Collision geometry and hadron/photon ratios

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The issue

In the quest to find the Quark-Gluon Plasma and explore its properties

the Glauber-model was our trusted good friend when when connecting
collision geometry (directly inaccessible) to experimental observables
→ "proven" in *large-on-large ion collisions*

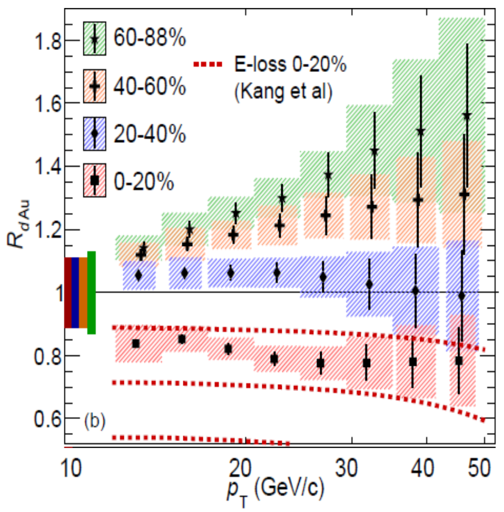
we used to think about *small-on-large collisions* only as a reference,
→ revealing initial state effects, if any (assumption: no QGP is formed)

since 2012, many unexpected observations in asymmetric collisions: formation of QGP even there?
→ signs of collectivity (mainly low p_T)?
→ jet modification (high p_T)?
→ onset of "thermal" photon production? (see Axel Drees' talk)
→ similar effects even in "extreme" *pp* collisions?

"If it looks like a duck, swims like a duck, quacks like a duck, probably it ***is*** a duck".
But don't forget, where this saying came from!
It is possible that it swims like a duck, because it's made of foam, and quacks because of the speaker built in. Or it might as well be a real duck. Only further *consistency checks* will tell.

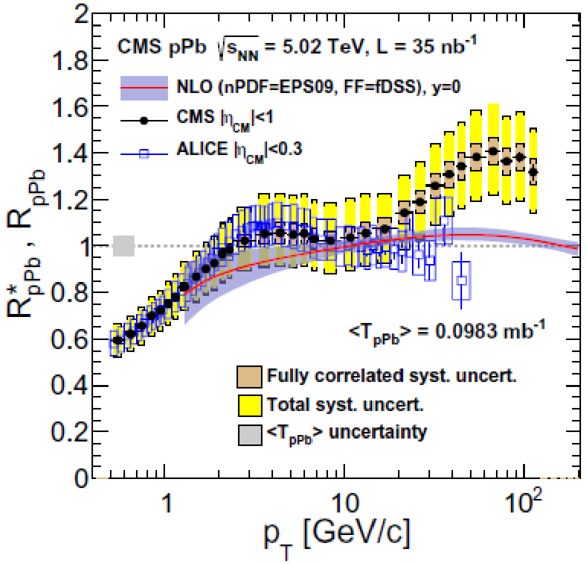
Our issue: artifact or genuine new physics at high p_T?

PHENIX, PRL 116, 122301



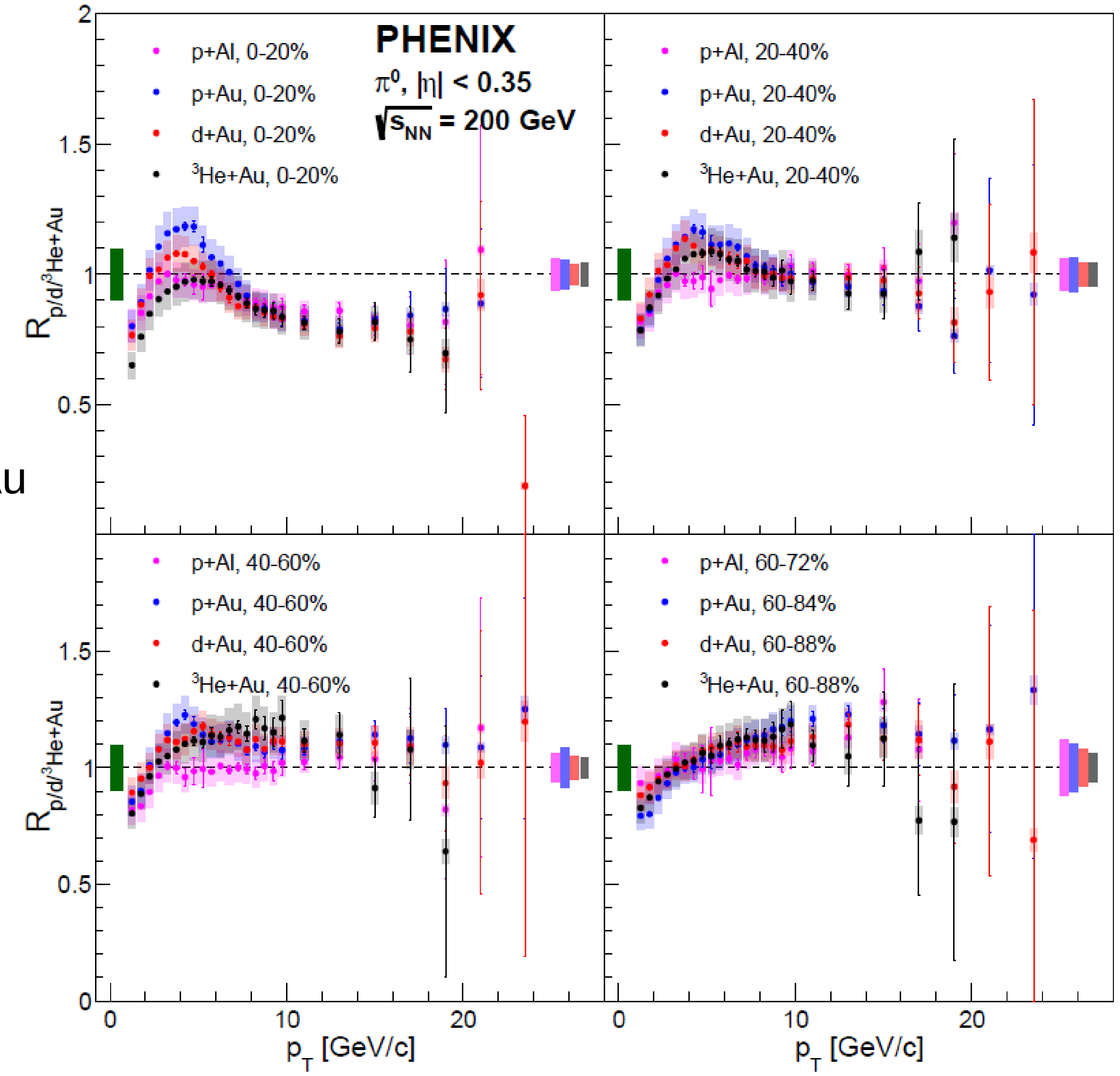
Jets, dAu

CMS (w/ ALICE) EPJC 75 (2015) 237



Charged hadrons pPb

π^0
pAl, pAu
dAu, 3HeAu



Theory is great, but is it verifiable?

Since QM'12, p/d+A results – specifically, strong suppression in "central" and large enhancement in "peripheral" R_{pA} at high p_T caused pretty vivid discussion.

Claims of "new physics" vs claims of bias in centrality determination (essentially a ***breakdown in factorization of hard and soft processes***)

Some examples (there are many more):

PRC 93, 034914 (2014) → "flickering" , ***x***-dependent color fluctuation; kinematics also plays a role at mid-rapidity

PRC 94, 044901 (2016) → hard scattering (large ***x***) reduces soft production; basically empirical approach with a touch of kinematics

PRC 94, 024915 (2016) → color fluctuations; large ***x*** connected to "shrinking" of the nucleon plus "impact parameter dependent shadowing and saturation effects"

Issue: all these resulted in re-interpretation of centrality based on some model except for ALICE who simply "gave up" (in a positive sense) and stopped showing "R_{pA}" referring to a purely experimental quantity instead (Q_{pA}).

Reminder: event geometry → event activity

Ann.Rev.Nucl.Part.Sci.57:205-243,2007
(arXiv:nucl-ex/0701025)

Geometry is *convenient* for theorists
to describe nuclear density, nPDFs, bulk phenomena, path lengths, initial fluctuations… etc.

Experimentally it is *inferred* from some
observable reflecting average interactions (event activity)

The usual tool to make the connection
is the Glauber-model (and its extensions)

"In heavy ion collisions, we manipulate the fact that the majority of the initial state nucleon-nucleon collisions will be analogous to minimum bias p+p collisions…"

3.1 Methodology

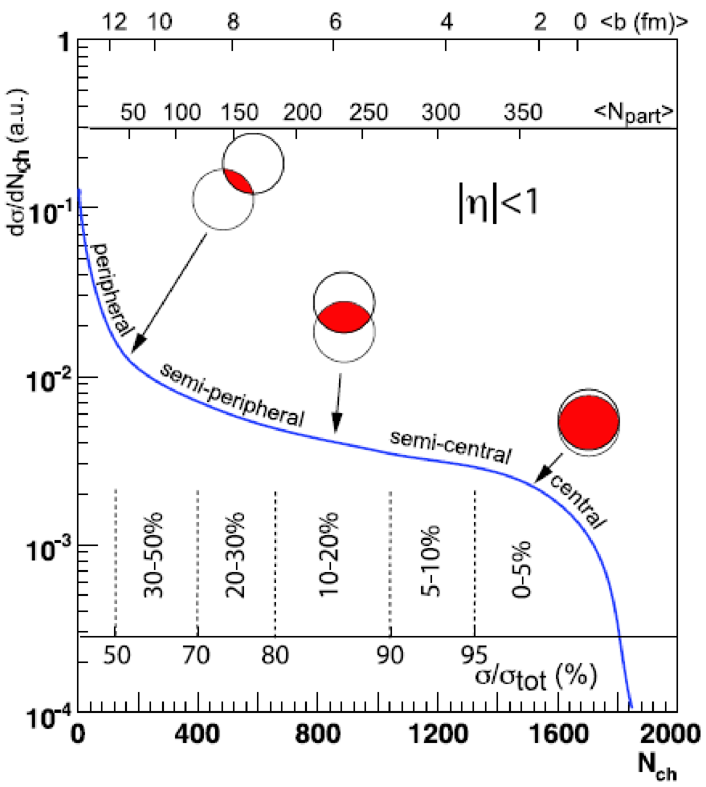
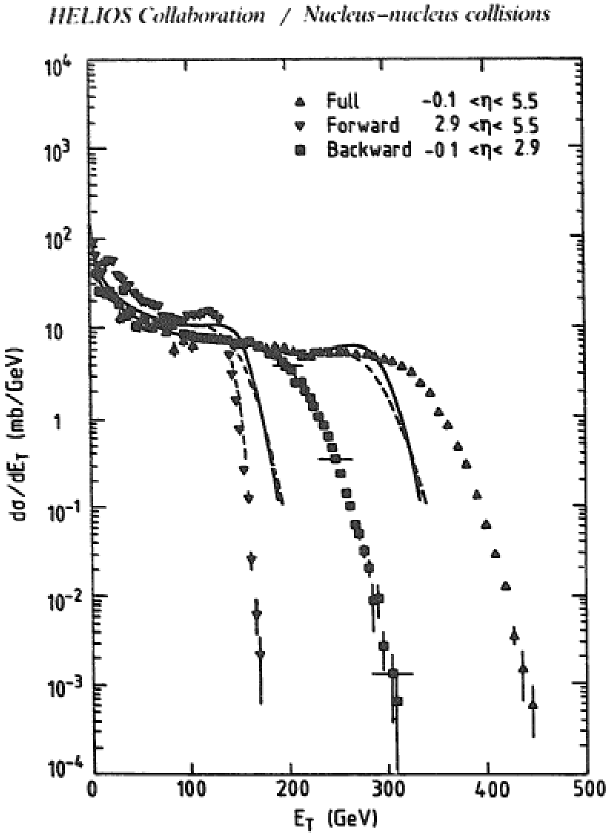


Figure 8: A cartoon example of the correlation of the final state observable N_{ch} with Glauber calculated quantities (b, N_{part}). The plotted distribution and various values are illustrative and not actual measurements (T. Ullrich, private communication).

