

# Emission of Low Momentum Particles at Large Angles from Jet

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## Introduction

### • Jet quenching in heavy ion collisions

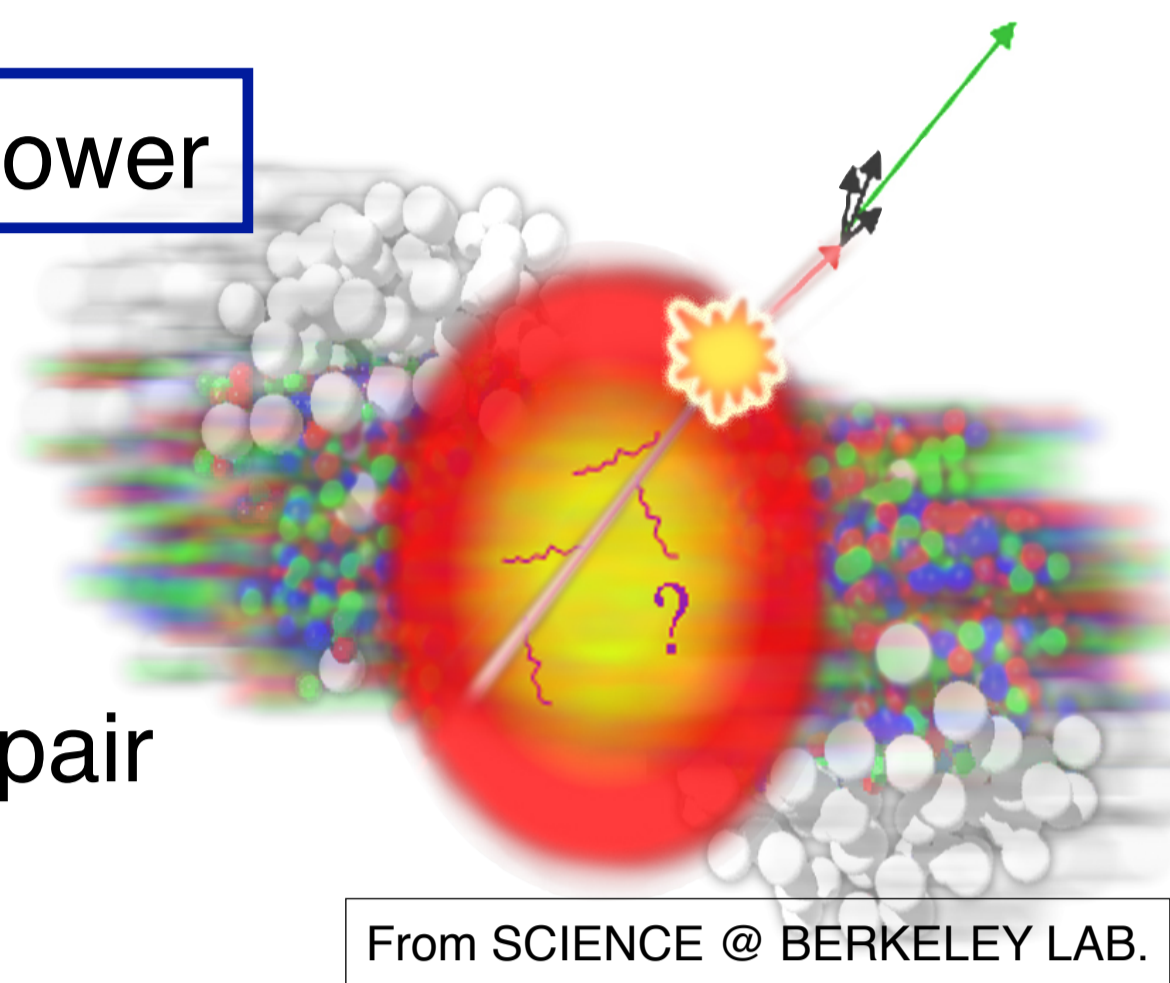
Creation of high-energy partons (jets) at the same time as a QGP  
Energy loss of jets due to strong interactions with the medium

