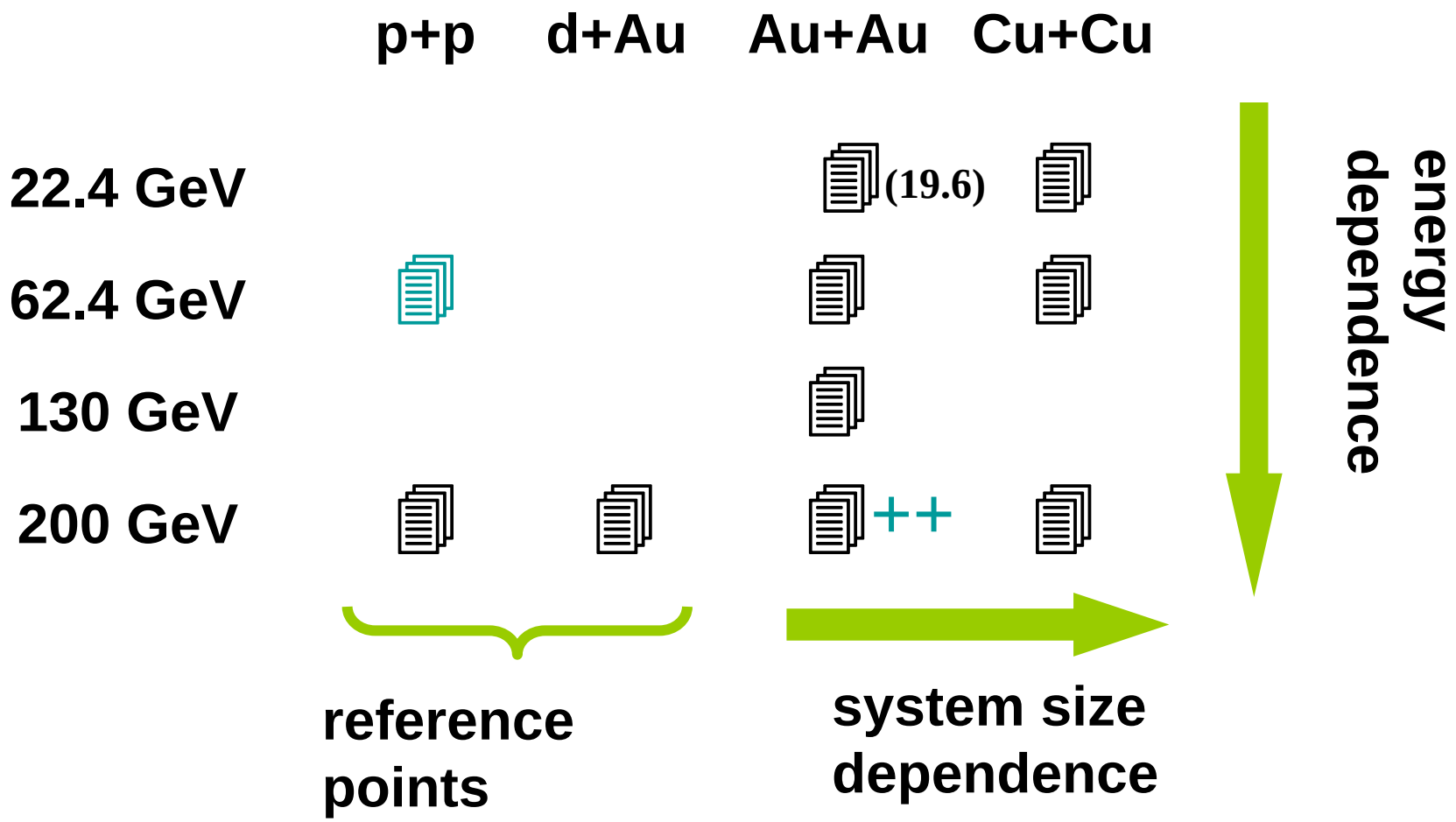
# New results from PHENIX on energy loss and direct photons

***Zimanyi Memorial Workshop***
***July 2-4, 2007 – Budapest***

***G. David, BNL***

# Reminder: PHENIX data sets




Upgrades, new possibilities

# High $p_T$ $\pi^0$-s in Au+Au – birds-eye view

Run-1, 130GeV Au+Au:

- First observation of large $\pi^0$ 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:

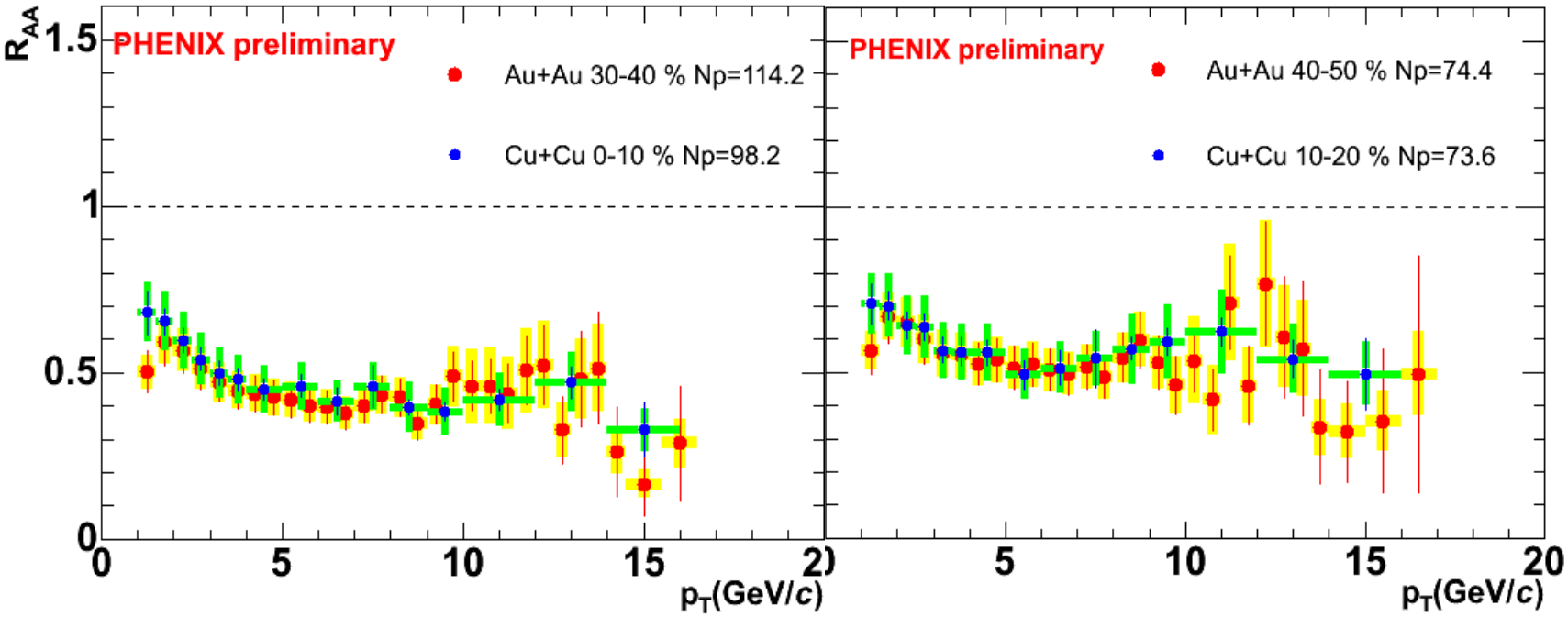
- suppression commensurate to 200GeV Au+Au at similar $N_{part}$

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.

