KOBE UNIVERSITY Graduate School of Science

KOBE UNIVERSITY

DM HALO

"CYGNUS" co

G. C.

CYGNUS / NEWAGE

CYGNUS

Solar system

$v_{\odot}$=230km/s

Dec.

Jun.

Kentaro Miuchi

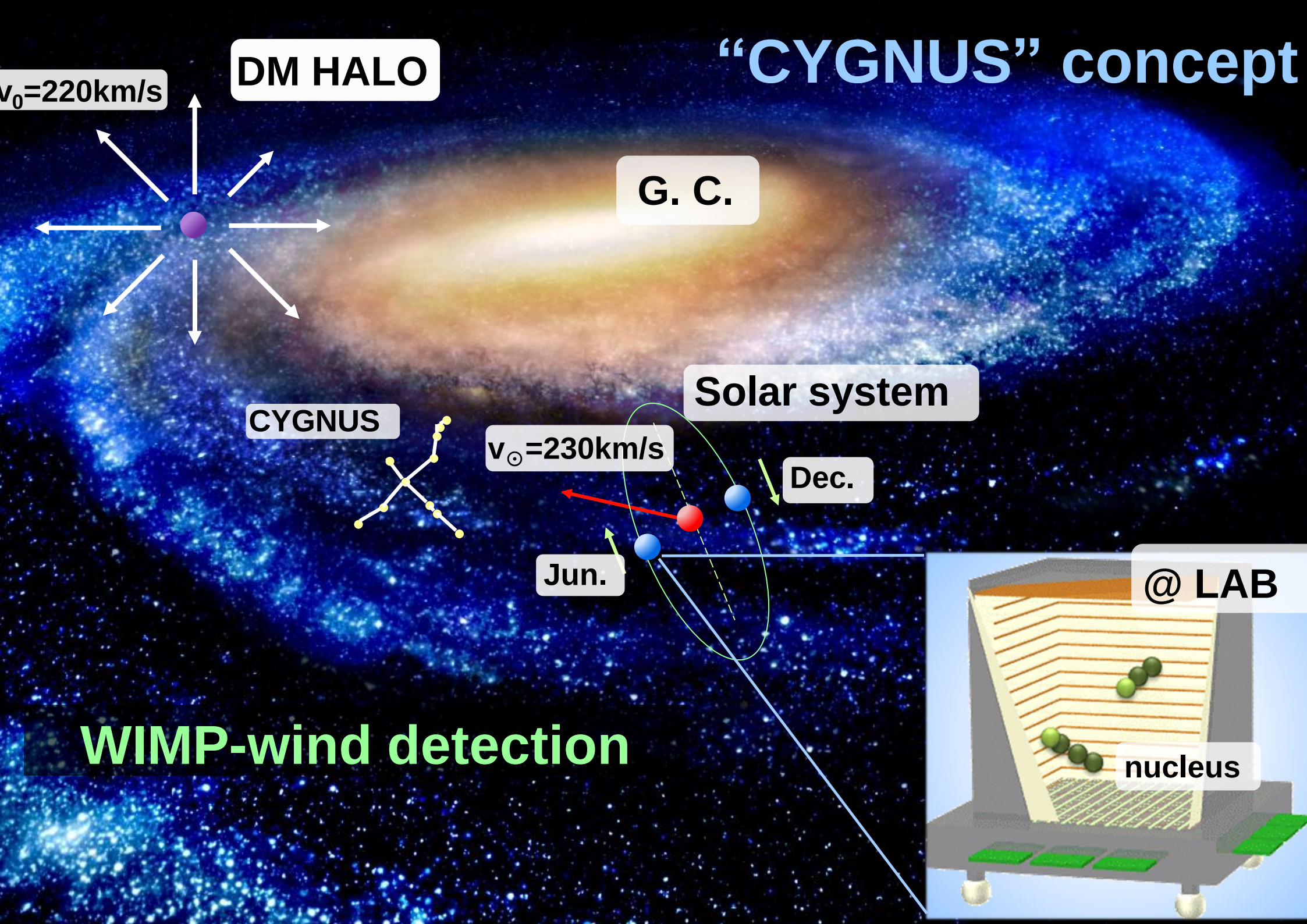
KOBE University

@ LAB

nucleus

Direction-Sensitive WIMP-search NEWAGE

科研費 KAKENHI


“CYGNUS” concept
DM HALO
v_0=220km/s
G. C.
CYGNUS
Solar system
$v_\odot$=230km/s
Dec.
Jun.
@ LAB
nucleus
WIMP-wind detection

CYGNUS

CYGNUS: community

7×bi-annual workshops (2007-)

- CYGNUS 2017 Xichang, Sichuan, China June 13 - 16, 2017
- CYGNUS 2015 Occidental College, Los Angeles, California, USA June 2 - 4, 2015.
- CYGNUS 2013 Toyama, Japan June 10 - 12, 2013.
- CYGNUS 2011 Aussois, France June 7 - 10, 2011.
- CYGNUS 2009 Massachusetts Institute of Technology, Cambridge, Massachusetts, USA June 11 - 13, 2009.
- CYGNUS 2007 Boulby Underground Laboratory, Saltburn-by-the-Sea, Cleveland, UK July 22 - 24, 2007.

CYGNUS 2019 @Roma

2×review papers

International Journal of Modern Physics A
Vol. 25, No. 1 (2010) 1–51

World Scientific
www.worldscientific.com

THE CASE FOR A
DIRECTIONAL DARK MATTER DETECTOR AND
THE STATUS OF CURRENT EXPERIMENTAL EFFORTS

Readout technologies for directional WIMP Dark Matter detection

J.B.R. Battat [1,*], I.G. Irastorza [2], A. Aleksai
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A. Di Crescenzo [3], N. Di Marco [13], G. Druitt [15], R. Eggleston [15], E. Ferrer-Ribas [12],
T. Fusayasu [16], J. Galán [2], G. Galati [3,9], J.A. García [2], J.G. Garza [2], V. Gentile [17],
M. Garcia-Sciveres [18], Y. Giomataris [12], N. Guerrero [15,10], O. Guillaudin [7],
A.M. Guler [4], J. Harton [19], T. Hashimoto [20], M.T. Hedges [21], F.J. Iguaz [2],
T. Ikeda [20], I. Jaegle [22], J.A. Kadyk [18], T. Katsuragawa [5], S. Komura [23], H. Kubo [23],
K. Kuge [24], J. Lamblin [7], A. Lauria [3,9], E.R. Lee [25], P. Lewis [21], M. Leyton [15,10],
D. Loomba [25], J.P. Lopez [10,26], G. Luzón [2], F. Mayet [7], H. Mirallas [2], K. Miuchi [20],
T. Mizumoto [23], Y. Mizumura [23], P. Monacelli [27], J. Monroe [15,28],

Physics Reports 662 (2016) 1–46

CYGNUS: collaborative works

- 2×monthly TV meetings
  - physics (S. Vahsen)
  - detector (K. Miuchi)
- 2×review papers

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T. Papevangelou [12], J.D. Parker [29], N.S. Phan [25], F. Pupilli [13], J.P. Richer [7],
Q. Riffard [30], G. Rosa [31,27], D. Santos [7], T. Sawano [23], H. Sekiya [32], I.S. Seong [21],
D.P. Snowden-Ifft [33], N.J.C. Spooner [34], A. Sugiyama [16], R. Taishaku [20],
A. Takada [23], A. Takeda [32], M. Tanaka [28], T. Tanimori [23], T.N. Thorpe [21],
V. Tioukov [3], H. Tomita [10,35], A. Umemoto [5], S.E. Vahsen [21], Y. Yamaguchi [20],
M. Yoshimoto [5], E. Zayas [10]

Physics Reports 662 (2016) 1–46

CYGNUS: collaboration

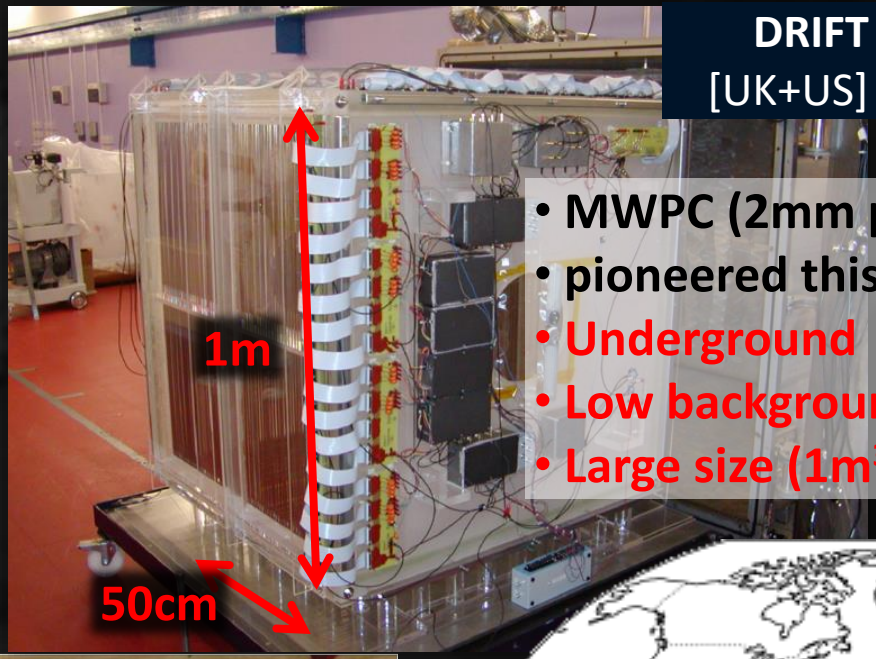
- proto-collaboration (2016-)
  - >50 researchers

The CYGNUS Galactic Directional Recoil Observatory
Proto-Collaboration Agreement

Now that conventional WIMP dark matter searches are approaching the neutrino floor, there has been a resurgence of interest in the possibility of introducing recoil direction sensitivity into the field. Such directional sensitivity would offer the powerful prospect of reaching below this floor, introducing both the possibility of identifying a clear signature for dark matter particles in the galaxy below this level but also of exploiting observation of coherent neutrino scattering from the Sun and other sources with directional sensitivity. There has also been significant progress recently in development of technology able to record the directional information from nuclear recoils at low energy (sub-100 keV) necessary for these goals. This includes progress on improving the sensitivity of low pressure gas time projection chamber technology but also on novel ideas with higher density targets, such as ultra-fine grain emulsions, scintillation materials, columnar recombination with noble gas targets and concepts using nano-technology. Such world-wide directional expertise, if pooled together and directed at converging on an optimised design, likely at multiple underground sites and different

steering committee
N. Spooner (Sheffield)
K. Miuchi (Kobe)
S. Vahsen (Hawaii)
E. Baracchini (GSSI)
G. Lane (Melborne)

