5D related literature overview

1st in-person CALO5D meeting

02-03.12.2024

Bohdan Dudar

bdudar@uni-mainz.de

Motivation

(1) What other’s in the field have already done?

(2) What is lacking?

(3) What can we do?

(4) How?

Disclaimers

(1) Only related to timing

I will not discuss parts of the papers not related to timing

(2) I am only human

I tried to do my best, but I still could misunderstand things.

You are encouraged to investigate the papers to get the full grasp

Today's program

Main menu

(1) N. Akchurin et al	2021	JINST 16 P12036
(2) C. Graf and F. Simon	2022	JINST 17 P08027
(3) Jack Rolph	2023	PhD thesis
(4) Jack Rolph et al	2024	arXiv:2407.00178

and

◆ Imad Laktineh	2024	TSDHCAL talk (DRD6 WP1 colab. m.)
◆ Manqi Ruan et al	2024	arXiv:2411.06939
◆ Yevhenii Padniuk	2024	Master thesis

On the Use of Neural Networks for Energy Reconstruction in High-granularity Calorimeters

N. Akchurin et al **2021** **JINST 16 P12036**

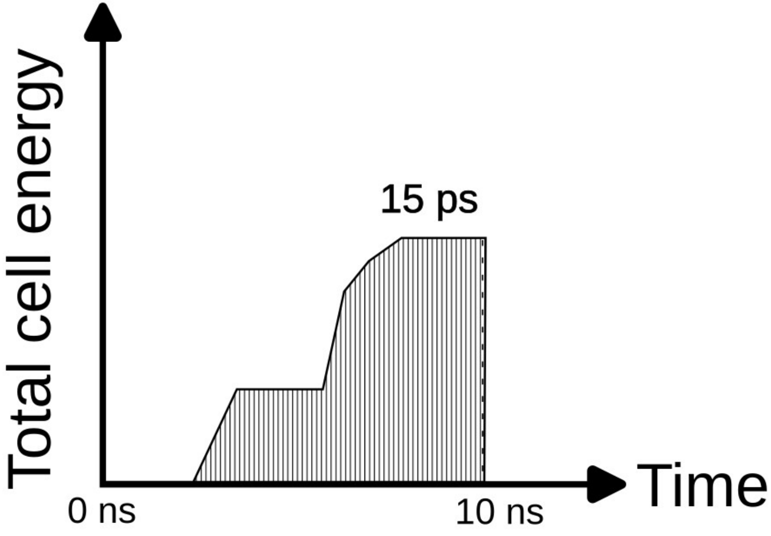
N. Akchurin et al

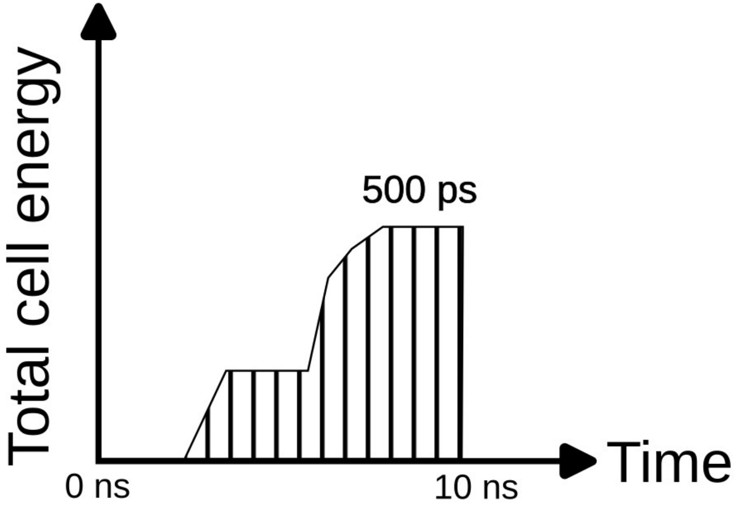
Shooting: single particles - pions
30 GeV and 100 GeV
smeared: 4x4cm

Detector: custom Si/Cu HCAL
tot: 1x1x1.5m (x/y/z)
cells: 2x2x2cm (1.7 cm Copper, 0.3 cm Si)

NN: Dynamic Graph CNN.
four EdgeConv blocks with two-layer
MLP ([64,64], [96,96], [128,128], [256,256])
and k-NN parameter set to 10.

Timing: **a cumulative series of cell energies up to 10 ns**



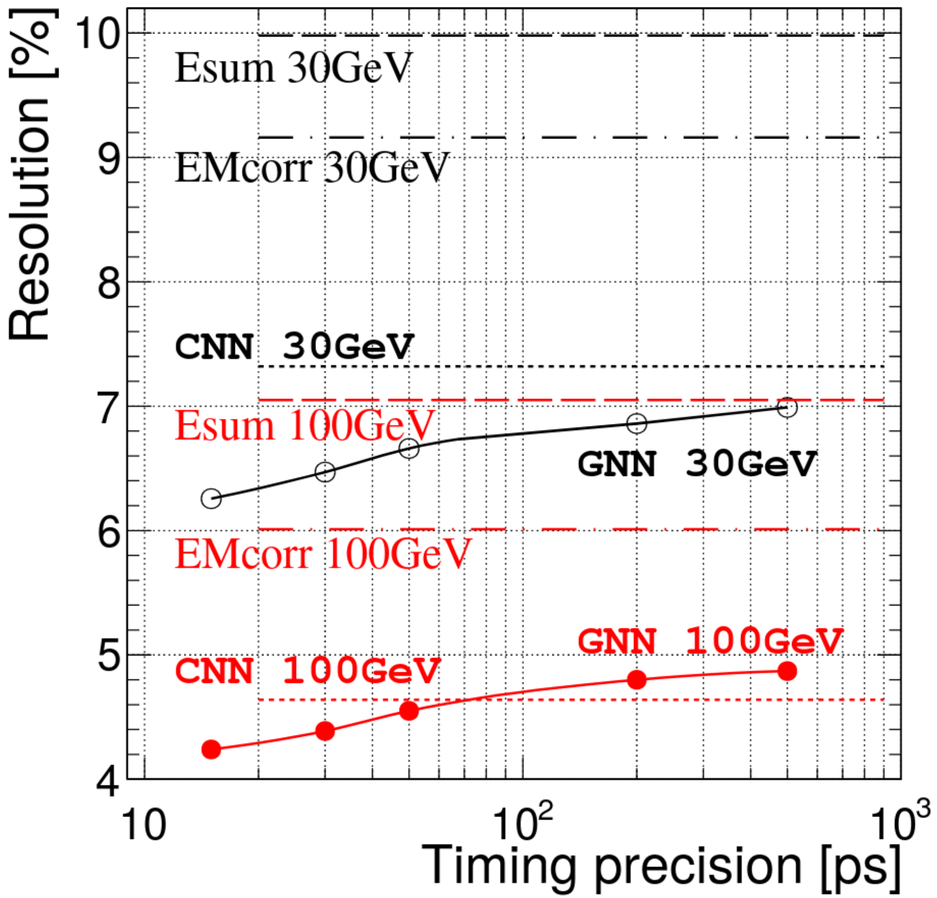


N. Akchurin et al

Time sampling from 500 ps → 15 ps improves pion energy resolution by ~0.7%

Comments:

- Least pion energy is 30 GeV
- only HCAL
- True hit times are used
- GNN architecture is very poorly explained
- How does timing enter GNN is not explained
- GNN vs CNN w/o timing is not elaborated
- 3 mm of Si



Time-assisted energy reconstruction in a highly granular hadronic calorimeter

C. Graf and F. Simon **2022** **JINST 17 P08027**

C. Graf and F. Simon

Shooting: single particles - pions
10 GeV to 80 GeV energies

Detector: extended CALICE AHCAL
tot: 72x72cm x60 layers (x/y/z)
cells: 30x30x3mm Sc+SiPM / steel (~17 mm)

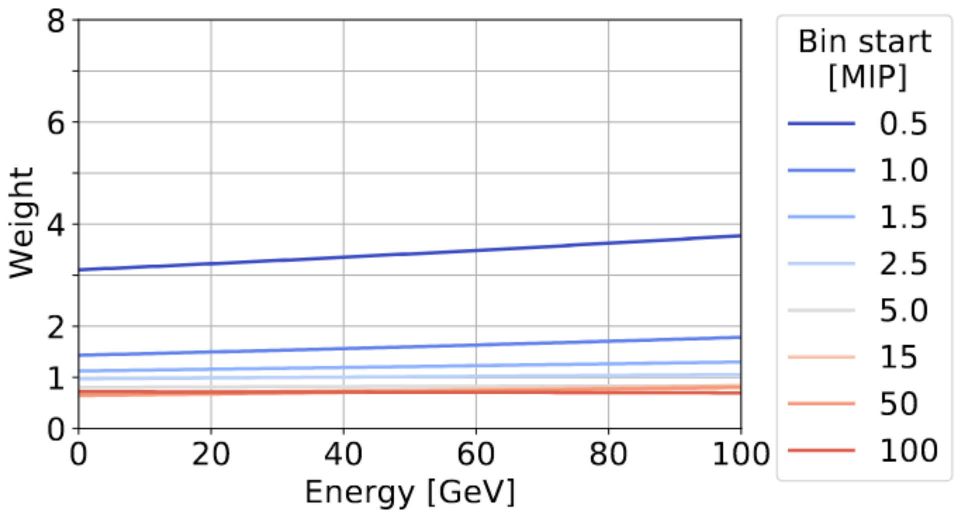
Algorithm: local software compensation

Bin	0	1	2	3	4	5	6	7
Range [MIP]	0.5–1.0	1.0–1.5	1.5–2.5	2.5–5.0	5.0–15	15–50	50–100	> 100

