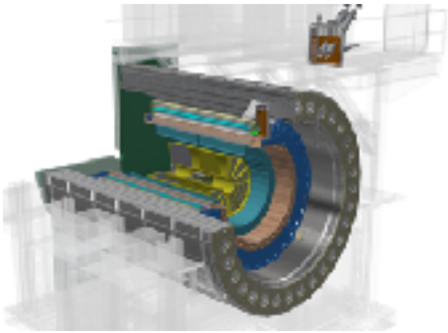
Physics at sPHENIX



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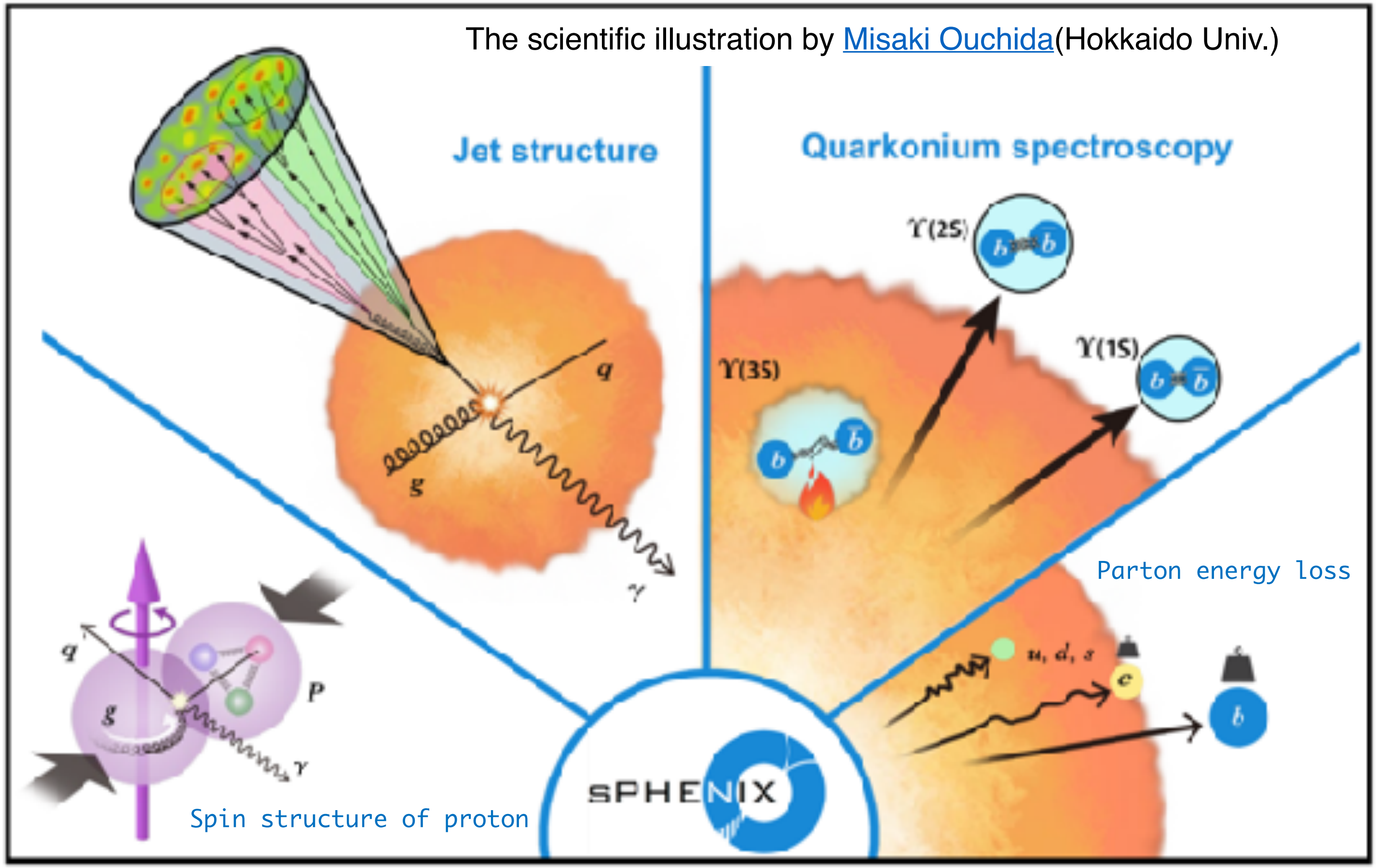
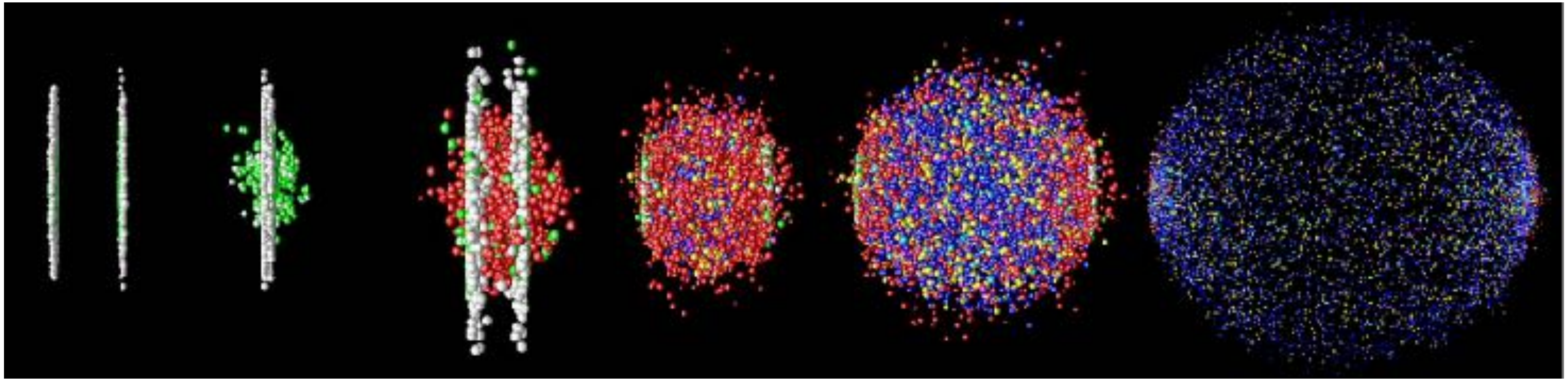
Physics goals of RHIC- sPHENIX

Quark Gluon Plasma(QGP) physics
- Parton energy loss
  - Flavor dependence energy loss
- Quarkonium spectroscopy
  - Melting of different state upsilons with RHIC temperature
- Jet structure and modification
  - Parton-QGP interaction

Cold-QCD study
- Spin structure of proton



Time evolution of the collisions

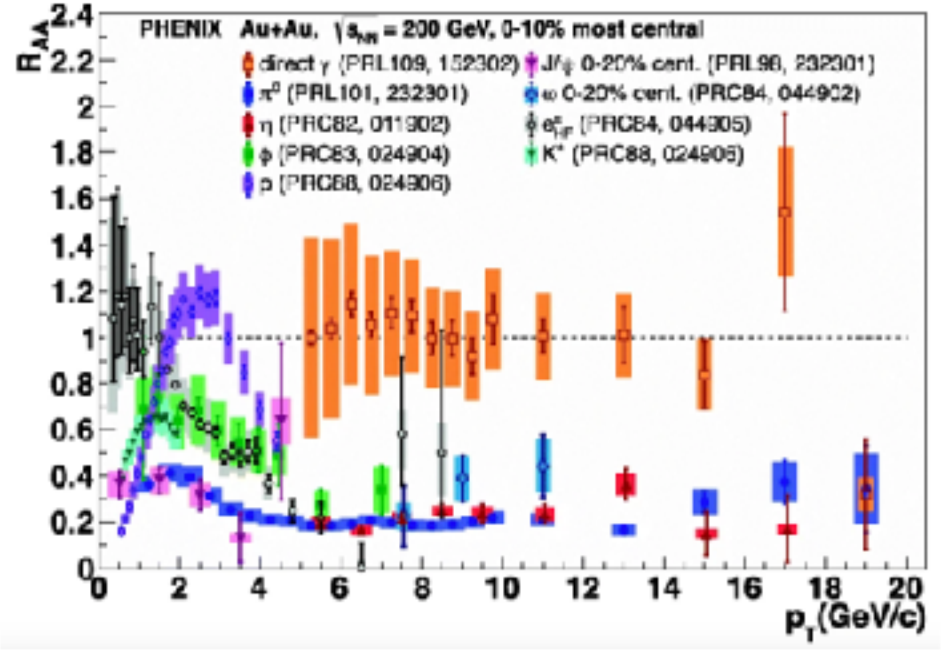


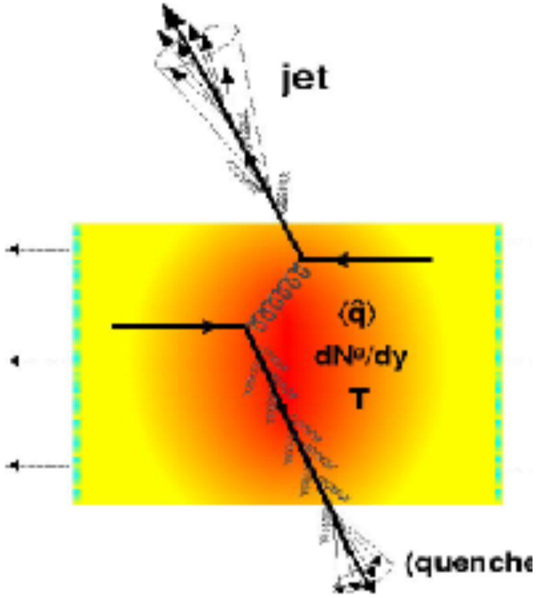
(1) Before collision | (2) Soon after collision | (3) Parton scattering | (4) QGP | (5) Hadron production | (6) To detector → time

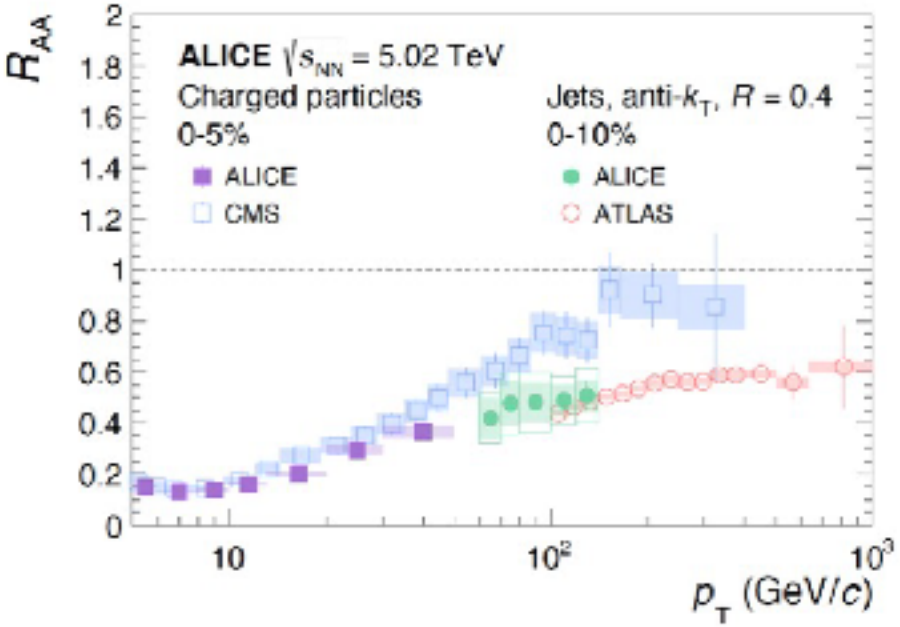
QGP lasts for a very short time.
Therefore, QGP cannot be observed directly.
Also, it is not possible to use the probe from the outside.
The probe from collision itself is used.

Jet quenching (Parton energy loss)

$$R_{AA}(p_T) = \frac{\frac{dN_{AA}}{dp_T}}{\langle N_{coll}\rangle \frac{dN_{pp}}{dp_T}}$$







Partons lose their energy while photons are not.
p+p is the reference as non QGP matter.

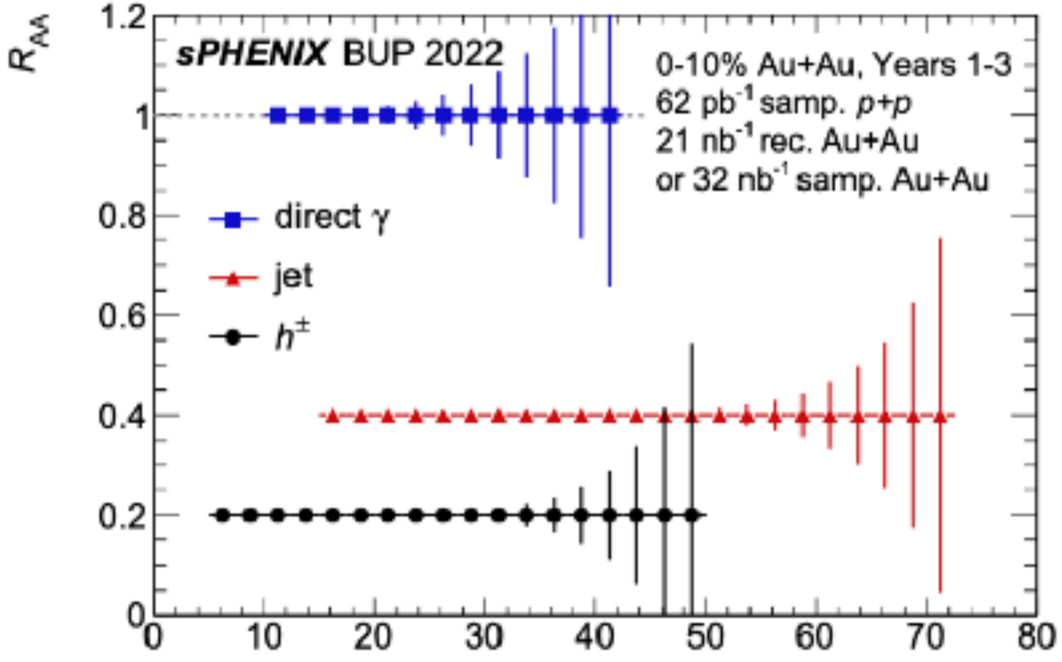
Jet R_{AA} is smaller than hadrons at the same p_T range

