Super-resolution for calorimetry

F. A. Di Bello, S. Ganguly, E. Gross, M. Kado, M. Pitt, L. Santi, J. Shlomi,

IML WS
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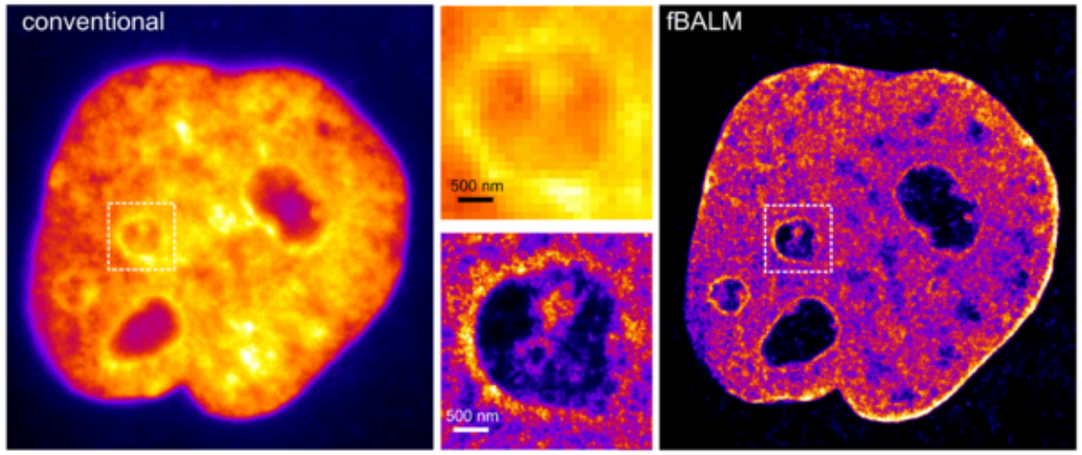
arxiv pre-print

Introduction

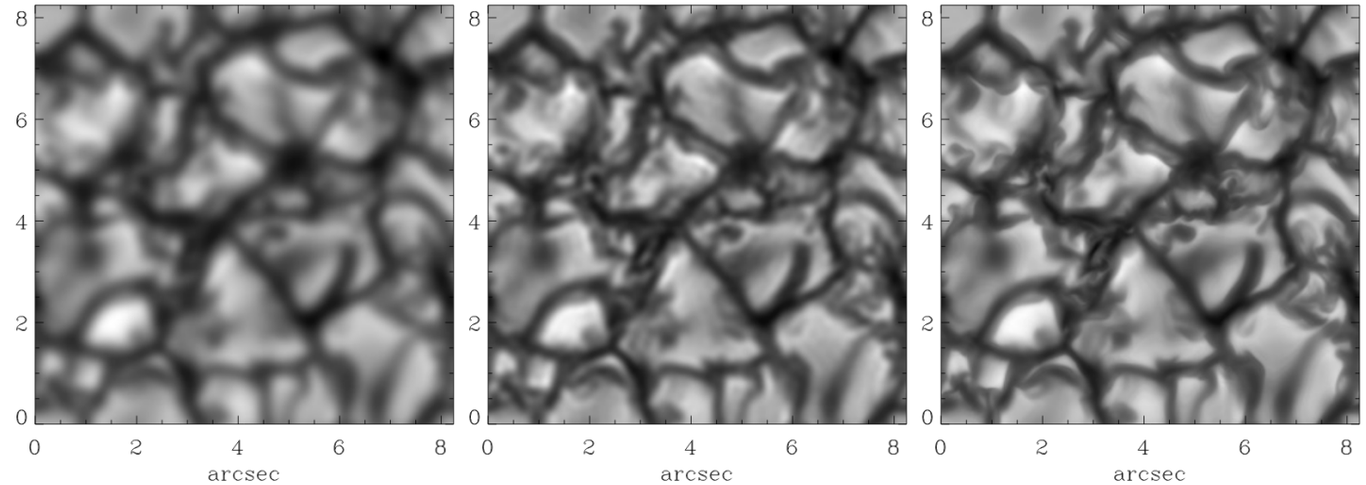
- Super-resoltion is typically referred to as algorithms used to enhance the resolution of the measuring device
- Outside HEP, it has a large field of application (not a complete list):

- Super-Resolution microscopy [Ref.]
  - Molecule -



2014 chemestry nobel: "for the development of super-resolved fluorescence microscopy"

- Astronomy [Ref.]
  - solar granulation -



and industrial application....

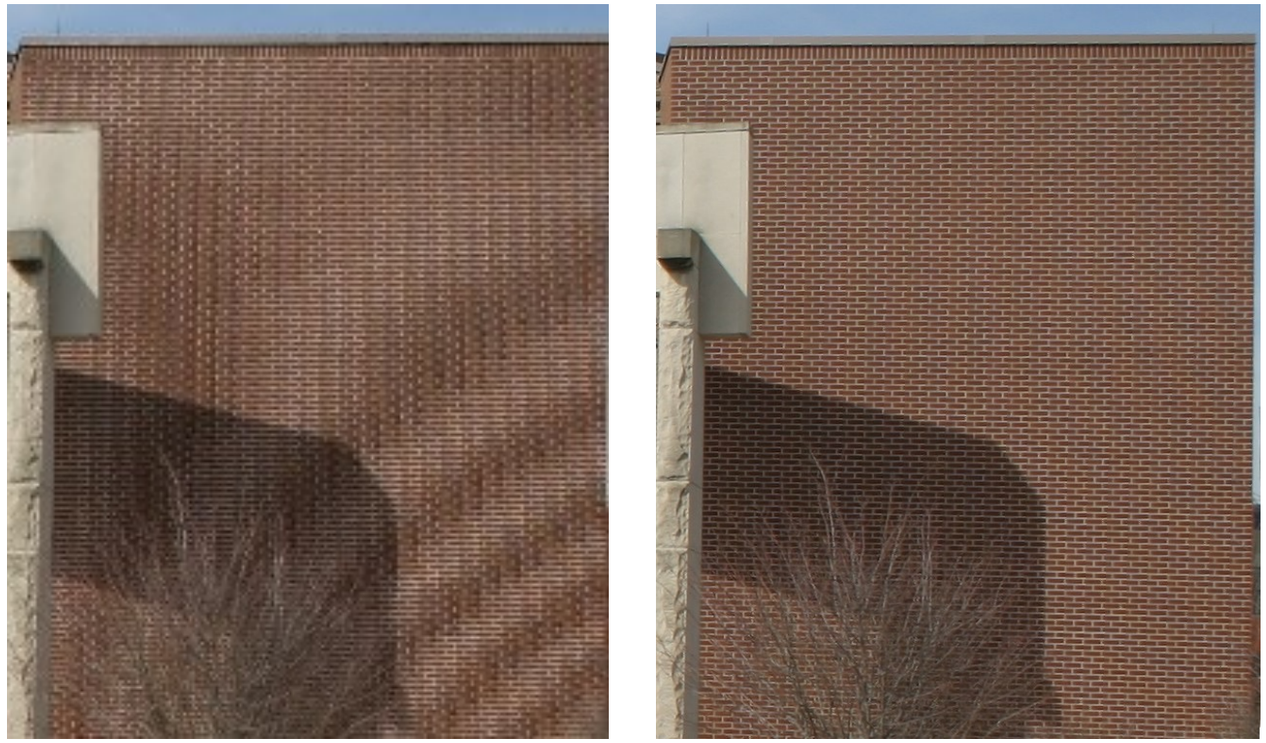
Introduction

- Imaging for camera etc [Ref., Ref.]

