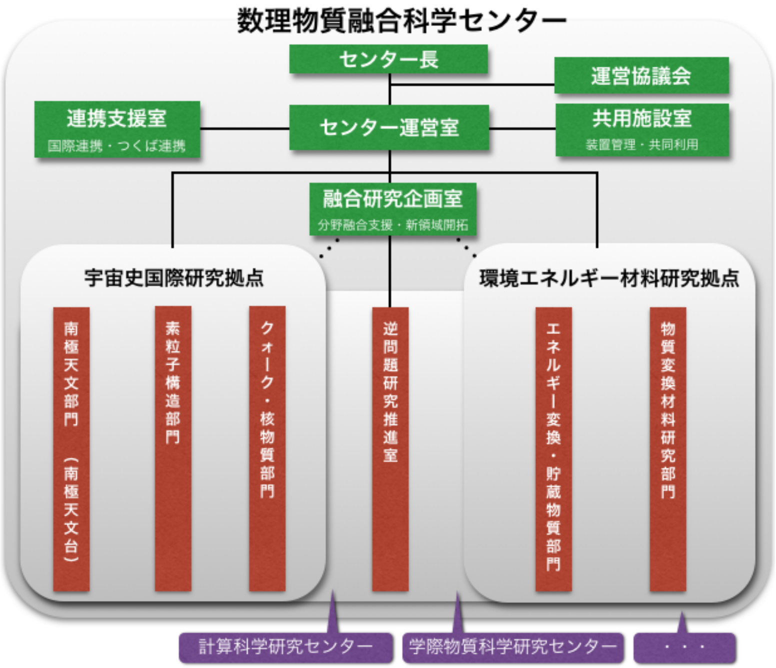
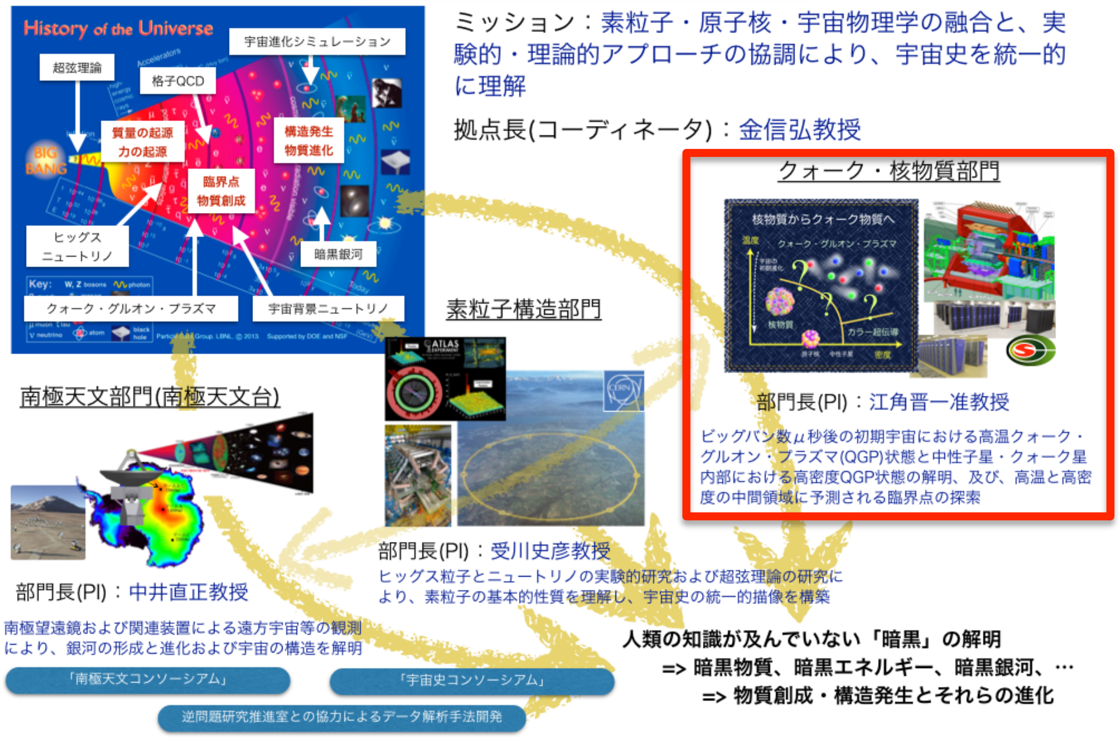
数理物質融合科学センター
クォーク・核物質 部門

数理物質系

Center for Integrated Research in Fundamental Science and Engineering, University of Tsukuba



宇宙史国際研究拠点



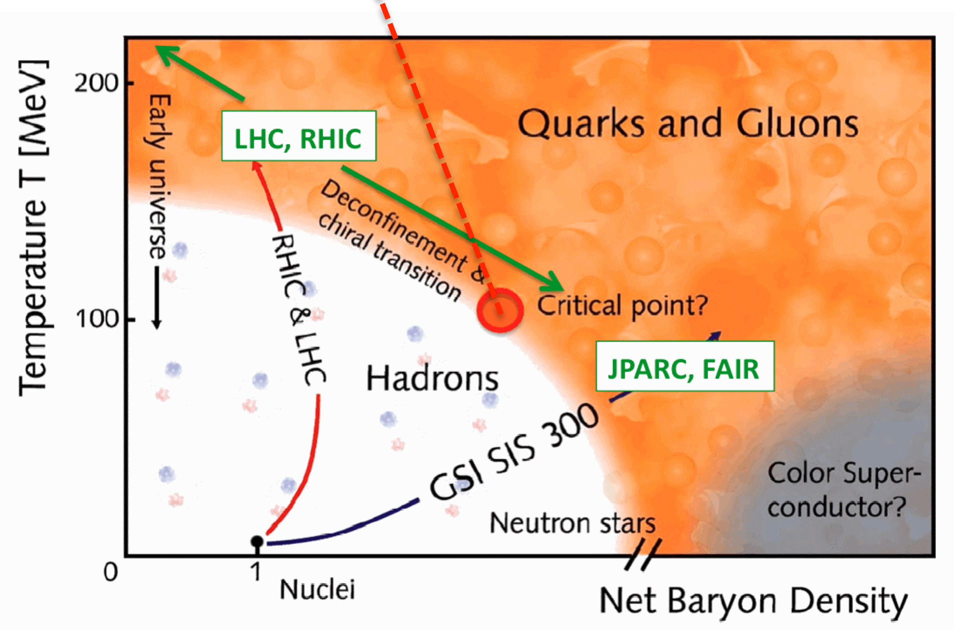
- Experiments
- Recent results
- Future plans

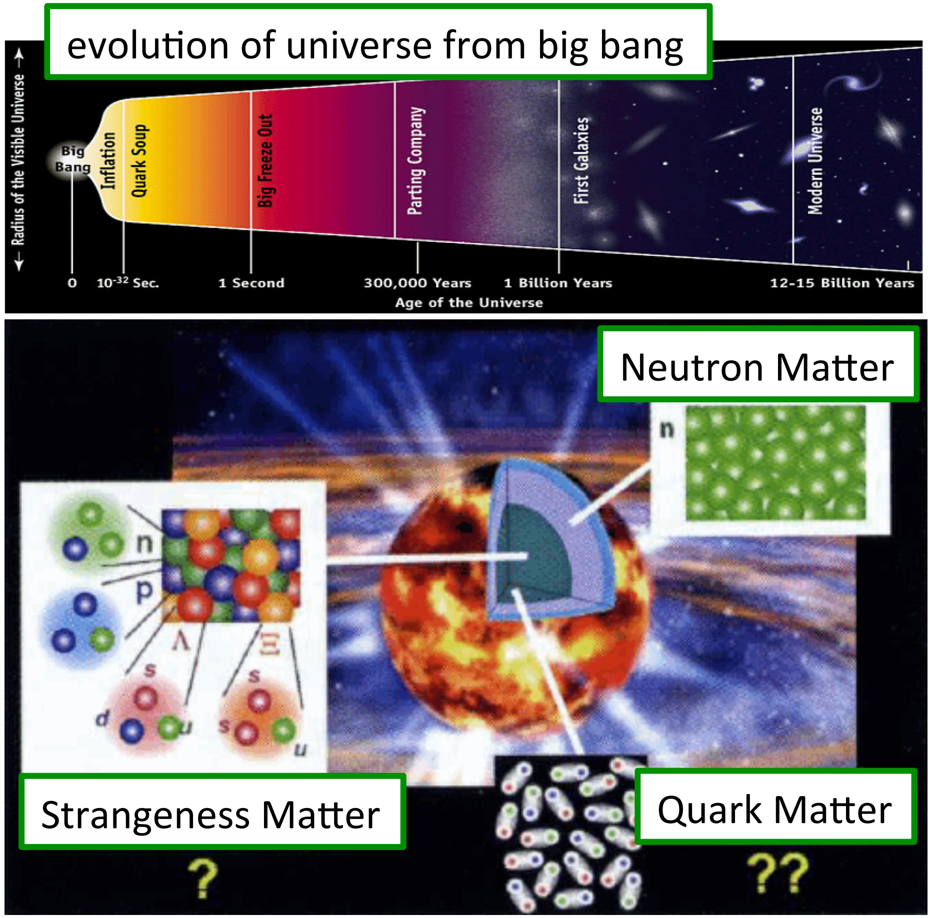
CiRfSE

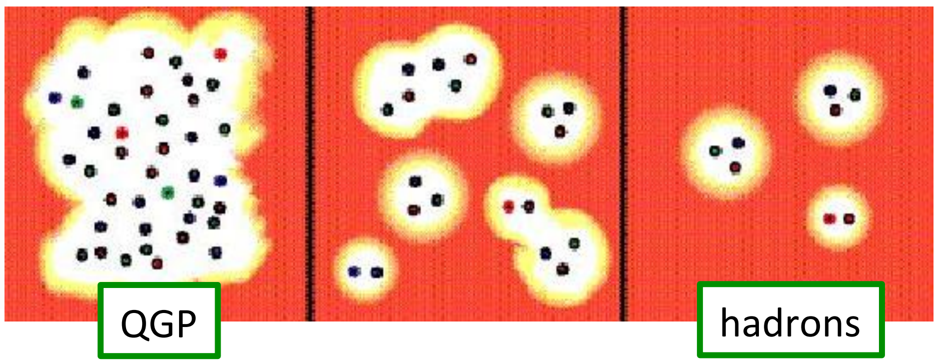
筑波大学 数理物質系 数理物質融合科学センター
宇宙史国際研究拠点 クォーク･核物質部門
江角 晋一 (筑波大学 数理物質系 物理学域)

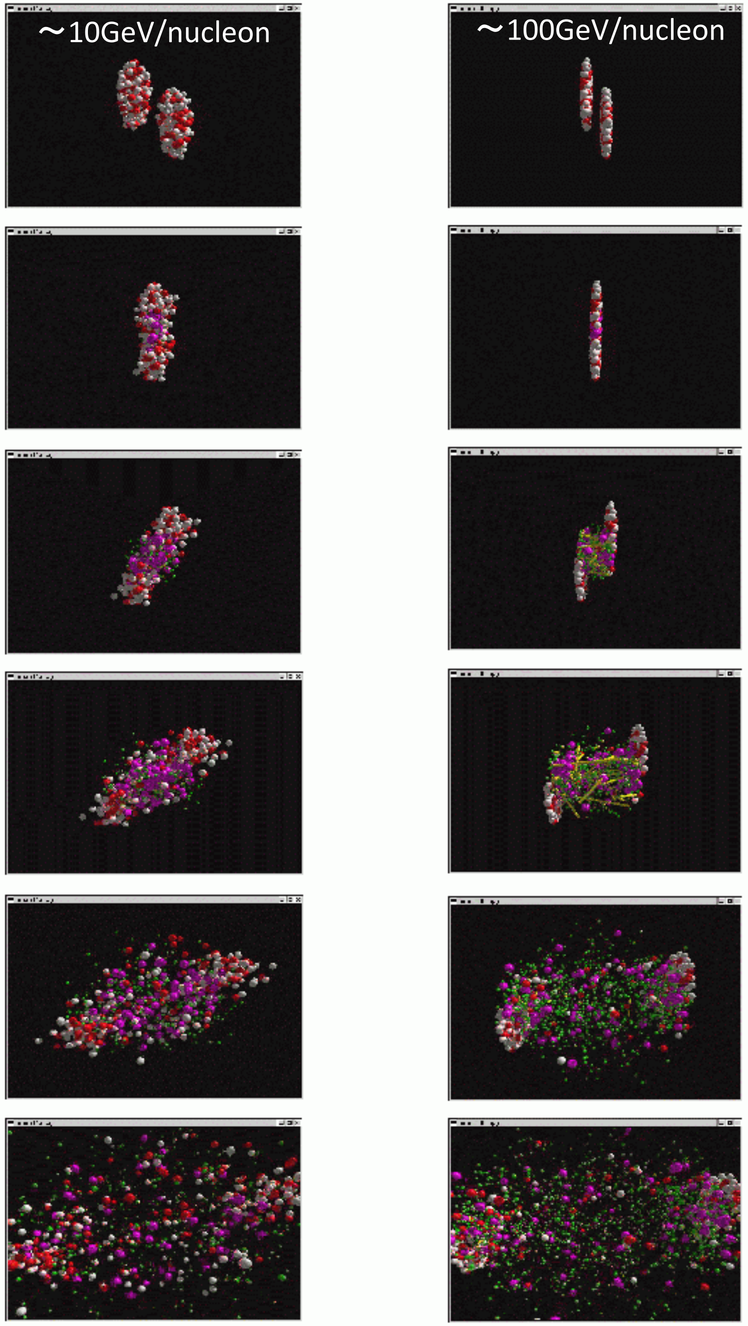
Quark Gluon Plasma (QGP)

early universe
neutron stars
phase transition (hadron : quark)
de-confinement
critical point search

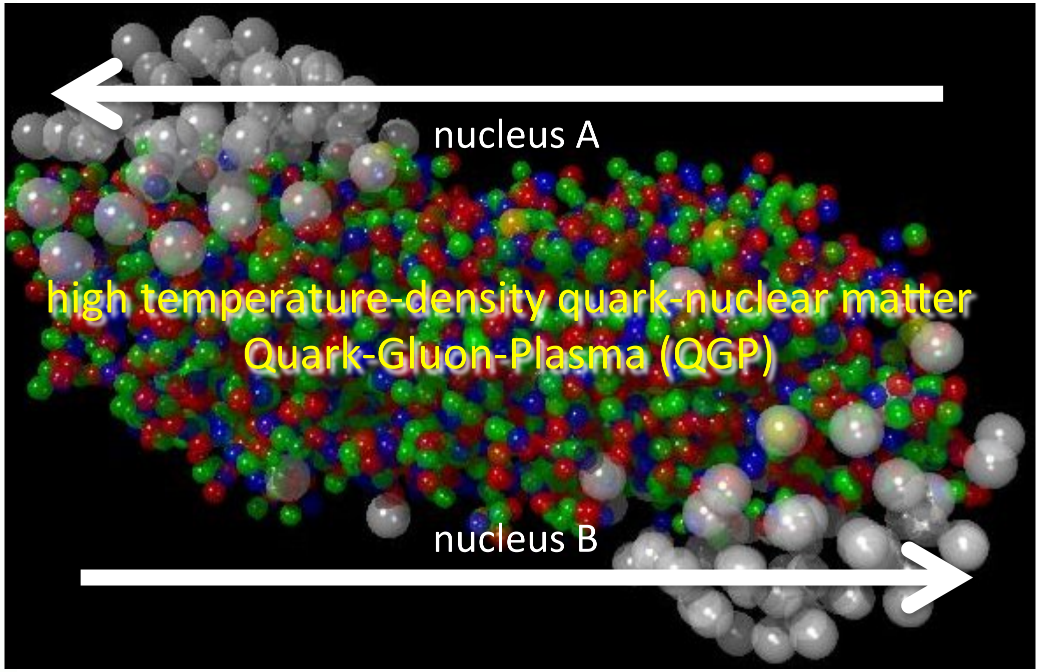






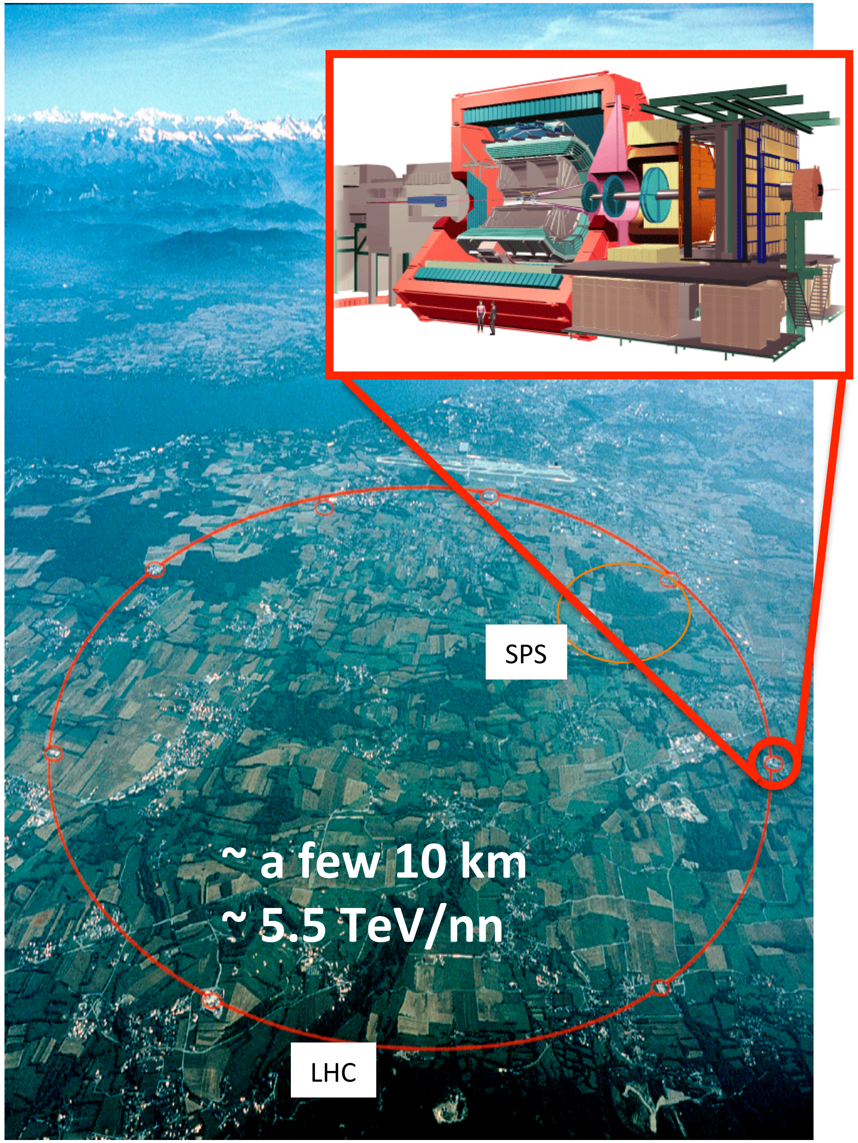


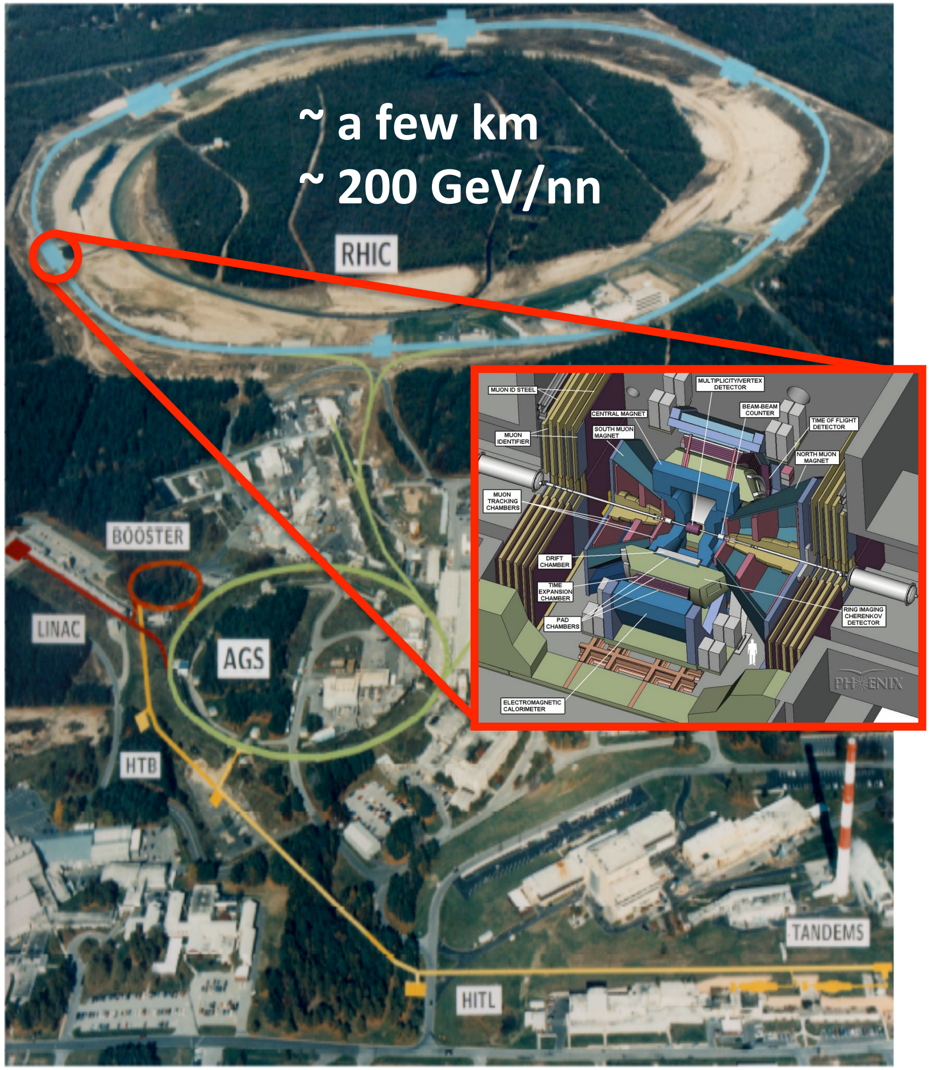
Nucleus-Nucleus collision simulation
nucleon-hadron cascade in uRQMD

