A Field Guide for Event Isotropy

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What do we want to learn from event shape observables?

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→ Study underlying dynamics

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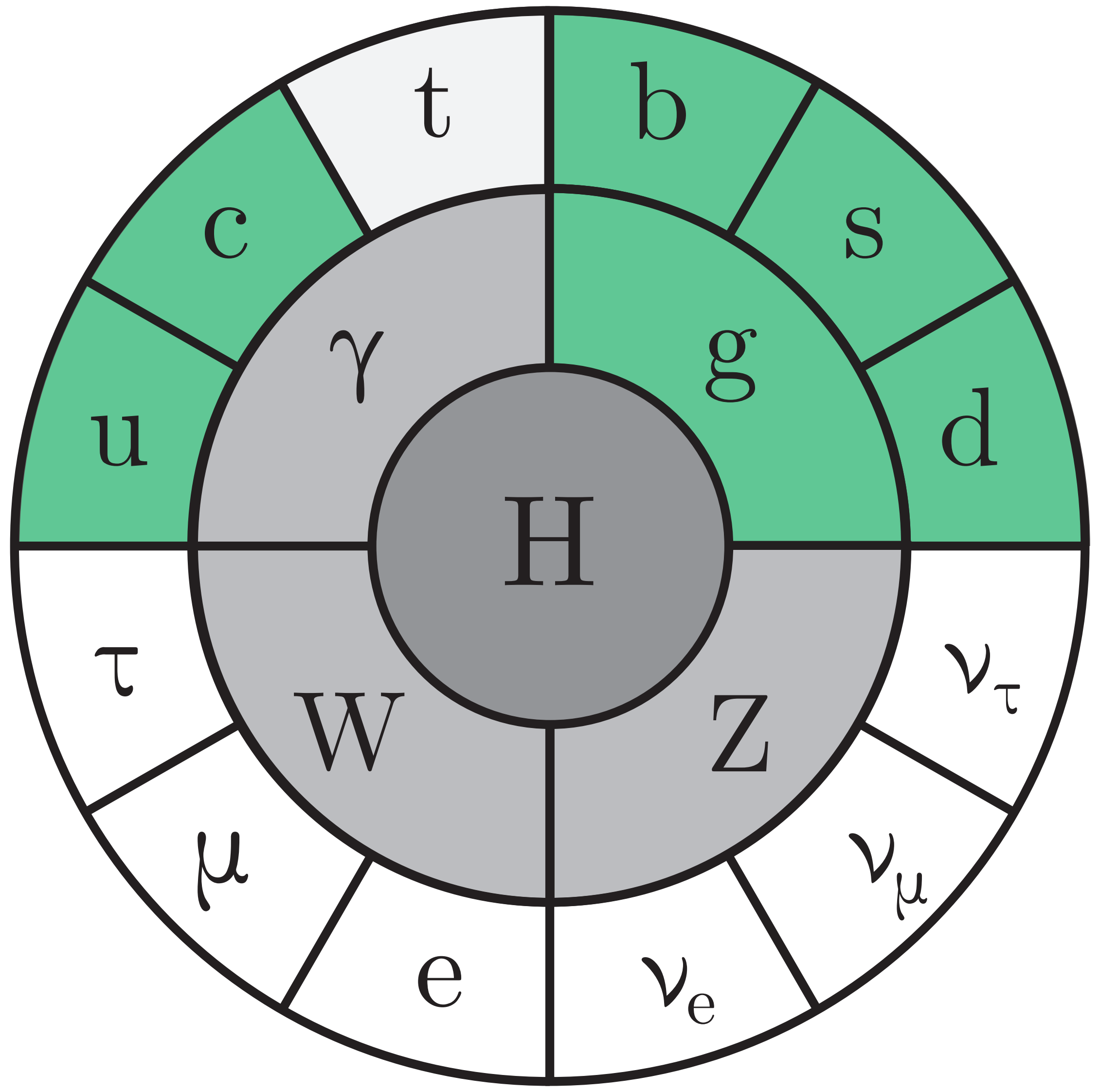
→ Study underlying dynamics

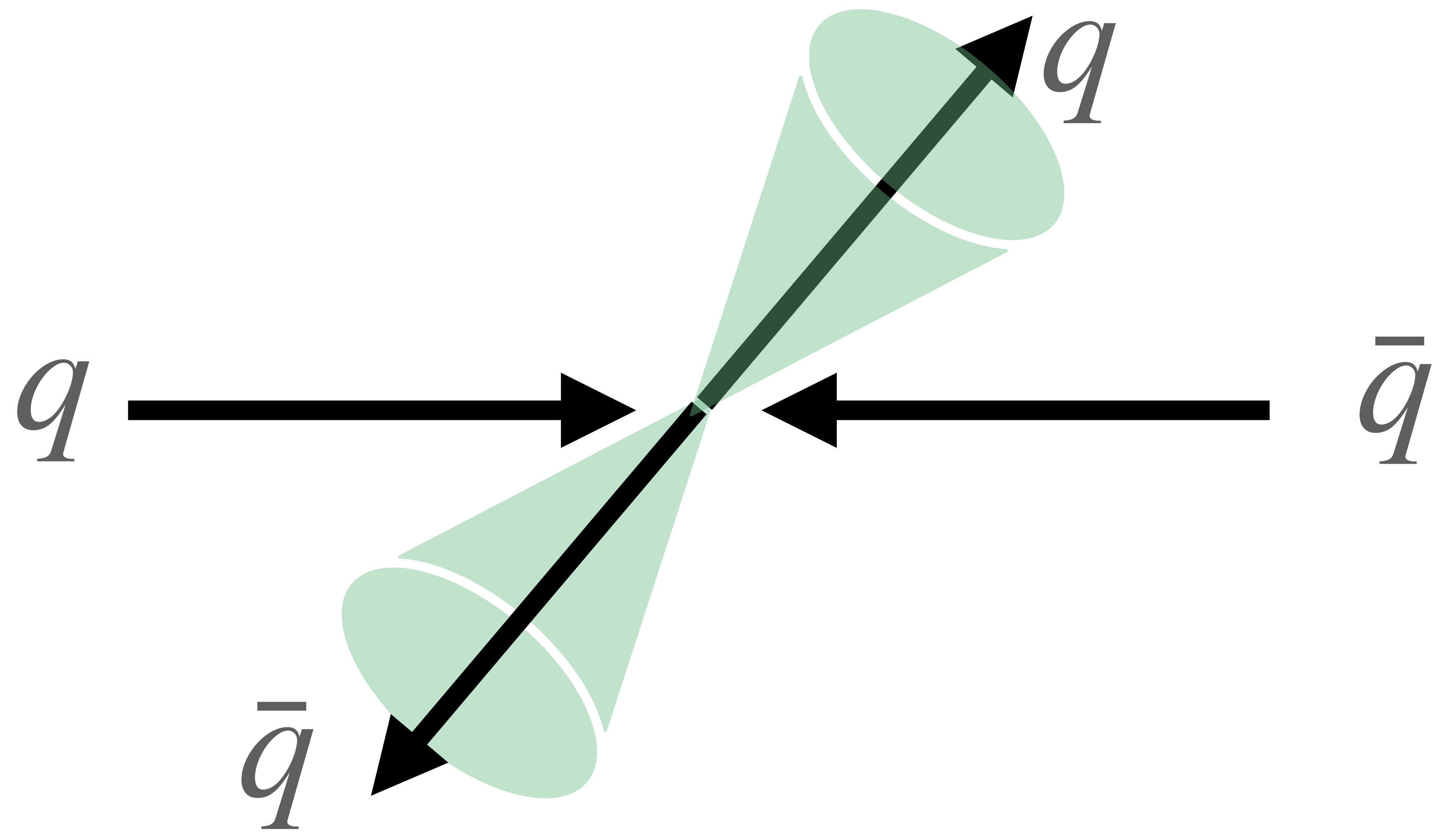
But in what regime?

Previous Observables

Near-dijet regime well explored

QCD at TeV scale is characterized by soft, collinear splittings





Novel Observables

There are many other features of radiation patterns that are interesting to study

- Quasi-isotropic regime
- Multijet events
- Other features of hard QCD

→ Need observables that are sensitive to relevant features and insensitive to others

Event Isotropy & More

We can design observables using the Earth Mover Distance (EMD)

Control the sensitivity by varying

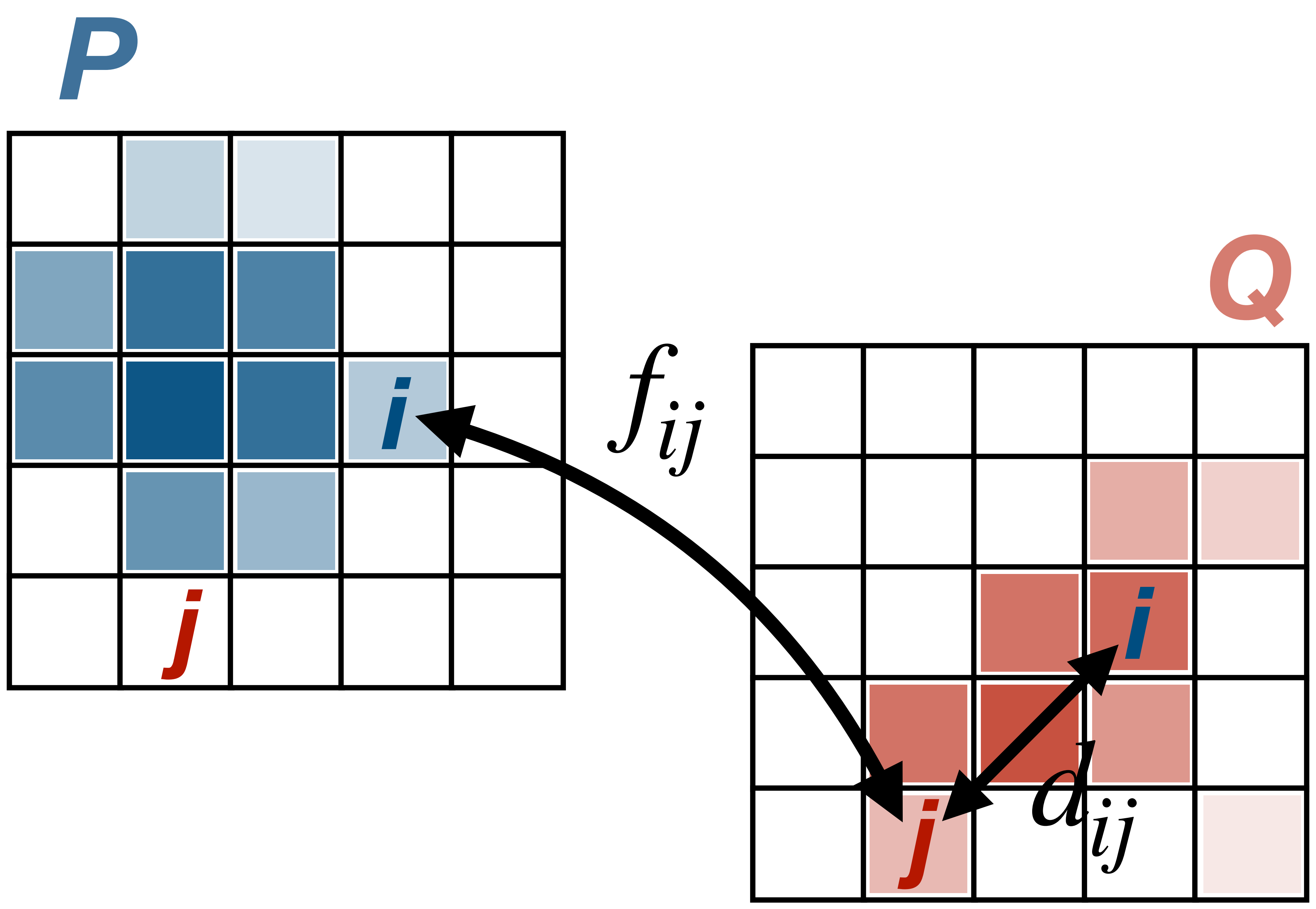
- Reference geometry
- Distance metric

Defining EMD

Energy mover's distance (**EMD**):

