6 th International Conference on Physics and Astrophysics of Quark Gluon Plasma
6 – 10 December 2010
Goa, India

Event by Event Hydrodynamics and Particle Correlations

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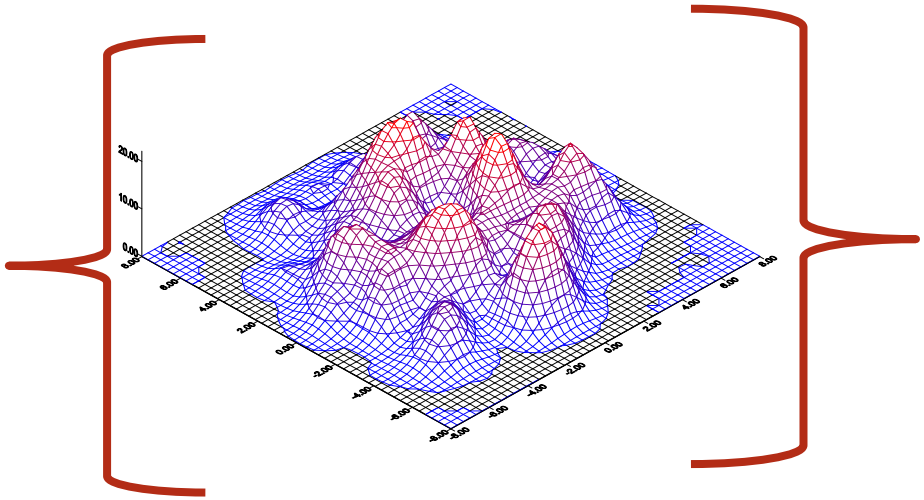
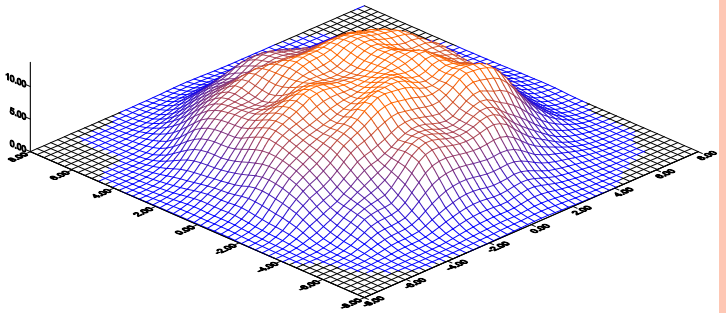
+ Nu Xu (LBL)

Fluctuations in the Initial Condition

- Normal hydrodynamic approach, the initial condition is taken as smooth distribution
- For one collisional event, there may appear very strong inhomegeniety in the initial energy density profile.
- Since physical obervables are taken over average of many events, we may use the average initial condition,... (?)

We may think of smooth averaged initial condition



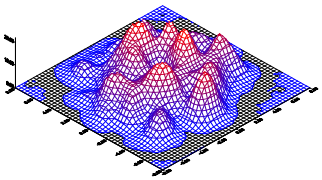


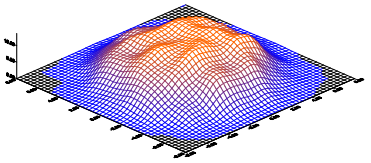
Ensemble of spiky initial distribution

Smooth distribution as average of events.

However, this may not give a good description of final observables …..

$$\left\{ F\left[\quad \right] \right\} \Rightarrow ? \quad F\left[\quad \right]$$





Technical Issue

To perform hydro calculation for spiky initial conditions, a very tough and stable hydro code is required,…

- **S**moothed **P**article **H**ydrodynamics
- Based on variational principle
- Lagrangian coordinate
- Need to circumvent the problem of zero baryon chemical potential by following entropy profile

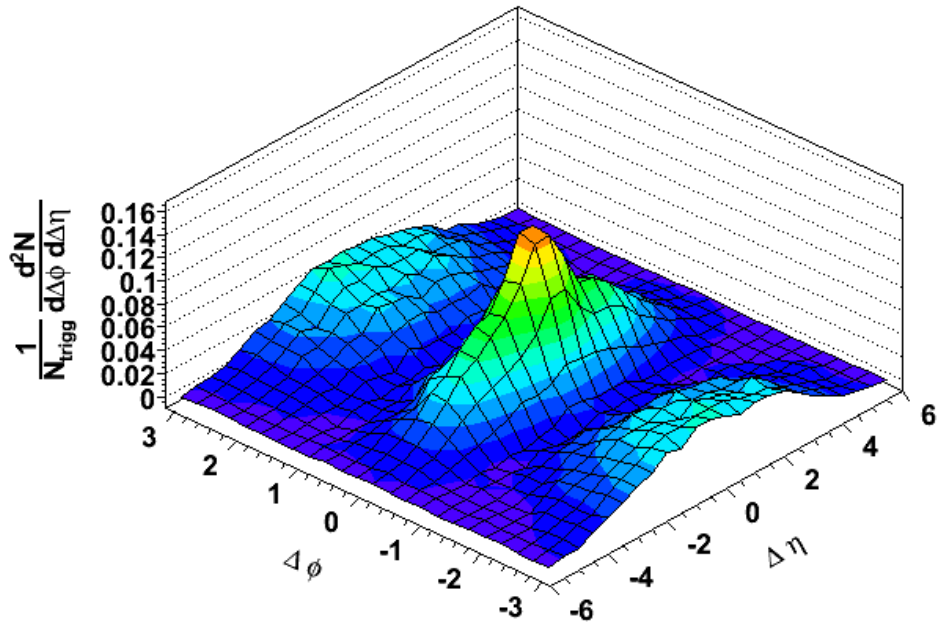
T.K, et al, J. Phys. G. 25, 1935 (1999).
C. Aguiar, T.Osada, T.K. , J. Phys. G27, 75 (2001)
:
:

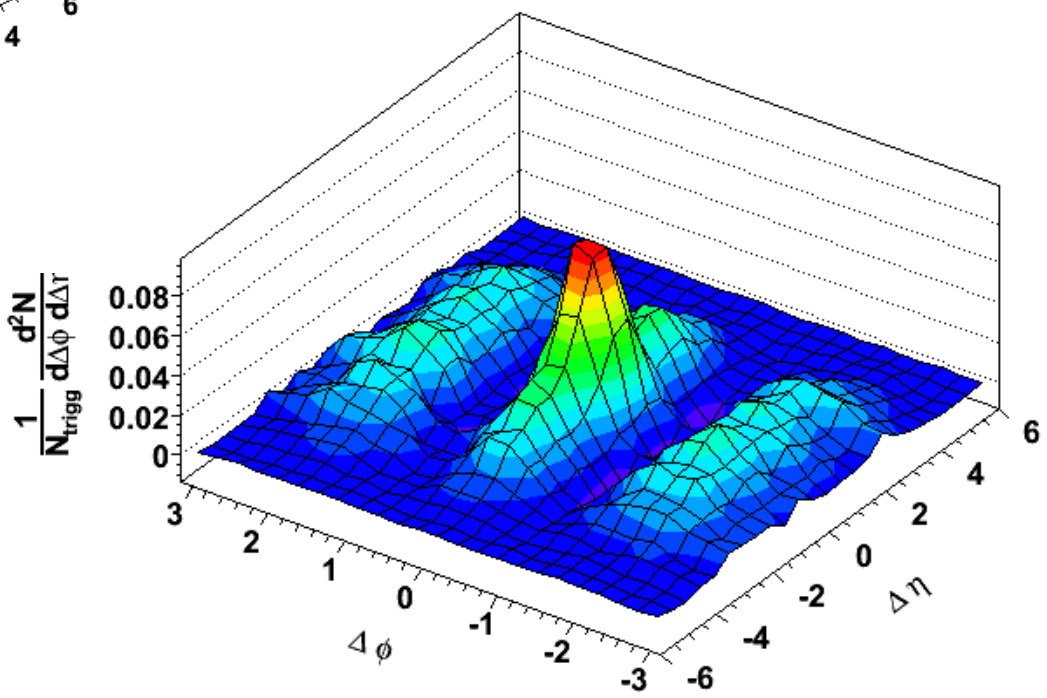
SPHERIO code + NEXUS (K. Werner) initial condition + Freezeout (Hadronization)

Smoothed **P**article **H**ydrodynamical **E**volution of **R**elativistic Heavy **IO**ns

→ Event generator

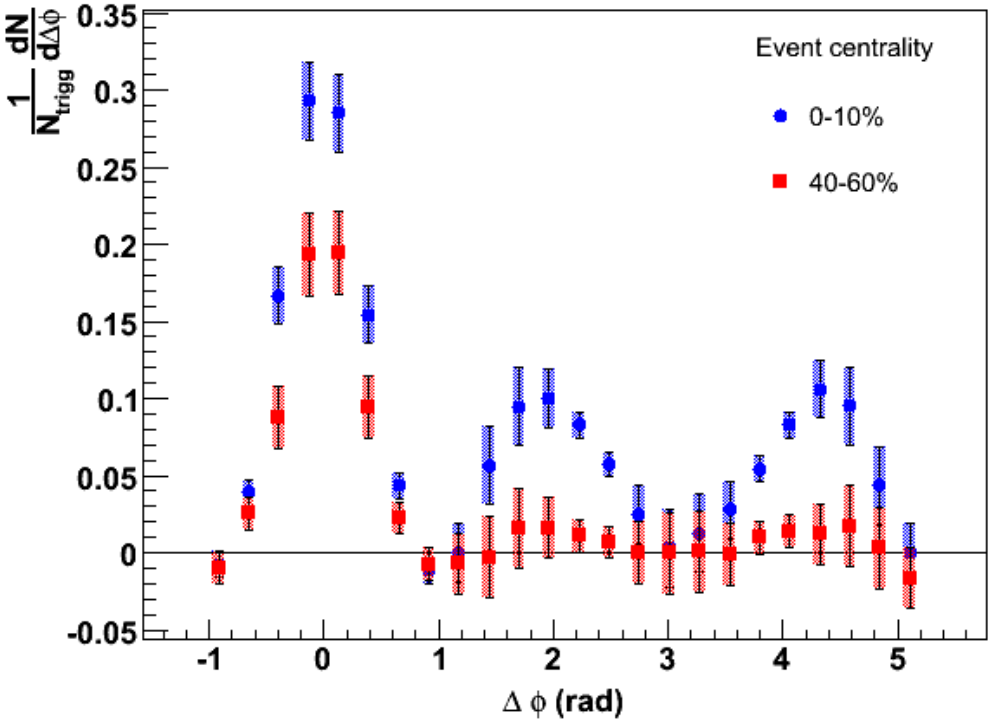
Ridge Structure in Pure Hydro Calculation by NexuSPHerio