→ Extraction of QGP's stopping power

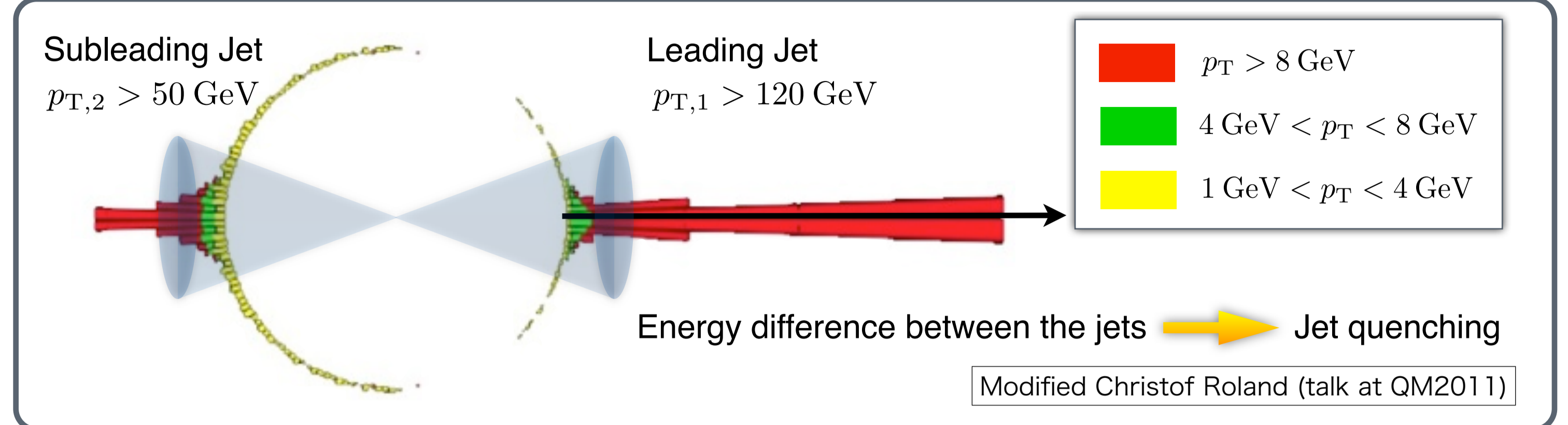
Pair creations of jets

Difference of energy loss between the pair particles due to position of the creation

→ Energy difference between the observed jets



### • Jet quenching observed at LHC CMS (2011)



Many **small  $p_T$  particles** in large angle region from the subleading jet (Necessary to balance the whole  $p_T$ )

→ **Originated from the medium flow?**

### • Purpose of the current study

#### Study dynamics of QGP fluid induced by jets

Construct a model describing the dynamics of QGP and jets  
Simulate using the model and study flows induced by jets

## Hydrodynamic Model with a Source Term

### • Relativistic hydrodynamic equation with a source term

Hydrodynamic equation with deposited energy and momentum

$$\partial_\mu T^{\mu\nu} = J^\nu$$

$T^{\mu\nu}$ : energy-momentum tensor of the QGP fluid

$J^\nu$ : **source term** (Effect of energy-momentum deposit from jets)

### Assume sudden thermalization inside the fluid

#### • Source term

$$J^0(x) = J^1(x) = \left[ -\frac{dp_{\text{jet}}^0(t)}{dt} \right] \delta^{(3)}(x - x_{\text{jet}}(t)), \quad J^2(x) = J^3(x) = 0$$

