The Dual Light-emitting Crystals Detector for WIMPs Direct Searches

Xuan Zhang
IHEP
PASCOS 2016, Quy Nnon, Vietnam

Contents

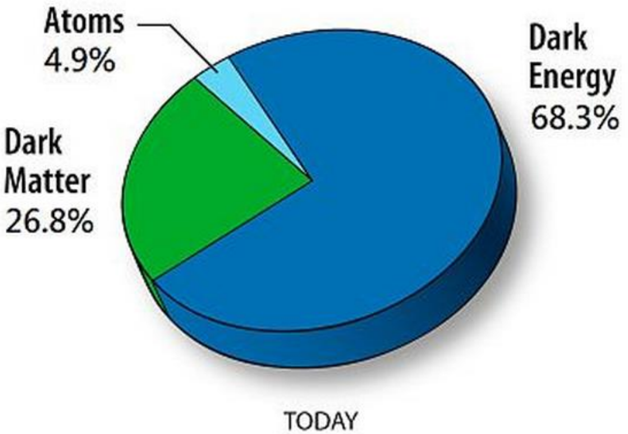
Introduction

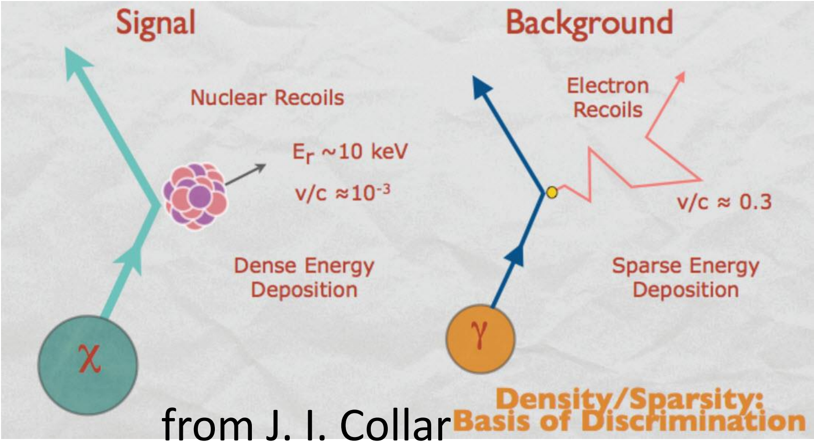
- Weakly Interacting Massive Particles (WIMPs) direct detection
  - dark matter may scatter on ordinary matter through

$$DM + SM \rightarrow DM + SM$$

$$SM \rightarrow phonons, \text{scintillation}, \text{ionization}$$

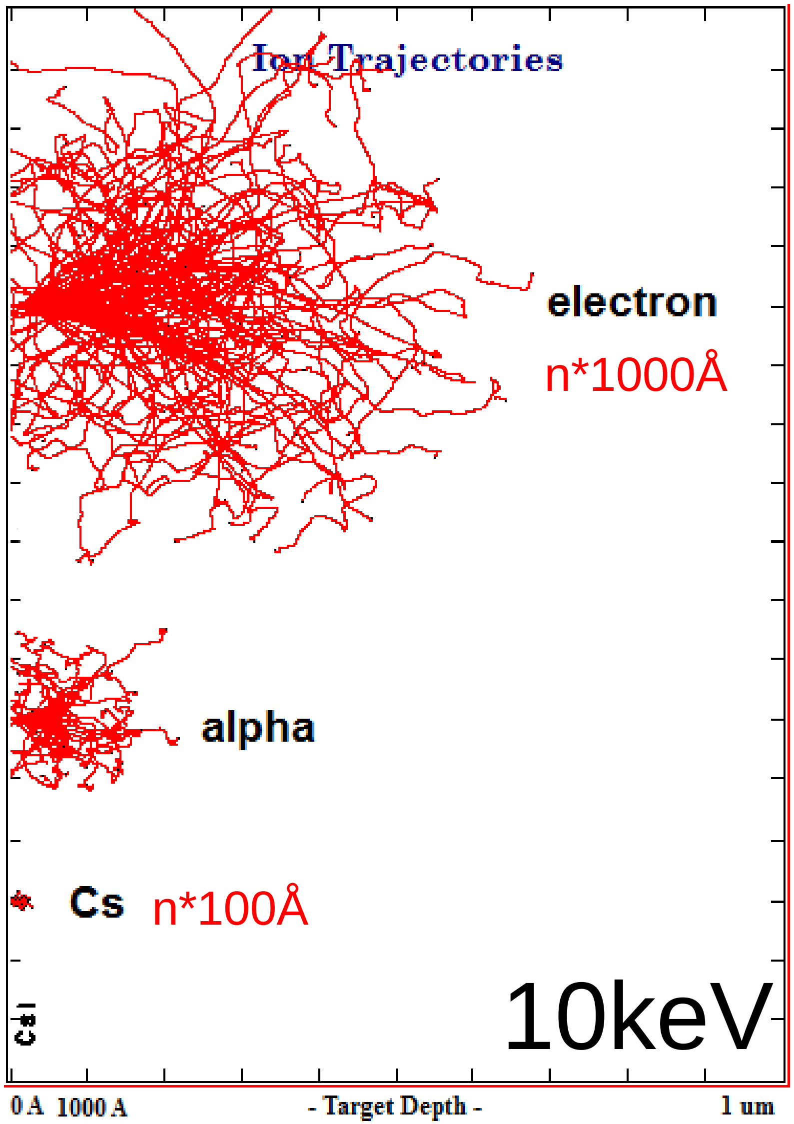
- Detector requirements:
  - Low energy threshold
  - Low background (background rejection)
  - Can be easily scaled to large mass





from J. I. Collar

The Main Differences: Interaction Region



The main differences:

●Electron recoil

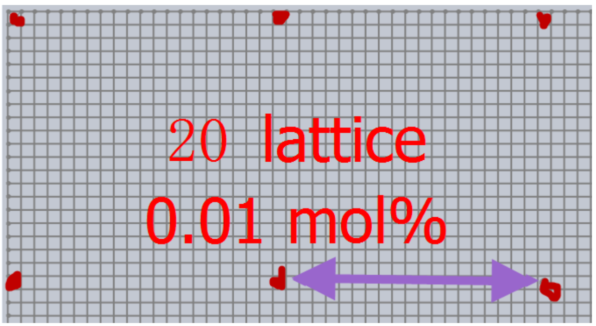
has lower dE/dx, the rang is large n*1000Å

●Nuclear recoil

has higher dE/dx, the rang is local n*100Å

0.01 mol% dopping

Space is 20 lattice ~100Å

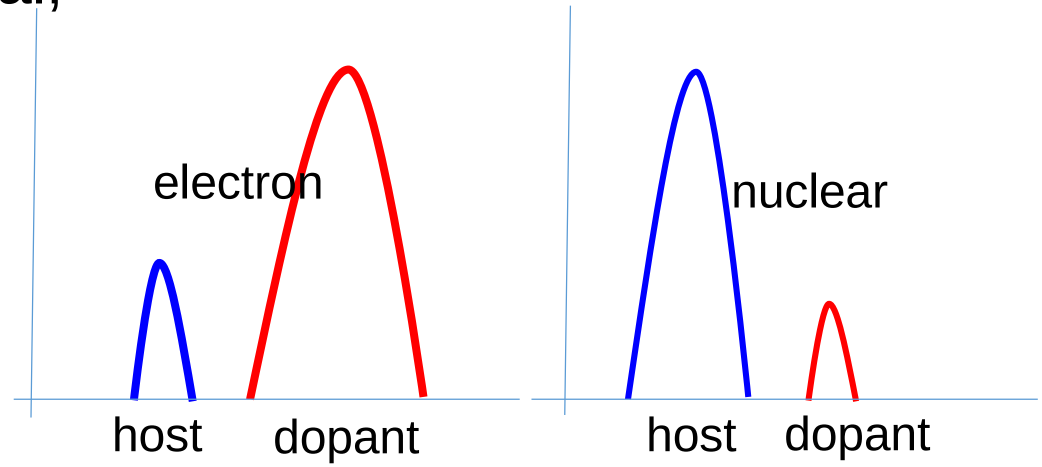


Dual Light-emitting Crystals can reflect the different ranges of different particles by the ratio of different scintillation components.

Dual Light-emitting Crystals

Doped crystals has two scintillation components, one is from the host material, another is from the dopant.

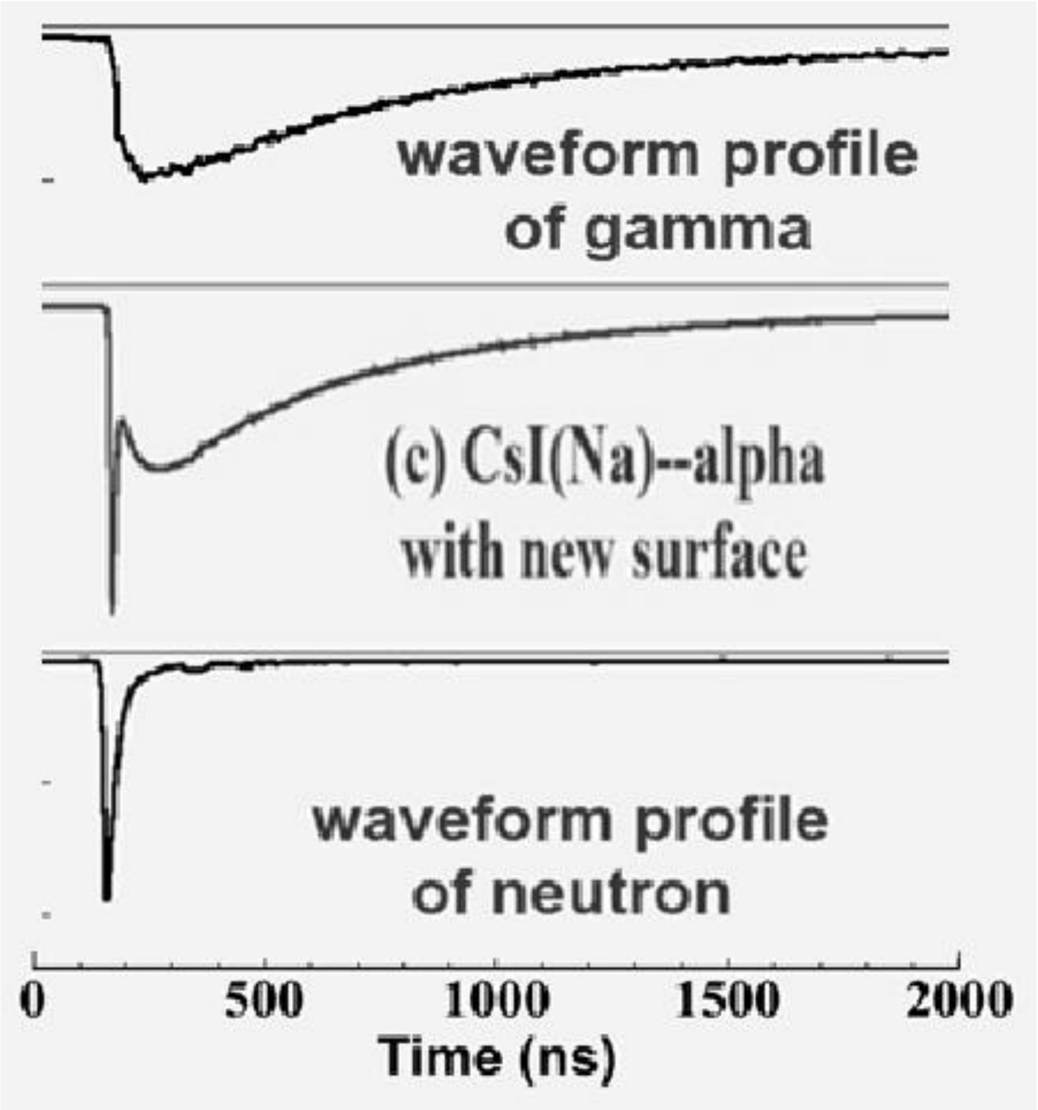
- Large range electron recoils, dopant dominate the light emition
- Nuclear recoils range Host dominate light



The ratio of the two luminescence is different for nuclear recoils and electron recoils.

CsI:Na is confirmed as one dual light-emitting

Performance of CsI(Na): Waveform



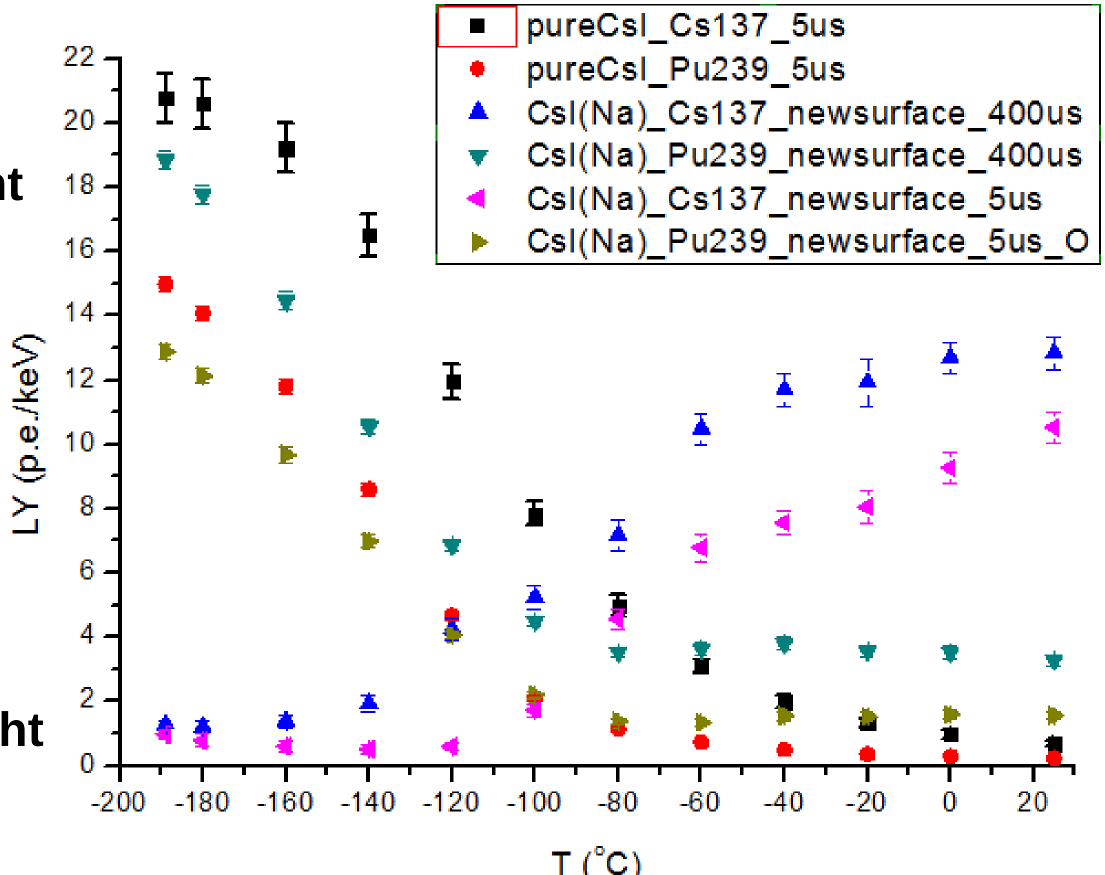
Dopant dominates

Both dopant & solvent

Solvent dominates

The light yield

fast light



slow light

light yield variation with temperature.

