Selected topics from RHIC/LHC HI collisions

G. David, BNL

EDS Blois, 2013 – Saariselka, Finland

Selected topics from RHIC/LHC HI collisions

or

"how much what?"

G. David, BNL

Captain to the engineer:
- *How much?*

Engineer:
- *Thirty.*

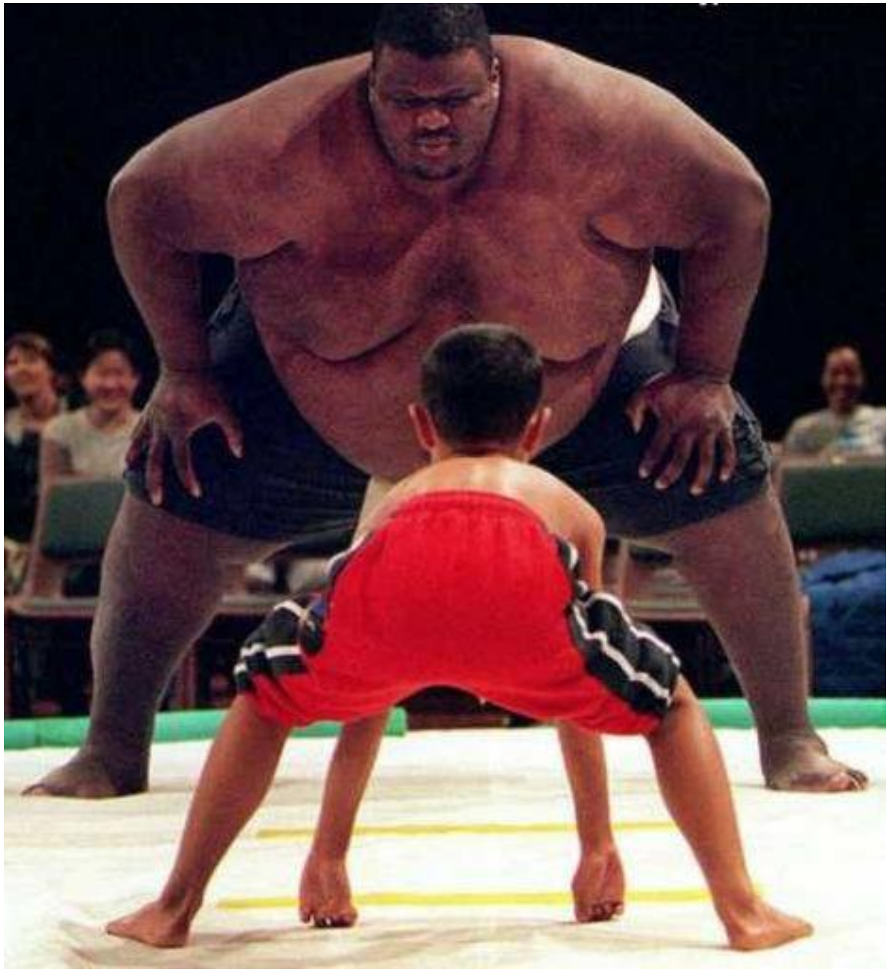
Captain, confused:
- *Thirty what???*

Engineer, confused:
- *Why, how much what???*

(If this reminds you of some interactions between theorists and experimentalists, it's pure coincidence.)

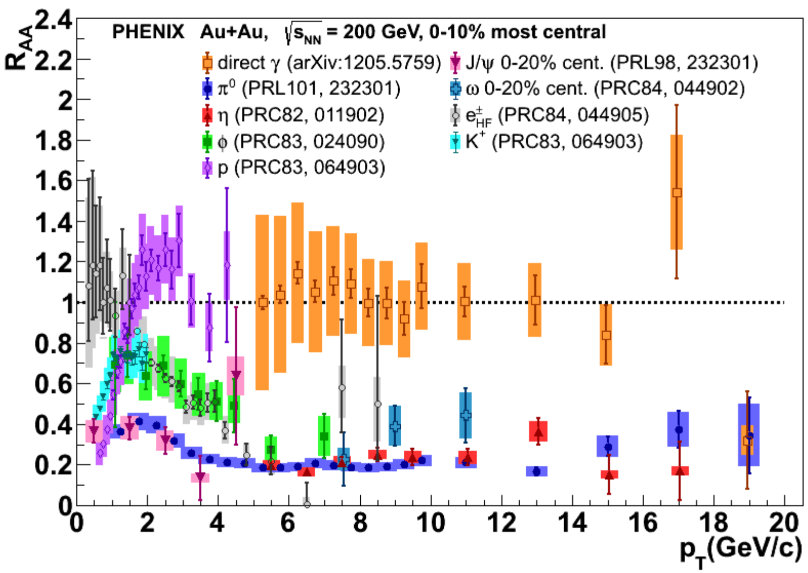
I'll discuss questions about
centrality
temperature (possibly)
But don't worry:
I won't overload you
with answers…

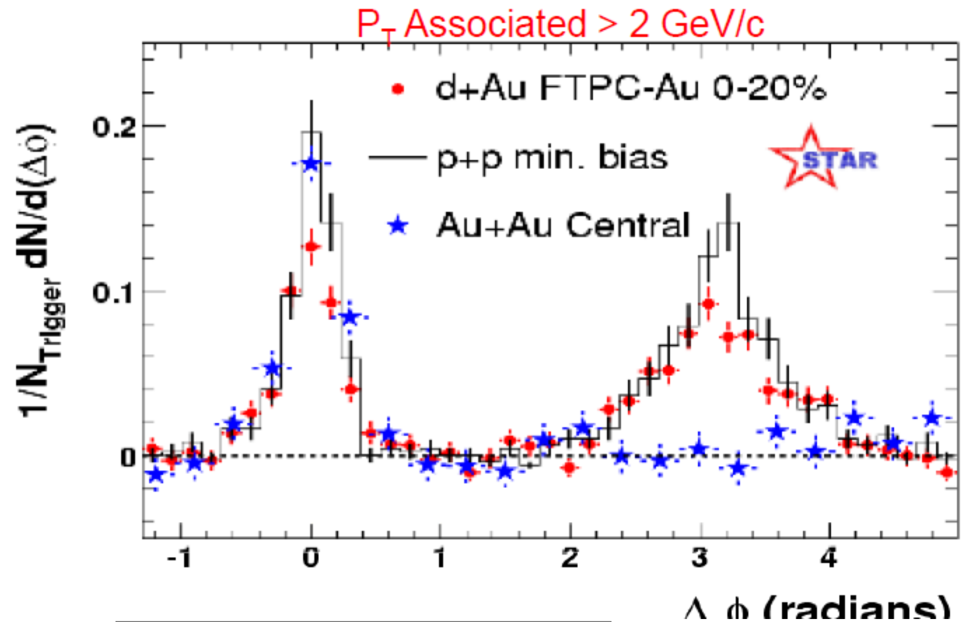
Theme 1: small on large systems
(a.k.a. p/d + A at RHIC, LHC)

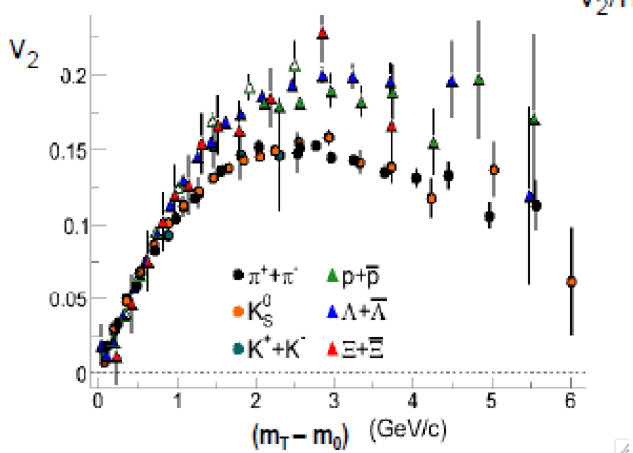


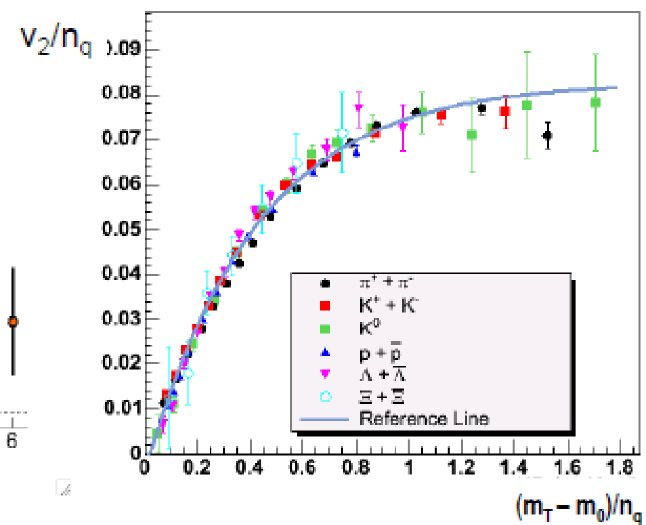
Small on large systems – p/d+A – why?

Recall iconic **A+A** plots from the past:





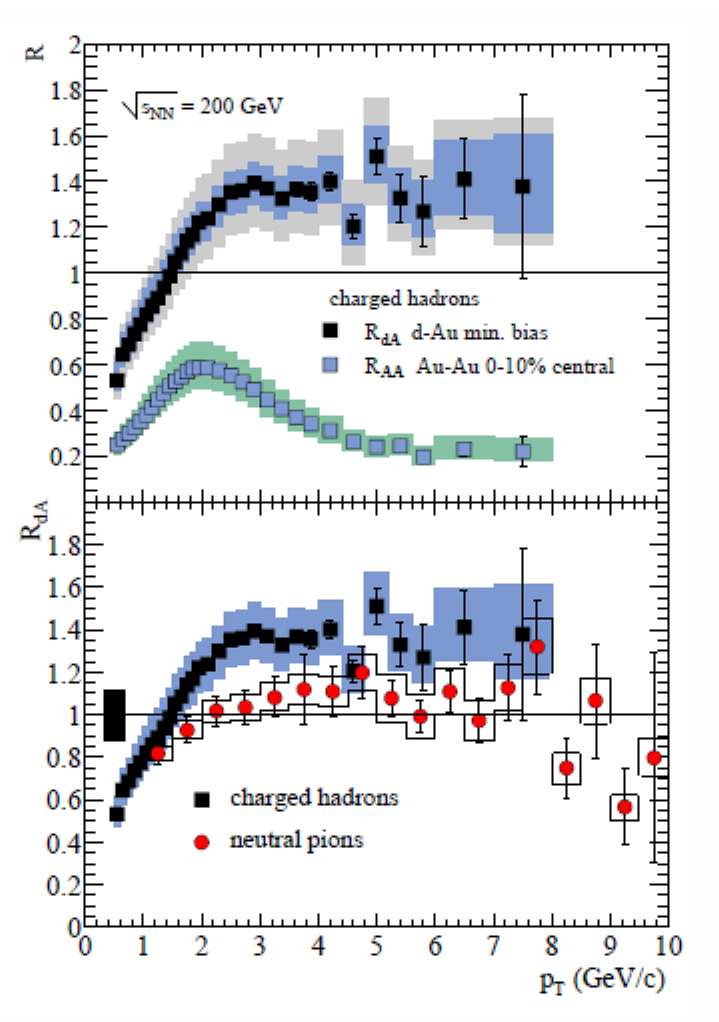


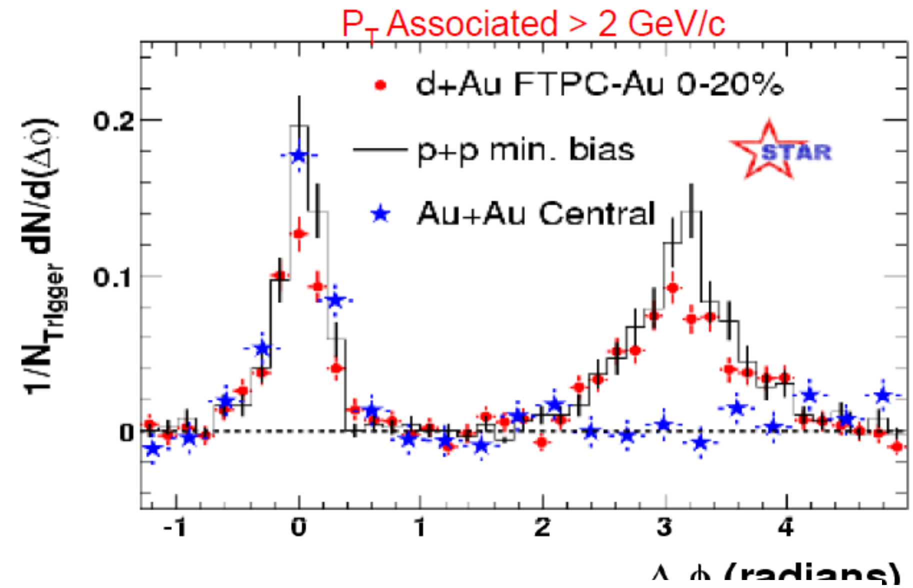


Fluid→QuasiParticles→Hadrons

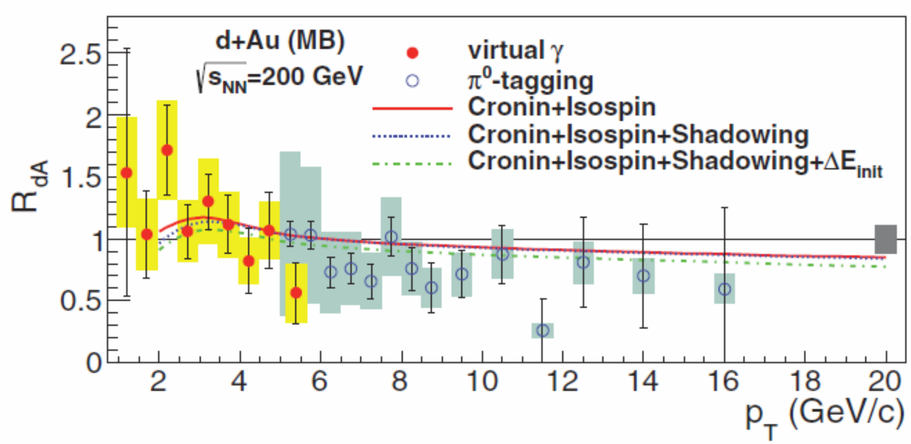
p/d+A – “just control” for CNM (?)

