MPGD and negative-ion gas

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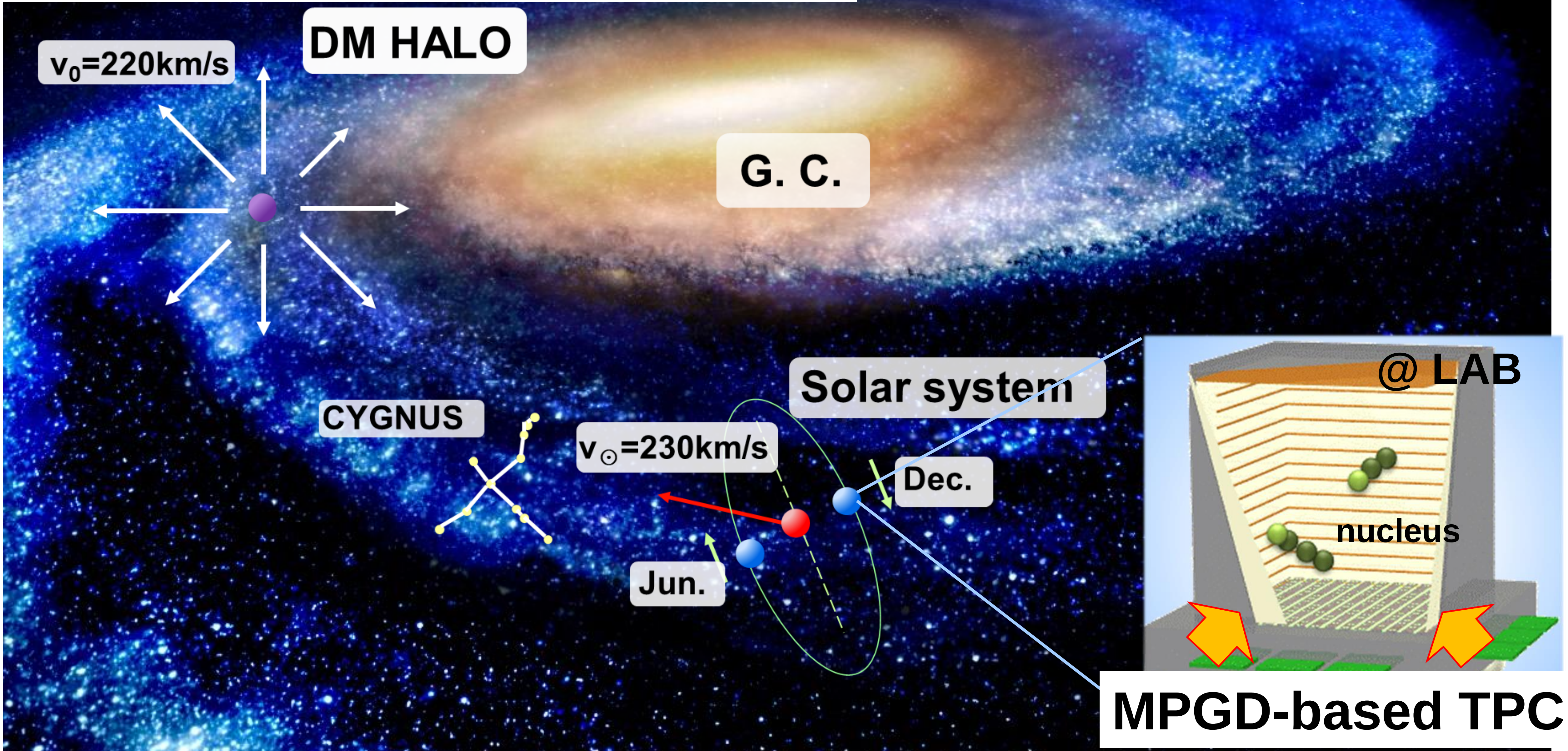
KUBEC DM 2019
28 Aug 2019

SPECIAL thanks
Dinesh Loomba,
CYGNUS gas WG

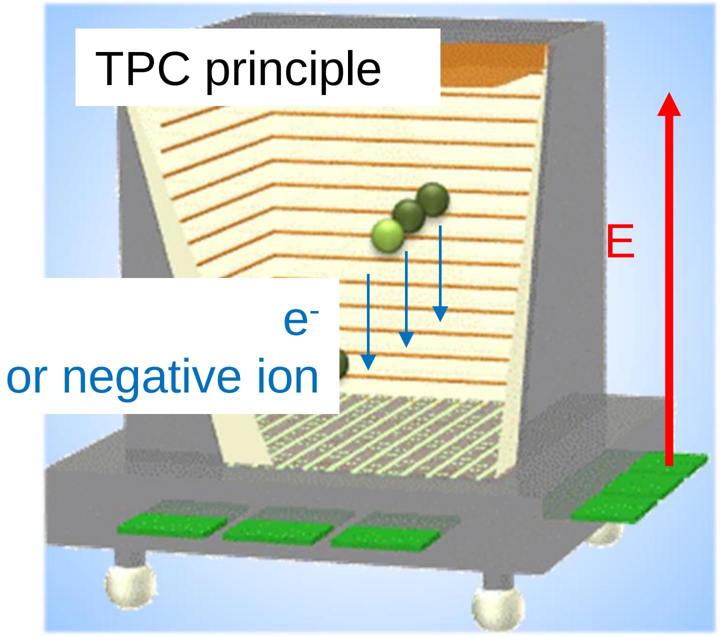
MPGD for Dark Matter:
direction sensitive direct search