2.5x2.5x2.5cm CsI(Na)
Test by PMT R8778
~30% QE @ 300-400nm

-180C
LY 12 p.e./keVee for alpha
Nuclear recoils:
QF: 10% of alpha
Light collection: 50% of 2.5cm
~0.6p.e./keVnr
Threshold 10p.e. is
16keVnr with
10^{-6} rejection power

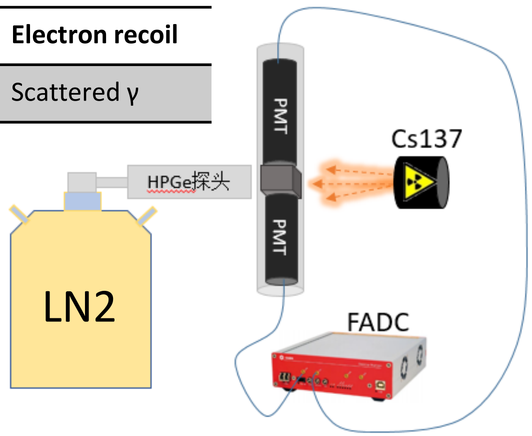
Quenching factor of alpha/gamma for pure CsI increase from 35% to 68% with temperature drop from 25 to -180°C, Reveal that luminous intensity for high dE/dx particles has larger increase as the temperature drops.

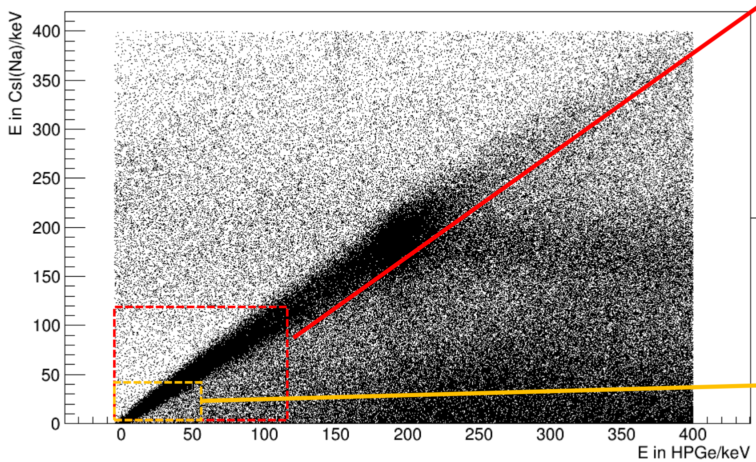
Qf of n/gamma maybe large than 6.8%, but difficult to measure.

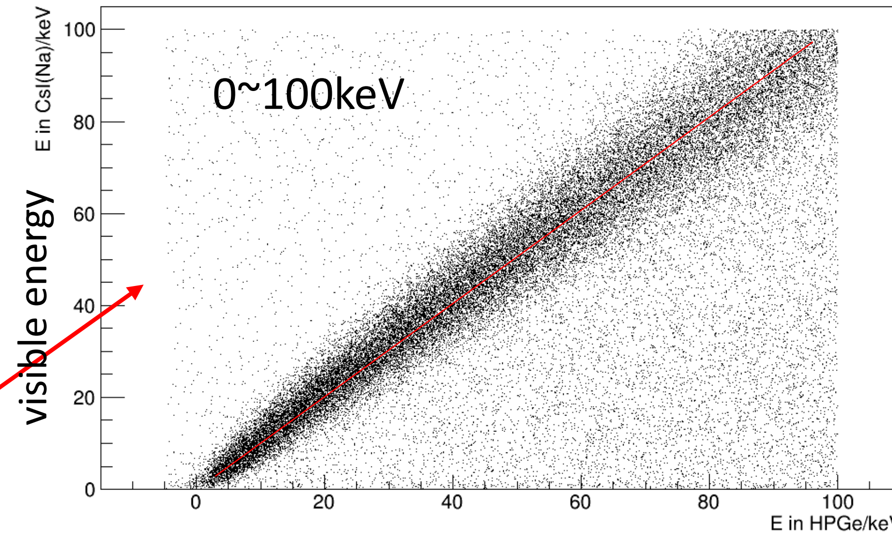
Energy response of CsI(Na)

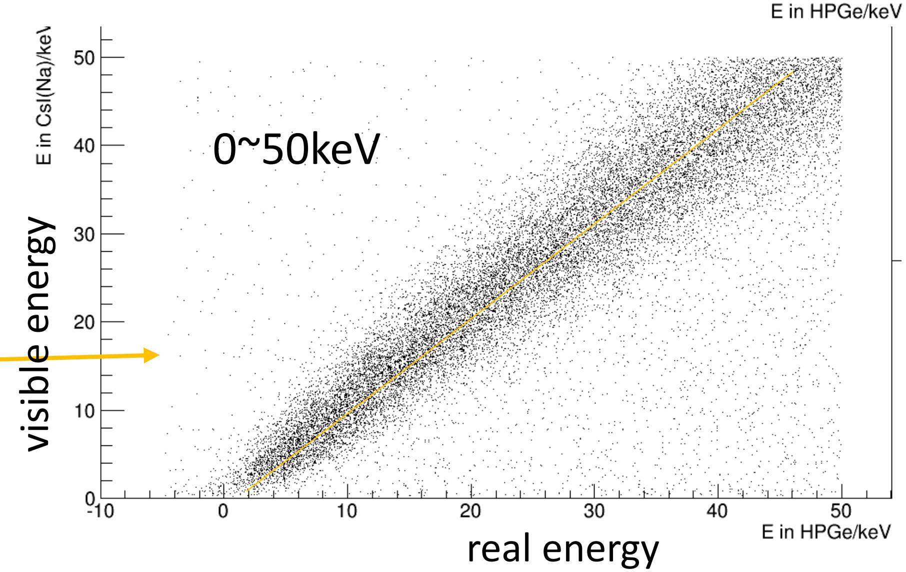
HPGe spectrum：FWHM<4keV@662keV

PMT	Electron recoil
HPGe	Scattered γ



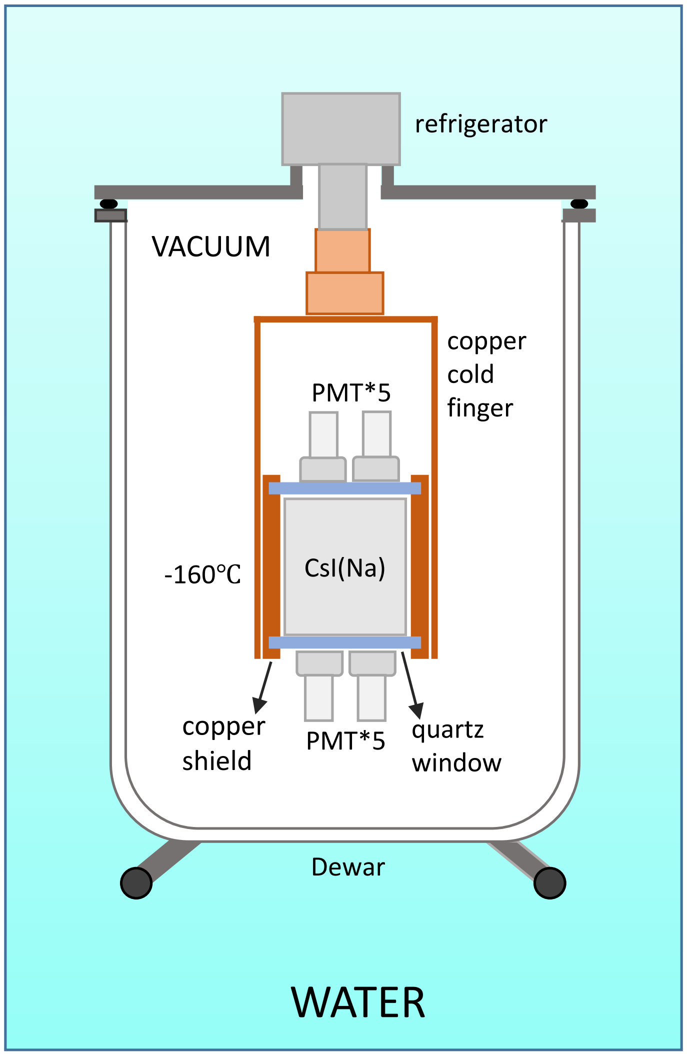






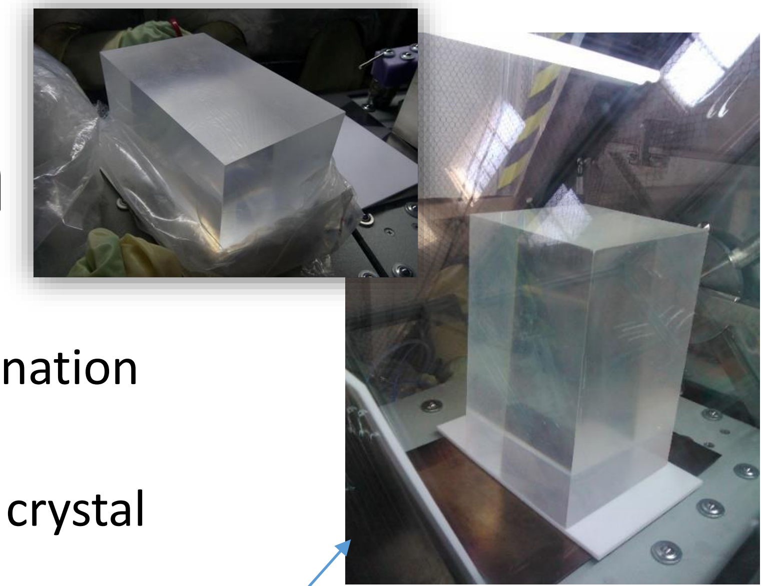
CsI(Na) energy response remains linear at low energy

Detector design

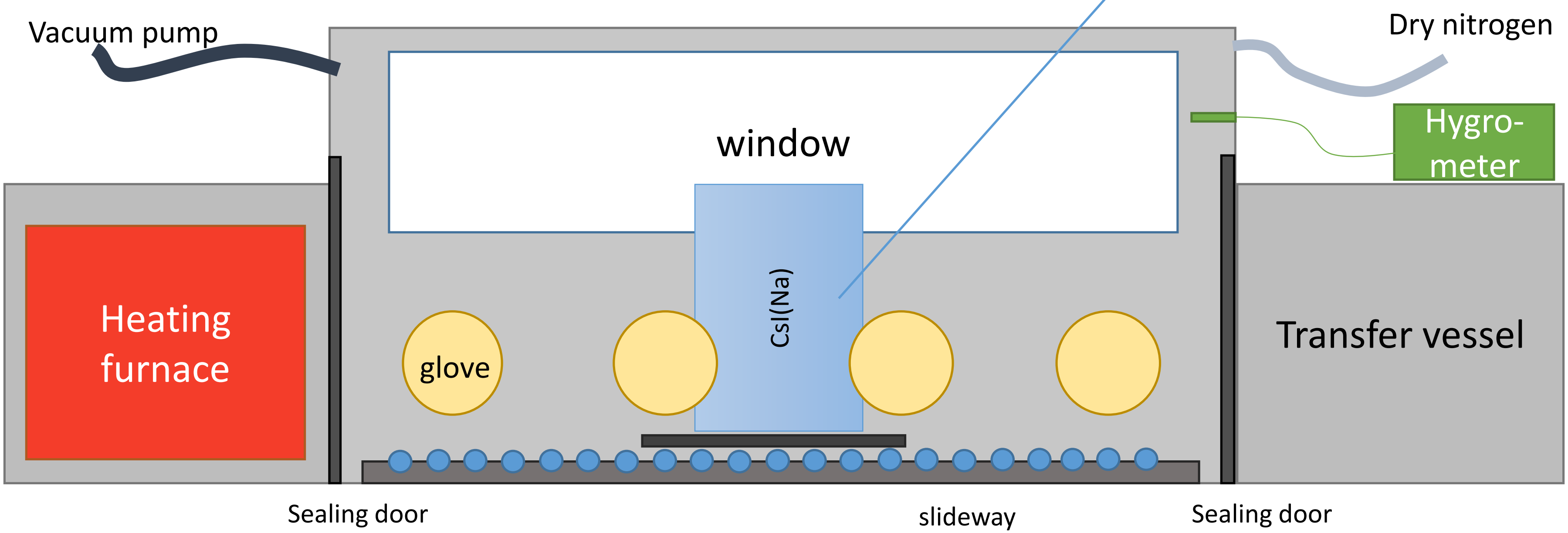


- CsI(Na):18*18*30cm(40kg) encapsulated in 4cm thick Cu shield and 1.5cm quartz window
- Cu shield,80kg, connected to chiller with Cu cold finger, ~160℃
- Water shield outside dewar>2m

