Study of the Low-Energy ER/NR Discrimination and its Electric-Field Dependence with Liquid Argon

22/9/2017 LIDINE 2017 @ SLAC

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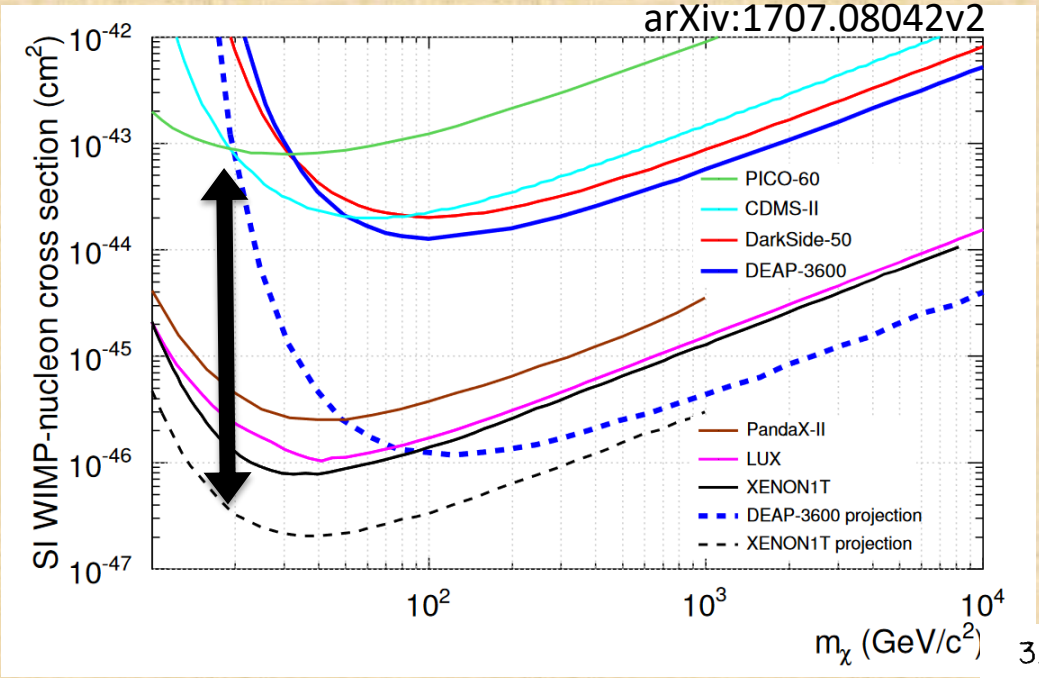
WIMP Search with Liquid Noble Gas



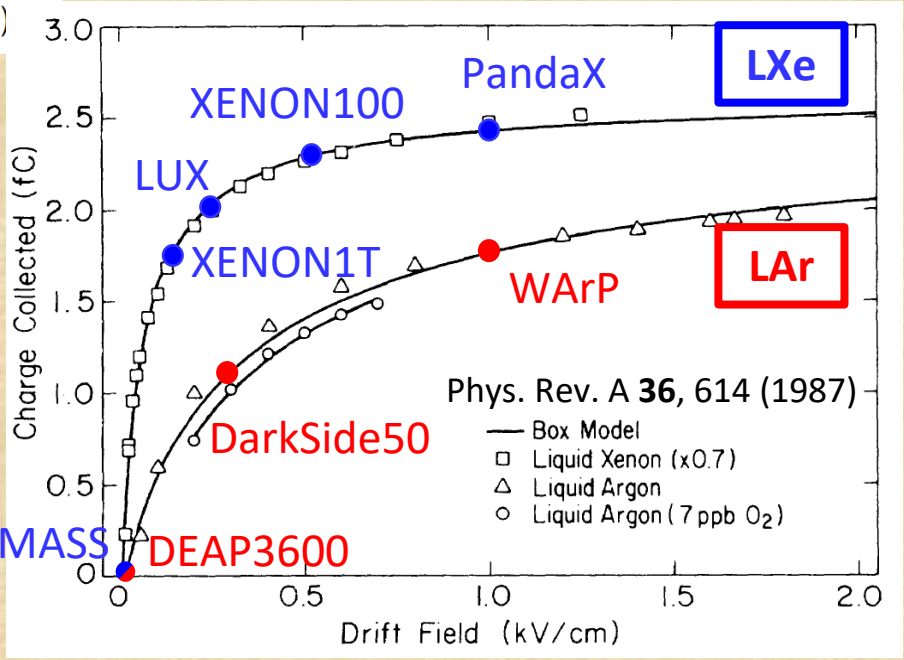
Energy Threshold for BG Rejection

- Xenon : a few keV_{nr}
- Argon : ~ 40 keV_{nr}

Sensitivity for low mass region is very different!!

We are interested in S2/S1 performance especially its electric field dependence in Argon.

LAr 200V/cm ≠ LXe 200V/cm ??
Drift field may be a key of low threshold.



Previous Studies of BG Rejection by S2/S1

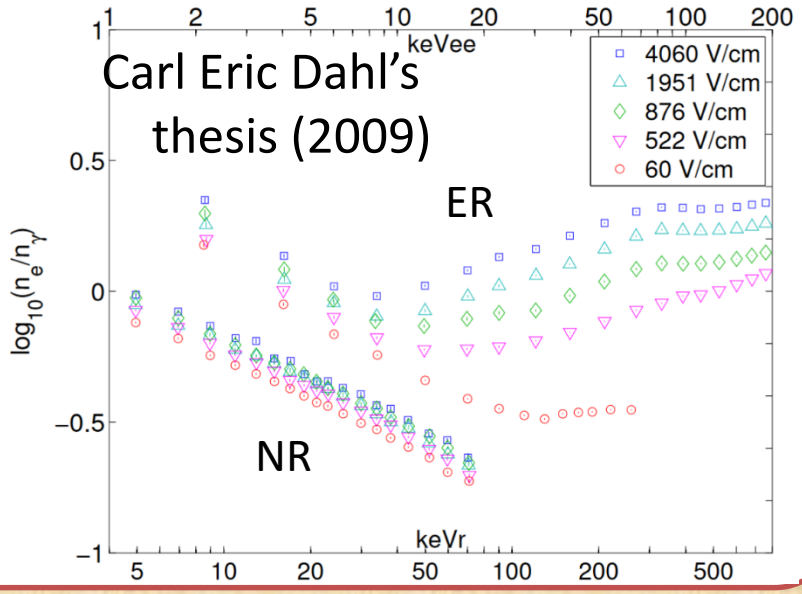
Xenon

Many groups evaluate the ER/NR discrimination power of S2/S1.

- Improve @ lower energy
- No significant drift field dependence above 200 V/cm (Kaixuan Ni, APP14)

Basic properties are well-known

⇒Improve sensitivity of current experiments



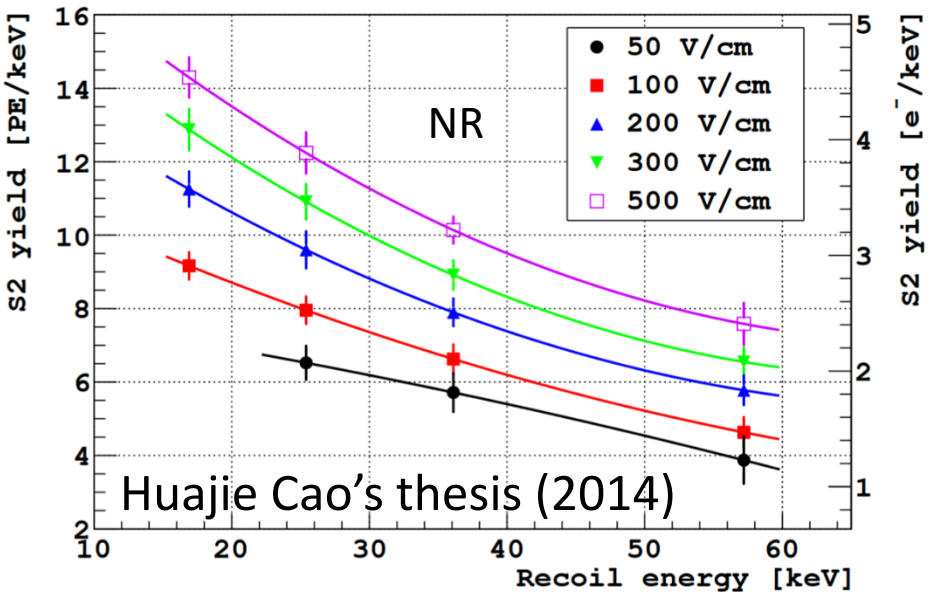
Argon

S2 information is not enough at higher drift field and for BG rejection.

S2/S1 is not effectively used in current experiments.

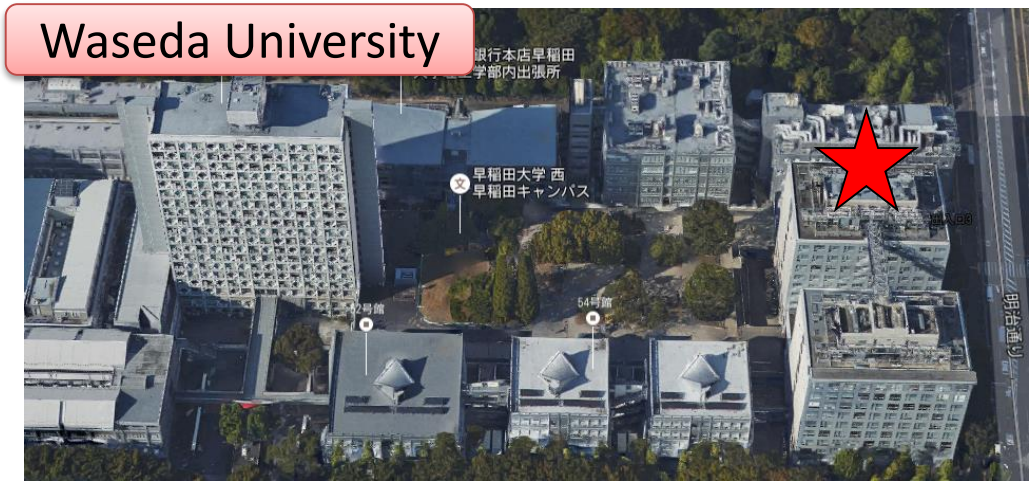
SCENE measured basic property of NR events at drift field < 500 V/cm.

➢ We measure the ER/NR discrimination above 1 kV/cm!

