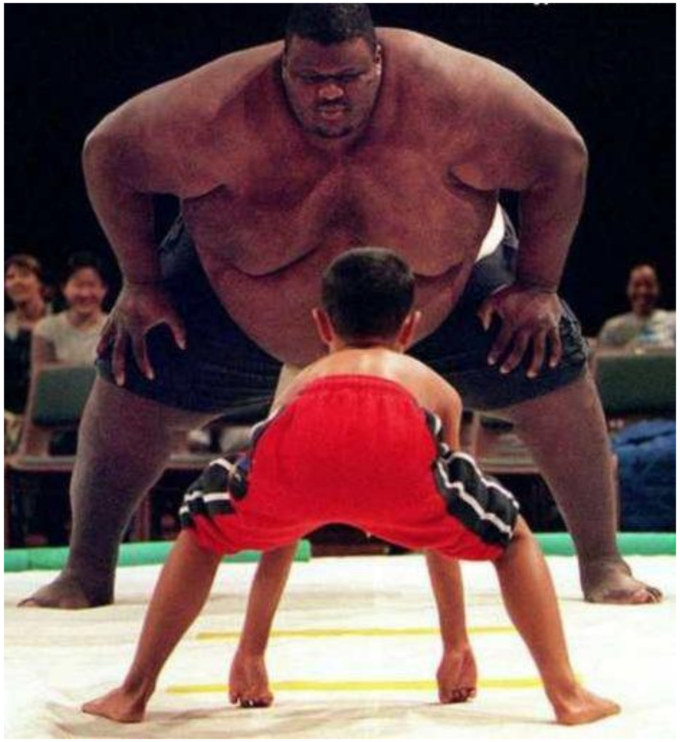
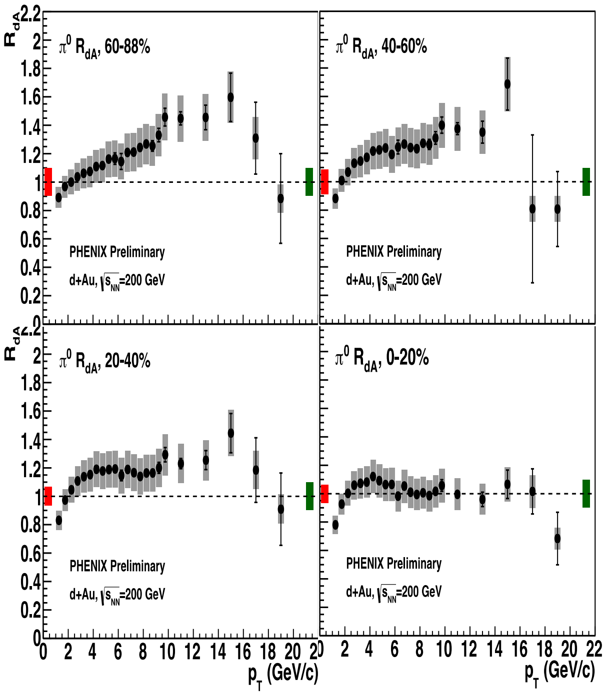
Updates/puzzles of dAu at RHIC

G. David, BNL



(Picture shamelessly stolen
from Kwangbok Lee)



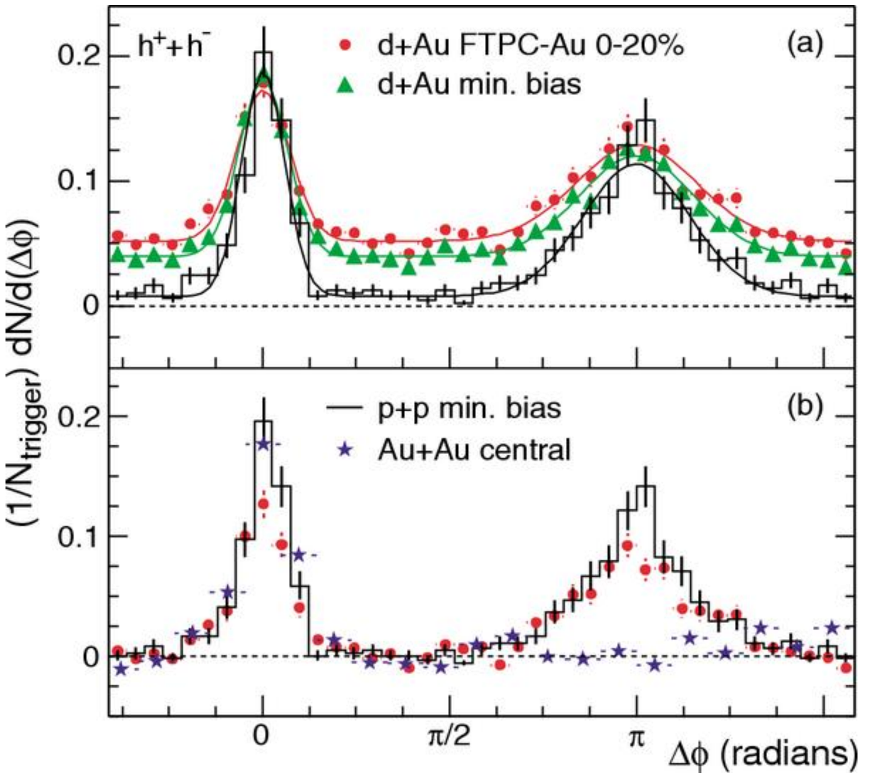
?

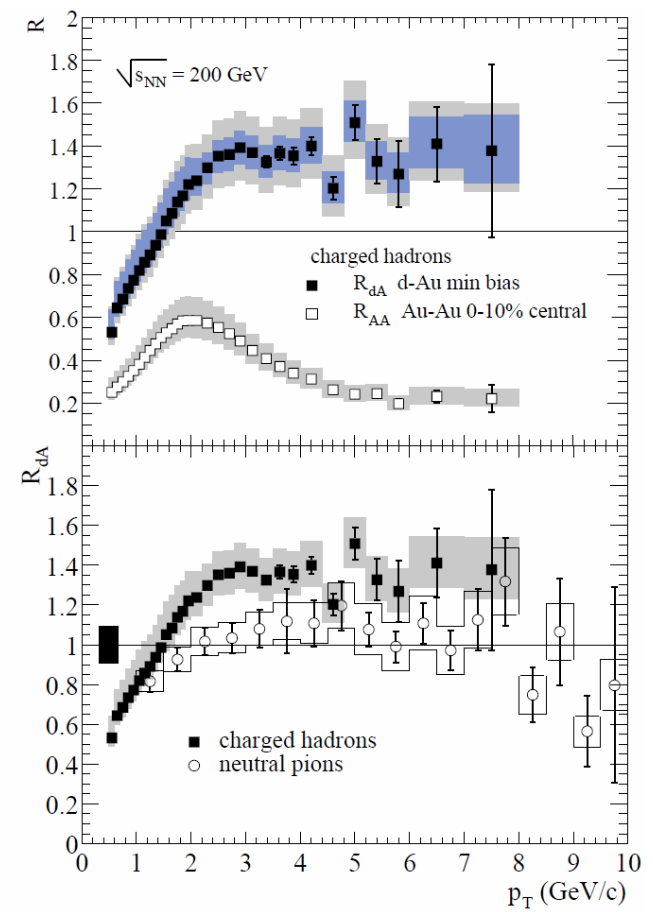
(Will focus on results at η ~ 0 and higher p_T)

