# Stimulation of deconfined medium by multiple hard partons

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6.12. 2013

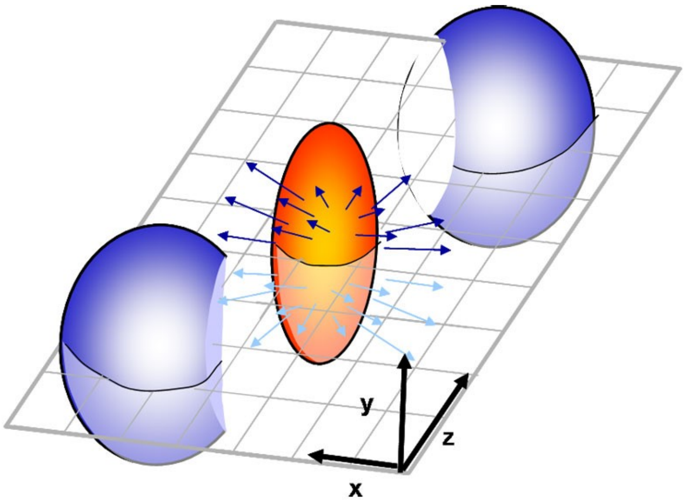
Zimányi Winter School 2013

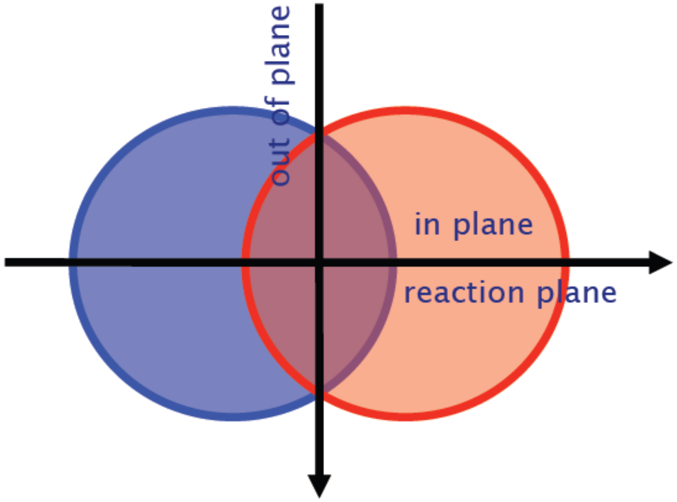
# Outline

- Elliptic flow
- Ideal hydrodynamics and jets
- Results
  - Static medium
  - Expanding medium
- Conclusions

# Elliptic flow

- Hydrodynamic phenomenon
- Asymmetry in particle production in non-central collisions
- Anisotropy in production correlated to collision geometry
- Stronger expansion in reaction plane due to higher pressure gradient in this direction

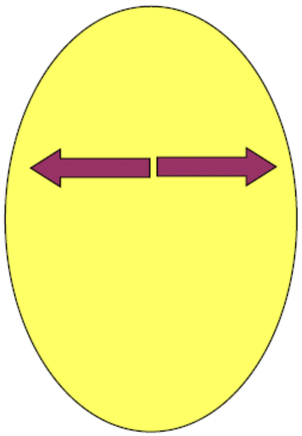


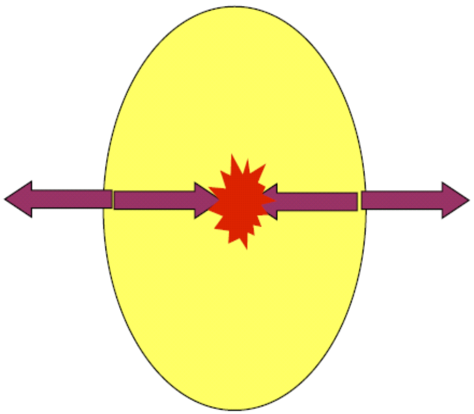

$$\frac{dN}{d\varphi} = \frac{1}{2\pi}(1 + 2v_1 \cos\varphi + 2v_2 \cos 2\varphi + \ldots)$$