First issues with the "naïve" Glauber model

HELIOS S-W, Nucl. Phys. B 353 (1991) 1



E_T fw, bw, total, dominated by average soft processes. Models: FRITIOF, IRIS. Plateau – average process – well described, but the tails are missed.

Introducing color fluctuations:
PRL 67 (1991) 2946 based on
SPS/AGS ω values estimated

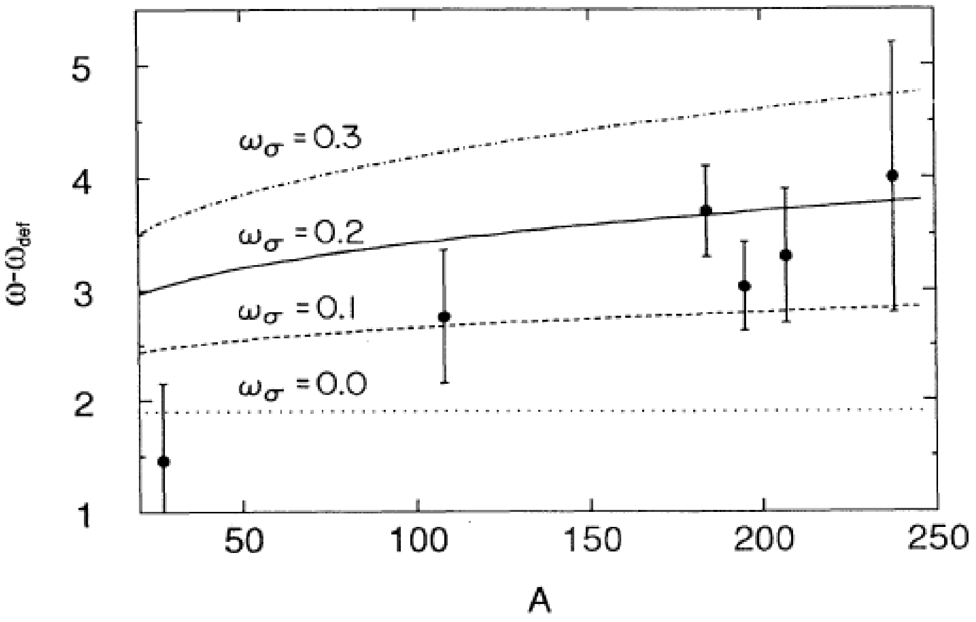
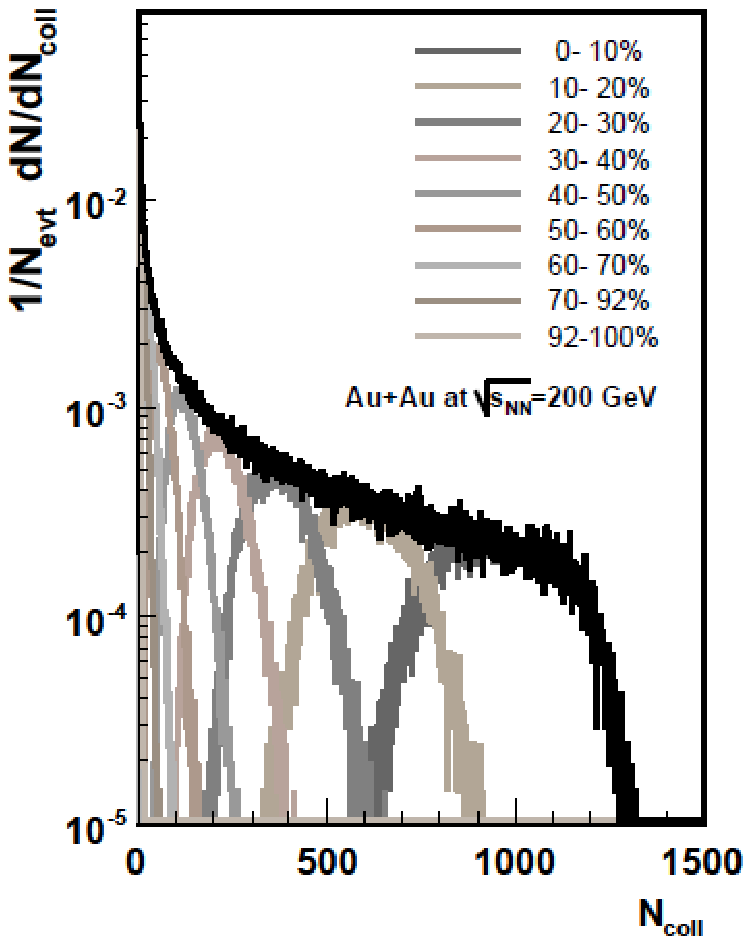


FIG. 1. Fluctuations $\omega - \omega_{def}$ for central collisions of ^{32}S on different targets calculated with Eq. (13) for various values of ω_σ. The experimental values (dots) are taken from Ref. [12].

Similar ω as used two decades later
by ATLAS (Glauber-Gribov) + Strickman

“Naïve” Glauber model for experimental determination of centrality (RHIC, LHC)



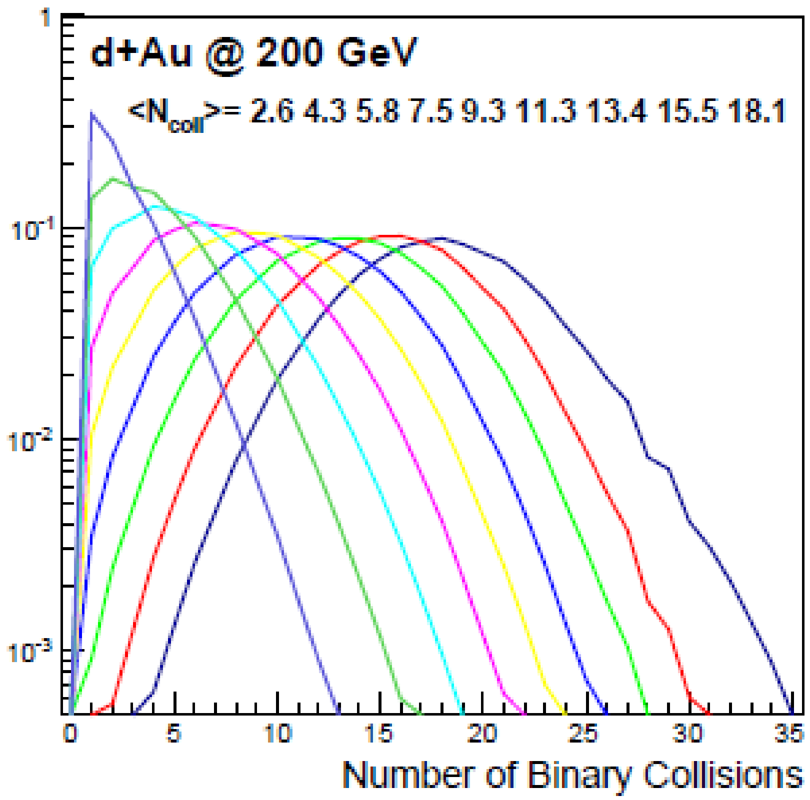


FIG. 4: Extracted distribution of the number of binary collisions in each of the nine centrality quantiles: 0%–5%, 5-10%, 10%–20%, 20%–30%, 30%–40%, 40%–50%, 50%–60%, 60%–70%, and 70%–88%.

Both still based on “soft production” only

ALICE: Q_{pPb} instead of R_{pPb}

What happens in pPb if you select extreme multiplicities? (Simulation, standard Glauber MC)

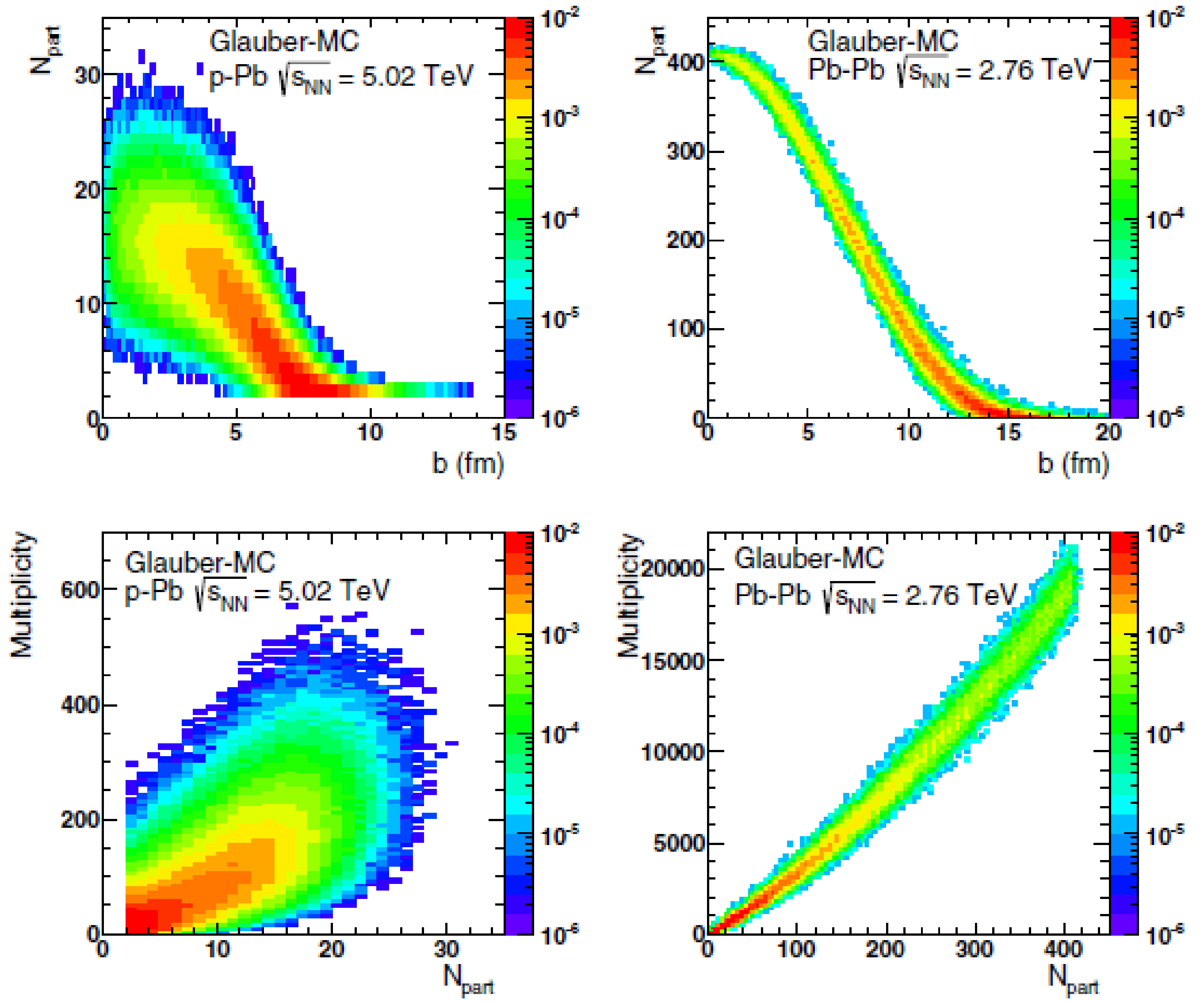
PRC 91, 064905 (2015)

B. Nuclear modification factors

As discussed in Sec. V, the various centrality estimators induce a bias on the nuclear modification factor depending on the rapidity range they cover. In contrast to minimum-bias collisions, where $\langle N_{coll} \rangle = 6.9$ is fixed by the ratio of the pN and p-Pb cross sections, in general, N_{coll} for a given centrality class cannot be used to scale the pp cross section or to calculate centrality-dependent nuclear modification factors. For a centrality selected event sample, we therefore define Q_{pPb} as

$$Q_{pPb}(p_T; \text{cent}) = \frac{dN^{pPb}_{cent}/dp_T}{\langle N^{Glauber}_{coll} \rangle dN^{pp}/dp_T} = \frac{dN^{pPb}_{cent}/dp_T}{\langle T^{Glauber}_{pPb} \rangle d\sigma^{pp}/dp_T} \quad (15)$$

for a given centrality percentile according to a particular centrality estimator. In our notation we distinguish Q_{pPb} from R_{pPb} because the former is influenced by potential biases from the centrality estimator which are not related to nuclear effects. Hence, Q_{pPb} can be different from unity even in the absence of nuclear effects.



