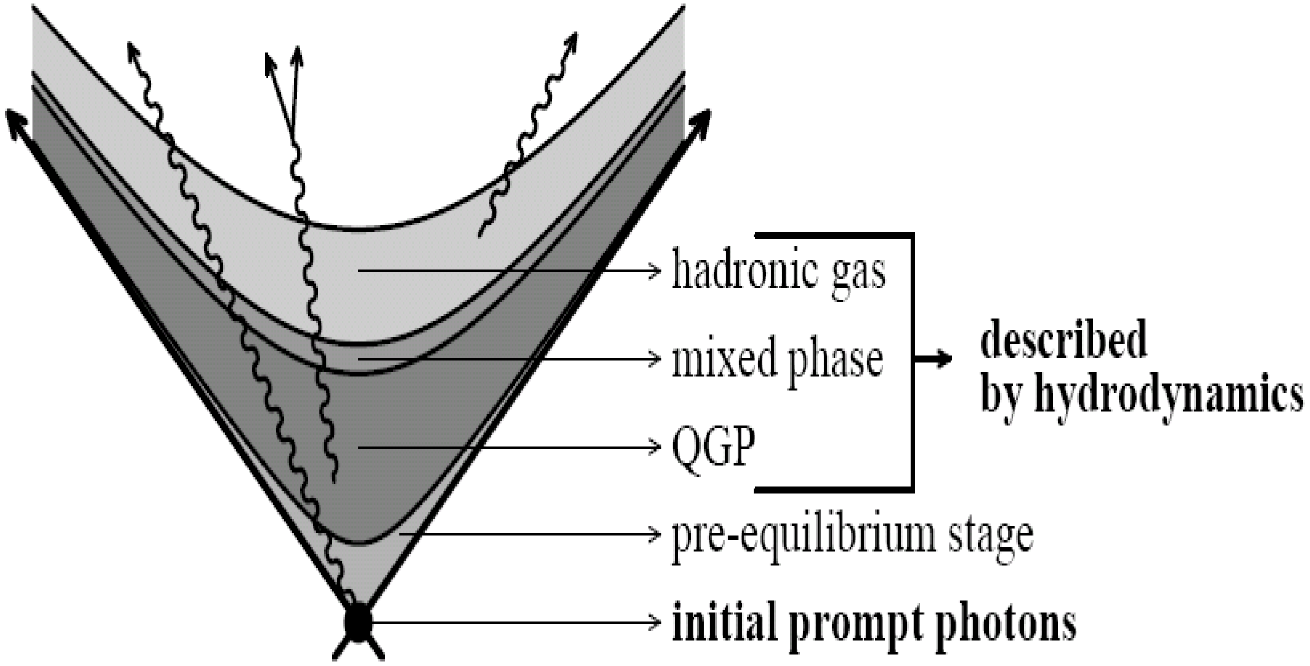
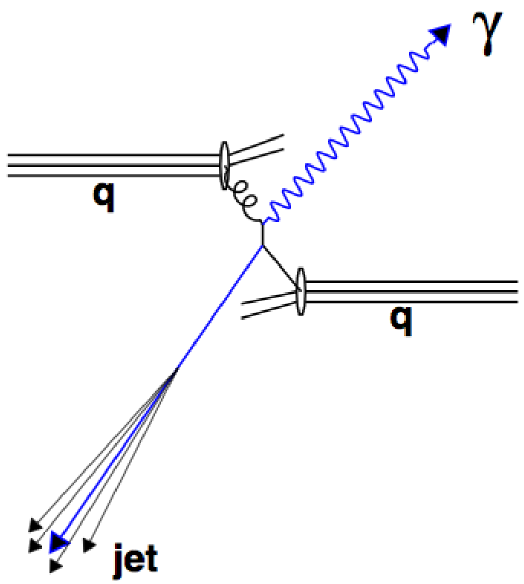
Direct photon overview

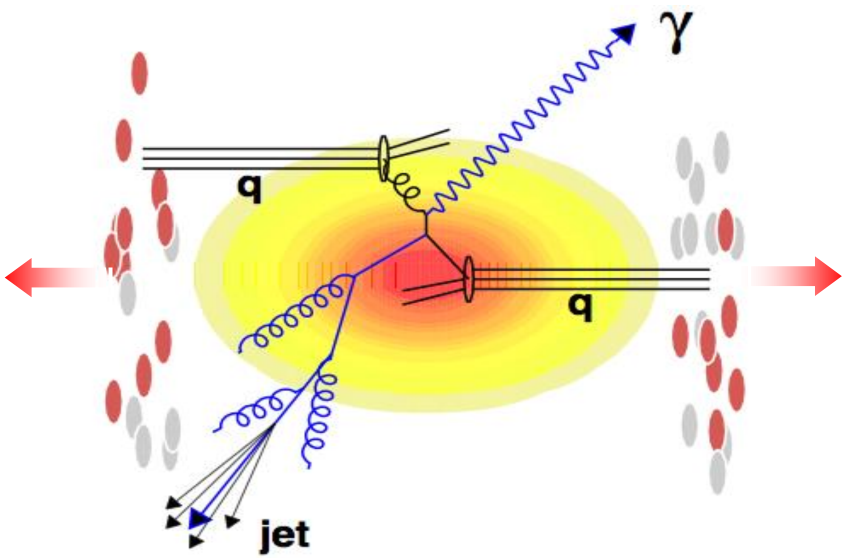
G. David
Stony Brook University

The Relativistic Heavy Ion Group at Stony Brook University is looking for graduate student(s) (PhD) starting the Fall semester 2018. If you are interested, please talk to me!

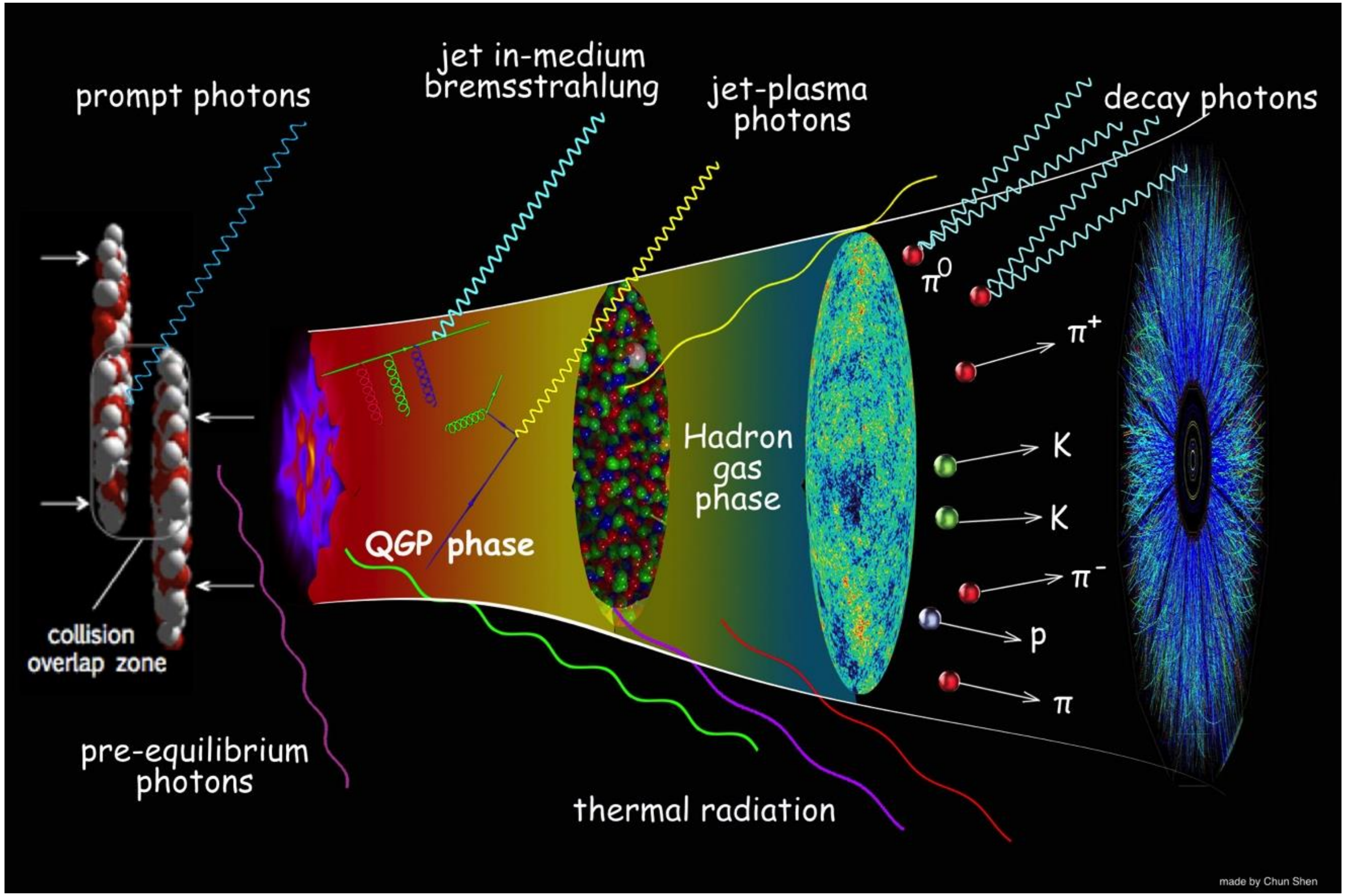
The educational slide







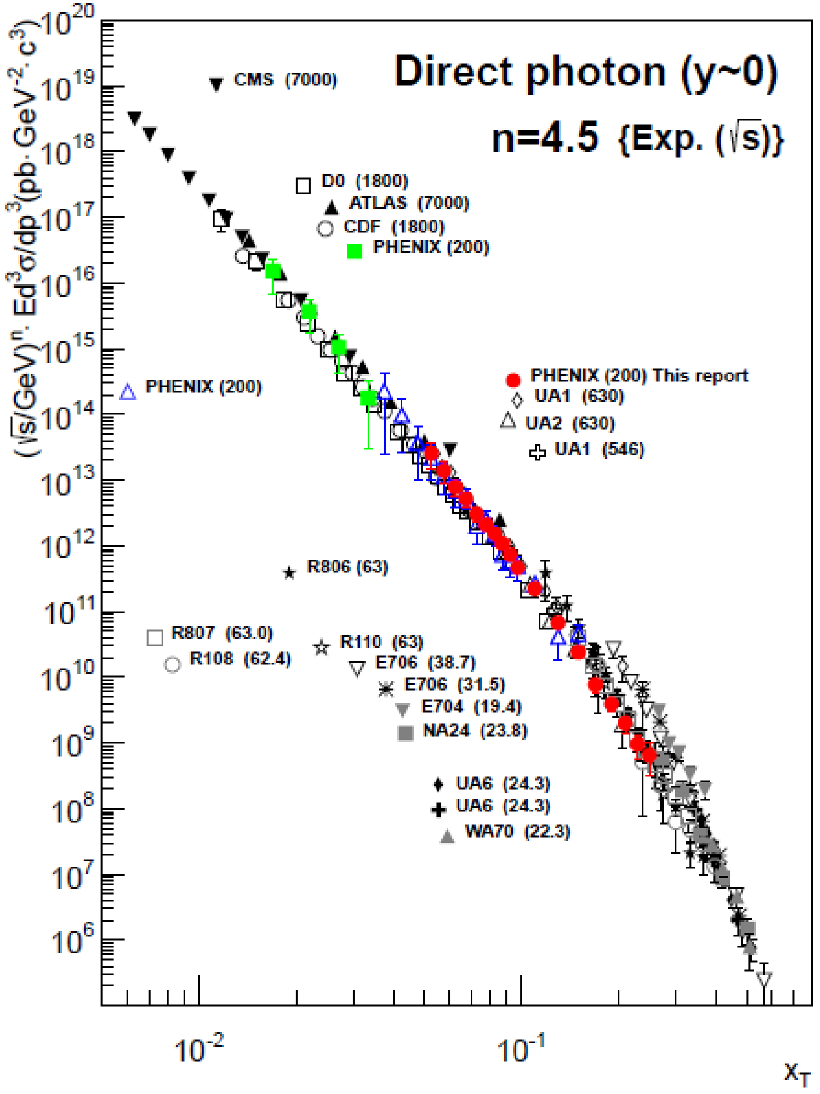
The educational slide



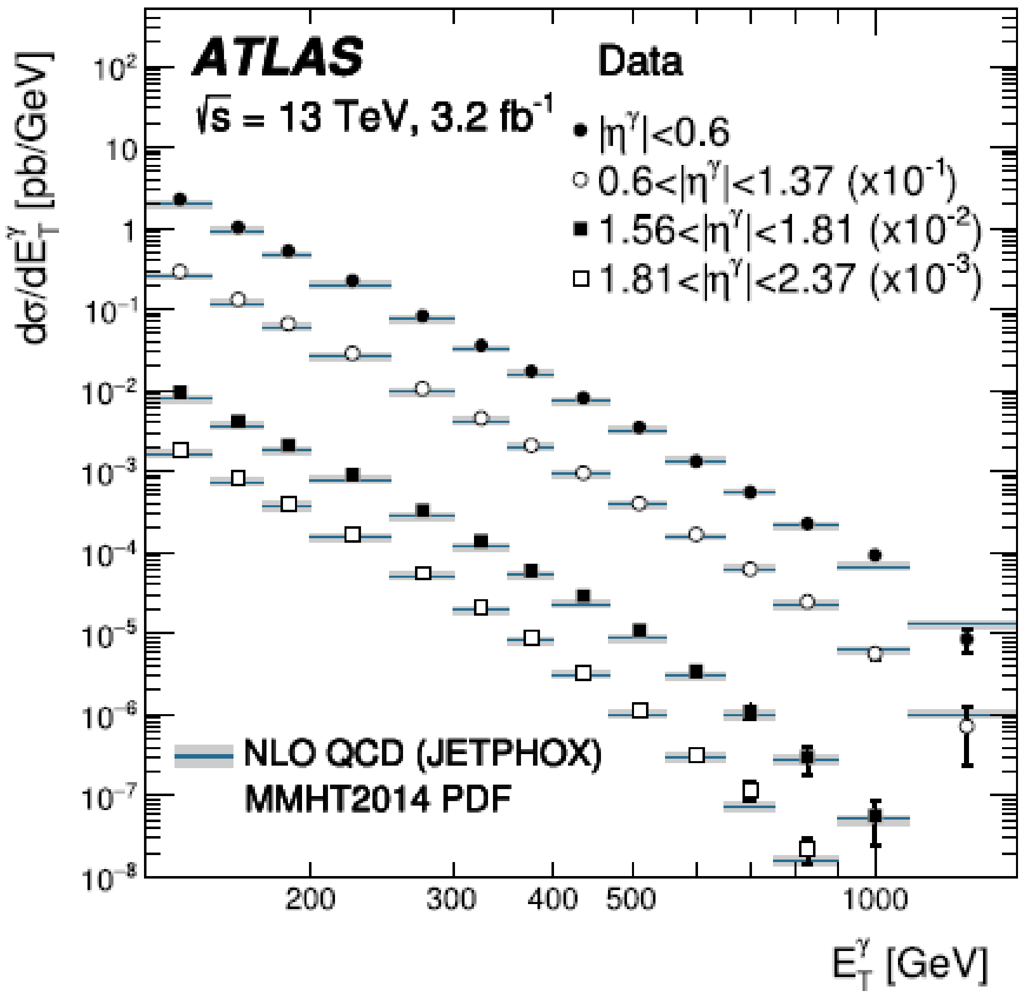
High pT direct photons
standard candle for “centrality”

