

NEWAGE

Direction-Sensitive Dark Matter Search

Kentaro Miuchi

KOBE University

July 28th 2017

Exploring the Dark Universe 2017

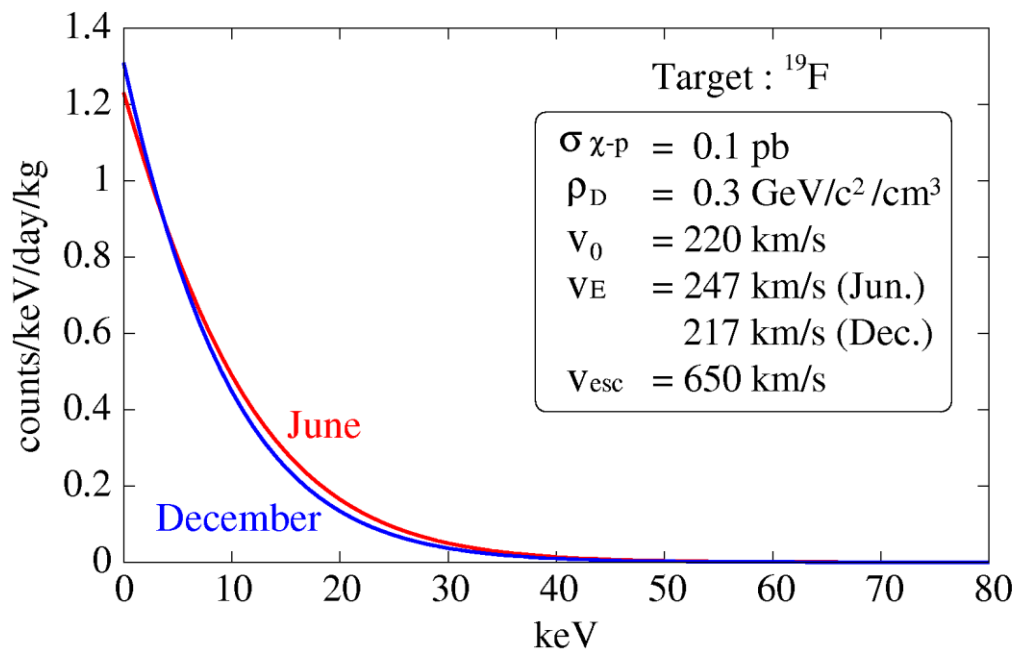
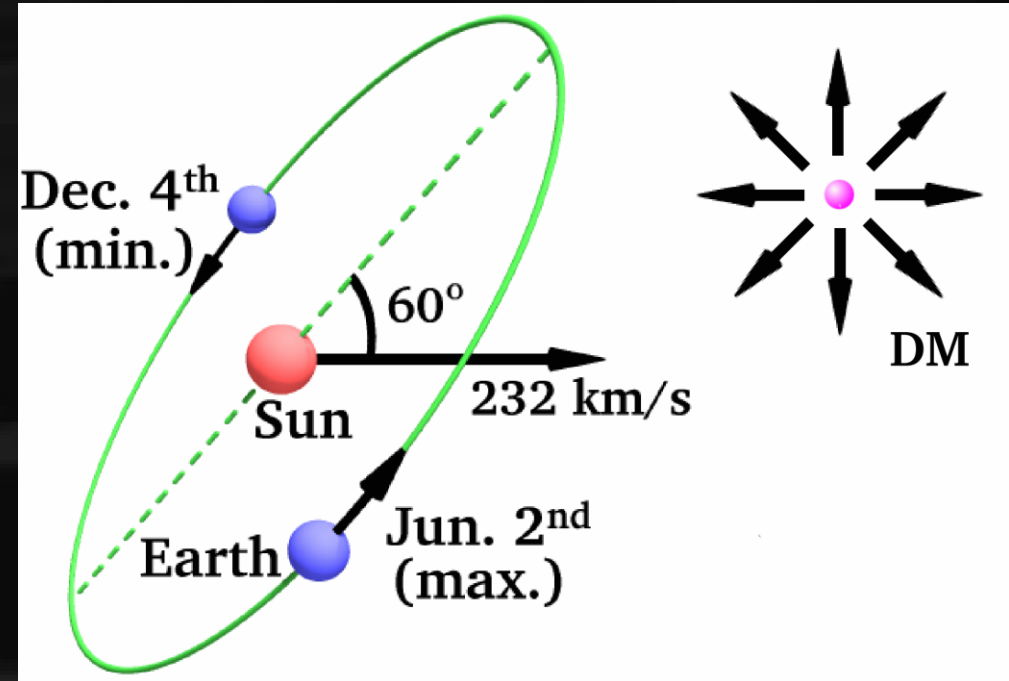
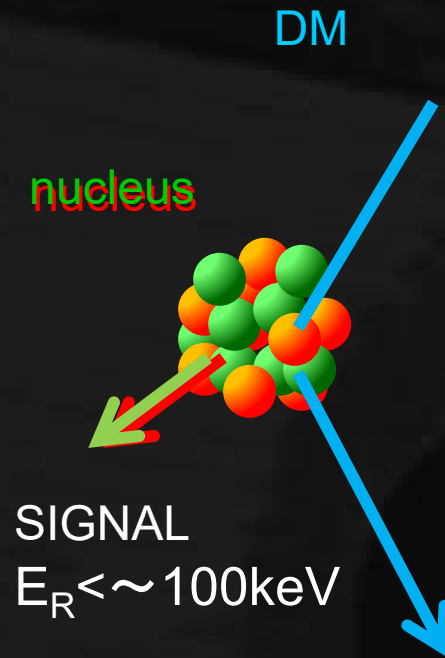
Contents

Physics

NEWAGE



DM direct detection



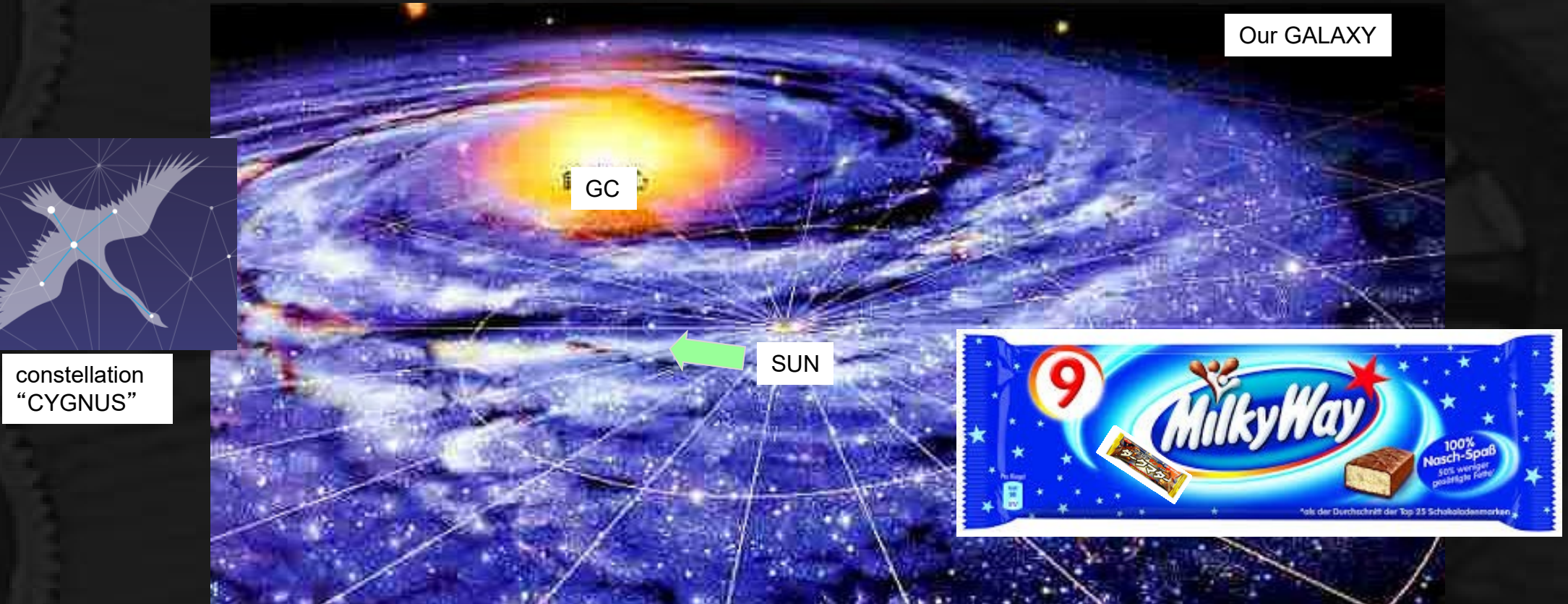
expected direct DM signals

- ① observed * events
- ② energy spectrum
- ③ seasonal modulation
- ④ material dependence
- ⑤ direction-sensitive

A dark, stylized illustration of a hand holding a pen, with the text "Physics cases" overlaid in white. The background is a dark, textured surface, possibly a book cover or a piece of paper, with a large, dark, oval shape in the center. The text is centered within this oval.

Physics cases

Direction-Sensitive Dark Matter Search concept “CYGNUS”



WIMP-WIND from “CYGNUS”

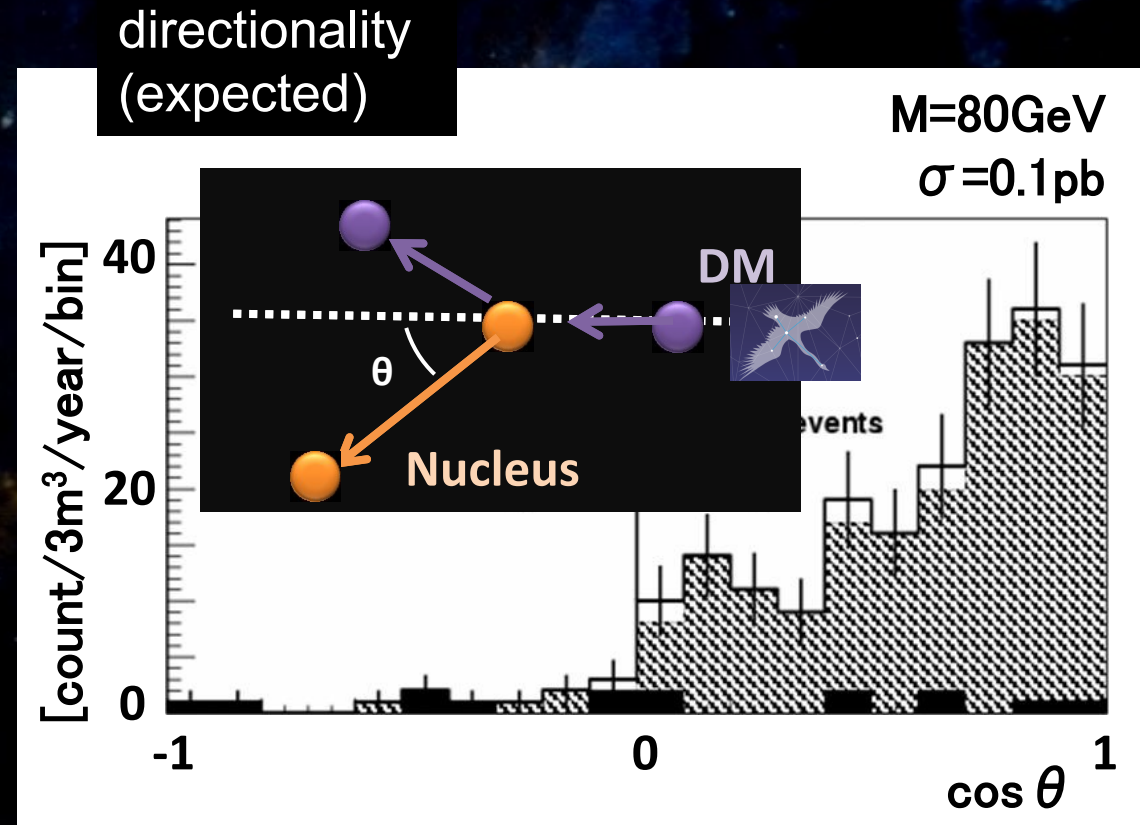
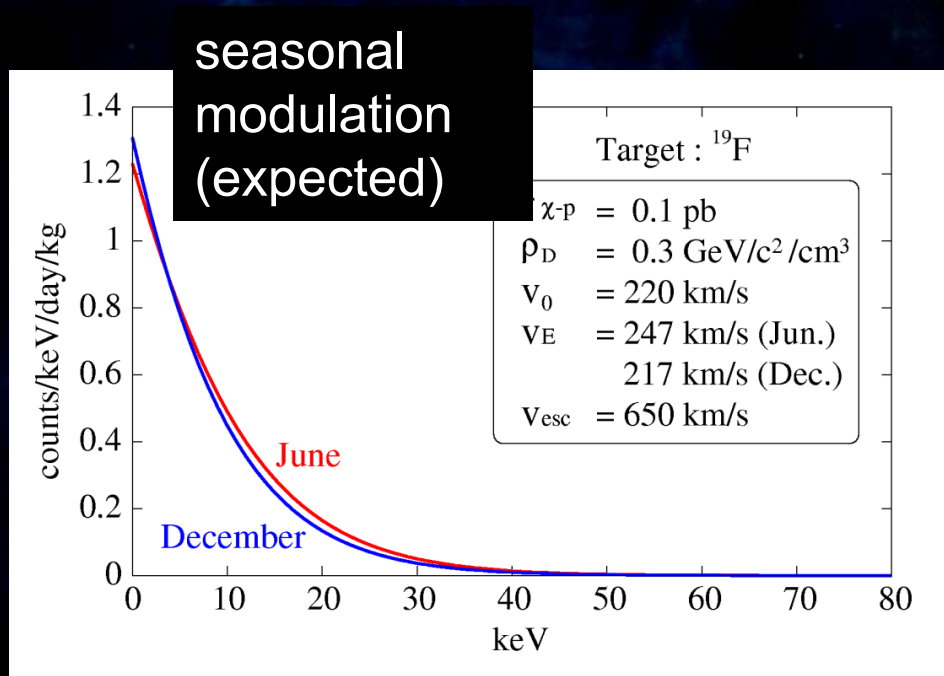
Direction-Sensitive Dark Matter Search concept “CYGNUS”



Direction-Sensitive Dark Matter Search concept “CYGNUS”



"CYGNUS" concept



clear discovery (now: Before Clear discovery)