- The difference is described by the model with virtuality

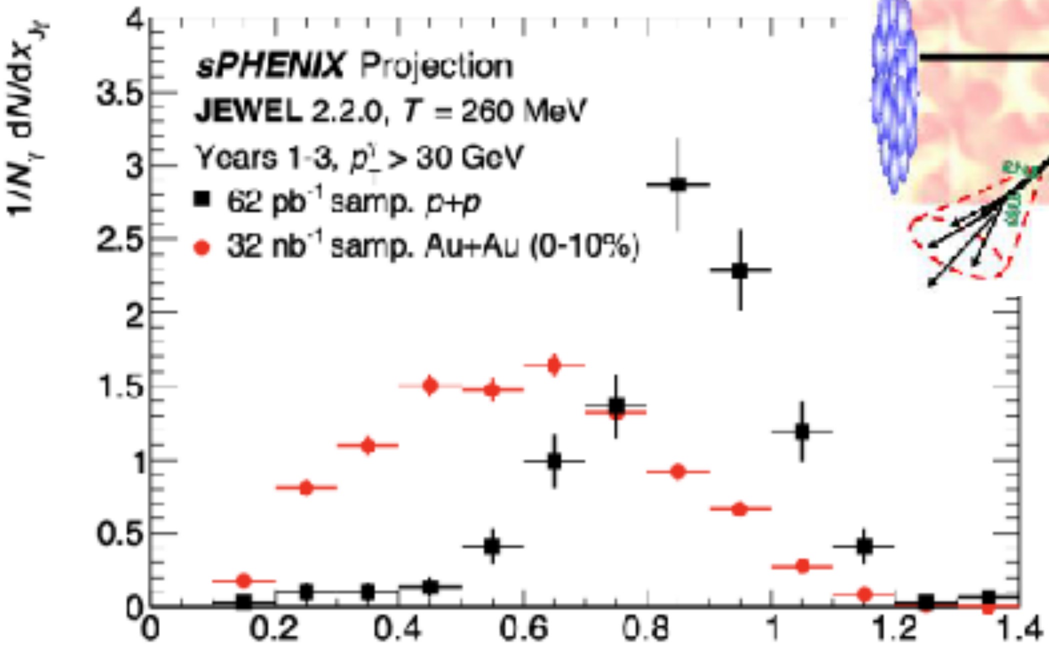
Jet and Hadron R_{AA} is increasing at higher p_T

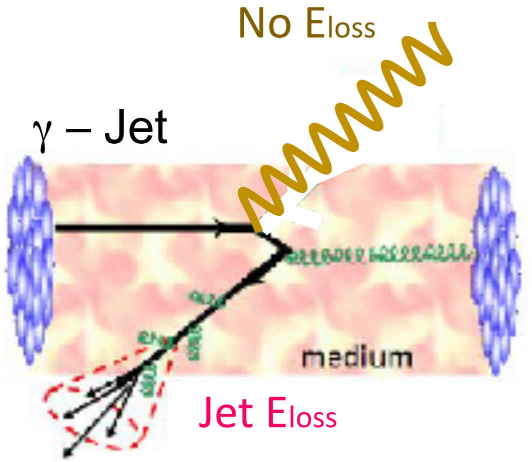
HF measurement – mass dependences

Jet at sPHENIX



γ - Jet imbalance





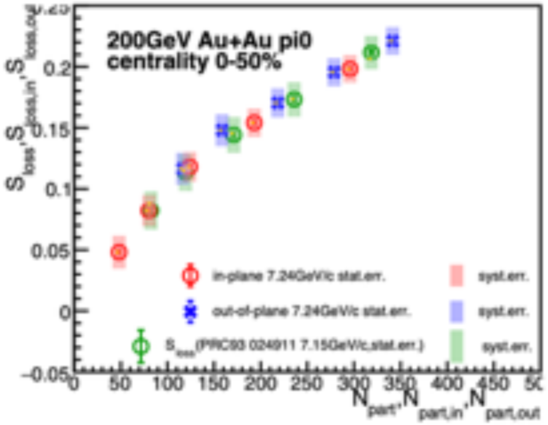
p_T [GeV]

sPHENIX extends:

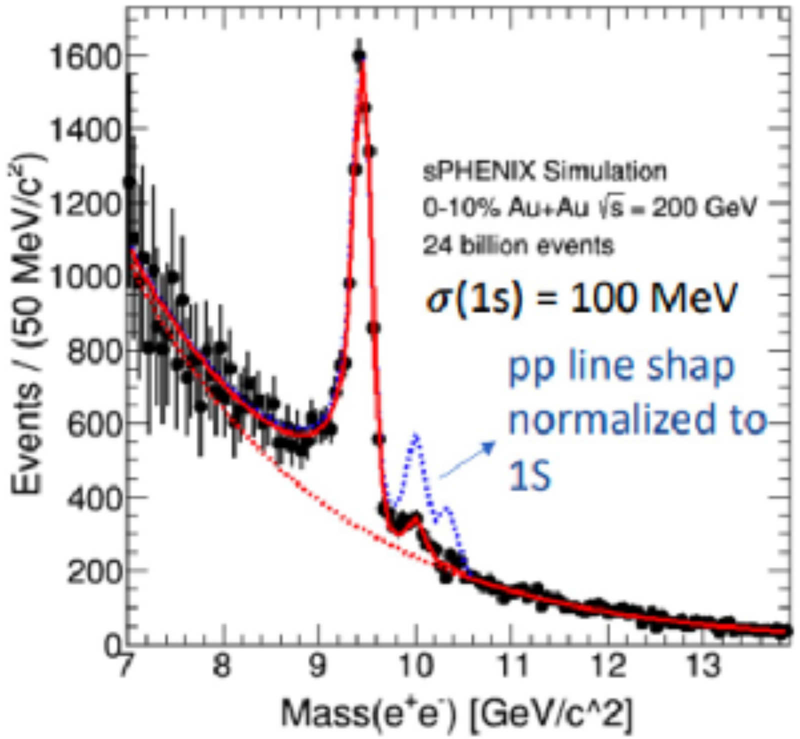
- Jet : p_T~70 GeV/c, Direct photons: ~ 40 GeV/c, hadrons: ~ 50 GeV/c,

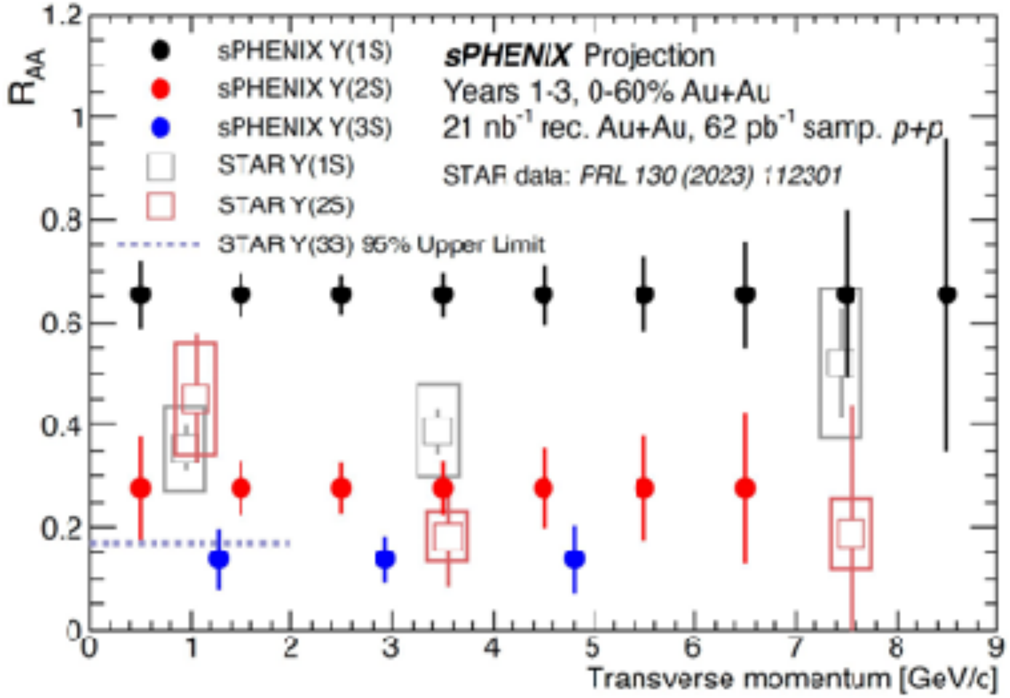
- γ - Jet : To study the modification of the jet in QGP
  - Can see the lower p_T at RHIC
- single and jet sloss, s'loss, jet-substructure(R dependence), b-tag jet etc
- kinematics overlap with LHC and lower p_T

s'loss

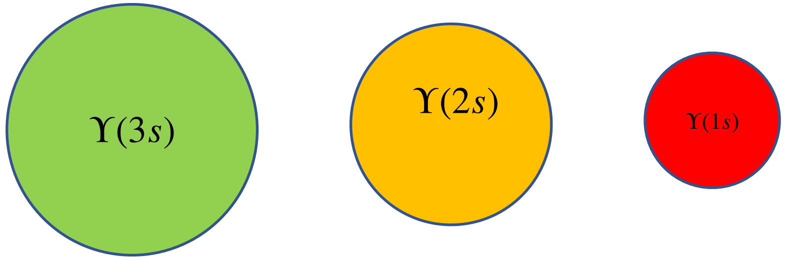


Upsilon spectroscopy

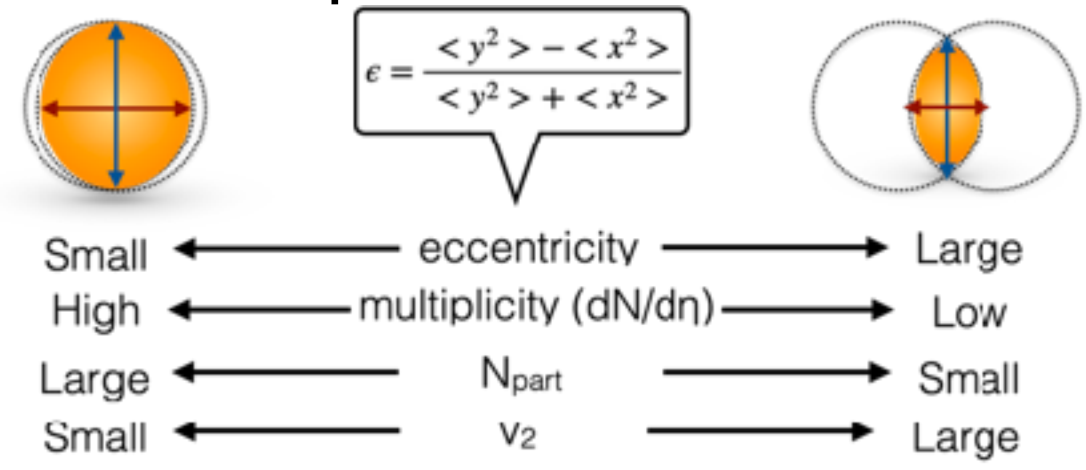


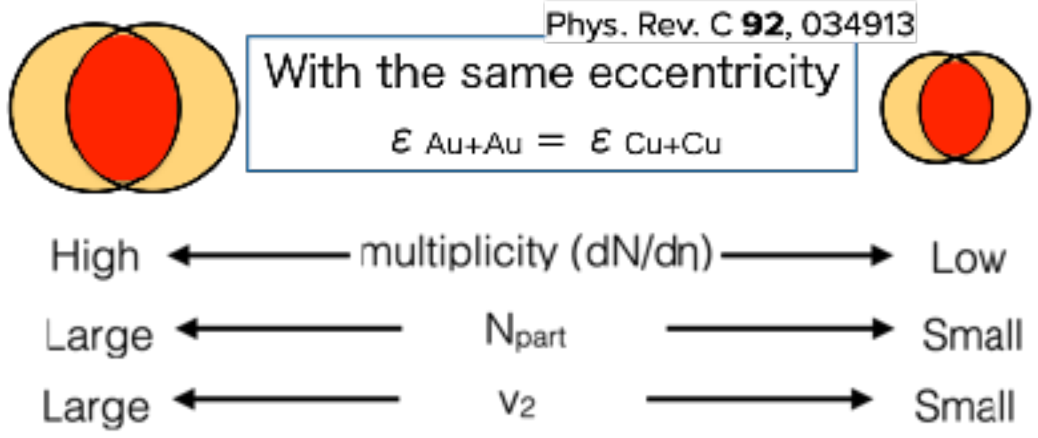


- Separate three Upsilon states (1s, 2s, 3s)
  - Υ(3s) is quantified if suppression is less
- Study centrality and p_T dependence
- RHIC is more clean than LHC
  - No regeneration of Upsilon at RHIC

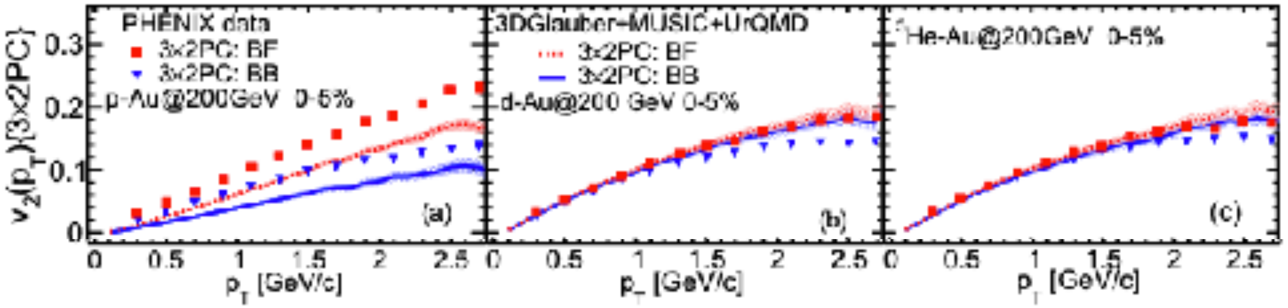


v_2 vs. N_{part} , multiplicity

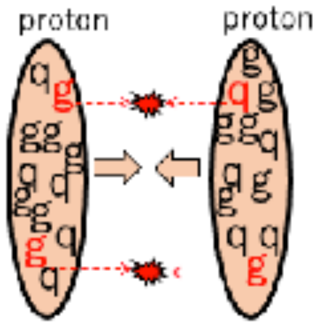




[PHENIX: PRC107.024907(2023)]
[W. Zhao et al PRC107.014904(2023)]

