Status of the neutron detector array for LAMPS at RAON

Korea Univ. / CENuM

Lee Jong-won for LAMPS collaboration

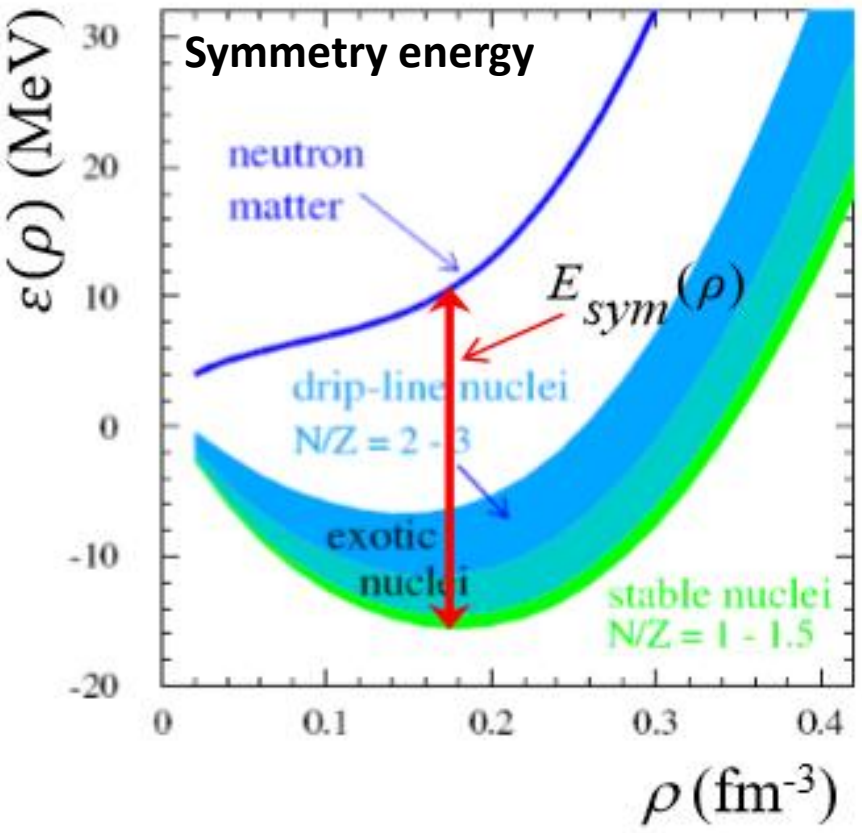
LAMPS Experiment

Energy of nuclei and nuclear matter

$$\varepsilon(\rho,\delta)A = Zm_p + Nm_n - B(A,Z)$$

$$\varepsilon(\rho,\delta) = \varepsilon(\rho,\delta=0) + E_{sym}(\rho)\delta^2 + \mathcal{O}(\delta^4) + \cdots$$

where $a_{sym} \approx E_{sym}(0.6\rho_0)$

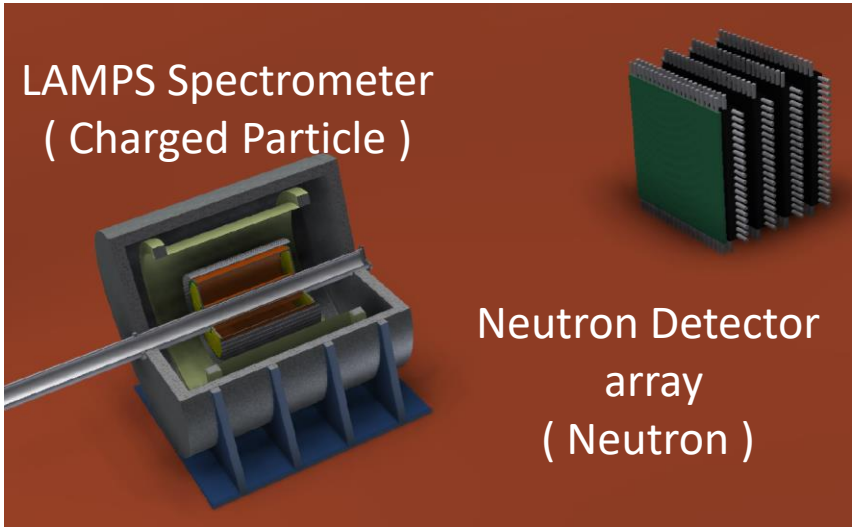


Equation of state

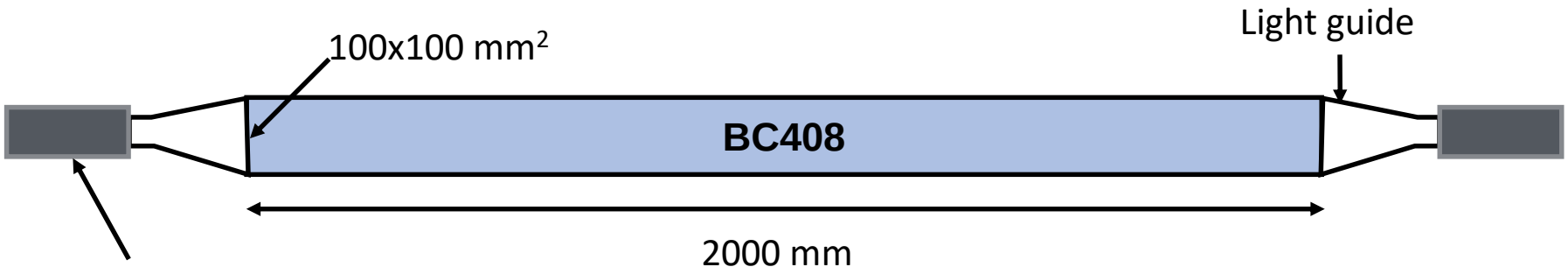
↘ **Symmetry energy**

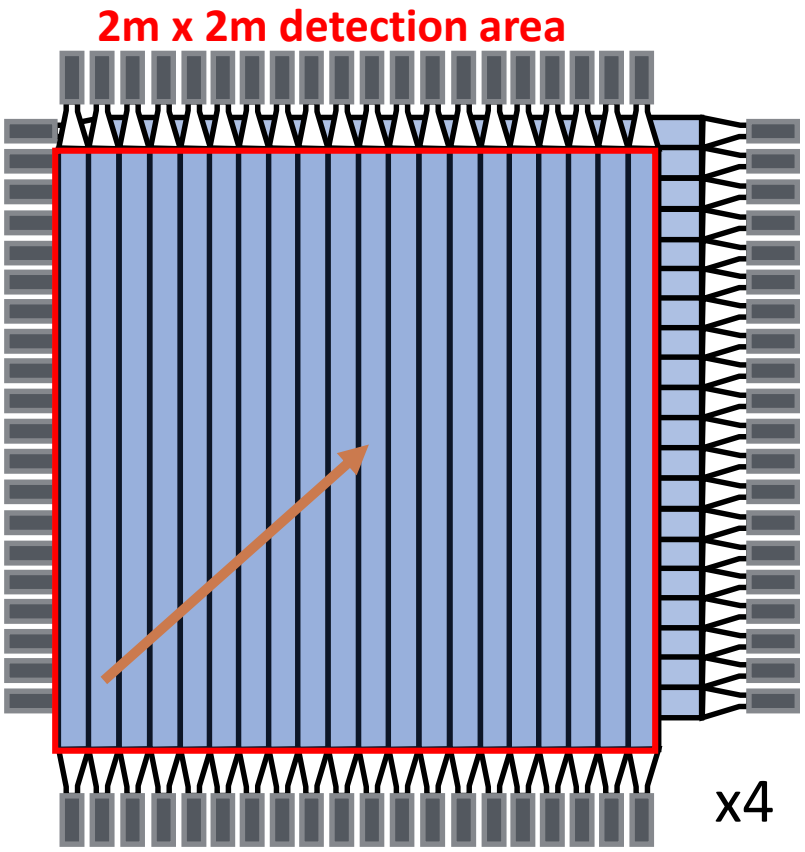
↘ **n/p, ^{3}H/^{3}He, π^-/π^+, N/Z…**

LAMPS detector system



Neutron detector array





- 2m-long BC408 scintillator
- Light readout with two PMTs
- Make two 2 x 2 m^2 detection plane with 40 neutron detectors.
- Two detection plane consisted single layer (4 layers in total).
- Readout : Notice 500 MHz FADC
- 20 Veto & 160 Neutron detector
- Measure timing, position, deposit energy of neutrons.

