Study of Parton Energy Loss with High-p_T π_0 in Au+Au Collisions at PHENIX

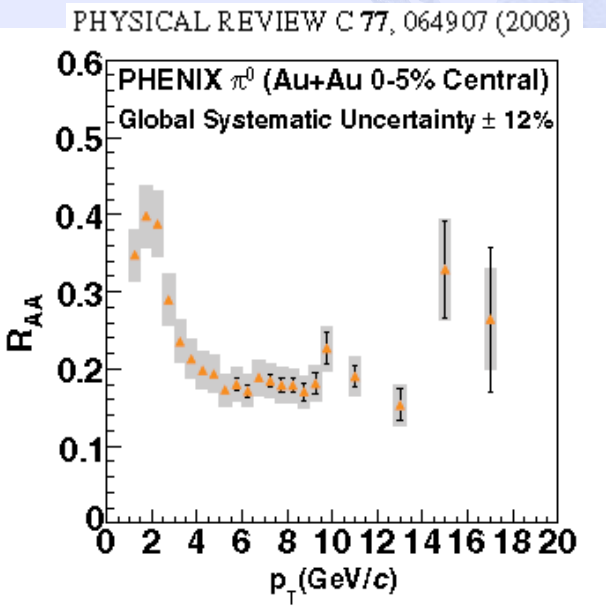
***Yoki Aramaki**, for the PHENIX Collaboration*

Center for Nuclear Study, University of Tokyo

Physics Motivation

Observation of Jet Quenching

- Yield Suppression at high p_T (A factor of 5 !)
- Parton lose the energy with strong interaction



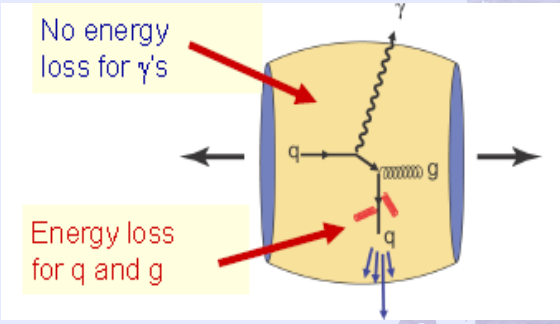
Nuclear modification factor

$$R_{AA}(p_T, cent) = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA}(p_T, cent)/dp_T d\eta}{d^2\sigma^{NN}/dp_T d\eta}$$

Energy Loss and Path Length (L)

- Radiative Process in pQCD $E_{loss} \propto L^2$
- Collisional Process in pQCD $E_{loss} \propto L$
- Radiative Process in AdS/CFT $E_{loss} \propto L^3$

(Ex. Phys.Lett.B685(2010)270)



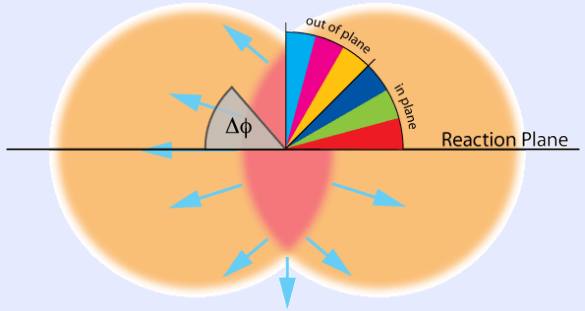
Jet Quenching as Observable

- Sensitive to the density of the medium
- Test for the nature of the medium (Strong or Weak coupled?)

Measurement of $R_{AA}(p_T, L)$

Correspondence Relation

Path length (L) ↔ Azimuthal angle ($\Delta\phi$) and Centrality



$R_{AA}(p_T, L) \leftrightarrow R_{AA}(p_T, \text{centrality}, \Delta\phi)$

Light blue : long path length
Red : short path length

Extraction of $R_{AA}(p_T,\Delta\phi)$

$$R_{AA}(p_T,\Delta\phi) \cong R_{AA}(p_T) \times \frac{N(p_T,\Delta\phi_i)}{\sum_{\phi_i} N(p_T,\Delta\phi_i)}$$

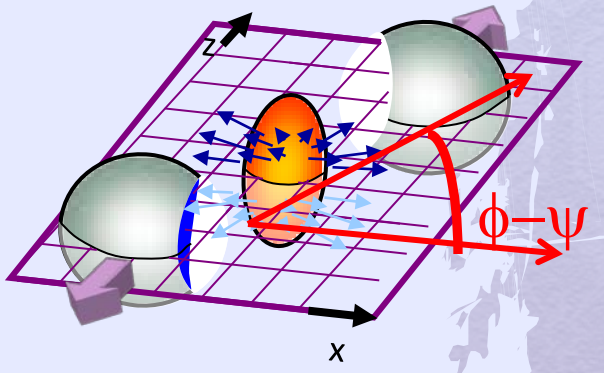
$$N(p_T,\Delta\phi_i) \cong N(1+2v_2\cos(2\Delta\phi_i))$$

