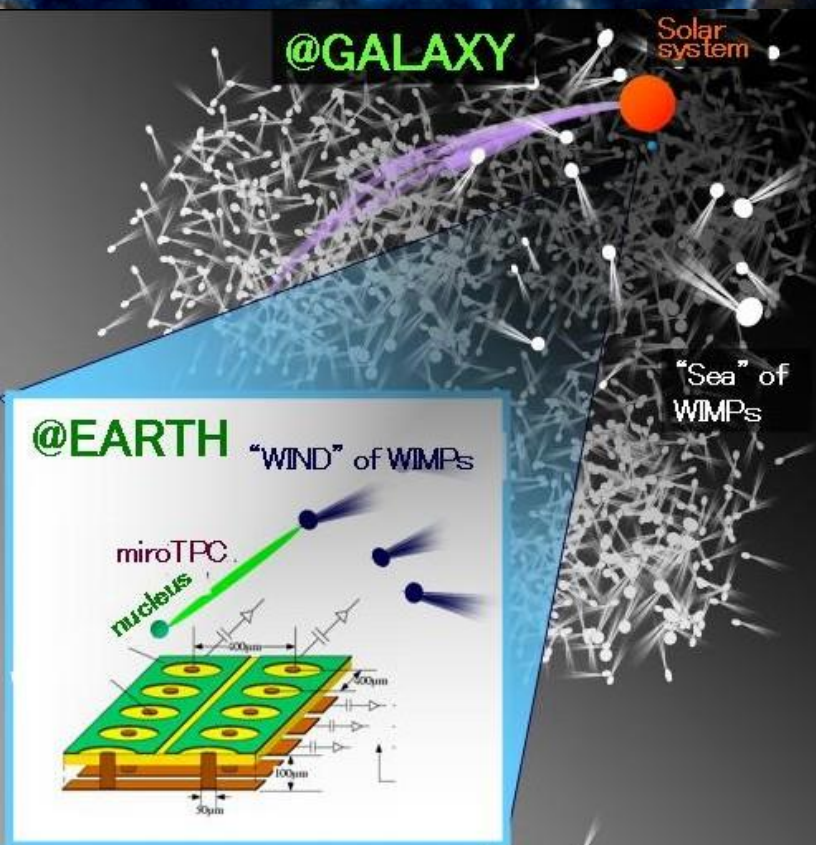


NEWAGE

Kiseki Nakamura (Kyoto university)

T.Tanimori⁽¹⁾, K.Miuchi⁽²⁾, K.Kubo⁽¹⁾,
 T.Mizumoto⁽¹⁾, J.Parker⁽¹⁾, A.Takada⁽³⁾,
 H.Nishimura⁽¹⁾, T.Sawano⁽¹⁾, Y.Matsuoka⁽¹⁾,
 S.Komura⁽¹⁾, Y.Yamaguchi⁽²⁾, S.Nakaura⁽²⁾

(1) Kyoto university department of physics
 (2) Kobe university department of physics
 (3) Kyoto university RISH



- What's NEWAGE ?
- New result by NEWAGE-0.3a'
- Commissioning of NEWAGE-0.3b'
- Head-tail R&D with NEWAGE-0.1a
- Summary

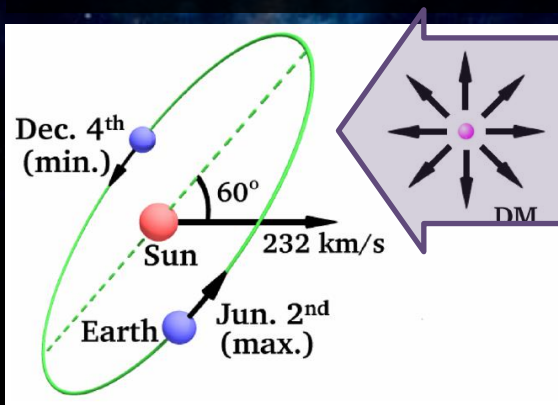
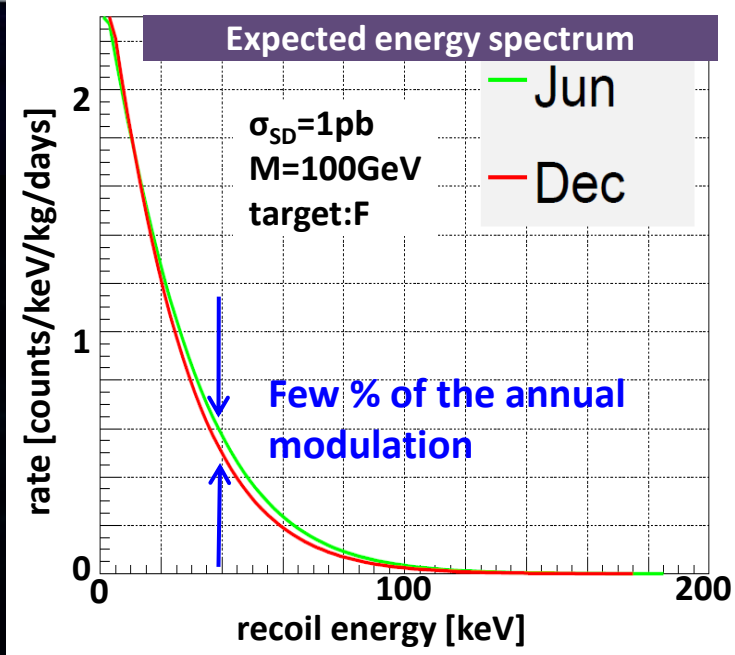
Direction Sensitivity

1. Annual modulation (conventional)

Large mass \rightarrow Solid or liquid detector
 Require for 3σ : ~ 10000 events

2. Direction sensitivity (new)

Nuclear track \rightarrow Gas detector (or emulsion)
 Require for 3σ : ~ 20 events



CYGNUS 2013
 4th International Workshop on Directional Dark Matter Detection

10 - 12 June 2013,
 Oarks Canal Park Hotel,
 Toyama, Japan

Scientific Program

Technical program on direction sensitive detectors
 Data analysis (2D/3D track reconstruction, background rejection, ...)
 Sense recognition : analysis strategies & measurements
 Experimental results from directional prototype
 Theoretical studies
 Dark matter halo dynamics
 Related activities

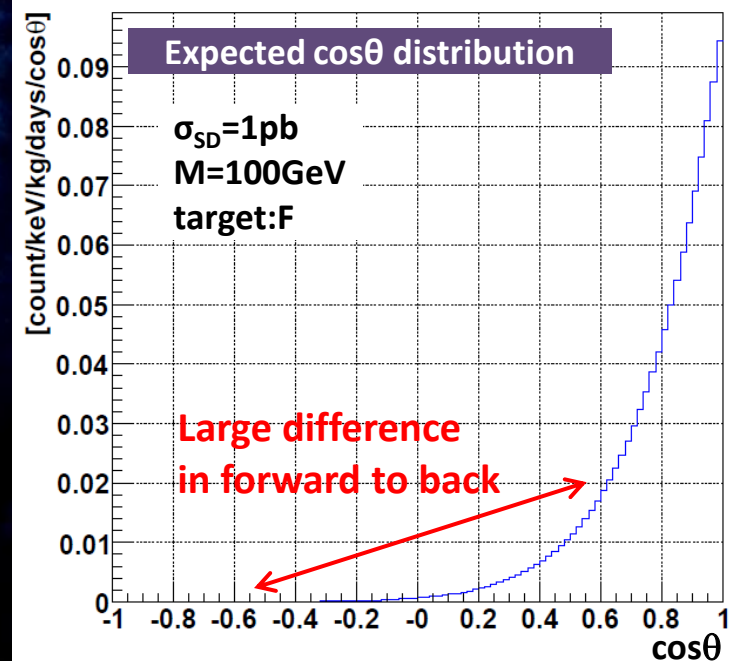
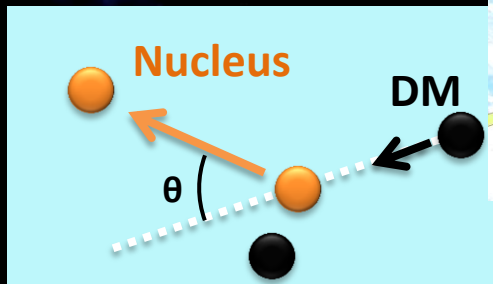
International Organizing committee

James Beacom (Brandeis College, USA)
 Ismael Comas-Forgas (CEA Saclay, France)
 Anne Green (U. of Nottingham, UK)
 Agnieszka H. & Zanglauer, Spain
 Daniel Lindsley (University of New Mexico, USA)
 Patrick Moore (IPSC Grenoble, France)
 Kazuo Maeda (Kobe University, Japan)
 Jordan Madsen (Hull University, UK)
 Ludovic Niles (Nagoya University, Japan)
 Daniel Sauer (IPSC Grenoble, France)
 Daniel Steigman (Brown University, USA)
 Neil Spooner (U. of Sheffield, UK)
 Tom Ralston (University of Warwick, UK)

Local Organizing committee

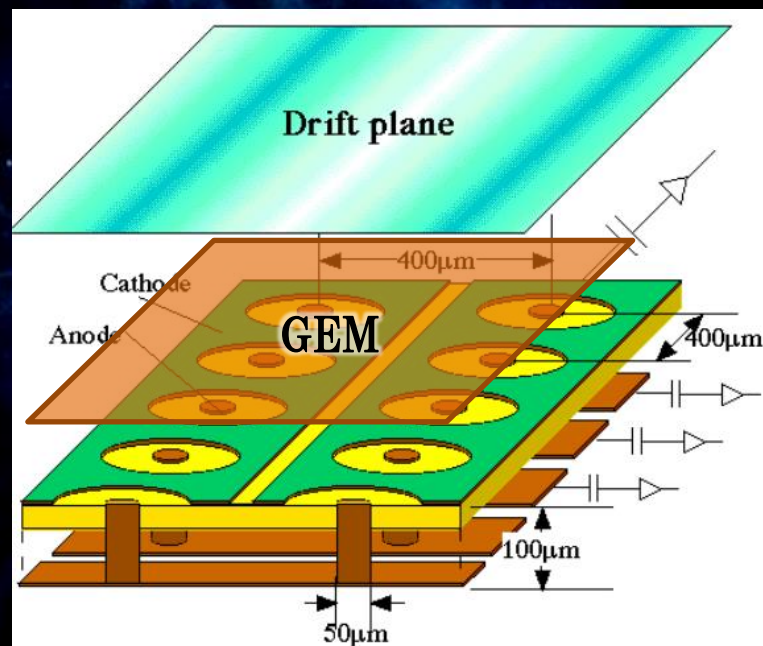
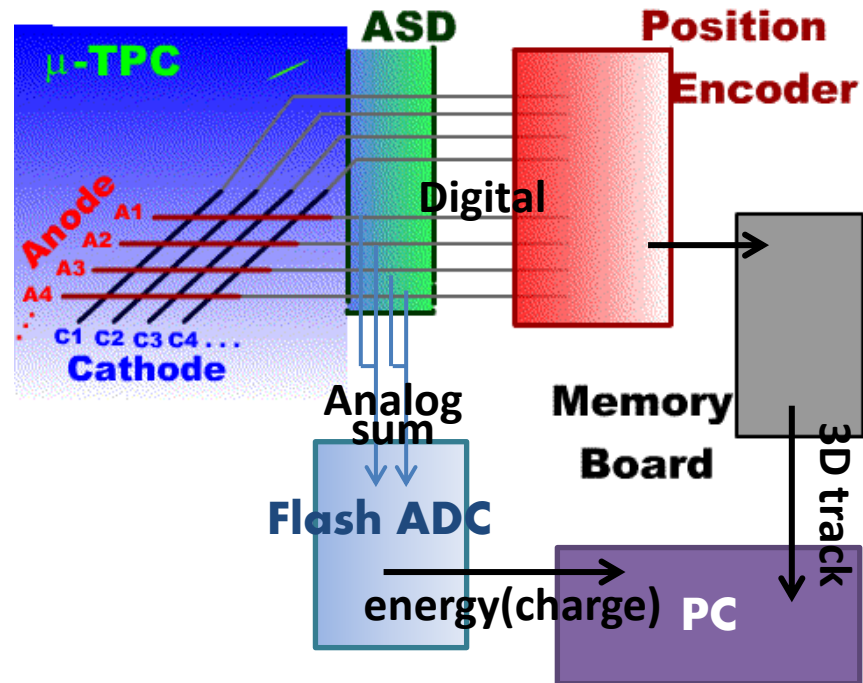
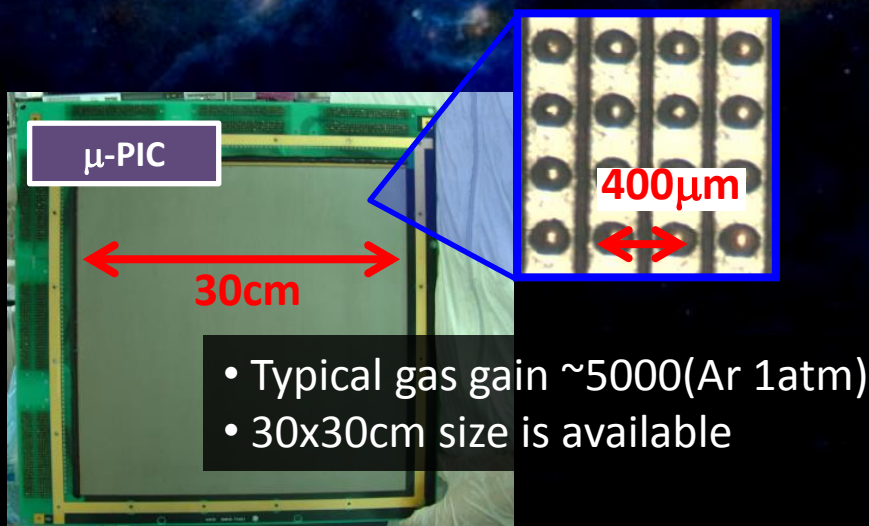
K. Maeda (Kobe Univ.)
 T. Naka (Nagoya Univ.)
 A. Takahashi (Kobe Univ.)
 H. Sekiya (JCR, Univ. of Tokyo)
 K. Nakamura (Kobe Univ.)
 K. Horiuchi (Kobe Univ.)

