Computer vision: prompt vs displaced

Based on

Discrimination between prompt and long-lived particles using convolutional neural network

BB, Swagata Mukherjee and Rhitaja Sengupta.

e-Print: arXiv:1904.04811

Biplob Bhattacherjee

Centre for High Energy Physics

Indian Institute of Science, Bengaluru, India

Searching for long-lived particles at the LHC: Fifth workshop of the LHC LLP Community, CERN, 28th May 2019

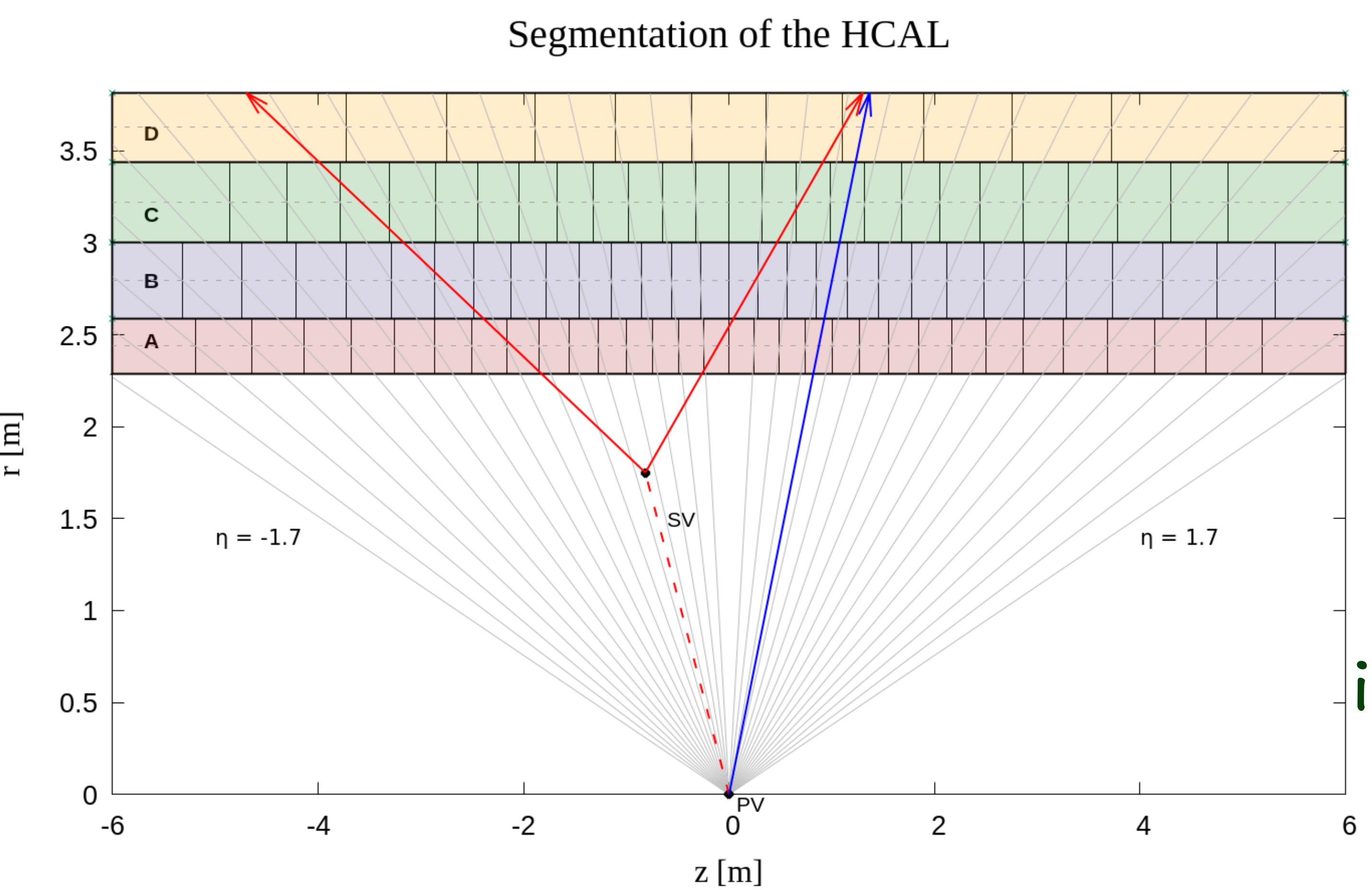
Motivation

Many well motivated models where long lived particle(LLP) can decay to quarks or gluons (direct decay or indirect decay through SM particles)

Is energy deposition pattern of displaced jets different from jets originating from the primary vertex ?

If yes => significant difference or small ?

Jets from LLP : energy deposition pattern



mismatch of particle's eta-phi with calorimeter

(similar feature is used for the identification of non-pointing photon)

Jets consist of many particles:

effect more prominent or washed out ?

Another problem : HCAL has coarser resolution than ECAL

Fast detector simulation

Standard analysis?

- Standard displaced jets analysis of ATLAS and CMS loses sensitivity with increasing distance of the secondary vertex — different energy deposition patterns in the HCAL compared to the standard pattern of prompt jets make reconstruction of displaced jets challenging.

Fast Detector Simulator?

- Actual segmentation of the calorimeter needed for observing features associated with displacement of a particle. Fast detector simulation (e.g., `Delphes`) has $\eta - \phi$ segmentation of the calorimeters but no layered calorimeter structure and no segmentation in the physical z direction.

Models

- Scenario I: Jets coming from displaced Z

$$X(LLP) \to Z(SM) + Y(Invisible), \quad Z \to j\, j, \quad [m_X = 800 \text{ GeV}]$$

- Scenario II: Jets coming directly from decay of LLP

$$X(LLP) \to j\, j\, j, \quad [m_X = 100 \text{ GeV}]$$

Energy range: $(400, 500)$ GeV for both cases.
Both scenarios boosted enough to bring the displaced jets closer in the $\eta - \phi$ plane.

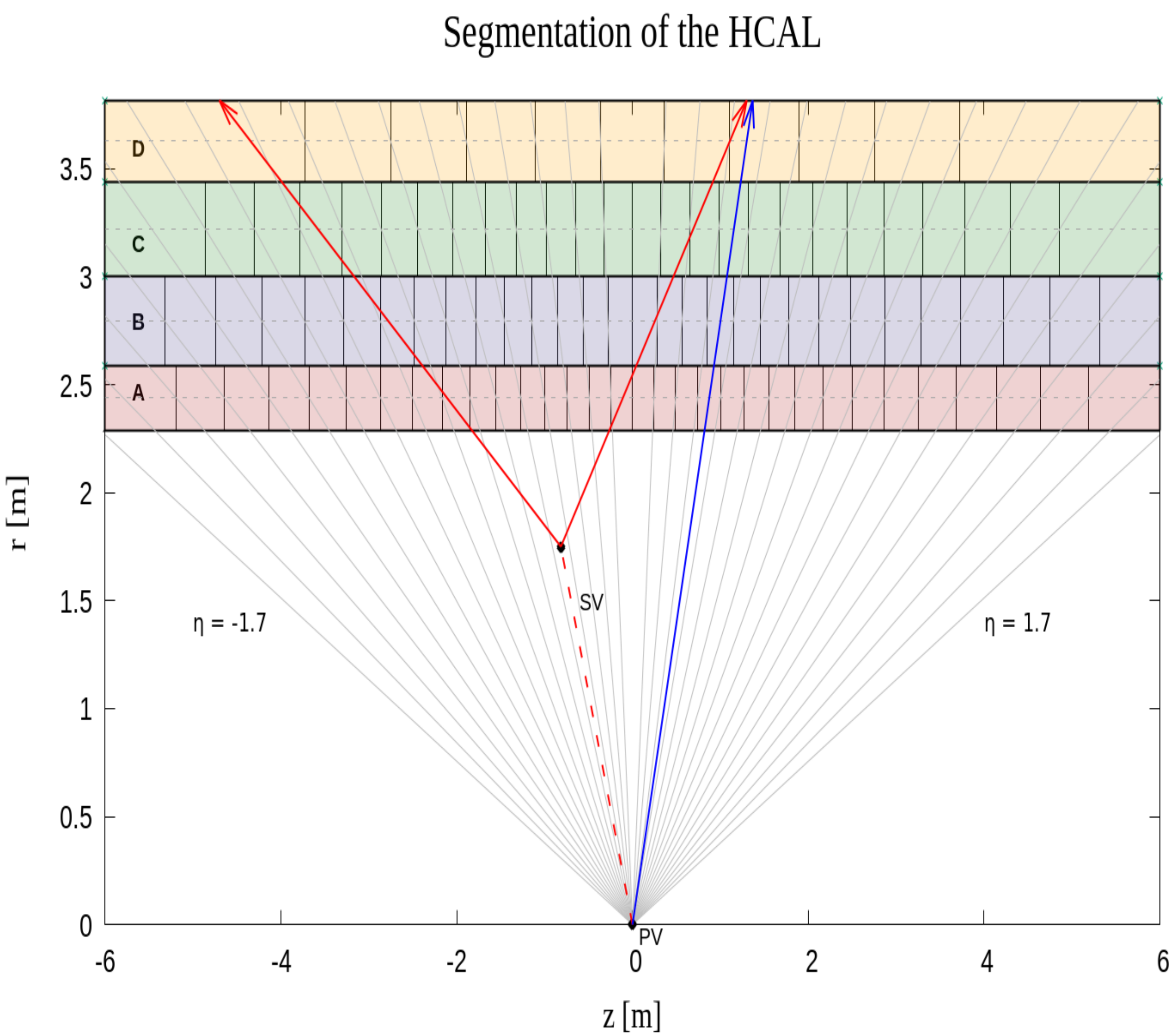
Also considered stopped particles decaying to quarks

Image generation: Any tower of the HCAL having energy deposit < 1 GeV is ignored.