HARDWARE / Detector construction

=

Neutron detector production/construction

2018/05 : Prepare assembly
2018/06 : Start assembly

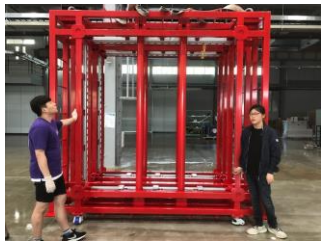
2018/08 : Frame arrived

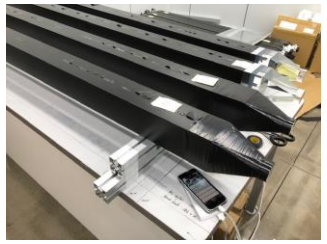
2018/11: End assembly
2018/12 : Install module

2019/05 : Connect cable &
Setup single crate base DAQ

2019/09 : LAMPS Trigger Electronics
2019/10 : DAQ & Performance test
with cosmic











DAQ electronics development (Notice Korea)

Proto-type TCB/FADC

TCB/FADC for NDA

LAMPS Trigger Electronics

2014 400MHz FADC

2015 500MHz FADC Box type,
24 channel for test

2017 500MHz FADC Crate/Board type
TCB/FADC 24 channel for test

2018 500MHz FADC Crate/Board type
TCB/FADC 360 channel

2019 LAMPS Trigger electronics

- 400 MHz FADC
  - No sync. with other board
  - No proper event ID
- 500 MHz FADC/Box type
  - Connection Error, clock sync error
- 500 MHz FADC/Crate type
  - No sync. method with other crate
- LAMPS Trigger Electronics
  - Complete All DAQ electronics

Debugging & Improving

LAMPS (Neutron detector) DAQ electronics

LAMPS Trigger electronics

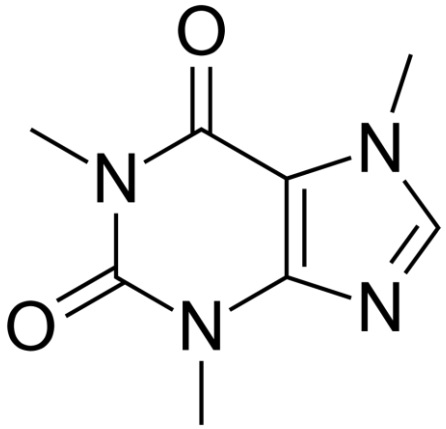
DAQ PC

Notice 500 MHz FADC System

CAEN HV system

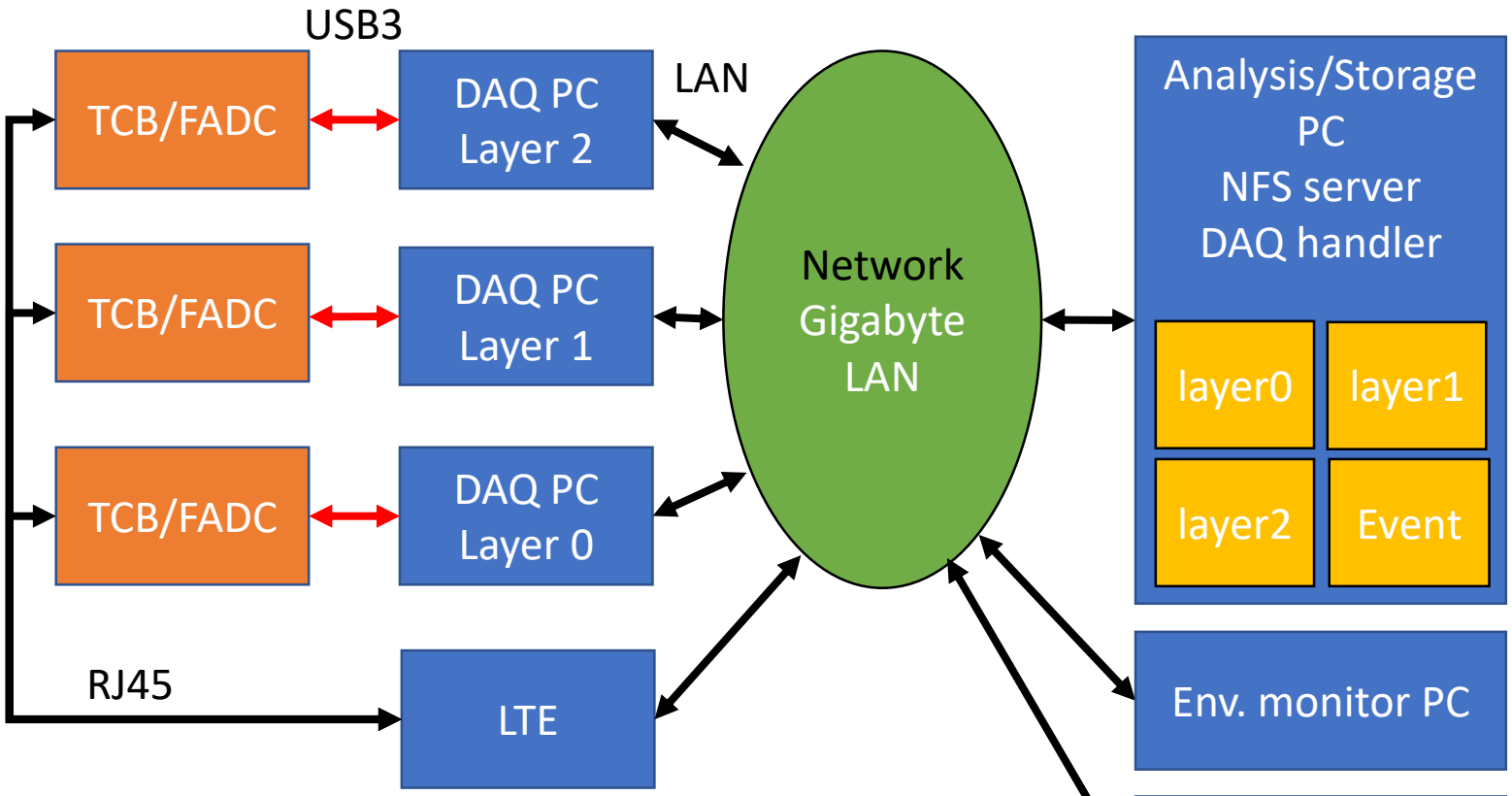
Software / DAQ and Calibration programming

Convert



to code

DAQ structure & control programs



Data acquisition program

- Worked continuously for 24 hr w/o problem
- Data rate : 4 MB/sec
- Semi-real time event build

CAEN HV : control ON/OFF HV, monitor status

Automated Timing / Gain adjustment

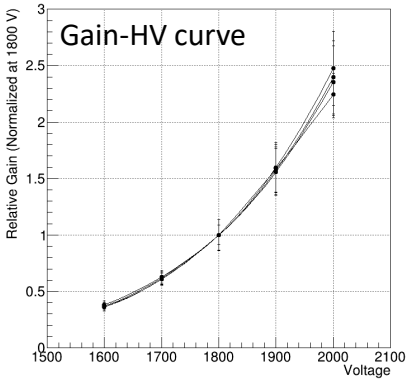
Timing Calibration

Get timing offset from timing difference distribution of two pmt signals

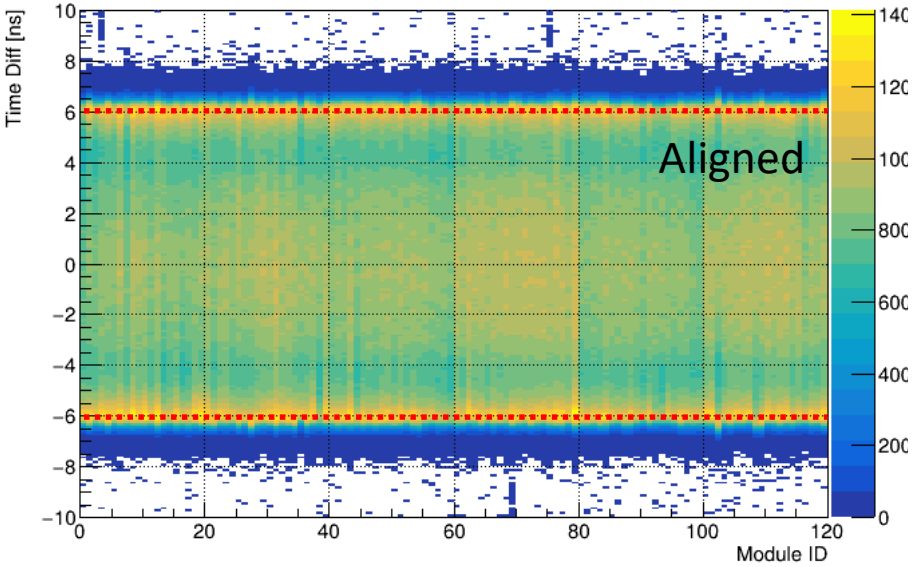
$$T' = T - \frac{T_R - T_L}{2}$$

Gain adjustment

Get MIP peaks of cosmic ray events and adjust HV based on Gain-HV curve.

