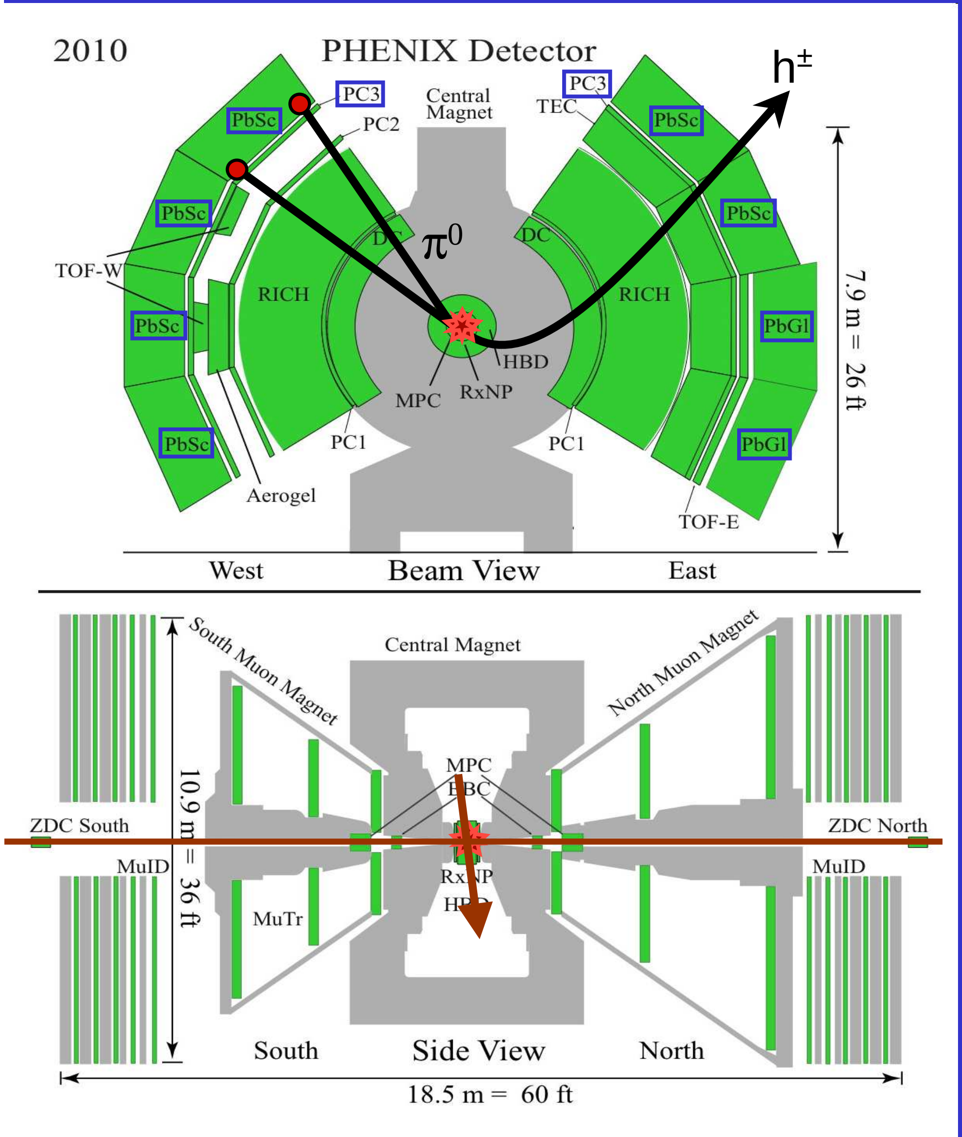
Latest Heavy Ion Results from PHENIX

Chris Pinkenburg

for the

PHENIX collaboration

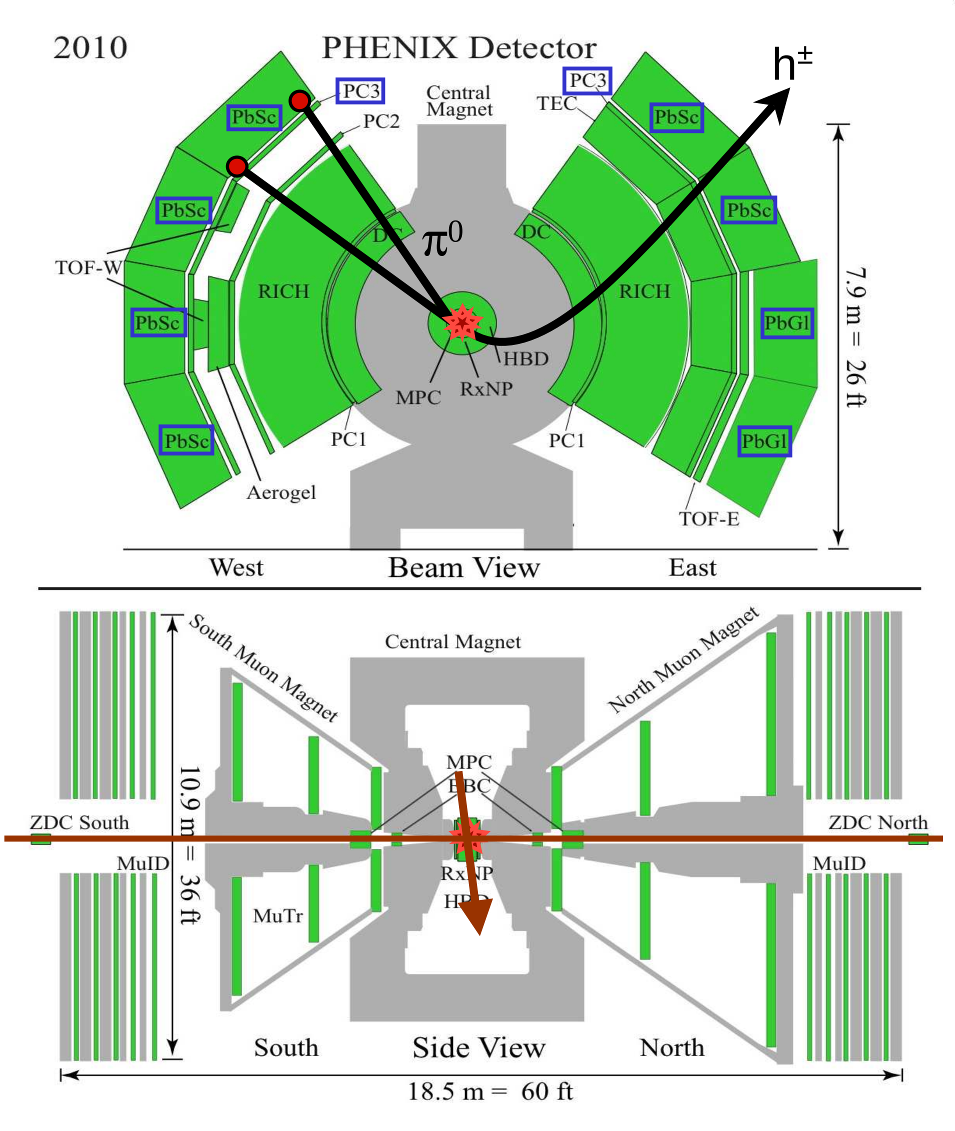
The PHENIX Detector



Heavy Ion Physics with PHENIX
Purpose: Characterize the QGP
Approach: study penetrating probes, hard scattering and perform systematic measurements

Selected topics of this talk
- Elliptic flow of direct photons
- Cold nuclear matter effects
- Beam energy scan
- Future plans

The PHENIX Detector



Event Characterization

- Vertex,centrality, reaction plane:
  Zdc, Bbc, Mpc, Rxnp

Single Particle reconstruction

- Charged Particle Tracking:
  DC,PC1,RICH,PC3
  clean up to $p_t \approx 5$GeV/c
- Photon and π^0 Reconstruction:
  PbSc, PbGl, PC3
  easy π^0 id up to p_t=20GeV/c
- Single Muons:
  MuTr, MuId
  $2 < p_\mu < 50$GeV/c, π/μ rej ~ 10^{-4}

Acceptance
Central Arms: $|\eta| < 0.35$
Muon Arms: $2.4 < |\eta| < 1.1$
Mpc: $3.8 < |\eta| < 3.1$

R_{AA}/R_{dA}

"Ratio of measured particle yields to what would have been measured if a Heavy -Ion collision was just a superposition of independent p-p collisions"

If it is just such a superposition, the ratio is 1, by definition

Any deviation denotes differences to a simple-minded superposition image

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

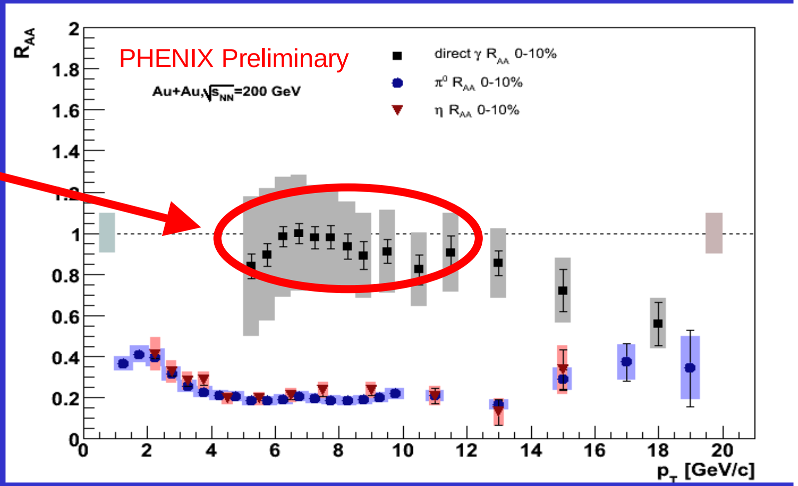
R_{cp}

Ratio of measured particle yields from central events and peripheral events, used if pp reference is not available

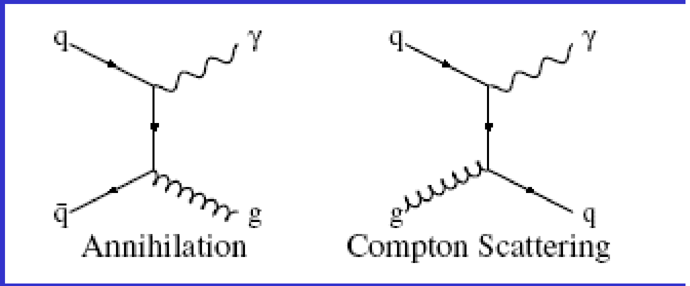
Caveat: an enhancement in peripheral events looks like a suppression in central events

Direct (prompt) Photons

γ penetrates the medium,
direct γ $R_{AA} \approx 1$ → no medium effect
direct photons are produced in partonic hard scattering, emitted by fragmenting partons or by the media

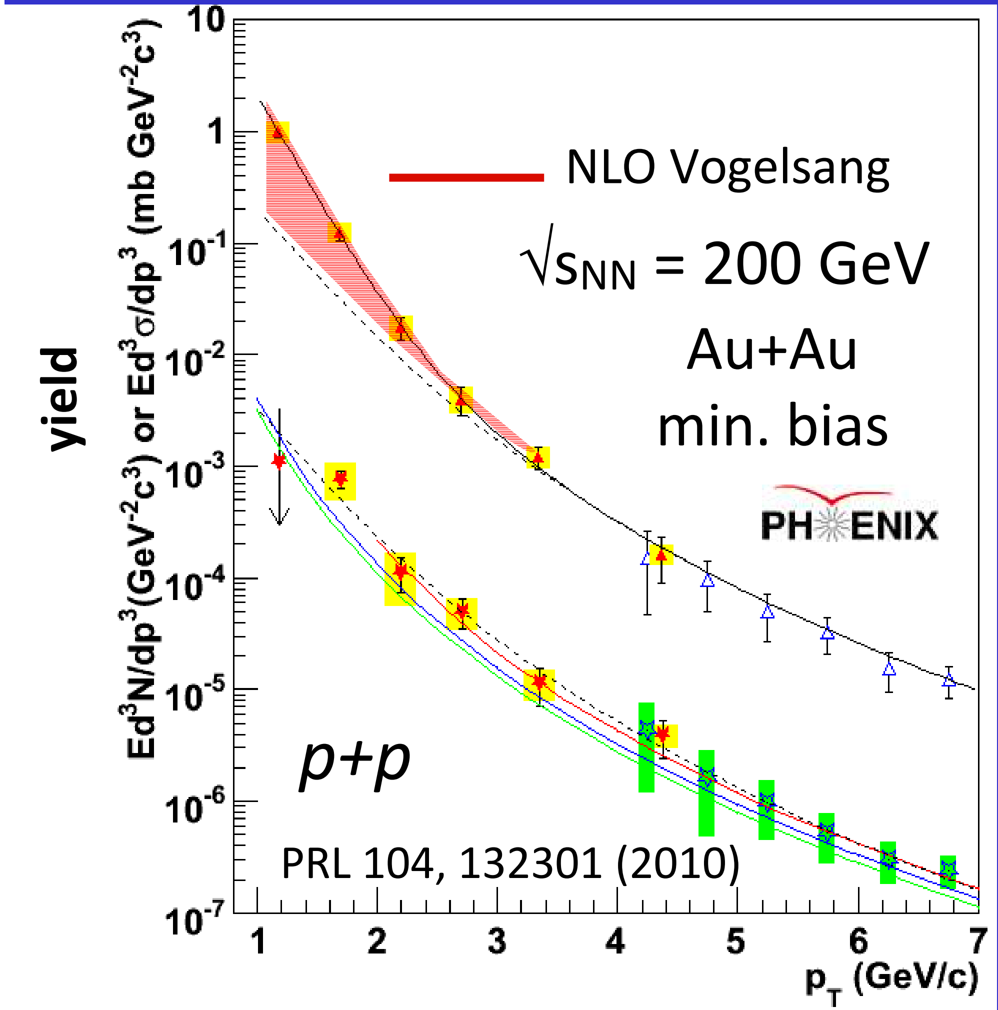


Those due to hard scattering are also called prompt, they are well studied in NN interactions and commonly used as a proof of the validity of pQCD treatment and the use of N_{Coll} Scaling in R_{AA}