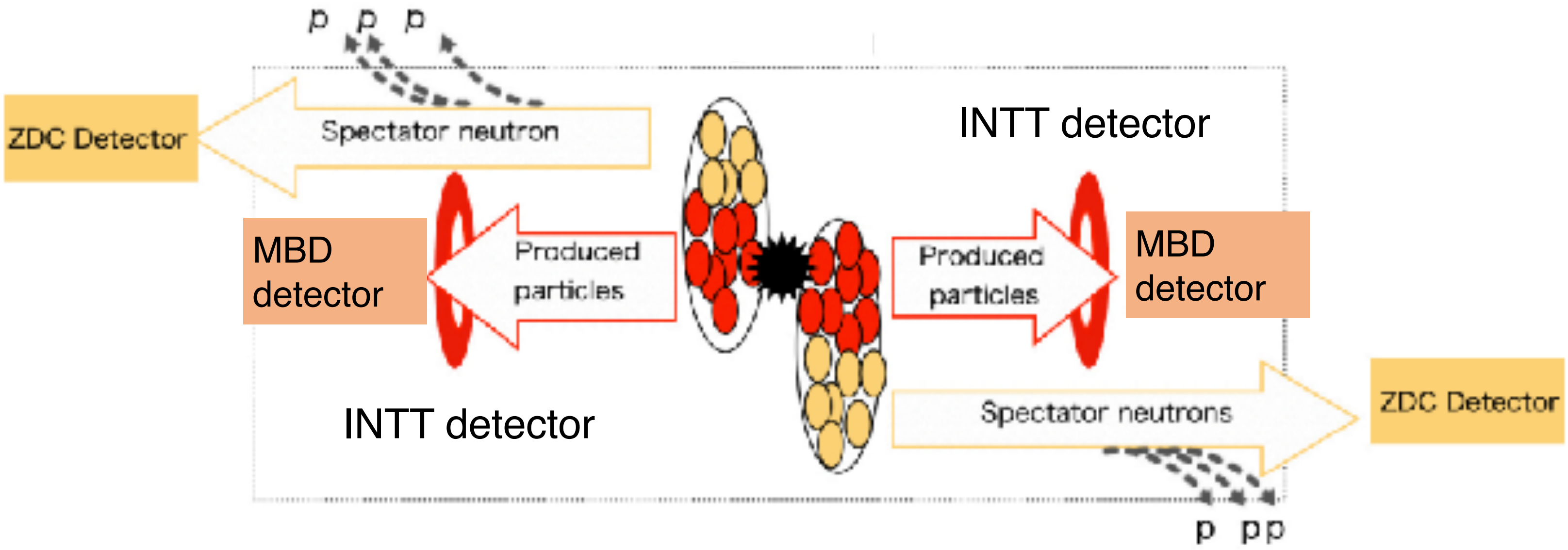


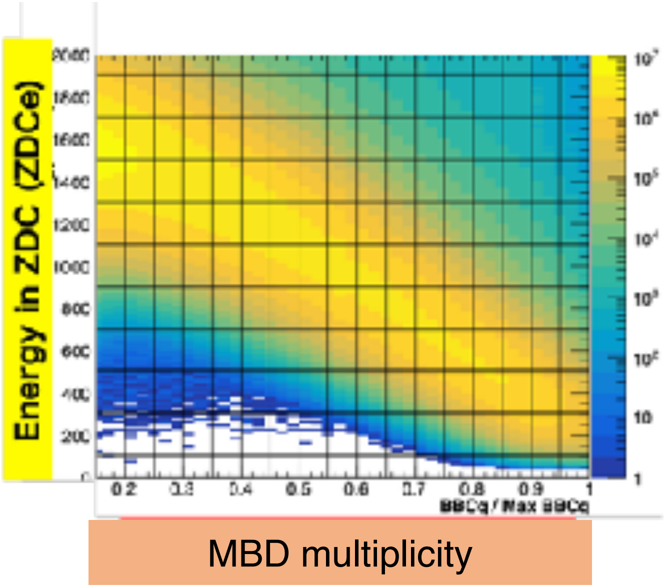
- QGP seems to be formed in small system collisions with relatively large multiplicity.
- A wide range of multiplicities exists at fixed N_{part} because of various effects like MPI, different N_{coll} values, etc.



Multi-parton interaction(MPI)

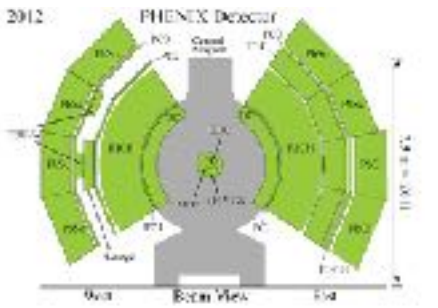
v2 vs. 2D multiplicity (event categorization)



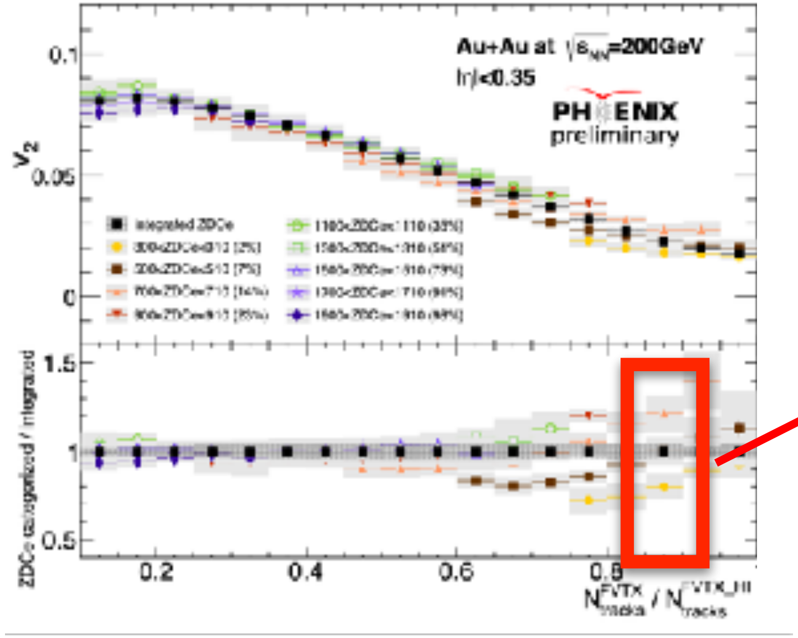


- Particles produced by collision are going into MBD(INTT). → Multiplicity
- Spectator neutrons are going into ZDC. → $N_{part} + N_{spec} = \text{Const.}$
- Measuring v_2 with 2D categorization of N_{part} and multiplicity.

v_2 at different ZDCe event categorization



With fixed ZDC bins, measure v_2 as a function of multiplicity.



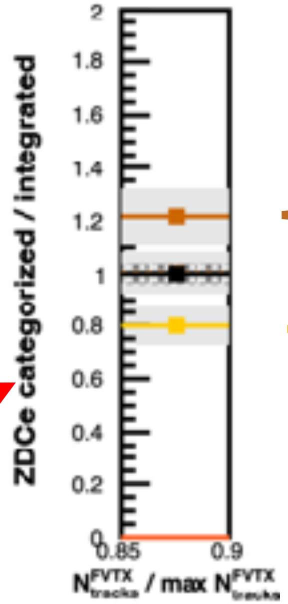
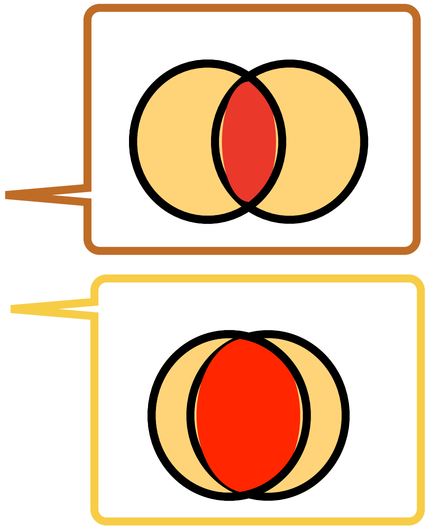
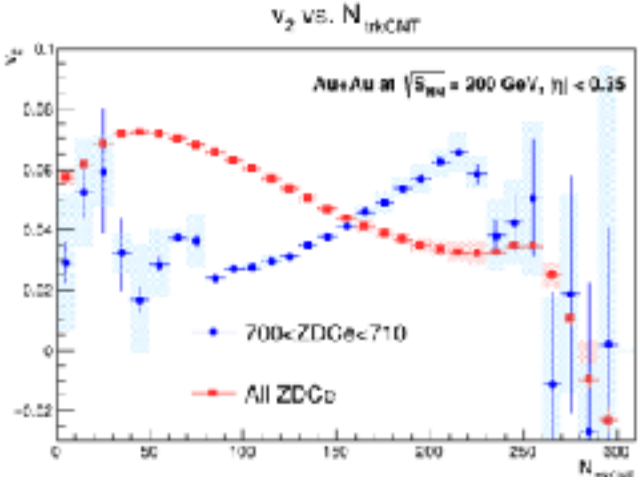


Image of the initial geometry



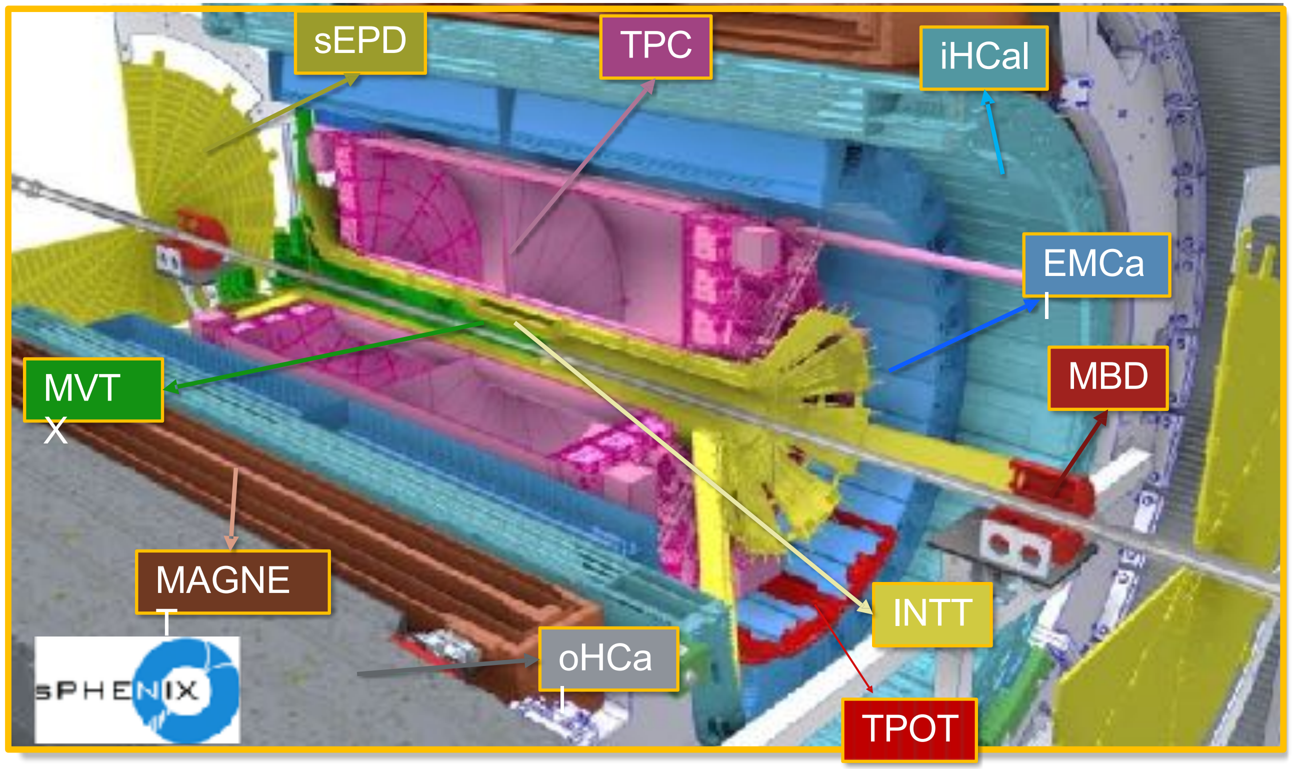


Biased by the detector shape.

These v_2 seem to reflect initial geometry differences, but they have the same multiplicity. →N_{part} is different but multiplicity is the same.

sPHENIX with 2πdetector will give non-biased measurement at mid-rapidity.

sPHENIX detectors



sPHENIX: First full jet & b-jet detectors at RHIC

- First HCAL + EMCAL at RHIC
- Acceptance: |η|<1.1, 2π in ϕ
- 1.4 T solenoid (BaBar)
- High-speed DAQ: 15 kHz for all subdetectors
- Inner layer tracking system

Tracking system

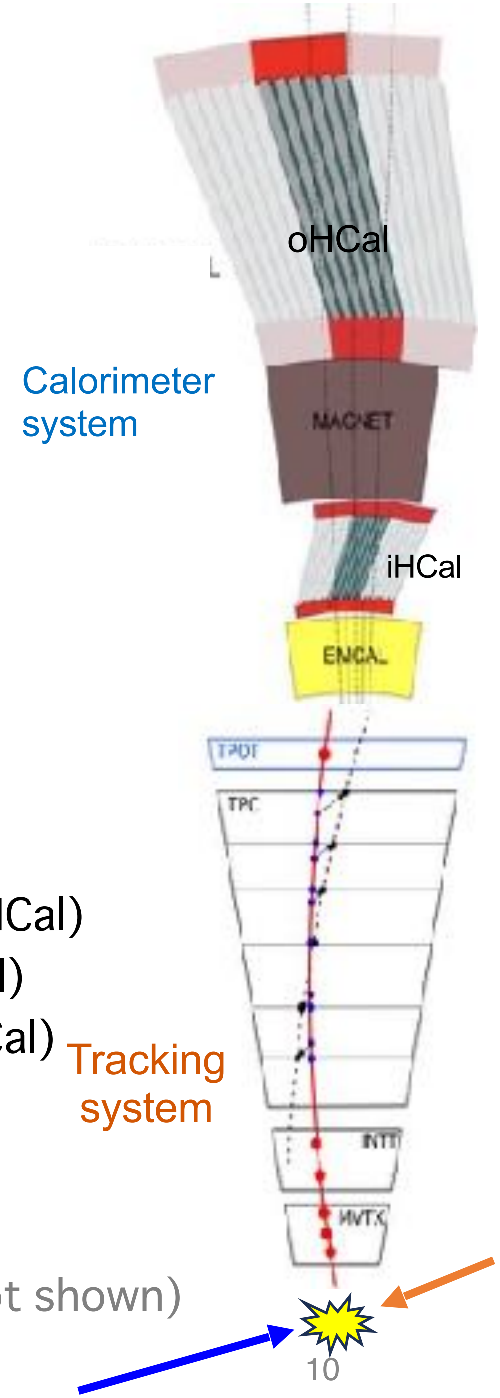
- Time Projection Chamber(TPC)
- Time Projection Chamber Outer Tracker(TPOT)
- Intermediate Tracker(INTT)
- Micro-Vertex Detector(MVTX)