8x8 | 32x32 | 32x32, truth

google CNN (2017) for large up-scaling factor

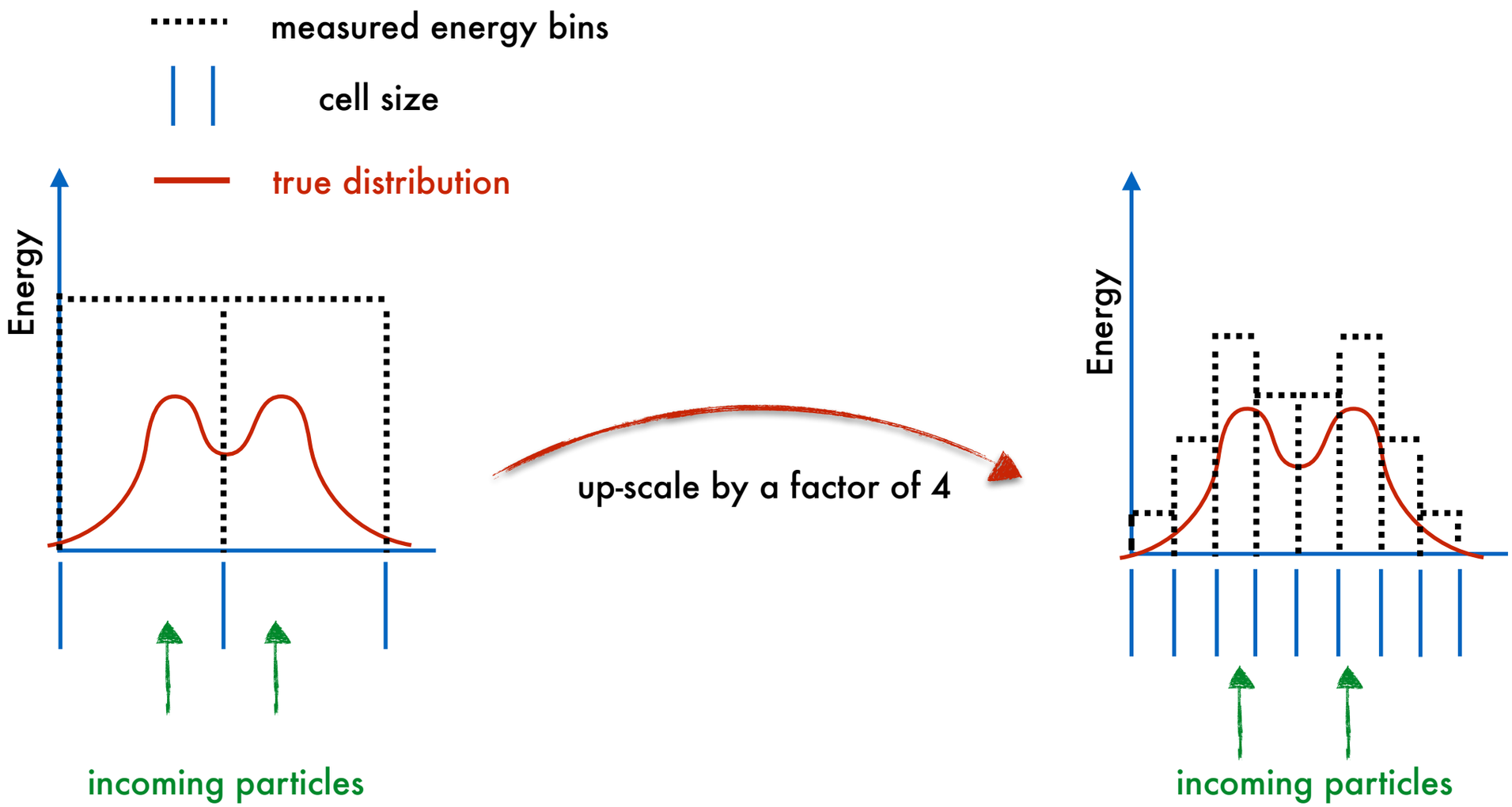
One of the main problem: how to get the HR target?



"Super-resolution usually involves applying prior knowledge about the object and the imaging process [...] in order to produce a single higher-resolution image"

Application to HEP

- The granularity of the measuring device is identified by the pixel/cells sizes (tracking/calorimetry)



Impossible to distinguish two particles or single particle hitting in between

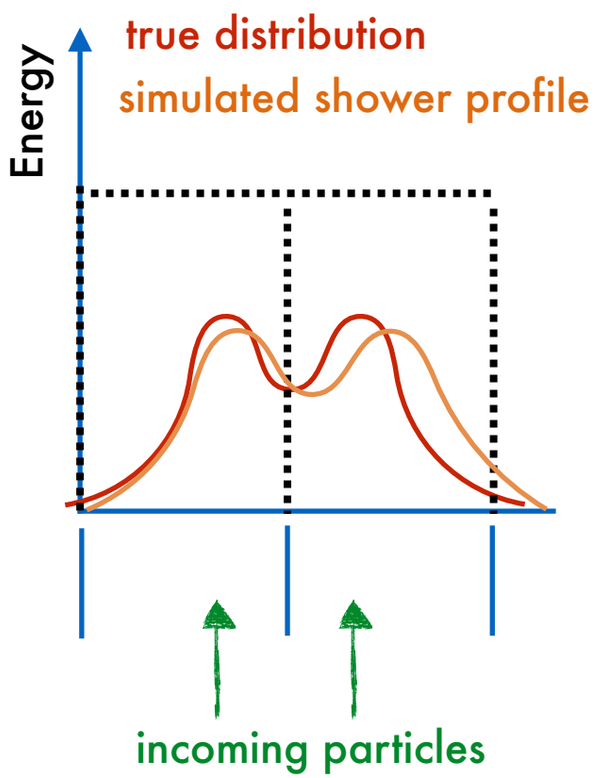
So far trivial statement:

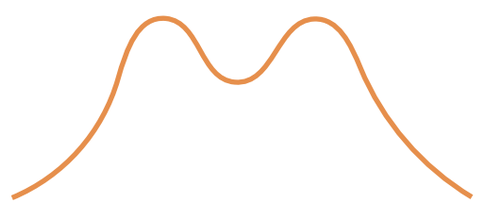
"higher spatial resolution allows to resolve additional features "

but how to construct the high-resolution image?