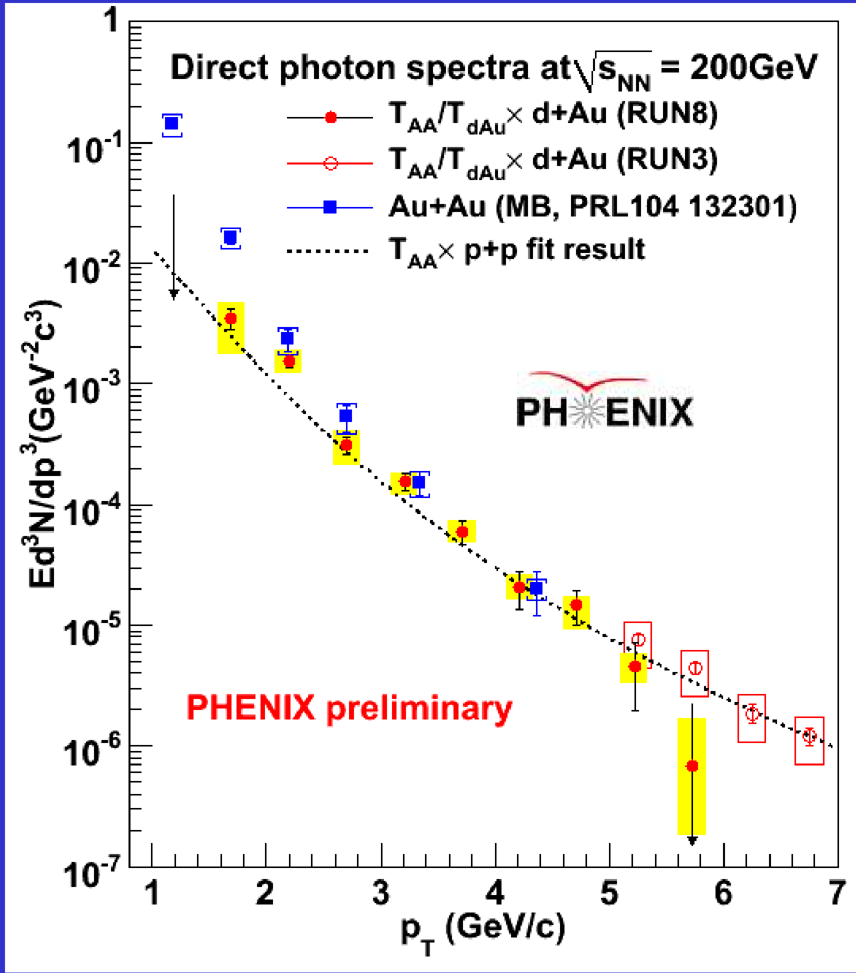
BUT: Most photons are products of electromagnetic decays of secondary hadrons and leptons. Measuring direct photons is hard!

Direct Photon Excess in Au+Au



- Direct photon excess above *p+p* spectrum
- Exponential (consistent with thermal)
- Inverse slope = 220 ± 20 MeV
- T_i from hydro
  - 300 . . . 600 MeV
  - Depending on thermalization time

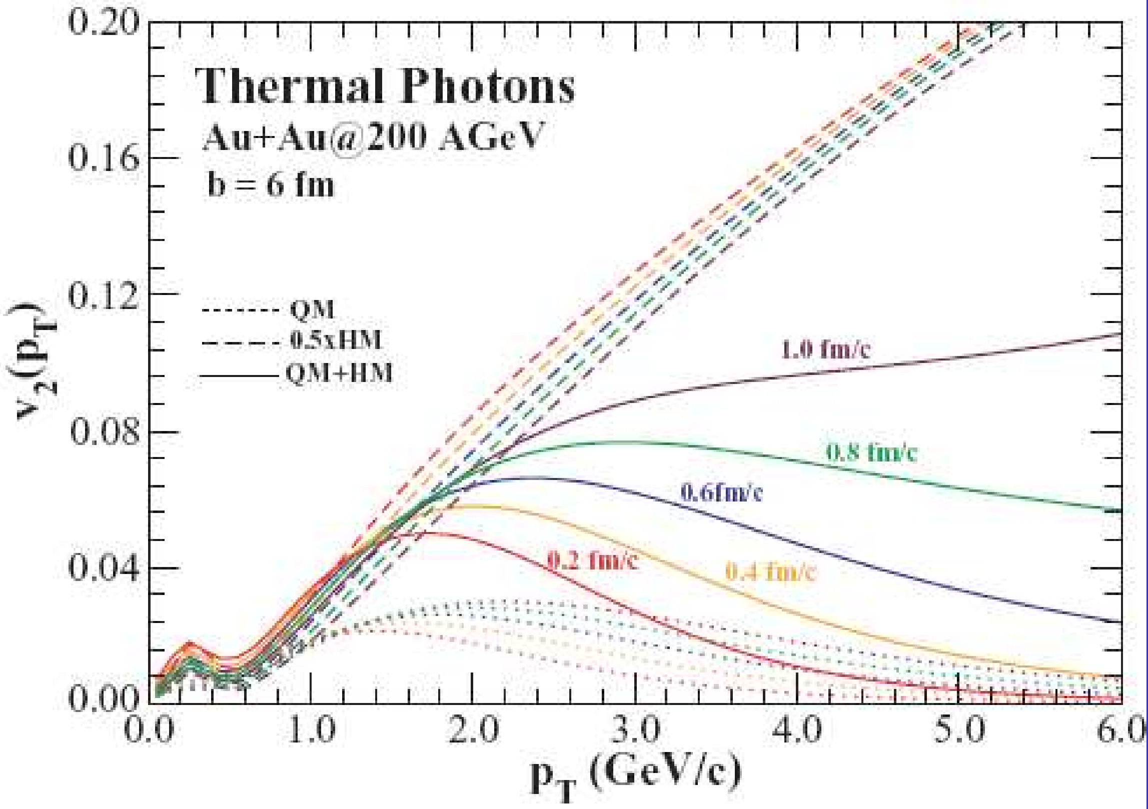
Critical *d*+Au Check



no exponential excess in *d*+Au

Direct photon v_2 further constrains T_i

Hydro after τ_0



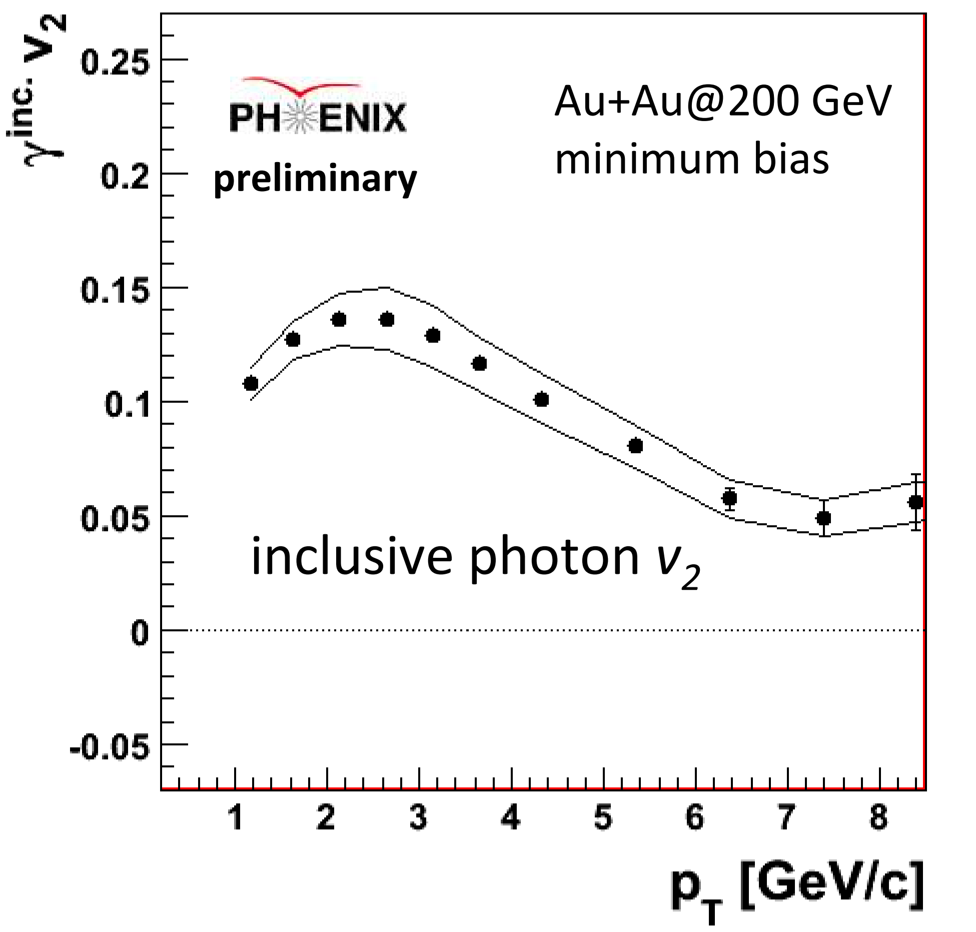
- ***expected v_2 :***
  - ***prompt photons: 0 (time zero)***
  - ***thermal photons***

early → small (flow not built up)

late → large (like hadrons)

Chatterjee, Srivastava
PRC79, 021901 (2009)

Direct Photon v_2



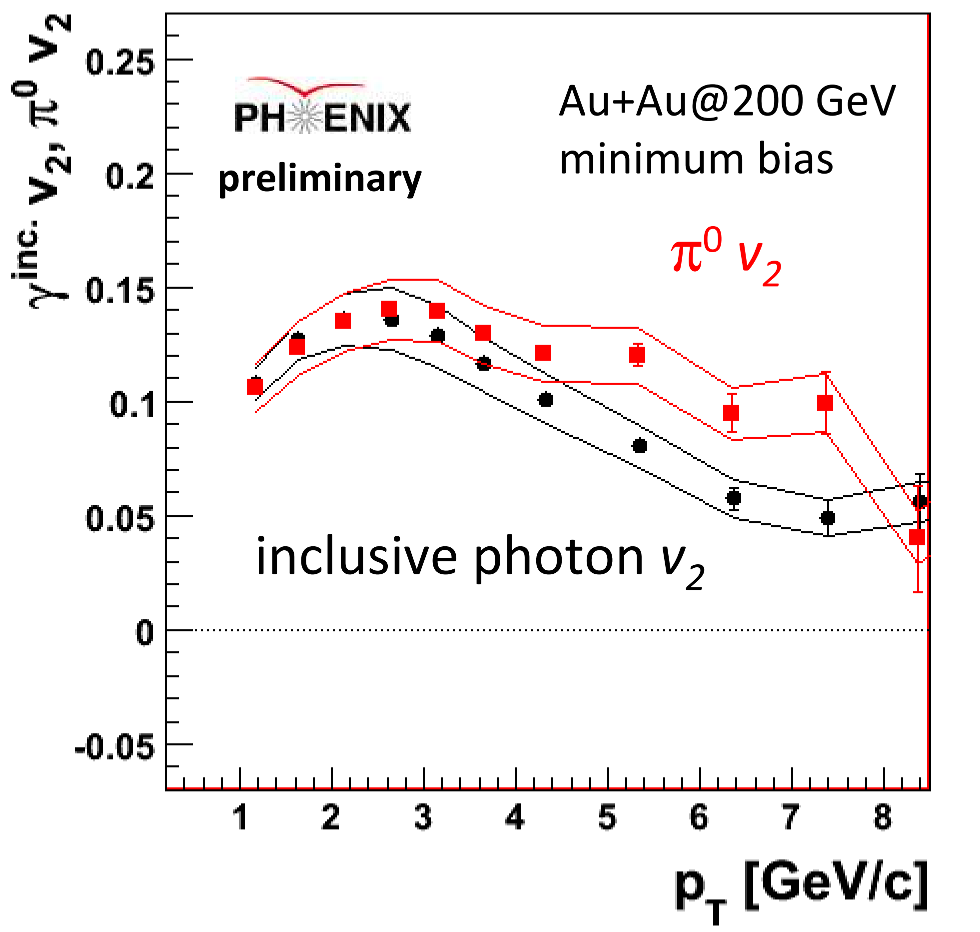
Statistical subtraction

inclusive photon v_2
- decay photon v_2
(from π^0, η, …)

= direct photon v_2

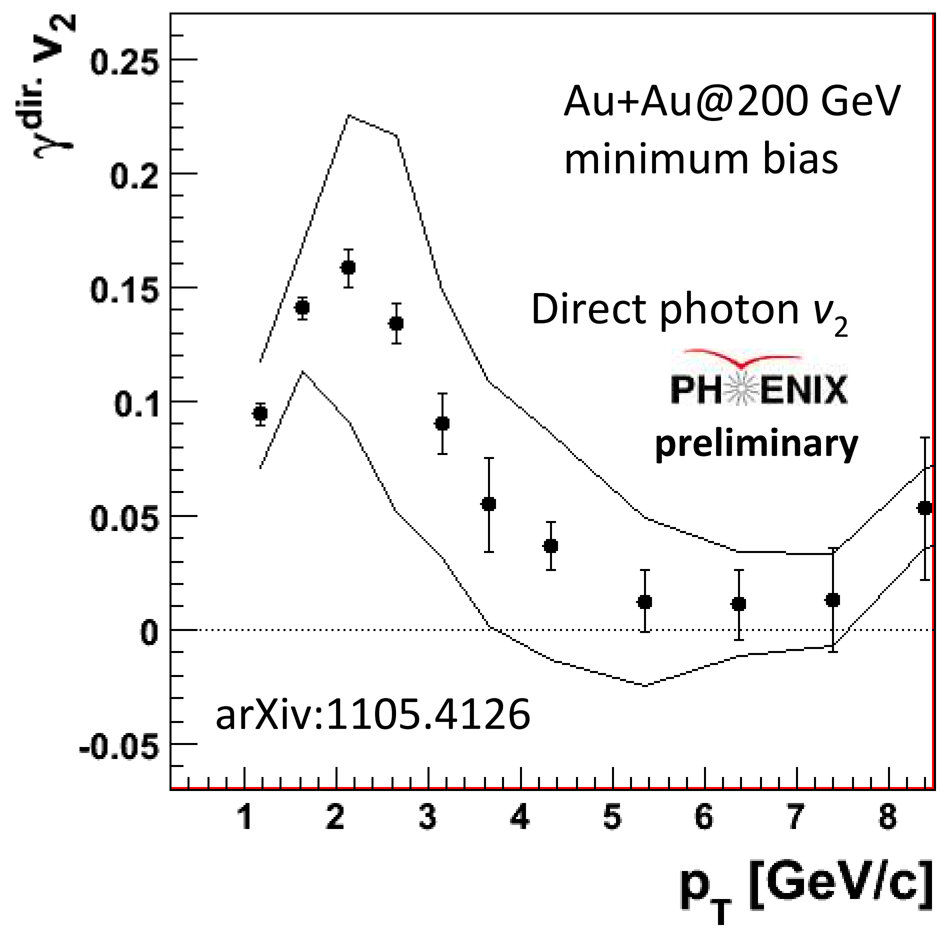
$$v_2^{dir.} = \frac{R_\gamma v_2^{inc.} - v_2^{BG}}{R_\gamma - 1}$$