Scintillator capsulation

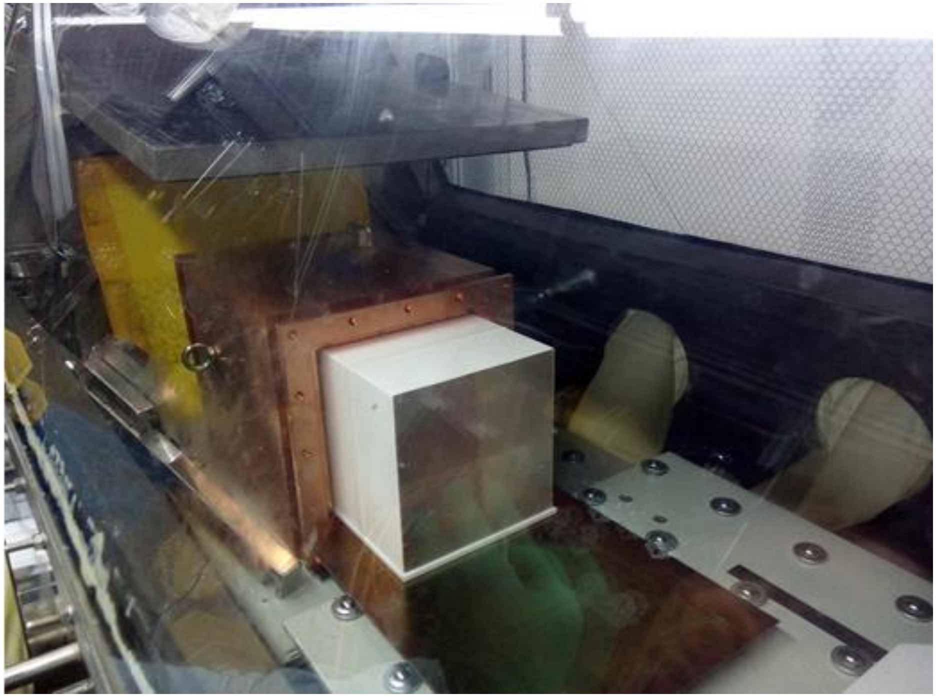


- CsI(Na) crystal will lost background discrimination capability when it's deliquescent
- Baking, testing and capsulation of the 40kg crystal are done in the glove box in a cleanbooth.



Scintillator assembly

- Wrap PTFE films outside the scintillator after baking
  - Insert into the copper shield， grease the 2 ends with optical Si gel
- Mount Si pad, Cu flange
- Leakage test

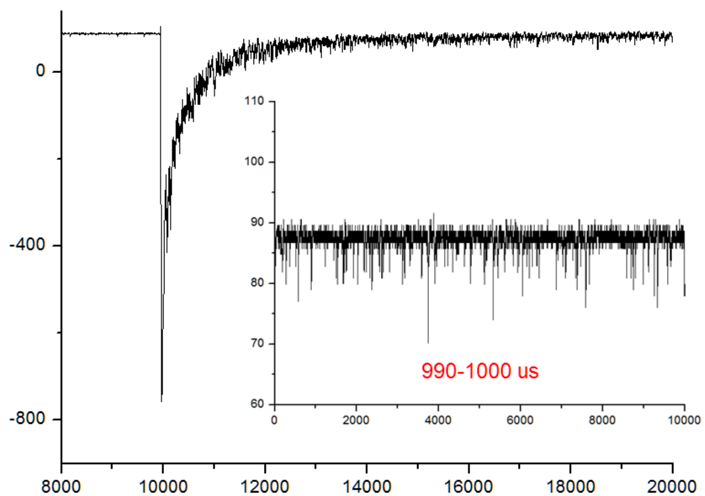


Performance of dry run

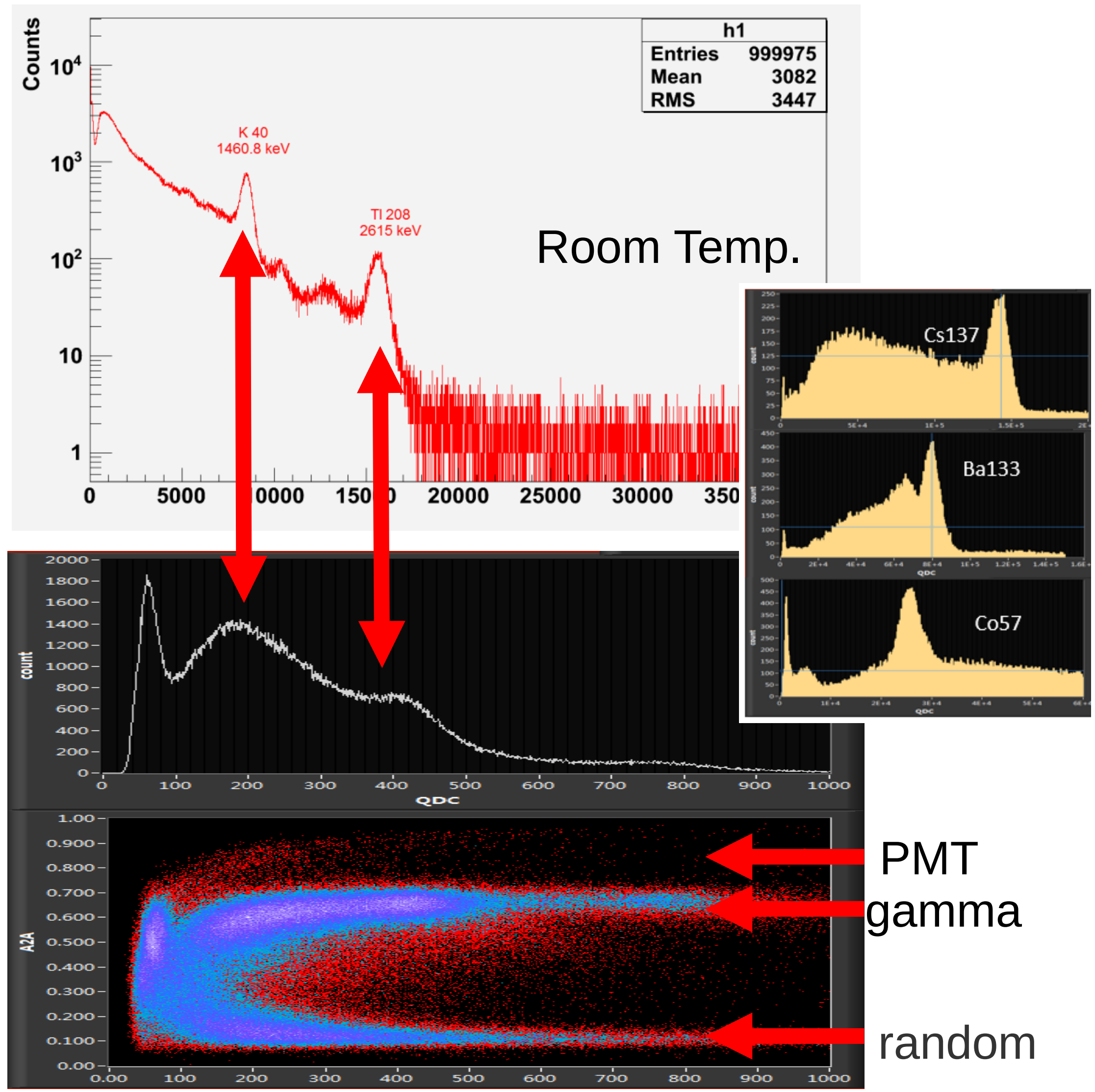
	Activity [Bq/Kg]
^{137}Cs	<0.009
^{134}Cs	0.050±0.004

Confidence Level 95%

Room temp.
Trrige: 2pe/100ns,
Hold off: 100μs
Integration time: 10μs
Light output: 5.5pe/keV
Energy resolution: 10% @662keV
Event rate：800Hz

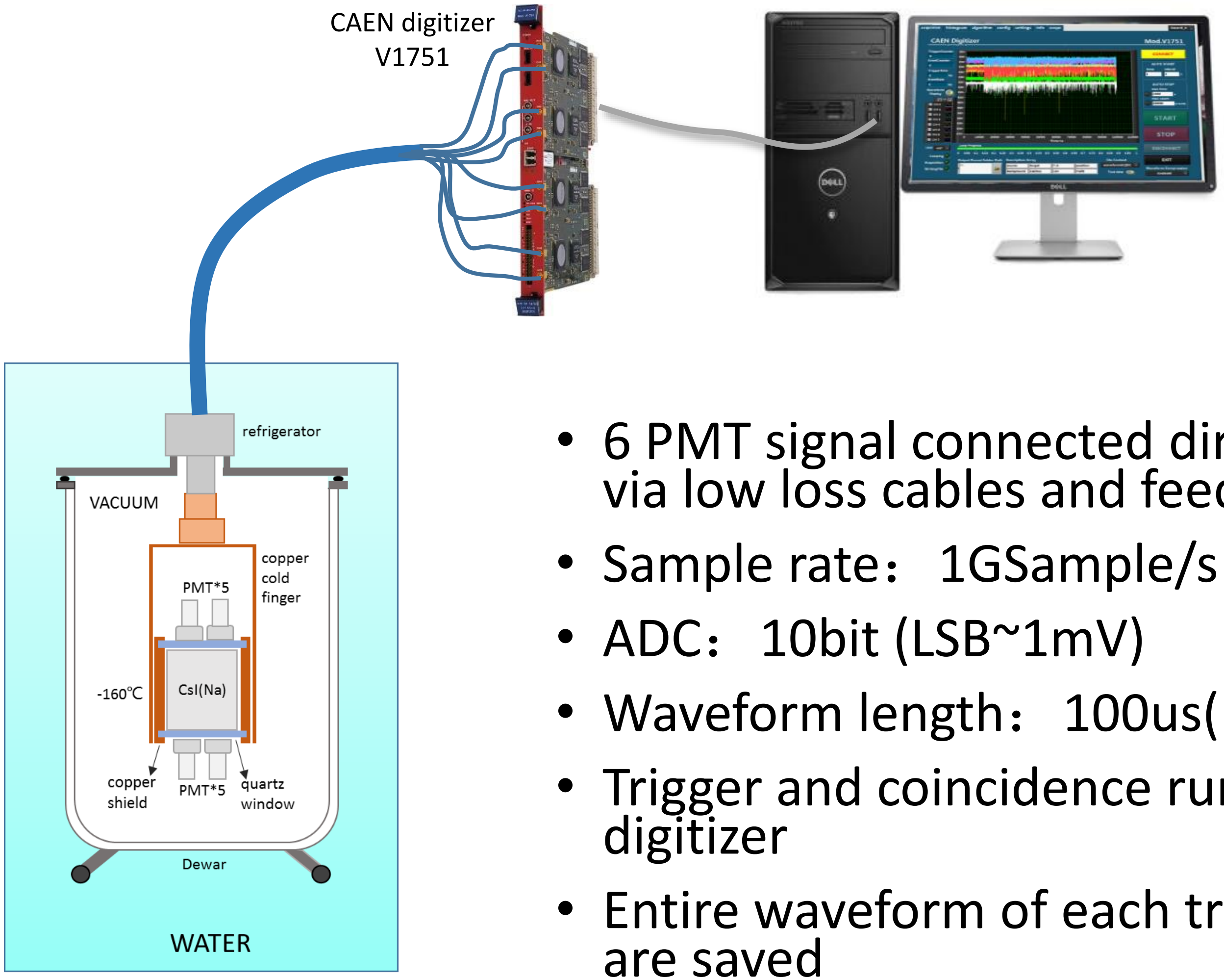


Waveform of muon event at -180C



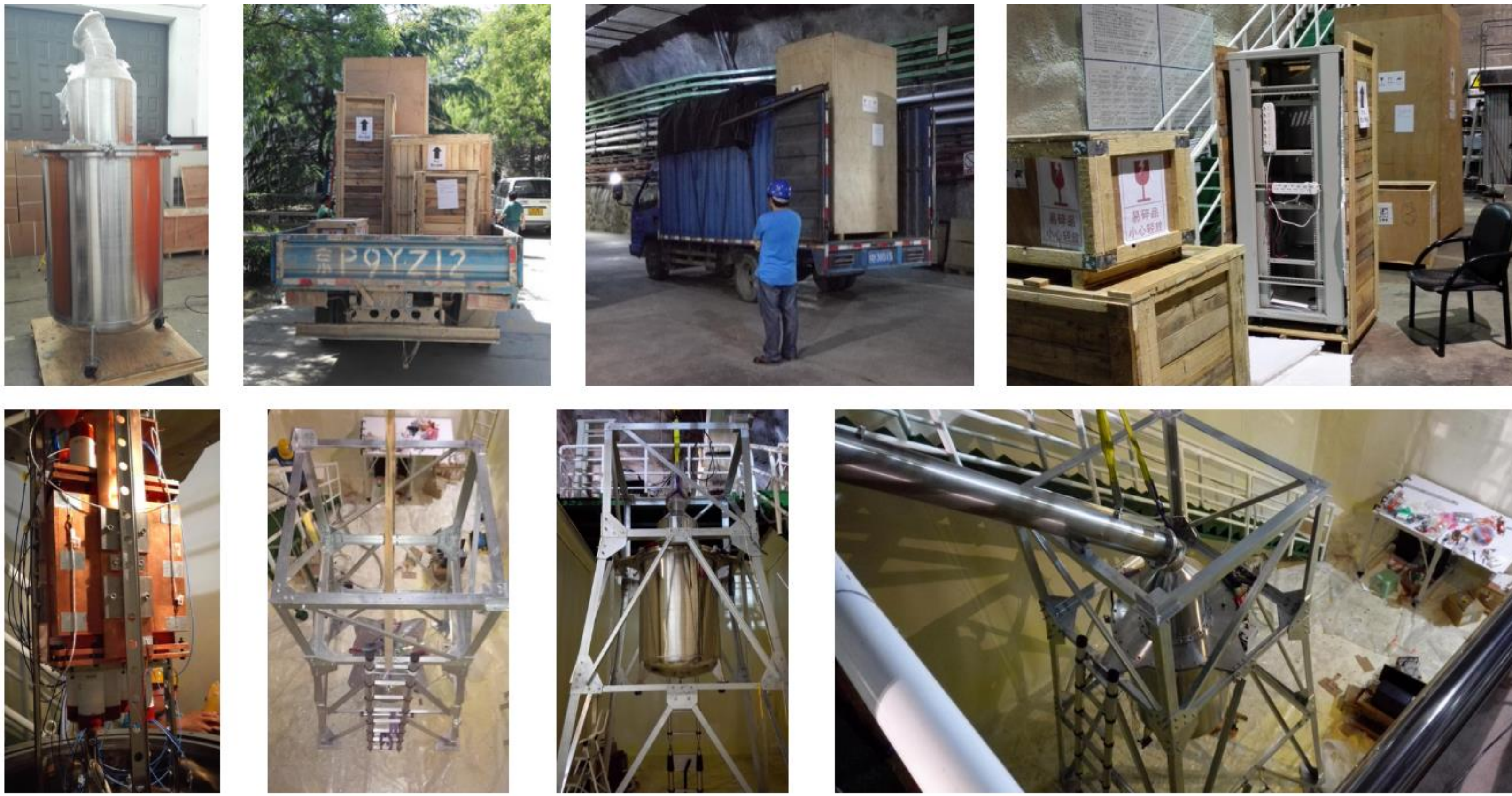
Long decay times and a large number of background make it difficult to see Neutron scattering event without water shield. Further study are underway.

