TTU Report

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The IDEA Dual-Readout Calorimetry Meeting, Feb-2023

01-Feb-2023 https://indico.cern.ch/event/1248301/

Update on HiDRa module construction,	Gabriella Gaudio
Report on ECFA Calorimetry DRD process,	Robert Ferrari
Hadronic energy resolution with GNN	Shuichi Kunori
Update on test beam (2021) paper	Giacomo Polesello

ECFA European Strategy Update

Status and Plans for Calorimetry DRD

DRD TF6+ Task Force

Martin Aleksa, Etiennette Auffray-Hillemanns, Dave Barney, *Roberto Ferrari*, Gabriella Gaudio, Roman Pöschl, Felix Sefkow, Frank Simon, Tommaso Tabarelli de Fatis

Roberto
February 1st, 2023

Implementation of TF6 Calorimetry
https://indico.cern.ch/event/1213733/

First Meeting, 12-Jan-2023
https://indico.cern.ch/event/1212696/

ECFA

Towards Implementation of DRD Calorimetry (2)

European Strategy Update

- Debriefing of 1st Calorimeter Community Meeting on Jan 19

- Proposal phase until July 1s, 2023 (officially launch it on next weekend):
  - Quite exhaustive picture for input proposal drafting already from 1st community meeting talks

  - Collect input (until April 1st)
    - Proposal team will contact stakeholders
    - Contact persons assigned for different topics (i.e. conveners and speakers of 1st c.m.)

  - 2nd community meeting on April 20th
    - Presentation of input proposals (w/o disclosing confidential information)
    - Presentation of proposed WP Structure of DRD Calorimetry

      → NOT reinvent wheel: learn from existing R&D collaboration experience

  - Input proposals condensed into DRD Calorimetry Proposal until (about) June 1st
    - Further iterations with stakeholders, community and higher level bodies

ECFA

Final remarks

European Strategy Update

- Few points:
  - Non-European groups declared interest (need to keep them fully on board)

    → explicit support expressed by DoE person ←
  - Must be sure no one is forgotten and no important topic is missed

  - Many synergies to be exploited both internally to Calo DRD and wrt other DRDs
  - Continuous and effective communication is crucial

  - Communication:

    News will be spread through mailing function of DRD-Calo indico page

    Setting up dedicated DRD-Calo work environment

- ***Finally: very positive and constructive attitude of all players***
  - ***DRD process looks to be felt as opportunity to foster progress***

Challenge in Hadron Calorimetry

(from sk's talk on 01-Feb-2023)

❖ Invisible energy:

In hadron-nuclei interactions, large fraction of hadron energy is transferred to mass of secondary hadrons and becomes invisible in calorimeter. We need to estimate the invisible energy from visible quantity.

- Compensation using slow neutrons
- Dual Readout using R=Scintillation/Cherenkov
- Vertex Imaging using ML technique in high granularity calorimeter

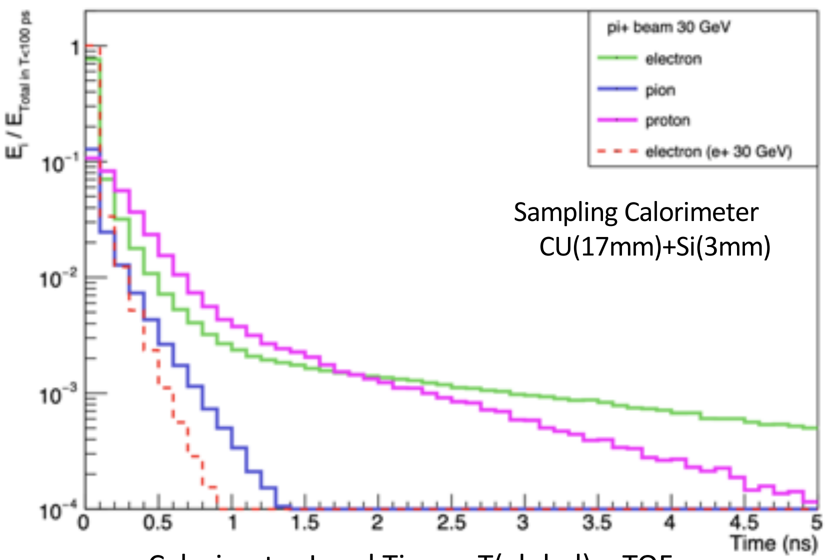
❖ Large volume:

Very high granularity pushes the cost up quickly as the granularity increases.

- 3D readout: CMS HGCAL, CALICE
- 2D readout: Fiber calorimeter with longitudinal segmentation with timing

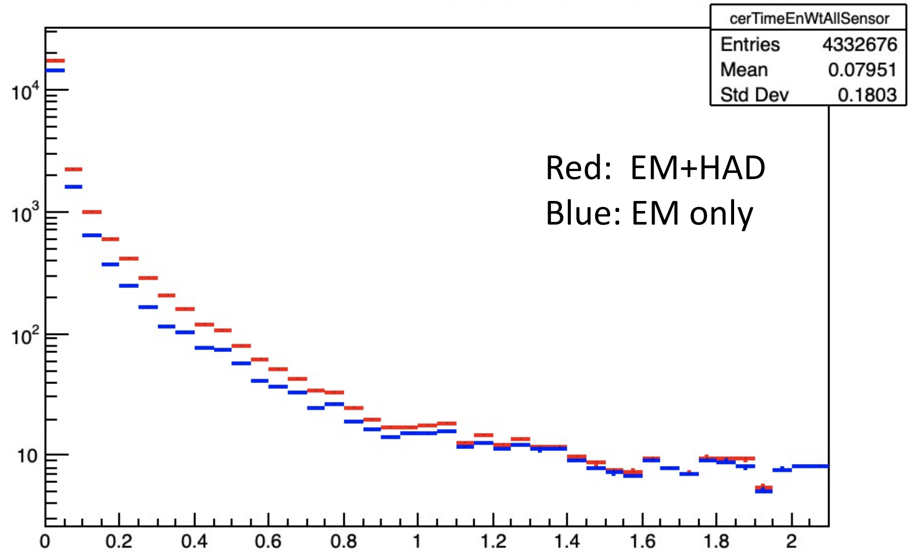
Vertex Imaging using Fast Components of Shower

dEdx (ionization) signal (< 5 ns)