P. Komiske, E. Metodiev, J. Thaler 2019

What is the minimum work to rearrange the energy distribution in an event *P* to look like event *Q*?



$$\text{EMD}(P, Q) = \min_{\{f_{ij}\}} \sum_{ij} f_{ij}\, d_{ij}$$

f_{ij} : energy transported

d_{ij} : distance measure

$$f_{ij} \geq 0 \qquad \sum_{ij} f_{ij} = E_P^{\text{tot}} = E_Q^{tot} = 1$$

Defining EMD as Event Shape Observables

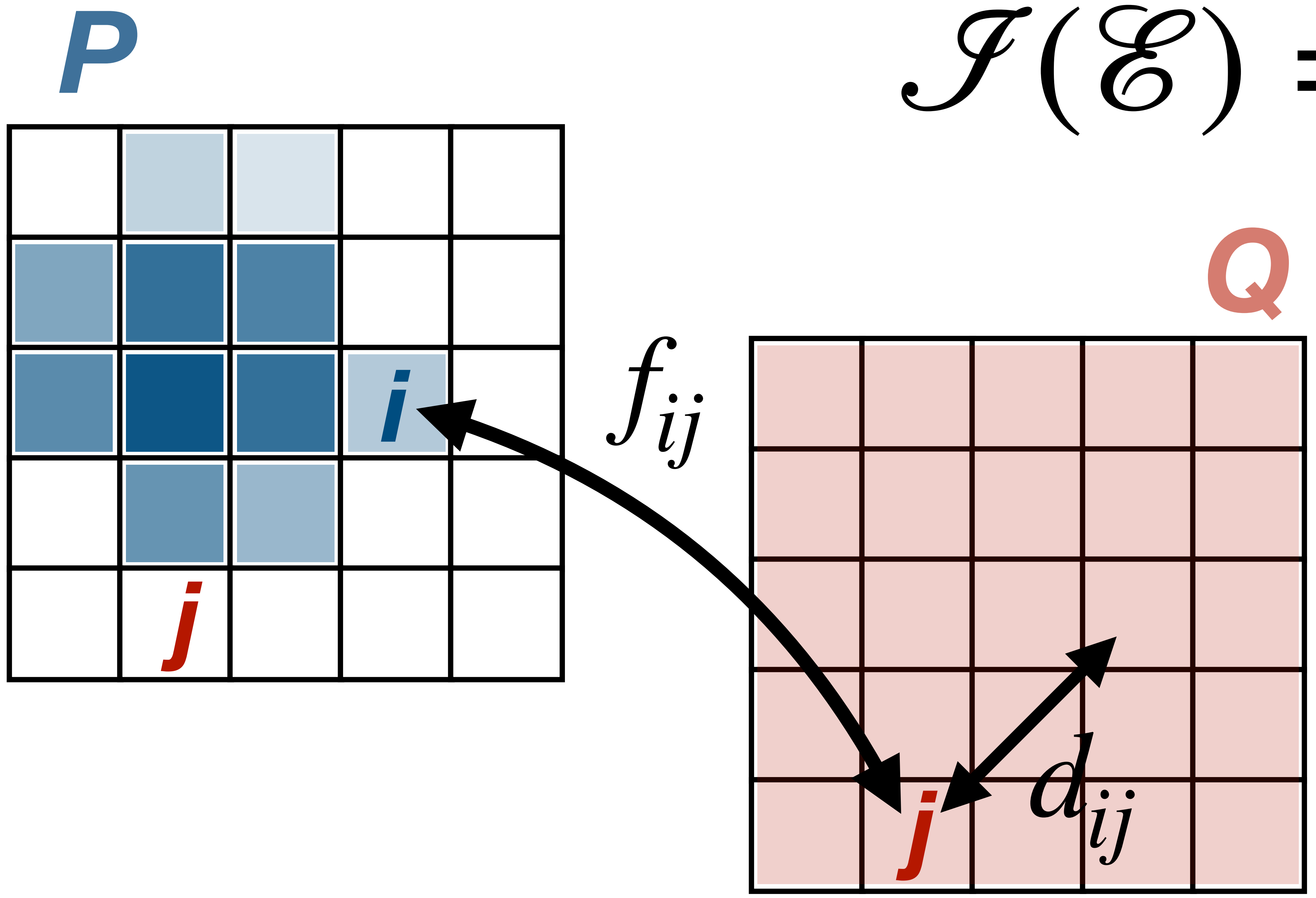
We can used the EMD as a well-defined distance between a reference topology and collider event

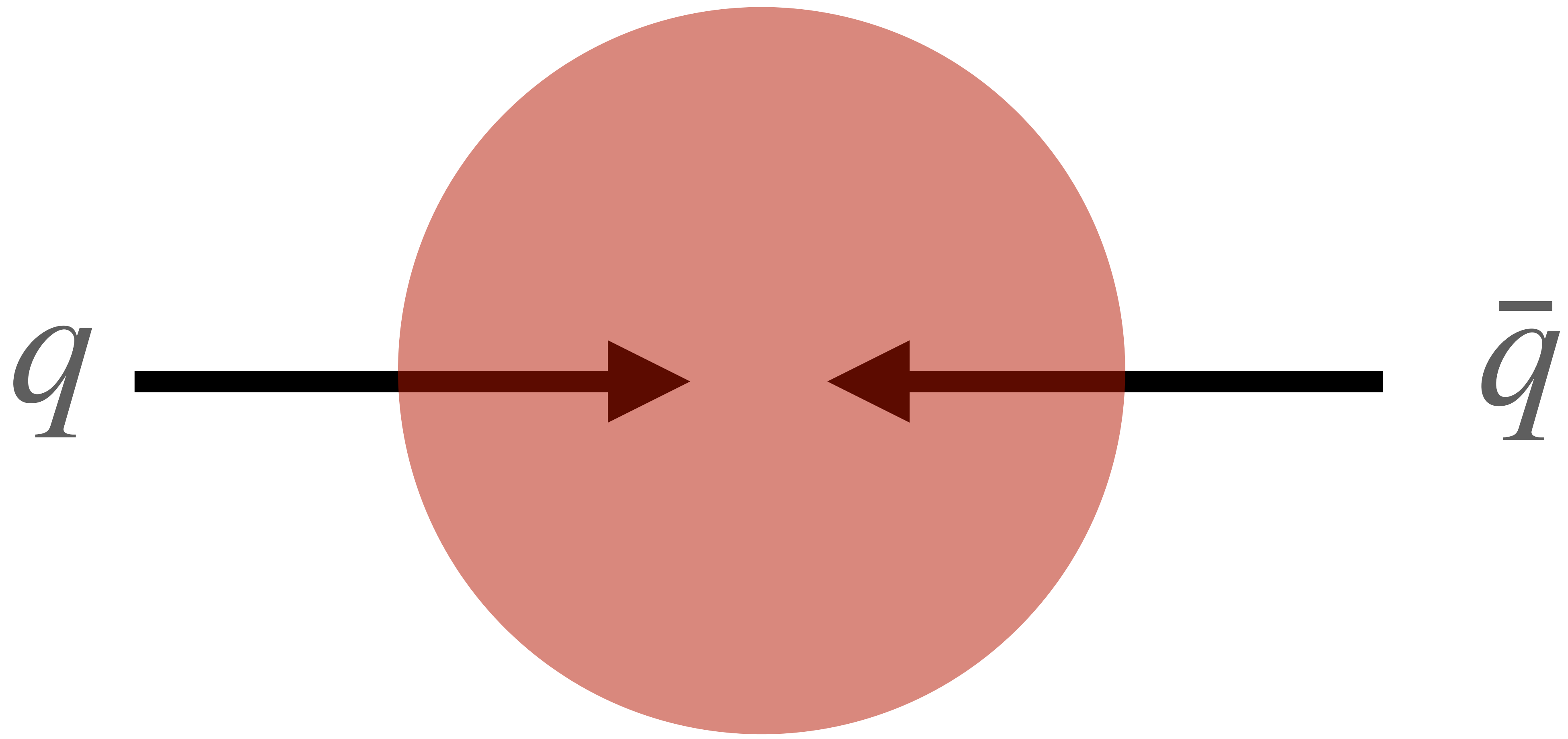
(This is what observables are secretly doing already)

Defining Event Isotropy

Event Isotropy: EMD of an event $\mathscr{E}$ to a uniform radiation pattern $\mathscr{U}$

$$\mathscr{I}(\mathscr{E}) = \text{EMD}(\mathscr{U}, \mathscr{E})$$





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Event Isotropy: EMD of an event $\mathscr{E}$ to a uniform radiation pattern $\mathscr{U}$

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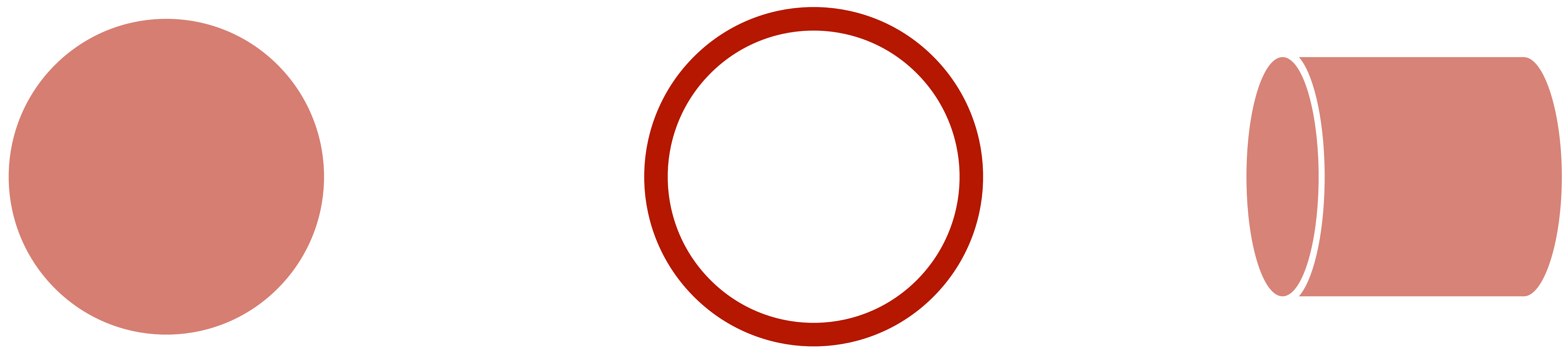
Geometries:



