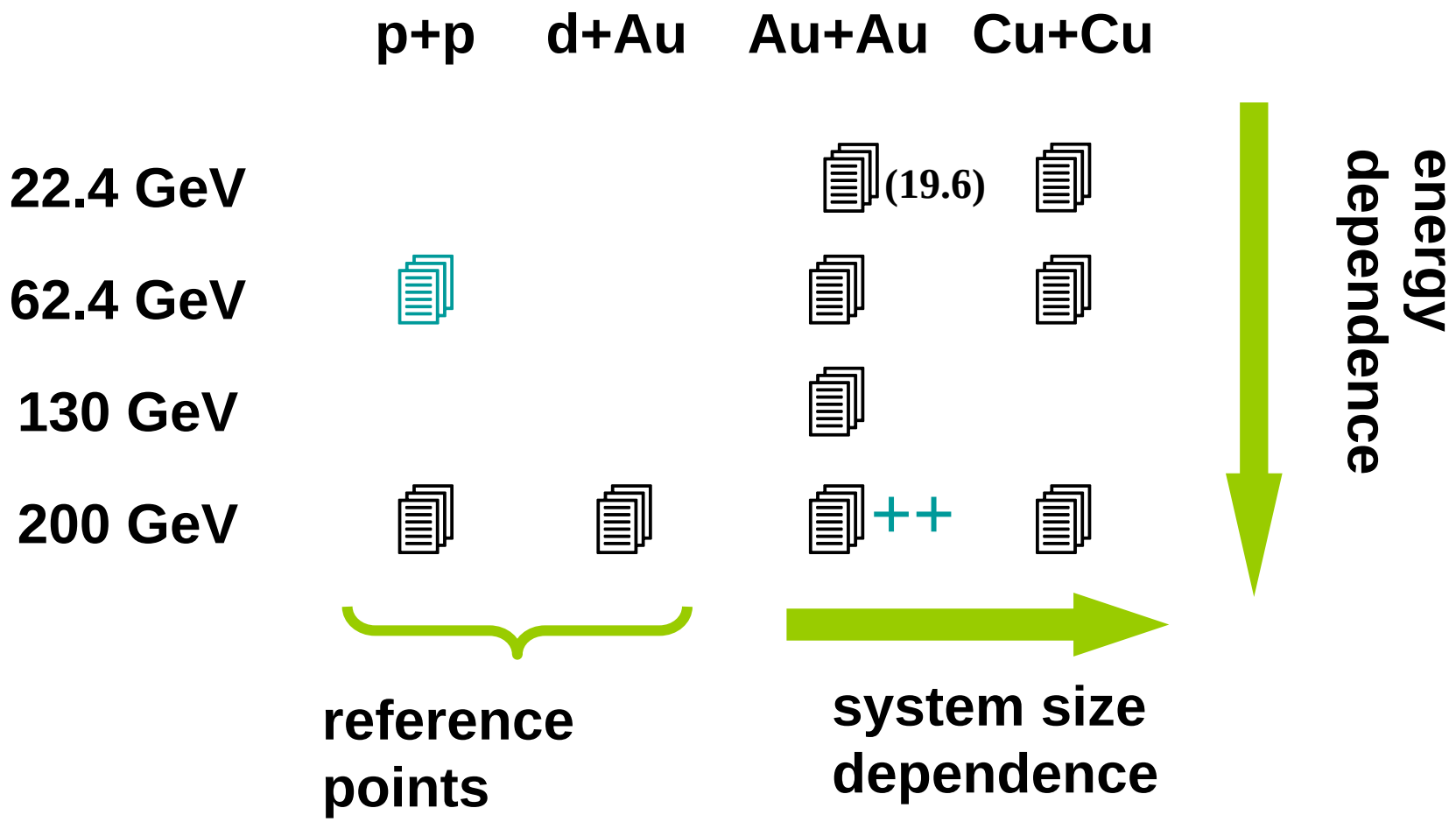
New results from PHENIX on energy loss and direct photons

Zimanyi Memorial Workshop
July 2-4, 2007 – Budapest

G. David, BNL

Reminder: PHENIX data sets



Upgrades, new possibilities

High p_T π^0-s in Au+Au – birds-eye view

Run-1, 130GeV Au+Au:

- First observation of large π^0 suppression above 2GeV (PRL **88**, (2002))
  ("world data" interpolation as reference)

Run-2, 200GeV Au+Au:

- spectra up to 14GeV, suppression is constant (pQCD reference)

Run-4, 200GeV Au+Au + Run-3 p+p

- spectra up to 18GeV, suppression is constant (measured reference)

Run-4, 62GeV Au+Au

- "fast track analysis", smaller suppression than at 200GeV
  ("world data fit" as reference)

Run-5, 200GeV Cu+Cu and p+p:

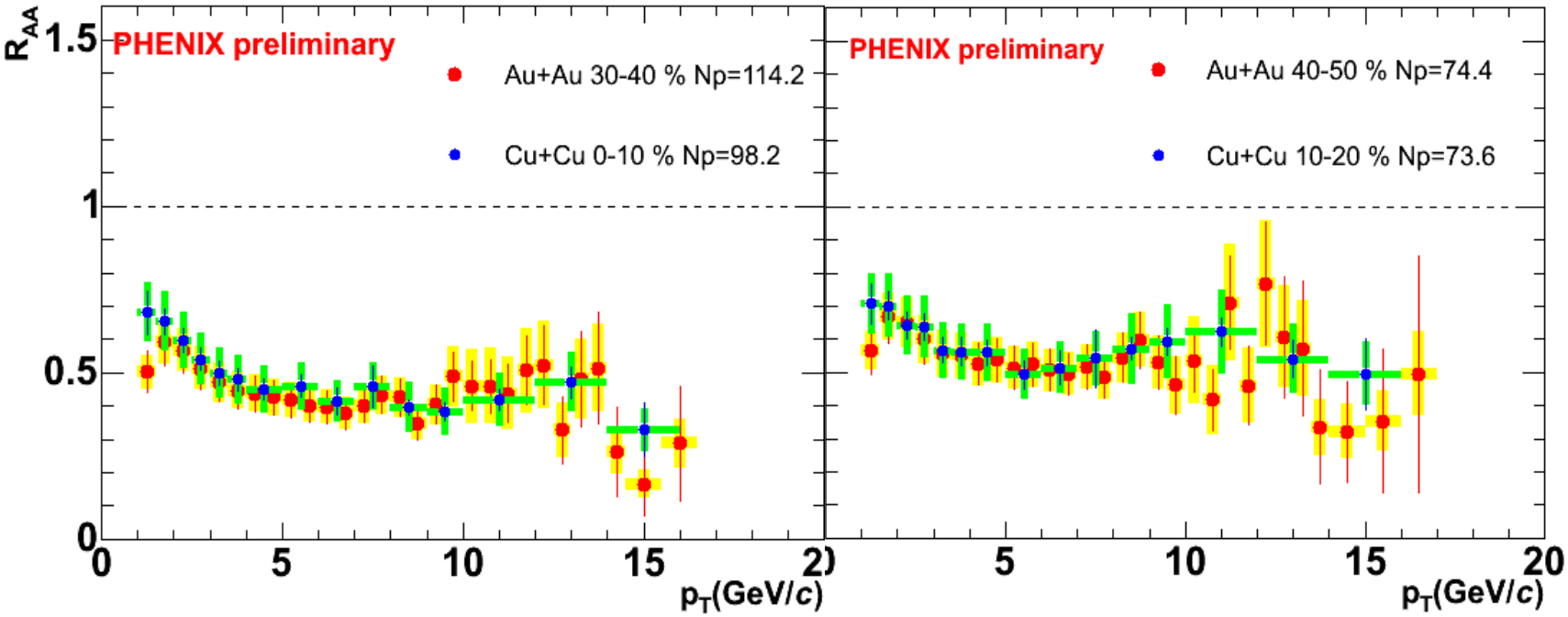
- suppression commensurate to 200GeV Au+Au at similar N_{part}

Run-4, 62GeV Au+Au R_{AA} revisited (Au+Au data points are the same!)

- suppression very similar to 200GeV if measured p+p is used as ref.

π^0 in 200GeV Au+Au and Cu+Cu

Suppression pattern similar for comparable N_{part}
(despite very different geometry – limitations of ϕ-integrated measurements)