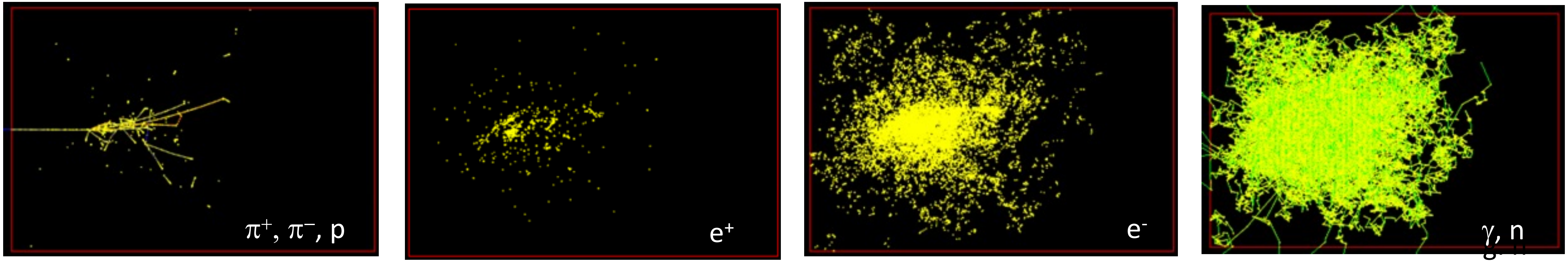
Calorimeter Local Time = T(global) – TOF

Cherenkov Signal (< 2ns)



TOF = z/c

Particles in a hadronic shower in a solid Cu block (1x1x1.5 m^3) for 30 GeV π+



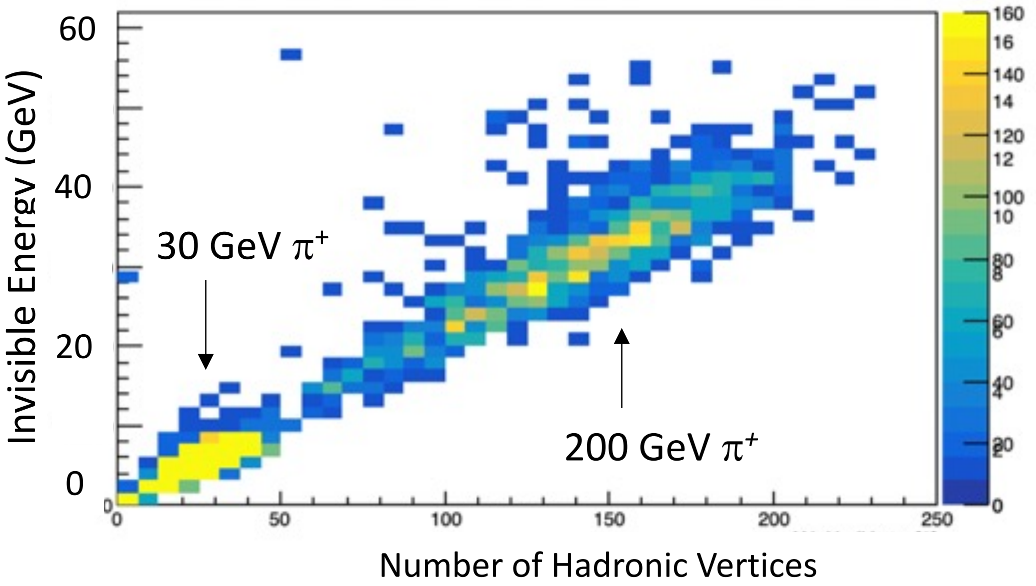
FAST components

SLOW components

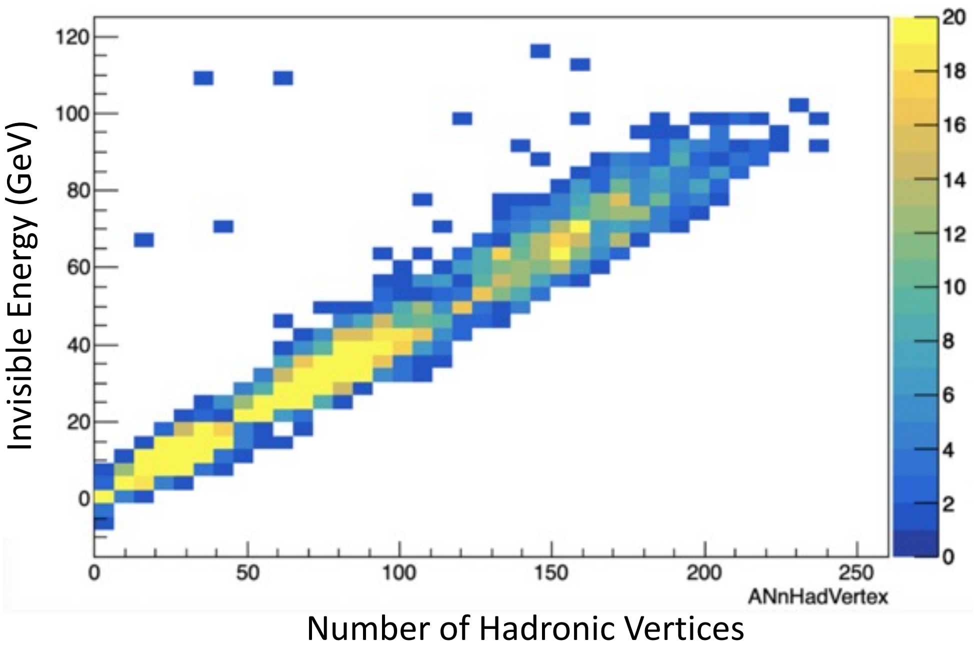
Invisible Energy in Cu vs Number of Hadron Vertices (G4 truth)

Total invisible energy of hadronic shower increases with the number of hadronic vertices.

