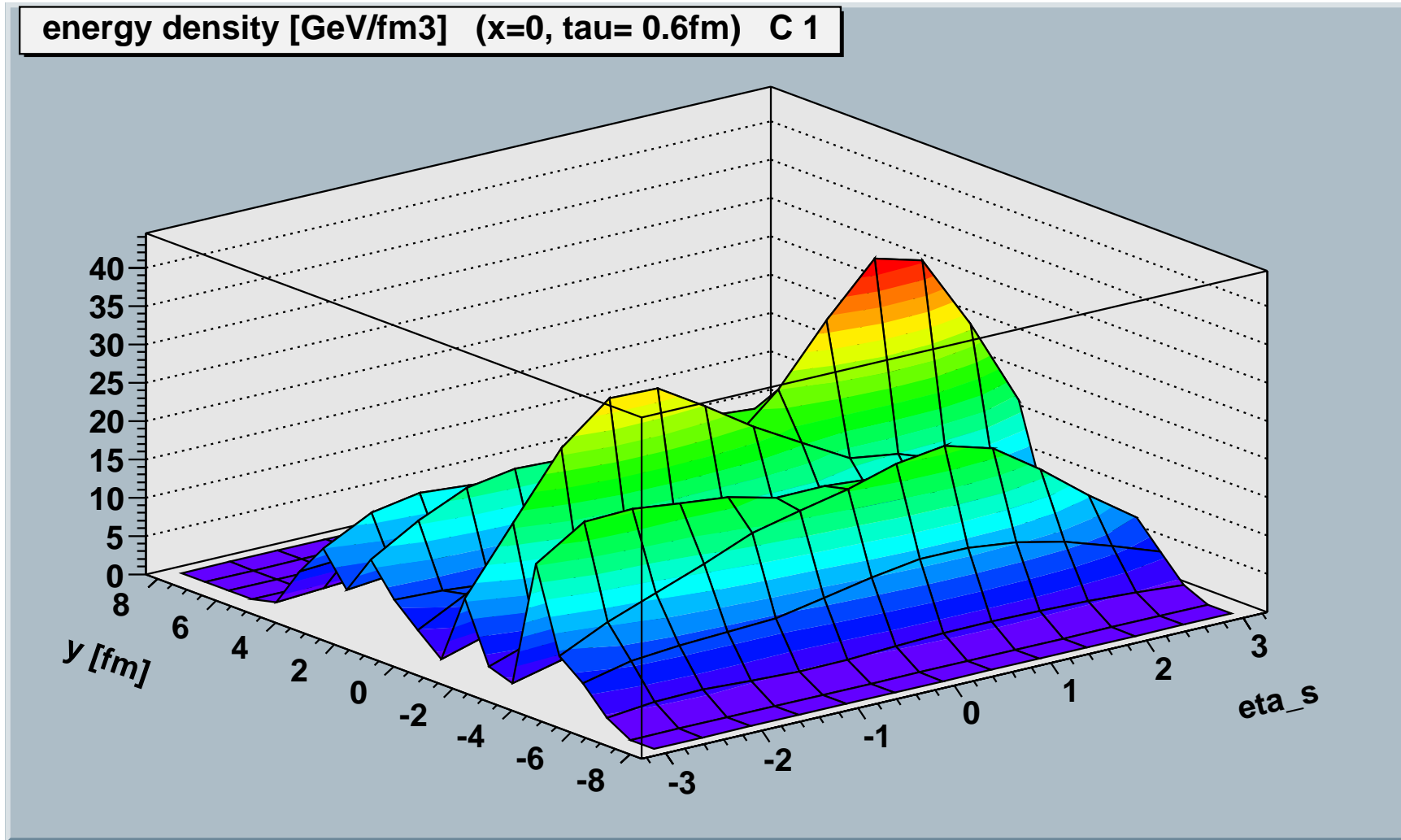


Collective effects in pp scattering

Klaus Werner
<werner@subatech.in2p3.fr>

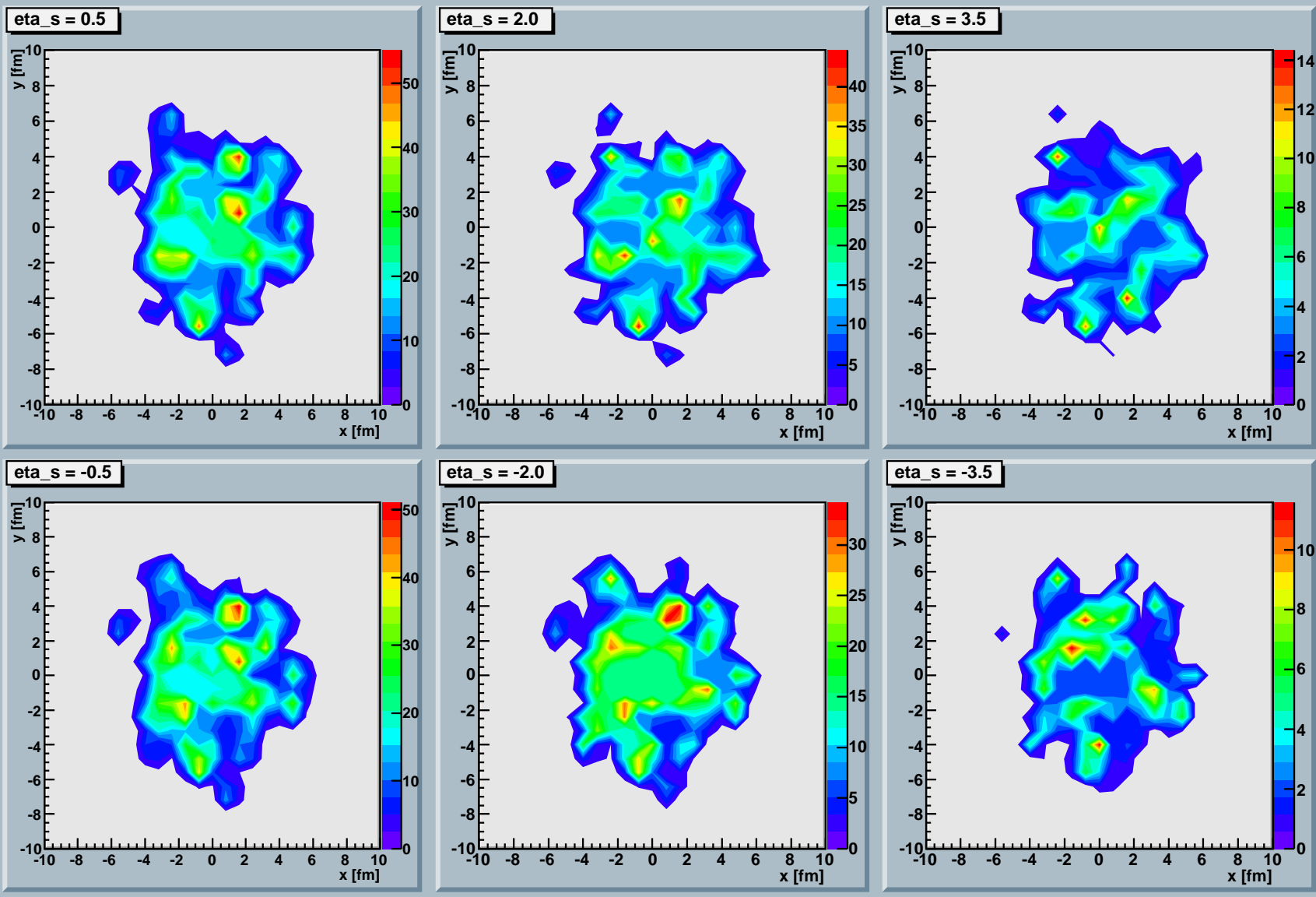
in collaboration with Y. Karpenko, T. Pierog, M. Bleicher

EPOS energy density (0.6fm/c) central AuAu



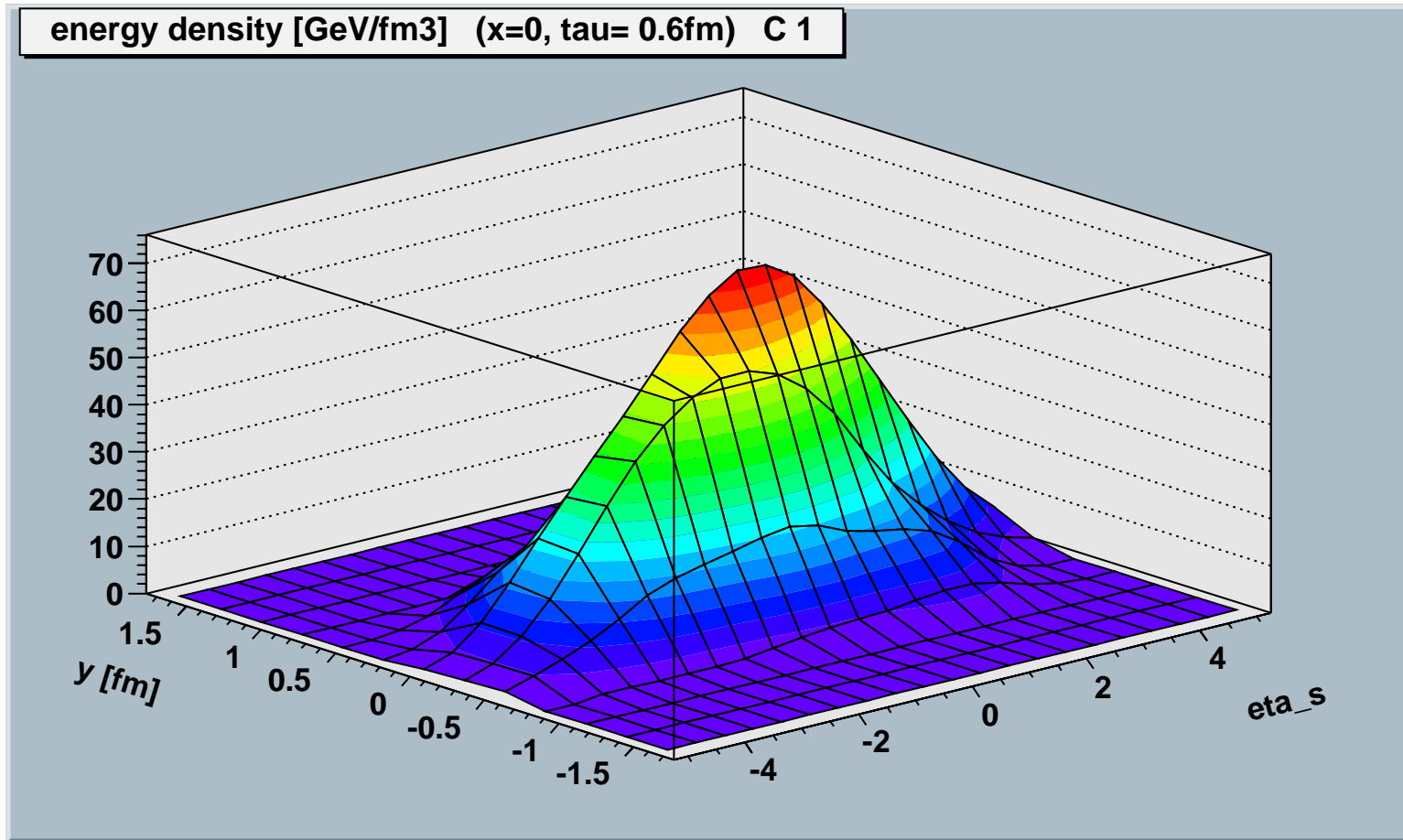
typically several ridges

energy density [GeV/fm³] ($\tau = 0.6$ fm) C 1



several peaks in x - y ($\hat{=}$ ridges in $\eta - y$)

