Hydrodynamics with sources

work in progress

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Motivation

- Thermalization during the pre-equilibrium stage does not happen globally at one constant proper time
- Nuclei overlapping time in low energy collisions is not negligible
- Medium response from Jet energy deposition
- Hadronized particles re-absorbed by the hot medium
- Magnetohydrodynamics

Hydrodynamics with sources

Energy-momentum current and net baryon density are feed into hydrodynamic simulations as source terms

$$\partial_\mu T^{\mu\nu} = J^\nu_{\mathrm{source}}$$

$$\partial_\mu J^\mu = \rho_{\mathrm{source}}$$

here

$$J^\nu_{\mathrm{source}} = \delta e u^\nu + (e + P)\delta u^\nu$$

$$\delta u^\nu = \frac{\Delta^\nu_\mu J^\mu_{\mathrm{source}}}{e + P}$$

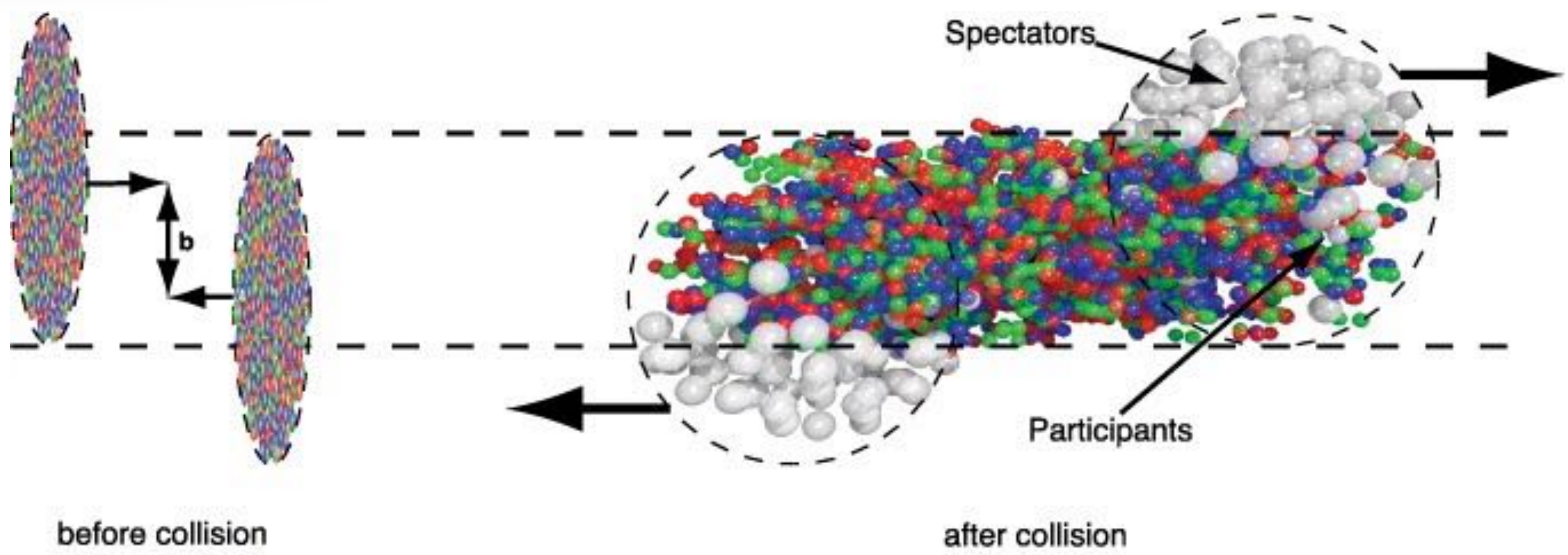
heats up the system — accelerates the flow velocity

ρ_{source} dopes baryon charges into the system

- Source terms are smeared with Gaussians in space and time

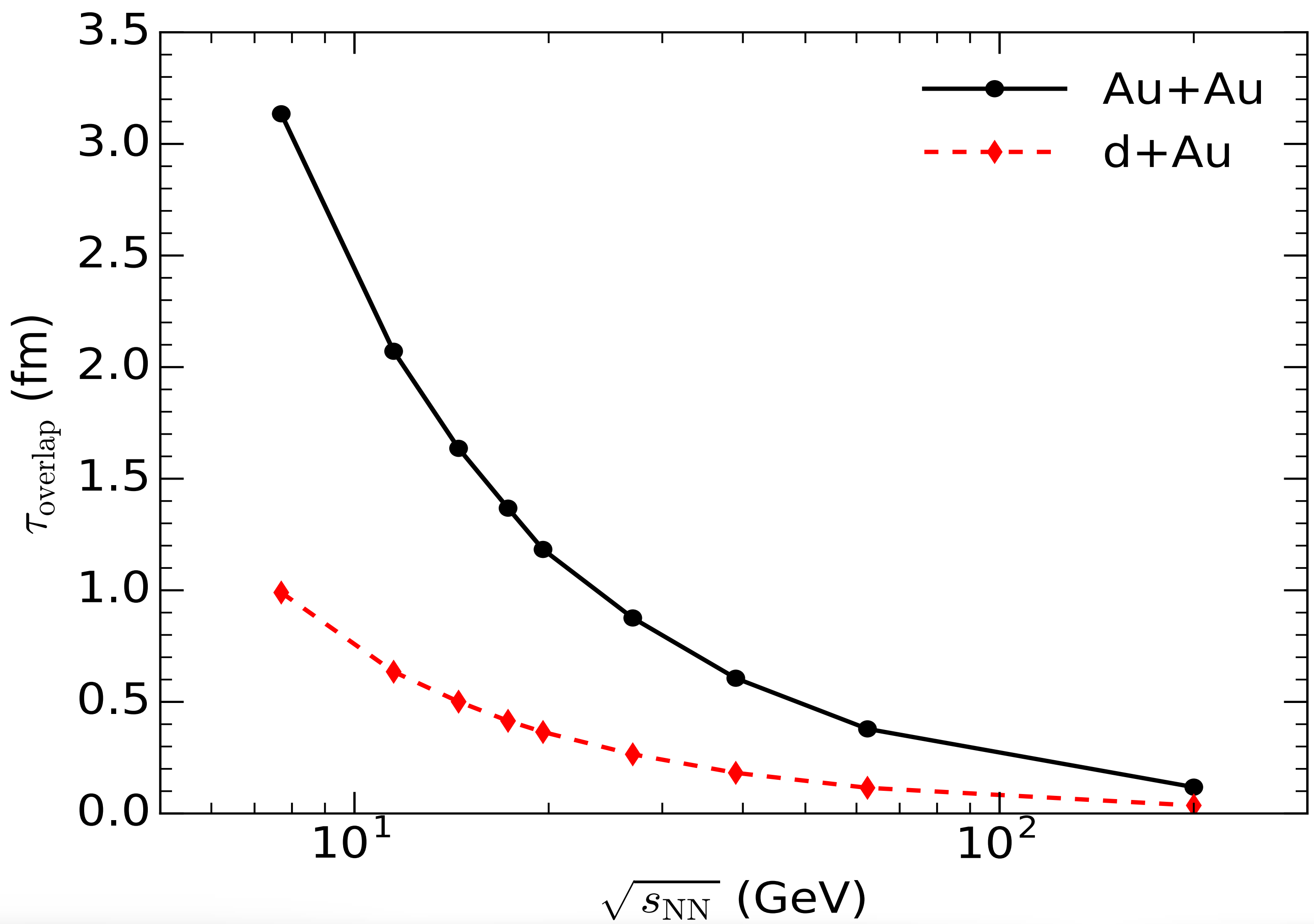
Applications

Hydrodynamics at BES energies



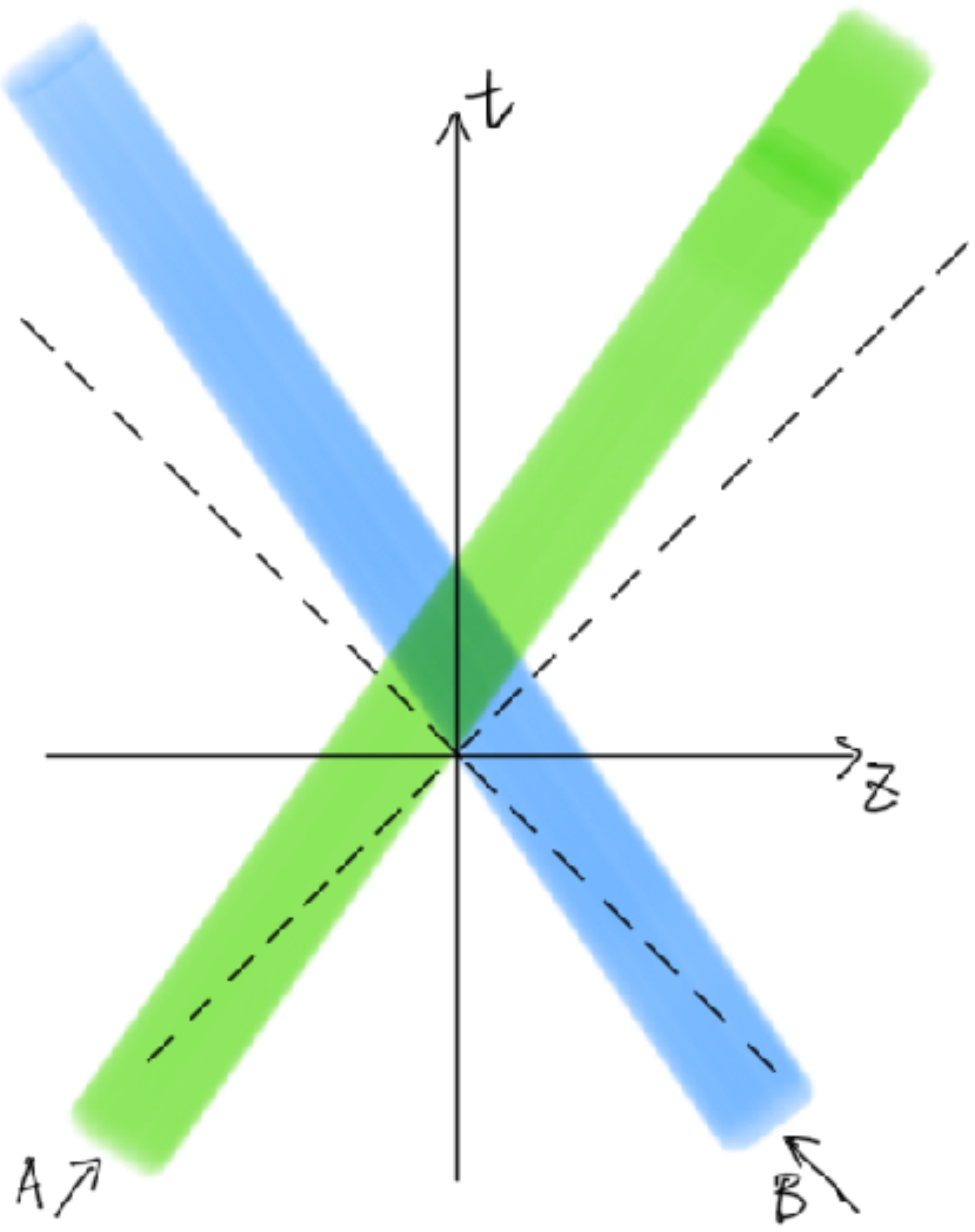
Two nuclei overlapping time

$$\tau \sim \frac{2R}{\gamma v_z}$$



- Nuclei overlapping time is large at low collision energy
- Pre-equilibrium dynamics can play an important role

Go beyond the Bjorken approximation



- The finite widths of the colliding nuclei are taken into account

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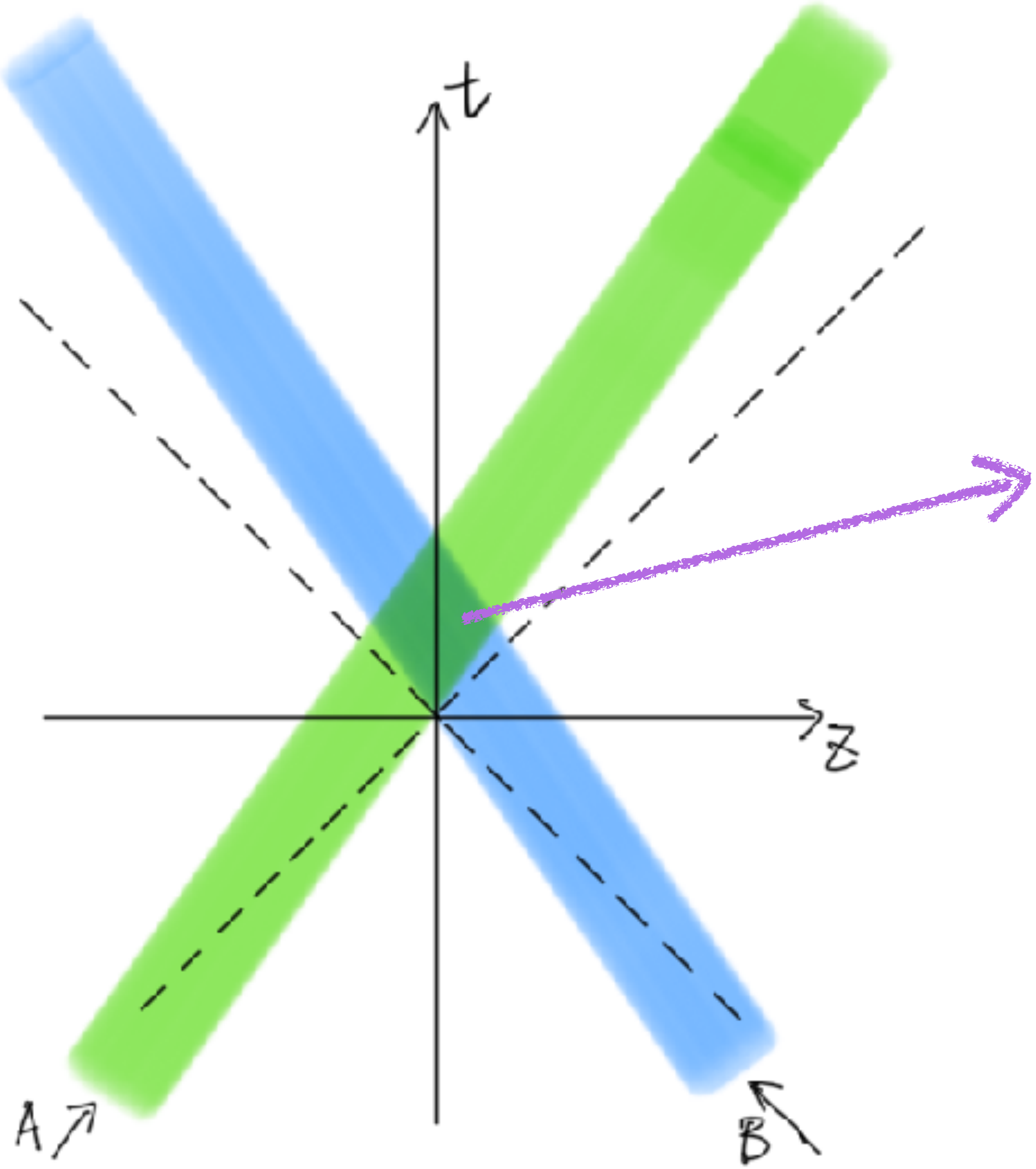
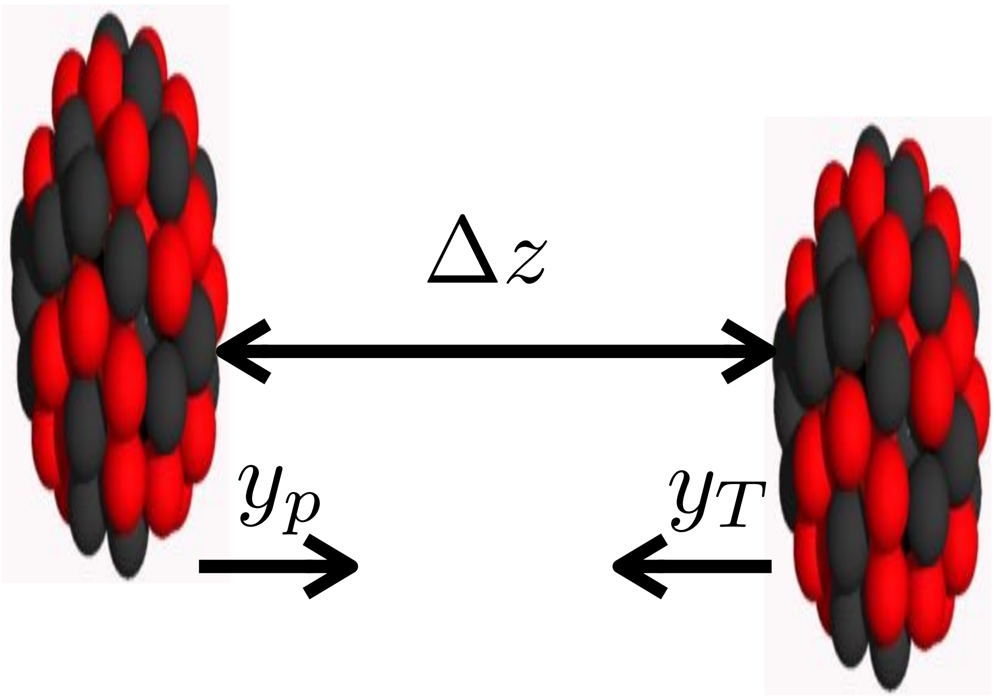


- The finite widths of the colliding nuclei are taken into account

The interaction zone is not point like

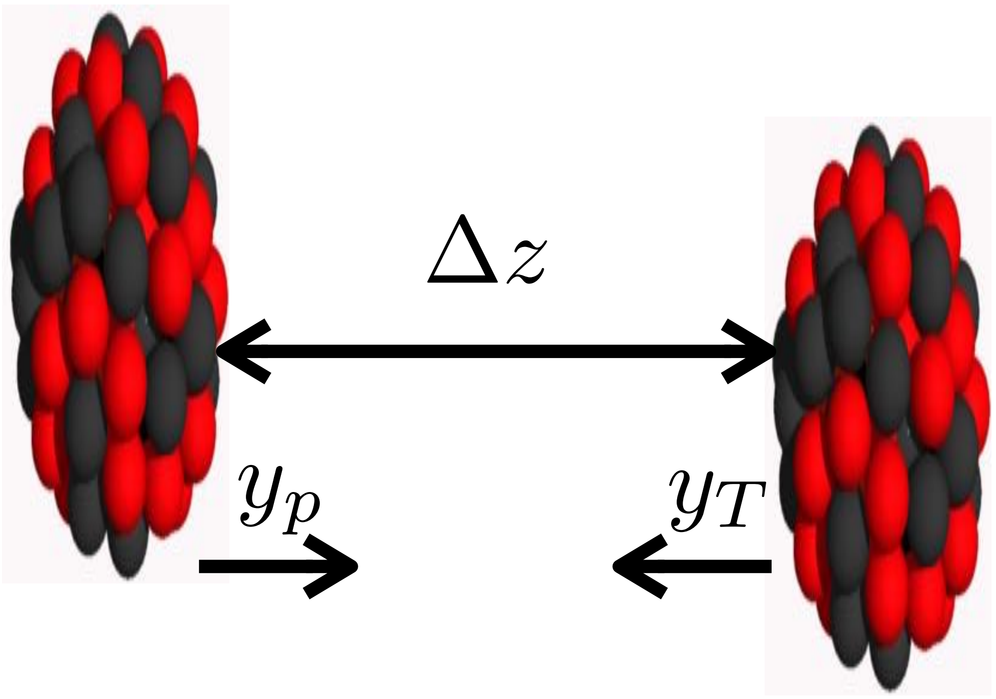
$$y \neq \eta_s$$

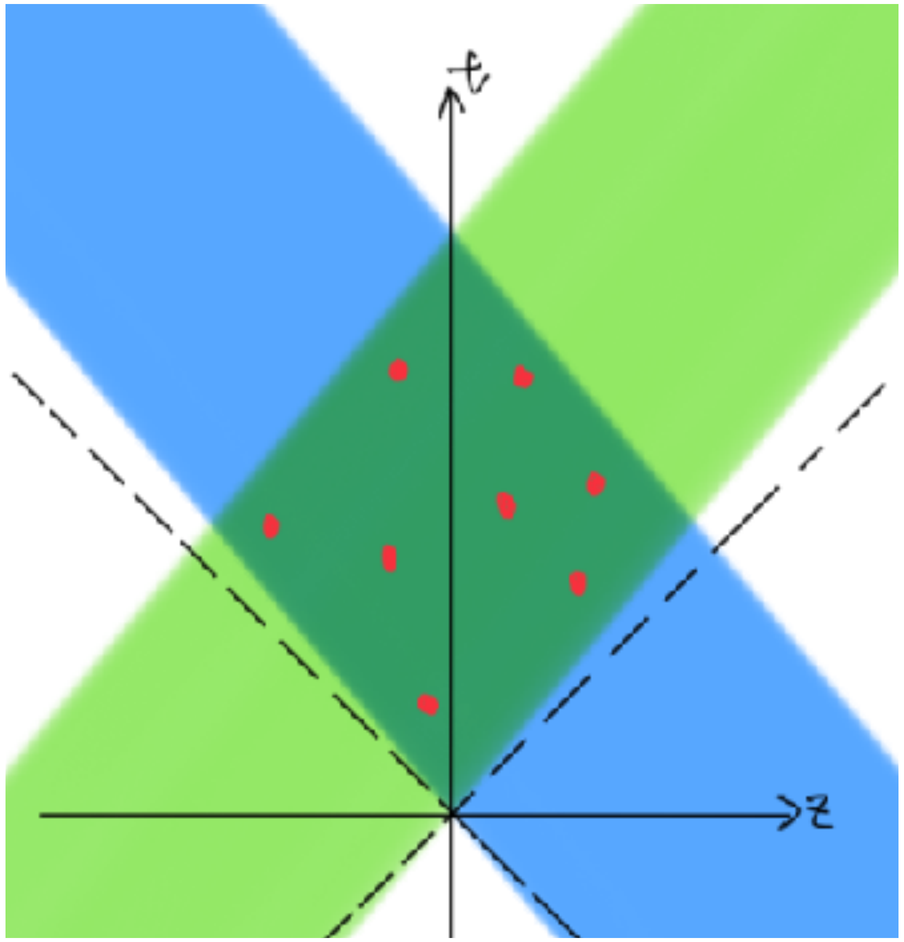
The 3D MCGlauber-LEXUS model



- Collision time and 3D spatial position are determined for every binary collision