DAQ system

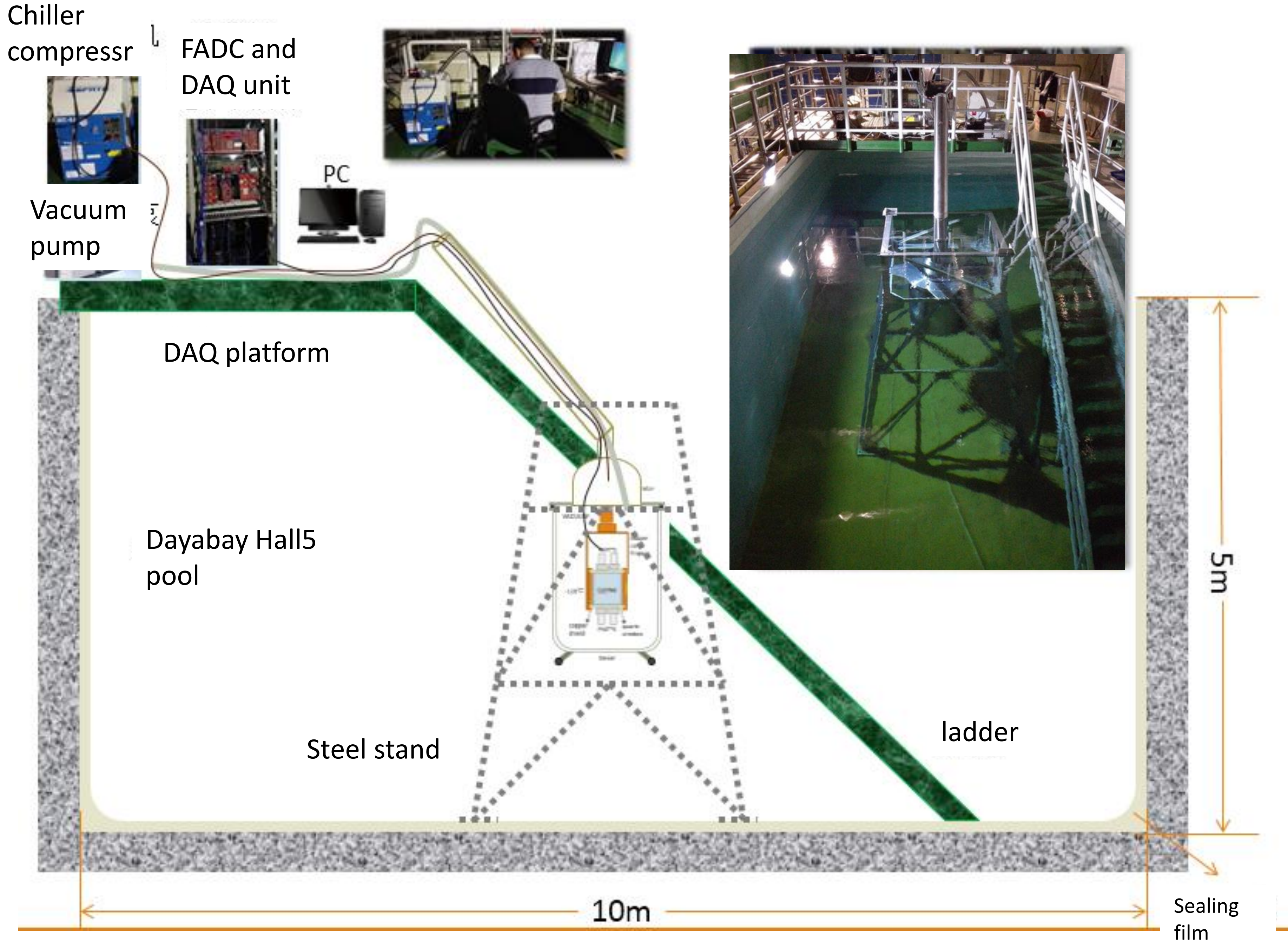


- 6 PMT signal connected directly to digitizer via low loss cables and feedthrough
- Sample rate： 1GSample/s
- ADC： 10bit (LSB~1mV)
- Waveform length： 100us(100k points/event)
- Trigger and coincidence run on FPGA digitizer
- Entire waveform of each triggered events are saved

Field assembling

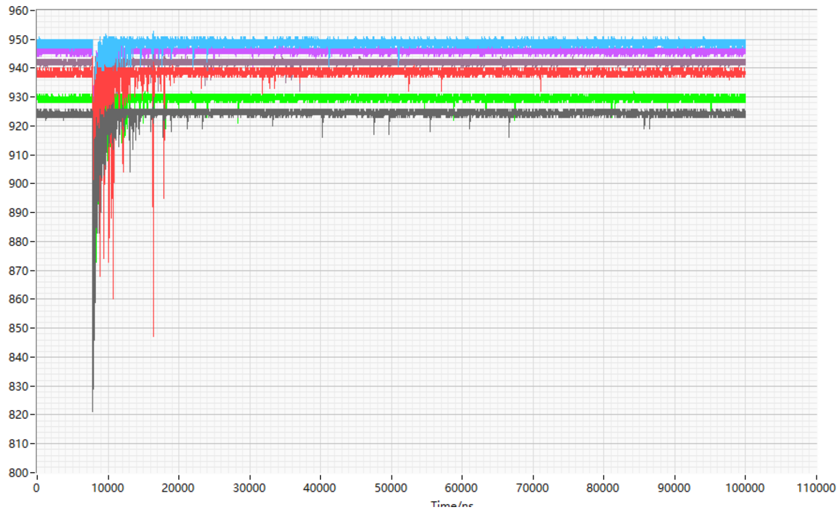


In Dayabay Hall5, 30m deep underground

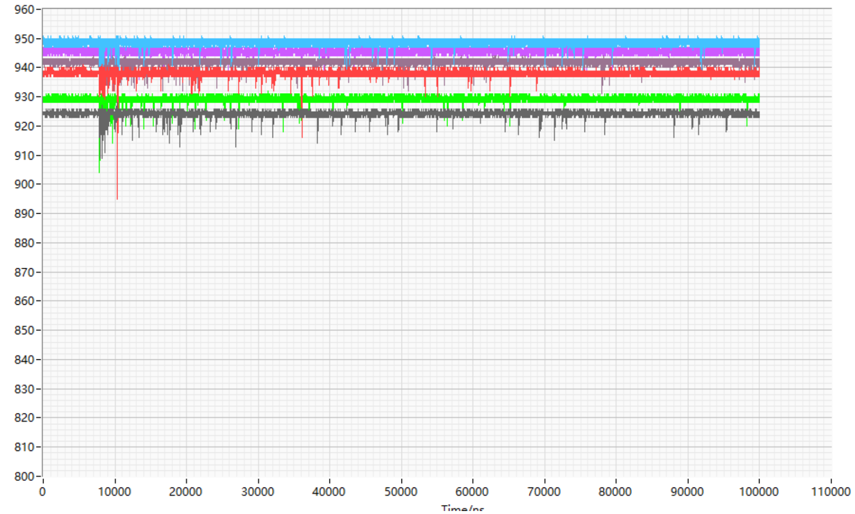


Chiller
compressr
FADC and
DAQ unit
PC
Vacuum
pump
DAQ platform
Dayabay Hall5
pool
Steel stand
ladder
5m
10m
Sealing
film

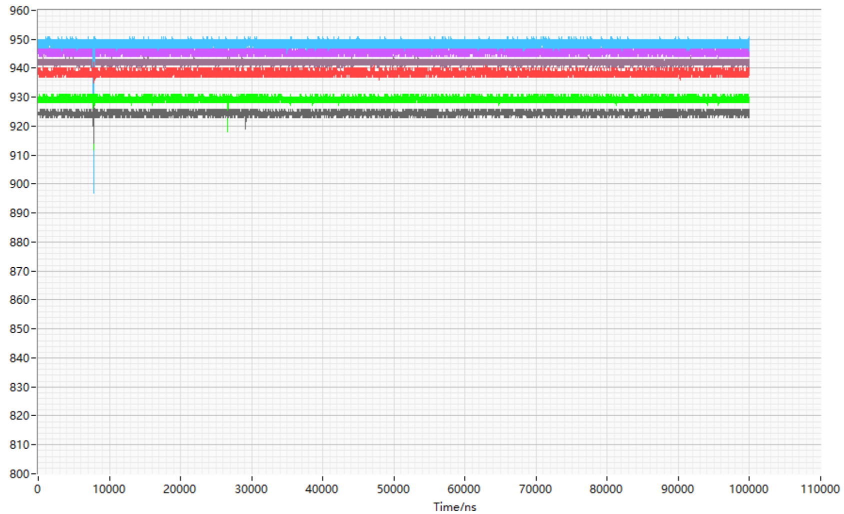
Typical waveforms



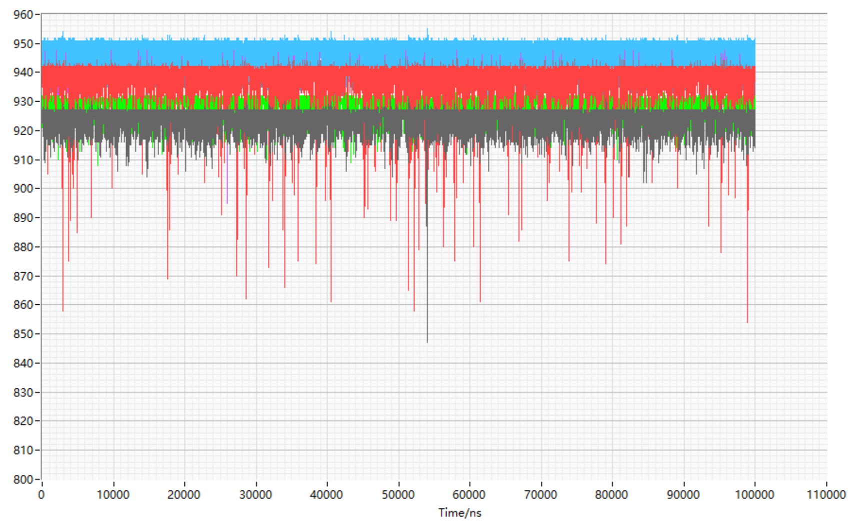
alpha



gamma

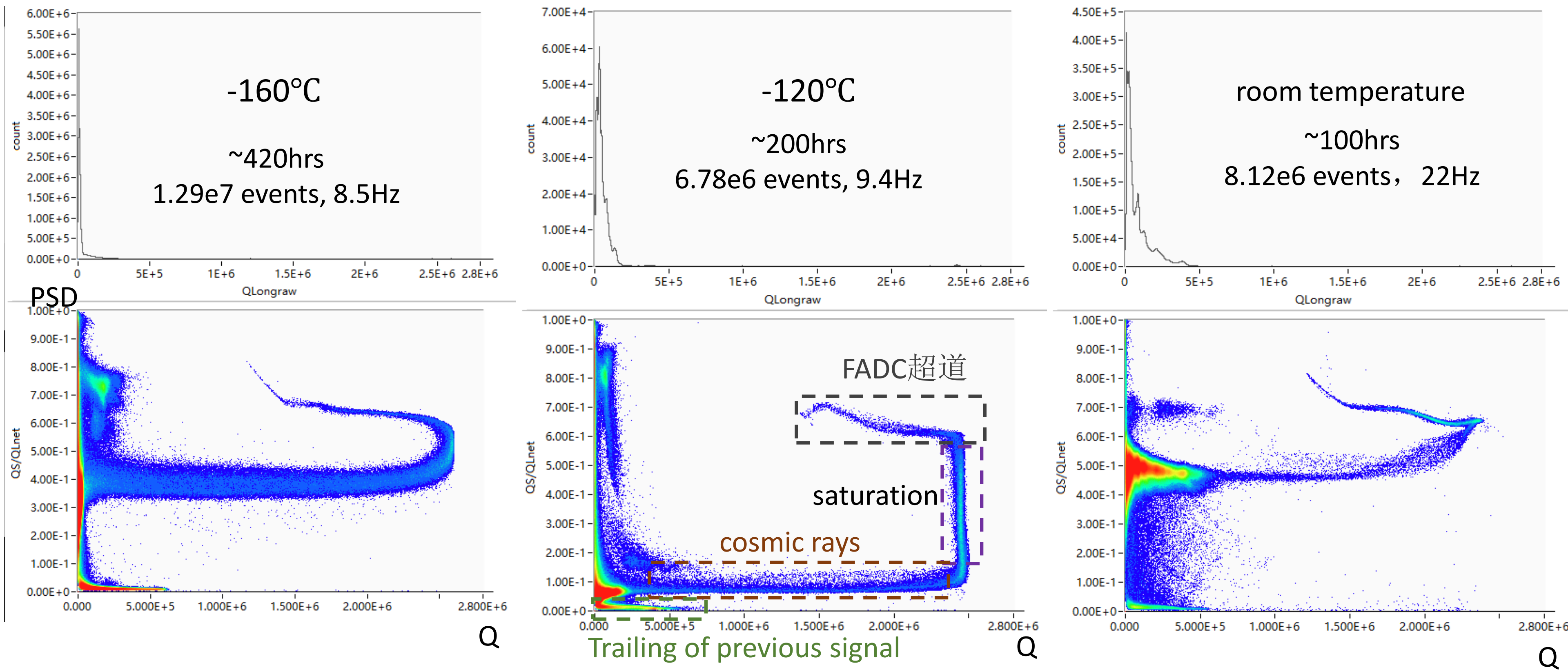


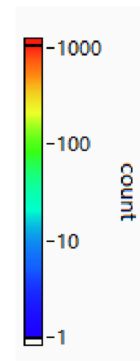
Cerenkov



Trailing of cosmic rays

Count rate on ground	~800Hz
Count rate in Dayabay hall (under 30m rock+2m water)	~9Hz