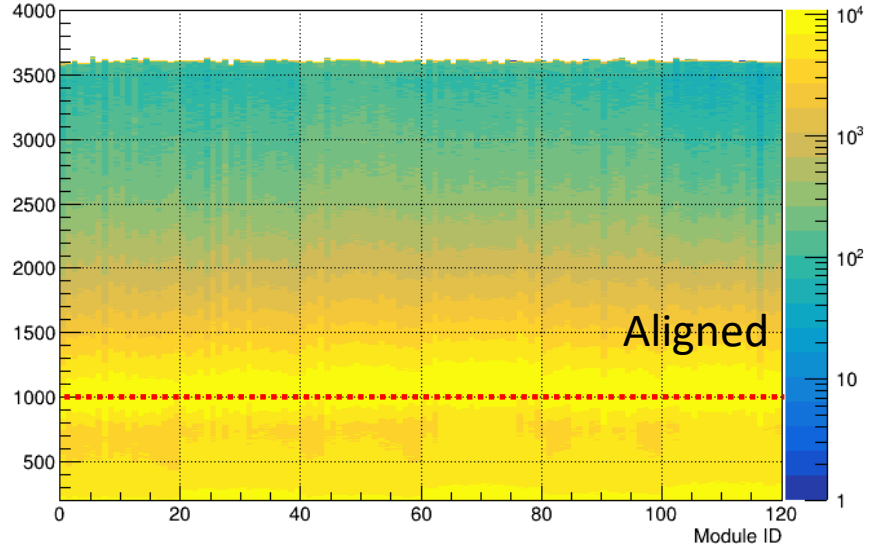


Time difference(~Position) vs ID



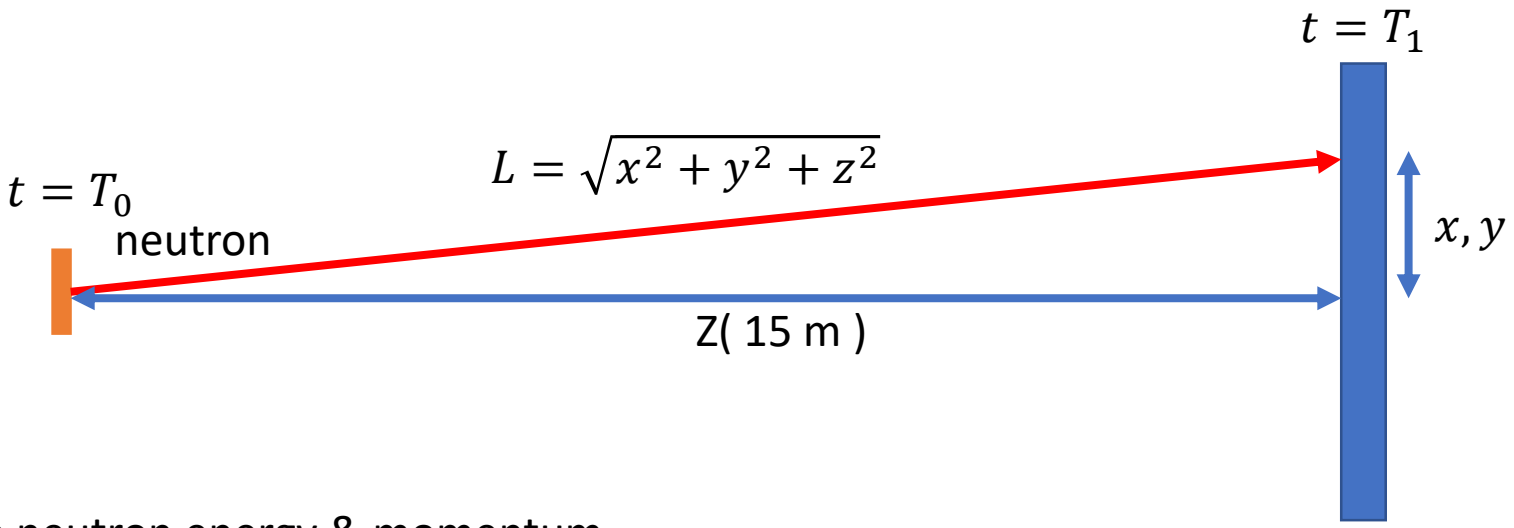
~ 10 minutes of data

Cosmic output vs ID



30~60 minutes of data

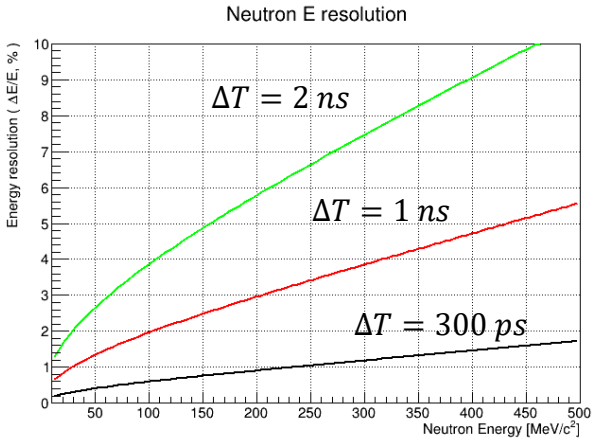
Performances of NDA?



Measure neutron energy & momentum

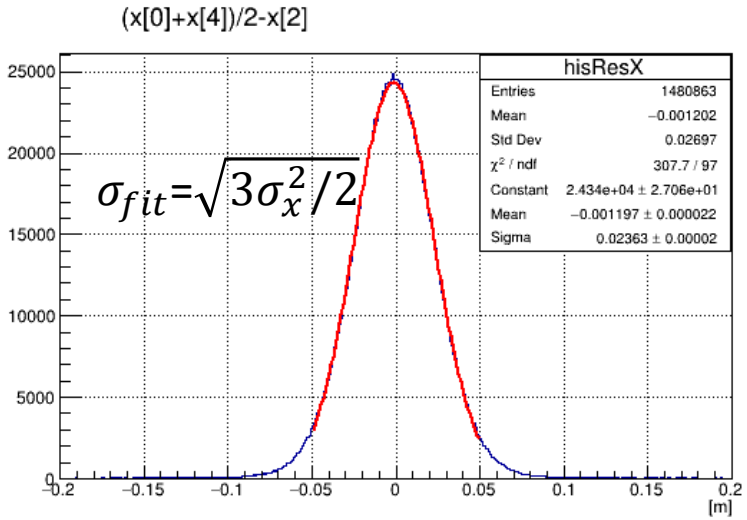
Neutron energy : $E_n = M_n \left(\frac{1}{\sqrt{1 - \left(\frac{L}{(T_1 - T_0)c} \right)^2}} \right)$

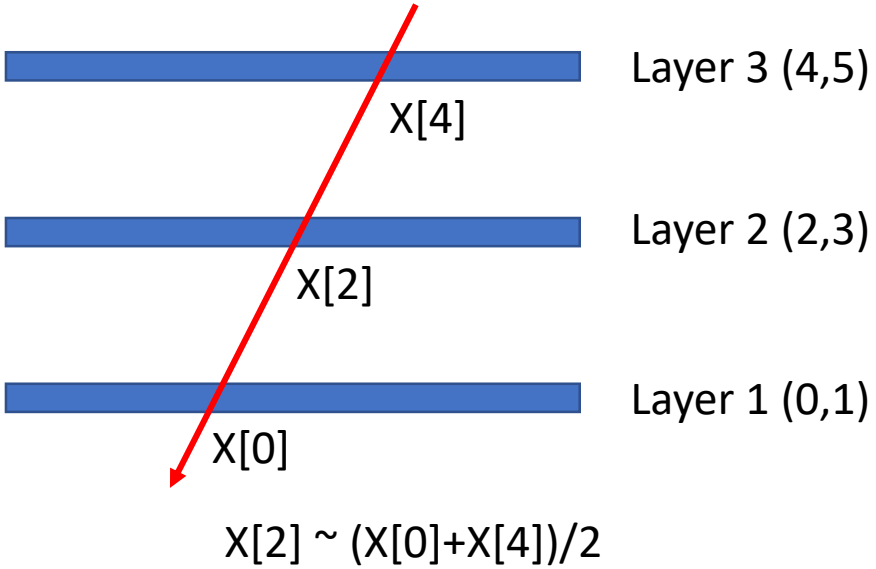
Neutron momentum : p = $M_n \left(\frac{1}{\sqrt{1 - \left(\frac{L}{(T_1 - T_0)c} \right)^2}} \right) \left(\frac{x}{T_1 - T_0}, \frac{y}{T_1 - T_0}, \frac{z}{T_1 - T_0} \right)$



To measure neutron energy and momentum accurately, position and timing resolutions are important.

