Nuclear Surface Effects in Heavy Ion Collision at RHIC and SPS [1]

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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 and SPS heavy-ion data.

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

[1] hep-ph/0603064 hep-ph/0603195

Surface effect in nuclear collisions:

- **The "surface 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 pA (dAu) collisions at RHIC and SPS .**

- **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 (“background subtraction”).**

EPOS is a parton model, with many binary parton-parton interactions, each one creating a parton ladder.

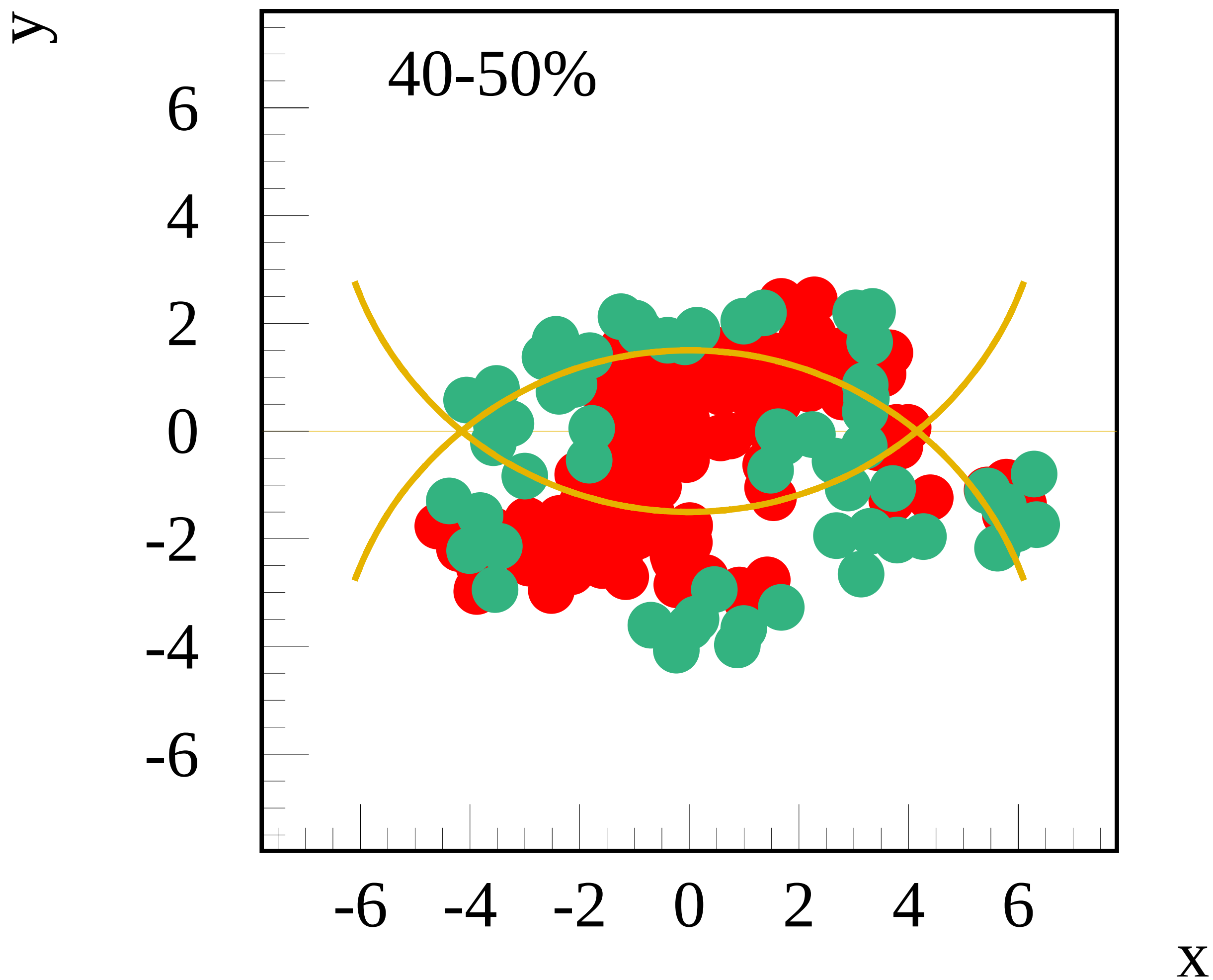
- **In certain regions: many parton ladders in parallel, impossible to hadronize independently** (hadronization: using string model)
- **We have a look at the situation at an early proper time τ_0, long before the hadrons are formed** $(\tau_0 = 1\,\mathrm{fm})$**: We distinguish between string segments in dense areas (more than ρ_0 segments per unit proper volume), from those in low density areas** $(\rho_0 = 1\,\mathrm{fm}^{-3})$**.**

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

Semi-peripheral AuAu@200GeV

longitudinal slice ± 0.8 fm

randomly chosen event



Semi-peripheral AuAu@200GeV

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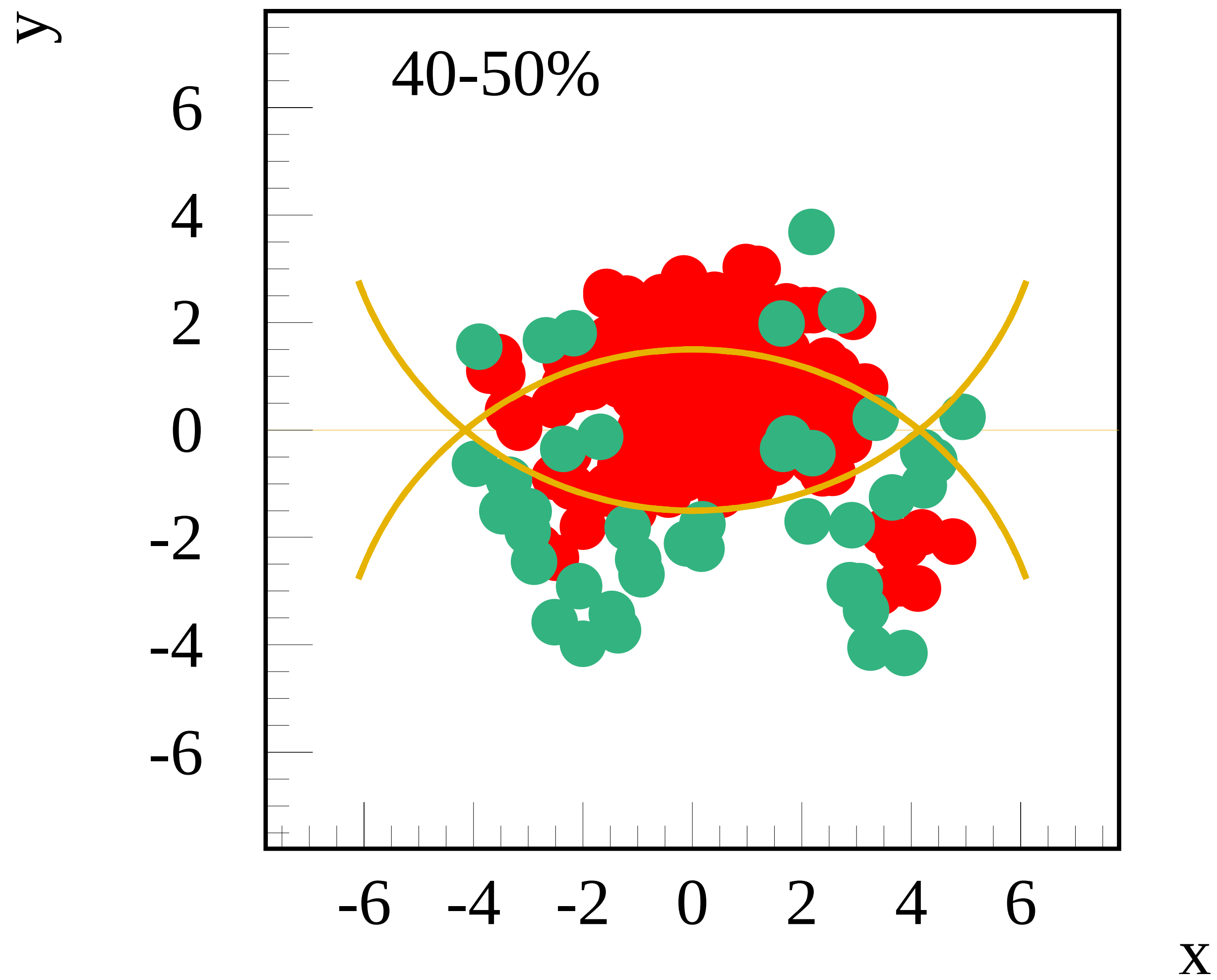


Clusters are considered to be collectively expanding: Bjorken-like in longitudinal direction, with in addition some transverse expansion.

- ☐ **We assume that the clusters hadronize at some given energy density $\varepsilon_{\mathrm{hadr}}$, 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 $1+\epsilon\, f_{\mathrm{ecc}}$ and $1-\epsilon\, f_{\mathrm{ecc}}$, 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 (RHIC):

