

MPGDの暗黒物質探索 への応用

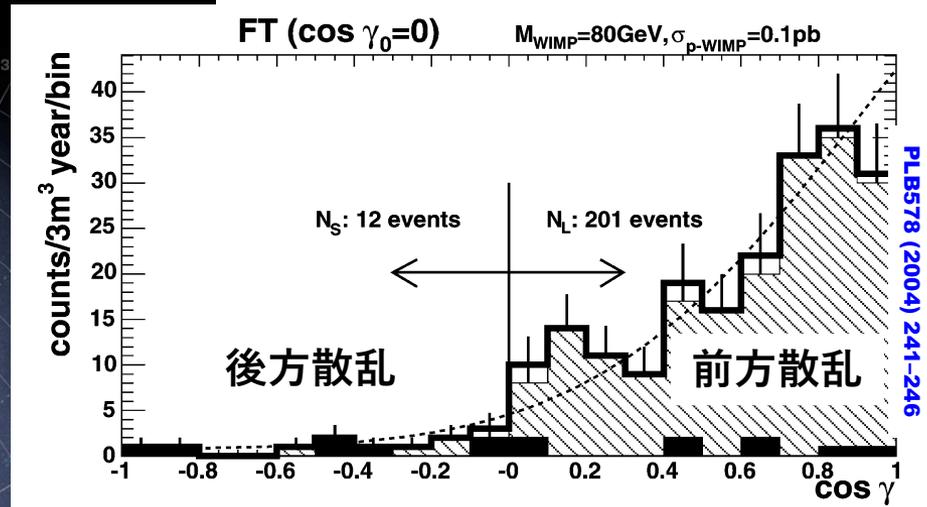
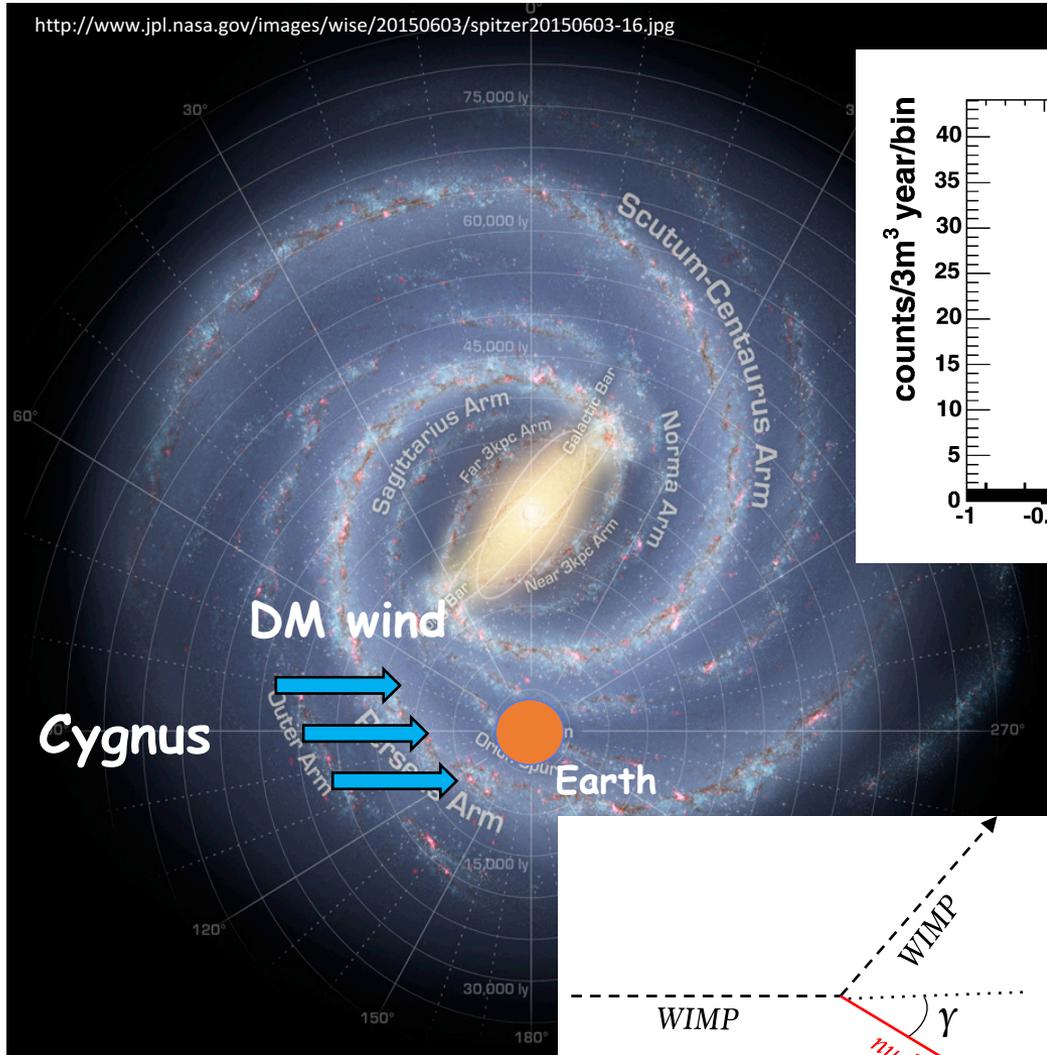
池田 智法

他NEWAGEグループ

2018年12月14日

第15回MPGD研究会@京都大学

方向に感度を持った暗黒物質探索



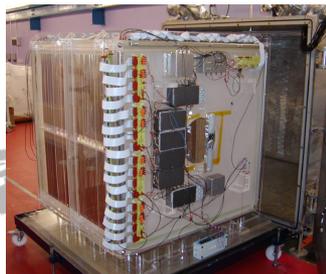
- ✓ 方向に感度を持つ利点
 - 暗黒物質の角度の高い証拠
- ✓ 典型的なエネルギーは数十keV
 - ターゲット：ガス
 - トラッキング：MPGD

世界情勢



D3@Hawaii

- GEM
- Pixel
- R&D



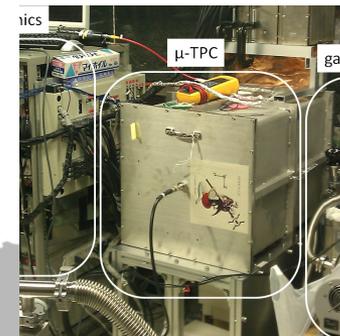
DRIFT@UK

- MWPC (2mm pitch)



MIMAC@France

- Micromegas (424um)
- R&D



NEWAGE@Japan

- μ-PIC+GEM



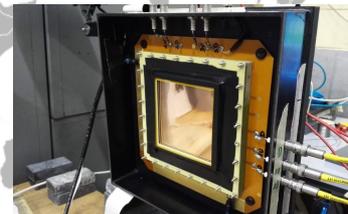
DMTPC@US

- CCD (256um)
- 2D track



TREX-DM@Italy

- Micromegas (500um)
- Only energy R&D



Orange/cygn@Italy

- GEM
- CMOS R&D

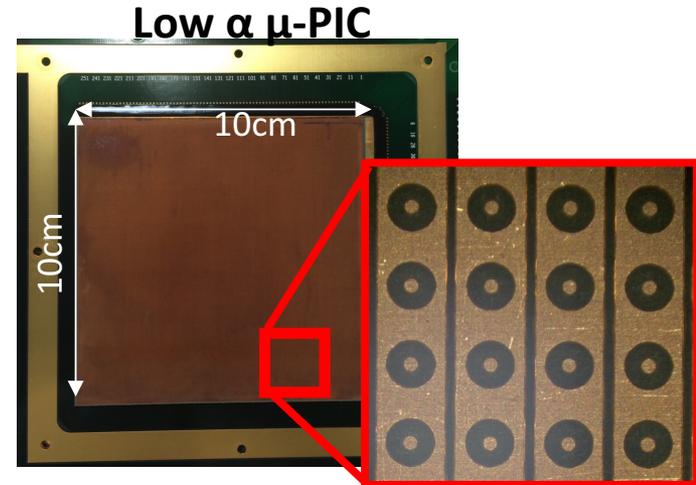
世界の動向

✓ 低BGなMPGDのR&Dへ

✓ Low-alpha μ -PIC

- μ -PIC表面素材を低BG素材に変更
- 表面アルファ線を削減 (橋本work)

