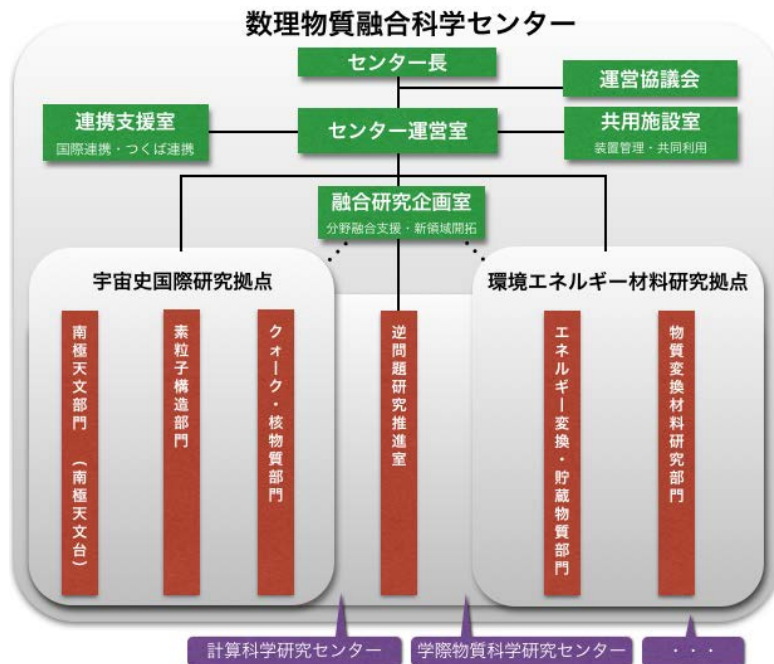


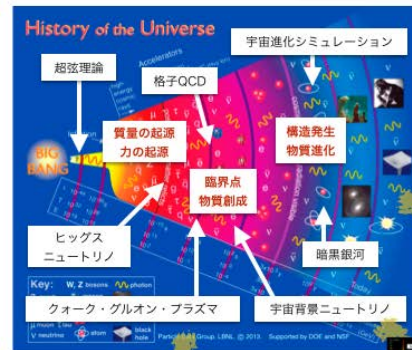
数理物質融合科学センター クォーク・核物質 部門

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



ミッション：素粒子・原子核・宇宙物理学の融合と、実験的・理論的アプローチの協調により、宇宙史を統一的に理解

拠点長(コーディネータ)：金信弘教授

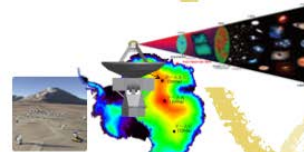
クォーク・核物質部門

核物質からクォーク物質へ
クォーク・グルオン・プラズマ

部門長(PI)：江角晋一准教授

ビッグバン数 μ 秒後の初期宇宙における高温クォーク・グルオン・プラズマ(QGP)状態と中性子星・クォーク星内部における高密度QGP状態の解明、及び、高温と高密度の中間領域に予測される臨界点の探索

南極天文部門(南極天文台)



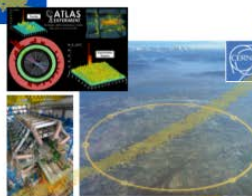
部門長(PI)：中井直正教授

南極望遠鏡および関連装置による遠方宇宙等の観測により、銀河の形成と進化および宇宙の構造を解明

「南極天文コンソーシアム」

「宇宙史コンソーシアム」

逆問題研究推進室との協力によるデータ解析手法開発



素粒子構造部門

部門長(PI)：受川史彦教授

ヒッグス粒子とニュートリノの実験的研究および超弦理論の研究により、素粒子の基本的性質を理解し、宇宙史の統一的描像を構築

人類の知識が及んでいない「暗黒」の解明

=> 暗黒物質、暗黒エネルギー、暗黒銀河、…
=> 物質創成・構造発生とそれらの進化

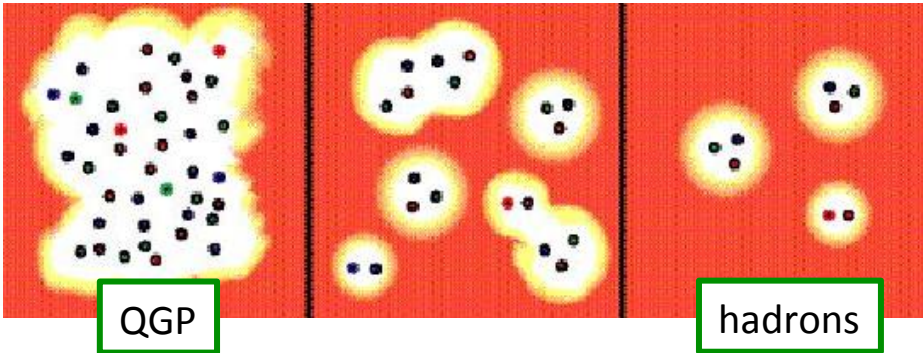
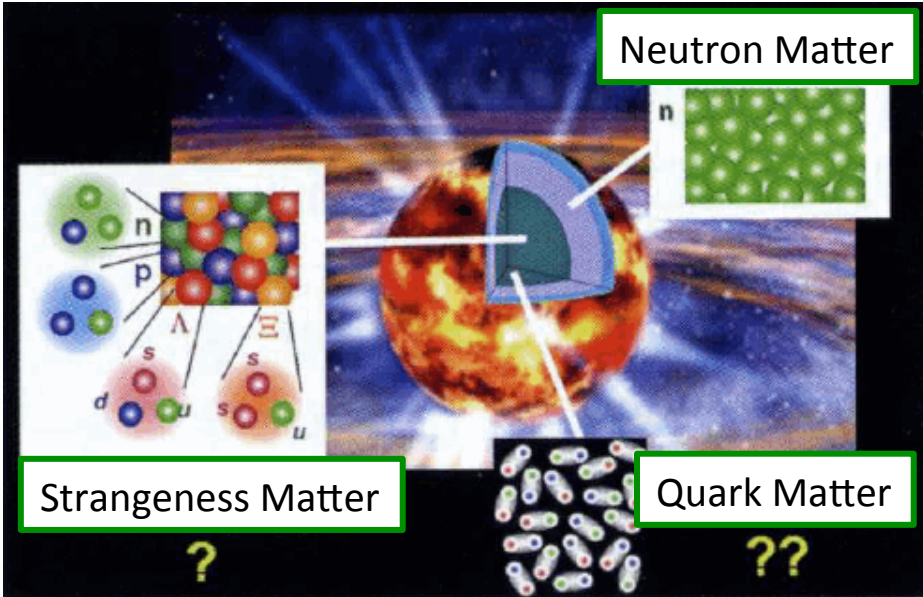
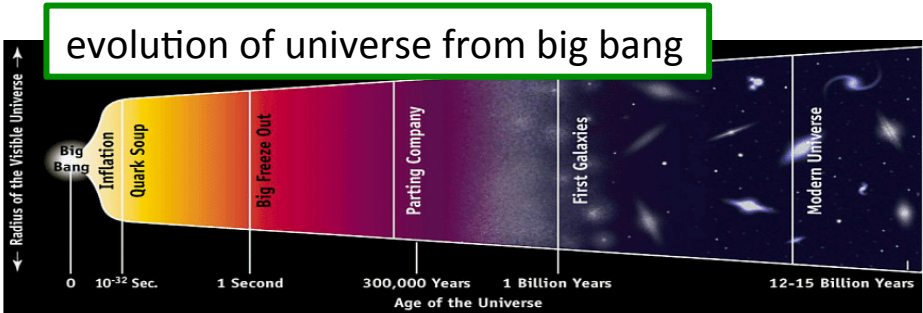
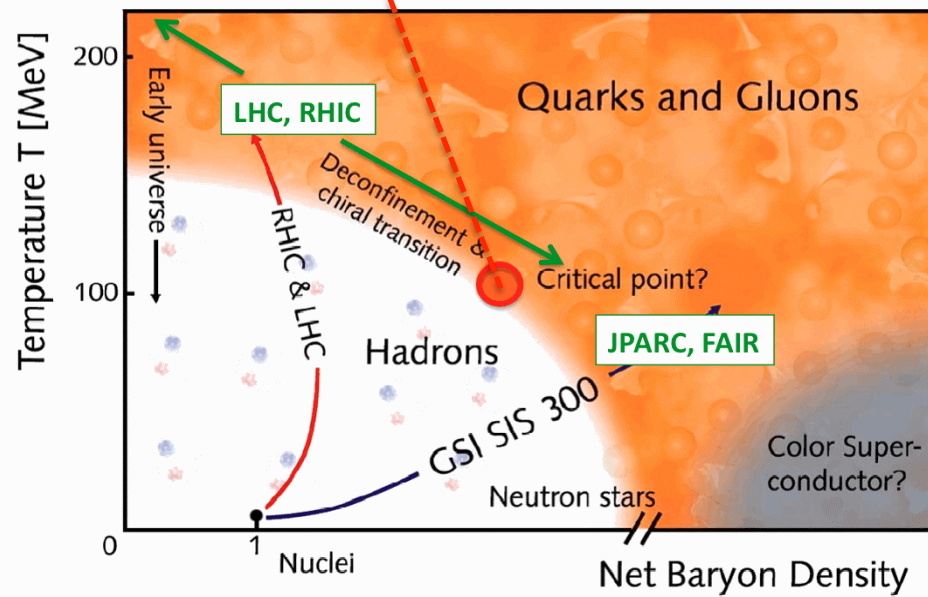
- Experiments
- Recent results
- Future plans

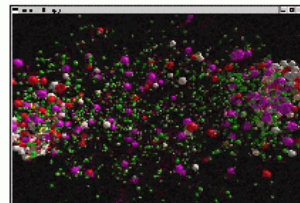
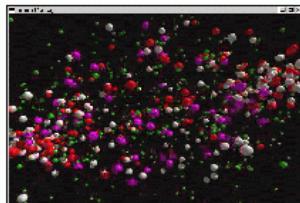
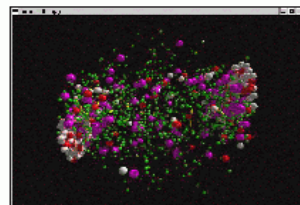
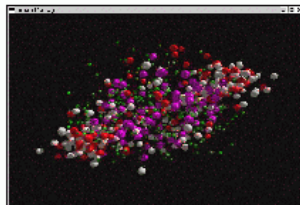
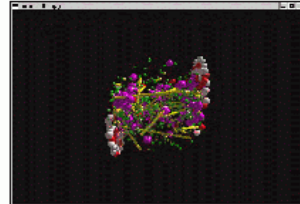
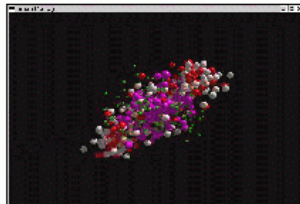
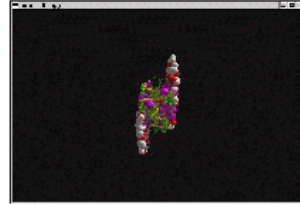
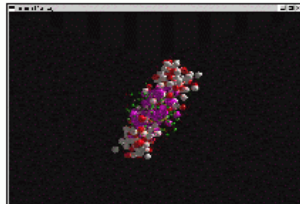
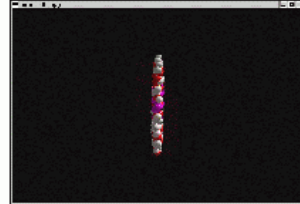
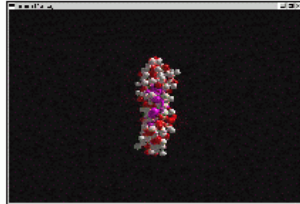
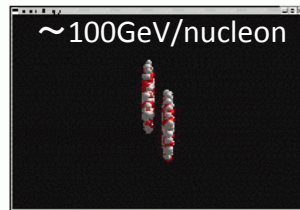
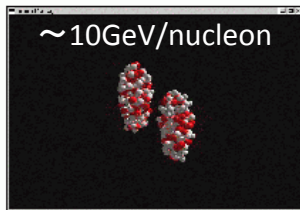


筑波大学 数理物質系 数理物質融合科学センター
宇宙史国際研究拠点 クォーク・核物質部門
江角 晋一 (筑波大学 数理物質系 物理学域)

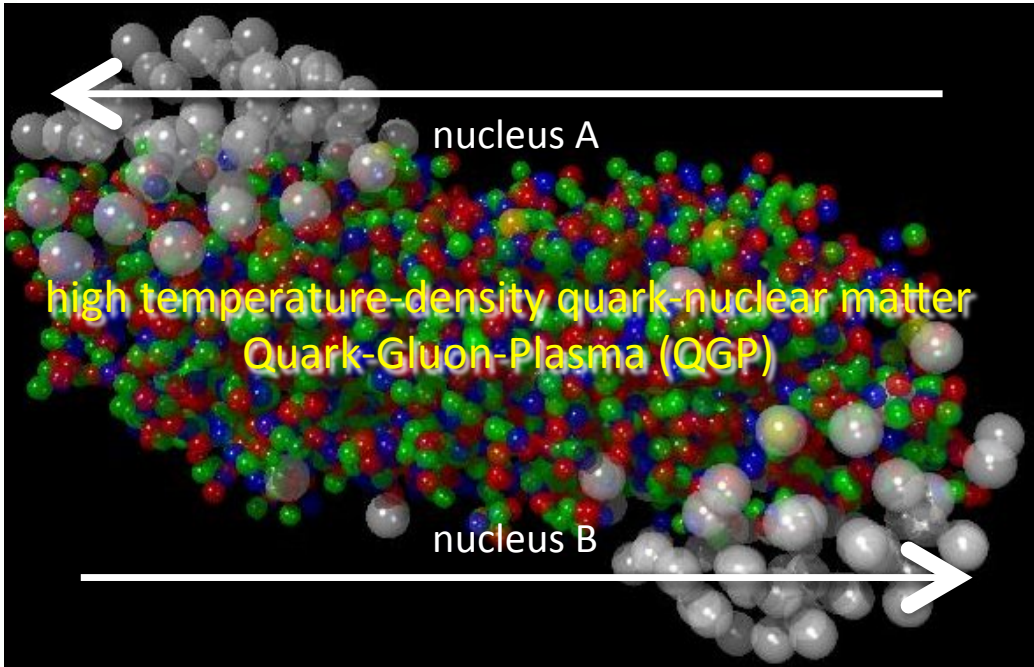
Quark Gluon Plasma (QGP)

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

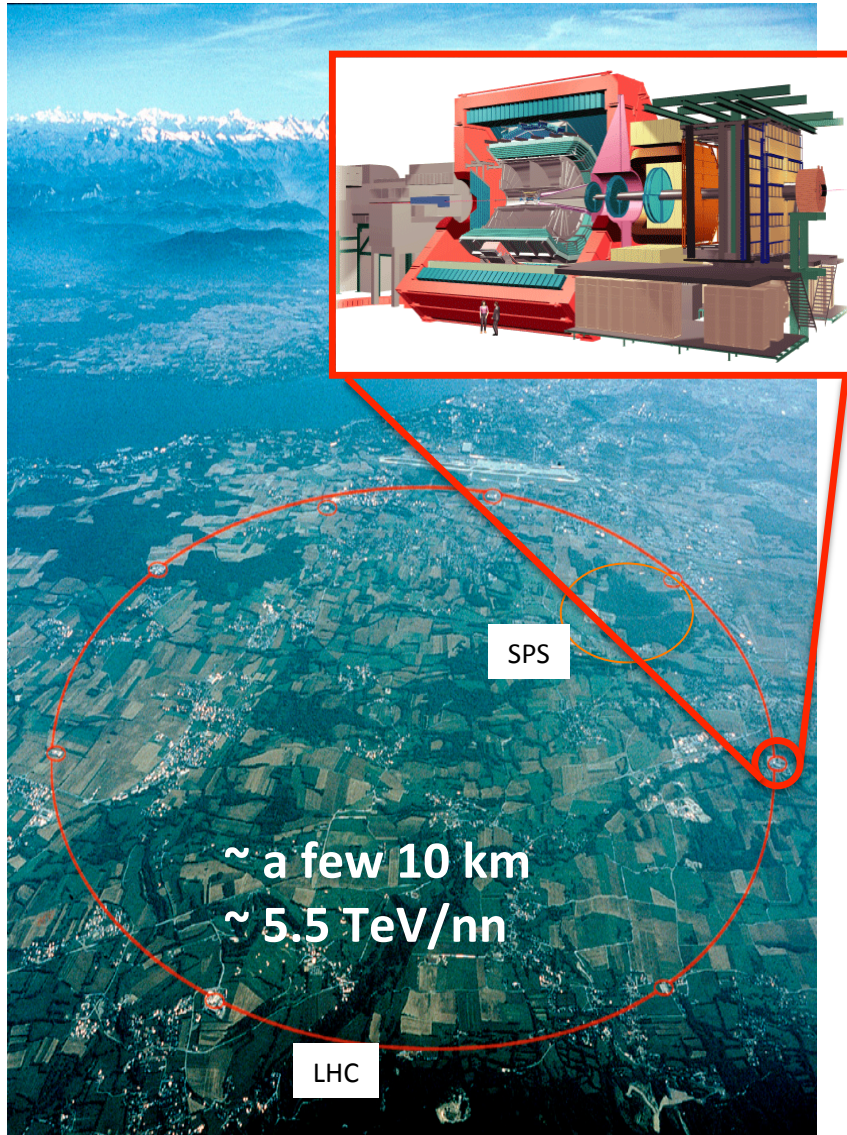




Nucleus-Nucleus collision simulation
nucleon-hadron cascade in uRQMD

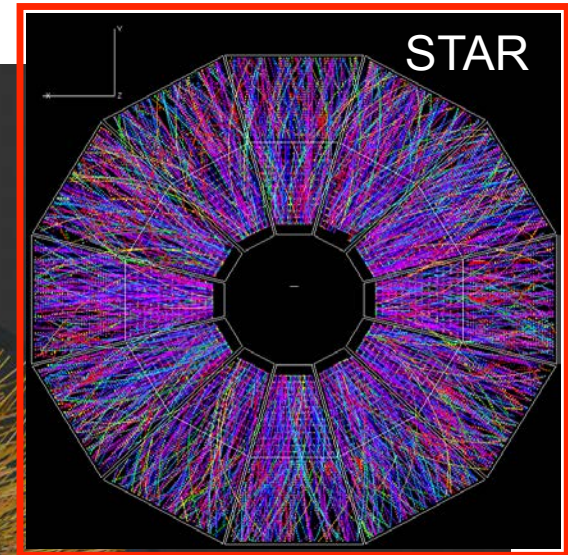
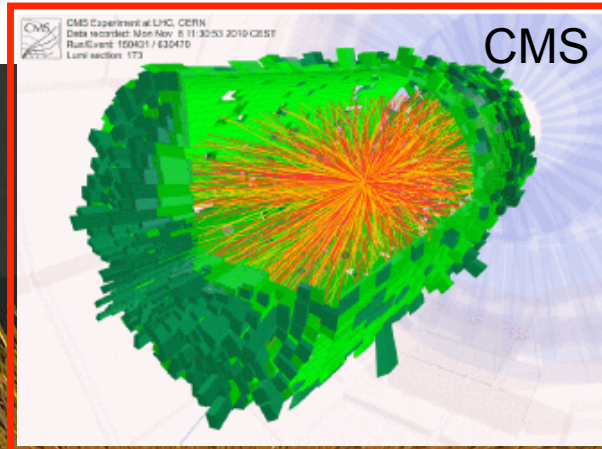
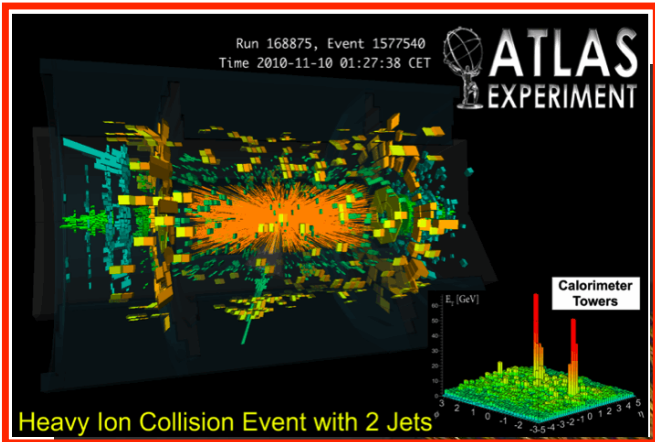


European Organization for Nuclear Study (CERN) at Large Hadron Collider (LHC) and ALICE experiment in Geneva, Switzerland

