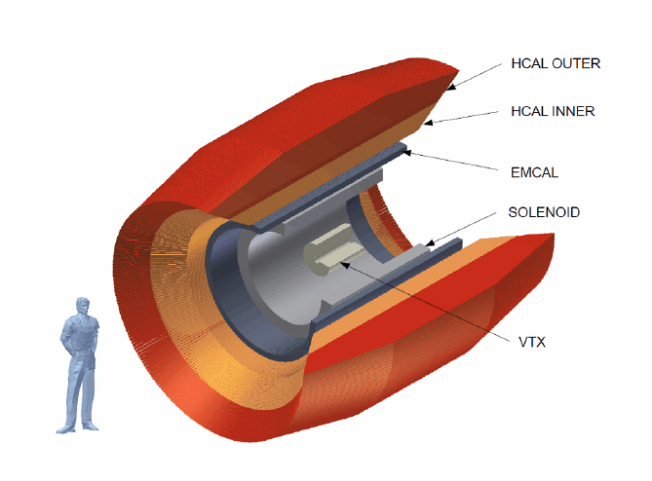
Beam energy dependence of charge asymmetry and flow (v_1, v_2, v_n…) signals in order to look for any non-monotonic behavior

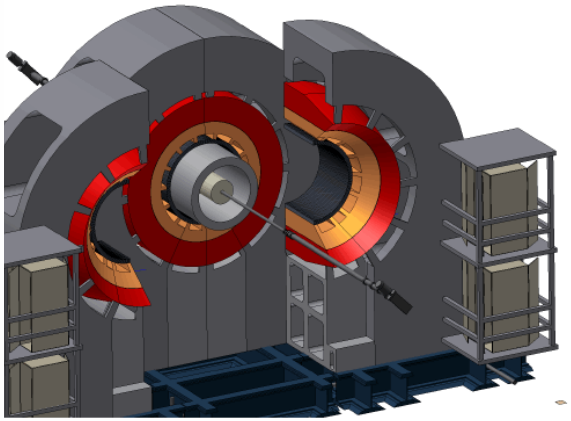


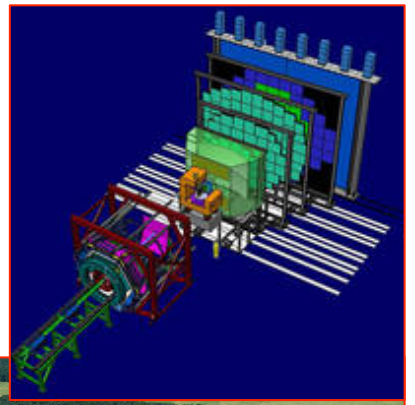
ALICE: Phys. Rev. Lett. 105, 252302 (2010)
PHENIX: Phys. Rev.Lett. 98, 162301 (2007).
PHOBOS: Phys. Rev.Lett. 98, 242302 (2007).
CERES: Nucl. Phys. A 698, 253c (2002).
E877: Nucl. Phys. A 638, 3c(1998).
E895: Phys. Rev. Lett. 83, 1295 (1999).
STAR 130 and 200 GeV: Phys. Rev. C 66,873 034904 (2002); Phys. Rev. C 72,790 014904 (2005)

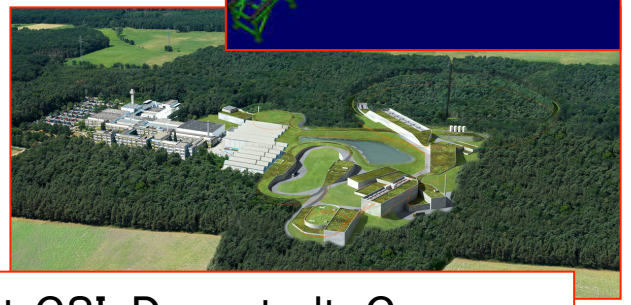


sPHENIX upgrade at RHIC, New York, USA

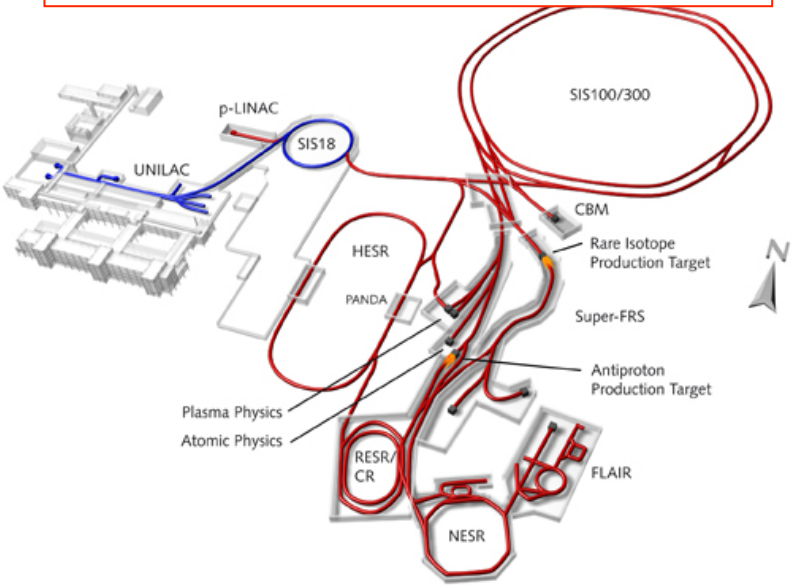








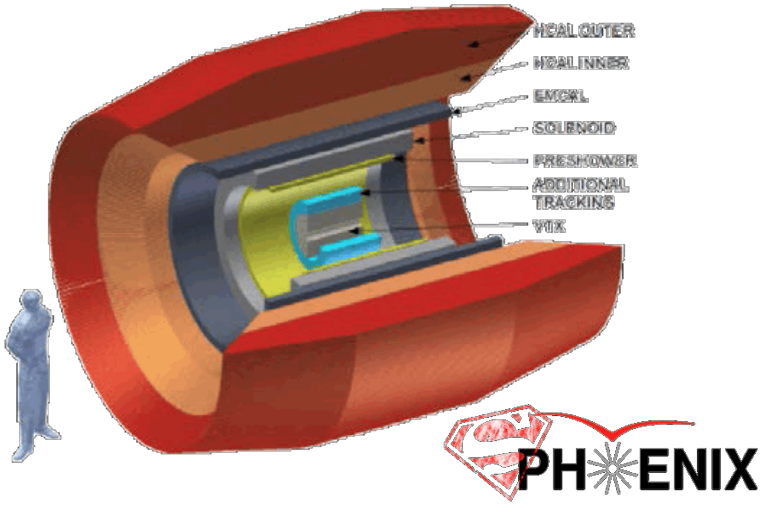
FAIR at GSI, Darmstadt, Germany



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

Summary

Initial and freeze-out temperature
Collective expansion
Partonic energy-loss
Hard-soft interaction
Critical point and energy scan
Future directions



at sPHENIX workfest in Japan