Distances: d_{ij}

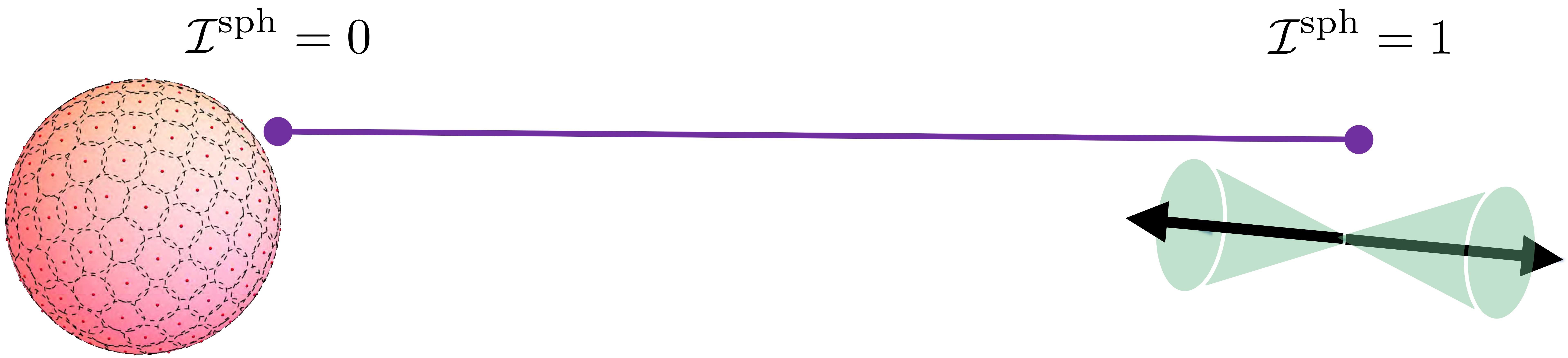
$(1 - \cos\theta_{ij})^{\beta/2}$ $\qquad$ $(1 - \cos\phi_{ij})^{\beta/2}$ $\qquad$ $\sqrt{\Delta\phi_{ij}^2 + \Delta\eta_{ij}^2}$

2004.06125 CC, J. Thaler

Defining Event Isotropy $\mathscr{I}(\mathscr{E}) = \text{EMD}(\mathscr{U}, \mathscr{E})$

Event Isotropy: EMD of an event $\mathscr{E}$ to a uniform radiation pattern $\mathscr{U}$

- IRC safe & dimensionless
- Defined on sets $m = 0$, $\Sigma\vec{p} = 0$



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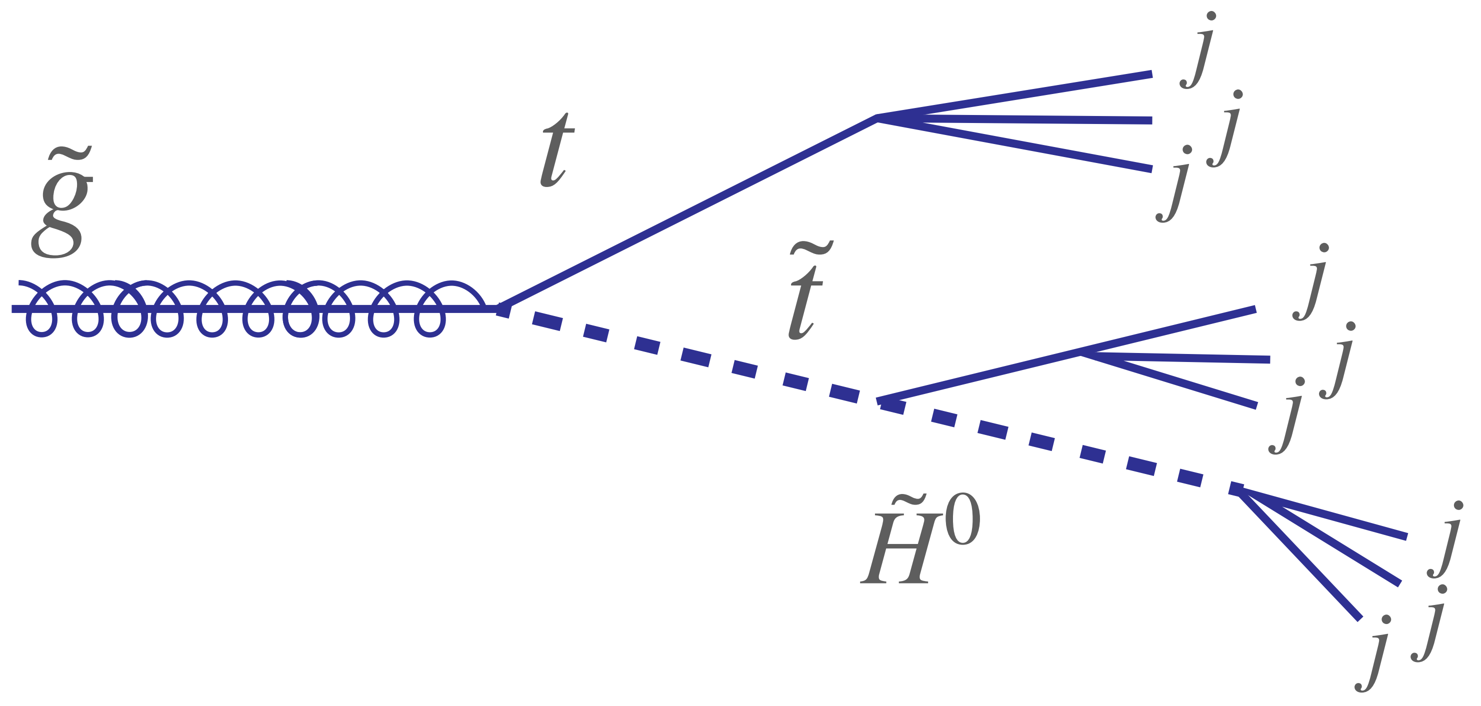
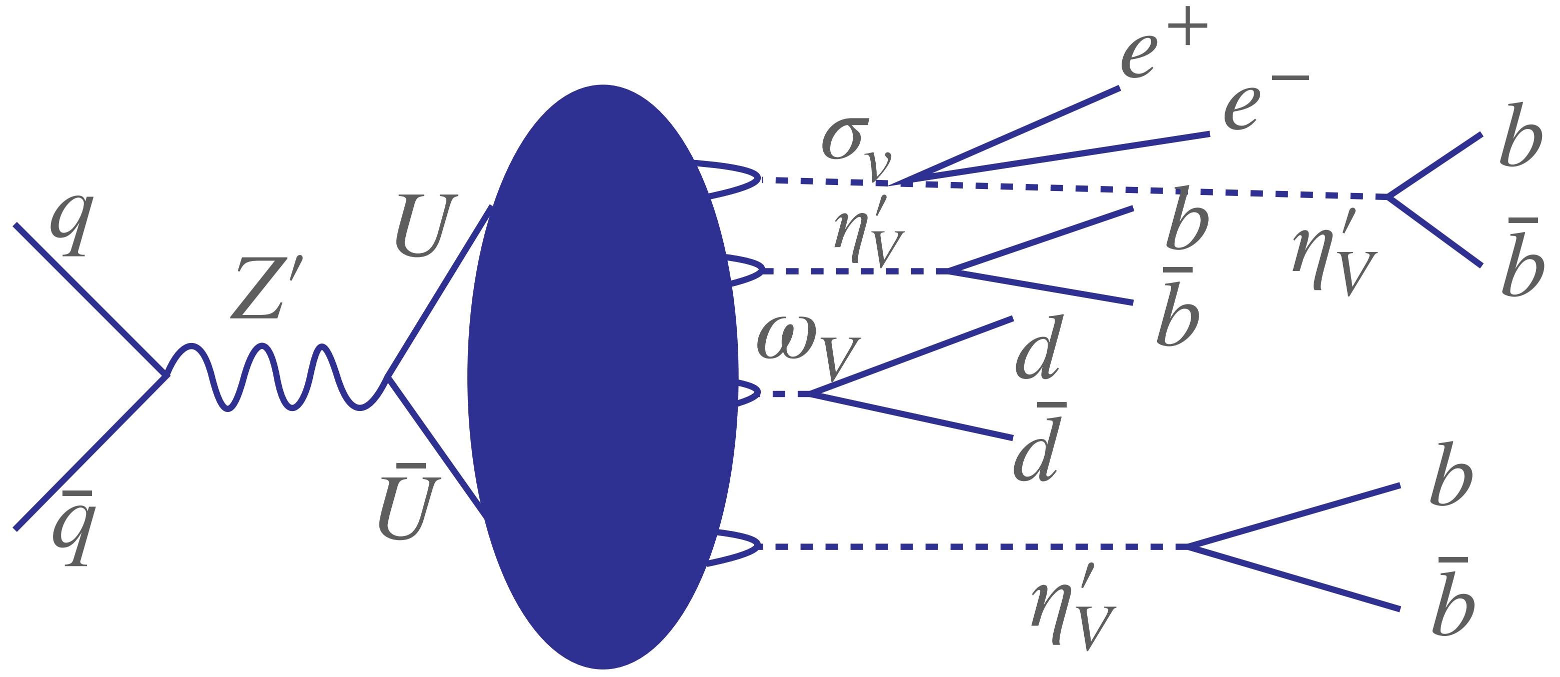
Event Isotropy

Designed to study quasi-isotropic events





Originally motivated for BSM

…but can be used for SM purposes as well!

Event Isotropy & ATLAS

Differential Cross Section Measurements with isotropy & more EMD observables

What can we learn about **QCD**
and how we model it?

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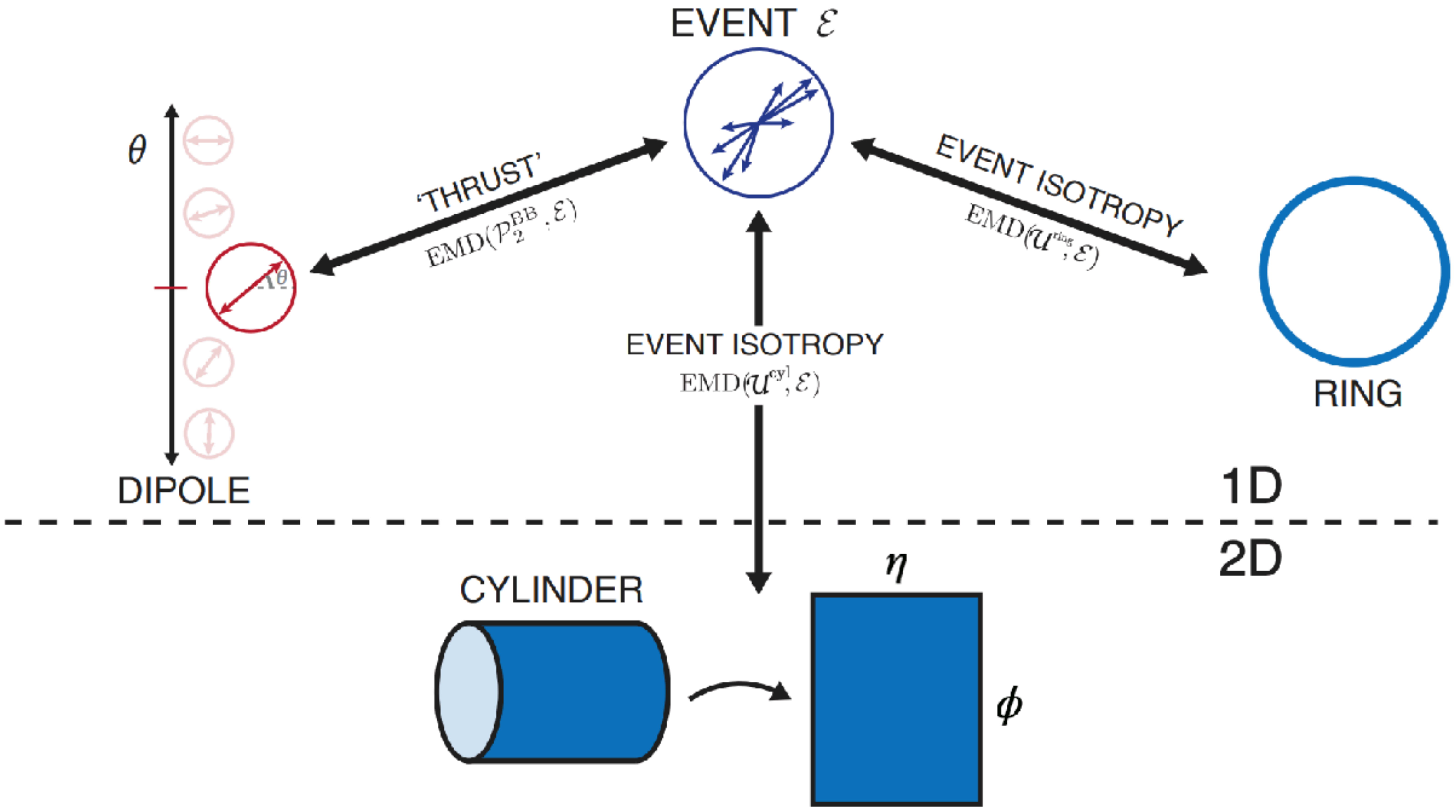
Event Isotropy & ATLAS