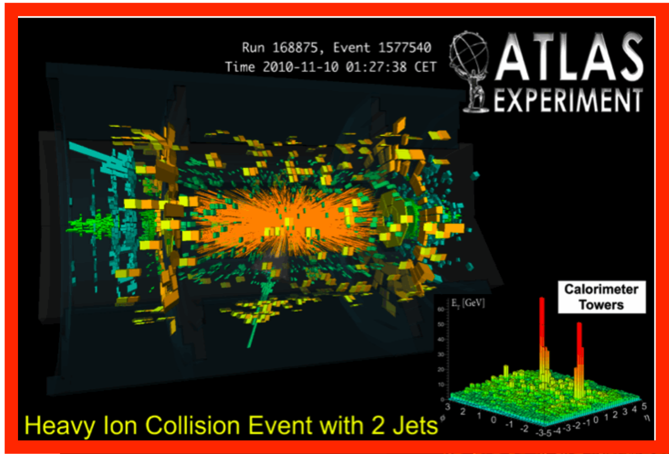


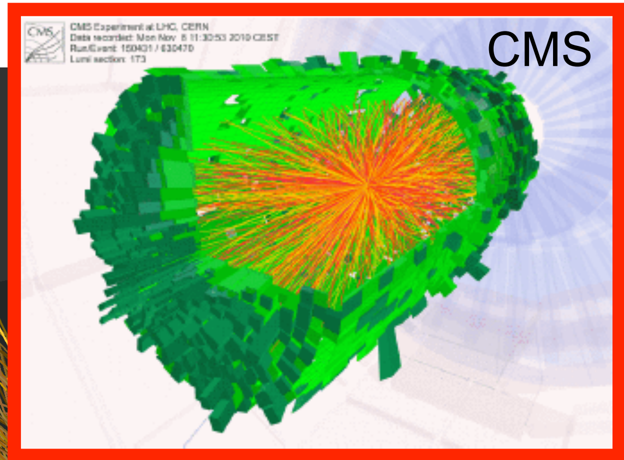
European Organization for Nuclear Study (CERN) at Large Hadron Collider (LHC) and ALICE experiment in Geneva, Switzerland

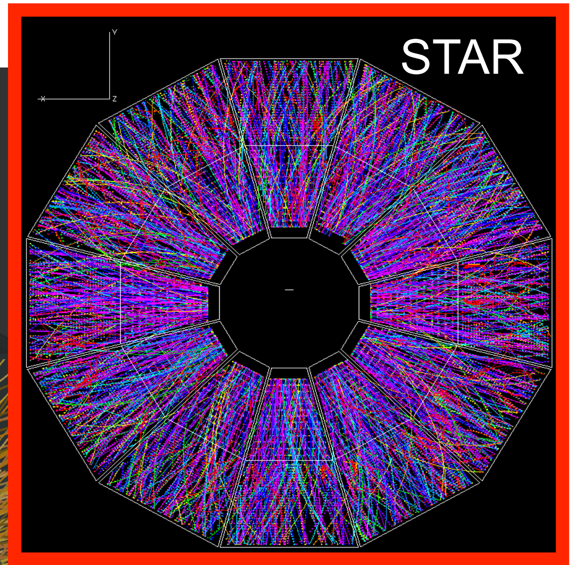
Brookhaven National Laboratory (BNL) at Relativistic Heavy-Ion Collider (RHIC) and PHENIX experiment in New York, USA





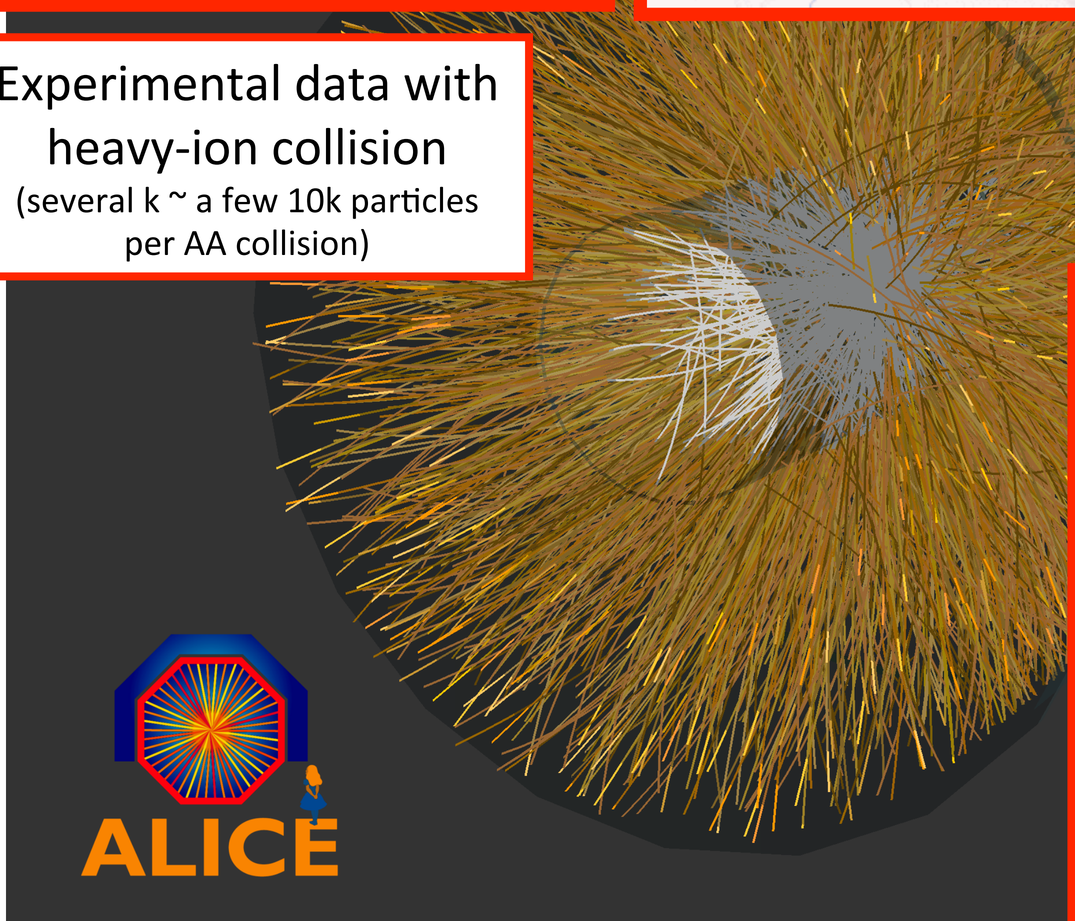


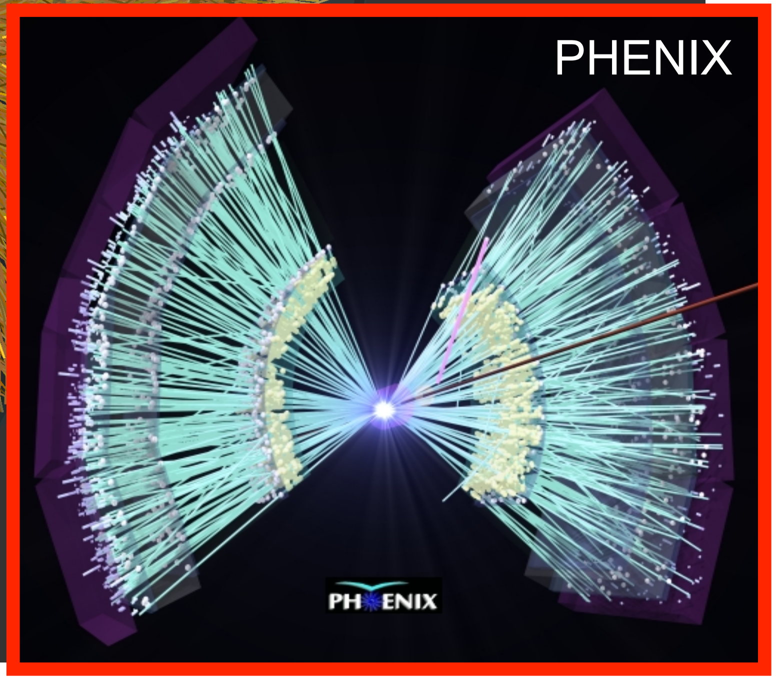




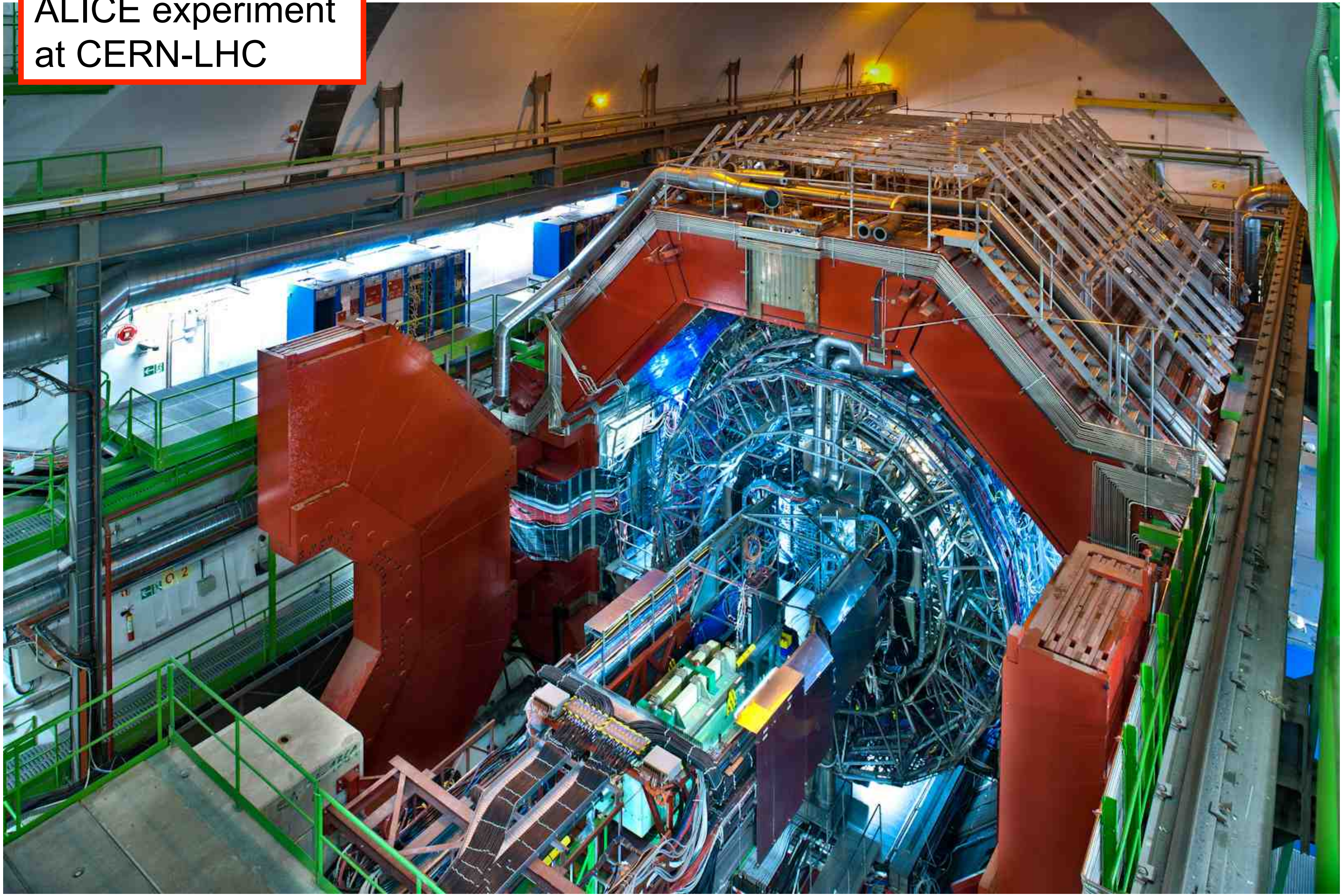
Experimental data with heavy-ion collision

(several k ~ a few 10k particles per AA collision)

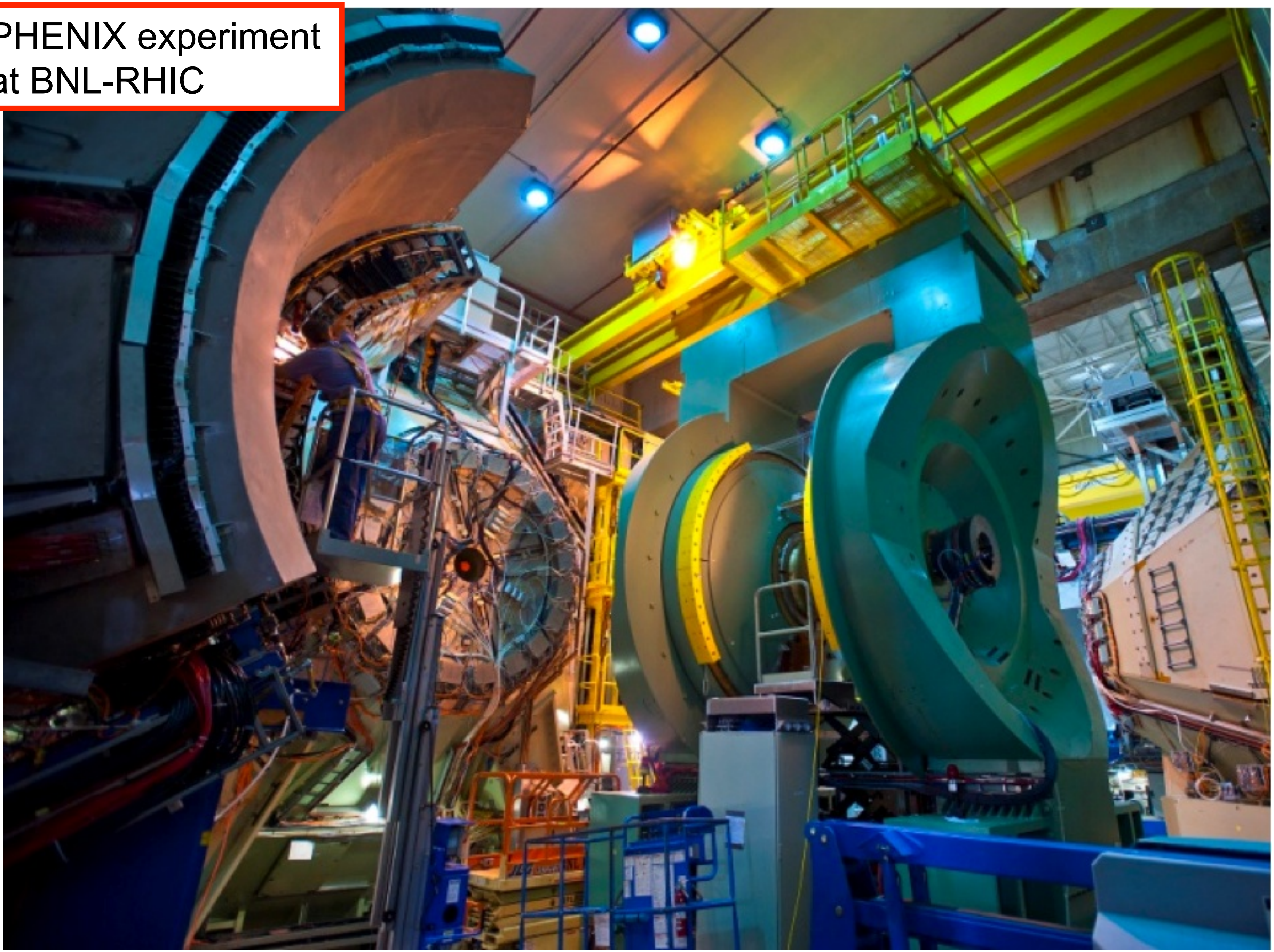




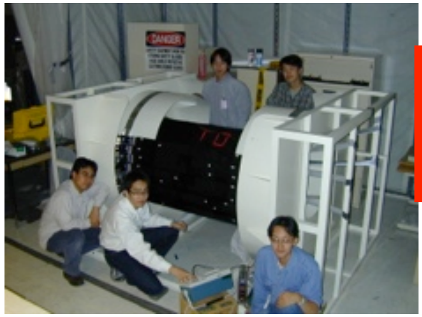
ALICE experiment at CERN-LHC

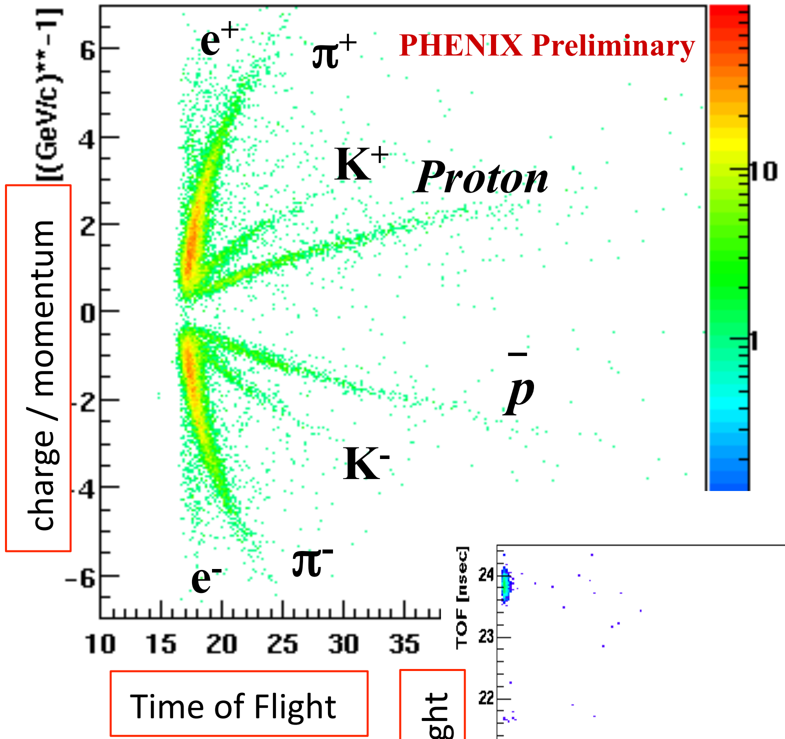


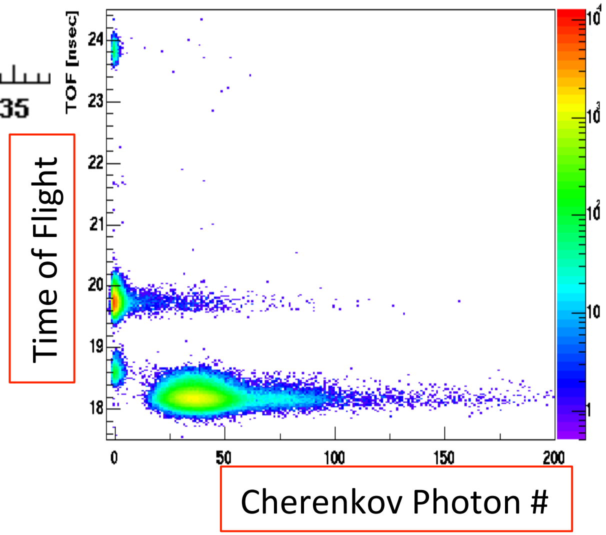
PHENIX experiment at BNL-RHIC

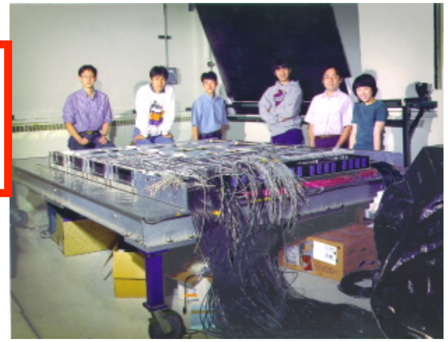


Time of Flight and Aerogel Cherenkov detector for particle identification (PHENIX)