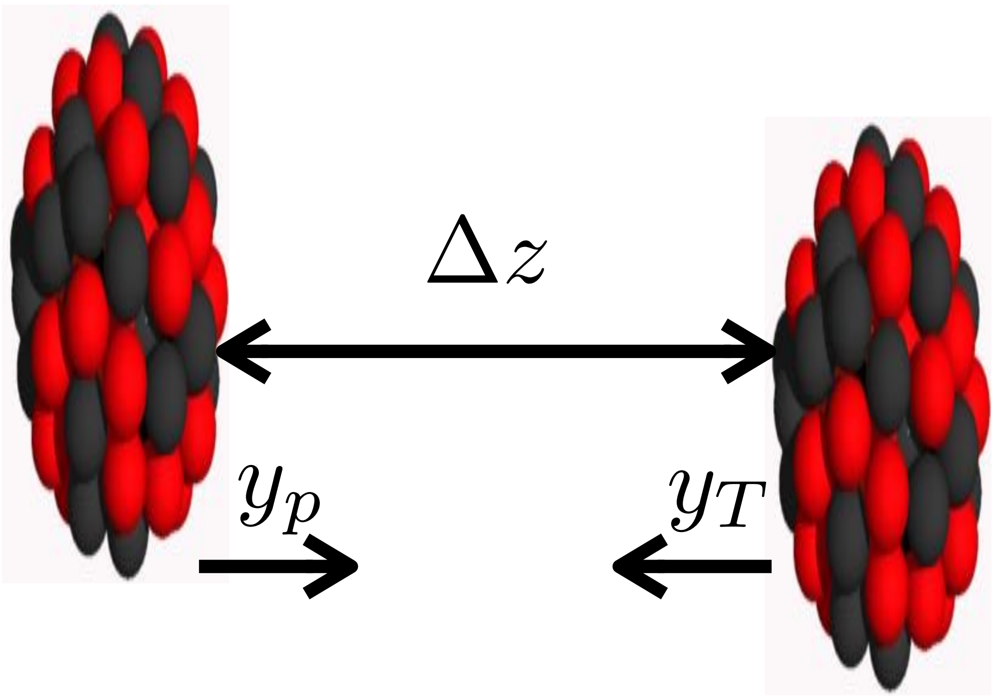
The 3D MCGlauber-LEXUS model

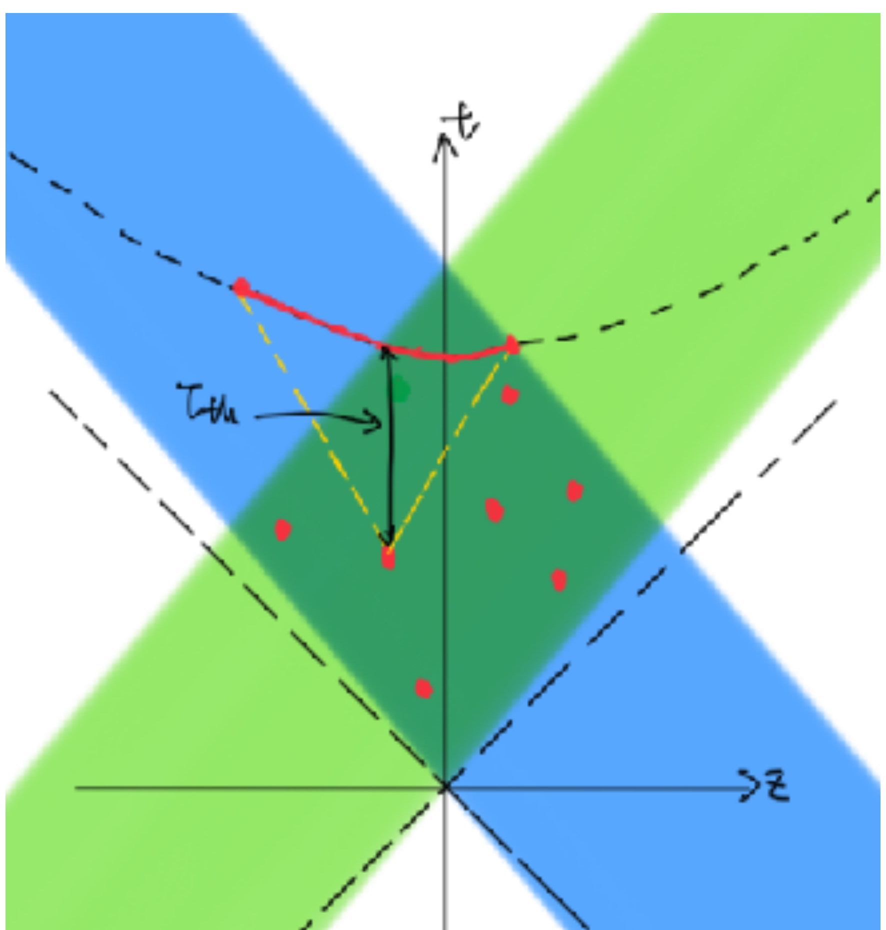




- Collision time and 3D spatial position are determined for every binary collision
- QCD strings are produced from those collision points

The 3D MCGlauber-LEXUS model



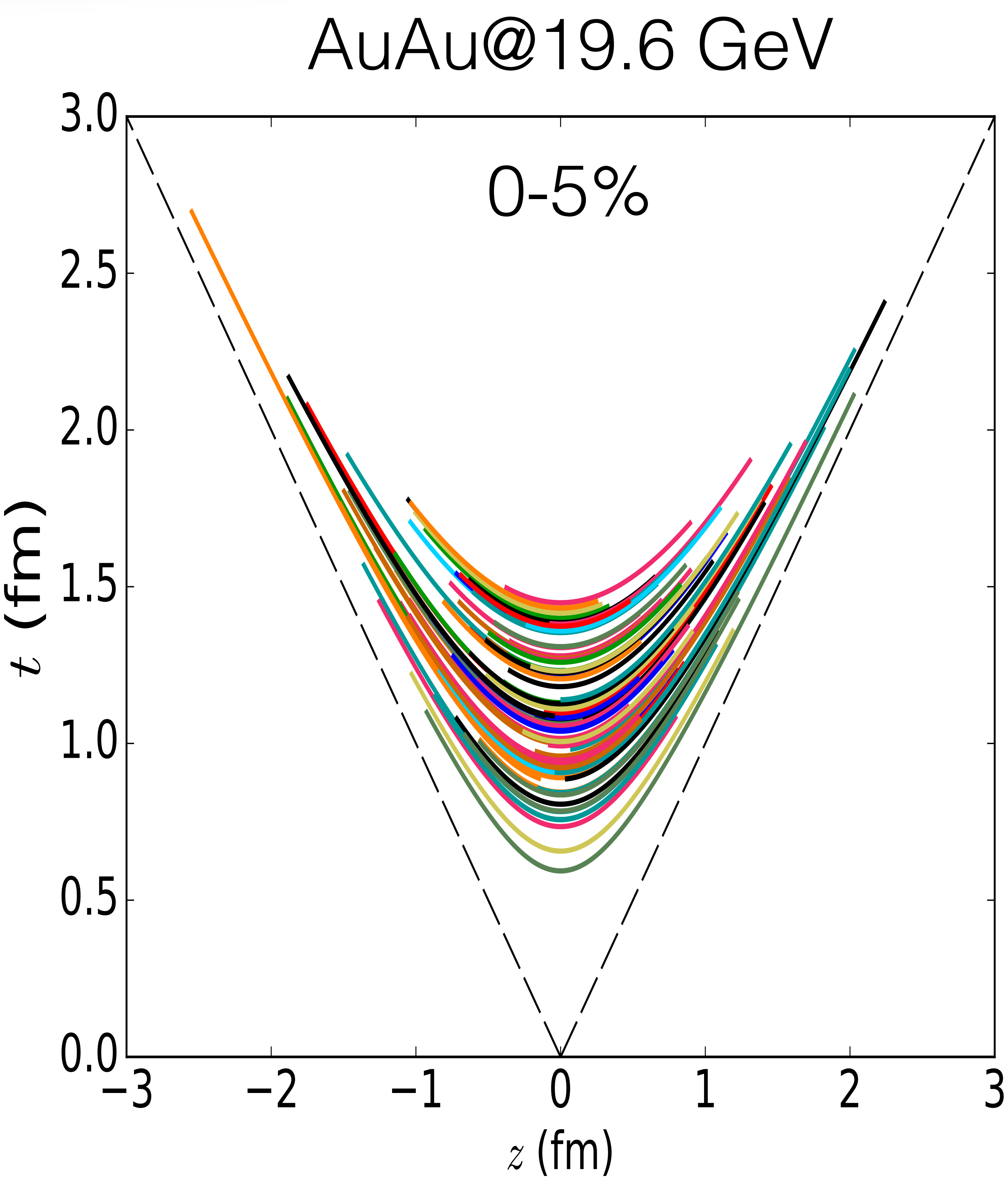


- Collision time and 3D spatial position are determined for every binary collision
- The rapidity loss is determined by the LEXUS model

$$P(y_p, y_T, y) = \lambda \frac{\cosh(y - y_T)}{\sinh(y_P - y_T)} + (1 - \lambda)\delta(y - y_P)$$

- Each string is free-streaming by $\tau_{\rm th} = 0.5 fm$ before thermalized to medium

The 3D MCGlauber-LEXUS model



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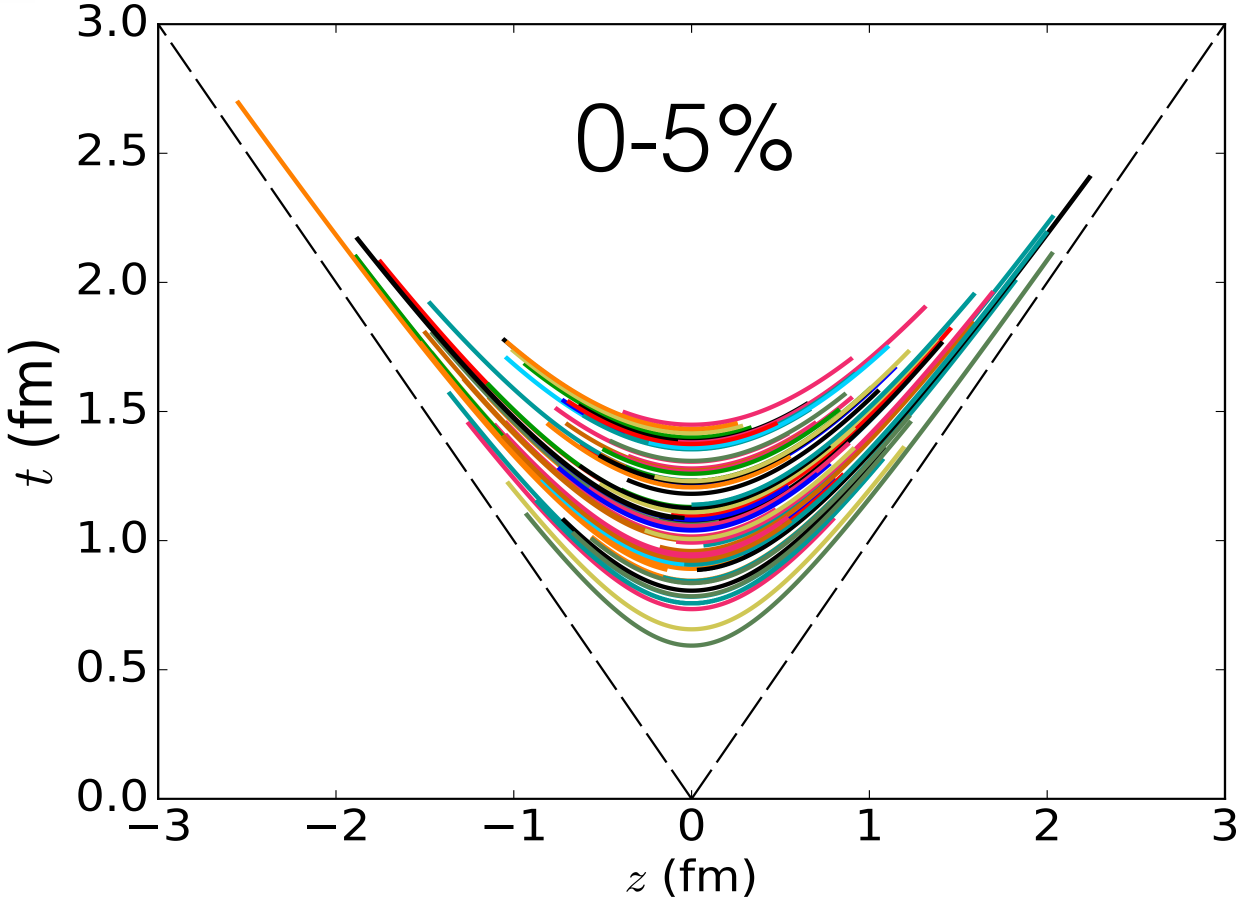
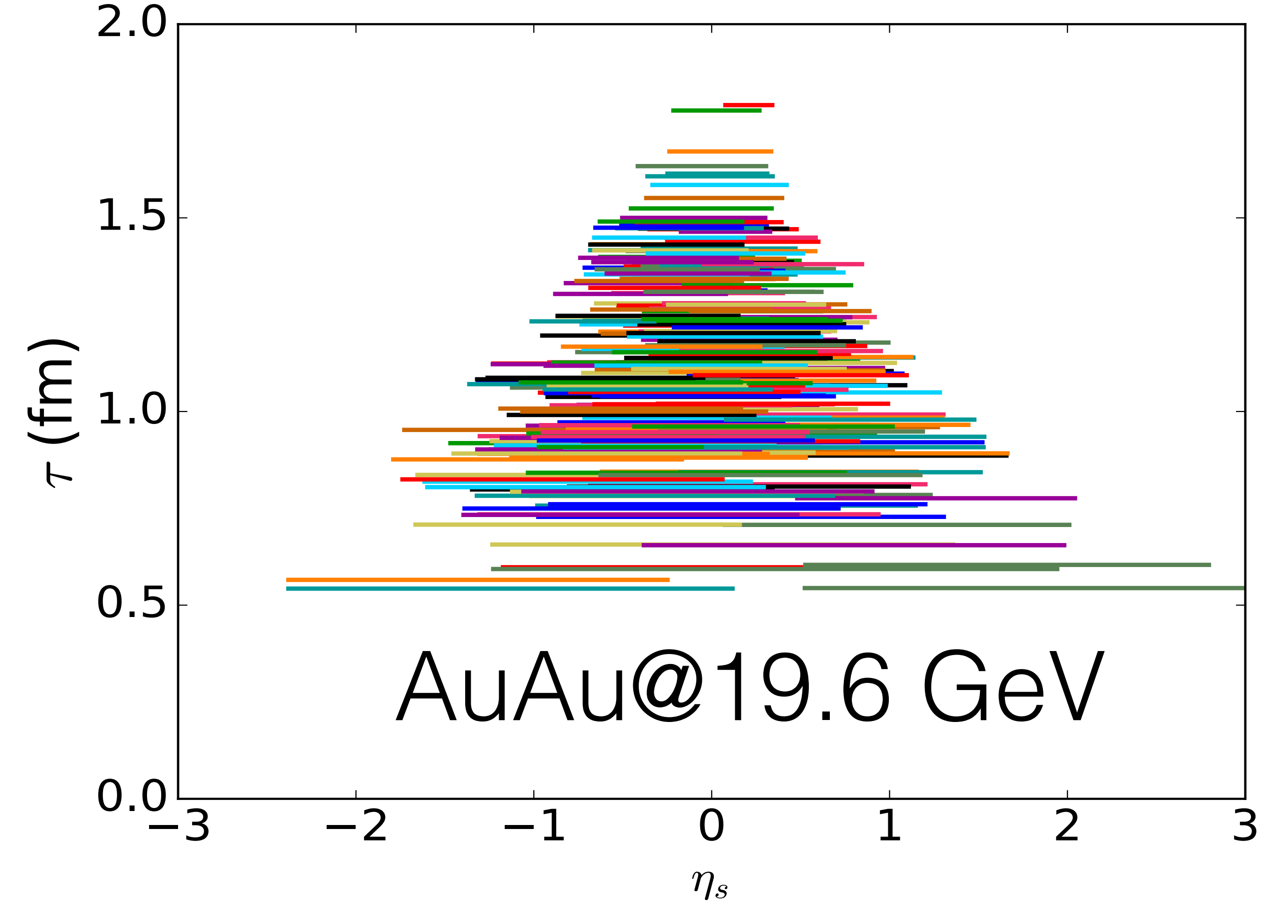
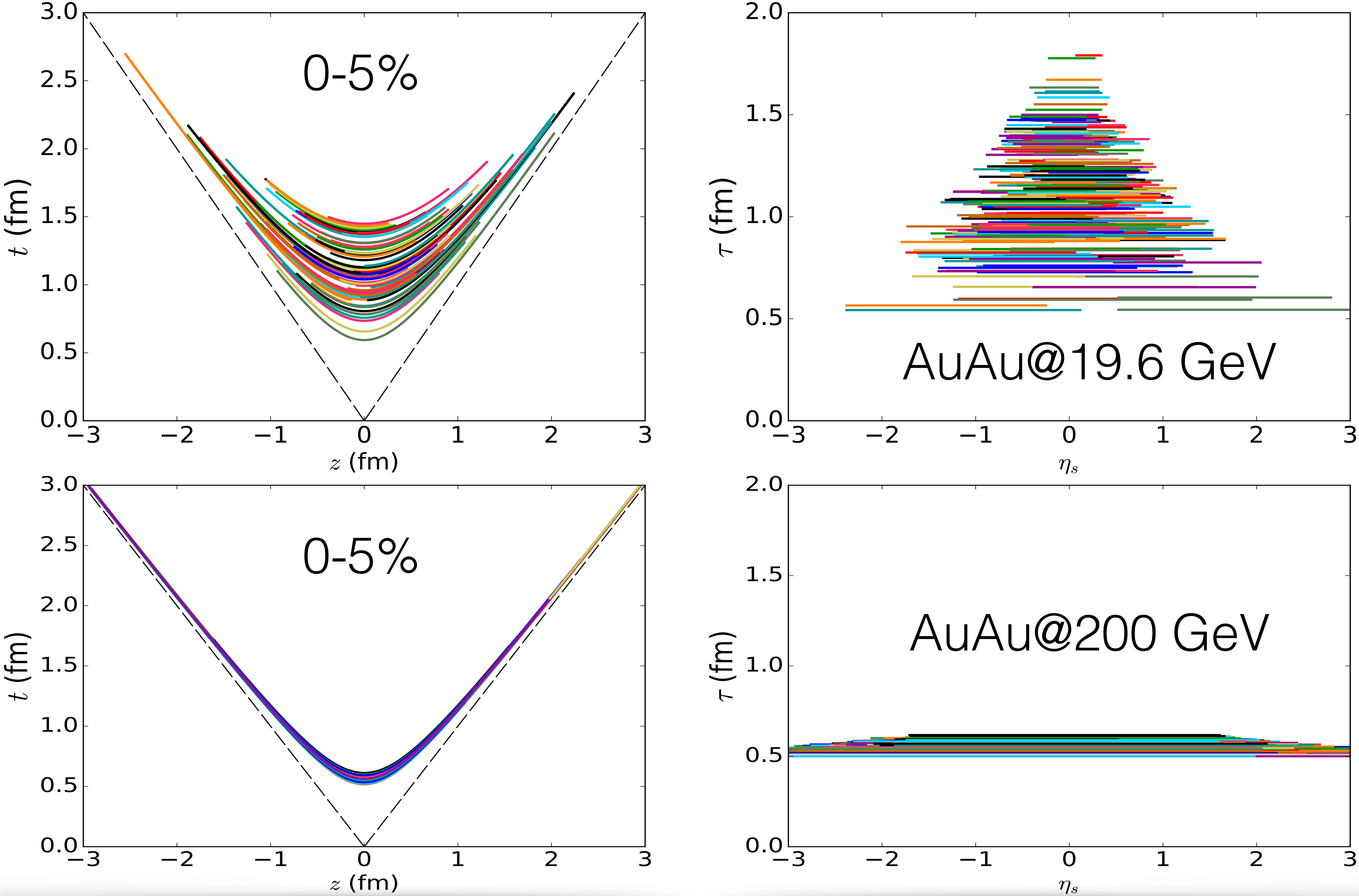