EPOS energy density (0.6fm/c) “central” pp



single ridge

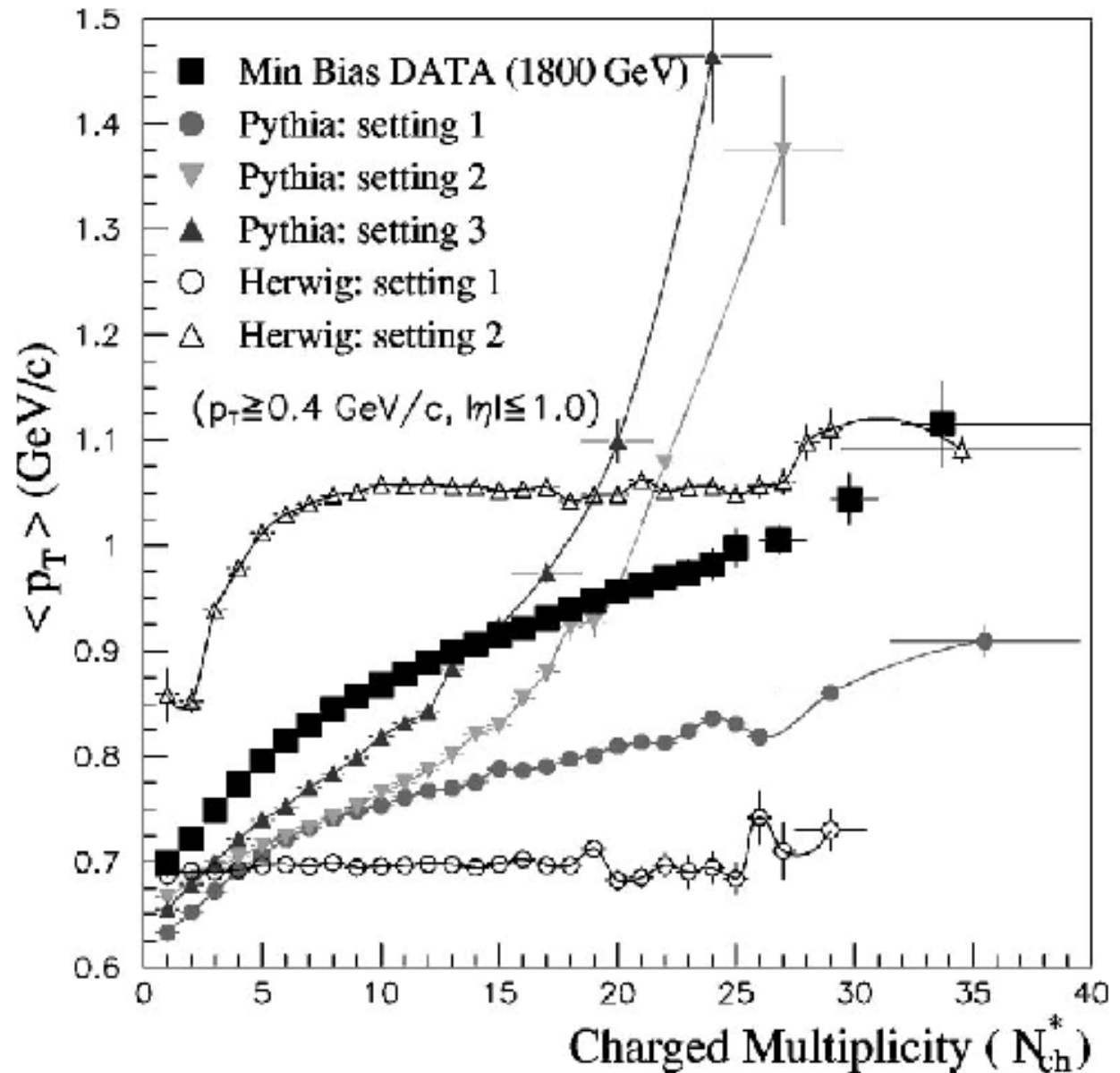
- ▷ Size of the fluctuations in AuAu small, similar to what will be achieved in pp@LHC
- ▷ If hydro is applicable for AuAu@RHIC, it should be so for pp@LHC, if one reaches high energy densities...
- ▷ Here, **multiple scattering** will help !!

Multiple scattering in pp

pp@1800GeV
data: CDF

Phys. Rev. D
Vol 65,
072005 (2002)