Calorimeter system

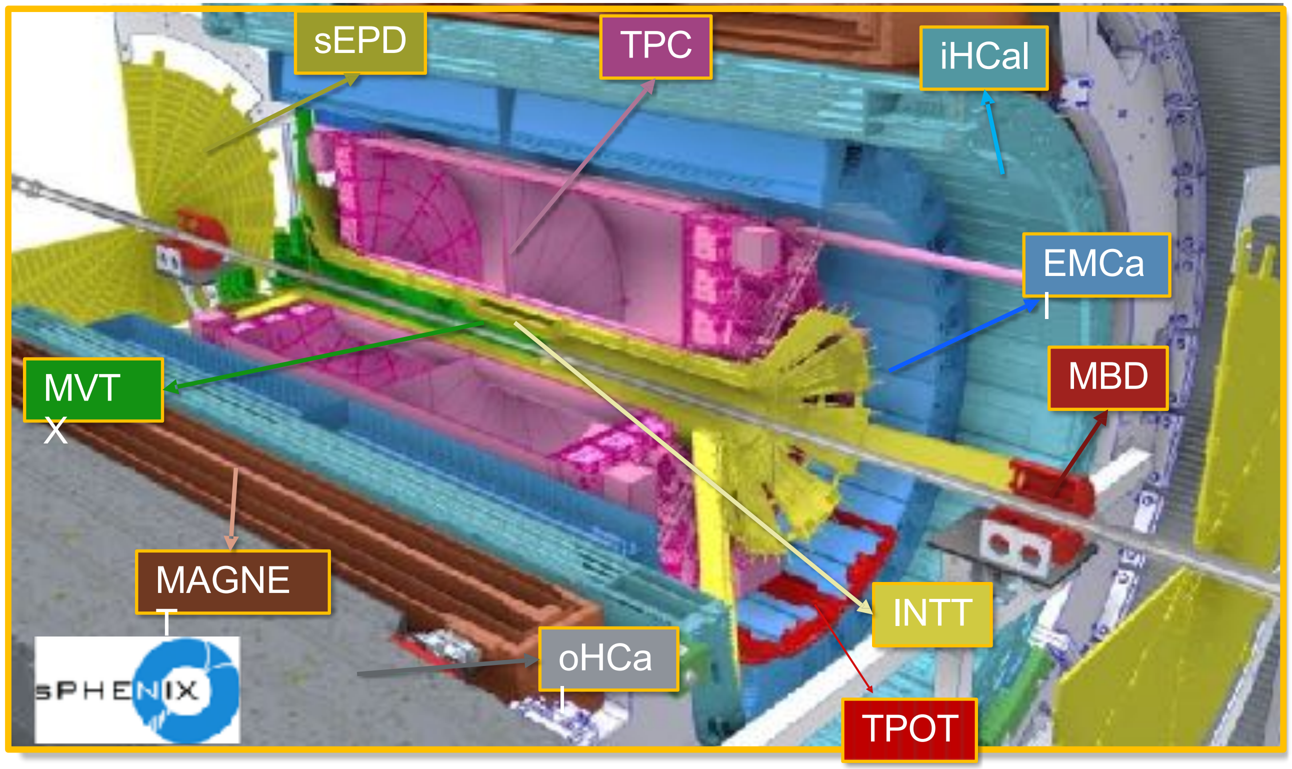
- Electromagnetic Calorimeter(EMCal)
- Inner Hadronic Calorimeter(iHCal)
- Outer Hadronic Calorimeter(oHCal)

Global detectors

- Minimum Bias Detector(MBD)
- Event Plane Detector (sEPD)
- Zero degree Calorimeter(ZDC not shown)



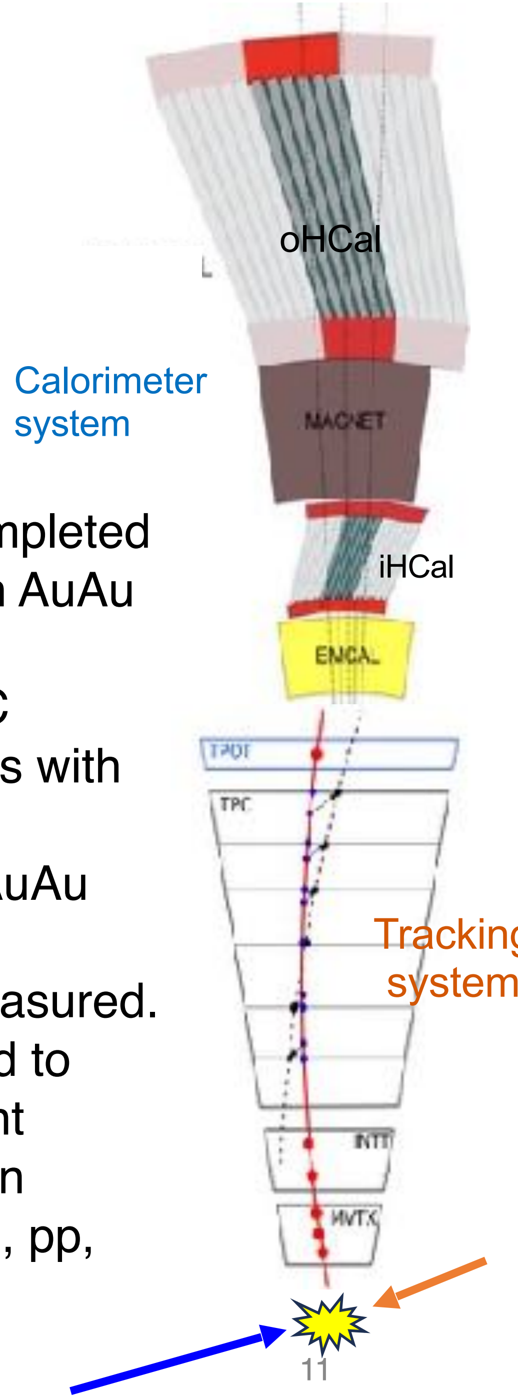
sPHENIX detectors



sPHENIX: First full jet & b-jet detectors at RHIC

- First HCAL + EMCAL at RHIC
- Acceptance: |η|<1.1, 2π in φ
- 1.4 T solenoid (BaBar)
- High-speed DAQ: 15 kHz for all subdetectors
- Inner layer tracking system

2023
March: Detector construction completed
April: Commissioning begins with AuAu collisions.
August: Beam stops due to RHIC trouble. Commissioning continues with cosmic rays.
2024:Measurement of p↑p and AuAu collisions (see next page)
2025: March: AuAu collisions measured.
March: AuAu collisions scheduled to start. Priority is to collect sufficient amount of data for AuAu. Work on additional programs such as pAu, pp, OO, etc. as opportunities arise



Run for three years

Year	Species		Cryo-Weeks	Goal
2023	Au+Au	200	10.5	Commissioning and Au+Au
2024	p↑+p↑	200	24	Au+Au baseline and Cold-QCD physics
2024	Au+Au	200	3	
2025	Au+Au ??	200	28	Au+Au large dataset

Commissioning and
1st physics Au + Au 200 GeV

Reference p + p
Cold QCD/small systems

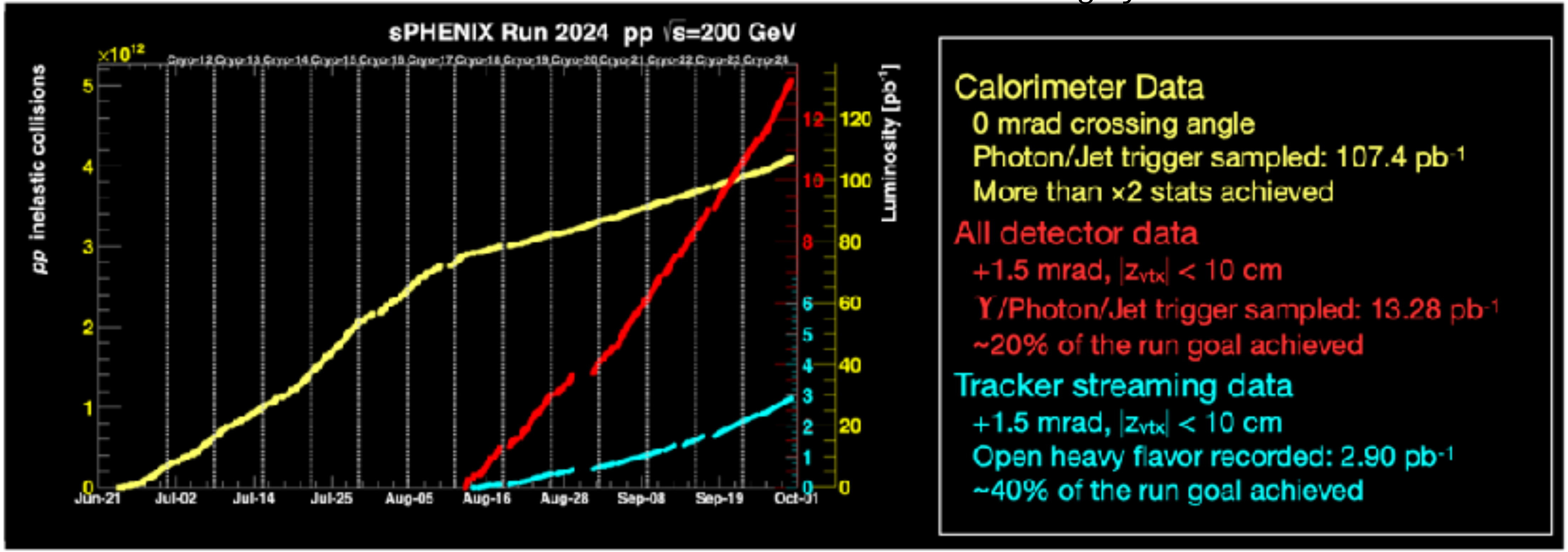
High statistics Au + Au

sPHENIX data taking in 2024 successfully finished.

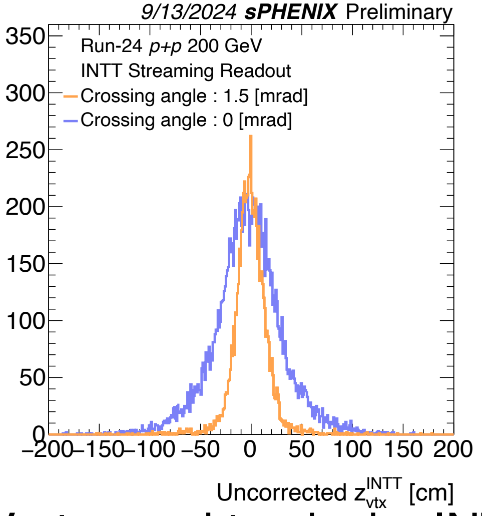
Run2024

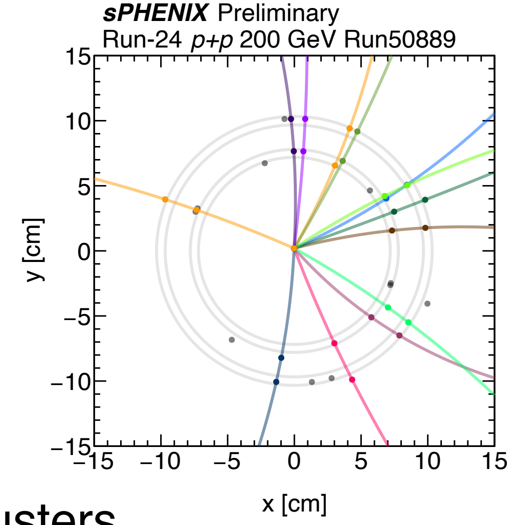
- Transversely polarized proton p↑p↑ @√s = 200 GeV
  - Commissioning
  - Physics data taking (2024/06 - 2024/09)
- Commissioning for AuAu @√s = 200 GeV

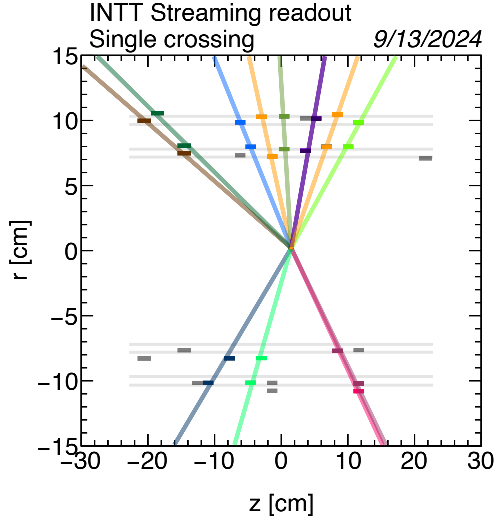
‣ March: maintenance of TPCs completed. Set-up reconstruction completed.
‣ April: commissioning by p↑p↑ begins.
‣ June: Start of physical data collection (Calorimeter Data).
‣ August: start of stable operation of TPC. Start of physics data collection with full set-up.
(All detector data, Tracker streaming data).
‣ October: commissioning by AuAu.