Role of Anisotropy v_2 at High p_T

Spatial anisotropy in non-central collisions influences R_{AA} for each azimuthal angle.

$$\frac{dN}{d(\phi-\Psi)} = N[1+\Sigma 2v_n\cos(n(\phi-\Psi))]$$

ϕ : Azimuthal angle of emitted particles
Ψ : Azimuthal angle from reaction plane



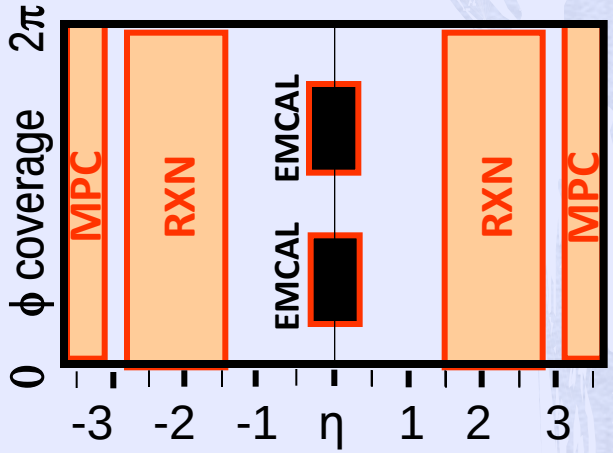
Detector Upgrade for Au+Au Run in RHIC-Year2007

☐ Muon Piston Calorimeter (MPC)

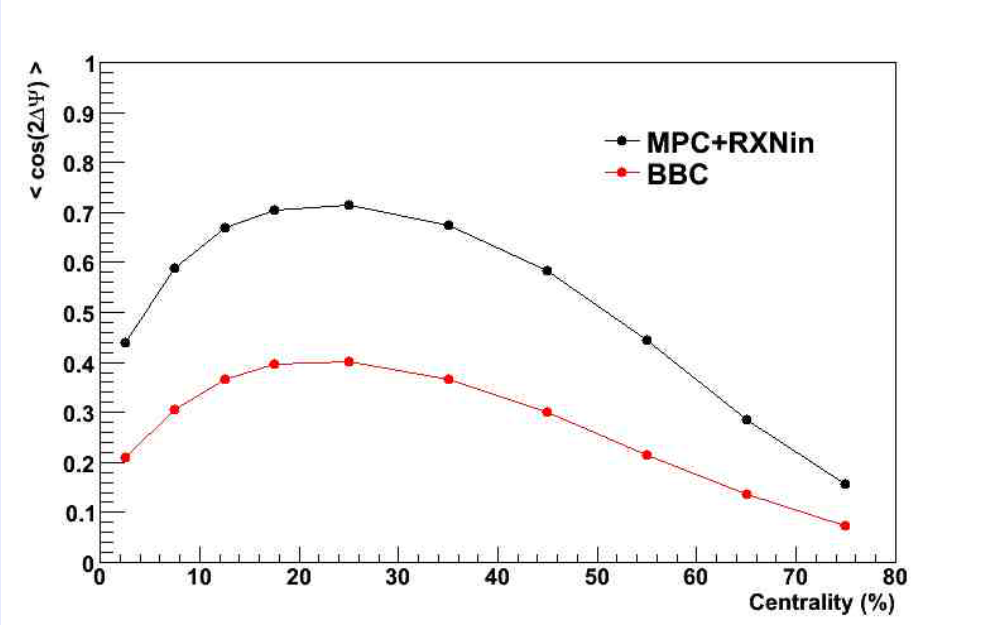
- Rapidity coverage $3.1 < |\eta| < 3.7$
- PbWO4 Crystals + Avalanche Photodiodes

☐ Reaction Plane Detector (RXN)

- Rapidity coverage $1.5 < |\eta| < 2.8$
- Pb + Scintillator, PMT



MPC/RXN Acceptance View



Beam Beam Counter (BBC) :

Reaction plane detector before RHIC-Year 2007

Similar rapidity coverage as MPC ($3.0 < |\eta| < 3.9$)

