Study of Negative-Ion TPC using μ-PIC for Directional Dark Matter search

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+NEWAGE Group

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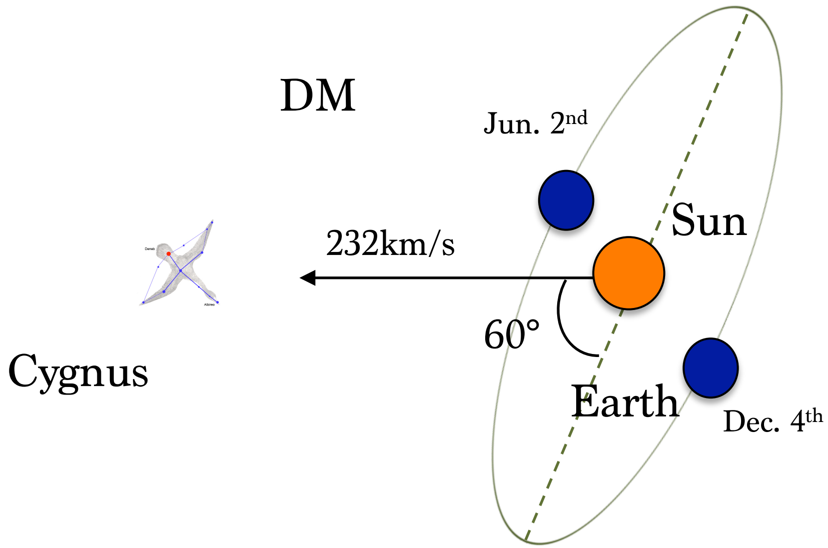
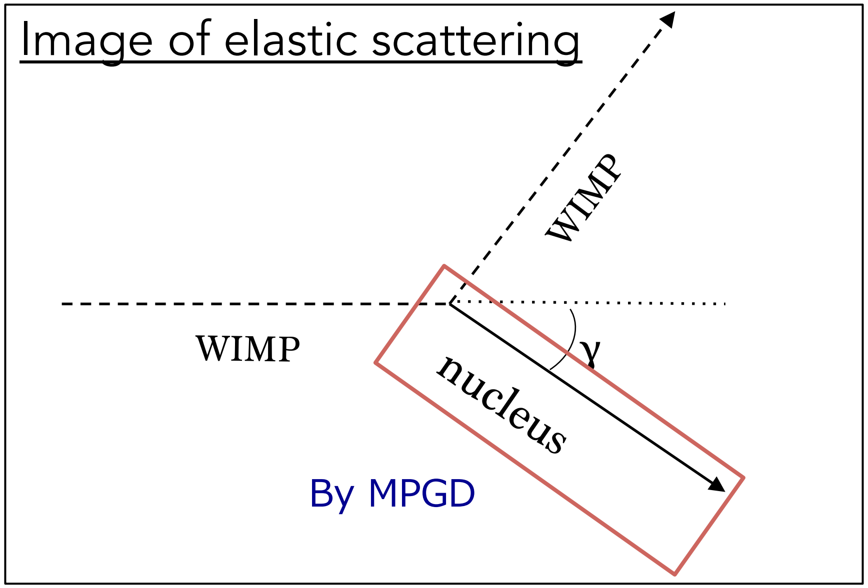
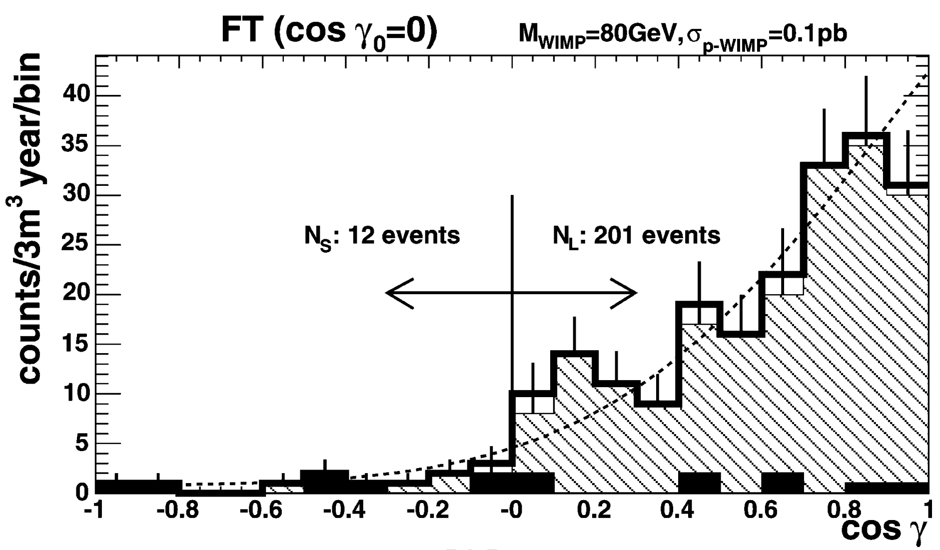
1. DM experiment with MPGD

Directional Dark Matter Search with MPGD





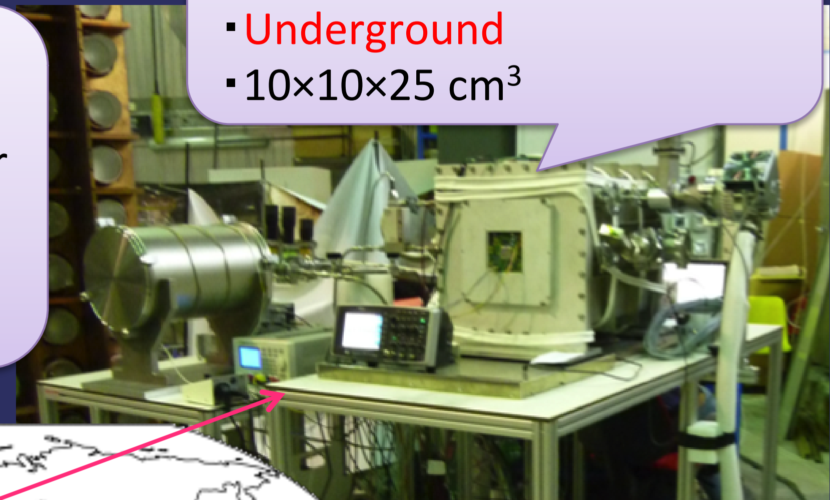
- Dark matter is coming to the earth from Cygnus
- Reconstruct 3D track of nuclear recoil using MPGD
- Recoil angle distribution gives strong evidence.