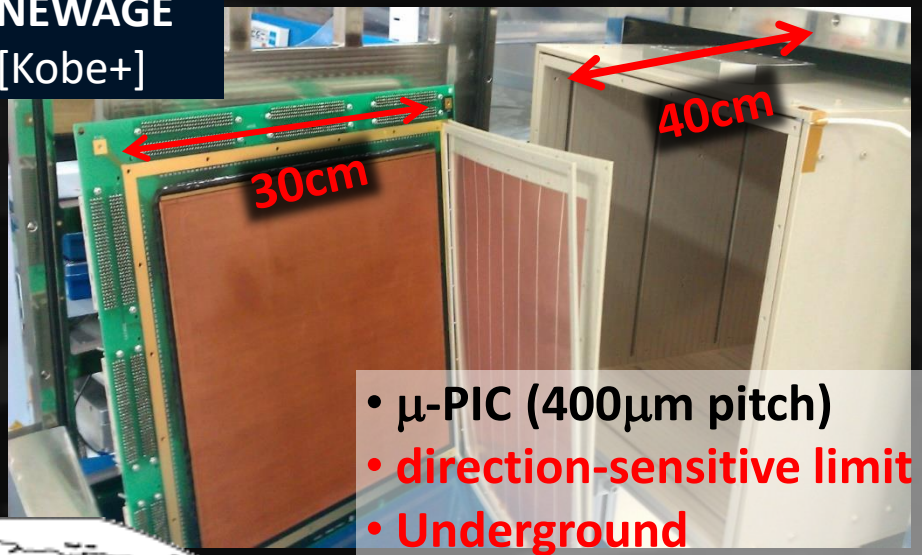
CYGNUS in the world



DRIFT
[UK+US]

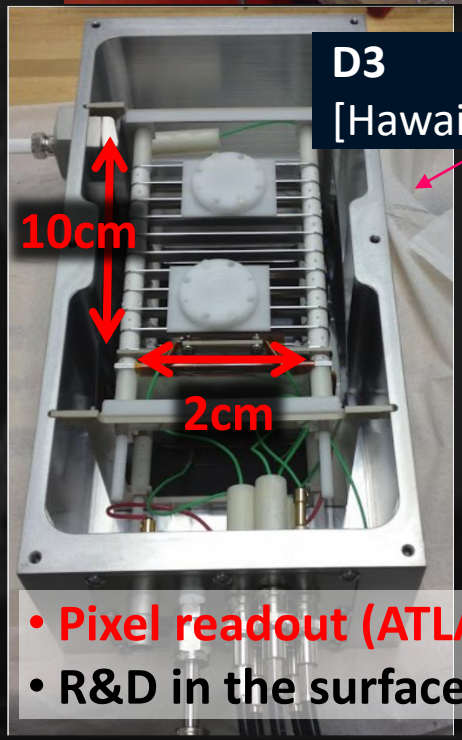
- MWPC (2mm pitch)
- pioneered this field
- Underground
- Low background
- Large size ($1m^3$)

NEWAGE
[Kobe+]



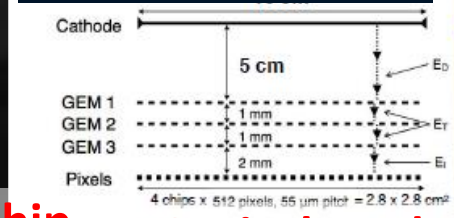
- μ-PIC (400μm pitch)
- direction-sensitive limit
- Underground

D3
[Hawaii]

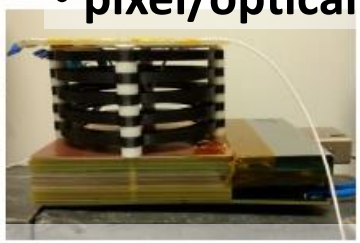


- Pixel readout (ATLAS FE-I4) chip
- R&D in the surface lab

CYGNO/INITIUM
[Italy]

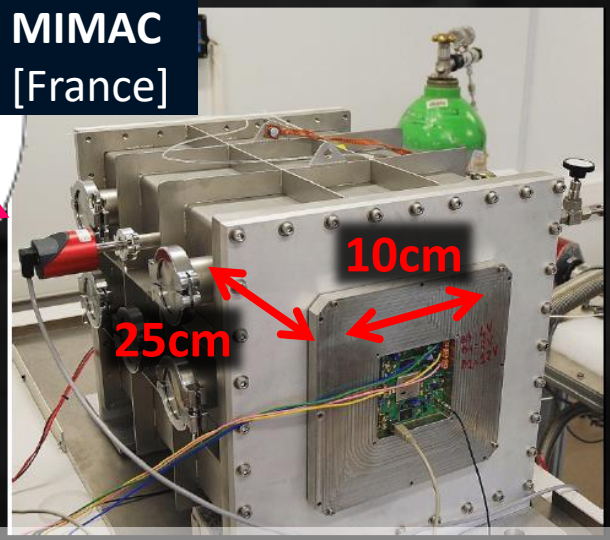


- pixel/optical



- Optical readout
- normal and NI gas

MIMAC
[France]



- Micromegas (~400μm pitch)
- quenching factor measurement
- Underground

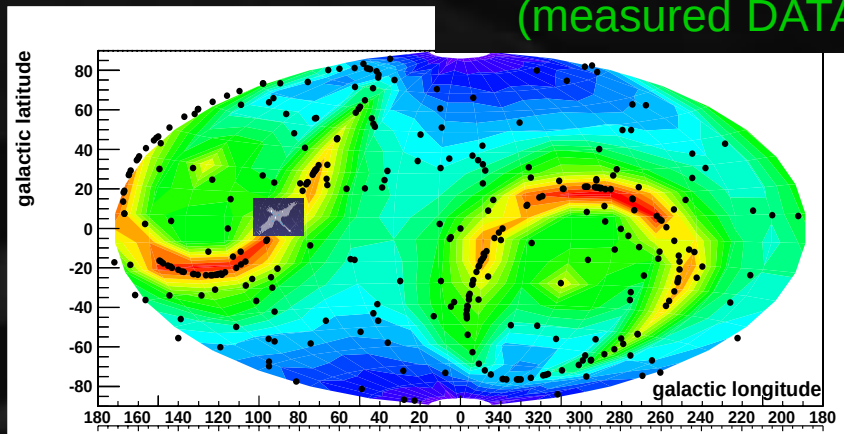
NEWAGE

New general WIMP search with an Advanced Gaseous tracker Experiment

NEWAGE history

- μ-PIC(MPGD) based TPC
  - 3-D tracks SKYMAP
- CF4 gas for SD search

SKYMAP
(measured DATA)