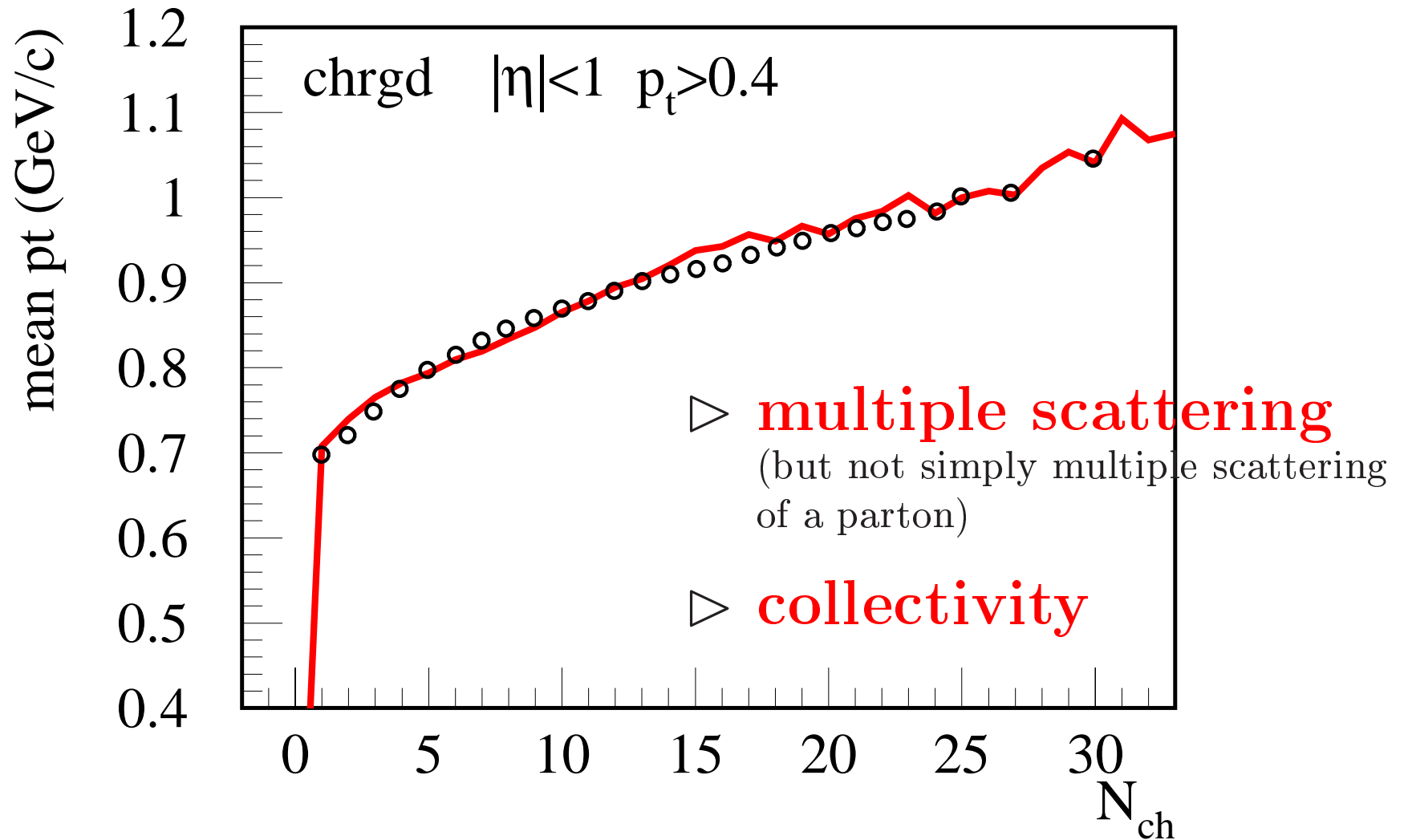
recent activities in
Pythia community



pp@1800GeV

points: CDF

curve EPOS



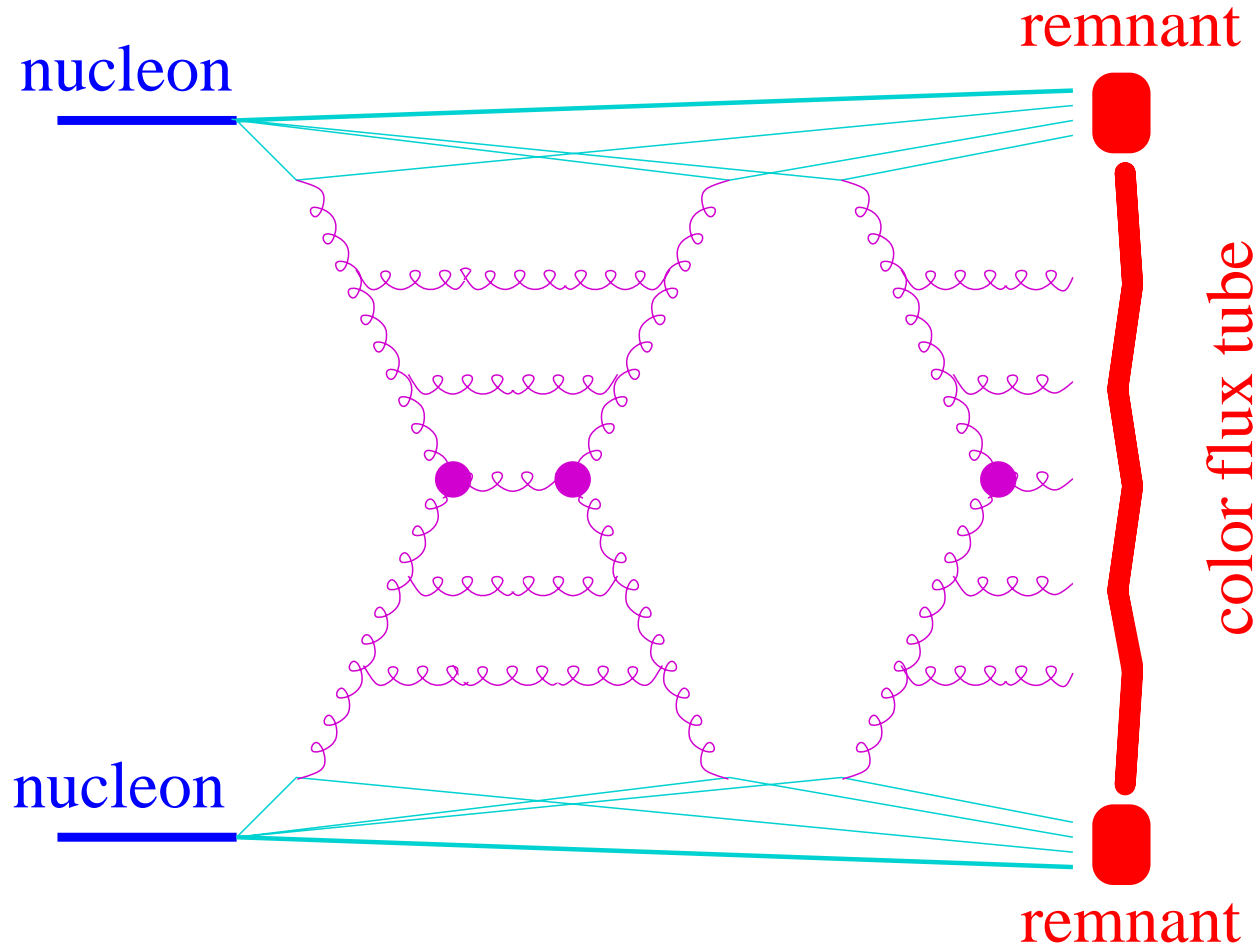
EPOS: multiple exchange of ladders

Multiple scattering
with energy sharing

Squaring graphs
→ cut diagrams
→ cutting rule techniques

Energy sharing:
Markov chain
techniques

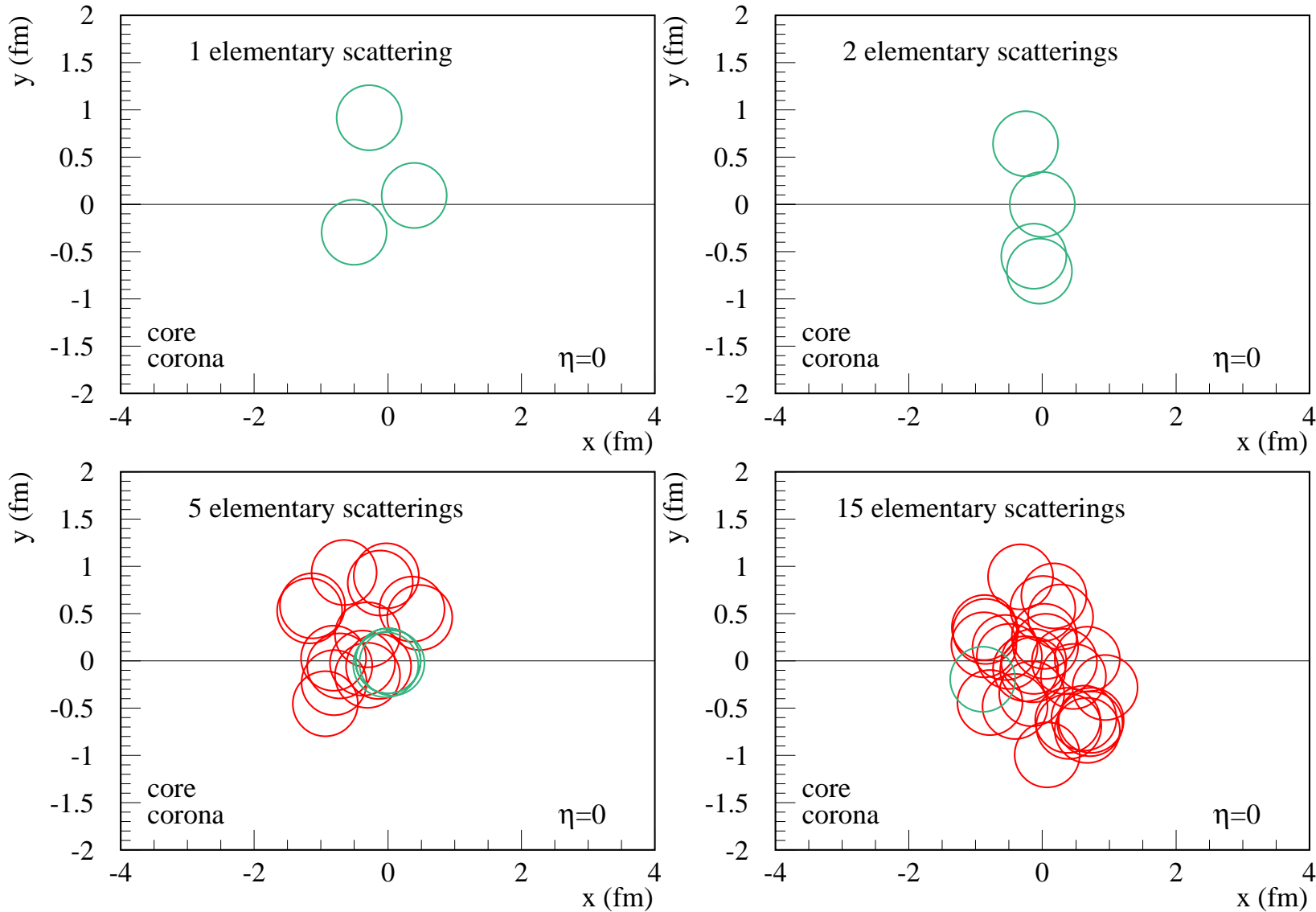
Particle production
from **remnants** and **flux tube** decays (→strings)



Parton-based Gribov-Regge Theory, H. J. Drescher, M. Hladik, S. Ostapchenko, T. Pierog, and K. Werner, Phys. Rept. 350 (2001) 93-289; Parton ladder splitting and the rapidity dependence of p_t spectra in dAu collisions at RHIC, K. Werner, F.M. Liu, T. Pierog, Phys. Rev. C 74, 044902 (2006)

Core-corona

pp : separation of events into two event classes



- ▷ Energy density comparable to AuAu@RHIC
- ▷ Size comparable to size of fluctuations in AuAu@RHIC
- ▷ we propose (and we do) for pp:
hydrodynamical expansion + statistical decay
based on EPOS flux tube initial conditions –
event-by-event

Checking hydro procedures against AuAu@RHIC

Features:

- ▷ flux-tube initial condition
- ▷ EbE treatment
- ▷ 3D core-corona procedure
- ▷ three flavor cross-over EoS (X3F)
- ▷ 3+1 D hydro
- ▷ complete hadron set (latest PDG)
- ▷ hadronic cascade (HC), here UrQMD

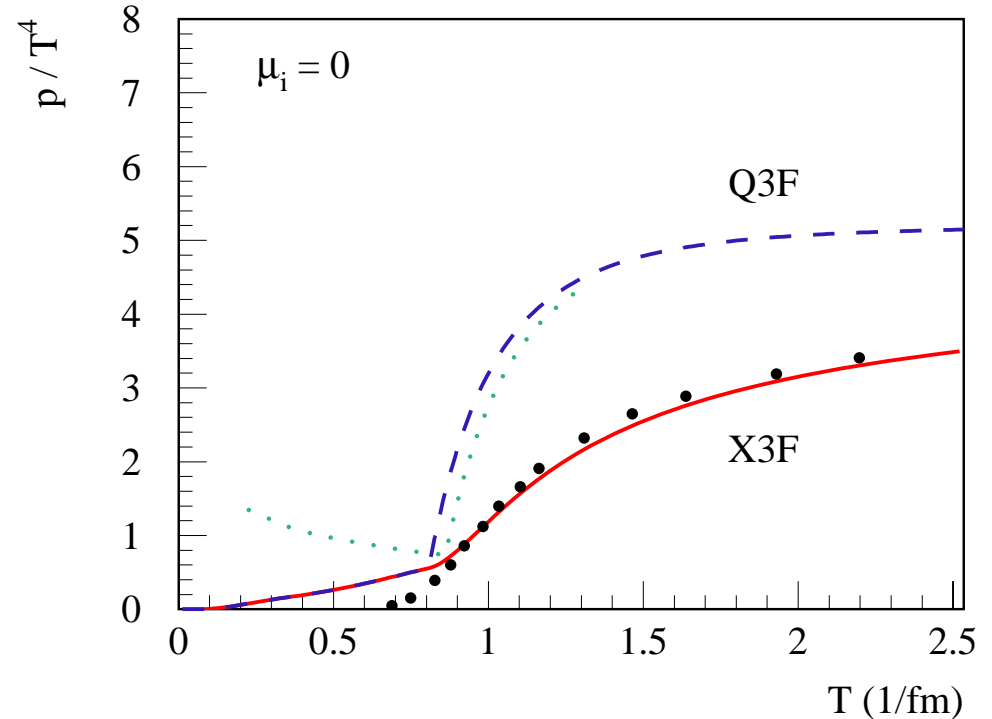
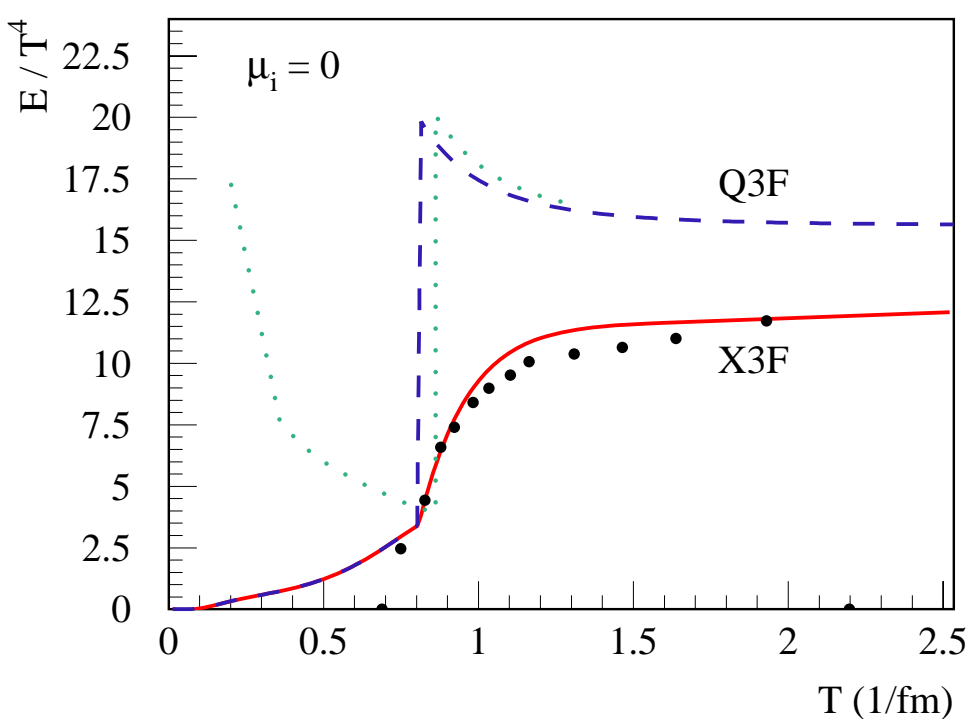
EoS:

Hirano: QG & resonance gas \Rightarrow 1st order PT, PCE, $\mu_B = \mu_S = \mu_Q = 0$

Q3F: QG & “complete” resonance gas \Rightarrow 1st order PT, excl volume correction, μ_B, μ_S, μ_Q considered, parameters as in Spherio

X3F: crossover : $p = p_Q + \lambda(p_H - p_Q)$, $\lambda = \exp(-\frac{T-T_c}{\delta})\theta(T - T_c) + \theta(T_c - T)$

“data”: Y. Aoki, Z. Fodor, S.D. Katz, K.K. Szabo, JHEP 0601:089,2006



Mandatory checks:

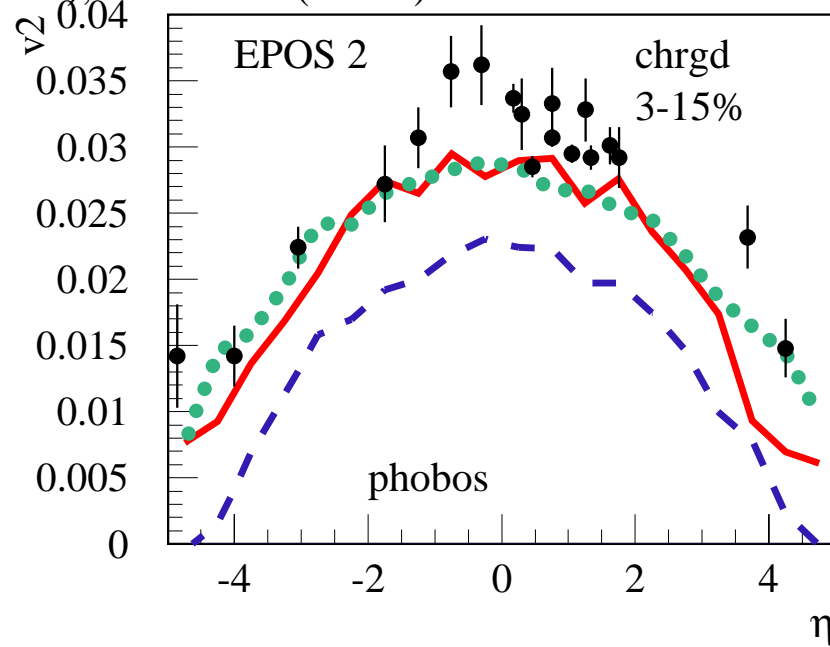
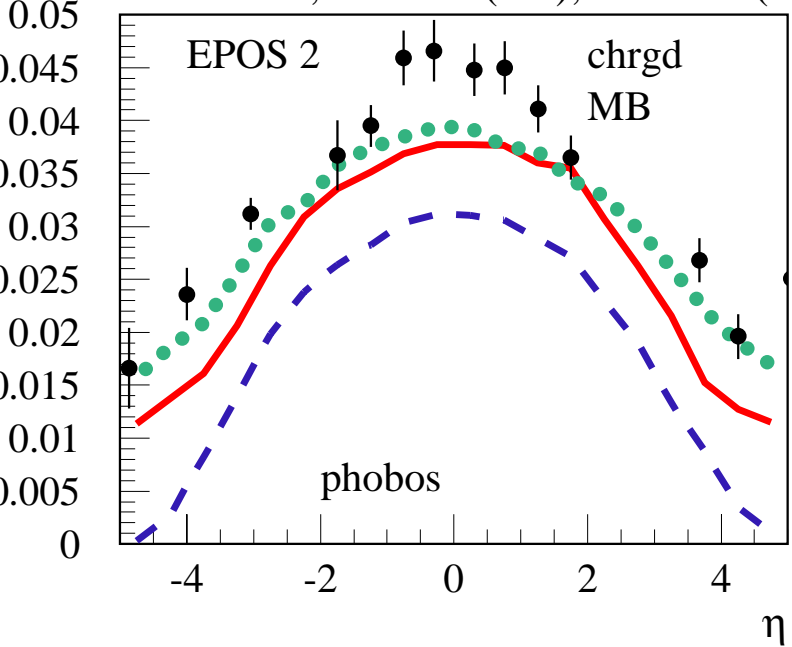
Centrality dependence of

- ▷ yields of identified hadrons
- ▷ pt spectra of identified hadrons
- ▷ v_2 of identified hadrons
- ▷ pt dependence of v_2
- ▷ particle correlations
 - eta-phi
 - HBT (in progress)
 - ... (in progress)