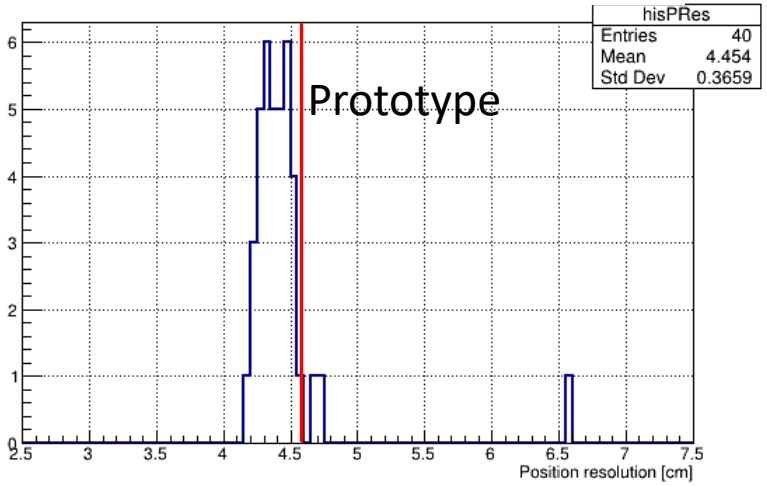
Detector Performance – Position resolution





X[2] ~ (X[0]+X[4])/2

Position resolution by module IDs



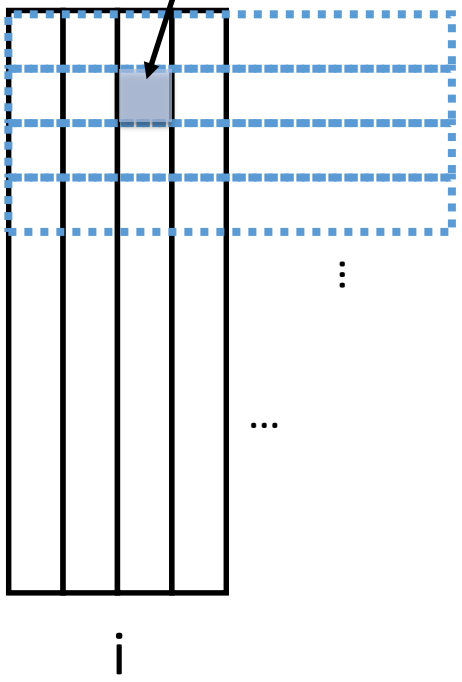
X resolution (global): 4.5 cm (FWHM)
Y resolution (global): 4.7 cm (FWHM)
Position resolution by module : 4.1~4.6 cm
Two large resolution module

Consisted with prototype module result (4.56 cm)

Detector Performance - Timing resolution

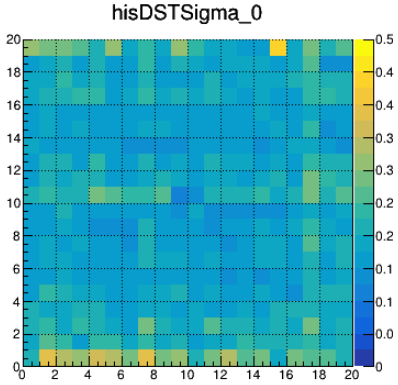
Time difference between orthogonally overlapped two modules in same layer

400 combinations of (i,j)

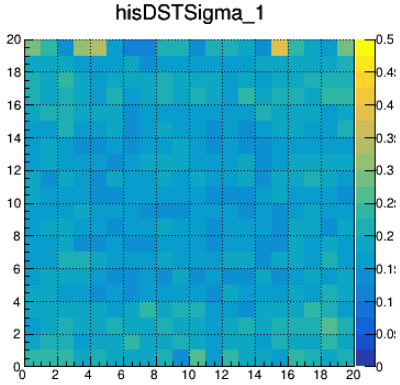


Sigma of (T_i - T_j) distribution

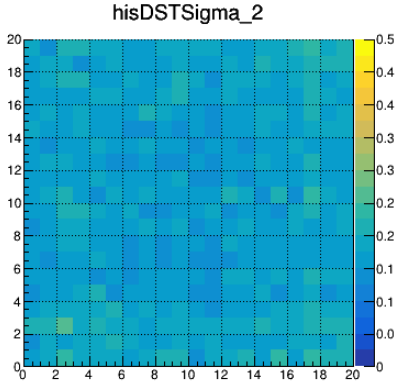
Layer 1

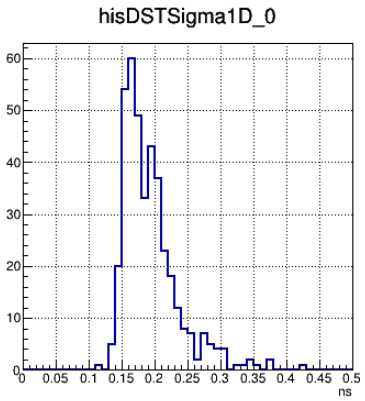


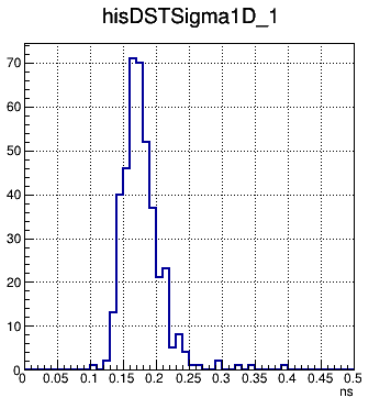
Layer 2

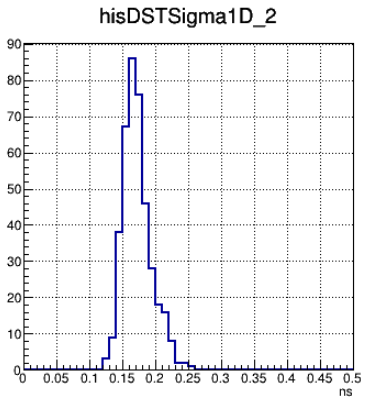


Layer 3







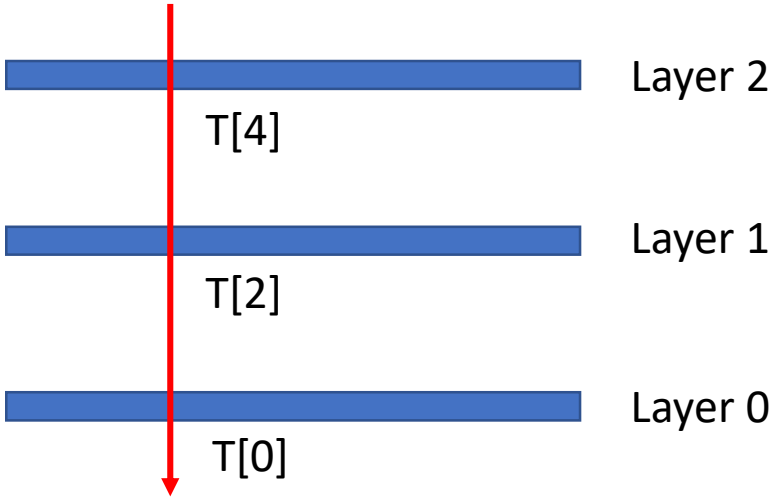


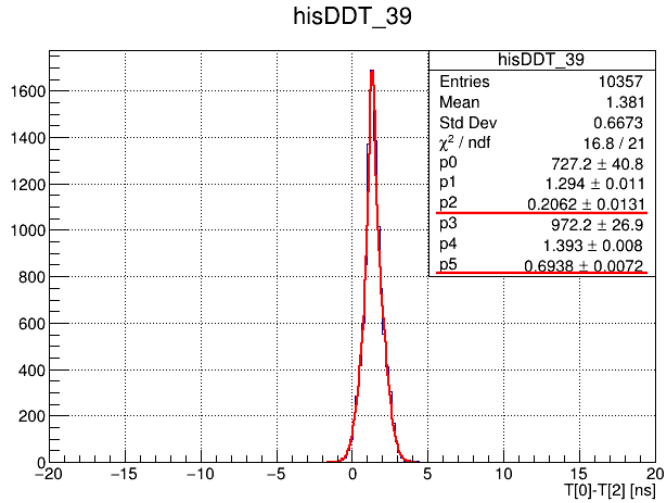
Mean value : 181 ps -> **Expected Timing resolution = 301 ps**

