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

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

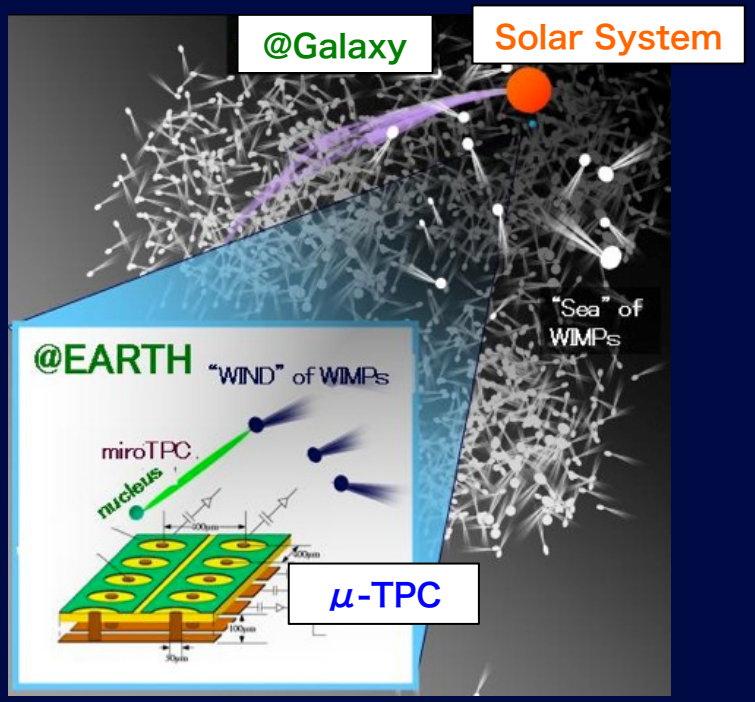
Outline

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

Kobe University
Ryota Yakabe

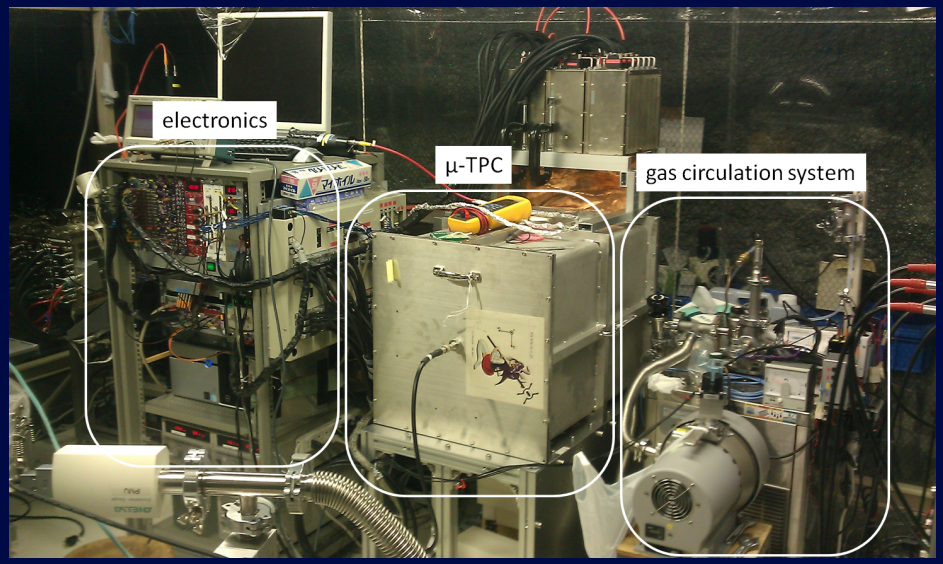
□ NEWAGE

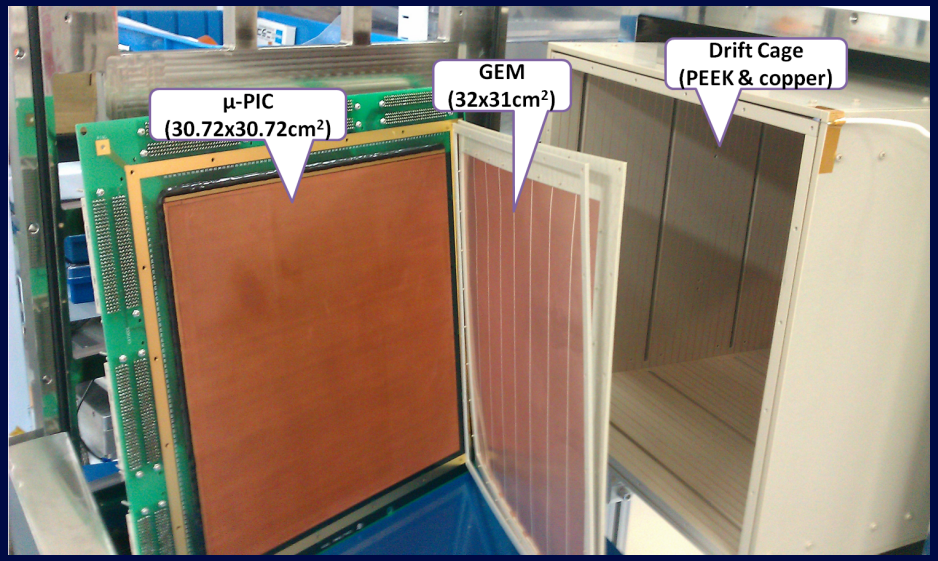
- Direction-Sensitive
  Dark Matter Search Experiment
- Detect DM "WIND" using
  3-D Gaseous Tracking Detector
- Study of kinematics
  DM Particles in the Galaxy
- Detector for DM Search
  NEWAGE-0.3b'@underground Kamioka Lab.
  2700m water equivalent



□ Detector NEWAGE-0.3b'

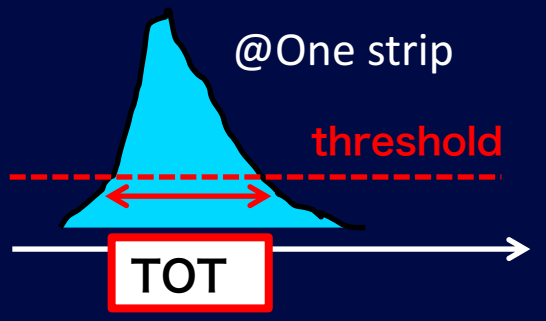
- CF_4 0.1 atm
- Detector Volume : 30 × 30 × 41 cm^3 ~ 0.037m^3
- GEM : LCP100μm, ϕ70μm, 140μm pitch
- μ-PIC : 30.72 × 30.72 cm^2 、400 μm pitch
- Gas Gain (μ-PIC + GEM) : 2500