Recall iconic **d+A** plots from the past:



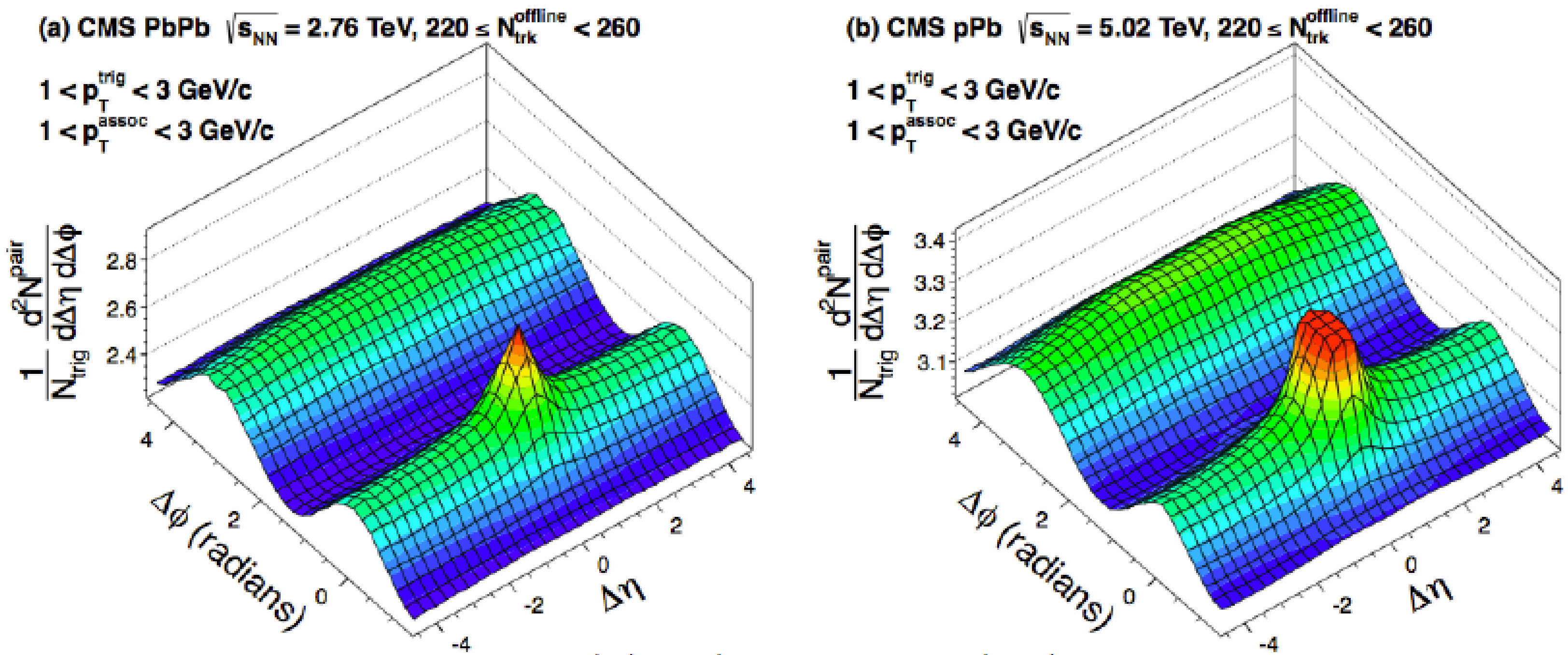


PHYSICAL REVIEW C **87**, 054907 (2013)



Recent shocks - LHC

Long-range $\Delta\phi$ correlations observed in p+Pb



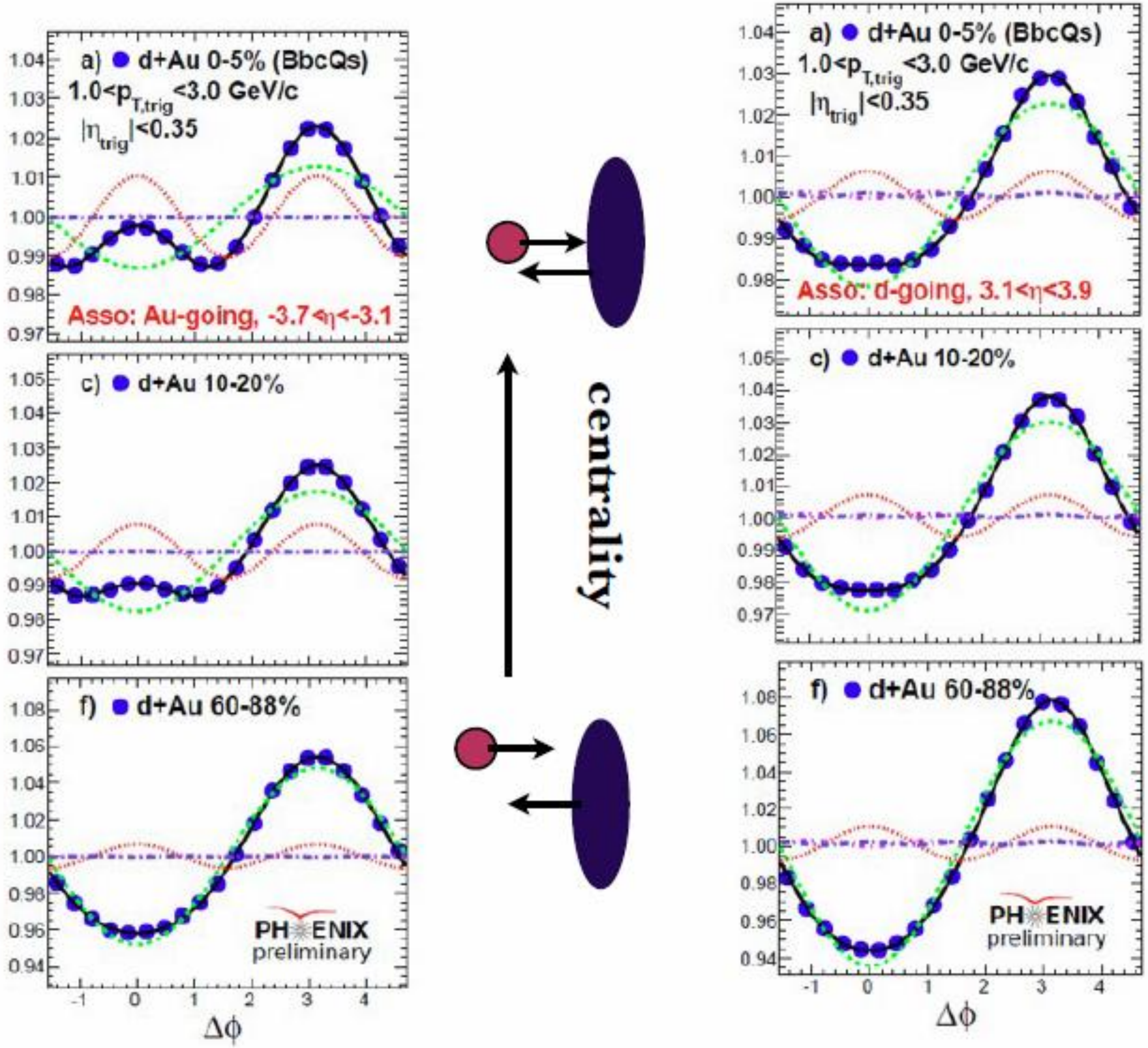
Multiplicity and transverse-momentum dependence of two- and four-particle correlations in pPb and PbPb collisions, CMS, 2013 data, Phys.Lett. B724 (2013) 213-240, 1305.0609.

Semi-central events

Collectivity – almost like in A+A?

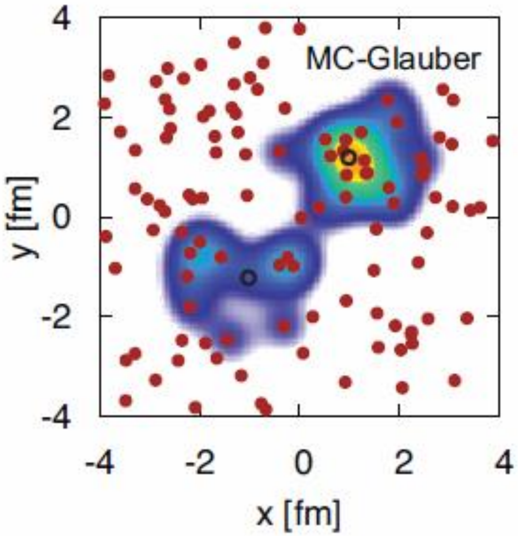
Mid- forward-rapidity correlations, d+Au, RHIC

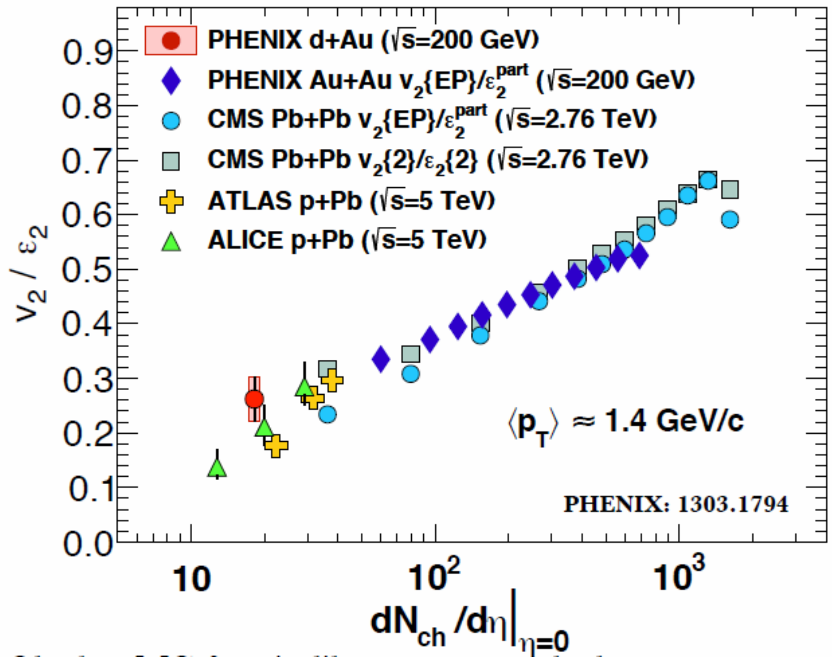
Similar observation at RHIC, in d+Au



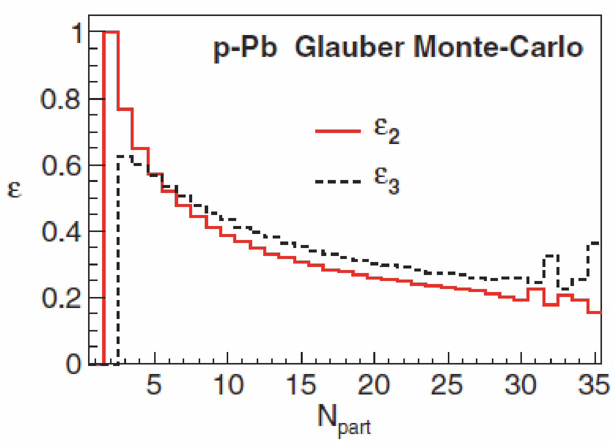
(Shengli Huang, Anne Sickles, PHENIX)

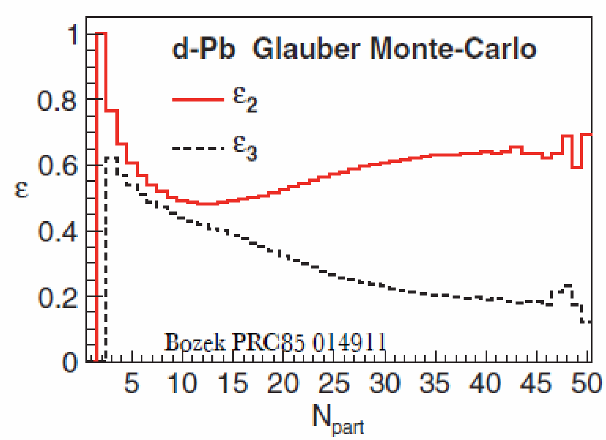
Same scaling of v_2 with geometry (???)