In the beginning…

STAR, PRL 91 (2003) 072304

PHENIX, PRL 91 (2003) 072303





STAR: back-to-back jets reappear in d+Au

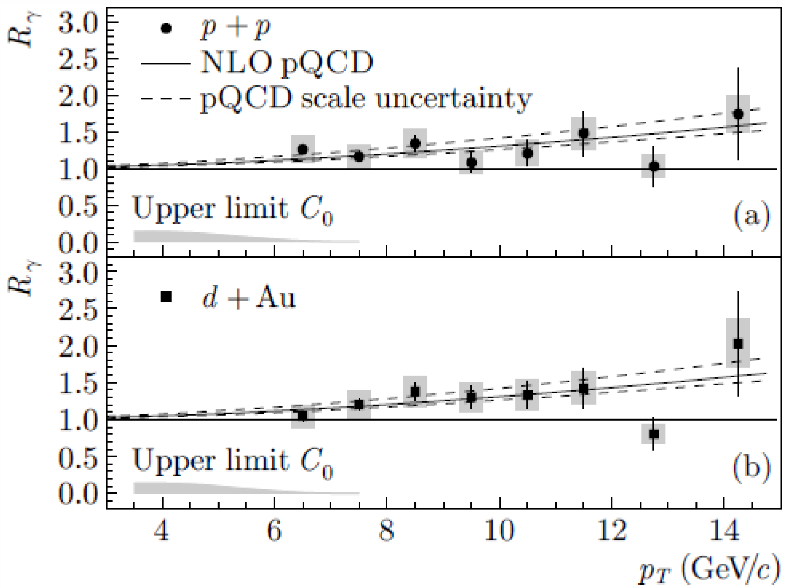
PHENIX: large suppression in Au+Au,

no suppression in d+Au

→ ***final state effect (as of 2003)***

What the photons tell

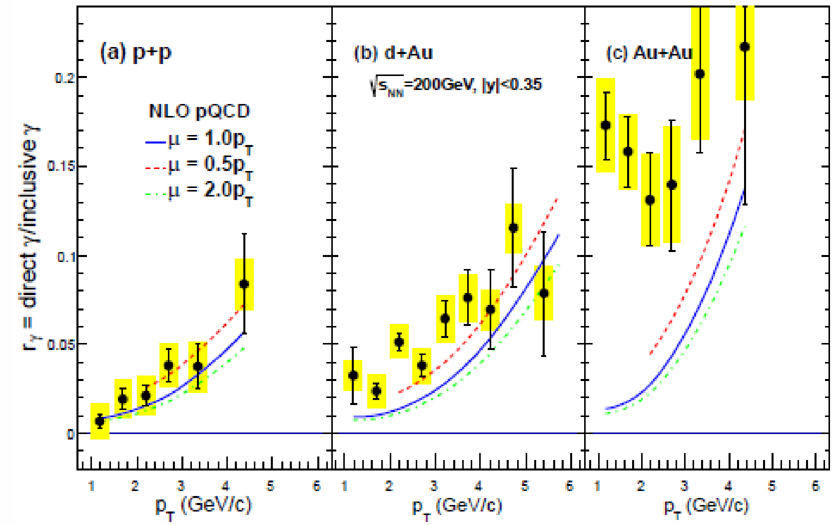
STAR, d+Au, PRC 81 (2010) 064904



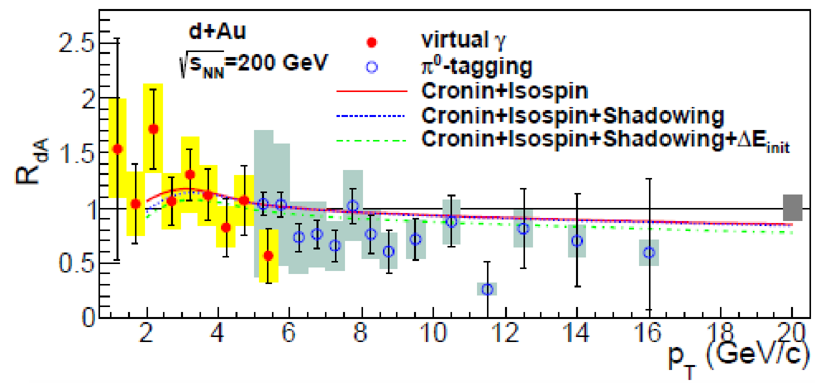
First published direct photons in d+Au at high p_T (shown here as R_γ)

No hint of medium formation so far

PHENIX, arXiv:1208.1234



No (thermal) radiation at low p_T



No nuclear modification (modulo isospin effect)

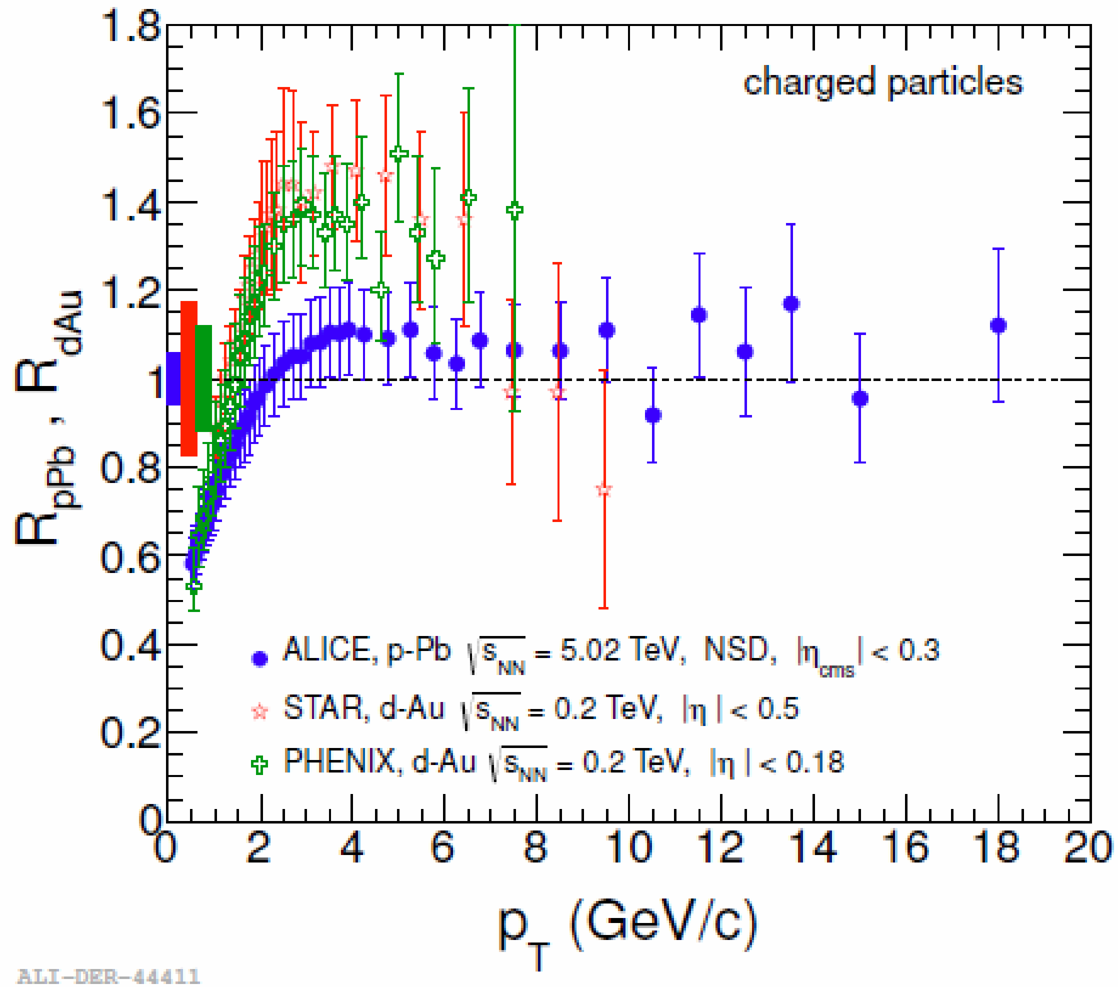
Low to medium p_T – Cronin-effect

ALICE, arXiv:1210.4520

For unidentified charged particles R_{AA} enhanced at RHIC, but consistent with one at LHC

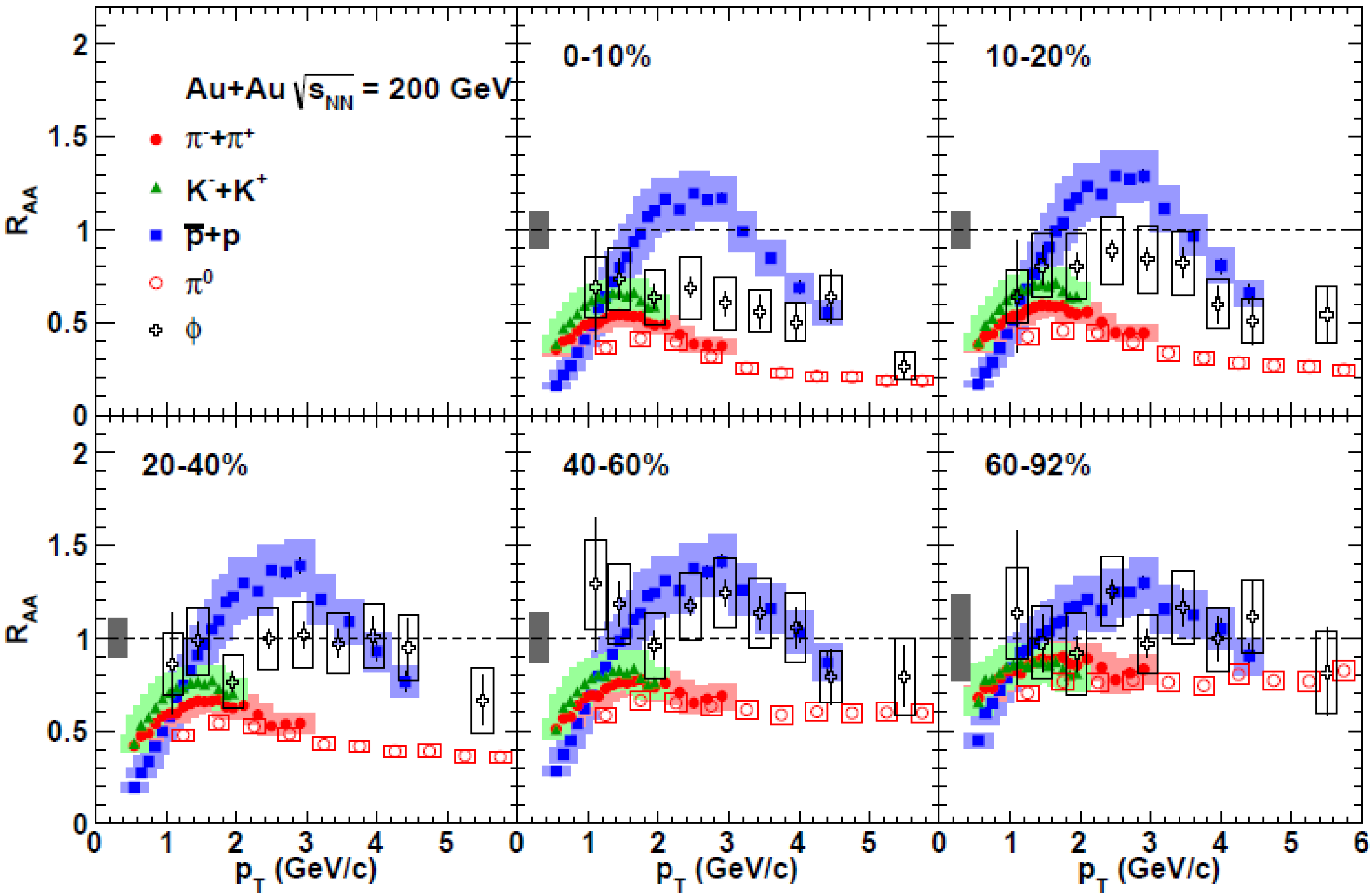
The Cronin-effect appears to fade away at higher energies (why would it?)
→ but maybe it is because of some E_{loss}?