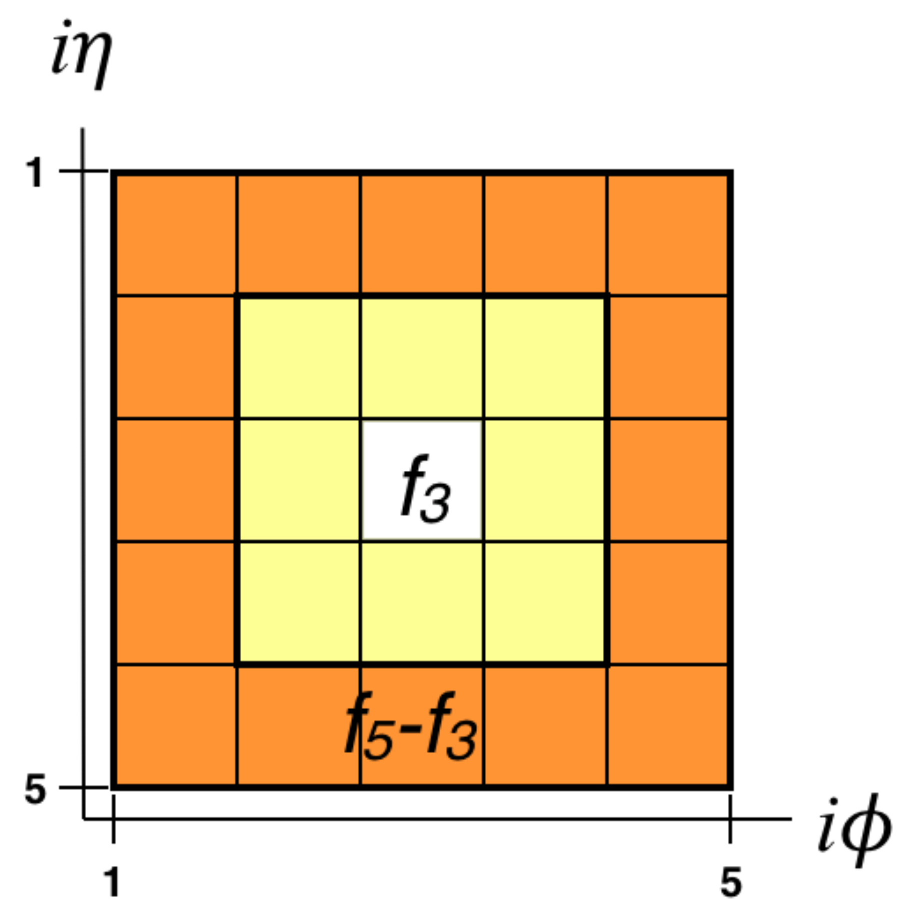
Normalise the energy in each tower of an event using the maximum energy deposited in the HCAL.

We store the energy deposition of an event as a 28×28 image with the energy depositions in each tower as intensity values of each pixel of the image with the highest intensity (energy) pixel at the centre of the $i\eta - i\phi$ plane.

simplified segmentation of HCAL



simulated a simplified version of the segmentation following Tile Calorimeter of ATLAS.

