



Direction-sensitive dark matter search with three-dimensional gaseous tracking detector

*24 - 28 July 2017
SNOLAB / Laurentian University
Sudbury, Canada*

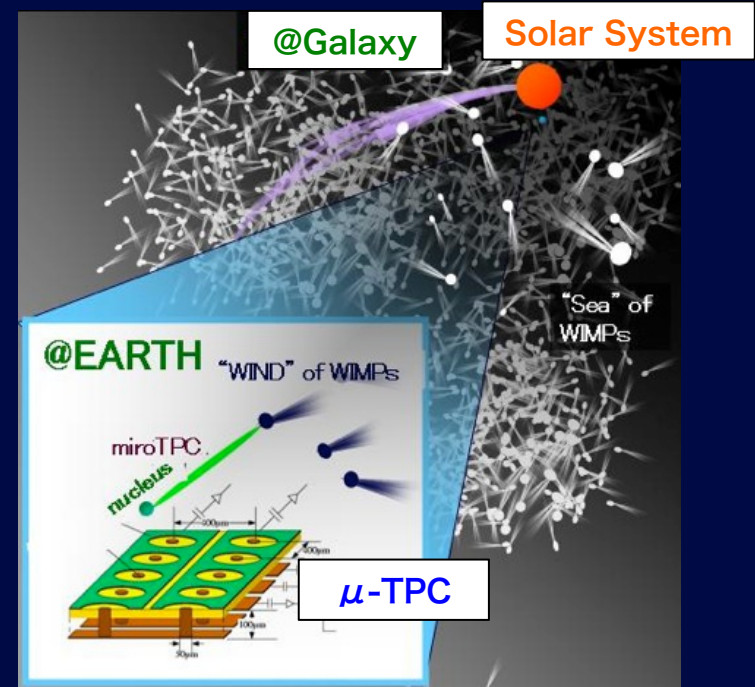
Outline

- *NEWAGE*
- *Detector*
- *Underground measurement*
- *R&Ds*
- *Summury*

*Kobe University
Ryota Yakabe*

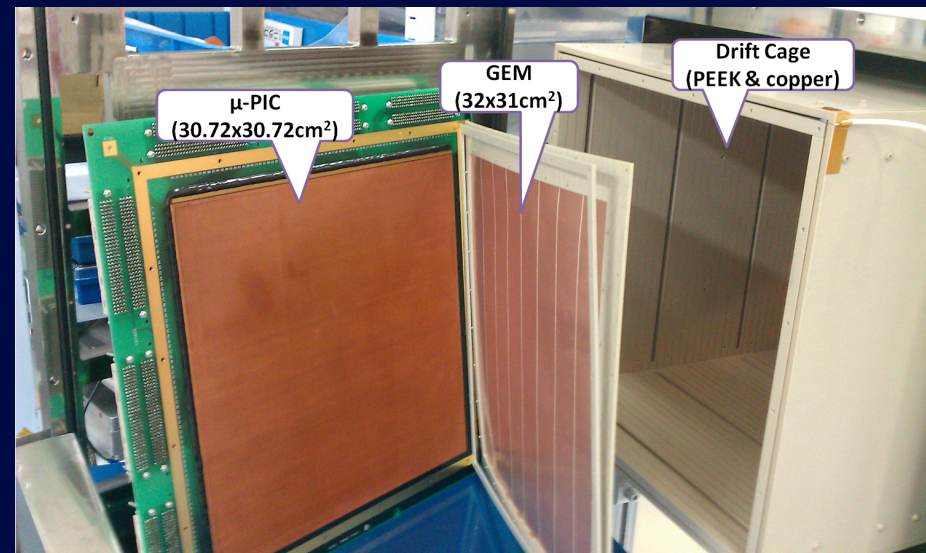
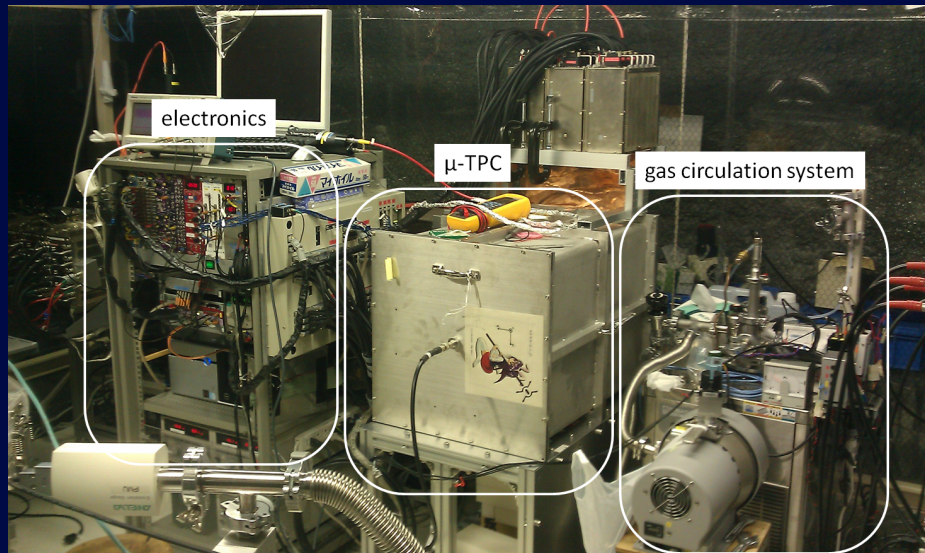
NEWAGE

- ◆ Direction-Sensitive
Dark Matter Search Experiment
- ◆ Detect DM "WIND" using
3-D Gaseous Tracking Detector
- ◆ Study of kinematics
DM Particles in the Galaxy
- ◆ Detector for DM Search
NEWAGE-0.3b'@underground Kamioka Lab.
2700m water equivalent



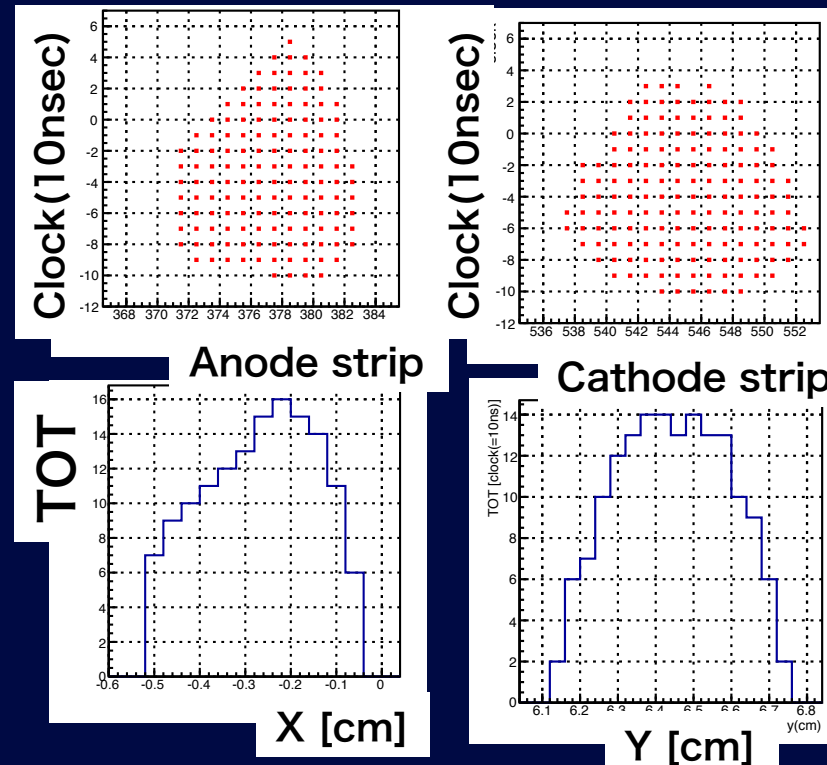
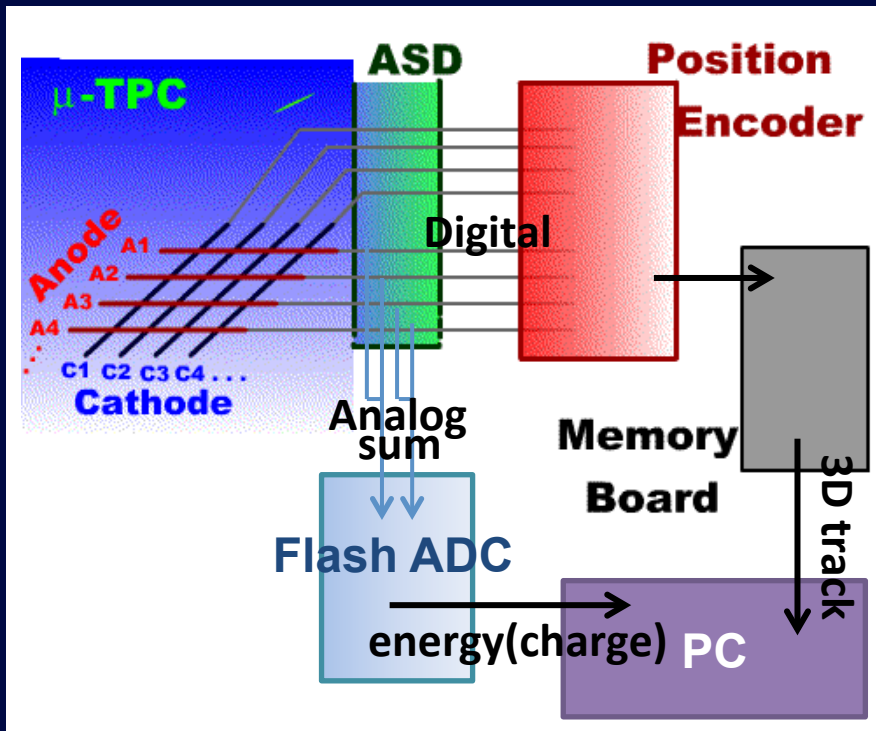
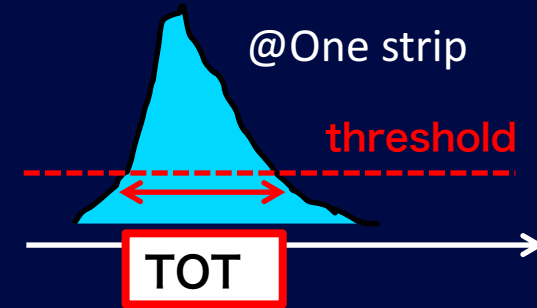
Detector NEWAGE-0.3b'