Application to HEP

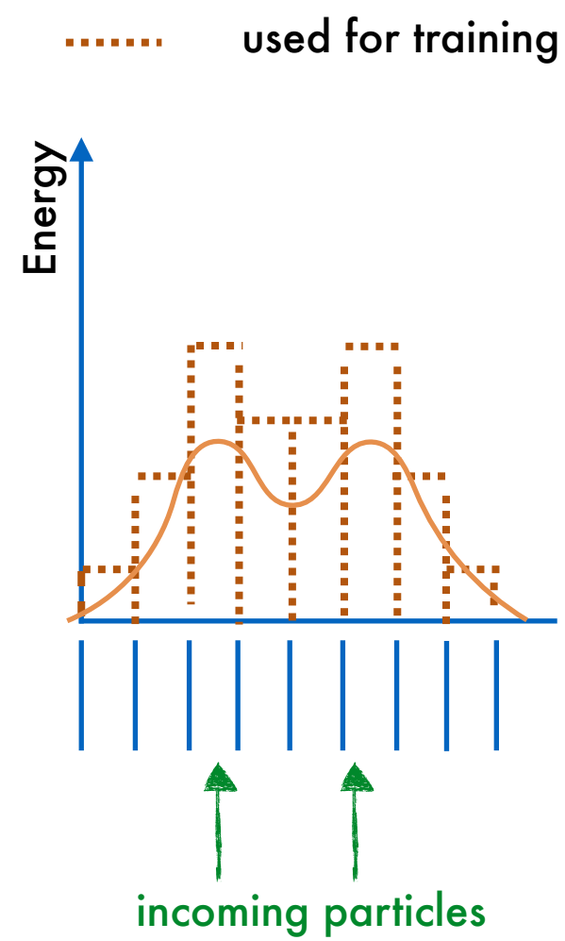
- Profit from MC simulations to build the "super" detector used as the target for training





GEANT4 based simulation

for our purposes this is a continuous line that can be used to build high-resolution detector



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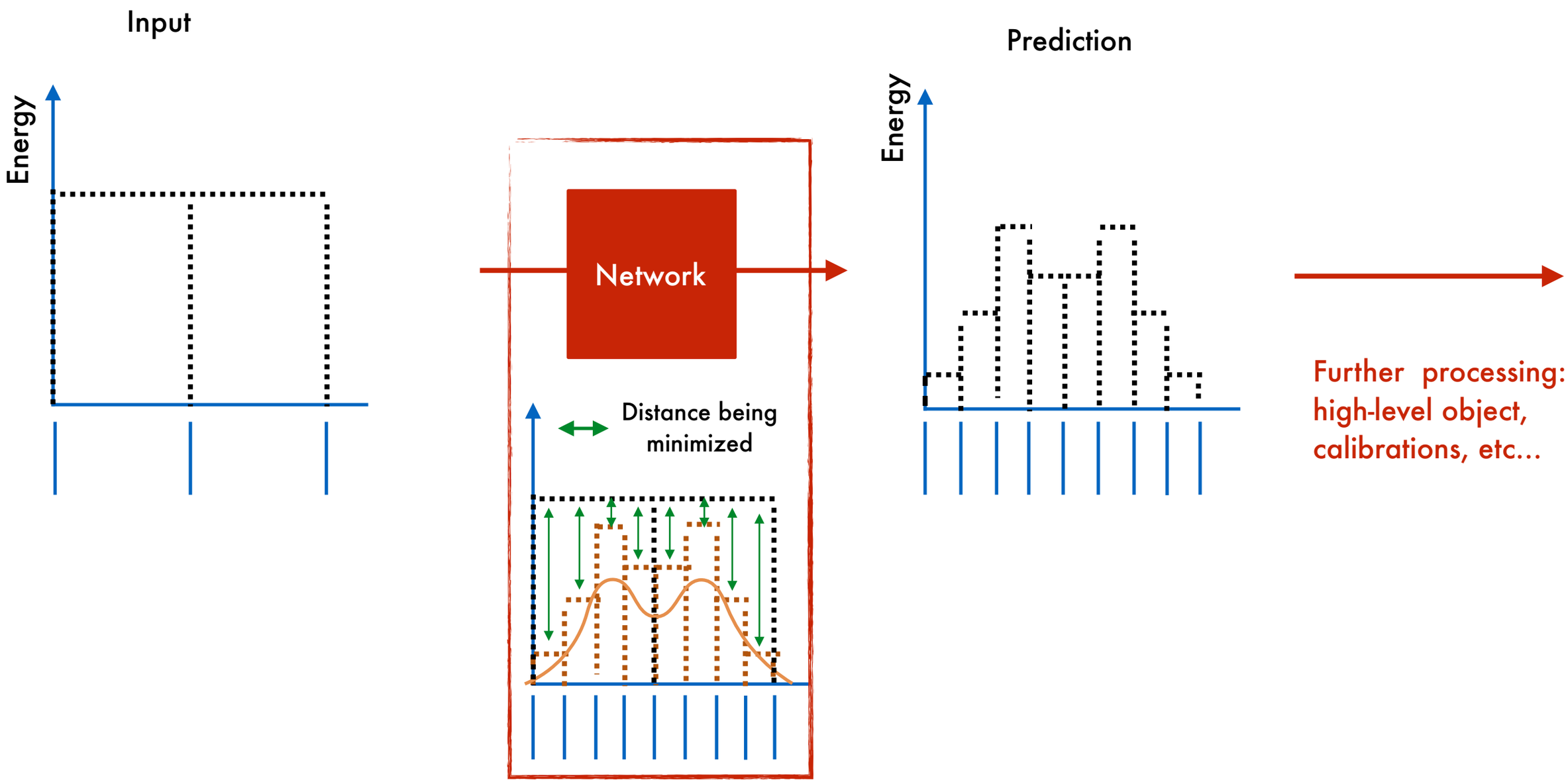
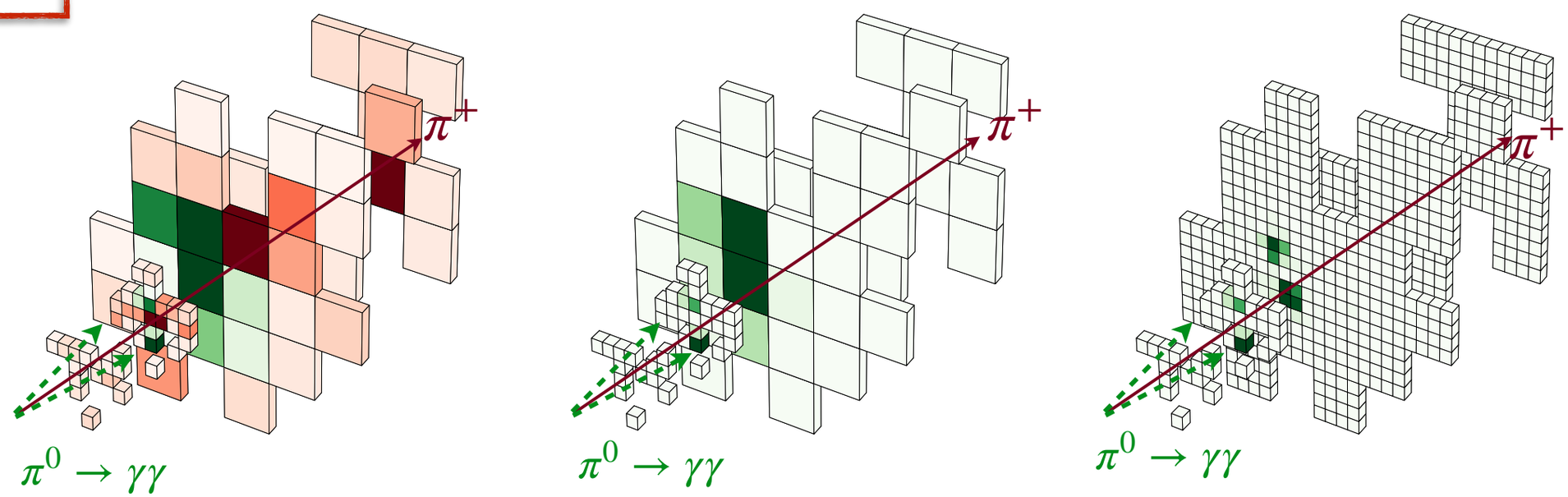