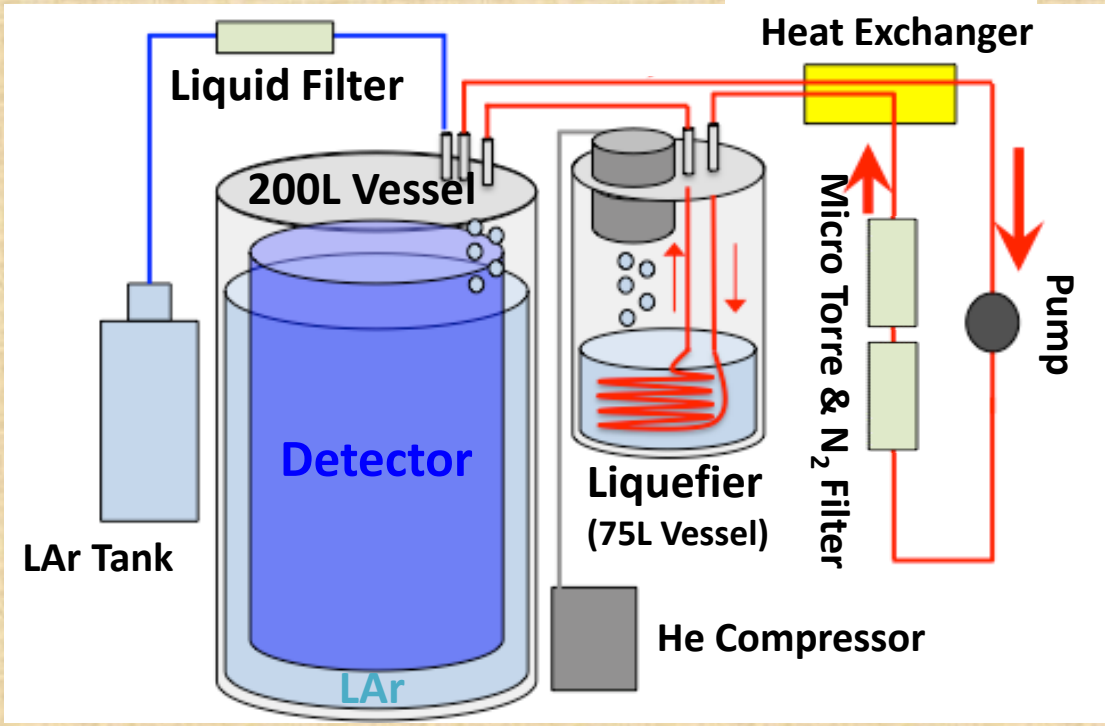


Test Stand and Purification System

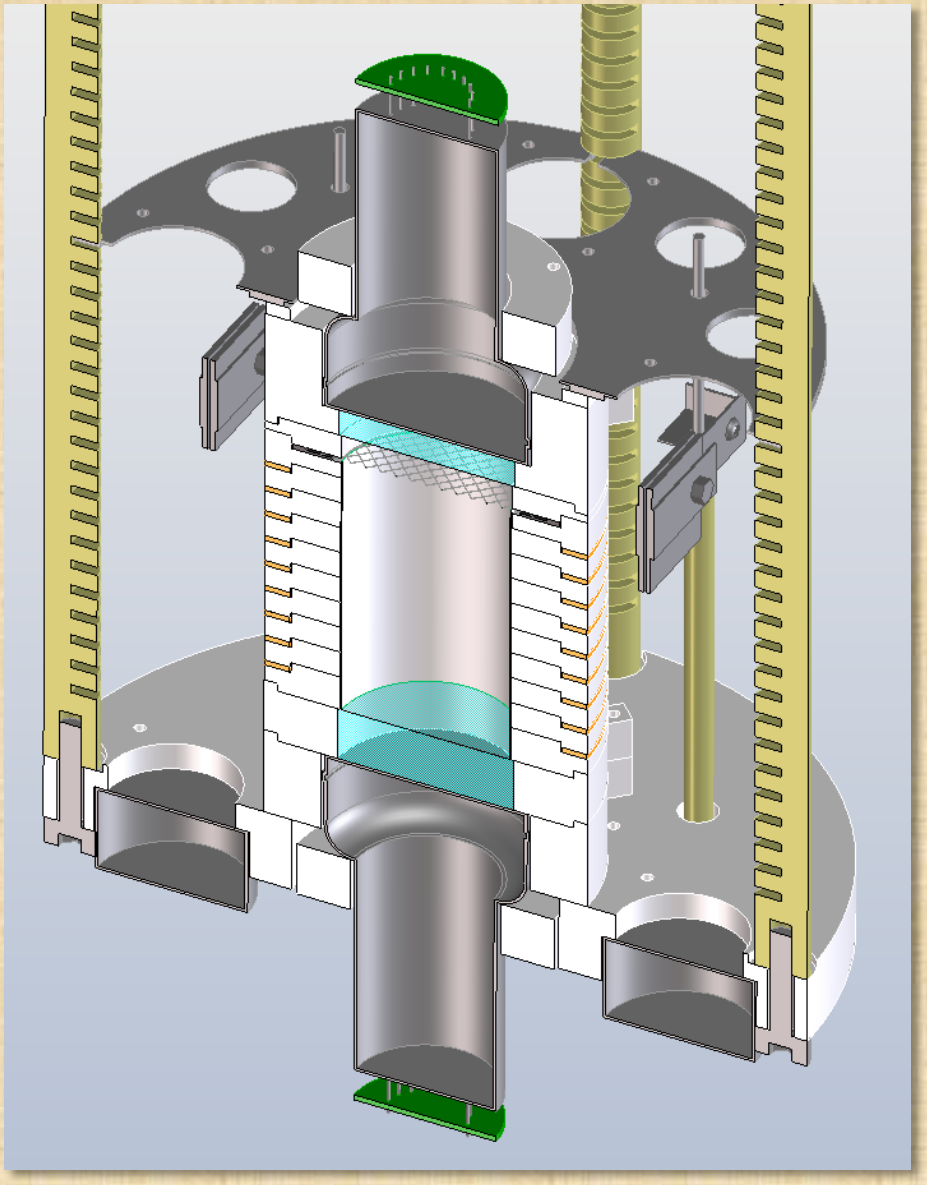
Waseda University



200L Vessel



2-Phase Argon TPC

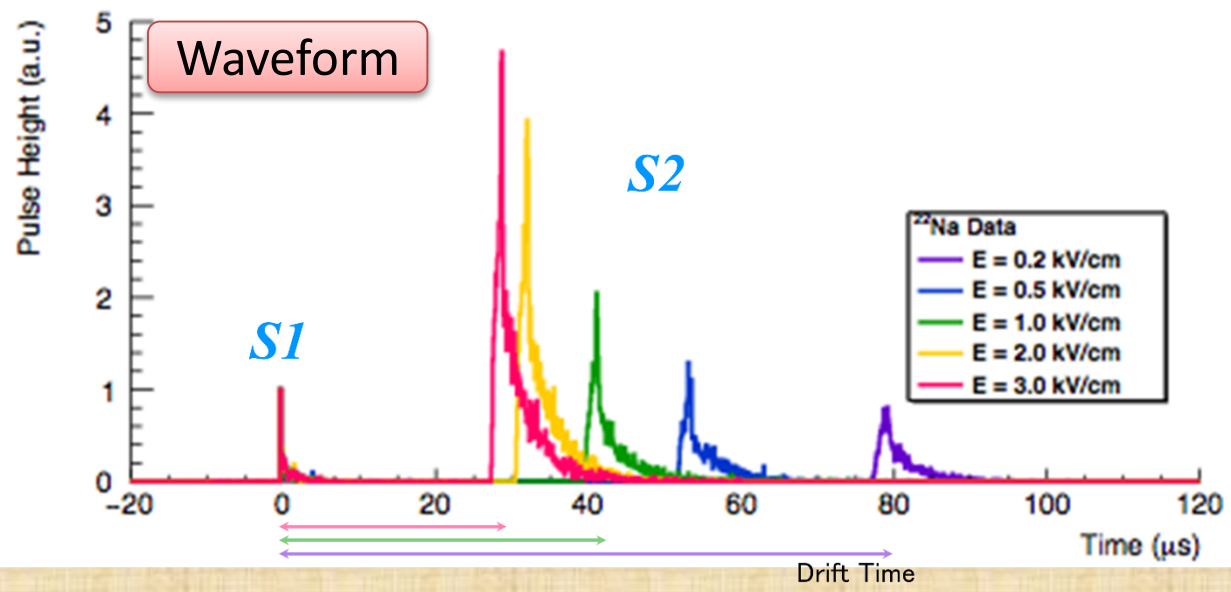


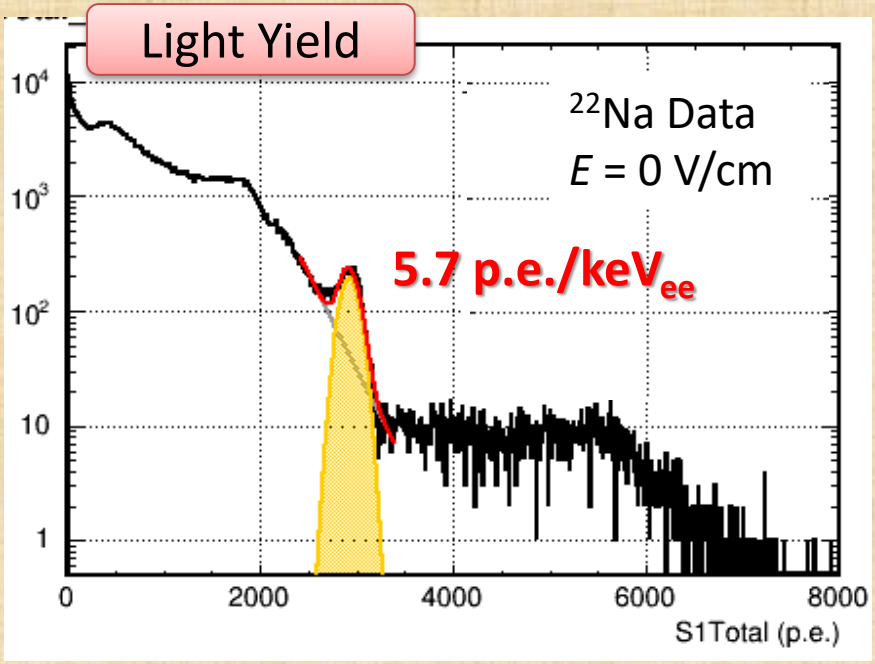
Basic Parameters

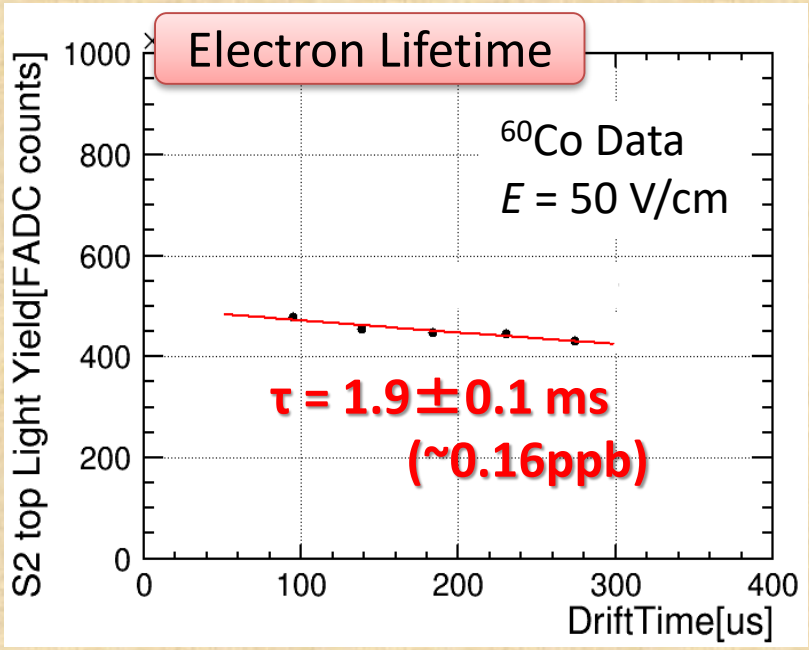
- Active Volume : ϕ6.4cm × H10 cm (0.5kg)
- Gate Grid : 4mm pitch with 100um wire
- Anode - Grid : 1.0 cm , 4.5 kV
- Liquid level : ~ 5 mm
- Drift field: 0 ~ 3 kV/cm