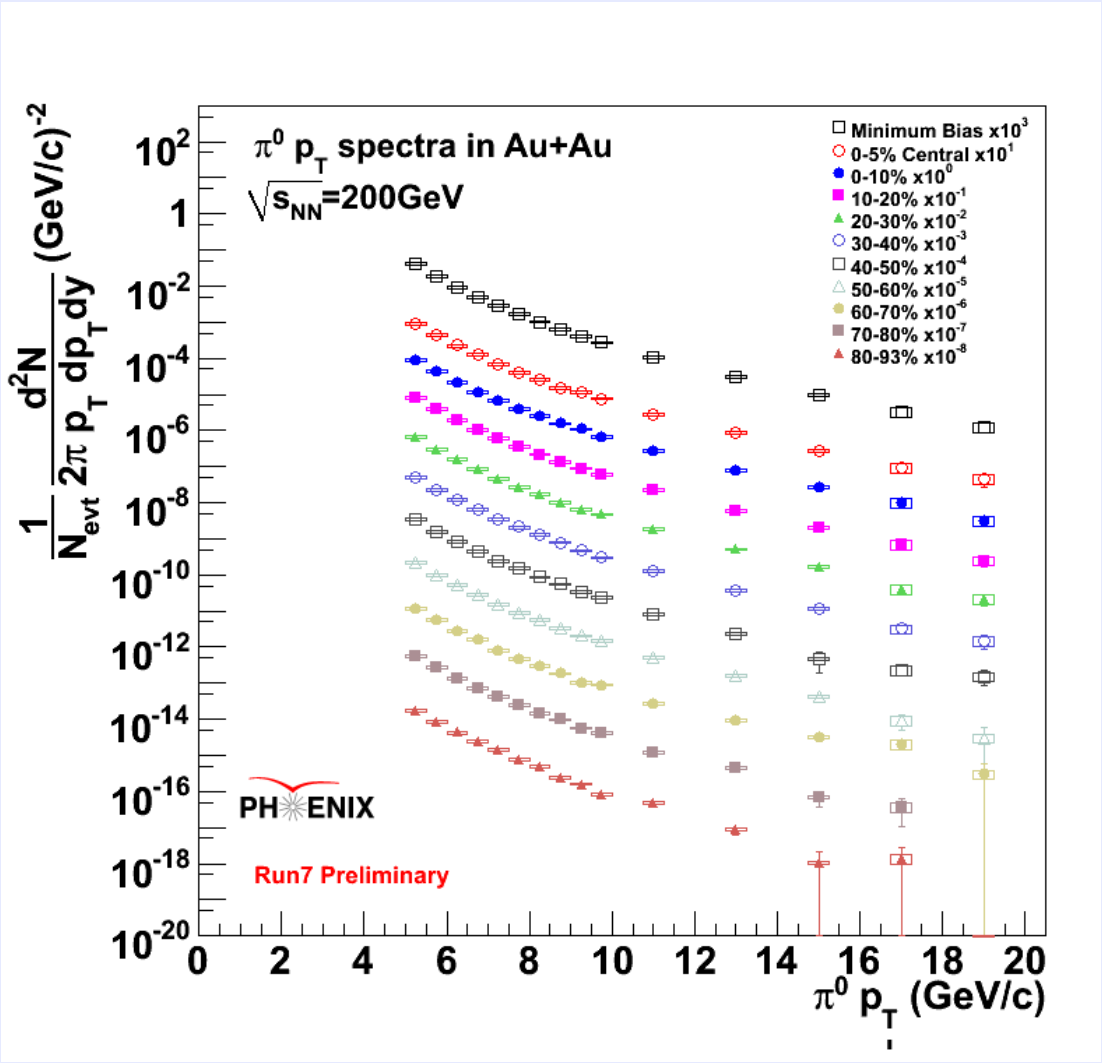
Reaction plane resolution

$$\sigma_{RP} = < \cos(2\Delta\Psi) >$$

$$v_2^{corrected} = v_2^{measured} \Big/ \sigma_{RP}$$

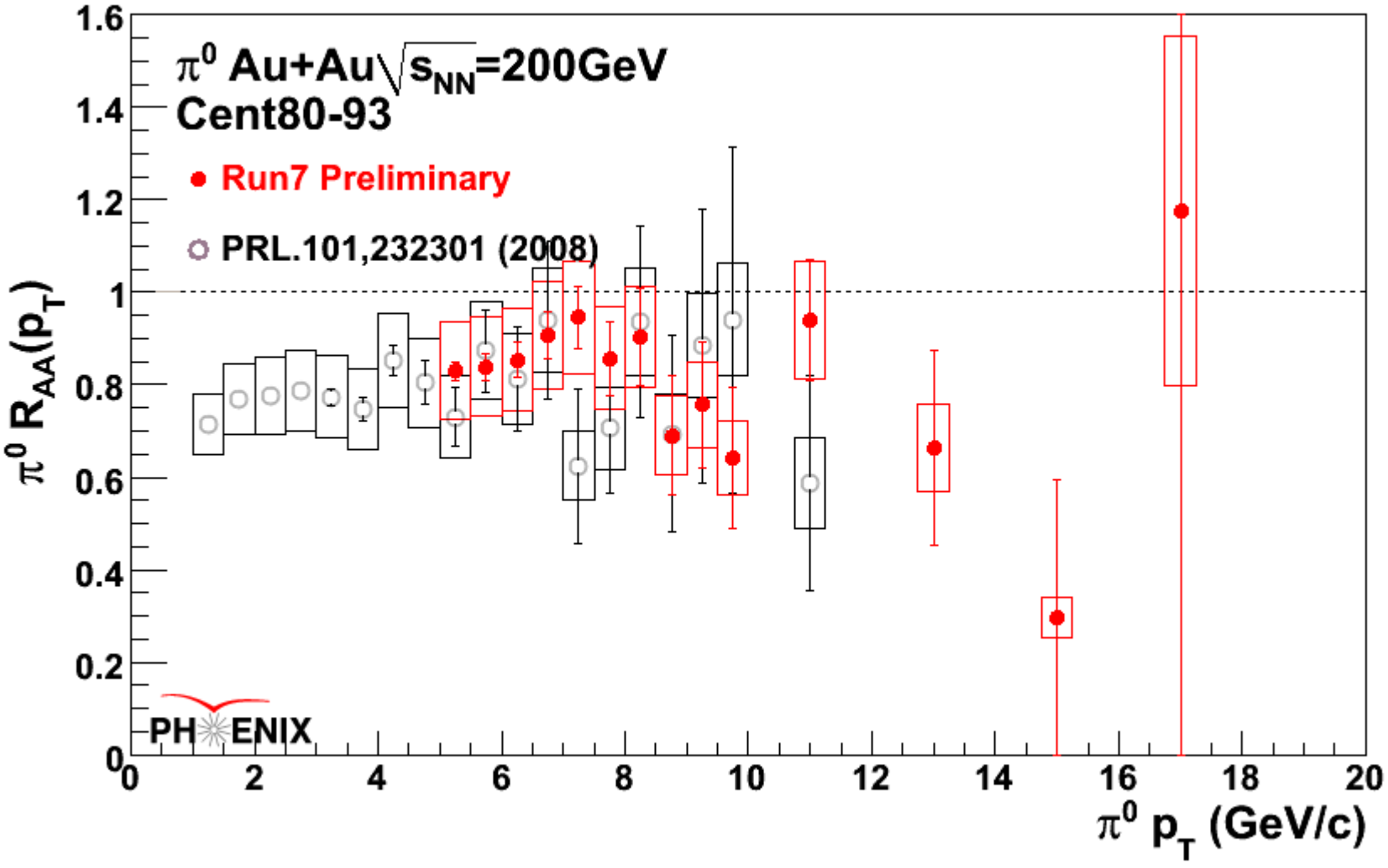
Error is reduced ~80%

Improved Integrated Luminosity in RHIC-Year2007



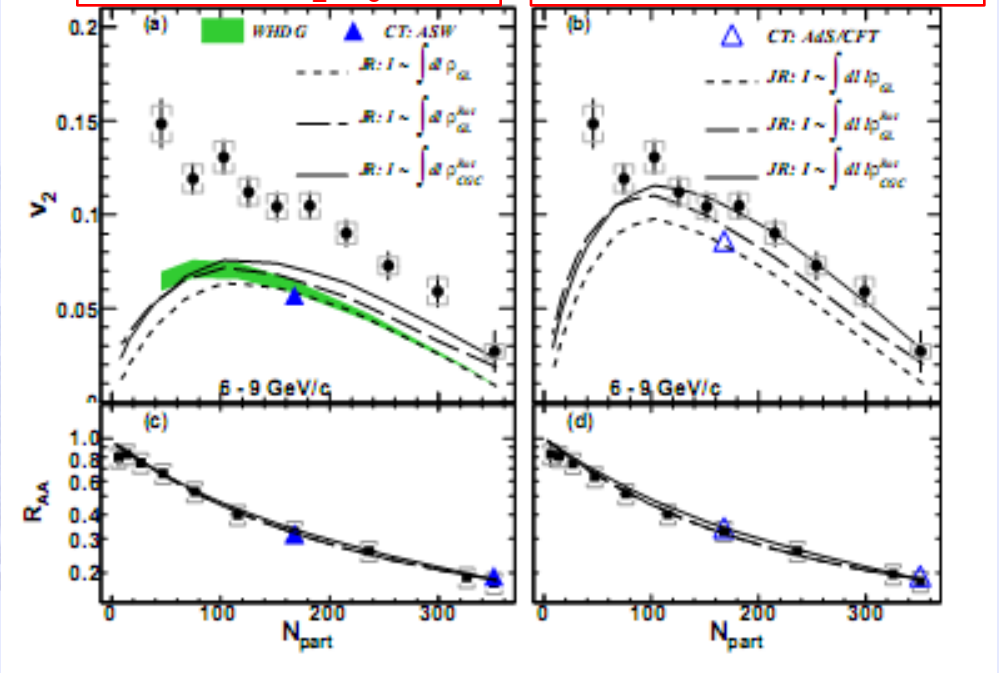
Integrated Luminosity : 241μb^{-1}(Run4) → 813μb^{-1}(Run7)
For most of centrality classes, pT reach is extended up to 20GeV/c !

p_T dependence of π^0 $R_{AA}(p_T)$
– Published Paper and New Preliminary –



Centrality Dependence of π^0 $R_{AA}(p_T)$ and v_2

ASW in pQCD | ASW in AdS/CFT



Energy loss model

- WHDG Calculation (pQCD)
  Only radiative process
- CT Calculation (AdS/CFT)
  only radiative process
- JR Calculation (AdS/CFT)
  Same as CT model

Initial geometry in JR Calc.