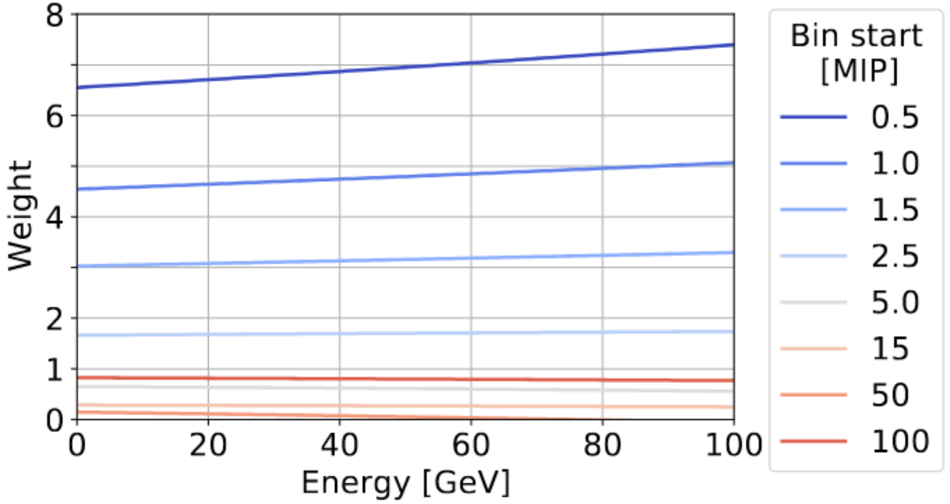
$$w(e_j, E) = e_j \cdot (c_{k,0} + c_{k,1}\, E + c_{k,2}\, E^2),$$

$$L = \sum_{i\,\in\,\text{events}} \frac{\left[\sum_{j\,\in\,\text{hits}} e_{j,i} \cdot w(e_{j,i}, E_{\text{beam},i}) - E_{\text{beam},i}\right]^2}{E_{\text{beam},i}}$$

Timing: **use separate weights for early (<3ns) and late (>3ns) hits**



(a) Early hits



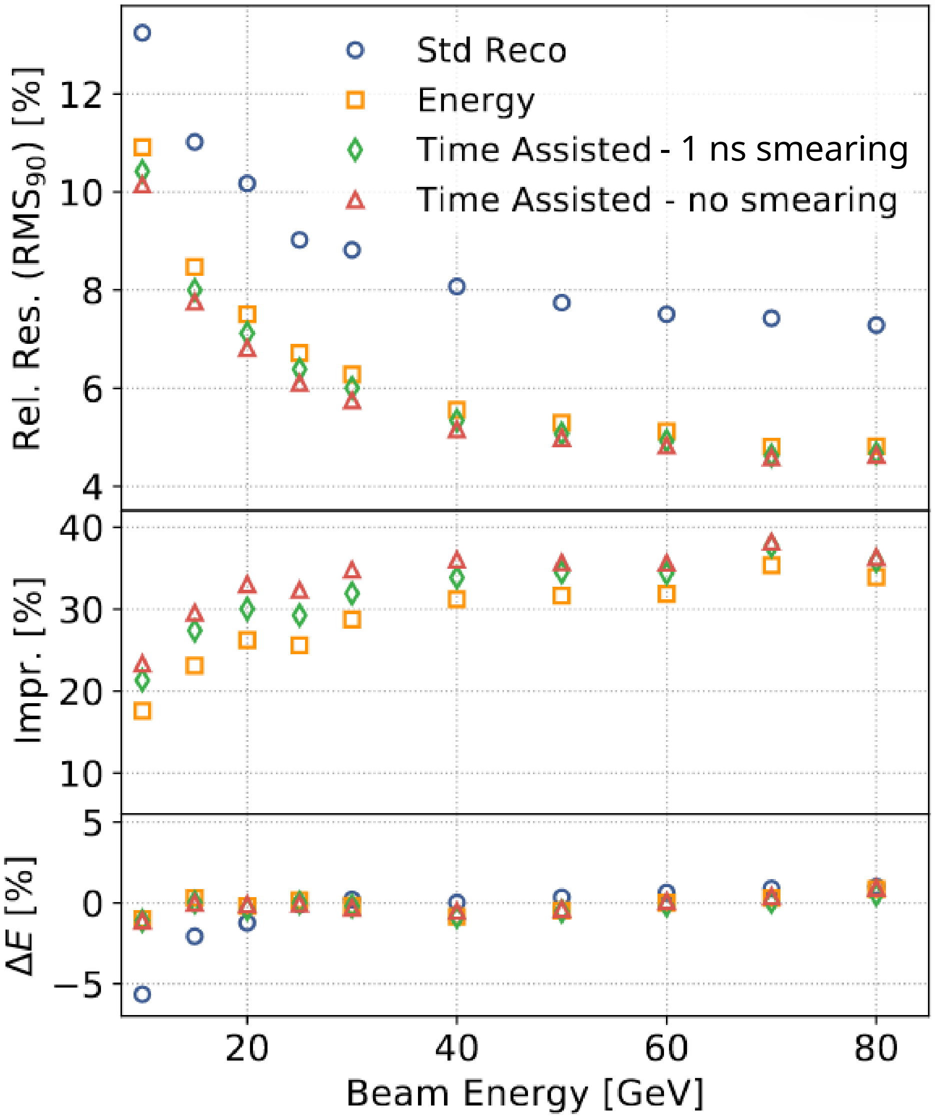
(b) Late hits

C. Graf and F. Simon

Early/late hit timing improves energy resolution by ~3-4%

Comments:

- Least pion energy is 10 GeV
- only HCAL
- Great paper!
- Logical continuation – improve 3 ns cut: use NN to utilise continuous time spectrum/ more than two time bins



SHOWER SEPARATION IN FIVE DIMENSIONS FOR HIGHLY GRANULAR CALORIMETERS USING MACHINE LEARNING

Jack Rolph	**2023**	**PhD thesis**
Jack Rolph et al	**2024**	**arXiv:2407.00178**

Jack Rolph: software compensation

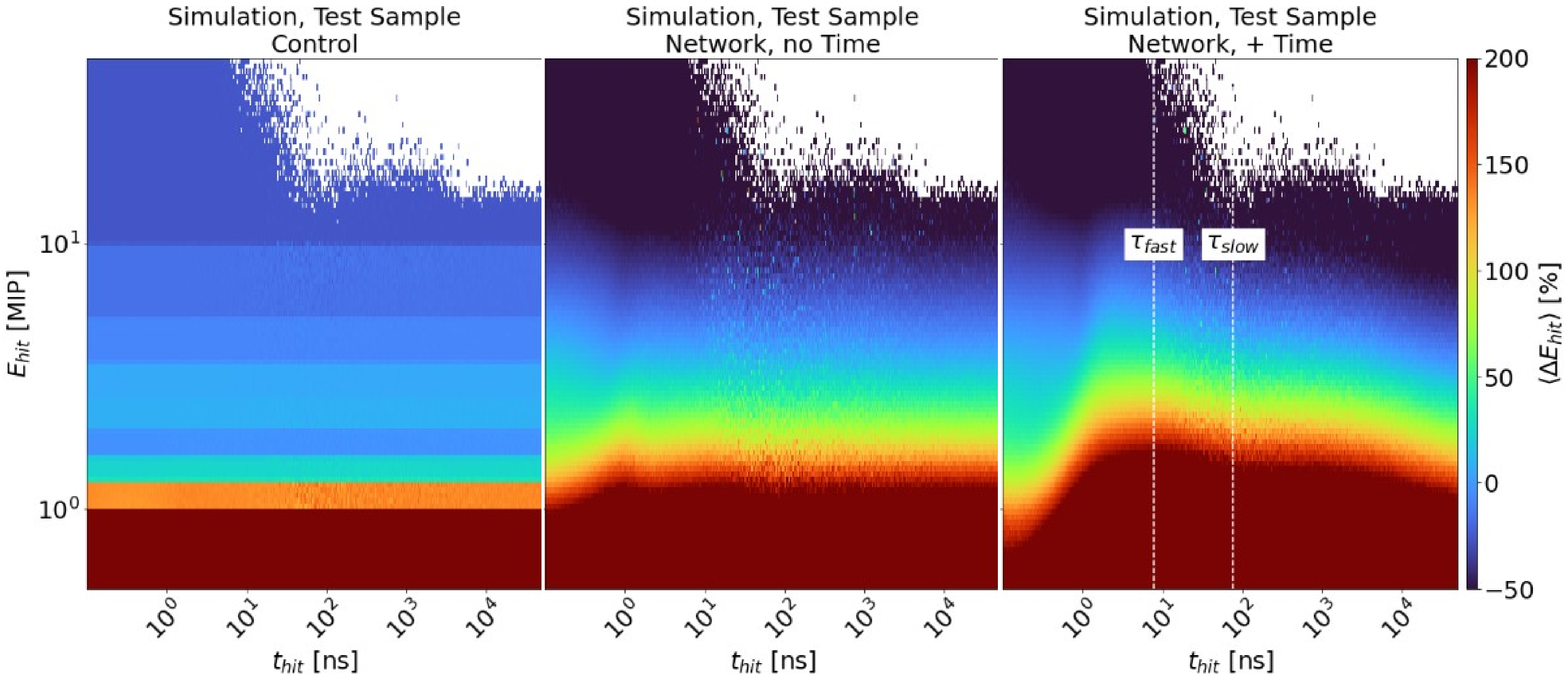
Shooting: single particles – pions (software comp.)
10 GeV to 100 GeV energies

Detector: CALICE AHCAL
tot: 72x72x 38 layers (x/y/z)
cells: 3x3cm Sc+SiPM / stailess steel (~17 mm)

