UNIVERSITY OF JYVÄSKYLÄ

PHENIX

HELSINKI INSTITUTE OF PHYSICS

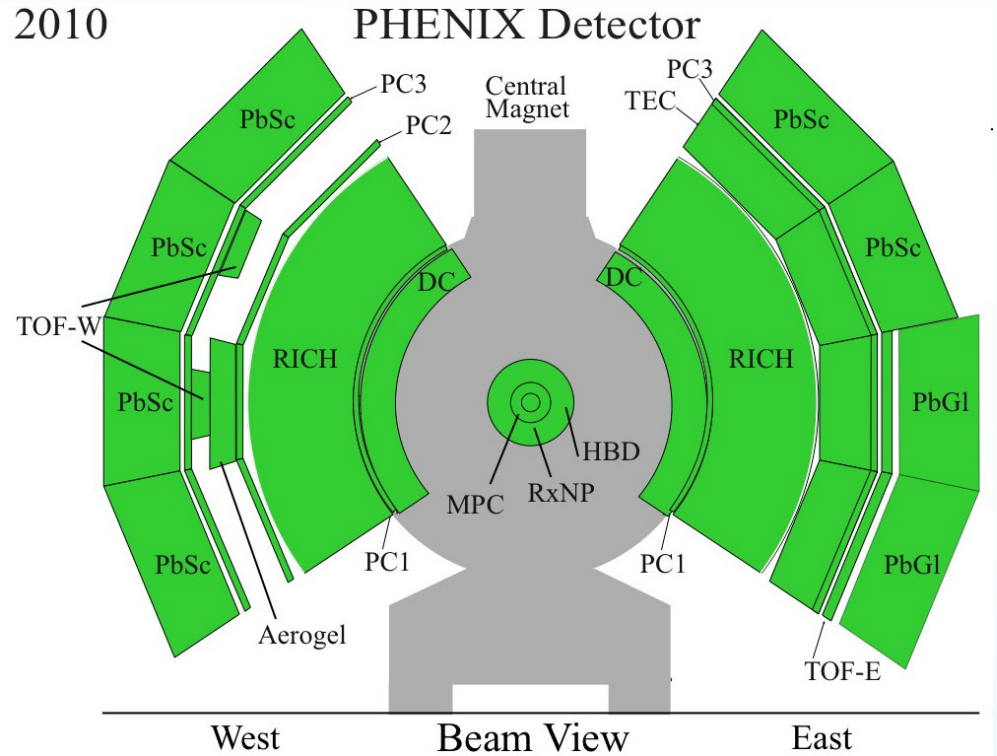
Heavy Ion Physics, R_{AA} and flow measurements in PHENIX

Norbert Novitzky for PHENIX collaboration
University of Jyväskylä, Finland
Helsinki Institute of Physics, Finland

Outlook

- Introduction
  - PHENIX detector
  - High-p_T physics
- Reaction plane
  - Flow and R_{AA} measurements at high p_T
- Low-energy scan:
  - Motivation
  - New results from 39 and 62 GeV
- Summary

PHENIX detector



2010-2011 upgrades:
HBD, VTX

Central arm tracking
- Drift chamber
- Pad chambers
- Time expansion chamber

Muon Arm tracking
- Muon tracker

Calorimetry
- PbGl, PbSc
- MPC

Particle ID
- Muon identifier
- RICH
- TOF
- Aerogel, TEC

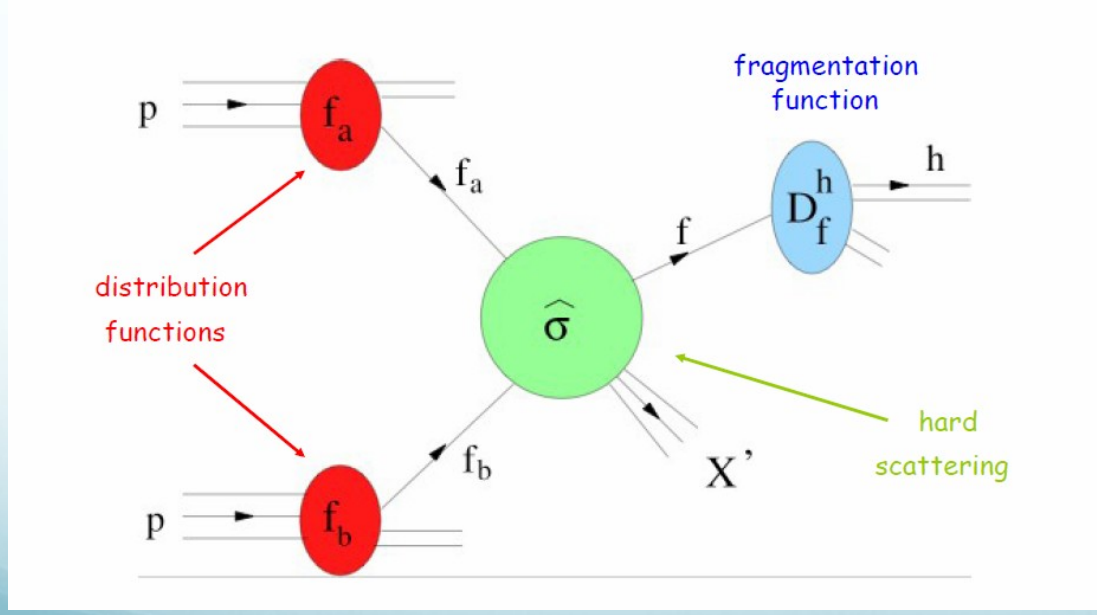
Global Detectors
- BBC, ZDC
- RXNP

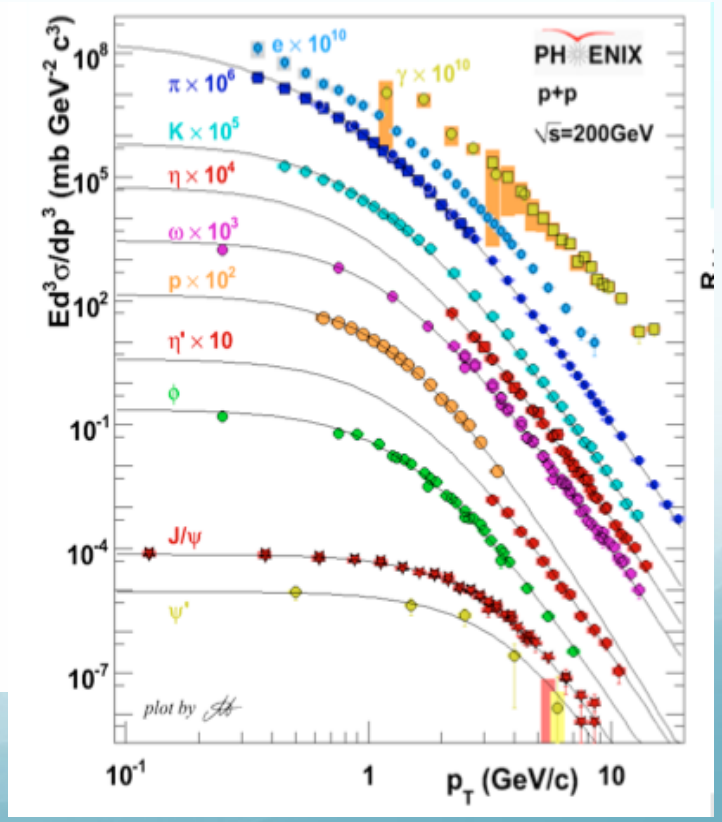
High p_T particle production

pQCD calculation works well in p+p collisions:

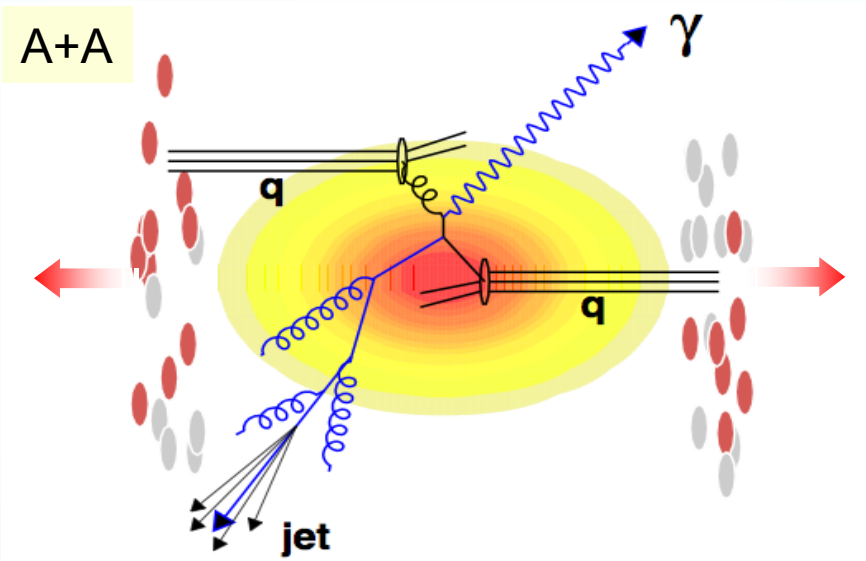
$$\frac{d\sigma^{AB->h}}{dp_T^2 dy} = \sum \int dx_1\, dx_2\, \frac{dz}{z^2}\, x_1 f_{i/A}\left(x_1, Q^2\right) x_2 f_{j/B}\left(x_2, Q^2\right) \frac{d\hat{\sigma}^{ij->kl}}{d\hat{t}}\, D_{k\to h}\left(z, \mu_F^2\right)$$

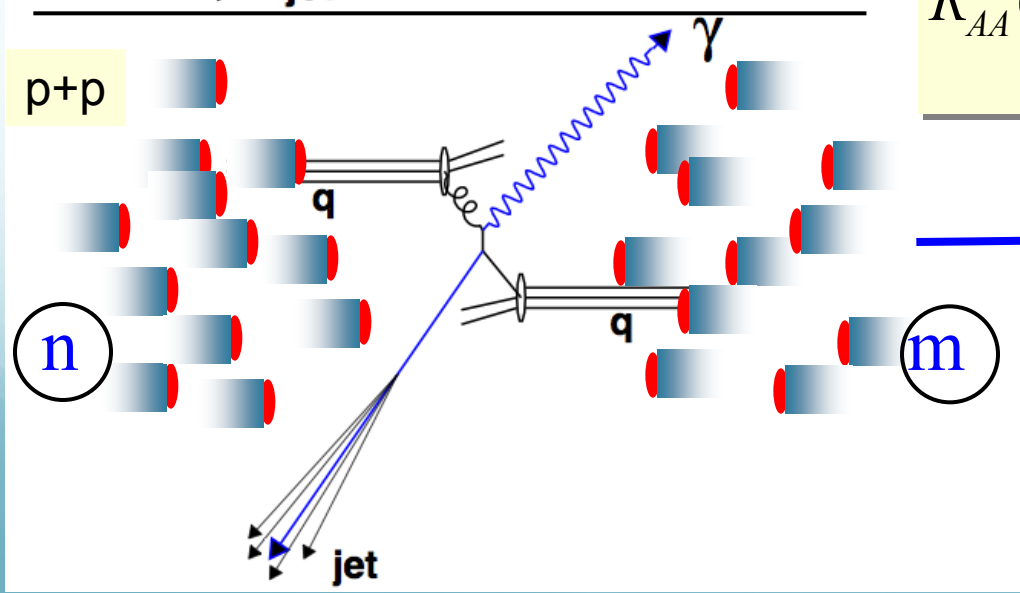
Collinear factorization: separation of long and short distances