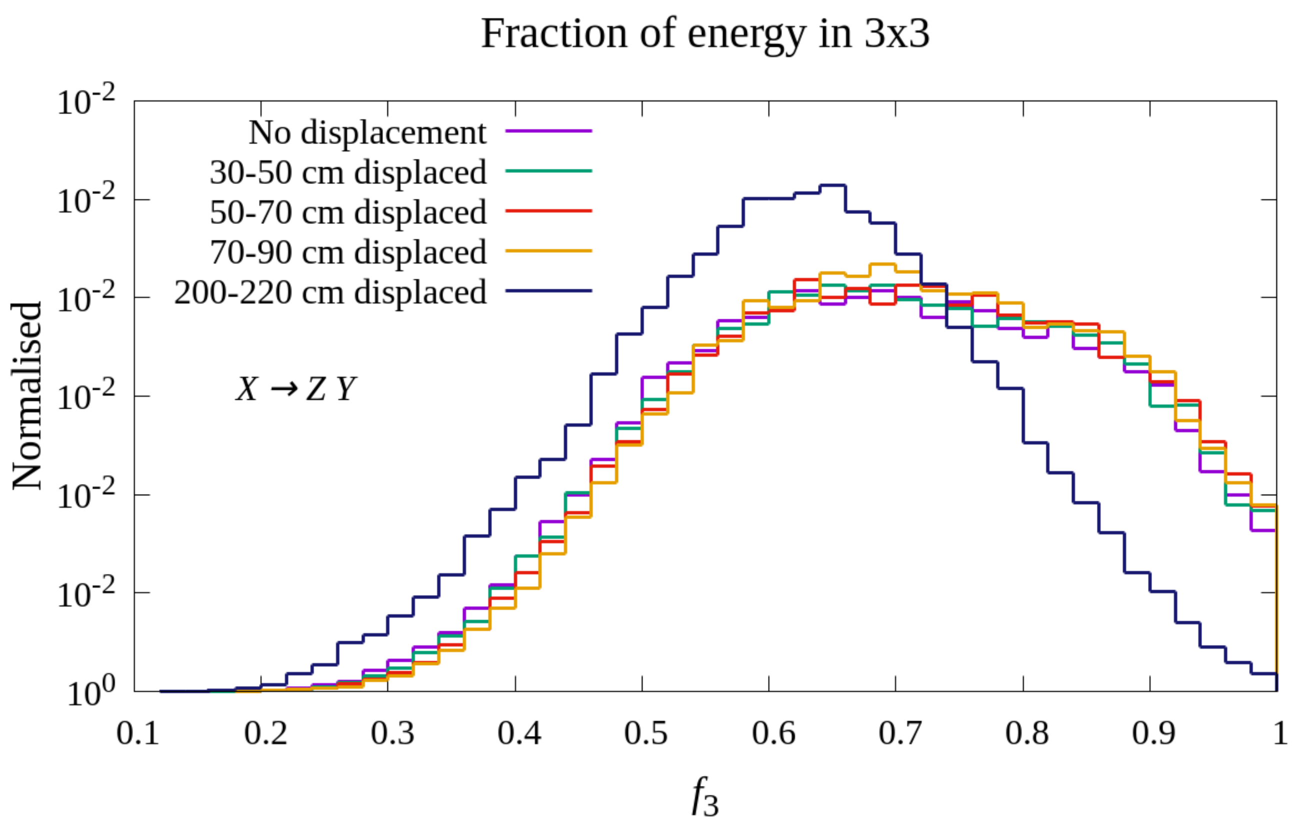


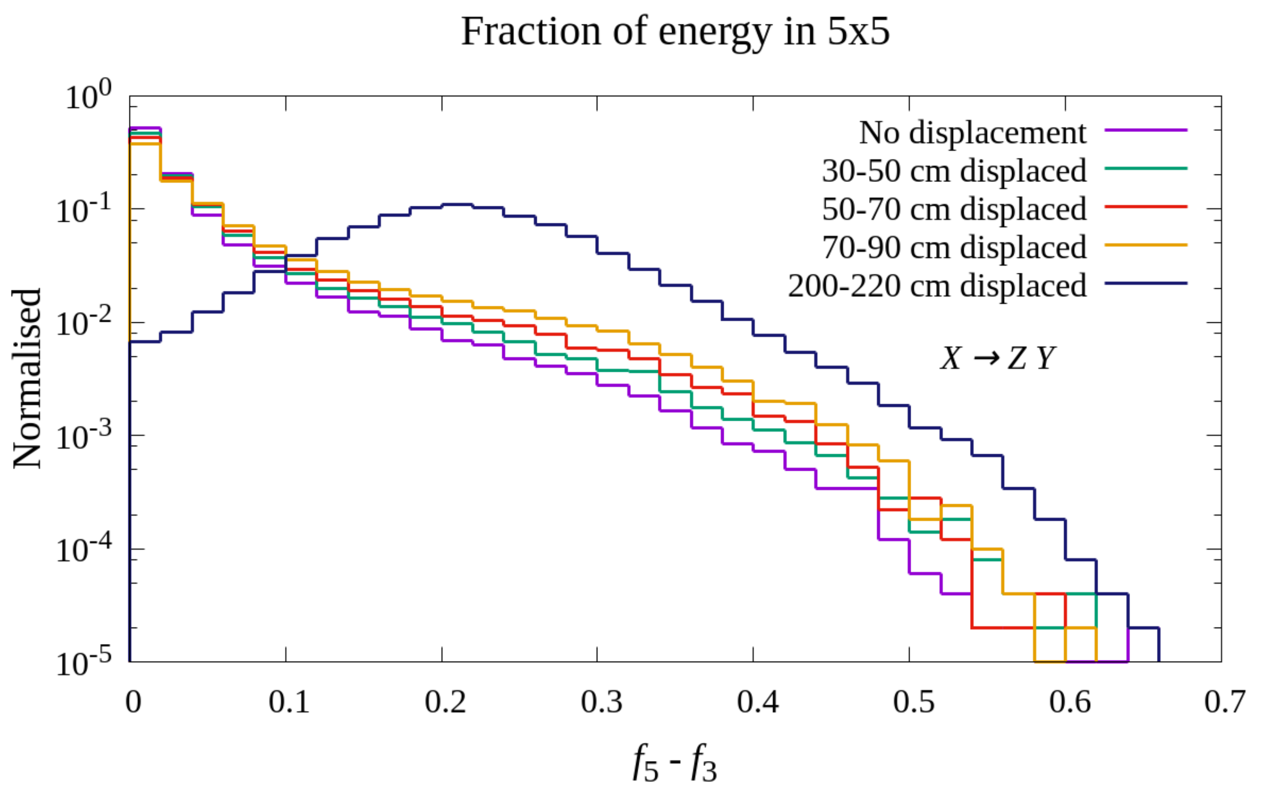
$$f_i = \frac{\text{Energy deposited in } i \times i \text{ block of the image}}{\text{Energy deposited in the full } 28 \times 28 \text{ image}}$$

