

Jet substructure correlations in quark gluon plasma

Bas Hofman

NNV Lunteren
November 3, 2023



Utrecht
University



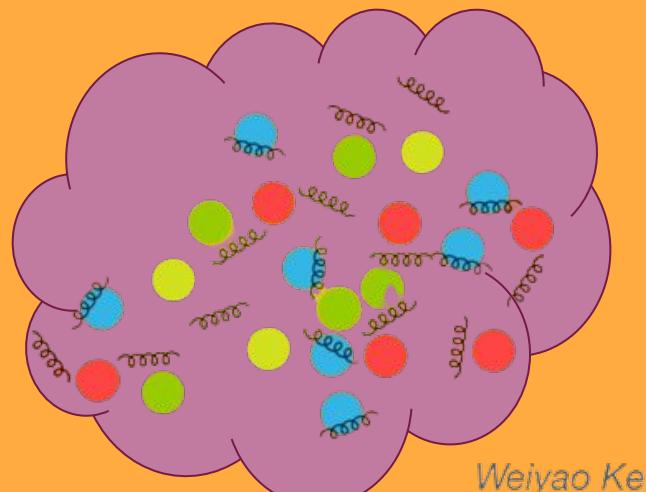
Quark gluon plasma

Lifetime $\sim 10 \text{ fm/c} \sim 10^{-24} \text{ s}$

Cannot probe externally

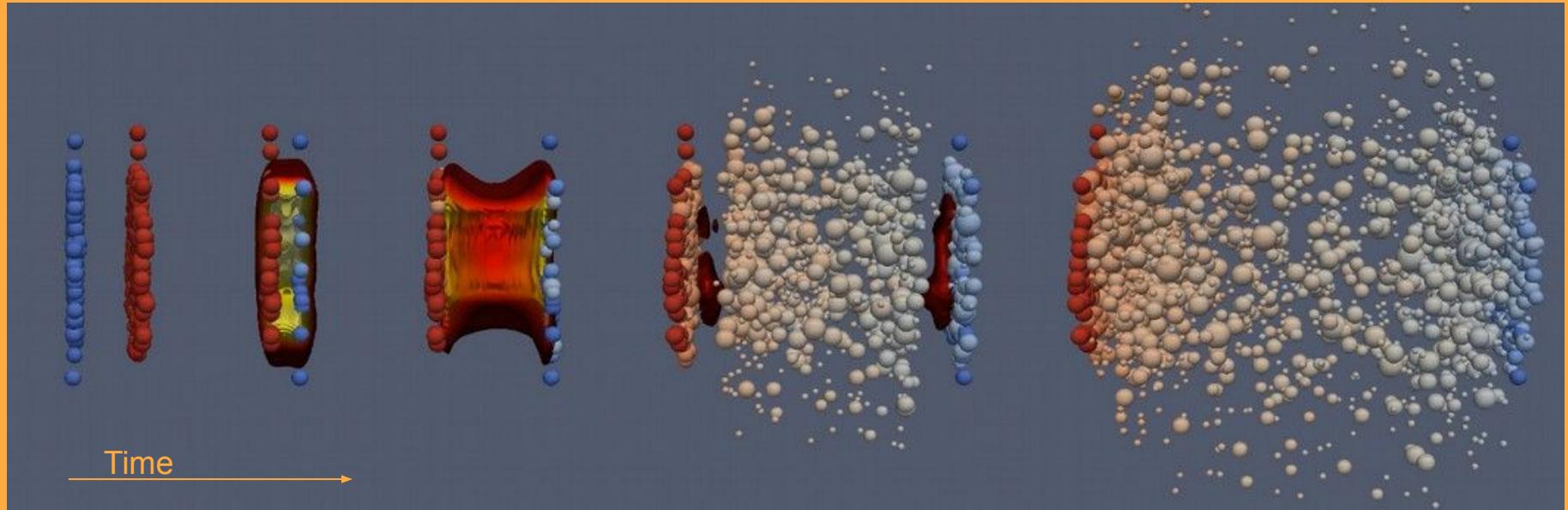
$T > 150 \text{ MeV} \sim 10^{12} \text{ K}$
Hadronic matter unstable