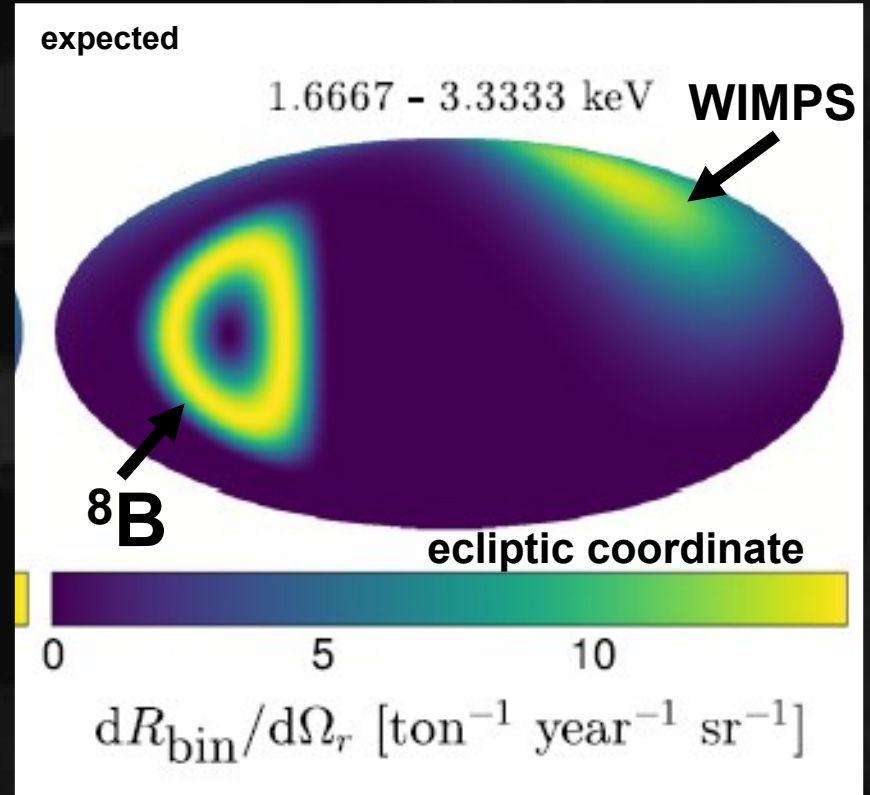
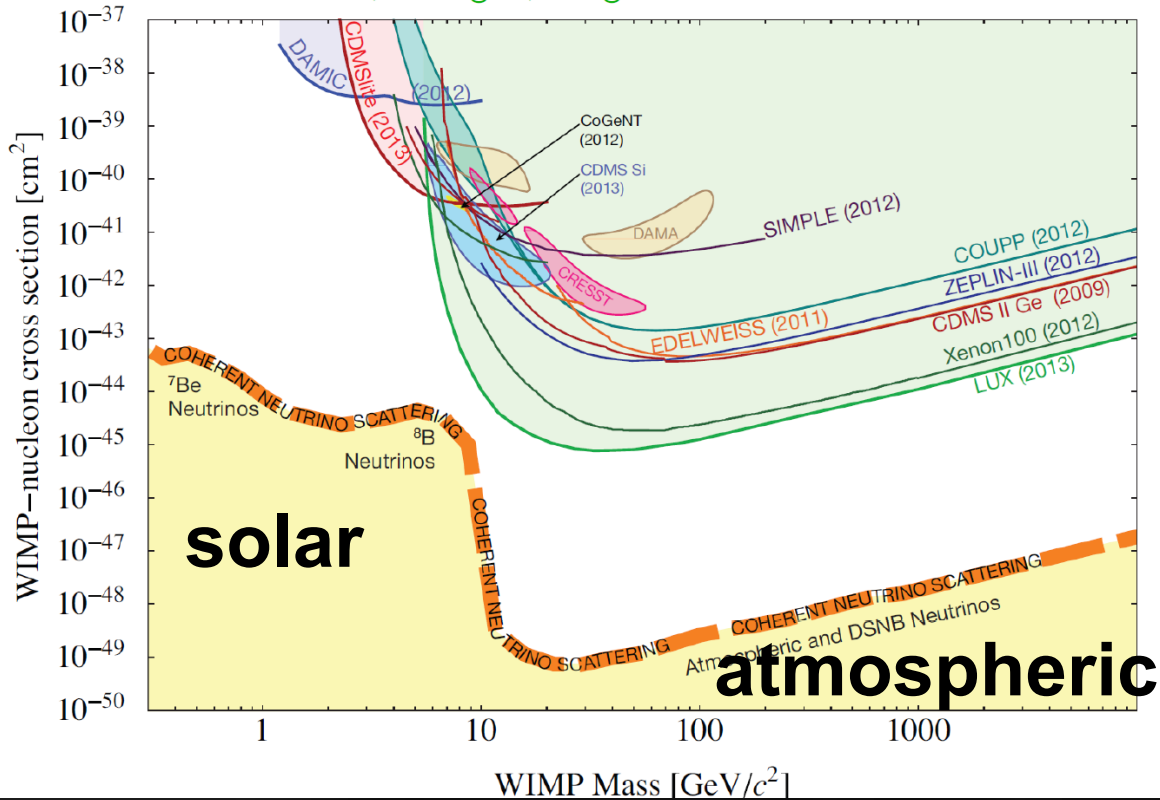
+ study the nature of DM in the After Discovery era

“CYGNUS” physics towards discovery

Potential to search beyond the “neutrino floor”

F. Mayet et al. / Physics Reports 627 (2016) 1–49

J Billard, L Strigari, E Figueroa-Feliciano arXiv:1307.5458



clearly distinguishable
(with low energy recoil detection)

“CYGNUS” physics After Discovery

Test the halo model

standard halo (1-r) + co-rotating halo (r)

arXiv:1707.05523v1

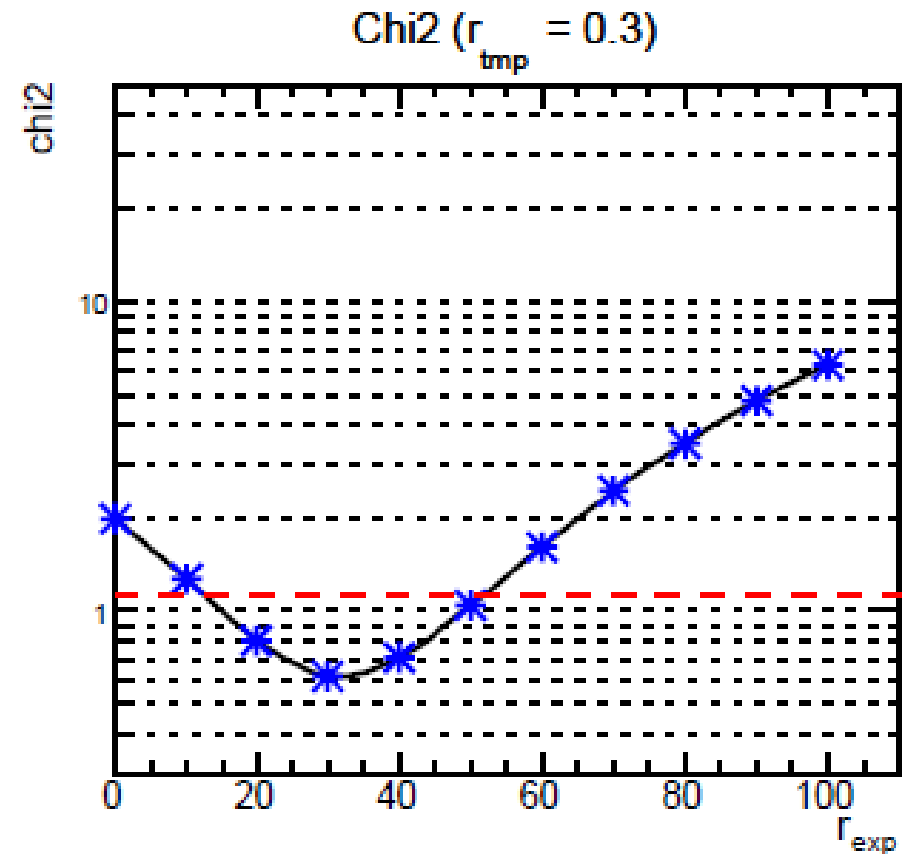
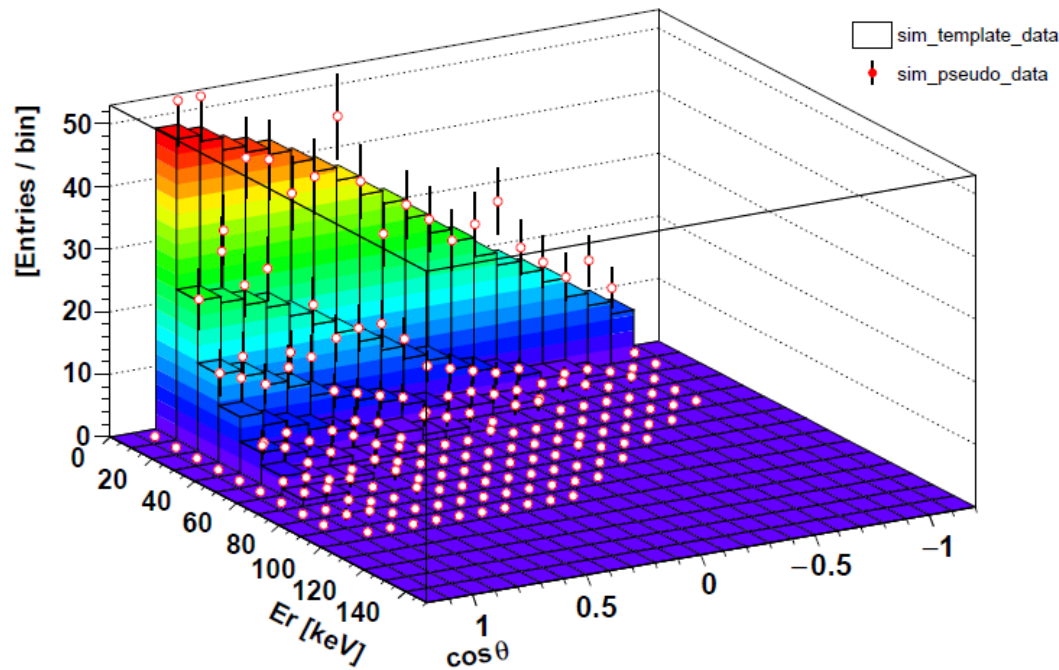
Discrimination of anisotropy in dark matter velocity distribution with directional detectors

Keiko I. Nagao*, Ryota Yakabe†, Tatsuhiro Naka‡, Kentaro Miuchi§

target: F
 $M_{\text{WIMP}}=60\text{GeV}$

standard “spectrum”
in AD era

$r = 0.3$

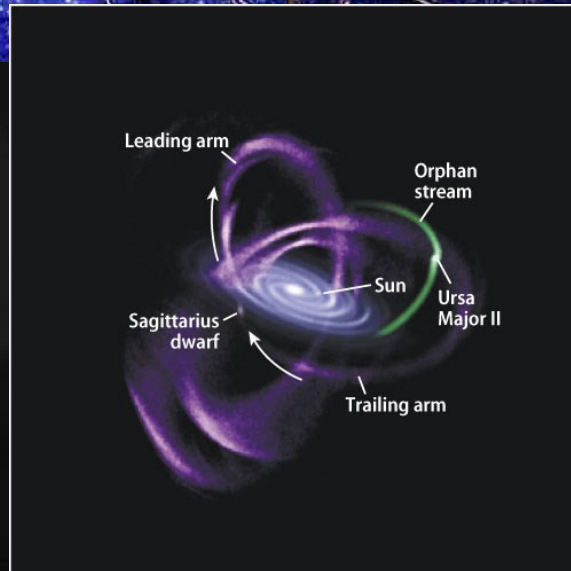
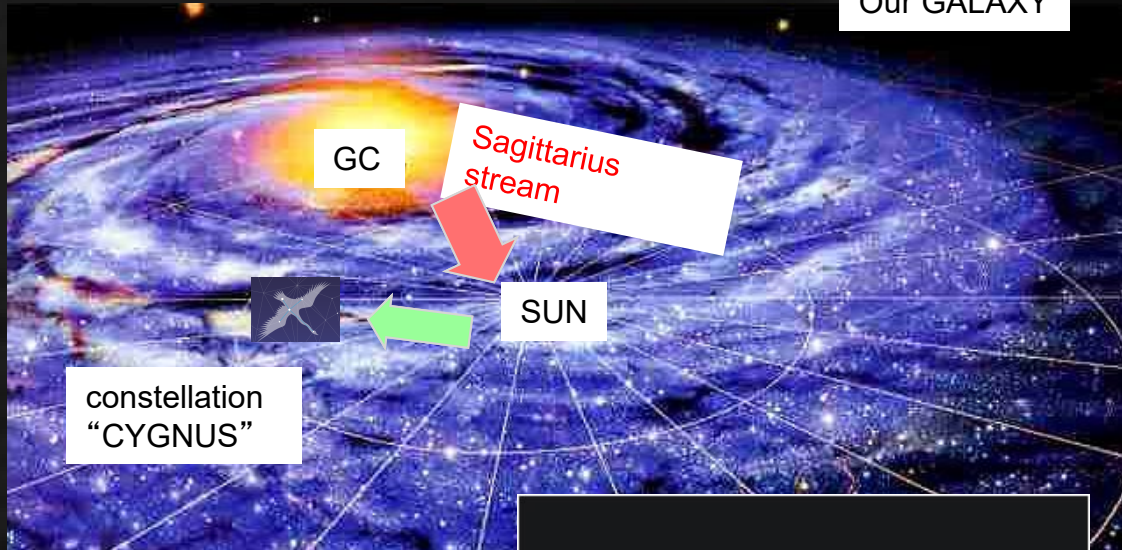