Experimental setup

- Going back to 3D in a pi+ and pi0 environment - similar geometry to what presented by Sanmay

Detector Layer	Res. (HG)	Res. (LG)	Noise [MeV] (cf)
ECAL1	64×64	32×32	13 (4)
ECAL2	32×32	8×8	34 (16)
ECAL3	32×32	8×8	17 (16)
HCAL1	16×16	8×8	14 (4)
HCAL2	16×16	8×8	8 (4)
HCAL3	8×8	8×8	14 (1)



Low-Resolution

charged + neutral+noise

Low-Resolution - neutral only

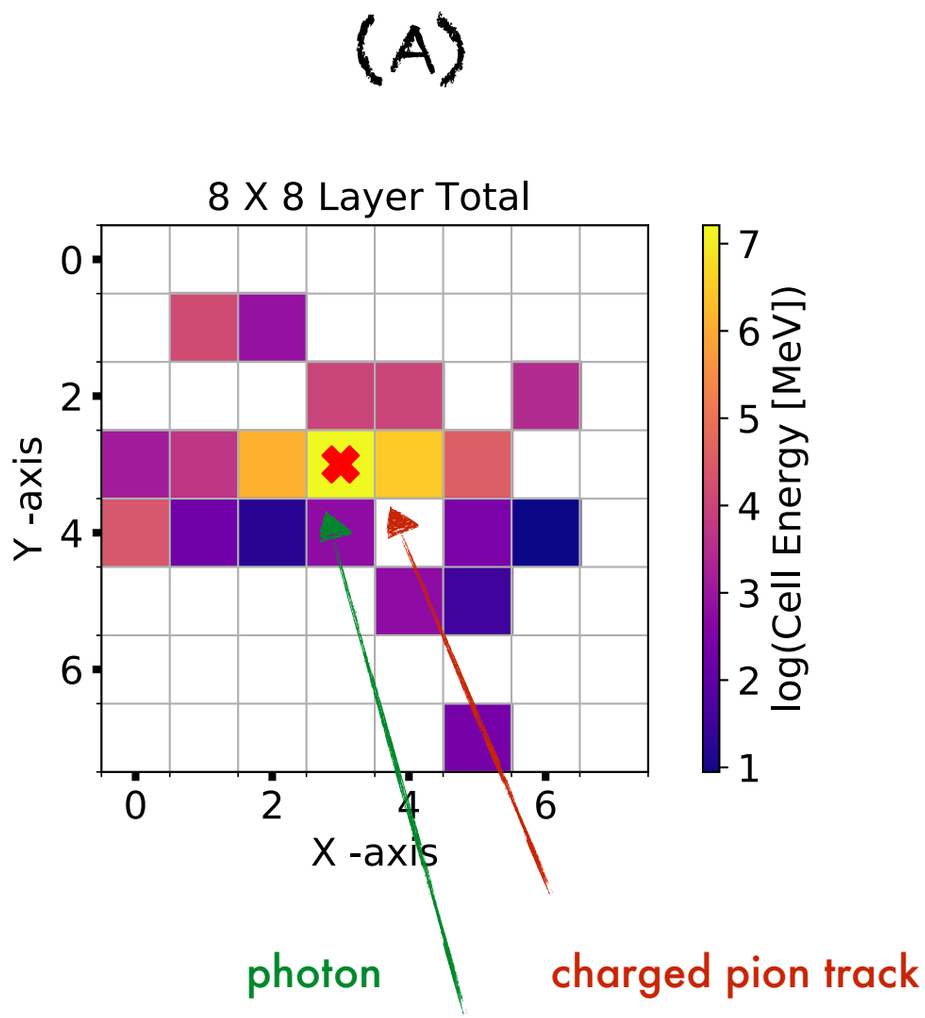
second layer: 8x8

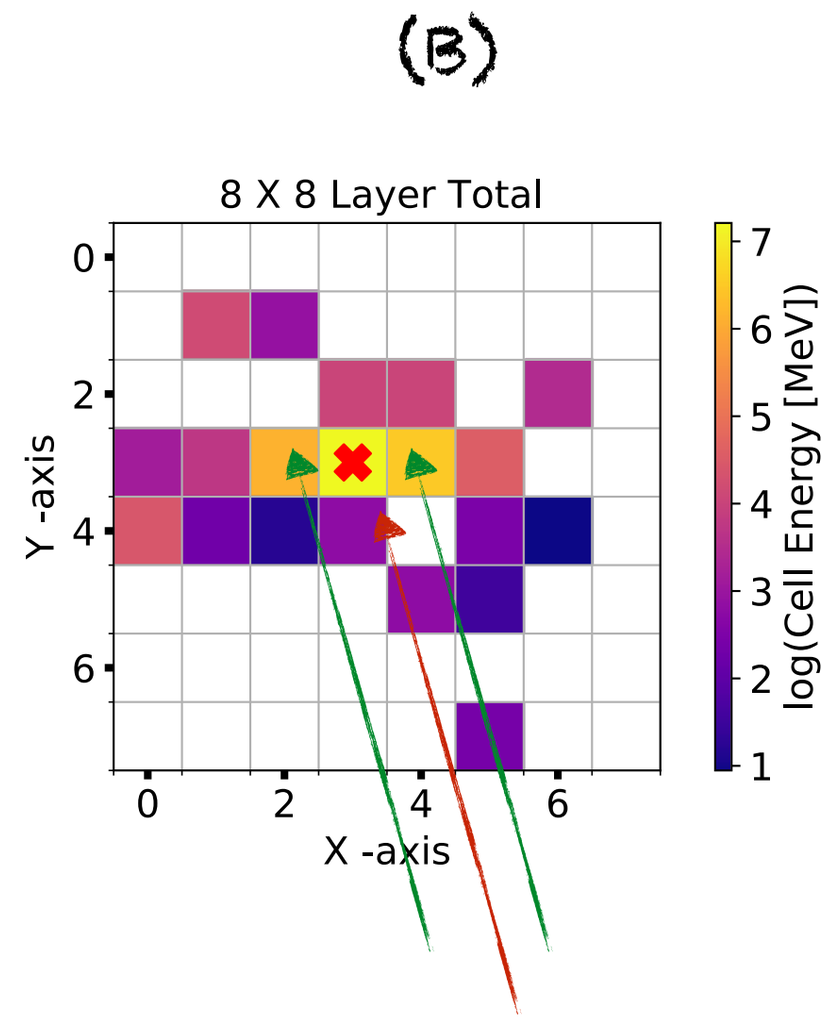
High-Resolution - neutral only

second layer: 32x32

A quiz

- Which one is correct?