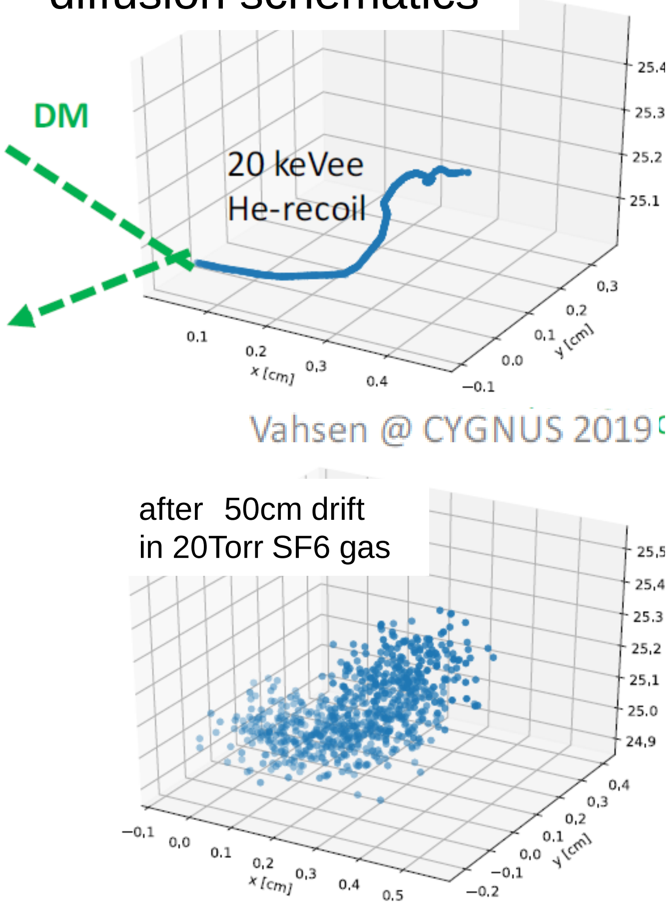
Requirements for MPGD-based DM TPC

①large volume

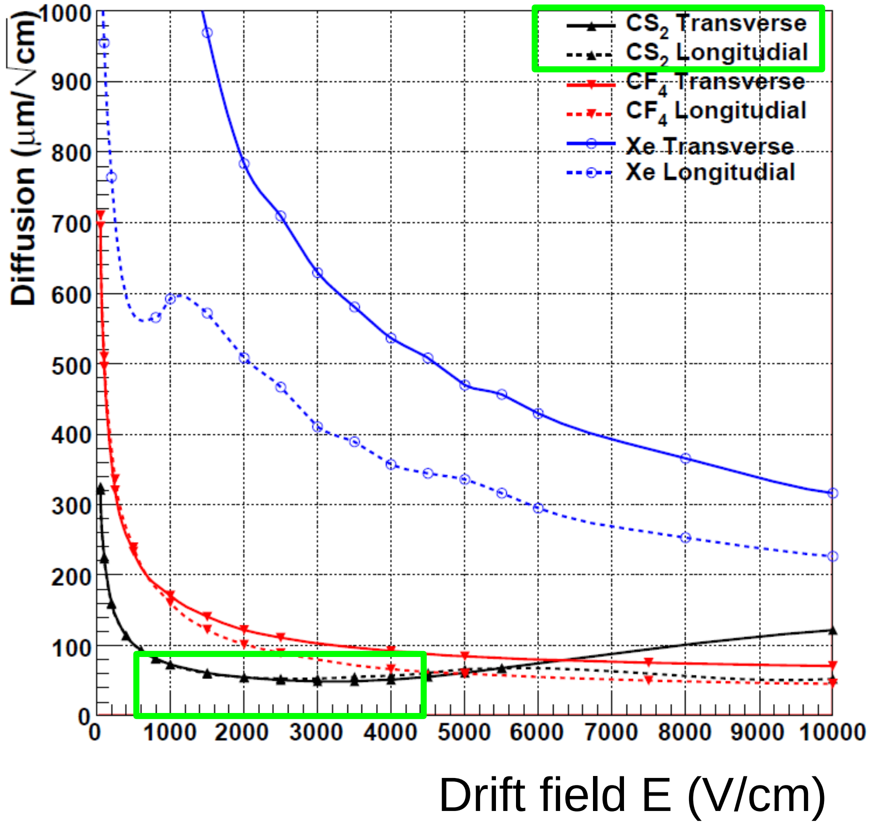
- ⇒ small diffusion



diffusion schematics



diffusion

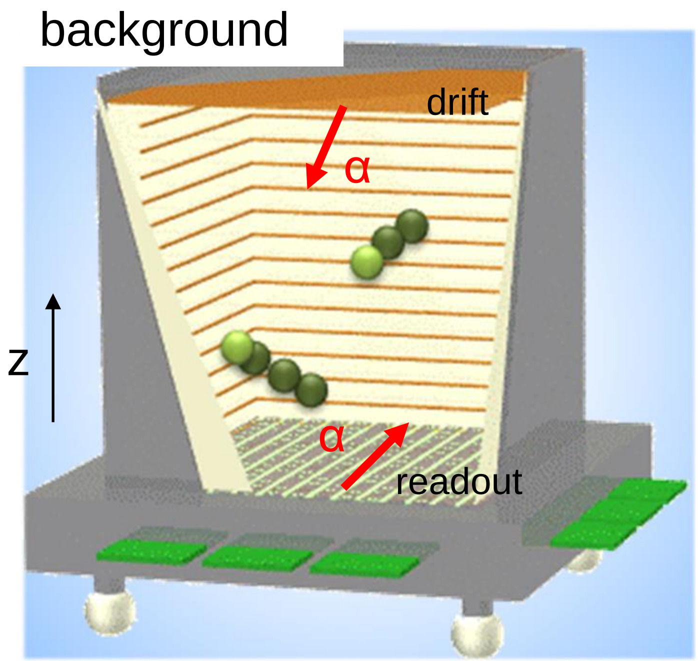


CS_2(one of the negative-ion gas) shows smaller diffusions

Requirements for MPGD-based DM TPC

②low background

- z fiducialization



common typical background:
α's from readout plane (MPGDs) and drift plane

2D image: available

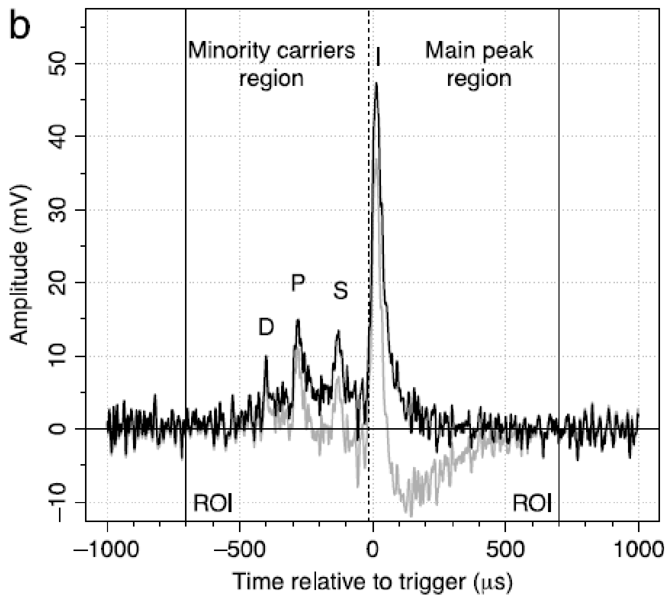
absolute z-position: not straight-forward for self triggering TPCs.

z-fiducialization has been wanted for years,
negative-ion TPC was found to solve it.

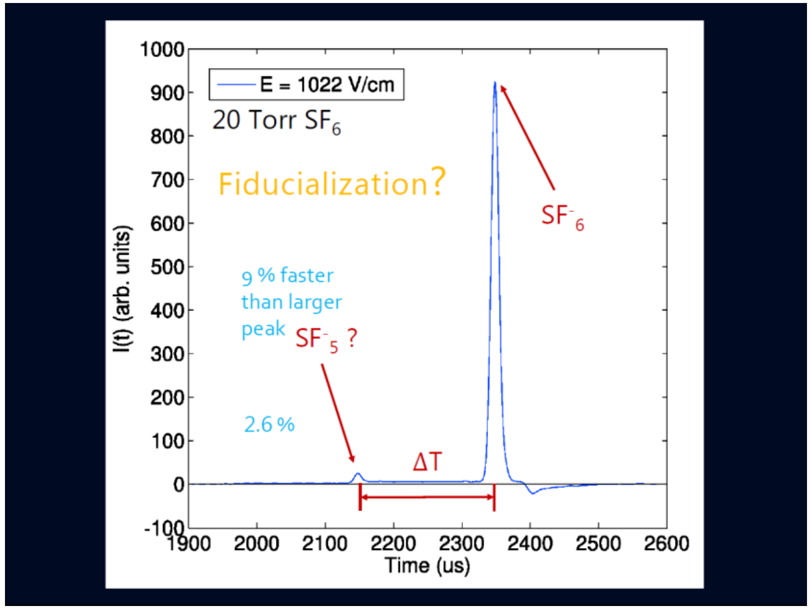
Negative ION gas for direction-sensitive DM search

- Pioneered by DRIFT group ⇒ small diffusion
- Minority carrier discovery (CS_2+O_2, Occidental group).
- SF6 discovery (2015, UNM group). ⇒ fiducialization

⇒ several groups are working together exchanging information.

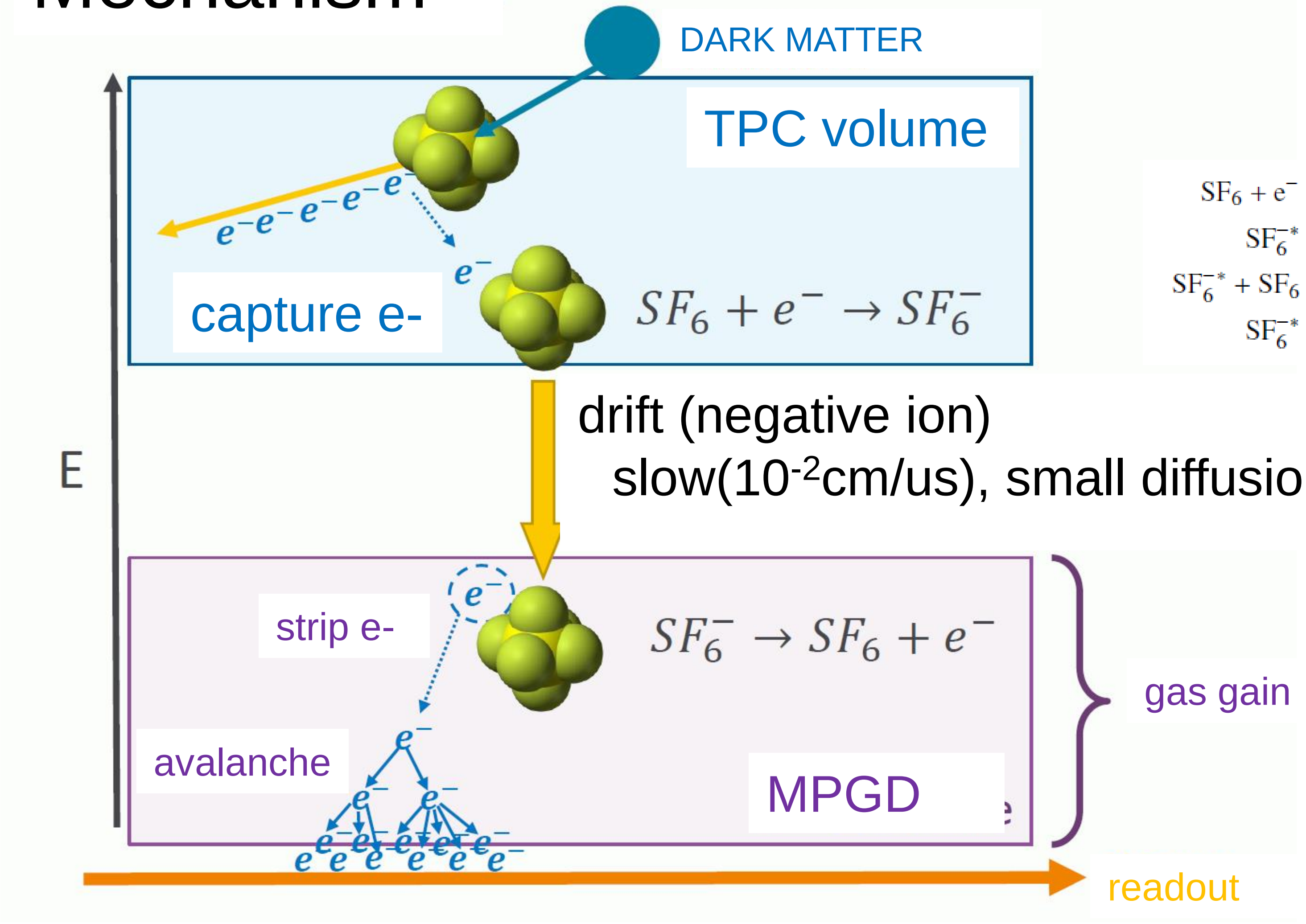


J.B.R. Battat et al. / Physics of the Dark Universe 9–10 (2015) 1–7



CYGNUS2015
2017 JINST 12 P02012

Mechanism



drift (negative ion)
slow(10^{-2}cm/us), small diffusion

well known

$SF_6 + e^- \rightarrow SF_6^{-*}$ (attachment, metastable)

$SF_6^{-*} \rightarrow SF_6 + e^-$ (auto-detachment)

$SF_6^{-*} + SF_6 \rightarrow SF_6^- + SF_6$ (collisional stabilization)

$SF_6^{-*} \rightarrow SF_5^- + F$ (auto-dissociation)