	^{238}U [ppb]	^{232}Th [ppb]
PI including glass cloth (旧素材)	390 \pm 10	1810 \pm 40
PI+epoxy (新素材)	< 2.98	< 6.77

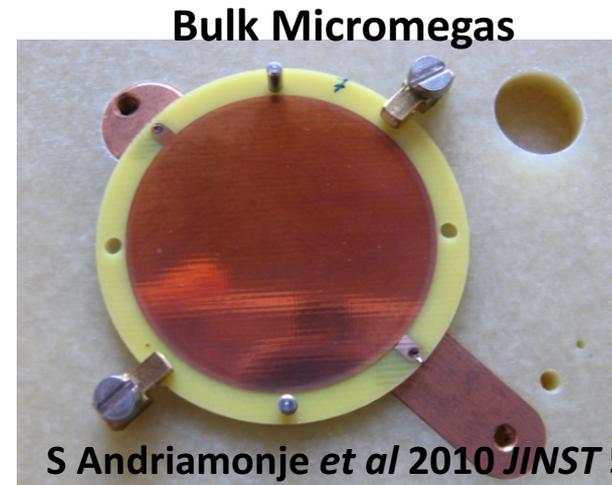


✓ Low-background Micromegas

- T-REX project

Astroparticle Physics 34 (2011) 354–359

	^{238}U [ppb]	^{232}Th [ppb]
Copper-kapton-copper foil	< 70.8	< 91.5

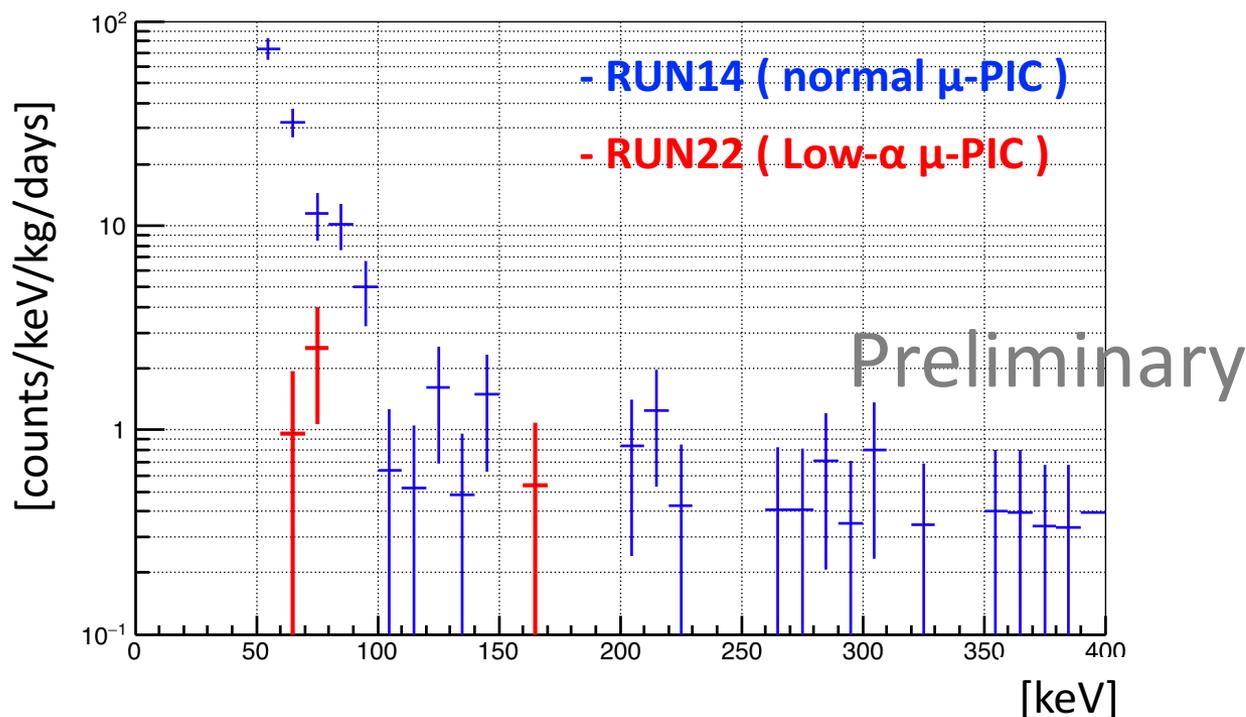


S Andriamonje *et al* 2010 JINST 5 P02001

Low- α μ -PICの地下実験

✓ 2018年1月から神岡にてRUNを開始 (橋本work)

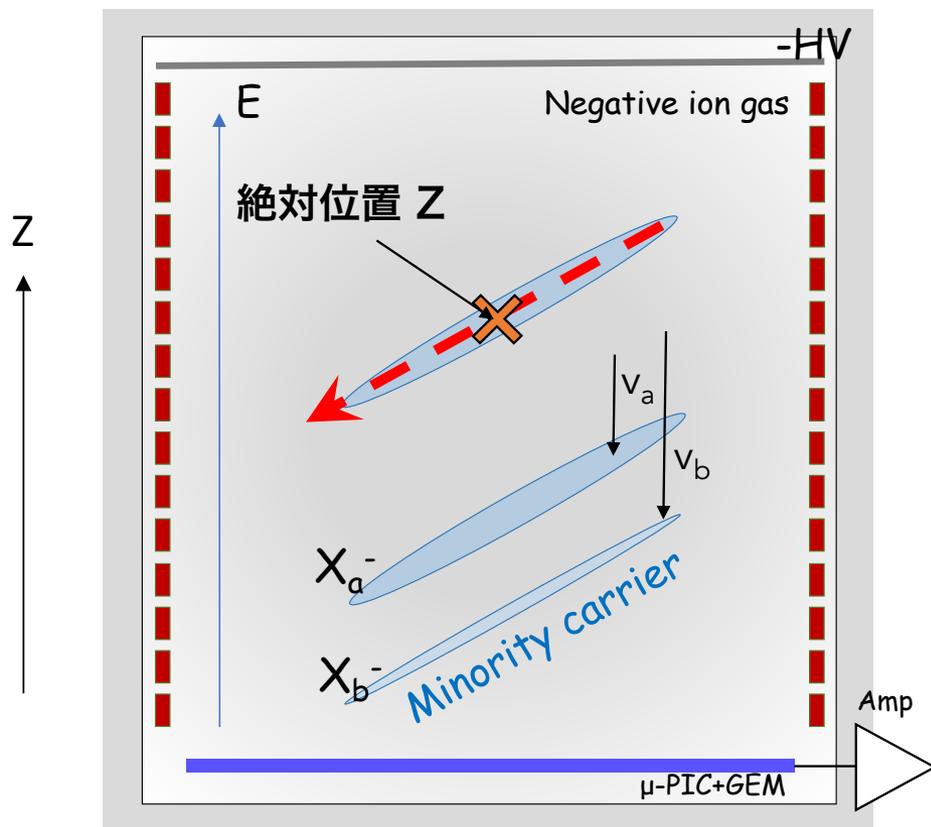
- Live time : 47days
- Exposure : 0.49kg \cdot days