- Color Glass Condensate (CGC) → Solid
- Standard Glauber → Short dashed
- Glauber including fluctuations → Long dashed

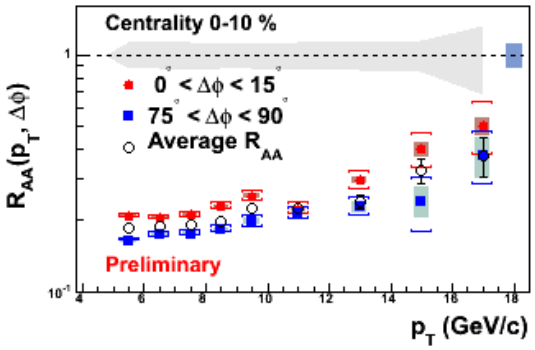
→ *arXiv:1006.3770 , PHENIX new published paper*
(Accepted in Phys.Rev.Lett.)

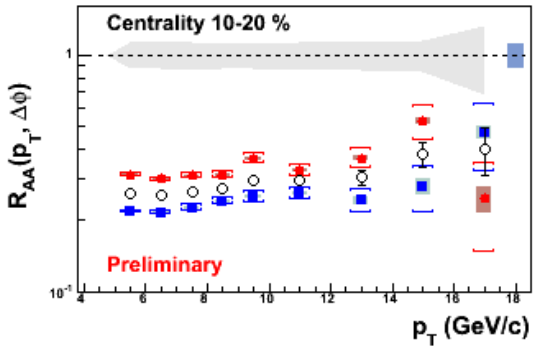
3-D hydro + *Energy loss in weakly/strongly coupled medium*

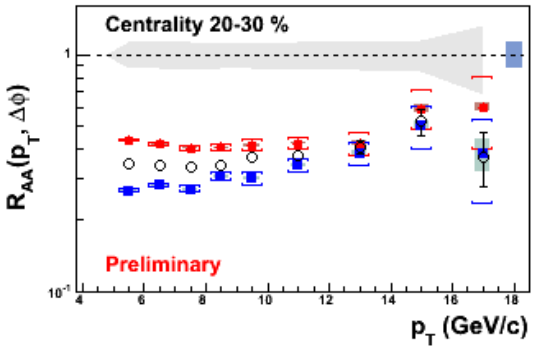
Data ≈ R_{AA}(AdS/CFT) ≈ R_{AA}(pQCD)

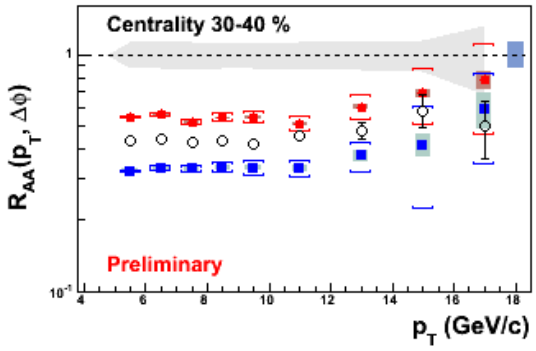
v_2 (AdS/CFT) > v_2 (pQCD)

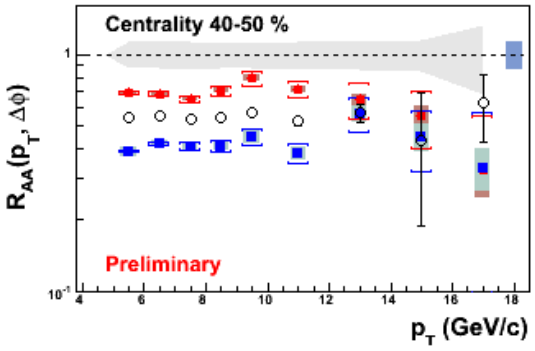
In-plane/Out-of-plane/Average π^0 $R_{AA}(p_T, \Delta\phi)$ – p_T dependence –

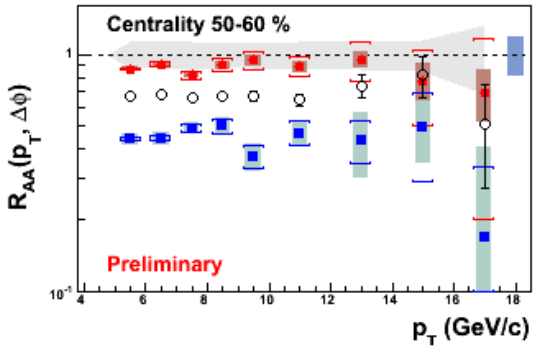












Gray band
: $R_{AA}(p_T)$ p_T correlated

Light blue band
: Global syst.err.