<http://ppwww.phys.sci.kobe-u.ac.jp/~newage/cygnus2013/>



NEWAGE

- 3D tracking : μ -TPC
 - 2D : μ -PIC (400 μ m pitch)
 - 1D : Drift timing (100MHz)
- gas: CF₄ 76~152torr



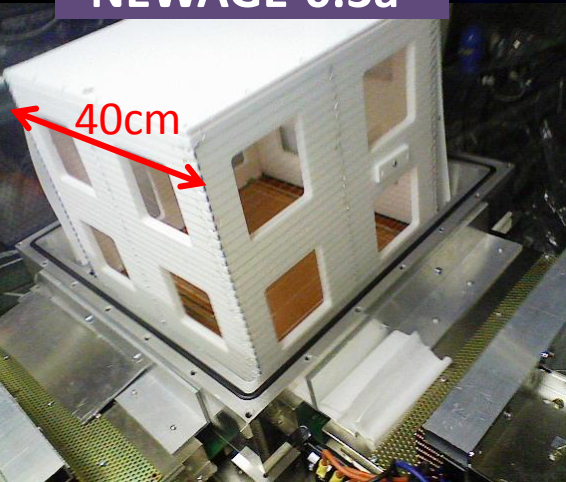
| Detector Name | NEWAGE-0.3a' | NEWAGE-0.3b' | NEWAGE-0.1a |
|------------------|------------------------------|------------------------------|------------------------------|
| Detection volume | 23 x 28 x 31 cm ³ | 30 x 30 x 41 cm ³ | 10 x 10 x 10 cm ³ |
| Gas | CF ₄ 152torr | CF ₄ 76torr | CF ₄ 152torr |
| DAQ-mode | mode3 | mode5 | mode5 |
| Place | Kamioka | Kamioka | Kobe |
| Status | DM search | Commissioning | Head-tail R&D |

1st talk

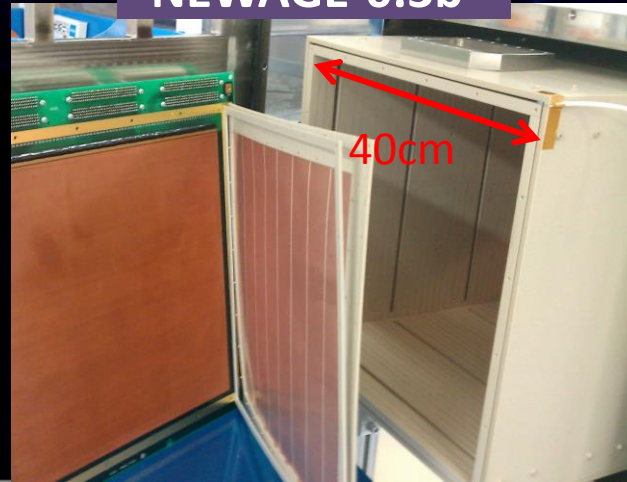
2nd talk

3rd talk

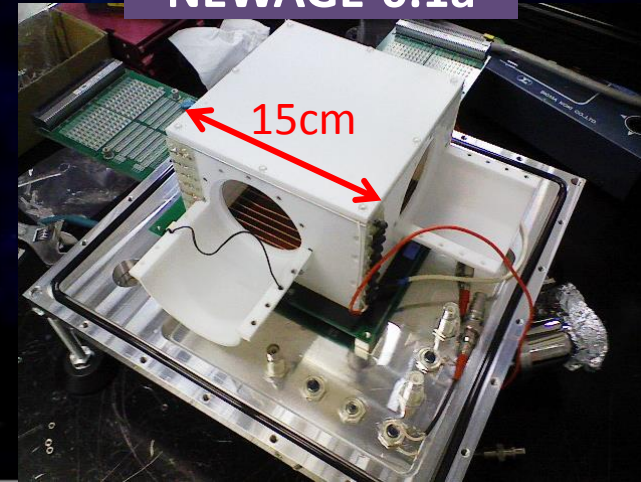
NEWAGE-0.3a'



NEWAGE-0.3b'



NEWAGE-0.1a



| Detector Name | NEWAGE-0.3a' | NEWAGE-0.3b' | NEWAGE-0.1a |
|------------------|------------------------------|------------------------------|------------------------------|
| Detection volume | 23 x 28 x 31 cm ³ | 30 x 30 x 41 cm ³ | 10 x 10 x 10 cm ³ |
| Gas | CF ₄ 152torr | CF ₄ 76torr | CF ₄ 152torr |
| DAQ-mode | mode3 | mode5 | mode5 |
| Place | Kamioka | Kamioka | Kobe |
| Status | DM search | Commissioning | Head-tail R&D |

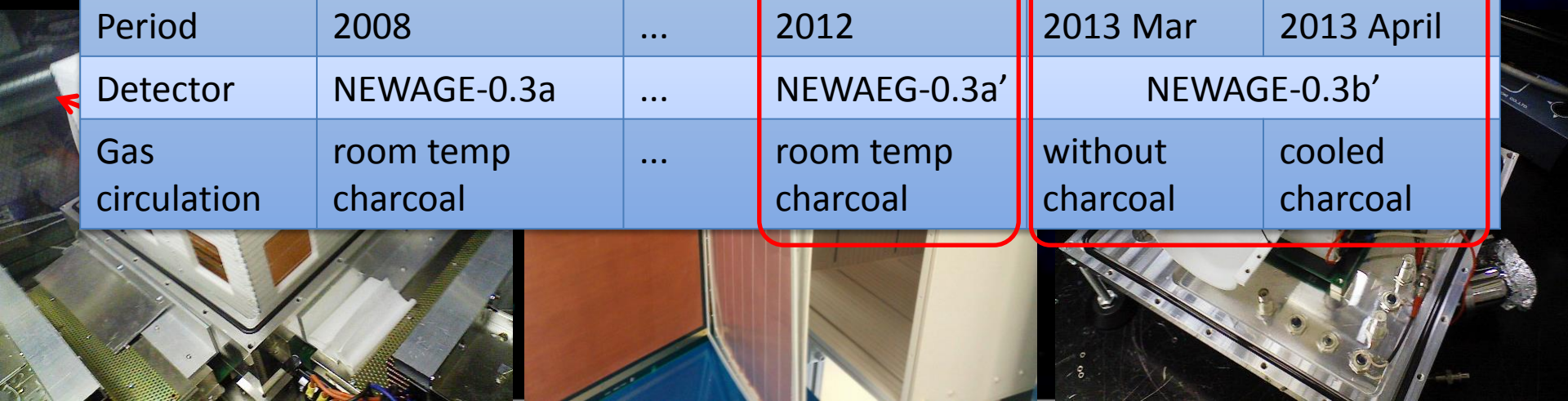
1st talk

2nd talk

3rd talk

Underground runs

| run# | RUN5 (PLB2010) | ... | RUN13 | RUN14 | RUN15 |
|-----------------|--------------------|-----|--------------------|------------------|-----------------|
| Period | 2008 | ... | 2012 | 2013 Mar | 2013 April |
| Detector | NEWAGE-0.3a | ... | NEWAEG-0.3a' | NEWAGE-0.3b' | |
| Gas circulation | room temp charcoal | ... | room temp charcoal | without charcoal | cooled charcoal |

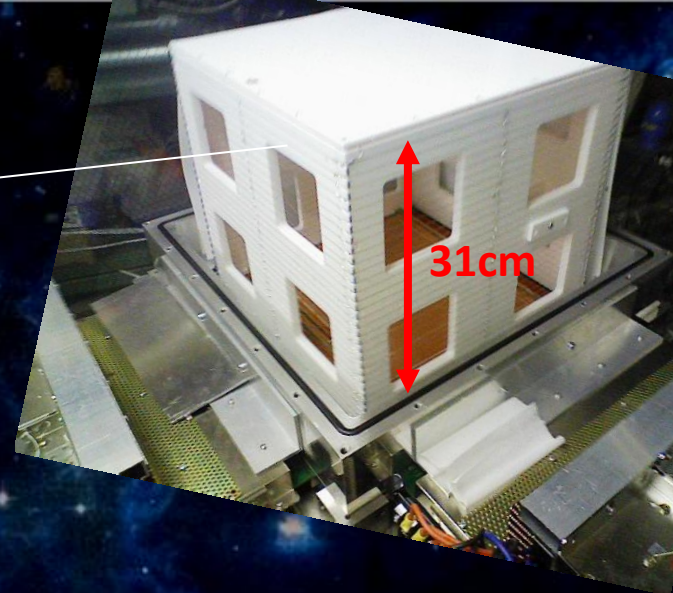
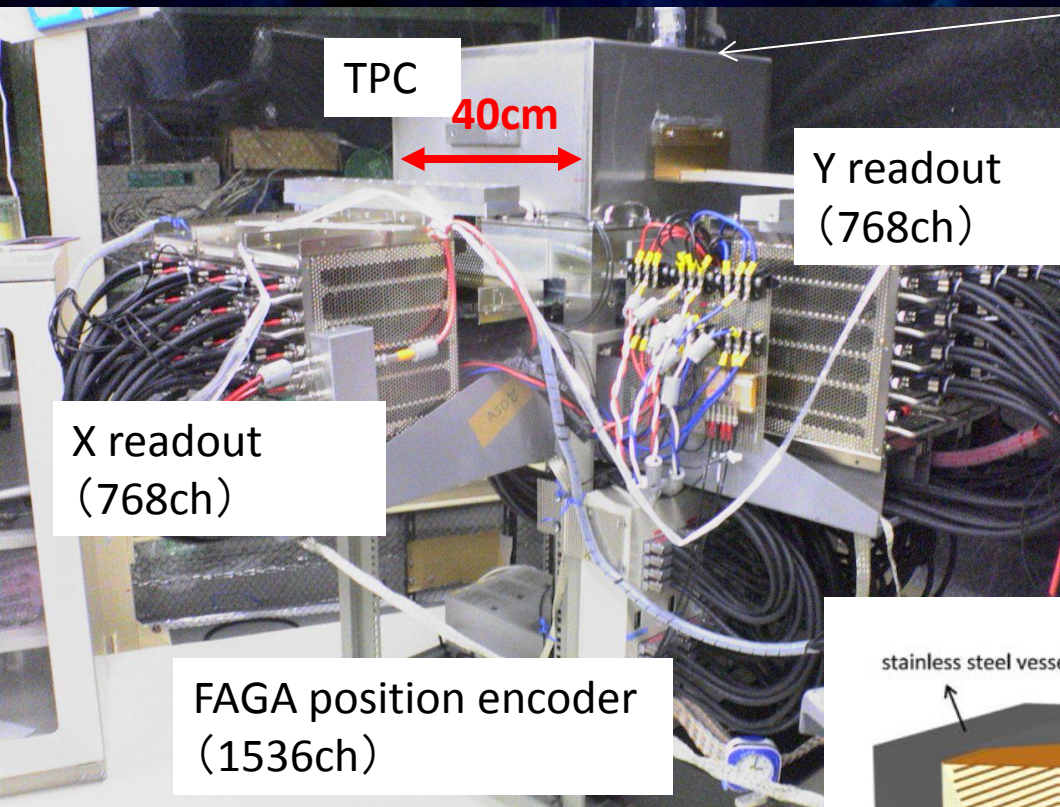


New result

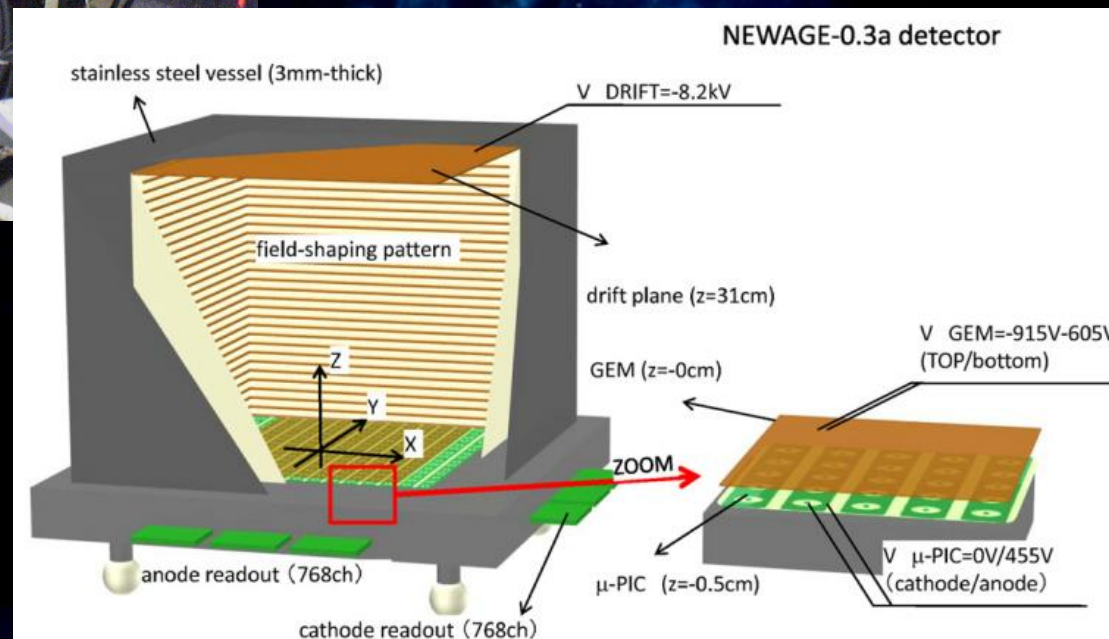
(NEWAGE-0.3a')

| Detector Name | NEWAGE-0.3a' | NEWAGE-0.3b' | NEWAGE-0.1a |
|------------------|------------------------------|------------------------------|------------------------------|
| Detection volume | 23 x 28 x 31 cm ³ | 30 x 30 x 41 cm ³ | 10 x 10 x 10 cm ³ |
| Gas | CF ₄ 152torr | CF ₄ 76torr | CF ₄ 152torr |
| DAQ-mode | mode3 | mode5 | mode5 |
| Place | Kamioka | Kamioka | Kobe |
| Status | DM search | Commissioning | Head-tail R&D |

NEWAGE-0.3a'



- $23 \times 28 \times 31 \text{ cm}^3$
- $152 \text{ torr CF}_4 = 11.48 \text{ g}$



NEWAGE-0.3a' updates

- Sensitivity Improvement

- α particle
 - radon gas
 - gamma rays
 - DAQ upgrade
- > Low BG aiming 1/10
- > Low threshold

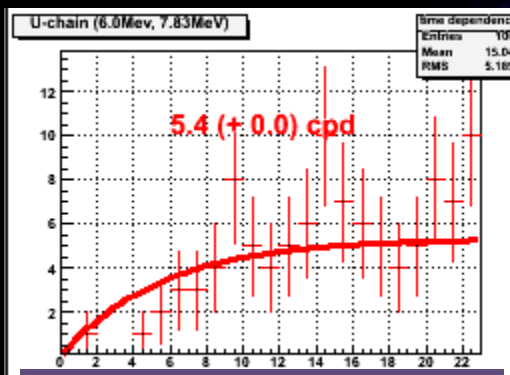
• radon, gamma, alpha: "clean" materials

• to <1/10 radon emanation level

NEWAGE-0.3 α
glass-reinforced
fluoro-plastic



NEWAGE-0.3 α'
PTFE + copper wire



Time dependence of Rn rate measured by Rn detector

Radon: charcoal

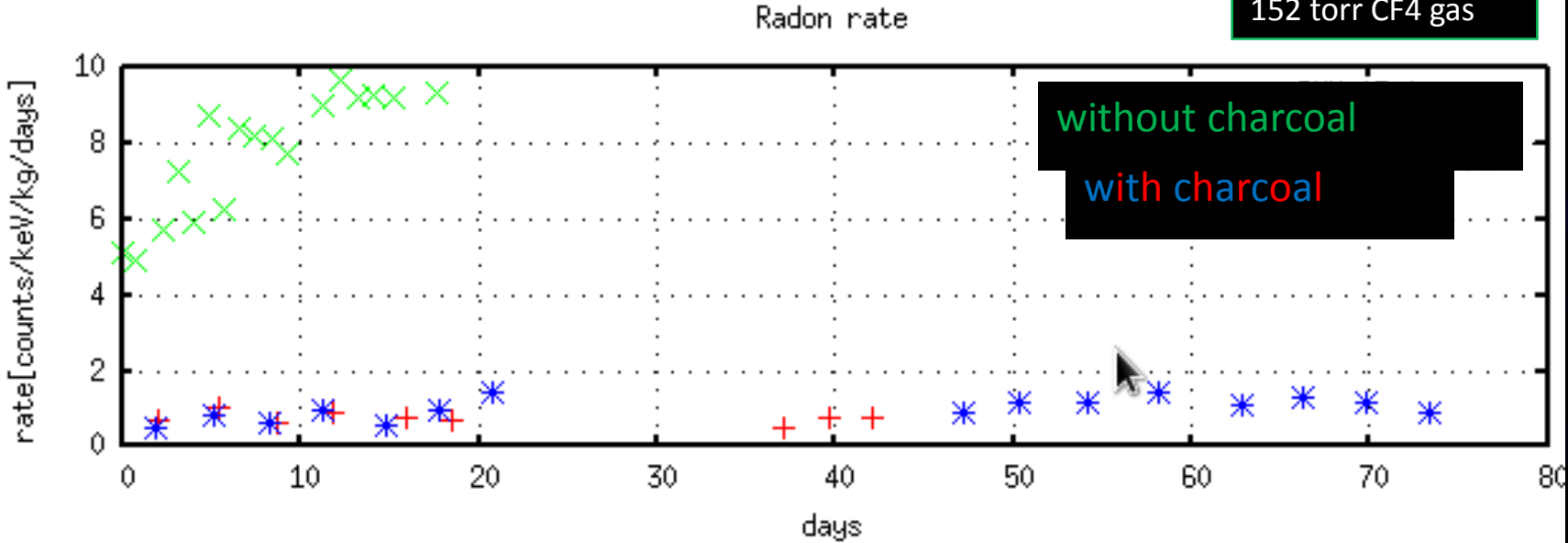
- gas circulation system
- monitor radon rate ($\sim 6\text{MeV}$)
- radon rate $\sim 1/10$ after days10

charcoal filter $\sim 100\text{g}$
(TSURUMICOAL 2GS)

getter pump
(SAES GETTER C400-2DSK)

circulation
(Teflon bellows pump)