More than semantics!

Are things different with (rare!) hard scattering present? Multiplicity vs highest p_T observed

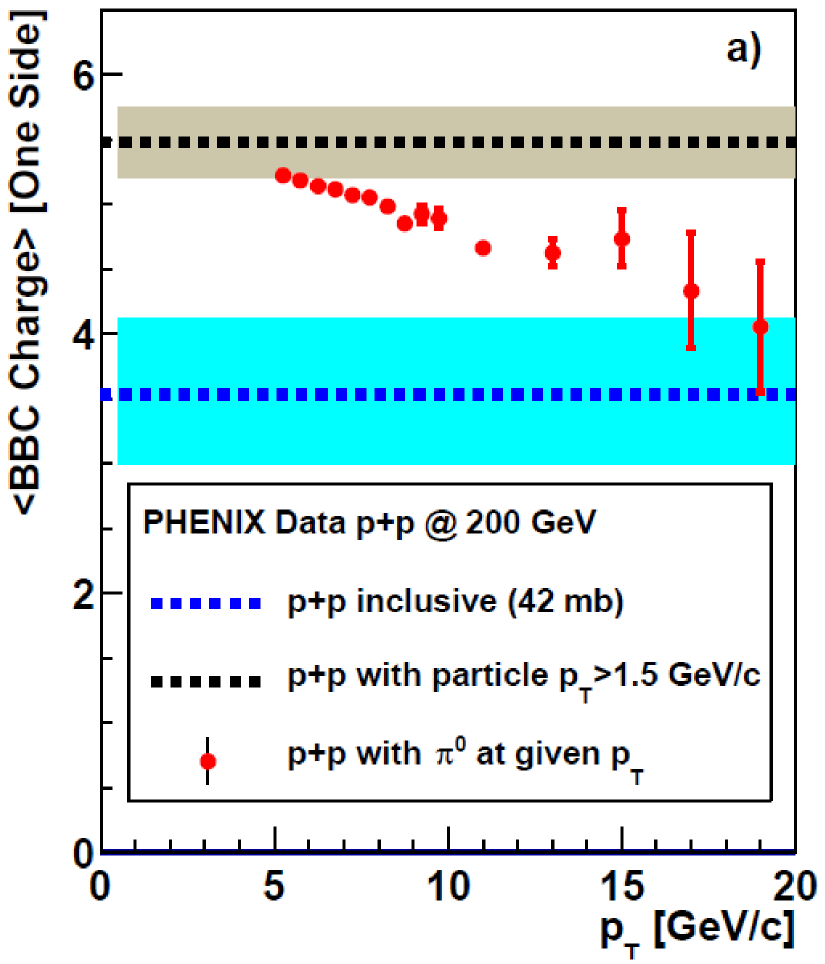
So far color fluctuations:
explained the global distribution of all events, including (but not treating differently) those, that have one or more rare, special interactions

Can centrality still be determined the usual way, or does the picture change?

Experimentally, the only thing you can safely claim is what you observed in single hadron-hadron collisions. Everything elase is hypothesis, even if very reasonably founded.

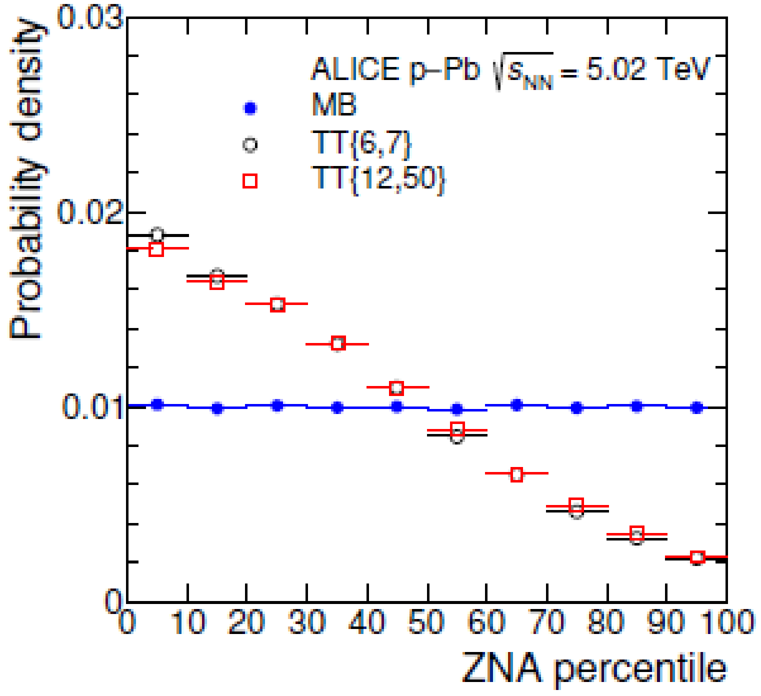
Fact: the observed multiplicity does change if a hard scattering is present. This change happens way before (and is larger) than kinematic constraints would dictate, ***and it is strongly p_T dependent!***

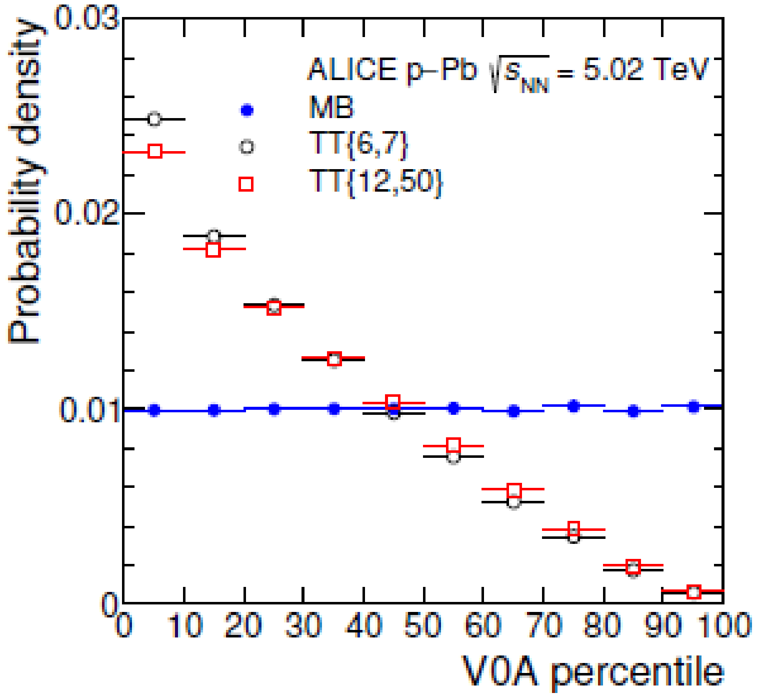
PHENIX PRC 90 034902



ALICE – high p_T central vs forward rapidity event activity measures

PLB 783 (2018) 95-113





High-pT trigger at mid-rapidity: how the event-centrality measures are re-distributed at forward rapidity?

V0A – charged hadrons forward; ZNA – spectator neutrons

Similarity of the two measures is non-trivial!

Are peripheral PbPb collisions so different from pPb? Maybe not!

Initial question: is there really strong suppression (QGP?) even in very peripheral A+A collisions?

(Loizides, Morsch, PLB 773 (2017) 408-411)

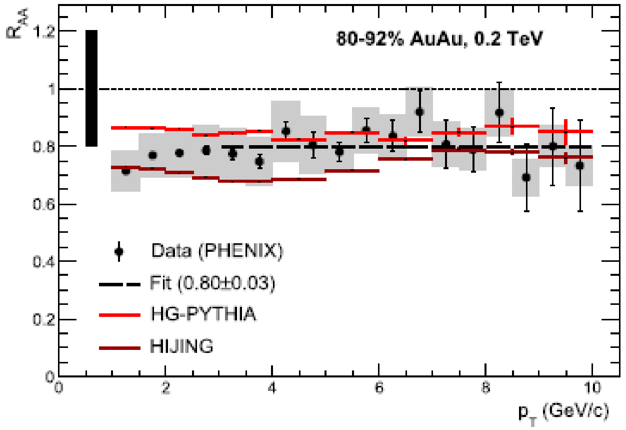


Fig. 1. R_{AA} versus p_T in 80–92% central AuAu collisions at $\sqrt{s_{NN}} = 0.2$ TeV. The PHENIX data from [10,11], which were averaged as explained in the text, are compared to HG-PYTHIA and HIJING calculations. For details, see text.

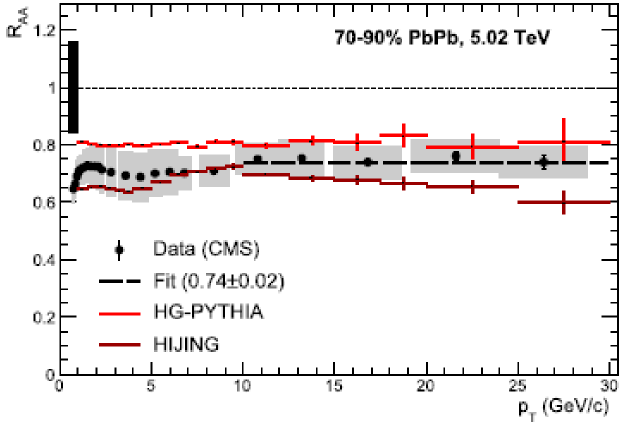


Fig. 2. R_{AA} versus p_T in 70–90% central PbPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV. The CMS data from [12] are compared to HG-PYTHIA and HIJING calculations. For details, see text.