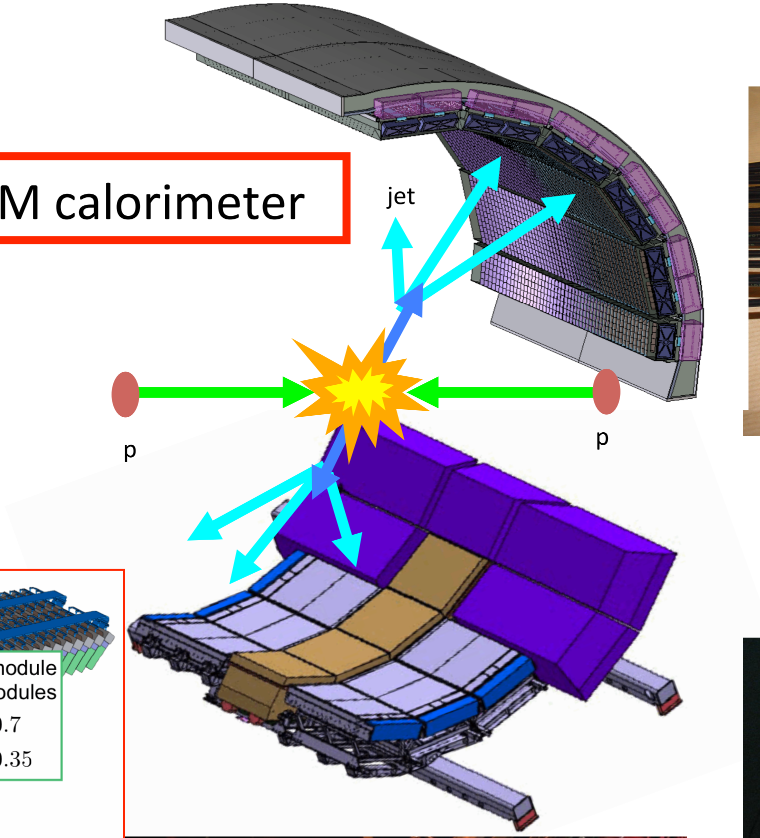


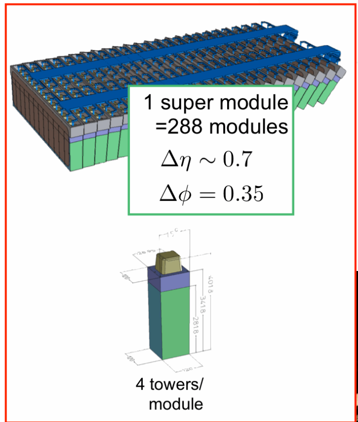




Di-jet EM calorimeter

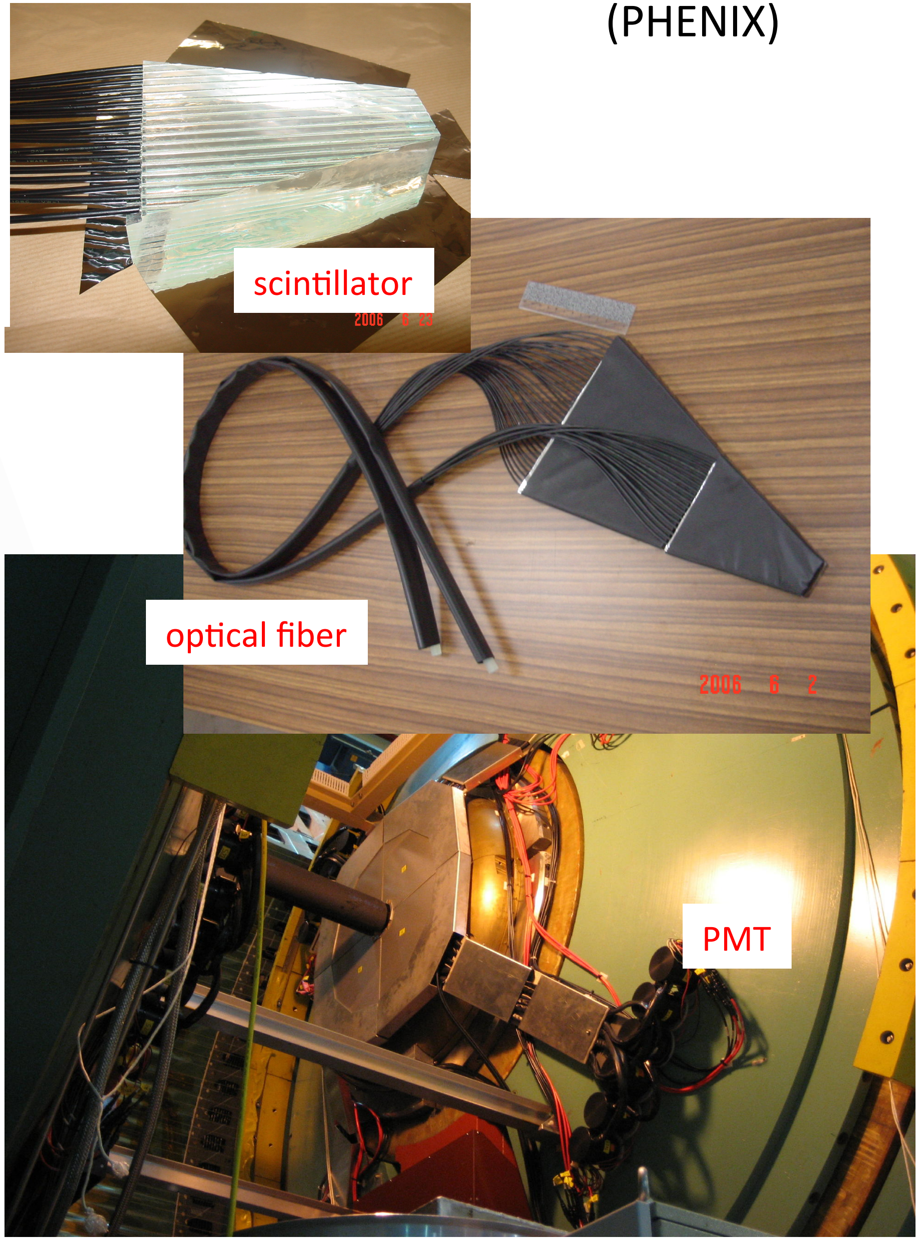
(ALICE)



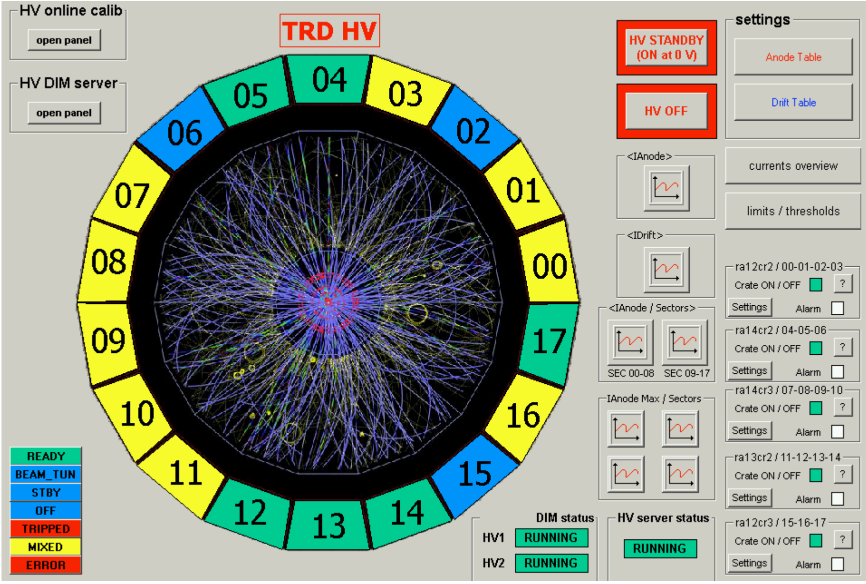


Reaction Plane Detector

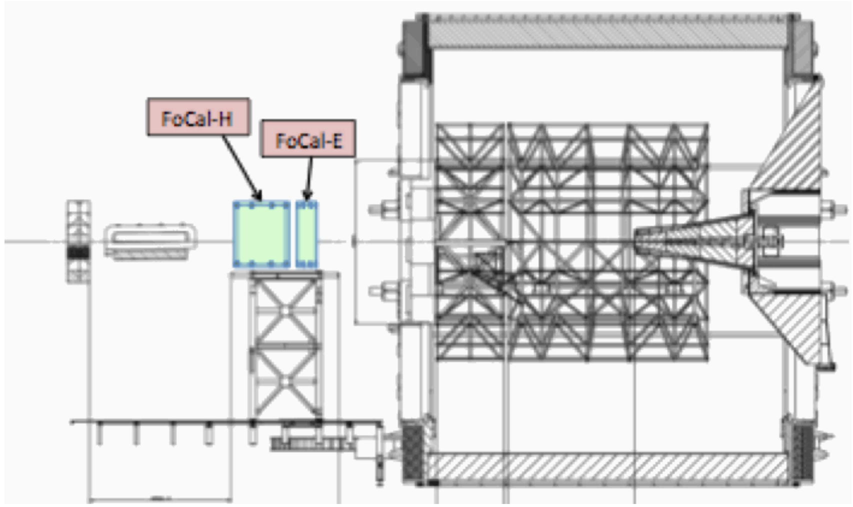
(PHENIX)



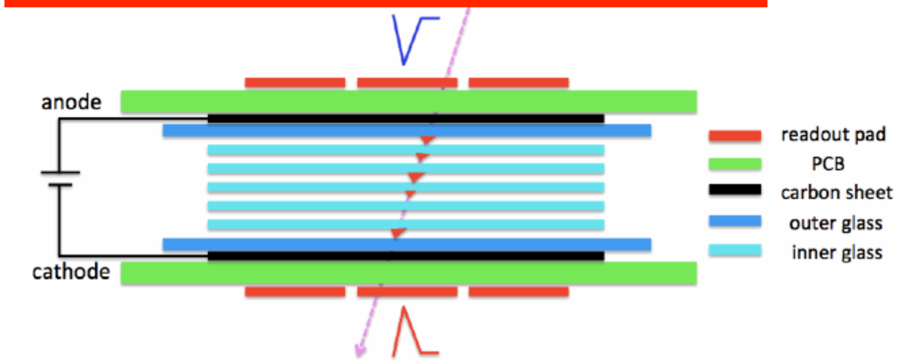
TRD detector control system
for ALICE experiment

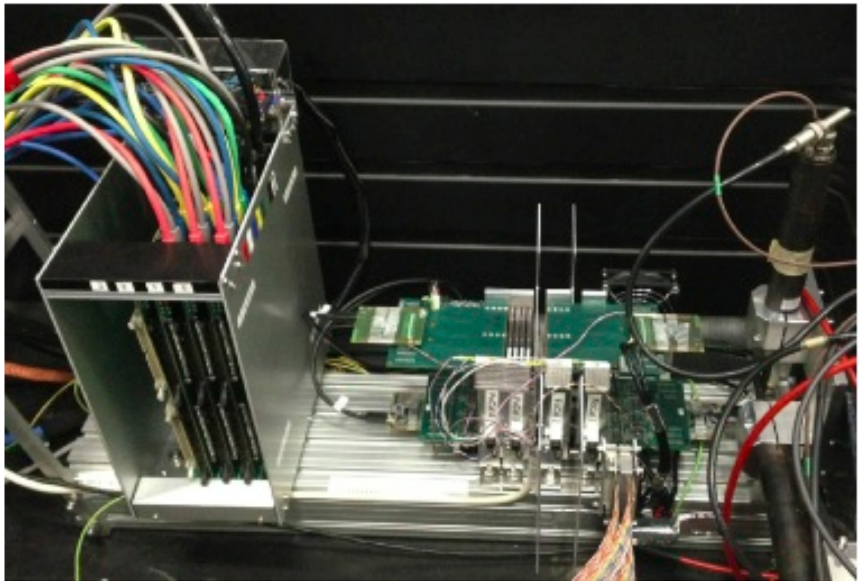


Forward calorimeter upgrade
for ALICE experiment

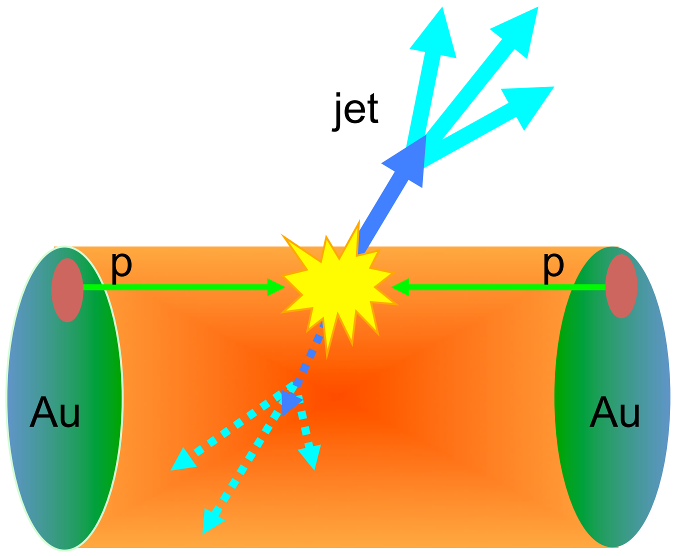


MRPC (and MPPC, ...) TOF R&D
for future experiments

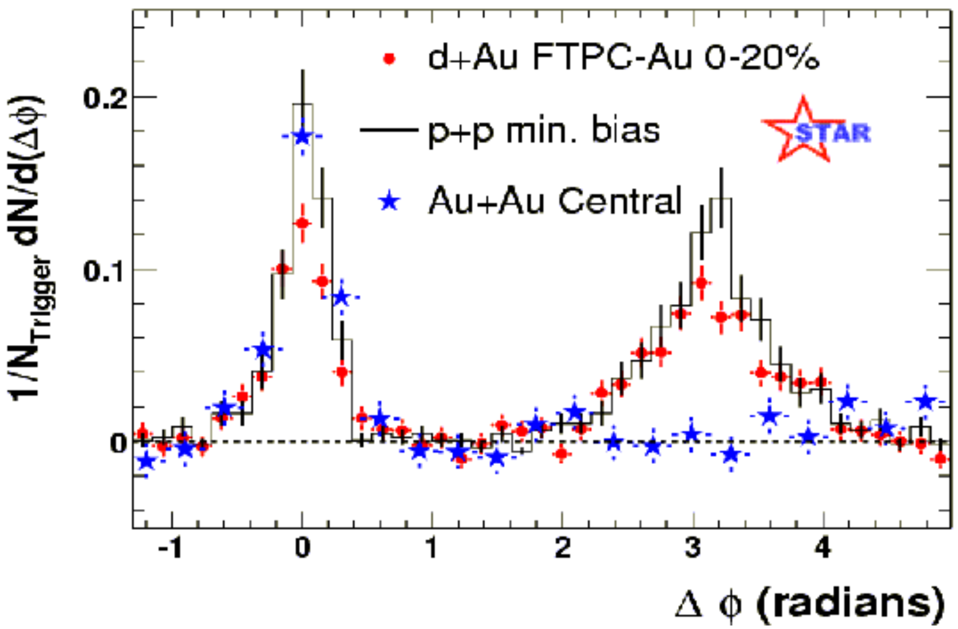


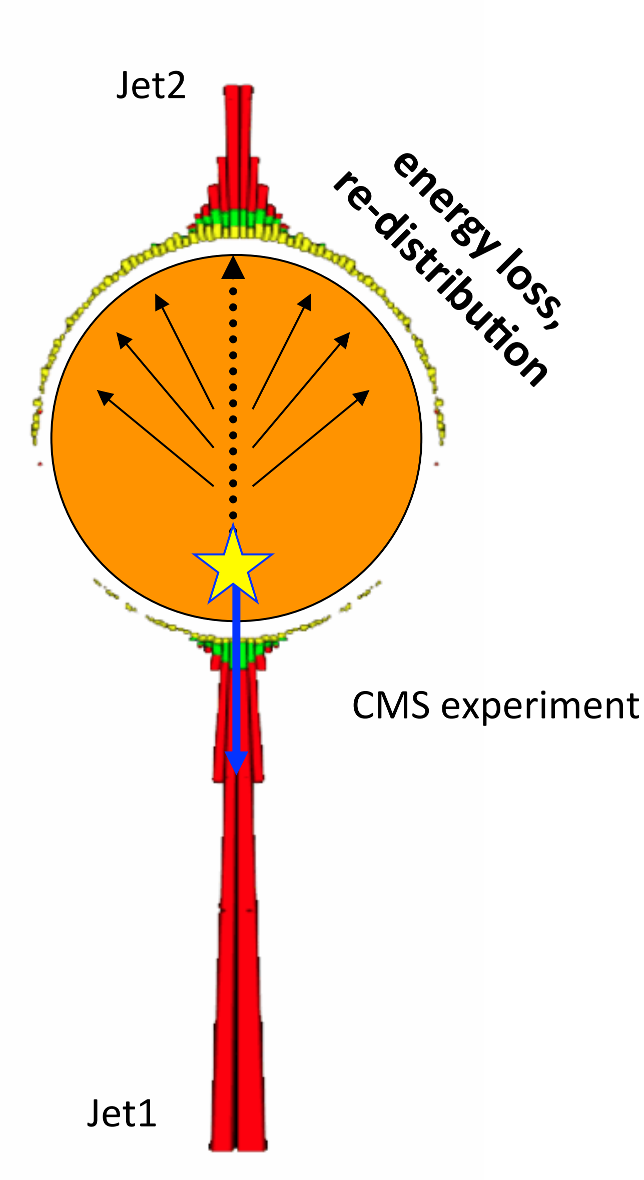


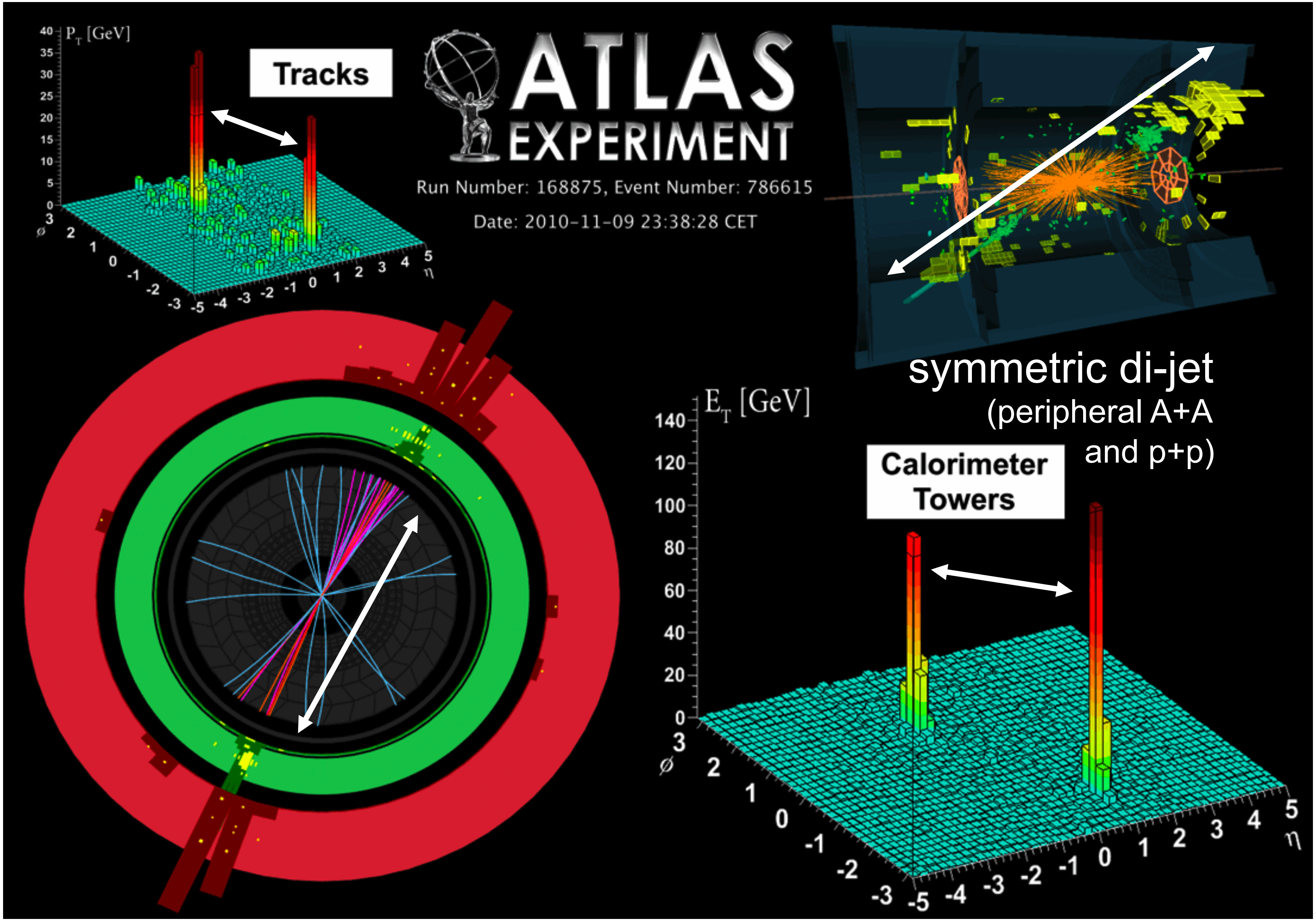
Energy loss of quark inside QGP



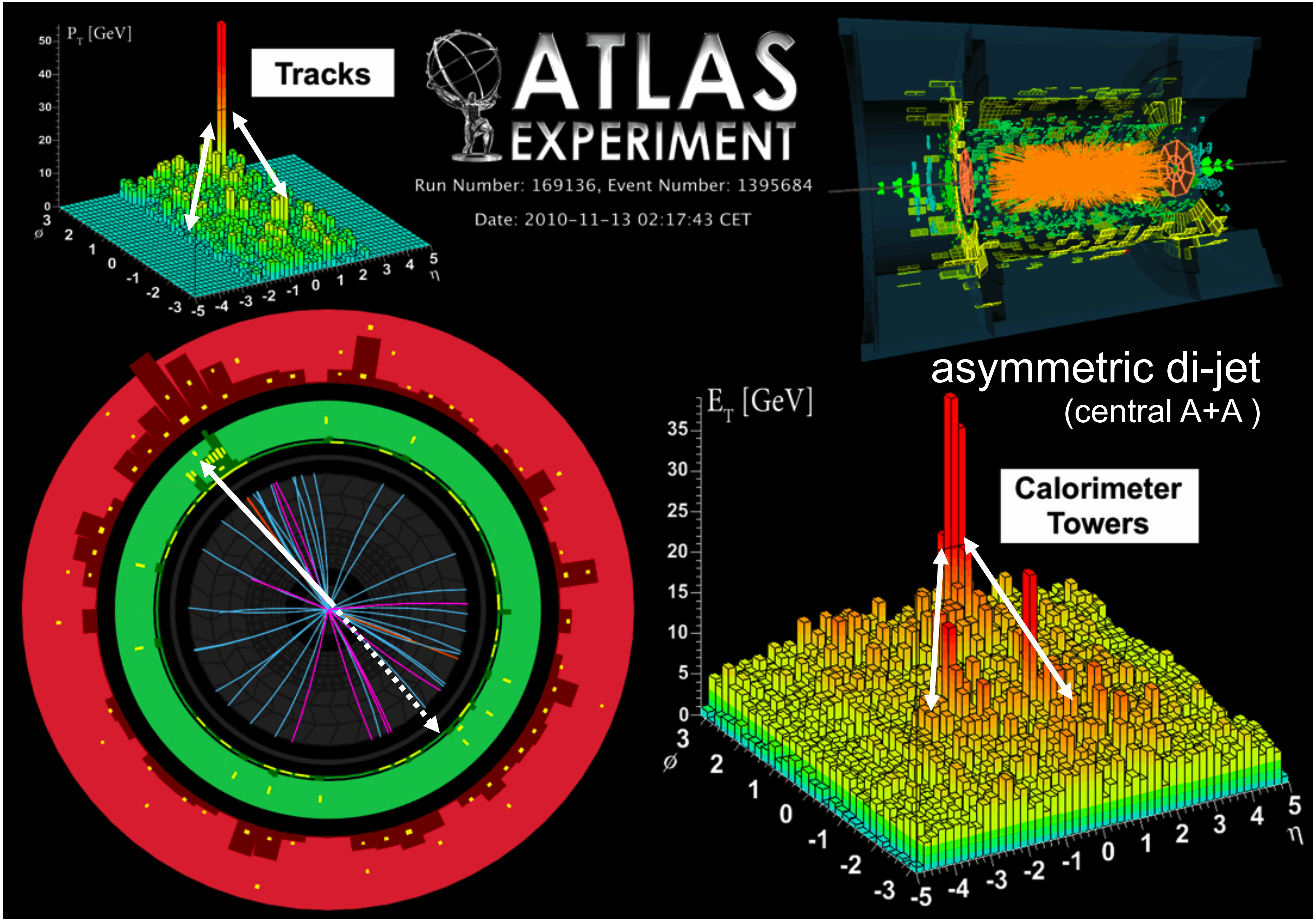
Phys. Rev. Lett. 91, 072304 (2003)