More pieces to the puzzle on the next slides



Identified hadron R_{AA} in Au+Au (medium p_T)

PHENIX, arXiv:1304.3410



Proton: small variation with centrality.

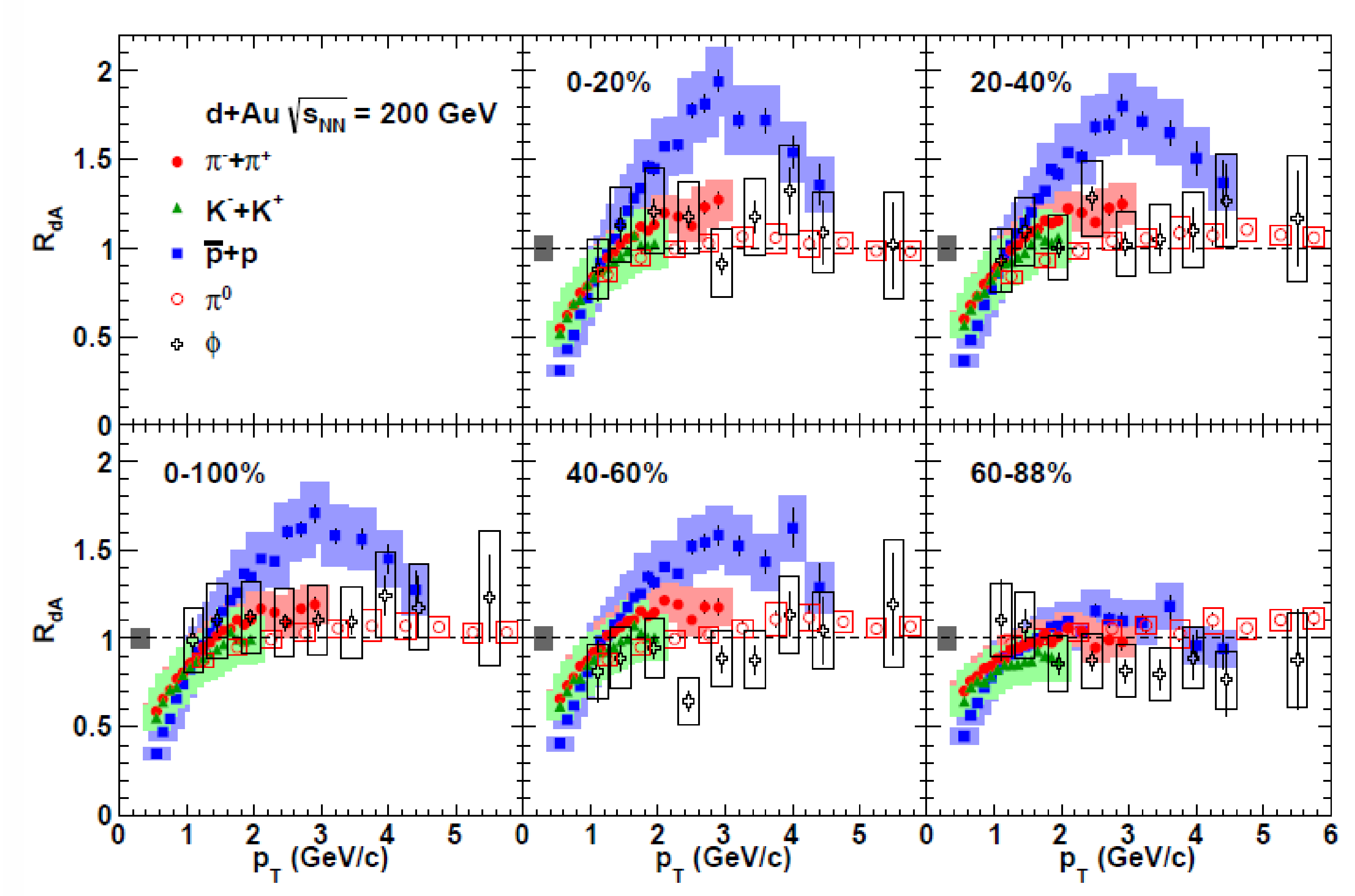
K, π very similar (although kaons slightly higher): large variation with centrality

Φ: intermediate

Baryon vs meson; radial flow would order by mass

Identified hadron R_{dA} in d+Au (medium p_T)

PHENIX, arXiv:1304.3410



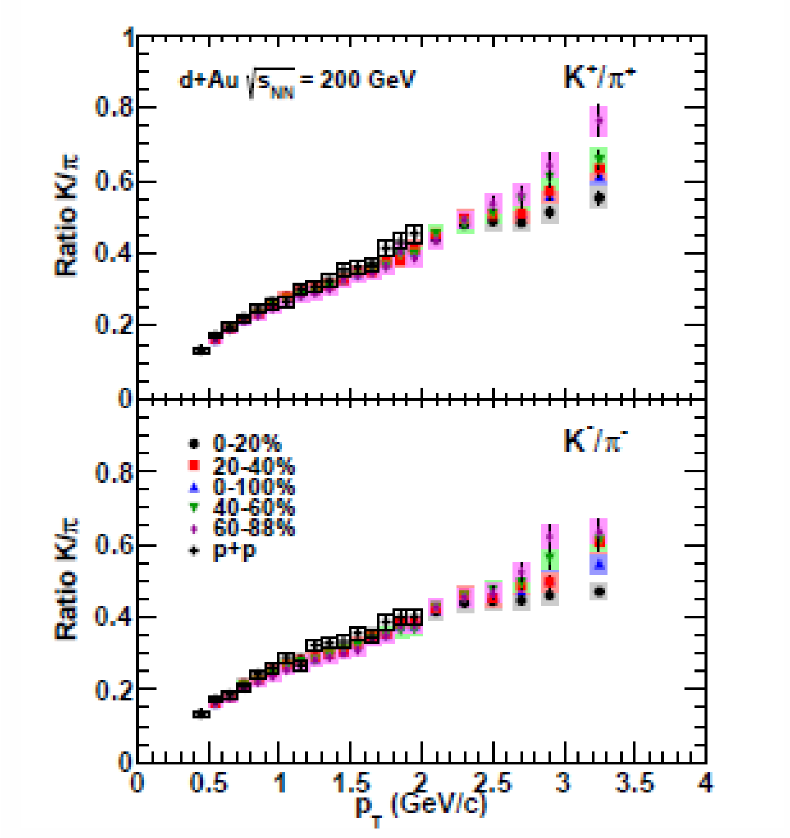
Proton: large variation → Cronin larger for baryons, and strongly depends on centrality

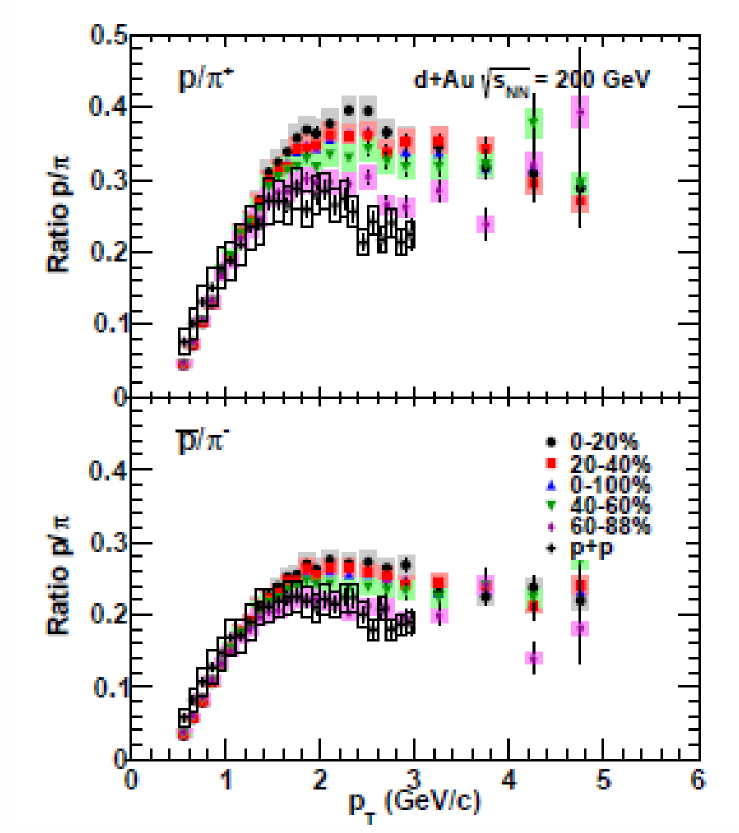
Φ, K, π very similar: little if any change with centrality

Mass irrelevant, valence quarks count – recombination?

Corollary: particle ratios

PHENIX, arXiv:1304.3410





All very similar: strangeness production is the same for all centrality classes and consistent with p+p

Enhanced with centrality (similar trend as in Au+Au): recombination? (Which would favor protons.)

Peripheral Au+Au – central d+Au
Why are they similar?

PHENIX, arXiv:1304.3410

Au+Au 60-92% and d+Au 0-20% have similar N_{part}, N_{coll}.

