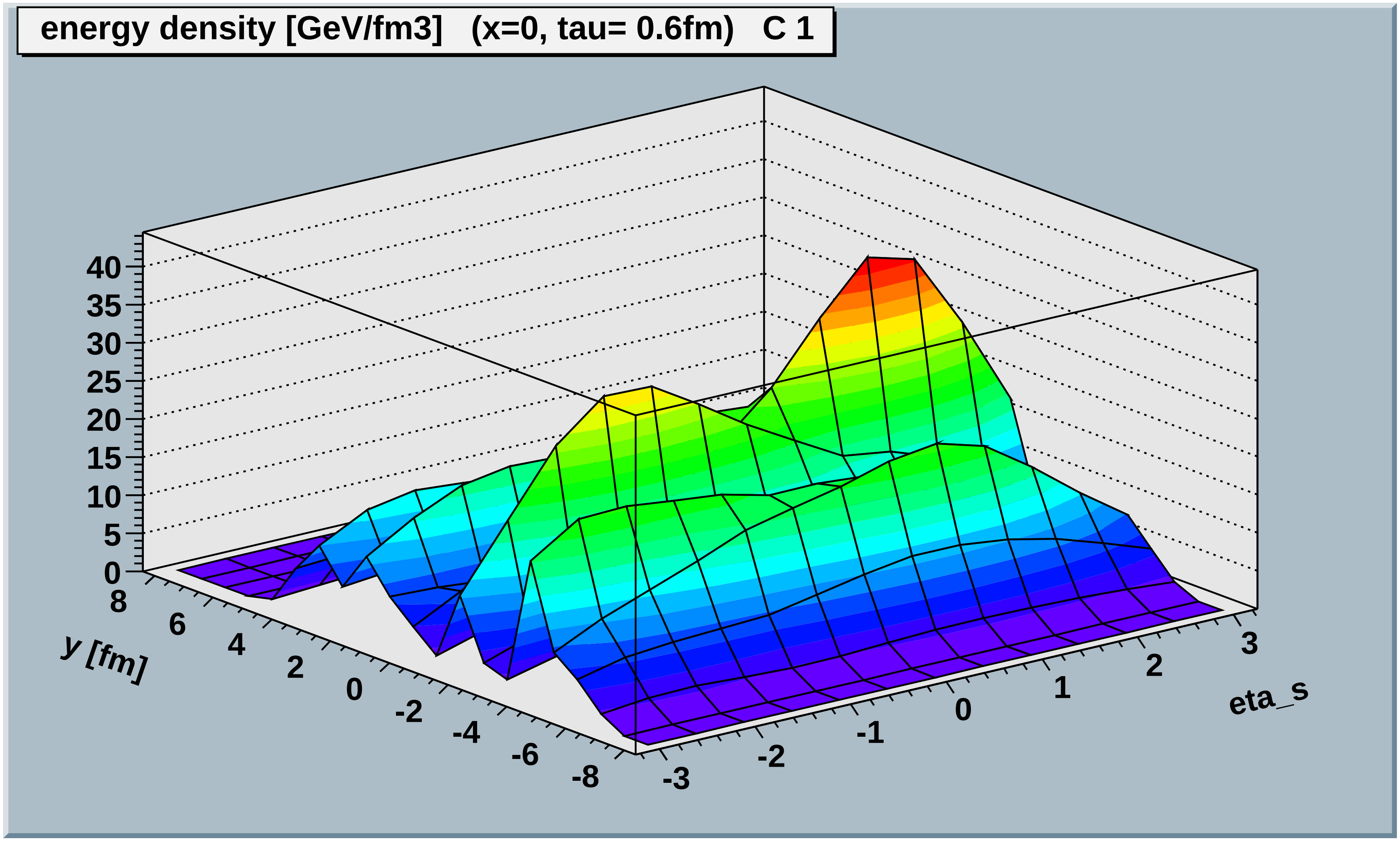
Collective effects in pp scattering

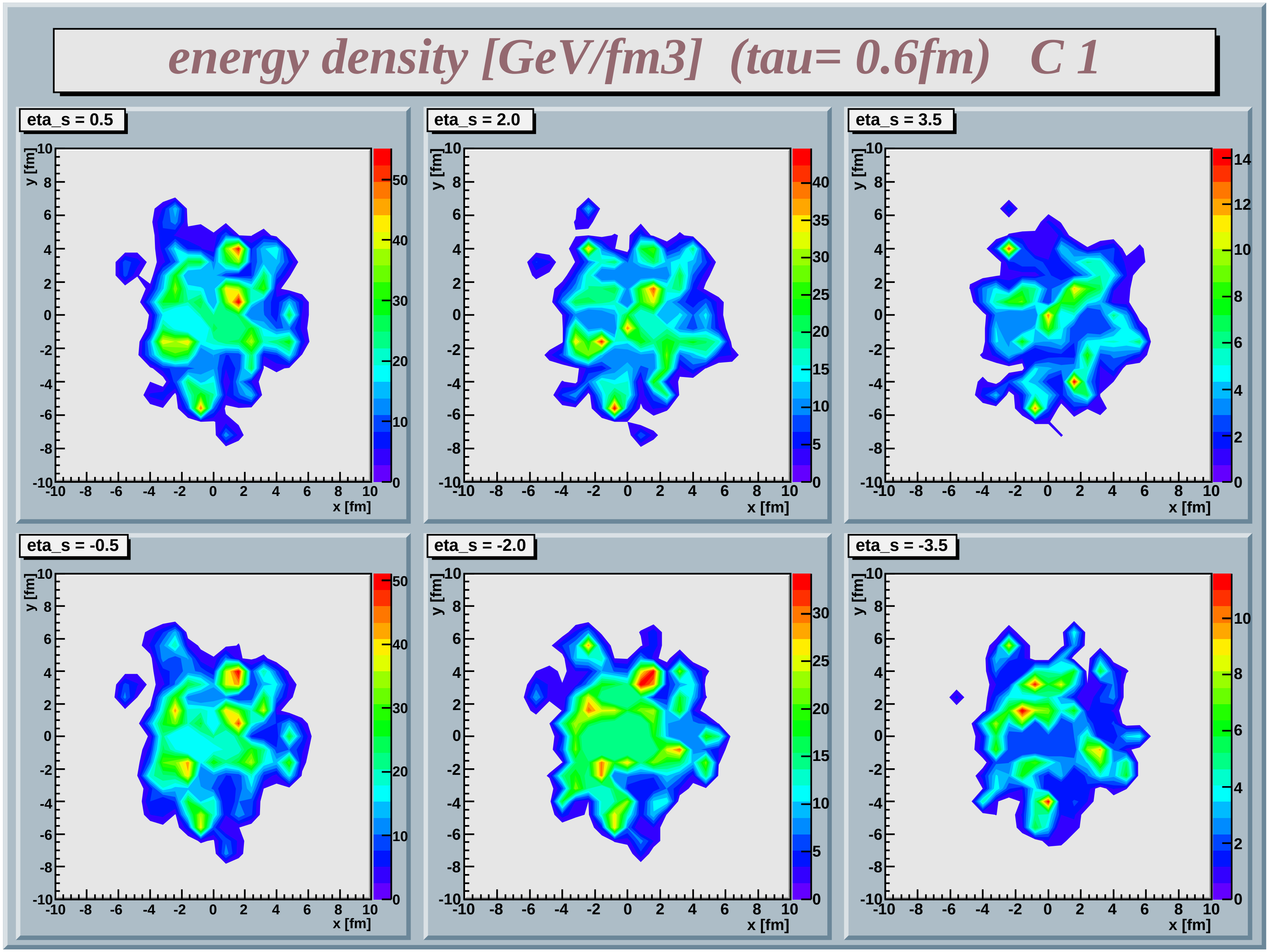
Klaus Werner
<werner@subatech.in2p3.fr>

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

EPOS energy density (0.6fm/c) central AuAu

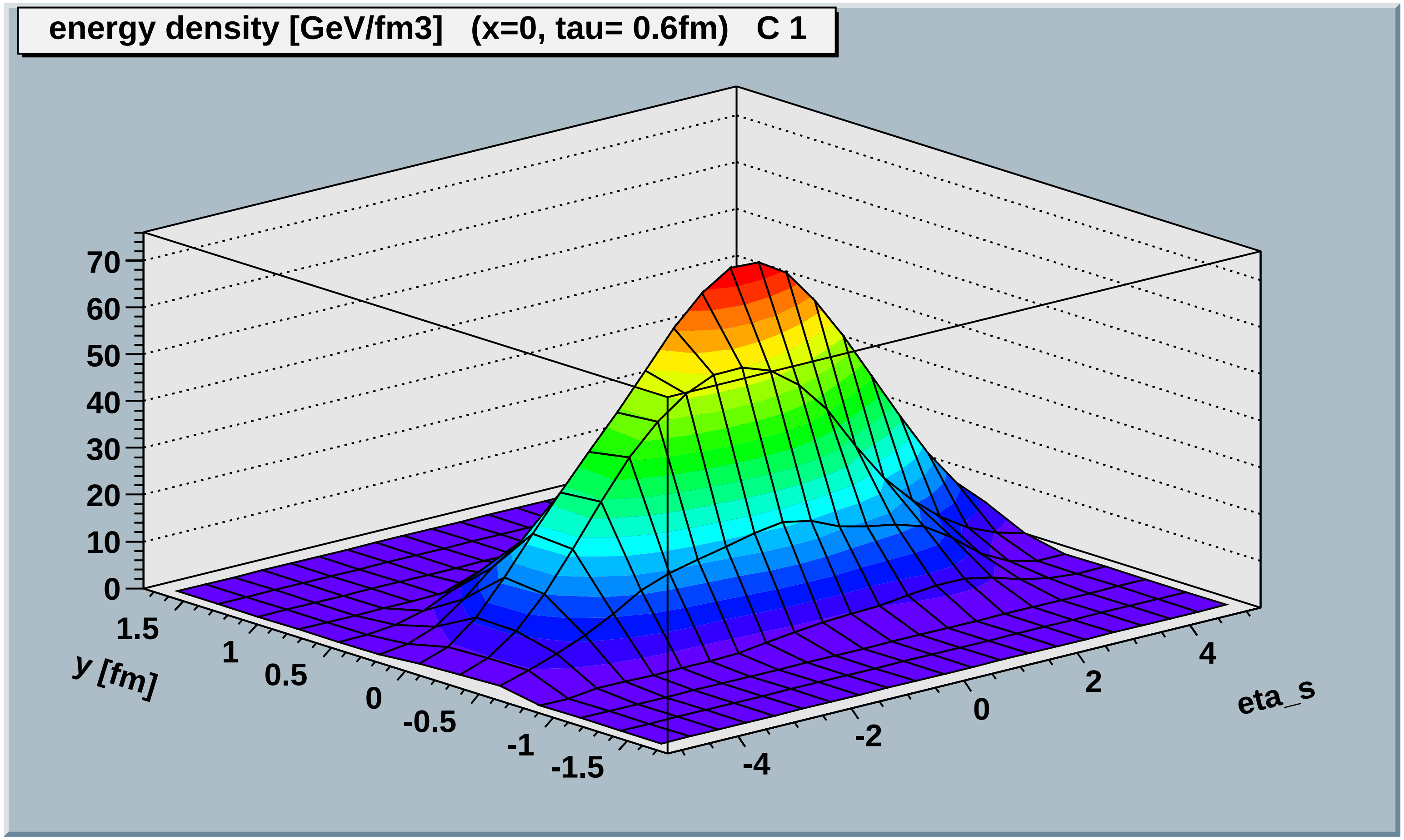


typically several ridges



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...**