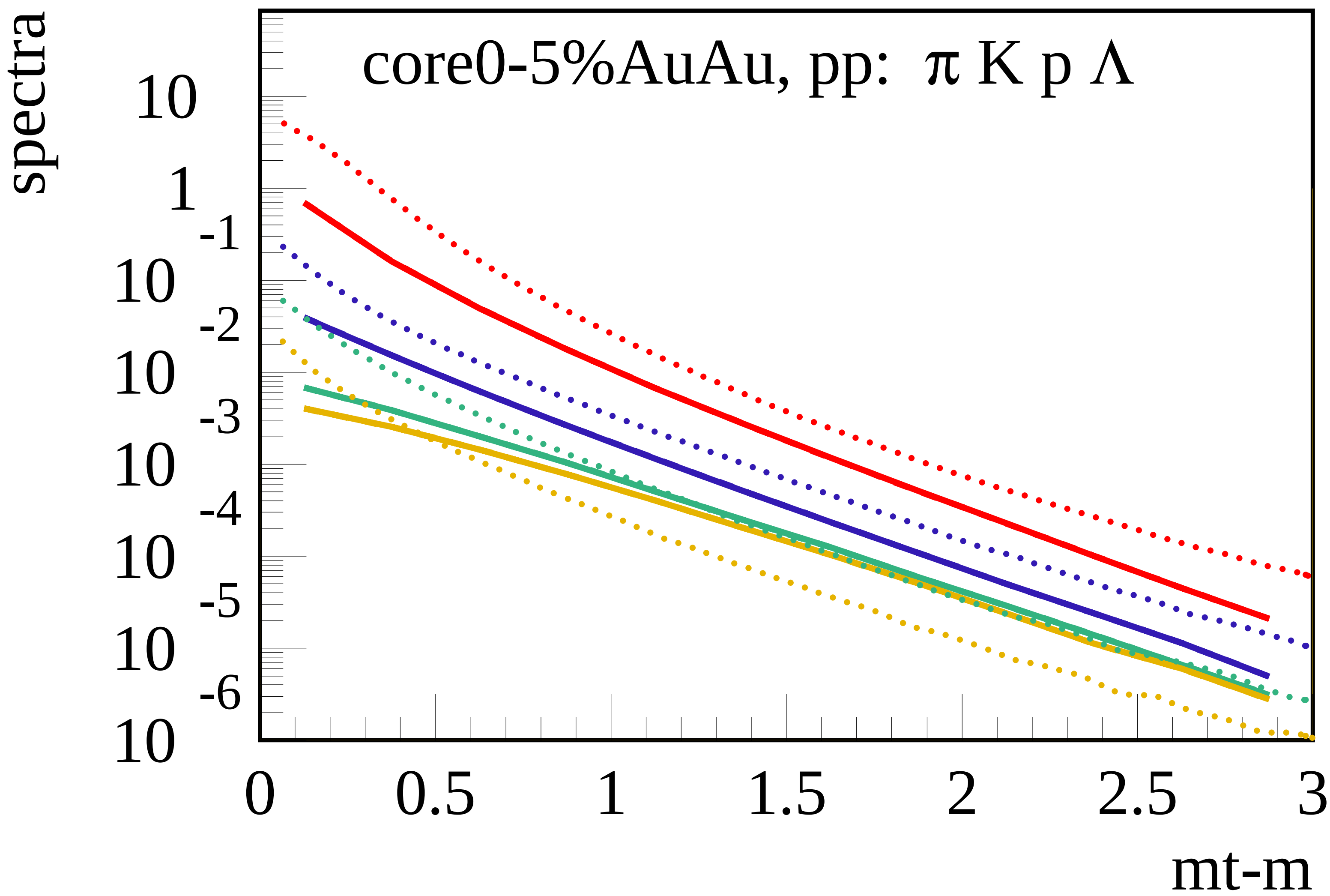
τ_0	1 fm	core formation time
ρ_0	1 / fm^3	core formation density
$\varepsilon_{\rm hadr}$	0.22 GeV/fm^3	hadronization energy density
$y_{\rm rad}$	0.83	maximal radial flow rapidity
$f_{\rm ecc}$	0.5	eccentricity coefficient
γ_s	1.3	hadronization factor

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

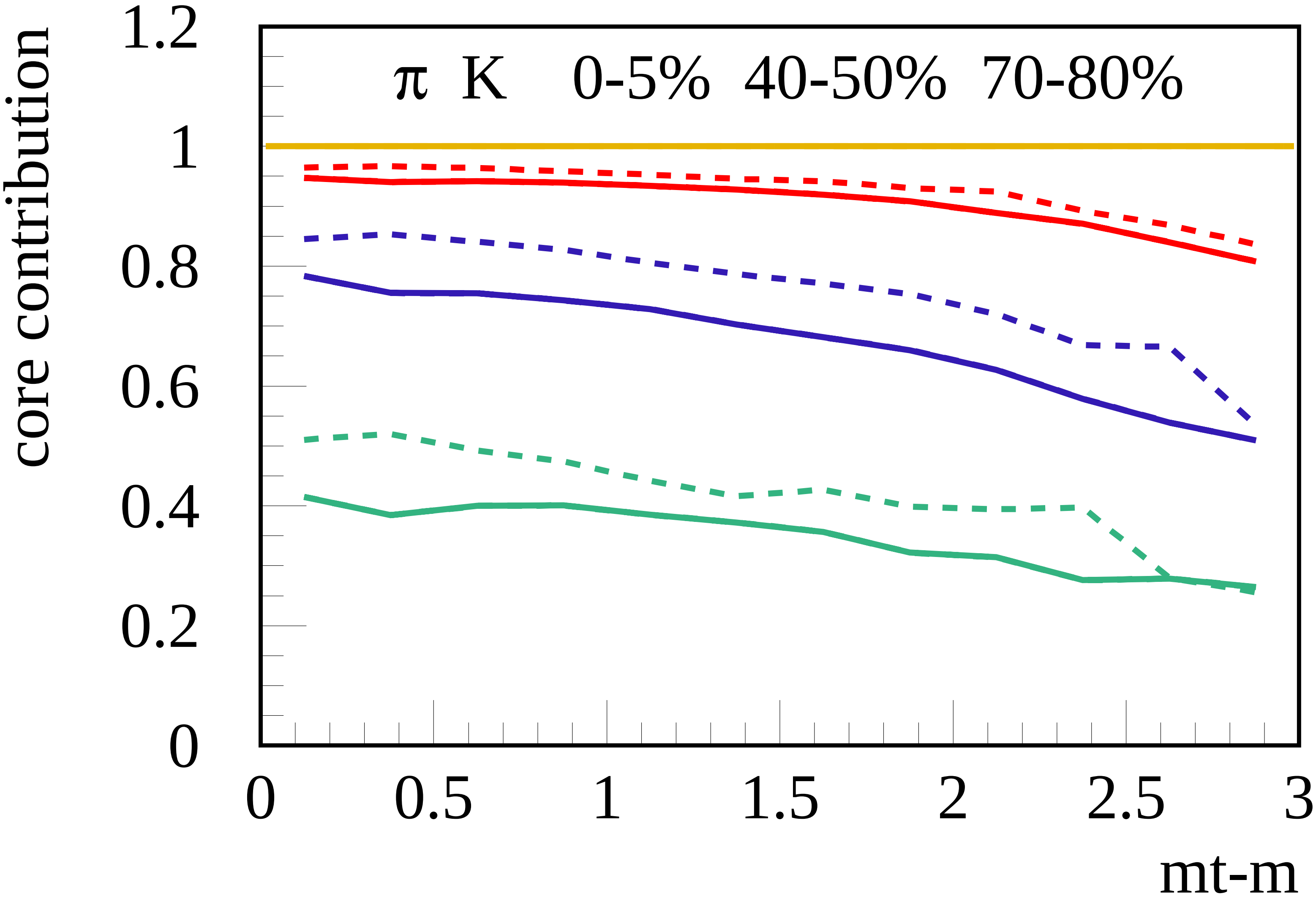
SPS: core parameterized in exactly the same way as at RHIC, with one exception: less flow ($y_{\rm rad} = 0.6$).

So there is one free parameter available to account for ALL low / intermediate pt results at the SPS!

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

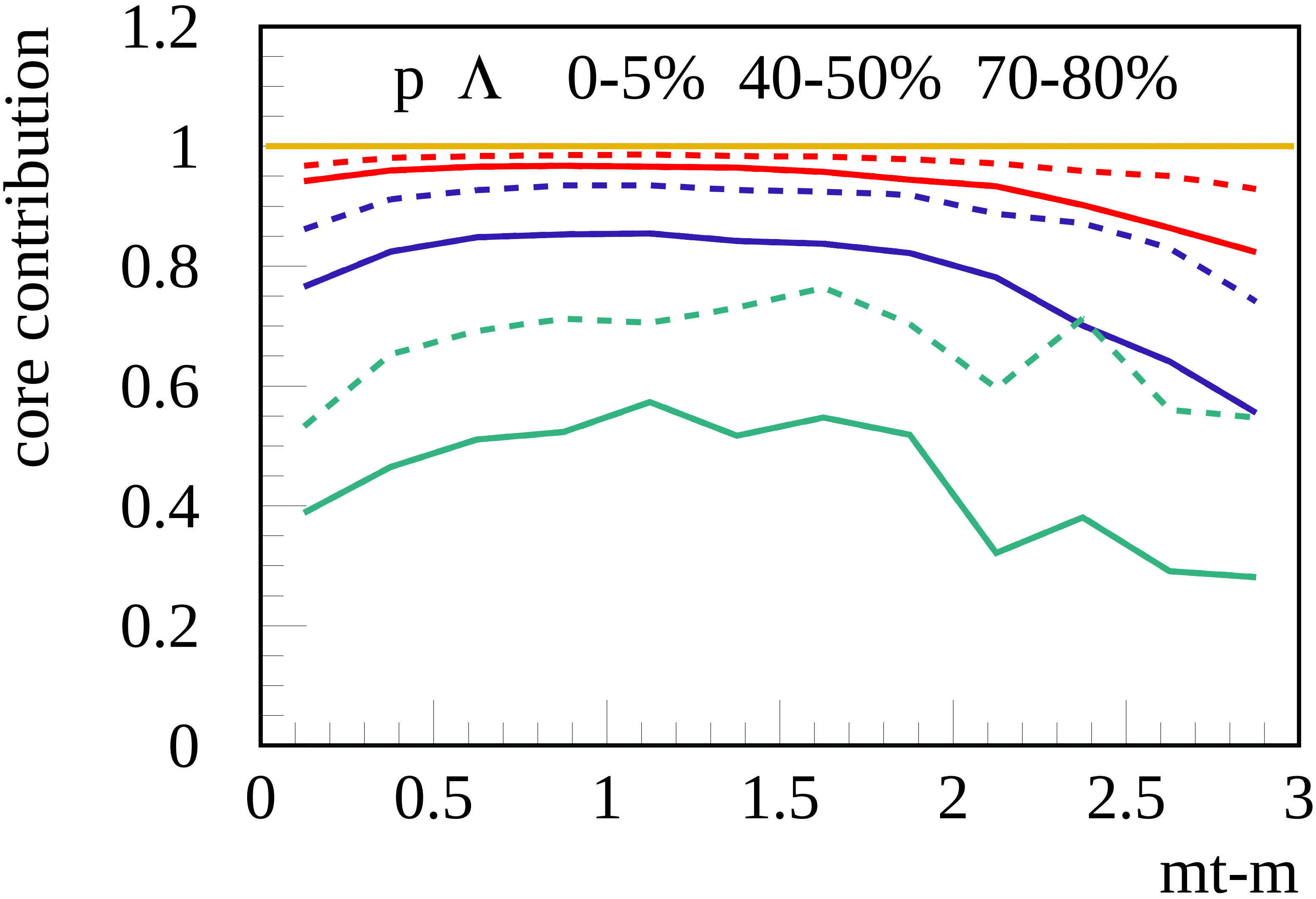


The relative contribution of the core (core/(core+corona)) (SPS results similar)