- ◆ CF_4 0.1 atm
- ◆ Detector Volume : $30 \times 30 \times 41 \text{ cm}^3 \sim 0.037\text{m}^3$
- ◆ GEM : LCP100 μm , $\phi 70\mu\text{m}$, 140 μm pitch
- ◆ μ -PIC : $30.72 \times 30.72 \text{ cm}^2$ 、400 μm pitch
- ◆ Gas Gain (μ -PIC + GEM) : 2500



DAQ

- ◆ record charge and track
- ◆ charge : Summed waveform 100MHz FADC
- ◆ track : μ -PIC strip address and time-over-threshold(TOT) by 100MHz clock



Detector Response

◆ Energy Calibration

- $^{10}\text{B}(n, \alpha)^7\text{Li}$: 1.5MeV

◆ Energy resolution

- ^{220}Rn and ^{222}Rn α : 10%@6MeV
- ^{55}Fe 40%FWHM@5.9keV

◆ Drift Velocity

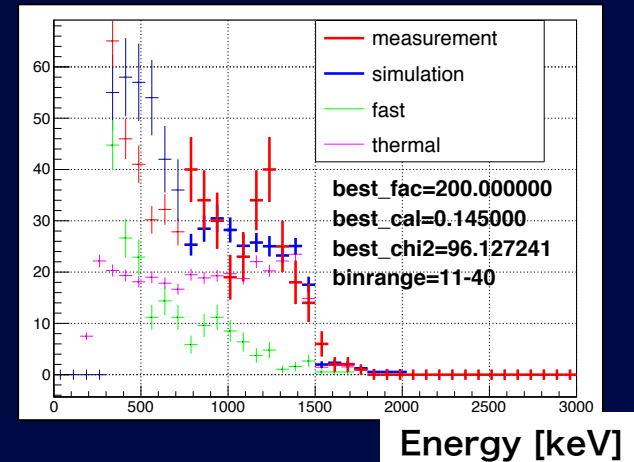
~ 9.3 cm/ μs

◆ Nuclear detection efficiency

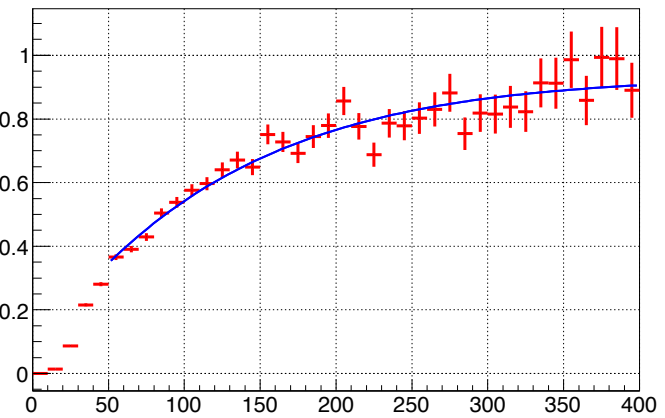
- 40%@50keV
- 80%@200keV

◆ Gamma rejection power

- $\sim 2 \times 10^{-5}$ @ 50-100keV
- $\sim 10^{-7}$ @ 100-400keV



Nuclear detection efficiency



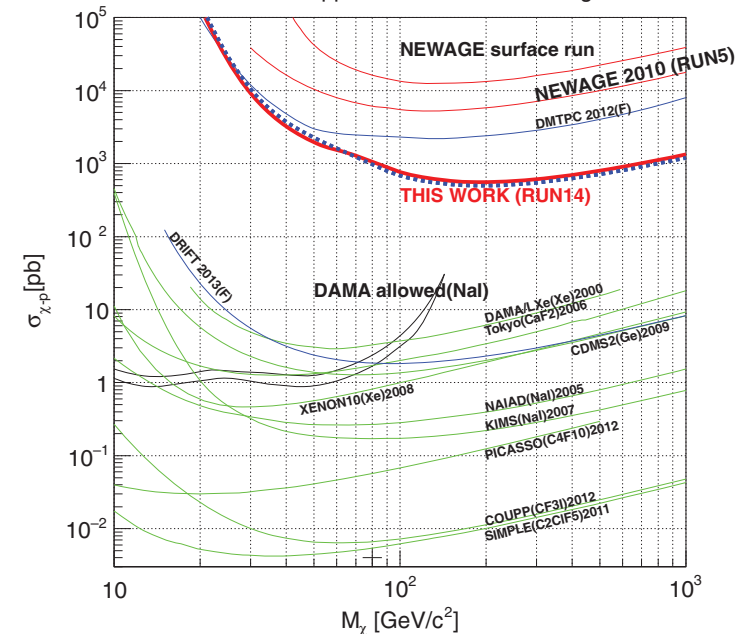
Energy [keV]

Underground measurement

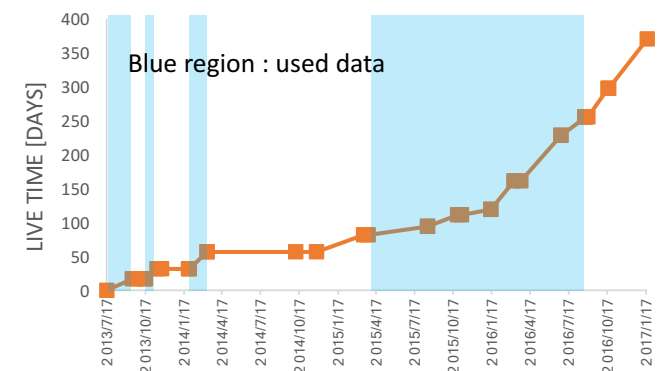
- **First underground measurement**
 - RUN14-1,2(NEWAGE2015)
 - Run14-1 : 2013/7/17 - 2013/9/16
 - Run14-2 : 2013/10/17 - 2013/11/14
 - live time : 31.6 days
 - Exposure : 0.327kg · days
- Directional-sensitive SD crosssection upper limit 557pb for 200 GeV/c²
- **Additional new Data**
 - Run14-3 : 2014/1/29 - 2014/3/12
 - run15 : 2015/3/30 - 2016/1/14
 - run16 : 2016/1/14 - 2016/6/28
 - run17 : 2016/6/28 - 2016/8/24
- total Data
 - live time : 230.16 days
 - exposure : 2.38 kg · days
- ~ 7 times statistics more than NEWAGE2015