Differential Cross Section Measurements with isotropy & more EMD observables

Distance to
Dijet



Distance to
Isotropic

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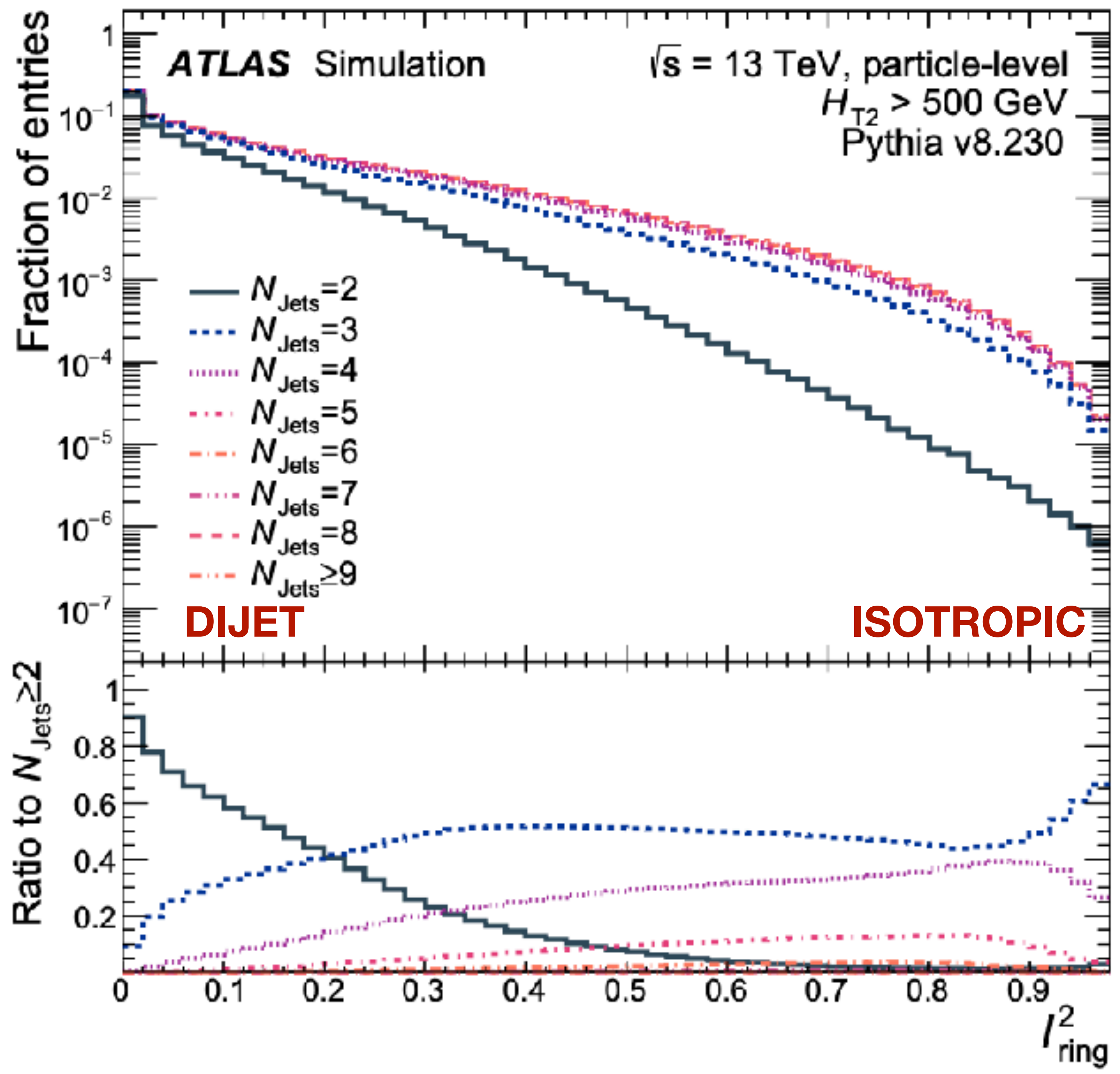
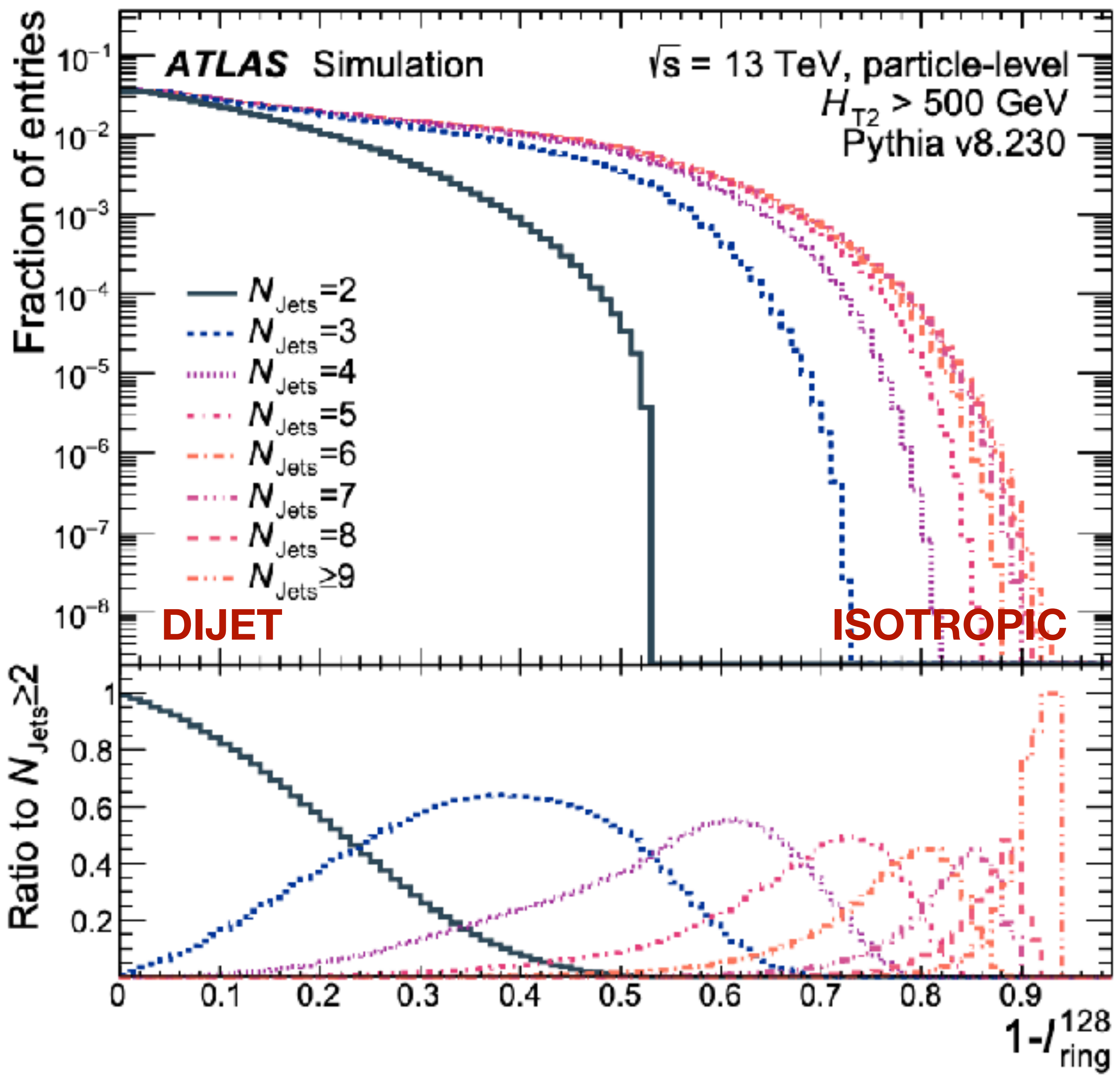
Event Isotropy & ATLAS (Simulation)