The ratio of all ID'd hadron spectra are on the same curve, and go to a constant ~ 0.65

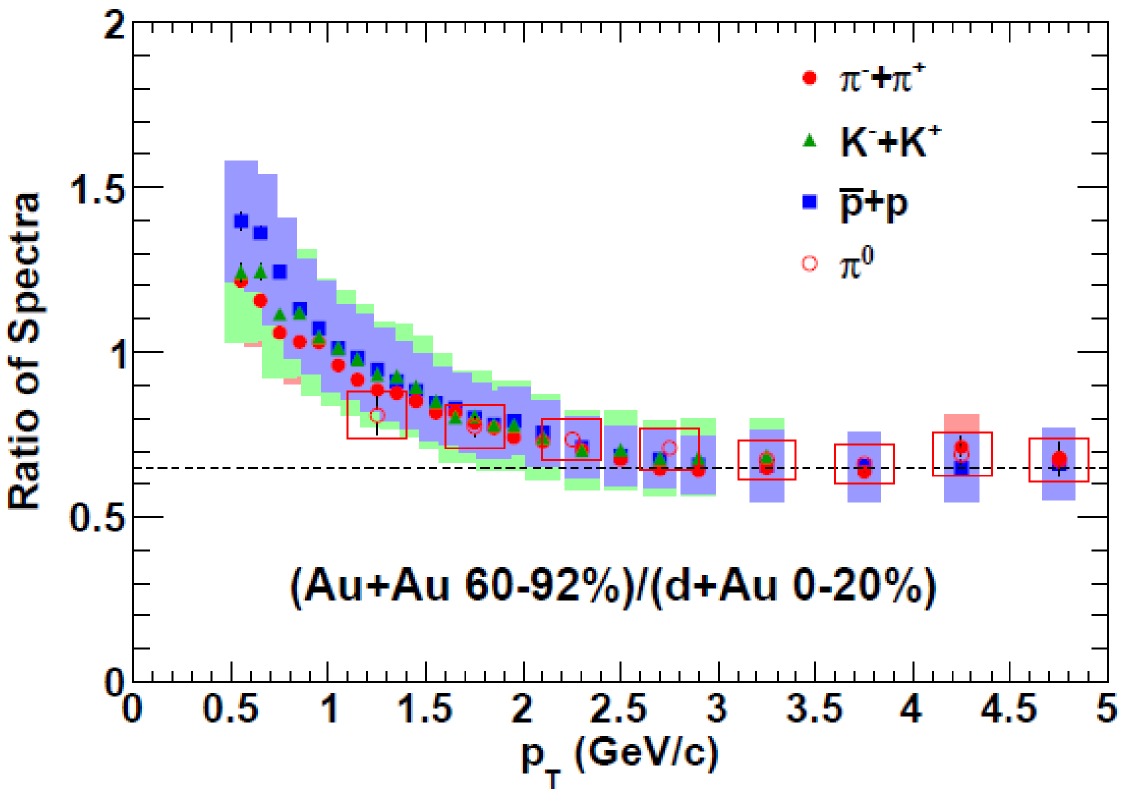
Common production mechanism?

Baryon enhancement the same?

If all CNM scales with N_{part}, does this ratio (non-unity) mean E_{loss} in the medium in peripheral Au+Au (even for protons?)

Rapidity shift in d+Au causing low p_T increase?

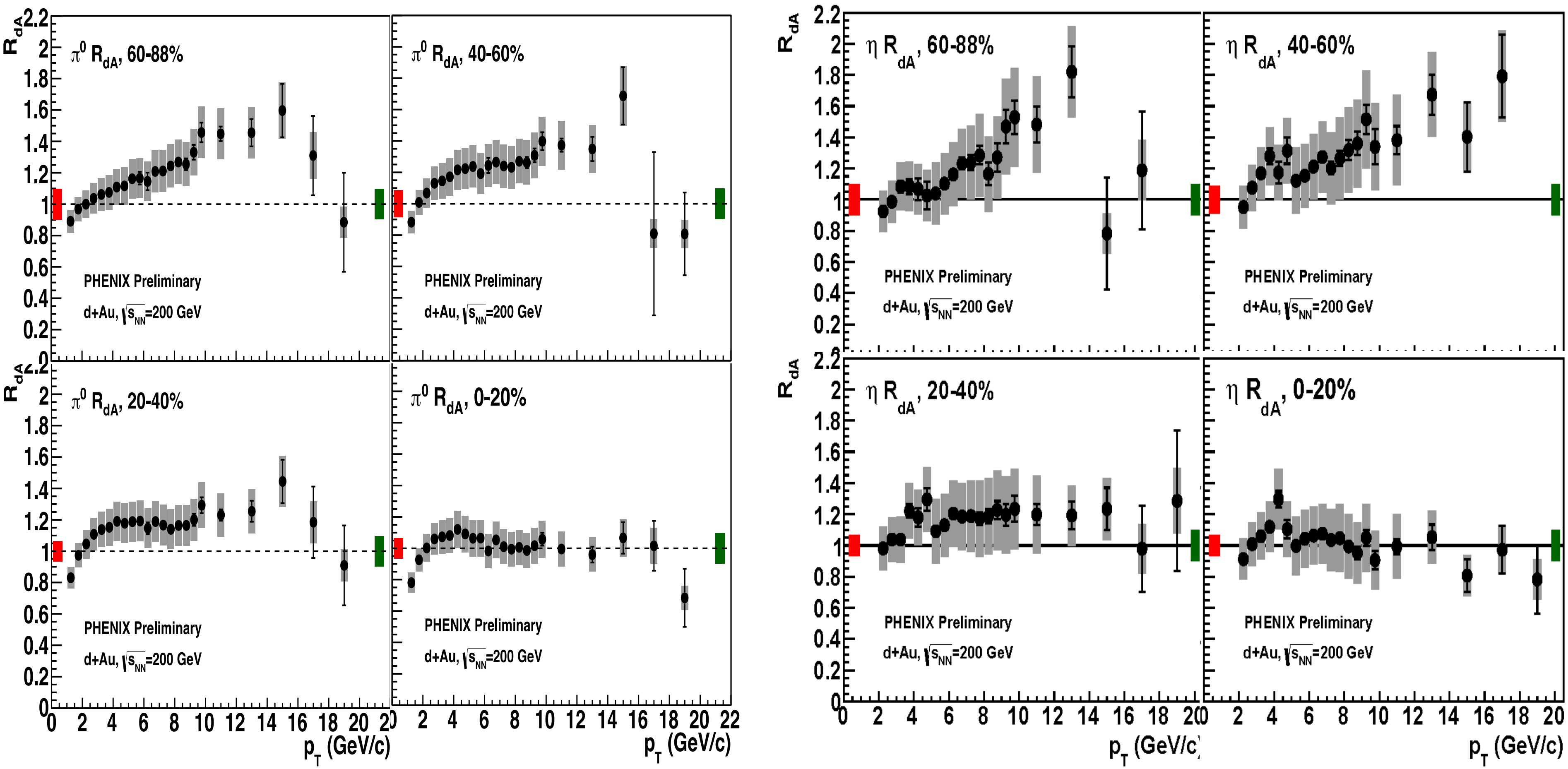
nPDF's modified?



Now some results to lose sleep over

PHENIX preliminary, QM'12

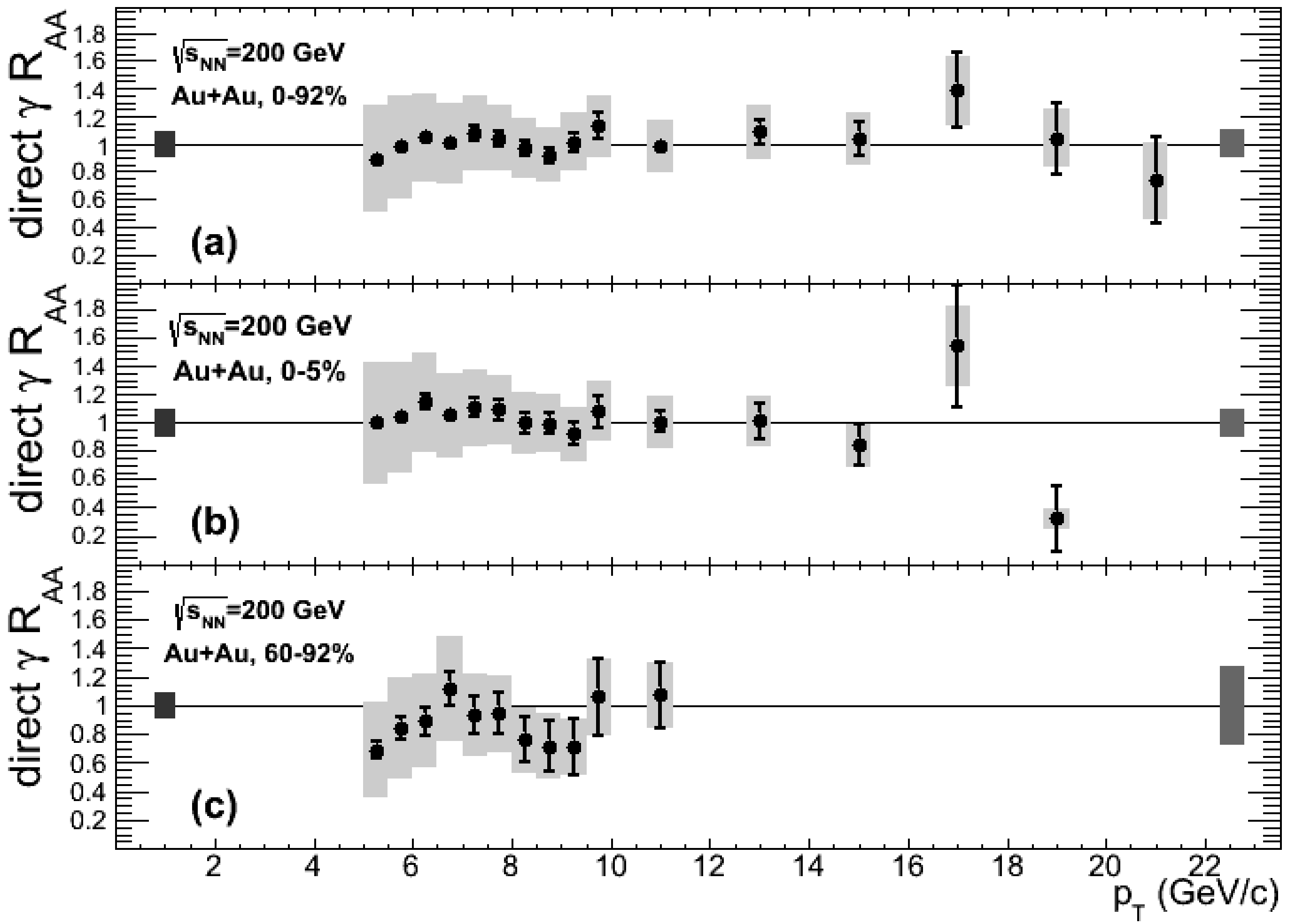
2008 (high) statistics d+Au data, nuclear modification factors vs centrality



Is it possible that π_0, η production at high p_T in peripherals is enhanced???