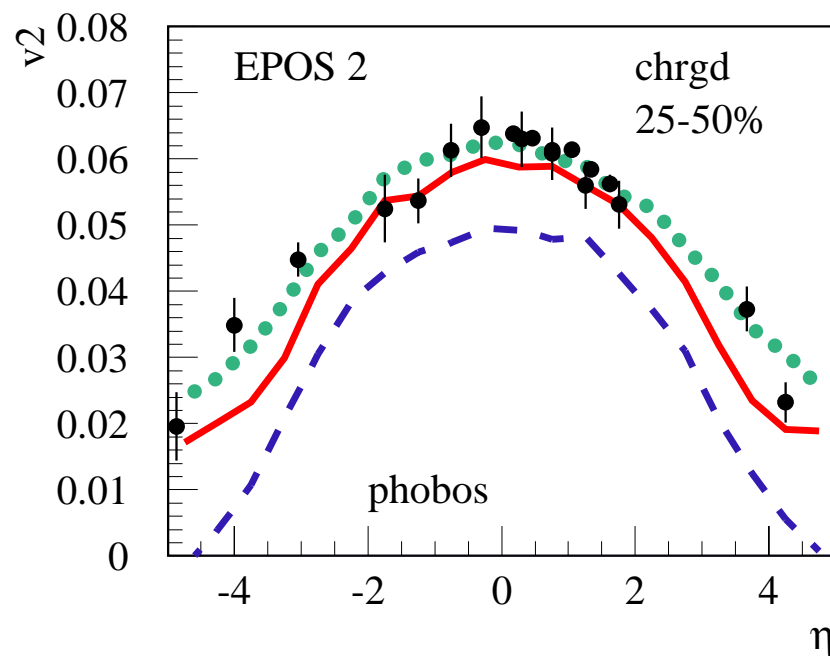
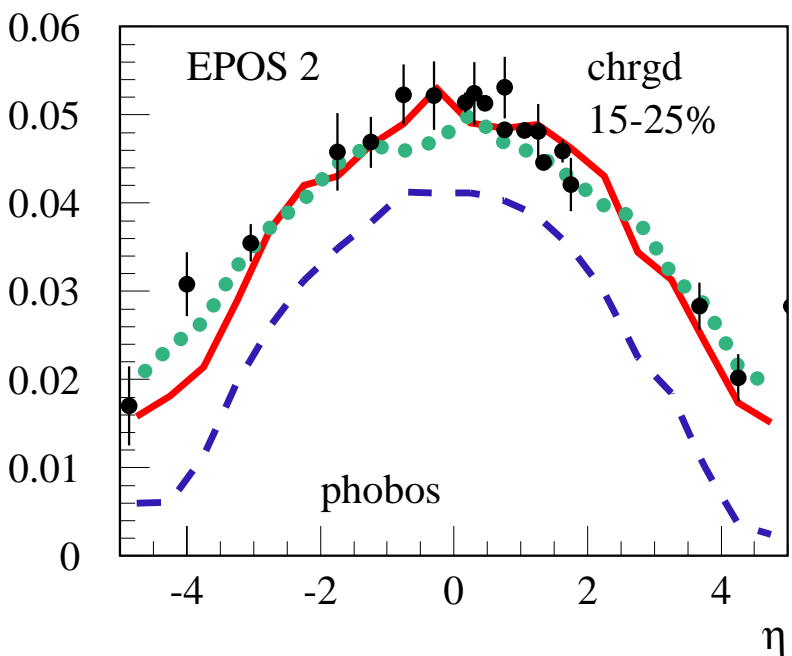
Needed: early freeze out (166 MeV) + hadr cascade

$v_2(\text{rapidity})$

FO 166 MeV, with HC (full); w/o HC (dashed); with HCe (dotted)

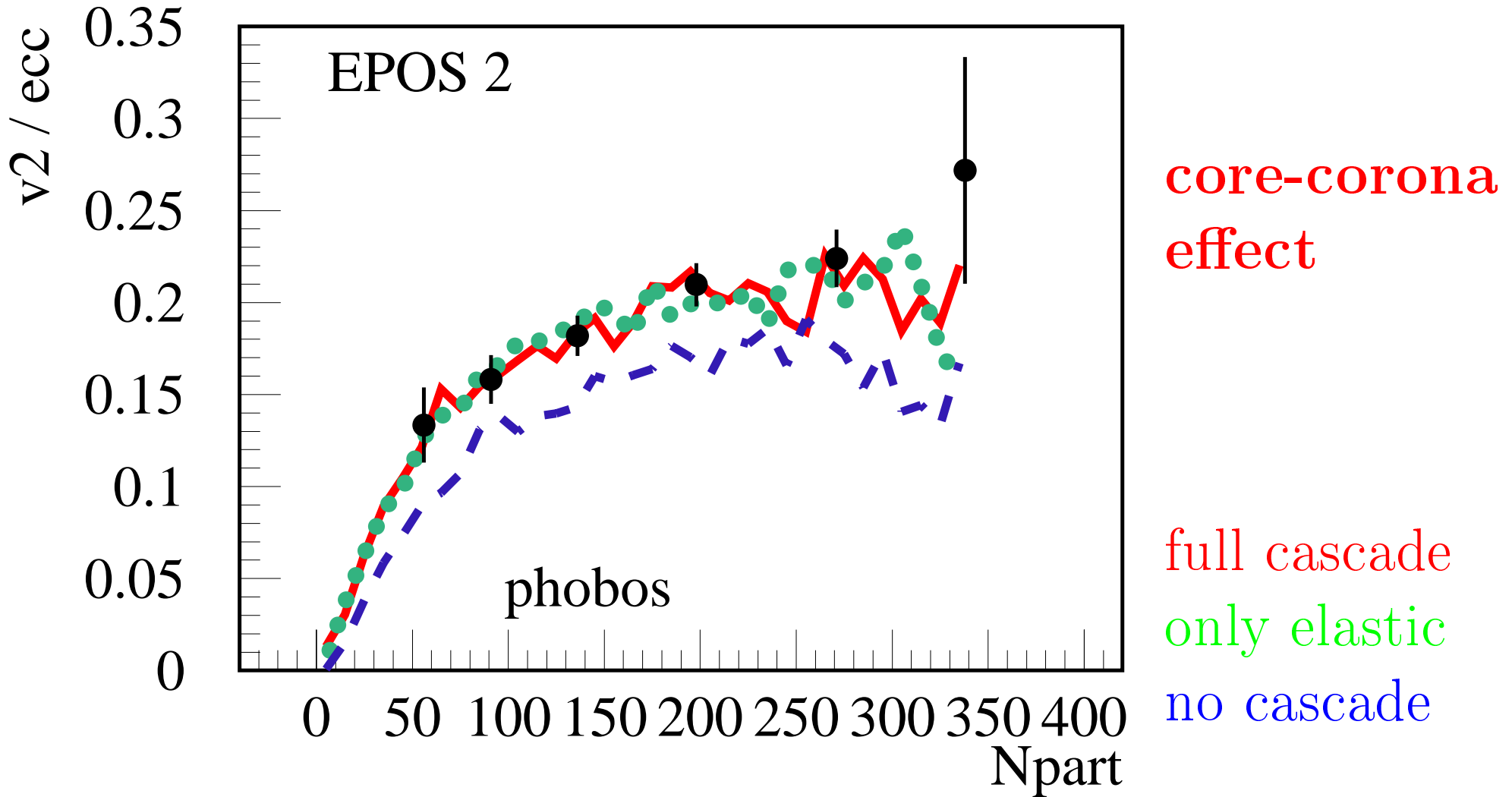


strong η dependence due to flux-tube IC and core-corona



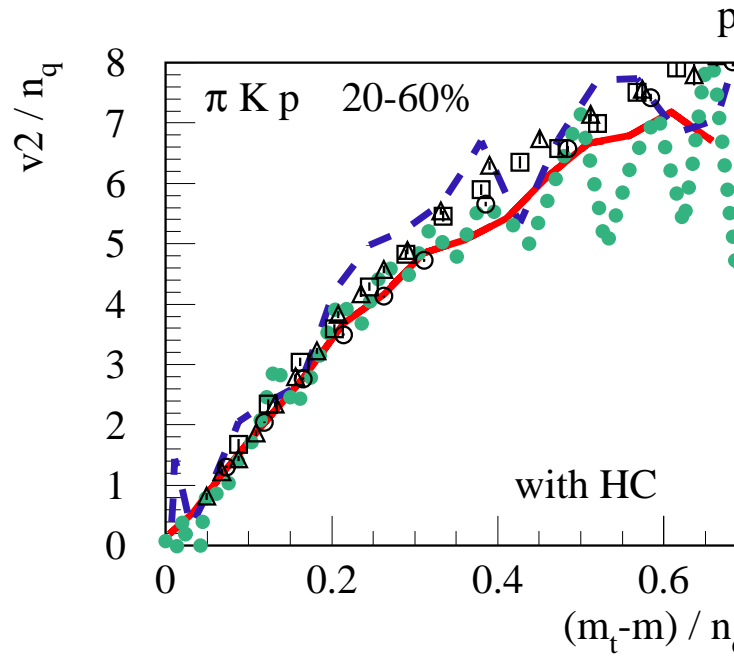
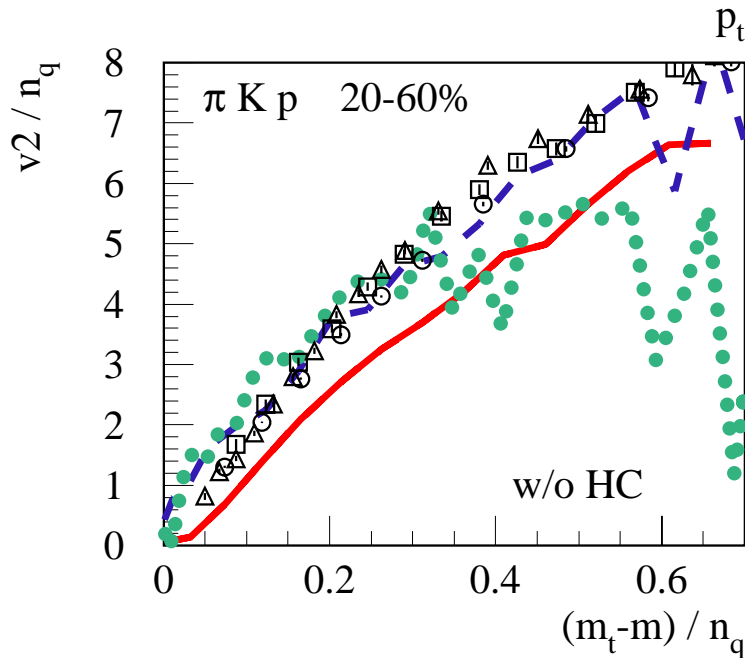
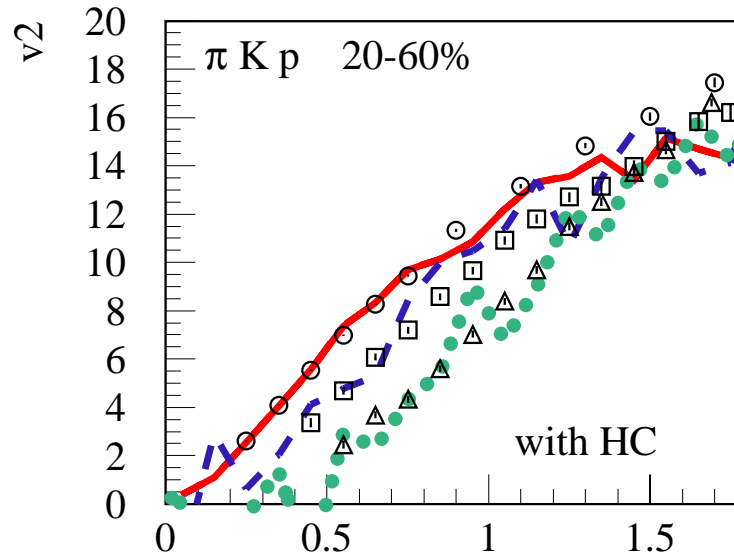
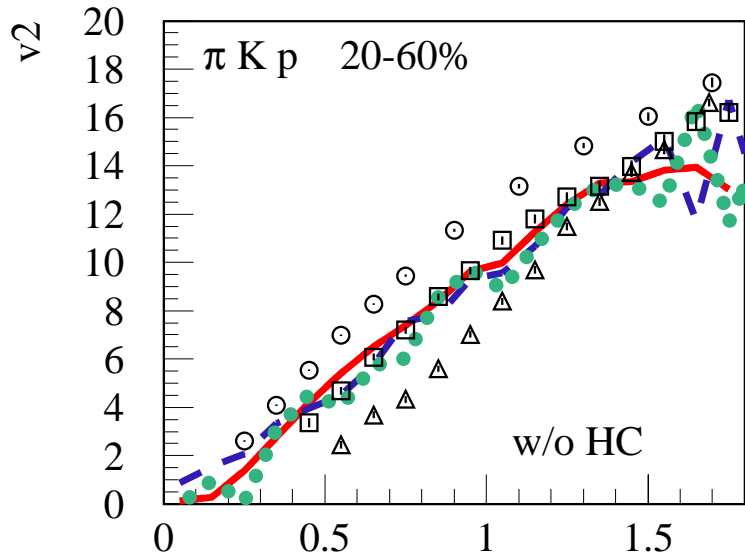
full cascade
only elastic
no cascade