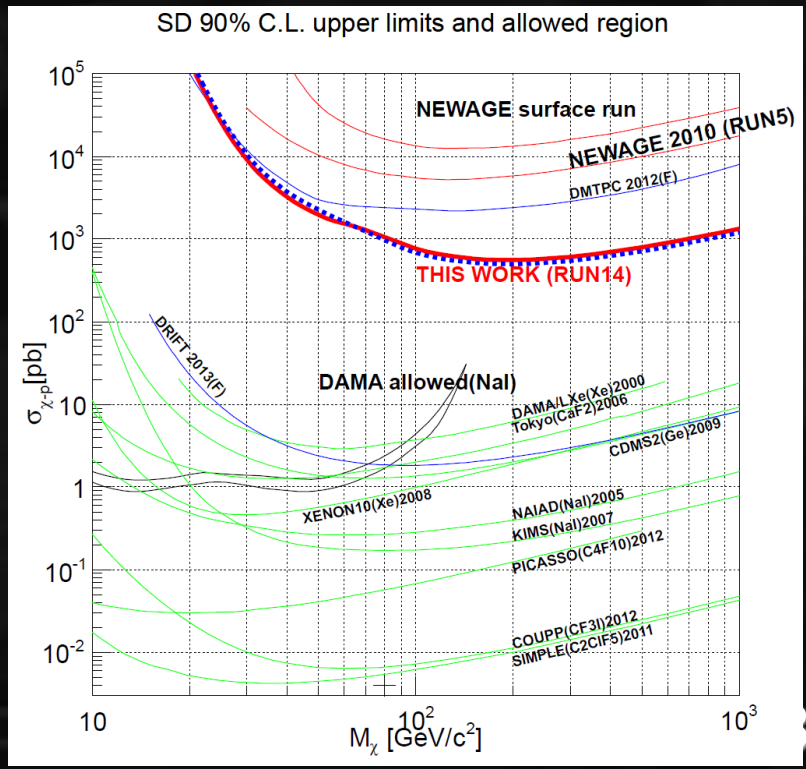


- Proposal PLB 578 (2004) 241
- First direction-sensitive limits

  PLB654 (2007) 58
- Underground results

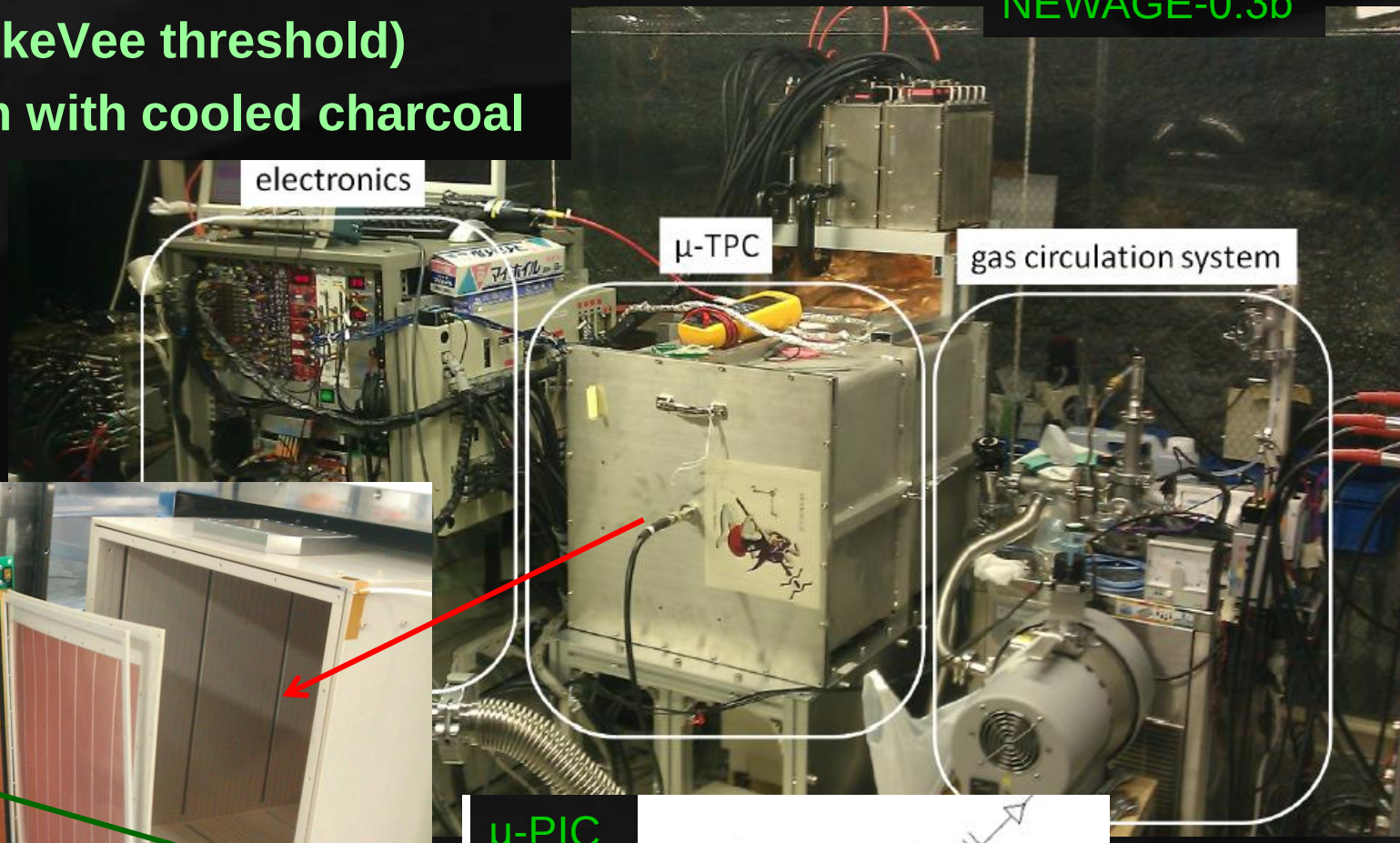
  PLB686 (2010) 11, PTEP (2015) 043F01s
- Phase for “low BG detector”

limits PTEP (2015) 043F01s

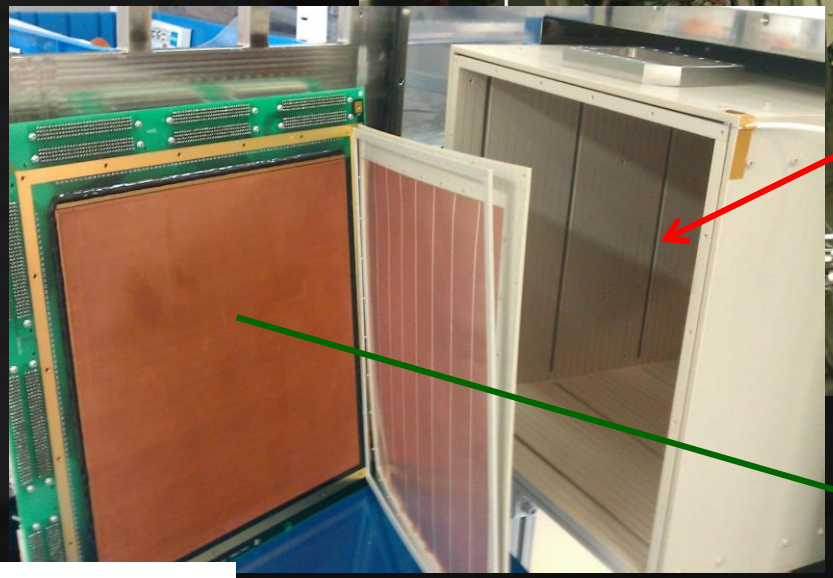


NEWAGE detector

- NEWAGE-0.3b'
- Detection Volume: 31×31×41cm^3
- Gas: CF4 at 0.1atm (50keVee threshold)
- Gas circulation system with cooled charcoal

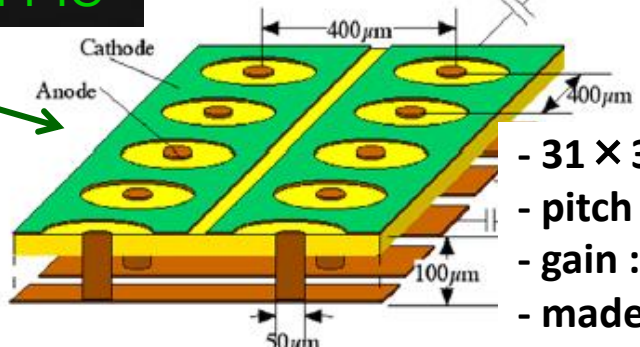


μ-TPC



Drift length: 41cm
PEEK + copper wires

μ-PIC



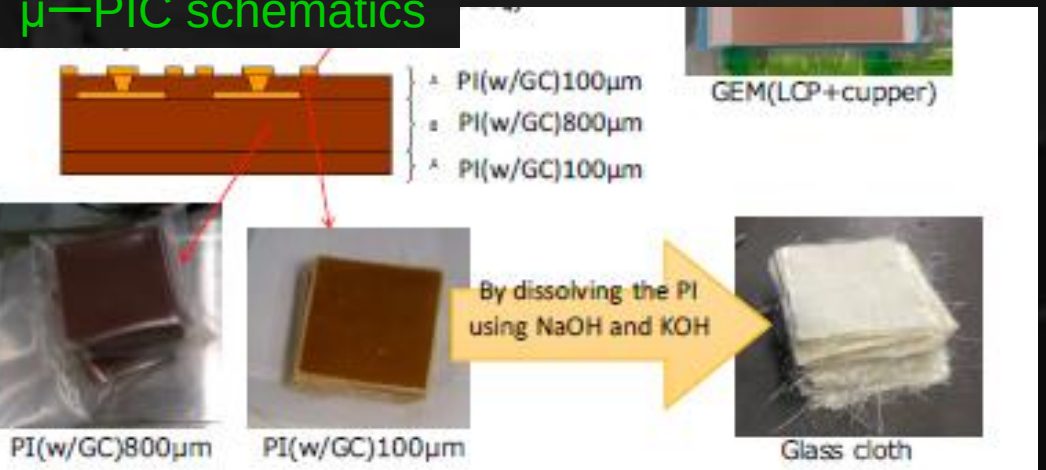
- 31×31cm^2
- pitch : 400μm
- gain : ~1000
- made by DNP, Japan

BG study

K. Nakamura
T. Hashimoto

BG source: alpha particle from μ-PIC

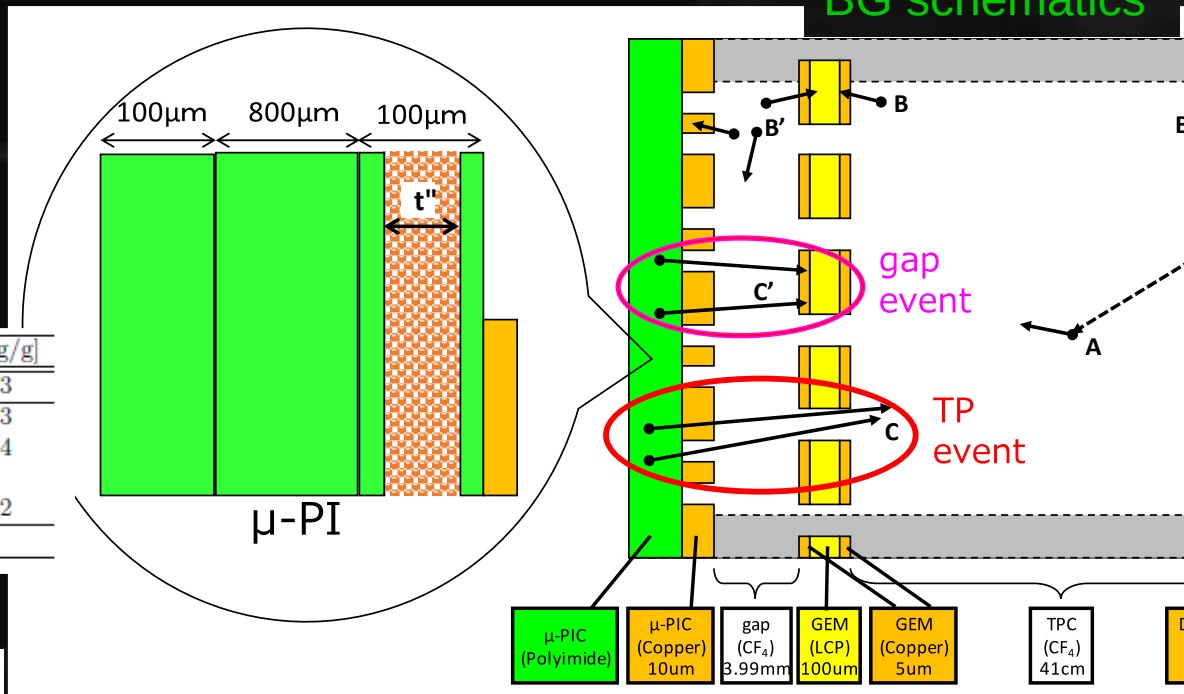
μ—PIC schematics



Glass cloth in PI had O(ppm) U/Th

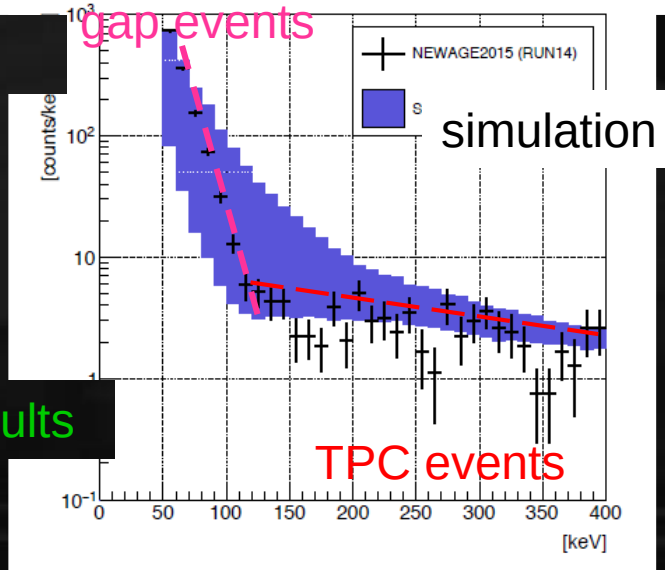
Sample	^{238}U middle stream [10^{-6} g/g]	^{238}U upper stream [10^{-6} g/g]	^{232}Th [10^{-6} g/g]
μ-PIC	1.17 ± 0.01	1.14 ± 0.01	5.84 ± 0.03
PI(w/GC)800 μmpart	0.78 ± 0.01	0.76 ± 0.01	3.42 ± 0.03
PI(w/GC)100 μmpart	0.39 ± 0.01	0.38 ± 0.01	1.81 ± 0.04
Plating solution[1]	< 0.01	< 0.13	< 0.06
Glass cloth	0.84 ± 0.03	0.91 ± 0.02	3.48 ± 0.12
GEM	< 0.02	< 0.17	< 0.12