Recreate early universe
before $\sim 10^{-6} \text{ s}$



Quark gluon soup

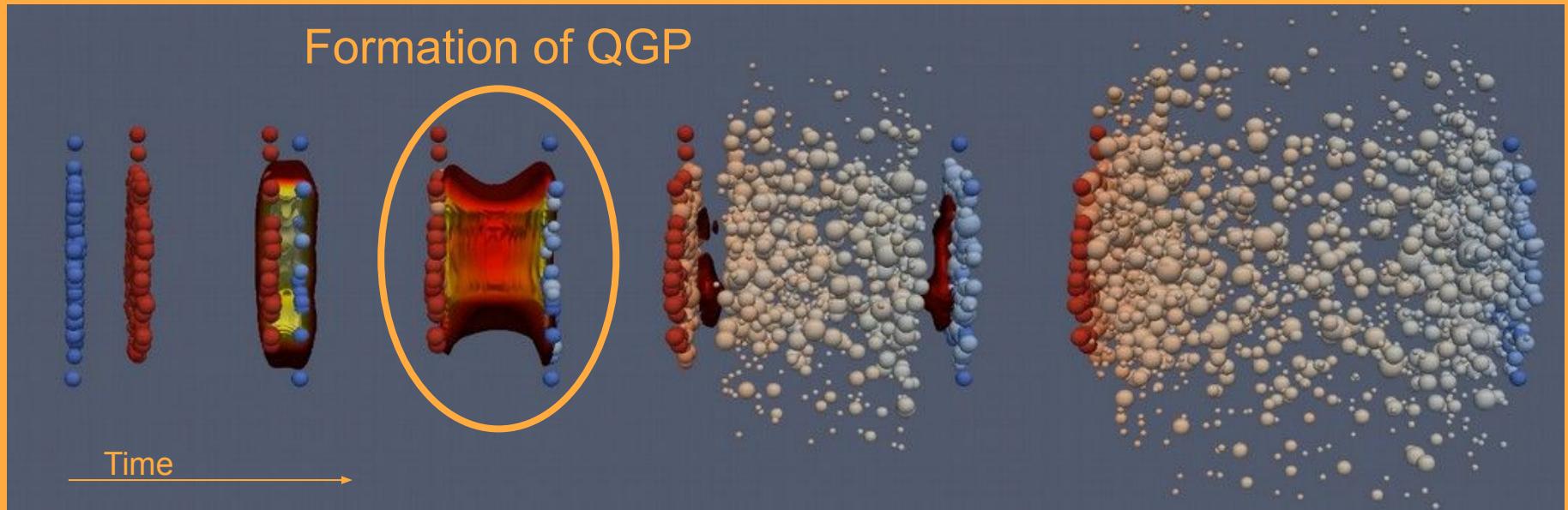
Quark gluon plasma



Evolution of a heavy ion collision

MADAI collaboration, Hannah Petersen and Jonah Bernhard

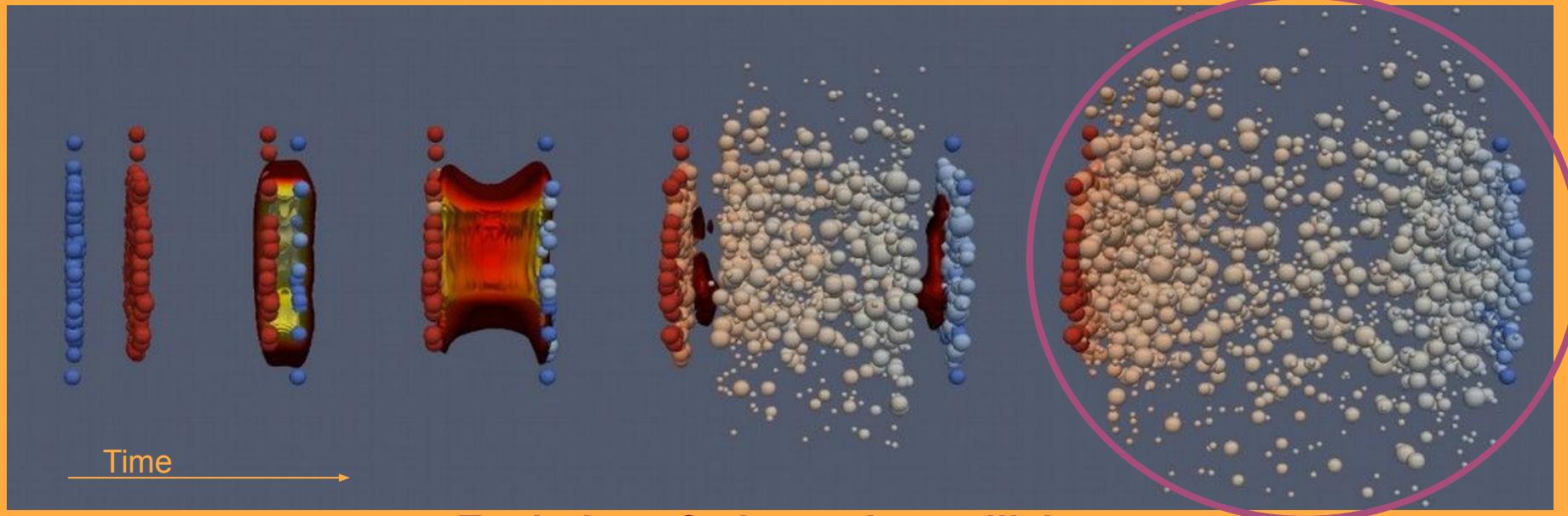
Quark gluon plasma



MADAI collaboration, Hannah Petersen and Jonah Bernhard

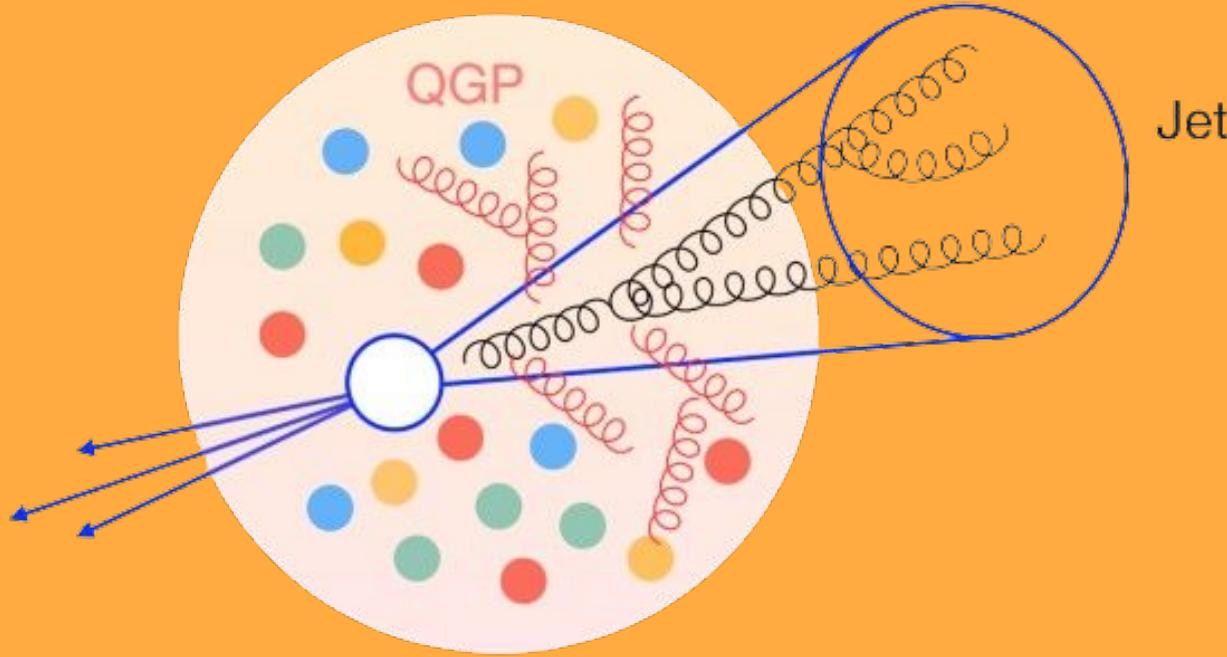
Quark gluon plasma

What reaches the detector



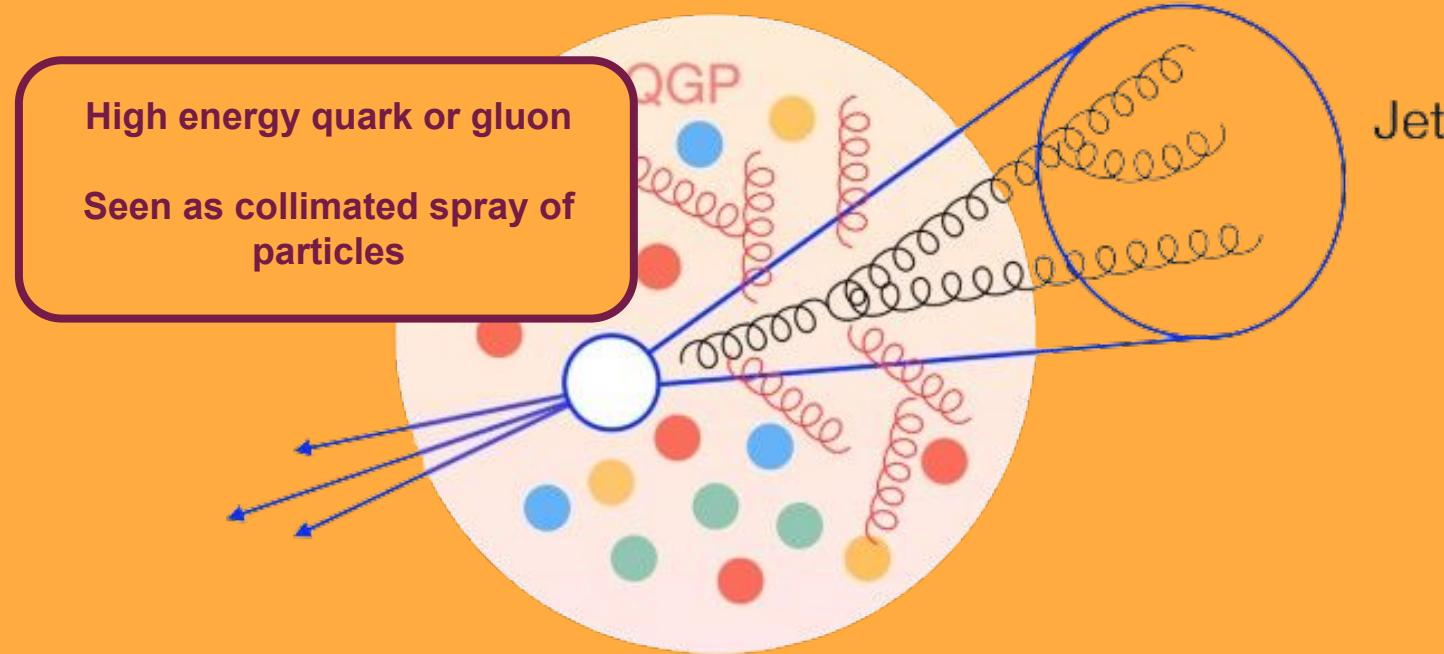
MADAI collaboration, Hannah Petersen and Jonah Bernhard