Direct Photon v_2



- π^0 v_2 similar to inclusive photon v_2
- Two possibilities
  - A: there are no direct photons
  - B: direct photon v_2 similar to inclusive photon v_2
- Key: precise measurement of direct photon excess

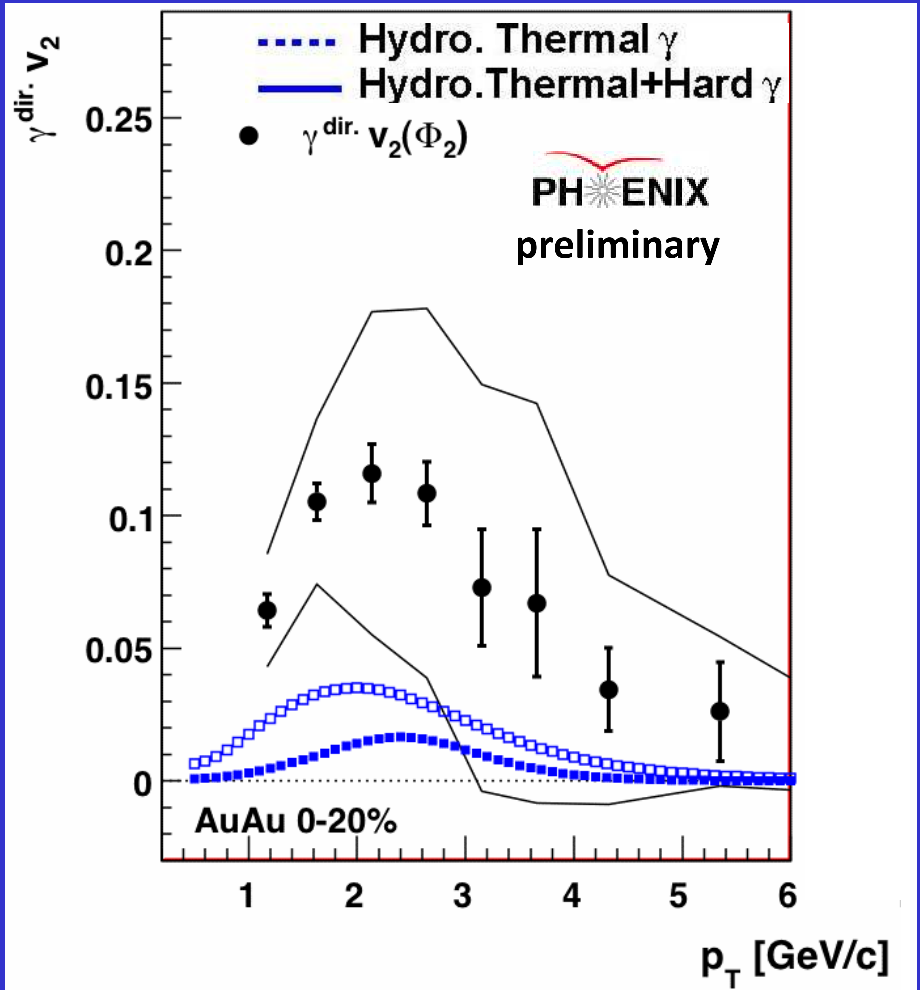
Direct Photon v_2



direct photon v_2 large (~15 %) at p_T =2.5 GeV

$v_2 \rightarrow 0$ where prompt photons dominate

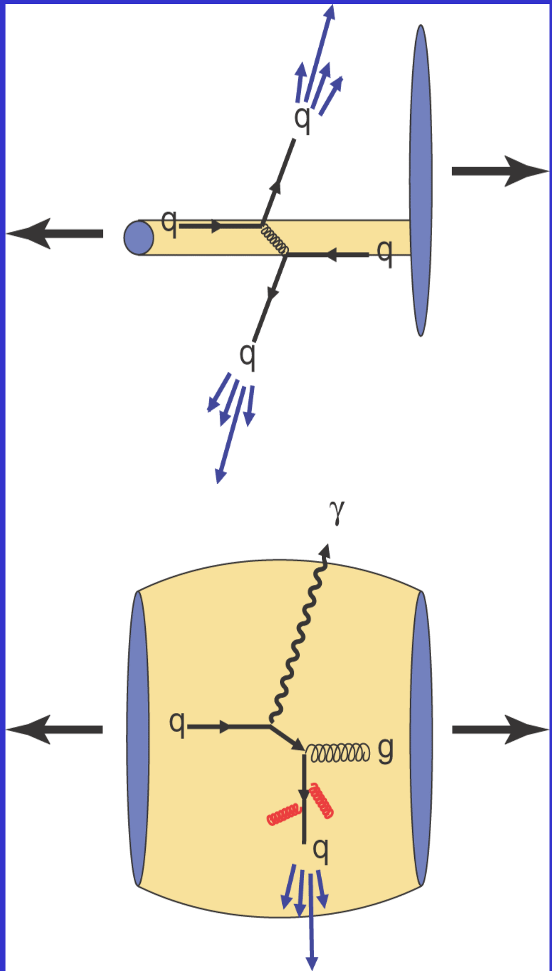
Theory Comparison: Direct Photon v_2



- Models under-predict direct photon v_2
- Measurement further constrains T_i and τ_i
- Challenge to theorists

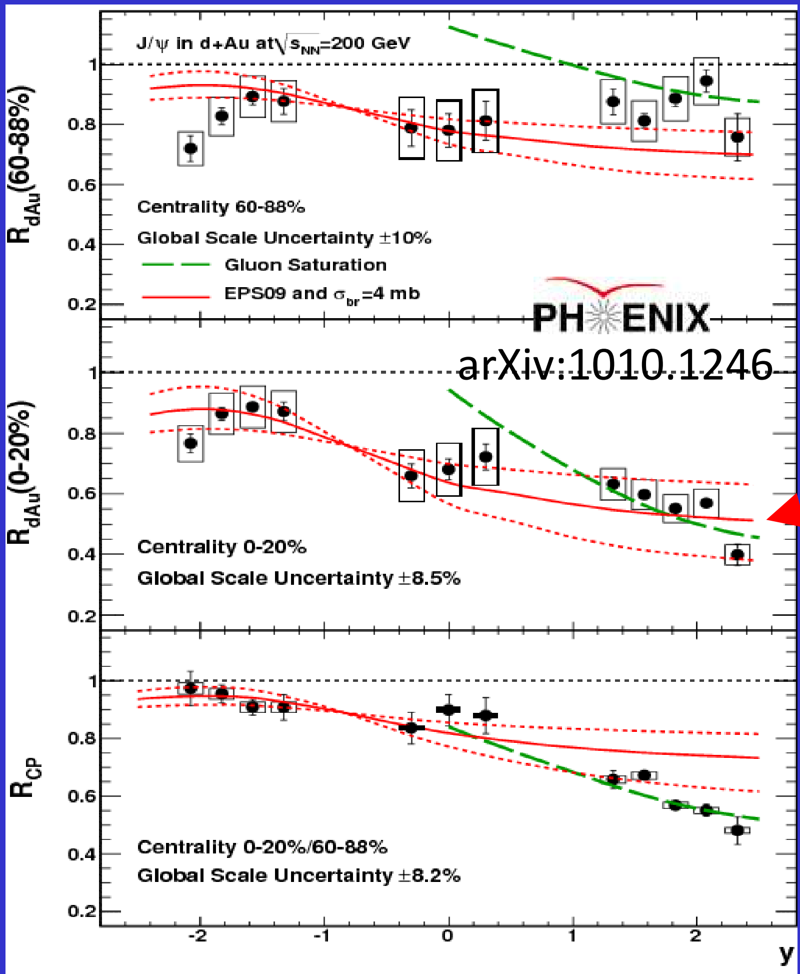
Theory calculation:
Holopainen, Räsänen, Eskola
arXiv:1104.5371v1

Cold Nuclear Matter Effects



- Important for interpretation of HI data
  - Measure Cold Nuclear Matter (CNM) effects in d+Au collisions
- RHIC versatile
  - Can collide any nuclear species on any other

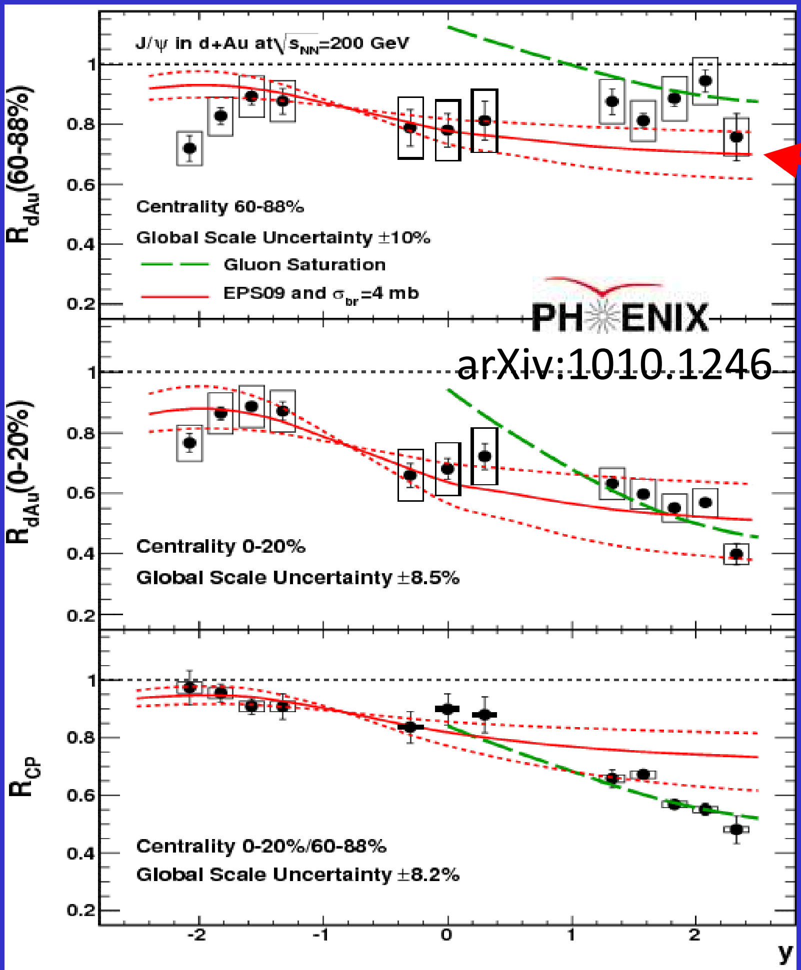
J/ψ in *d*+Au: Shadowing non-linear



Theory calculations: Eskola, Paukkunen, Salgado, JHEP04, 065
Vogt, PRC71, 054902
Kharzeev , Tuchin, NPA770, 40
Kharzeev ,Tuchin, NPA735, 248

- EPS09 shadowing with linear dependence on nuclear thickness matches for central collisions

J/ψ in *d*+Au: Shadowing non-linear



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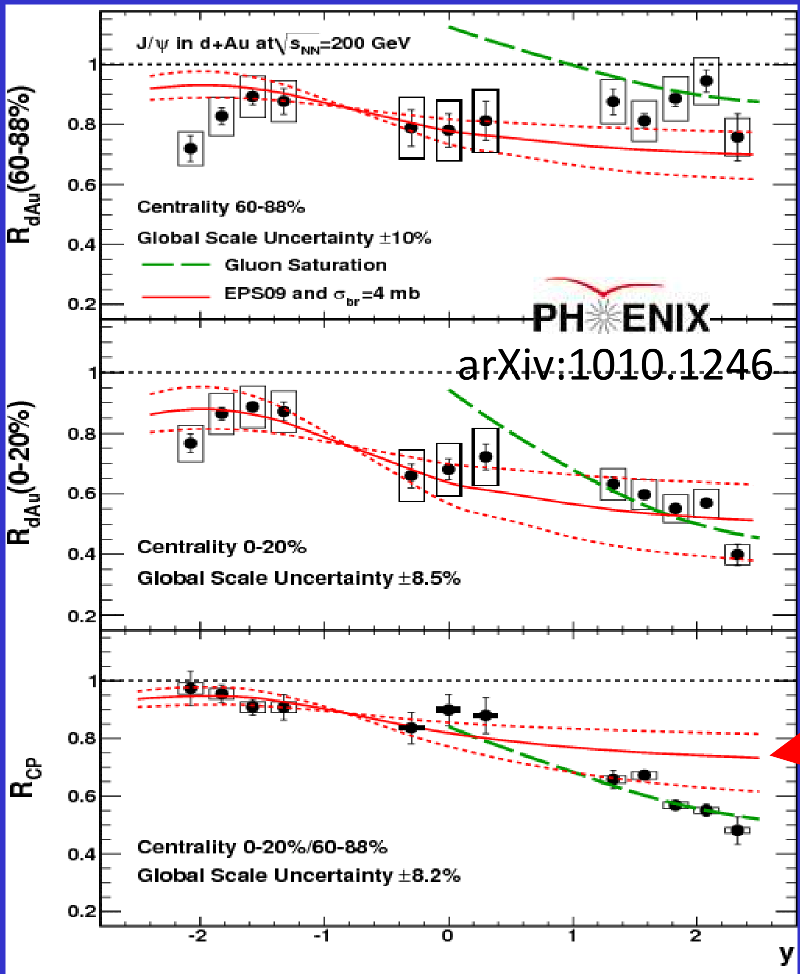
- EPS09 shadowing with linear dependence on nuclear thickness matches for central collisions