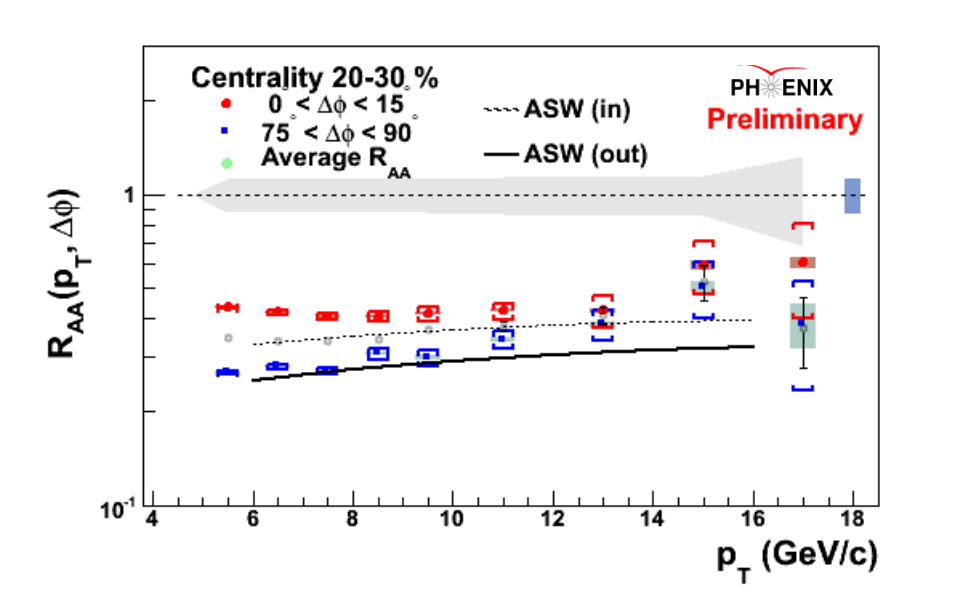
Bracket on data
: $R_{AA}(p_T, \Delta\phi)$ p_T uncorrelated

Band on data
: $R_{AA}(p_T,\Delta\phi)$ p_T correlated

Azimuthal angular dependence of R_{AA} is clearly seen !

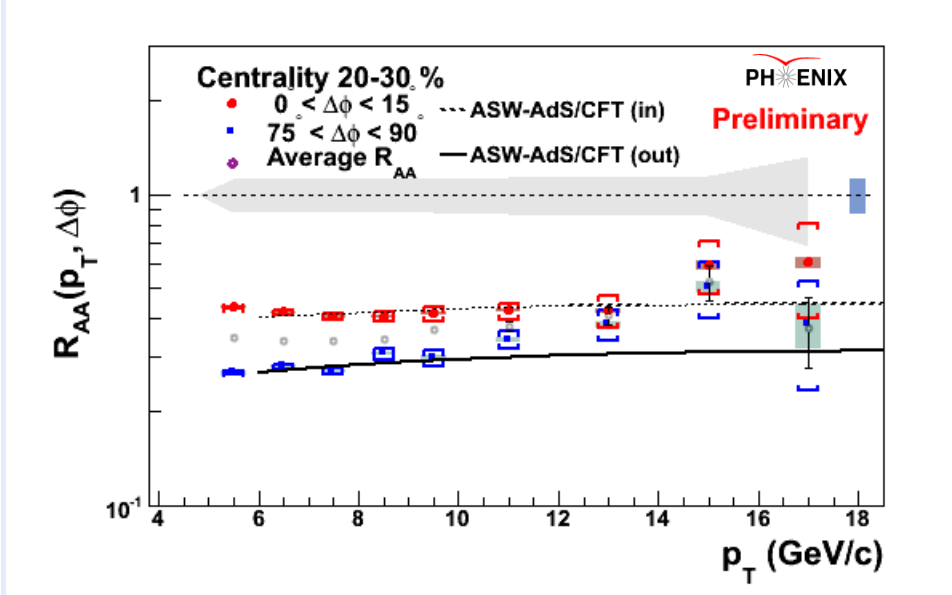
Model Comparison with π^0 $R_{AA}(p_T, \Delta\phi)$ in Centrality 20-30%

ASW in pQCD



Theoretical Curve: Phys.Rev.C79,024901(2009)

ASW in AdS/CFT



Theoretical Curve : Phys.Lett.B685,270(2010)

- Energy loss models in weakly coupled medium
  Weak azimuthal angular dependence
- Energy loss models in strongly coupled medium
  Strong azimuthal angular dependence