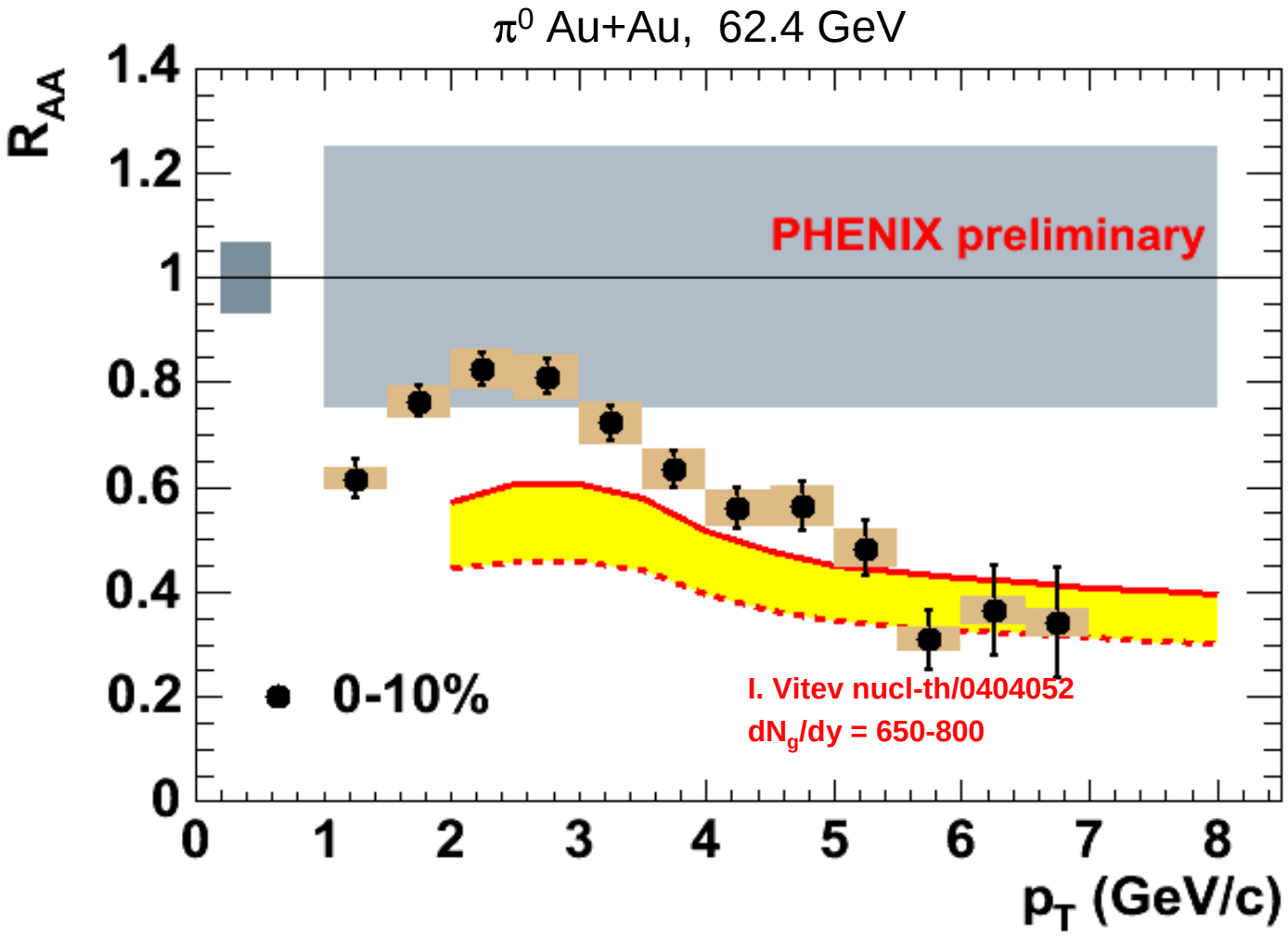


π^0 R_{AA} in Au+Au and Cu+Cu

Compare this to…

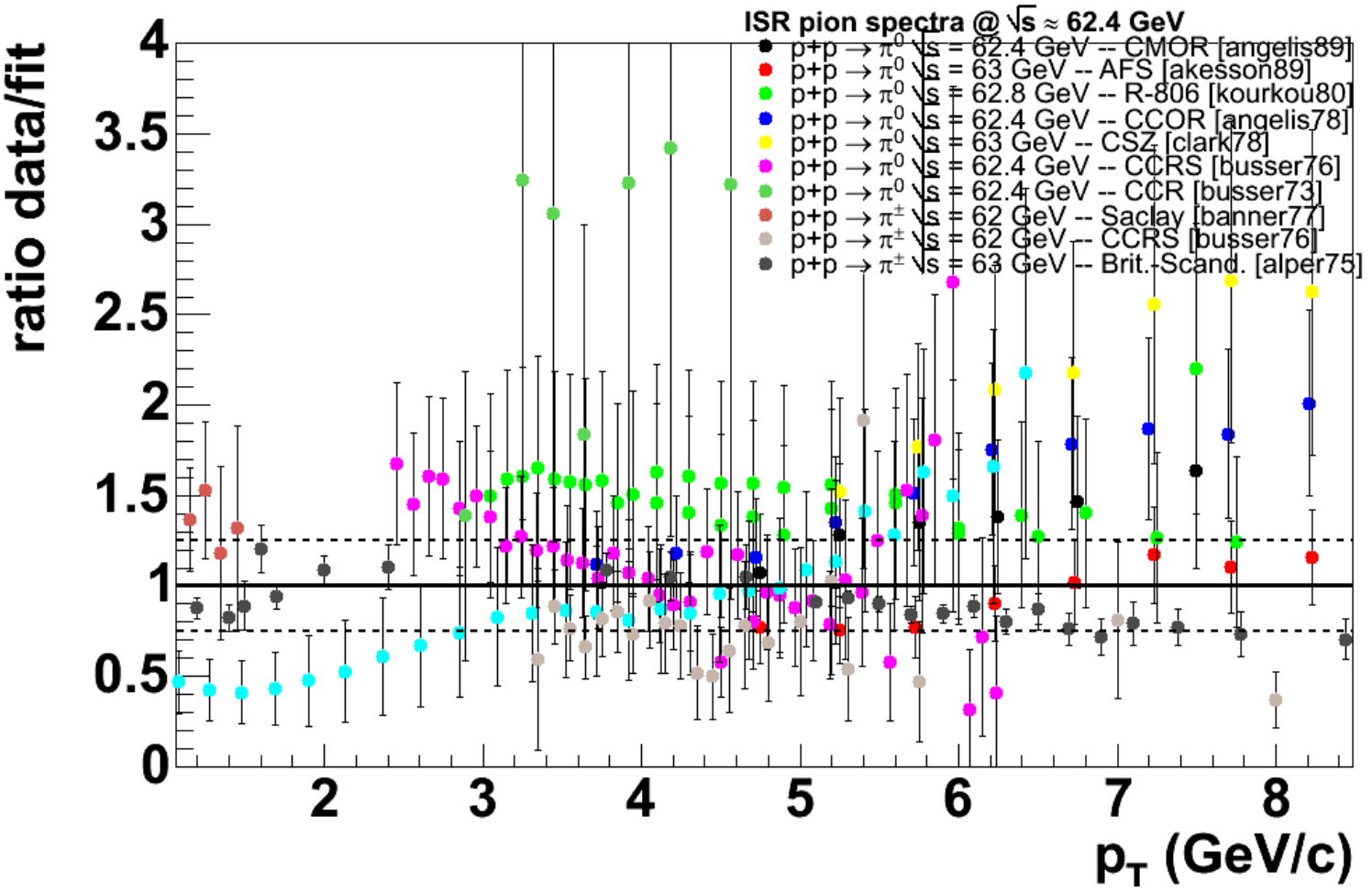
π^0 R_{AA} in 62GeV Au+Au – world data reference used

"Fast track analysis", 2 months after data taking



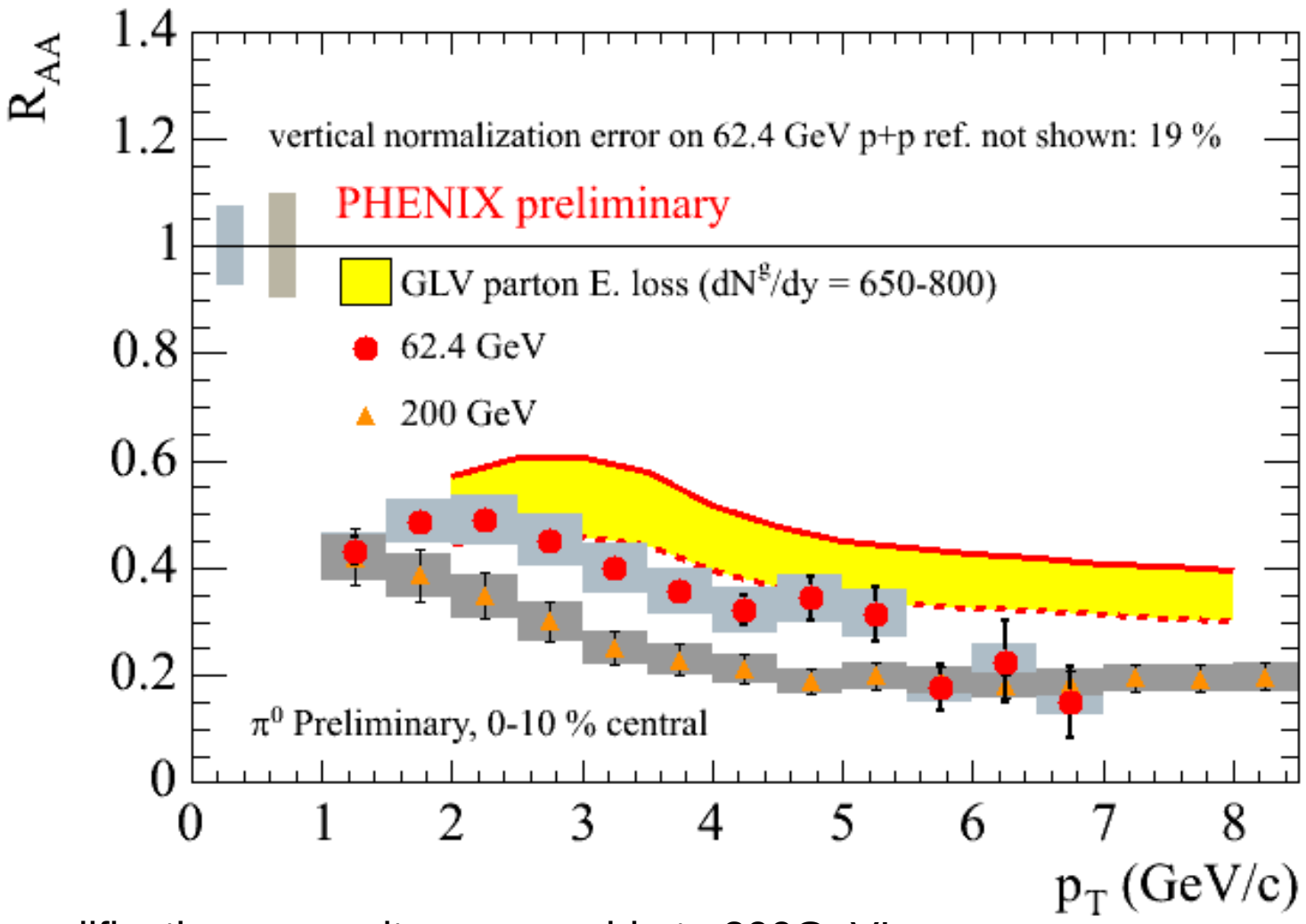
Suppression even in the most central collisions appears to be significantly smaller than at 200 Gev! (Note: but Cronin not observed, not even in d+Au)

π^0 at 62GeV p+p – world data reference



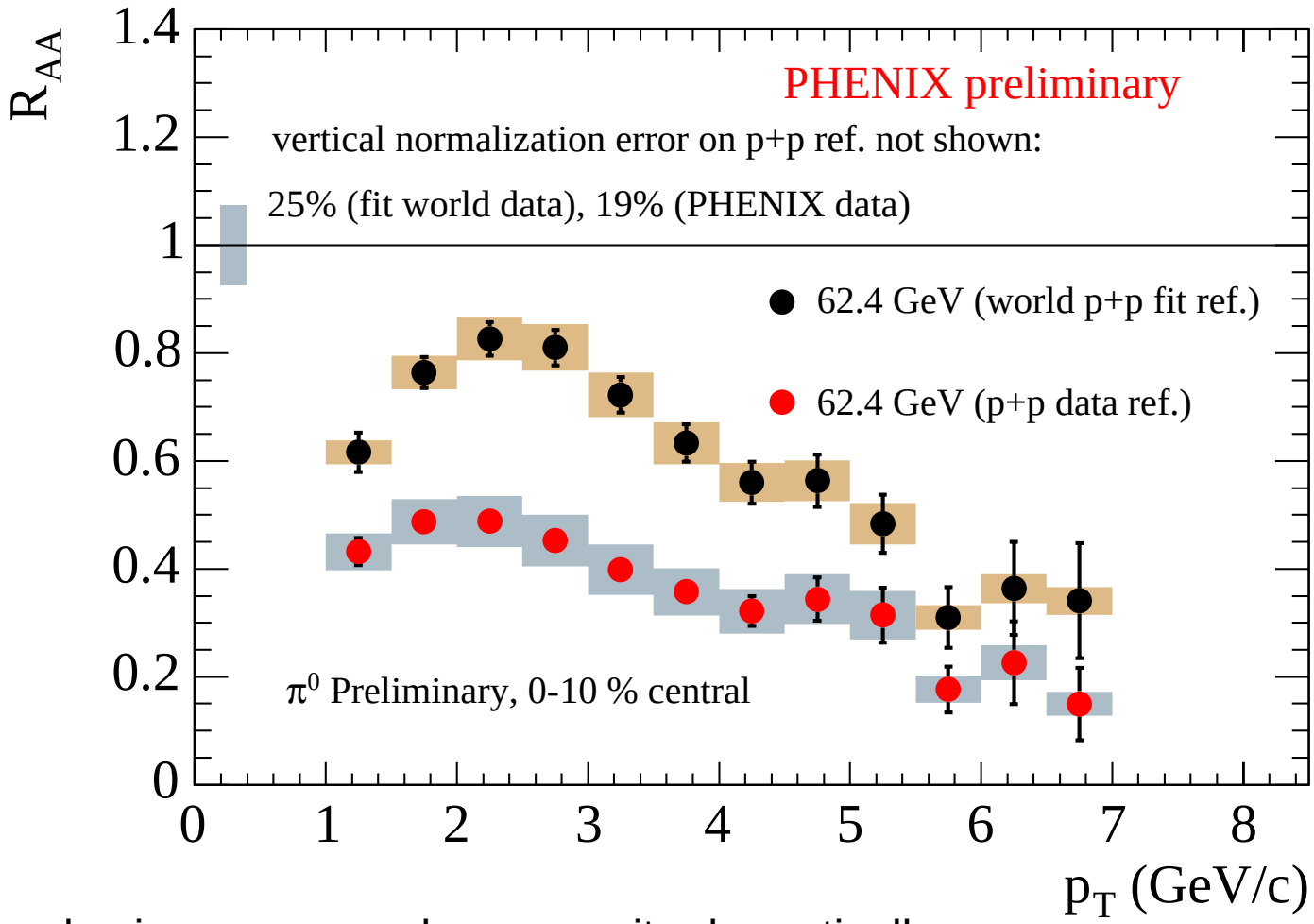
π^0 R_{AA} in 62GeV Au+Au – measured reference used

NEW



Nuclear modification now quite comparable to 200GeV!
(the medium is almost the same(?))

π^0 R_{AA} in 62GeV Au+Au – world data *vs* PHENIX data

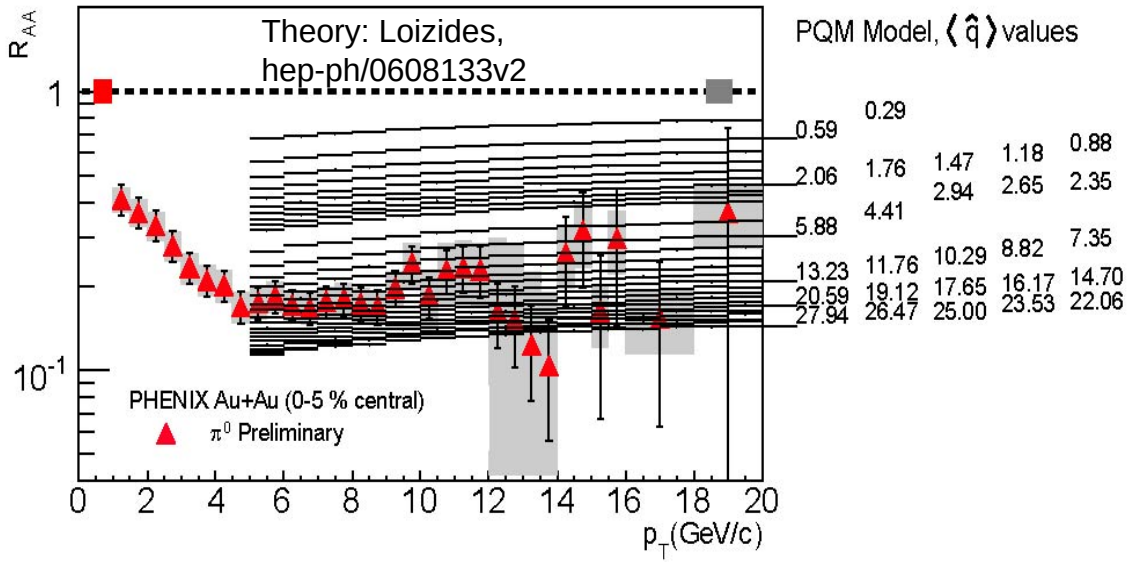


The physics message changes quite dramatically
(paranoid question: ***who is right*** ???)

Same experiment, same acceptance, many systematic errors the same!