# Elliptic flow

- Jets in the medium, one pair of jets x two pair of jets



higher contribution to $v_n$

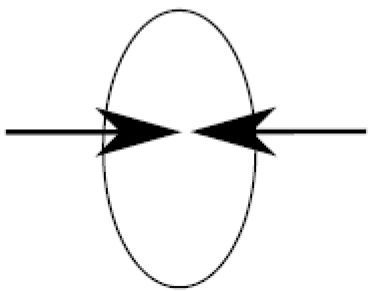


momenta cancel out
less $v_n$ generation

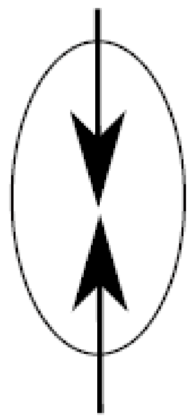
- But jets are produced isotropically

# Elliptic flow

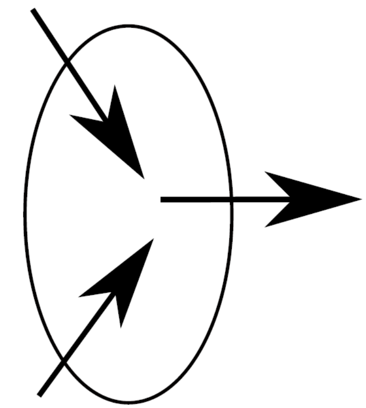
- Illustration of the likeness or unlikeness of two streams to meet



As the fireball is elongated out of the reaction plane, two streams which flow in the in-plane direction have more space to pass each other without merging.



Two streams flowing in the out-of-plane direction are likely to meet.



Merging of wakes in out-of-plane direction will contribute to the elliptic flow.

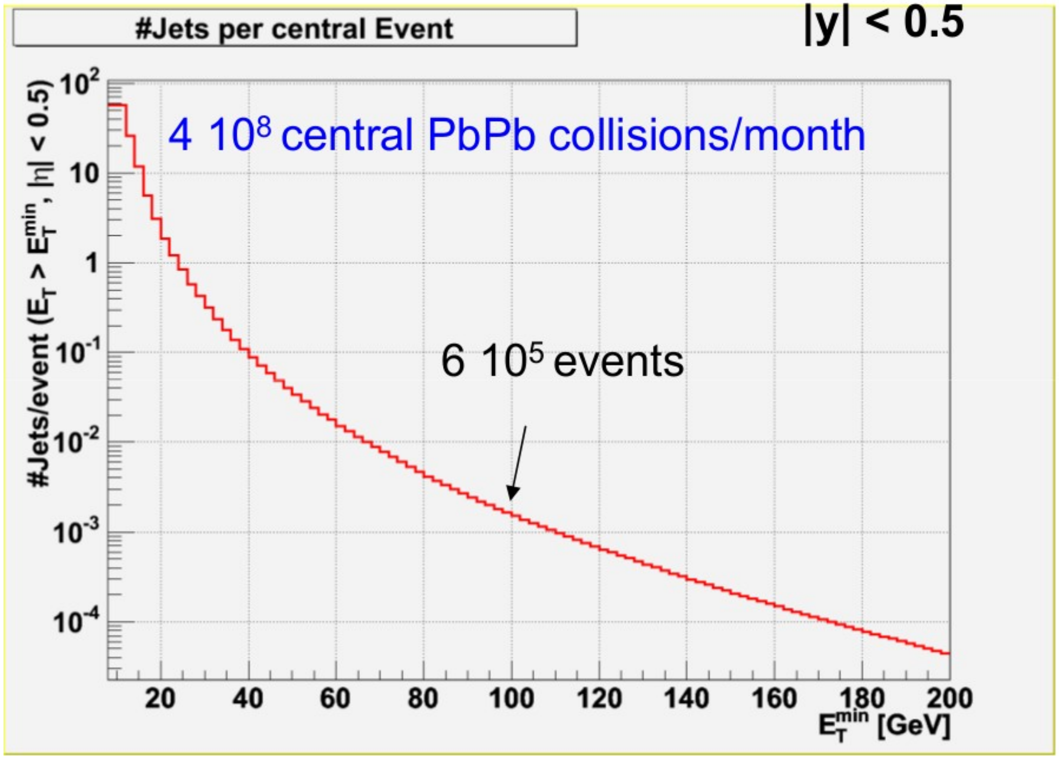
- Jets induce streams in the hydrodynamic medium. Can be this reproduced in hydrodynamics ? How do two wakes merge ?