# $\pi^0$ in 200GeV Au+Au and Cu+Cu

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

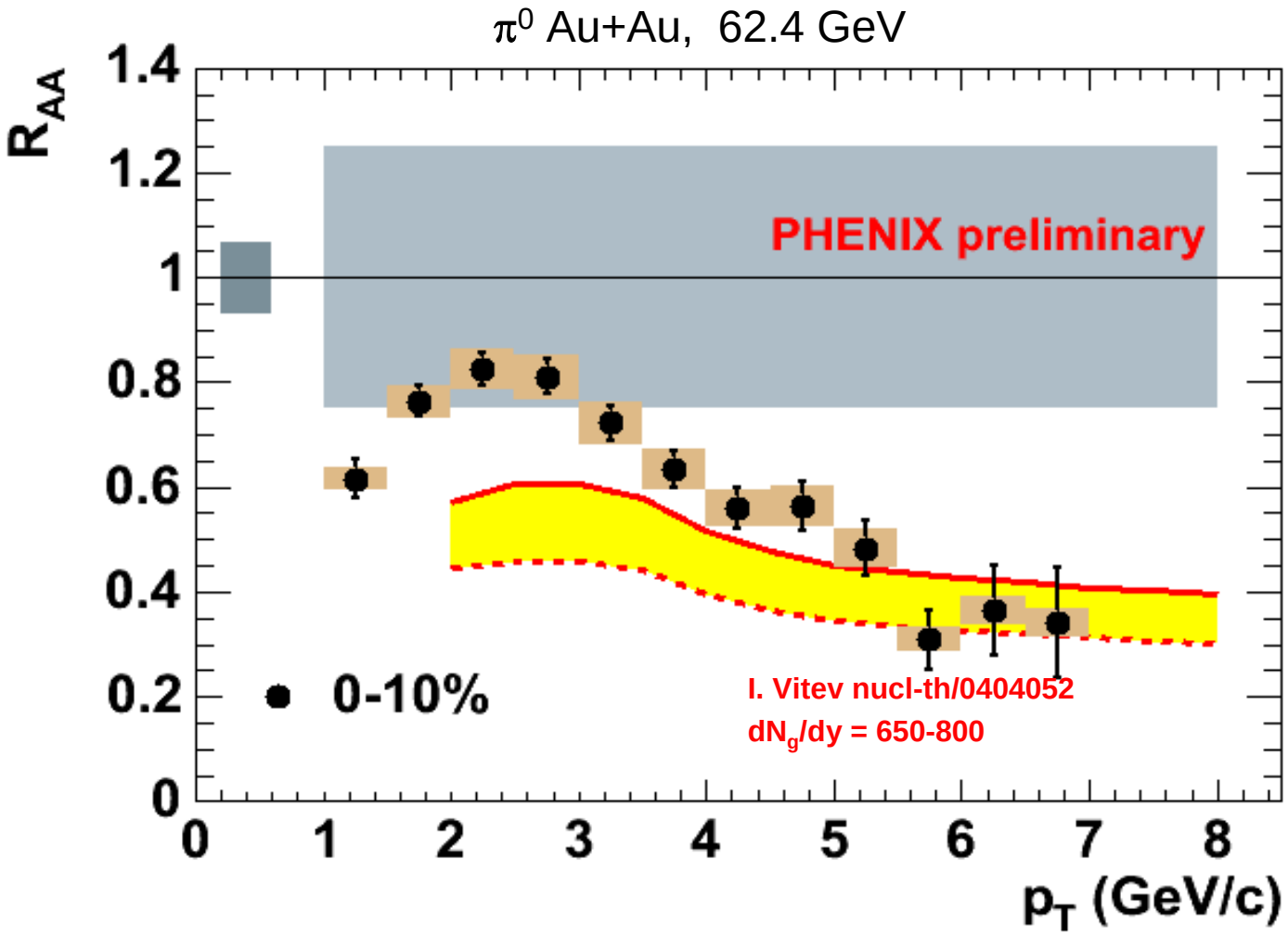



**$\pi^0$ $R_{AA}$ in Au+Au and Cu+Cu**

Compare this to…

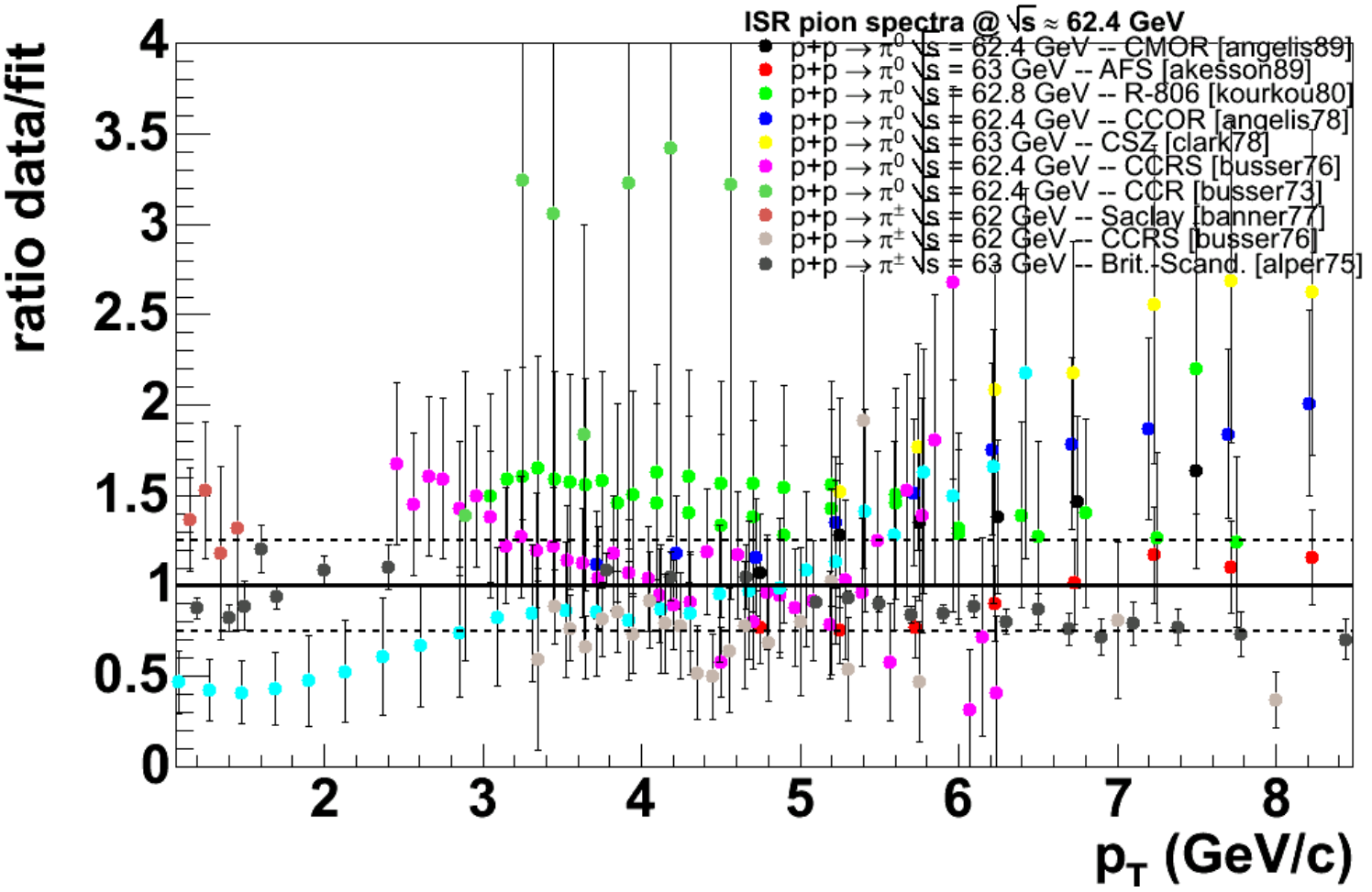
# $\pi^0$ $R_{AA}$ in 62GeV Au+Au – world data reference used

"Fast track analysis", 2 months after data taking



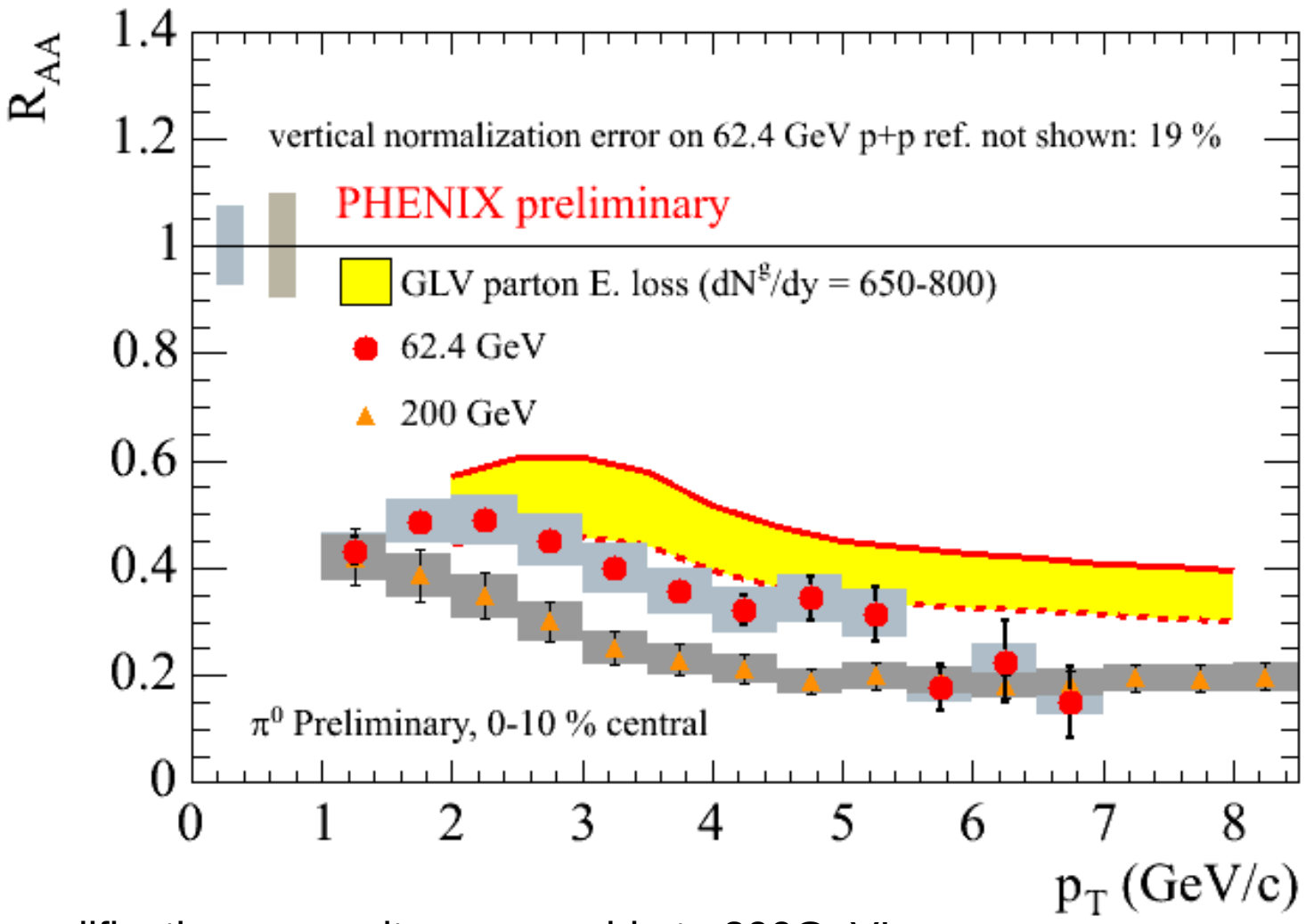

Suppression even in the most central collisions appears to be significantly smaller than at 200 Gev! (Note: but Cronin not observed, not even in d+Au)

# $\pi^0$ at 62GeV p+p – world data reference



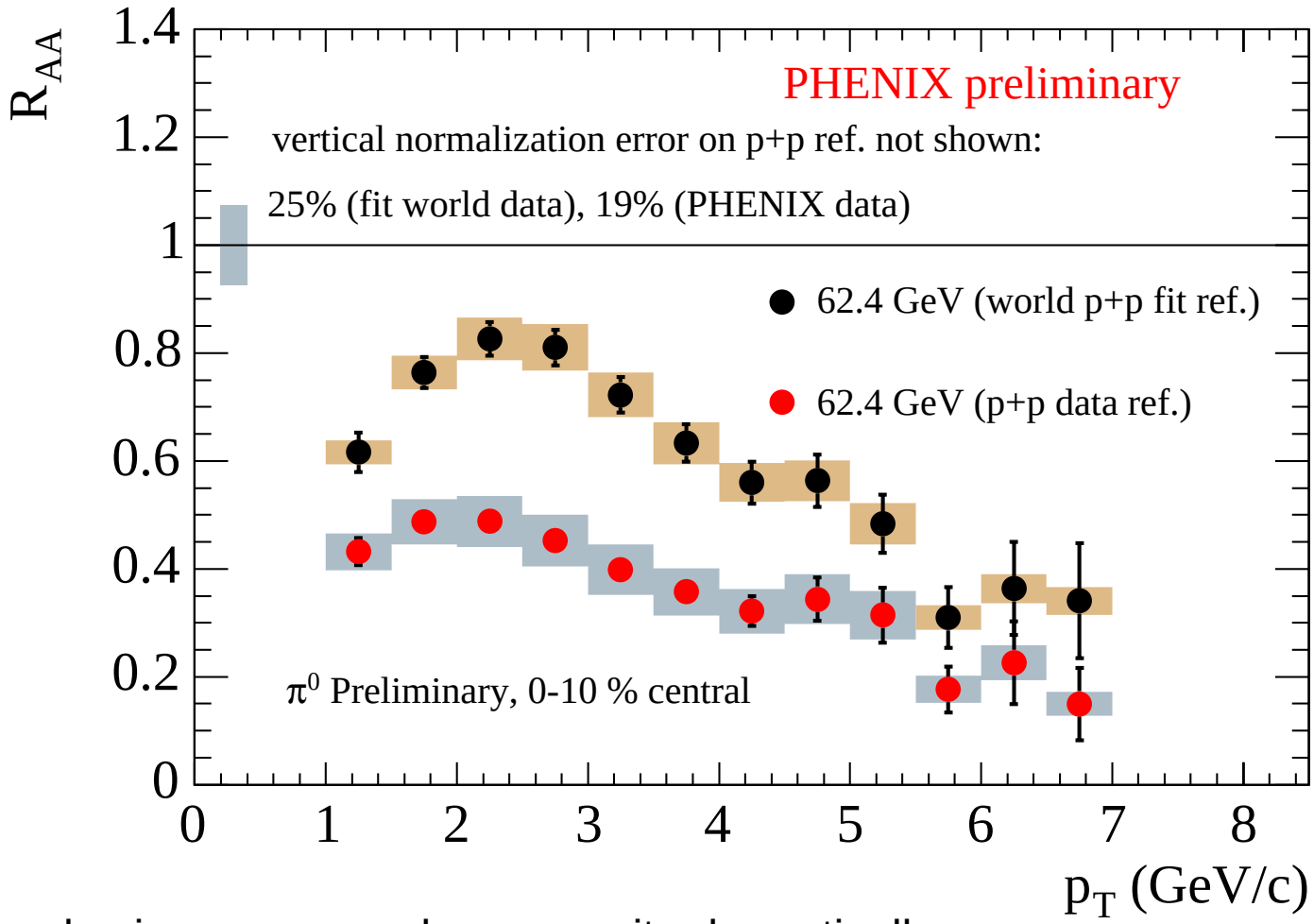
# $\pi^0$ $R_{AA}$ in 62GeV Au+Au – measured reference used

**NEW**




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

# $\pi^0$ $R_{AA}$ in 62GeV Au+Au – world data *vs* PHENIX data

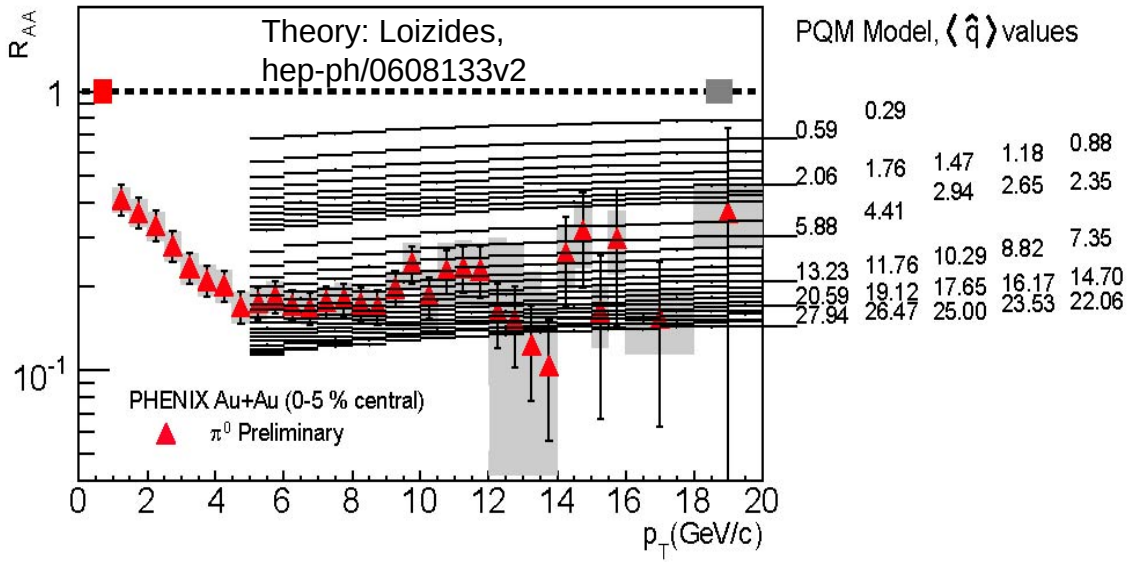



The physics message changes quite dramatically
(paranoid question: ***who is right*** ???)