Massless jet particle traveling straight in  $x$ -direction

Neglect the effect of the flow velocity on the energy loss

→ **Solve this nonlinear equation numerically**

## Simulations and Results

### • Settings and Assumptions

All particles are classical and massless

Ideal gas EoS  $P(e) = \frac{1}{3}e$

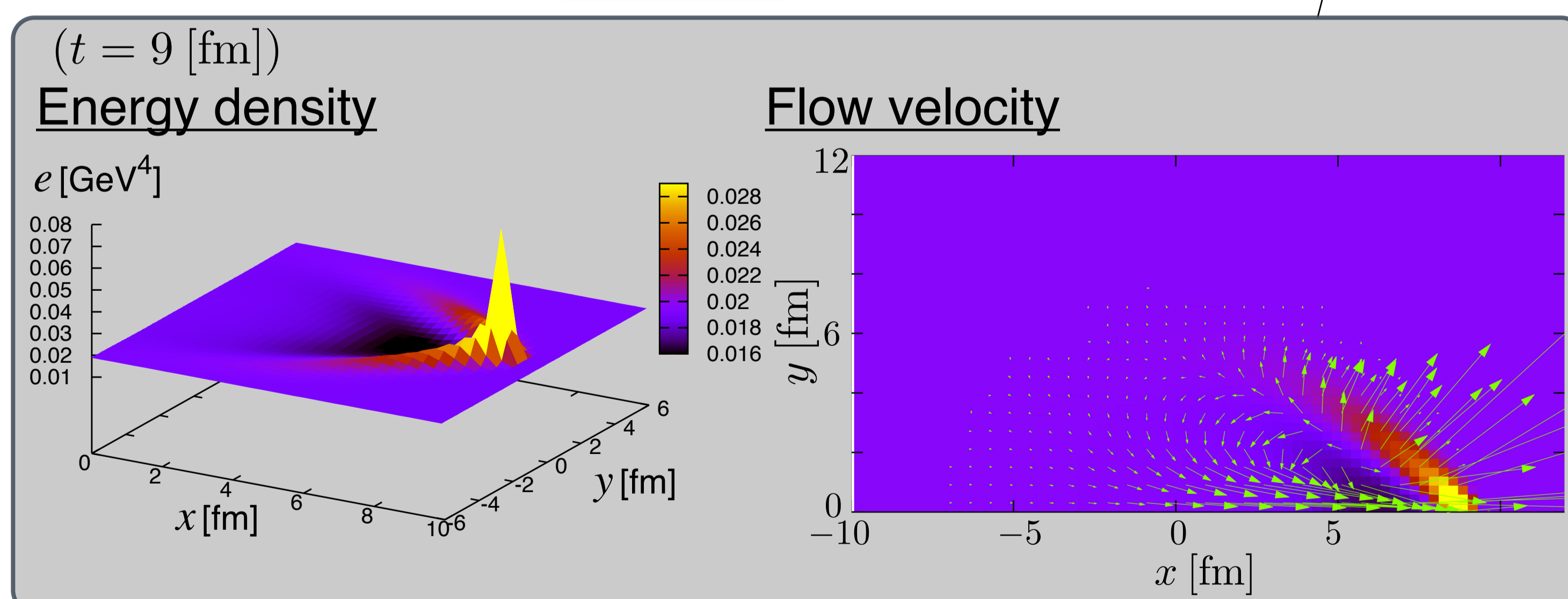
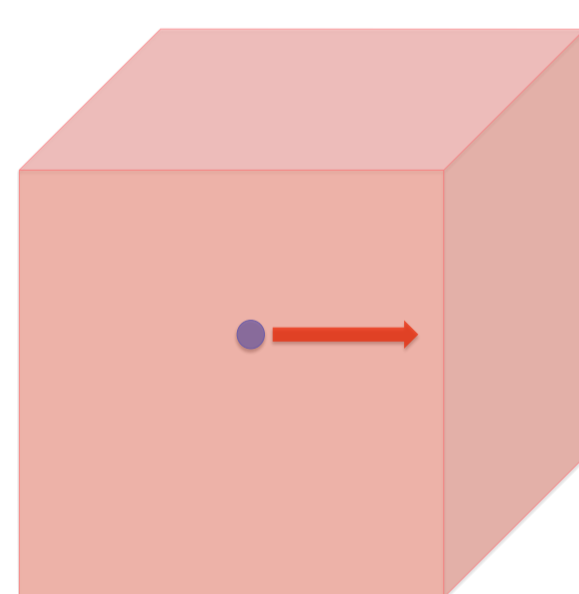
Jet particle traveling in a straight line