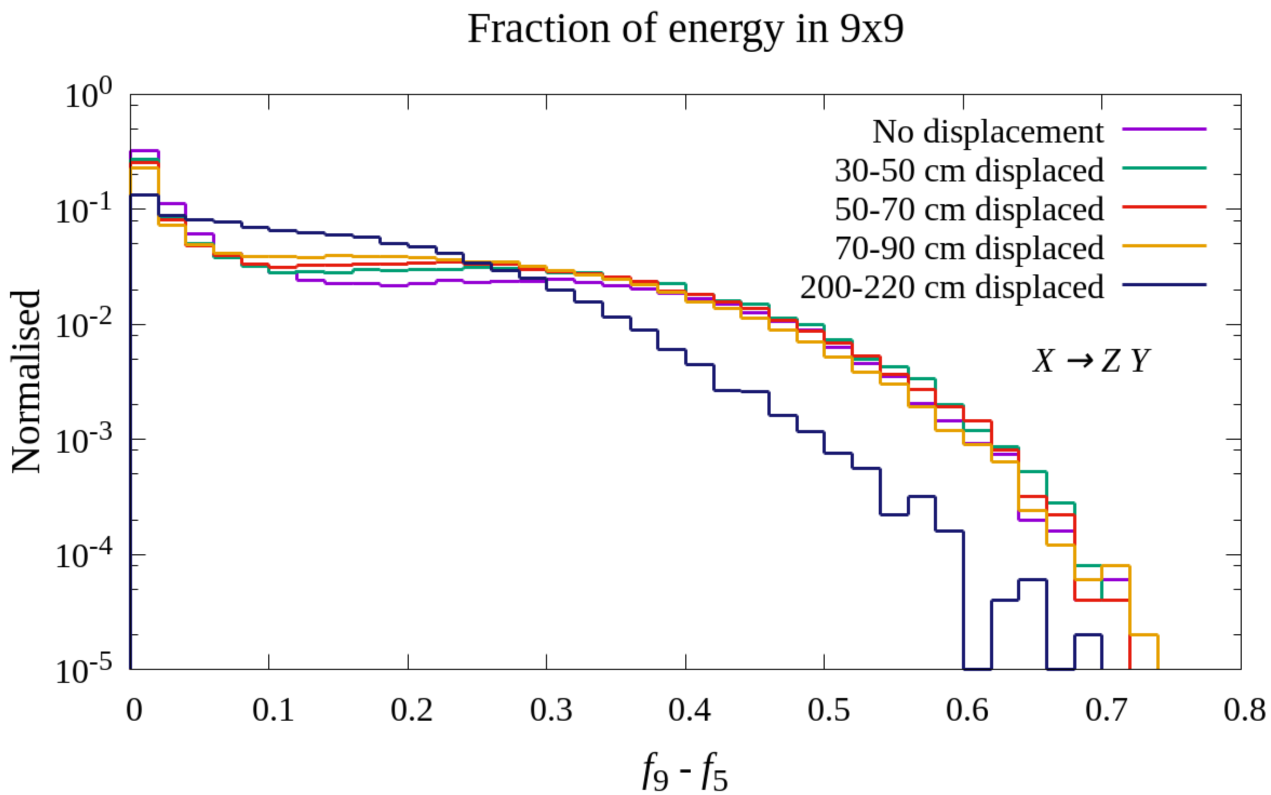
$$f_i, \quad i = 3, 5, 9, 11$$

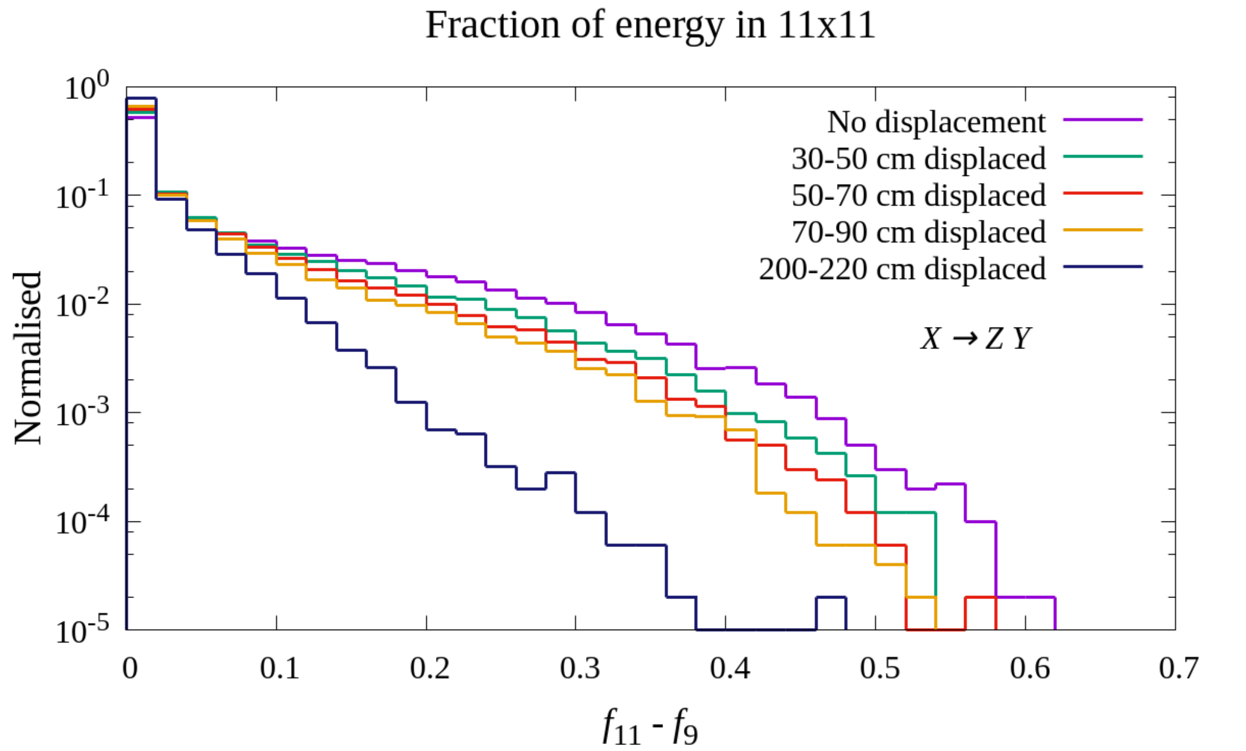
Scenario I : Energy deposition pattern

X(LLP)→Z(SM)+Y(Invisible), Z →j j



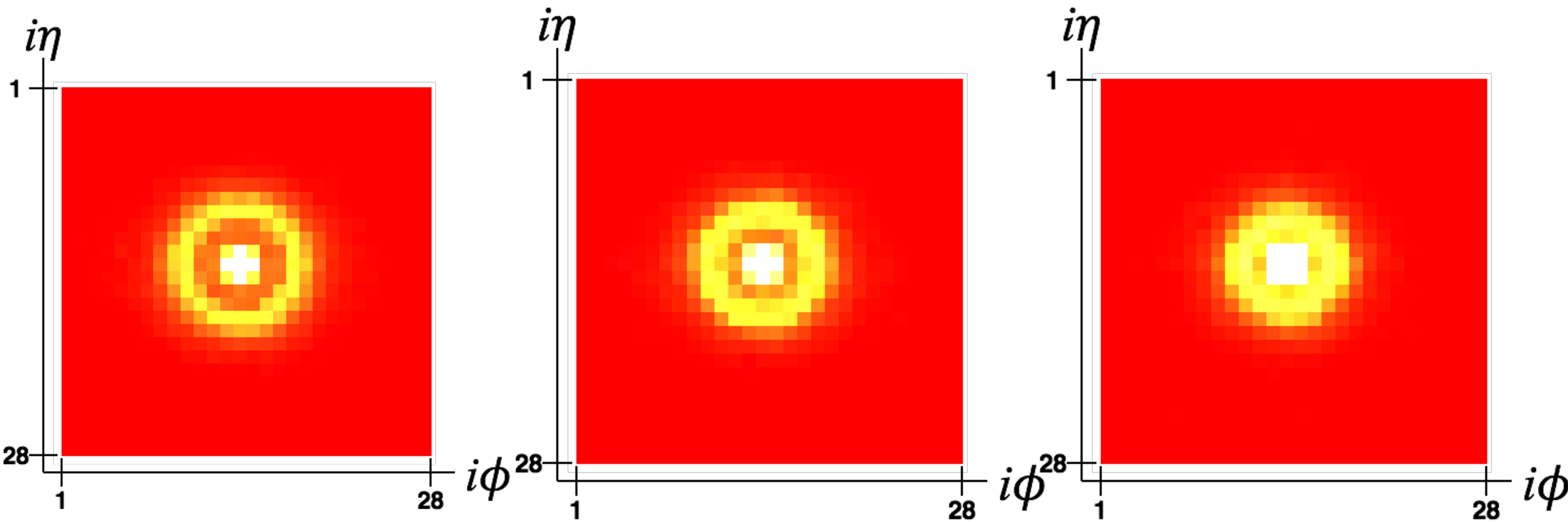






Displaced Z -> q $\bar{q}$