Prog. Theor. Exp. Phys. 2015, 043F01 K. Nakamura

SD 90% C.L. upper limits and allowed region

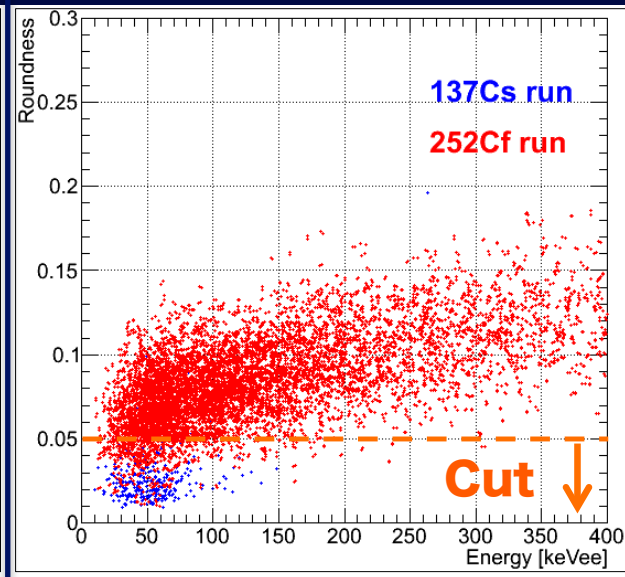
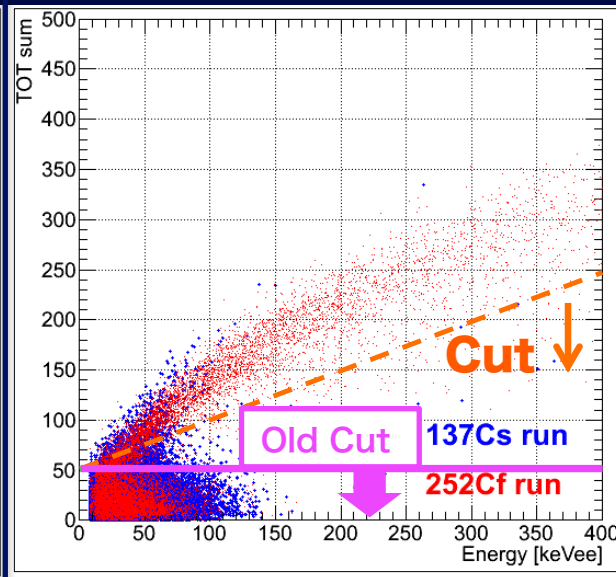
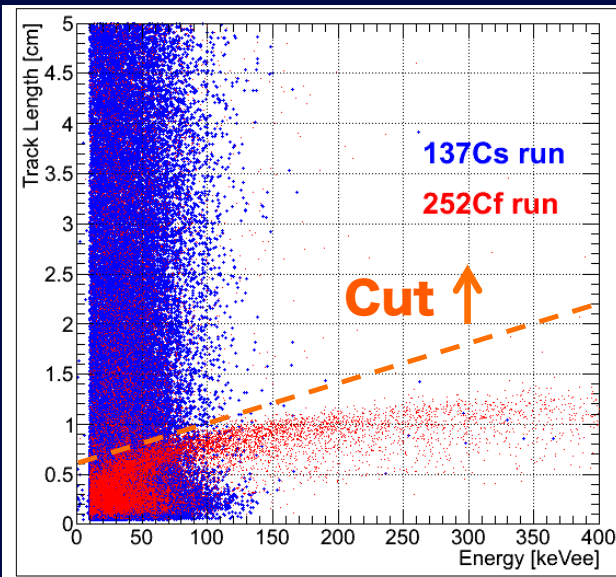


Total live time



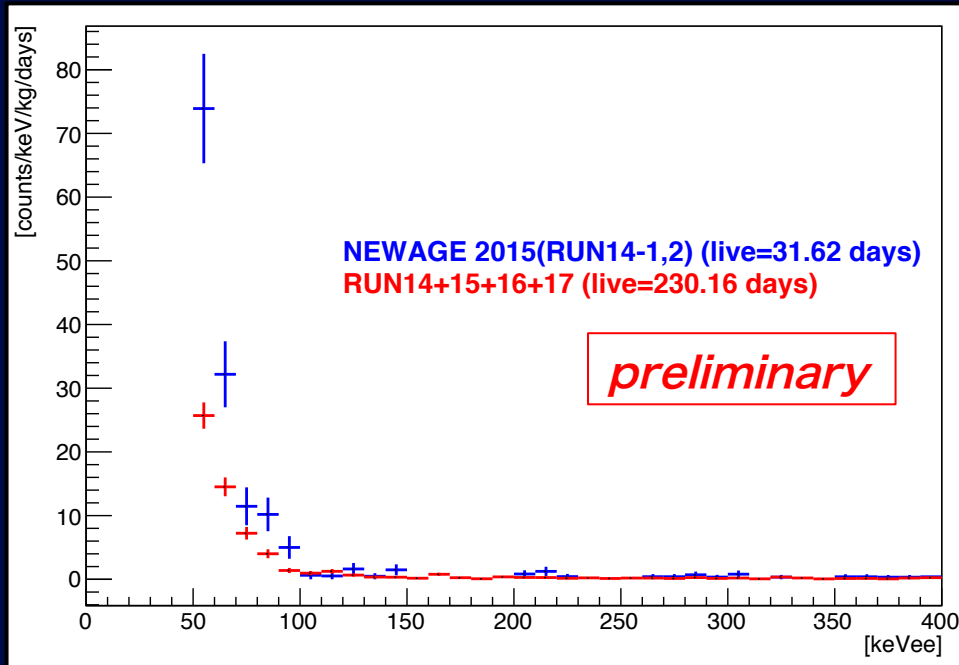
Update.

- ◆ Energy threshold : 50keV
- ◆ Fiducial Volume : $24 \times 28 \times 41 \text{ cm}^3$
- ◆ Track Length – Energy cut
- ◆ TOT sum cut **improved**
- ◆ Roundness cut



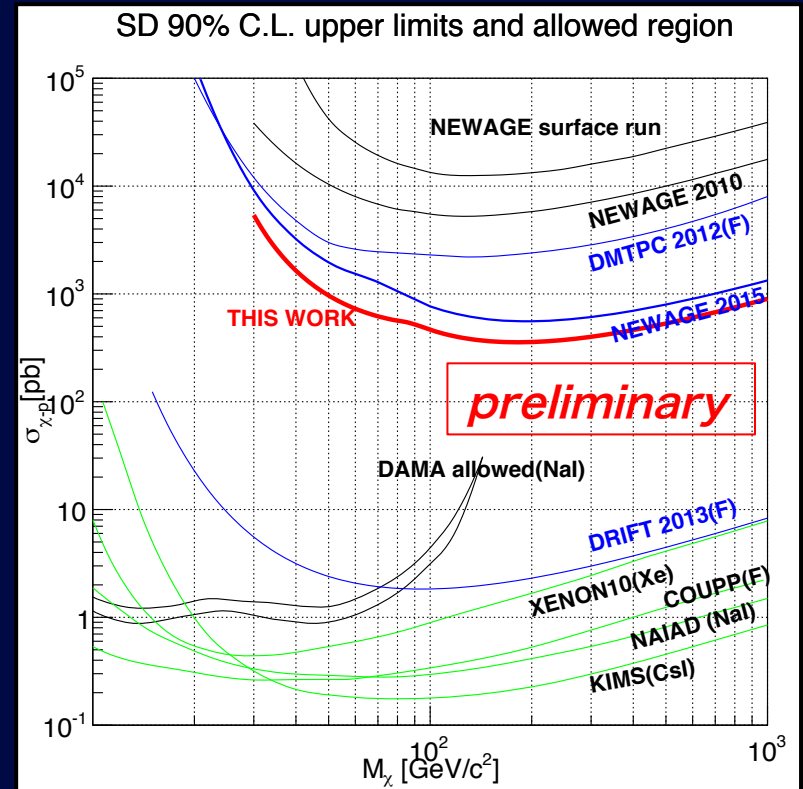
Result

- Energy spectrum



- BG : 1/3@50keV
- exposure : 2.38 kg · days
~ 7 times more than NEWAGE2015
- Directional-sensitive SD crosssection upper limit 356 pb@180GeV

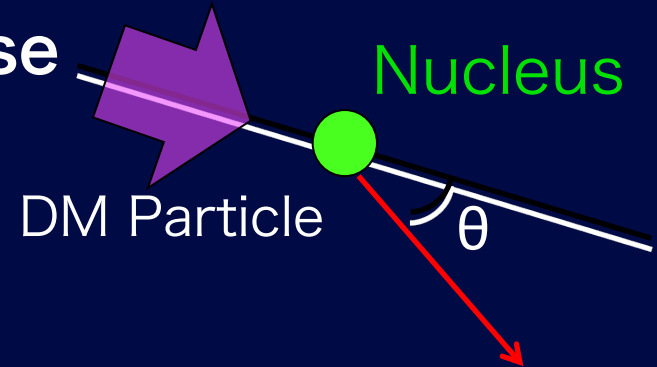
- limit



□ R&Ds (Head-Tail Analysis)