EMD2 ~ Thrust



1-Isotropy



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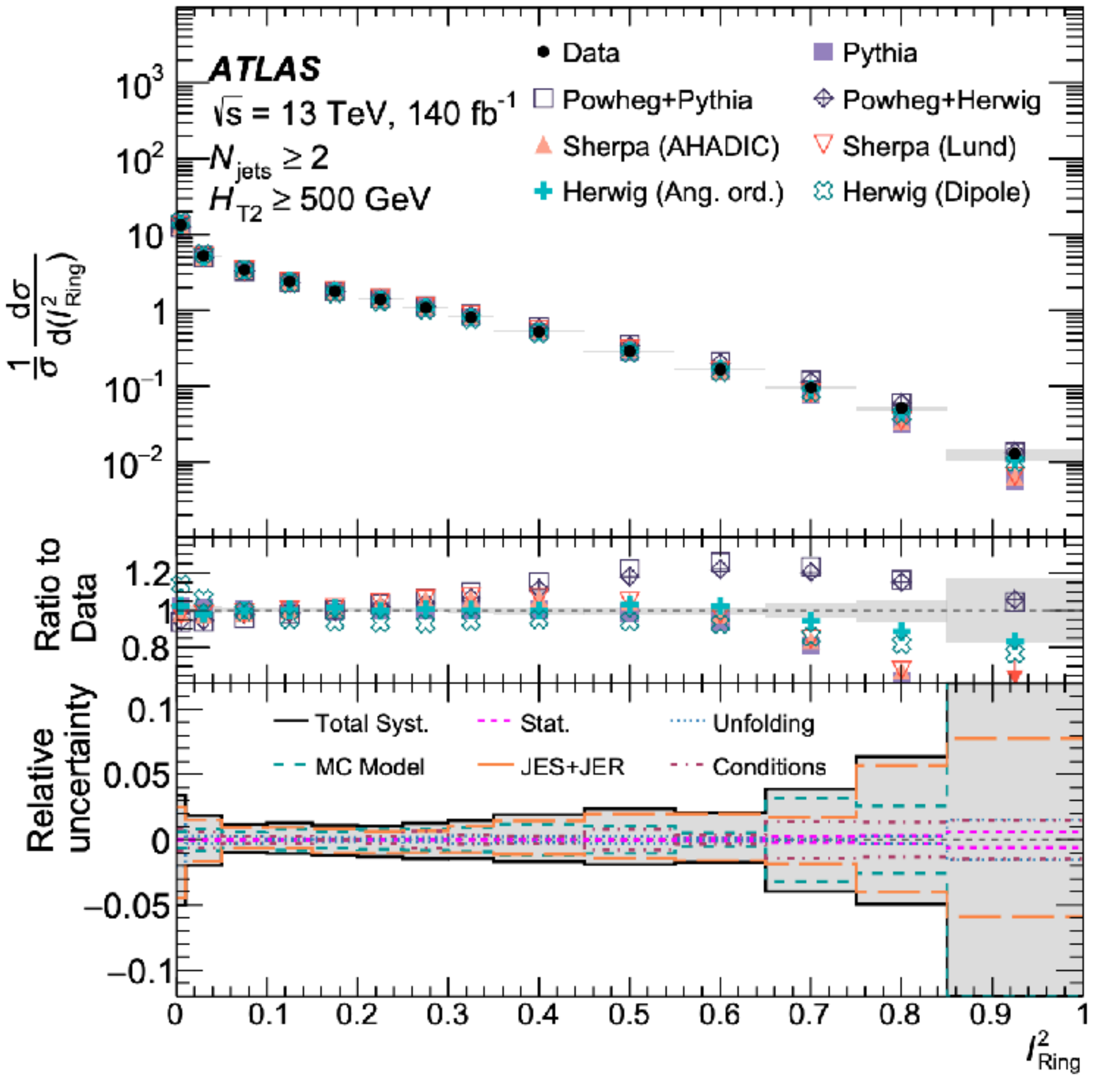
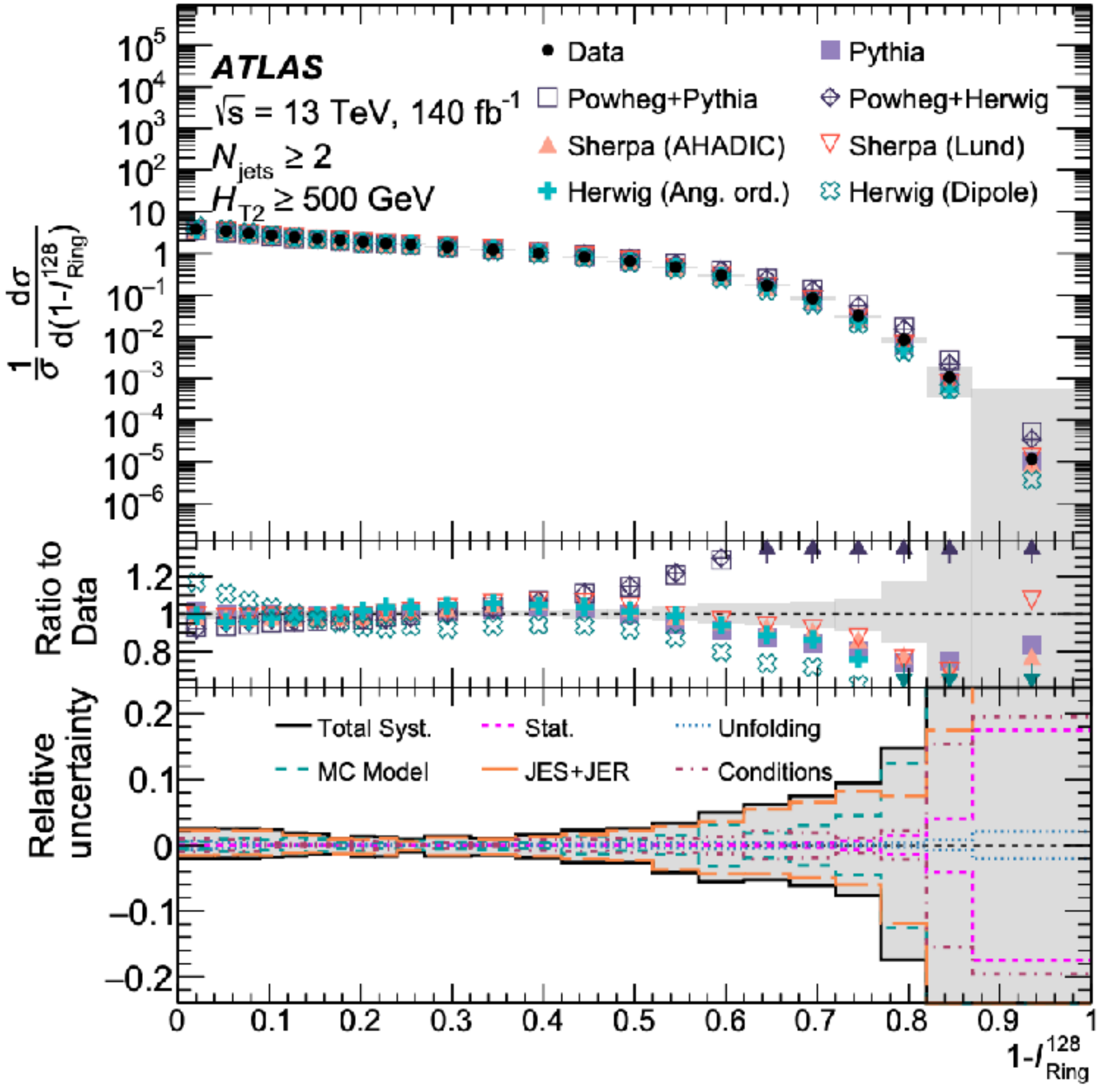
Event Isotropy & ATLAS

EMD2 ~ Thrust



1-Isotropy



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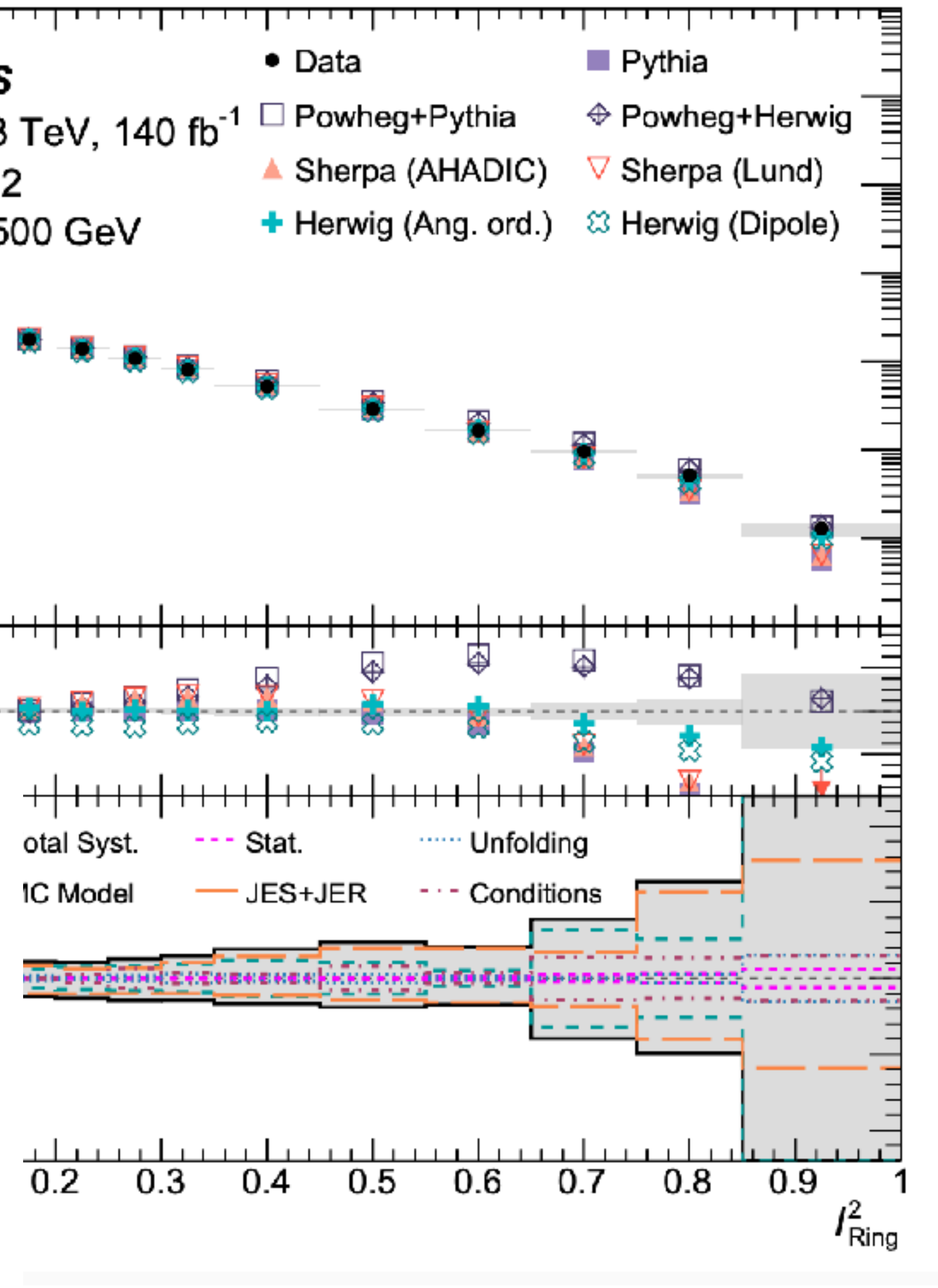
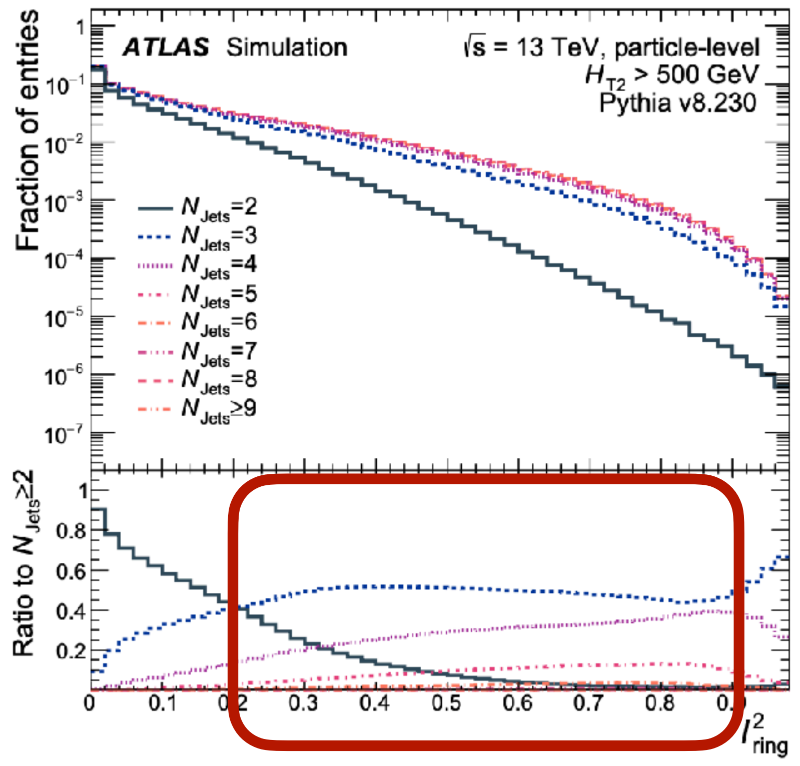
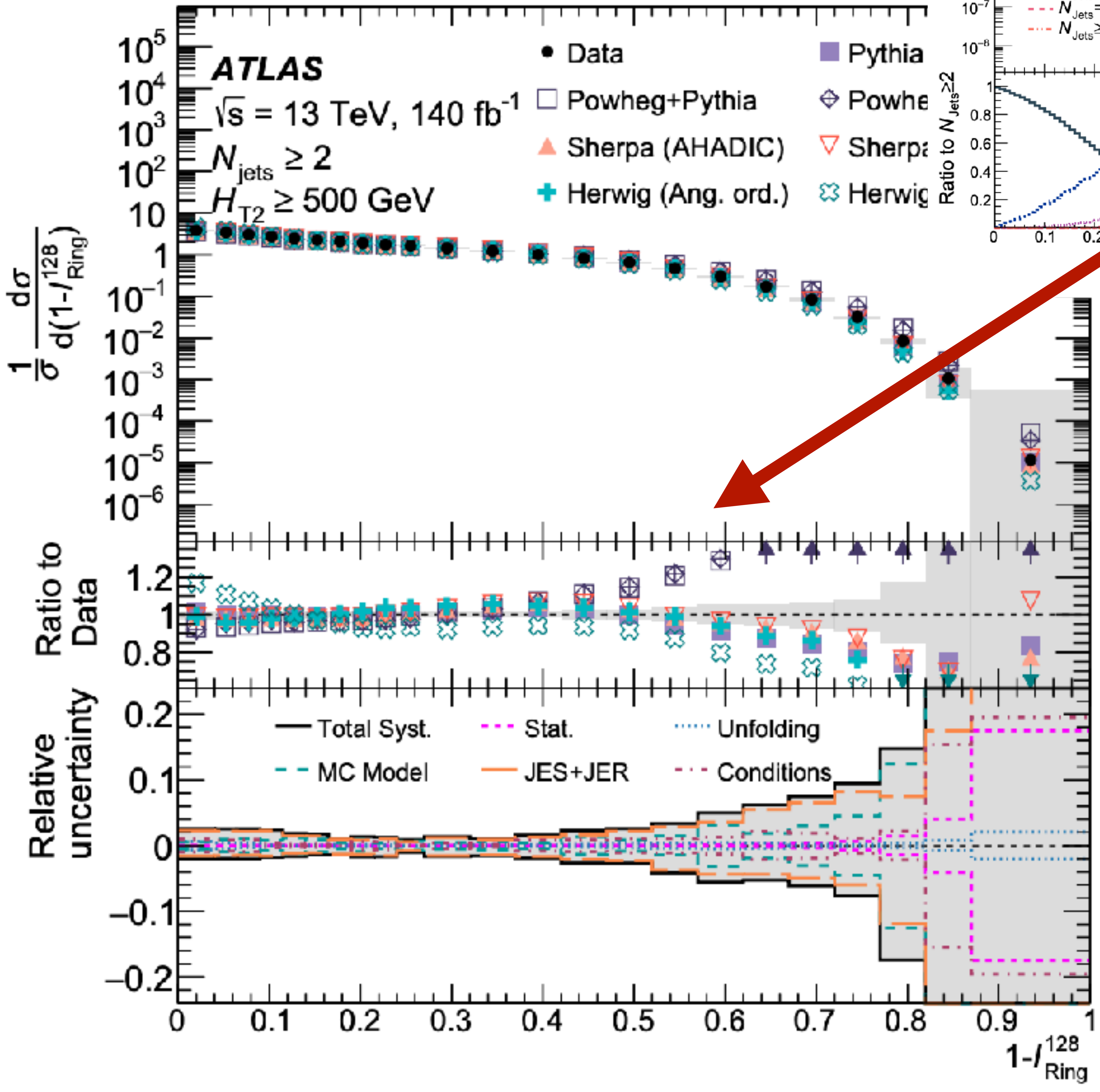
Event Isotropy & ATLAS