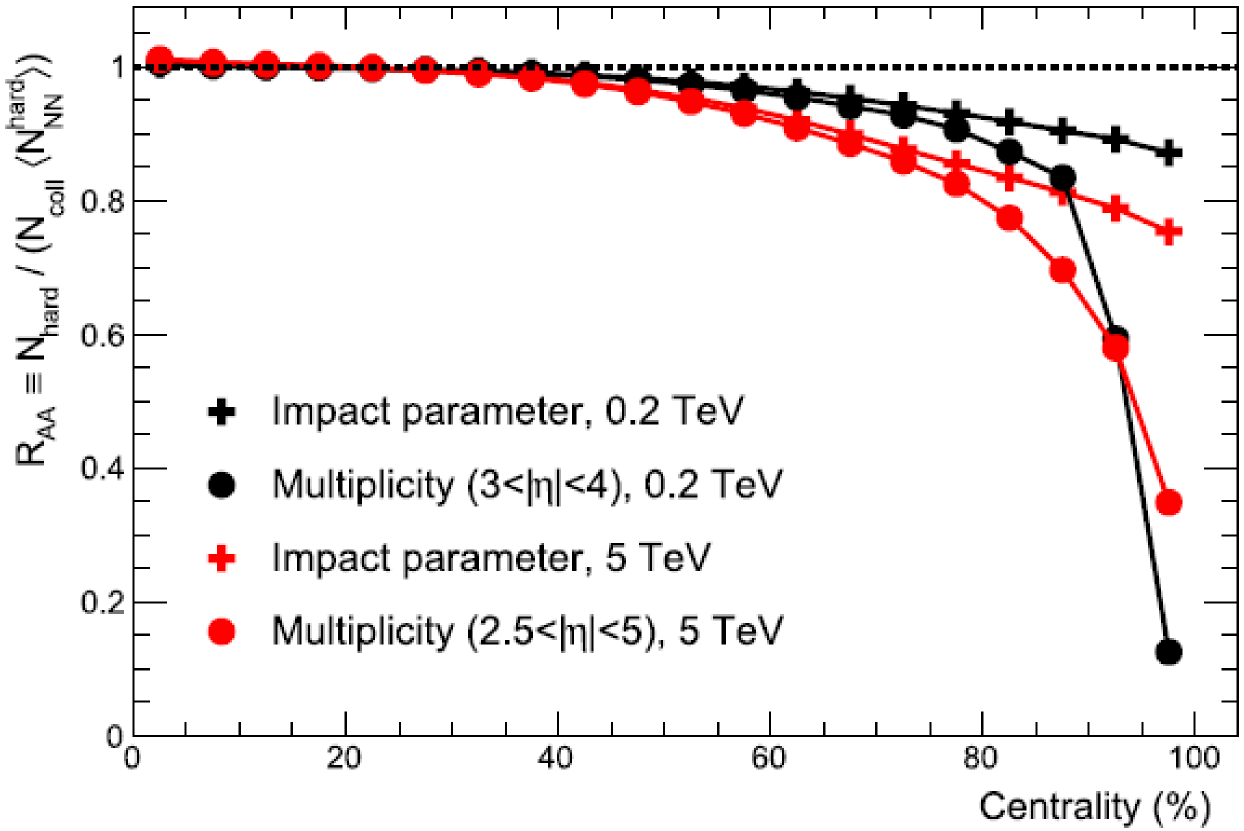
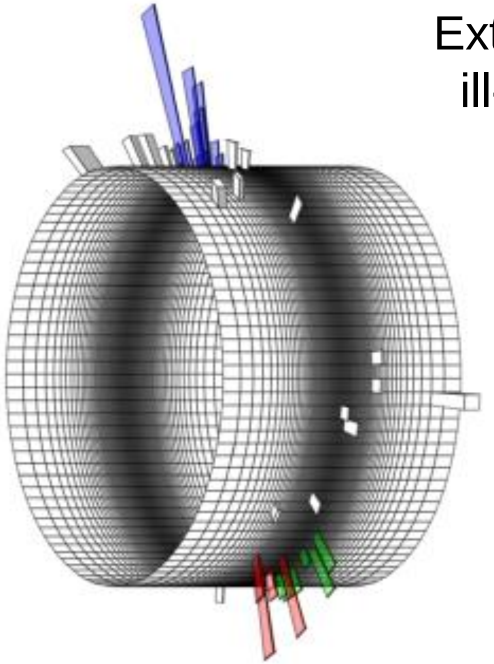


Fig. 3. R_{AA} versus centrality for AuAu and PbPb collisions at $\sqrt{s_{NN}} = 0.2$ and $\sqrt{s_{NN}} = 5.02$ TeV, respectively, calculated with HG-PYTHIA, where $R_{AA} \equiv N_{hard}/(N_{coll}\left\langle N_{NN}^{hard}\right\rangle)$ by construction. For details, see text.

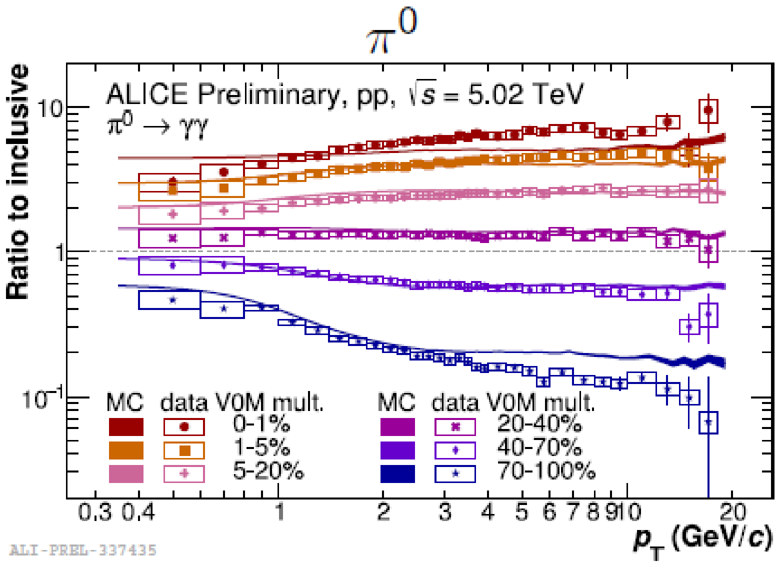
A new – and important – distinction in pp
(or small N_{coll} in general)

Mike Sas, QM'19

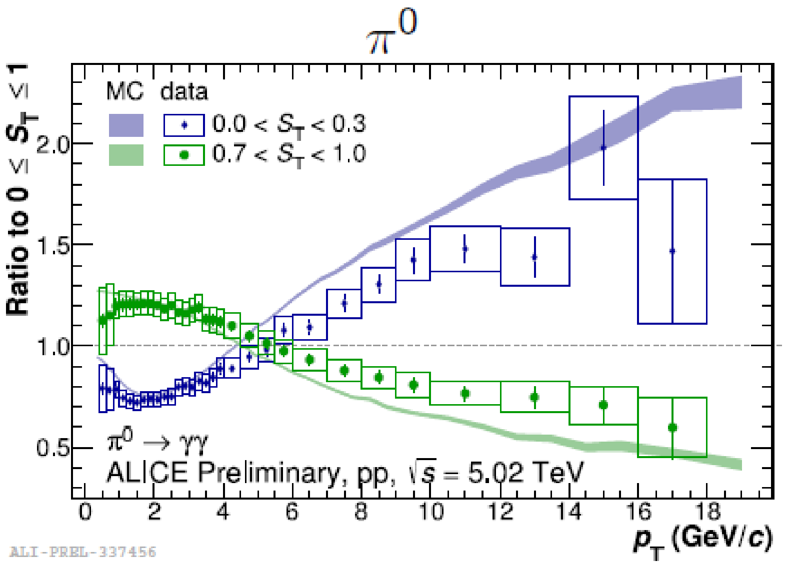
- vs. event multiplicity
- vs. event shape: $0 < S_T < 1$
  - Pencil-like: $S_T \approx 0$
  - Spherical: $S_T \approx 1$
- In-jet production
  - Reconstruct neutral mesons inside charged jets
  - Algorithm: anti-k_t, $R = 0.4$, $E > 10$ GeV



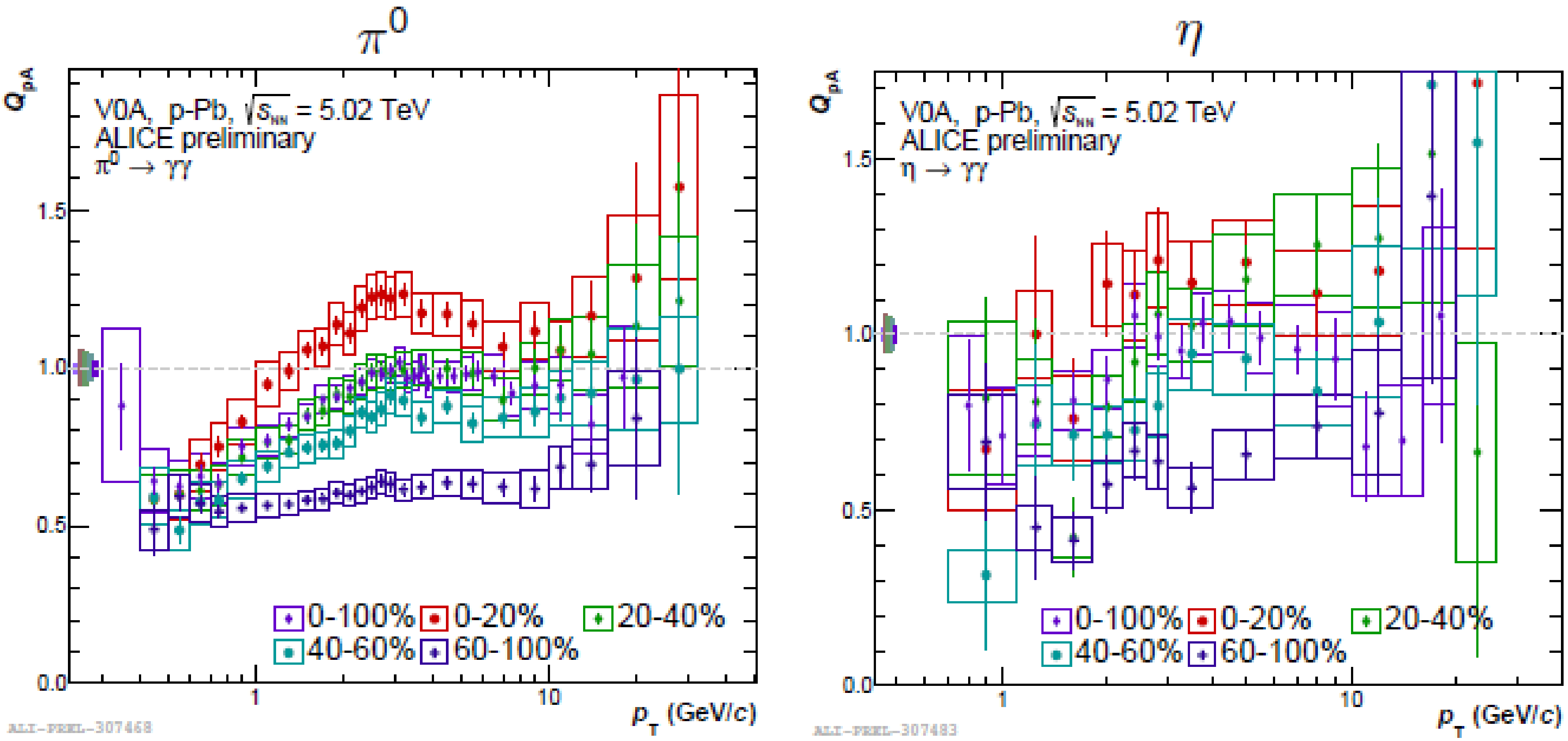
Ratio to inclusive (MB))
Extremes ill-described



Pencil-fraction overpredicted, spherical underpredicted



ALICE: Q_{pA} in pPb collisions (Mike Sas, QM'19)