BG schematics



HPGe results

MC results



TARGET:
low-α emitting μ-PIC development

Low-α μ-PIC

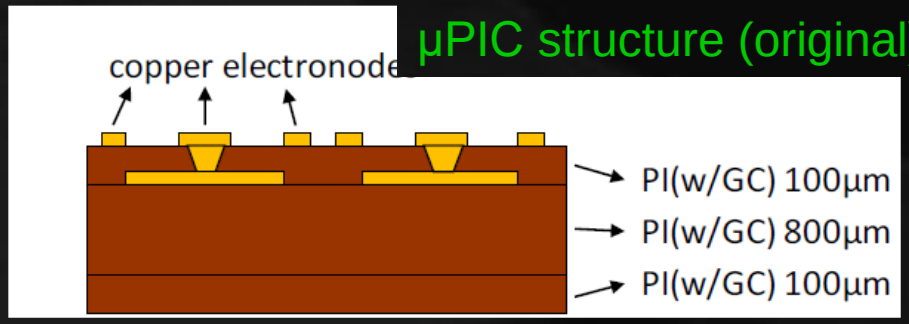
T. Hashimoto
helped by K. Ichimura, K.Abe (XMASS)

- **2014 material selection**
  - **new material :PI + epoxy**
  - **BG level: < 1/100**

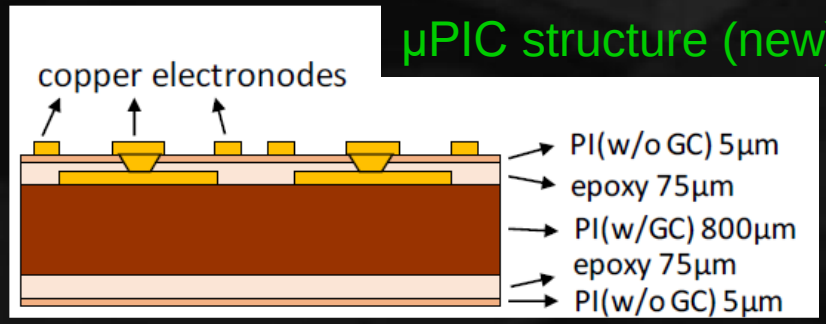
material selection results

	^{238}U[ppm]	^{232}Th[ppm]	
PI including glass cloth	0.39±0.01	1.81±0.04	
PI+epoxy	$< 2.98\times10^{-3}$	$< 6.77\times10^{-3}$	← New material

μPIC structure (original)



μPIC structure (new)



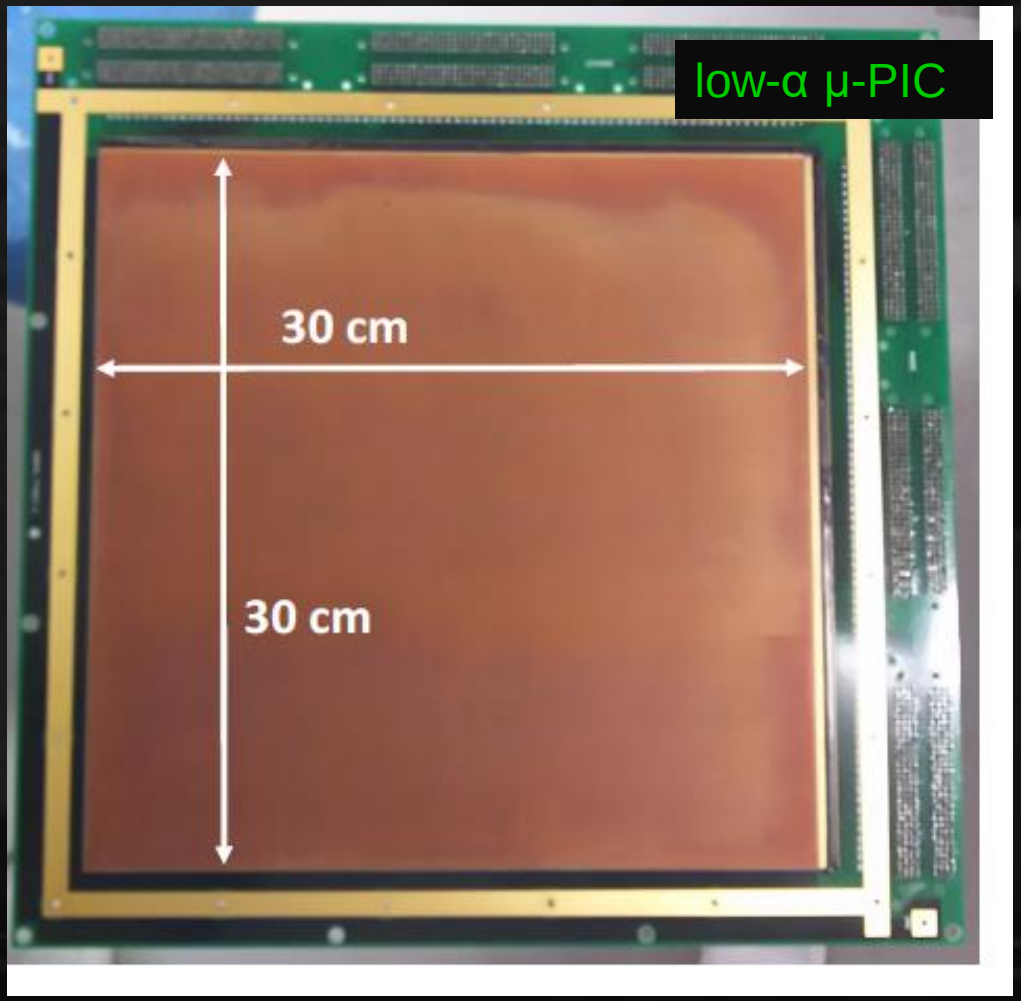
Direction Sensitive WIMP-search NEWAGE

Low-α μ-PIC：development

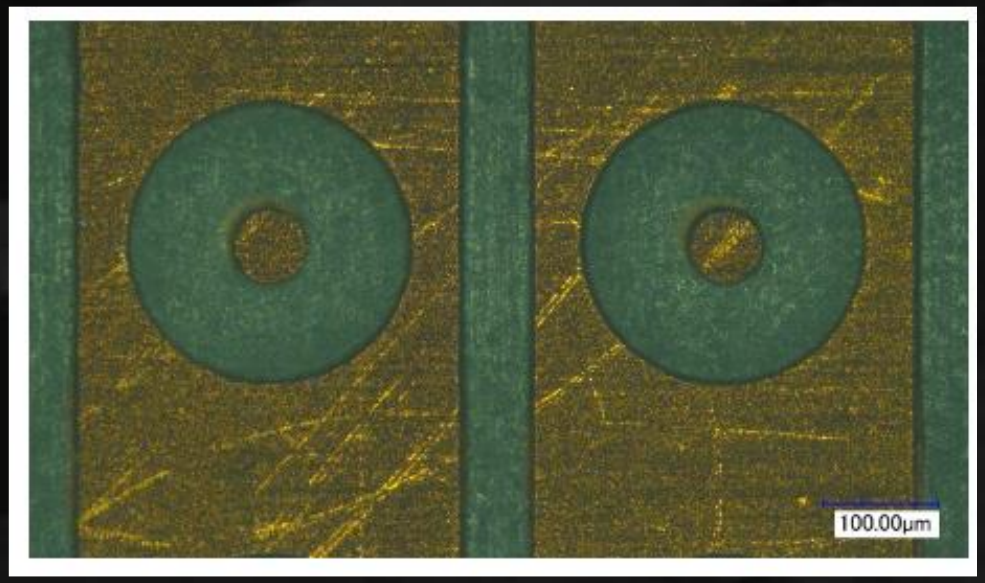
T. Hashimoto

& DNP Co.

- **Development of low-α emitting μ-PIC**
  - **2015: 10×10 cm² μ-PIC**
  - **2016: 30×30 cm² μ-PIC**



low-α μ-PIC electrodes

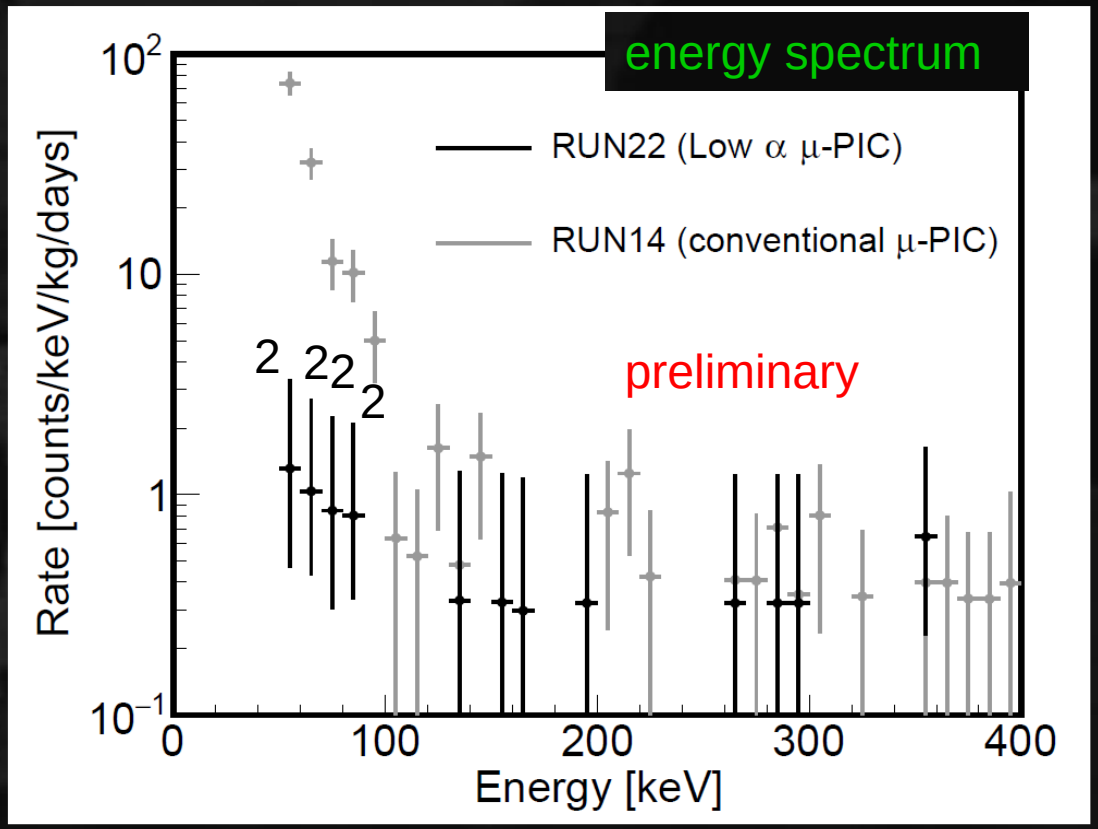


perfectly produced !

