Search for Critical Point with Beam Energy Scan

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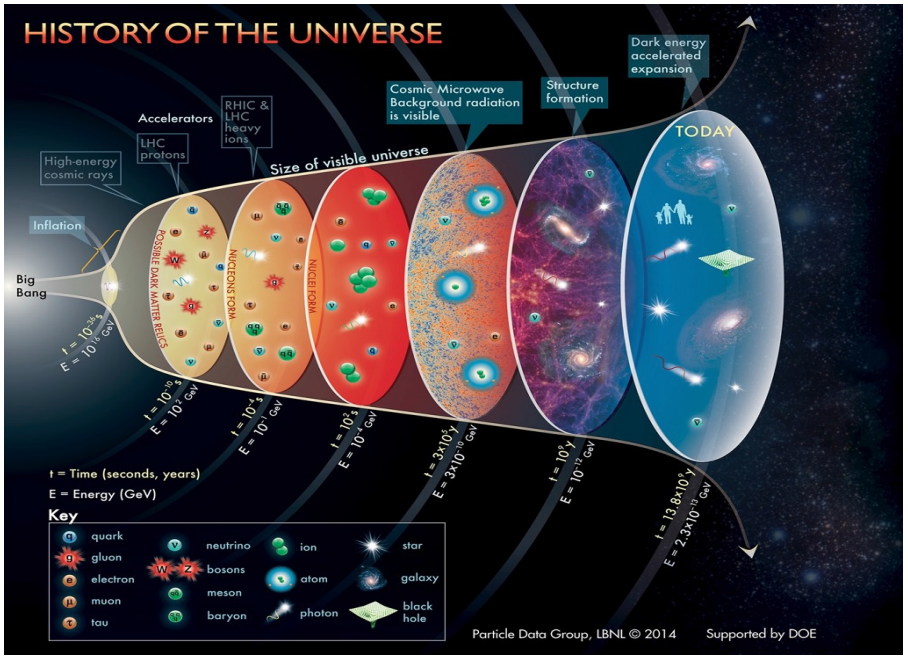
Contents

- Facilities and Experiments
- Collective flow and freeze-out
- Vortical and chiral magnetic fluid
- Fluctuation and critical point
- Summary



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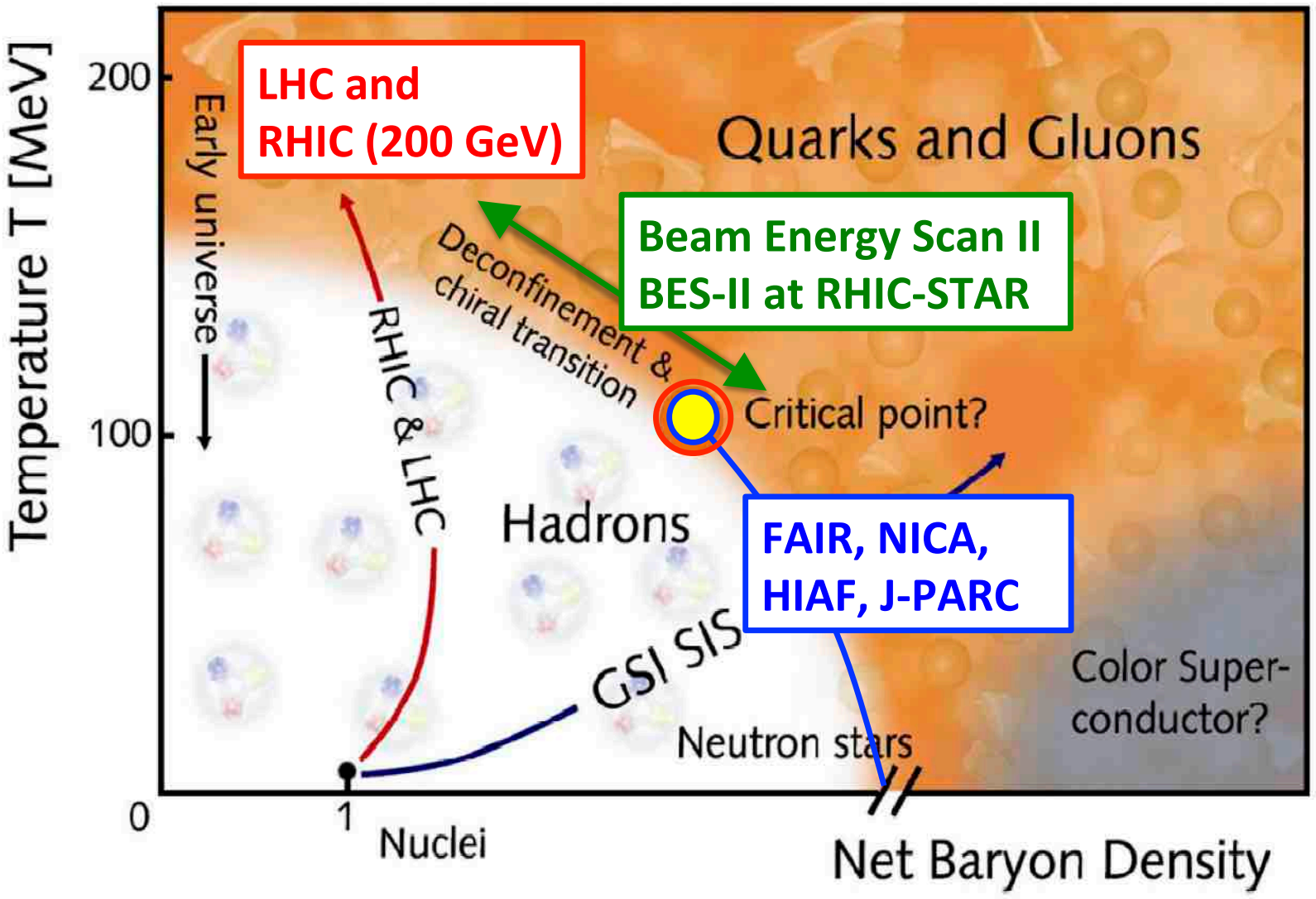
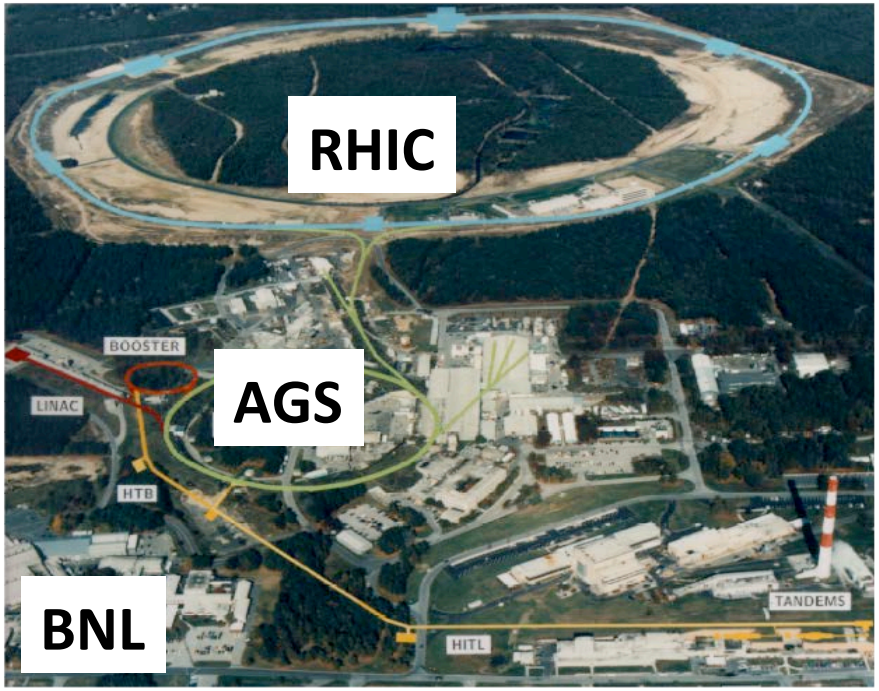
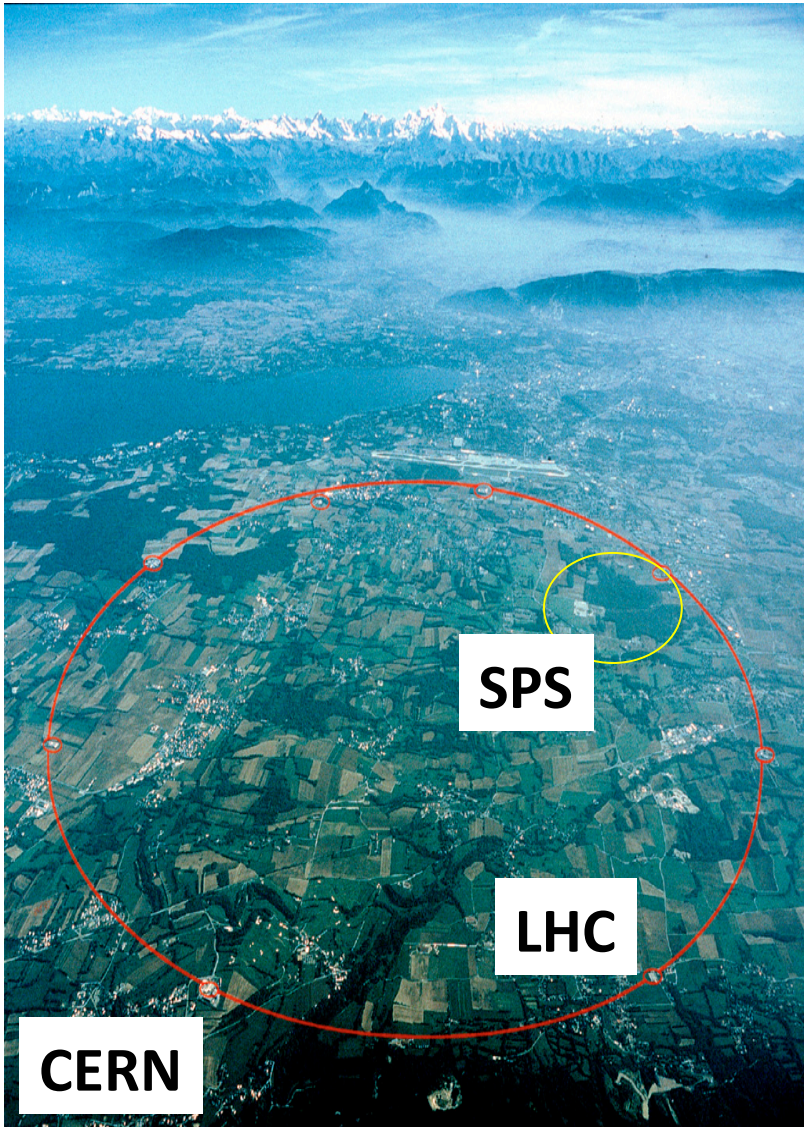
University of Tsukuba

QCD Phase-Diagram



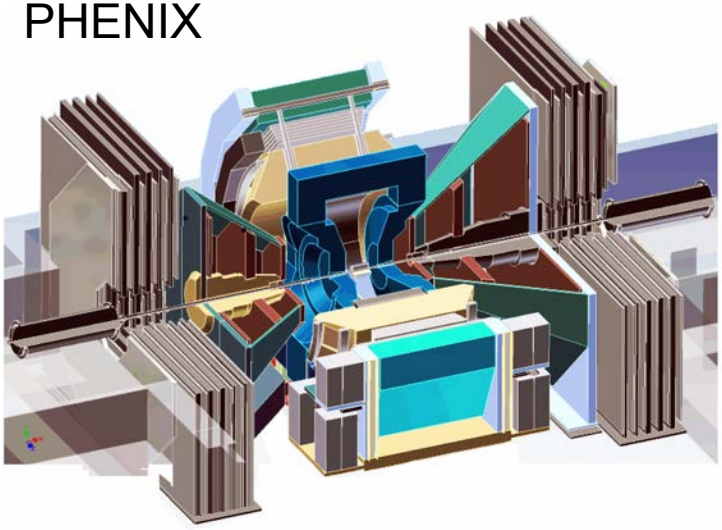
High-energy heavy-ion accelerators :
AGS/RHIC at BNL (New York)
SPS/LHC at CERN (Geneva)
From few GeV to few TeV

