A Shashlyk Electromagnetic calorimeter system for NICA-MPD

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Oct. 15, 2019

Outline

I. **Background introduction**

II. **Assembling of MPD ECal**

III. **Test of two THU ECal modules of 16 tower prototypes on electron beams**

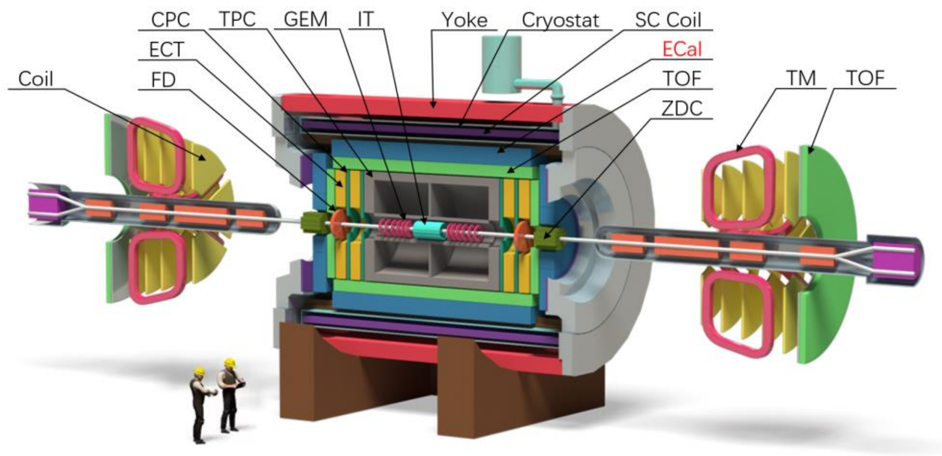
- *Schematic view of the test setup*
- *Traditional method for Energy& Time& Spatial resolution*
- *Convolutional neural networks(CNN) for Energy& Time*

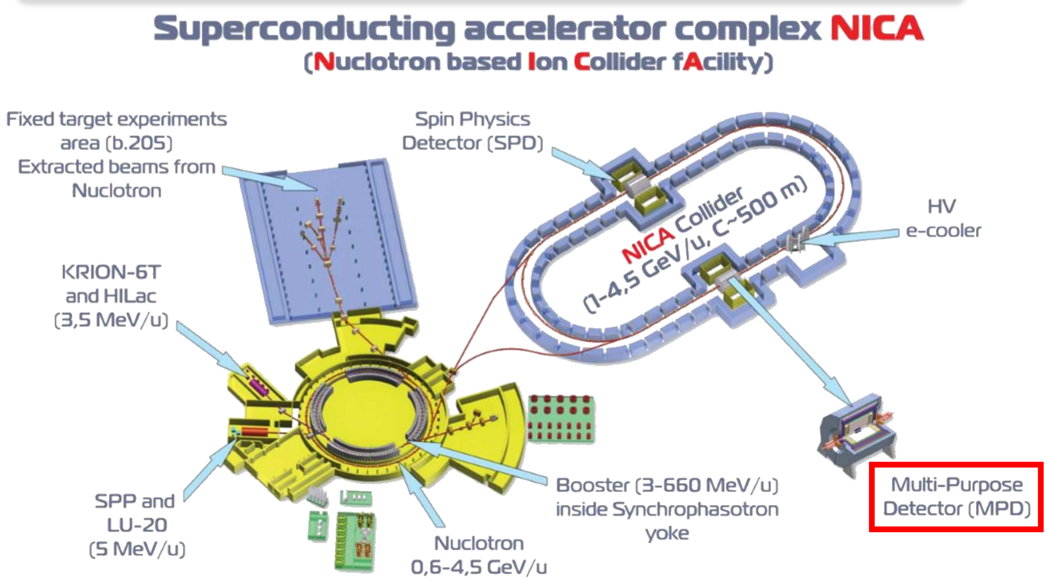
IV. **Test of KI-IHEP tower proto on muon beams**

V. **Summary**

Introduction

The main goal of the **Nuclotron based Ion Collider fAcility (NICA)**, a new accelerator designed for JINR, is an experimental investigation of the properties of nuclear matter in the energy region of the maximum baryonic density. The **MPD (MultiPurpose Detector)** experiment is one of the important experiments on NICA.

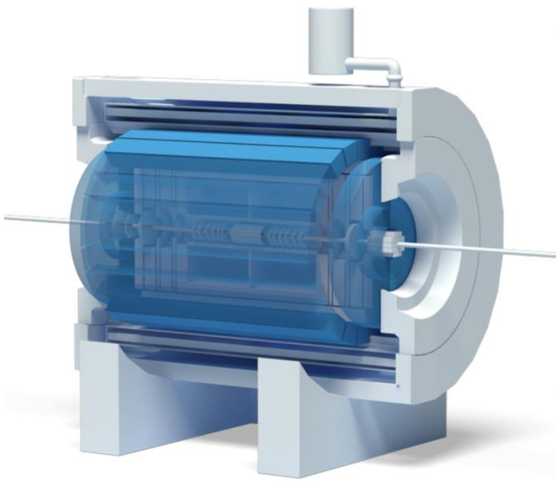


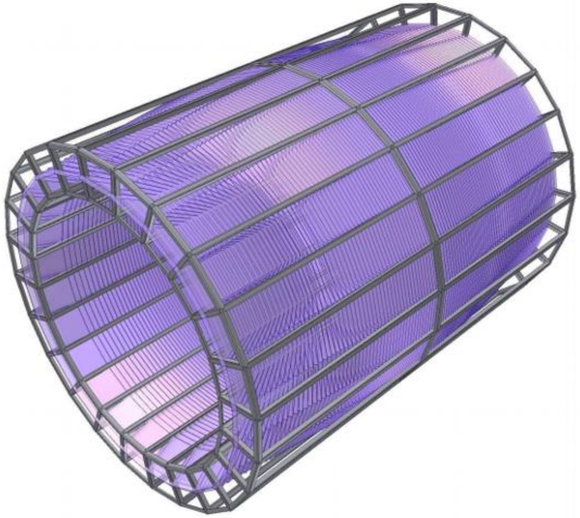


Performance of MPD experiment:

- 4π spectrometer capable
- Total charged particle multiplicity : 1000+
- Beams from p to Au
- L : 10^{27} (Au), 10^{32} (p)[$см^{-2}s^{-1}$]
- $\sqrt{SNN}$: 4-11 GeV
- High Luminosity : 6 kHz

Introduction of ECal

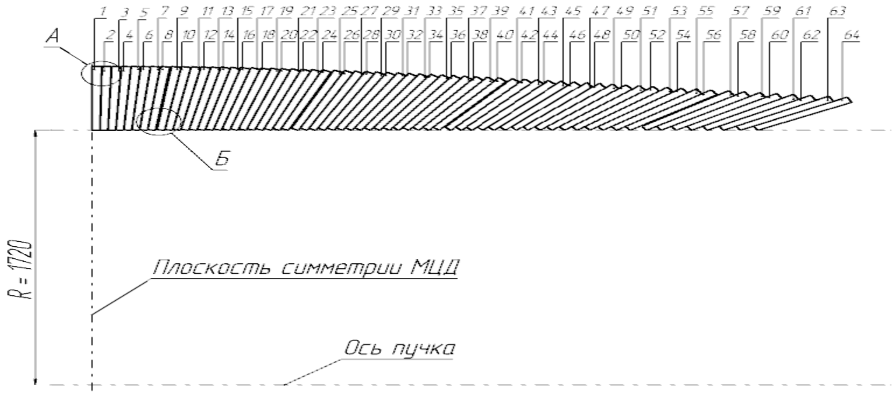




The whole barrel part of MPD electromagnetic calorimeter will be constructed from 25 sectors.

Arrange all the ECal at an polar angle is absolutely necessary to avoid died space and as a result drop of particle detection efficiency and degradation of calorimeter energy resolution.

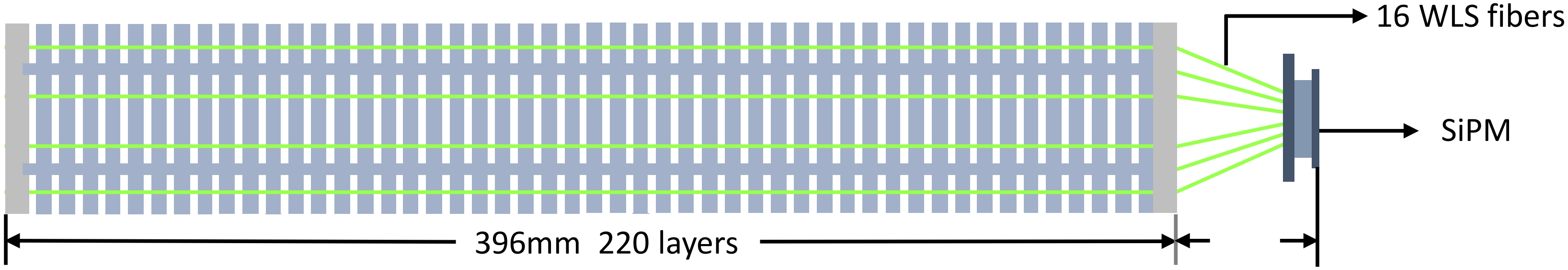
MPD-ECal requirements:
particle occupancy : < 5%
Time resolution : <1ns
Energy resolution : < 5% @1GeV
Operate in the magnetic FIELD : ~ 0.5T
Adequate space resolution.



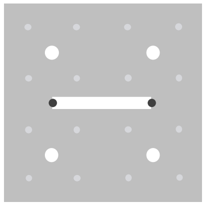
Structure diagram

I

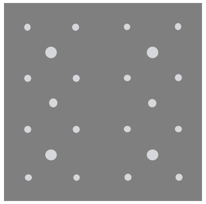
■ Structure diagram of shashlyk ECal (One tower)



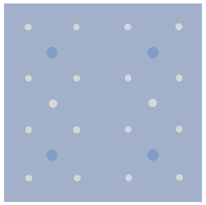
One layer： 1.5mm scintillator+0.3mm lead



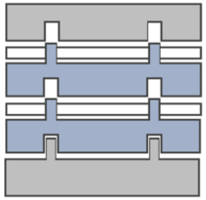
Supporting plate



Lead plate (powder painting)



Scintillator plate



‘LEGO’ structure

The ”Shashlyk” tower is a lead-scintillator sandwich which read out by means of Wave Length Shifting (WLS) fibers passing through the holes in scintillator and lead.