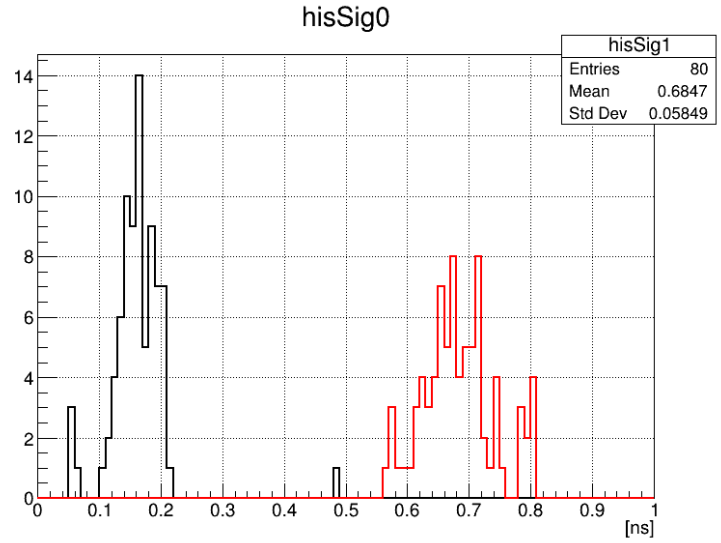
Consisted with prototype module result (309 ps)

Detector performance – Time Jitter

Time jitter between crates







T[0]-T[2] or T[0]-T[4] for vertical events
Distributions were double gaussian distribution
σ(Narrow) : 0.1~0.2 ns , ~Timing resolution
σ(Wide) : 0.6~0.8 ns ,Under investigation.
-> **<u>Clocks between crates were synchronized.</u>**

Summary

Summary

- 3 Layers of LAMPS neutron detector array were stacked and connected with electronics.
- All LAMPS DAQ electronics were completed and installed.
- Basic Performances of LAMPS neutron detector array were measured.
  - Timing resolution : 301 ps (FWHM)
  - Time jitter between crates : < 200 ps (sigma)
  - Position resolution : 4.5 cm (x), 4.7 cm (y)
- We made one of best neutron detectors in the world!

	LAMPS	MoNA	NEBULAR	LAND
Dimensions(cm^3)	10x10x200	10x10x200	12x12x180	10x10x200
Time resolution(ps)	301	423	376	588
Position resolution (cm)	4.5(x),4.7(y)	5.2	6.1	7.1

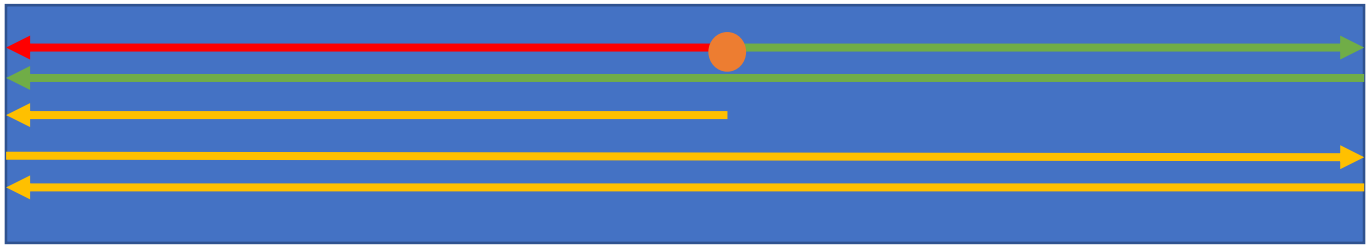
Waveform analysis

LAMPS waveform Fitting function : Error Function * Exponential

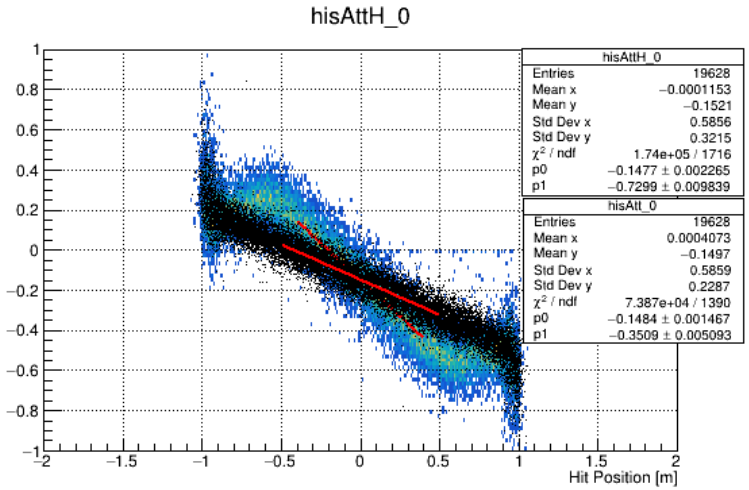
- [0] * {Tmath::Erf ((x –[1])/[2]) +1 } * Tmath::Exp(-(x-[1])/[3])
  - [0] : Signal Height equiv. value
  - [1] : Signal Timing
  - [2] : Rising constant
  - [3] : Decay constant

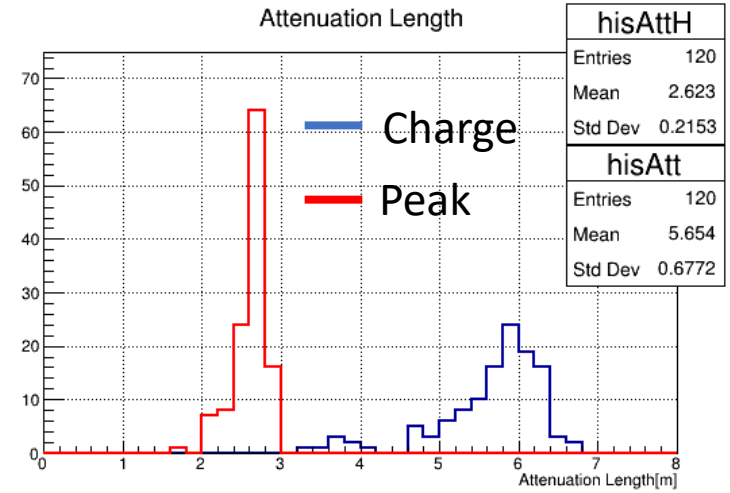
=>4 parameters / peak

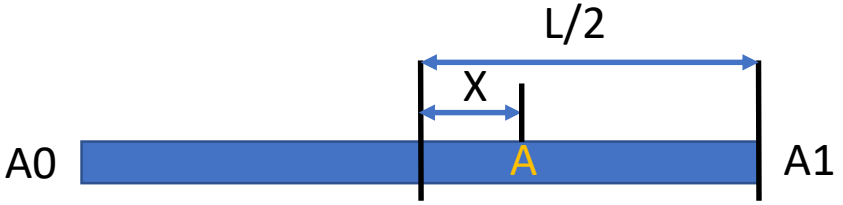
- Parameter for light reflection
  - Attenuation
  - Delay
  - Reflection
  - Two time reflection
  - 13 parameters



Detector Performance - Attenuation length







$$A_0 = A\exp\left(-\frac{\frac{L}{2}+X}{\lambda}\right) \quad A_1 = A\exp\left(-\frac{\frac{L}{2}-X}{\lambda}\right)$$

$$\log\left(\frac{A_0}{A_1}\right) = -\frac{2}{\lambda}X + \delta$$

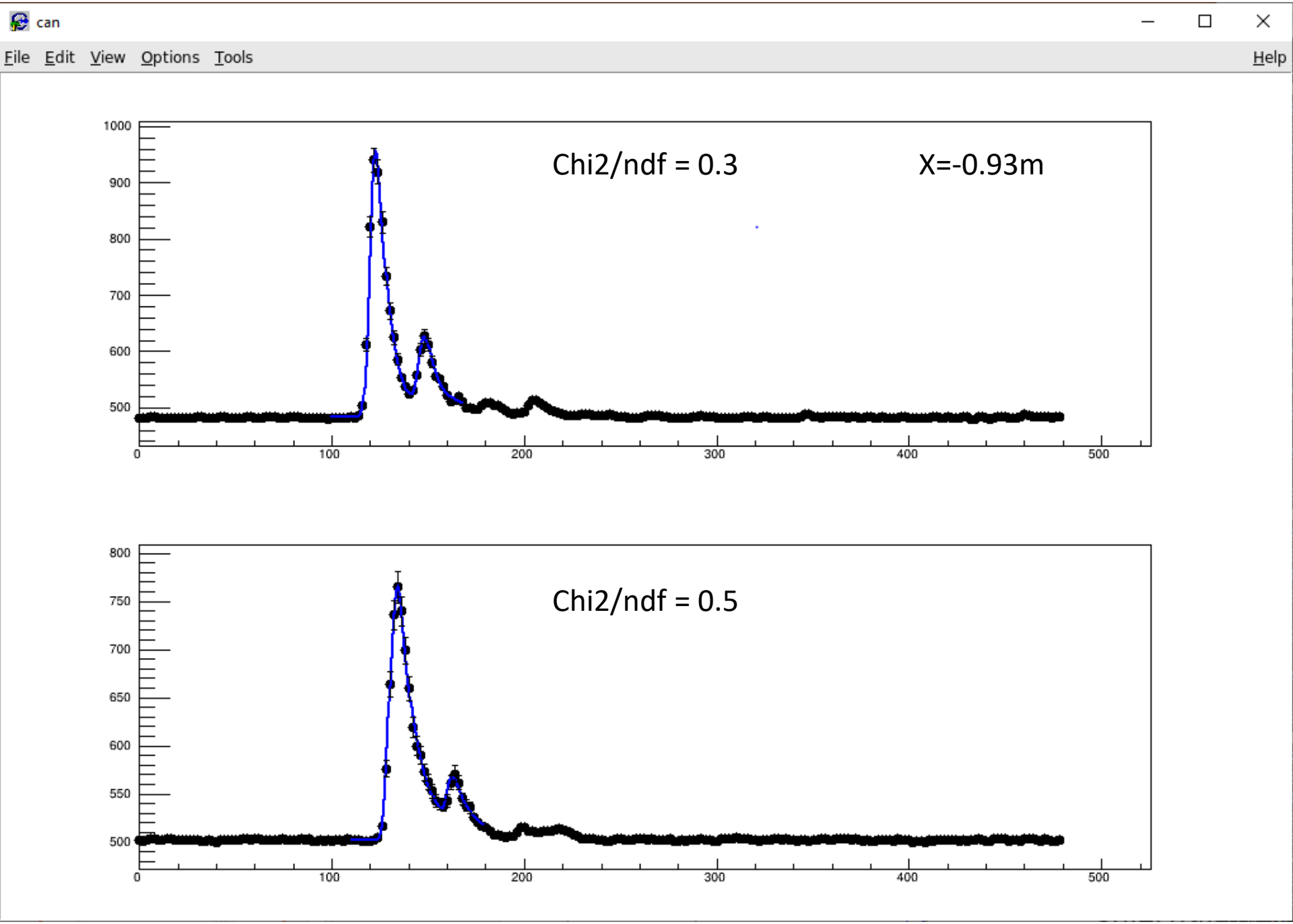
Two attenuation lengths of ln(A0/A1) vs X