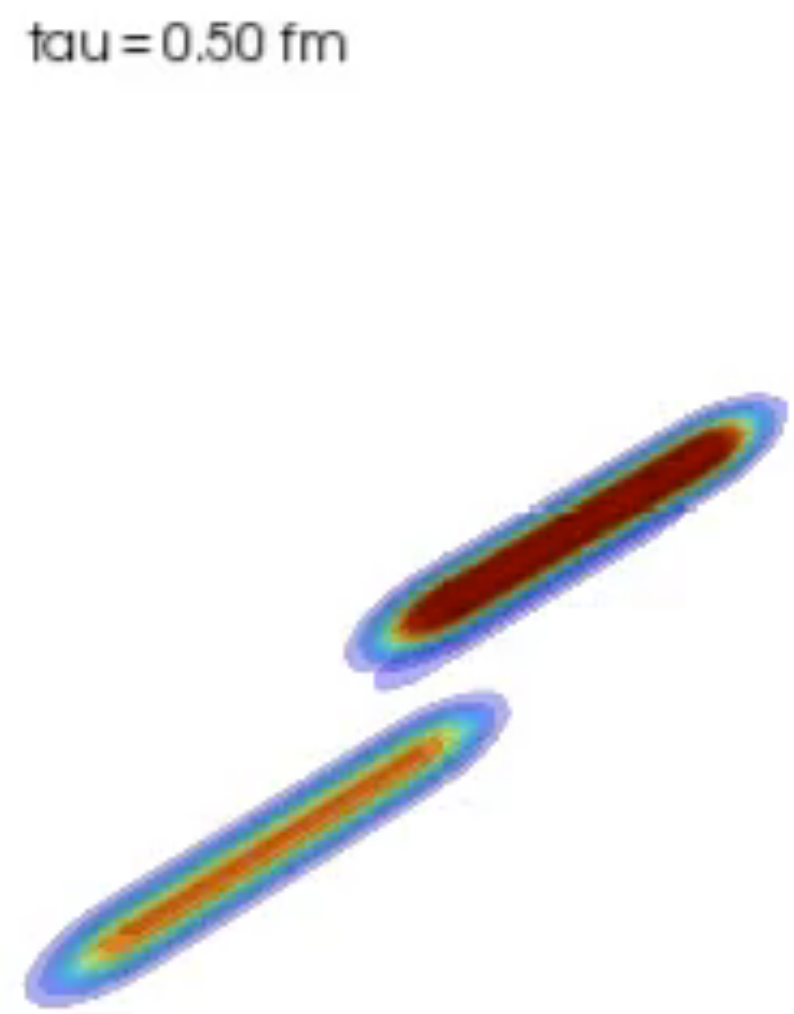


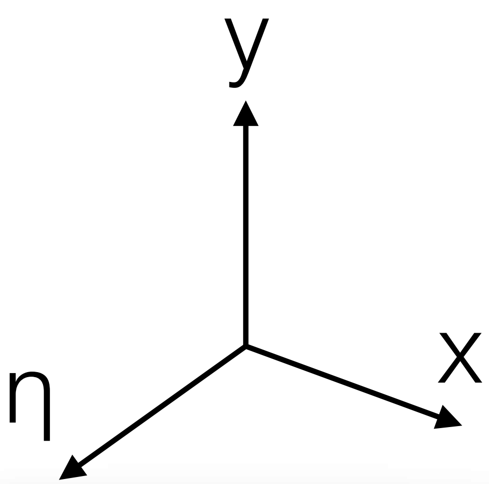
Recover ordinary Glauber at the high energy limit



Hydrodynamical evolution with sources

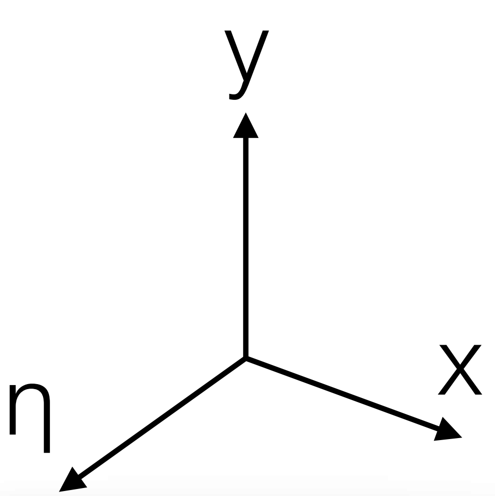
energy density



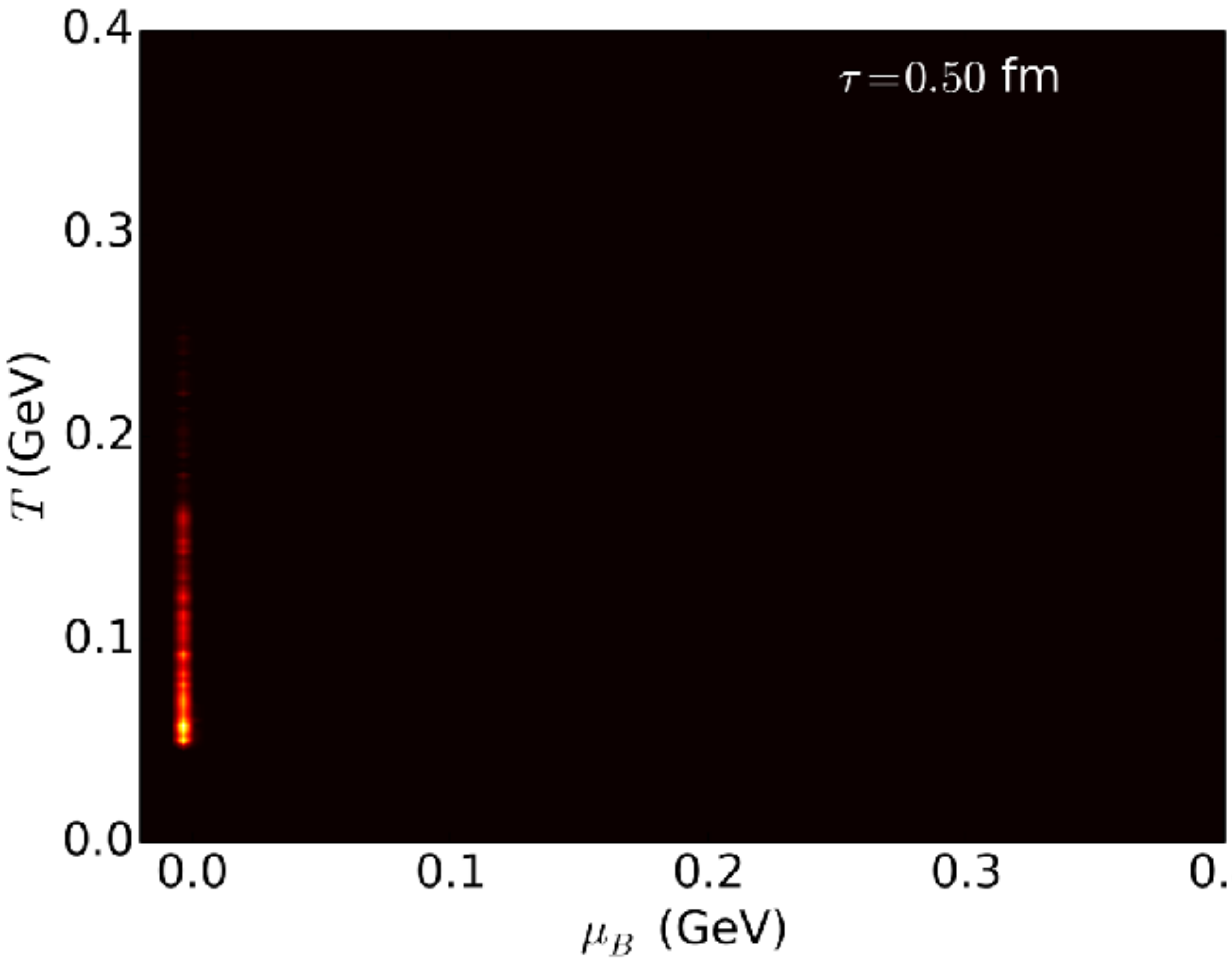


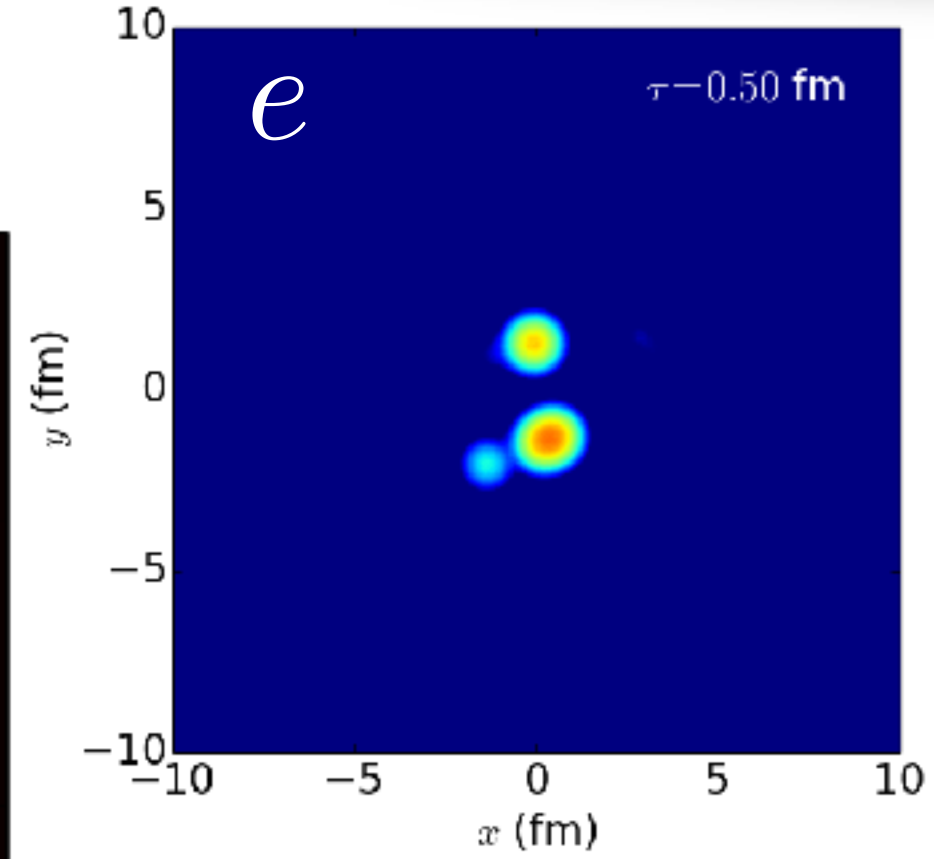
Hydrodynamical evolution with sources

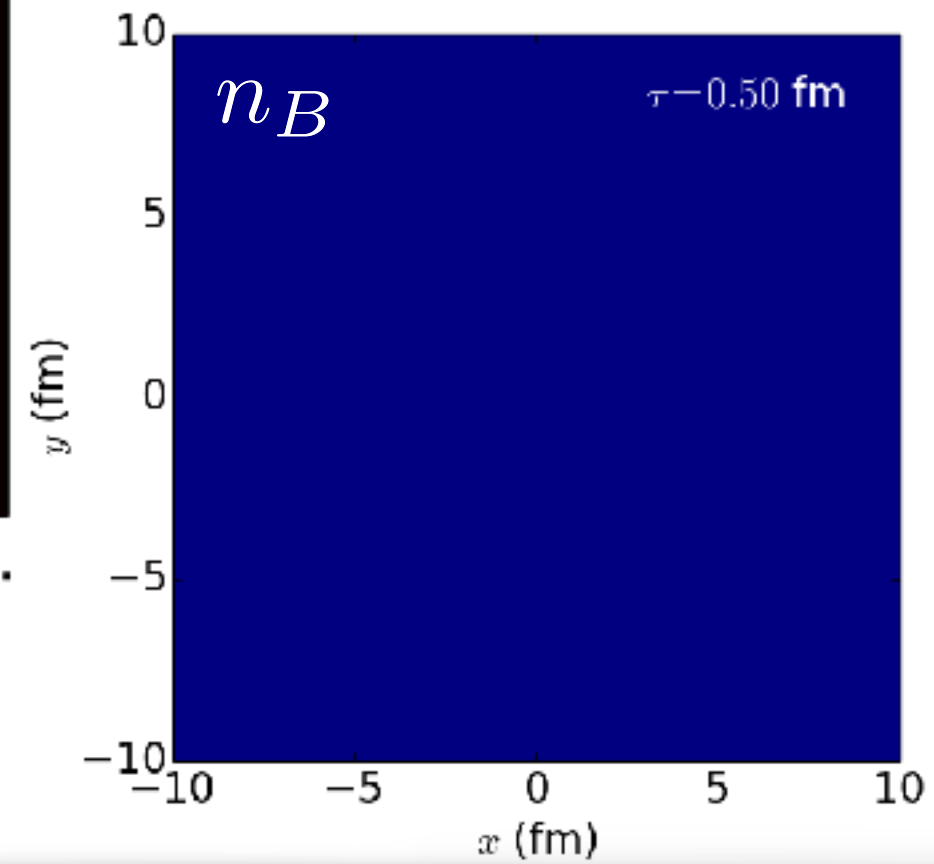
net baryon density



Fireball evolution in the QCD phase diagram







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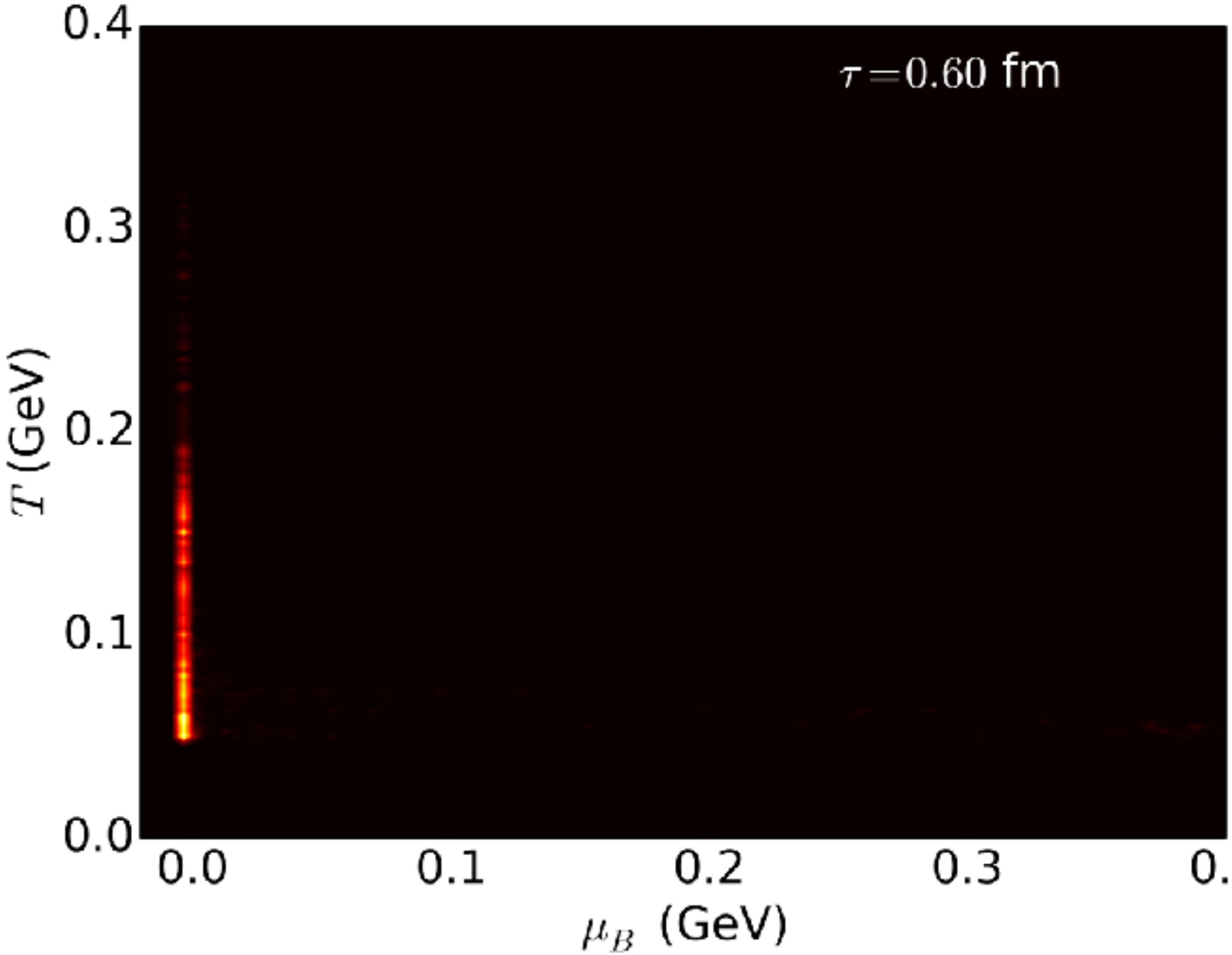

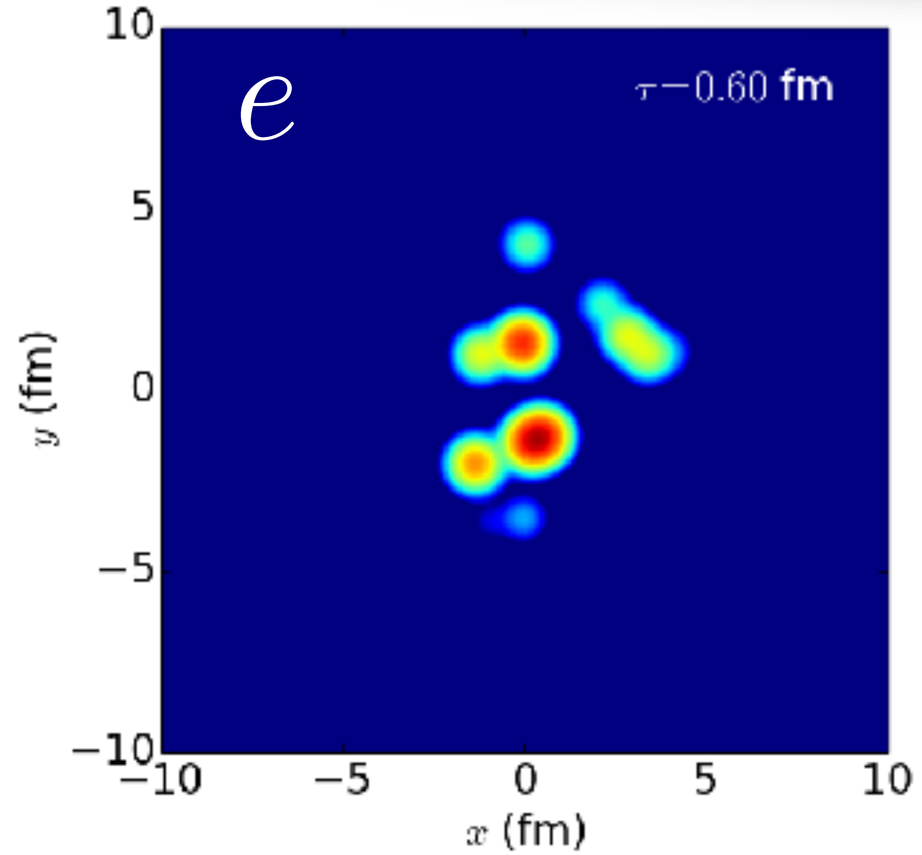

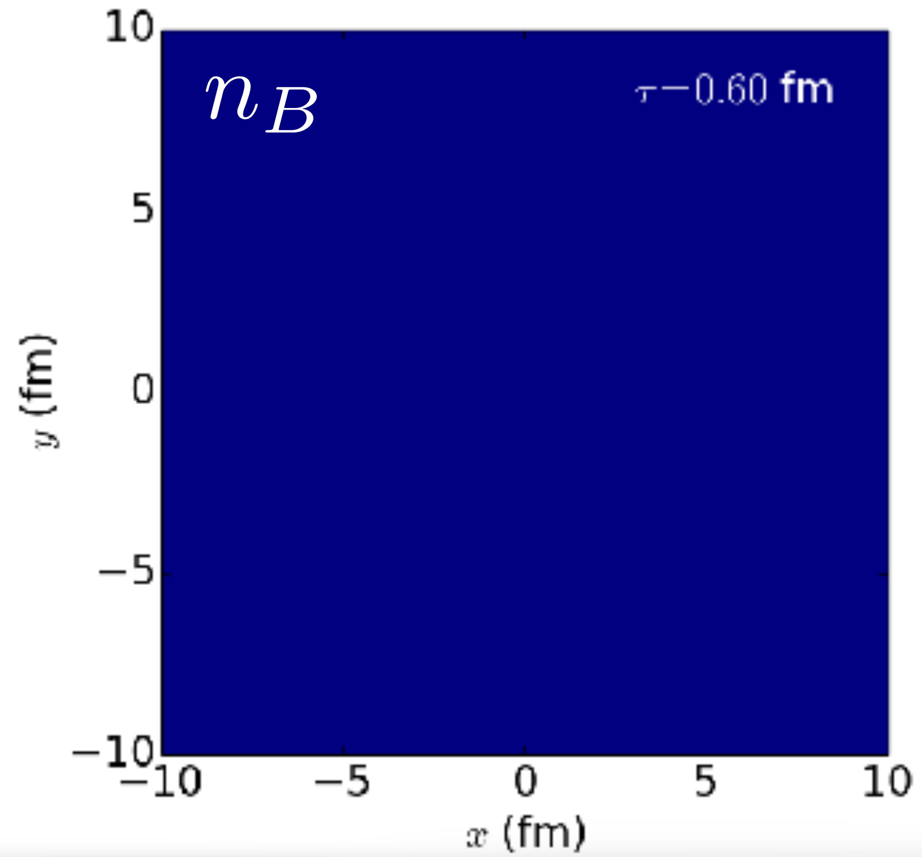

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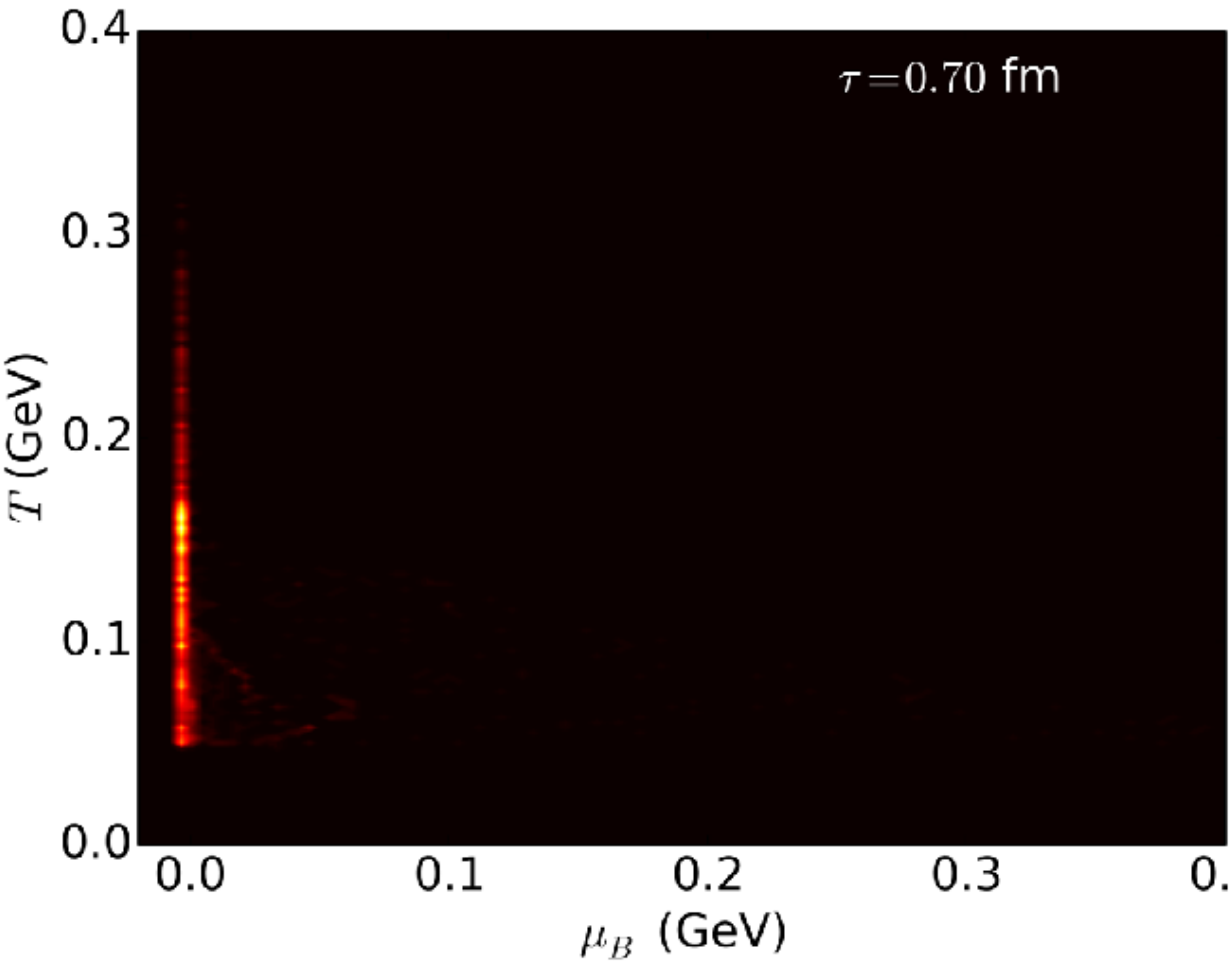