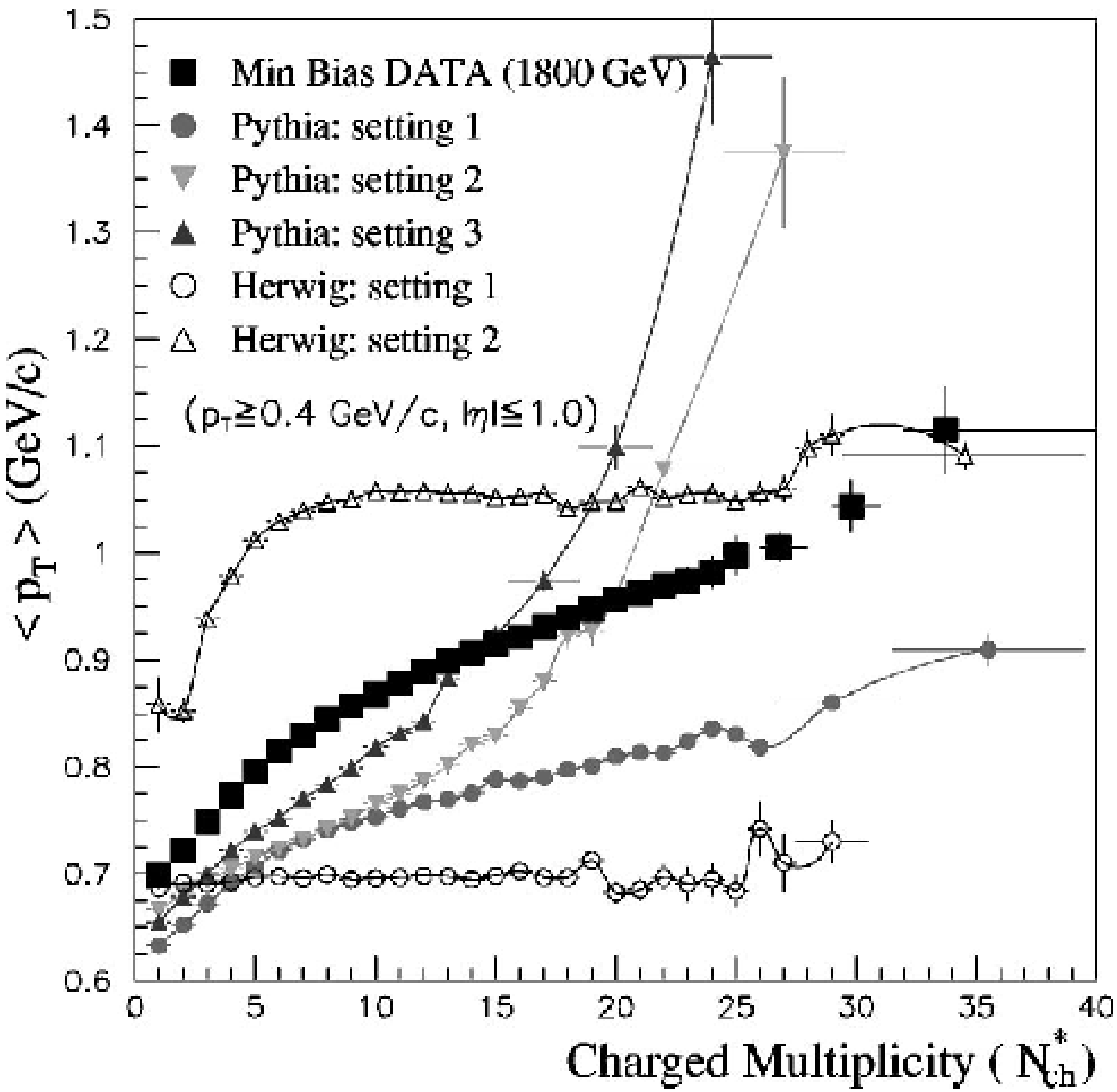
▷ **Here, multiple scattering will help !!**

Multiple scattering in pp

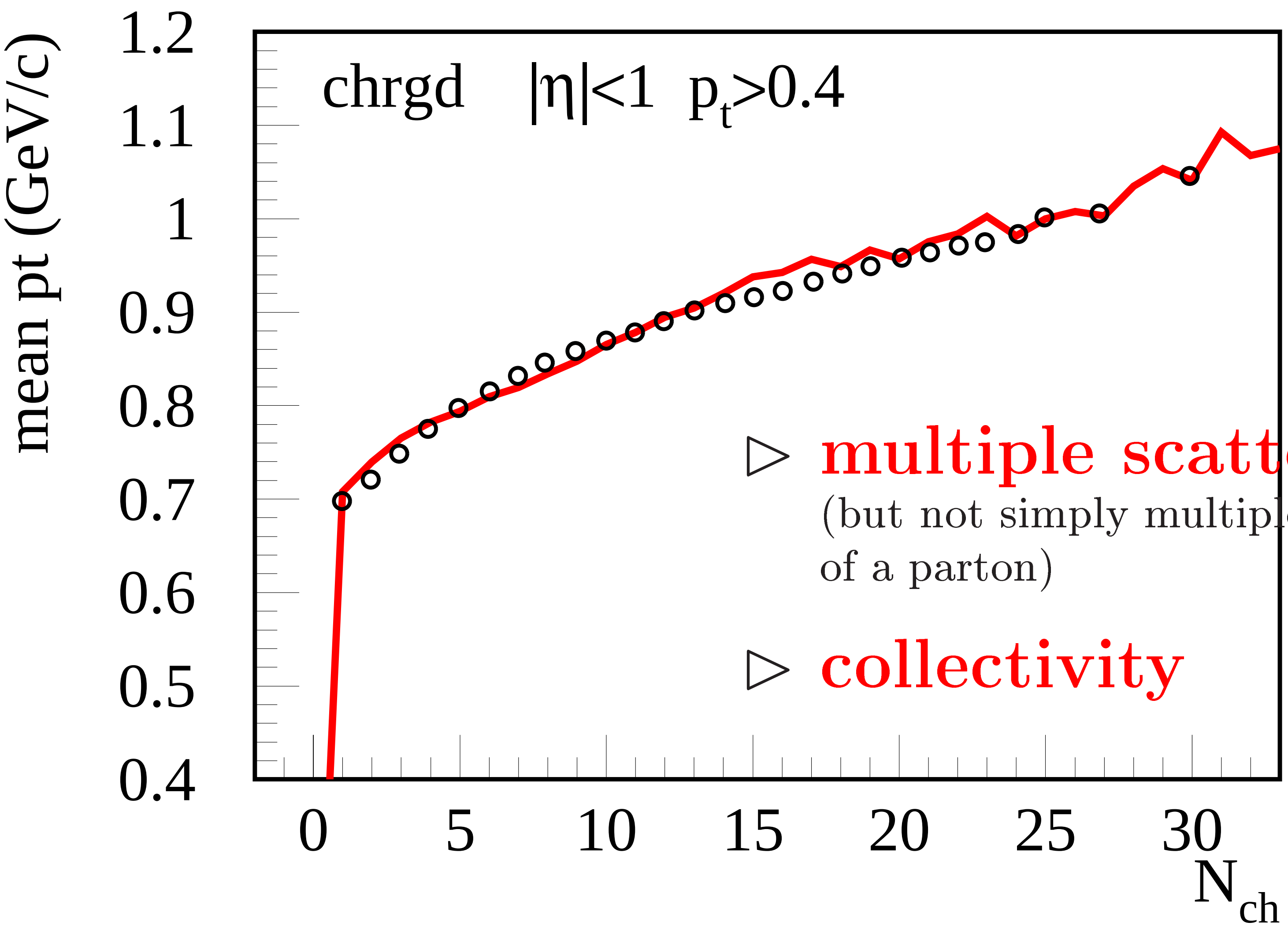
pp@1800GeV
data: CDF

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

recent activities in Pythia community



pp@1800GeV **points: CDF** **curve EPOS**



▷ **multiple scattering**
(but not simply multiple scattering of a parton)