Ellipticity





Normalized flow depends mostly on multiplicity, not on collision energy or colliding system?

Only the number of collisions/participants count?

Orwellian geometry: all collisions are NOT created equal

Careful: v_2 is a relative measurement. Look at some absolute quantity, like spectra, and compare again:

arXiv:1304.3410

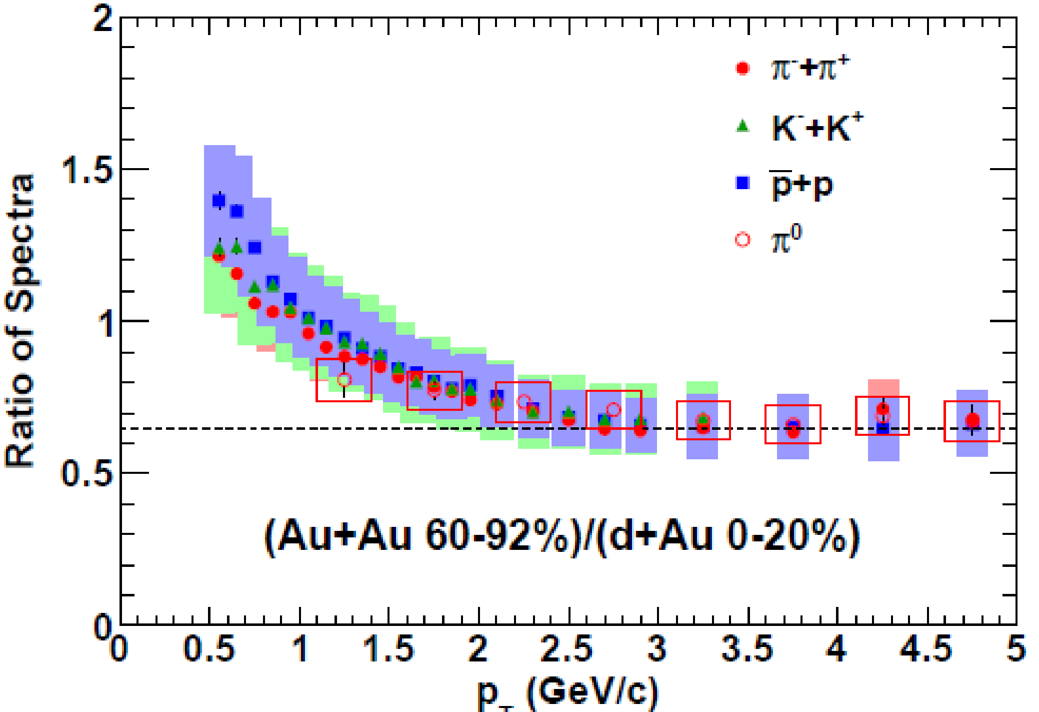
Ratios of identified hadron spectra in periph. Au+Au and central d+Au

Both N_{part} and N_{coll} virtually identical (eccentricity of course is not)

The ratios are constant (up to the highest p_T) ***but not one***! (0.65)

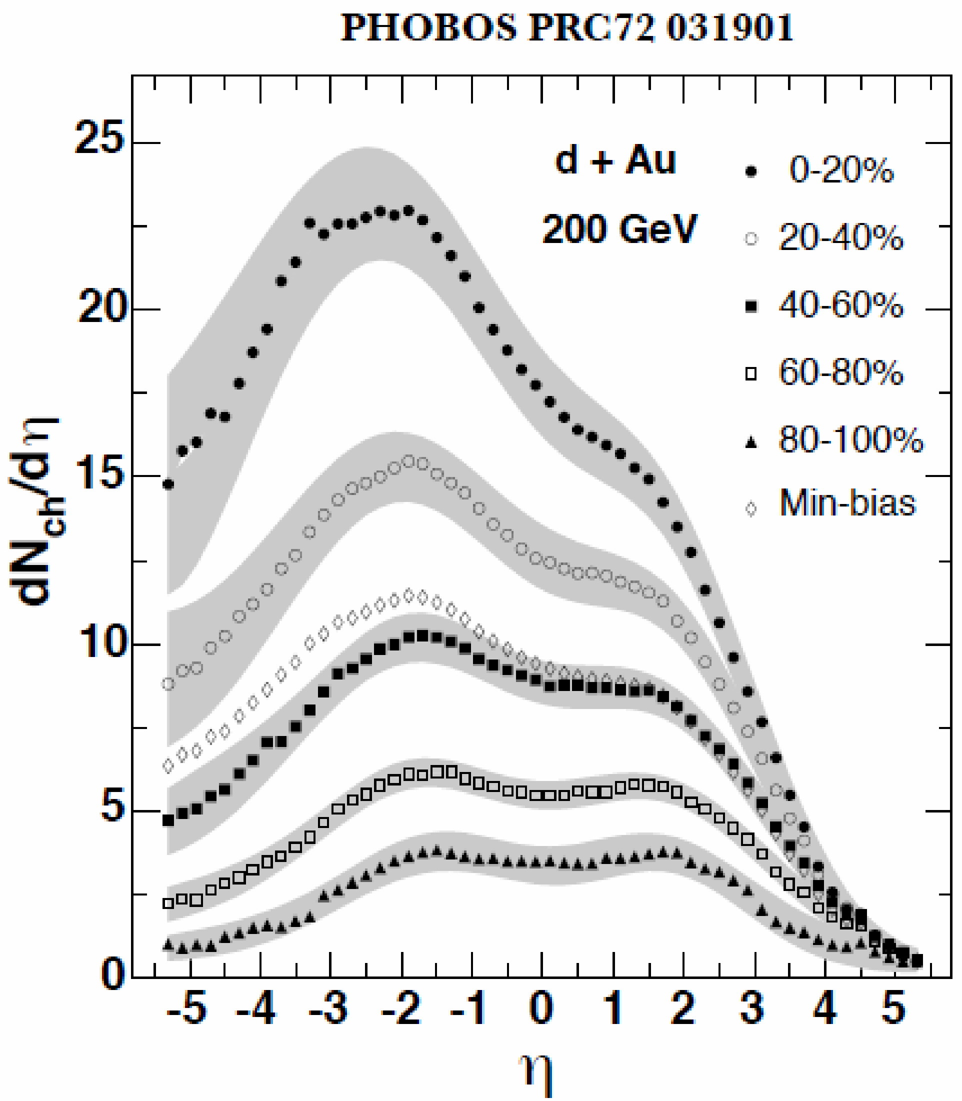
Isn't the Glauber counting too simplistic?

Is a "collision" in Au+Au the same thing as in d+Au (or p+Au)?



Of course it isn't…

Add some more complications to the mix



Actually, d+Au is trickier than just small on large

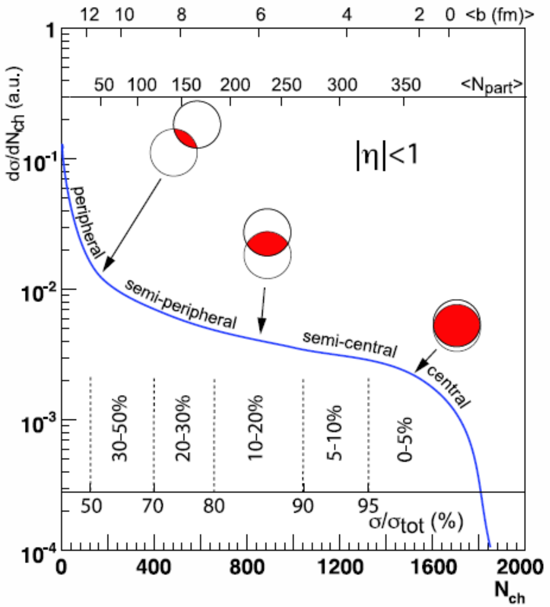


Figure 8: A cartoon example of the correlation of the final state observable N_{ch} with Glauber calculated quantities (b, N_{part}). The plotted distribution and various values are illustrative and not actual measurements (T. Ullrich, private communication).

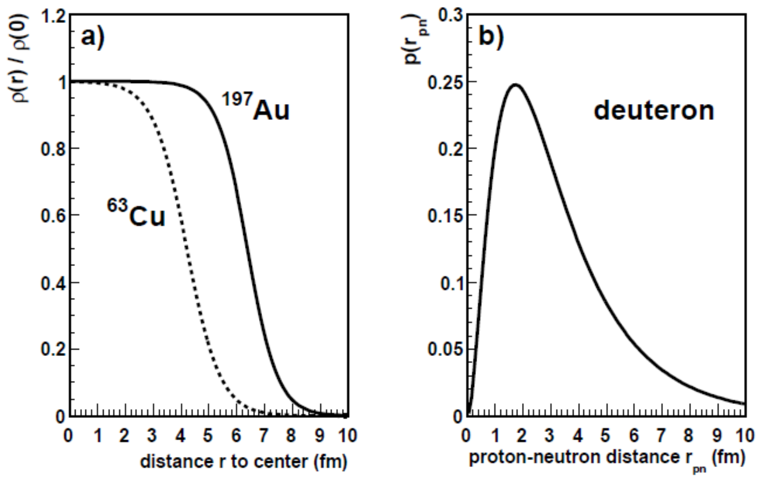


Figure 1: Density distributions for nuclei used at RHIC (a) and distribution of the proton-neutron distance in the deuteron as given by the Hulthen wave function (b).

Very diffuse and large
(what really is “b”, centrality?)
Large Ncoll
→ “multiple times wounded nucleon”

Take diffuseness out → pA at LHC (but higher E)

ALICE

Biases on pN Collisions ?

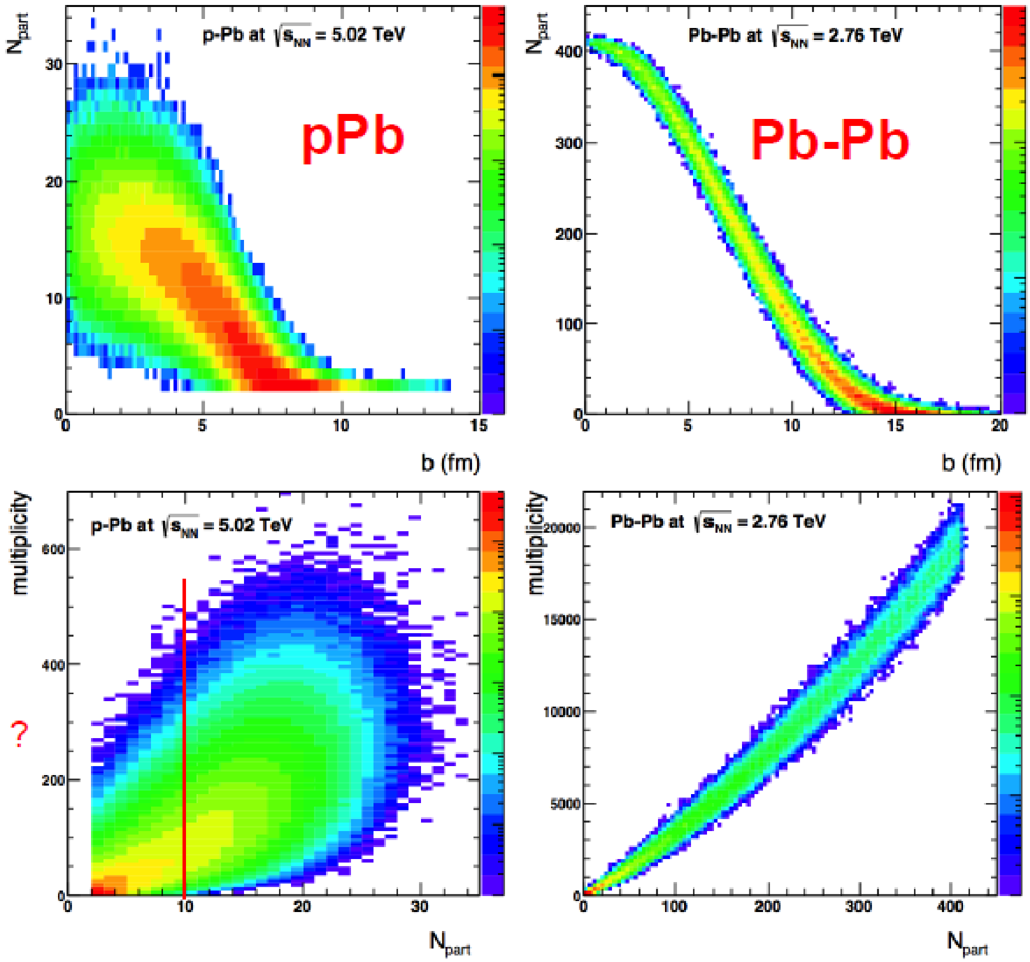
Compared to Pb-Pb

- Looser correlation between N_{part} and impact parameter (b)

- Looser correlation between N_{part} and Multiplicity

What distinguishes cent1 from cent2 for the same N_{coll} ?

Is it relevant for other physics observables ?