What do we want to learn from this – and what precision is needed? / 1

Using π^0 R_{AA} in 200GeV Au+Au to constrain parameters in theories

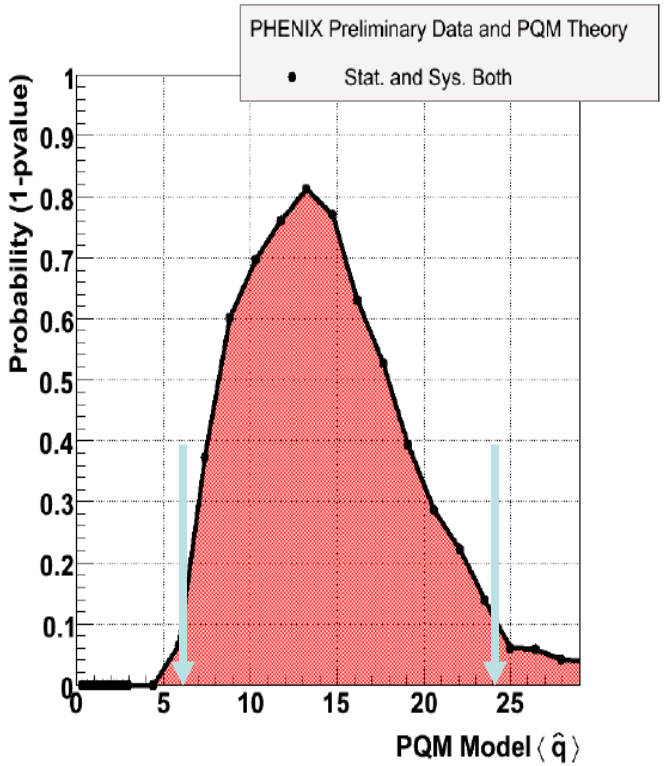


$$6 \le \langle \hat{q} \rangle \le 24 \ \ \mathrm{GeV}^2/\mathrm{fm}$$

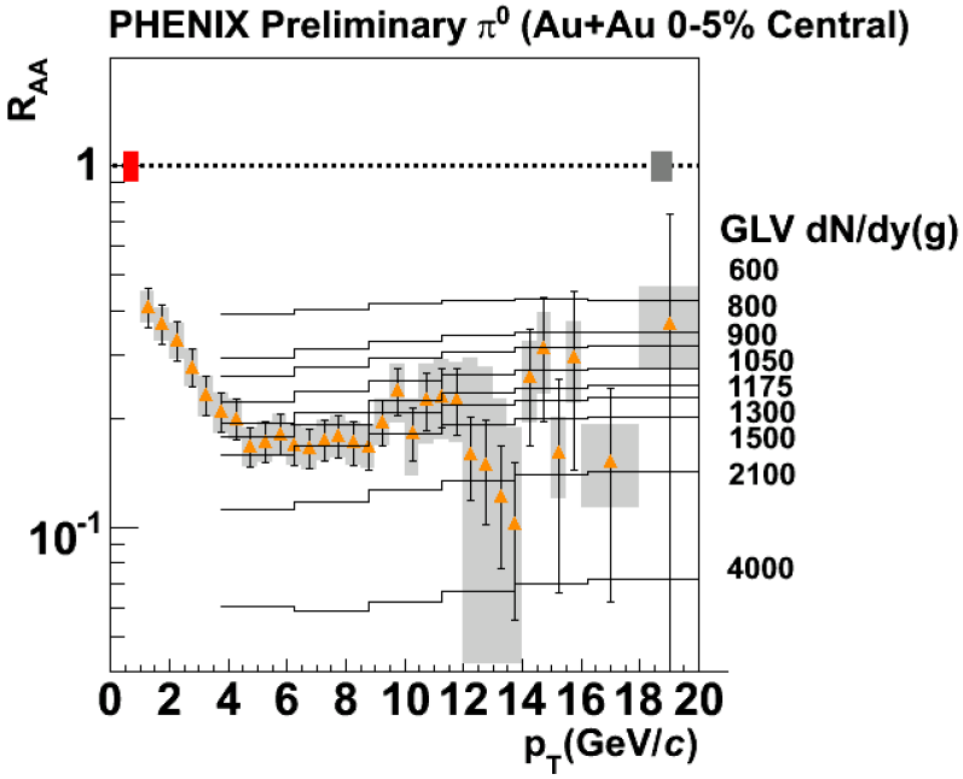
$$(\mathrm{Probability} > 10\%)$$

Nice first try, but not very restrictive…

PQM, C. Loizides
hep-ph/0608133v2



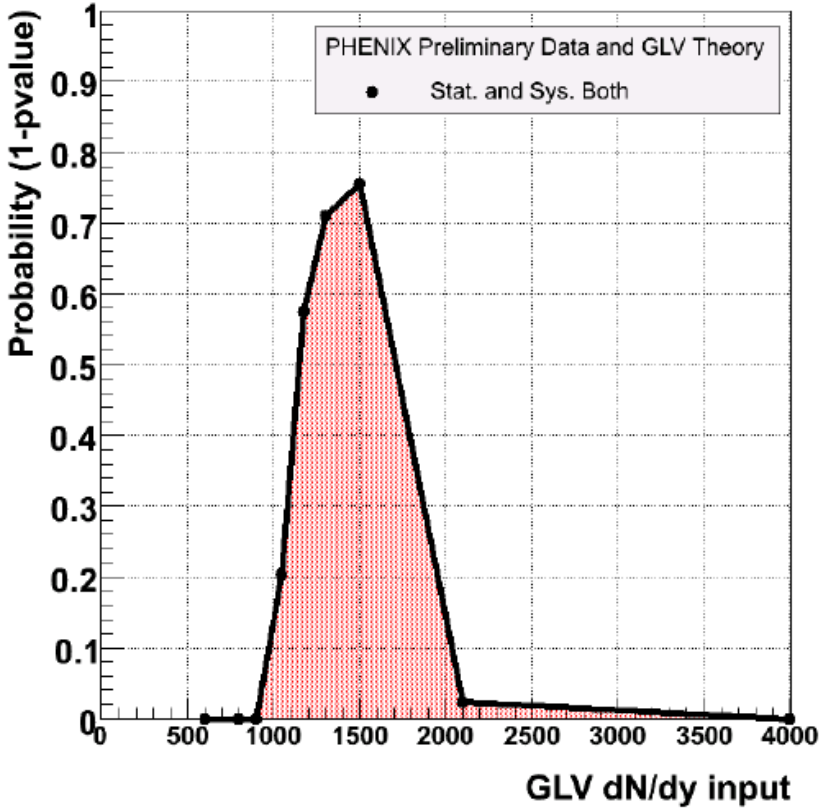
What do we want to learn from this – and what precision is needed? / 2



$$1000 \leq {dN_g}/{dy} \leq 2000\ \mathrm{GeV}^2/\mathrm{c}^2\mathrm{fm}$$

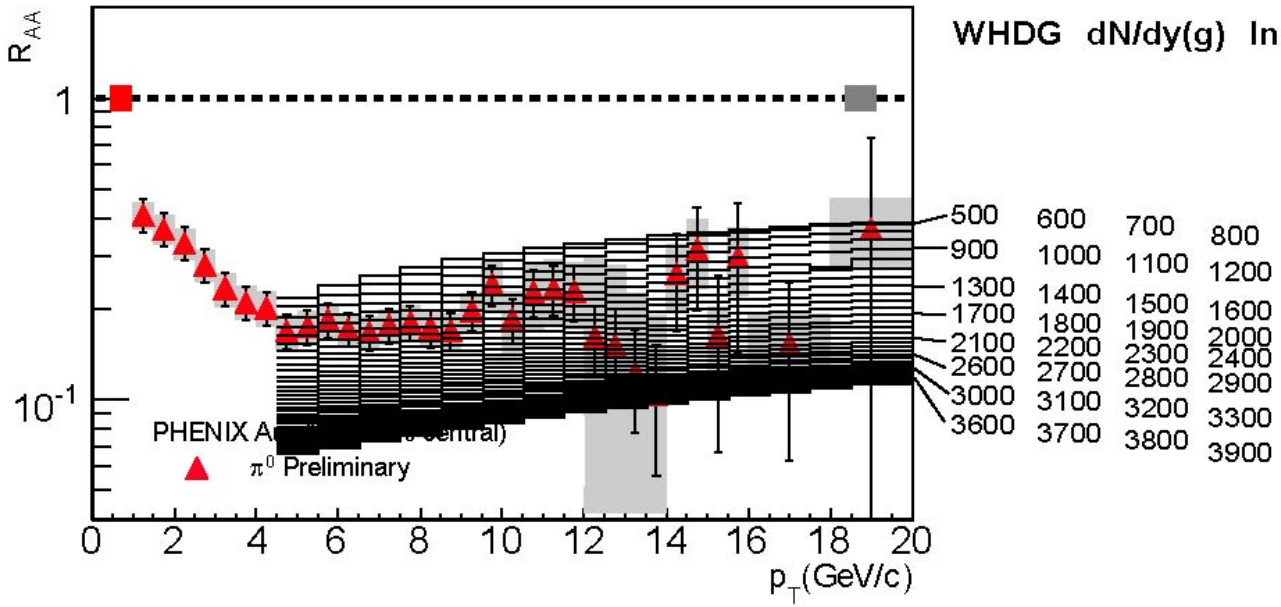
(Probability > 10%)

GLV, I. Vitev
Phys.Lett.B639:38-45,2006



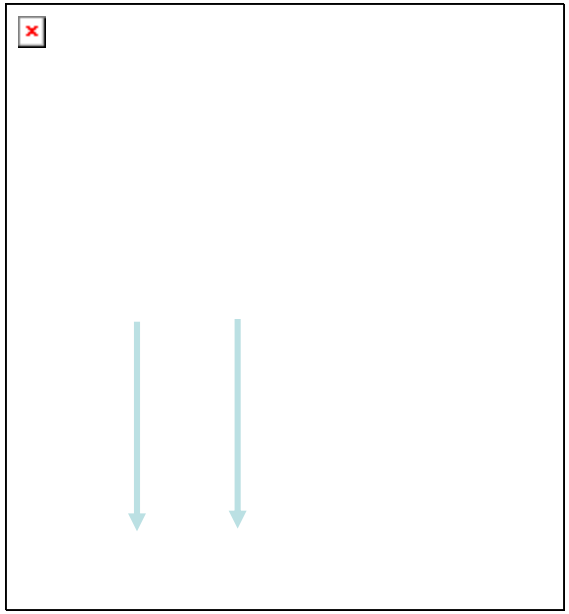
What do we want to learn from this – and what precision is needed? / 3

WHDG, William Horowitz



$$600 \leq {dN_g}/{dy} \leq 1600$$

$$(\text{Probability} > 10\%)$$



Precision, physics theorists and experimentalists

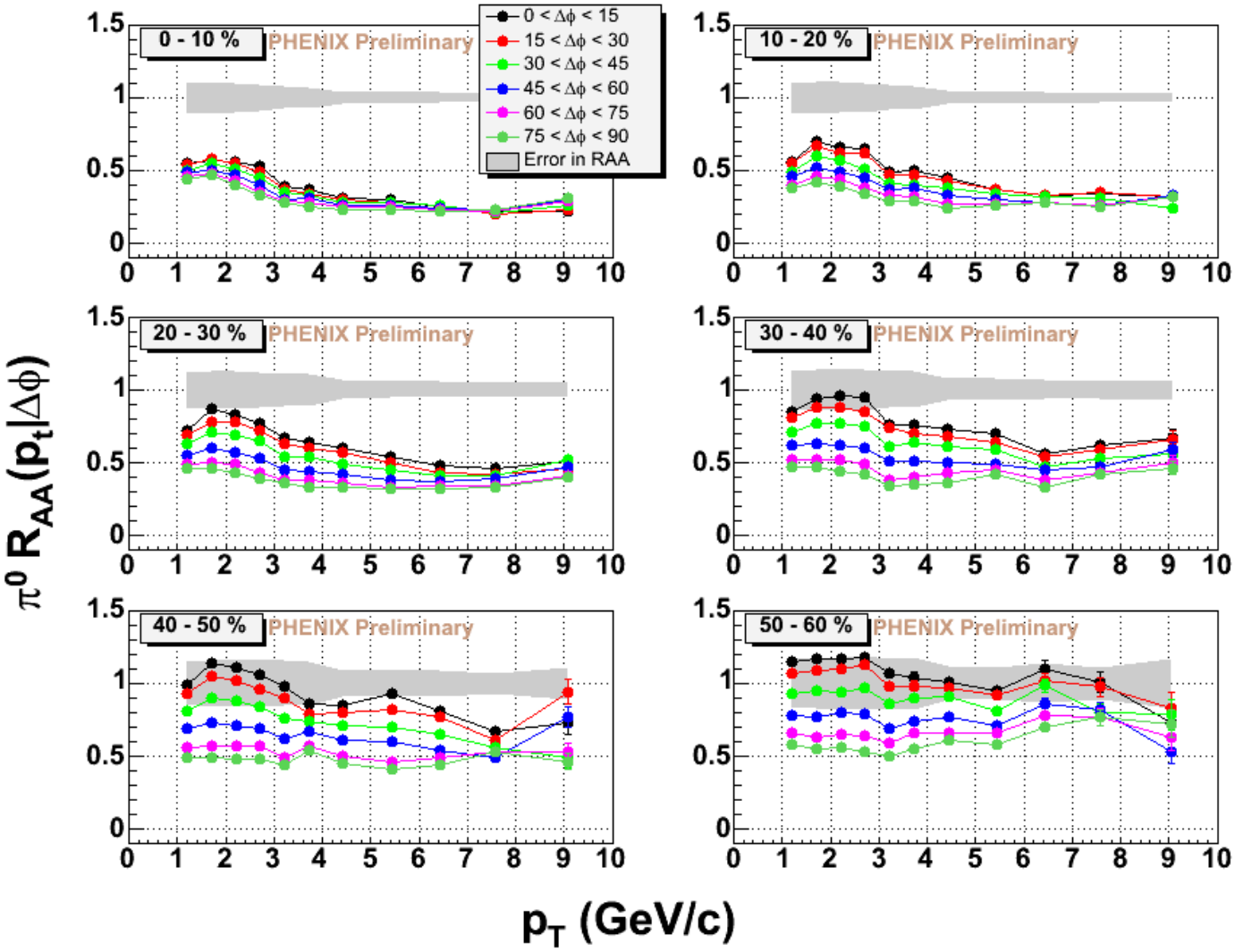
Our field is very rich, and doesn't cease to surprise us:

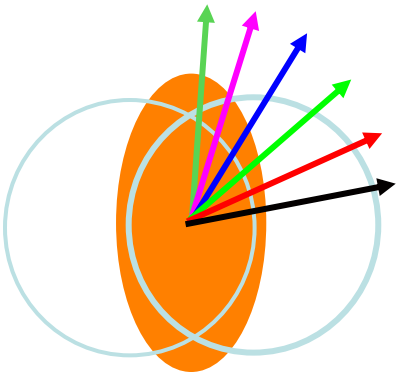
- some much anticipated signals of the QGP (like thermal photons, medium modifications of vector mesons, γ-jet correlations, …) are somewhat lagging behind for technical reasons
- other – less anticipated – signals became the rage overnight, sparking tremendous theoretical activity (like hadron suppression, parton scaling of flow, "baryon anomaly", charm suppression and flow, J/Psi suppression commensurate to SPS, …)
- still we are far from a coherent picture: none of the results is powerful enough to reject all but one explanation

"Powerful enough" usually means "precise". But "precision" is not a goal for itself. **The goal is to understand the physics,** and sometimes it is best served by pushing, say, an inclusive spectrum to the limits and beyond, other times may be better served with a less precise, but more complex and more constraining measurement (double differential, correlation, …)

No single recipe here: this is decided by the intense interaction between theory and experiment, which was excellent in the past years.
Let's keep it that way!

One way out: differential quantities





High p_T direct photons in Au+Au – birds-eye view

Run-2, 200GeV Au+Au:

- spectra up to 14GeV, excess (double ratio) consistent with NLO pQCD
- integrated R_{AA} (using NLO pQCD as reference) consistent with 1 (QM'04, PRL **94**, 232301 (2005))

Run-4, 200GeV Au+Au:

- spectra up to 18GeV
- double ratio at mid-pT above T_{AA} scaled NLO pQCD, but below it at high pT (?) (Hard Probes 2006, Nucl. Phys. A **783** (2007) p359 and p569)

Run-5, 200GeV p+p:

- spectra 5-23GeV, shape different from NLO pQCD, new fit to the data

Run-4, 200GeV Au+Au R_{AA} revisited (200GeV photon data still the same):

- suppression in photon R_{AA} at high p_T, even beyond isospin-effects?

Run-4, 62GeV

- photon R_{AA} with NLO pQCD as it did in step 2… analyzing 62GeV p+p

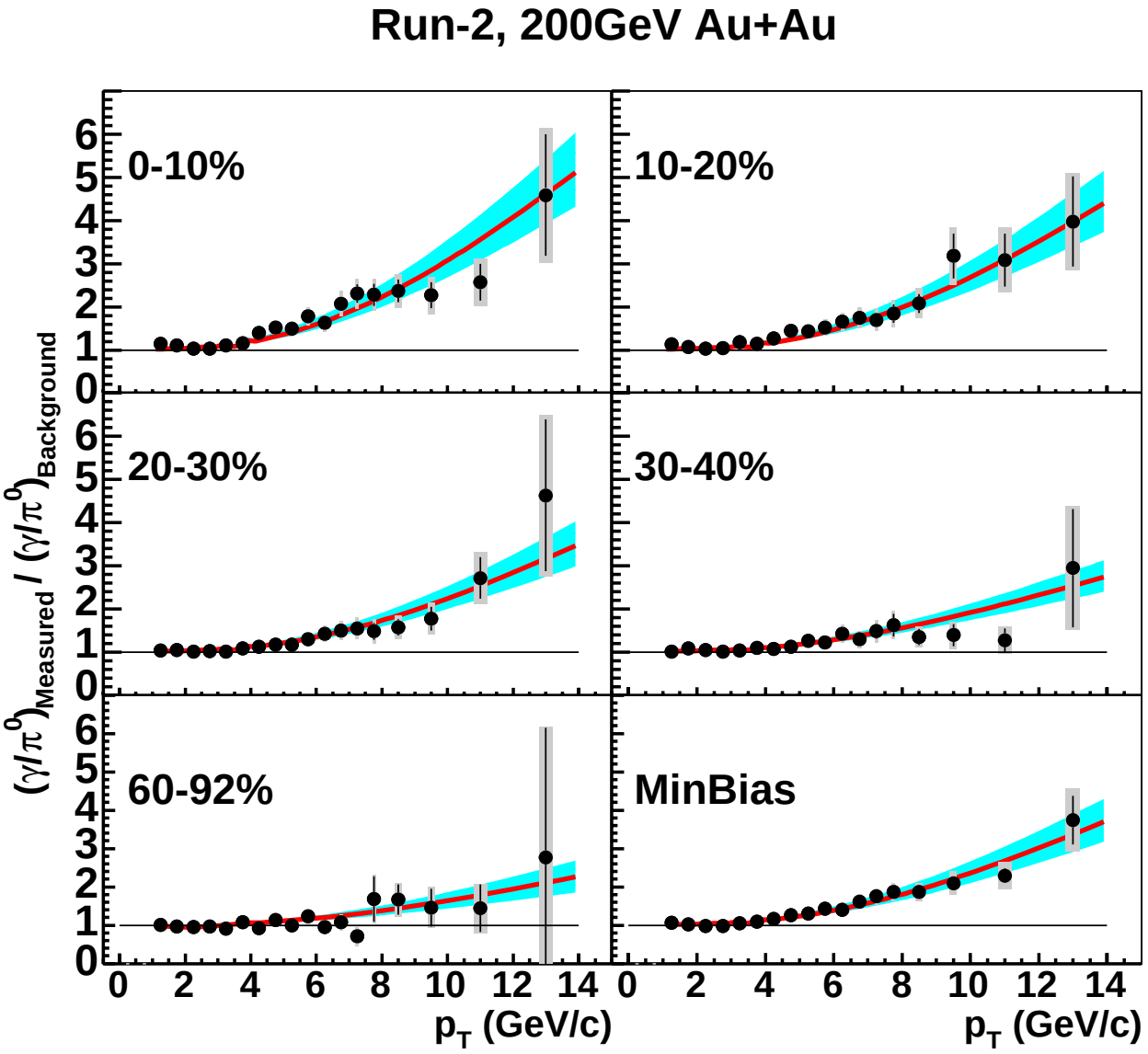
First: direct photon excess, compared to NLO pQCD

Inclusive/decay photons
Technically:
"double ratio"

$(\gamma/\pi^0)_{meas}/(\gamma/\pi^0)_{had}$

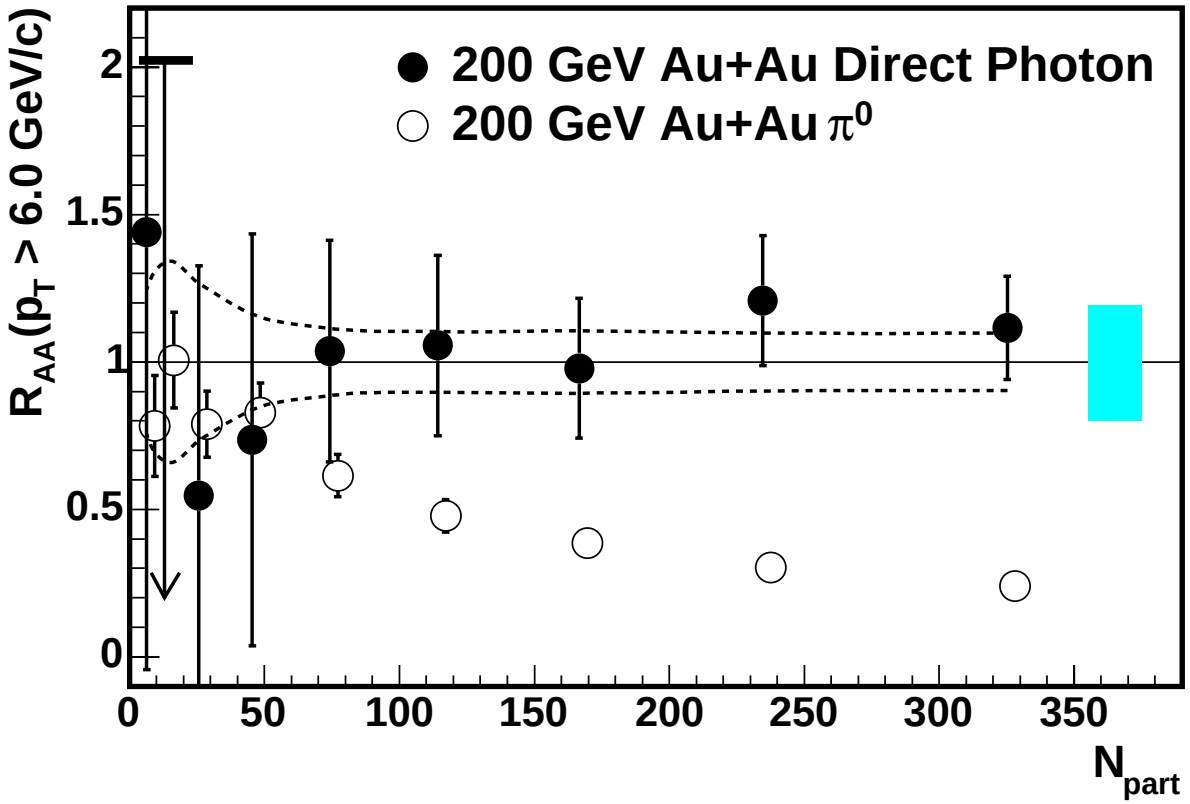
Curve, bands:
NLO pQCD, scaled with T_{AB}
Reasonable agreement

Large signal due to π^0 suppression
No statement on intermediate p_T



Integrated photon R_{AA} (using NLO pQCD)

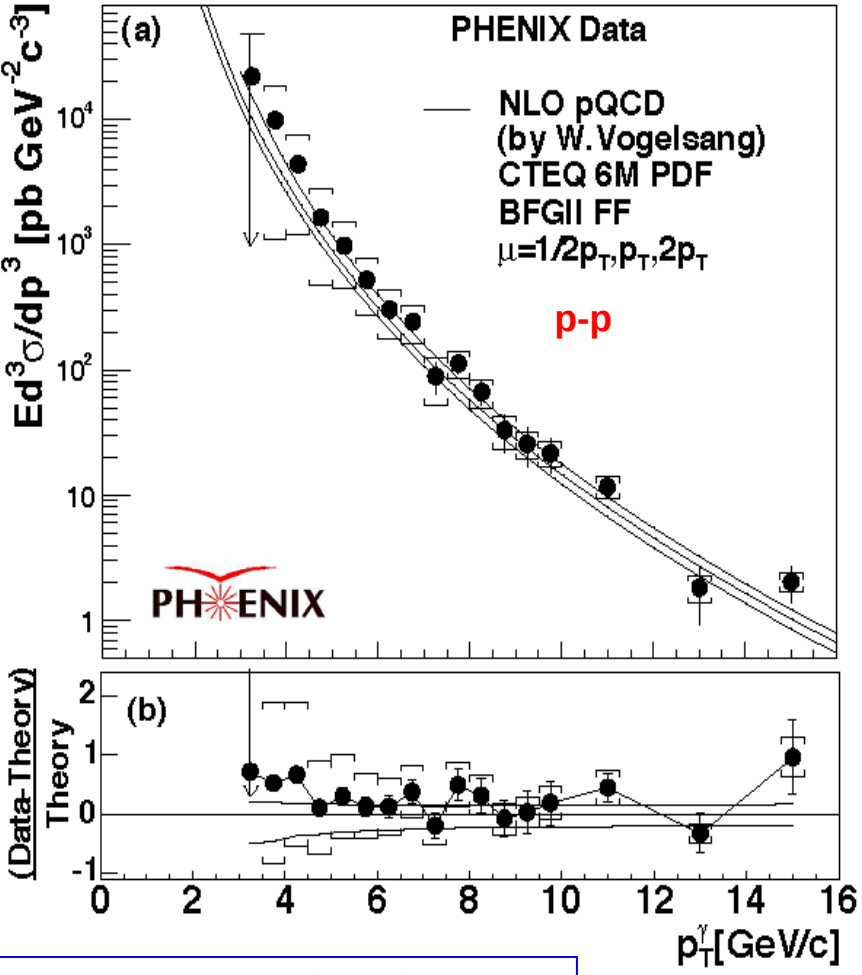
Consistent with unity at all centralities
Measurement up to 14GeV/c
Dominated by hard scattering (>6GeV/c) and unaffected by the medium
→ T_{AB} scaling is a valid concept