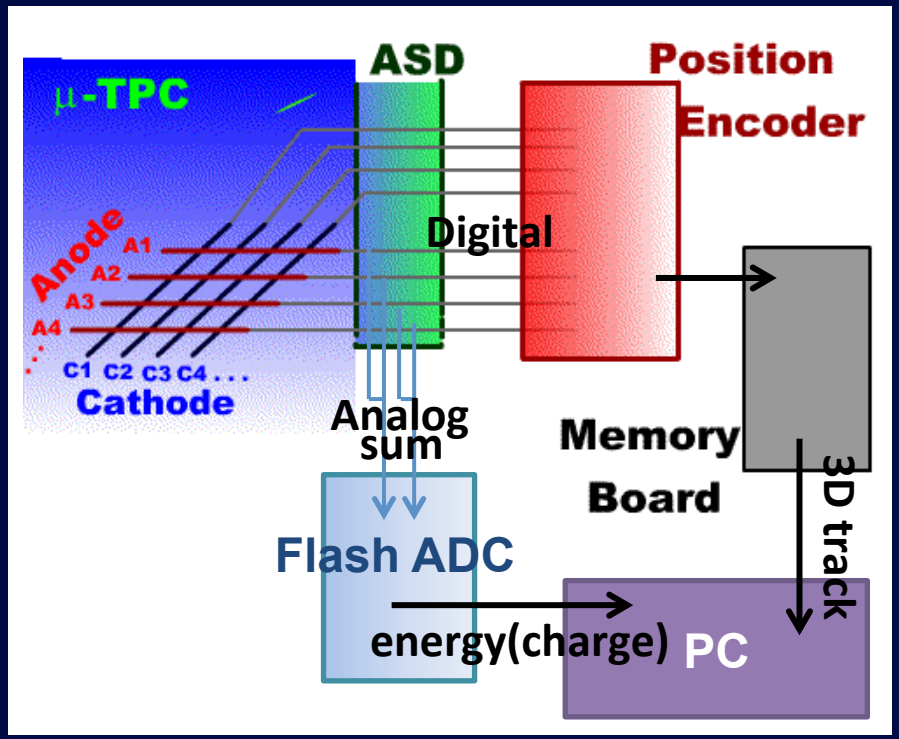


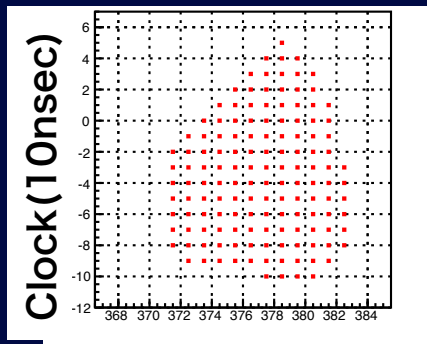


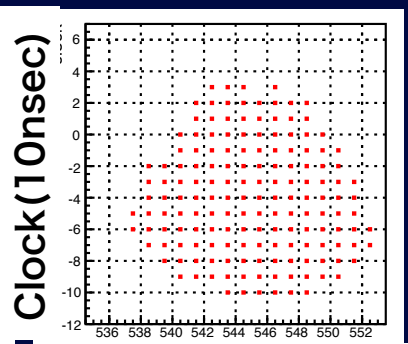
DAQ

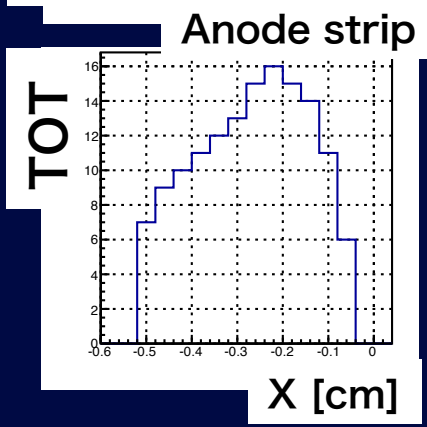
- record charge and track
- charge : Summed waveform 100MHz FADC
- track : μ-PIC strip address and time-over-threshold(TOT) by 100MHz clock

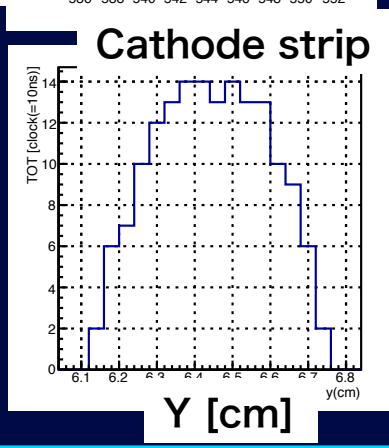






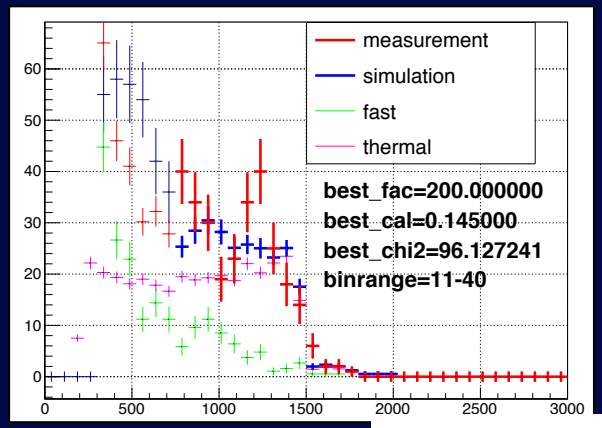


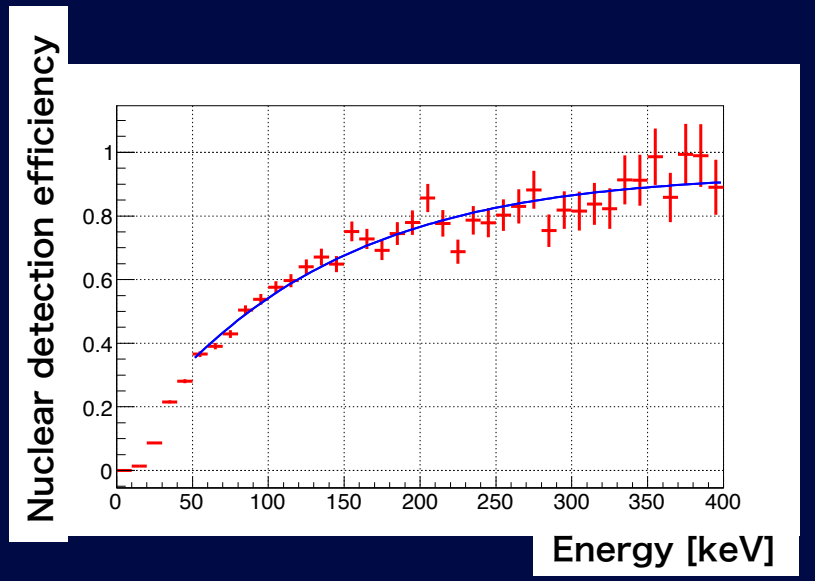




Detector Response

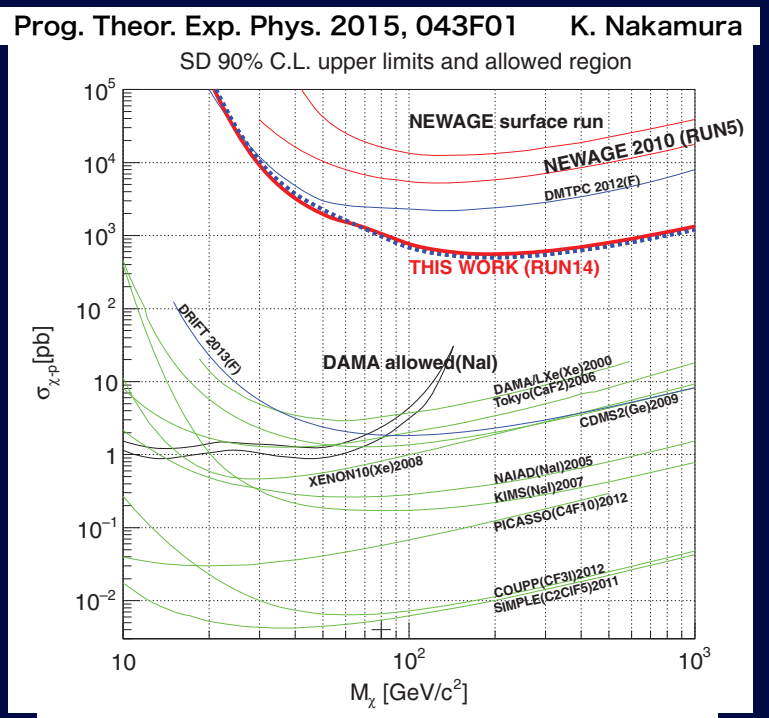
- Energy Calibration
  - 10B(n,α)7Li : 1.5MeV
- Energy resolution
  - 220Rn and 222Rn α : 10%@6MeV
  - ^{55}Fe 40%FWHM@5.9keV
- Drift Velocity
  - ~ 9.3 cm/μs
- Nuclear detection efficiency
  - 40%@50keV
  - 80%@200keV
- Gamma rejection power
  - ~ 2 × 10^{-5} @ 50-100keV
  - ~ 10^{-7} @ 100–400keV

