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Nuclear surface effects in AuAu@RHIC¹

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The fact that nuclei have diffuse surfaces (rather than being simple spheres) has dramatic consequences on the interpretation of the RHIC heavy-ion data.

The effect is quite small (but not negligible) for central collisions, but gets increasingly important with decreasing centrality.

¹ hep-ph/0603064

- **The nuclear diffuseness is typically “just” half a fermi, but this is actually big enough to have very sizable effects.**
- **Well known in pA scattering: the nuclear diffuseness is very important.**

The hard sphere approximation does not only modify the correct results slightly, it destroys them!

Example: even though the proton suffers on the average several collisions when it traverses a big nucleus, the most likely situation is still just one interaction, due to the surface diffuseness.

In nuclear collisions, the surface effect is as well present, and also very important:

- The peripheral nucleons of either nucleus essentially perform independent pp or pA-like interactions, with a very different particle production compared to the high density central part.**
- For certain observables, this “background” contribution completely spoils the “signal”, and to properly interpret RHIC data, we need to subtract this background.**

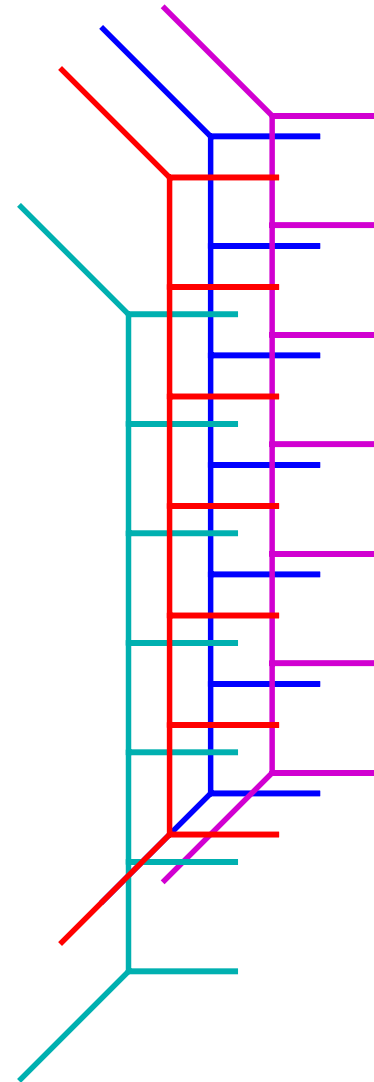
- To get quantitative results, we need a simulation tool, and here we take EPOS, which has proven to work very well for pp and dAu collisions at RHIC.**

- The main results of this study do not depend on whether or not the model treats the high density part 100% correctly.**

- The crucial point is that the model describes pp and pAu to a high precision, so we can safely subtract the peripheral low density part.**

EPOS is a parton model

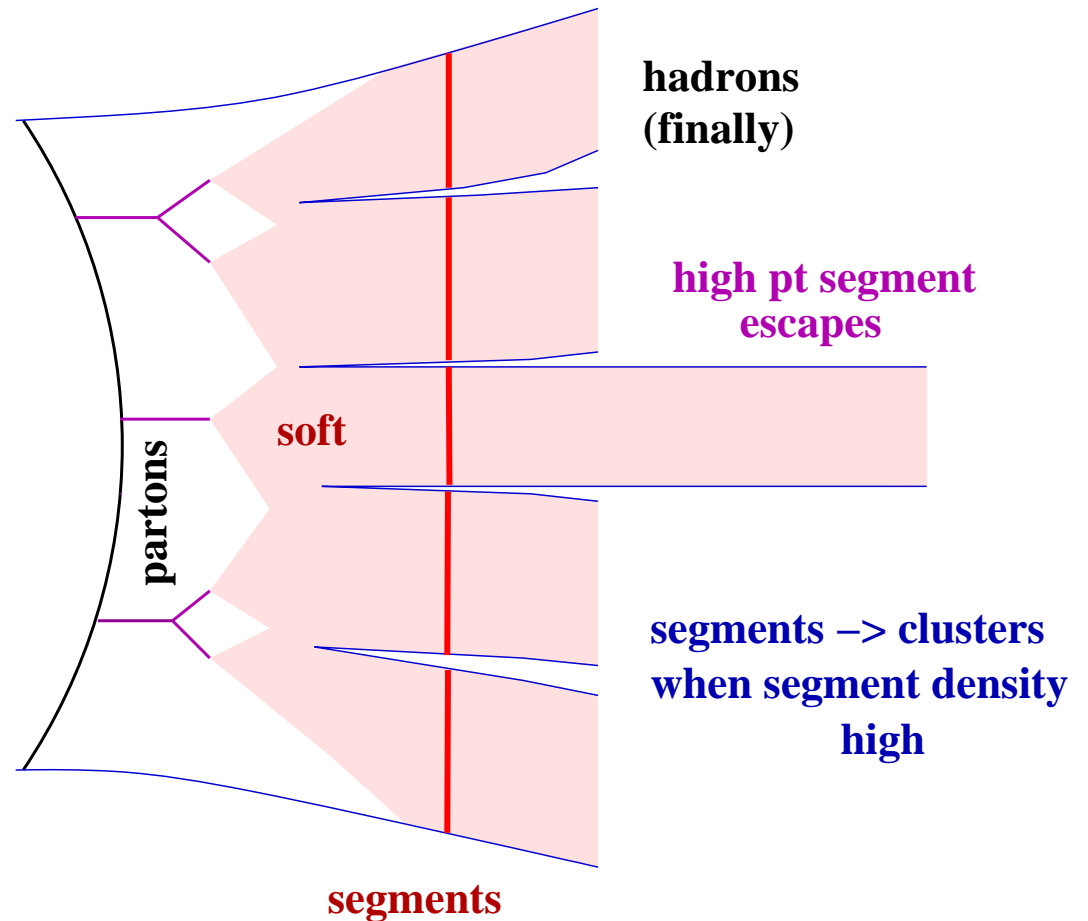
- many binary interactions creating partons, with initial and final state radiation**
- in certain regions:**
 - many parton ladders in parallel,**
 - impossible to hadronize independently ...**



Hadronization: via string

We have a look at the situation at an early proper time τ_0 , long before the hadrons are formed ($\tau_0 = 1 \text{ fm}$).