Fast dedx signal (t<5ns) (silicon)



Cherenkov (t<2 ns)

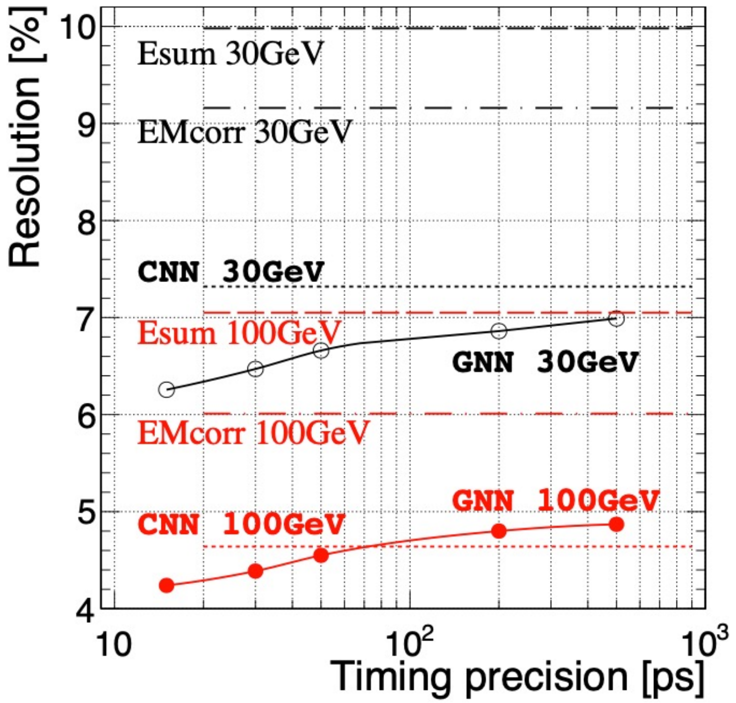


(Invisible Energy) = (Beam Energy) – (Observed Energy)

(Hadronic Vertices) = (hadron inelastic interaction vertex) excluding neutron interactions dE/dx (ionization) Calorimeter [ref 1]

20x20x20 mm^3 cube
Cu (17) +Si (3)

CNN: 0-5 ns 1 image/cube
GNN: 0-10 ns 8 images/cube



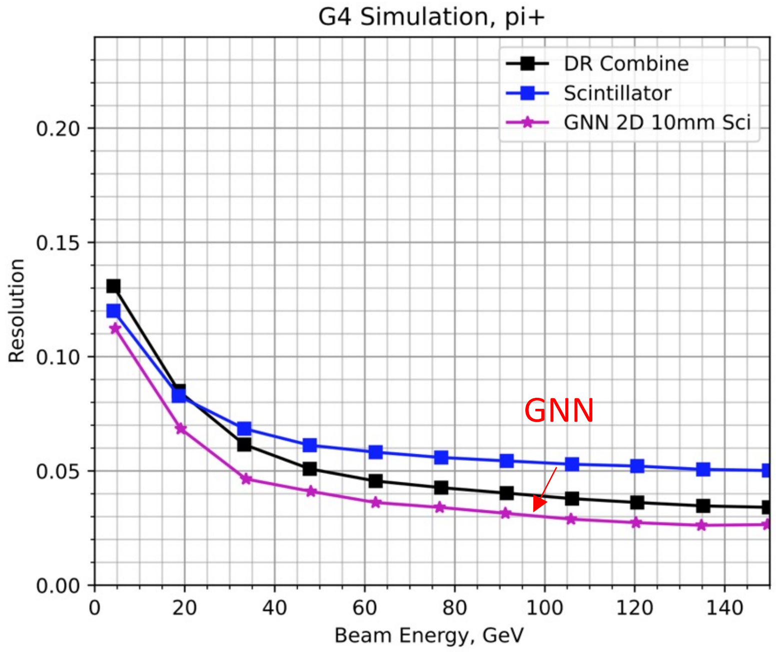
NN trained with pi+ works well for electrons/photons and jets.

Dual Readout Fiber calorimeter [ref 2]

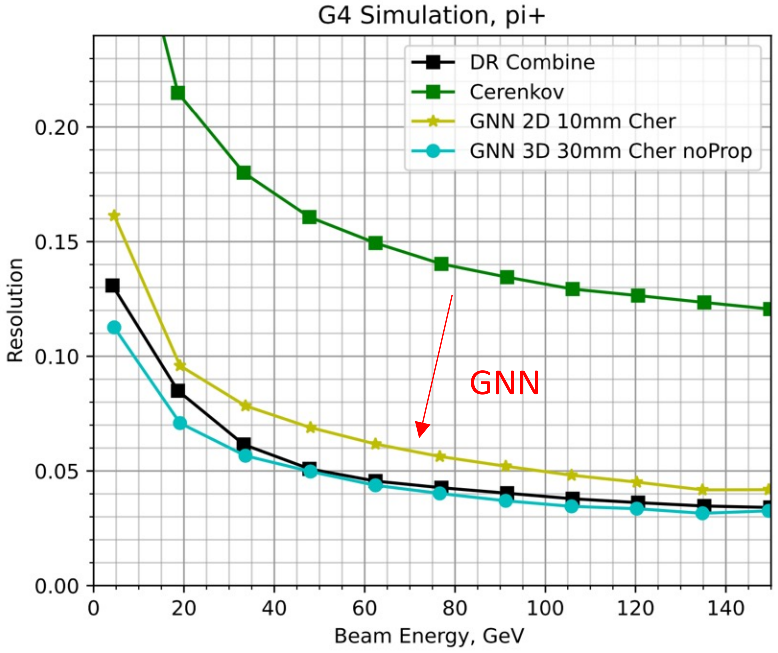
No optimization.