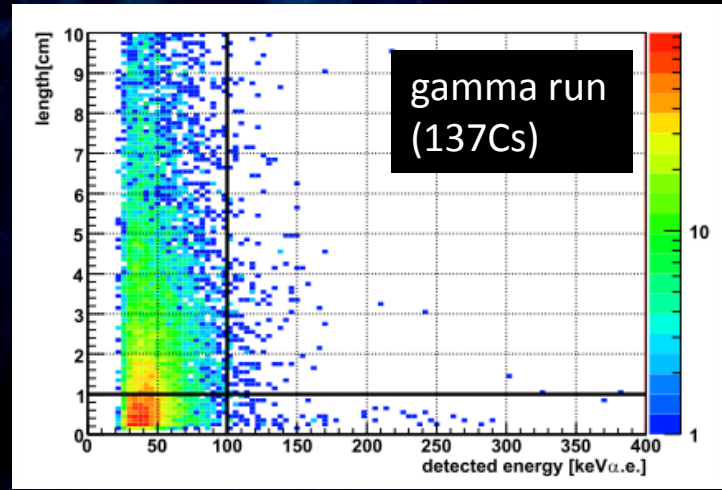
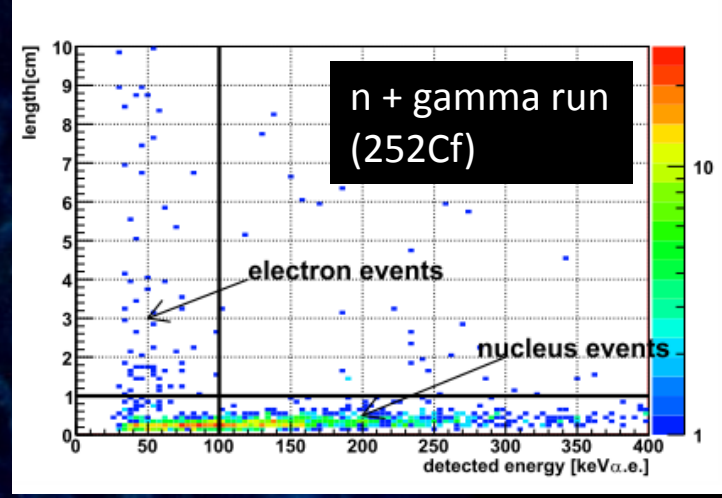
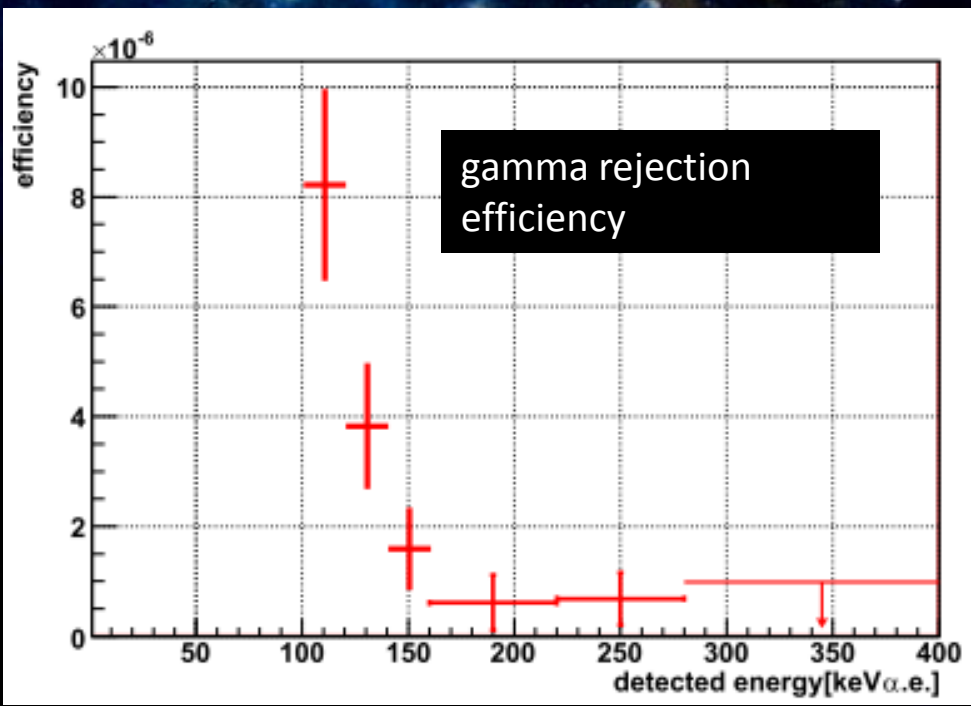
NEWAGE0.3a
152 torr CF4 gas



cf: $1e5\text{counts/kg/days} \sim 1\text{Bq/m}^3$

Gamma: ① length-cut

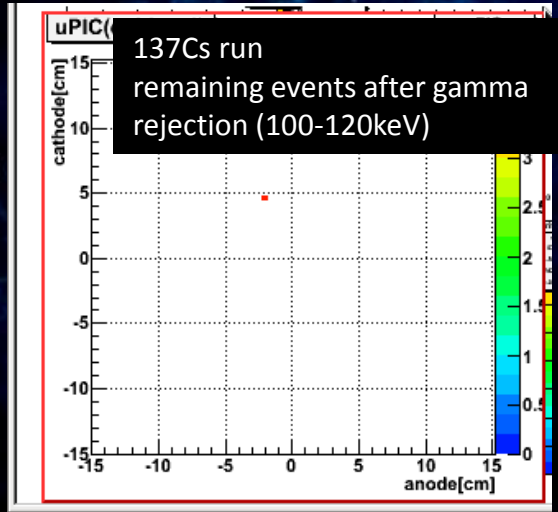
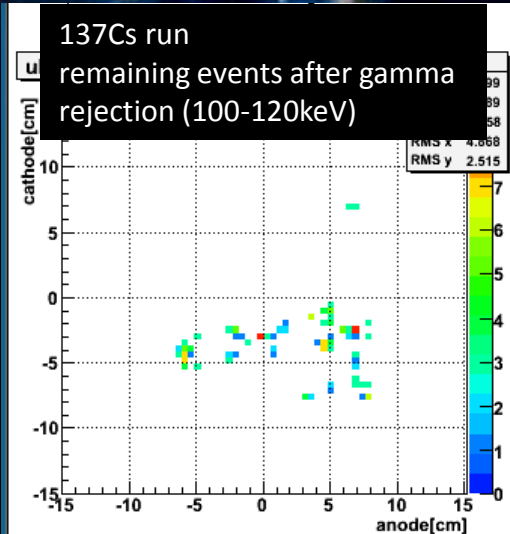
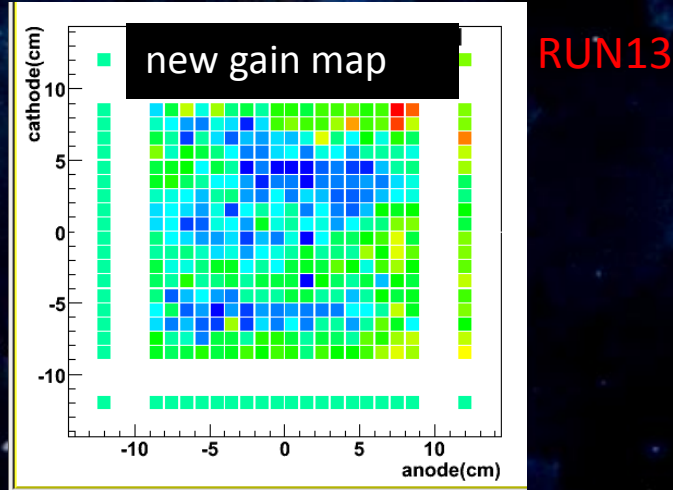
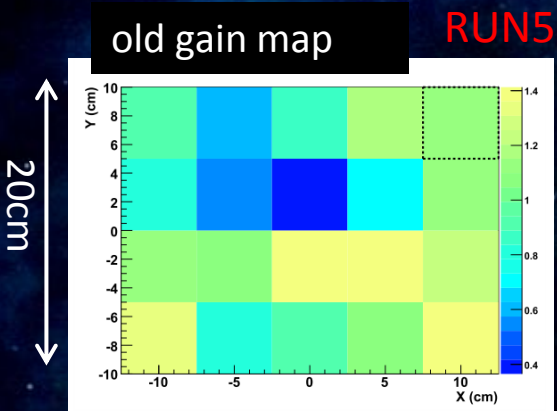
- energy vs length cut
- gamma rejection efficiency*: 8.1×10^{-6}



* gamma rejection efficiency=electron detection efficiency

Gamma: ② precise gain-map

gas gain is not uniform in 30 x 30 cm²



gamma rejection
8.1e-6

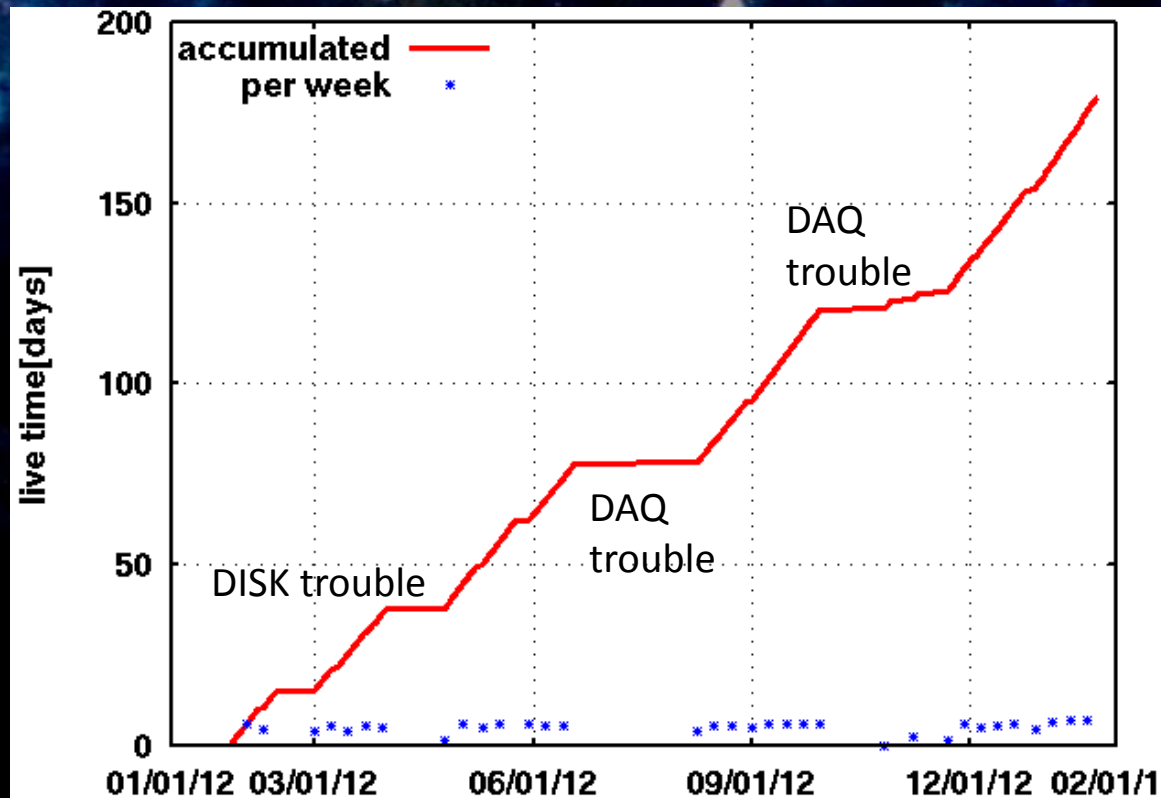
gamma rejection
1.0e-6>

NEWAGE-0.3a' underground run

- Underground run in 2012 (RUN13)

- Target gas: CF_4 152torr
- Fiducial volume: $14 \times 13 \times 31 \text{ cm}^3$
- Target mass: 0.00424kg

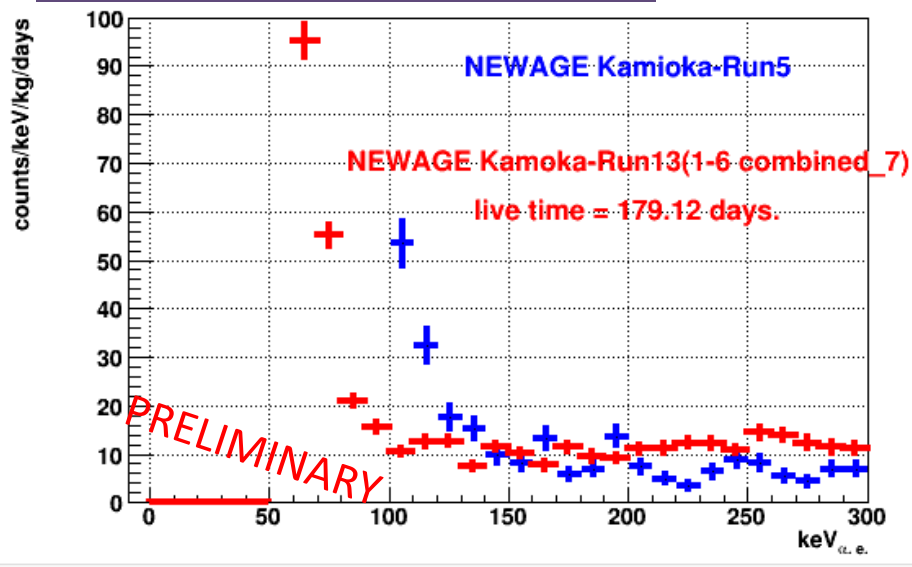
- Date: Jan. 23, 2012 - Jan. 24, 2013
- Live time: 179.12 days
- Exposure: 0.760 kg days



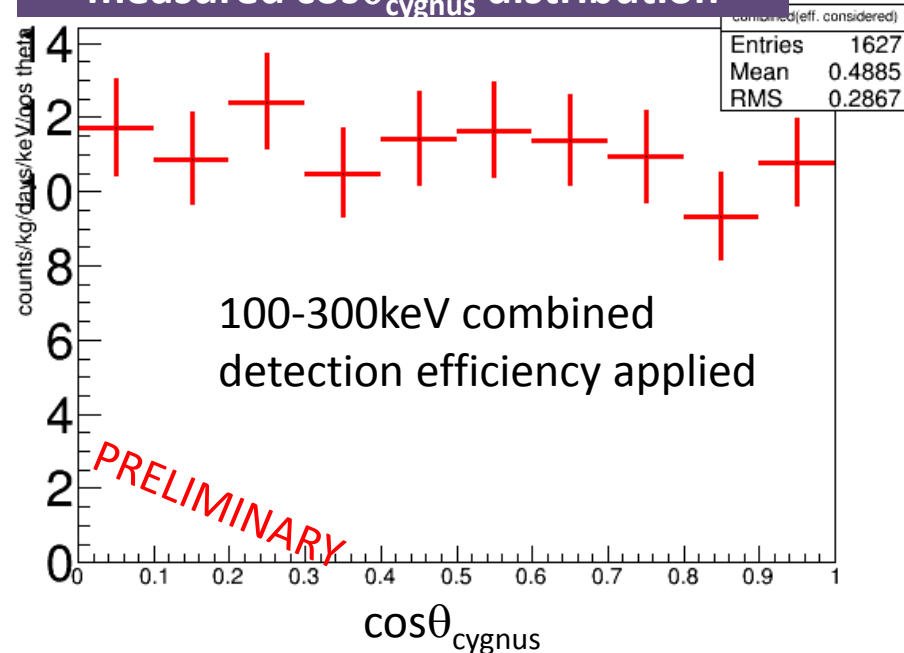
RUN13 result

- exposure: 0.760 kg days
- spectrum threshold: 100keV \Rightarrow 50keV
- rate: $\sim 1/5$ at 100keV
- $\cos \theta$ distribution: flat