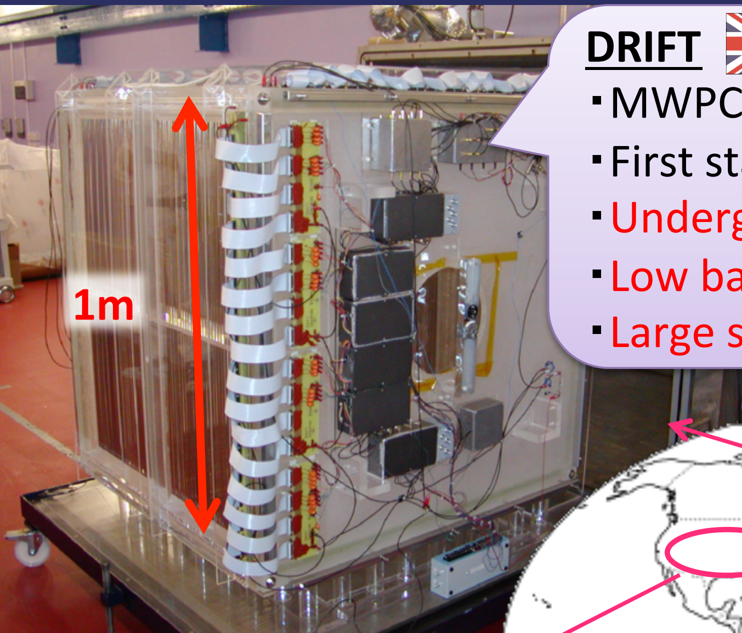
PLB578 (2004) 241–246

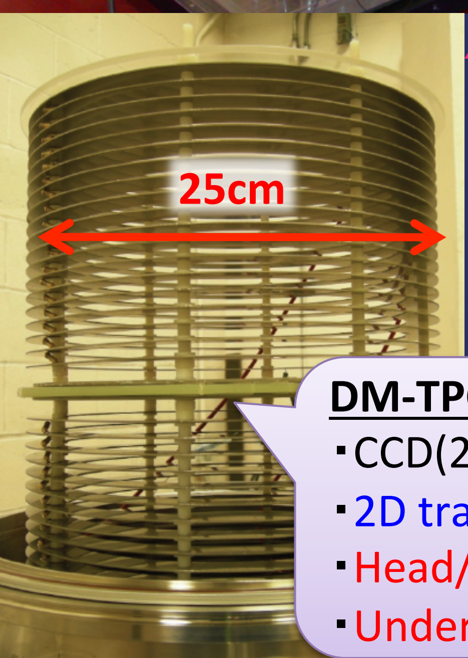
DM experiments using Gas Detector

MIMAC
- MicroMegas(~424um pitch)
- Underground
- 10×10×25 cm^3

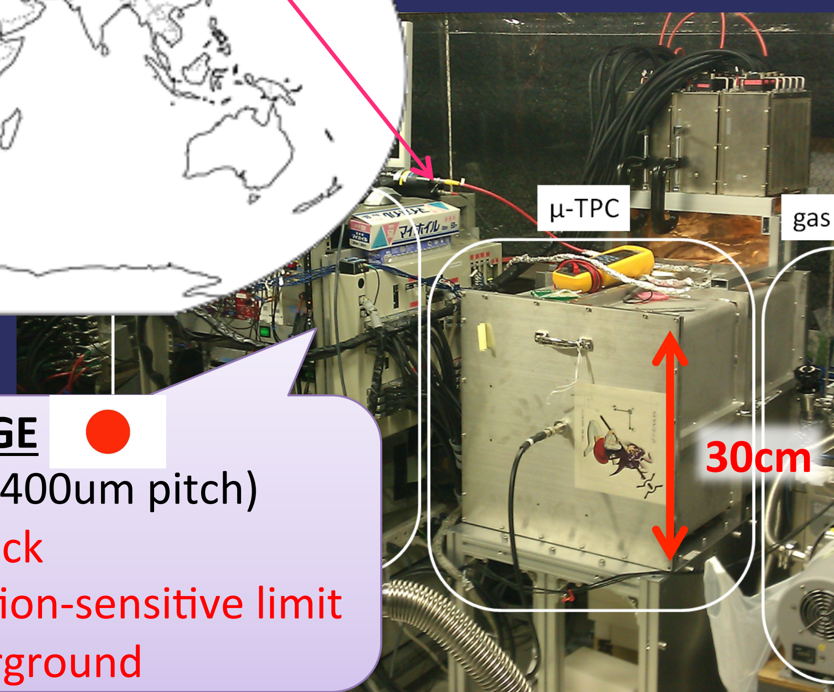


DRIFT
- MWPC(2mm pitch)
- First started gas detector
- Underground
- Low background
- Large size(~$1m^3$)





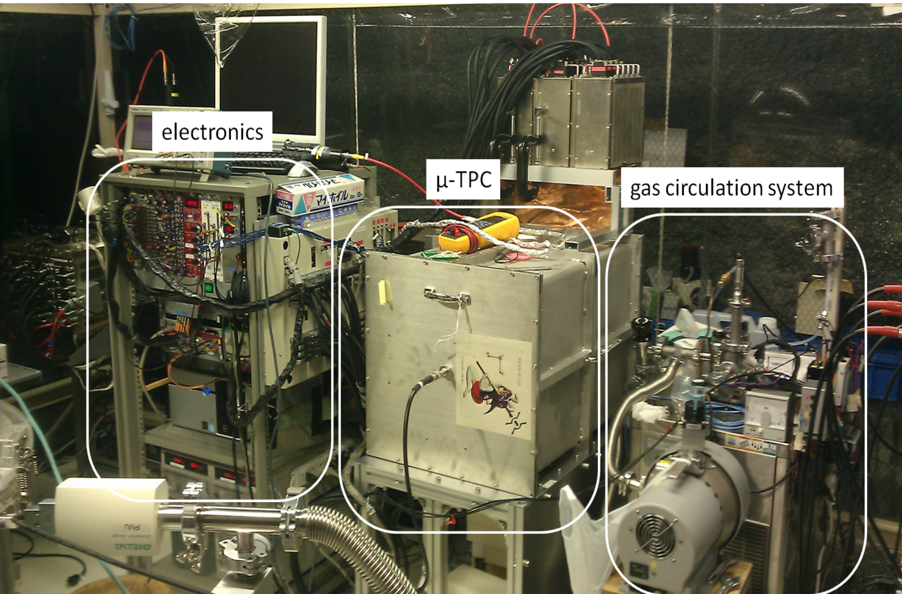
DM-TPC
- CCD(256um pitch)
- 2D track
- Head/tail recognition
- Underground

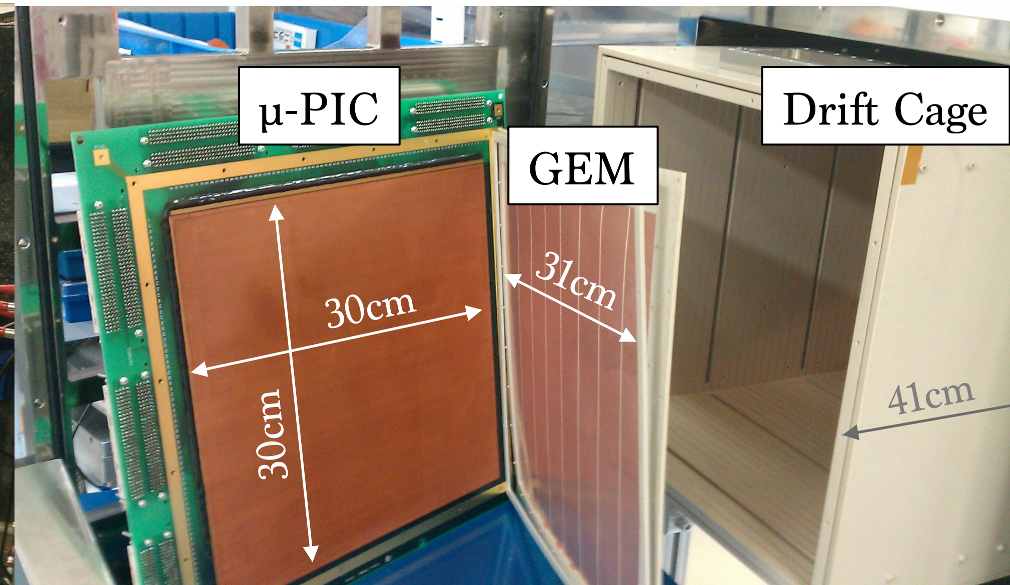


NEWAGE
- μ-PIC(400um pitch)
- 3D track
- Direction-sensitive limit
- Underground

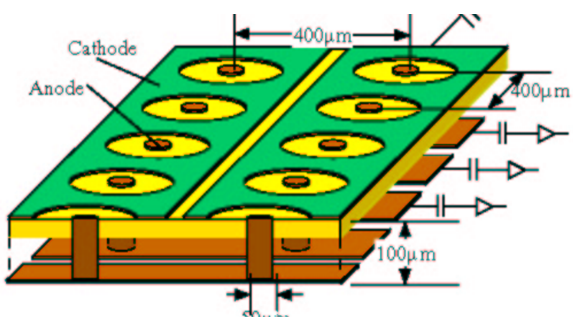
2. NEWAGE

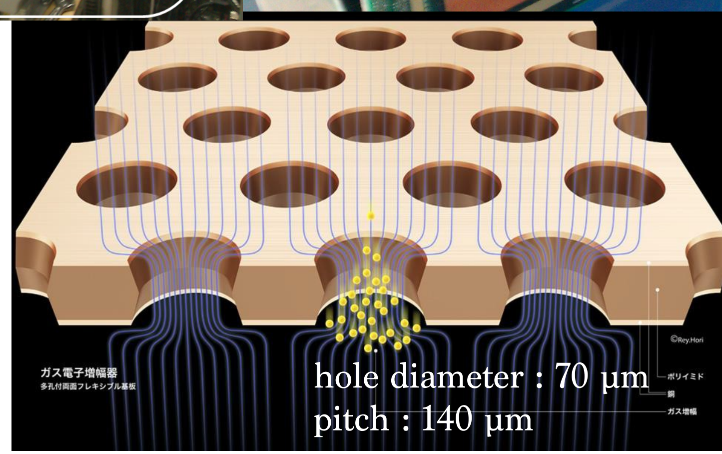
NEWAGE0.3b' Detector @Kamioka mine





μ-PIC: Anode pitch 400 μm
Gasgain ~10^3





GEM : Preamplifier (Gas gain ~10)
LCP 100μm

- Detection volume
  30×30×41 cm^3
- Gas
  CF_4(76 torr)