Software compensation: DGCNN

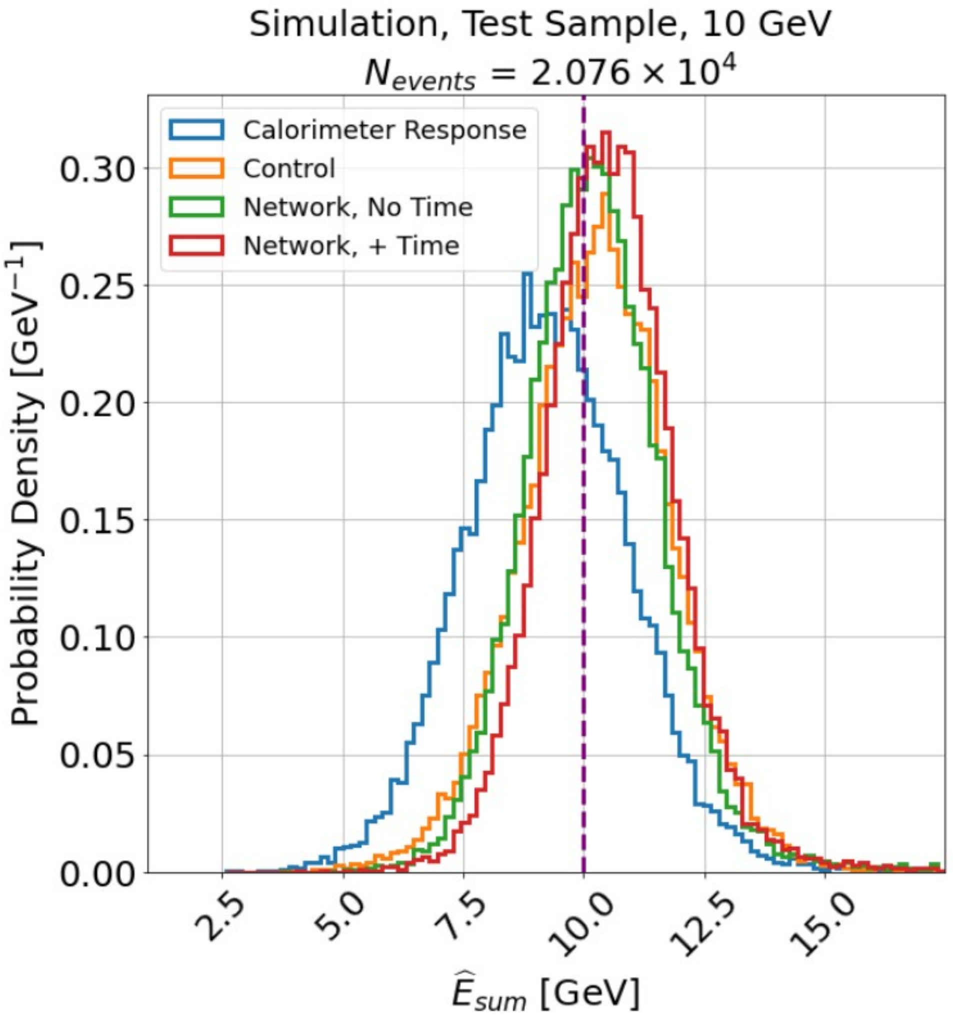
Time resolution: unclear 100 ps / 5 ns / perfect ?

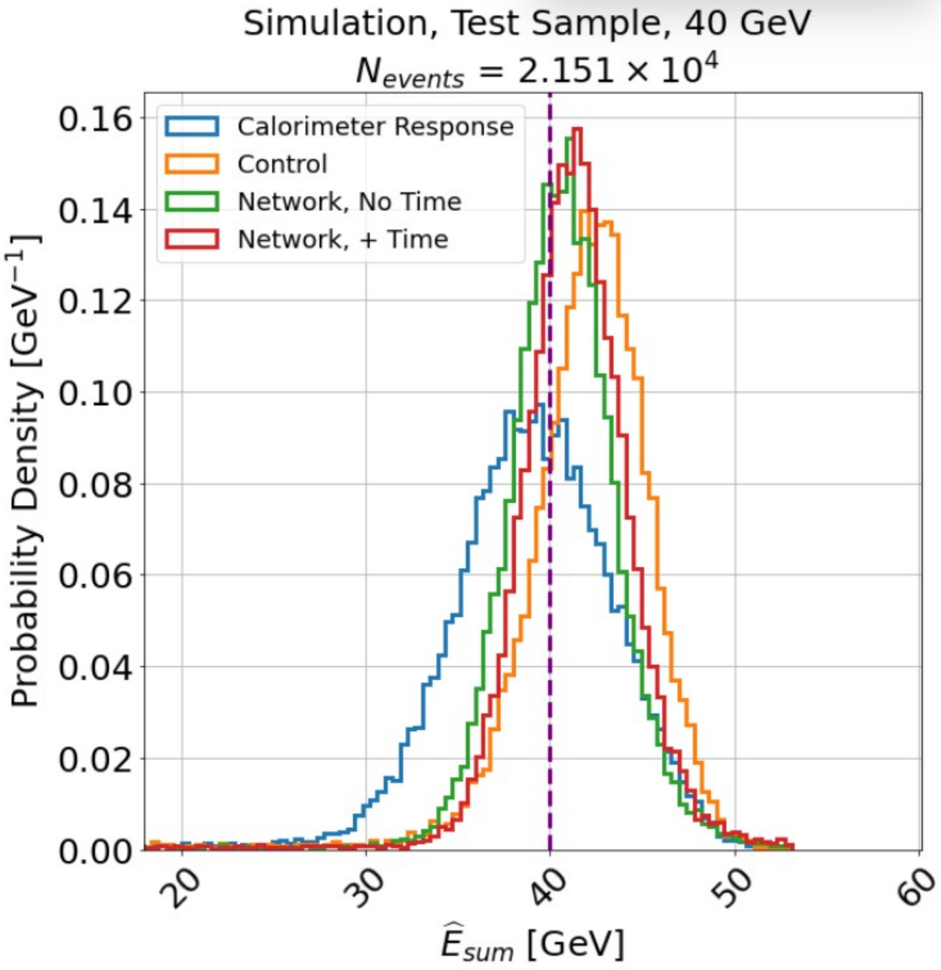
Jack Rolph et al: software compensation weights



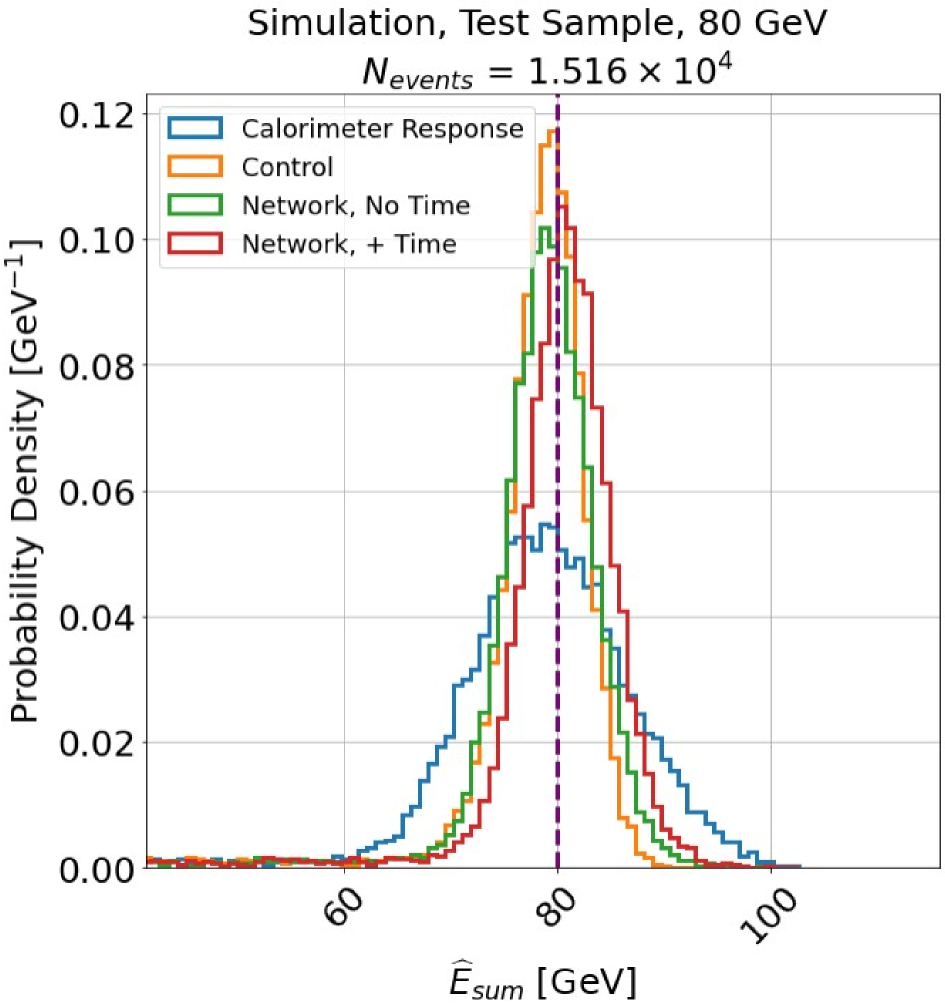
*Time resolution is unclear. Perfect/100 ps/5ns?