J/ψ in *d*+Au: Shadowing non-linear



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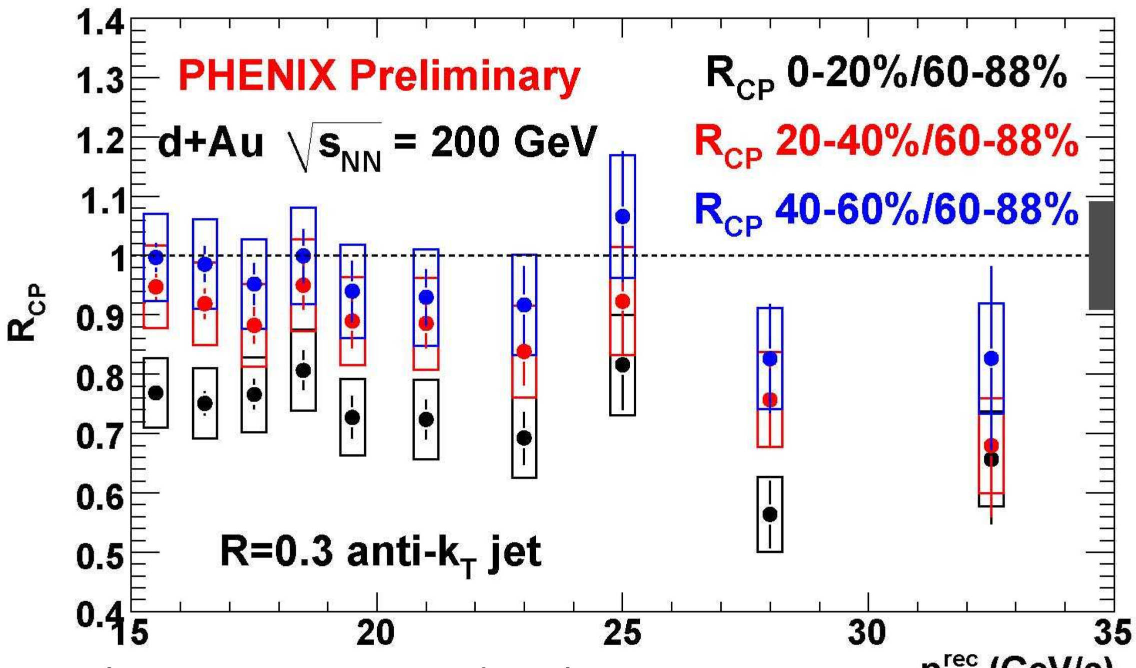
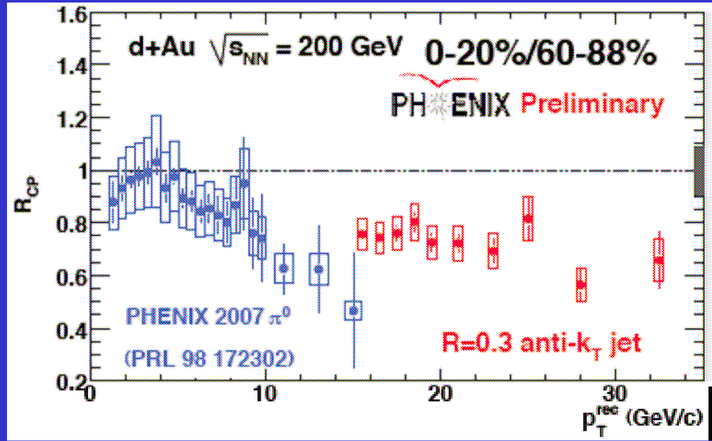
- Overpredicts suppression for peripheral collisions
- EPS09 shadowing with linear dependence on nuclear thickness matches for central collisions
- R_{CP} shows this clearly

→ Thickness (impact parameter) dependence of shadowing is non-linear!

Reconstructed Jets in *d*+Au

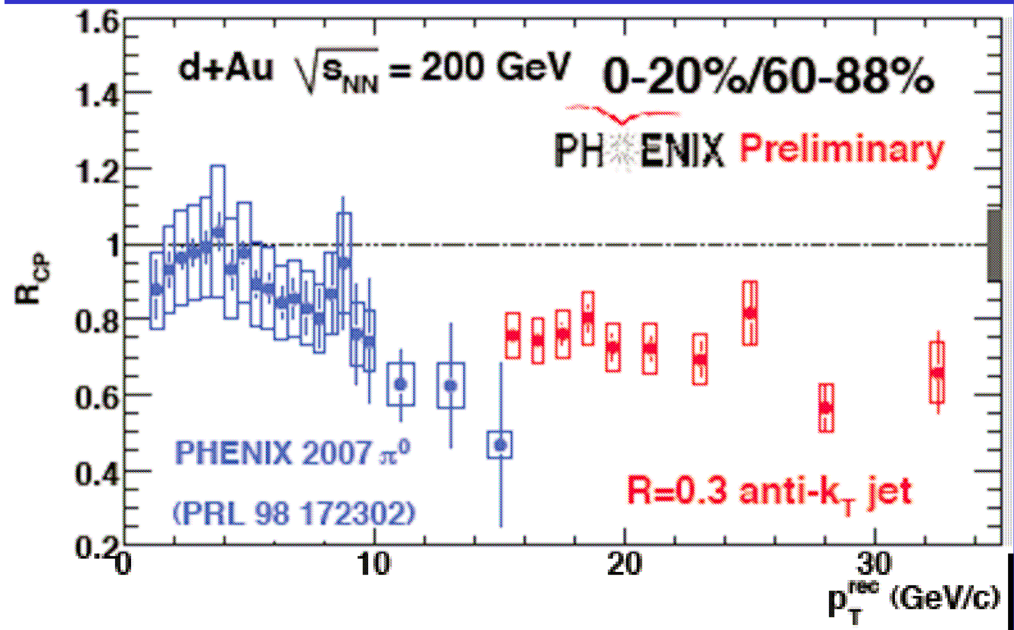


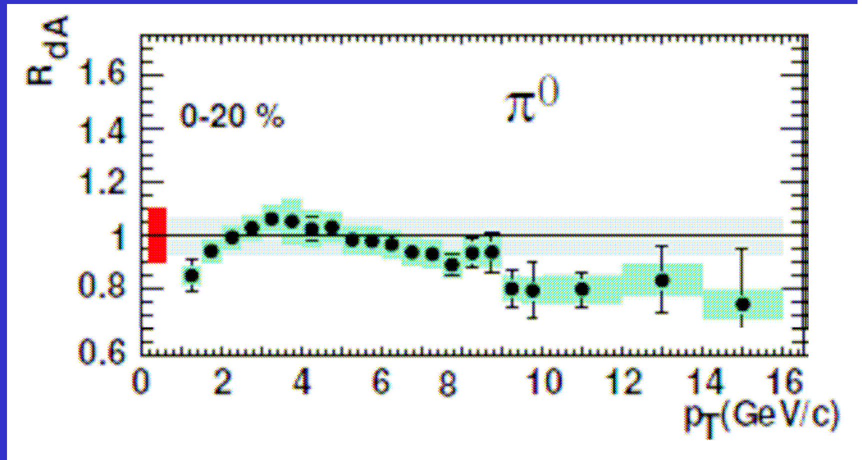
at the p+p uncorrected scale



Jet R_{cp} in central *d*+Au modified
- caution: this is not R_{dA}!
- consistent with π^0 R_{cp}

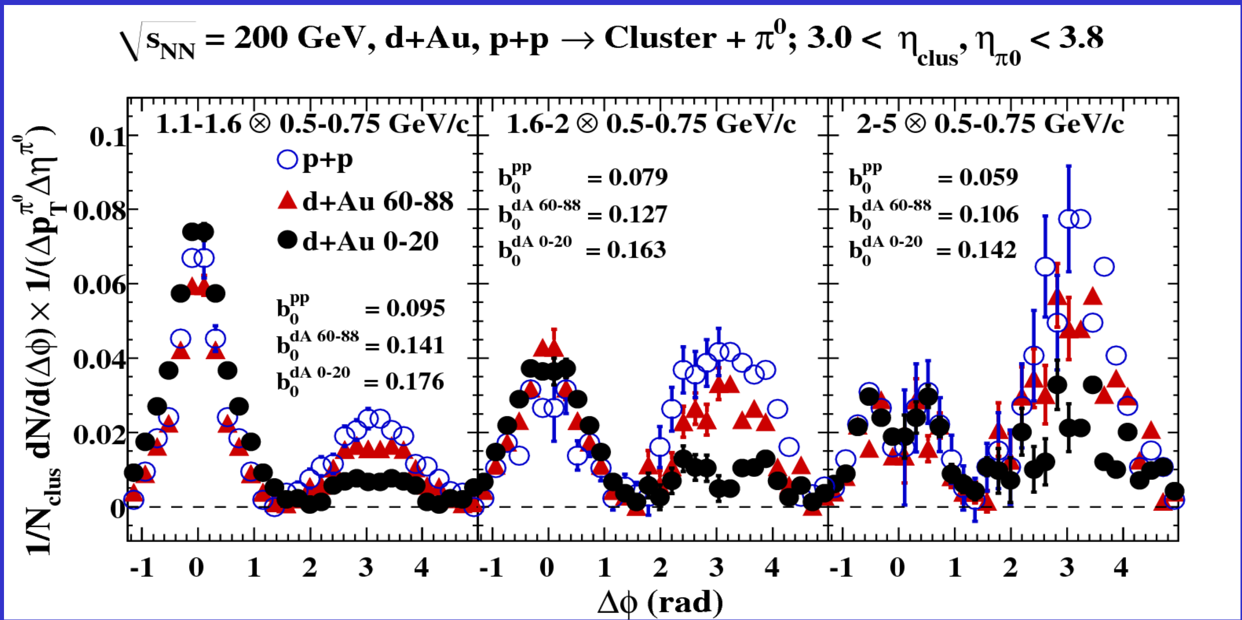
Reconstructed Jets in *d*+Au

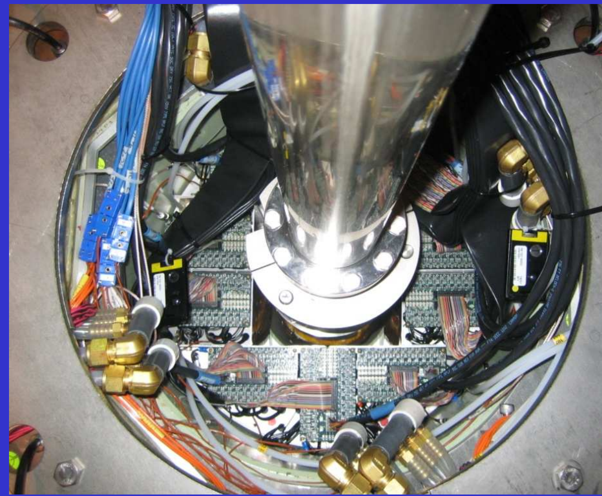




Jet R_{cp} in central *d*+Au modified
- caution: this is not R_{dA}!
- consistent with π^0 R_{cp}
- *Jet R_{cp} in central d+Au looks compatible with π^0 R_{AA}*

Forward di-hadron correlations





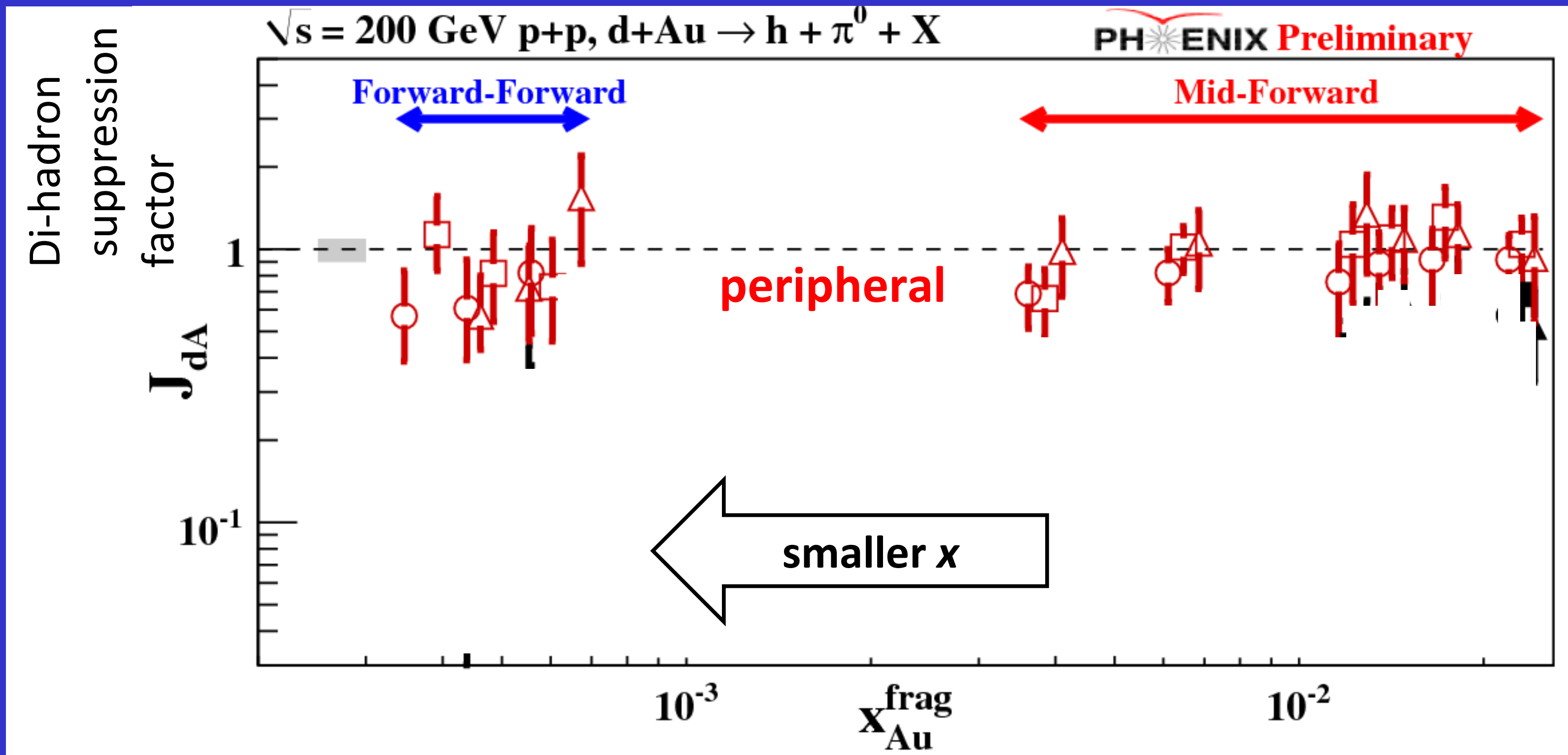
new forward EM calorimeter $|\eta_{Mpc}| = 3.1\text{-}3.8$