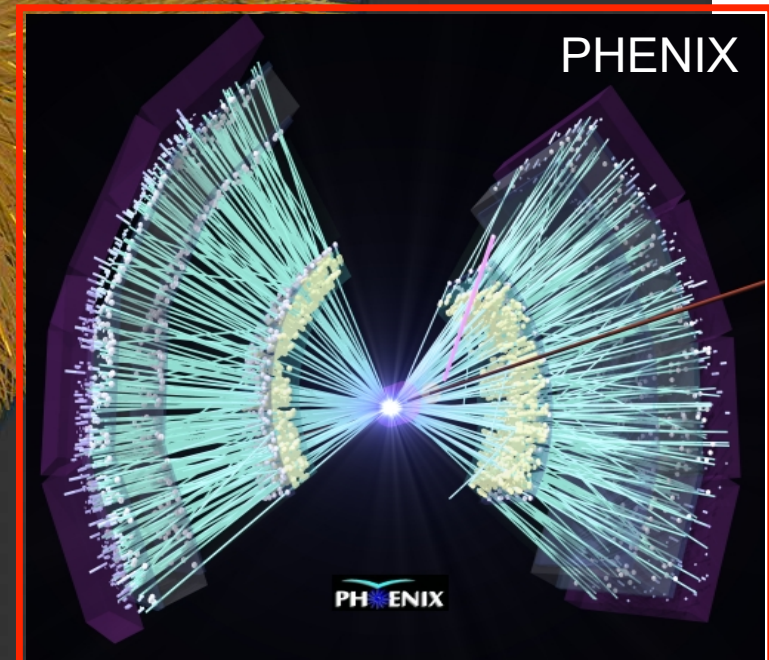
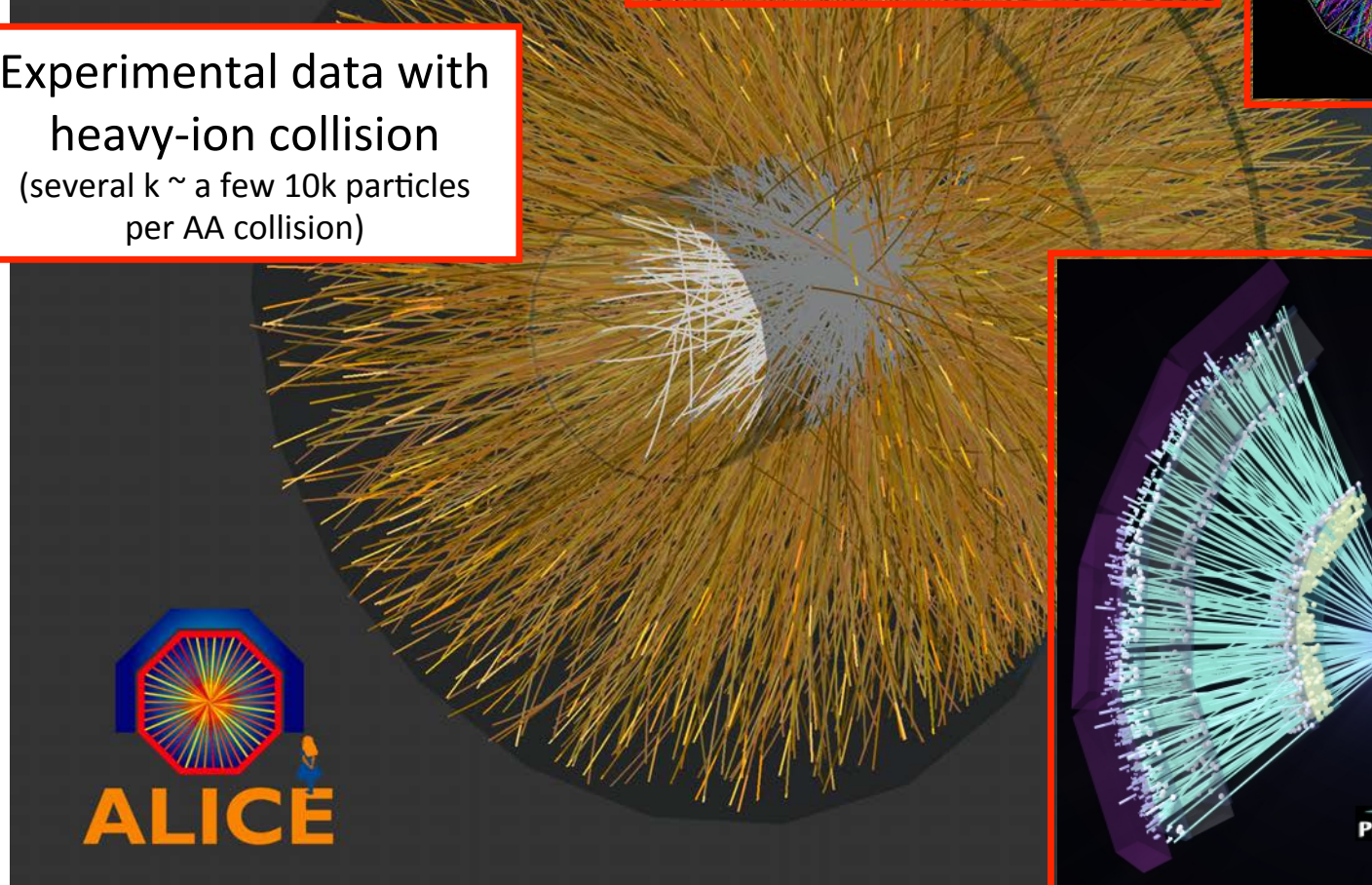


Brookhaven National Laboratory (BNL) at Relativistic Heavy-Ion Collider (RHIC) and PHENIX experiment in New York, USA

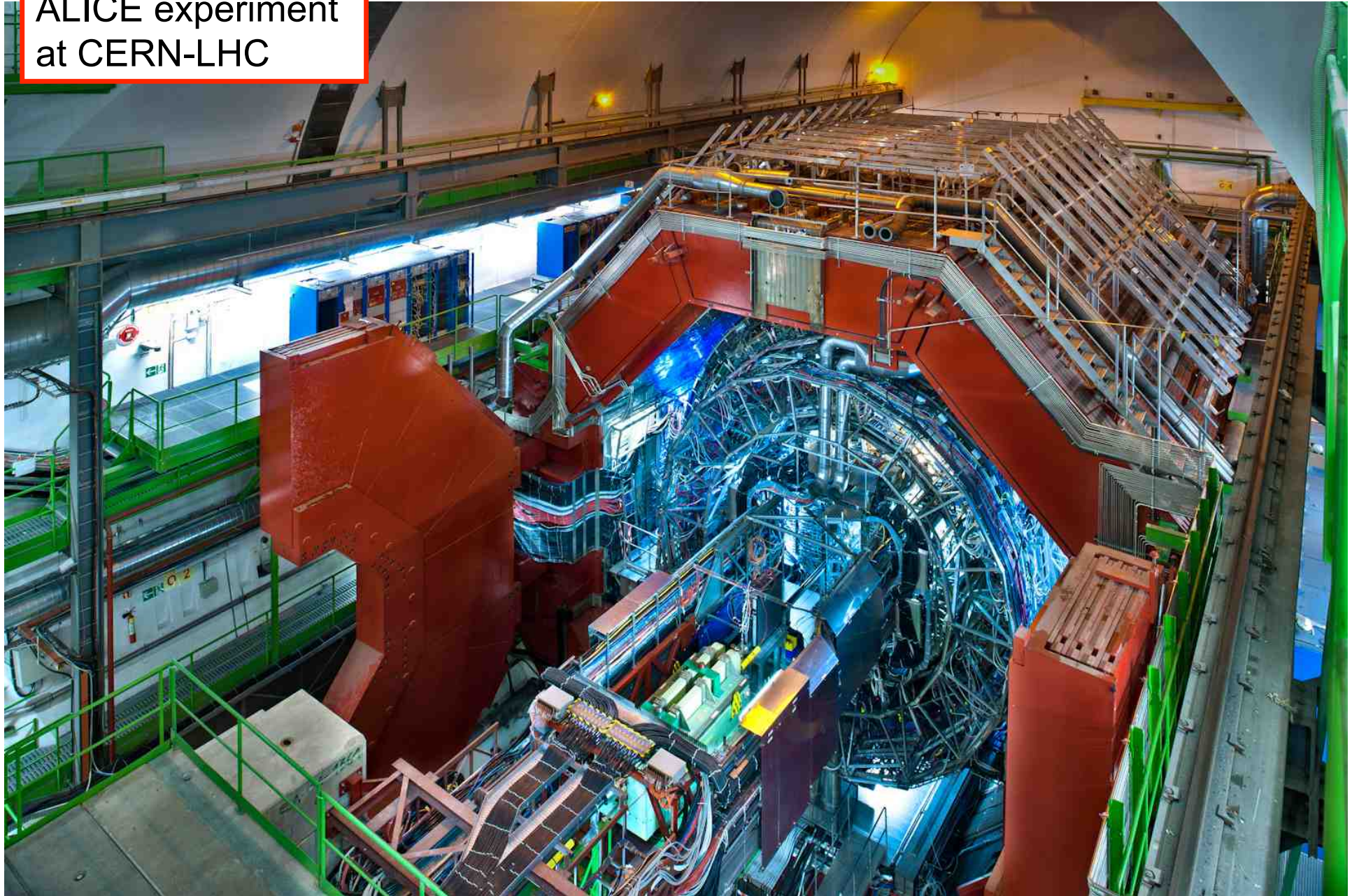




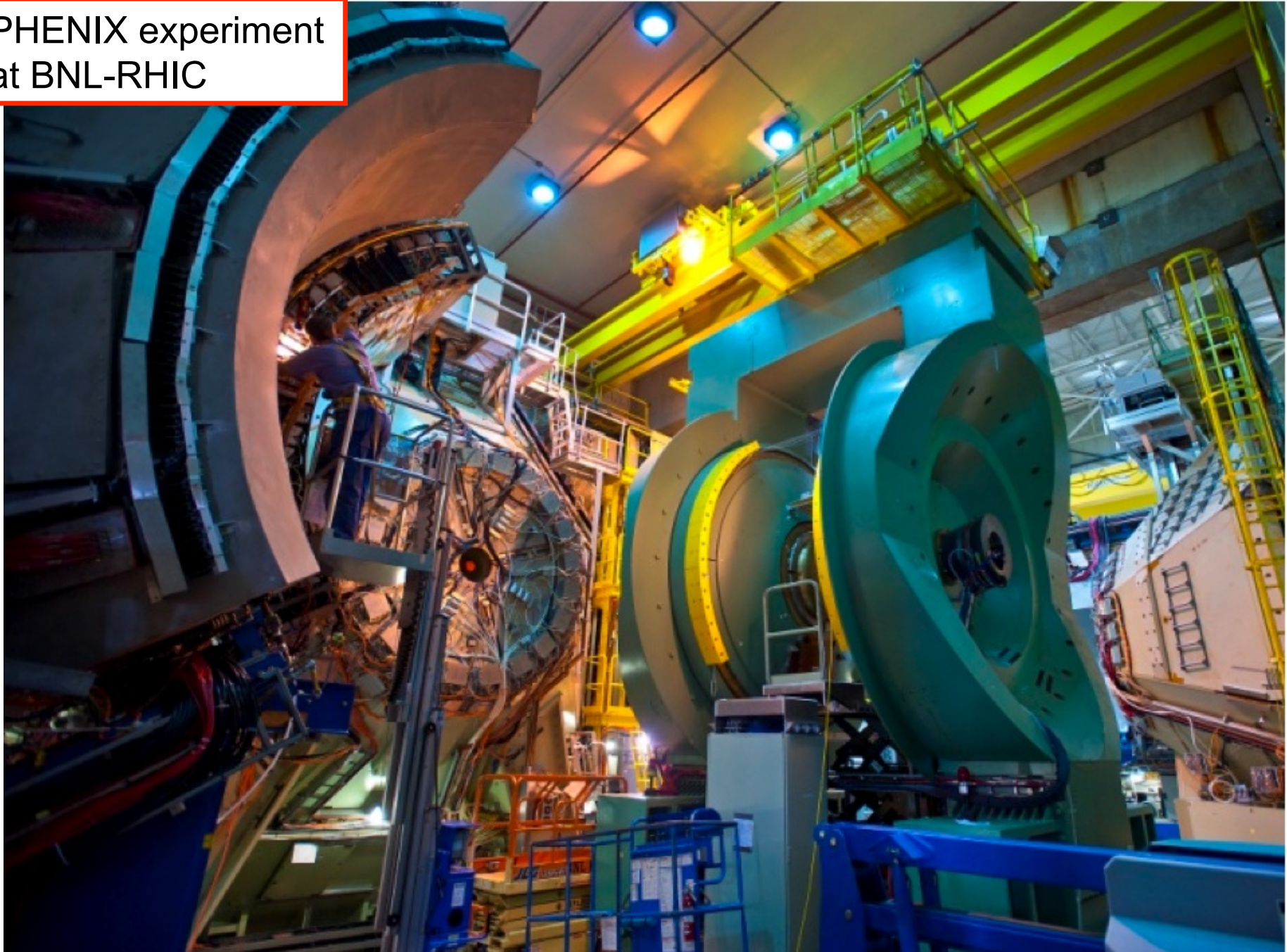
Experimental data with heavy-ion collision
(several $k \sim$ a few 10k particles per AA collision)



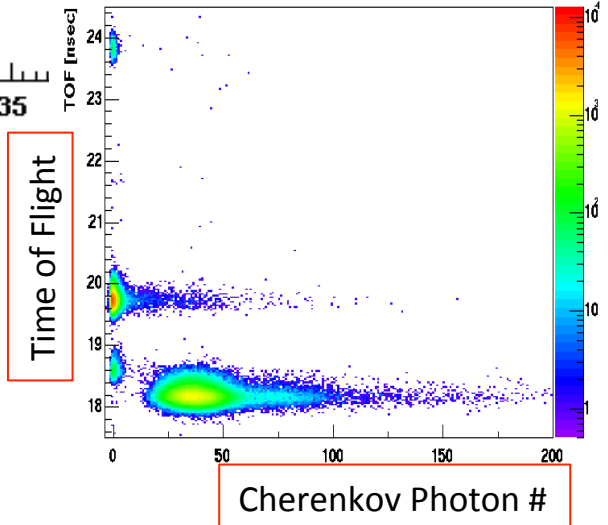
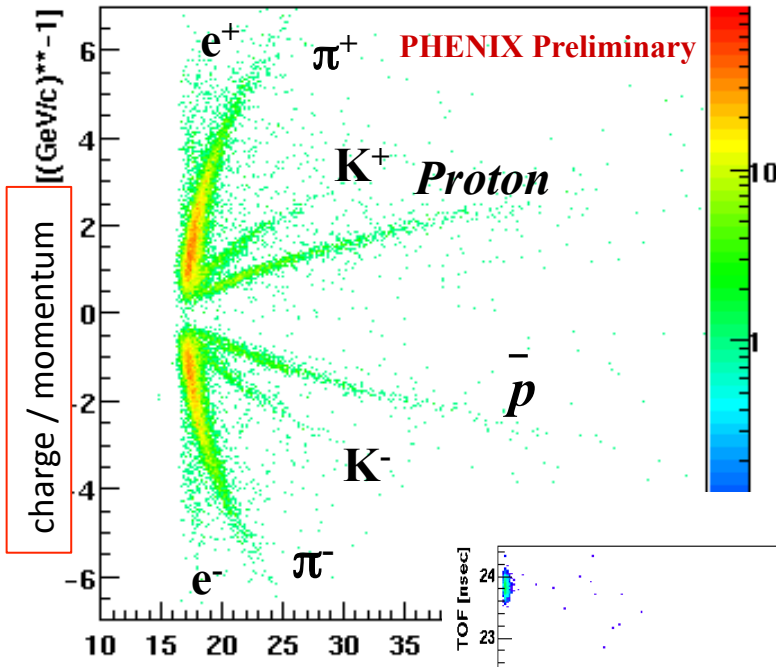
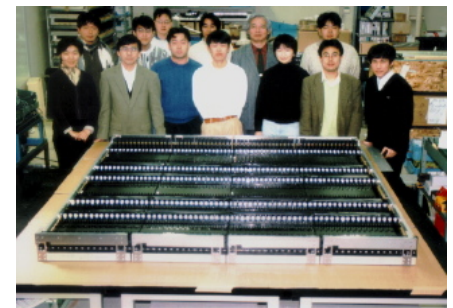
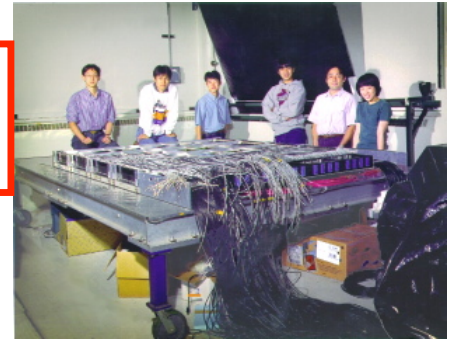
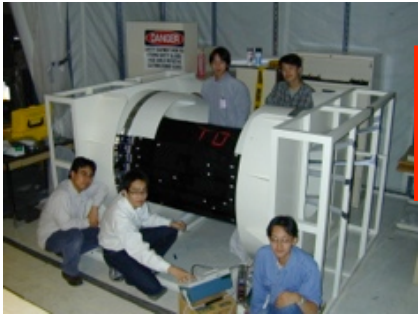
ALICE experiment
at CERN-LHC



PHENIX experiment
at BNL-RHIC

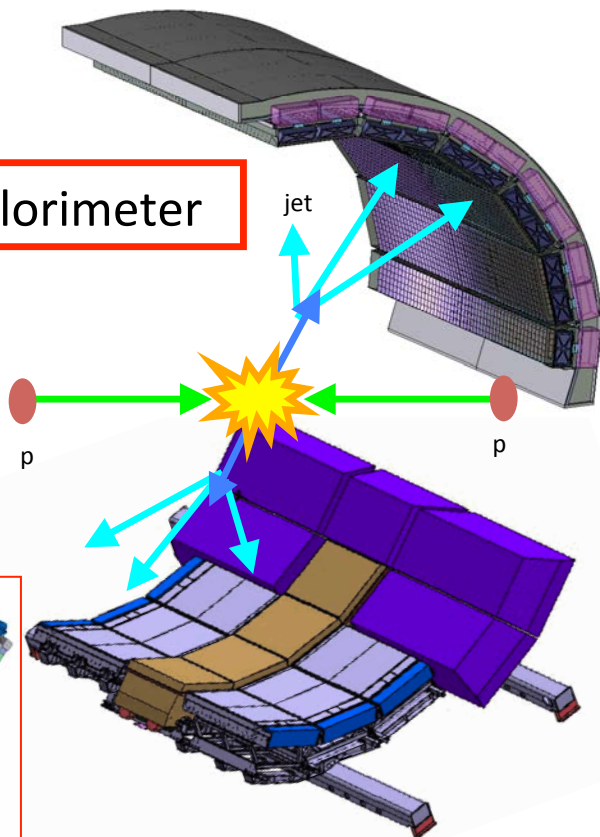


Time of Flight and Aerogel Cherenkov detector for particle identification (PHENIX)



Di-jet EM calorimeter

(ALICE)