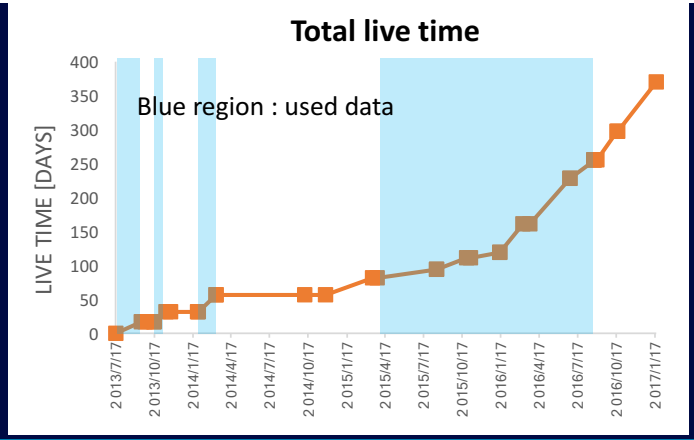




□ Underground measurement

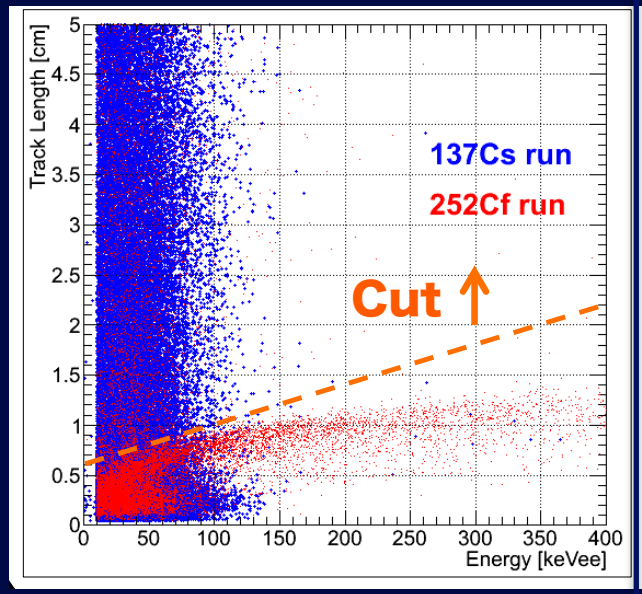
- First underground measurement
  - RUN14-1,2(NEWAGE2015)
  - Run14-1 : 2013/7/17 - 2013/9/16
  - Run14-2 : 2013/10/17 - 2013/11/14
  - live time : 31.6 days
  - Exposure : 0.327kg・days
- Directional-sensitive SD crosssection upper limit 557pb for 200 GeV/c^2
- Additional new Data
  - Run14-3 : 2014/1/29 - 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

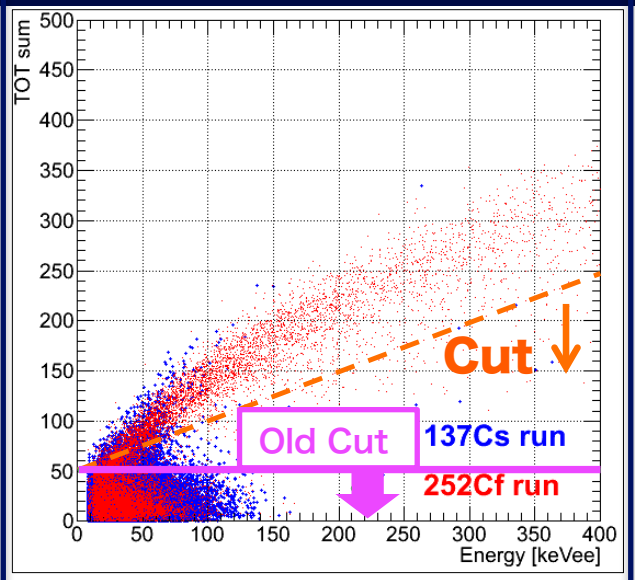


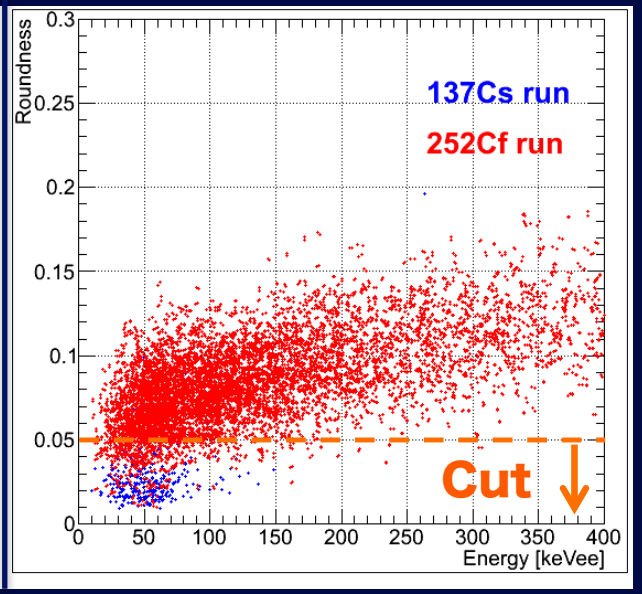


Update.

- Energy threshold : 50keV
- Fiducial Volume : 24 × 28 × 41 cm^3
- Track Length – Energy cut
- TOT sum cut improved
- Roundness cut

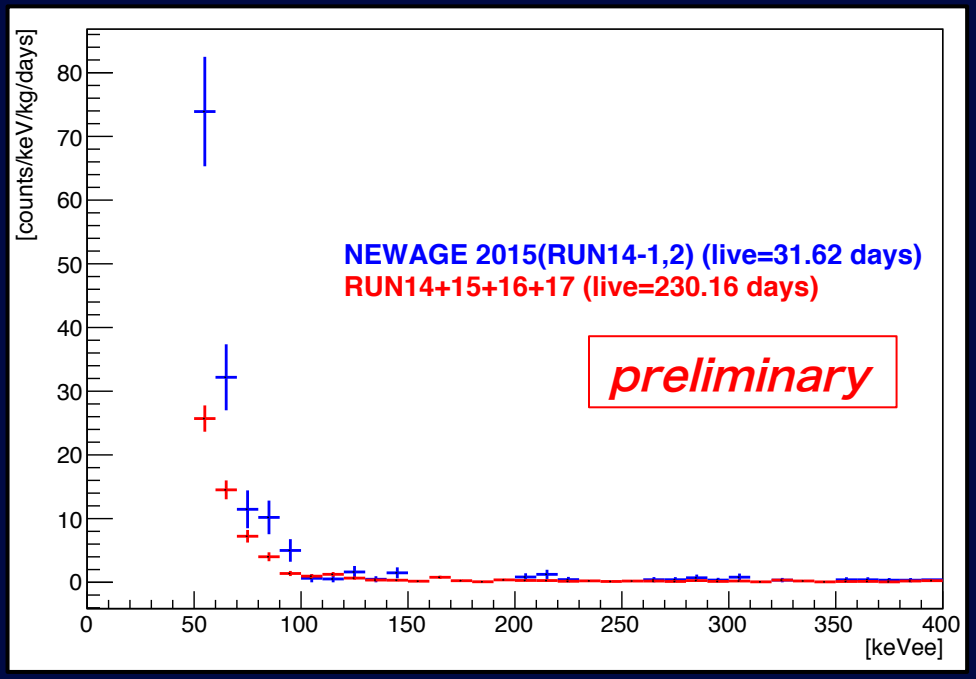




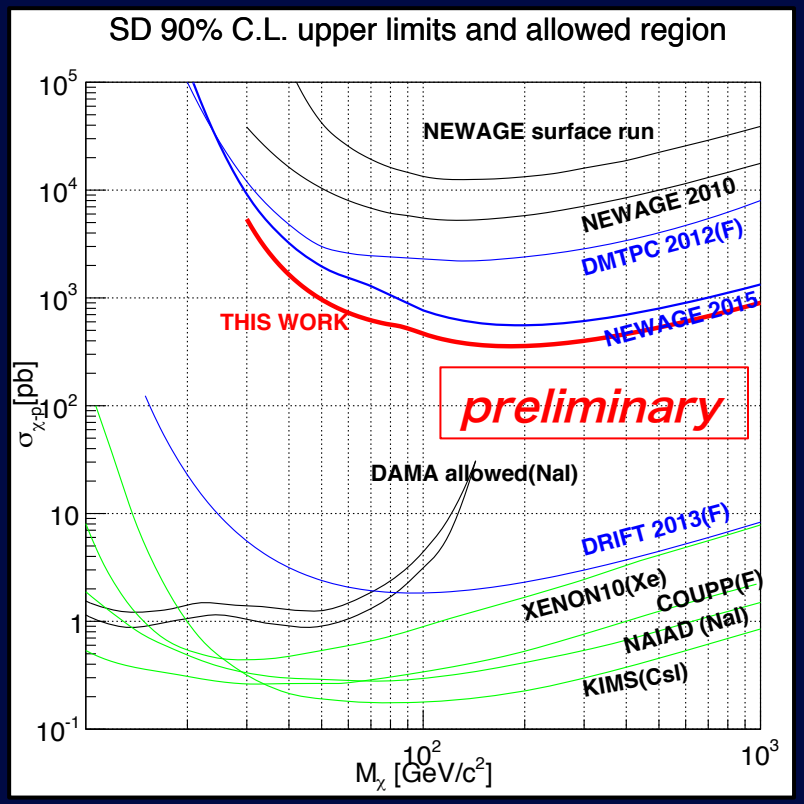


Result

- Energy spectrum



- limit

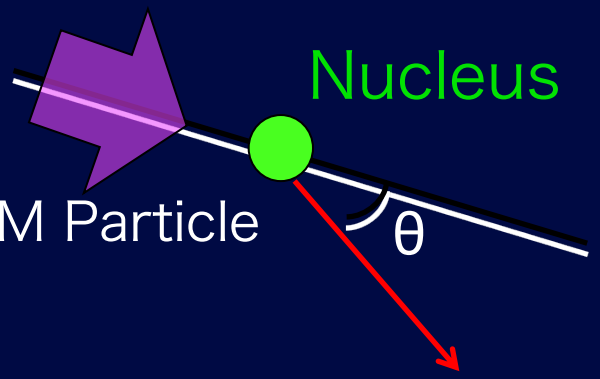


- BG : 1/3@50keV
- exposure : 2.38 kg・days

  ~ 7 times more than NEWAGE2015
- Directional-sensitive SD crosssection upper limit 356 pb@180GeV