Pocket formula:

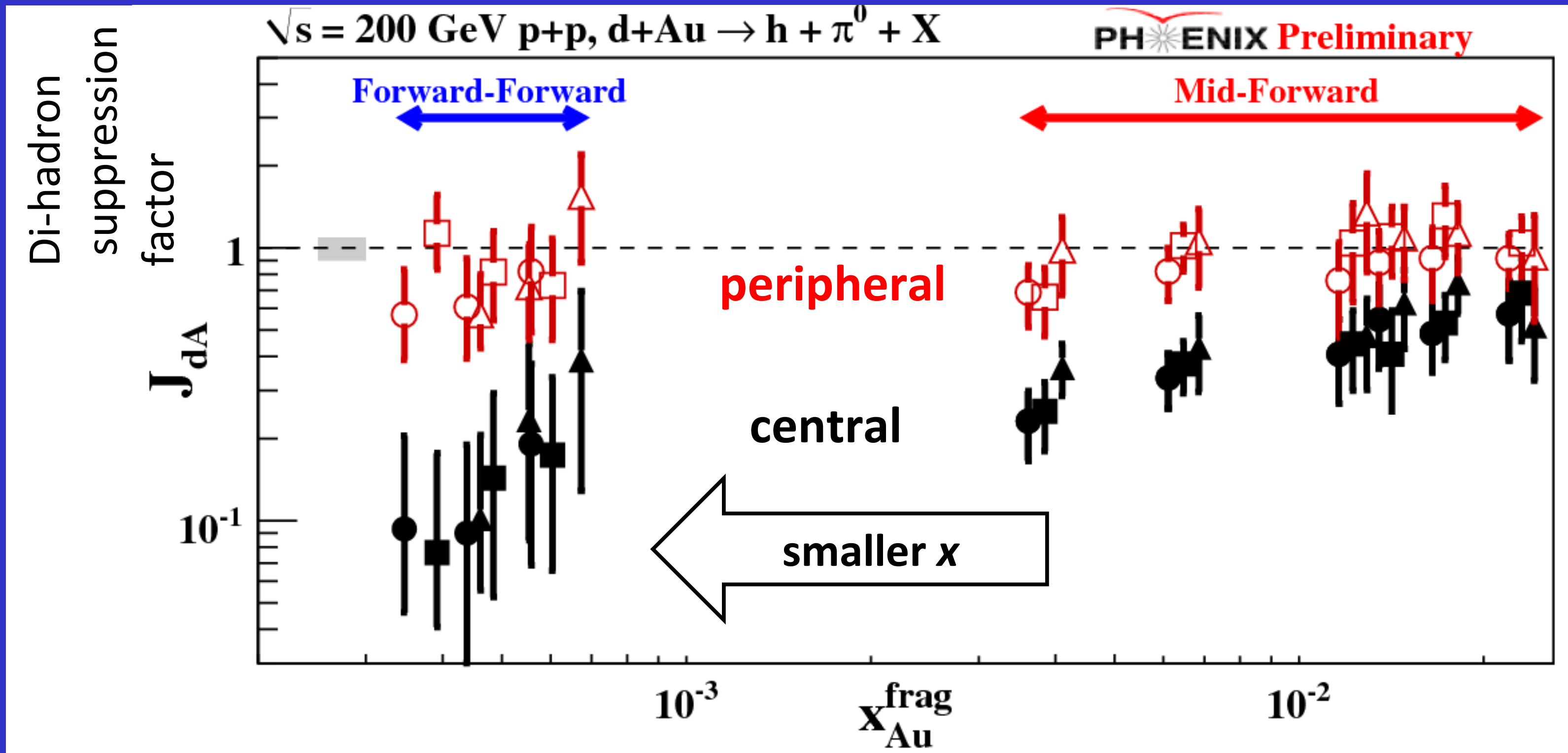
$$x_{Au}^{frag} = \frac{< p_{T1} > e^{-<\eta_1>} + < p_{T2} > e^{-<\eta_2>}}{\sqrt{s}}$$

$$J_{dA} = \frac{1}{\langle N_{coll} \rangle} \frac{\sigma_{dA}^{pair} / \sigma_{dA}}{\sigma_{pp}^{pair} / \sigma_{pp}}$$

Initial state low-x gluon suppression

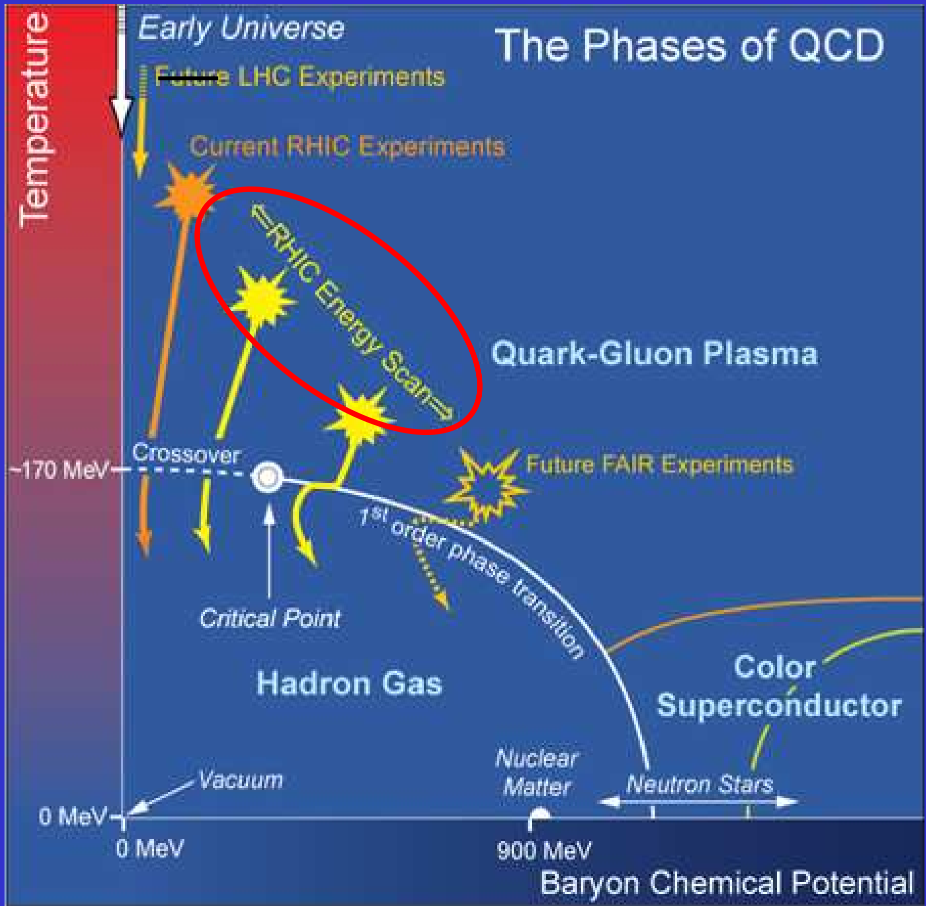


Initial state low-x gluon suppression



- Di-hadrons suppressed at low *x*

Beam Energy Scan

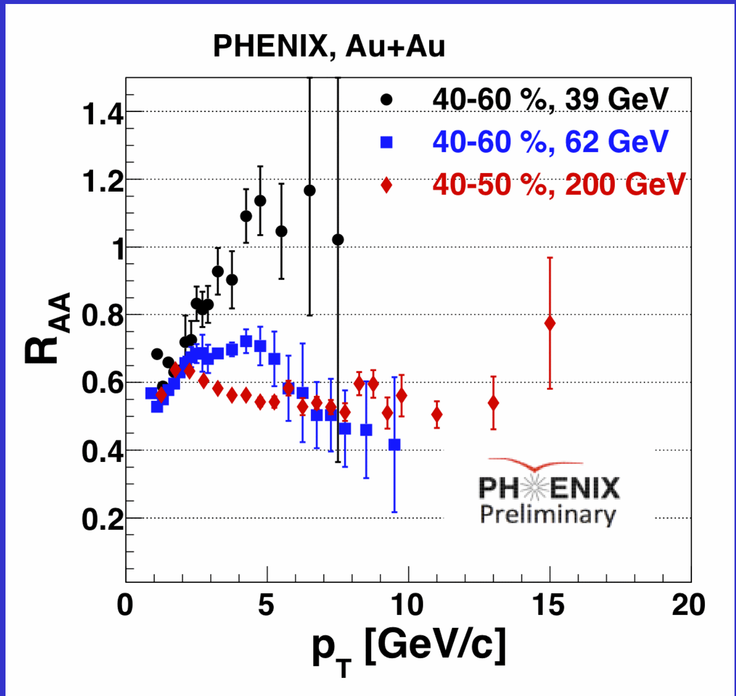


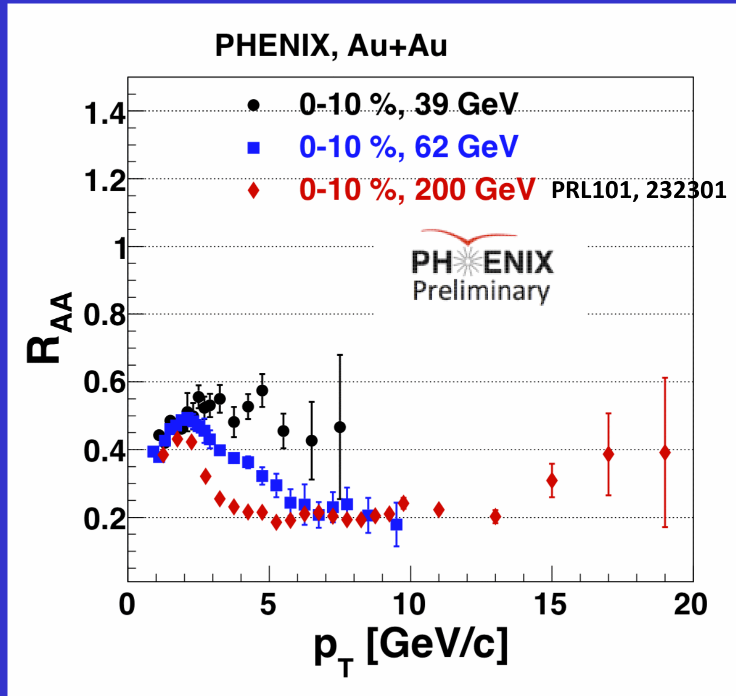
A central goal in experimental nuclear physics is to map out the QCD phase diagram.

RHIC experiments at beam energy 200GeV showed that QGP is created and cools down to hadron gas via crossover transition.

RHIC is versatile: AuAu Collisions from 7.7 GeV to 200 GeV, 5GeV planned

R_{AA} in Au+Au at 39, 62 and 200 GeV





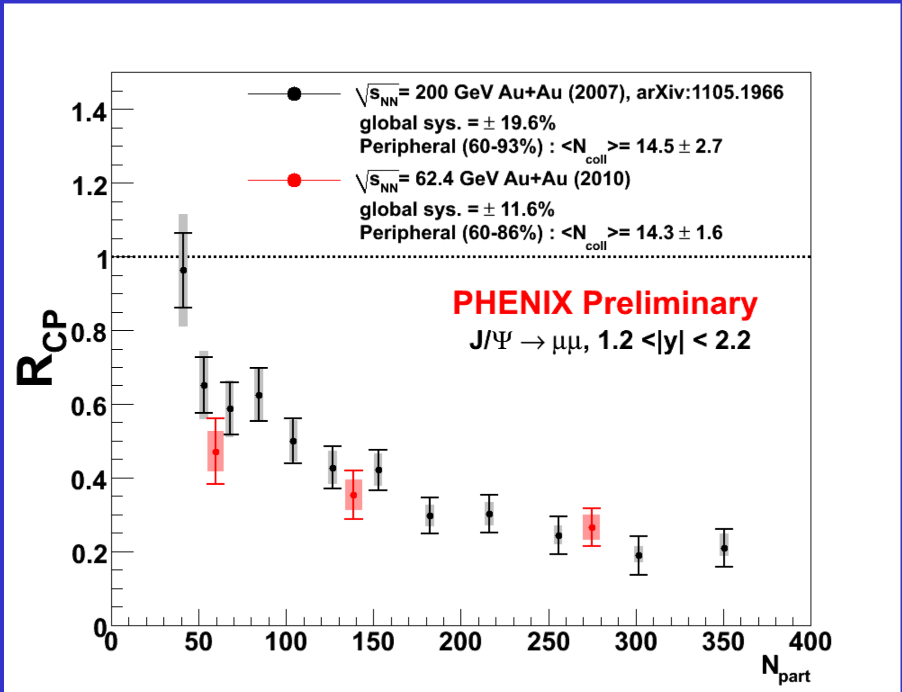
R_{AA} suppressed in central collisions also at 39 GeV