High pT photons are well behaved in p+p

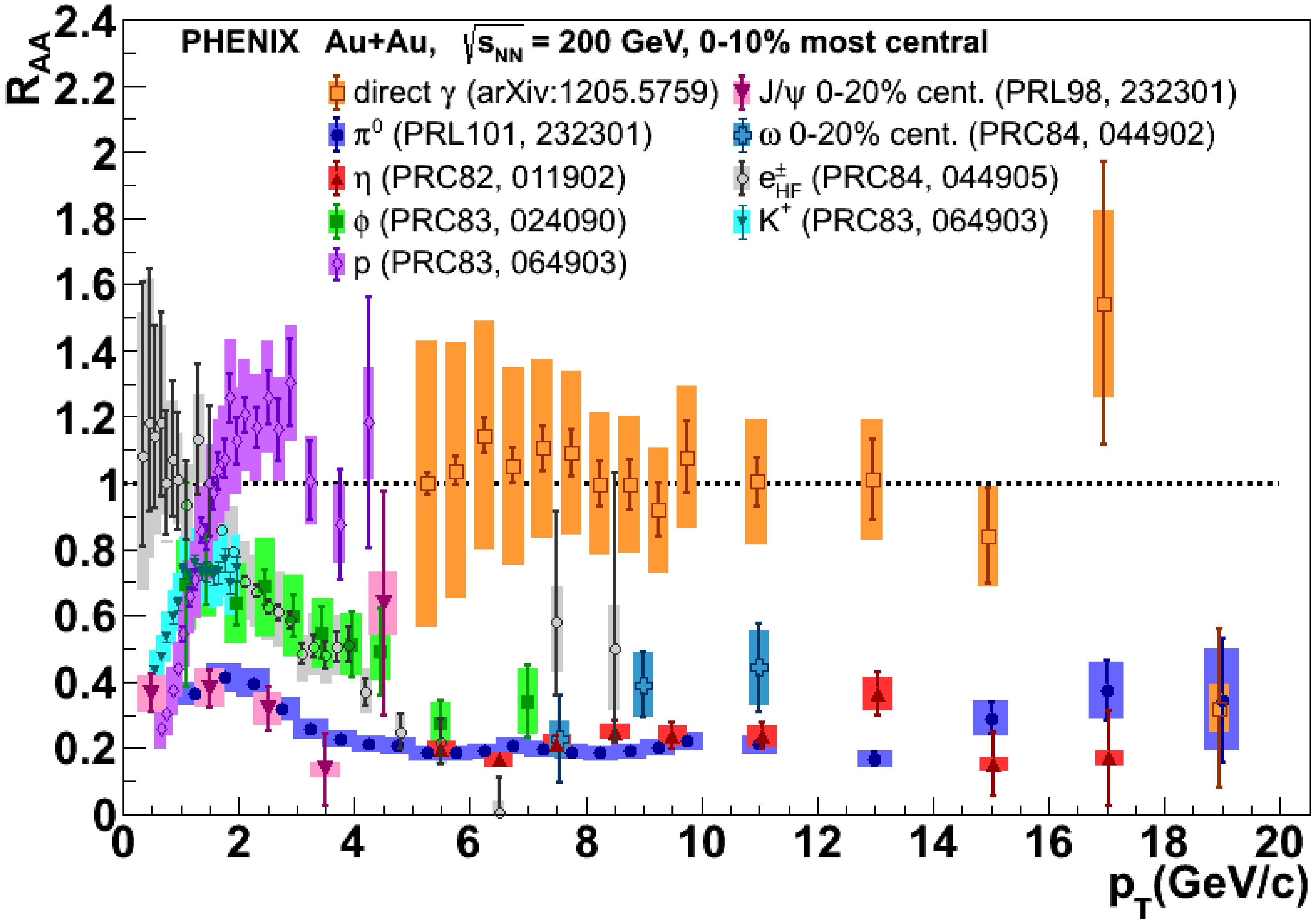
PRD 86 072008



ATLAS PLB 770 (2017) 473



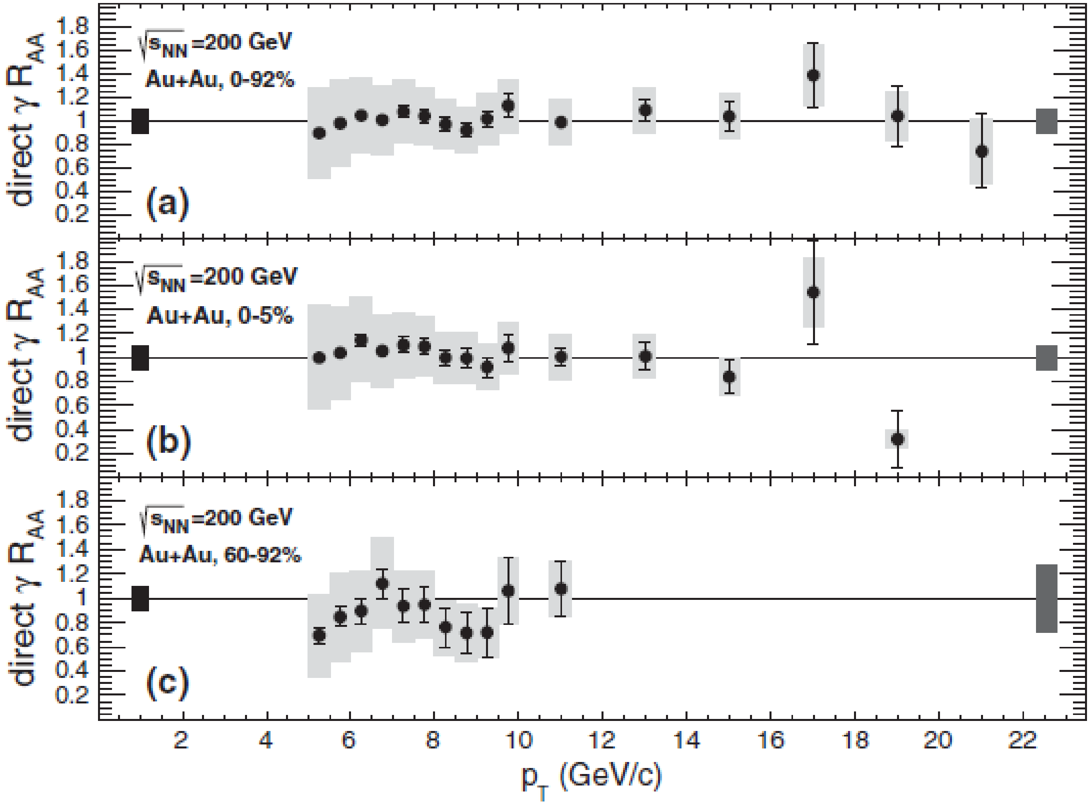
High pT (isolated) photons are immune to the medium



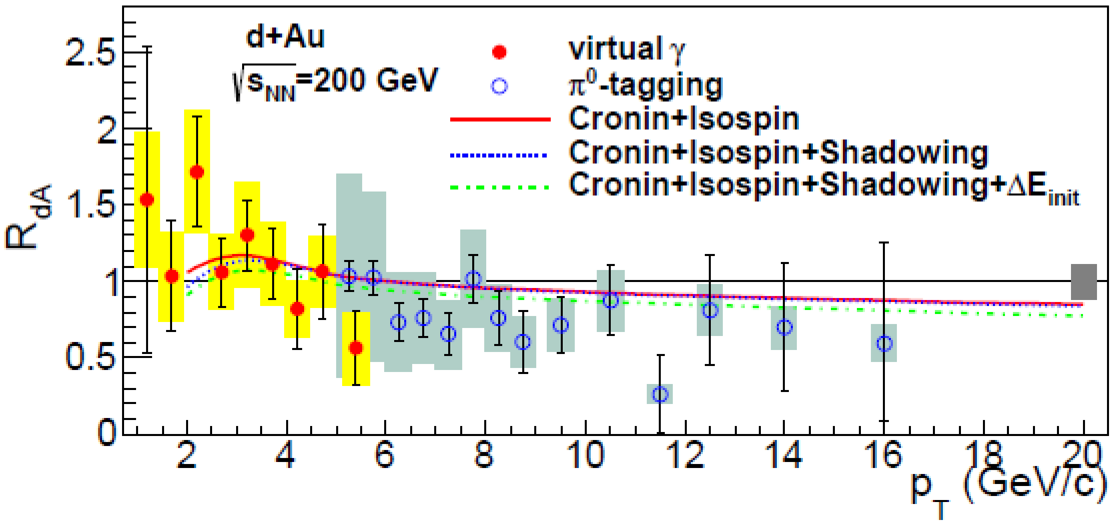
High pT (isolated) photons are immune to the medium

In A+A collisions, while hadrons are strongly suppressed,
and in a p_T-dependent way, photons appear to be unaffected

PHENIX PRL 109, 152302 (2012)



PRC 87, 054904 (2013)



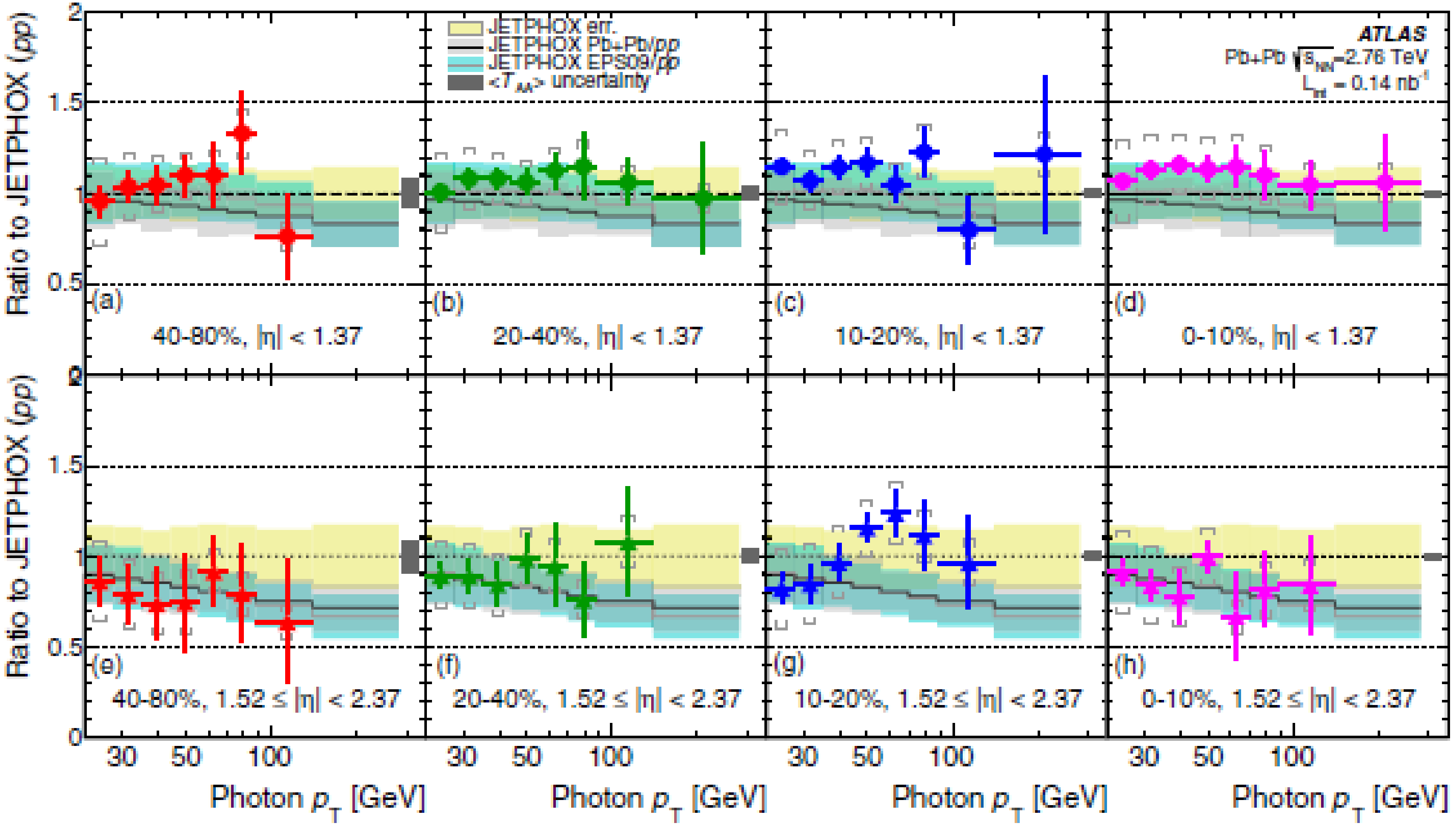
Watch out for the slight deviation from unity
due to the isospin effect

All right, this is MB, but stay tuned!

ATLAS, Pb+Pb

ATLAS, PRC 93, 034914 (2016)

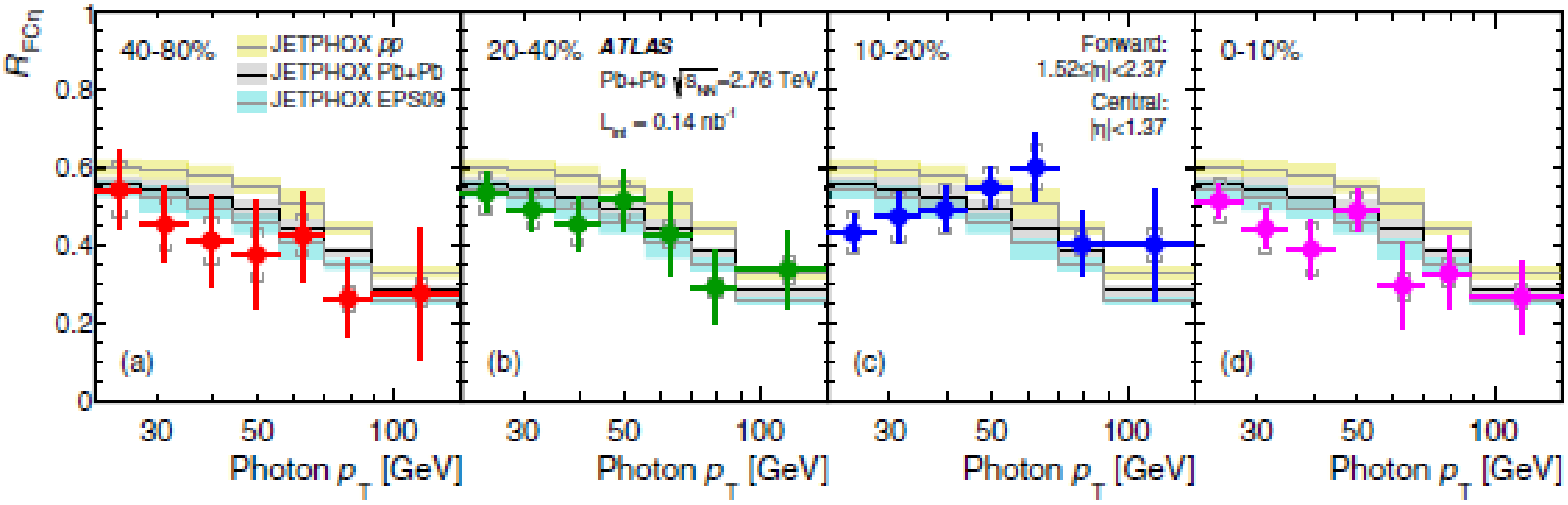
At midrapidity, consistent with 1; fw some depletion
PbPb – includes isospin effect (n/p) - EPS09 includes neutron skin effect



ATLAS, Pb+Pb

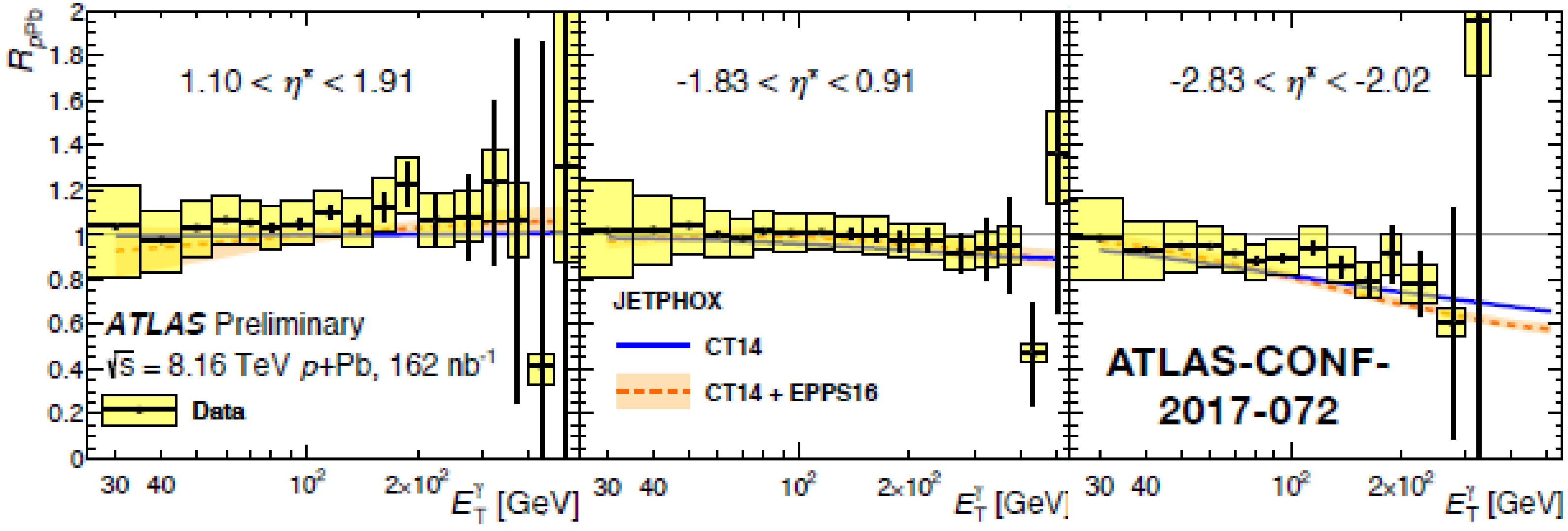
ATLAS, PRC 93, 034914 (2016)

Forward / central rapidity ratios: many sys. uncertainties cancel (efficiency, bin-by-bin correction, T_{AA})
All calculations consistent, but those taking isospin effect into account are closer.

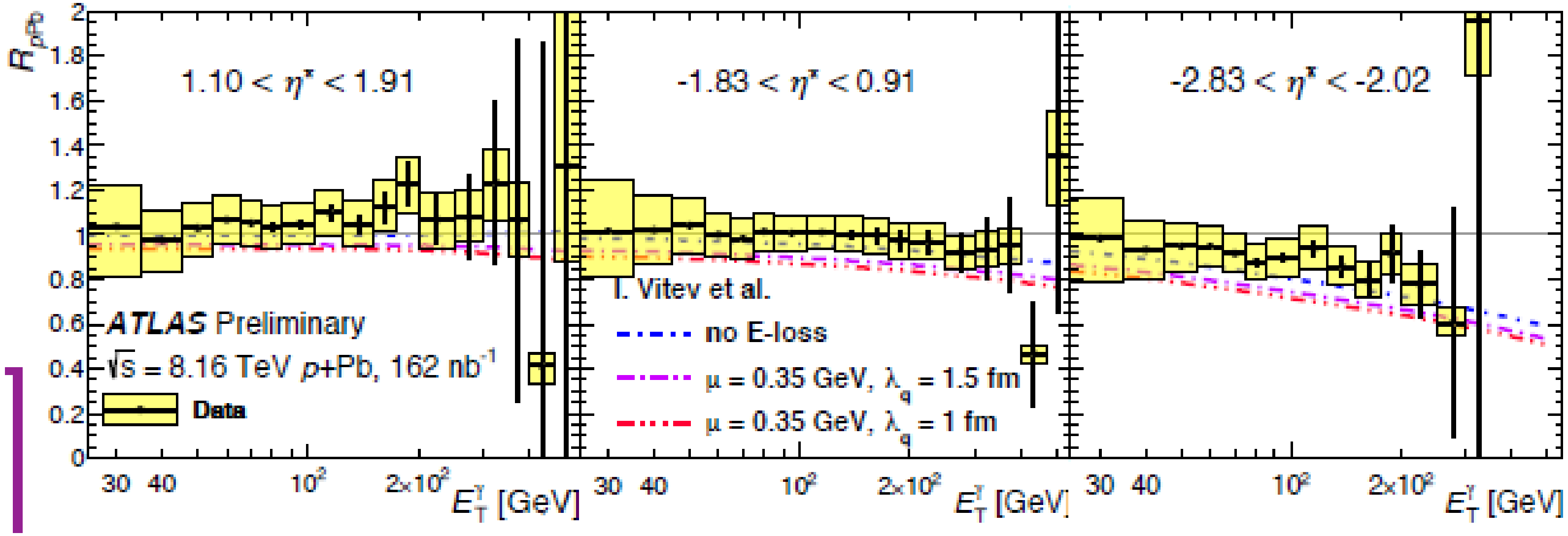


"…demonstrates that photon yields in heavy ion collisions scale as expected with the mean nuclear thickness"