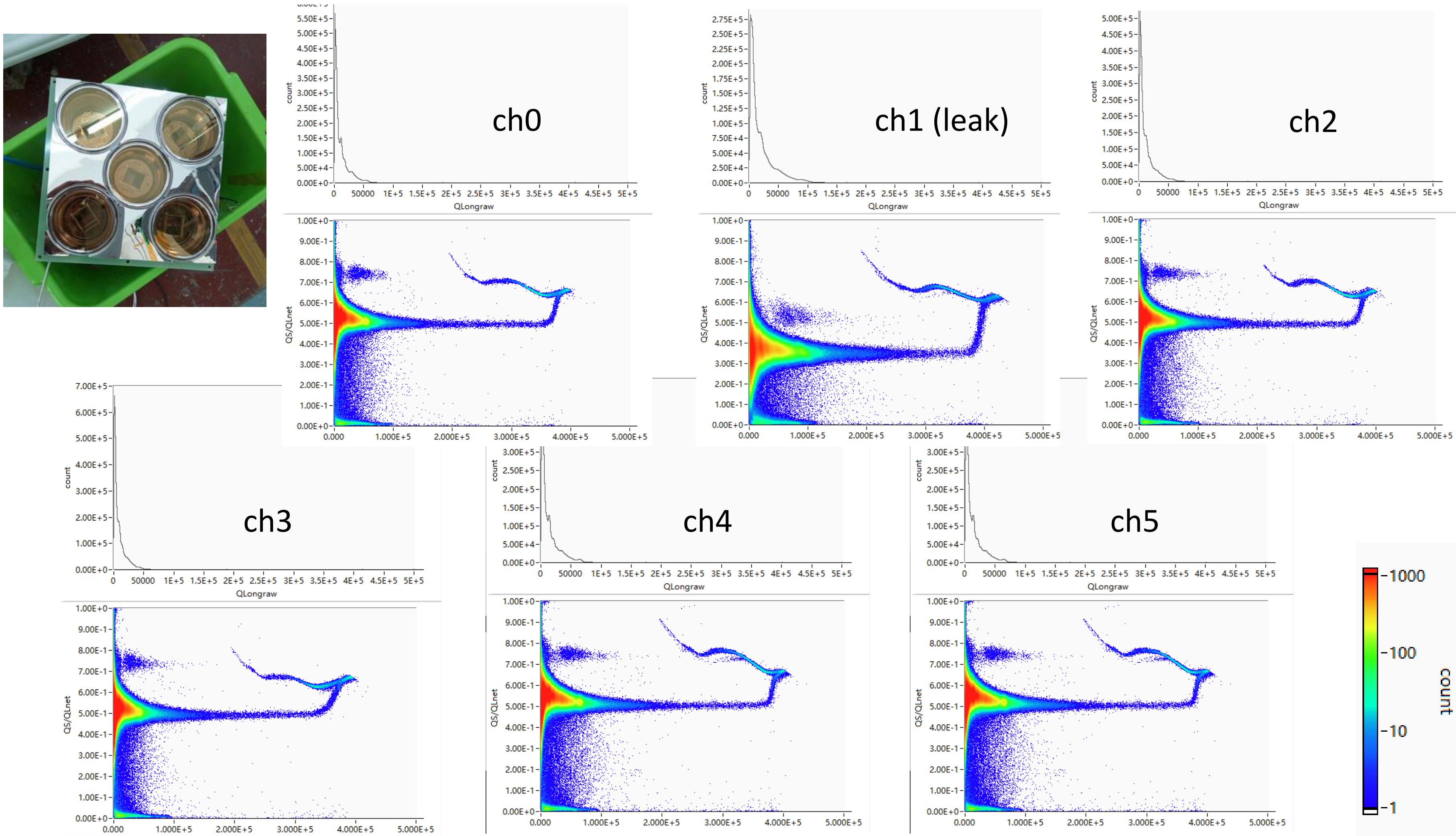


Pulse shape discrimination using $\frac{Q_{short}}{Q_{long}}$,

where Q_{short} is the photons collected in 1us，

Q_{long} is the photons collected in 100us.

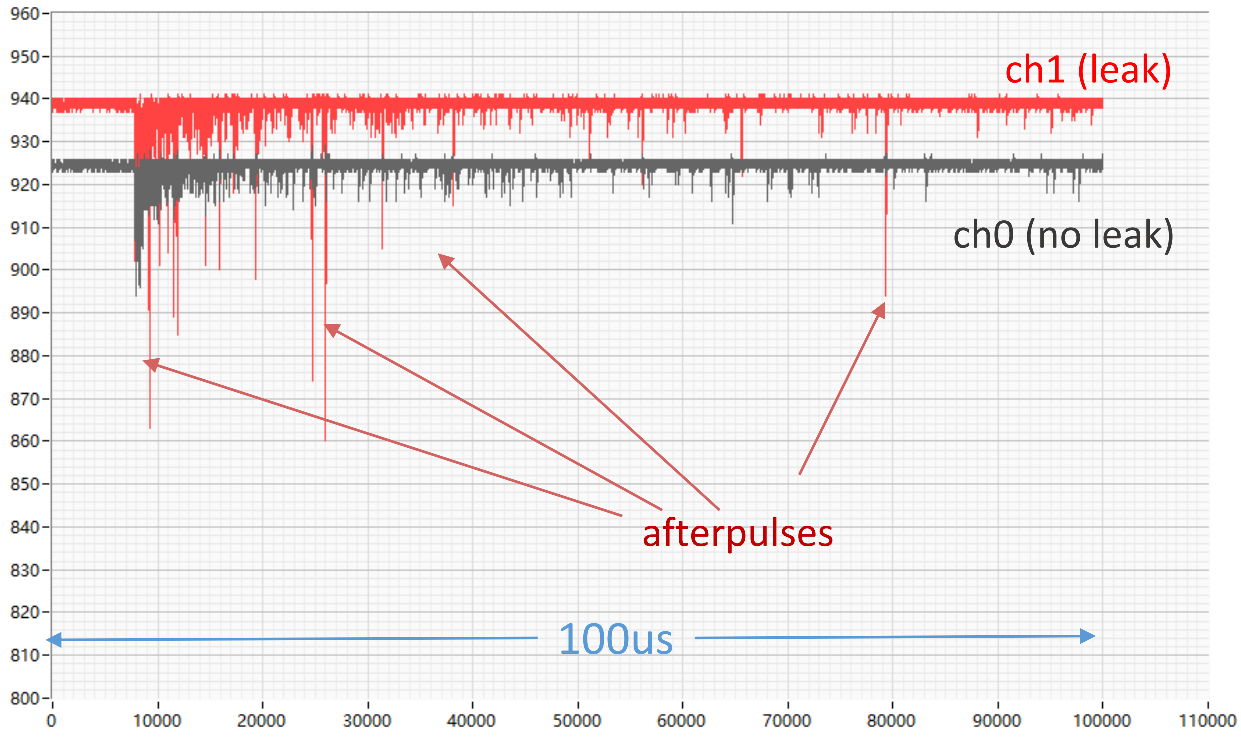
Zero suppression algorithm is applied to avoid fluctuation of baseline in 100us being integrated.

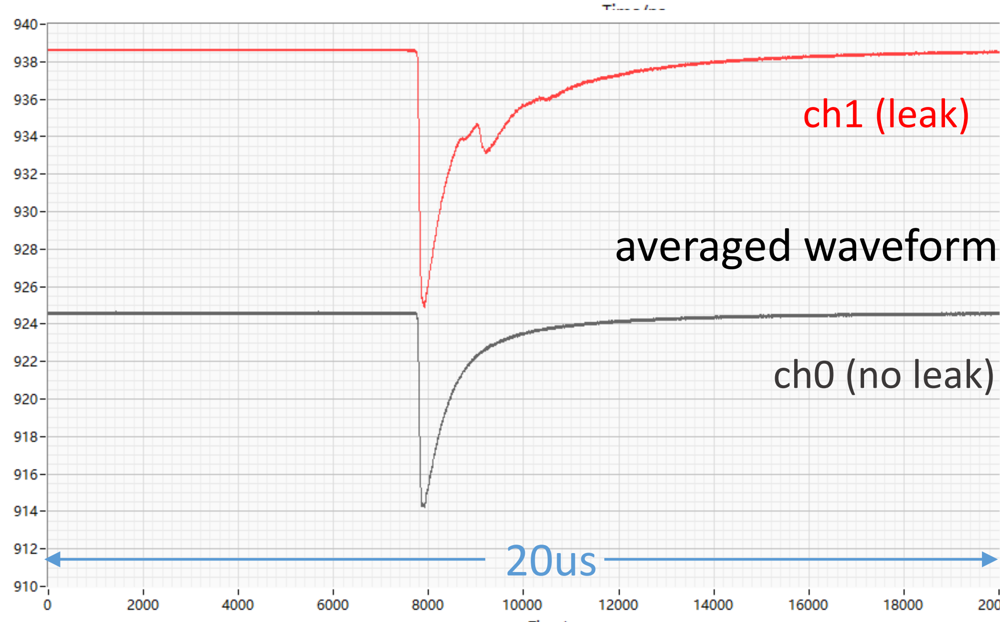


Planned to use10 PMTs， 4 are dead during ground test and replaced with reflective film