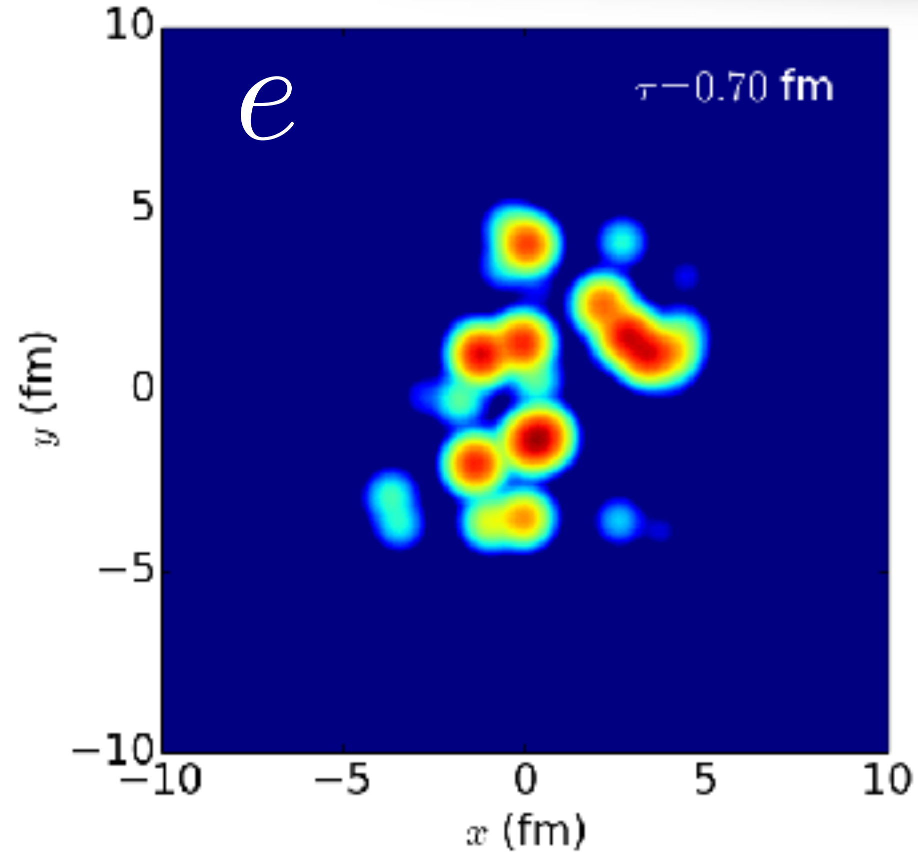

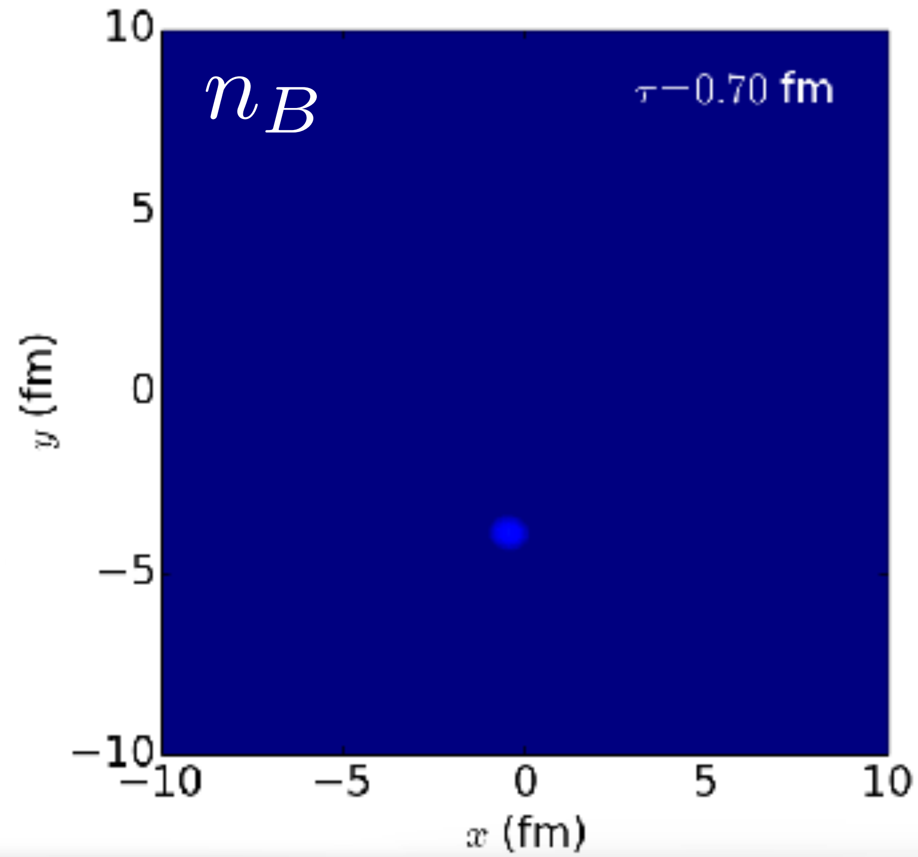

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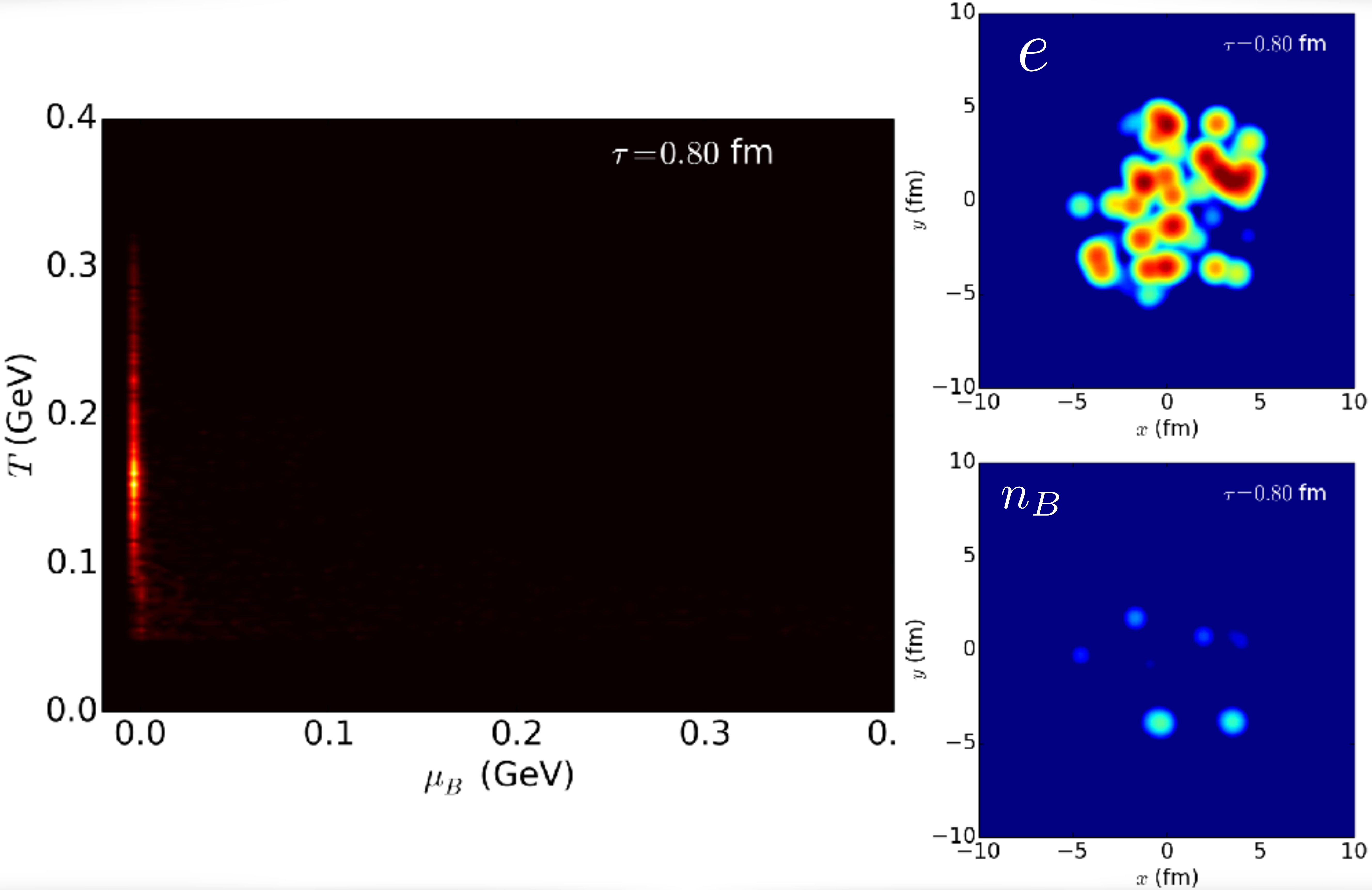

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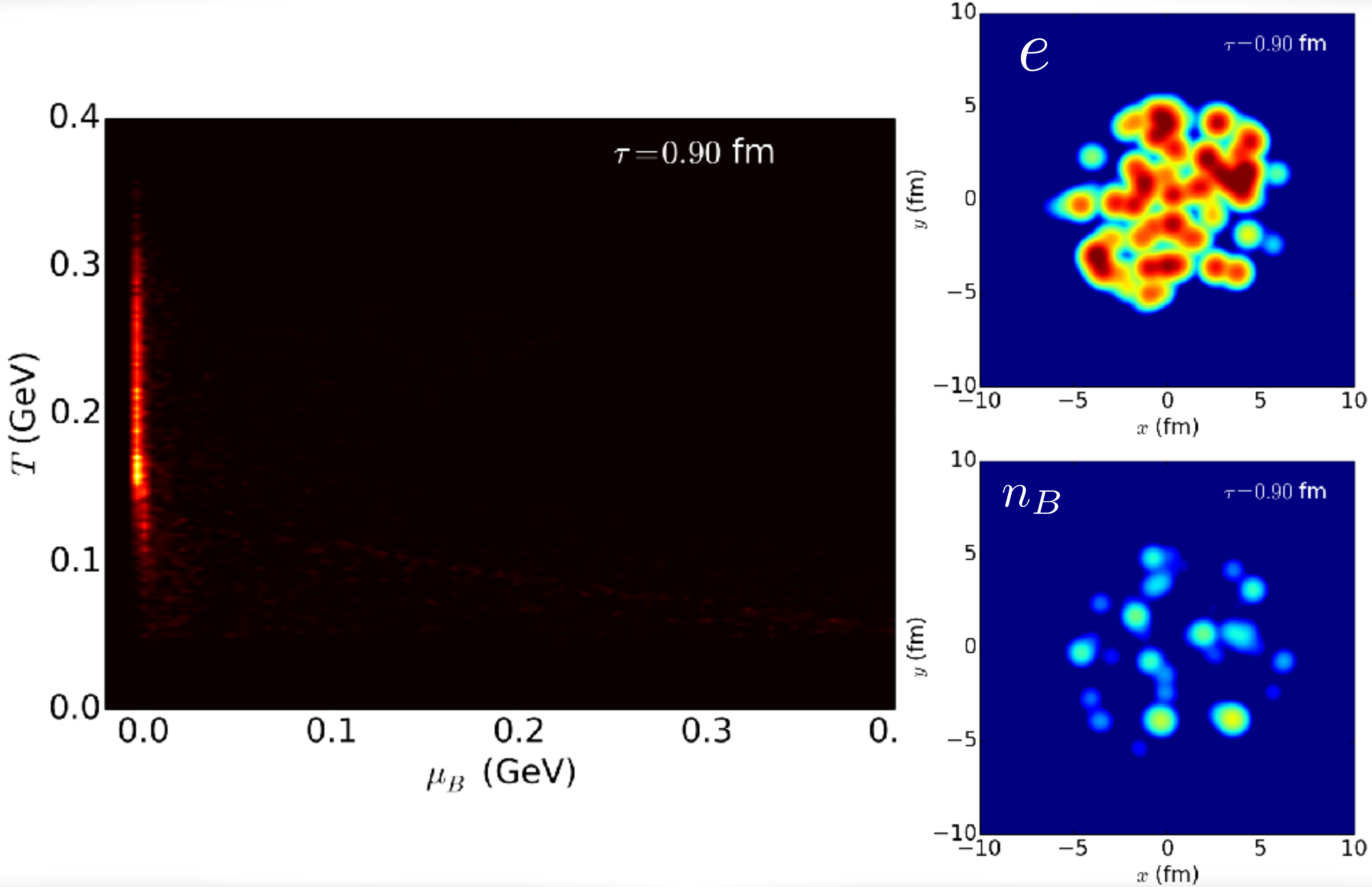

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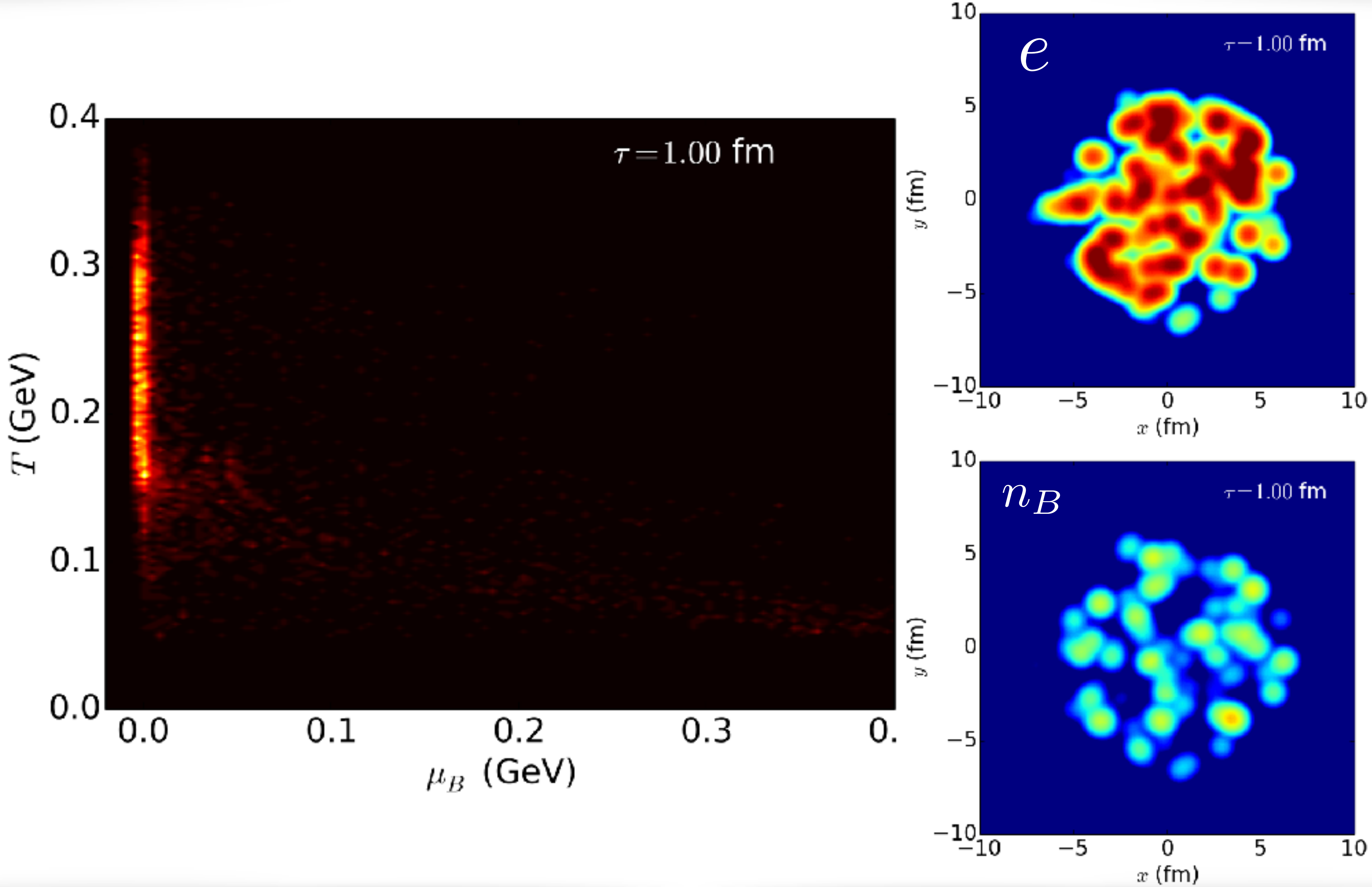

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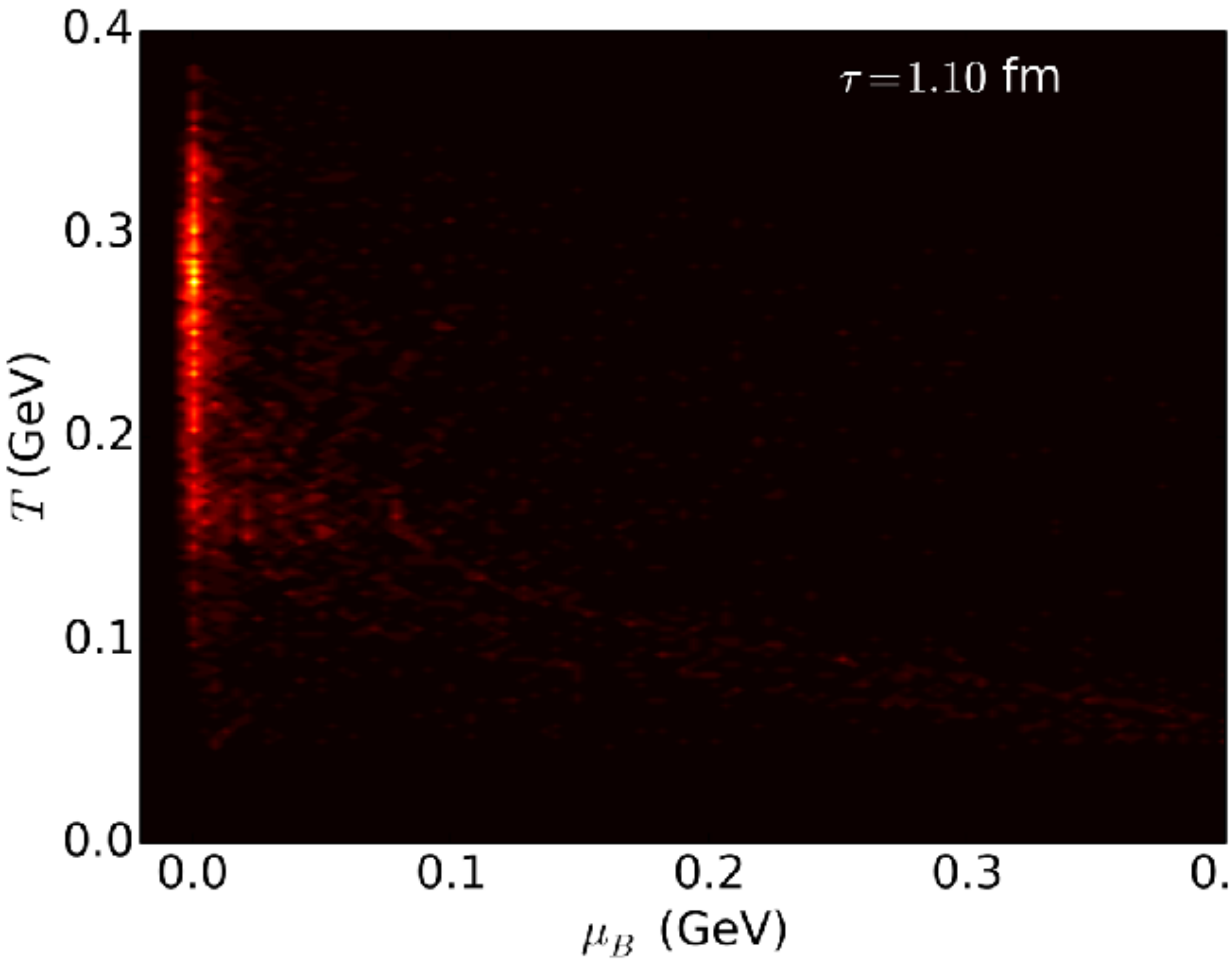