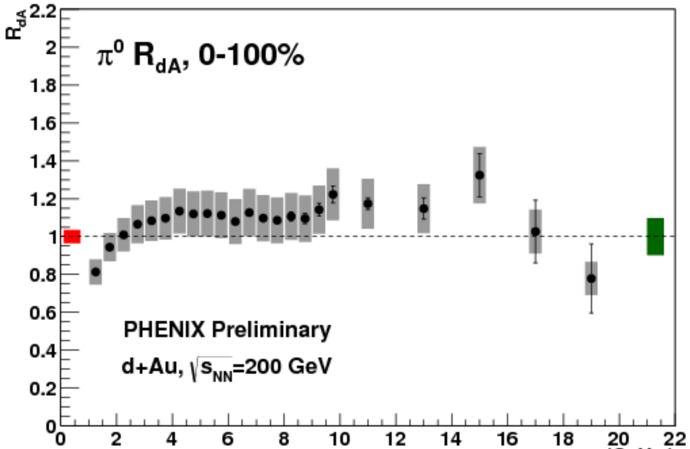
Reminder: N_{coll} scaling works!

Remember: direct photons yields in Au+Au (presumed to be blind to any medium formed) should be proportional to the ("N_{coll}" times) ***increased, but still very-very small probability*** of photon production in p+p. And this is exactly what is seen here.

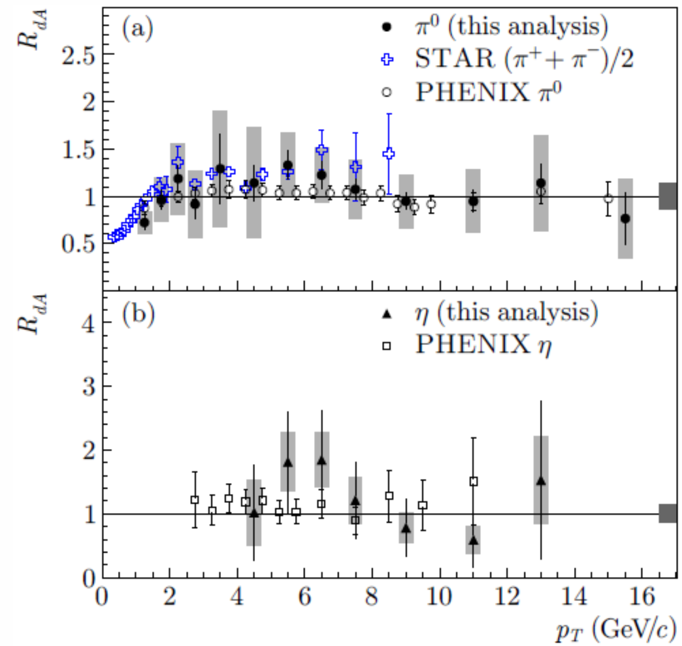


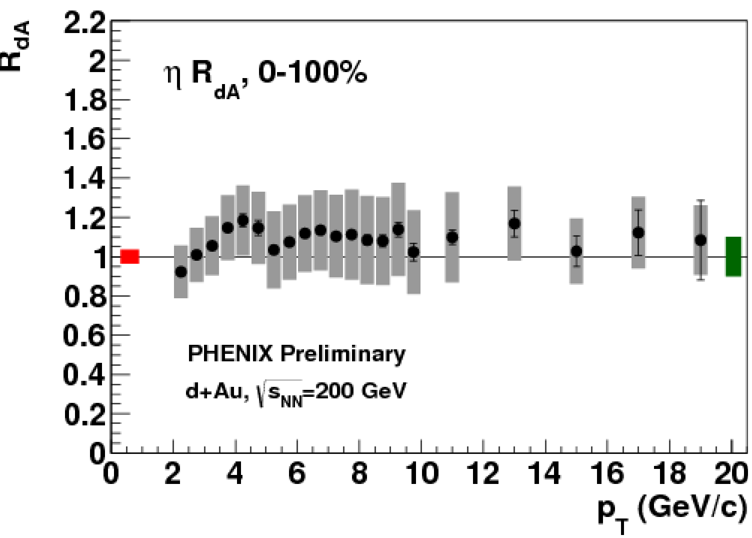
PHENIX, PRL 109, 152302 (2012)

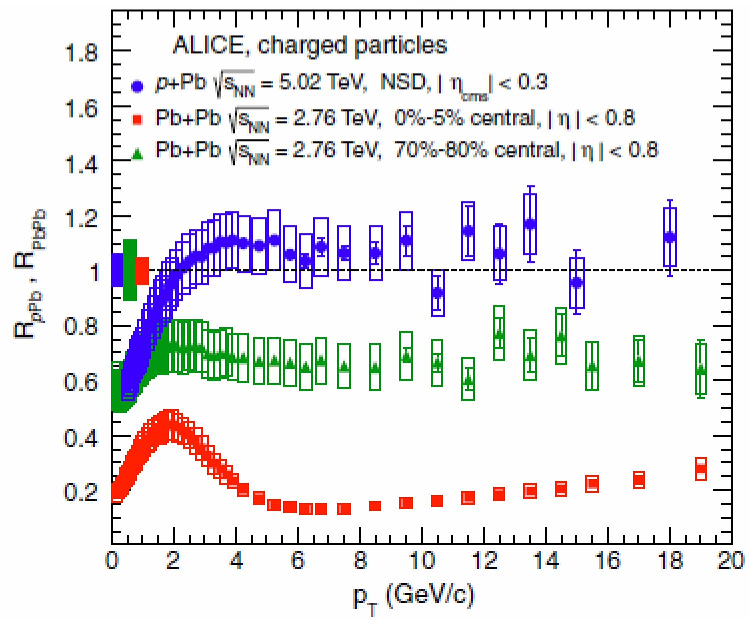
Minimum bias R_{dA} is unity as expected everywhere



STAR, PRC 81 064904 (2010)