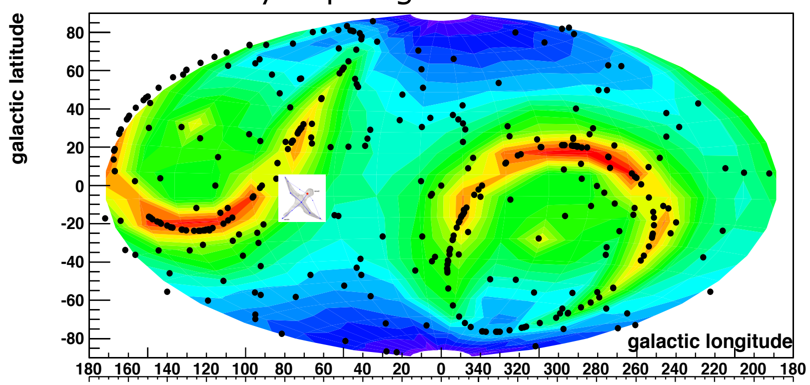
Good for spin dependent DM search

Latest Result

Conditions RUN14

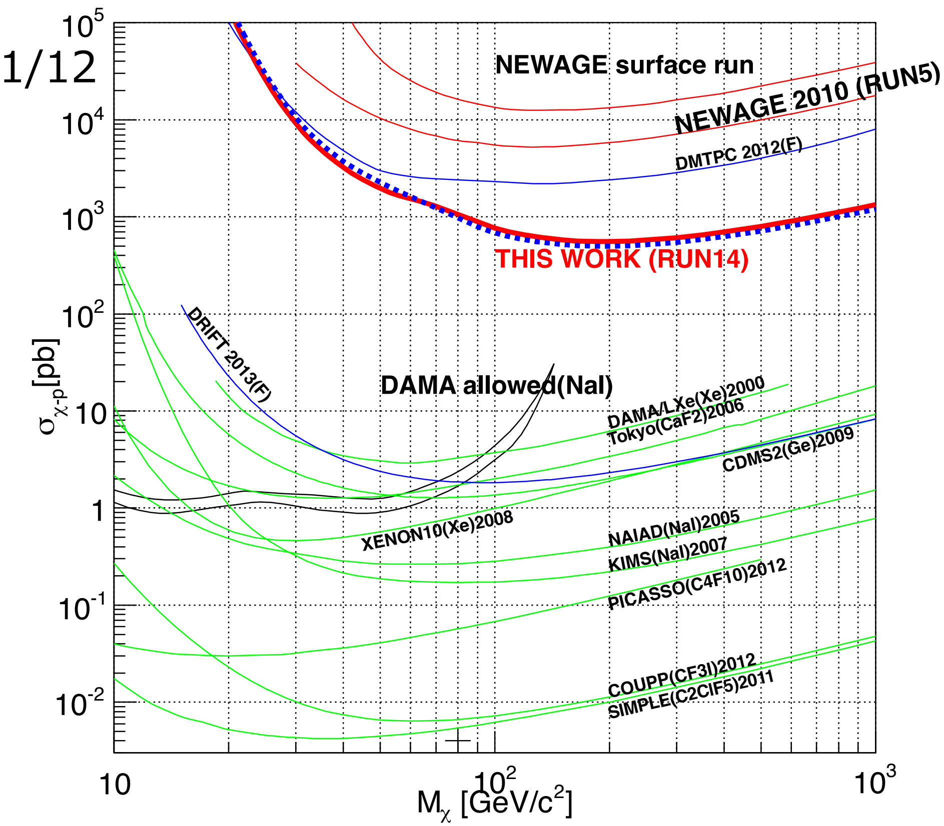
- period : 2013/7/20~8/11, 10/19~11/12
- live time : 31.6 days
- fiducial volume : 28×24×41 cm^3
- CF_4 gas(76Torr)
- mass : 10.36 g
- exposure : 0.327 kg・days

Skymap in galactic coordinate



- Black point is nuclear recoil event
- Gradation color: detector eficiency

SD 90% C.L. upper limits and allowed region

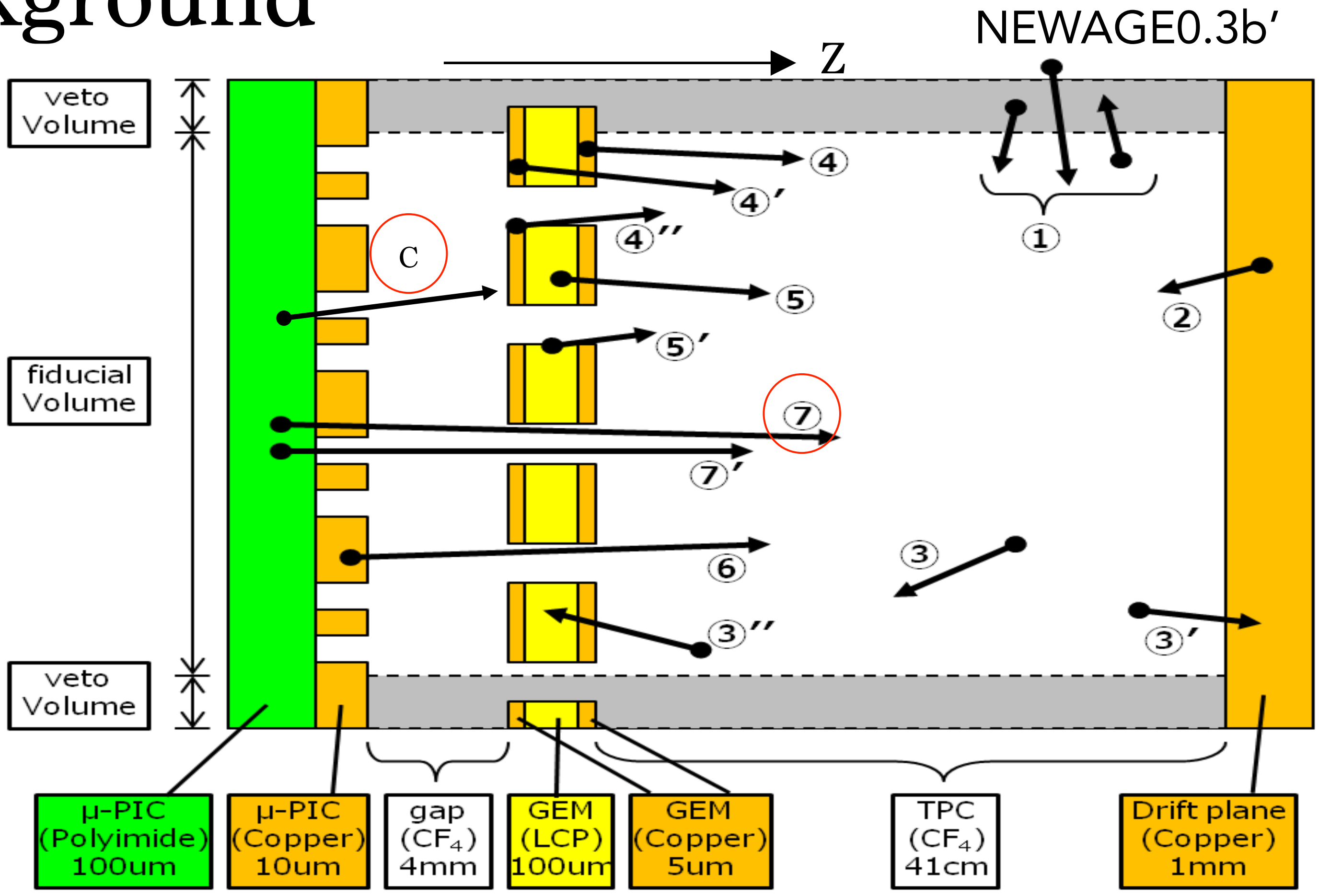


- the best direction-sensitive limit

(K.Nakamura et.al, PTEP(2015)043F01s)

3. Motivation

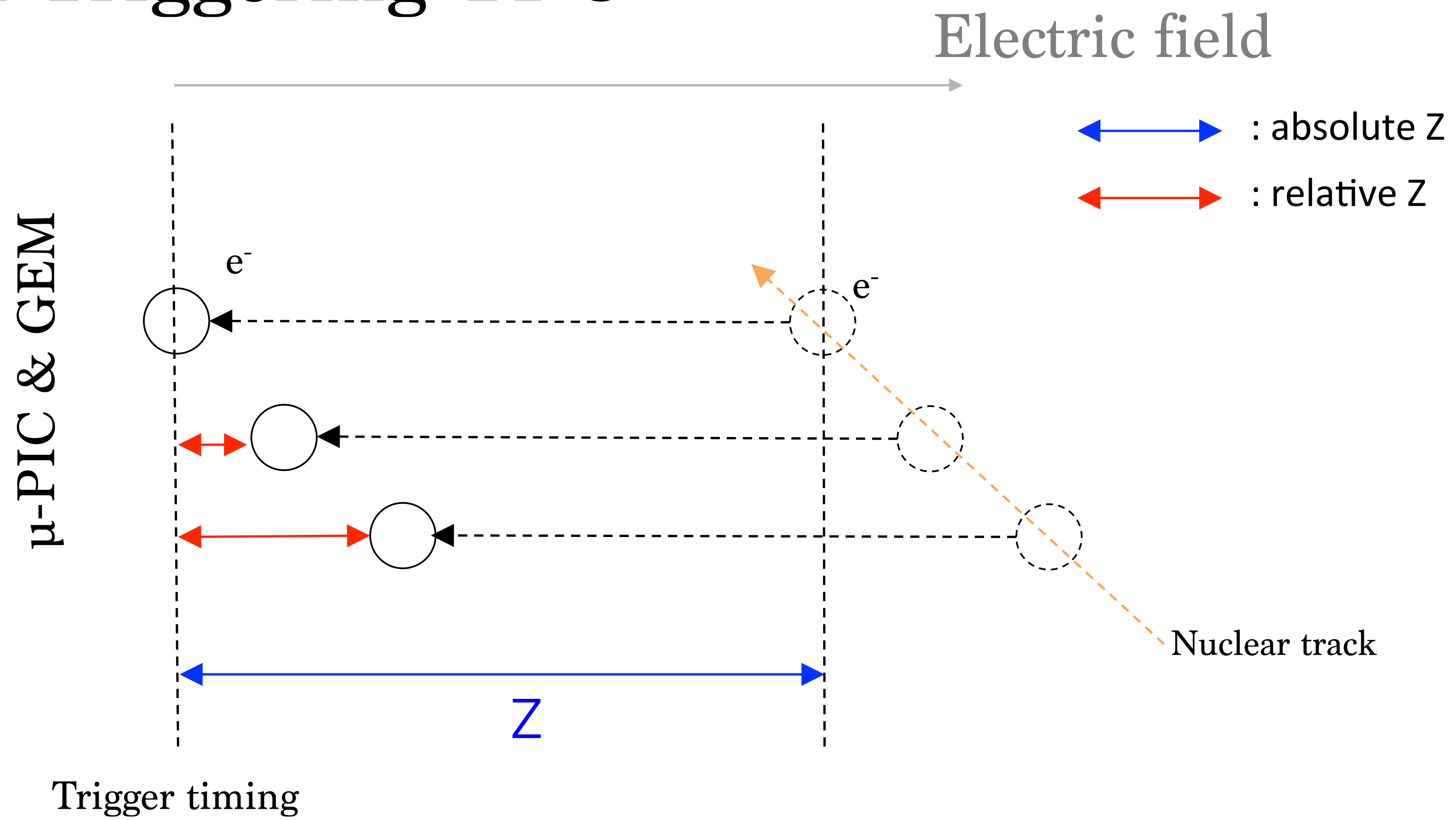
Background



- Main background event in μTPC
  - ⑦ in the high energy region
  - C in the low energy region
- α-rays (U/Th-chain) from the glass cloth in PI 100μm of μ-PIC is dominant
- We already could XY fiducialize

The Z fiducialization is, if possible , very important.