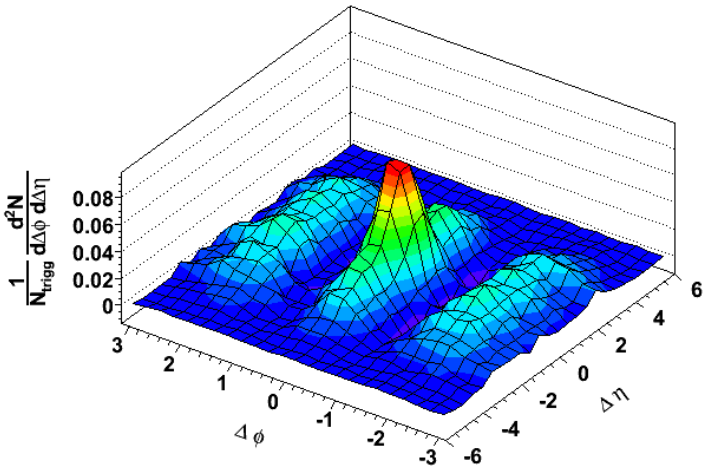




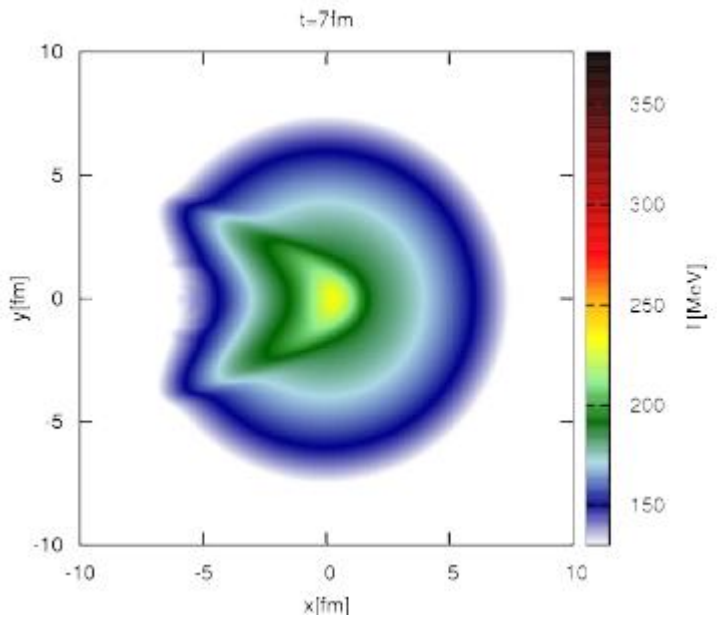
J. Takahashi et al, PRL2009

Double peak structure in far-side

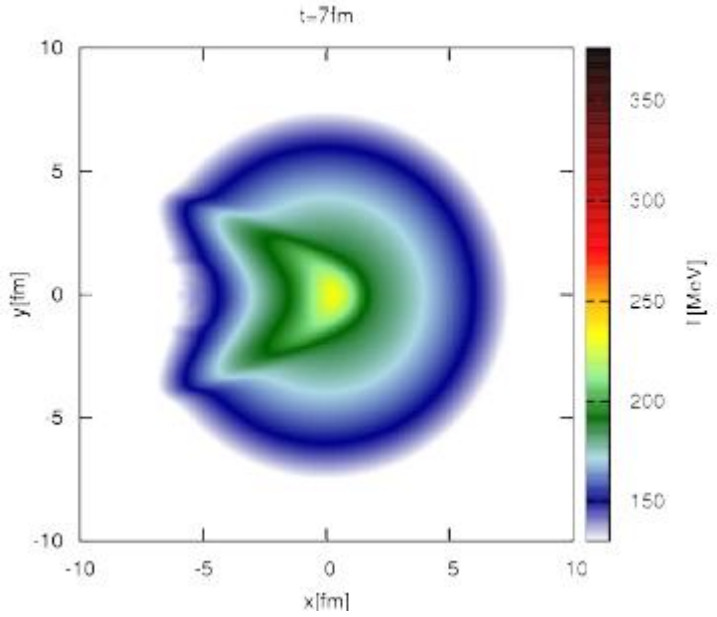




Mach cone .. ?

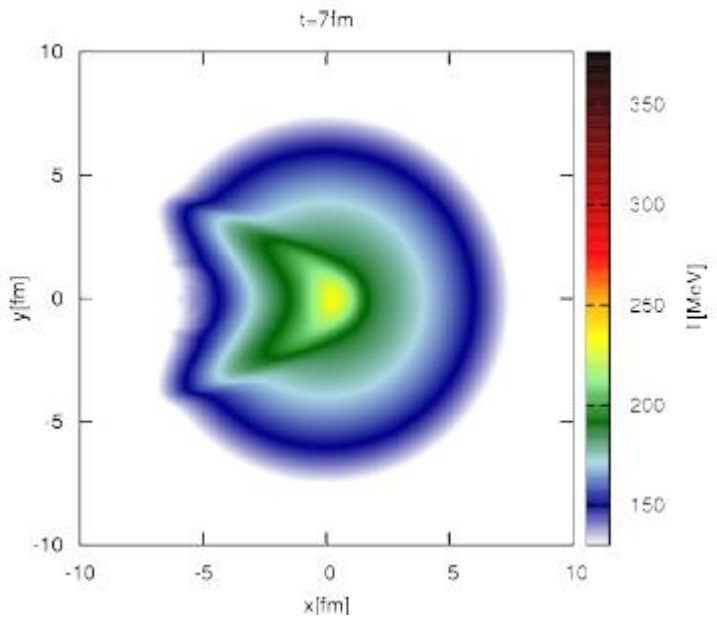


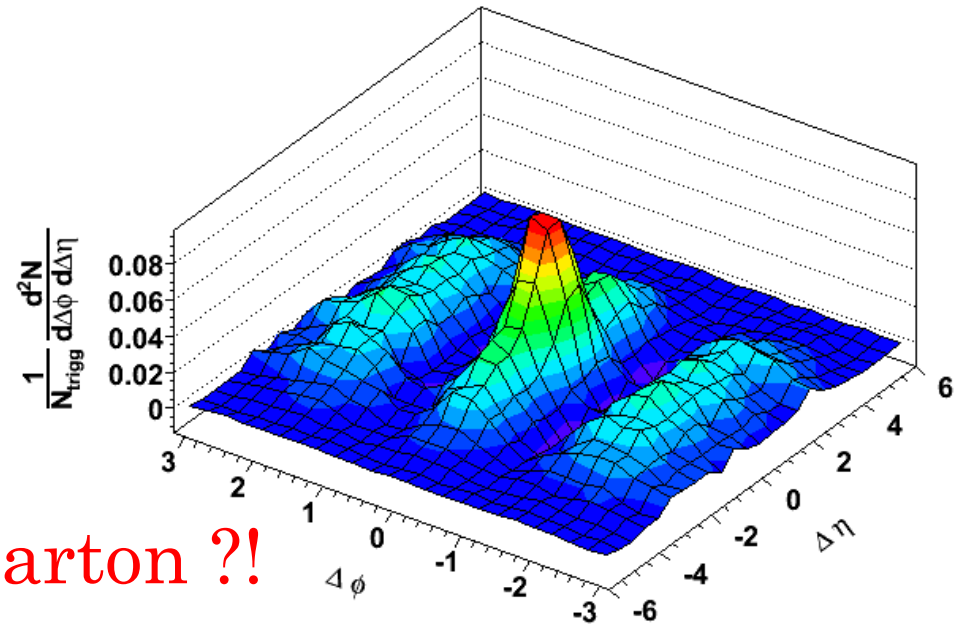
Mach cone .. ?



Where is the supersonic parton. ?!

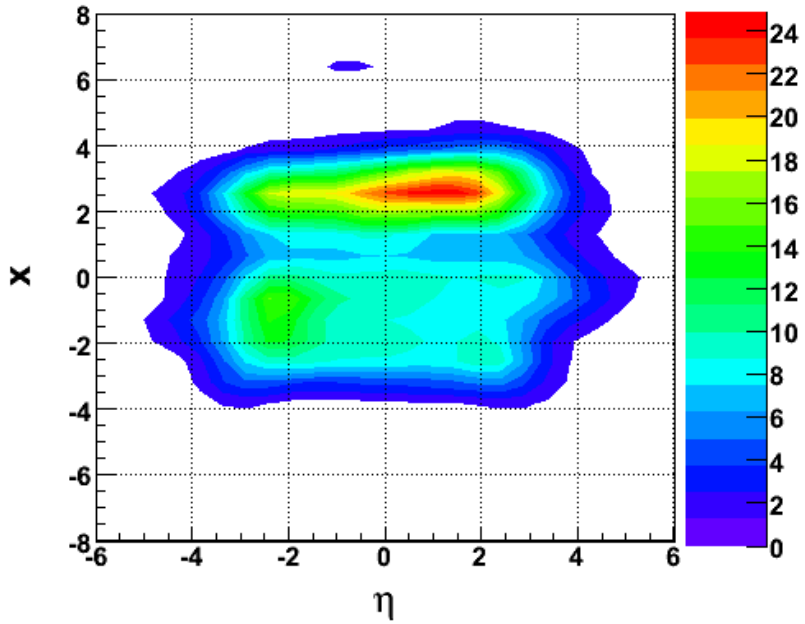
MACH CONE .. ?