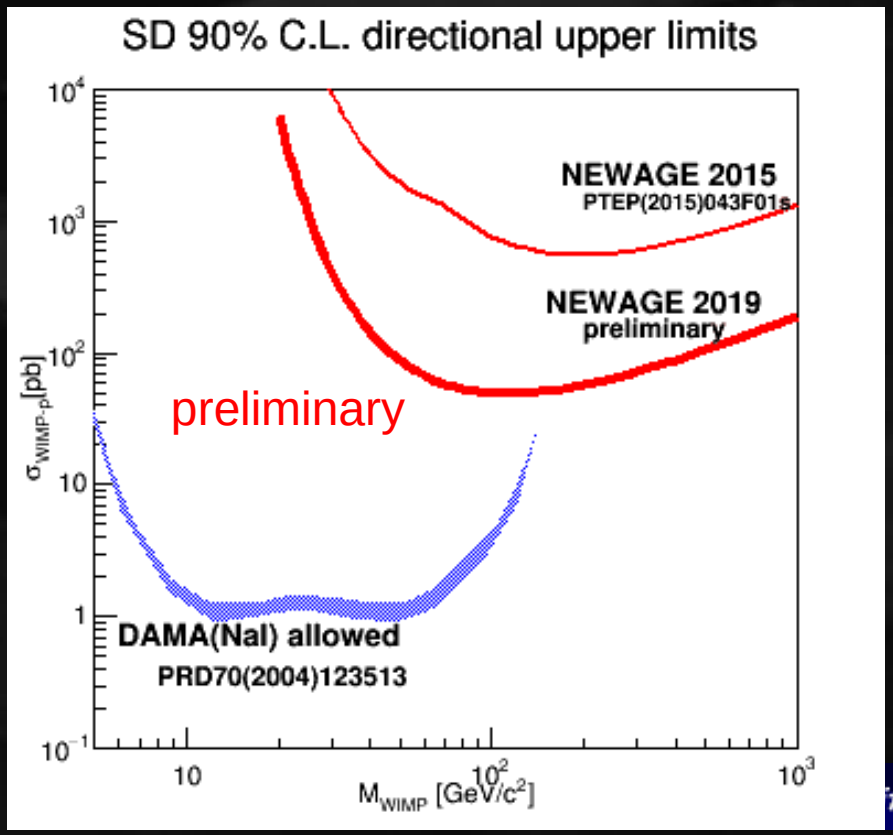
in spite of the material change

Low-α μ-PIC：DM run

- **Installation: Dec. 2017**
- **DM run: 2018-**
  - **RUN22-1 2018/6/6~2018/8/24 (47days)**
  - **RUN22-2 2018/9/20~2018/12/3 (61days)**



directional limits



～×10 improvements

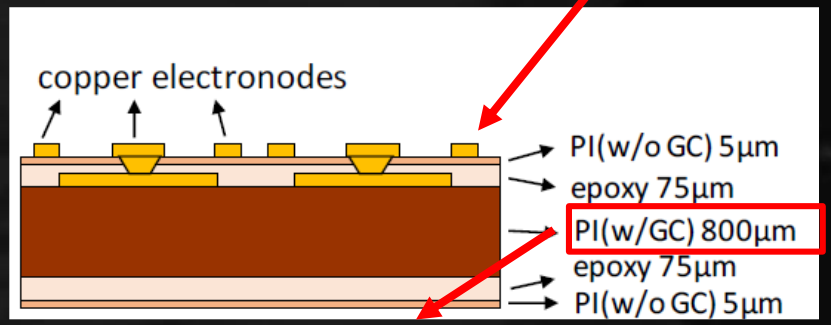
NEWAGE
and beyond

NEWAGE：next

- **new main BG:**
  - **μ-PIC: surface BG**
  - **radons**

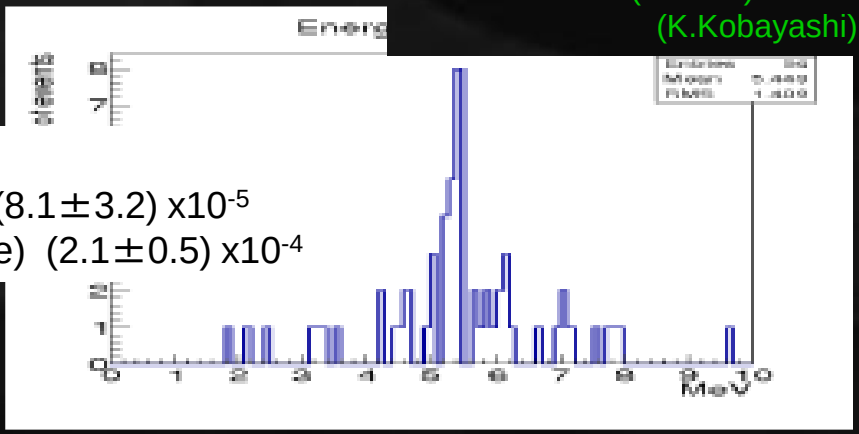
μPIC structure (now)

surface BG was observed



β-rays from the 800 μm "core substrate" (near future BG)

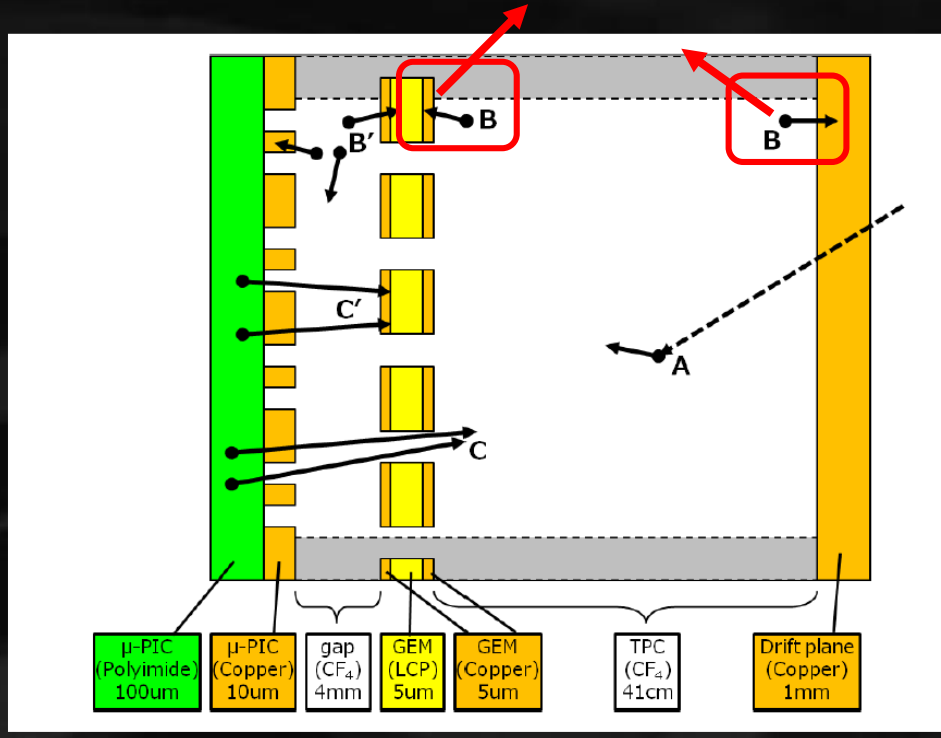
α counter (Ultra-lo) results (K.Kobayashi)



[α/cm²/hr]
2.5<E<4.8MeV(bulk) (8.1±3.2) x10⁻⁵
4.8<E<5.8MeV(surface) (2.1±0.5) x10⁻⁴

BG schematics

Radon BG



- **plans**
  - **low BG μ-PIC**
  - **negative ion TPC**

Direction Sensitive

more than ×10 improvements in next 5 years

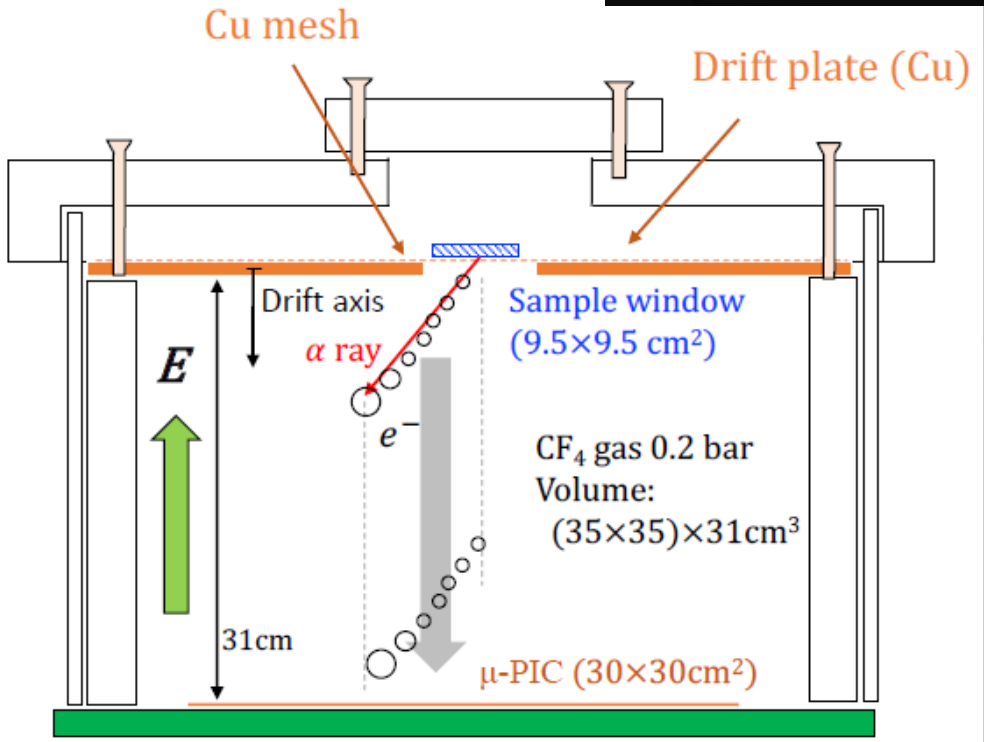
NEWAGE
and low BG activities

α-ray imaging chamber (AI-cham)