Self Triggering TPC

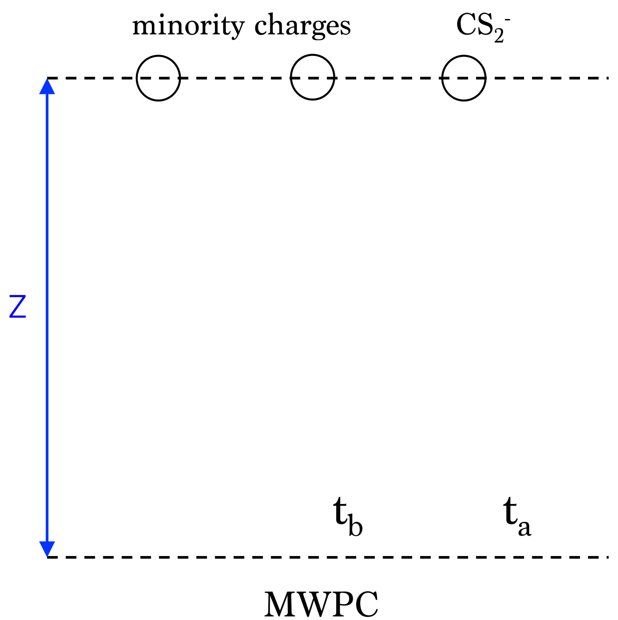


Absolute Z-position cannot be known in self-trigger.

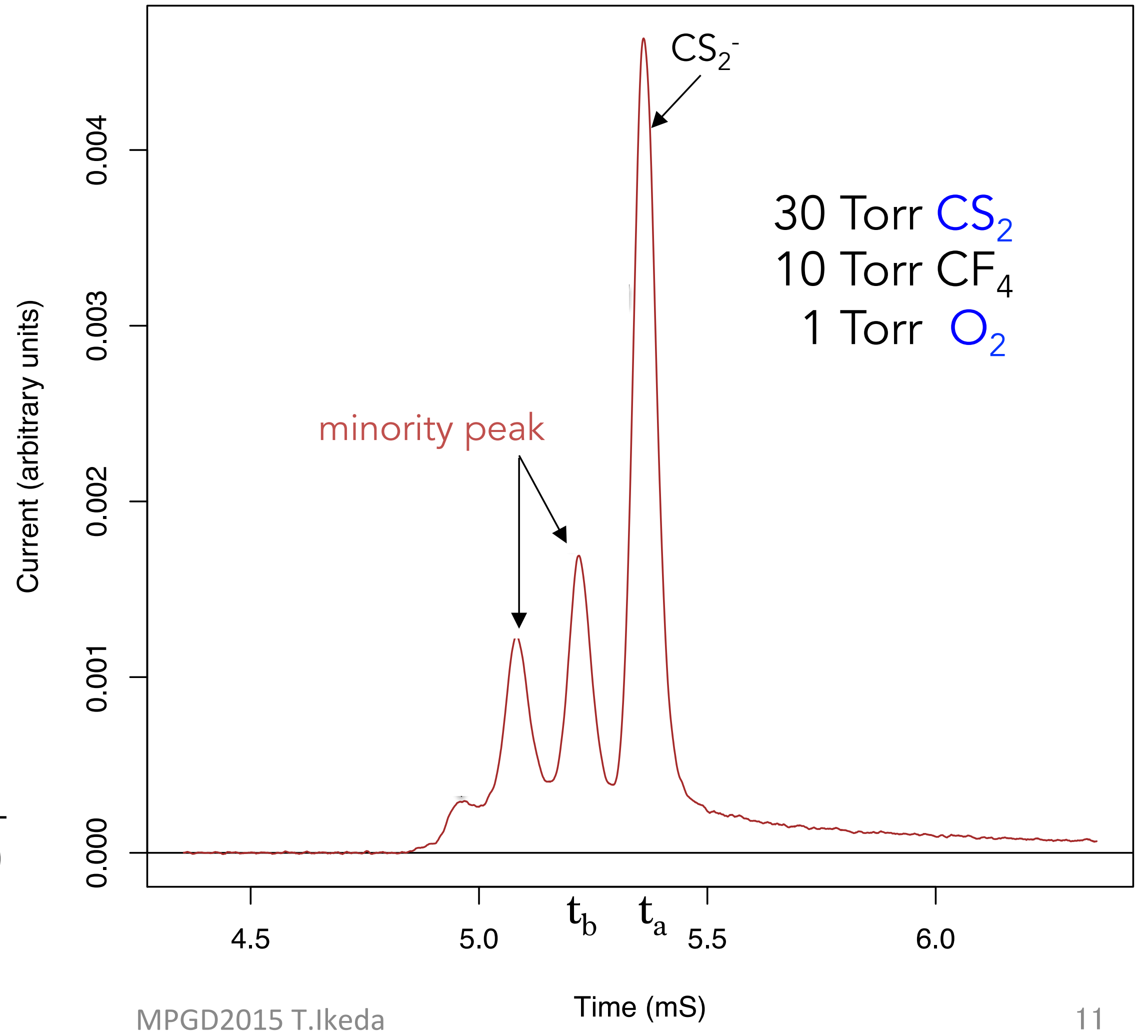
Z-fiducialization used by DRIFT

[Physics of the Dark Universe 9-10(2015)1-7]

- The first measurement of absolute Z-position in a self-triggering TPC
- Using negative ion gas CS_2 with a few percent O_2



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



Negative Ion Gas Candidates

$CF4$(electron drift(normal) gas)

- Being used for NEWAGE
- Typical drift velocity : ~cm/μs
- Operation Gas gain 3000 (76Torr)
- Amplifer gain 160mV/pC(ASDchip)

Negative Ion Gas

CS_2

- Toxic, Volatile, inflammable
- Electron Affinity 0.89eV
- Used with MWPC
- Requirement of gas gain

$$\sim 480 \cdot \frac{76\text{Torr}}{P}$$

using amplifier(1V/pC)

- Doesn't have Flourine

We need to add CF_4.

SF_6

- Non-toxic, Non-volatile, Nonflammable
- Electron Affinity 1.1eV
- Insulating gas
- High electric field is necessary
- Recently demonstrate with THGEM [N.Phan talk at CYGNUS2015 , June 2015]
- Requirement of gas gain

$$\sim 980 \cdot \frac{76\text{Torr}}{P}$$

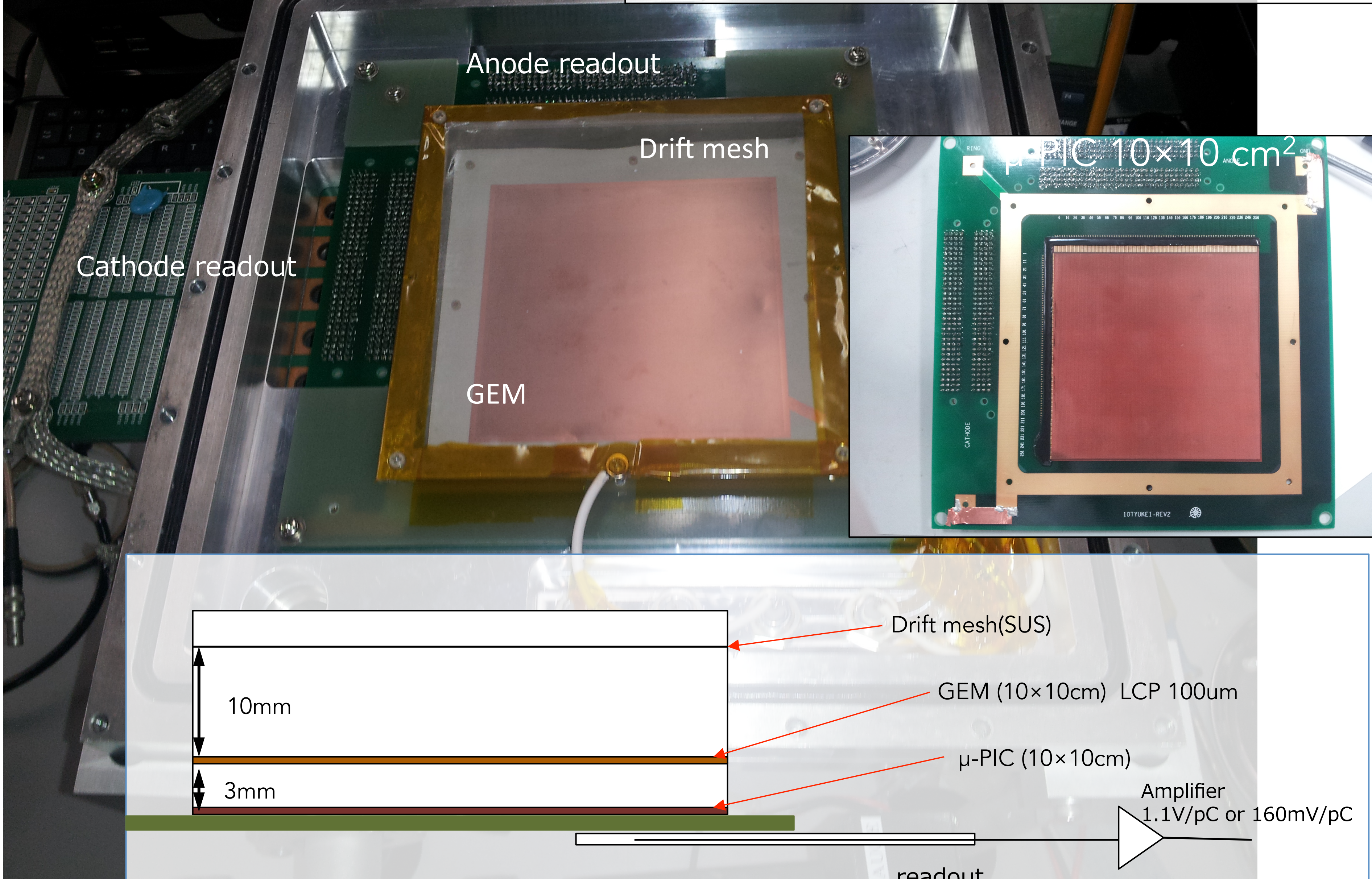
,using amplifier[1V/pC], then the amplitude of minority peak will be 15mV at Nuclear recoil (50keV)

Typical drift velocity: 10^{-2}cm/μs

We can use slow shaping time amplifier(good S/N).