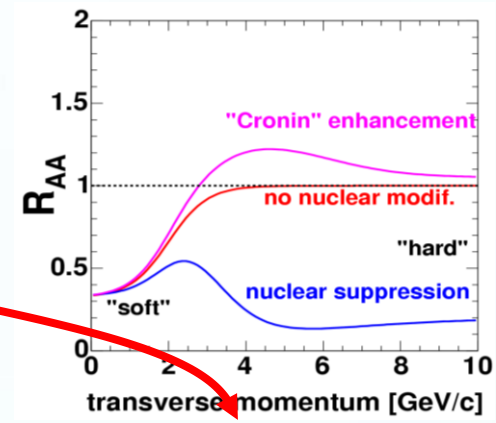




Nuclear modification factor





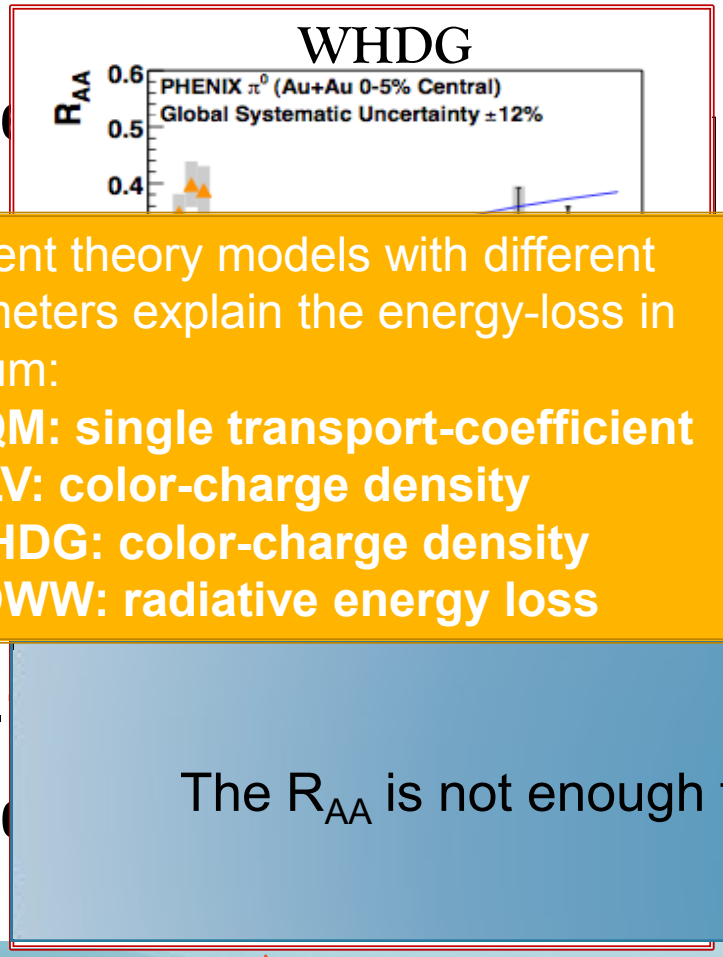


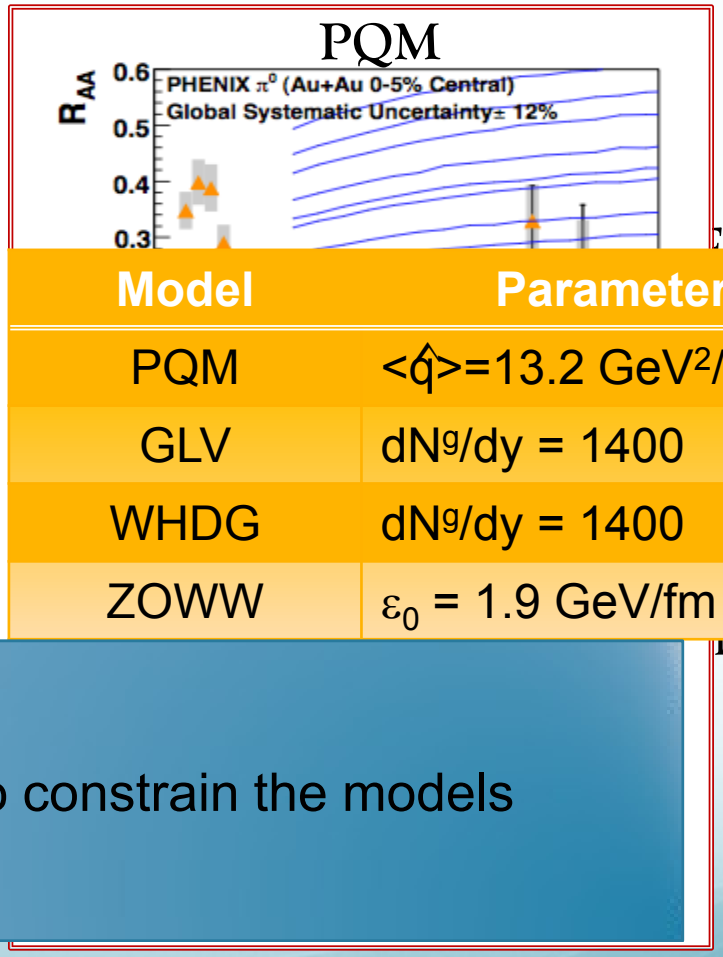
$$R_{AA}(p_T) = \frac{d^2N^{AA} / dp_T d\eta}{\langle N_{binary} \rangle d^2N^{pp} / dp_T d\eta}$$

$\propto \langle N_{\text{bin coll}} \rangle$ varies with impact parameter ***b***

Nuclear modification factor and theory models

Phys. Rev. C 77, 064907 (2008)





Different theory models with different parameters explain the energy-loss in medium:

- **PQM: single transport-coefficient**
- **GLV: color-charge density**
- **WHDG: color-charge density**
- **ZOWW: radiative energy loss**

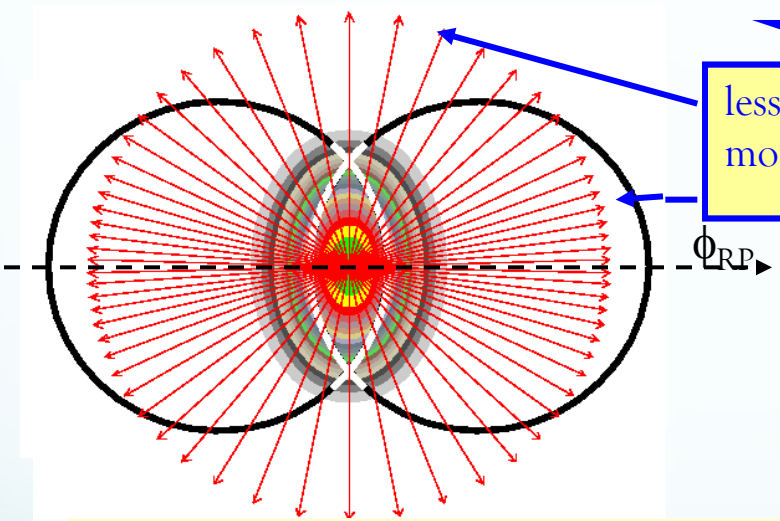
Model	Parameter
PQM	$\langle\hat{q}\rangle$=13.2 GeV^2/fm
GLV	dN^g/dy = 1400
WHDG	dN^g/dy = 1400
ZOWW	ε_0 = 1.9 GeV/fm

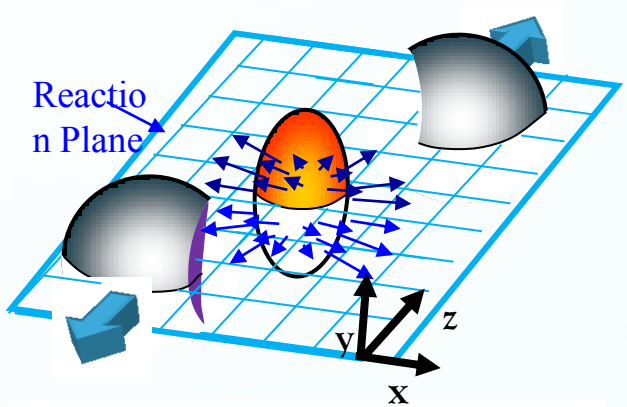
The R_{AA} is not enough to constrain the models

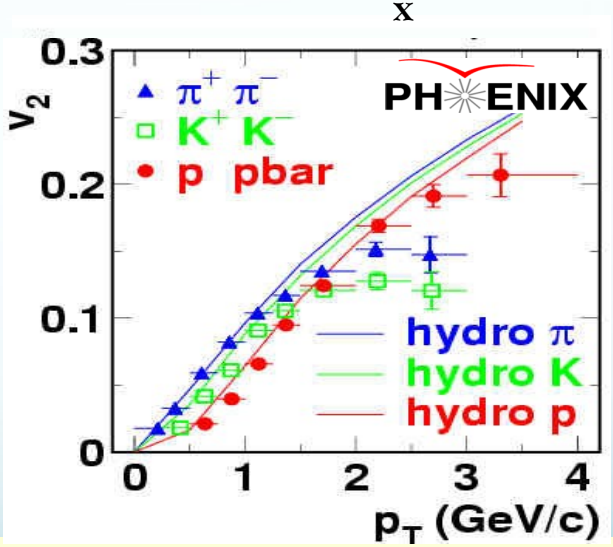
Nuclear Geometry and Hydrodynamic flow

multiple scattering → larger pressure gradient in plane

less yield out
more in plane







Spatial asymmetry
eccentricity

$$\varepsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

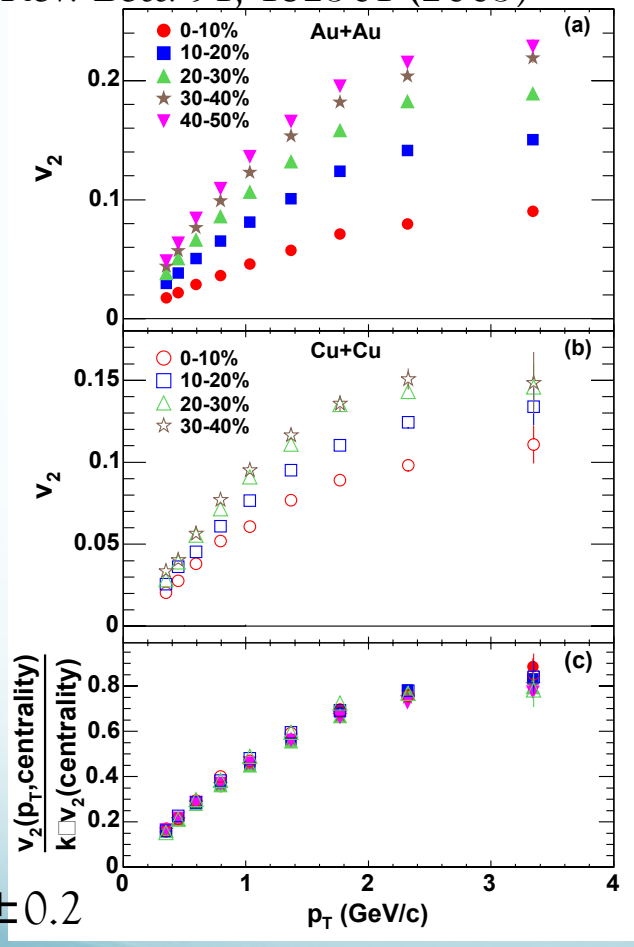
Mom. Asymmetry
elliptic flow

$$v_2 = \frac{\langle p_y^2 \rangle - \langle p_x^2 \rangle}{\langle p_y^2 \rangle + \langle p_x^2 \rangle}$$

$$\frac{d^3N}{p_T dp_T dy d\varphi} \propto [1 + 2v_2(p_T)\cos 2(\varphi - \phi_{RP}) + \ldots]$$

Flow "universal" scaling

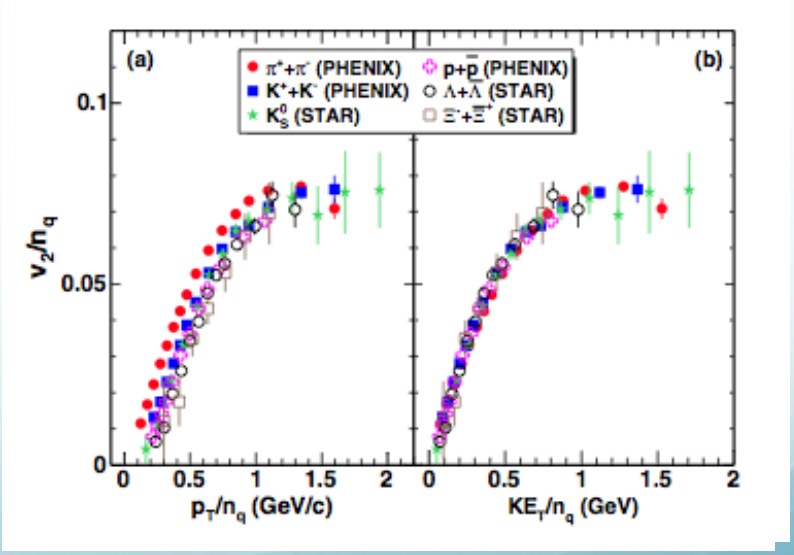
Phys. Rev. Lett. 91, 182301 (2003)



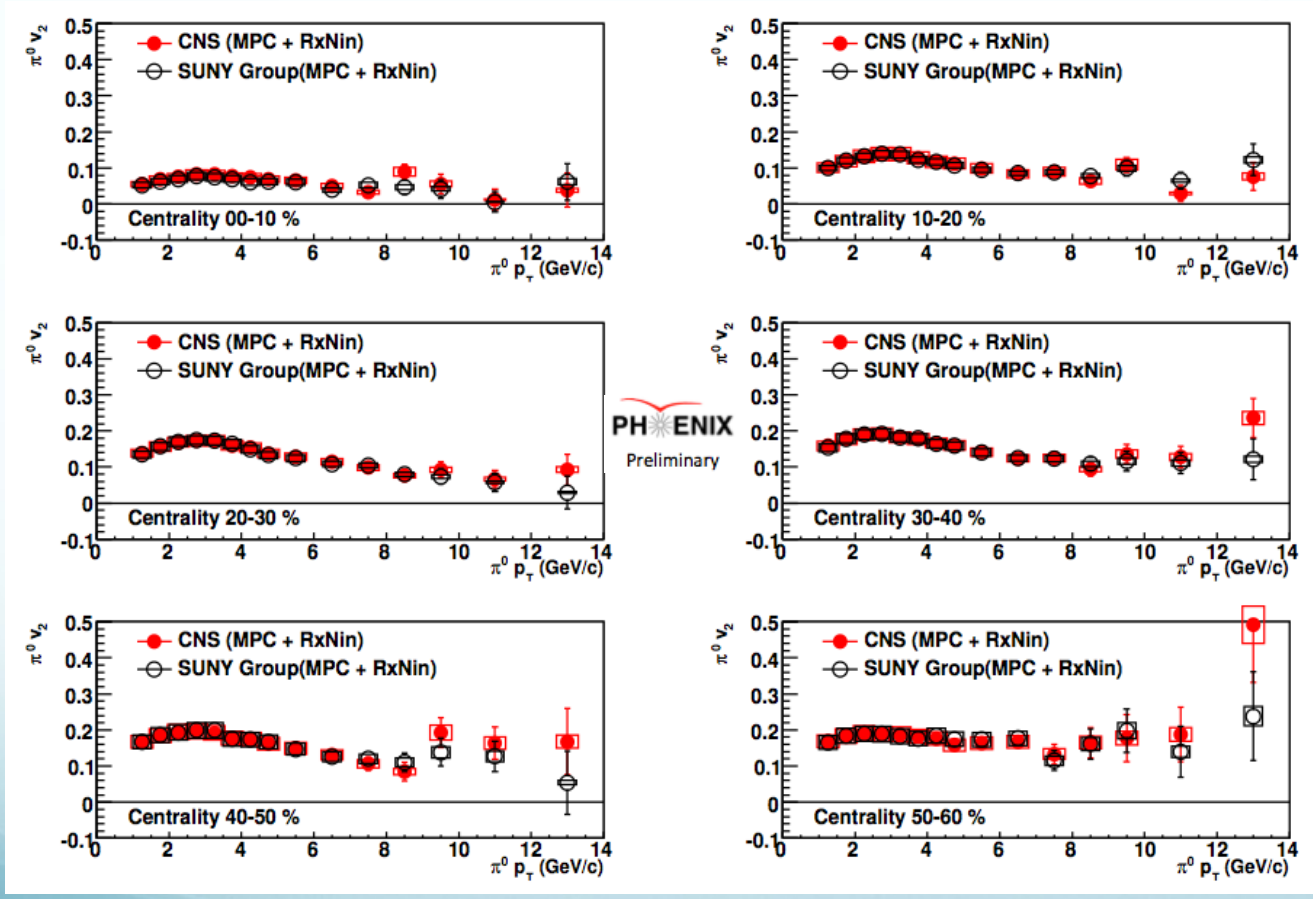
k=3.1±0.2

- The v_2 is independent of colliding system and centrality.
- The azimuthal anisotropy scales with the number of constituent quarks.