0-10

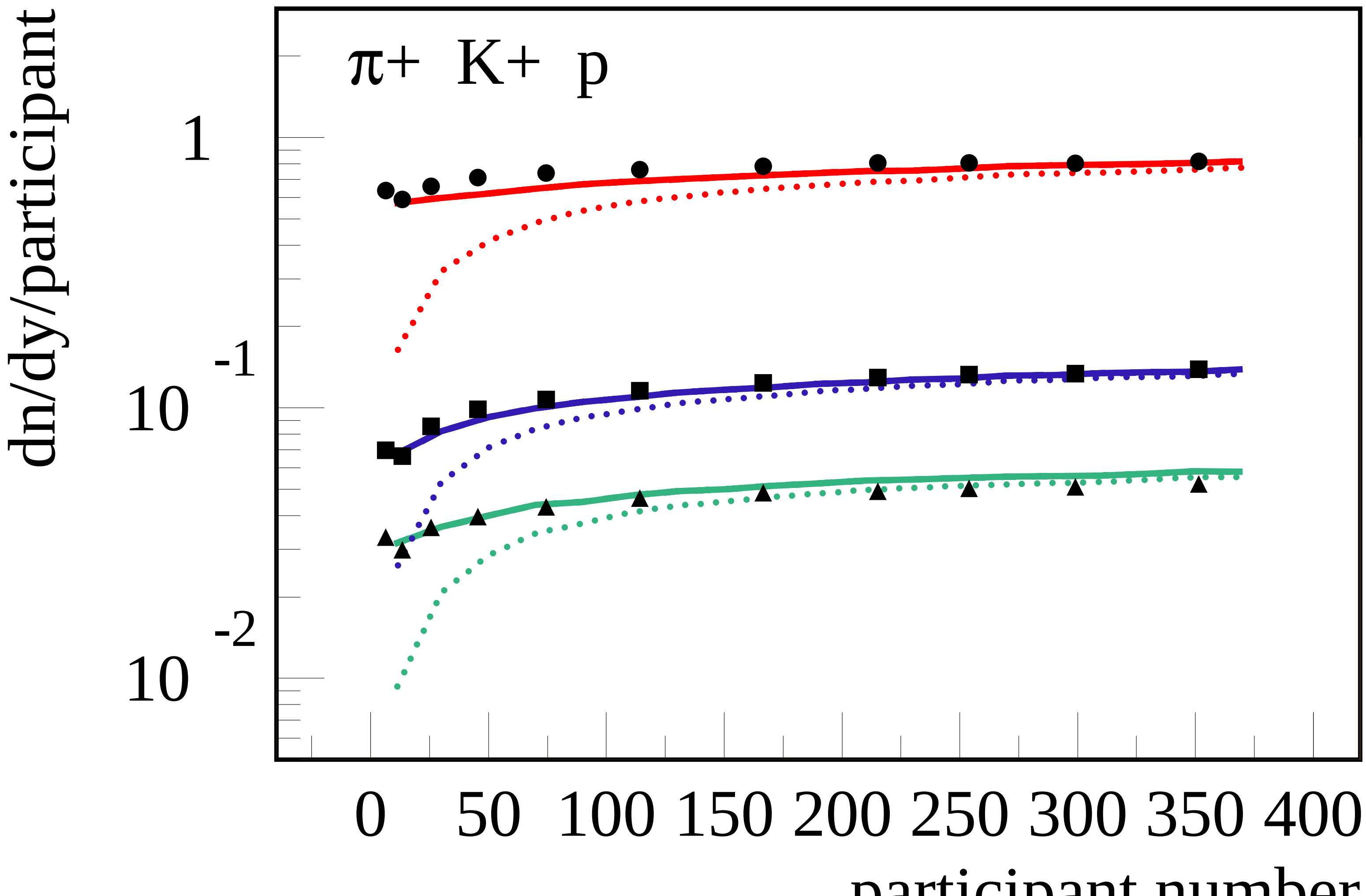
The relative contribution of the core (core/(core+corona)) (SPS results similar)



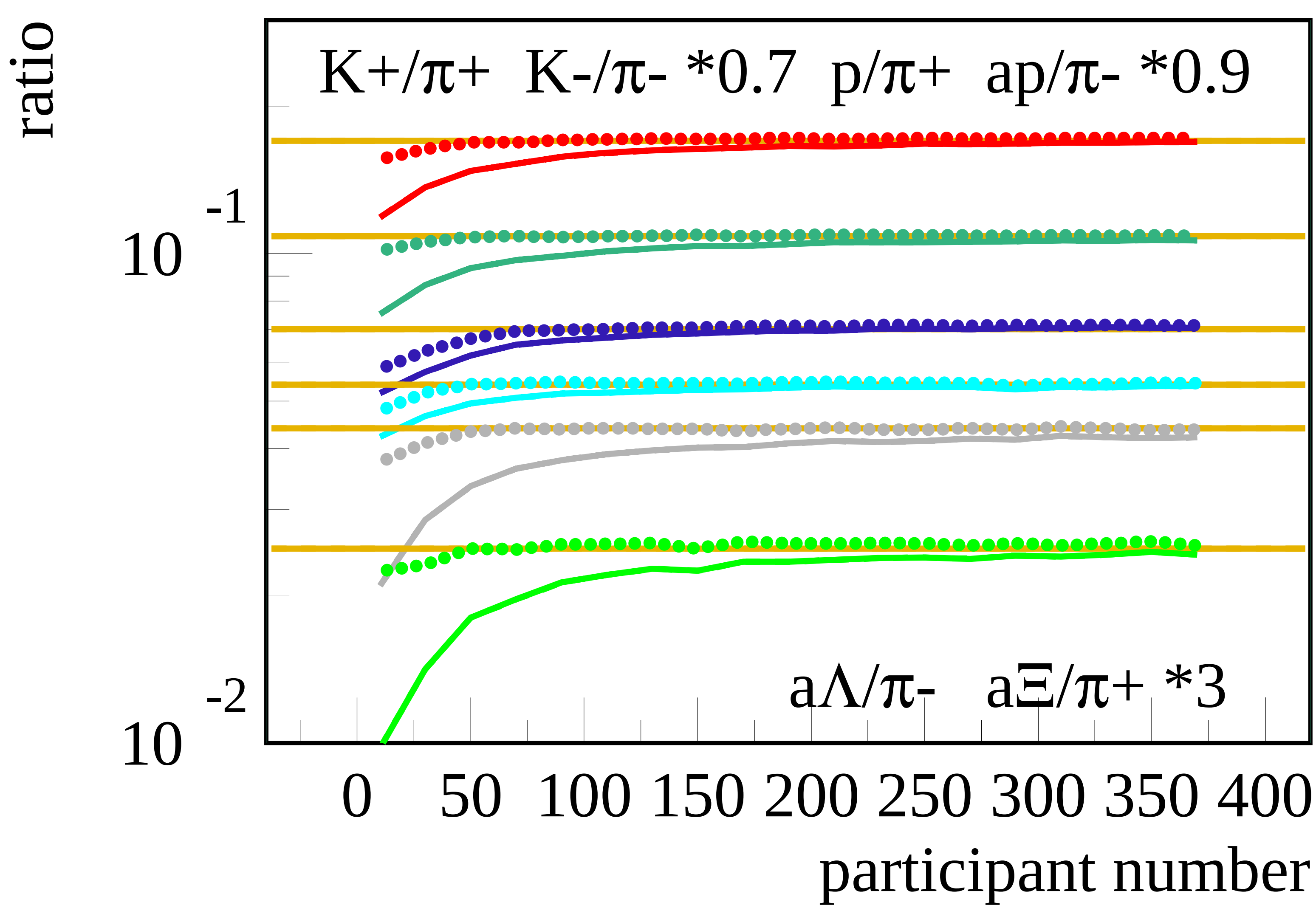
Centrality dependence

of hadron yields

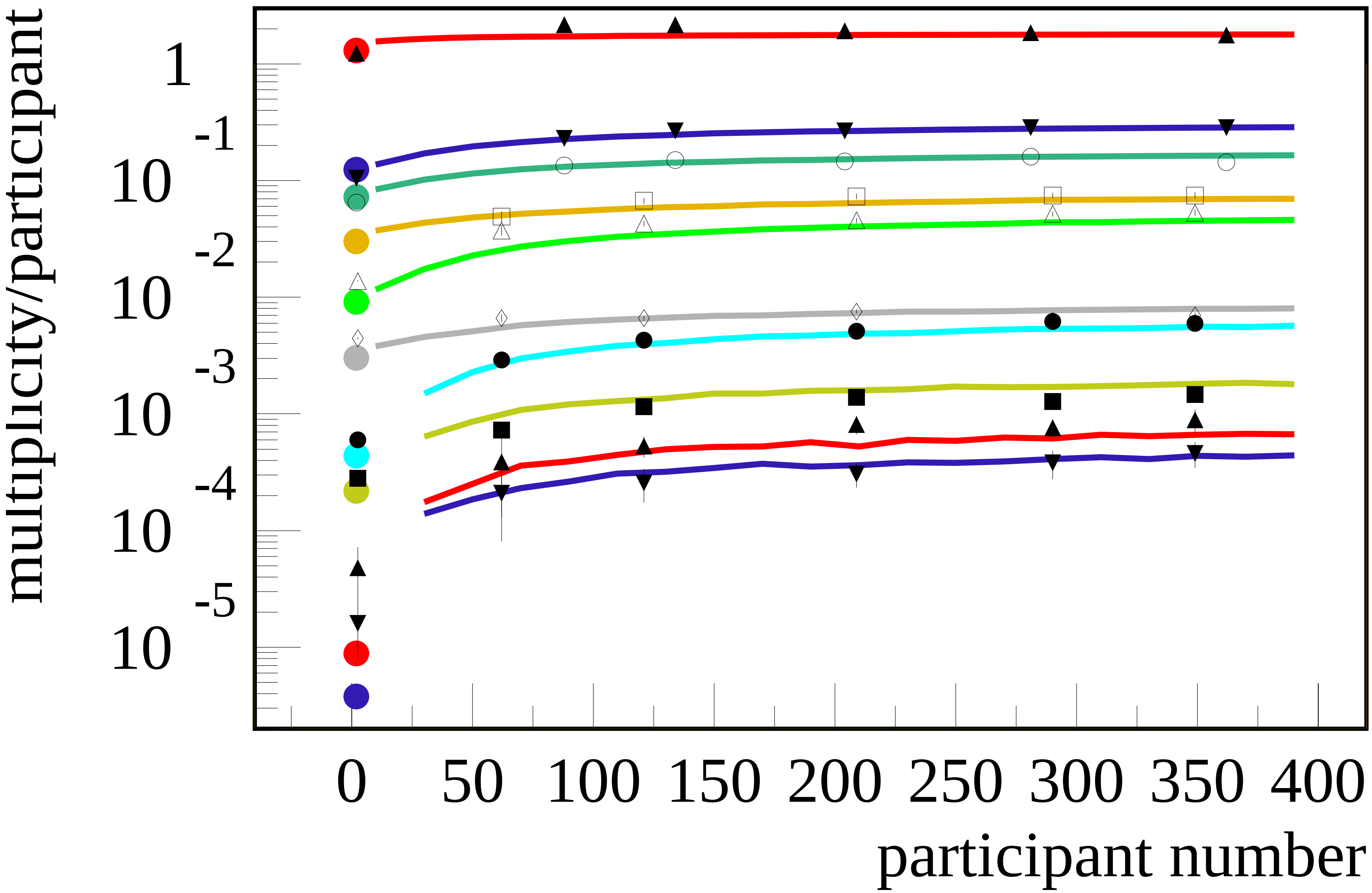
Rapidity density dn/dy per participant as a function of the number of participants, at RHIC AuAu200, for π^+, K^+, p . Dotted: core.