ATLAS, p+Pb

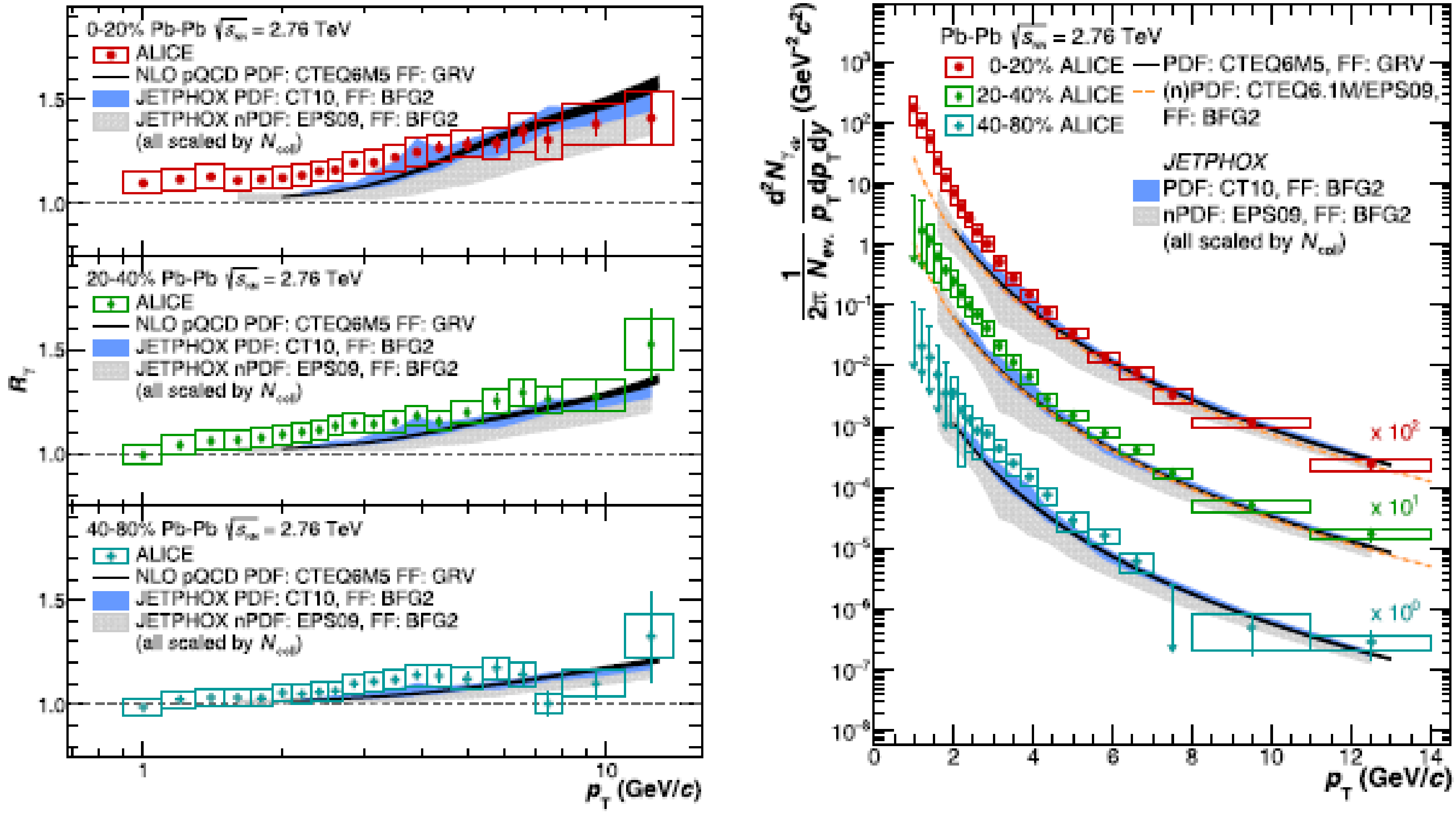


➡ *favorable comparison to pQCD & nPDF*



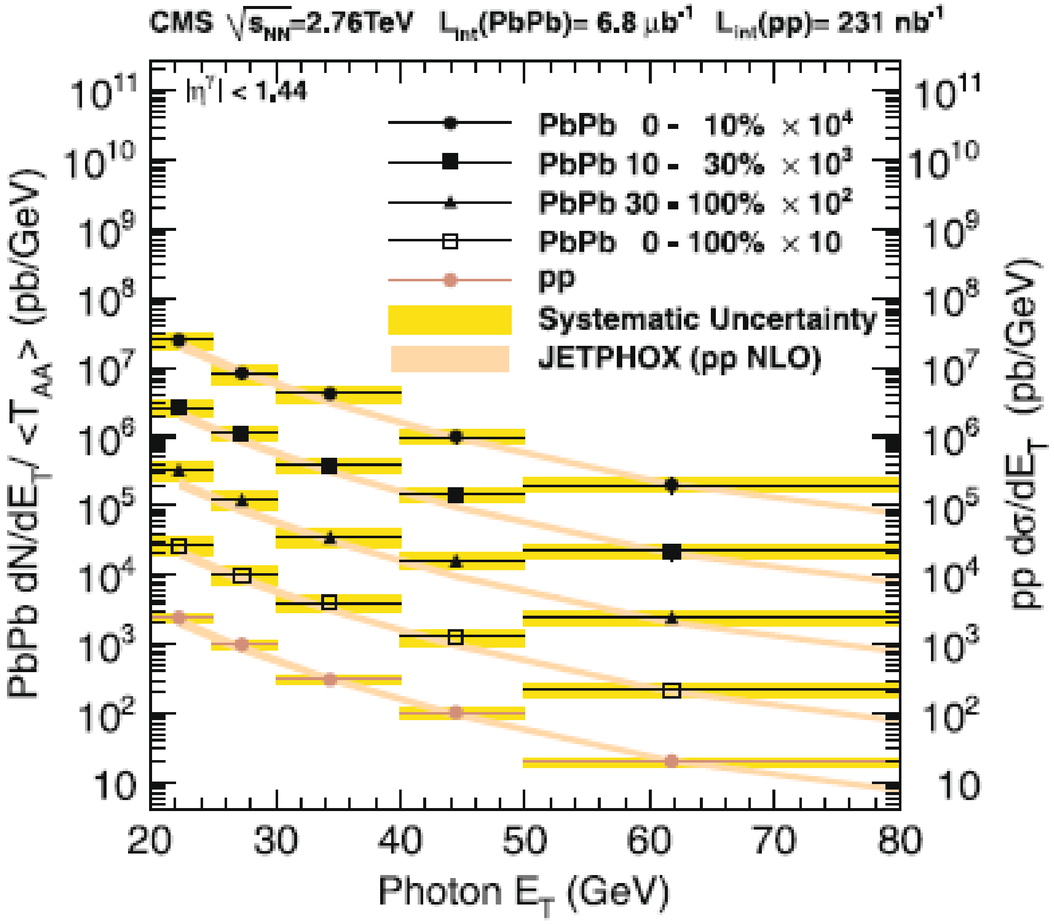
ALICE, Pb+Pb

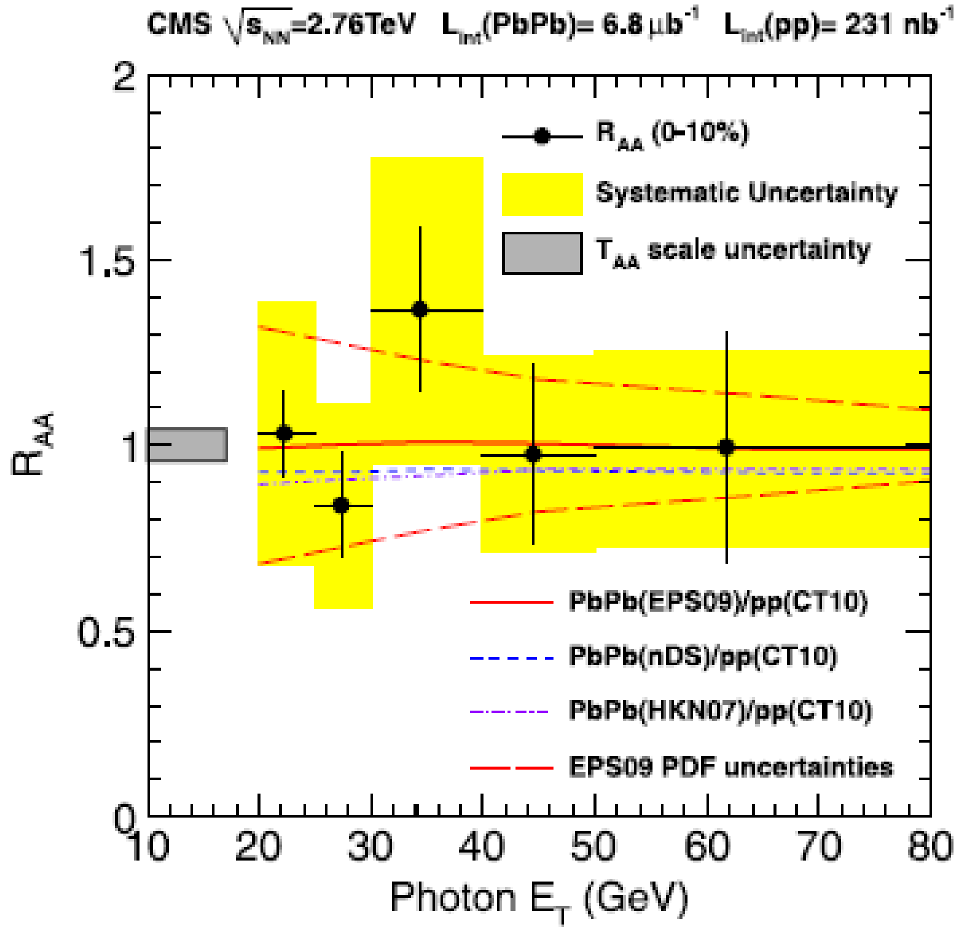
ALICE PLB 754 (2016) 235



CMS, PbPb

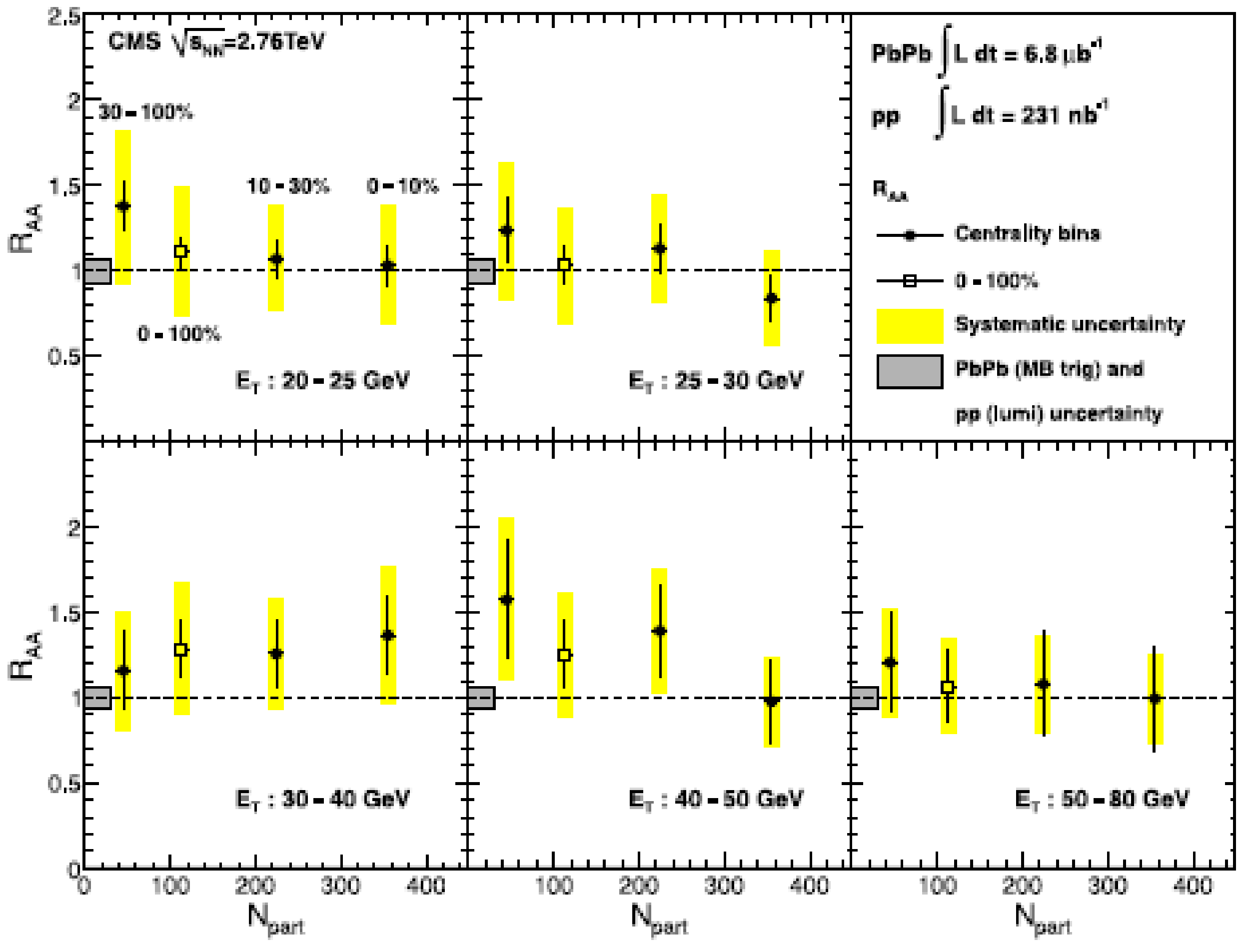
CMS PLB 710 (2012) 256





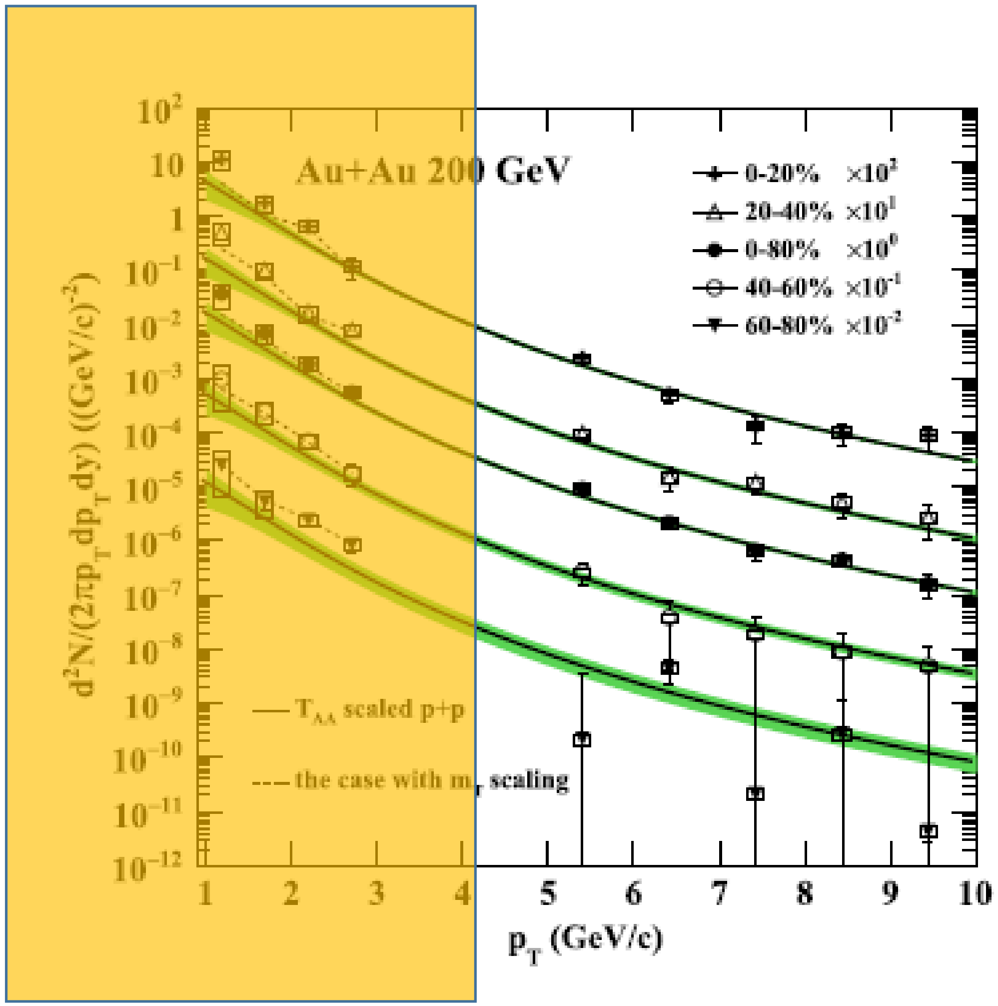
CMS, PbPb

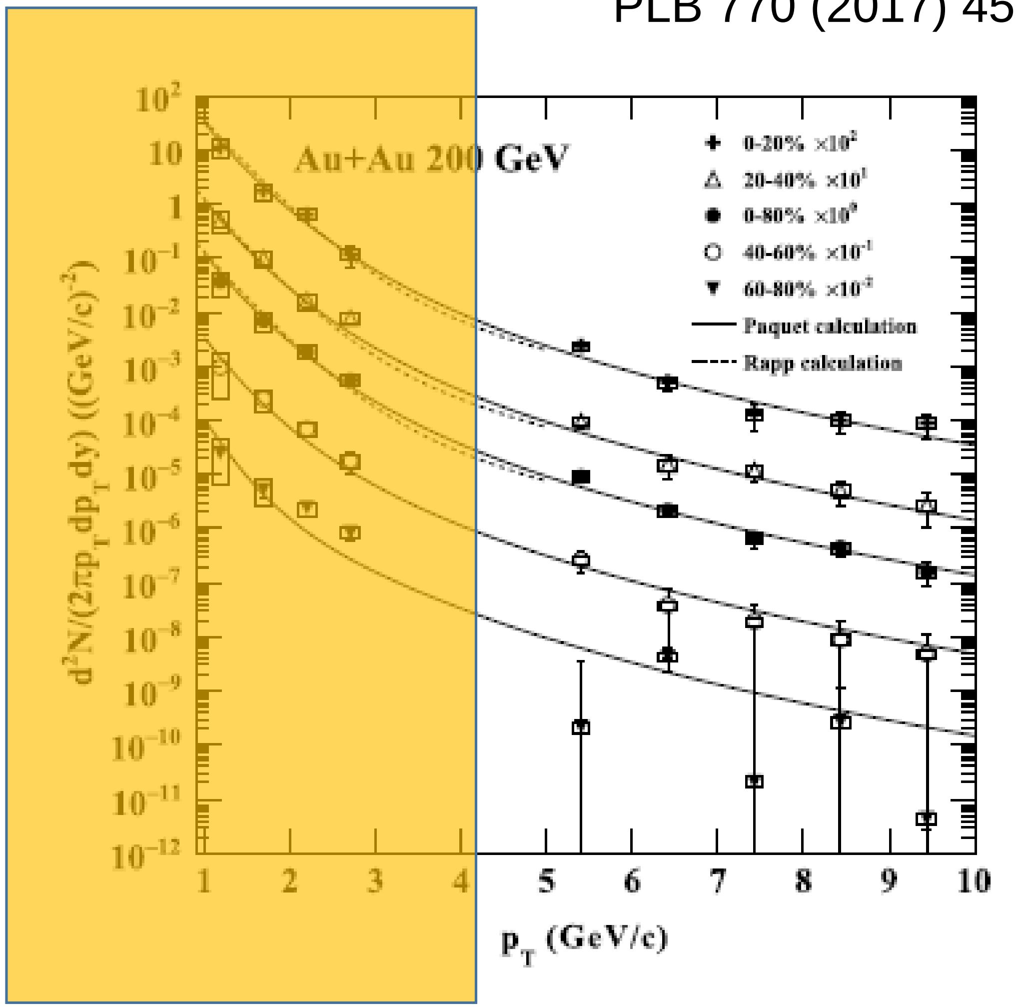
CMS PLB 710 (2012) 256



STAR – look at high p_T for the moment

PLB 770 (2017) 451





At high p_T no surprises, T_{AA} scaling, R_{AA} (not shown) would be around unity

Now an observation and an Ansatz:

1/ Observation: Glauber model (and the connection between geometry – multiplicity) works in A+A well (logical: only a few participants have "extreme" collisions, this is swamped by the regular particle production of the remaining "average" binary collisions)

2/ Assumption: whatever effect (IS, FS, modifying R_{AA}) does NOT exist in A+A, will not exist in p+A, p+p (doesn't mean it is necessarily measurable in A+A)

-> Corollary a/ ***if photons prove to be "standard candle" in A+A (p+p), they will be standard candle in p+A***

3/ for all we know, photon (W? Z?) IS a standard candle (SC) at high p_T (pQCD region) – modulo isospin (pp, pn, nn, calculable)

-> Corollary b/ ***since photons are not modified in A+A (where centrality is unambiguous), there's little reason to assume they will be modified in p+A***

Disclosure: the only new mechanism able to spoil high p_T ISOLATED photon spectrum is jet-photon conversion, but this 1/ is small in current calculations 2/ could in principle be measured in the back-to-back isolated photons channel

A truly experimental way to "centrality"

Assume that high p_T photons are indeed standard candle of N_{coll}

Feel free to play with any phenomenological model of hard/soft production, bias, specifics of frozen initial conditions, generalized PDFs, fluctuations of interaction strength, nucleon size, diquarks… etc., ***try*** anything you want, but…

…once you came up with a model to connect geometry to observables, ***test it against production of high p_T photons***, and over the largest p_T range available

If you find that the photon "nuclear modification factor" (defined with your method) is not unity, your model is wrong.