How the v_2 behave in high p_T region?



Flow measurement in AuAu at 200 GeV



The v_2 measured with two independent analysis, the difference is <5%.

The v_2 is decreasing in high-pT?

High p_T: v_2 versus R_{AA}

What is the connection of measure v_2 and $R_{AA}(\Delta\phi, p_T)$ in high-p_T?

The R_{AA} with respect to reaction plane:

$$R_{AA}\left(\Delta\phi_i^{rp}, p_T\right) = F\left(\Delta\phi_i^{rp}, p_T\right) \cdot R_{AA}\left(p_T\right)$$

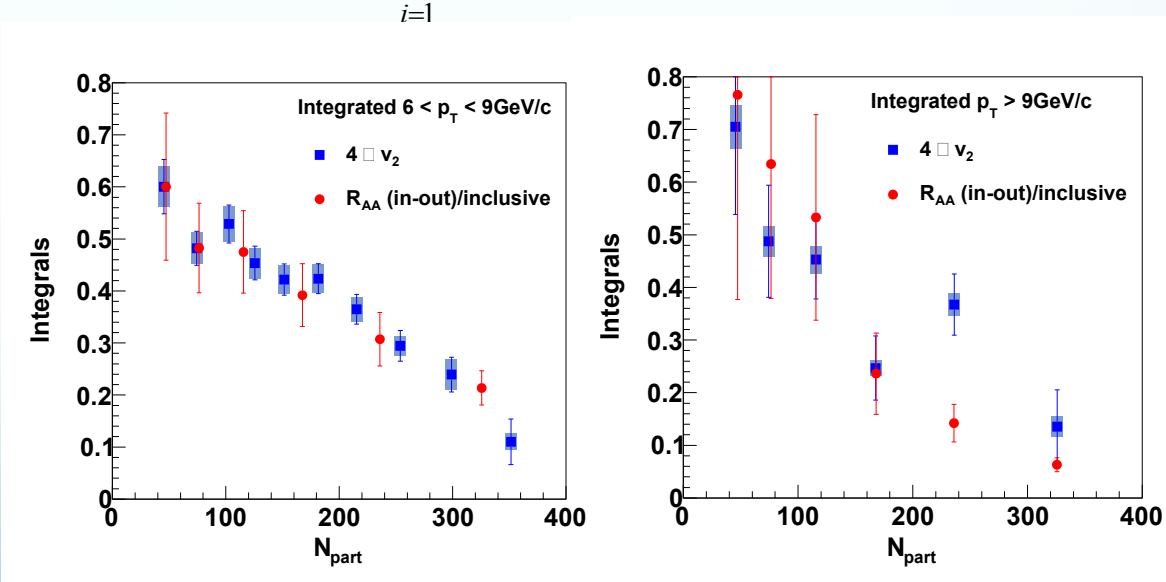
where

approximation

$$F\left(\Delta\phi_i^{rp}, p_T\right) = \frac{N\left(\Delta\phi_i^{rp}, p_T\right)}{\sum_{i=1}^{6} N\left(\Delta\phi_i^{rp}, p_T\right)} \approx 1 + 2v_2^{raw}\cos(2\Delta\phi_i^{rp})$$

The connection between R_{AA} and v_2 at high p_T:

$$\frac{R_{AA}(0, p_T) - R_{AA}(\pi/2, p_T)}{R_{AA}^{incl}(p_T)} \square 4 \square v_2$$



R_{AA} with respect to the reaction plane – I.

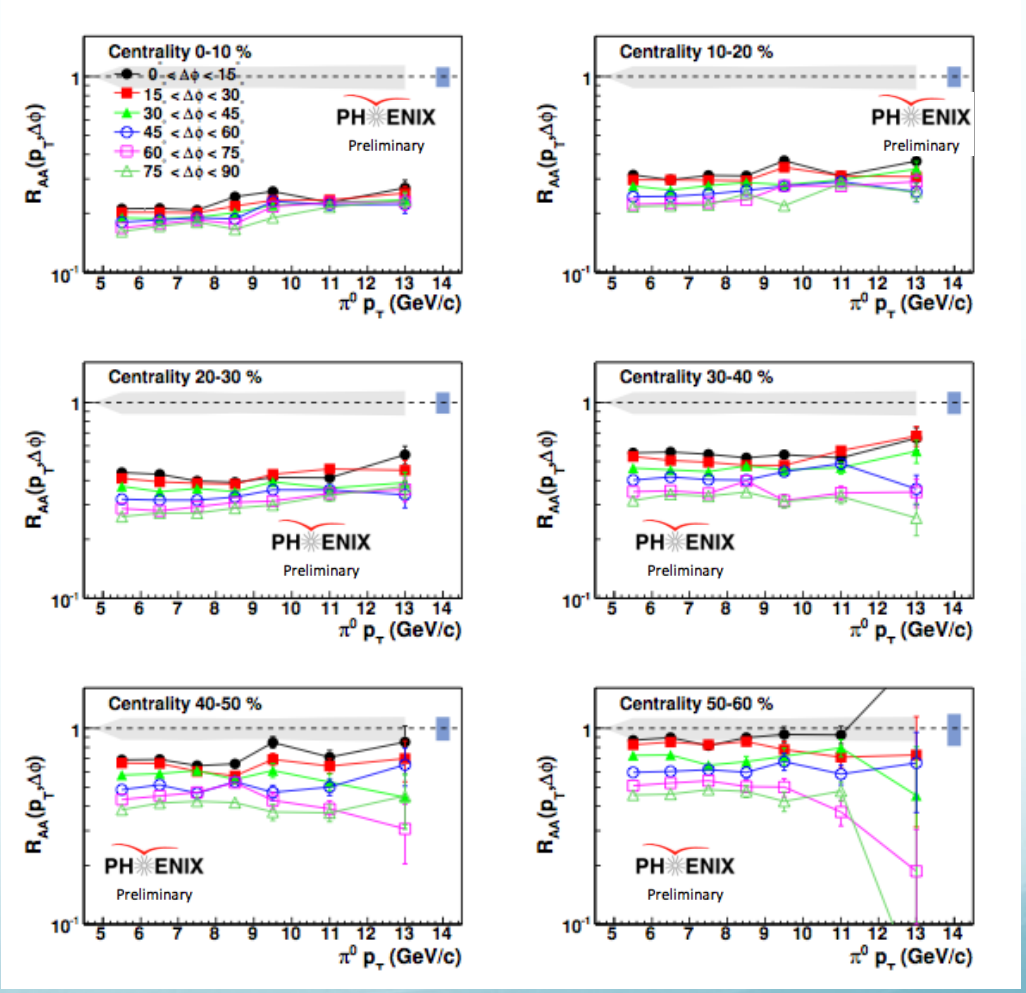
Black: 0° -15°

…

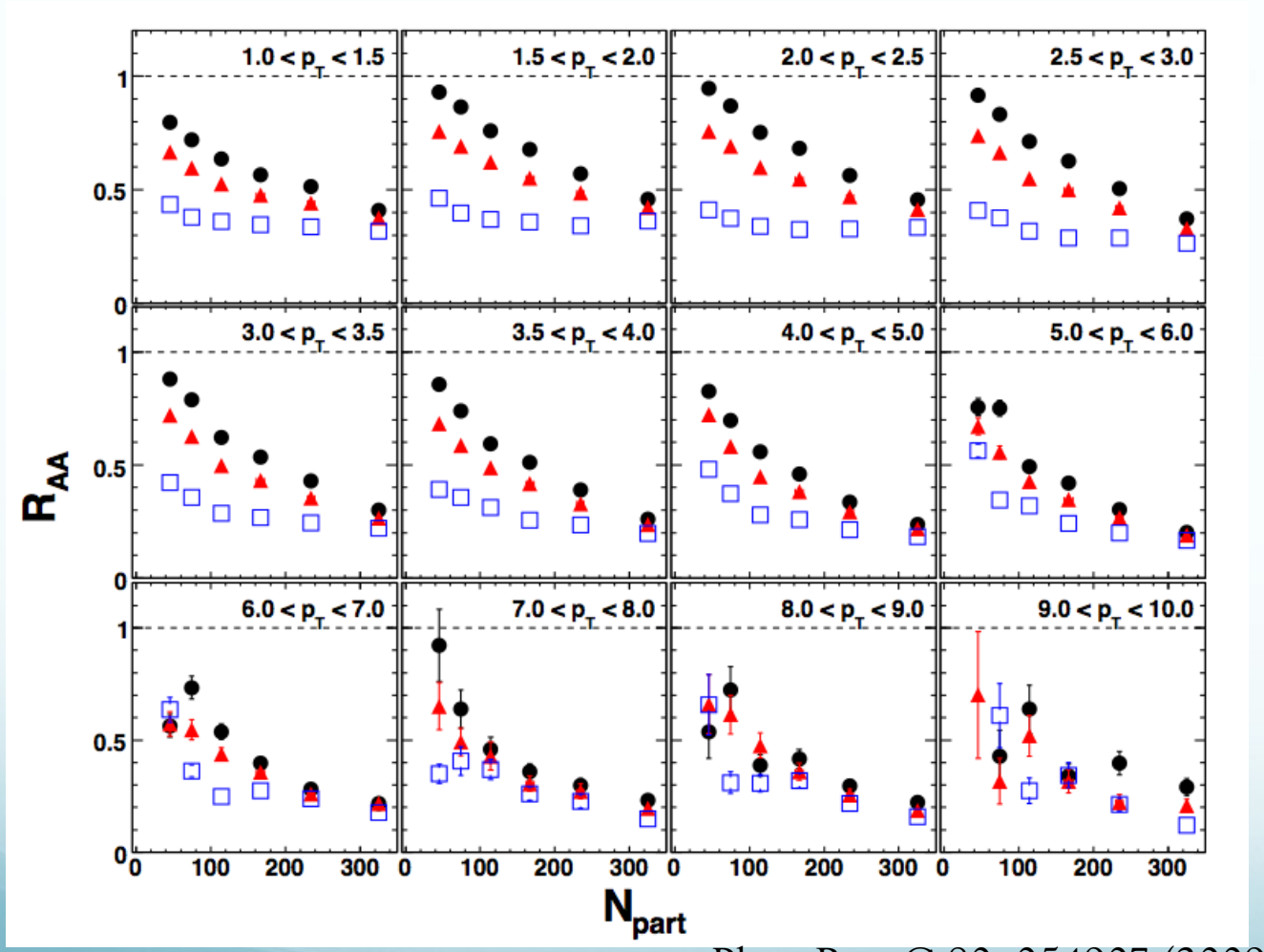
Green: 75° -90°

The difference is larger in more peripheral collision.

Higher p_T reach



R_{AA} in-plane vs. out-of-plane



Black: in-plane

Blue: out-of-plane

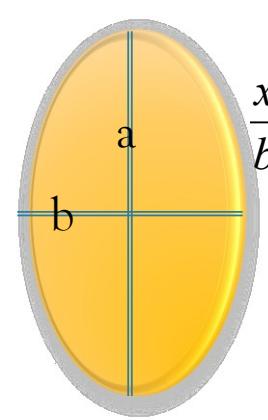
Red: inclusive

The out-of-plane data are less dependent on the centrality.

How can we describe the data?