Quark gluon plasma



How can we probe this medium?
Jets

Quark gluon plasma



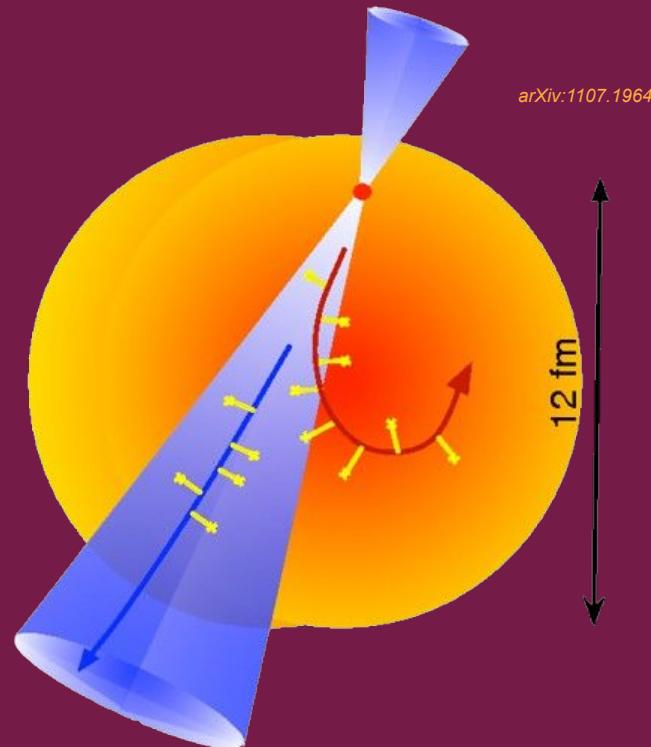
How can we probe this medium?
Jets

Jets in heavy ion collisions

Travel in the plasma

Can interact with the plasma

Gluon can radiate off



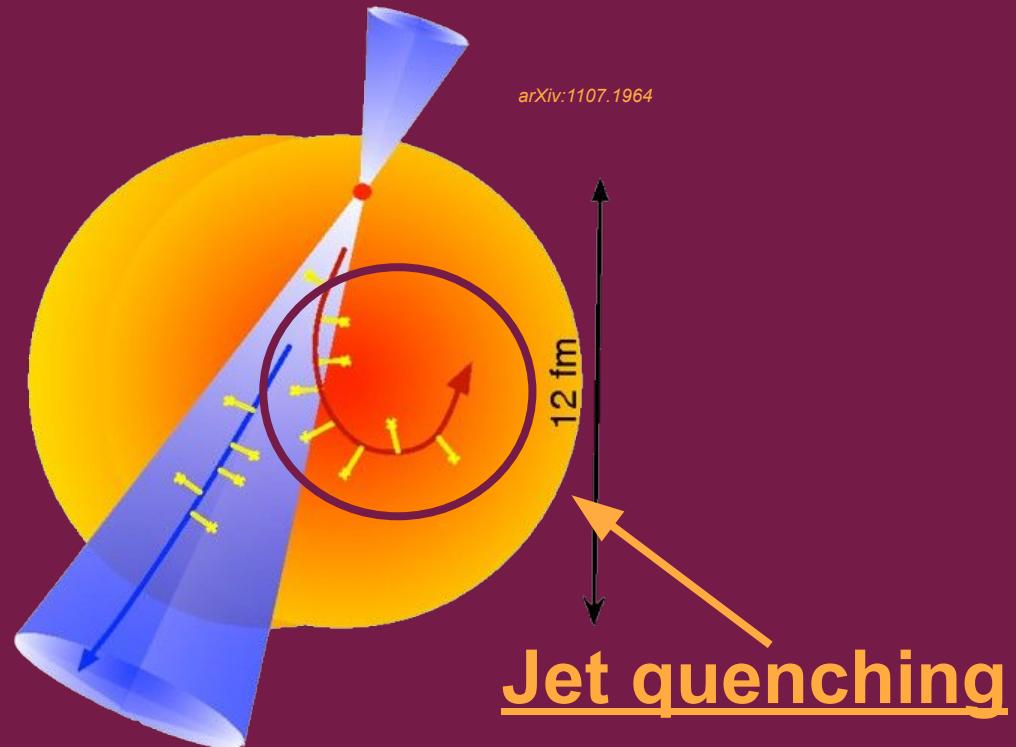
arXiv:1107.1964

Jets in heavy ion collisions

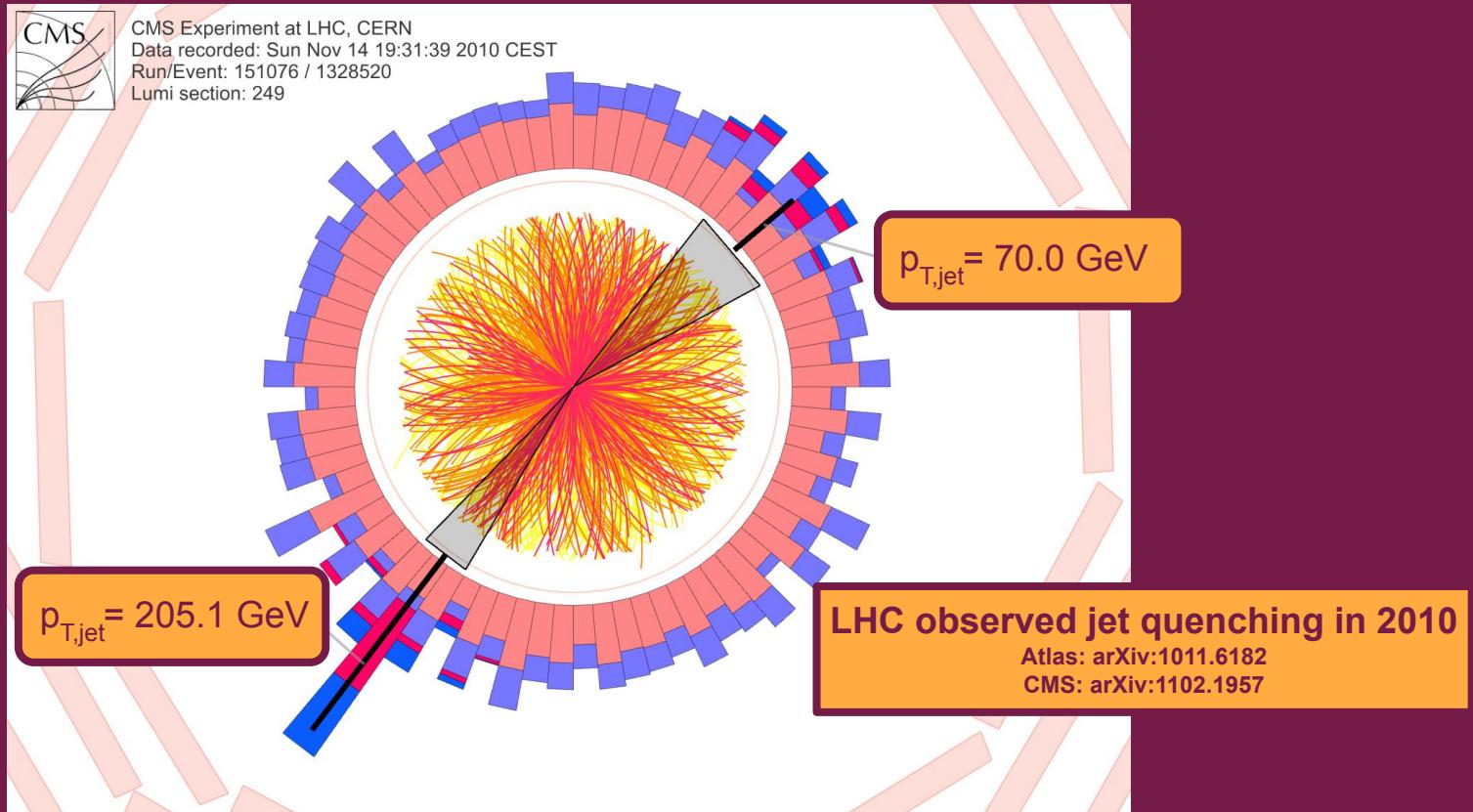
Travel in the plasma

Can interact with the plasma

Gluon can radiate off



Jets in heavy ion collisions



Jets in heavy ion collisions



CMS Experiment at LHC, CERN
Data recorded: Sun Nov 14 19:31:39 2010 CEST
Run/Event: 151076 / 1328520
Lumi section: 249

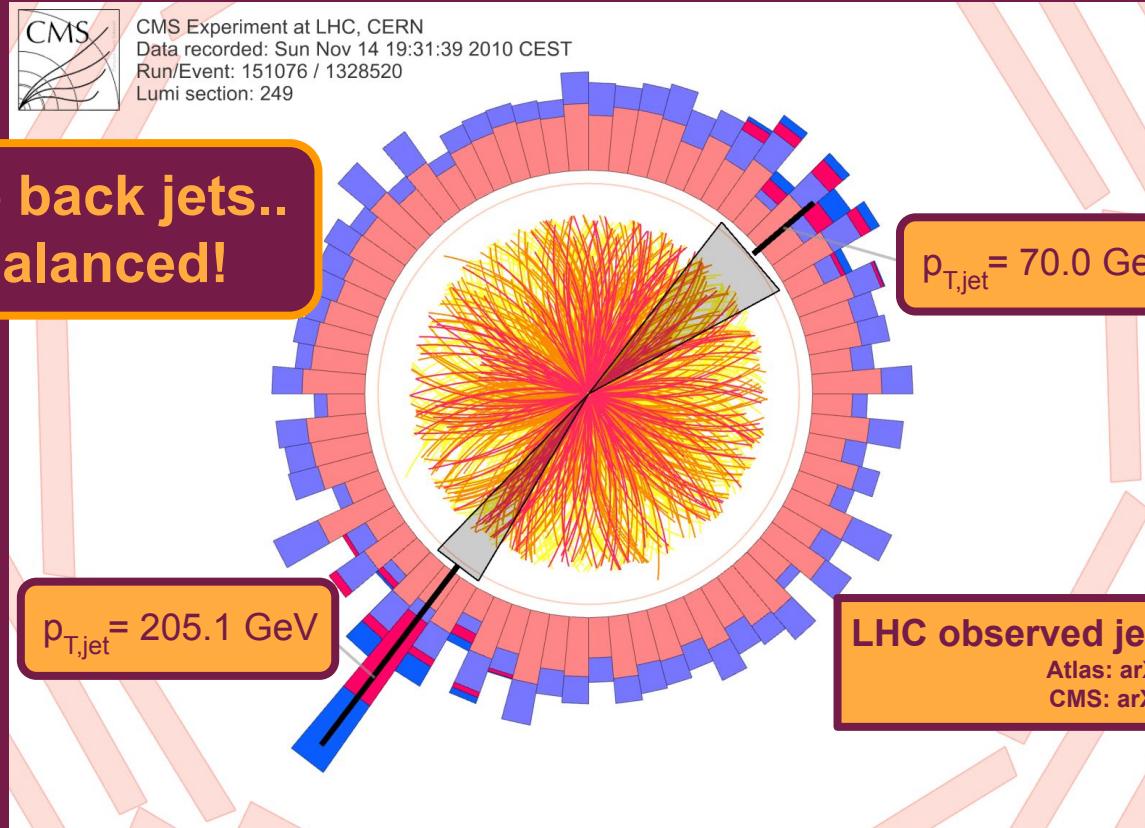
Back to back jets..
Not balanced!

$p_{T,jet} = 70.0 \text{ GeV}$

$p_{T,jet} = 205.1 \text{ GeV}$

LHC observed jet quenching in 2010

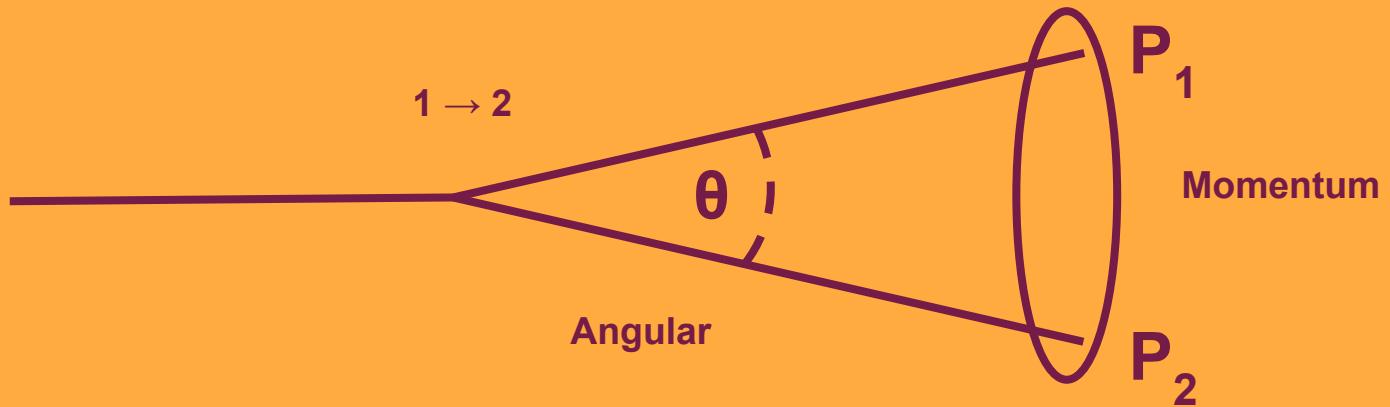
Atlas: arXiv:1011.6182
CMS: arXiv:1102.1957



Jet substructure

Not only the **energy** of the jet can be modified

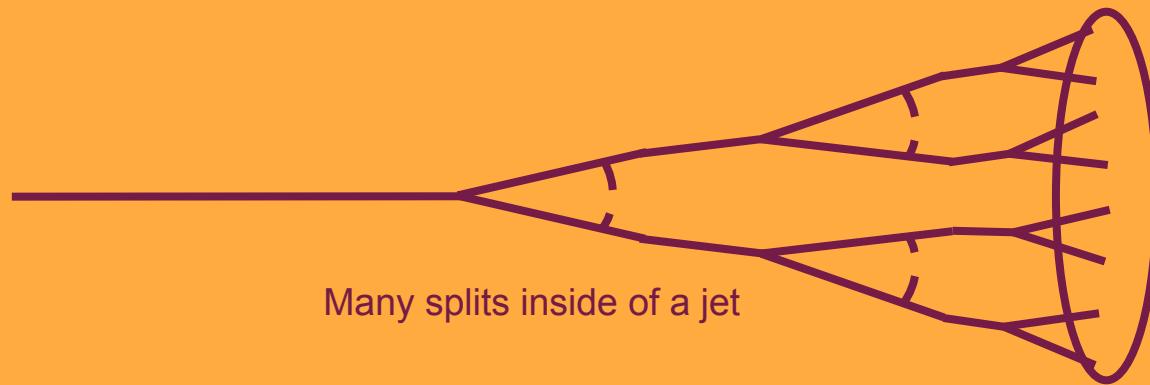
Also the **structure** of the jet might change