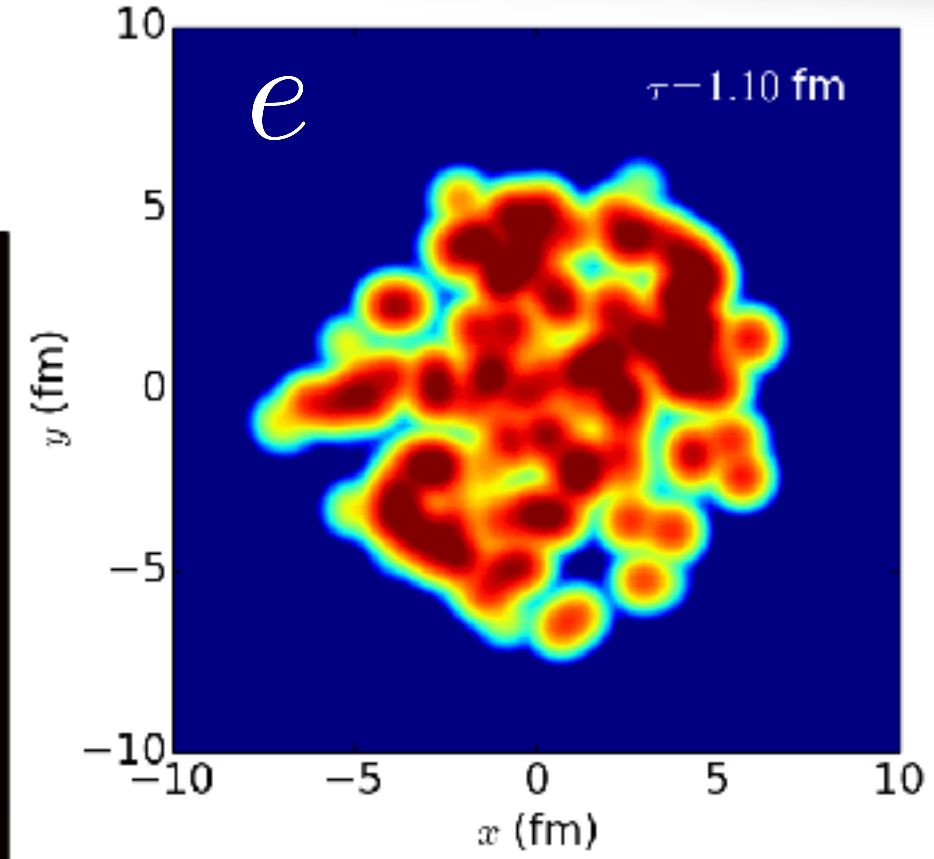

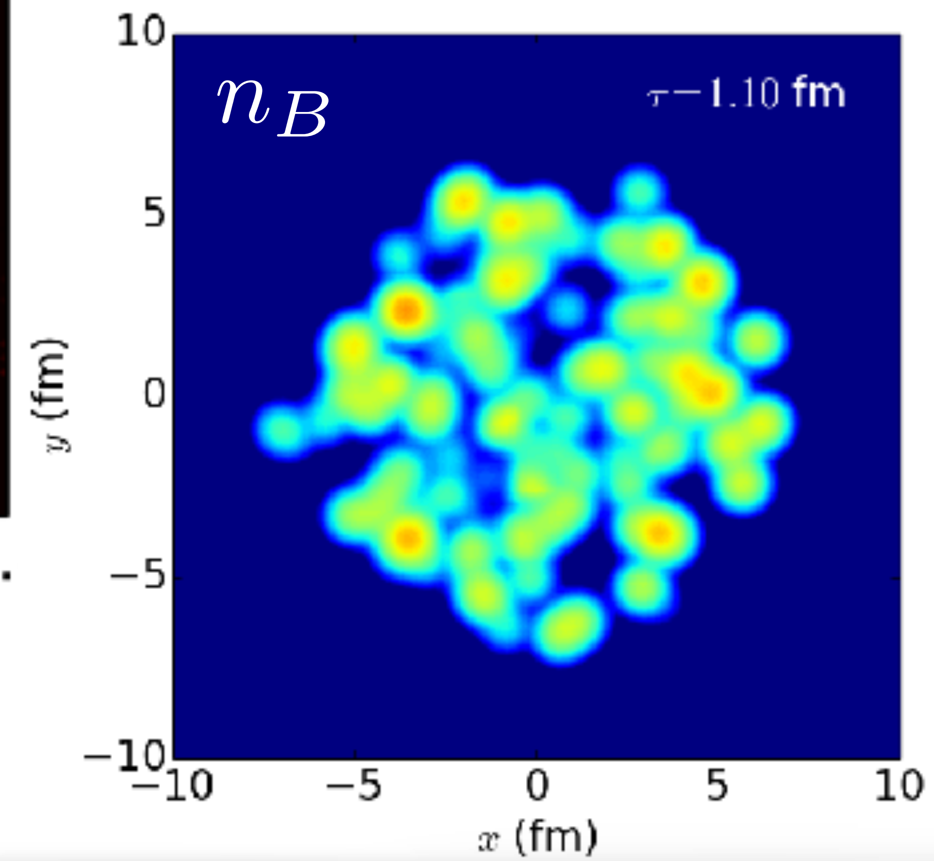

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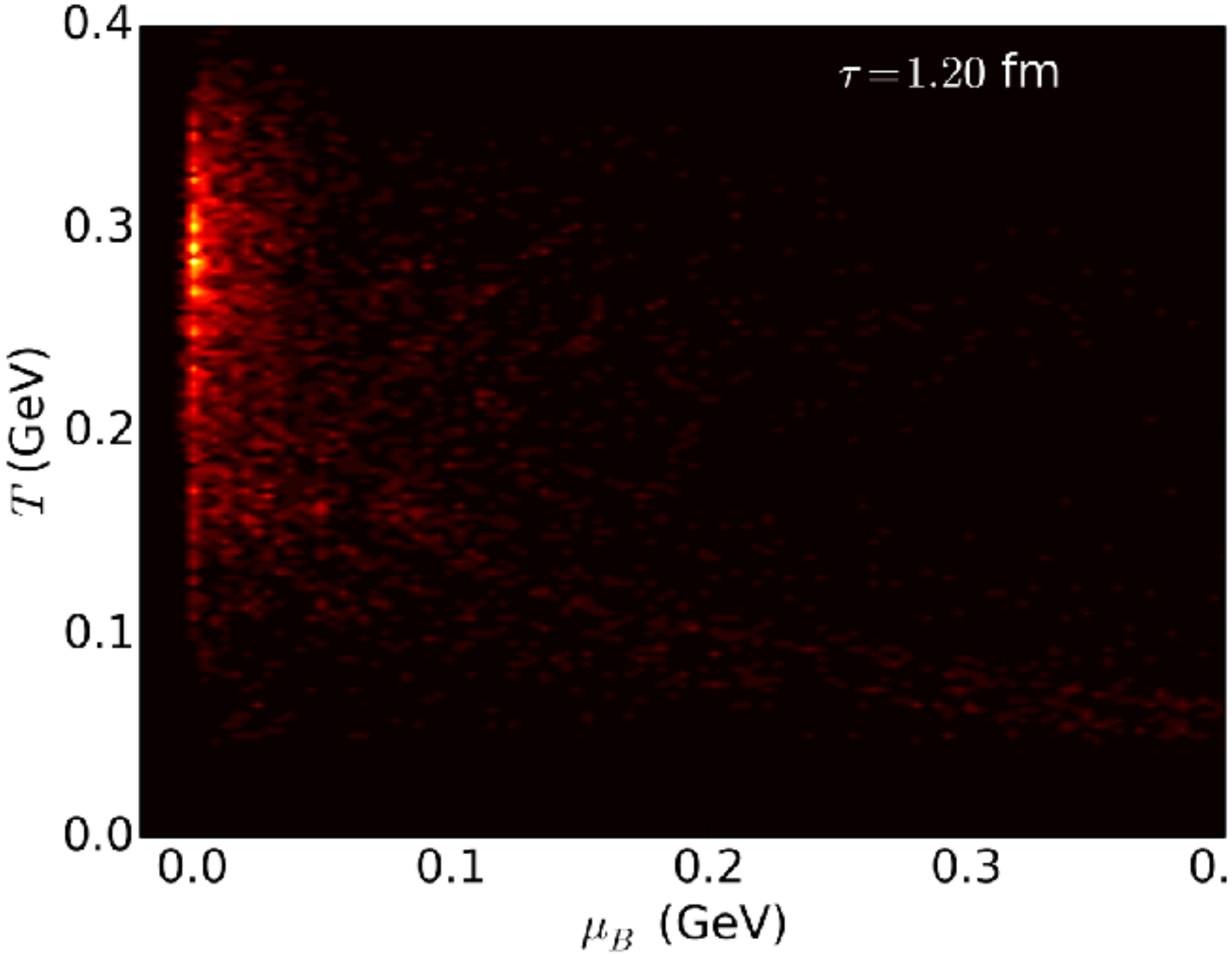

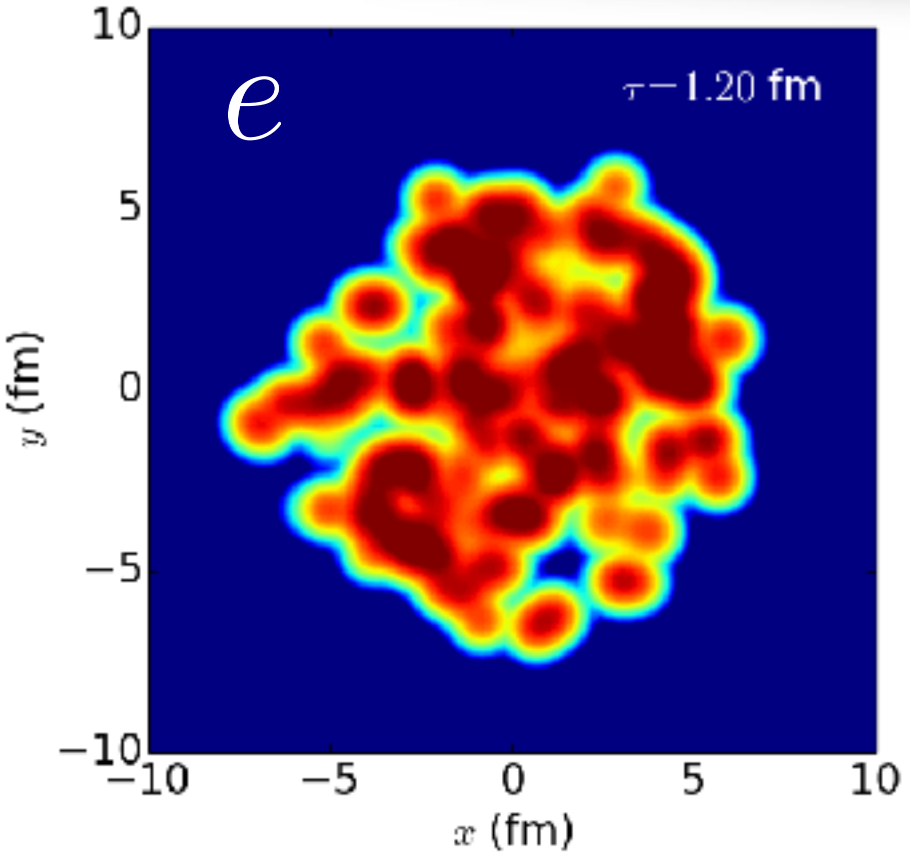

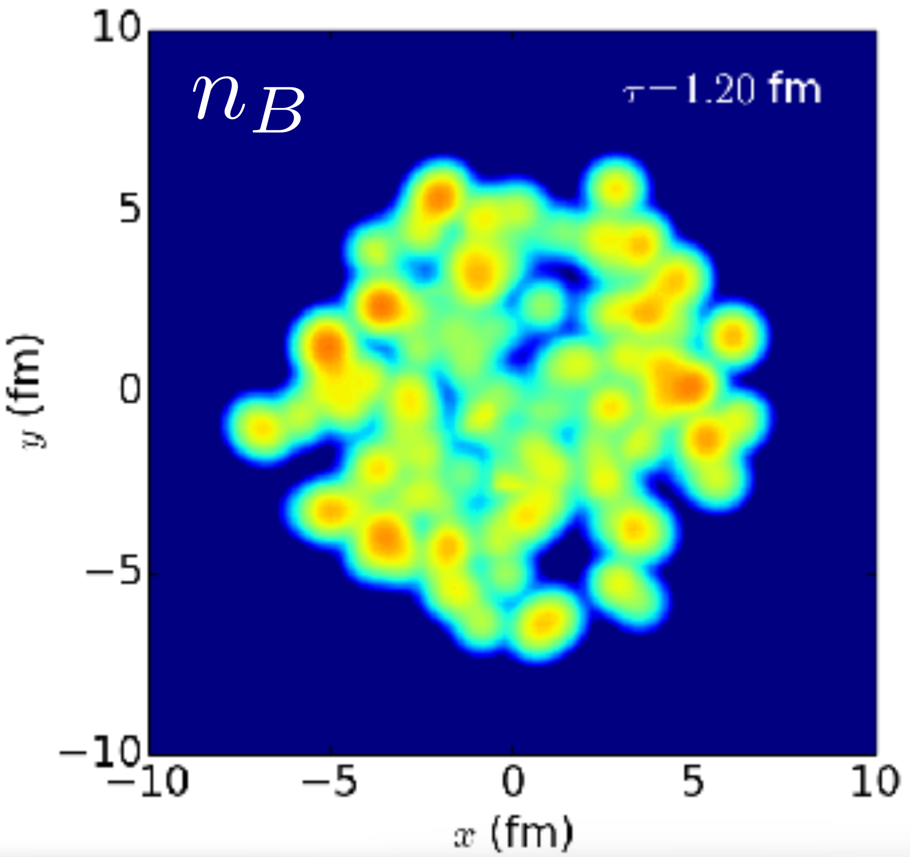

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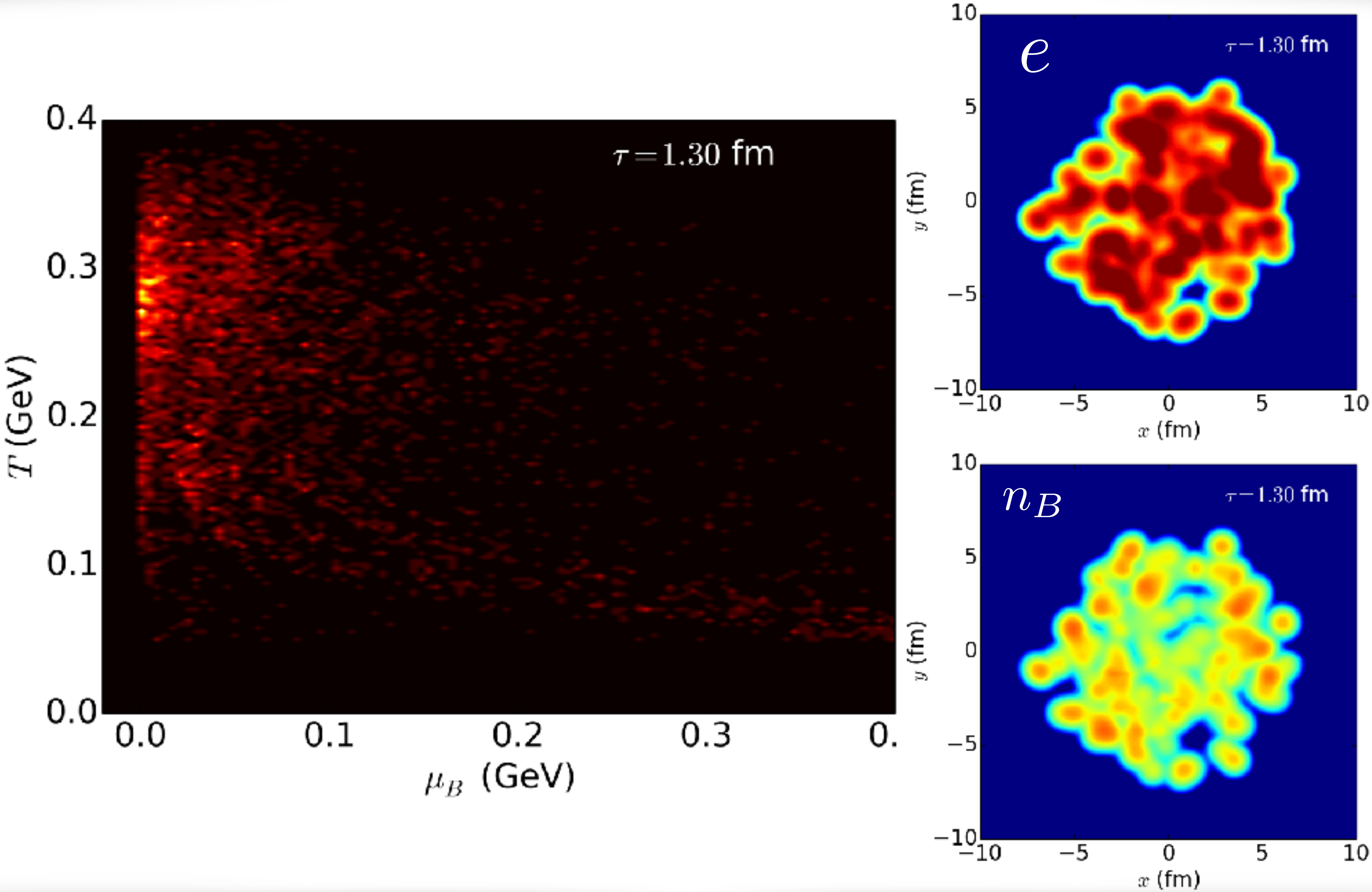

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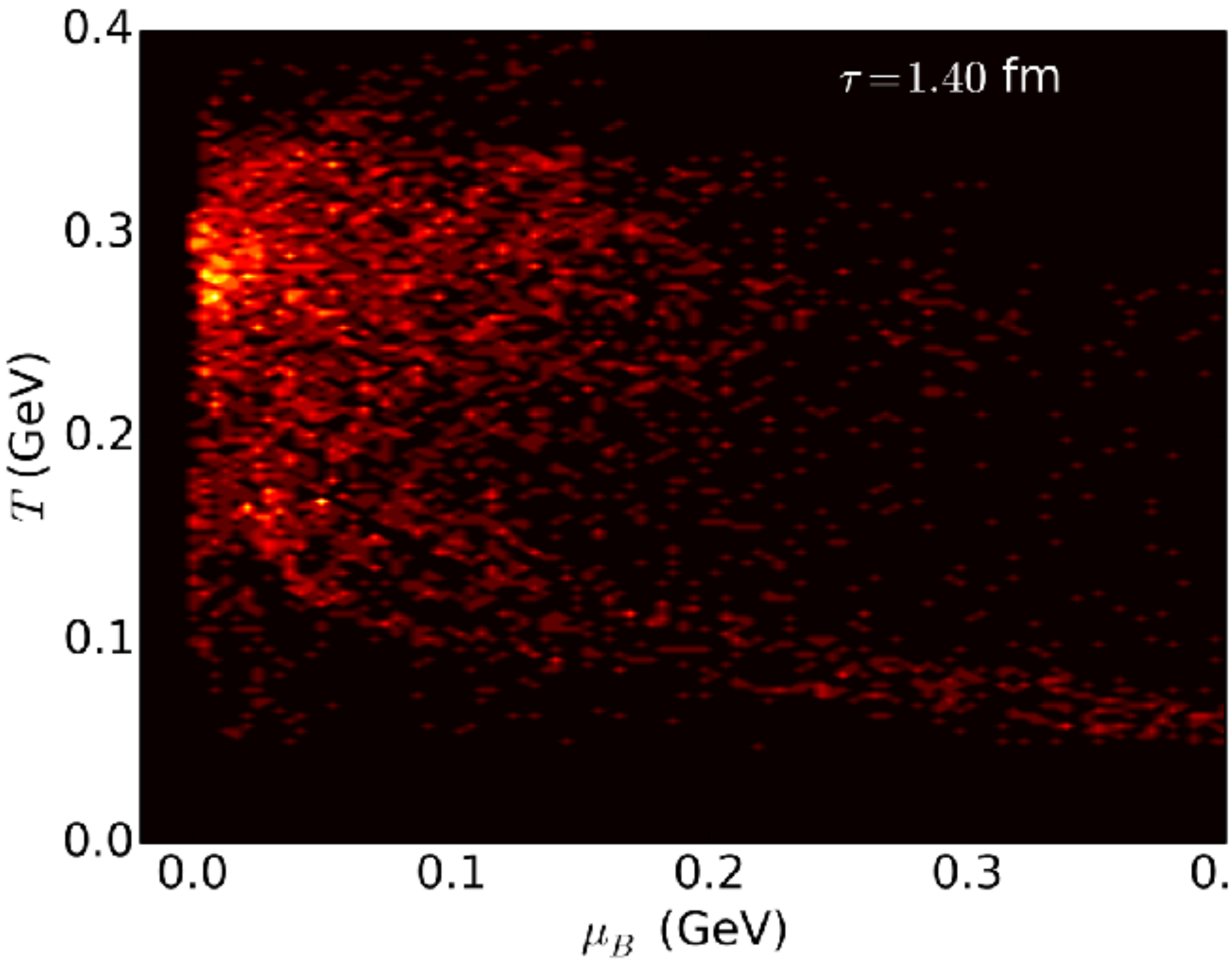