Phys. Rev. C 80, 054907 (2009)

R_{AA} "universal length" scaling



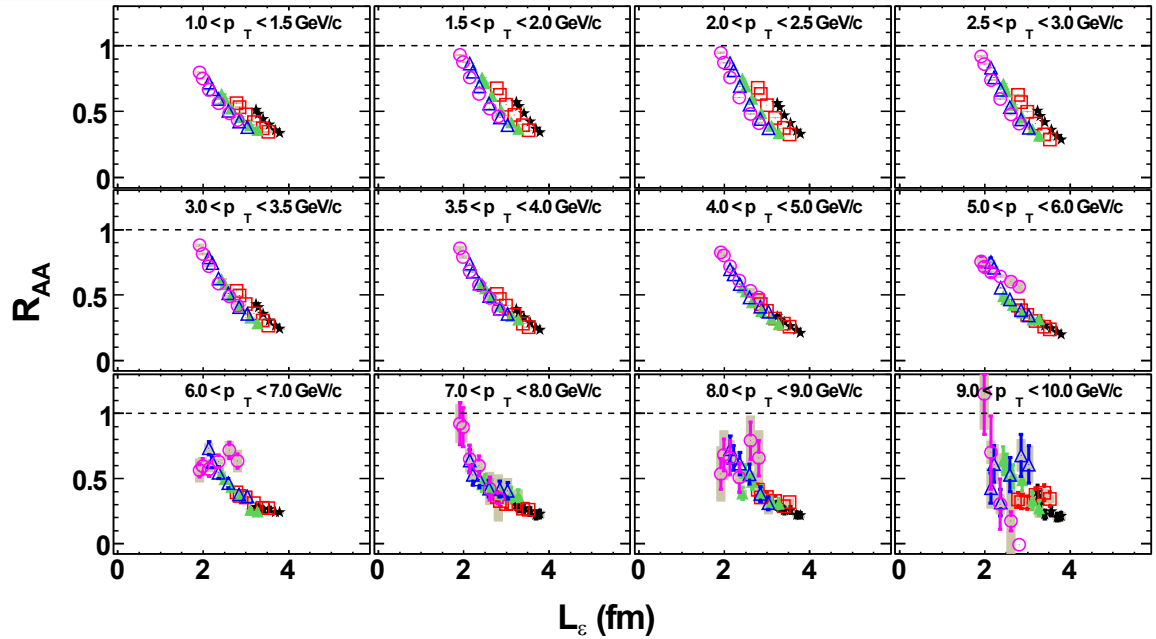
$$\frac{x^2}{b^2}+\frac{y^2}{a^2}=1$$

The ellipsoid parameterization: The length parameter refers to the distance from the origin in given $\Delta\phi$:

$$L_\varepsilon(\Delta\phi)=\frac{\sqrt{x^2(1+\varepsilon)}}{\sqrt{1+\varepsilon\cos 2\Delta\phi}}$$

Black: 10-20%
Red: 20-30%
Green: 30-40%
Blue: 40-50%
Magenta: 50-60%.

The R_{AA} at higher p_Ts scales with a L_ε.

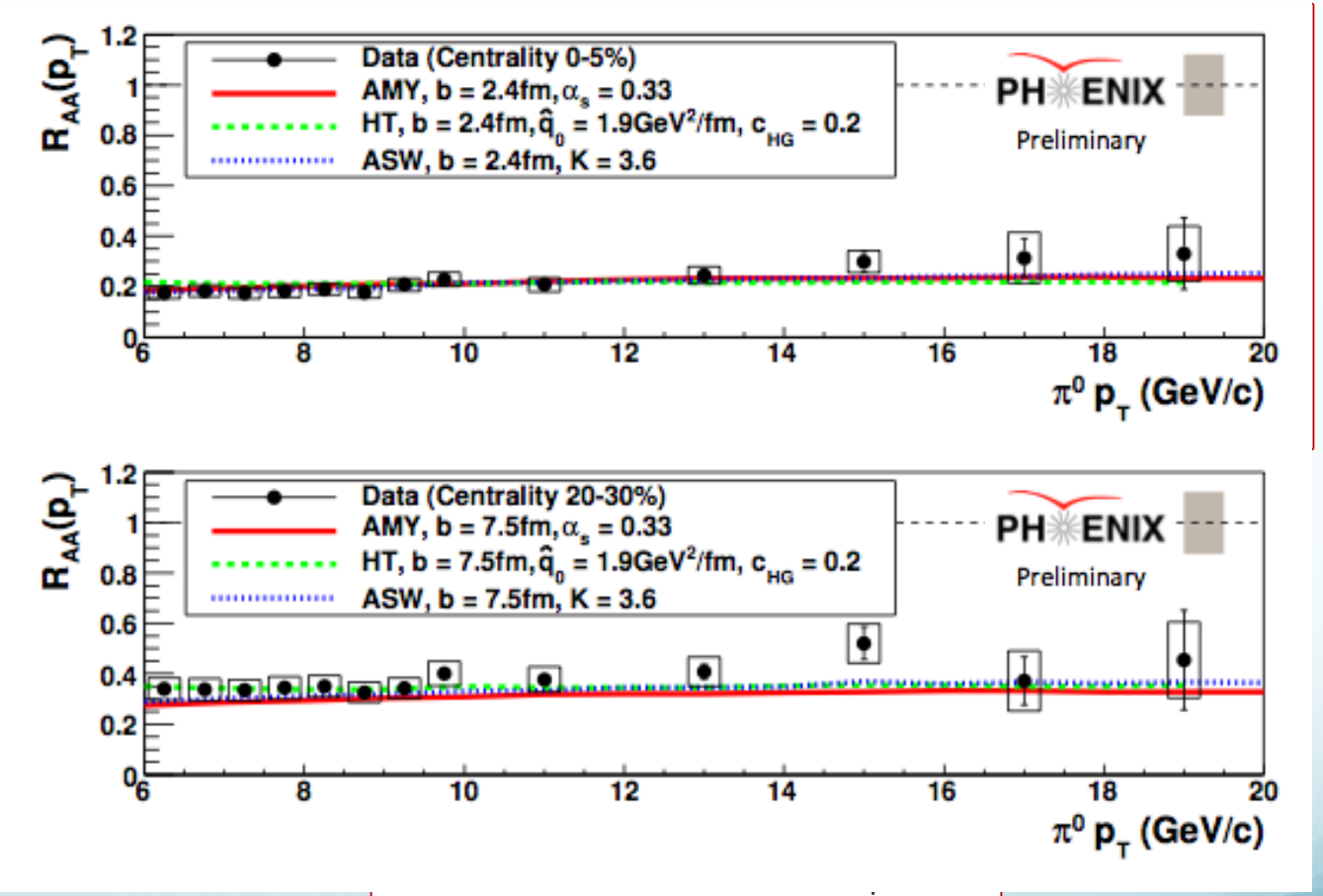


Phys. Rev. C 80, 054907 (2009)

$R_{AA}(\Delta\phi, p_T)$ and theory

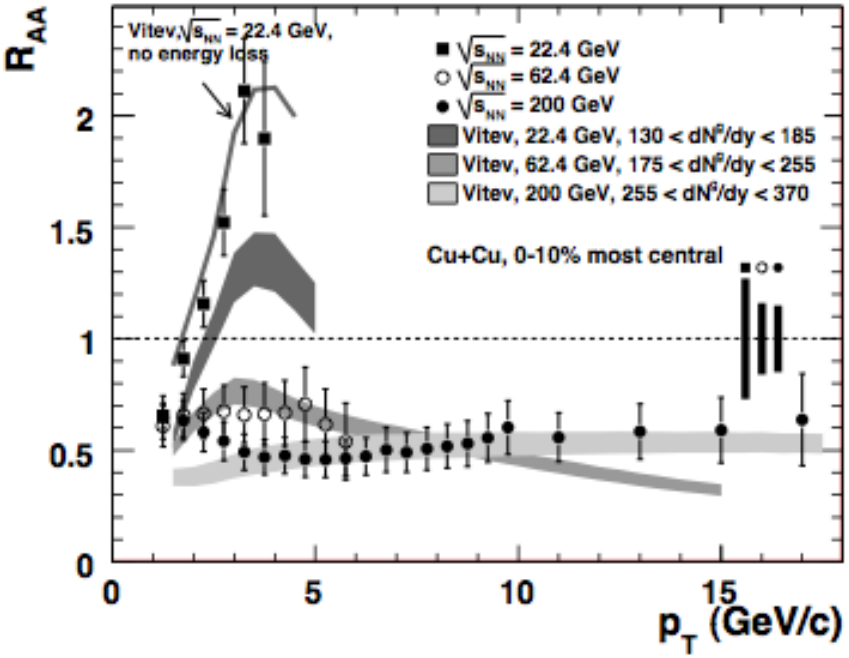
The data are described with different models.

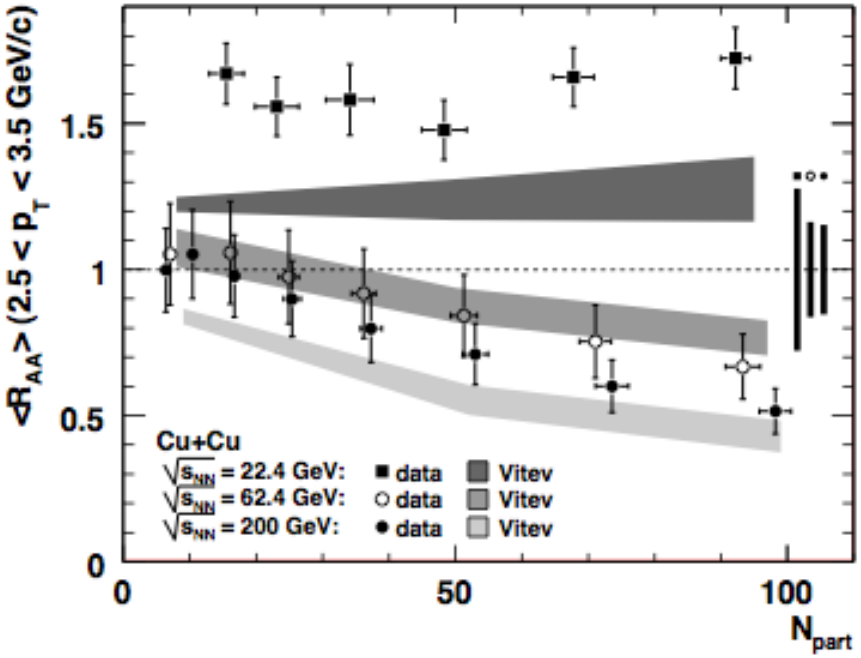
Models need tuning for $R_{AA}(\phi, p_T)$



Low-Energy scan at RHIC

Motivation – Low energy scan





Phys. Rev. Lett.101, 162301 (2008)

When the suppression occurs? In Cu+Cu system it is between $\sqrt{s}$ = 22 – 62 GeV

Low Energy Survey in 2010

In 2010 low-energy survey of RHIC:

- 700M events in 62.4 GeV Au+Au (350M planned),
- 250M events in 39 GeV Au+Au (50M planned),
- 1.6M events in 7.7 GeV Au+Au.

π^0 measurement

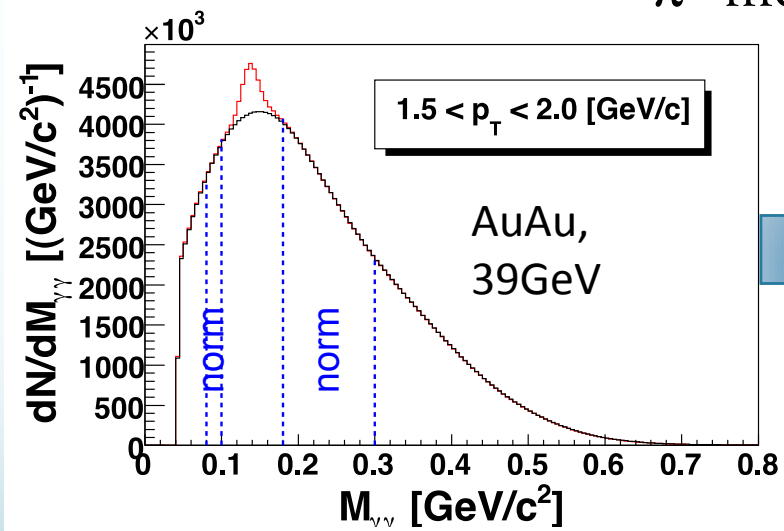


Fig.1: the raw invariant mass calculated for γ–γ pairs. Red is the real, black is from mixed events

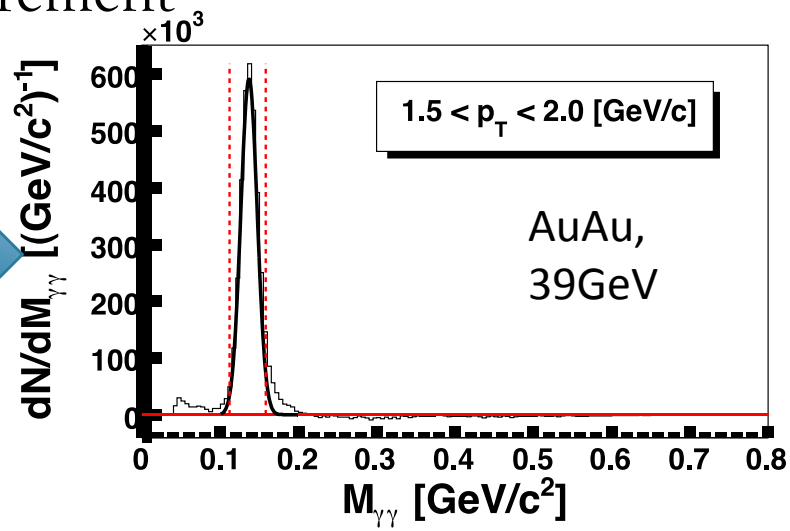
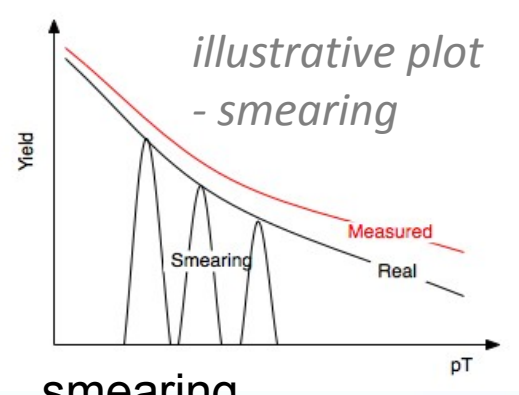


Fig.2: after combinatorial background subtraction.