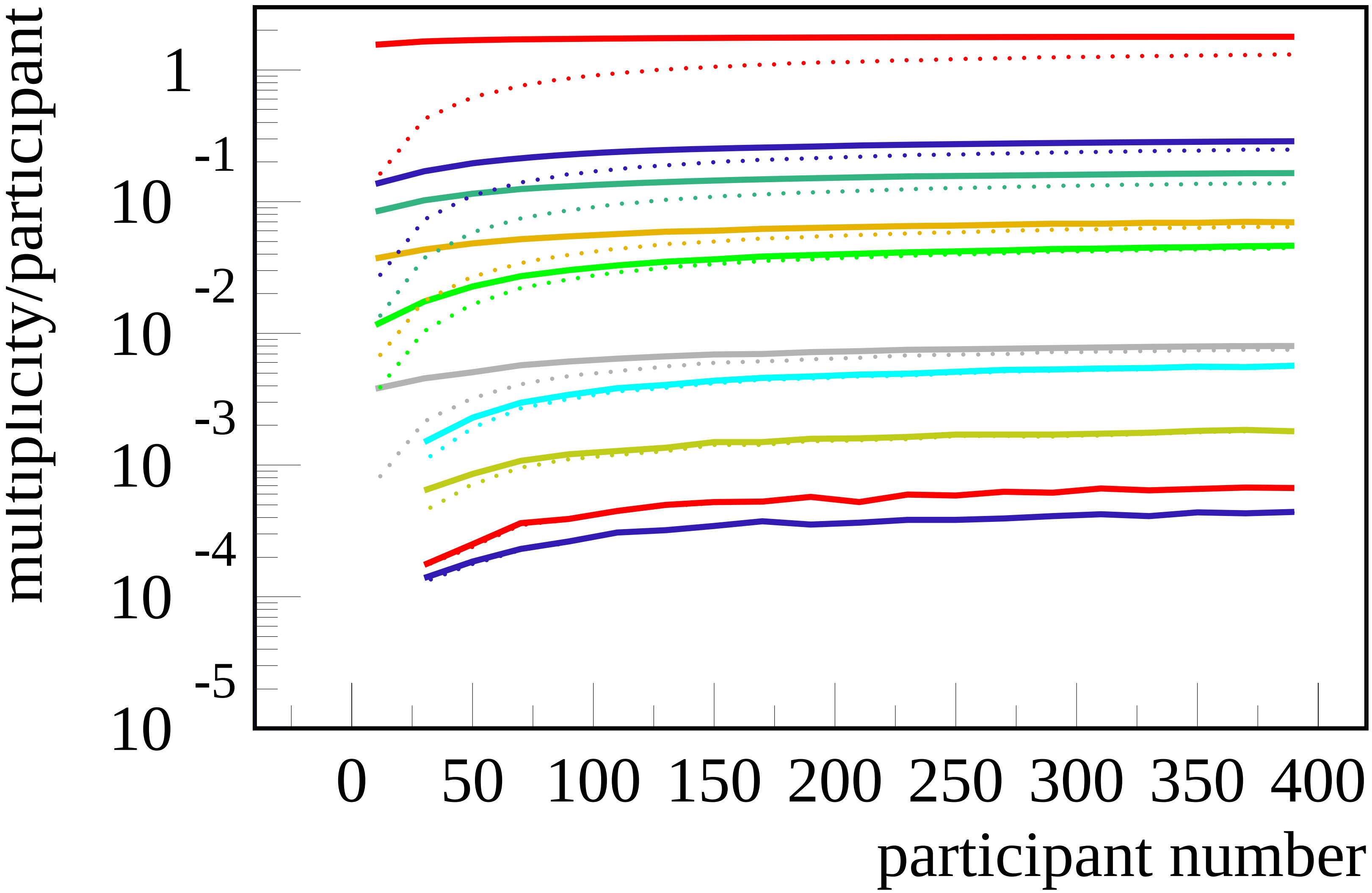
Particle ratios as a function of the number of participants. Solid line: all(core+corona). Dotted: core.



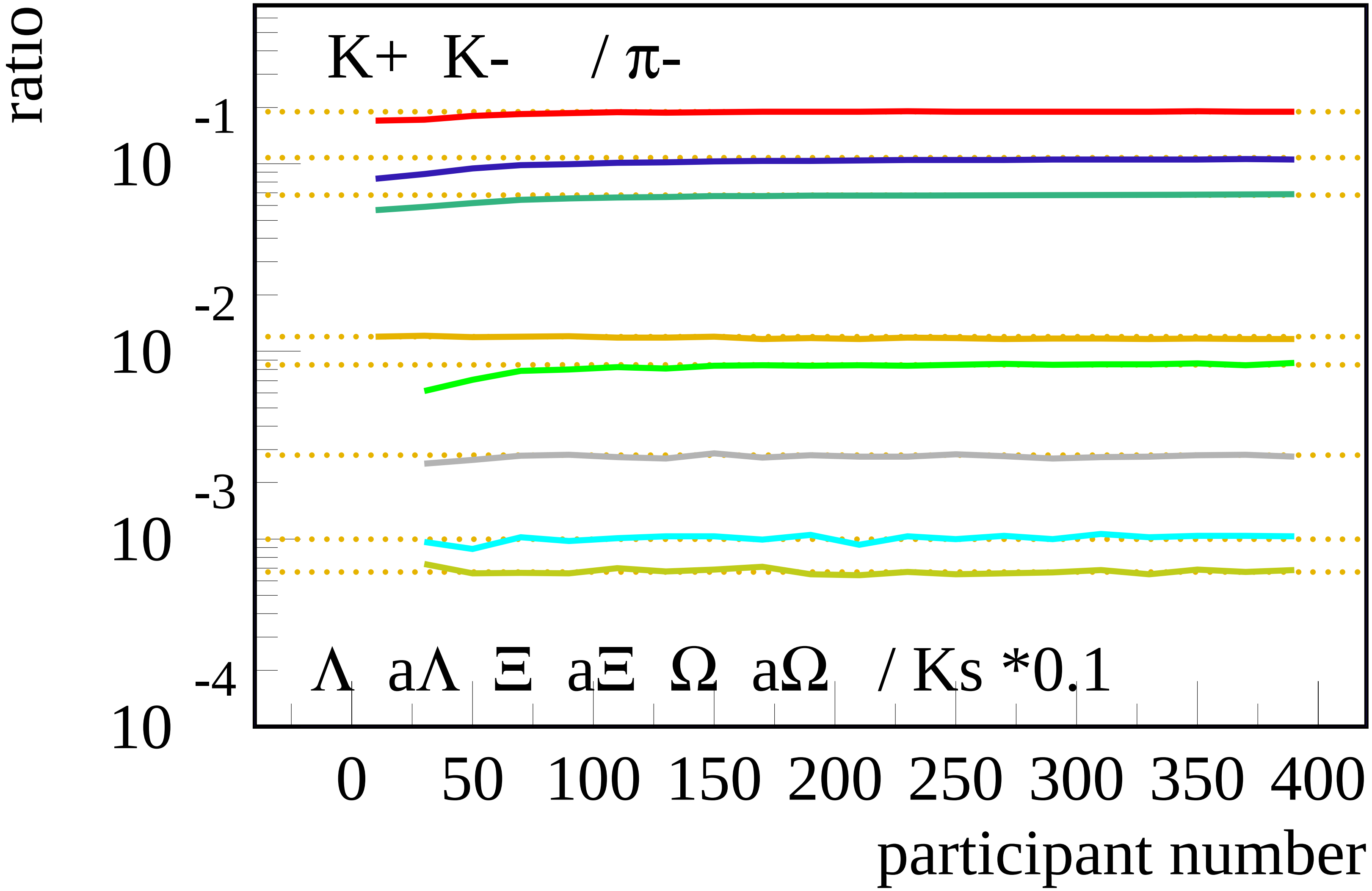
Yields per participant as a function of the number of participants, at the SPS, for π^-, K^+, K^-, K_s, Λ, $\bar{\Lambda}$, Ξ, $\bar{\Xi}$, Ω, $\bar{\Omega}$.