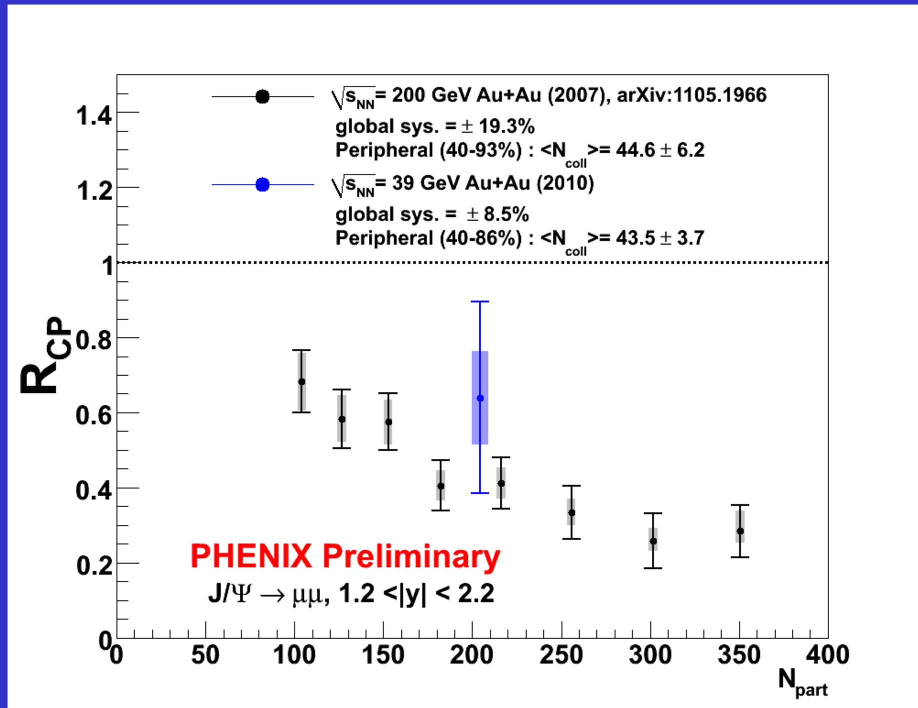
R_{AA} at 62 GeV approaches 200 GeV level at high p_T

But: 39 GeV pp reference from Tevatron E706

62 GeV pp reference from PHENIX but extrapolated for p_t > 6GeV/c

Energy dependence of J/ψ R_{CP}





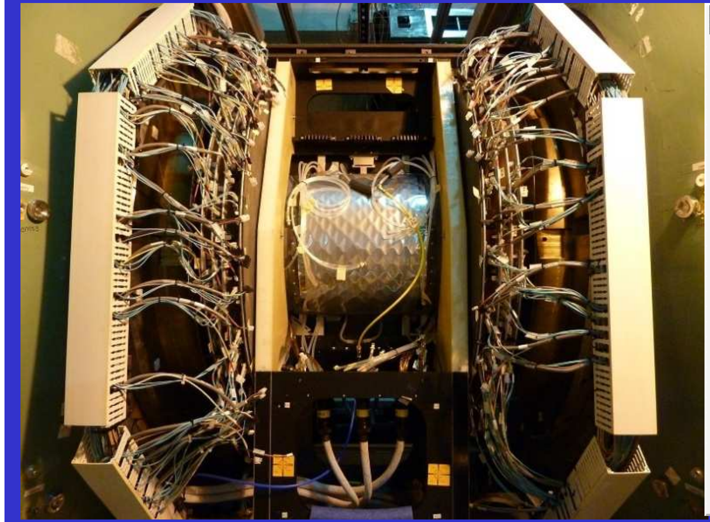
- PHENIX doesn't have a p+p reference at 62 and 39 GeV
- Suppression is of similar level within uncertainties

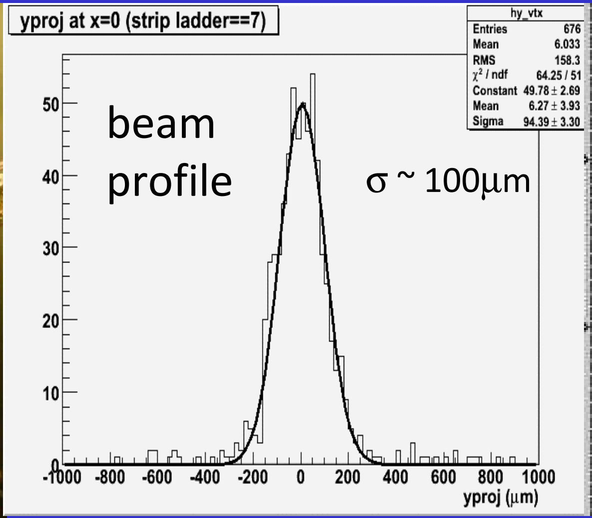
Near-Term Future: Silicon Vertex Detector

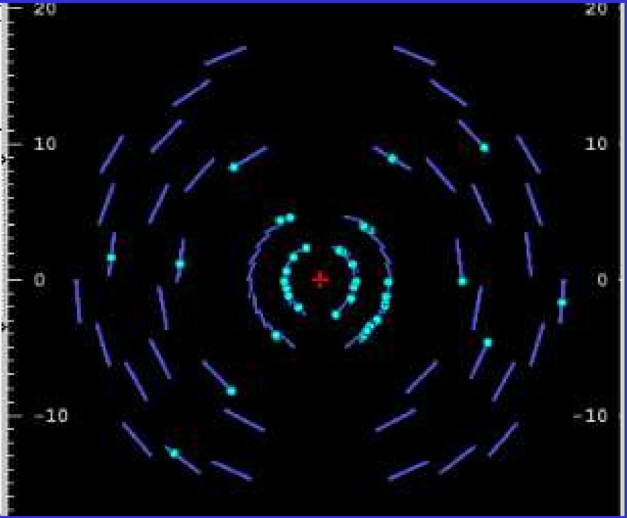
Status

- VTX successfully commissioned in 2011 *p+p* run
- VTX taken data in Au+Au

Data: p+p@500 GeV, 2011







Physics

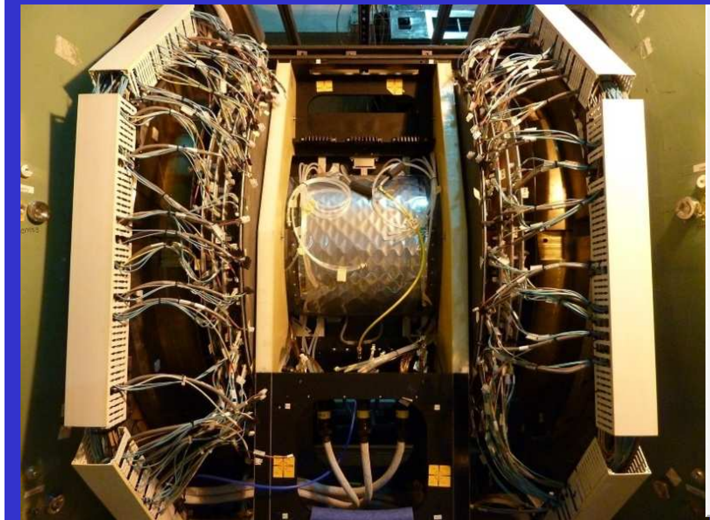
- R_{AA} of *c*, *b* separately
- v_2 of *c*, *b* separately
- Jet tomography (di-hadron, γ-*h*, *c*-*h*, c-$\bar{c}$)

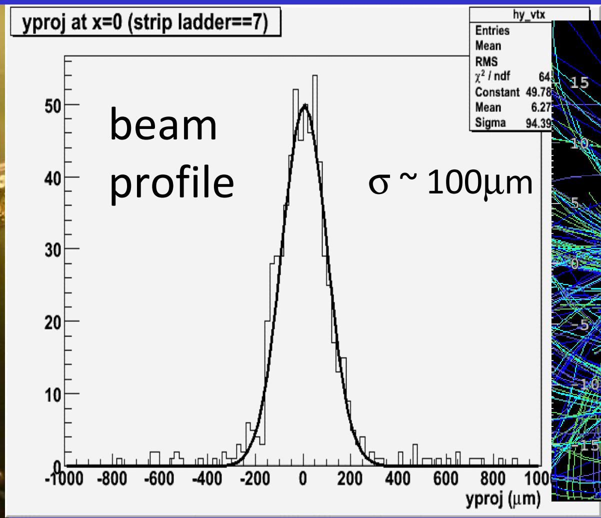
Near-Term Future: Silicon Vertex Detector

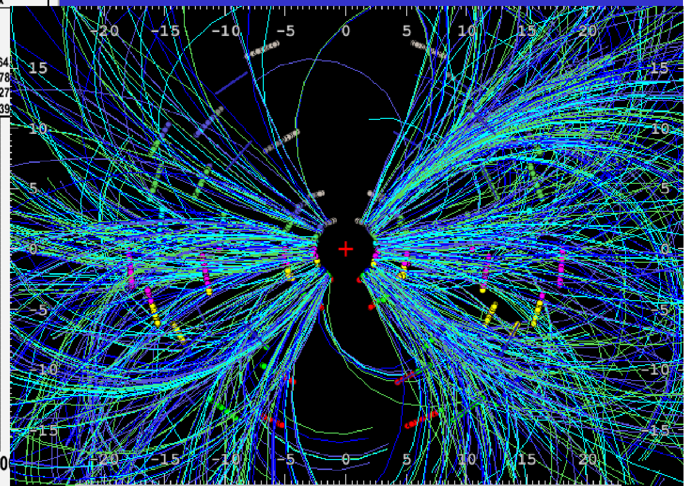
Status

- VTX successfully commissioned in 2011 *p*+*p* run
- VTX taken data in Au+Au

Data: Au+Au@200 GeV, 2011



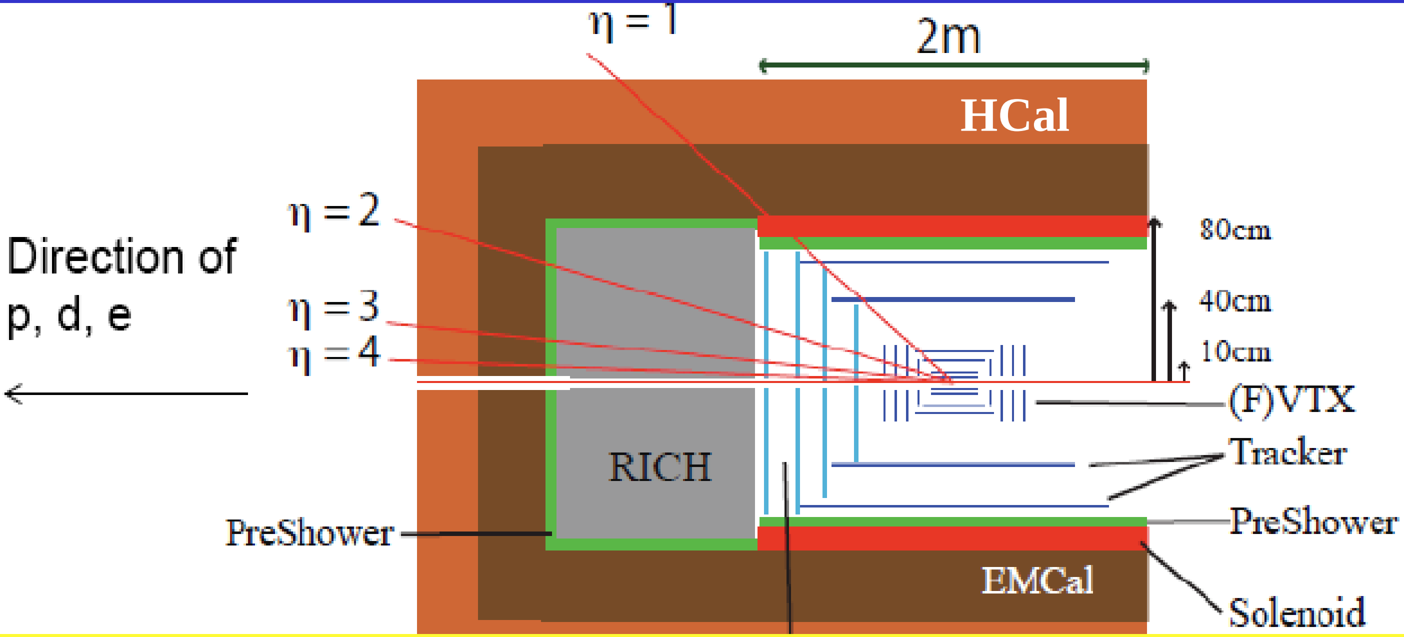




Physics

- R_{AA} of *c*, *b* separately
- v_2 of *c*, *b* separately
- Jet tomography (di-hadron, γ-*h*, *c*-*h*, *c*-$\bar{c}$)

Long-Term Upgrade Concept

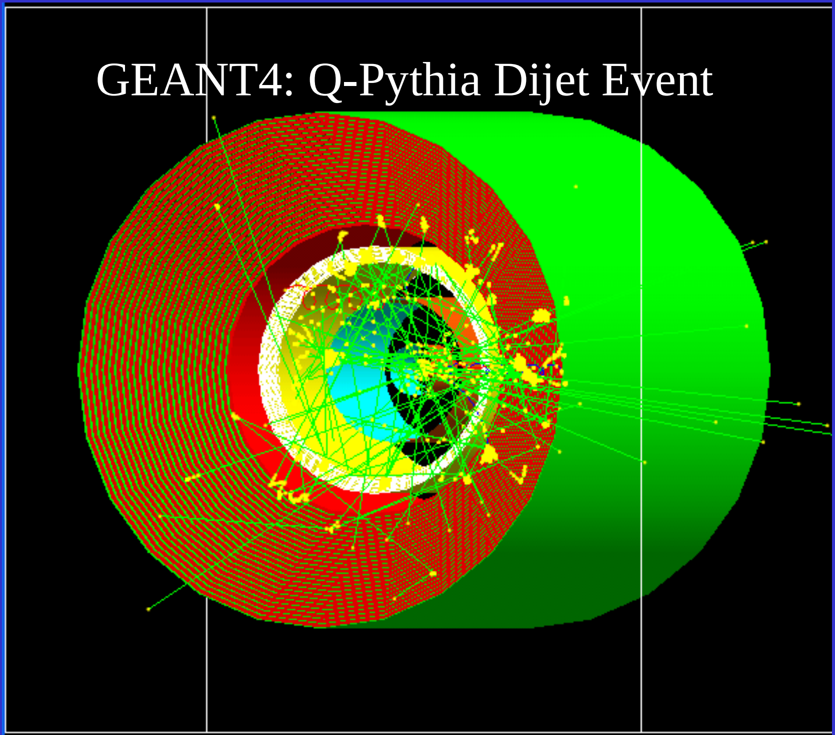


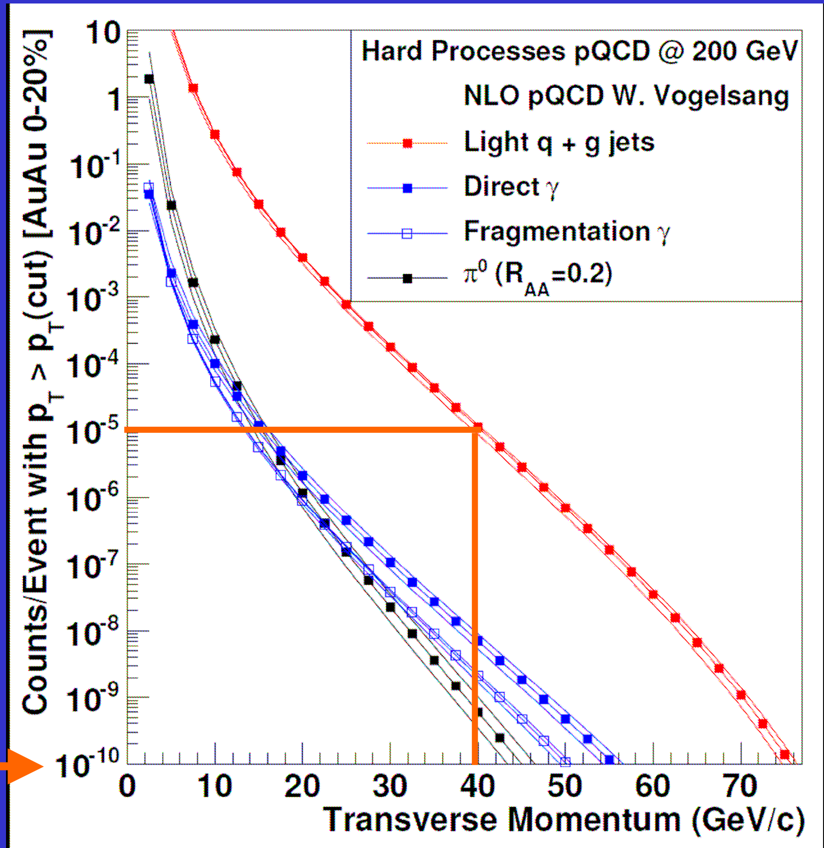
Focused on capabilities to answer compelling questions
Don't try to do everything

- Compact detector covering $-1 < \eta < 4$
- Measure jets, electrons and photons in mid-rapidity → Measure QGP properties
- Gluon saturation physics at forward region ($\eta > 1$)
- First eRHIC detector (not yet optimized)

Future PHENIX (Super-PHENIX, sPhenix, Sphnx..?)