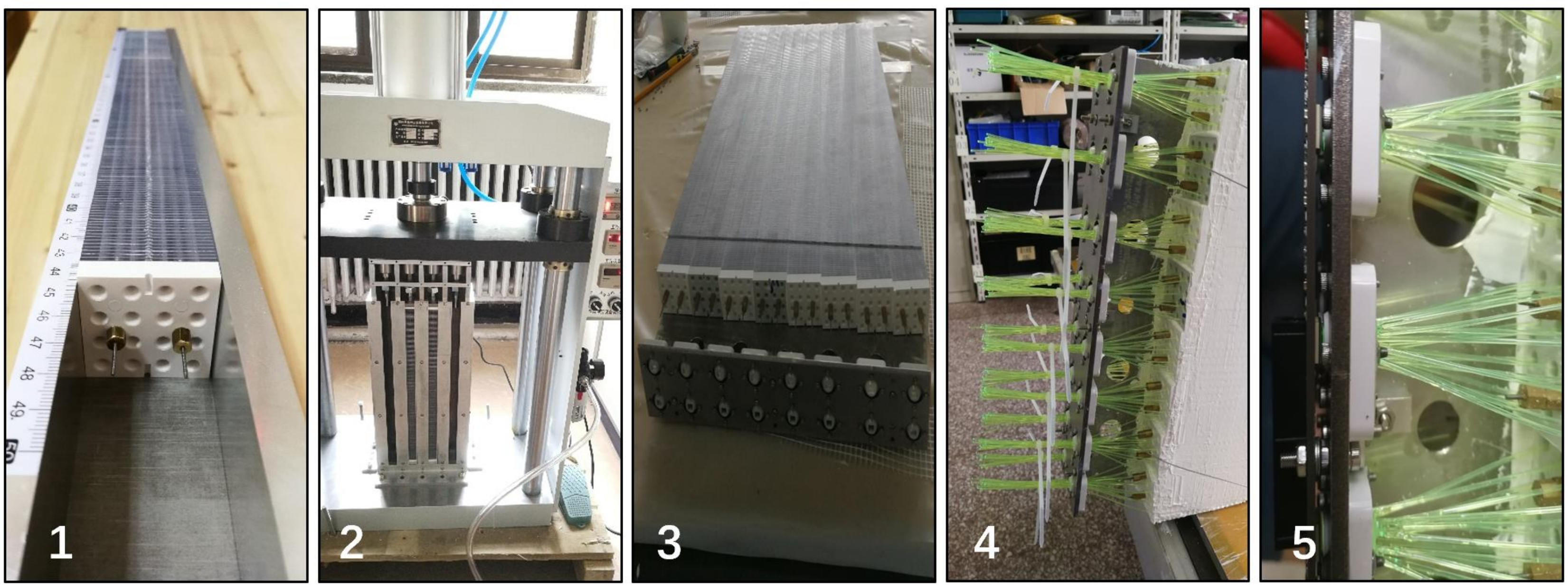
Parameters of Ecal tower

Max. transverse size, mm^2	40 x 40	Scintillator thickness, mm	1.5
WLS fibers	16	Molière radius, mm	62
Number of layers	220	Radiation length, X_0	11.8
Lead absorber thickness, mm	0.3	Effective radiation length, mm	32.4

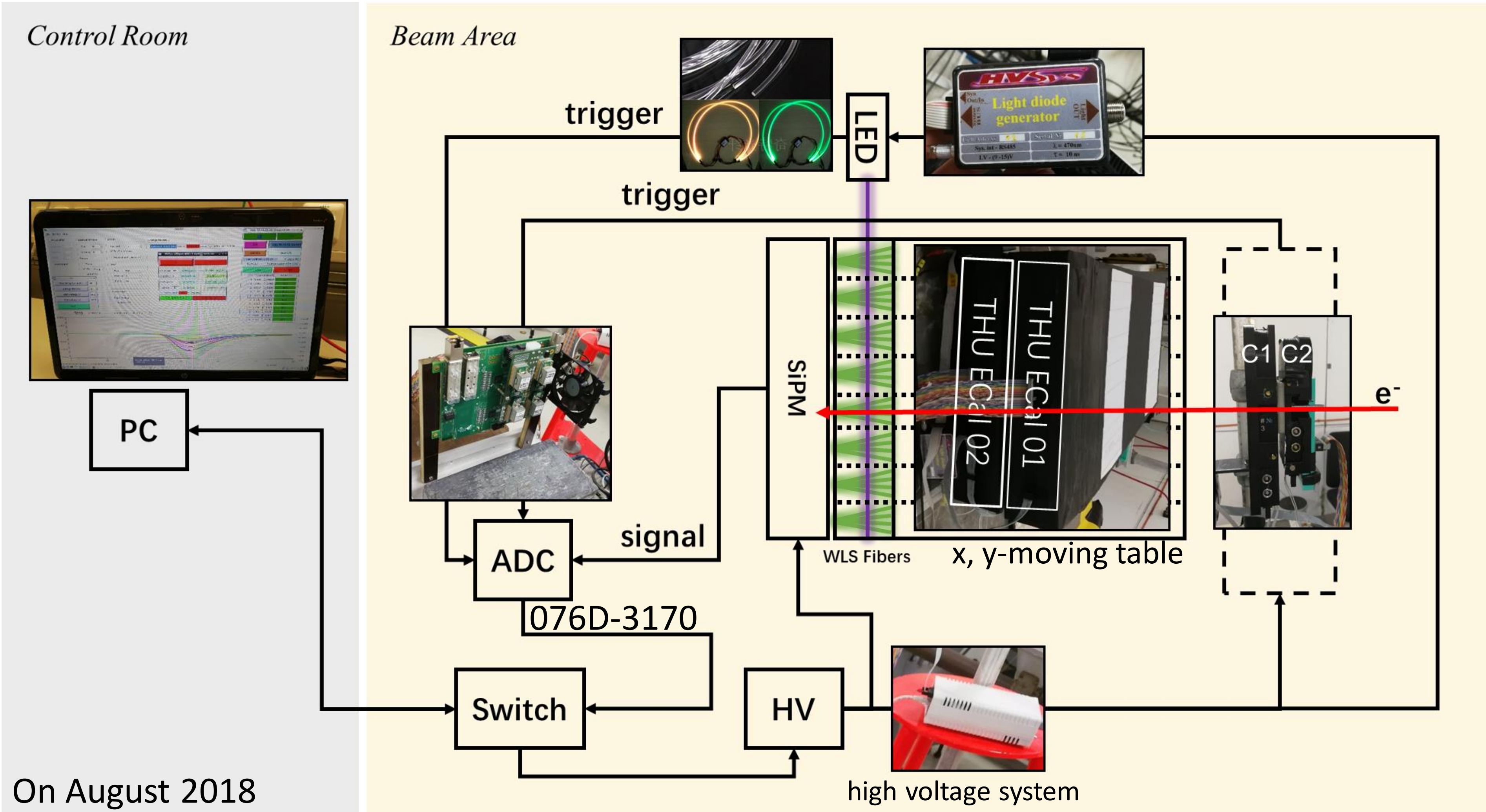
Assembling

■ Assembling steps:

- Assembling single towers one by one
- Pressurizing eight towers at the same time. (~60kg / tower)
- Cutting and gluing.
- Inserting the WLS fibers and gluing
- Cutting the fibers, connecting the PCB plate with SiPM detector and wrapping.

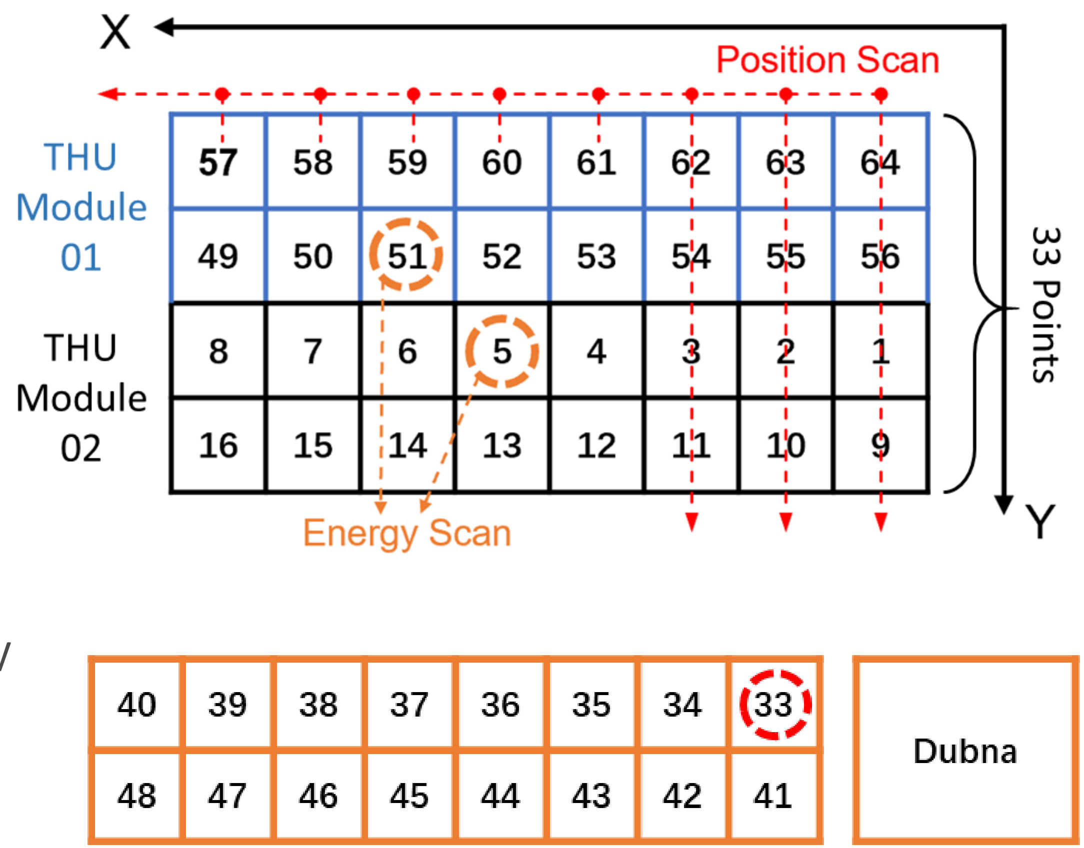


Beam test DESY, Electron beams.



Position & Energy scanning

- Eight columns were scanned along the y-axis direction, and each position was scanned every 5 mm for a total of 264 position points, each time at the center of each column, for the purpose of correction.
- Energy scanning for two points (Tower51&05), from 1.0GeV to 5 GeV.
  - Energy Range : 1.0 GeV - 5.0 GeV
  - Step Length: 0.2 GeV
  - Number of Events: 200K+ / point



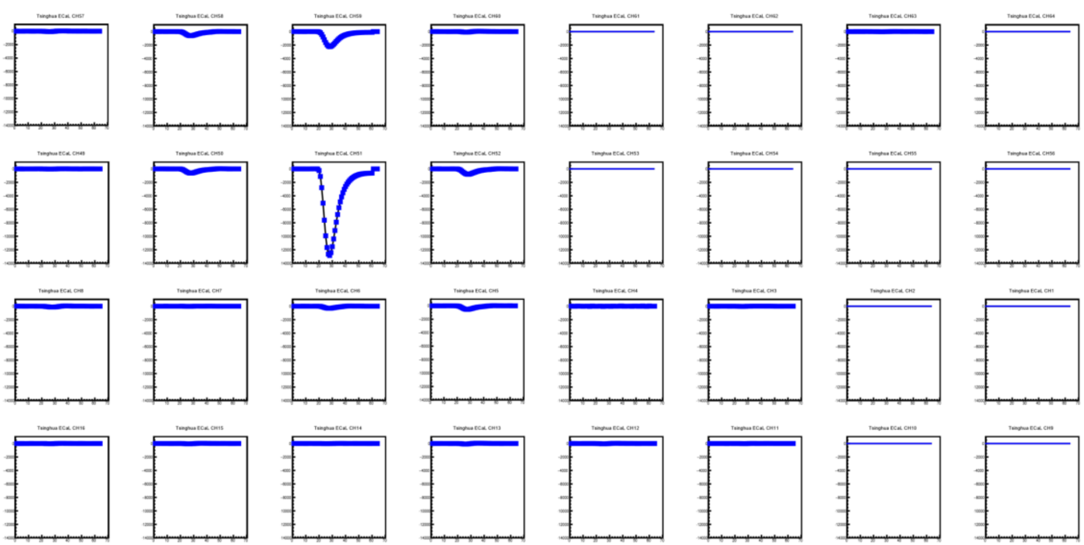
- 4-bit DRS4 (sampling rate 5 GHz) was changed for the time scanning of Dubna module for high time resolution.