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

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

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

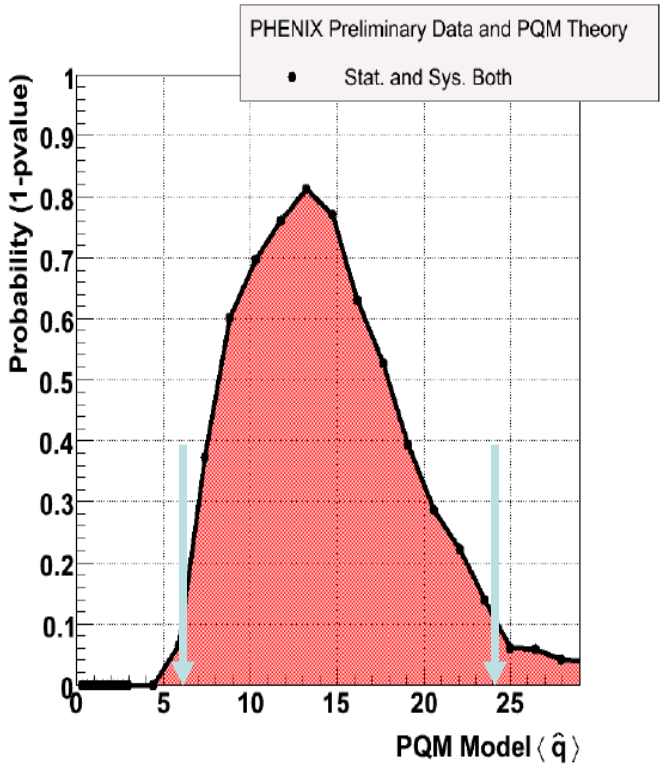



$$6 \le \langle \hat{q} \rangle \le 24 \ \ \mathrm{GeV}^2/\mathrm{fm}$$

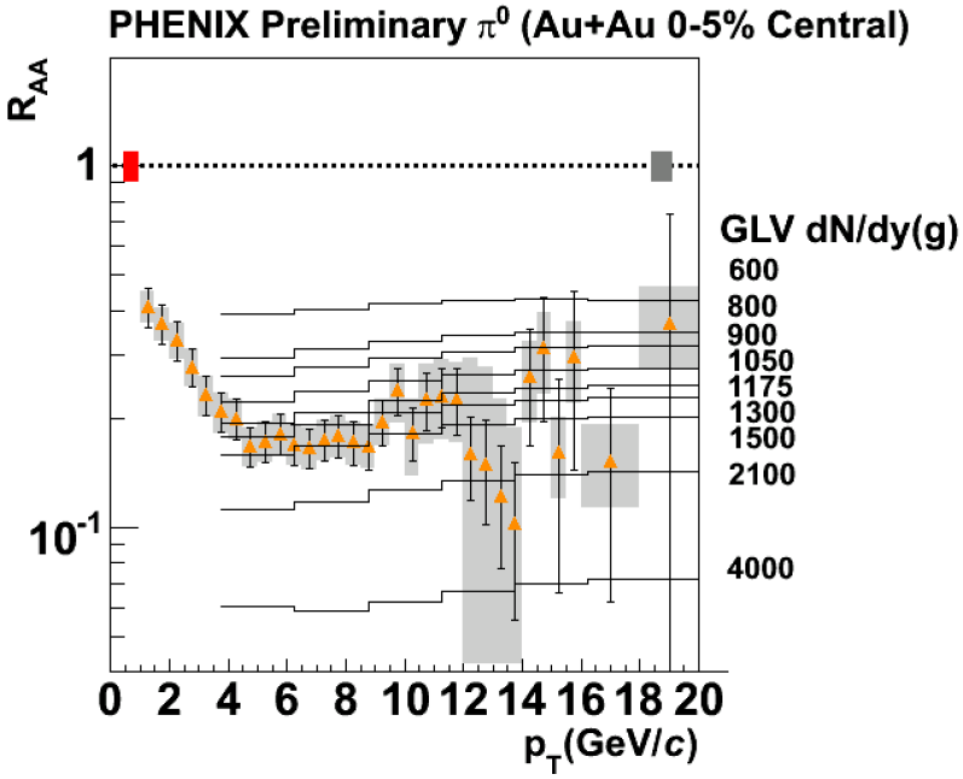
$$(\mathrm{Probability} > 10\%)$$

**Nice first try, but not very restrictive…**

**PQM, C. Loizides**
**hep-ph/0608133v2**



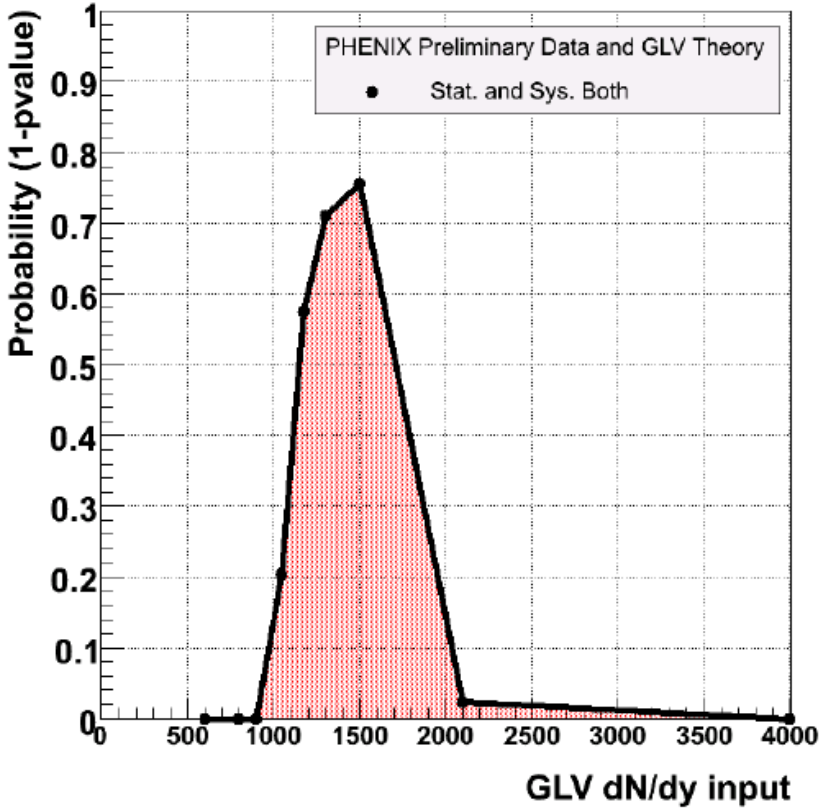
# What do we want to learn from this – and what precision is needed? / 2




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

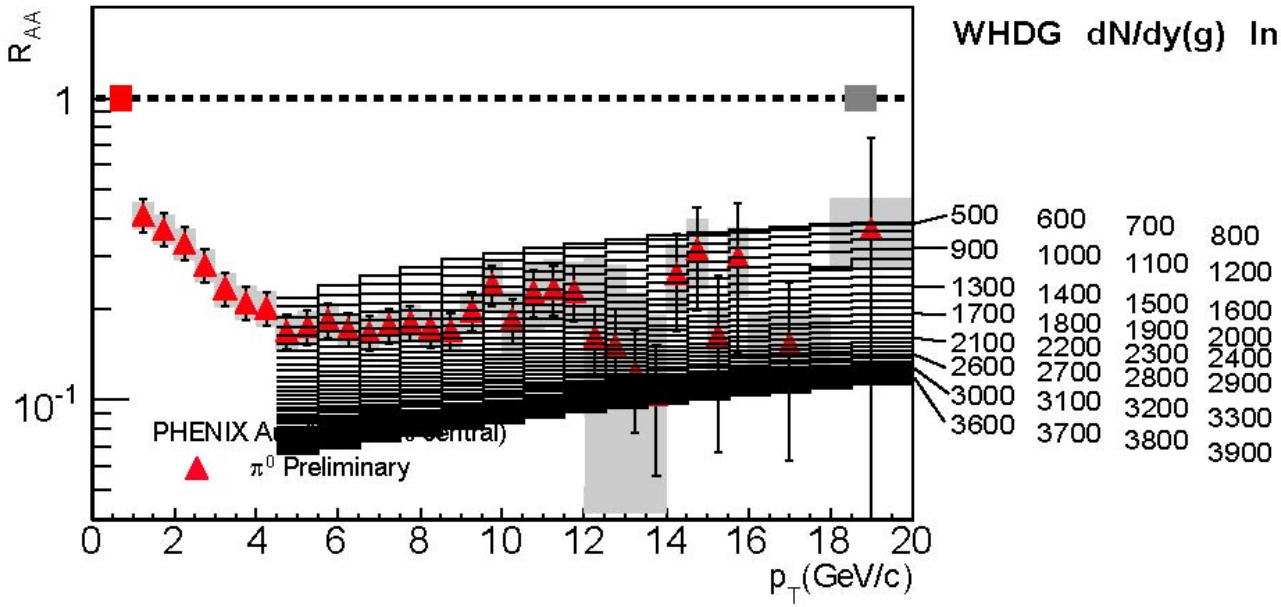
(Probability > 10%)

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



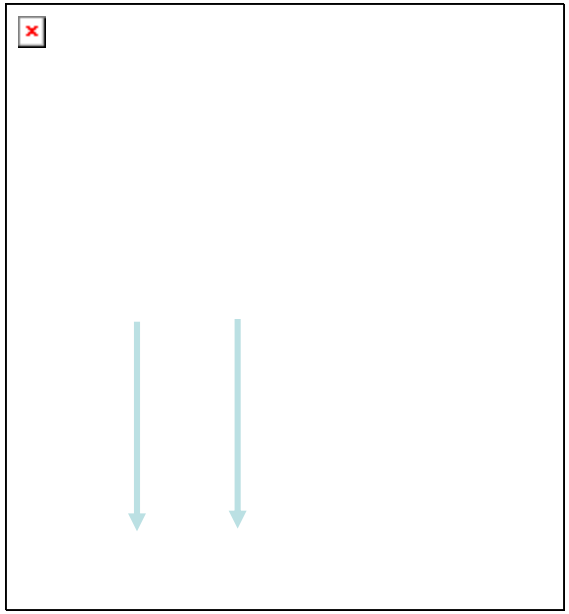
# What do we want to learn from this – and what precision is needed? / 3

**WHDG, William Horowitz**




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

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



# Precision, physics theorists and experimentalists

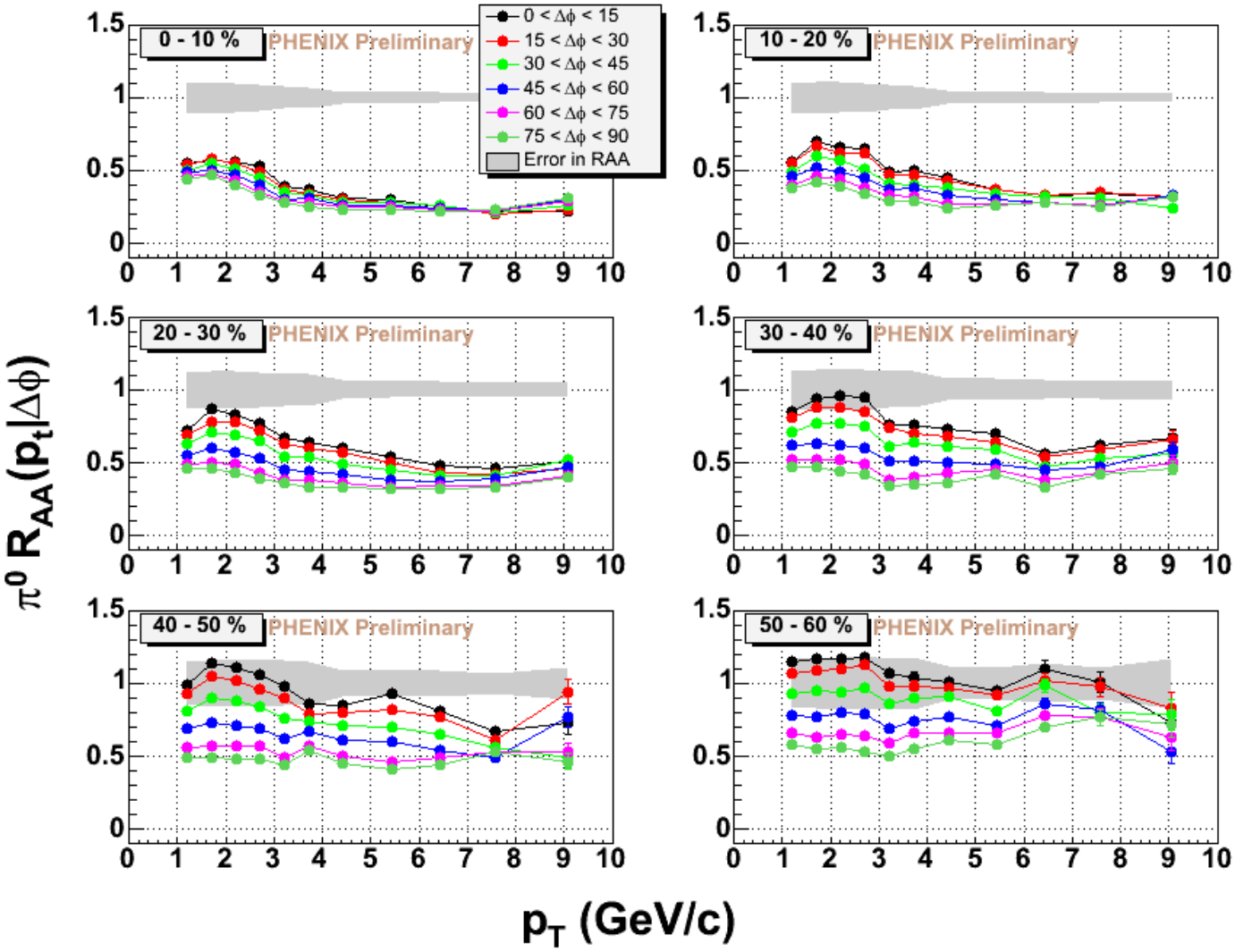
Our field is very rich, and doesn't cease to surprise us:

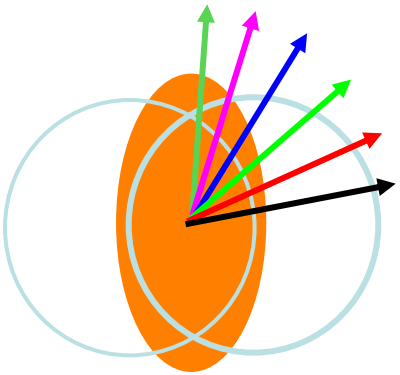
- some much anticipated signals of the QGP (like thermal photons, medium modifications of vector mesons, $\gamma$-jet correlations, …) are somewhat lagging behind for technical reasons
- other – less anticipated – signals became the rage overnight, sparking tremendous theoretical activity (like hadron 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

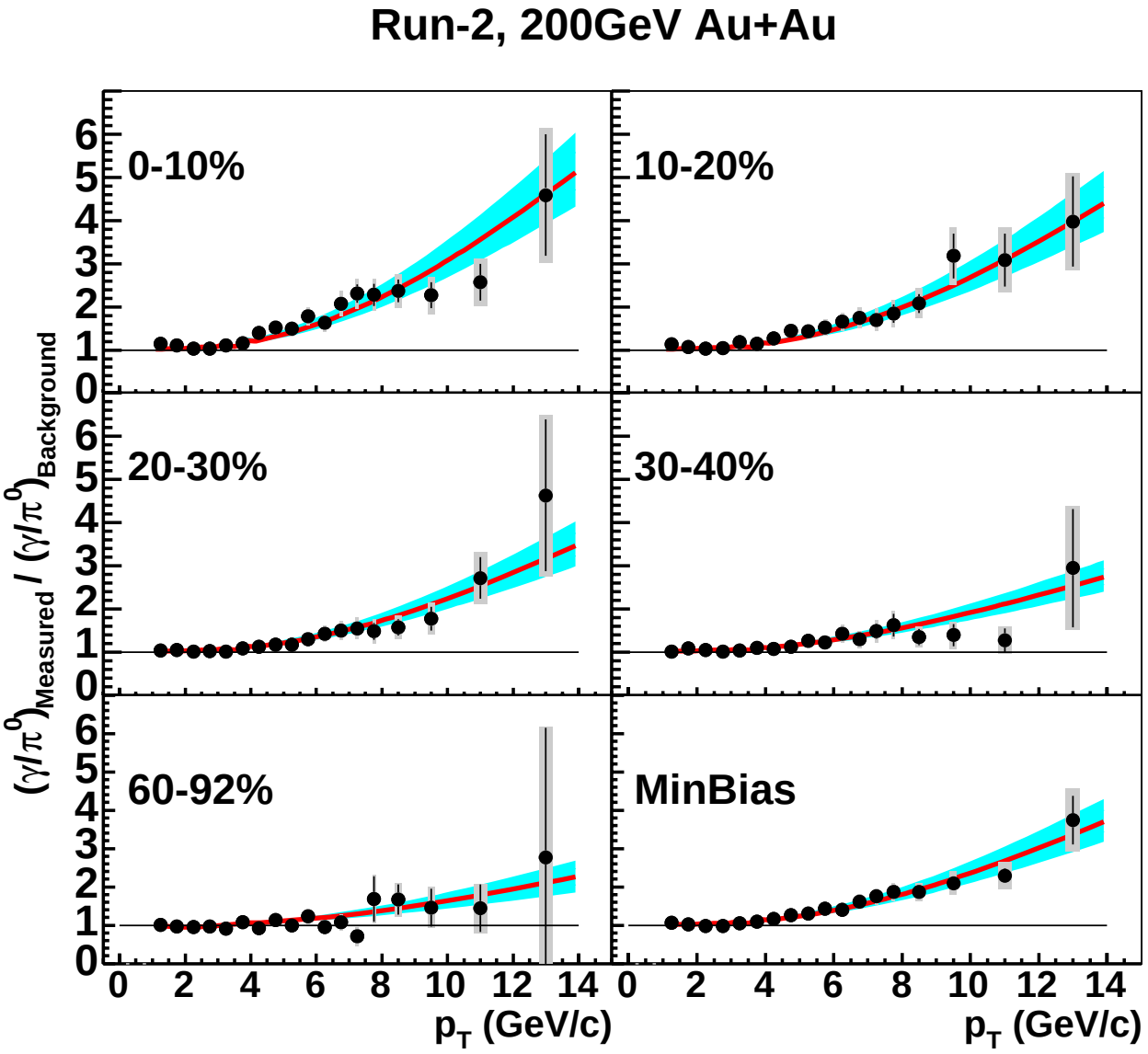
# First: direct photon excess, compared to NLO pQCD

Inclusive/decay photons
Technically:
"double ratio"

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

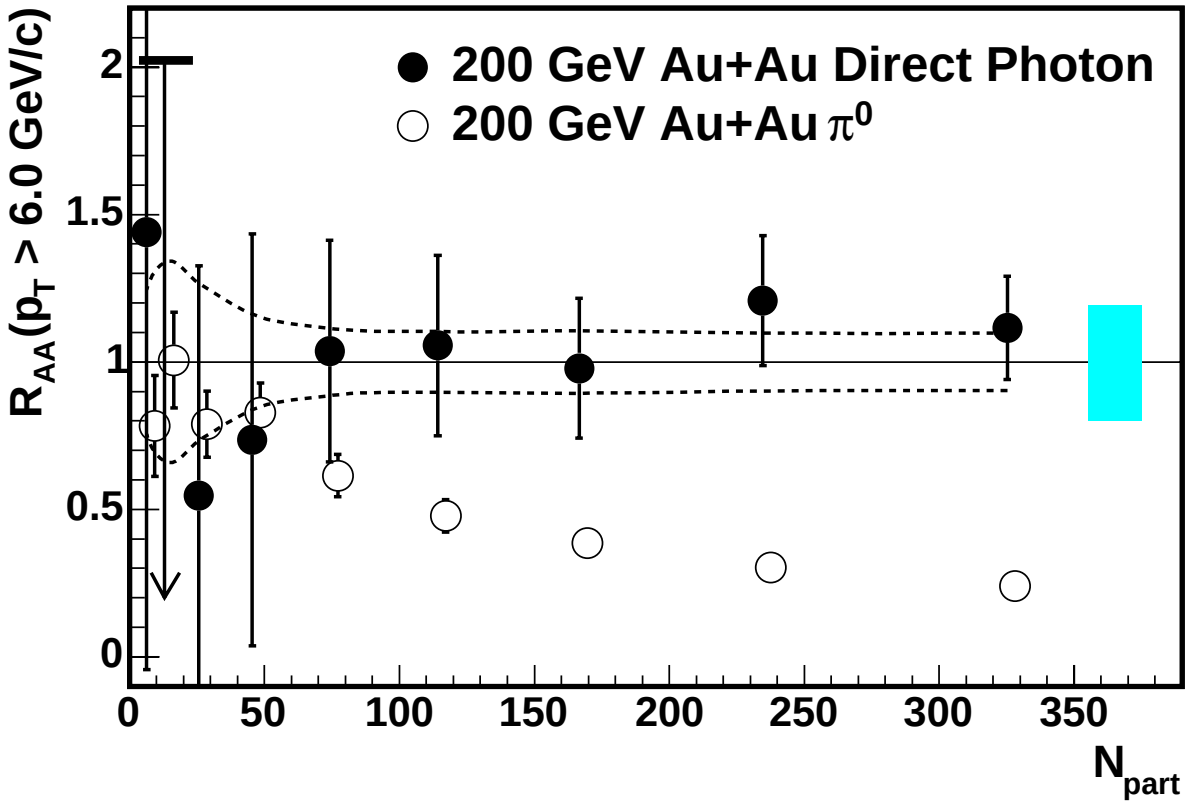
Curve, bands:
NLO pQCD, scaled with $T_{AB}$
Reasonable agreement

Large signal due to $\pi^0$ suppression
No statement on intermediate $p_T$



# Integrated photon $R_{AA}$ (using NLO pQCD)

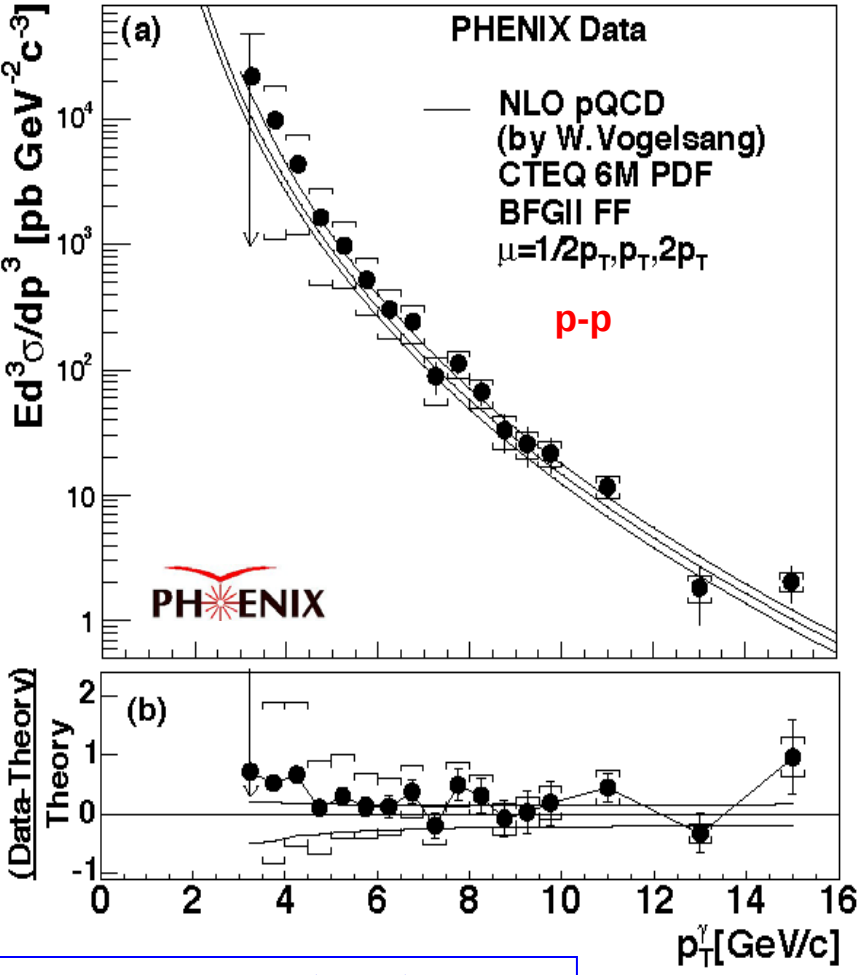
Consistent with unity at all centralities
Measurement up to 14GeV/c
Dominated by hard scattering (>6GeV/c) and unaffected by the medium
→ $T_{AB}$ scaling is a valid concept