Average over 50K images



Z with no displacement

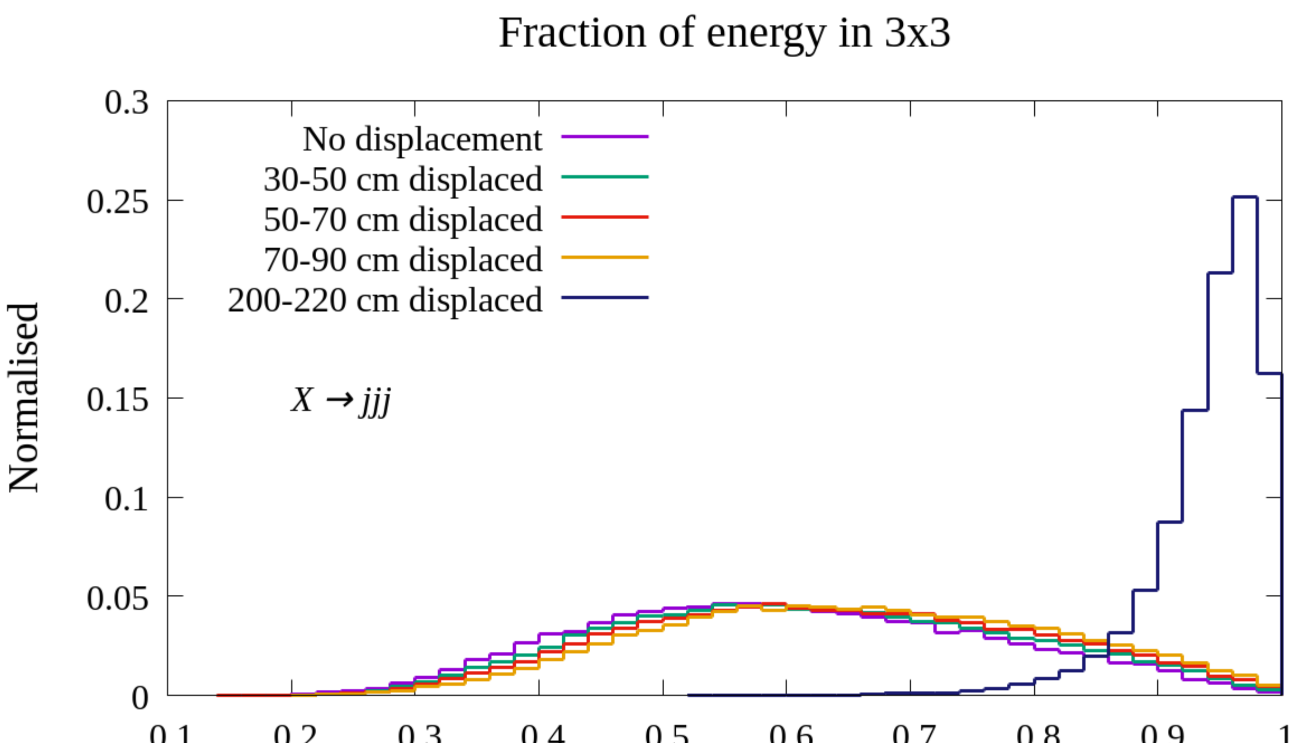
displaced Z 30<d_T<50 cm

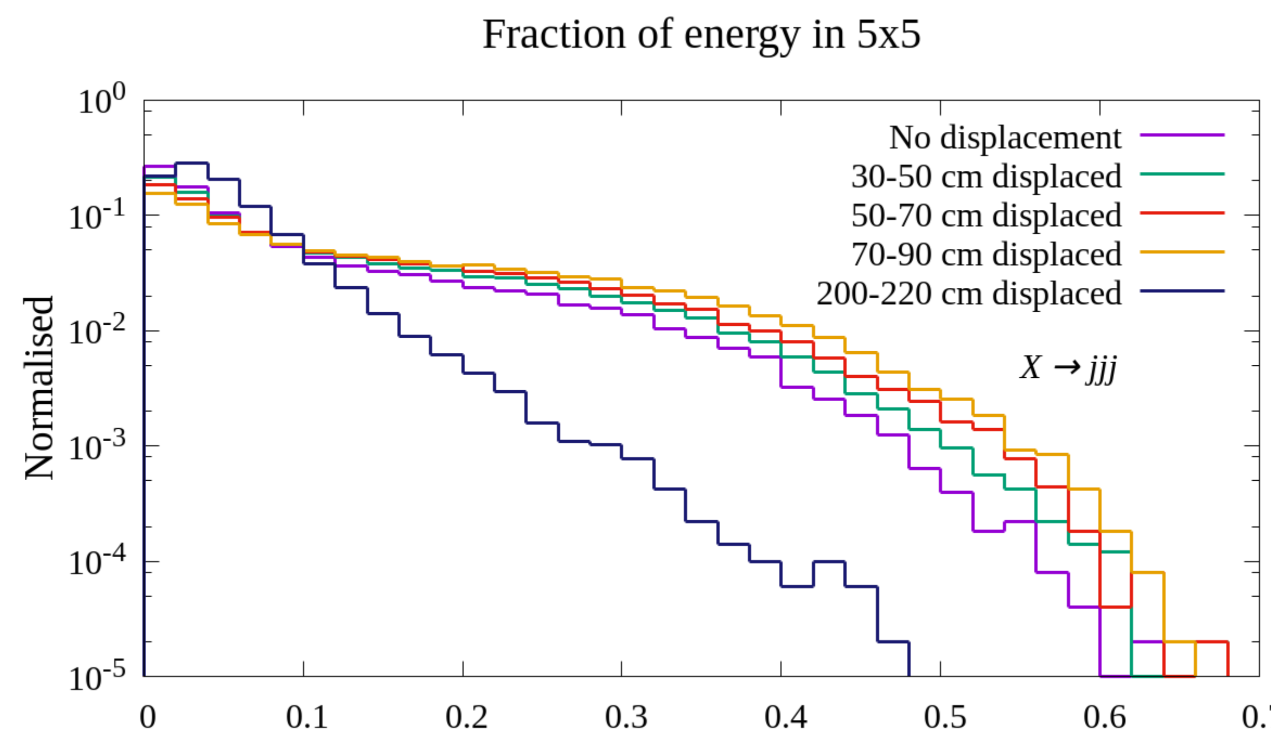
displaced Z 70<d_T<90 cm

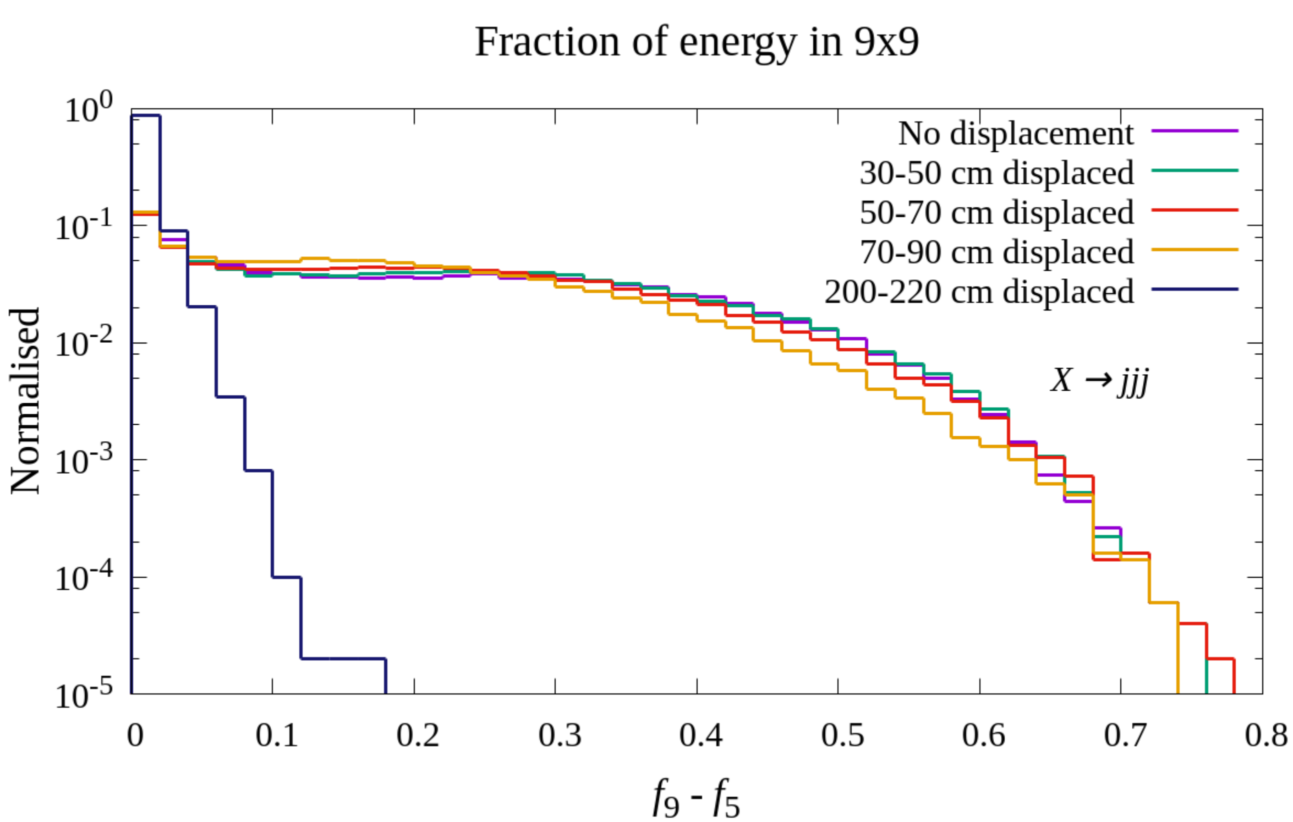
displacement in the transverse plane -> d_T