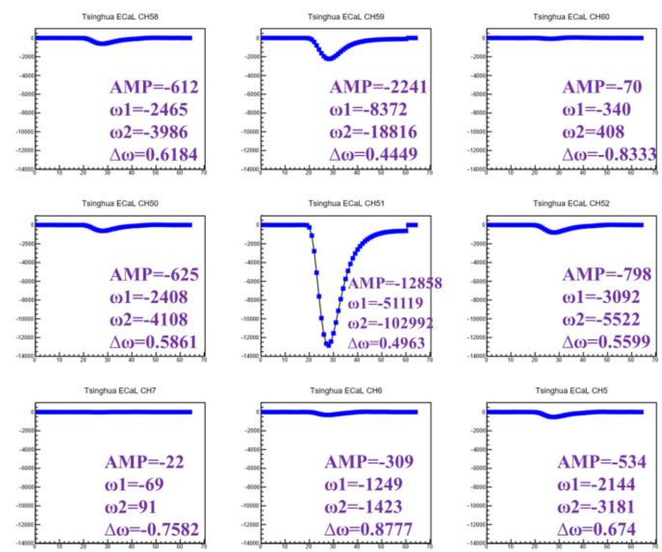
Waveform of signal

57	58	59	60	61	62	63	64
49	50	51	52	53	54	55	56
8	7	6	5	4	3	2	1
16	15	14	13	12	11	10	9

THU 01
THU 02

- The beam hit the tower 51.
- After corrections & calibration.
- The waveform of the 32 tower were obtained.

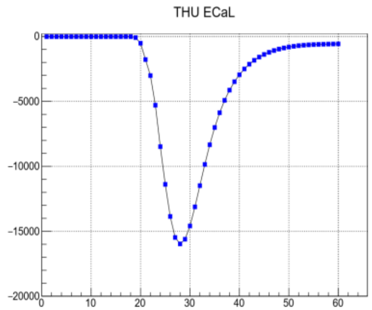




Linear Fit of Beam Energy and $N_{ph.e}$

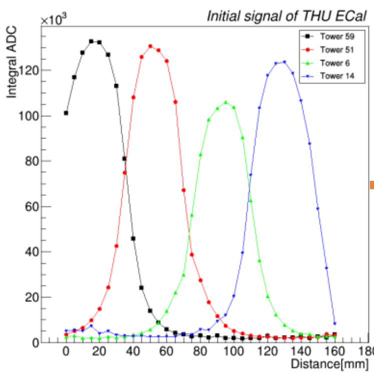
III

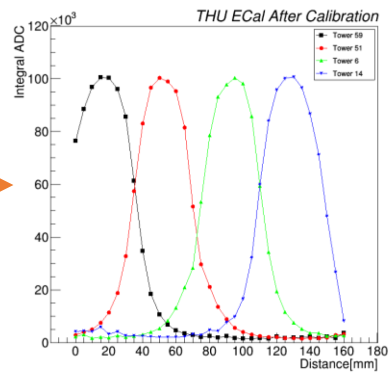
1.After ped.



- The Npe(Number of Photoelectron) @1GeV is about 3500.
- Show good consistency & good linearity

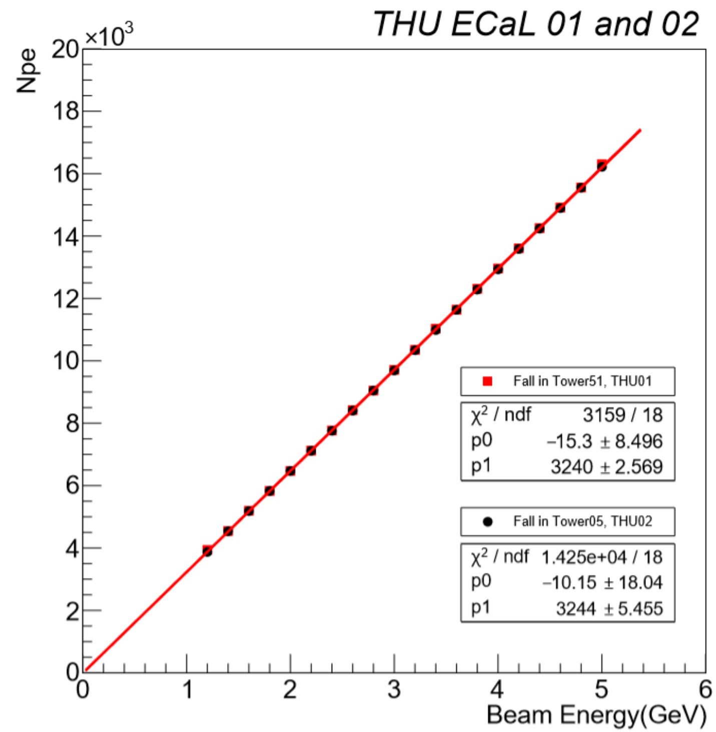
2.Calibration for each tower.





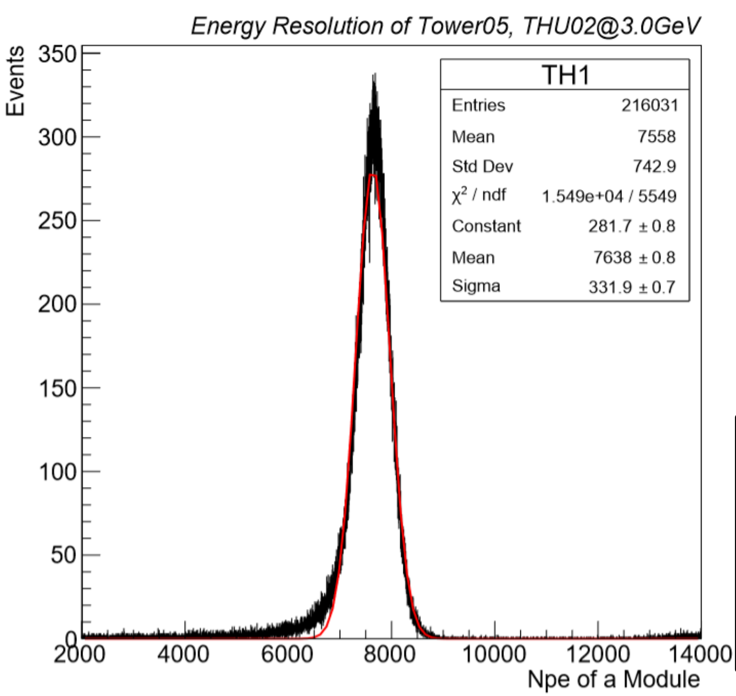
3. After data integration

4. Calibration for SiPM



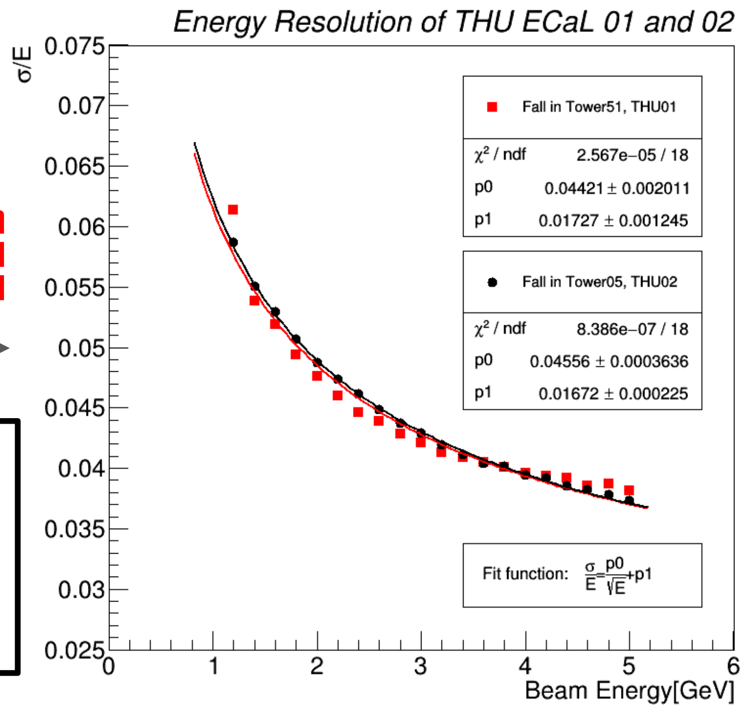
Energy resolution

- Obtained from the peak through Gaussian fit.
- Got the *sigma* for different energy.
- Energy resolution is 4.5% and 4.4%.
- Show good consistency and fitting.