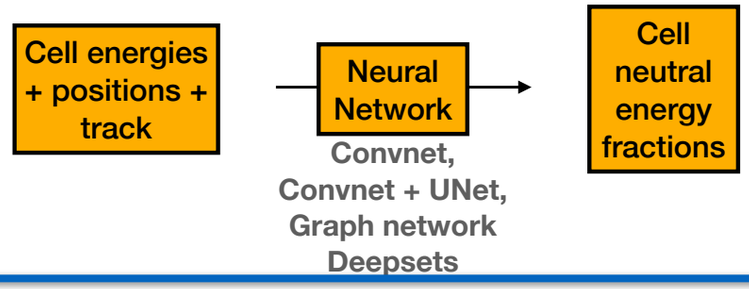




The model

This is what Sanmay discussed in the previous talk

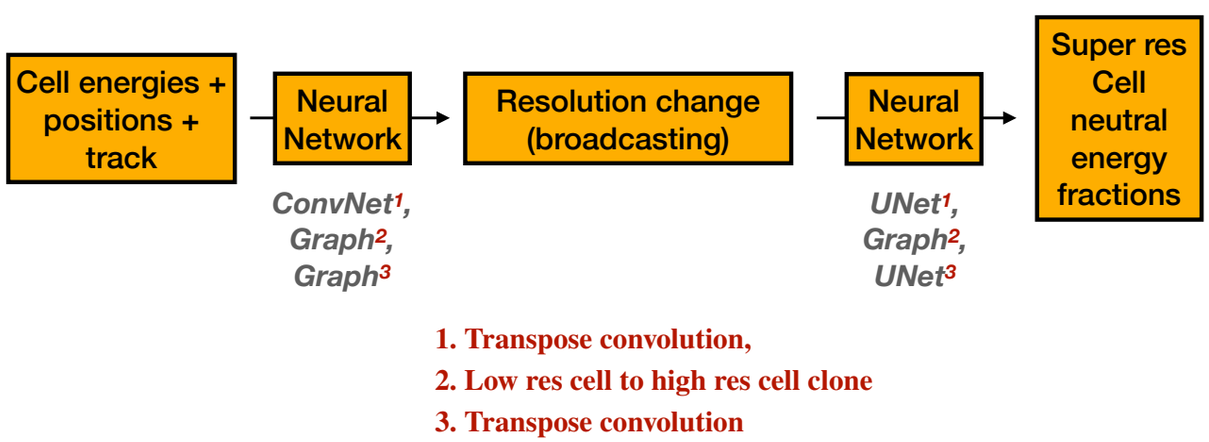
Common network structure for energy overlap removal task



$$L_{event} = \frac{1}{E_{tot}} \sum_c E_c (f_t^c - f_d^c)^2$$

This is what we discuss now

Common network structure for super-resolution task



Track traded as point in an image for CNN and as a global graph feature for the GNN

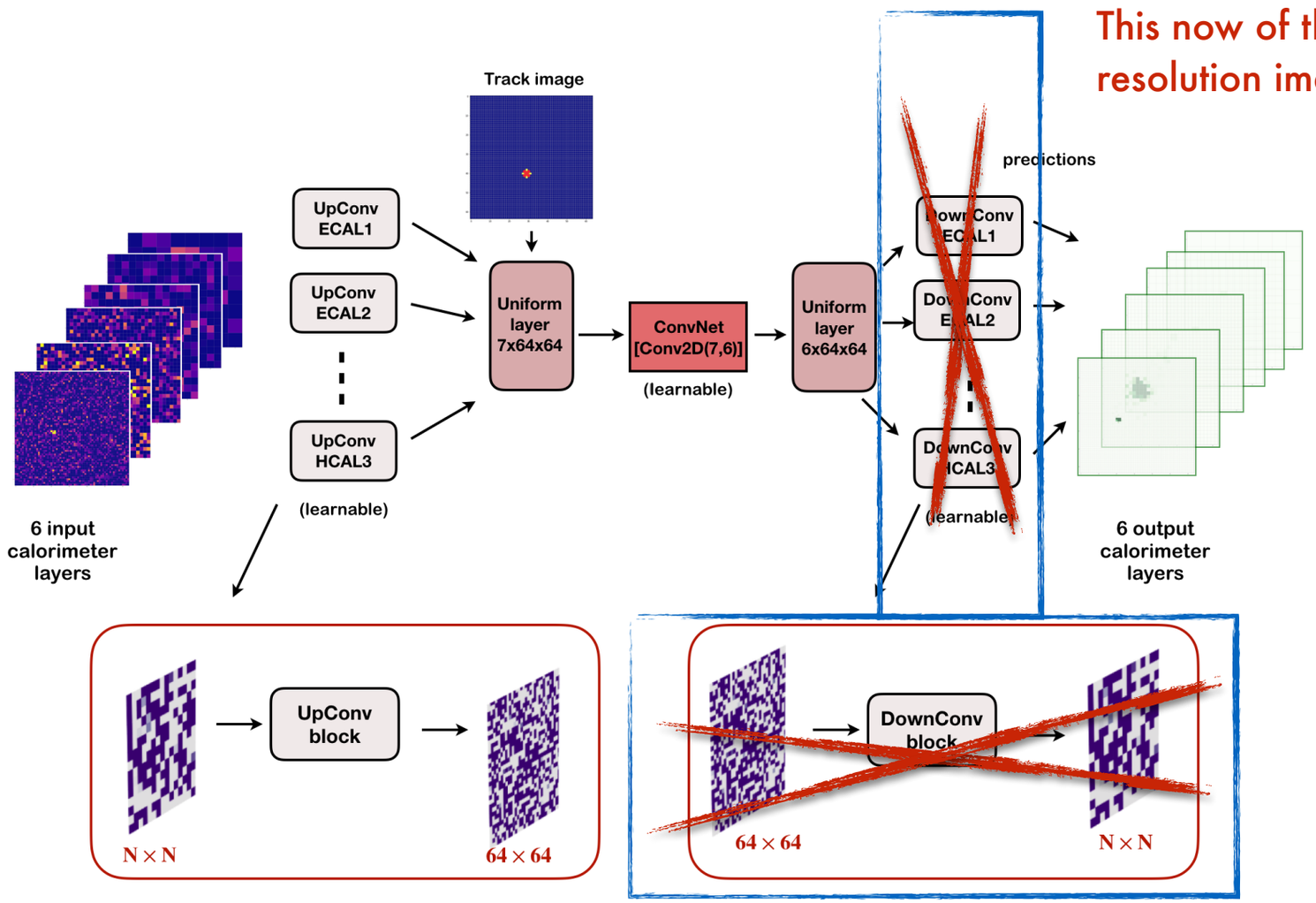
$$L_{event}^{\text{super-res}} = \frac{1}{E_{tot}} \sum_c E_c \sum_{s=0}^{us^2} (f_t^{sc} - f_d^{sc})^2$$

now we minimize each HR cell (s) in a given standard cell (c)