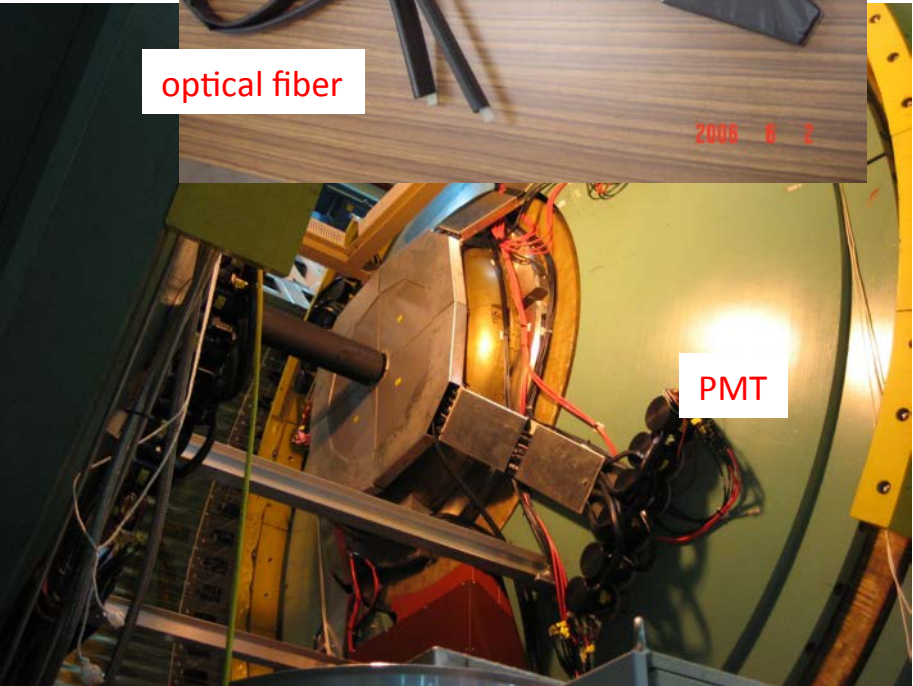
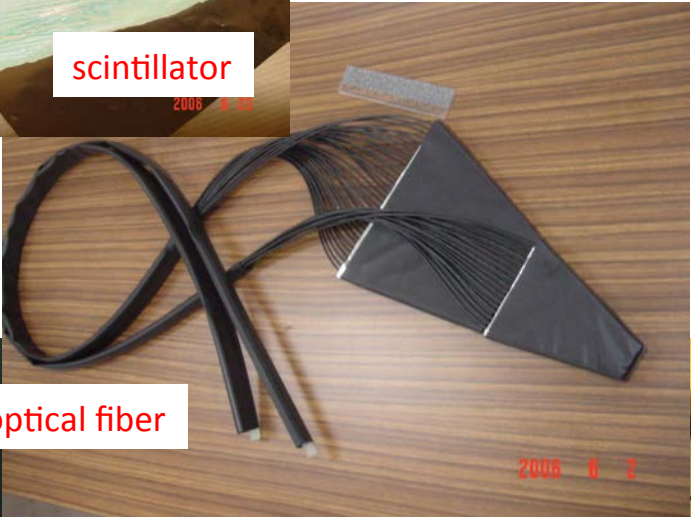
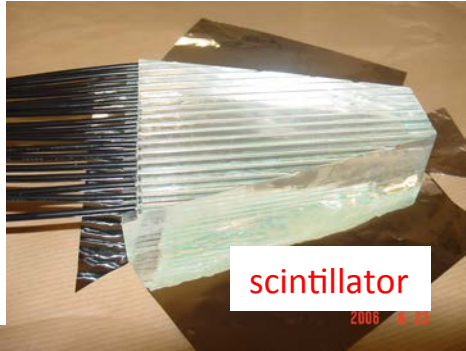
1 super module
=288 modules
 $\Delta\eta \sim 0.7$
 $\Delta\phi = 0.35$

4 towers/
module

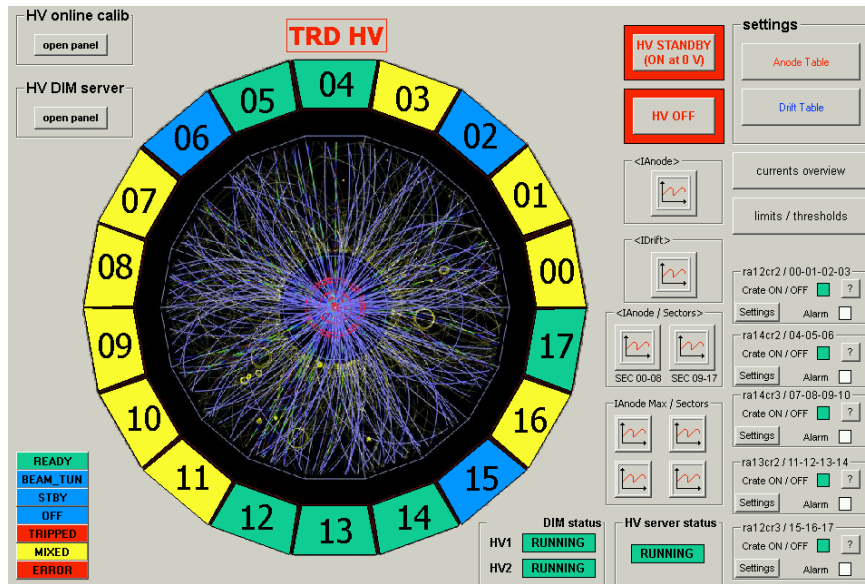


Reaction Plane Detector

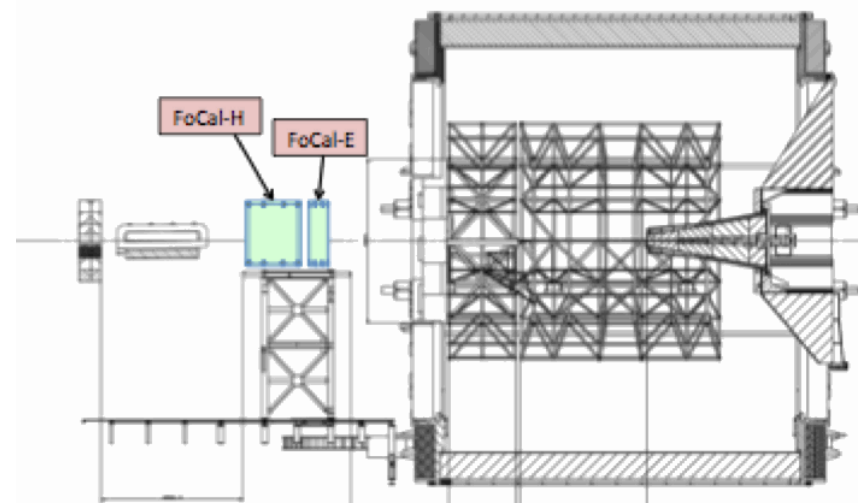
(PHENIX)



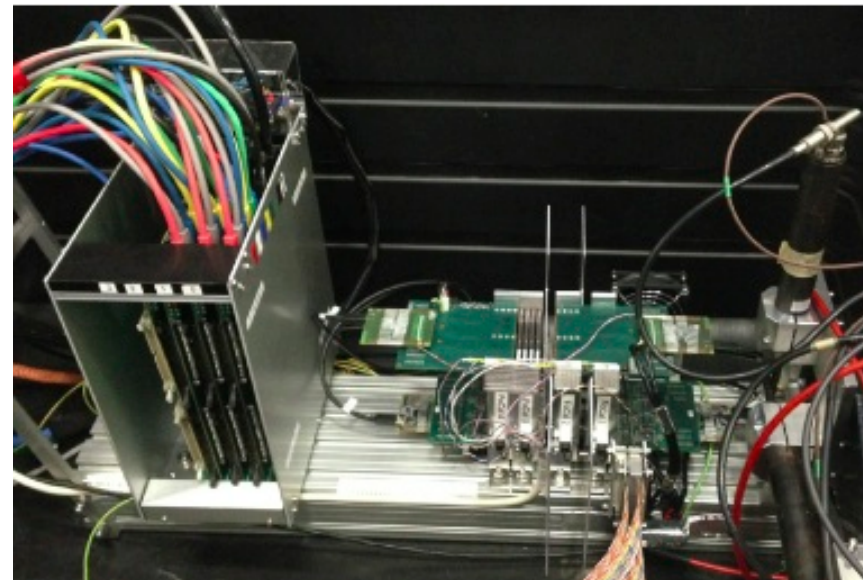
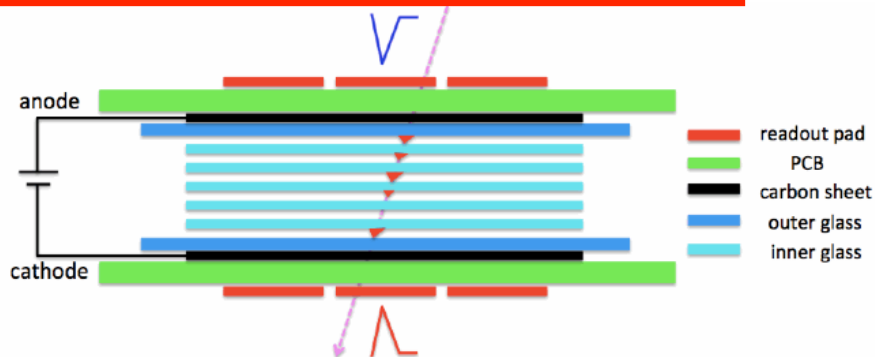
TRD detector control system for ALICE experiment



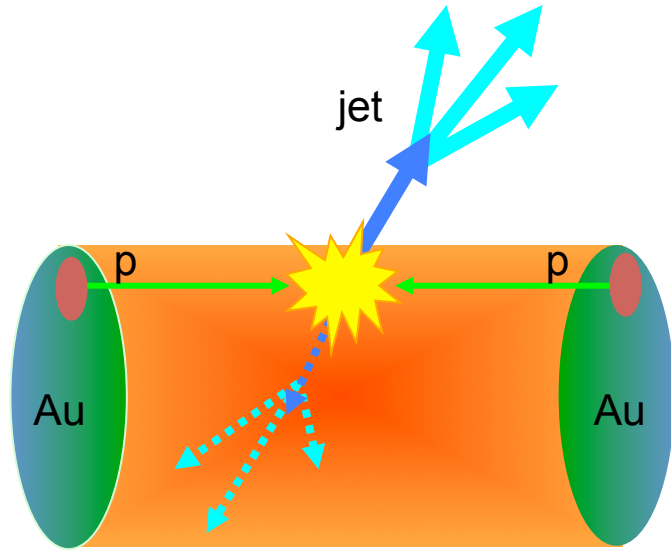
Forward calorimeter upgrade for ALICE experiment



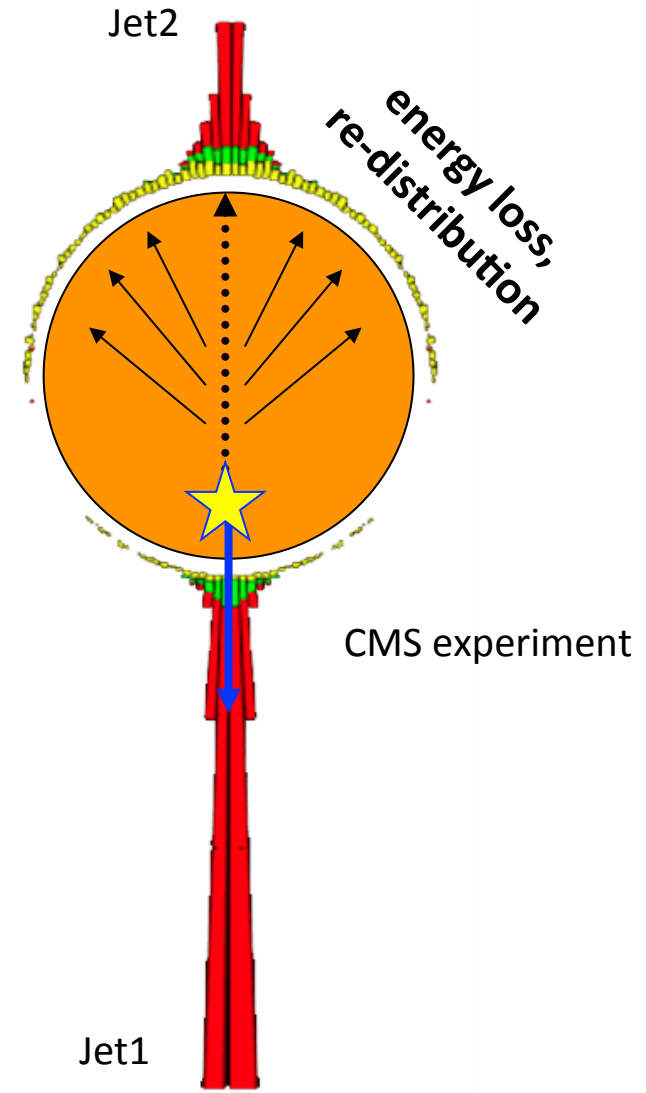
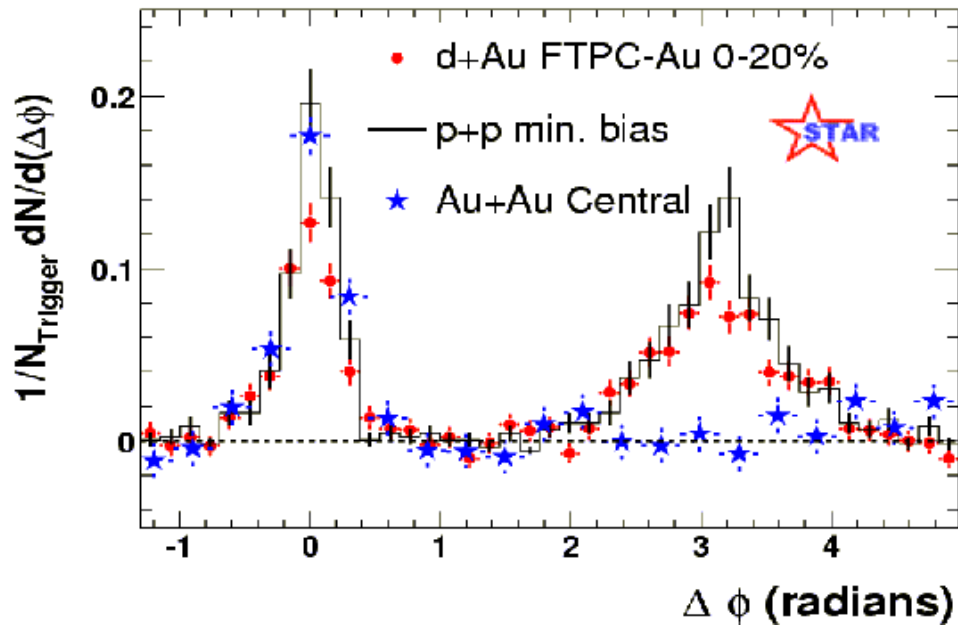
MRPC (and MPPC, ...) TOF R&D for future experiments