AD "CYGNUS" physics

Test the DM motion

ex. Sagittarius stream

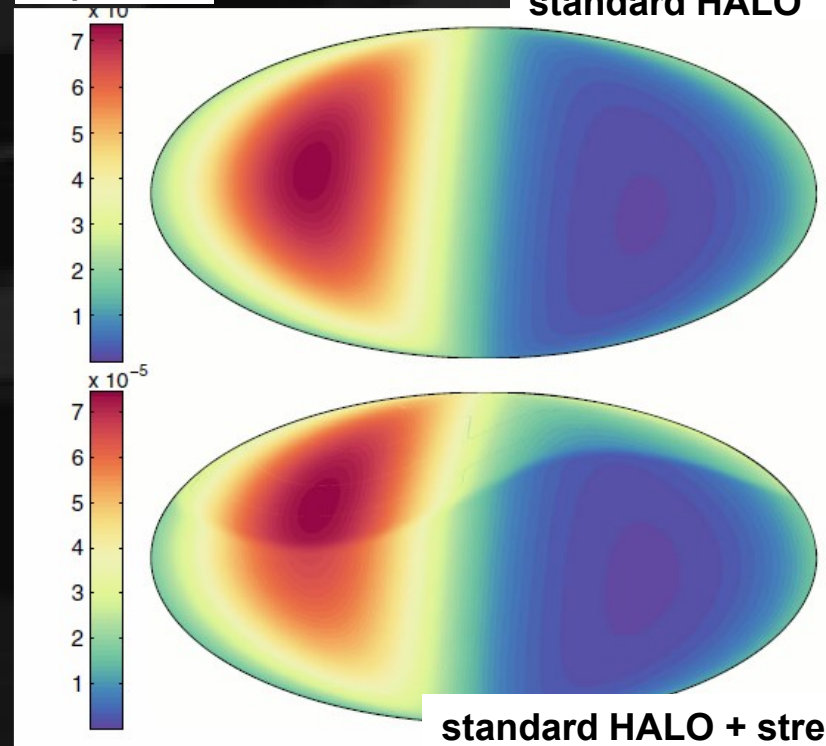
Our GALAXY



PHYSICAL REVIEW D 90, 123511 (2014)

expected

standard HALO



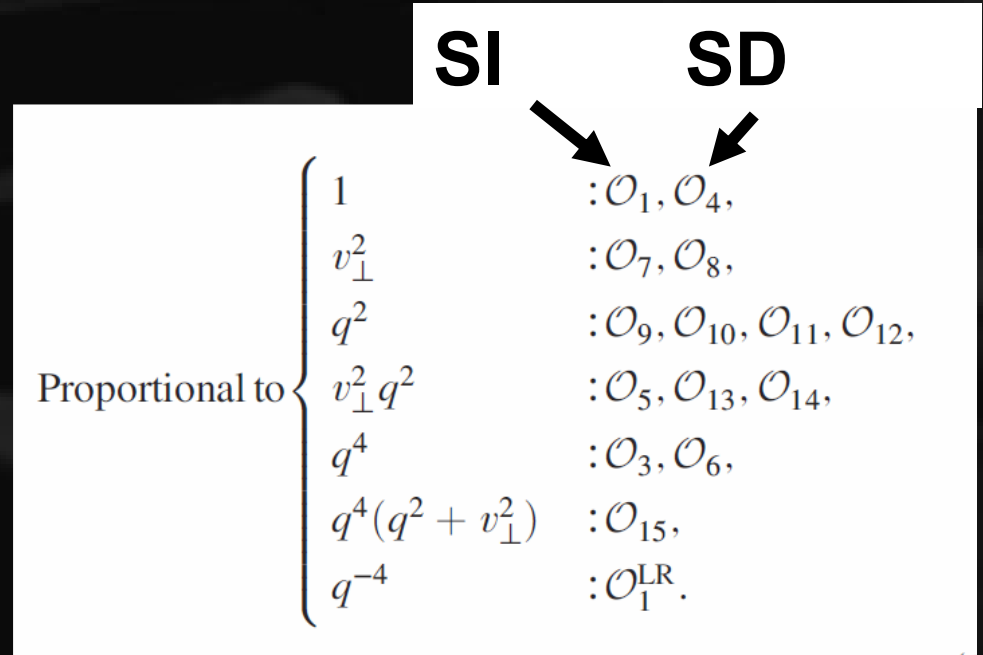
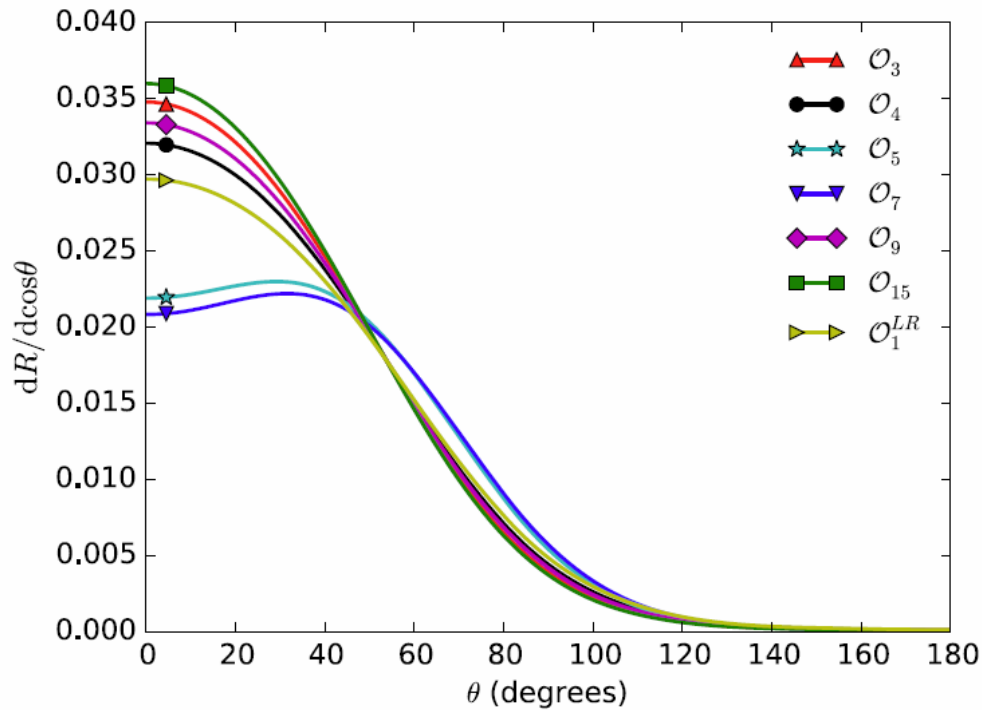
galactic coordinate

streams, halo model...

AD “CYGNUS” physics

Test the interaction by scattering angle

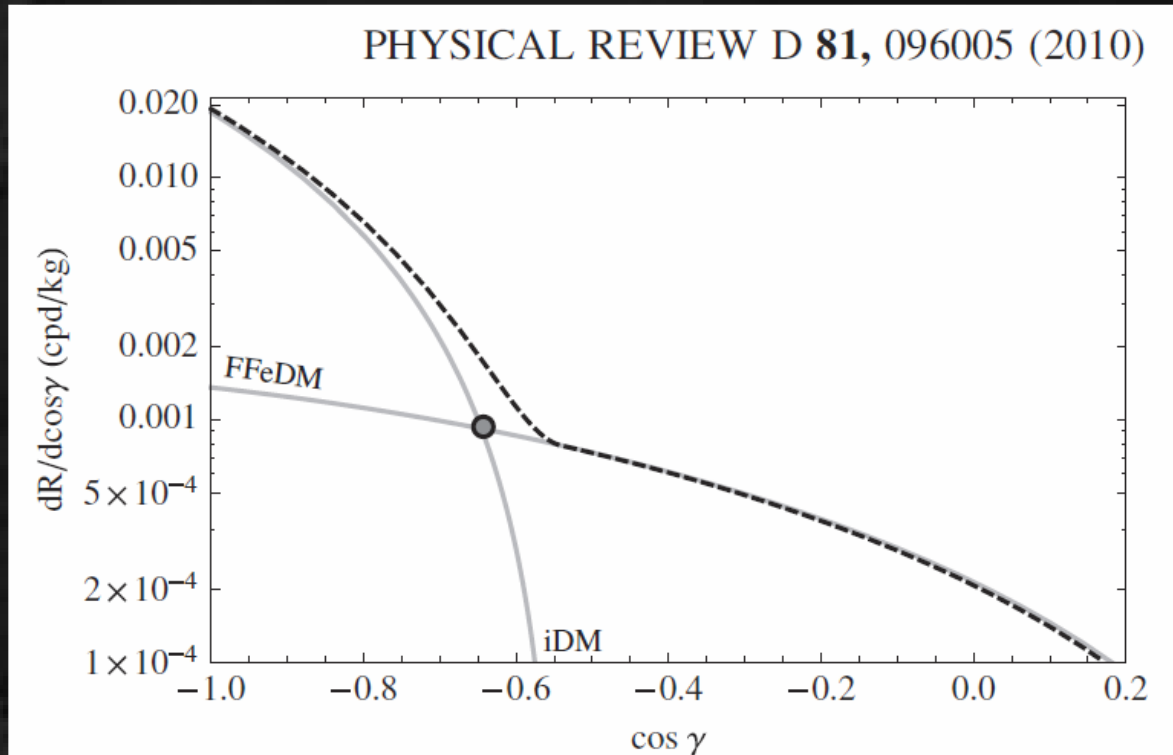
PHYSICAL REVIEW D 92, 023513 (2015)



some operators are distinguishable

AD “CYGNUS” physics

■ Test the interaction by scattering angle ②



- **iDM (inelastic scatterings dark matter) and normal darkmatter (FFeDM (form factor elastic dark matter)) show different angular DISTRIBUTION**

The background is a dark, monochromatic illustration of a hand holding a pen, rendered in shades of gray and black. The hand is positioned as if writing, with the pen held between the fingers. The overall aesthetic is technical and professional.