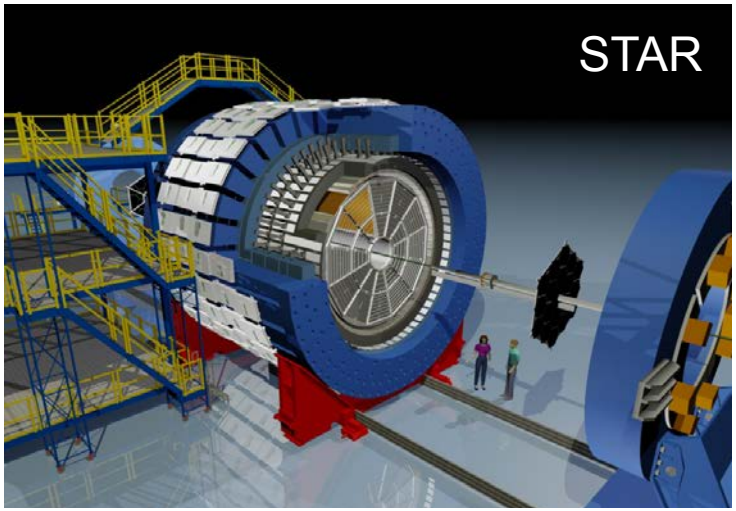




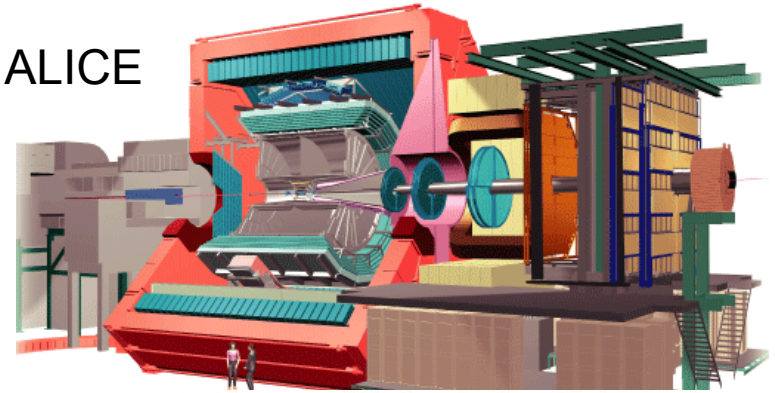
Experiments at RHIC and LHC

PHENIX

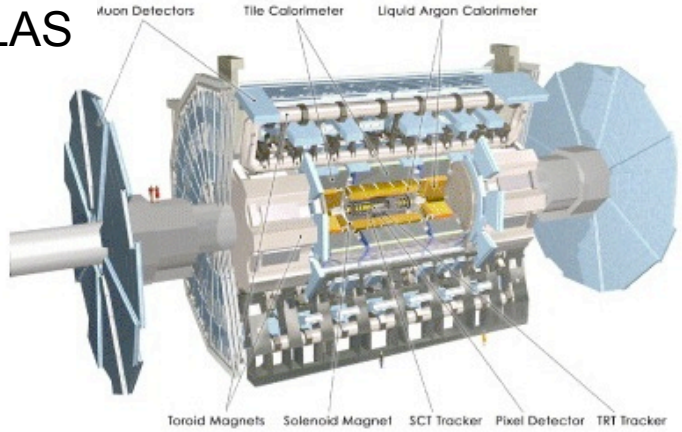




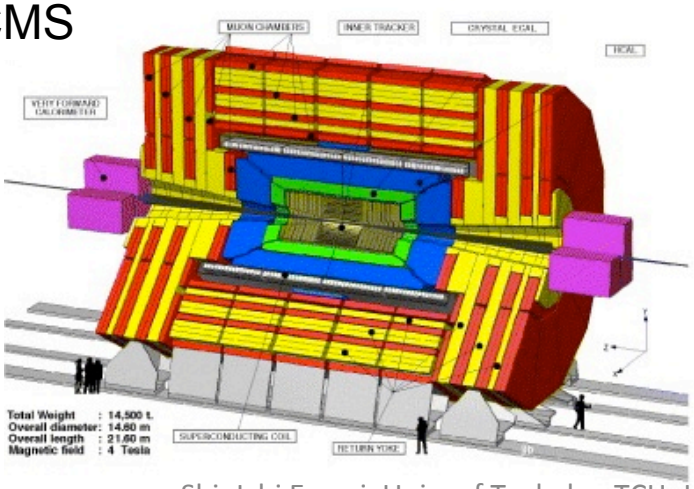
ALICE

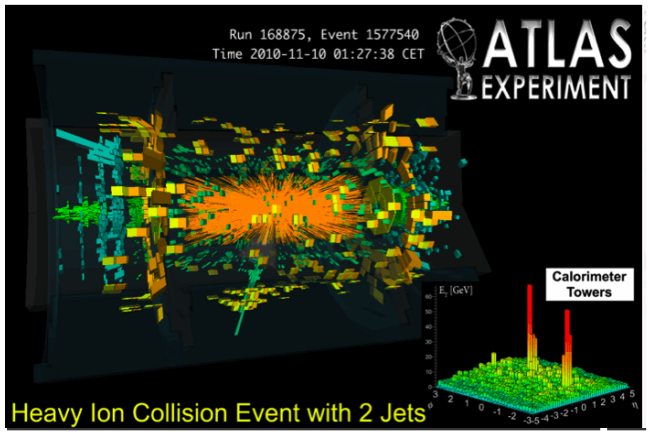


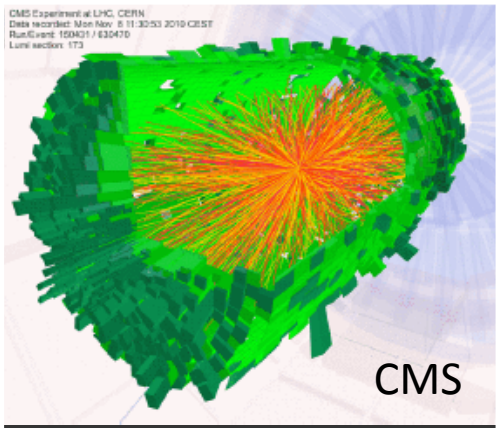
ATLAS

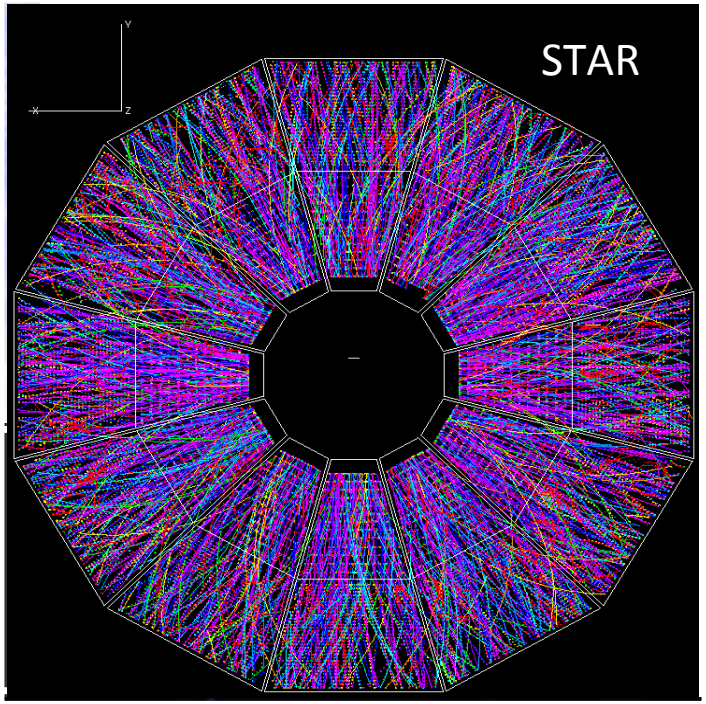


CMS

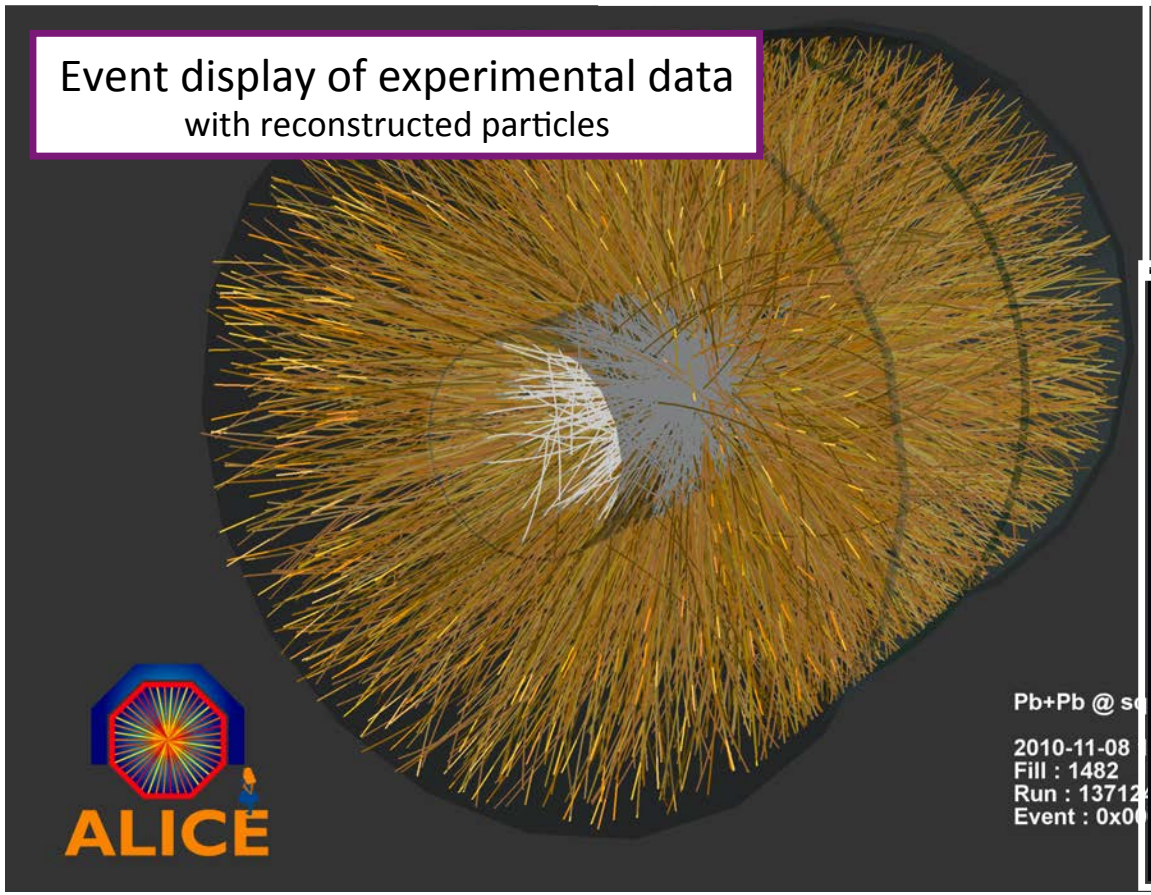


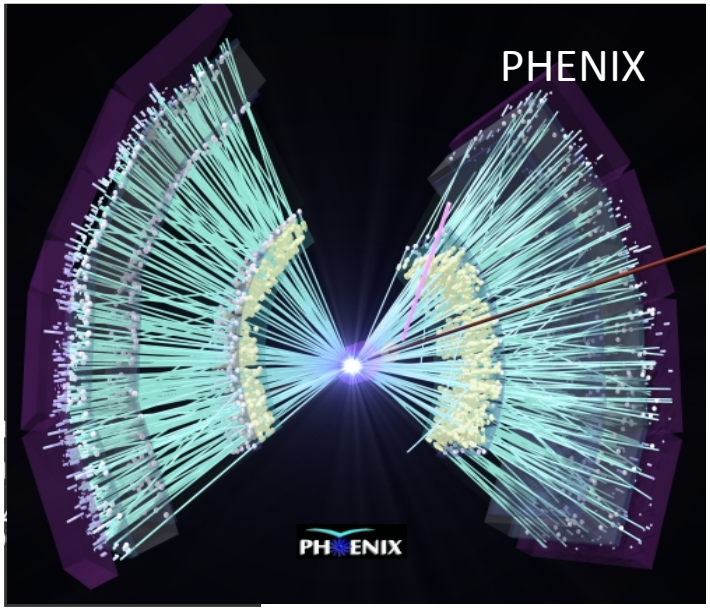




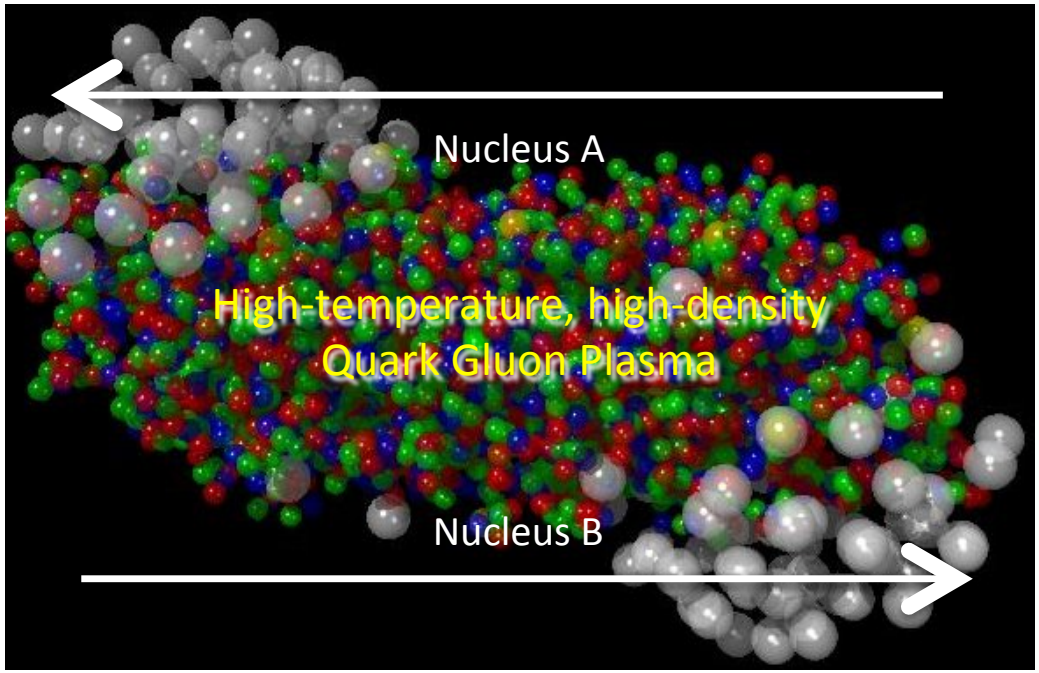


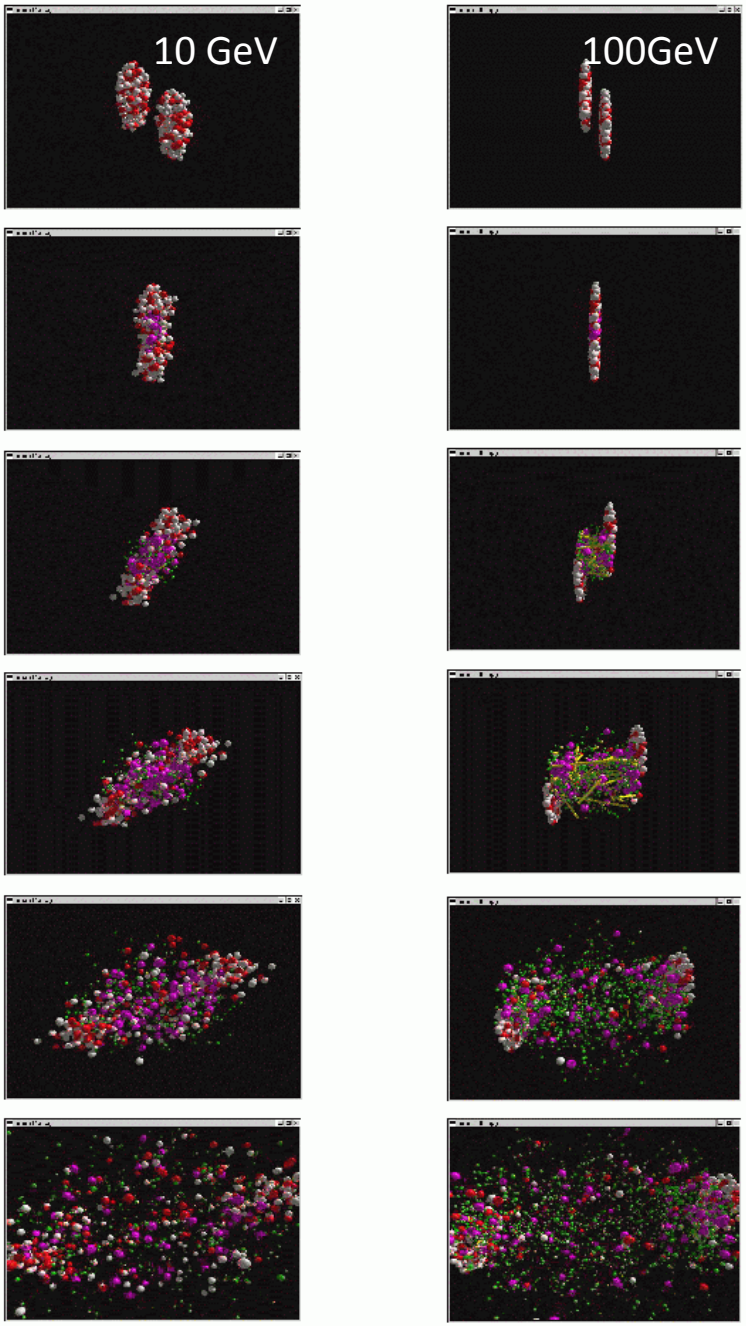
Event display of experimental data
with reconstructed particles