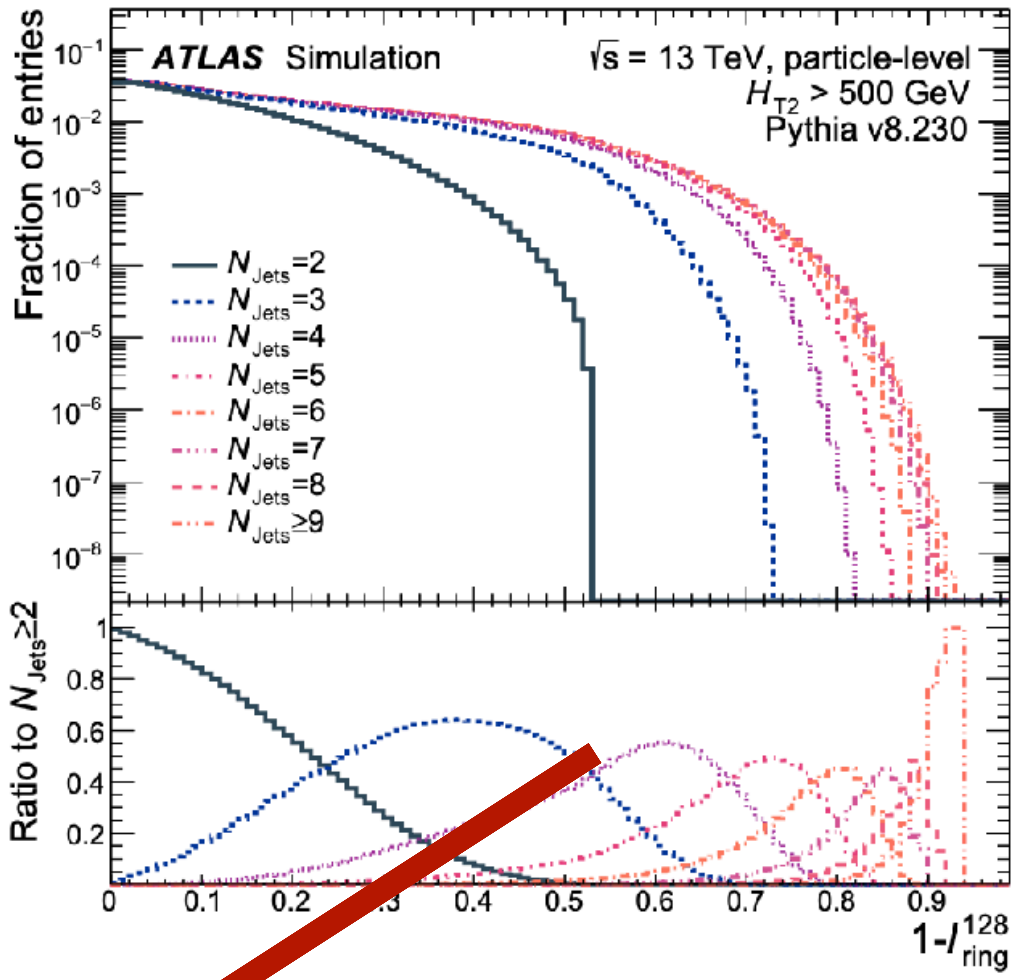
EMD2 ~ Thrust

1-Isotropy









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Event Isotropy & ATLAS

With event isotropy we are more sensitive to rare events, even in QCD dynamics!

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Event Isotropy & Your Analysis

Let's consider more geometries
& distance metrics

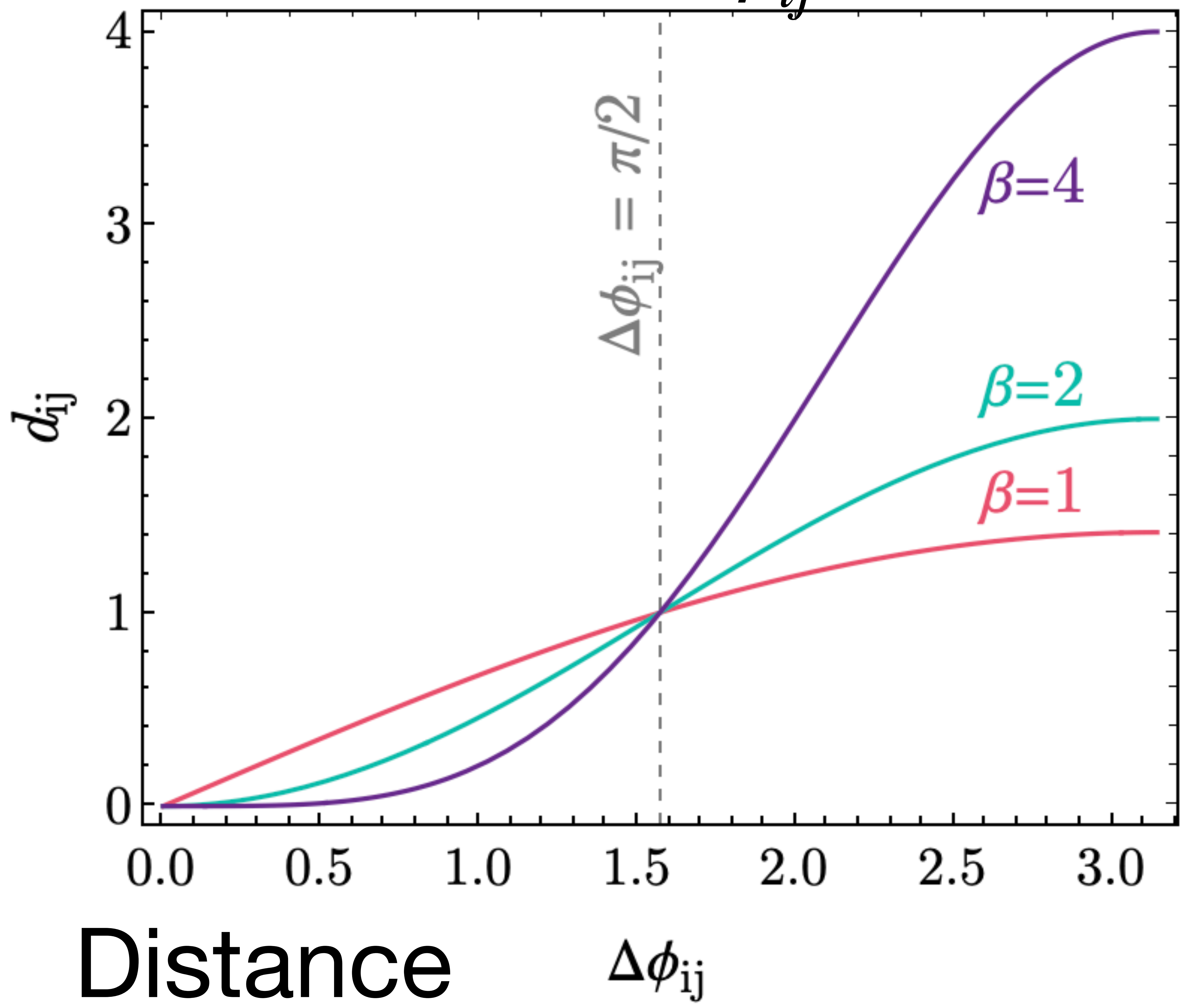
Design the observable best for your analysis