Jet substructure

Not only the **energy** of the jet can be modified

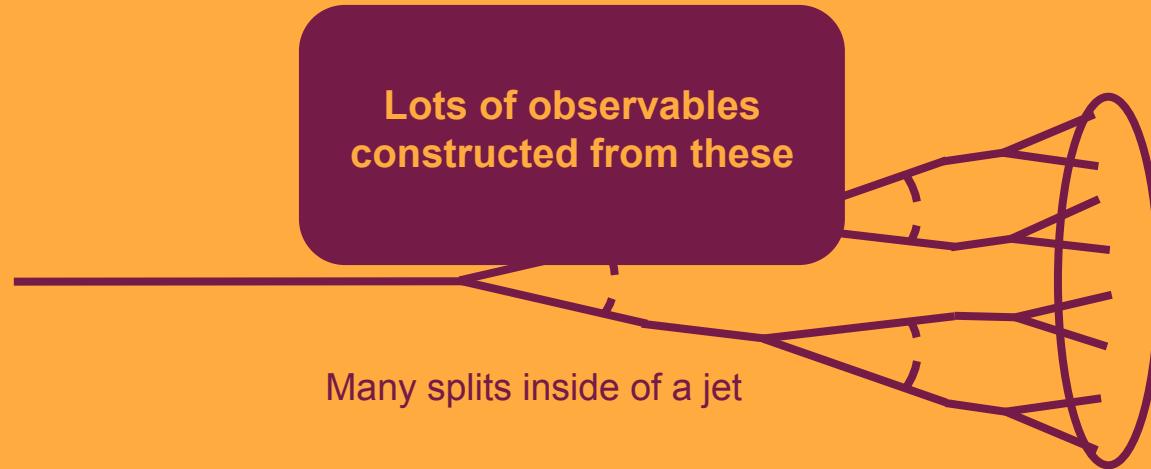
Also the **structure** of the jet might change



Jet substructure

Not only the **energy** of the jet can be modified

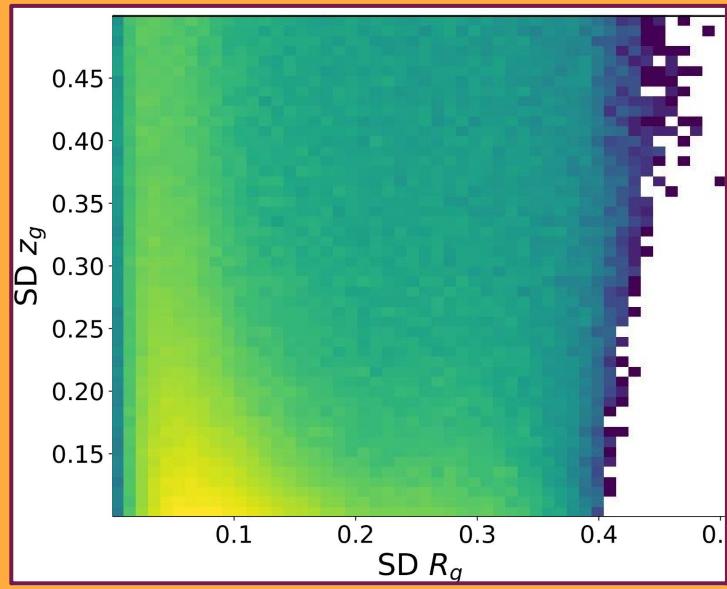
Also the **structure** of the jet might change