Andreas Morsch, SQM 2013, July 22-27 2013

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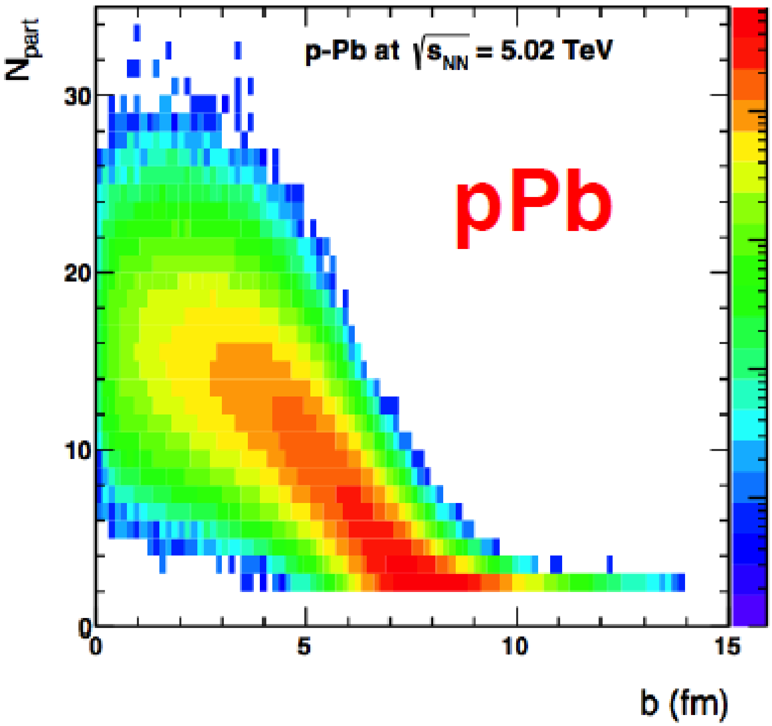
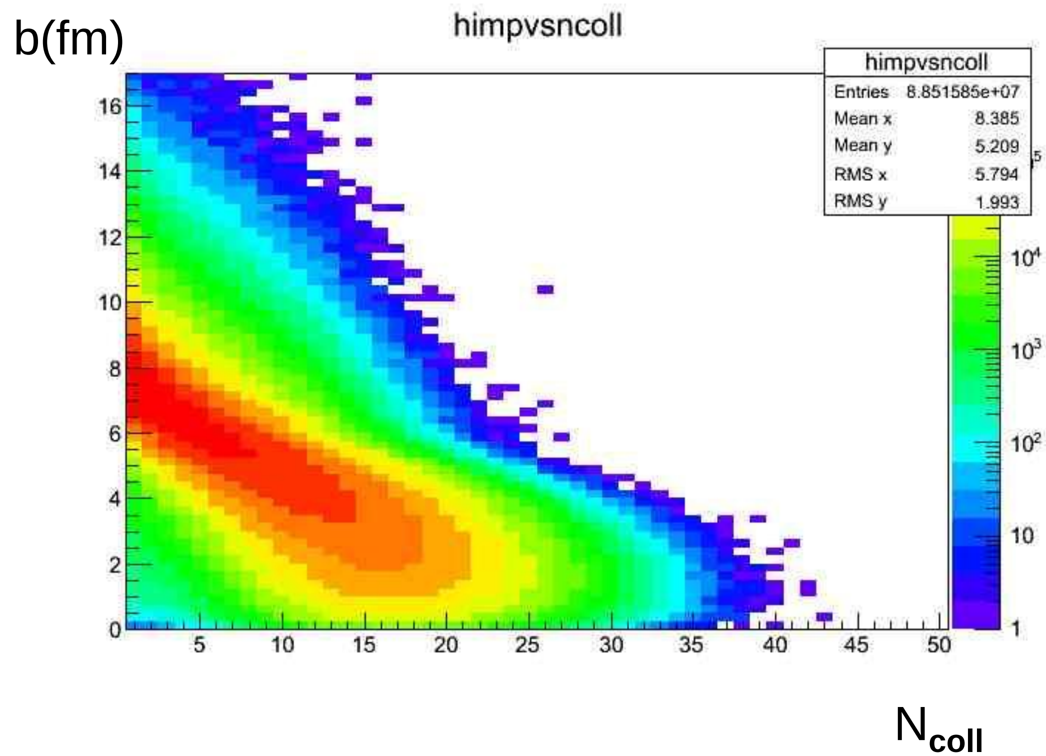
p+A and d+A, impact vs N_{part} ($\sim N_{coll}$)

p+Pb, Glauber MC



d+Au, AMPT



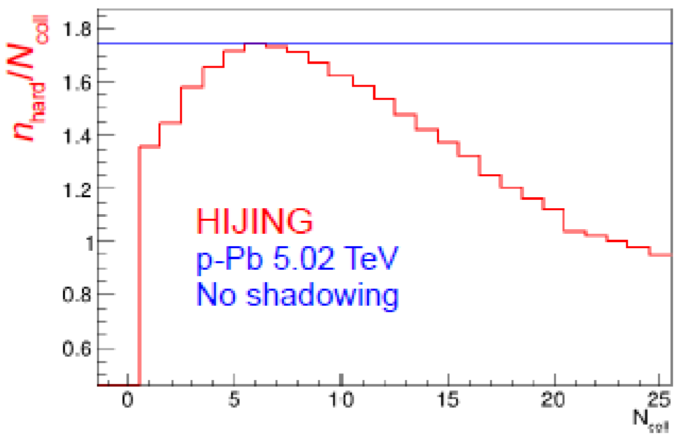
Strange shape (diffuseness)

HIJING and Glauber MC at LHC

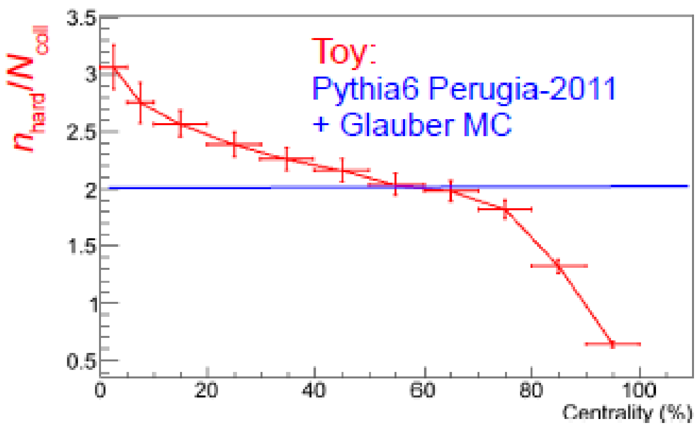
ALICE

Insights from Monte Carlo

N_{coll} scaling: n_{hard}/N_{coll} = const.



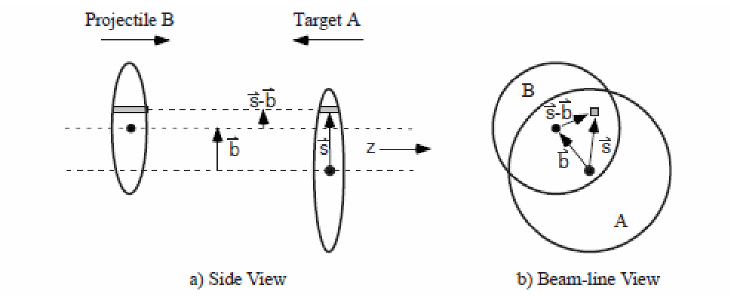
Number of hard scatterings per p-N collision
- vs N_{coll} (no multiplicity bias here !)
- Deviation from N_{coll} scaling
  - at low N_{coll} : geometry b_{NN}
  - at high N_{coll} : energy conservation (break down of factorization)



p-Pb collisions described as incoherent superposition of nucleon-nucleon

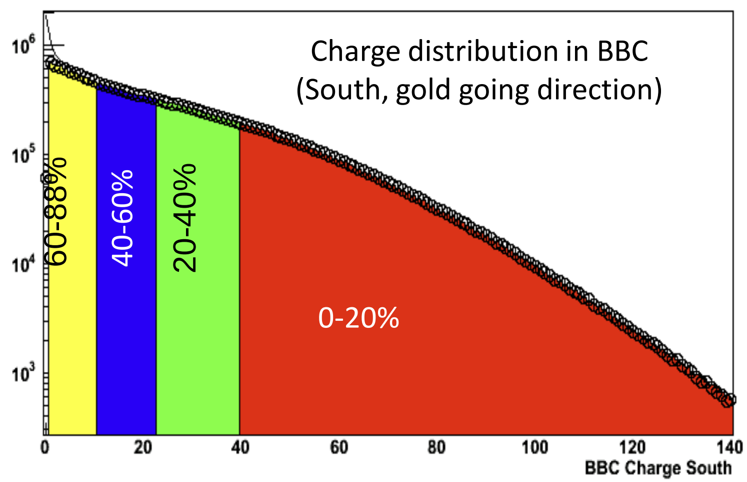
- vs centrality from multiplicity $|\eta| < 1.4$
- only multiplicity bias
- strong deviation from N_{coll} -scaling at low and high centralities.

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

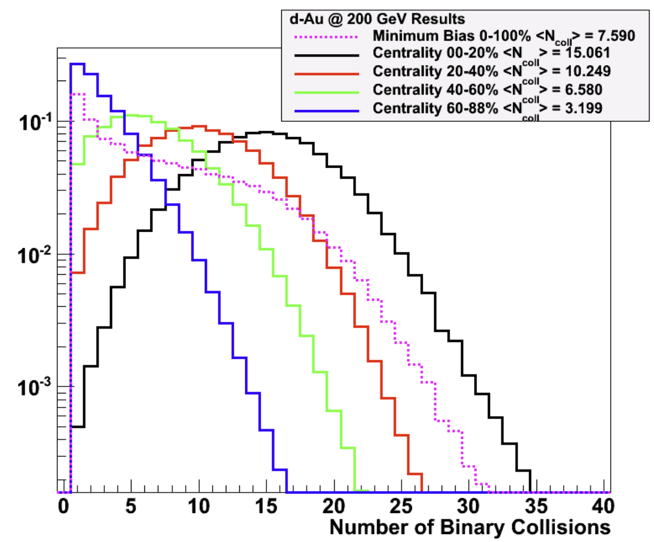


Straight path, independent collisions with the same probability (cross section) → N_{coll}, N_{part}
Folding with the *average response* observed in p+p can tie N_{coll}, N_{part} to observed N_{ch} *statistically*
Weather or not fluctuations are taken into account is irrelevant here

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)

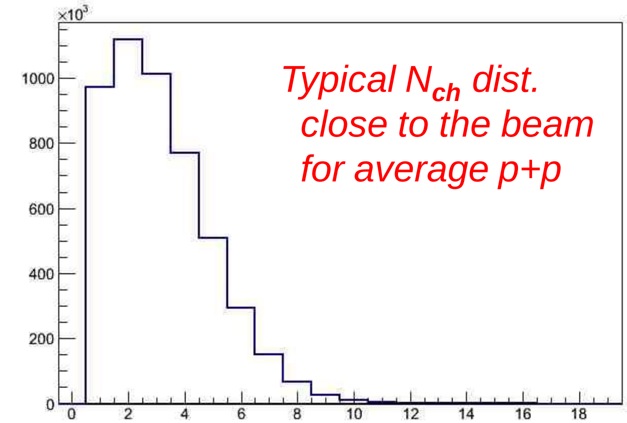
The verifiable case: p+p

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!

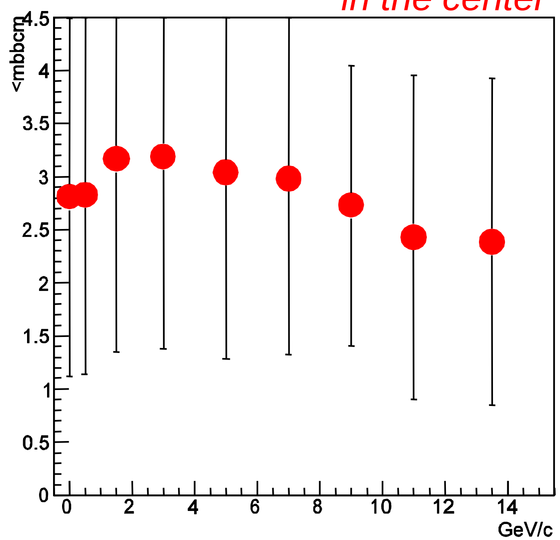


Note the characteristic rise initially (well-known: higher activity when hard scattering occurs)

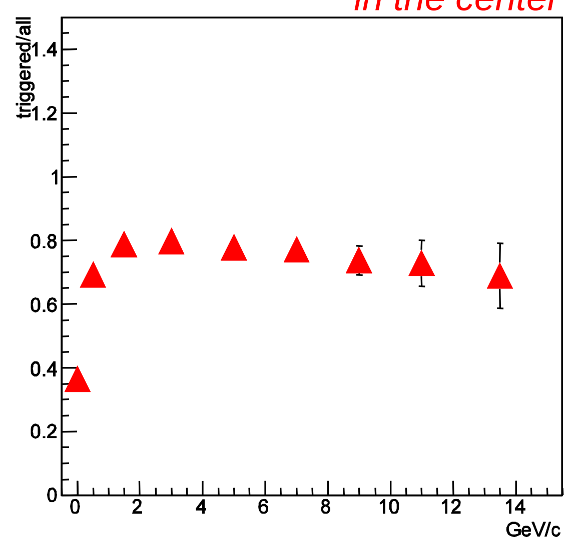
However, at higher pT they start to drop slowly.