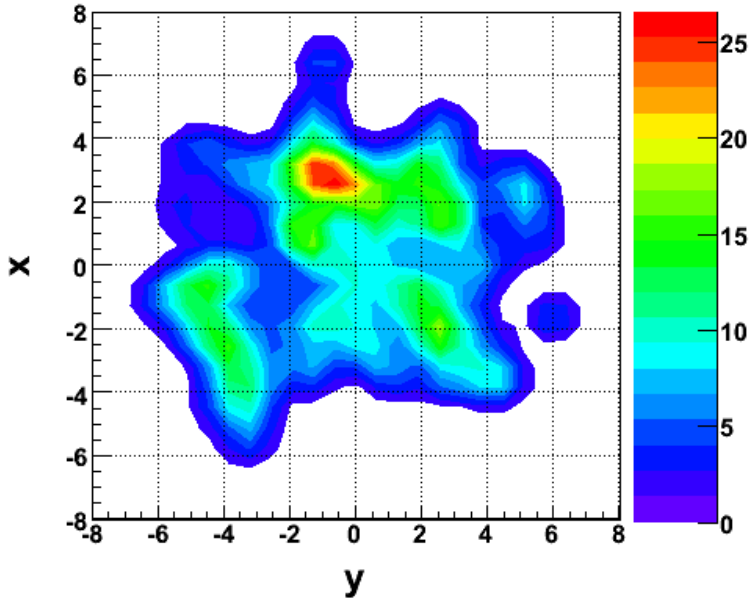


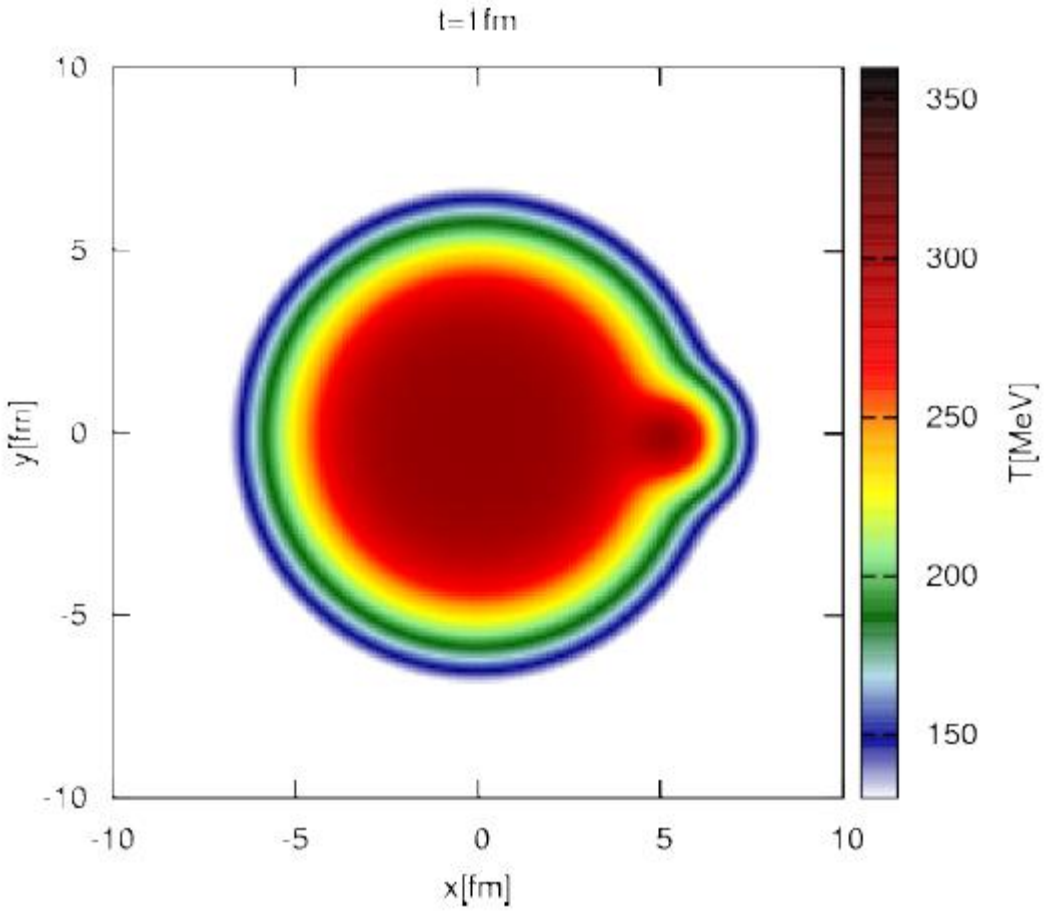


Where is the supersonic parton ?!
How come the ridge??

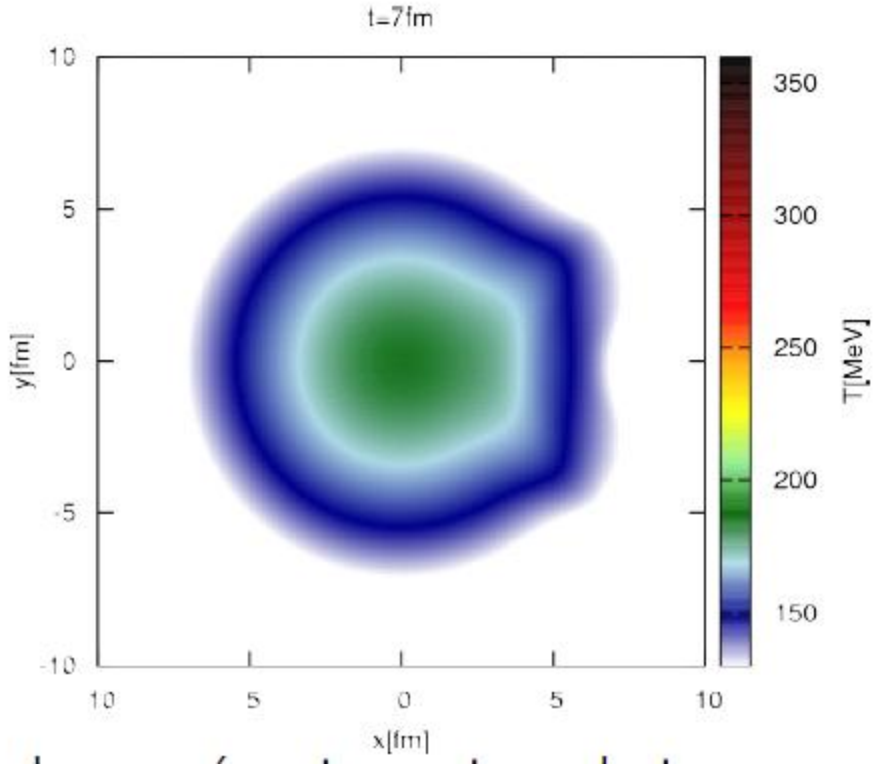
Initial condition by nexus -> no jets, but tube like structure in the longitudinal direction

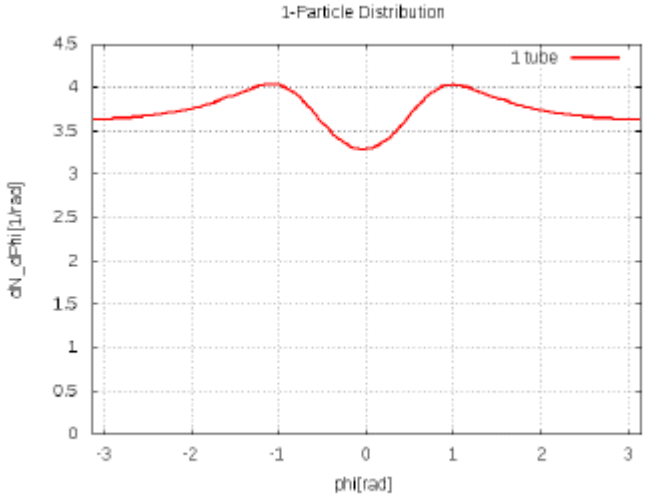




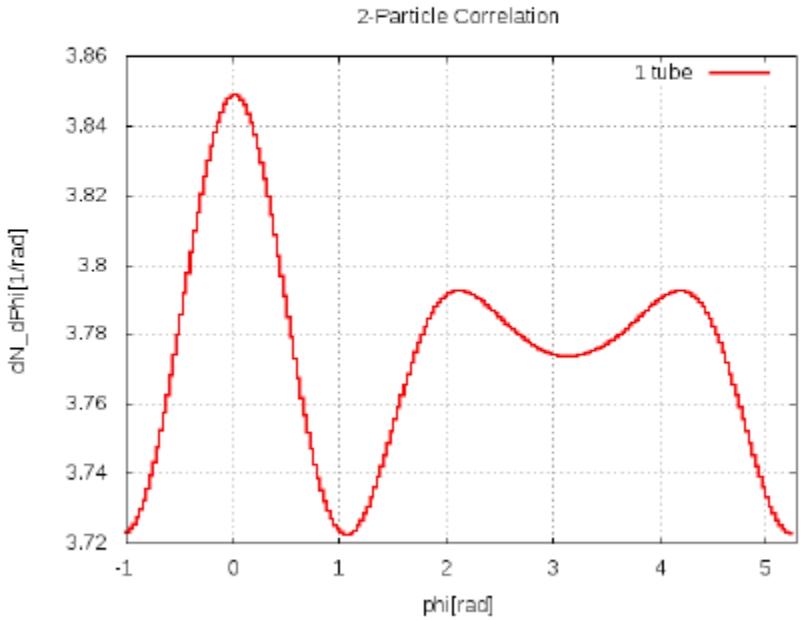

t=1fm
10
5
0
-5
-10
y[fm]
-10
-5
0
5
10
x[fm]
350
300
250
200
150
T[MeV]

- perfil de temperatura em $t = 7\,\mathrm{fm}$

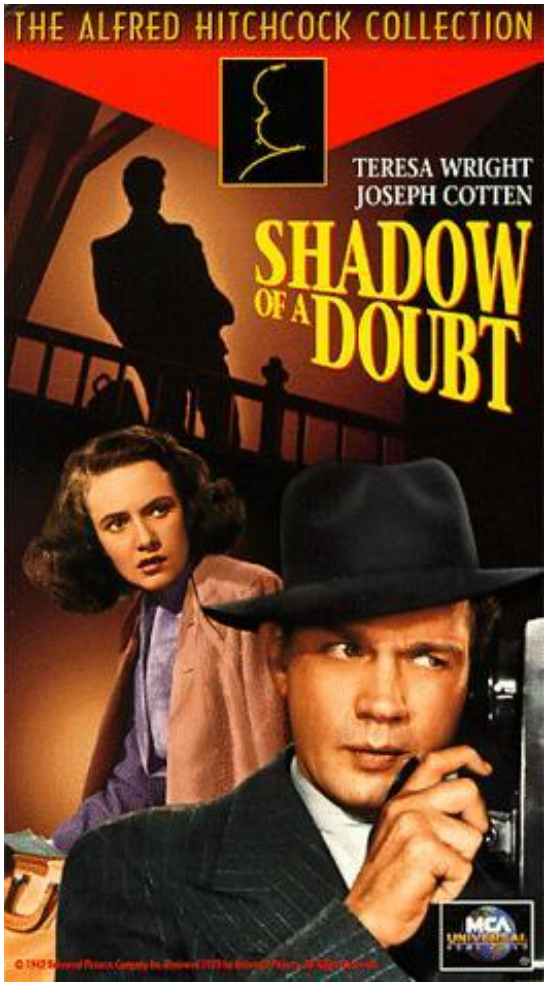



1-Particle Distribution
1 tube
dN_dPhi[1/rad]
phi[rad]
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-3
-2
-1
0
1
2
3