We distinguish between string segments in dense areas (more than ρ_0 segments per unit proper volume), from those in low density areas ($\rho_0 = 1 \text{ fm}^{-3}$).

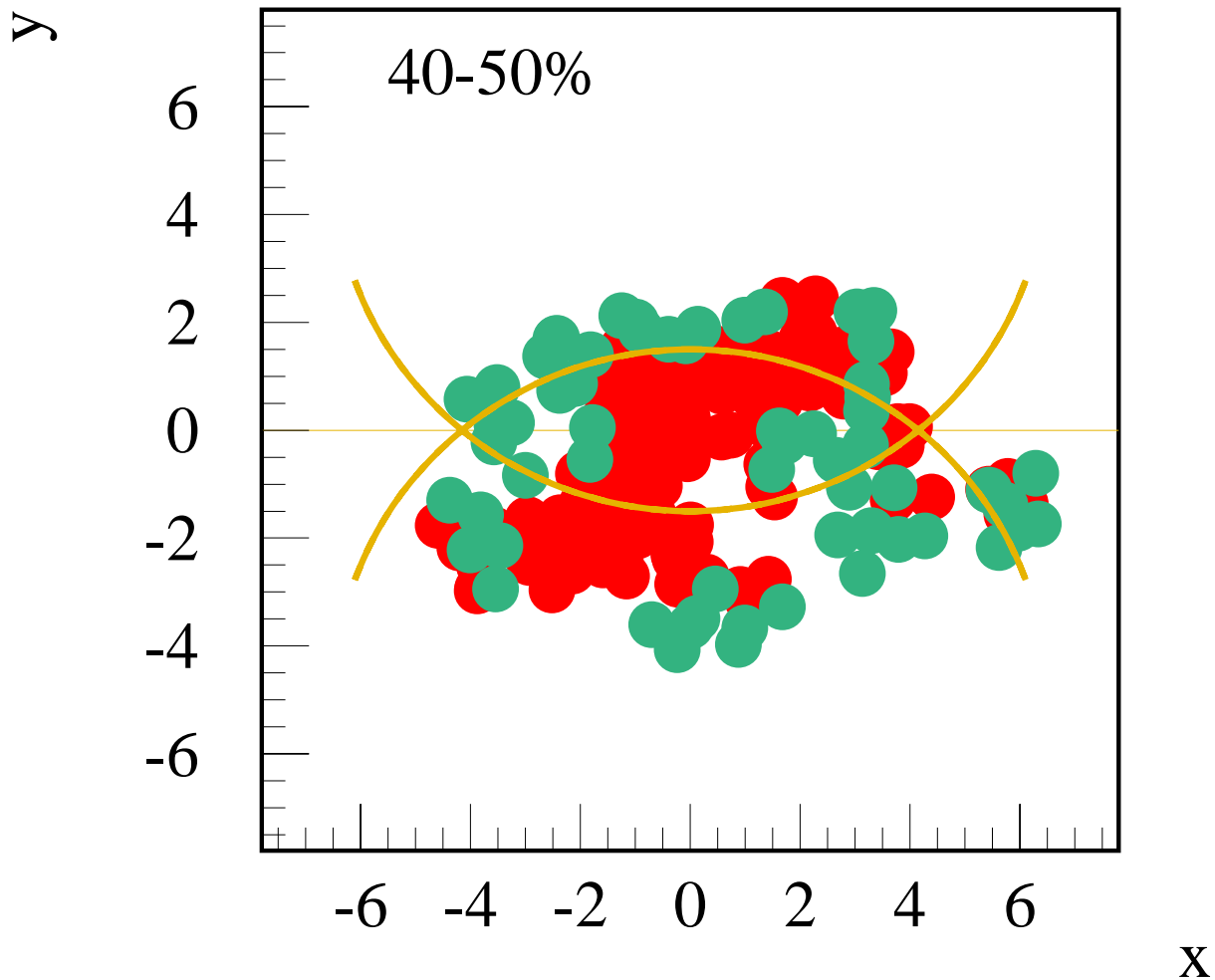


We refer to high density areas as core, to low density areas as corona. Connected high density areas in given longitudinal slices are referred to as clusters.