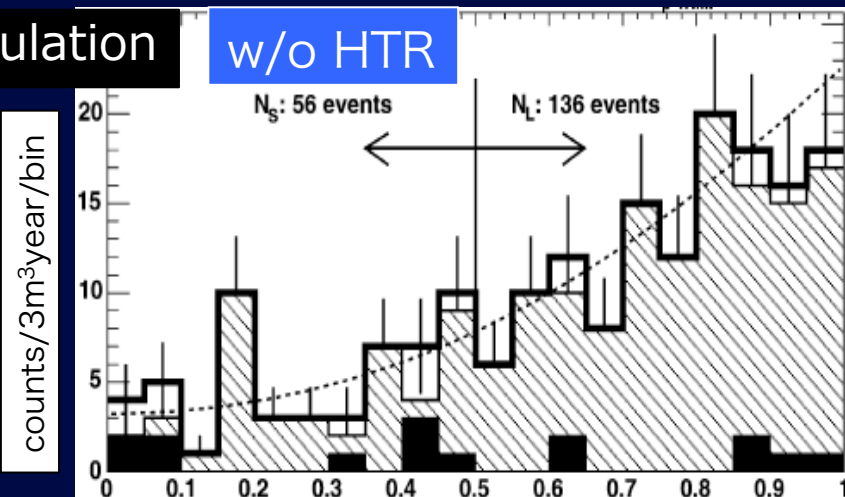
◆ Current : w/o Head-Tail Sense
get $|\cos \theta|$ information

◆ This work : w/ Head-Tail Sense
get $\cos \theta$ information
~ 3 times good sensitivity



Simulation

w/o HTR

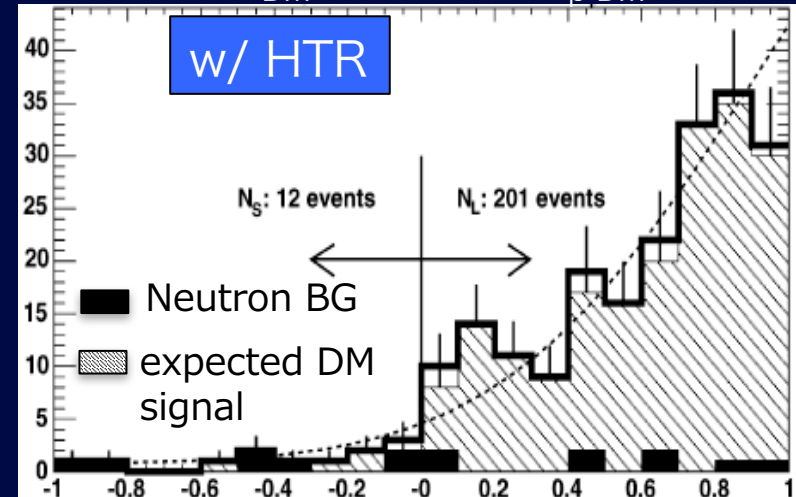


$|\cos \theta|$

Physics Letters B 578 (2004) 241-246

$M_{DM}=80\text{GeV}$ $\sigma_{p-DM}=0.1\text{pb}$

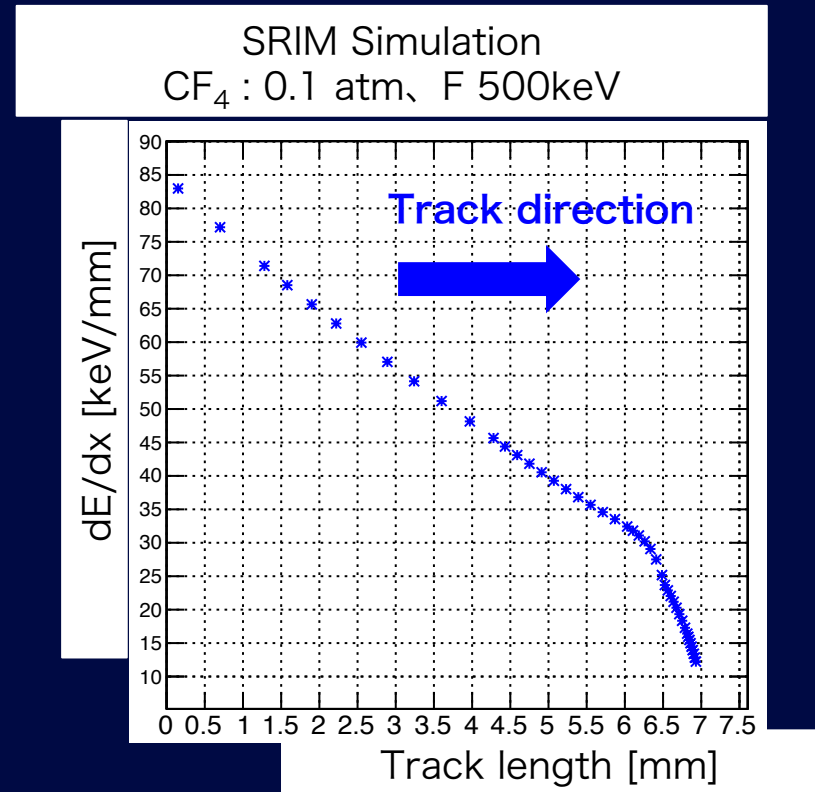
w/ HTR



$\cos \theta$

□ Head-Tail Analysis

- Use dE/dx information of Bragg curve in low energy region
 - dE/dx decreases along recoil nuclear track
 - initial point : large dE/dx
 - end point : small dE/dx
- HTS need detailed dE/dx information along recoil nuclear track
- dE/dx information
 - X-Y
 - Charge(x, y) (μ -PIC)
 - Z
 - Charge(t) FADC



□ Head-Tail Analysis

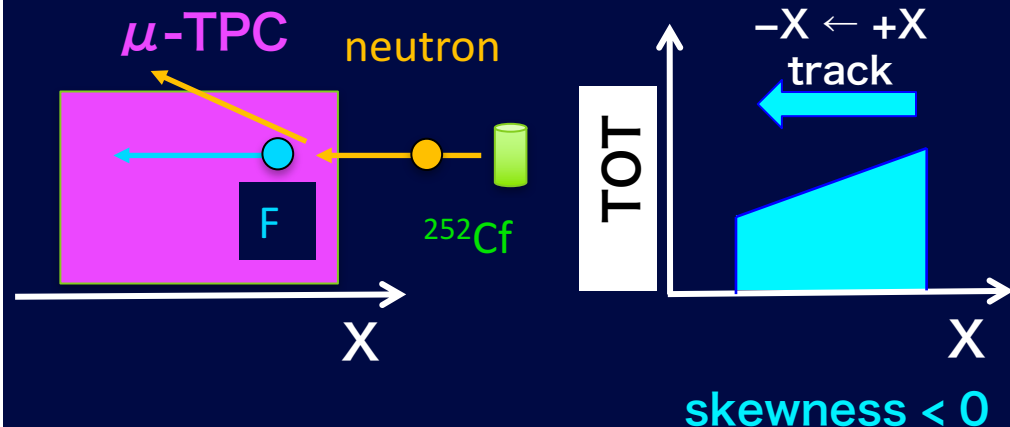
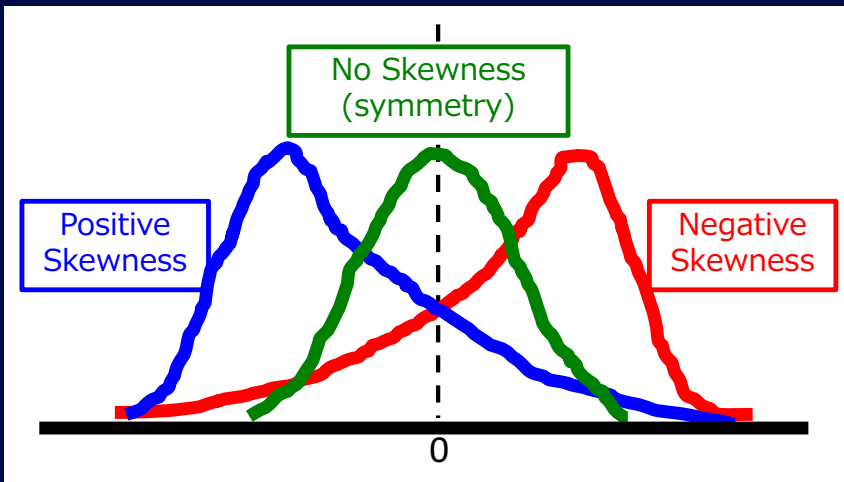
● Head-tail parameter

$$skewness = \frac{m_3}{m_2^{3/2}}$$

$$m_n \equiv E[(x - \langle x \rangle)^n] = \int_{min}^{max} dx (x - \langle x \rangle)^n \cdot \frac{TOT(x)}{\int TOT(x) dx}$$

$$\langle x \rangle = \int_{min}^{max} dx \frac{x \cdot TOT(x)}{\int TOT(x) dx}$$