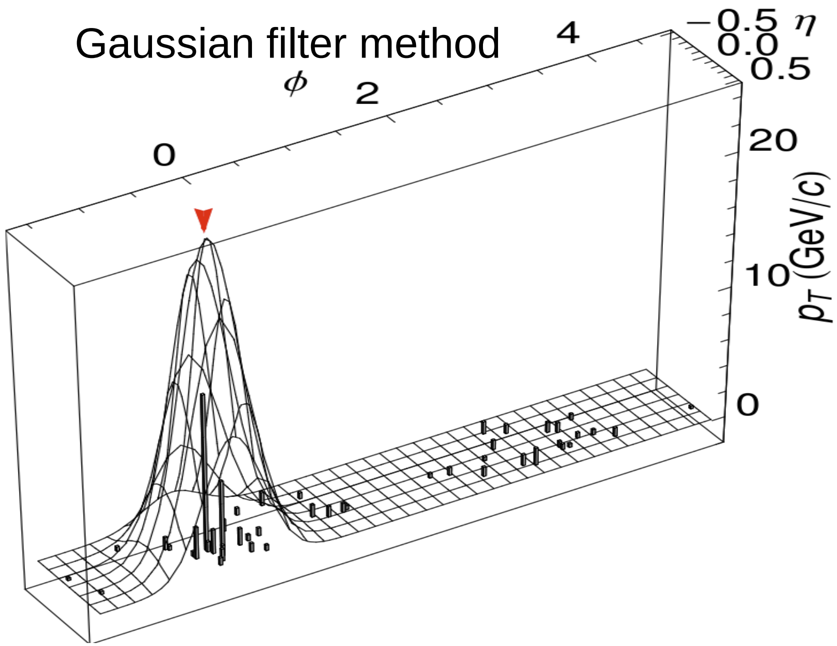


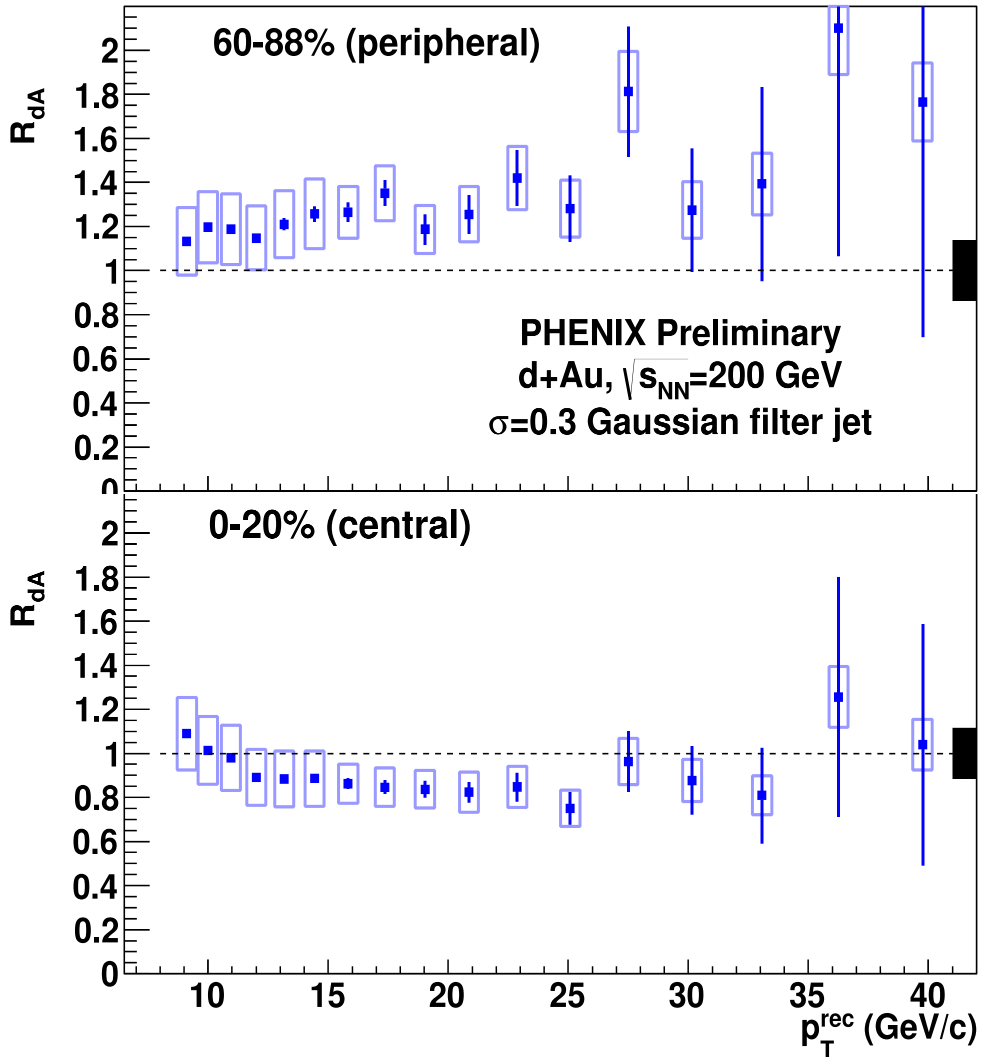
ALICE, PRL 110 082302 (2013)

Jets – a very different kind of analysis

Inclusive (leading) particle
vs jet reconstruction
(related, yet quite different
observable, analyzed differently)

Gaussian filter method





The energy scale is different,
but shows the same overall trend

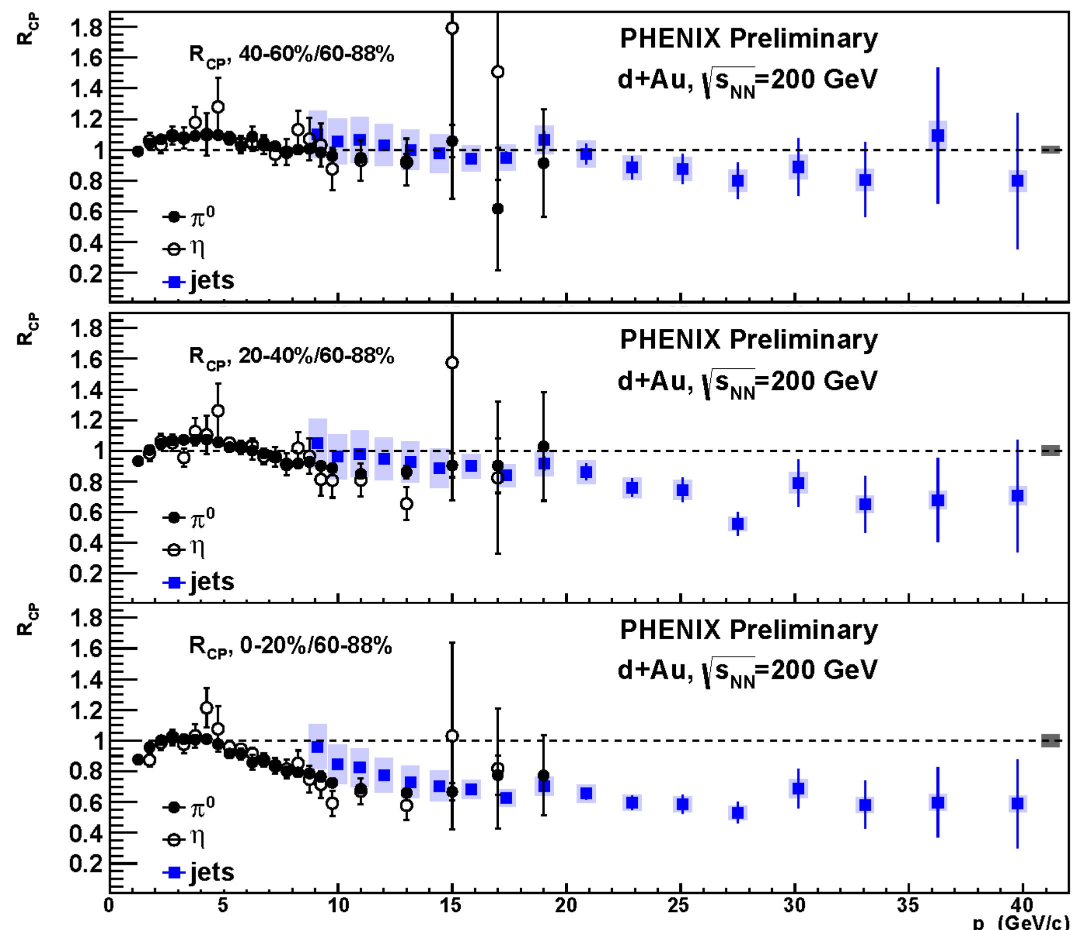
Jets, π^0, η – central to peripheral

For π^0, η this is true p_T, for jets it is total jet energy.

There is no unambiguous transformation, but 1./0.7 is a reasonable compromise, and would put the points almost on top of each other.

Important: R_{CP} is *independent of any p+p reference*!

The only "external" quantity here is the N_{coll} value attributed to the individual centrality classes



Note that R_{CP} drops sharply, indicating major shape change from peripheral to central

Something to be made VERY clear

I am **not** speaking for PHENIX this time – only and exclusively for myself

Of course I'm aware that there is very intense work going on in PHENIX to verify this result (there's a reason why it is called ***preliminary***!) The result, if it survives scrutiny, is extraordinary – extraordinary care is warranted.

However, even if I knew the answer, **I will not comment** on this specific work, checks, discussion in PHENIX related to this issue. Progress will be reported by the experiment in due time.

What I will do is to grab the opportunity to give a close look how ***centrality***, a crucial quantity in heavy ion collisions, is interpreted and connected between experiment and theory, deliberately avoiding (almost always) any numbers, since ***nothing here is specific to PHENIX***.

"Anybody thinking otherwise is itching for a fight" ☺

Centrality: thinking out loud

The theorist tends to think in terms of impact parameter (b), or N_{part}, N_{coll}, T_{AB}, ε, …
none of which is directly accessible in the experiment

The experimenter is concerned whether a/ the event is taken at all (*trigger* bias/efficiency)
b/ there are some *global* observables that can be tied to the theorists' quantities and while they are correlated to those quantities, they are as *uncorrelated* as possible to the *specific features* of the event (like presence of jets, flow, etc.)

Assuming such observable(s) exist, a model is agreed upon that makes the translation between experimental observables and theoretical quantities

Since you want to avoid introducing biases as much as possible, the model is *tuned with* a large number of (more or less) *average events*, in regions preferably "far" from the regions with the "specific features" studied (like a large η gap)

The correlation between the global observable and the theoretical quantity is typically wide: events on the average will be properly classified – but not necessarily individually.

Connecting theoretical and experimental quantitites

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

3.1 Methodology

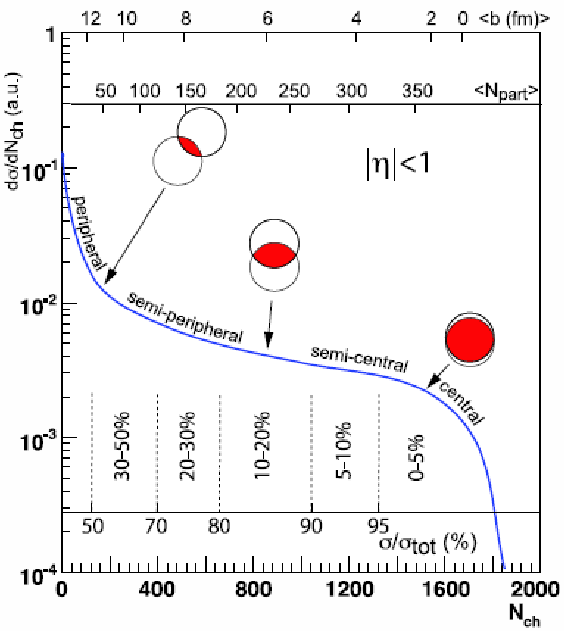


Figure 8: A cartoon example of the correlation of the final state observable $N_{\rm ch}$ with Glauber calculated quantities (b, $N_{\rm part}$). The plotted distribution and various values are illustrative and not actual measurements (T. Ullrich, private communication).

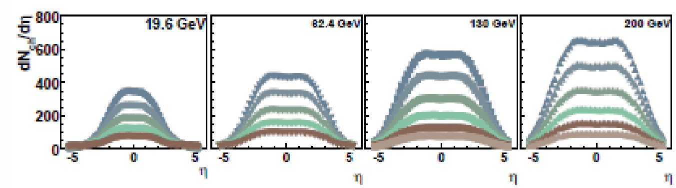


Figure 10: Charged particle multiplicity (PHOBOS) in Au+Au collisions at various center-of-mass energies for $|\eta| < 5$ (57, 58). The different colors represent different centrality selections.

tion (41). However, the multiplicity is also known to scale with the hardness (q^2) of the collision – the multiplicity for hard jet events is significantly higher than that of MB collisions. 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, with a small perturbation from much rarer hard interactions. The final integrated multiplicity of heavy ion events is then roughly described as a superposition of many negative binomial distributions, which quickly approaches the Gaussian limit.