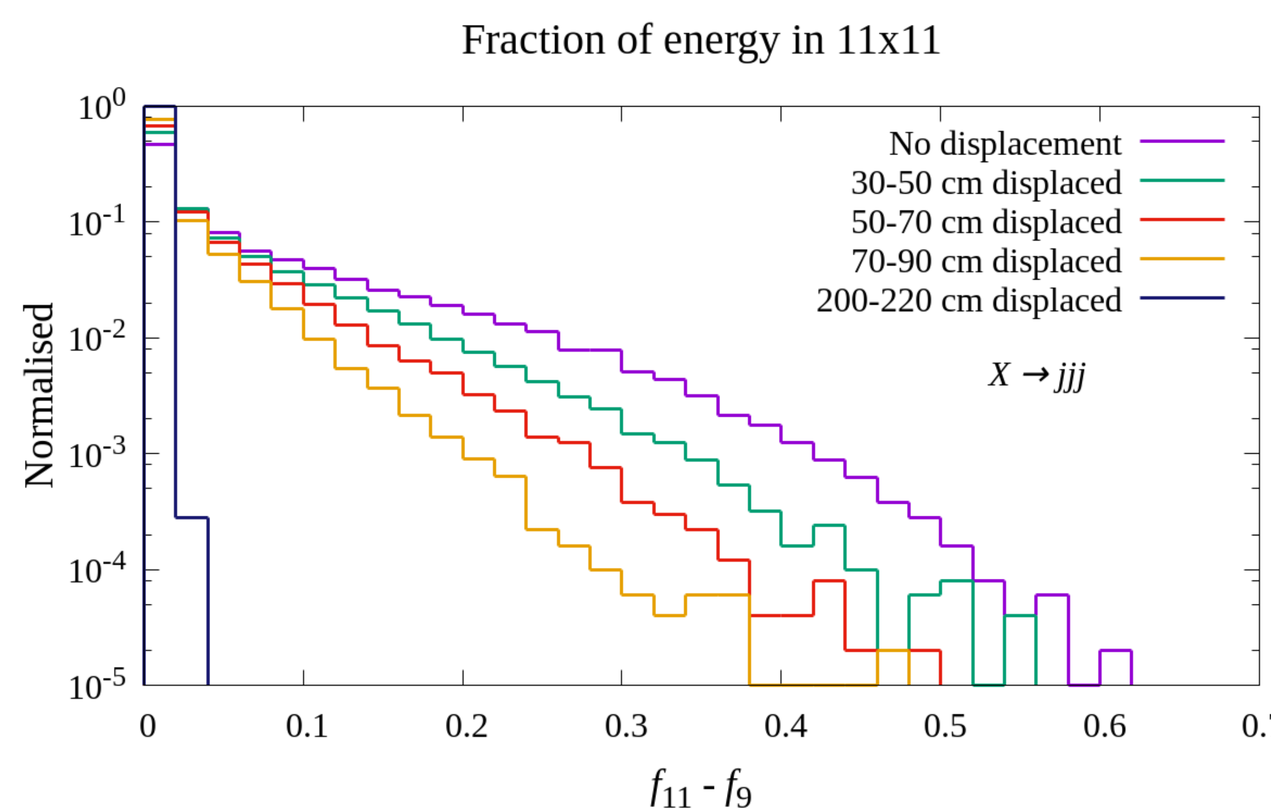
Scenario II: Energy deposition pattern

X(LLP)→j j j



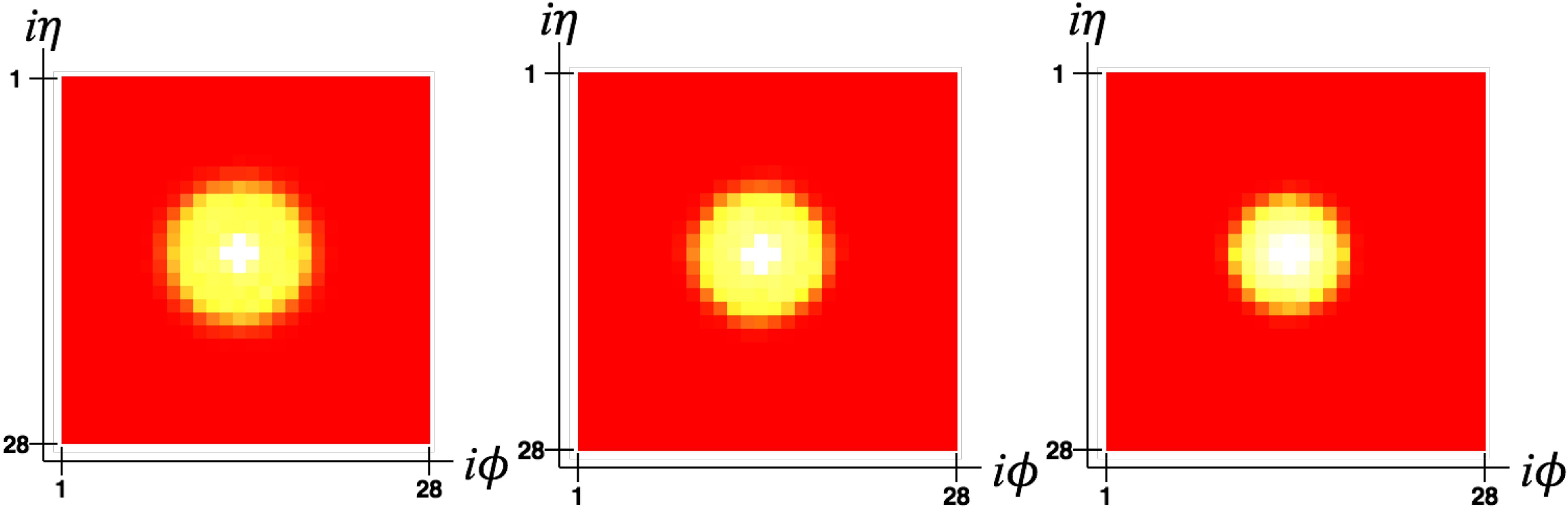






Displaced X -> q q q

Average over 50K images



X with no displacement

displaced X $30 < d_T < 50$ cm

displaced X $70 < d_T < 90$ cm

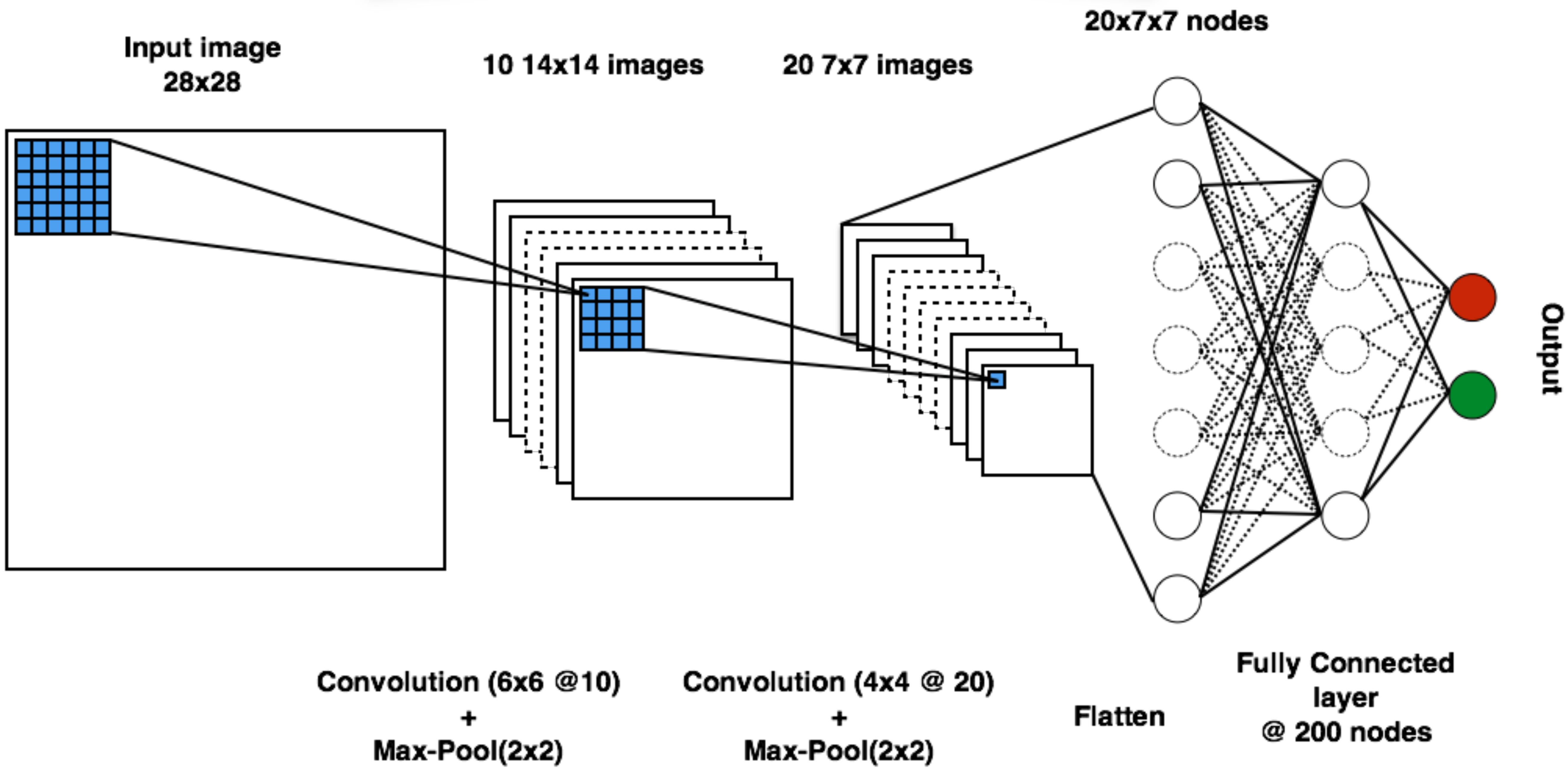
displacement in the transverse plane = > d_T

Observations

- **Elongated energy deposition in the HCAL**
  Mismatch of displaced particles' $\eta - \phi$ direction with standard calorimeter $\eta - \phi$ towers – energy deposition of displaced jets have more elongated patterns different from standard patterns of prompt jets

- **Total energy deposit more contained in the $i\eta - i\phi$ region**
  Physical segmentation of the detector (in z direction) increases with increasing radial distance – displaced jets from X have smaller energy deposit even if ΔR between them is same as in prompt decay