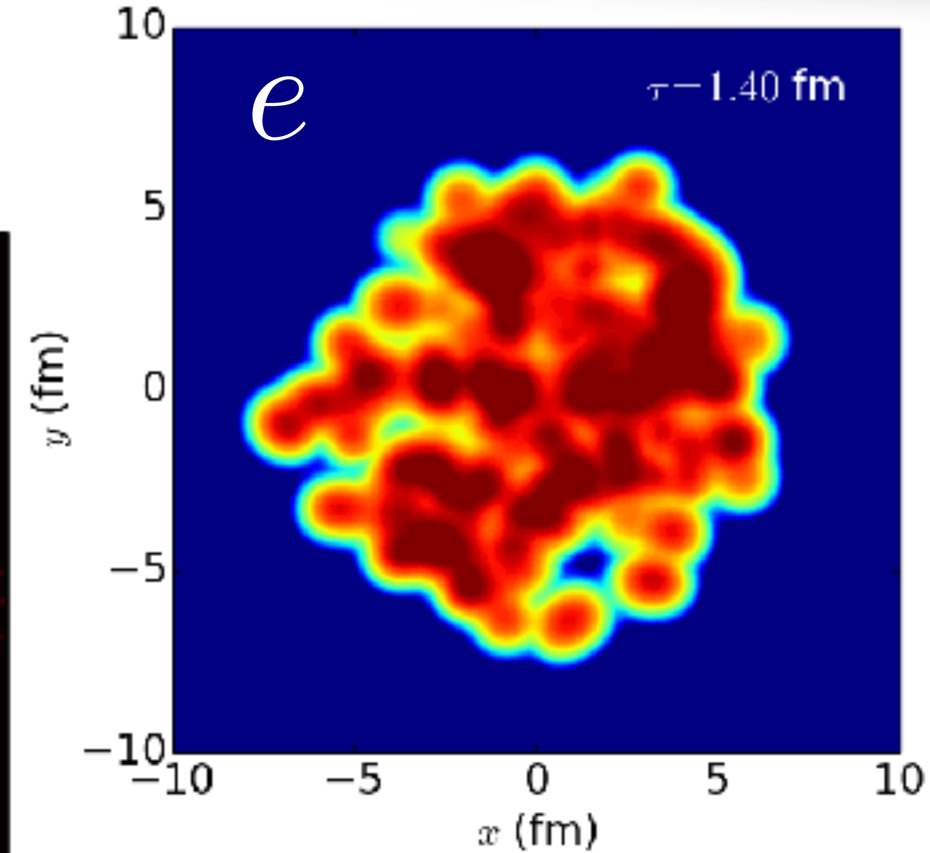

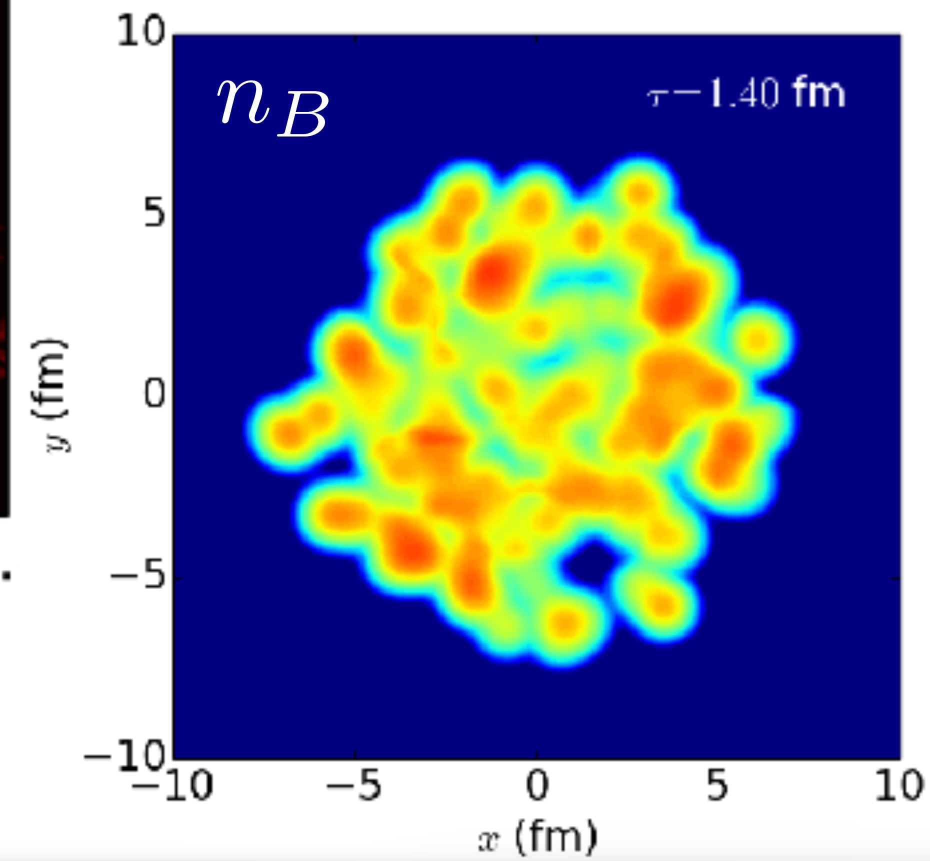

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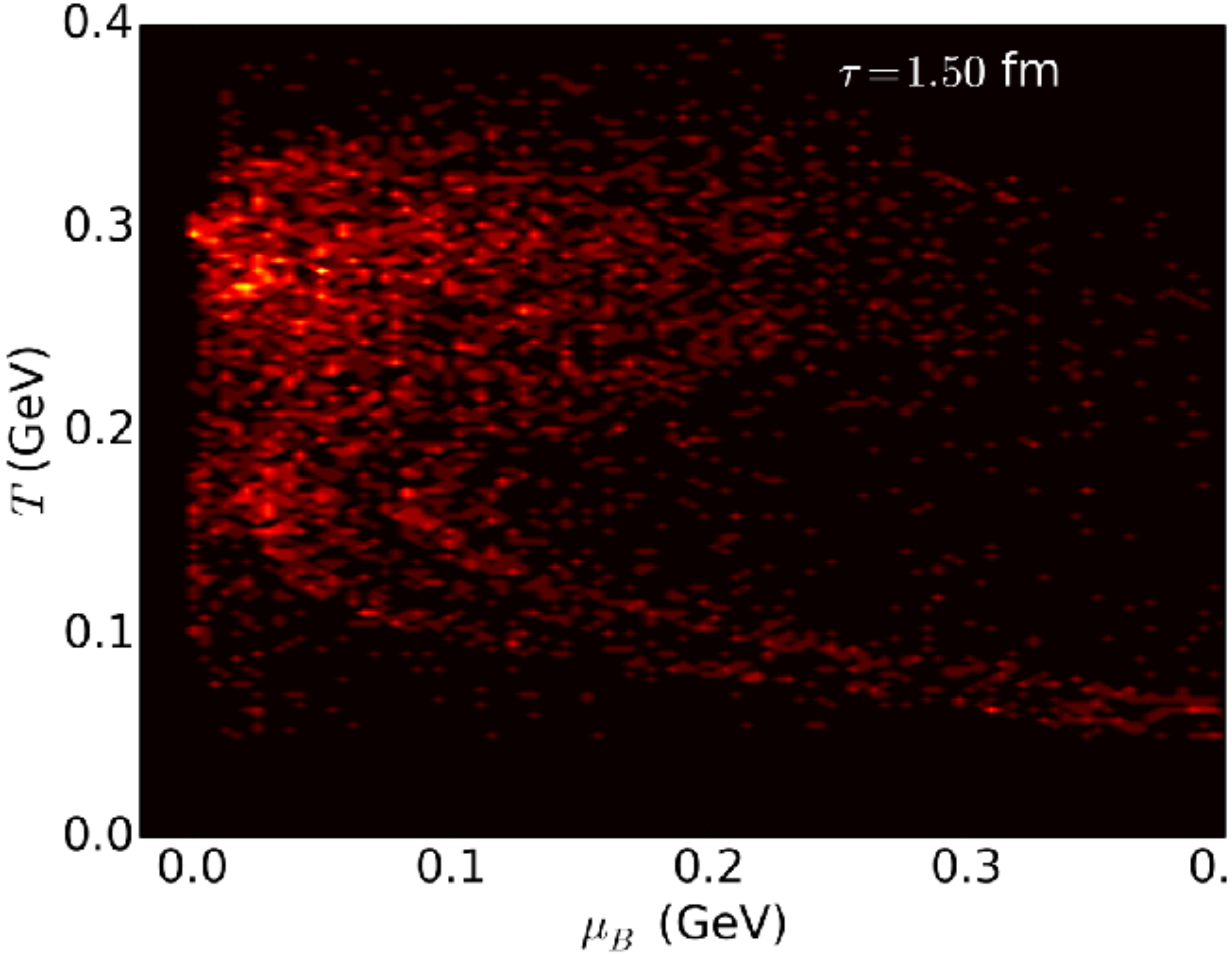

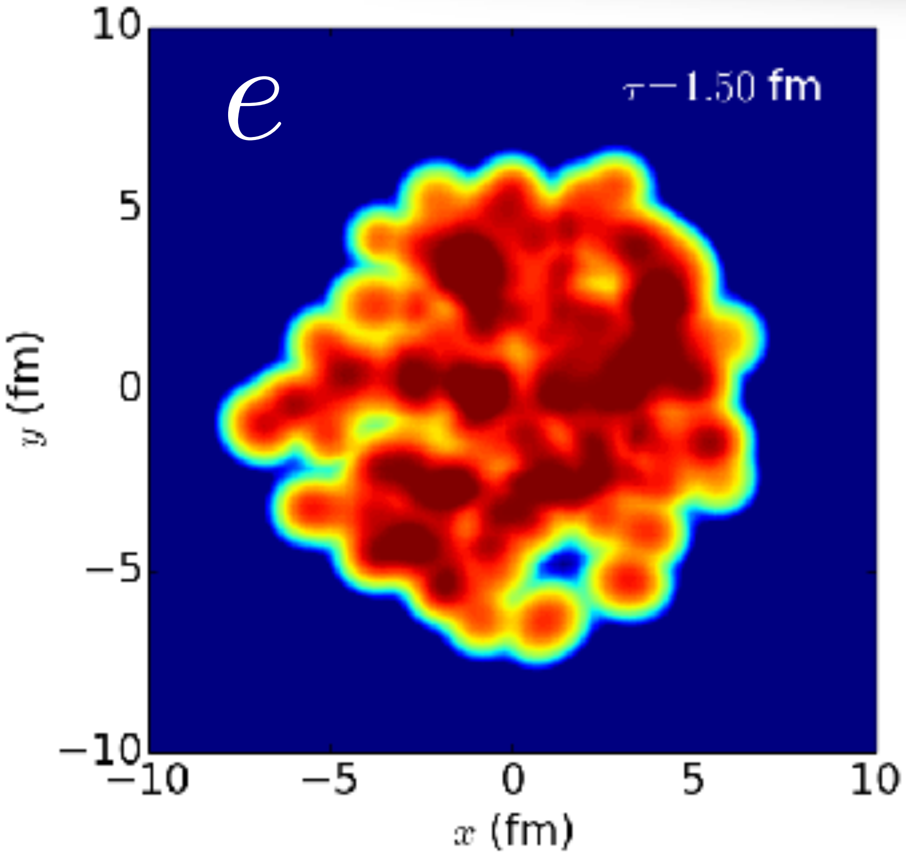

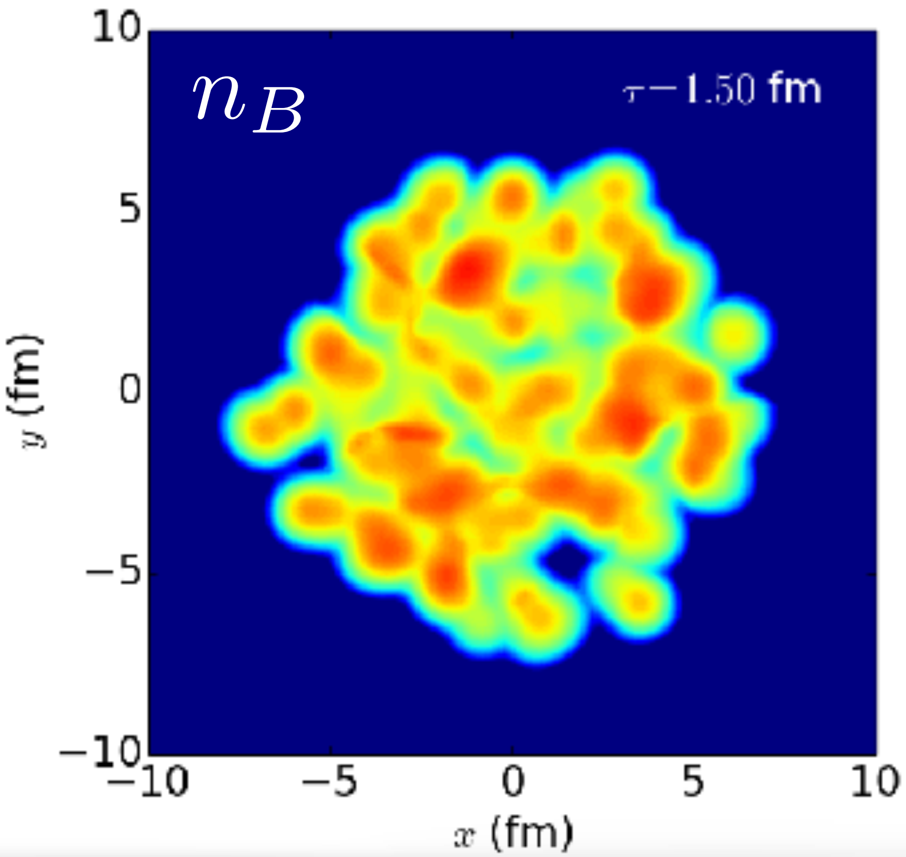

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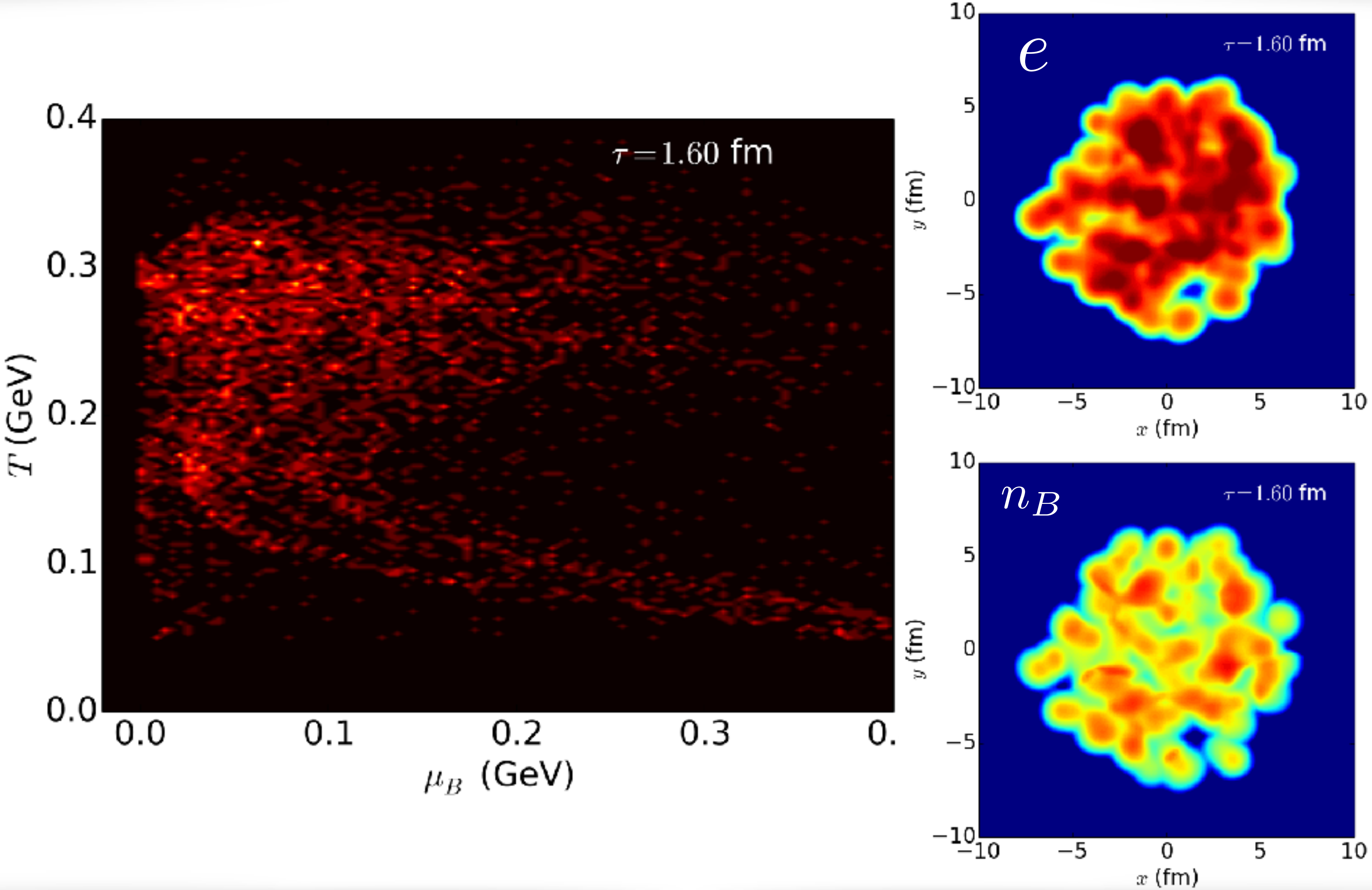

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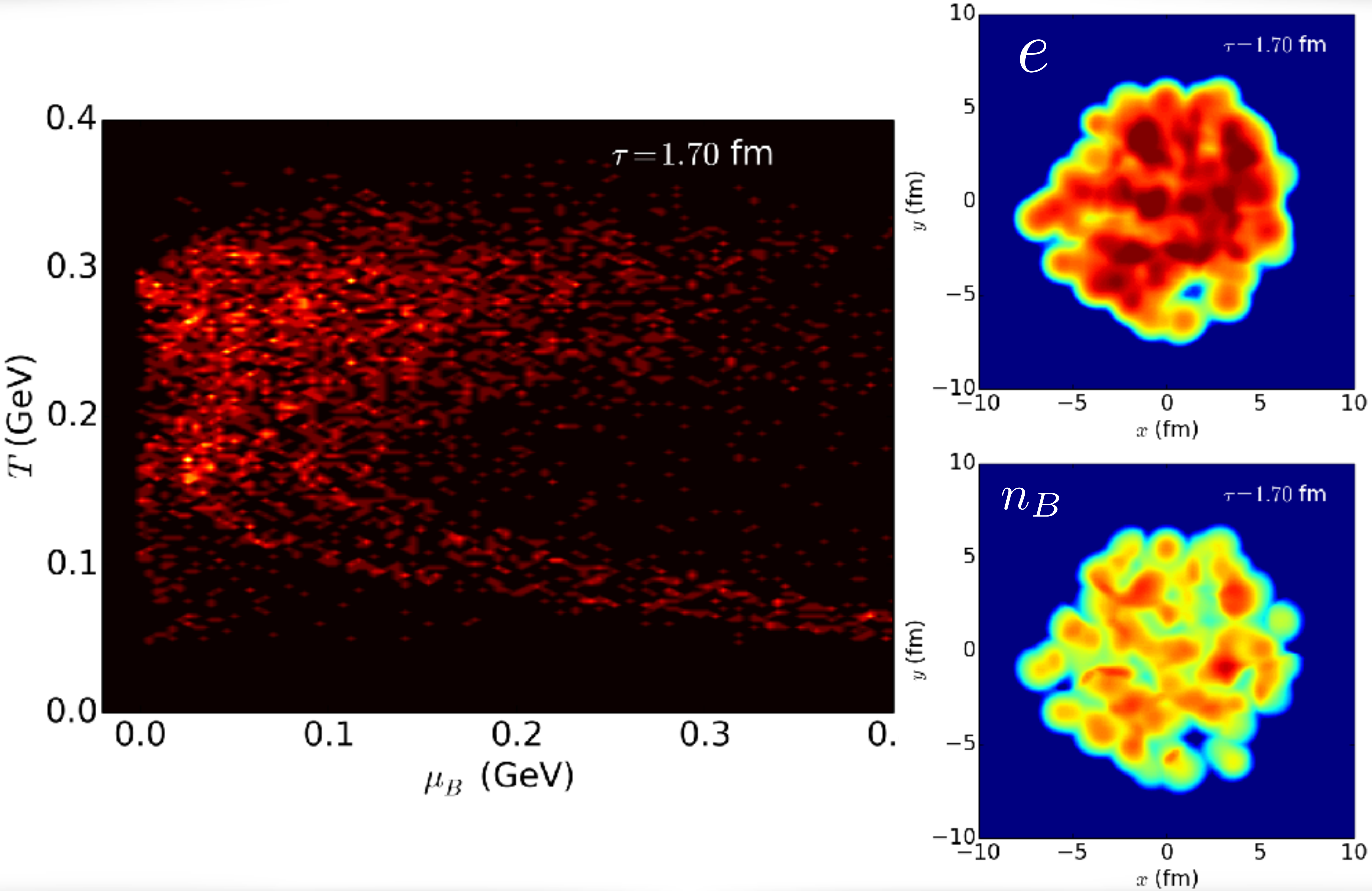