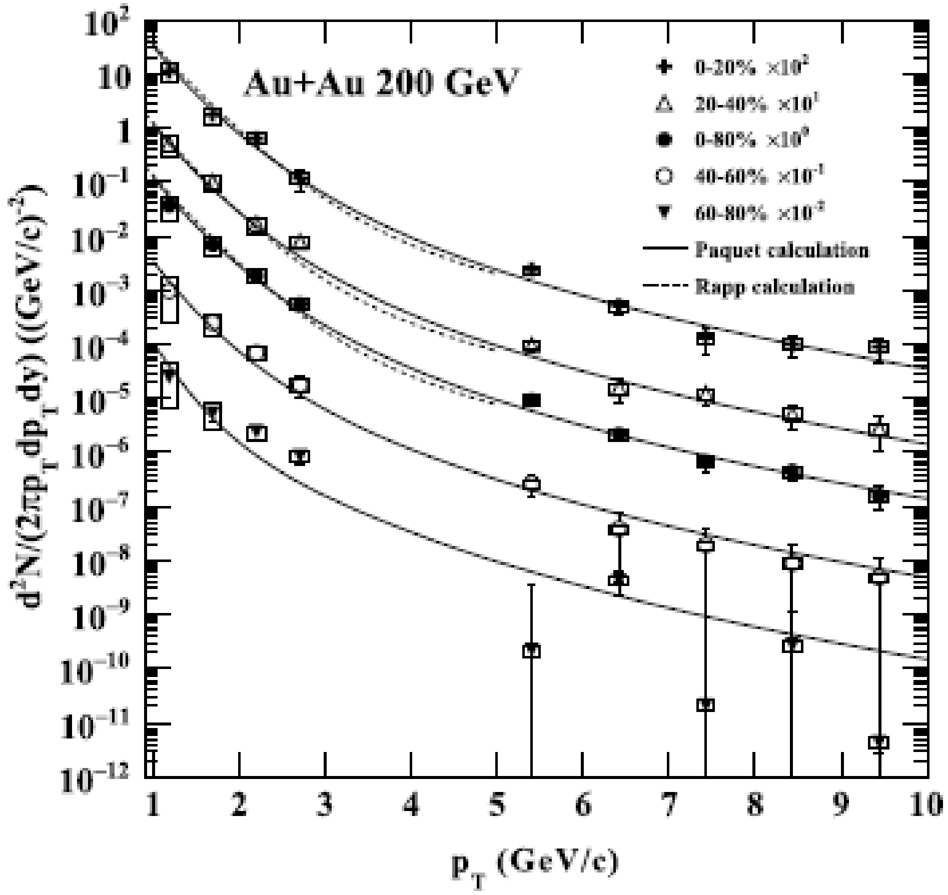
(Small deviations from being a "standard candle" may exist, but they are testable.)

“Thermal” photons and the “puzzle”

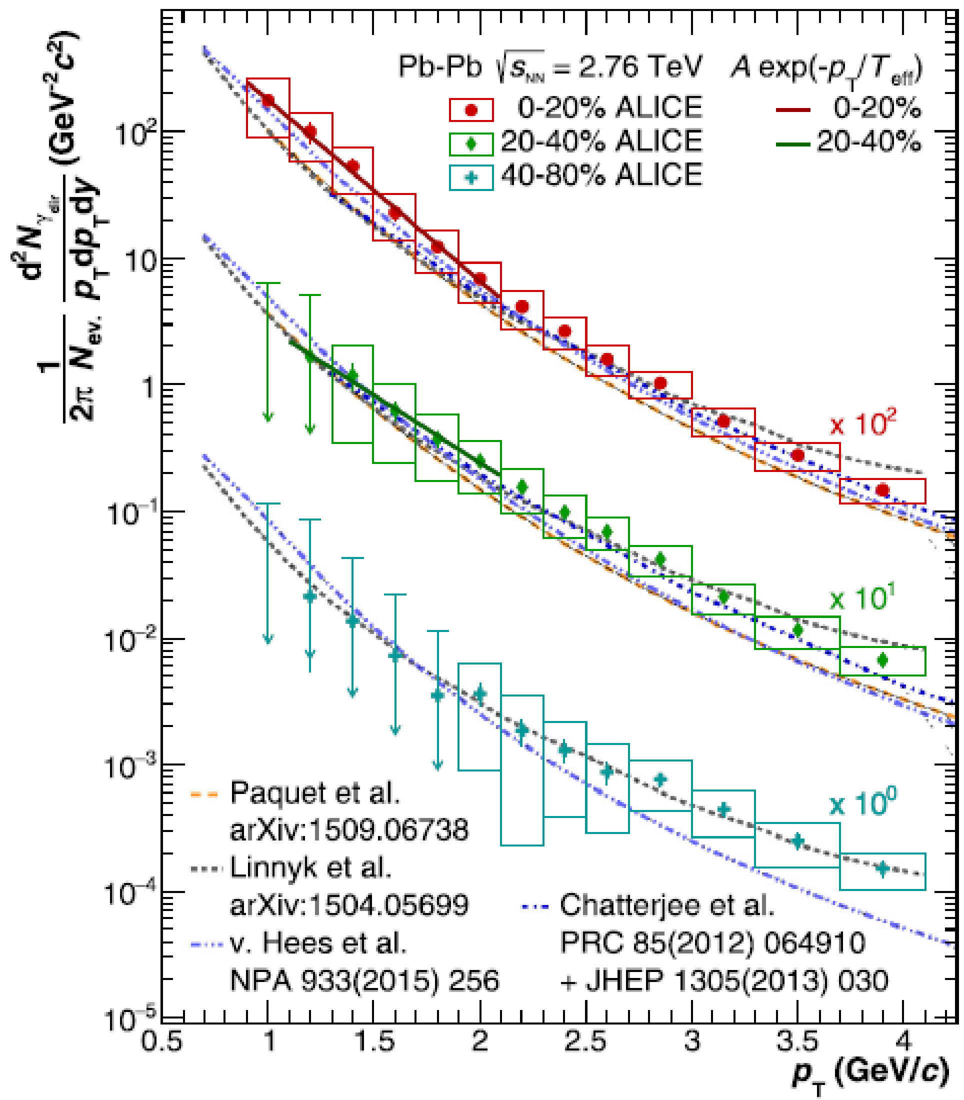
"Thermal" photons

Everybody sees some excess (apparently exponential) above simple scaled p+p – the argument is only how much is it

STAR, PLB 770 (2017) 451

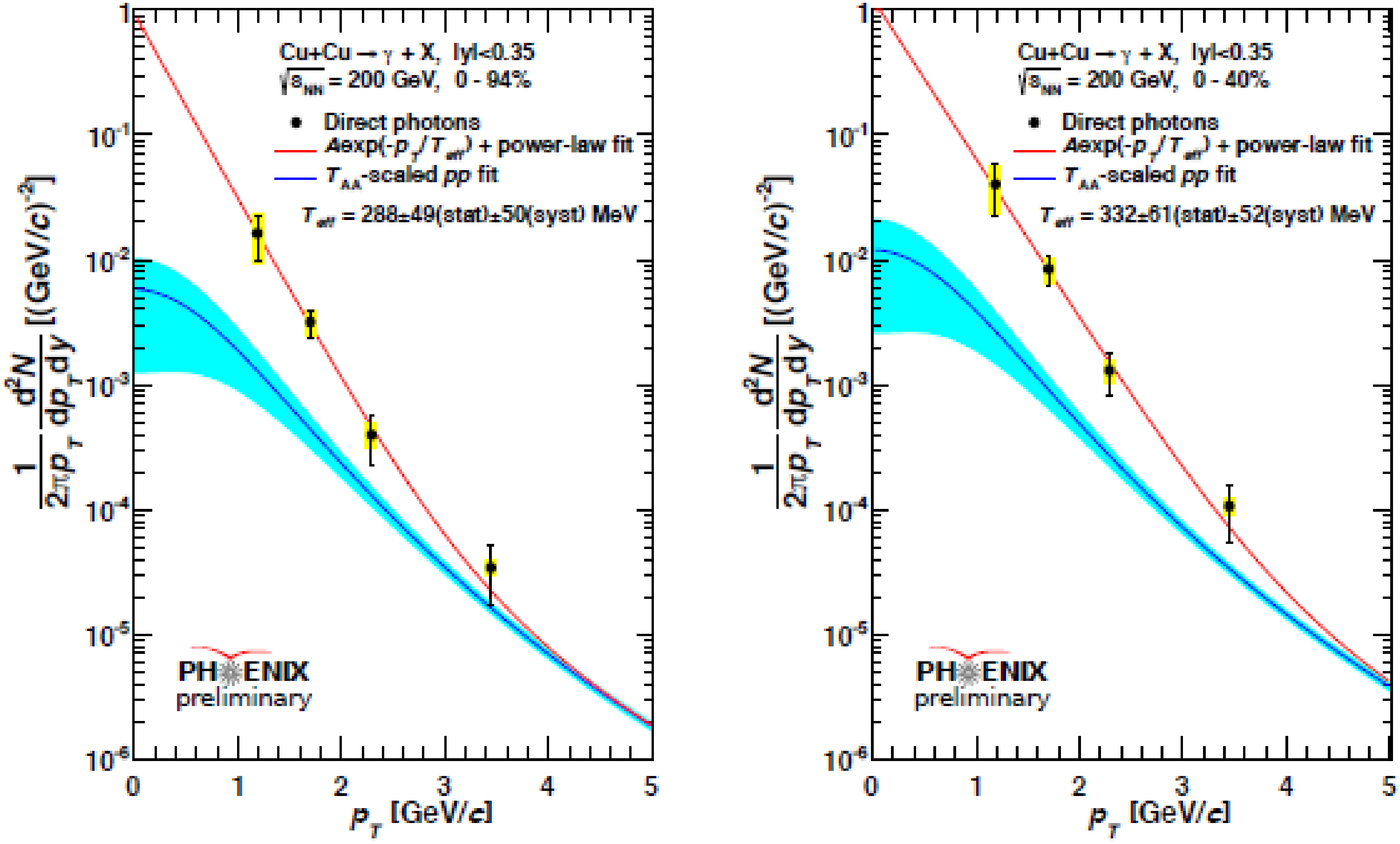


ALICE, PLB 754 (2016) 235



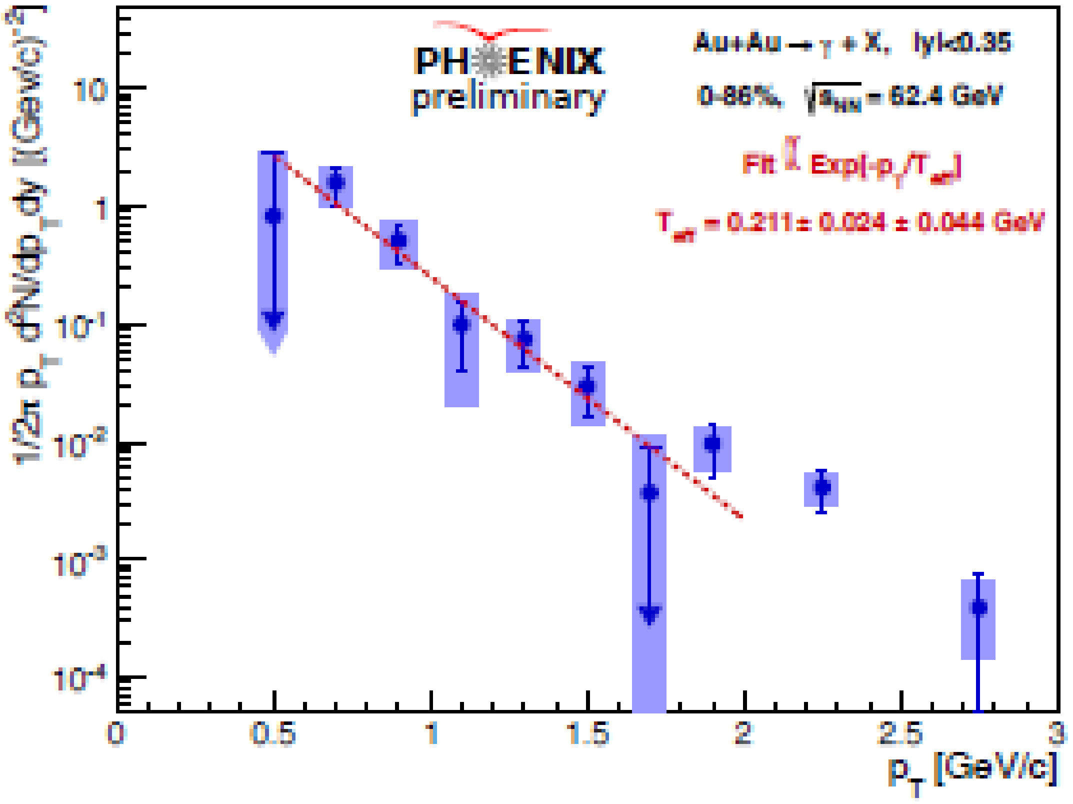
PHENIX, Cu+Cu, 200GeV, internal conversion

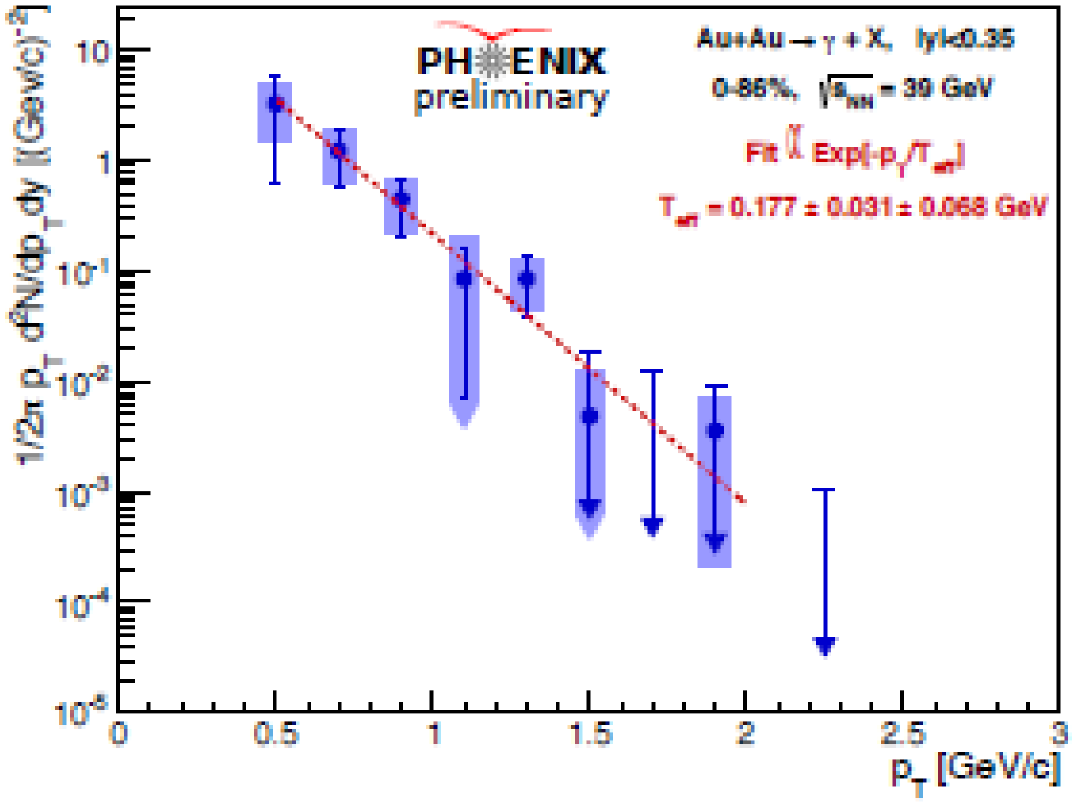
Relatively new results from PHENIX, internal conversion



PHENIX, Au+Au, 62, 39 GeV, external conversion

Relatively new results from PHENIX, external conversion, on HBD backplane (same as PRC 91, 064904 (2015))