Jet substructure

No plasma

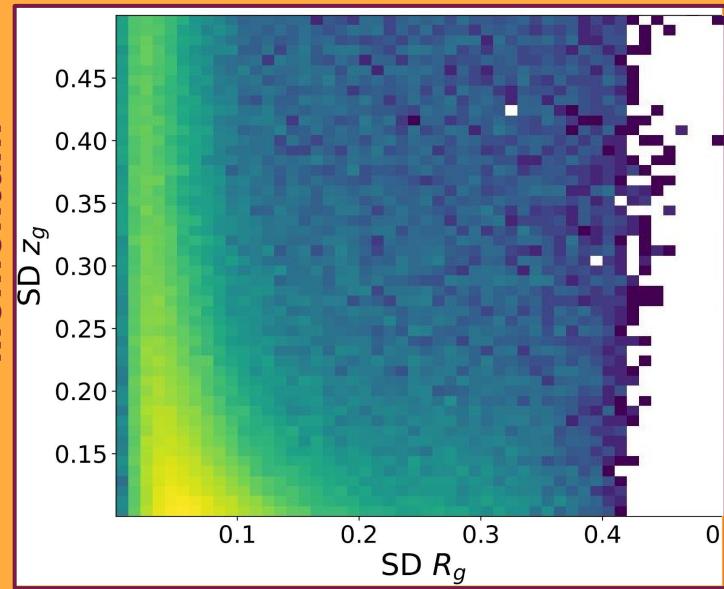
Momentum



Angular

Quark gluon plasma

Momentum



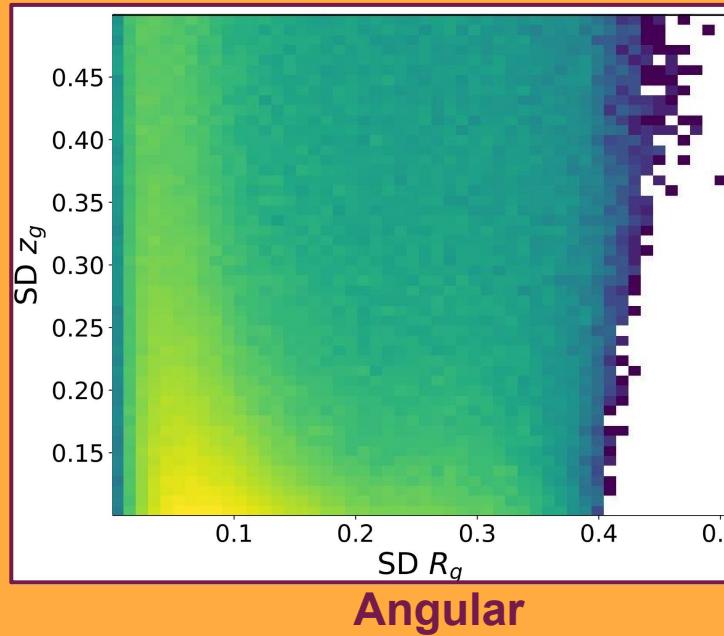
Angular

Jewel monte carlo simulations

Jet substructure

No plasma

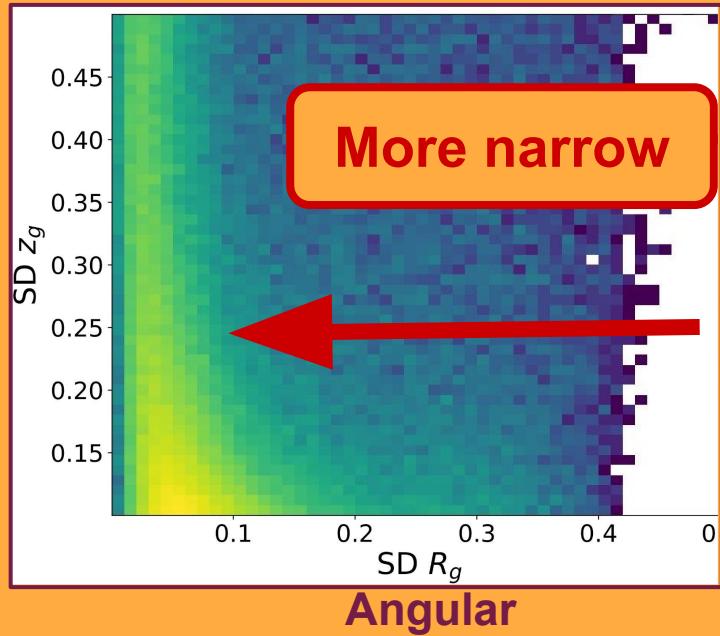
Momentum



Angular

Quark gluon plasma

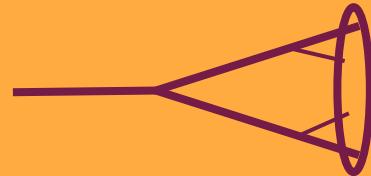
Momentum



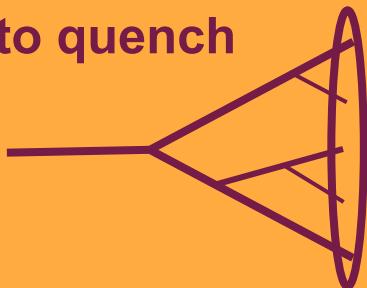
Angular

Jewel monte carlo simulations

Jet substructure

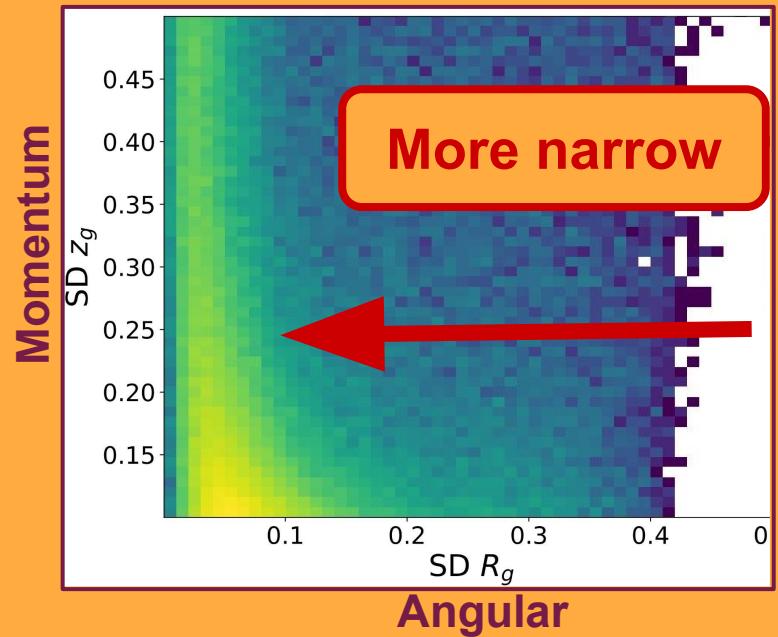


Wider jets have more opportunity to quench



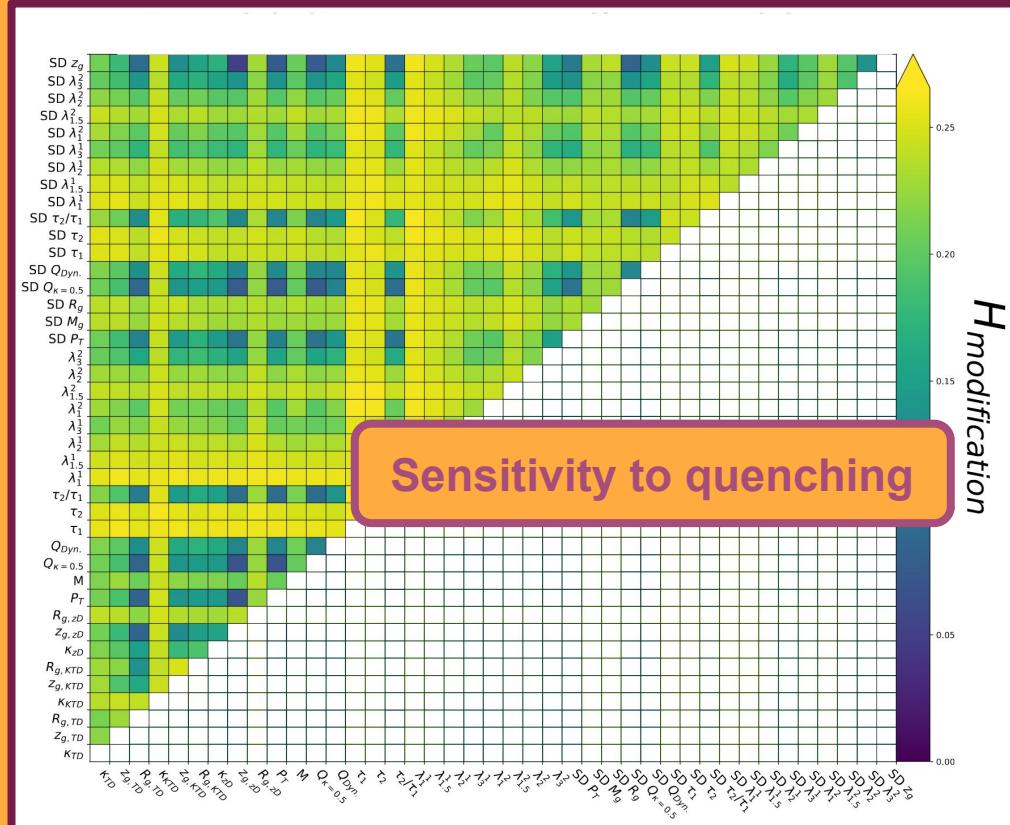
Jewel monte carlo simulations

Quark gluon plasma



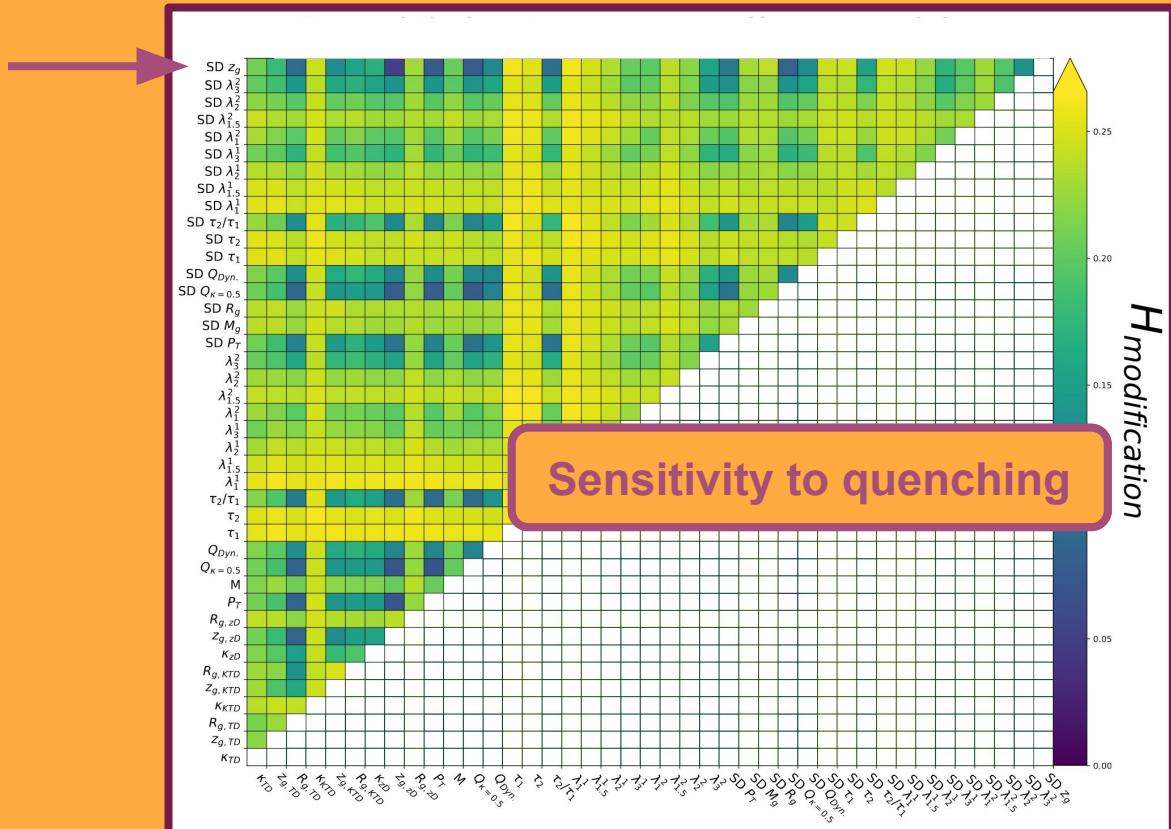
Jet substructure

Monte Carlo: check many correlations to sensitivity



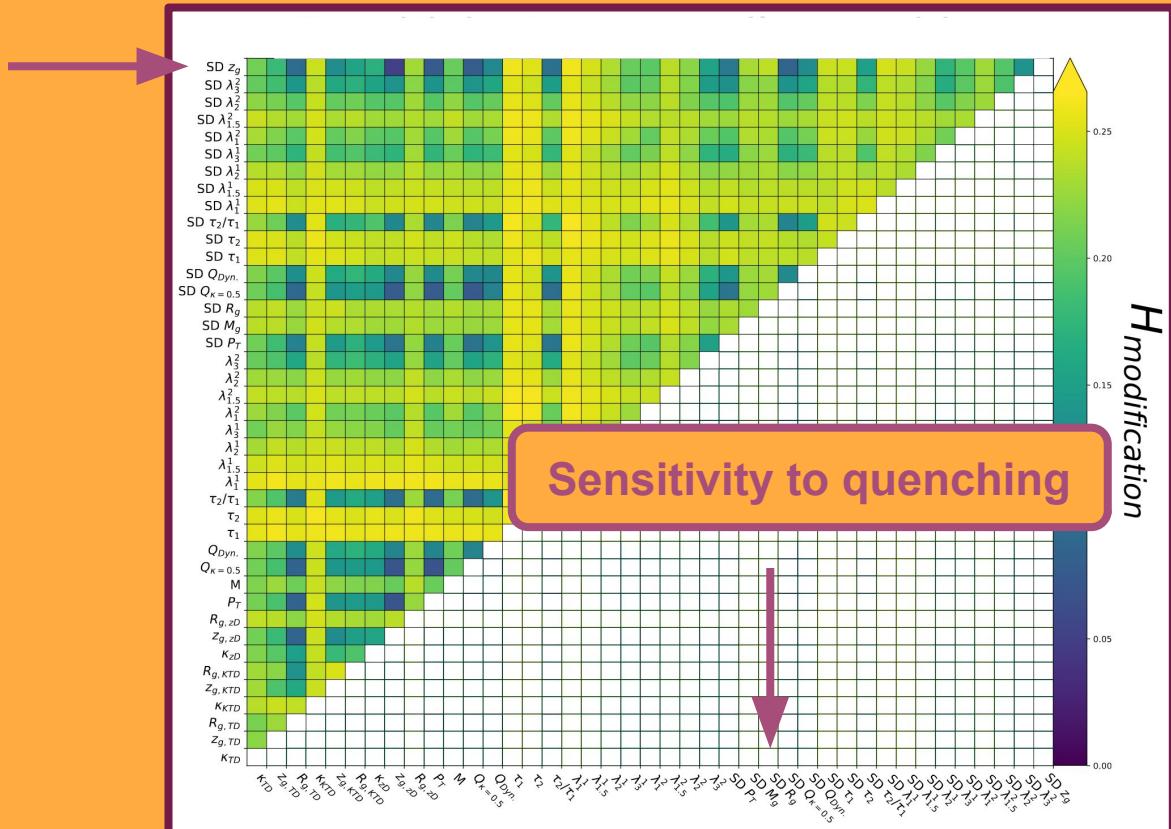
Jet substructure

Monte Carlo: check many correlations to sensitivity



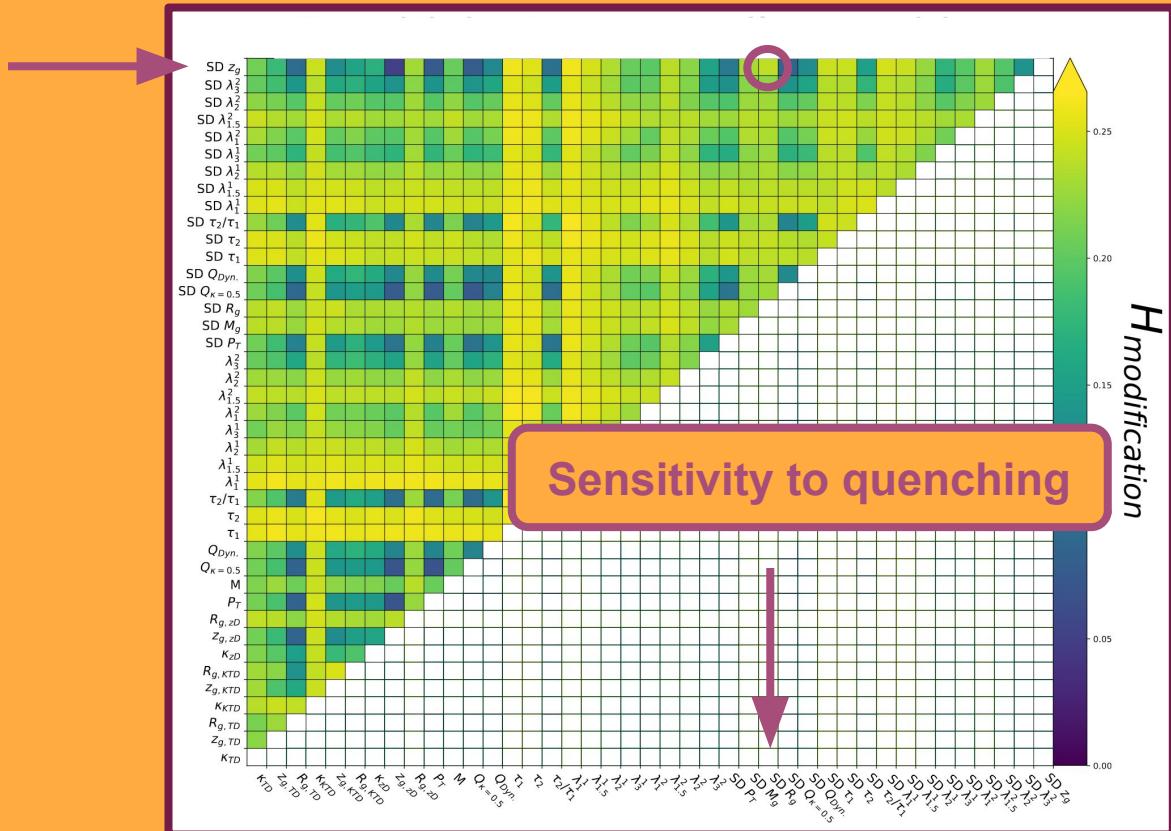
Jet substructure

Monte Carlo: check many correlations to sensitivity