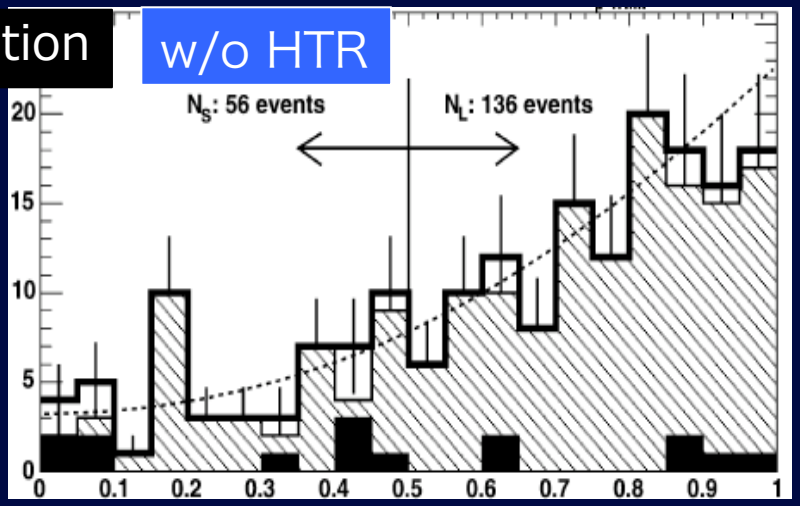
□ R&Ds (Head-Tail Analysis)

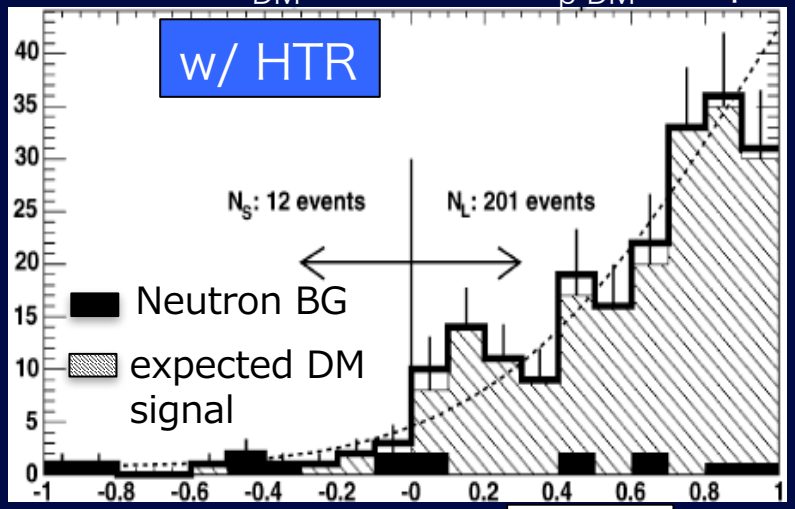
- **Current : w/o Head-Tail Sense**
  get $|\cos\theta|$ information
- **This work : w/ Head-Tail Sense**
  get $\cos\theta$ information
  ~ 3 times good sensitivity