Neural network architecture

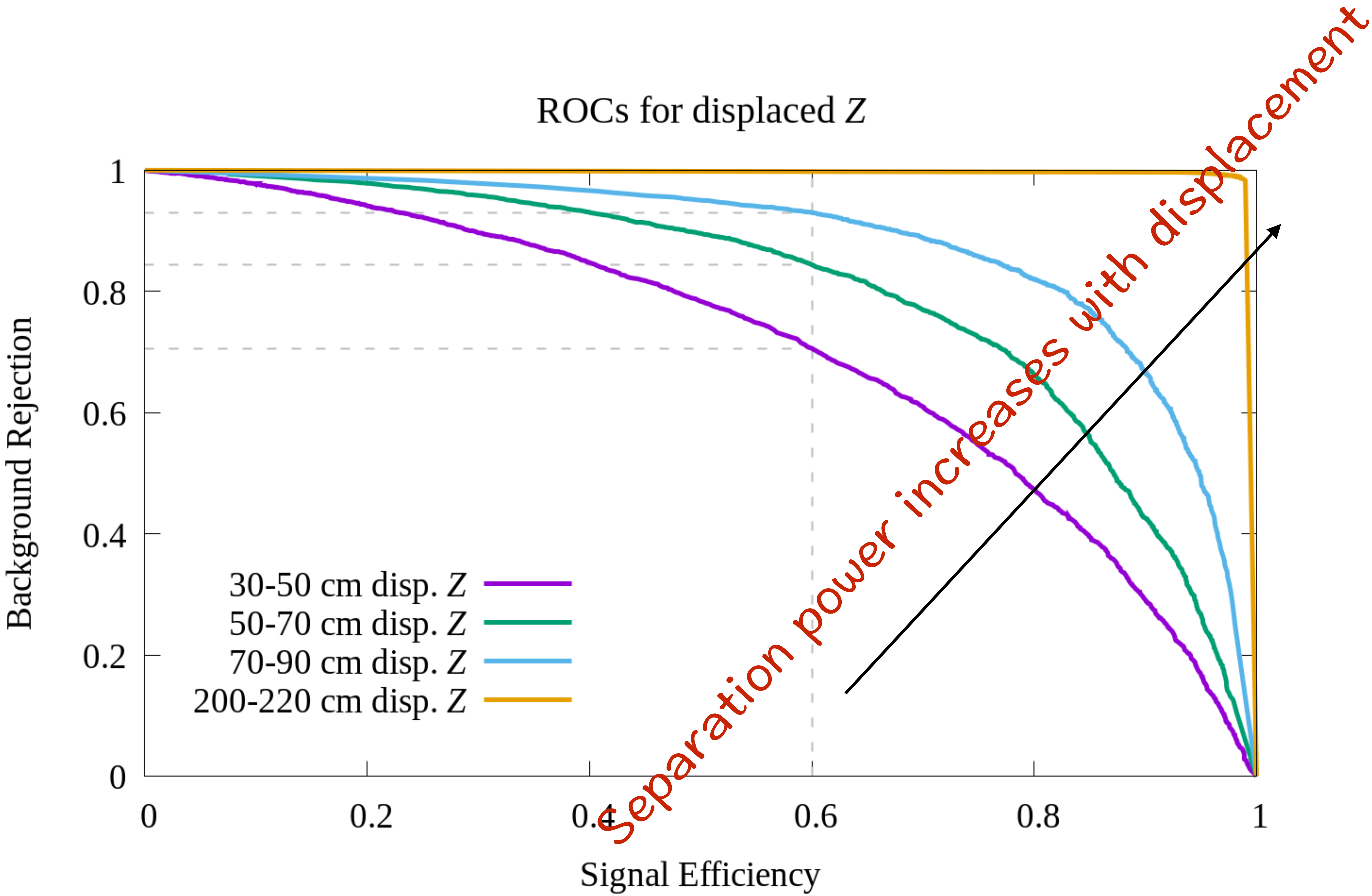


Adam Optimizer with a learning rate of 0.001 Batch size: 200, Dropout: 50%

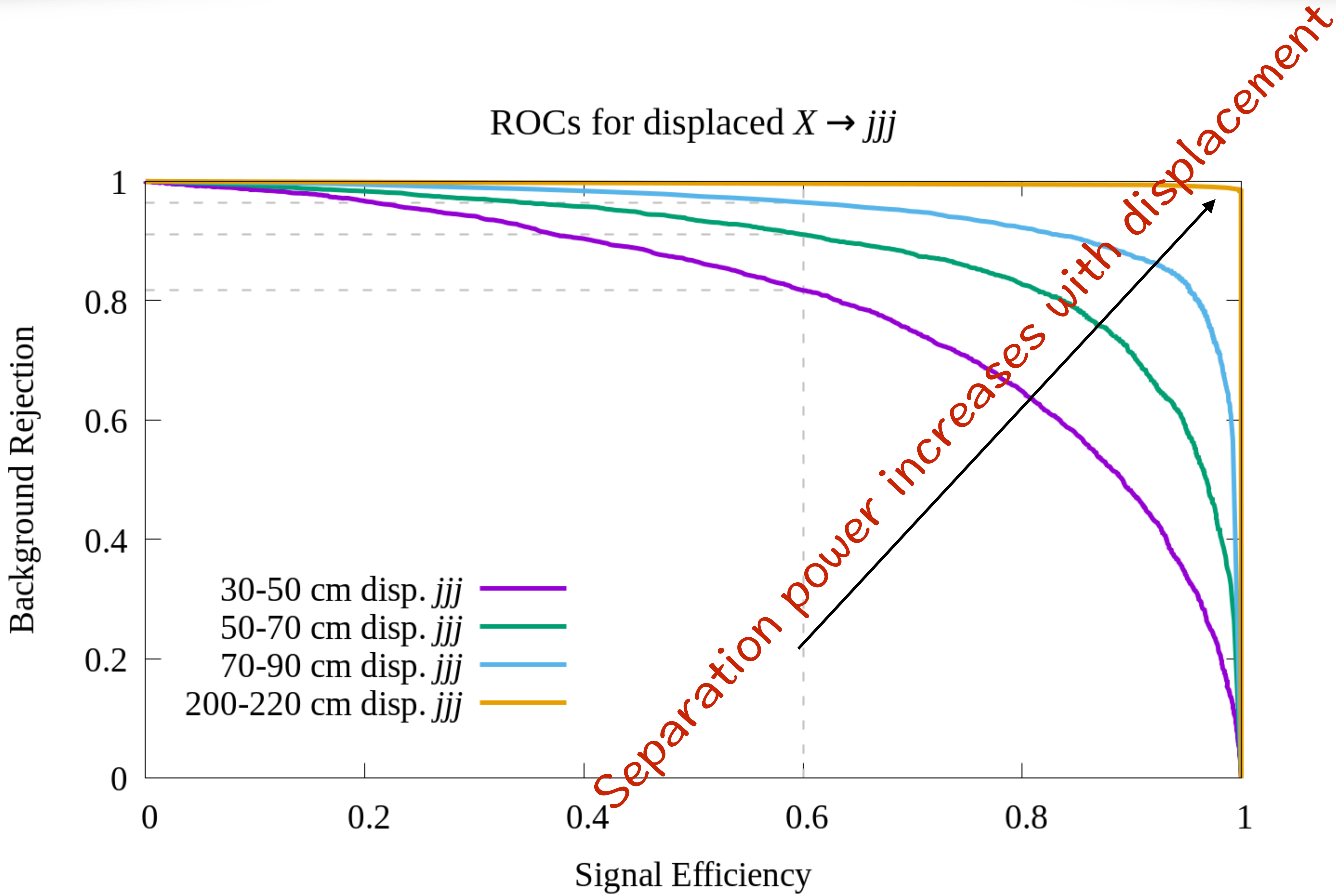
60,000 images for training, 20,000 for validation and another 20,000 for testing the network.

Training was stopped at the epoch with minimum validation loss.

Scenario I : discrimination between displaced vs non- displaced

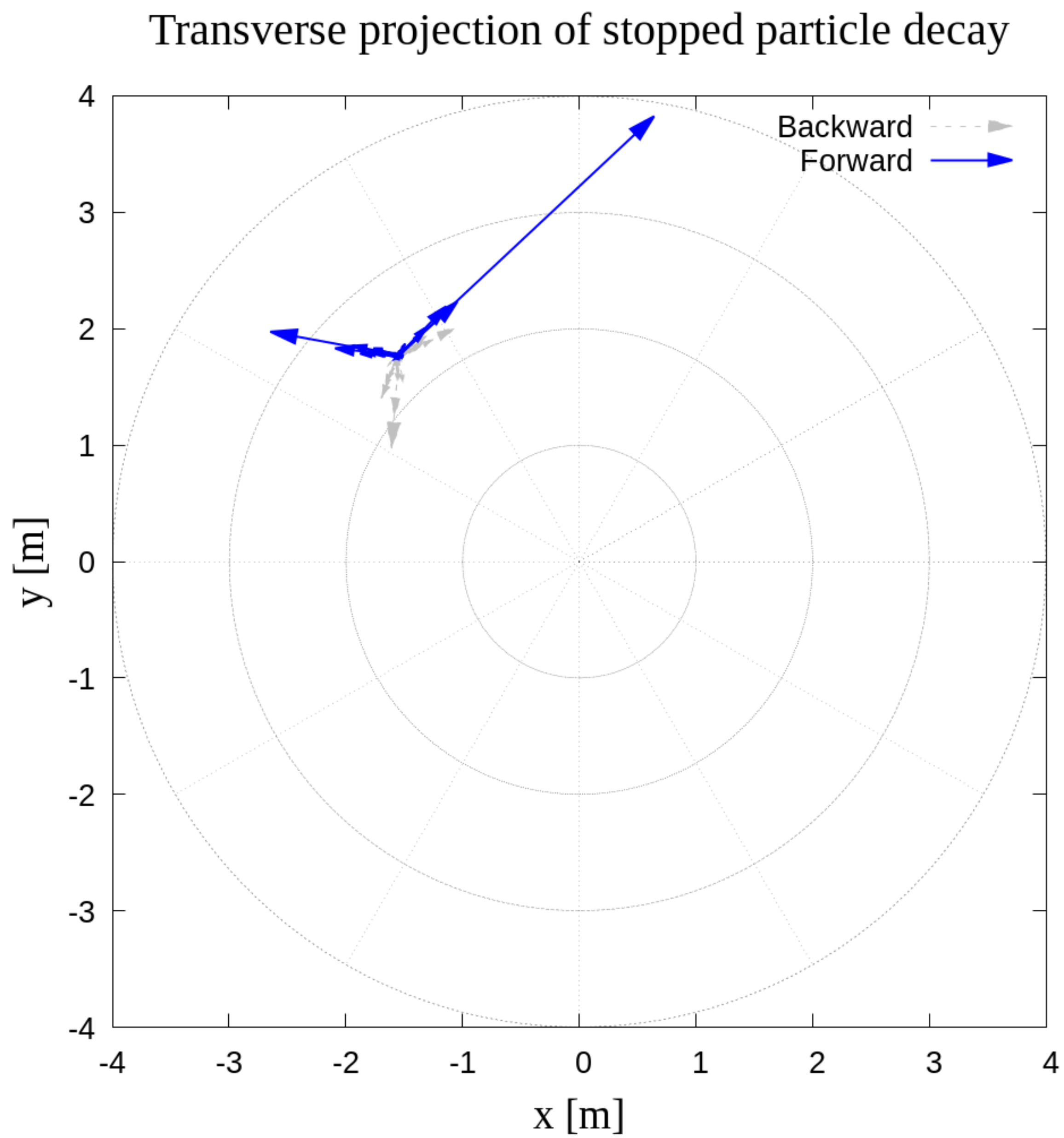


Scenario II : discrimination between displaced vs non- displaced



Decay of stopped particle inside the HCAL

A typical event display : X -> j j j (M_X= 1TeV)