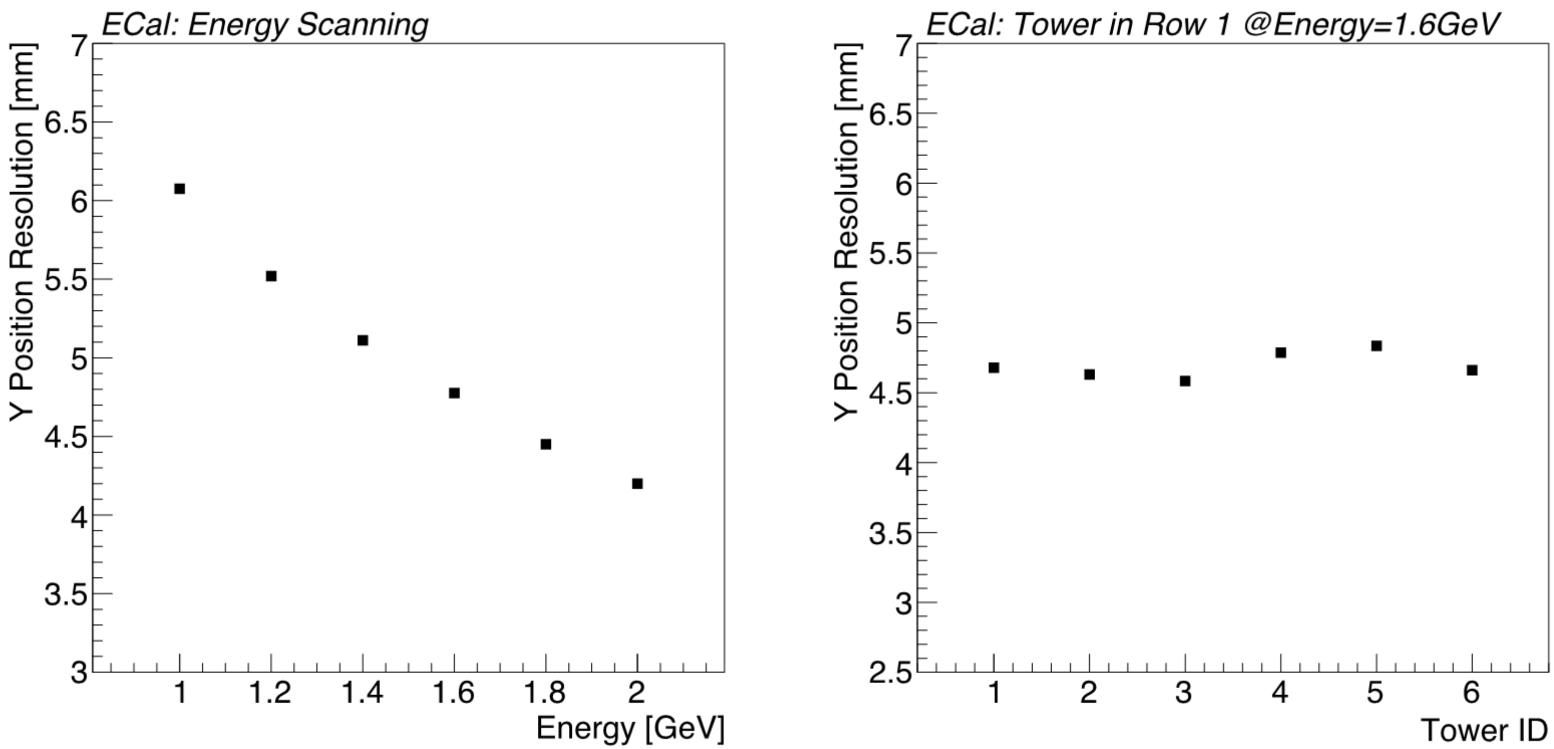


$$\frac{Sigma}{E} = \frac{p_0}{\sqrt{E}} + p_1$$

4.42% < 5%
4.56% < 5%
@1GeV



Spatial resolution

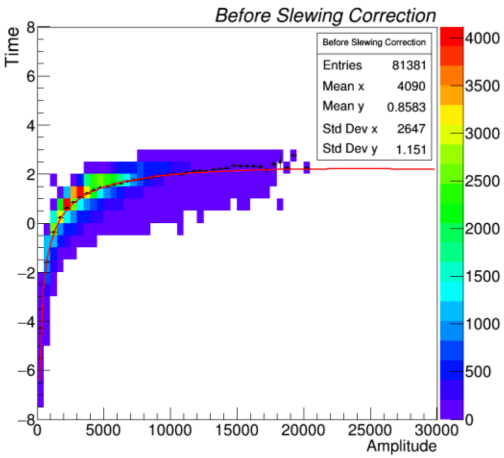


- The spatial resolution is around 4.7 mm @1.6GeV
- The resolution gets improved with energy.

By using Center of Gravity (COG) algorithm

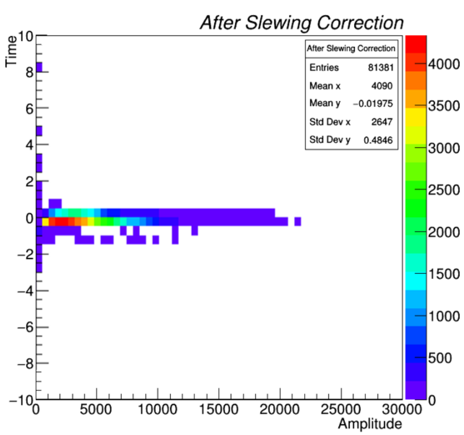
More details can be found here: https://arxiv.org/abs/1902.03629

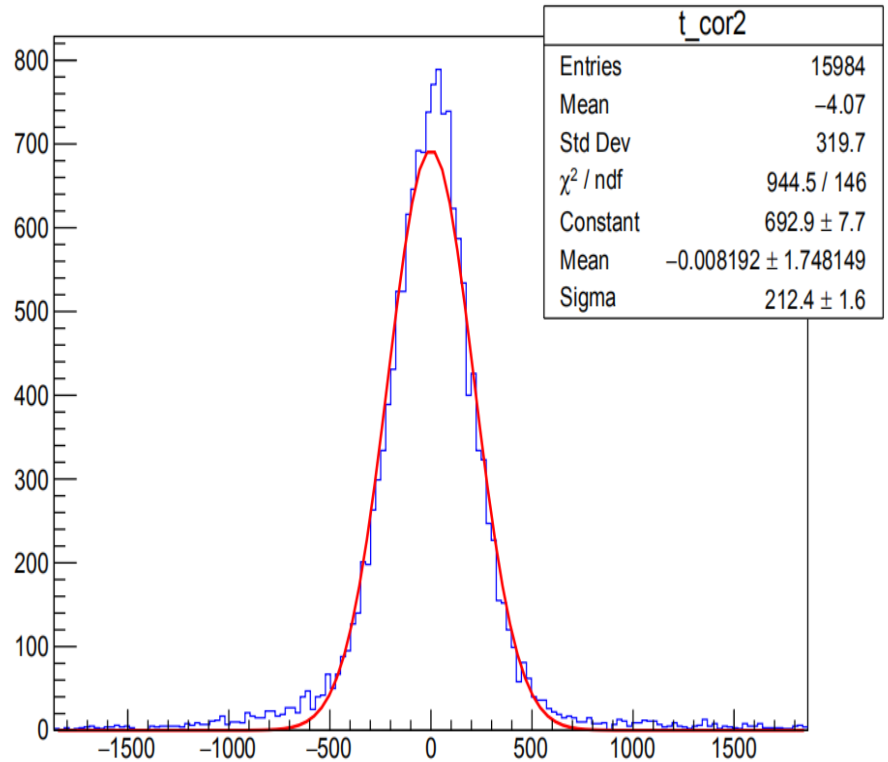
Time resolution



$$t = a + \frac{p_1}{\sqrt{a}} + \frac{p_2}{a} + p_3 a$$

Correction function





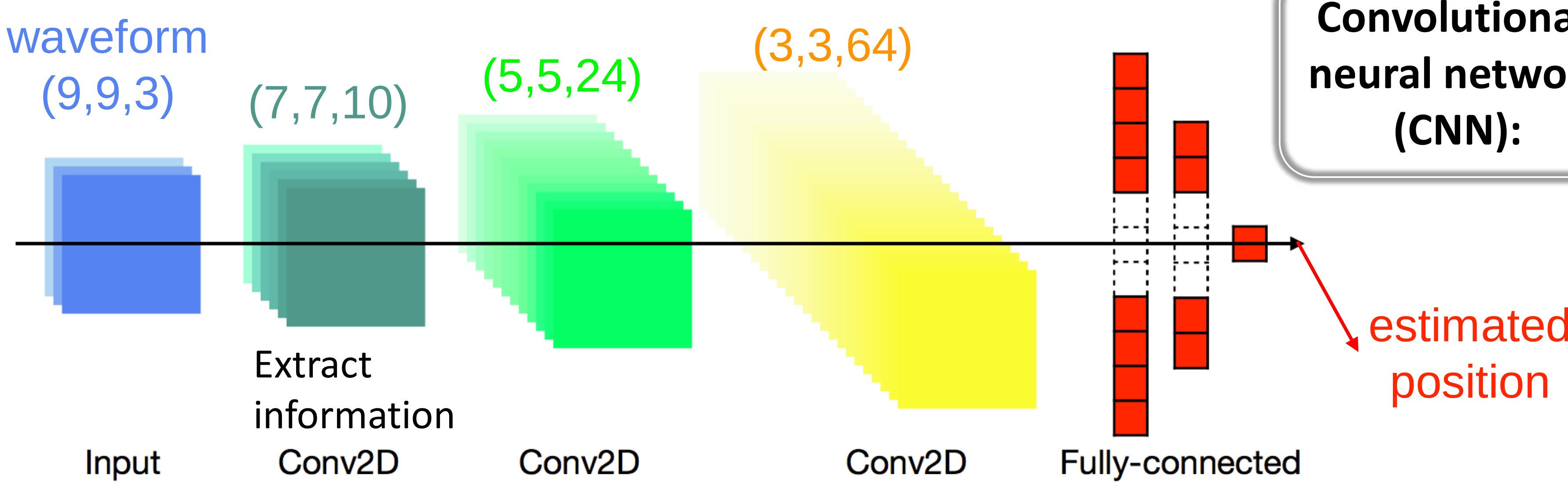
- After the slewing correction, the final time resolution: 212.4ps.

212.4ps < 1ns

Convolutional Neural Network

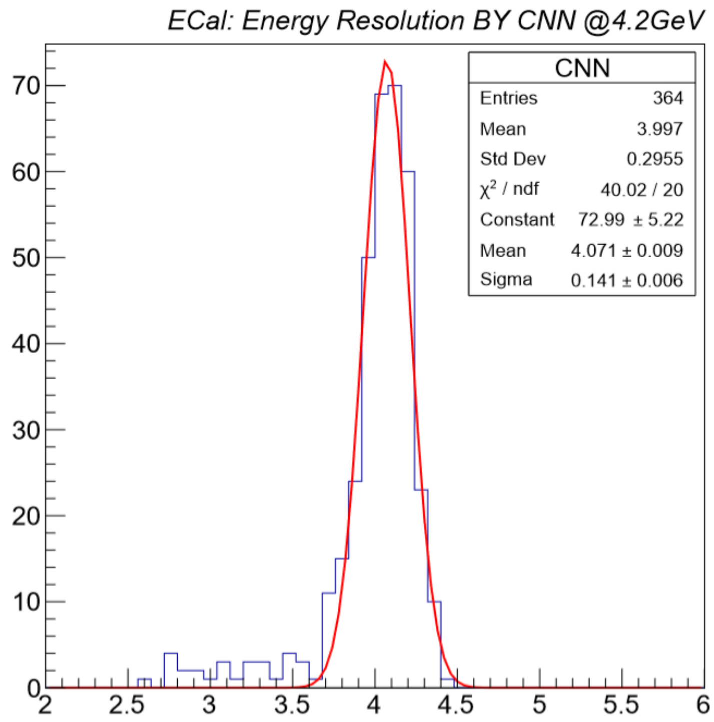
- Neural network and machine learning are powerful tools for solving non-linear problems.
- In 1998, CMS ECal has tried the fully-connected neural networks. Results are similar to the COG(Center of Gravity algorithm).
- A more general and powerful convolutional neural network(CNN) was designed, train and validate the network with recently developed hardware and technologies.