Event Isotropy & Your Analysis

E.g. Transverse plane

Geometry

$$(1 - \cos \phi_{ij})^{\beta/2}$$



Distance

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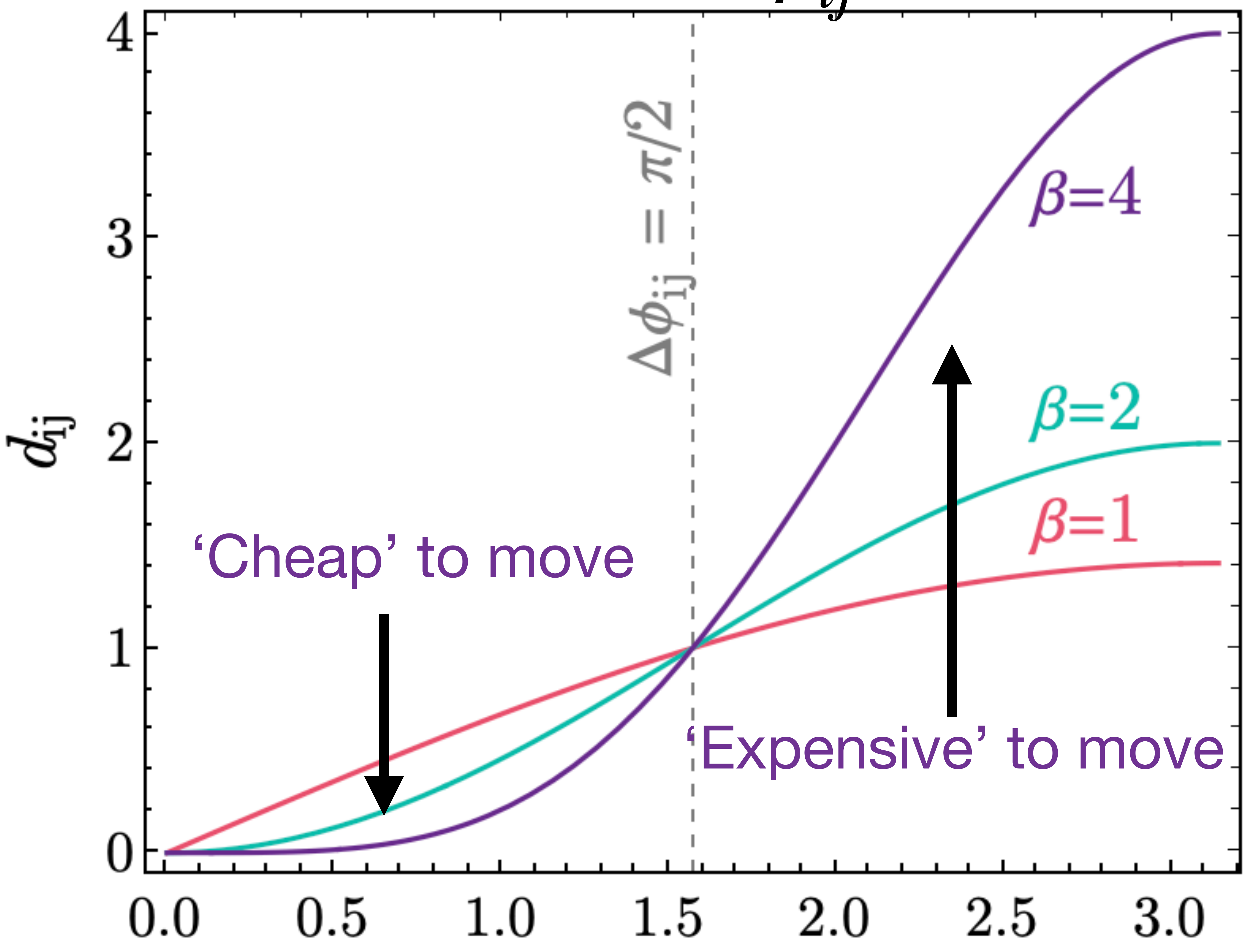
Event Isotropy & Your Analysis

E.g. Transverse plane

Geometry

$$(1 - \cos\phi_{ij})^{\beta/2}$$



Distance $\Delta\phi_{ij}$

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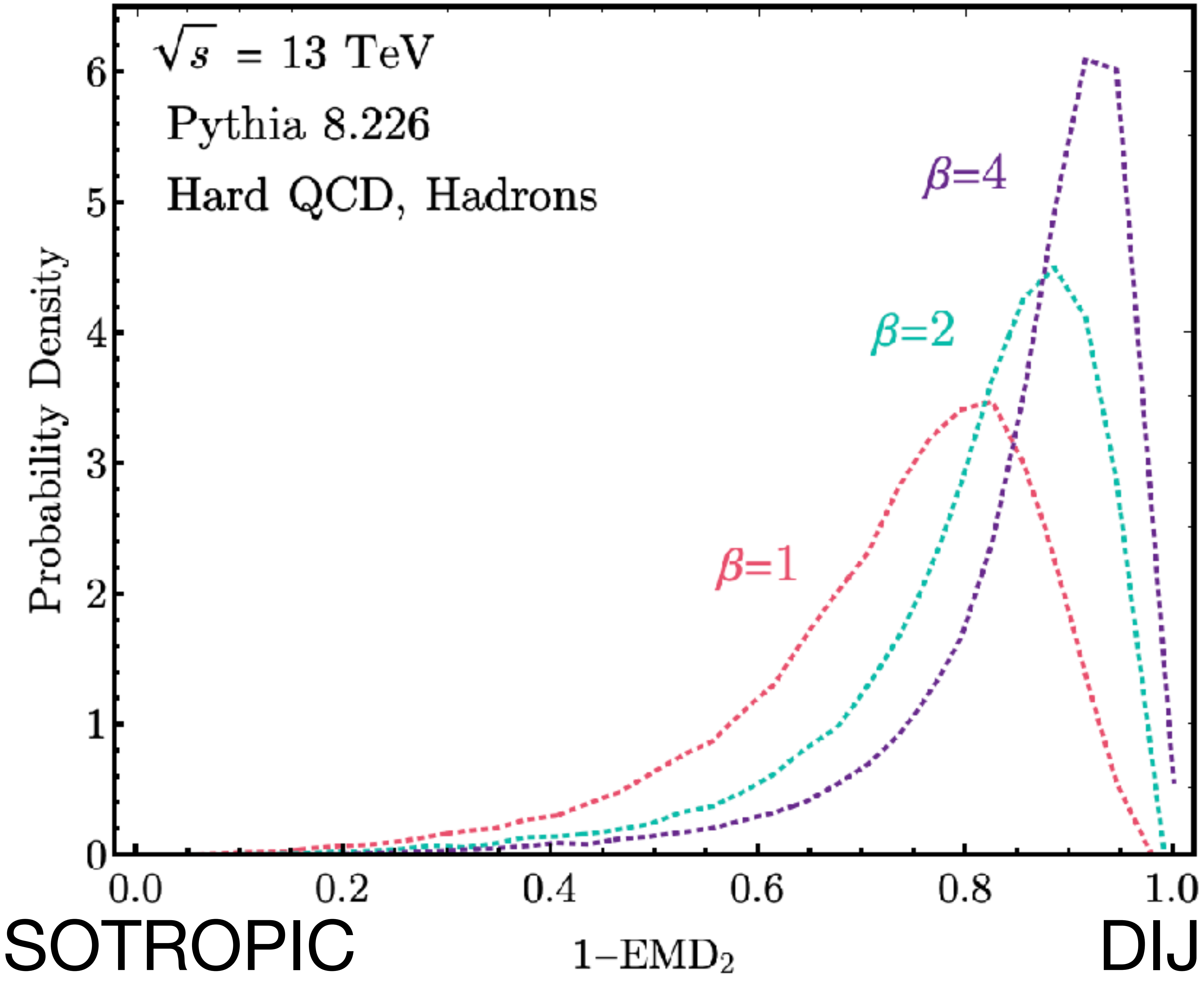
Example: Hard QCD at 13 TeV