**Semi-
peripheral
AuAu@200GeV**

longitudinal
slice ± 0.8 fm

randomly
chosen event



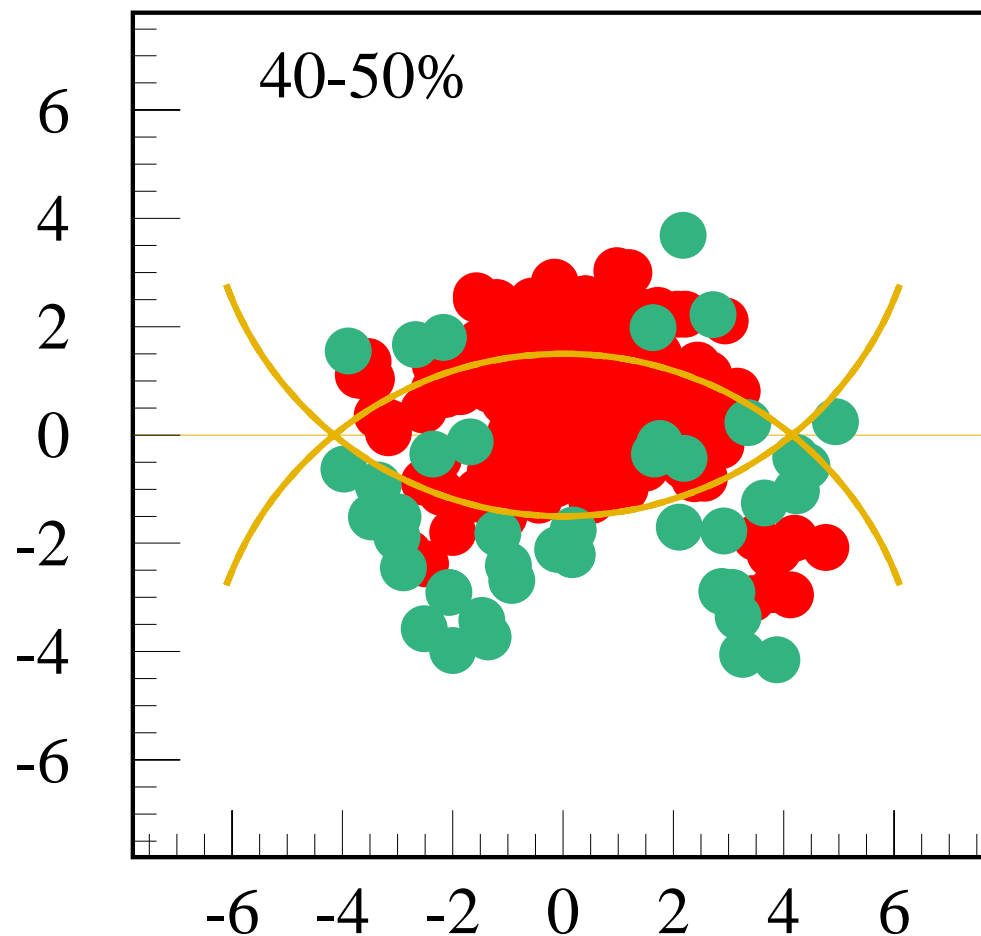
0-6

**Semi-
peripheral
AuAu@200GeV**

longitudinal
slice ± 0.8 fm

randomly
chosen event

y



x

0-7

Clusters are considered to be collectively expanding: Bjorken-like in longitudinal direction, with in addition some transverse expansion.

- We assume that the clusters hadronize at some given energy density $\varepsilon_{\text{hadr}}$, having acquired at that moment a collective radial flow, with a linear radial rapidity profile from inside to outside, characterized by the maximal radial rapidity y_{rad} .**
- In addition, we impose an azimuthal asymmetry, by multiplying the x and y component of the flow four-velocity with $1 + \epsilon f_{\text{ecc}}$ and $1 - \epsilon f_{\text{ecc}}$, where ϵ is the the initial space eccentricity.**

We rescale the cluster mass to account for the flow!

Hadronization then occurs according to covariant phase space, which means that the probability dP of a given final state of n hadrons is given as

$$dP = \prod_{\text{species } \alpha} \frac{1}{n_\alpha!} \prod_{i=1}^n \frac{d^3 p_i}{(2\pi\hbar)^3 2E} g_i s_i W \delta(E - \Sigma E_i) \delta(\Sigma \vec{p}_i) \delta_{f, \Sigma f_i}.$$

There is a factor $s_i = \gamma_s^{\pm 1}$ for each strange particle (sign plus for a baryon, sign minus for a meson), with γ_s being a parameter.

The number n_α counts the number of hadrons of species α .

E is the total energy of the cluster in its cms, W is the cluster proper volume.

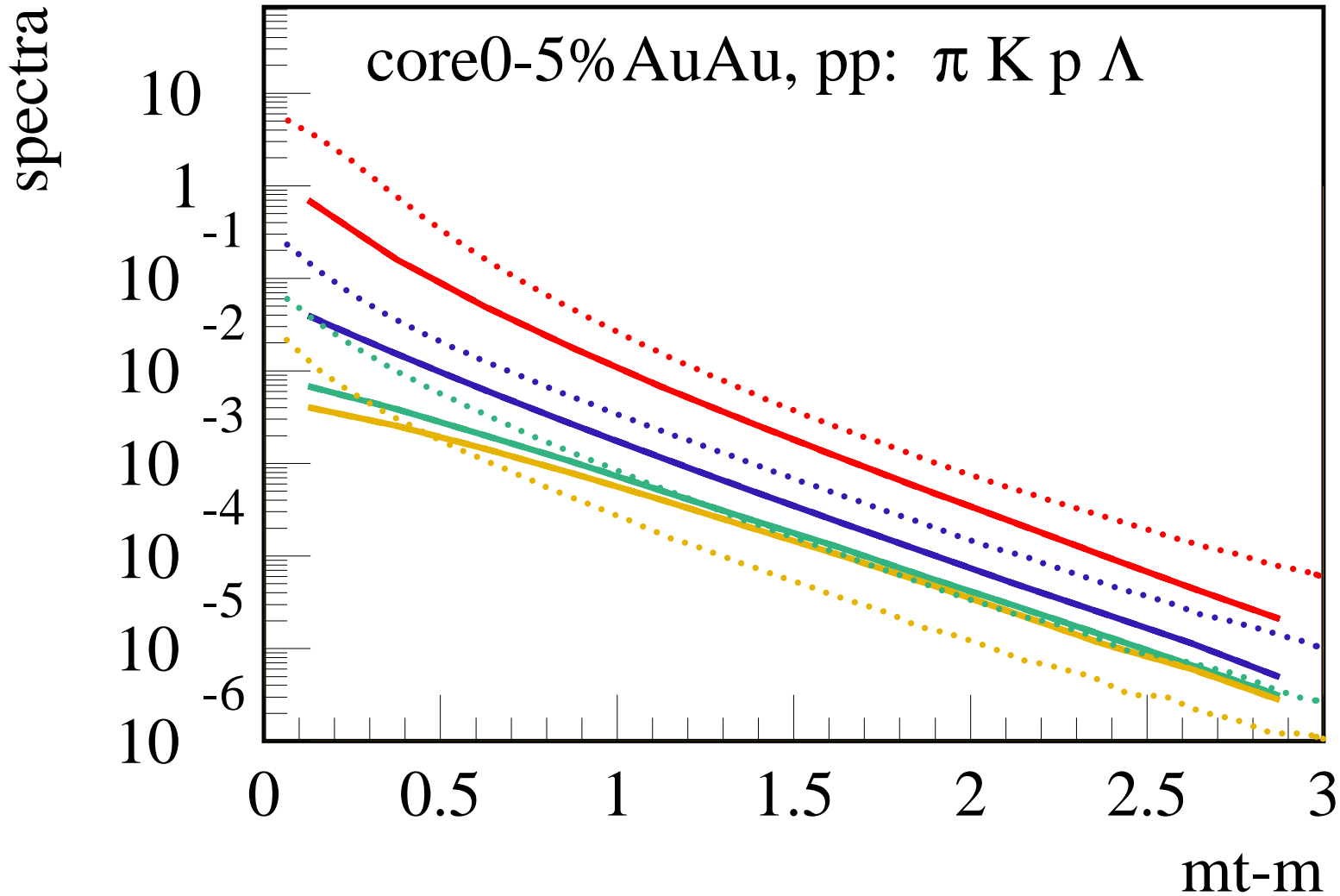
The whole procedure perfectly conserves energy, momentum, and flavors (microcanonical procedure).