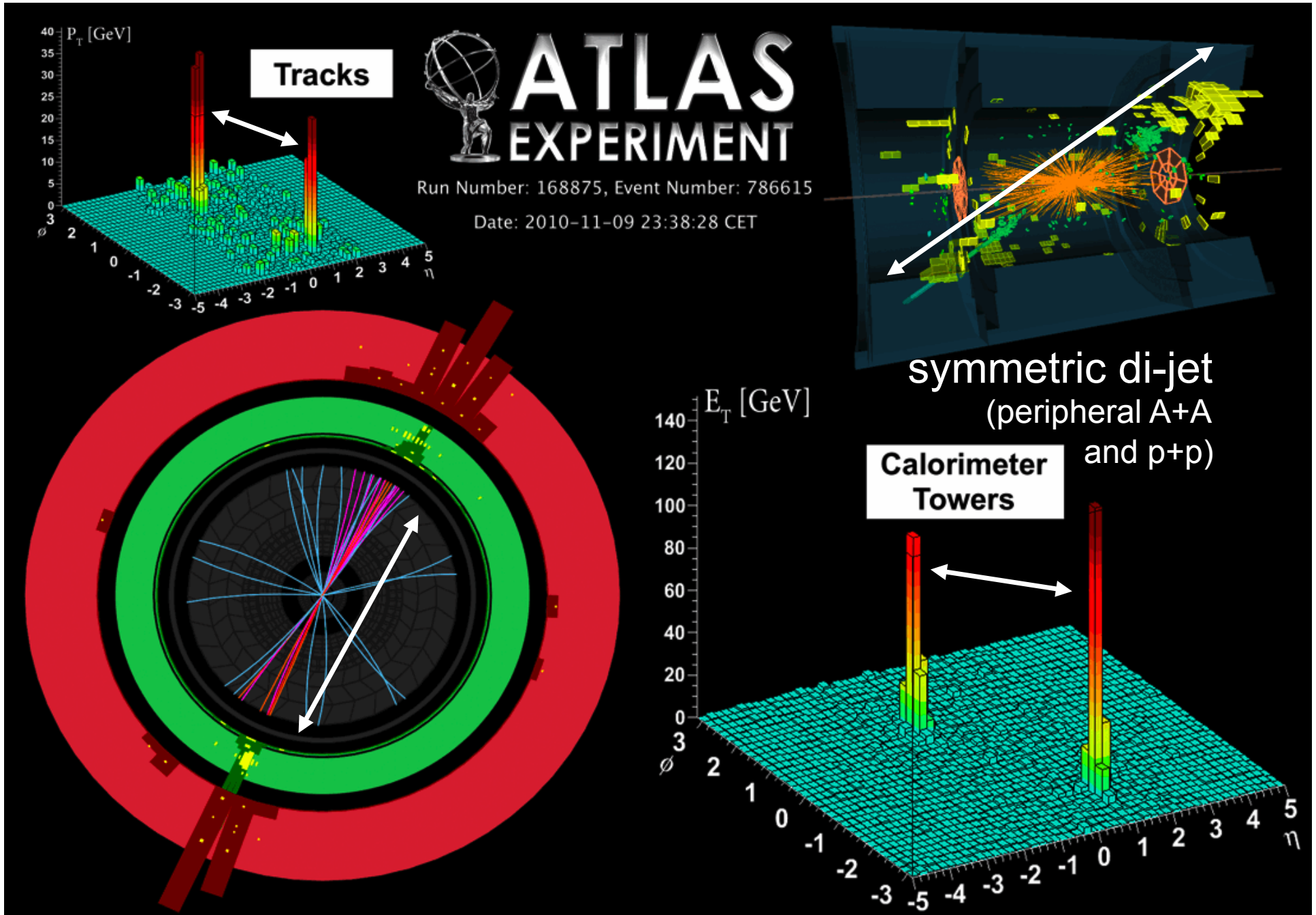


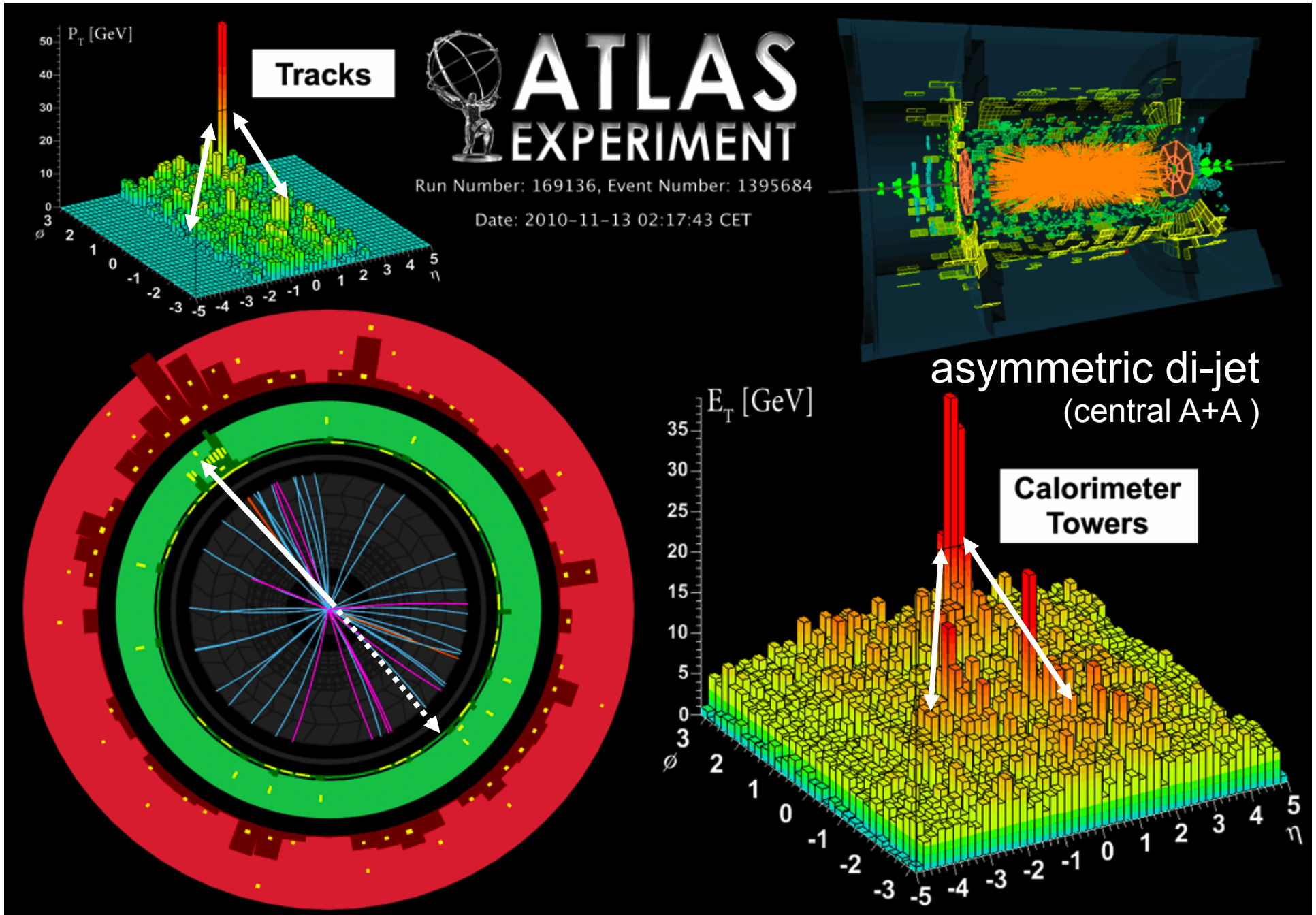
Energy loss of quark inside QGP



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

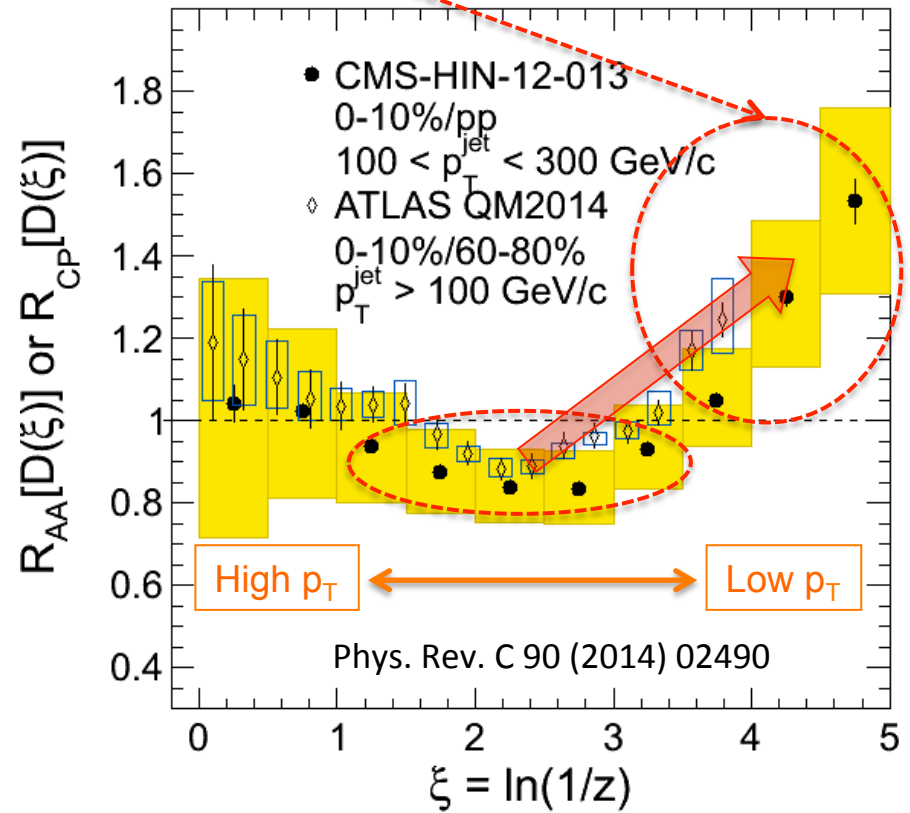
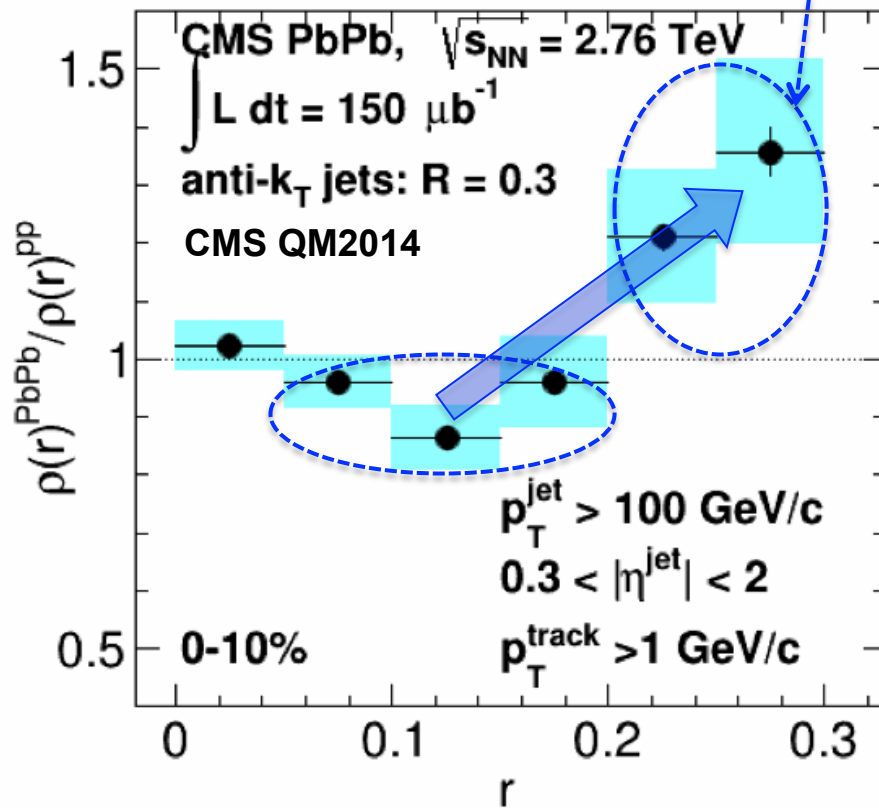
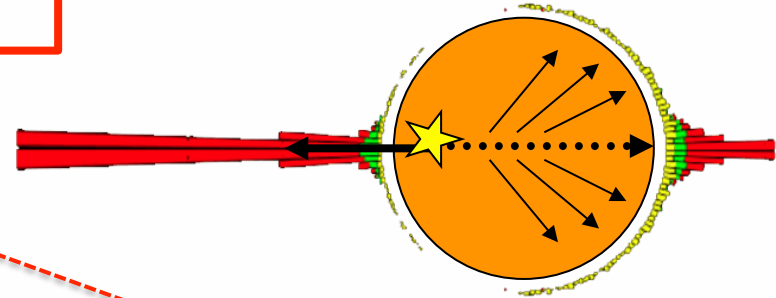






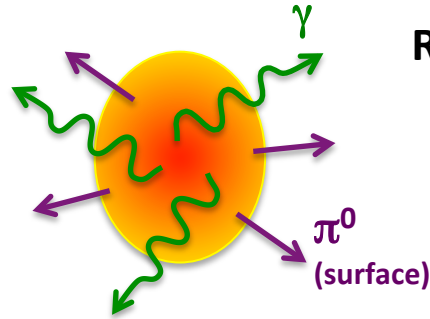
Modification of fragmentation function within a jet

- redistribution to low p_T
- redistribution to wide angle

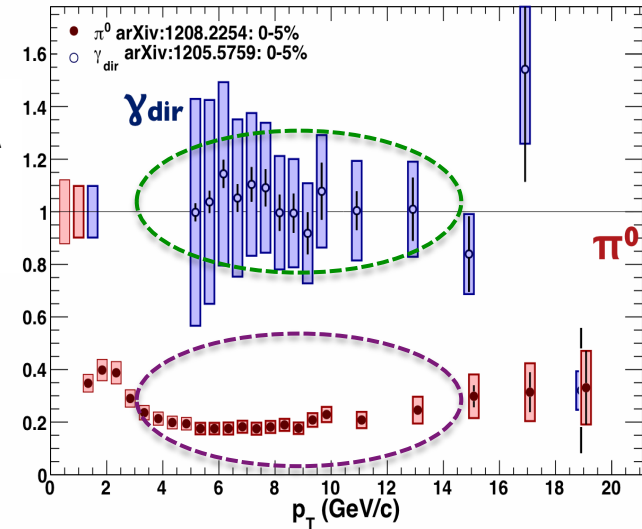


High p_T direct photon as penetrating probe

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

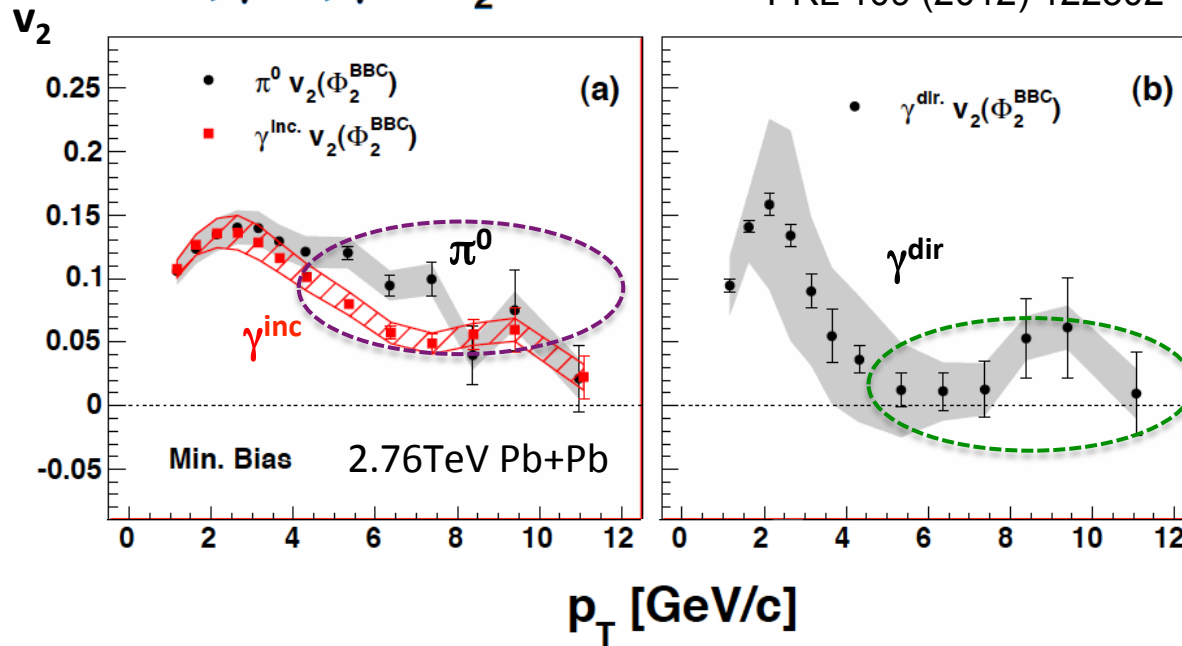


PRL 109 (2012) 152302



PRL 109 (2012) 122302

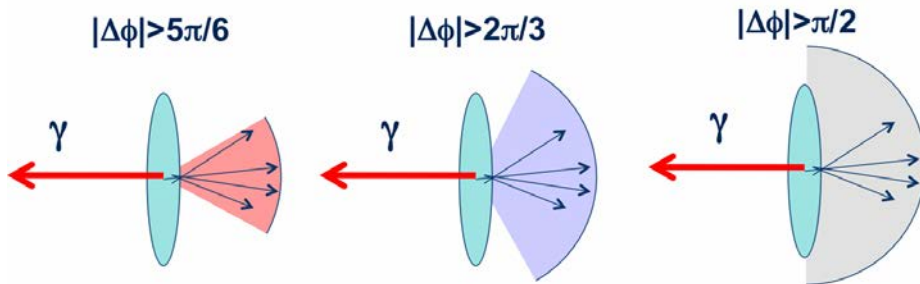
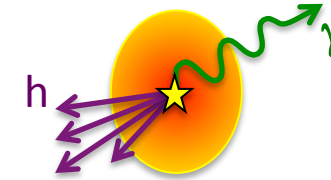
$\pi^0, \gamma^{\text{inc.}}, \gamma^{\text{dir.}} v_2$



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

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

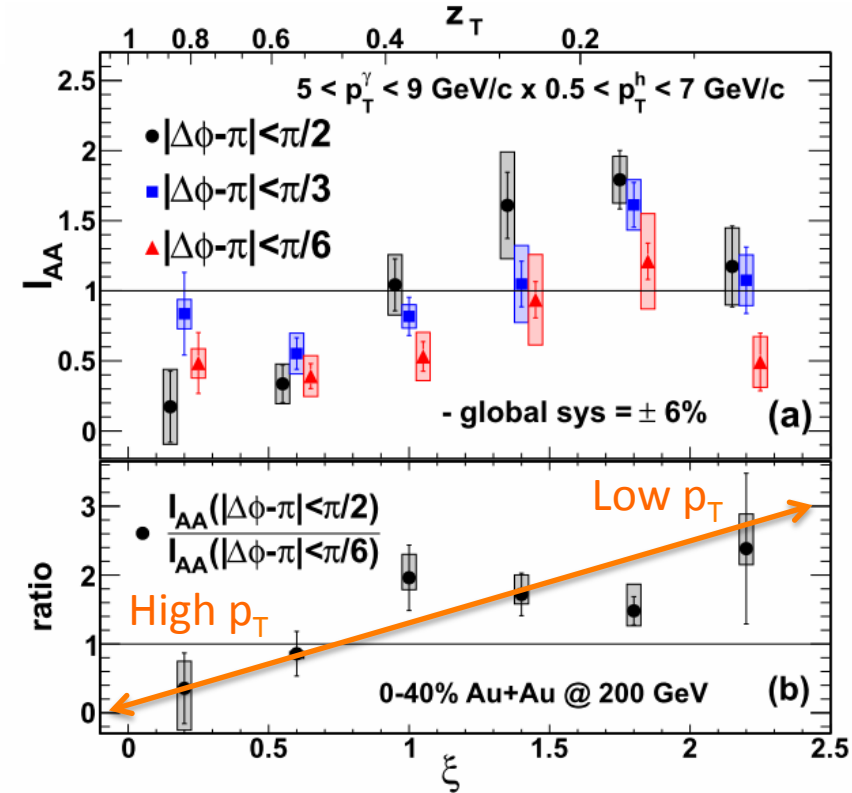
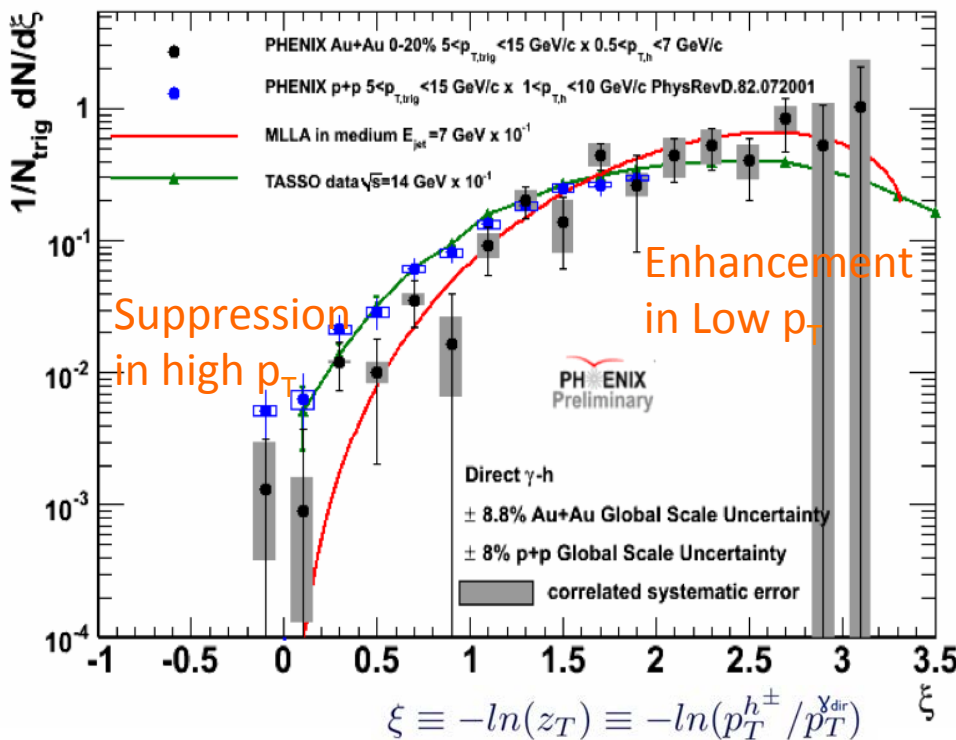


prompt photon - hadron correlation

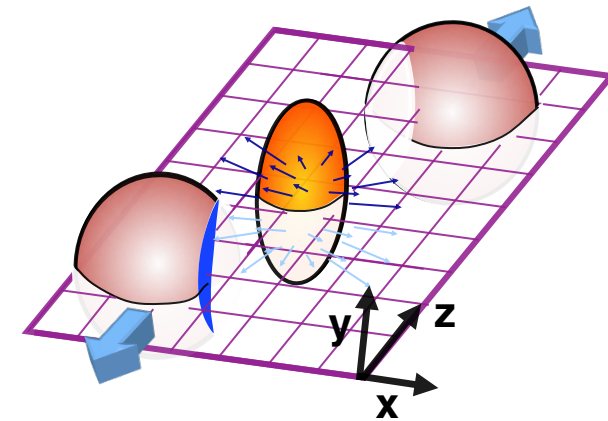
N_{PTY} = associate hadron yield per trigger γ

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

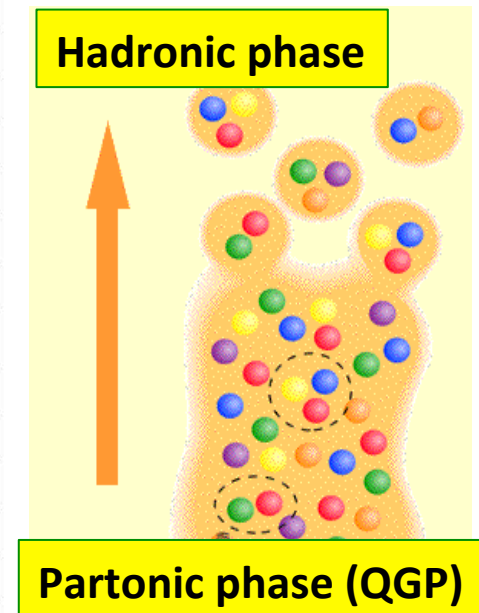
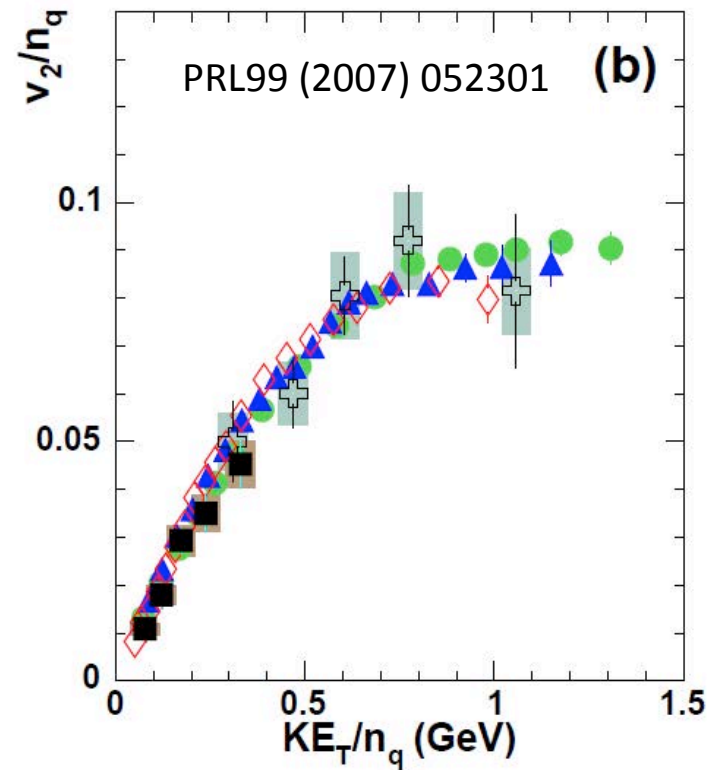
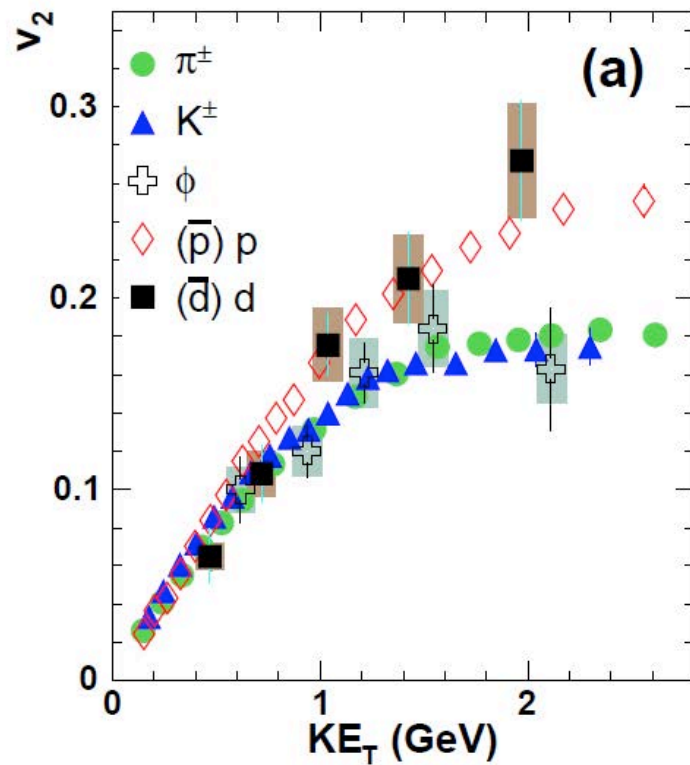
PRL 111 (2013) 032301