# Jets in LHC

- LHC: Minijets will be copious and deposit energy and momentum to the medium and will induce and influence collective flow

- Possible influence on elliptic flow and/or higher harmonics

- Several jets of E~20 GeV in one central event expected at ALICE




A. Accardi et al., Hard probes in heavy ion collisions at the LHC, Chapter 2: Jet physics, CERN, Yellow Report CERN, hep-ph/0310274.

# Hydrodynamic equations

- Relativistic tensor of energy and momentum

$$T^{\mu\nu}=(\varepsilon+p)u^{\mu}u^{\nu}-pg^{\mu\nu}=\varepsilon u^{\mu}u^{\nu}-p\Delta^{\mu\nu} \qquad \Delta^{\mu\nu}=g^{\mu\nu}-u^{\mu}u^{\nu}$$

- Charge current $N^{\mu}=nu^{\mu}$

- Statement of conservation of energy, momentum and charge

$$\partial_{\mu}N^{\mu}=0$$
$$\partial_{\mu}T^{\mu\nu}=0$$

➡

$$u^{\mu}\partial_{\mu}n+n\partial_{\mu}u^{\mu}=0$$
$$(\varepsilon+p)\partial_{\mu}u^{\mu}+u^{\mu}\partial_{\mu}\varepsilon=0$$
$$(\varepsilon+p)u^{\mu}\partial_{\mu}u^{\alpha}-\Delta^{\mu\alpha}\partial_{\mu}p=0$$

- Closing the set of equations, EoS ε=ε(p,n)

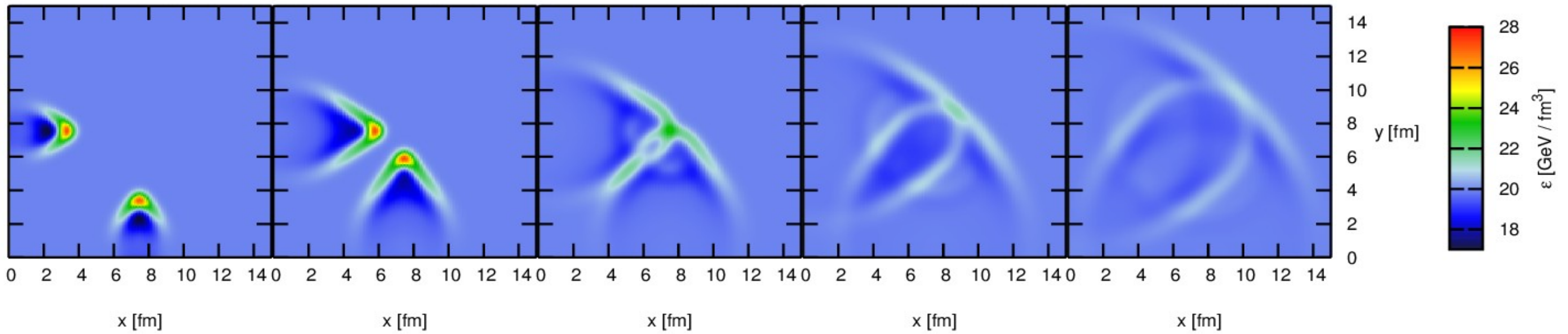
- Jet four-momentum deposition mechanism unclear
  - Assumption: energy lost by the jet thermalizes and gives rise to a source term

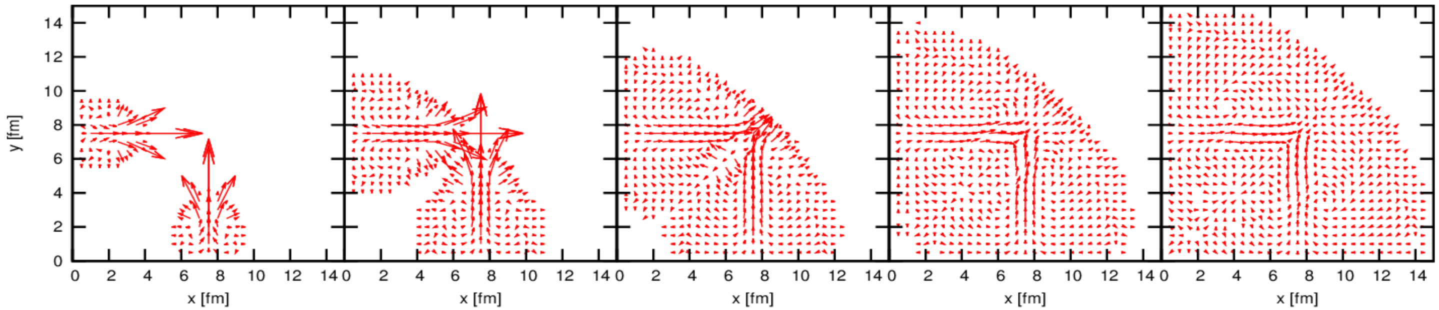
Residue of energy and momentum given by the jet ➡ $\partial_{\mu}T^{\mu\nu}=S^{\nu}$