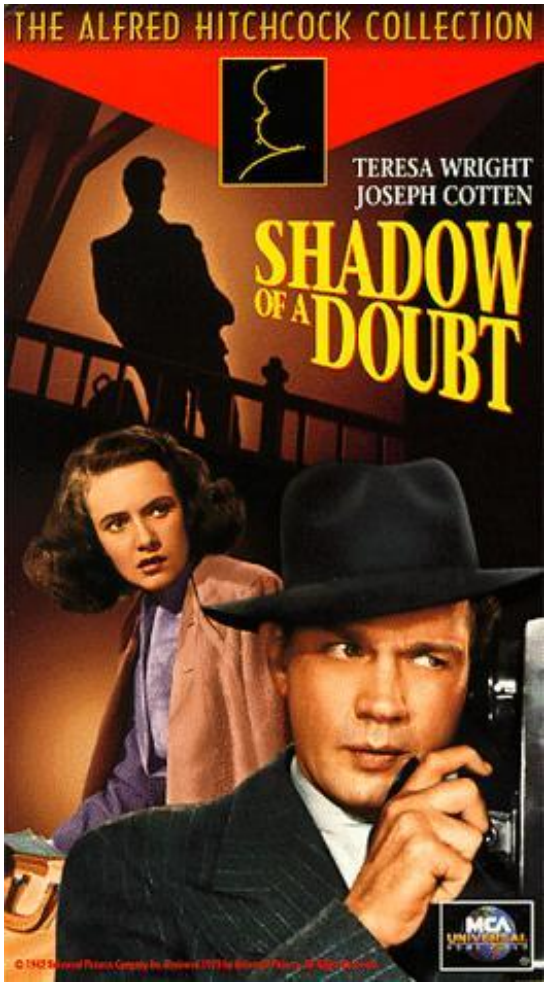
- 2 particle correlation



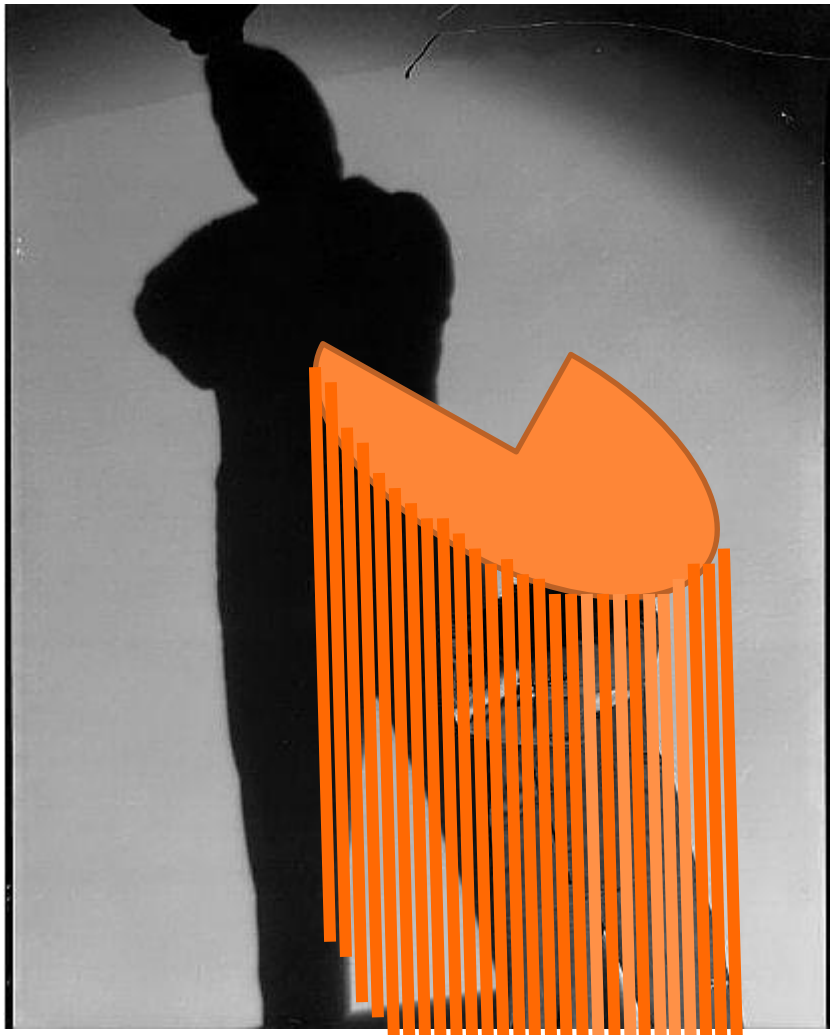
R. Andrade, Y. Hama et al, J.Phys.G 2010



Alfredo Hitchcock 1943


THE ALFRED HITCHCOCK COLLECTION
TERESA WRIGHT
JOSEPH COTTEN
SHADOW OF A DOUBT
MCA UNIVERSAL


THE ALFRED HITCHCOCK COLLECTION
TERESA WRIGHT
JOSEPH COTTEN
SHADOW
OF A
DOUBT
TUBE
MCA
UNIVERSAL



Is initial condition so simple..??

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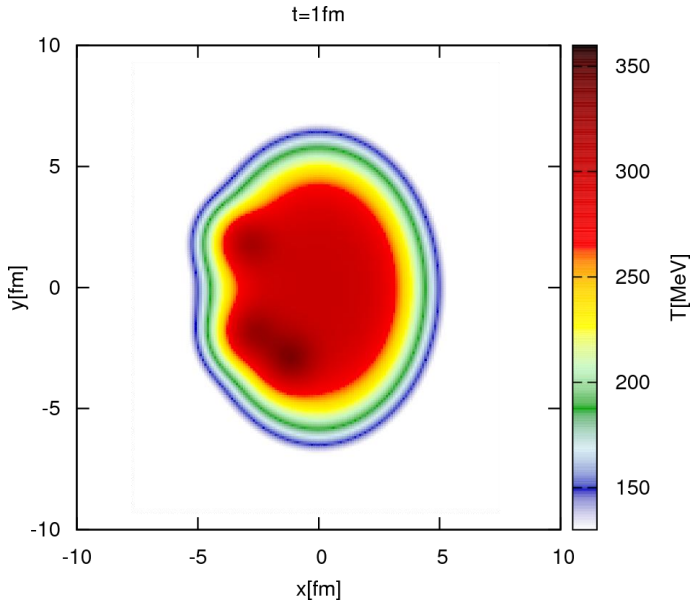
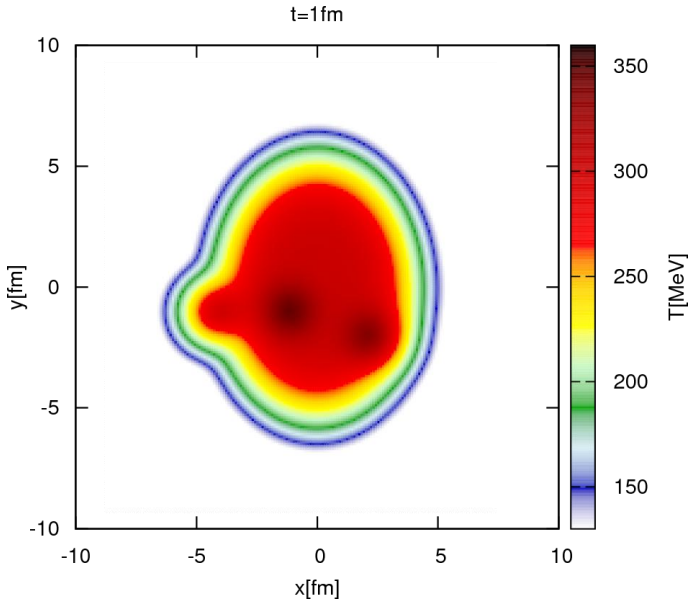
Why not more tubes..?

3 TUBES RANDOMLY GENERATED IN MEDIUM FOR NON-CENTRAL COLLISION (2+1D CALCULATION)

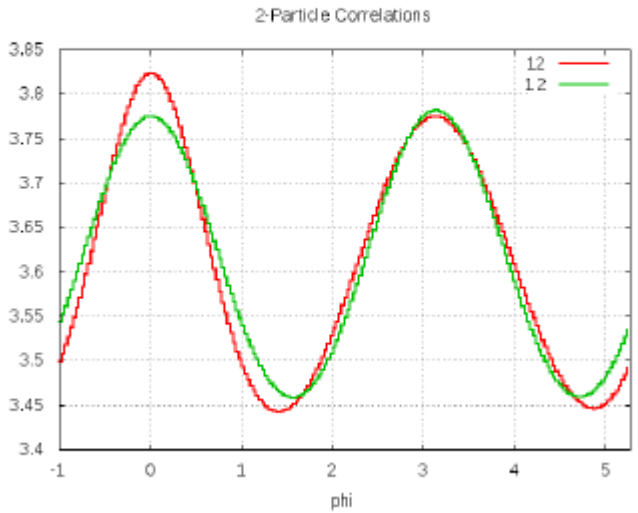
Event 1



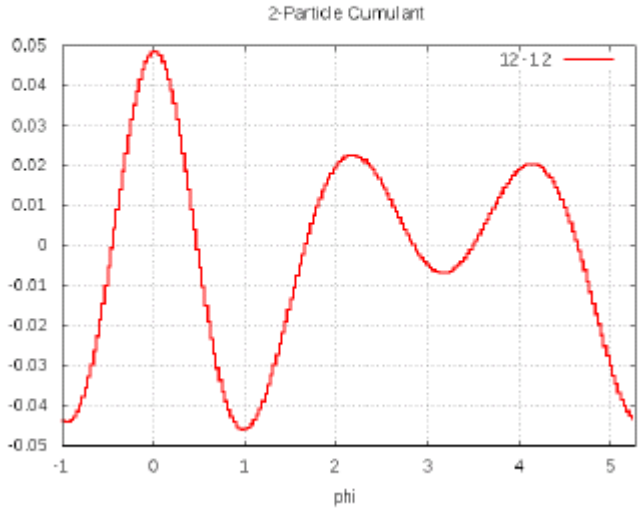
Event 2



- medium + shadow



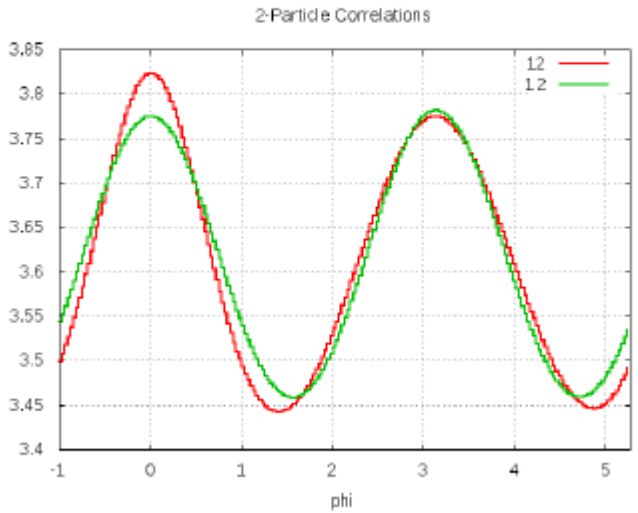
- shadow



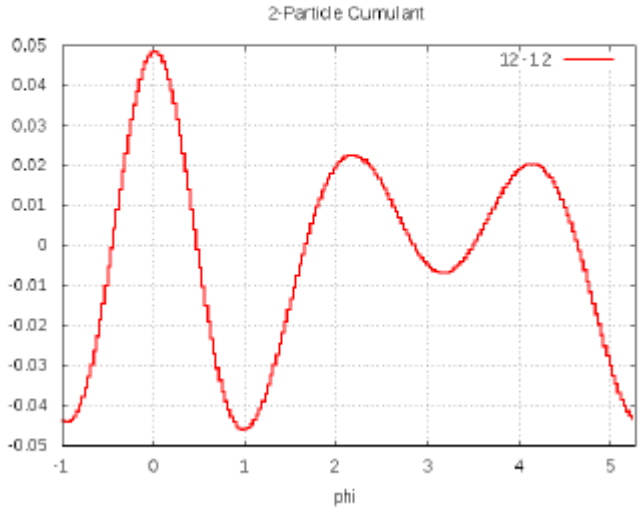
$$\int \mathrm{d}\phi \langle f^1(\phi) f^2(\phi + \Delta\phi) \rangle$$