Centrality dependence of v_2

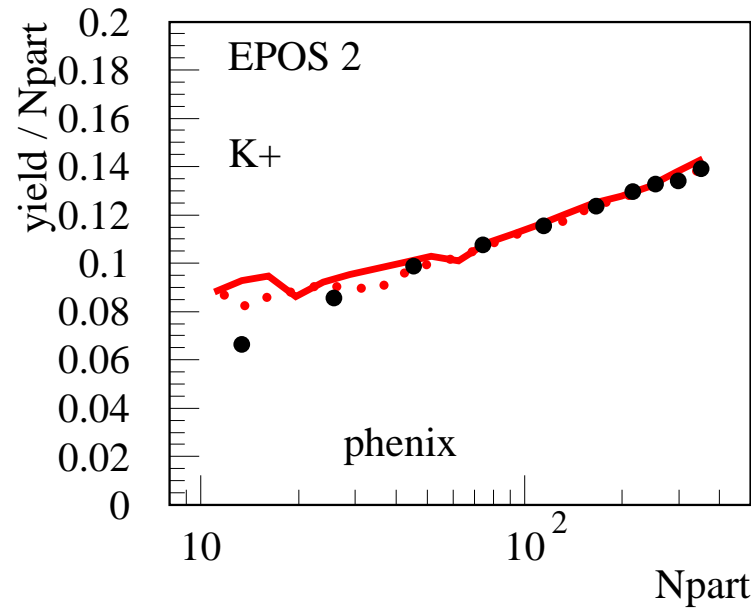
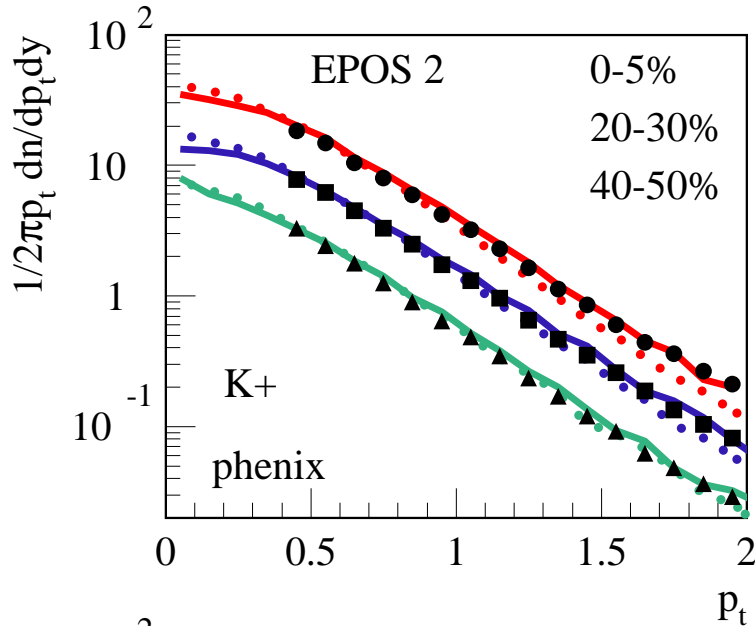


v2 scaling

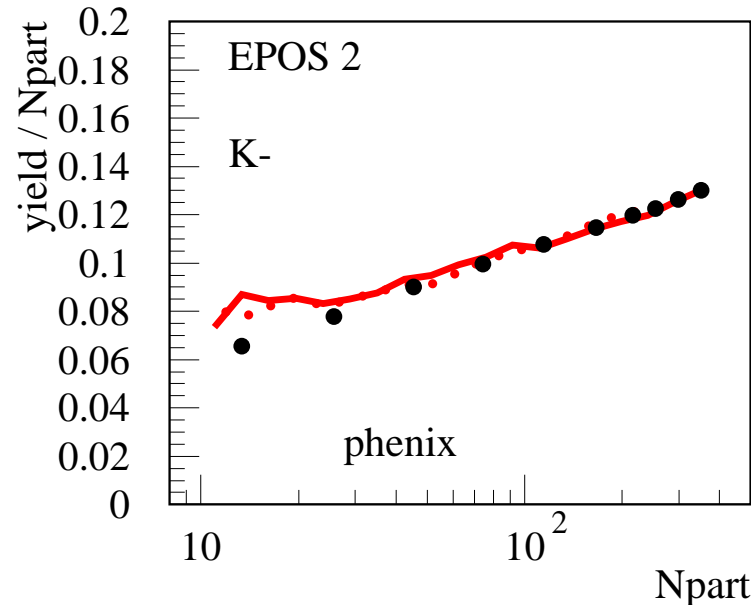
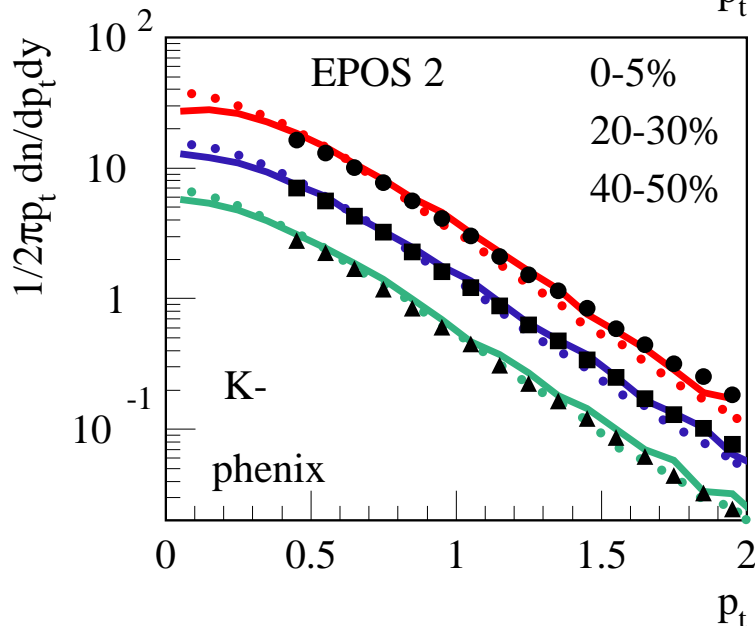
EPOS 2 FO 166 MeV



Kaons (vs p_t , vs N_{part})



solid lines:
with
hadronic
cascade



dotted lines:
w/o cascade

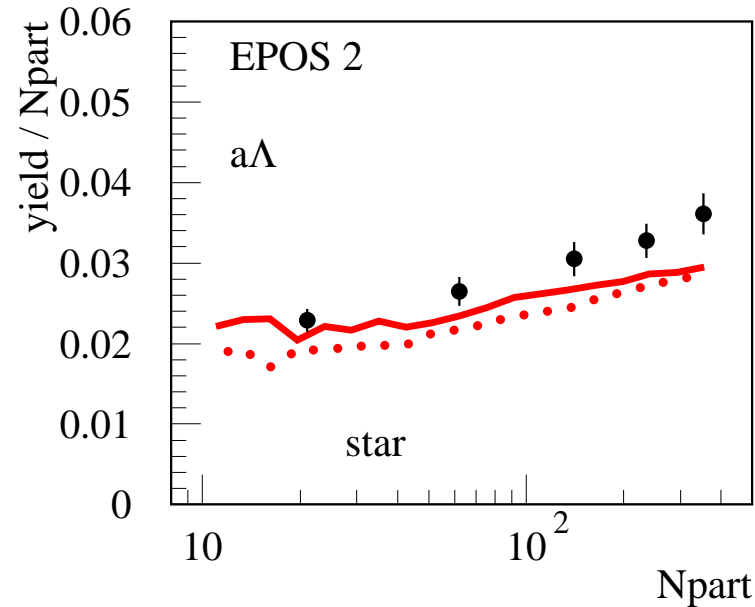
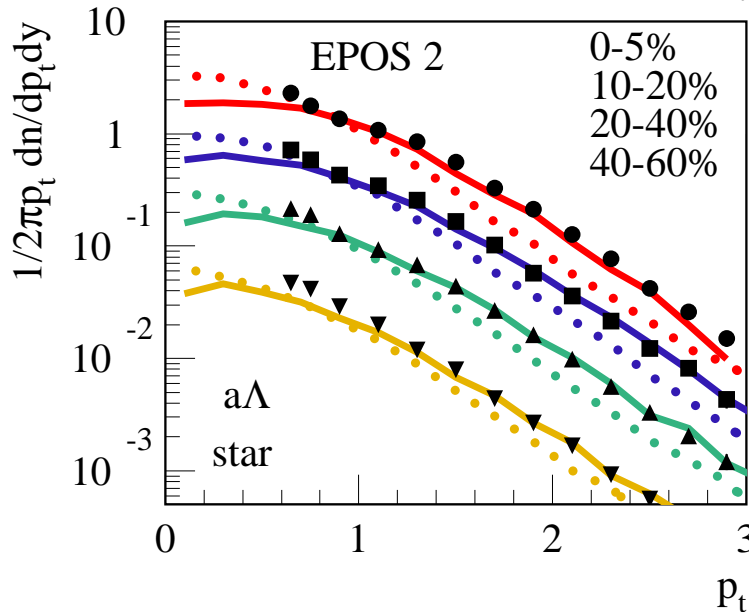
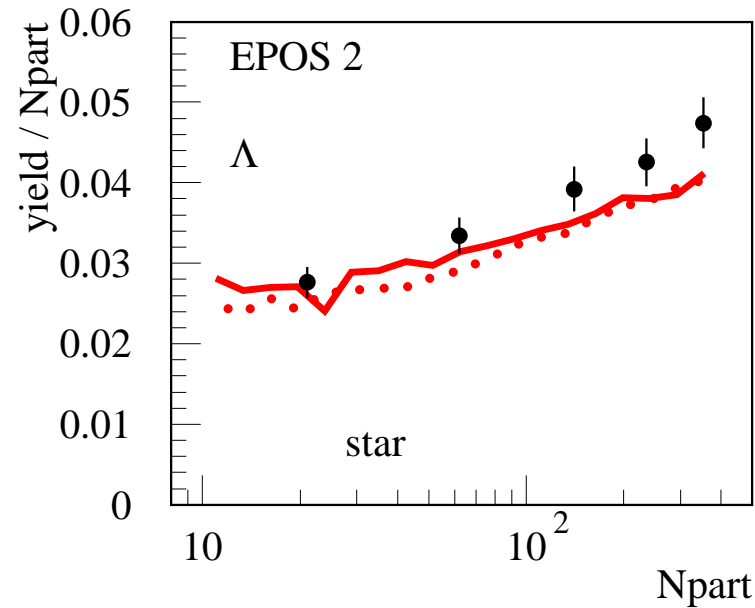
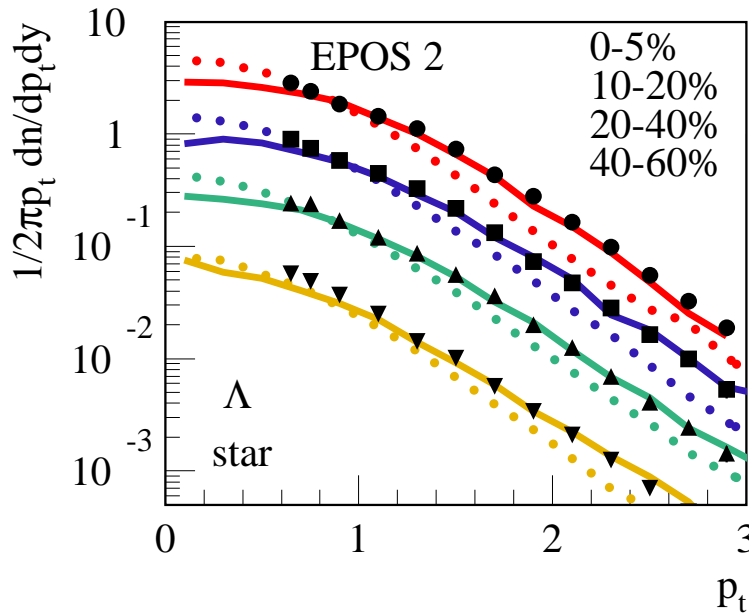
Lambdas (vs p_t , vs Npart)

EPOS 2 FO 166 MeV : without HC (dotted), with HC (full)

for better
visibility:

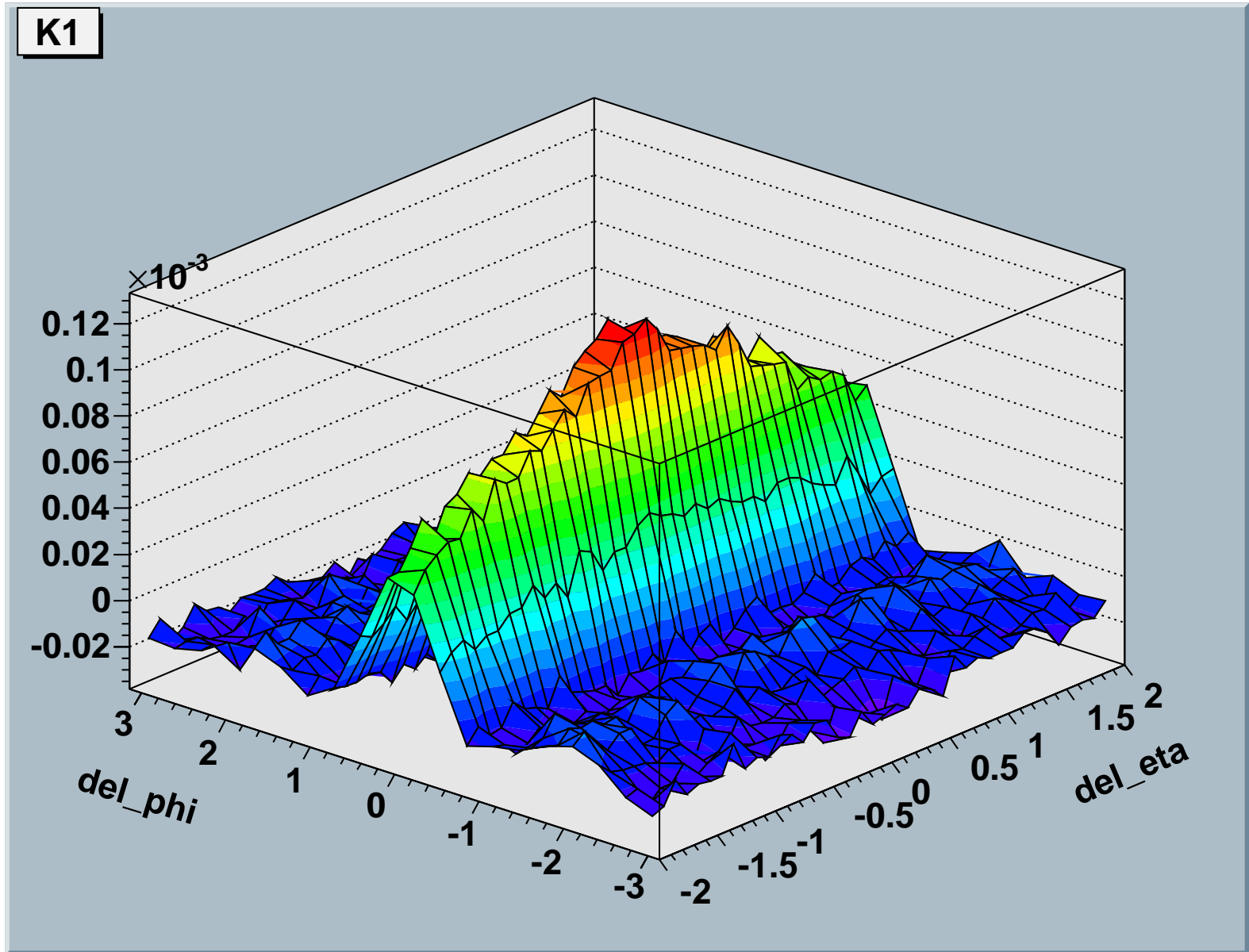
p_t spectra
scaled by

- 1/2 (10-20%)
- 1/4 (20-40%)
- 1/8 (40-60%)



EPOS 2

di-
hadron
correl.



AuAu 0-10%,

$3 < p_t^{\text{trig}} < 4 \text{ GeV}/c$

$2 < p_t^{\text{assoc}} < p_t^{\text{trig}}$

back to pp ...

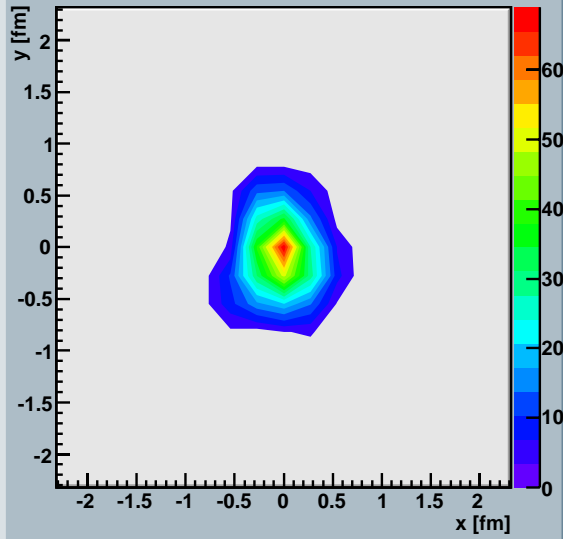
In the following

the first real hydro calculation
for $pp@1800$ GeV

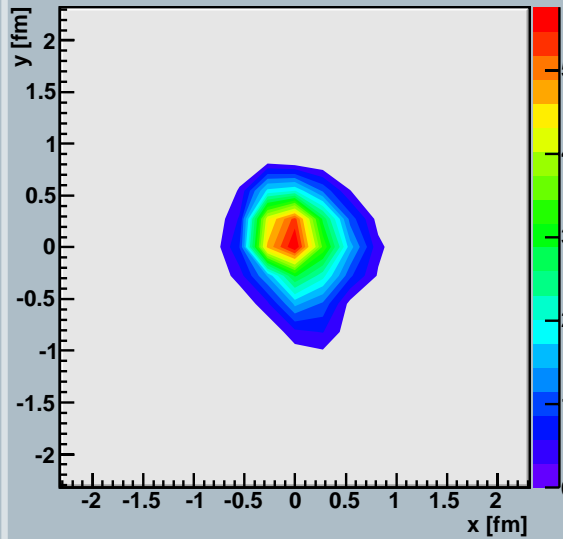
Parameters (except flux-tube radius)
obtained from AuAu