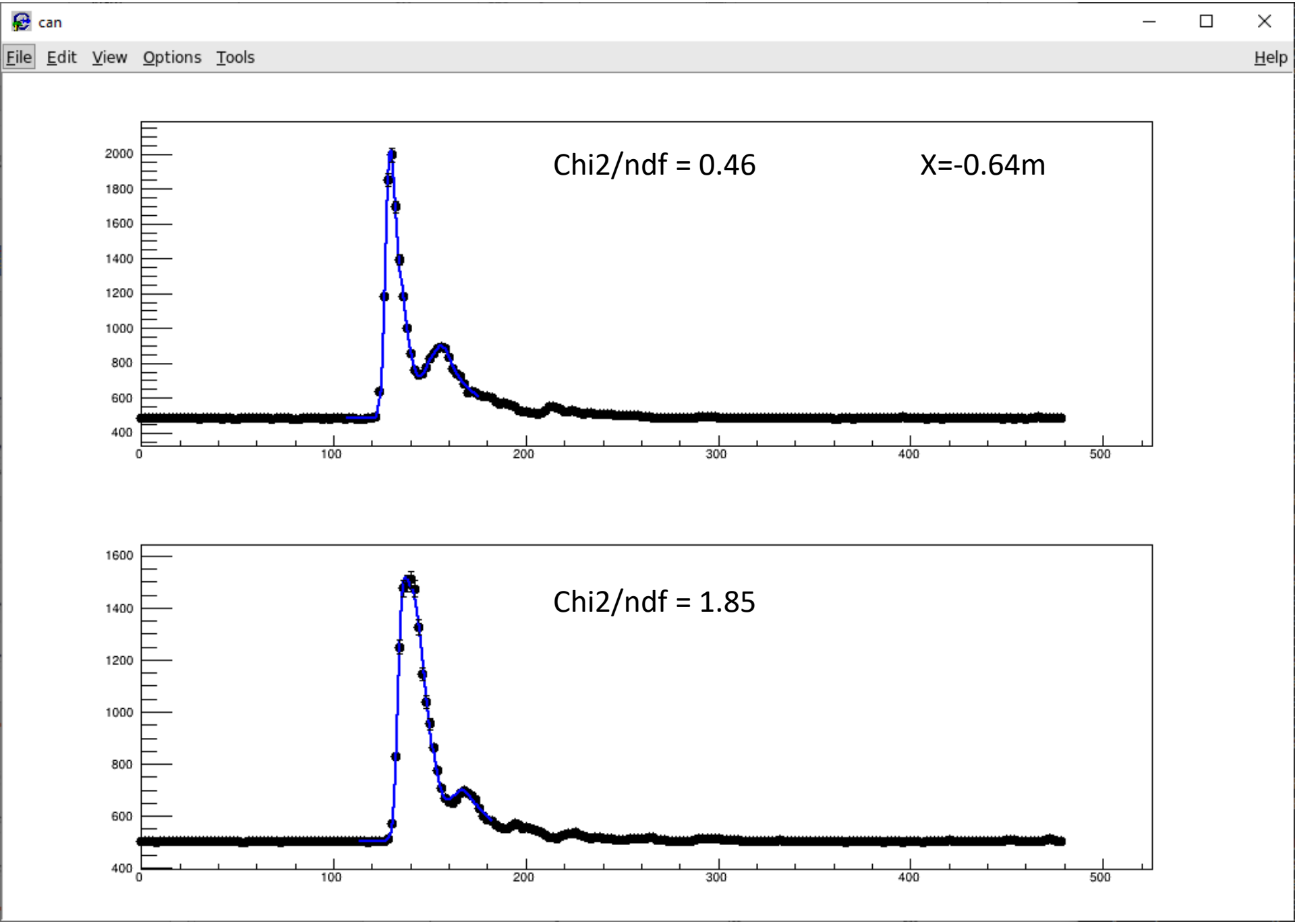
- Peak ratio : 2.6 m
- Charge ratio : 5.7 m

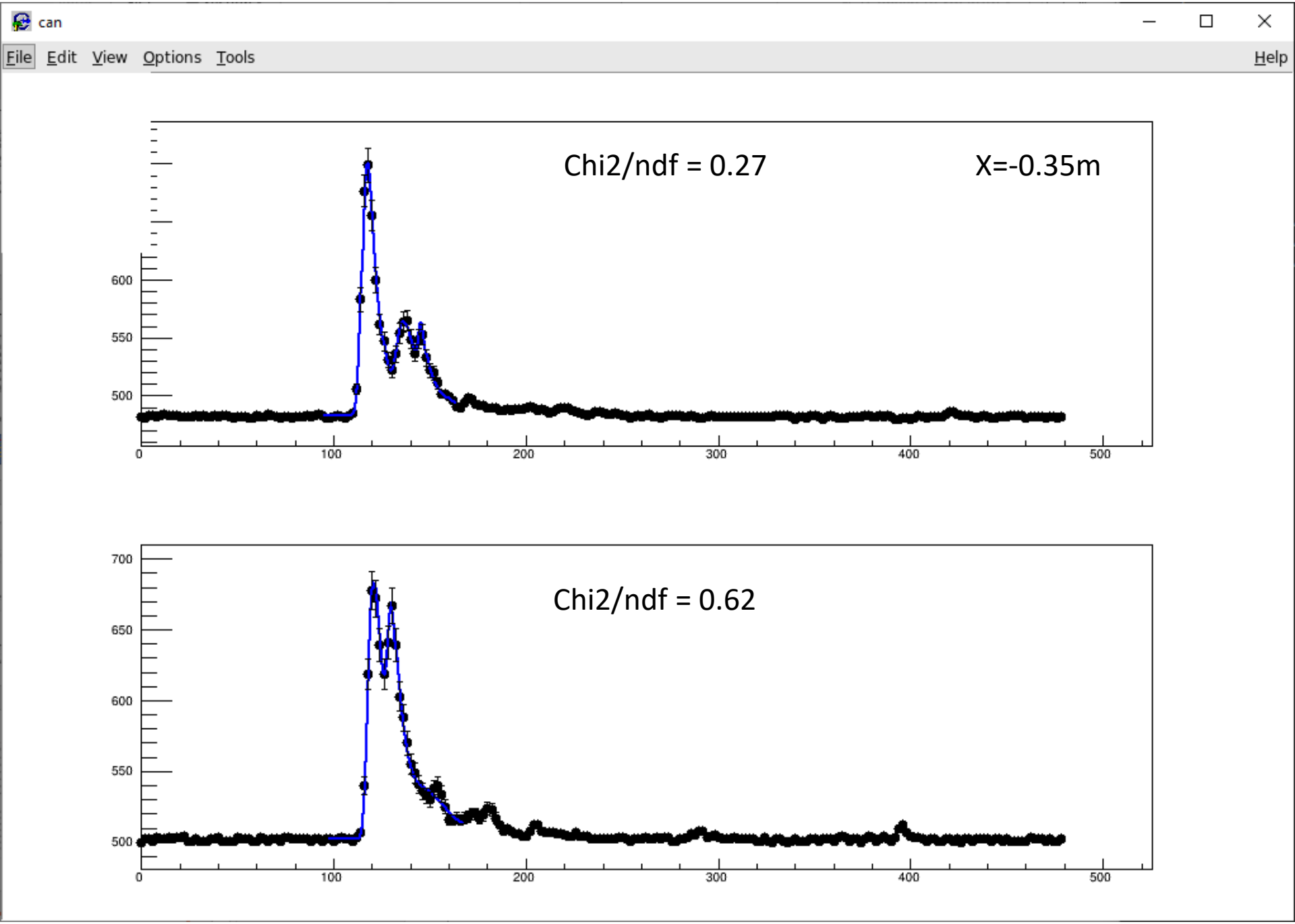
(Reflection & Light collection effect)