Neglect the effect of the flow velocity on the energy loss

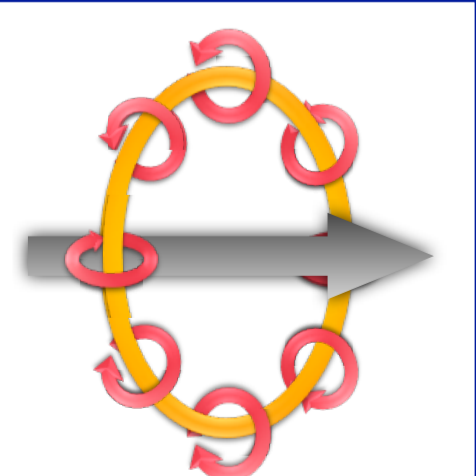
2-body → 2-body elastic scatterings between a jet and a constituent particle of the QGP

$t$ -channel dominant, Debye mass cut-off

### • Result 1: 1-jet going through a uniform fluid



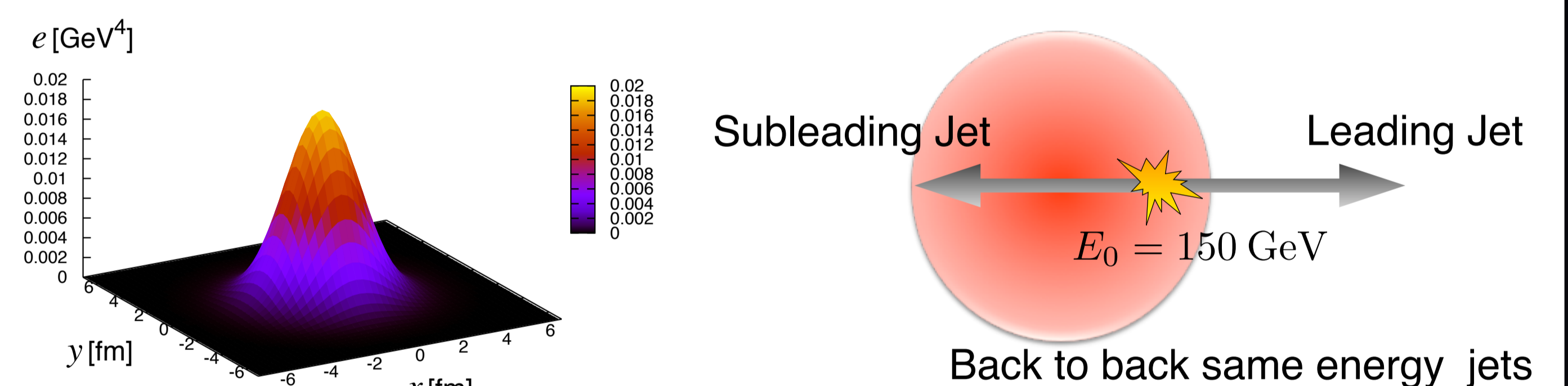
- Flow velocity perpendicular to the cone
- Flow following the jet on the passage
- **Vortex ring** around the passage