... comparing full calculation and just core (dotted)



... and ratios, just core



First conclusion (both RHIC and SPS):

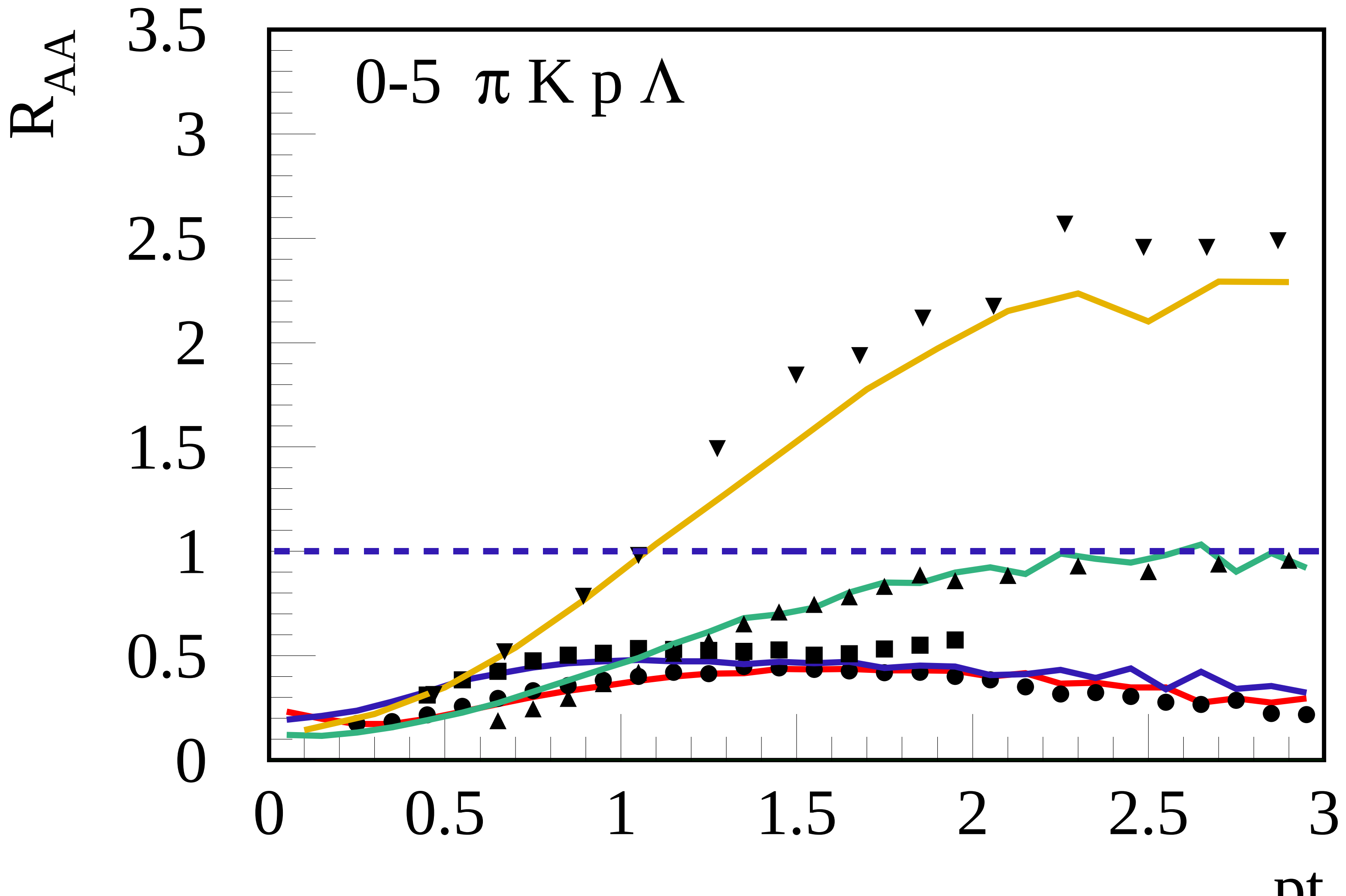
after subtracting the “corona background”, the interesting part, the core contribution, shows an extremely simple behavior:

- ☐ **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.

mt spectra

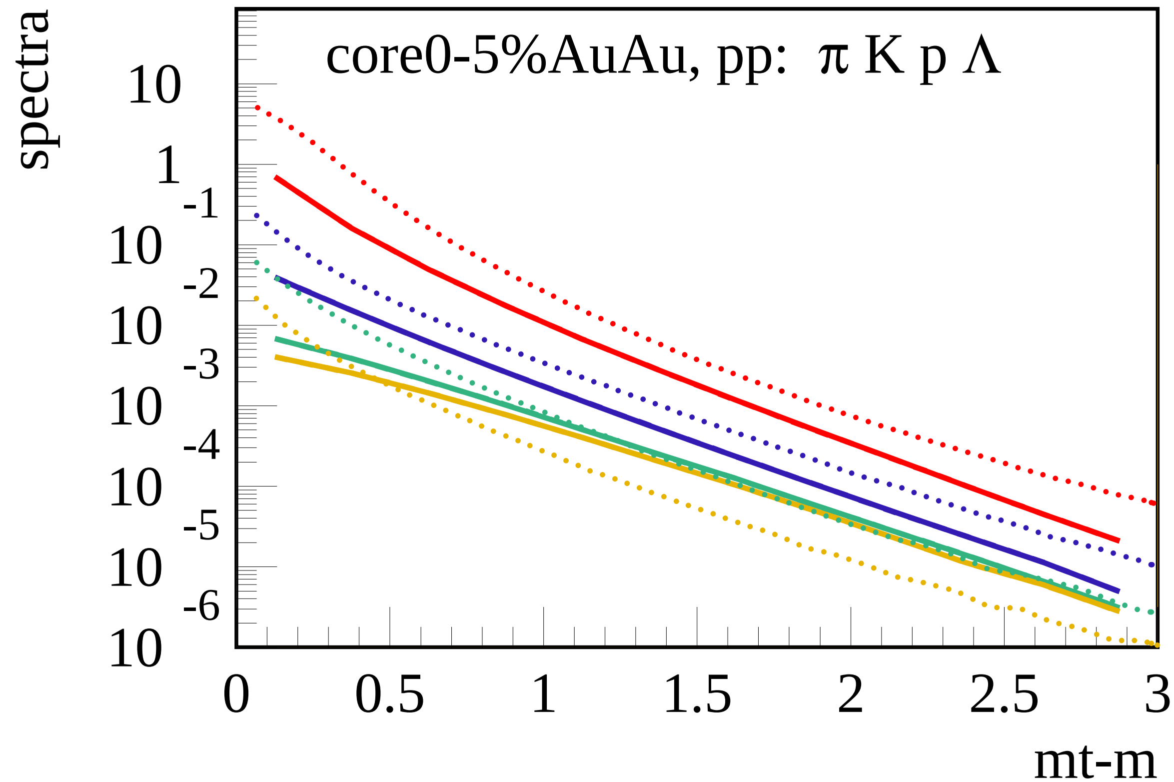
Nuclear modification factors in central AuAu collisions at 200 GeV. pions (red; circles), kaons (blue; squares), protons (green; triangles), and lambdas (yellow; inverted triangles)



0-20

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

Many SPS results checked:

rapidity and mt spectra for CC, SiSi, PbPb...

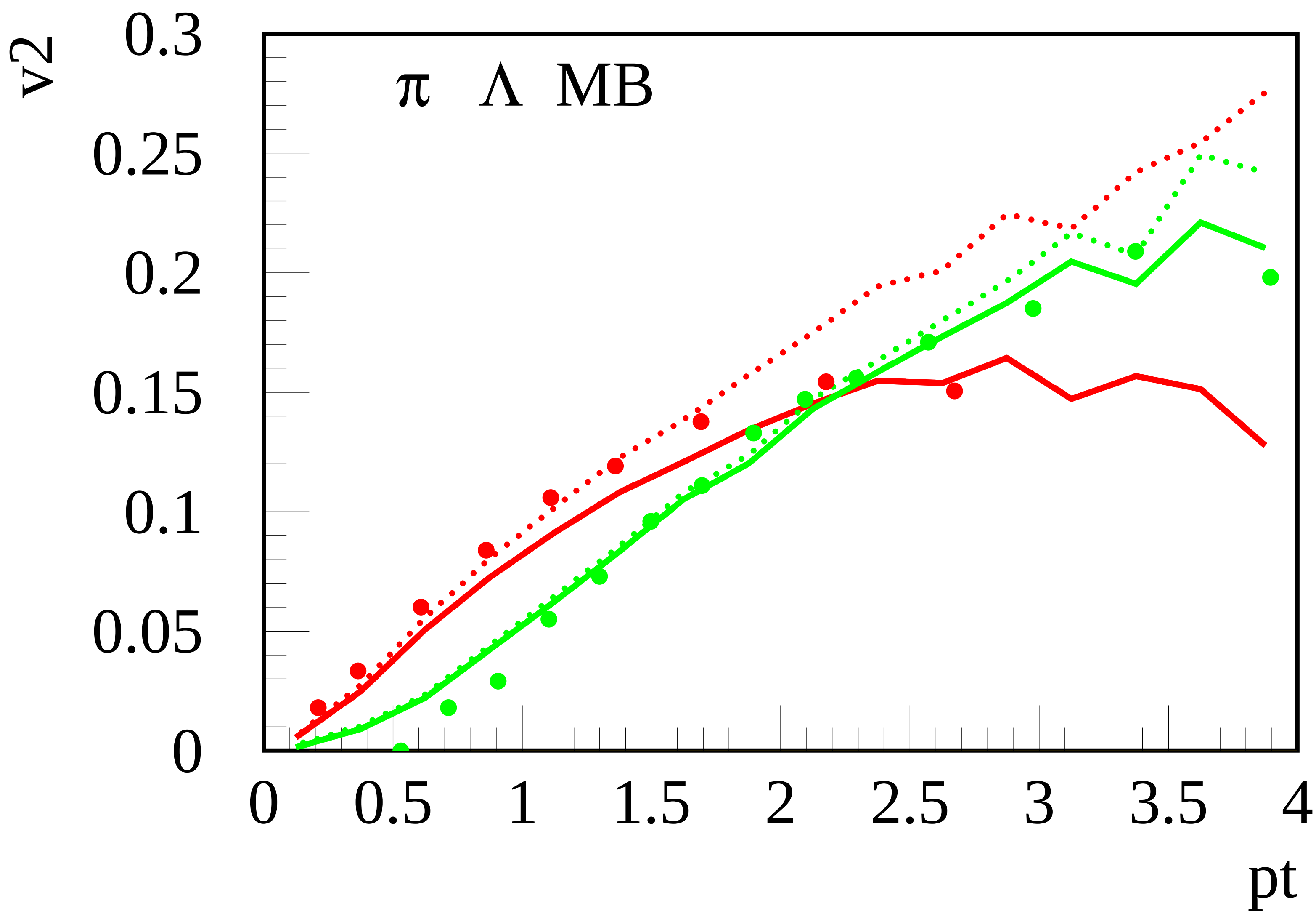
(see hep-ph/0603195)

Elliptical flow (RHIC)

Elliptical flow in MB AuAu collisions at 200 GeV.