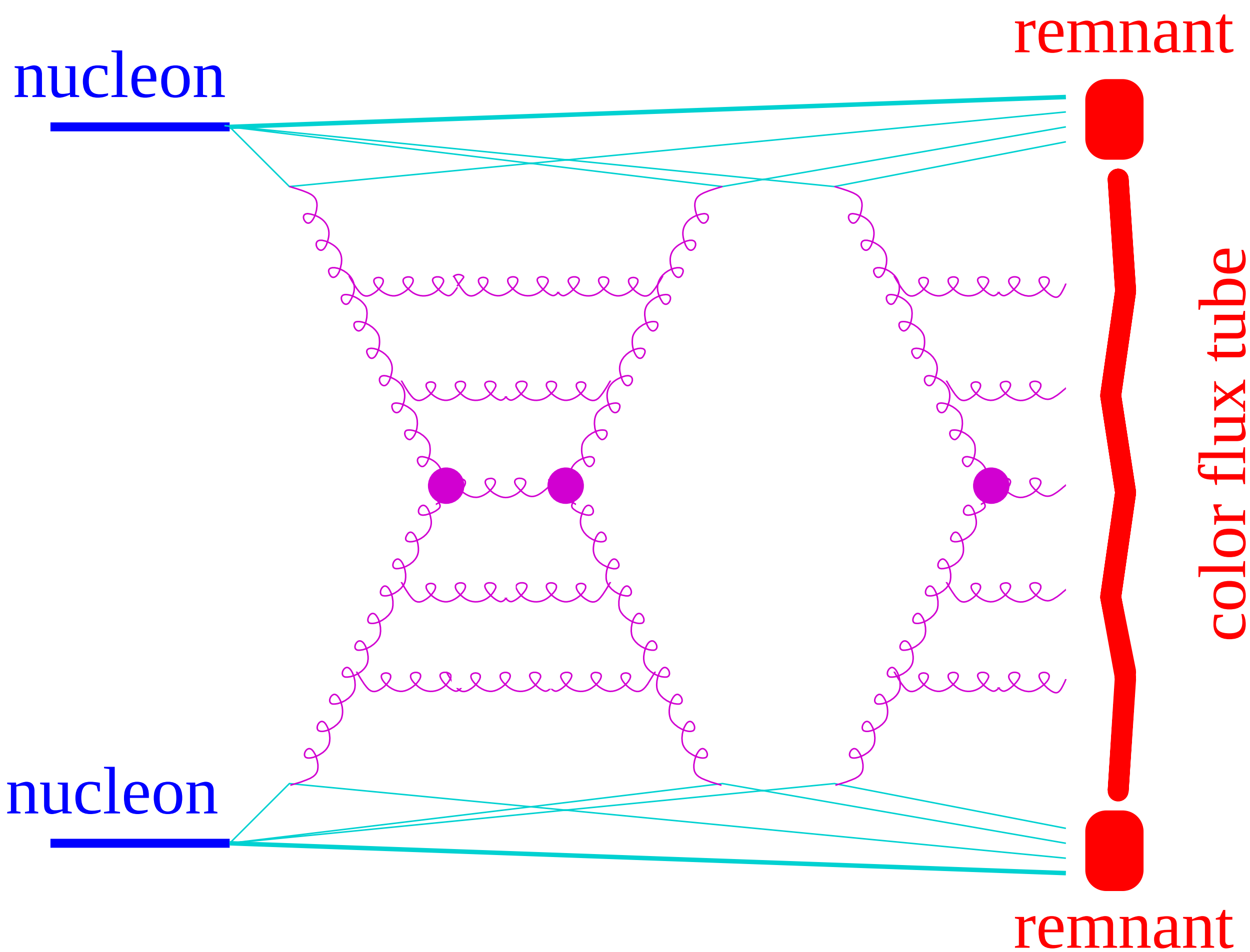
▷ **collectivity**

EPOS: multiple exchange of ladders

Multiple scattering
with energy sharing

Squaring graphs
→ cut diagrams
→ cutting rule techniques

Energy sharing:
Markov chain
techniques

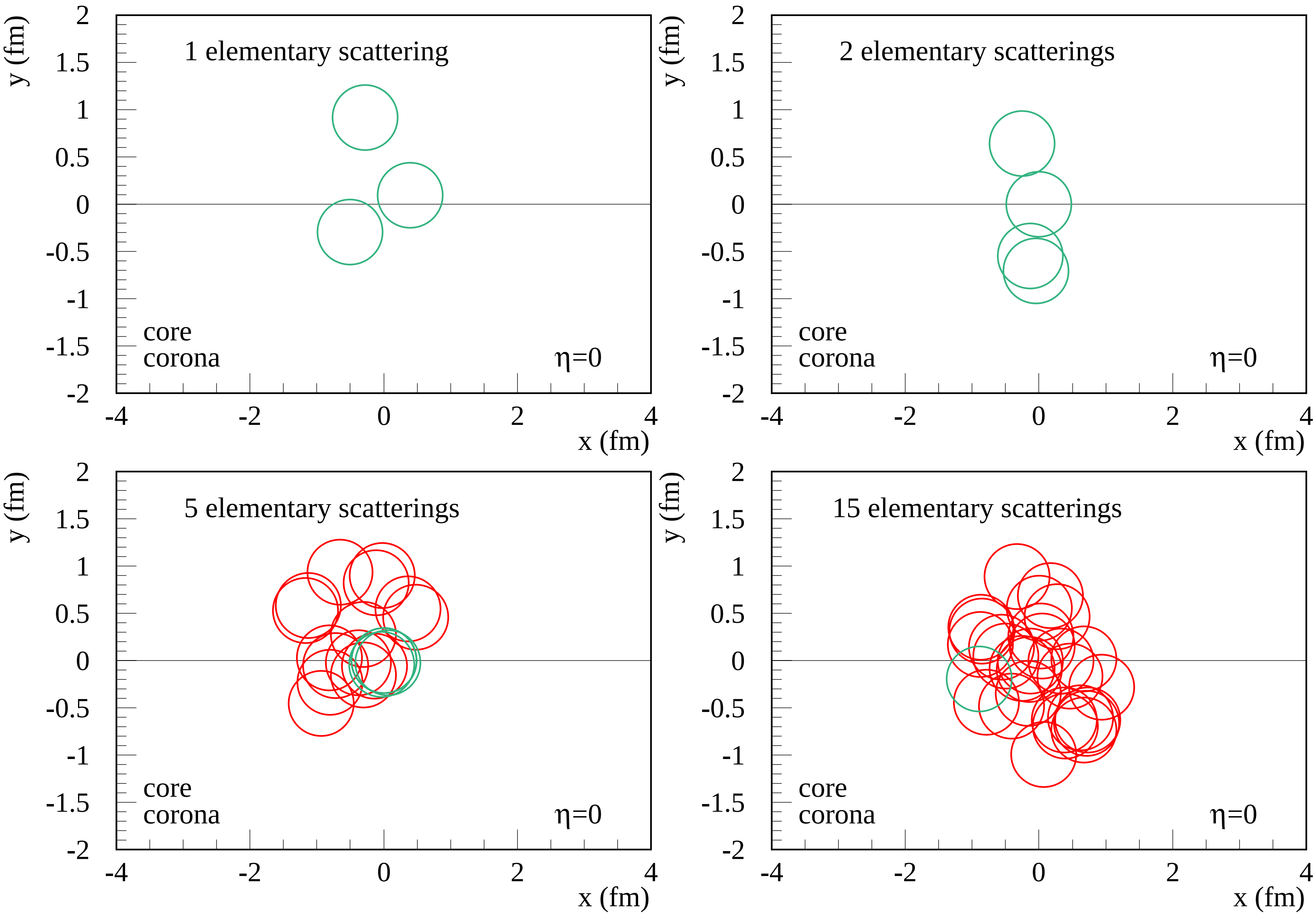


Particle production
from **remnants** and **flux tube** decays (→strings)

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 pt spectra in dAu collisions at RHIC, K. Werner, F.M. Liu, T. Pierog, Phys. Rev. C 74, 044902 (2006)

Core-corona (WWND 2006)

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

FIRST, for checking, same condition as Hirano et al (*), apart of initial condition:

▷ average initial conditions

▷ no corona

▷ simplified EoS (1st order PT, $\mu_B = \mu_S = \mu_Q = 0$)

▷ limited hadrons set

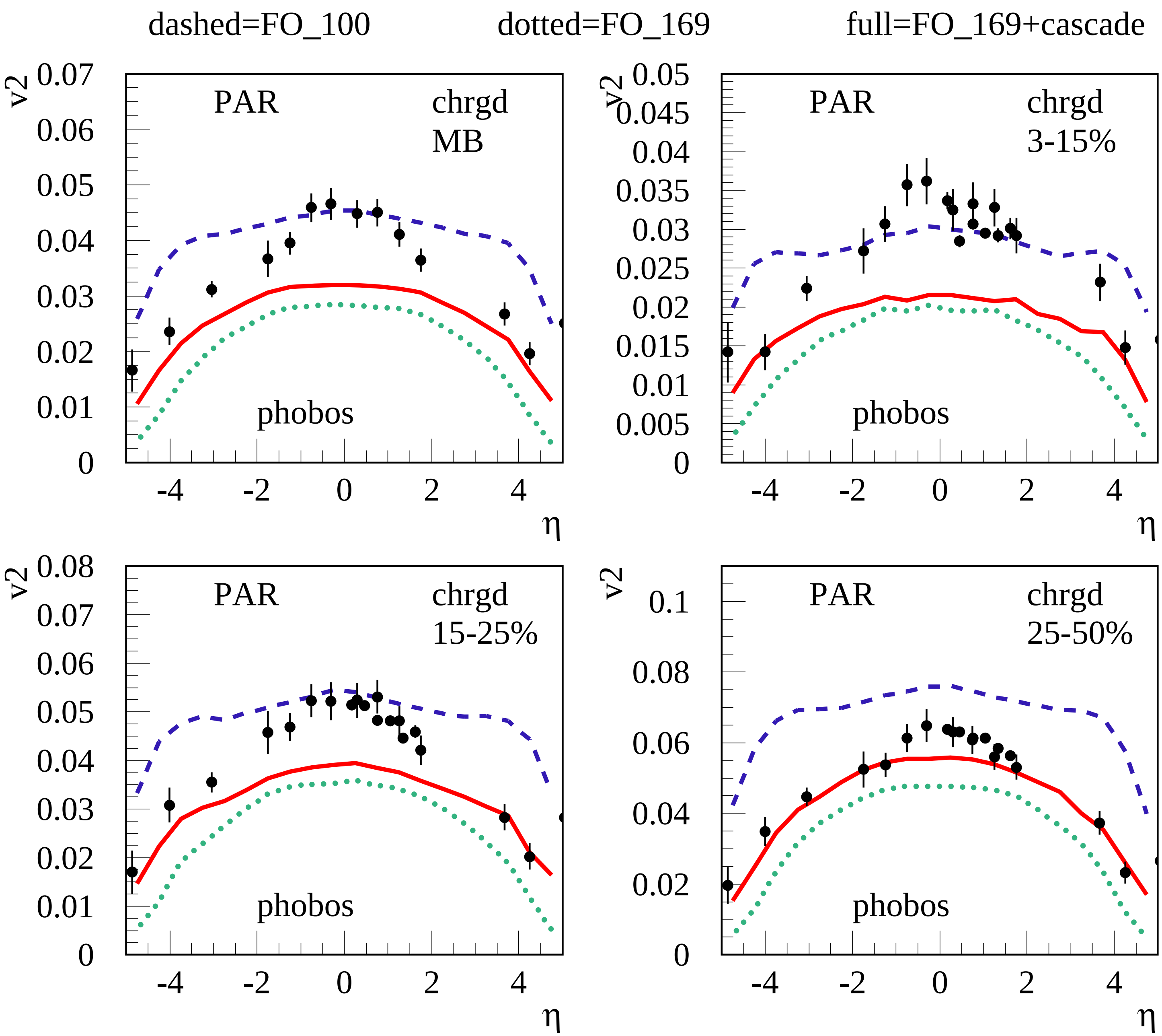
We compare flux tube (**EPOS**) initial conditons (averaged) with parameterized ones (**PAR**) from (*)

Most striking difference:
v2 rapidity dependence

————————————————————————————————-

$*$ Hirano, Heinz, Kharzeev, Lacey, Nara, Phys.Rev.C77: 044909,2008

Elliptical flow *(Hirano initial condition & PCE EoS)*



dashed:
pure hydro, FO at 100 MeV

dotted:
pure hydro, FO at 169 MeV.