The parameters:

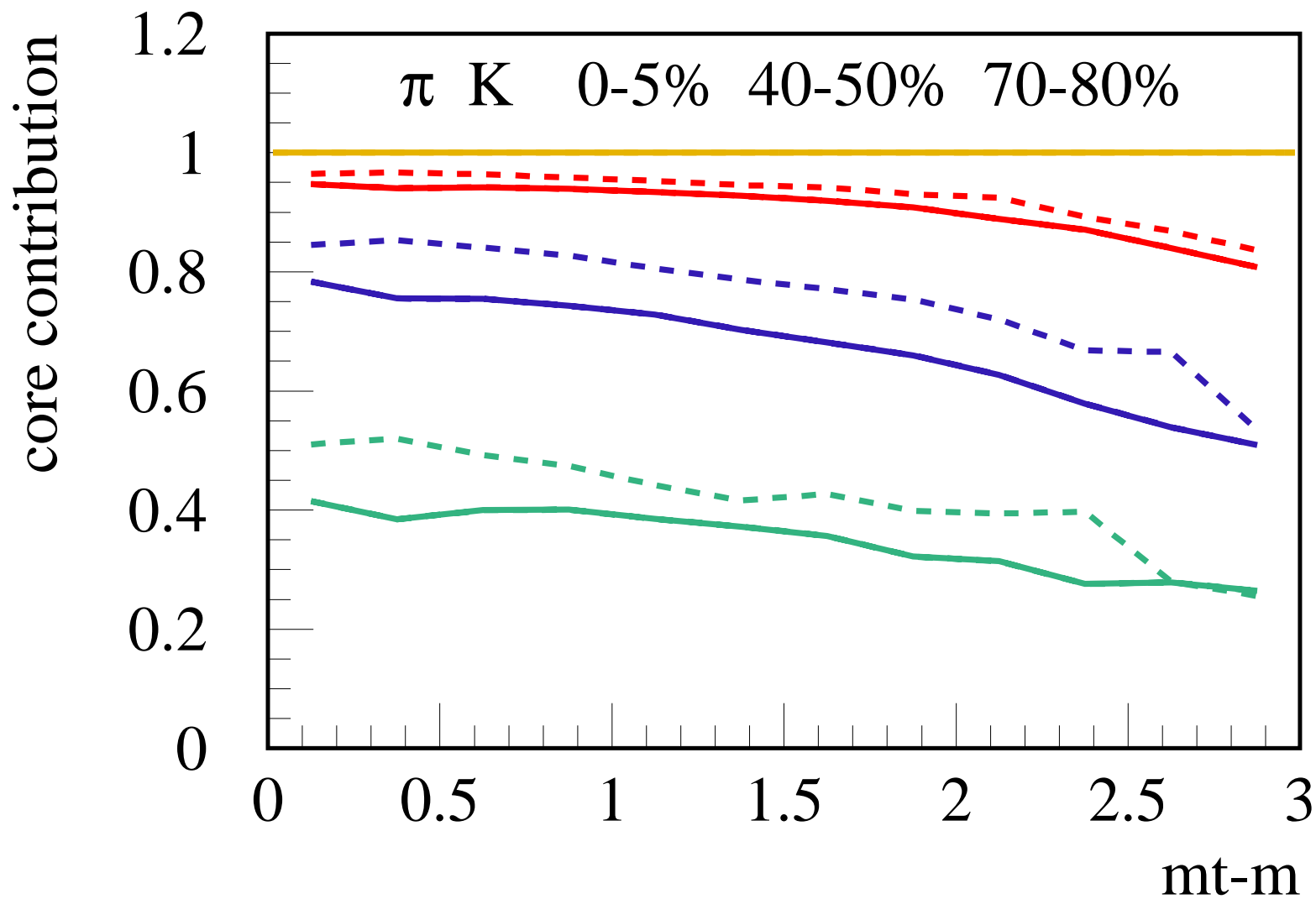
τ_0	1 fm	core formation time
ρ_0	1 / fm ³	core formation density
$\varepsilon_{\text{hadr}}$	0.22 GeV/fm ³	hadronization energy density
y_{rad}	0.83	maximal radial flow rapidity
f_{ecc}	0.5	eccentricity coefficient
γ_s	1.3	hadronization factor

Results depend very little on τ_0 and ρ_0 (if changed in a “reasonable” range) and not too much on γ_s .