(B. Betz, *et al.*, Phys.Rev.C **79** (2009) 034902)

# Static medium results

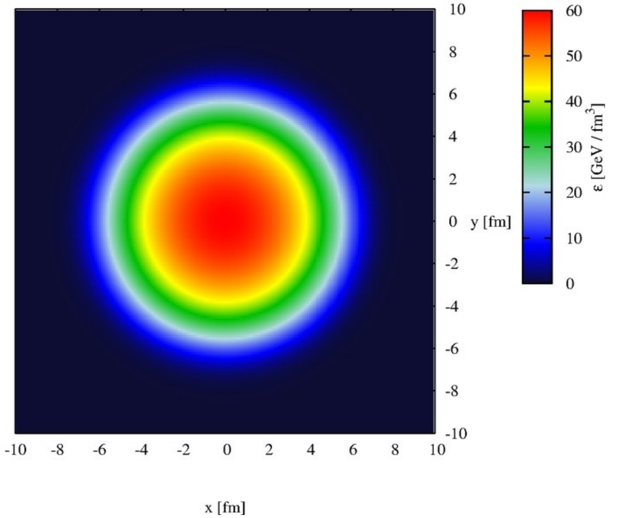
- Hydrodynamic simulations confirm the toy model scenario by Tomášik and Lévai, B. Tomášik, P. Lévai, J.Phys.G G**38** (2011) 095101
- Two diffusion wakes merge, explosive burst of four-momentum in the end of jets' evolution, simple Bethe-Bloch scenario
- More information concerning static results, J. Phys.G: Nucl. Part. Phys. 40 125104



# Initial conditions

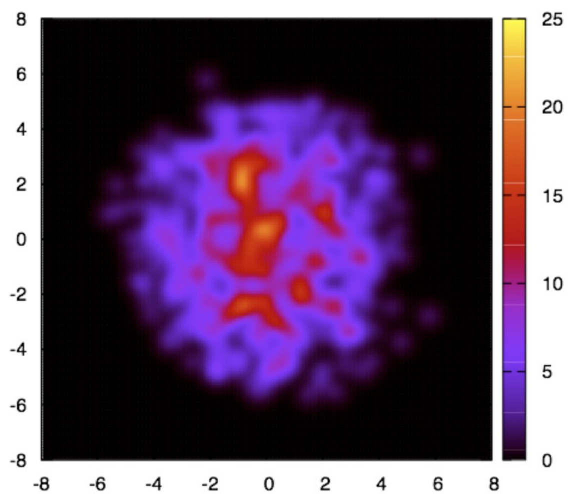
- EoS: Petreczky, Huovinen Nucl.Phys. A837 (2010) 26-53 (s95p-PCE-v1)
- Optical Glauber – smooth IC
- Parameters for LHC:




- Initial energy density $\varepsilon(0,0,0) = 60.0$ GeV/fm$^3$
- Jet four-momentum deposition is scaled as s/s(0)
- Longitudinal profile $H(\eta_s)$ is composed of two parts, flat region around $\eta = 0$ and half a Gaussian in the forward and backward direction
- Total energy density distribution:
  - $W(x, y, b) = (1 - \alpha)\, n_{WN}(x, y, b) + \alpha\, n_{BC}(x, y, b)$
  - $\varepsilon(x, y, \eta_s, b) = \varepsilon_0 H(\eta_s) W(x, y, b)/W(0, 0, 0)$
  - No burst of four-momentum at the end of jets' evolution