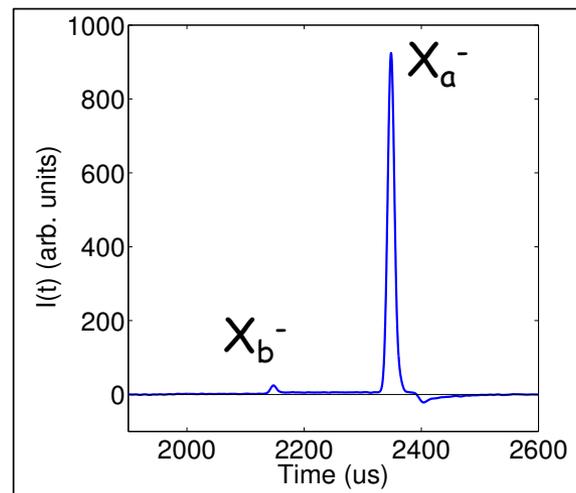
➤ α 線バックグラウンドの減少を確認

陰イオン+MPGD

- ✓ 陰イオンガス検出器を μ TPCに応用 = Negative ion μ TPC



信号波形



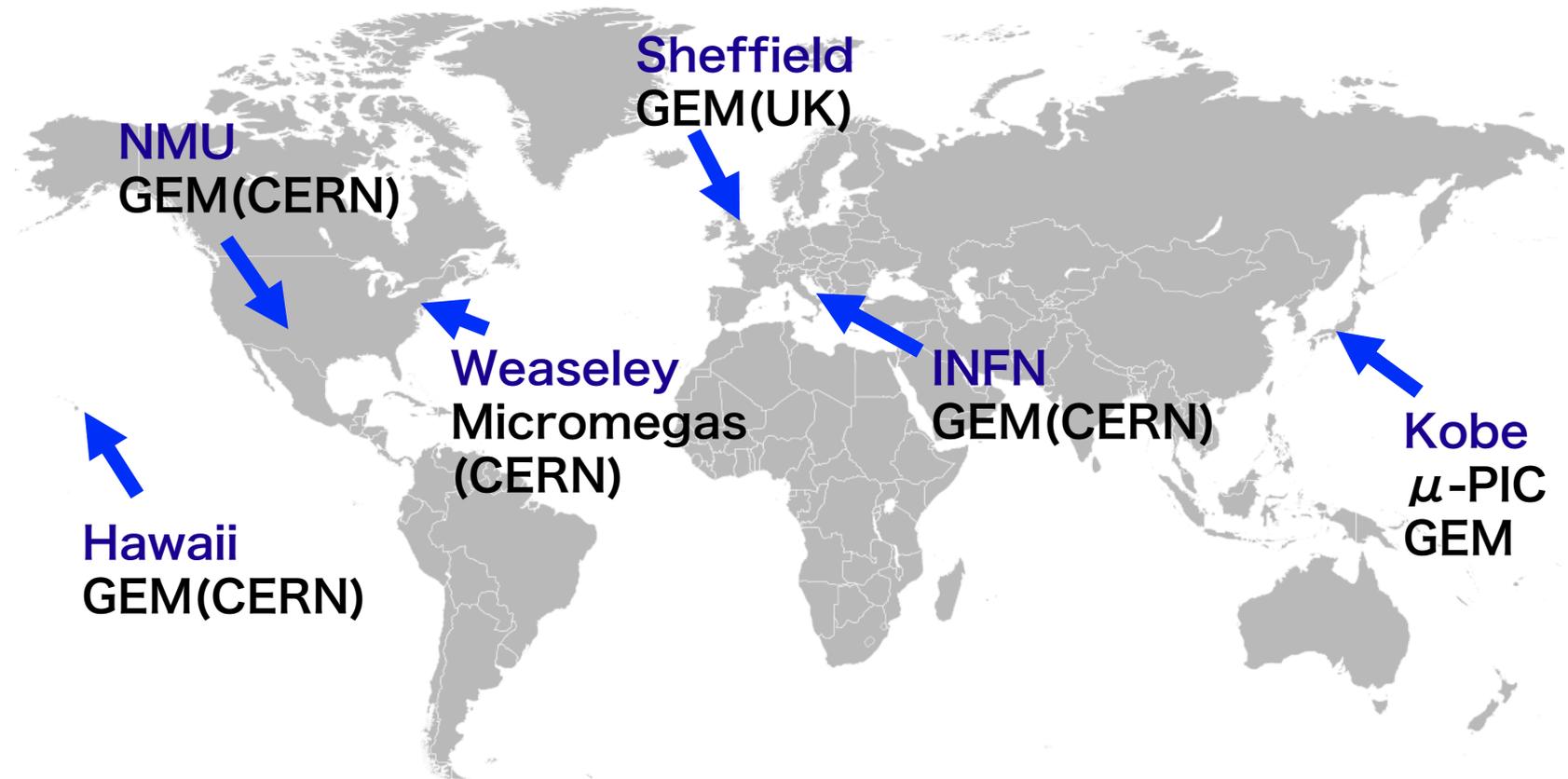
N.Phan talked @CYGNUS2015

$$z = (t_a - t_b) \frac{v_a v_b}{(v_b - v_a)}$$

- 陰イオンガス特有の信号(マイノリティピーク)を用いることで z 軸方向の絶対位置を決定できる

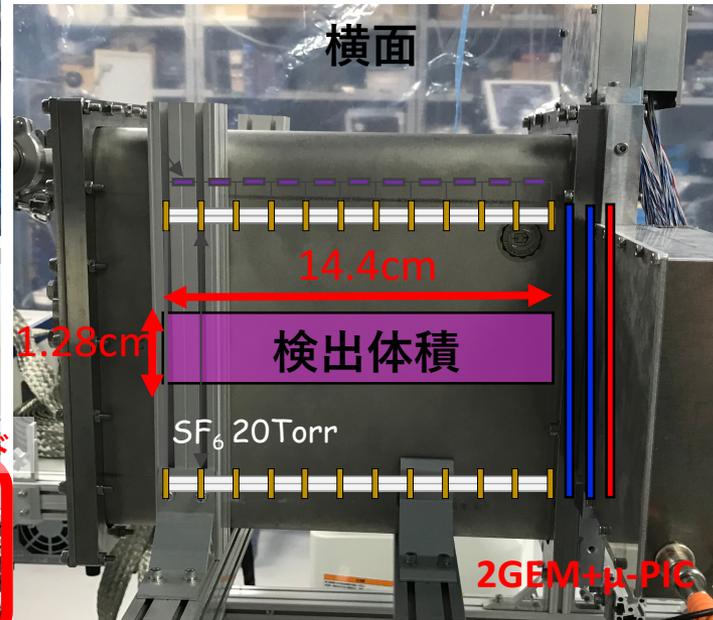
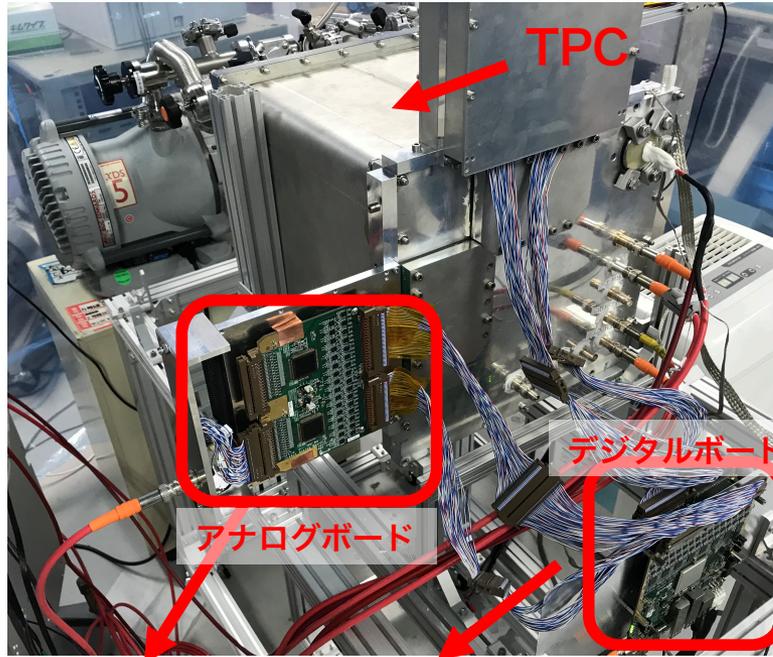
世界情勢 - 陰イオンラッシュ