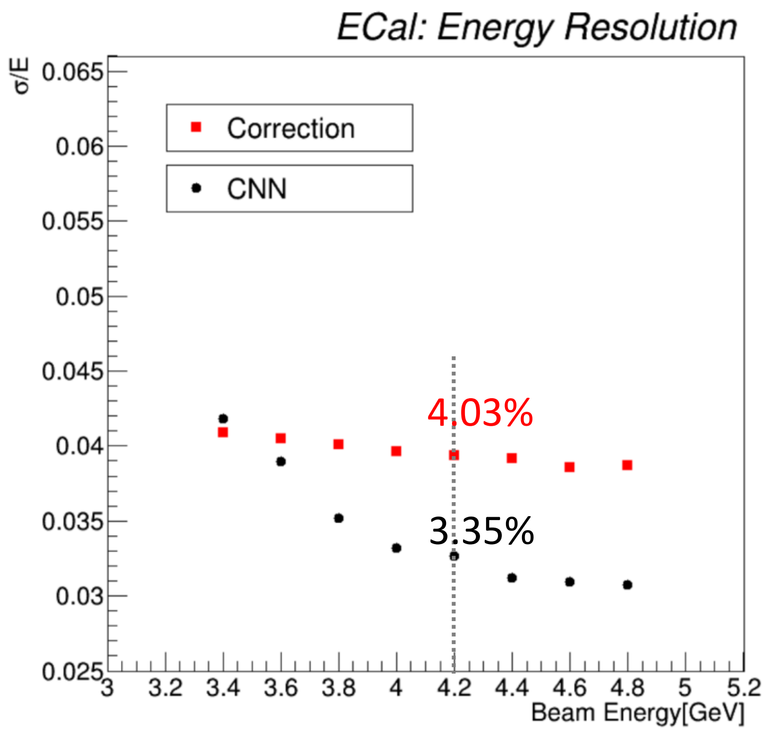
Convolutional neural network (CNN):



Energy resolution

- Energy resolution is obtained after with CNN.

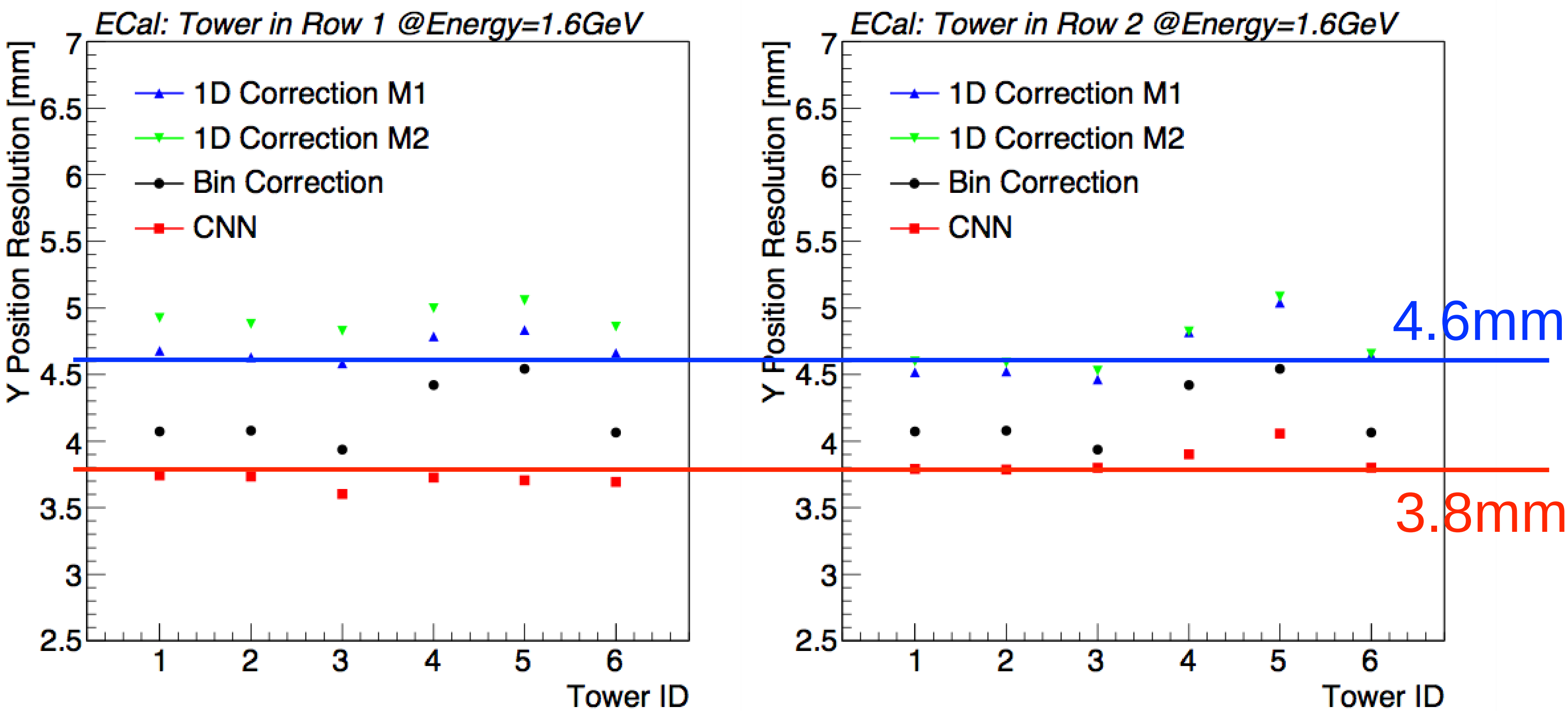




- CNN works much better than the traditional method in the high energy zone(Defects in the low energy zone are being discussed).

Spatial resolution in Y direction

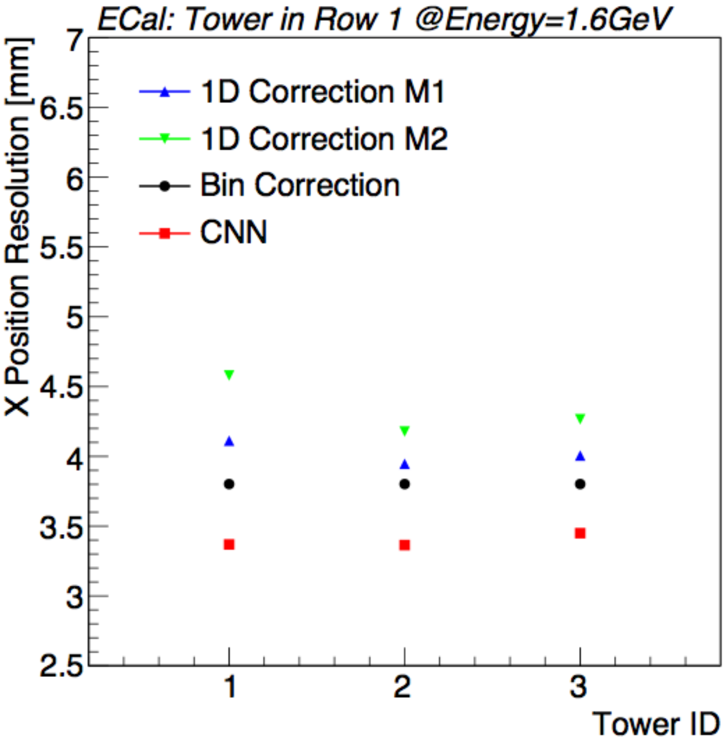
- Position resolution in Y direction
- Position resolution: standard deviation of the 3-sigma gaussian fit

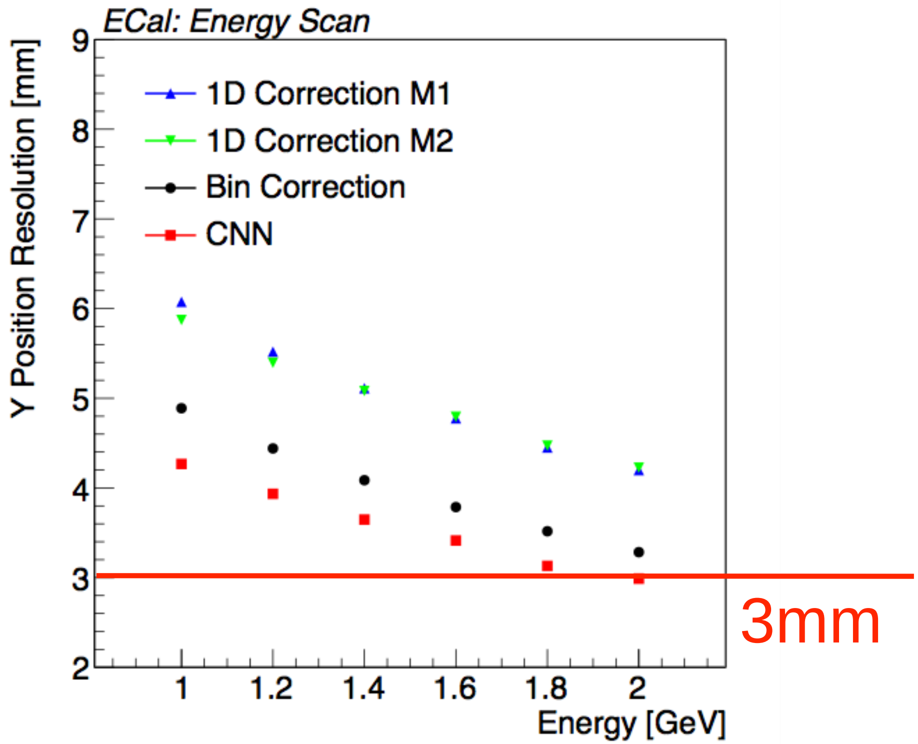


- Bin correction achieves the best position resolution from COG
- CNN works much better than the COG

Spatial resolution in X direction

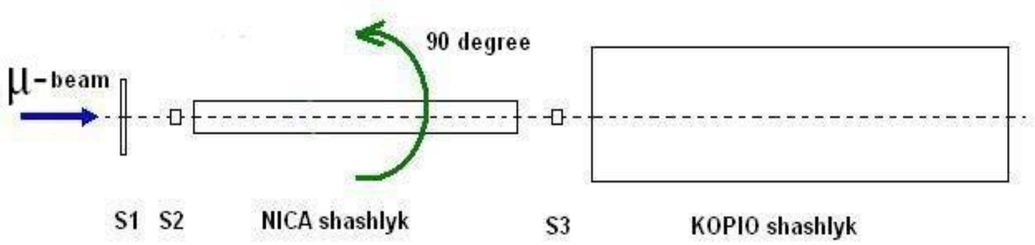
- Position scanning in X is also done with different beam energy.





- The position resolutions are improved by **about 30%** with the CNN compared to the correction method 1 in all the energy scans, and it is also under **3 mm** @2 GeV.
- Good training finds the most appropriate model for the problem.