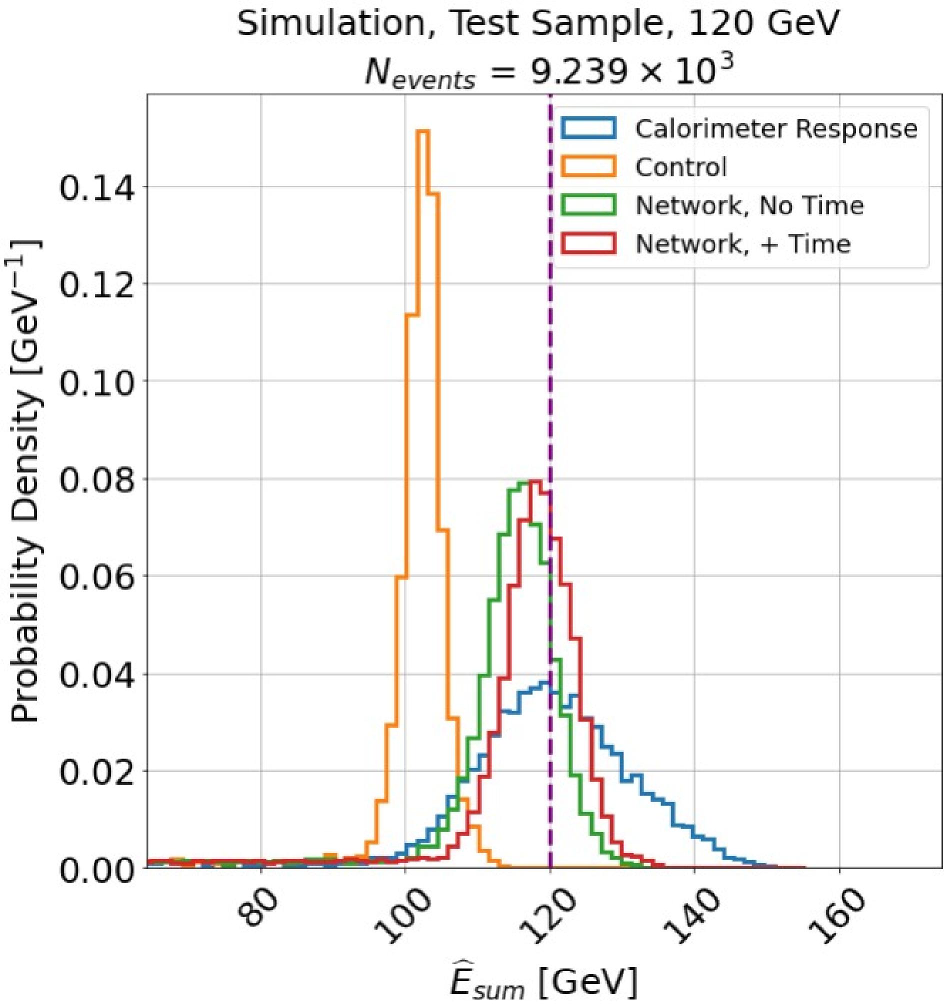
Jack Rolph: energy resolutions



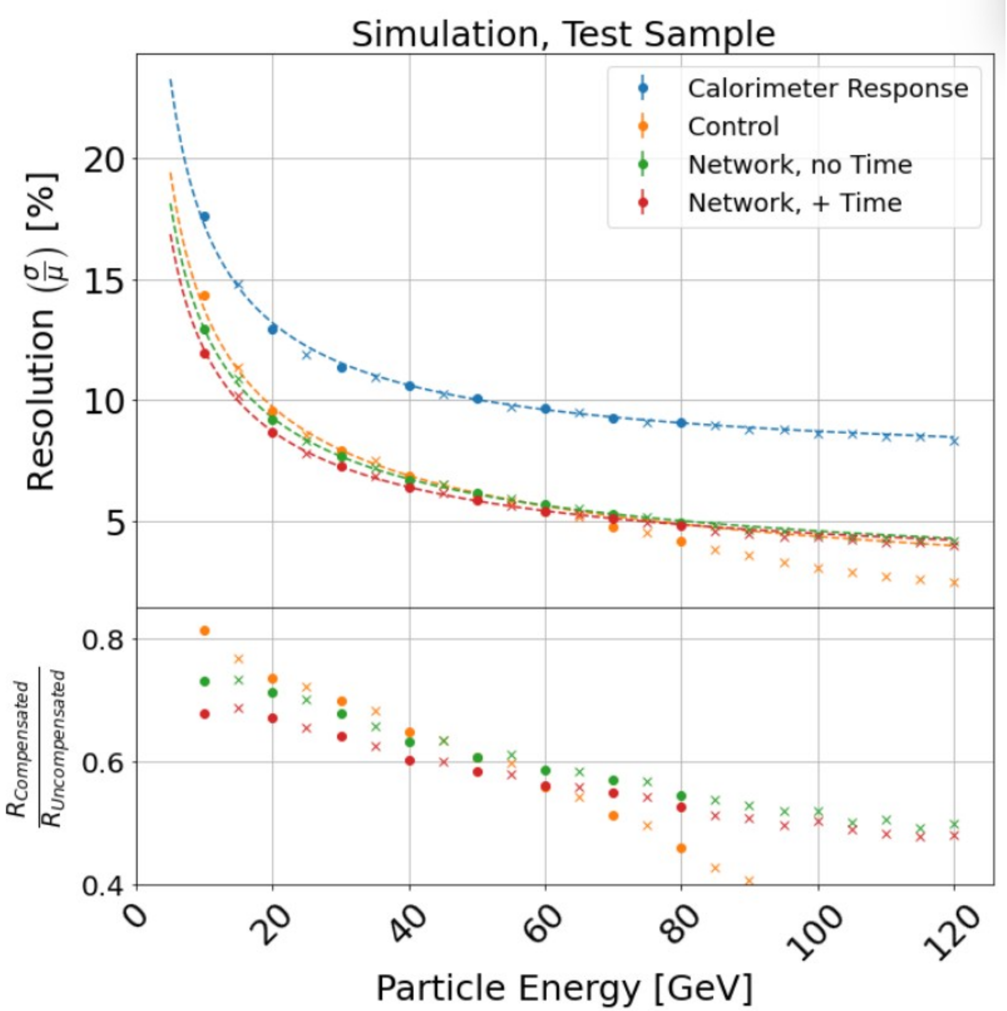


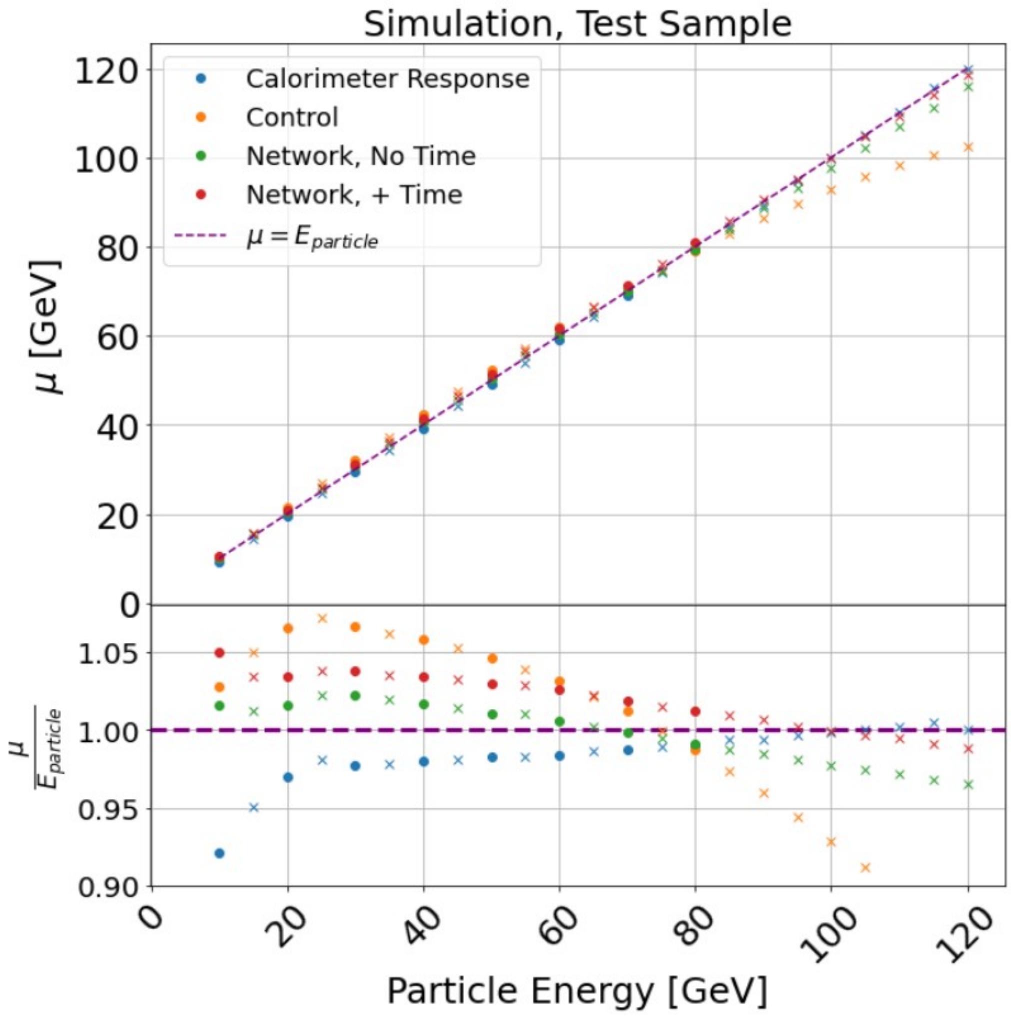
Jack Rolph: energy resolutions





Jack Rolph: resolution and linearity





Jack Rolph: conclusion on software compensation

	a [%]	b [%]	χ^2/NDF
Calorimeter Response	49.516 ± 0.401	7.147 ± 0.067	4.575
Control	43.387 ± 0.119	0.010 ± 2.873	14.333
Network, no Time	40.236 ± 0.217	2.158 ± 0.087	0.857
Network, + Time	37.275 ± 0.208	2.448 ± 0.070	1.440

Timing gives:
3% improvement in the stochastic term
for pion energy resolution using DGCNN