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

Full lines: core + corona; dotted lines: core

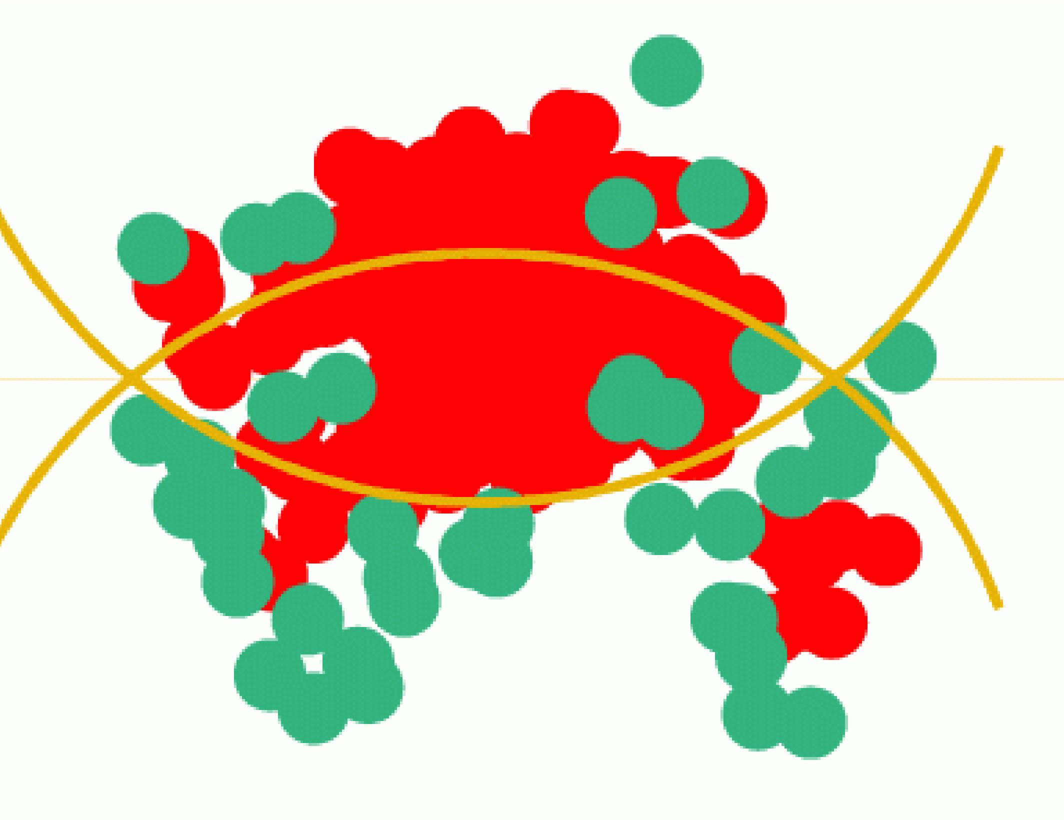


The pion curve seems to saturate at high p_t, which is here simply due to the fact that with increasing p_t the continuously increasing core curve is more and more "contaminated" by corona contributions.

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.

Summary



Nuclear diffuseness

$\Downarrow$

separation
core - corona

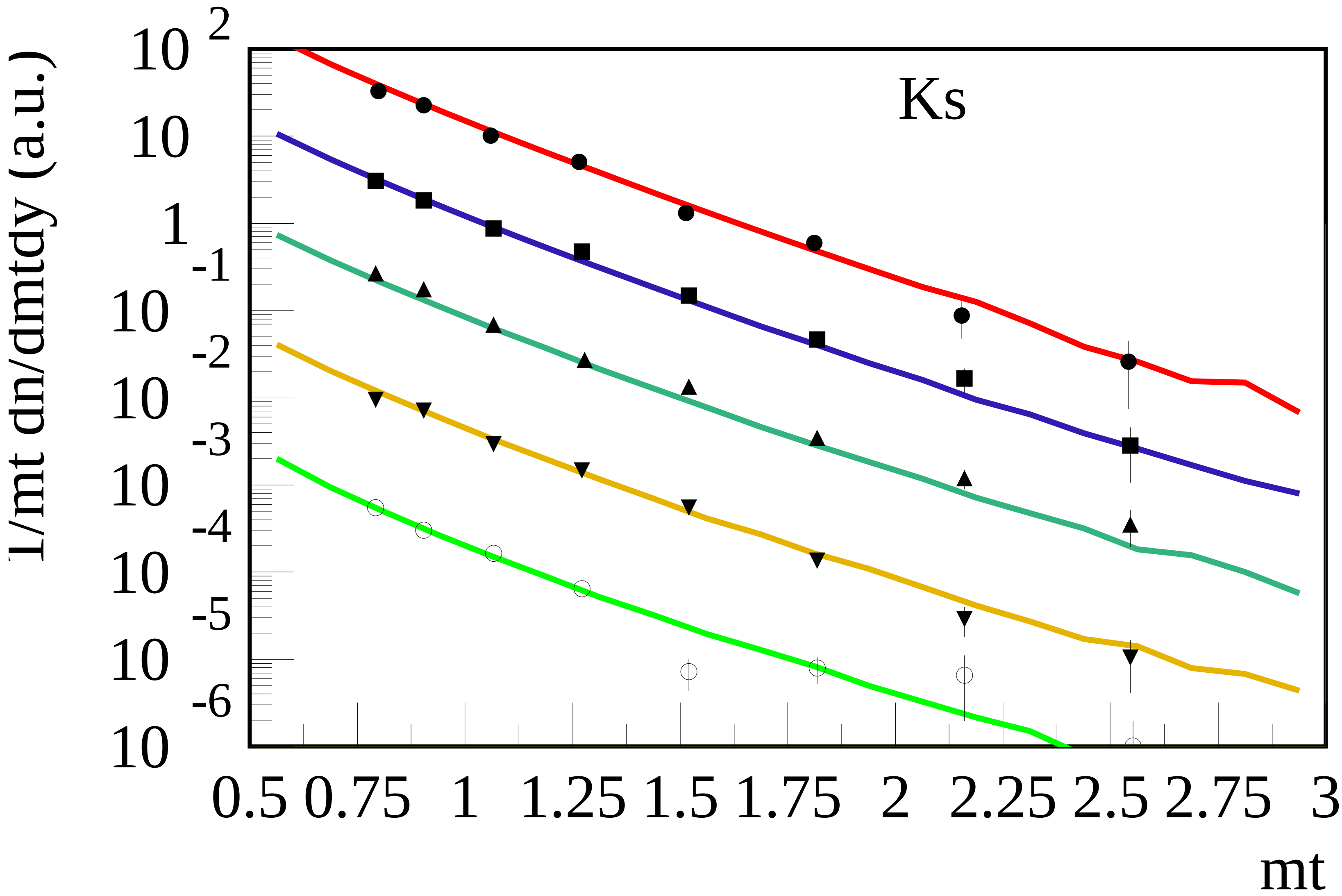
corona = background,
to be subtracted

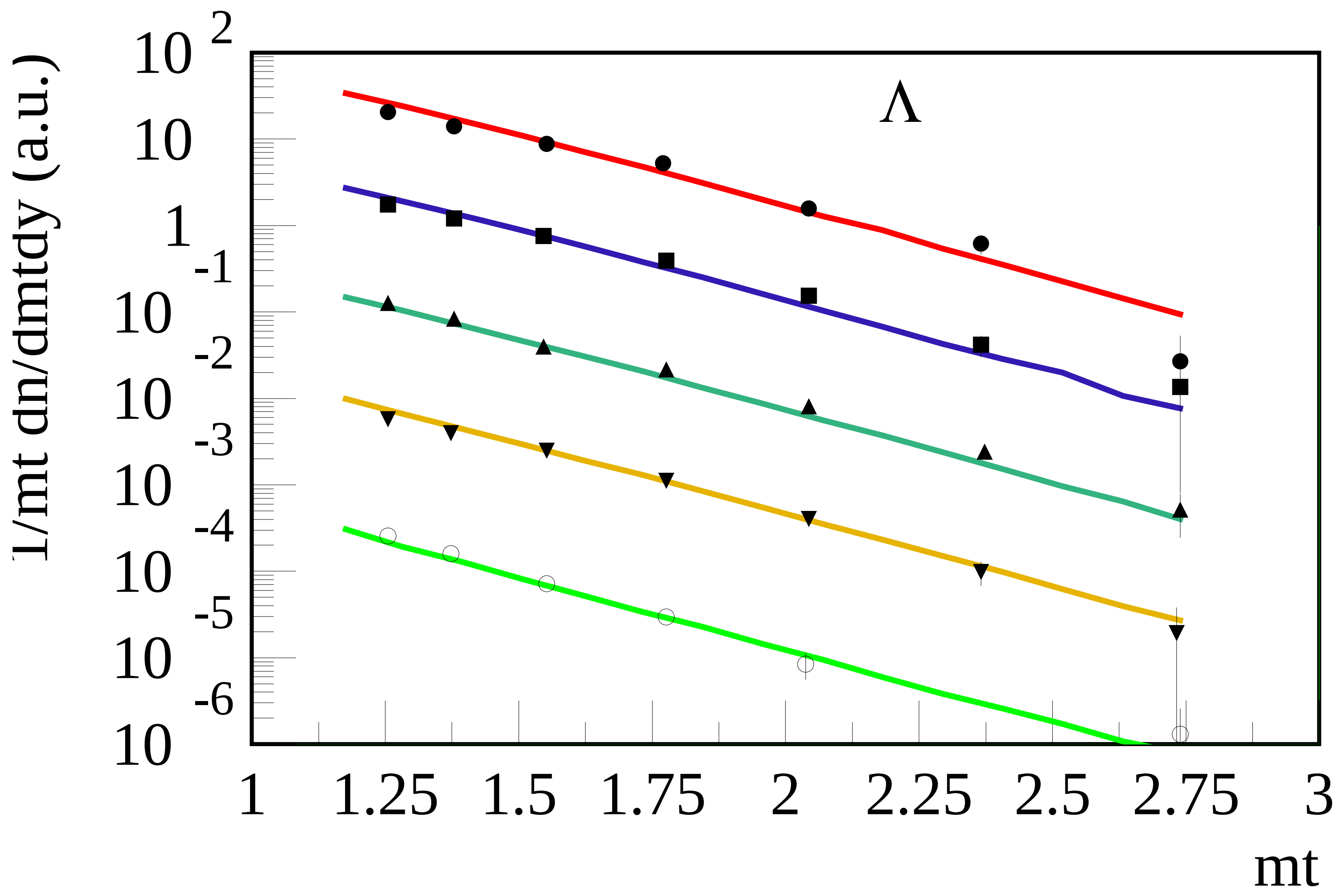
The core shows a very simple behavior !
core(SPS)=core(RHIC) apart of somewhat more flow at RHIC