Test of towers prototype on muons beams from U-70 accelerator NRC KI-IHEP



- μ-beam from target in the ring of the U-70 (background mode, target in the halo of circle beam)
- μ-beam from target in the U-70 ring with 50GeV protons (background mode, target in the halo of circle beam)

Artur Durum (*durum@rcf.rhic.bnl.gov*)

- **μ-beam from target in the ring of the U-70 (background mode, target in the halo of circle beam)**
- **Sc counters:**
  - S1 (square100x100mm), S2, S3 (circle 20mm diameter)
- **KOPIO shashlyk prototype:**
  - sandwich structure Pb/Sc 110x110 mm, Z=15.9 X_0
- **Trigger**
  - S1 & S2 & S3 & KOPIO
  - 300MeV threshold for signal from KOPIO module
- **Towers of shashlyk prototype :**
  - Towers was wrapped by TYVEK
  - Our readout: PMT 115M, green extended
  - Two option of fiber coating: Al Maylar and Al mirror on the end of WLS fibers
  - Al mirror thermally applied in the IHEP factory, Al Maylar applied by the Scotch

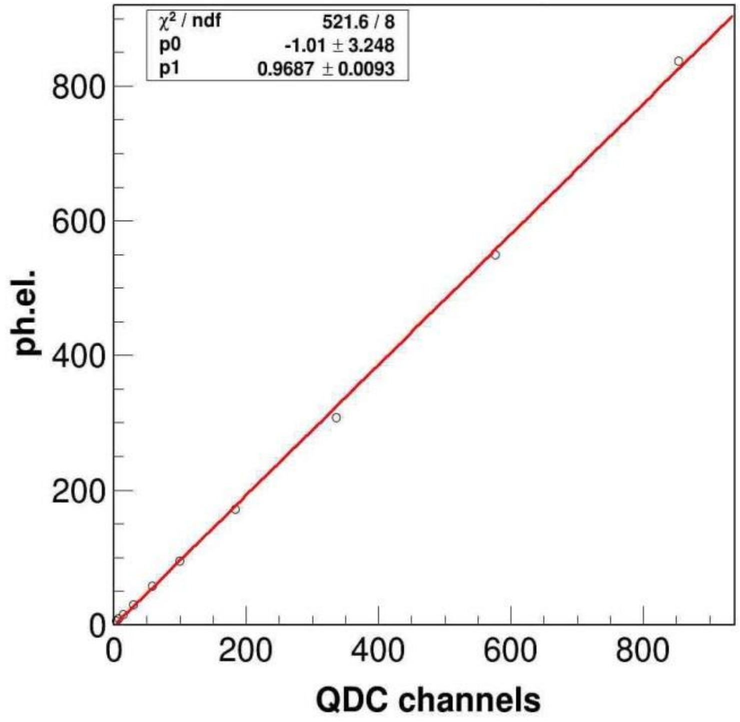
Beam test KI-IHEP, Muon beams.

- Calibration on LED to get photoelectrons per QDC channels

$$N_{ph.e} = \left({}^{Amp}/_{Sigma} \right)^2$$

- Getting from Gauss fit after ped. subtraction,
- Check the linearity and dynamic range of readout.
- Avoid time shifts of the light pulse.

Linearity of the signals over the dynamic range and conversion of QDC counts.



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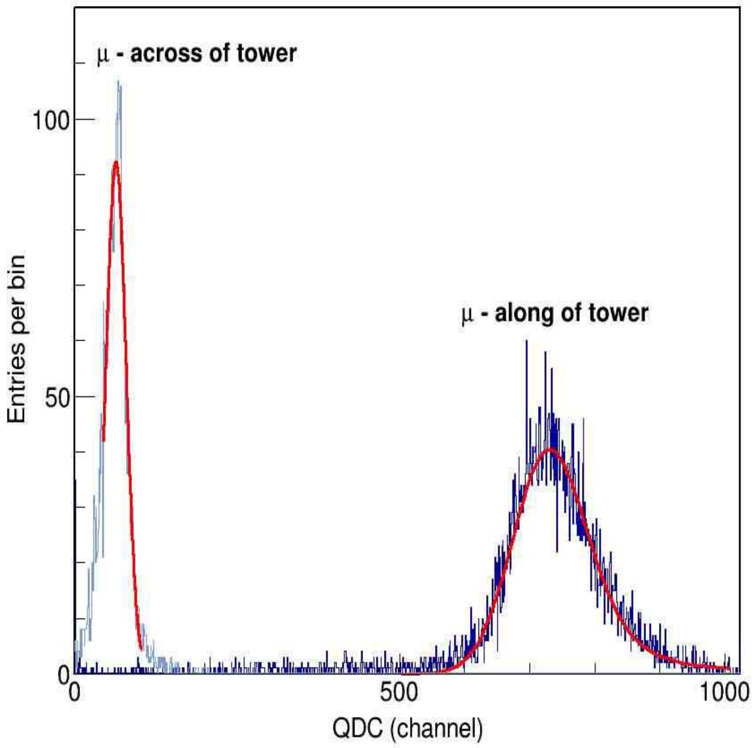
Results for along & across muons

IV

Comparison of the spectra for muons



Artur Durum (*durum@rcf.rhic.bnl.gov*)

For Al Maylar on the ends of WLs fibers

μ-across, center, **65.7 +/- 3% $N_{ph.e}$**

μ-along, **607 +/- 3% $N_{ph.e}$**

For Al Mirror on the ends of WLS fibers

μ-across, center, **73.3 +/-3 $N_{ph.e}$**

μ-along, **707 +/- 3% $N_{ph.e}$**

- Light Yield for ideal case LY_{along}/LY_{across} = 8.25, which correspond, 220 layers Sc 1.5mm along/40mm across
- Our result LY_{along}/LY_{across} =9.18-9.81 discrepancy explained for a cross muon when muon is going through of Pb plate instead of Sc plate and light attenuations length of WLS fiber
- $LY_{Al\ Mirror}/LY_{Al\ Maylar}$ =1.16 +/- 0.03

Summary

V

- The two THU prototypes model of ECal has been done.
- A set of complete **assembling method** was given.
- Beam test have been completed in DESY and some results have been obtained with traditional method.
  - The **calibration method** of the detector has been mastered
  - Have good **linearity**
  - Energy resolution : **4.4% & 4.5%** < **5% @1GeV**
  - Spatial resolution : **4.7mm @1.6 GeV**
  - Time resolution : **212.4ps** < **1ns**
- CNN gets much better results.
  - Energy resolution: **3.8mm @1.6 GeV**
  - Spatial resolution: **3.35% @4.2GeV (4.03% @4.2GeV)**
- Results of test on muons beams from U-70 accelerator NRC KI-IHEP.
  - The Al-mirror coating of the WLS fiber ends is better than mylar film(about 1.16).
  - Maximal light output of about 700 photoelectrons was observed.

Thanks for your attention!

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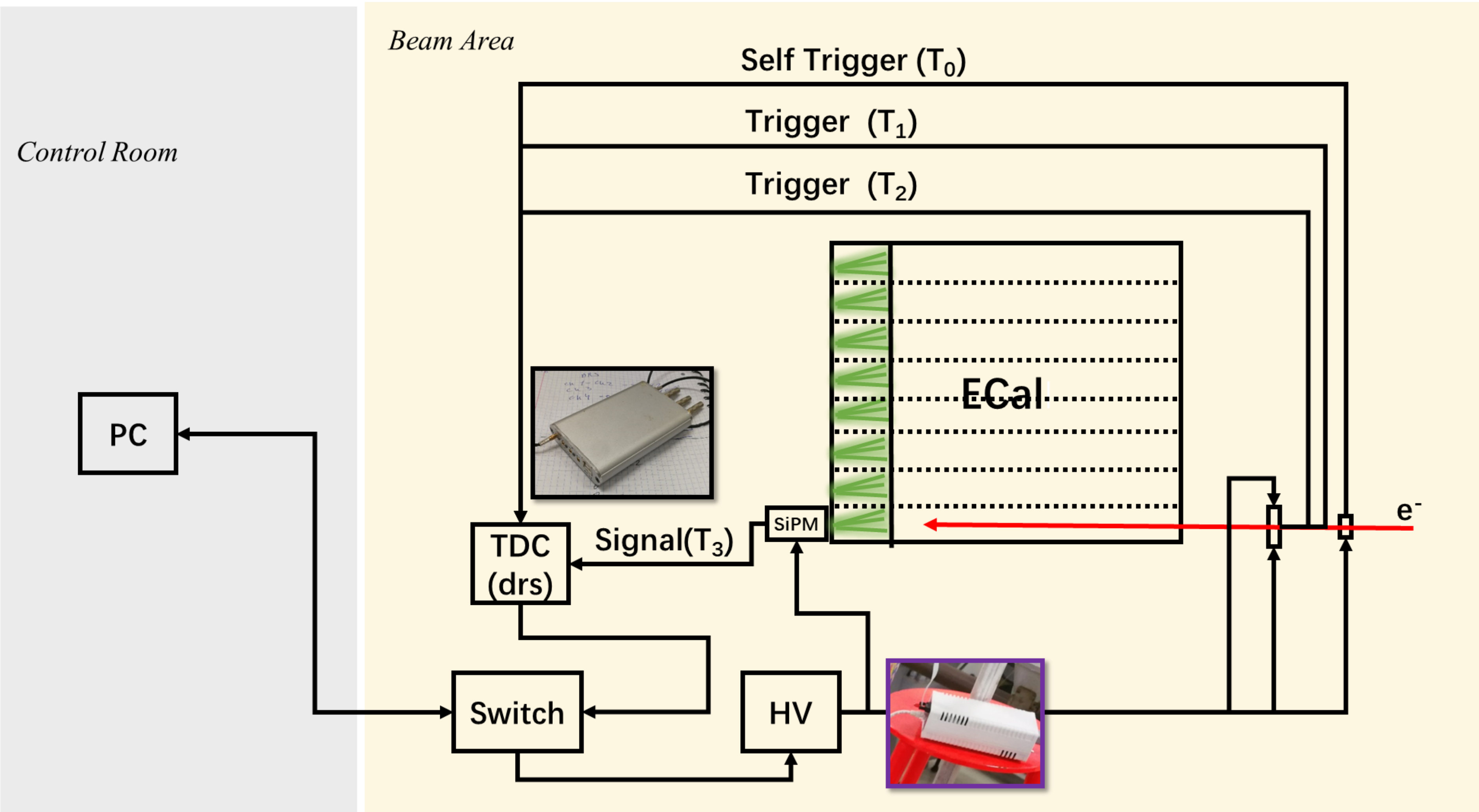
*** The reported study in IHEP was partially supported by the Russian Foundation for Basic Research (RFBR) within the framework of the research project № 18-02-40083.**

Back up

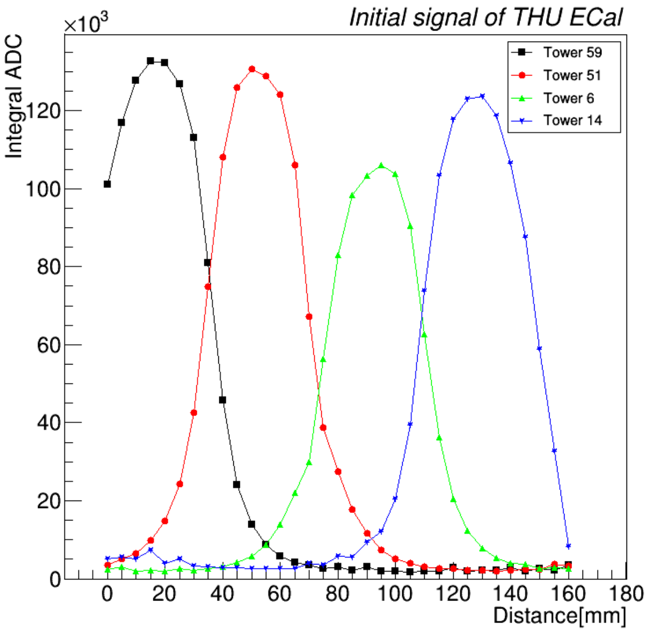
Beam test



Control Room
Beam Area
Self Trigger (T_0)
Trigger (T_1)
Trigger (T_2)
PC
TDC (drs)
Signal(T_3)
SiPM
ECal
e^-
Switch
HV