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

Simulation





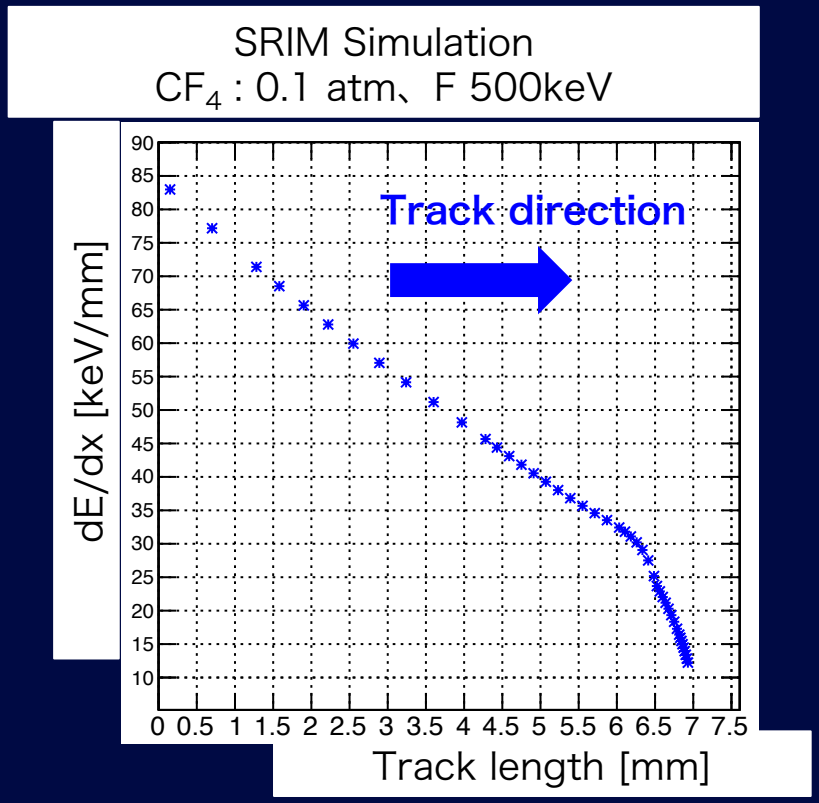
Physics Letters B 578 (2004) 241–246

□ 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

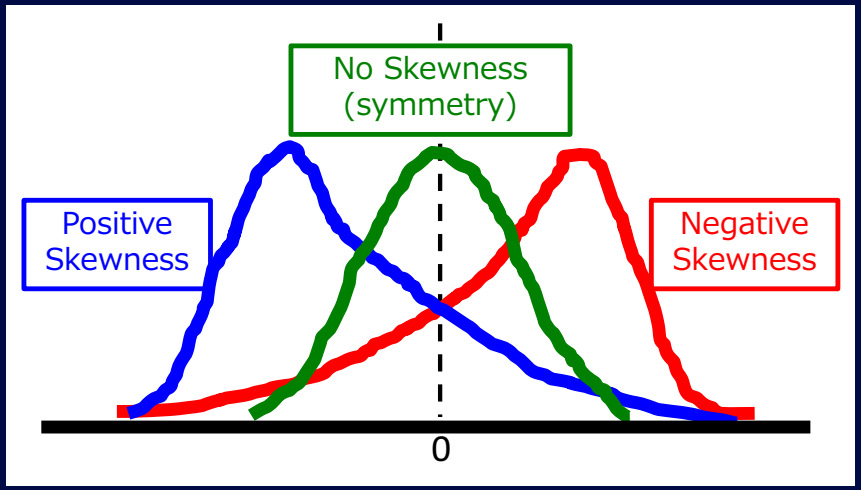
- Head-tail parameter

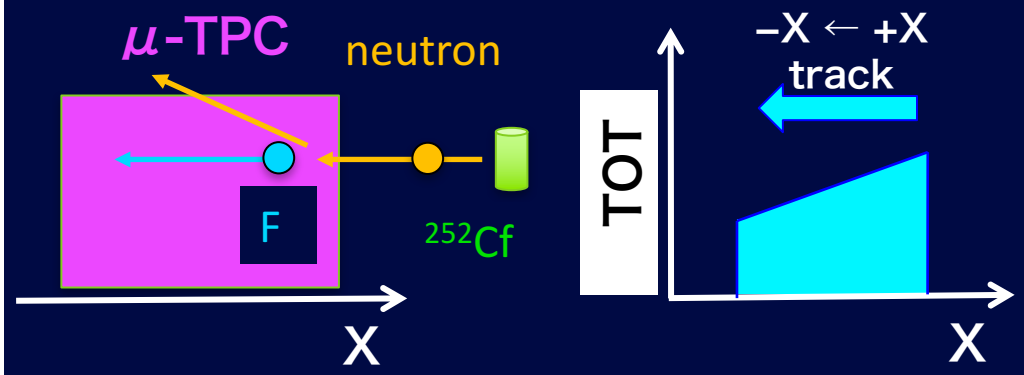
$$skewness = \frac{m_3}{m_2^{3/2}}$$

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

$$< x >= \int_{min}^{max} dx\,\frac{x \cdot TOT(x)}{\int TOT(x)dx}$$

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



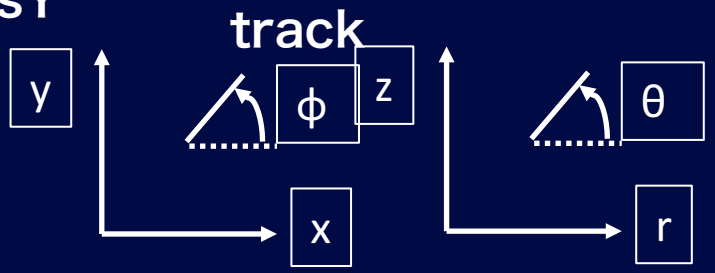


skewness < 0

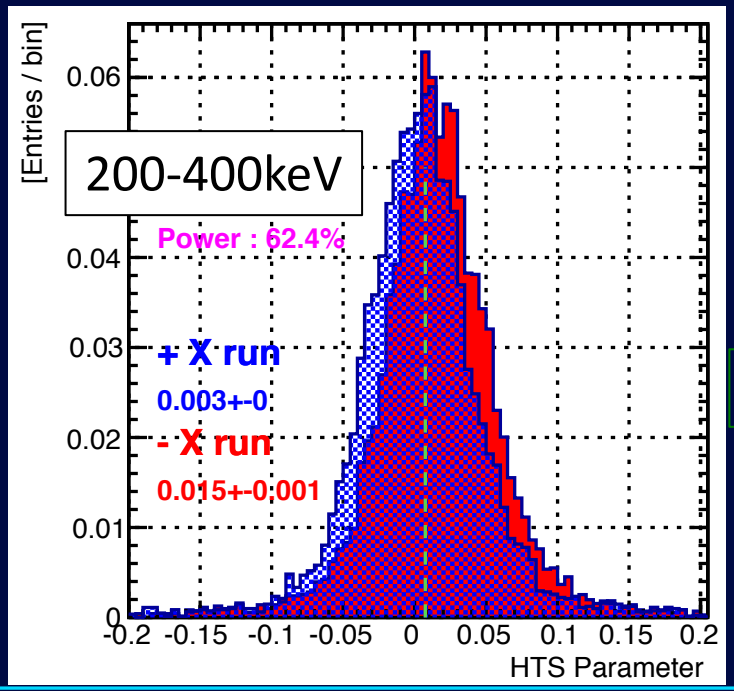
Head-Tail Analysis

- 3-dimensional Head-Tail parameter

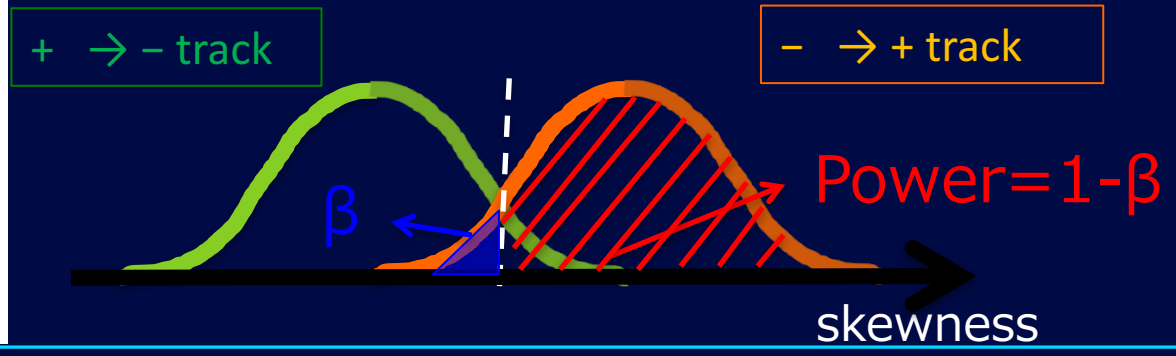
HTS_xyz = (1- 2/π*θ)*(1- 2/π*ϕ)*skewnessX
+ (1- 2/π*θ)(2/π*ϕ)*skewnessY
+(2/π*θ)*skewnessZ



CF4 0.1atm ^{252}Cf run

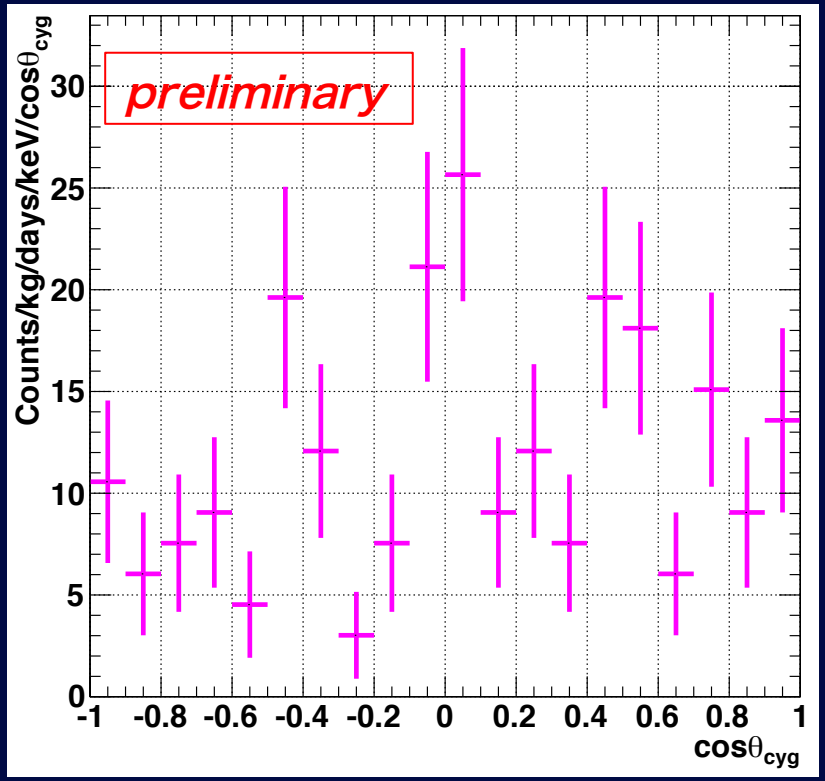


- We analysis
  Head-tail sense power
  ~ 50% @50-200keV
  ~ 60% @200-400keV



□ R&Ds (Head-Tail Analysis)

- Cosθ spectrum

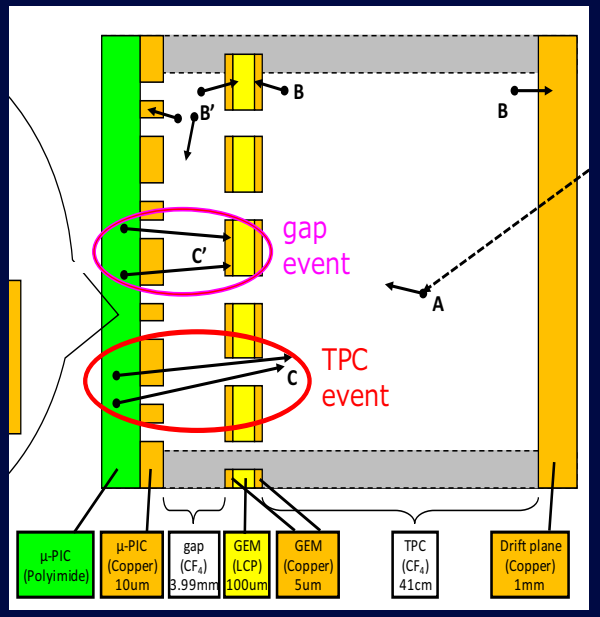


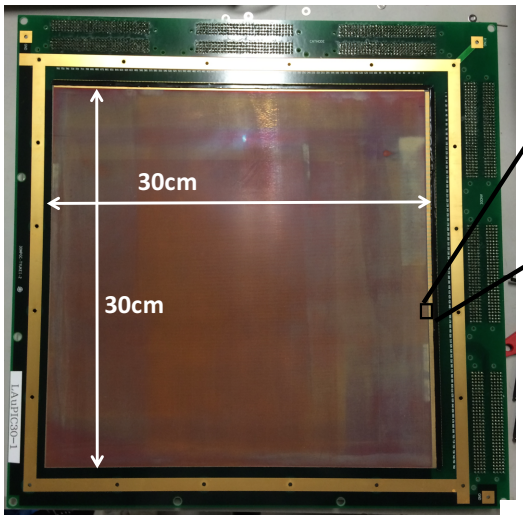
@50-60keV

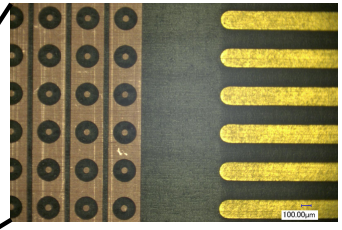
- Directional limit
  using cosθ distribution is in progress