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



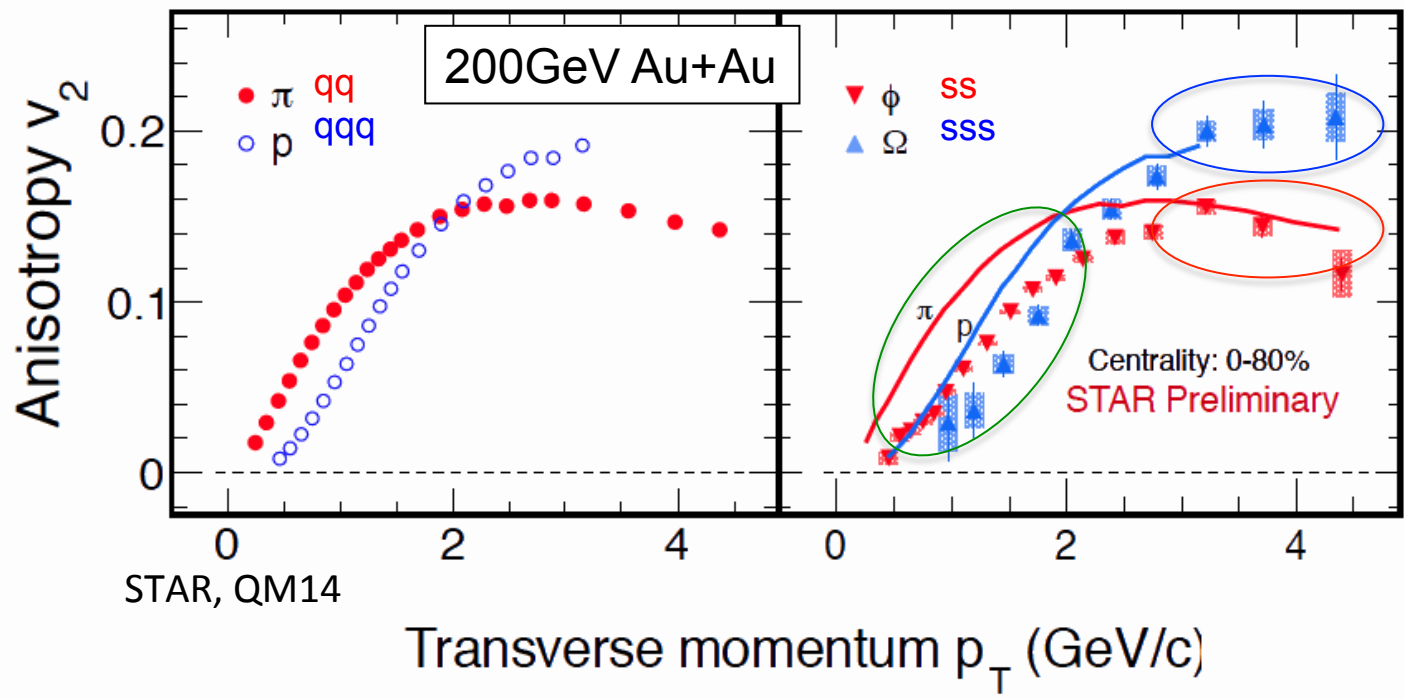
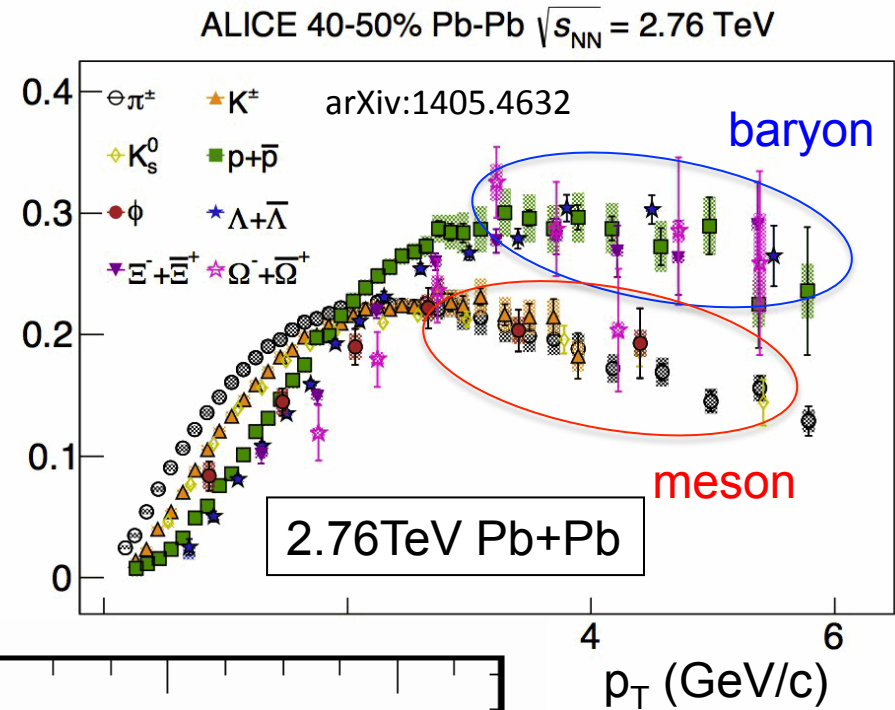
Indication of quark flow (in partonic phase)



“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

$v_2\{SP, |\Delta\eta| > 0.9\}$

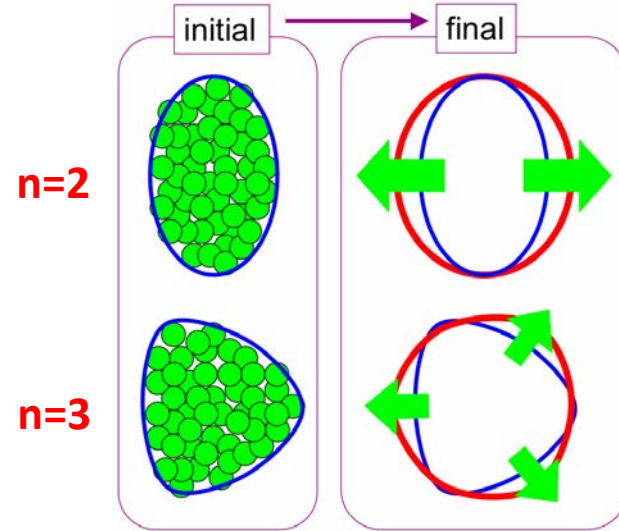
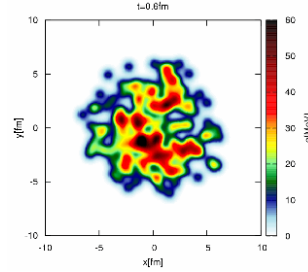
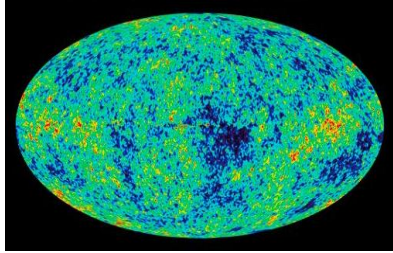


baryon

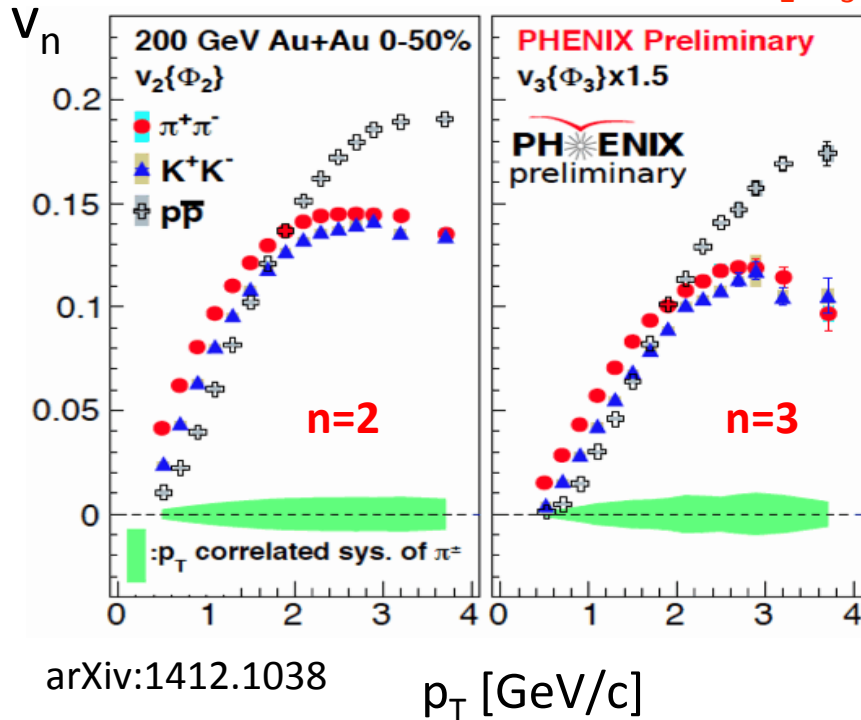
meson

Number of quark scaling as a signal of partonic phase

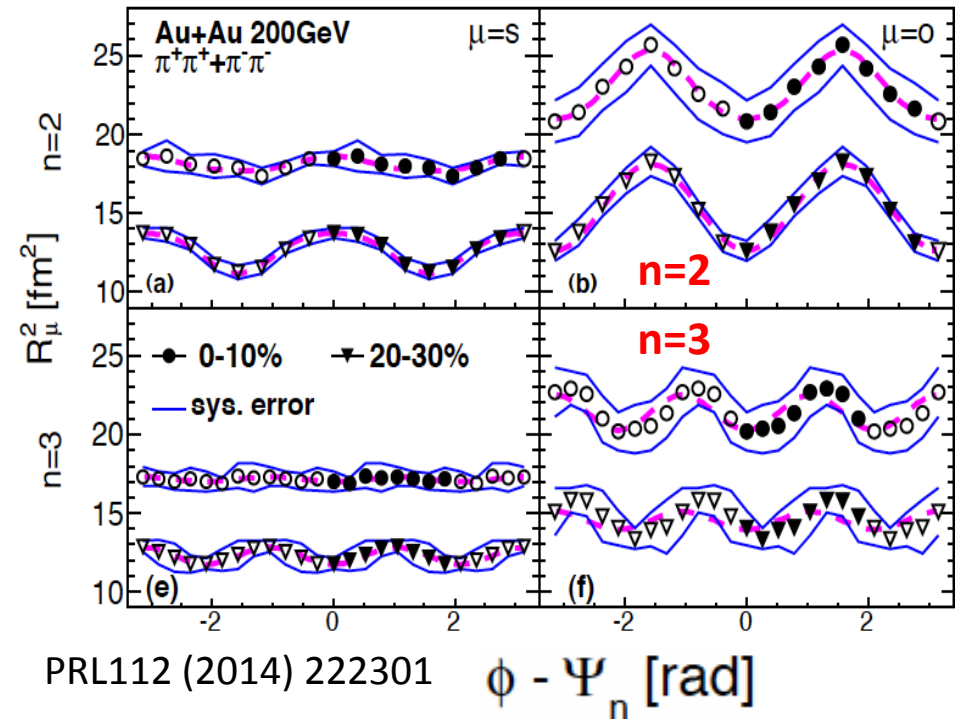
Elliptic and triangular expansion and freeze-out geometry



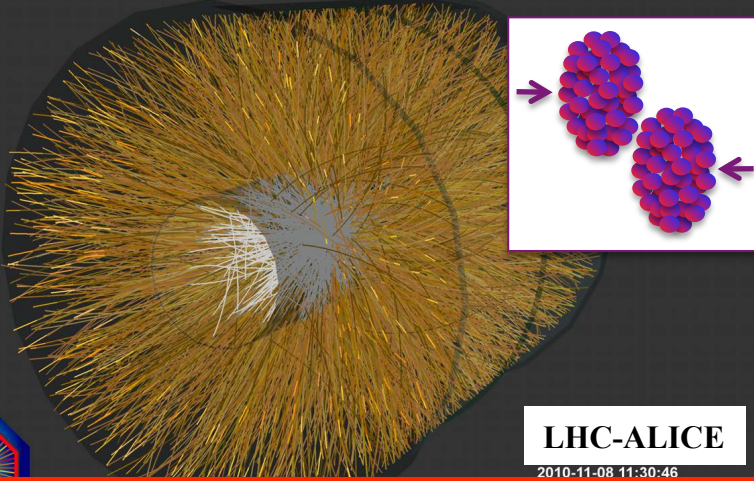
Elliptic and Triangular expansion : v_2, v_3



Elliptic and Triangular shape : $R_{\Phi_2}^{\text{HBT}}, R_{\Phi_3}^{\text{HBT}}$



A+A collision : a large system

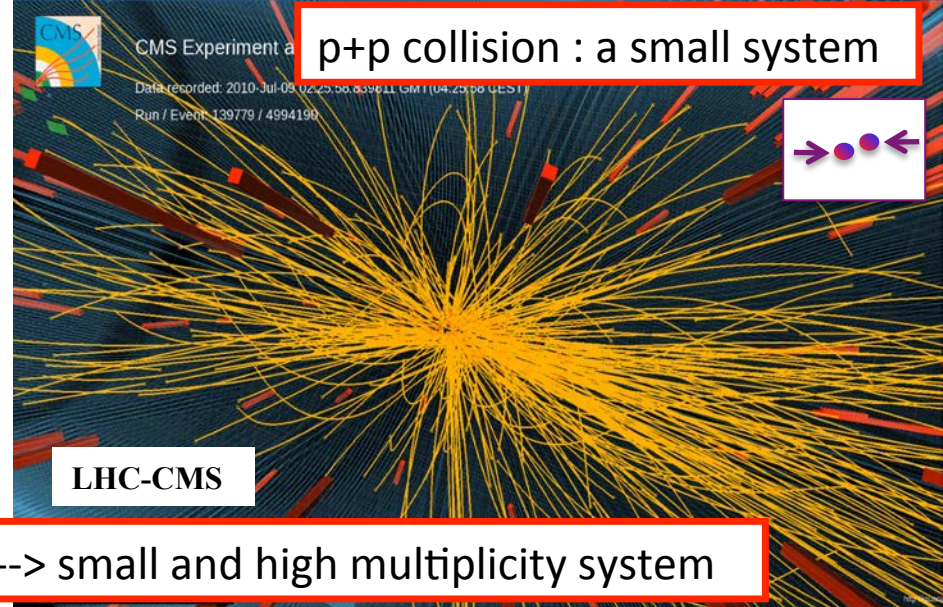


LHC-ALICE

2010-11-08 11:30:46

Results from High Multiplicity pp

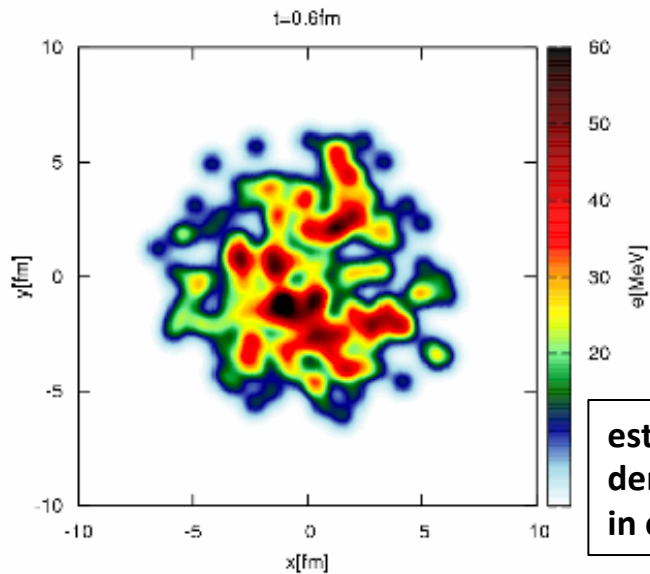
p+p collision : a small system



LHC-CMS

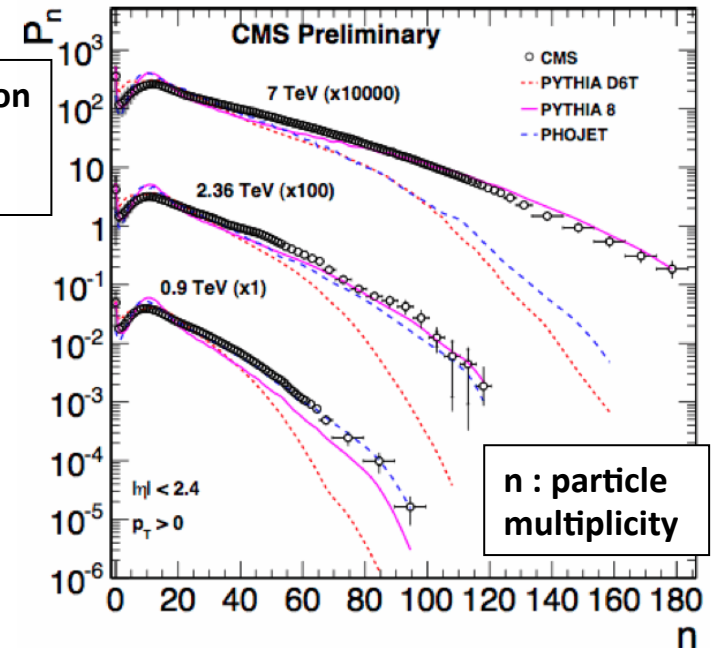
ALICE

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



Probability distribution of event with "n" particles production

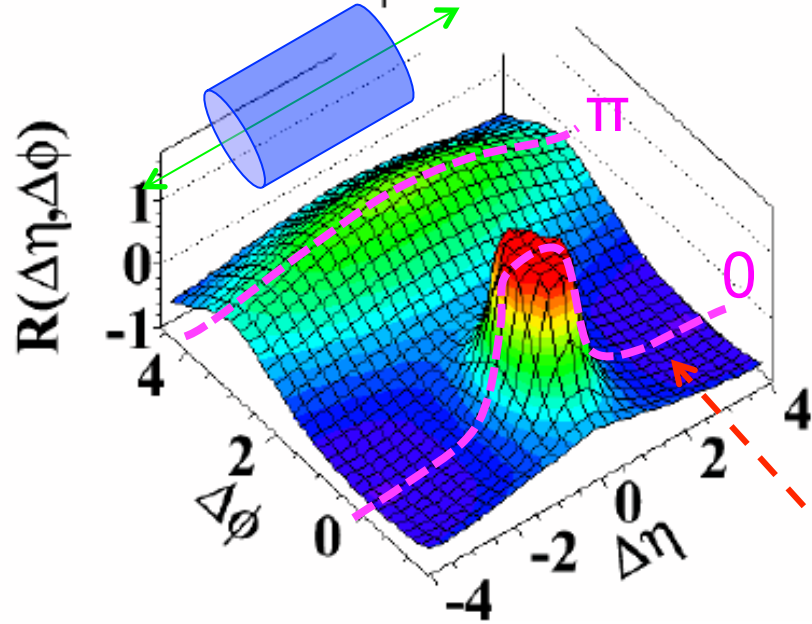
estimated initial energy density distribution in central A+A collision