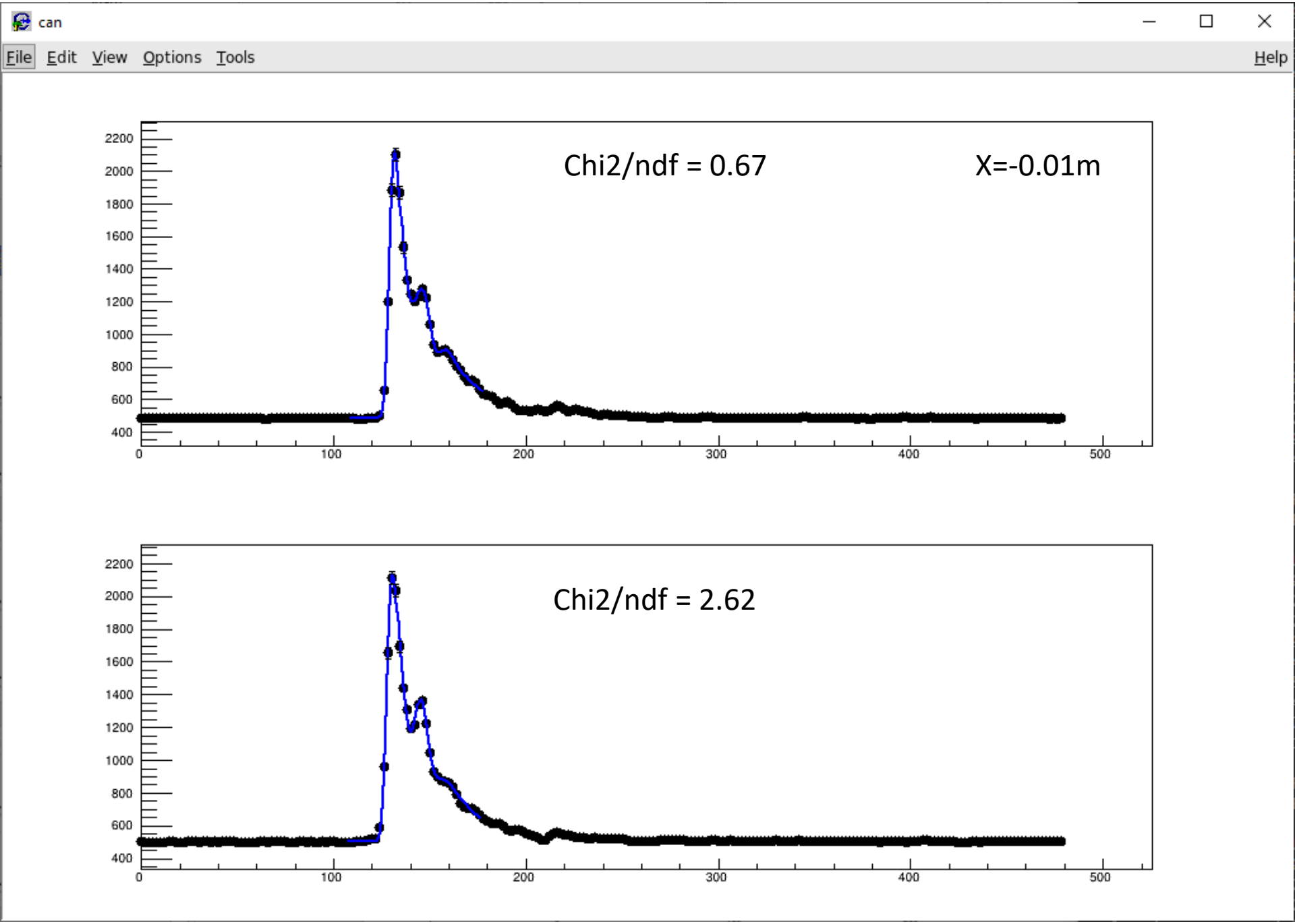
BC408 properties

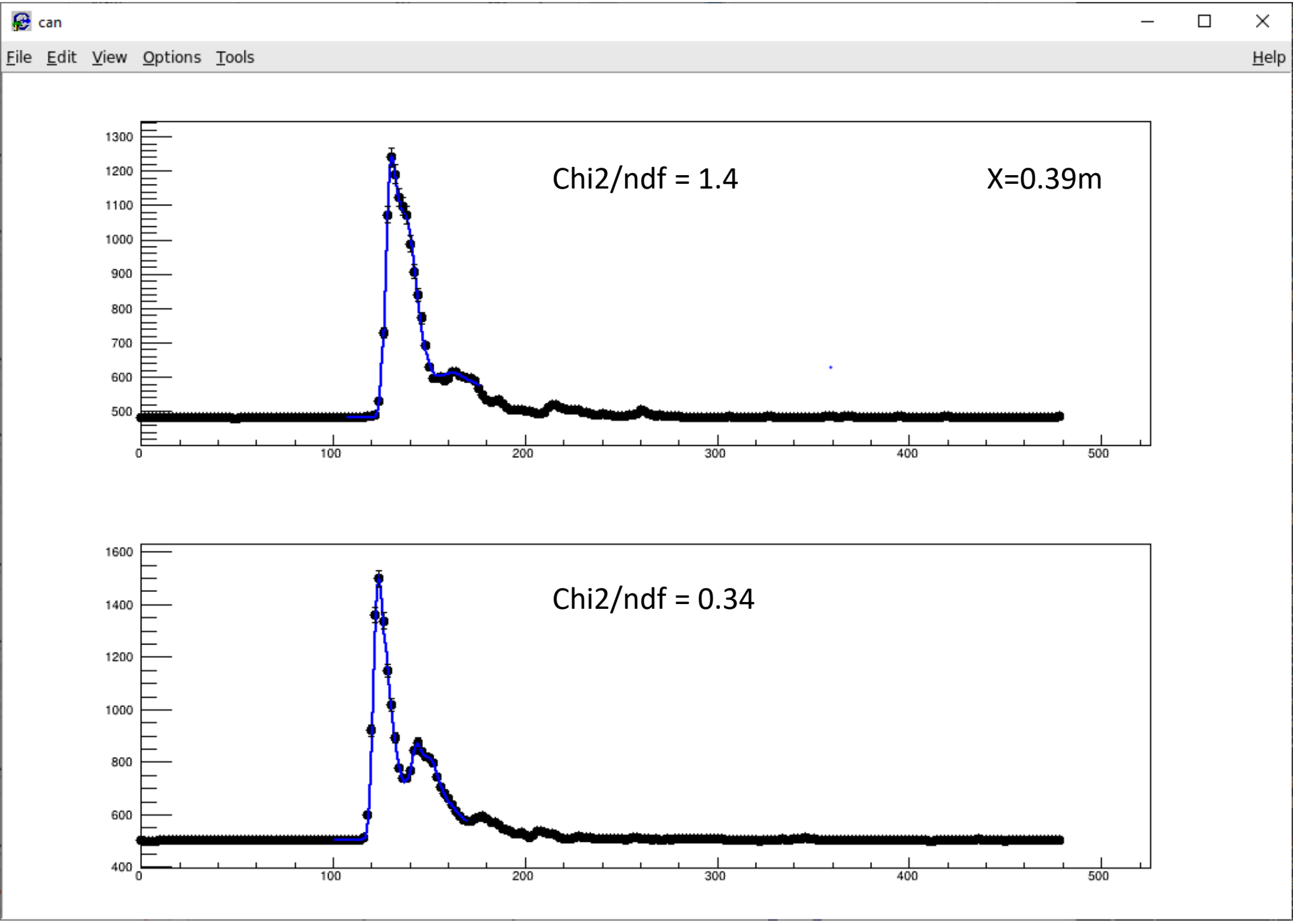
- Light attenuation length 2.1 m
- Bulk light attenuation length 3.8 m