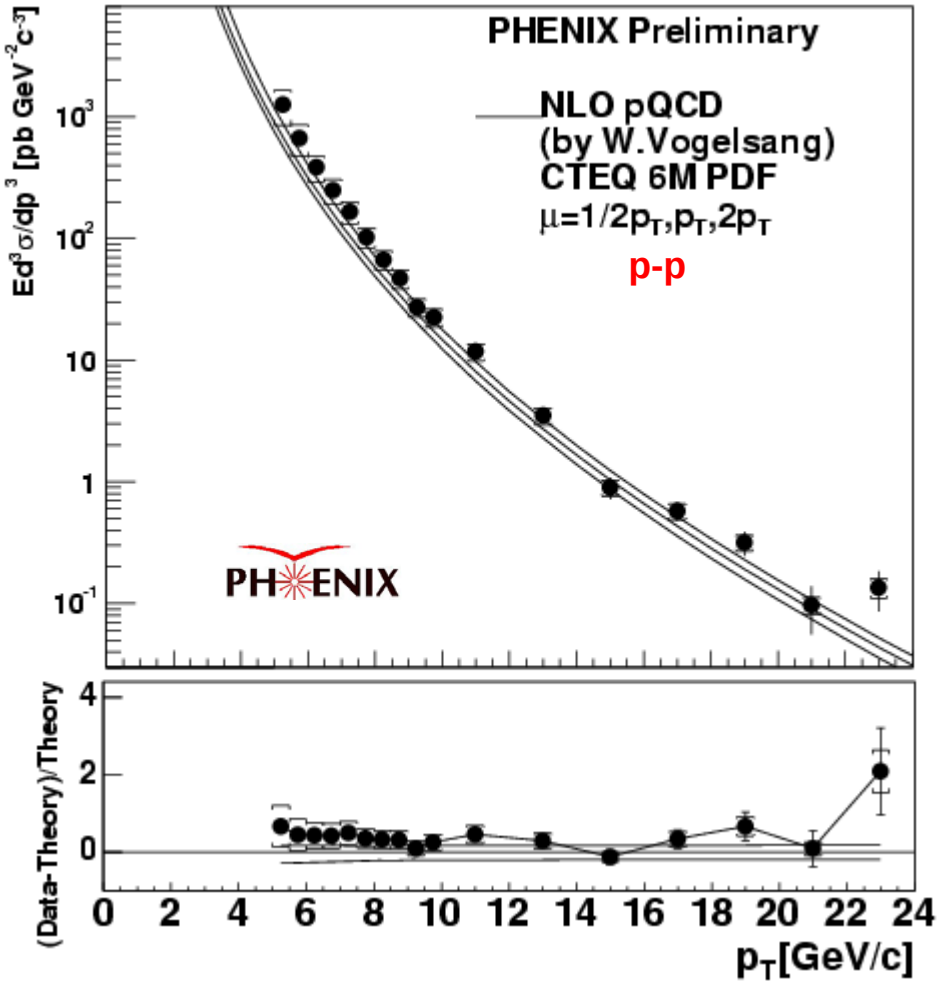
Integrated above 6GeV

Left the door open for
- extra sources at medium pT
- shape differences
- …

Direct γ in p+p, PHENIX – data *vs* theory, old *vs* new



PHENIX PRL **98** (2007) 012002



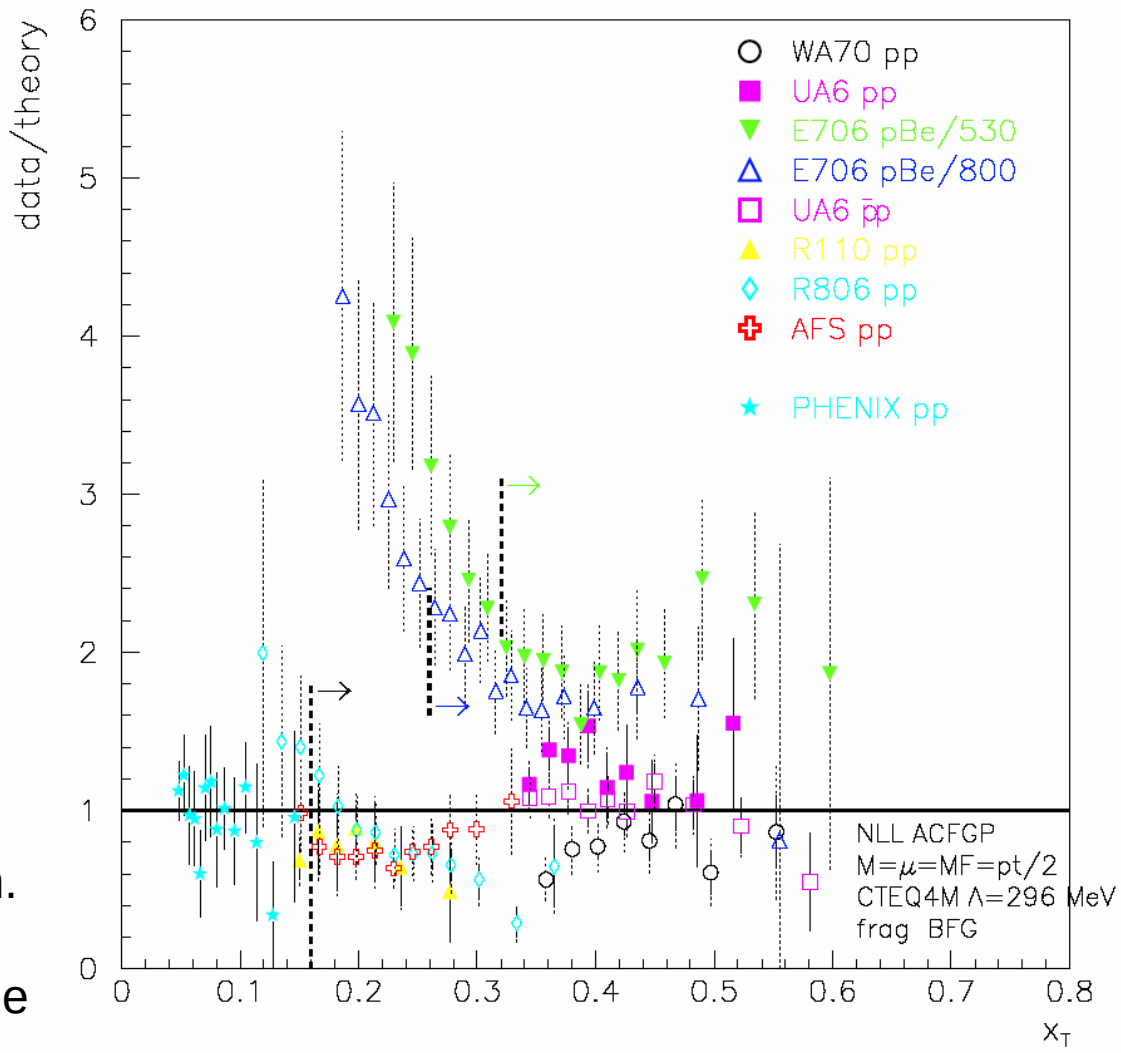
Published results $3<p_T<15$ GeV/c

Preliminary results for $5<p_T<24$ GeV/c

Direct γ in p+p, PHENIX – comparison w/ other data and pQCD

Aurenche et al Eur. Phys. JC**9** (1999)107

Plot by Monique Werlen at RHIC&AGS users meeting 2005



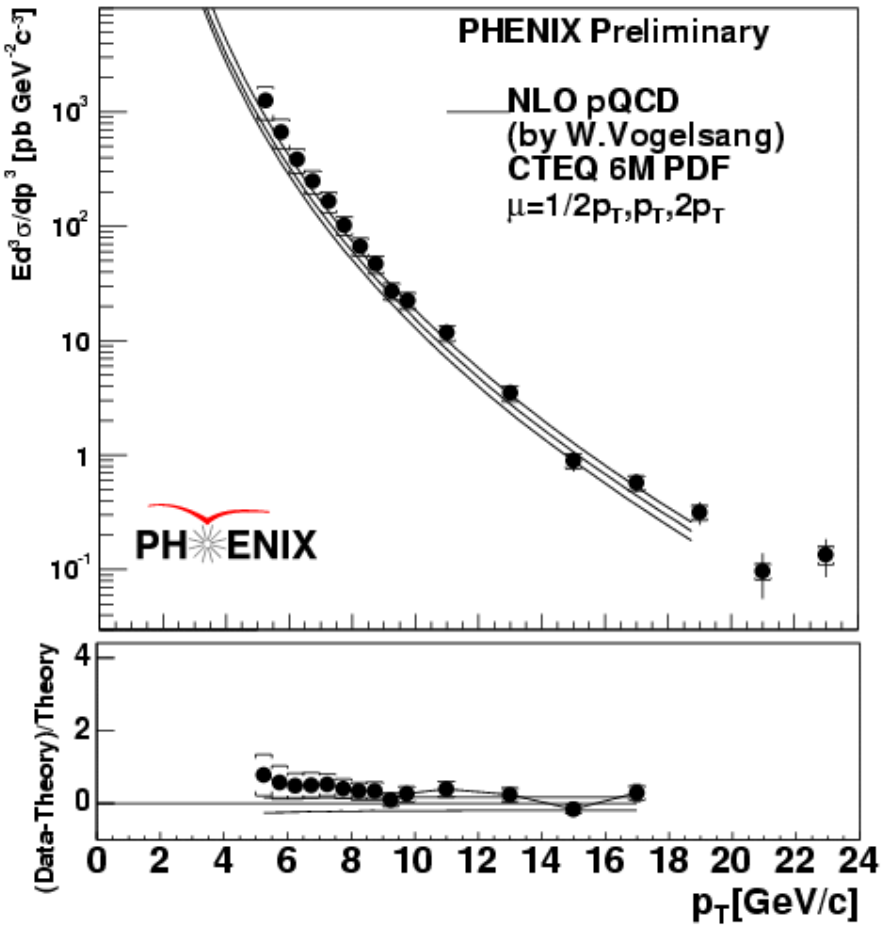
Published PHENIX data ("old", Run-3)

Longstanding issue with theory
→ seems to be settled now

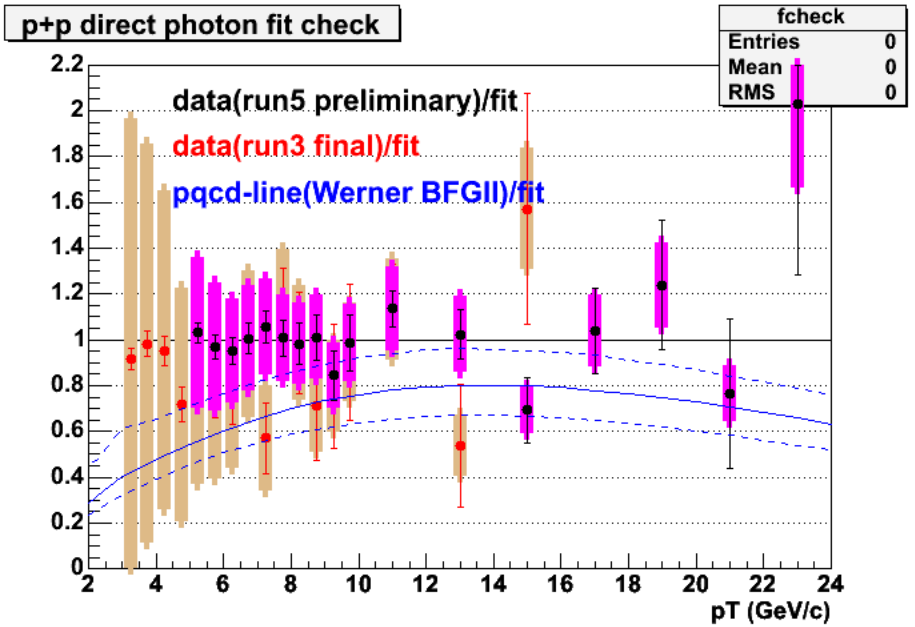
But note: the new, Run-5 prelim. data are ~20% higher; also seem to have a different shape than pQCD

What Is The p+p Reference? Calculation vs Data

Photons in 200GeV p+p (Run-5)
0.5pT favored, but even this misses the shape



Black circles: Run-5 data divided by an empirical fit.
Blue lines: NLO pQCD (different both in magnitude and shape)