$$\langle f^1(\phi) \rangle \langle f^2(\phi + \Delta\phi) \rangle$$

- medium + shadow

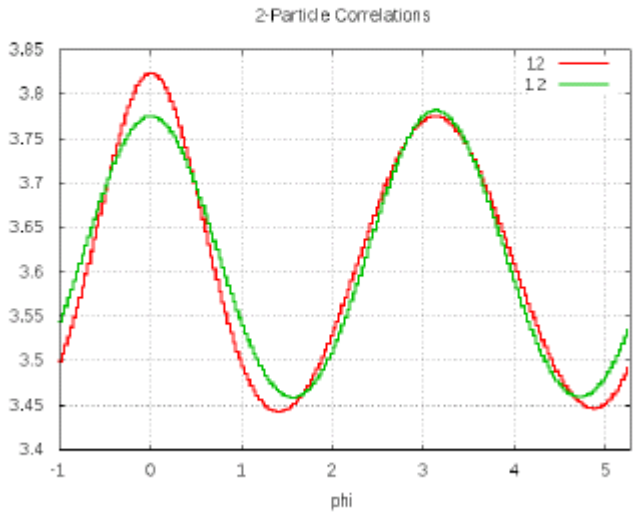


- shadow

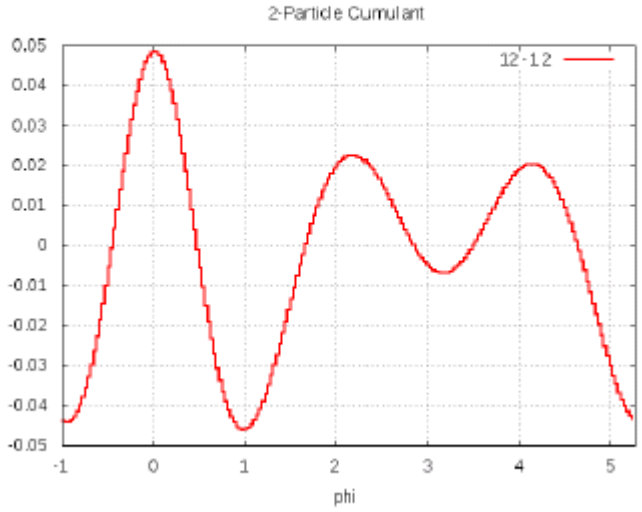


$$\int \mathrm{d}\phi \left\langle f^1(\phi) f^2(\phi+\Delta\phi)\right\rangle - \left\langle f^1(\phi)\right\rangle \left\langle f^2(\phi+\Delta\phi)\right\rangle$$

- medium + shadow



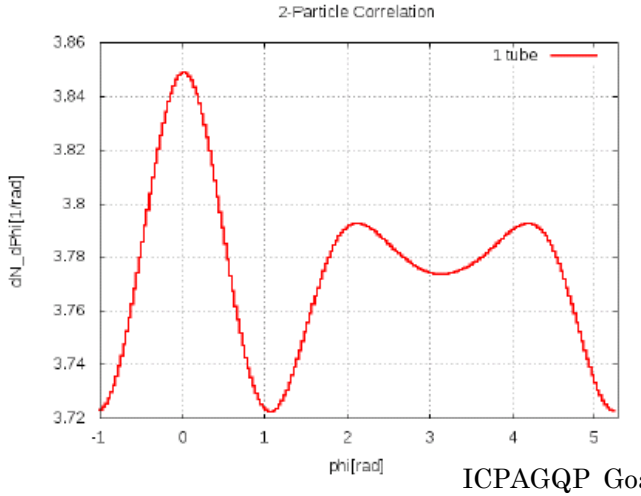
- shadow



Signal survives !!

One tube case for central collision

- 2 particle correlation

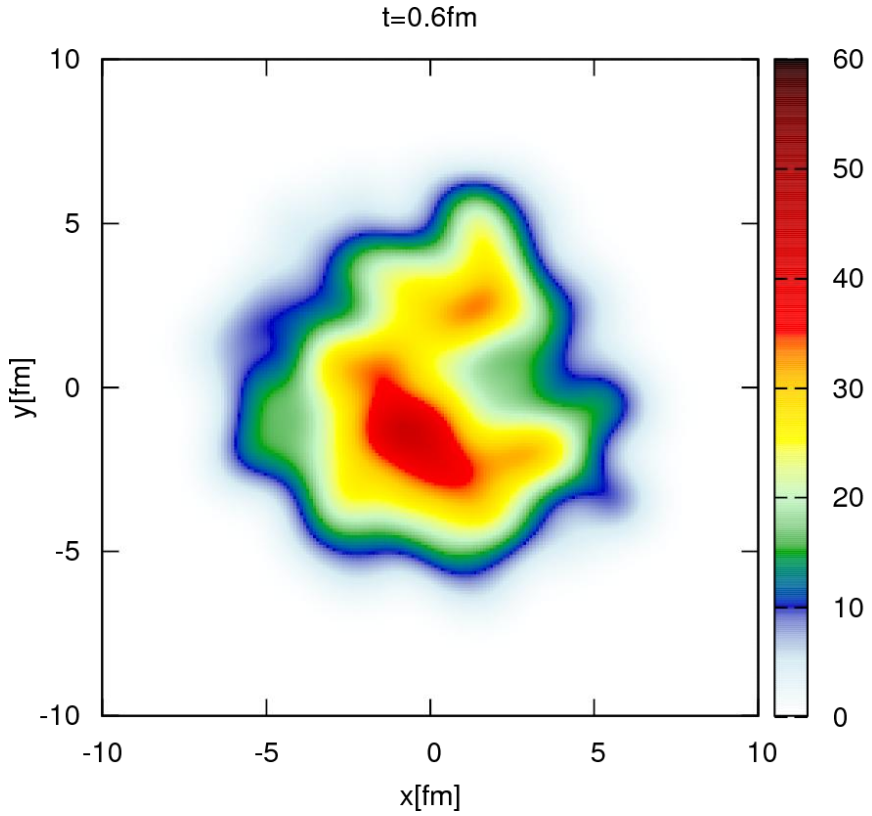


What is the "medium part",..?

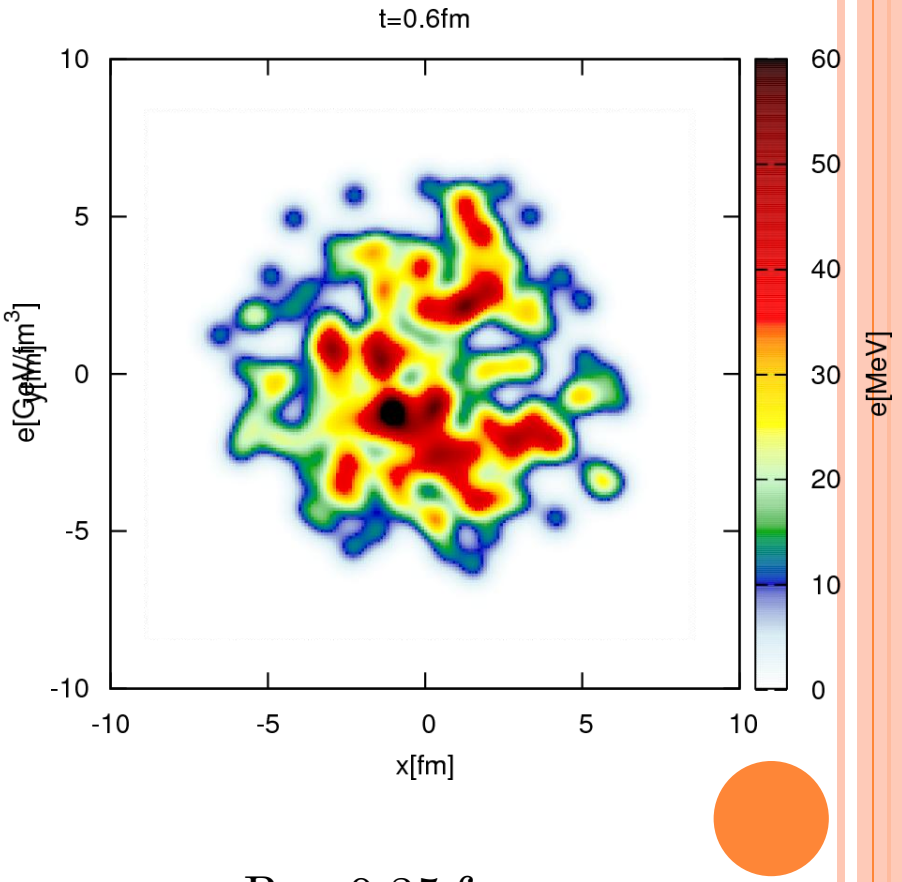
What is the "medium part",..?

Why not "only tubes" ?