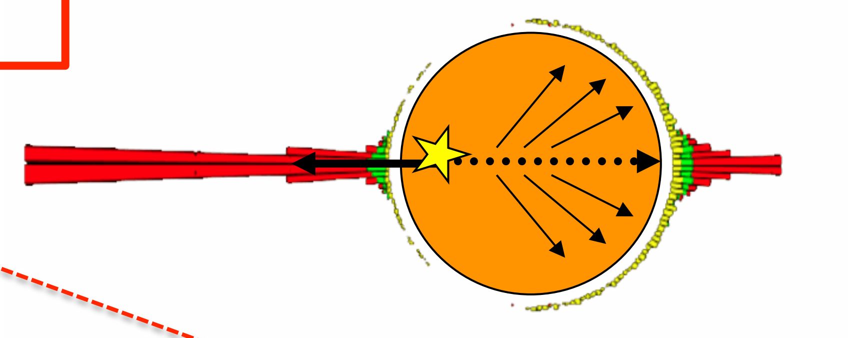
Tracks
ATLAS EXPERIMENT
Run Number: 168875, Event Number: 786615
Date: 2010-11-09 23:38:28 CET
symmetric di-jet
(peripheral A+A
and p+p)
Calorimeter
Towers



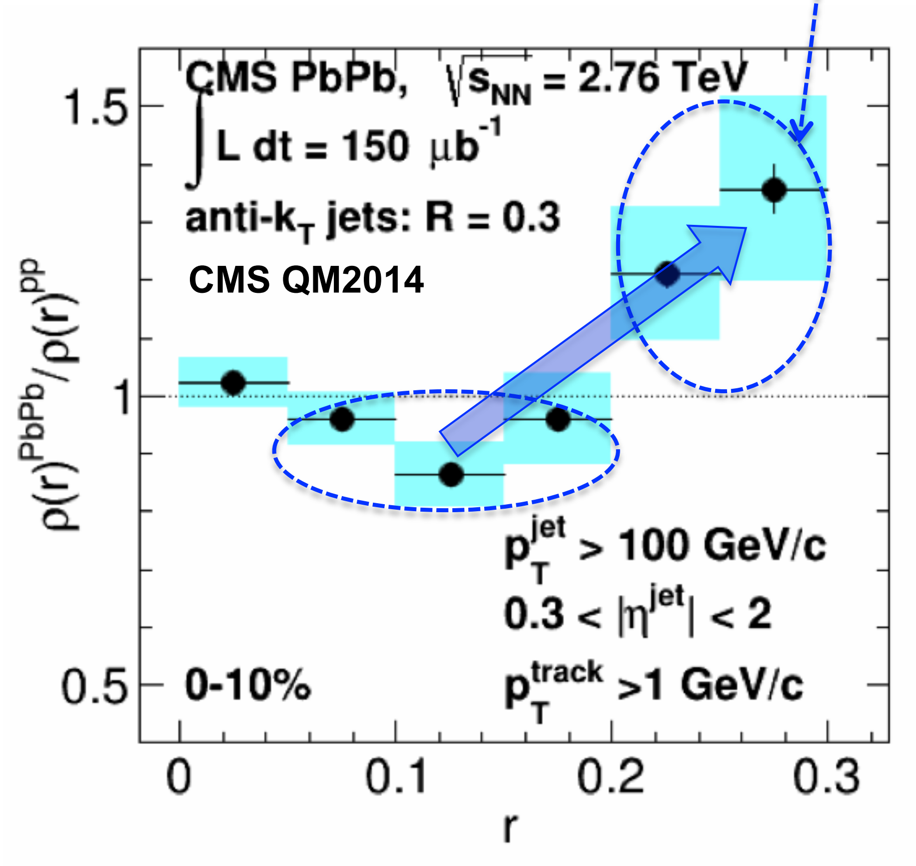
Tracks
P_T [GeV]
ATLAS EXPERIMENT
Run Number: 169136, Event Number: 1395684
Date: 2010-11-13 02:17:43 CET
asymmetric di-jet
(central A+A)
Calorimeter Towers
E_T [GeV]
φ
η

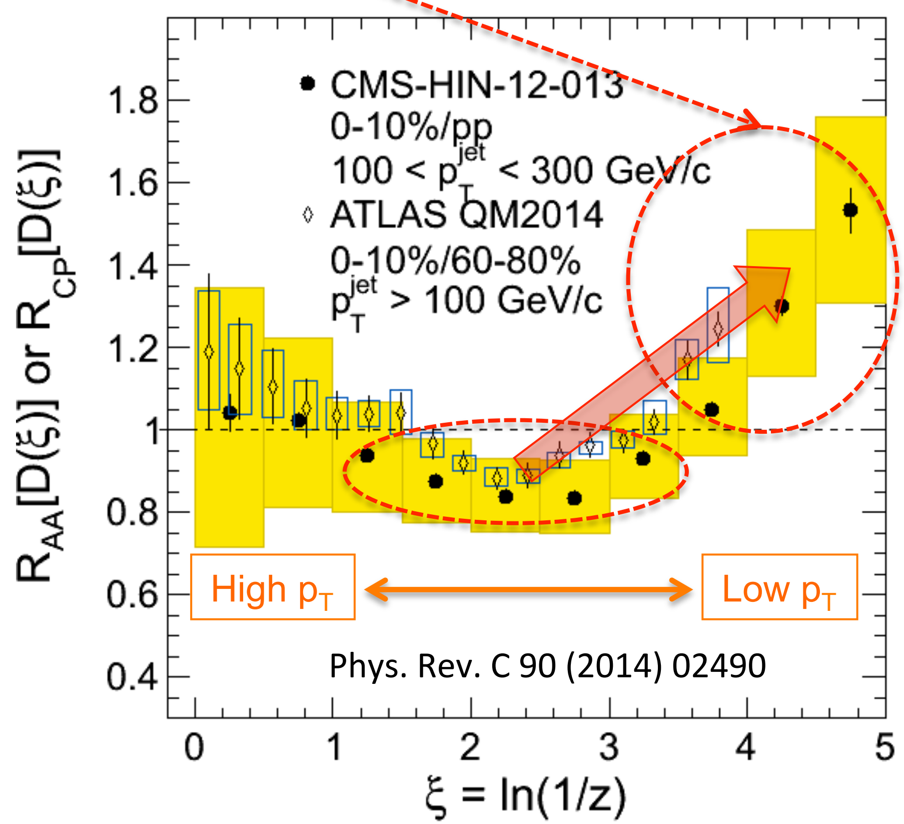
Modification of fragmentation function within a jet

Jets in ALICE, Oliver-san's talk



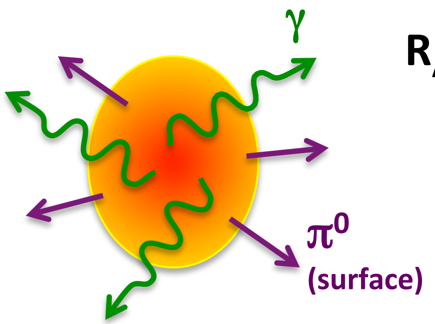
- redistribution to low p_T
- redistribution to wide angle



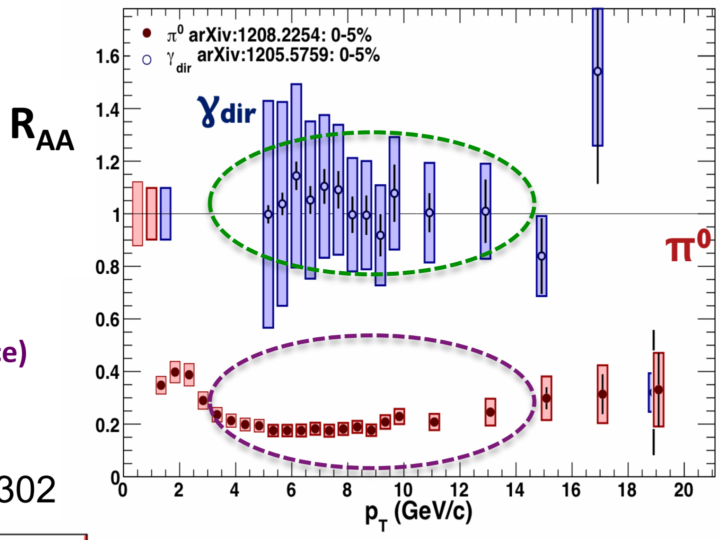


High p_T direct photon as penetrating probe

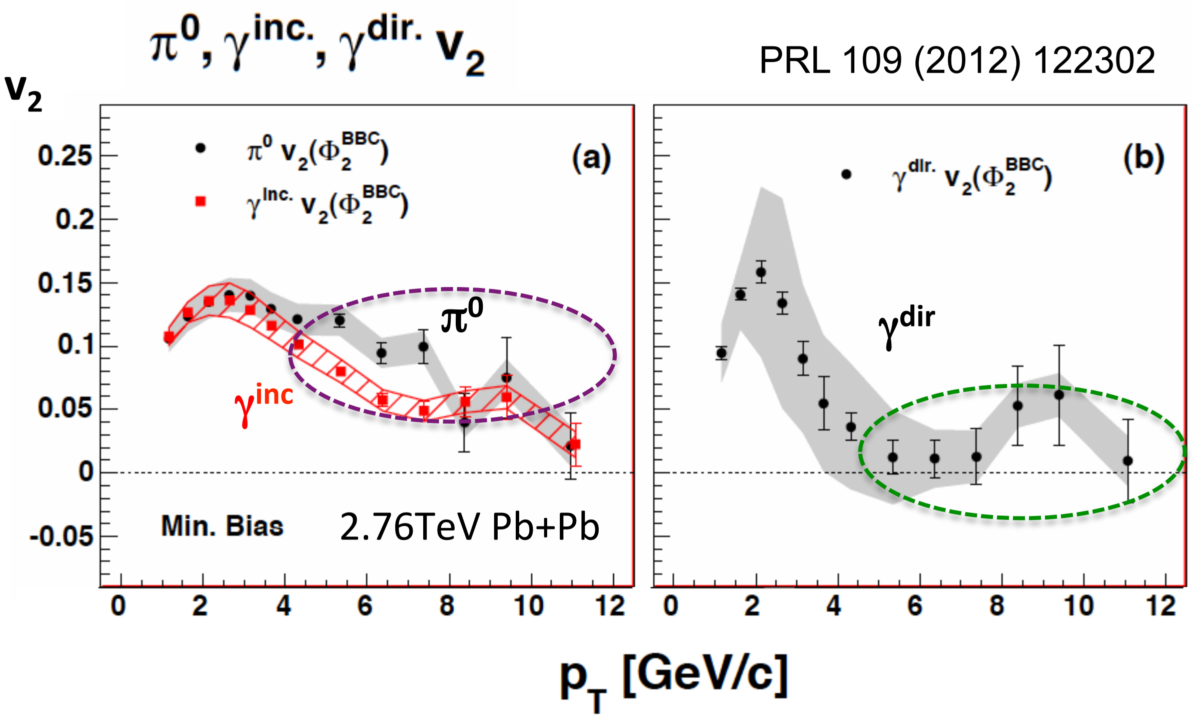
$p_T > 5$ GeV/c	hadron	γ^{dir}
R_{AA}	< 1	~ 1
v_2	> 0	~ 0



PRL 109 (2012) 152302



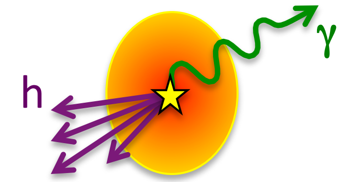
PRL 109 (2012) 122302

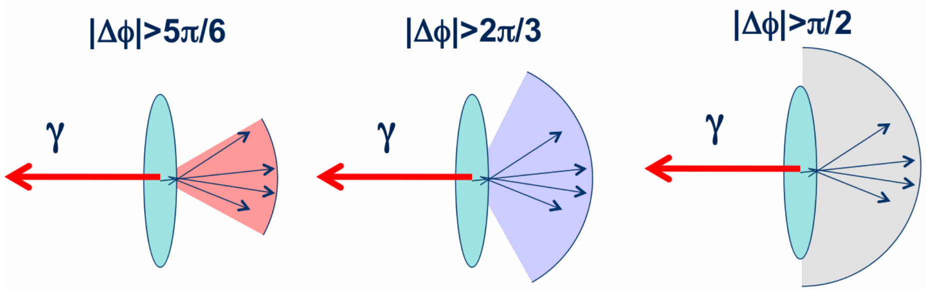


$$R_{AA} = \frac{N\,(A+A)}{N_{coll}\;N(p+p)}$$

relative yield with respect to a simple independent superposition of pp data

Energy loss at high p_T and re-distribution of the lost-energy at low p_T at RHIC