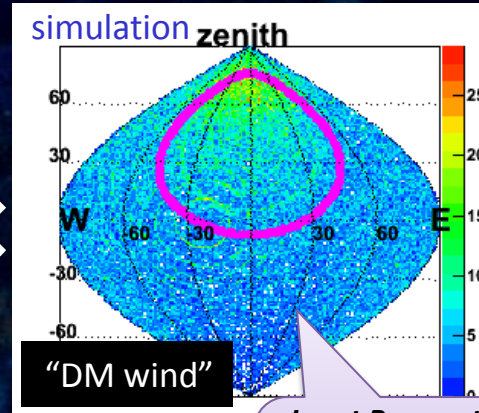
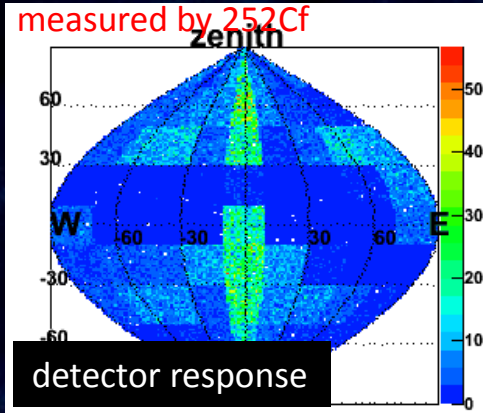
measured energy spectrum



measured $\cos \theta_{\text{cygnus}}$ distribution

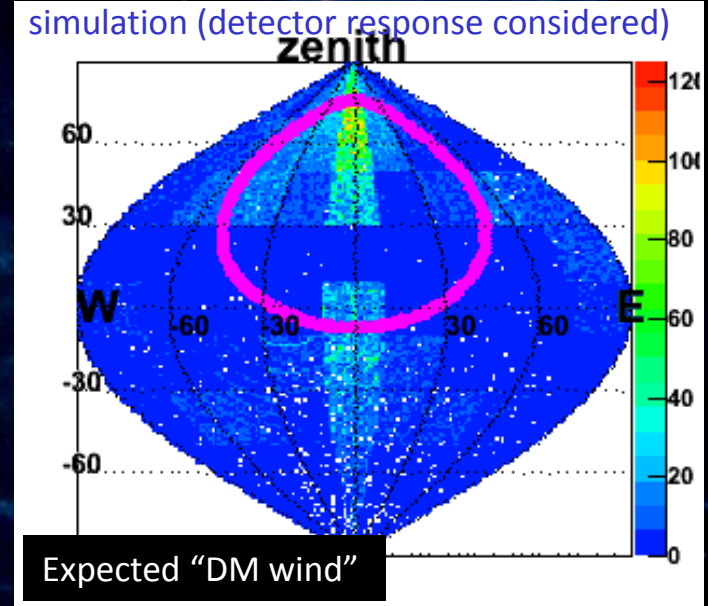


How to get direction sensitive limit

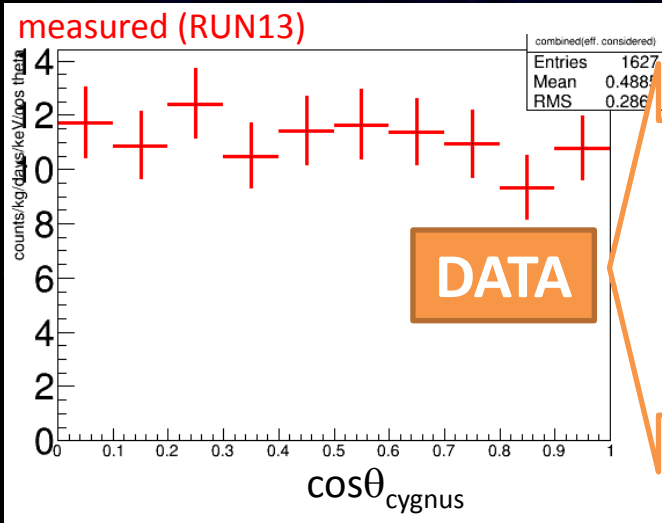


×

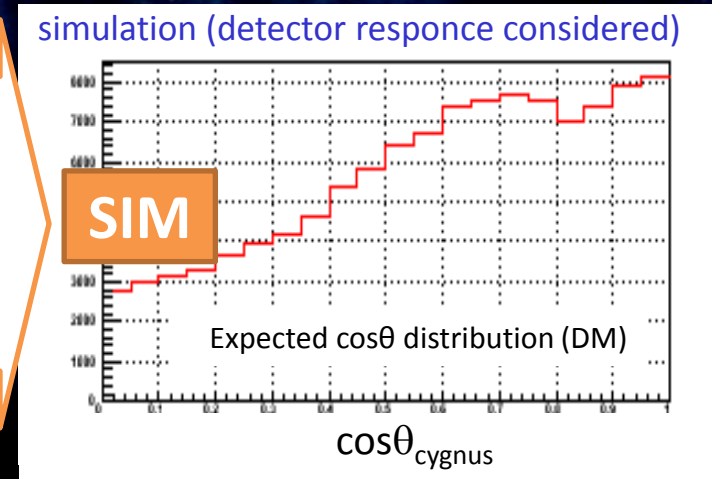
=



Input Parameters
 energy resolution
 angular resolution
 WIMP mass
 energy range

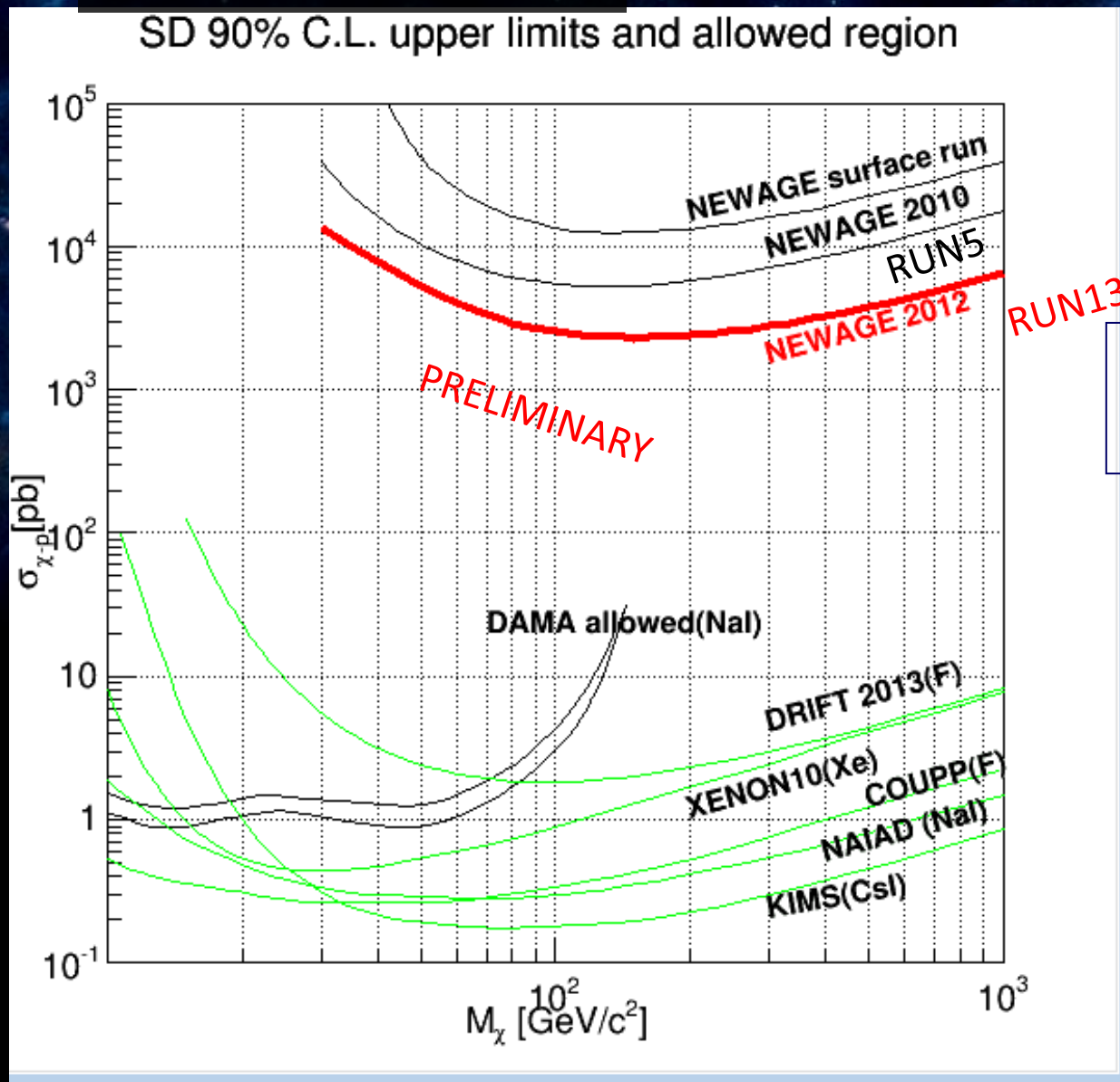


Comparison
 Scanning σ_{DM} , we set
 direction sensitive limit.



Direction sensitive limits

- 3100pb @ 150GeV



threshold=100keV
E resolution=30%
Ang. resolution 55°

Commissioning (NEWAGE-0.3b')

K. Nakamura *et al* 2012 *JINST* 7 C02023

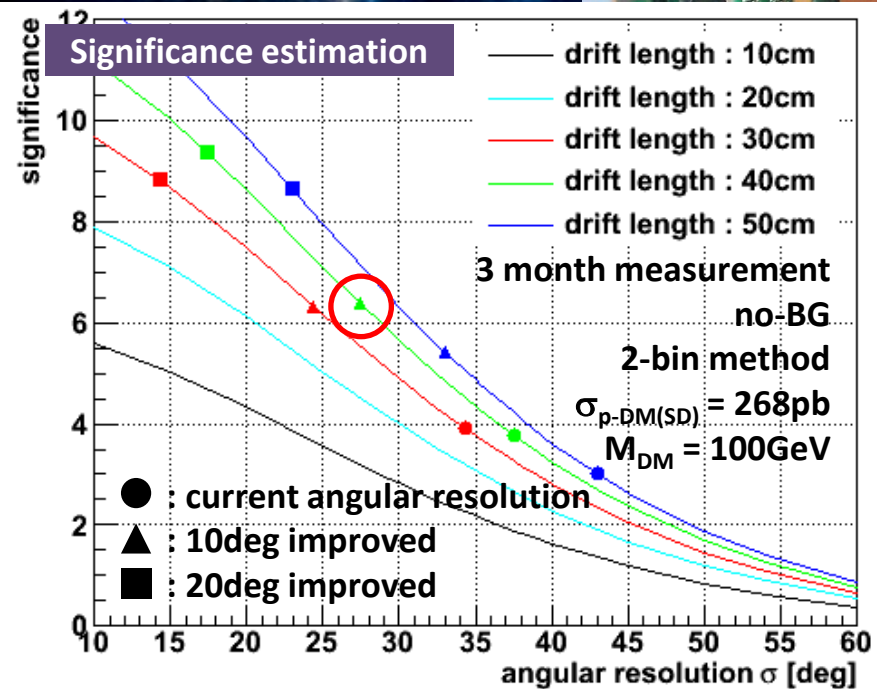
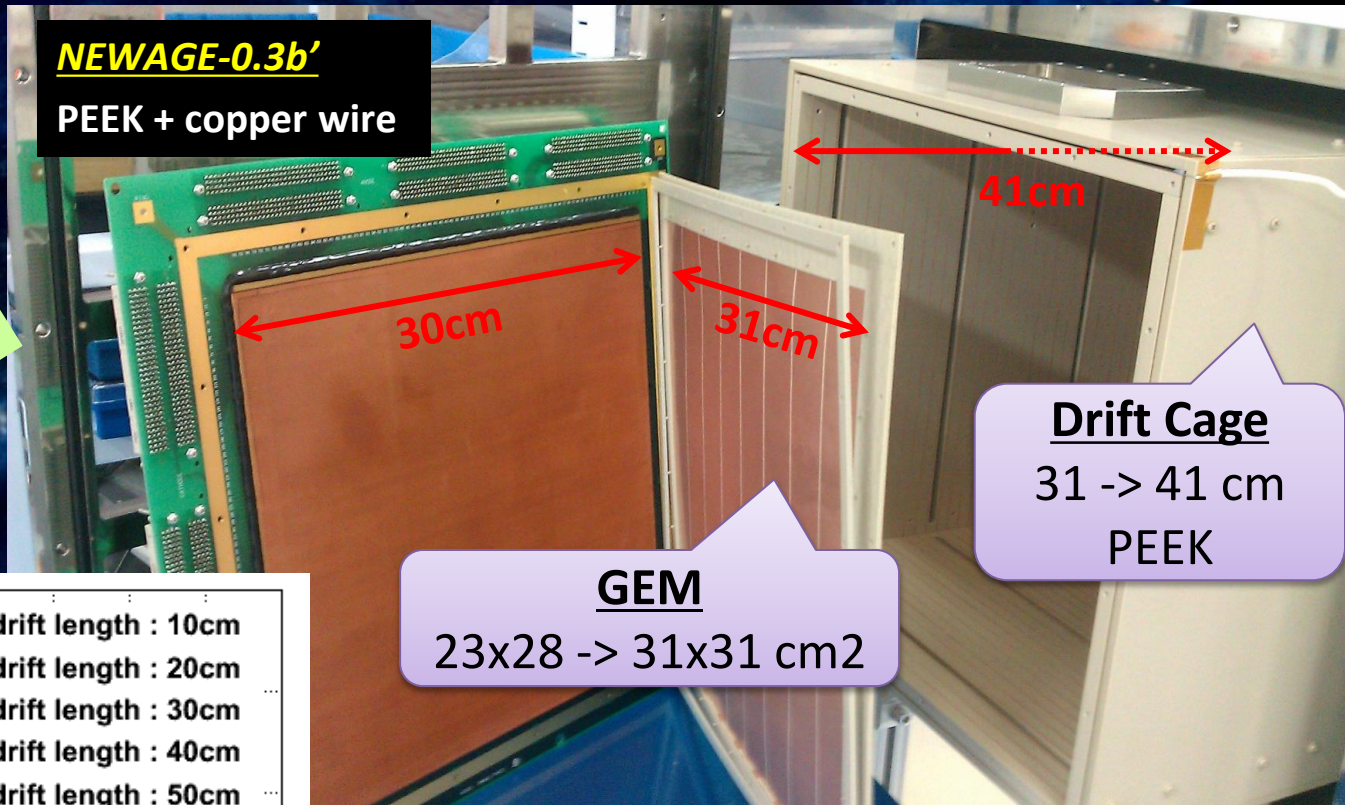
| Detector Name | NEWAGE-0.3a' | NEWAGE-0.3b' | NEWAGE-0.1a |
|------------------|------------------------------|------------------------------|------------------------------|
| Detection volume | 23 x 28 x 31 cm ³ | 30 x 30 x 41 cm ³ | 10 x 10 x 10 cm ³ |
| Gas | CF ₄ 152torr | CF ₄ 76torr | CF ₄ 152torr |
| DAQ-mode | mode3 | mode5 | mode5 |
| Place | Kamioka | Kamioka | Kobe |
| Status | DM search | Commissioning | Head-tail R&D |