The model

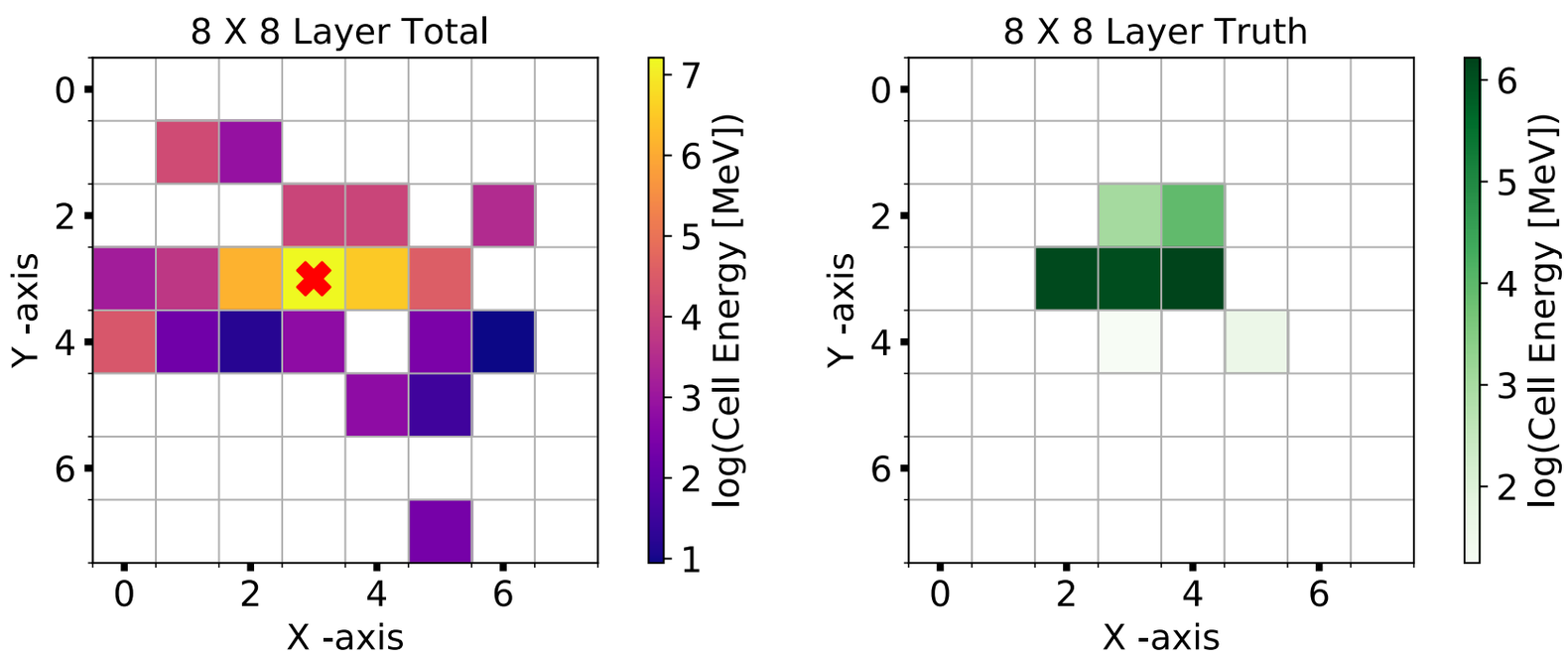
- For CNN, the same model with minor modifications can be used
- SImilarly for the graphs, even if not shown in an image

This now of this images as High-resolution images



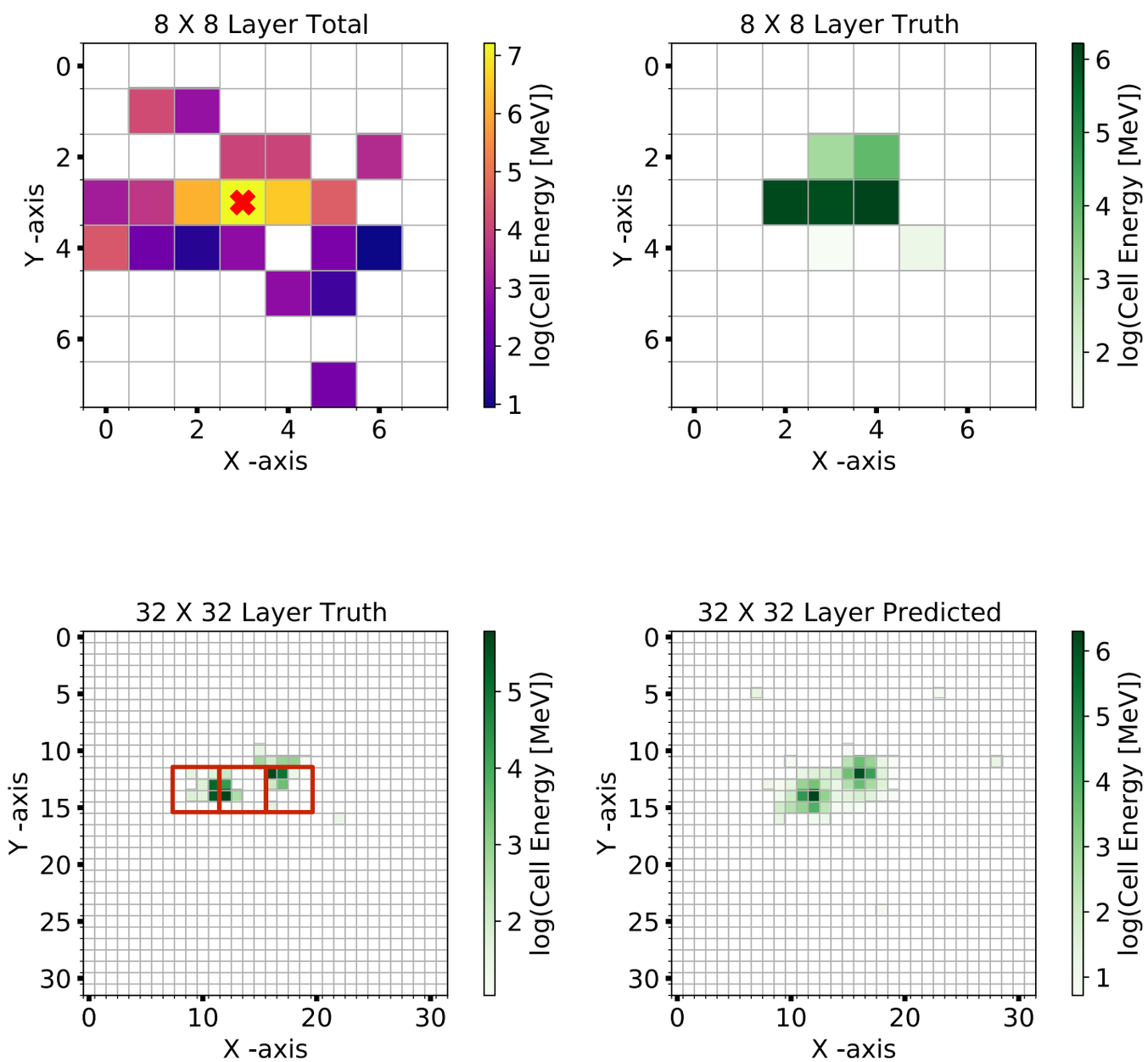
Results 1 - quiz answer

- Let's first divide charged and neutral (similar to what shown in the previous talk)