1 PMT has leakage and causes afterpulses.

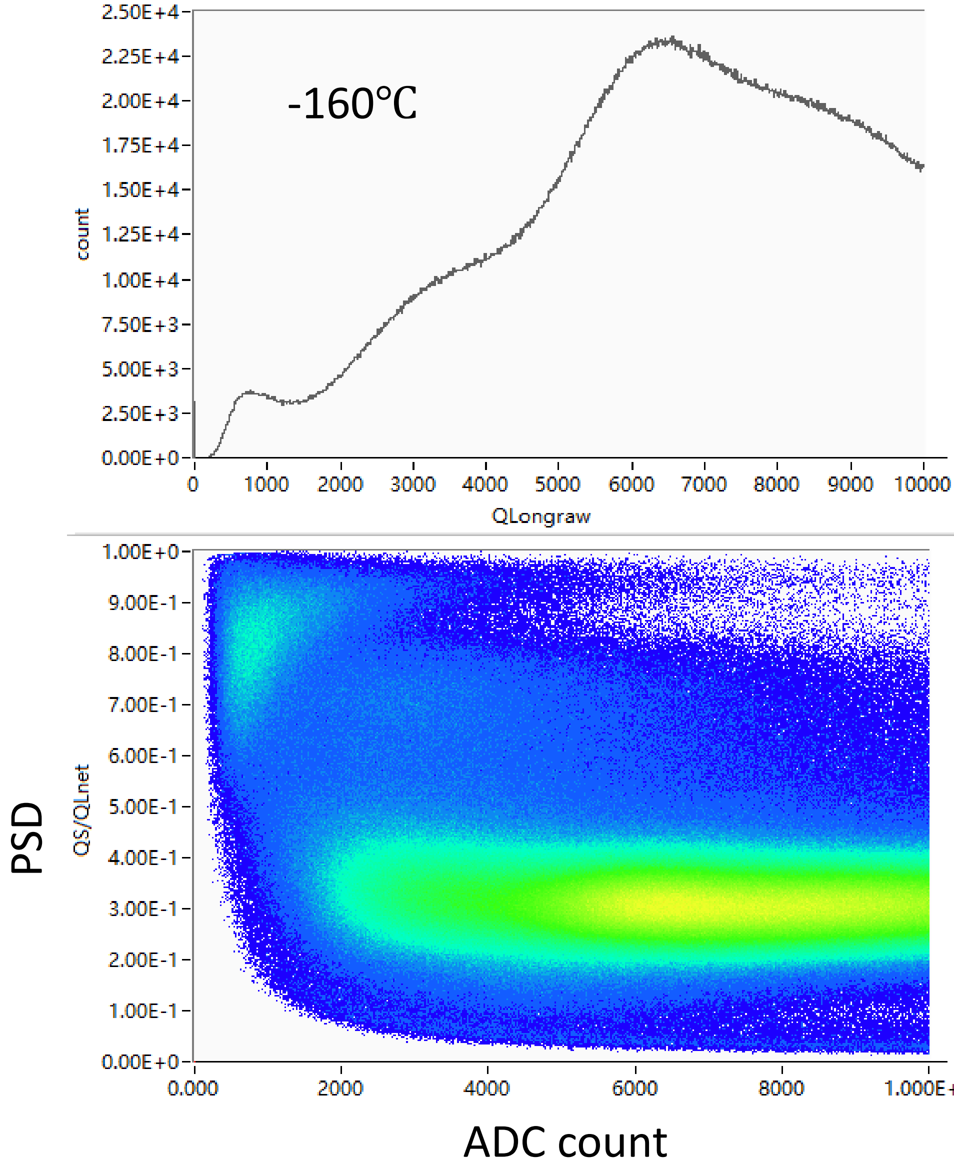
The remaining 6 PMTs can collectef


ch1 (leak)
ch0 (no leak)
afterpulses
100us

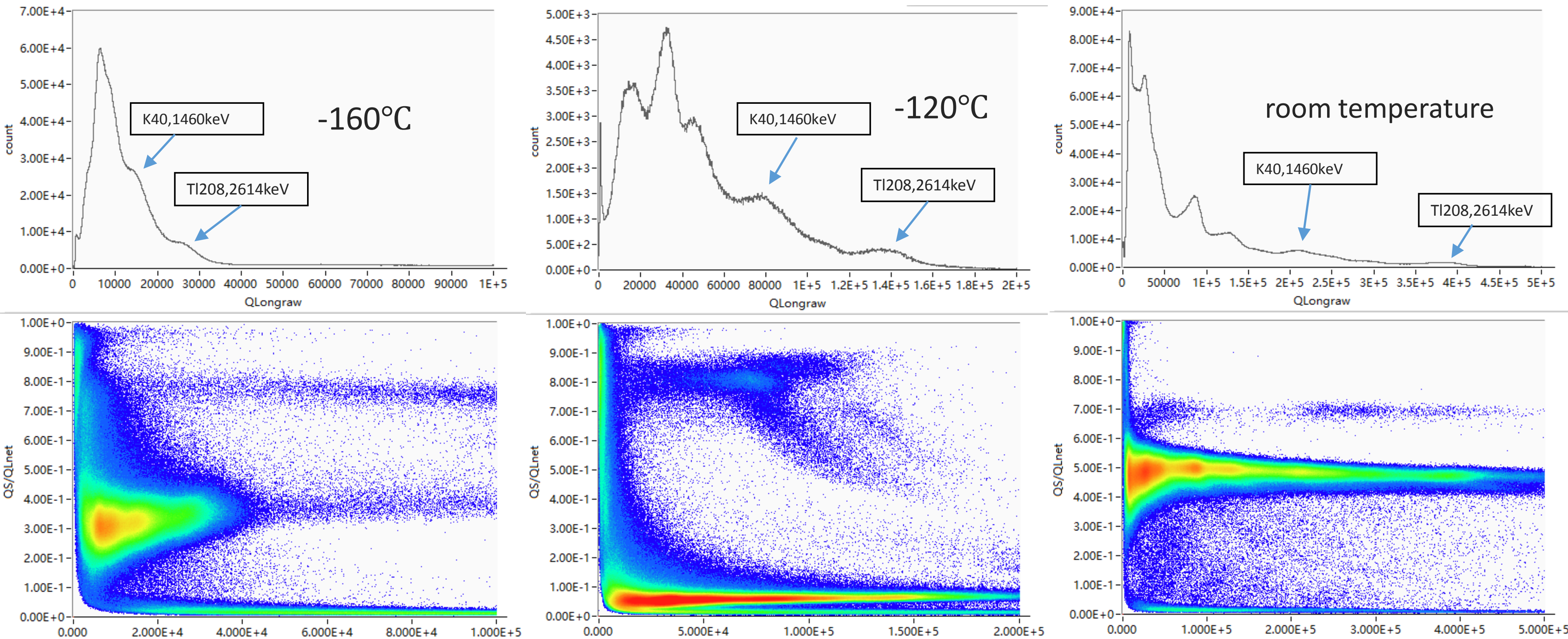

ch1 (leak)
averaged waveform
ch0 (no leak)
20us

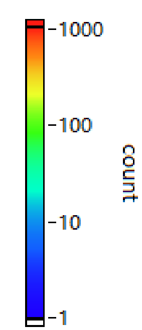
Trigger threshold

- 4mV threshold, 3 channel coincidence
- Actual min energy event，~40keV



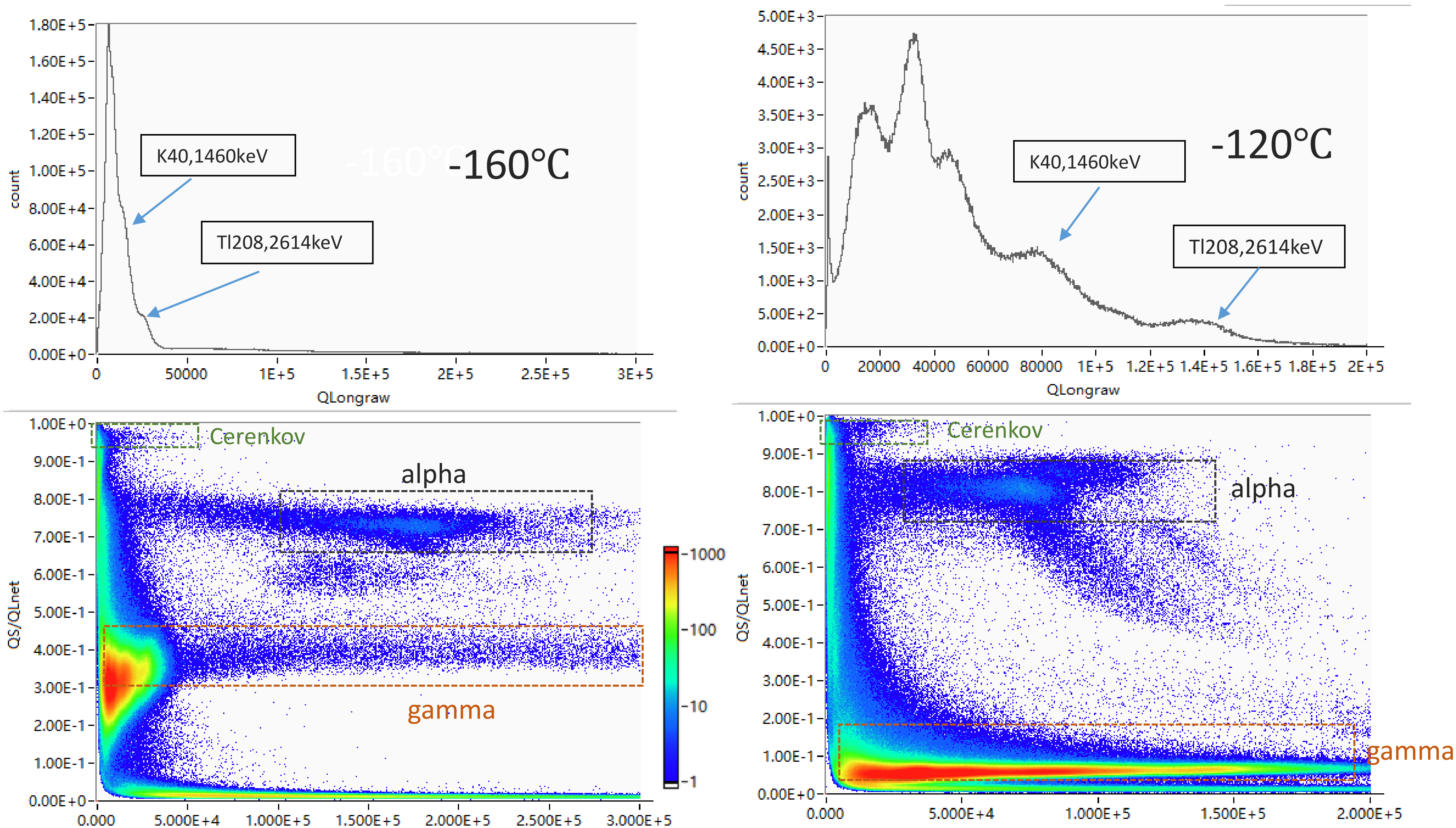
Energy calibration





Energy calibration using gamma background.

PSD



K40,1460keV
Tl208,2614keV
-160℃
count
QLongraw
-120℃
Cerenkov
alpha
gamma
QS/QLnet
1000
100
10
1

Future improvments

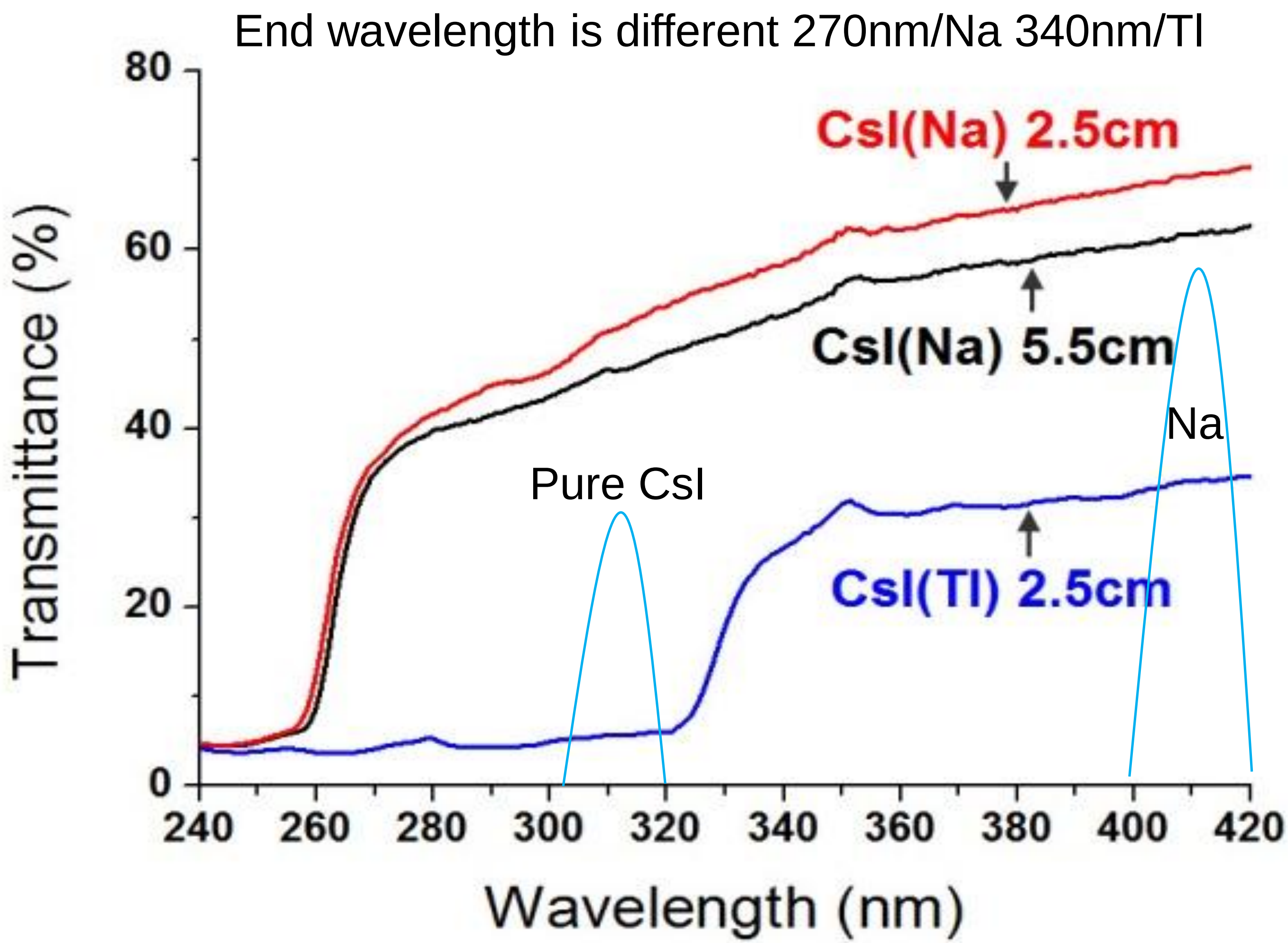
- Replace PMT with SiPM and get rid of thick quartz window
- Using 2 fold coincidence instead of 3 to lower energy threshold
- Change the dimension of scintillator to shorten light path and increase fast light (low wavelength) output

Summary

- Dual Light-emitting Crystals are proposed for WIMPs searches
- 40kg CsI(Na) has good performance
  - waveforms of fast and slow light are different
  - High light output
- The whole module are tested
  - Capsulation of big scintillator succeeded
  - Chilling system and DAQ system worked as planned
  - PMTs under low temperature and vacuum has leakade problem
- Future improvements are settled