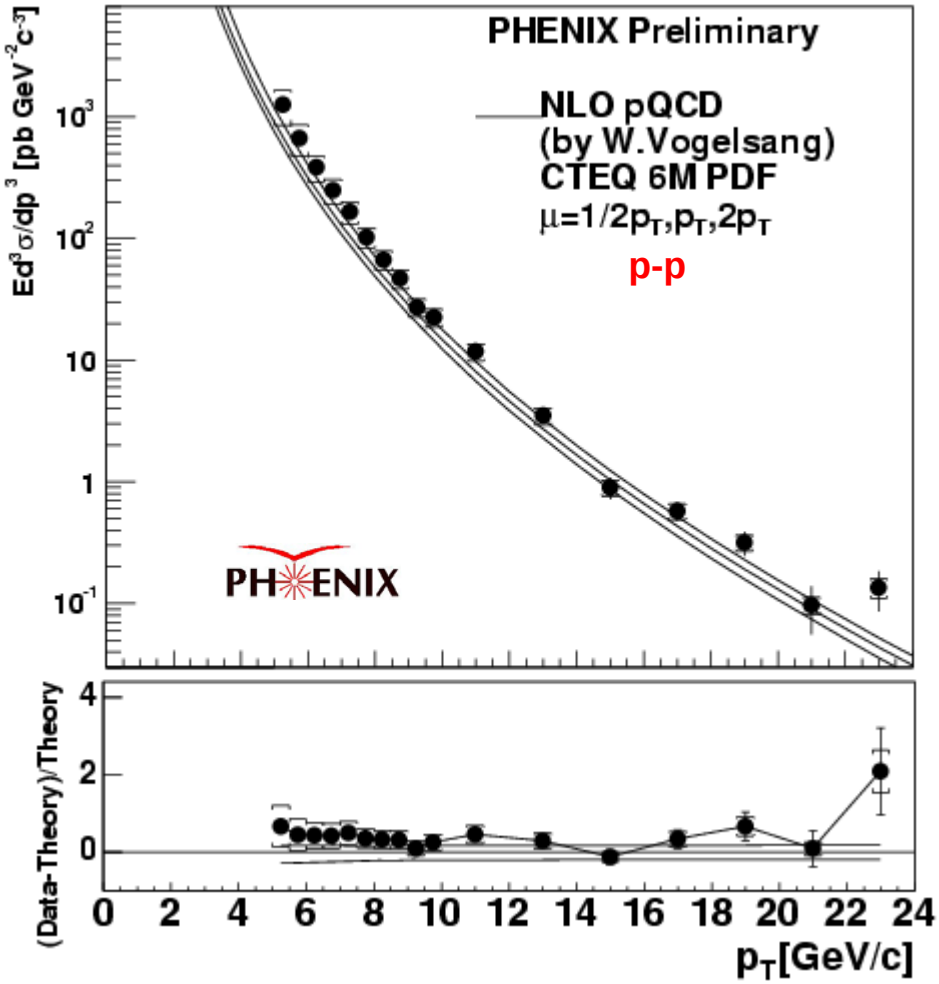

Integrated above 6GeV

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

# Direct $\gamma$ in p+p, PHENIX – data *vs* theory, old *vs* new




PHENIX PRL **98** (2007) 012002



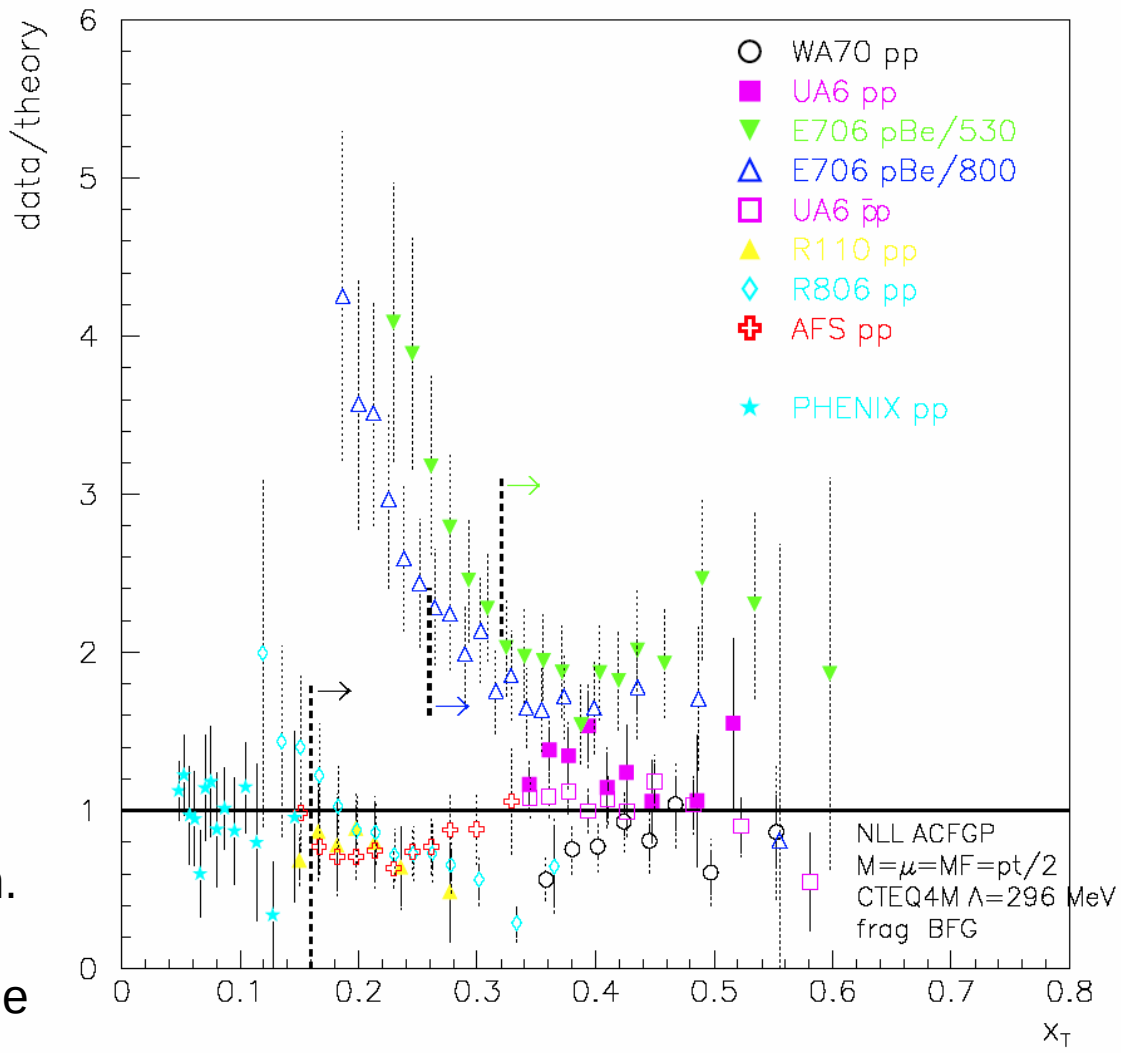

Published results $3<p_T<15$ GeV/c

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

# Direct $\gamma$ 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



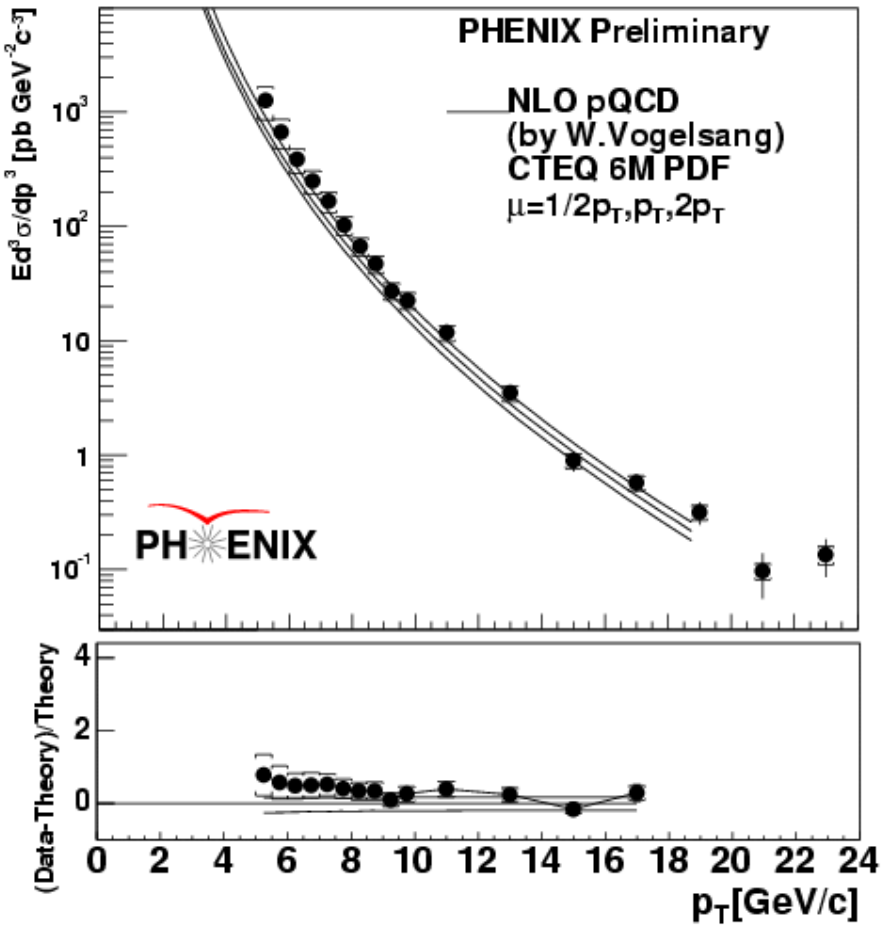

Published PHENIX data ("old", Run-3)

Longstanding issue with theory
→ seems to be settled now

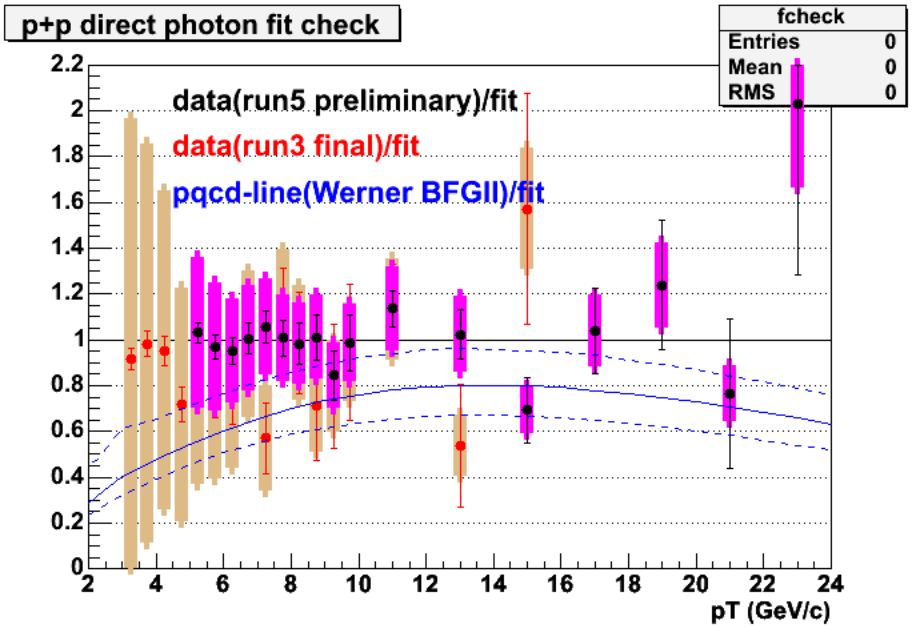
But note: the new, Run-5 prelim. data are ~20% higher; also seem to have a different shape than pQCD