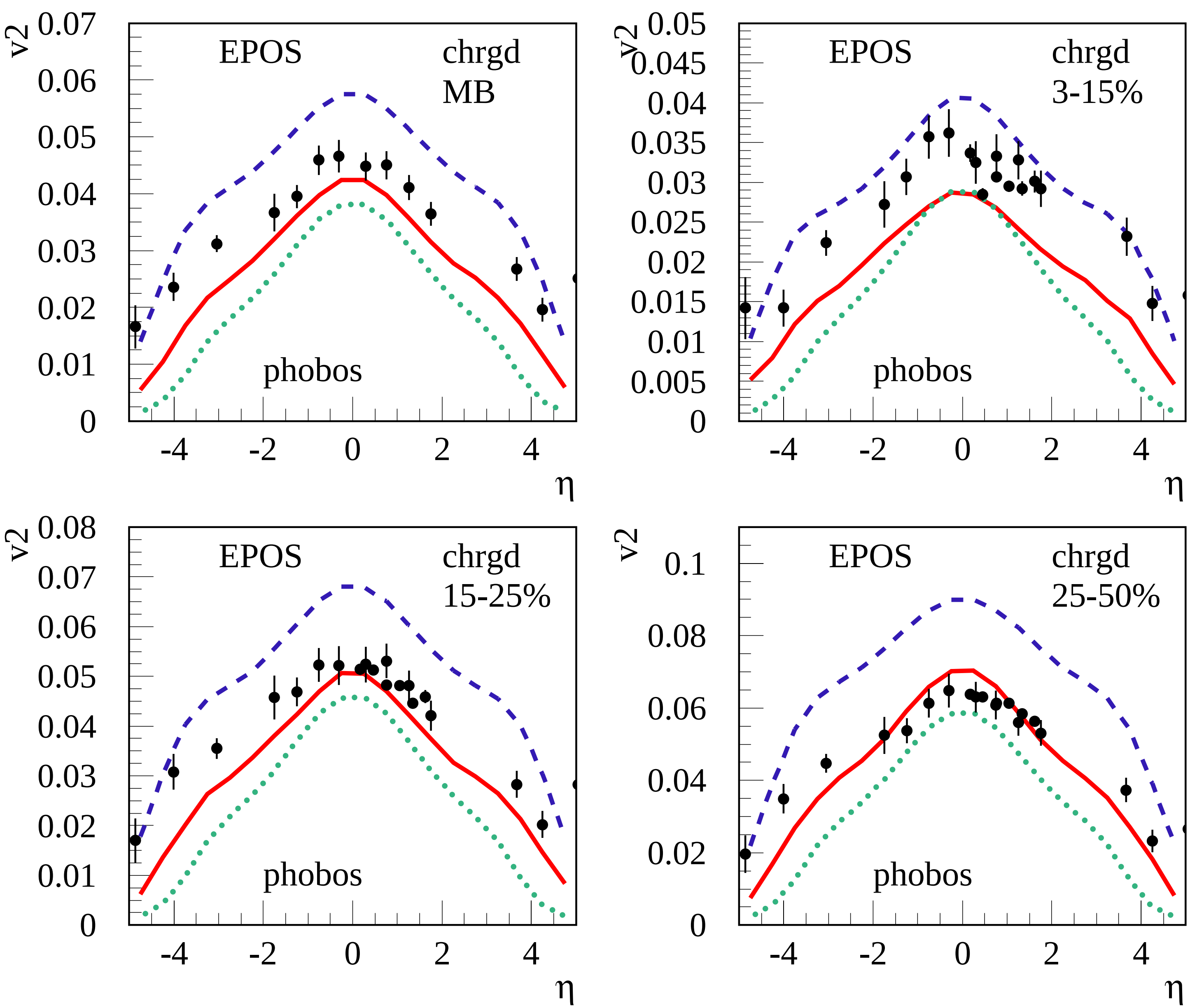
full:
hydro, FO at 169 MeV, + hadronic cascade

(UrQMD in collaboration with S.Haussler, M.Bleicher, S. Porteboeuf)

$T_c = 170\text{MeV}$

Elliptical flow *(EPOS **flux tube** initial condition, core)*

dashed=FO_100 dotted=FO_169 full=FO_169+cascade



dashed:
pure hydro, FO at 100 MeV

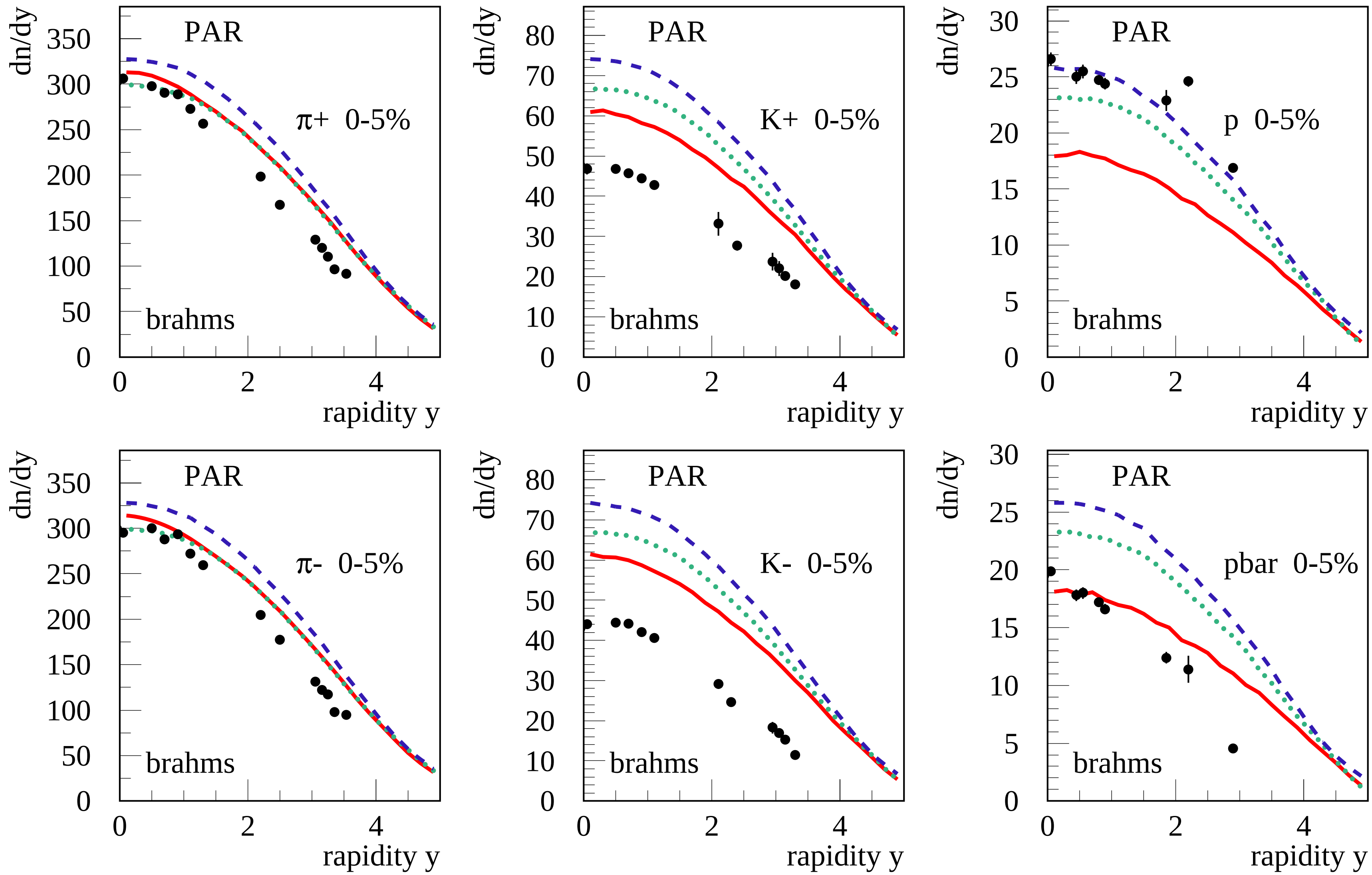
dotted:
pure hydro, FO at 169 MeV.

full:
hydro, FO at 169 MeV, + hadronic cascade

EPOS here means pure hydro, no corona

Yields *(Hirano initial cond & PCE EoS)* ≈*EPOS*

dashed=FO_100 dotted=FO_169 full=FO_169+cascade



In the following:

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

Needed: early freeze out (166 MeV) + HC

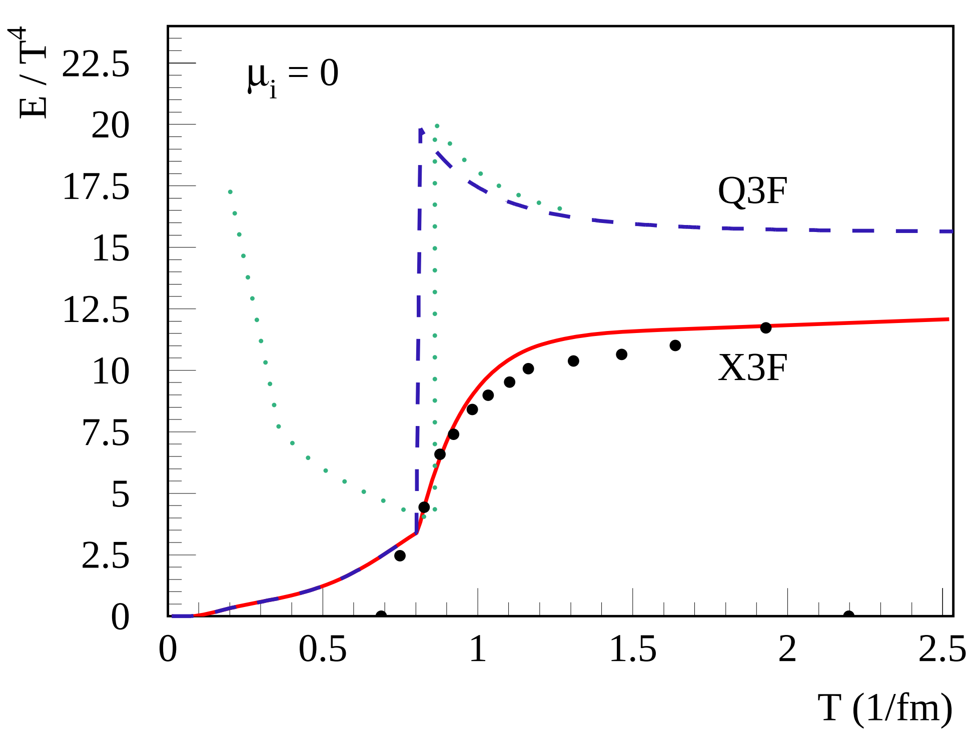
EoS:

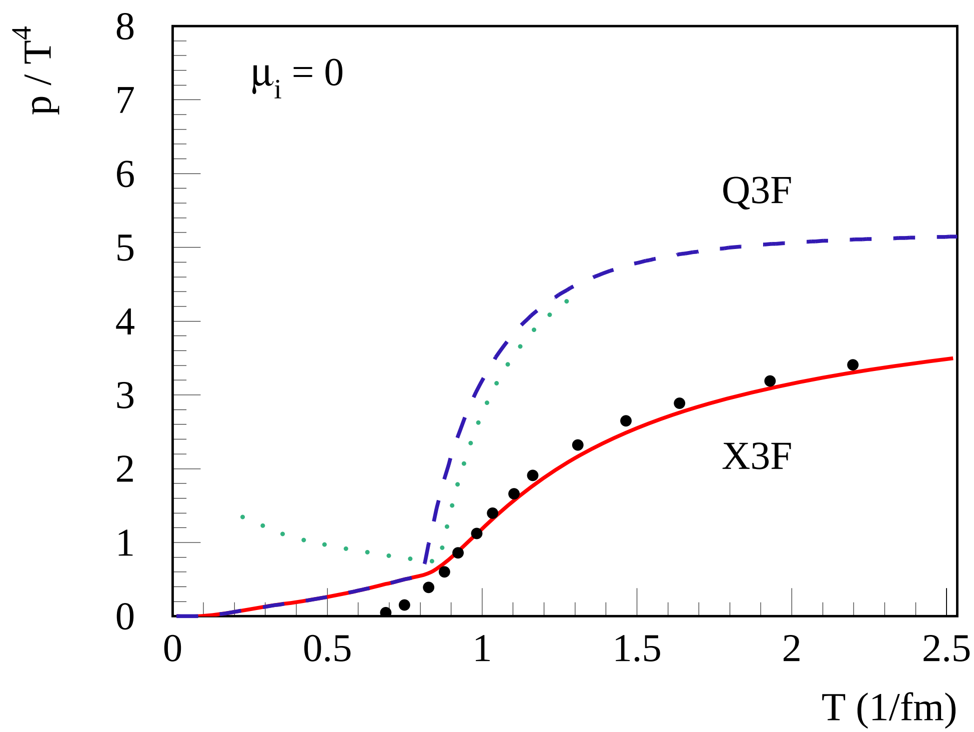
Hirano: QG & resonance gas => 1st order PT, PCE, $\mu_B = \mu_S = \mu_Q = 0$

Q3F: QG & "complete" resonance gas => 1st order PT, excl volume correction, μ_B, μ_S, μ_Q considered, parameters as in Spherio

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

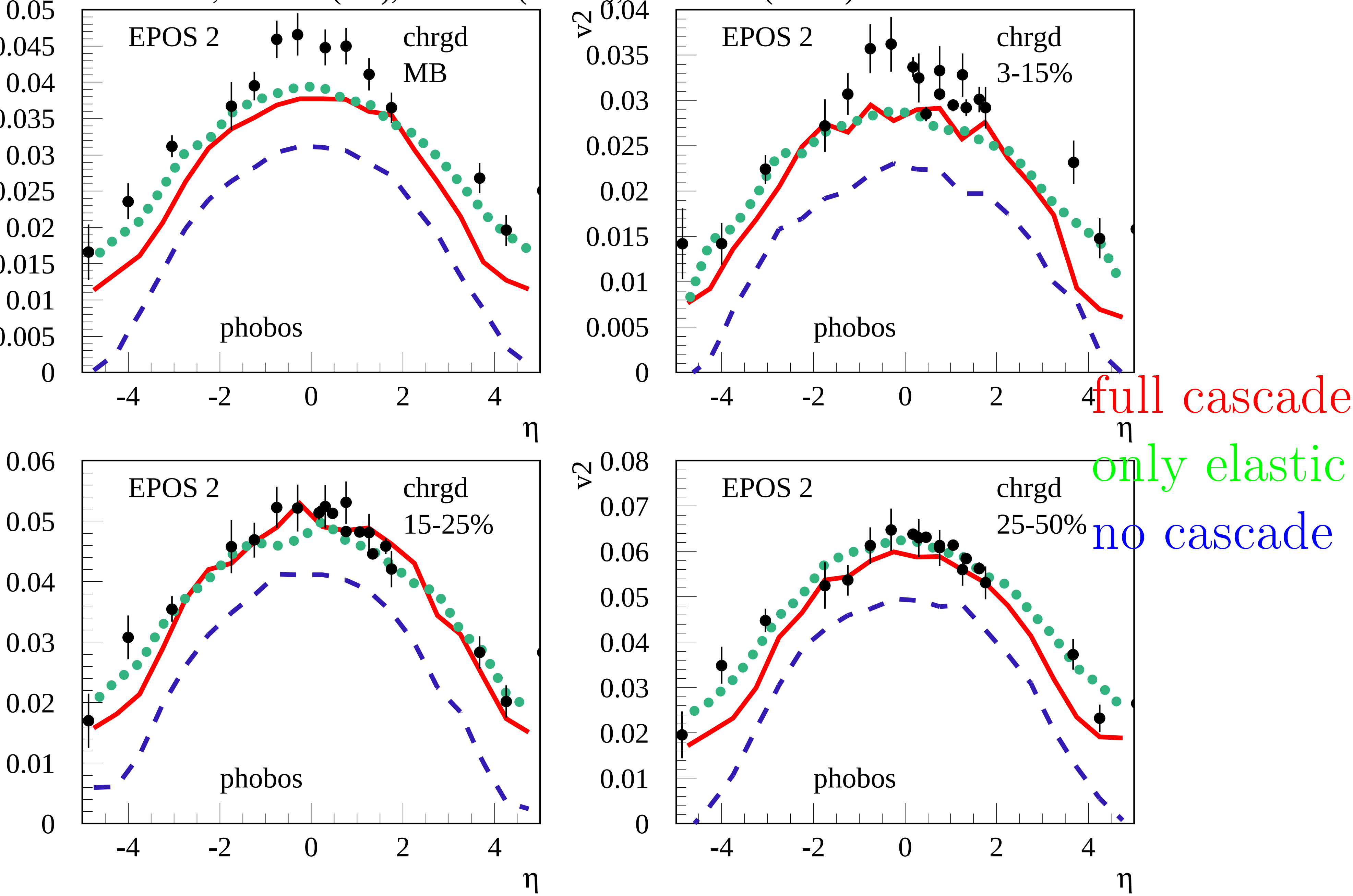
"data": Y. Aoki, Z. Fodor, S.D. Katz , K.K. Szabo, JHEP 0601:089,2006





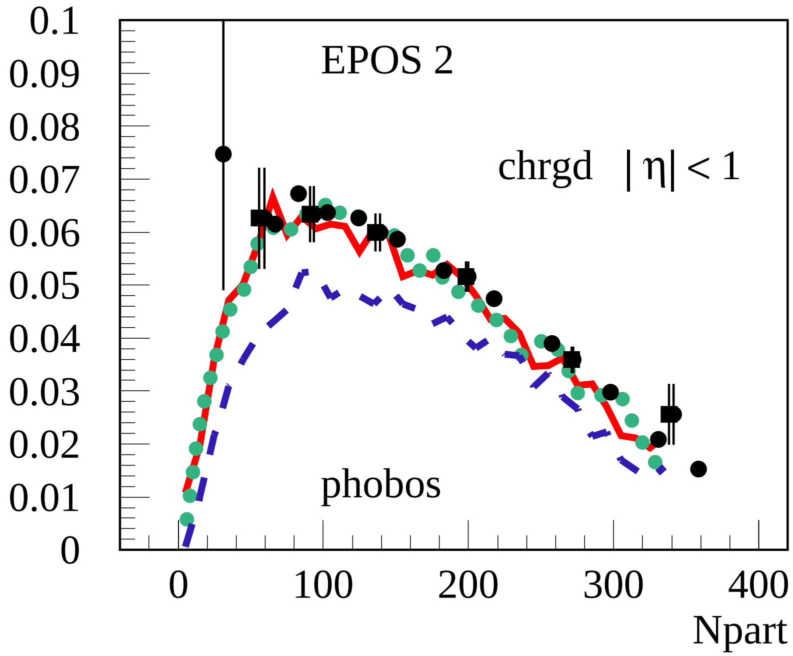
v2(rapidity)