- **PMT (HAMAMTSU R11065)**
- **ESR Reflector**
- **ITO Quartz**
  - 10 nm of ITO on the Quartz
- **TPB**
  - evaporated on ESR & ITO Quartz
- **CW Circuit**
  - Makes high voltage (~30kV) in the LAr , and supplies to the TPC

Detector Performance





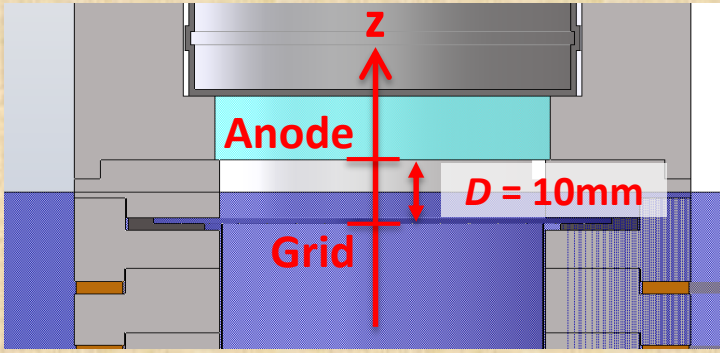


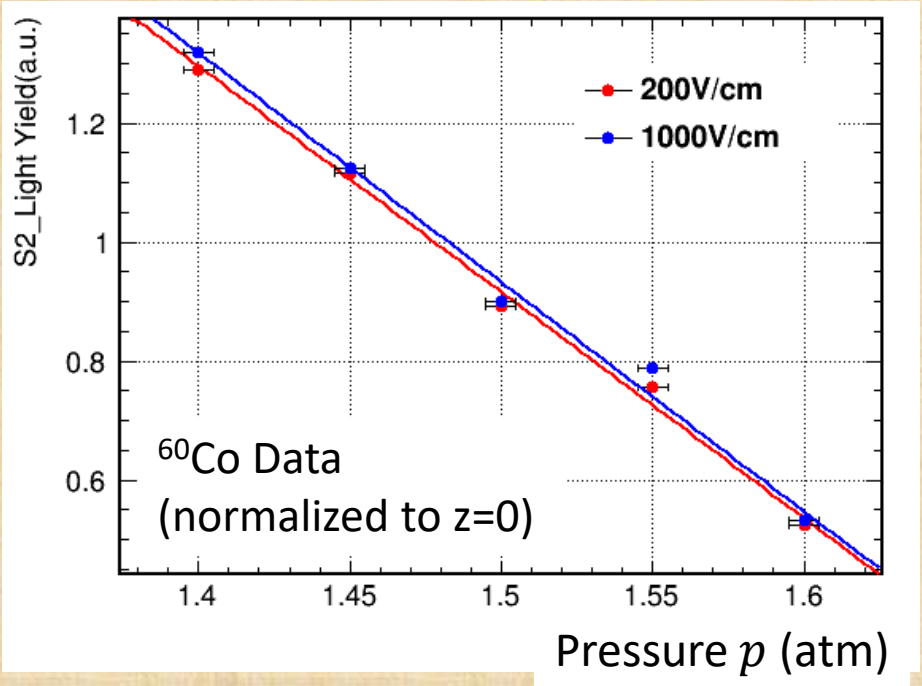
Pressure and Liquid Level Dependence of S2 at Higher Energy (*O*(100keV))

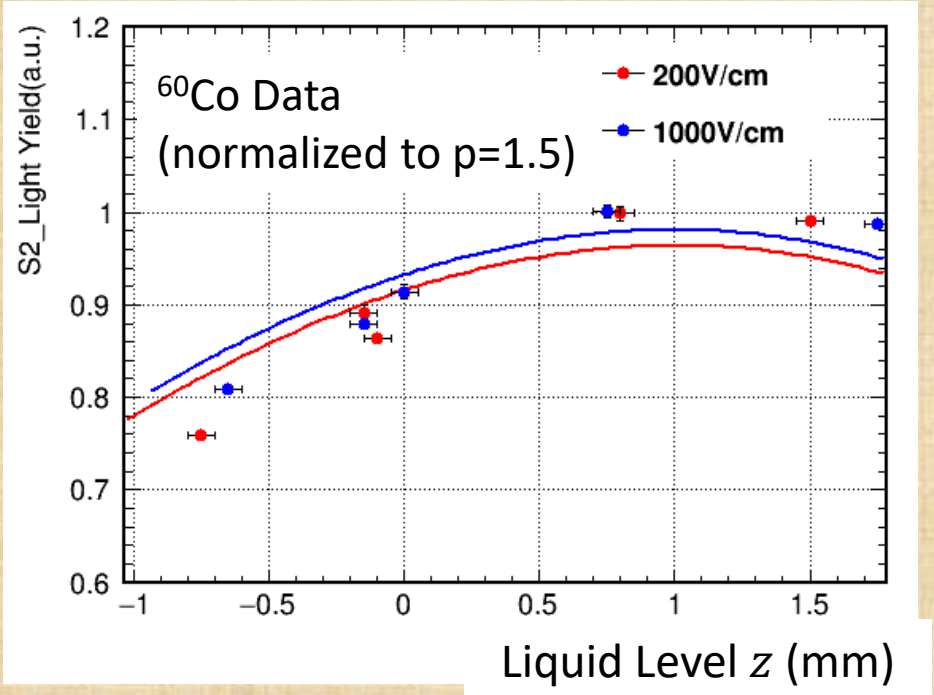
$$S2/p \propto \left(E(z)/p - \text{const.}\right) \times (D/2 - z)$$

$$E(z) = \frac{V_{\text{anode}} - \phi(z)}{D/2 - z}$$

$$\phi(z) = \frac{(D+2z)\varepsilon_{\text{GAr}} V_{\text{anode}} + (D-2z)\varepsilon_{\text{LAr}} V_{\text{grid}}}{(D+2z)\varepsilon_{\text{GAr}} + (D-2z)\varepsilon_{\text{LAr}}}$$



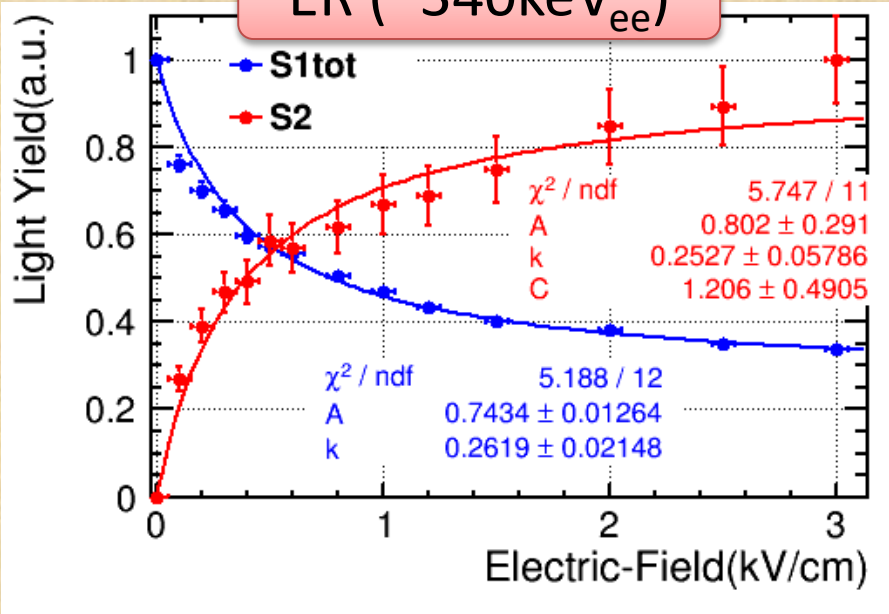




The environment is under control & behavior is well understood

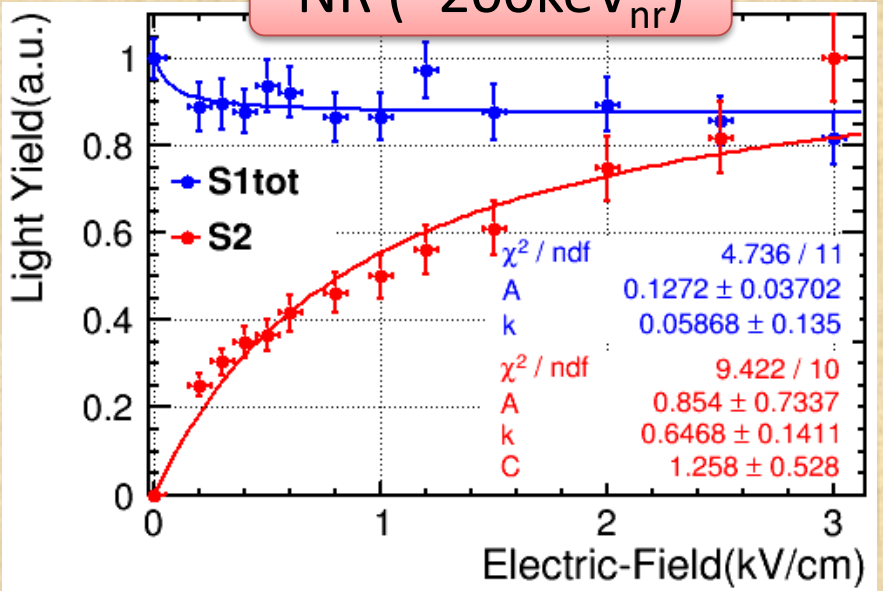
Drift-Field Dependence of S1 and S2 at Higher Energy (*O*(100keV))