Cu absorber (2 m deep)
Fibers along beam direction
1 mm ϕ fibers, 1.5 mm spacing, 34%
Transverse segmentation:
1x1 cm^2 for 2D analysis, 3x3 cm^2 for 3D analysis

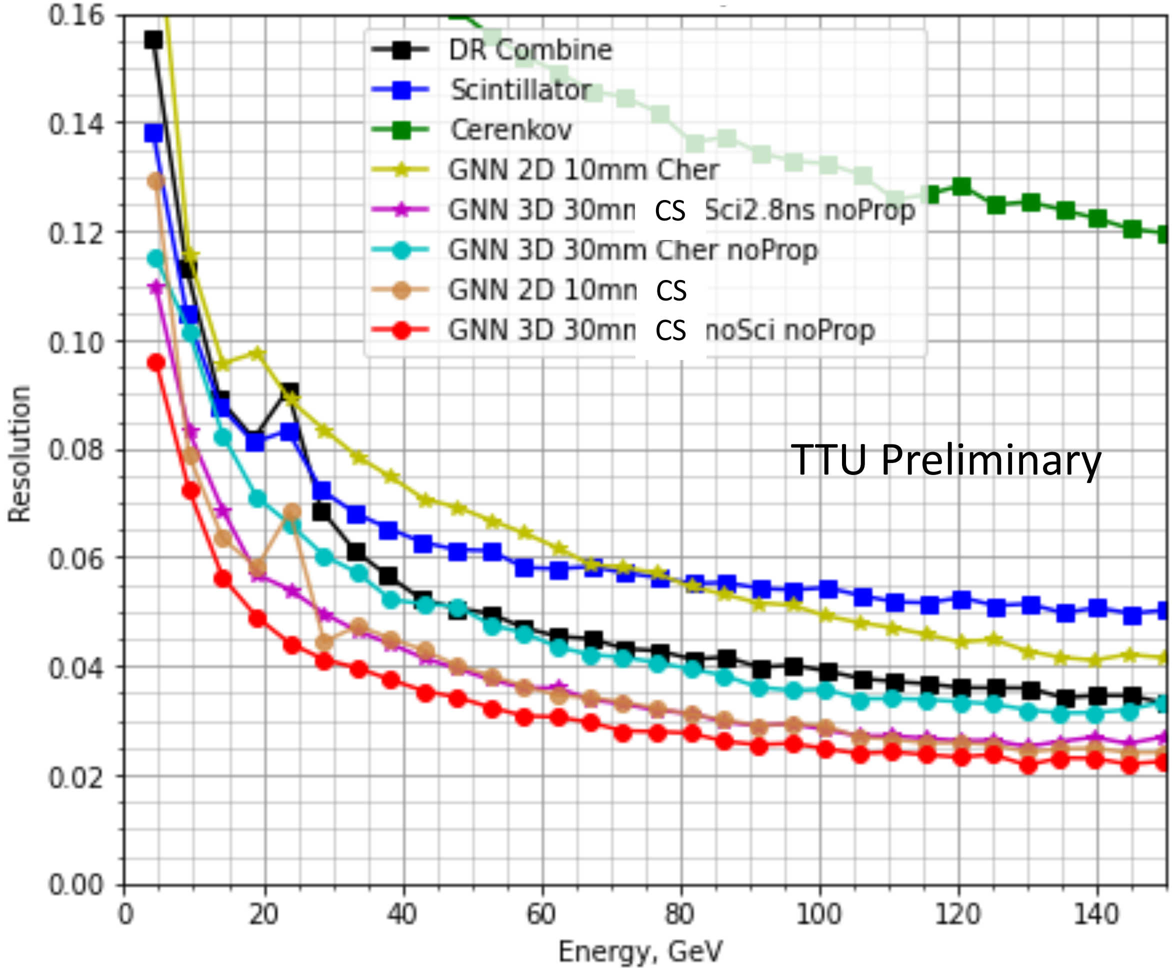
scintillation



Cherenkov



Potential of Fiber Calorimeter



Resolution at 100 GeV

a) DualReadout	3.9 %	black
b) C+C (3D)	3.6 %	light blue
c) C+S (3D)	2.5 %	red
d) S+S (3D)	? %	

Note:

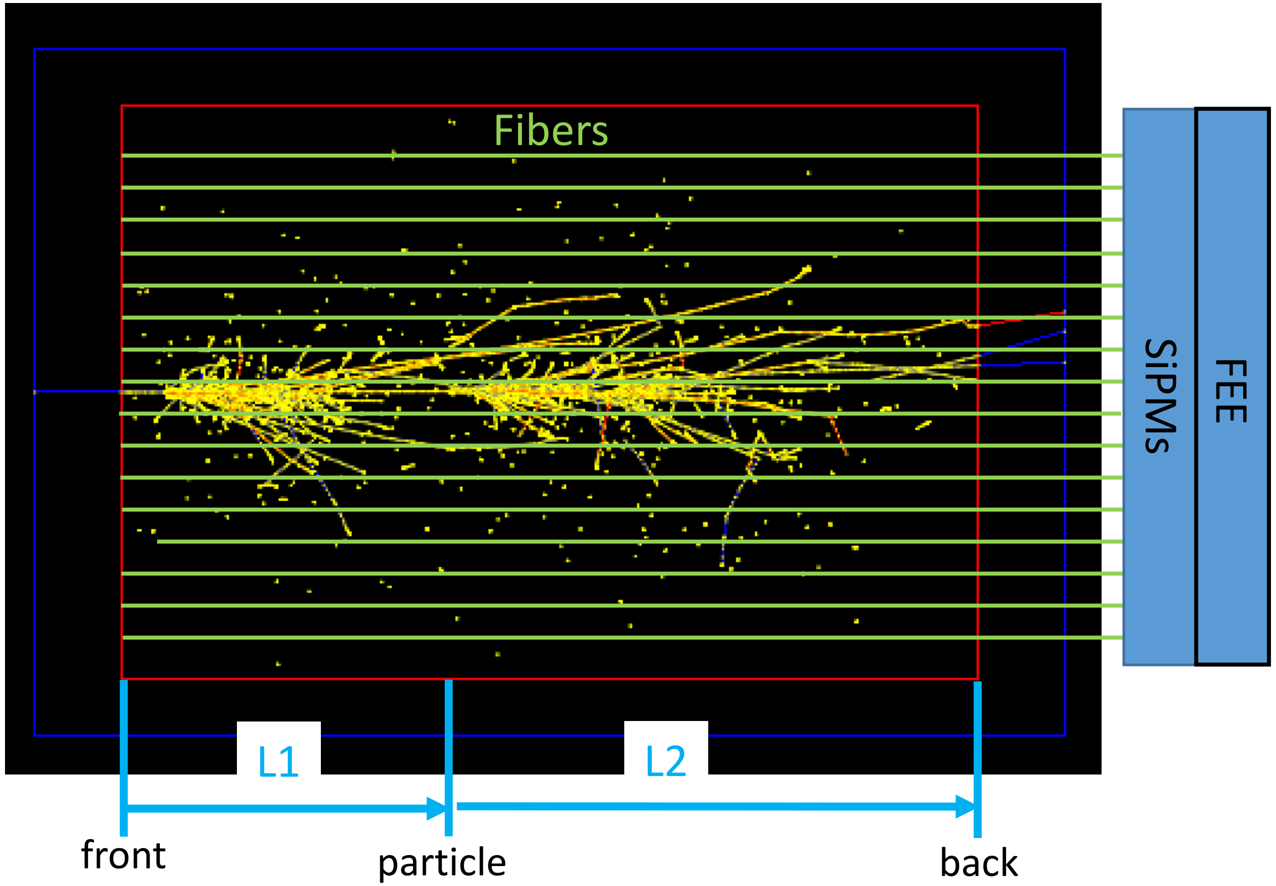
- Z-positions from G4 Truth (no propagation, no smearing)
- 2D hits may saturate in jet
- S-decay time 2.8 ns slow for 3D
- C-signal may provide the timing resolution O(10ps)