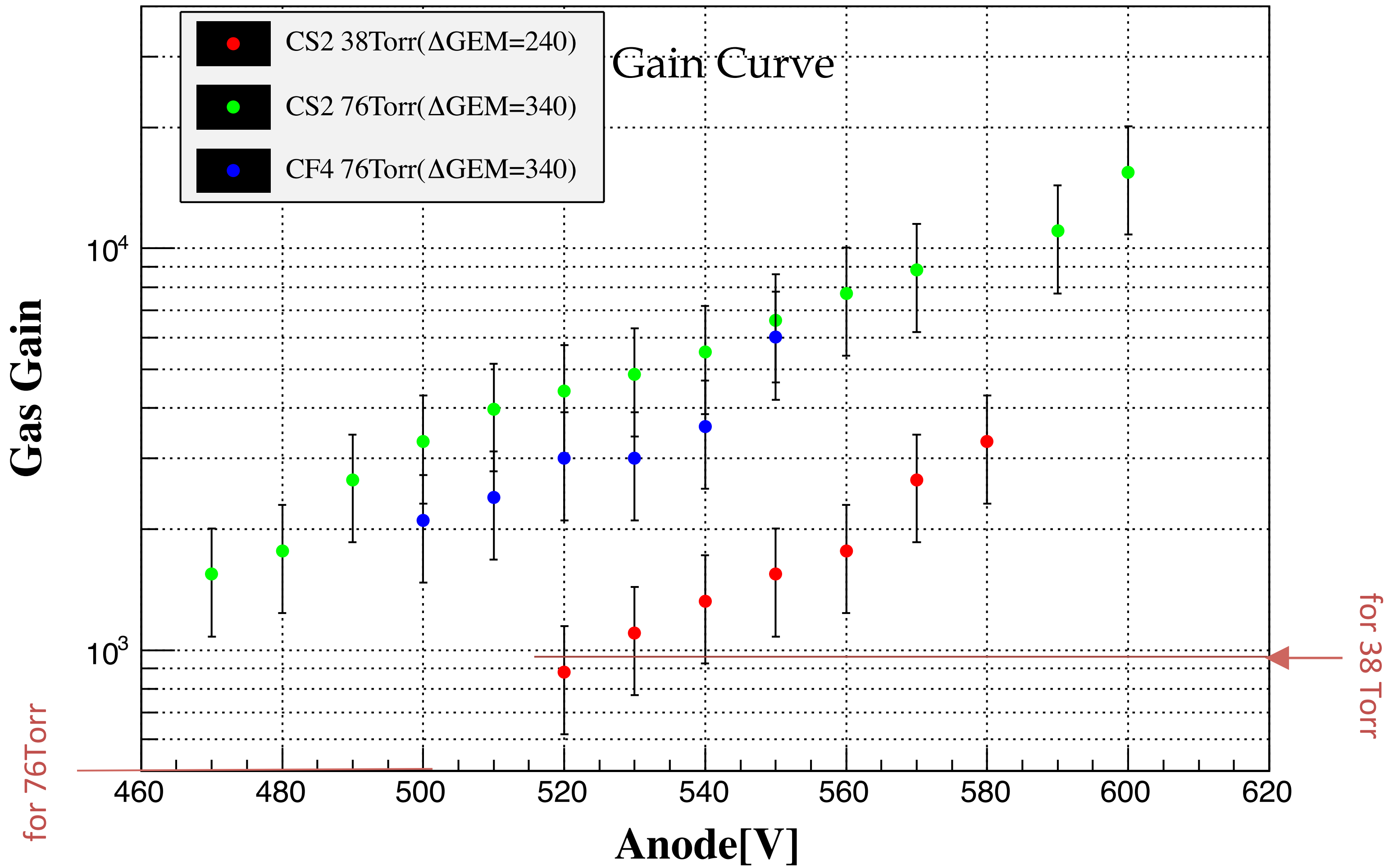
4. Measurement

NEWAGE0.1c detector



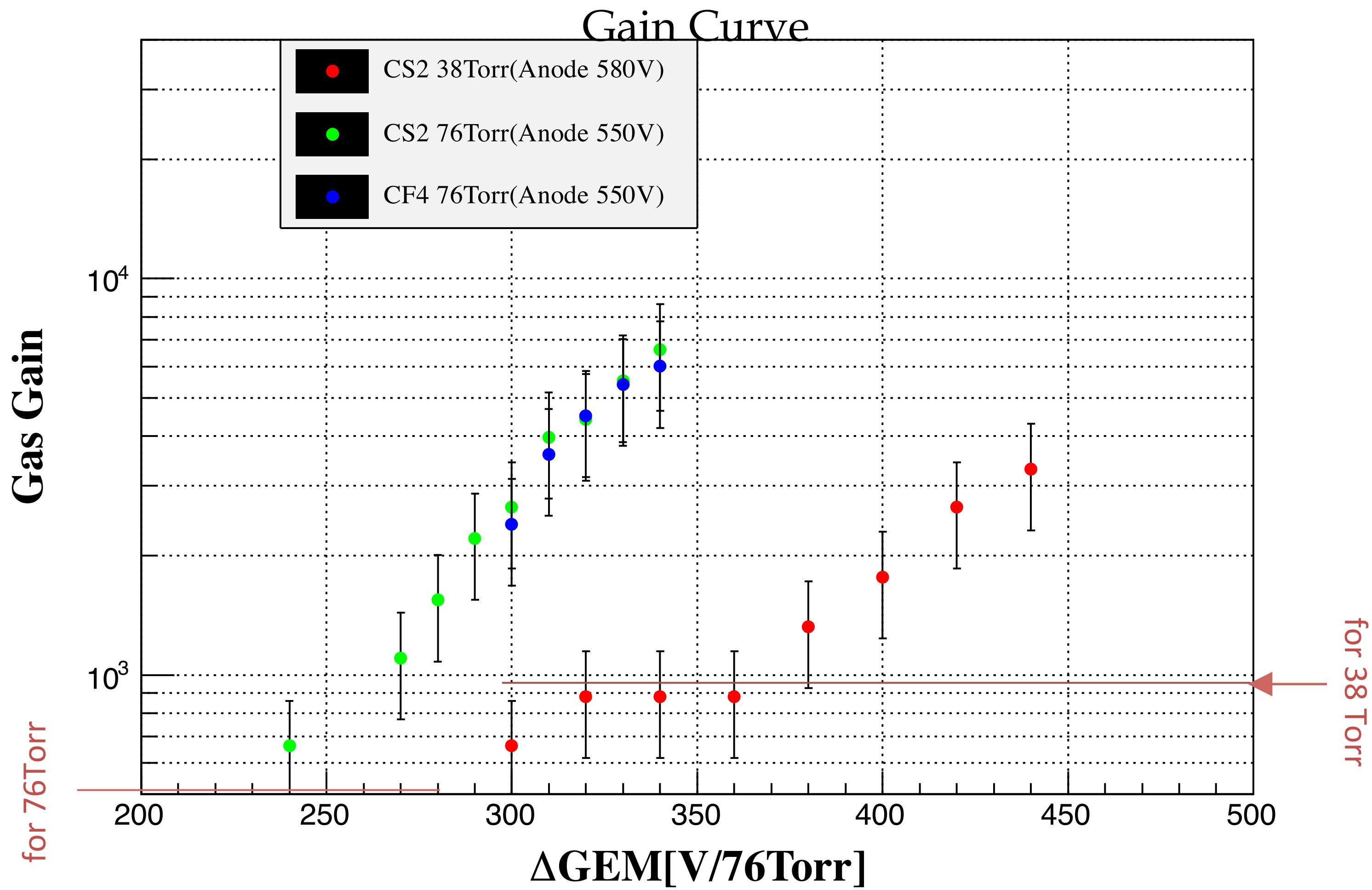
4.1 CS_2

Test CS2 with u-PIC+GEM @Occidental collage



- CS_2 76Torr and 38Torr give more than 1000 total gain!