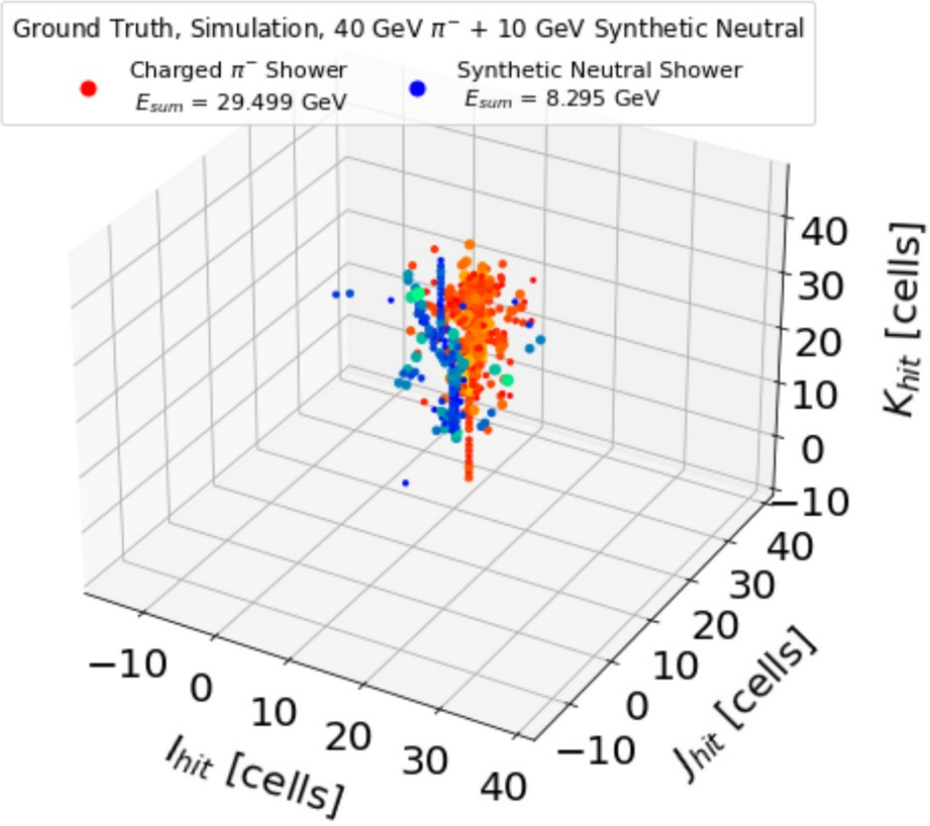
Jack Rolph: shower confusion

Shooting: pions + syntetic neutral
10 GeV to 100 GeV energies

Detector: CALICE AHCAL
tot: 72x72x 38 layers (x/y/z)
cells: 3x3cm Sc+SiPM / stailess steel (~17 mm)

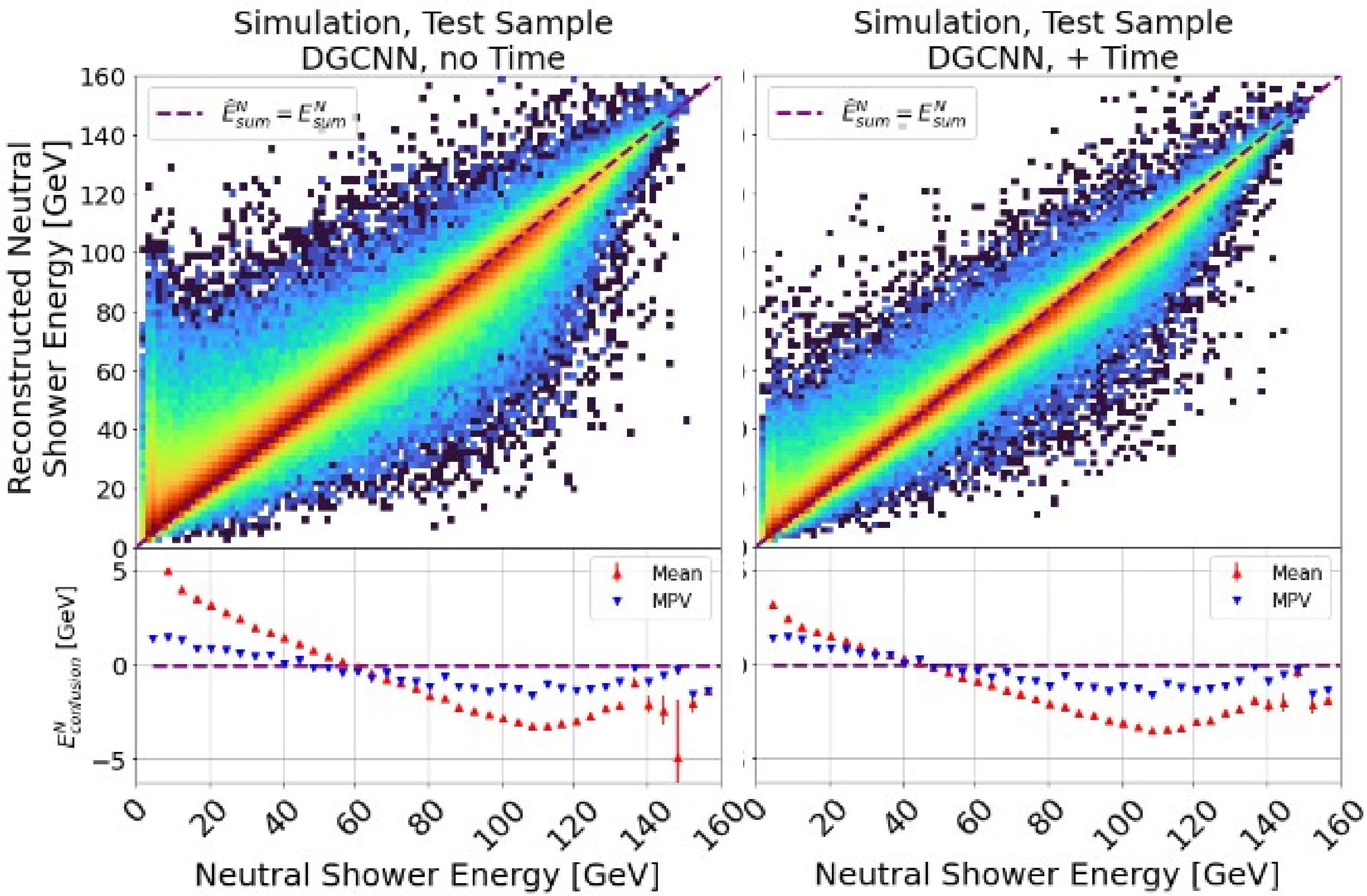
Shower separation: ~~PointNet~~ – didn't improve with time
DGCNN
GravNet