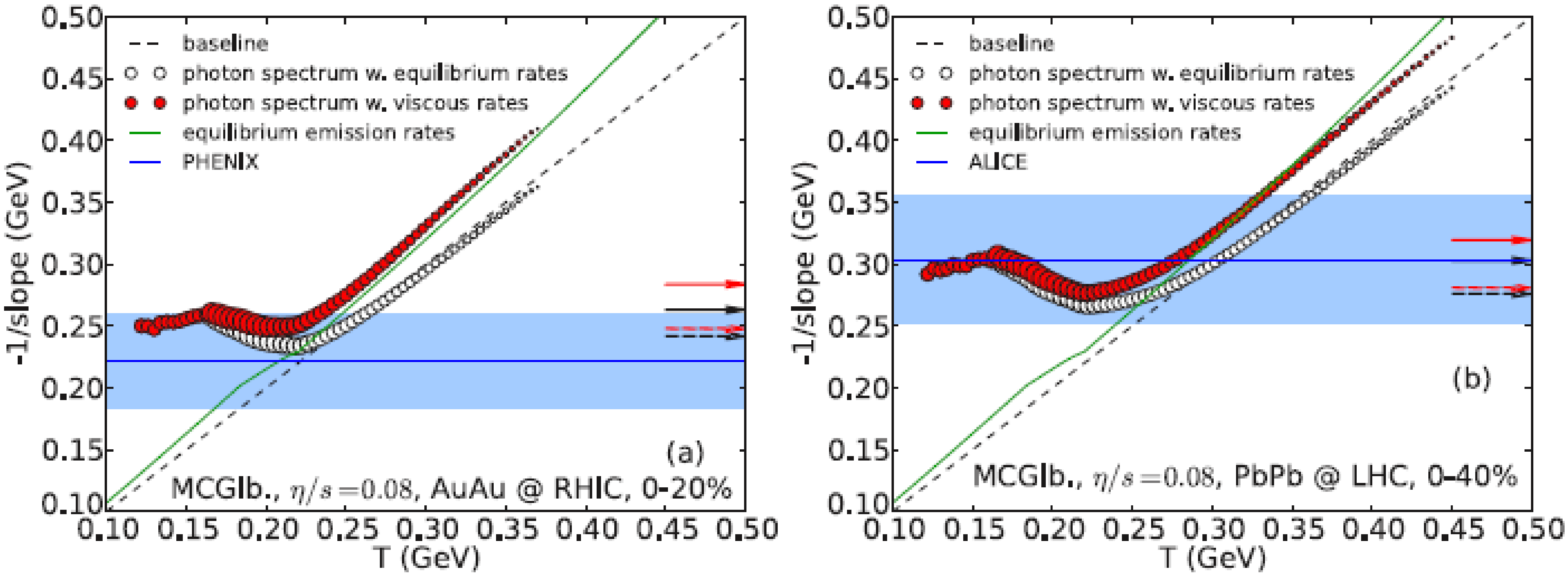




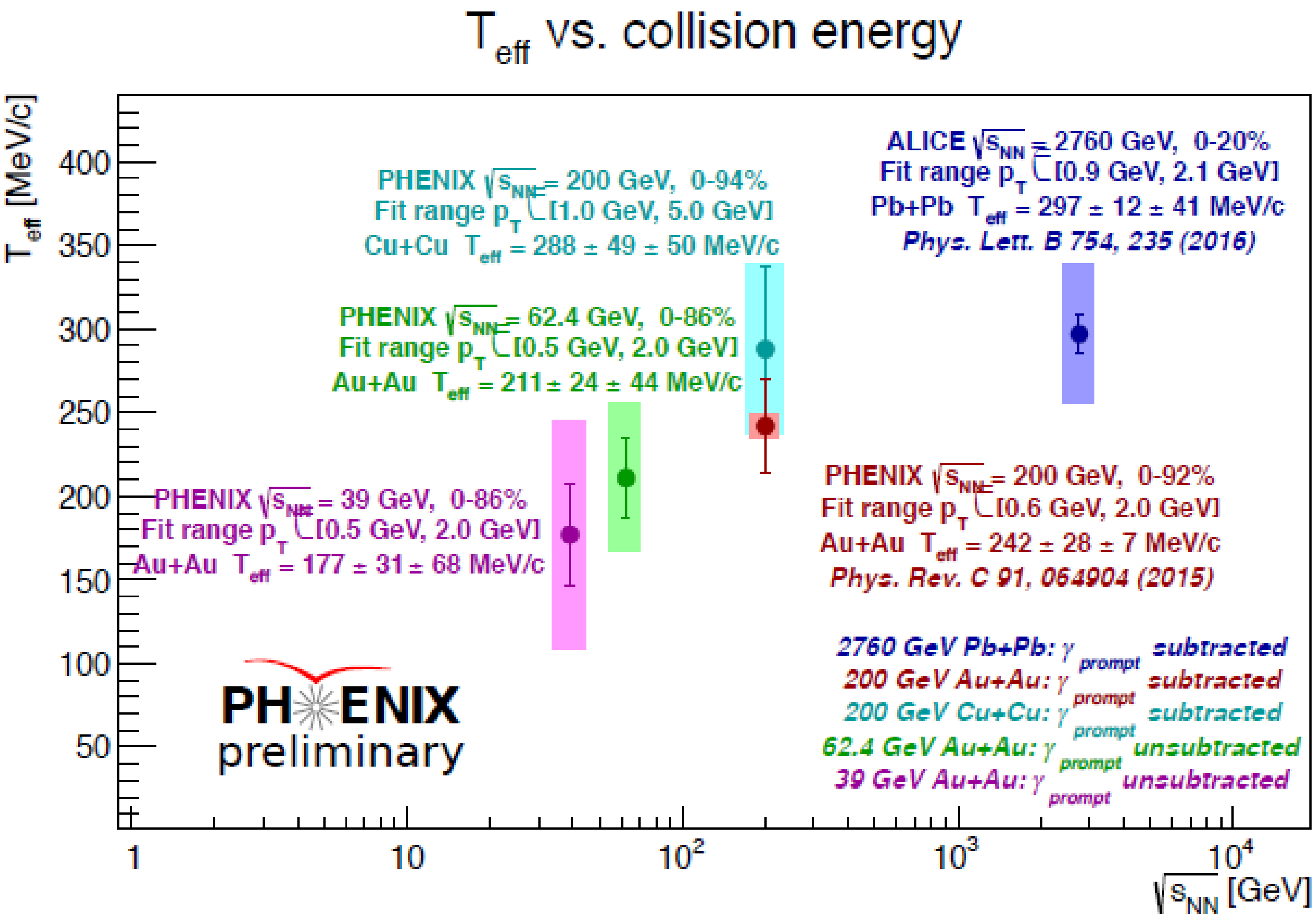
Upper limits due to downward luctuation of R_γ

“Temperature” vs temperature

PRC 89, 044910 (2014)



"Temperature" – whatever it means



"Direct photon puzzle" in a nutshell

- Thermal photons (HG+QGP), pQCD with fireball scenario

- H.van Hees, C. Gale, R. Rapp PRC 84 054906 (2011)
- Include finite initial flow at thermalization
- Include resonance decays and hadron-hadron scattering
- Blue shift of HG spectrum included

- Microscopic transport (PHSD)

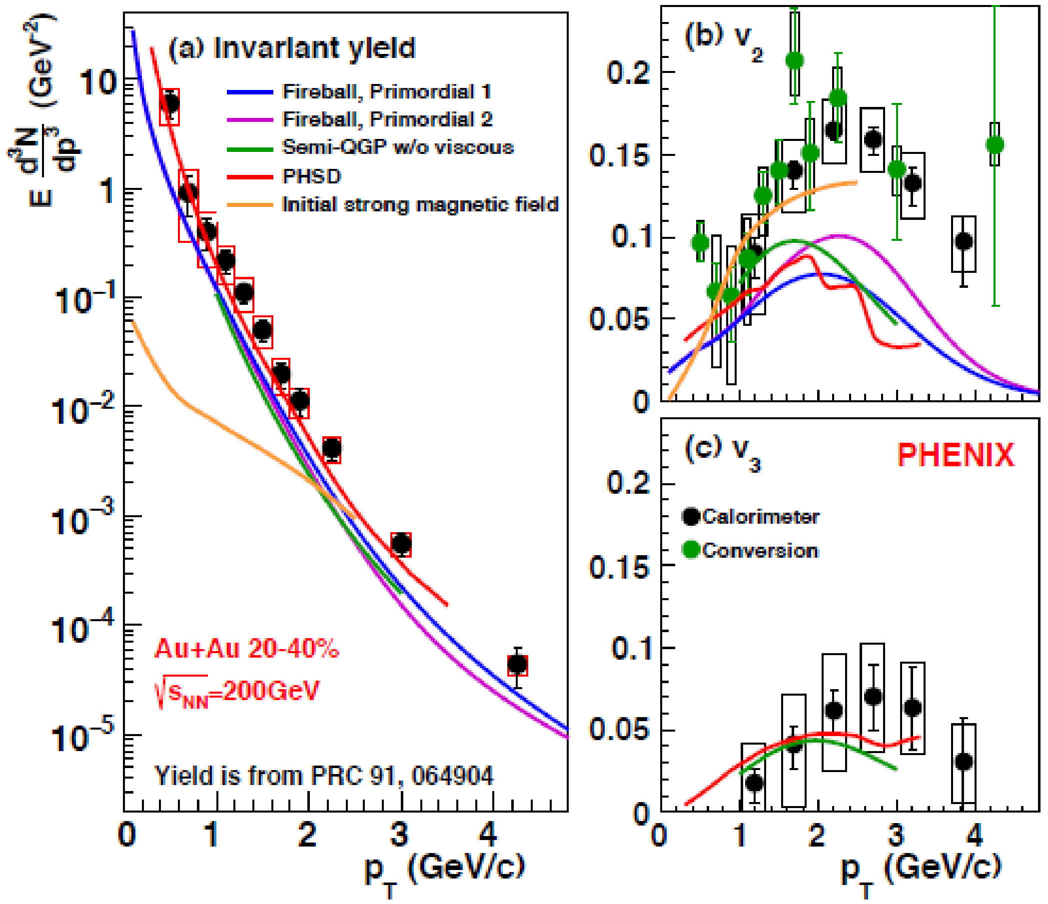
- O. Linnyk, W. Cassing, E.L. Bratkovskaya, PRC 89, 034908 (2014)
- Parton-Hadron-String dynamics
- Include large contribution from hadron-hadron interaction in HG using Boltzmann transport
- Include thermal photons from QGP

- Enhanced emission from non-equilibrium effects (glasma, etc.)

- C. Gale et al., PRL114, 072301 + priv.comm. with Y Hidaka and J-F. Paquet
- Semi-QGP is the QGP near T_c
- Annihilation and Compton processes around hadronization time are naturally included

- Enhanced early emission from magnetic field

- G. Basar, D. E. Kharzeev, V. Skokov, PRL 109 202303 (2012)
- Initial strong magnetic field produces anisotropy of photon emission
- magnetic field + thermal photons (lattice QCD)



Direct photon puzzle: *is there any?*
(A deliberately provocative slide)

Does the QGP radiate at all?

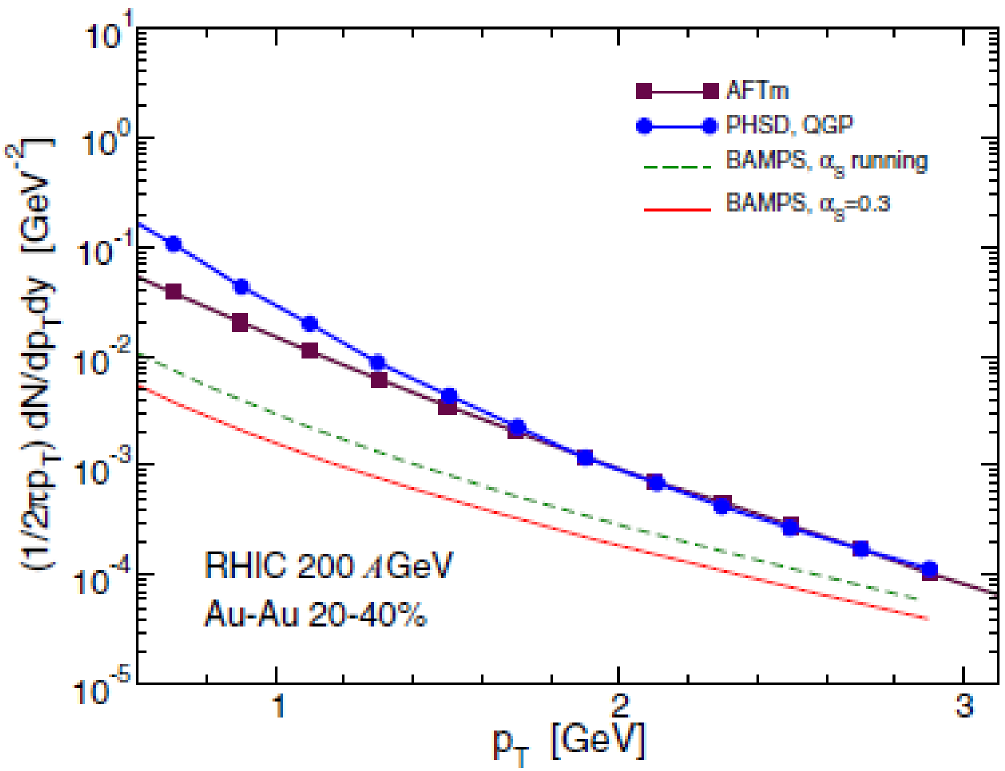
Are the “thermal” yield measurements correct?

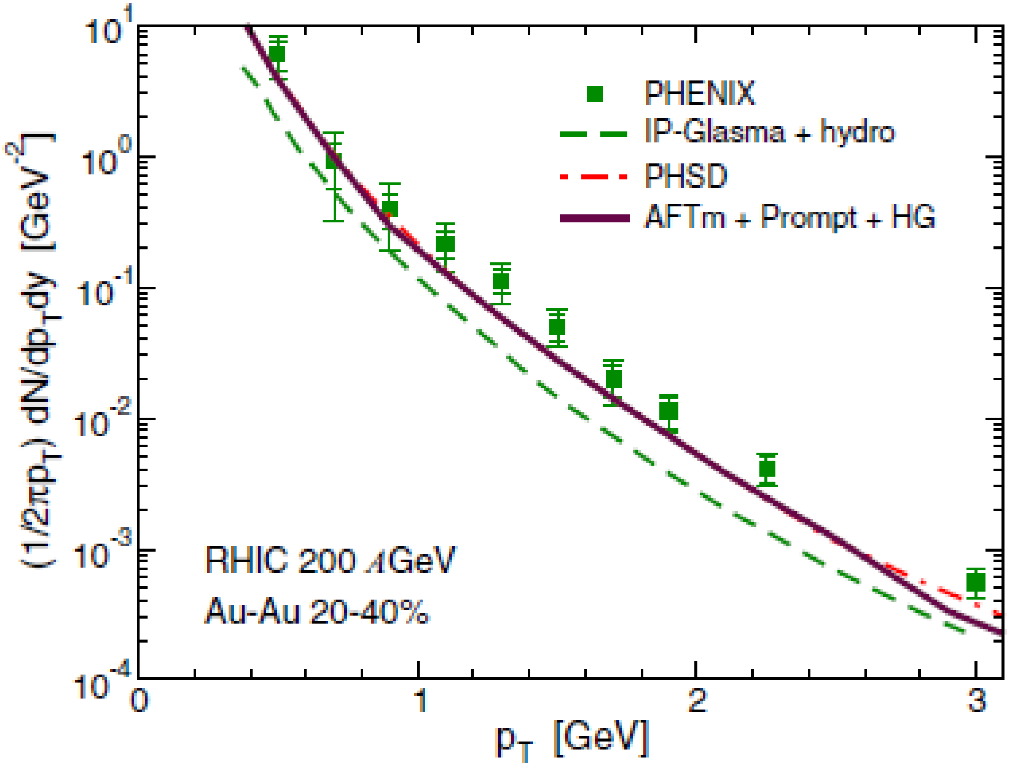
Are the elliptic flow measurements correct?

Does the QGP radiate at all?

If it exists, it should. But how much?

PRC 96, 014914 (2017)



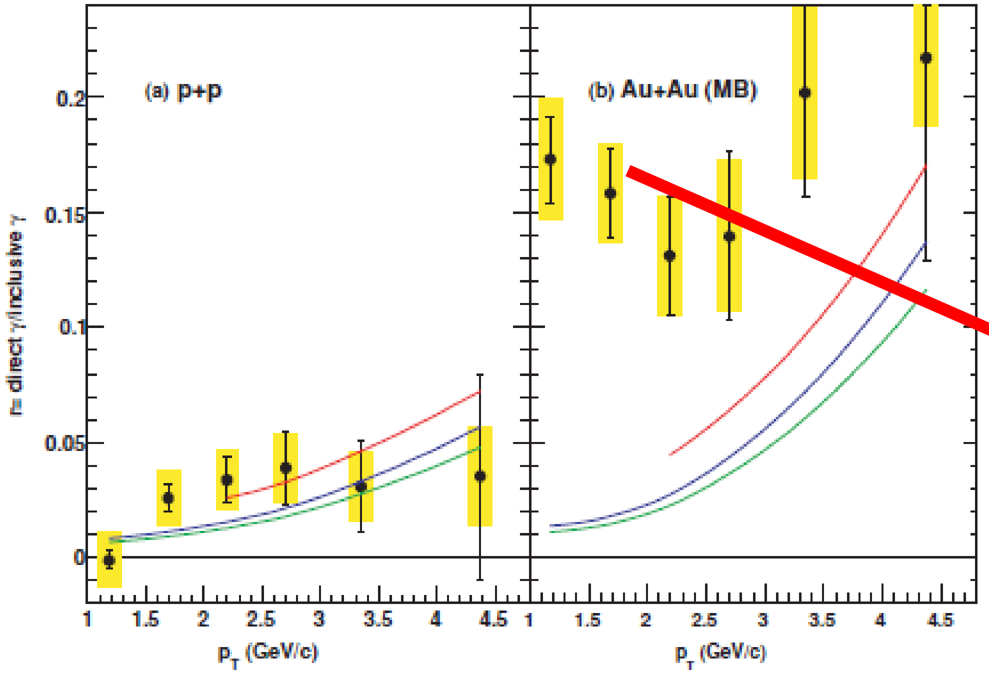


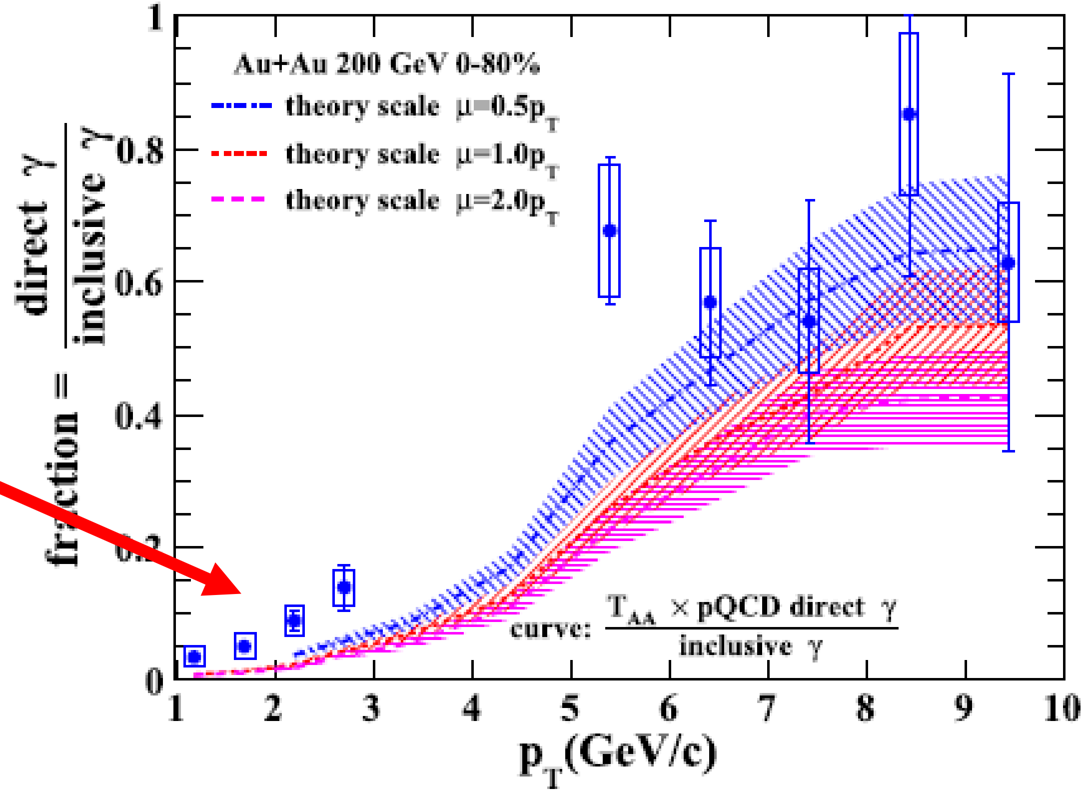
BAMPS: gluon dominated initial state, quarks only by inelastic scattering (delayed radiation) – HG not treated
AFTm: fast decay of initial fields, “bottom-up thermalization”, increased pre-equilibrium radiation
There are other models giving very early production (and flow) or very late production

Are the "thermal" yield measurements correct?