Approaches to get c) C+S (3D):

- longitudinal segmentation

1) Software – pulse shape analysis with FFT, NN
2) Hardware – SPAD array/fast FE/new fibers

Cherenkov Fiber Calorimeter: Longitudinal Segmentation with Timing



Signal Time = L1/c + L2/kc,
c = velocity of particle
kc = velocity of light in fiber (k~0.6)

- 2D readout: Fewer readout channels
- SiPM, readout electronics on backside: Lower radiation environment
- Easier calibration, no need to calibrate in depth
- Longitudinal Segmentation:

Δt=150 ps, corresponding to Δz =7 cm along fibers. (~1/3 λ)

Timing Resolution	σ/E @ 100 GeV
0 ps	3.6 %
100 ps	3.9 %
150 ps	4.0 %
200 ps	4.2 %

TTU Status: Feb 2023

CAEN FERS readout system with 64-ch SiPM array is working well. The objective to use this system with the refurbished dual-readout fiber hadronic calorimeter. (see Sonaina's report in November).

We are in construction of 2-meter long (4.4 cm x 4.4 cm) copper absorber structure with embedded quartz fibers. We will use this detector for "bench-top" pulse shape and timing studies.

We simulated the original DREAM module with modified readout scheme for high granularity and started testing the energy reconstruction with GNN. → Very positive result.

We are working on various designs and 3D printed prototypes for the optical coupling of fibers to SiPMs.

We are developing conceptual design of fast SiPM readout system for "Longitudinal Segmentation with Timing". → SPAD array with 3D-chip readout system. O(10 ps) timing resolution with Cherenkov fibers.

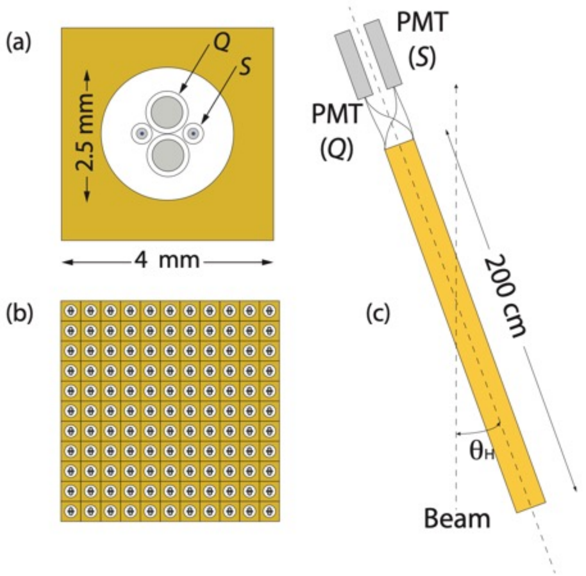
We are studying various methods to get the ultimate performance with the (C+S) fiber configuration.

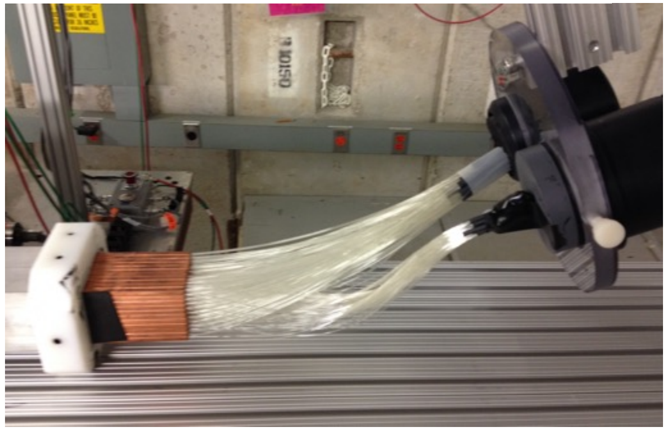
Beam tests

Refurbish two old prototype modules with SiPMs for beam tests.

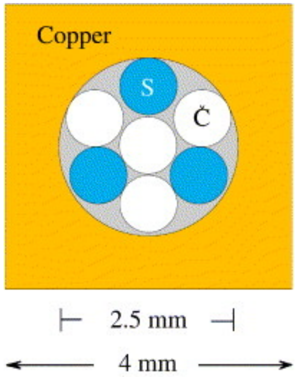
Goal:
1. Verify Cherenkov calorimetry with NN
2. R&D of fast SiPM and readout

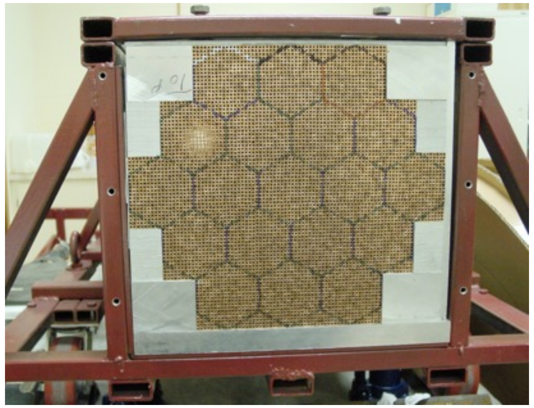
[1] Module-1





[2] Module-2 (DREAM module)





36 x 32 x 200 cm^3
1000 kg

5130 rods (total)