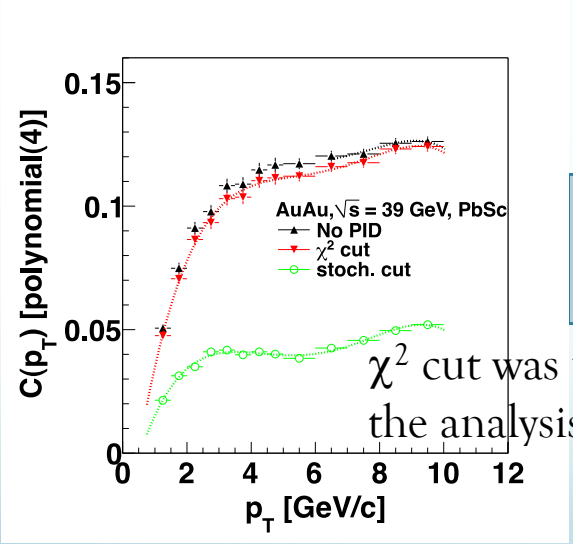
Correction factor

In order to reconstruct the invariant yield we run GEANT simulation and embedding studies to find the correction factor:

- Acceptance correction: ϕ: π, $|\eta|<0.35$
- Efficiency of reconstructing π^0 in the detector
- Energy-smearing



smearing



The combined correction factor reconstruct the true π^0 spectrum.

$$C(p_T) = S(p_T) \square \varepsilon(p_T) \square Acc(p_T)$$

efficiency

acceptance

Shower shapes for γ PID:

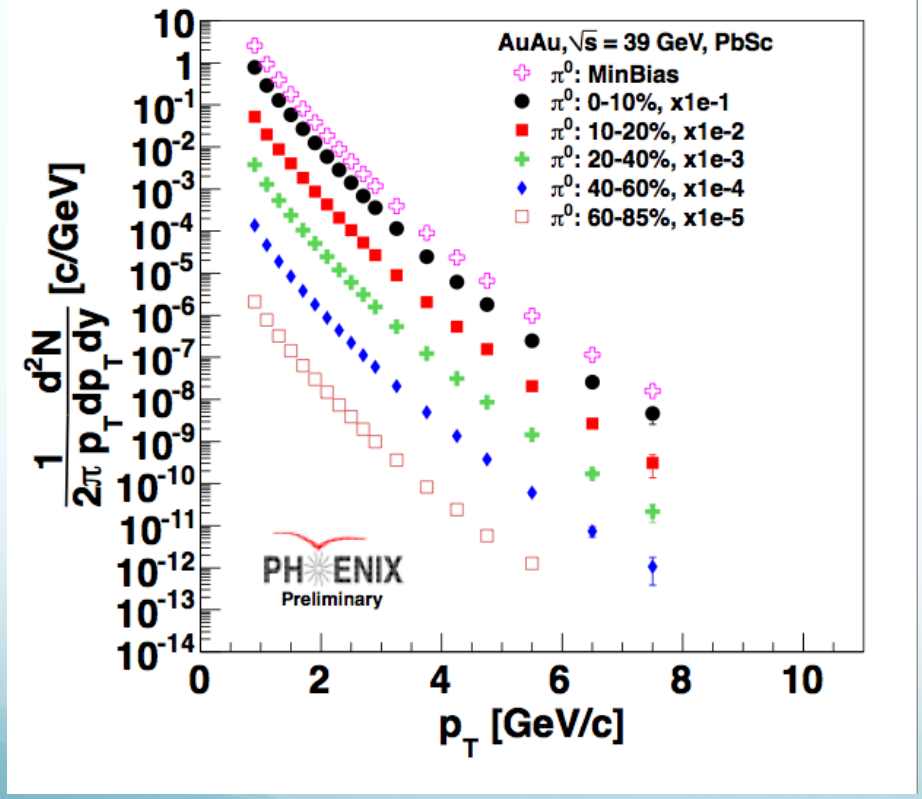
- χ^2,
- Stochastic.

χ^2 cut was used in the analysis of π^0

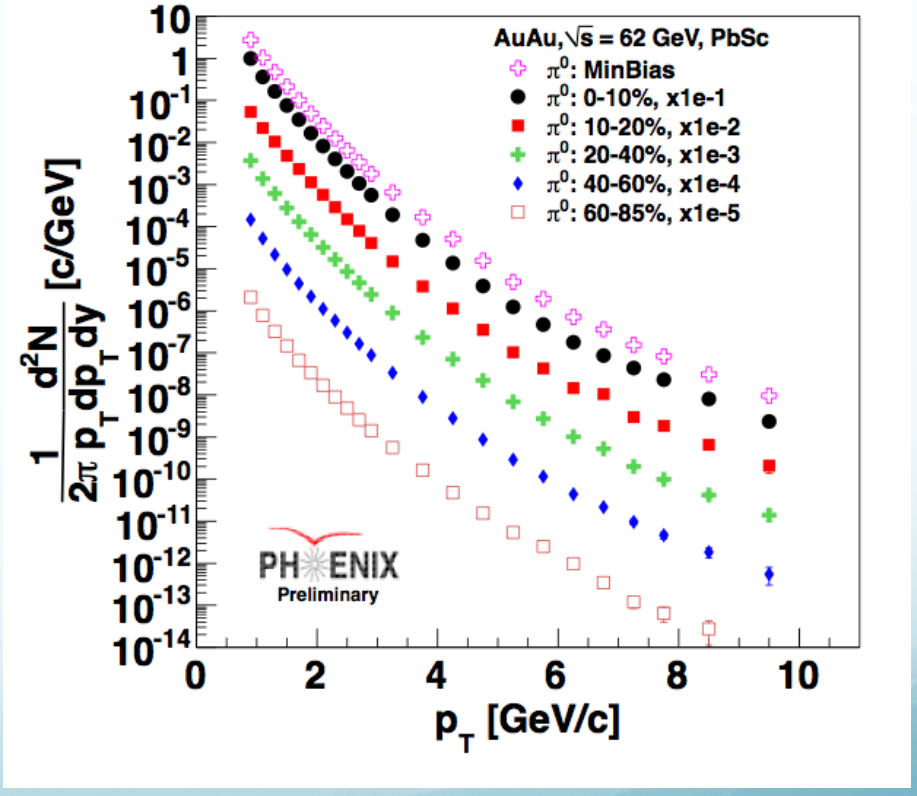
Invariant yields of π^0

Slopes fitted $p_T > 4$ GeV/c, only on minimum bias data:

$n = 12.1 \pm 0.1$



$n = 10.9 \pm 0.03$



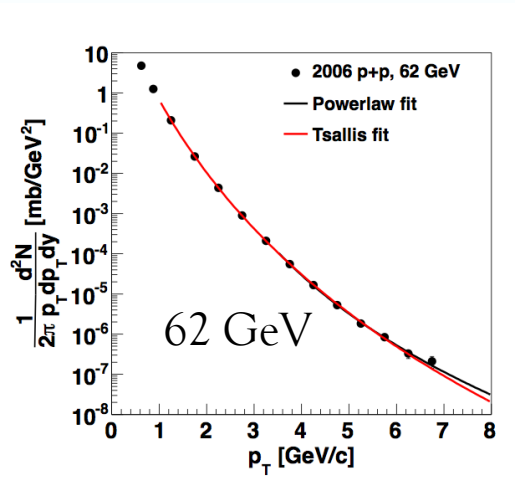
Reference problem

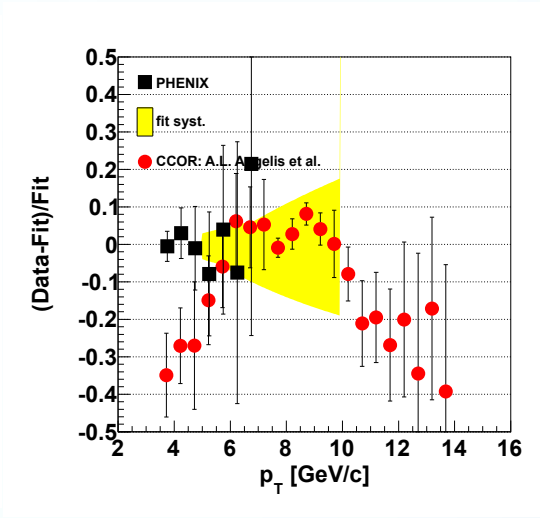
200 GeV – no problem

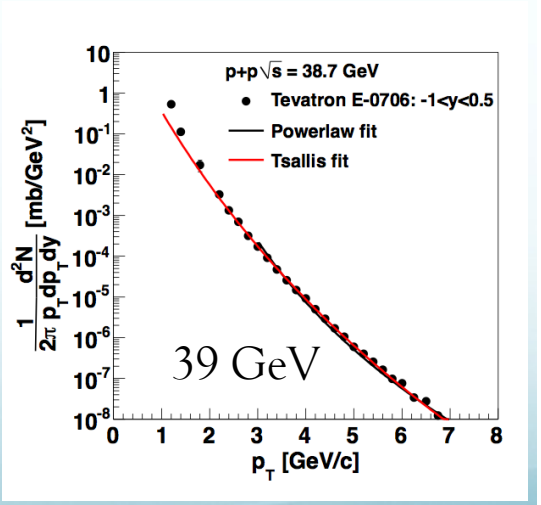
62 GeV:
- Reference up to pT < 7 GeV/c
- Upper p_T with power-law extrapolation

39 GeV:
- Only E0706 reference exists
- Different rapidity window

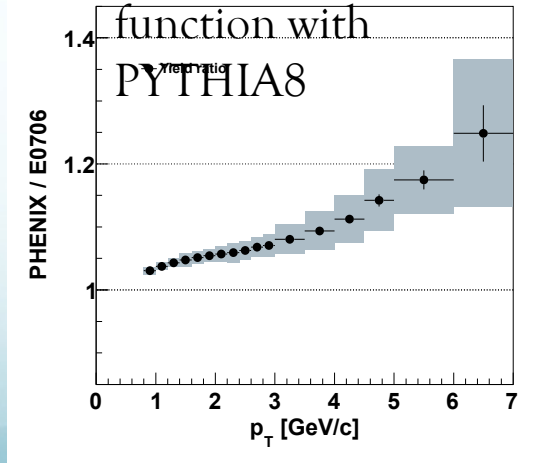
-> Additional systematic uncertainties are introduced to R_{AA}