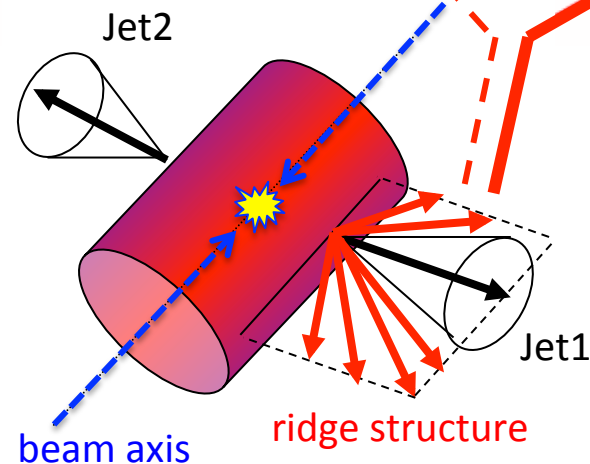
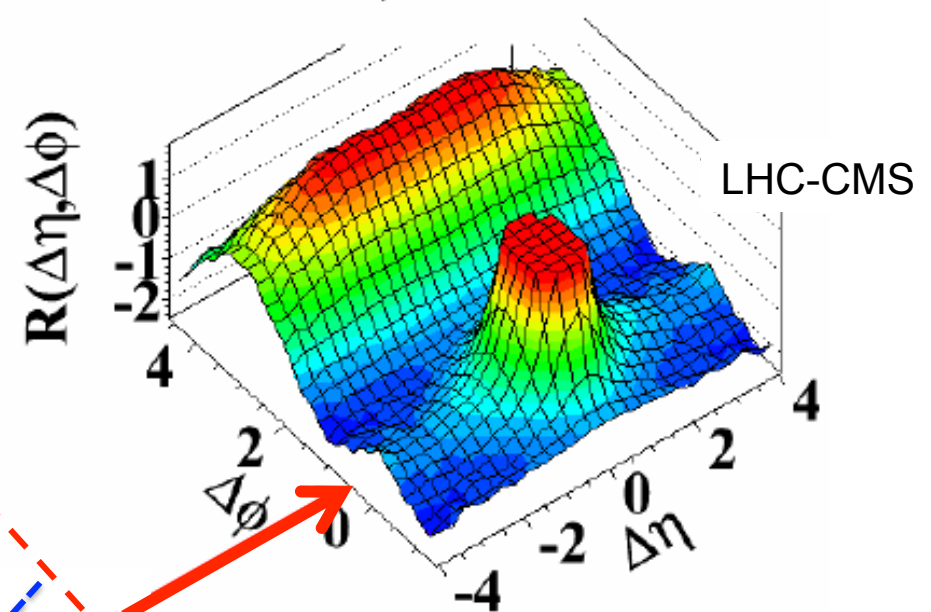
minimum bias p+p events

high multiplicity p+p events

(b) MinBias, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$

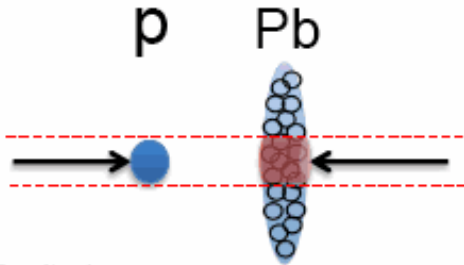


(d) $N > 110$, $1.0\text{GeV}/c < p_T < 3.0\text{GeV}/c$



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

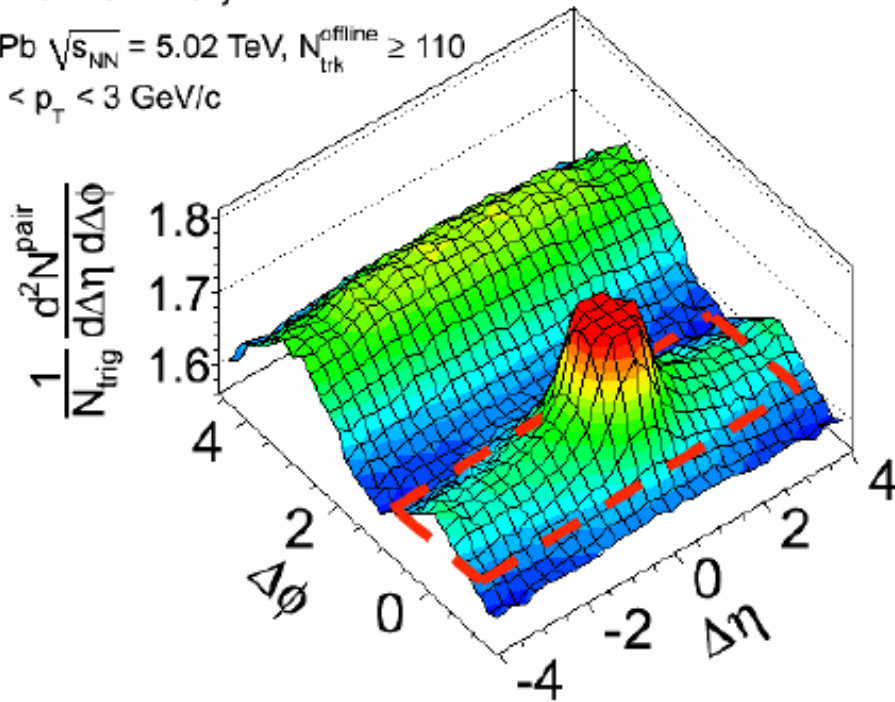
p+A collisions



CMS Preliminary

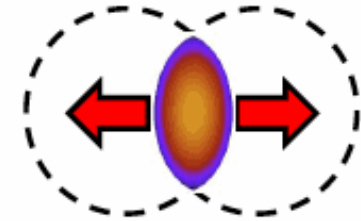
pPb $\sqrt{s_{NN}} = 5.02$ TeV, $N_{trk}^{offline} \geq 110$
 $1 < p_T < 3$ GeV/c

LHC-CMS



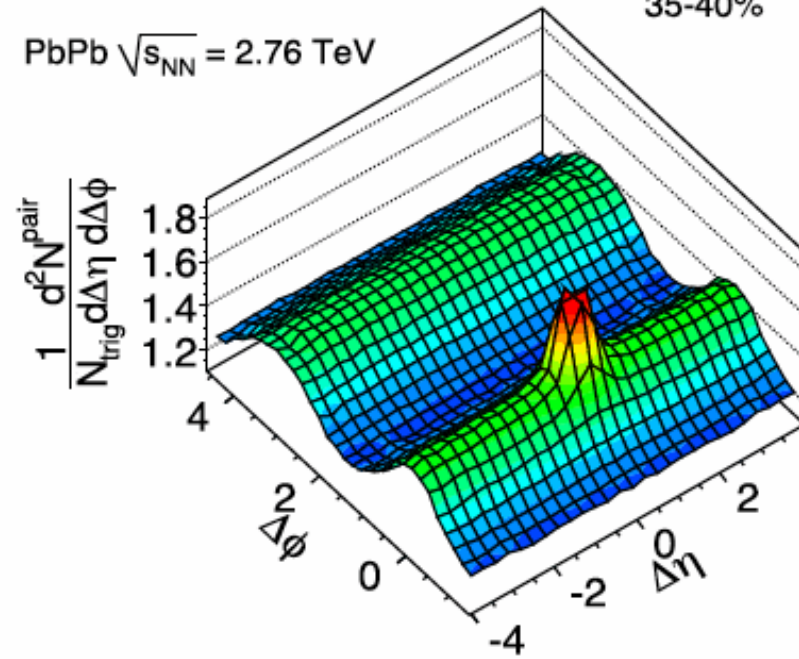
A+A collisions

Initial-state geometry
 +
 collective expansion

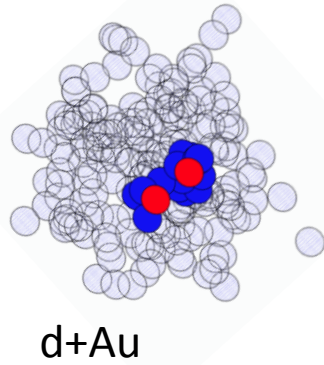


35-40%

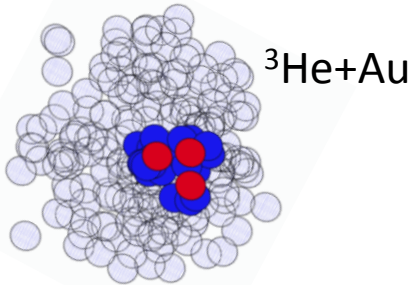
PbPb $\sqrt{s_{NN}} = 2.76$ TeV



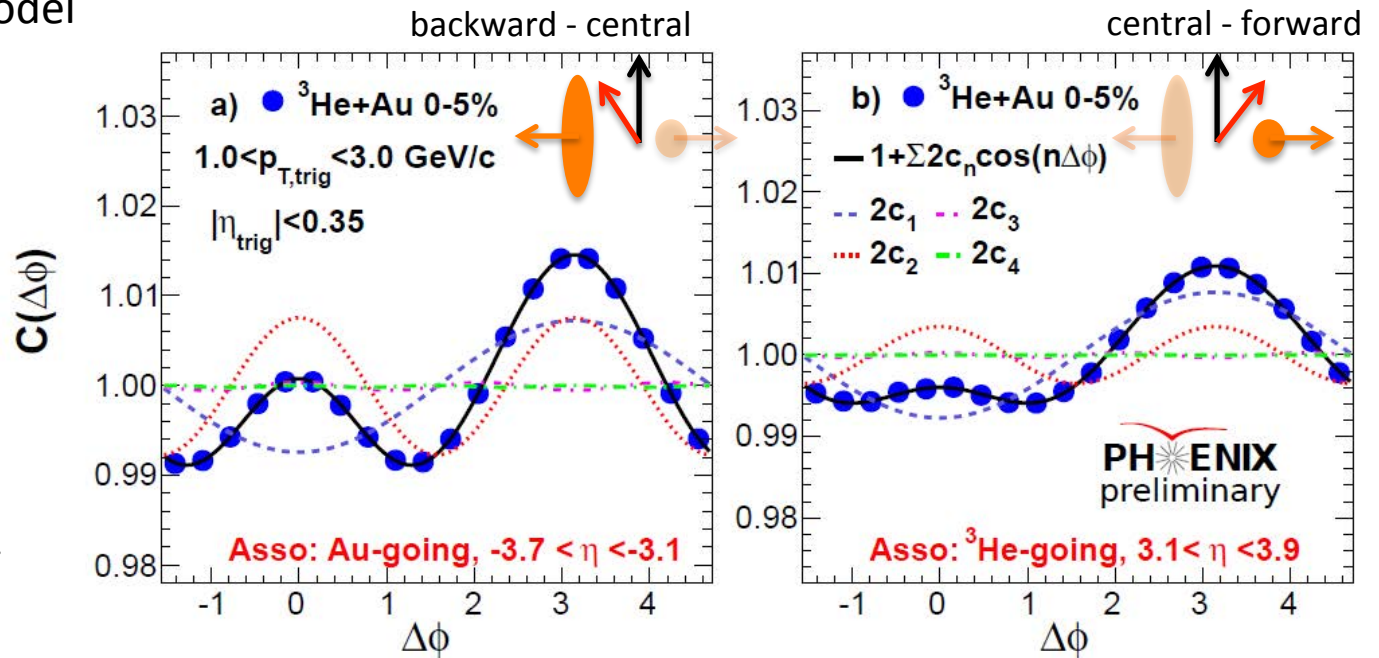
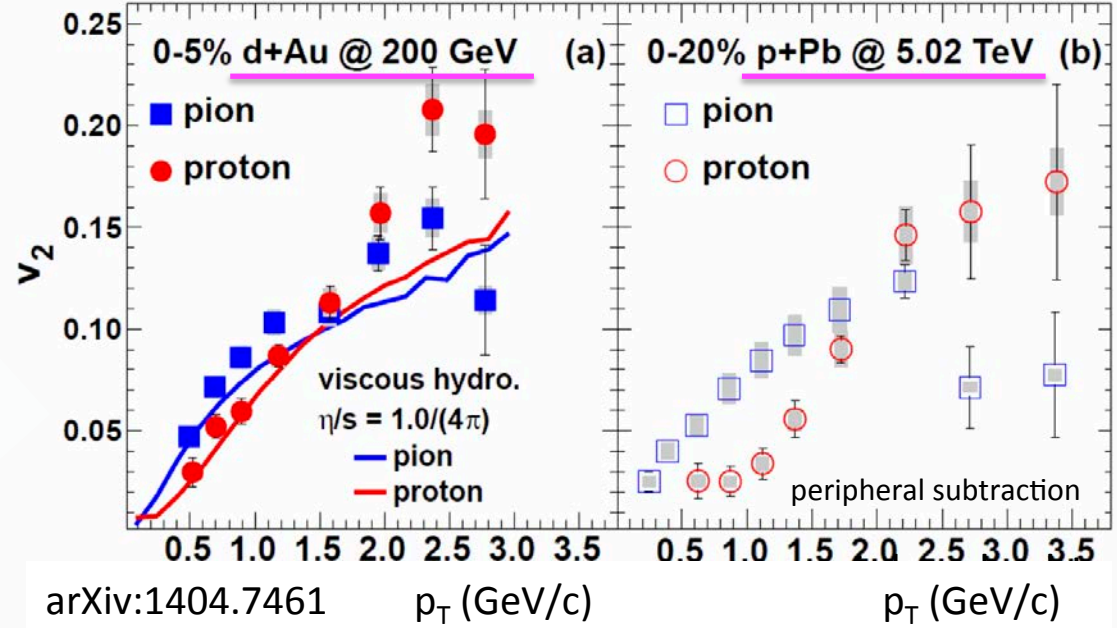
Elliptic flow
in small system?



Glauber model

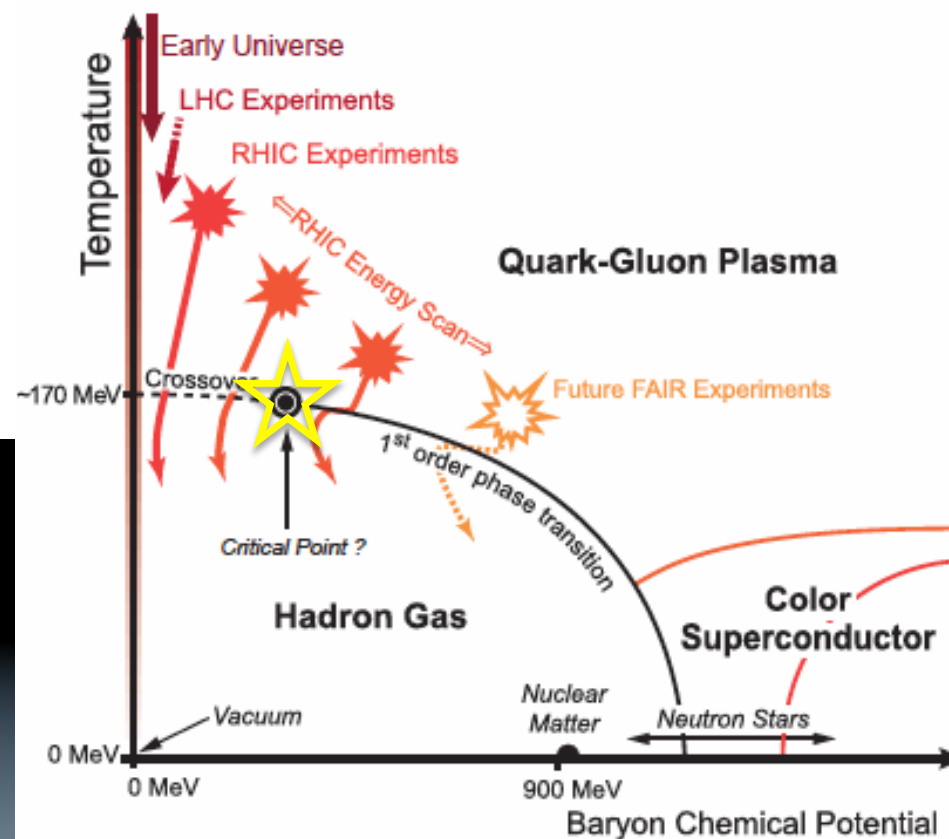
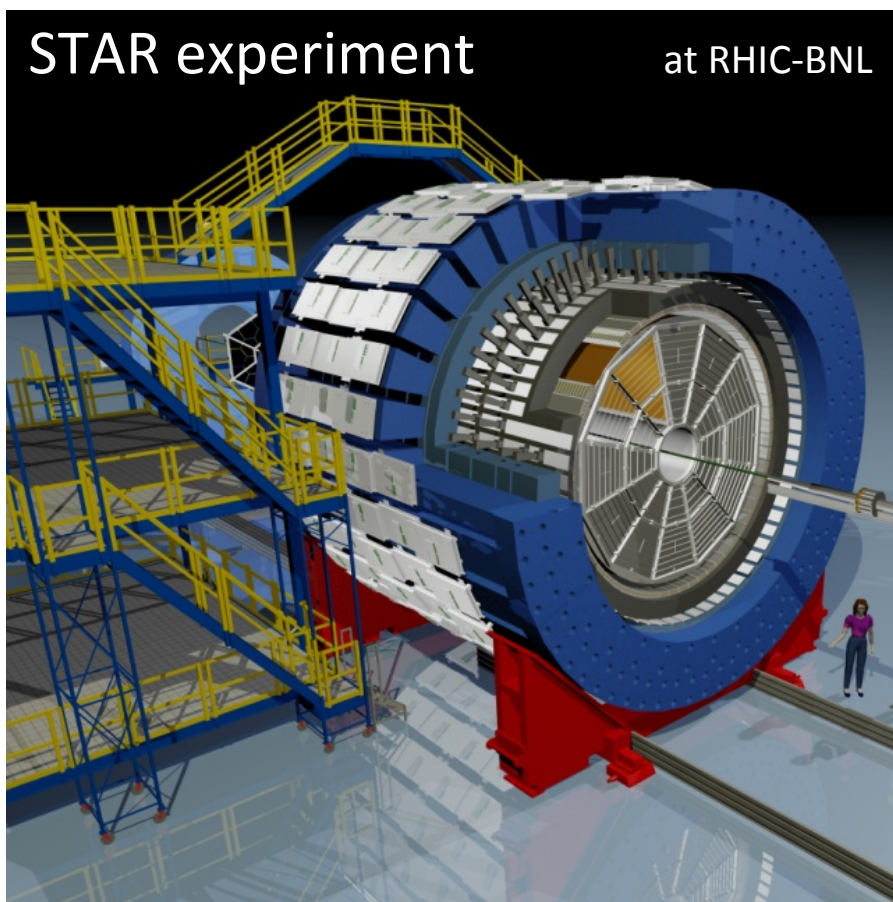


new ³He+Au collision
data from RHIC-RUN14



Critical Point Search

Beam Energy Scan Program
at RHIC beam energy regime

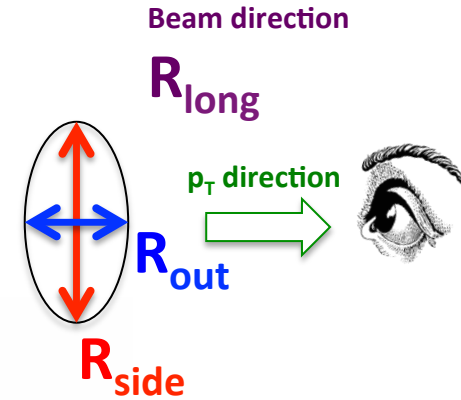
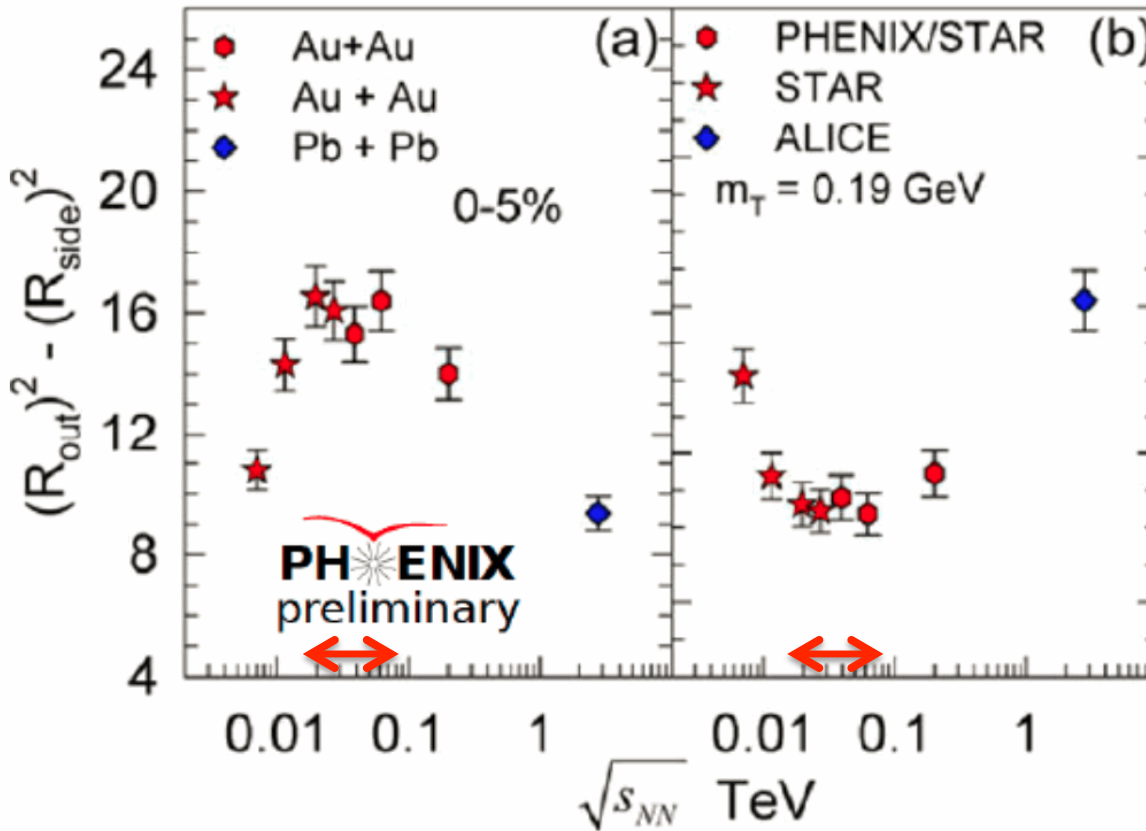