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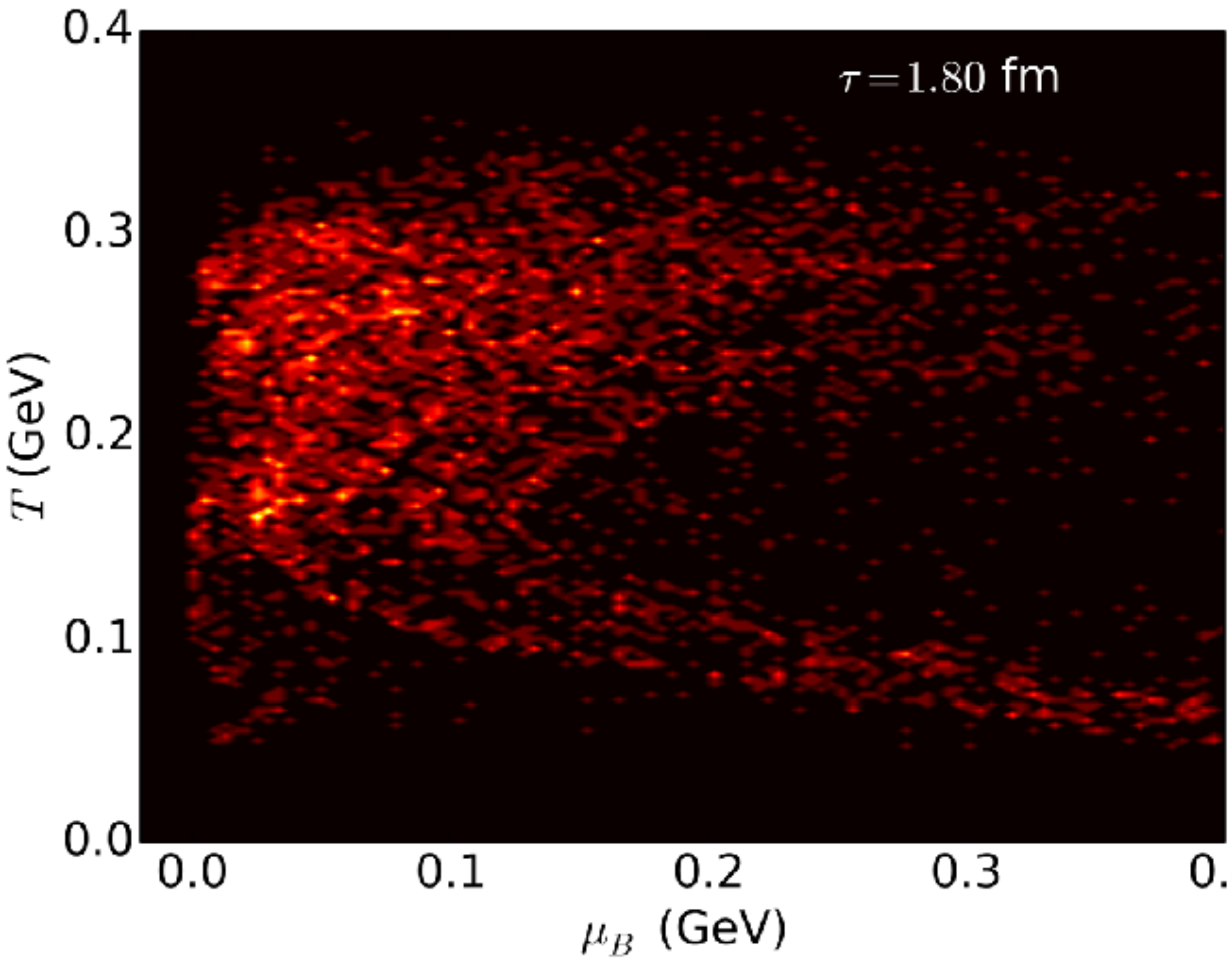

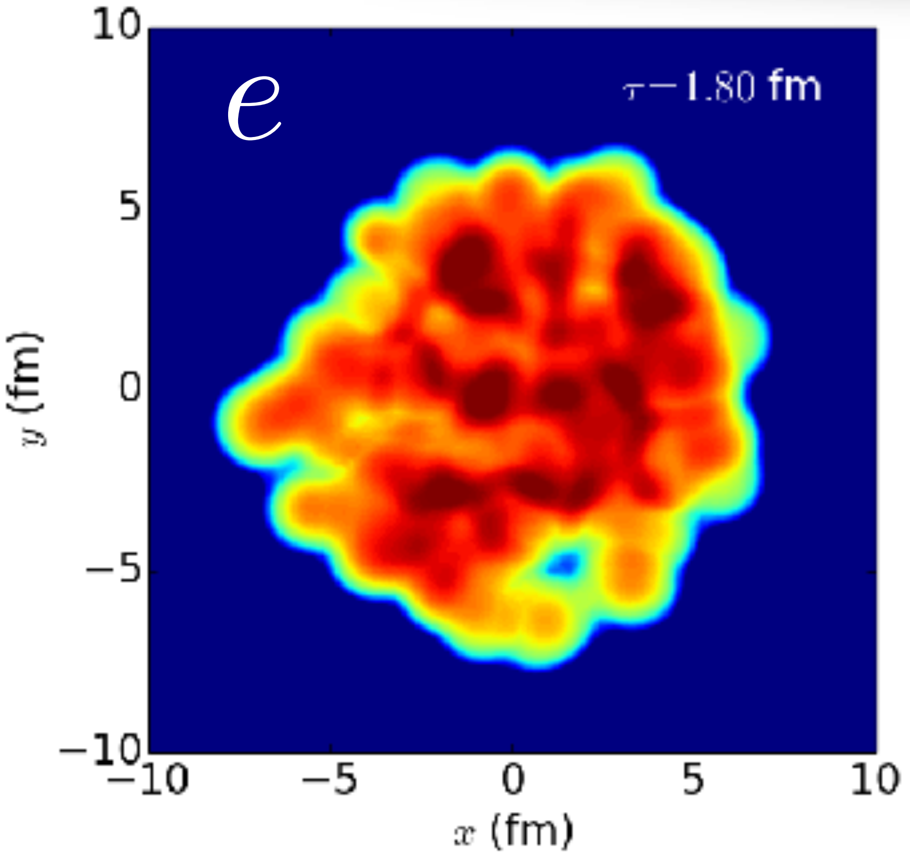

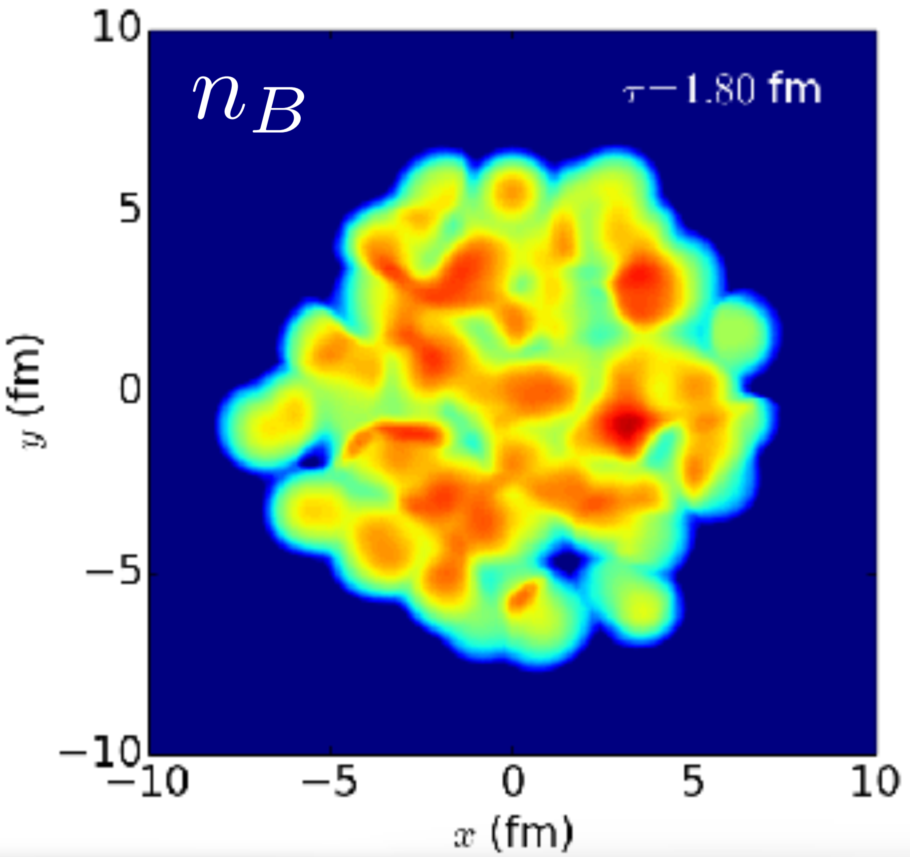

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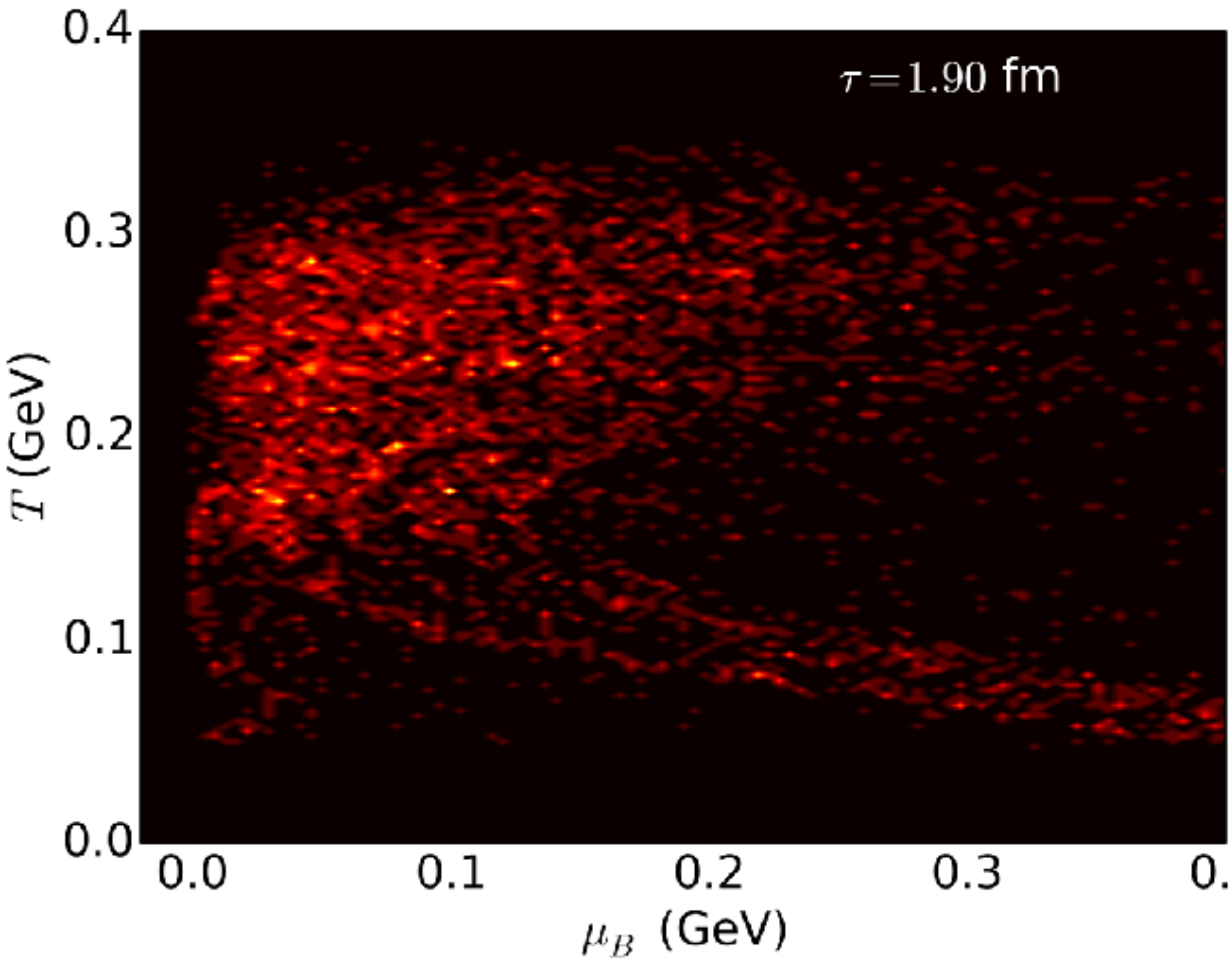

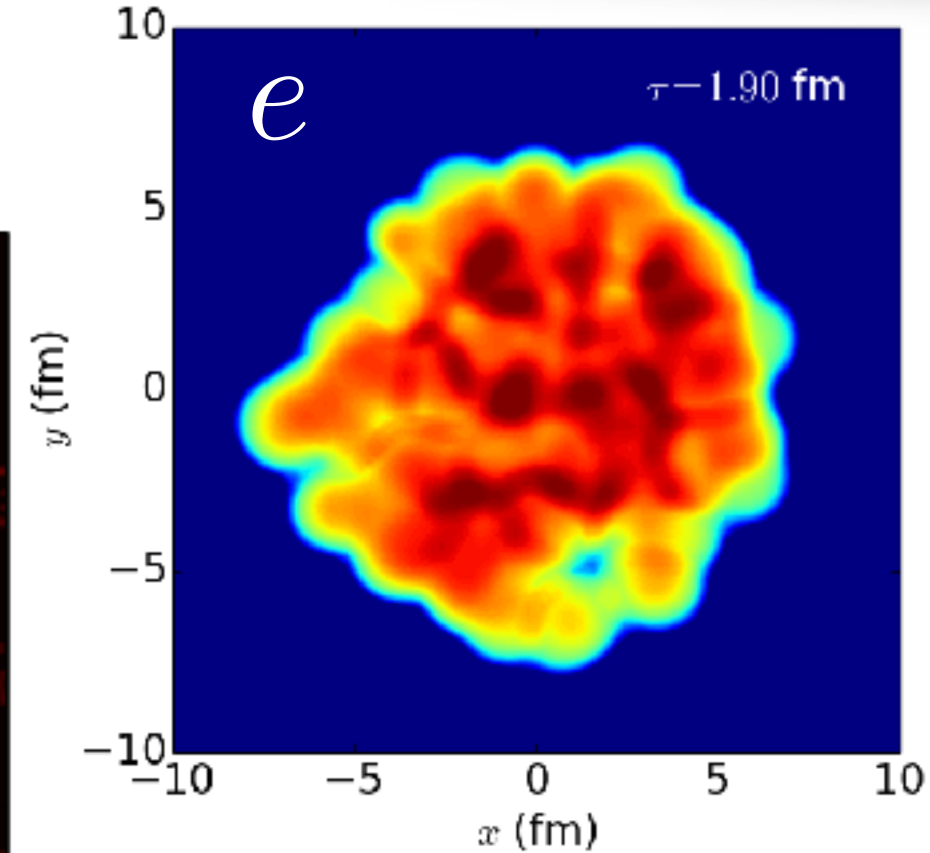

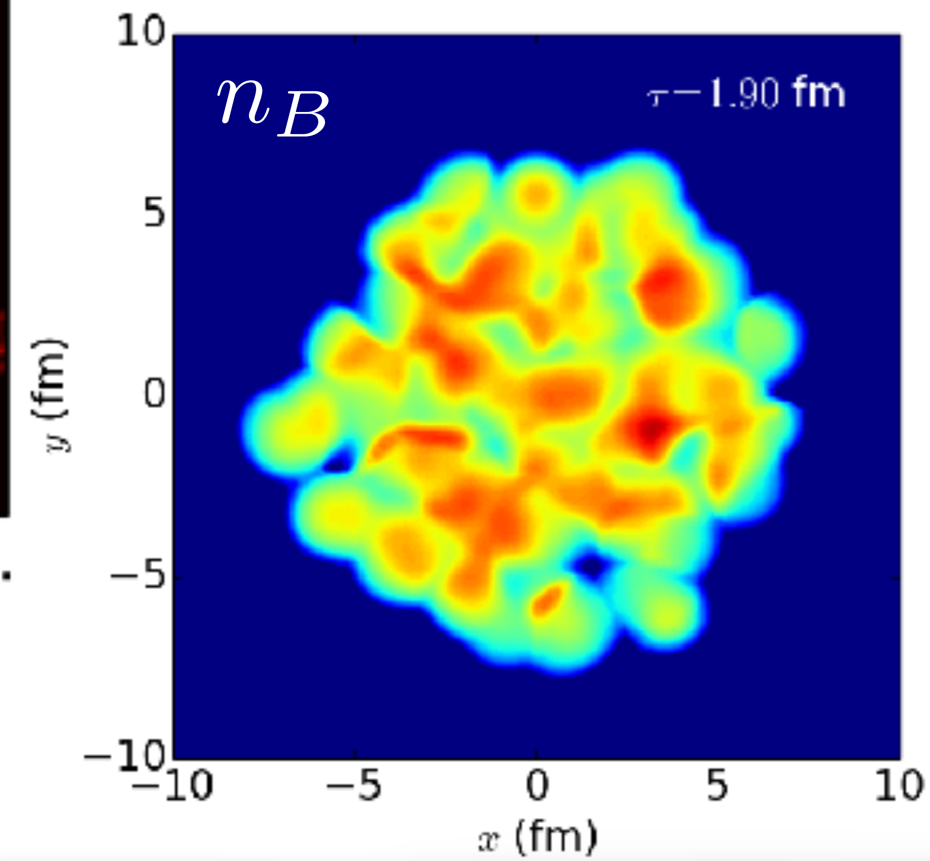

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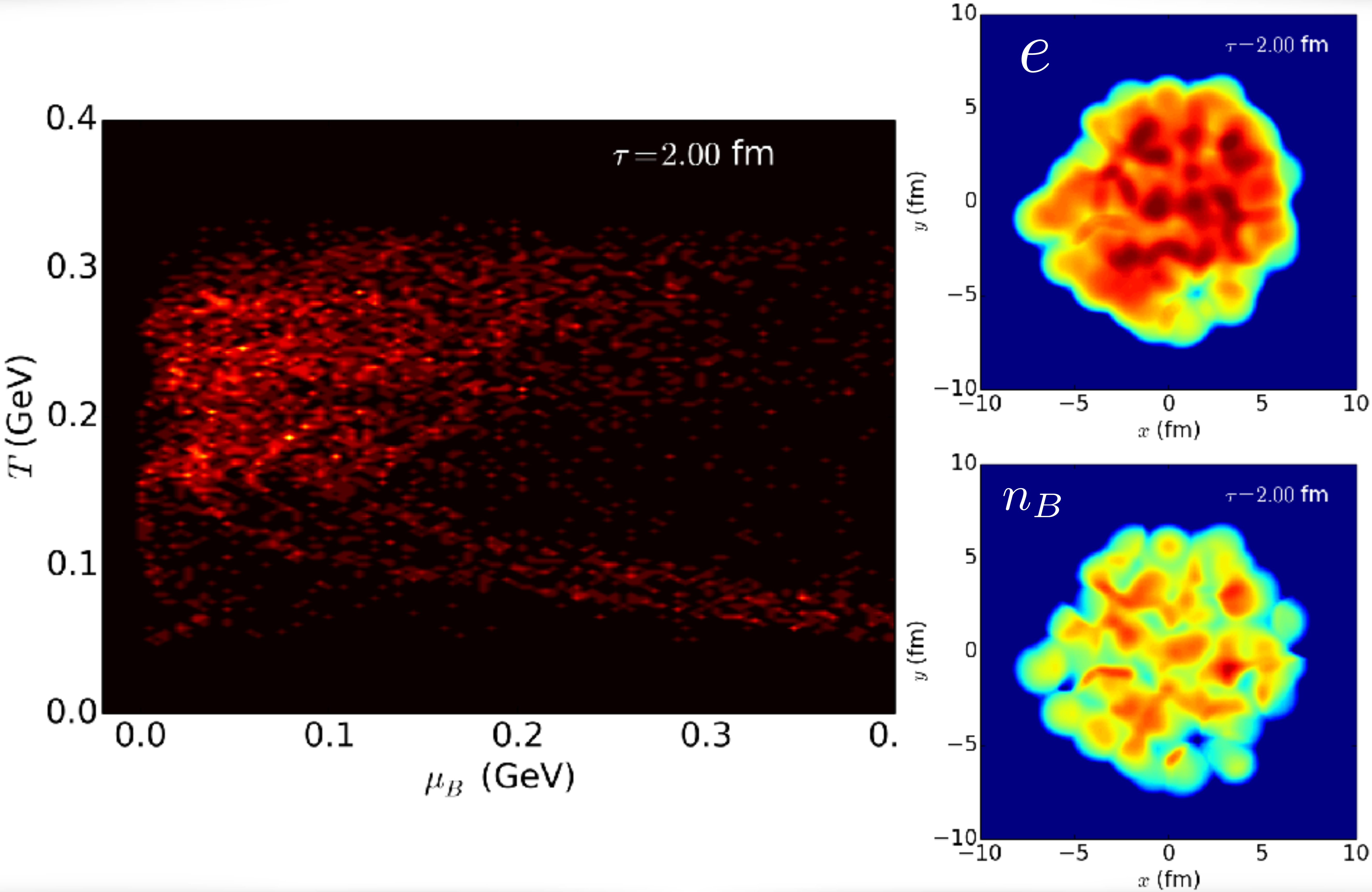