2017 JINST 12 P02012

well known

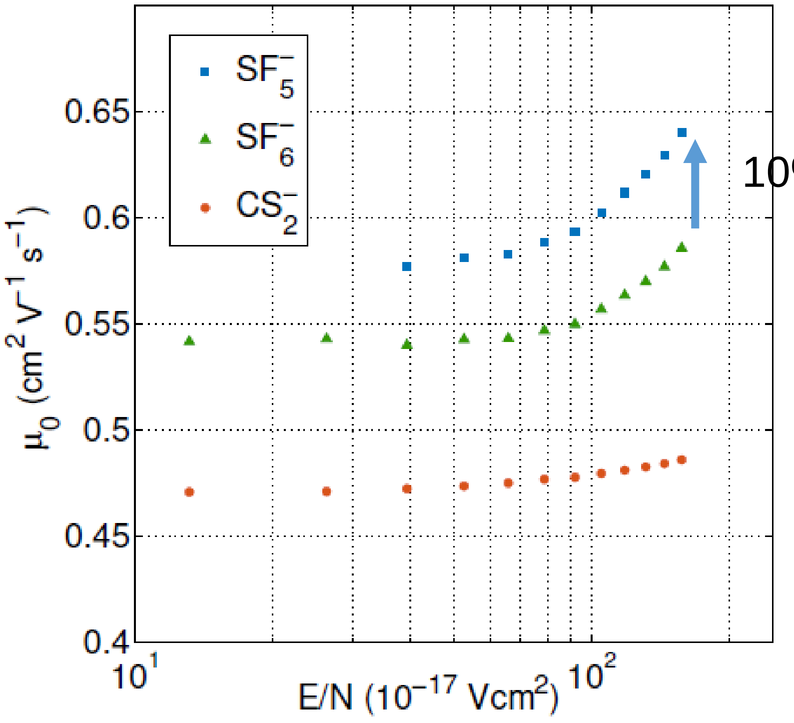
gas gain → not well understood

Pioneer: New Mexico group

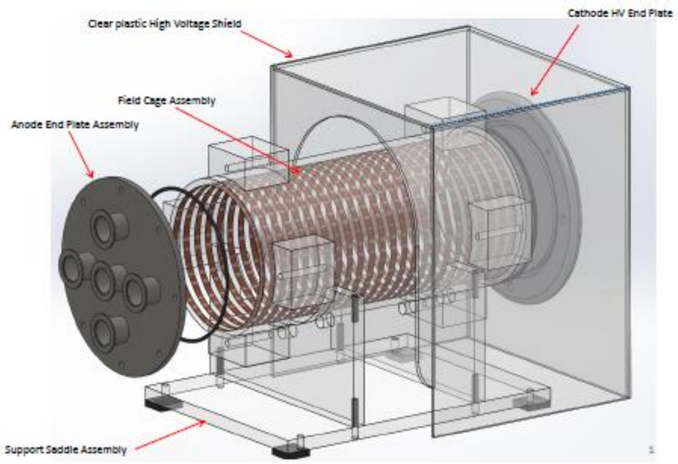
- gas amplification with thick (400um) GEM
- 60cm drift length
- shoot laser to the cathode
  (electrons travel full drift length)

2017 JINST 12 P02012

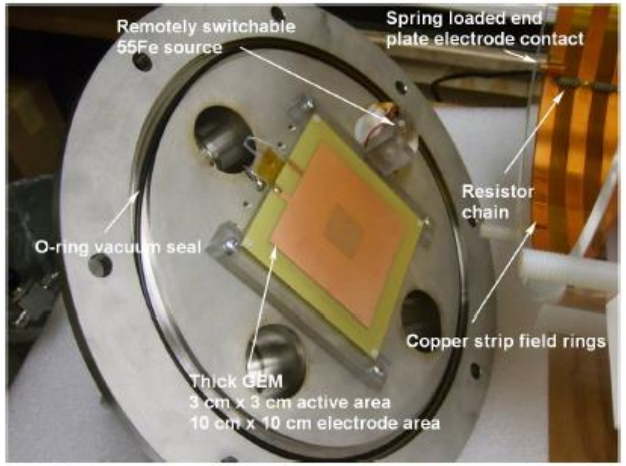
ion mobility



10% faster



(a) Acrylic cylindrical detector

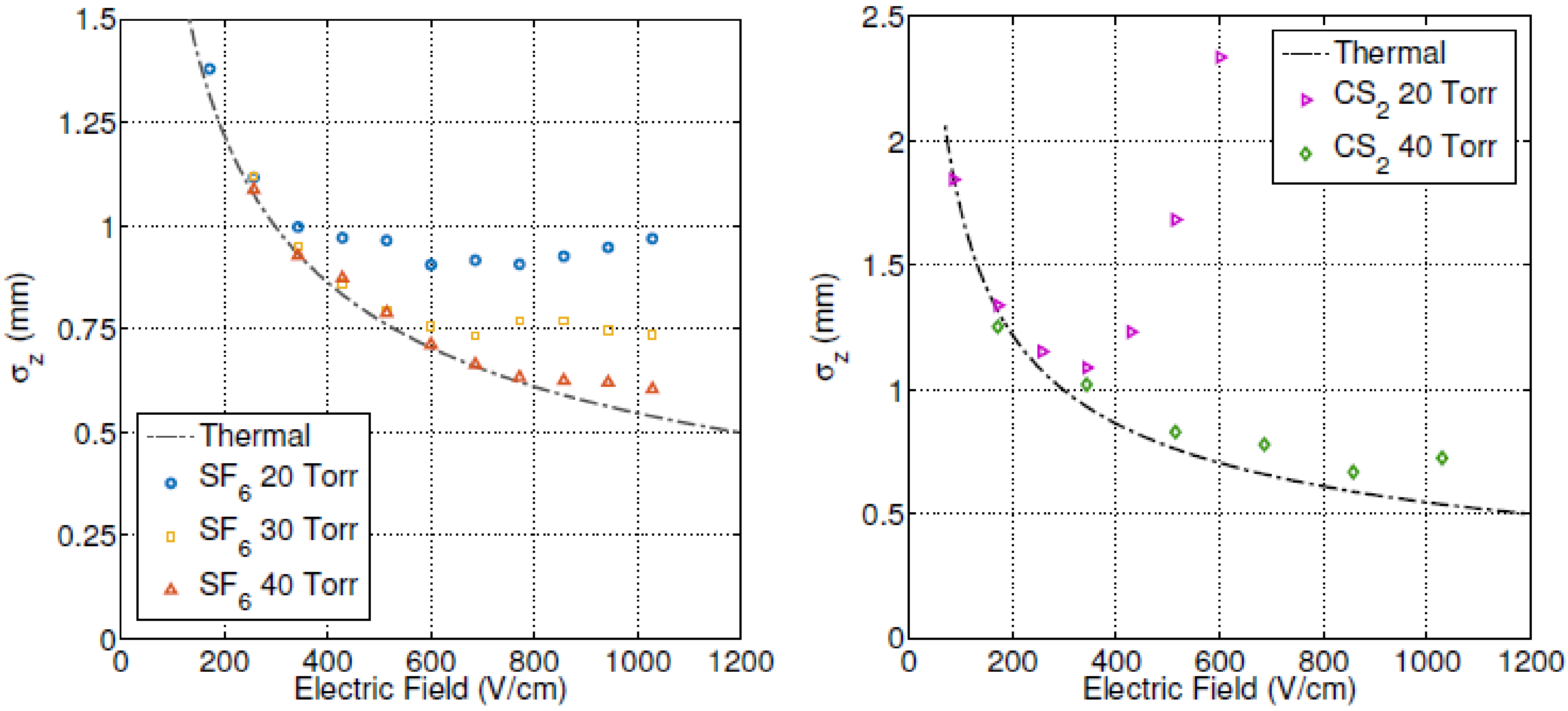


(b) Inner view of anode end plate

- Small diffusion?