✓ 2015-2018に陰イオンガスに乗り出した人たち



NEWAGEでの取り組み

- ✓ 10cm角の μ -PICを使った小型のNI μ TPCの開発



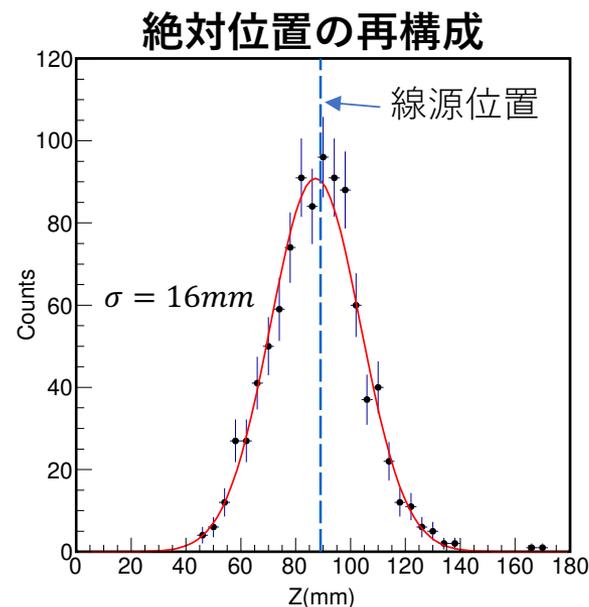
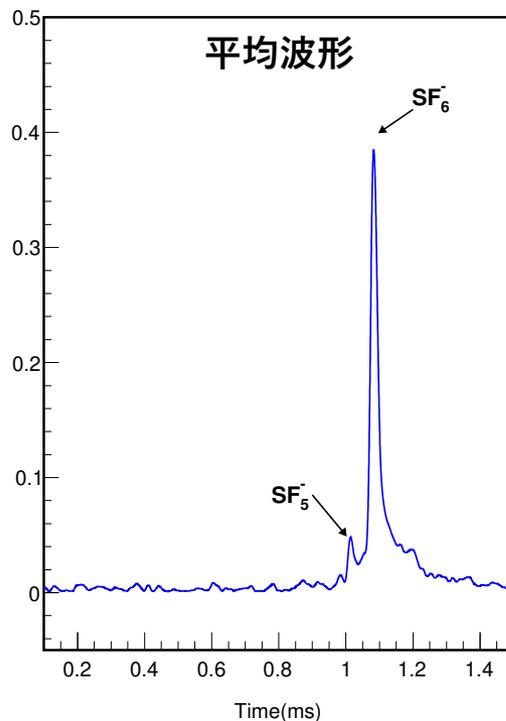
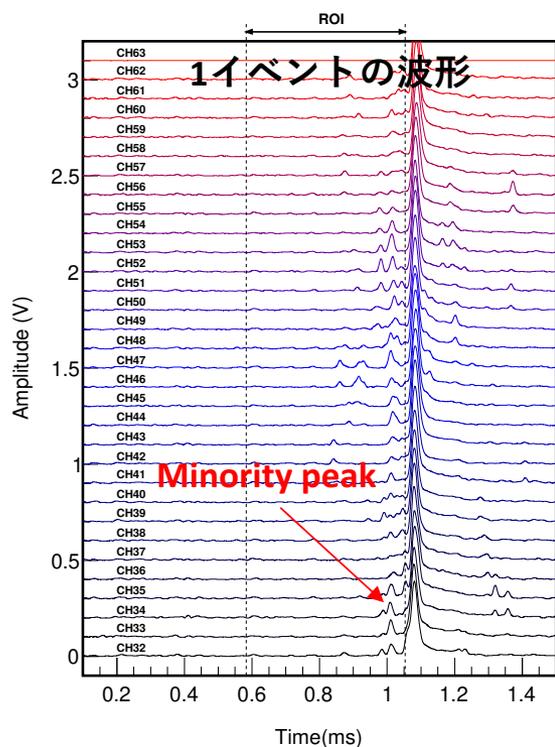
- ✓ 検出体積は1.28cm × 2.56cm × 14.4cm

← KEKで開発された液体アルゴン検出器用の読み出しボードを利用

- 64 × 2チャンネル読み出し

NEWAGEの取り組み

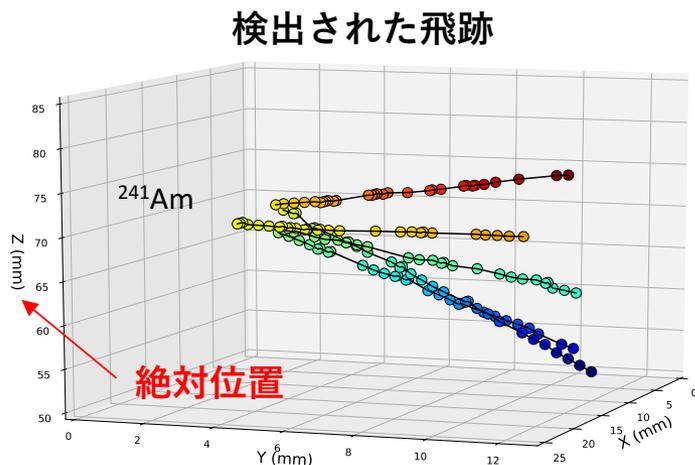
- ✓ 多チャンネル読み出しボード(LTARS-2014)を用いてマイノリティチャージの読み出しに成功



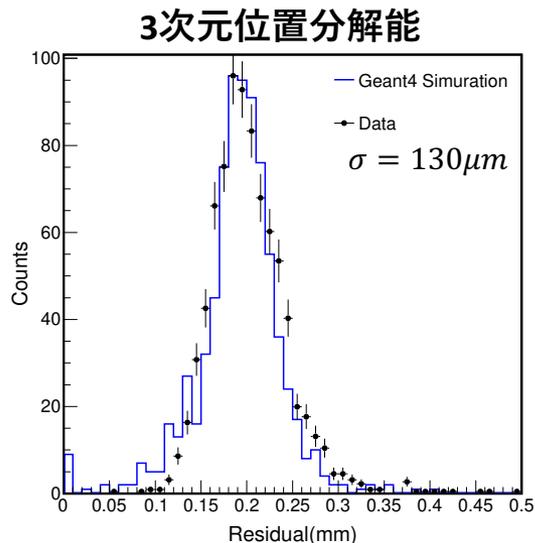
- 絶対位置zの位置分解能16mmを達成

NEWAGEの取り組み

- ✓ NI μ TPCの飛跡検出能力の評価を行った

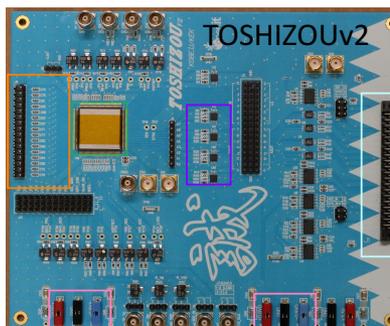


- **3次元位置分解能130 μ m**を達成
- Zの位置決定と飛跡検出の同時測定が可能

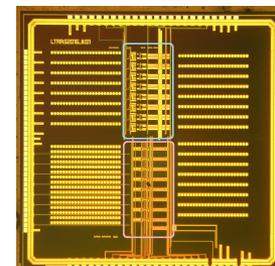


- ✓ 大面積読み出しに向けて、NI μ TPC専用の読み出しボードを開発中

	要請値	測定値
Gain high/low [mV/fC]	10/0.5	10.05/0.54
ENC@300pF	4000	6000
Dynamic range high/low [fC]	80/1600	160/2400