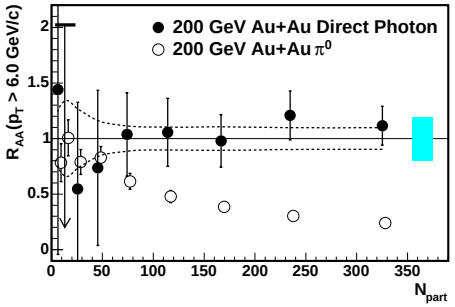


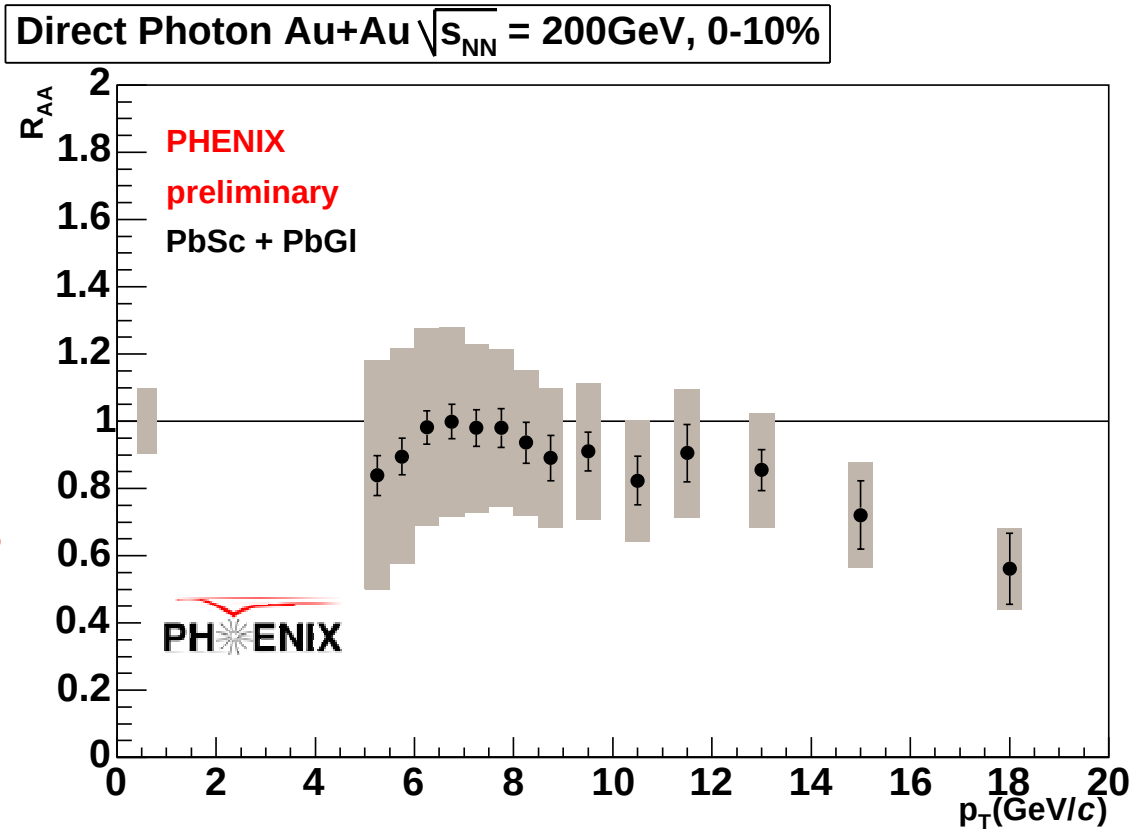
Photon R_{AA} central, 200 GeV with fit to p+p data

One of the big sensations at Quark Matter 2006: our direct photon R_{AA} in Au+Au

Remember: integrated R_{AA} with NLO pQCD (as published)

Most central collisions



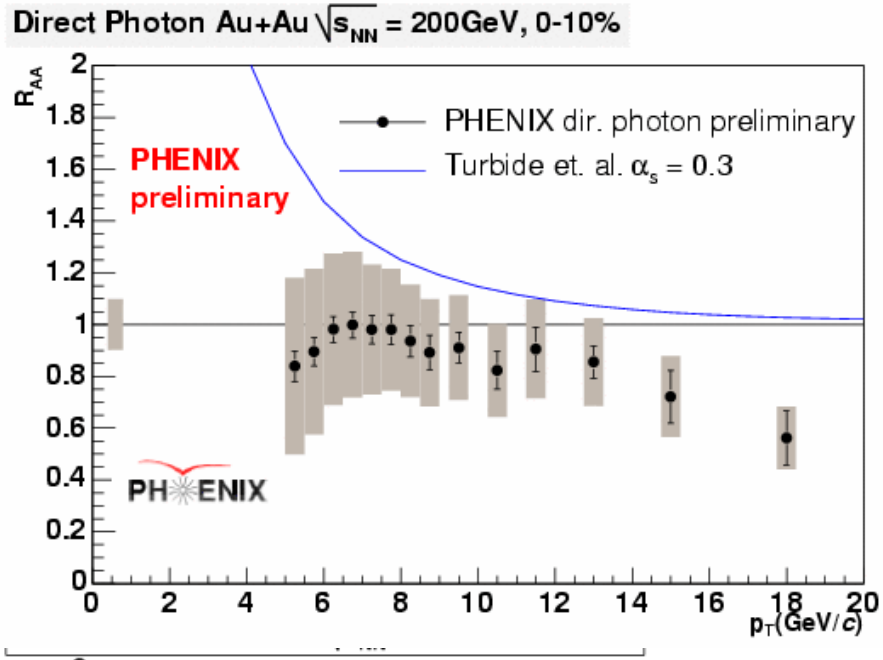


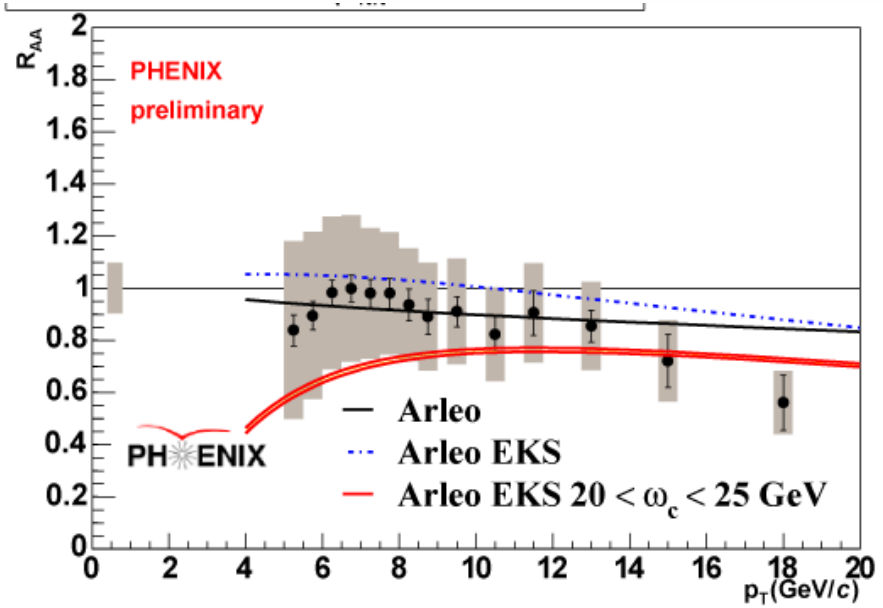
Is the high p_T suppression real?

Is it suppression at all?

Are p+p data the right thing to normalize photon R_{AA}?

Comparisons to *pre*dictions





- Turbide et al.
  - Jet photons + pQCD + thermal
  - AMY formalism for jet-quenching of fragmentation photons
  - Data systematically below theory
  - Phys. Rev. C72 (2005) 014906 + private communication

- F. Arleo
  - pQCD photons only
  - High-p_T suppression due to isospin effect, shadowing, and energy loss
  - BDMPS for jet-quenching
  - JHEP 0609 (2006) 015

Why isn't the γ R_{AA} unity at high p_T?

Evolution of the gluon structure function?

"Isospin" effect (different charge squared content of p and n)?

Note
- pions care about color, not charge
- pion x_T is $2p_T$/ sqrt(s),
  photon x_T is $2p_T$/z*sqrt(s)

Your favorite model here ☺

Yet another dreaded explanation:
it could be an experimental error
so we started looking for a cross-check

Eskola,Kolhinen,Ruuskanen
Nucl. Phys. B**535**(1998)351

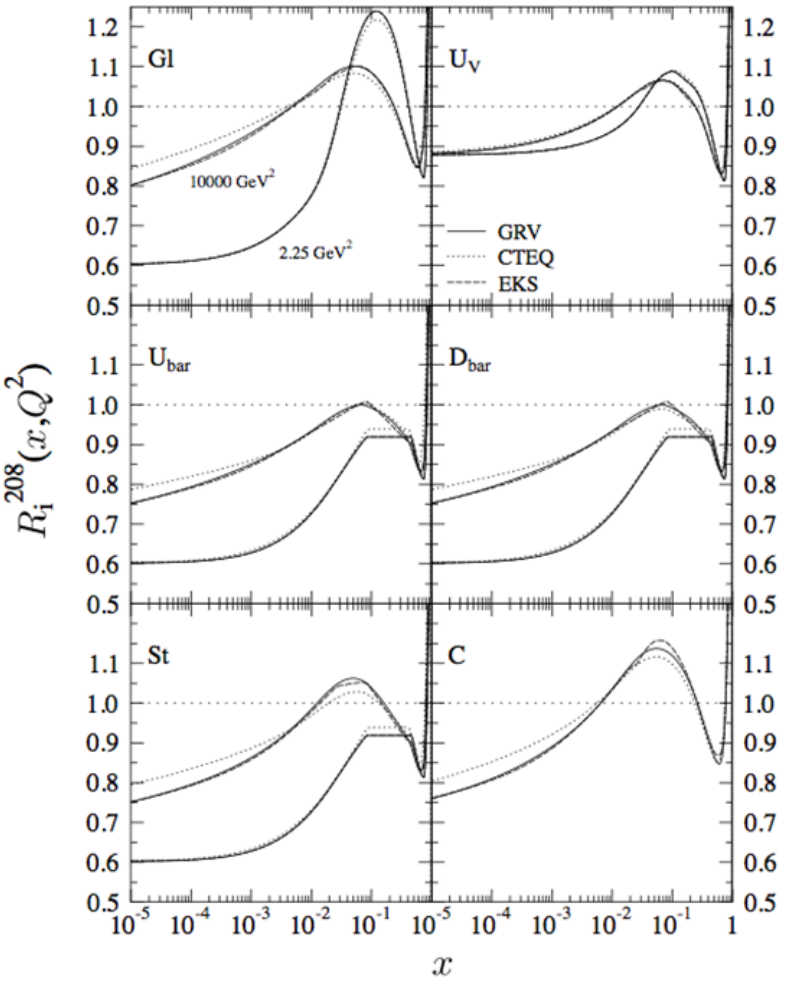


Fig. 1. The nuclear ratios $R_i^A(x,Q^2)$ for individual parton flavours $i = g, u_V, \bar{u}, \bar{d}, s, c$ of a lead nucleus $A = 208$ as functions of x at fixed values of $Q^2 = Q_0^2 = 2.25$ GeV^2 and $Q^2 = 10000$ GeV^2 as obtained by using the GRV-LO [25] distri-

PHENIX – "Isospin Effect" (?)

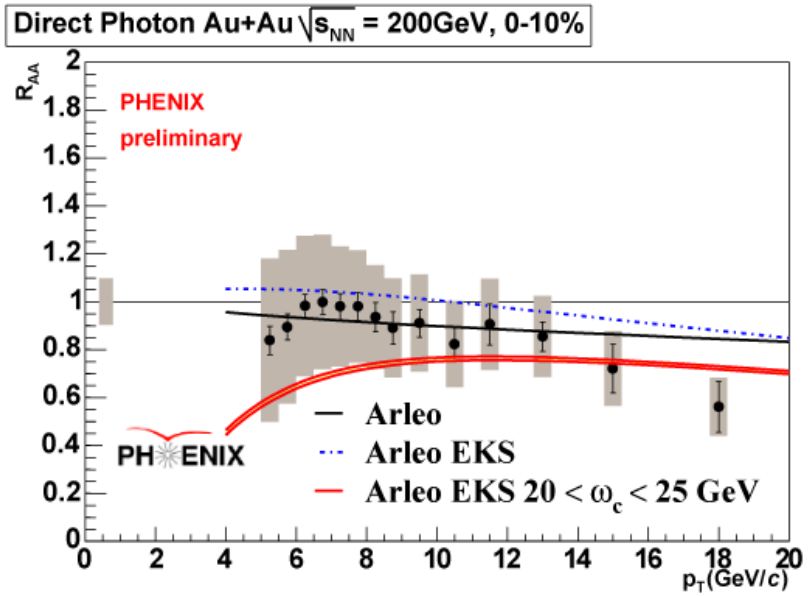
The isospin effect (charge square difference between **uud** and **udd**) **SHOULD** be there, but is this (and only this "trivial effect") what we see?

Or do we see in addition some genuine photon suppression?