Experimental Status

Experimental concept

Recoil nuclear track detection $< 100\text{keV}$

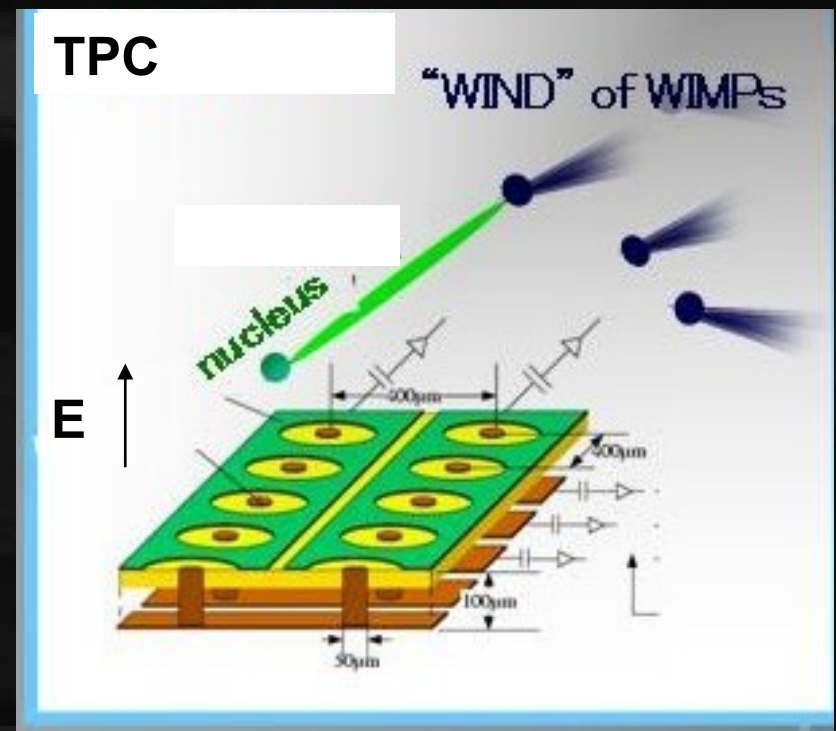
challenge: short track

a few mm in low pressure gas

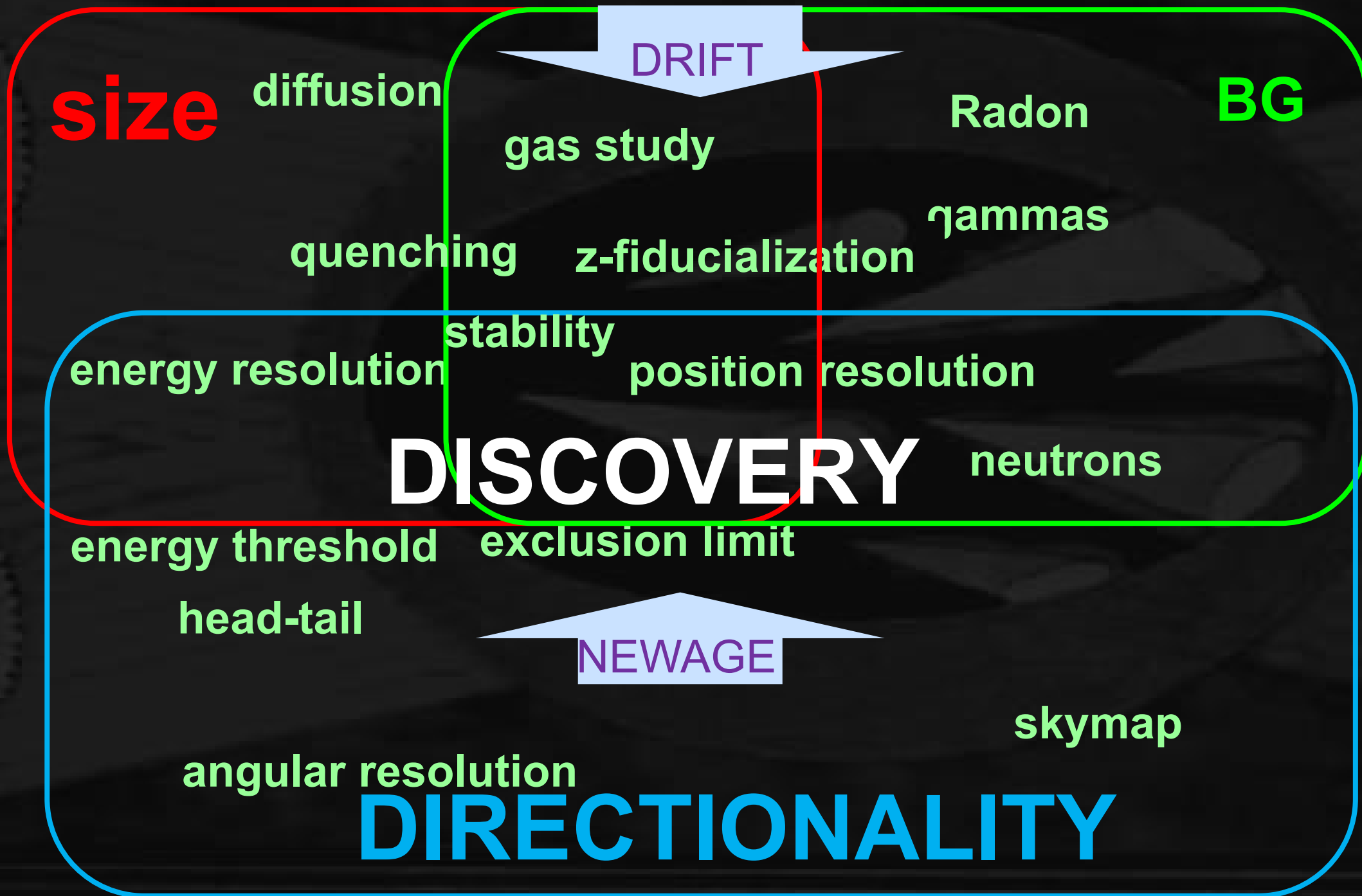
a few 100 nm in solid

Most typical “CYNGUS”:
low pressure gas TPC

2D readout + timing
→ 3D tracking



NEWAGE strategy since its new ages



NEWAGE: always direction-sensitive

New general WIMP search with an Advanced Gaseous tracker Experiment

■ μ -PIC(MPGD) based TPC

■ 3-D tracks SKYMAP

■ CF_4 gas for SD search

■ Proposal PLB 578 (2004) 241

■ First direction-sensitive limits

PLB654 (2007) 58

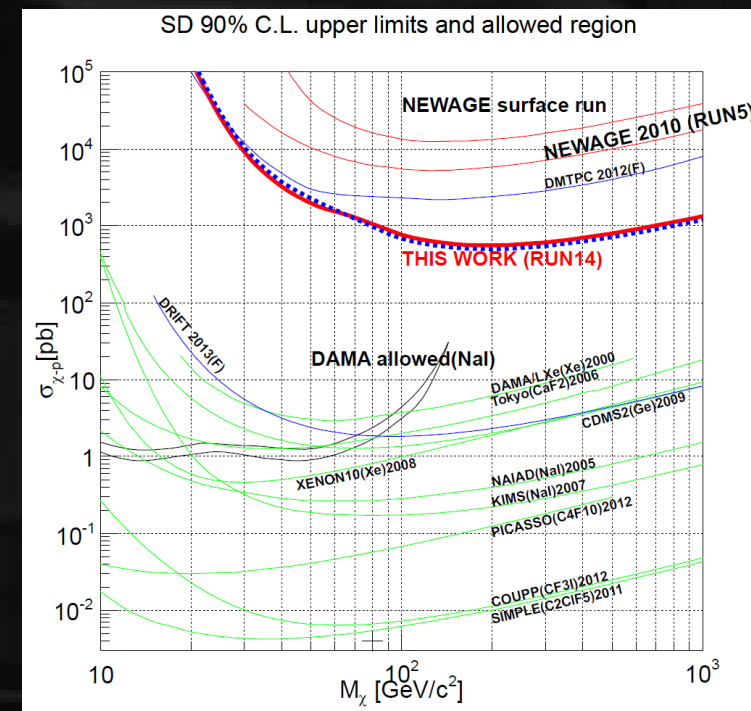
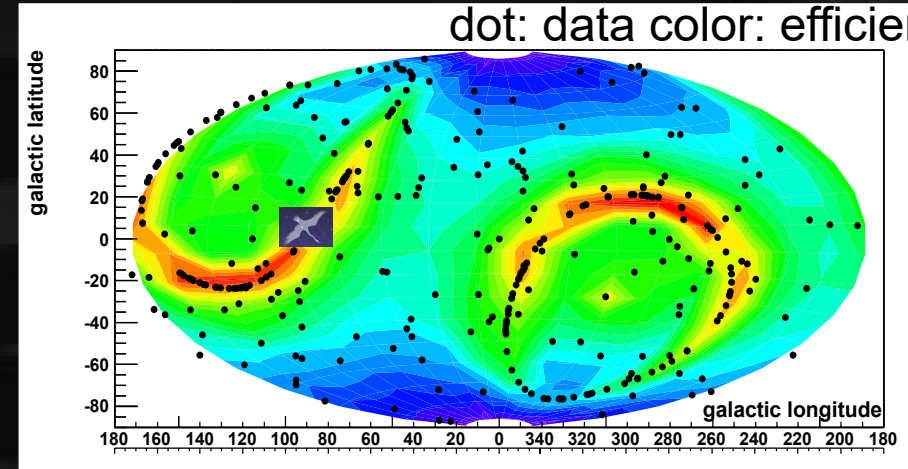
■ Underground results

PLB686 (2010) 11, PTEP (2015) 043F01s

■ Phase for “low BG detector”

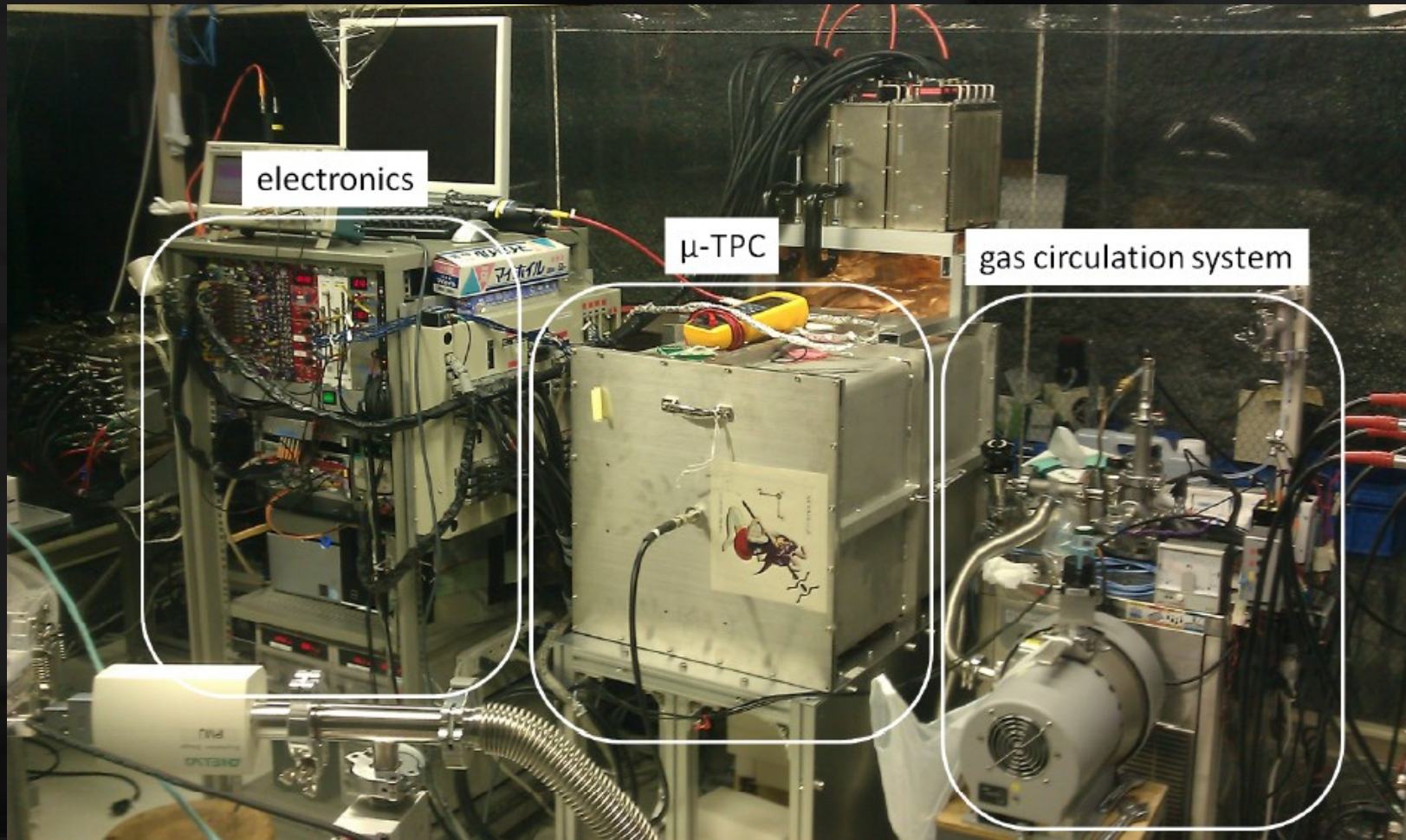
SKYMAP (measured DATA)

dot: data color: efficiency



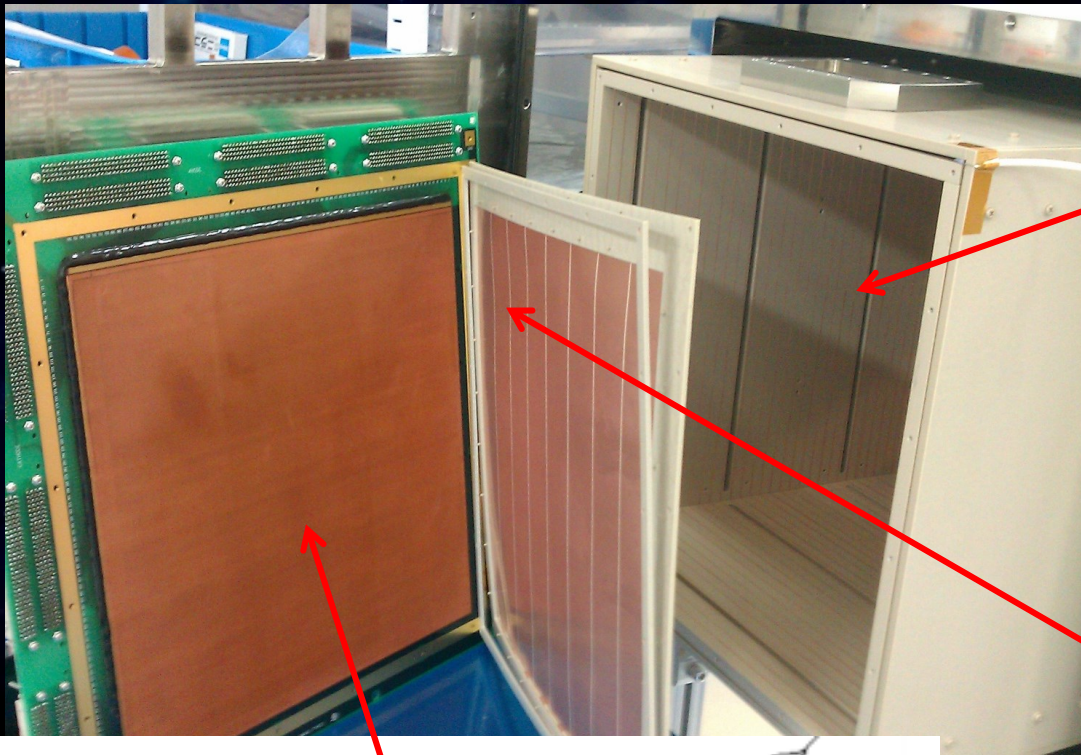
NEWAGE detector

- **NEWAGE-0.3b'**
- **Detection Volume: $31 \times 31 \times 41 \text{cm}^3$**
- **Gas: CF₄ at 0.1atm (50keVee threshold)**
- **Gas circulation system with cooled charcoal**

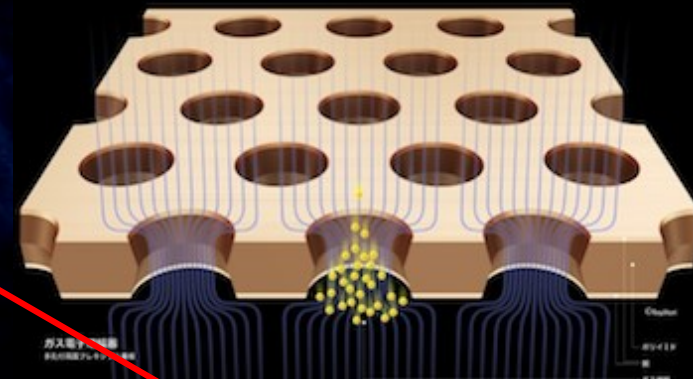


NEWAGE-0.3b' inside view

Detection Volume: $30 \times 30 \times 41 \text{cm}^3$

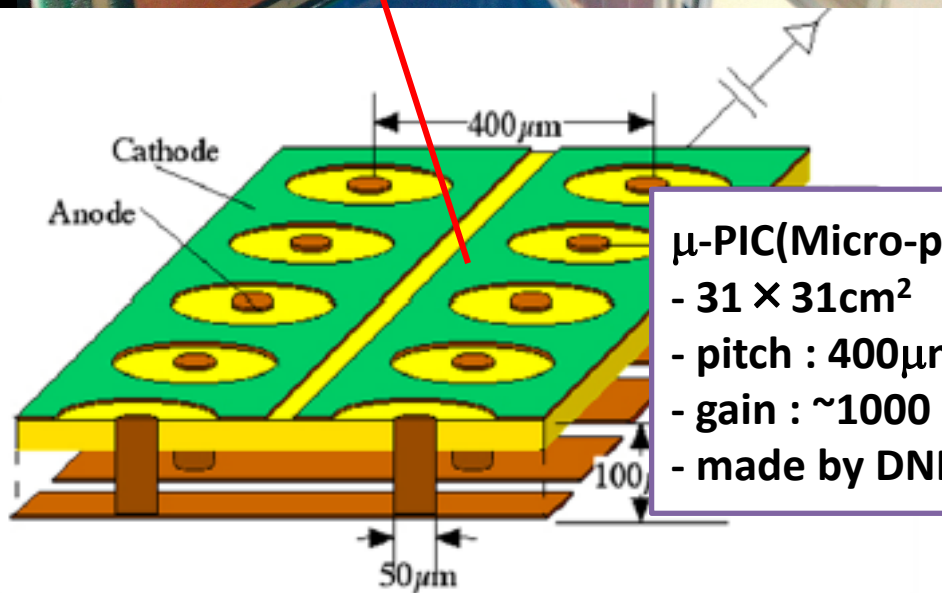


Field cage
Drift length: 41cm
PEEK + copper wires



GEM

- $31 \times 32 \text{cm}^2$
- 8-segmented
- hole pitch : $140 \mu\text{m}$
- hole diameter: $70 \mu\text{m}$
- insulator : LCP $100 \mu\text{m}$
- gain : ~ 5
- made by Scienergy, Japan



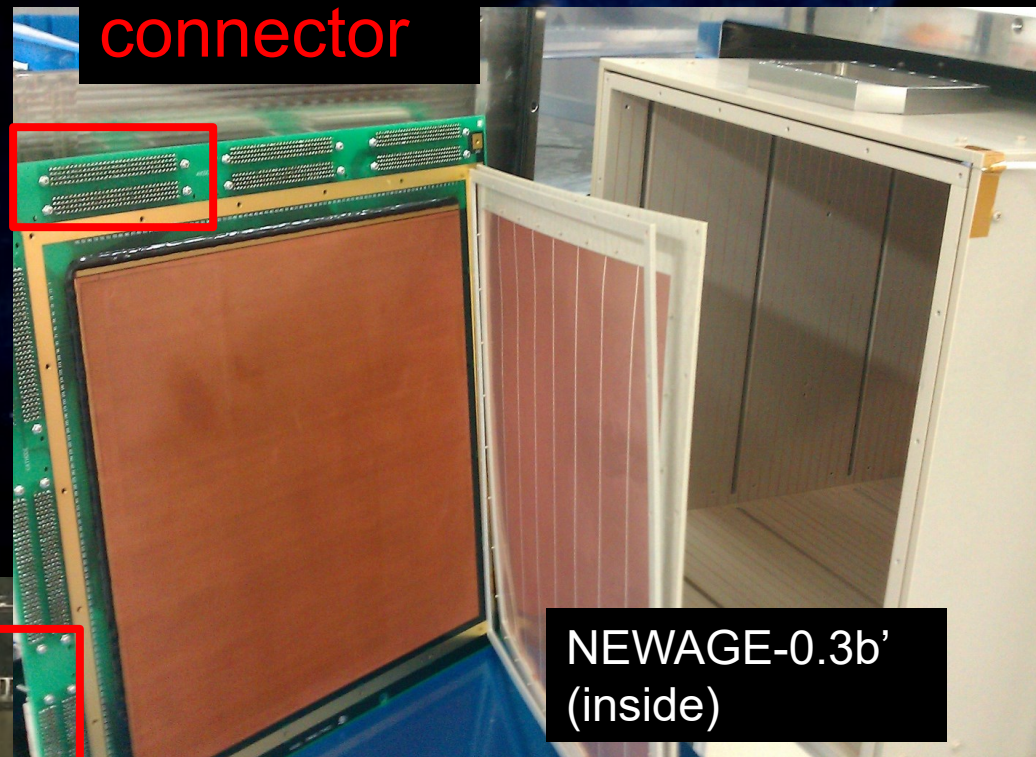
μ-PIC(Micro-pixel chamber)