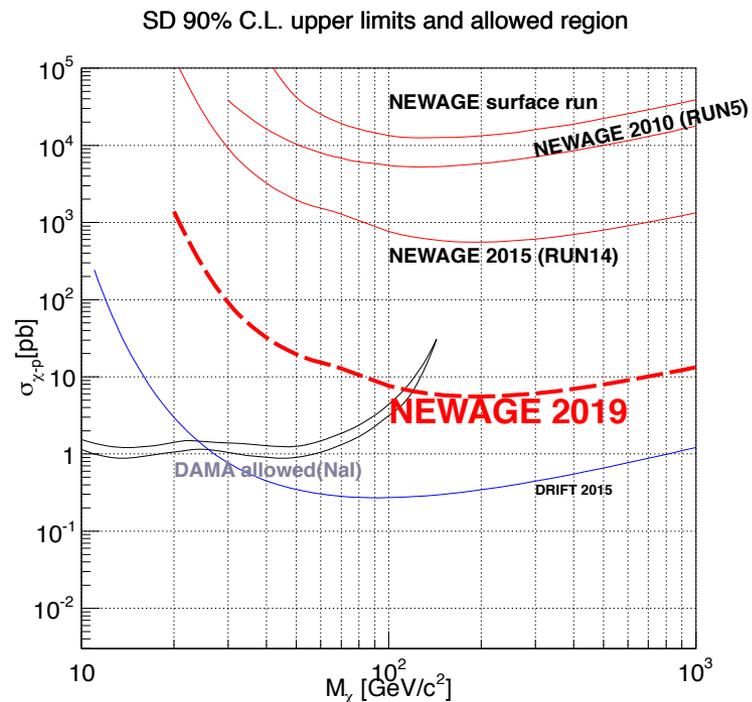
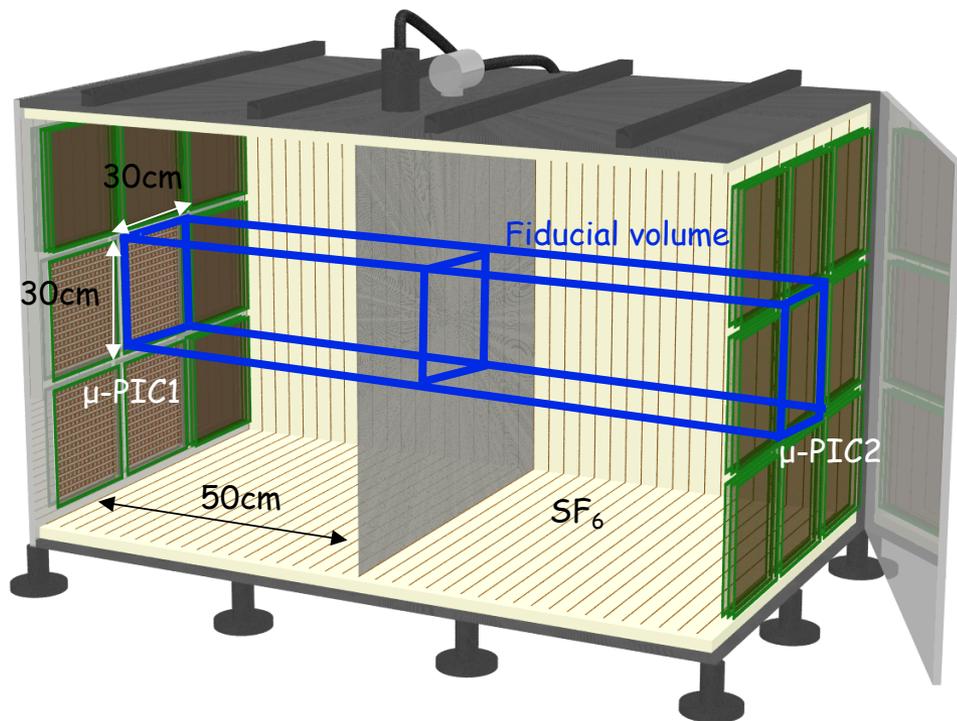
←ASICチップ評価用ボード



ASICチップ
LTARS2016_K01

TPCの大型化に向けて

CYGNUS/NEWAGE vessel



- 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

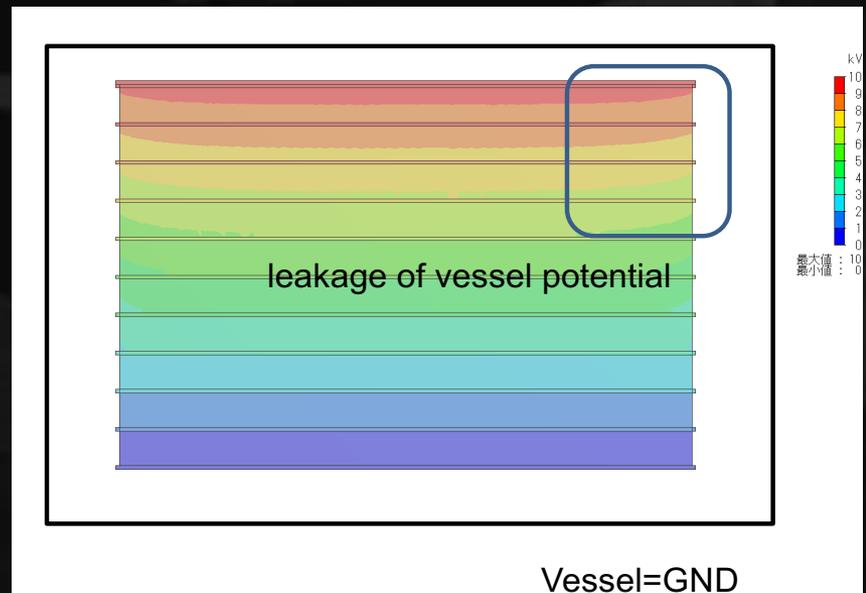
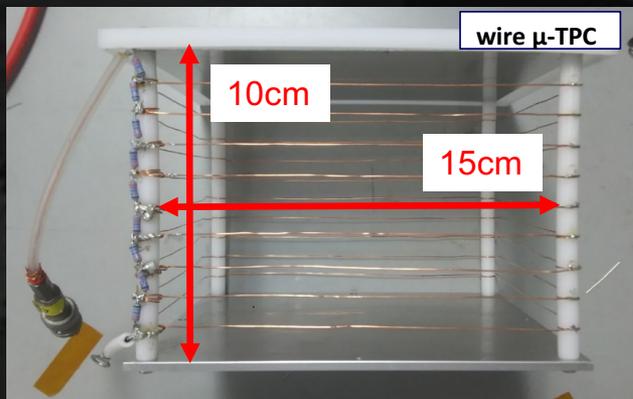
➤ TPCケースの制作に着手

Sheet Resistor μ -TPC (by 身内)

◆ motivation

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

⇒ Sheet Resistor (SR) μ -TPC



Sheet Resistor μ -TPC (by 身内)

● Proof-of-concept SR μ -TPC ($\sim 10\text{G}\Omega/\square$)

ASONE通販

commercially available materials

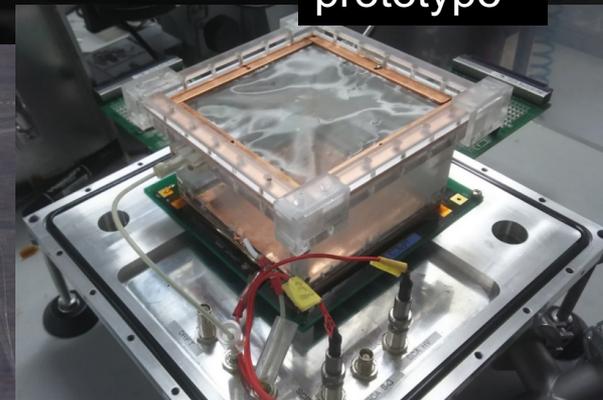
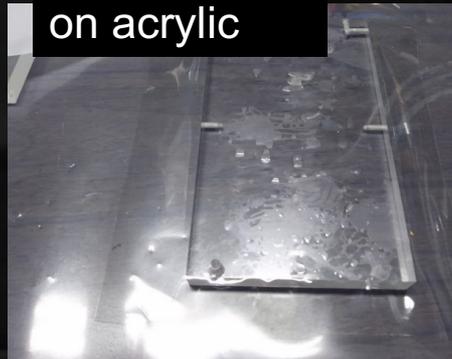


chosen one : "Achilles Vynilas"
(in terms of) resistivity and
uniformity

prototype

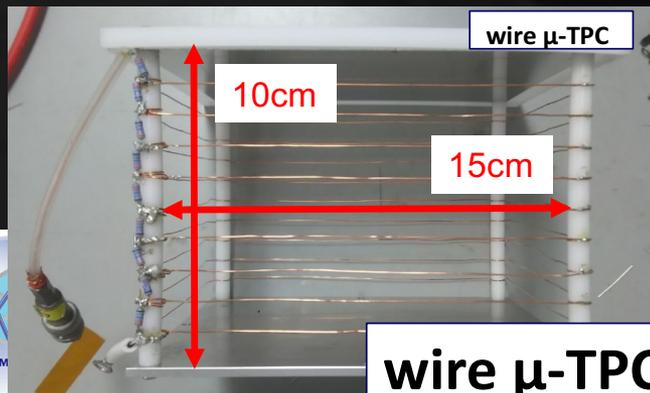
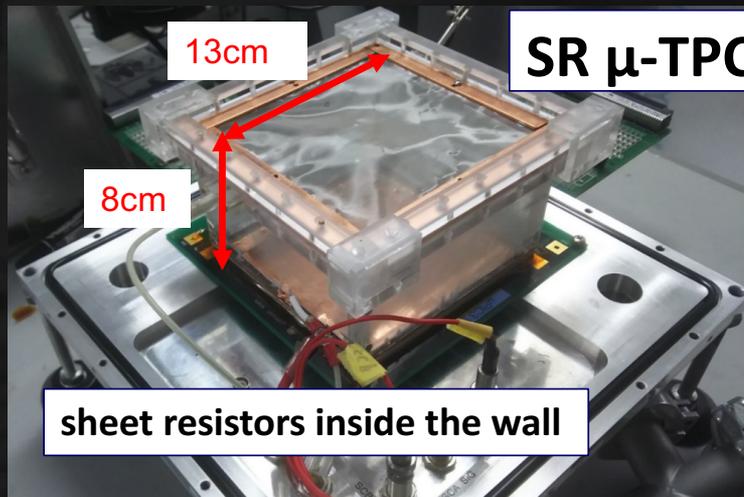