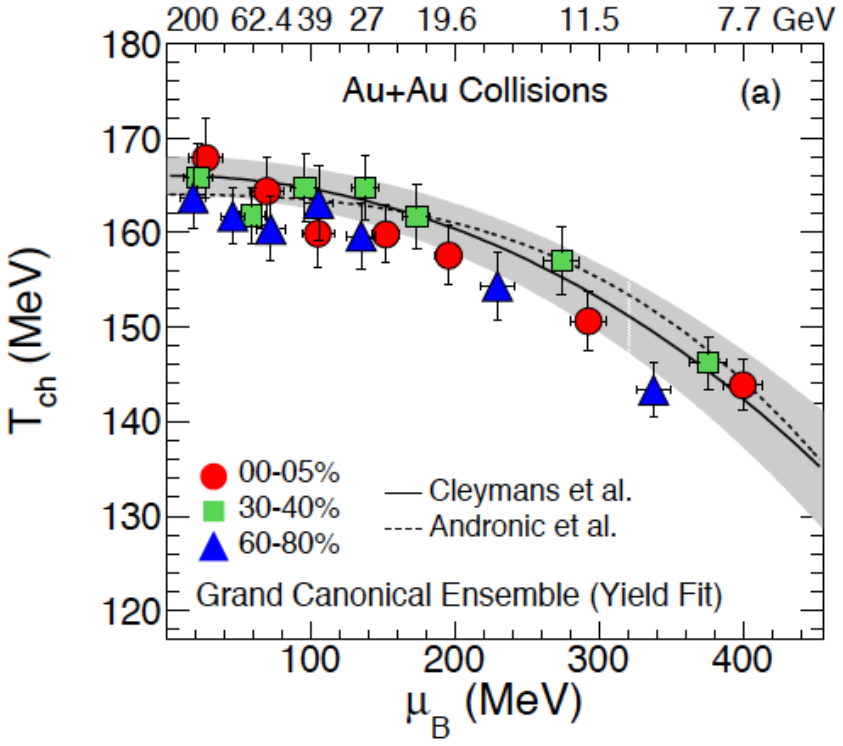


Nucleus-Nucleus collision hadronic-cascade simulation

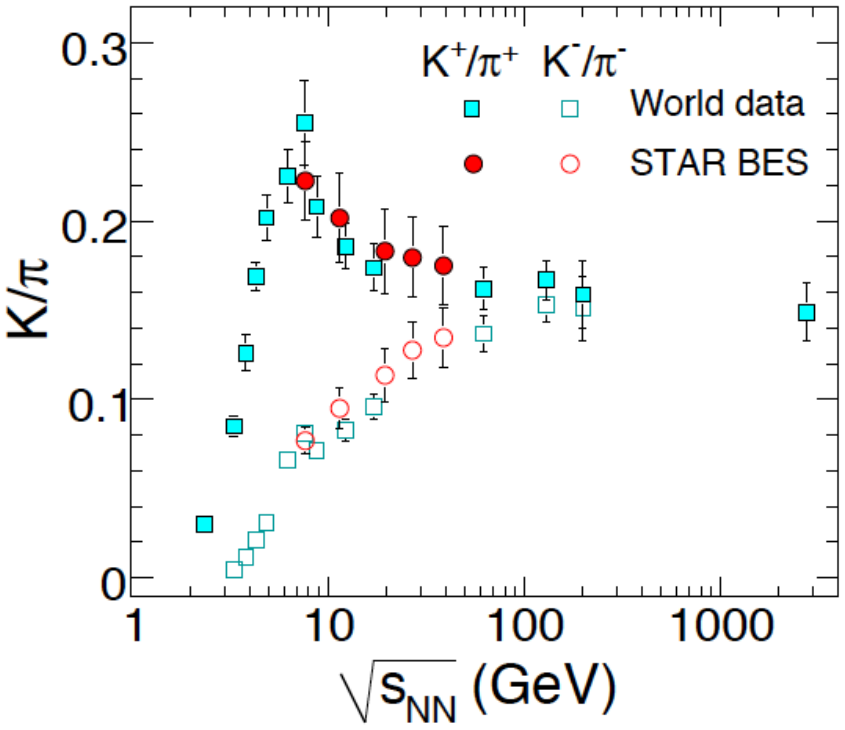




Chemical freeze-out and Baryon density



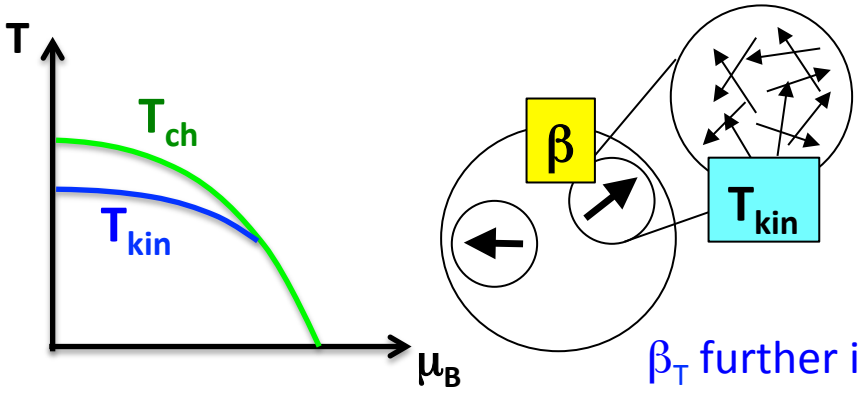
Phys. Rev. C **96** (2017) 44904



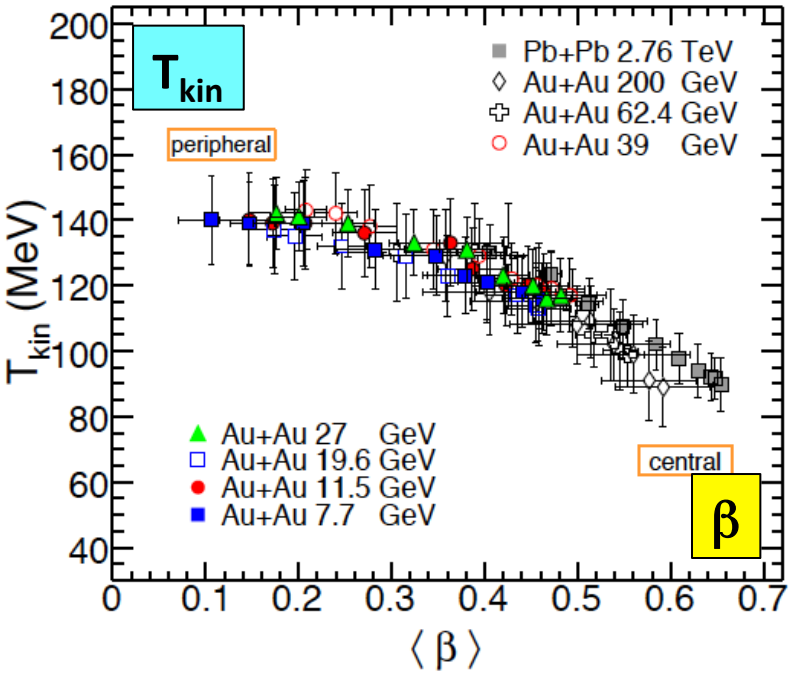
Baryon density increases with decreasing beam energy.

Baryon density is also known to have a peak at about 8 GeV based on transport models.

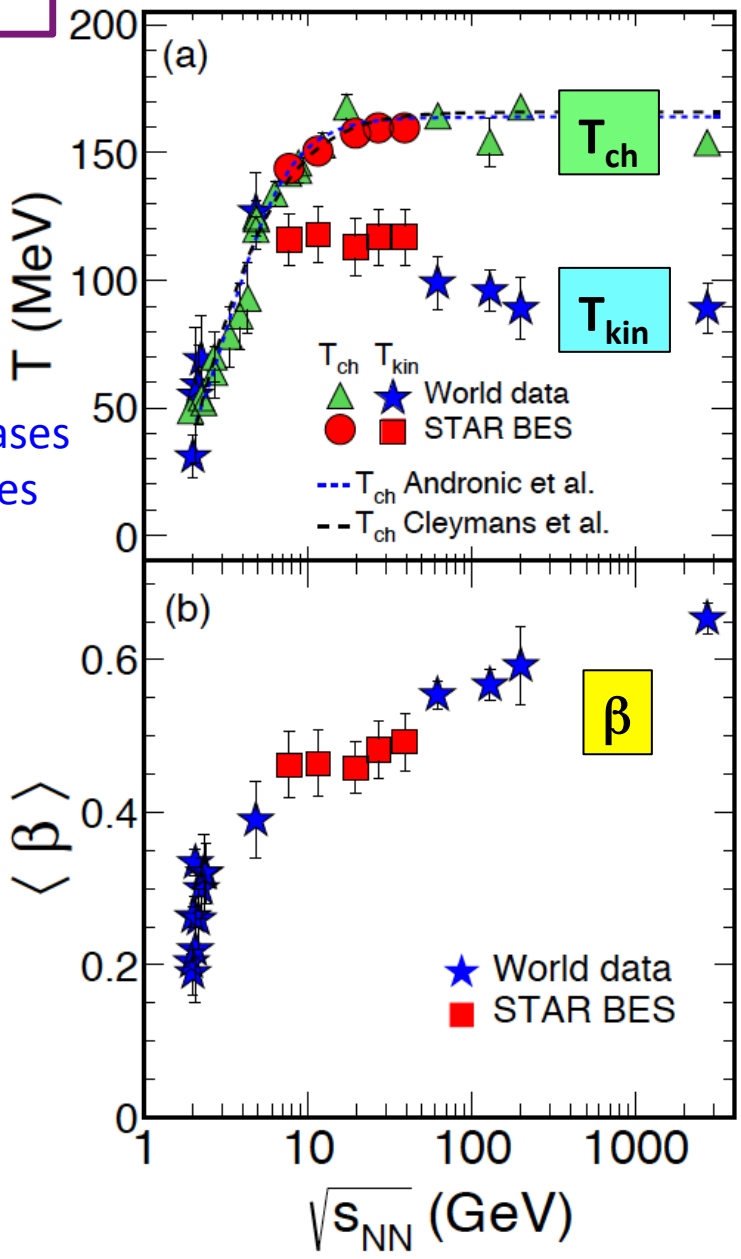
Blast-wave fit at kinetic freeze-out



β_T further increases and T_{kin} decreases by expansion

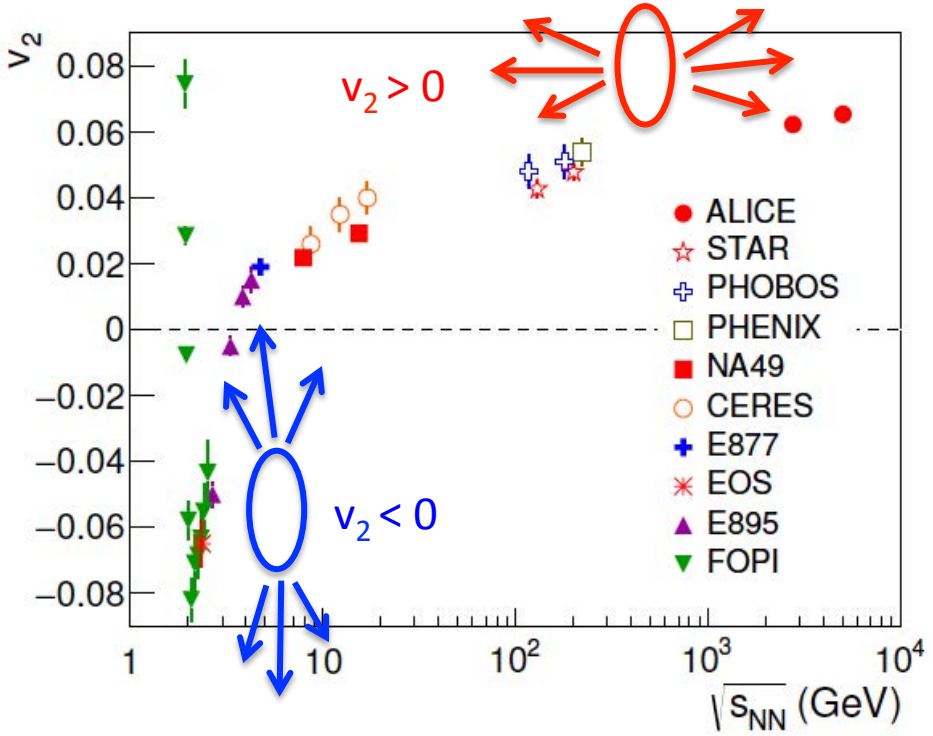


Phys. Rev. C 96 (2017) 44904

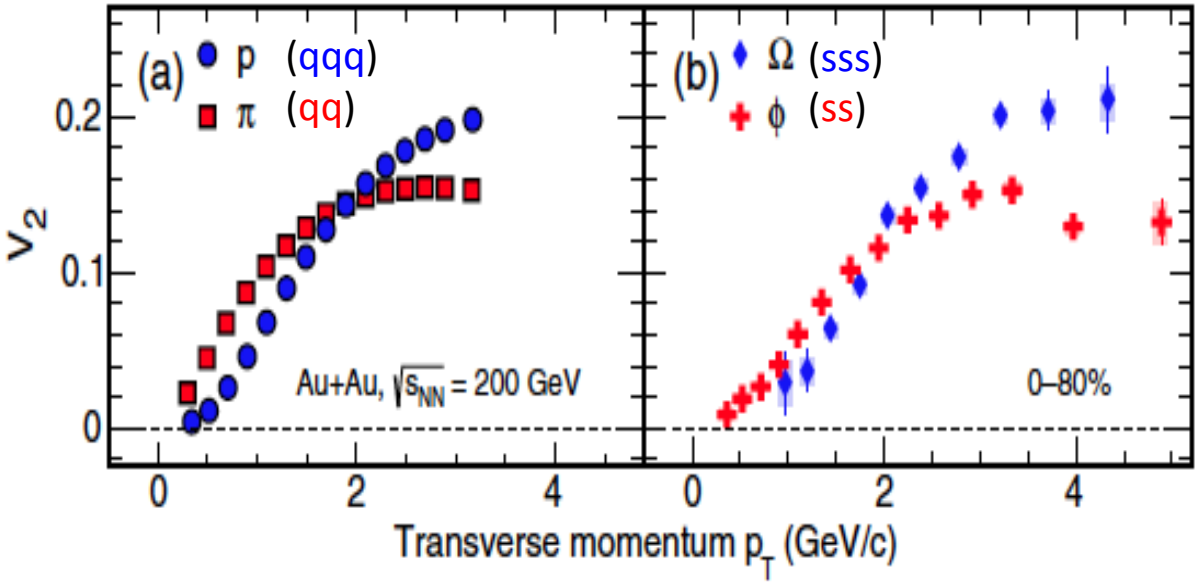


v_2 evolution with beam energy and quark coalescence

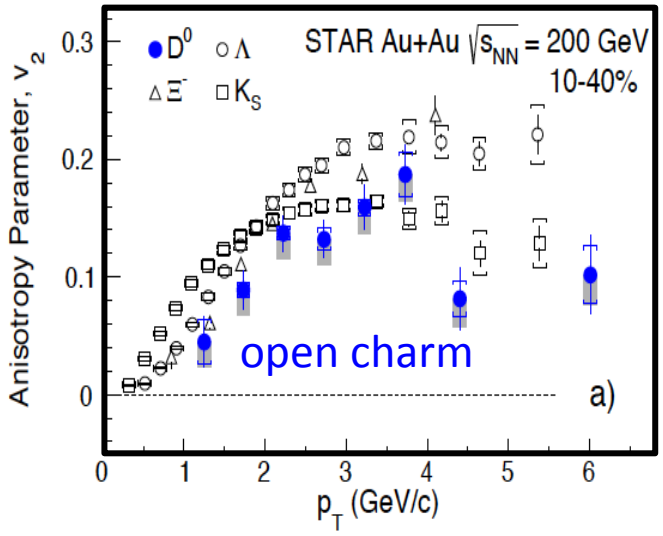
- Squeeze-out and sign change
- Mass splitting from hydro expansion
- Number of constituent quark scaling