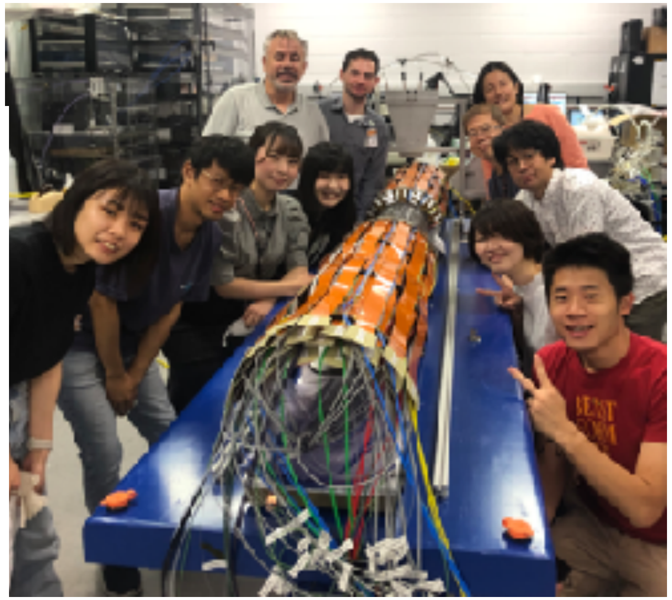


INTT works well

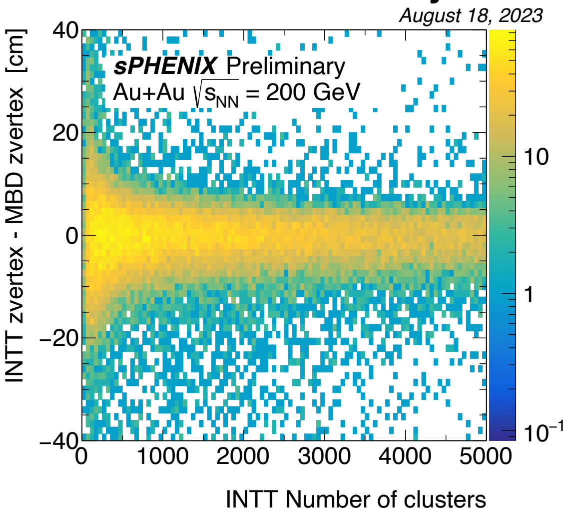




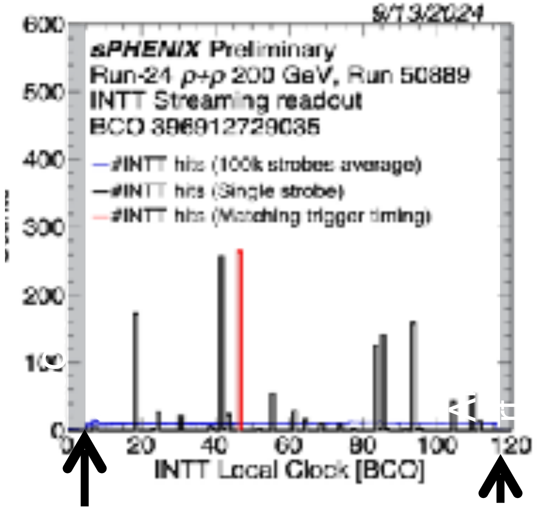


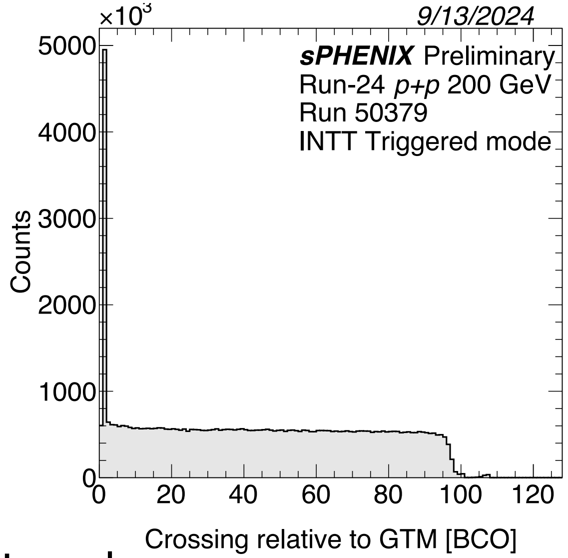


Vertex and tracks by INTT clusters

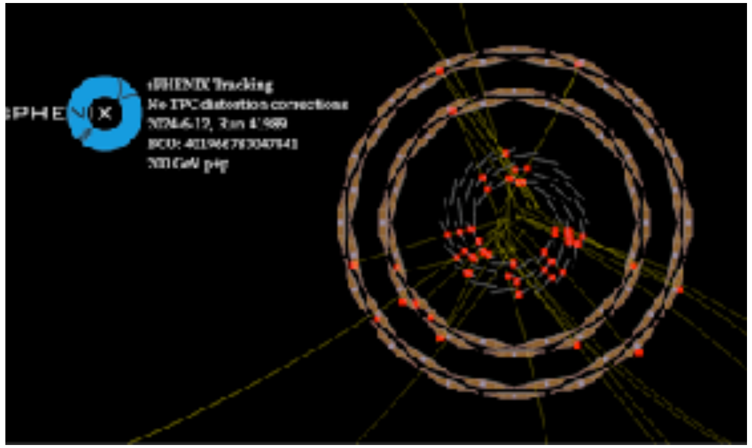


MBD and INTT vertex correlation



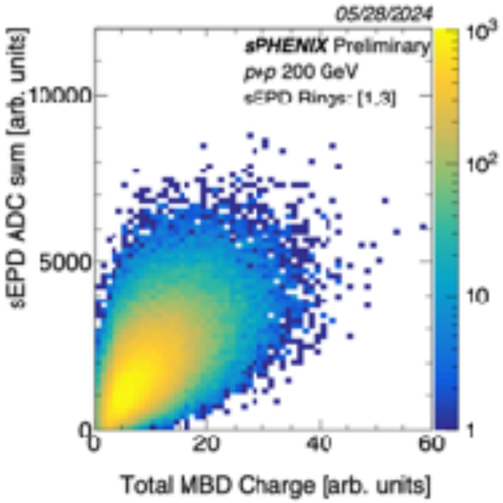


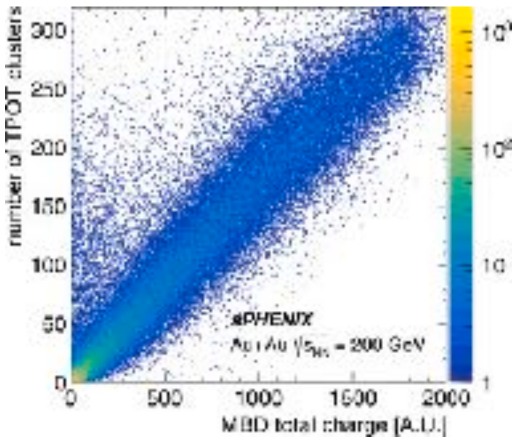
Streaming read out works.

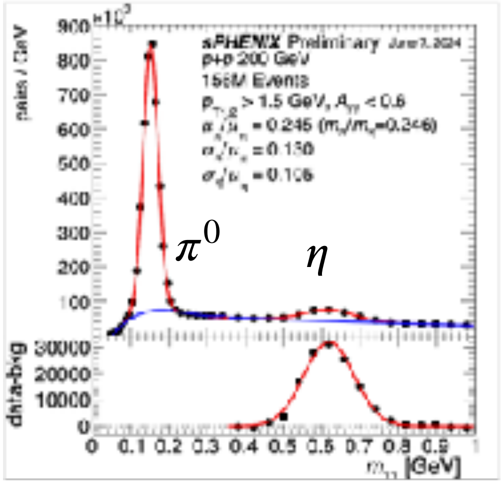


MVTX and INTT tracklet

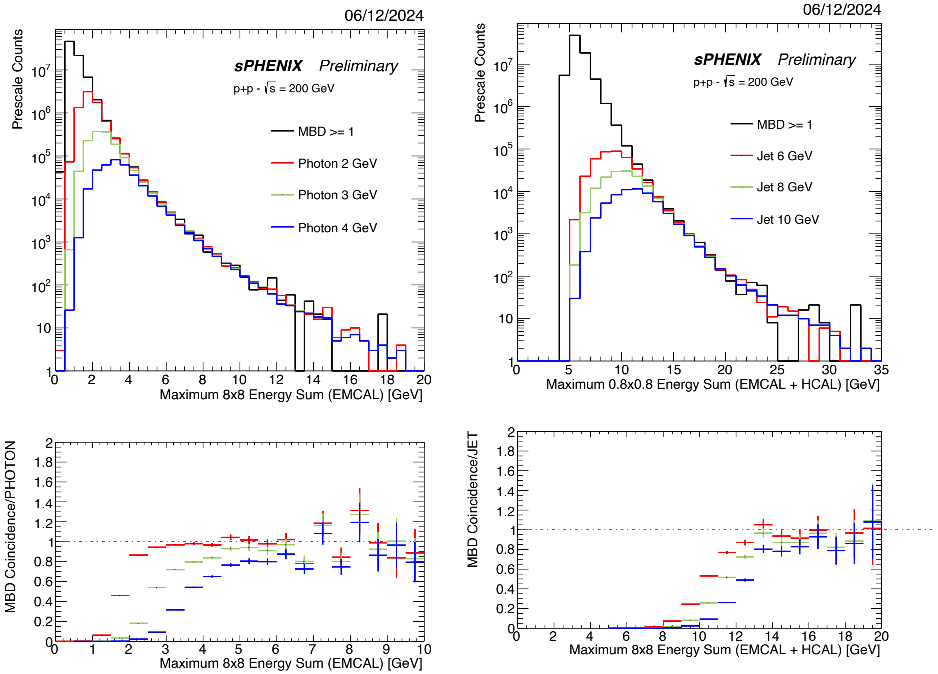
Detectors works well



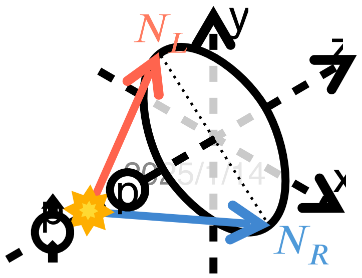




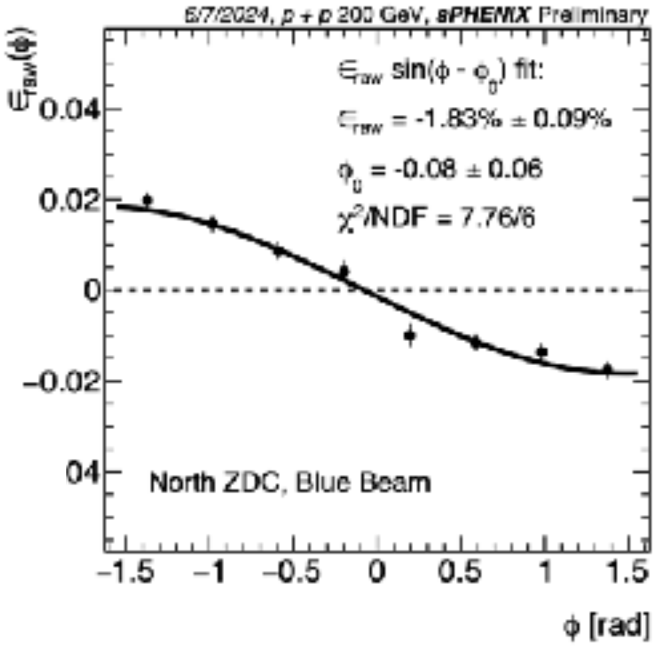
$M_{\gamma\gamma}$ 分布

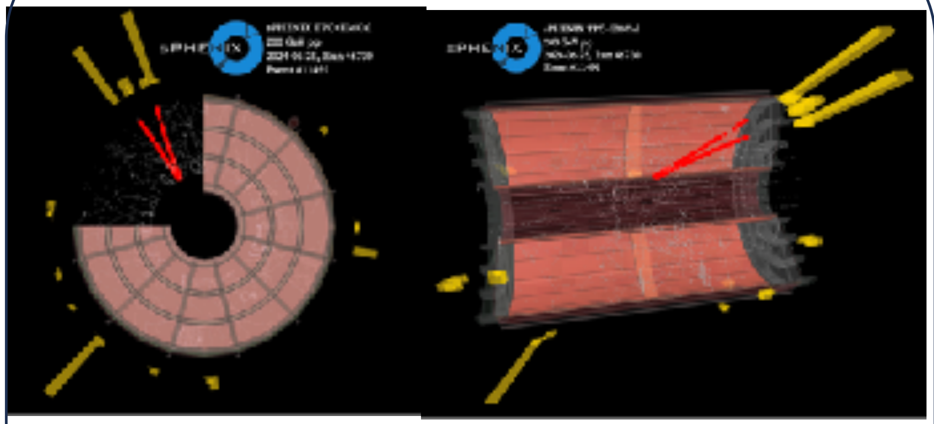


Photon, jet triggers compared with MB.



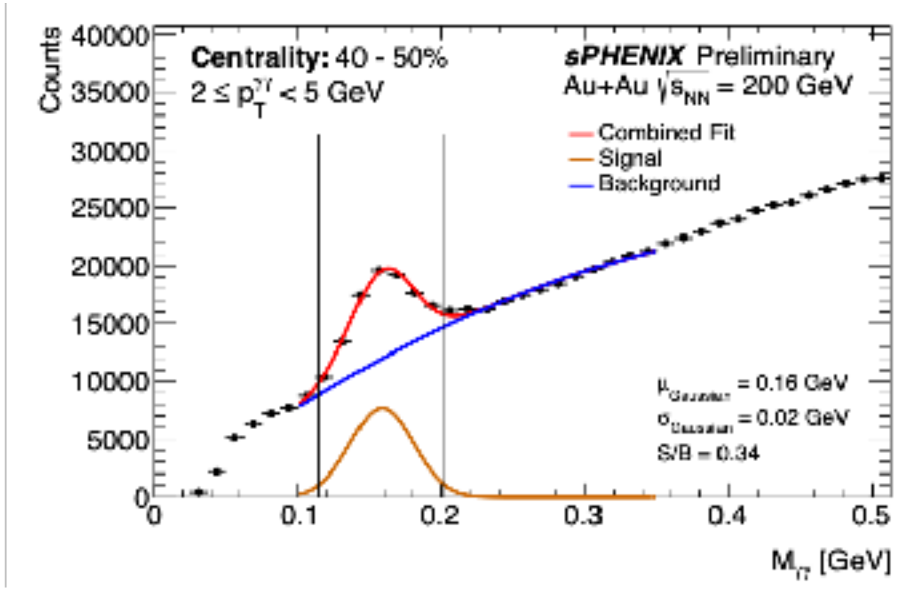
$A(\phi) \sim -1.5\%$→ Beam polarization approx. 30%. The results of the PHENIX era were reproduced.

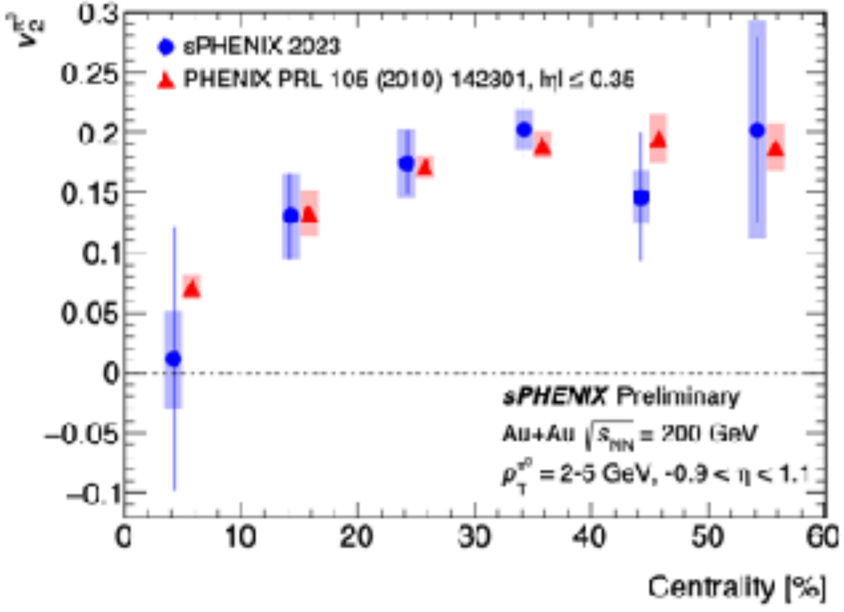


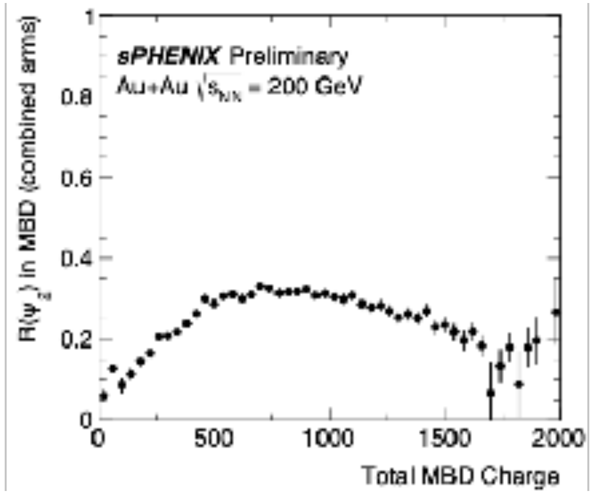


TPC track is associated to the calorimeter energies.