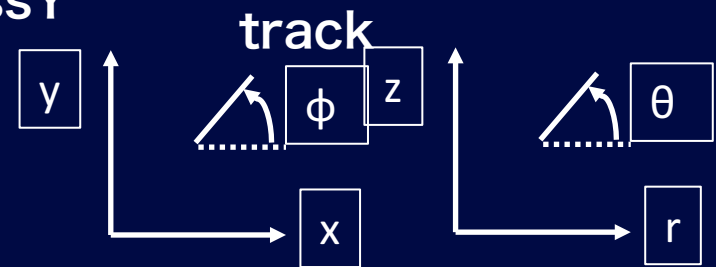
X : strip position
 So as Y
 Z : TOT(x) → FADC(t)



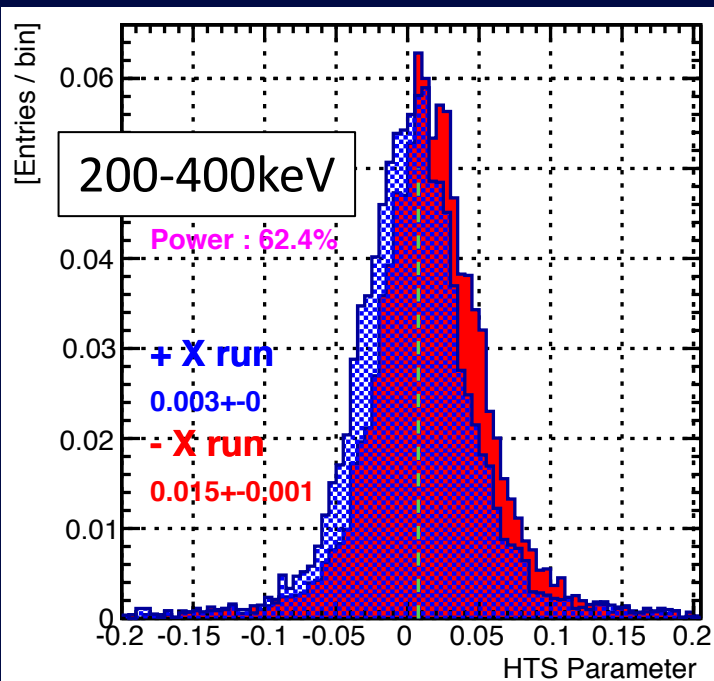
□ Head-Tail Analysis

- 3-dimensional Head-Tail parameter

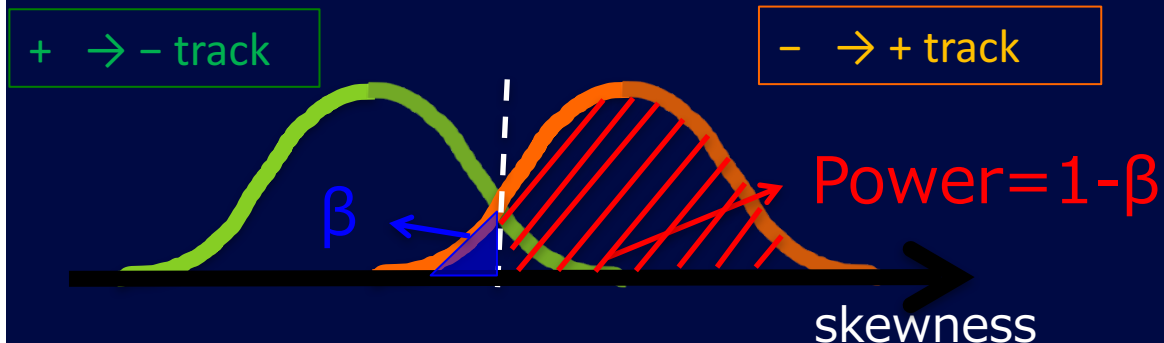
$$\text{HTS}_{xyz} = (1 - 2/\pi * \theta) * (1 - 2/\pi * \phi) * \text{skewness}X \\ + (1 - 2/\pi * \theta) * (2/\pi * \phi) * \text{skewness}Y \\ + (2/\pi * \theta) * \text{skewness}Z$$



CF4 0.1 atm ^{252}Cf run

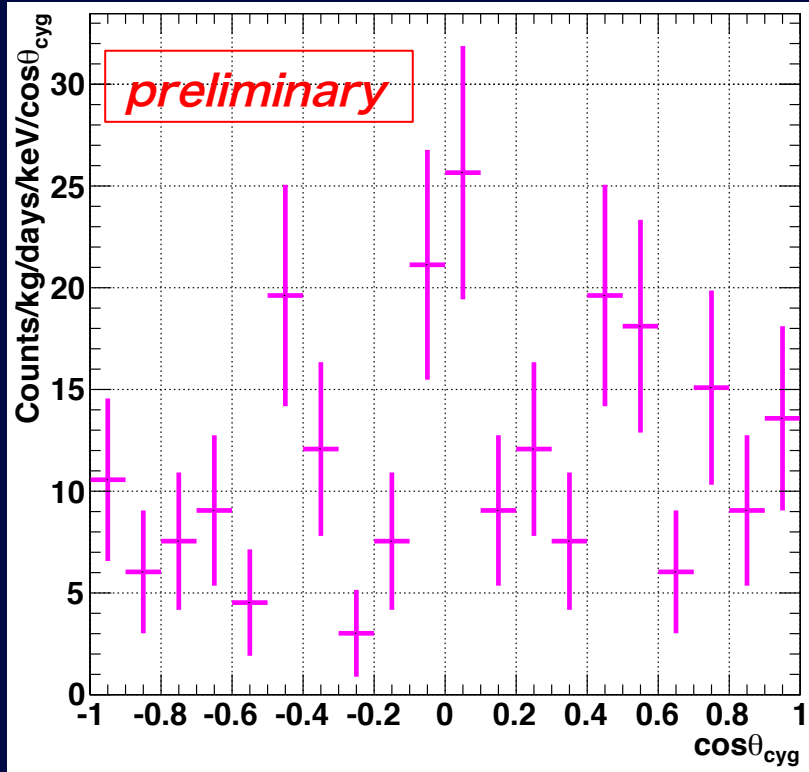


- We analysis Head-tail sense power
 ~ 50% @50-200keV
 ~ 60% @200-400keV



R&Ds (Head-Tail Analysis)

- Cos θ spectrum



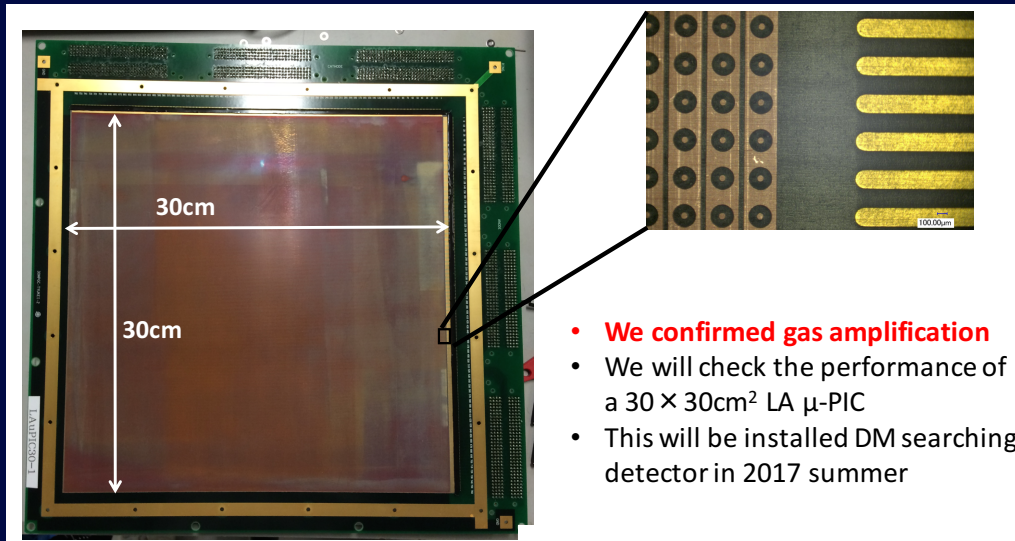
- Directional limit using $\cos\theta$ distribution is in progress