on acrylic

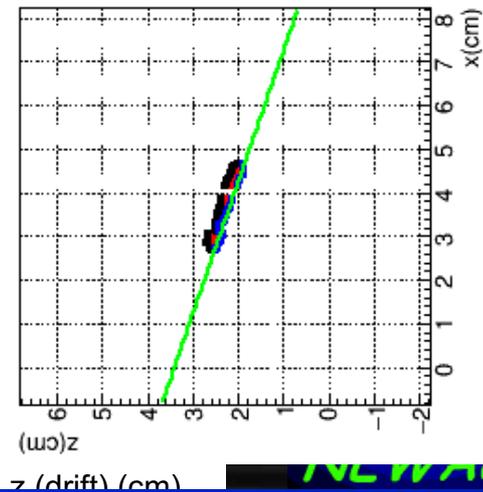
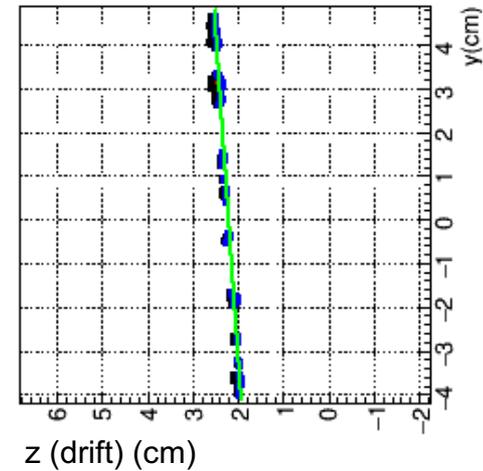


Sheet Resistor μ -TPC (by 身内)

- performance test
 - coupled with 10cm μ -PIC
 - compared with wire μ -TPC



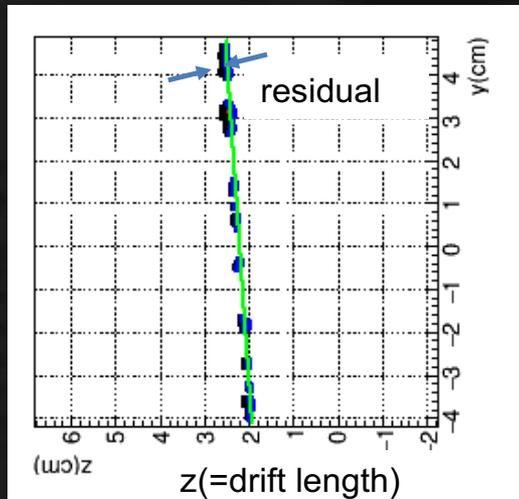
muon track
measured by SR μ -TPC



Sheet Resistor μ -TPC (by 身内)

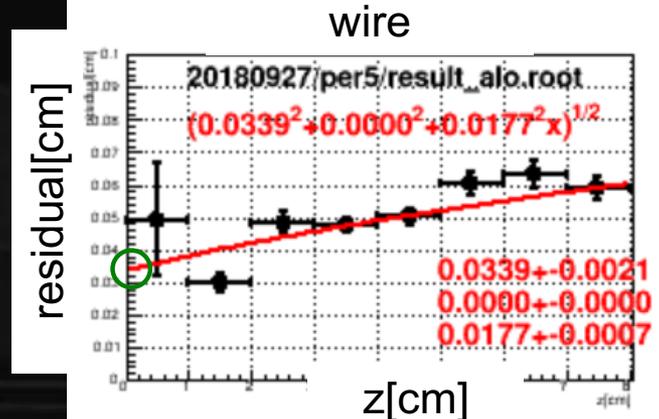
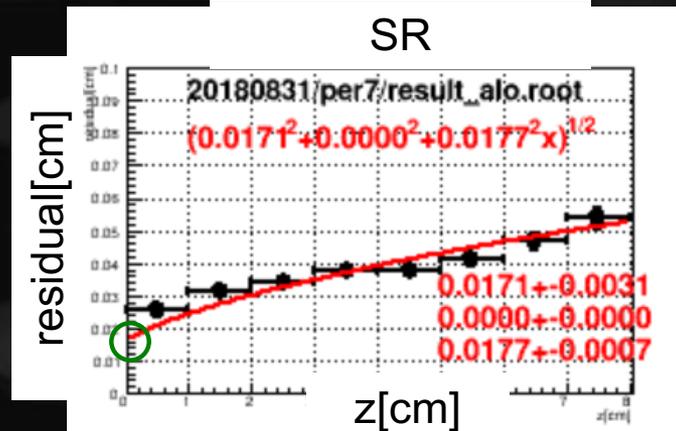
Result

- z-dependence of residual
- calculate z-independent term



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

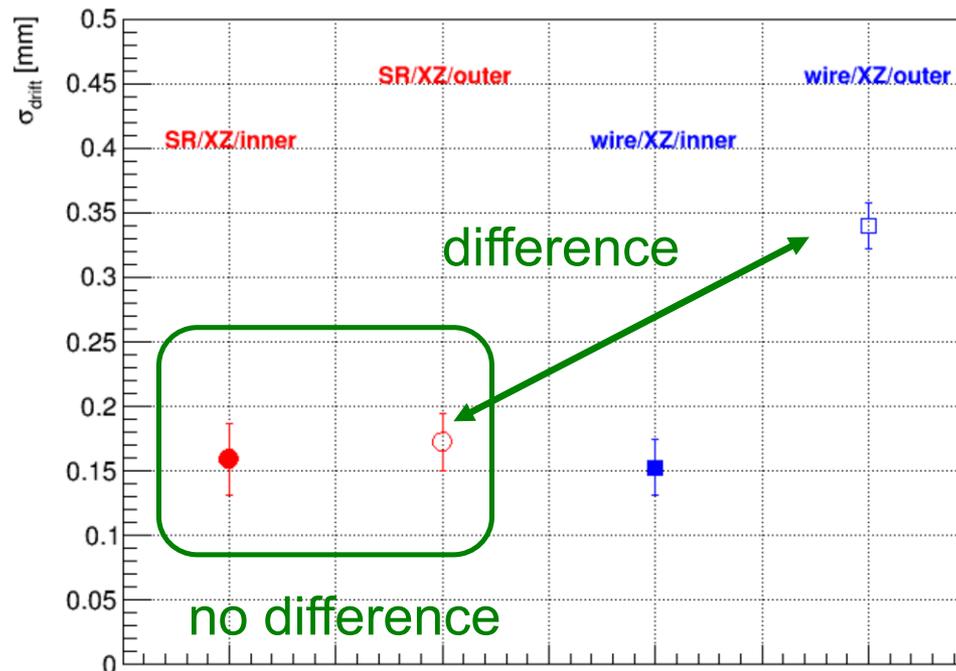
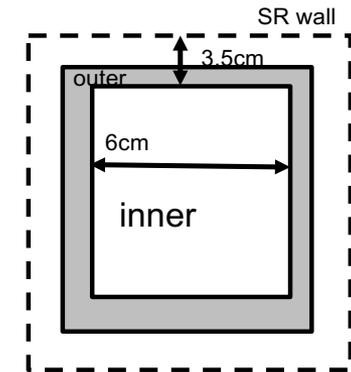
$$\sigma_{diff,(i,j,k)} = D_{diff,(i)} \sqrt{z}$$



Sheet Resistor μ -TPC (by 身内)

Results (residual distributions)

- compare SR/wire \otimes inner/outer
- SR shows better position resolution @ outer than wire



まとめ

- ✓ MPGDを使った暗黒物質探索実験では低BGなMPGDの開発が行われている
 - 低BG素材を使用したMPGD
 - 陰イオンガスTPC
- ✓ NEWAGE実験ではLow- α μ PICを使った暗黒物質探索実験が行われている
 - 現在もデータ取得を継続 & BGstudy中
- ✓ 大型検出器のSRを使ったTPCゲージを開発中