- $31 \times 31 \text{cm}^2$
- pitch : $400 \mu\text{m}$
- gain : ~ 1000
- made by DNP, Japan

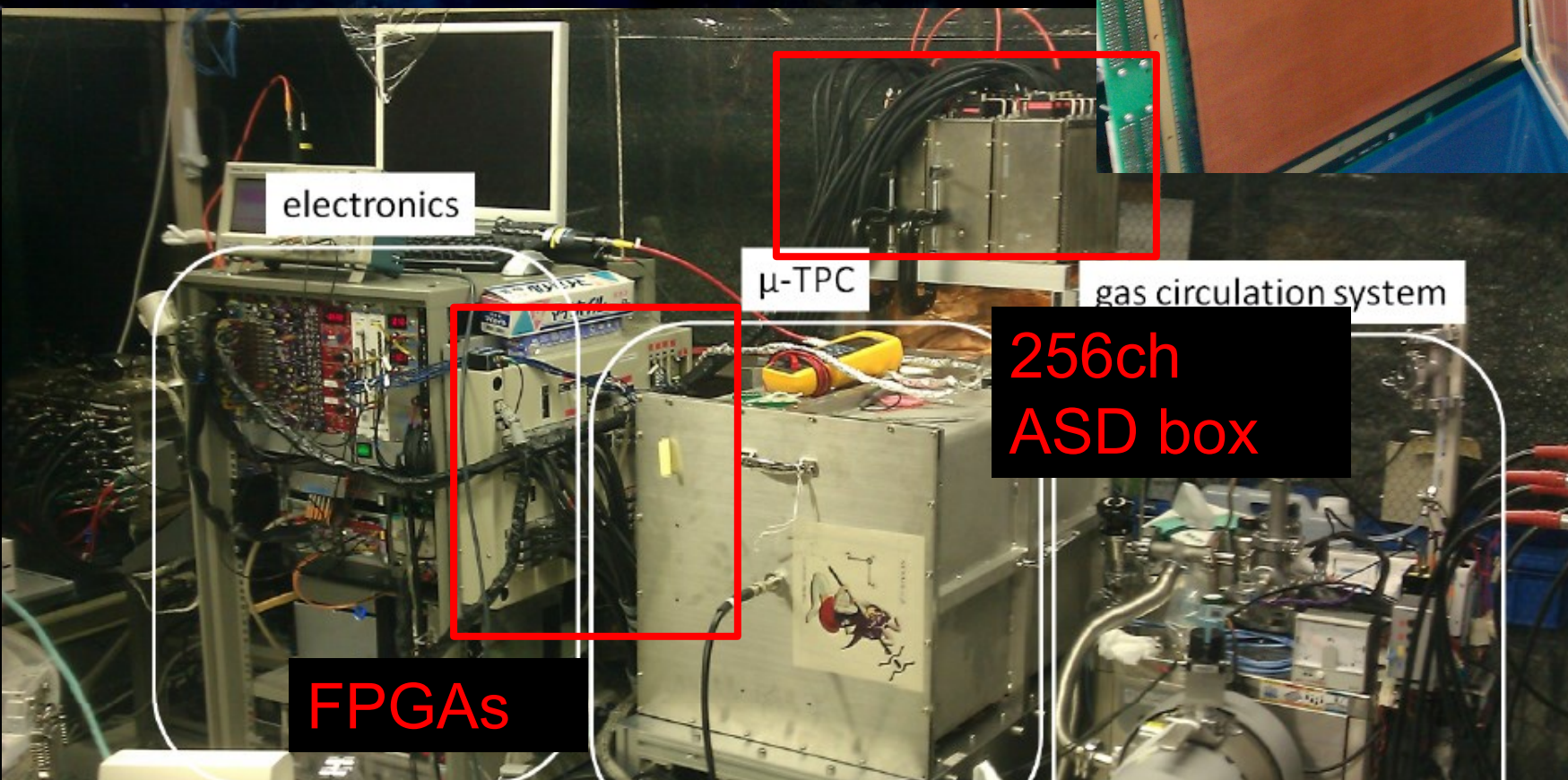
NEWAGE-0.3b' readouts

- μ -PIC is X-Y readout
- ALTAS TGC ADS chips
- General purpose FPGA-based electronics since early 2000's

256ch
connector



NEWAGE-0.3b'
(inside)

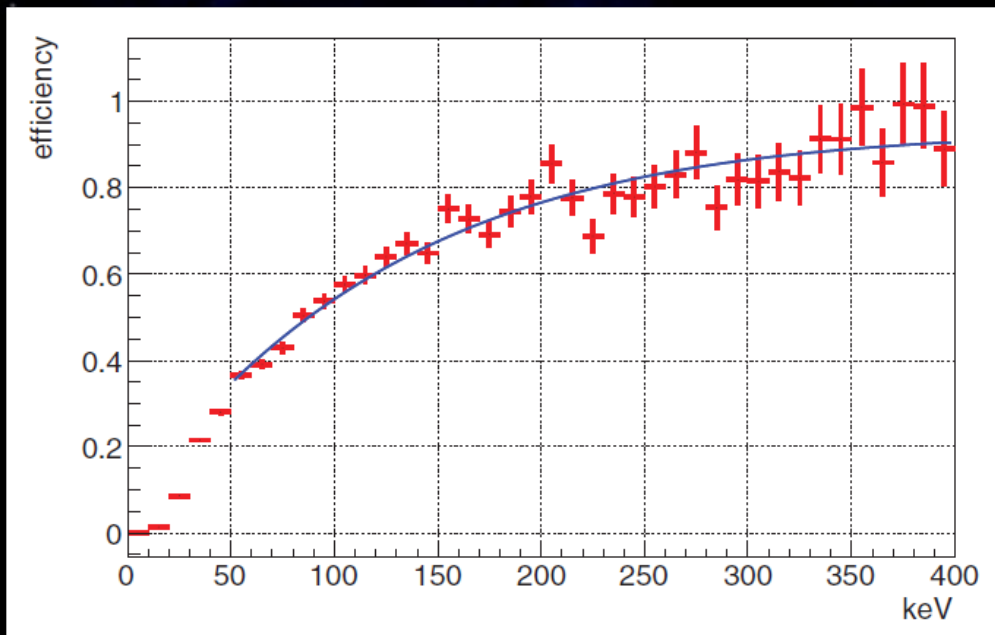


NEWAGE-0.3b' performance

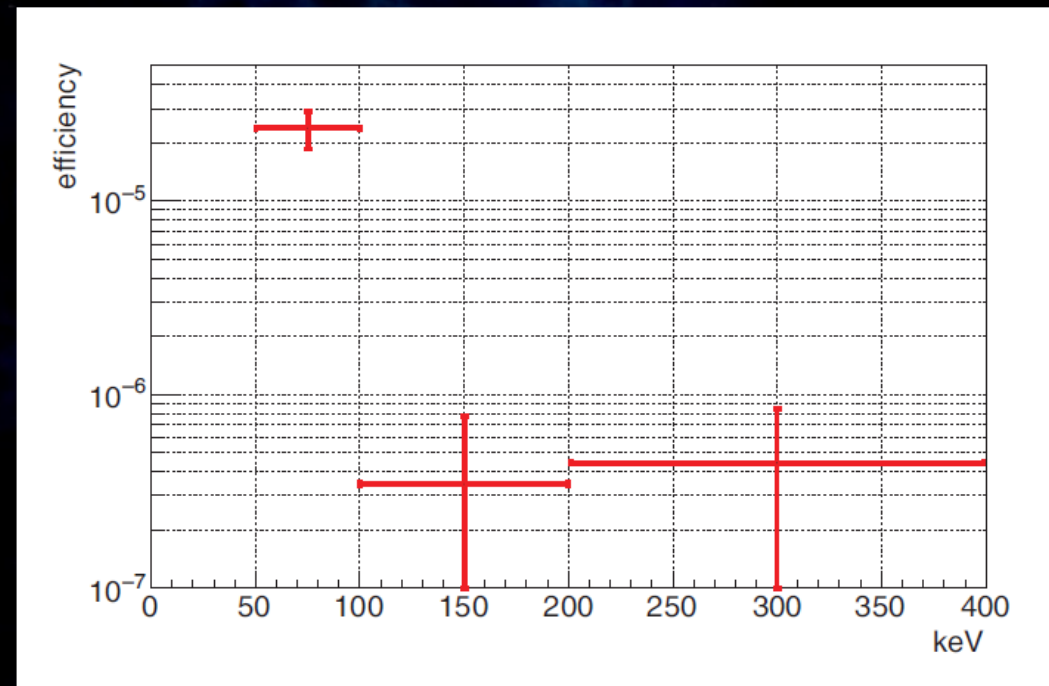
PTEP (2015) 043F01s

- nuclear track detection efficiency: 40% @50 keVee
- gamma rejection: $2.5e-5$ @ 50keVee
- energy resolution: 7.8keV σ @50keVee
- angular resolution: 40° σ @ 50keVee

nuclear track detection efficiency



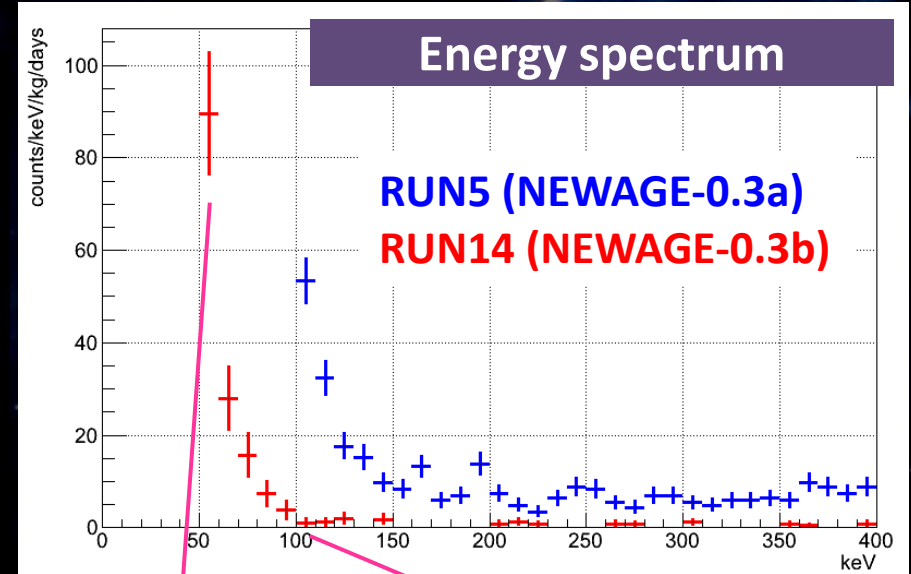
electron track detection efficiency
(gamma rejection factor)



NEWAGE underground run

RUN14

- period : 2013/7/20-8/11, 10/19-11/12
- live time : 31.6 days
- fiducial volume : $28 \times 24 \times 41 \text{cm}^3$
- mass : 10.36g
- exposure : 0.327 kg·days

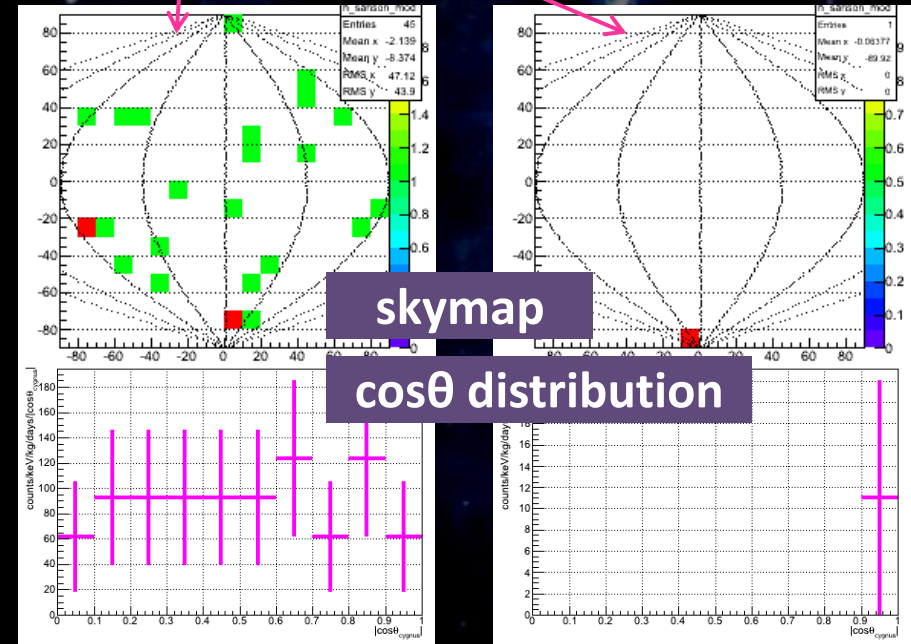


Energy spectrum

- Threshold : 100 => **50keV**
- BG rate : **1/10**@100keV

Skymap, $\cos\theta$ distribution

- Set limit by significant difference in 2-binned measured $\cos\theta$ and DM-wind simulated $\cos\theta$



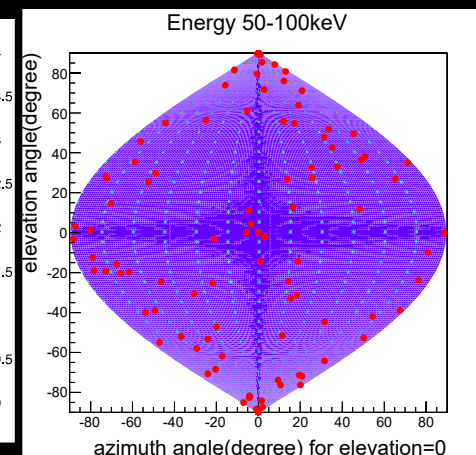
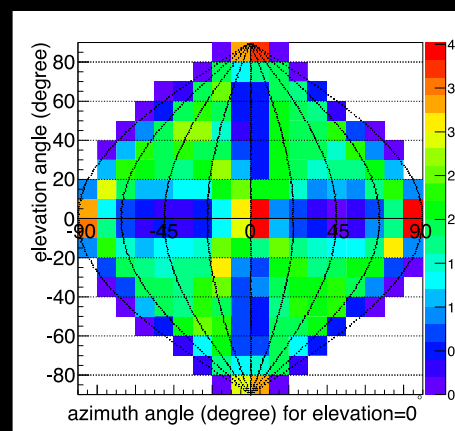
50-60keV