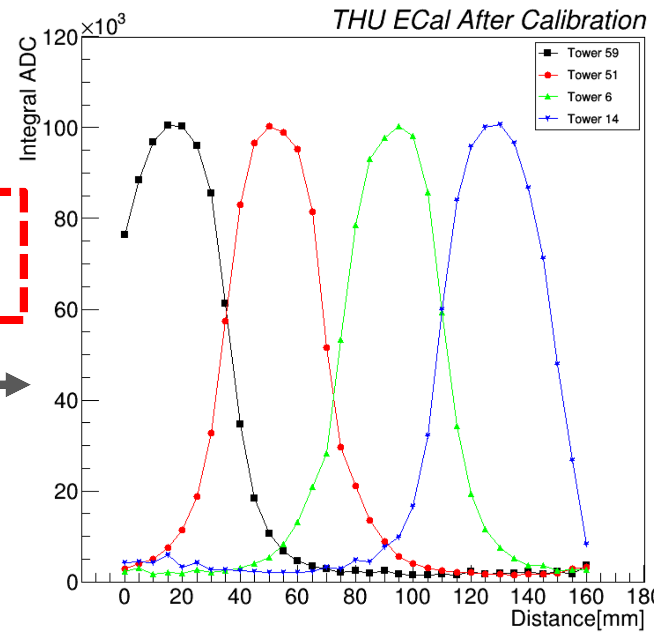
Calibration

■ Before calibration



Normalized processing

■ After calibration

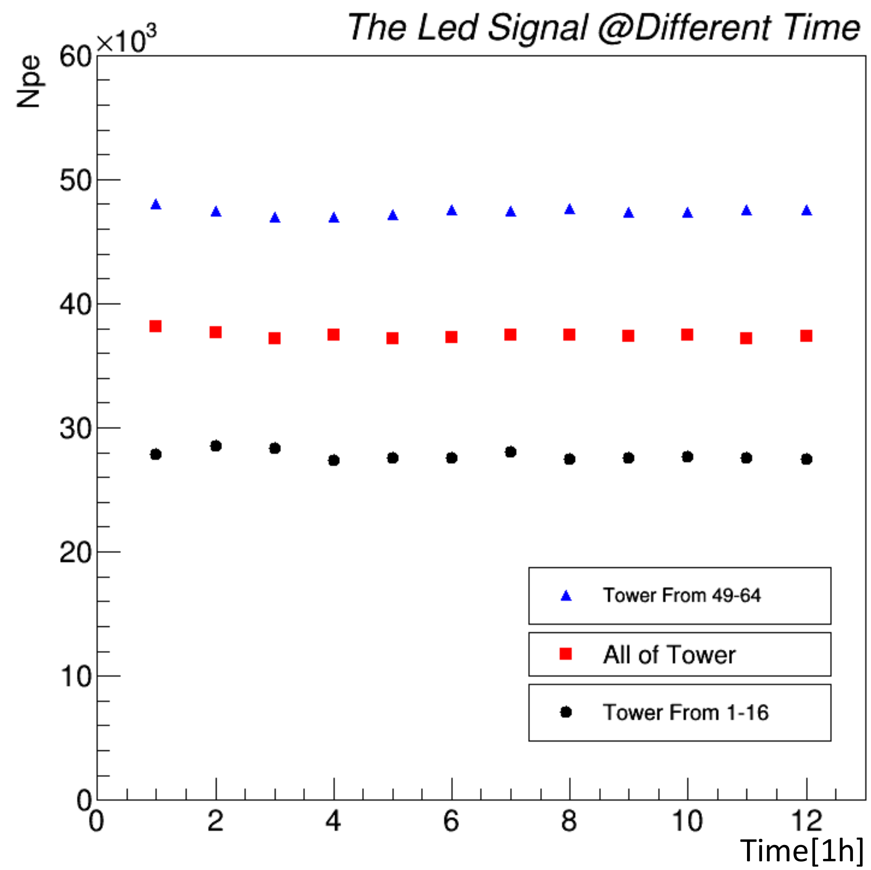


-1.27445652993383890	-1.66650443914489005	-1.32313080021065456	-1.20272116168101332
-1.14456066352792608	-1.09656324374119431	-1.30302009954622131	-1.14820885520411509
-1.10302839938808014	-1.08529947692487272	-1.05644468820401903	-1.15444981543348491
-1.21341040340686362	-1.17330385032835984	-1.22824430770609324	-1.19352091101312034

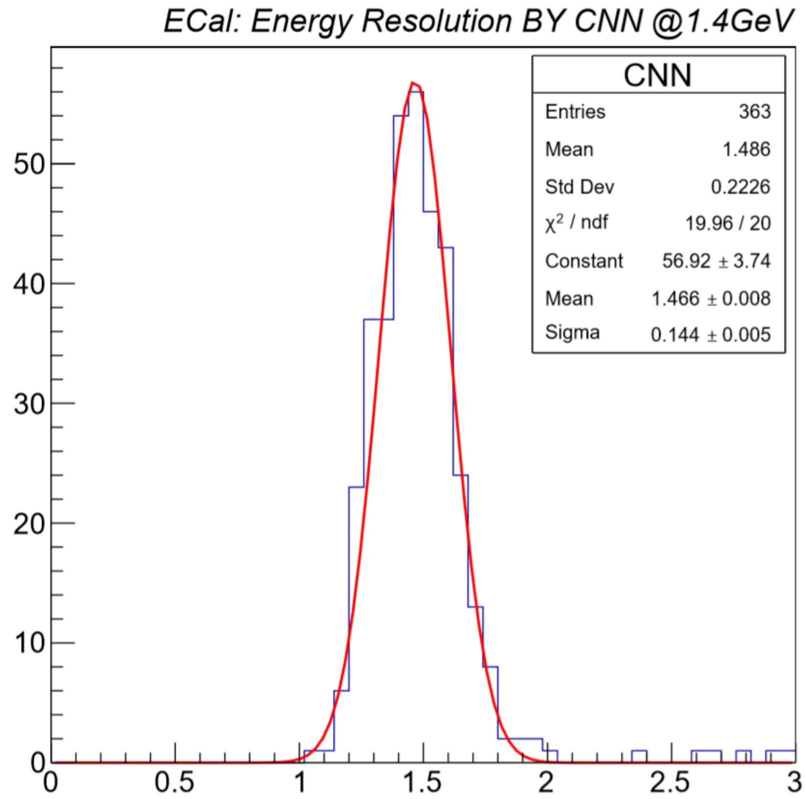
57	58	59	60
49	50	51	52
8	7	6	5
16	15	14	13

Stability

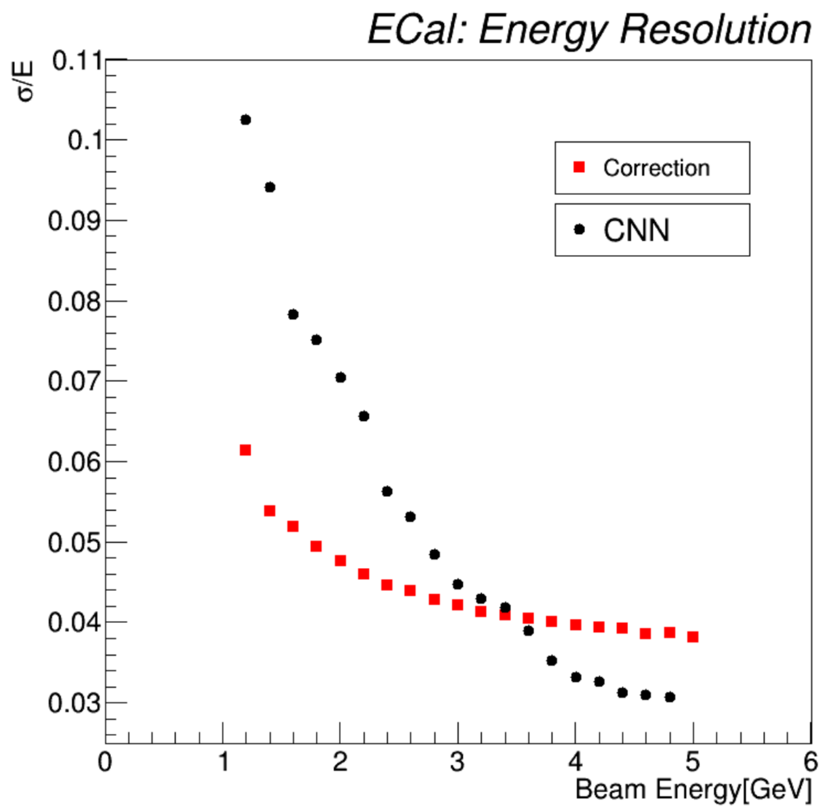
- The stability of the led detection system has been proven @Different time.