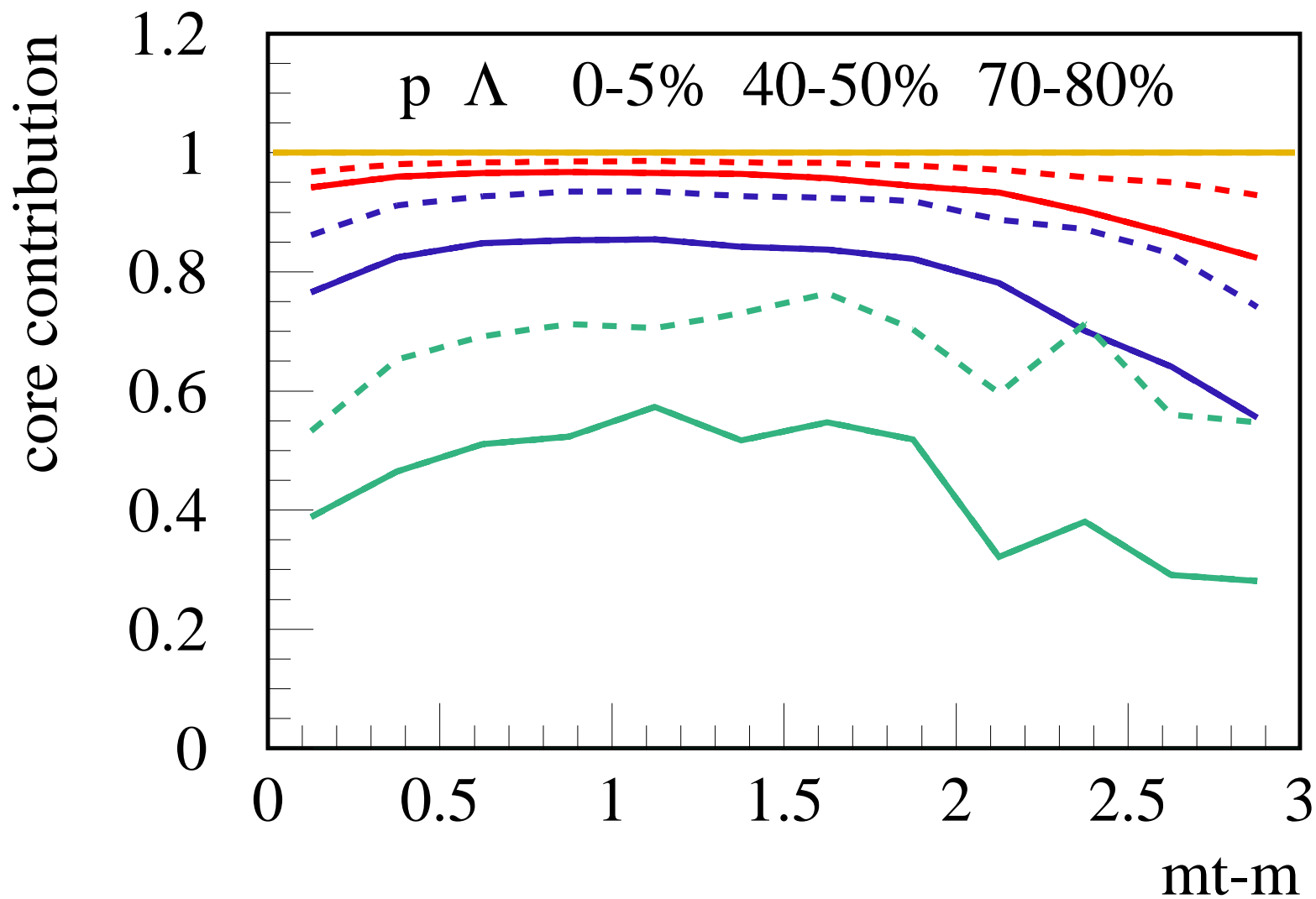
Comparison core(AuAu@200GeV) with pp (which is very similar to the corona contribution)



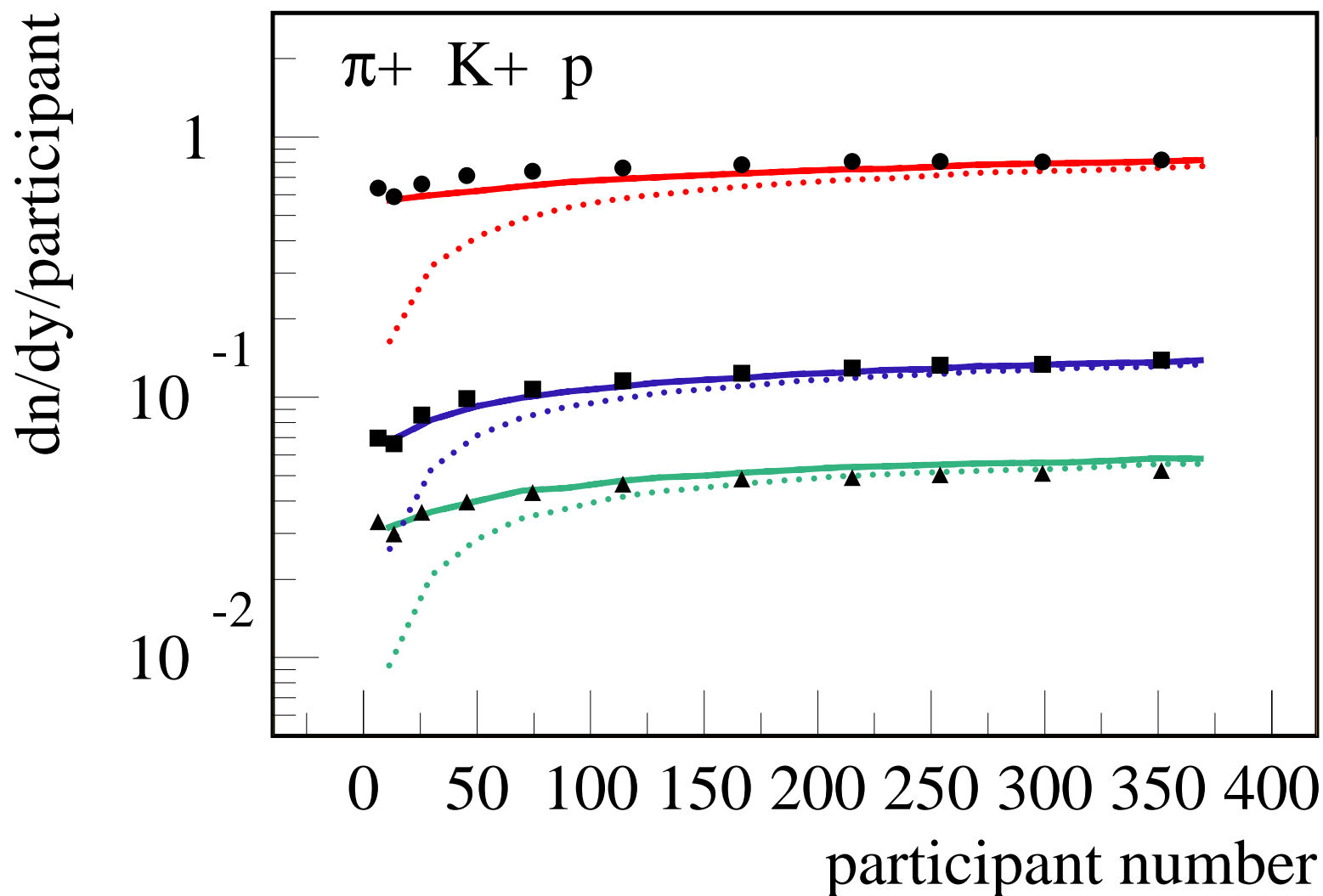
The relative contribution of the core (core/(core+corona))