# 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)

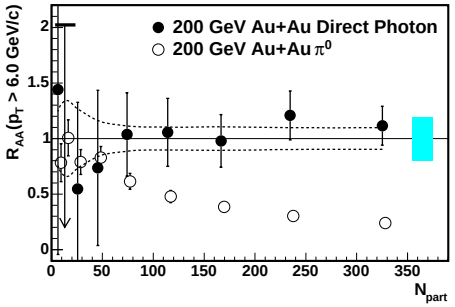


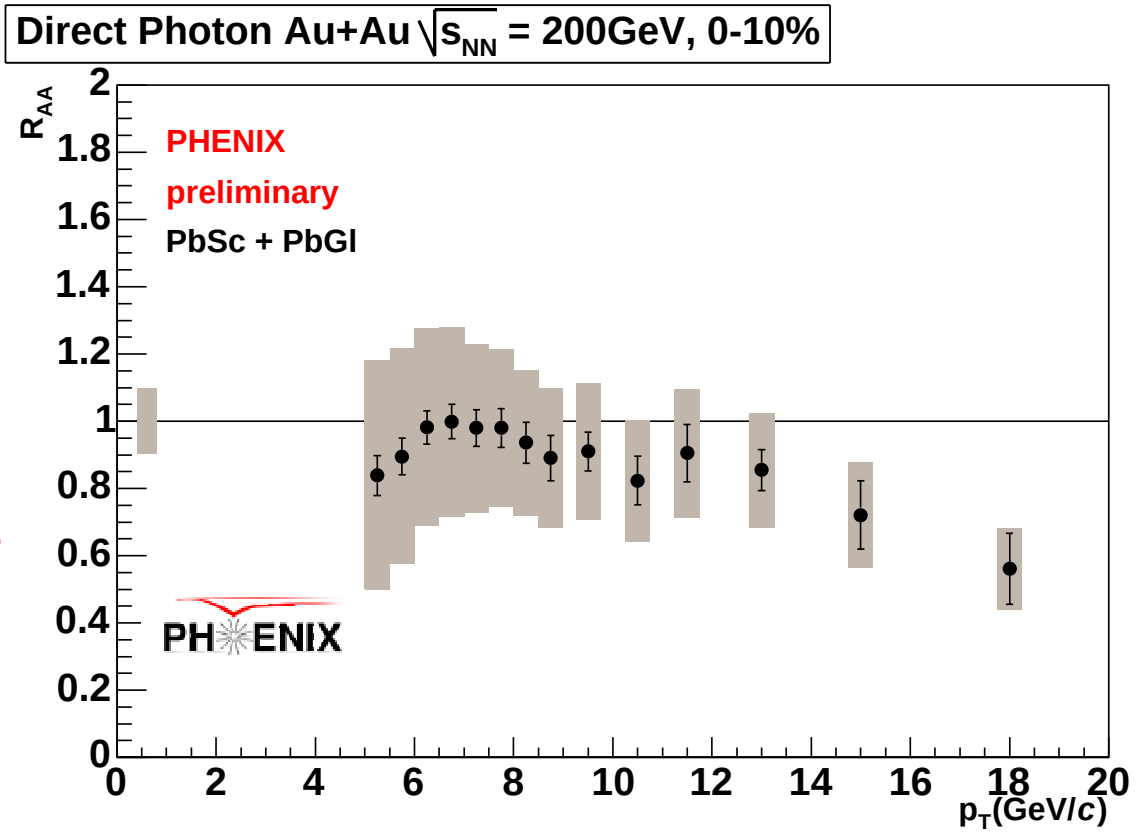
# Photon $R_{AA}$ central, 200 GeV with fit to p+p data

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



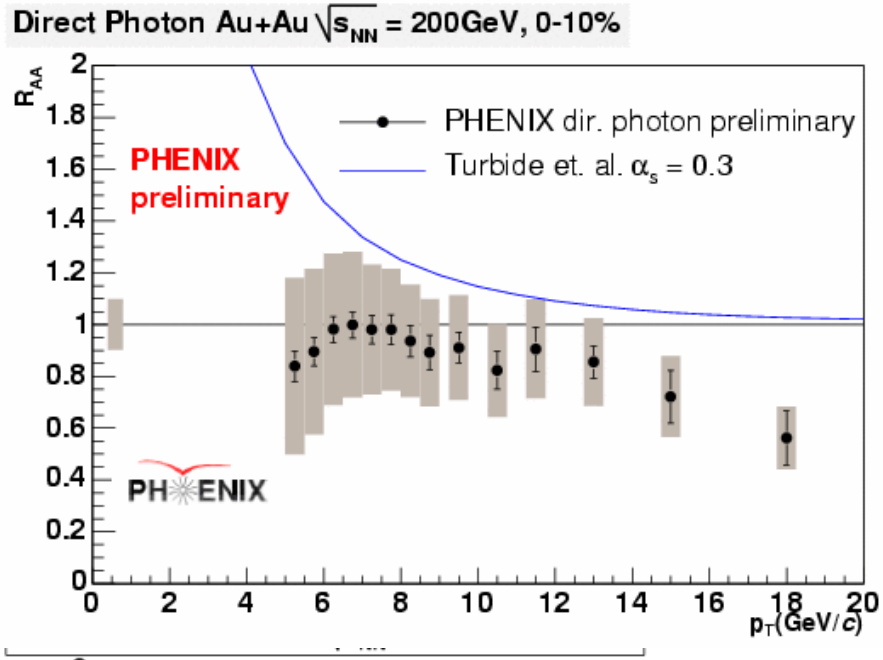



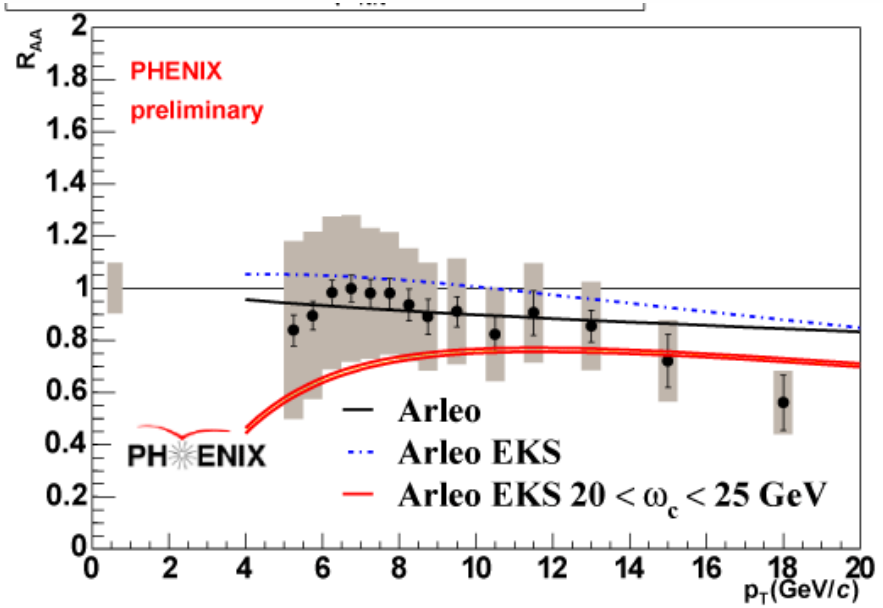

***Is the high $p_T$ suppression real?***

***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 $\gamma$ $R_{AA}$ 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

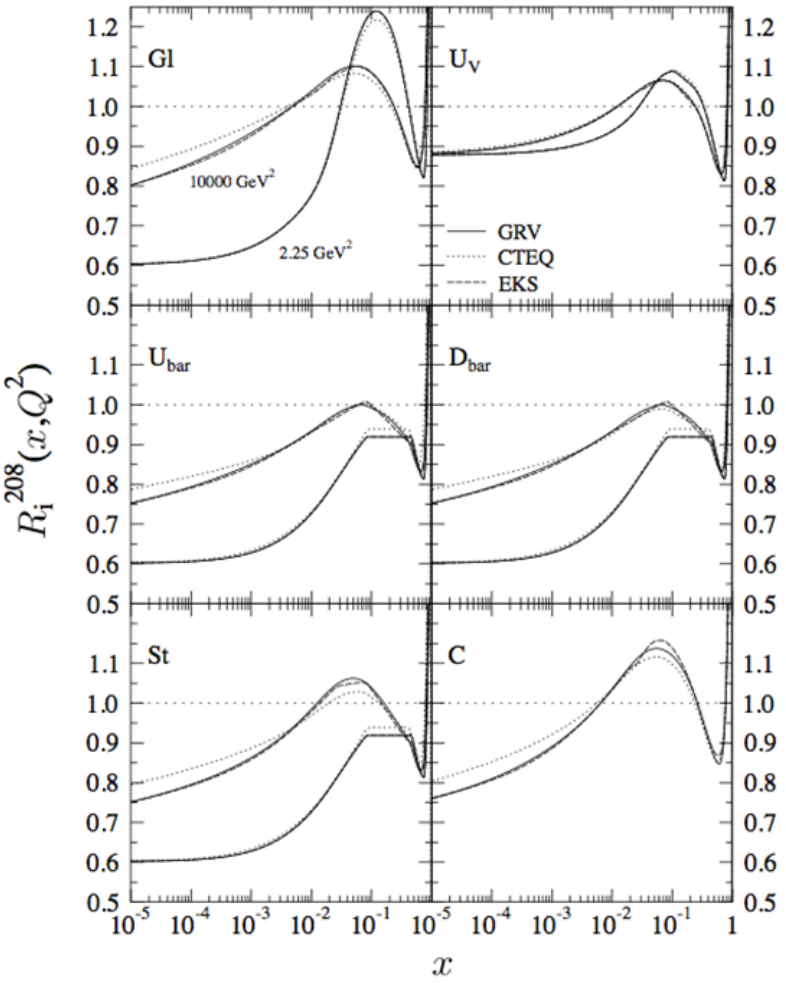



**Fig. 1.** The nuclear ratios $R_i^A(x,Q^2)$ for individual parton flavours $i = g, u_V, \bar{u}, \bar{d}, s, c$ of a lead nucleus $A = 208$ as functions of $x$ at fixed values of $Q^2 = Q_0^2 = 2.25$ GeV$^2$ and $Q^2 = 10000$ GeV$^2$ as obtained by using the GRV-LO [25] distri-

# PHENIX – "Isospin Effect" (?)

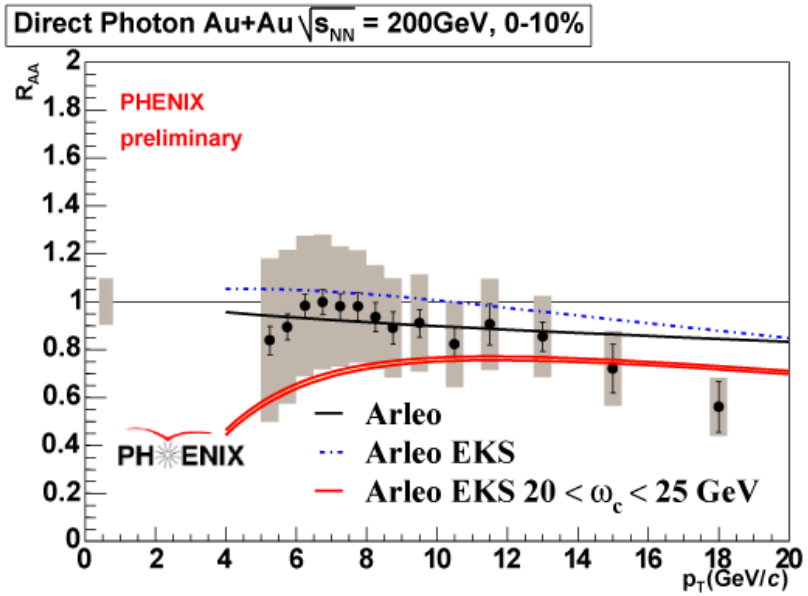
The isospin effect (charge square difference between **uud** and **udd**) **SHOULD** be there, but is this (and only this "trivial effect") what we see?

Or do we see in addition some genuine photon suppression?