3x3 rods/tower
➔ 324 ch
(in 21.6 x 21.6 cm^2)

[1] https://iopscience.iop.org/article/10.1088/1748-0221/13/04/P04010
[2] https://www.sciencedirect.com/science/article/pii/S0168900204018091

Additional Slides

References

[1] On the Use of Neural Networks for Energy Reconstruction in High-granularity Calorimeters
N. Akchurin, C. Cowden, J. Damgov, A. Hussain, S. Kunori
arXiv:2107.10207, 2021_JINST_16_P12036

[2] The (Un)reasonable Effectiveness of Neural Network in Cherenkov Calorimetry
N. Akchurin, C. Cowden, J. Damgov, A. Hussain, S. Kunori
CALOR 2022, 20-May-2022, *Instruments* **2022**, *6*(4), 43; https://doi.org/10.3390/instruments6040043

[3] Value of Timing in Calorimetry
N. Akchurin, C. Cowden, J. Damgov**, A. Hussain**, S. Kunori
CALOR 2022, 19-May-2022,

[4] Dynamic Graph CNN for Learning on Point Cloud
Y. Wang, Y. Sun, Z. Liu, S. E. Sarma, M. M. Bronstein, J. M. Solomon
arXiv:1801.07829

[5] Longitudinal Segmentation of Multi-readout Fiber Calorimeters by Timing for 3D Imaging Calorimetry
N. Akchurin, C. Cowden, J. Damgov, A. Hussian, **S. Kunori**
CPAD Instrumentation Frontier Workshop 2021, March 18-22, 2021
https://indico.fnal.gov/event/46746/contributions/210063/

Conclusions

- High granularity Cherenkov calorimeter and ML technique provide very fast and excellent performance to future experiments.
  - Granularity: a Moliere radius (transverse) and 1/3 interaction length (longitudinal)
  - GNN training: Input (E_{Cher}, x, y, z) in cells and target (Ebeam)

- Longitudinal segmentation with timing of Cherenkov lights will be a cost-effective way to build a calorimeter for 3D GNN energy reconstruction.
  - Fast photo detectors (SiPM) and high-performance readout are required [2][3][5].

- Prototype calorimeter with 2D readout in beams verifies Cherenkov calorimetry with GNN.

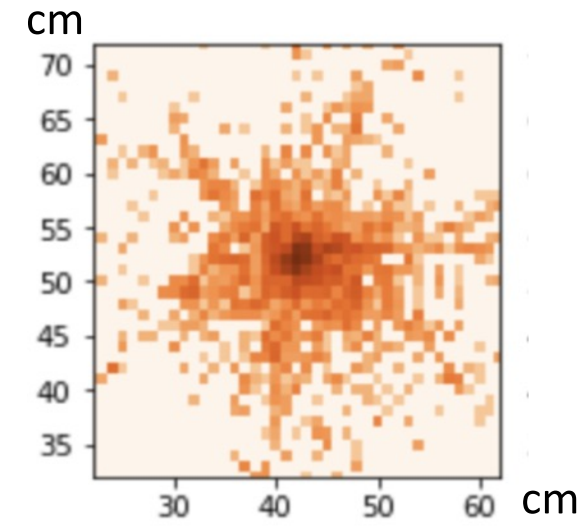
- Vertex Imaging in space and time domain with NN techniques looks promising. CNN and GNN have been used so far. We continue studying NN technique for hadron calorimetry and develop calorimeter designs that match with the new technique.

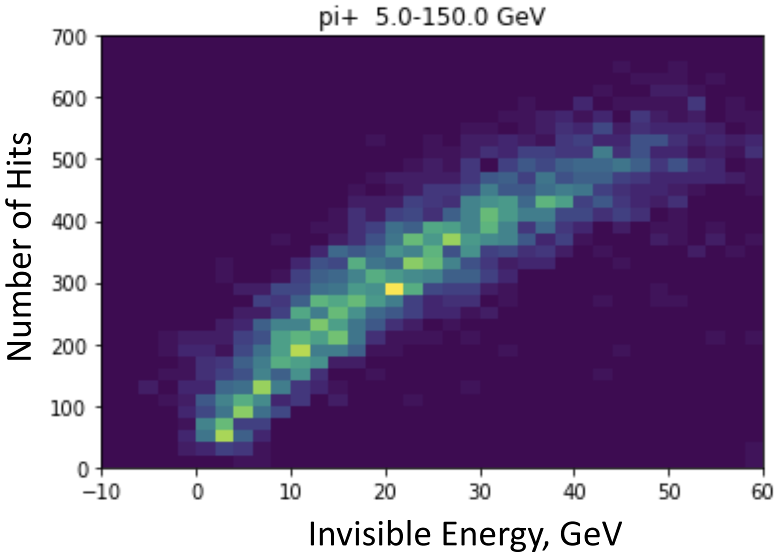
Invisible Energy vs Number of Cherenkov Hits in 2D (x,y)

(Invisible Energy = Beam Energy – Cherenkov Signal)

Hit map of log(E)
In 40 x 40 cm^2 area
(grid 1 x 1 cm^2)