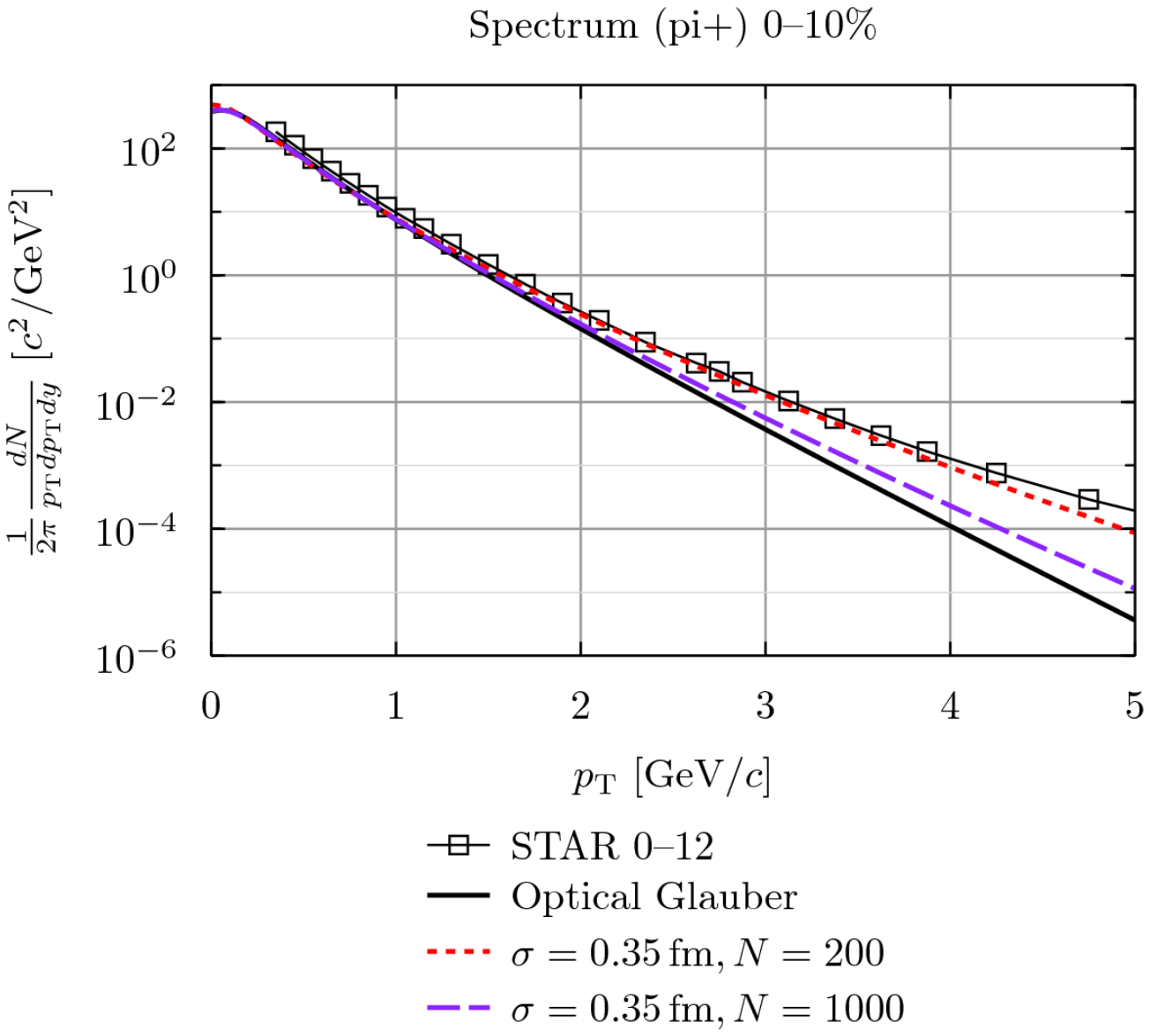
Two energy distributions for different size (50 gaussian tubes)



R = 0.7fm



R = 0.35 fm

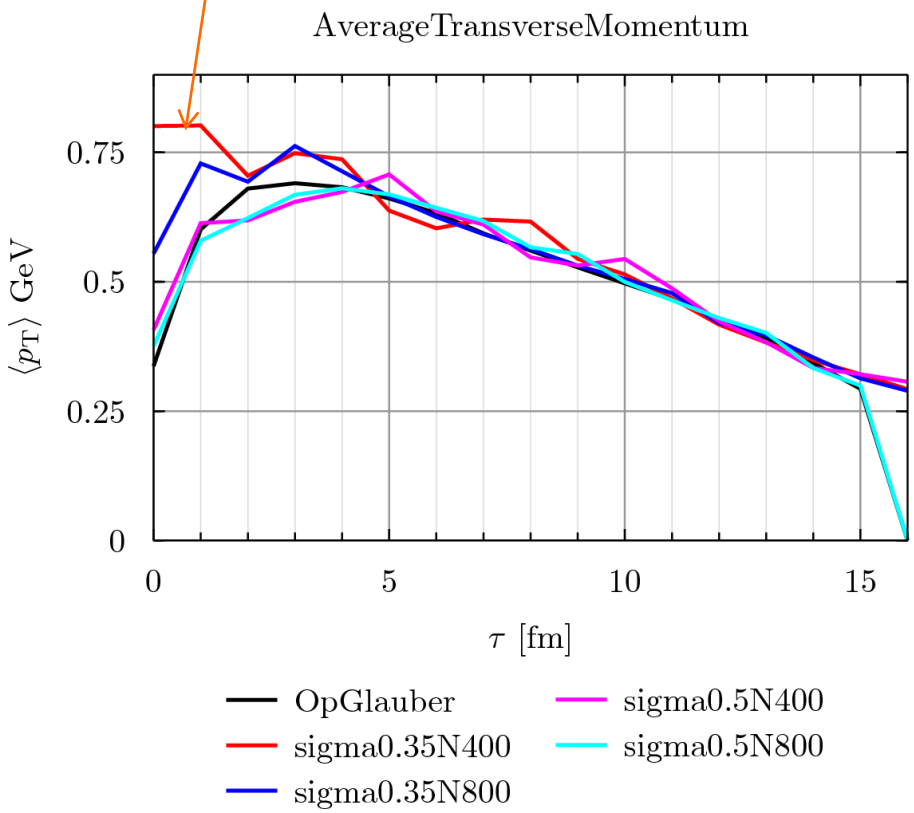

Spectrum (pi+) 0–10%
$\frac{1}{2\pi}\frac{dN}{p_T dp_T dy}\ [c^2/\mathrm{GeV}^2]$
10^2
10^0
10^{-2}
10^{-4}
10^{-6}
0
1
2
3
4
5
p_T [GeV/c]
STAR 0–12
Optical Glauber
$\sigma = 0.35$ fm, $N = 200$
$\sigma = 0.35$ fm, $N = 1000$

The more spiky initial condition is, the more hard the spectrum becomes..

The more spiky initial condition is, the more hard the spectrum becomes..

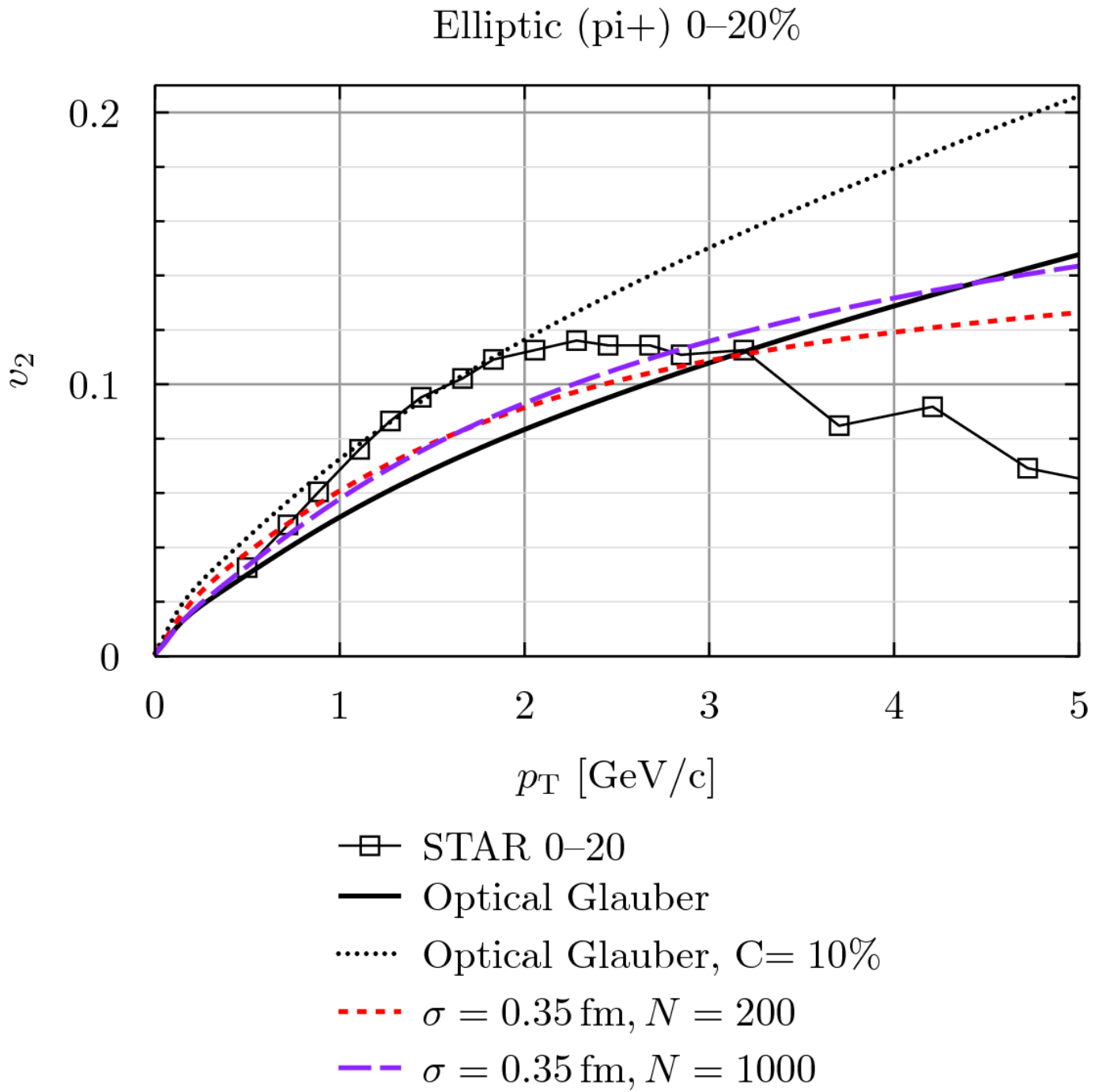
- Isolated (near the surface) high density small tubes explode quickly and emi high momentum particles
- Superposition of tubes generate slow collective flow and the dynamics of freezeout surface is slower