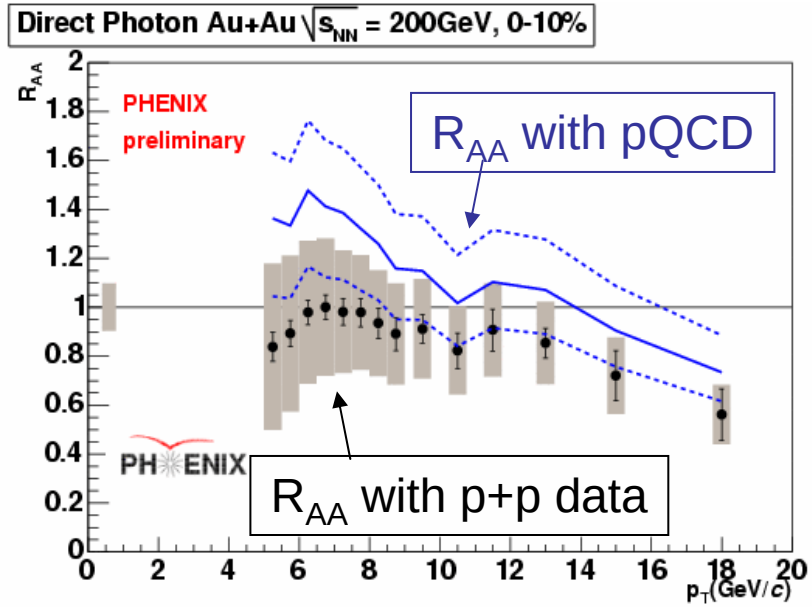
No contradiction here: only "primordial" photons should be unaltered, "medium-induced" photons can be enhanced or suppressed

$$\sigma_{AA}/N_{coll} = (1/A^2) \times (Z^2\sigma_{pp} + 2Z(A-Z)\sigma_{pn} + (A-Z)^2\sigma_{nn})$$

F. Arleo, JHEP09 (2006) O15

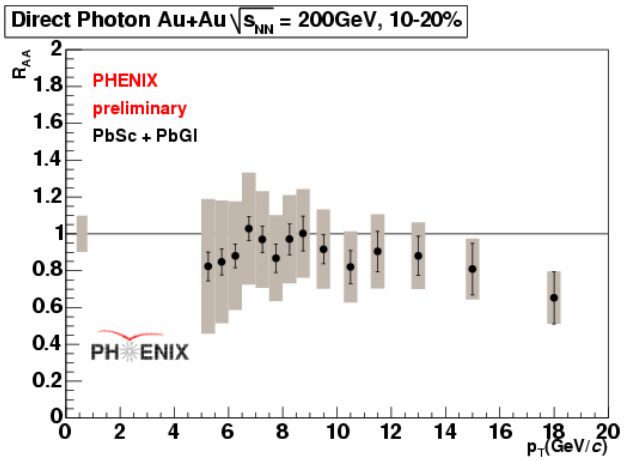


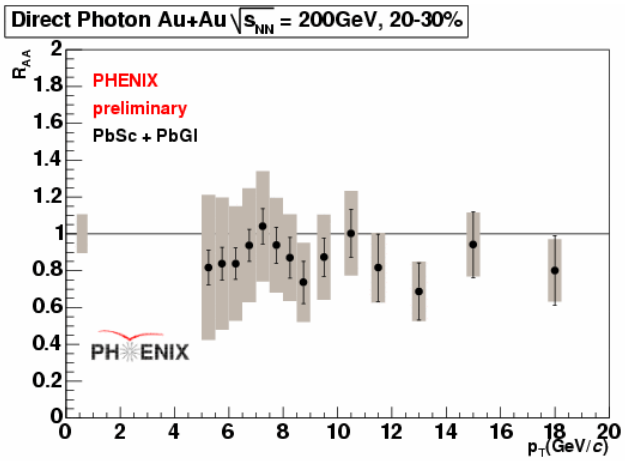
W. Vogelsang, NLO pQCD + isospin

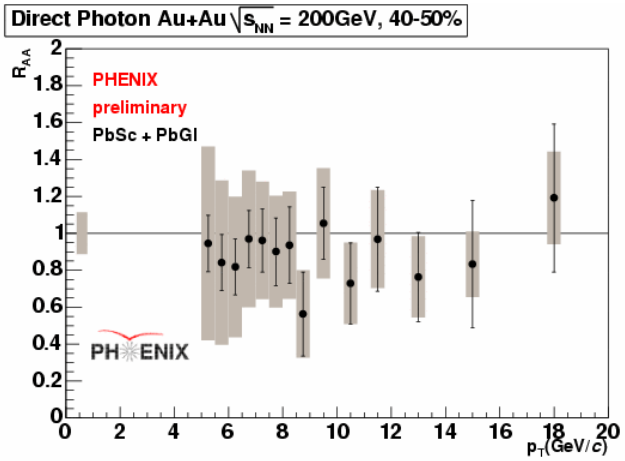


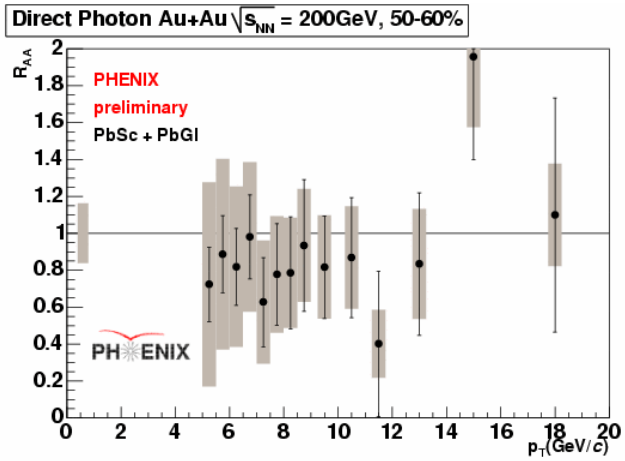
Isospin Effect – Statistics?

If this is real, we should convincingly see it in **ALL** centralities
(need much higher statistics – and smaller systematics… - to reduce errors)









Isospin Effect – x_T scaling

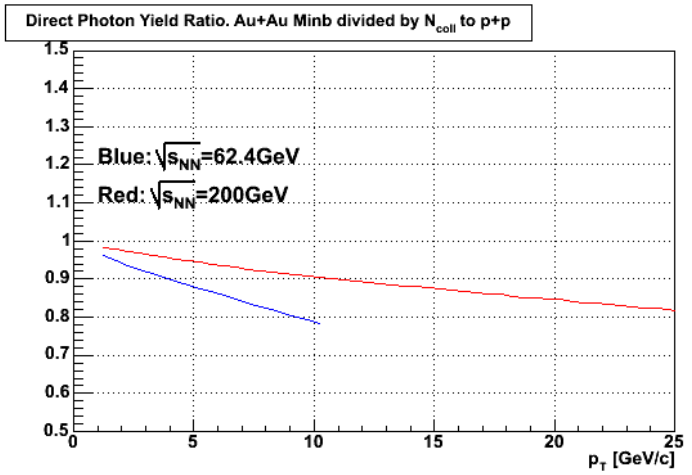
Unfortunately the suppression is seen in a region where we are very sensitive to detector bias (cluster merging).

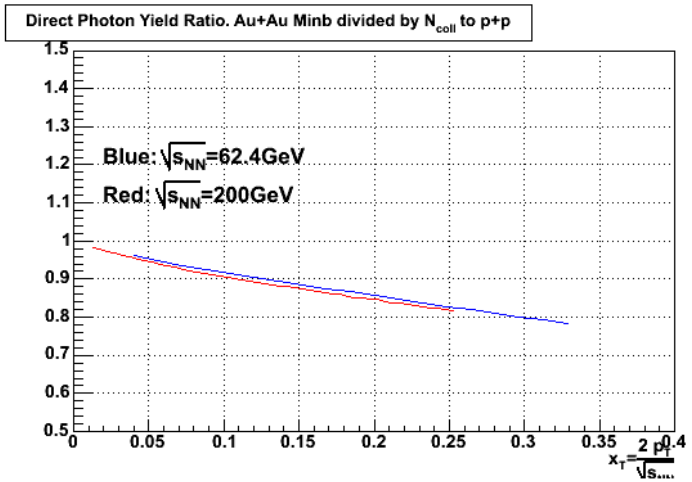
Also, so far it was seen only in one of the detectors (the one more prone to merging)

x_T scaling to the rescue?

The reason:
certain known detector imperfections (like shower merging, nonlinearity…) are smaller at lower p_T!
Yes, we do our best to correct for them but nothing beats not having the problem in the first place…

The catch:
sources at intermediate p_T (like jet conversion) that are so far of unknown magnitude, come into play, too!