PHENIX, PRC 81, 034911 (2010)

STAR, PLB 770 (2017) 451

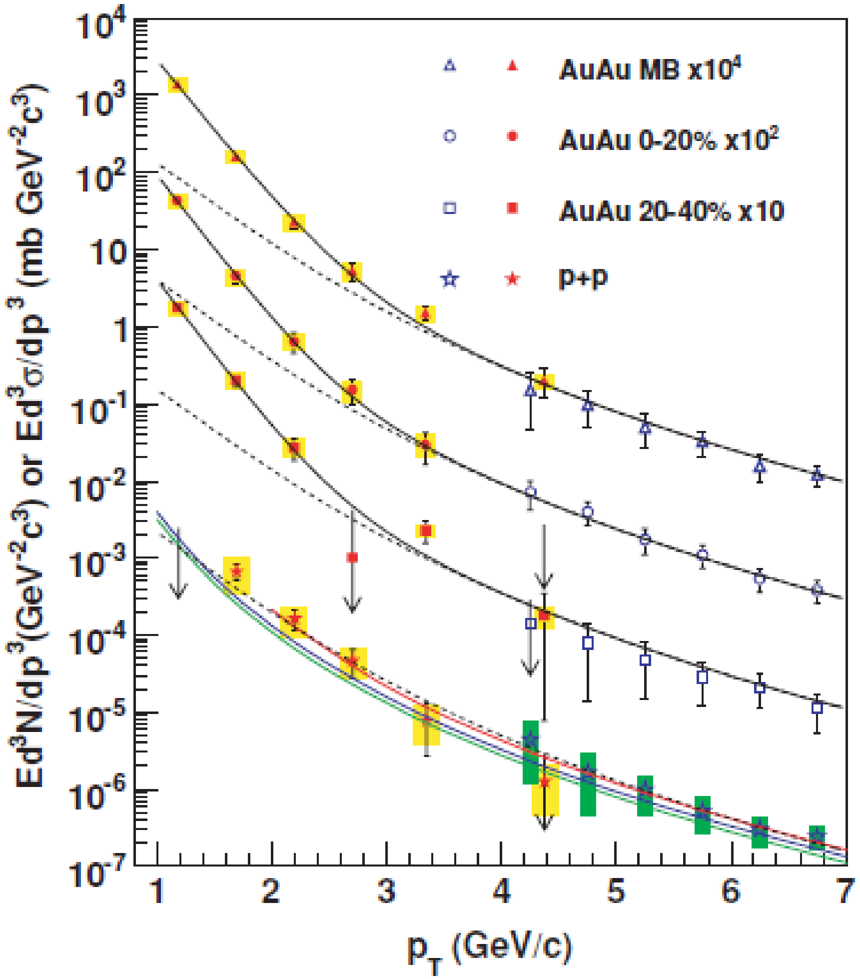




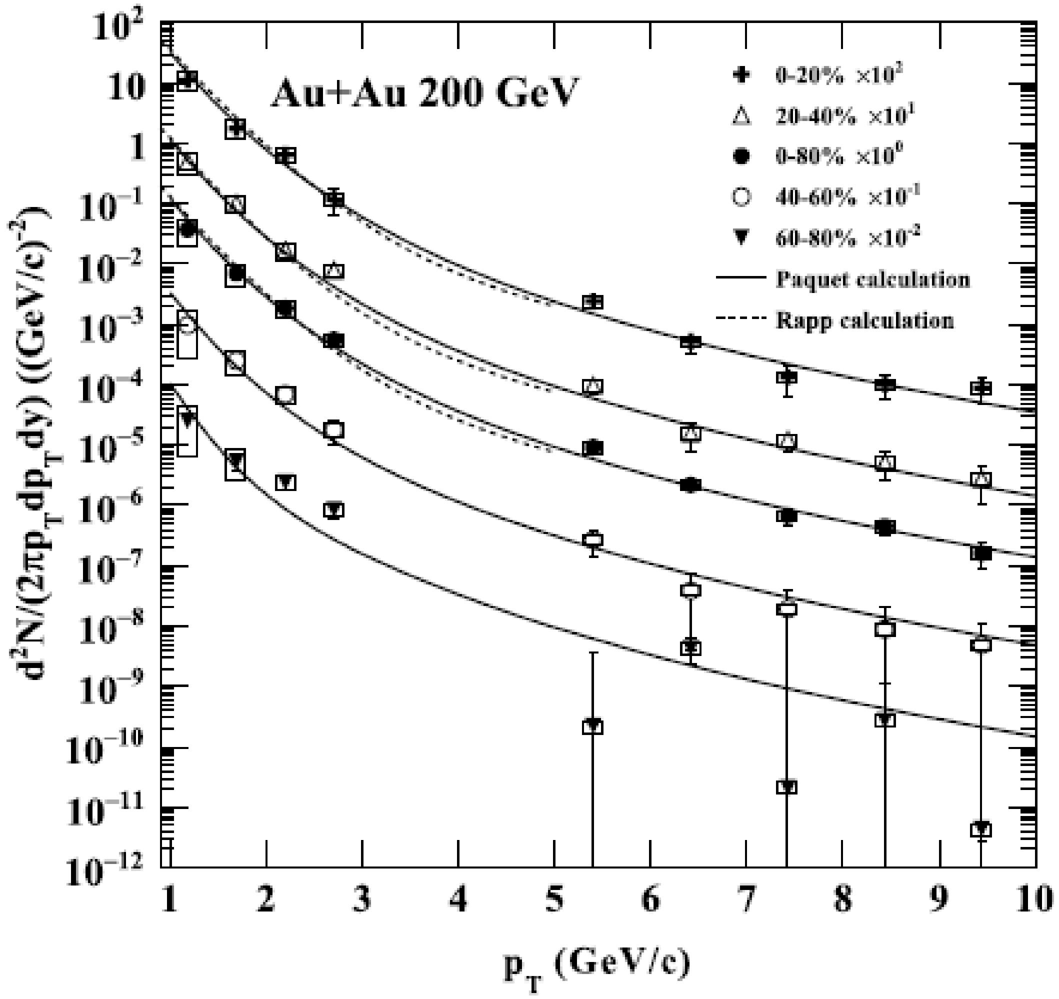
There is an obvious "tension". Both measurements are virtual photons, $\gamma^* \rightarrow e^+e^-$

Are the “thermal” yield measurements correct?

PHENIX, PRC 81, 034911 (2010)



STAR, PLB 770 (2017) 451



Are the "thermal" yield measurements correct?

STAR, PLB 770 (2017) 451

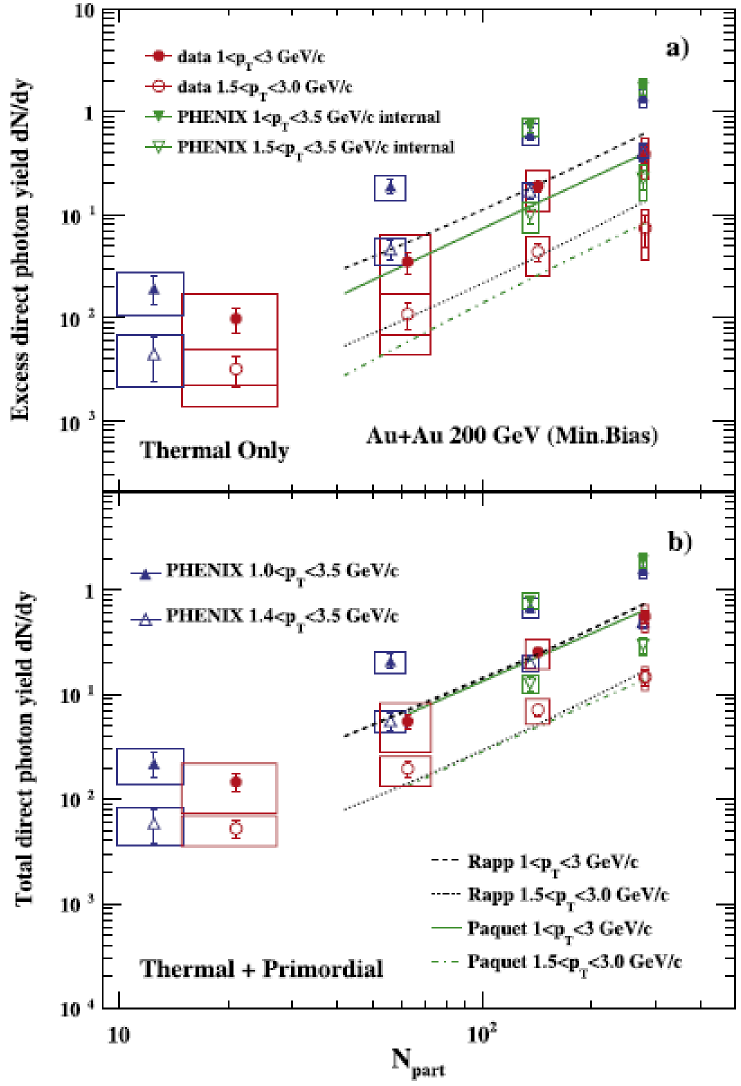
Validity of γ^* (for γ) irrelevant here:
both measurements use virtual photons
(a discrepancy of 15%, as predicted in
PRC 82, 054909 (2010) can not be
excluded by PHENIX – but *irrelevant here*!)

Both use the same $S(m_{ee},p_T)$ process-dependent factor

Difference looks more like a difference on absolute scale than shape (similar powers of N_{part})

Adopting the PHENIX way to get low p_T η doesn't help

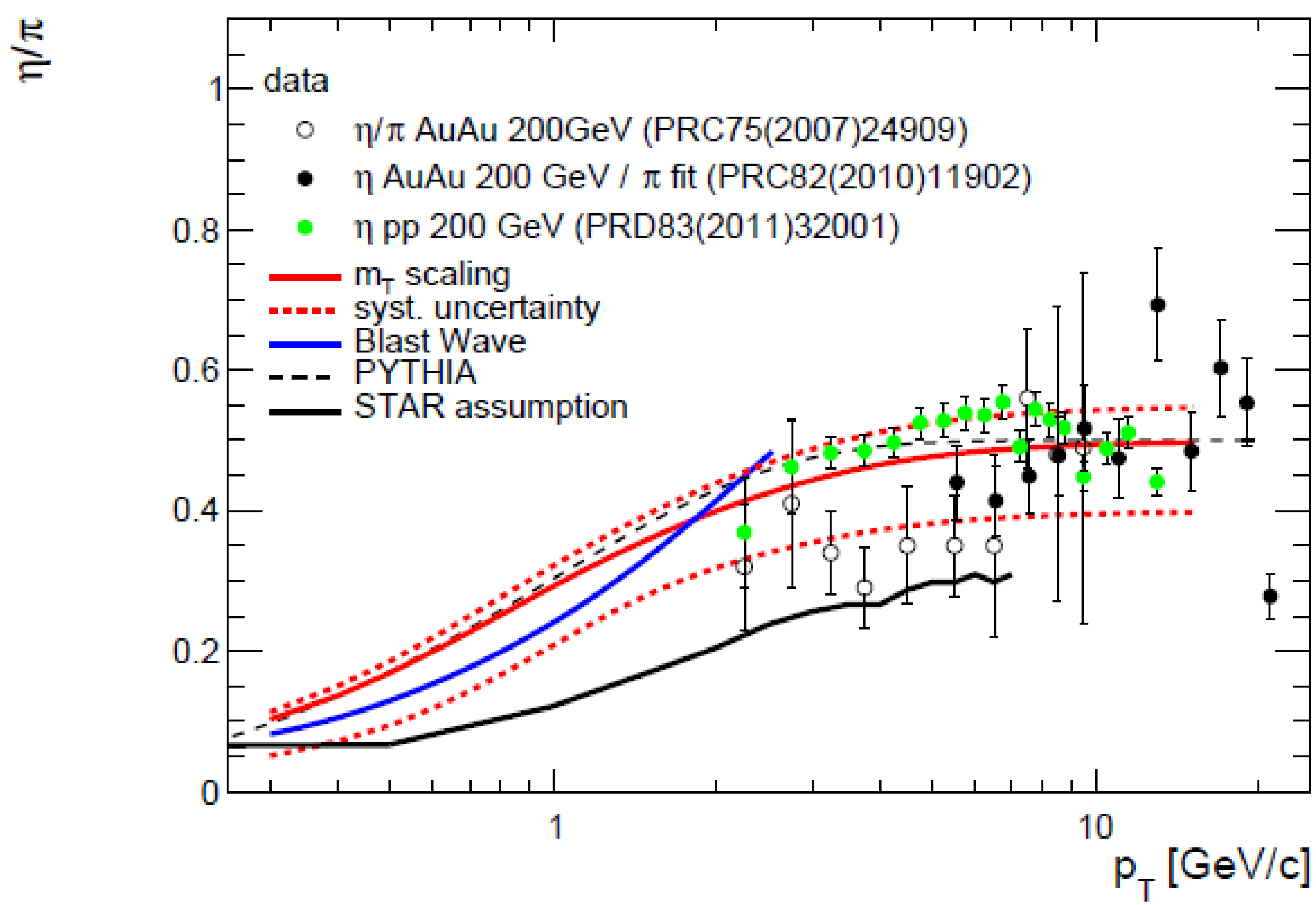
Electron identification / contamination from hadrons?

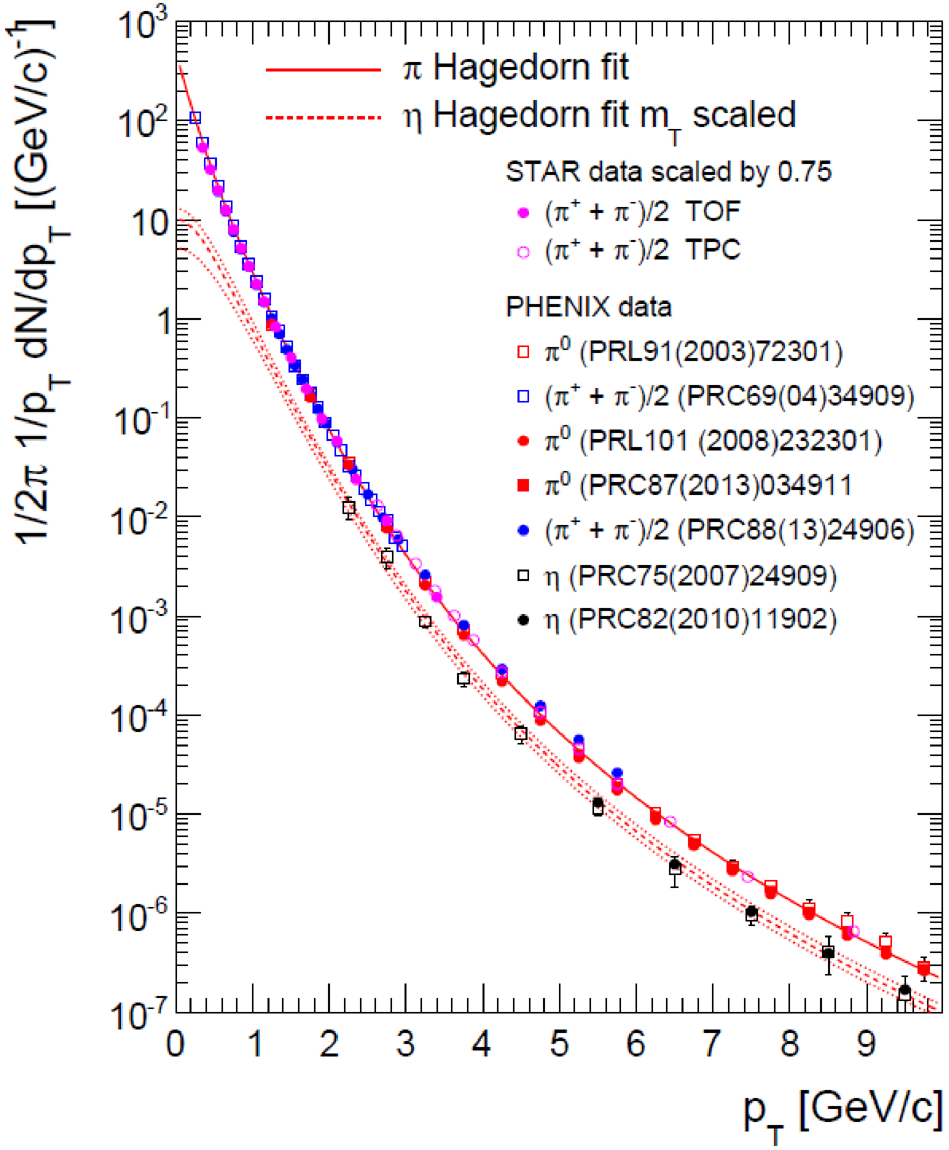


Are the “thermal” yield measurements correct?

STAR and PHENIX MB different

Limited η measurements: extrapolation to low p_T?