Time resolution: 100 ps

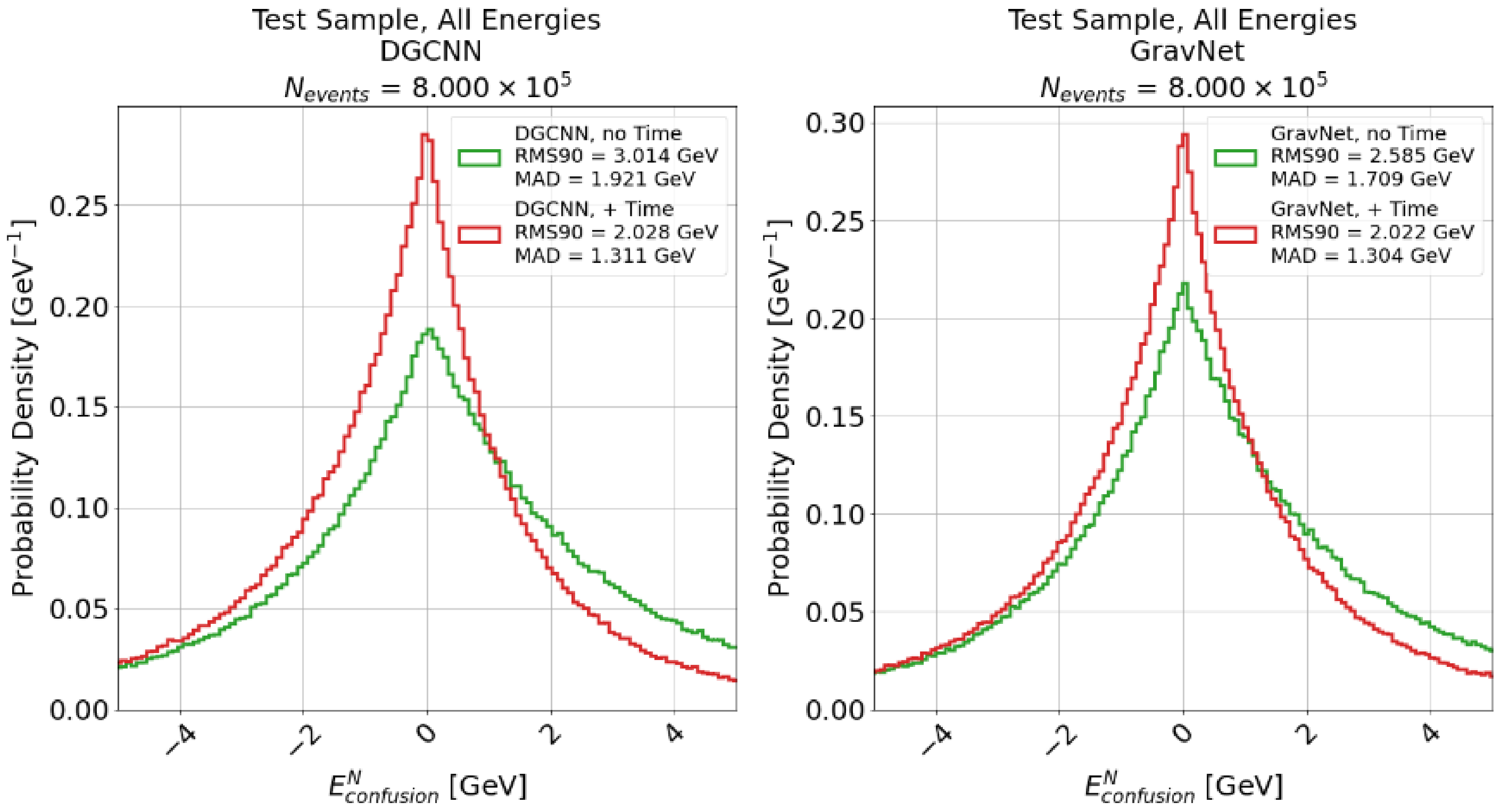


Jack Rolph: shower confusion

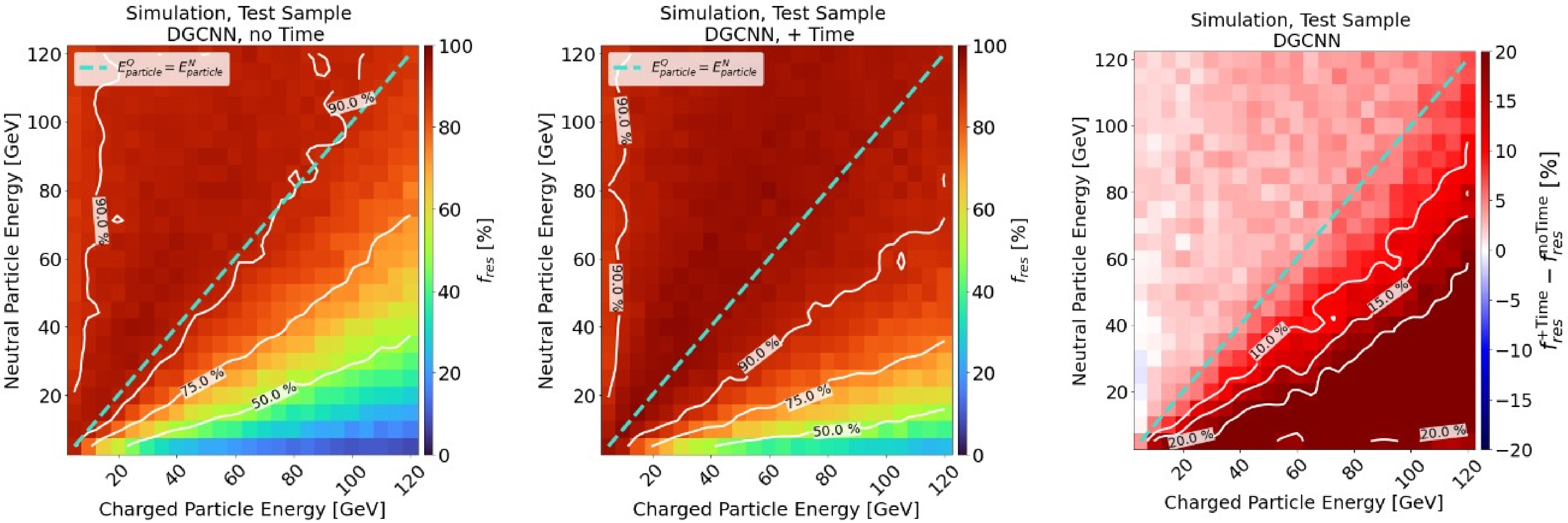
*GravNet shows similar results



Jack Rolph et al: shower confusion

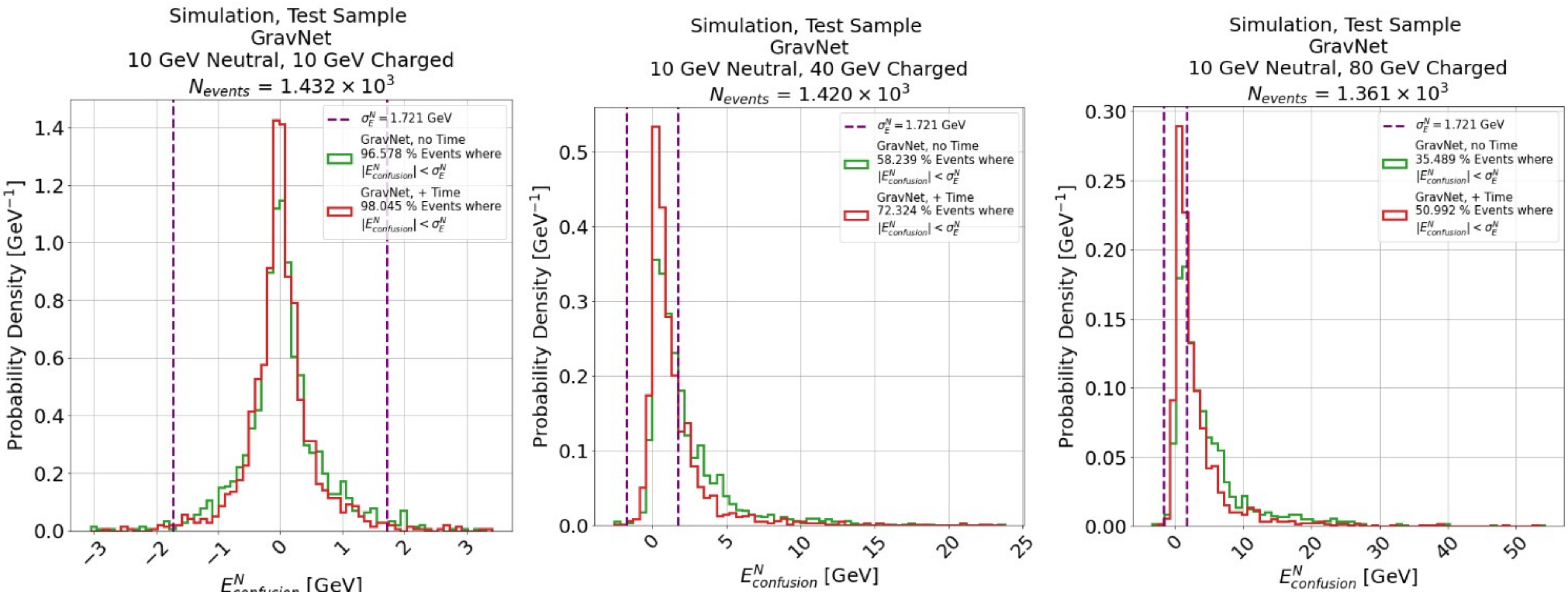


Jack Rolph: shower confusion



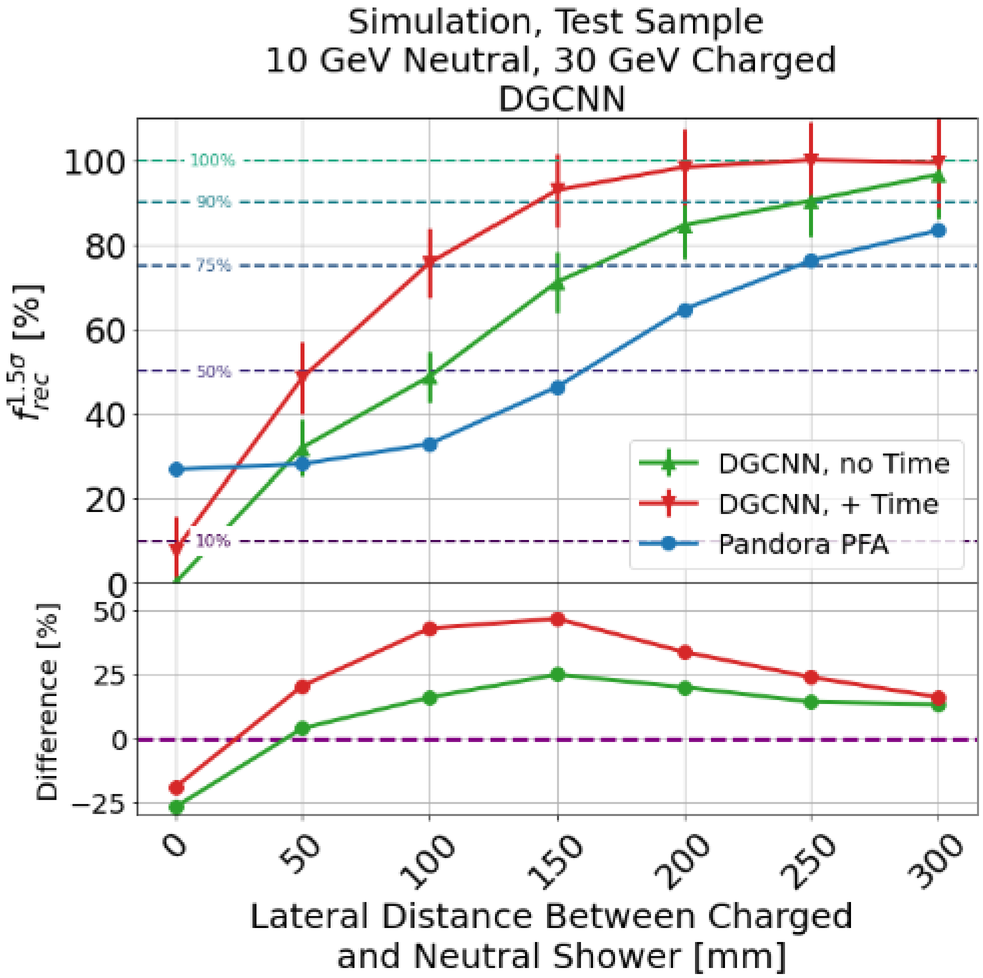
Timing gives up to 20% improvement when neutral shower is lower energy than charged shower