energy density [GeV/fm³] (tau= 0.6fm) C 1

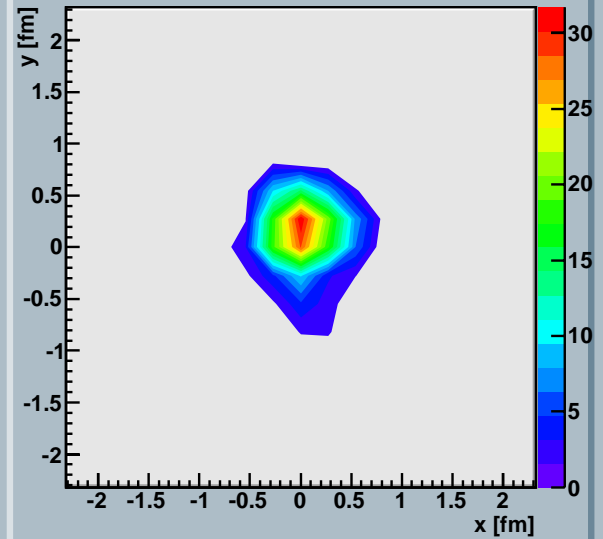
eta_s = 0.5



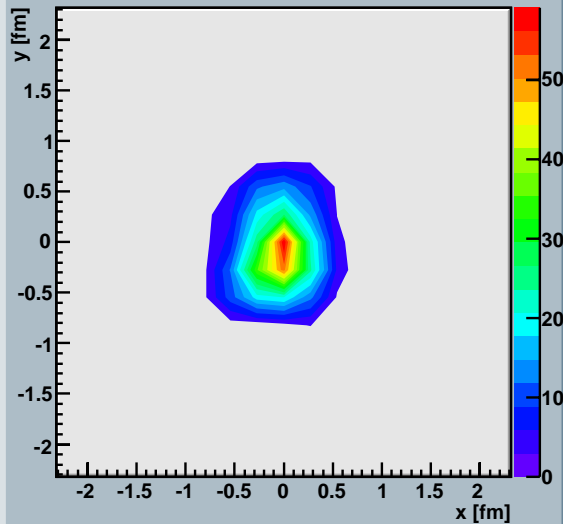
eta_s = 2.0



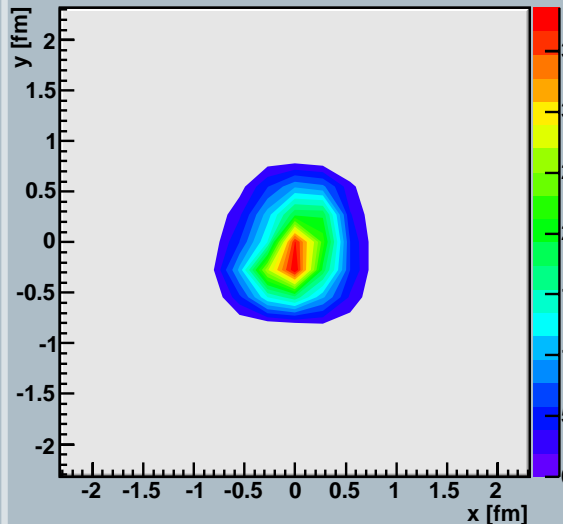
eta_s = 3.5



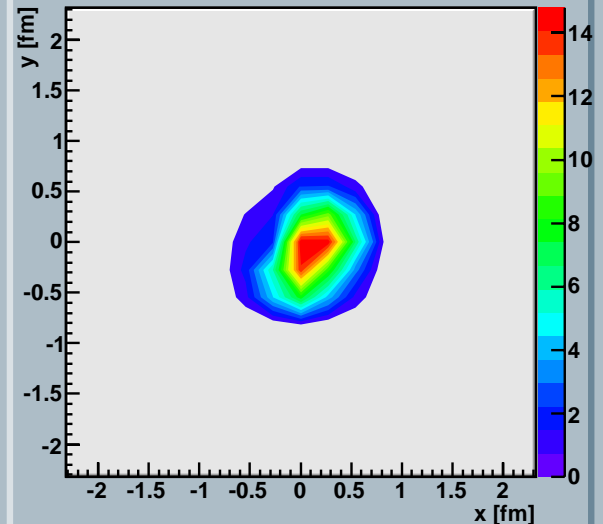
eta_s = -0.5



eta_s = -2.0

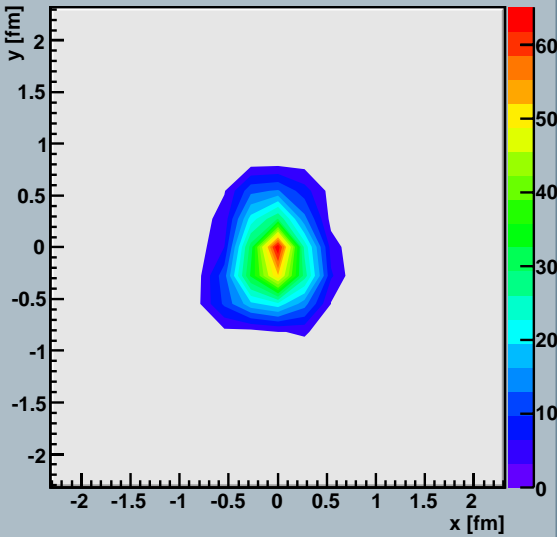


eta_s = -3.5

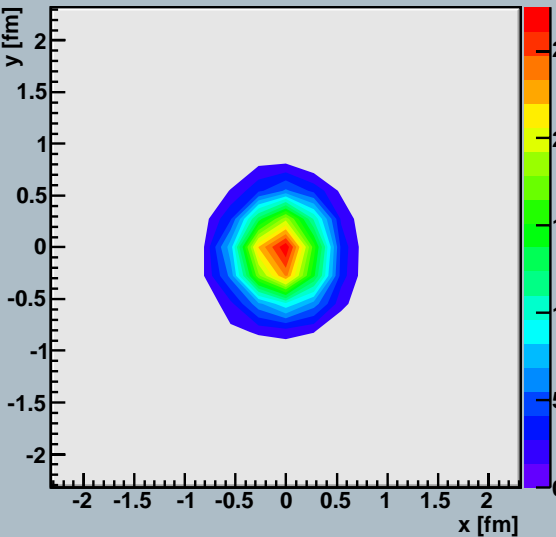


energy density [GeV/fm³] (eta_s=0) C 1

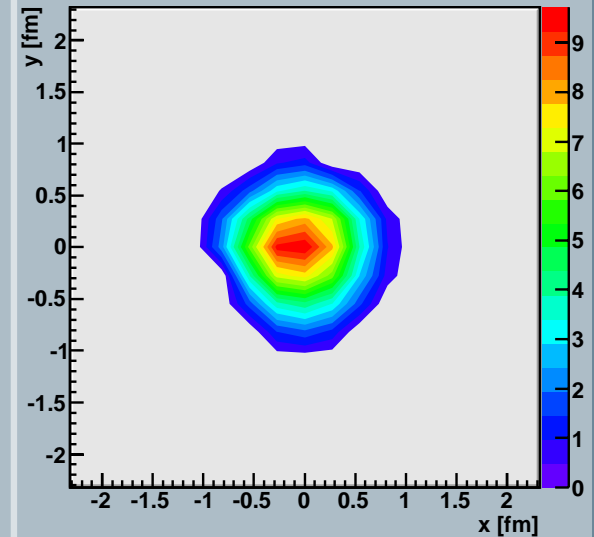
tau = 0.6



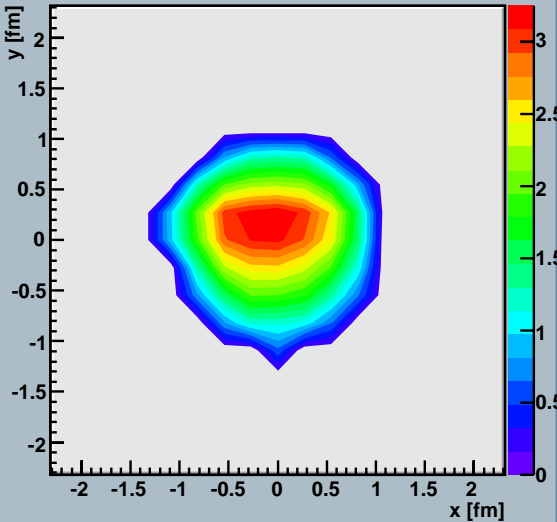
tau = 1.0



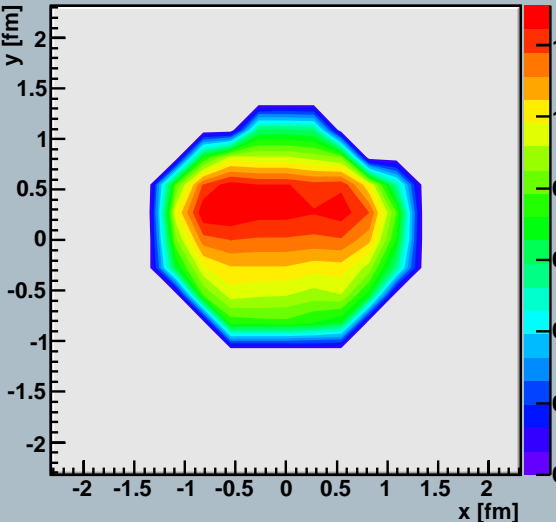
tau = 1.4



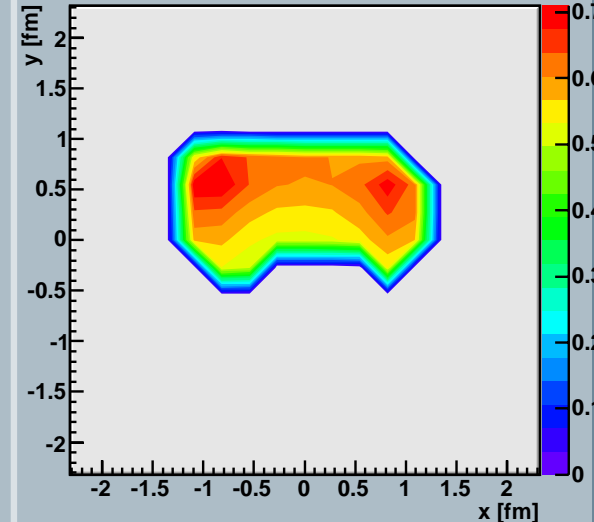
tau = 1.7



tau = 2.1

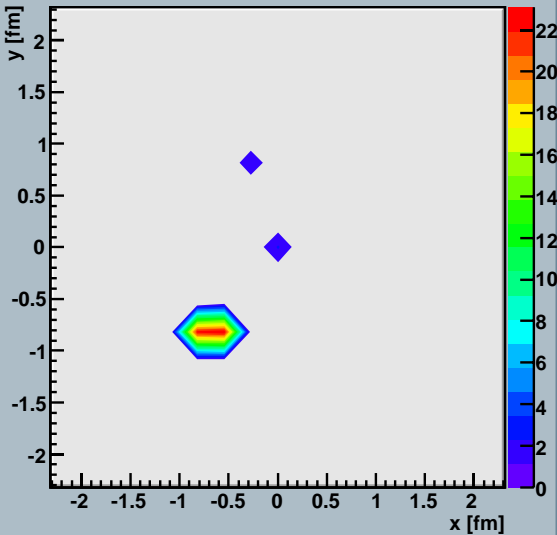


tau = 2.5

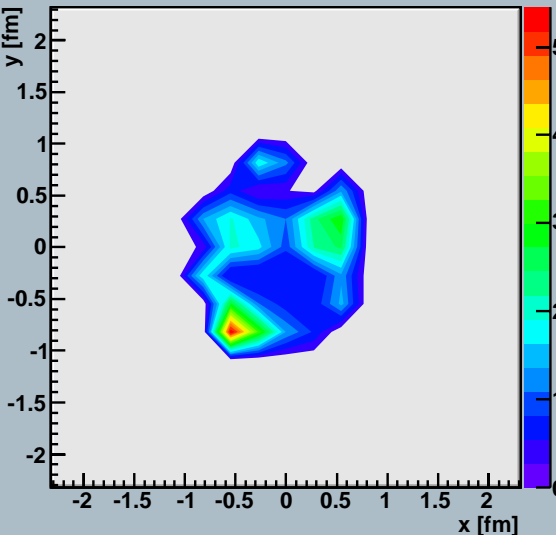


rad velocity [% of c] (eta_s=0) C 1

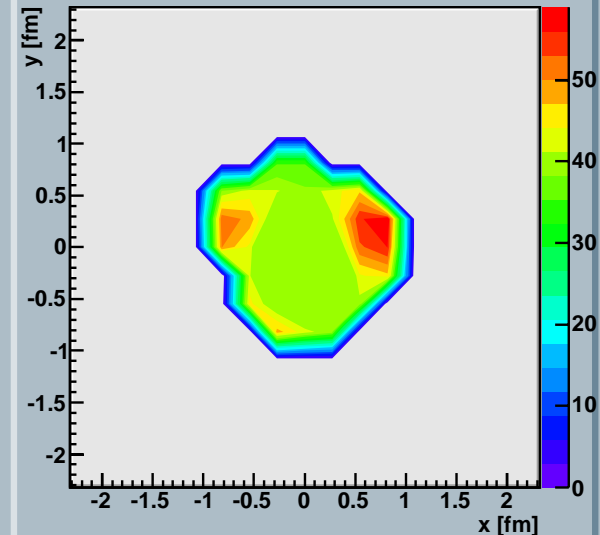
tau = 0.6



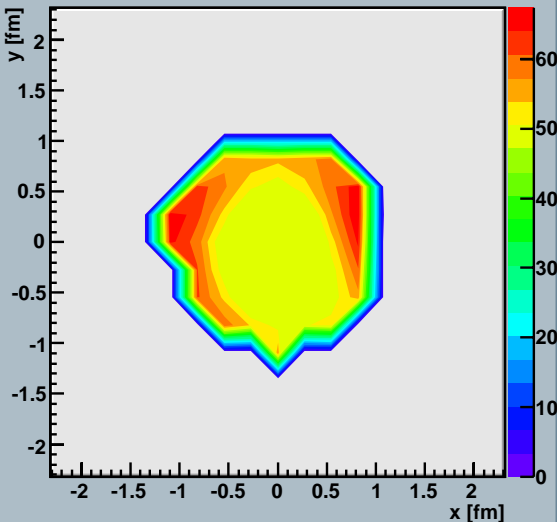
tau = 1.0



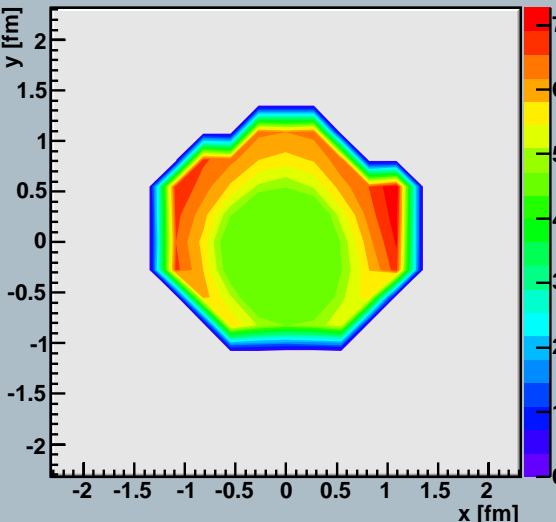
tau = 1.4



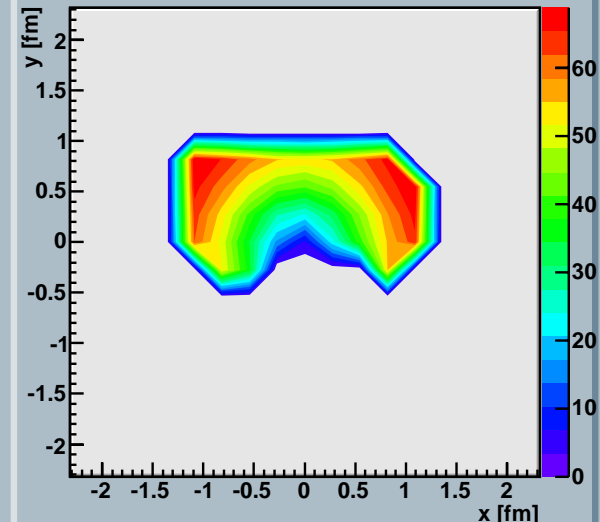
tau = 1.7



tau = 2.1



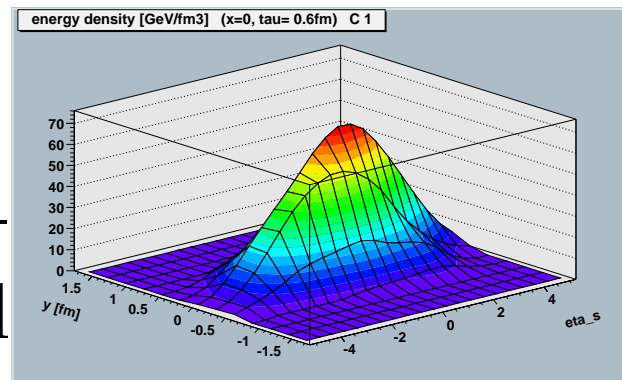
tau = 2.5



How to verify ?

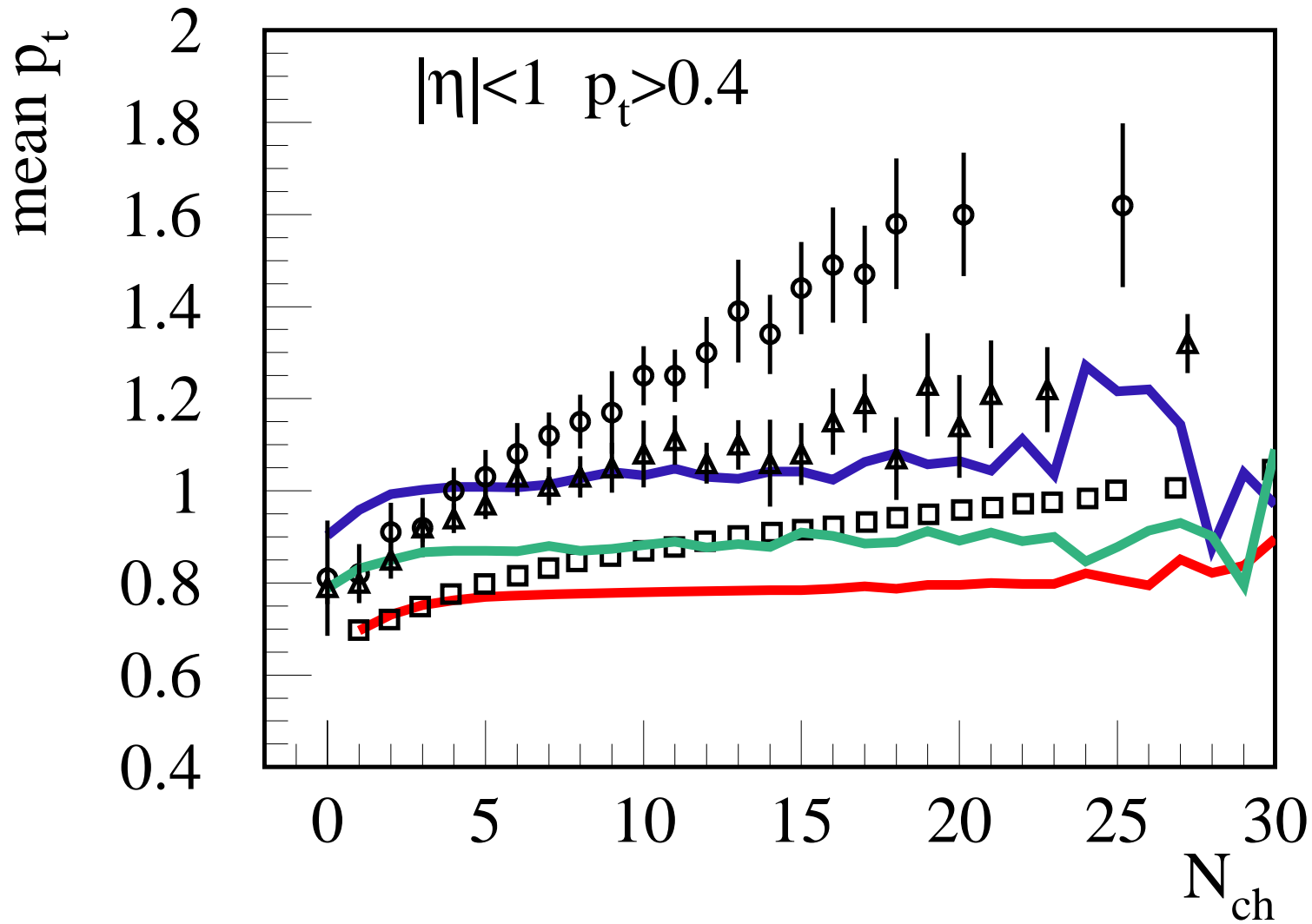
- ▷ multiple scattering events should exhibit long range y correlations