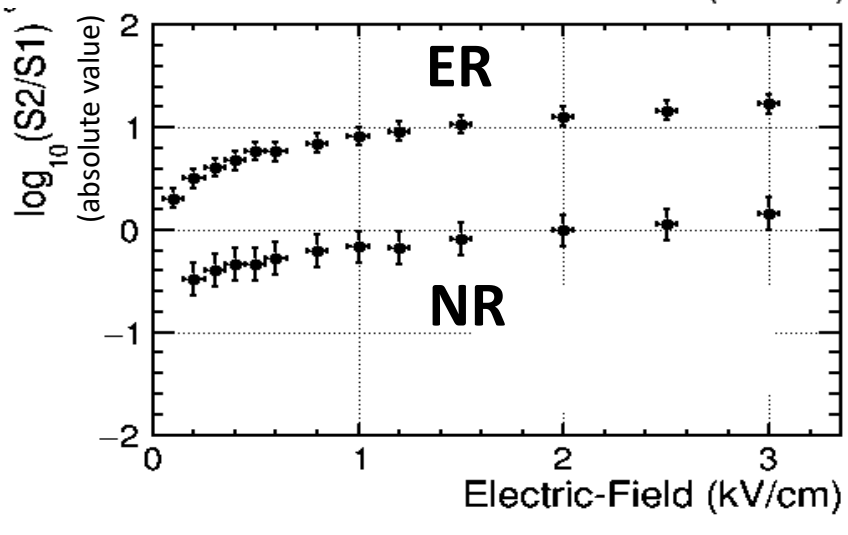
ER (~340keV$_{ee}$)



(Normalized at 0 kV/cm for S1 , at 3 kV/cm for S2)

NR (~200keV$_{nr}$)





In general, S1(S2) decreases (increases) at higher E-Field due to recombination effect.

However, its behavior is much different between ER and NR (S1 is almost flat).

Experimental Setup

【Source】

ER Calibration : ^{22}Na BTB

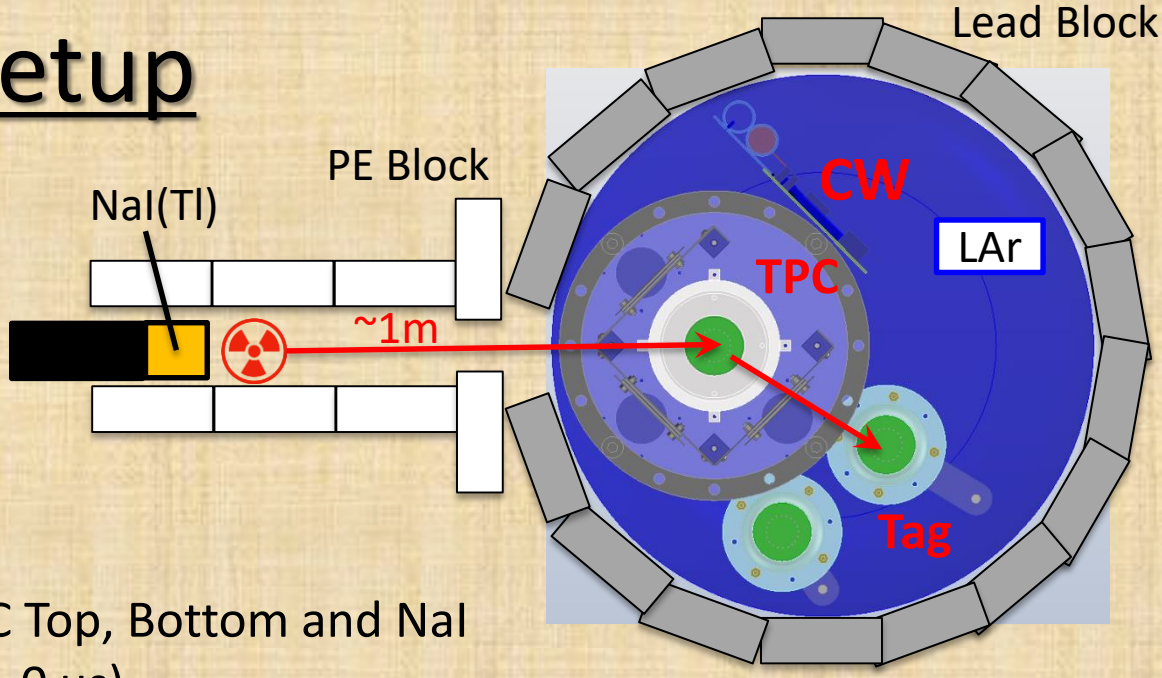
NR Calibration : ^{252}Cf TOF

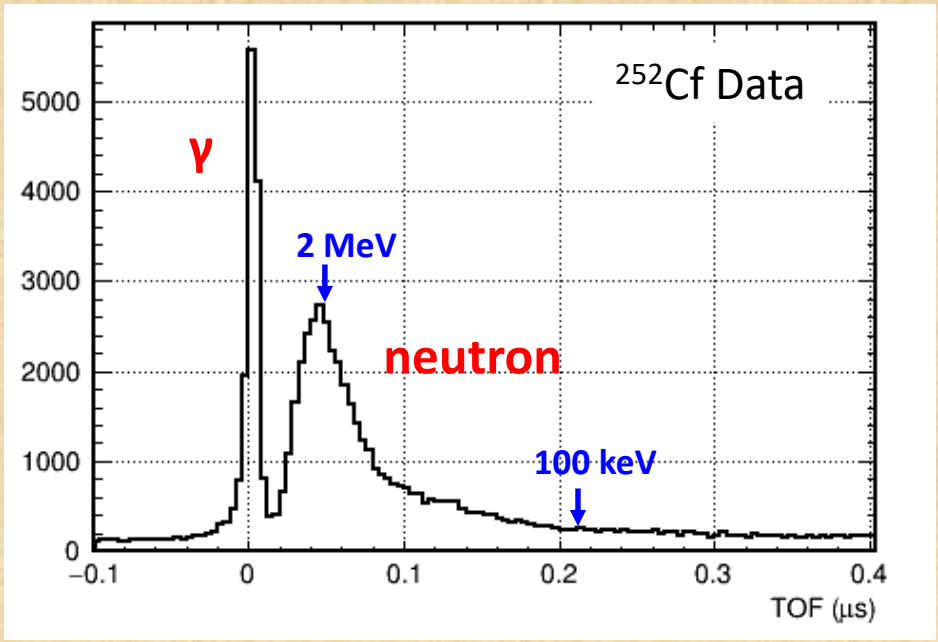
【DAQ】

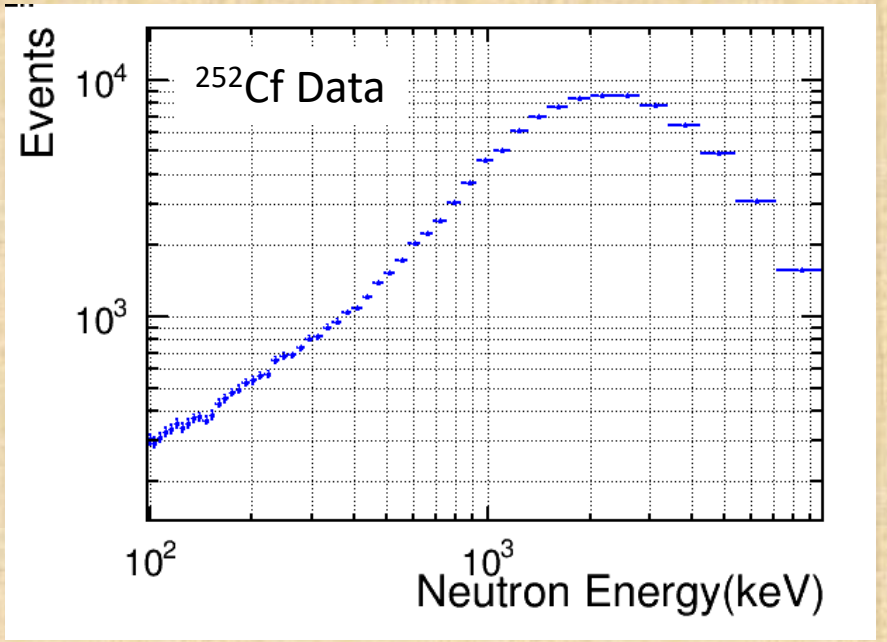
FADC : SIS3316 (250MS/s)

Trigger : 3ch coincidence of TPC Top, Bottom and NaI

(coincidence width = 1.0 us)