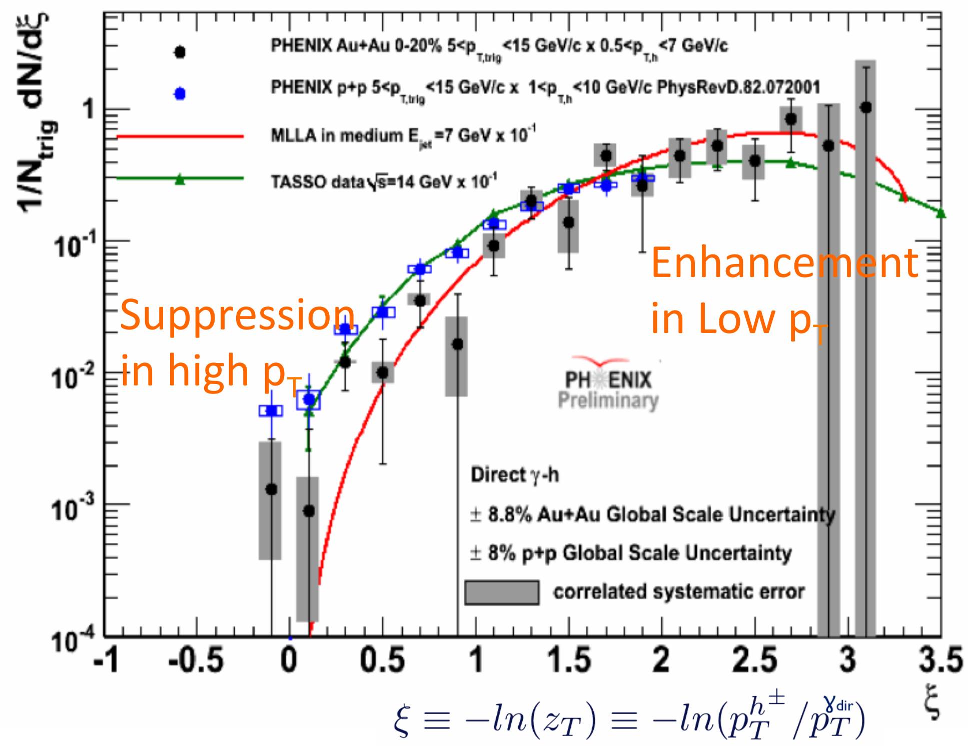


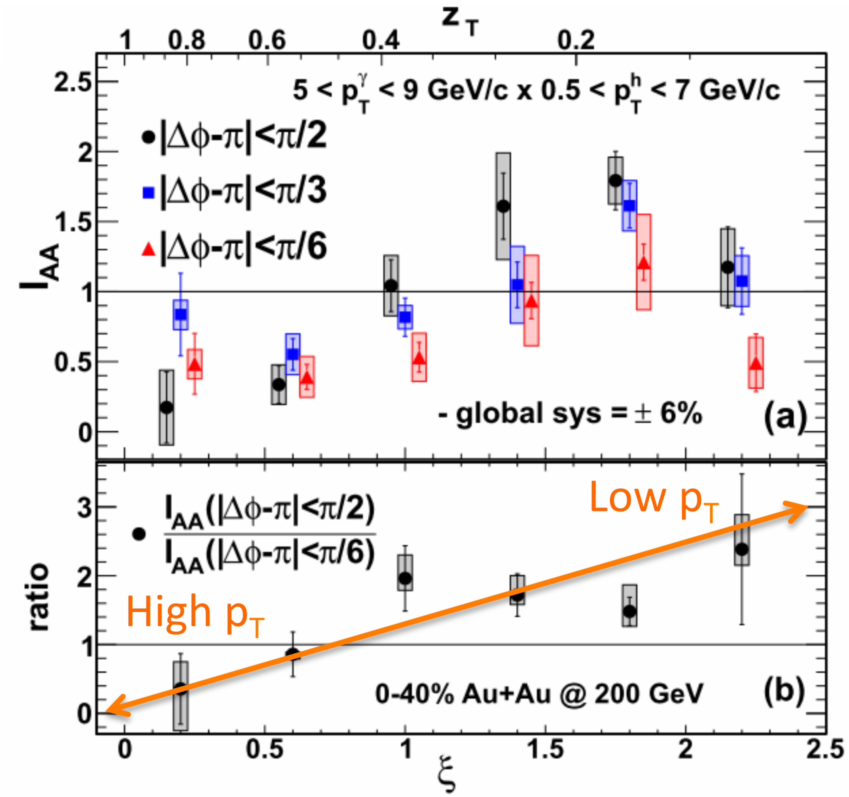
prompt photon - hadron correlation

N_{PTY} = associate hadron yield per trigger γ

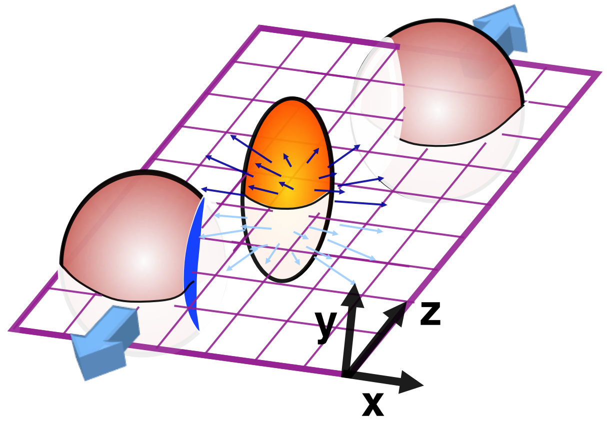
$I_{AA} = N_{PTY}(AA) / N_{PTY}(pp)$

PRL 111 (2013) 032301

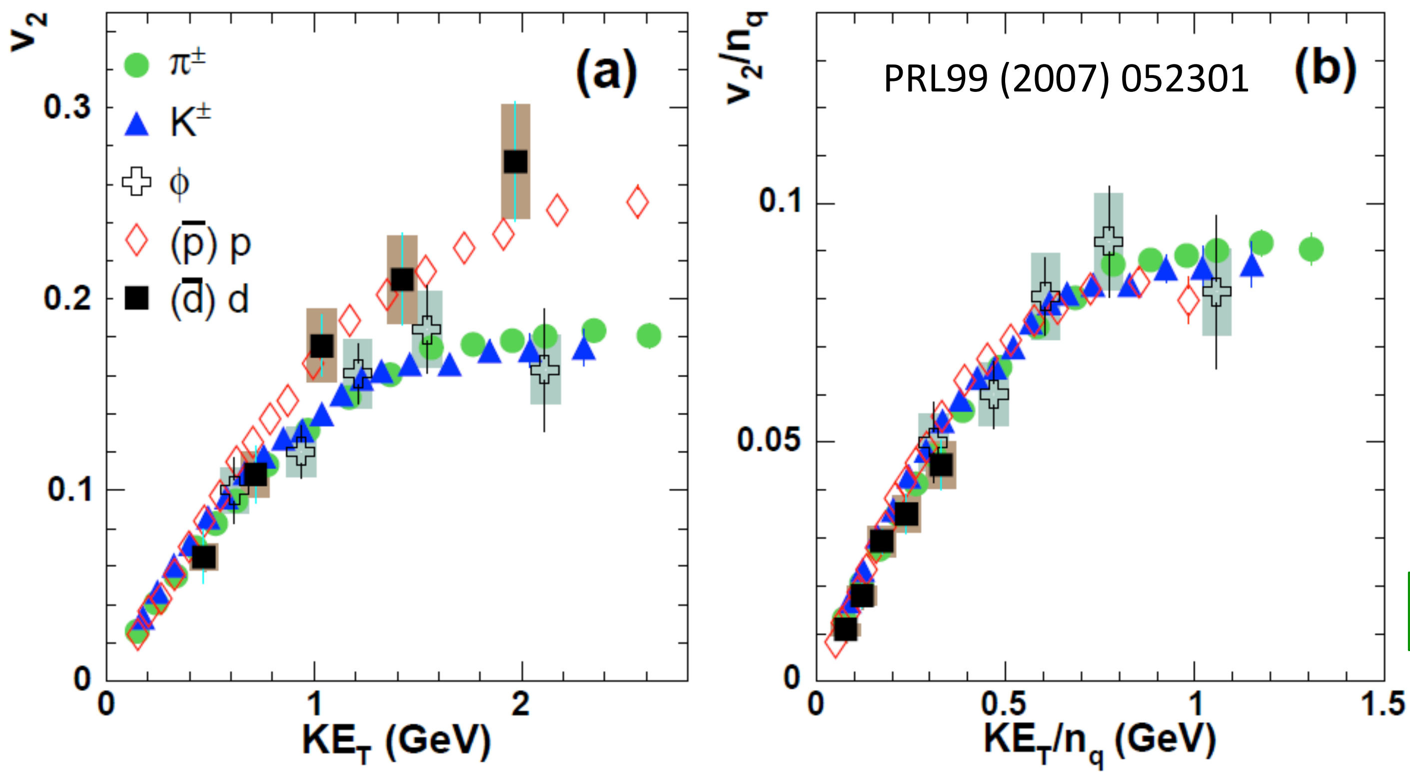


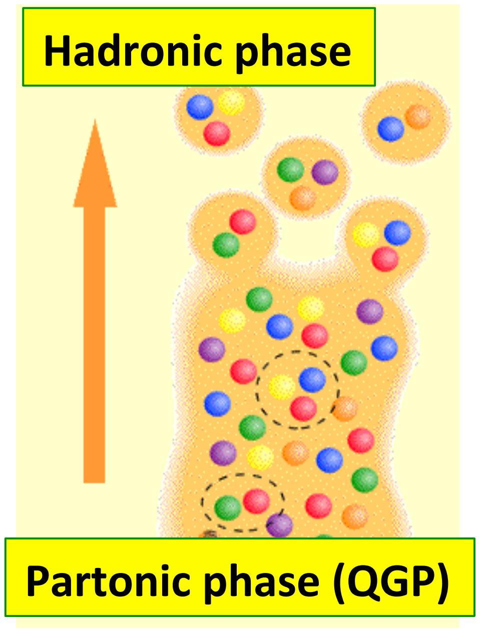


Number of quark scaling in elliptic flow
--- quark coalescence feature ---



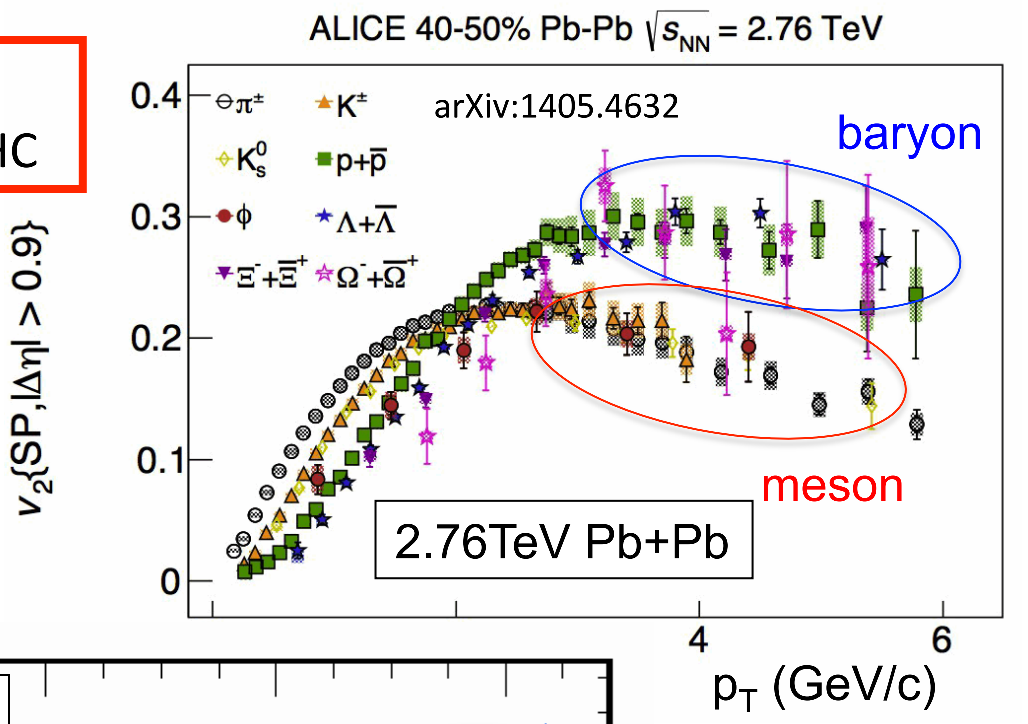
Indication of quark flow (in partonic phase)

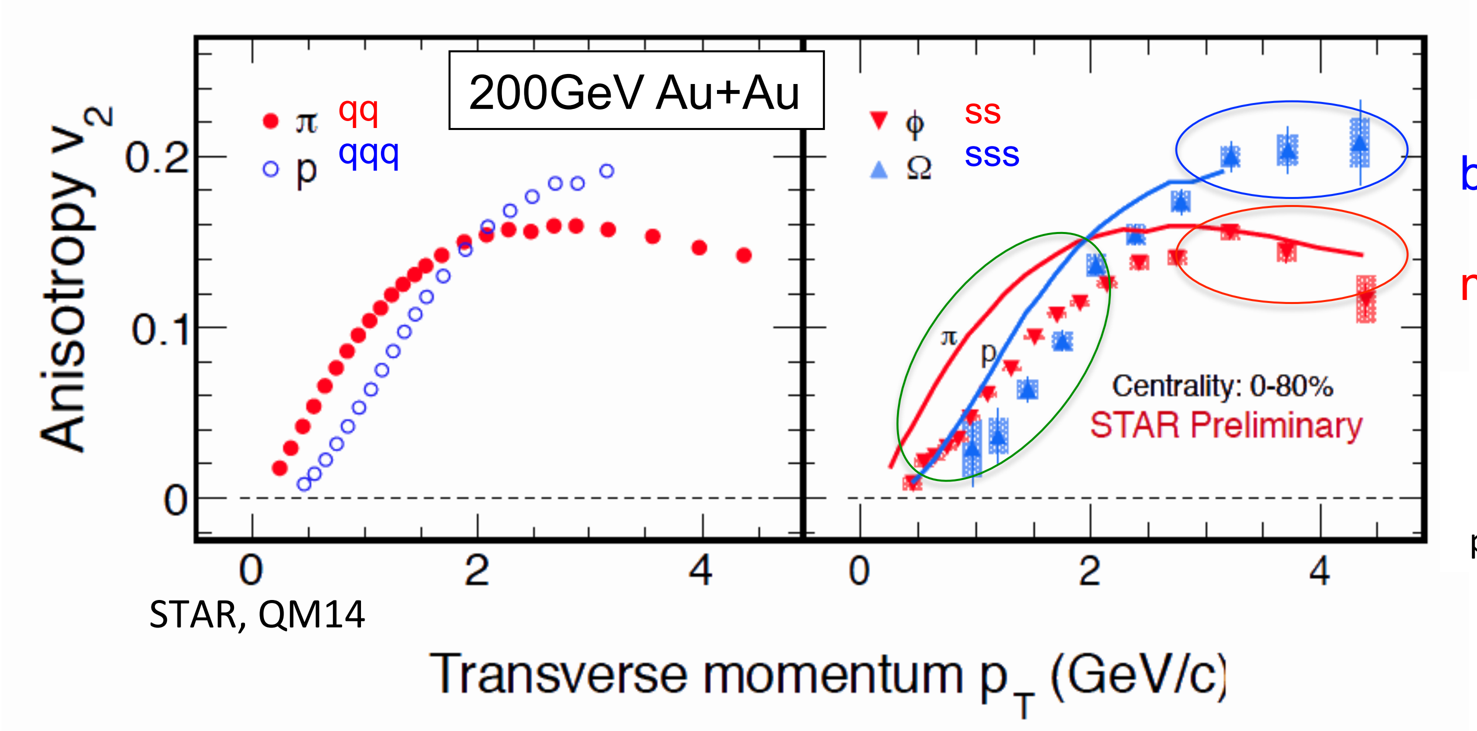




“state-of-art” measurements of Elliptic flow with PID at RHIC and LHC

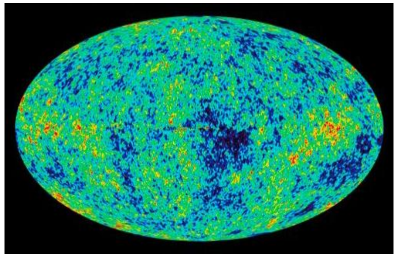
- High statistics measurements allow a precise comparison of $v_2(p)$ and $v_2(\phi)$.
- Some small deviation from hydro-like mass dependence of v_2 at low p_T

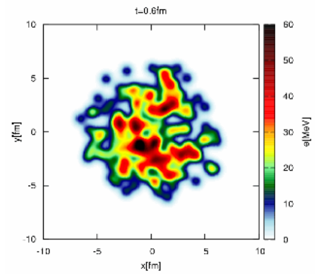


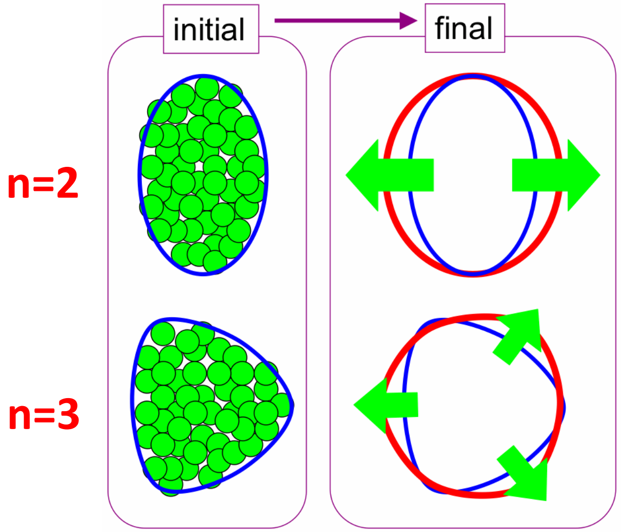


Number of quark scaling as a signal of partonic phase

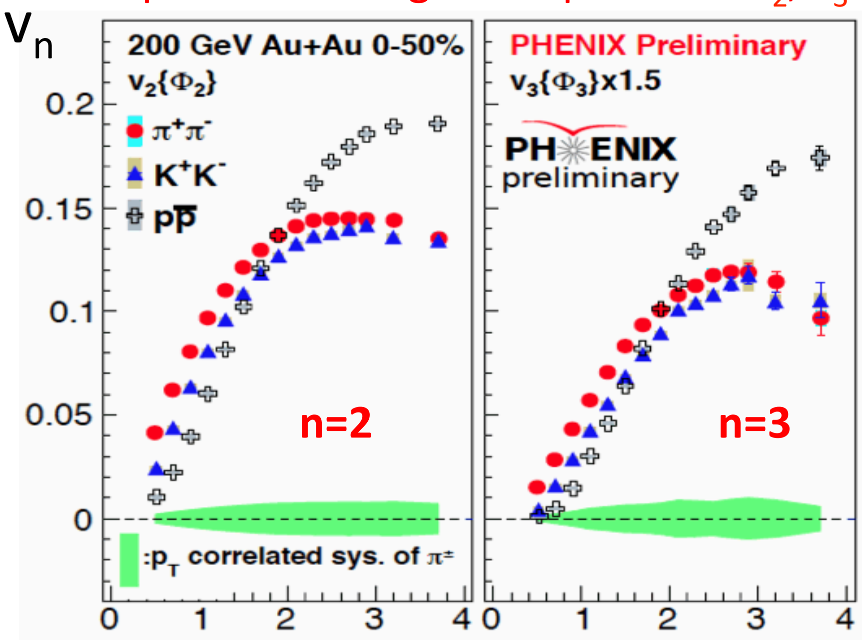
Elliptic and triangular expansion and freeze-out geometry







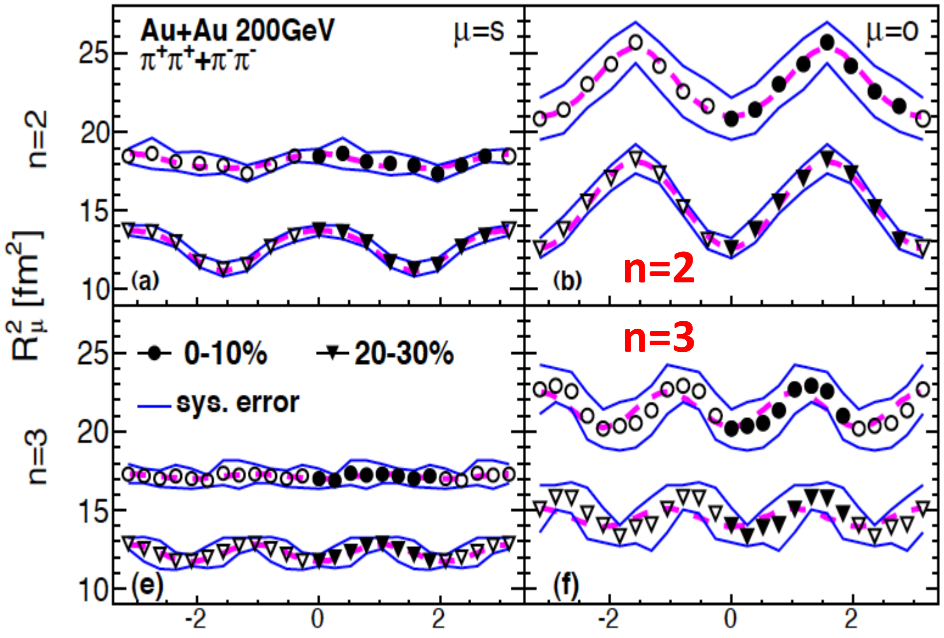
Elliptic and Triangular expansion : v_2, v_3



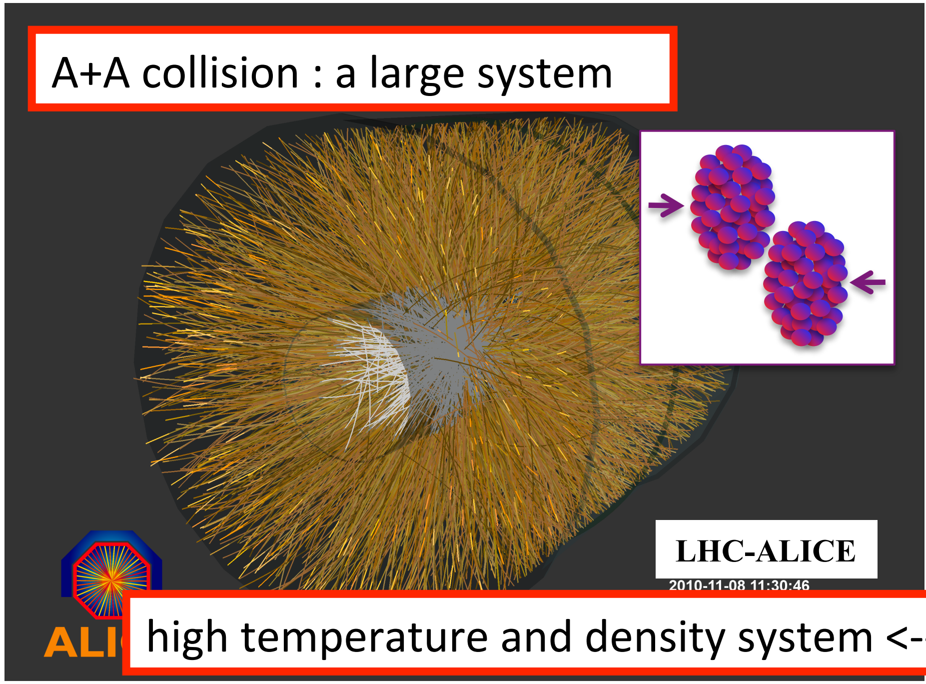
arXiv:1412.1038

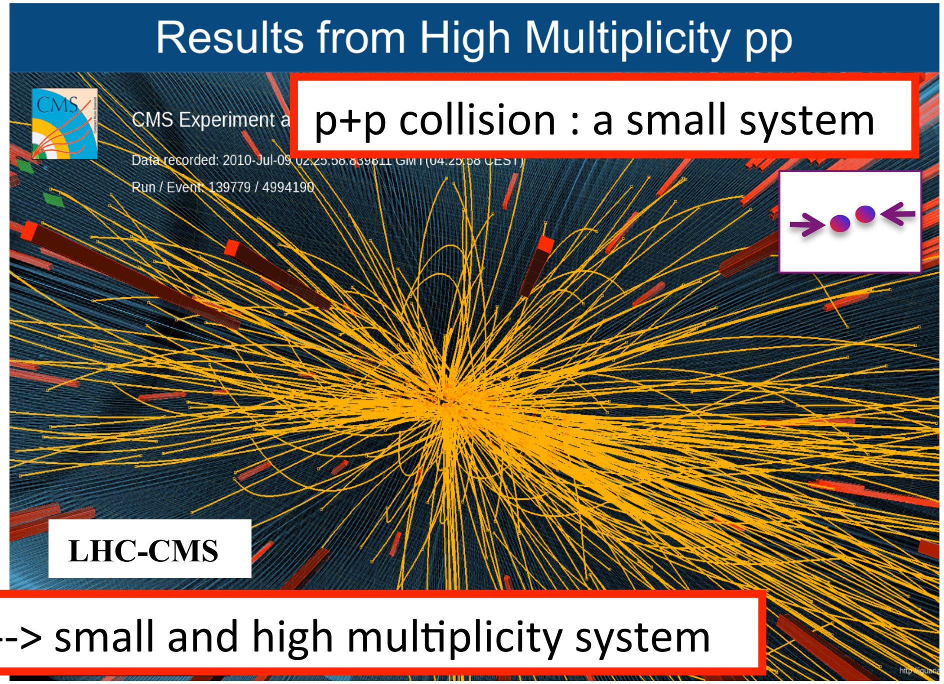
p_T [GeV/c]