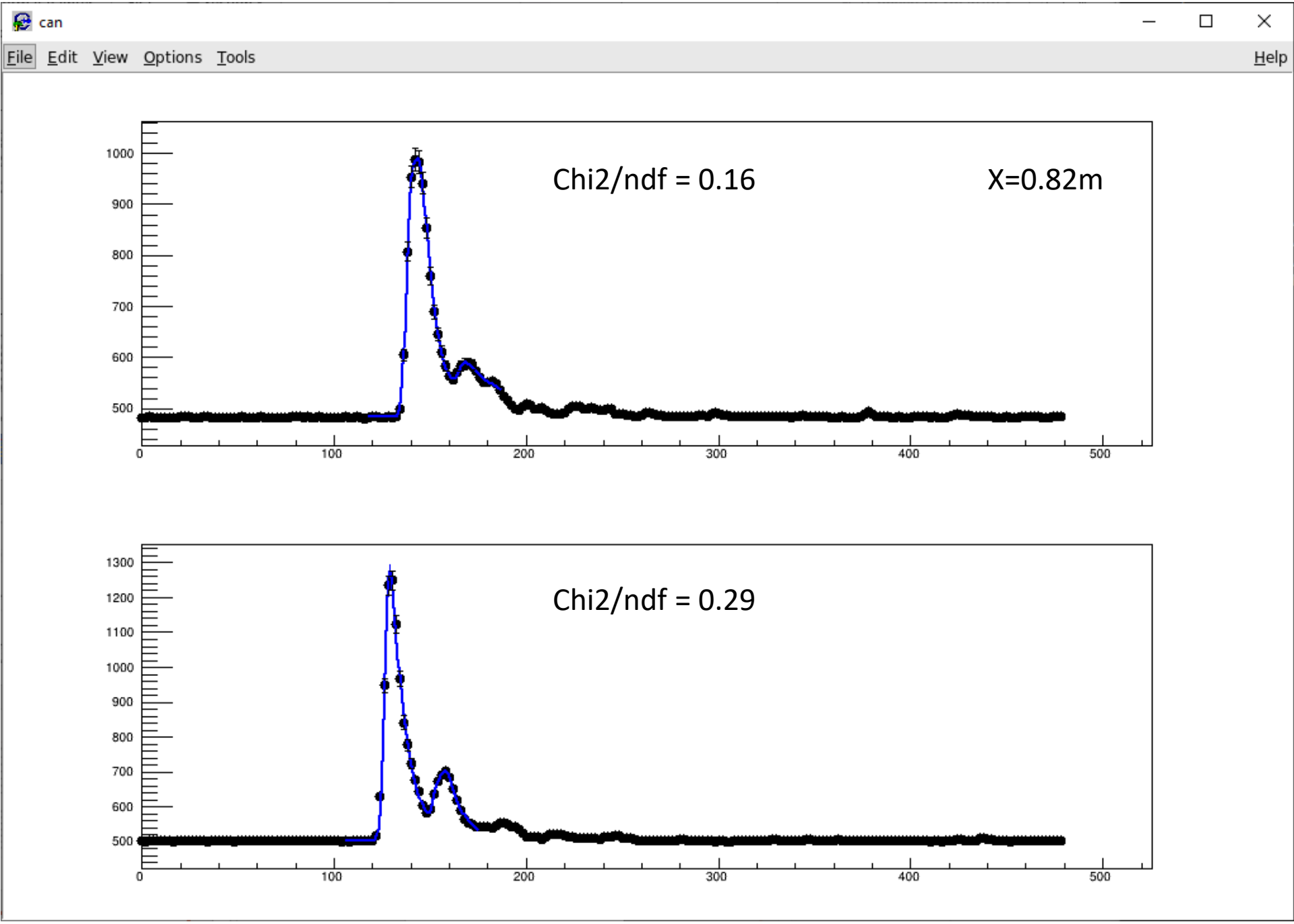

can
File Edit View Options Tools Help
Chi2/ndf = 0.3
X=-0.93m
Chi2/ndf = 0.5


can
File Edit View Options Tools Help
Chi2/ndf = 0.46
X=-0.64m
Chi2/ndf = 1.85


can
File Edit View Options Tools Help
Chi2/ndf = 0.27
X=-0.35m
600
550
500
0
100
200
300
400
500
Chi2/ndf = 0.62
700
650
600
550
500
0
100
200
300
400
500


can
File Edit View Options Tools Help
Chi2/ndf = 0.67
X=-0.01m
Chi2/ndf = 2.62
2200
2000
1800
1600
1400
1200
1000
800
600
400
0
100
200
300
400
500

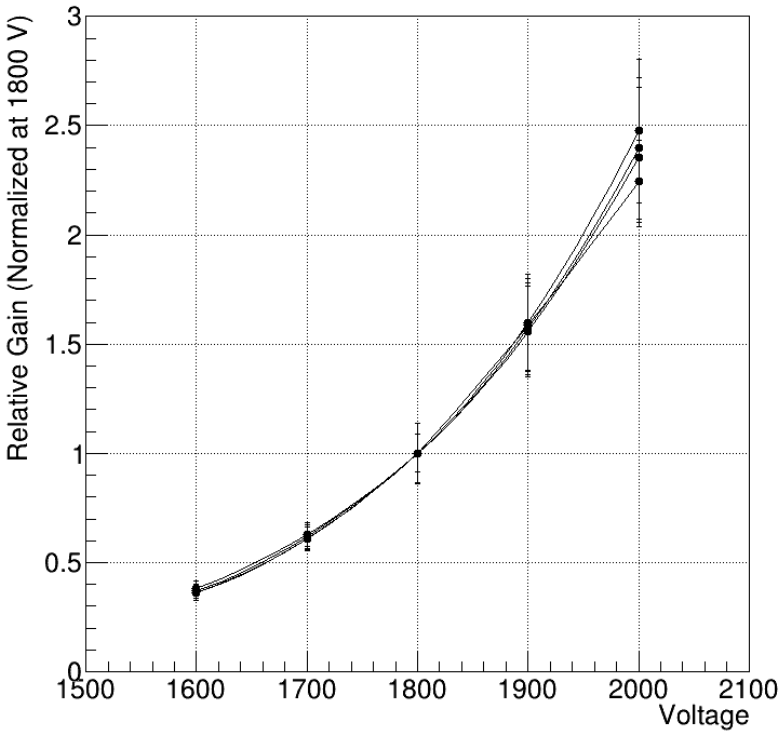

can
File Edit View Options Tools Help
Chi2/ndf = 1.4
X=0.39m
Chi2/ndf = 0.34


can
File Edit View Options Tools Help
Chi2/ndf = 0.16
X=0.82m
Chi2/ndf = 0.29

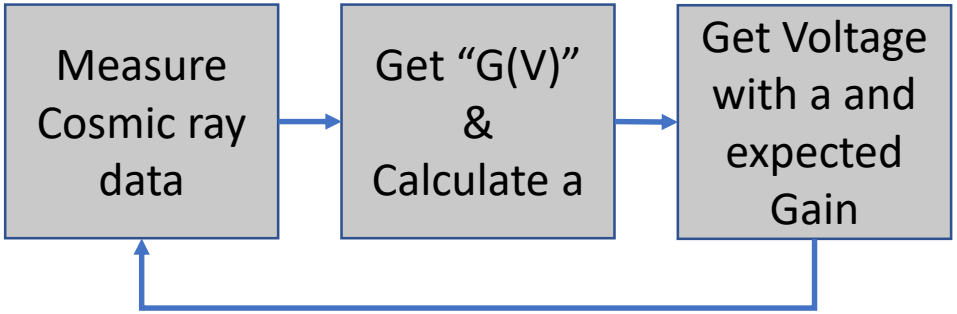
Output alignment

$$V = e^{\frac{1}{8.56} \times \ln(Gain/a)}$$

Measured PMT HV Gain curve (H7195)

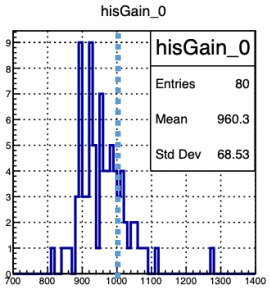


$$G(V) = a\,(V/1000)^{8.56}$$

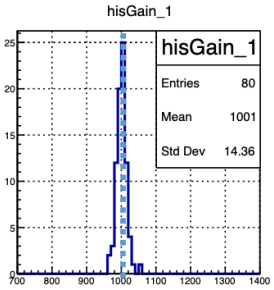


Make script for auto HV adjustment

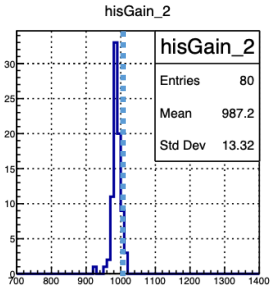
Initial Gain Dist.



Adjust 1 times



Adjust 2 times



All gains were aligned with ~2% by two times of HV adjustments

Each measurement took 1~2 hr (3~6 hr total)