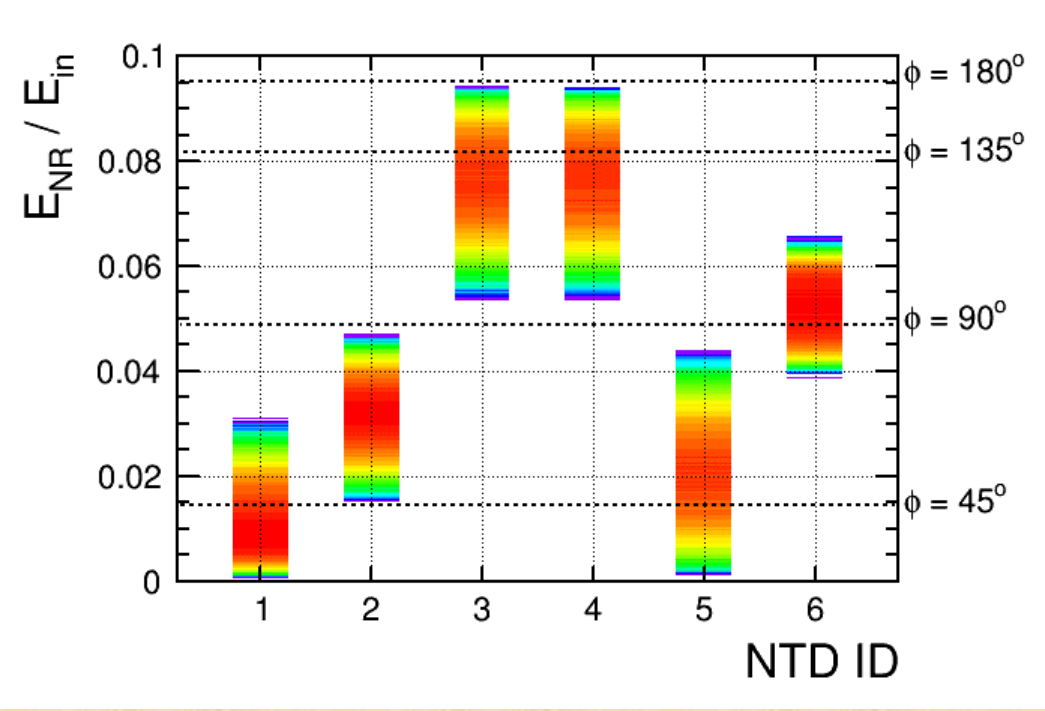


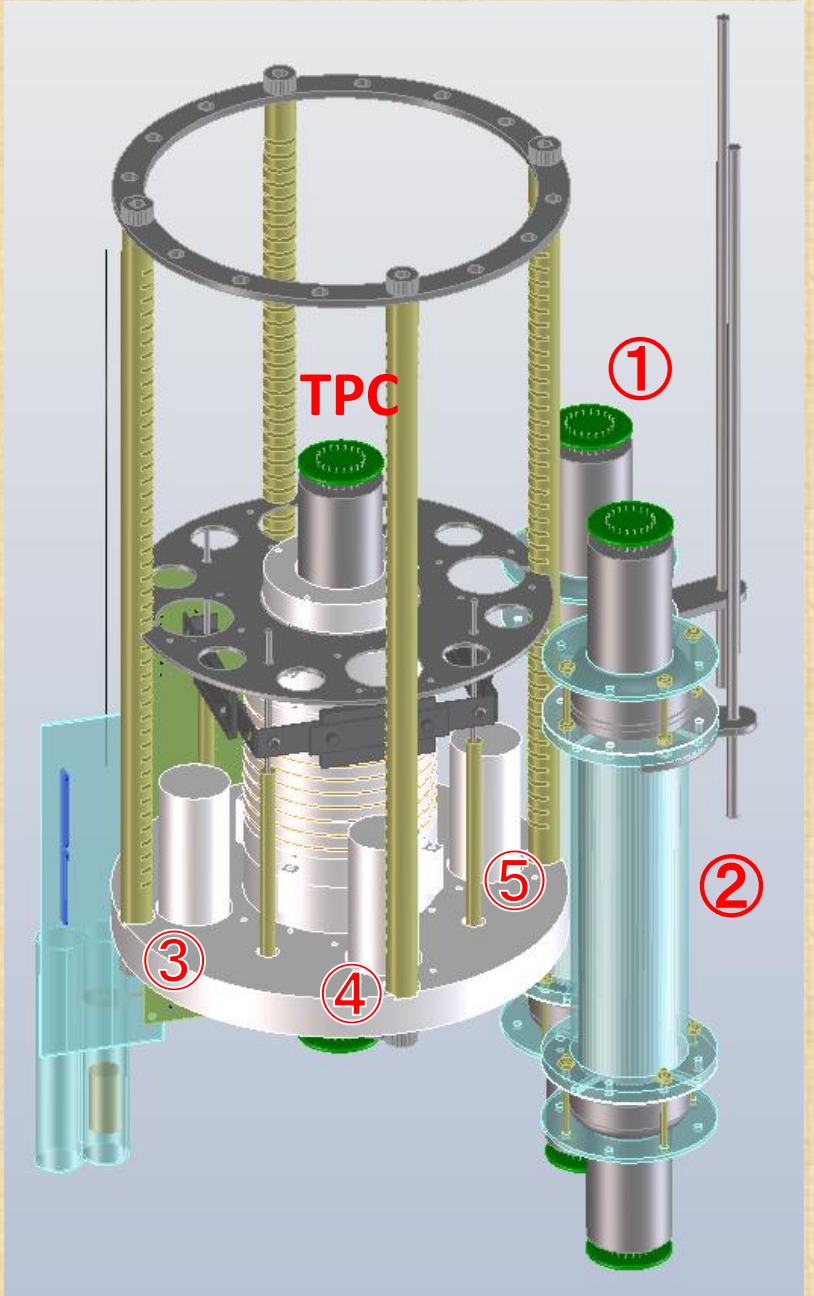
Neutron-Tag Detectors (NTDs)

⑥ (outside of chamber)

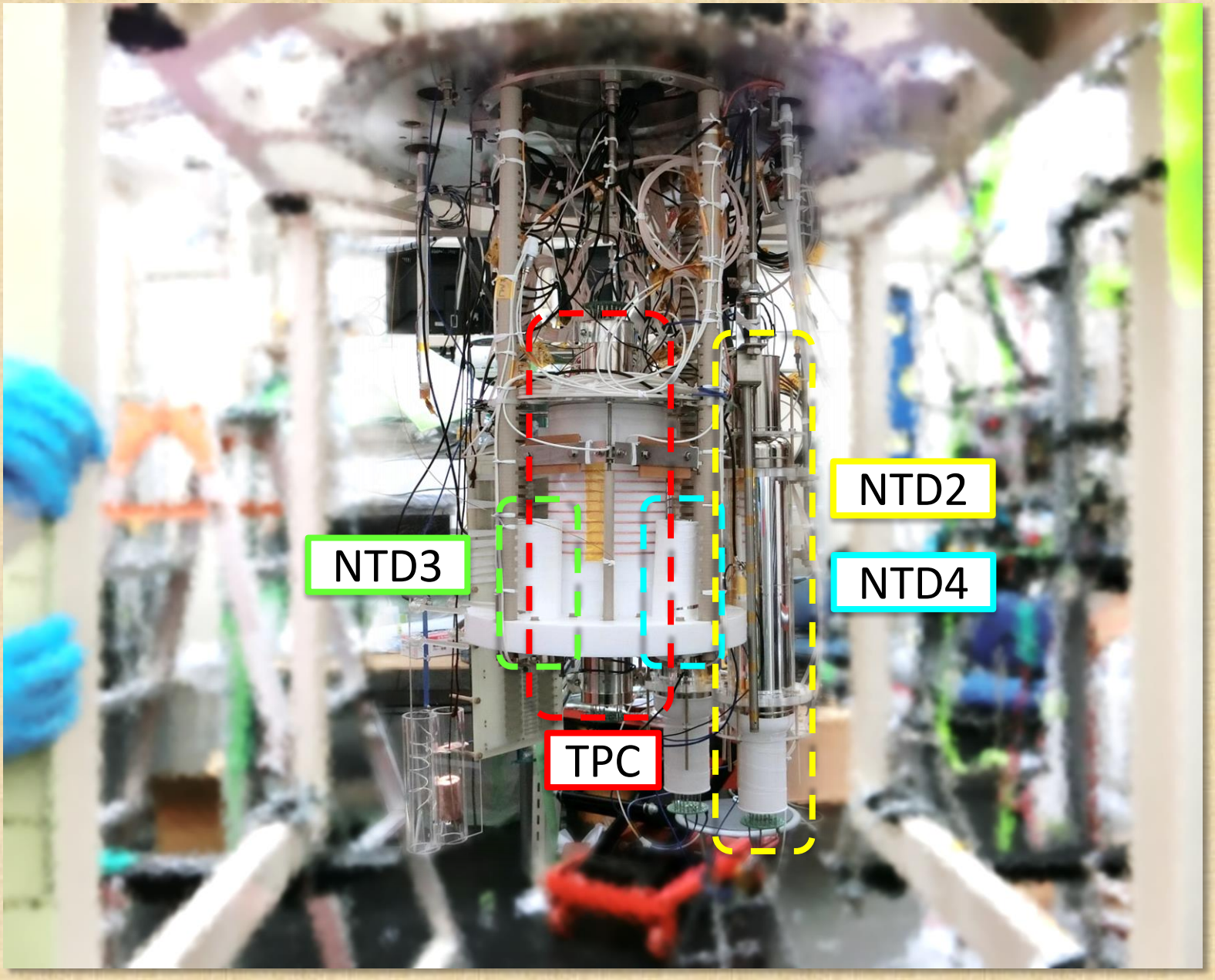
①② : LAr (2 PMTs readout)
③④⑤ : LAr (1 PMT readout)
⑥ : Liquid Scintillator (BC501A)

$$\frac{E_r}{E_{in}} = \frac{2(A+1-\cos^2\phi-\cos\phi\cdot\sqrt{A^2-1+\cos\phi})}{(A+1)^2}$$



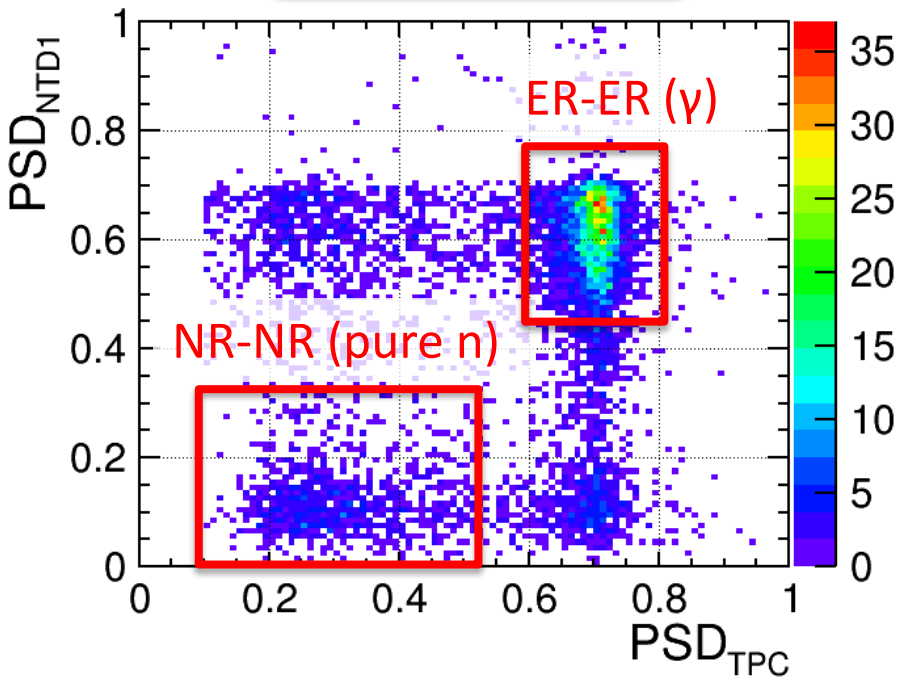


View from RI source position

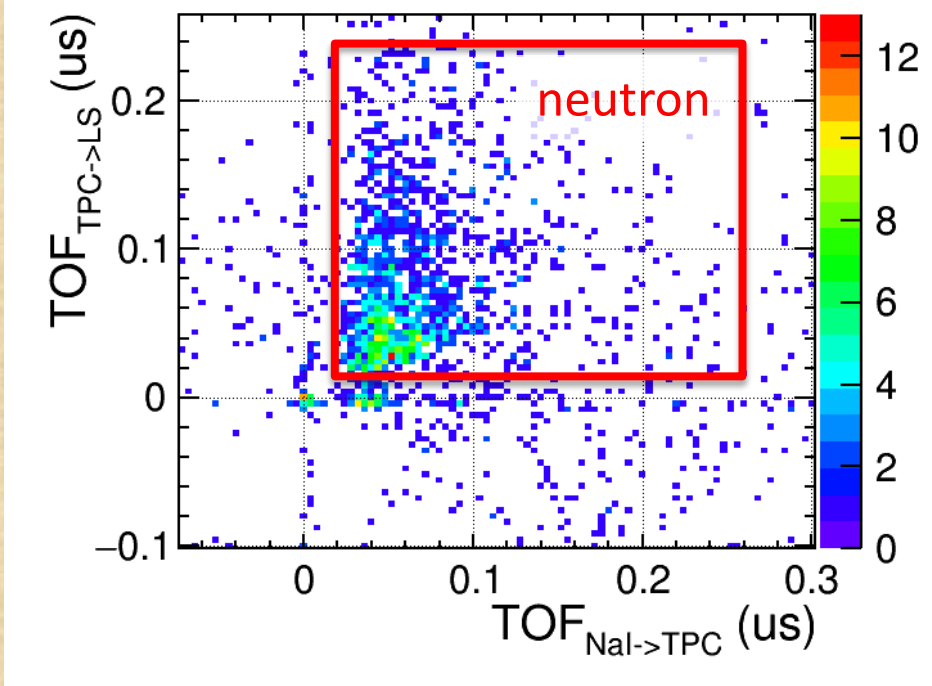


Neutron Identification by NTDs

NTD1 (LAr)