close to the thermal limit

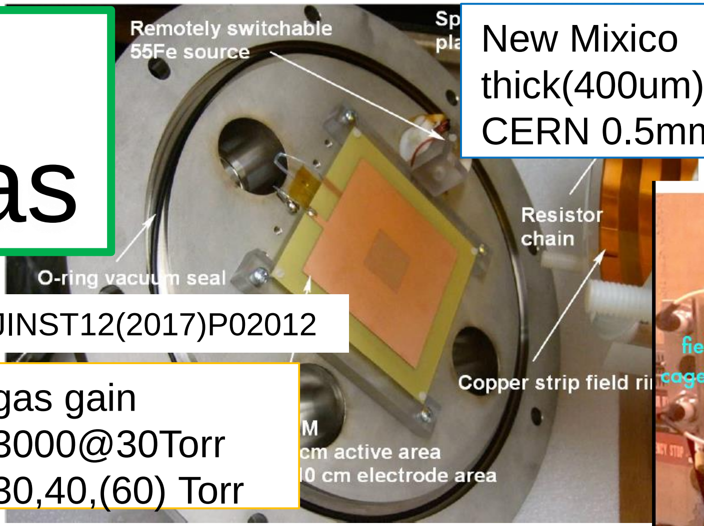
2017 JINST 12 P02012



(a) SF_6 diffusion

(b) CS_2 diffusion

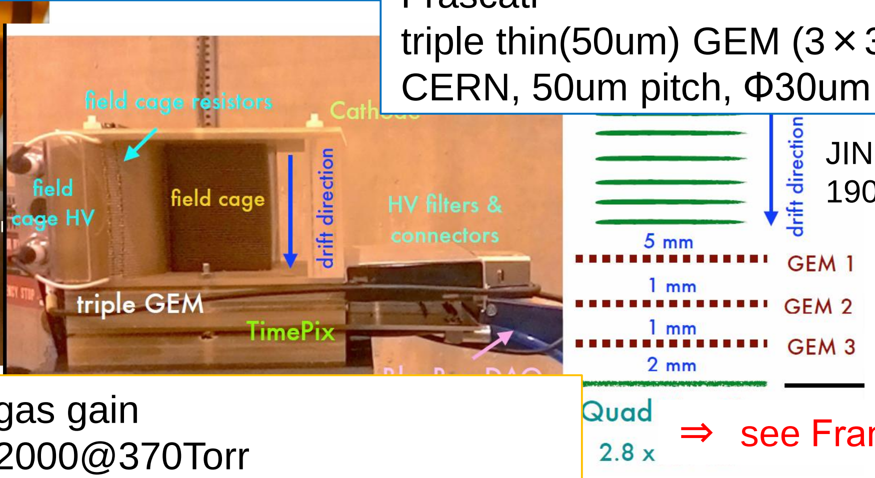
MPGDs for negative ion gas



New Mixico
thick(400um) GEM (3×3cm^2)
CERN 0.5mm pitch, Φ0.3mm

JINST12(2017)P02012

gas gain
3000@30Torr
30,40,(60) Torr



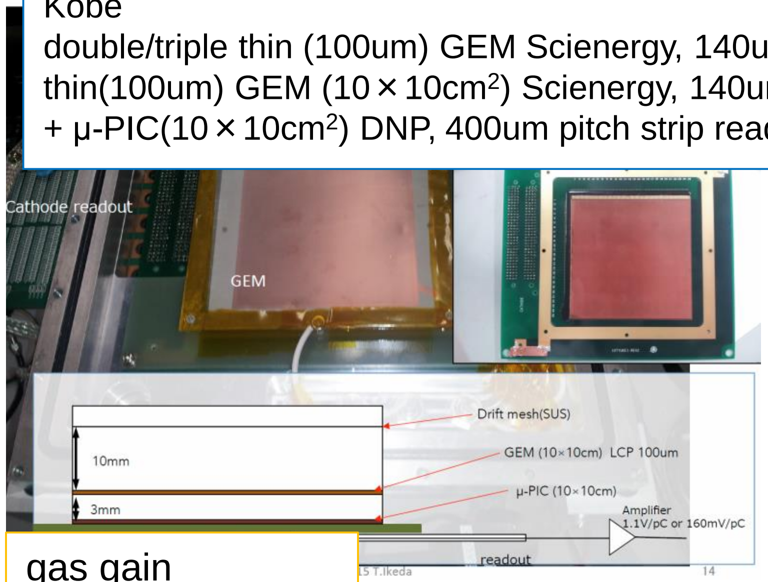
Frascati
triple thin(50um) GEM (3×3cm^2)
CERN, 50um pitch, Φ30um

JINST13(2018)P04022
1905.04066

gas gain
2000@370Torr

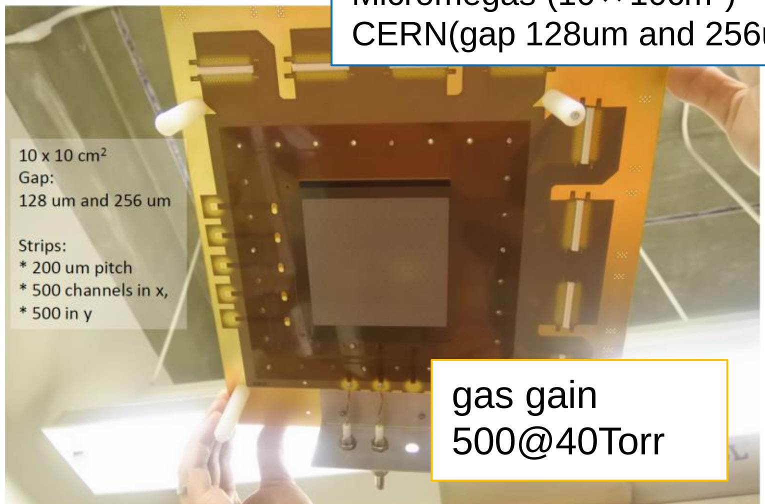
⇒ see Francesco's talk

Kobe
double/triple thin (100um) GEM Scienergy, 140um pitch, Φ70um
thin(100um) GEM (10×10cm^2) Scienergy, 140um pitch, Φ70um
+ μ-PIC(10×10cm^2) DNP, 400um pitch strip readout



gas gain
7000@100Torr

Wellesley
Micromegas (10×10cm^2)
CERN(gap 128um and 256um)



gas gain
500@40Torr

Sheffield
thick(400um) GEM(50×50cm^2)
UK , 0.5 um pith Φ0.3um

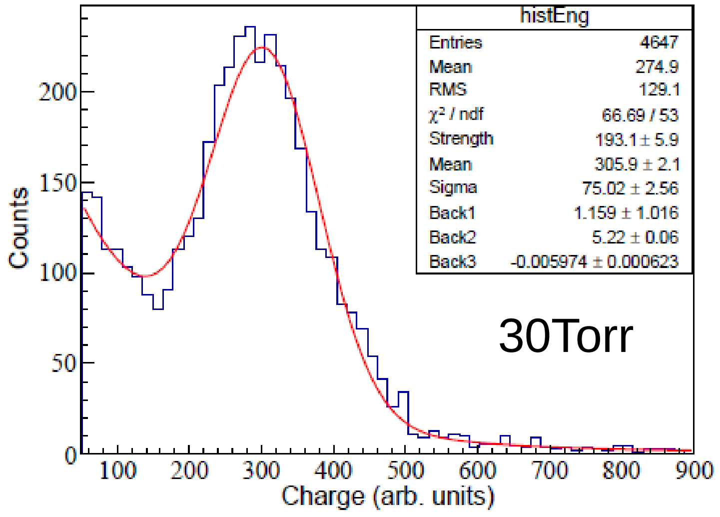
⇒ see Callum's talk

gas gain
1500@30,40Torr

55Fe spectrum and gain curves with MPGDs

New Mexico
(JINST12(2017)P02012)

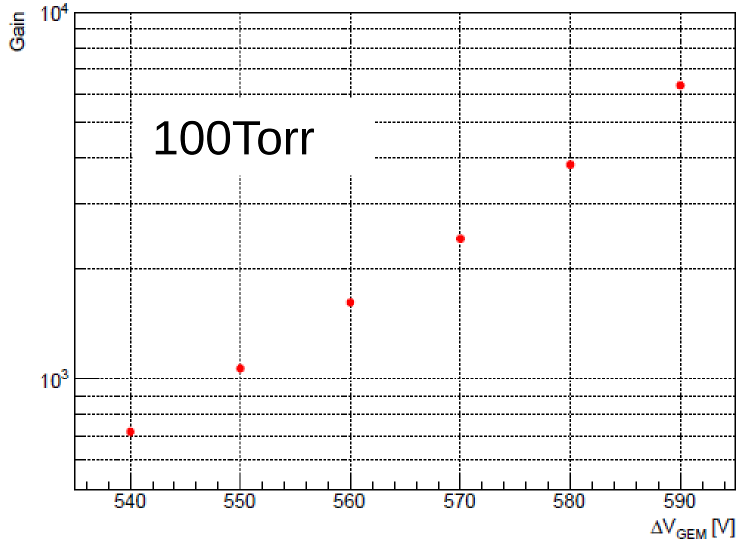
CERN 400μm-thick GEM



(a) Raw spectrum

gain ~3000
σ/E 25%
30-60Torr

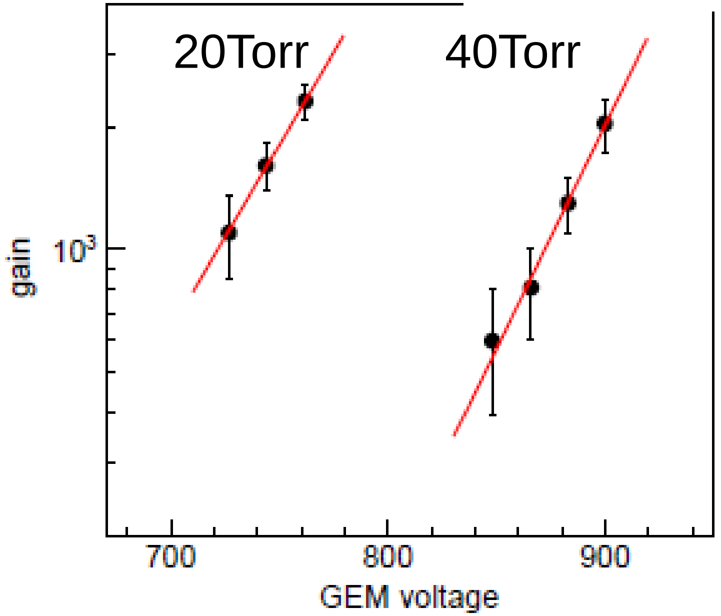
Kobe
(MPGD 2019, [1907.12729](1907.12729))
Siceneregy 2 × 100μm-thick GEM



gain ~7000
σ/E 25%
100Torr
(60-120Torr with triple GEM)

Hawaii
(T. Thrope PhD thesis 2018)
CERN 400μm-thick GEM

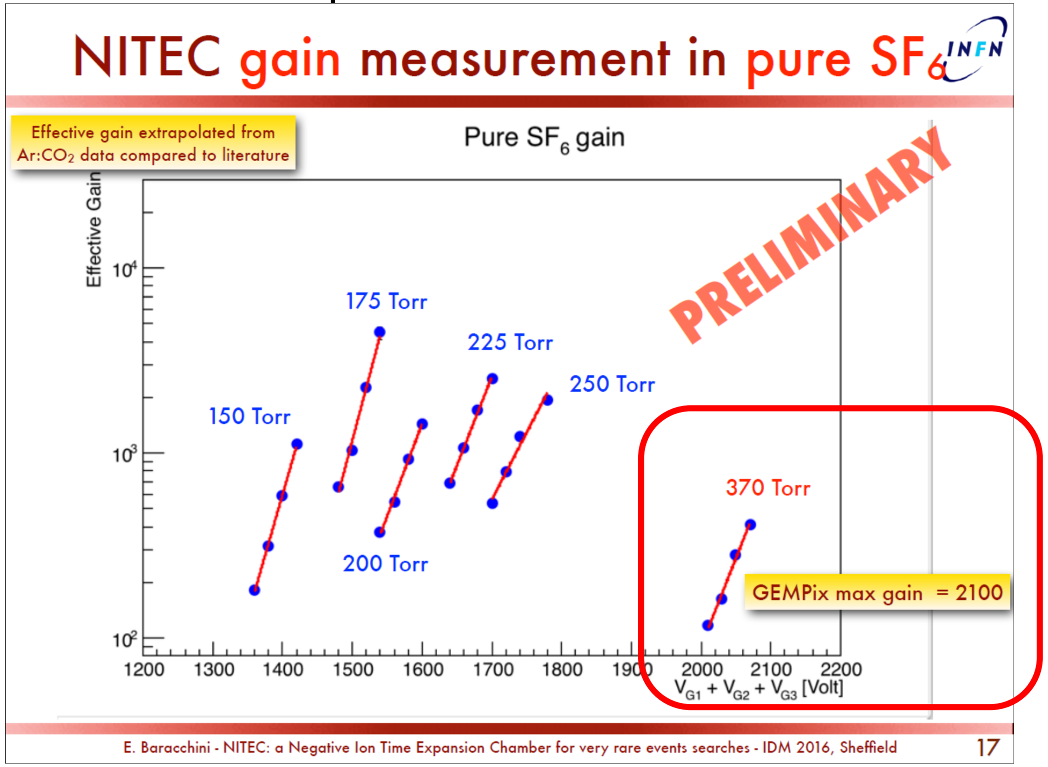
⇒ see Tom's talk



gain ~3000
σ/E 35%
20-40Torr

55Fe spectrum and gain curves (contn'd)