Background Study

By Takashi Hashimoto

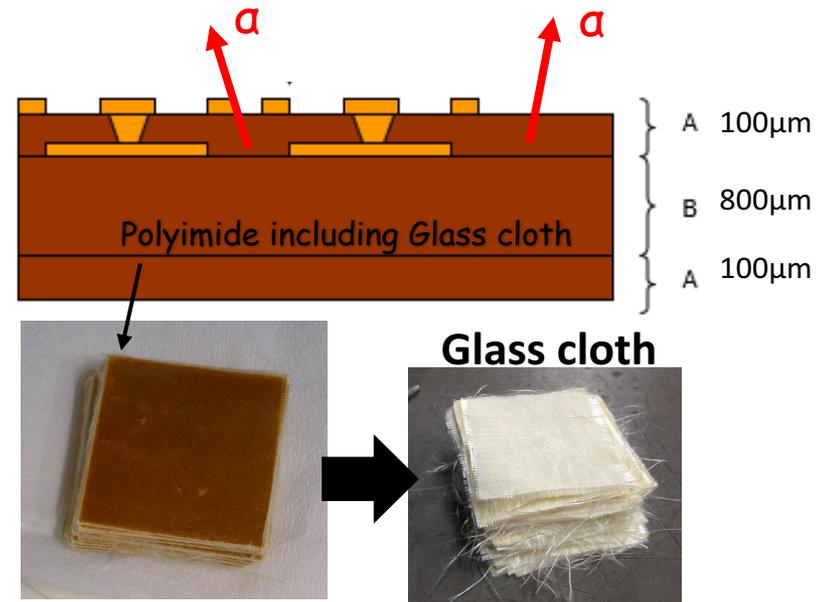
- Main BG is **alpha particle from μ -PIC**
 - Measured by high pure Ge detector

U/Th contamination

	^{238}U [$\mu\text{Bq}/\text{cm}^2$] middle stream [†]	^{232}Th [$\mu\text{Bq}/\text{cm}^2$]
PI 100 μm	68.5 ± 1.5	102.1 ± 2.3
Glass cloth	64.5 ± 0.1	86.8 ± 1.1
(PI)-(Glass cloth)	4.0 ± 1.5	15.3 ± 2.6

- U/Th in the Polyimide 100 μm can be explained by U/Th of **glass cloth**
- Two approach for reduction of BGs
 - Low α μ -PIC
 - Full-fiducialization analysis using **Negative Ion**

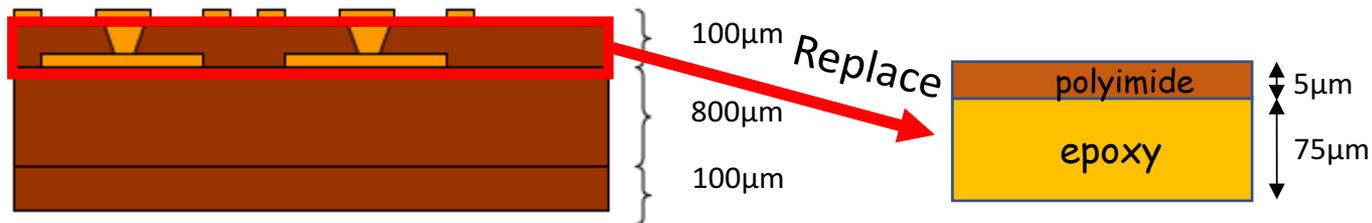
Cross-section view of μ -PIC



Development of Low α μ -PIC

By Takashi Hashimoto

- Production of μ -PIC with low radioactive materials
 - Glass cloth was used as reinforced material
 - Epoxy can be replacement

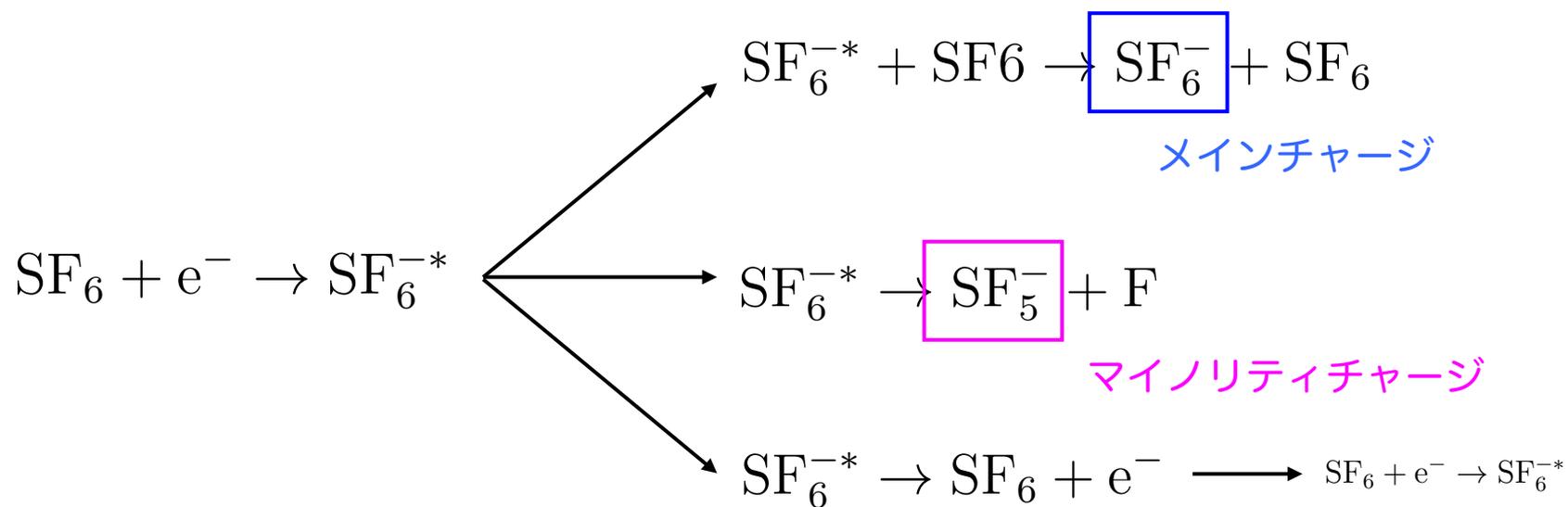


U/Th contamination

	^{238}U [ppm]	^{232}Th [ppm]
PI including glass cloth	0.39 ± 0.01	1.81 ± 0.04
PI+epoxy	$< 2.98 \times 10^{-3}$	$< 6.77 \times 10^{-3}$