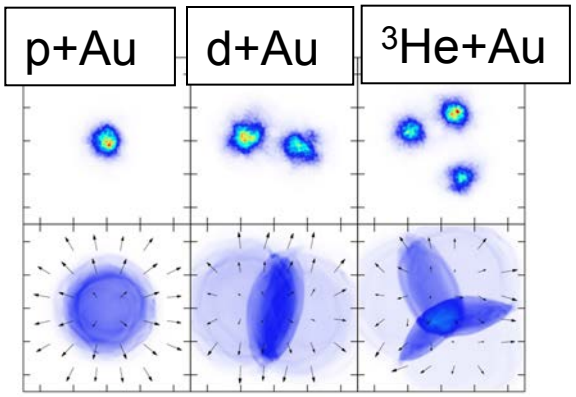
Phys. Rev. Lett. 116 (2016) 062301

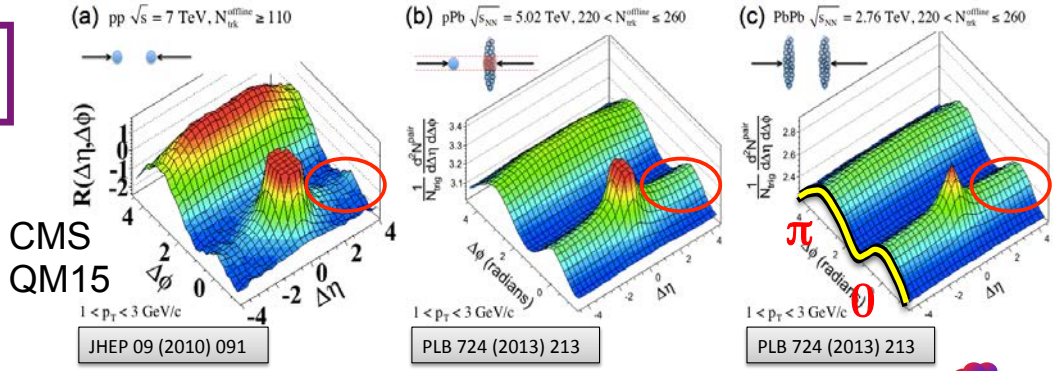


Phys. Rev. Lett. 118 (2017) 212301



Flow in small systems

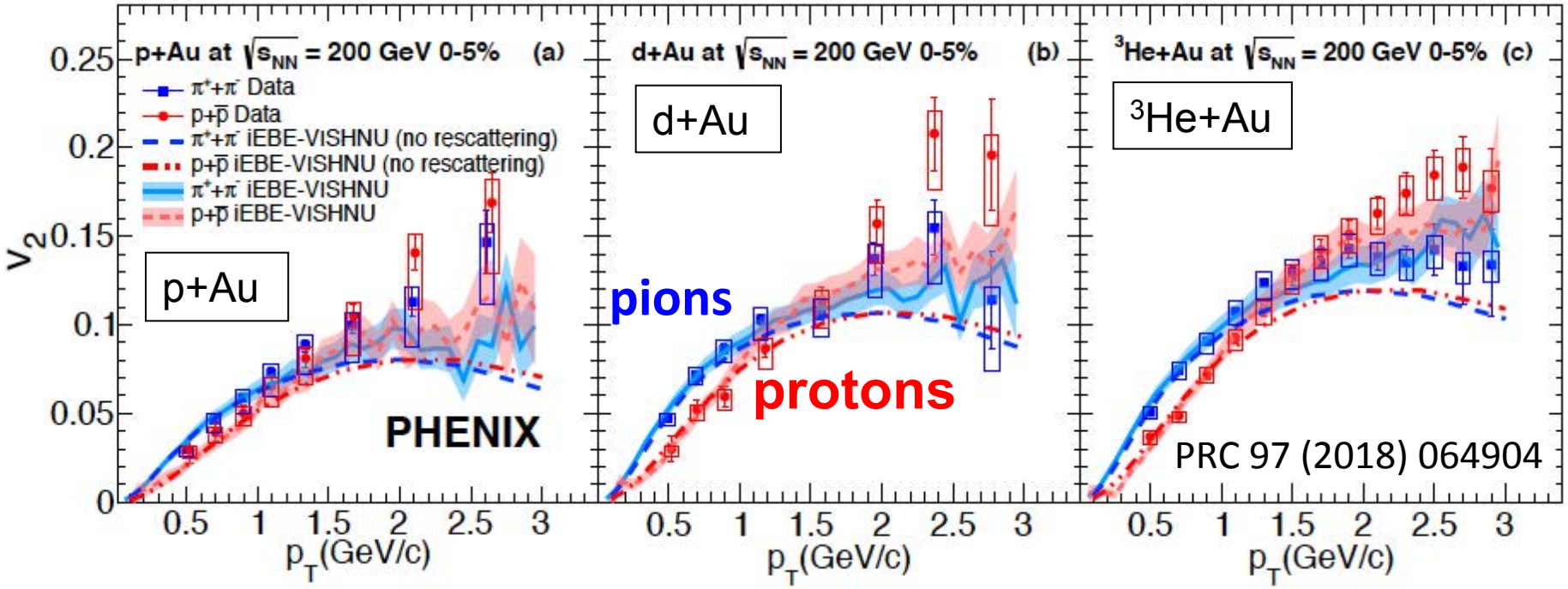




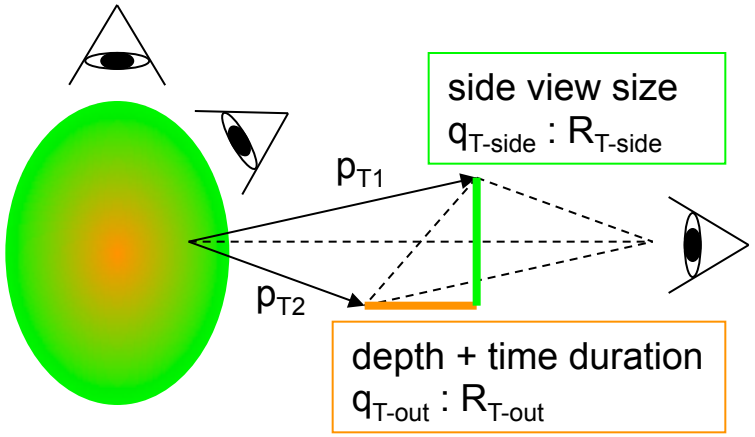
p+p (high mult.)

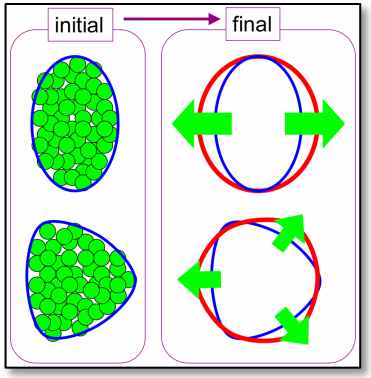
p+A

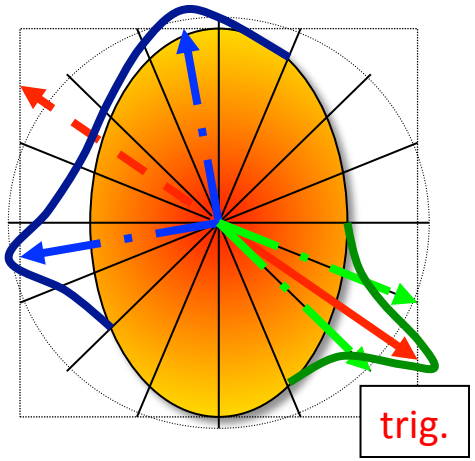
A+A



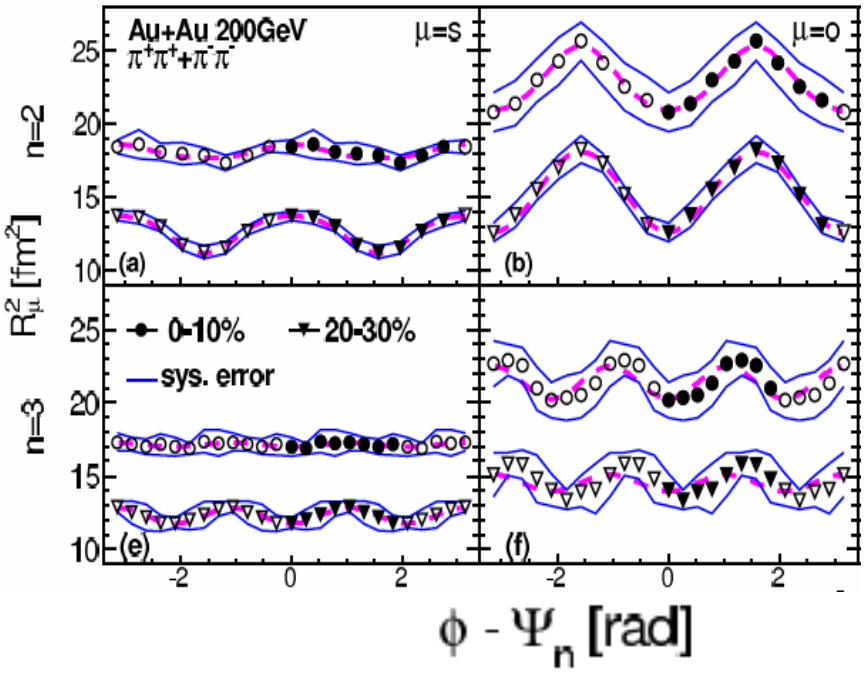
System shape and jet modification







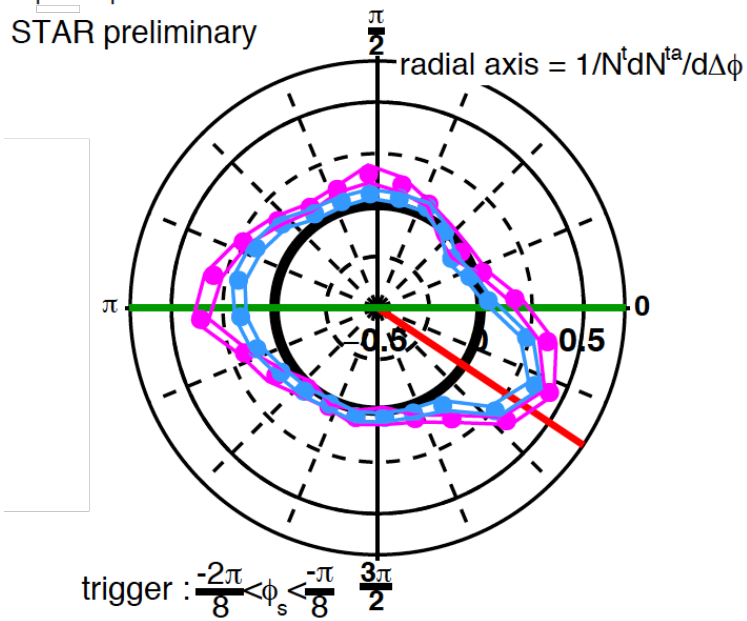
PRL112 (2014) 222301



Au+Au $\sqrt{s_{NN}}$ = 200 GeV 30-40%

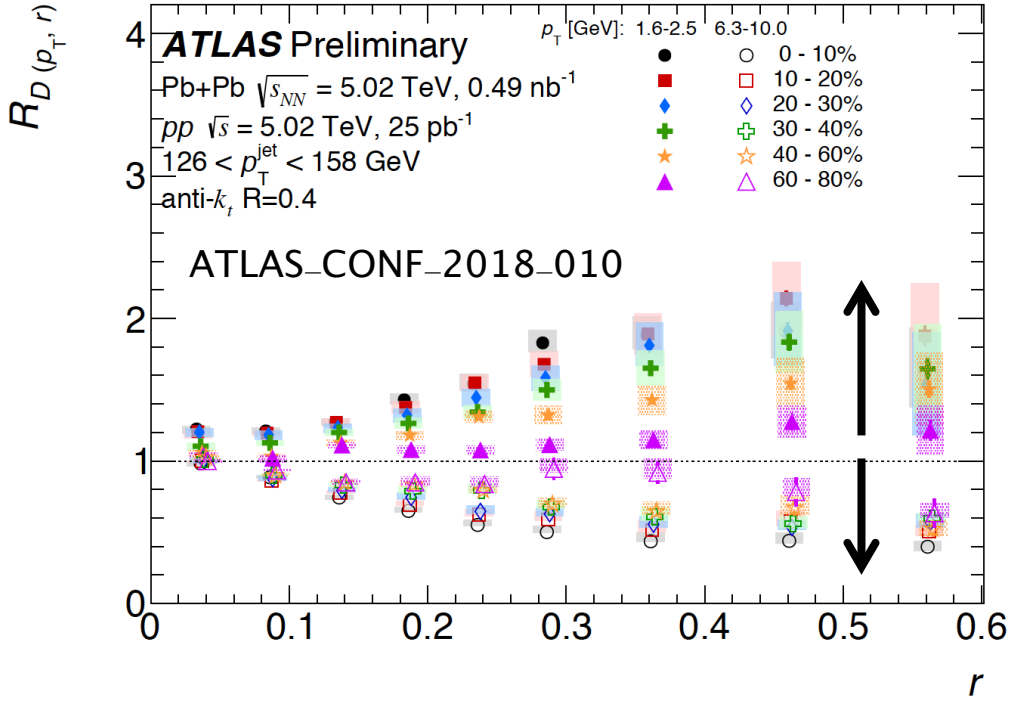
$p_T^t \otimes p_T^a$=4-10 ⊗ 1-2 (GeV/c)

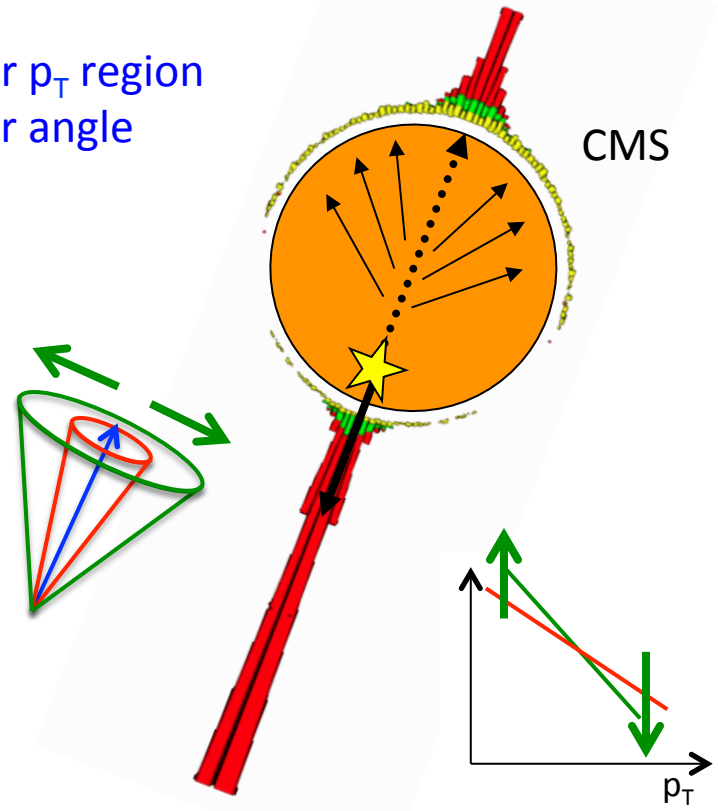
STAR preliminary

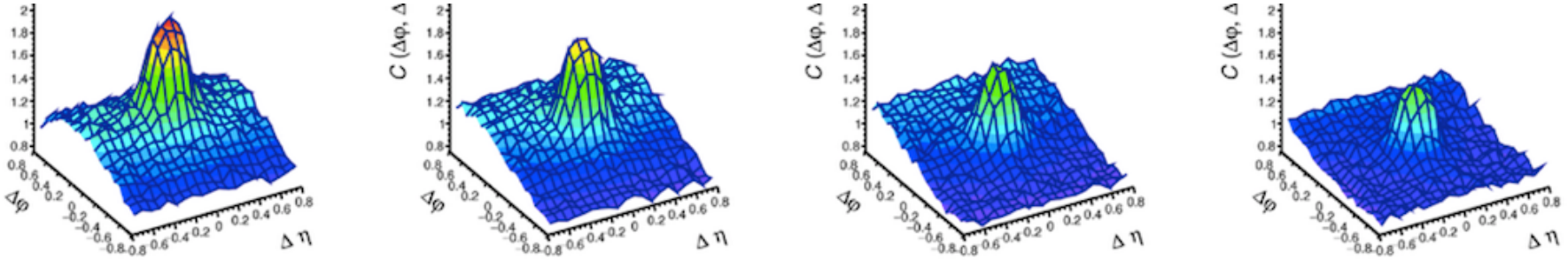


Jet shape modification

- re-distribution towards lower p_T region
- re-distribution towards wider angle

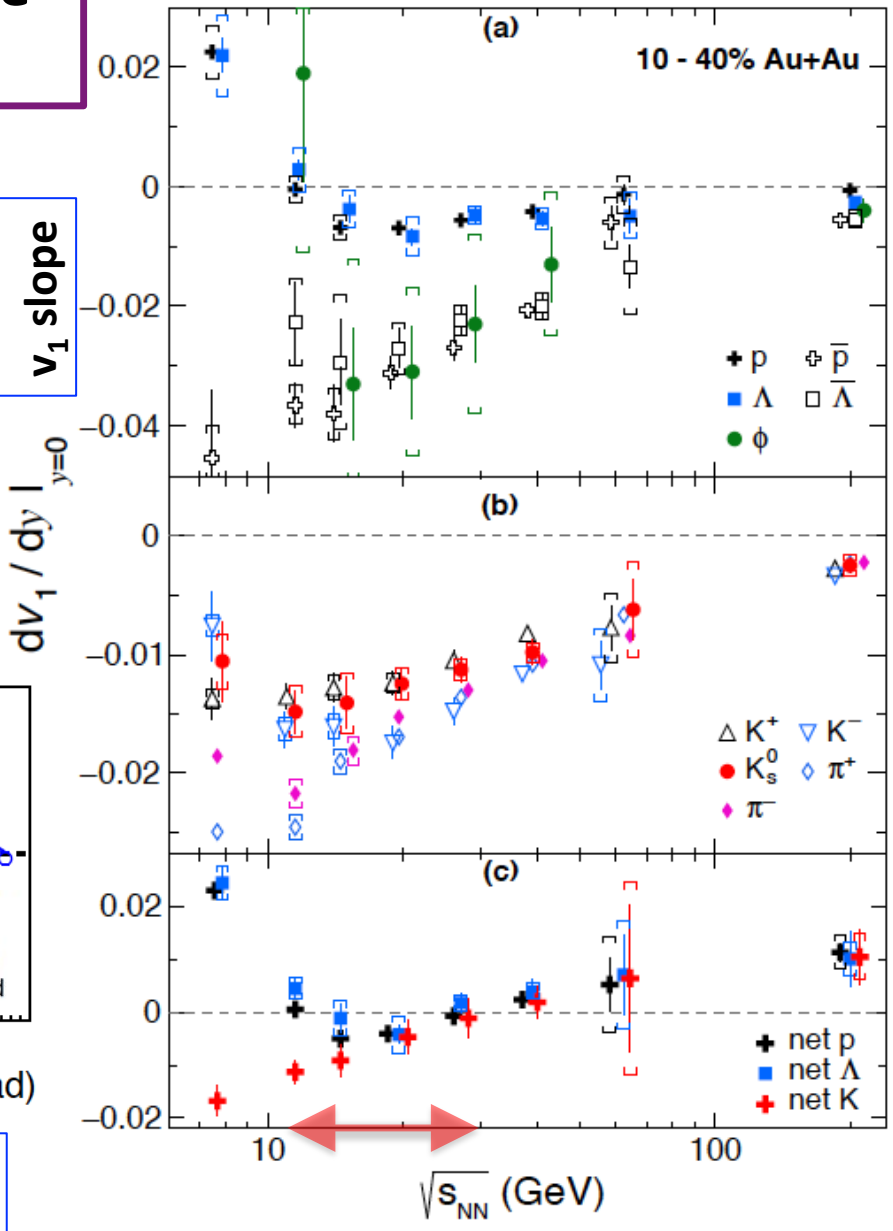






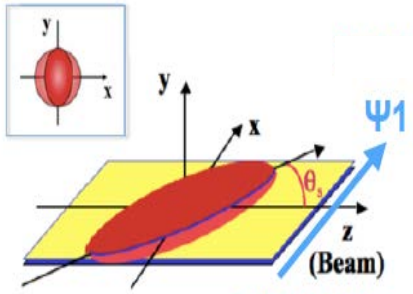
Directed flow v_1 slope and source tilt with respect to rapidity