ΔGEM Dependence



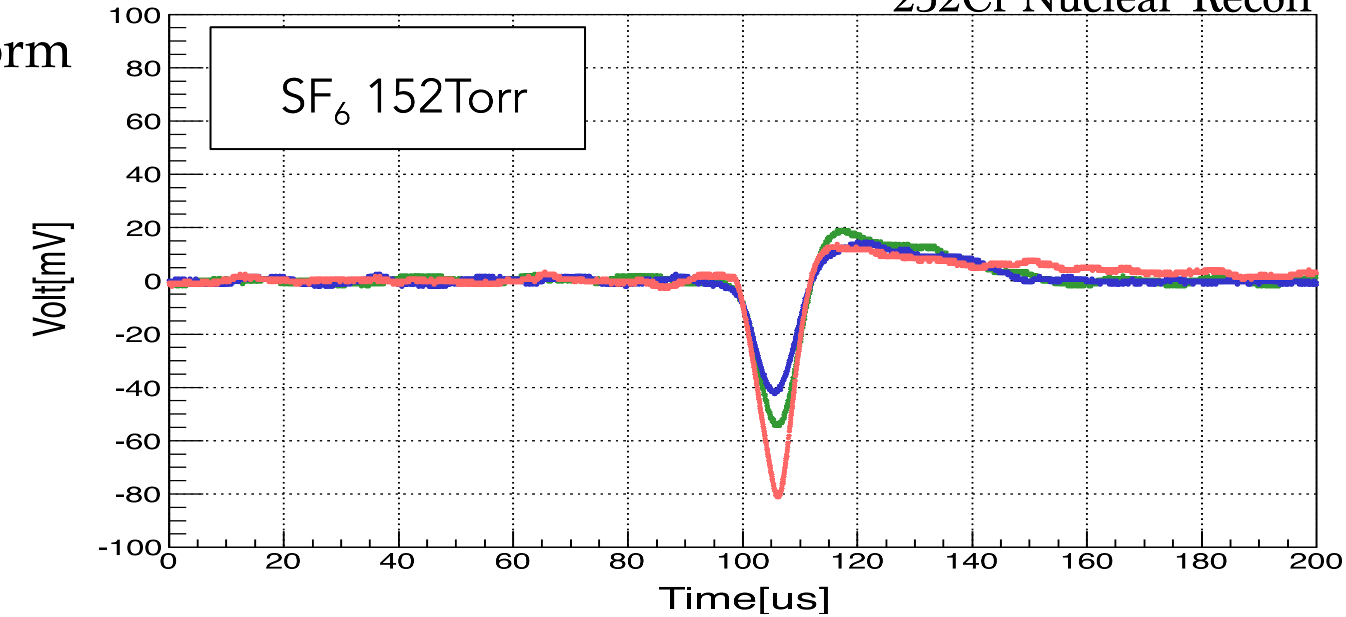
- μ -PIC+GEM system with CS2 worked very well.
- Adding O_2 gas , we will be able to observe minority peak.

4.2 SF_6

test SF6 with uPIC+GEM @ Kobe Univ.