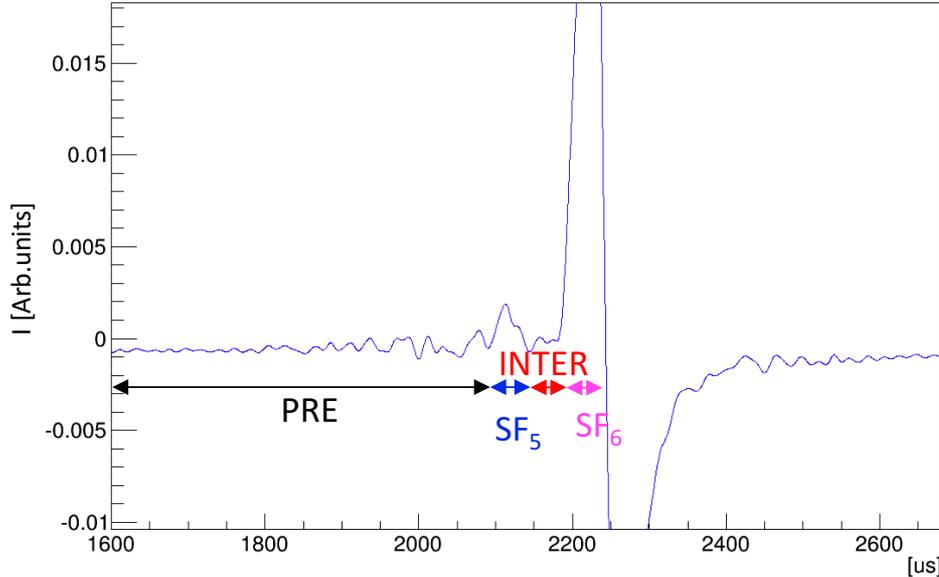
← New material

- Polyimide+epoxy is **100 times as pure as current materials**

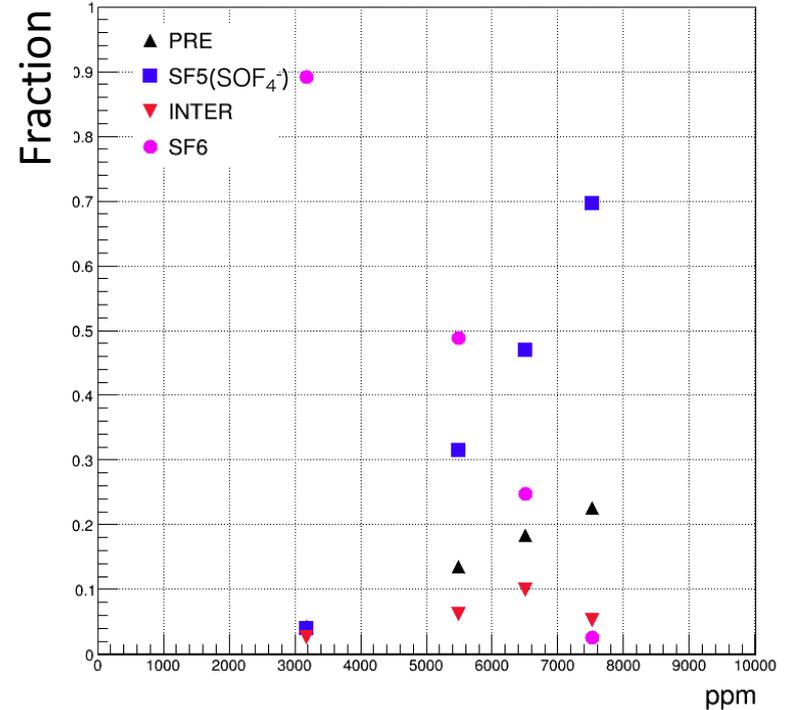


アウトガスによる影響

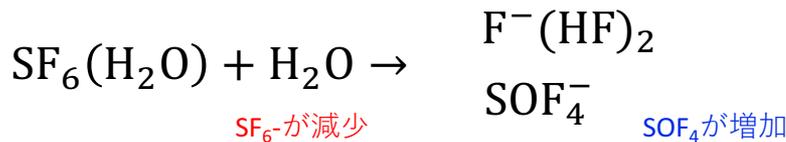
電荷の定義図



水分と電荷量の変化



- $\text{SF}_6\text{-(H}_2\text{O)}$ と H_2O の反応



- 電荷量の変化は SF_6 と H_2O の反応で説明できる
- SF_5 -領域の電荷の増加は SOF_4^- が寄与している
- F-(HF)_2^- と SF_4O^- の生成比は1:4(*J. Phys. Chem. A* **2001**, 105, 3527-3531)、PREチャージは F-(HF)_2^- で説明可能

SF_5 の質量 : 127.05g/mol
 SOF_4^- の質量 : 124.05g/mol
 F-(HF)_2^- の質量 : 59.00g/mol

読み出し回路の開発

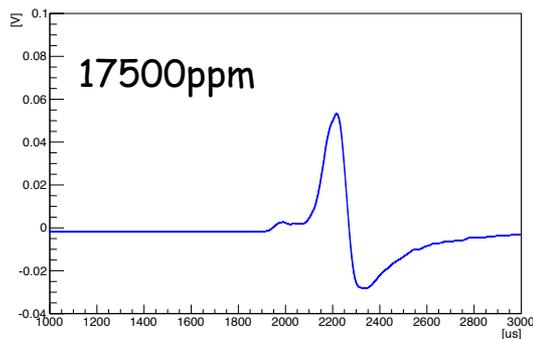
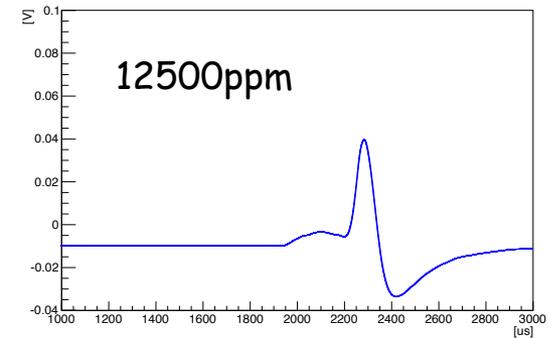
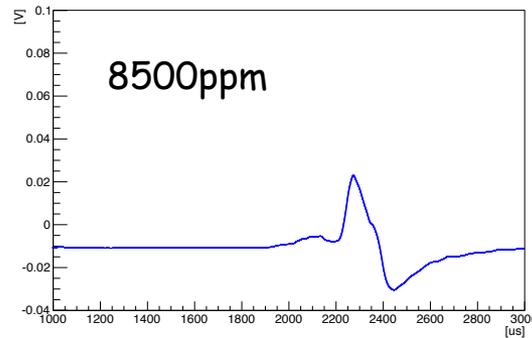
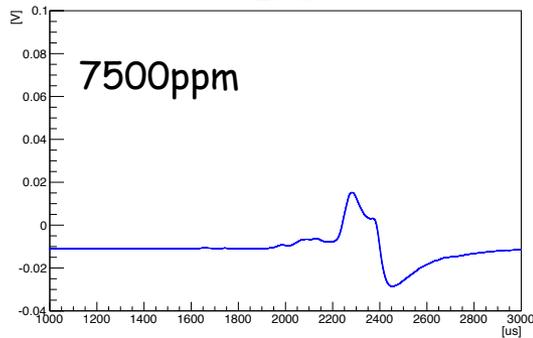
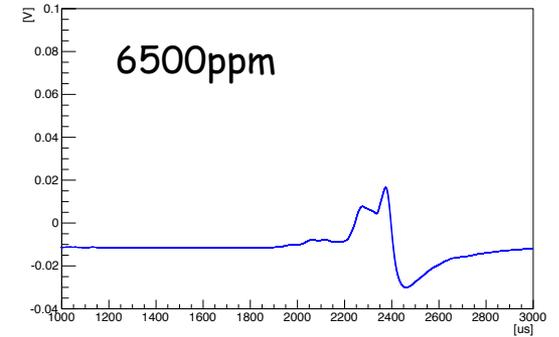
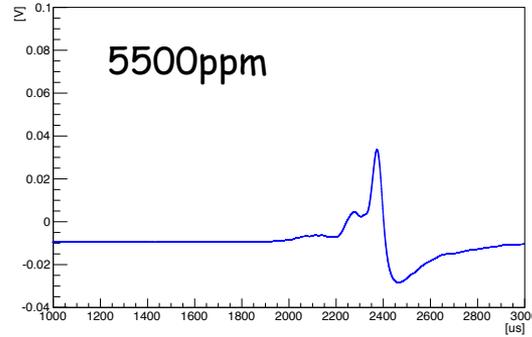
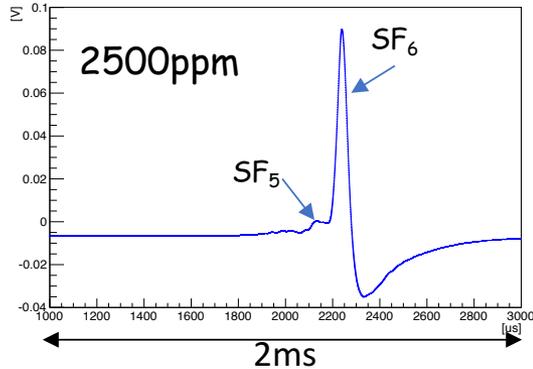
読み出し回路の要請値

parameter	value	comment
C _{det}	300pF	
pulse shape	4 μ sec, 1 μ sec	gas, LAr 切り替え可能に
power	<50mW/32ch	LTARS2014と同じ
その他の機能	16ch input、低温動作、(出力differential :まずTEGで確認)	

parameter	narrow range	wide range	comment
signal size	3fC, 30fC	100fC, 150fC	gas, LAr
noise (ENC)	2000以下	6.25 x 10 ⁴ 以下	S/N 10以上
gain	10mV/fC	0.5mV/fC	
dynamic range	80fC	1600fC	出力電圧~800mV

- マイノリティチャージの信号サイズが非常に小さいため、ダイナミックレンジの大きな回路が必要になる

アウトガスによる影響



- H₂Oの混入量が増加すると
 - SF₅のピークが大きくなるように見える
 - SF₅よりドリフト速度の速い電荷が増える