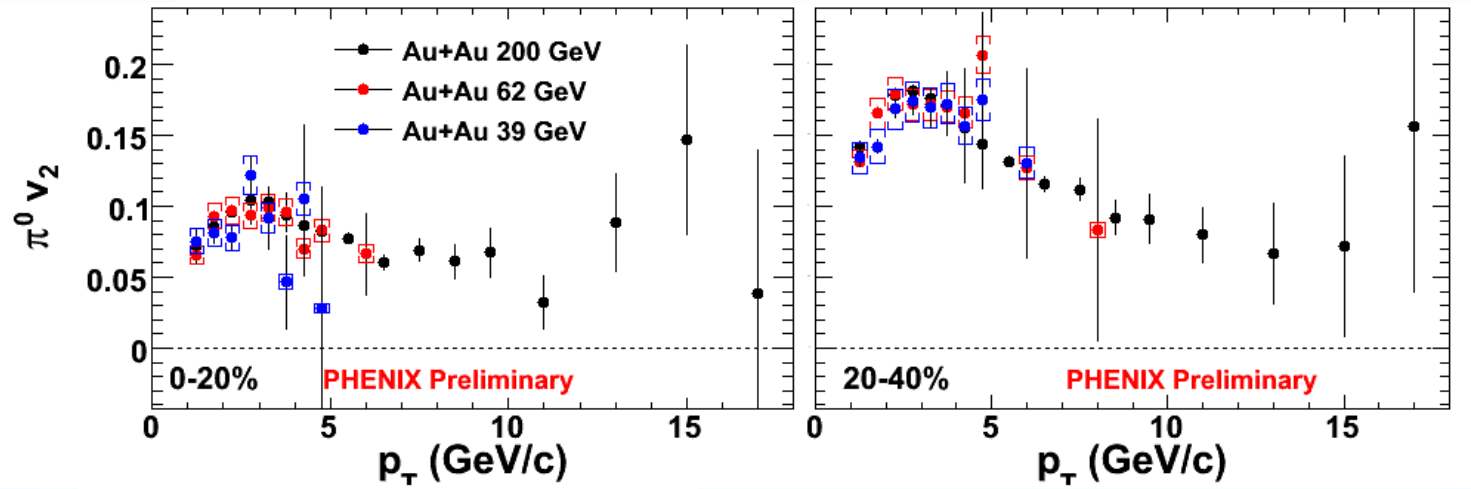


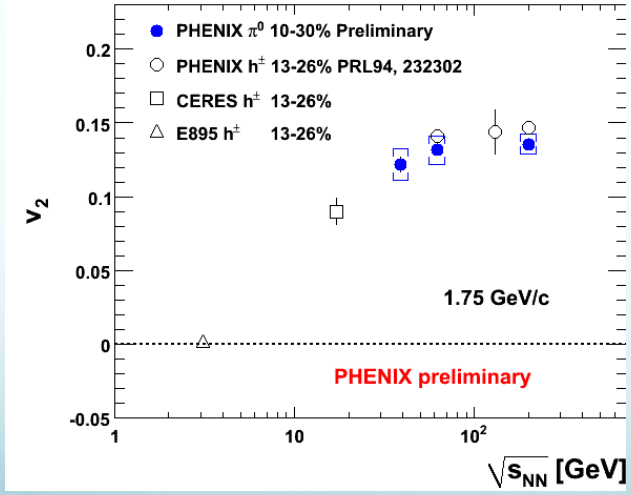


Acceptance correction function with PYTHIA8



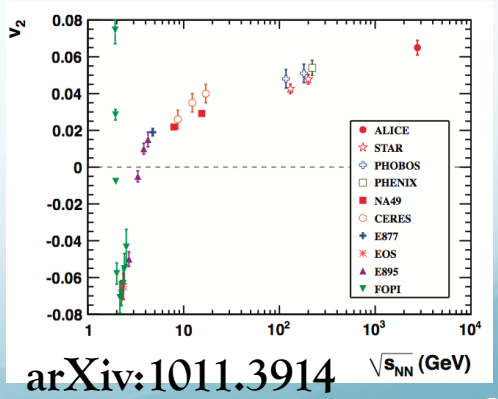
Energy Scan – v_2 measurement





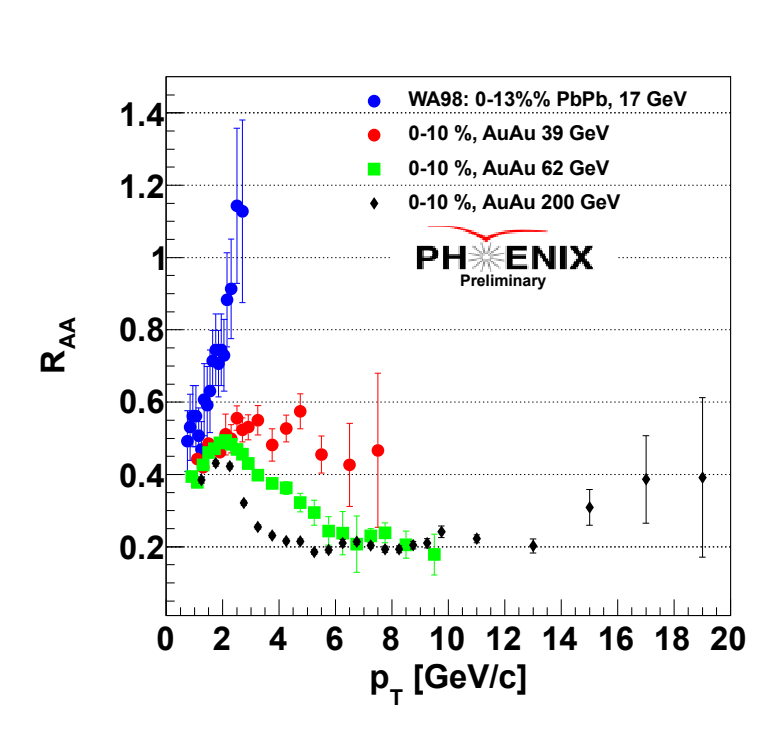
Is v_2 saturated in $\sqrt{s}$=39-200GeV?

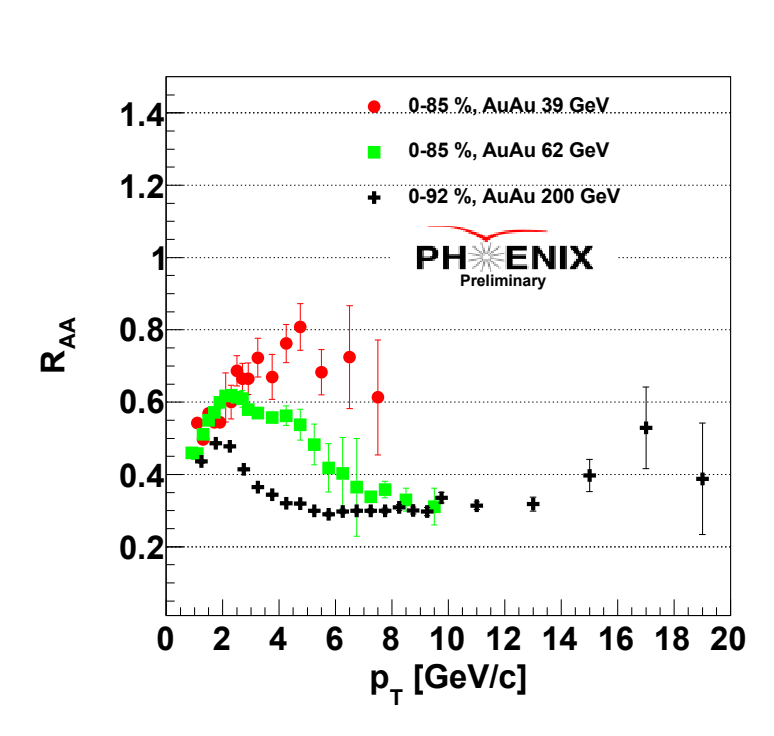
From RHIC to LHC the increase is due to the increase of mean-p_T



arXiv:1011.3914

Energy Scan – AuAu results

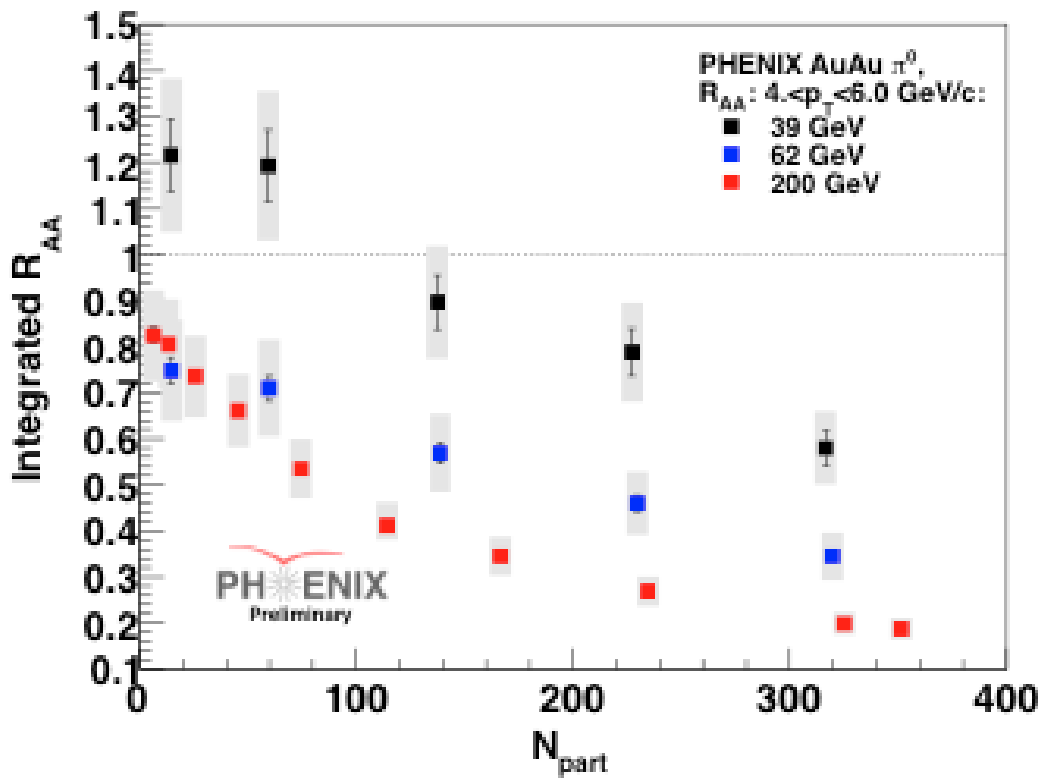




The evolution of π^0 R_{AA} in $\sqrt{s}$ from SPS to RHIC energies. The suppression in most central bin is already visible at $\sqrt{s}$ = 39 GeV.

The 62 GeV data at p_T > 6 GeV/c reach the 200 GeV points.

Energy Scan – Integrated R_{AA}s



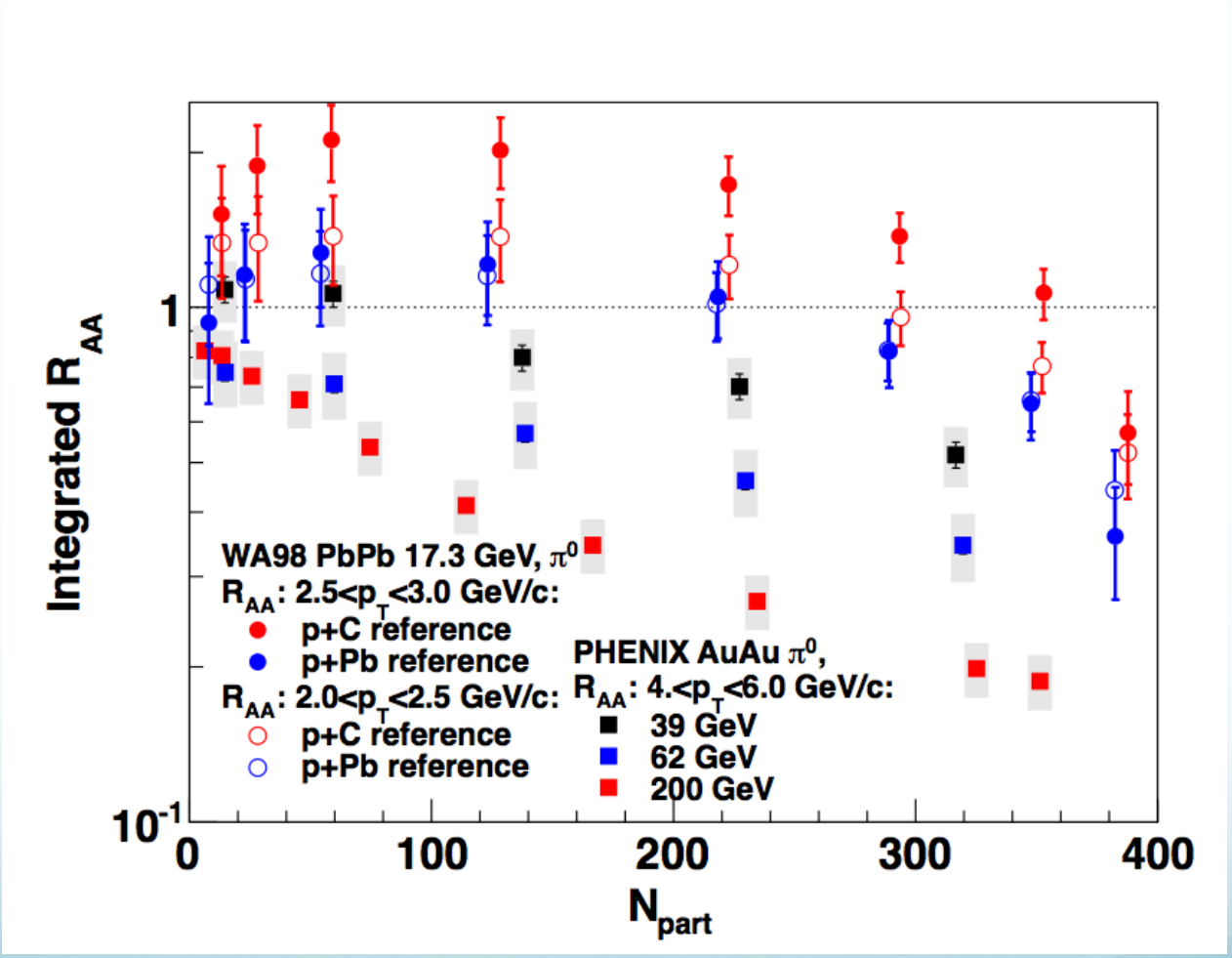
WA98 results:

- No p+p reference,
- p+C : $N_{coll} \approx 1.7$
- Suppression in "ultra-central" collisions only (0-1%).
- In Npart < 100 same "constant" behavior as CuCu 22 GeV.