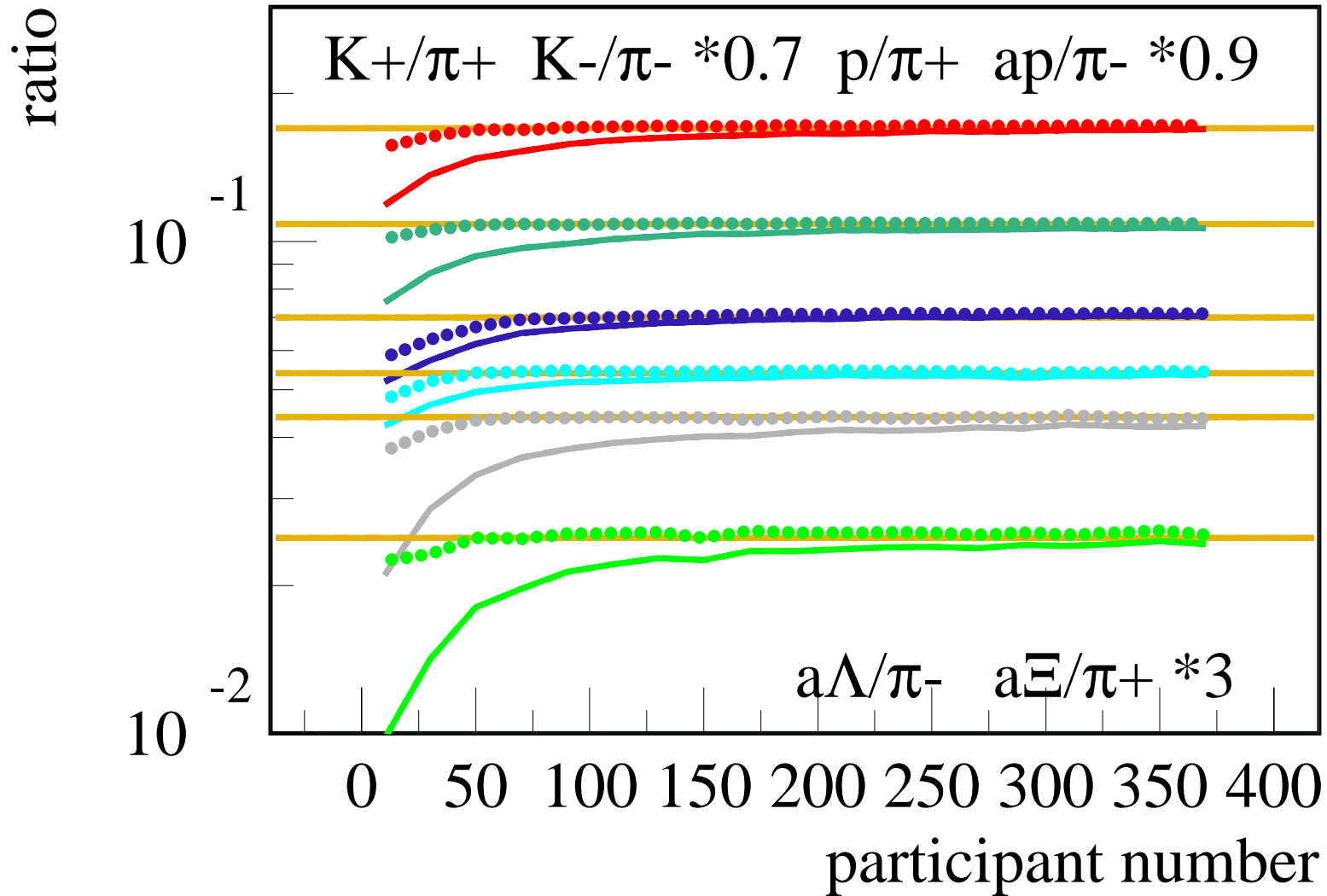
The relative contribution of the core (core/(core+corona))



Rapidity density dn/dy per participant as a function of the number of participants, for π^+ (red), K^+ (blue), and p (green). Dotted: core.



Particle ratios as a function of the number of participants. Solid line: all(core+corona). Dotted: core.