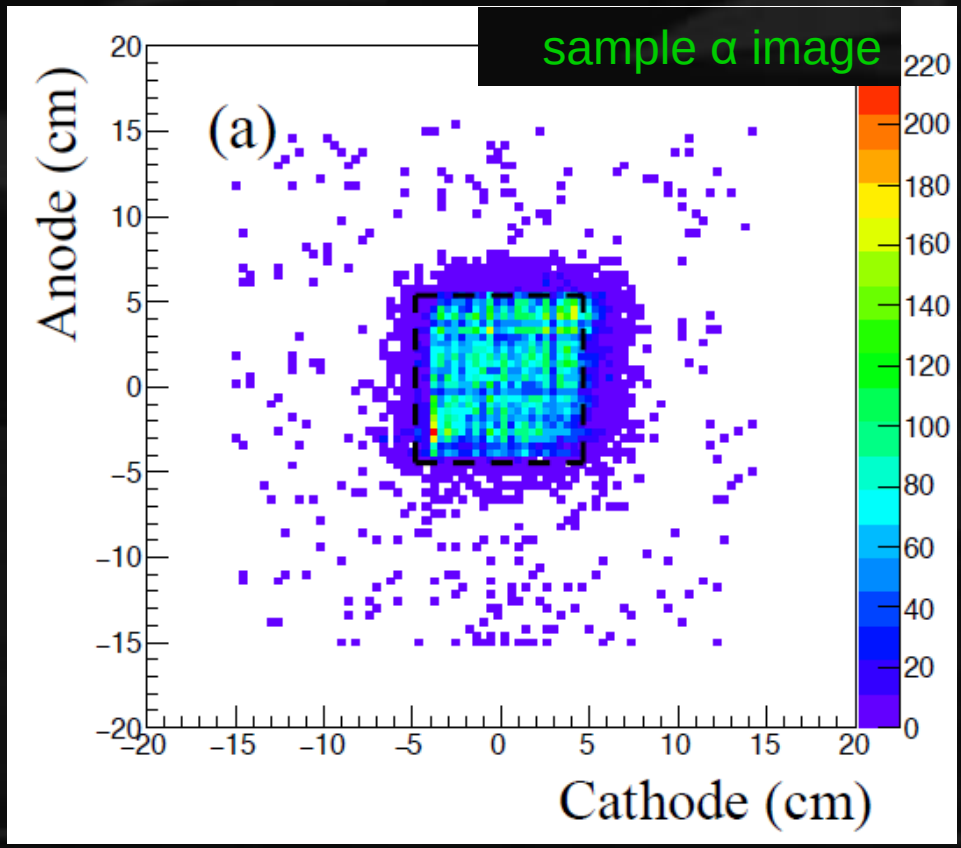
- application of low-α μ-PIC
- α-ray imaging (pos. res. = 0.7cm)
- BG level = 1.58×10^{-2} α/h/cm^2 (subtraction possible)

H. Ito. (NIMA submitted, 1903.01090)

AIcham profile



sample α image

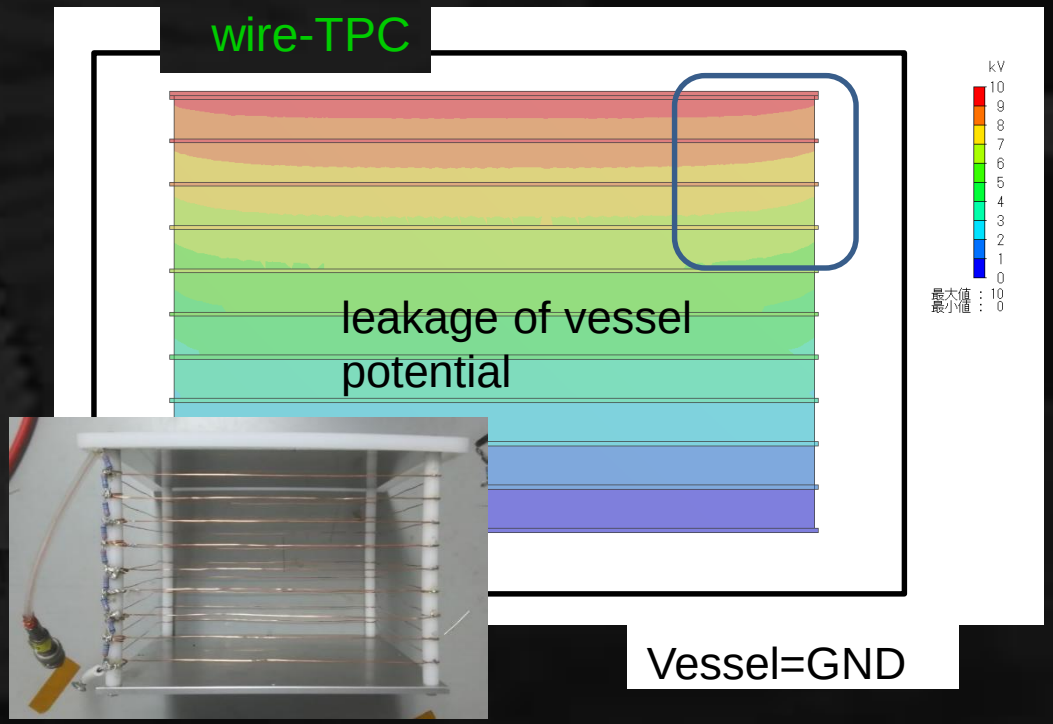


New concept TPC with sheet resistor

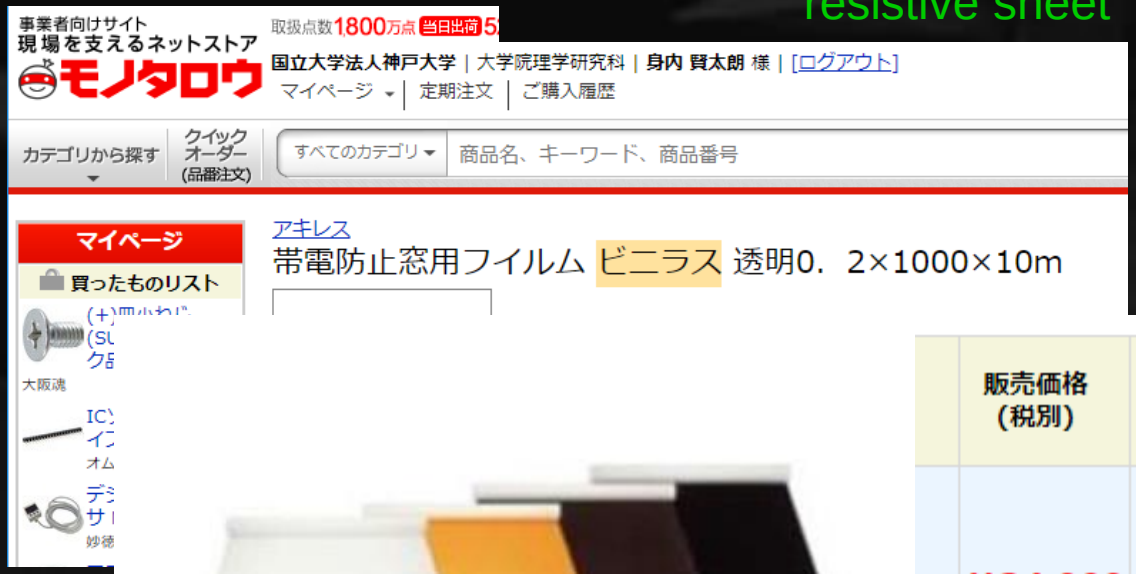
- to overcome potential problem of existing TPCs:
  - distortion of field cage or complicated design
  - radioactive background

K. Miuchi (PTEP 2019 (2019)063H01 **)**

E filed of wire-TPC



Commercially available resistive sheet



(～10GΩ/□)