@50-60keV

□ R&Ds (Low-alpha μ -PIC)

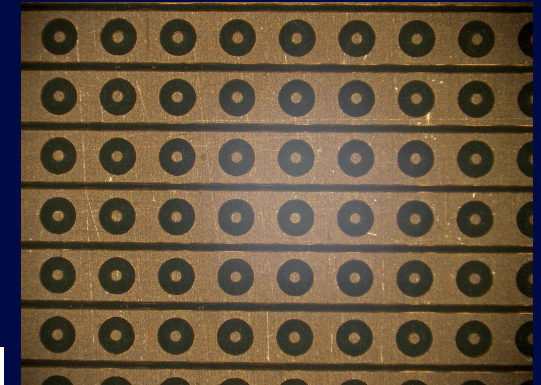
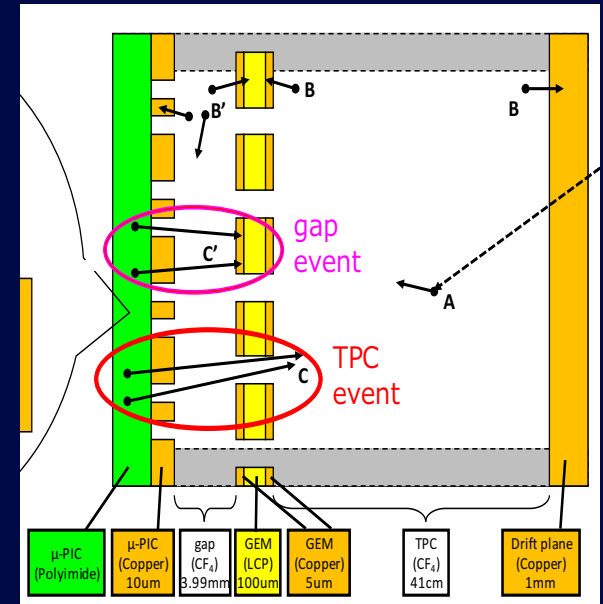
- Low-BG μ -PIC

- α from μ -PIC is Large BG.
- radio-pure(1/100) 30×30cm² μ -PIC is made and tested
- 2017 ~ underground run



- **We confirmed gas amplification**
- We will check the performance of a 30 × 30cm² LA μ -PIC
- This will be installed DM searching detector in 2017 summer

studied by Takashi hashimoto



□ R&Ds (Negative-Ion TPC)

Development of NI- μ TPC



Drift Group, Physics of the Dark Universe 9-10(2015)1-7

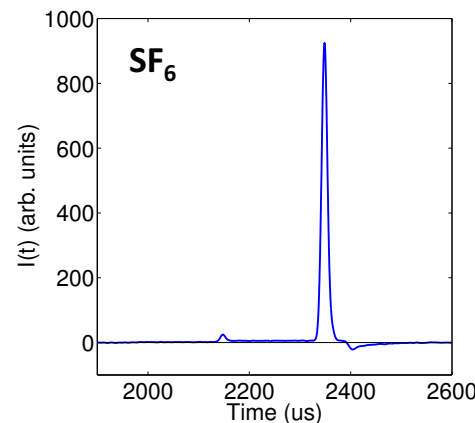
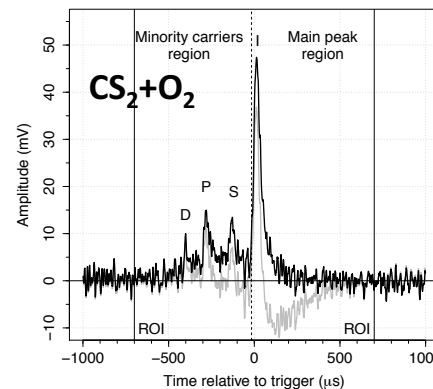
- **Minority peaks** “discovery” by DRIFT group
 - Used negative ion gas : $\text{CS}_2 + \text{O}_2$
 - First full-fiducialization with a gas detector

Physics of the Dark Universe 9-10(2015)1-7

- New negative ion gas : SF_6
 - First studies by N. Phan (NMU)
 - Also detected minority peaks

N.S. Phan *et al* 2017 JINST 12 P02012

- Minority peaks is very powerful tool!!
 - Able to reject μ -PIC BGs
- Negative Ion μ TPC
 - ✓ Gas gain
 - ✓ XY position resolution
 - ✓ Z position resolution



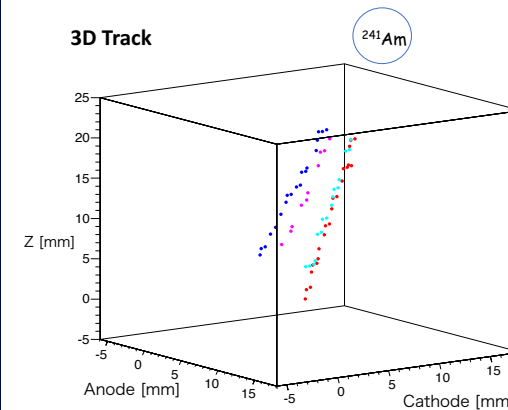
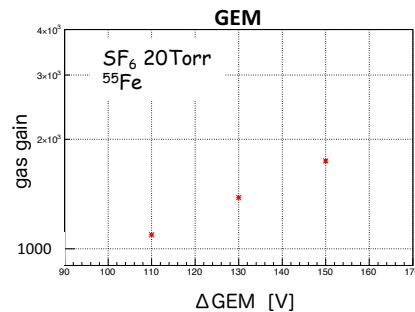
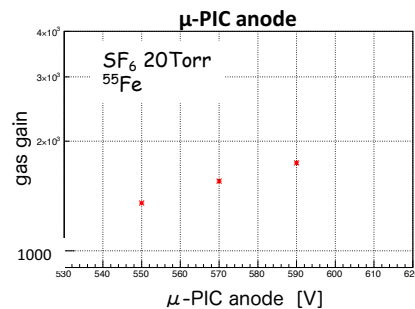
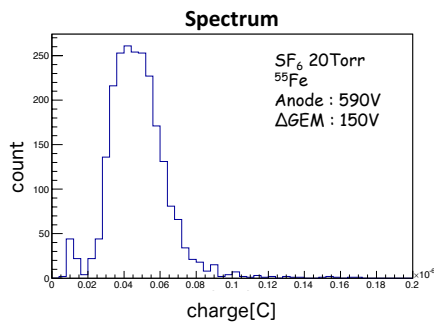
Drift Group Study

N.S. Phan *et al* 2017 JINST 12 P02012

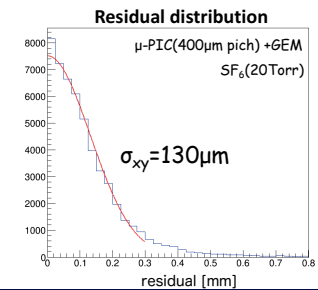
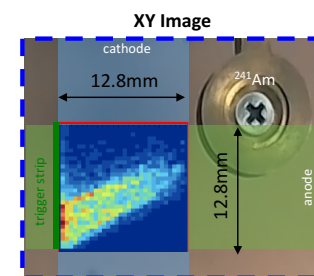
□ R&Ds (Negative-Ion TPC)

● NEWAGE Group Study

- Gas gain of μ -PIC + GEM in SF_6
 - Max gas gain is about 2000 @20Torr
 - Energy resolution FWHM70%@5.9keV
 - In more high pressure , less than 1000



- Tracking was succeed
- 2D position resolution : $130\mu m$ (RMS)



Studied by Tomonori Ikeda

□ Summary

- NEWAGE is a direction-sensitive direct dark matter search experiment with μ -TPC.
- I present the latest our result of dark matter search for RUN14-17.
- We improve TOT-sum cut to reduce gamma background decrease to 1/3@50keV.
- I add head-tail sense methode to analysis : $|\cos \theta| \rightarrow \cos \theta$ and directional limit is in progress
- Low-alpha μ -PIC, Negative-Ion TPC R&Ds are on going . . .