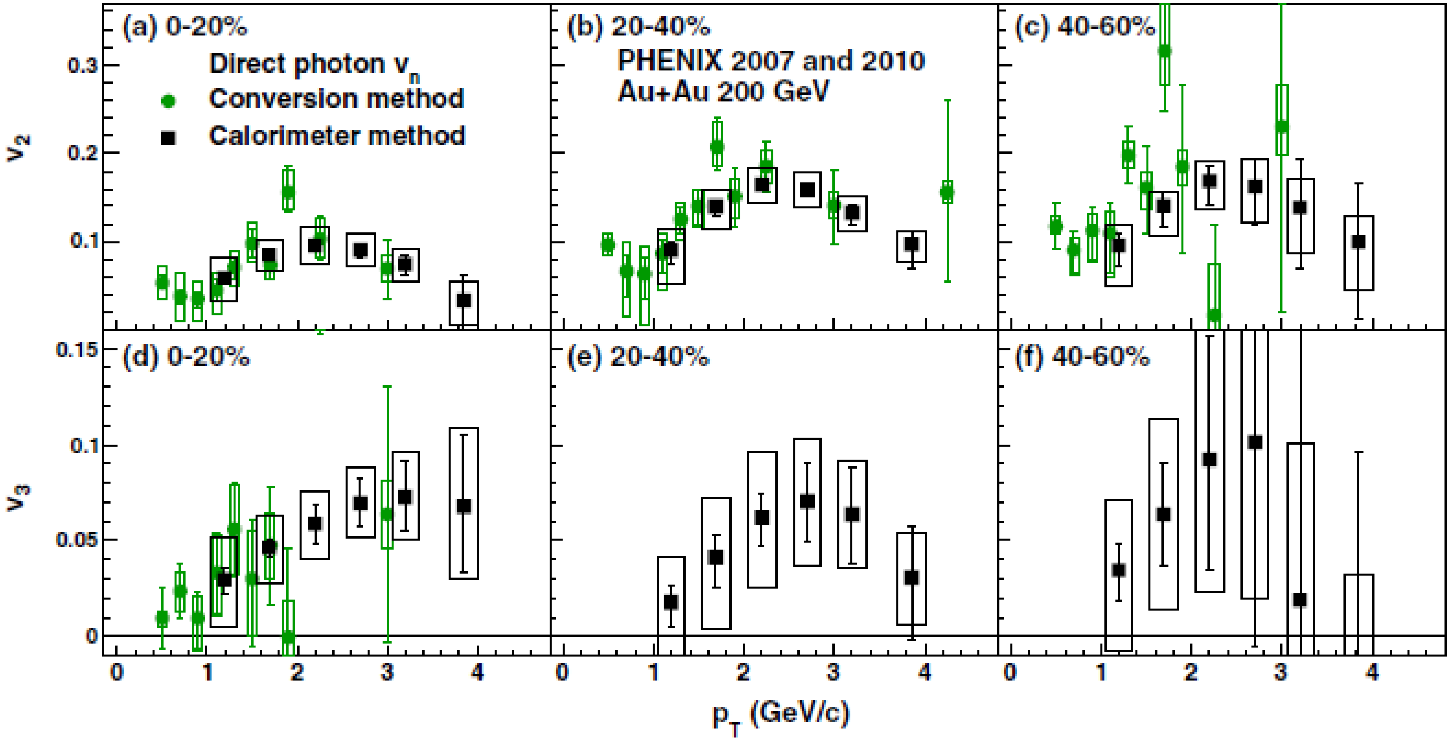


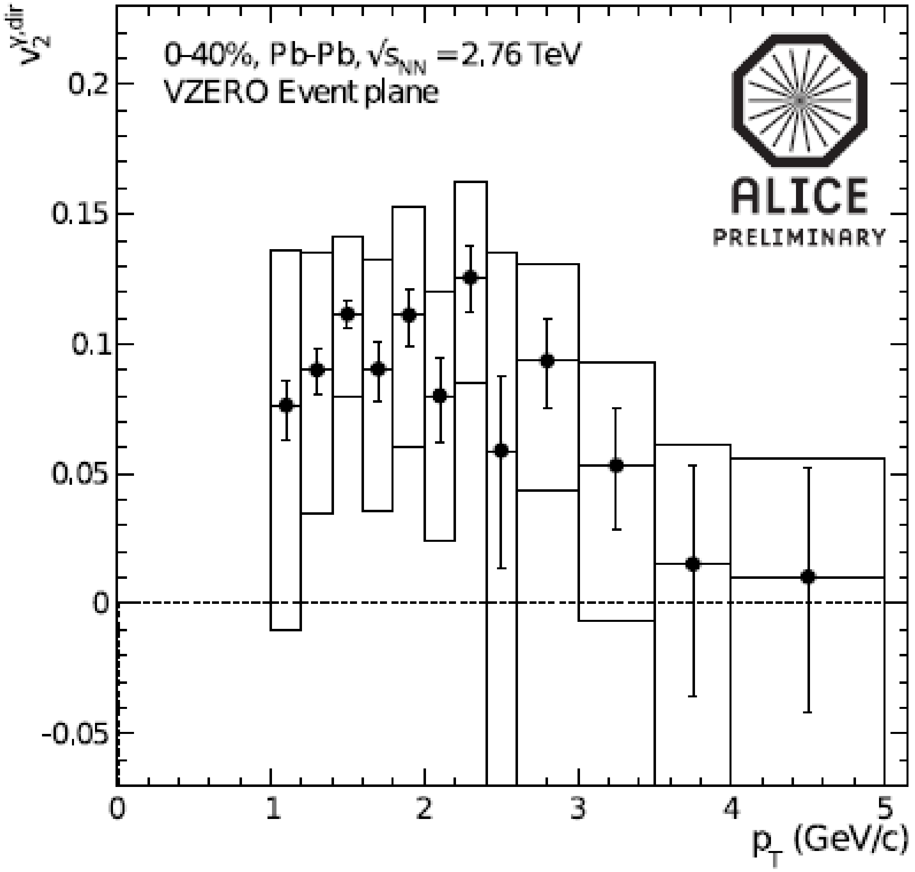


Are the elliptic flow measurements correct?

PHENIX, PRC 94, 064901

ALICE, J. Phys. Conf. Ser. 446 (2013) 012028
(not published as final yet)





PHENIX: two different techniques, but same R_γ

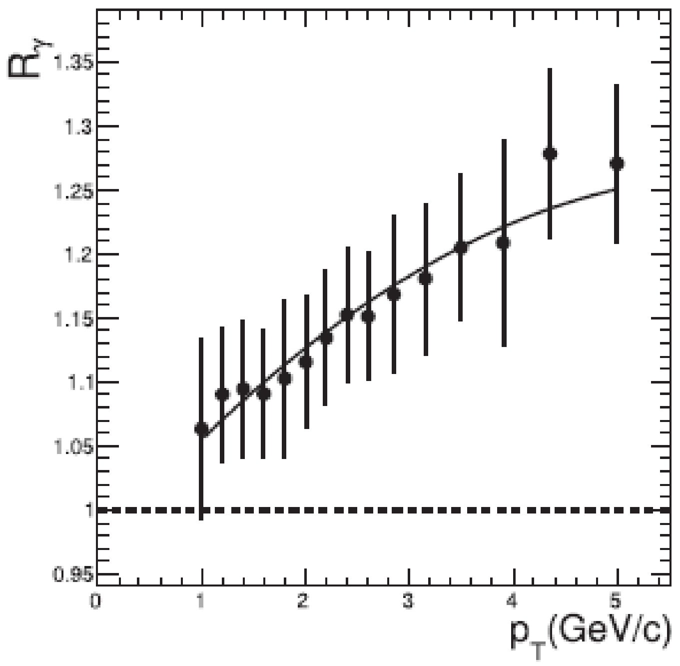
Are the elliptic flow measurements correct?

$$v_2^{\gamma,\mathrm{dir}} = \frac{R_\gamma v_2^{\gamma,\mathrm{inc}} - v_2^{\gamma,\mathrm{dec}}}{R_\gamma - 1}$$

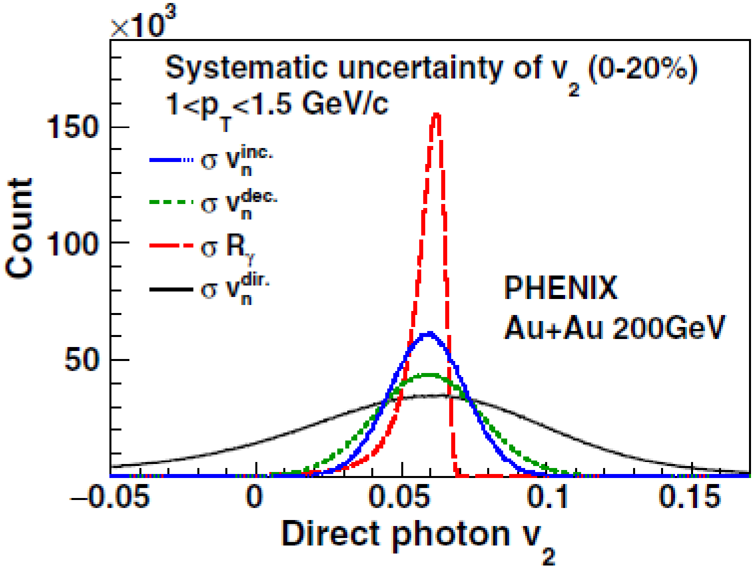
Crucially dependent on R_γ

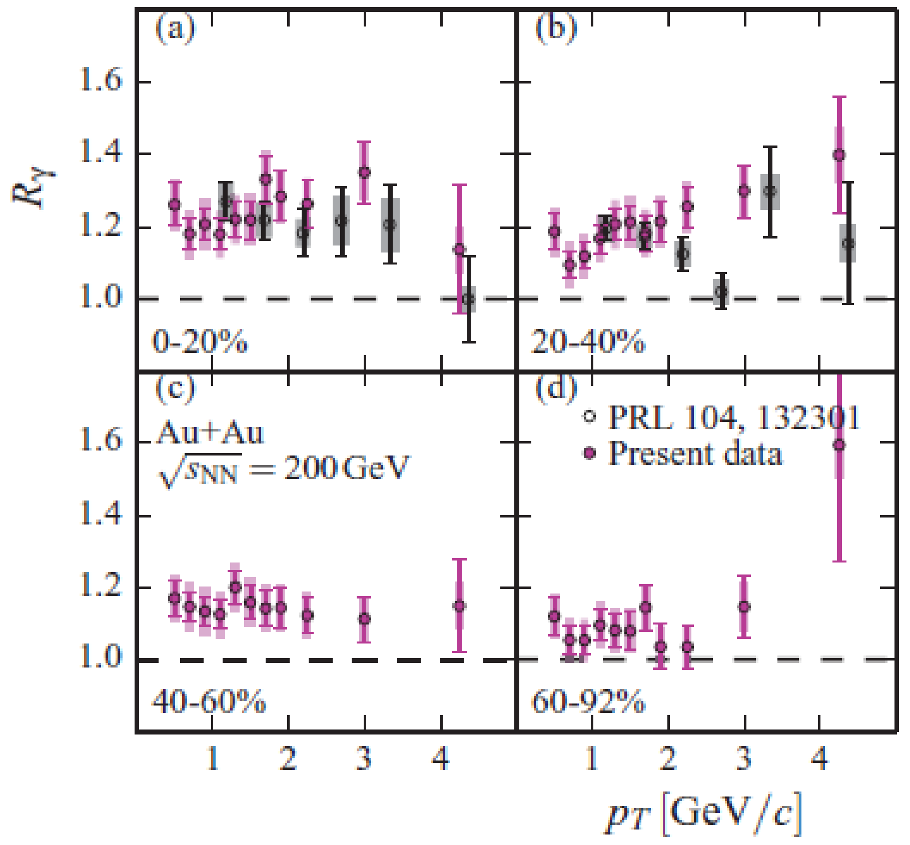
PHENIX, PRC 94, 064901 (2016)

ALICE data, J. Phys. G. 44 (2017) 025106



(Asymmetric) errors:

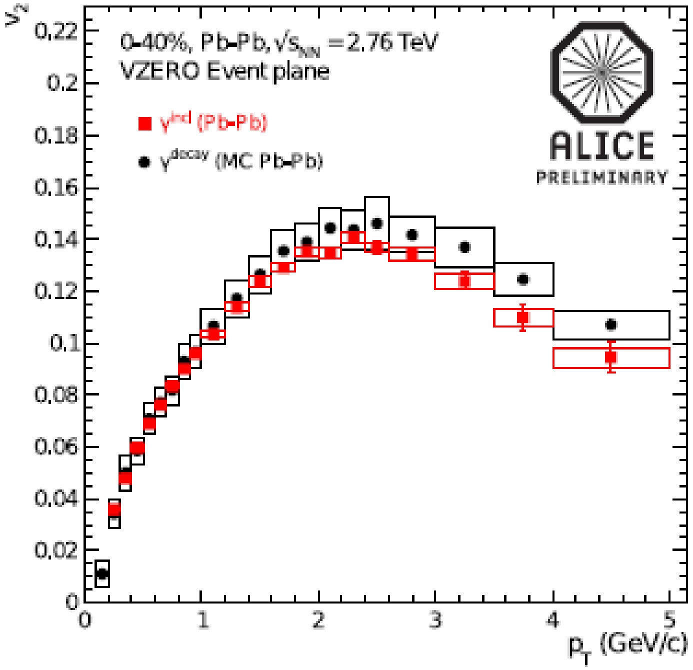




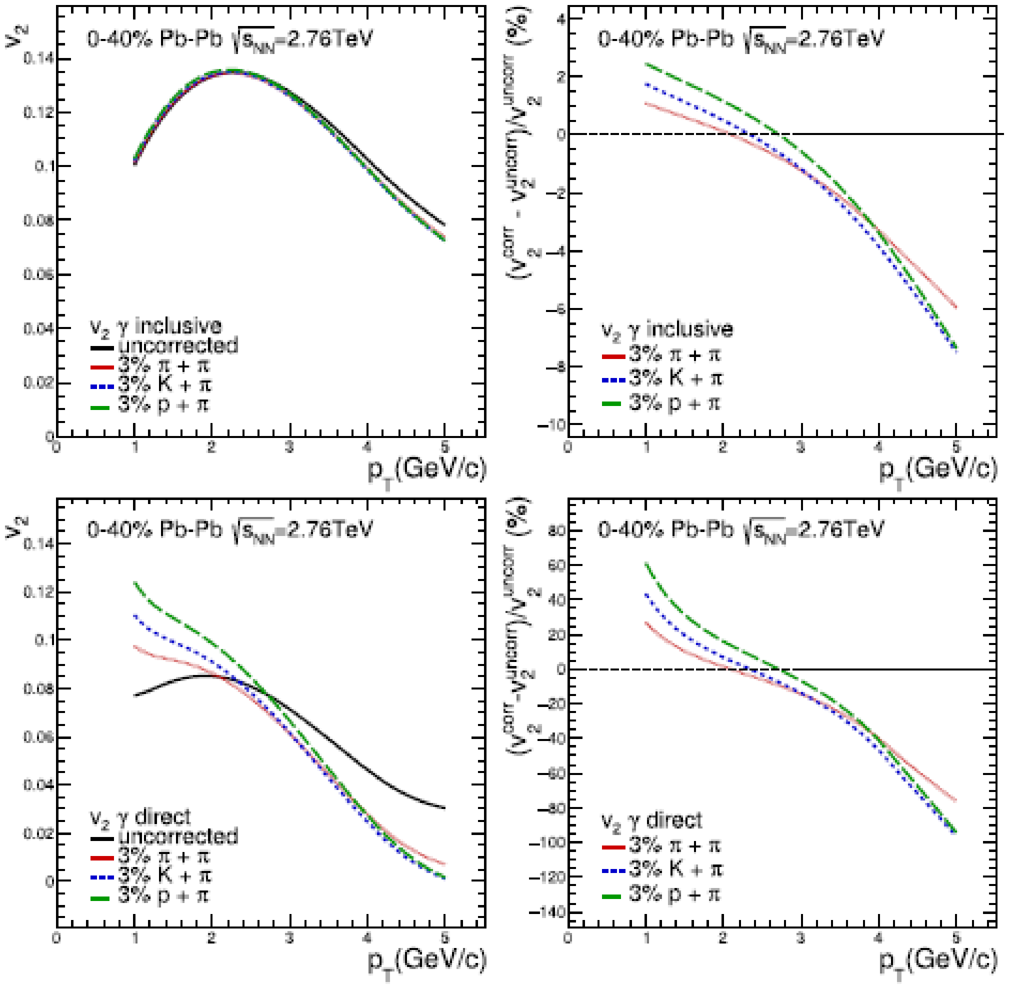
Unofficial ALICE caveat

J. Phys. G: Nucl. Part. Phys 44 (2017) 025106

$$v_2^{\gamma,\mathrm{dir}} = \frac{R_\gamma v_2^{\gamma,\mathrm{inc}} - v_2^{\gamma,\mathrm{dec}}}{R_\gamma - 1}$$



A few % hadron contamination can change the direct photon flow by large amount!

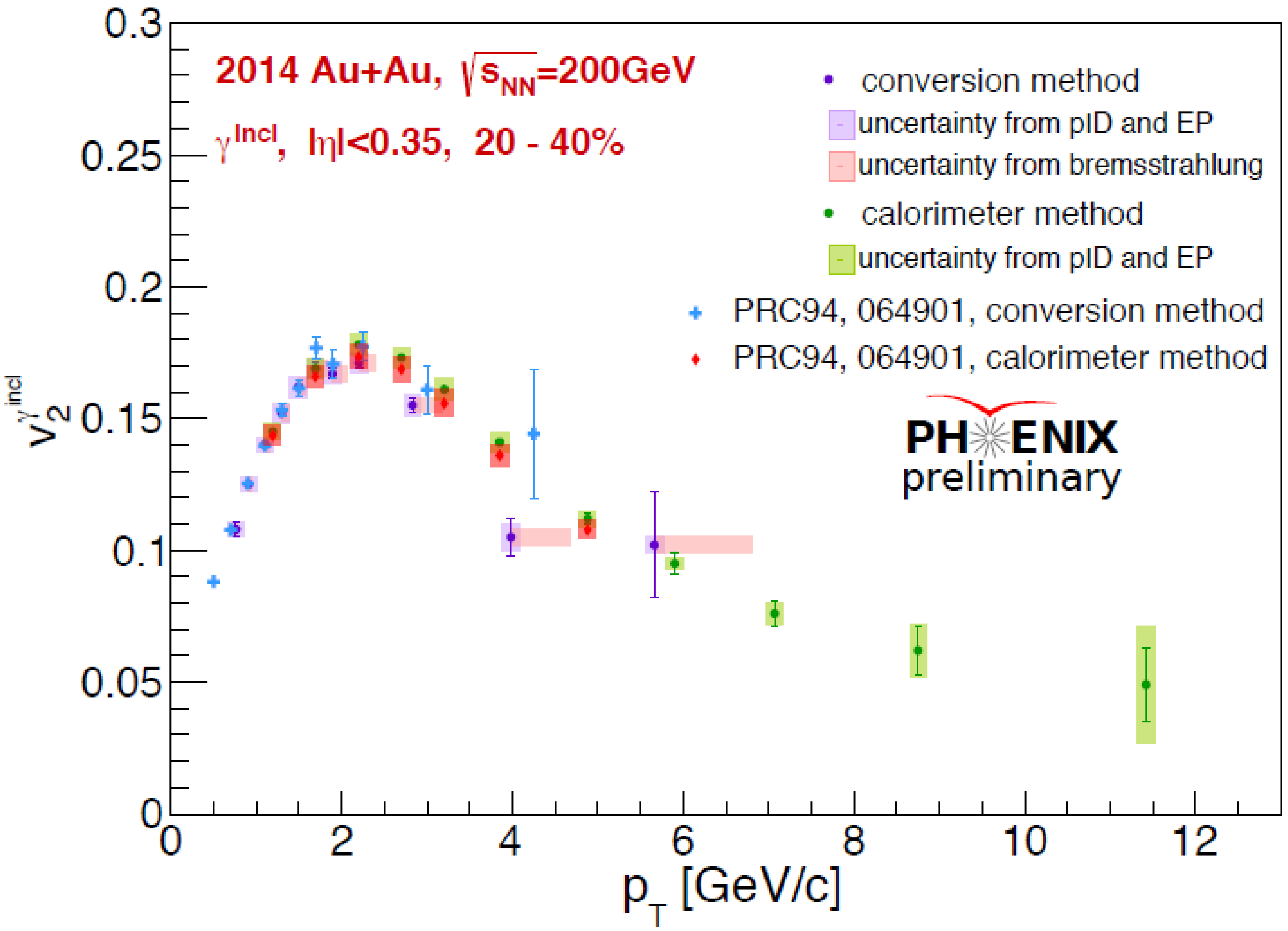


New method, new data

PHENIX has more than 10 times the statistics of the published data in the analysis pipeline