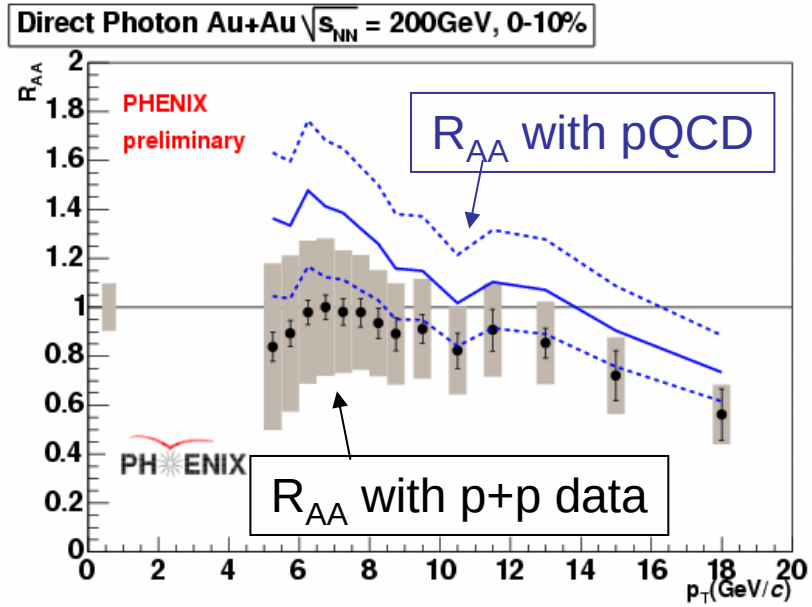
**No contradiction here: only "primordial" photons should be unaltered, "medium-induced" photons can be enhanced or suppressed**

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

**F. Arleo, JHEP09 (2006) O15**

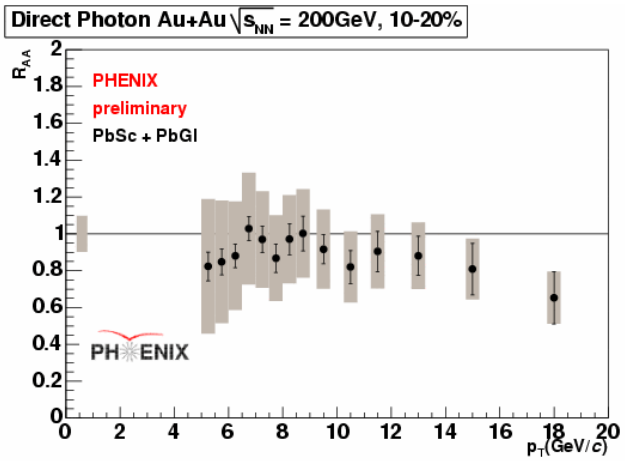


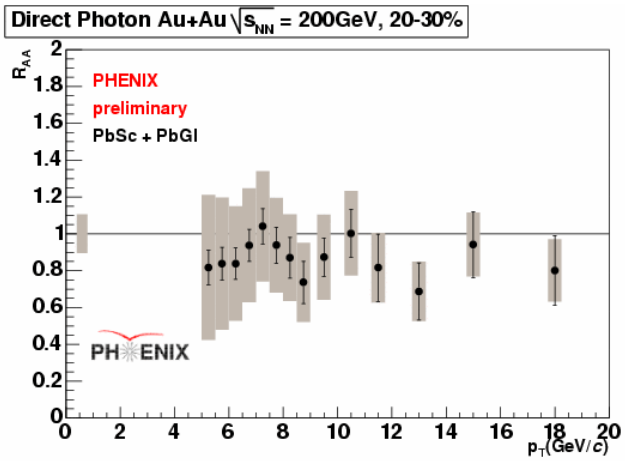

**W. Vogelsang, NLO pQCD + isospin**

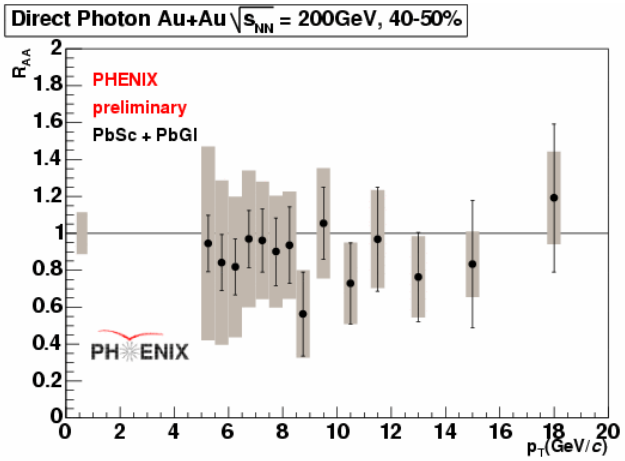


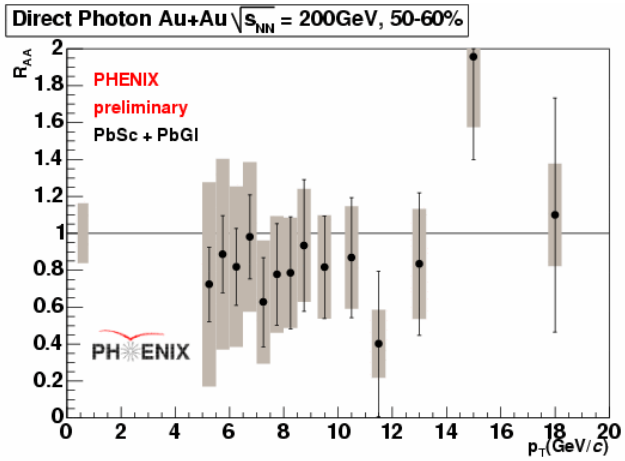
# Isospin Effect – Statistics?

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

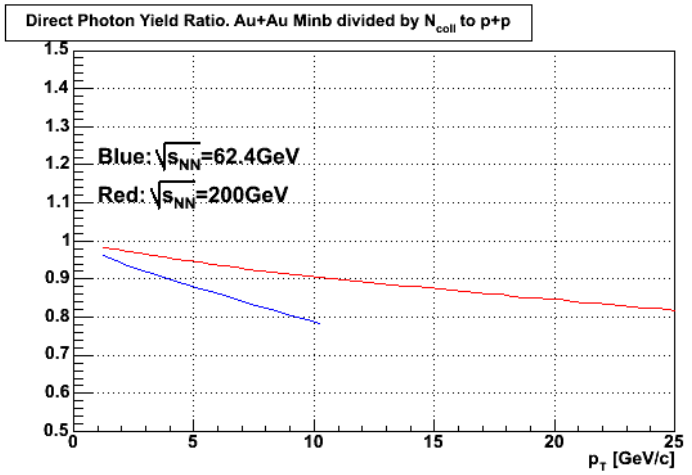
Unfortunately the suppression is seen in a region where we are very sensitive to detector bias (cluster merging).

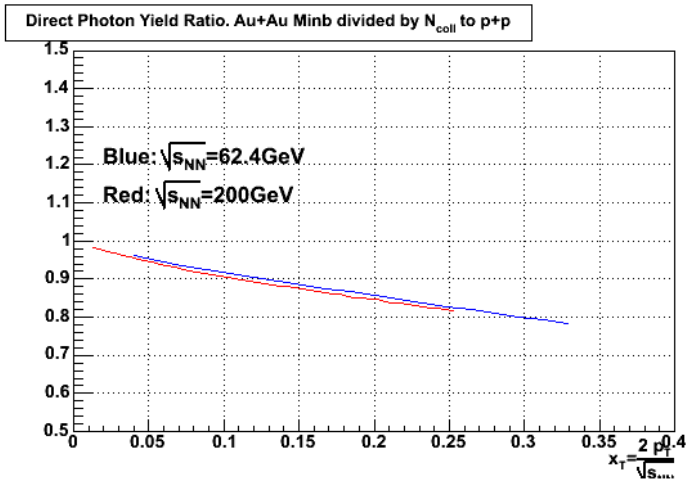
Also, so far it was seen only in one of the detectors (the one more prone to merging)