The suppression study from 39 to 200 GeV in AuAu collisions:

- 62-200 GeV large suppression
- 39 GeV suppression only in N_{part}>100

All together – Integrated R_{AA}



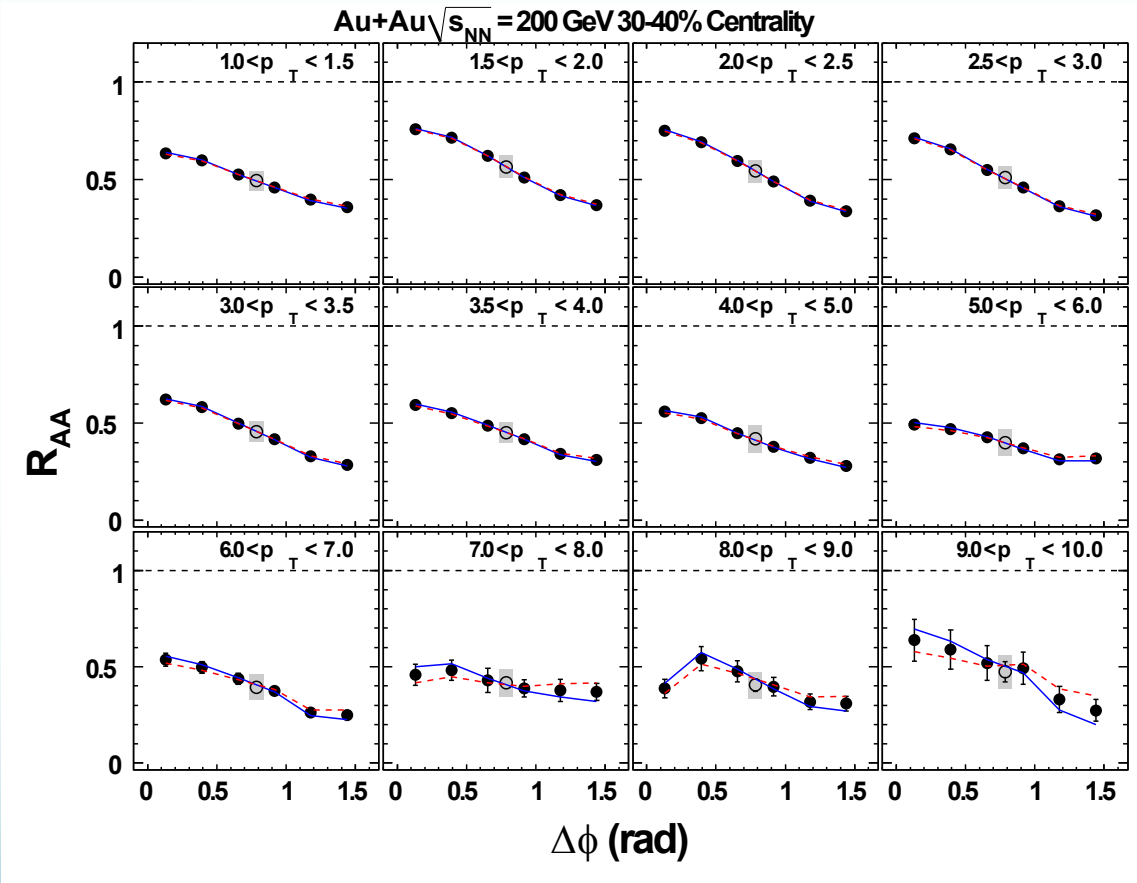
Summary

PHENIX after 10 years of data taking in the inclusive sector:

- The R_{AA} and R_{AA} w.r.t EP provide useful inside into the energy loss mechanism.
- The v_2 at higher p_T does not vanish. What is the origin?
- Energy scan:
  - Scanning to lower energies was very successful for PHENIX
  - π^0 v_2 seems to saturate already at 39
  - π^0 R_{AA} was measured in lower energies:
    - Indicates continues trend, no indication for sharp transition.

Backup

R_{AA} with respect to the reaction plane – II.



R_{AA}:
Left: in-plane,
Right: out-plane,
Middle: inclusive.

The difference between decreasing with p_Ts.

Phys. Rev. C 80, 054907 (2009)

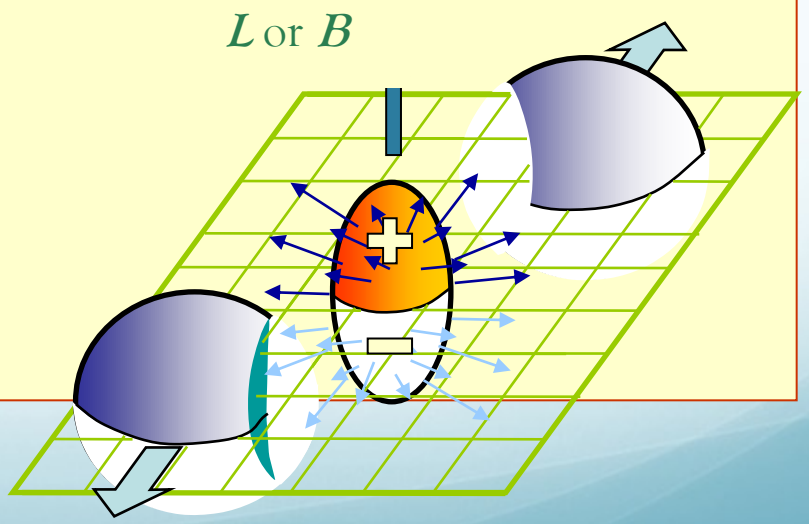
Local Parity Violation at RHIC

It has been proposed [1] that in heavy ion collisions, metastable domains may be created in which parity and CP symmetries are violated.

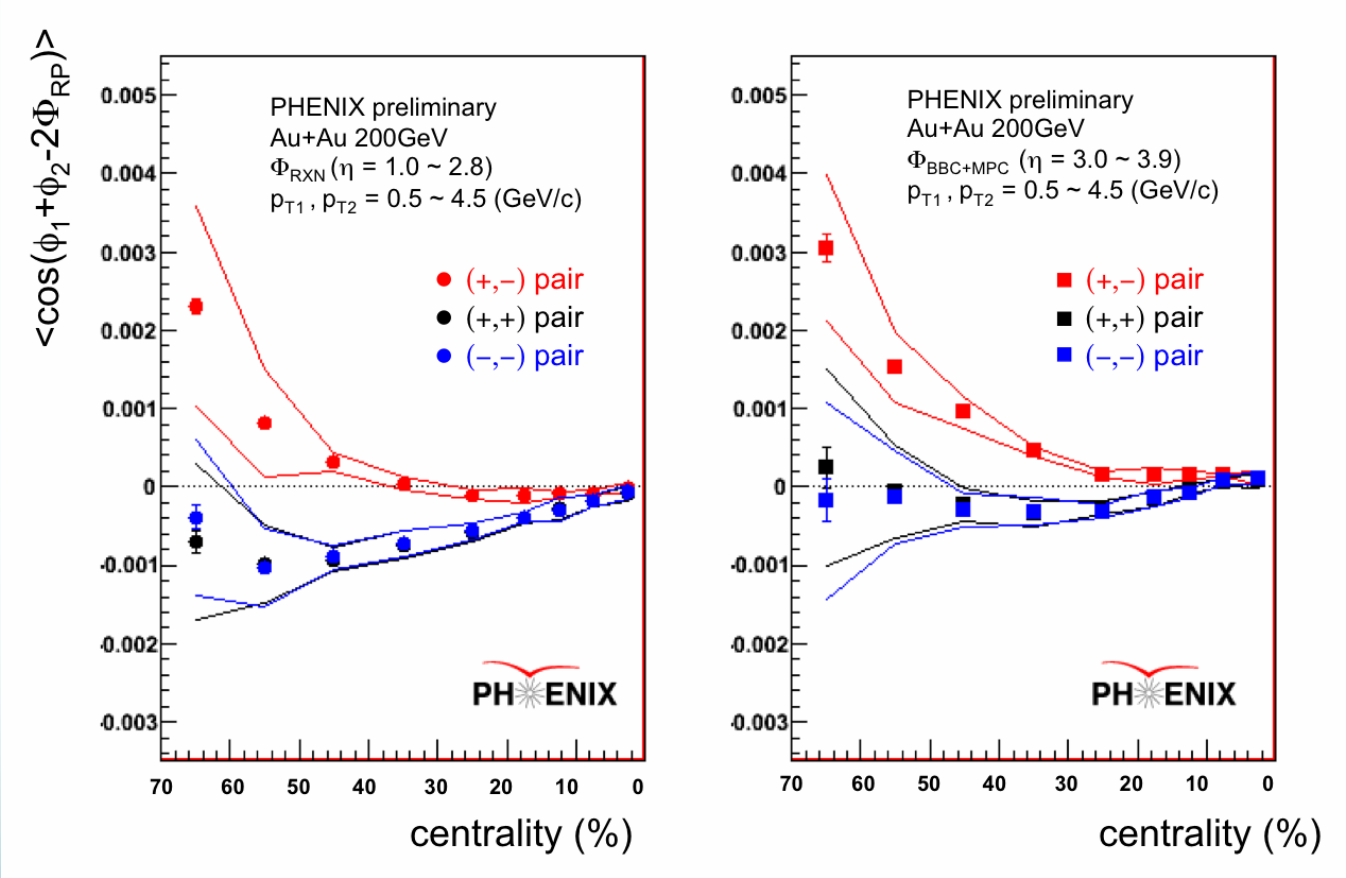
A combination of a net chirality of quarks within a domain and the extremely strong magnetic field in a heavy ion collision could lead to the manifestation of parity violation as a separation of charges along the angular momentum vector of the collision system [2].

1.D. Kharzeev, R. D. Pisarski, and M. H. G. Tytgat, Phys. Rev. Lett. 81, 512 (1998).

2.D. Kharzeev and R. D. Pisarski, Phys. Rev. D 61, 111901 (2000).

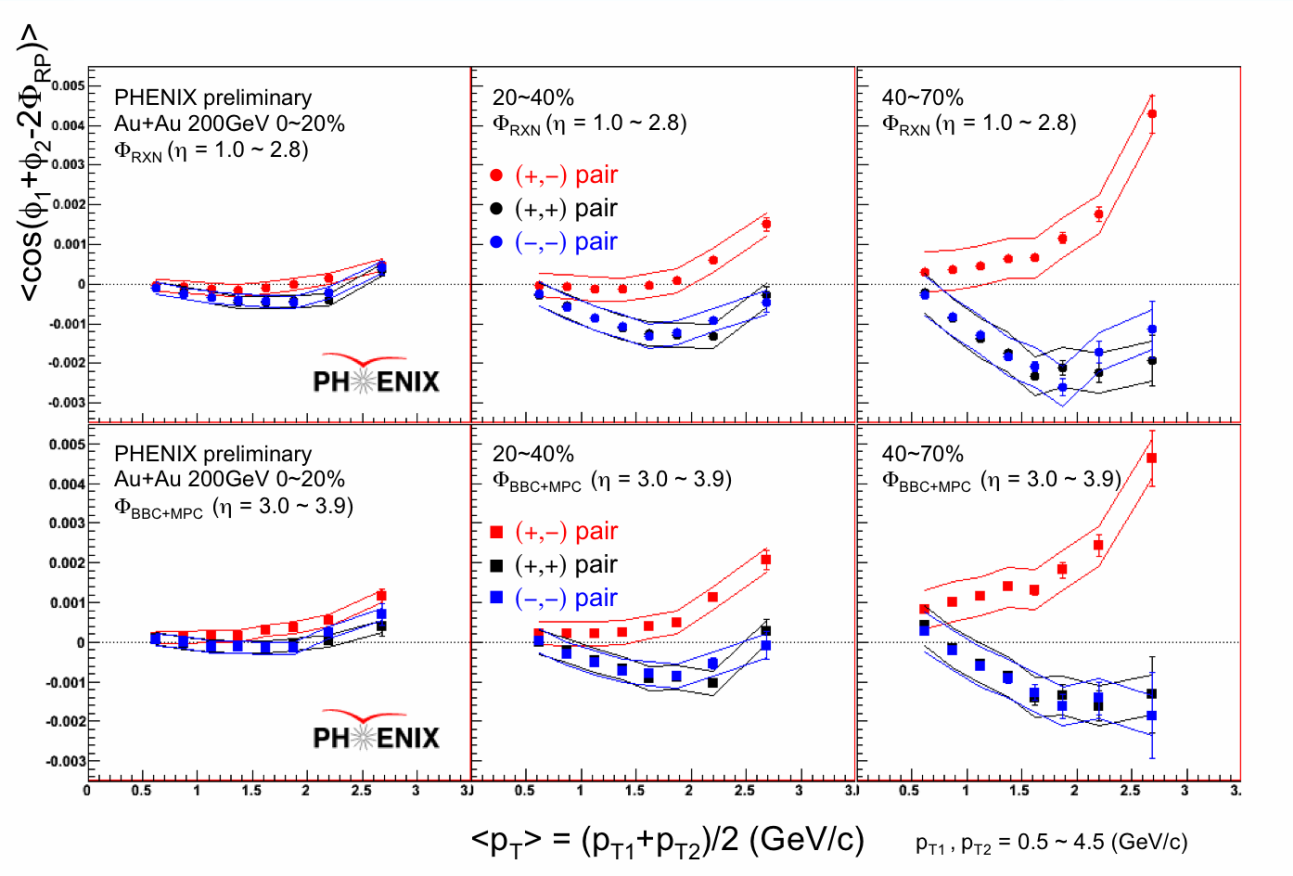


Two-particle correlation Results



Signal is sensitive to collision centrality

Two-particle correlation Results



Signal grows with centrality and p_T

$$S = \sin(\Delta\phi)$$

$$\Delta\phi = \phi - \Psi_{RP}$$

Evaluate real event averages of S

$\left\langle S_p^{h+} \right\rangle$ = average S over the p positively charged hadrons in the event

$\left\langle S_n^{h-} \right\rangle$ = average S over the n negatively charged hadrons in the event