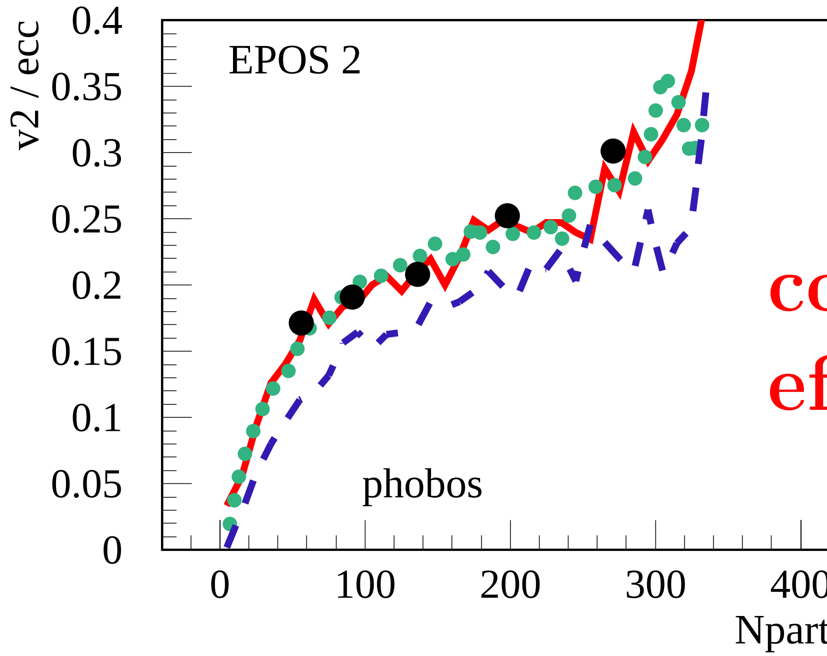
FO 166 MeV, with HC (full); w/o HC (dashed); with HCe (dotted)

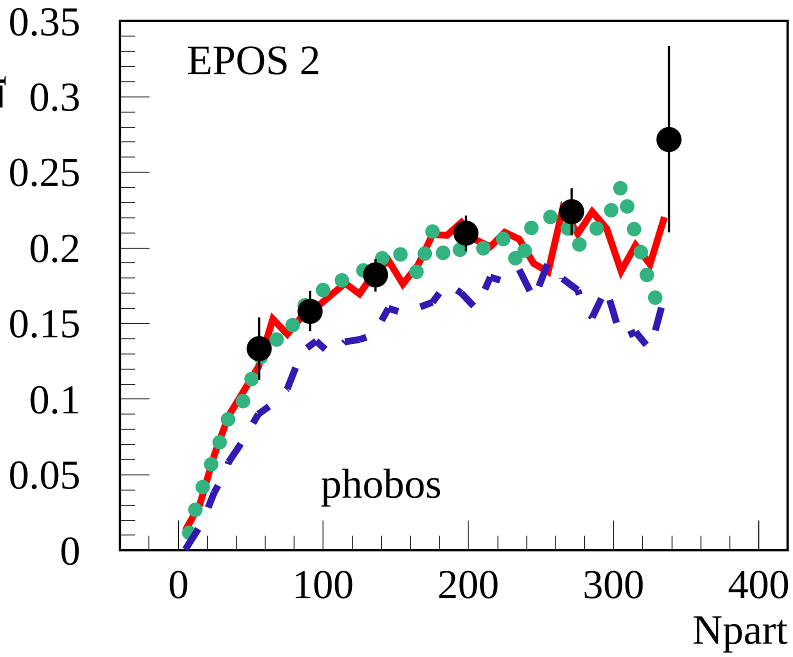


v2 and v2/ecc vs Npart

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







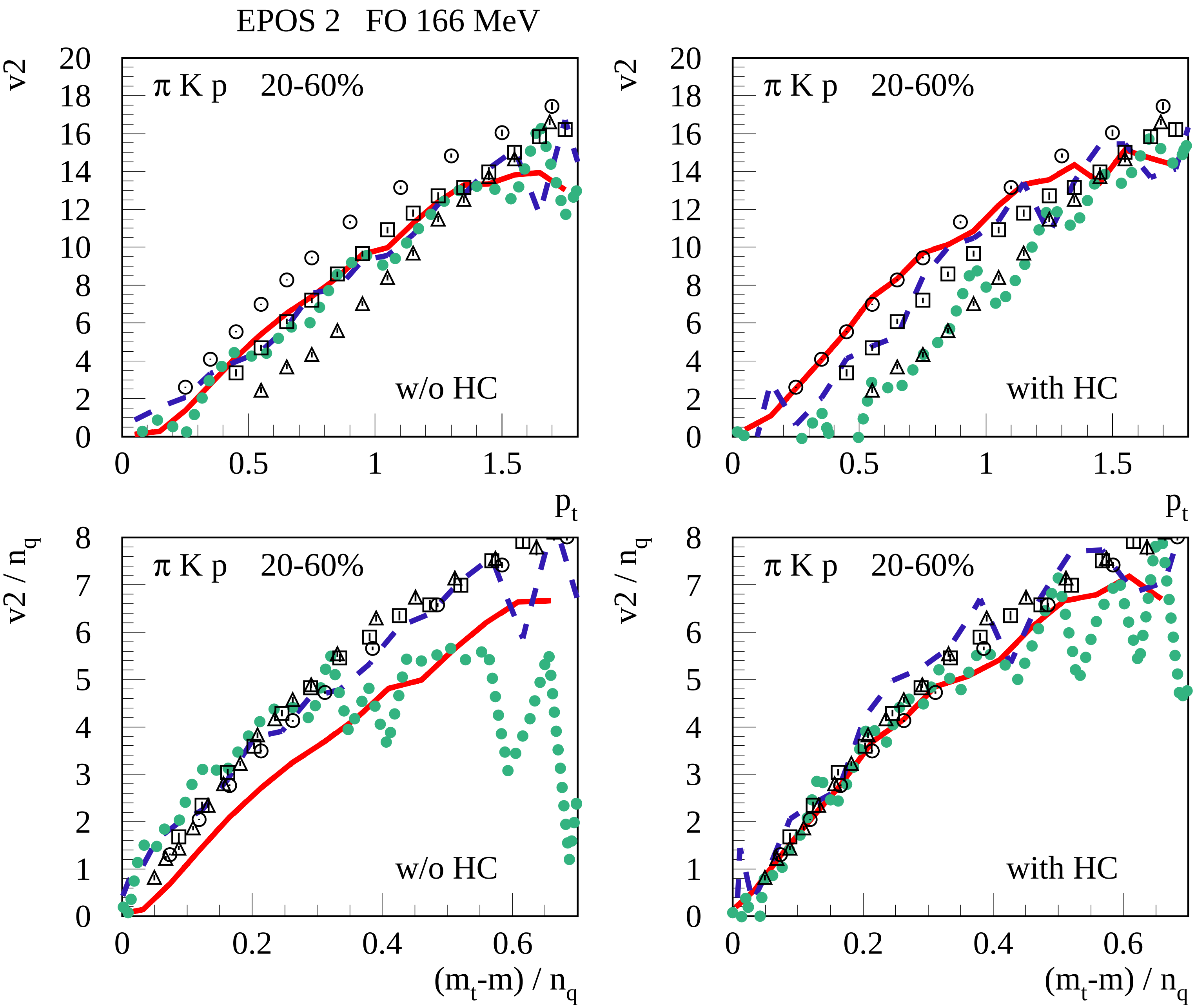
core-corona effect

full cascade

only elastic

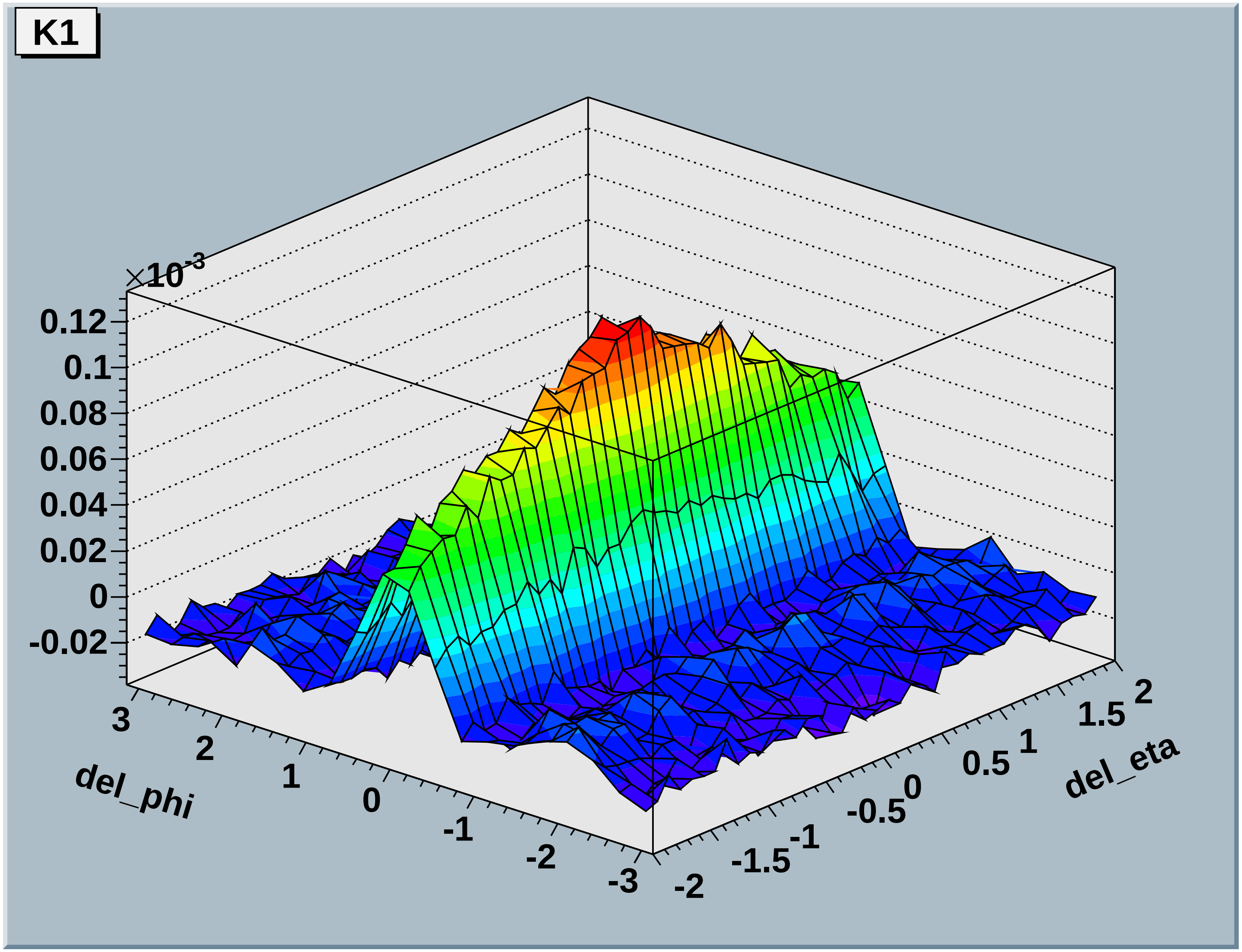
no cascade

v2 vs pt



EPOS 2

di-hadron correl.