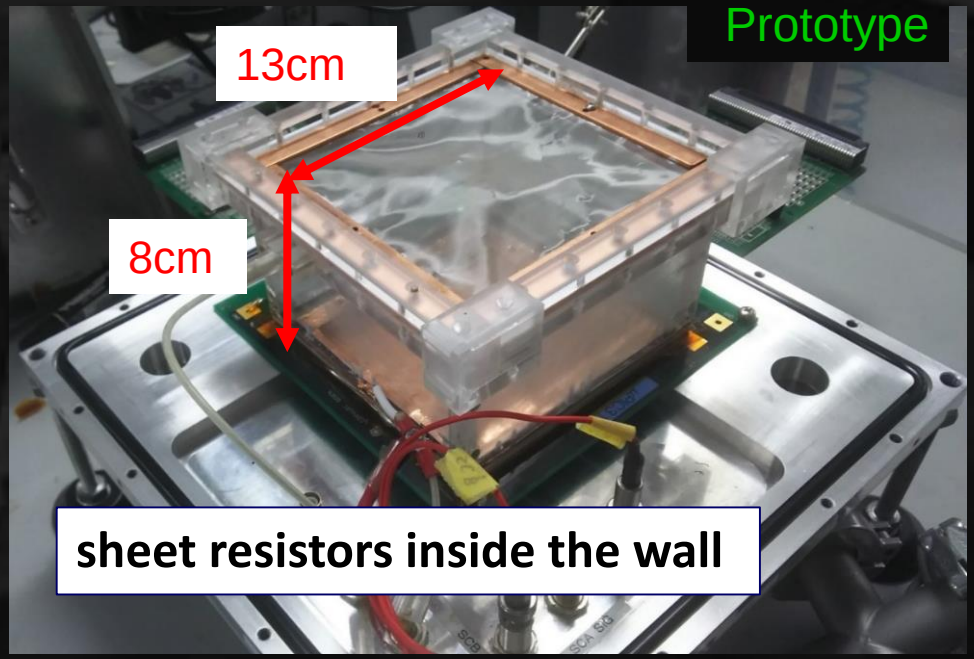
prototype of SR μ-TPC

K. Miuchi (PTEP 2019 (2019)063H01)

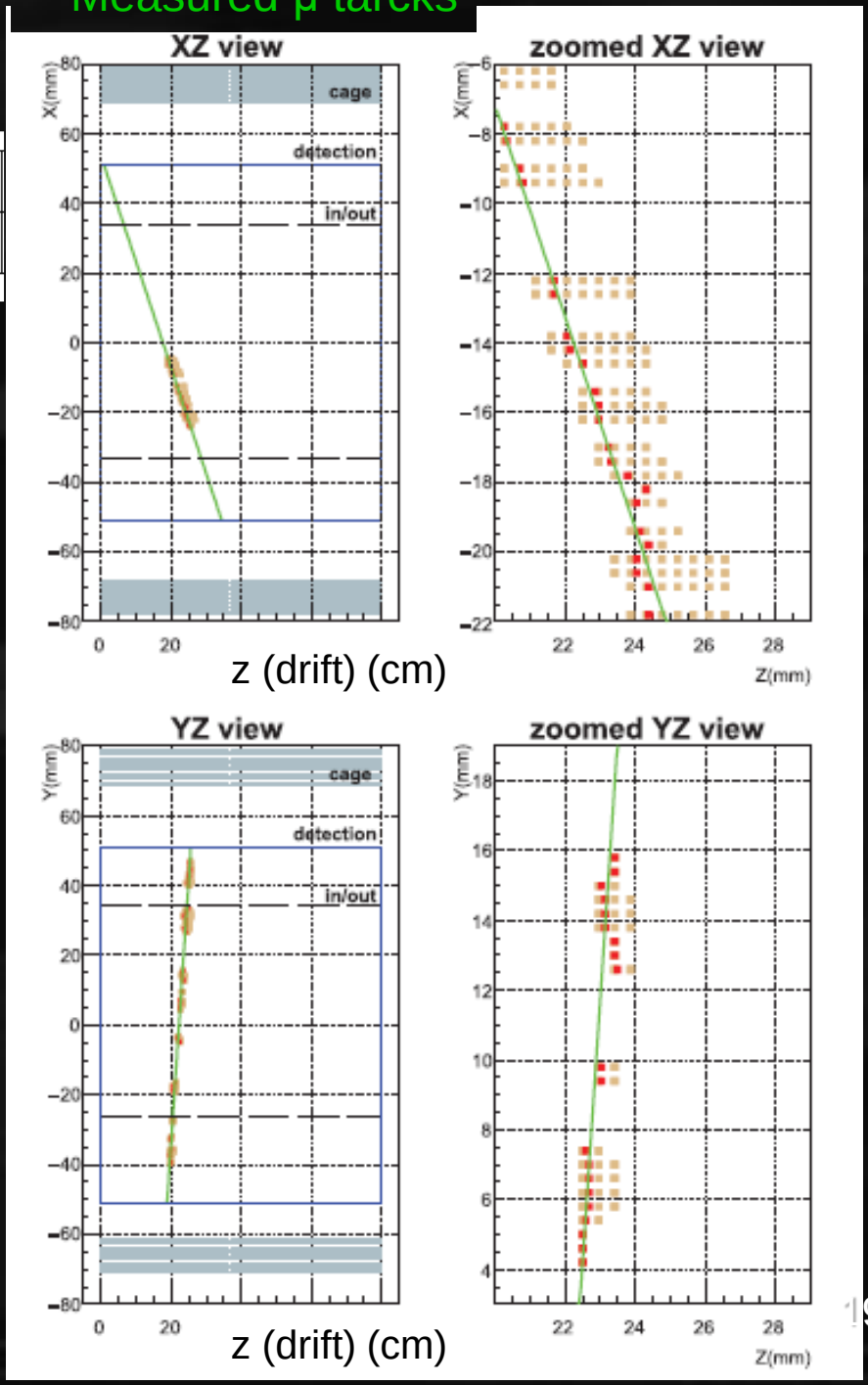
RI measurement (mBq/kg)

Upper U-chain	Middle U-Chain	^{210}Pb	^{232}Th	^{40}K
< 59.6	< 18.4	< 134	< 7.77	< 112

Prototype



Measured μ tarcks



SR μ-TPC performance

K. Miuchi (PTEP 2019 (2019)063H01)

z-dependence of residuals

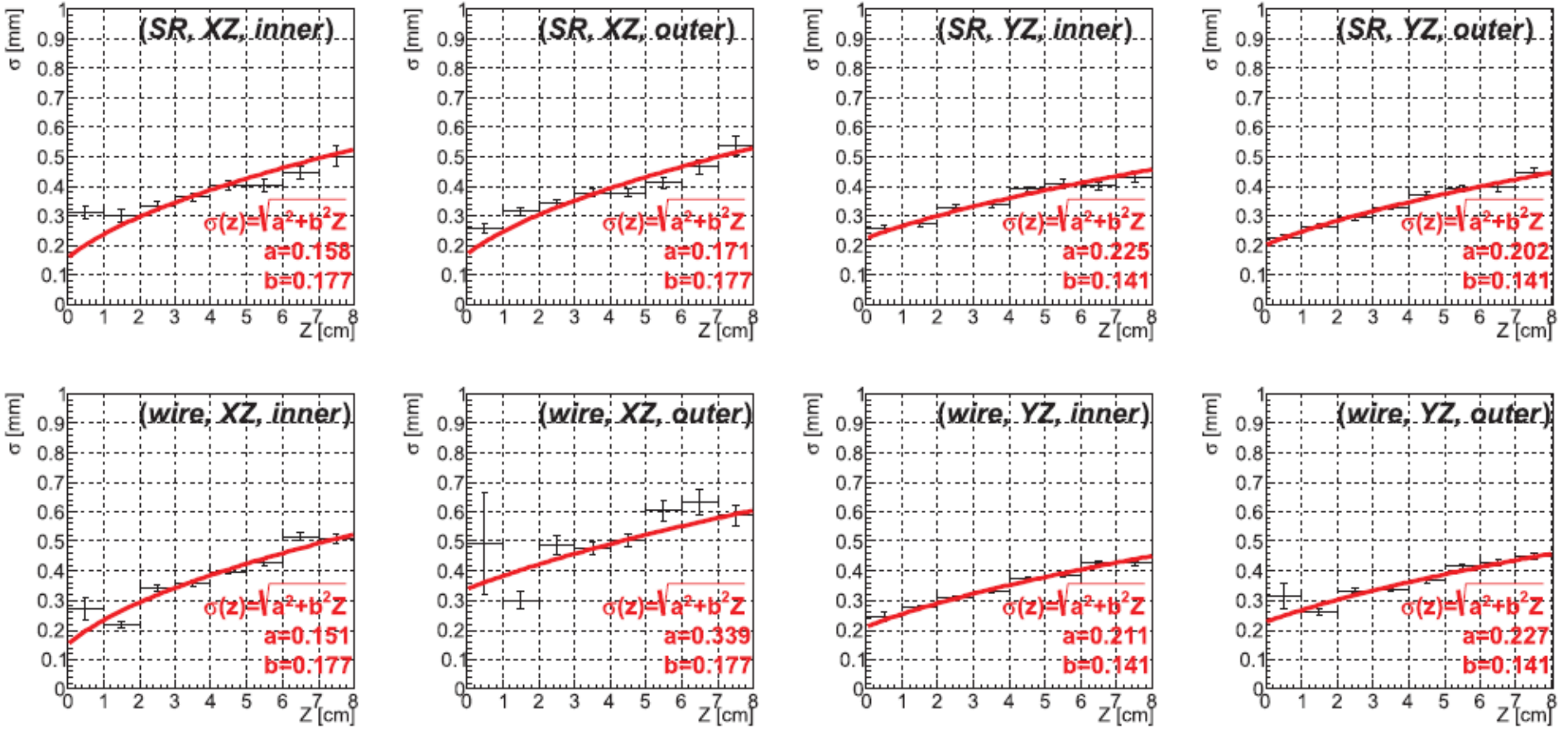


Fig. 5. σ dependence on Z for eight data-sets.

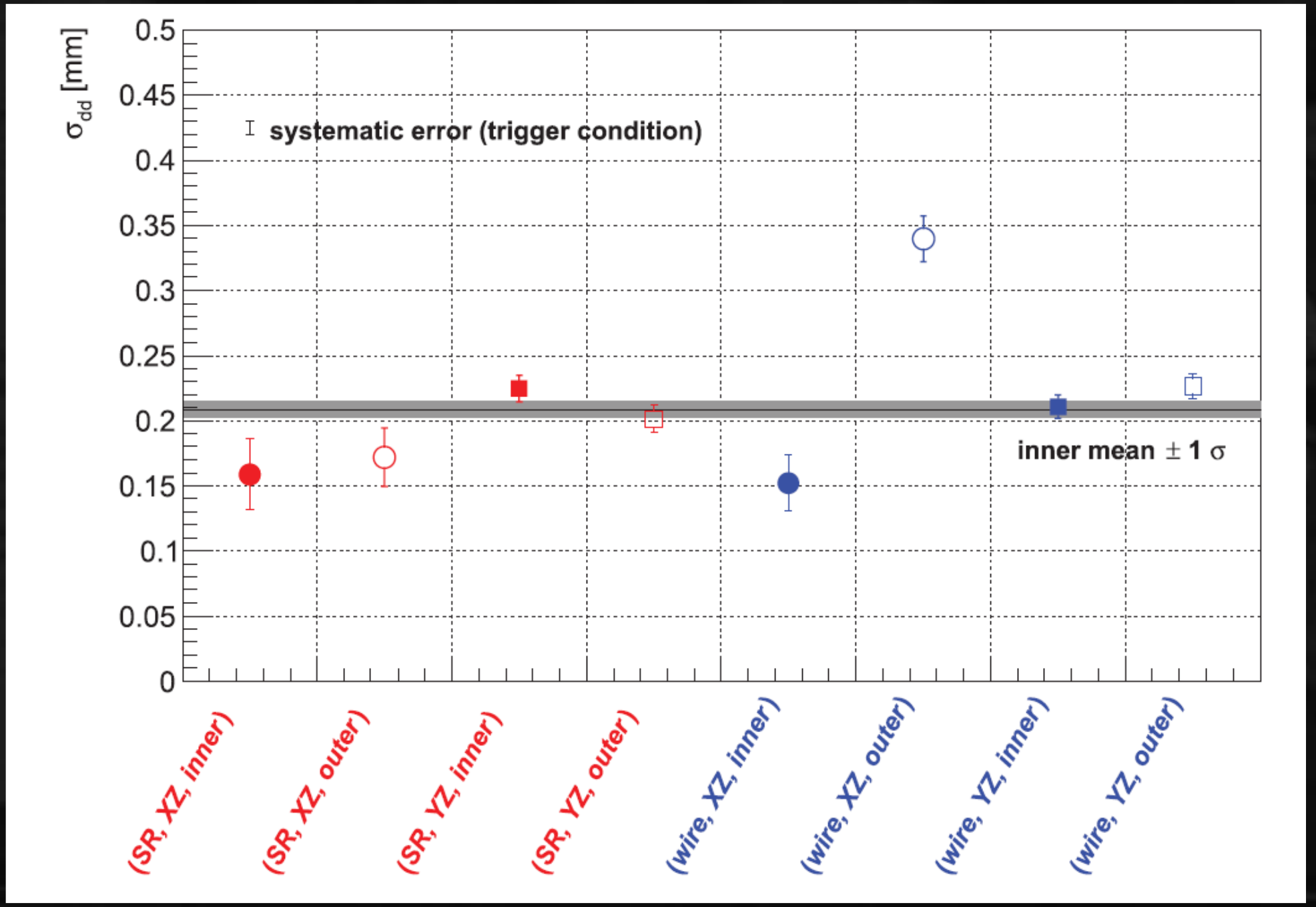
$$\{\sigma_{i,j,k}(Z)\}^2 = \{\sigma_{\mathrm{dd},(i,j,k)}\}^2 + \{\sigma_{\mathrm{diff},(i,j,k)}(Z)\}^2.$$