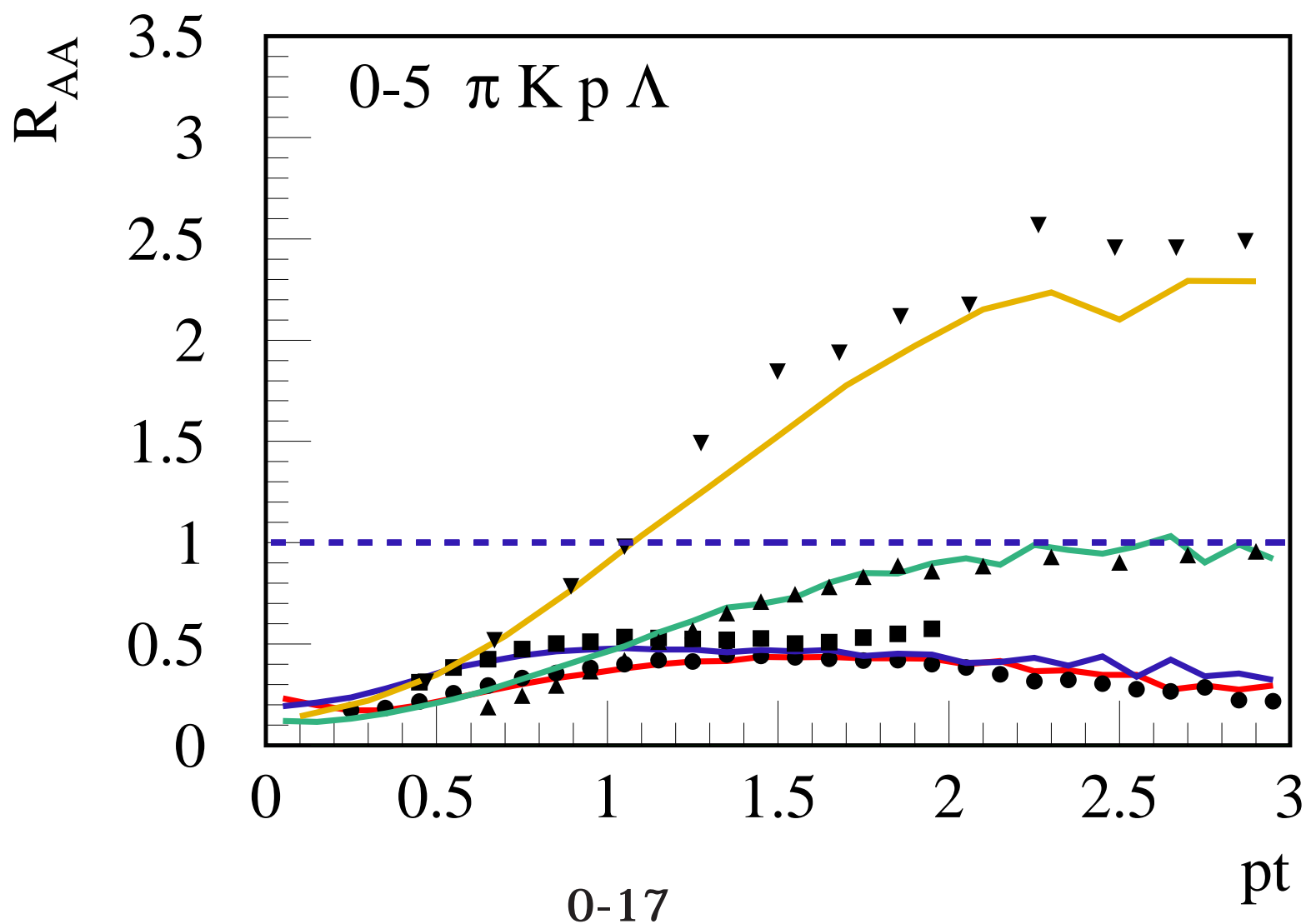
First conclusion:

after subtracting the “corona background”, the interesting part, the core contribution, shows an extremely simple behavior:

- there is no centrality dependence, the systems are simply changing in size**

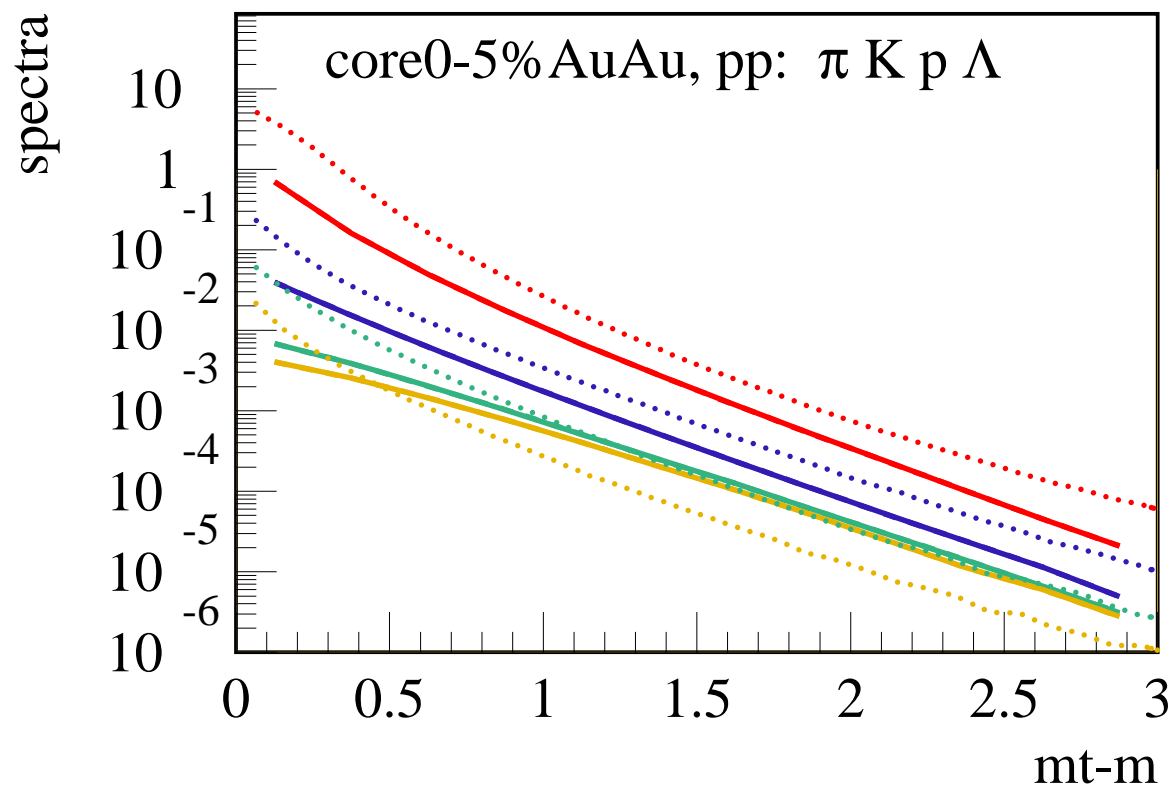
... and the participant number is certainly not a good measure of the volume of the core part, this is why the overall multiplicities per participant decrease with decreasing centrality.