NTD6 (LS)

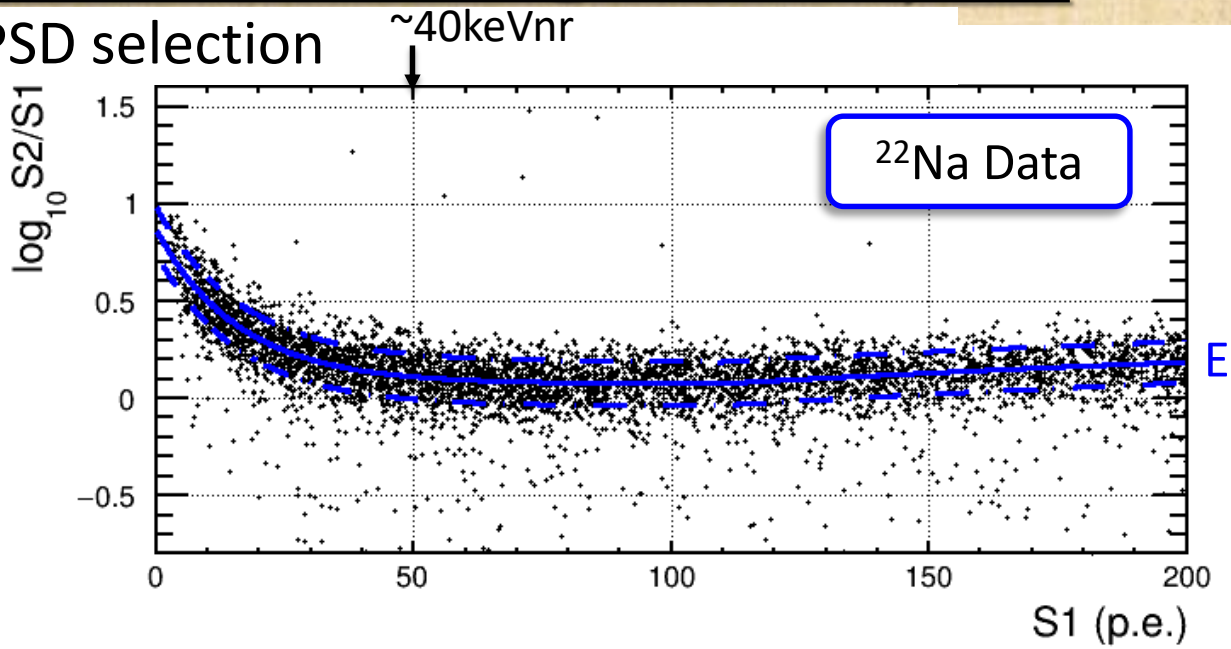


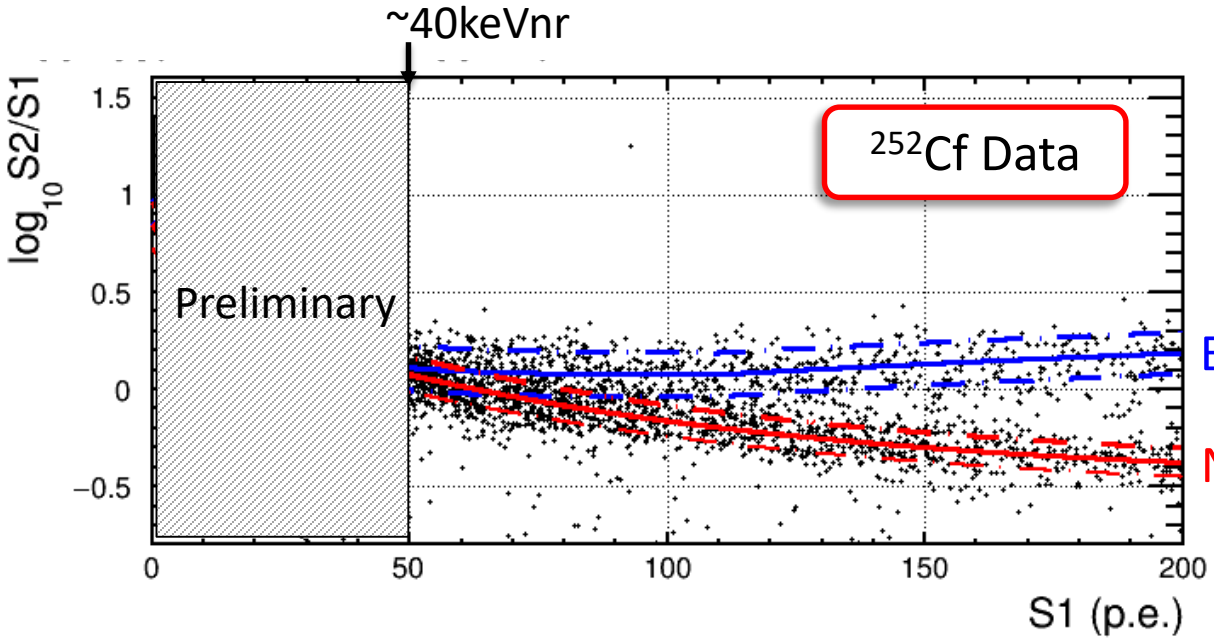
(PSD = Slow/Total = 1 - F_{prompt})

- Event topology is well separated and NR-NR events can be selected.
- This data is useful for measurements of recoil energy and quenching factor (analysis is ongoing)