$$\sigma_{\mathrm{diff},(i,j,k)}(Z) = d'_j\sqrt{Z},$$

SR μ-TPC performance

K. Miuchi (PTEP 2019 (2019)063H01)

results TPC-dependent term



21

Columnar recombination

K. D. Nakamura (JINST 13(2018)P7015)
With AXEL

- SI (Xe), high pressure

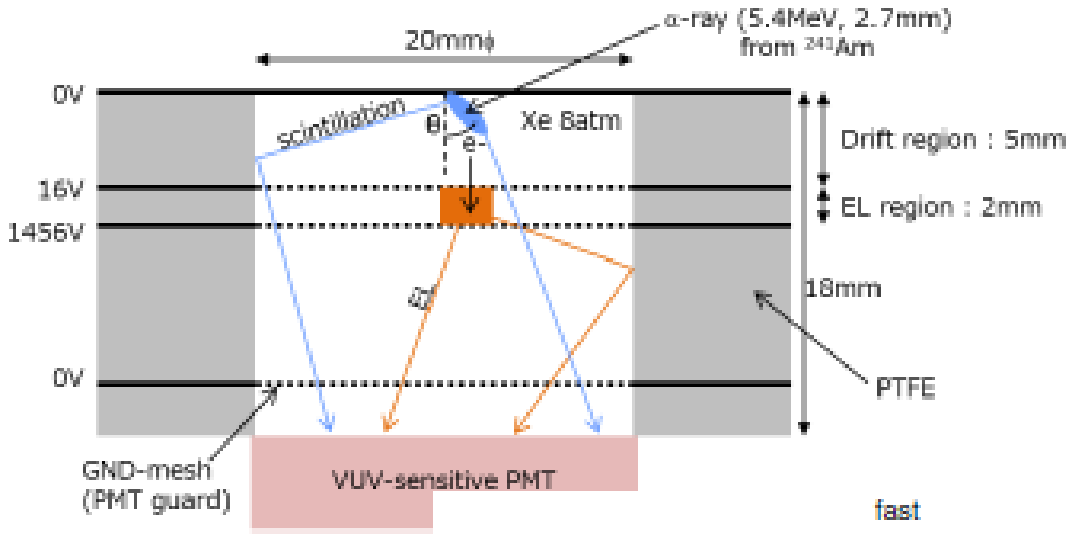
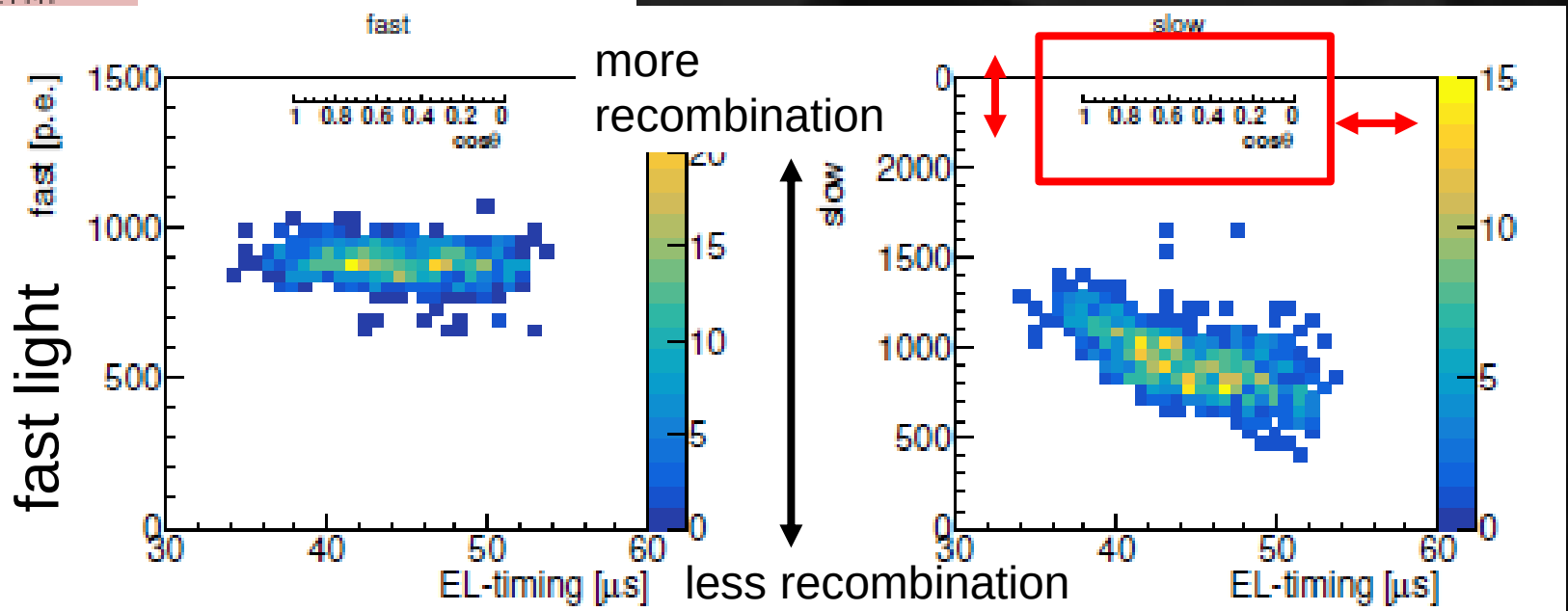


Figure 1.

See K. Nakamura's talk

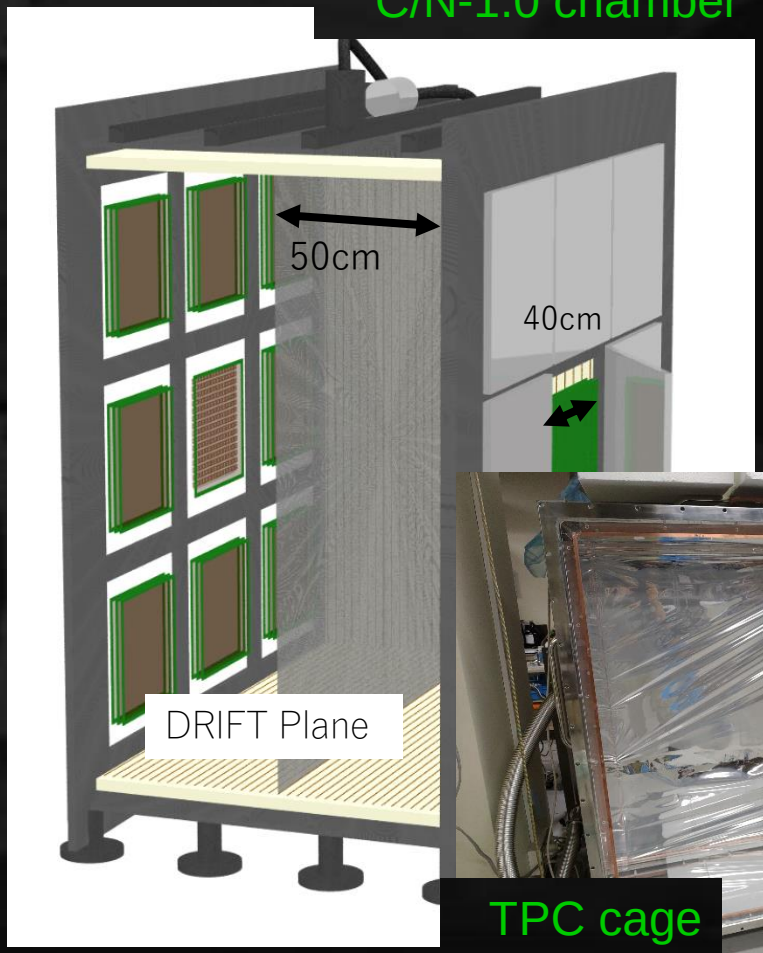
- proof of concept
  (for high energy α's)



CYGNUS/NEWAGE

- **C/N-1.0 chamber (18 × 30×30 cm² detectors)**
  - chamber ready
  - TPC cage (w/ resistive sheet), feedthrough being commissioned

C/N-1.0 chamber



TPC cage

- **ASICs for negative ion strip readout**
  - > 5k channels made
  - chip test stgarted

⇒ system design and development

- **collaboration**
  - w/ US groups: KEK-DOE funding (2017)
  - w/ Sheffield: JSPS-RS funding (2018-2019)
  - w/ MMAC: TYL-FJPPL funding (2019)

⇒ welcoming more !

Summary

- NEWAGE ： low-α μ-PIC development
  ⇒ DM sensitivity ×10 improvement

- Further low BG μ-PICs
- ASIC development (LTARS 2018)

- α-imaging chamber (AI-cham)
- low BG TPC with sheet resistor (SRμ-TPC)