Results 1.1 - quiz answer

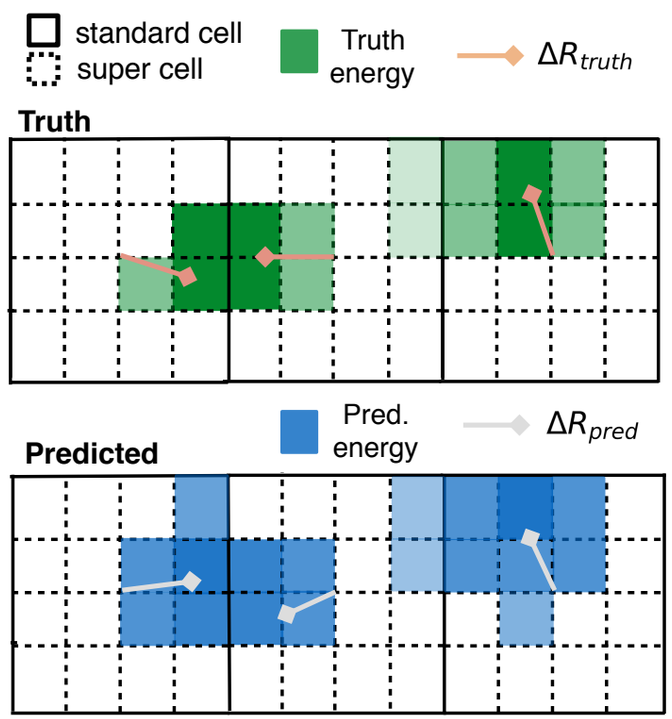
- And now super-resolution at work

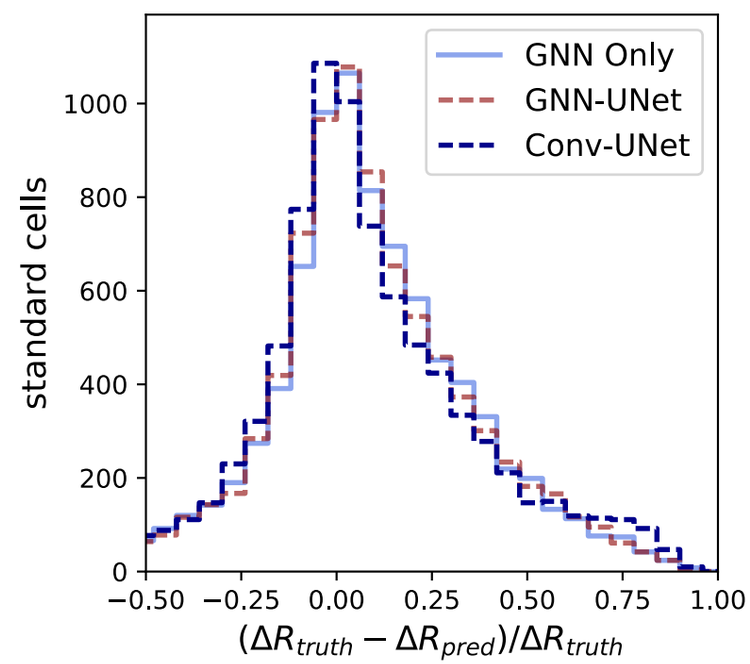


Results 2

- Expect correlation between the radial distance of each standard cell

$$\Delta R = \sum_{sc}^{up^2} E_{sc}\sqrt{x_{sc}^2 + y_{sc}^2} / \sum_{sc}^{up^2} E_{sc}$$





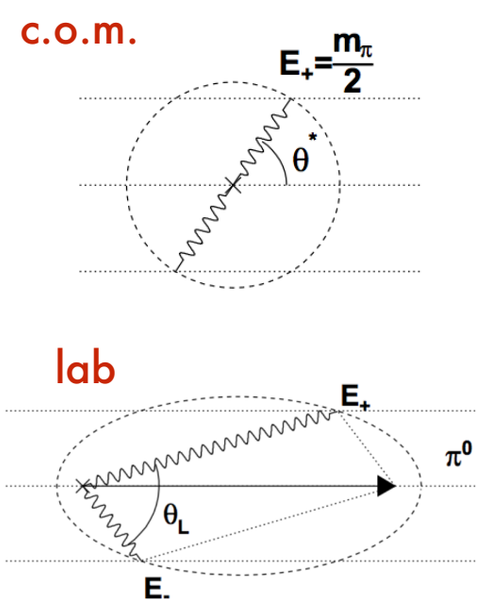
Learning high-resolution patterns

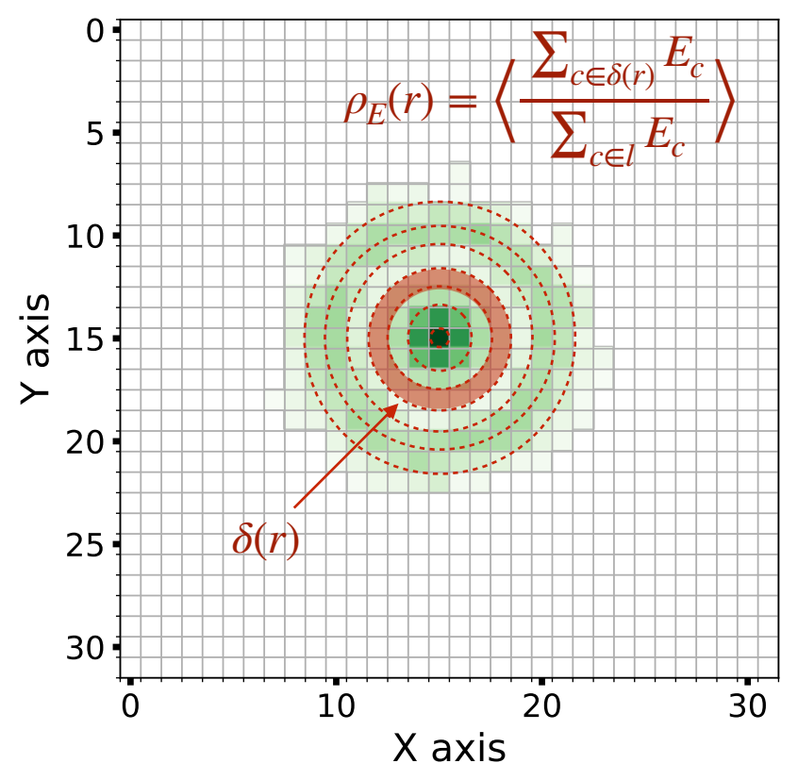
Asymmetryc tails, the NN tend to smooth a bit the output image