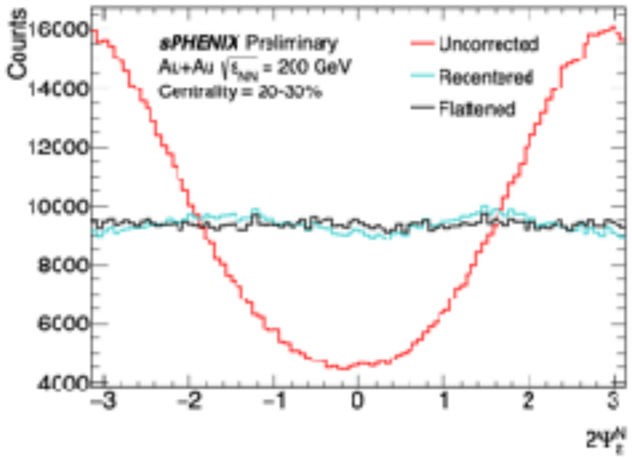
sPHENIX measurement: π^0 v_2





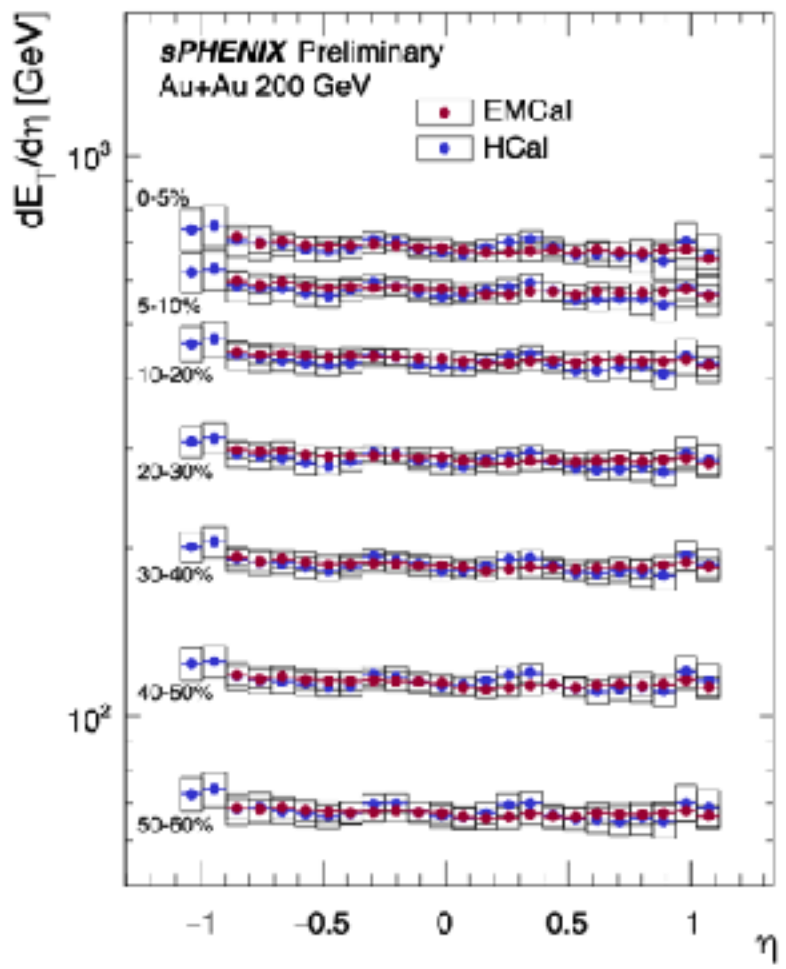


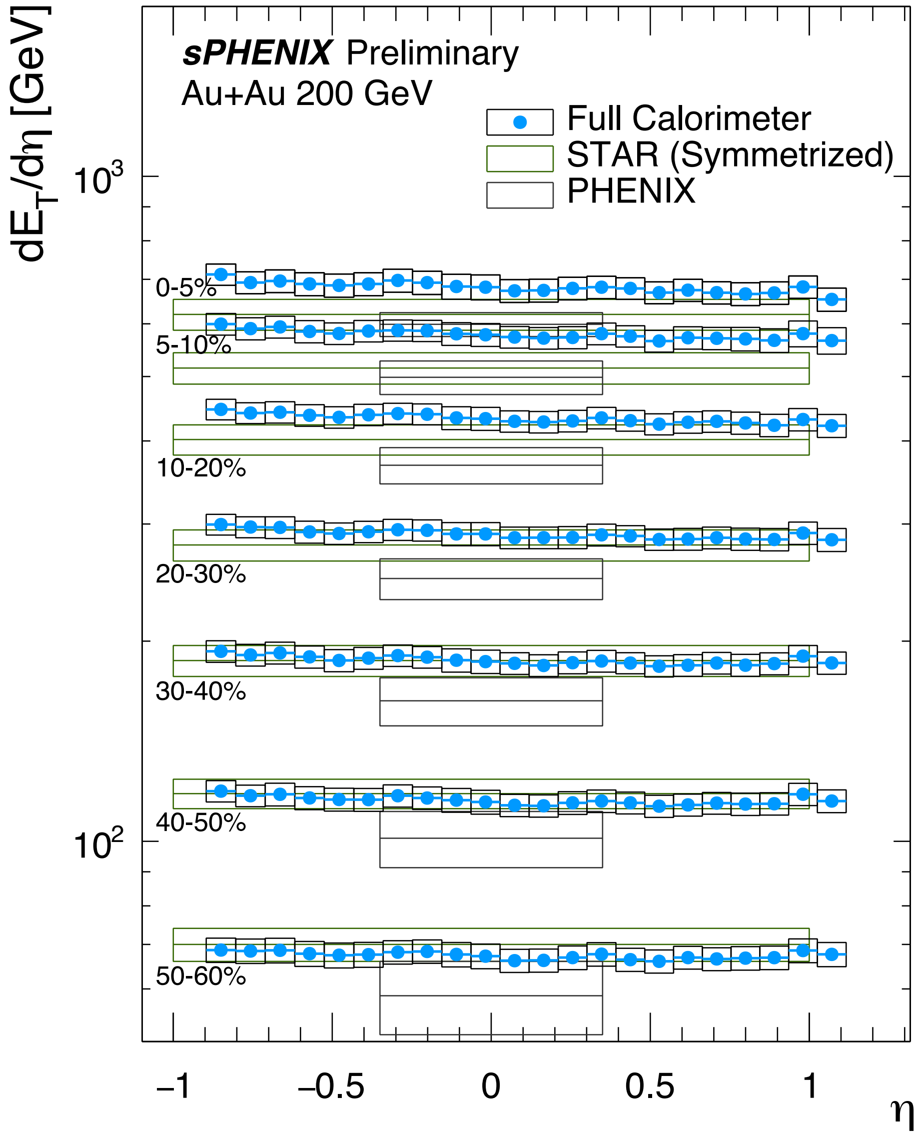
MBD RP resolution



- π^0 is reconstructed. RP is calibrated.
- Event plane detector(sEPD) give better resolution for RP. Analysis is on-going.
- v_2 vs. centrality agree to previous measurement.

Calorimeter $dE/d\eta$

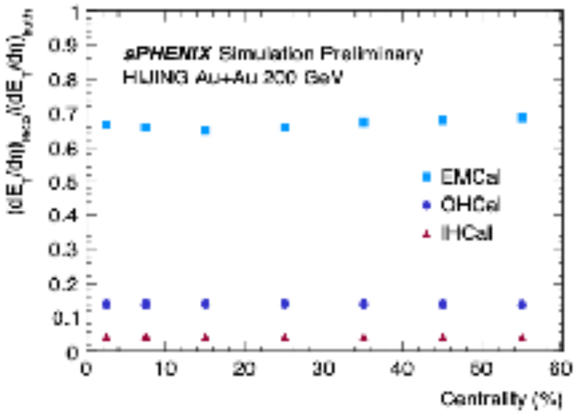




Successfully obtained dE/ $d\eta$

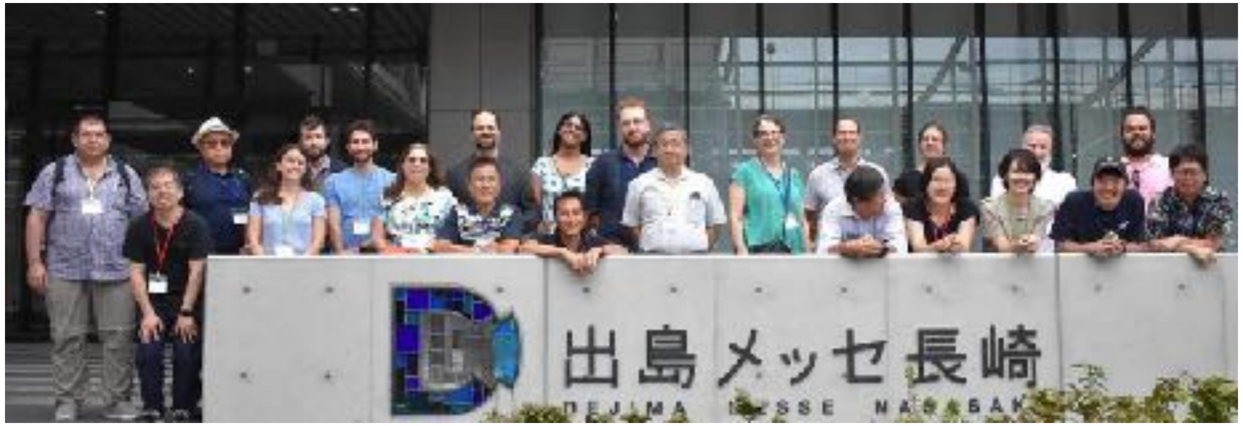
dE/ $d\eta$ by EMCal and Hcal agreed well.

Comparable results with previous measurement.



summary

- sPHENIX took p+p data and were commissioned with Au+Au collision.
- The streaming readout and trigger readout are both working for the tracking detectors.
- The analysis show the detectors properly worked. Analysis for new physics results in p+p are on-going.
- sPHENIX is ready to take massive Au+Au data in this coming run.



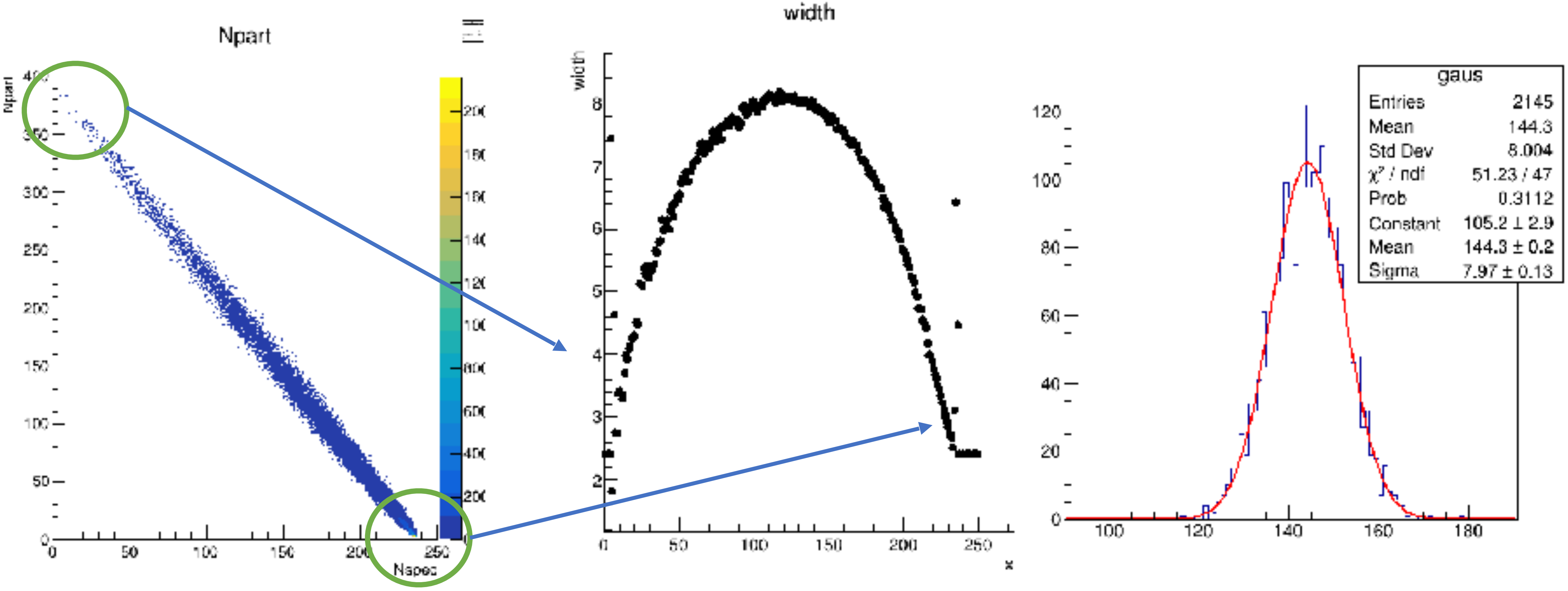
End of Run24 p+p party (Sep 30)

End of Run24 Au+Au party (Oct 21)

Thank you.

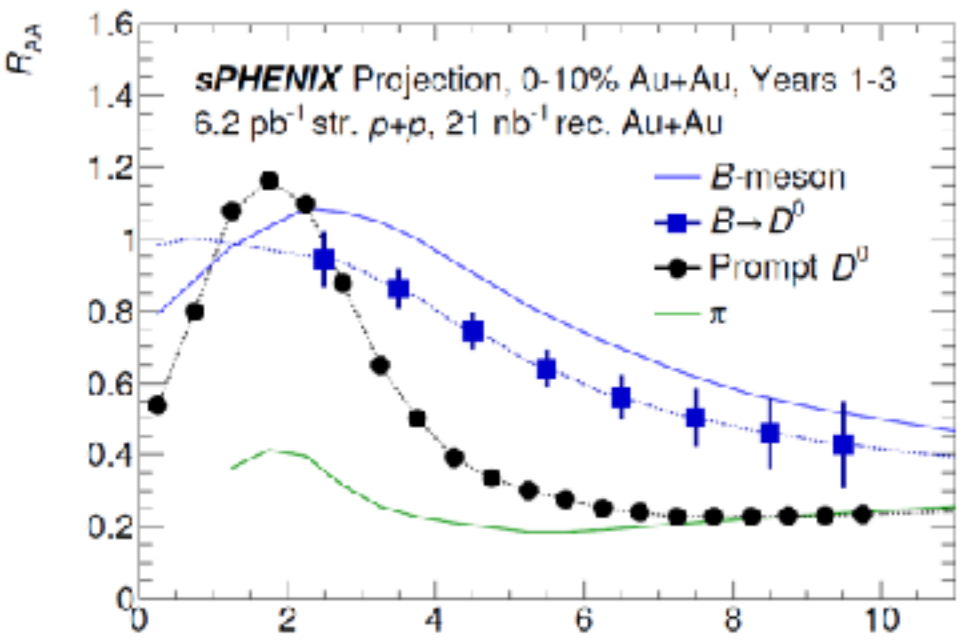
Back up

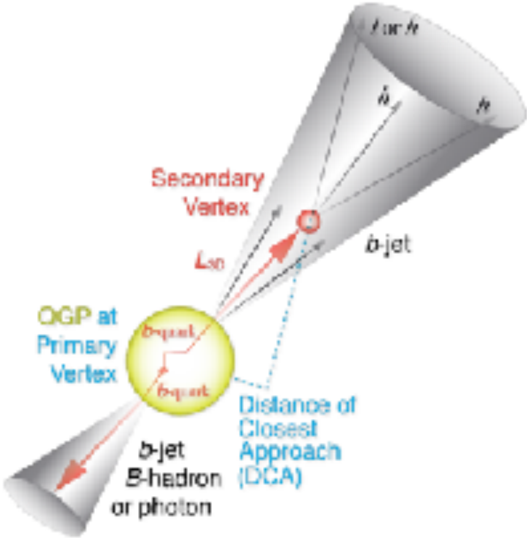
Effect of the ZDC detecting only neutrons.