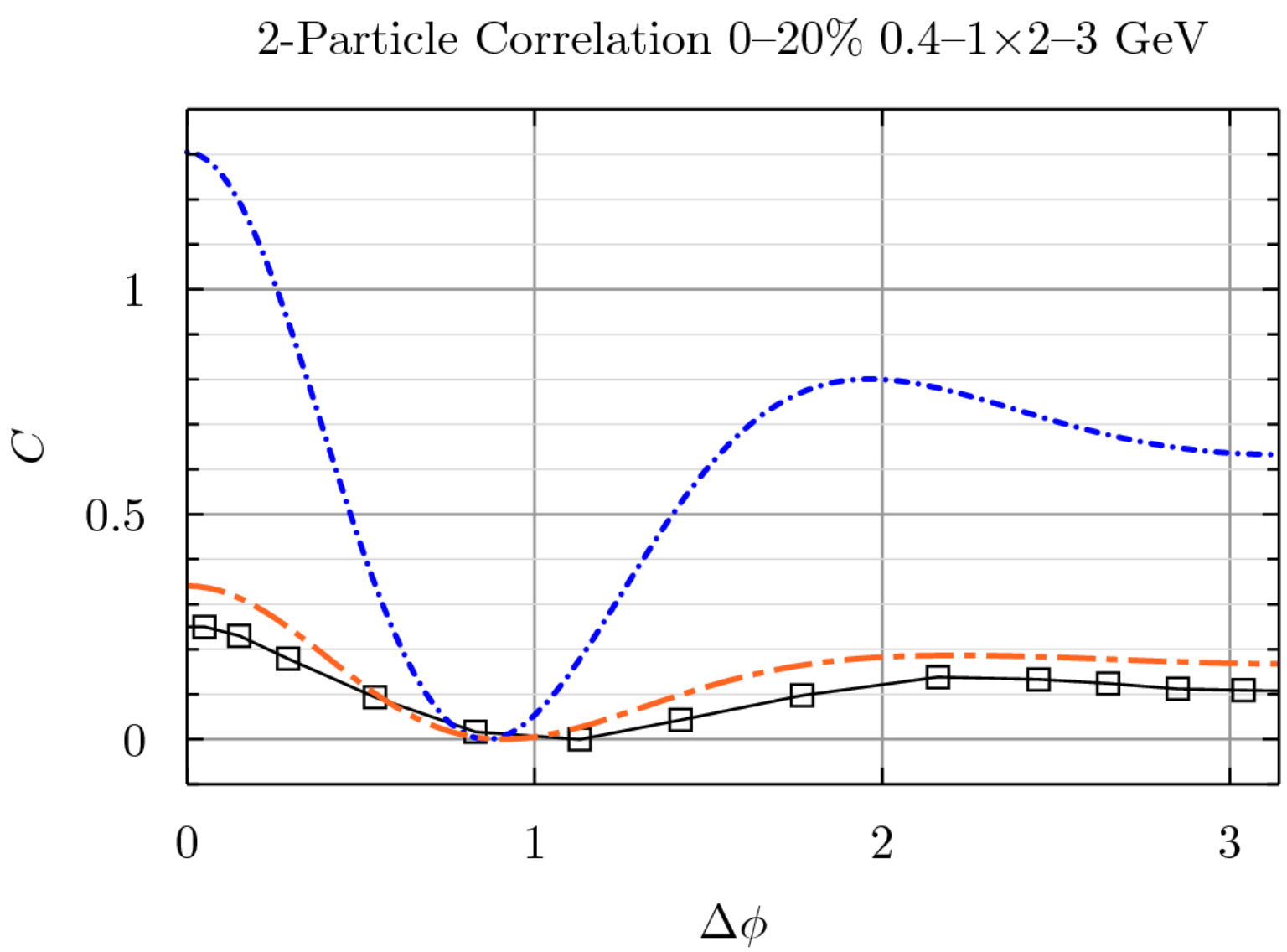
High pt comes earlier,…

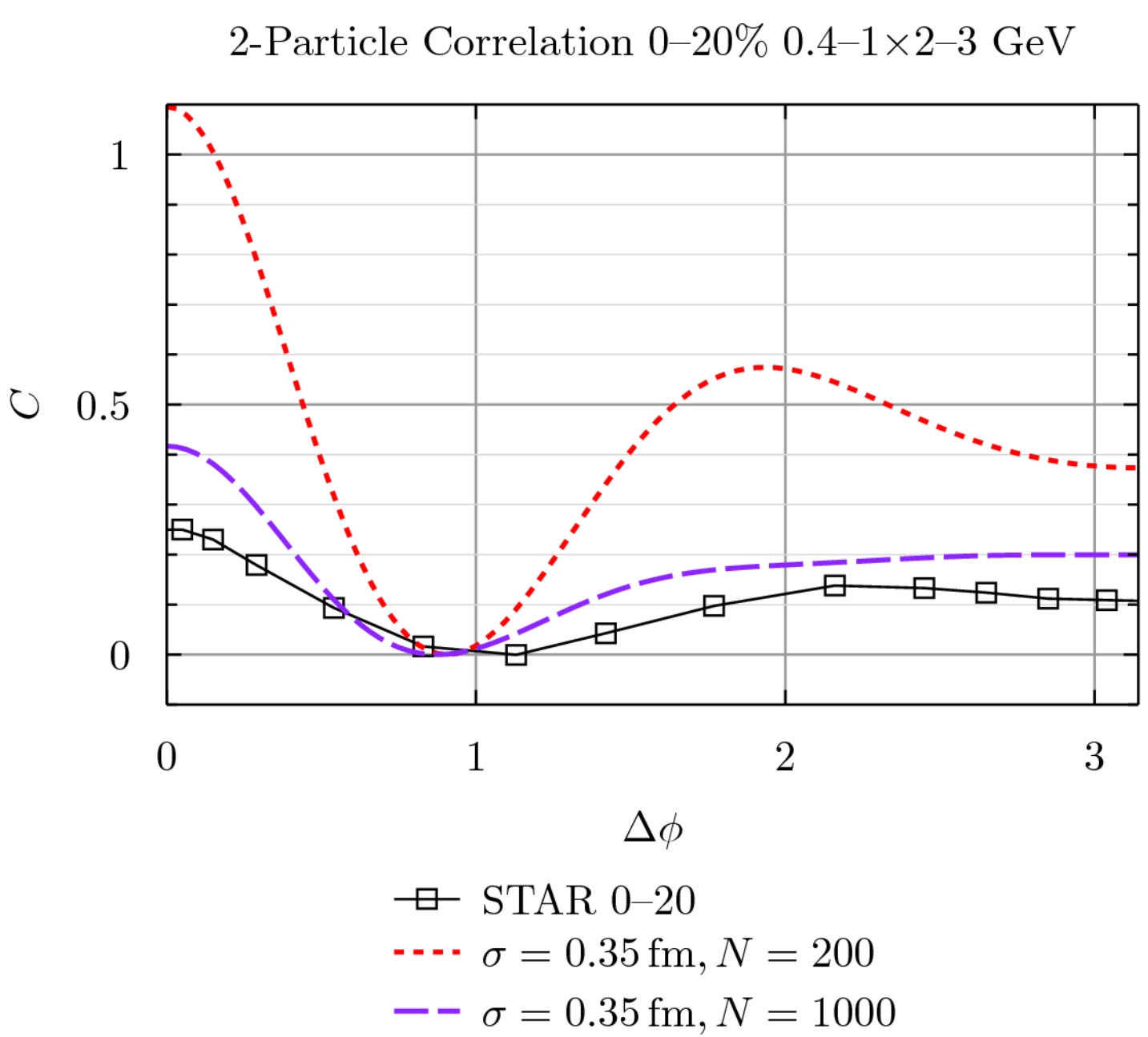


Medium ⟹ Collective nature

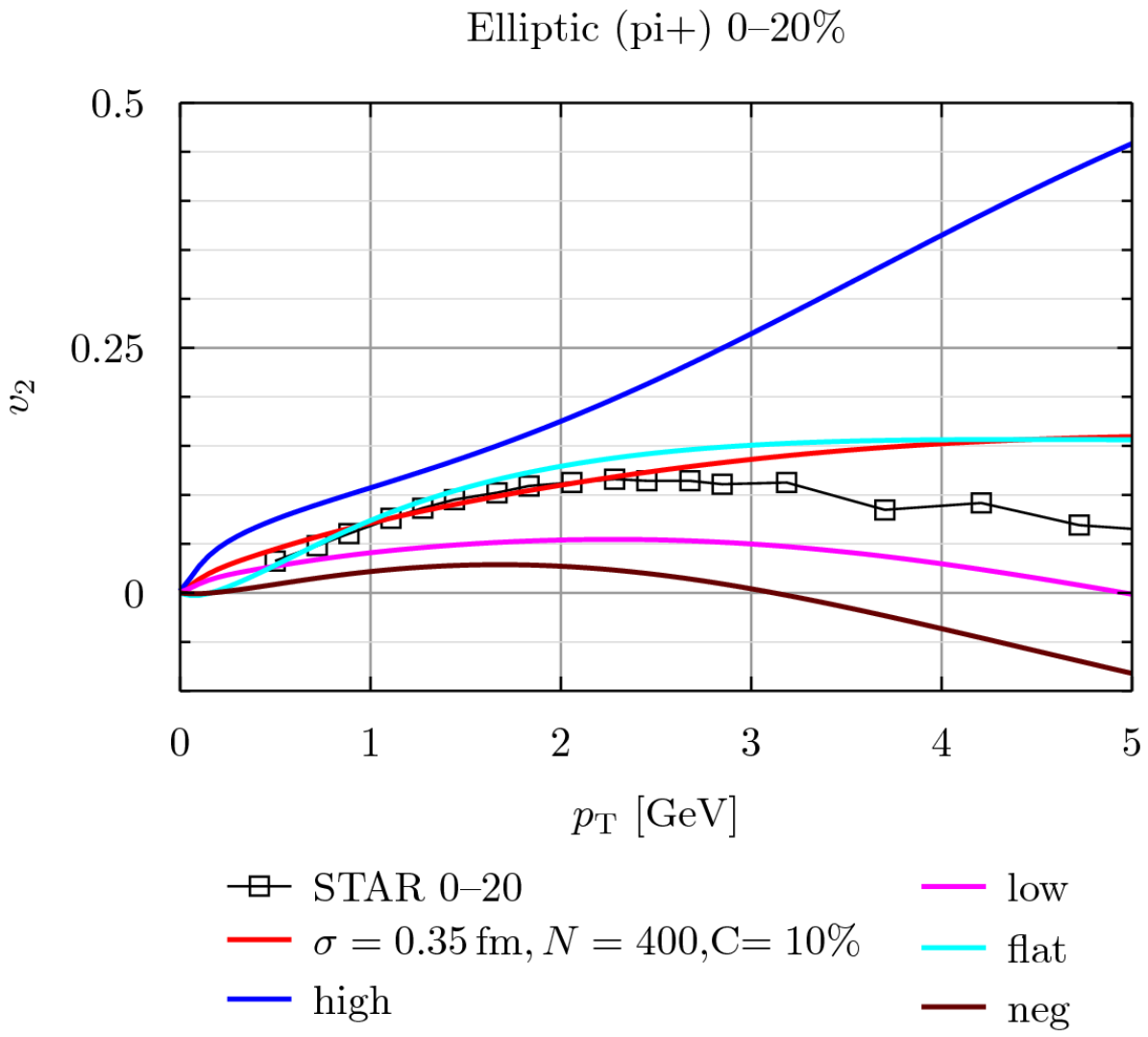
Elliptic flow coefficient v_2


Elliptic (pi+) 0–20%
0.2
0.1
0
v_2
0
1
2
3
4
5
p_T [GeV/c]
STAR 0–20
Optical Glauber
Optical Glauber, C= 10%
$\sigma = 0.35$ fm, $N = 200$
$\sigma = 0.35$ fm, $N = 1000$