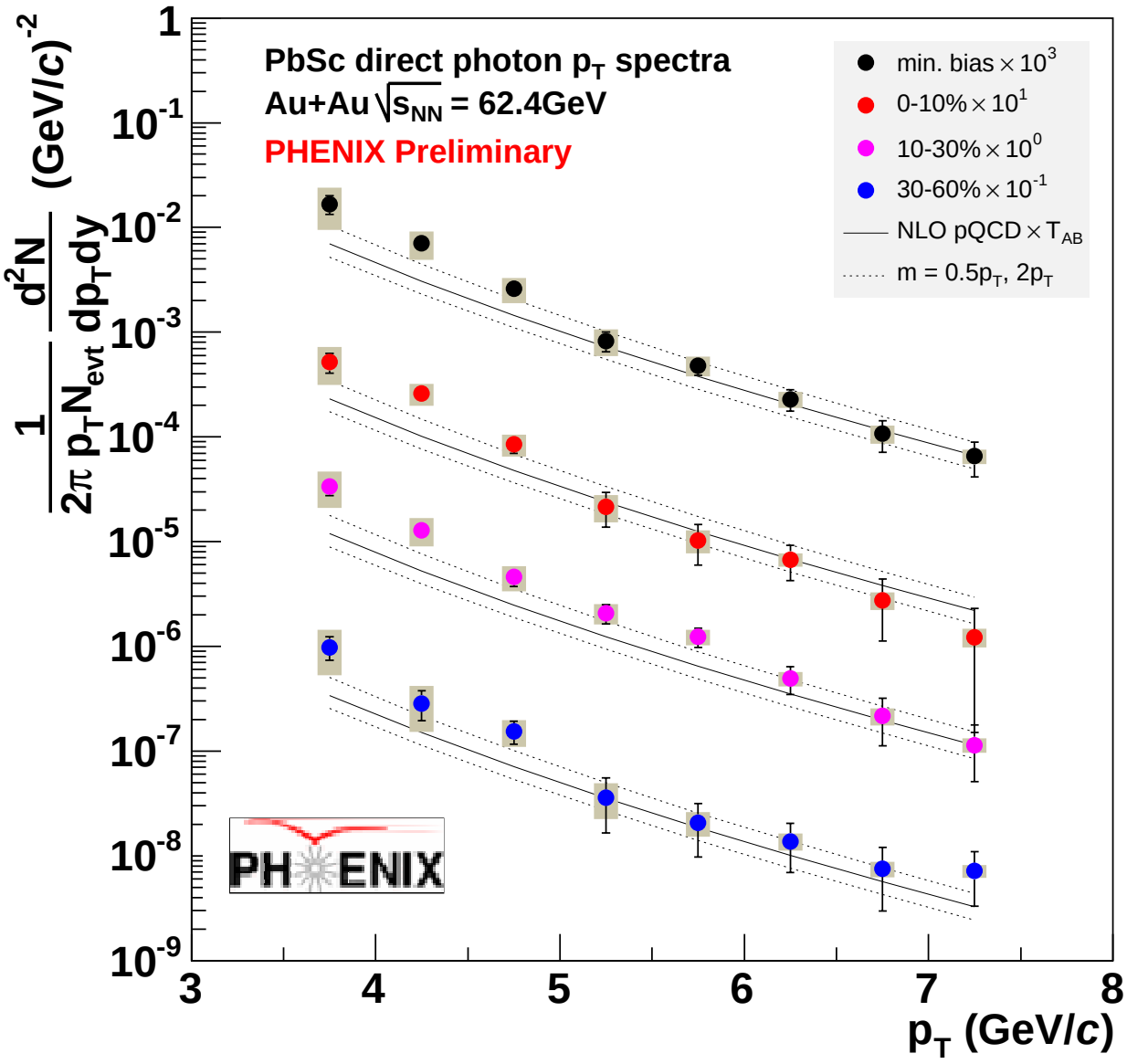


Brand new: direct photons in 62GeV Au+Au

So we analyzed our 62GeV AuAu data, and that's what we got

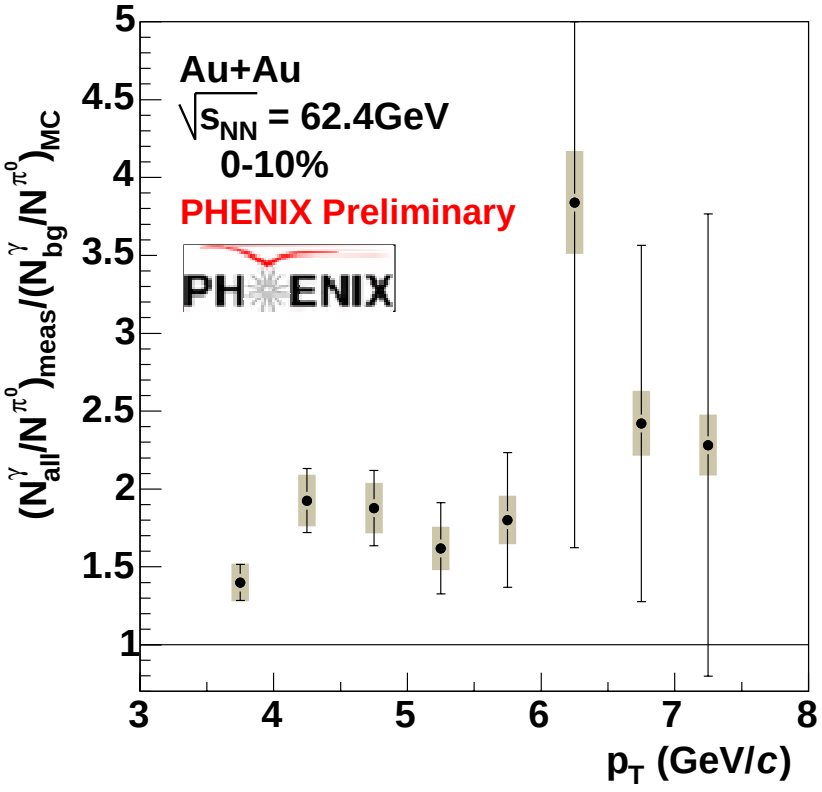
Lines: T_{AB}-scaled pQCD

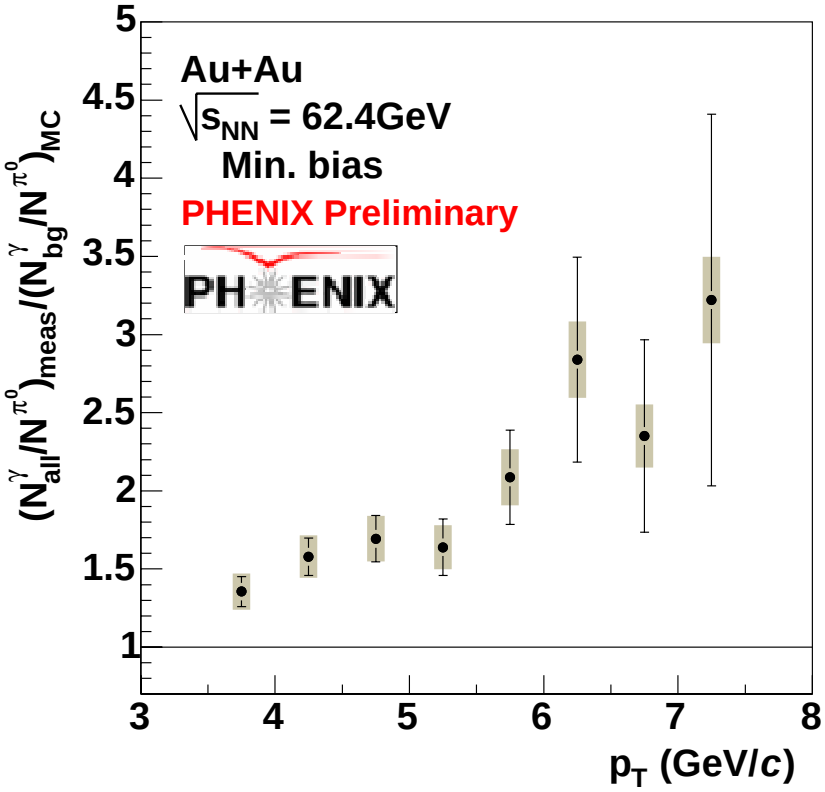
Note the same tendency as for π^0 (and 200GeV p+p): favors $0.5p_T$ scale



Photon excess (double ratios) in 62GeV Au+Au

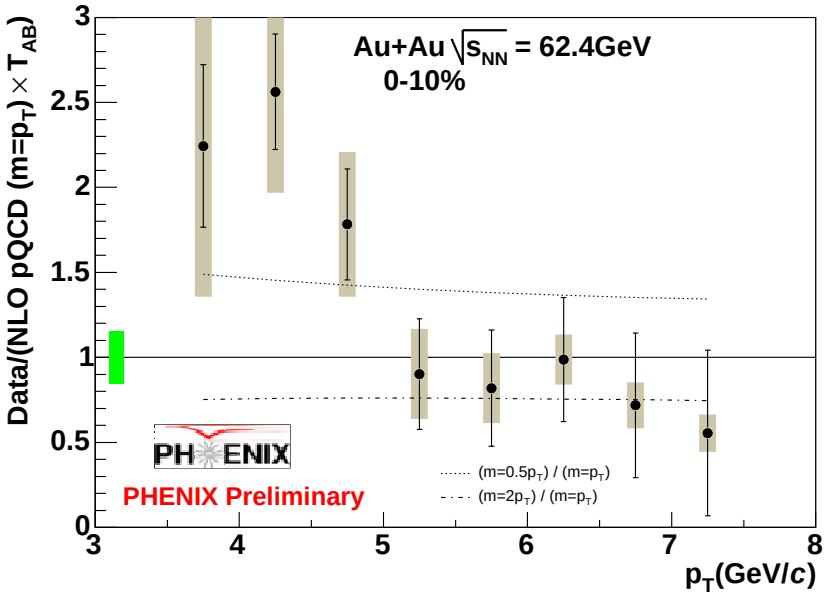
$(\gamma/\pi^0)_{meas}/(\gamma/\pi^0)_{had}$

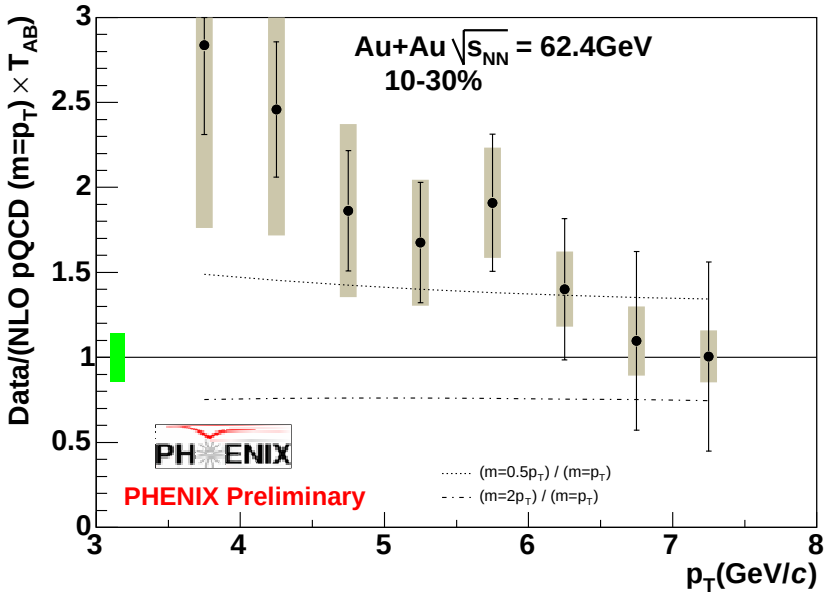


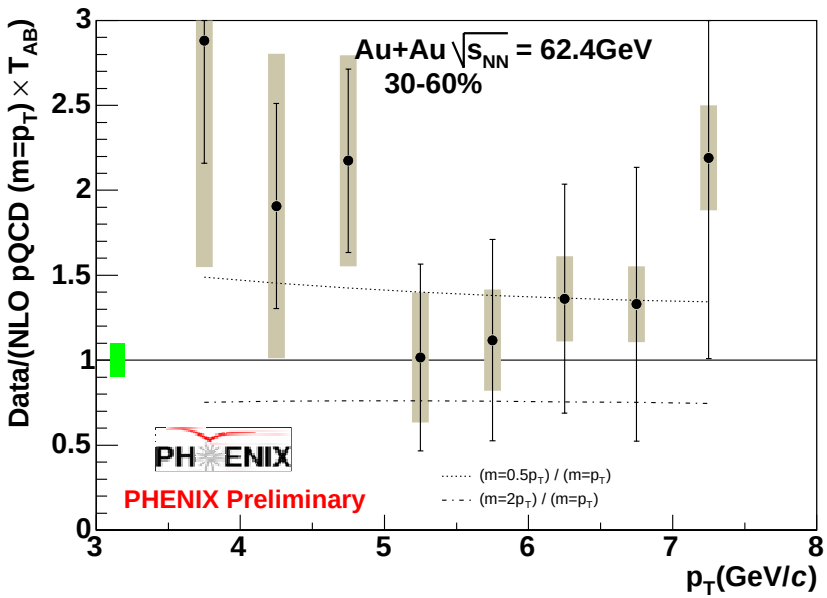


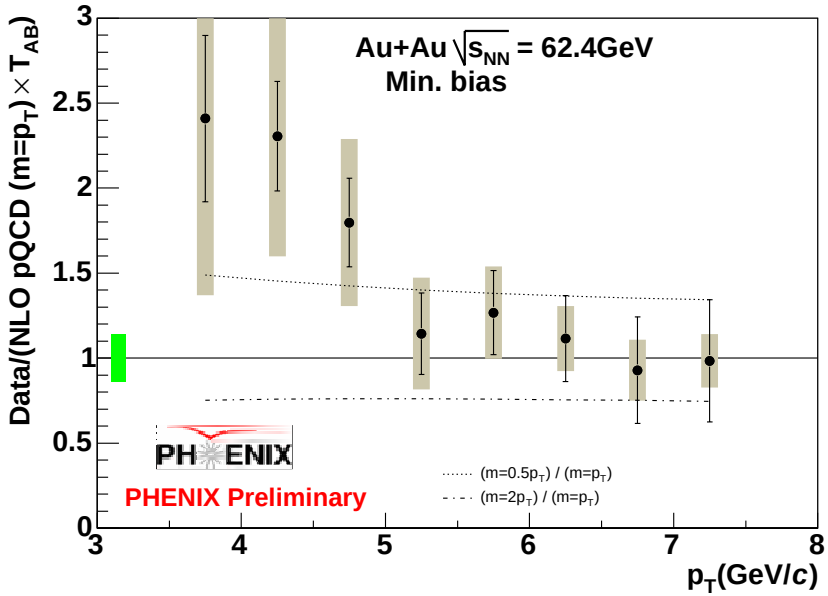
Remarkably high – keep in mind pion suppression!

Photon R_{AA} (with pQCD) in 62GeV Au+Au

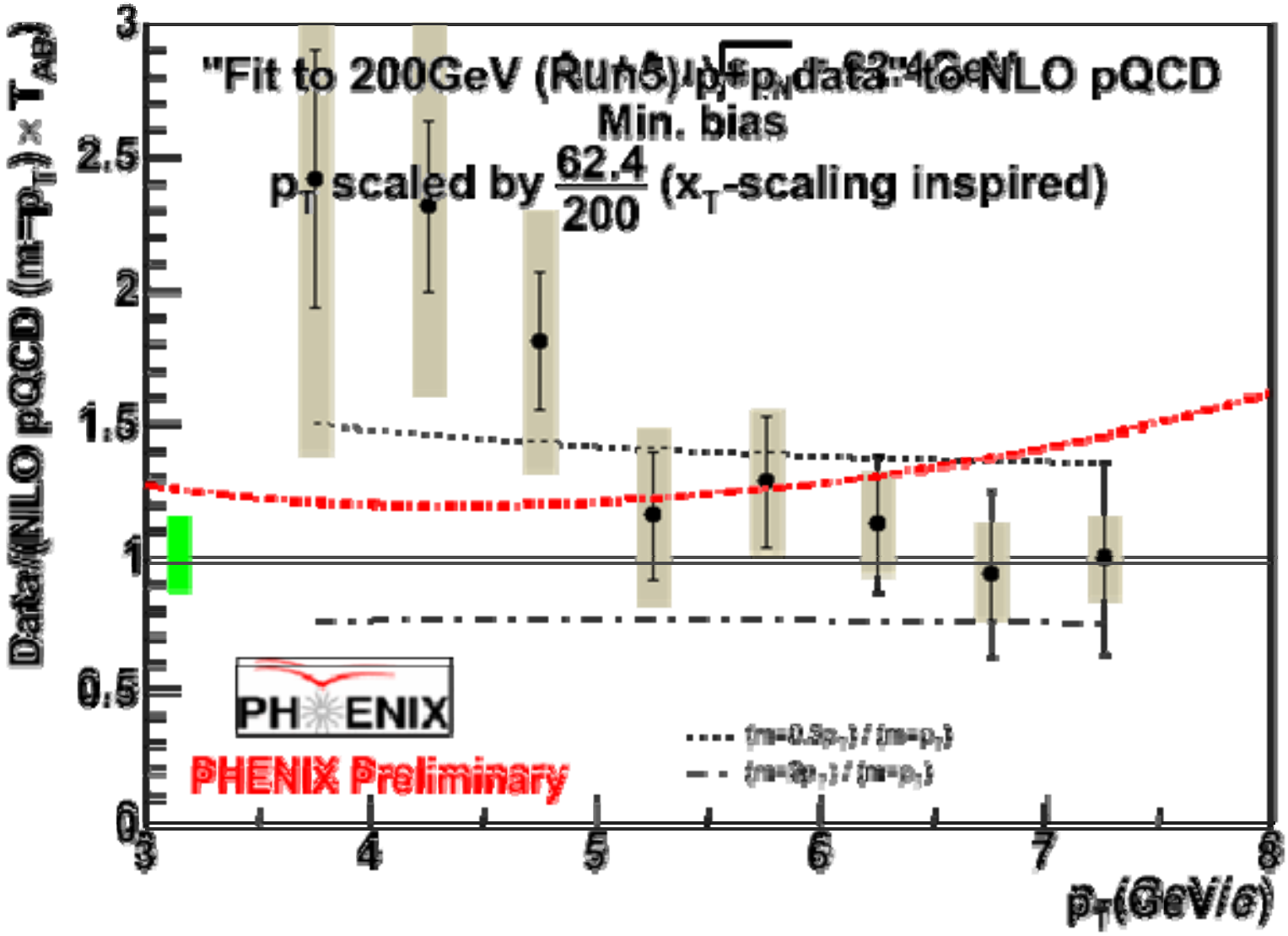








Photon R_{AA} : don't take this literally!



Summary

Waning (albeit not the end) of the era of single inclusive measurements

Tremendous benefits from measuring the reference in the same experiment

Physics message of 62 GeV Au+Au π^0 R_{AA} revised – medium almost the same as the one at 200GeV Au+Au

Photons suppression at high p_T in 200GeV Au+Au will likely be confirmed by the final 62GeV results

Nothing beats a detailed energy/species scan in the same experiment:

RHIC-II is coming!