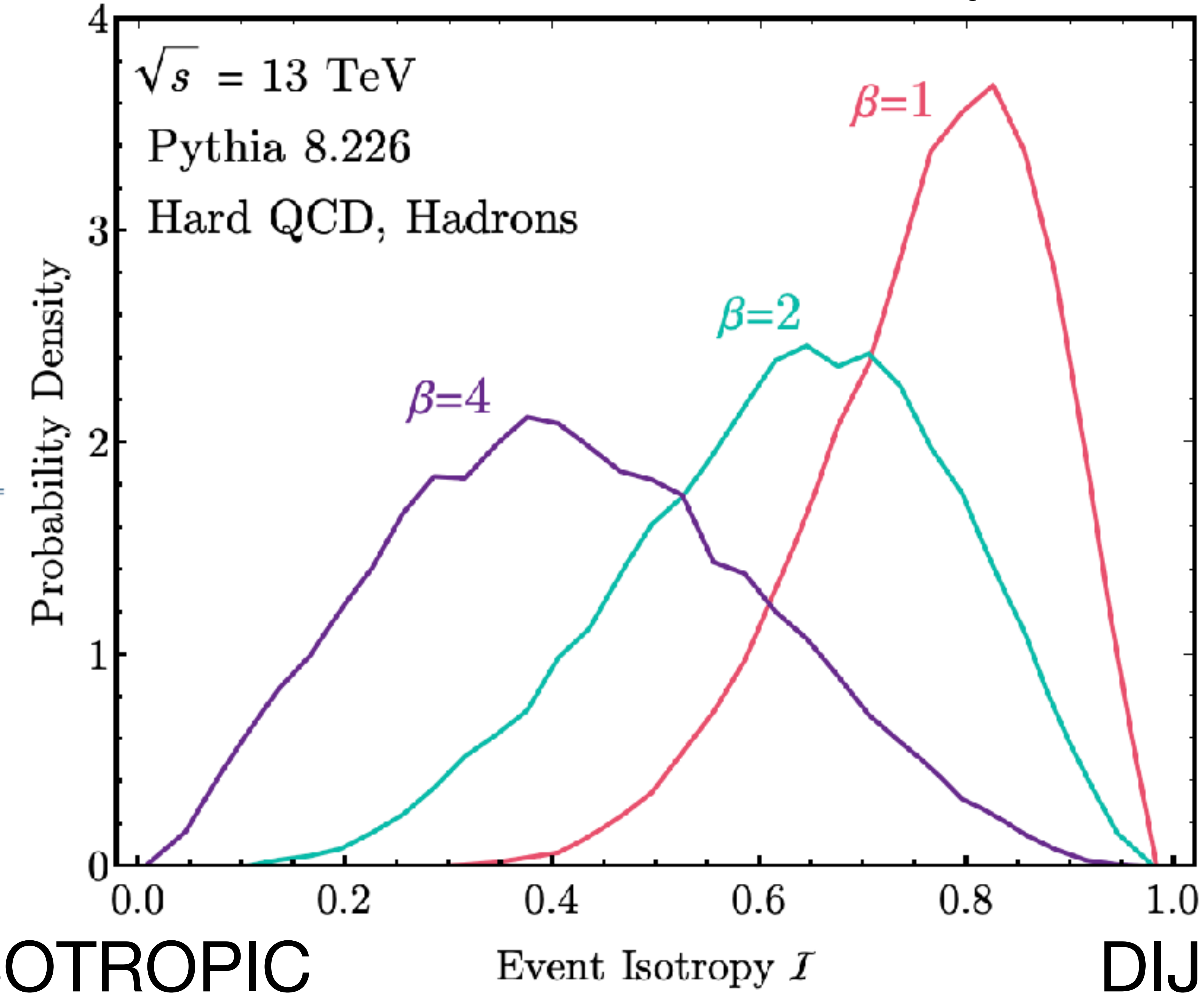
$$(1 - \cos\phi_{ij})^{\beta/2}$$

Distance to Dijet



ISOTROPIC DIJET

Distance to Isotropy



ISOTROPIC DIJET

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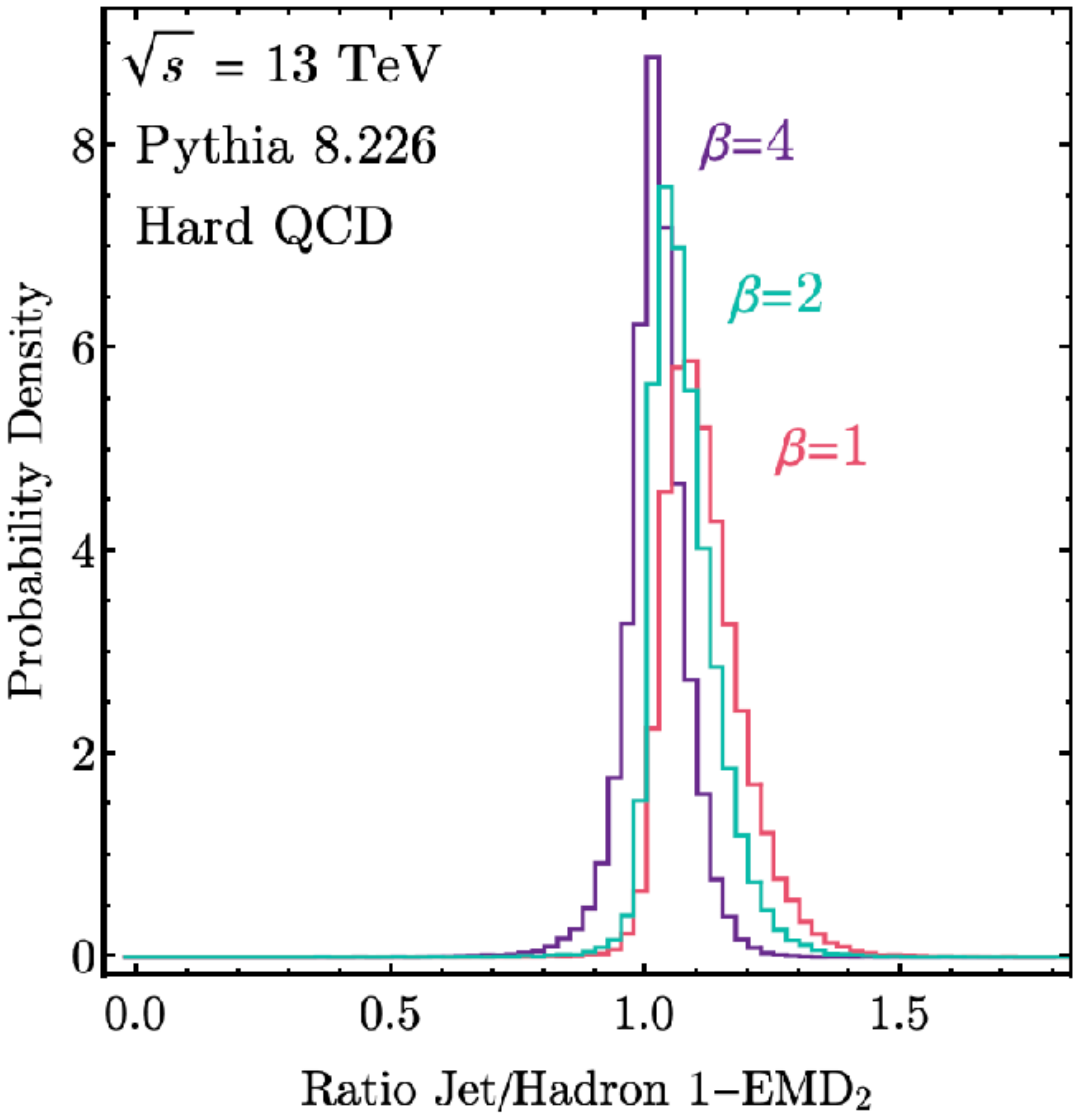
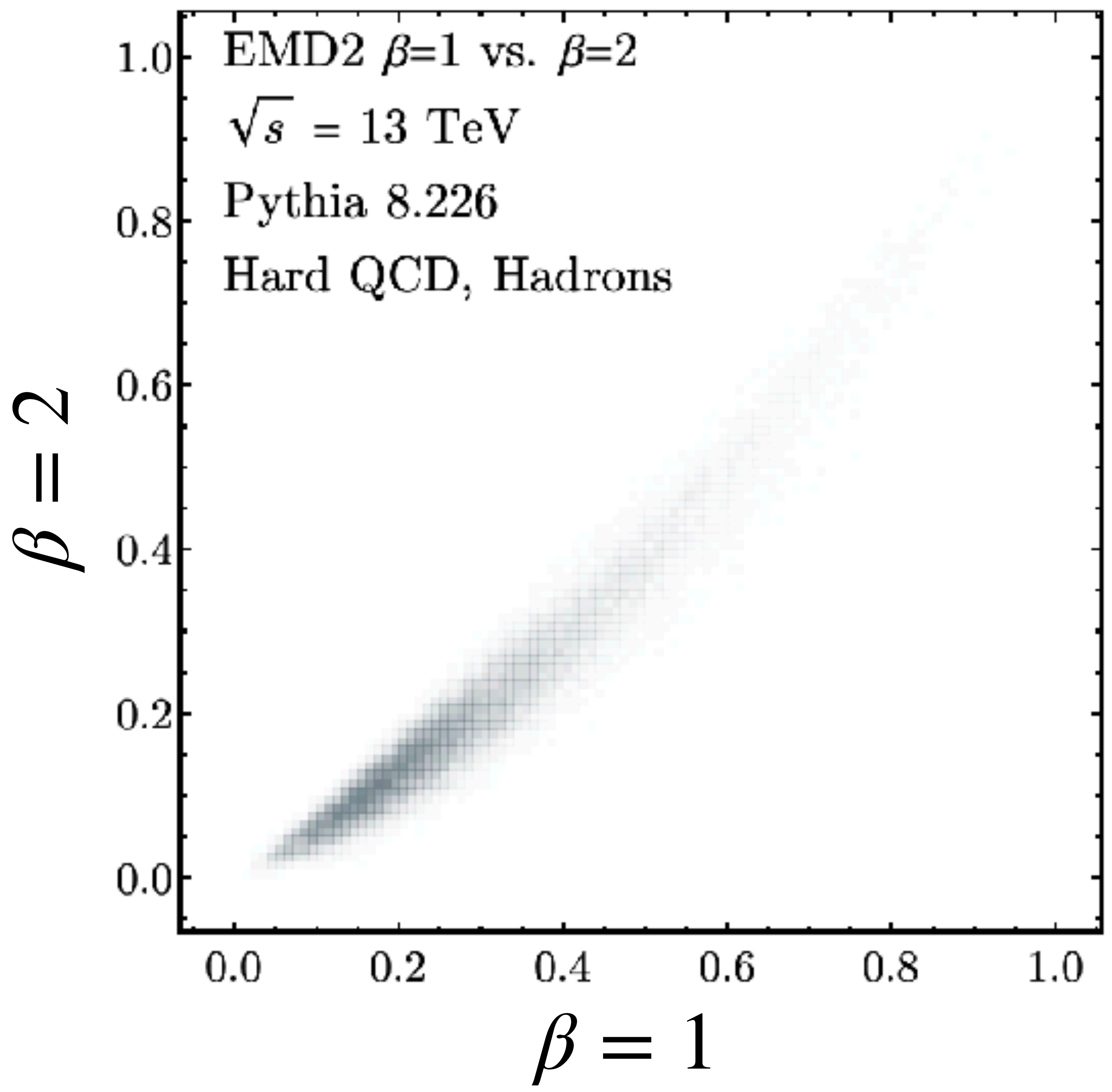
Example: Hard QCD at 13 TeV

$$(1 - \cos \phi_{ij})^{\beta/2}$$

Sensitivity to Jet Radius

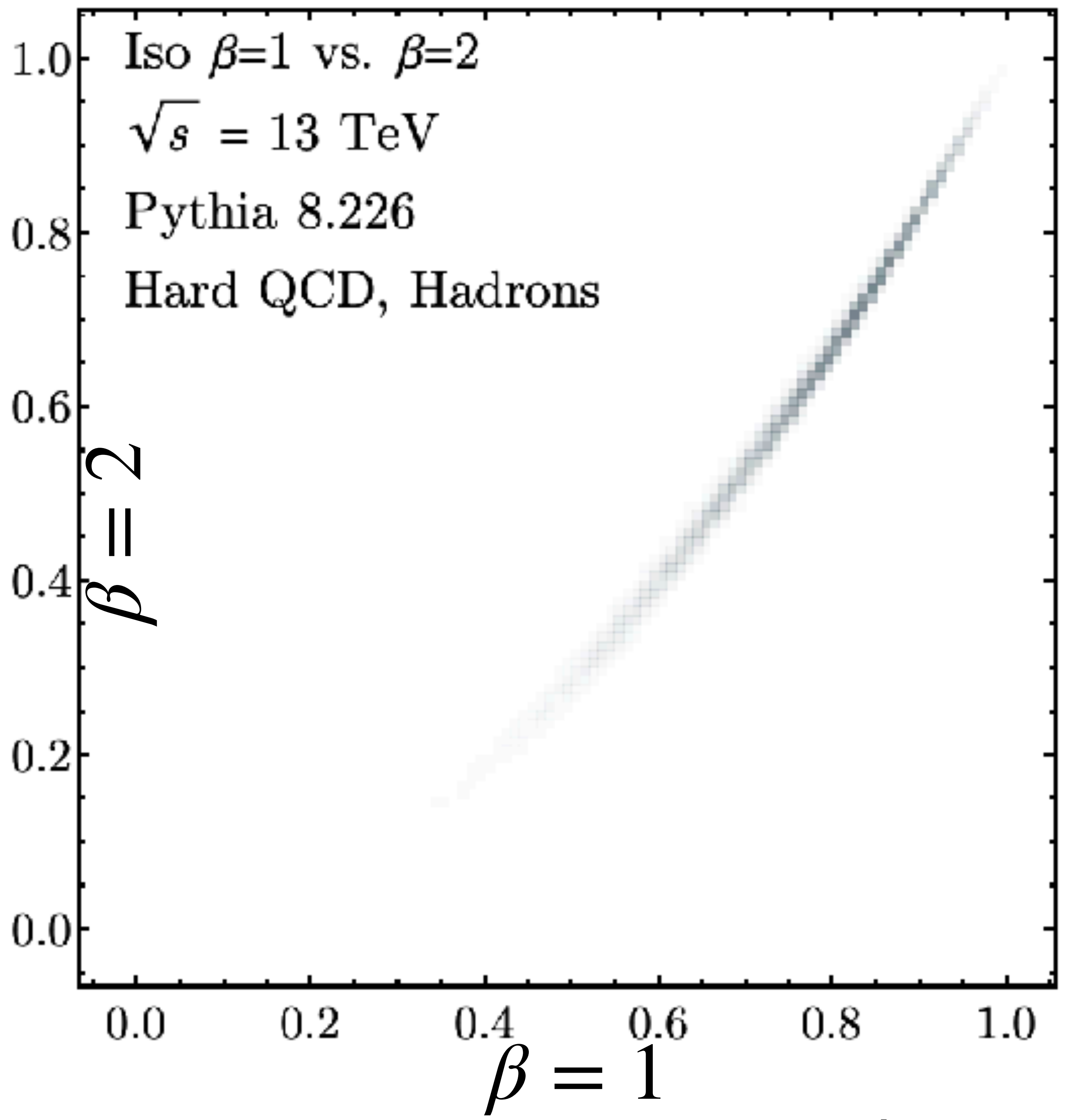


2D Distributions



EMD2

Isotropy



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Outlook

EMD-observables can reveal novel information in hard-to-access kinematic regimes while still understanding analytics

Applicable for BSM event shapes & QCD

The construction of the observable can determine what you are and are not sensitive to, depending on what your analysis or pheno study needs