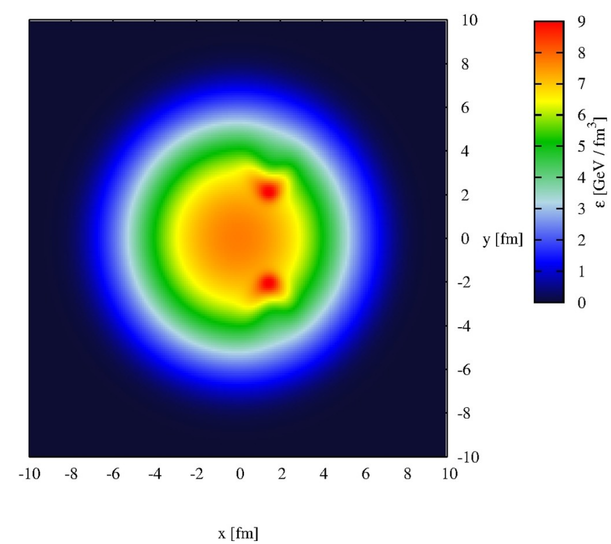
# Hotspots vs. Jets

- Hotspots scenario or fluctuating IC – popular in 3+1D hydrodynamics
  - Deposition of energy only at the start of simulation
- Jets scenario
  - Deposition of energy and momentum during the hydrodynamic simulation