Summary and Outlook

- Jet Quenching (Hard scattered parton)
  - Good probe for studying the property of dense matter.
  - Sensitive to gluon density in the medium
- Azimuthal Angular Dependence of $R_{AA}(p_T, \Delta\phi)$
  - Out-of-plane R_{AA} (i.e. Long path length)

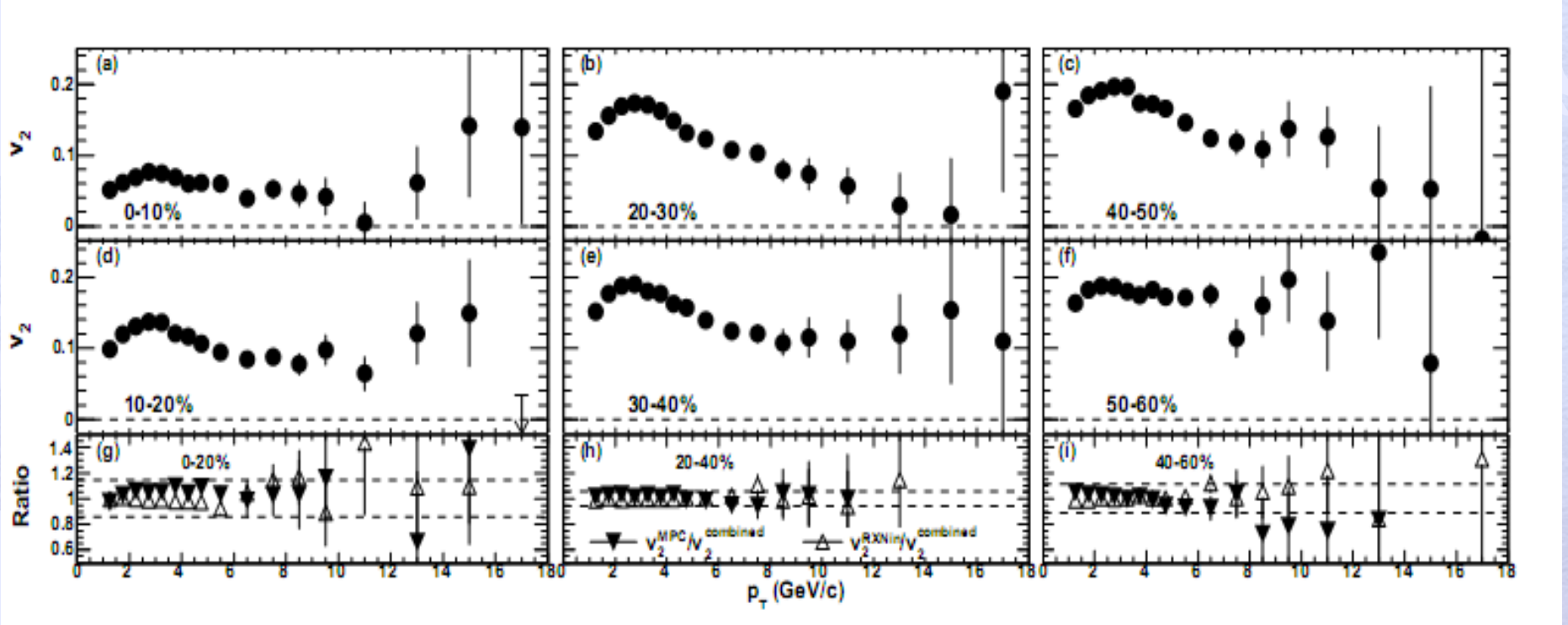
    Reproduce R_{AA} for both cases of pQCD and AdS/CFT
  - In-plane R_{AA} (i.e. Short path length)

    Difference between pQCD and AdS/CFT models

- Ongoing Work
  - Constrain the model parameters in the medium
  - Extract the path-length dependence of R_{AA}
- Probe the Nature of the Medium at LHC
  - Path-length dependence of R_{AA} is a valid and powerful tool

Backup

Determination Error for Reaction plane



Central Collision : ~ 10 % difference
Mid-central Collision : ~ 5 % difference
Peripheral Collision : ~ 10 % difference