Coverage 2π, $\Delta\eta = \pm 1$
Build on existing vtx, fvtx
RHIC II Luminosity 50 bio events/year sampled
Hi speed daq (25bio events/year on tape)





1 Evt/a

→ 10^5 Evts/a with Jets $p_t > 40$GeV/c

Future PHENIX (Super-PHENIX, sPhenix, Sphnx..?)

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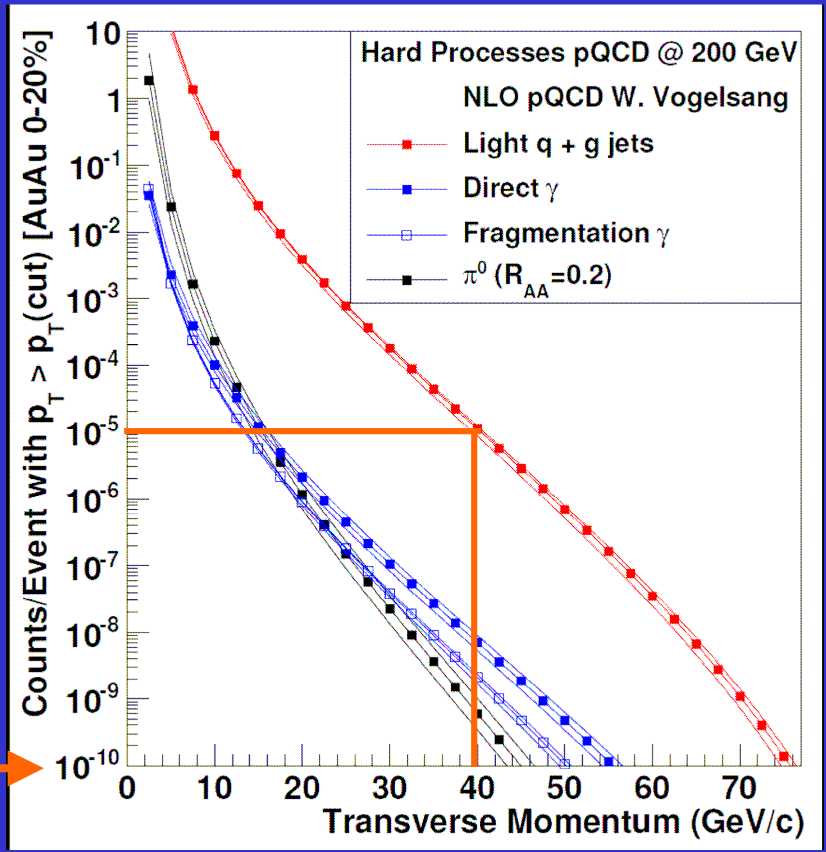
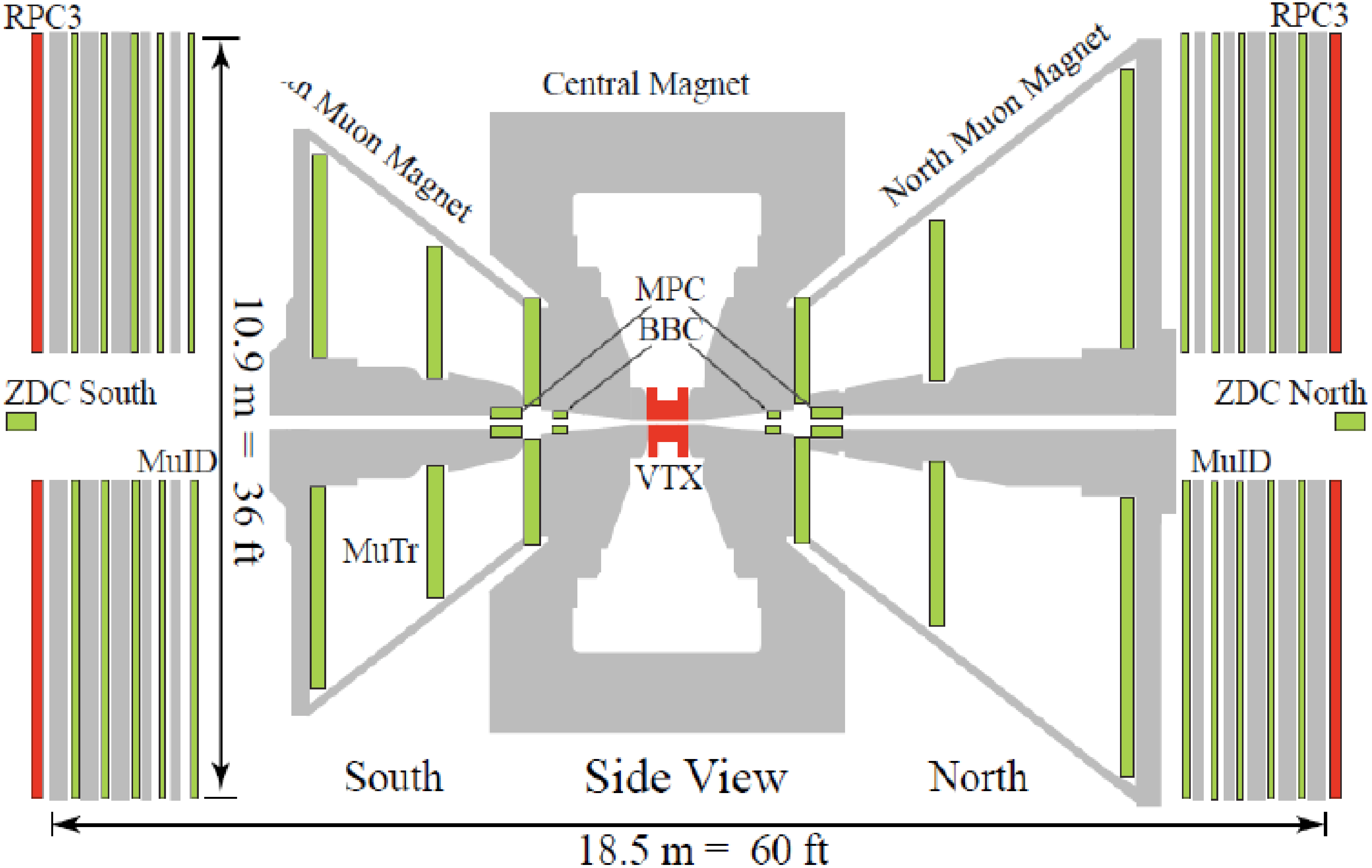


1 Evt/a

→10^5 Evts/a with Jets p_t> 40GeV/c

PHENIX → sPHENIX



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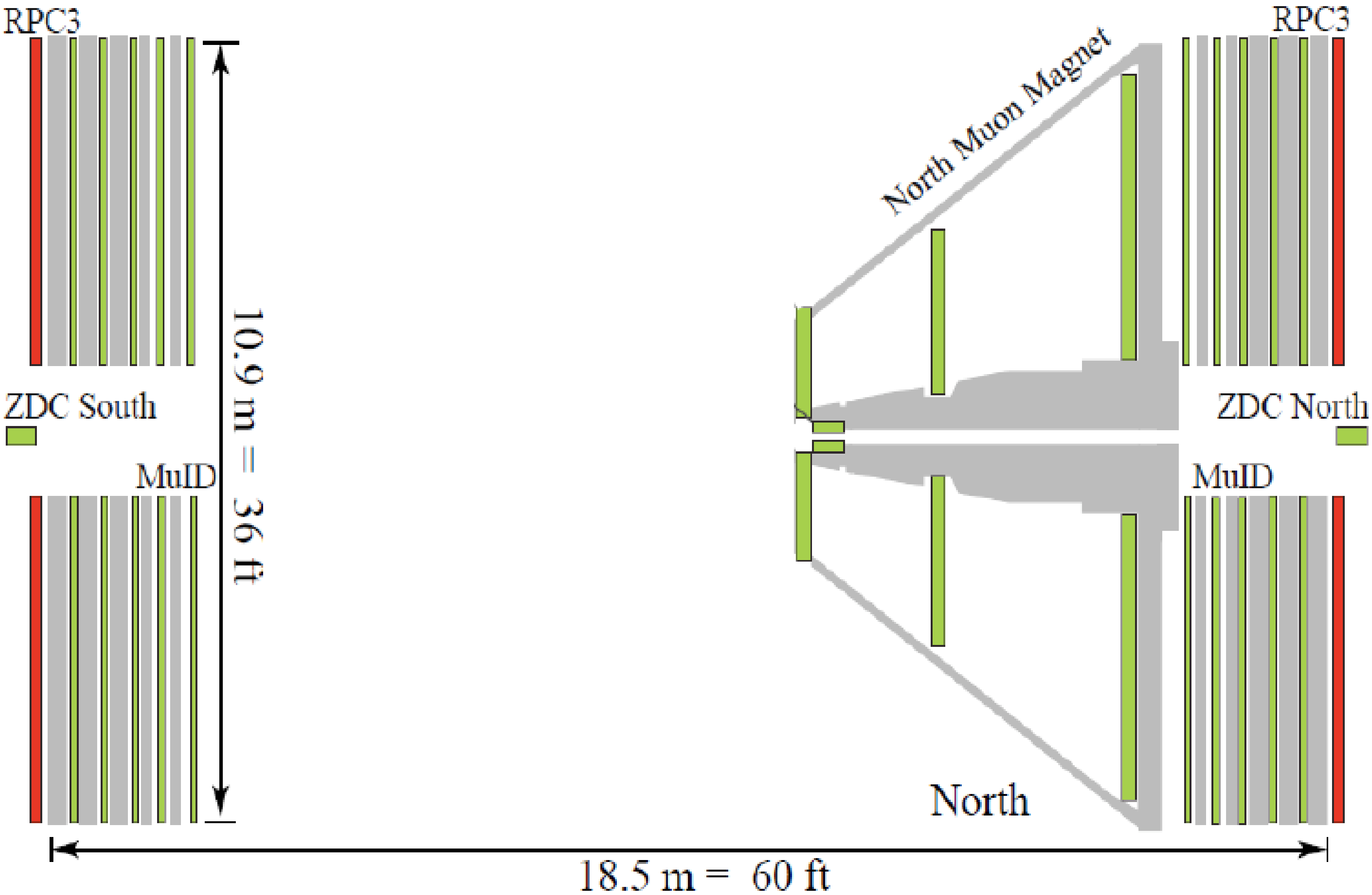
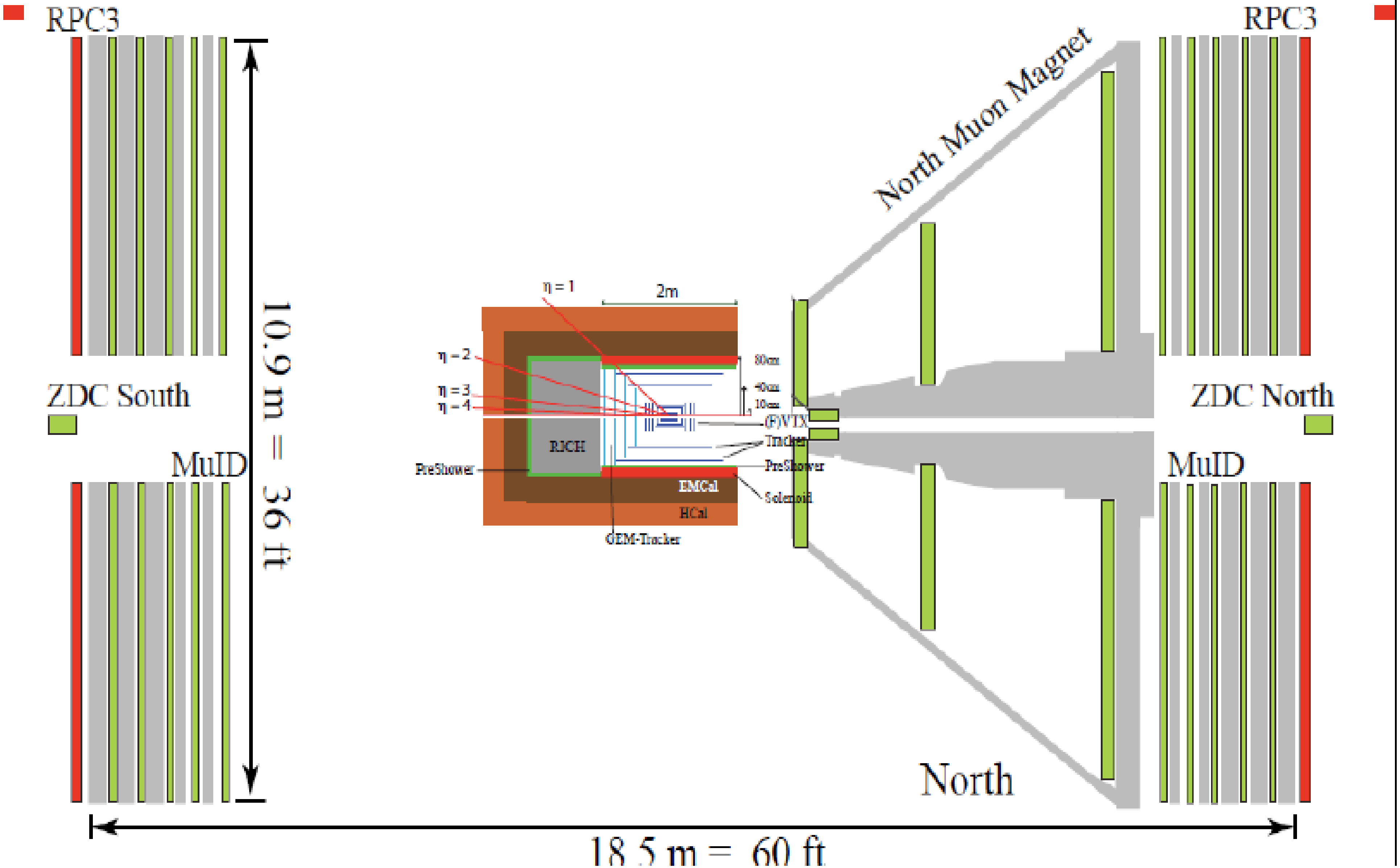