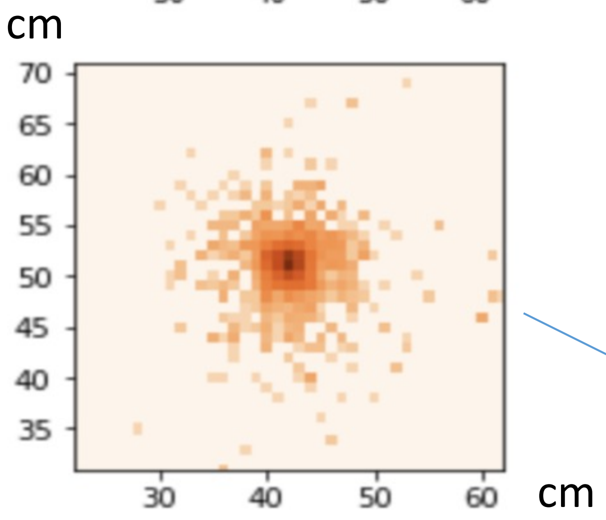
Beam 126 GeV
Inv. energy 53 GeV

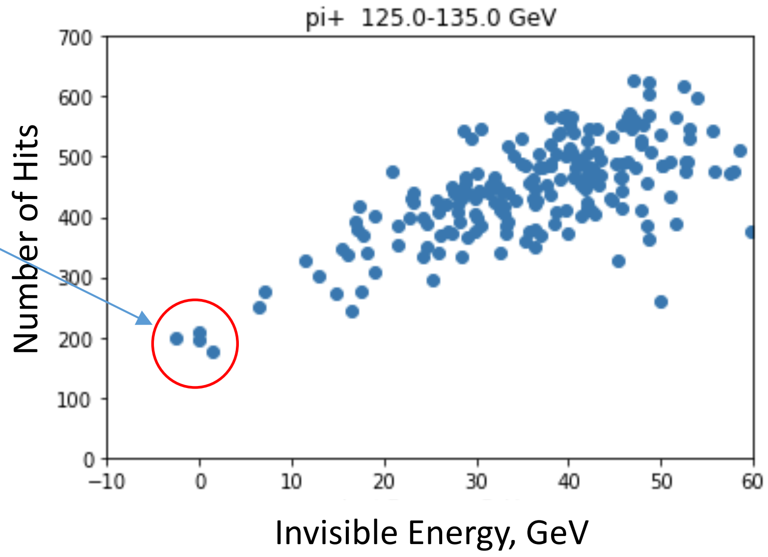




Invisible energy depends on the number of hits in 2D hit map.

Beam 127 GeV
Inv. energy 1 GeV

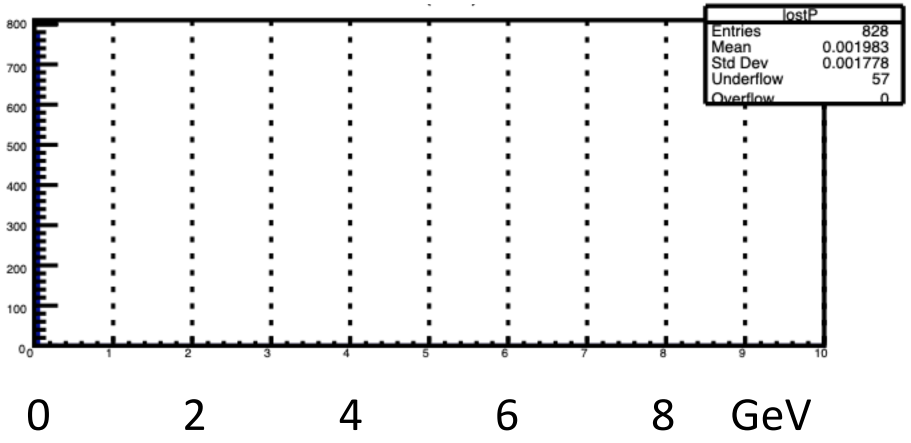




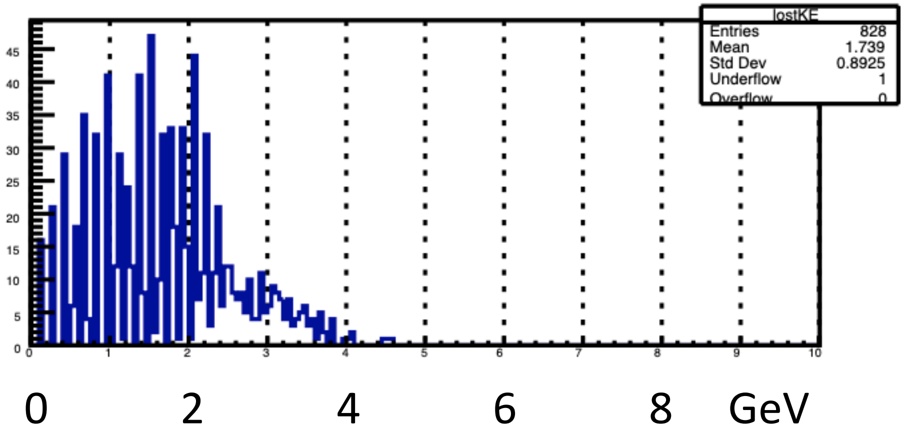
GNN analyzes this heat map (not only the hit counts) for estimation of the lost kinetic energy.