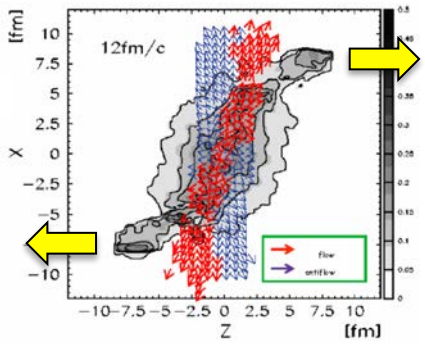
Phys. Rev. Lett. 120 (2018) 62301



v_1 slope

M A Lisa et al. New J. Phys. 13 (2011) 065006

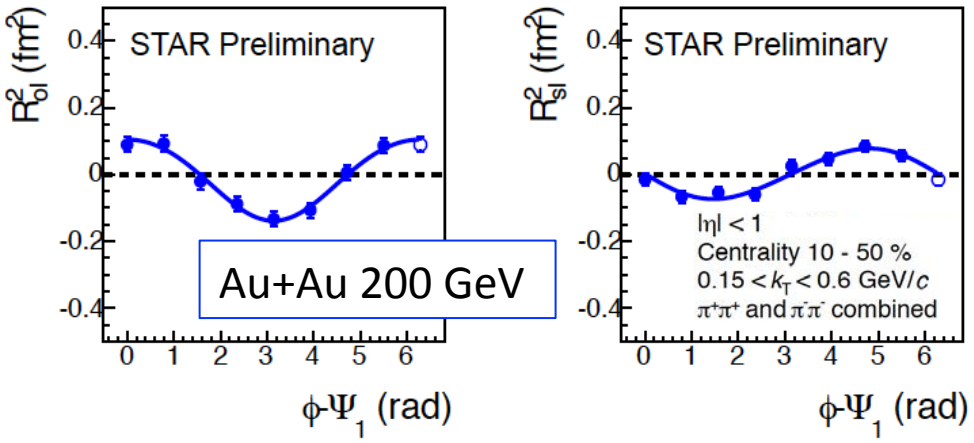




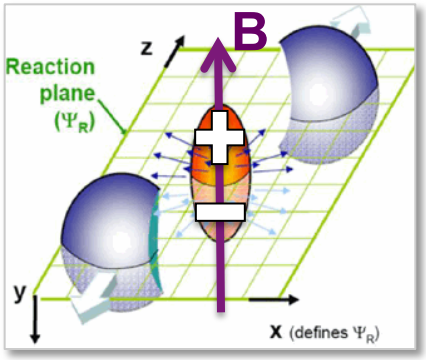
J. Brachmann et al., PRC 61, 24909 (2000).

source tilt

STAR, APS/JPS 2018



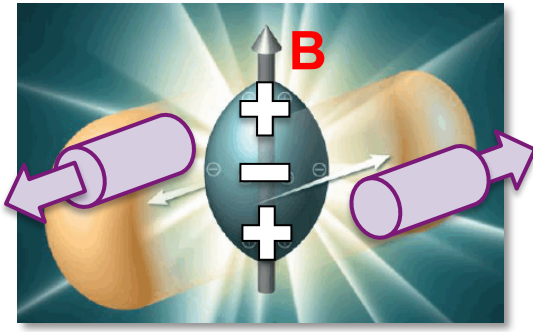
note : E.P. resolution correction has not yet been applied for both data sets. (σ_{EP} : 0.2-0.3)



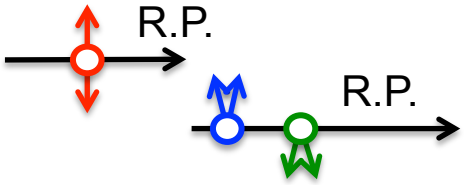
Strong magnetic field and charge asymmetry

--- Chiral Magnetic Effect (CME) ---

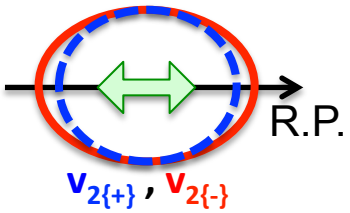
--- Chiral Magnetic Wave (CMW) ---



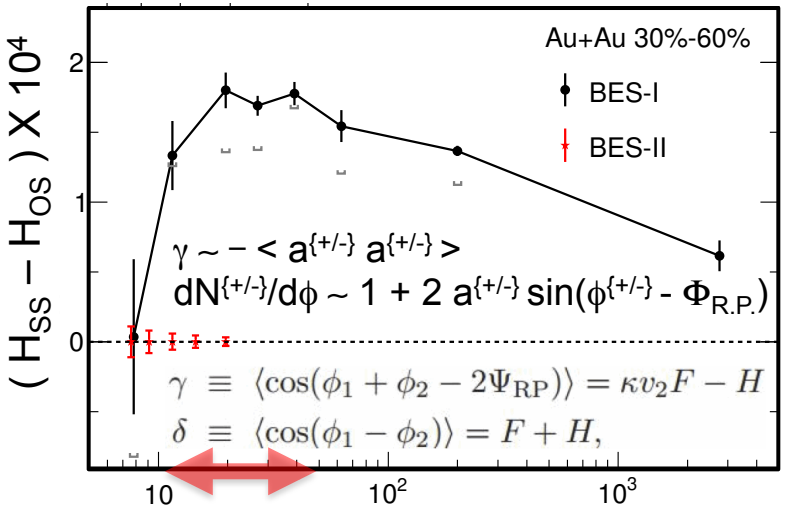
CME



CMW



Phys. Rev. Lett. 113 (2014) 052302

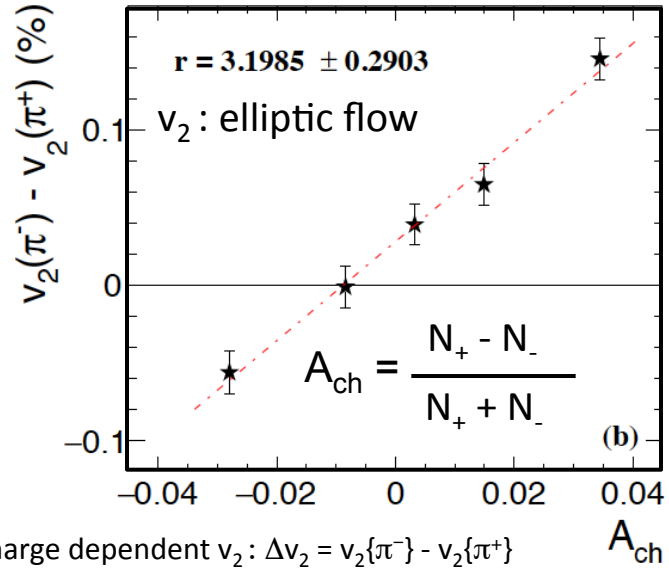


charge separation w.r.t. reaction plane

"Same-sign" - "Opposite-sign" charged pair

~10% of observed signal after BG subtraction

Phys. Rev. Lett. 114 (2015) 252302



Charge dependent v_2 : $\Delta v_2 = v_2\{\pi^-\} - v_2\{\pi^+\}$

vs charge asymmetry of event : A_{ch}

Global polarization via Lambda decay

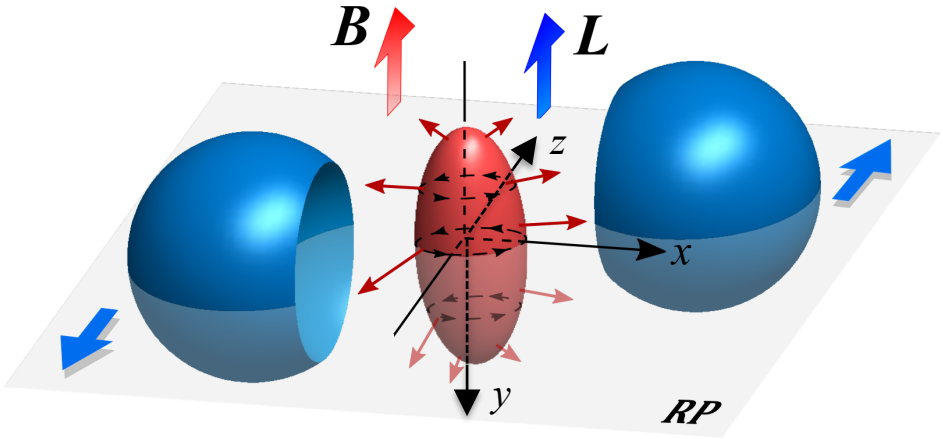
#38

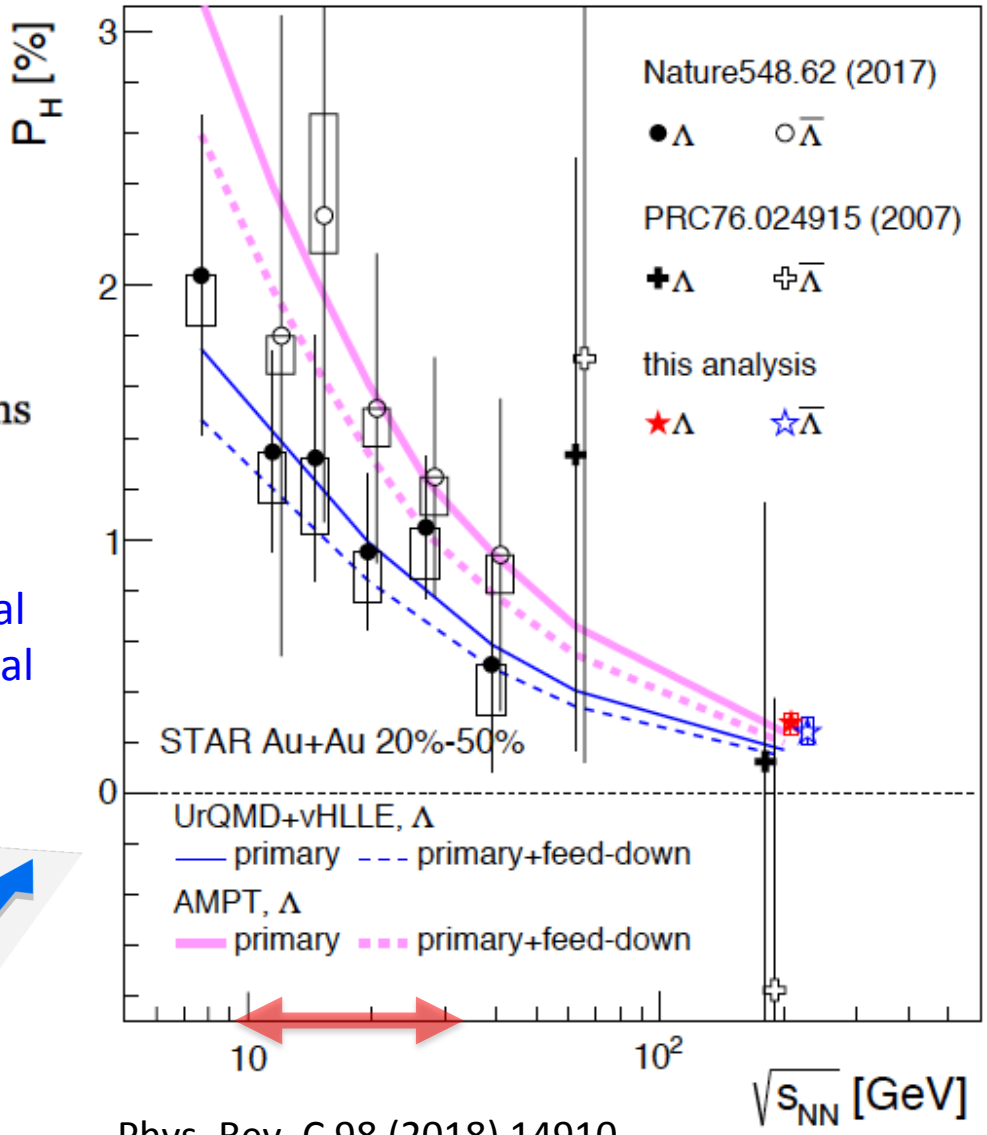
The Fastest Fluid

by Sylvia Morrow

Superhot material spins at an incredible rate.

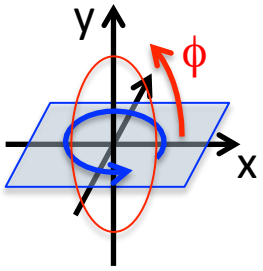
Clearly positive **L** signal
Possible hint of **B** signal



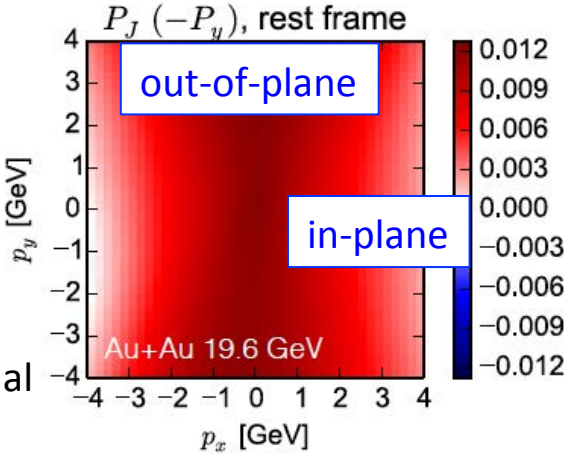


Phys. Rev. C 98 (2018) 14910

Global polarization via Lambda

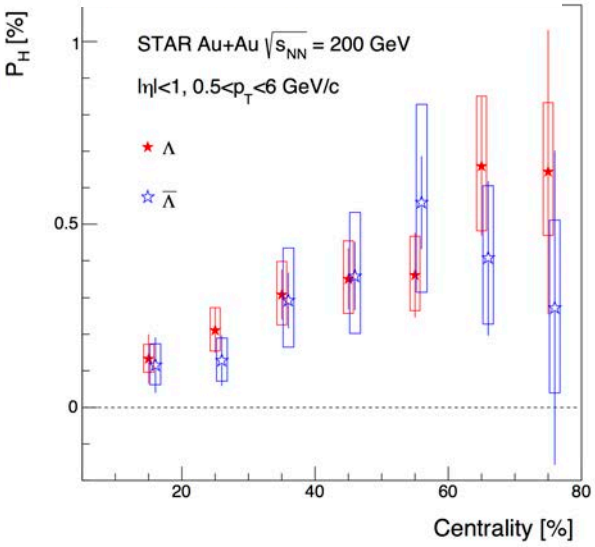


Hydrodynamics predicts opposite trend in azimuthal dependence.