Elliptic and Triangular shape : $R^{HBT}_{\Phi2}$, $R^{HBT}_{\Phi3}$

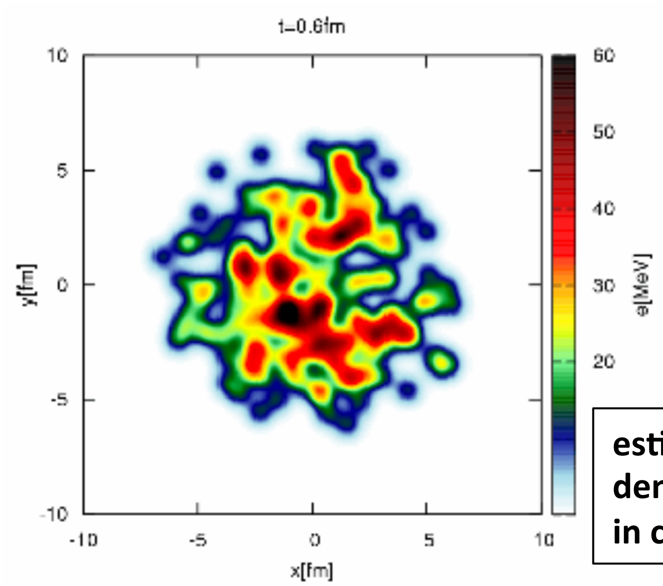


PRL112 (2014) 222301



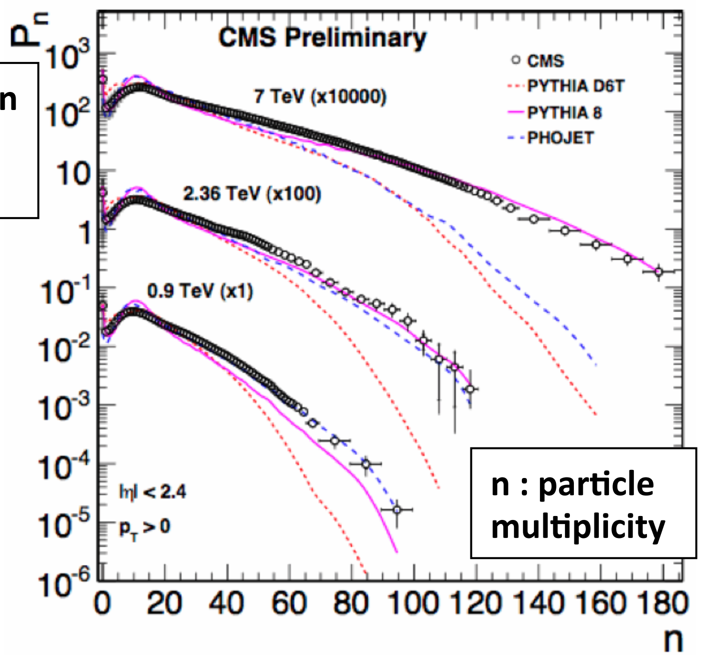


high temperature and density system <---> small and high multiplicity system



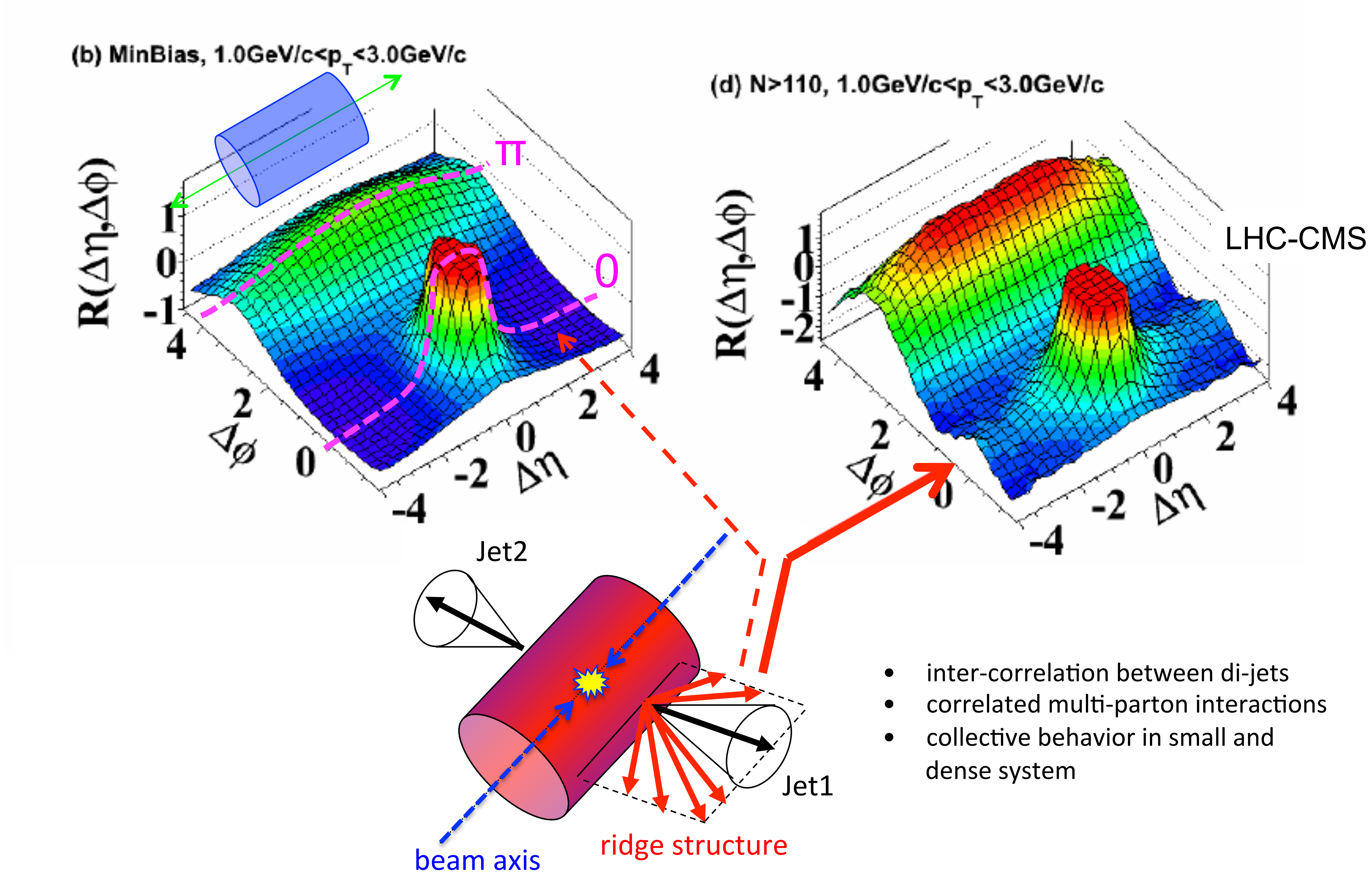
estimated initial energy density distribution in central A+A collision

Probability distribution of event with "n" particles production



n : particle multiplicity

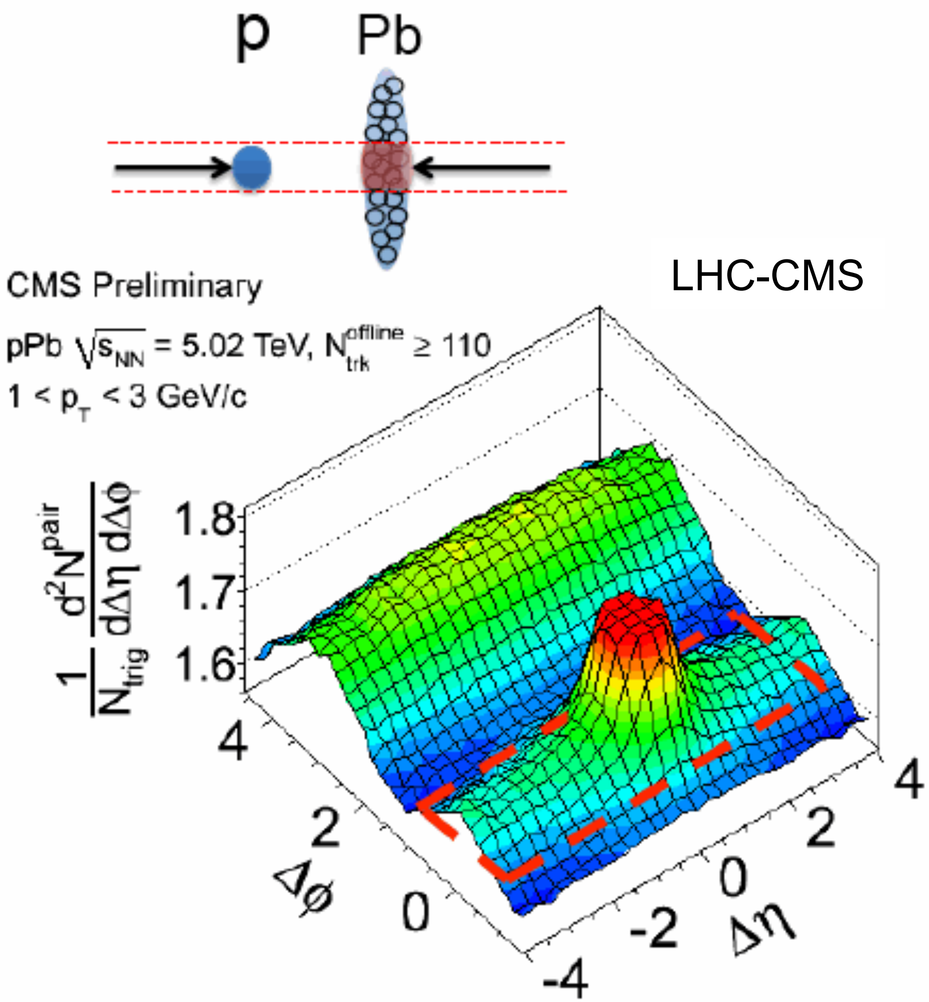
minimum bias p+p events ↔ high multiplicity p+p events

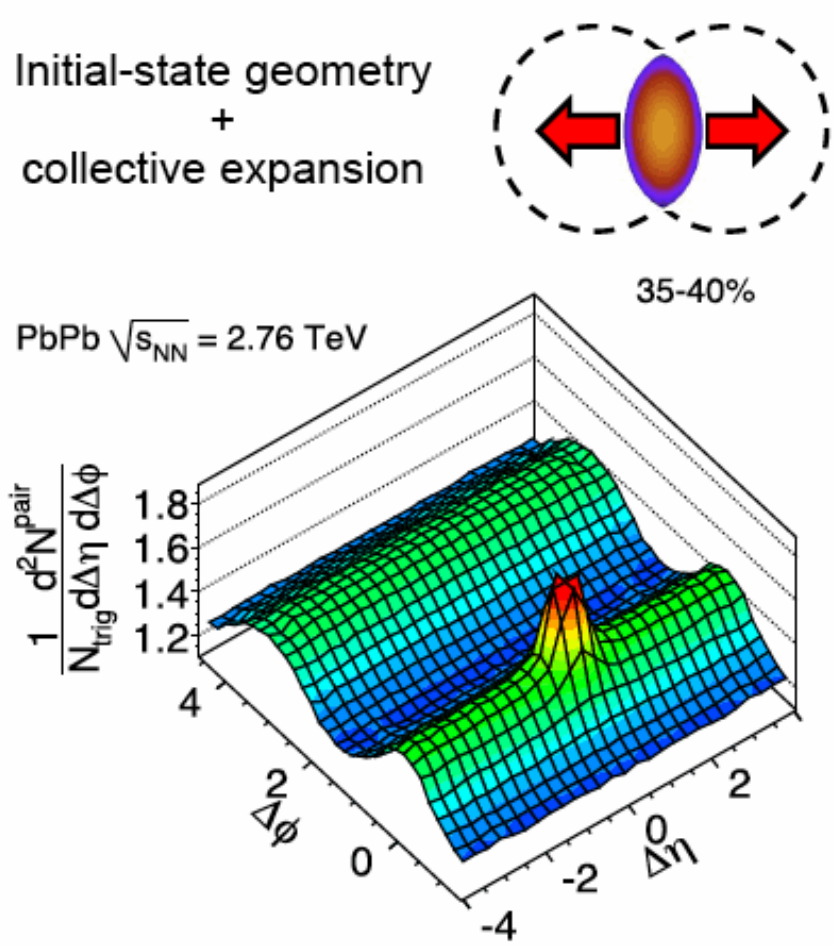


- inter-correlation between di-jets
- correlated multi-parton interactions
- collective behavior in small and dense system

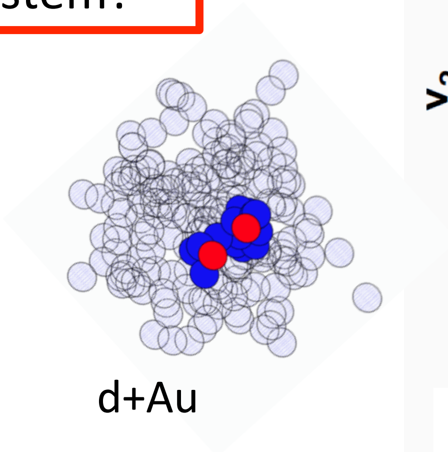
p+A collisions

A+A collisions

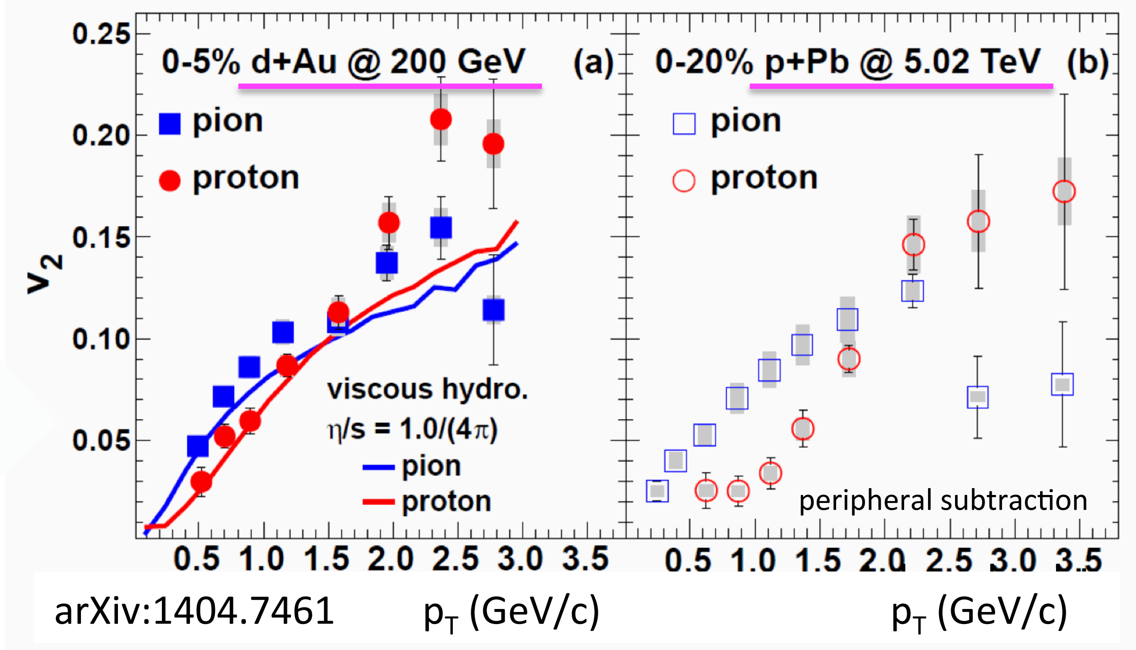




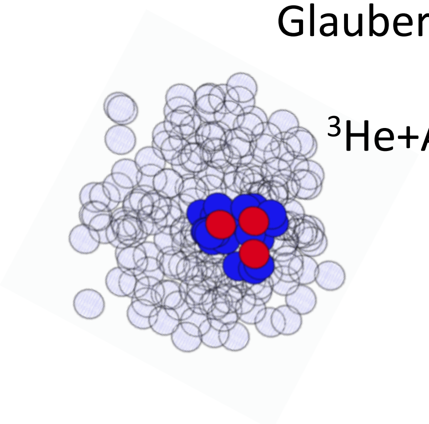
Elliptic flow
in small system?