Bjoern Schenke, Sangyong Jeon, Charles Gale
PhysRevC.85.024901

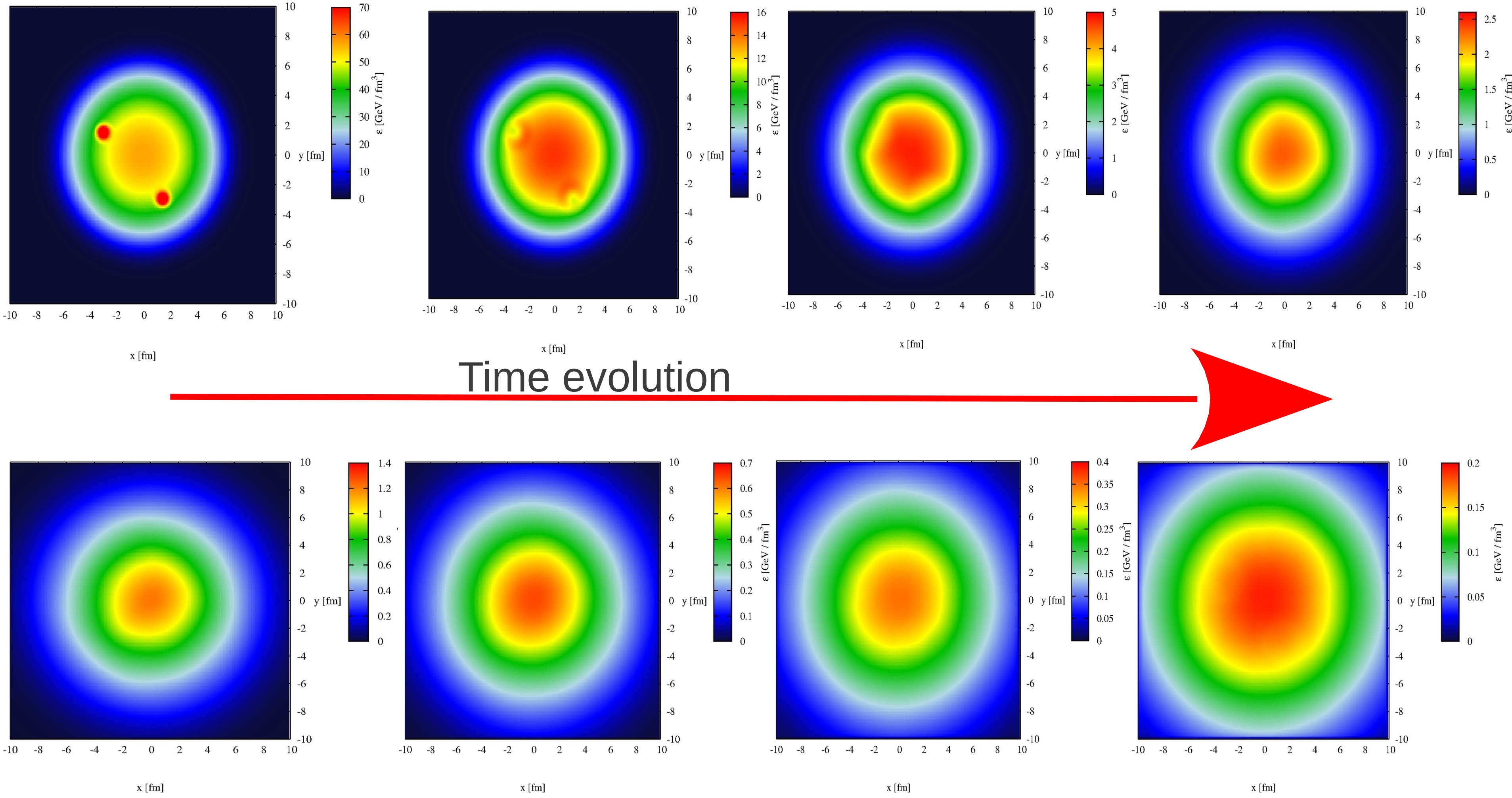
X




Our scenario

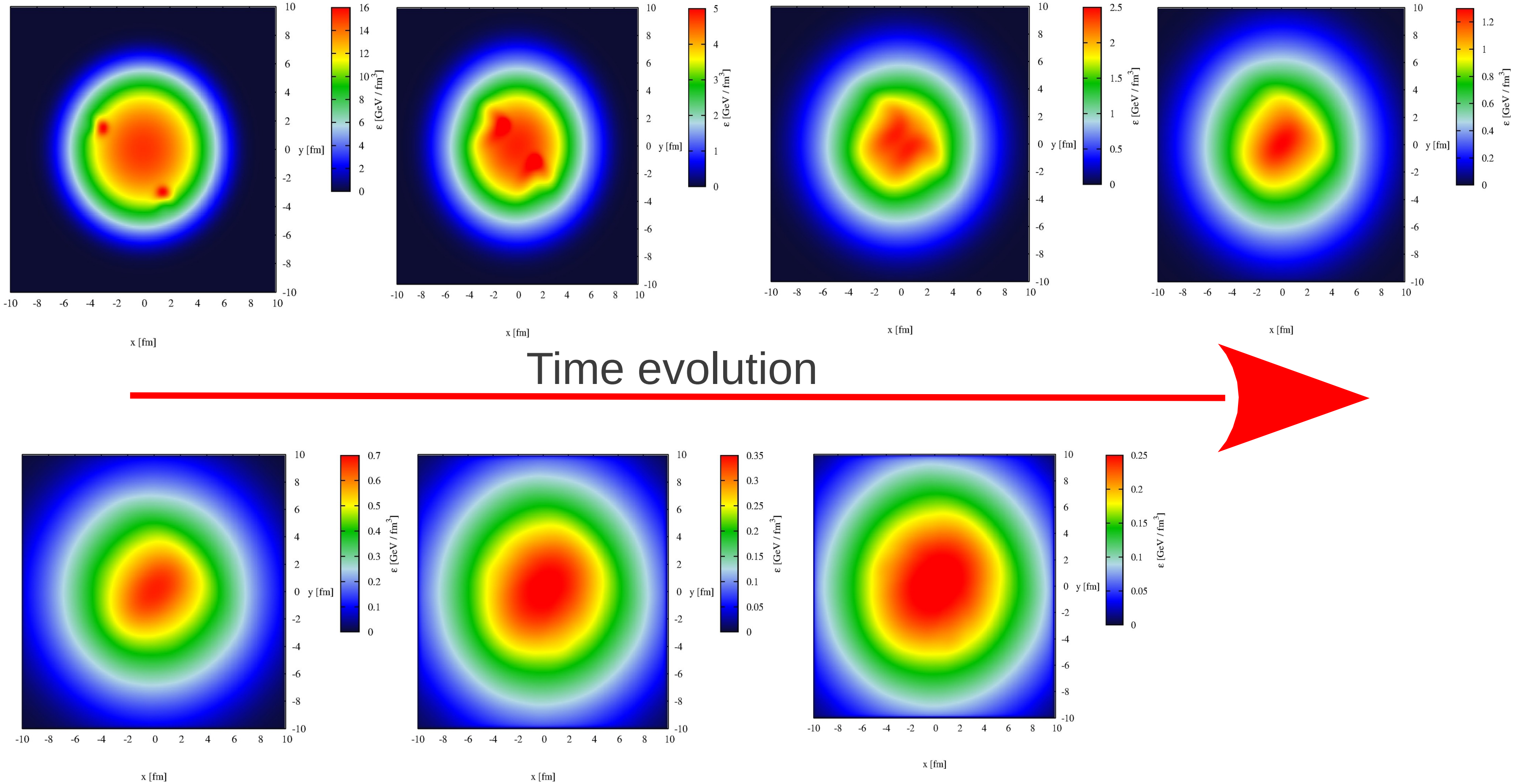
# Results – expanding medium

- 2 hot spots, Sequence of energy density profiles



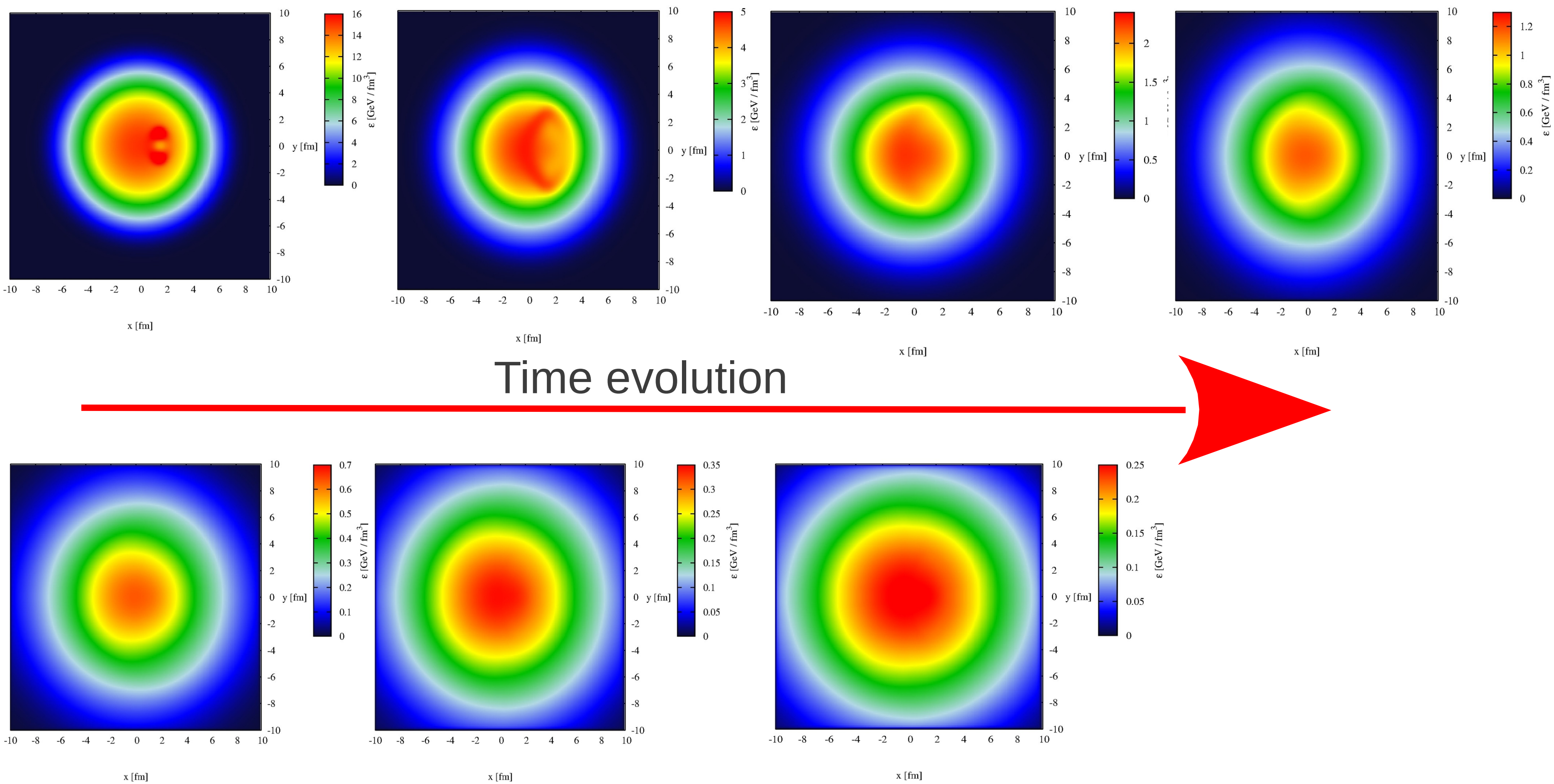