Nuclear modification factor:

$$Q_{pA} = \frac{dN^{pA}/dp_T}{< T_{pA} > d\sigma^{pp}/dp_T}$$

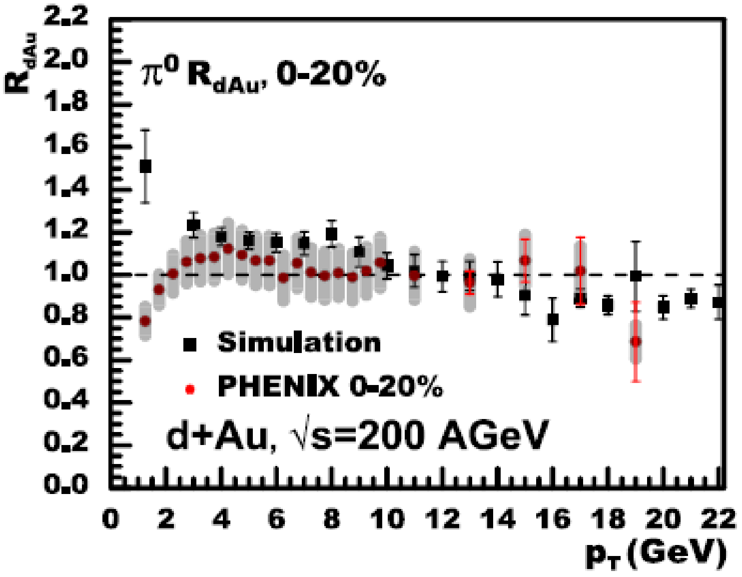
Quite different from PHENIX R_{pA}

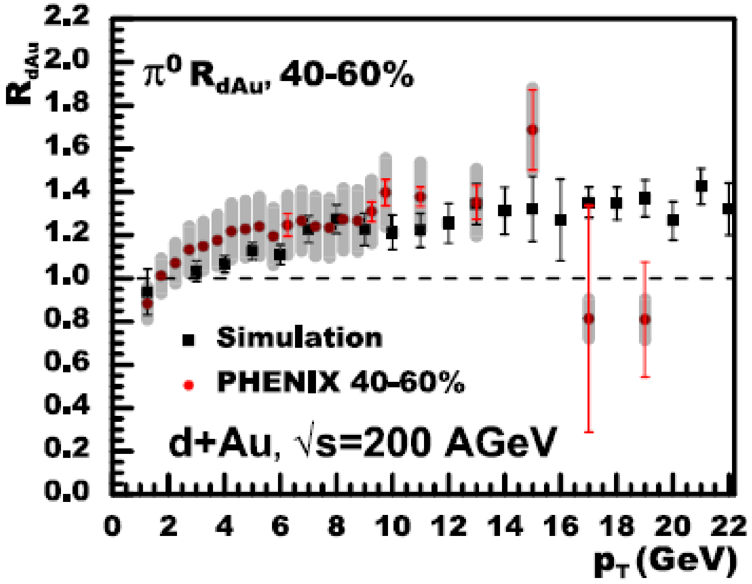
π^0 from 0.4GeV/c , η from 0.8GeV/c!

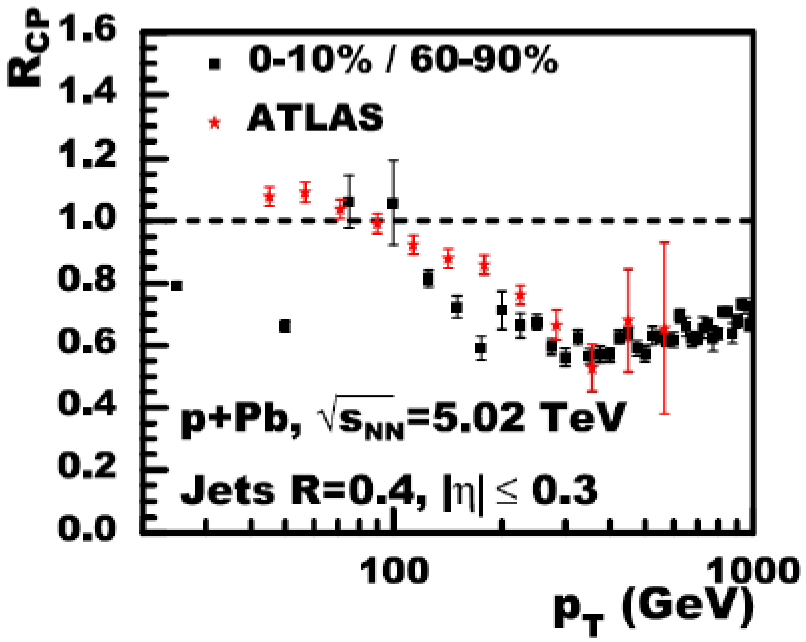
Medium effect – or "centrality" bias?

Color fluctuations – or energy conservation?

In PRC **97**, 054904 (2018) it is pointed out that in p/d+Au "the puzzling enhancement seen in peripheral events at RHIC and the LHC, as well as the suppression seen in central events at the LHC are possibly due to mis-binning of central and semi-central events, containing a jet, as peripheral events... partonic correlations built out of simple energy conservation are responsible for such an effect". An illustration of these calculations is shown in Fig. 6.







A truly experimental way out

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…

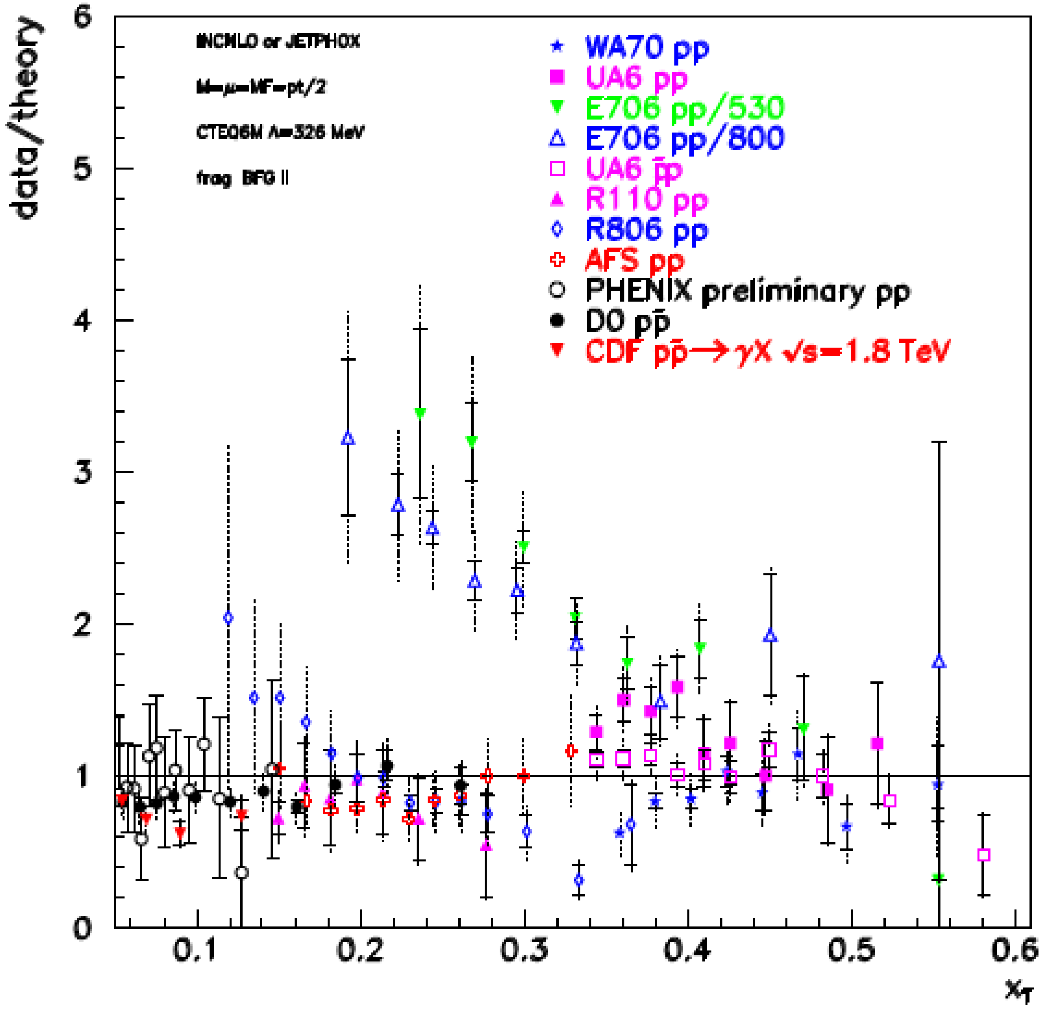
…once you came up with a model to connect geometry to observables, test it against production of high p_T photons, and over the largest p_T range available

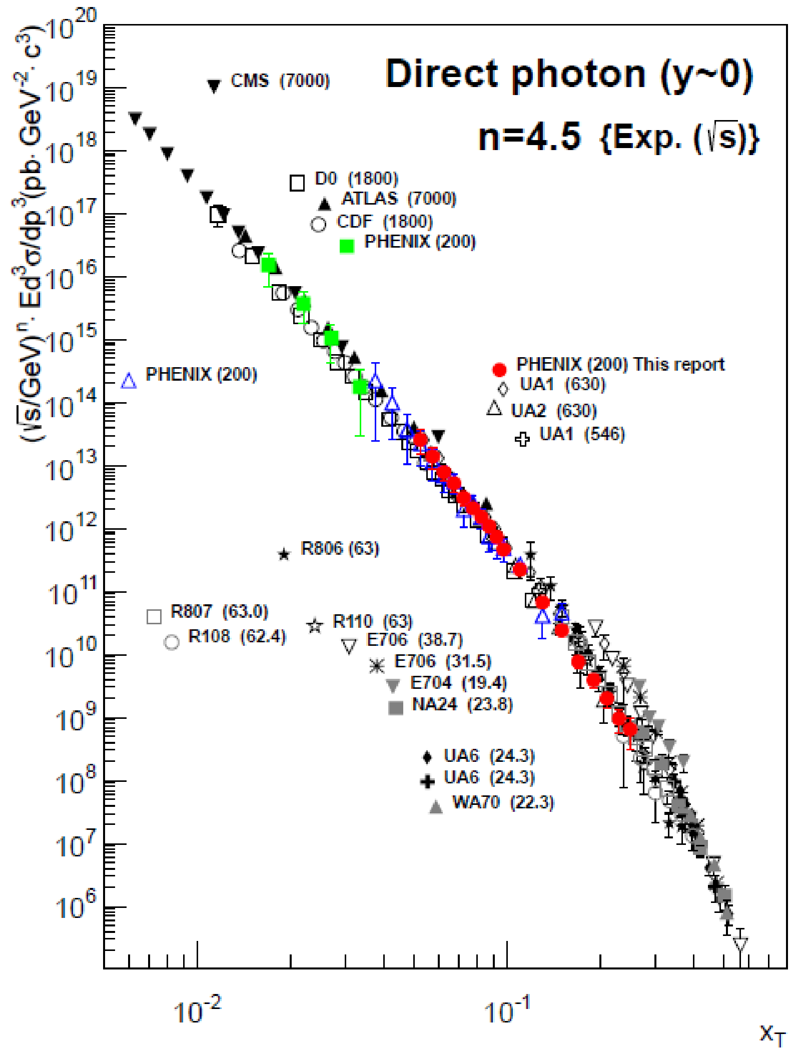
If you find that the photon “nuclear modification factor” (defined with your method) is not unity, your model is wrong.

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

If this is all true, traditional R_{pA} should be replaced by photon/hadron ratios!