Jet substructure

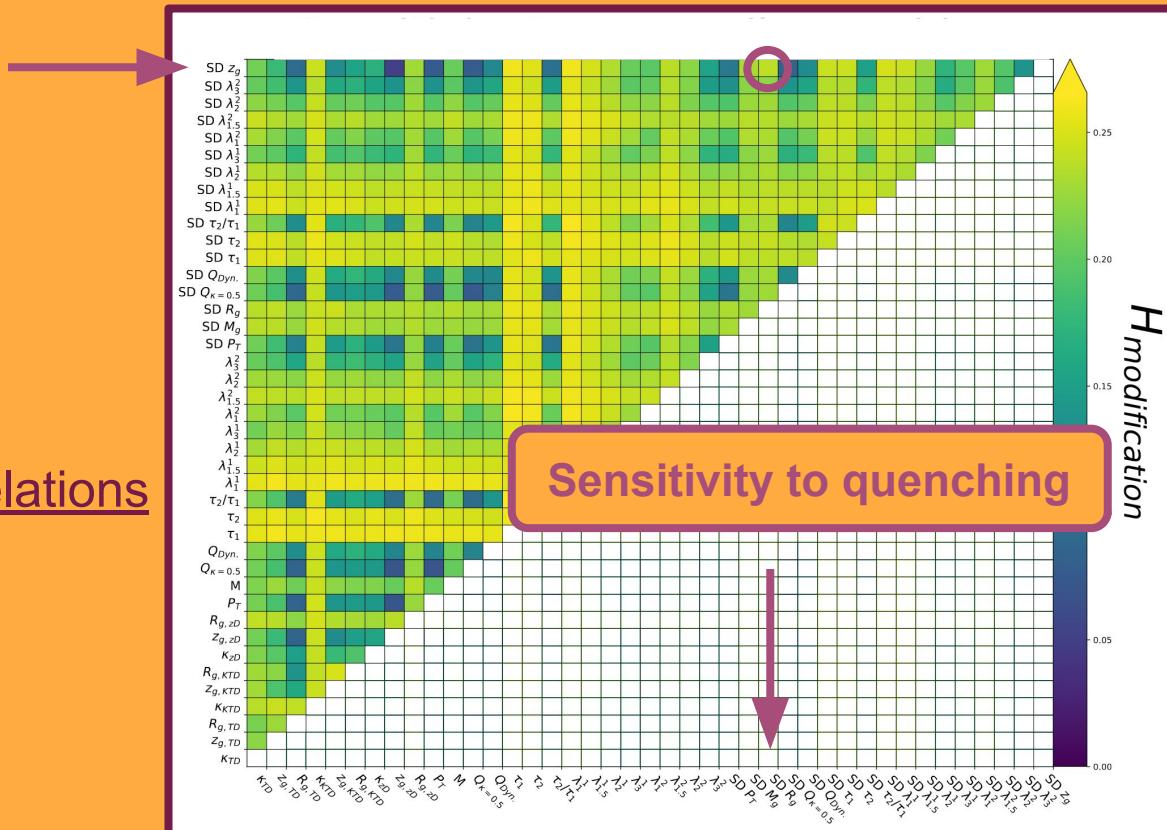
Monte Carlo: check many correlations to sensitivity



Jet substructure

Monte Carlo: check many correlations to sensitivity

Data: measure interesting correlations



Jet mass vs. angularity

Angularity: observable with
2 parameters

Tune dependence to:

Momentum: κ

Angular: β

$$\lambda_{\beta}^{\kappa} = \sum_{i \in \text{jet}} \left(\frac{p_{T_i}}{p_{T_{\text{jet}}}} \right)^{\kappa} \left(\frac{\Delta R_i}{R_{\text{jet}}} \right)^{\beta}$$

Jet mass vs. angularity

Angularity: observable with
2 parameters

Tune dependence to:

Momentum: κ

Angular: β

$$\lambda_{\beta}^{\kappa} = \sum_{i \in \text{jet}} \left(\frac{p_{T_i}}{p_{T_{\text{jet}}}} \right)^{\kappa} \left(\frac{\Delta R_i}{R_{\text{jet}}} \right)^{\beta}$$

With $\kappa = 1$, $\beta = 2$
strongly correlated to **mass**

Jet mass vs. angularity

Angularity: observable with
2 parameters

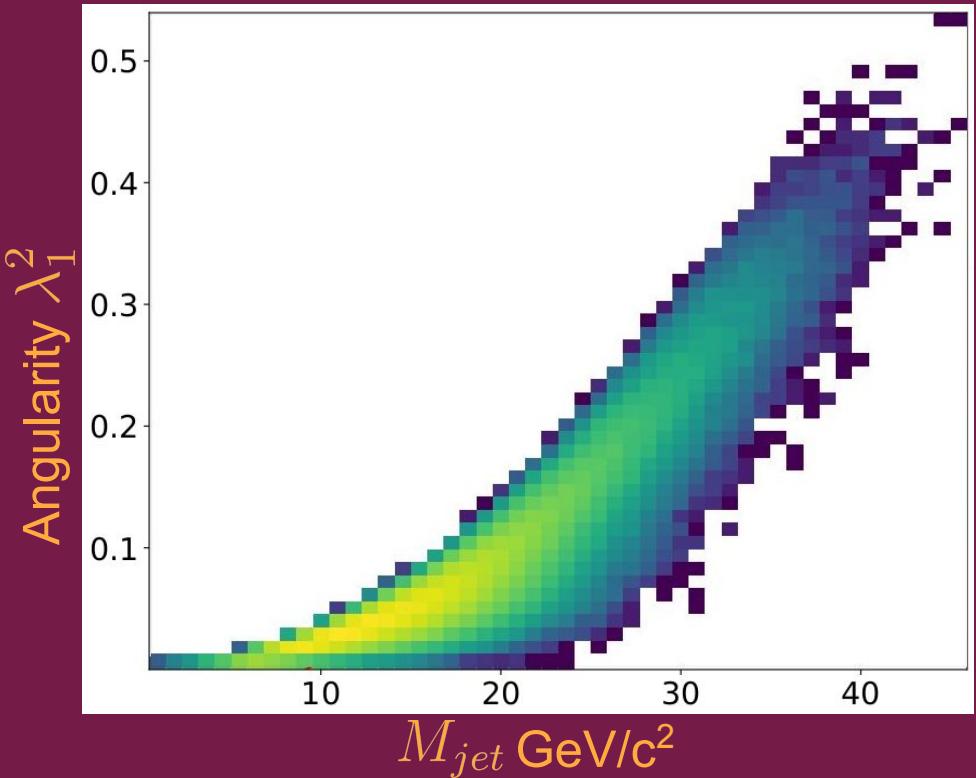
Tune dependence to:

Momentum: κ
Angular: β

$$\lambda_{\beta}^{\kappa} = \sum_{i \in \text{jet}} \left(\frac{p_{T_i}}{p_{T_{\text{jet}}}} \right)^{\kappa} \left(\frac{\Delta R_i}{R_{\text{jet}}} \right)^{\beta}$$

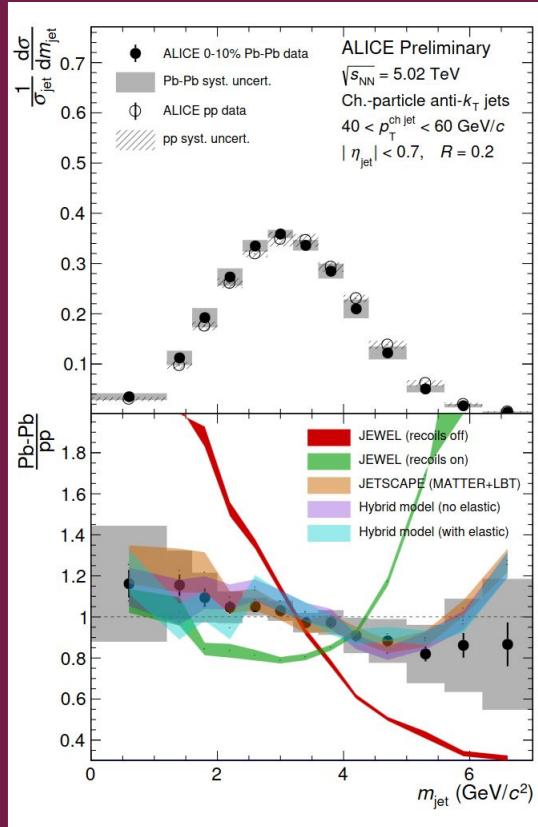
With $\kappa = 1$, $\beta = 2$

strongly correlated to **mass**



Jet mass vs. angularity

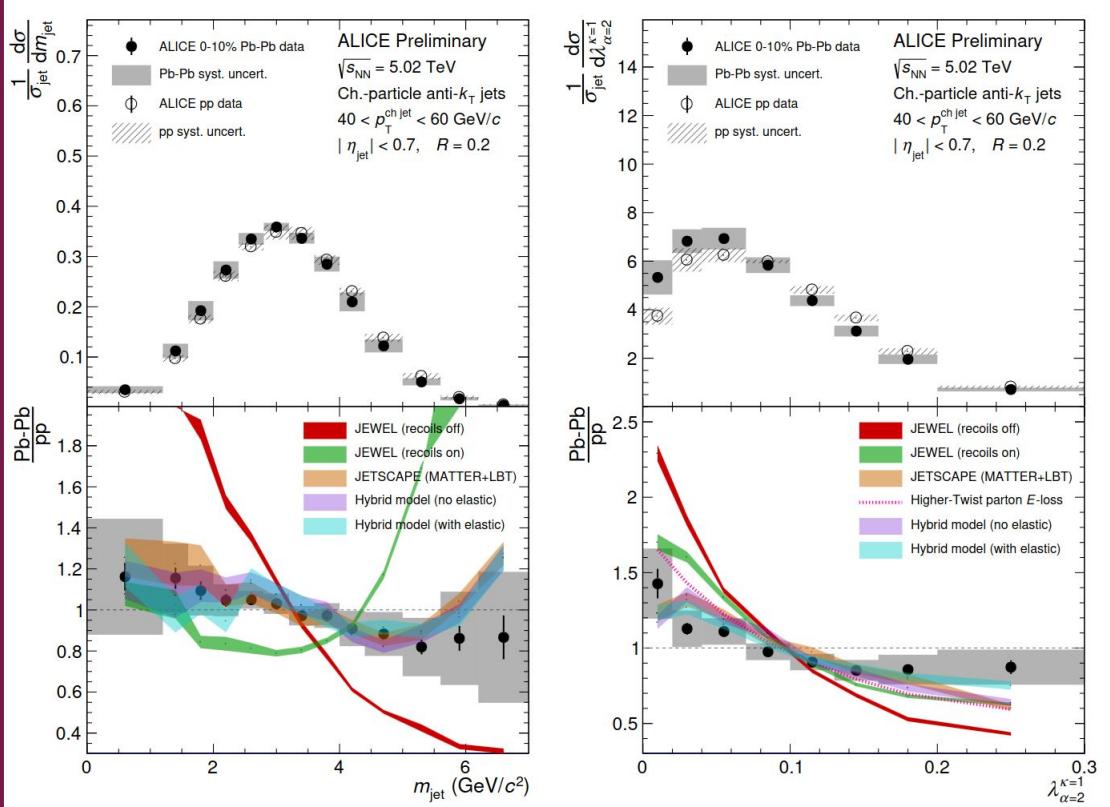
Jet mass: Slightly shifted



Jet mass vs. angularity

Jet mass: Slightly shifted

Angularity $\lambda_{\alpha=2}^{k=1}$: Stronger modification

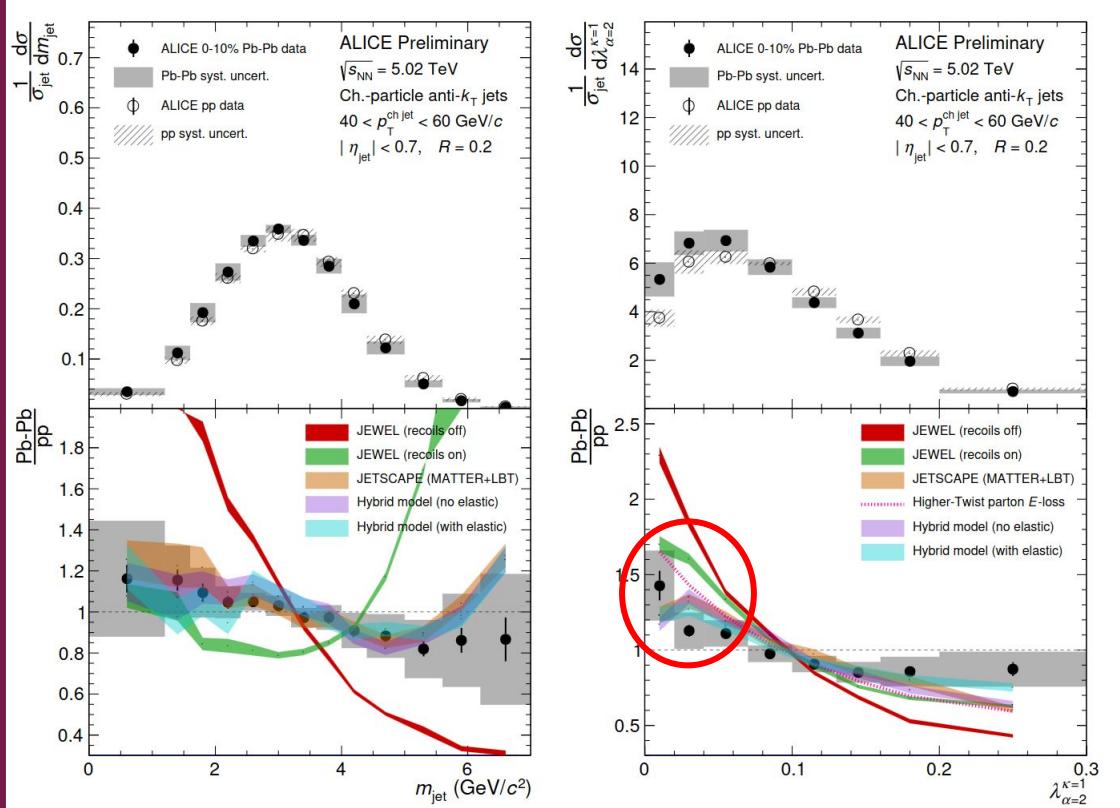


Jet mass vs. angularity

Jet mass: Slightly shifted

Angularity $\lambda_{\alpha=2}^{k=1}$: Stronger modification

Models: Predict varying sensitivity



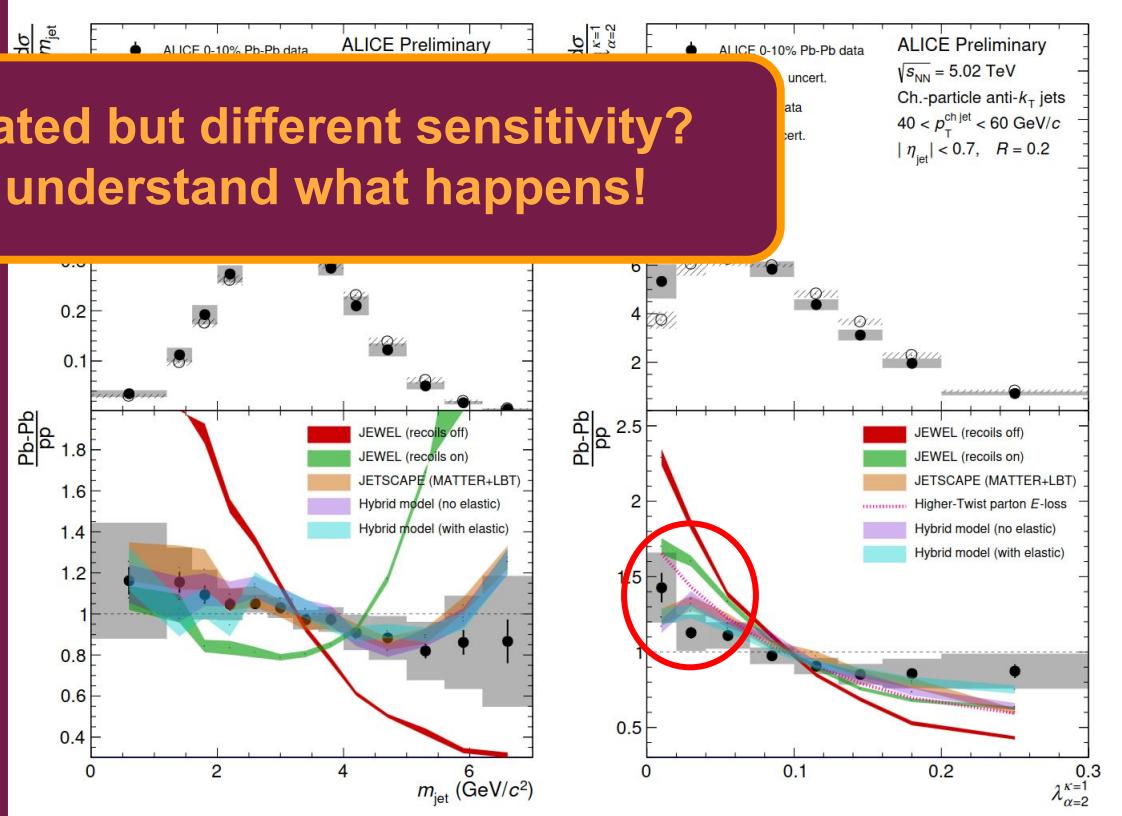
Jet mass vs. angularity

Strongly correlated but different sensitivity?
Measure to understand what happens!