100-110keV

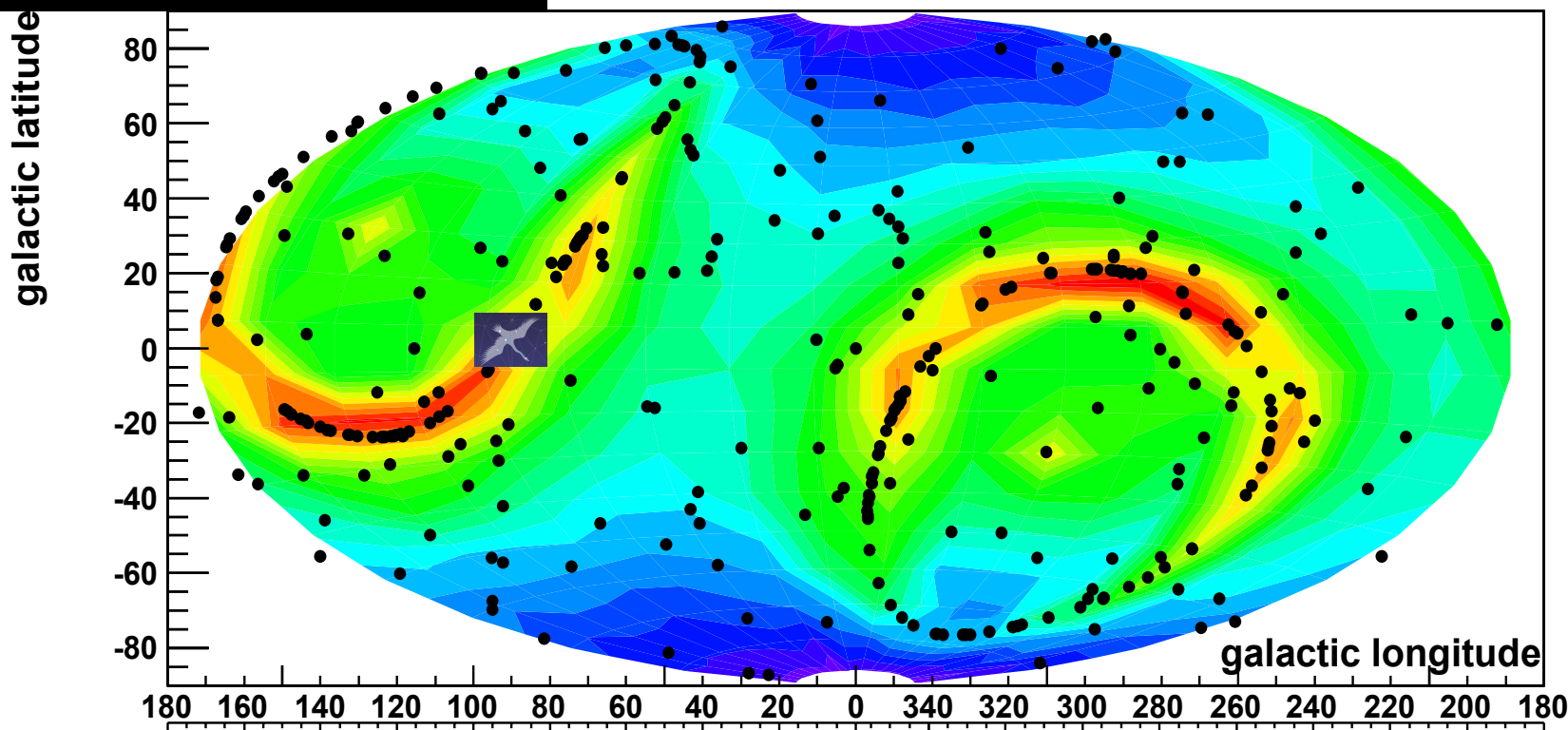
Galactic-plane sky-map

correlation with efficiency
= consistent with isotropic

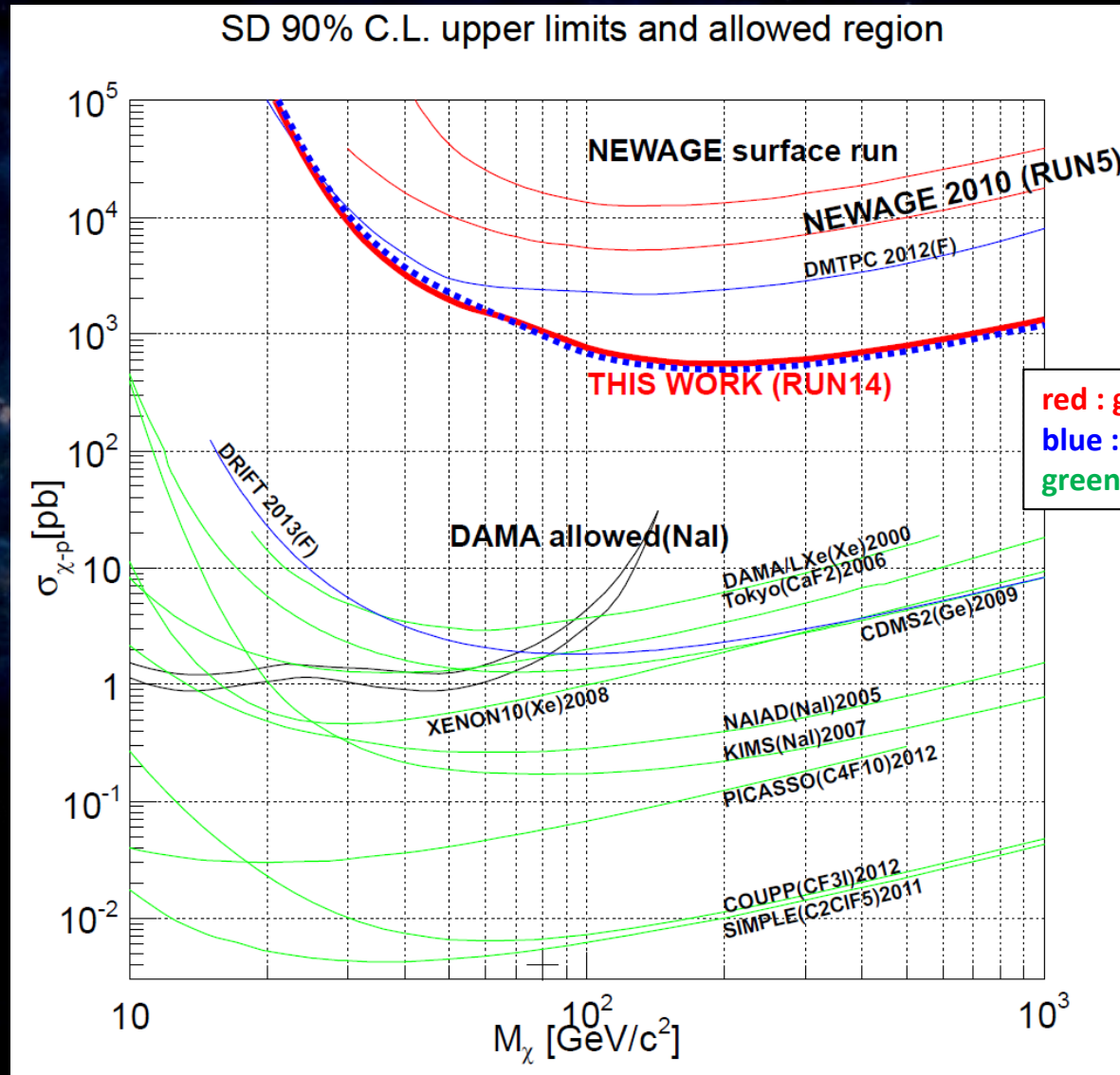
lab-coordinate



galactic coordinate



Direction-sensitive limit (NEWAGE2015)



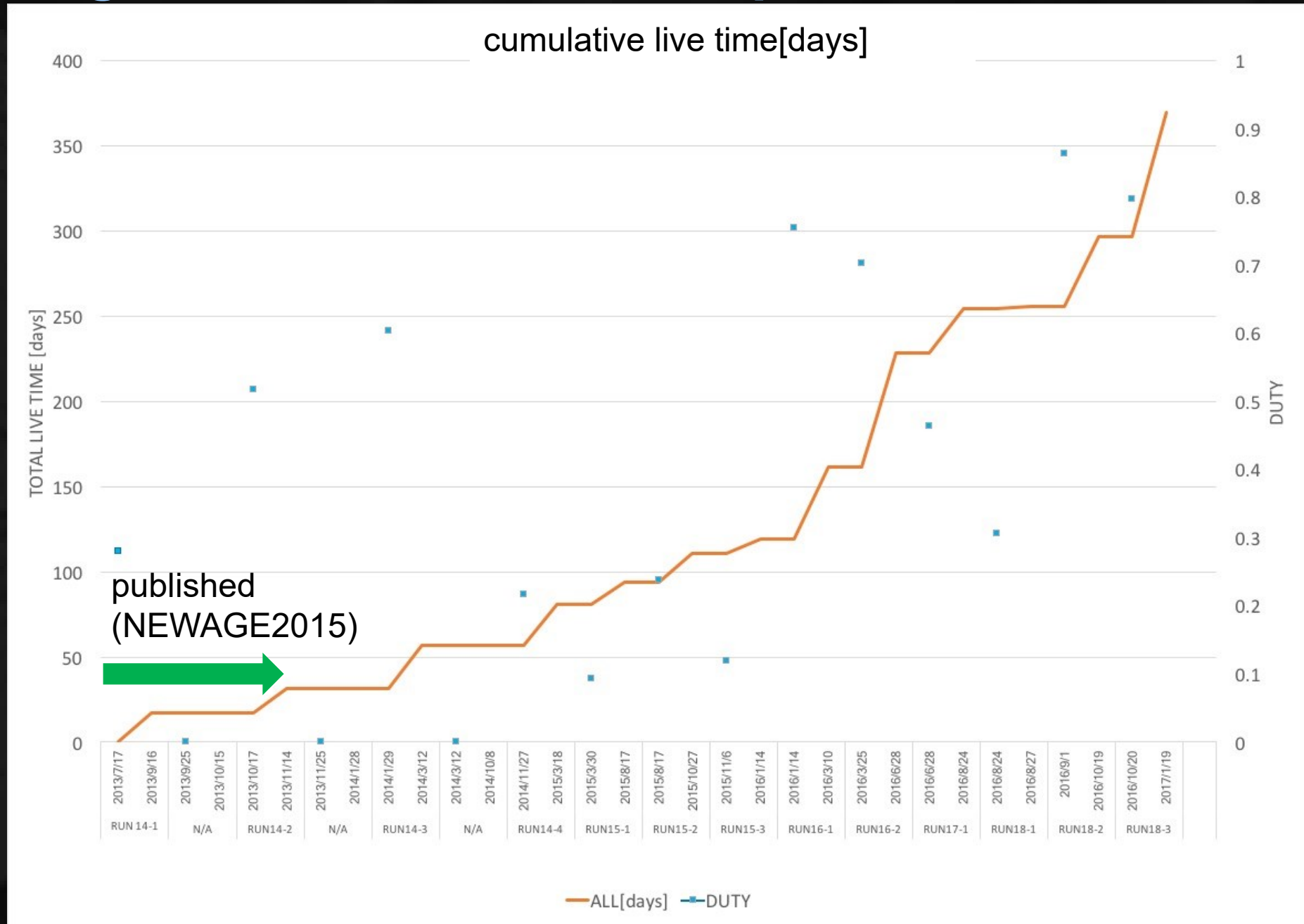
PTEP (2015) 043F01s

- Obtained limit : **557pb @200GeV**
(Best direction-sensitive limit)

A dark, stylized illustration of a hand holding a pen, with the text "Recent works" overlaid in white. The background is a dark, textured surface, possibly a book cover or a piece of paper, with a large, dark, oval shape in the center. The text is centered within this oval shape.