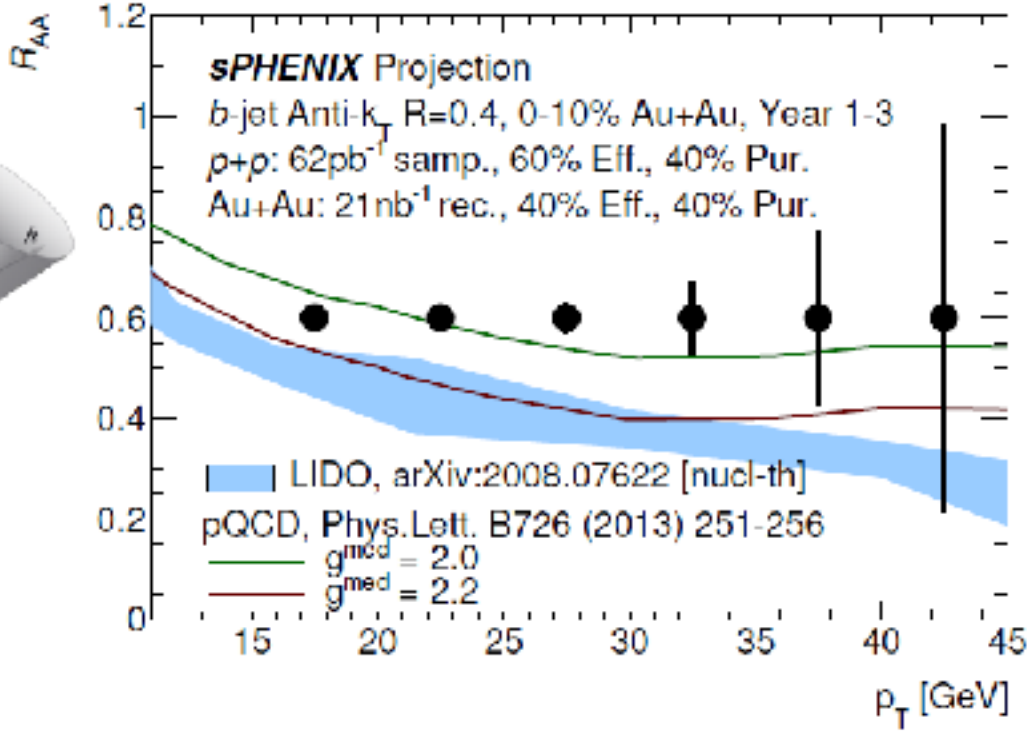


# of event 6.4M

Heavy Flavors and HF-Jets

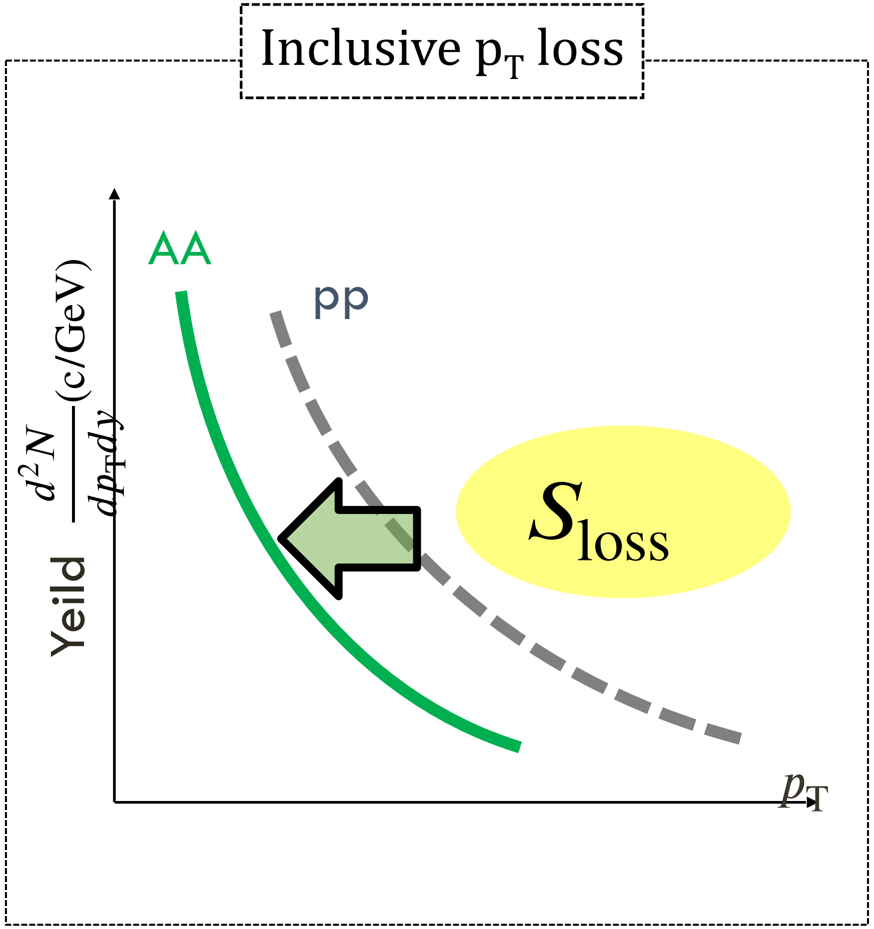


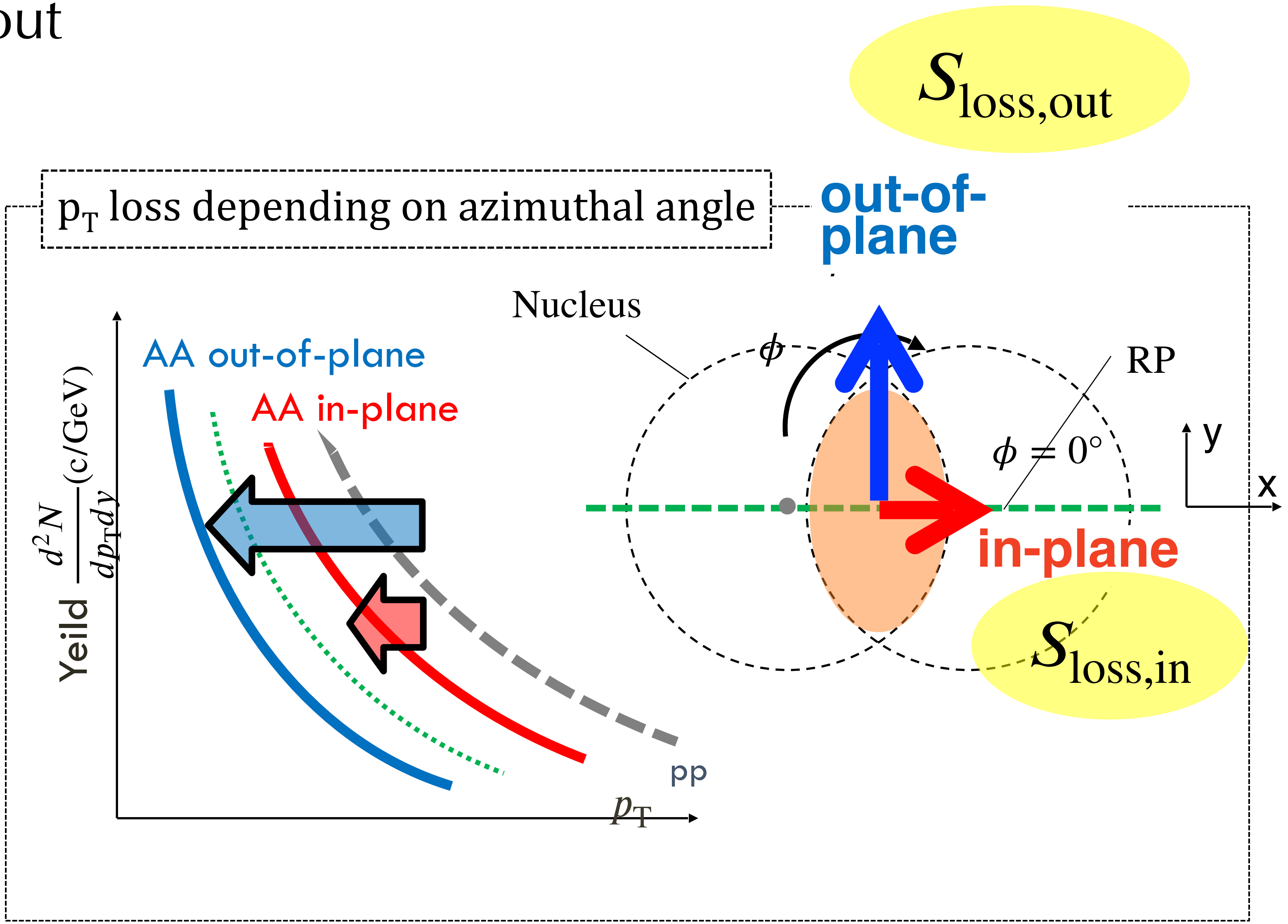




- Study radiative and collisional energy loss w/ broad p_T range
- First b-tagged jets at RHIC
  - Jet + displaced vertex

S_{loss}, $S_{loss,in}$ and $S_{loss,out}$

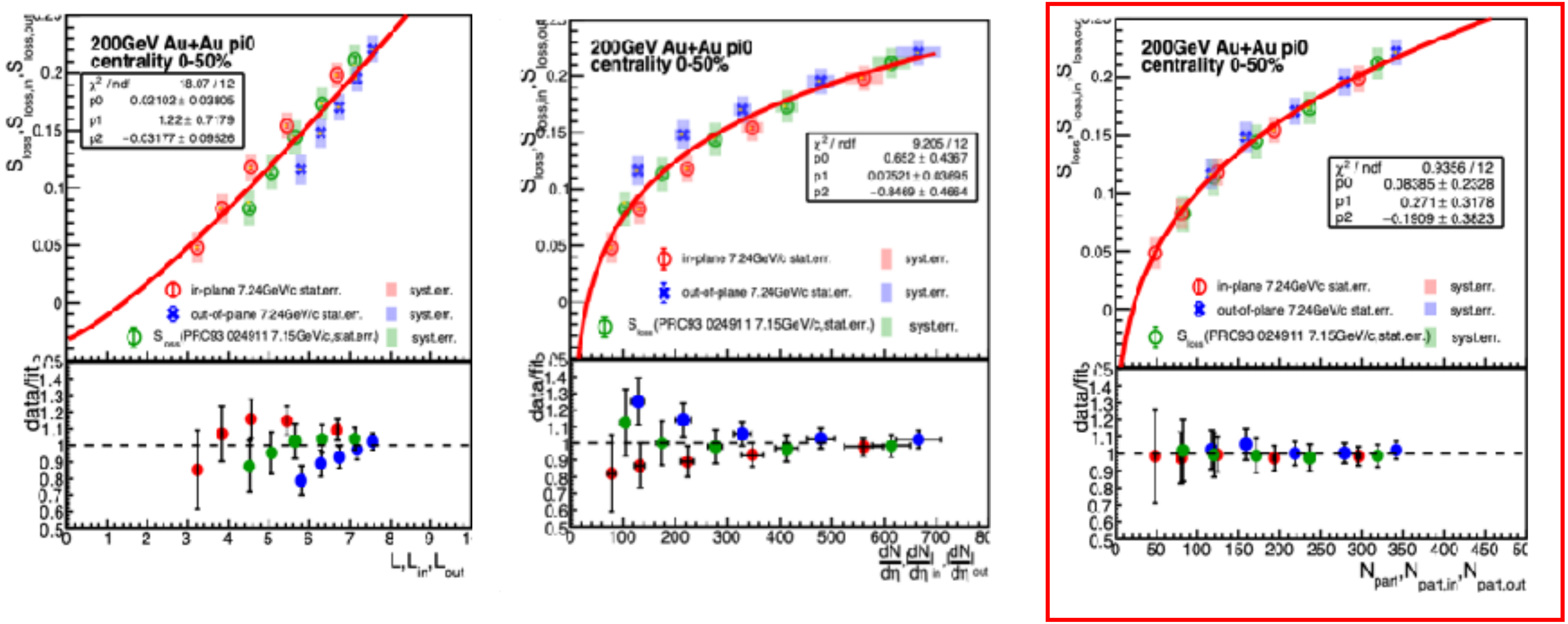




S_{loss} ,$S_{loss,in}$ $S_{loss,out}$ vs. L, $dN_{ch}/d\eta$, N_{part}

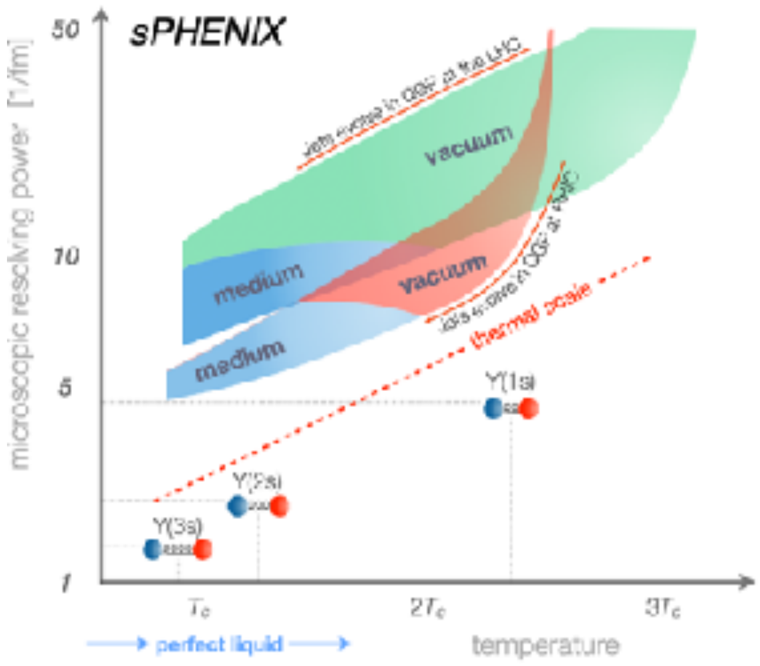
Fitting function
$f(x) = p0 * x^{p1} + p2$

*Similar results for the measured p_T regions (4-10GeV/c)



- S_{loss}, $S_{loss,in}$, $S_{loss,out}$ draw a curve as a functions of N_{part} better than L and dN/dη.