$x_T$ 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!**



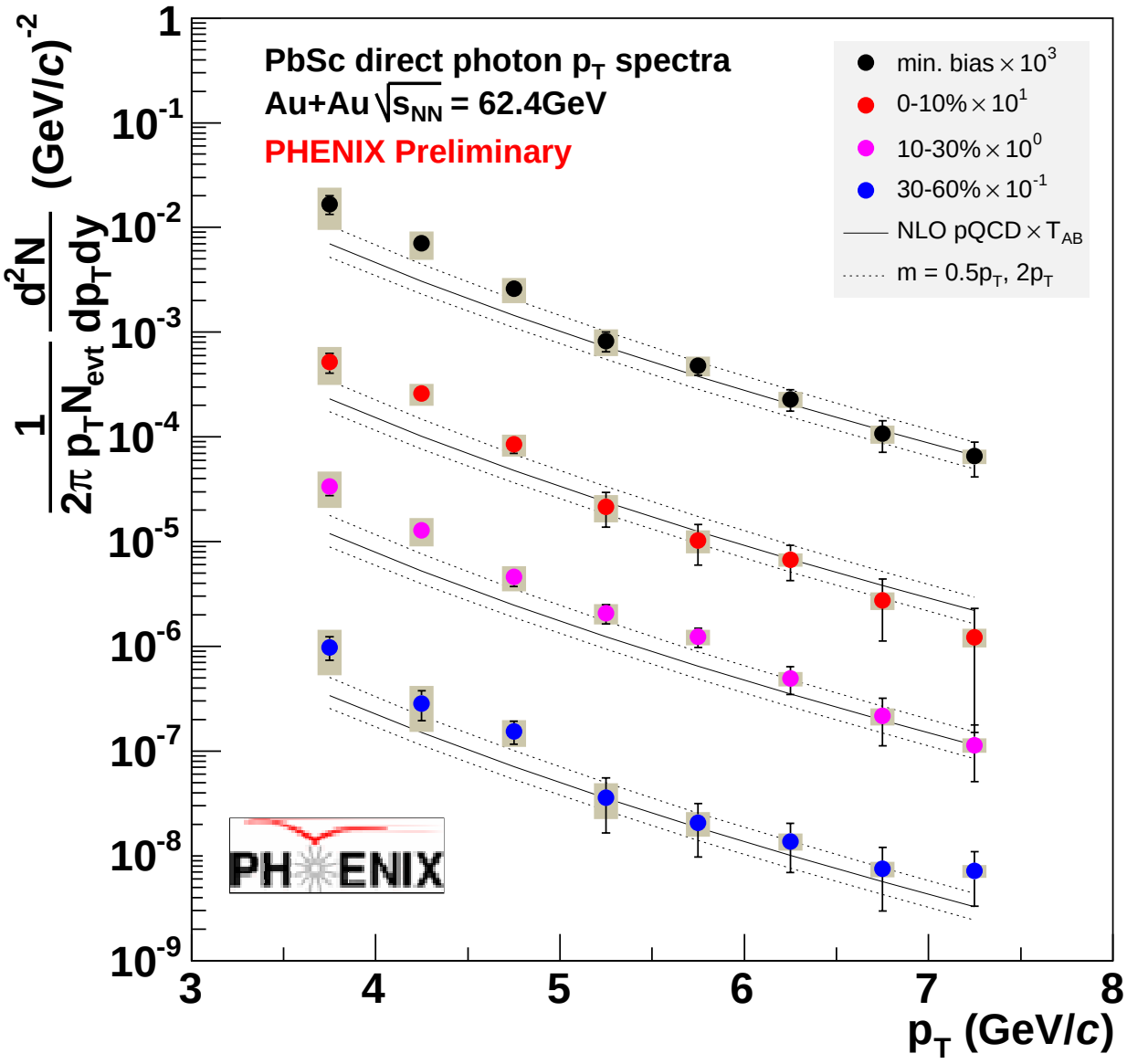



# Brand new: direct photons in 62GeV Au+Au

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

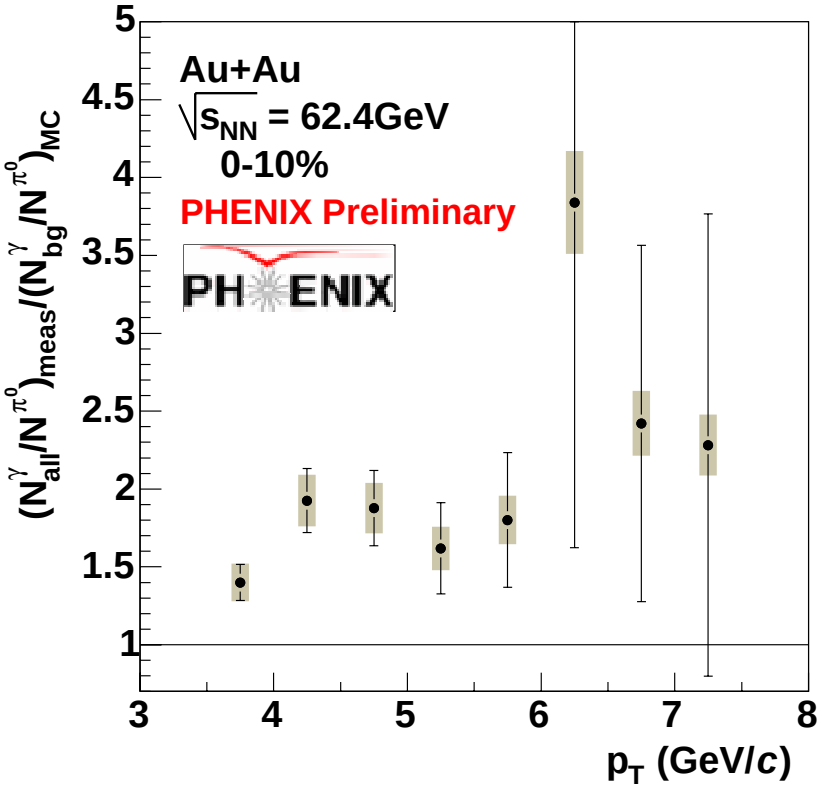
Lines: $T_{AB}$-scaled pQCD

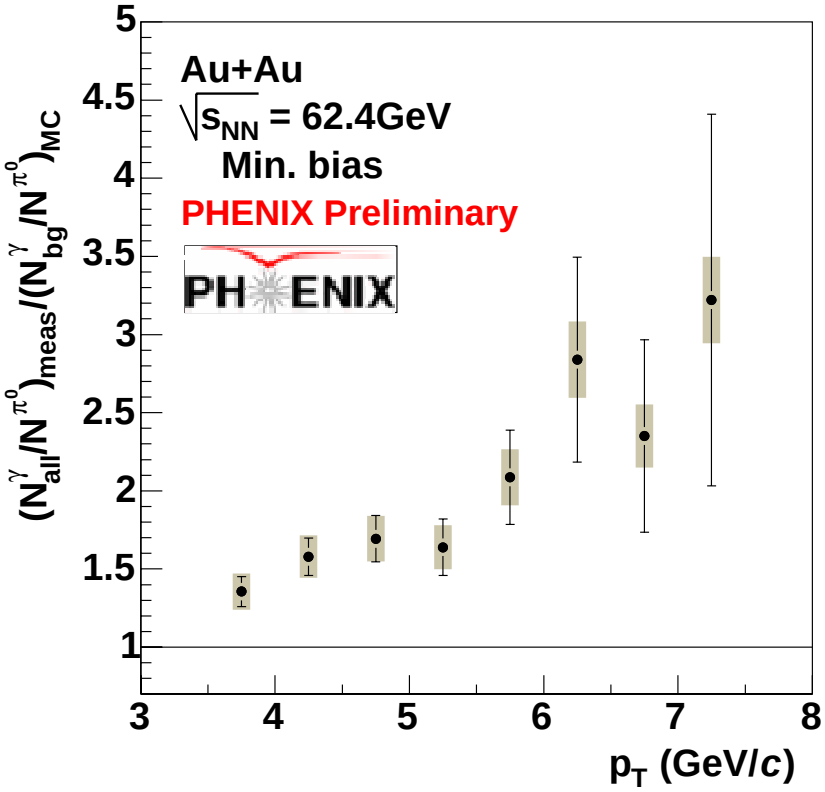
Note the same tendency as for $\pi^0$ (and 200GeV p+p): favors $0.5p_T$ scale



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

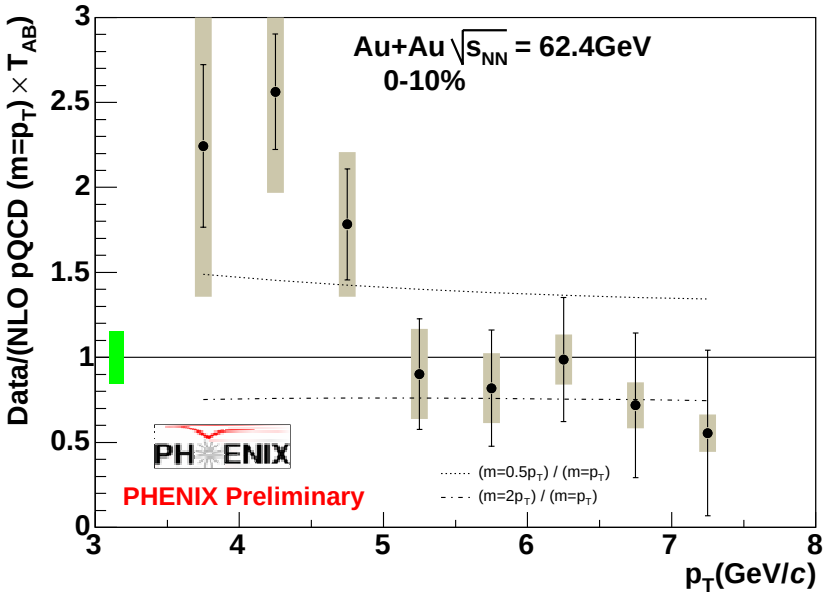
$(\gamma/\pi^0)_{meas}/(\gamma/\pi^0)_{had}$

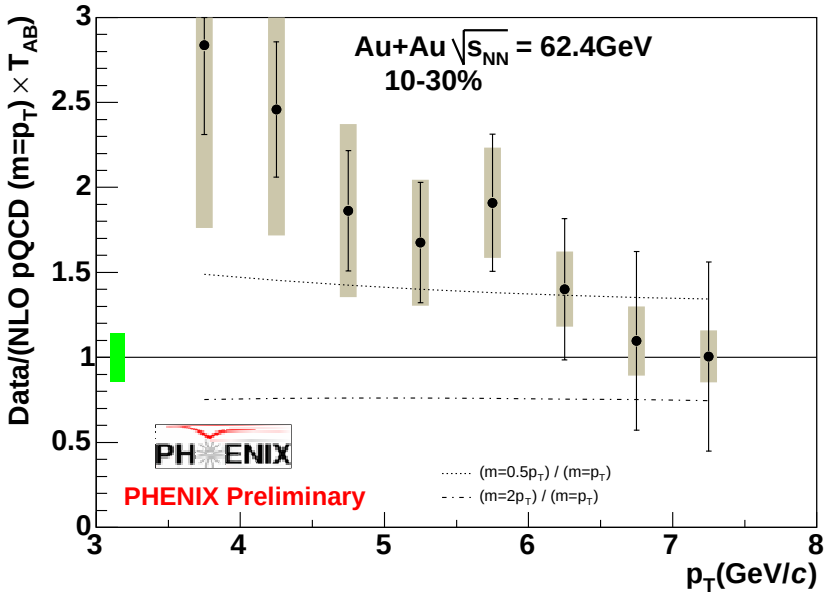


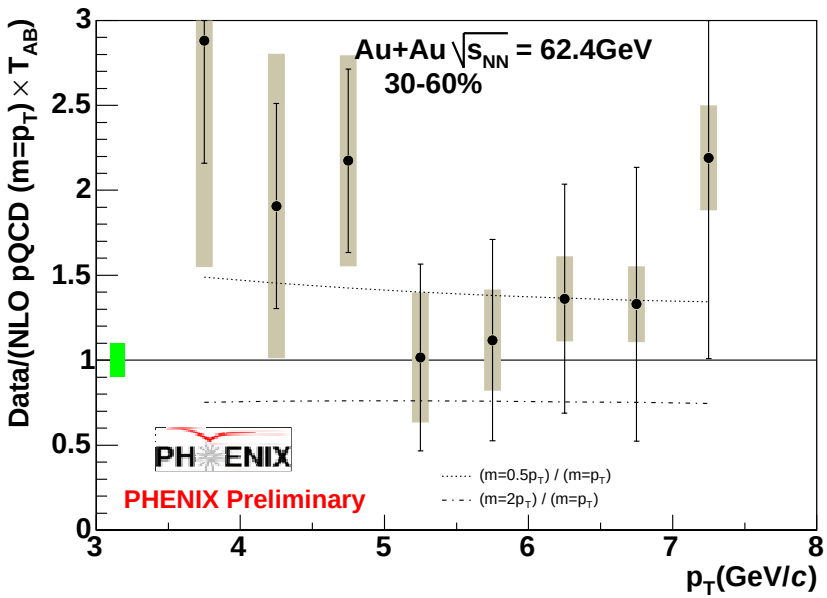



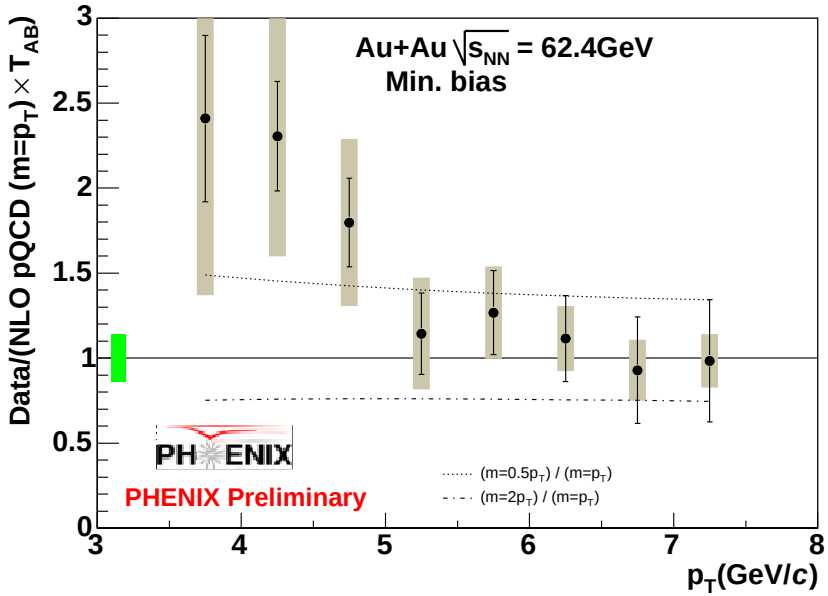

Remarkably high – keep in mind pion suppression!

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

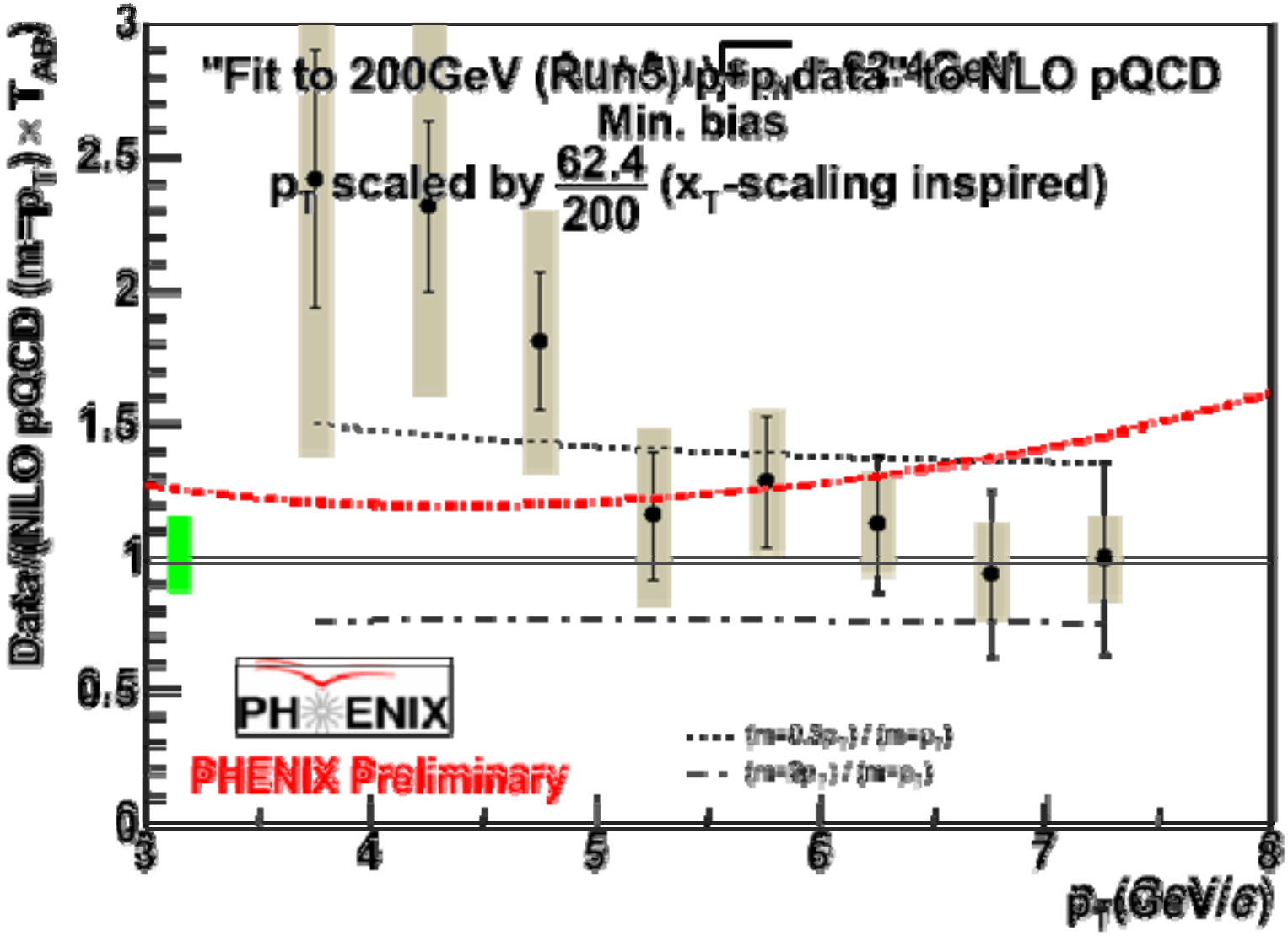


# Photon $R_{AA}$ : don't take this literally!



# 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 $\pi^0$ $R_{AA}$ 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!**