Italy
(IDM 2016)
CERN 3 × 50μm GEM



gain 2100
200-370 Torr
Landau spectrum

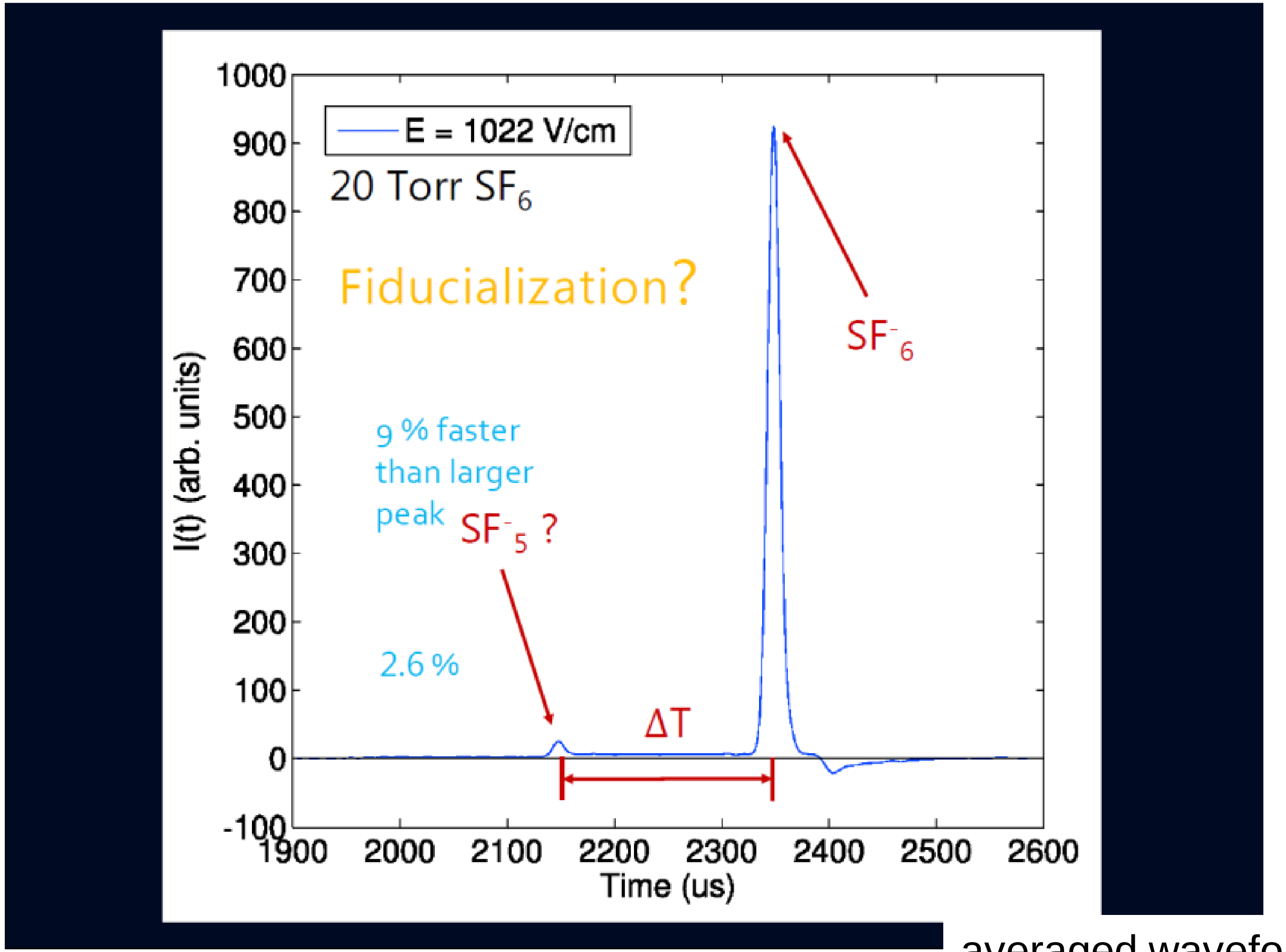
Sheffield thick GEM
gain ~1500 (9000, not reproduced)
20-50 Torr

Wellesley
256 μm gap CERN micromegas
gain 500
40 Torr

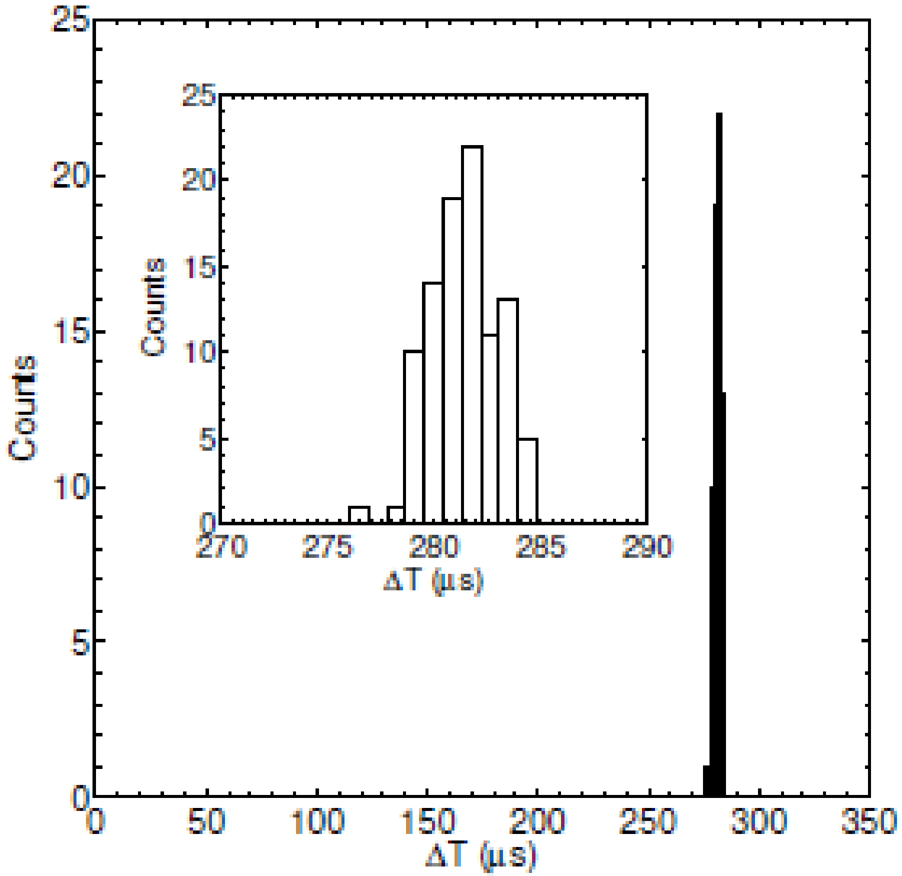
We understand so far…
Thick GEM for low pressure
Thin GEMM for high pressure
Micromegas needs some more study
Energy resolution not as good as electron-drift gas

SF6 fiducializtion studies:

New Mexico
(JINST12(2017)P02012)