They have to, at least asymptotically, for simple kinematic reasons.

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



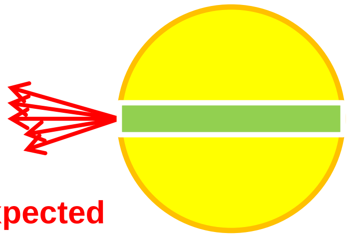
Trigger efficiency vs max p_T in the center



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

Illustration: shift between multiplicity classes / 1

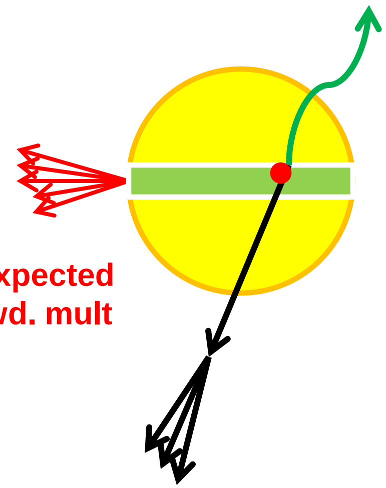
Here is your average,
higher centrality event



Expected fwd. mult

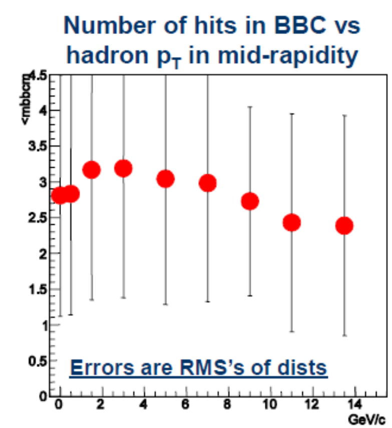
True b, N_{coll}

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



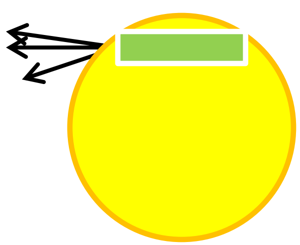
Expected fwd. mult

True b, N_{coll}



…this is how you classify
the event…

Observed fwd. mult

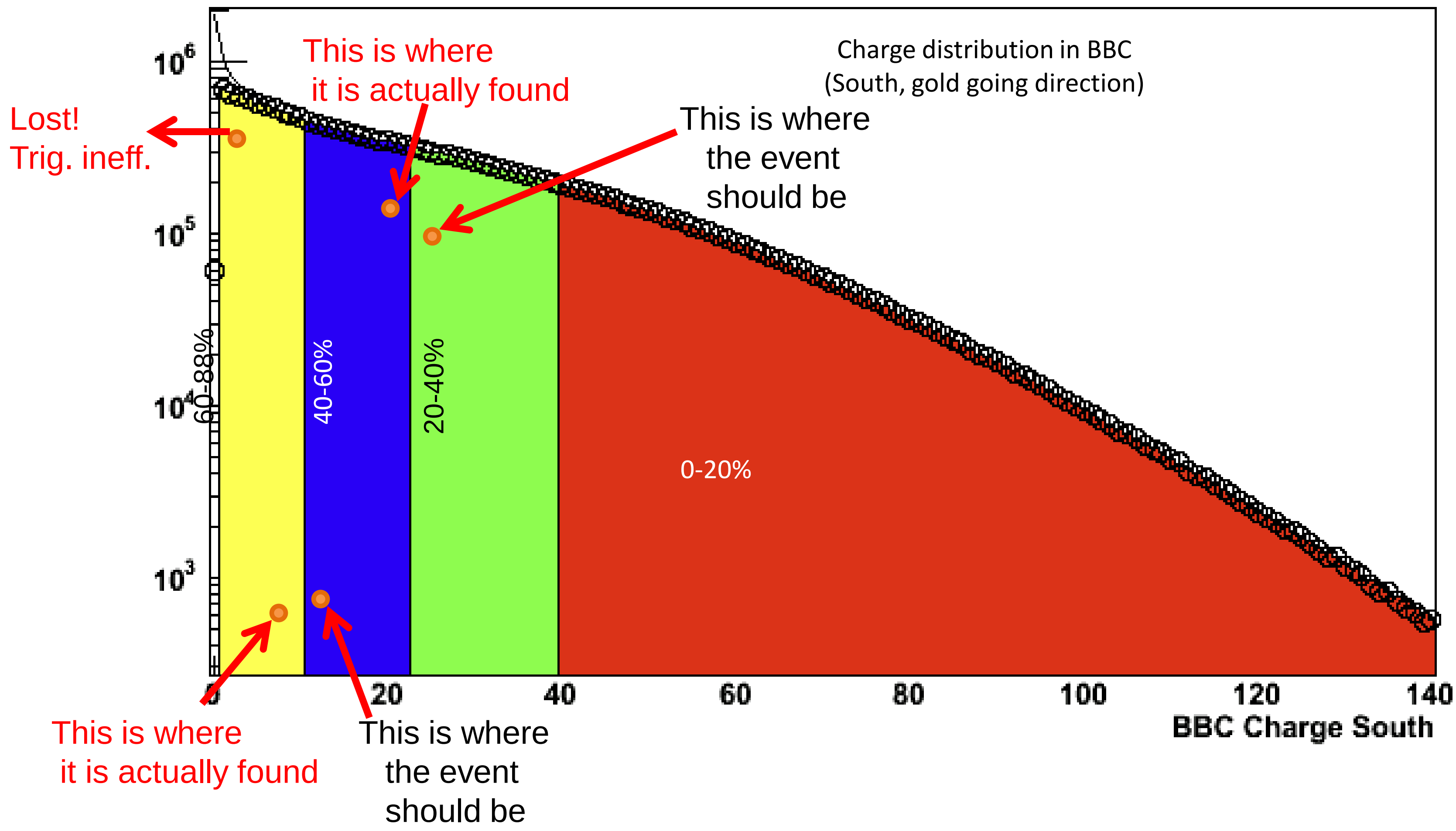


Percieved b, N_{coll}

…and when you calculate R_{AA},
the denumerator (N_{coll} * σ_{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 <N_{coll}>

More exotic possibilities

Indavertent 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 as the 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? Wounded or amputated nucleon?

This is a simplified, "static" picture, but it exhibits the crucial point:

the role of the nucleons is very asymmetric in p/d+A (as opposed to A+A)

Just to avoid confusion / misinterpretation

The Glauber-model is adequate and working for what is was originally meant (soft physics, average events and / or very large systems)

The fact that the presence of a high p_T particle biases distributions far away in rapidity, is not only a kinematic triviality, but also proven by data

In A+A even if one nucleon gets "out of the pool" this barely changes the **global** event, not even in peripheral**: ~equal number of nucleons from both**

However, in d+A (or even worse, in p+A) once a hard collision happened, **one nucleon** (or **the** nucleon!) **of the projectile** may be "out of the pool", → the global event changes drastically. Applying the same centrality classification as for the average event may be misleading in very asymmetric systems!

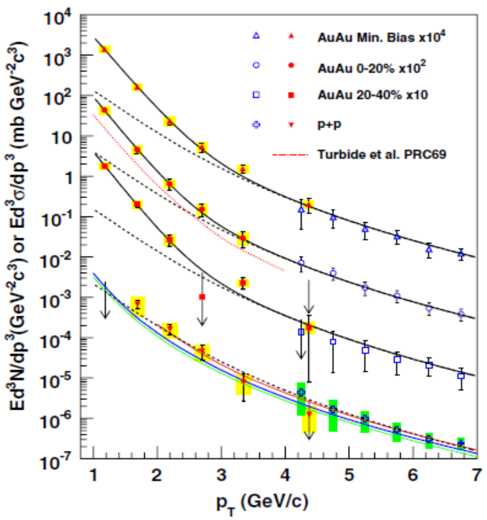
This is a very serious problem since we know little, if anything about what does a nucleon do **in a nucleus if there's also a (very) hard collision.** **Here I am talking 10 or tens of GeV, not 1GeV minijets!** The problem goes beyond energy conservation (which is easy to include).

Theme 2: the Grinch who stole QGP photons

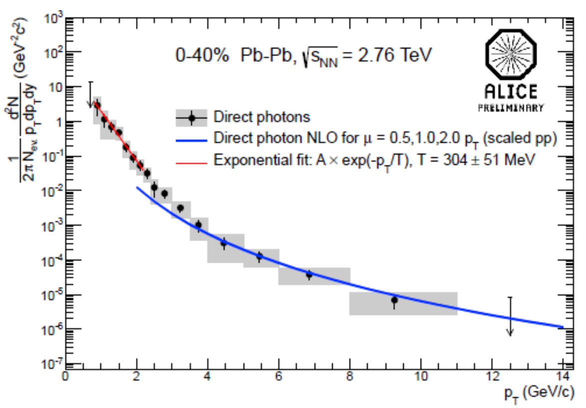
The Ianus-faced photons in heavy ion collisions

The ***most direct*** observables from the medium itself

PRL 104, 132301 (2010)



arXiv:1212.3995



The ***cleanest probes*** of pQCD, IS: they couldn't care less about the medium

PRL 109, 152302 (2012)

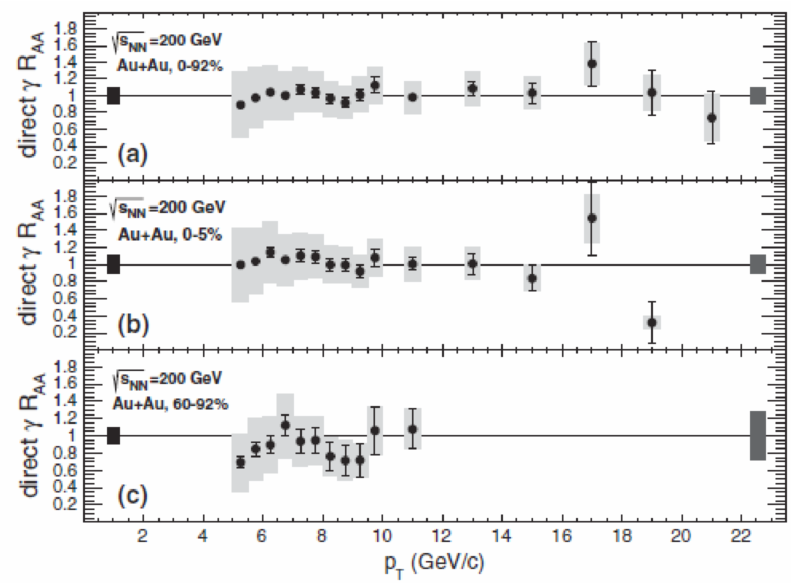


FIG. 3. Direct photon nuclear modification factor R_{AA} for three different centrality selections. The error bars show point-to-point uncertainties, the boxes around the points depict p_T correlated uncertainties. The boxes on the left show the uncertainty of the total inelastic $p + p$ cross section, the boxes on the right show the uncertainty in N_{coll}. Note that all errors from the $p + p$ reference spectrum are correlated between the centralities.

A big relief: N_{coll} scaling makes sense (at least in A+A and high p_T)

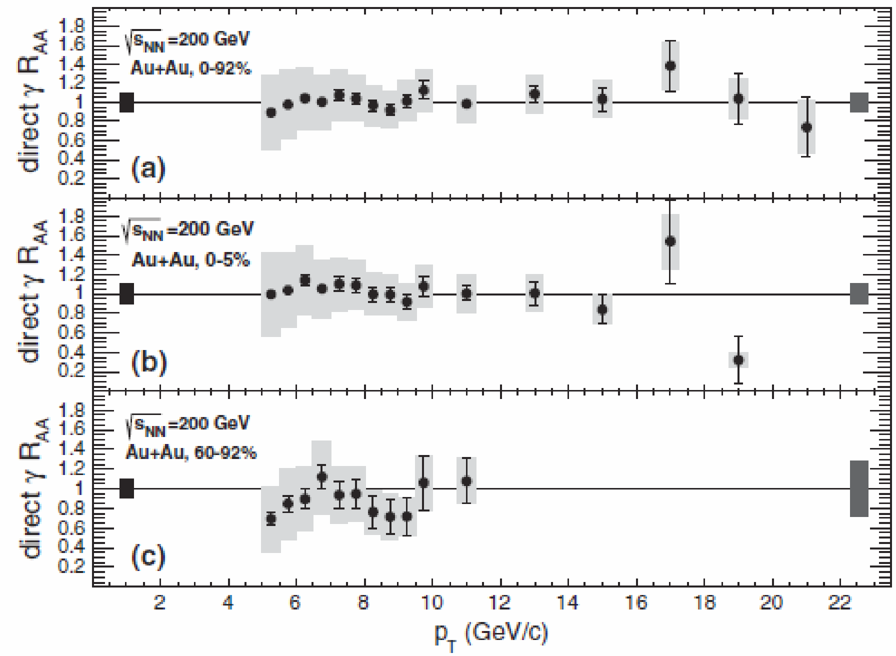
PRL 109, 152302 (2012)

The basic tenets behind all "E_{loss}", "jet quenching" and "tomography"

- hard probes are produced *before* any medium, collectivity emerges
- for hard probes A+A is an incoherent *superposition* of p+p collisions
- the proportionality (N_{coll}) can be derived from simple *geometry* and **σ** (analytic or MC Glauber)

Since photons (almost) don't interact with the medium, they should be uneffected → *as they apparently are*

Small perturbations (like isospin effect) possible, but the *fundamental* picture seems to hold



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The low p_T ("thermal") region – from p+p to A+A

arXiv:1208.1234

No excess in p+p,
apparently no excess
in d+Au,
substantial excess in Au+Au
in the p_T region where
thermal radiation would be
expected

Note: lack of "thermal"
radiation in d+Au →
isn't this evidence **against**
collectivity (in the hydro
"flow" sense)?