waveform

252Cf Nuclear Recoil

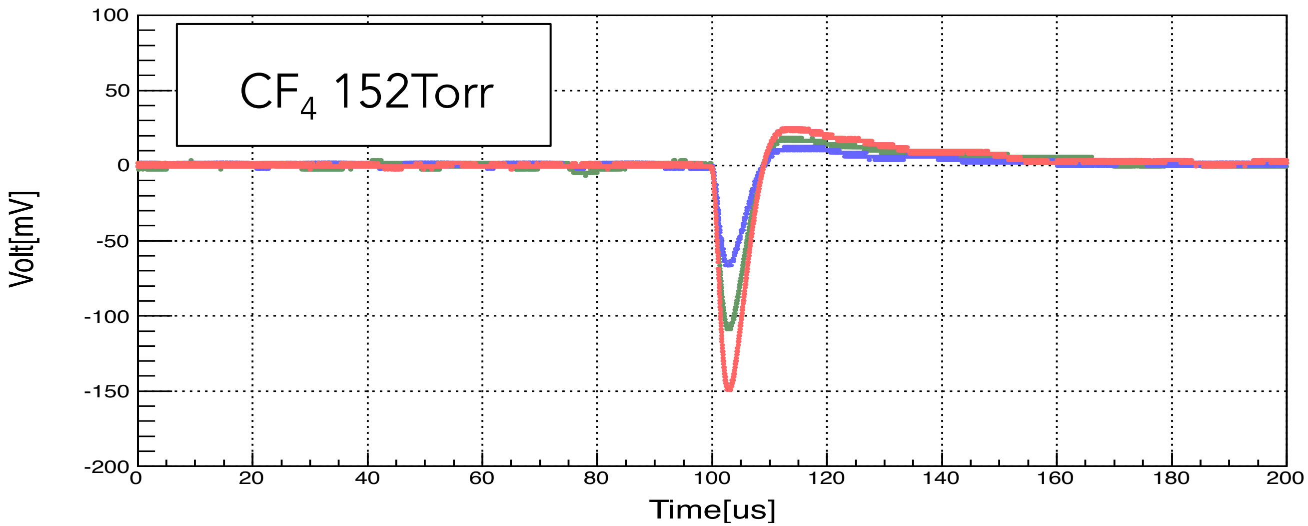


E = 1100 V/cm

Anode =630V

ΔGEM = 650V

Amp: τ =1μs



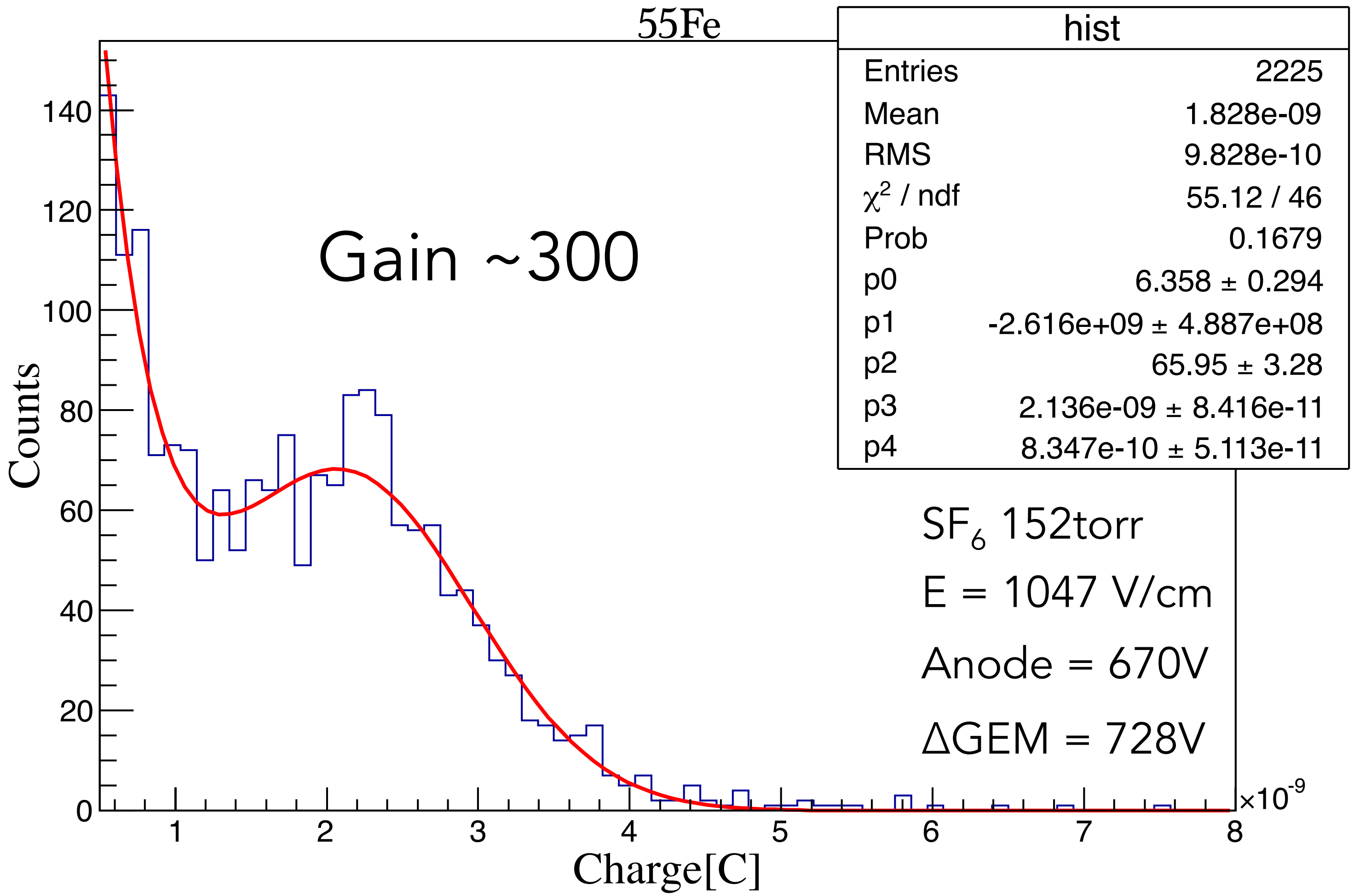
E = 674 V/cm

Anode = 539V

ΔGEM = 363V

Amp: τ =1μs

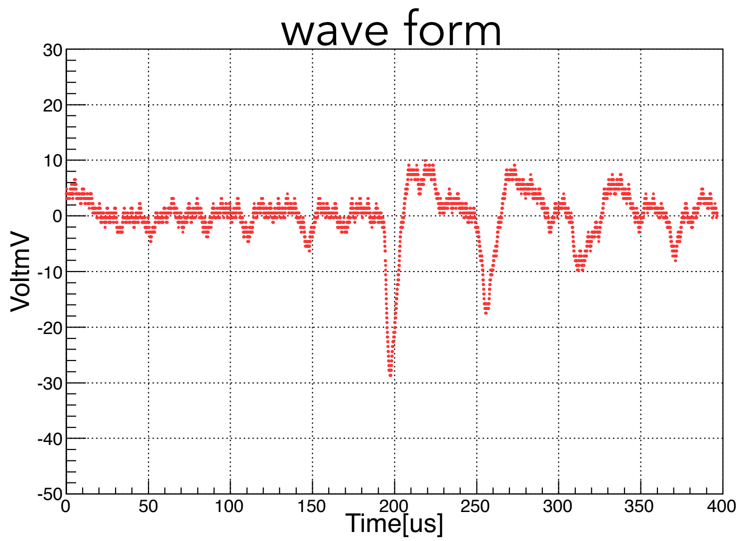
SF_6 Gas Gain

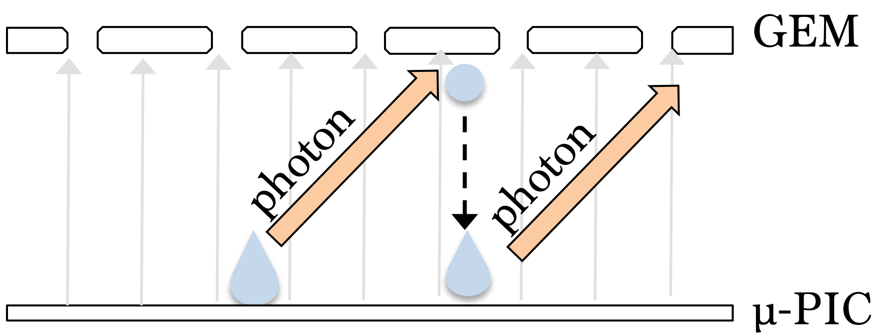


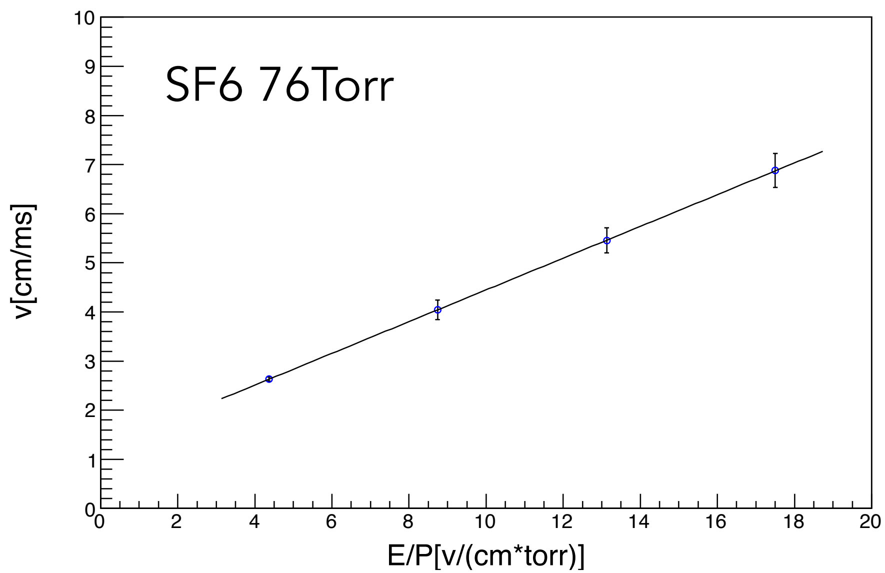
- Total gas gain is about 300.
- When we improve the amplifier , this gas gain is sufficient.
  Then minority peak will be appeared.

Drift Velocity of SF_6^-

- At 76Torr, Photon feedback was observed between u-PIC and GEM.







- Drift velocity
  ~10^{-2} cm/ μ s

5. Summary

- A first test of μ-PIC+GEM with negative ion gas was performed.
- For CS_2, the total gas gain is higher than 10000.
- For SF_6, the total gas gain is about 300.
- SF_6 gas needs optimization , going to study
- In the future, with both of them, minority peaks will be observed.

MPGDs with negative ion gas will create more opportunities for low background experiment.

Thank you for your attention!

4. Back-up

Electronics for CS_2

- We used CREMAT's CR-111 charge sensitive preamplifier.

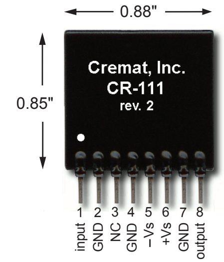
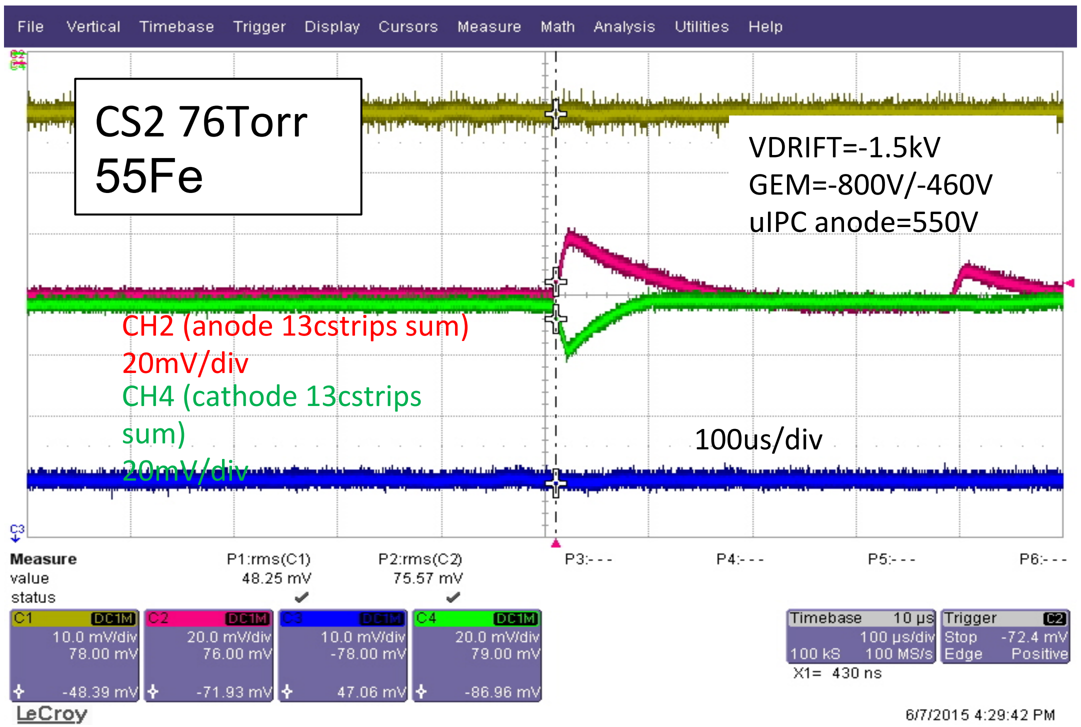