NEWAGE-0.3b'

- Developments at Kyoto (surface lab)

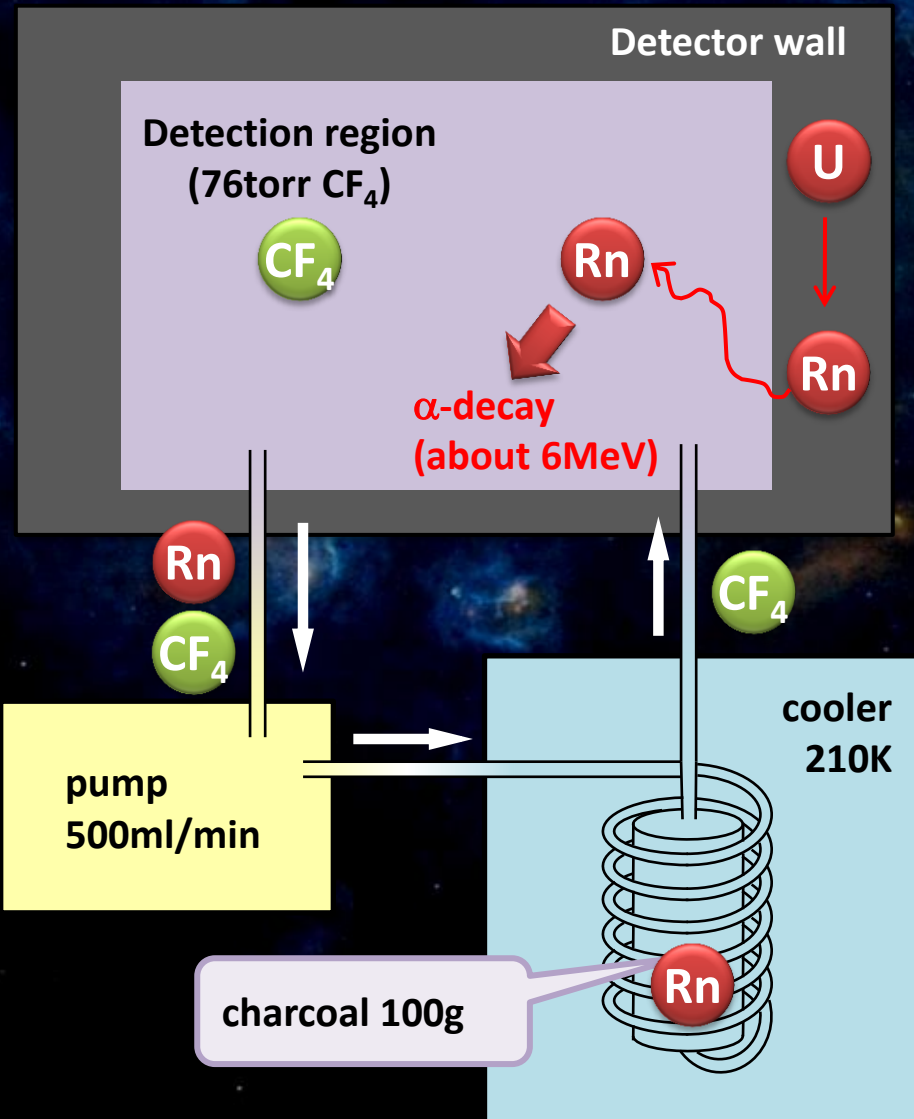
- Larger GEM
 - Longer drift length
 - PEEK drift cage
 - Cooled charcoal
 - Low pressure gas
 - DAQ upgrade
- Large size $\sim x2$
 - Low BG $\sim 1/10$
 - Low threshold $\sim 1/2$

NEWAGE-0.3b' : Geometry

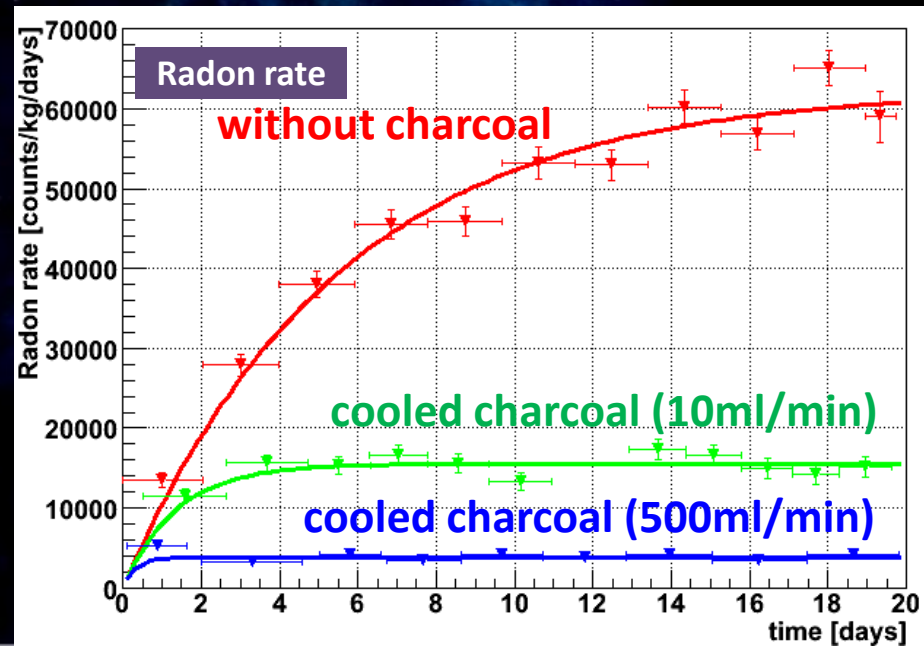


- Detection volume: 2 x NEWAGE-0.3a'
- PEEK for low BG

NEWAGE-0.3b : Circulation

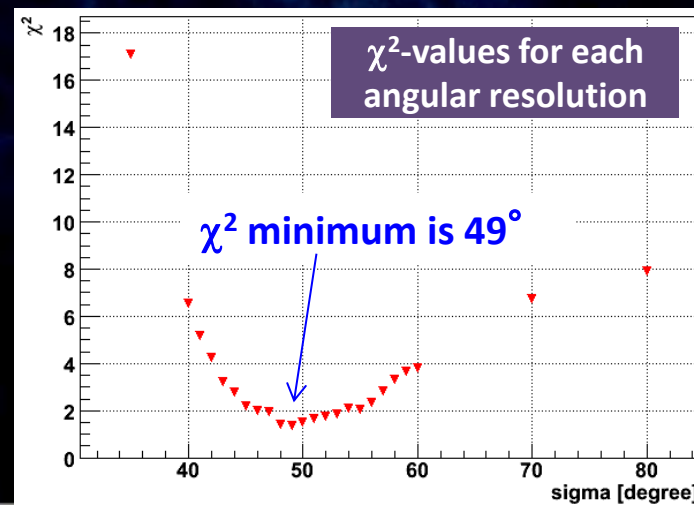
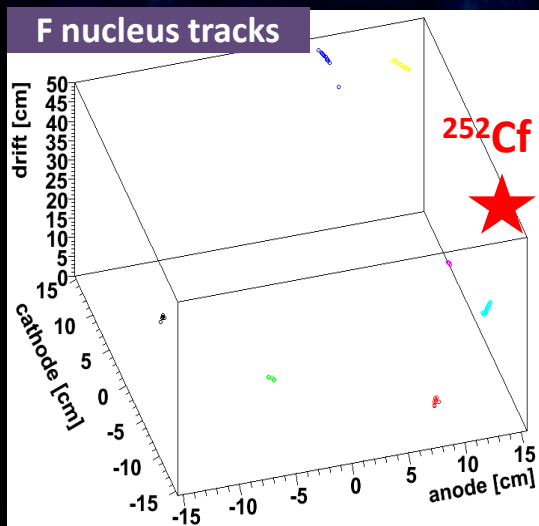
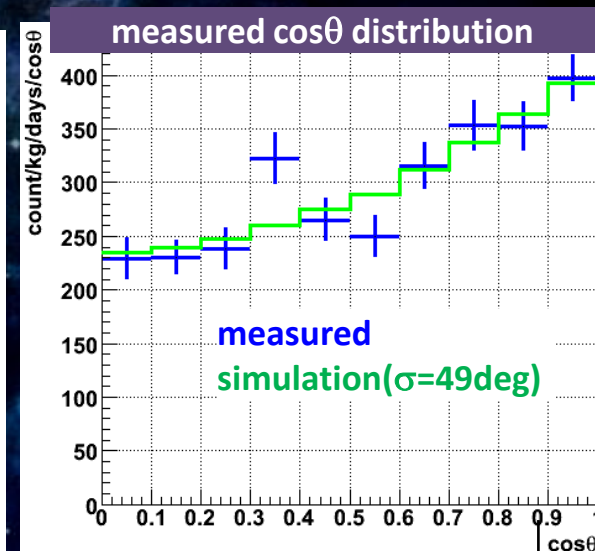
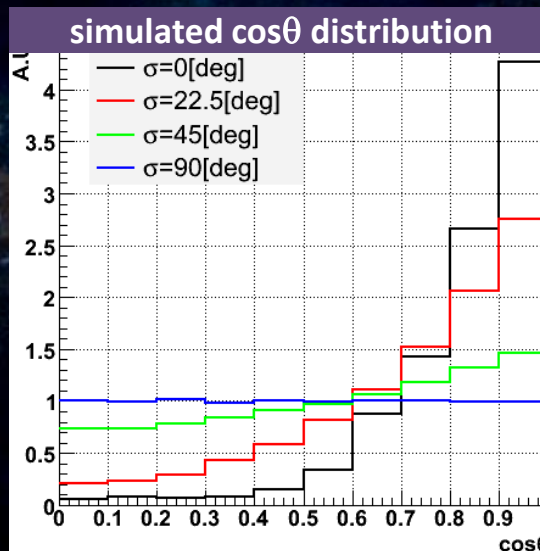
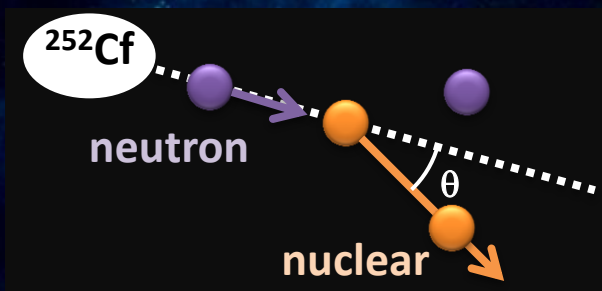


- Circulation with cooled charcoal
- Radon rate : $<1/10$



NEWAGE-0.3b: angular resolution

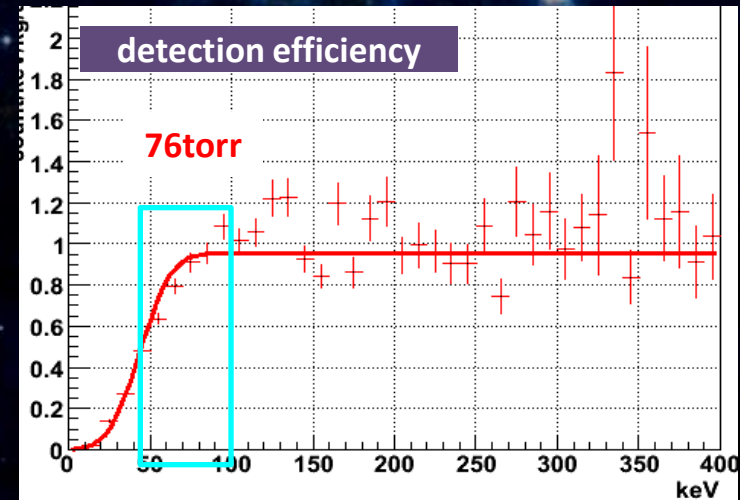
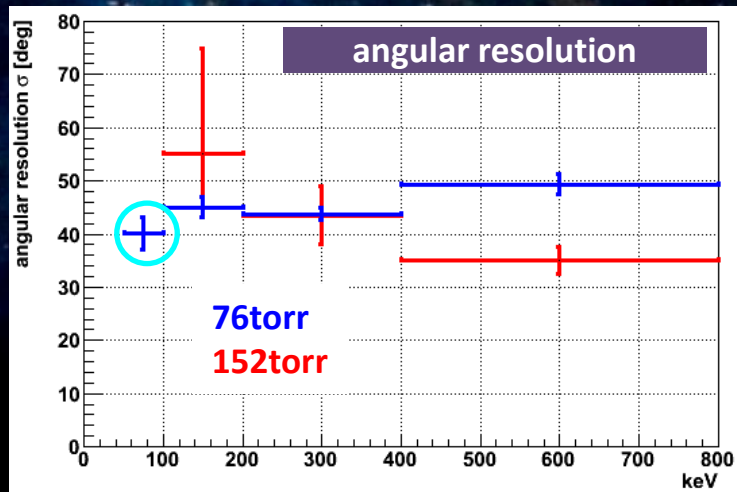
- Gas pressure: 152->76 torr (NEWAGE-0.3a'->NEWAGE-0.3b')
- Comparing $\cos\theta$ distribution measured to simulation



(measured with DAQ-mode1)

NEWAGE-0.3b : threshold

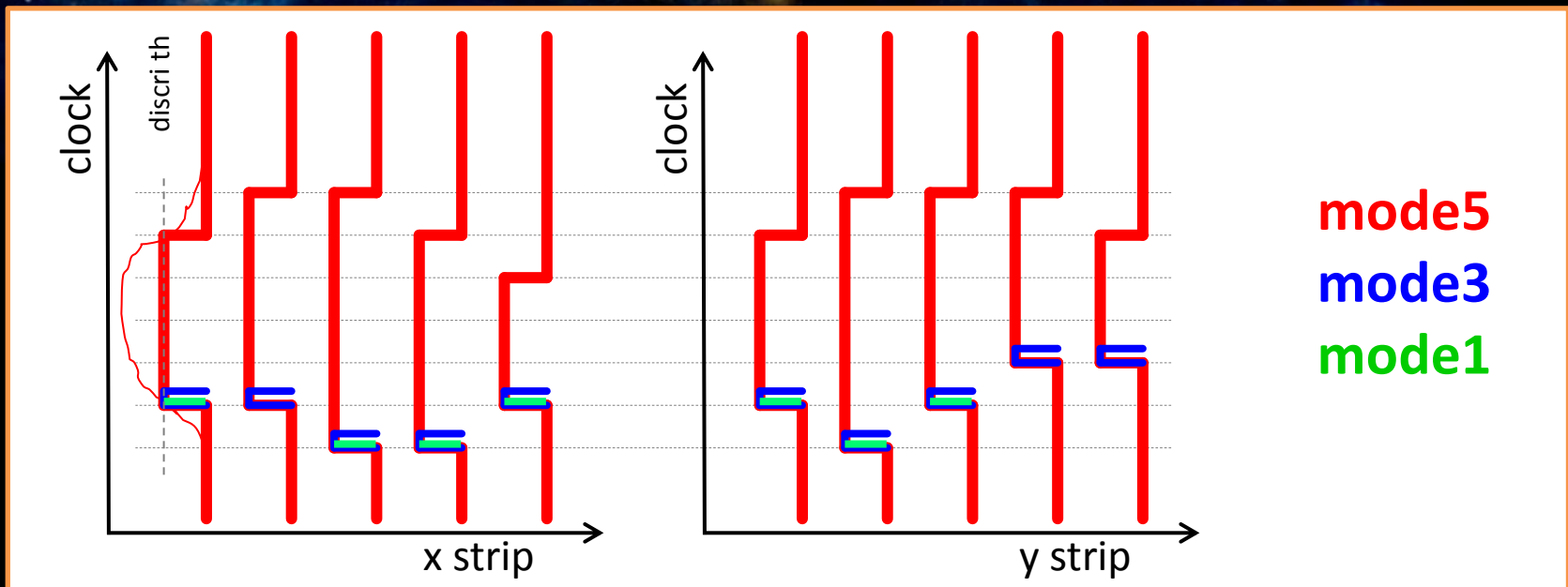
- Gas pressure: 152->76 torr (NEWAGE-0.3a'->NEWAGE-0.3b')
- Angular resolution: 40deg @50-100keV
- Detection efficiency: 60% @50keV