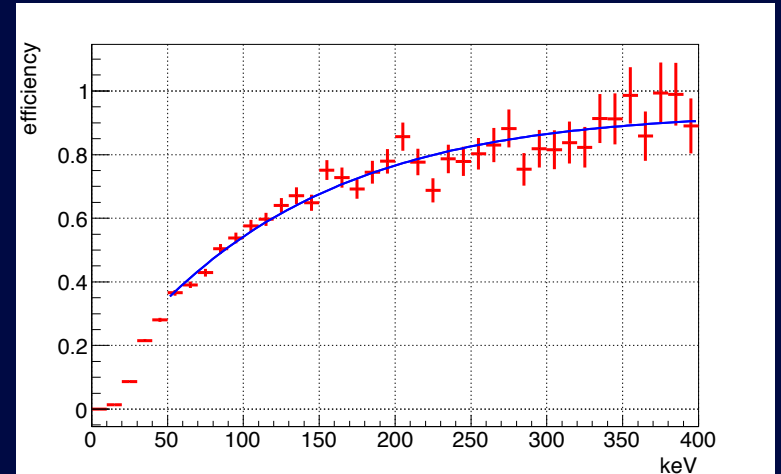
**Thank you
for your attention**

Backup

□ Detector Response

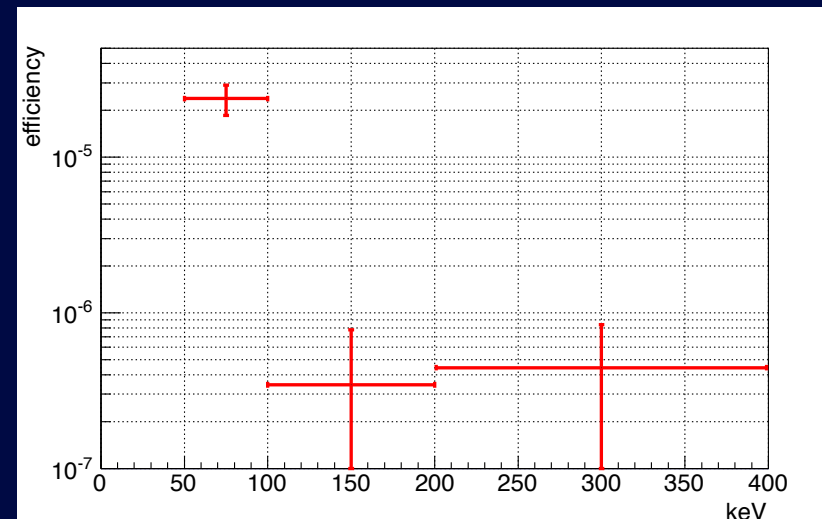
◆ Nuclear detection efficiency

- 40% @ 50keV
- 80% @ 200keV

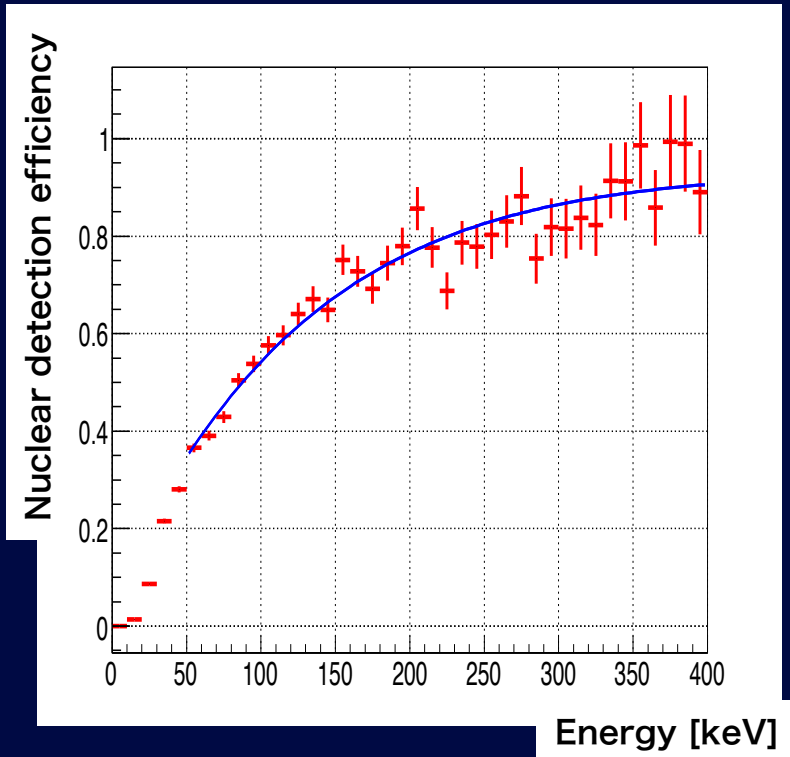


◆ Gamma rejection power

- $\sim 2 \times 10^{-5}$ @ 50-100keV
- $\sim 10^{-7}$ @ 100-400keV

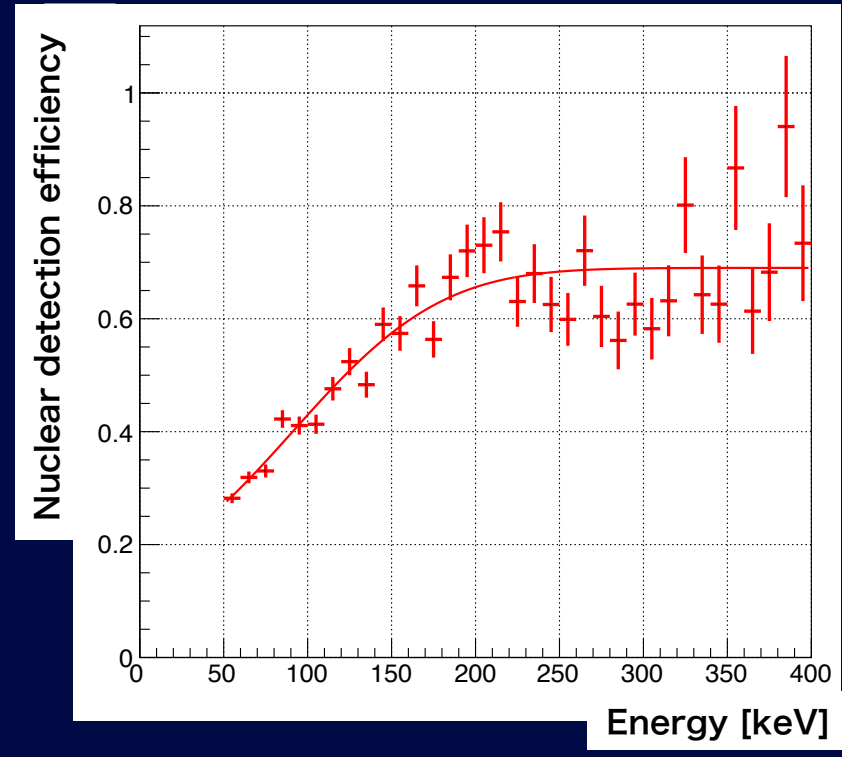


Old TOT-sum cut applied



improved TOT-sum cut applied

● Run14-1



● About 5~10 % decrease

Event selection

^{252}Cf run

- roundness cut

Prog. Theor. Exp. Phys. 2015, 043F01
K. Nakamura

$$\text{roundness}_x = \frac{\sum_{N_x} (z_{\text{rise}x} - a_x x - b_x)^2}{N_x}, \quad \text{roundness}_y = \frac{\sum_{N_y} (z_{\text{rise}y} - a_y y - b_y)^2}{N_y},$$