"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…"

The verifiable case: p+p

Triggering and event characterization:

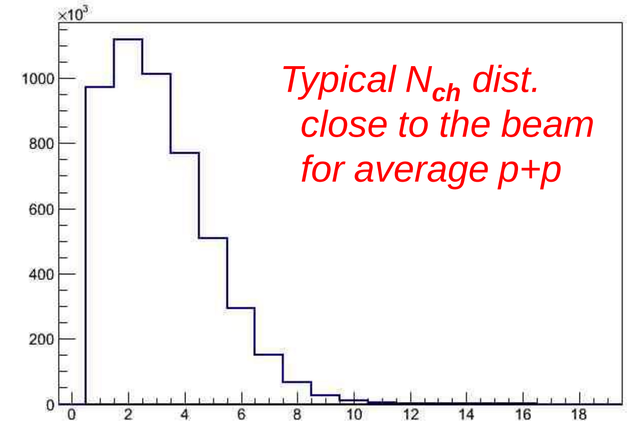
looking for activity (e.g. charged particle production N_{ch}, transverse energy E_T)

preferably **close to the beam and far from the region of interest** (mid-rapidity)

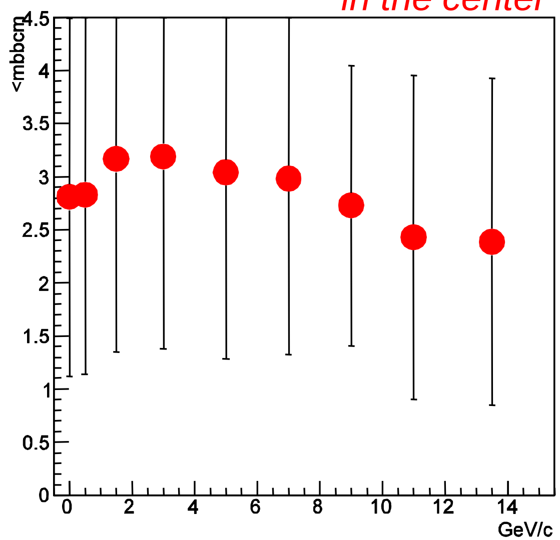
Now study those distributions as a function of the activity observed at η~0

"Activity" here is the **highest p_T for any particle seen around η~0**; could be jet energy, etc.

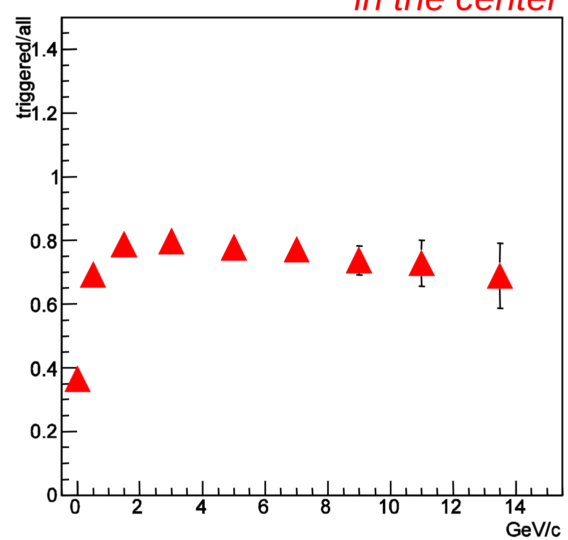
Can be done both in simulation and in data!



Mean and RMS of the N_{ch} dist. vs max p_T in the center



Trigger efficiency vs max p_T in the center

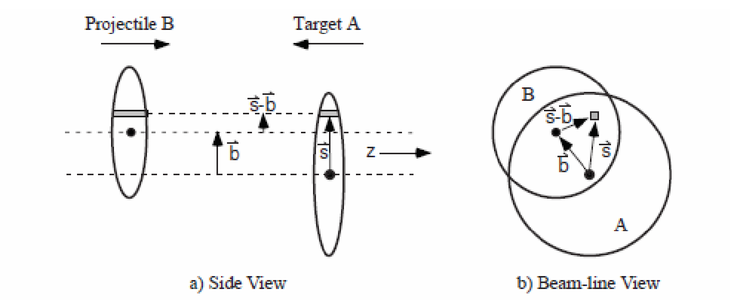


Note the characteristic rise initially (well-known: higher activity when hard scattering occurs)

However, at higher pT they start to drop slowly. They have to, at least asymptotically, for simple kinematic reasons.

Of course *other mechanisms can deplete* forward activity way before kinematics does!

Glauber-model and centrality in p+A, d+A, …

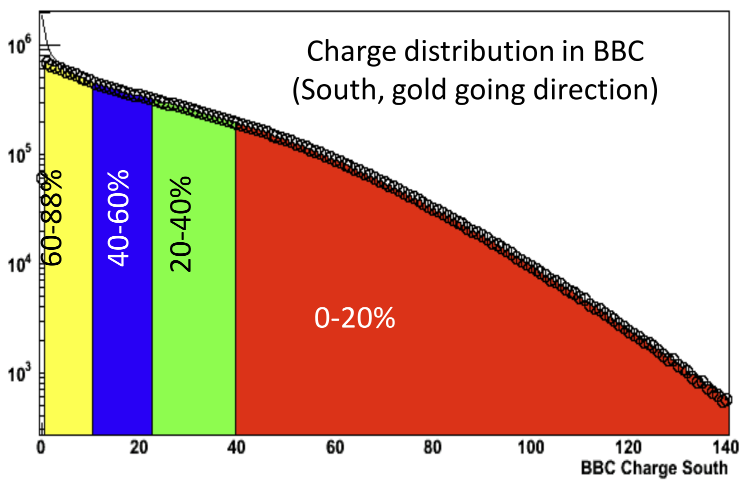


Straight path, independent collisions with the same probability (cross section) → N_{coll}, N_{part}

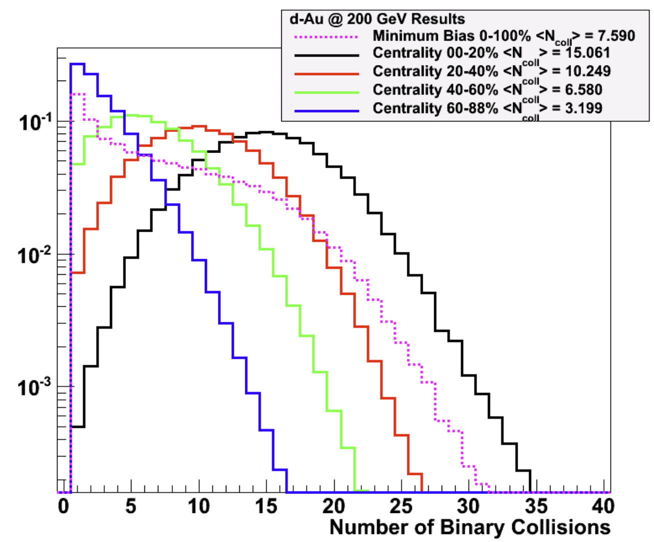
Folding with the *average response* observed in p+p can tie N_{coll}, N_{part} to observed N_{ch} *statistically*

Weather or not fluctuations are taken into account is irrelevant here

For instance:



Experimentally defined centrality classes



N_{coll} distribution for each class from the model

Based on average responses, does not take into account possible special features of rare events (like high p_T particle or jet in the central region)

Will this always work without further corrections?

Not necessarily.

For instance, as we have seen for p+p, the *trigger efficiency* decreases with increasing energy in the center. Since the trigger requires coincidence on both sides and in pA, dA on one side there are at most two nucleons, a similar drop in efficiency is expected. *This is well known and usually taken into account*.

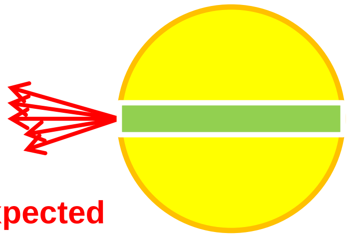
Centrality is usually defined in the direction where the large ion goes. Assume the projectile makes **N** collisions, one of them with very high p_T. Then the expected multiplicity forward is only (**N**-1) times the average plus one reduced response
→ the multiplicity observed by the experimenter (forward) is smaller than it would be for an event that is identical except that no high p_T is present

If centrality is defined with fixed multiplicity thresholds based on the *average* events but applied to the *rare, special* ones, those rare events may be (mistakenly) classified as lower centrality (lower average N_{coll}) than they really are.

At higher p_T this effect typically shifts to lower multiplicity (i.e. lower centrality) classes events that N_{coll}-wise – i.e. from the point of view of how probable a rare, hard collision is – would belong in a higher centrality class.