Evaluate mixed event averages of S

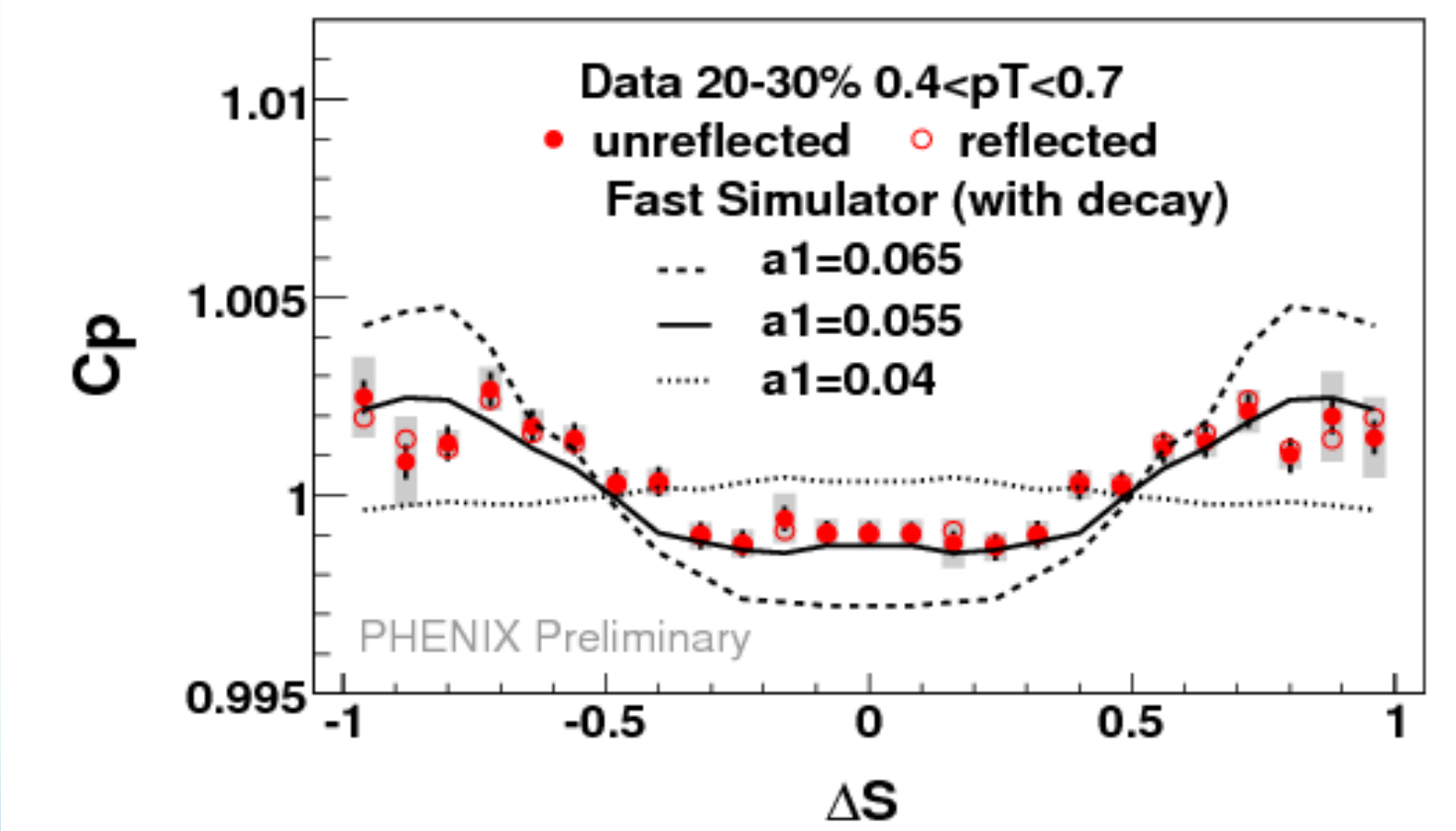
$\left\langle S_p^{h\mp} \right\rangle$ = average S over p randomly chosen hadrons in the same event

$\left\langle S_n^{h\mp} \right\rangle$ = average S over n remaining hadrons in the same event

$$C_p(\Delta S) = \frac{N\left(\left\langle S_p^{h+}\right\rangle - \left\langle S_n^{h-}\right\rangle\right)}{N\left(\left\langle S_p^{h\mp}\right\rangle - \left\langle S_n^{\mp}\right\rangle\right)} \quad \Delta S = \left\langle S_p\right\rangle - \left\langle S_n\right\rangle$$

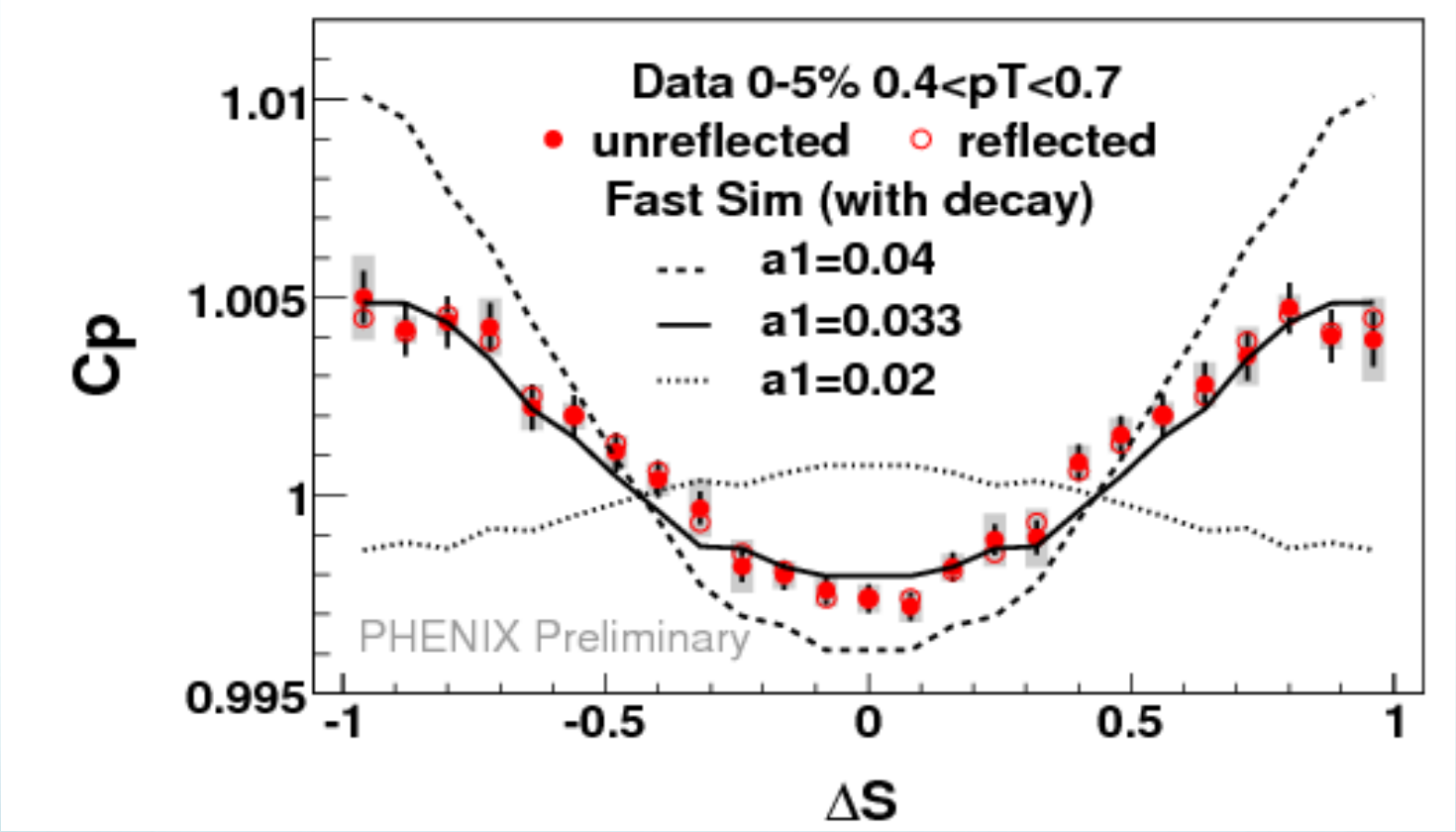
The new multi-particle correlator

Multi-particle correlation Results



Concave shape validates charge asymmetry

Multi-particle correlation Results

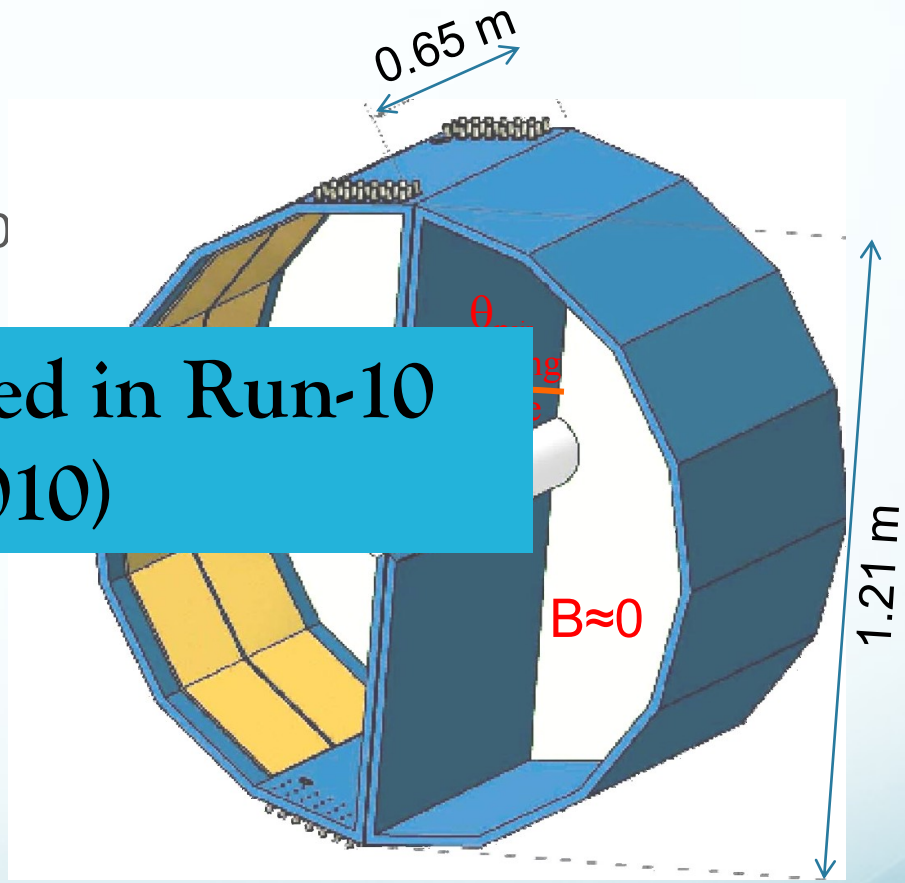


Concavity also observed for more central events
Simulation fits favor a lower value of a1

PHENIX upgrades: HBD

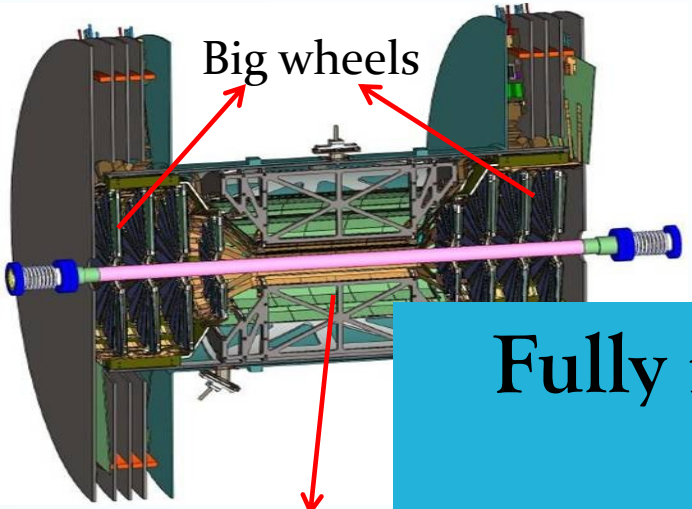
- ✓ The HBD is a windowless Cherenkov detector
- ✓ CF_4 radiator gas and active gas. L_{rad}=50 cm
- ✓ triple GEMs fo
- ✓ CsI photocath
- ✓ proximity focus configuration
- ✓ hexagonal pad readout (pad side a = 1.55 cm)
- ✓ total radiation length: ~4.4% + 0.9% (vessel) + 0.5% (CF_4) + ~3% (backplane)

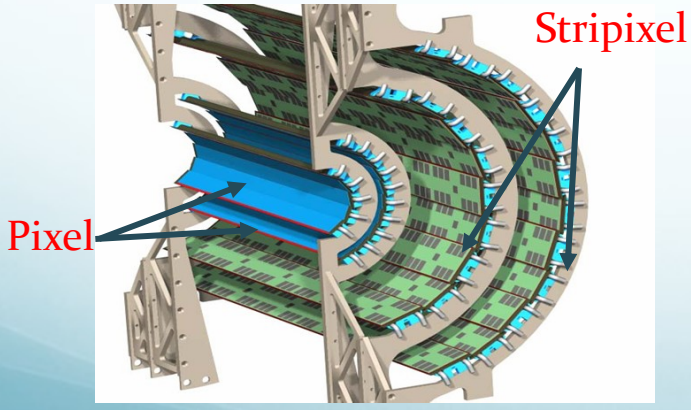
Fully installed in Run-10 (2010)



NIM A 546 (2005) 466-480, NIM A 523 (2004) 345-354

PHENIX upgrades: VTX





Fully installed in Run-11 (2011)

- Silicon VTX system consists of :
  - 4 layers of silicon detectors
    - 2 inner pixel hybrid detectors
      .5 cm and
      xel detectors at radius R3=10 cm and R4 =14 cm.
  - 2 big wheels to hold ladder transfer data boards (LDTBs)
  - Cooling system for ladder assembly.