Contrary to the general believe, there seems to be no centrality dependence of particle production, just the volume changes. True at RHIC and SPS!
(so corona subtraction is essential to understand centrality systematics)

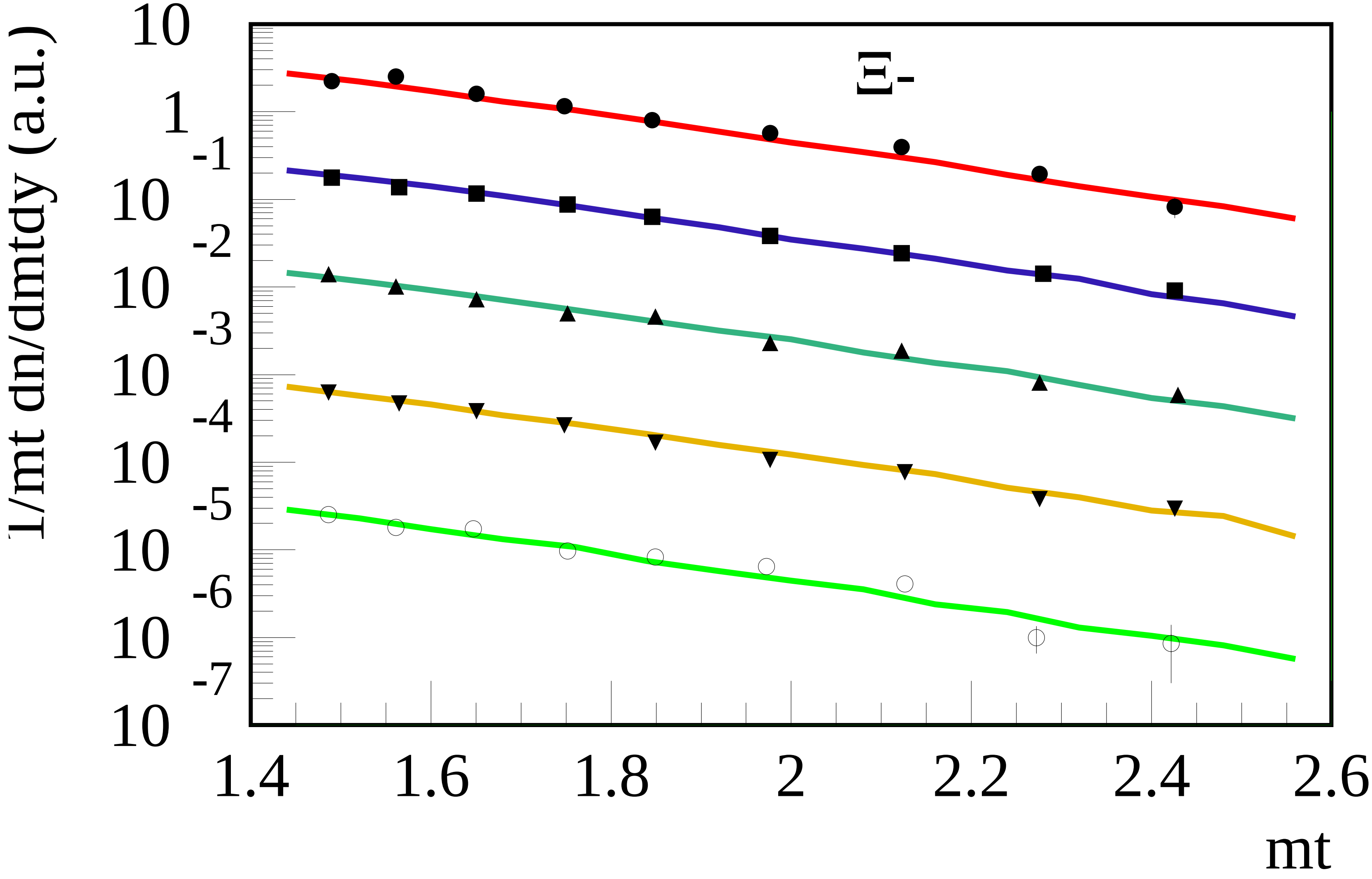
Elliptical flow even more ideal (after corona subtraction)

R_AA for identified hadrons: reflects simply the fact that pp (string fragmentation) and core hadronization are completely different. So we observe flow+statistical hadronization (of the core), not more !
(R_cp is complicated, since peripheral collisions are a mixture core/corona, so better avoid!)

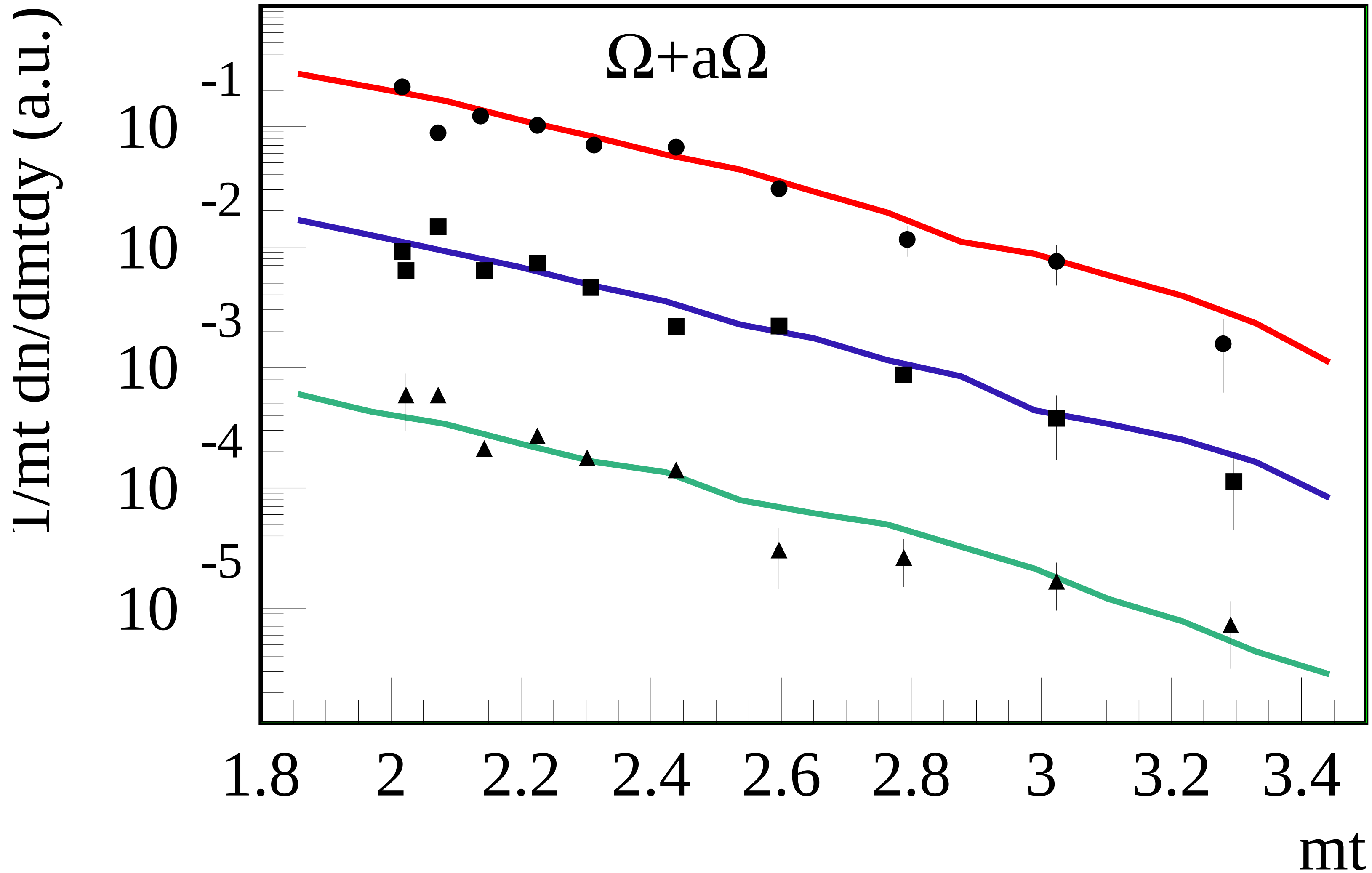

Ks
1/mt dn/dmtdy (a.u.)
mt
0.5 0.75 1 1.25 1.5 1.75 2 2.25 2.5 2.75 3
10 2
10
1
10 -1
10 -2
10 -3
10 -4
10 -5
10 -6