ER and NR bands @ 0.2 kV/cm

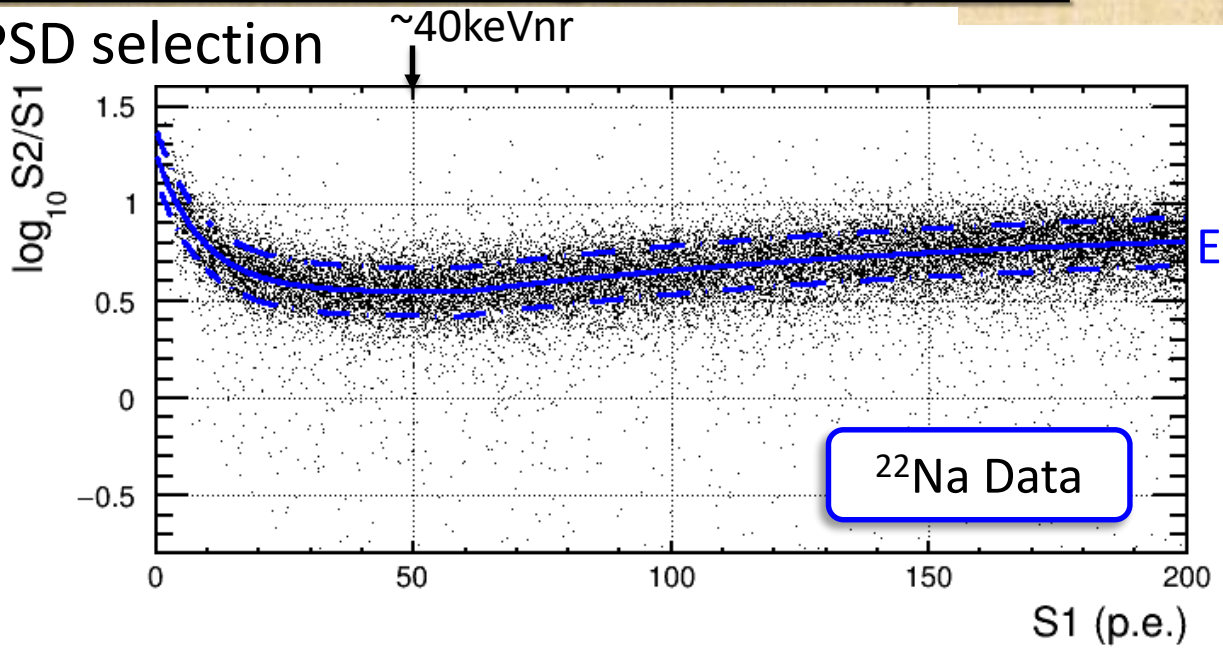
Before PSD selection

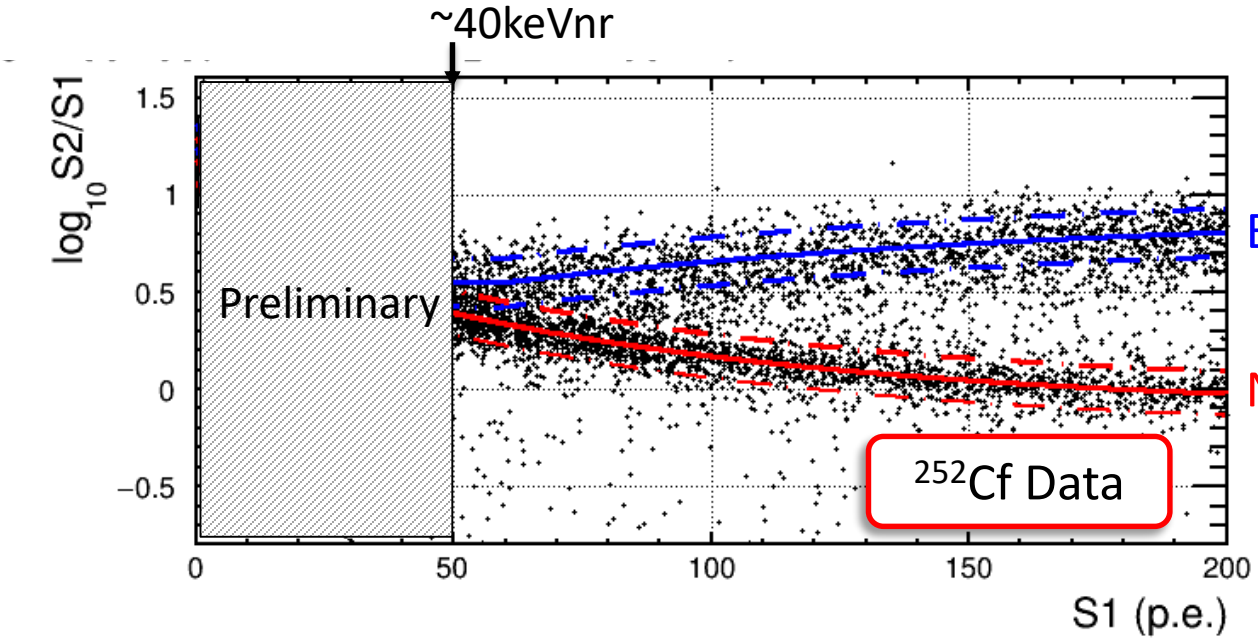




ER and NR bands @ 1.0 kV/cm

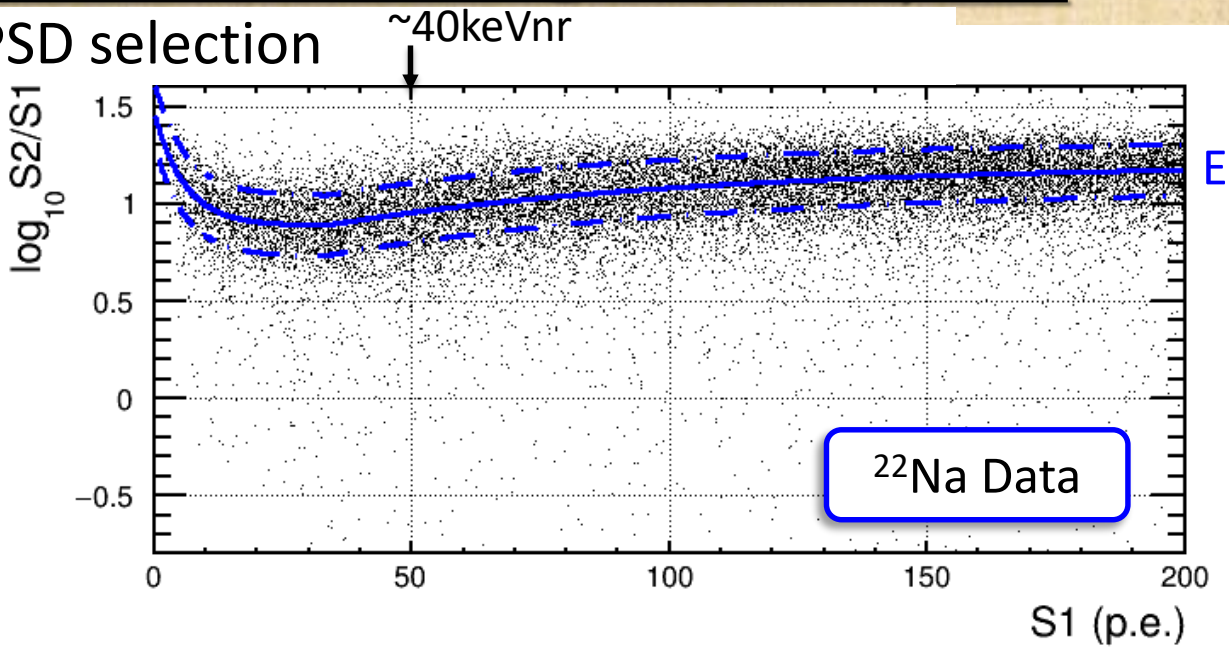
Before PSD selection



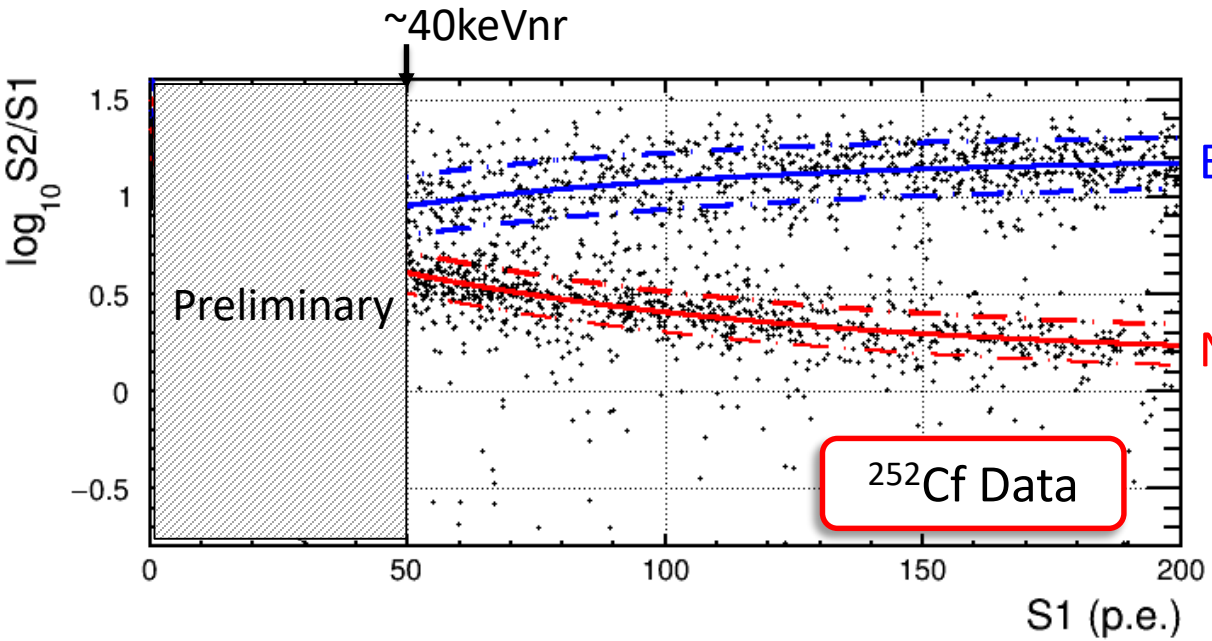


ER and NR bands @ 3.0 kV/cm

Before PSD selection



ER mean ± 1σ



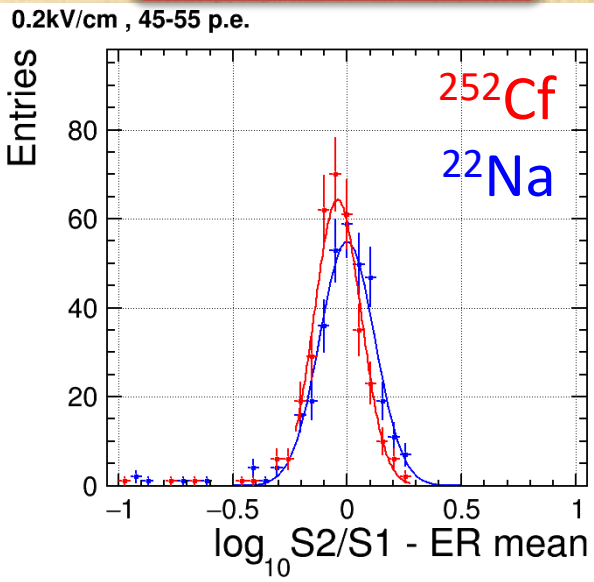
ER mean ± 1σ

NR mean ± 1σ

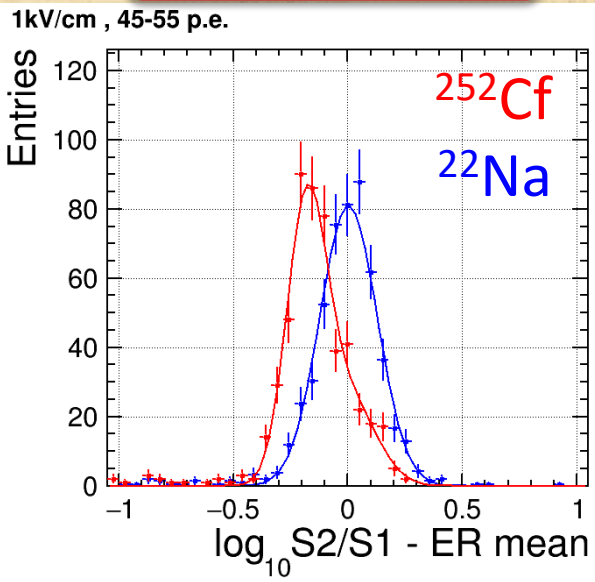
Gaussian Leakage Fraction @ 40keVnr (Very Preliminary)

Before PSD selection

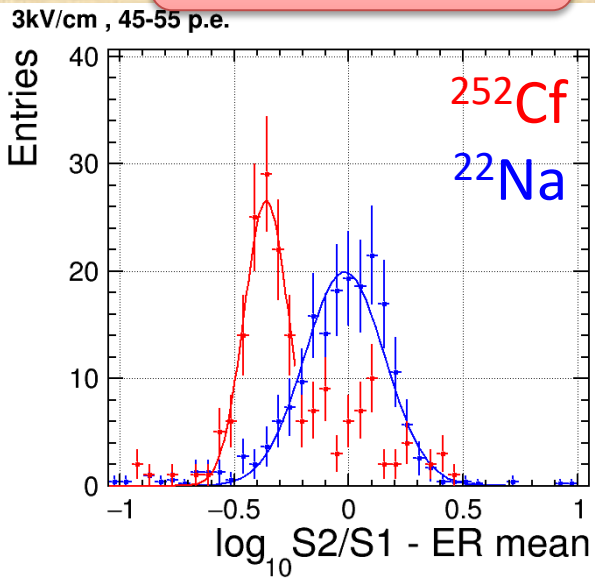
0.2 kV/cm



1.0 kV/cm



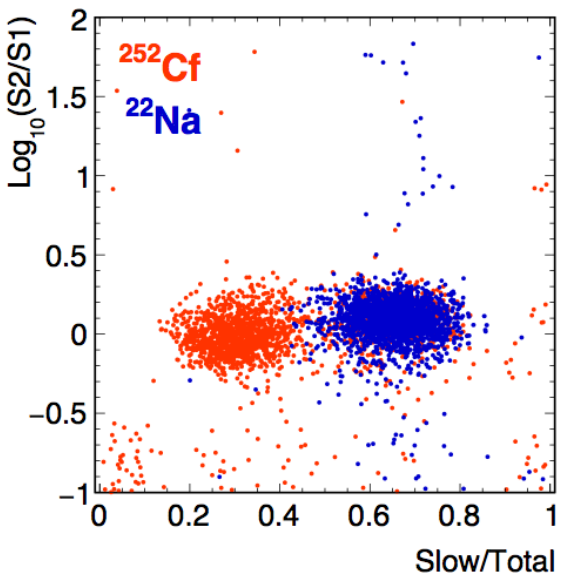
3.0 kV/cm



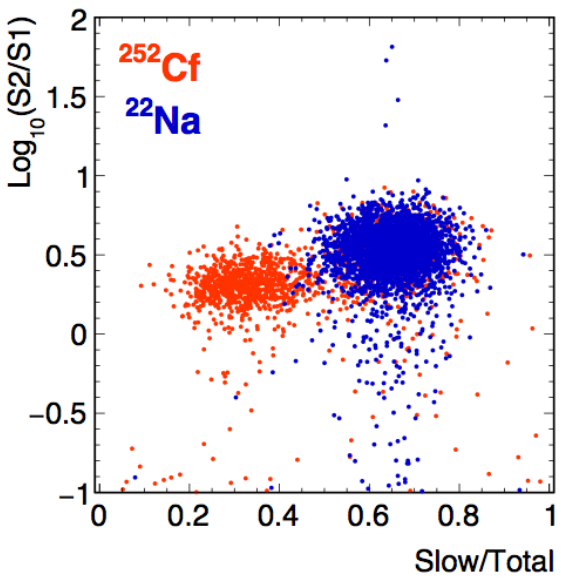
	0.2 kV/cm	1.0 kV/cm	3.0 kV/cm
$(\mu_{ER} - \mu_{NR}) / \sigma_{ER}$	0.3	1.4	2.0