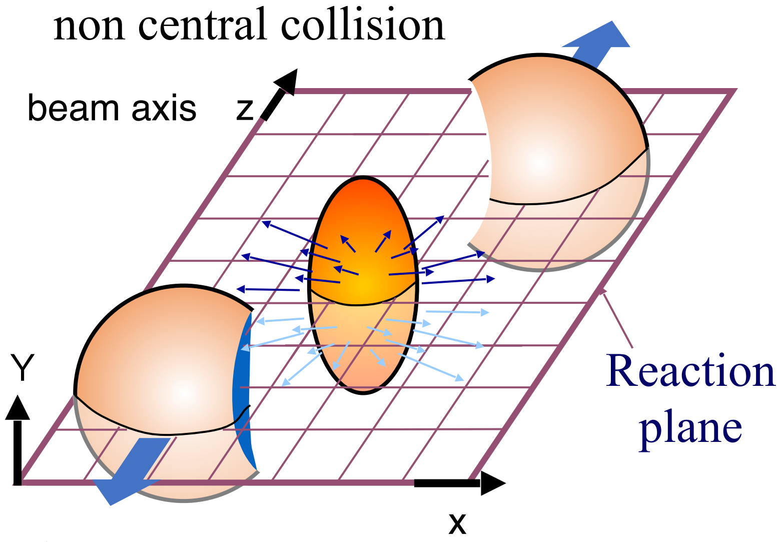
→ indicates the importance of initial particle density dependence.


sPHENIX
50
10
5
1
microscopic resolving power [1/fm]
vacuum
medium
vacuum
medium
thermal scale
Υ(1s)
Υ(2s)
Υ(3s)
T_c
$2T_c$
$3T_c$
perfect liquid
temperature

Elliptic flow (v_2) in Au+Au

v_2 is the strength of the elliptic anisotropy of produced particles.

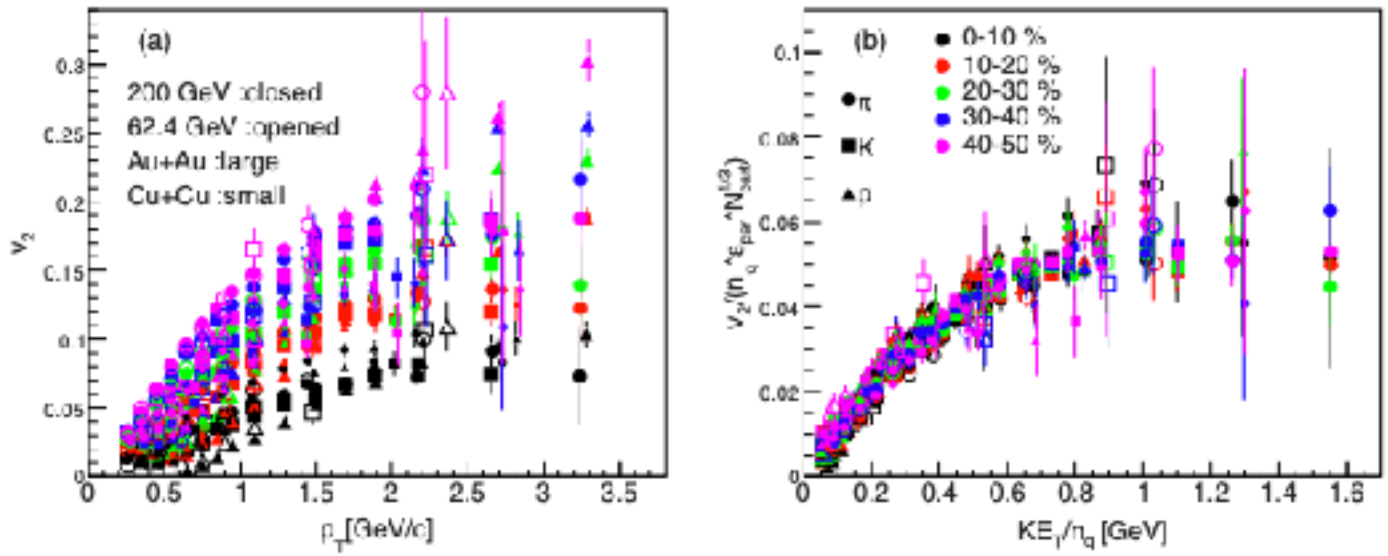
A sensitive probe to the properties of the hot dense matter produced by heavy ion collisions.



$$\frac{dN}{d\phi} \propto 1 + 2v_2 \cos\left[2(\phi - \Psi_{RP})\right]$$

- v_2 is the coefficient of the second term

[PHENIX: PRC92.034913]



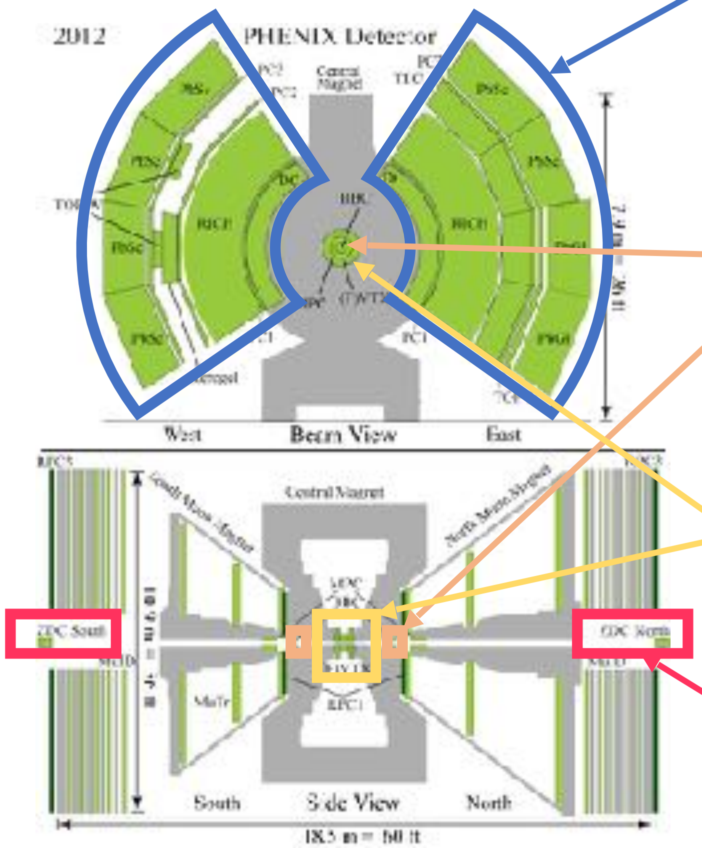
- v_2 of different centrality is scaled by $N_{part}^{1/3}$.

- Elliptic flow (v_2) is scaled by N_{part} or $dN/d\eta$?

PHENIX Detector

- PHENIX completed the data taking in 2016. Analyses are ongoing.
- The data of Au+Au collision at $\sqrt{s_{NN}}$ = 200GeV taken at RHIC-PHENIX in 2014 is analyzed.

$$v_2 = < \cos\{2(\phi - \psi_2)\} >$$



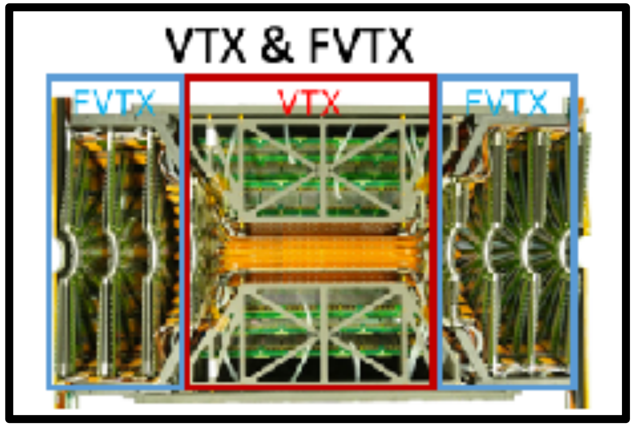
Central Arm (CNT)
- Track selection
- Azimuthal angle(ϕ) of the tracks

Beam Beam Counter (BBC)
- Multiplicity
- Reaction Plane (ψ)
- Z vertex

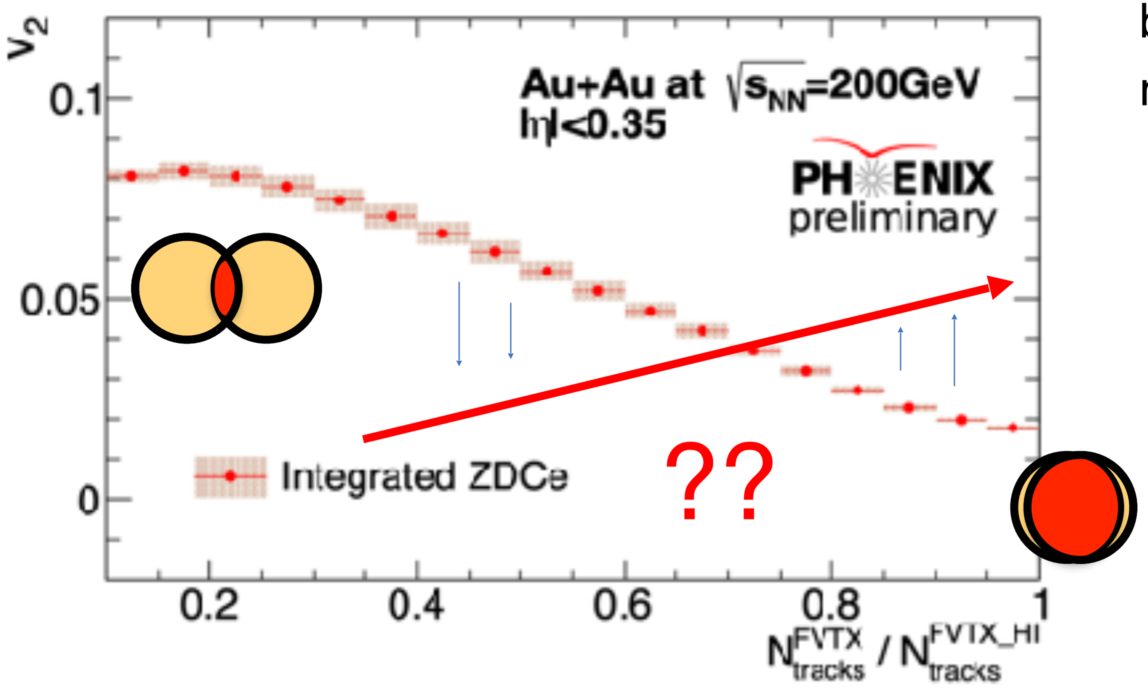
Forward Silicon Vertex Tracker (FVTX)
- Multiplicity

Zero Degree Calorimeter (ZDC)
- Energy of spectator neutrons ($\propto N_{spec}$)

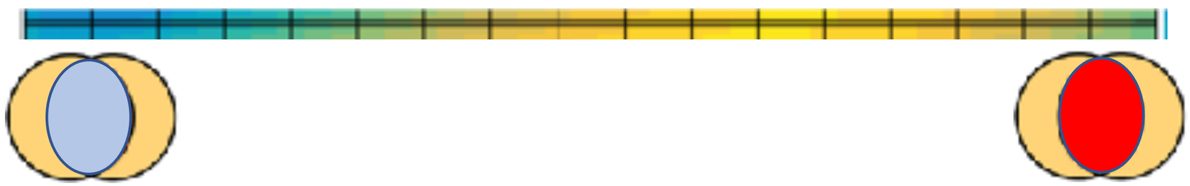
Silicon Vertex Tracker(VTX)
- X,Y,Z vertex



Results: v_2 vs. multiplicity without any ZDC cut



With new categorization, we expect the slope becomes positive **if** the same N_{part} but larger multiplicity gives larger v_2.



Same ←------- N_{part} ---------→ Same

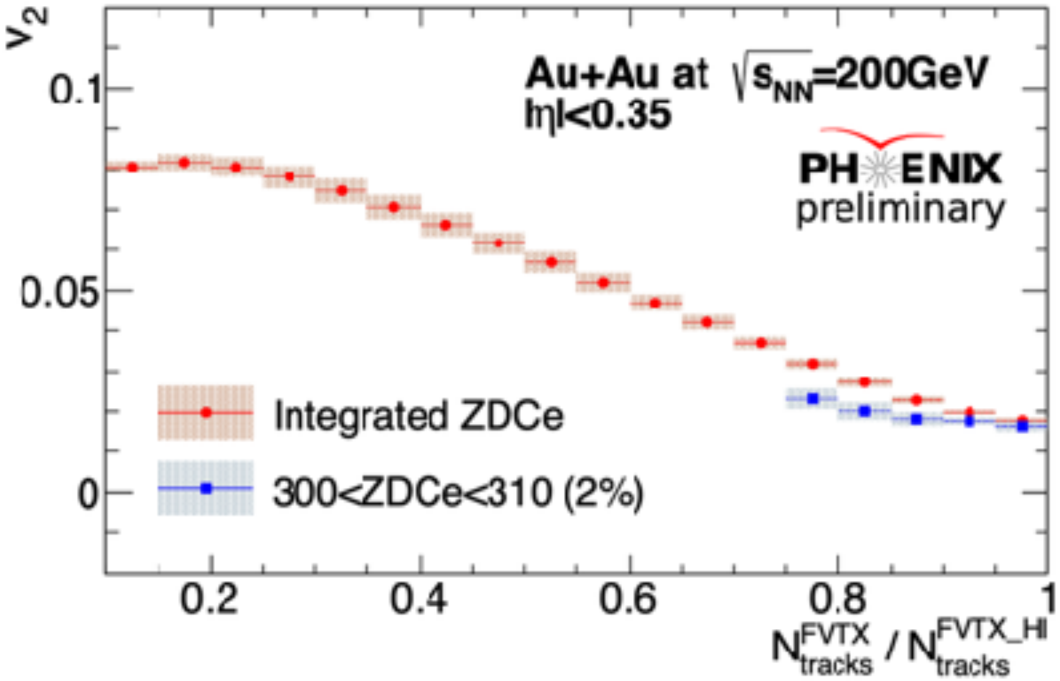
Same ←---- Eccentricity -------→ Same

Small ←---- Multiplicity -------→ Large

?? Small ←--------- v_2 ----------→ Large ??

- v_2 without ZDCe event categorization decreases with multiplicity.
- Consistent with the initial geometry.

Results: v_2 vs. multiplicity with new ZDC categorization at central collision



Red： without ZDCe event categorization

Blue： with ZDCe event categorization (300<ZDCe<310) which is corresponding to the collision centrality ~ 2%

- The ZDC categorization makes the slope flatter, but does not invert it to positive at very central.