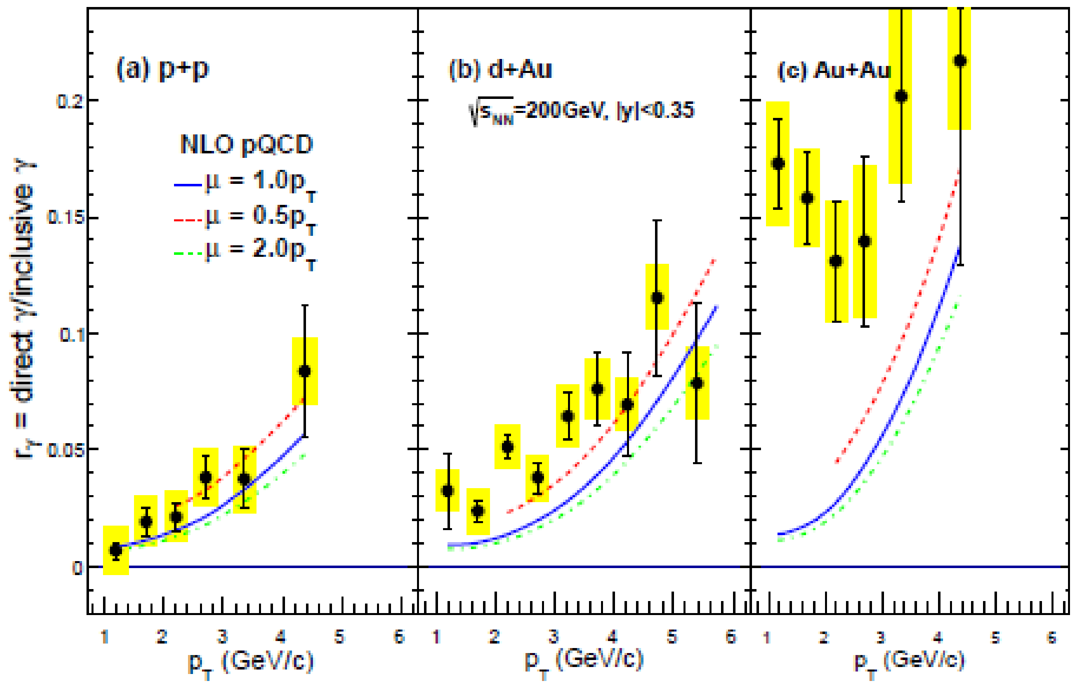
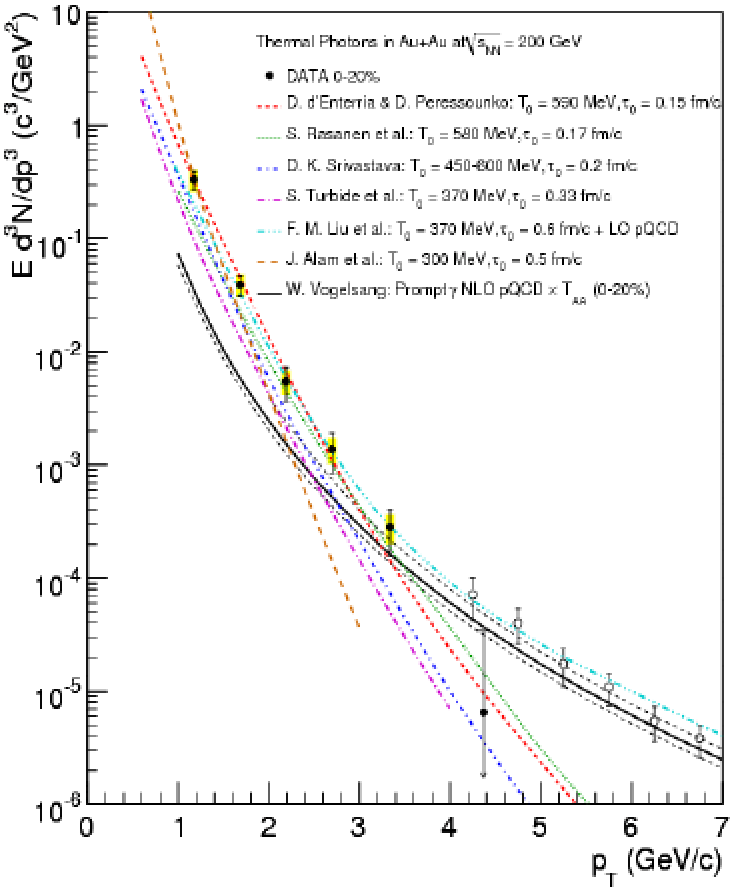
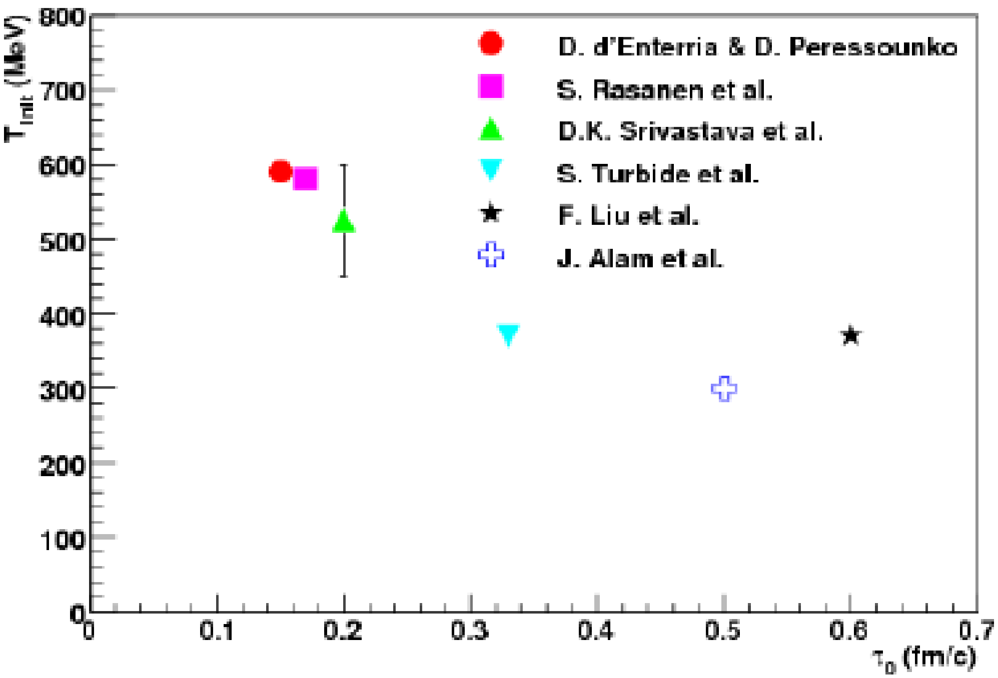


FIG. 1: (color online) The direct-photon fractions from the virtual-photon analysis as a function of p_T in (a) p+p, (b) d+Au, and (c) Au+Au (MB) [1] collisions. The statistical and systematic uncertainties are shown by the bars and bands, respectively. The curves show expectations from a NLO pQCD calculation [17, 18] with different cutoff mass scales: (solid) $\mu = 0.5\ p_T$, (dash) $\mu = 1.0\ p_T$, and (dash-dot) $\mu = 2.0\ p_T$.

Direct photons, Au+Au, at low p_T – rates only



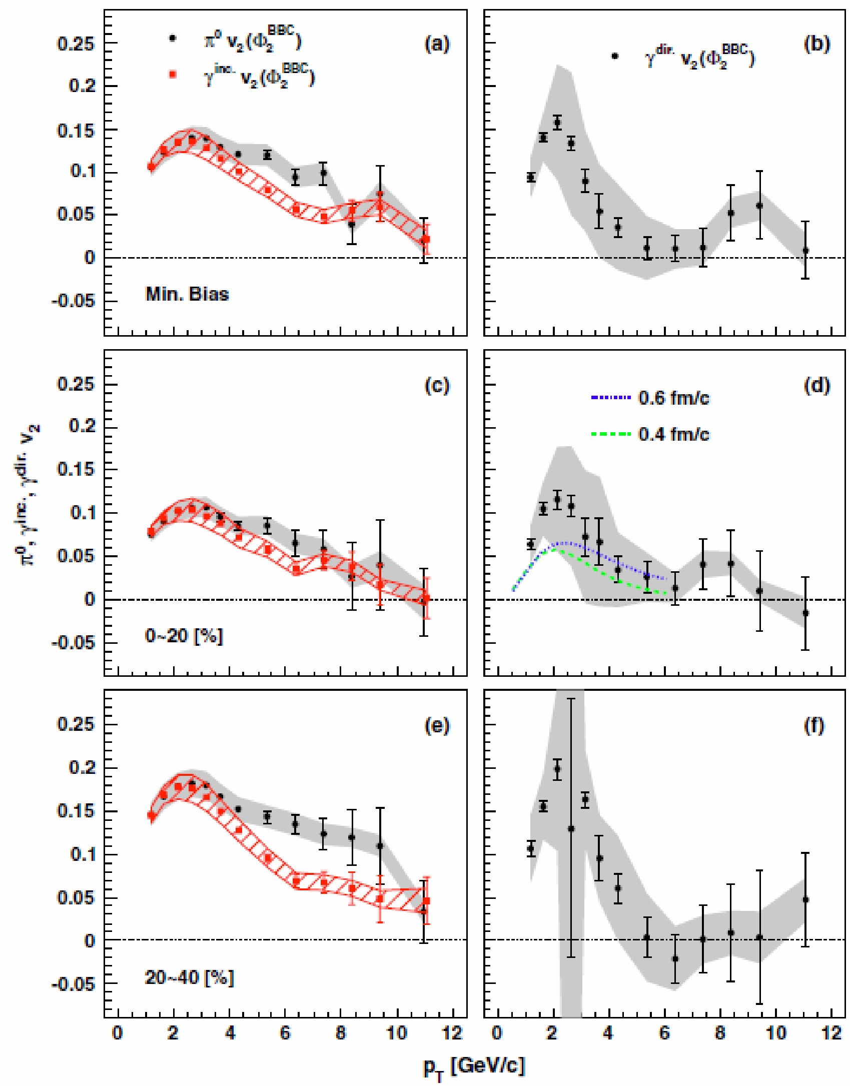


Shown in a zillion different versions, same conclusion: direct photon spectra alone, while important, not sufficient constraint

Direct photon flow at low p_T – is it real?

Initially treated with a liberal dose of scepticism, but finally got accepted for publication (around the same time when ALICE made the similar observation in Pb+Pb)

PRL 109, 122302 (2012)



QM'12, arXiv:1212.3995

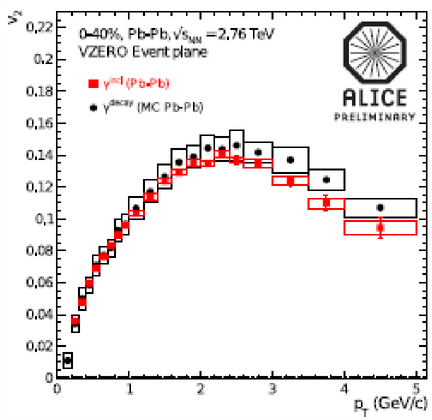


Figure 4: Inclusive photon $v_2^{\gamma,\mathrm{inc}}$ and decay photon $v_2^{\gamma,\mathrm{bg}}$ in 0–40 % Pb-Pb collisions.

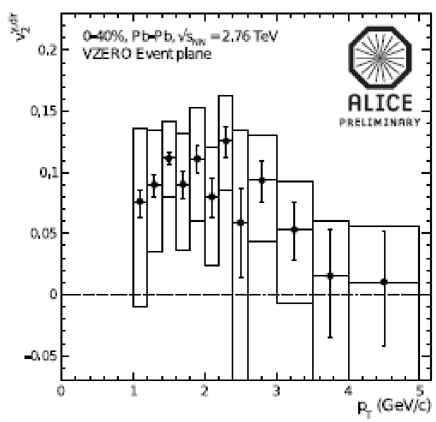


Figure 5: Direct-photon $v_2^{\gamma,\mathrm{dir}}$ in 0–40 % Pb-Pb collisions.