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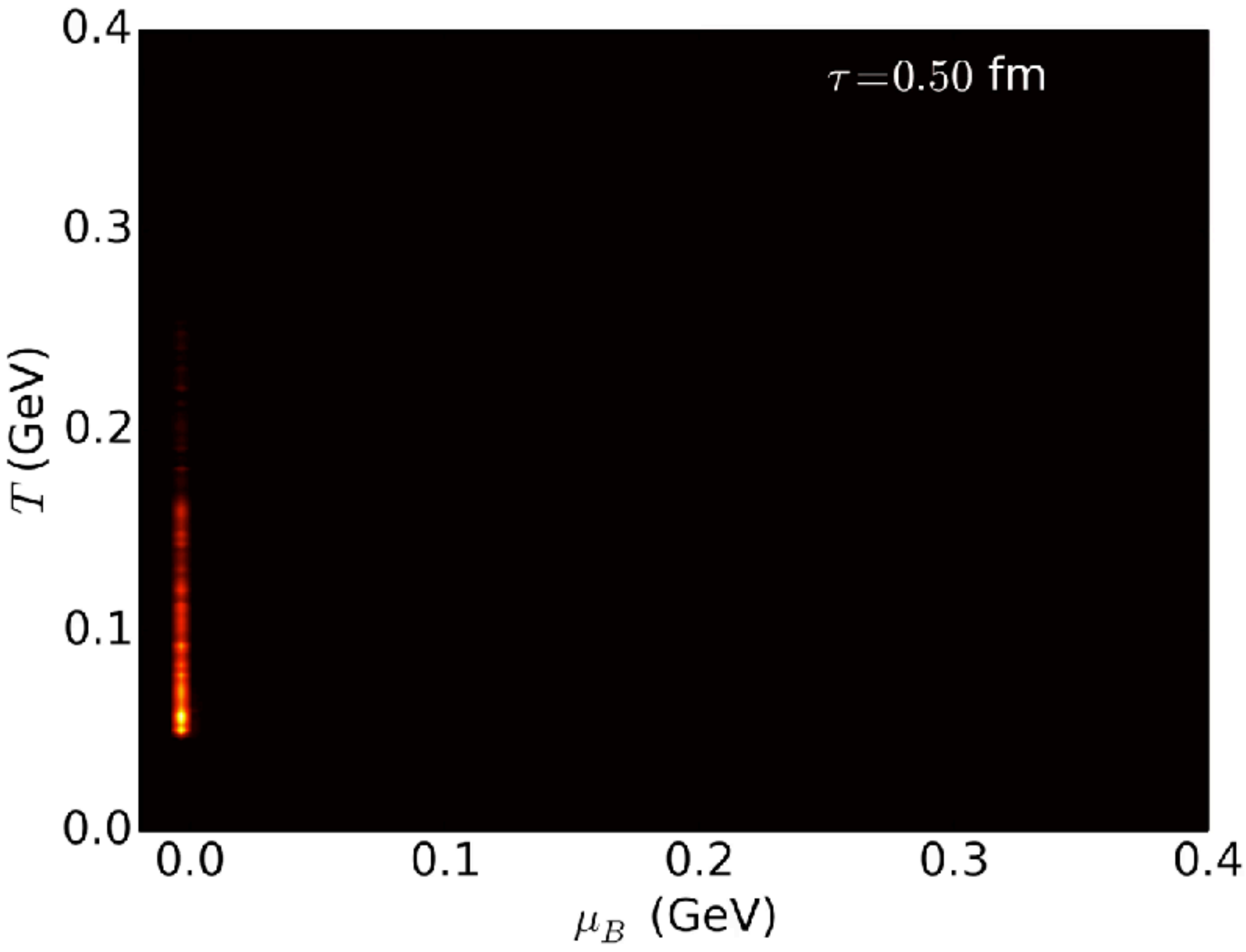


Jet energy deposition and hydro response

A toy model

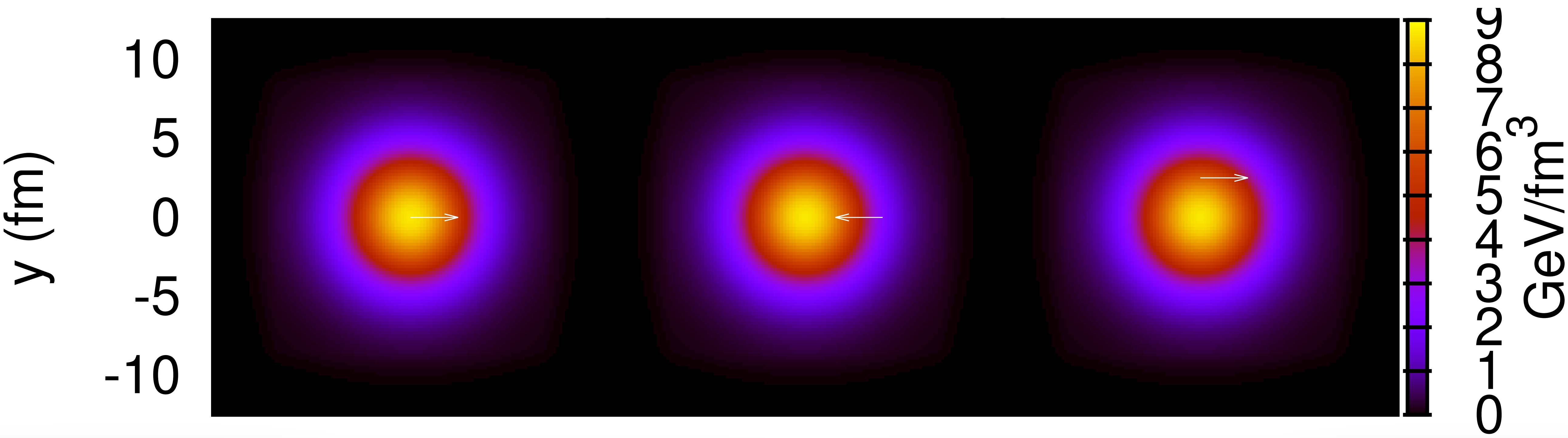
Collaboration with Mayank Singh

$$\frac{dE}{dx} = \frac{d|\vec{P}|}{dt} = -1\mathrm{GeV/fm}$$

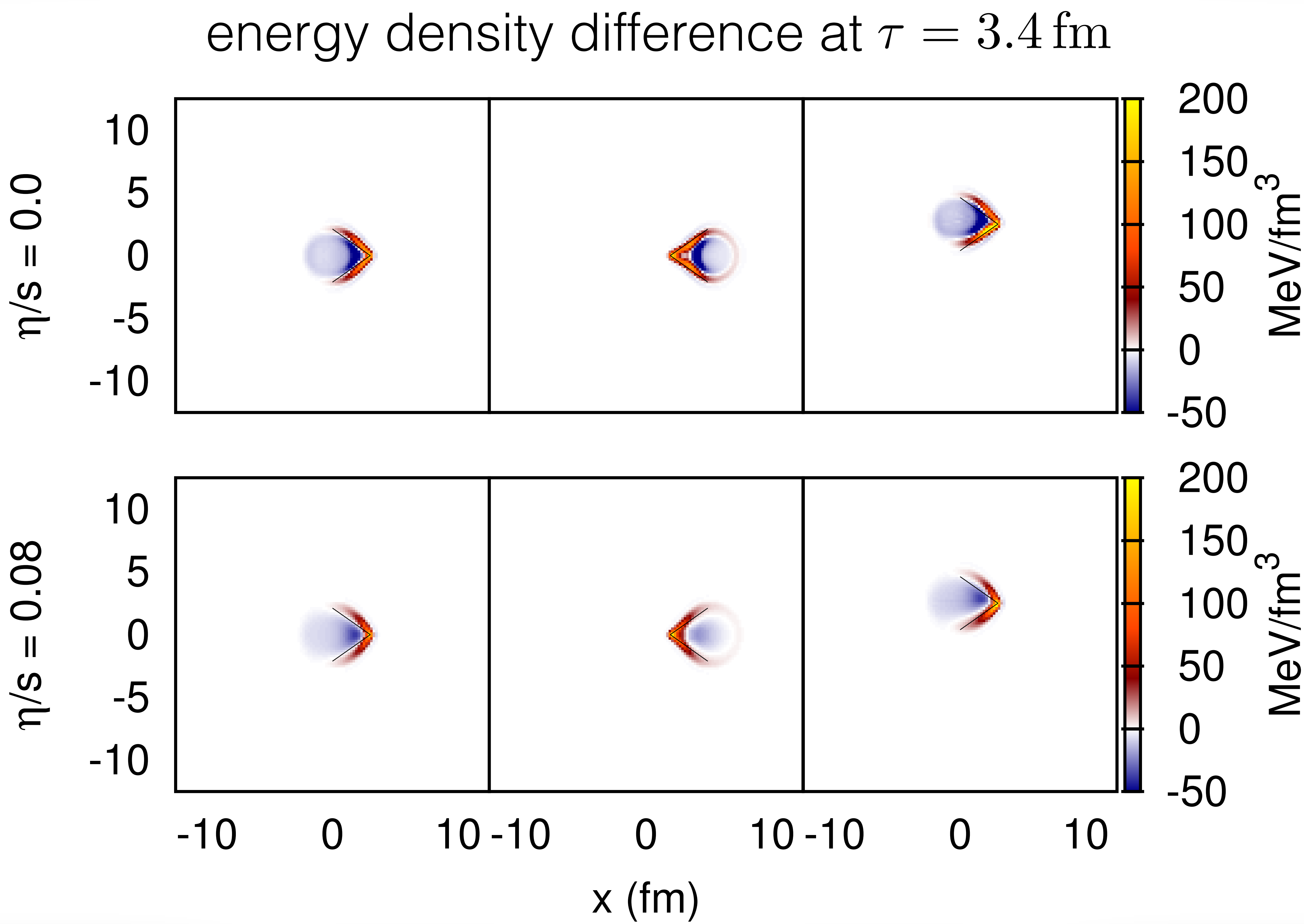
$$j^\mu_{\mathrm{source}}(t, \vec{x}) = -\frac{d|\vec{P}|}{dt}\frac{P^\mu}{P^0}\delta^3(\vec{x} - \vec{x}_i)$$

$$\vec{x}_i = \vec{x}_0 + \frac{\vec{P}}{P^0}t$$

$$\tau = 3.4\,\mathrm{fm}$$

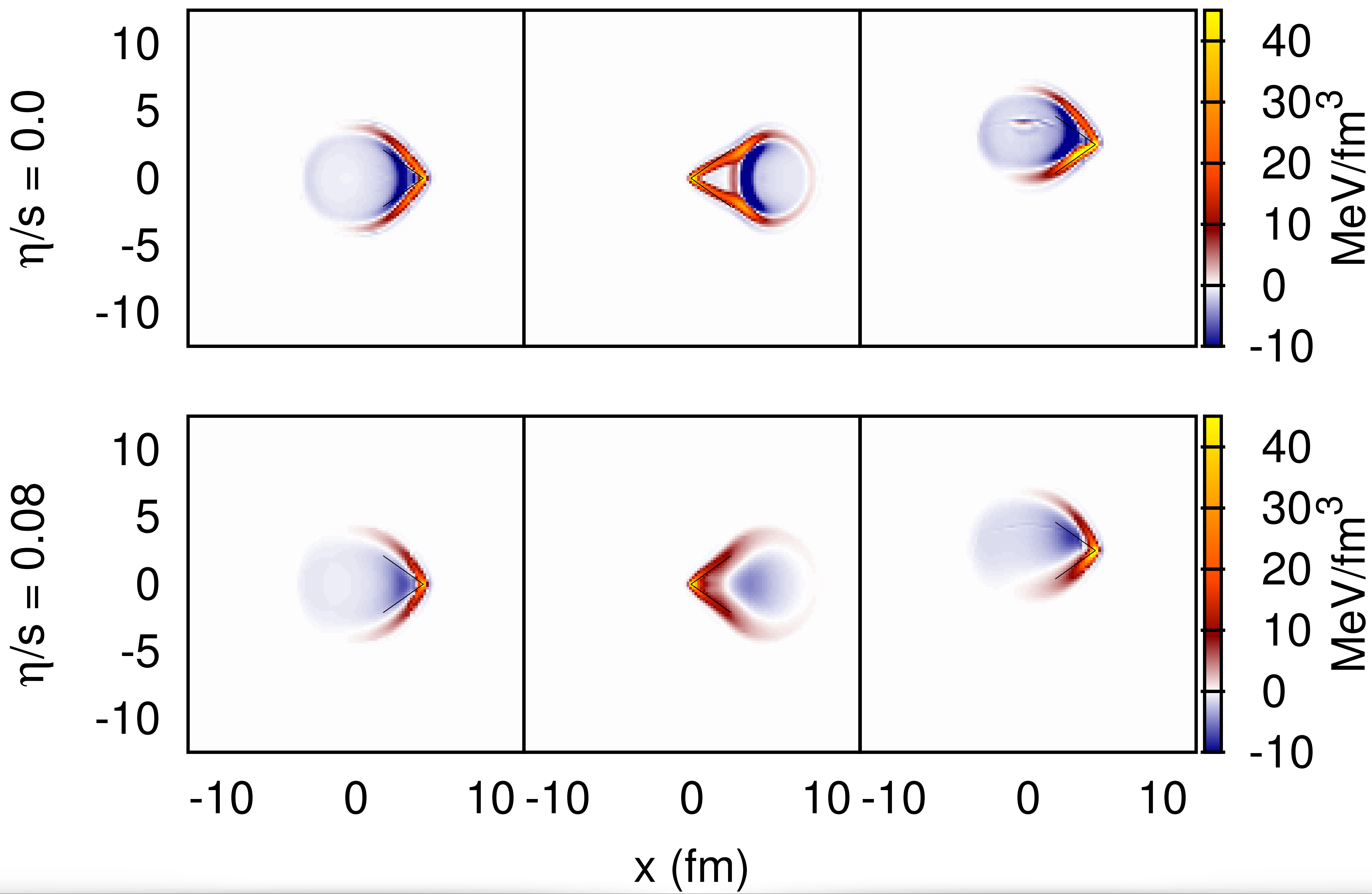


Jet energy deposition and hydro response



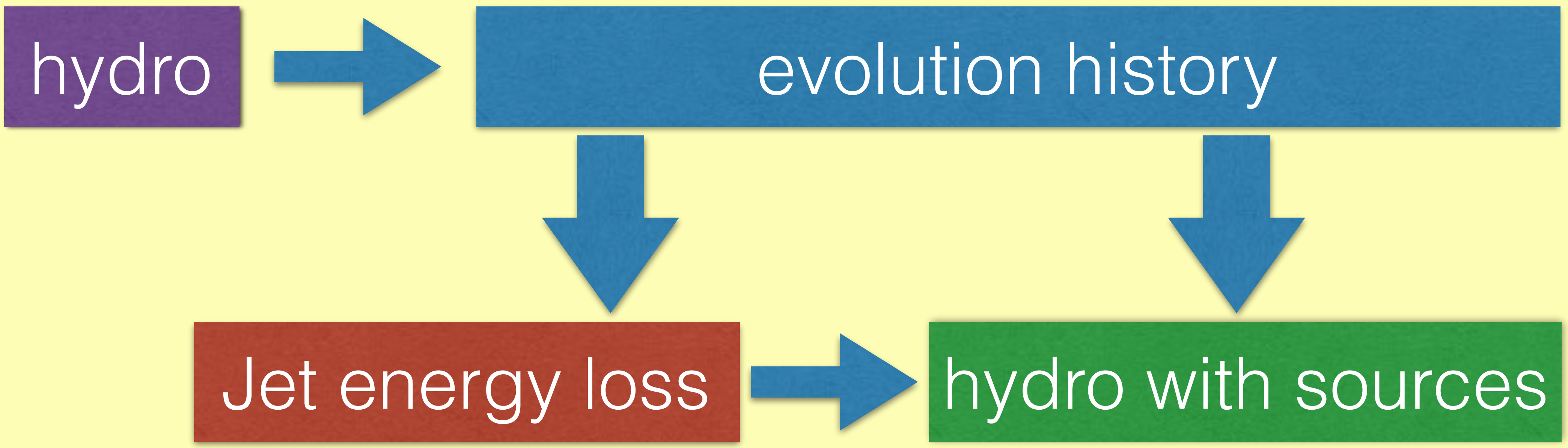
Jet energy deposition and hydro response

energy density difference at $\tau = 5.4\,\mathrm{fm}$



Connect to JETSCAPE

- "Afterburner" mode



Connect to JETSCAPE

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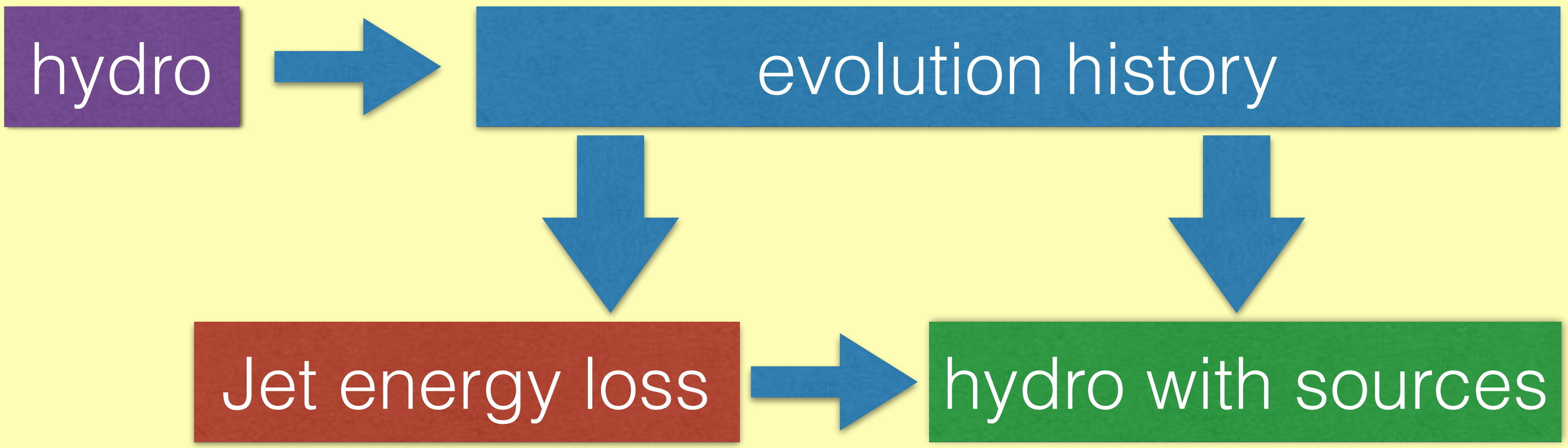
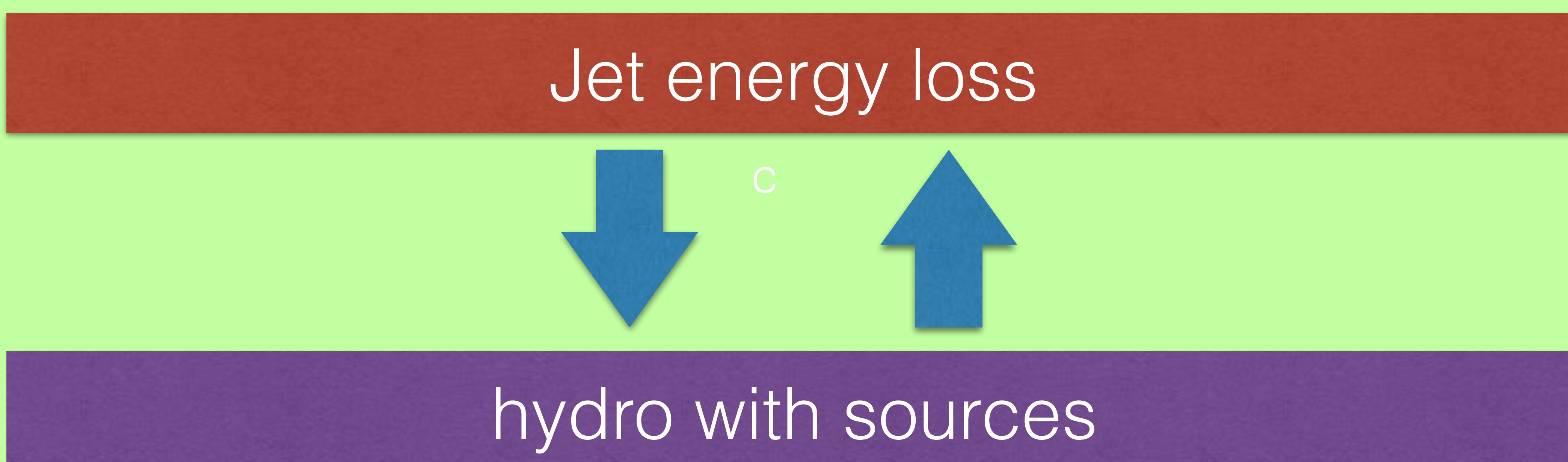


- Concurrent mode



Outlook

- We develop a general framework to feed sources into hydrodynamic simulations
- To achieve a smooth transition from the pre-equilibrium stage to the hydrodynamics phase
- Couple with realistic jet energy loss models to study the response in a viscous fluid
- Future extension to magnetohydrodynamics will be exciting