Jet mass: Slightly shifted

Angularity $\lambda_{\alpha=2}^{k=1}$: Stronger modification

Models: Predict varying sensitivity

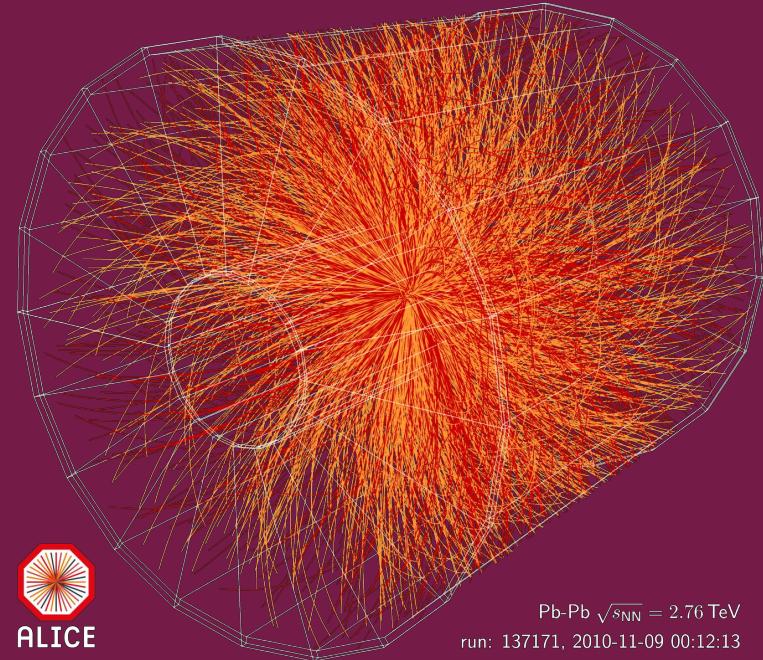


Heavy ion collisions

Not so easy in practice

Large background in heavy ions

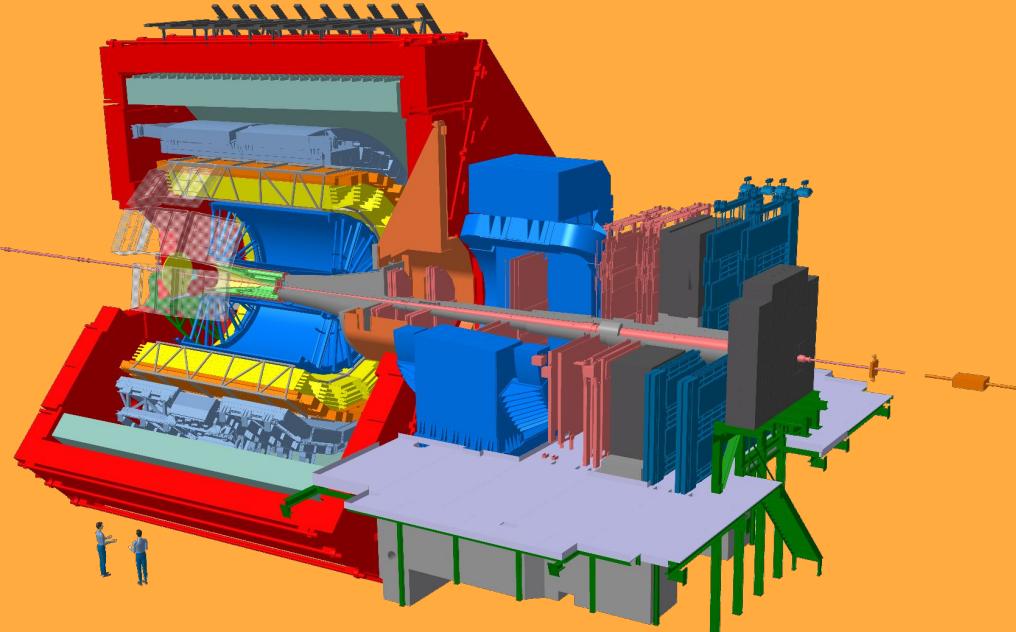
More than 100x times more particles w.r.t. proton collisions



$$\langle N_{\text{part}} \rangle = \sim \text{thousands}$$

Measurement

High precision tracking in high multiplicity environment



ALICE detector

Measurement

Measure in 2 dimension → **Unfold** detector in 3

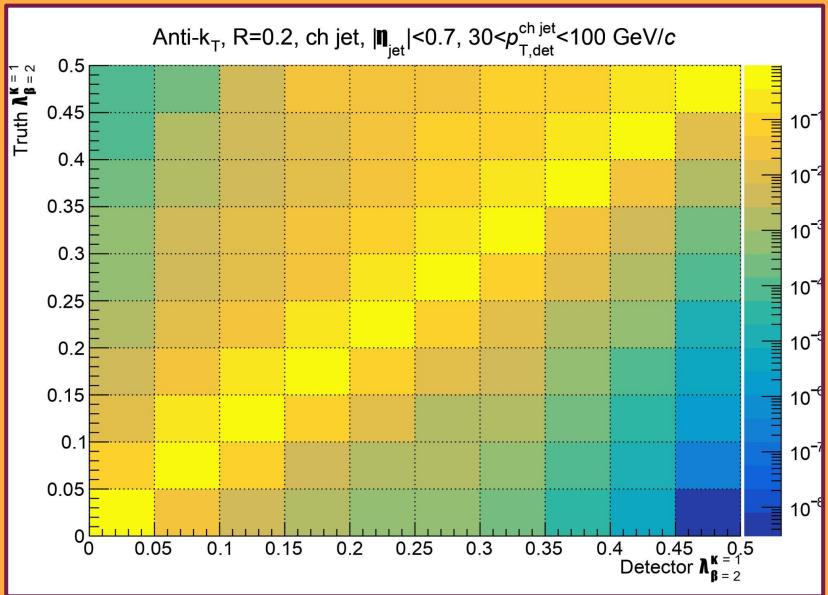
Mass
Angularity

Mass
Angularity
Momentum

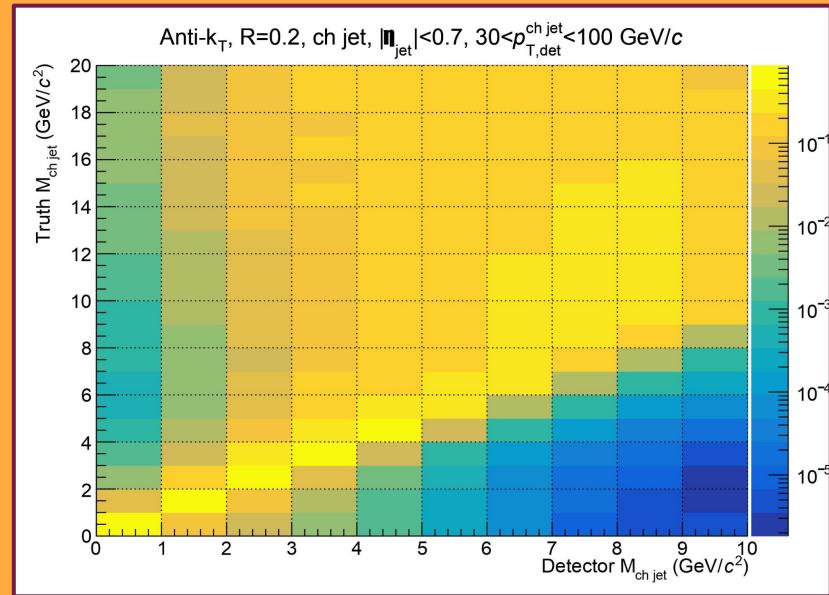
Need to understand behaviour of
detector in 3 observables

Measurement

Detector response



Angularity



Mass

Conclusion

**Quark gluon plasma + jets
created in heavy ion collisions**

Jets can lose energy in plasma

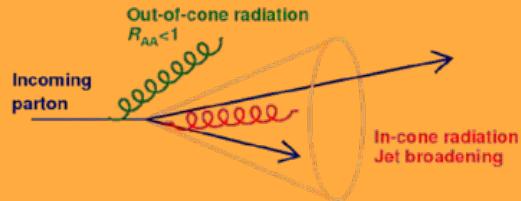
Also structure might change

Study correlations to find out how

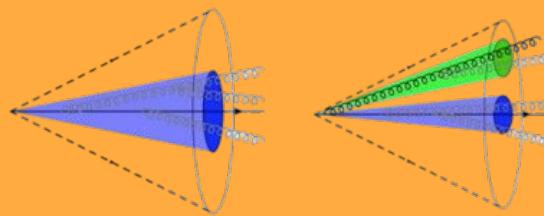
Back up

Medium interactions

Gluon radiation



Color coherence



Medium-induced radiation

Medium response