□ R&Ds (Low-alpha μ-PIC)

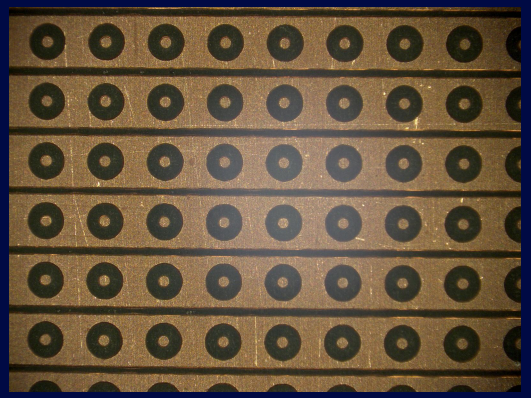
- Low-BG μ-PIC
  - α from μ-PIC is Large BG.
  - radio-pure(1/100) 30×30cm^2 μ-PIC is made and tested
  - 2017 ~ underground run







- **We confirmed gas amplification**
- We will check the performance of a 30 × 30cm^2 LA μ-PIC
- This will be installed DM searching detector in 2017 summer



studied by Takashi hashimoto

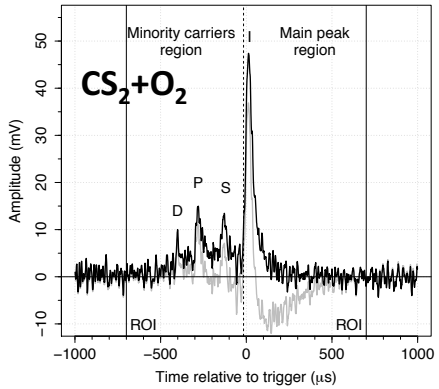
R&Ds (Negative-Ion TPC)

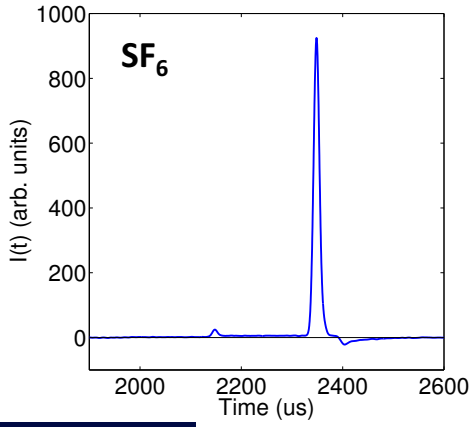
Development of NI-μTPC

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

- Minority peaks "discovery" by DRIFT group
  - Used negative ion gas : CS_2+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 μTPC
  - ✓ Gas gain
  - ✓ XY position resolution
  - ✓ Z position resolution





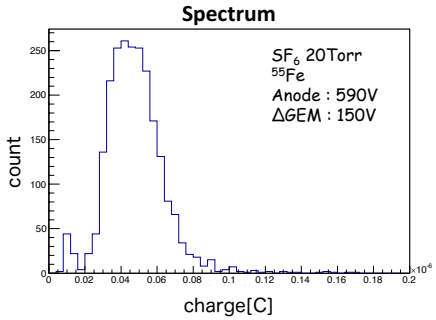
Drift Group Study

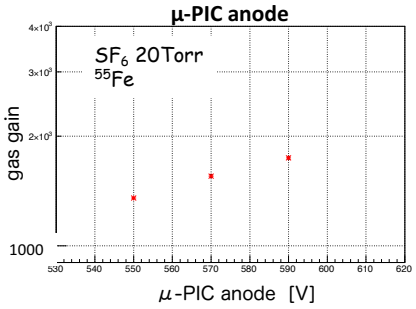
N.S. Phan et al 2017 JINST 12 P02012

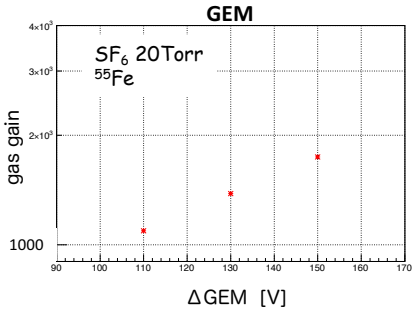
□ R&Ds (Negative-Ion TPC)

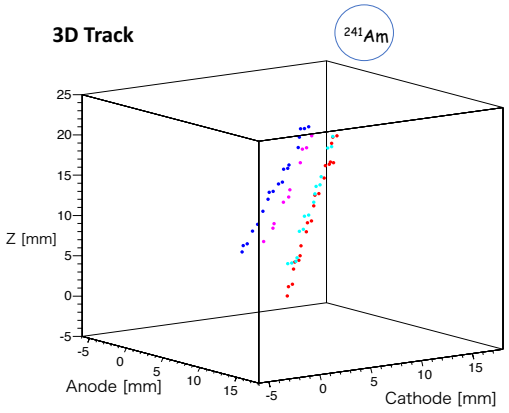
- NEWAGE Group Study

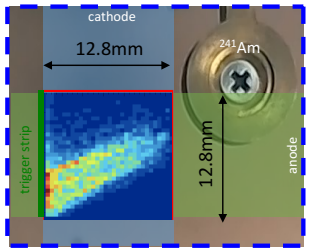
- Gas gain of μ-PIC + GEM in SF_6
  - Max gas gain is about 2000 @20Torr
  - Energy resolution FWHM70%@5.9keV
  - In more high pressure , less than 1000

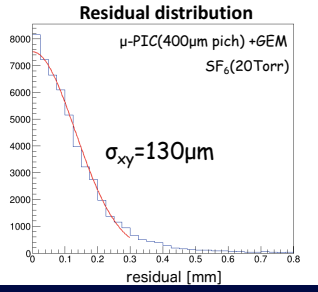












- Tracking was succeed
- 2D position resolution : 130μm(RMS)

Studied by Tomonori Ikeda

□ Summary

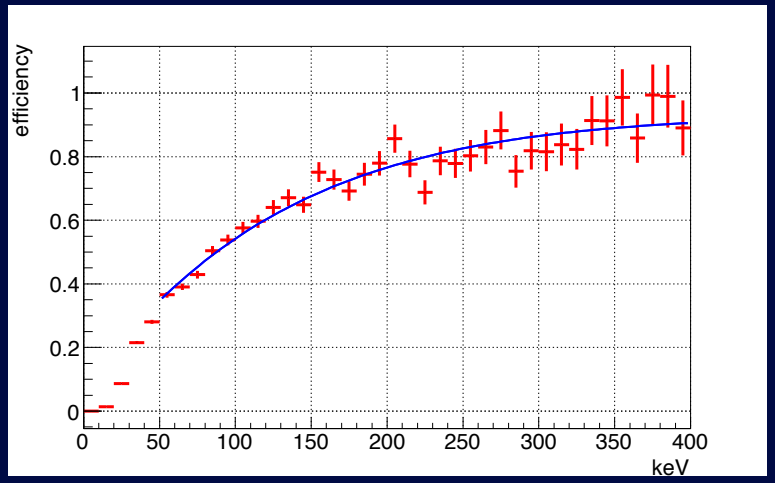
- NEWAGE is a direction-sensitive direct dark matter search experiment with μ-TPC.
- I present the latest our result of dark matter search for RUN14-17.
- We improve TOT-sum cut to reduce gamma background decrease to 1/3@50keV.
- I add headt-tail sense methode to analysis : $|\cos\theta| \rightarrow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