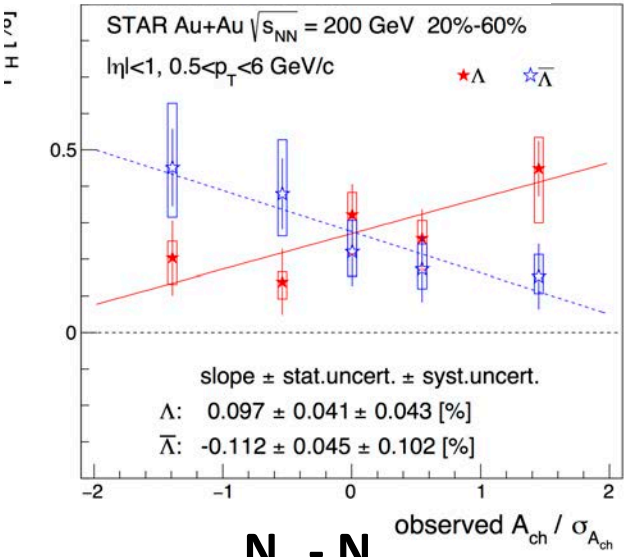
Centrality dependence

Phys. Rev. C 98 (2018) 14910



Charge asymmetry dependence

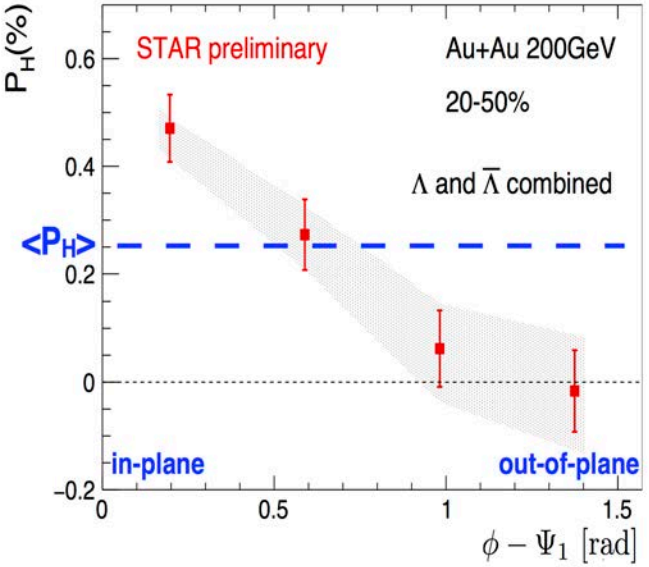
Phys. Rev. C 98 (2018) 14910



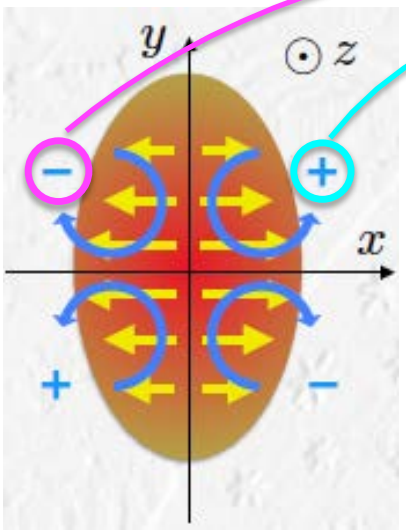
$$A_{ch} = \frac{N_+ - N_-}{N_+ + N_-}$$

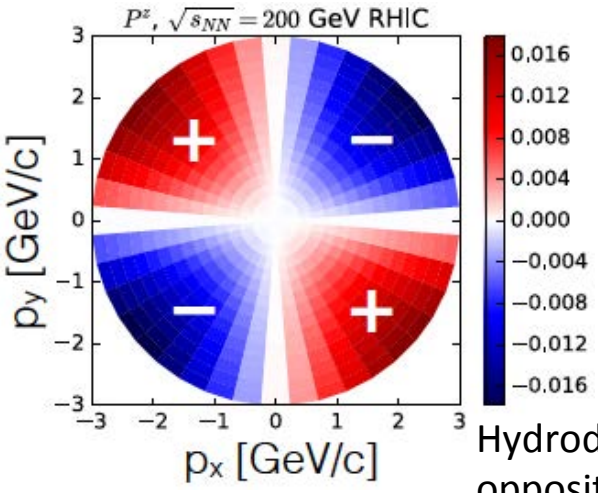
Azimuthal angle dependence

STAR, QM18



Lambda longitudinal-local polarization

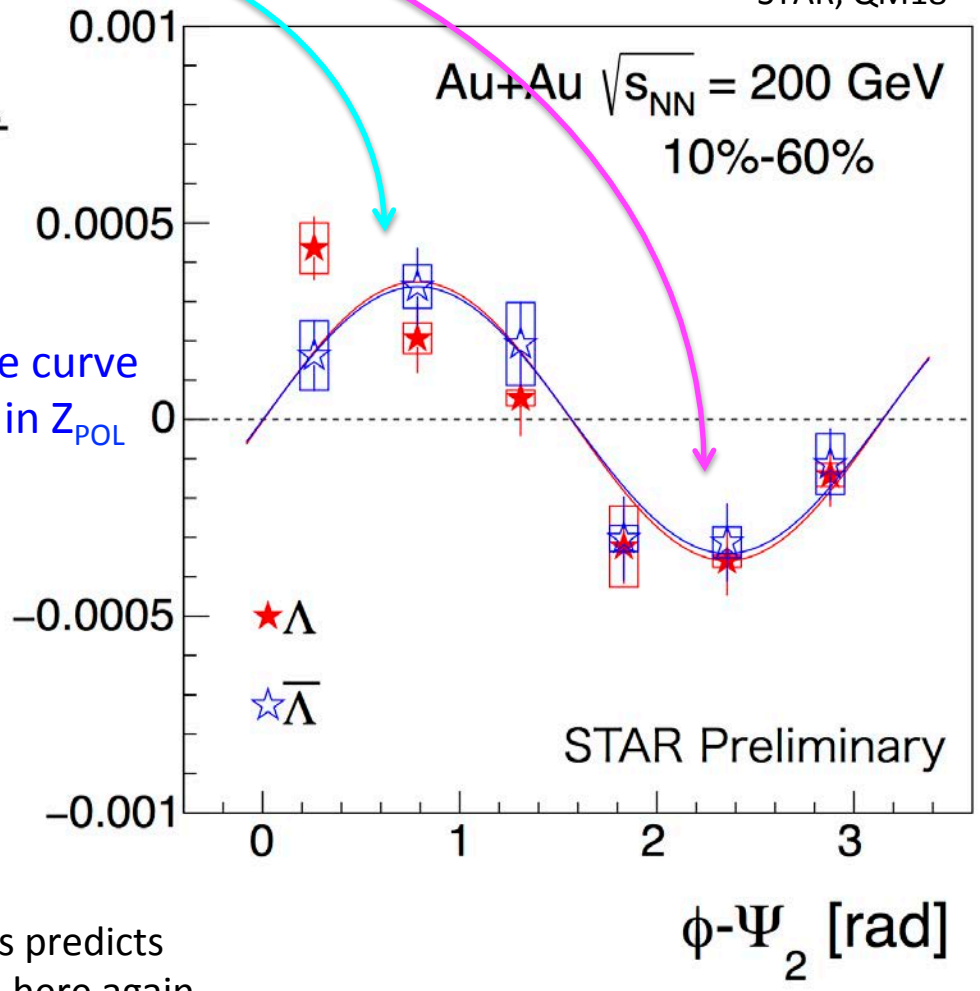




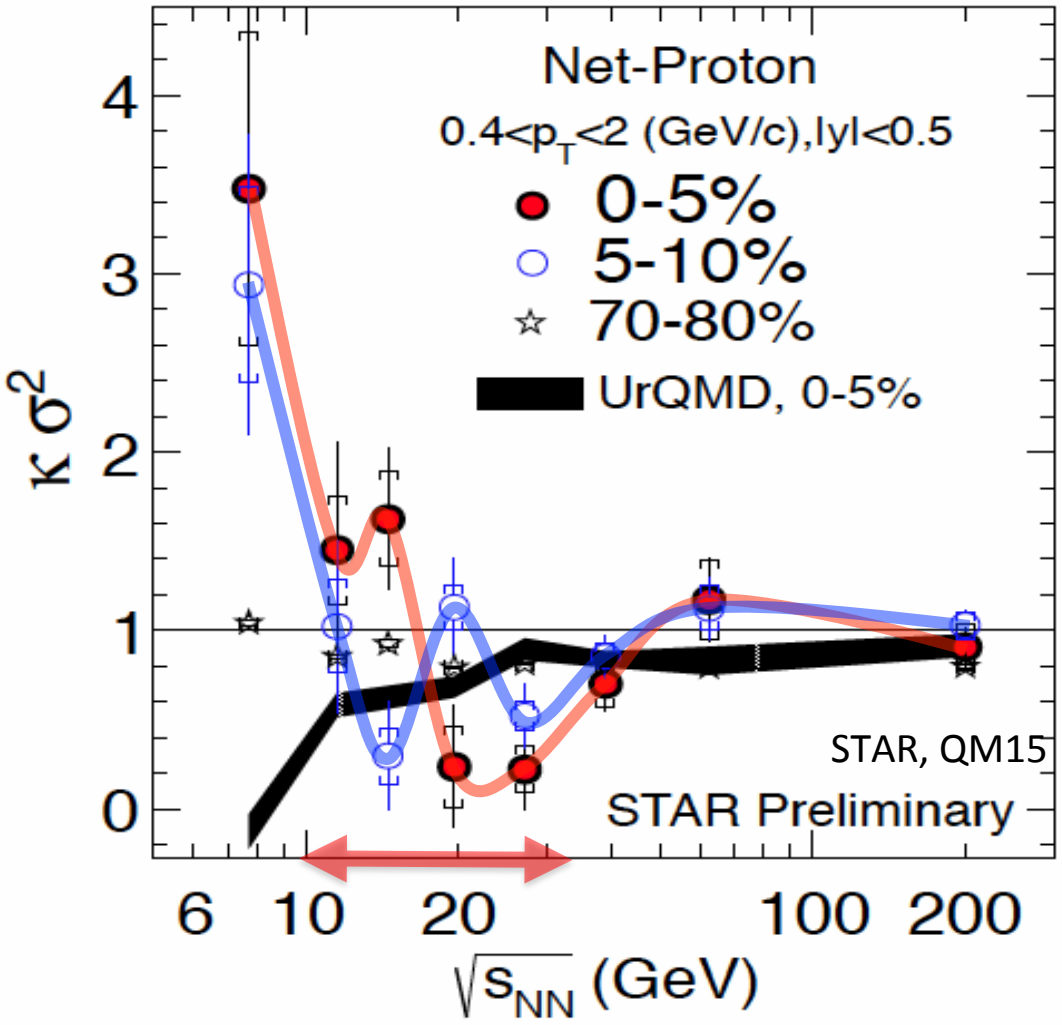
Clear sin-like curve is observed in Z_{POL}

Hydrodynamics predicts opposite trend here again ...

STAR, QM18

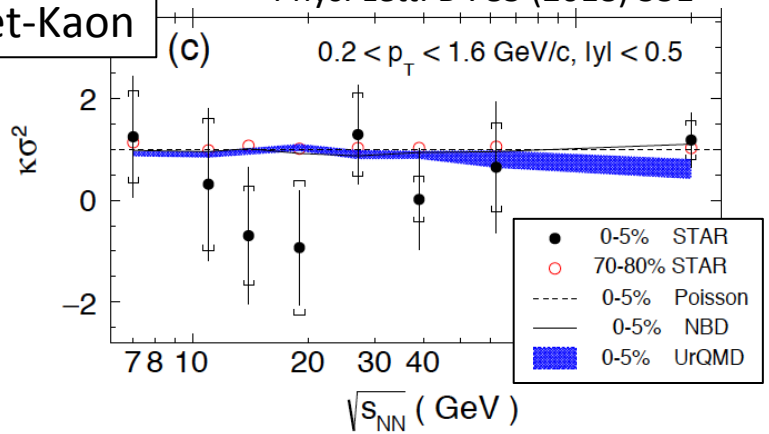


Net-proton as a proxy for conserved net-baryon fluctuation

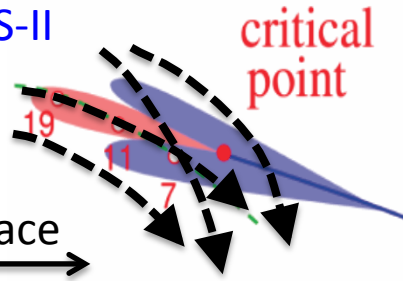


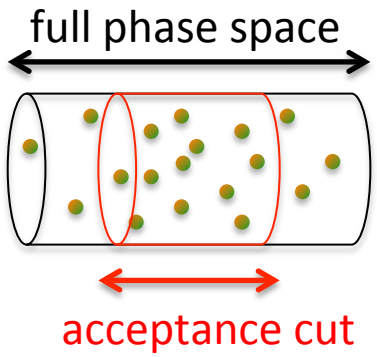
Net-Kaon

Phys. Lett. B 785 (2018) 551



Possible critical fluctuation depending on centrality, more data in BES-II

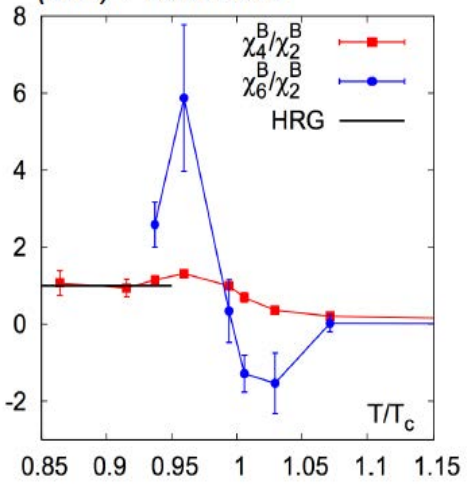




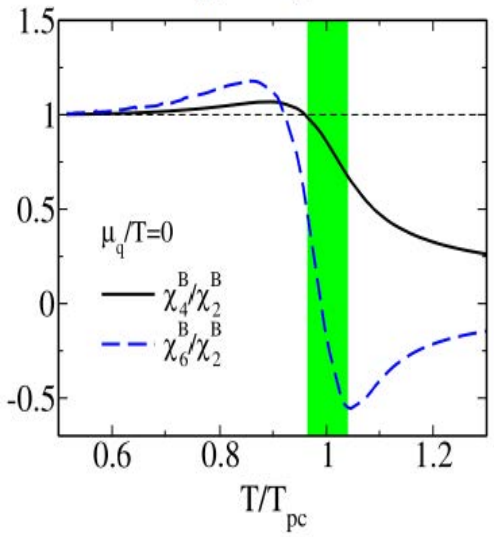
6th-order cumulants of net-proton and net-charge

Higher-order cumulants are expected to be more sensitive to the critical fluctuation than lower orders.
Even more statistics needed though ...