AuAu 0-10%, $3 < p_t^{trig} < 4\,\mathrm{GeV/c}$ $2 < p_t^{assoc} < p_t^{trig}$

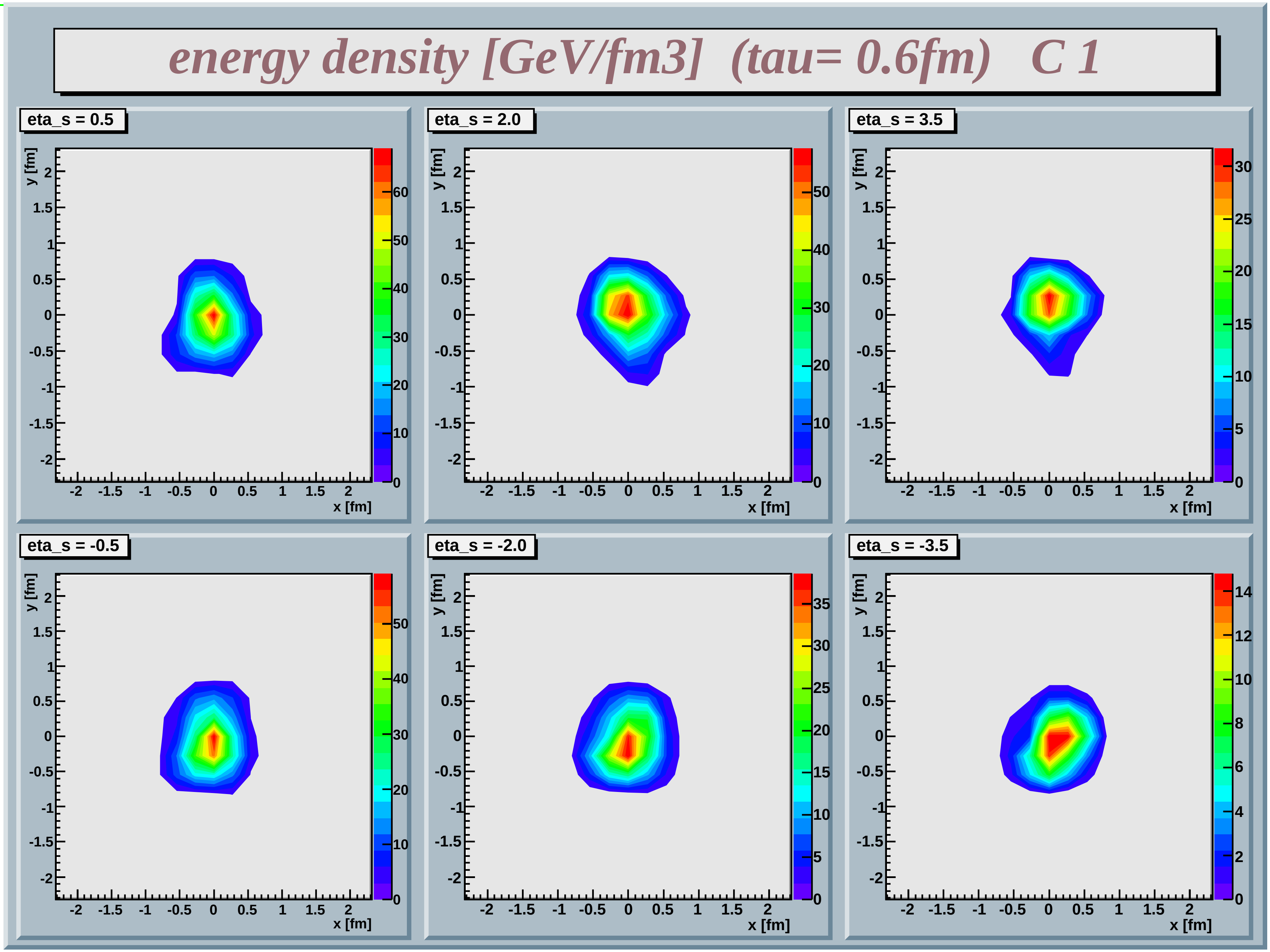
back to pp ...