Testing hot QCD matter: you need a reliable probe
high p_T photons, color neutral, well calculable in pp





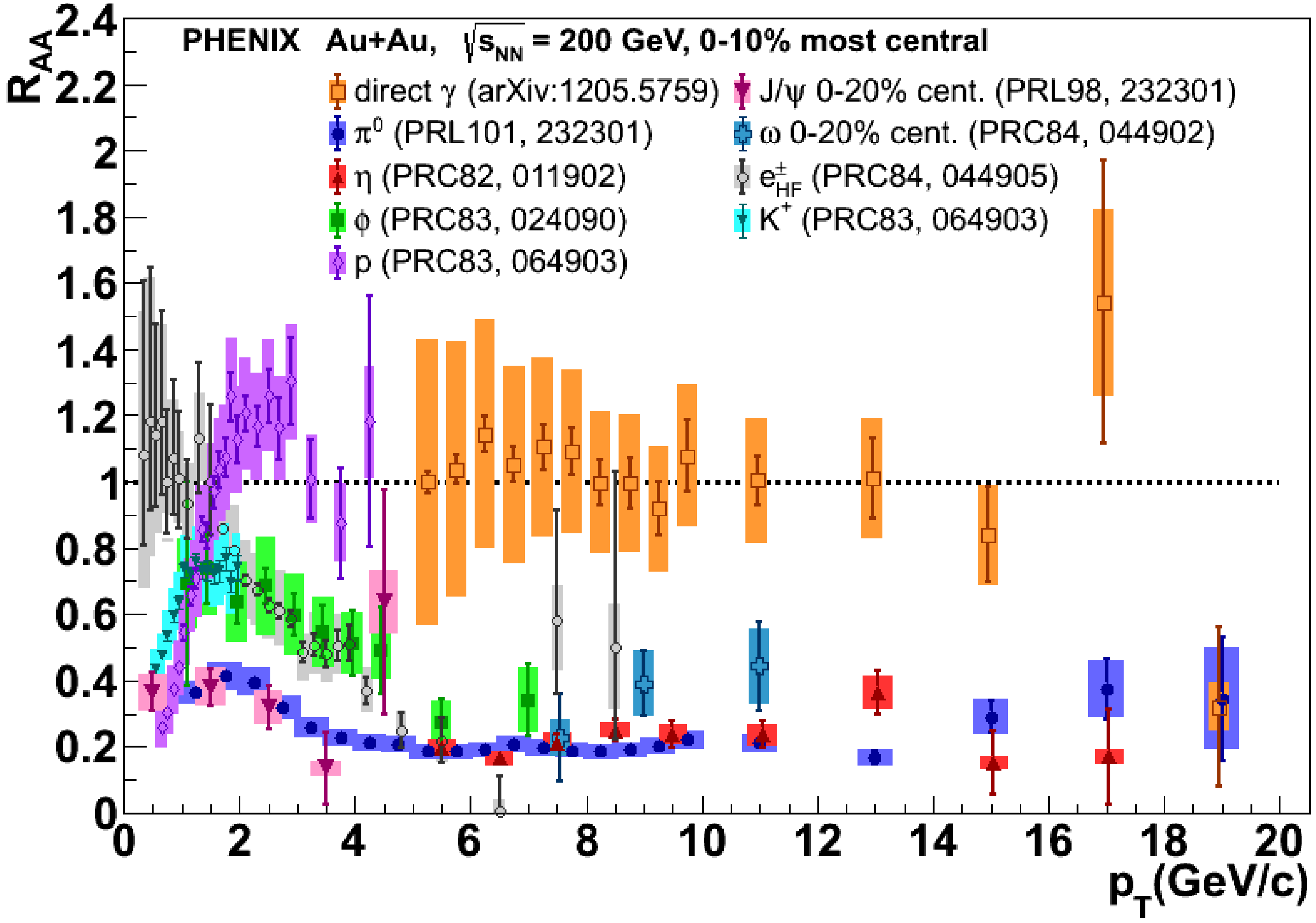
Data well described by NLO calculations

High pT photons: immune to the medium

Hard scattered partons lose energy → fragmentation hadrons are suppressed, but photons are insensitive to medium effects → will be the decisive tool or "centrality" in pA (small-on-large) collisions (***but that's a completely different talk -- GD, Pos(INPC2016)345***)

PHENIX
"T-shirt plot"

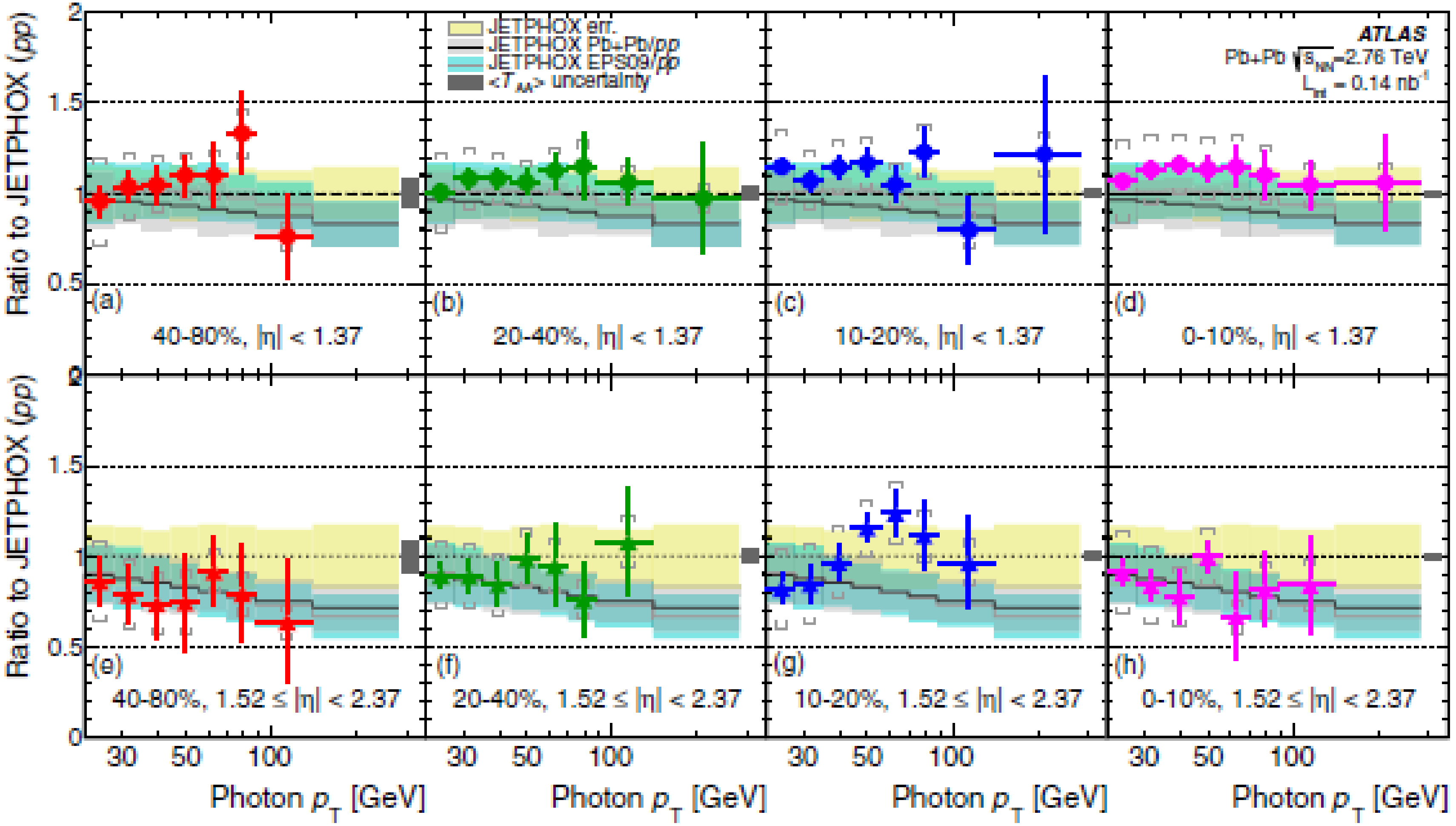
Strong evidence for parton energy loss in medium
as well as validity of the Glauber-model in large-on-large collisions



ATLAS, Pb+Pb

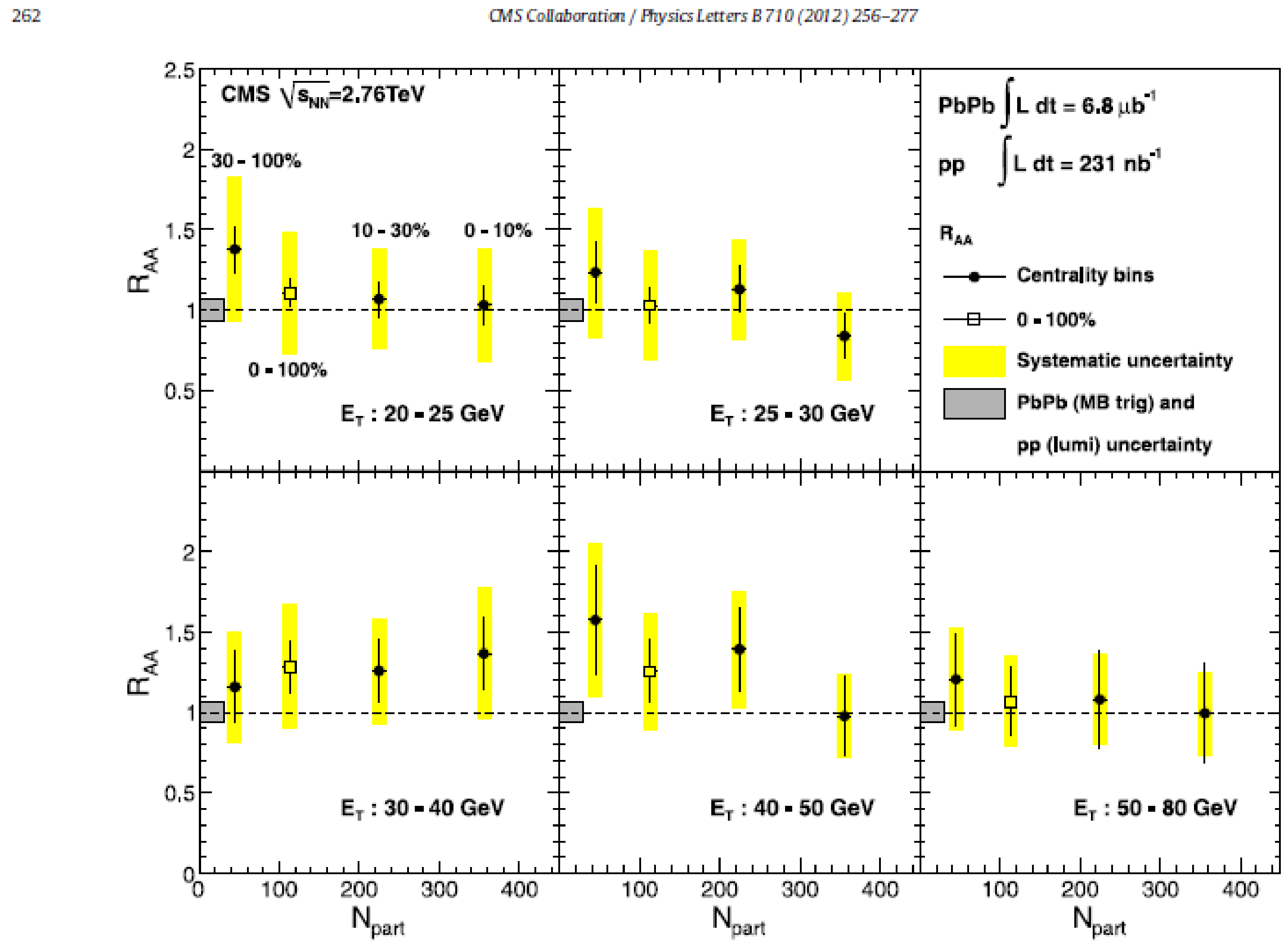
ATLAS, PRC 93, 034914 (2016)