averaged waveform



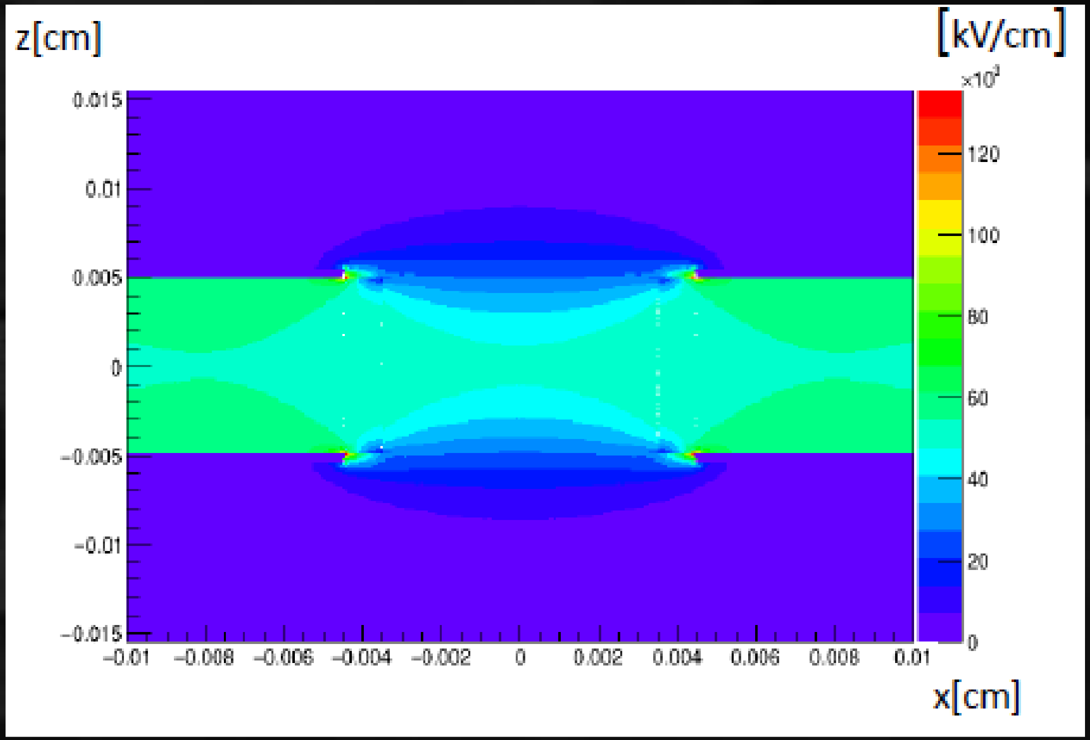
(a) ΔT laser calibration pulses

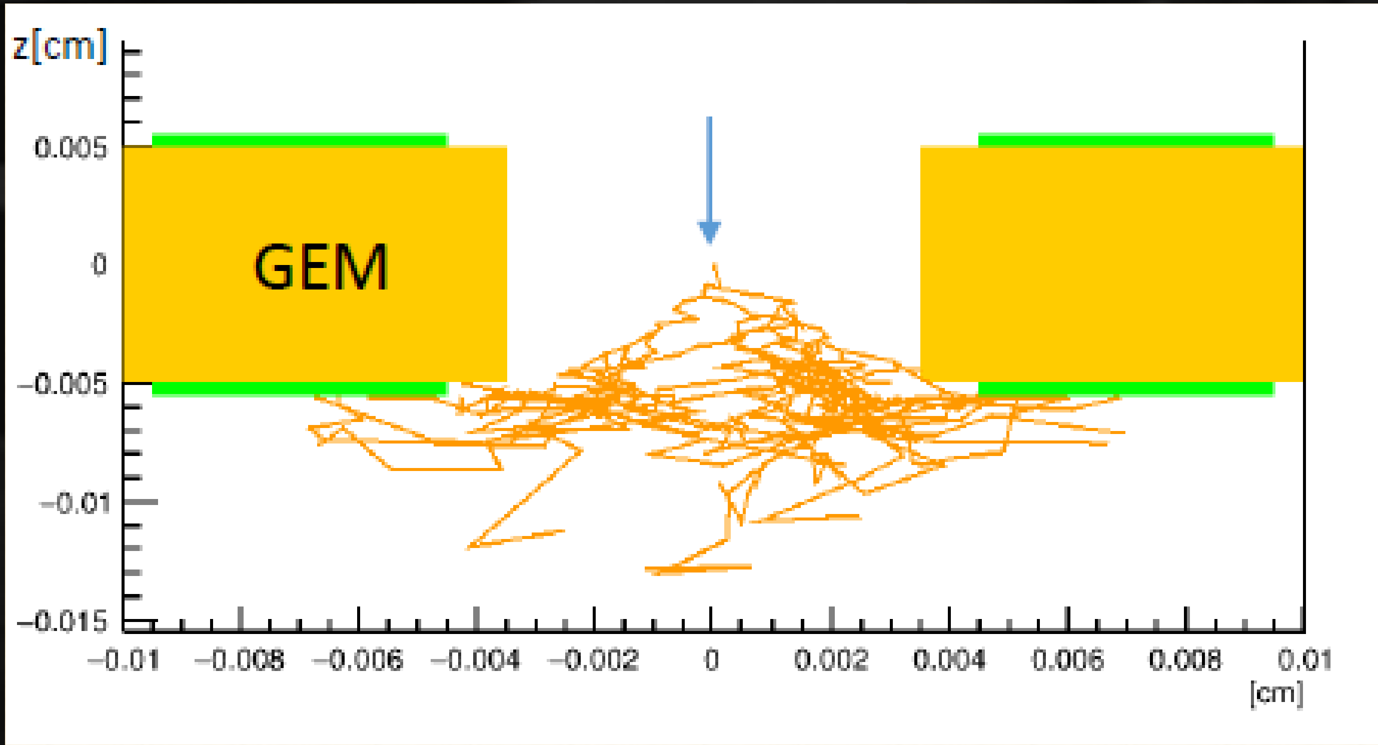
resolution
7.3mm FWHM

Garfield++ for negative ion

H. Ishiura @MPGD 2019
1907.12729

- First study: to reproduce 100μm GEM gain results
- Most of the process are already in Garfield++
- Detachment process needs to be implemented
- Two detachment models were made





less recombination

H. Ishiura @MPGD 2019
1907.12729

Detachment model ① : "cross section model"

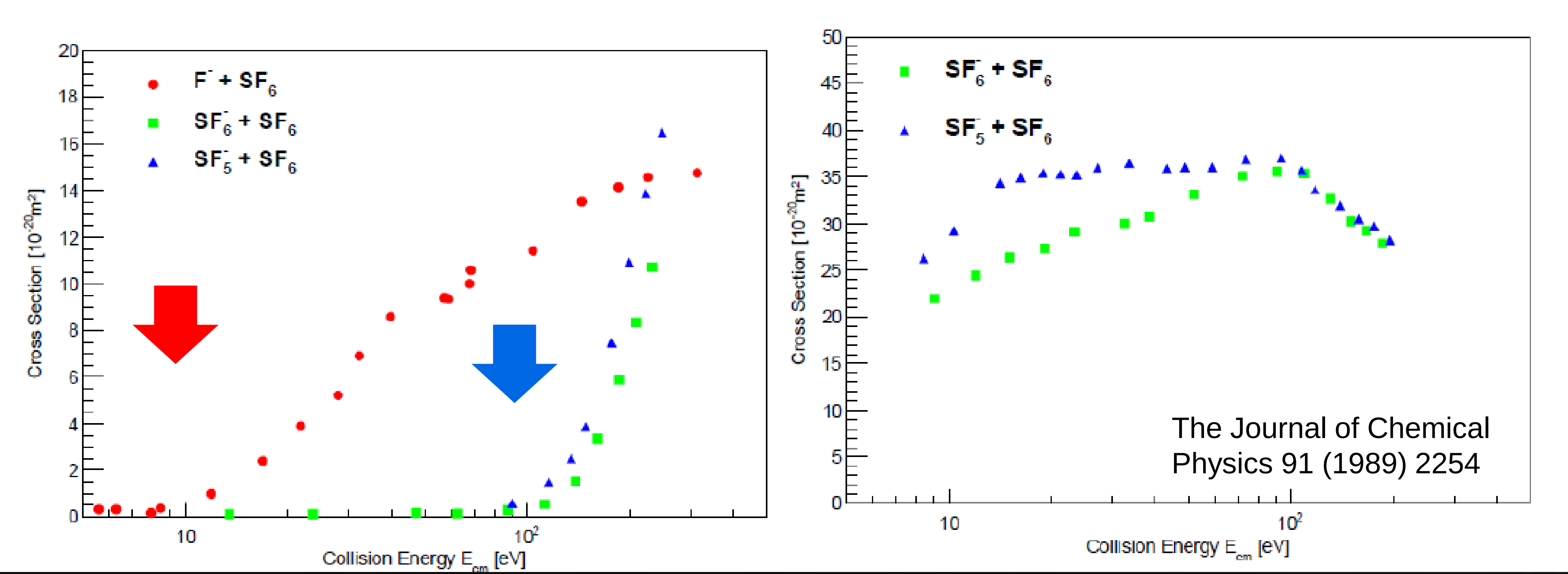
- based on "first principle"
- indirect detachment cross section
  ⇒ calculate detachment probability

direct detachment

$$SF_6^- + SF_6 \rightarrow e^- + SF_6 + SF_6 \quad (1)$$
$$SF_5^- + SF_6 \rightarrow e^- + SF_5 + SF_6 \quad (2)$$

indirect detachment

$$SF_6^- + SF_6 \rightarrow F^- + SF_5 + SF_6 \quad (3)$$
$$SF_5^- + SF_6 \rightarrow F^- + SF_4 + SF_6 \quad (4)$$
$$F^- + SF_6 \rightarrow e^- + F + SF_6 \quad (5)$$