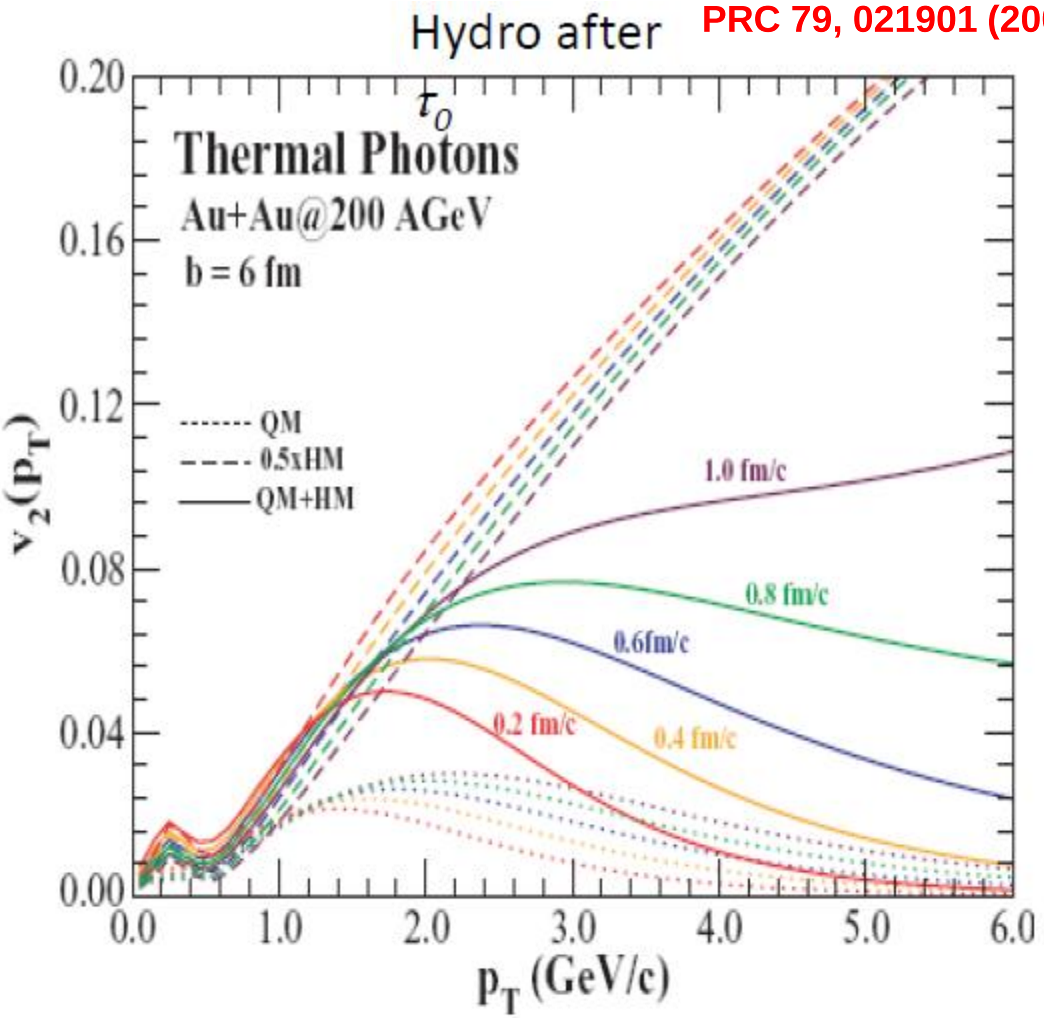
Direct photon flow – where does it come from?

The easiest way to get high rates is high (early) temperatures → but no flow there yet, just acceleration

The easiest way to get high flow is late (long acceleration), just before kinetic freeze-out but lower (thermal) rates

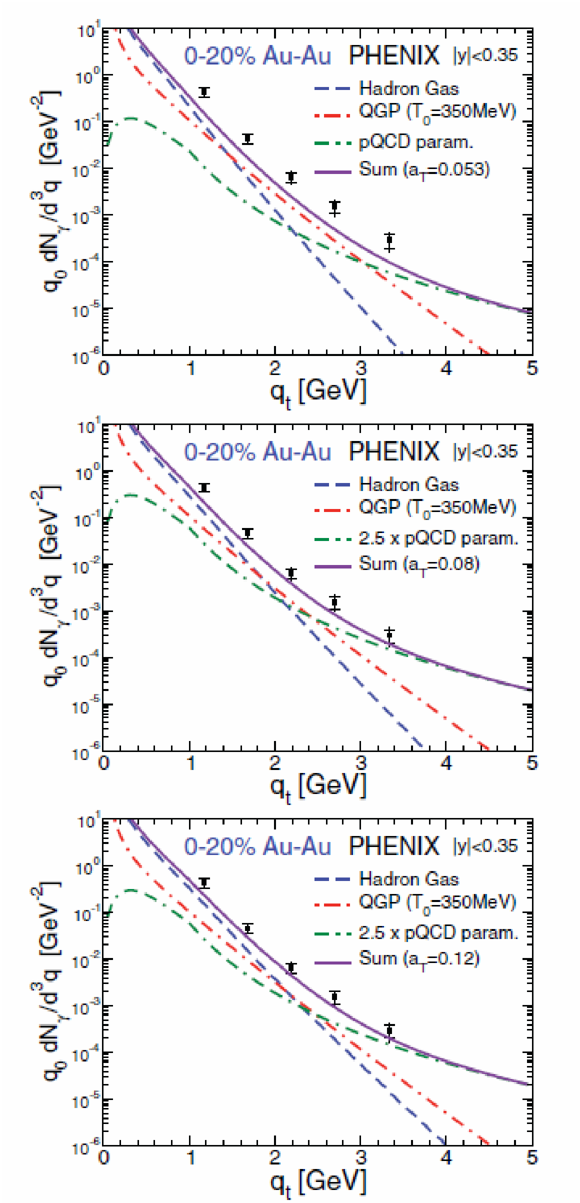
Having both high rates and high flow is something like “having your cake and eating it, too”, tantalizing theorists for years now.

PRC 79, 021901 (2009)



The mantra: you have to explain *yield* and *flow simultaneously*!

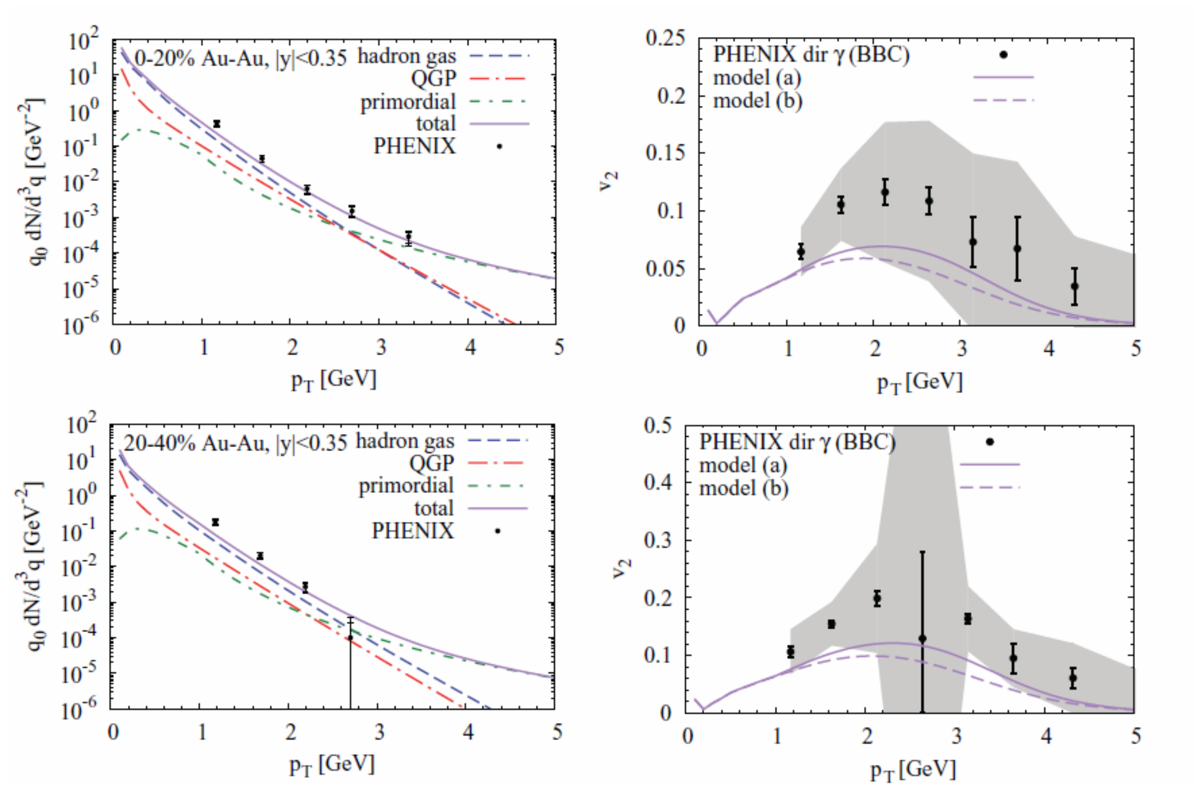
Direct photon flow – play with a_T (fireball acceleration)



If true, "QGP window" is essentially gone (QGP is not the dominant source at *any* p_T), and the large apparent temperature is mostly of hadronic (+ blue shift) origin.

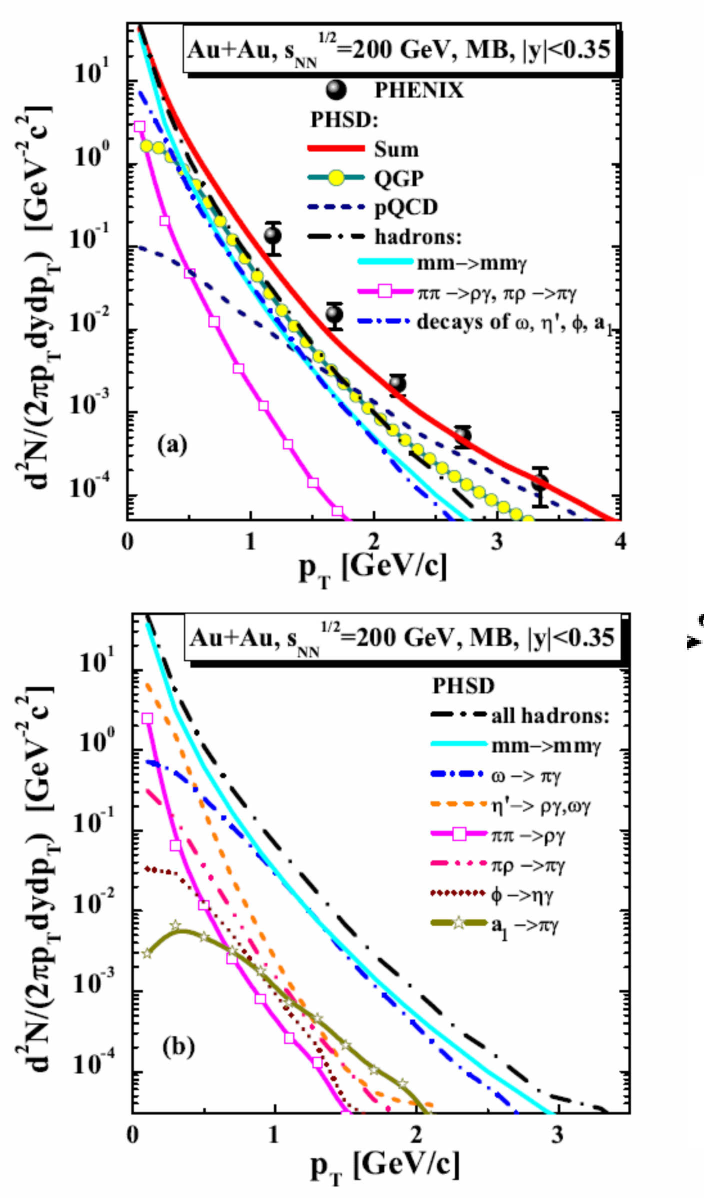
Van Hees, Gale, Rapp

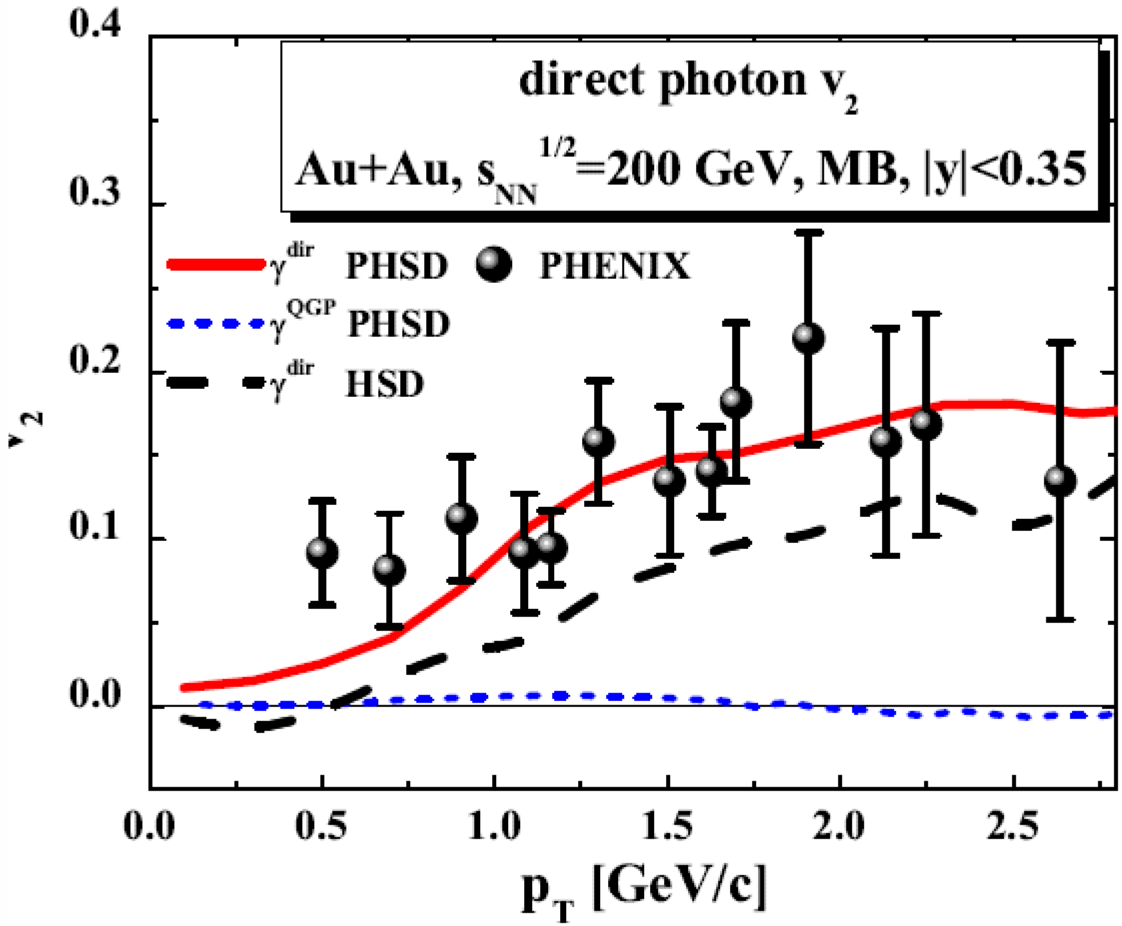
PRC 84, 054906 (2011)