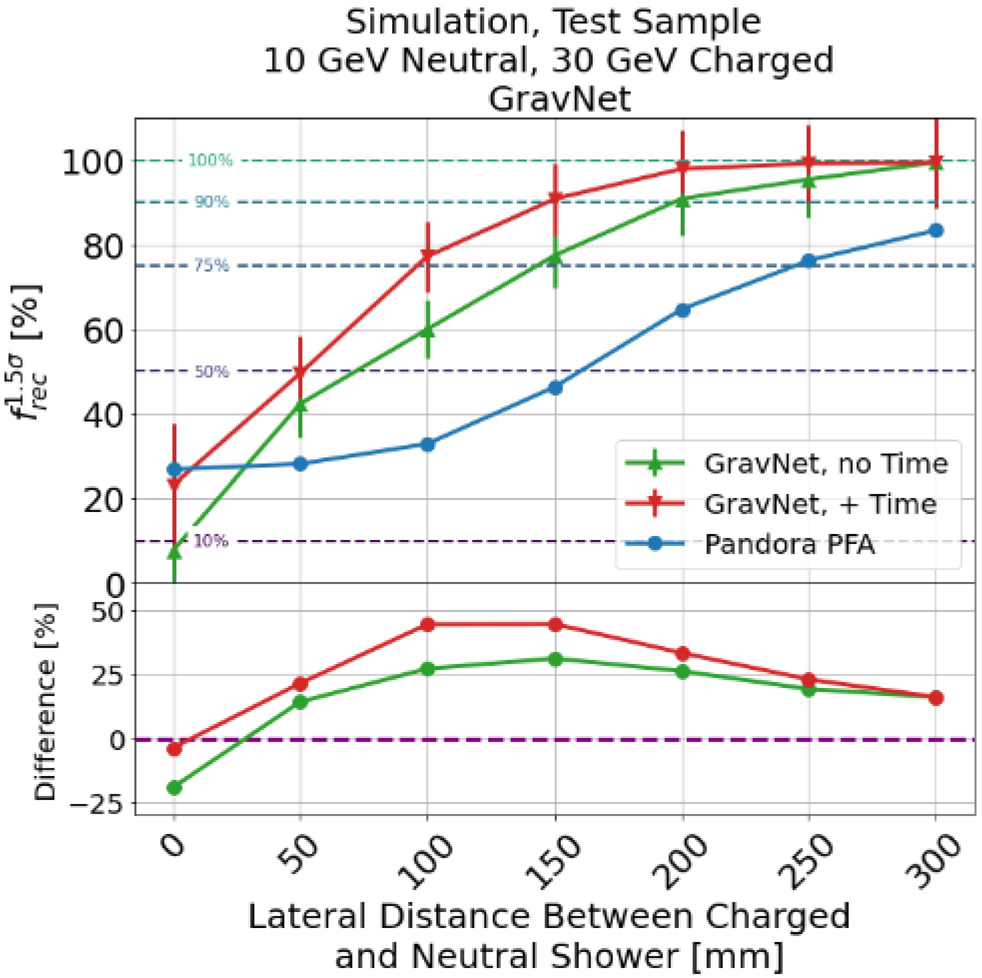
Jack Rolph: shower confusion



*20% meant fraction of particles in violet margins

Jack Rolph: shower confusion





Jack Rolph: conclusions

- Very interesting thesis!
- State-of-the-art machine learning techniques
- Well documented

Software compensation with timing:

stochastic term stochastic term is 3% improved

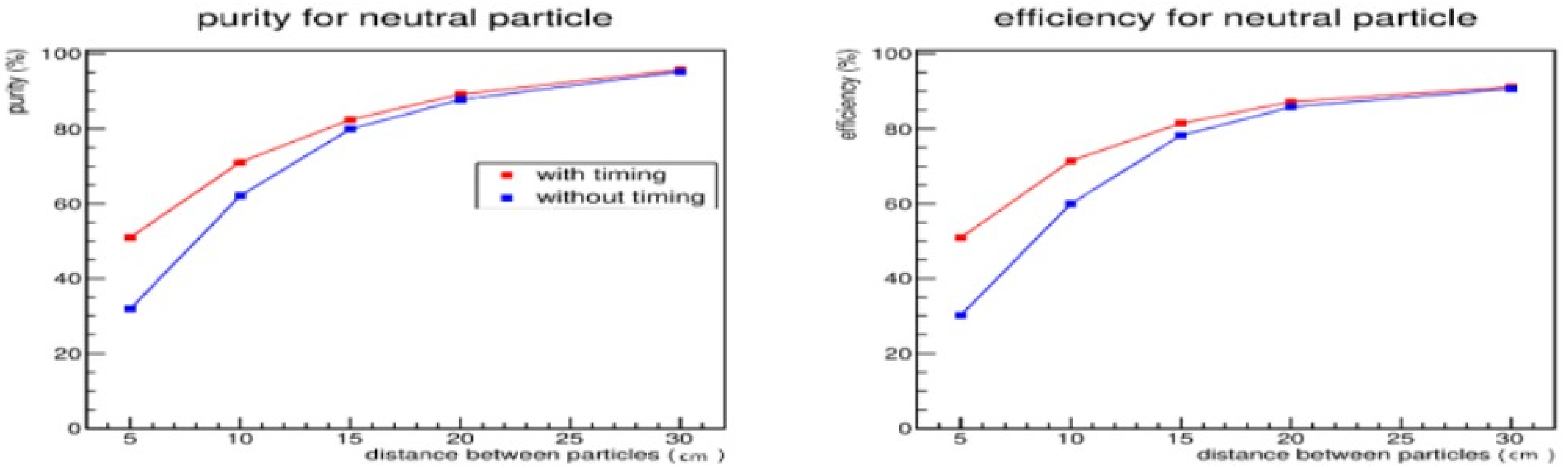
Shower confusion with timing:

up to 20% more cases when neutral shower
is reconstructed within HCAL energy uncertainty

Other mentions

TSDHCAL

In addition, we found that time information could improve significantly hadronic showers separation at lower distances. 1 time resolution of 100-150 ps seems sufficient to achieve a good separation at small distances.



- From TSDHCAL talk in WP1 parallel during DRD6 collaboration meeting
- Something is going on, but no link to publication/details...

Manqi Ruan preprint

One-to-one correspondence reconstruction at the electron-positron Higgs factory

Yuexin Wang[1,2], Hao Liang[1,3,4], Yongfeng Zhu[5], Yuzhi Che[1,3], Xin Xia[1,3], Huilin Qu[6], Chen Zhou[5], Xuai Zhuang[1,3], Manqi Ruan[1,3*]

General comments:

- very hard to read/understand
- I am skeptical

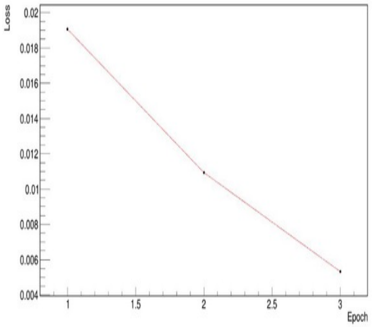
True \ Predicted	$e^\pm$	$\mu^\pm$	$\pi^\pm$	$K^\pm$	$p/\bar{p}$	γ	K_L^0	n	$\bar{n}$	others
$e^\pm$	0.999	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\mu^\pm$	0.000	0.985	0.015	0.000	0.000	0.000	0.000	0.000	0.000	0.000
$\pi^\pm$	0.000	0.019	0.977	0.003	0.000	0.000	0.000	0.000	0.000	0.000
$K^\pm$	0.000	0.001	0.003	0.985	0.011	0.000	0.000	0.000	0.000	0.000
$p/\bar{p}$	0.000	0.000	0.001	0.012	0.979	0.000	0.000	0.000	0.000	0.008
γ	0.000	0.000	0.000	0.000	0.000	0.973	0.003	0.004	0.000	0.020
K_L^0	0.000	0.000	0.000	0.000	0.000	0.007	0.756	0.070	0.048	0.119
n	0.000	0.000	0.000	0.000	0.000	0.003	0.083	0.803	0.027	0.084
$\bar{n}$	0.000	0.000	0.000	0.000	0.000	0.003	0.052	0.026	0.796	0.123
others	0.000	0.000	0.000	0.000	0.000	0.014	0.025	0.095	0.011	0.854

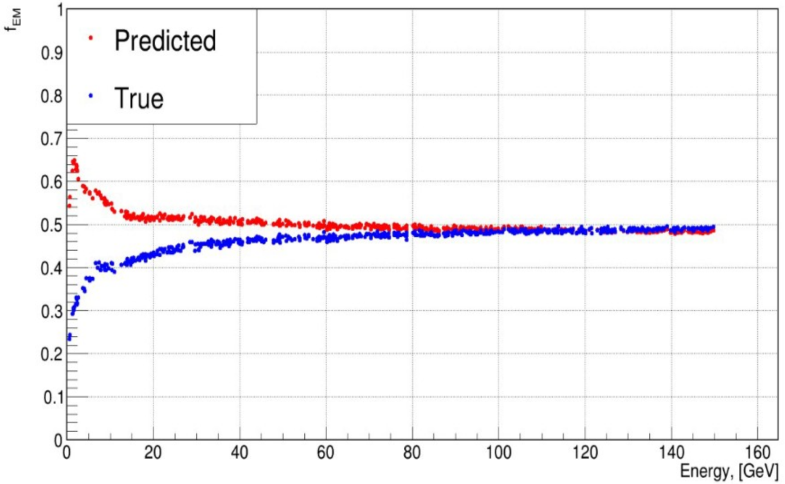
- Full detector simulation (modified CEPC baseline → AURORA)
- ARBOR reconstruction + Particle Transformer (?)
- **Assume 100 ps time res. in ECAL+HCAL** (?) | Hit time spectrum (the fastest time and quintiles)
- e+e- → ZH → invisible (H→gg) @ 240 GeV