- Energy threshold with angular resolution:
100->50keV (by 152->76torr)

NEWAGE-0.3b' : DAQ upgrade

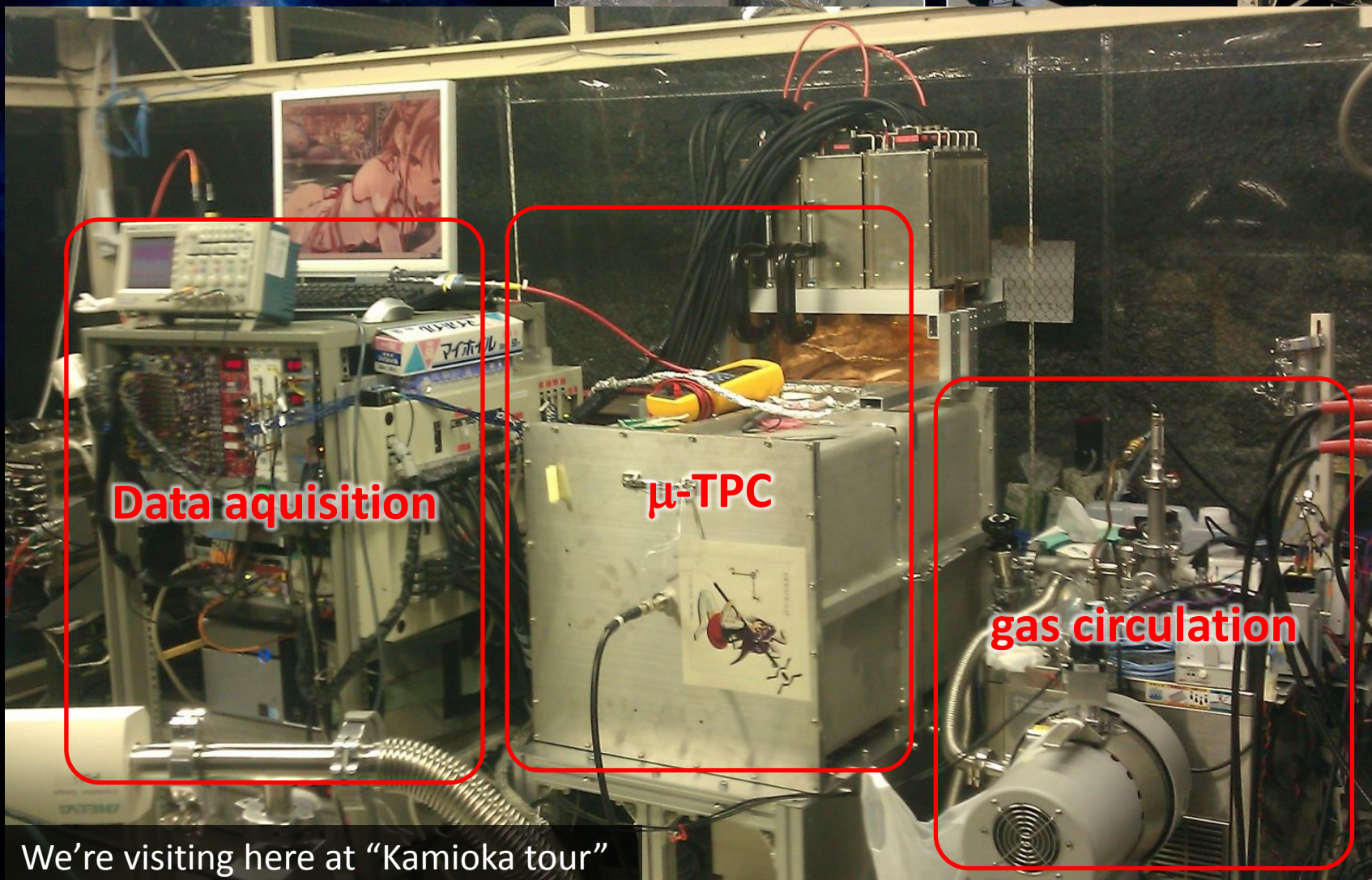
| | Strip information (for each clock) | Time Over Threshold | Detector |
|-------|---------------------------------------|--|-----------------------------|
| mode5 | all | Rise & Fall timing ("energy" of each strip) | NEWAGE-0.3b' NEWAGE-0.1a |
| mode3 | all | Rise timing | NEWAGE-0.3a' |
| mode1 | x-y coincidence max, min only | Rise timing | NEWAGE-0.3b |



- We confirmed DAQ-mode5 works with no bug

Transfer

From Kyoto to Kamioka
(Mar. 2013)



Data aquisition

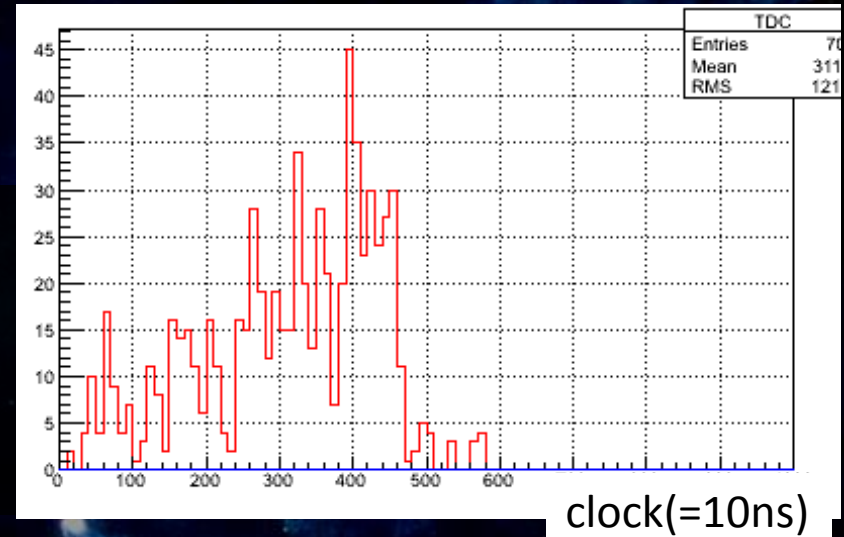
μ -TPC

gas circulation

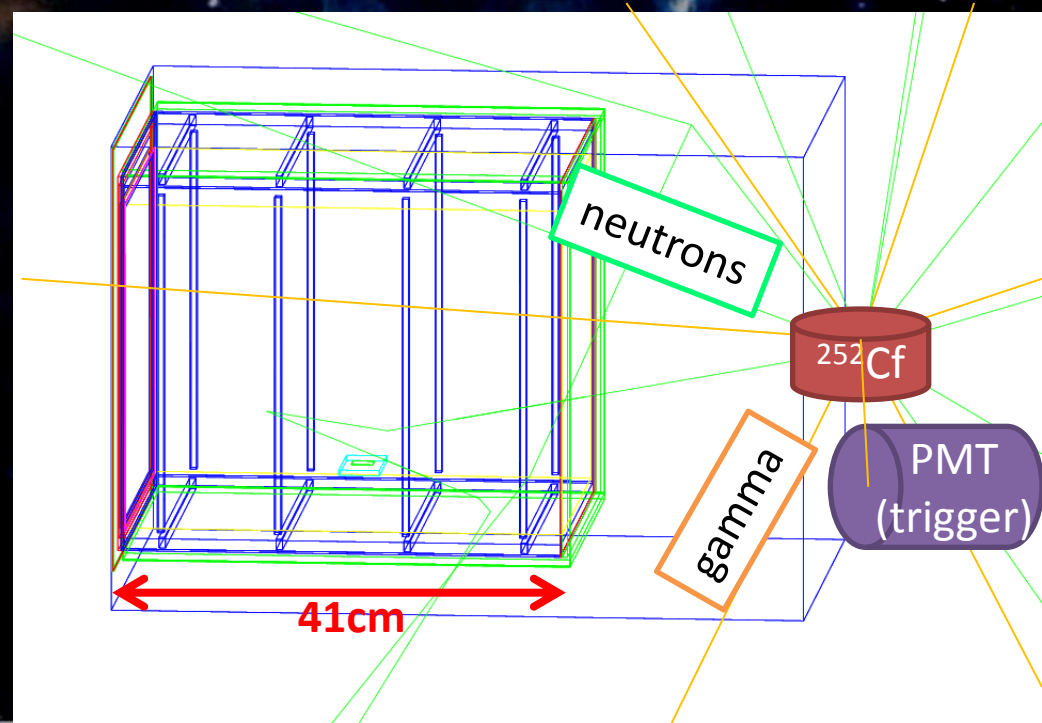
We're visiting here at "Kamioka tour"

drift velocity

- Measure clock of drift
 - $4.7\mu\text{s}$ for 41cm $\rightarrow v=8.7\text{cm}/\mu\text{s}$
- Consistent to surface measurement

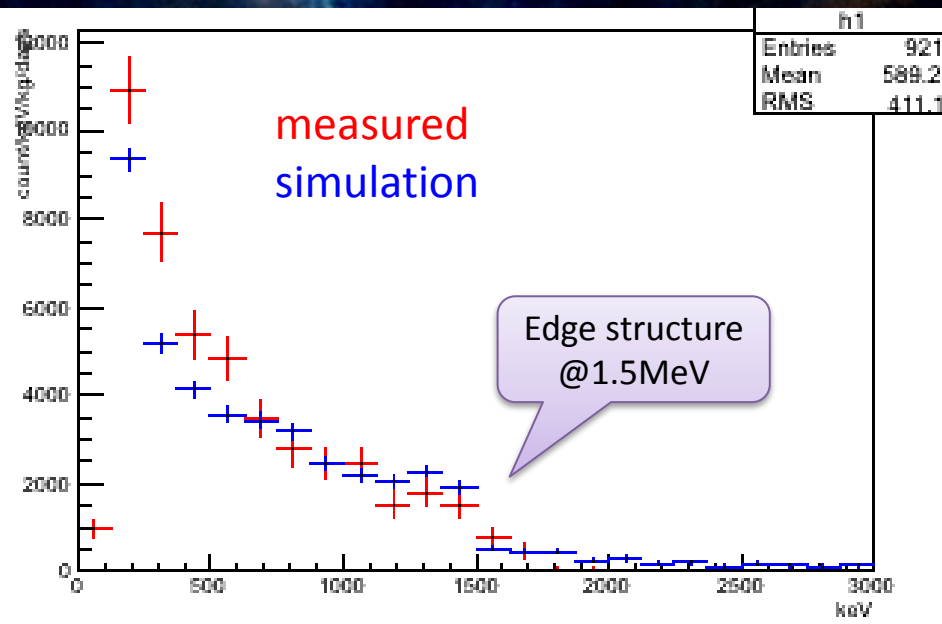


- Electric Field: $0.095\text{kV}/\text{cm}$
- gas: CF_4 76torr

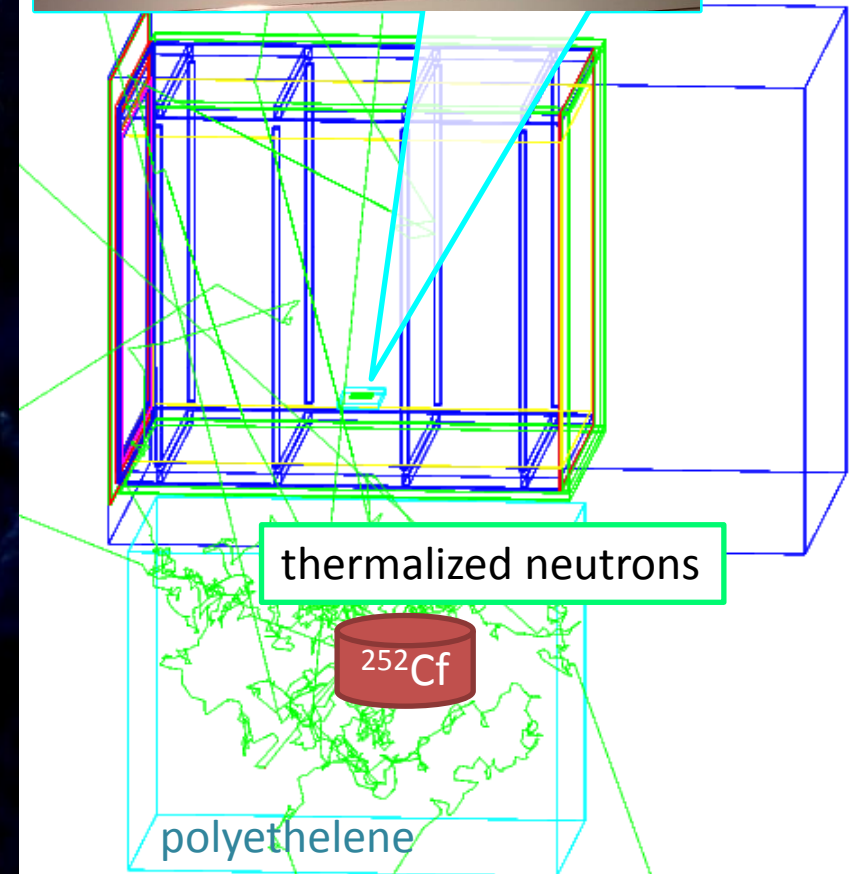
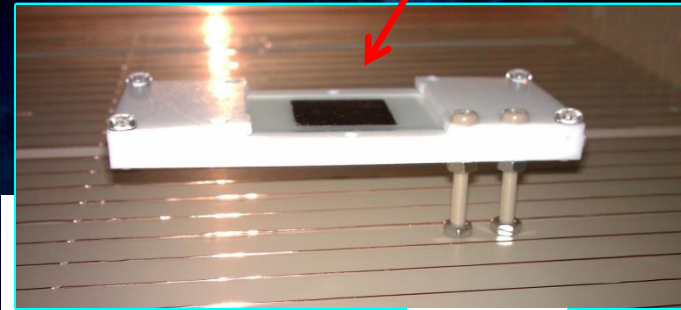


calibration

- Calibration with ^{10}B
 - $^{10}\text{B}(n,\alpha)^7\text{Li}$ reaction
 - ($Q=2.70\text{MeV} \sim 1.5\text{MeV } \alpha$)

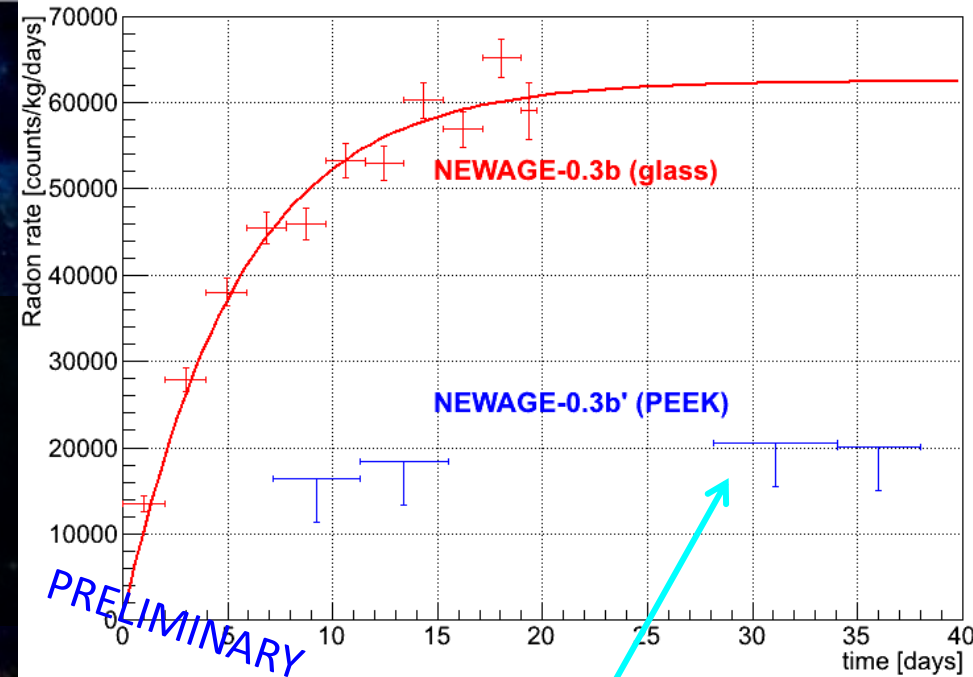


^{10}B (1.5 μm thickness) coated glass



BG radon

- Drift cage Material: glass -> PEEK
- radon rate: $< 1/3$
- Further $1/10$ with cooled charcoal