- Divergence of fluctuation around Critical Point
- end point of 1st order phase transition

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

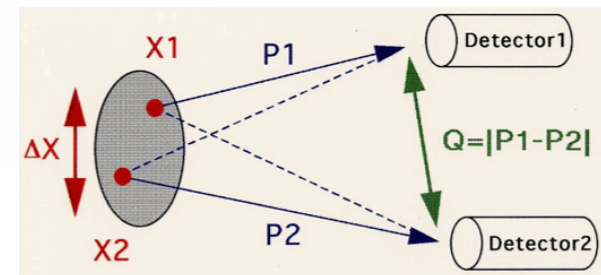
arXiv:1410.2559

$\sim \Delta\tau$



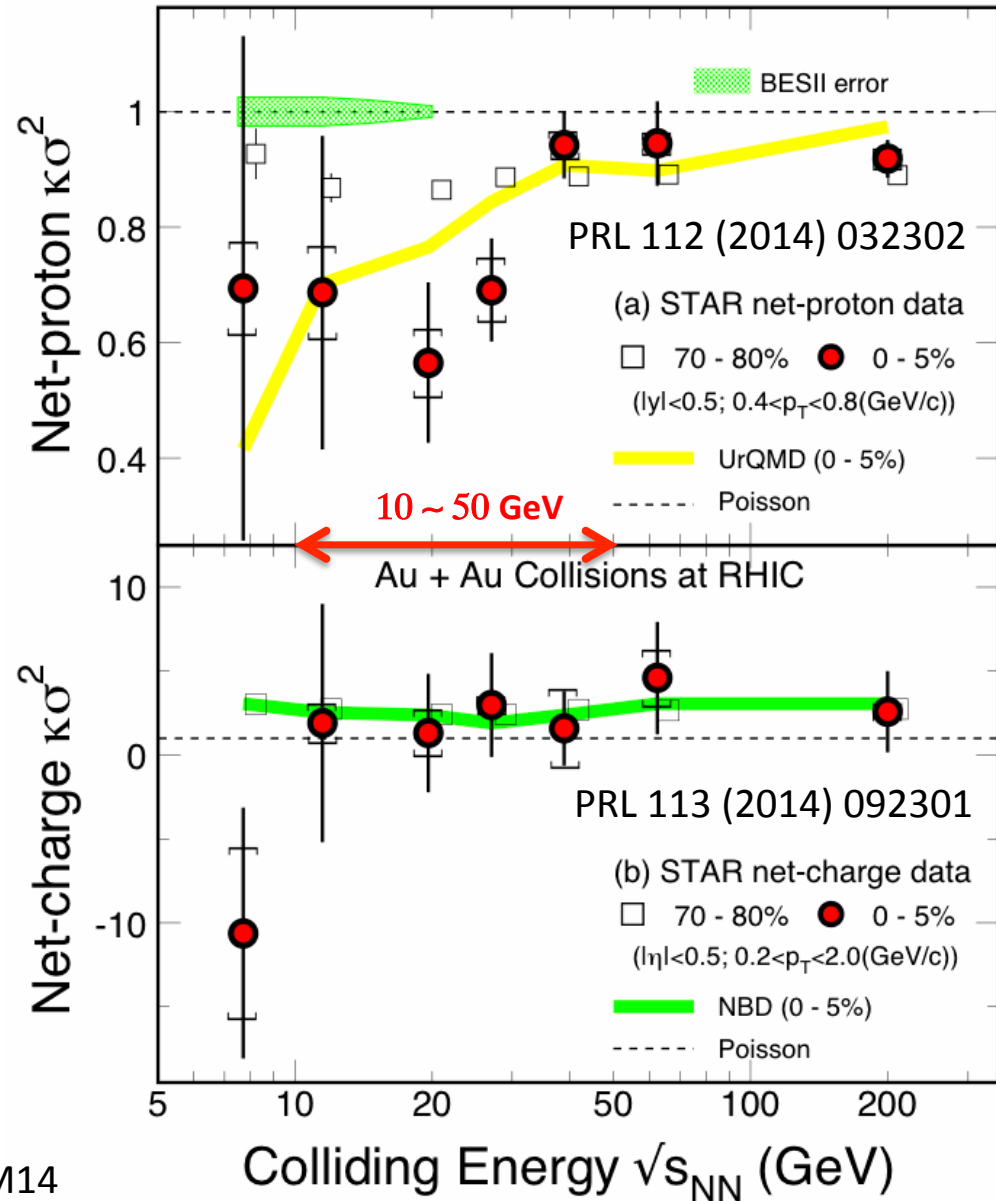
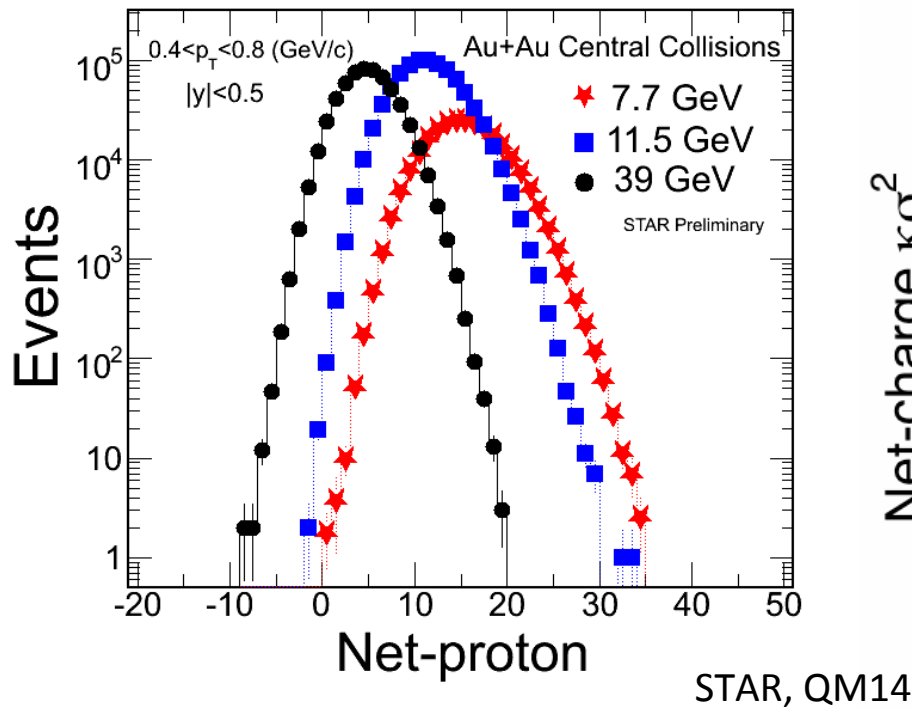
$(R_{side} - \sqrt{2R}) / R_{long}$

$\sim V_{expansion}$

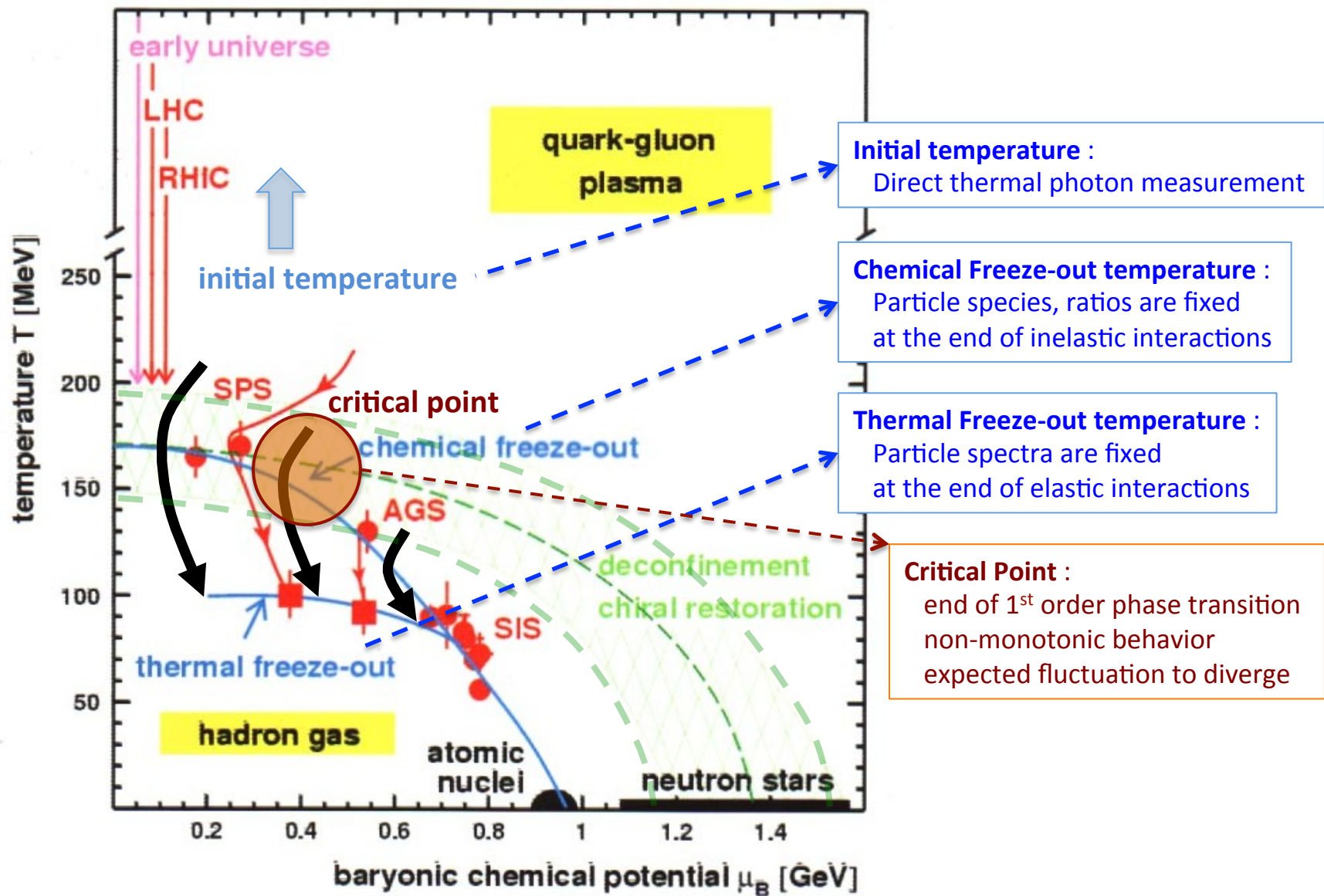


Fluctuation of conserved quantity vs beam energy

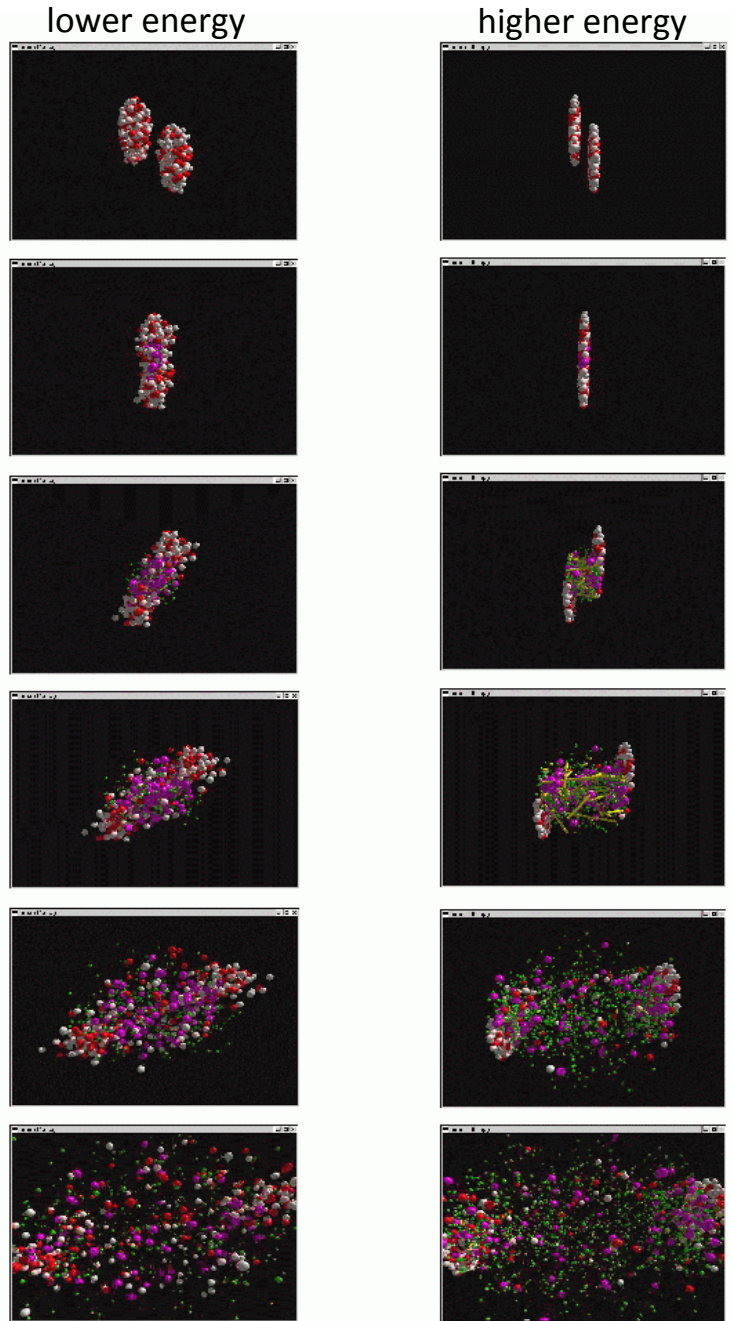
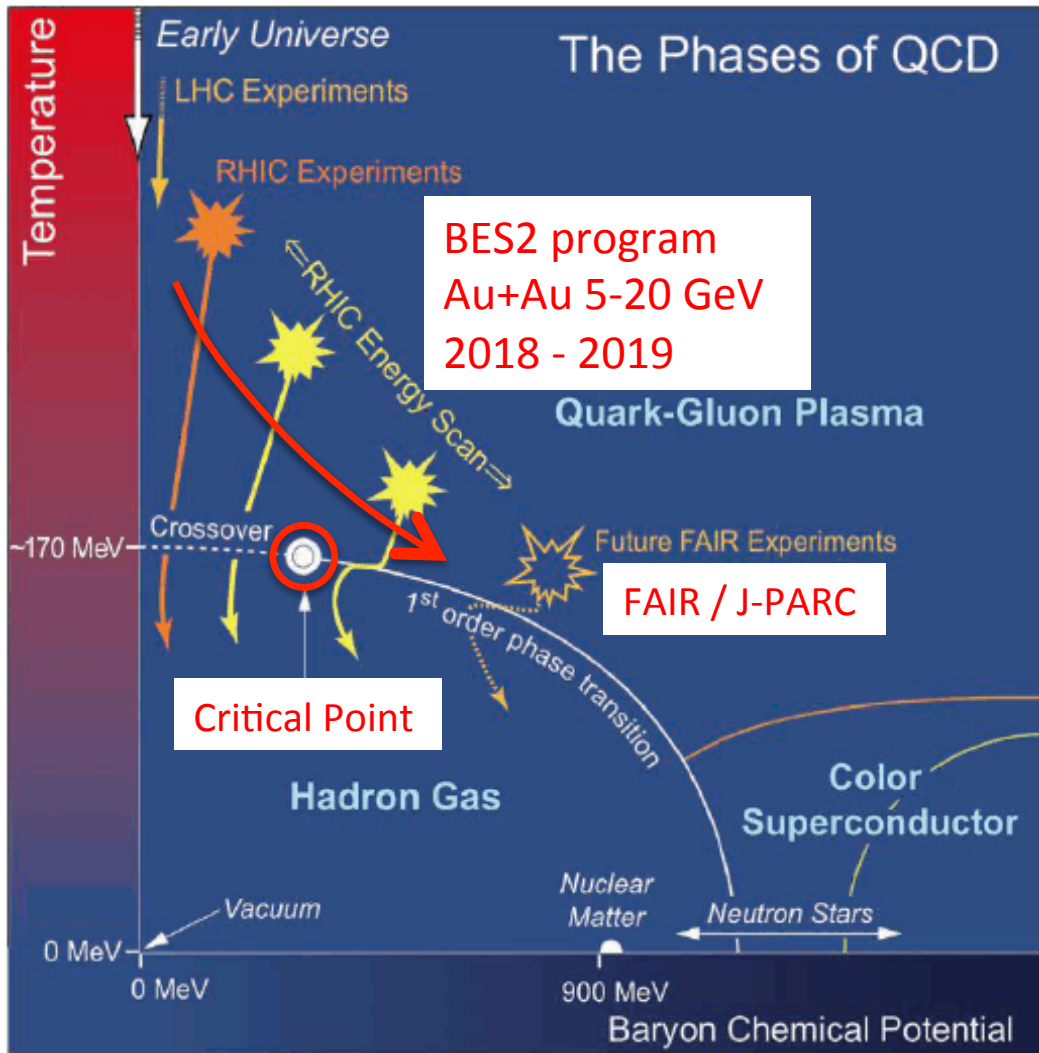
- Higher order moments (σ , S , κ) of net-baryon (net-proton) and net-charge distribution
- Non-monotonic behavior is expected around Critical Point.