Yevhenii Padniuk master thesis

Topic: software compensation using ML (w/o timing)
(similar to Akchurin paper / Jack Rolph thesis)
but reconstructing f_{EM} directly

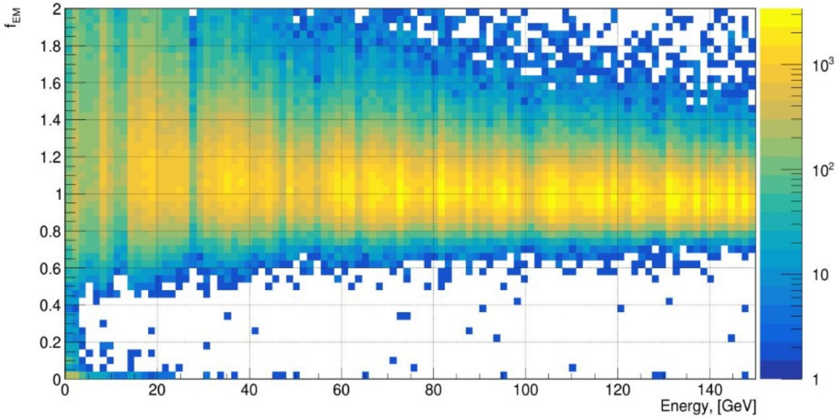
- Shooting: pions 0 – 150 GeV energies





Differences:

- Use full detector, not only HCAL!
- Quite simple CNN is used with 50x50x50 grid
  Not the state-of-the-art like Jack's PhD thesis



- Prospects for us: follow up including time

- General comment: no conclusive results

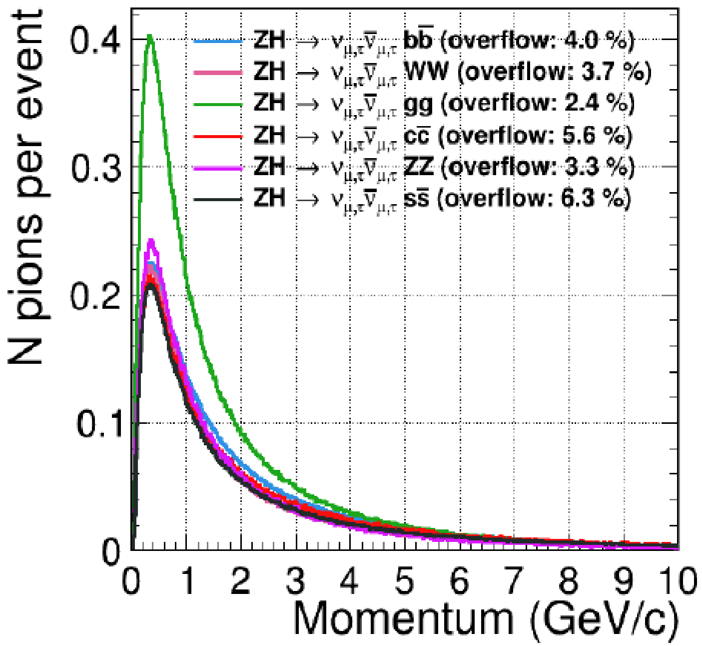
Summary

- Conceptual studies show clear advantage of timing for SC & shower separation

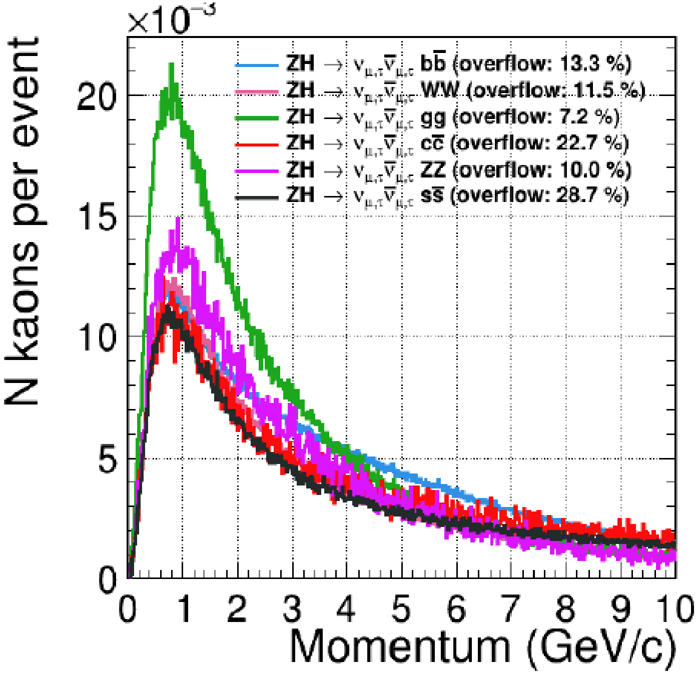
How to translate that to physics?

- different angles (not always perpendicular to the surface)
- busy events (not 1-2 showers per event)
- ECAL+HCAL (not only HCAL)
- Low momentum (below 10 GeV)

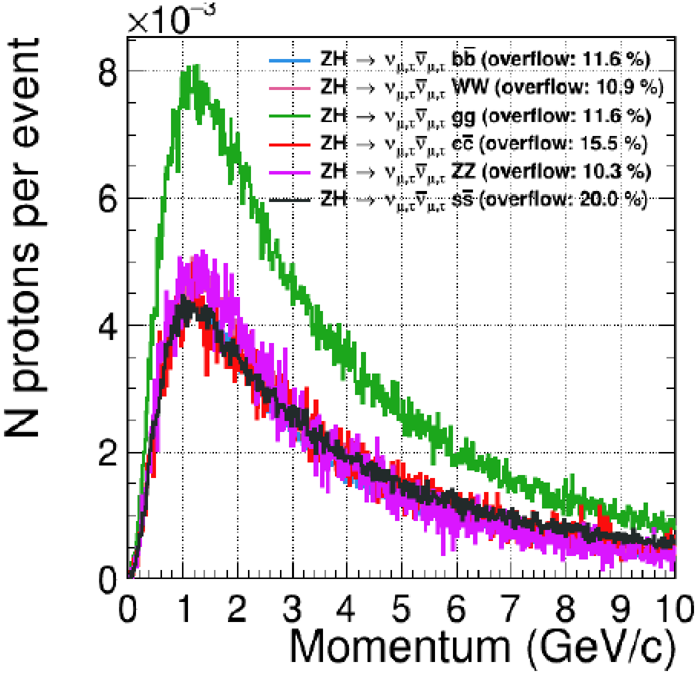
Generated momentum spectrum ZH@250GeV



94-98% pions



70-90% kaons



80-90% kaons

are generated below 10 Gev/c momentum

typically 1 data point in studies above

How do we start

Physics samples, e.g. ZH@250GeV vs single particles?

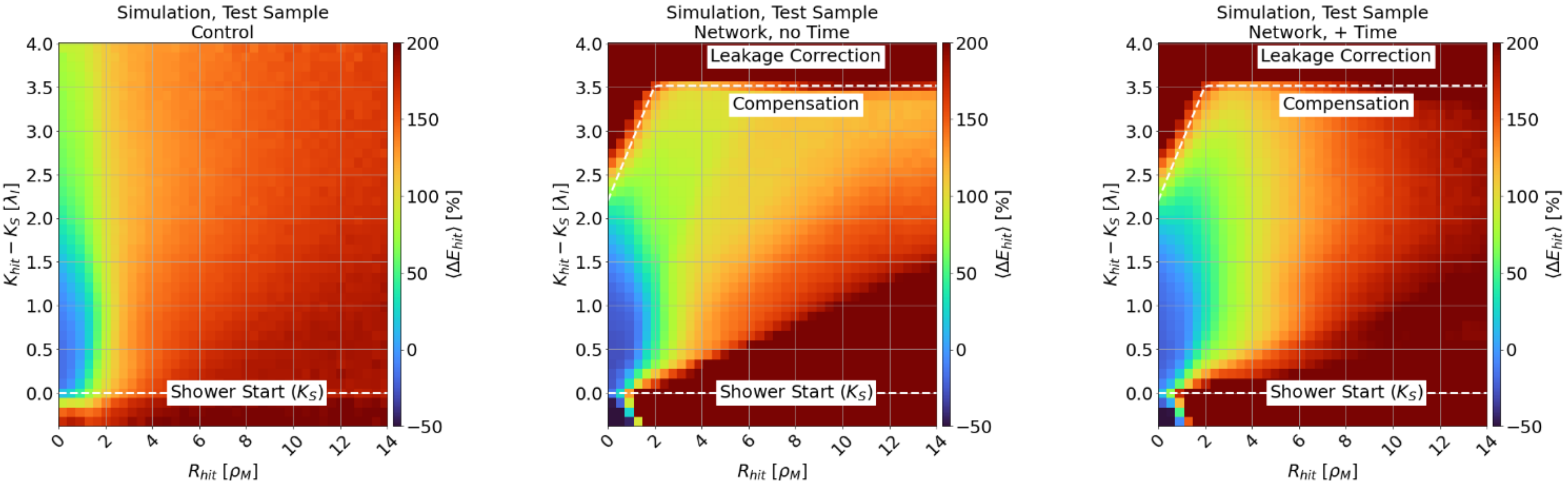
Developing ML vs Tweaking Pandora vs …

Yevhenii follow-up vs Jack follow-up vs …

f_{EM} vs energy resolution vs jet resolution vs …

Back up

Back up: Jack Rolph et al: software compensation weights



time reslution is unclear. Might be

Back up: Akchurin EM fraction (CNN, no timing)