Nuclear modification factors in central AuAu collisions at 200 GeV. pions (red; circles), kaons (blue; squares), protons (green; triangles), and lambdas (yellow; inverted triangles)



MNF(central coll)
 $\approx \text{core} / \text{pp} / N_{\text{coll}}$.

So compare (again)
core - pp :



So what we observe here, is nothing but the very different behavior of statistical hadronization (plus flow) on one hand, and string fragmentation on the other hand.

The suppression of pions here is not at all affected by parton energy loss (on has to look at di-hadron correlations to see it).

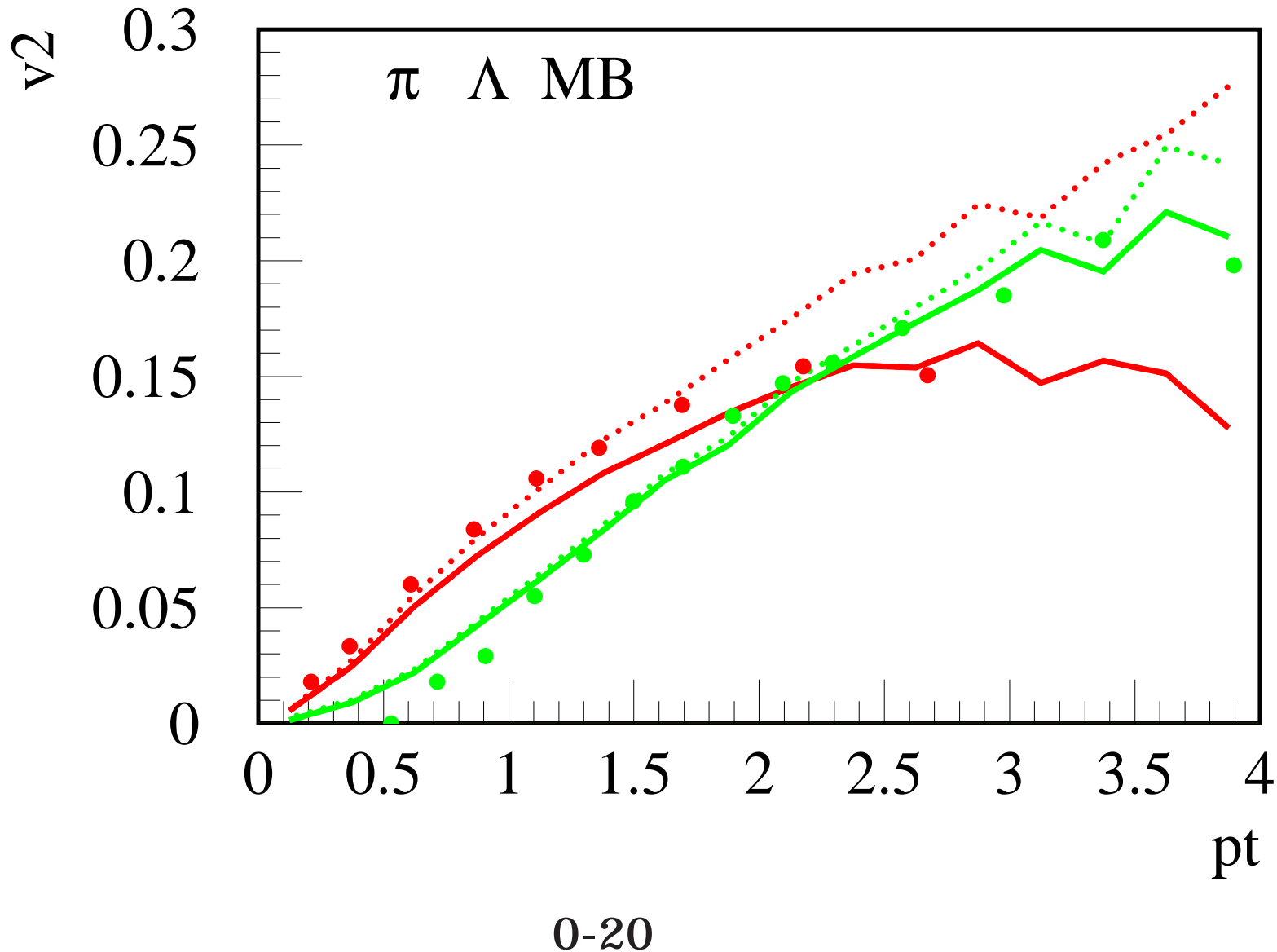
The R_{cp} modification factors (central over peripheral) are much less extreme than R_{AA} , since peripheral AuAu collisions are a mixture of core and corona (the latter one being pp-like),

so a big part of the effect seen in R_{AA} is simply washed out (therefore better take R_{AA} ...).

Elliptical flow in MB AuAu collisions at 200 GeV.

pions (red) and lambdas (green). data: PHENIX/STAR

Full lines: core + corona; dotted lines: core



The pion curve seems to saturate at high p_t , which is here simply due to the fact that with increasing p_t the continuously increasing core curve is more and more “contaminated” by corona contributions.

For the lambdas, the effect is much smaller, since the corona contributions are smaller.

Eventually, the lambda curve will also saturate, but at larger p_t .

What about quark-scaling???

To summarize:

we have discussed the influence of the corona contribution (originating from the periphery of nuclear collisions) in AuAu collisions at RHIC.

Our analysis is based on a model which works excellently for pp and pA, together with a very simple parameterization of the central (core) part.

The fact that this simple treatment works, allows us to identify our core contribution with the “background subtracted data” (and this is what we are really interested in).

The core shows a very simple behavior !

For example, contrary to the general believe, there seems to be no centrality dependence of particle production, just the volume changes.

We do not make any attempt here to explain these very interesting data, the only purpose here is to separate the interesting part (core) from the contamination (corona).

We also did not make any efforts to optimize the fits, actually most parameters are essentially first guesses.

Future: check more systems, more observables.