Kinetic Energy Loss in single 30 GeV π^+ + proton inelastic interaction

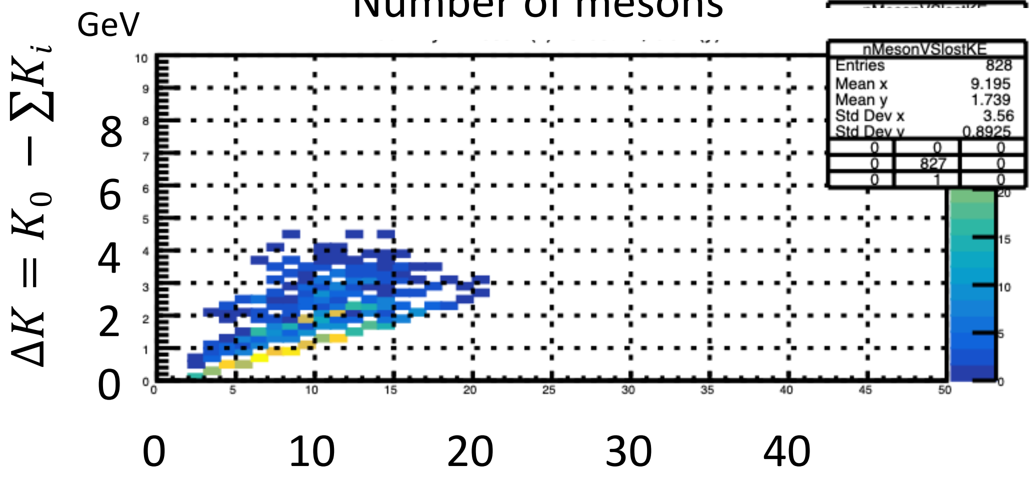
$\Delta P = P_0 - \sum Pi$



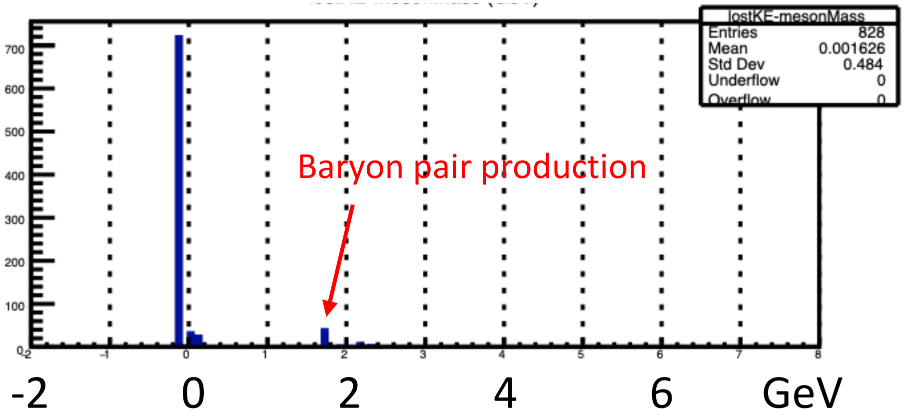
$\Delta K = K_0 - \sum Ki$



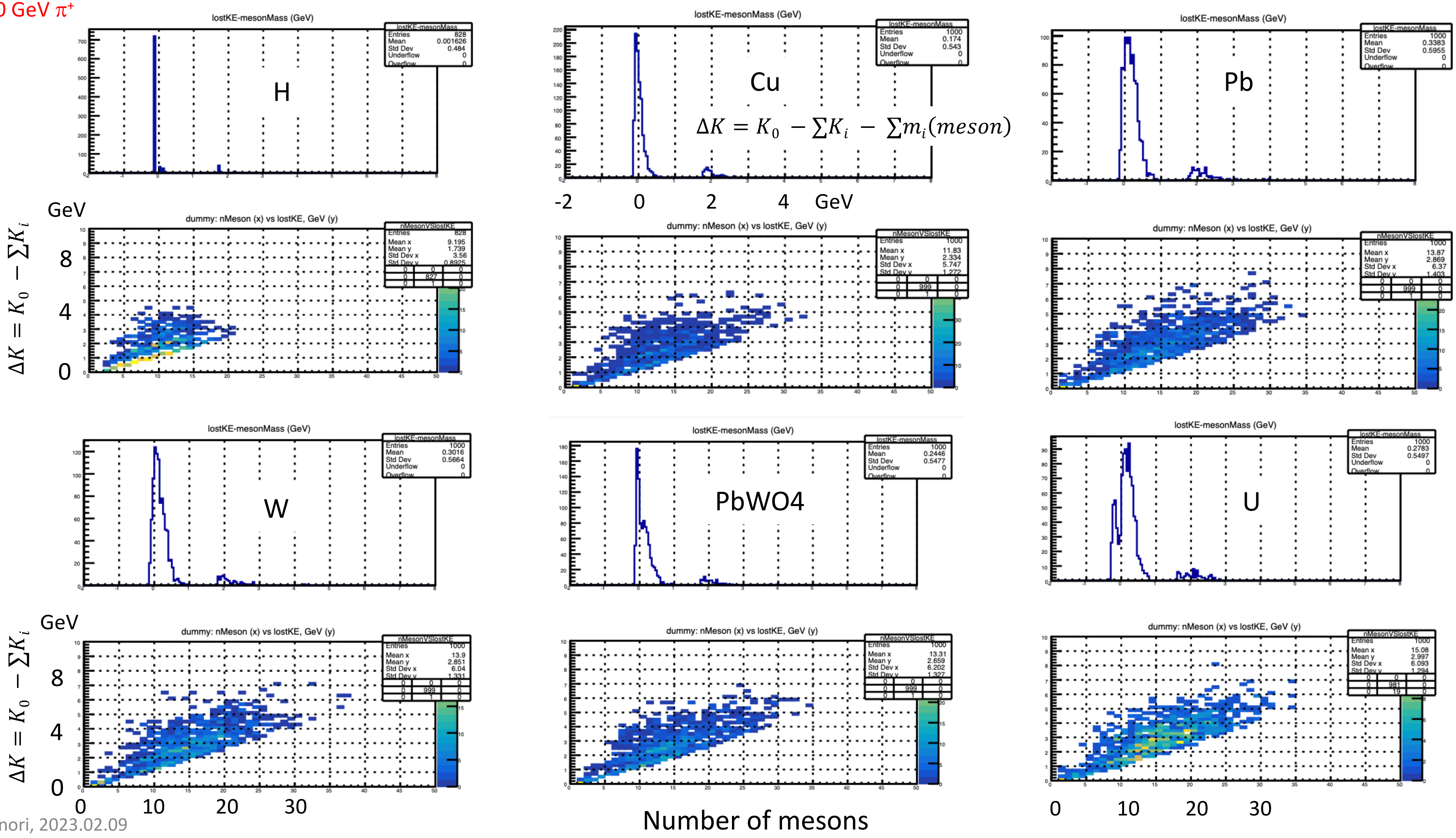
Number of mesons



$\Delta K = K_0 - \sum K_i - \sum m_i(meson)$



30 GeV π^+



H
Cu
Pb
W
PbWO4
U
$\Delta K = K_0 - \sum K_i - \sum m_i(meson)$
lostKE-mesonMass (GeV)
dummy: nMeson (x) vs lostKE, GeV (y)
GeV
$\Delta K = K_0 - \sum K_i$
-2
0
2
4
GeV
0
4
8
0
10
20
30
Number of mesons
Entries 828
Mean 0.001626
Std Dev 0.484
Entries 1000
Mean 0.174
Std Dev 0.543
Entries 1000
Mean 0.3383
Std Dev 0.5955
Entries 1000
Mean 0.3016
Std Dev 0.5664
Entries 1000
Mean 0.2446
Std Dev 0.5477
Entries 1000
Mean 0.2783
Std Dev 0.5497
Mean x 9.195
Mean y 1.739
Std Dev x 3.56
Mean x 11.83
Mean y 2.334
Std Dev x 5.747
Mean x 13.87
Mean y 2.869
Std Dev x 6.37
Mean x 13.9
Mean y 2.851
Std Dev x 6.04
Mean x 13.31
Mean y 2.659
Std Dev x 6.202
Mean x 15.08
Mean y 2.997
Std Dev x 6.093