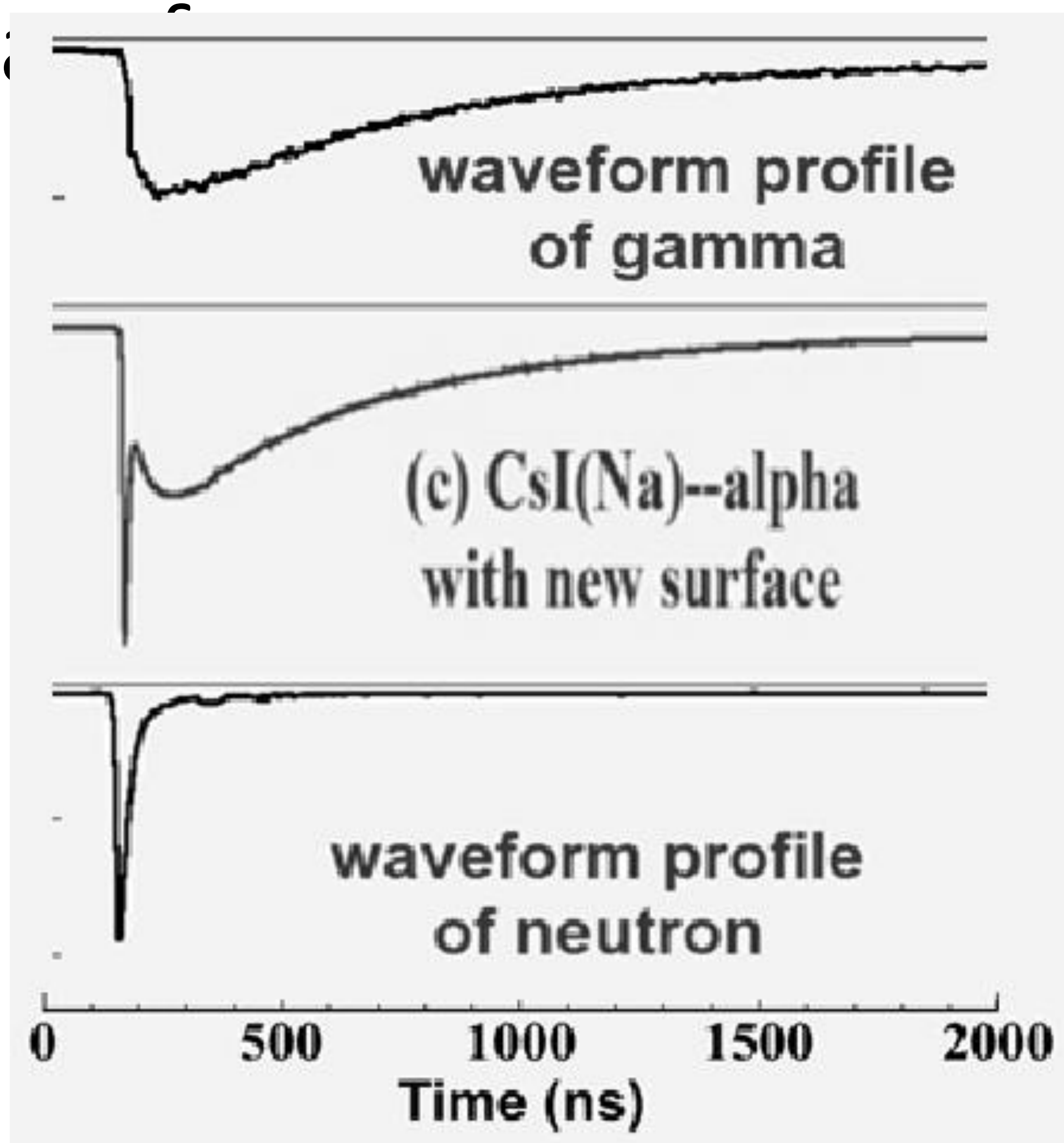
Thanks for your attention！

The Transmittance



CsI(Na) crystal is transparent for the scintillation of pure CsI, So there are two components of light for CsI(Na), but CsI(Tl) is not. NaI(Tl)

Performance of CsI(Na): Wa

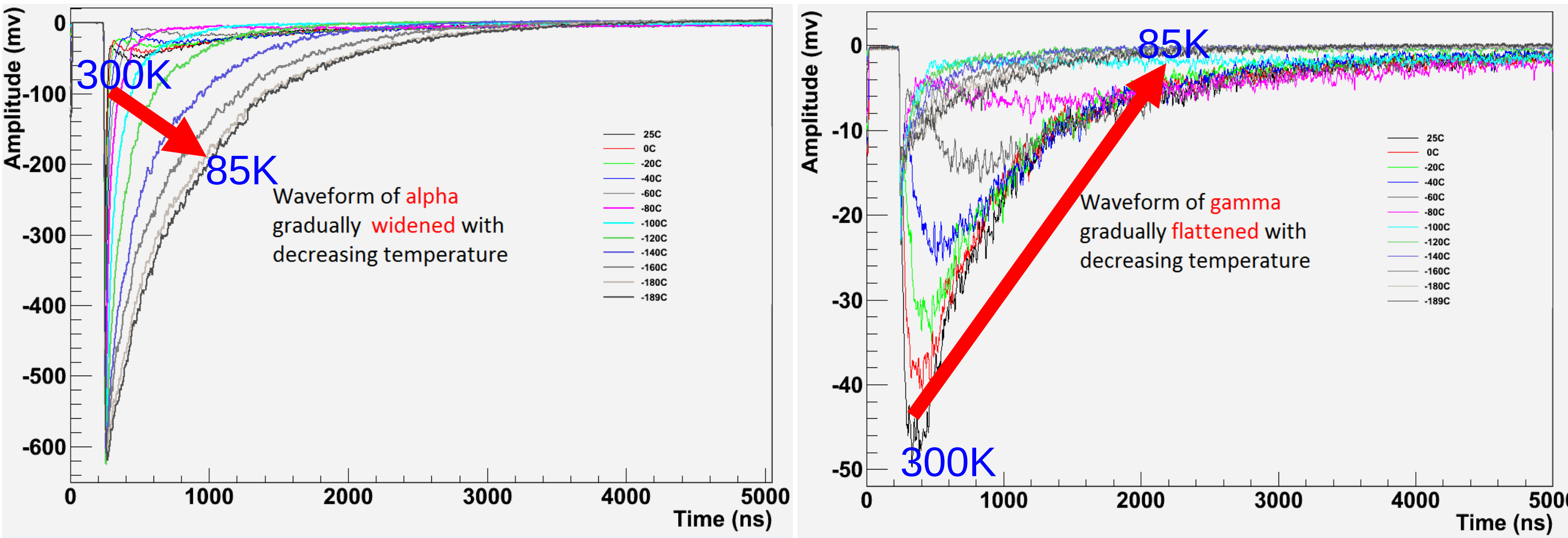


Dopant dominates

Both dopant & solvent

Solvent dominates

The waveforms variation are different

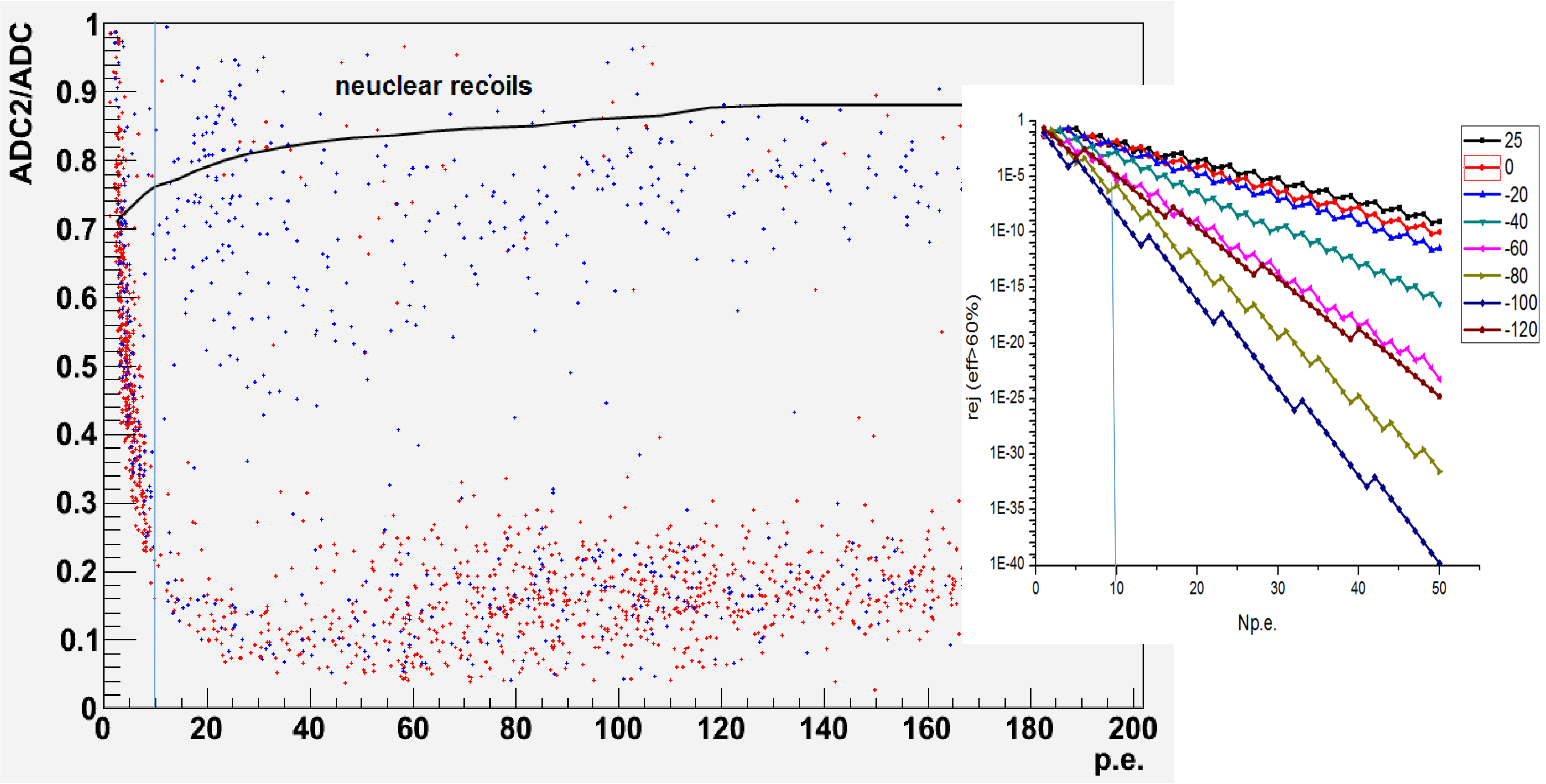


waveform variation with temperature

- Intensity of fast light enhance and 60 times for alpha, Decay time increases from 16ns to 800ns.
- Intensity of emission from Na^{+} decreased by 40 times, decay time increase to about 100us.

Separation by Waveform

Pulse Shape Discrimination (PSD) technique could be used for alpha/gamma separation based on different waveforms.



1.26μs/40μs separation for gamma /alpha @-120C

Separation by Wavelength

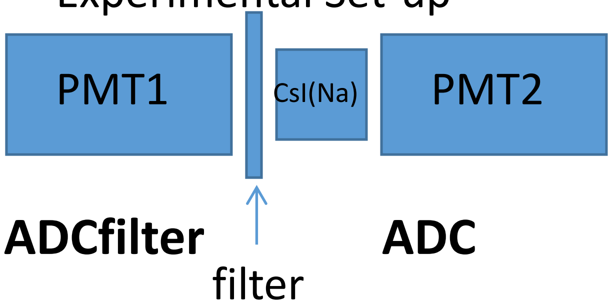
different wavelength of the two components can also be used for separation,

Na^{+} is 420nm slow

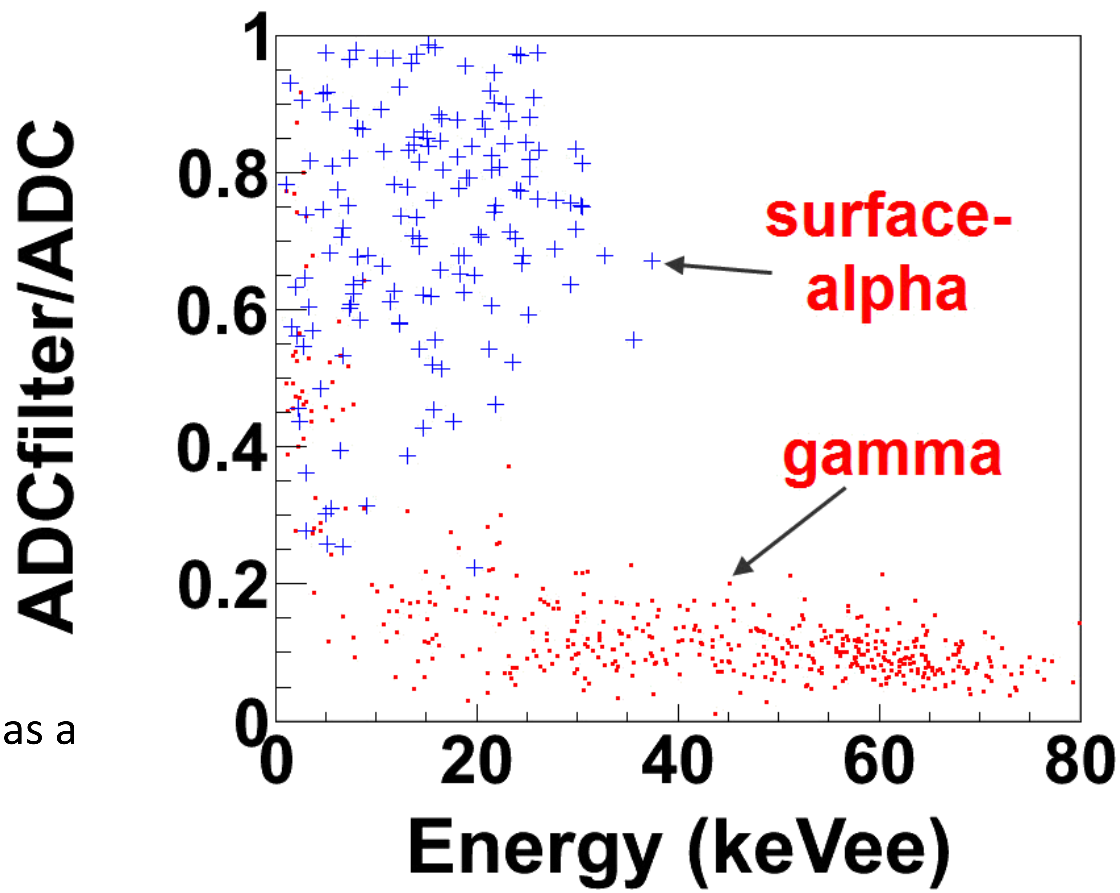
pure CsI is 310 nm fast

we use a filter to test.