PHENIX → sPHENIX



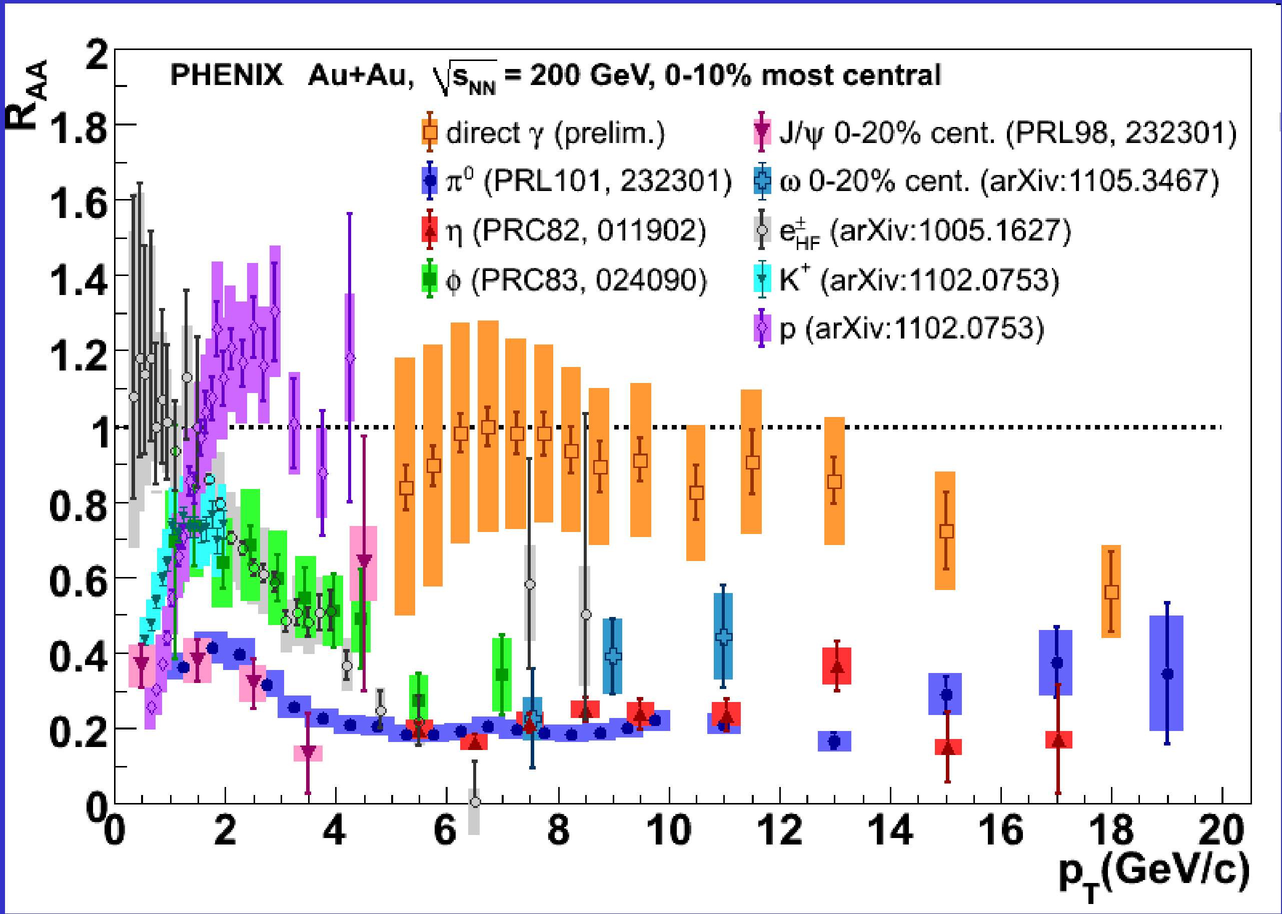
Conclusions

- v_2 of thermal direct photons **large**
  - Further constrains T_i and τ_0
- CNM effects in *d*+Au
  - **Non-linear** density dependence of shadowing from J/ψ
  - **Reconstructed jet** R_{cp} modified
  - **Low-*x* suppression** from forward di-hadron correlations
- Energy Scan
  - $\boldsymbol{R_{AA}}$ **suppressed** also at 39 GeV in central collision

- *No mentioning of Flow from PHENIX: That subject is covered in Robert Paks talk later today*

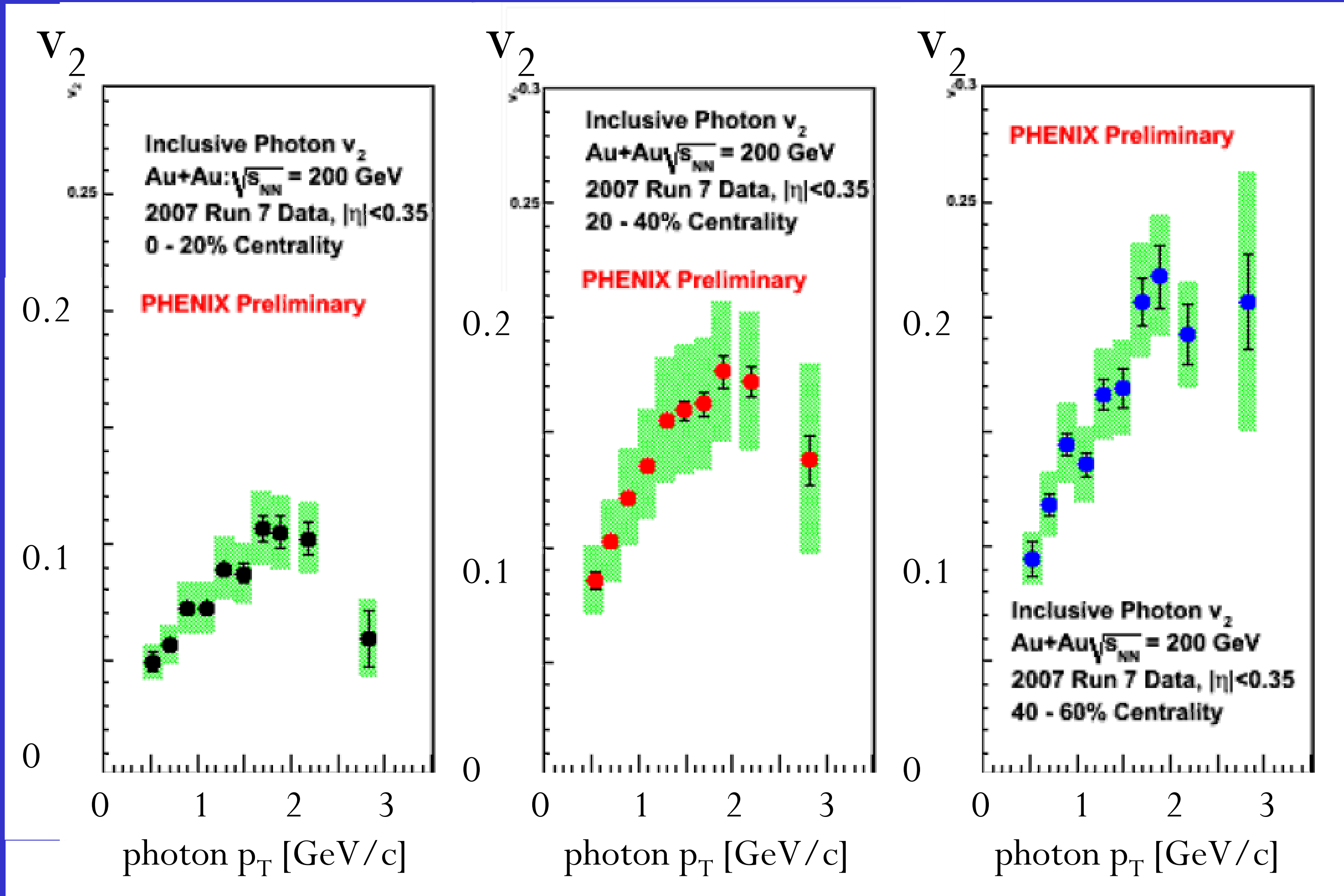
Backup

R_{AA} in AuAu at 200GeV



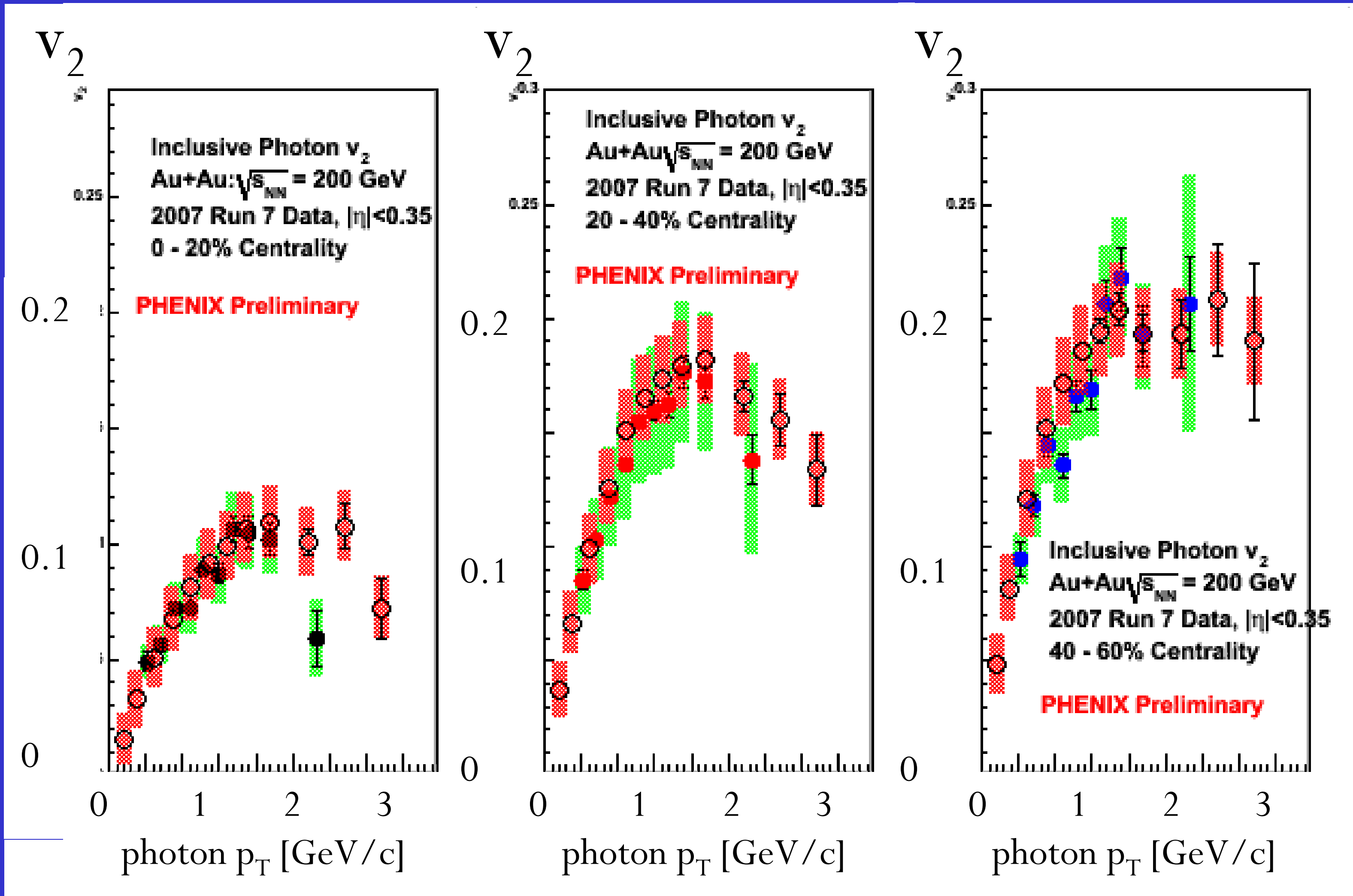
A wide variety of PHENIX measurements available for Theory comparison

Inclusive Photon v_2 with External Conversions



- Different method – use external converter to measure photons

Inclusive Photon v_2 with External Conversions



- Compare to PRL. 96, 032302 (2006) in the open symbols

What’s next?

- are quarks strongly coupled to the QGP at all distance scales?
- what are the detailed mechanisms for parton-QGP interactions and responses?
- are there quasiparticles at any scale?
- is there a relevant screening length in the QGP?
- how is rapid equilibration achieved?