PHSD – more photons from hadronic sources

1304.7030





Radial flow: disconnect between T and 1/slope

1308.2440

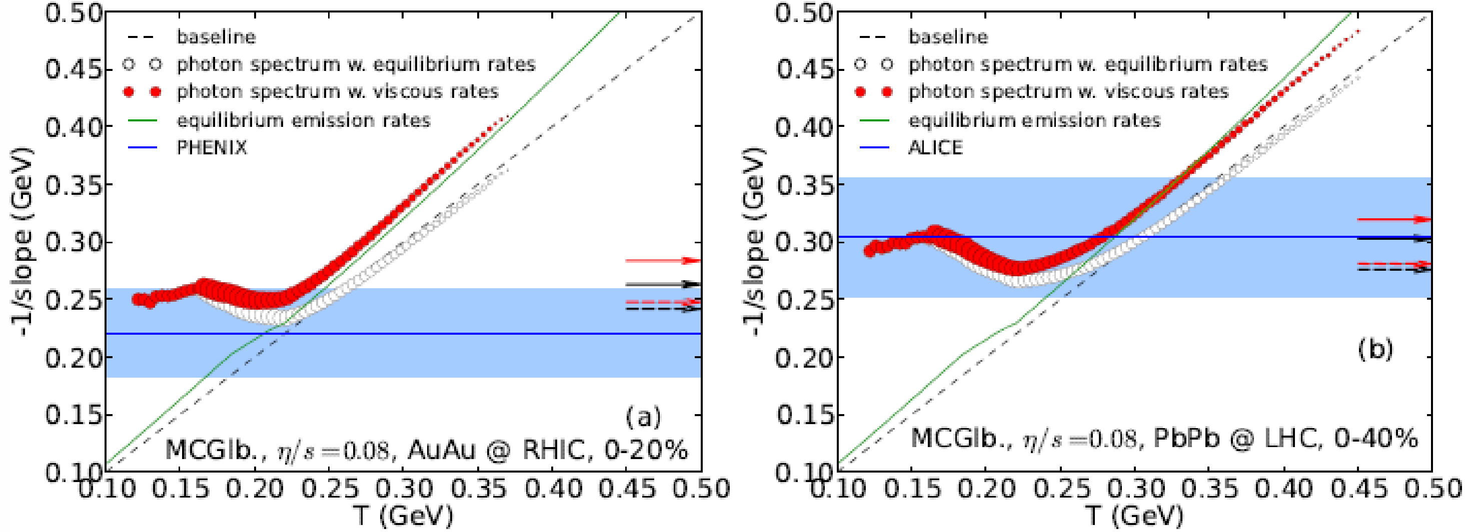


FIG. 1: (Color online) The inverse photon slope parameter $T_{\rm eff} = -1/\mathrm{slope}$ as a function of the local fluid cell temperature, from the equilibrium thermal emission rates (solid green lines) and from hydrodynamic simulations (open and filled circles), compared with the experimental values (horizontal lines and error bands), for (a) Au+Au collisions at RHIC and (b) Pb+Pb collisions at the LHC. See text for detailed discussion.

range of photon emission	fraction of total photon yield	
	AuAu@RHIC 0-20% centr.	PbPb@LHC 0-40% centr.
T = 120-165 MeV	17%	15%
T = 165-250 MeV	62%	53%
$T > 250$ MeV	21%	32%
$\tau = 0.6 - 2.0$ fm/c	28.5%	26%
$\tau > 2.0$ fm/c	71.5%	74%

TABLE I: Fractions of the total photon yield emitted from the expanding viscous hydrodynamic fireball from various space-time regions as indicated, for the two classes of collisions considered in this work.

Much lower true temperatures would allow much larger hadronic fraction in total yield

Are there other indications that this is the case?

Summary

Low p_T direct photons yields do NOT seem to be compatible with dominant production from the QGP if one tries to explain simultaneously the direct photon flow (as one should!)

A growing number of models (not all) de-emphasize QGP photons (the mantra of the 80's)

Predictions of the centrality dependence of v_2 and yield *would add credibility*…

The way we characterize event geometry ***may not be adequate in extreme cases***, like very asymmetric systems, large p_T "one in a million" type events

Time to re-think how we use the Glauber-model?

Unexpected photon v_2,
long-range jet correlations in d+Au,
rapidly rising R_{AA}, …
Nature punishes us if we get complacent , nevertheless

Look for the forest without cutting the tree: put in proper perspective!

Even good ideas can get too much ingrained in our thinking

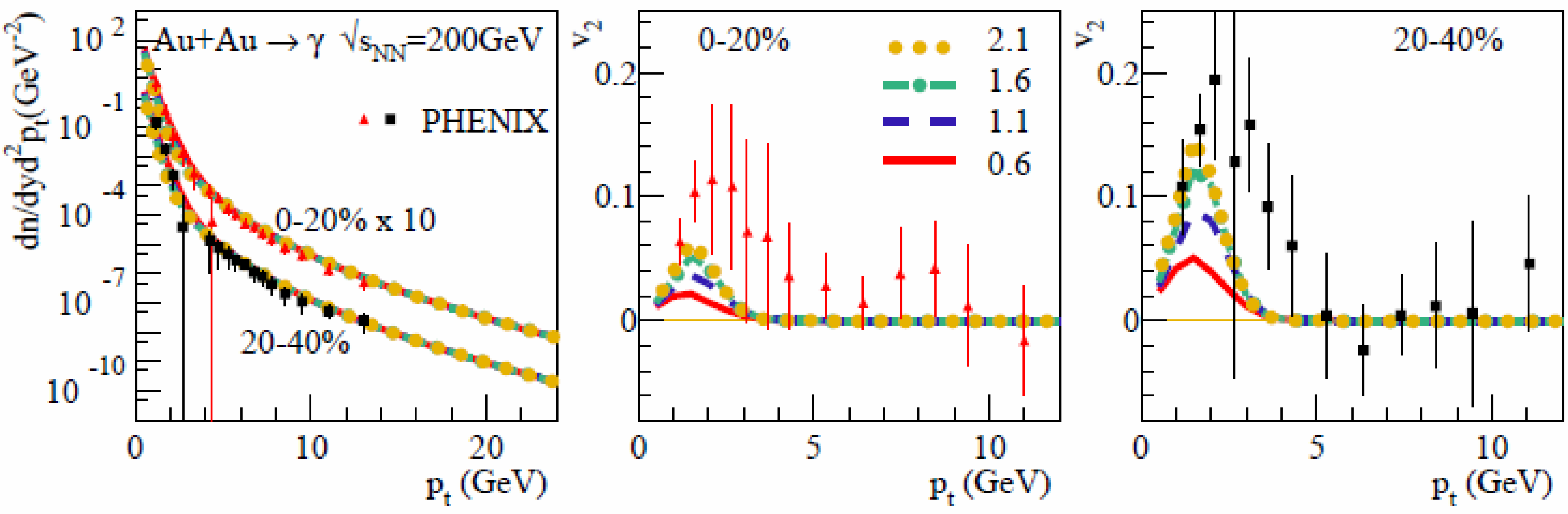
Additional material

Direct photon flow – play with time

F.-M. Liu

Early hydro initial time, QGP forms considerably later
(0.6 f/c vs QGP formation times up to 2.1 f/c)
→ early emission (no flow part) was overestimated

arXiv:1212.6587

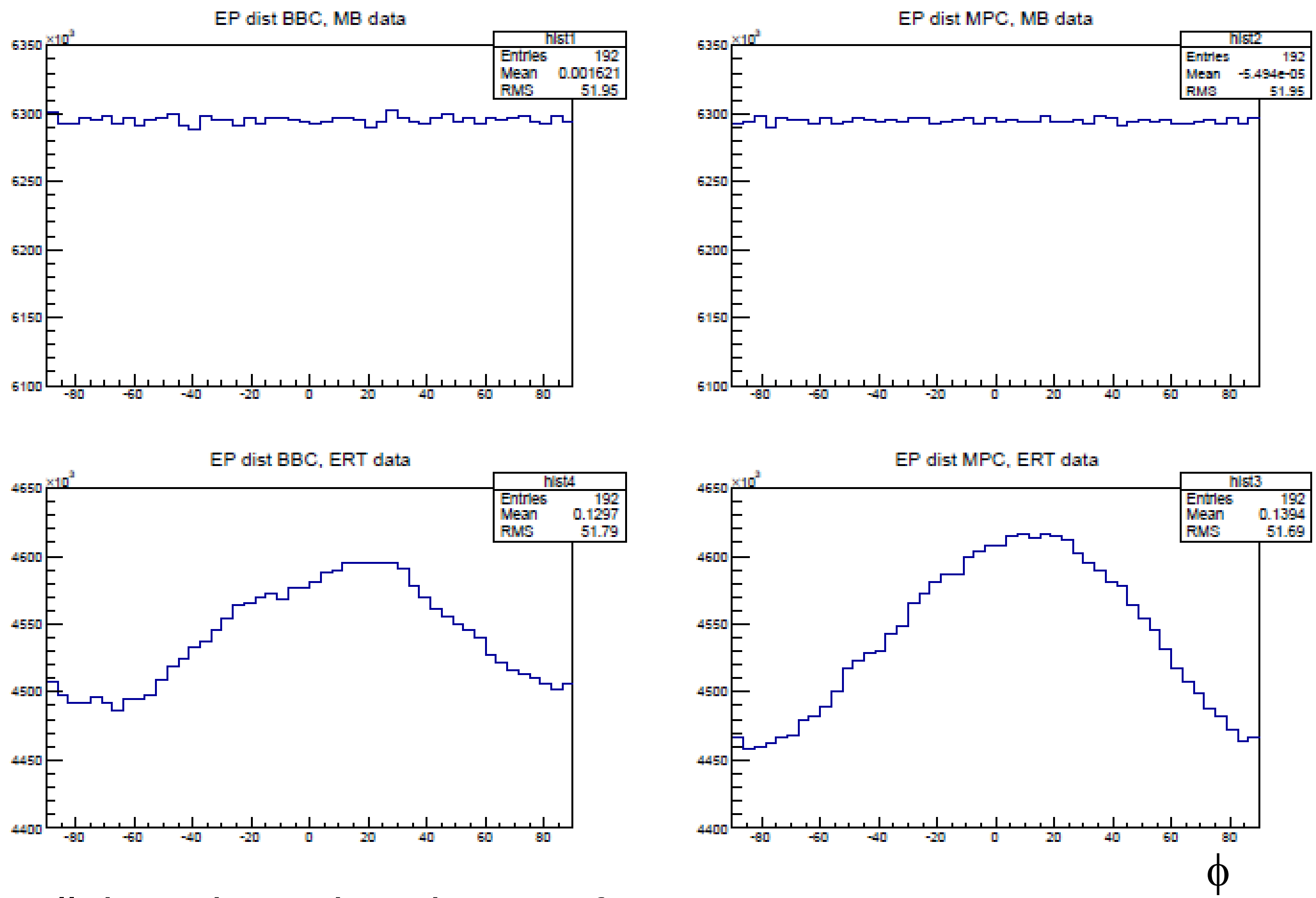


Q: what is the emission between τ_{hydro} and τ_{QGP}? Apparently unanswered
(looks a bit like a "**fiat**" type theory so far → where's the forest?

Short interlude: flow at high p_T

Event plane (EP)
Calibration with MB
Two detectors,
~same η,
different granularity
Large rapidity gap

EP for data where a high energy particle is present in a limited ϕ region at $\eta = 0$



The modulation is small, but where does it come from?
Is the jet sometimes biasing the EP as derived experimentally (faking “flow”)?
Is the EP unbiased, the flow is real, but there is jet suppression, that depends on pathlength?
How to tell the difference?