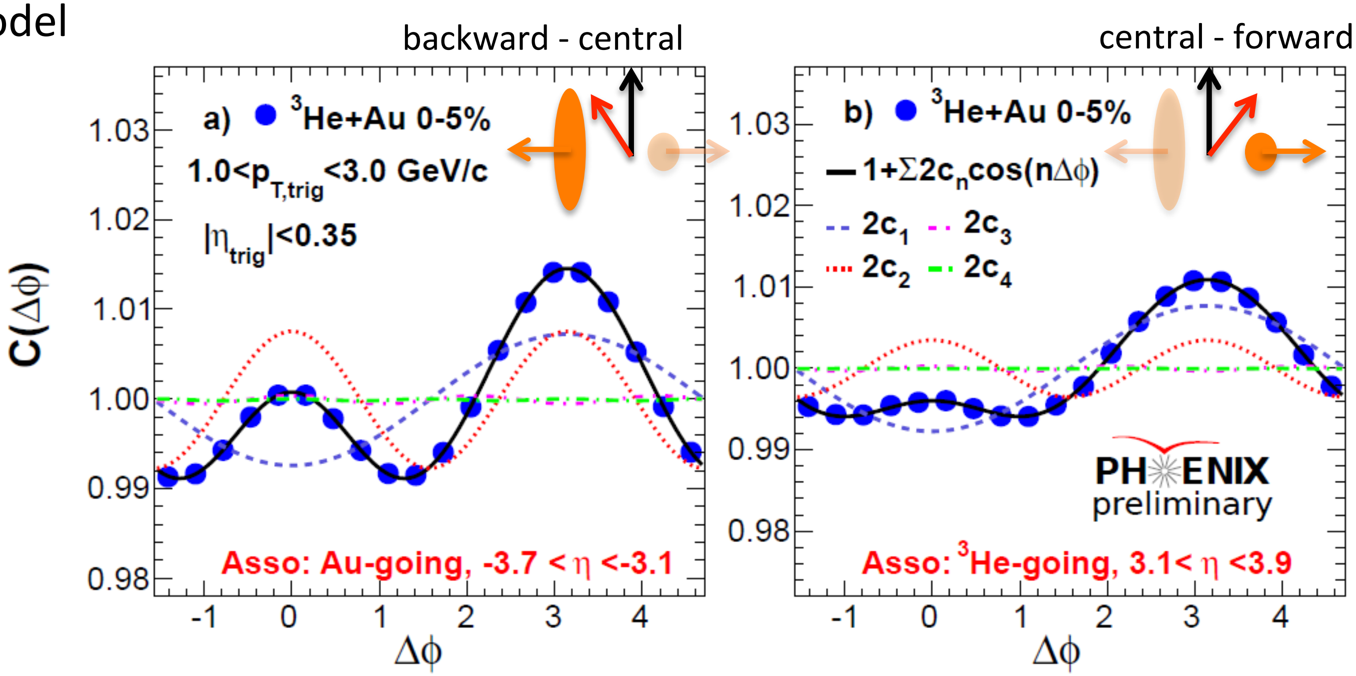
d+Au



Glauber model



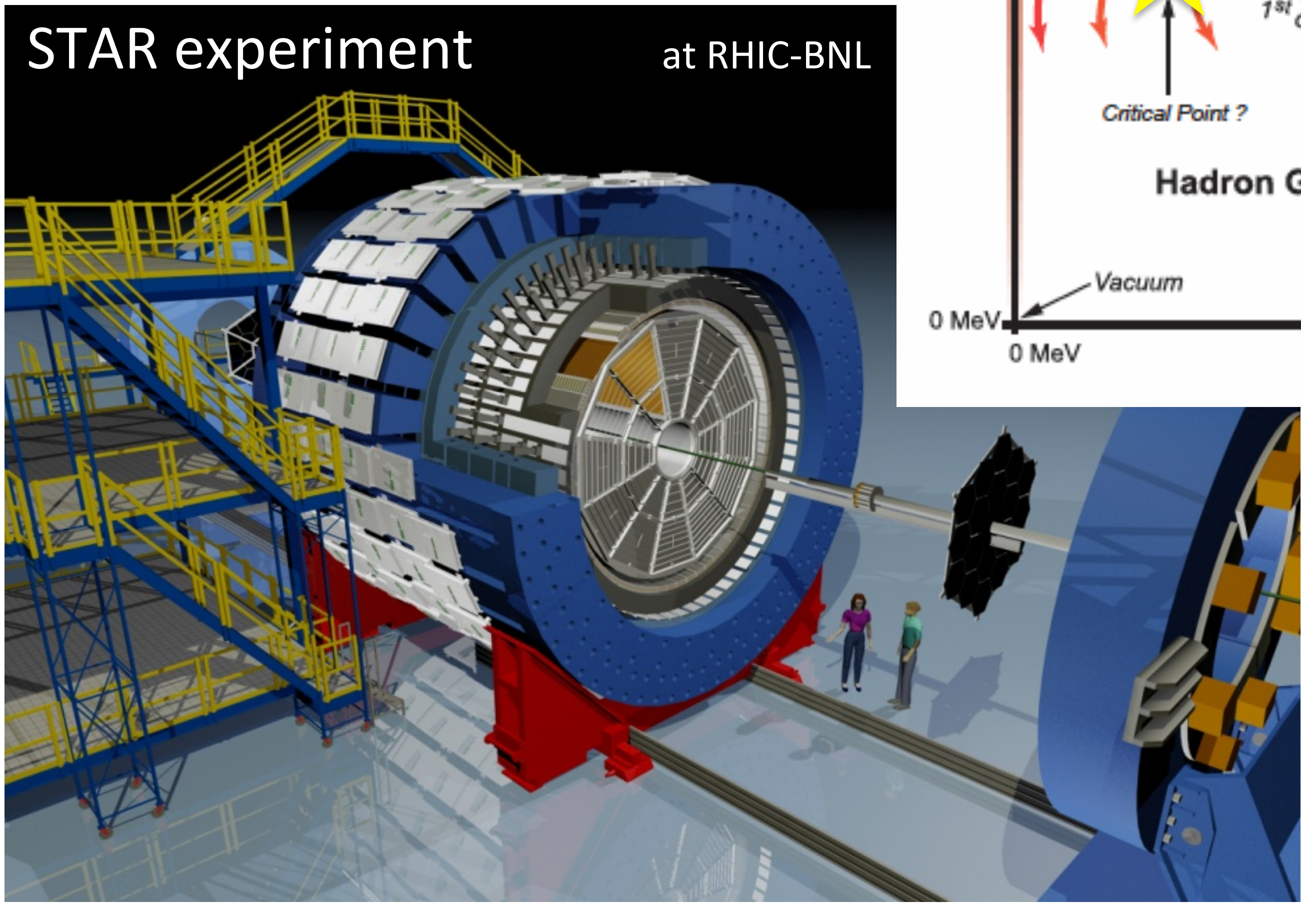
^{3}He+Au

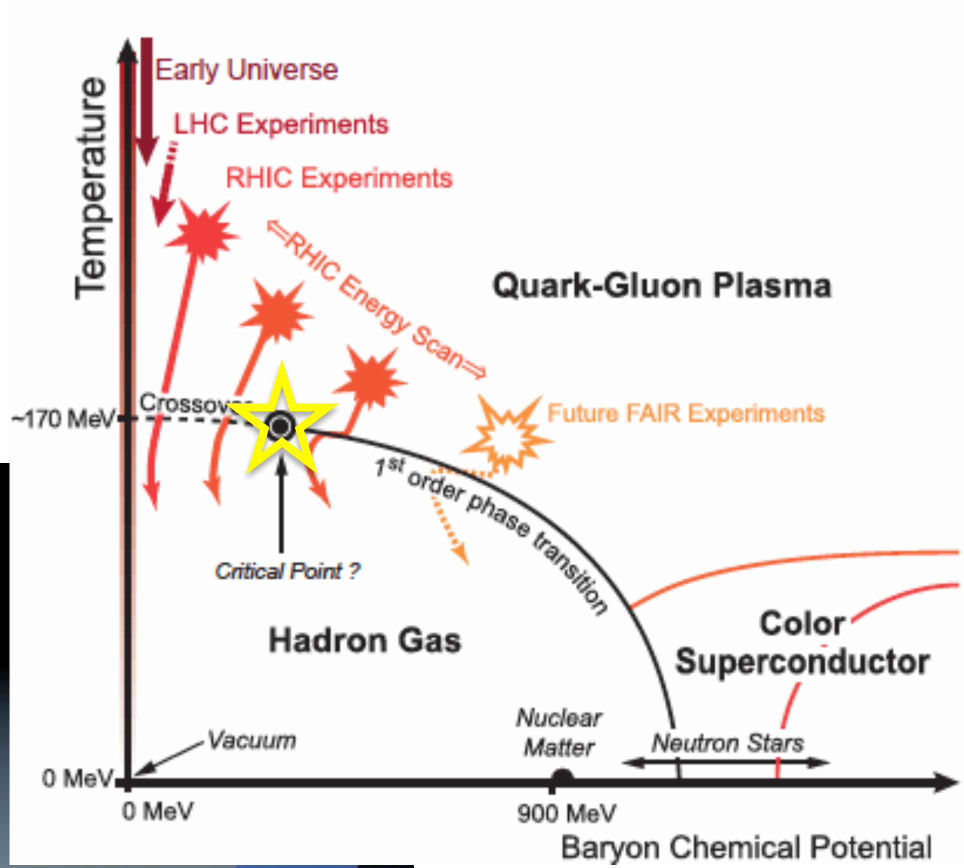


new ^{3}He+Au collision
data from RHIC-RUN14

Critical Point Search

Beam Energy Scan Program
at RHIC beam energy regime

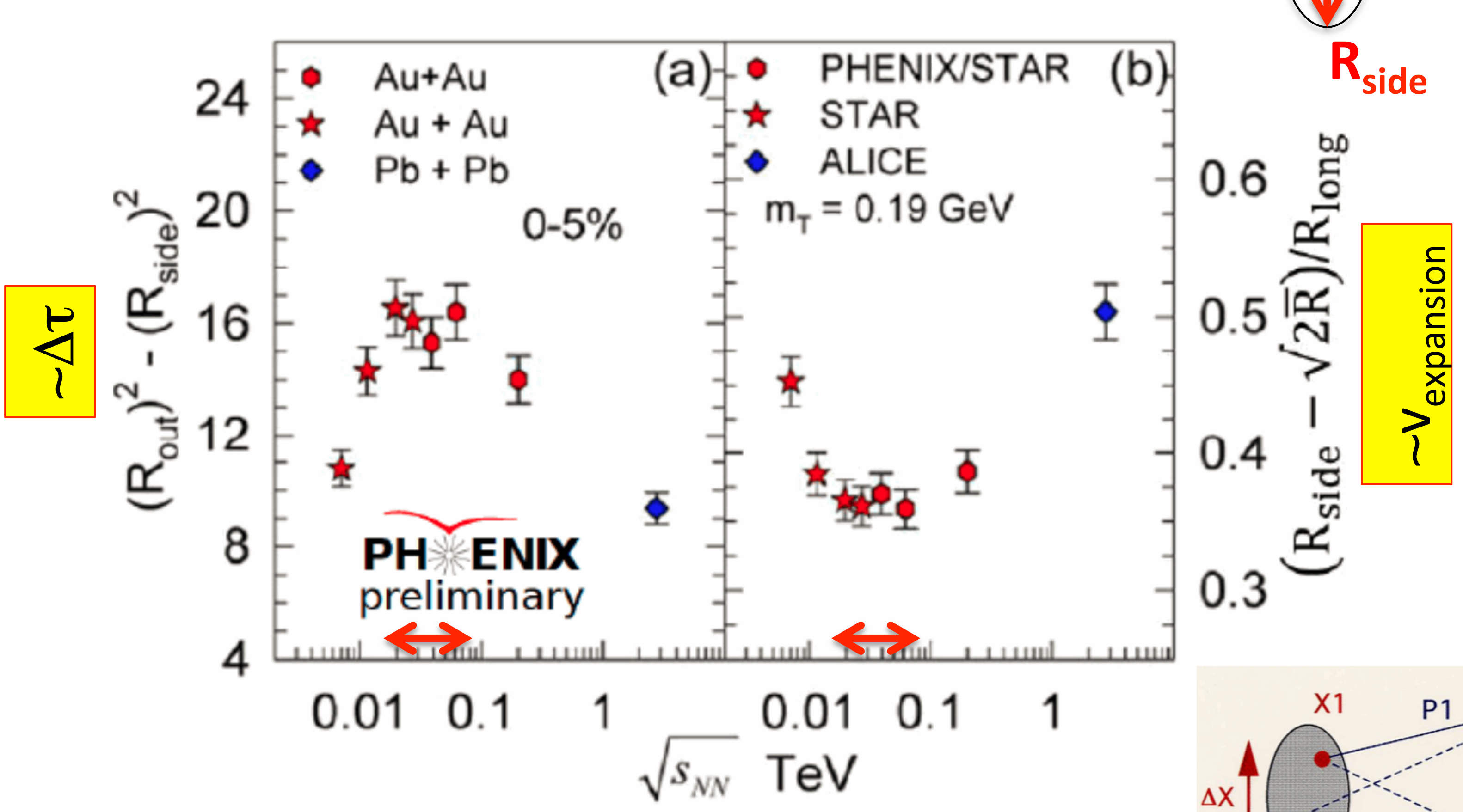


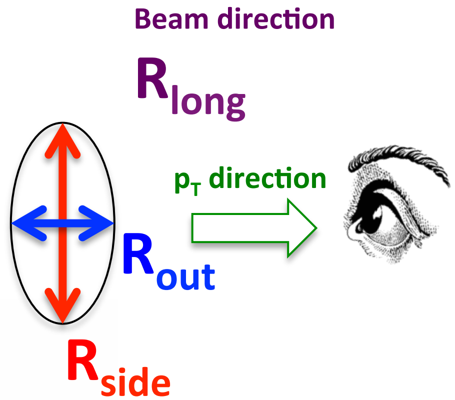


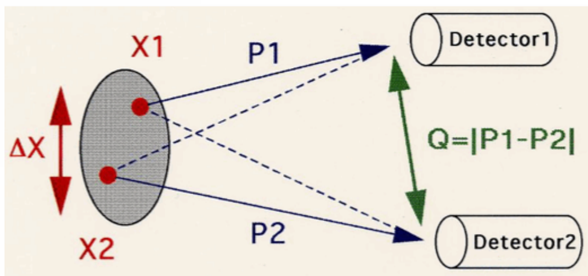
- Divergence of fluctuation around Critical Point
- end point of 1st order phase transition

Beam energy dependence of 2-particle interferometry measurement (HBT effect)

arXiv:1410.2559

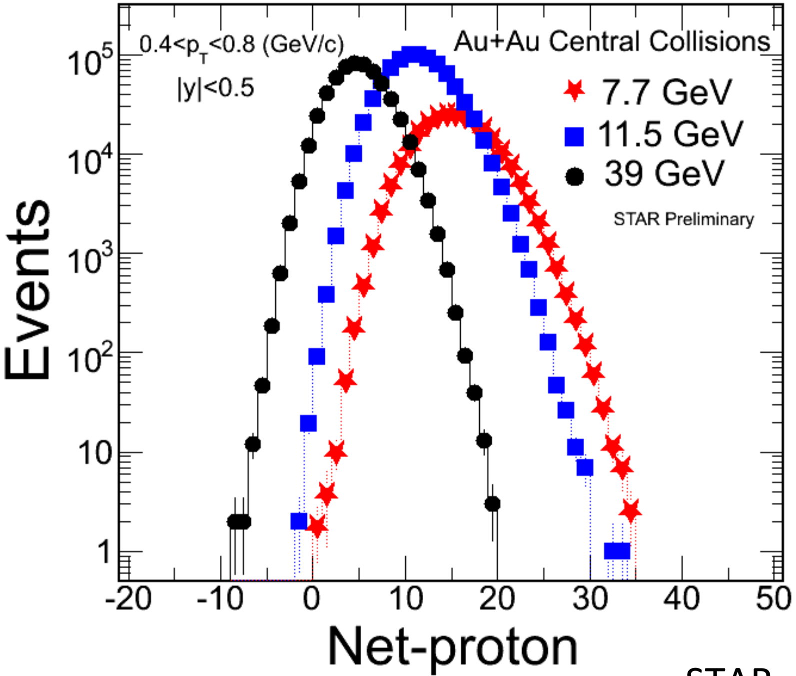




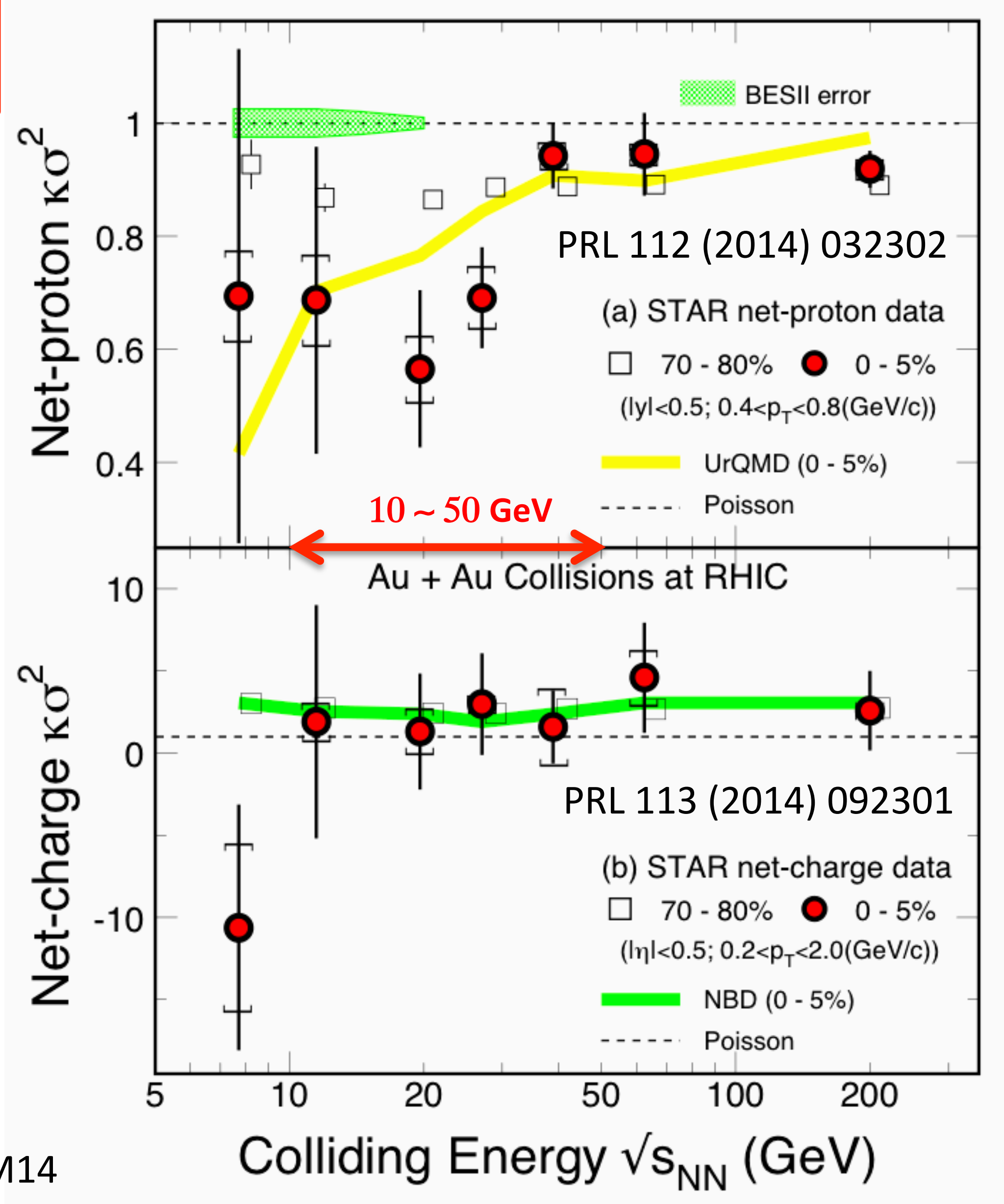


Fluctuation of conserved quantity vs beam energy

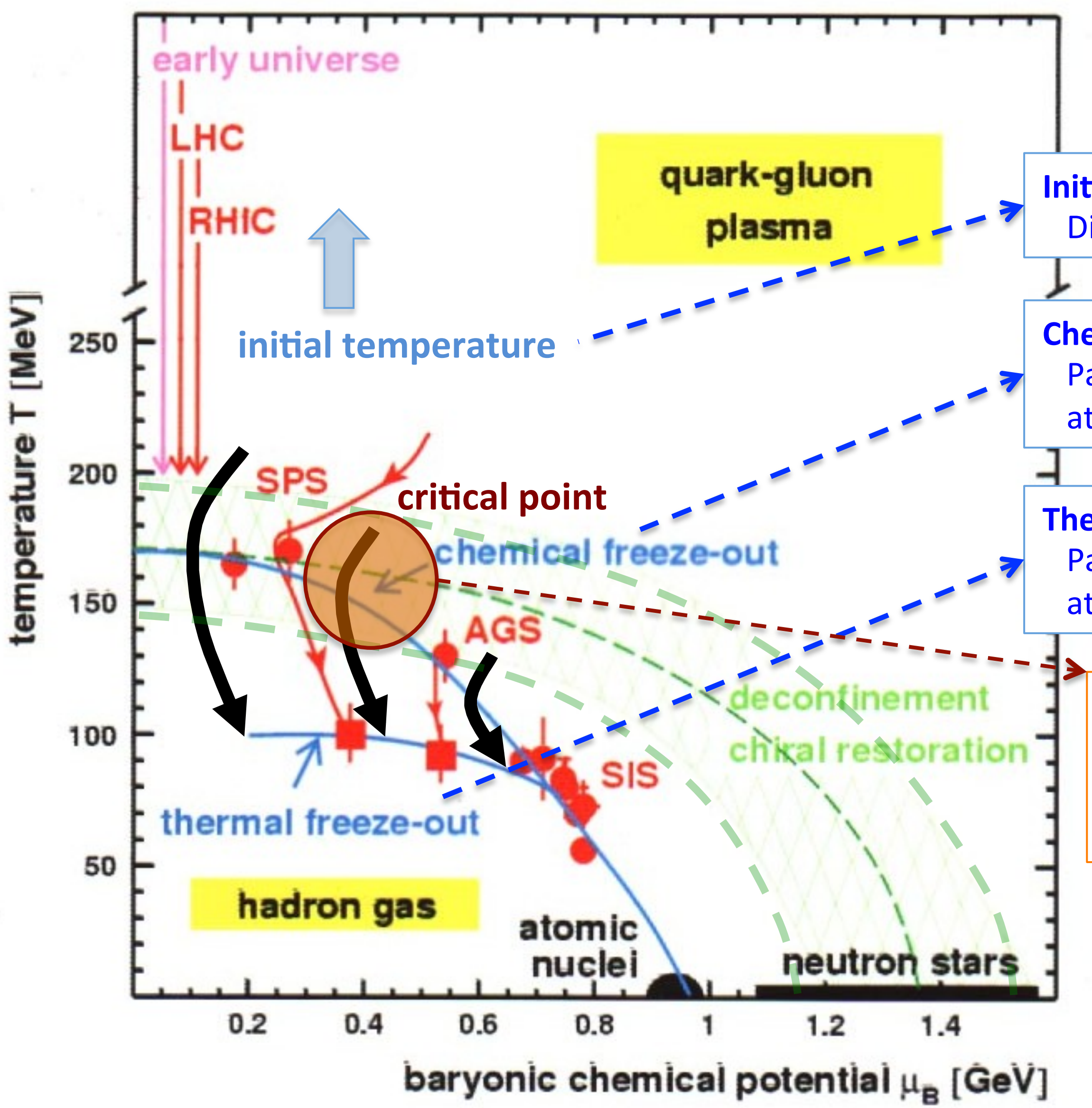
- Higher order moments (σ, S, κ) of net-baryon (net-proton) and net-charge distribution
- Non-monotonic behavior is expected around Critical Point.



STAR, QM14



History of temperature before/after the phase transition



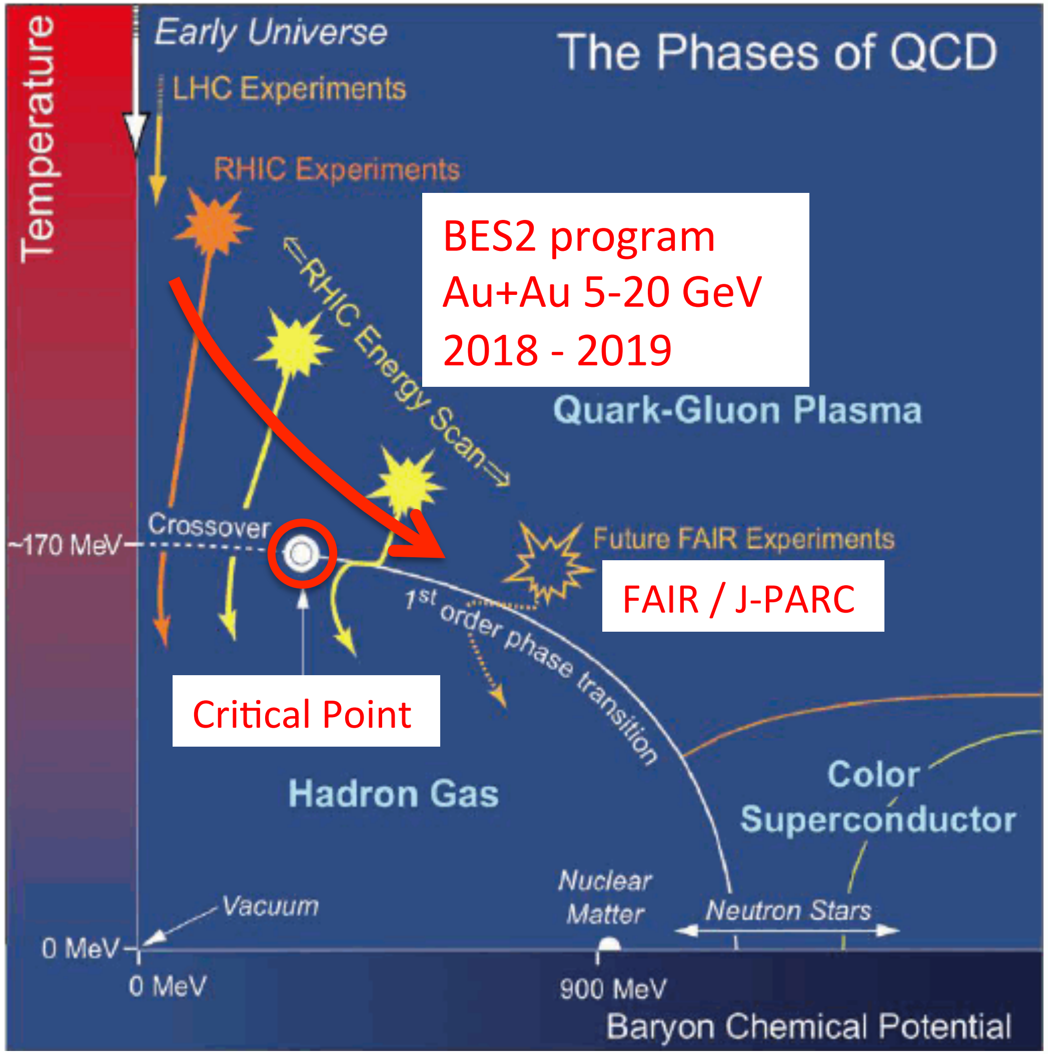
Initial temperature :
Direct thermal photon measurement

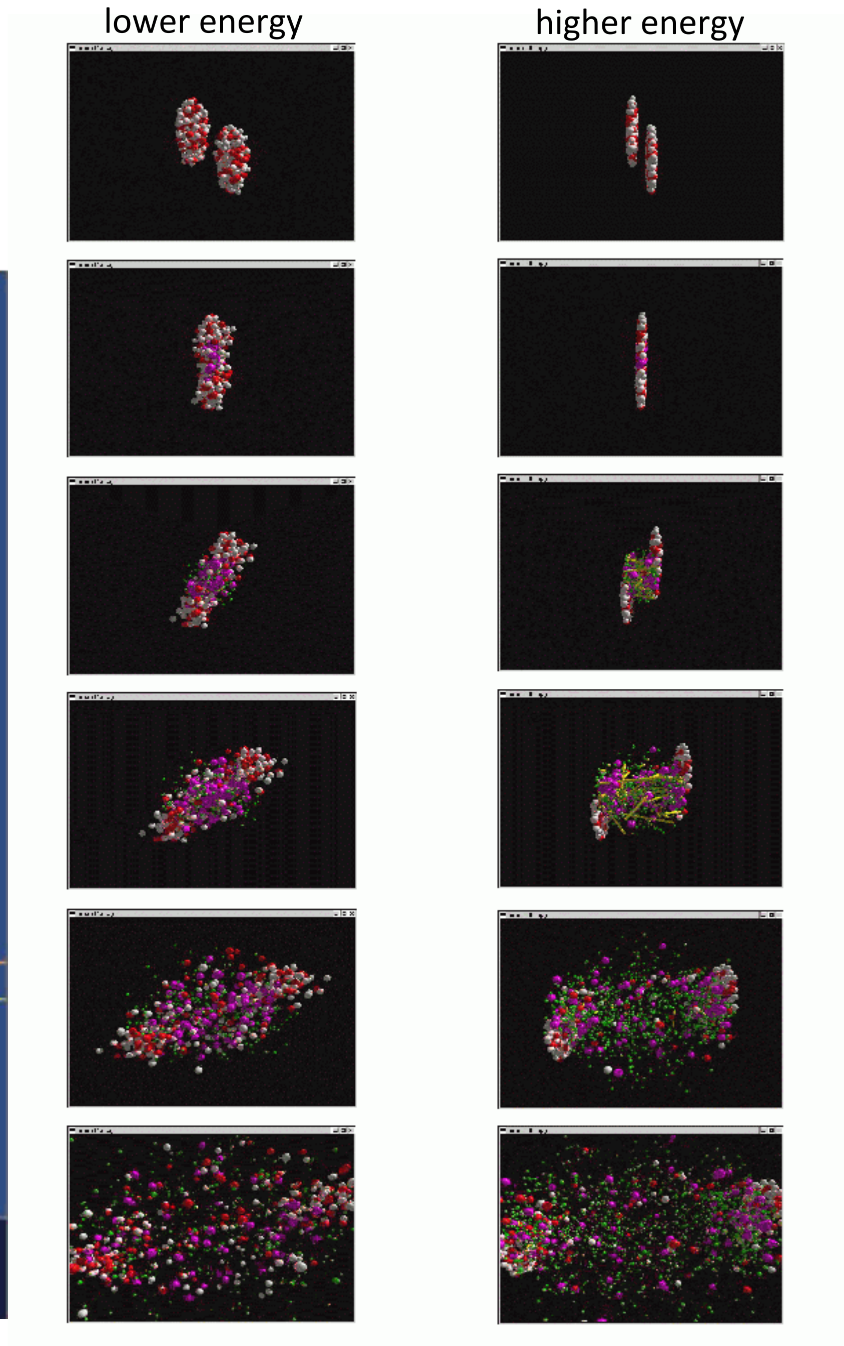
Chemical Freeze-out temperature :
Particle species, ratios are fixed
at the end of inelastic interactions