Underground runs

| run# | RUN5 (PLB2010) | ... | RUN13 | RUN14 | RUN15 |
|-----------------|--------------------|-----|--------------------|------------------|-----------------|
| Period | 2008 | ... | 2012 | 2013 Mar | 2013 April |
| Detector | NEWAGE-0.3a | ... | NEWAEG-0.3a' | NEWAGE-0.3b' | |
| Gas circulation | room temp charcoal | ... | room temp charcoal | without charcoal | cooled charcoal |

NEWAGE-0.3b' summary

- Commissioning almost done (analysis tuning now)
- DM run started (RUN15-)

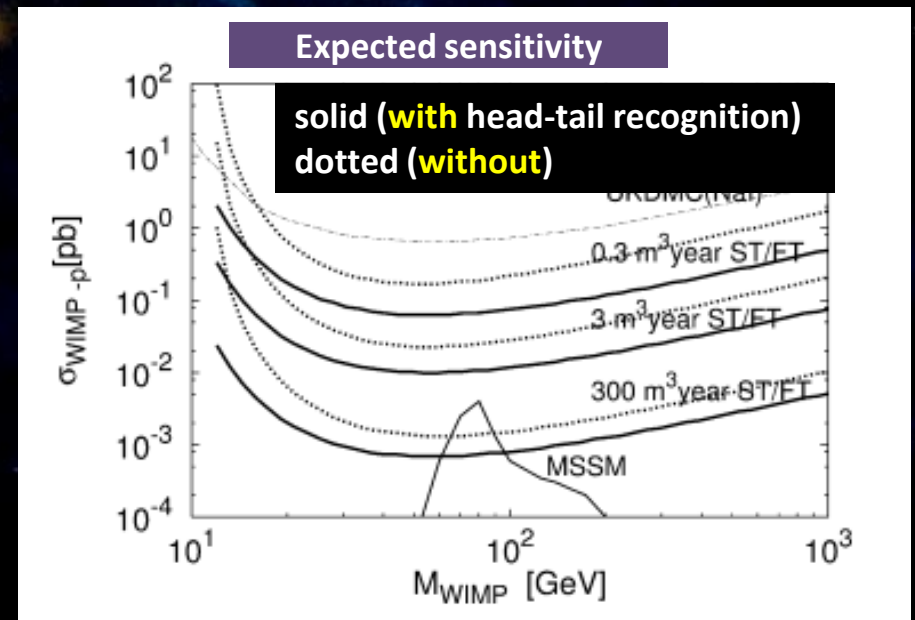
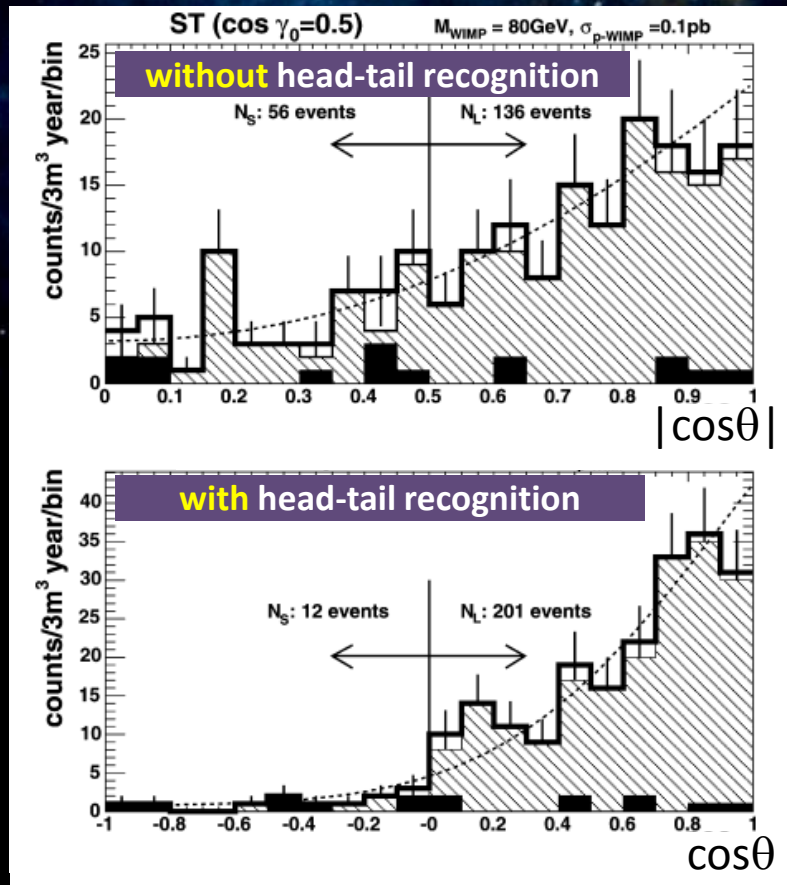
Head-tail R&D

(NEWAGE-0.1a)

| Detector Name | NEWAGE-0.3a' | NEWAGE-0.3b' | NEWAGE-0.1a |
|------------------|------------------------------|------------------------------|------------------------------|
| Detection volume | 23 x 28 x 31 cm ³ | 30 x 30 x 41 cm ³ | 10 x 10 x 10 cm ³ |
| Gas | CF ₄ 152torr | CF ₄ 76torr | CF ₄ 152torr |
| DAQ-mode | mode3 | mode5 | mode5 |
| Place | Kamioka | Kamioka | Kobe |
| Status | DM search | Commissioning | Head-tail R&D |

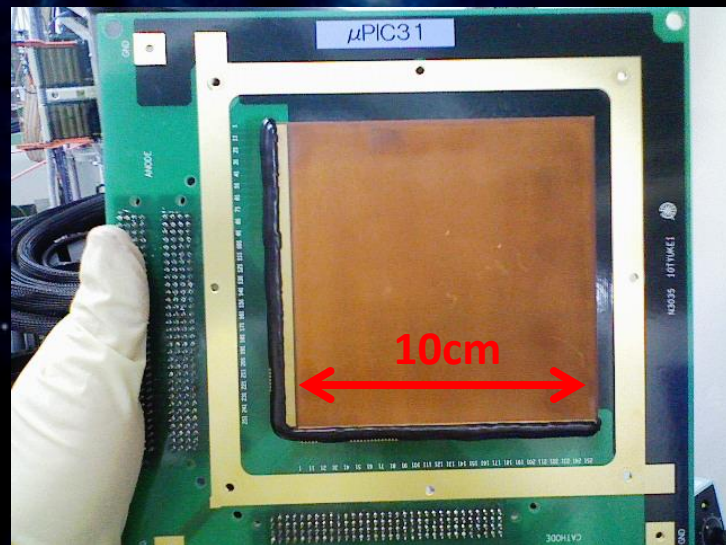
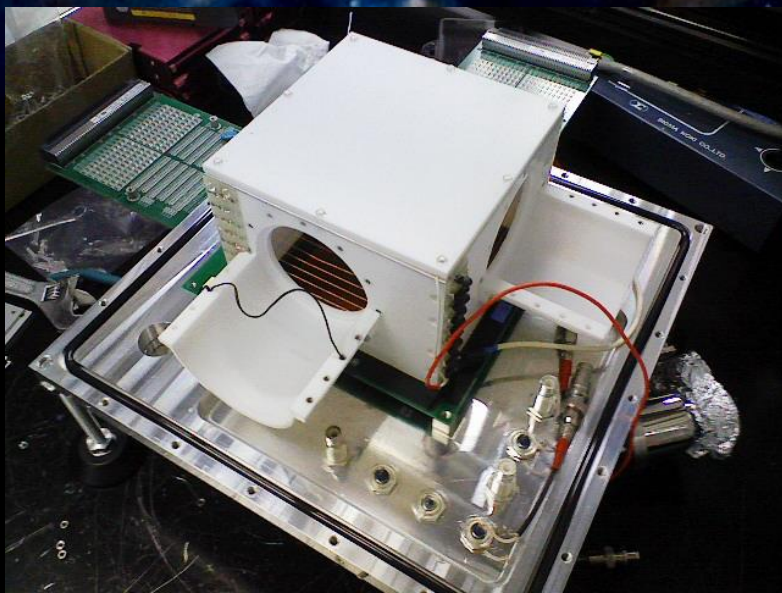
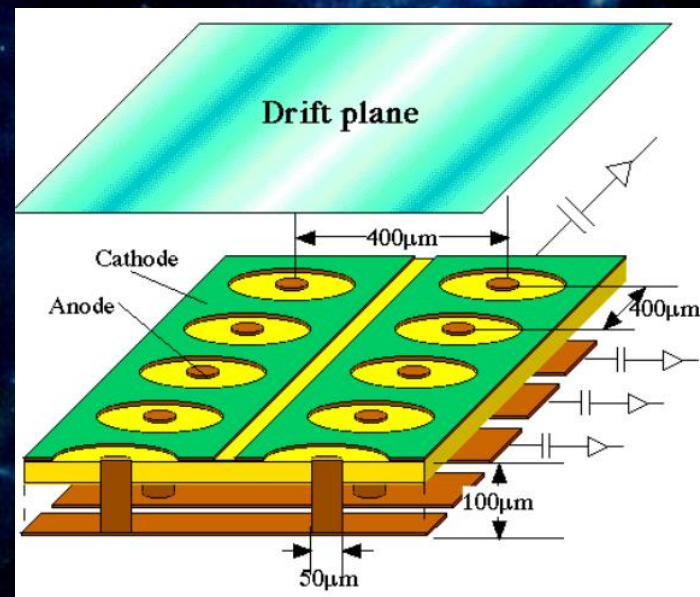
Head-tail introduction

- Head-tail recognition of nuclear track
-> Sensitivity improvement: 3 ~ 10 times



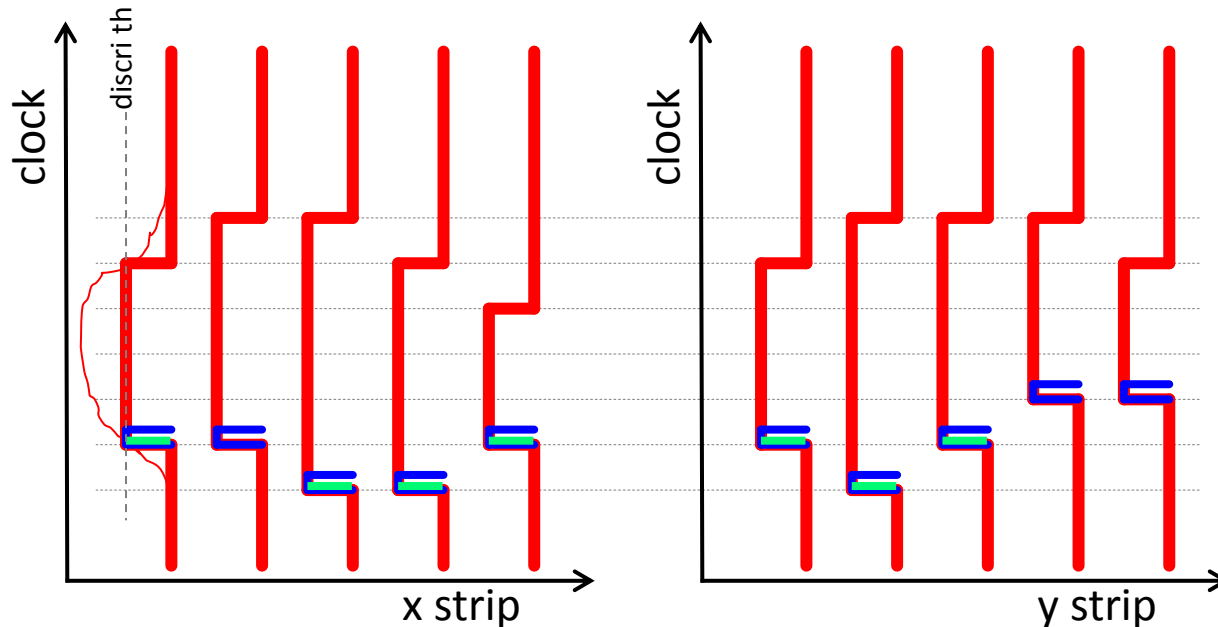
NEWAGE-0.1a detector

- μ TPC: 10 x 10 x 10cm³
- readout: 400 μ m pitch
- GEM: polyimide, 100 μ m
- gas: CF₄, 152torr



DAQ-mode5 (again)

| | Strip information (for each clock) | Time Over Threshold | Detector |
|-------|---------------------------------------|--|-----------------------------|
| mode5 | all | Rise & Fall timing ("energy" of each strip) | NEWAGE-0.3b' NEWAGE-0.1a |
| mode3 | all | Rise timing | NEWAGE-0.3a' |
| mode1 | x-y coincidence max, min only | Rise timing | NEWAGE-0.3b |



mode5
mode3
mode1

Event display

- observed "Bragg Curve"

20110512/per167

file 92 event 2

252Cf (0,-30,5)[cm]

length = 0.95 cm

FADCsum = 494.1

X hitsum = 40

mean = -2.815

skewness = -0.125

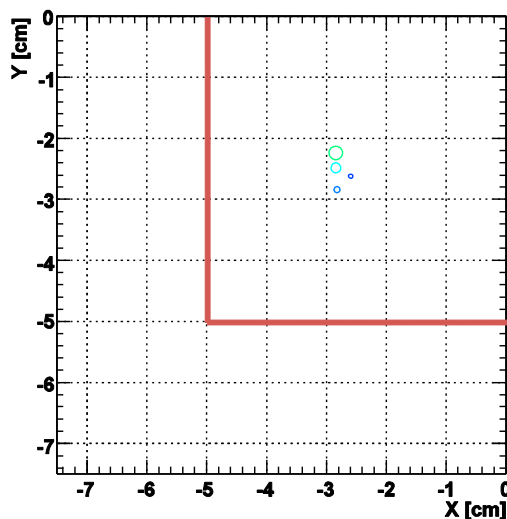
Y hitsum = 54

mean = -2.546

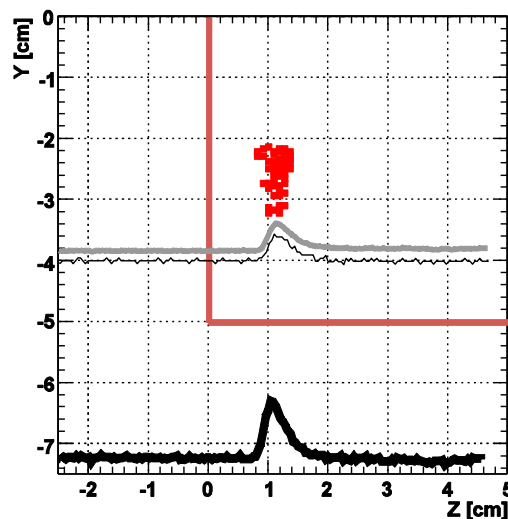
skewness = -0.437

130keV F track

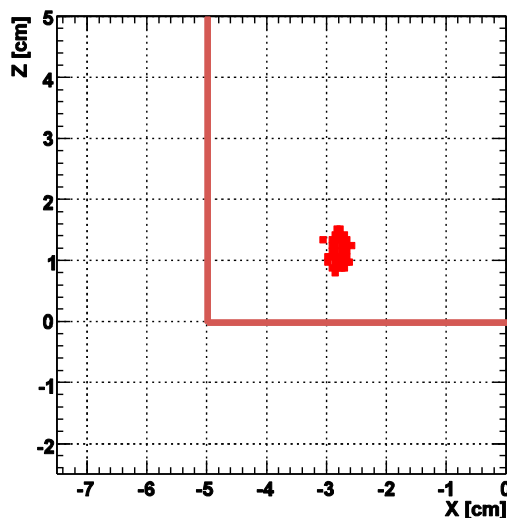
XY view



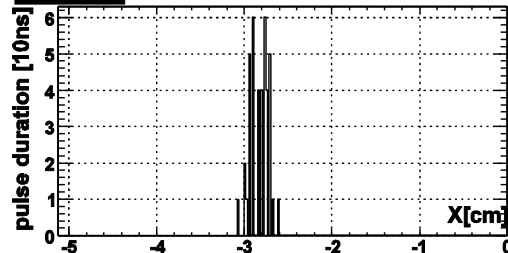
Z Y view



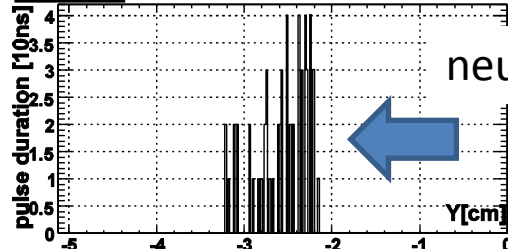
XZ view



Bragg curve(X)