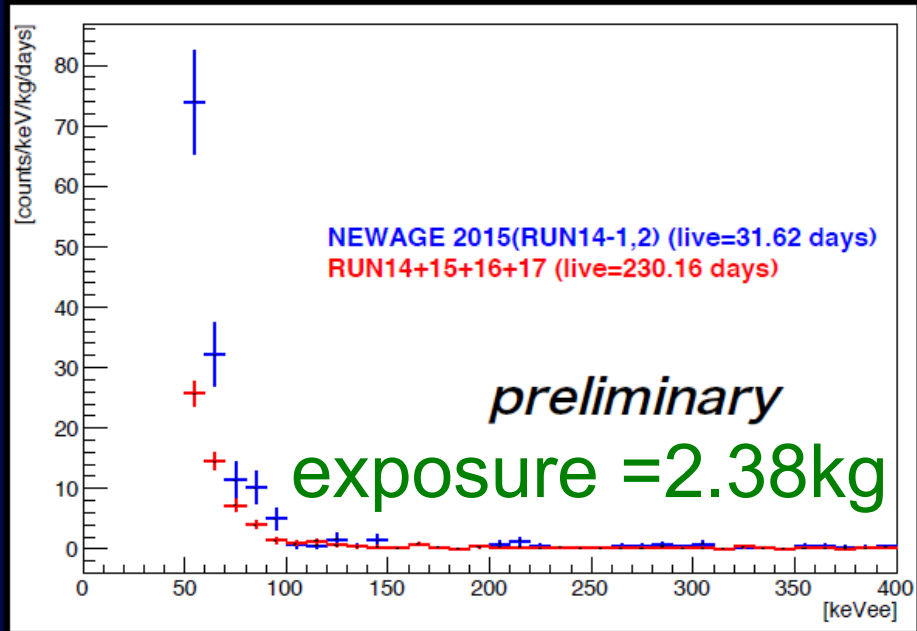
Recent works

Underground measurement updates

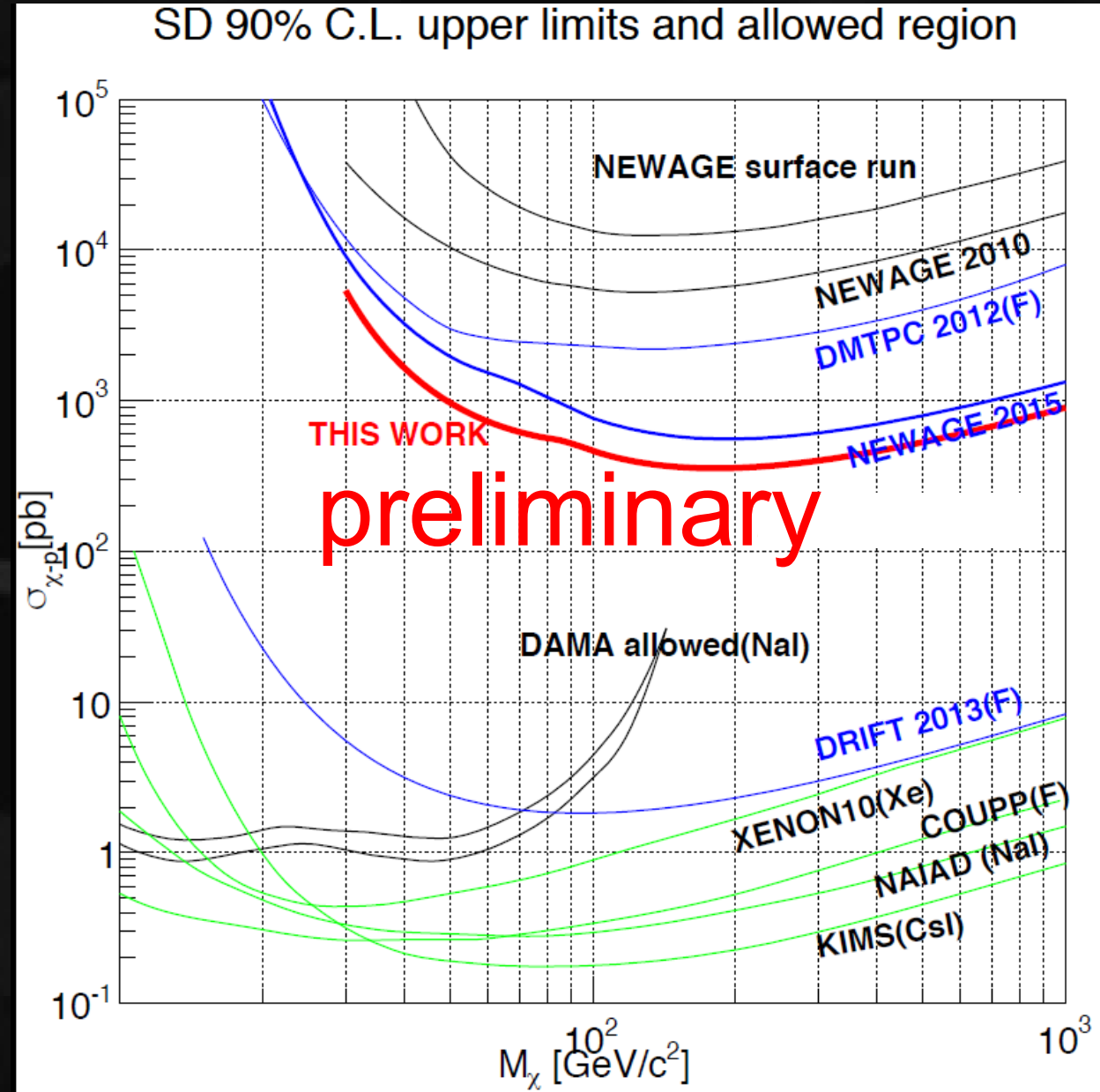


30 live-days → > 300 live days

■ sensitivity improvements



- analysis updates
- statistics increase
- $\times 2$ sensitivity improvements



Head/Tail study

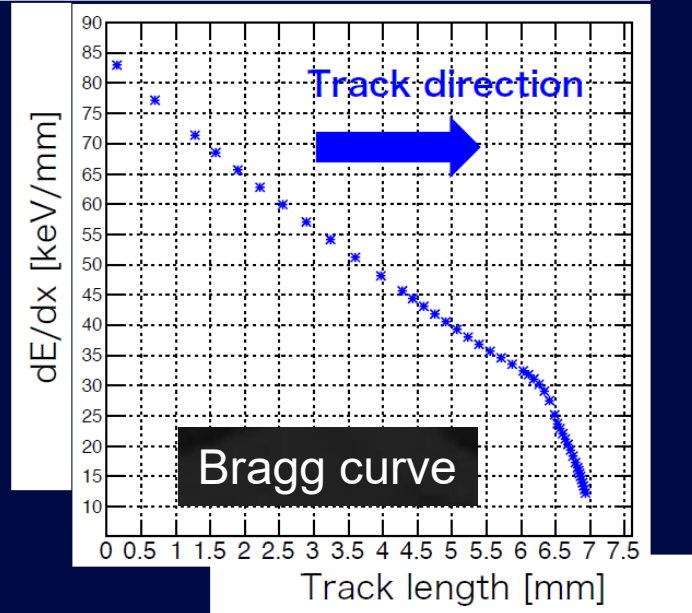
JPS Conf. Proc. 11, (2016) 040002

■ **Bragg curve**

■ **statistical discussion**

→ **event by event recognition**

SRIM Simulation
CF₄ : 0.1 atm, F 500keV



● Head-tail parameter

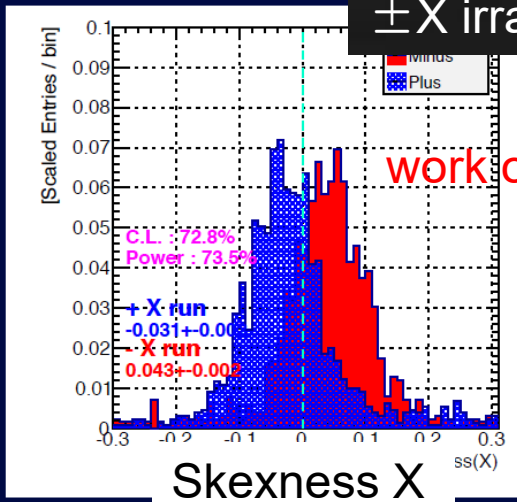
$$skewness = \frac{m_3}{m_2^{3/2}}$$

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

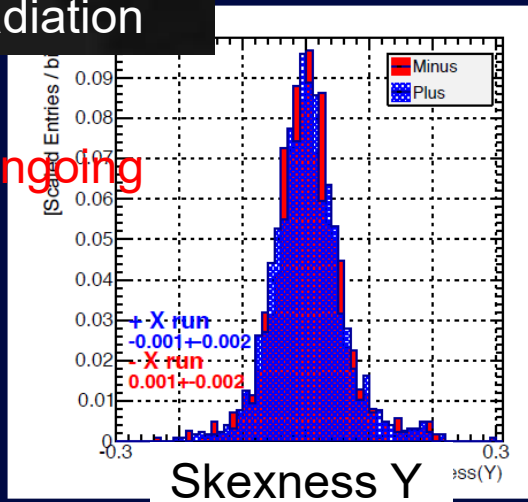
$$\langle x \rangle = \int_{min}^{max} dx \frac{x \cdot TOT(x)}{\int TOT(x) dx}$$

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

± X irradiation



work ongoing



CF4 0.1atm
252Cf run
200-400keV

length_y/length_X < 0.87
Skewness X
Power ~ 70 %

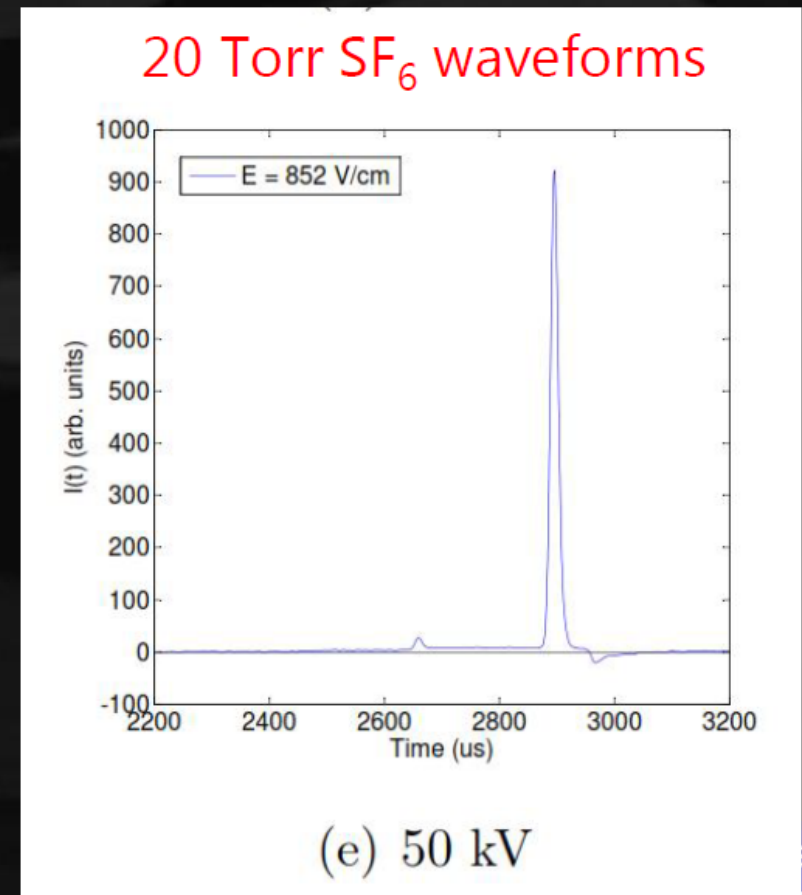
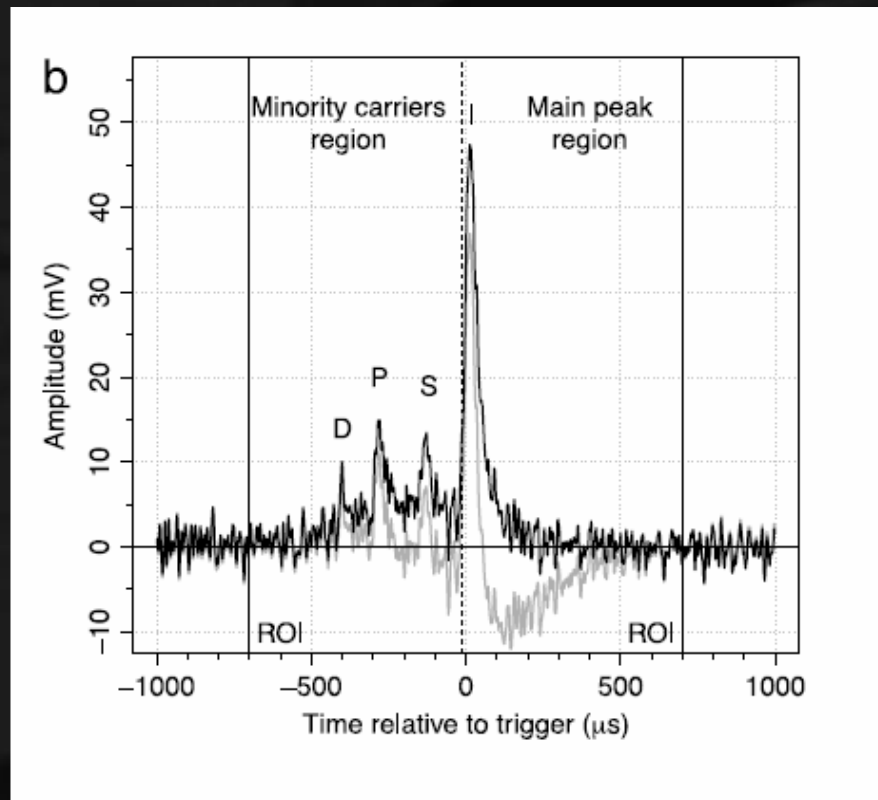
event by event

■ **NEXT:**
low energy
3D Head/Tail

Z-fiducialization

- minority peaks “discovery” by DRIFT group
- First with CS_2 , then with SF_6

minority peaks (DRIFT group)



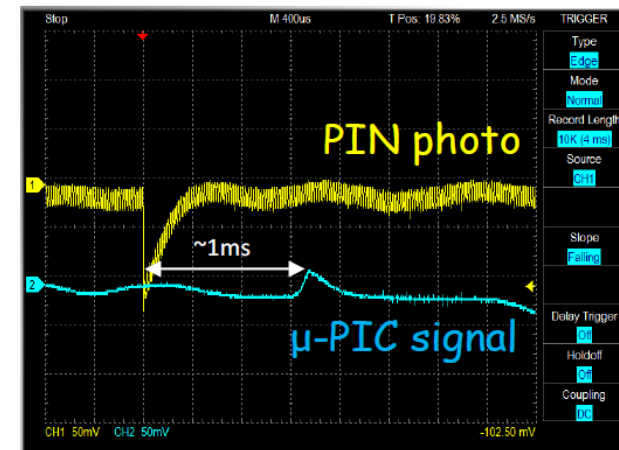
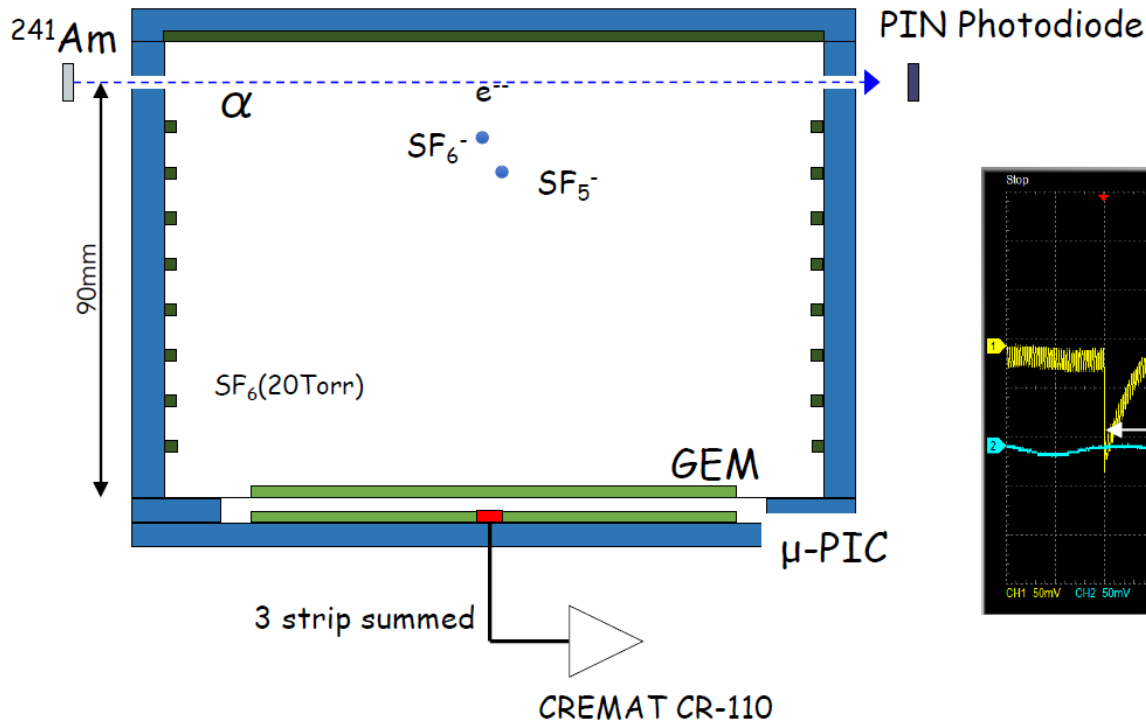
NEWAGE SF₆ study

■ SF₆ study for GEM+μPIC system

■ Wide dynamic-range ASIC development

- Minority carrier search using ²⁴¹Am α source
 - Drift length : 9cm
 - Electric field : 550V/cm
 - Signal of PIN Photodiode was used trigger