Illustration: shift between multiplicity classes / 1

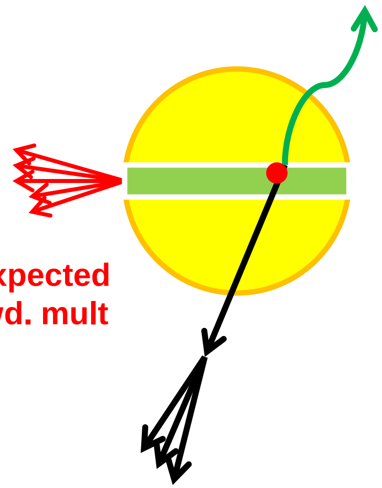
Here is your average,
higher centrality event



True b, N_{coll}

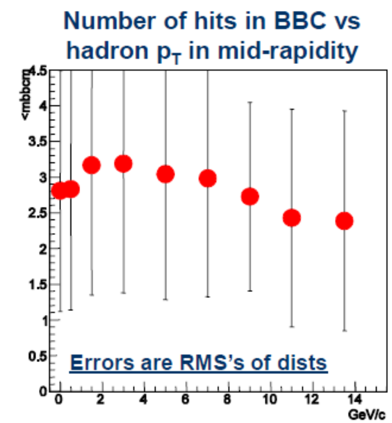
Expected fwd. mult

But now a very hard scattering happened (one in a million!), with reduced fwd. response, therefore…



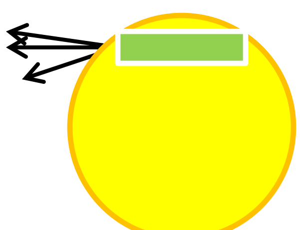
True b, N_{coll}

Expected fwd. mult



…this is how you classify
the event…

Observed fwd. mult

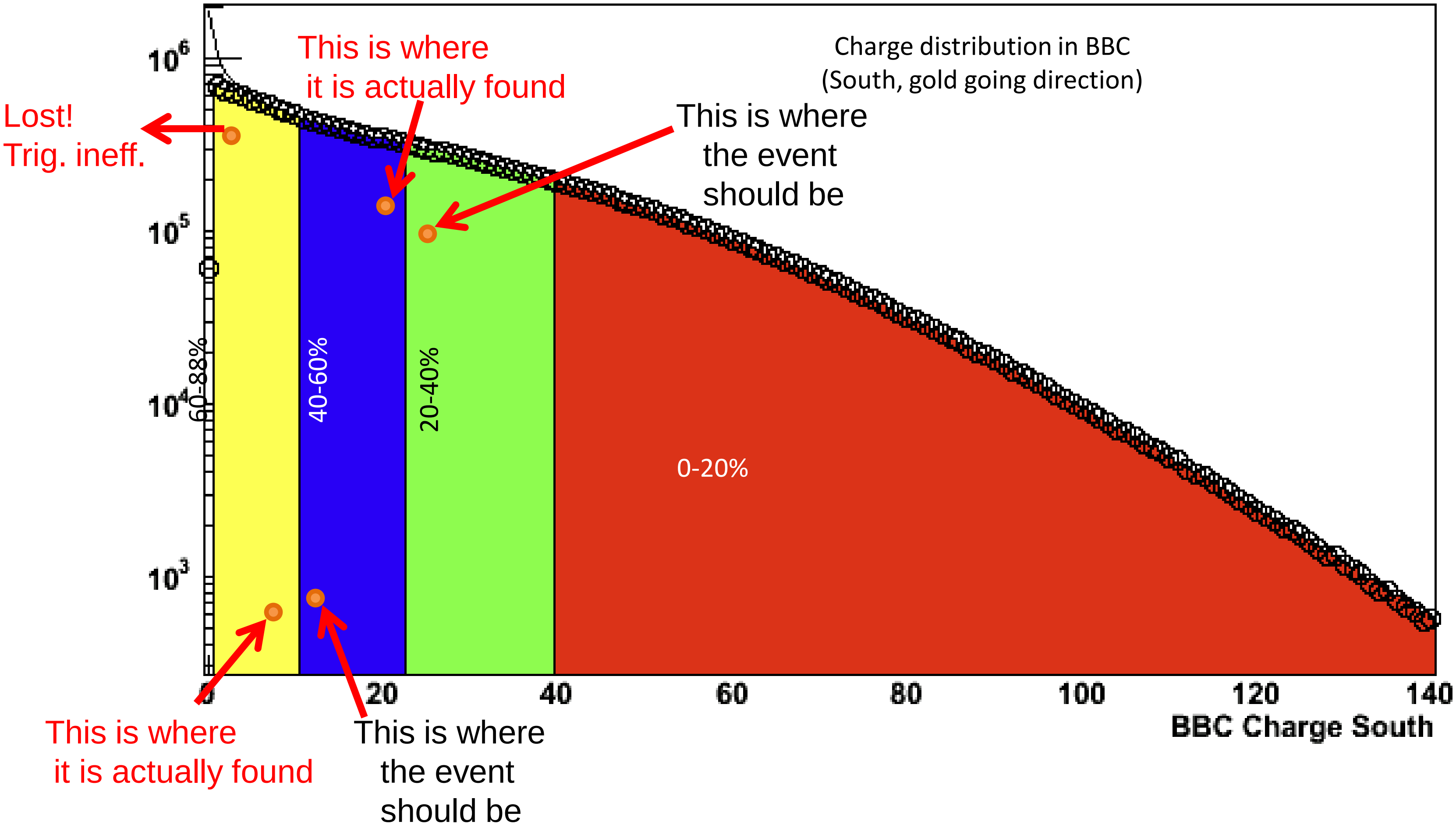


Percieved b, N_{coll}

…and when you calculate R_{AA},
the denumerator $(N_{coll} * \sigma_{pp})$
will be smaller than it should be
→ R_{AA} increases

(There can be other, even more serious effects, as we'll theorize later)

Illustration: shift between multiplicity classes / 2



If (experimental) centrality is determined with fixed (forward) multiplicity thresholds, irrespective of what happened at η~0, events may end up in the wrong centrality class – and attributed an incorrect $\langle N_{coll} \rangle$

More exotic possibilities

Confusion from the dual use of N_{coll} (???)

We use it both to estimate the average soft response by folding the p+p distribution (which assumes that the likes of N_{coll} average p+p collisions in fact do happen in the event)

but then we also use N_{coll} to estimate how much an extremely rare p+p process (hard scattering) is enhanced in p/d+A, where it is still very-very rare (<<1/event)

But in those very rare instances when hard scattering did in fact happen,

will the d/p nucleon for the rest of its path interact with the remaining A nucleons and original, intact nucleon (i.e. with the same σ_{pp} a la Glauber?)

If not, what will happen?

Will it keep interacting, but with reduced cross-section (like $\sigma_{\pi p}$)?

Will it be completely out of the pool (no more soft production whatsoever?)

Something in between? If so, what?

Can this be tested?

Reduced/vanishing cross-section in a different context:

Papp, Levai, Barnafoldi, Zhang, Fai -- nucl-th/0203075

A possible candidate for the reduction of the cross section in large systems is the proton dissociation mentioned in the introduction. Our pA collision study showed that each pp inelastic collision adds $\sim$ 400 MeV transverse momentum to the partons inside the proton (on the average). After a few such collisions the partons gain high enough transverse momenta to become free of the proton and during this transition process they do not interact (dead time). We assume that such a proton is "lost" for the reaction and does not participate in particle production anymore. We note that such a picture corresponds to a modification of the original Glauber model. It re-

High p_T biases

Renk, arXiv:1212.0646

However, it has to be realized that almost all current high P_T observables measure conditional probabilities of events, not probabilities. Thus, the correct starting point for their theoretical understanding is Bayes' formula, and the biases introduced by the conditioning are crucial to understanding the outcome. Once this is introduced properly into the modelling process, the counter-intuitive results are seen to find a natural explanation in terms of various biases and the puzzles largely disappear.

Would comparison to LHC help?

If (with similar centrality determination) LHC would see no effect in our p_T range, but similar effect at higher p_T, the "kinematic" effect (depletion of available energy forward) could be the culprit (or dominant)

If LHC would see a similar effect already in our p_T range, the "dynamic" effect (reduced or vanishing cross section) could be the dominant contributor

Summary

In d+Au thermal radiation is not there, but identified hadrons up to 6 GeV/c show features consistent with some medium formation

Specifically, all hadron (baryon and meson) spectra are similar in peripheral Au+Au and central d+Au

Preliminary π^0, η and jet nuclear modification factors show a very unexpected rise in peripheral collisions, while for minimum bias $R_{AA} \sim 1$

Very large drop in R_{CP}, too – i.e. the reference p+p can not be the source of such effect

Different observables, different groups, codes, systematic uncertainties – unlikely that the spectra have a substantial problem

Is it some new physics – or can there be some problem with the way centrality is inferred for these very rare events?

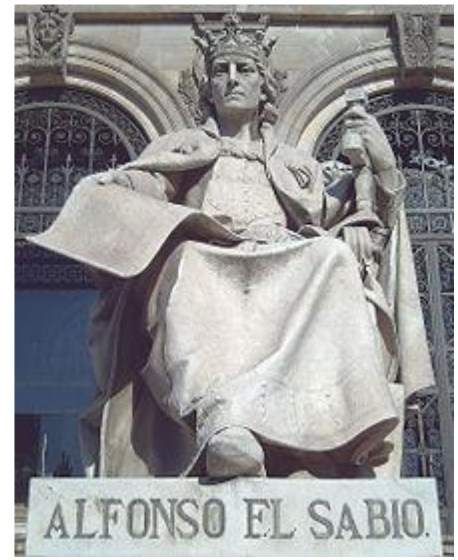
One thing is certain: just redefining centrality such that R_{AA} = 1 is not a good idea ☺

Alfonso the Xth ("Alfonse the Wise")

1221-1284
Monarch of Castilia
One of the best scientists of his age
(and big time supporter of science)

"Alfonsine tables" used even by Copernicus, superseded only by Kepler in 1627

So he knew what he was talking about, when sighed (and we all should agree…):



If the Lord Almighty had consulted me before embarking upon creation,

I should have recommended something simpler.

…or on a more serene note

Even if all these speculations turn out to be wrong, the measurement that prompted them is very tantalizing and certainly consequential – in one way or another.
No matter what the outcome, the process itself has been fun. Or to quote…

Albert Szent-Györgyi

In later years, - he worked in his newly organized Muscle Research Laboratory at the Marine Biological Laboratory in Woods Hole, Mass., USA, – when asked why, he passionately used such a big hook for his beloved fishing, he used to say,
"I think it is more exciting not to catch a big fish, than not to catch a small one."
He really made some big catches in his lifetime: the Nobel-Prize for discovering the vitamin-C and the biochemical steps of catalysis of the fumaric acid in the tricarboxylic acid cycle.