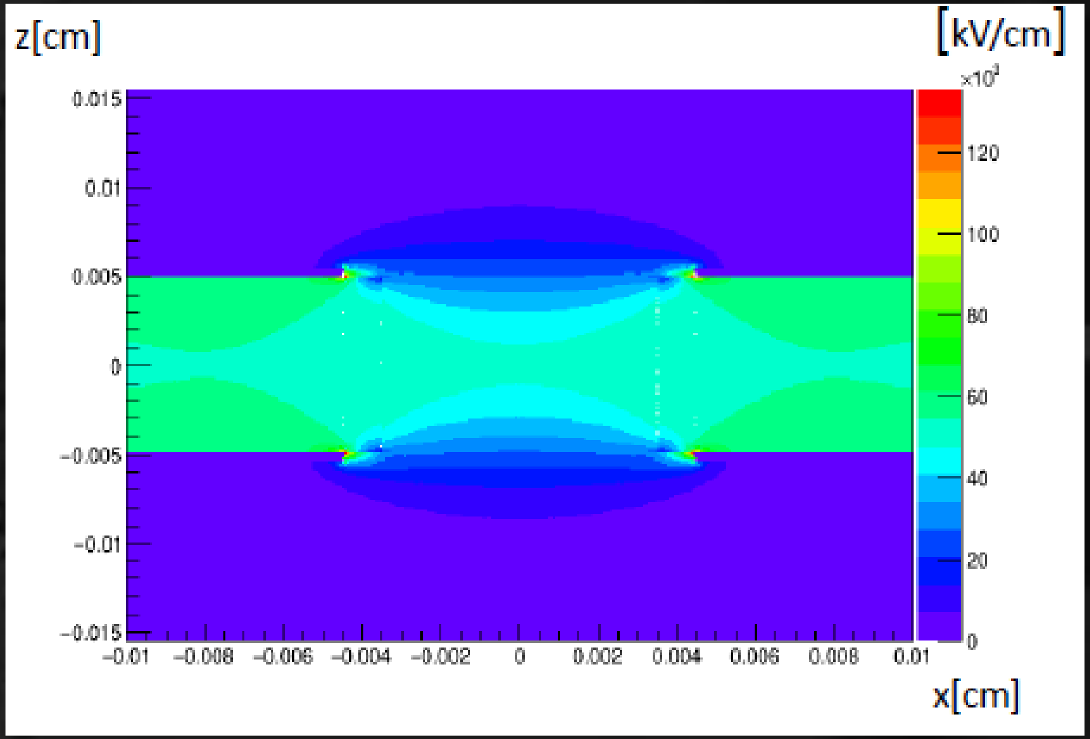


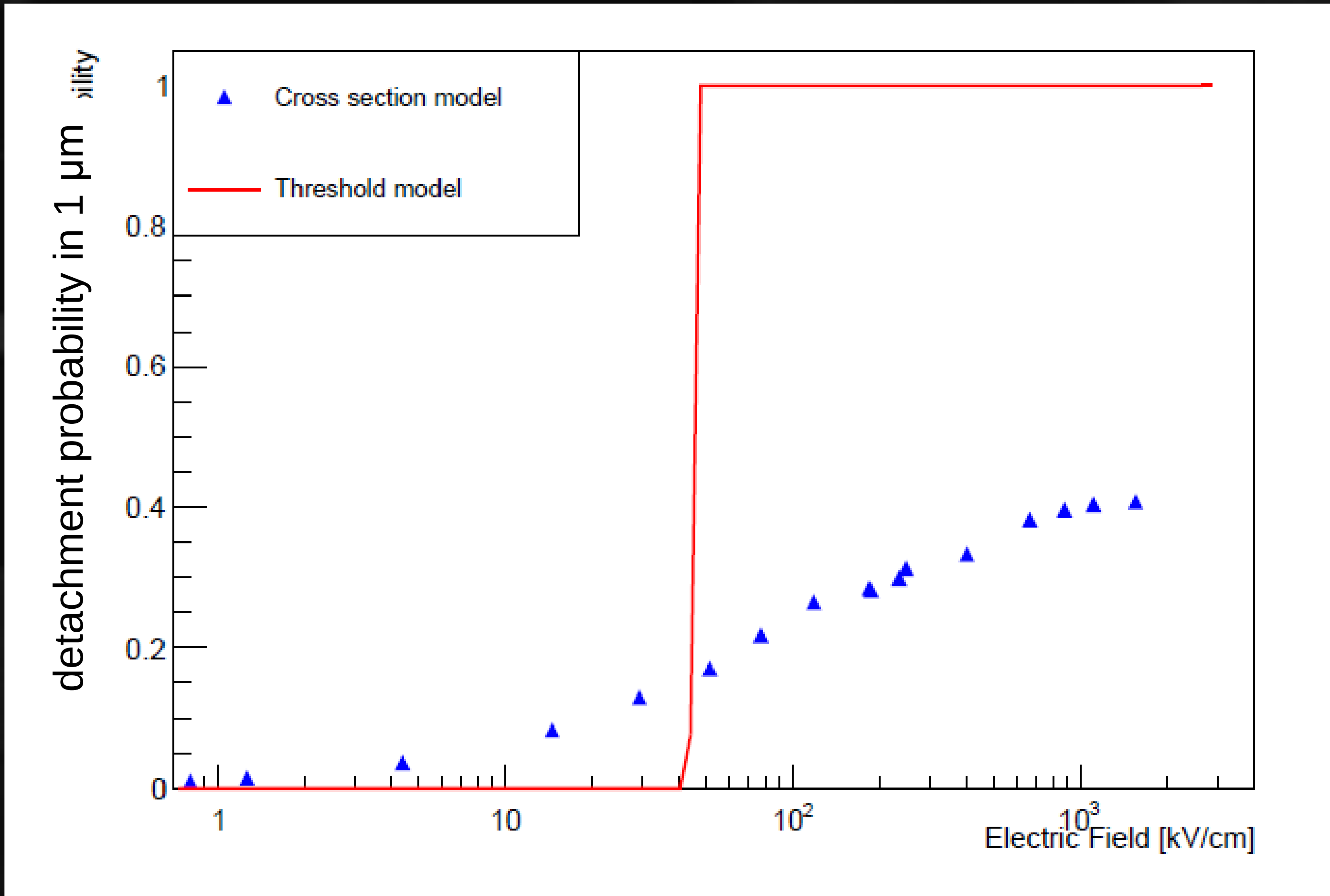
The Journal of Chemical Physics 91 (1989) 2254

H. Ishiura @MPGD 2019
1907.12729

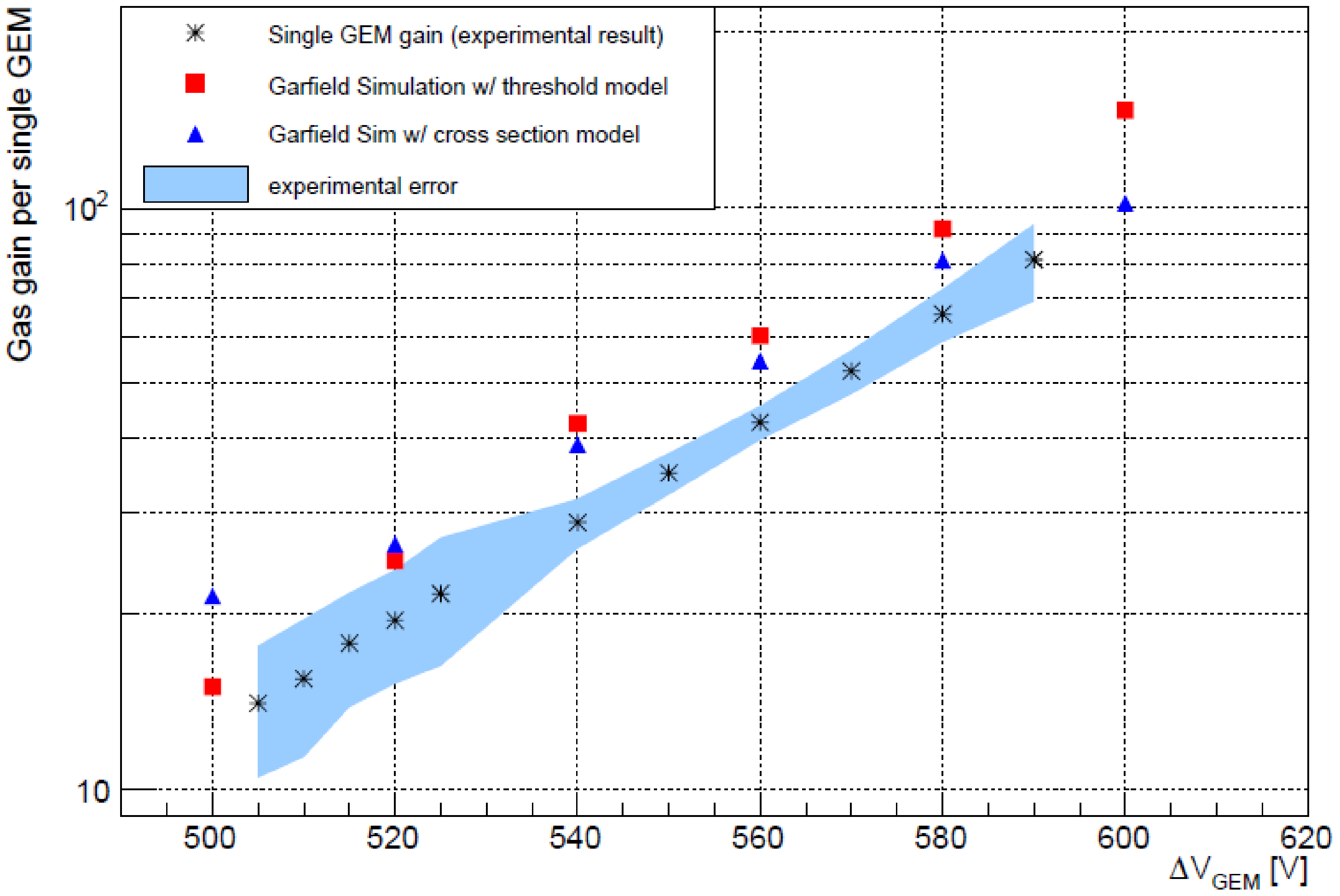
Detachment model ②: threshold model

- phenomenological model based on measument
- avalanche starts ~ 50kV/cm





Garfield++ results



- **gain curve reproduced (without any CORRECTION !)**
- **tuning and application for other MPGDs**

to be direction-sensitive…

- ASIC development for negative ion readout
  - Liq Ar electronics “LTARS2014”
  - slow shaaping time (～several μs)
  - Wide dynamic range(1.6pC)
  - Large Cdet (300pF)
  - need SPECS for nuclear track detection
    ⇒ LTARS 2016

2019 J. Inst. 14 T01008

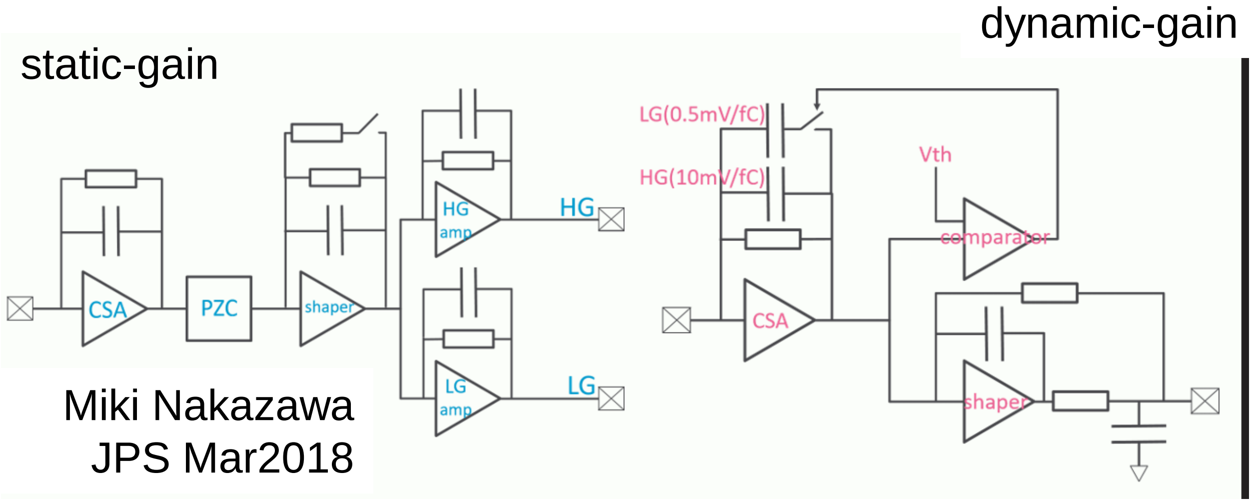
Table 1. Specification and requirements of the ASIC.