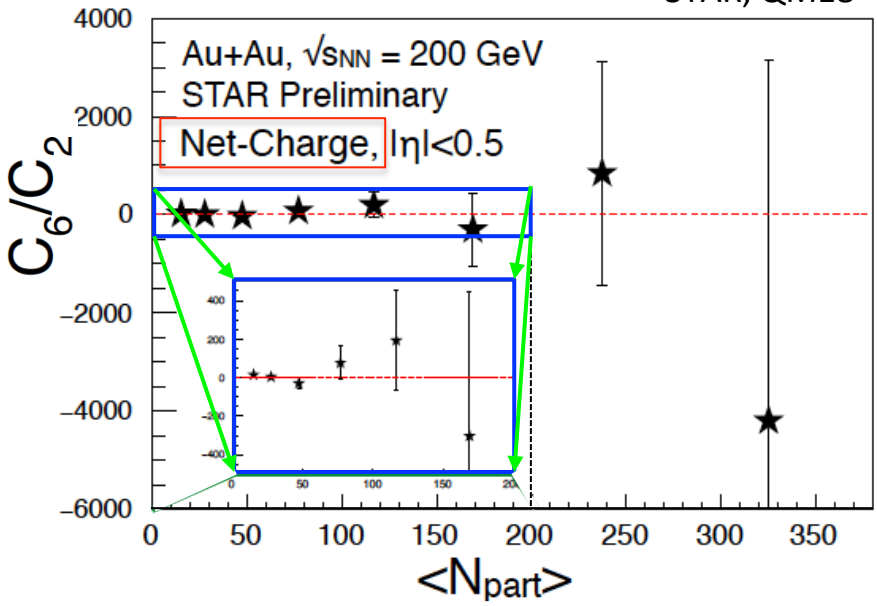
Cheng et al, Phys. Rev. D 79, 074505 (2009) : Lattice QCD



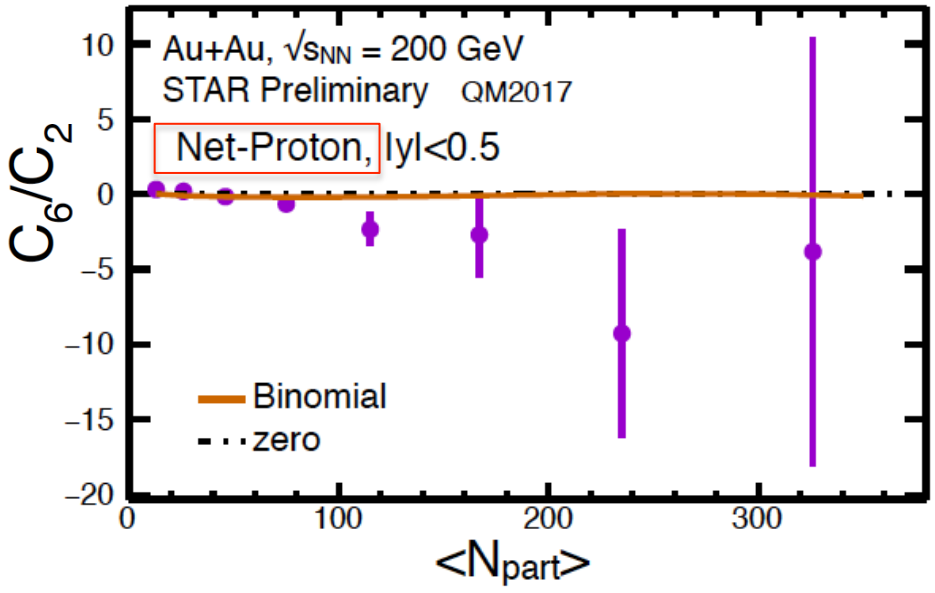
Friman et al, Eur. Phys. J. C (2011) 71:1694 : O(4) scaling functions



STAR, QM18

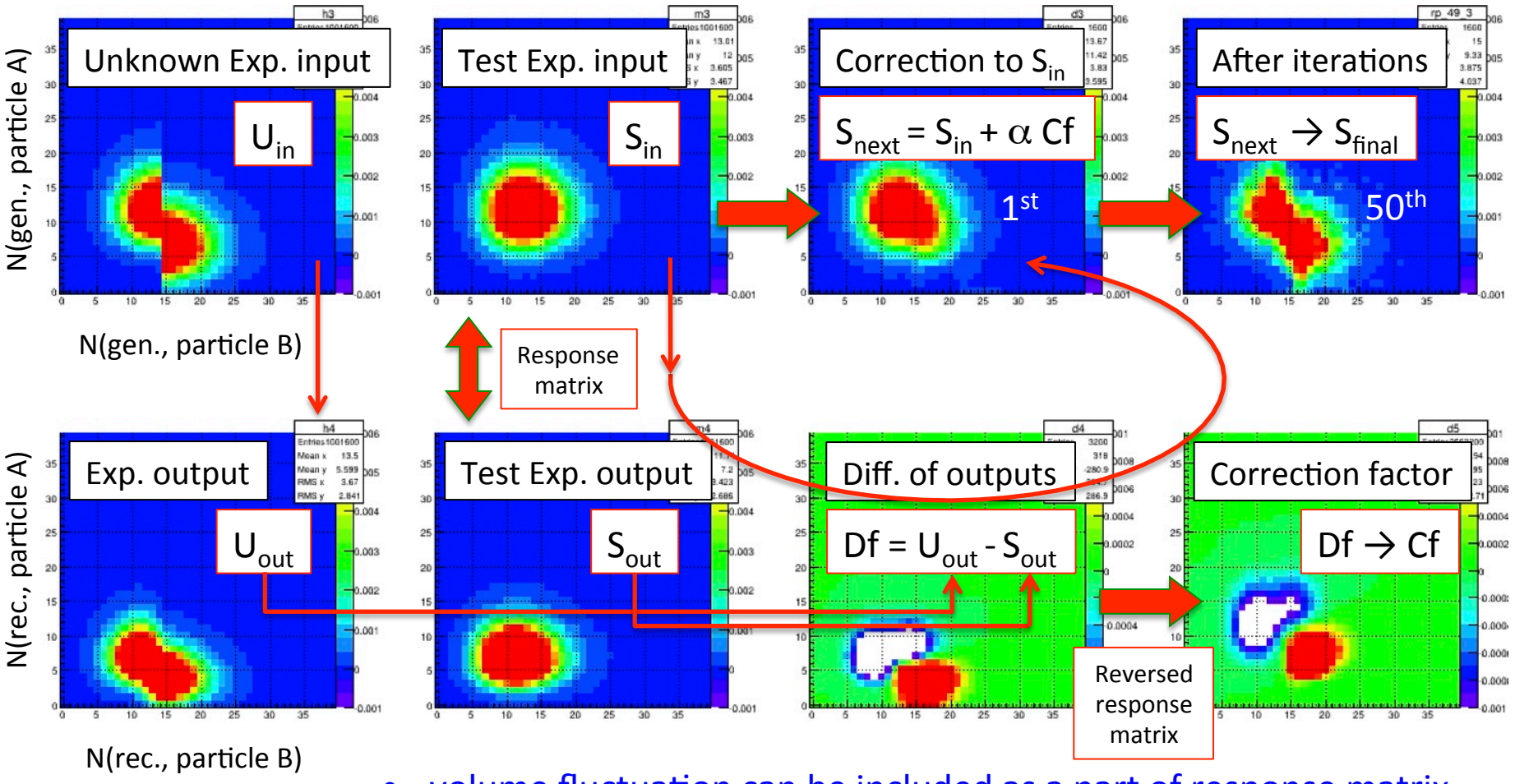


STAR, QM17



Unfolding of "unkown and critical" net-distribution

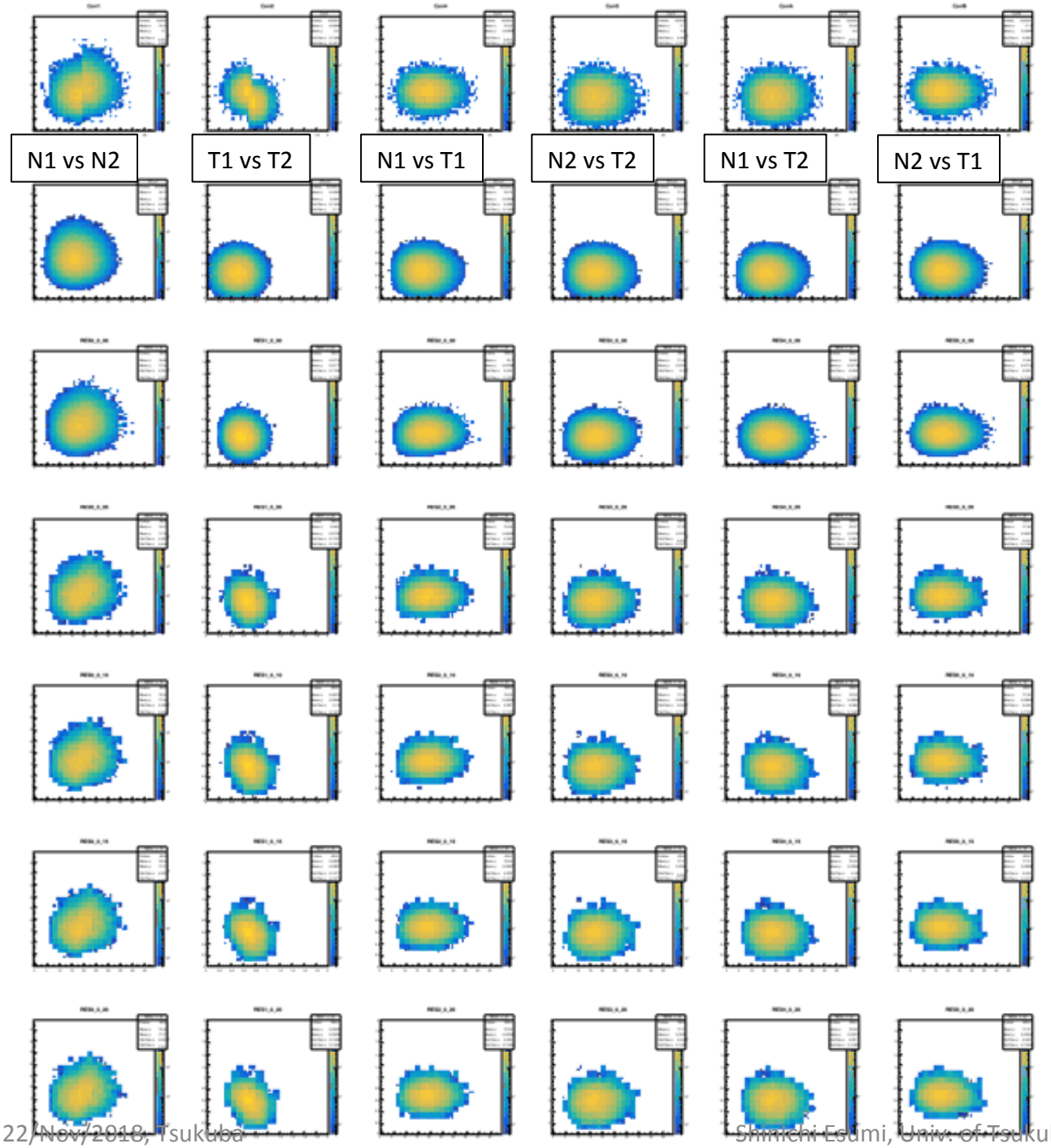
test simulation



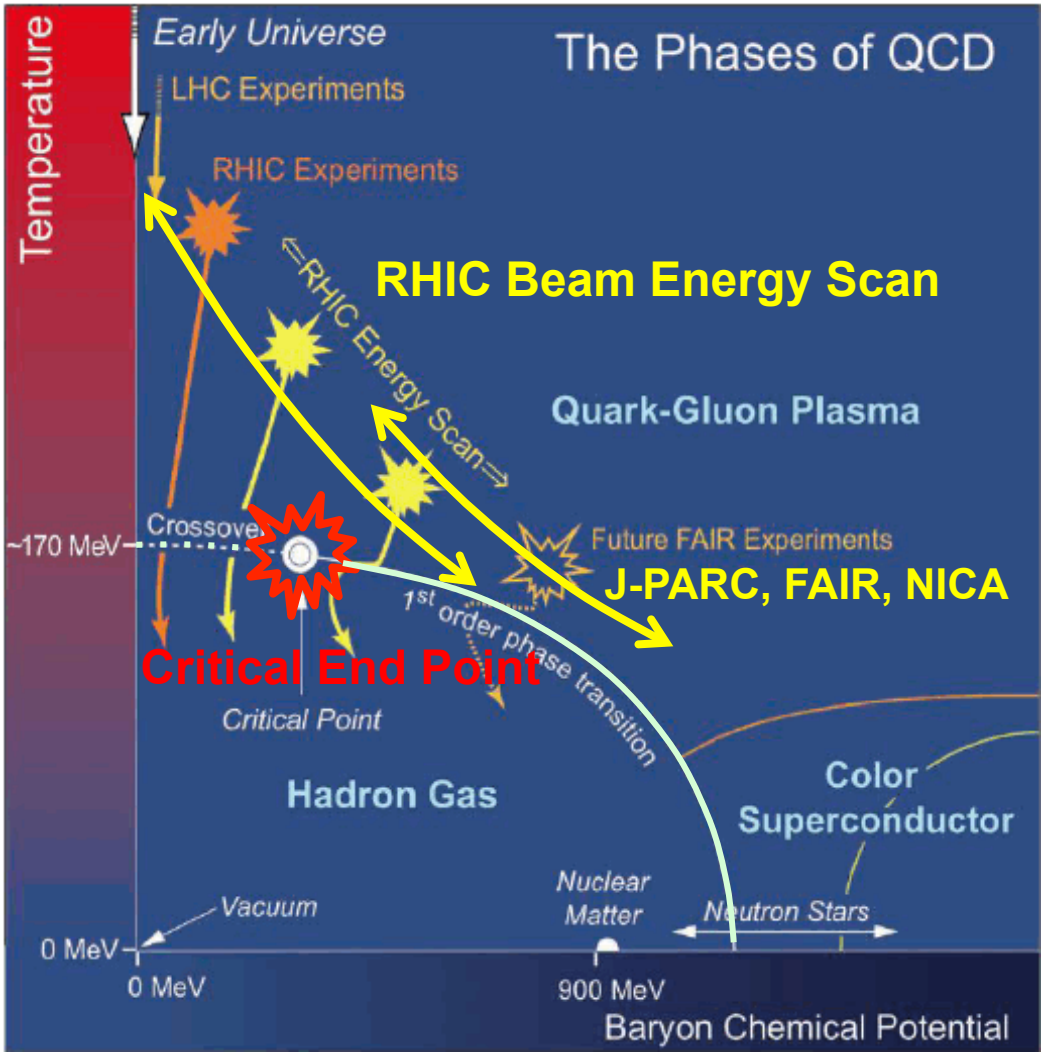
- volume fluctuation can be included as a part of response matrix
- temperature fluctuation could be unfolded via $\langle p_T \rangle$ fluctuation together with the number fluctuation, which is done in 4D-R.M.

EMMI workshop
in Wuhan 2017

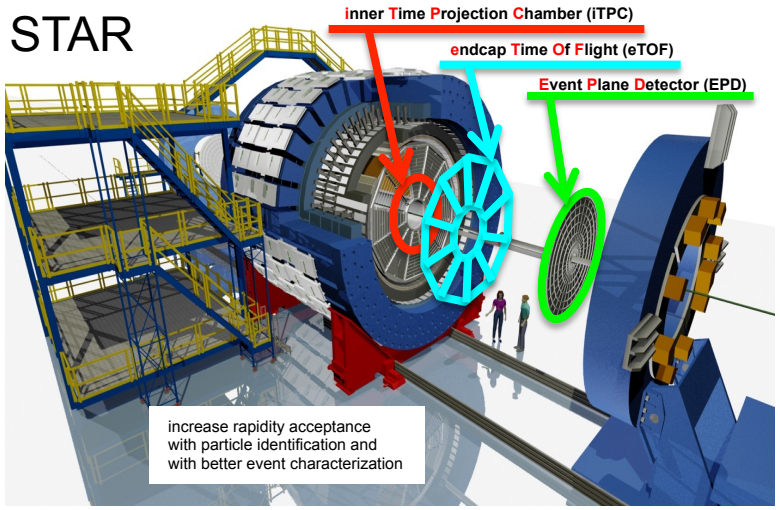
6 different 2D-projections of 4D correlation (N_1, N_2, T_1, T_2) along with iteration