Combination of PSD & S2/S1 @ 40keVnr (Very Preliminary)

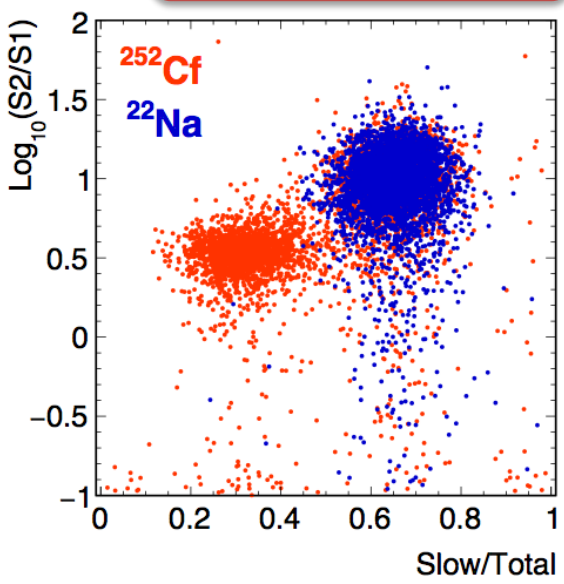
0.2 kV/cm



1.0 kV/cm



3.0 kV/cm



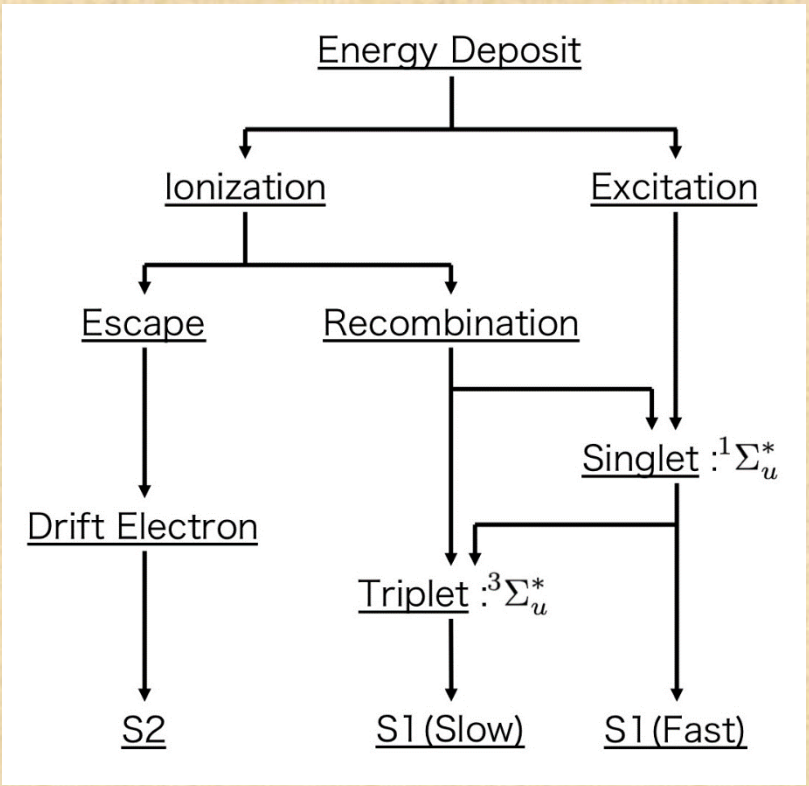
As higher drift field, ER/NR discrimination gets increased in Argon (different to Xenon case)

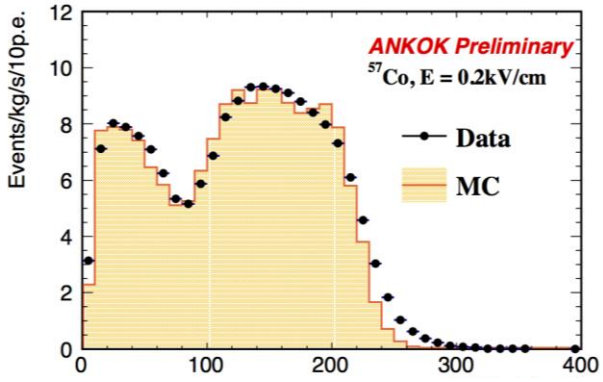
Modeling & Simulation

Take some approaches to get detailed understandings of LAr response in electric field.

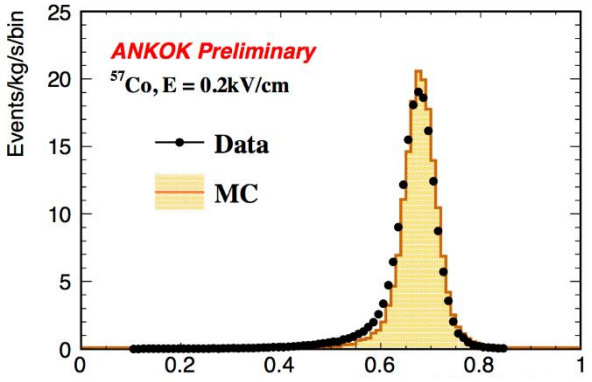
- Calculate the number of scintillation photon at each step of Geant4.
- Implement own Ar response model to the simulation. (refer to NEST)

See detail :
JPS Conf.Proc. 11, 040003 (2016)

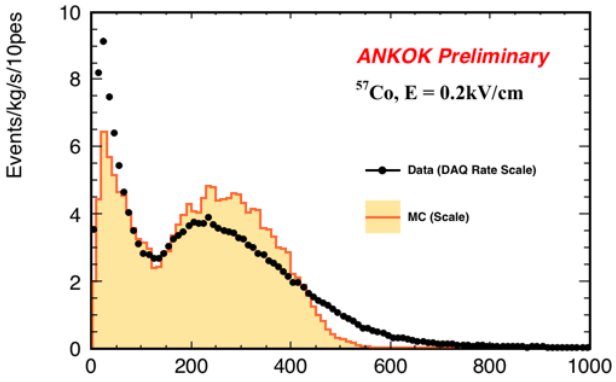




S1 Fast (p.e.)



S1 Slow/Total



S2 (p.e.)

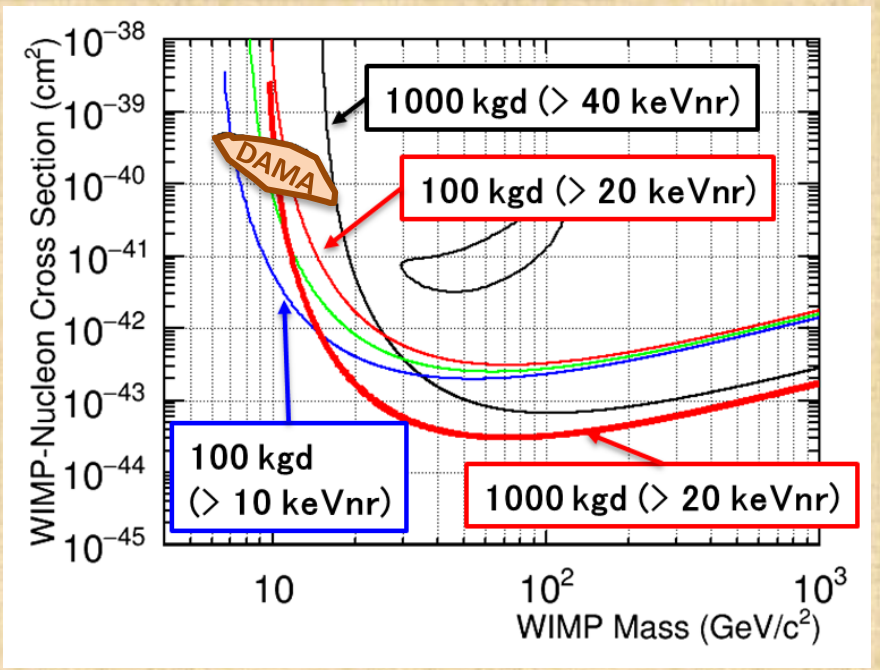
Application : low mass WIMP search

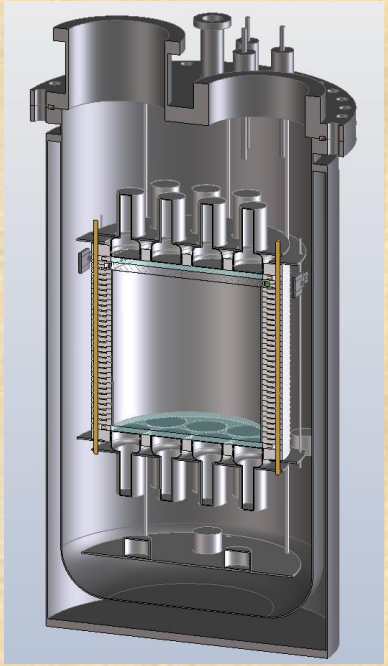
Some groups (DAMA, CoGeNT, CDMS2(Si)) claim the discovery of ~10GeV WIMP.

- Rejected by LXe experiments
- Not verified by LAr experiments

To search the low mass WIMP,

- Lower threshold is necessary
- rather than scaling up the detector mass





ANKOK project

Low mass WIMP search with

- Compact Detector (10 ~ 30kg)
- Optimization of electric field
- SiPM (Direct detection of 128nm, or Using TPB)

See detail : M.Kimura's Talk @ TAUP2017
https://indico.cern.ch/event/606690/contributions/2591649/

【Summary】

- ✓ We evaluate the ER/NR Discrimination power of S2/S1 with liquid argon.
- ✓ ER/NR separation are improved under higher drift field.

【Future Plan】

- Complete the analysis for this data
  - lower energy events (< 40keVnr) of ^{252}Cf data
  - combination analysis with PSD
  - identification of recoil energy (event by event)
- Further measurements & optimization
  - Still higher drift-field, gas phase field, ...
- Apply for the WIMP search