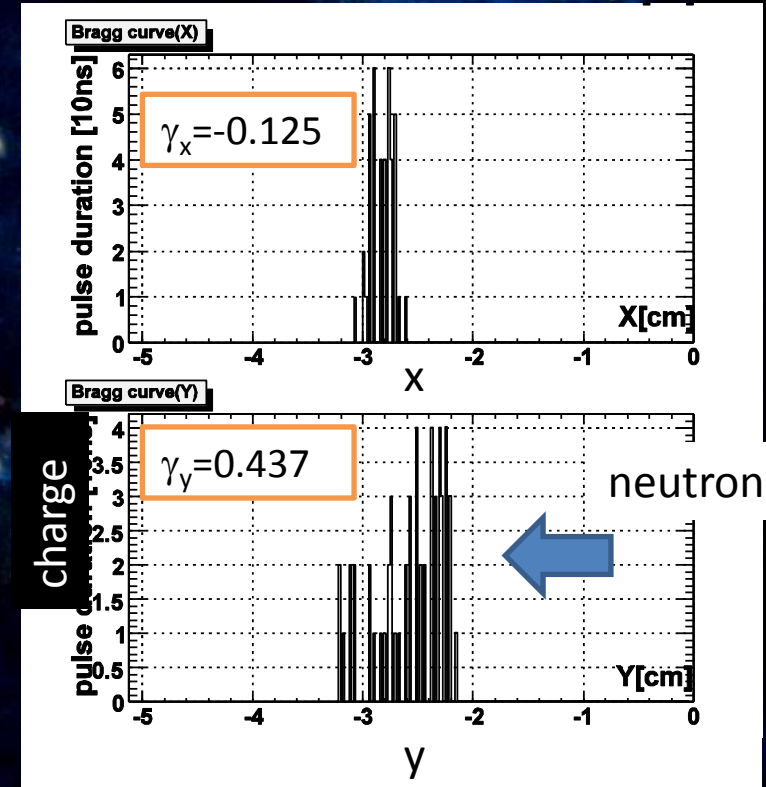
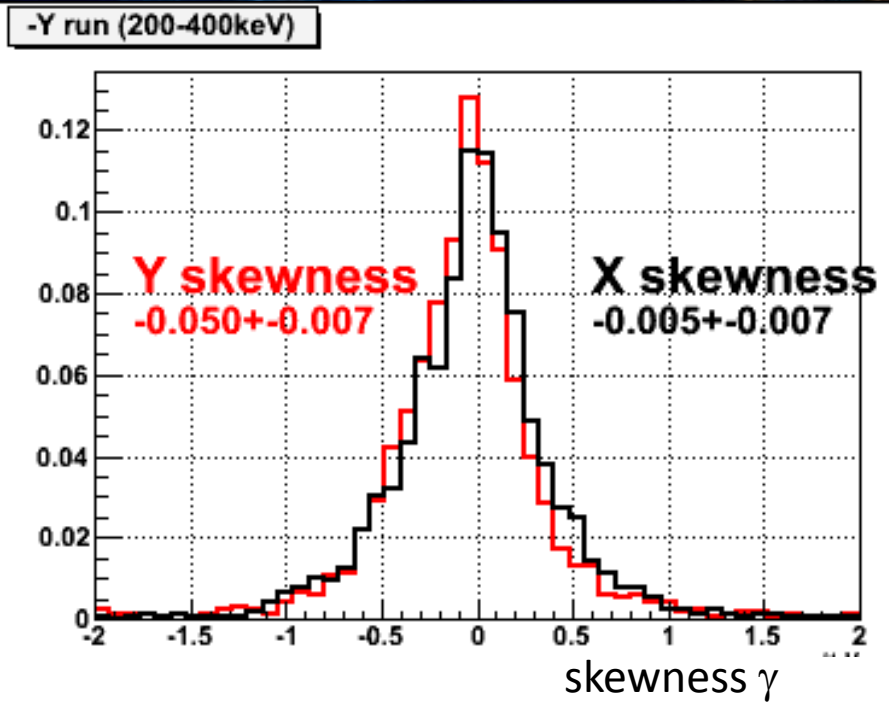
Bragg curve(Y)



Symmetry parameter: skewness

$$\gamma_{x_i} = \frac{\langle (q(x_i) \cdot (x_i - \langle x_i \rangle)^3) \rangle}{\langle (q(x_i) \cdot (x_i - \langle x_i \rangle)^2)^{3/2} \rangle}$$

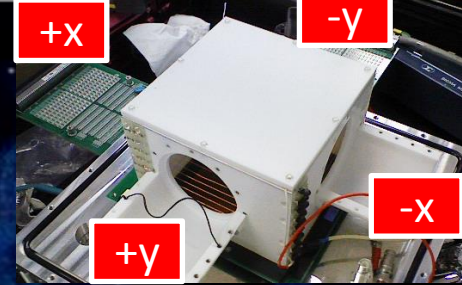
- If symmetric, $\gamma=0$



- difference was observed

Head-tail recognition

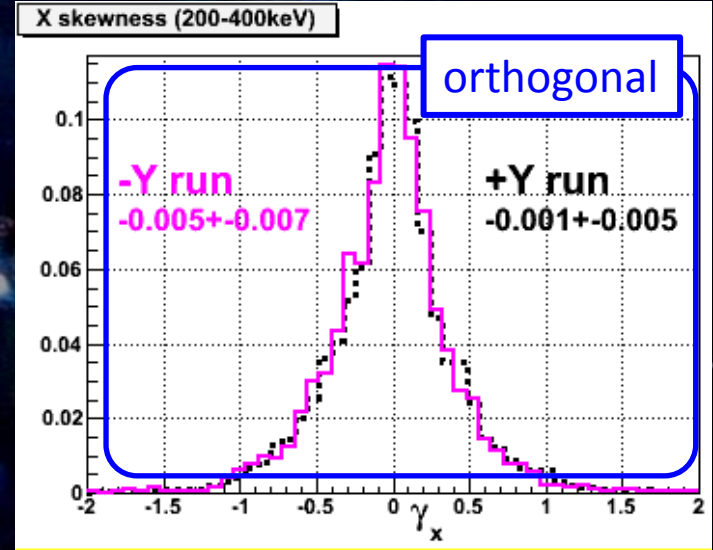
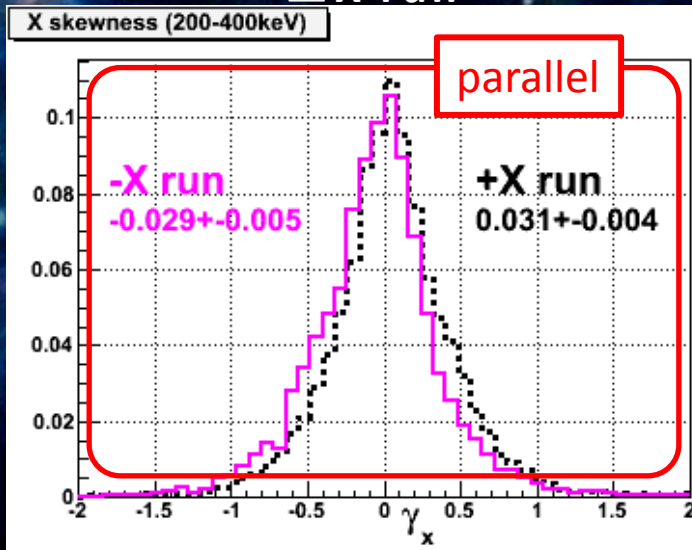
($^{252}\text{Cf}@30\text{cm}$)



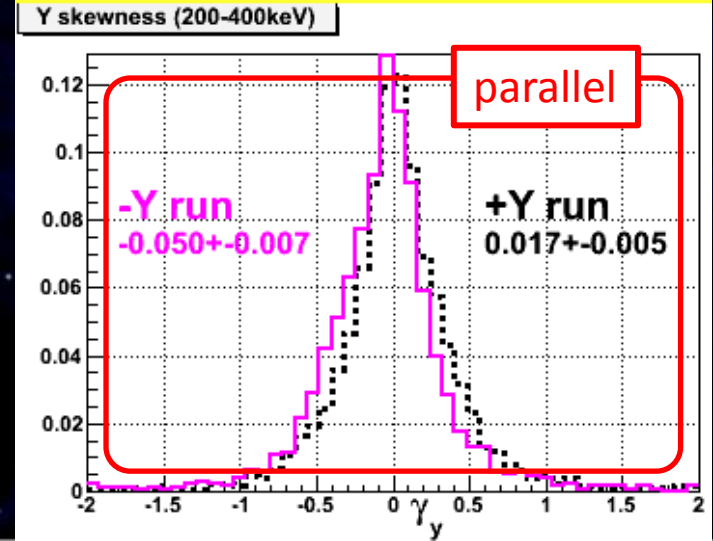
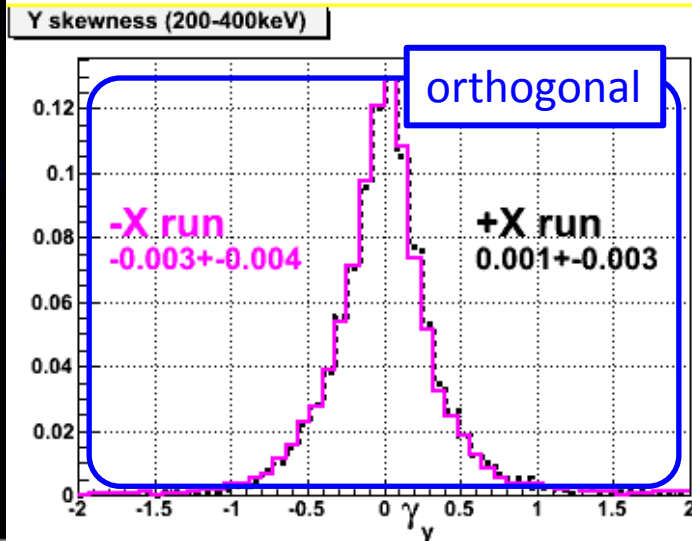
$\pm X$ run

$\pm Y$ run

X skewness

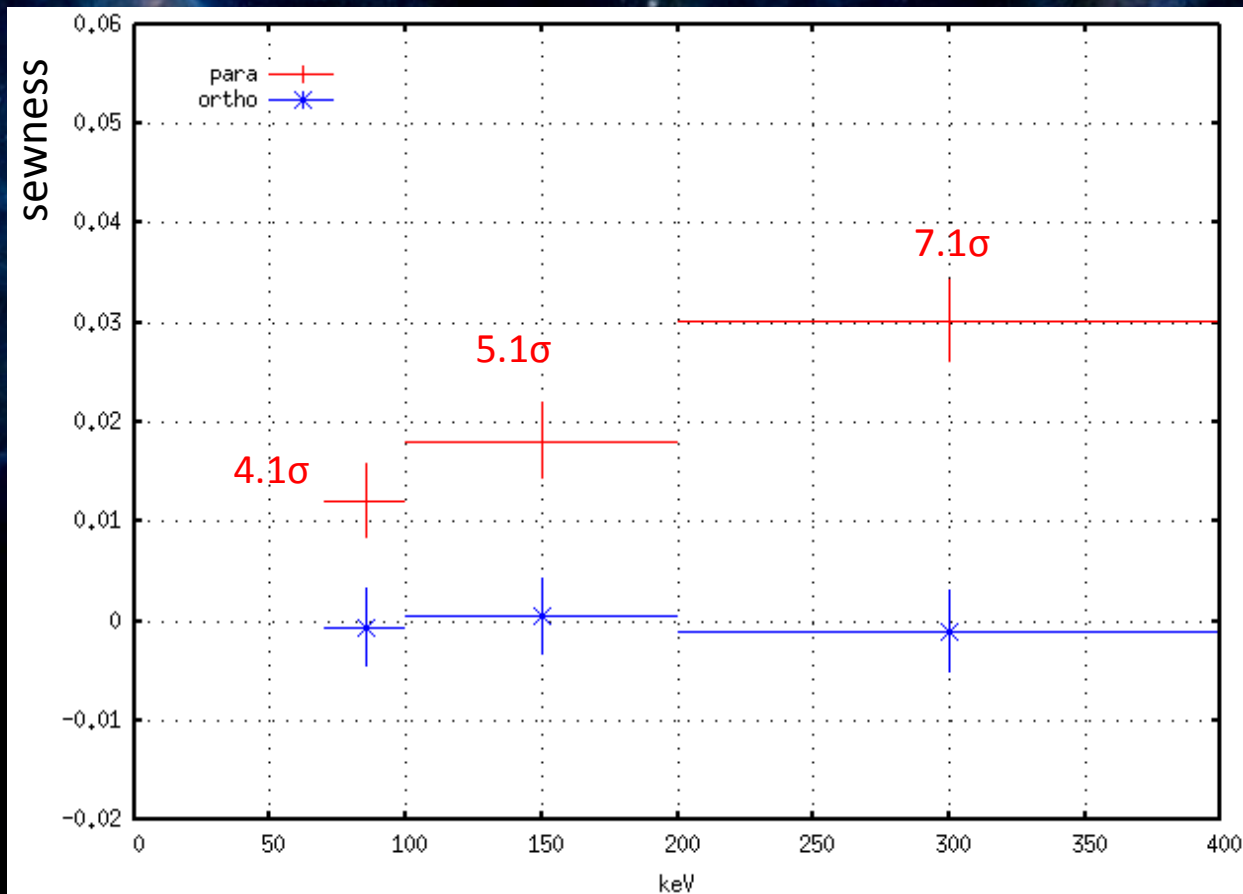


Y skewness



Combined results

- Energy dependence of parallel and orthogonal skewness
- statistically significant ($>70\text{keV}$)



- To do for next
 - the skewness definition improvement
 - 3-dimensional track

Summary

Latest limit by NEWAGE-0.3a'

- Direction sensitive limit updated:
450pb @150GeV

Commissioning of NEWAGE-0.3b'

- Commissioning almost done &
Started DM run

Head-tail R&D using NEWAGE-0.1a

- 2-dim Head-tail can be
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Thank you for
your attention!



Mascot of NEWAGE
"Daakumatan"