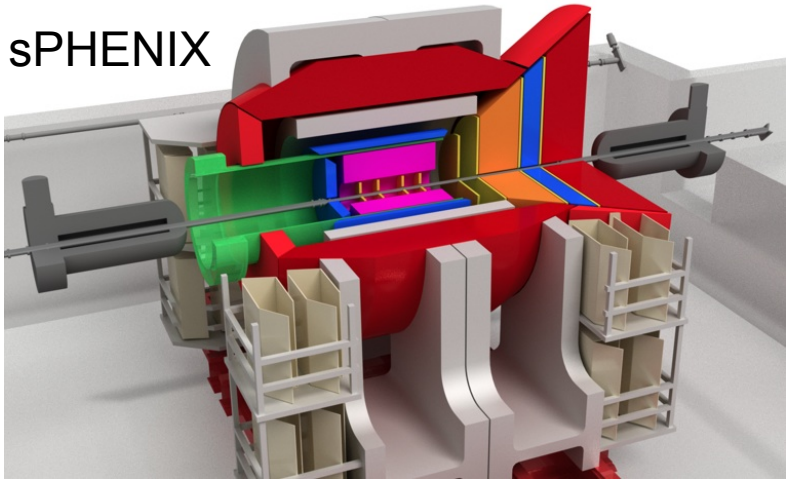
Near future : BES-II and sPHENIX/EIC



STAR

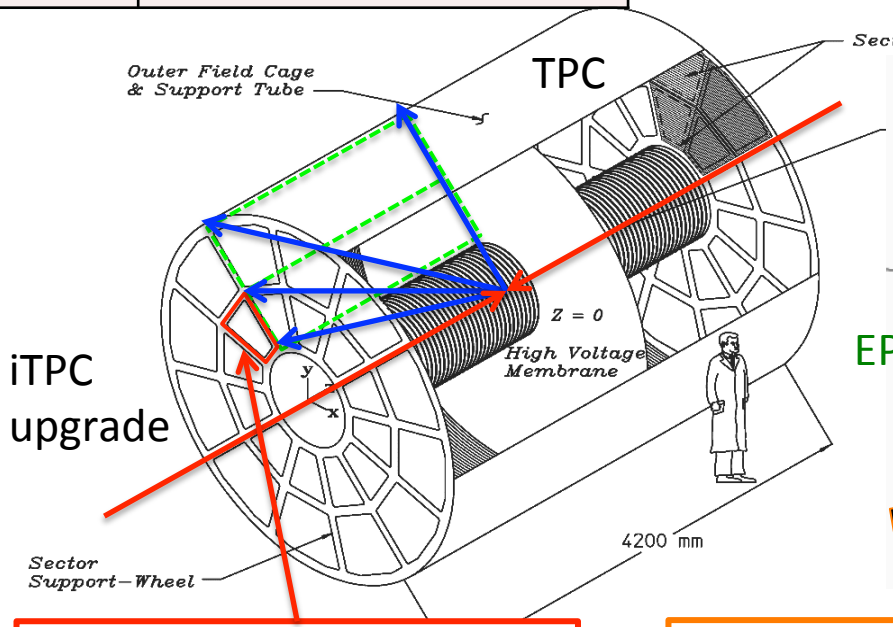


sPHENIX



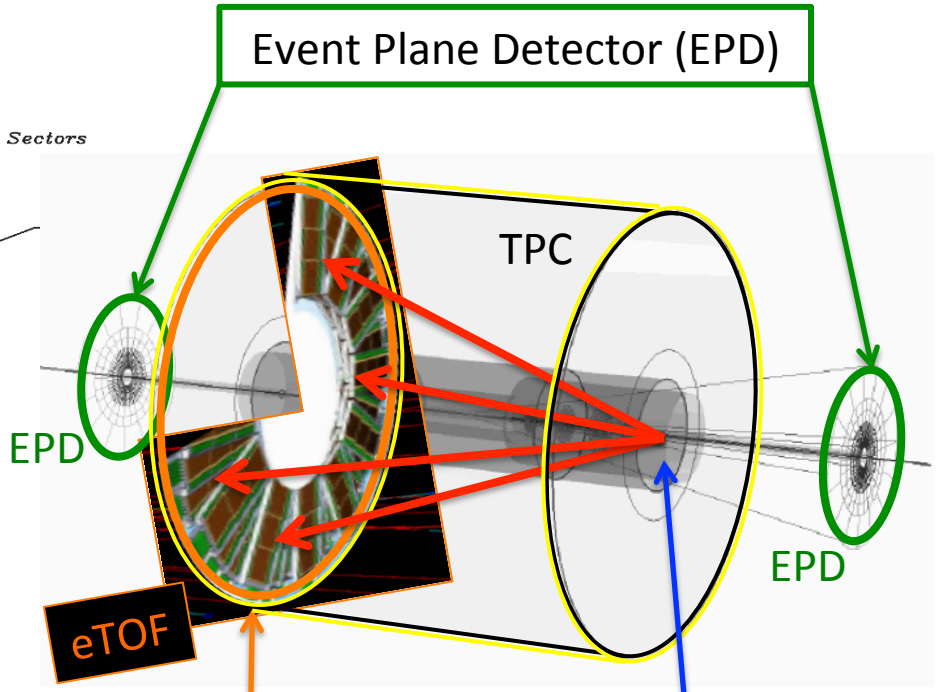
RUN17 RUN18	500 GeV p+p 54 GeV Au+Au 200 GeV Zr+Zr, Ru+Ru 27 GeV Au+Au Fixed-target test run
RUN19 RUN20 RUN21	14.5 - 20 GeV Au+Au 7 - 11 GeV Au+Au Fixed-target runs

STAR detector upgrade for BES-II



iTPC upgrade

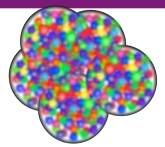
TPC inner sector readout with more segmentation



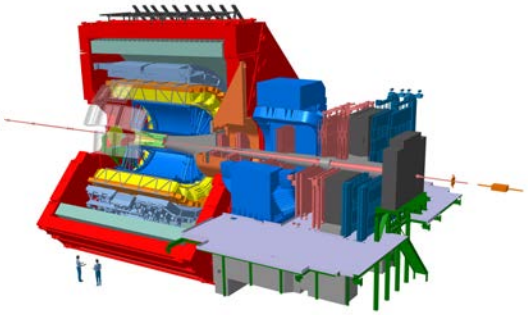
Endcap Time-of-Flight (eTOF) from FAIR-CBM

Fixed-target mode

ALICE FoCal プロジェクト

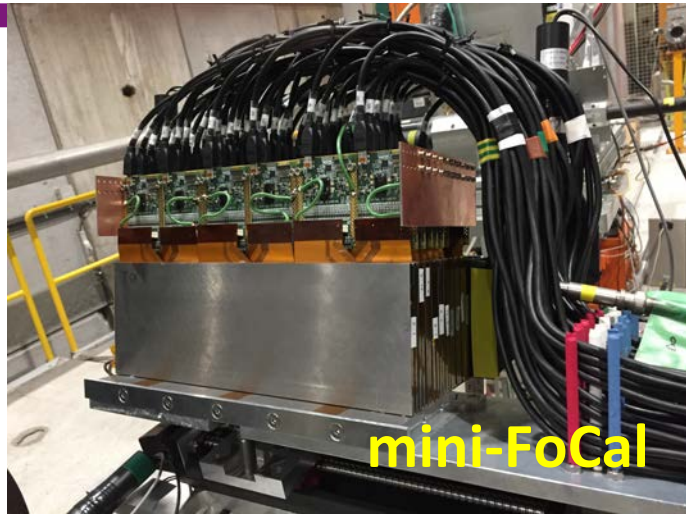


- LHC 超前方領域で、未開のQGP誕生の起源に迫る
- Si + W サンプリング型電磁カロリメータ
  - PAD (1x1cm^2)とMAPS (30x30μm^2) シリコンセンサを備えたハイブリッド検出器。2023年、実機 ALICE導入を計画中。
- 2018年、筑波大を中心とする FoCal 日本グループにより、新規試作機 (PAD, mini-FoCal) を設計・製作 (20 X_0, 3 tower 構造)。
  - CERN PS/ SPS 加速器によるテスト実験を経て、10月、ALICE 実験に初導入。pp 13 TeV 衝突事象データ取得に成功
  - 国内：筑波大、筑波技術大、広島大、奈良女子大、理研
  - 海外：ユトレヒト大学, Nikhef（オランダ）, RD51（CERN）
- 2019年3月、筑波大にて第3回FoCal コラボレーション会合開催予定

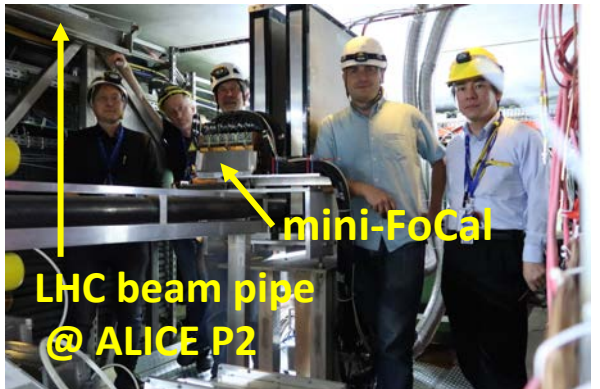


ALICE

Utrecht U. & U. TSUKUBA

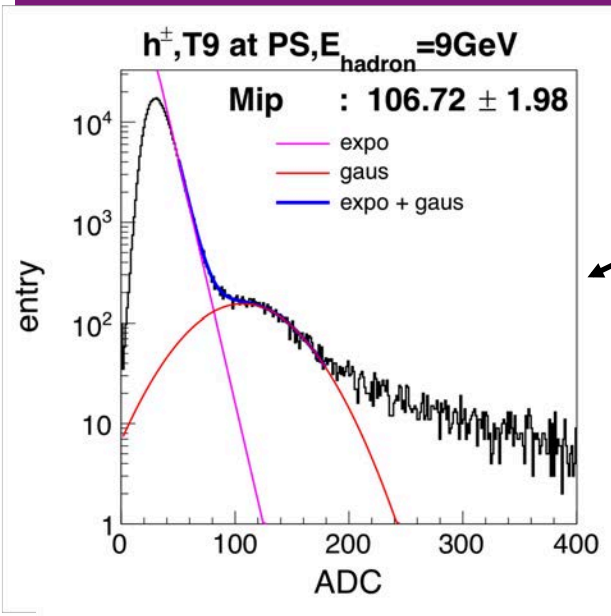


SPS テストビーム実験 (2018.8)



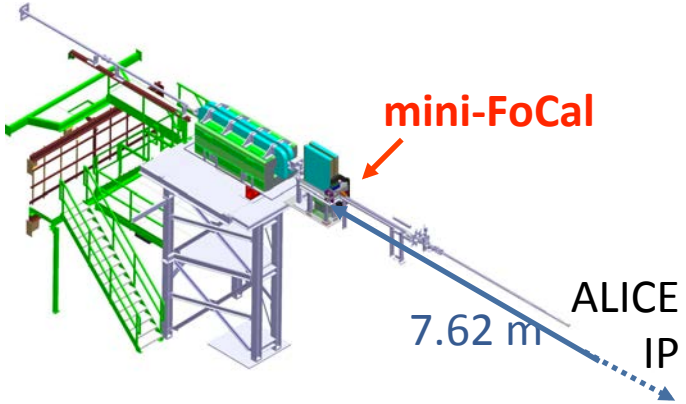
- 科研費（基盤A）ALICE 実験　ジェットと前方光子で探る高温クォーク物質生成の起源 (H29-H32, 中條)
- 筑波大学 CiC 海外教育研究リサーチユニット招致・ユトレヒト大学 (H29-H34)

PS, SPS, LHC ALICE で取得した FoCal データ



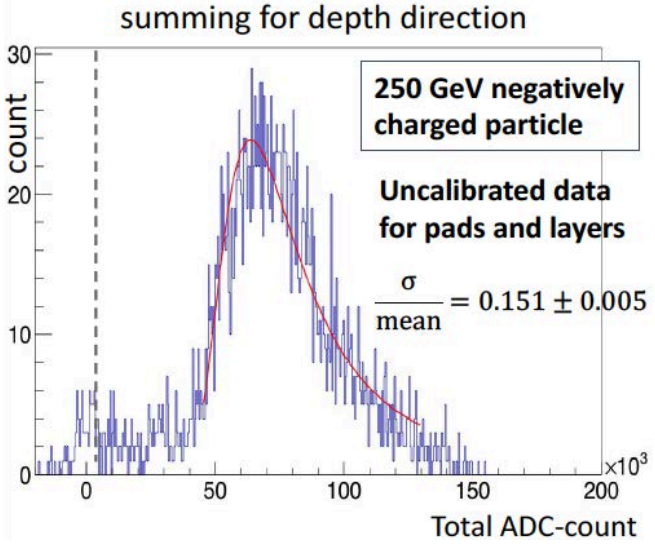
Y. Minato (QNP 2018, poster)

PS 加速器 9 GeV/c 荷電ハドロンビームによる最小電離粒子 (MIP) を確認

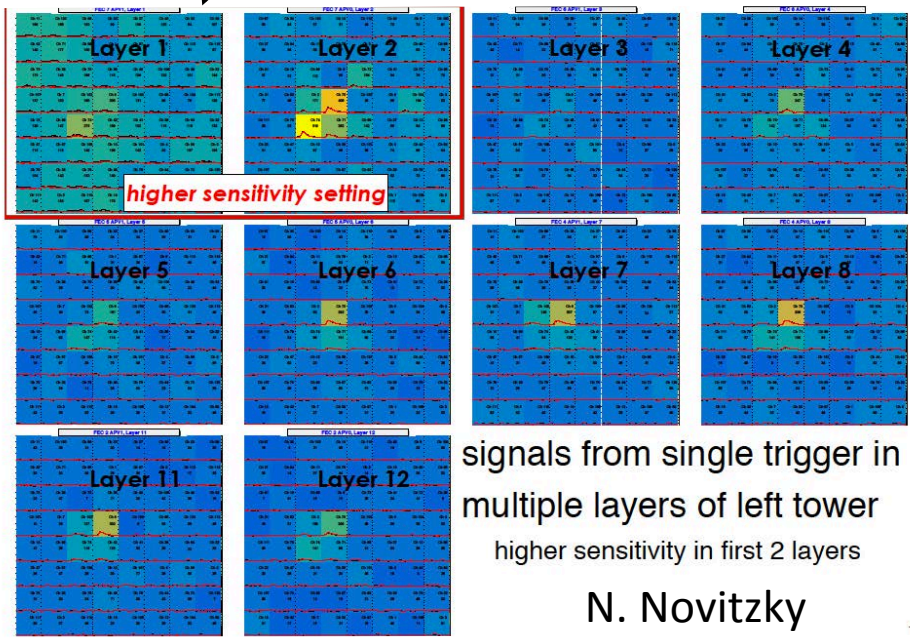


SPS 加速器 250 GeV/c 負荷電ビーム電磁シャワーによるエネルギー分解能の評価（PAD, layer 毎の補正前）

LHC 加速器 √s = 13 TeV 陽子・陽子衝突データ。ALICE IP =7.62 m の地点に mini-FoCal を設置。電磁シャワーシグナルの測定に成功



S. Takasu (JPS/DNP, Hawaii 2018)



signals from single trigger in multiple layers of left tower

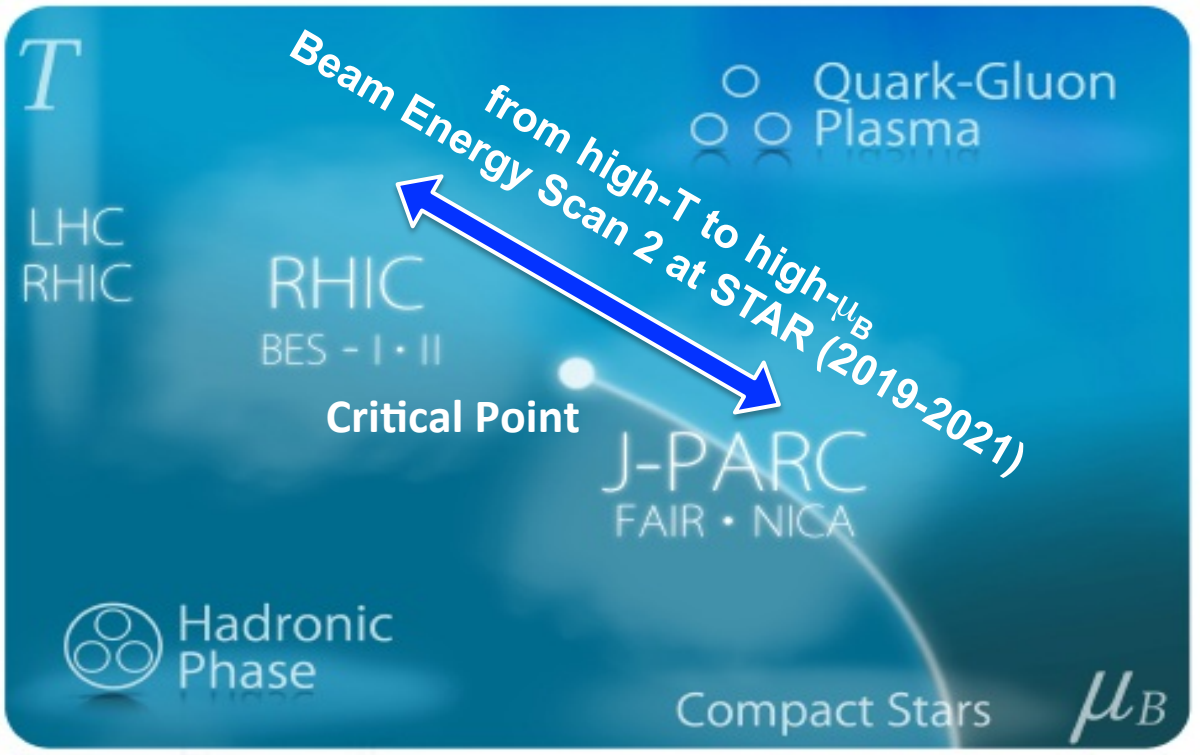
higher sensitivity in first 2 layers

N. Novitzky

Summary

- Collective expansion and thermal freeze-out
- Vortical correlation, chiral magnetic fluid
- Critical fluctuation to look for critical point

- Focal test beam and mini-Focal in ALICE



LOI for J-parc HI, H. Sako, M. Kitazawa, et. al.

筑波大学 宇宙史研究センター Tomonaga Center for the History of the Universe

筑波大学 University of Tsukuba