Thank you
for your attention

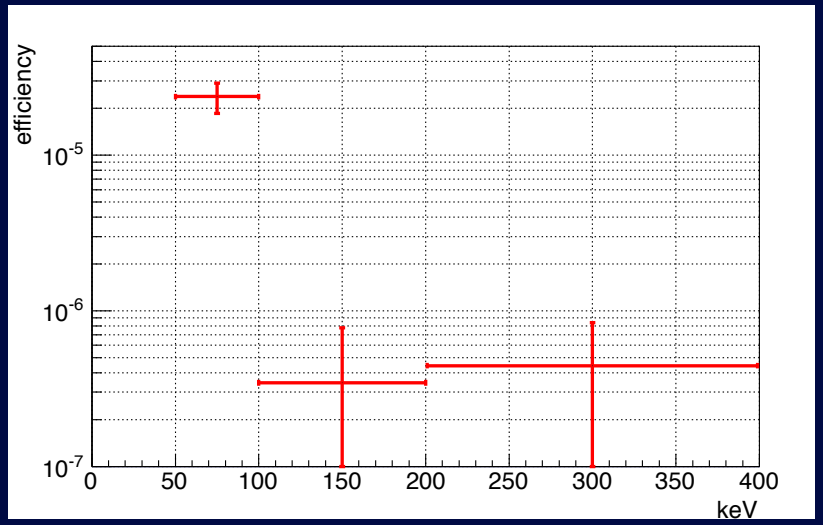
Backup

Detector Response

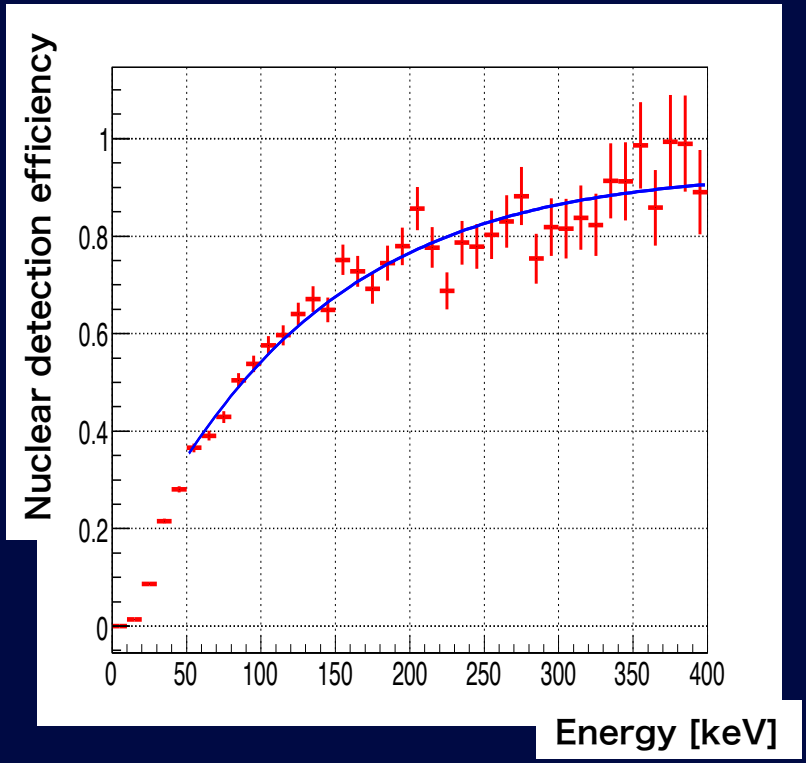
- Nuclear detection efficiency
  - 40%@50keV
  - 80%@200keV



- Gamma rejection power
  - ~ 2 × 10^{-5} @ 50-100keV
  - ~ 10^{-7} @ 100–400keV

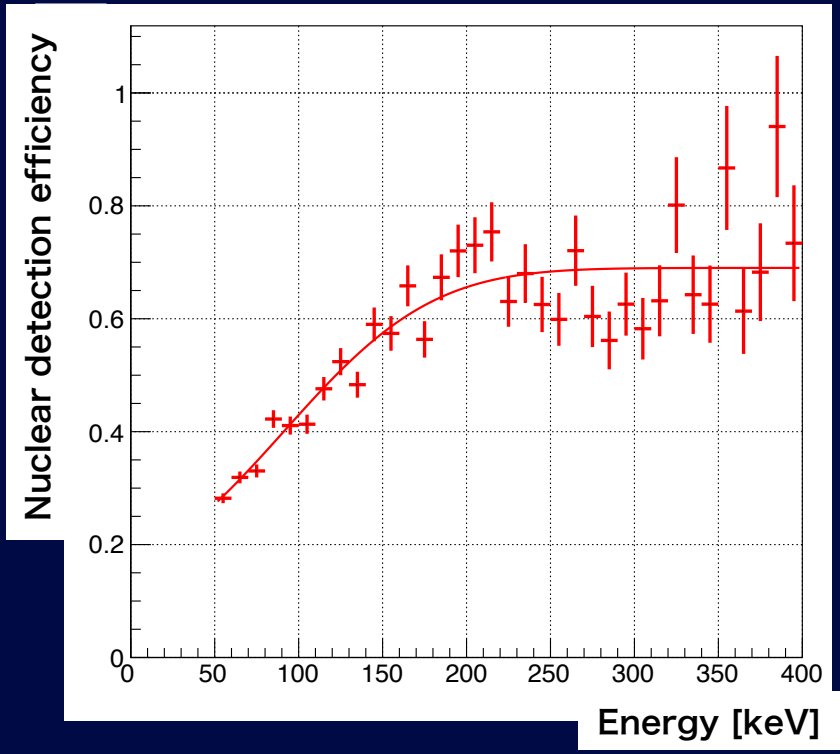


Old TOT-sum cut applied



improved TOT-sum cut applied

- Run14-1



- About 5~10 % decrease

Event selection

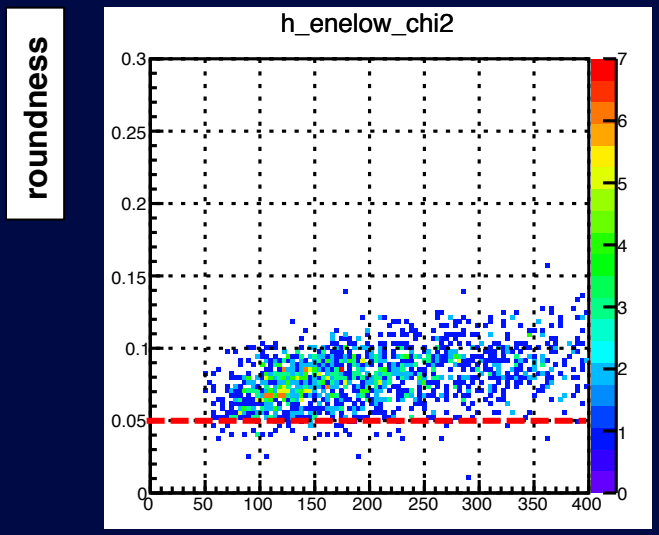
^{252}Cf run

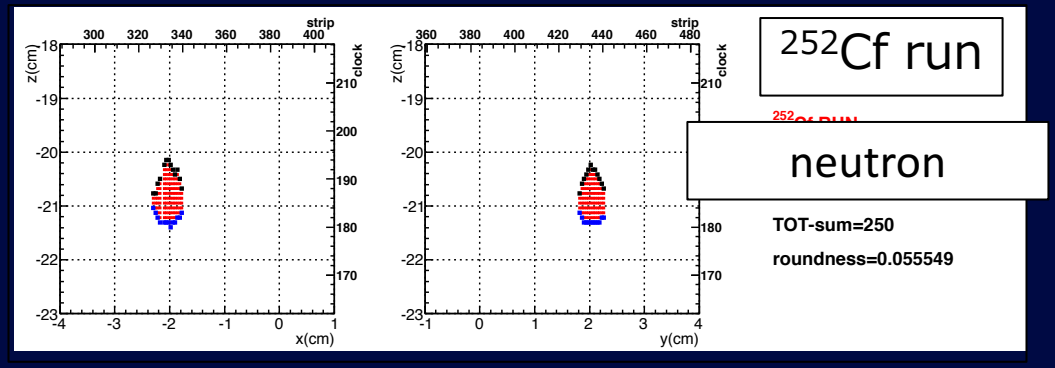
- roundness cut

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

$$\mathrm{roundness_x} = \frac{\sum^{N_x}(z_{\mathrm{risex}} - a_x x - b_x)^2}{N_x}, \qquad \mathrm{roundness_y} = \frac{\sum^{N_y}(z_{\mathrm{risey}} - a_y y - b_y)^2}{N_y},$$