### • Result 2: A pair of jets going through an expanding fluid

Initial condition of the energy density: 3D-Gauss + cut-off

Jet pair created at off-central position

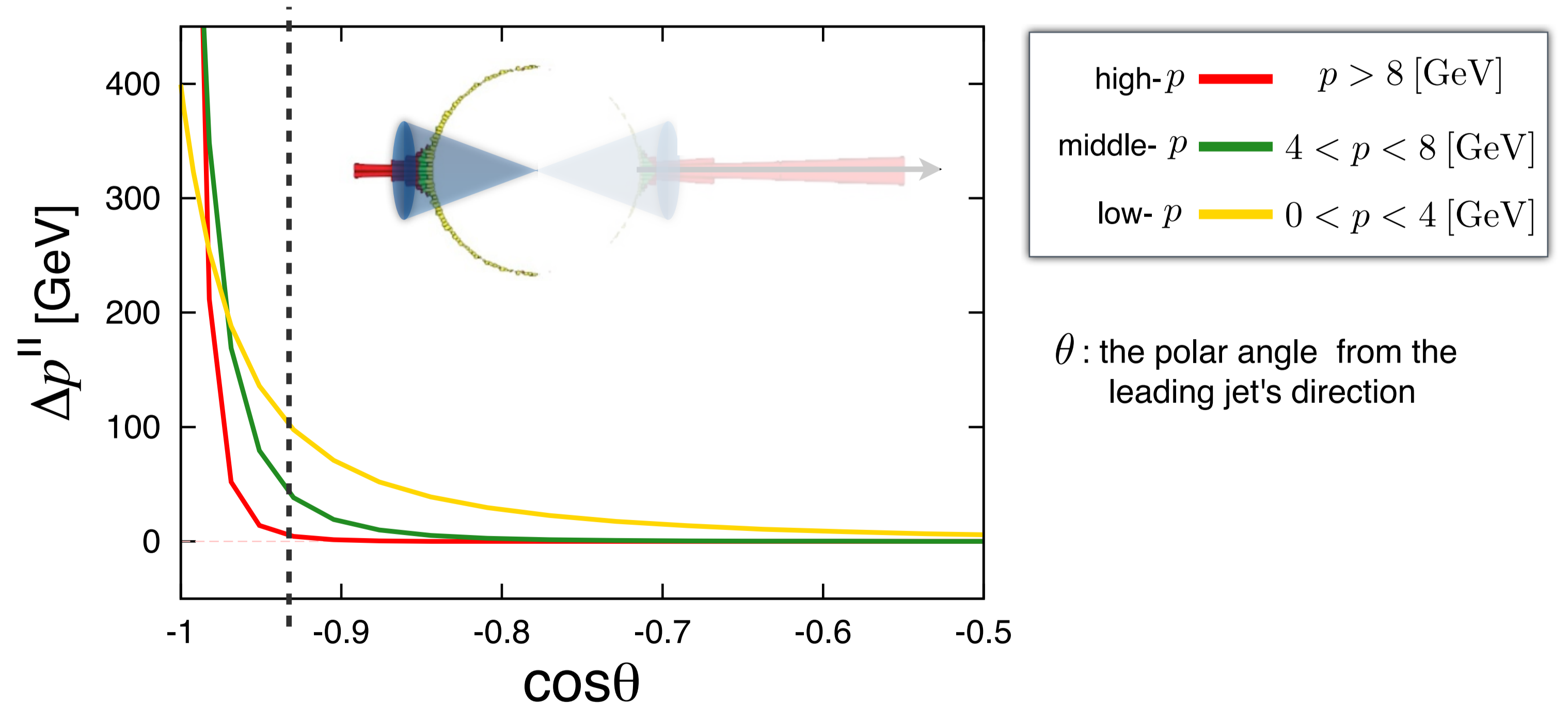


Increase of momentum along the jets

$$\Delta p_i^{\parallel} \equiv \sum_{p \in i} p^{\parallel} - \sum_{p \in i} p_{\text{no jet}}^{\parallel}$$

$p^{\parallel}$ : momentum component of the jet direction

$i = \text{high, middle, low}$



Low momentum particles are dominant at large angles from the jet

→ **Qualitative description of the CMS data**

## Summary

### • Model building to describe the dynamics of jets and the QGP fluid simultaneously

#### • Simulations

1-jet going through a uniform fluid

**Mach cone** structure

**Vortex ring** inside the cone

A pair of jets going through an expanding fluid

Low momentum particles are dominant at large angles from the jet

→ **Qualitative description of the CMS data**