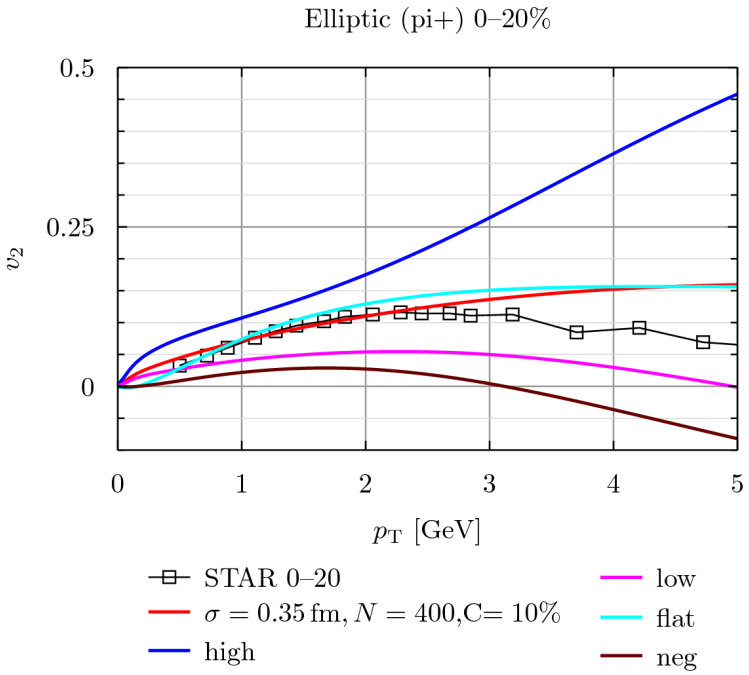

2-Particle Correlation 0–20% 0.4–1×2–3 GeV
C
1
0.5
0
0
1
2
3
Δφ
STAR 0–20
σ = 0.7 fm, N = 200
σ = 0.7 fm, N = 1000

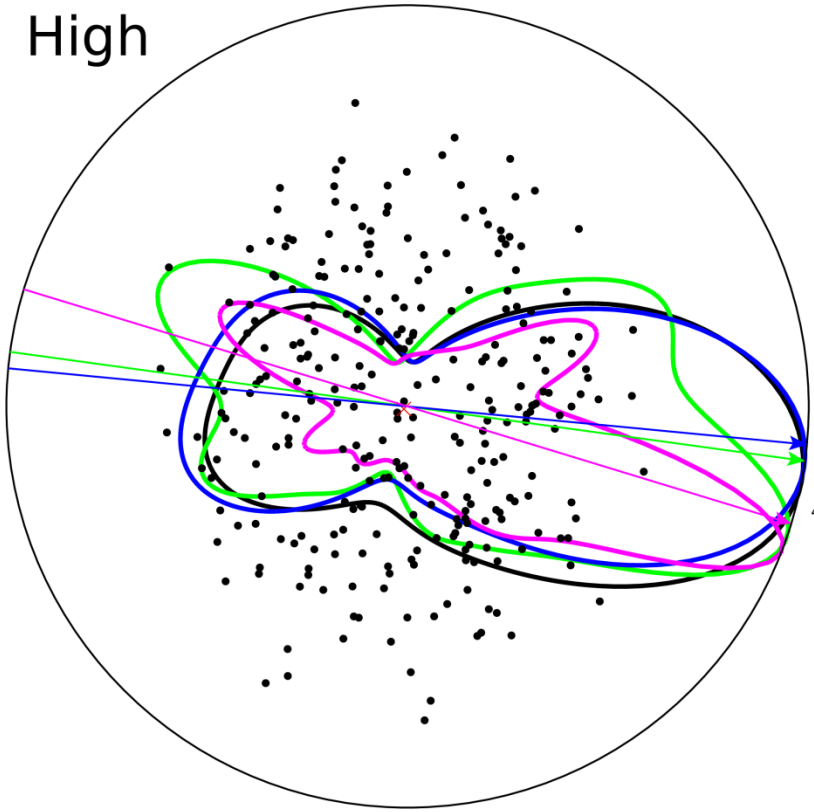

2-Particle Correlation 0–20% 0.4–1×2–3 GeV
C
1
0.5
0
0
1
2
3
Δφ
STAR 0–20
σ = 0.35 fm, N = 200
σ = 0.35 fm, N = 1000

Fluctuations of v_2

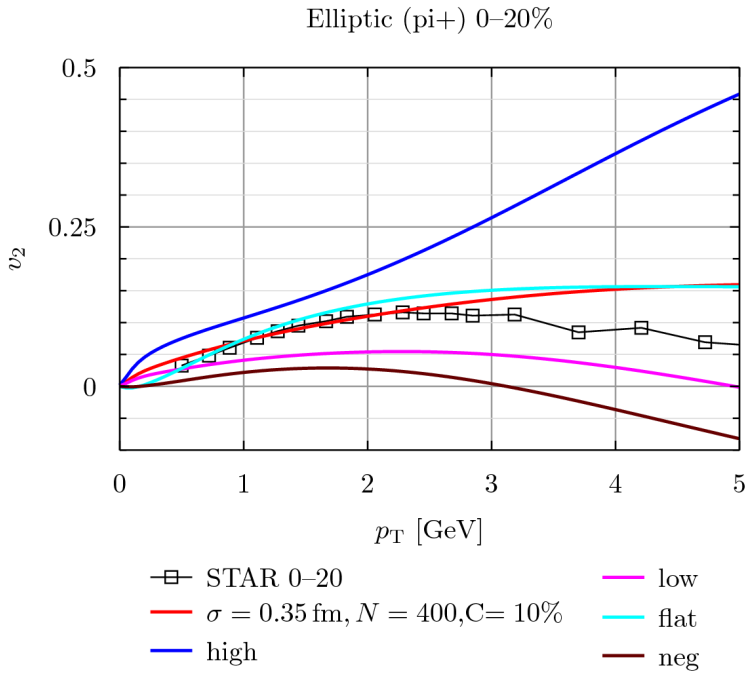


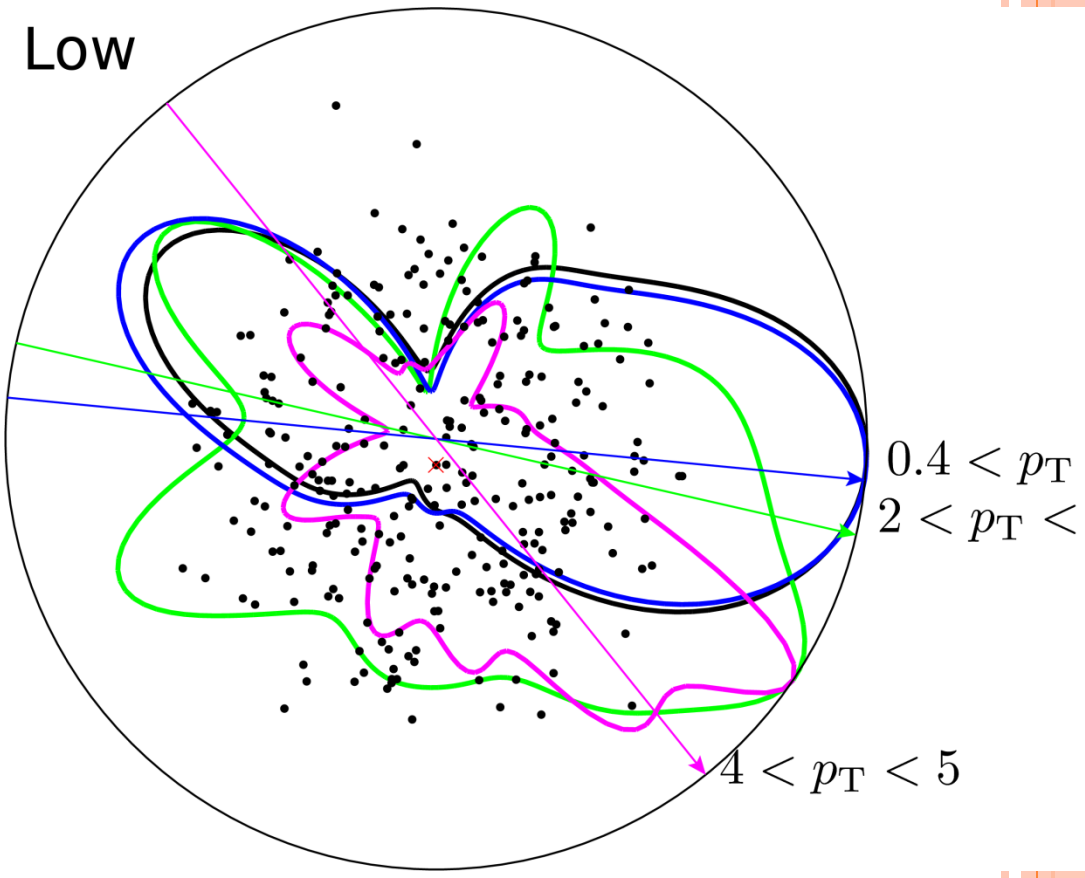
Fluctuations of v_2





Fluctuations of v_2





Conclusion

- Tube-like substructures in initial condition can be responsible for the ridge effect as well as the far-side double peak structure in angular correlation.
- Harder component from high density tubes may mixed up with jet contribution in the spectra and flow parameters
- Also entangles with the viscous effects
- Higher v_n coefficients in event by event analysis will be interesting
- Proton-proton in high multiplicity events in terms of tubes,…? (in progress)

Thank you !!