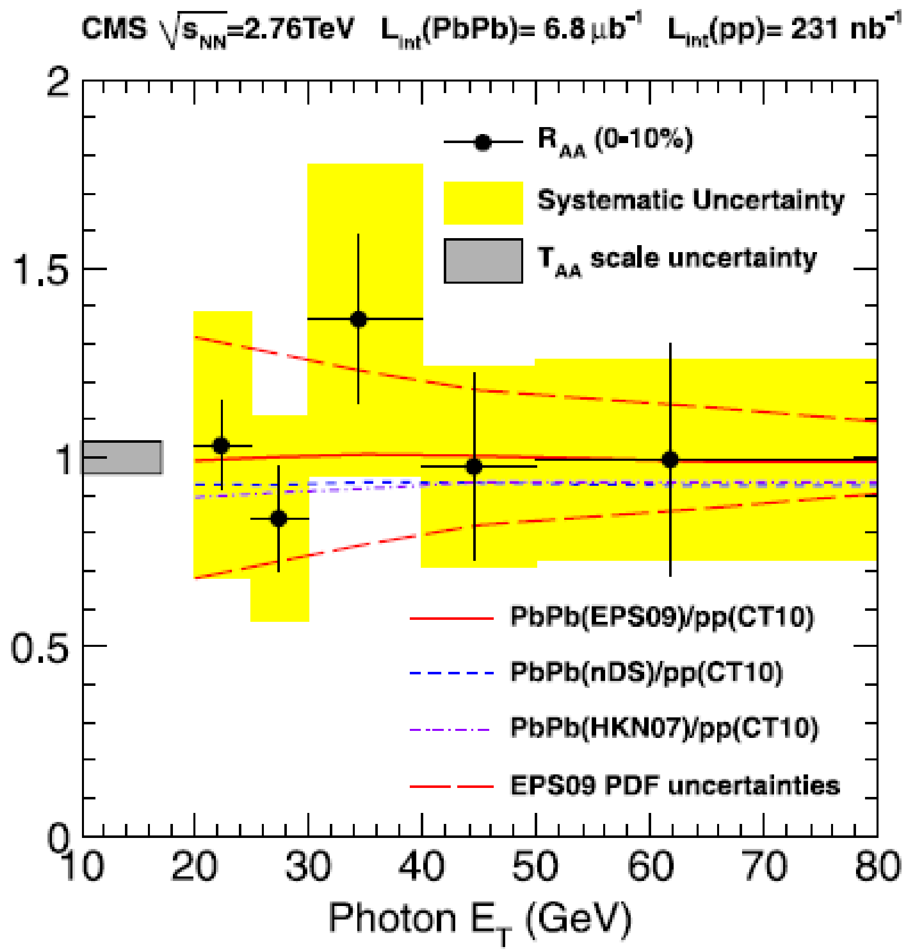
At midrapidity, consistent with 1; fw some depletion
PbPb – includes isospin effect (n/p) - EPS09 includes neutron skin effect



CMS – photons in PbPb

CMS PLB 710 (2012) 256
isolated photon, PbPb 0-10% centrality



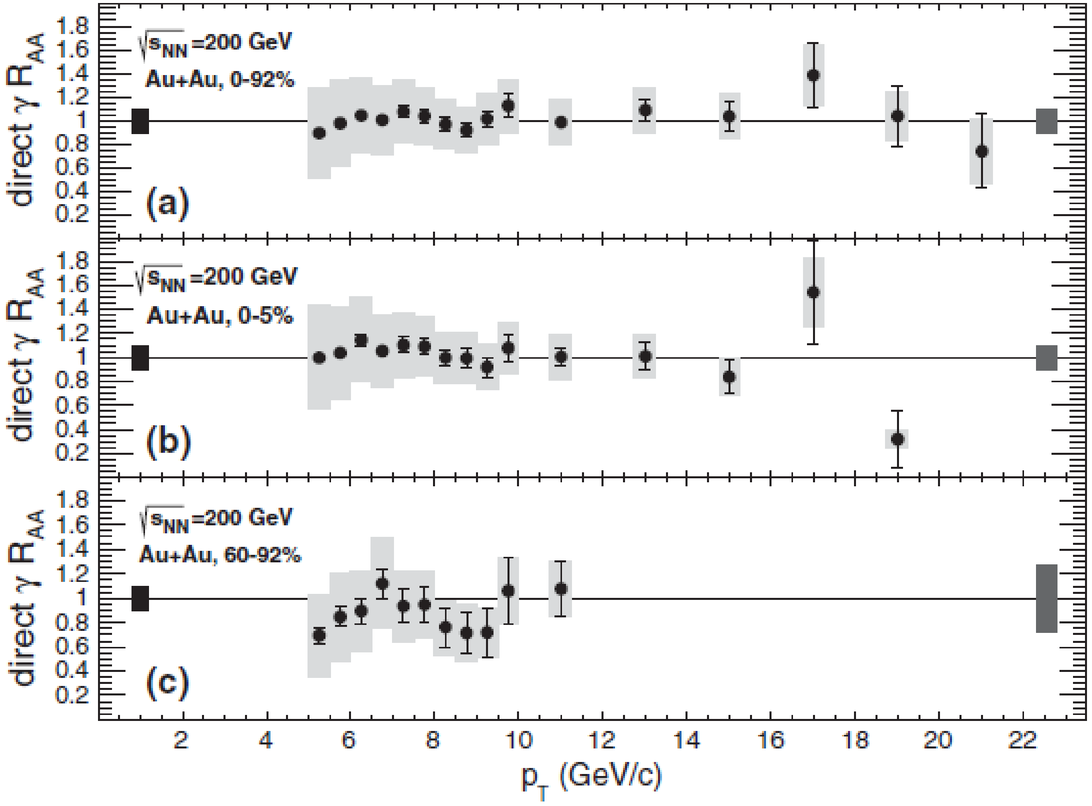


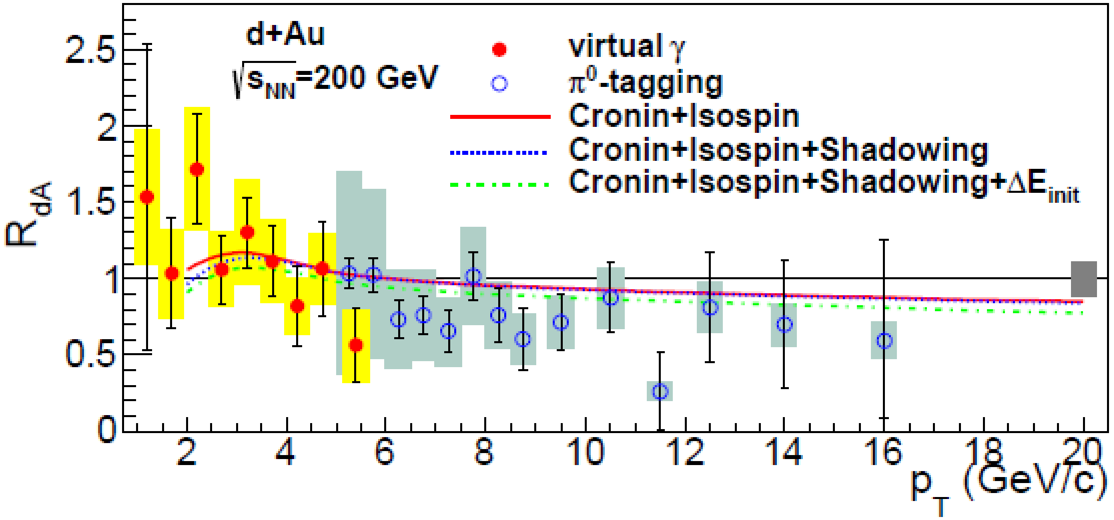
High pT (isolated) photons are immune to the medium – AuAu, dAu

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

PRC 87, 054904 (2013)

PHENIX PRL 109, 152302 (2012)





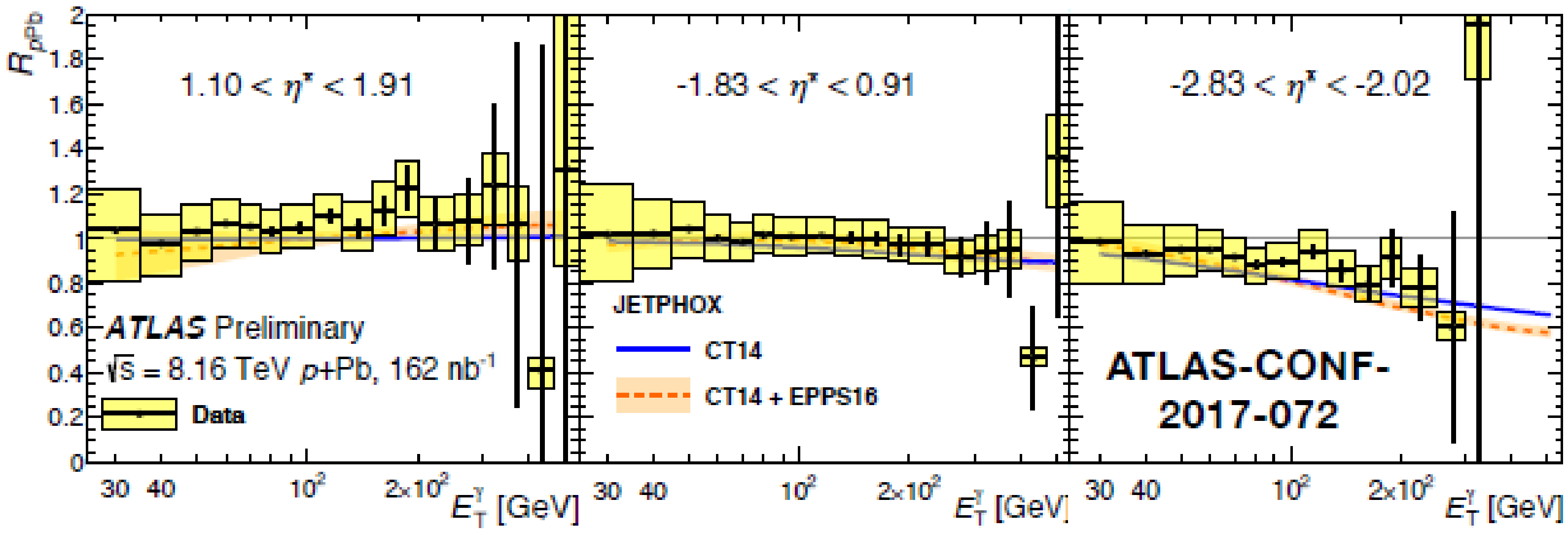
Watch out for the slight deviation from unity due to the isospin effect

All right, this is MB, but stay tuned!