$$\text{roundness} = \min(\text{roundness}_x, \text{roundness}_y),$$

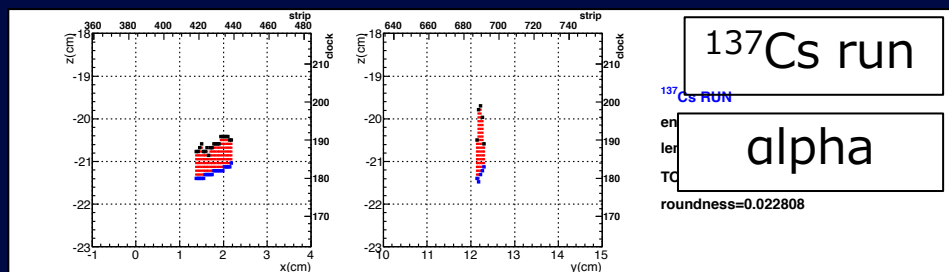
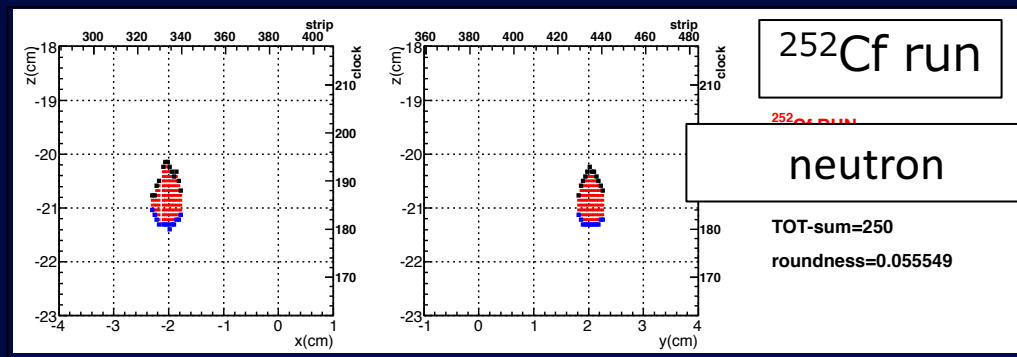
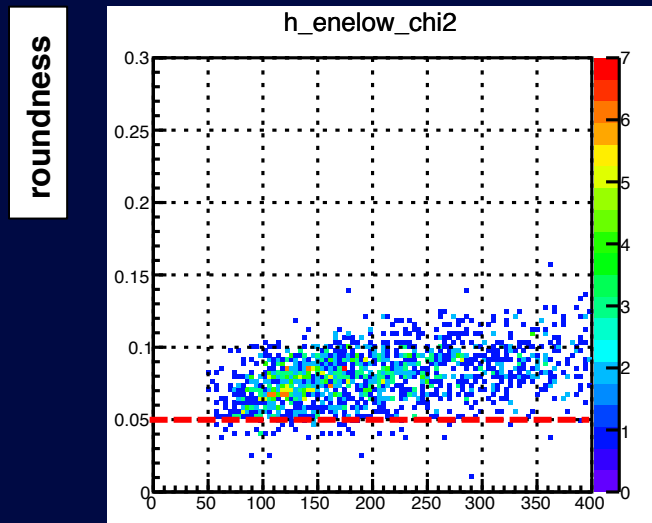


Fig. 6 Track sample of α particle background from μ -PIC, contaminating in ^{137}Cs run. This type of events are cut by the roundness-cut.

- linear fit of rise point for strips
- alpha event -> linear.
- neutron event -> round

□ Head-Tail Analysis

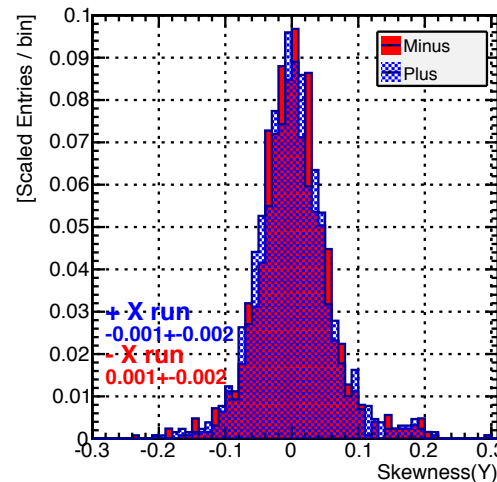
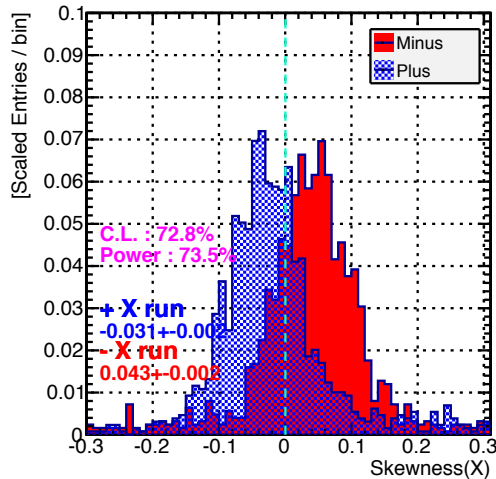
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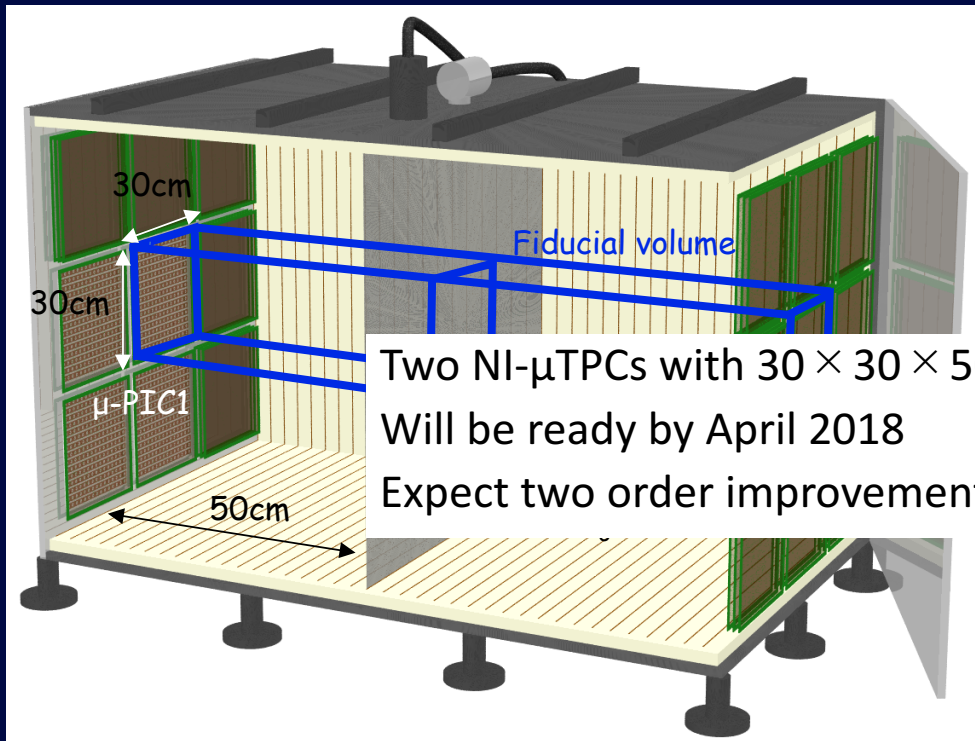
X : strip position
So as Y
Z : TOT(x) → FADC(t)



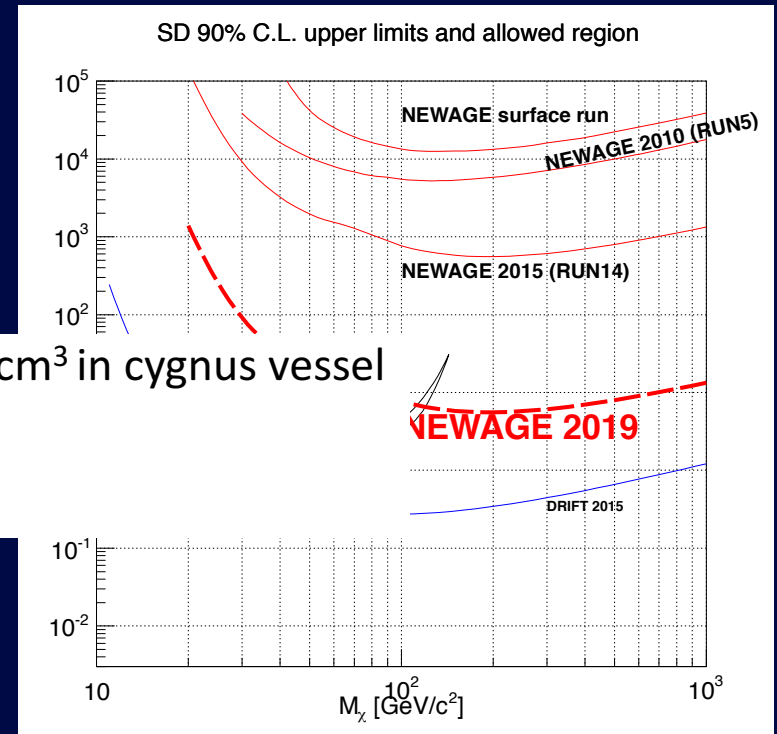
CF4 0.1 atm
252Cf run
200-400keV

length_y/length_X < 0.87
Skewness X
Power ~ 70 %

□ R&Ds (Upsizing)



Two NI- μ TPCs with $30 \times 30 \times 50 \text{ cm}^3$ in cygnus vessel
Will be ready by April 2018
Expect two order improvement



- Two NI- μ TPC with $30 \times 30 \times 50 \text{ cm}^3$ in cygnus vessel
- Two order improvement for directional limit
- Will be ready by April 2018