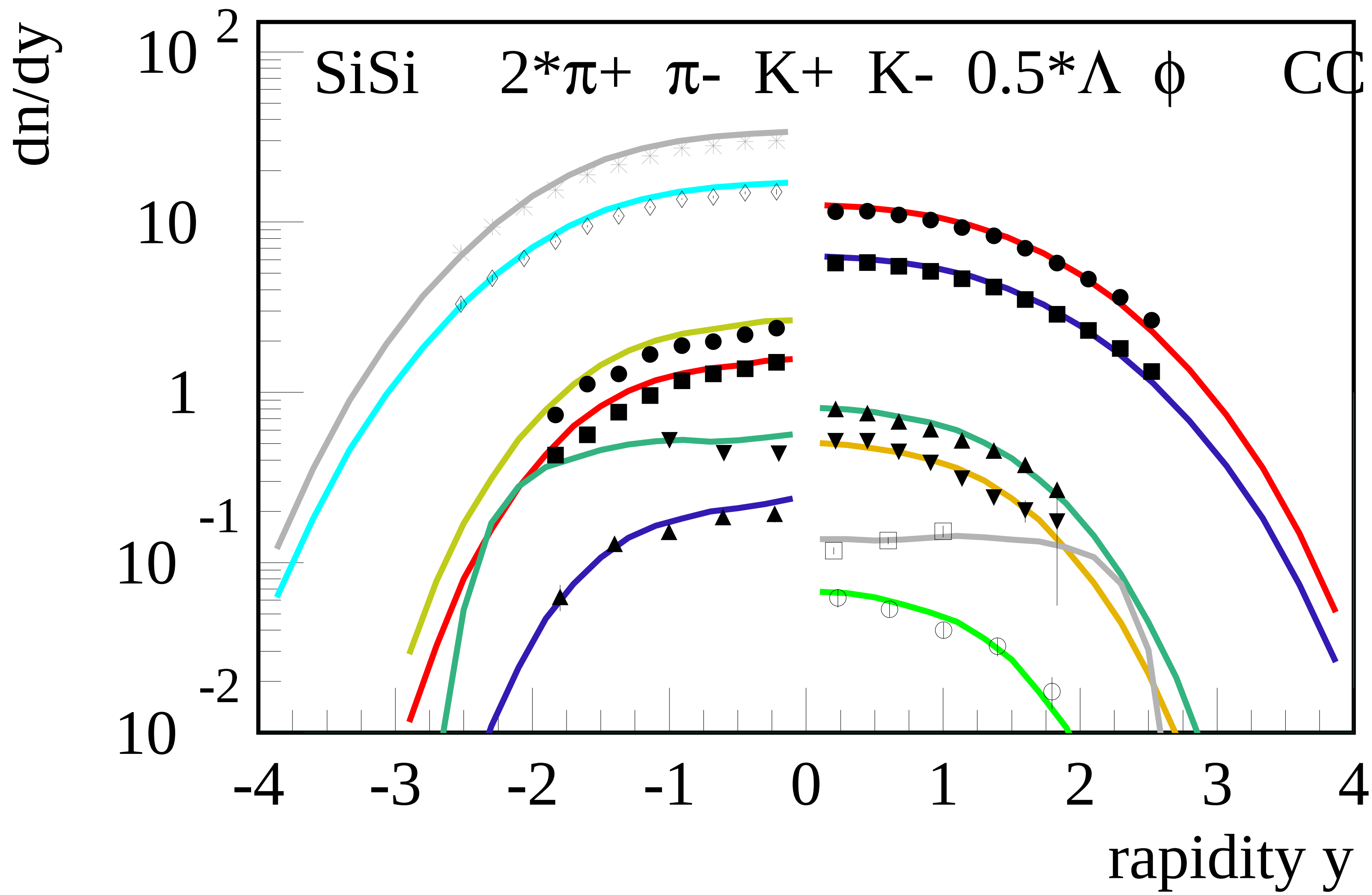


Λ
1/mt dn/dmtdy (a.u.)
mt
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1
1.25
1.5
1.75
2
2.25
2.5
2.75
3

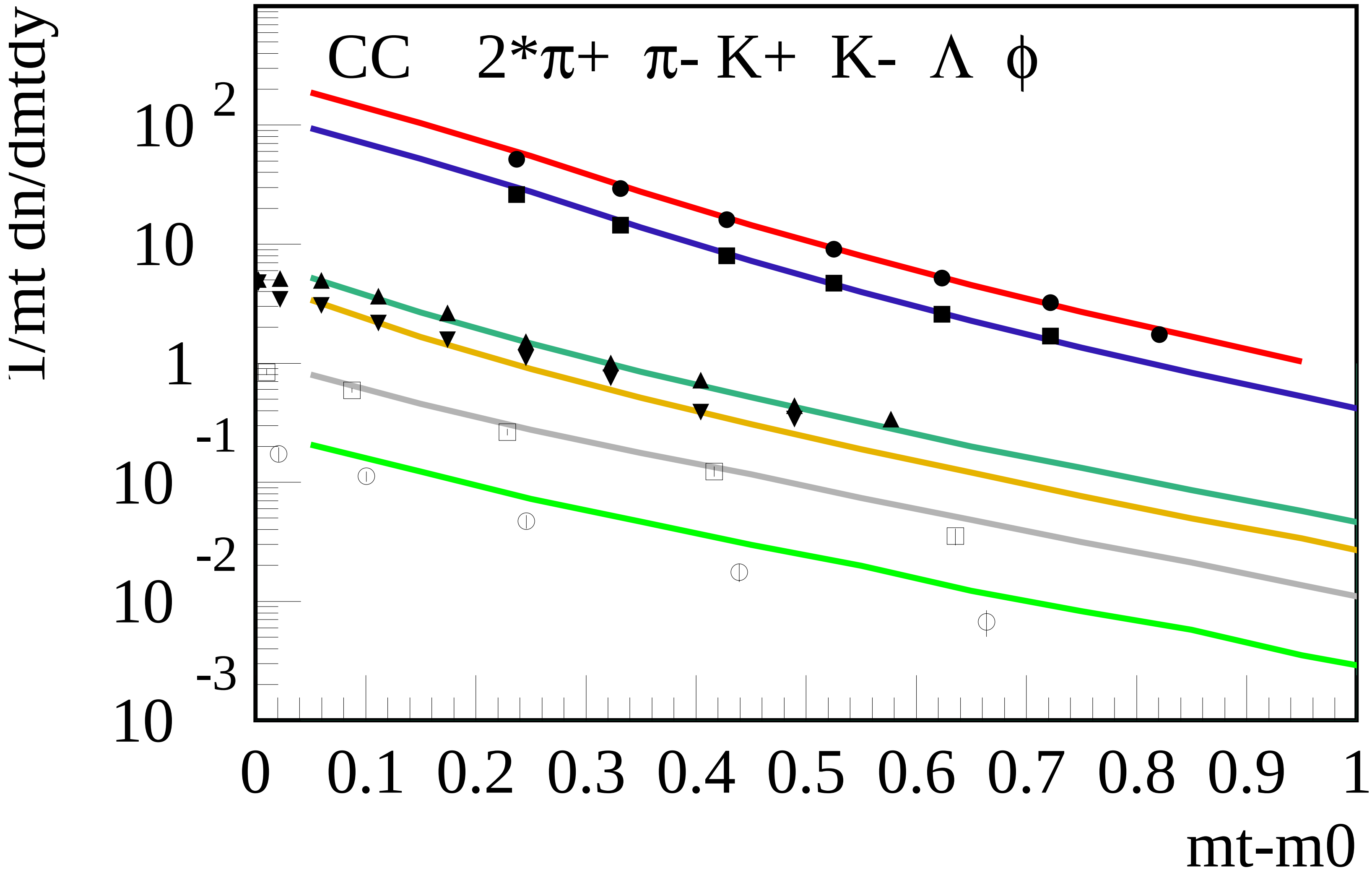


Ξ-
1/mt dn/dmtdy (a.u.)
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
1.4
1.6
1.8
2
2.2
2.4
2.6
mt

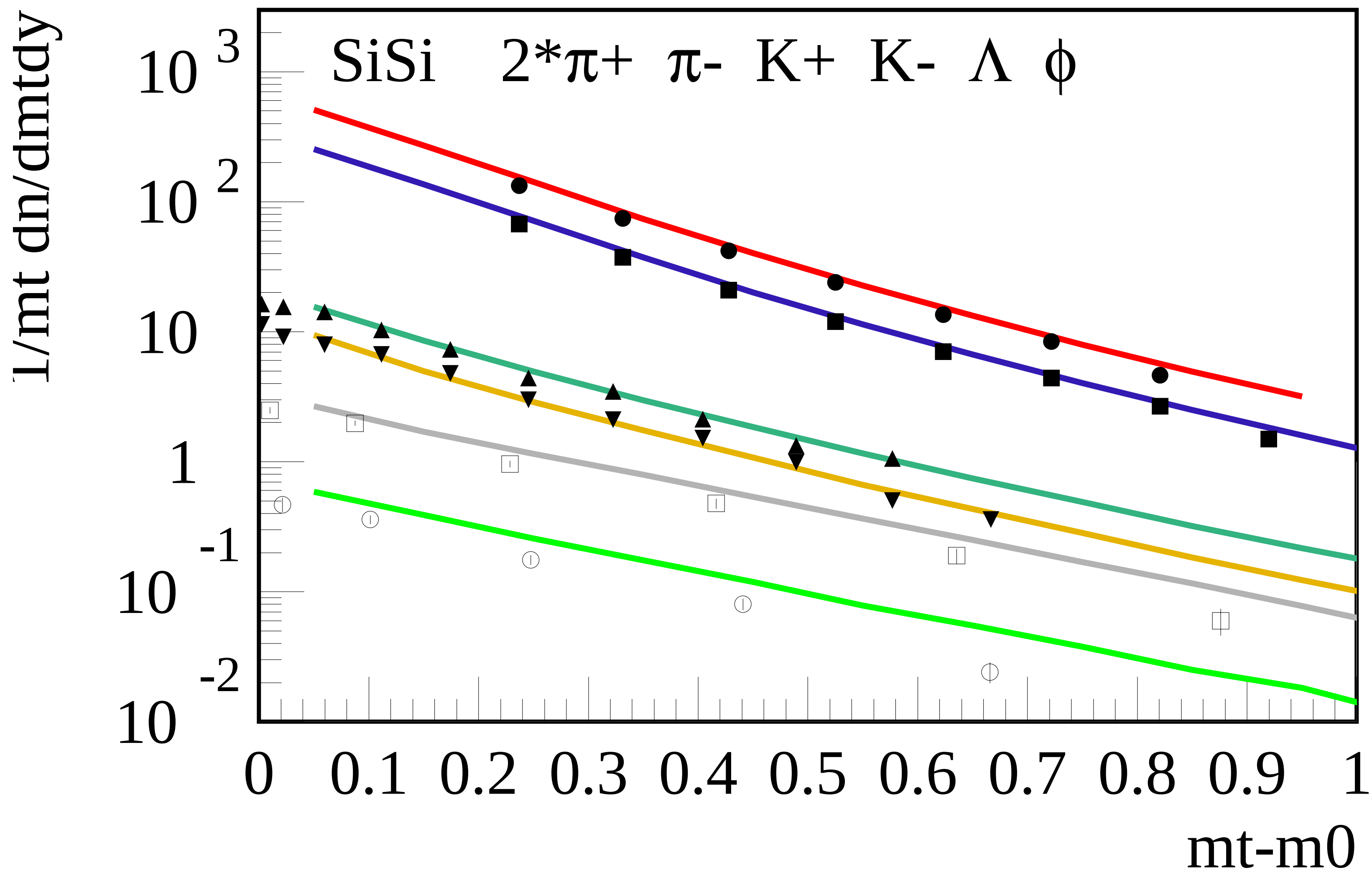

Ω+aΩ
1/mt dn/dmtdy (a.u.)
10^-1
10^-2
10^-3
10^-4
10^-5
1.8
2
2.2
2.4
2.6
2.8
3
3.2
3.4
mt



dn/dy
SiSi 2*π+ π- K+ K- 0.5*Λ φ CC
10 2
10
1
10 -1
10 -2
-4 -3 -2 -1 0 1 2 3 4
rapidity y



CC 2*π+ π- K+ K- Λ φ
1/mt dn/dmtdy
10 2
10
1
10 -1
10 -2
10 -3
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
mt-m0


SiSi 2*π+ π- K+ K- Λ φ
1/mt dn/dmtdy
mt-m0
10^3
10^2
10
1
10^-1
10^-2
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

0-35