# Results – expanding medium

- 2 perpendicular jets, Sequence of energy density profiles



# Results – expanding medium

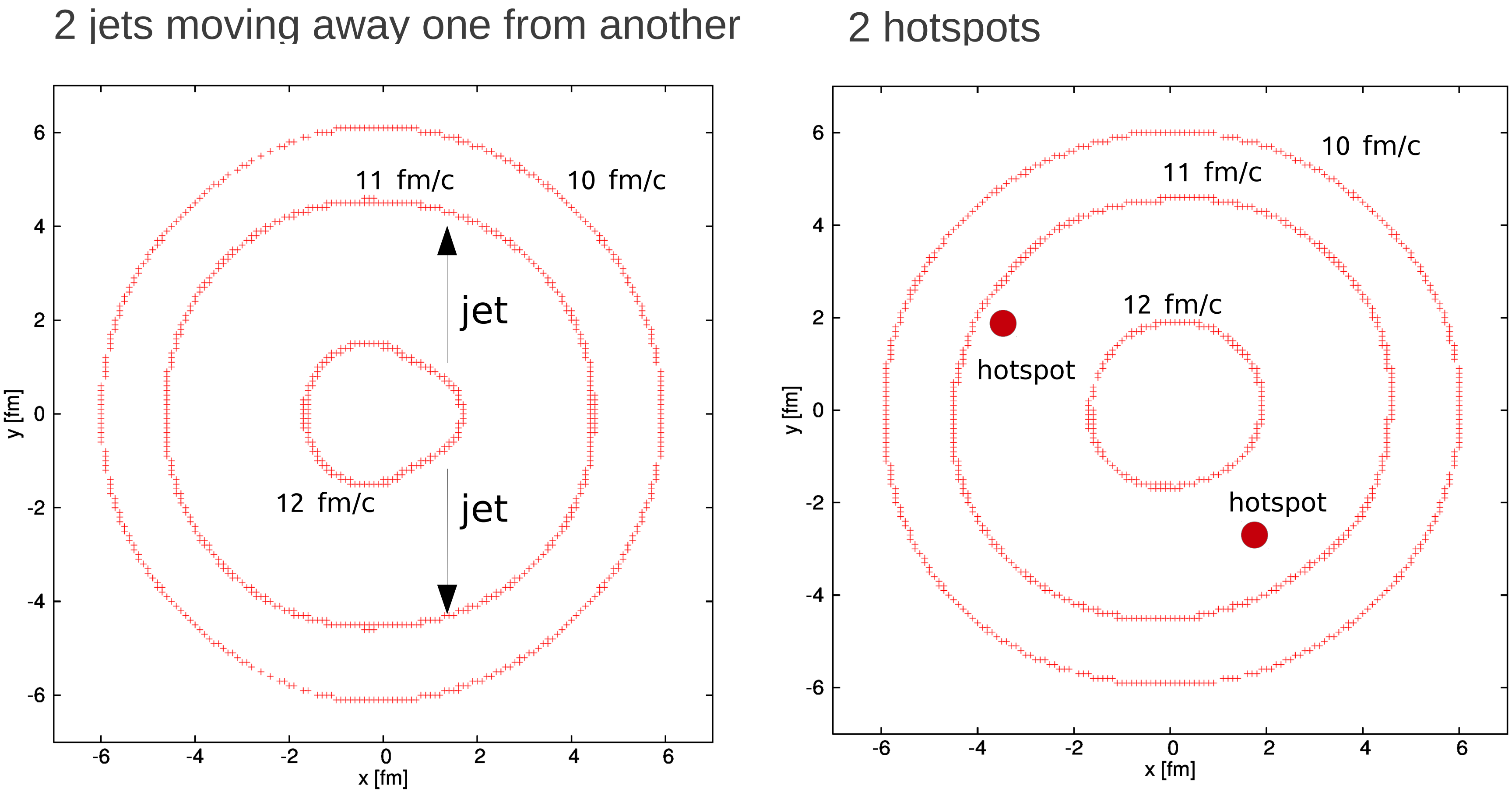
- 2 jets moving away one from another, Sequence of energy density profiles



# Results – expanding medium

- Comparison of freeze-out hypersurfaces

$\varepsilon_{freeze} = 0.25\ GeV/fm^3$




In case of jets the anisotropy survives until freeze-out.

EVIDENCE of jets' contribution to anisotropy !!!

# Conclusions

- We can perform 3+1D hydrodynamic simulation with evolving jets
- Jets contribute to anisotropy
- Freeze-out procedure is the next step in simulation

*Thank you for your attention!*