Experimental Set-up

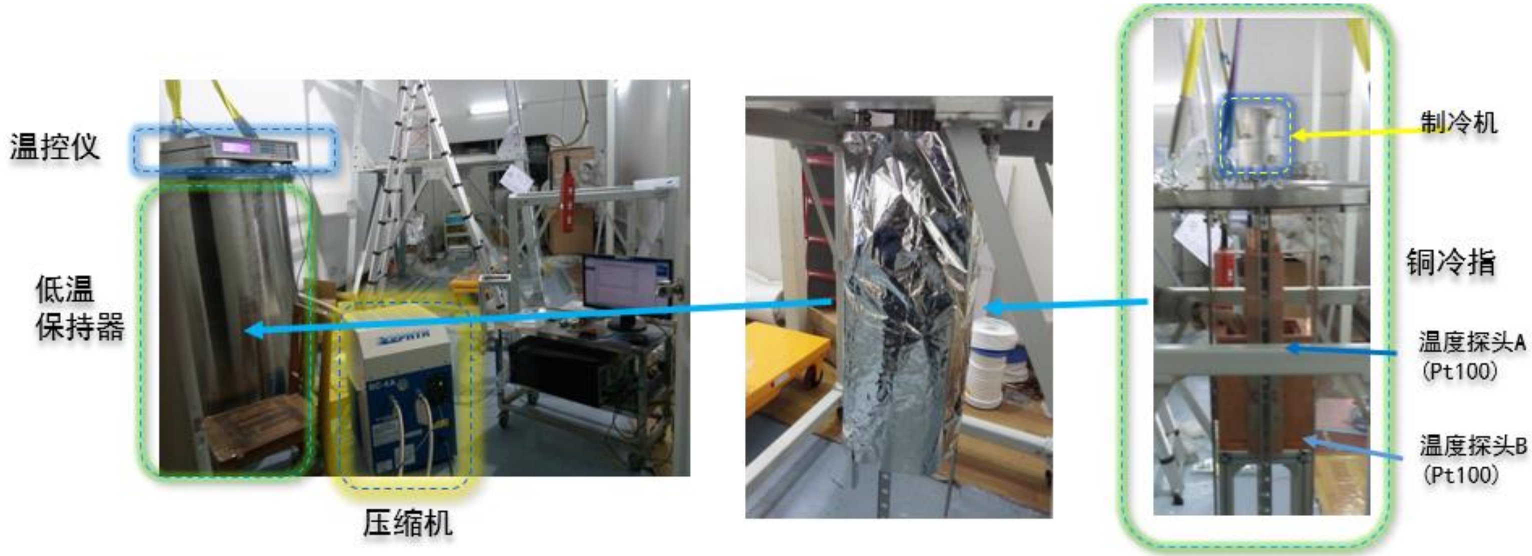


Transmittance of the wavelength filter as a function of wavelength

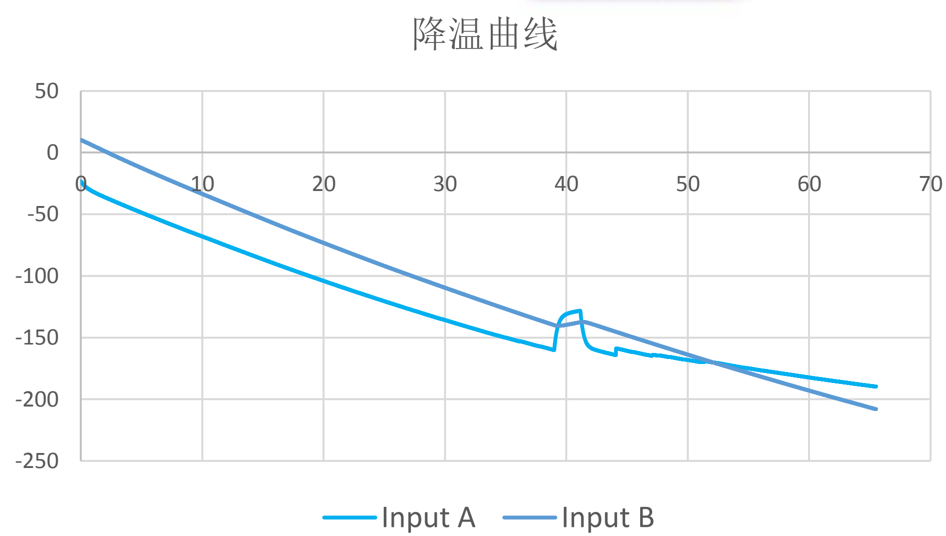


Scatter plot of ADCfilter/ADC for γ and surface-α.

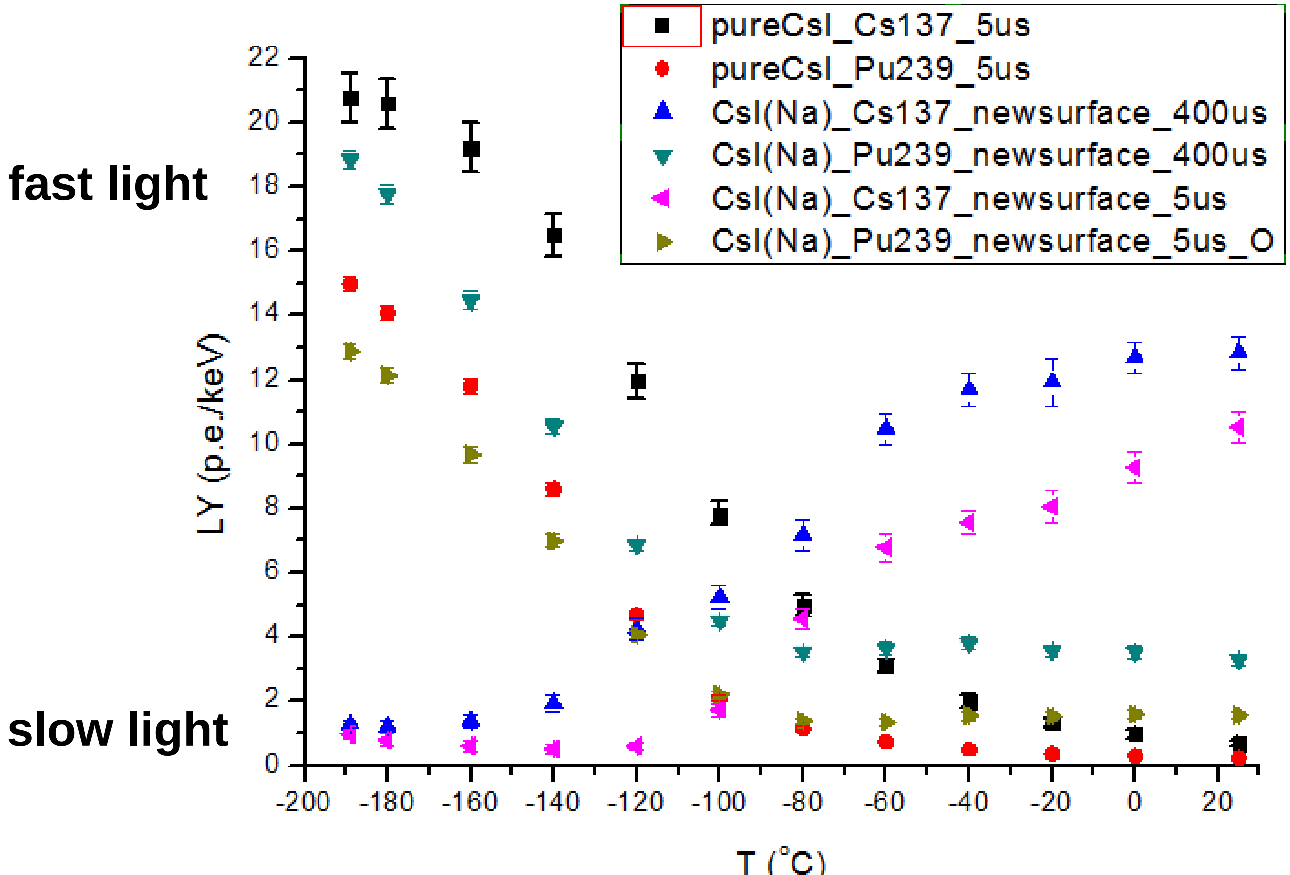
Cooling system testing



- 最终温度<-200℃，~65hr
- -100℃，~28hr



The light yield



light yield variation with temperature.

2.5x2.5x2.5cm CsI(Na)
Test by PMT R8778
~30% QE @ 300-400nm

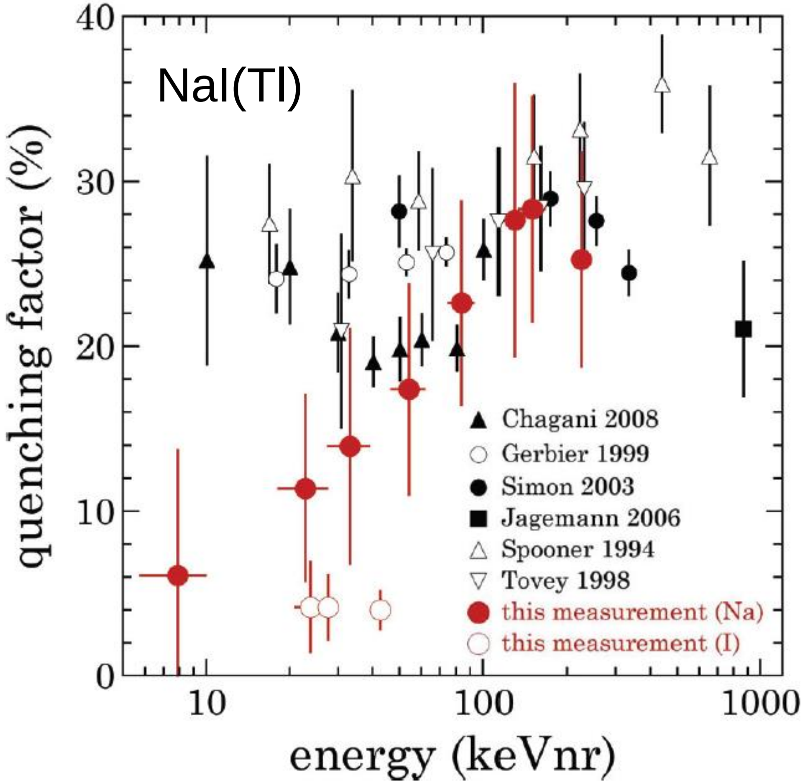
-180C
LY 12 p.e./keVee for alpha
Nuclear recoils:
QF: 10% of alpha
Light collection: 50% of 2.5cm
~0.6p.e./keVnr
Threshold 10p.e. is
16keVnr with
10^{-6} rejection power

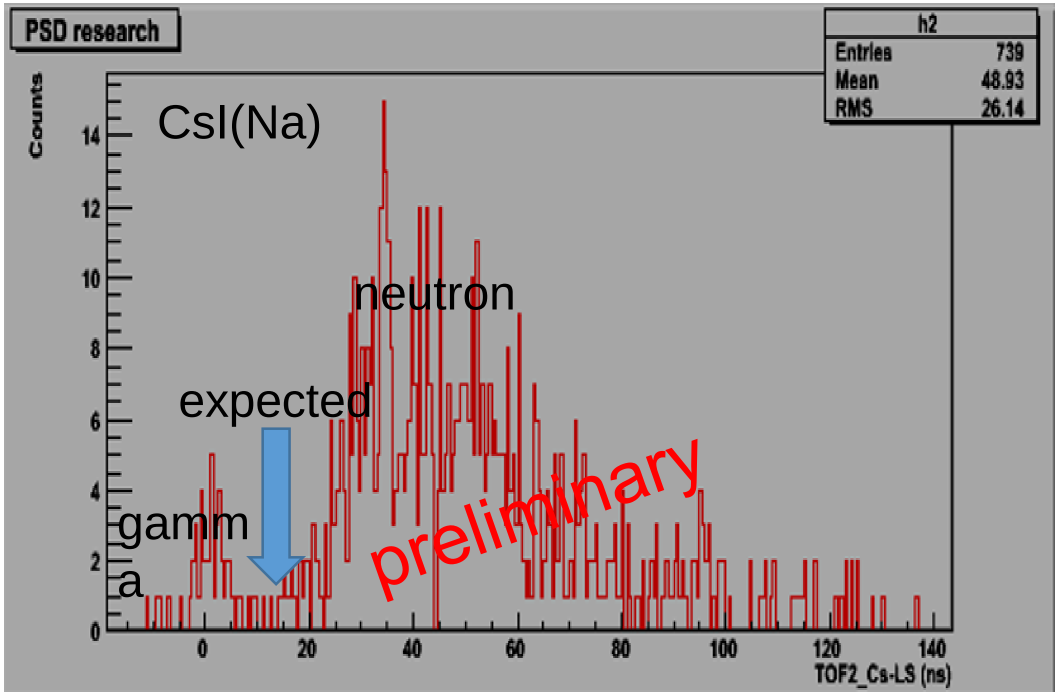
Quenching factor of alpha/gamma for pure CsI increase from 35% to 68% with temperature drop from 25 to -180°C, Reveal that luminous intensity for high dE/dx particles has larger increase as the temperature drops.

Qf of n/gamma maybe large than 6.8%, but difficult to measure.

QF new results

PHYSICAL REVIEW C **88**, 035806 (2013)





QF is 4% for I recoil, consistent with our expectations.

Flight time peaks delayed than expected, indicating a small QF at room temperature.

数据获取系统

- 针对CAEN digitizer V1751编写了一套labview的数据获取系统。
  - 8ch, 1GSa/s, 100us/event, 可获取的计数率~30Hz
  - 利用无损的波形压缩算法压缩比达到21%
  - 自动切换存储硬盘