Another interesting feature of LLP : backward moving particles (not covered here)

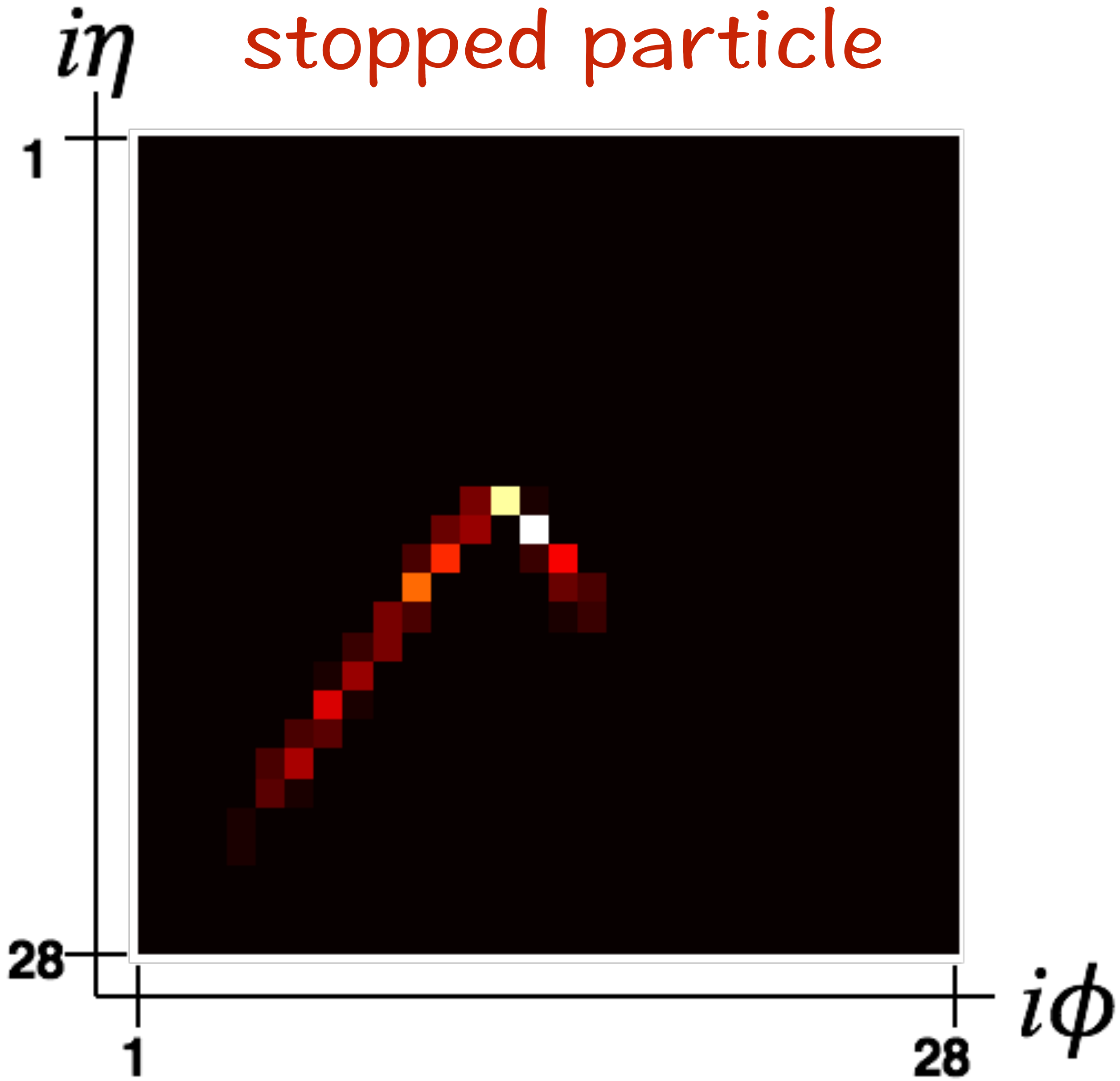
Novel signature for long-lived particles at the LHC

S. Banerjee, G. Bélanger, **BB**, F. Boudjema, R. Godbole, S. Mukherjee

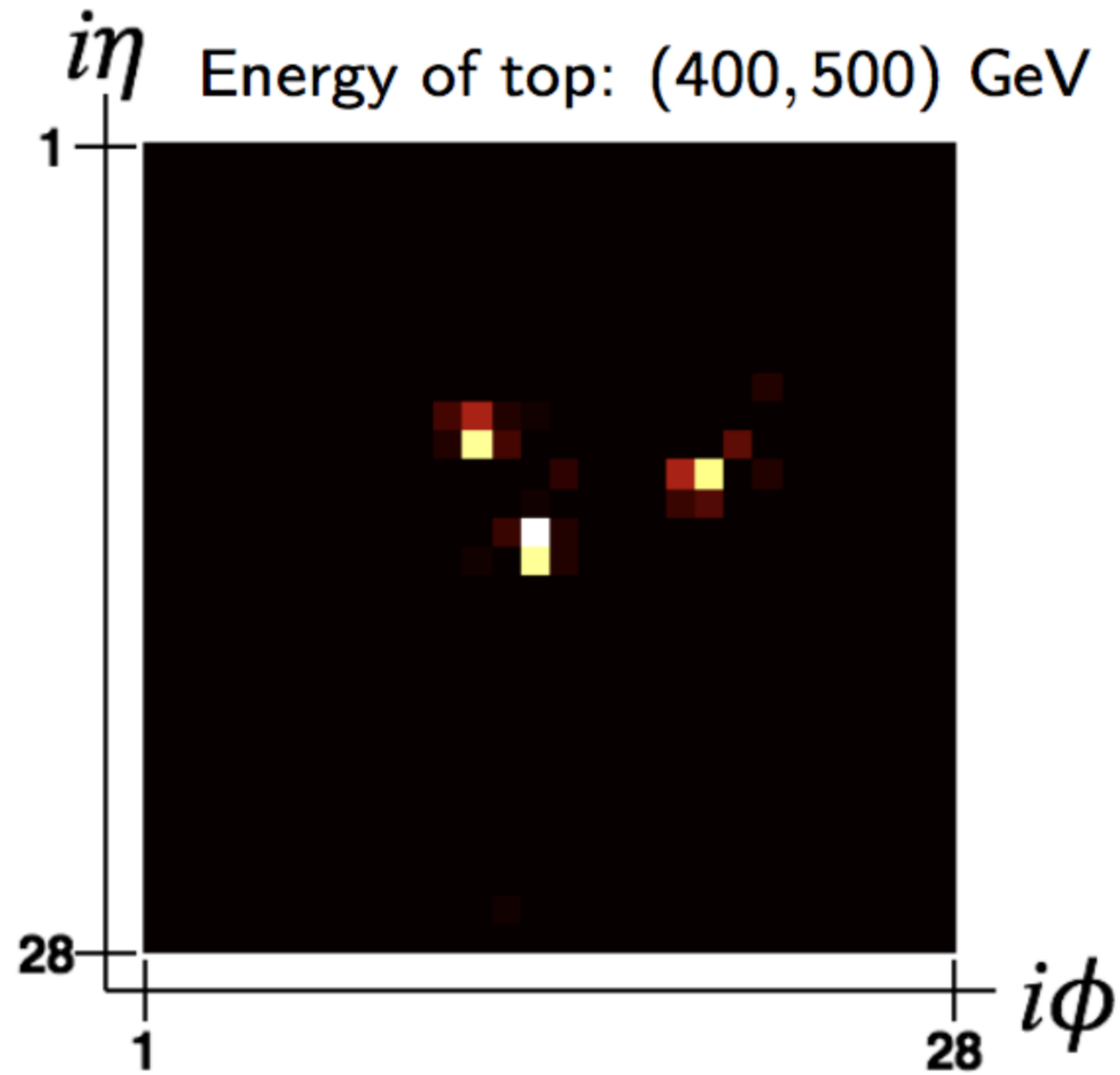
Phys.Rev. D98 (2018) no.11, 115026

Decay of stopped particle inside the HCAL

Typical stopped particle



Top quark



Energy deposition pattern is very different compared to SM processes (may not require empty bunch crossing to identify these events)

Conclusion

Our first attempt to understand the energy deposition patten of LLP decaying to jets using image recognition techniques

Delphes simulation will not capture the effect : absence of layered structure and z segmentation

Our work: simulated a simplified version of the segmentation following Tile Calorimeter of ATLAS.

Key features:

Elongation in energy deposition due to mismatch of η and ϕ of decay products starting from secondary vertex and the standard detector $\eta - \phi$ segmentation.

Later the decay of the LLP, smaller the physical region in which the energy deposition is contained in HCAL.

Our preliminary study shows that the energy deposition pattern can be identified by image recognition techniques.

Several improvements and directions identified : work in progress

Thank You