T. Ikeda @
CYGNUS2017



ation Sensitive
WIMP-search

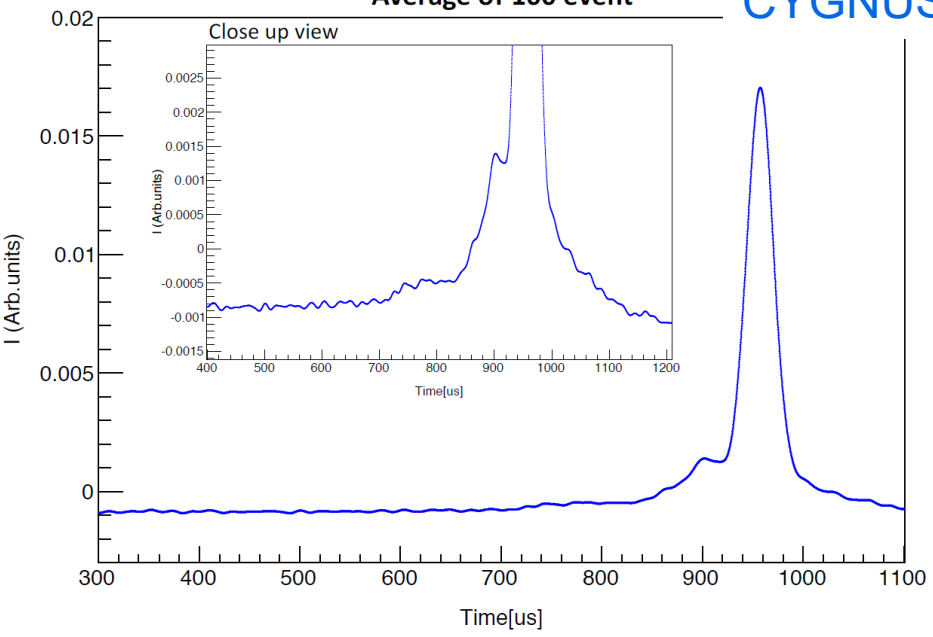
NEWAGE

Z-Position Resolution

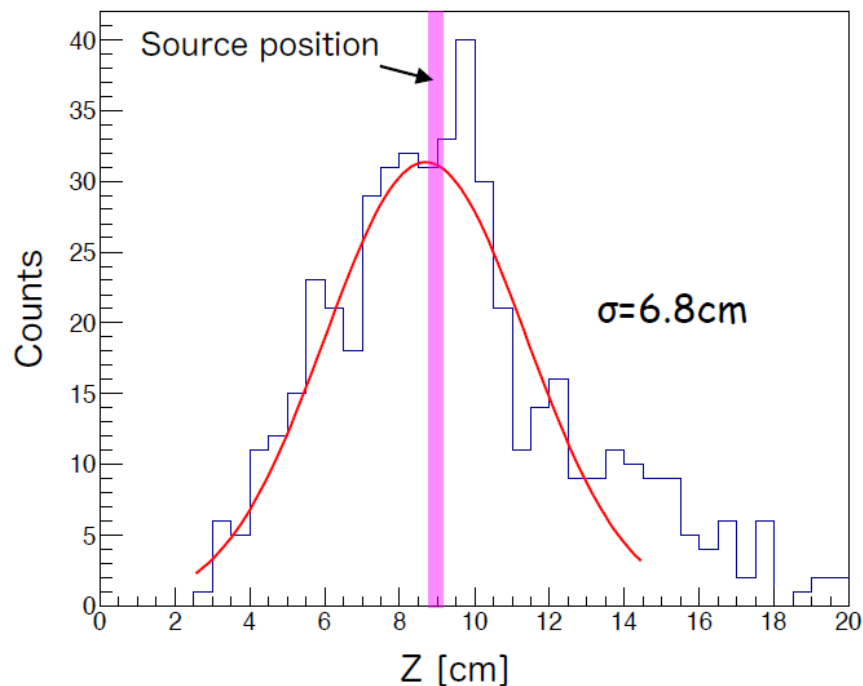
Waveform Feature

T. Ikeda @
CYGNUS2017

Average of 100 event



Z distribution



- Z-position resolution : 6.8cm(σ)
- Succeed demonstration
- Not investigate dependency of electric field yet
 - constrained by discharge

Electronics

- Using analog and digital board made by KEK for Liquid Argon detector

Analog Board (64ch RO)

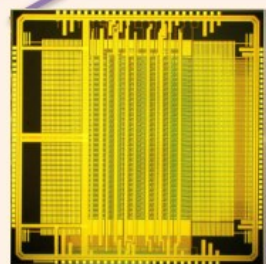
Digital Board (64ch RO)

cathode 32ch
(ID109~140)

anode 32ch
(ID109~140)

trigger(cathode ID107,108)

Ethernet → PC



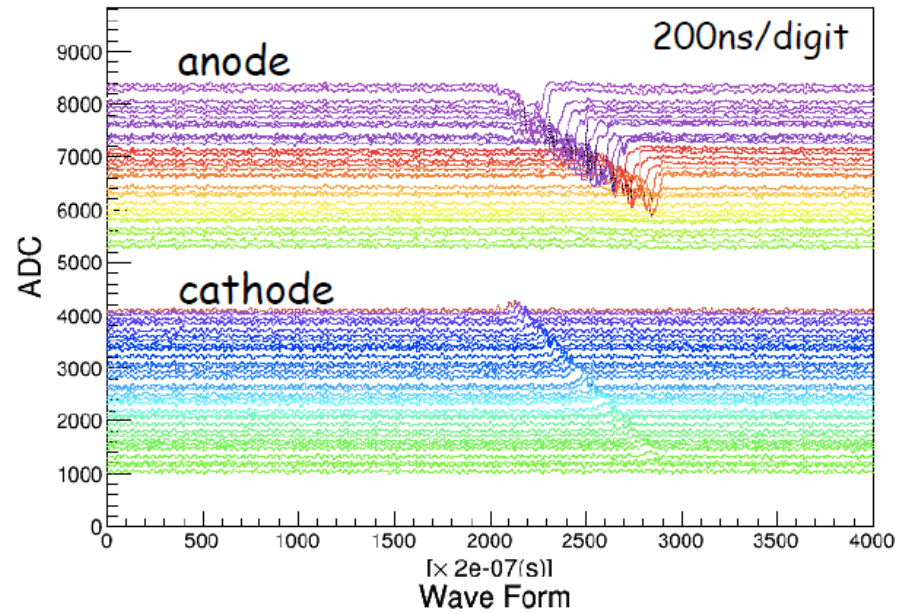
LTARS2014

Conversion gain : $\sim 9.0\text{mV/fC}$
Max input charge : 60~100fC
ENC : below 2000@300pF
Shaping time : 1us

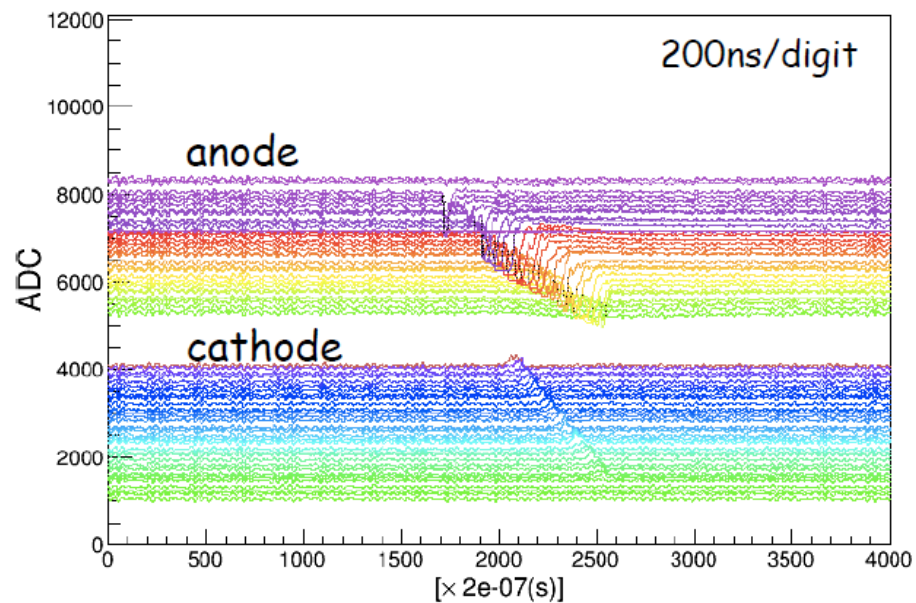
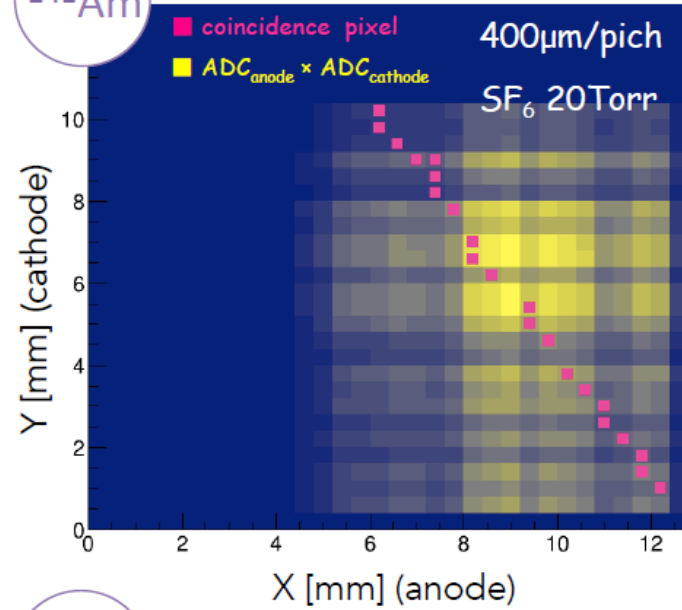
32ch differential inputs(2Vpp)
12bits FADC
4000 sampling
Sampling frequency <20MHz

Alpha Event Display

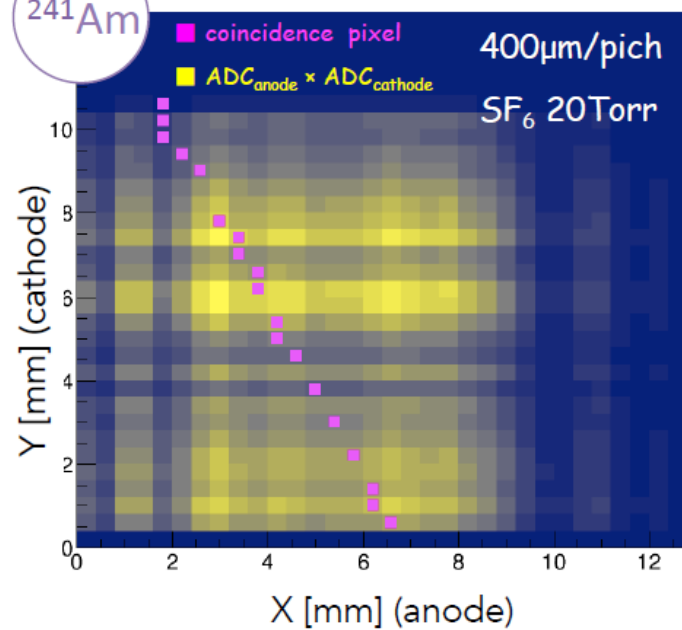
Wave Form



^{241}Am

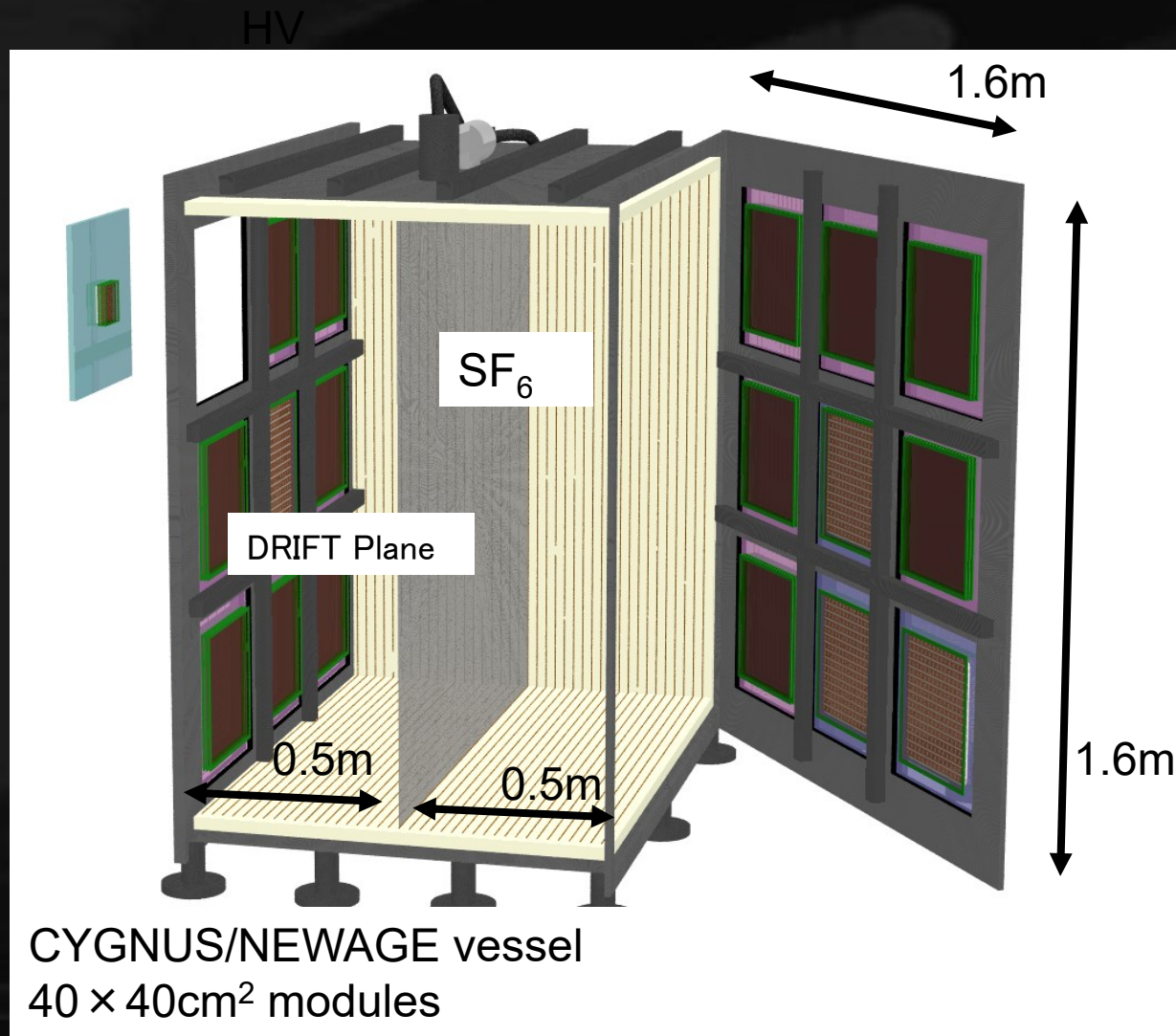


^{241}Am



■ scaling-up: modulated chamber

- being manufactured. will be ready by October 2017
- μ -PIC, GEMs, micromegas, pixels, MWPCs...
- CYGNUS version of “CUTE”, CUTE-G?



Take home chocolates



- **NEWAGE :**
direction sensitive with 3D track detection.
- **Sensitivity improvements are on-going.**



Visit us to get a 「ダークマター」