$$\mathrm{roundness} = min(\mathrm{roundness_x}, \mathrm{roundness_y}),$$





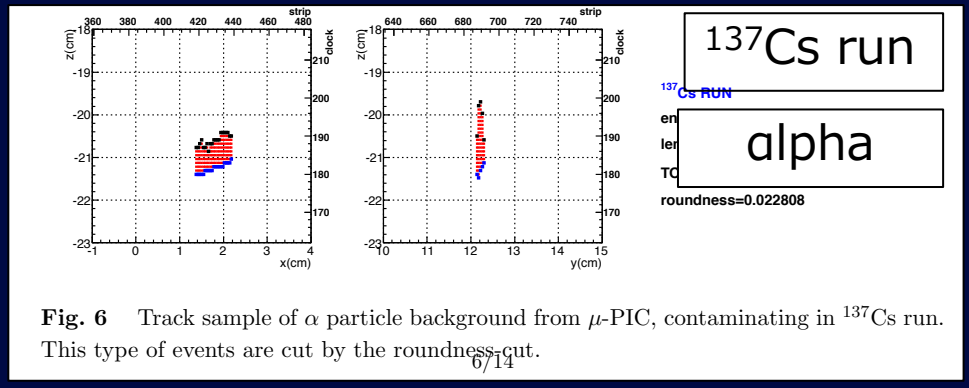


Fig. 6 Track sample of α particle background from μ-PIC, contaminating in ^{137}Cs run. This type of events are cut by the roundness-cut.

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

Head-Tail Analysis

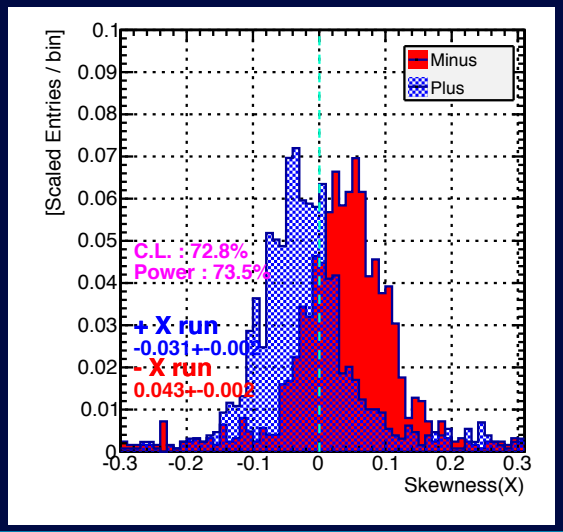
- Head-tail parameter

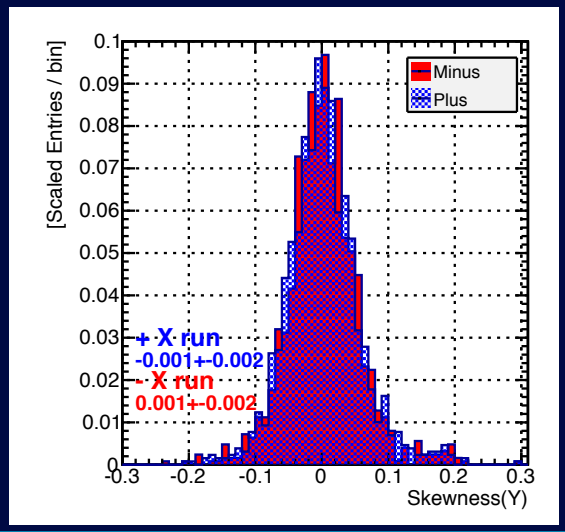
$$skewness = \frac{m_3}{m_2^{3/2}}$$

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

$$< x >= \int_{min}^{max} dx\,\frac{x \cdot TOT(x)}{\int TOT(x)dx}$$

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

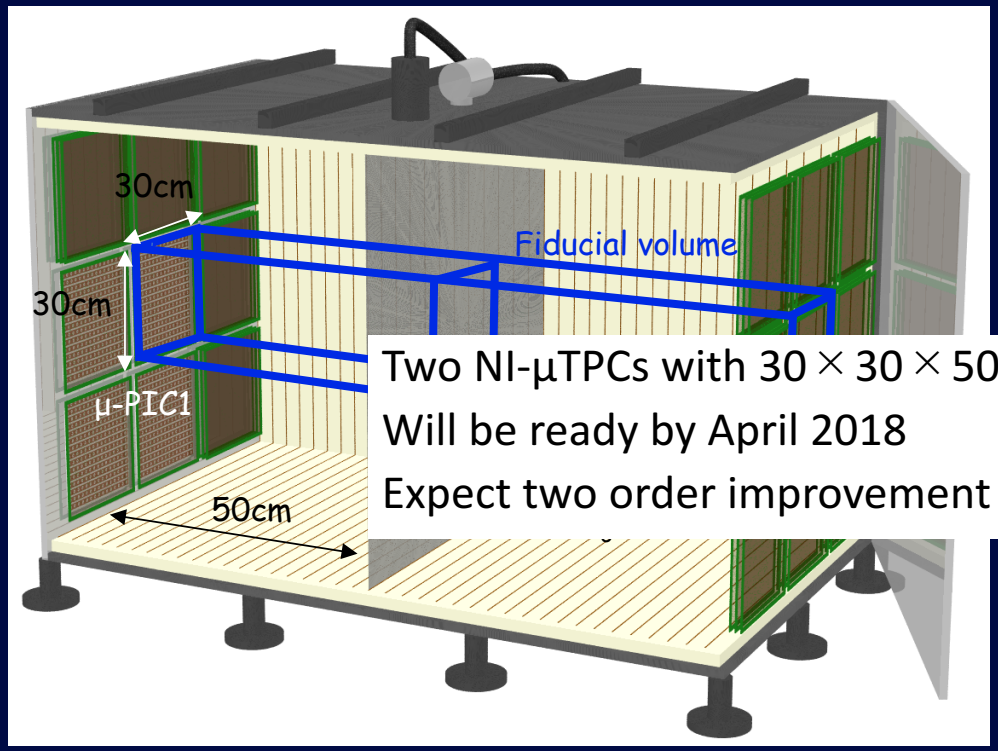




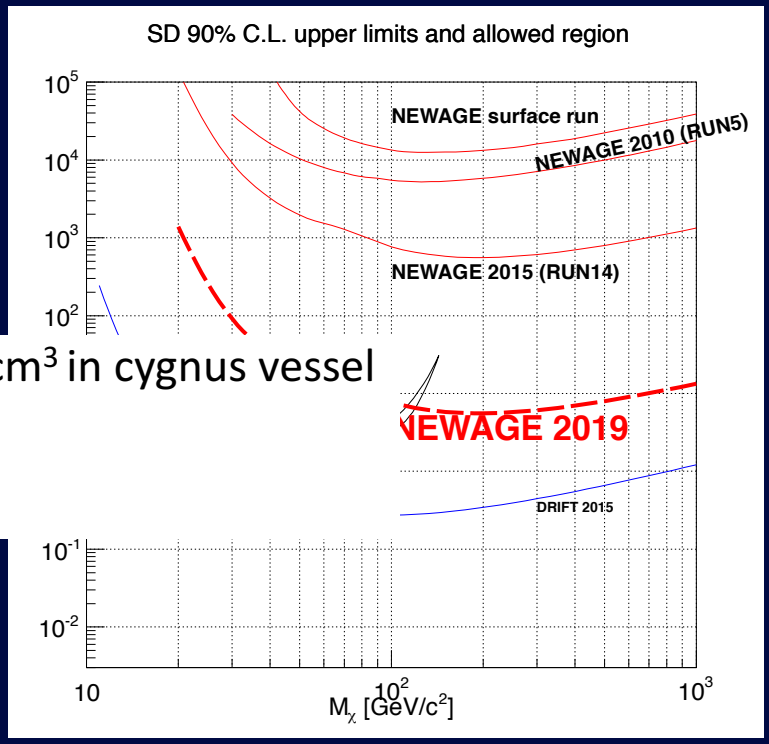
CF4 0.1atm
^{252}Cf run
200-400keV

length_y/length_X < 0.87
Skewness X
Power ~ 70 %

R&Ds (Upsizing)



Two NI-μTPCs with 30 × 30 × 50cm^3 in cygnus vessel
Will be ready by April 2018
Expect two order improvement



- Two NI-μTPC with 30 × 30 × 50 cm^3 in cygnus vessel
- Two order improvement for directioanl limit
- Will be ready by April 2018