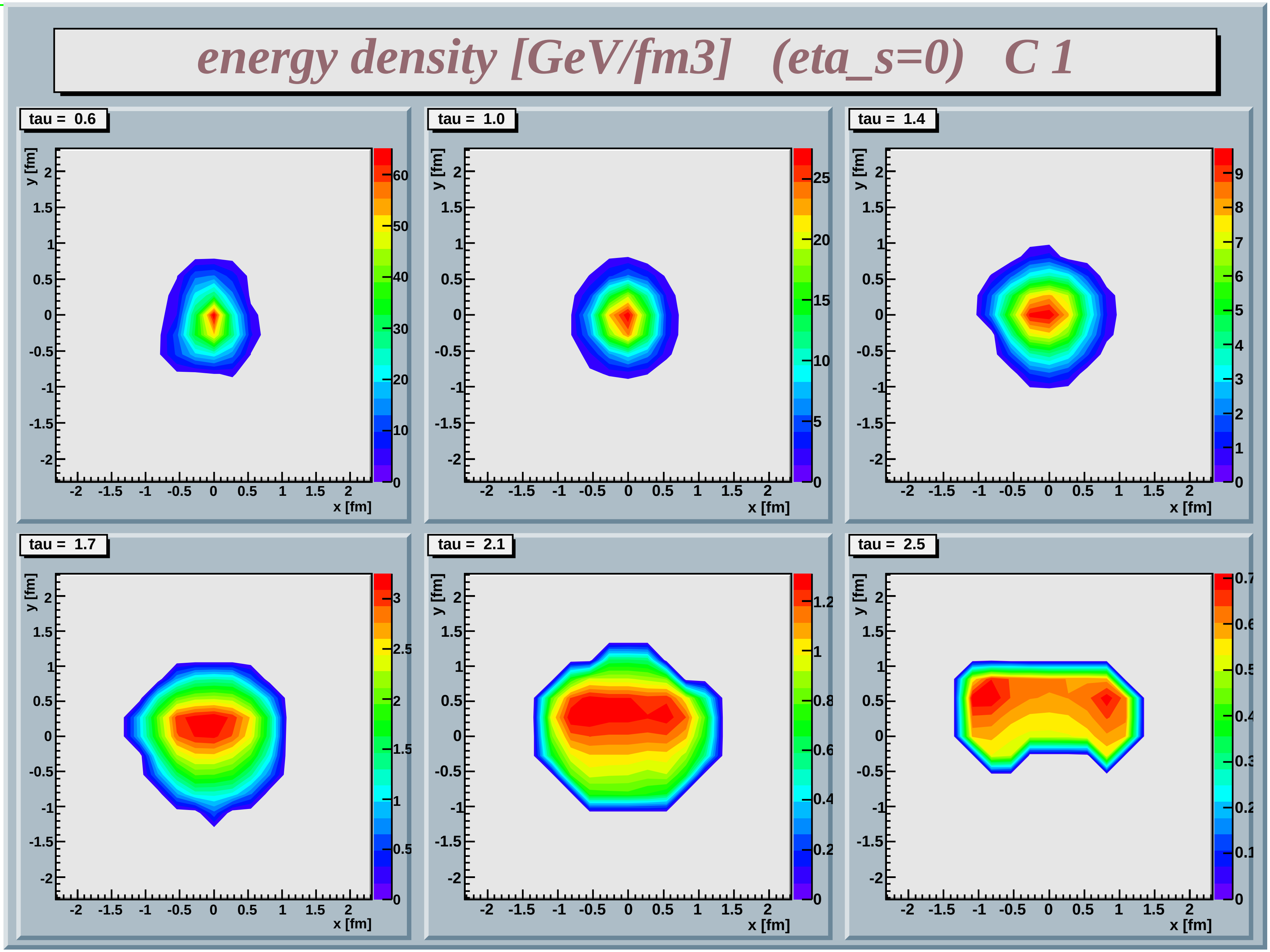
In the following

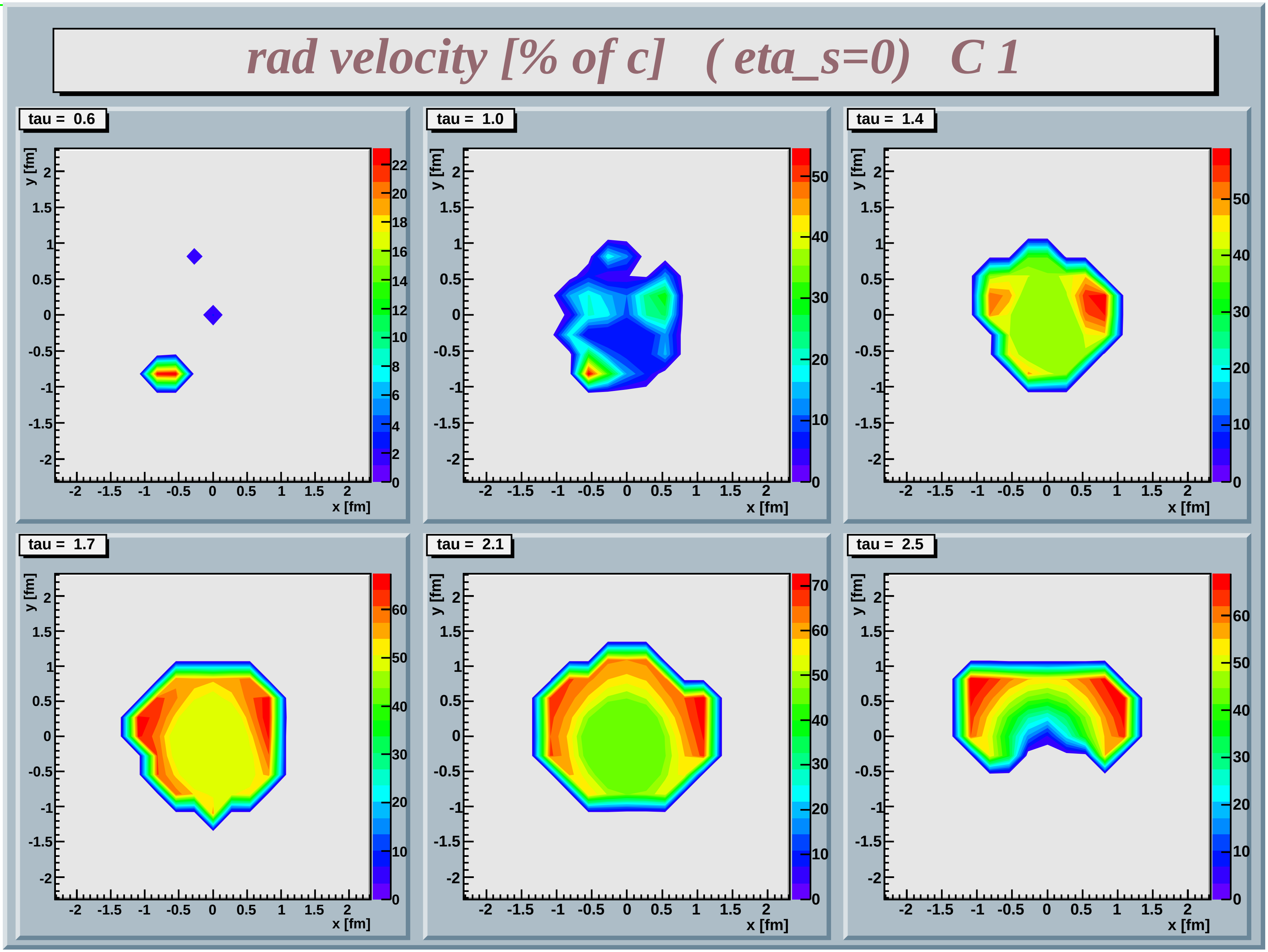
the first real hydro calculation

for pp@1800 GeV

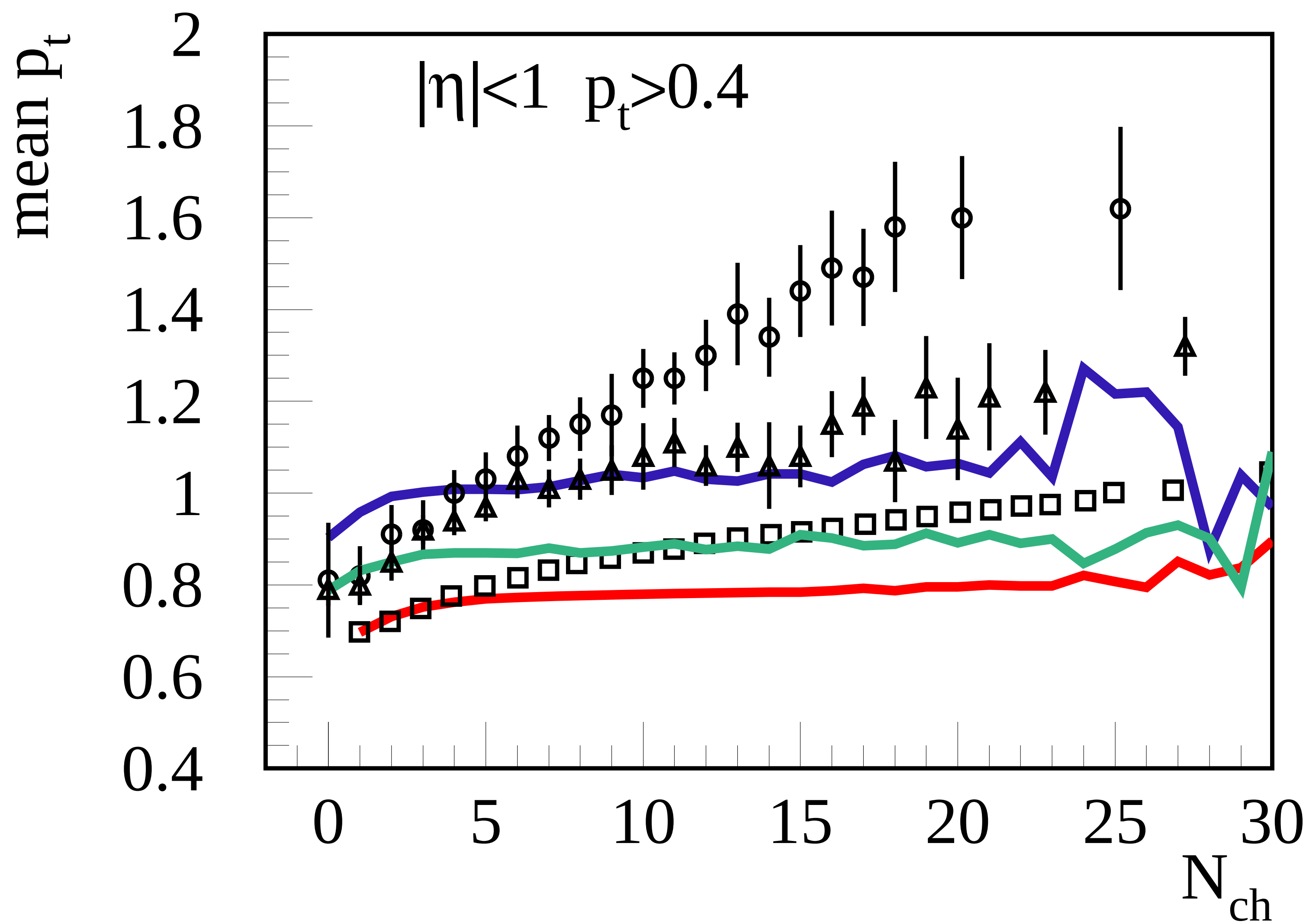
Parameters (except flux-tube radius)
obtained from AuAu


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
x [fm]
y [fm]

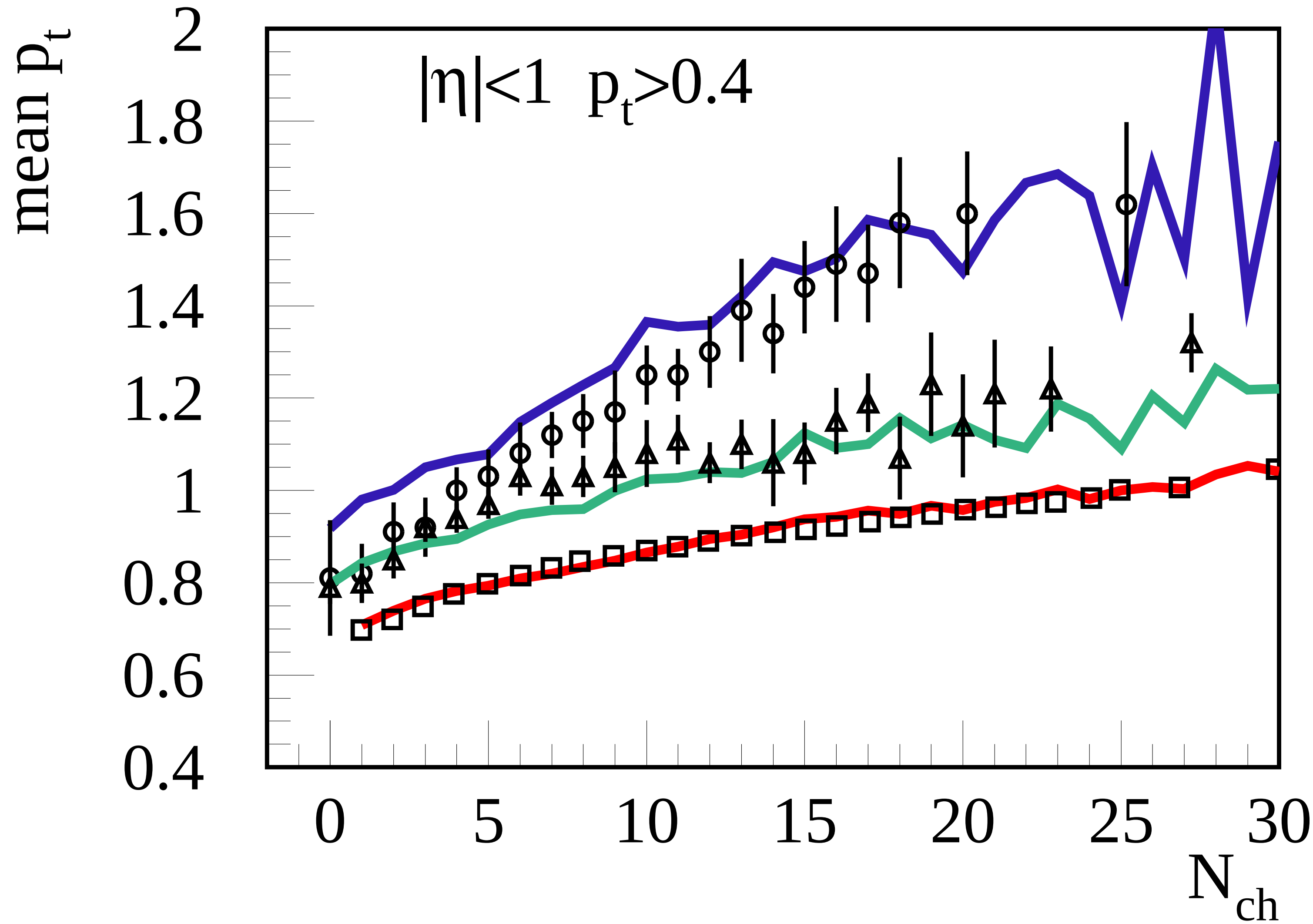

energy density [GeV/fm3] (eta_s=0) C 1
tau = 0.6
tau = 1.0
tau = 1.4
tau = 1.7
tau = 2.1
tau = 2.5
x [fm]
y [fm]


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
y [fm]
x [fm]

Multiple scattering, but no hydro



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



to summarize

- ▷ Core-corona procedure separates events into two classes: core and corona events
- ▷ Multiple scattering provides high energy density “core events”
- ▷ core events should expand collectively, decay statistically
- ▷ EPOS 2 features
  - flux-tube initial cond based on multiple scattering
  - core-corona procedure
  - three flavor cross-over EoS (X3F)
  - EbE treatment
  - hadronic FS cascade
  - full hadron set