Inclusive photon elliptic flow via external conversion on the VTX detector

Calorimeter measurement repeated, too, on much larger dataset

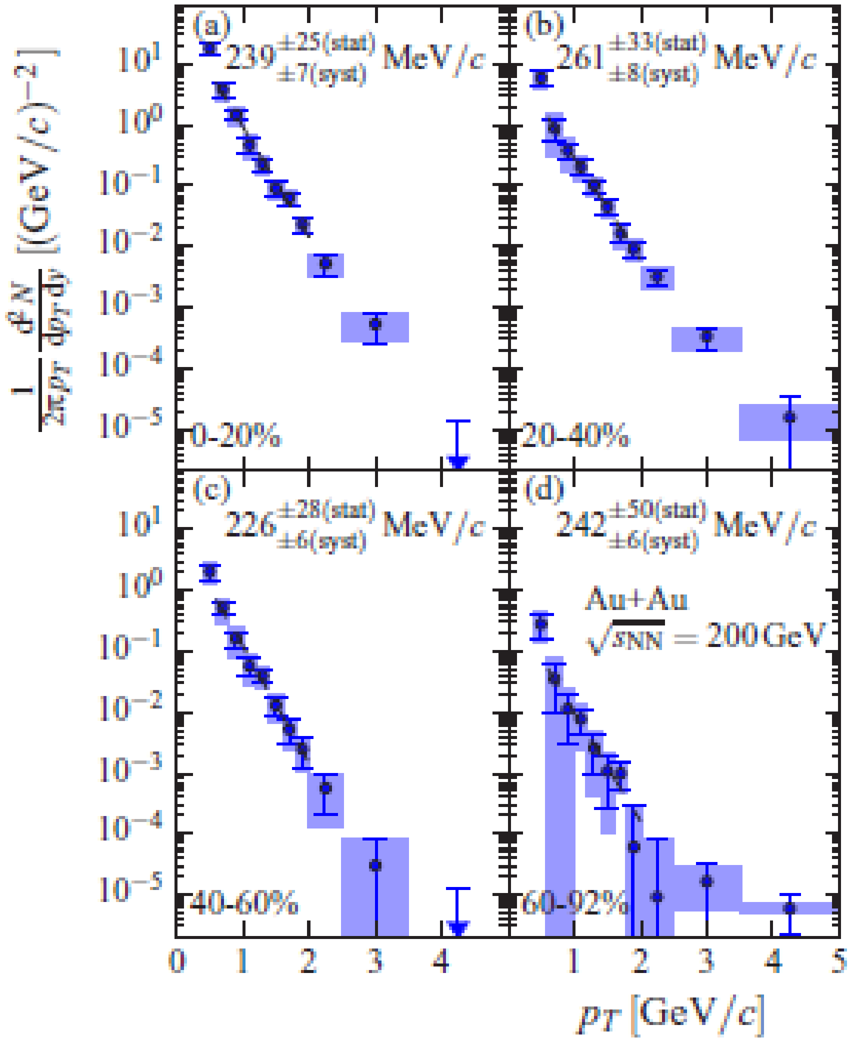


Thermal photons -- scaling with N_{part}, N_{ch}?

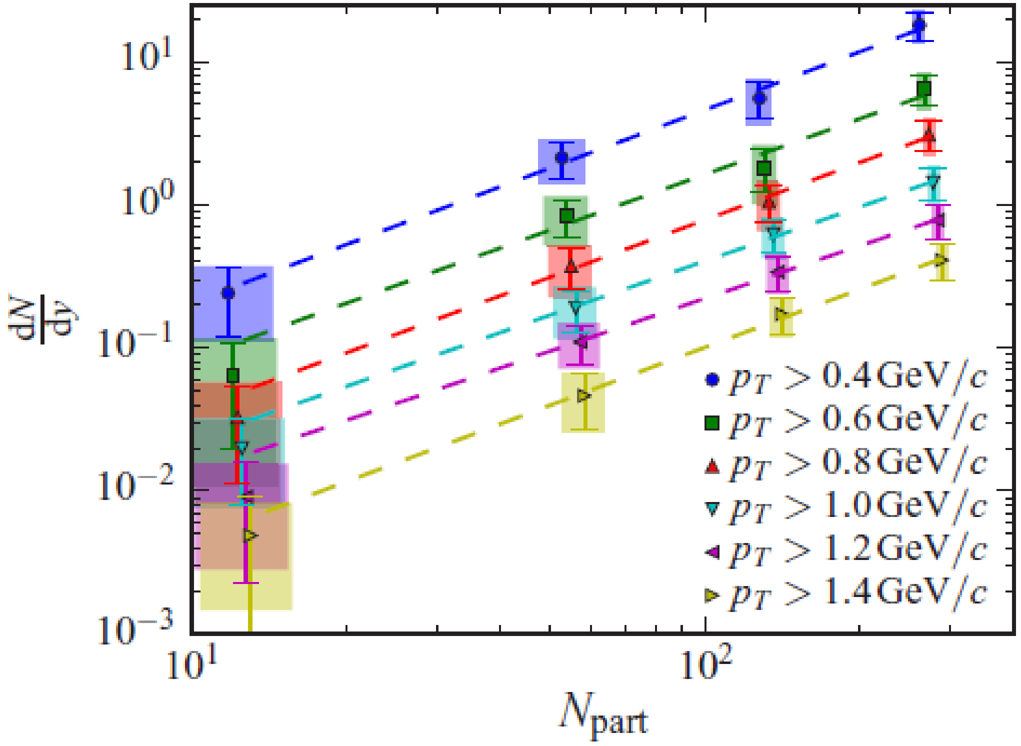
200 GeV Au+Au, scaling with N_{part}

PRC 91, 064904 (2015)

PHENIX, external conversion, HBD backplane



Slopes: α ~ 1.38 (independent of integration limit)



The shape appears to be the same down to the lowest measured p_T

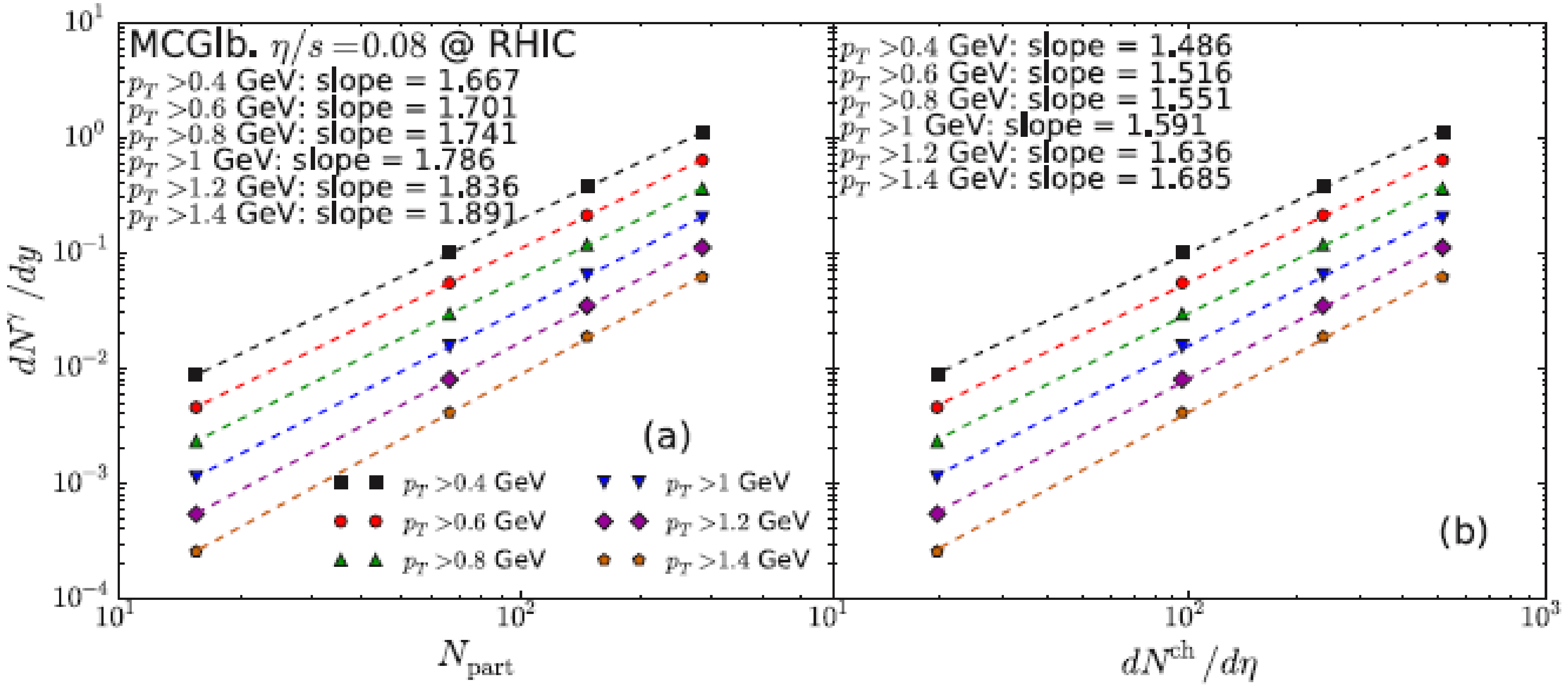
Model or scaling with N_{part}, N_{ch}

PRC 89, 044910 (2014)
(Shen, Heinz, Paquet, Gale)

yield with respect to the QGP photon yield. We find the HG photon yield above $p_T = 0.4$ GeV to scale as a function of N_{part} with power 1.46 and as function of $dN_{ch}/d\eta$ with power 1.23; the corresponding scaling powers for the QGP photons are larger, 2.05 and 1.83, respectively. QGP photons thus have

Model calculation (no data points) inspired by the prelim. data leading to PRC 91, 064904 (2015)

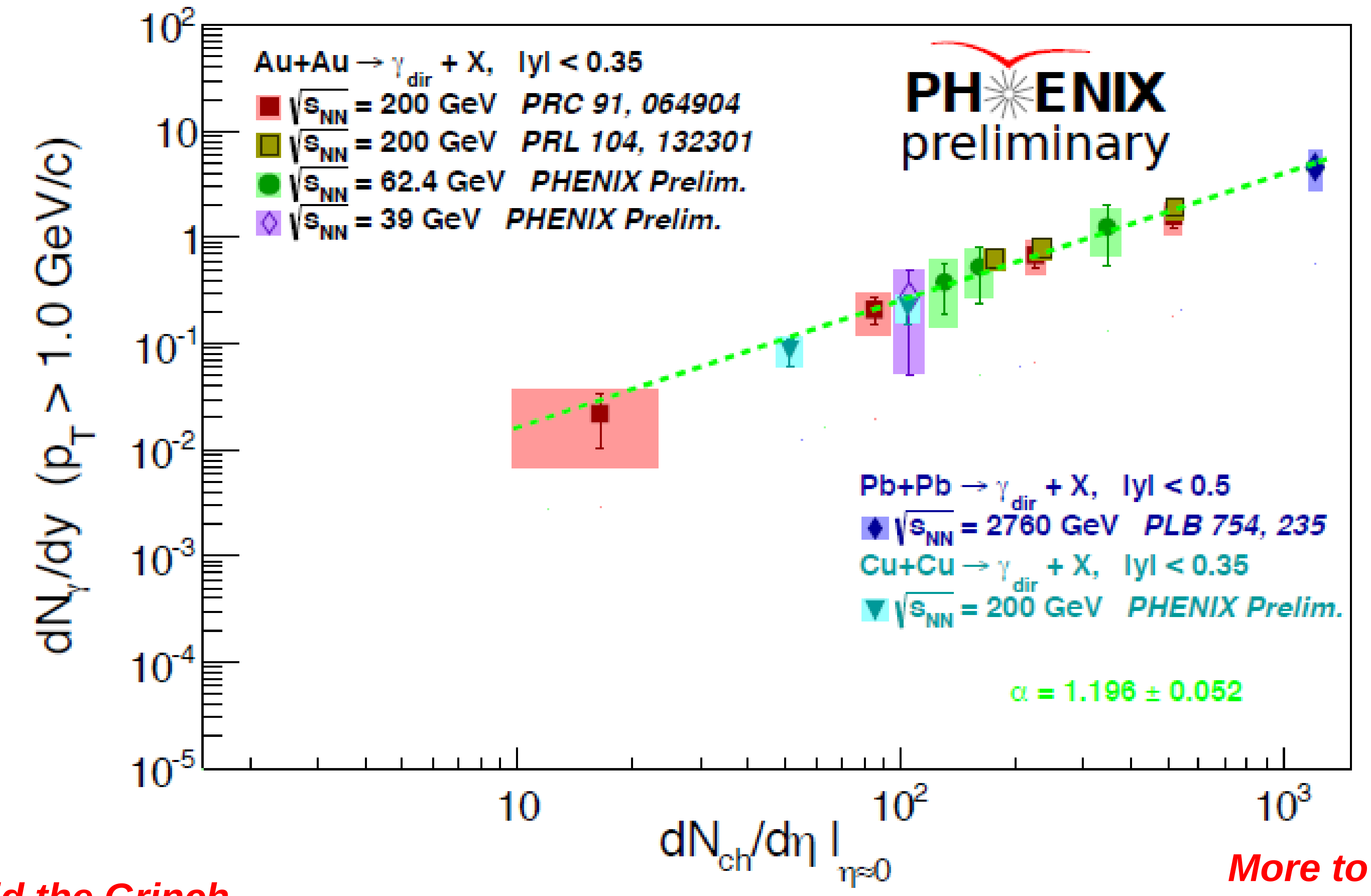
In terms of $dN_{ch}/d\eta$ hadron gas part should go with power 1.23



Scaling with $dN_{ch}/d\eta$, different systems and energies

α = 1.196

Uhm… what was it?
"In terms of $dN_{ch}/d\eta$ hadron gas part should go with power 1.23"
(QGP would give higher power)



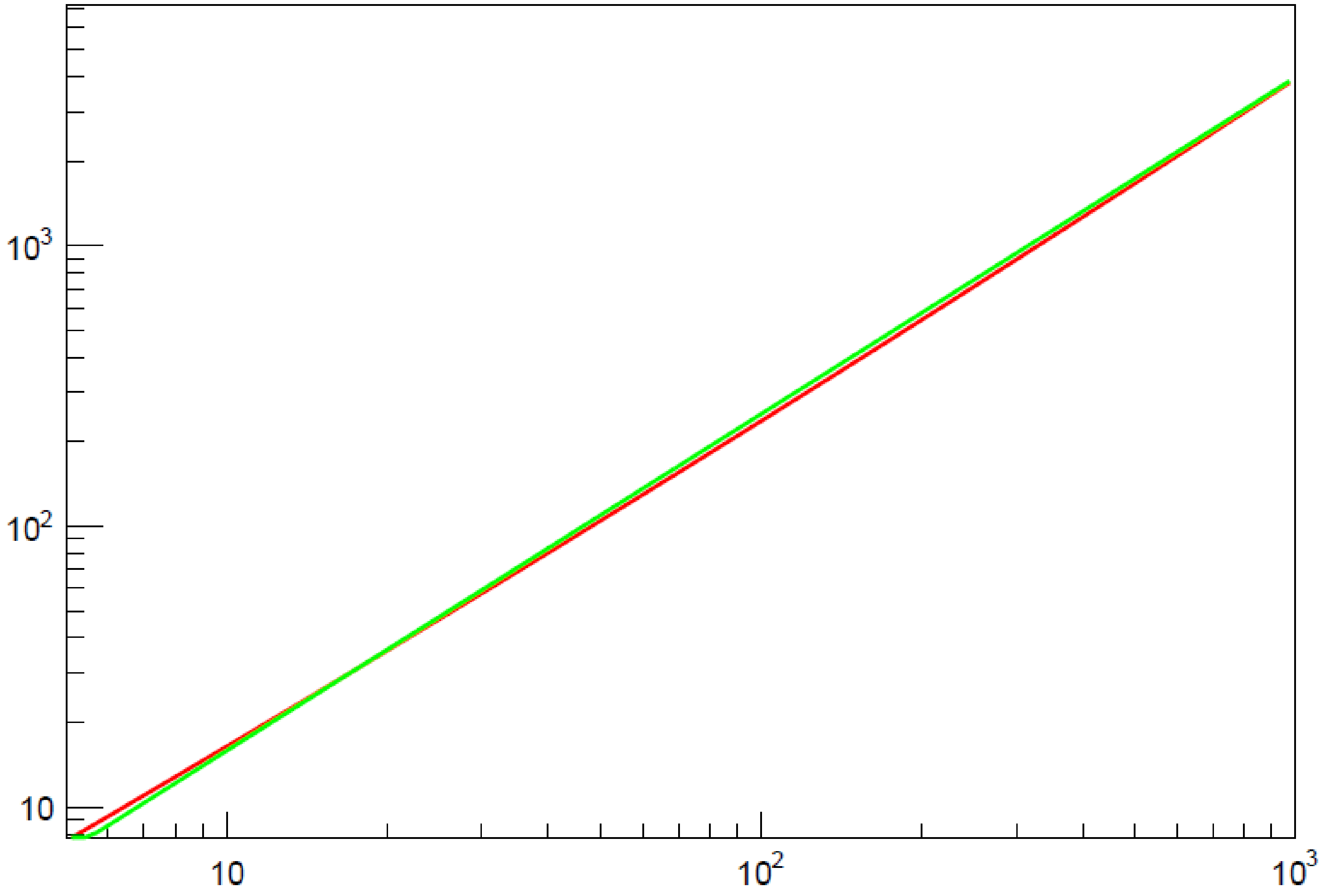
Did the Grinch steal the QGP???

More to come very soon!

Before we get carried away…

We are talking about 2 orders of magnitude in integrated yield, about the same in $dN_{ch}/d\eta$

Could you (or the data) differentiate between these two curves? (one is $x^{1.2}$, the other $x + x^{4/3}$ suggesting two completely different underlying scenarios)



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https://www.usnews.com/best-graduate-schools/top-science-schools/nuclear-science-rankings

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#2	University of Washington Seattle, WA
#3	Massachusetts Institute of Technology Cambridge, MA
#4	Stony Brook University—SUNY Stony Brook, NY
#5	Indiana University—Bloomington Bloomington, IN
#6	California Institute of Technology Pasadena, CA
#6	Duke University Durham, NC
#6	University of California—Berkeley Berkeley, CA
#6	Yale University New Haven, CT
#10	Columbia University New York, NY

Summary

High pT direct photons behave in all known cases as “standard candle”
no surprises in pp, AA, neither in theory, nor in experiment
→ try to think about them as the ***definition on “centrality”*** in questionable cases

“Thermal” photons – while defying initial expectations – resulted in a plethora of models, some seriously ***questioning what we thought*** of the QGP

The “thermal photon puzzle” is alive and well – but unclear whether part of it is an experimental issue or not (at the moment); ***more data*** coming soon

“Thermal” photons show interesting scaling – rich field for ***new phenomenology***?

Isn’t it a ~~shame~~ pity, that direct photons never got a ***dedicated*** experiment?

Backup

???

Direct photon overview

G. David
Stony Brook University

High p_T direct photons – standard candle

Thermal photons – and the “puzzle”

Thermal photons -- scaling