Thermal Freeze-out temperature :
Particle spectra are fixed
at the end of elastic interactions

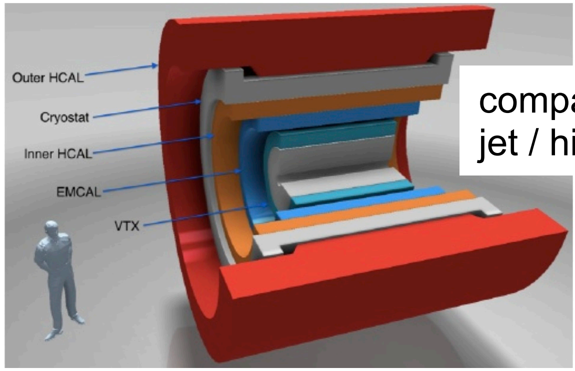
Critical Point :
end of 1st order phase transition
non-monotonic behavior
expected fluctuation to diverge

From high-temperature to high-density with Beam Energy Scan (BES) program



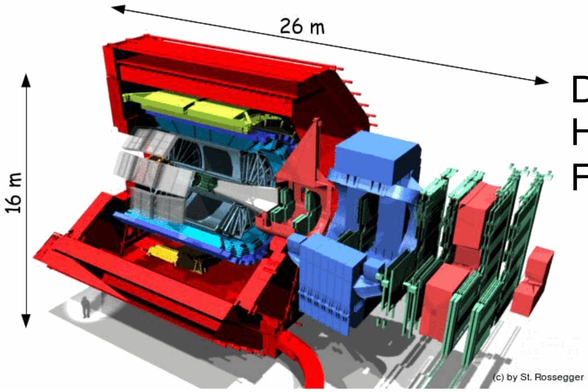


sPHENIX at RHIC-BNL (New York, USA)



compact calorimeter
jet / high p_T probes

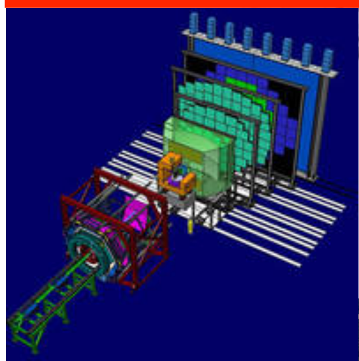
ALICE at LHC-CERN for Luminosity upgrade (Geneva, Switzerland)

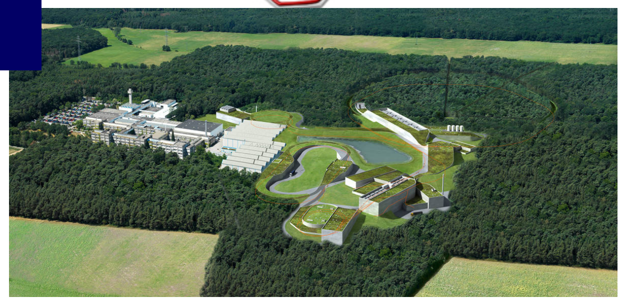


Di-jet calorimeter
High-speed read-out
Forward/Central upgrade

J-PARC at JAEA/KEK for heavy-ion collisions (Tokai, Japan)

FAIR at GSI (Darmstadt, Germany)

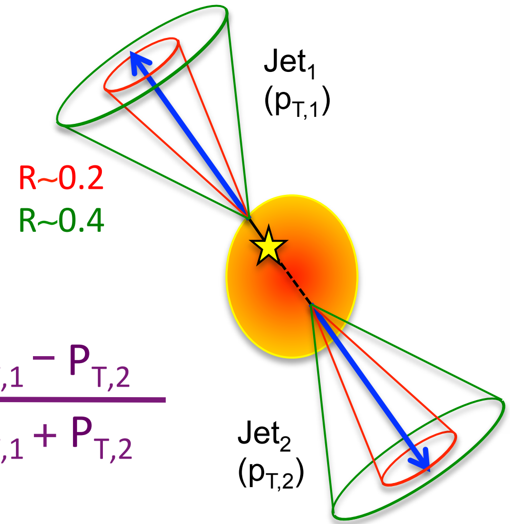


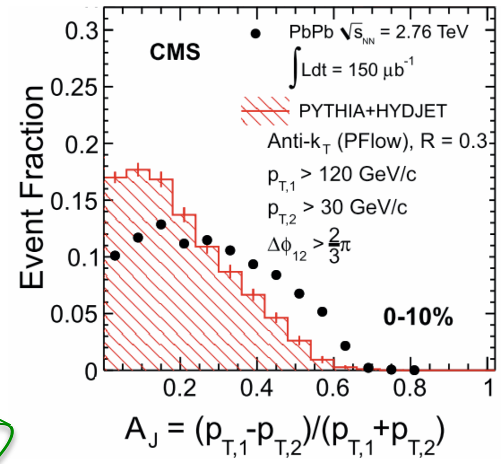


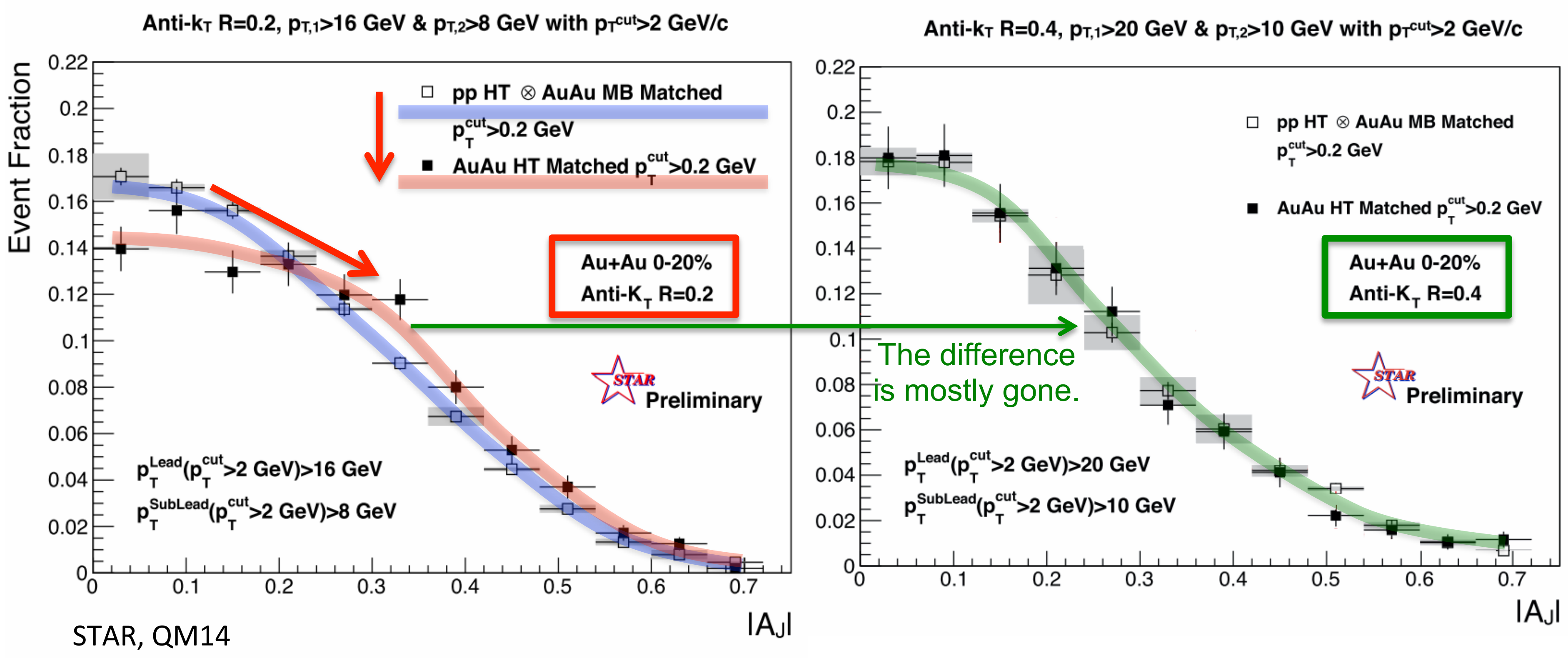
Difference of energy loss (A_J) between RHIC and LHC

- effect seen with smaller jet cone R~0.2 at RHIC
- mostly recovered jet energy within larger jet cone R~0.4

$$A_J = \frac{P_{T,1} - P_{T,2}}{P_{T,1} + P_{T,2}}$$



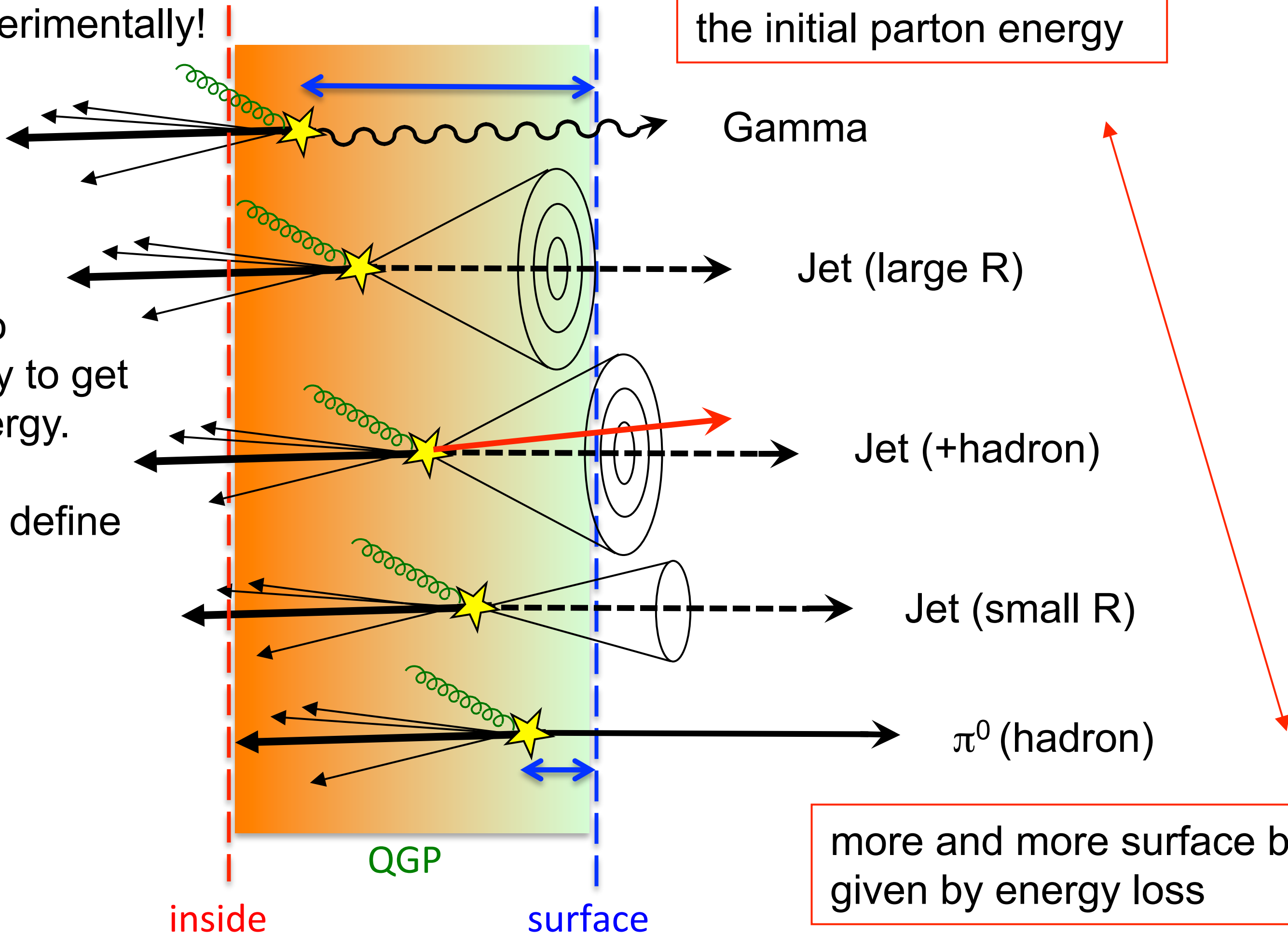




Systematic test of energy loss and redistribution with photons, jets and hadrons

These two effects (energy loss and redistribution) can not be clearly separated experimentally!

Closer and closer to the initial parton energy

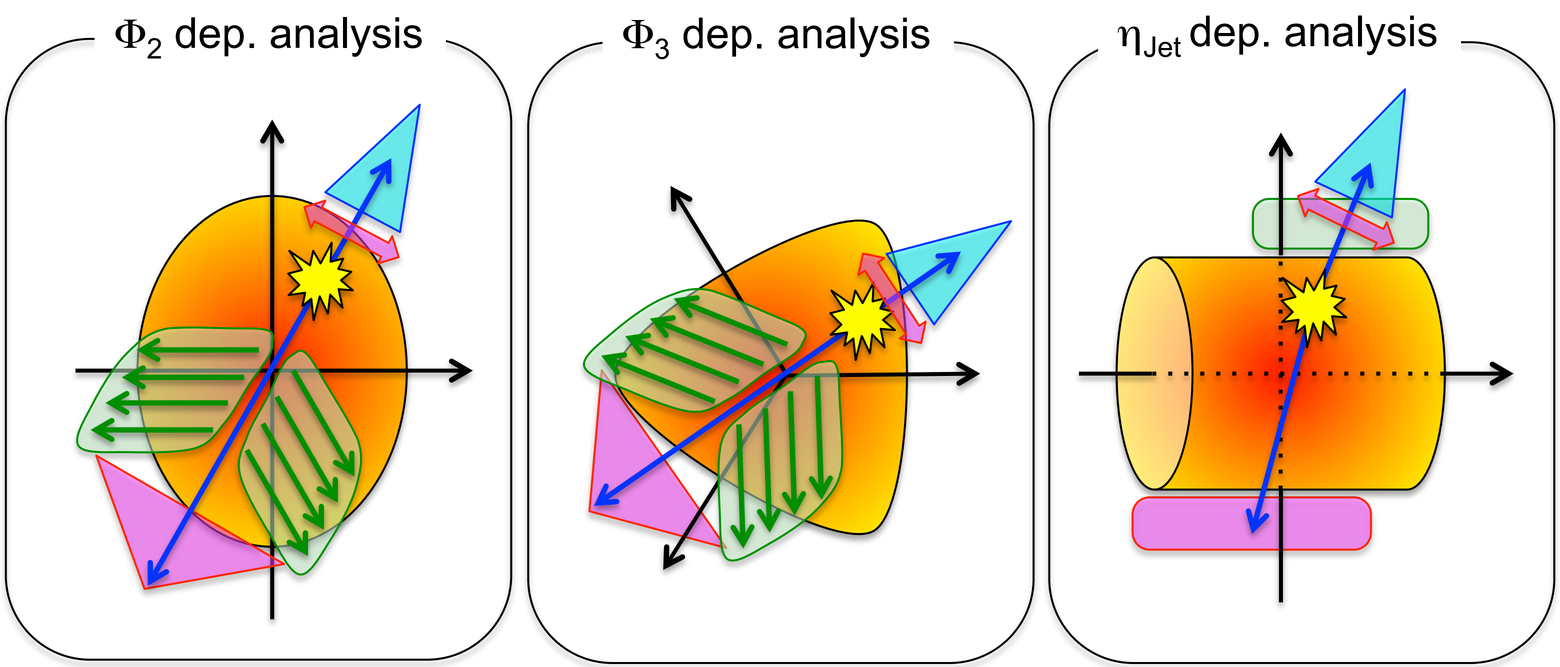


Jet reconstruction is to recover the lost energy to get the original parton energy.

Jet as a control tool to define path length

more and more surface bias given by energy loss

Further tests of hard-soft interplay using correlation between jet modification and geometry/expansion of QGP

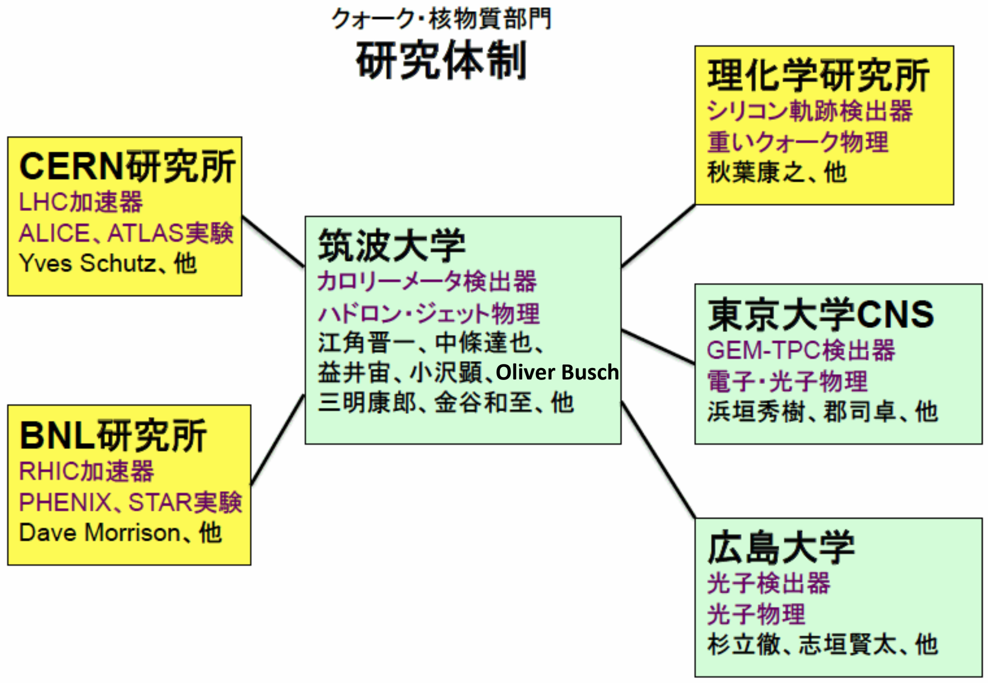


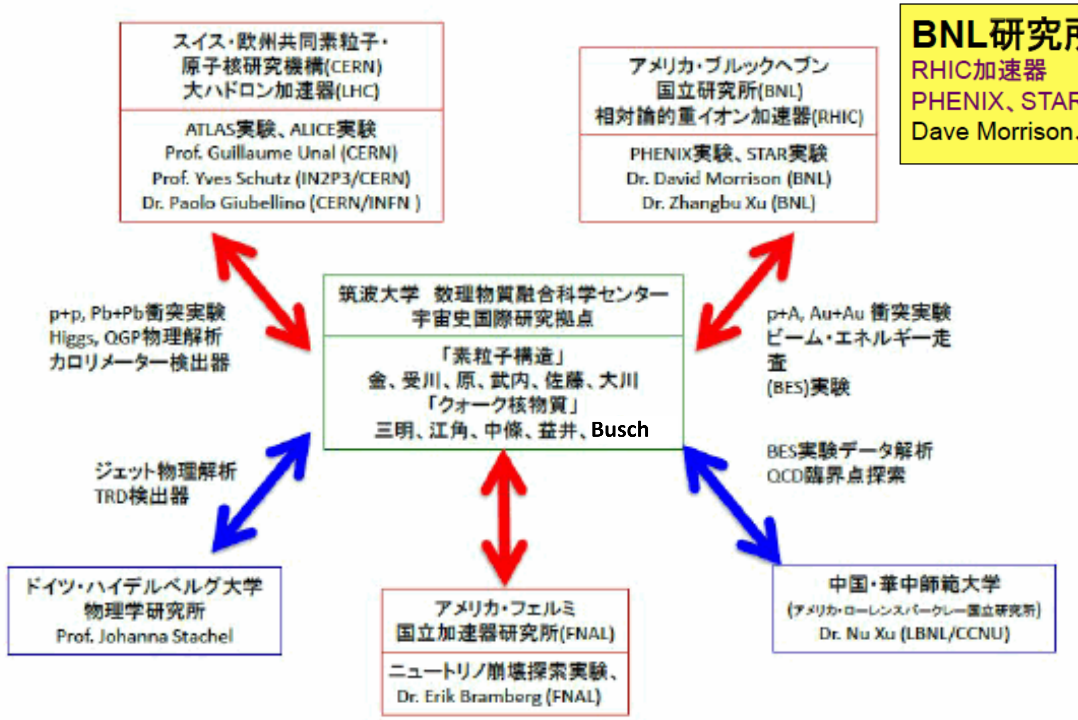
methods

- Multi-particle correlation
- Jet-hadron / γ-hadron correlation
- Jet fragmentation function
- Di-jet distribution

Yet another axis as a control parameter
to define path length, geometry and expansion.

Research Relation with other groups within and outside of Japan





Summary

- LHC --- RHIC --- FAIR/JPARC
- Partonic energy loss
- Collective behavior
- Hard-soft interplay
- Fluctuation and critical point