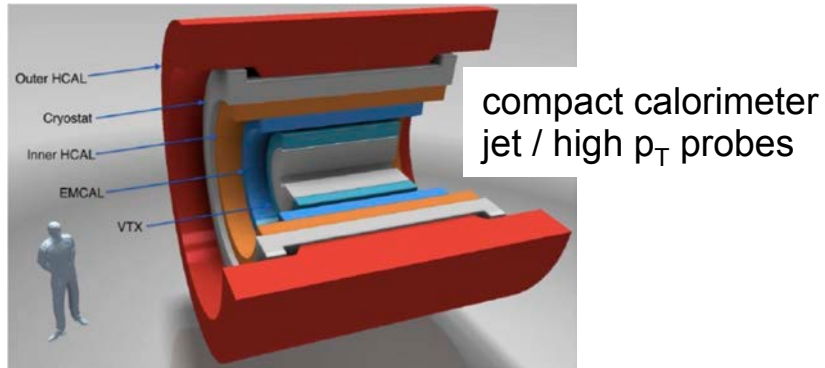
History of temperature before/after the phase transition



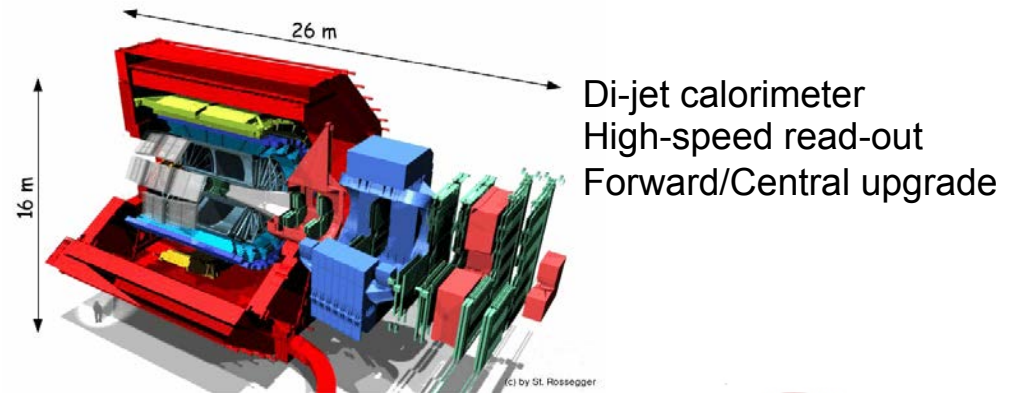
From high-temperature to high-density with Beam Energy Scan (BES) program



sPHENIX at RHIC-BNL (New York, USA)

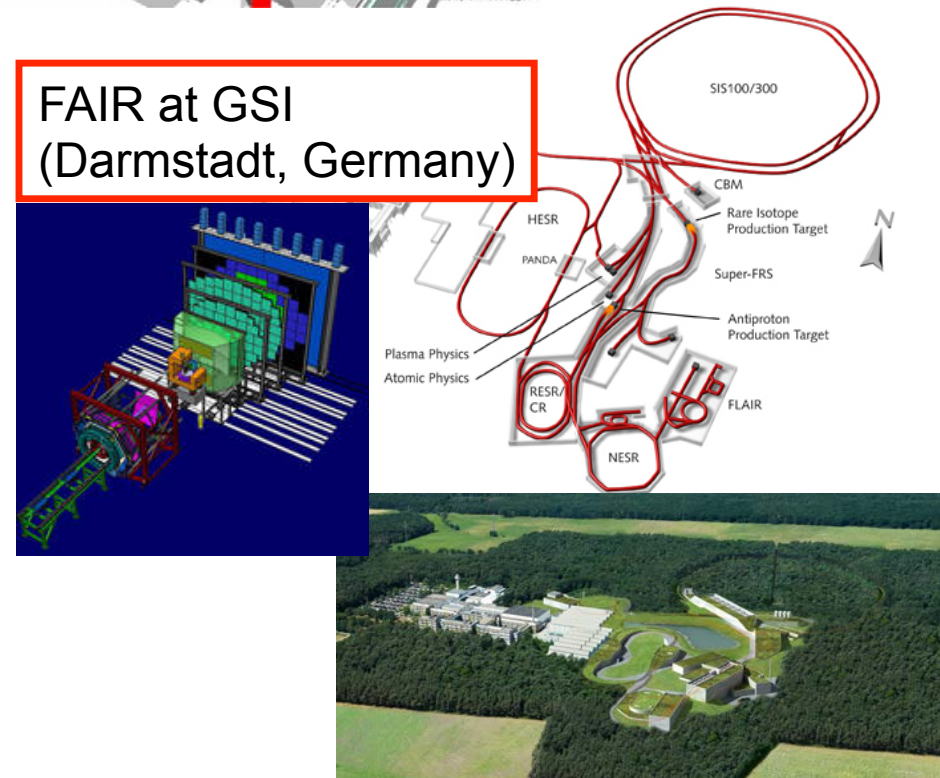


ALICE at LHC-CERN for Luminosity upgrade (Geneva, Switzerland)



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

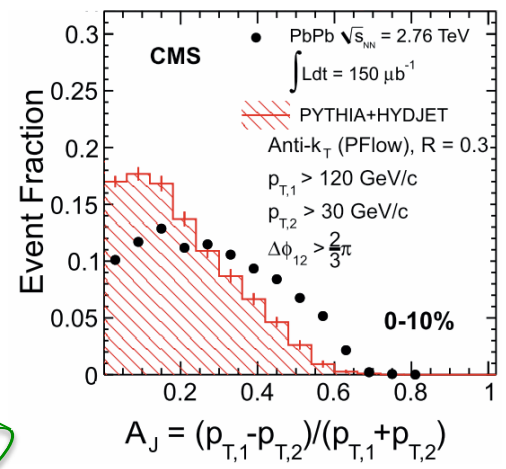
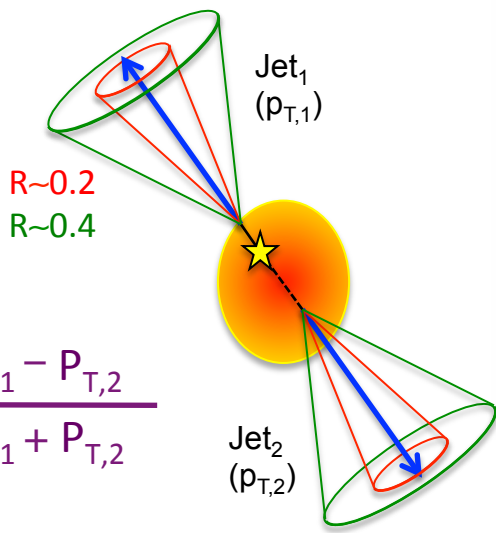
FAIR at GSI (Darmstadt, Germany)



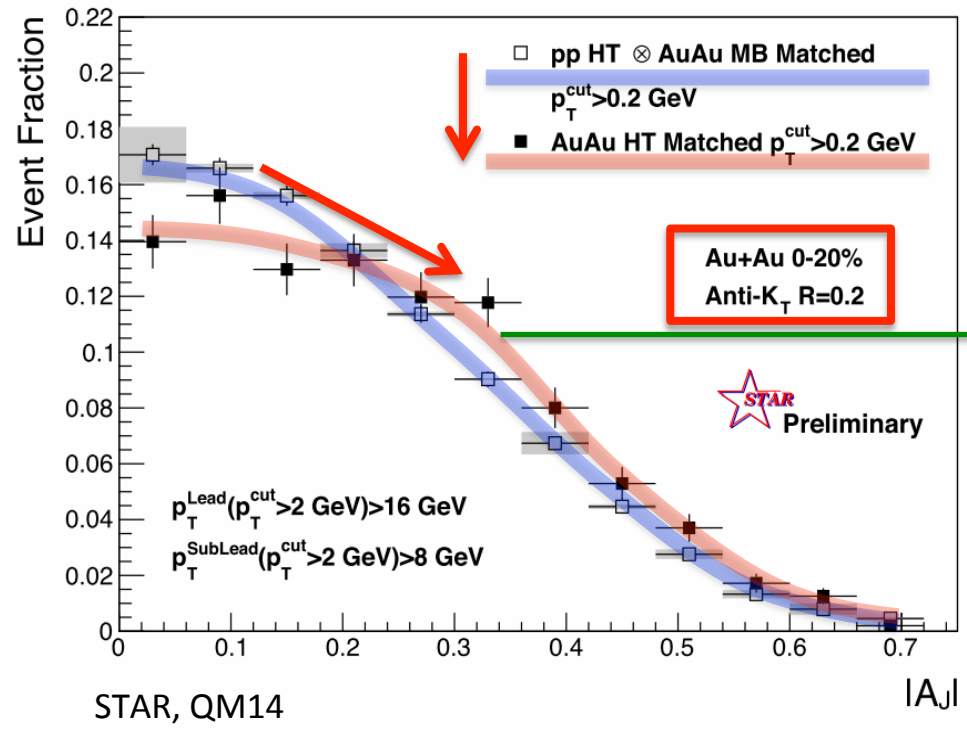
Difference of energy loss (A_J) between RHIC and LHC

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

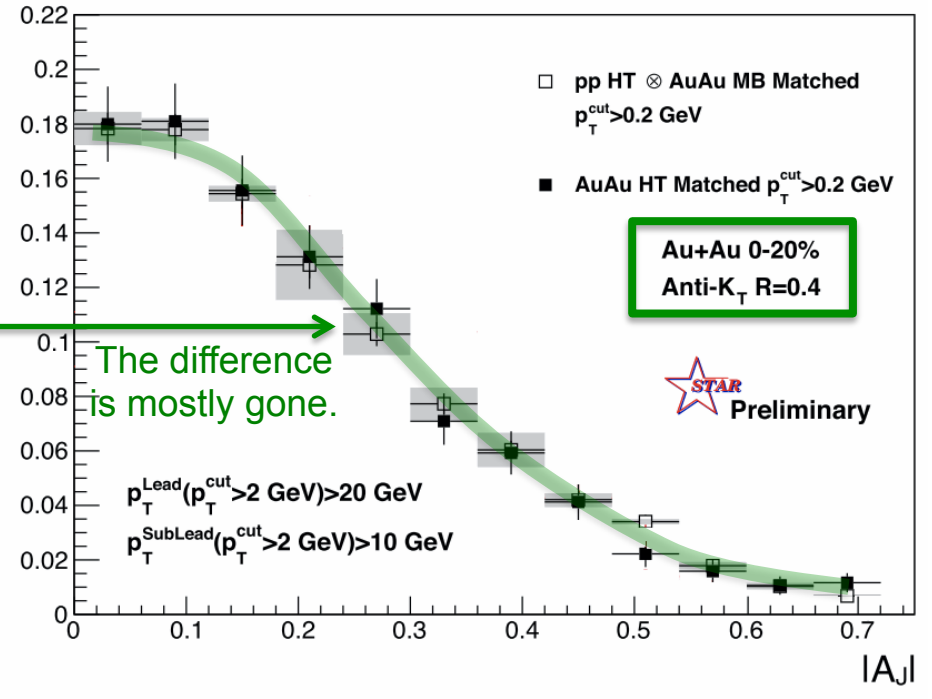
$$A_J = \frac{P_{T,1} - P_{T,2}}{P_{T,1} + P_{T,2}}$$



Anti- k_T $R=0.2$, $p_{T,1} > 16$ GeV & $p_{T,2} > 8$ GeV with $p_T^{cut} > 2$ GeV/c



Anti- k_T $R=0.4$, $p_{T,1} > 20$ GeV & $p_{T,2} > 10$ GeV with $p_T^{cut} > 2$ GeV/c



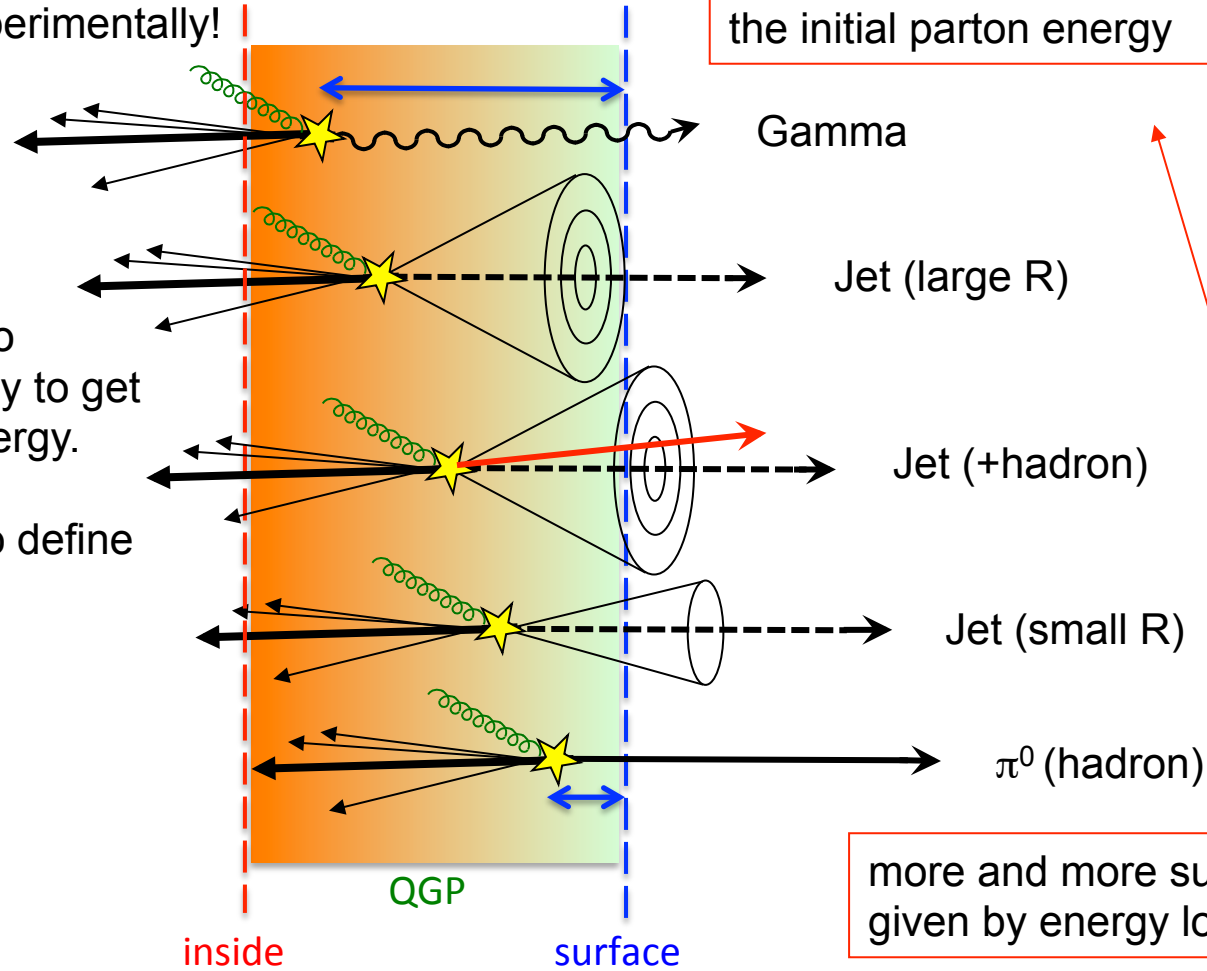
Systematic test of energy loss and redistribution with photons, jets and hadrons

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

Closer and closer to the initial parton energy

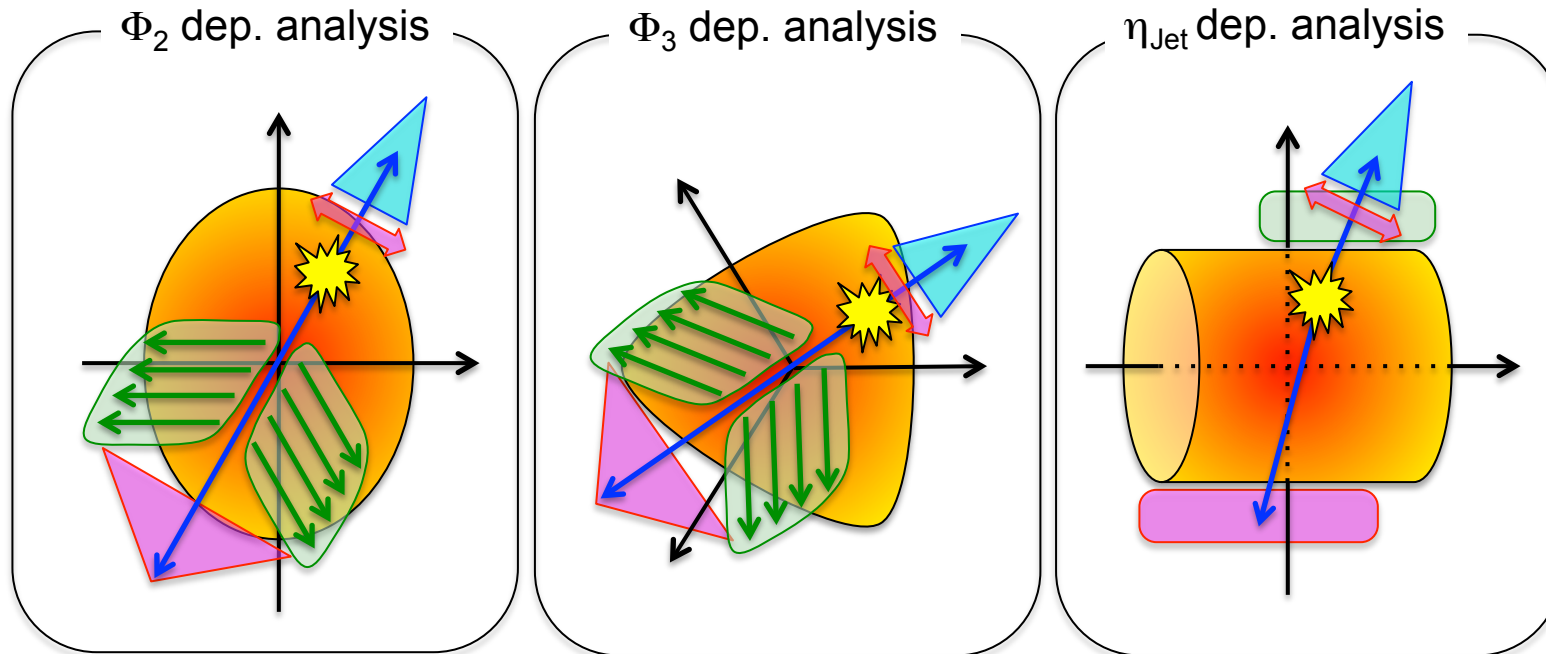
Jet reconstruction is to recover the lost energy to get the original parton energy.

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



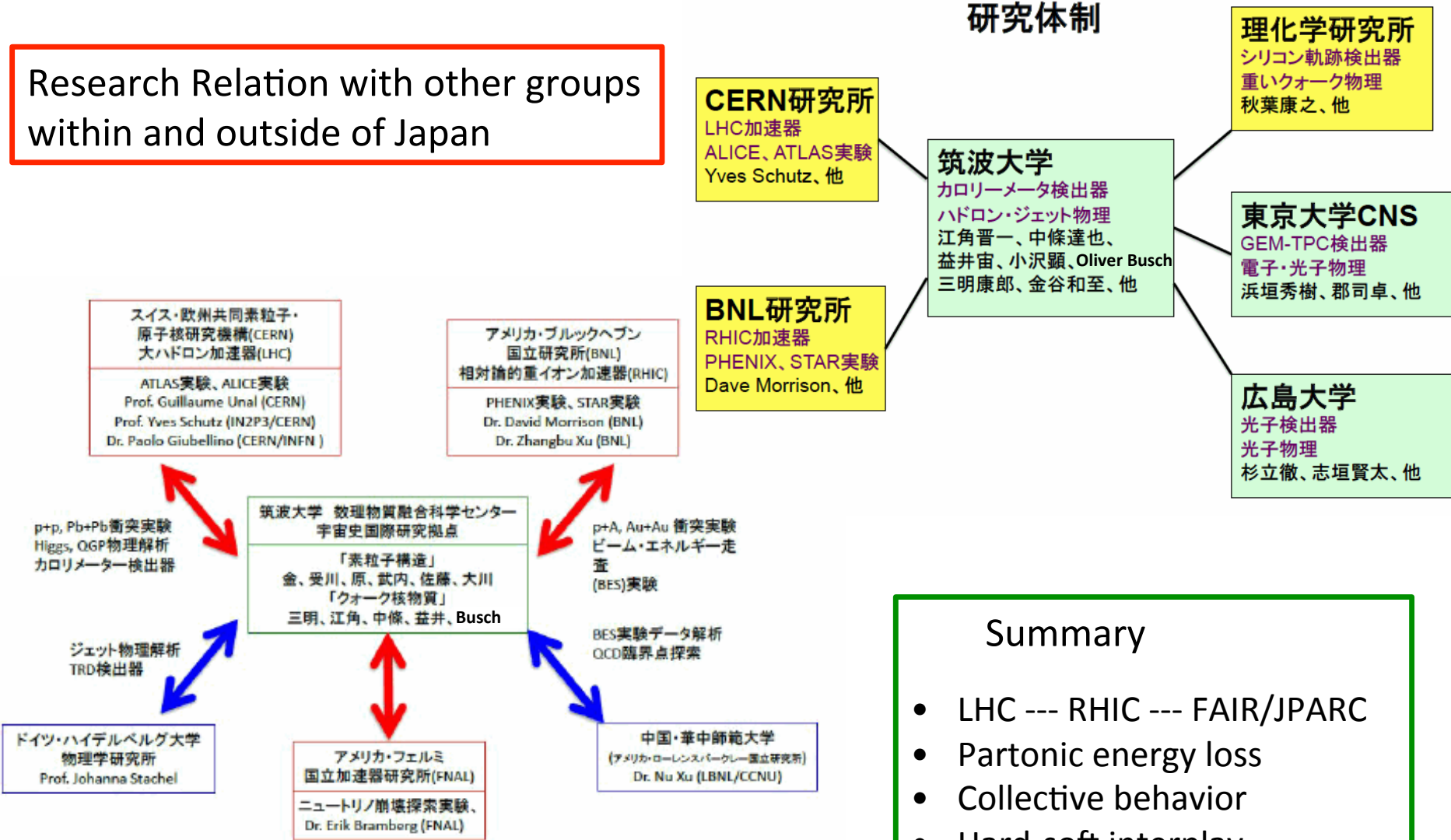
methods

- 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

クォーク・核物質部門
研究体制



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