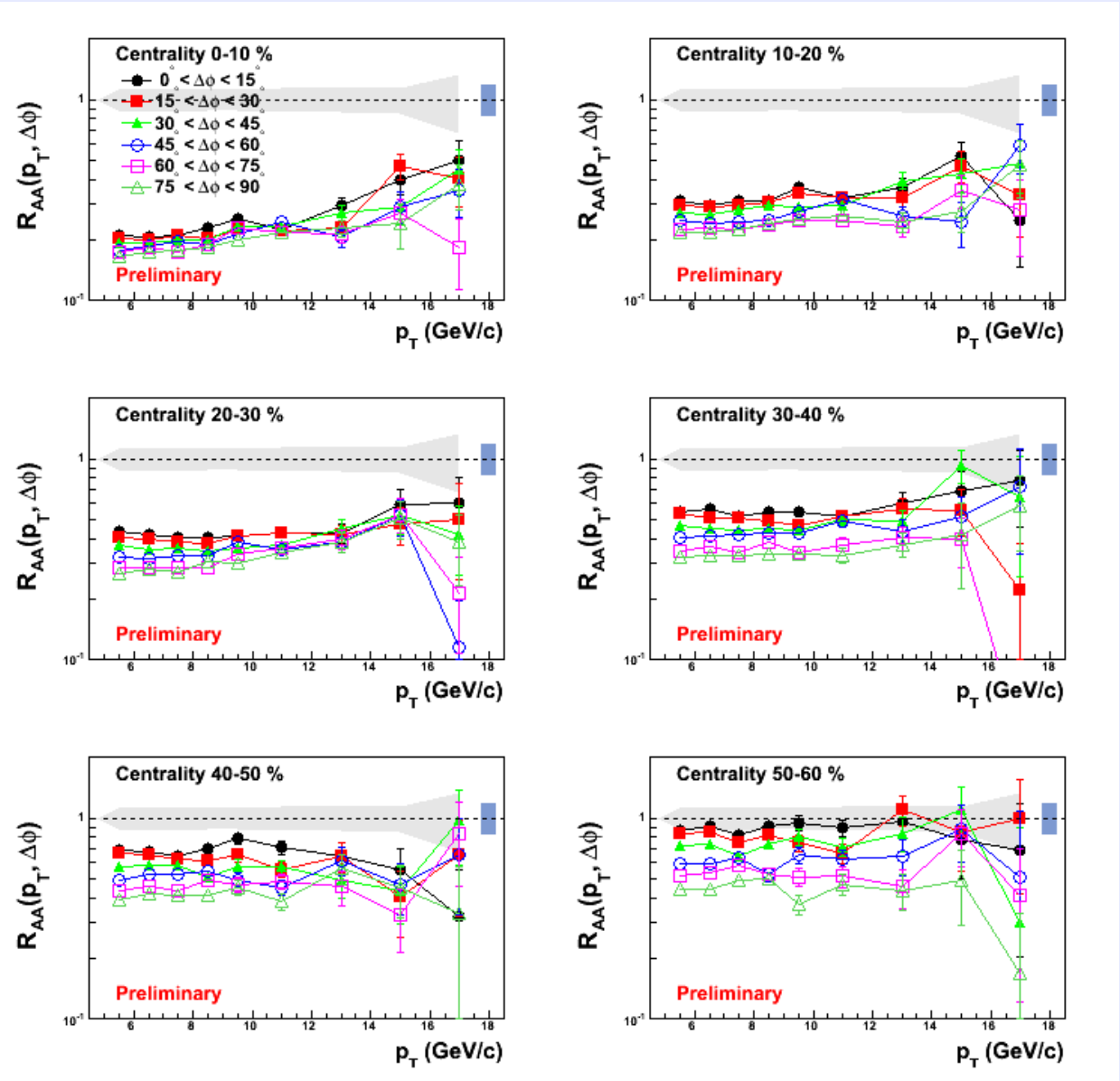
→ Systematic Error on v_2

Systematic Uncertainty Source on Integrated Angle $R_{AA}(p_T)$

PRL **101,** 232301 (2008)

p_T (GeV/c)	2	6	10	16
uncertainty source		PbSc (PbGl)		
yield extraction (%)	3.0 (4.1)	3.0 (4.1)	3.0 (4.1)	3.0 (4.1)
PID efficiency (%)	3.5 (3.9)	3.5 (3.5)	3.5 (3.7)	3.5 (3.9)
Energy scale (%)	6.7 (9.0)	8.0 (9.2)	8.0 (8.2)	8.0 (12.3)
Acceptance (%)	1.5 (4.1)	1.5 (4.1)	1.5 (4.1)	1.5 (4.1)
π^0 merging (%)	$\cdots$ ($\cdots$)	$\cdots$ ($\cdots$)	4.4 ($\cdots$)	28 (4.8)
Conversion (%)	3.0 (2.5)	3.0 (2.5)	3.0 (2.5)	3.0 (2.5)
off-vertex π^0 (%)	1.5 (1.5)	1.5 (1.5)	1.5 (1.5)	1.5 (1.5)
Total (%)	8.7 (12)	9.8 (11)	11 (11)	30 (15)
PbSc and PbGl combined: Total (%)	7.0	7.5	7.6	14

π^0 $R_{AA}(p_T, \Delta\phi)$ in Au+Au – Run7 PHENIX Preliminary



Gray band
: $R_{AA}(p_T)$ p_T correlated .err.

Light blue band
: Global syst.err.

Bars on data
: $R_{AA}(p_T,\Delta\phi)$ p_T uncorrelated err.

Azimuthal angular dependence of R_{AA} is clearly seen !