coming from the η_s correlation of the initial flux tubes

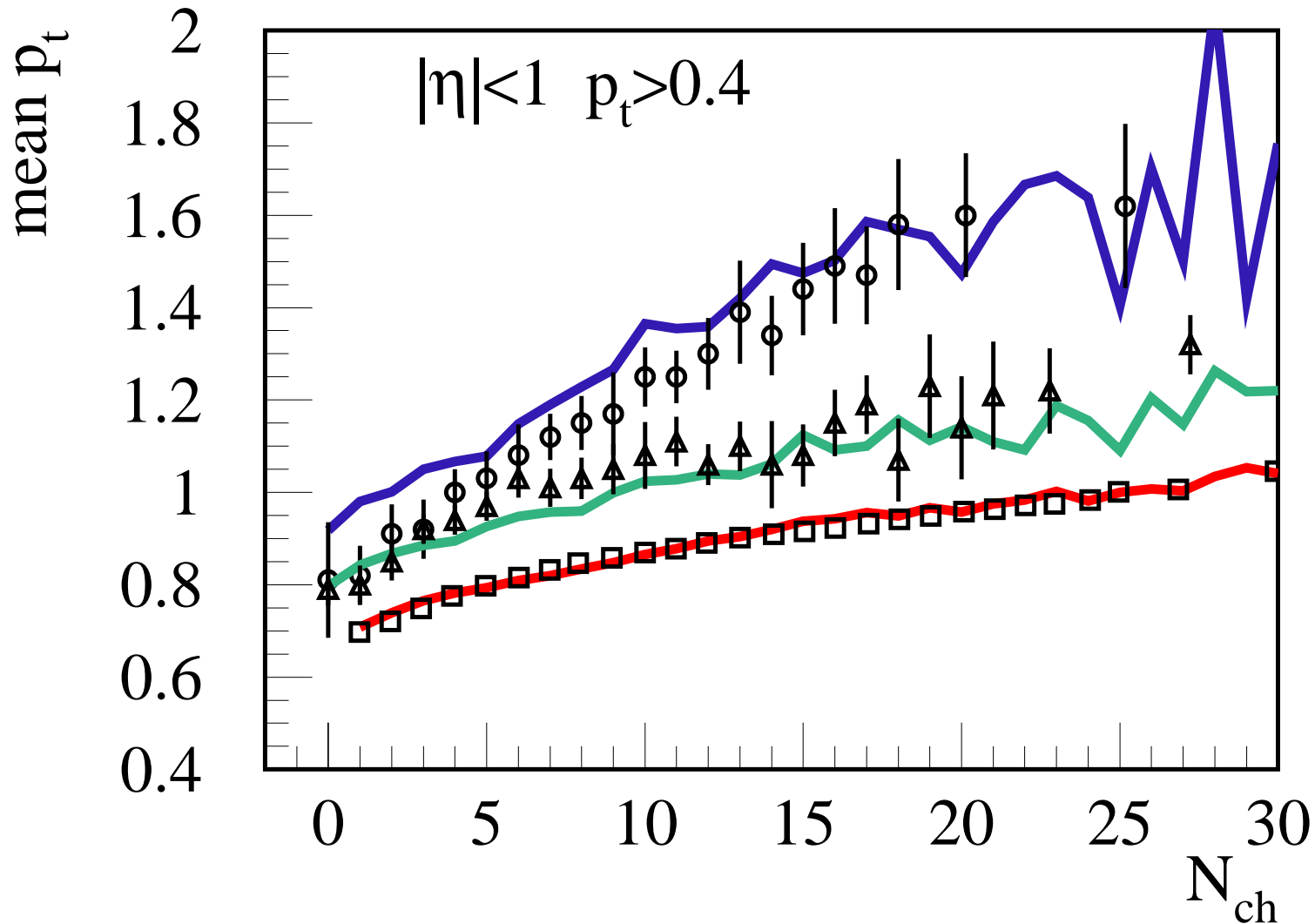


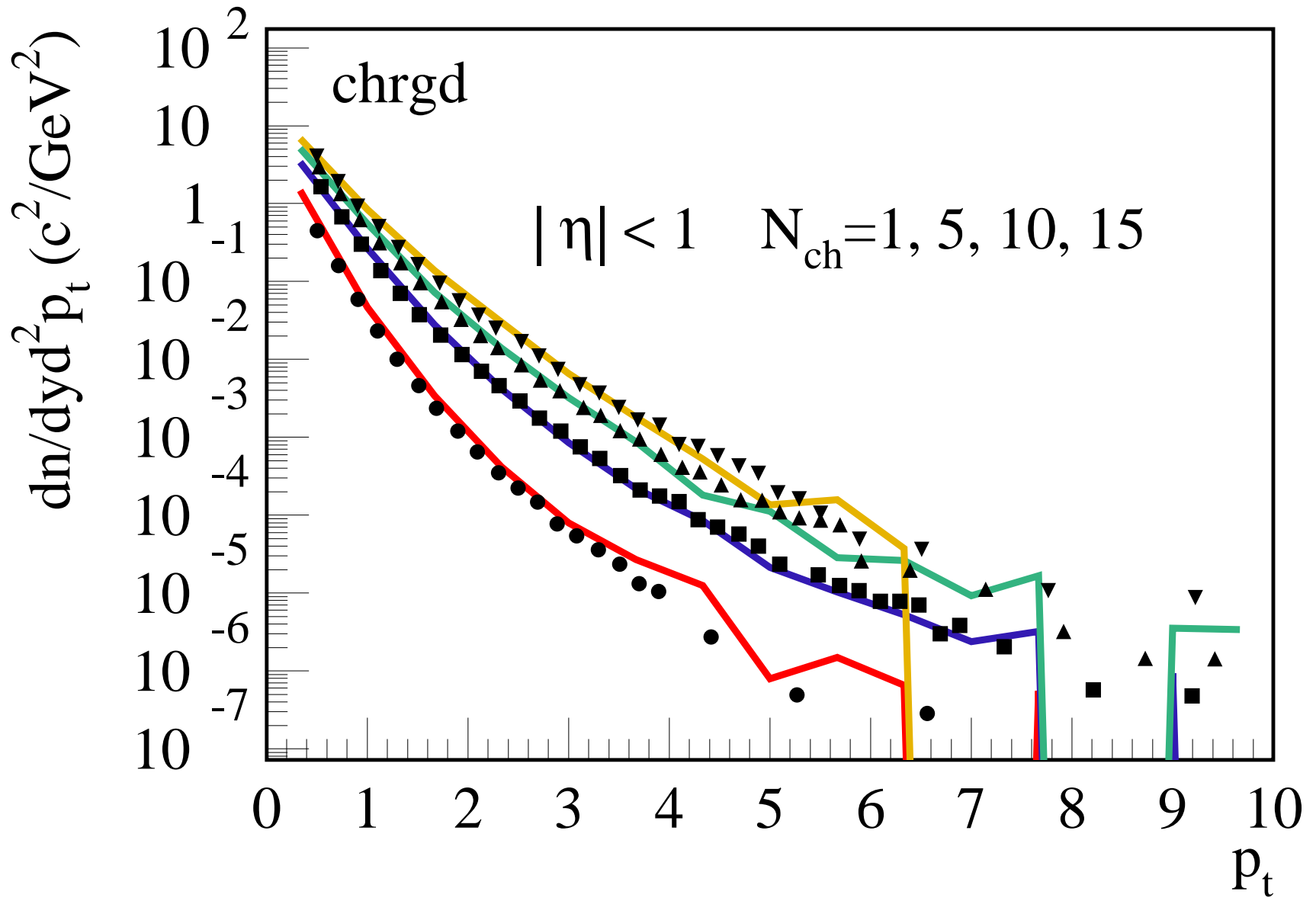
- ▷ First test: “centrality dependence” of particle yields

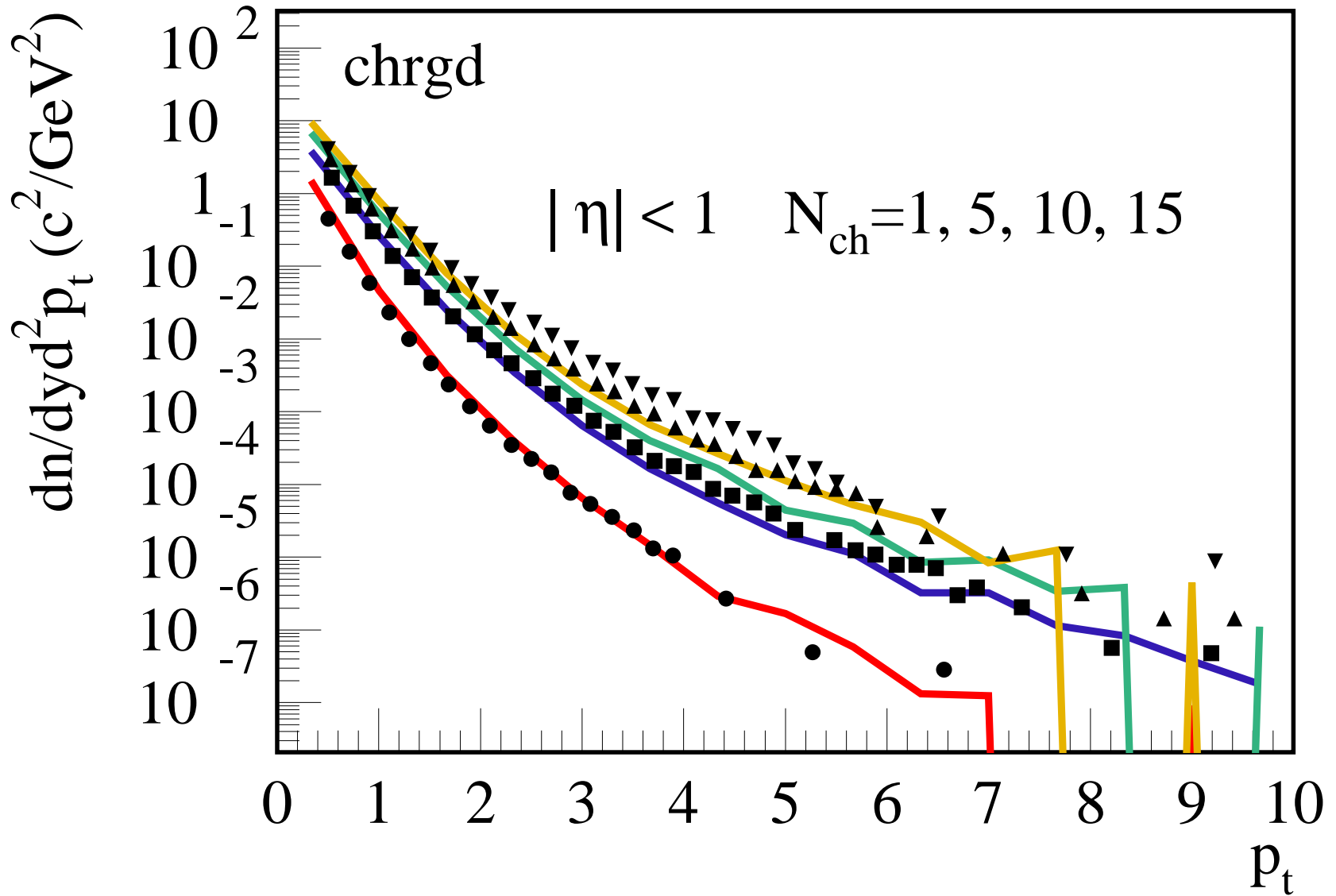
Multiple scattering, but no hydro



Multiple scattering, but **with hydro**
(and small flux tube size!!)







to summarize

- ▷ “Realistic“ hydro approach
 - flux-tube initial cond based on multiple scattering
 - EbE treatment
 - core-corona procedure
 - three flavor cross-over EoS (X3F)
 - 3+1 D hydro
 - hadronic FS cascade
 - full hadron set
- ▷ Explains many soft physics observations in AA
- ▷ Predicts collective behavior in pp@LHC