CNN

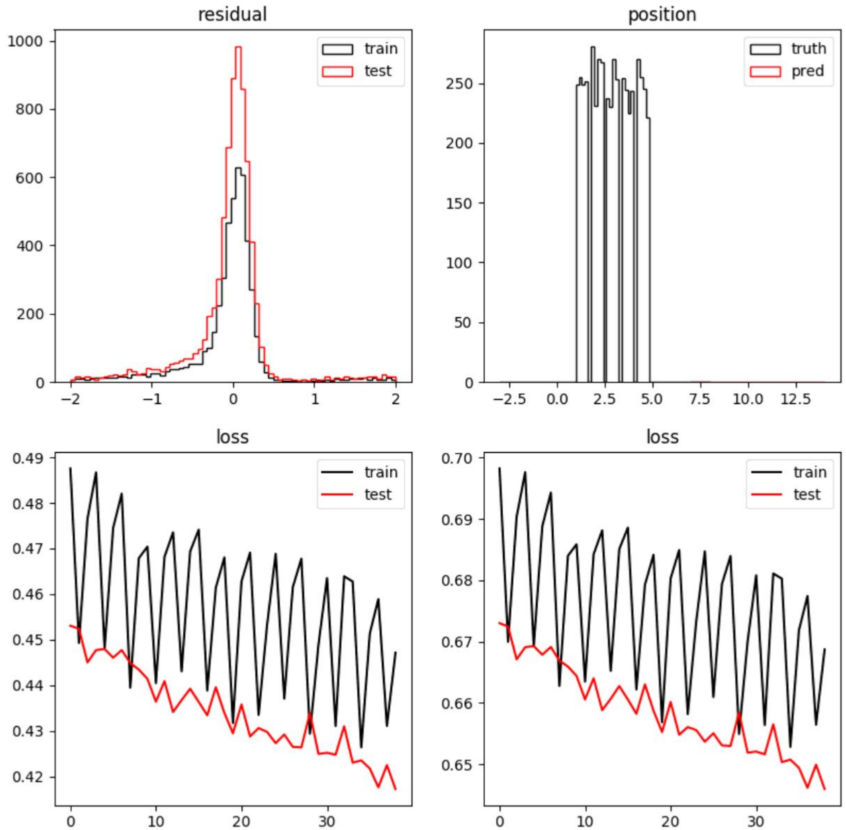


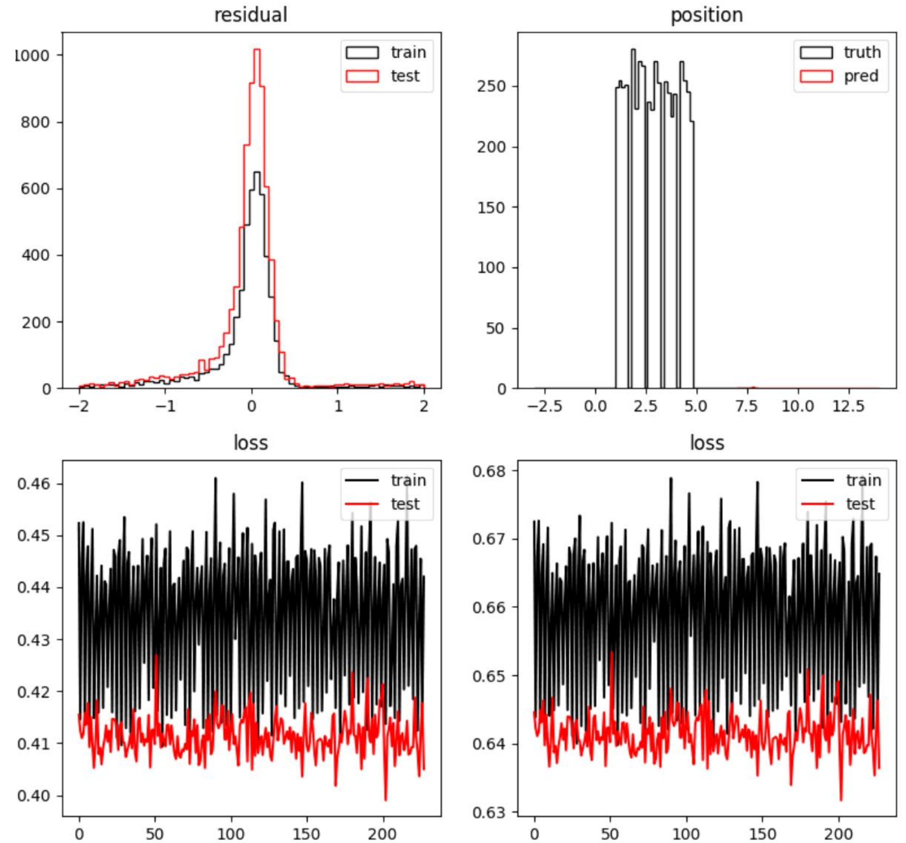
ECal: Energy Resolution BY CNN @1.4GeV
CNN
Entries 363
Mean 1.486
Std Dev 0.2226
χ² / ndf 19.96 / 20
Constant 56.92 ± 3.74
Mean 1.466 ± 0.008
Sigma 0.144 ± 0.005



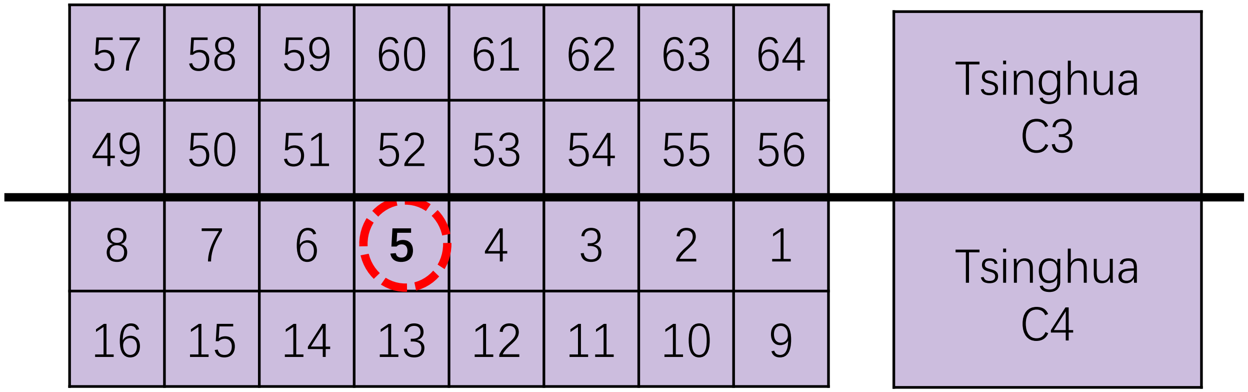
ECal: Energy Resolution
σ/E
Correction
CNN
Beam Energy[GeV]

Train& Test

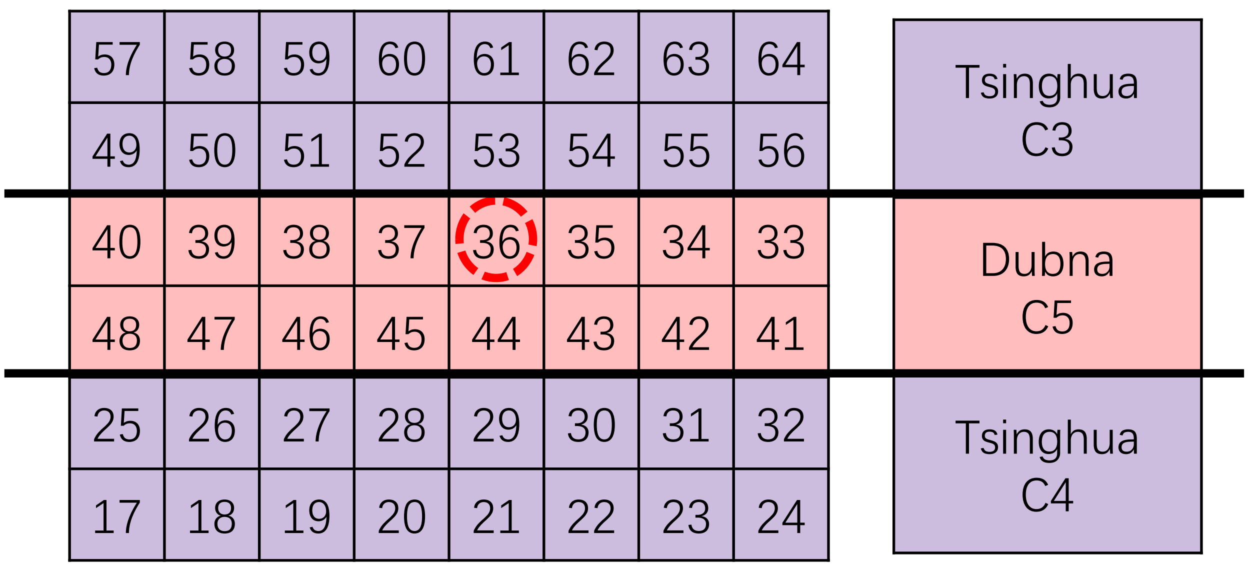

residual
train
test
position
truth
pred
loss
train
test
loss
train
test


residual
train
test
position
truth
pred
loss
train
test
loss
train
test

Back up

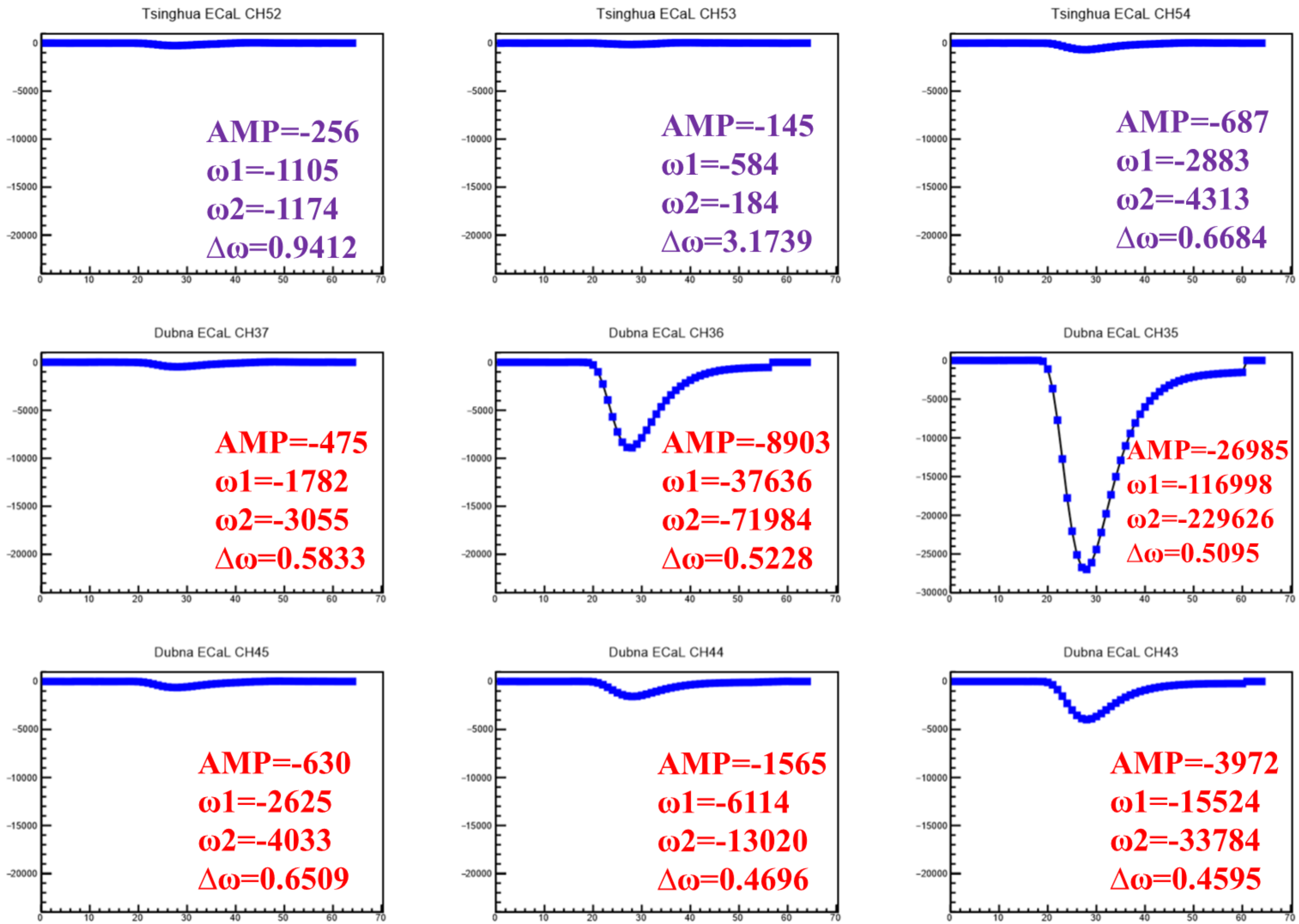


E=3.0GeV
Event=218663



E=3.0GeV
Event=214047

Back up


Tsinghua ECaL CH52
AMP=-256
ω1=-1105
ω2=-1174
Δω=0.9412
Tsinghua ECaL CH53
AMP=-145
ω1=-584
ω2=-184
Δω=3.1739
Tsinghua ECaL CH54
AMP=-687
ω1=-2883
ω2=-4313
Δω=0.6684
Dubna ECaL CH37
AMP=-475
ω1=-1782
ω2=-3055
Δω=0.5833
Dubna ECaL CH36
AMP=-8903
ω1=-37636
ω2=-71984
Δω=0.5228
Dubna ECaL CH35
AMP=-26985
ω1=-116998
ω2=-229626
Δω=0.5095
Dubna ECaL CH45
AMP=-630
ω1=-2625
ω2=-4033
Δω=0.6509
Dubna ECaL CH44
AMP=-1565
ω1=-6114
ω2=-13020
Δω=0.4696
Dubna ECaL CH43
AMP=-3972
ω1=-15524
ω2=-33784
Δω=0.4595