Figure 1

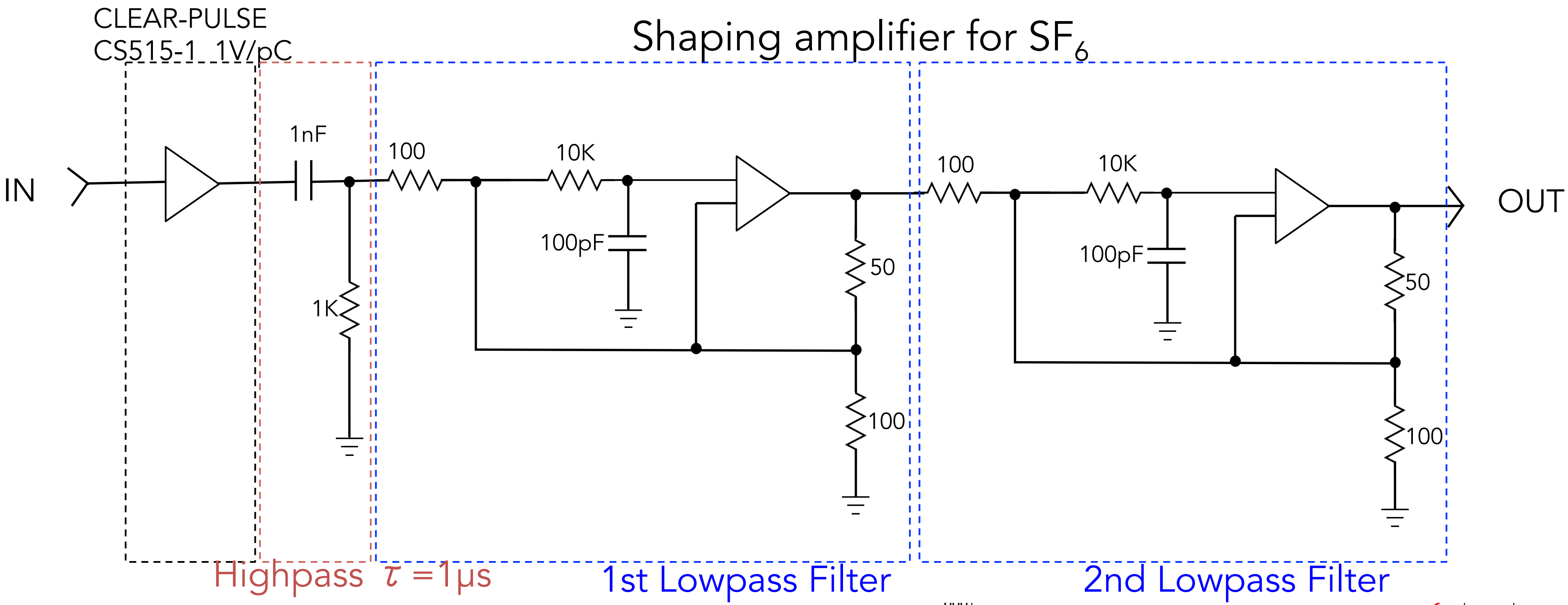


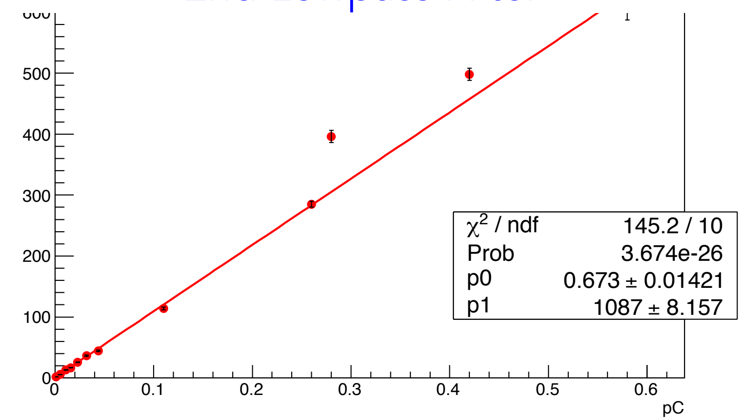
Specifications

Assume temp =20 °C, V_s = ±6.1V, unloaded output

	CR-111	units
Preamplification channels	1	
Equivalent noise charge (ENC)*		
ENC RMS	630	electrons
	0.1	femtoCoul.
Equivalent noise in silicon	6	keV (FWHM)
ENC slope	3.7	elect. RMS / pF
Gain	0.13	volts / pC
	6.2	mV / MeV(Si)
Rise time **	3	ns
Decay time constant	150	µs
Unsaturated output swing	-3 to +3	volts
Maximum charge detectable per event	1.3 $\times 10^8$	electrons
	21	pC
Power supply voltage (V_s)		
maximum	V_s = ±13	volts
minimum	V_s = ±6	volts
Power supply current (pos)	7.5	mA
(neg)	3.5	mA
Power dissipation	70***	mW
Operating temperature	-40 to +85	°C
Output offset	+0.2 to -0.2	volts
Output impedance	50	ohms

Electronics for SF_6





Amplifier 1.1 V/pC
120 nC/pC

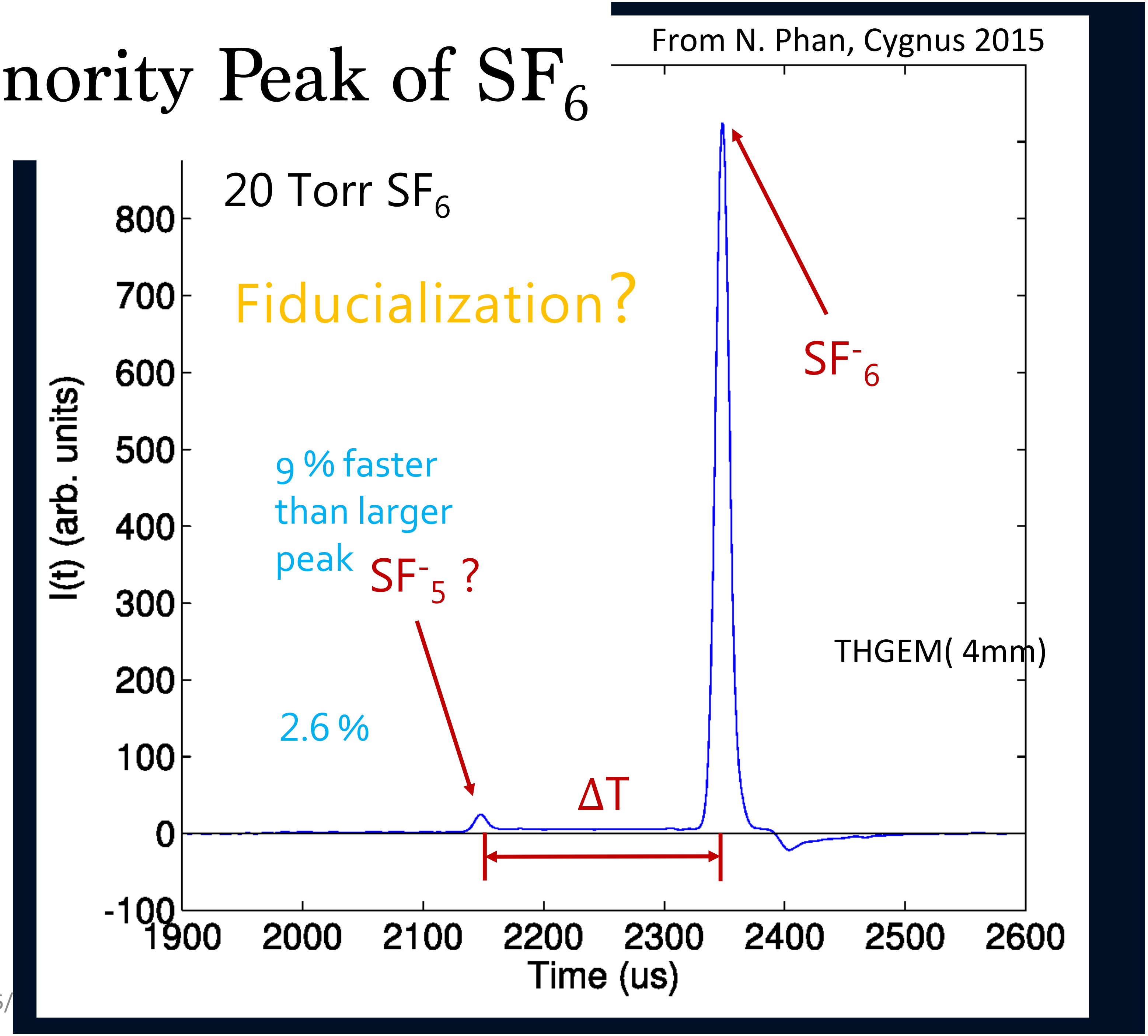
Spin dependent(SD) cross section

- The SD cross section is written using σ_{SD} as

$$\sigma^{\rm SD}_{\chi-{\rm N}} = \sigma^{\rm SD}_{\chi-{\rm p}} \frac{\mu^2_{\chi-{\rm N}}}{\mu^2_{\chi-{\rm p}}} \frac{\lambda^2 J(J+1)}{0.75}.$$

Isotope	J	Abundance(%)	$\mu_{\rm mag}$	$\lambda^2 J(J+1)$	unpaired nucleon
^{1}H	1/2	100	2.793	0.750	proton
^{7}Li	3/2	92.5	3.256	0.244	proton
^{11}B	3/2	80.1	2.689	0.112	proton
^{15}N	1/2	0.4	−0.283	0.087	proton
^{19}F	1/2	100	2.629	0.647	proton
^{23}Na	3/2	100	2.218	0.041	proton
^{127}I	5/2	100	2.813	0.007	proton
^{133}Cs	7/2	100	2.582	0.052	proton
^{3}He	1/2	1.0×10^{-4}	−2.128	0.928	neutron
^{17}O	5/2	0.0	−1.890	0.342	neutron
^{29}Si	1/2	4.7	−0.555	0.063	neutron
^{73}Ge	9/2	7.8	−0.879	0.065	neutron
^{129}Xe	1/2	26.4	−0.778	0.124	neutron
^{131}Xe	3/2	21.2	0.692	0.055	neutron
^{183}W	1/2	14.3	0.118	0.003	neutron

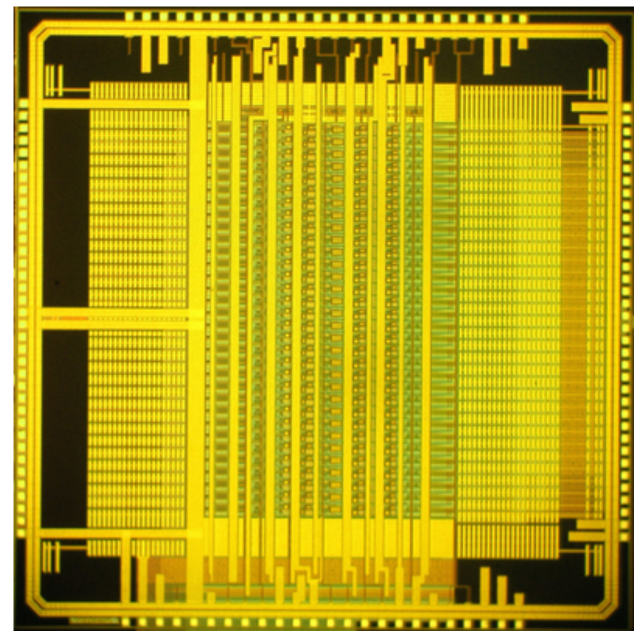
Minority Peak of SF_6



Amplifier for liquid Argon TPC

- Development of LTARS ASIC
  - pre-amp. & shapers in a chip
  - high density (32ch I n a chip)
  - power supply voltage ±0.9V
  - ENC ~2000@300pF
  - conv.gain ~9V/pC

LTARS2014 ASIC chip (5mm x 5mm)



(developed with KEK e-sys group,
one of Open-it projects http://openit.kek.jp/project/LTARS2014/LTARS2014)

Detection efficiency in detector coordinate