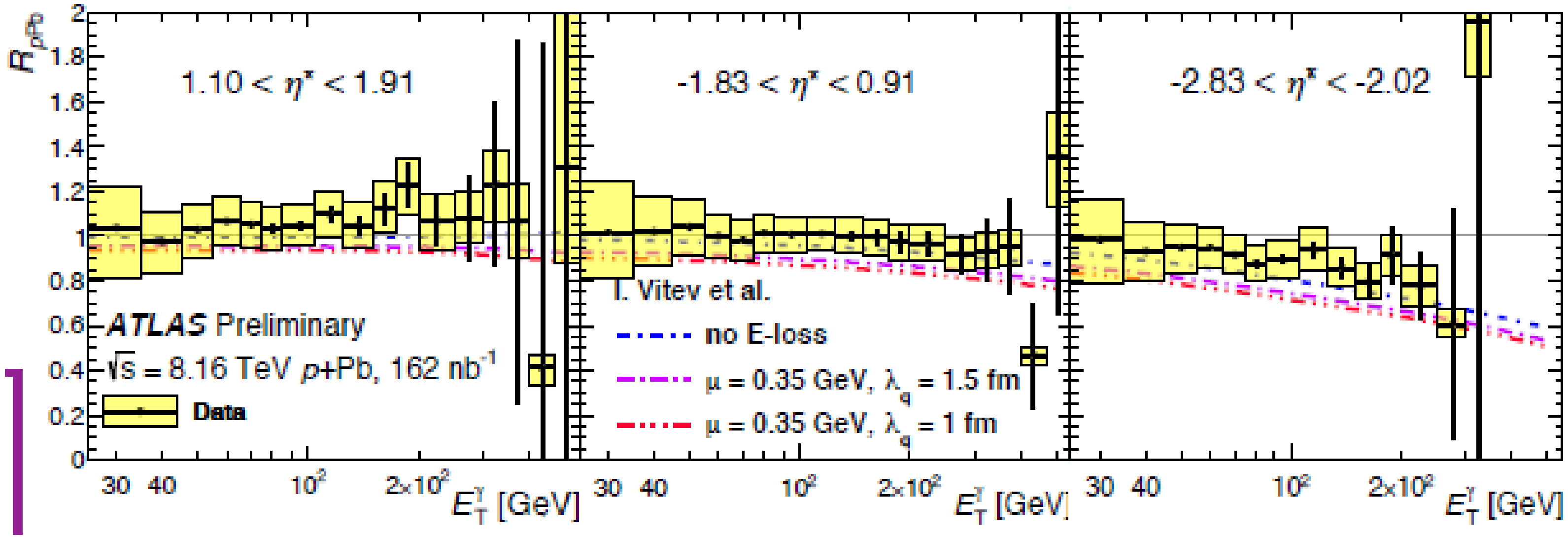
(And don't forget: centrality is non-trivial in very asymmetric collisions!)

ATLAS, p+Pb

Photon R_{AA} unity even for very asymmetric collisions (some deviation at high rapidity: gluon PDF's?)

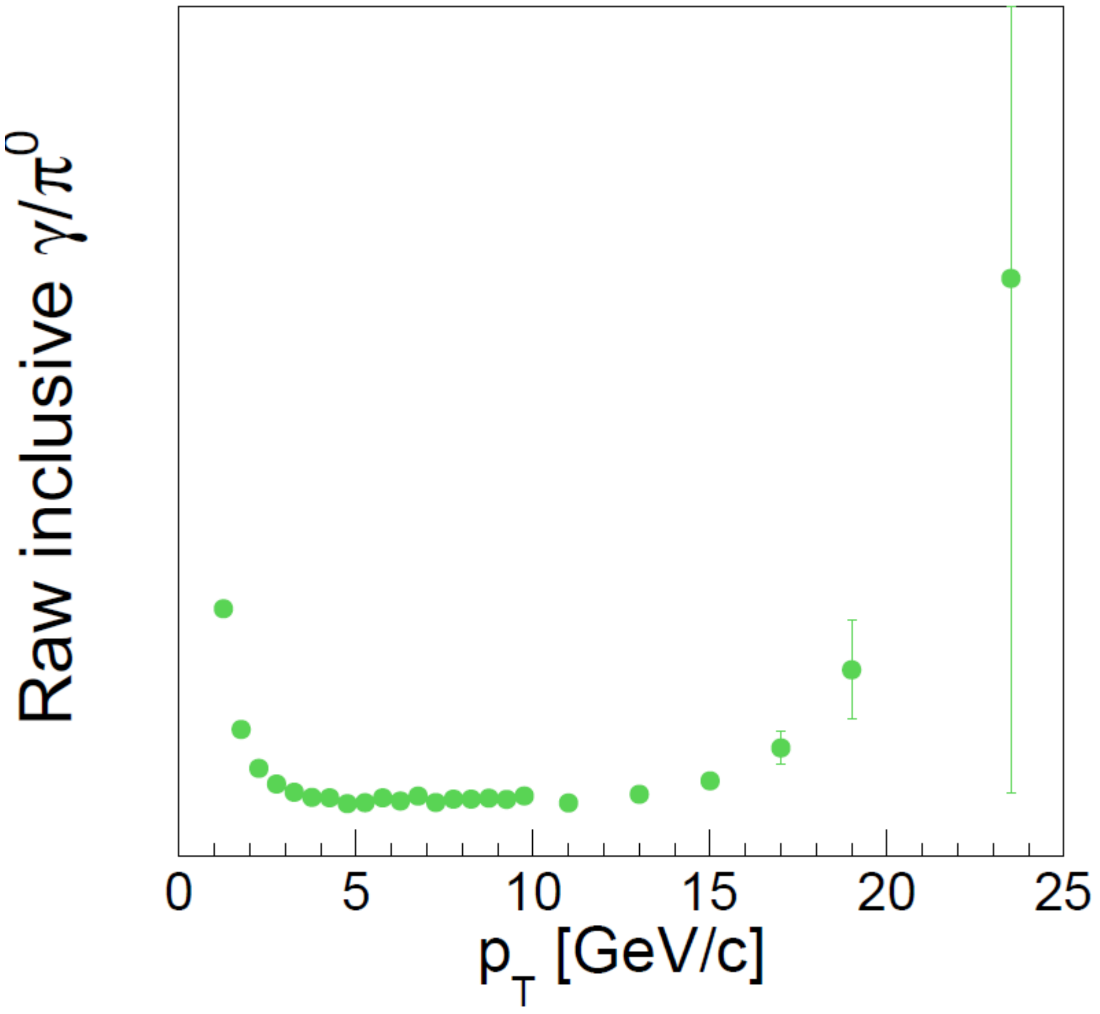


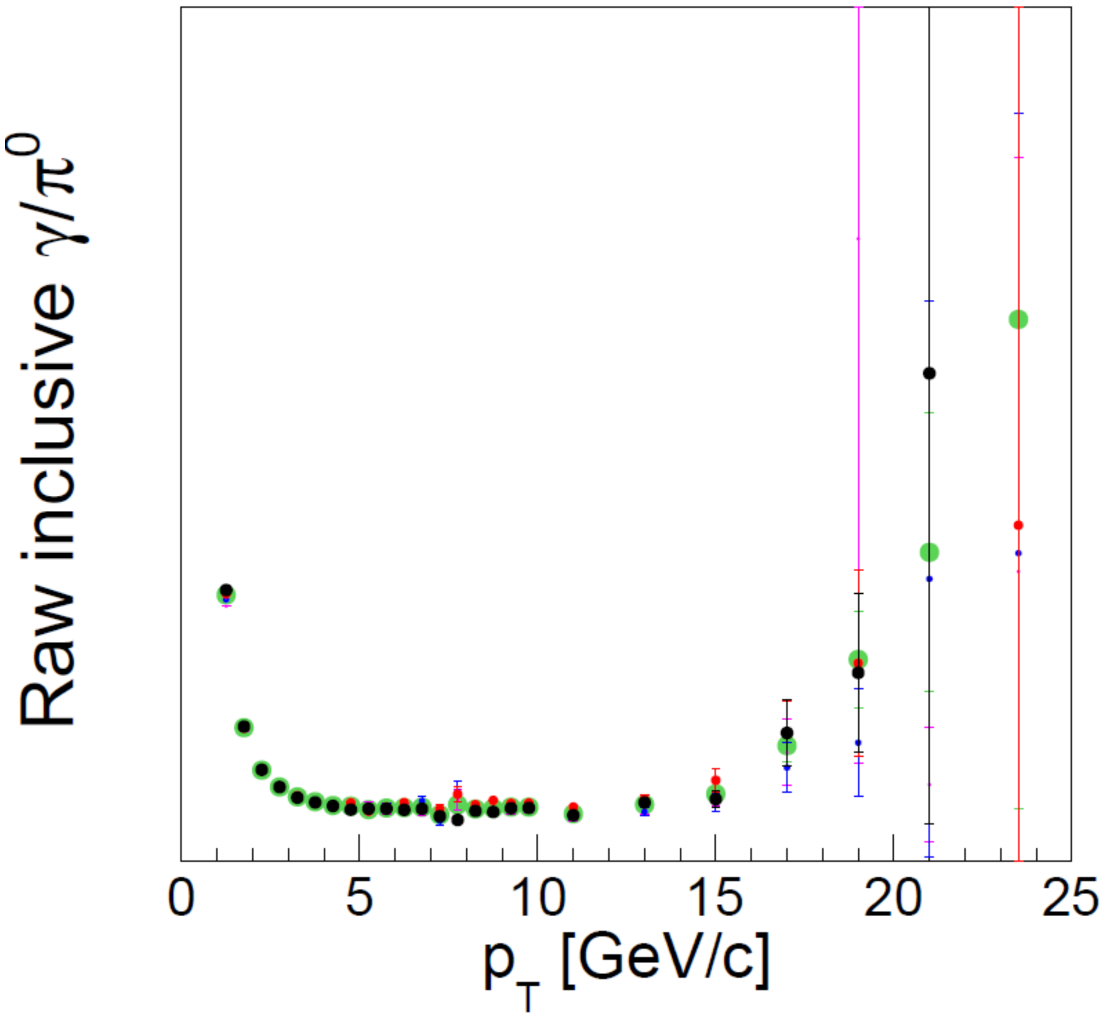
➡ *favorable comparison to pQCD & nPDF*



Model calculation – photon/hadron ratios in pp, pA

Assuming no FSI – photon/hadrons ratios independent of (multiplicity-based) "centrality" at all p_T





Summary

Some very ***counterintuitive*** new results seen at high p_T in p+A collisions
→ strong ***temptation to declare new physics***, discovery

My personal preference: if you found something ***revolutionary***, go ***back a dozen times***, and try to disprove it, asking: "***what did I miss or mess up***"? What assumptions did you make automatically that worked well – but not under these conditions? (Everybody makes his own choices, but this rule of thumb saved me more than once from declaring victory where there was none.) We ***don't need pseudo-discoveries***.

My belief (***unproven, but in part testable***) that traditional methods of connecting geometry to multiplicity (or other bulk variable) ***in p+A*** introduces a ***strong bias*** that changes (increases) with the ***momentum of the hardest scattering*** in the event

Suggestion: you can define/model centrality in p+A any way you want. It's fine: hypotheses are our basic modus operandi. However, if it doesn't pass the test, that ***prompt photon production is insensitive to centrality (R_{pA} ~ 1, modulo isospin effects at any high p_T)*** then your model is wrong.
USE PHOTON/HADRON RATIOS INSTEAD!

This admittedly doesn't give you a recipee how to find the right way to nail down collision geometry in p+A, but gives a ***decisive test to weed out unreasonable models***, and is a ***decisive test whether final state interactions are present.***

Sermon

Avoid ***ideomorphic*** science (looking at the data only in ways that favor your shining new idea)

Remember ***Occam***: if your result might be an Earth-shattering discovery, re-writing textbooks – or just a mistake or unintended bias, usually it is the latter

Yes, a big discovery means rapid promotion. Unfortunately, Nature couldn't care less about promotions – it does what it does. Listen to it!

Healthy paranoia is your best friend. Consistency (different signals pointing toward the same physics) is your second best friend. Try to see him as often as possible!

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