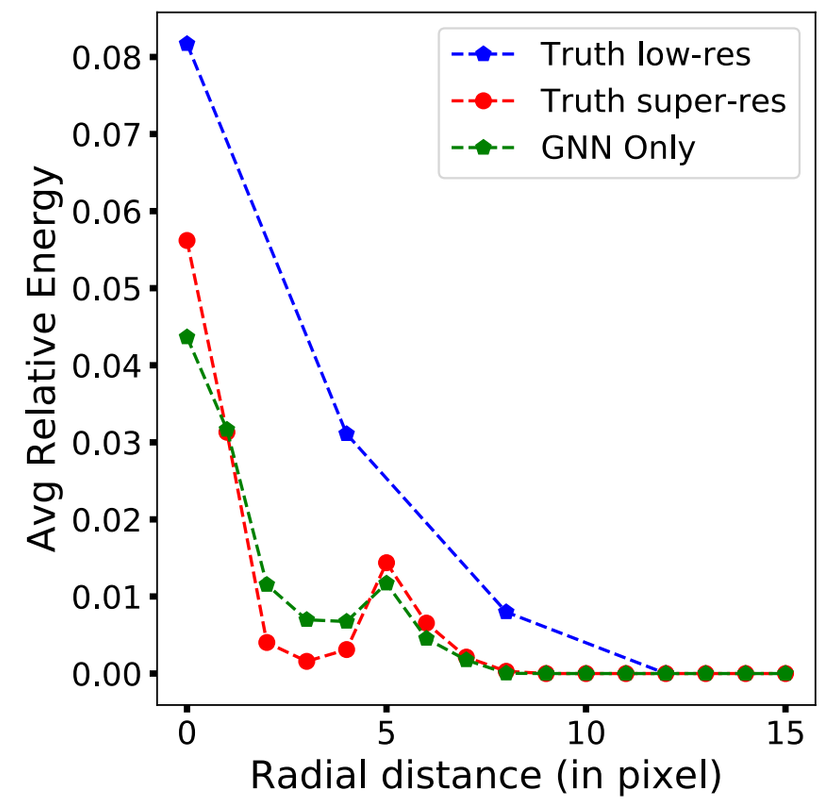
Results 3

- Can we resolve the two photons from the decaying pi0?
- Check by centering the image for each event around the most energetic cell and averaging for all the events
- For a fixed momentum of the p0 (and fiducial cuts to ask the two photons within detector acceptance), a circle representing the secondary photon is expected

truth average image

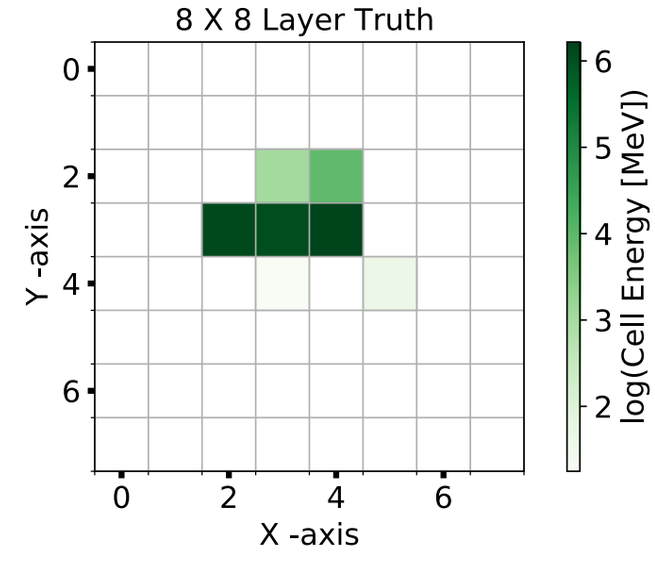


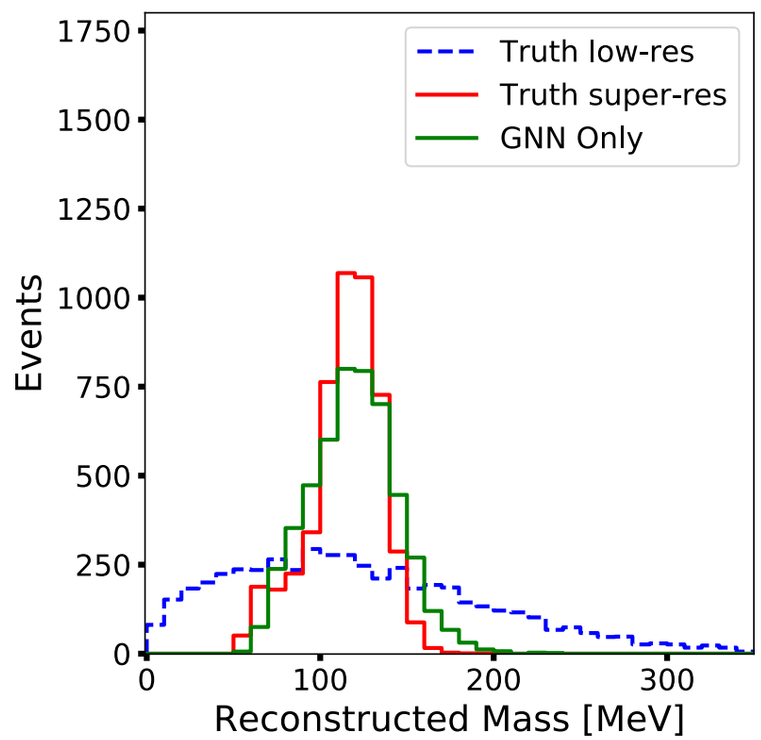




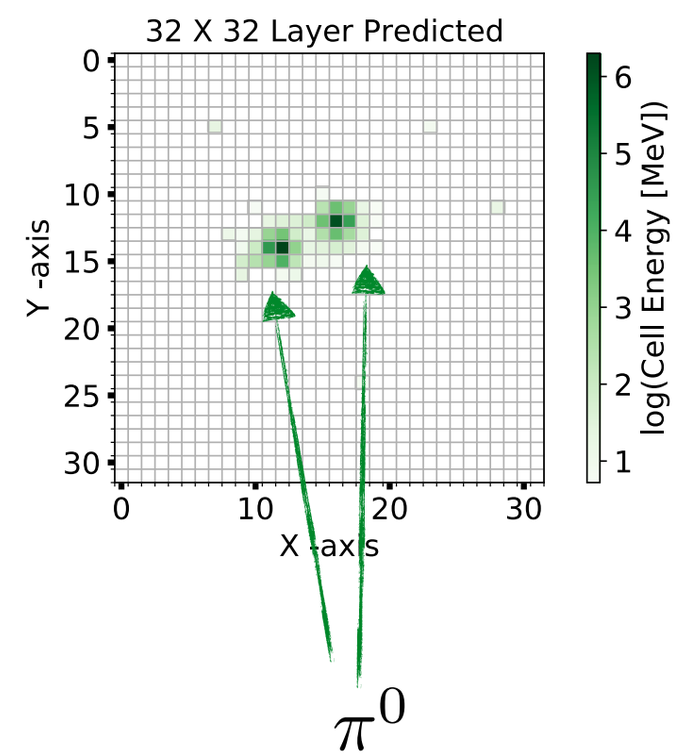
Results 4

- Can we reconstruct the mass of the pi0?
- K-mean clustering algorithm min n-cluster = 2 was used to cluster HR image
- Four-momenta of the photons computed from the production location of pi0
- SF applied to "calibrate" the truth as well as predicted to the pi0 mass





nice high-resolution peak



Conclusions

- Proposed super-resolution algorithms
- Performance evaluated on a simplistic pi0/pi+ overlap
- Results show promising advantages: improving spatial resolution of measuring systems
- Could be an Interesting “intermediate” steps toward construction of more complete Pflow algorithms

Graph model