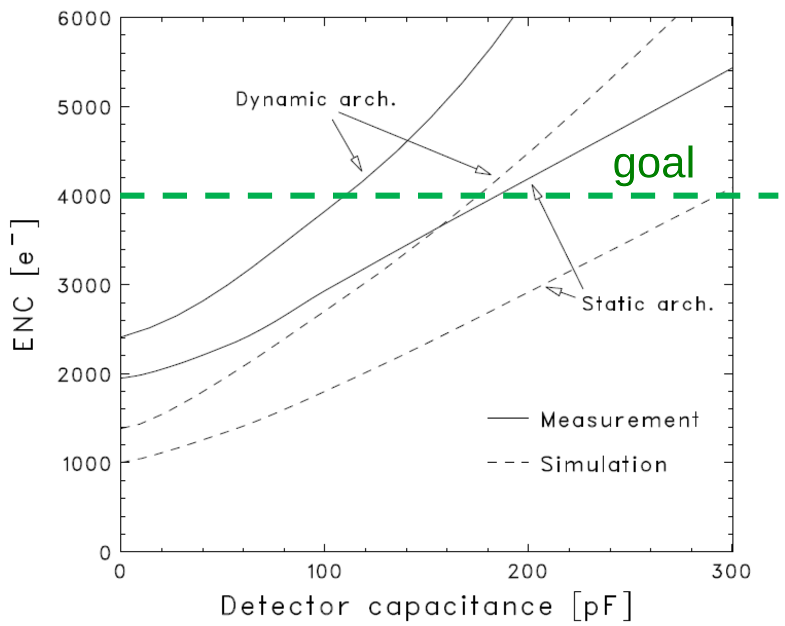
Technology	Silterra 180 nm CMOS	
Chip size	5×5 mm^2, 16 total channels	
Supply power	1.8 V core/IO, ±0.9 V operation, max. 2.4 mW/ch	
Fabrication options	6 metals, deep N-well, high-value poly res., MIM cap.	
Minimum signal charge	3 fC (minority species)	100 fC (main species)
ENC	2000 e^- (S/N=10) 4000 e^- (S/N=5, see Section 5)	$< 6.4 \times 10^4$ e^-
Dynamic range	±80 fC (narrow range)	±1600 fC (wide range)
Voltage gain	10 mV/fC	0.5 mV/fC
Shaping time	4–7 μs for NI μTPC / 1–4 μs for LAr-TPC	

• LTARS 2016

2019 J. Inst. 14 T01008

• two types of architectures



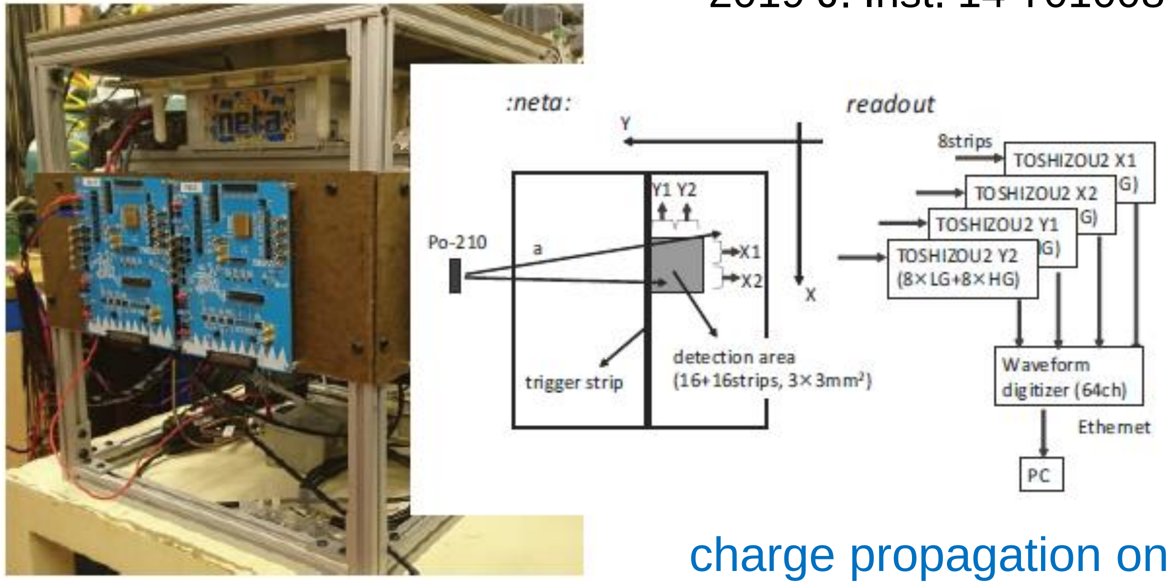


noise was larger than designed
→ modified for LTARS 2018

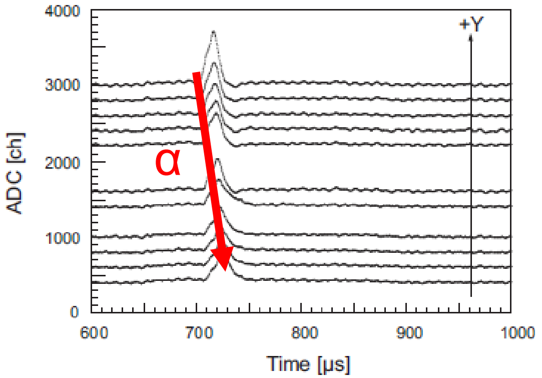
SF6 tracking: electronics for multi-channel charge-readout

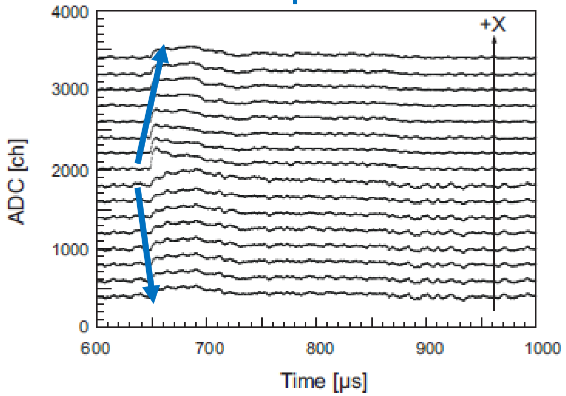
LTARS2016 + Wellesley's micromegas resistive-strip readout

2019 J. Inst. 14 T01008

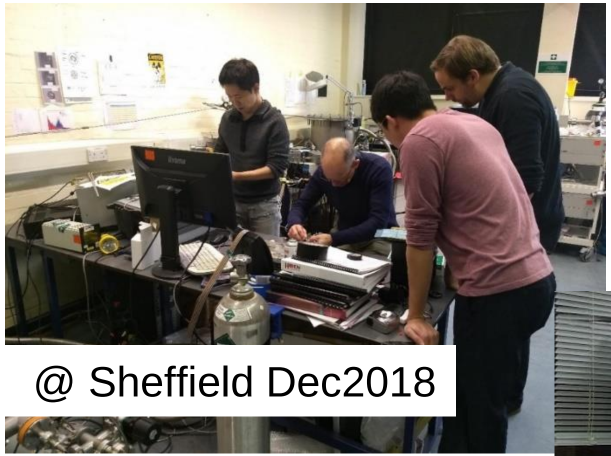


charge propagation on resistive strip were seen

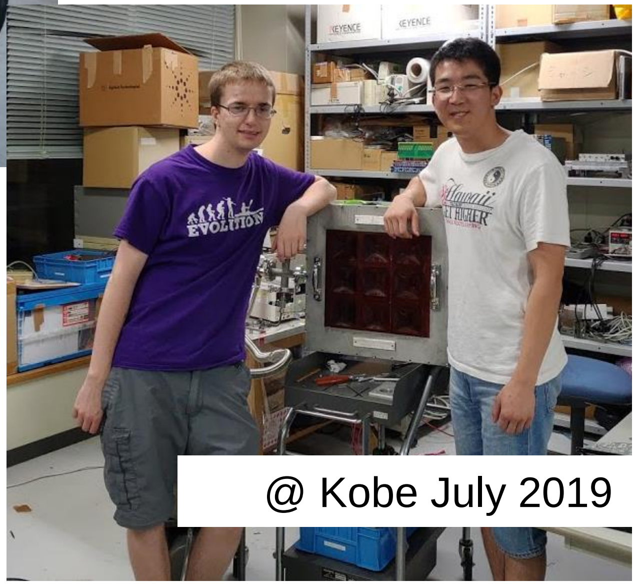




new: LTARS2016 + Sheffield detectors (wires, micromegas)



@ Sheffield Dec2018



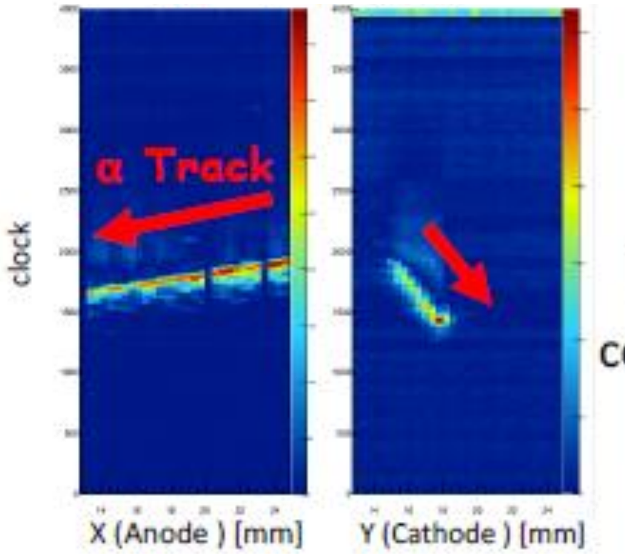
@ Kobe July 2019

See Callum Eldridge's talk

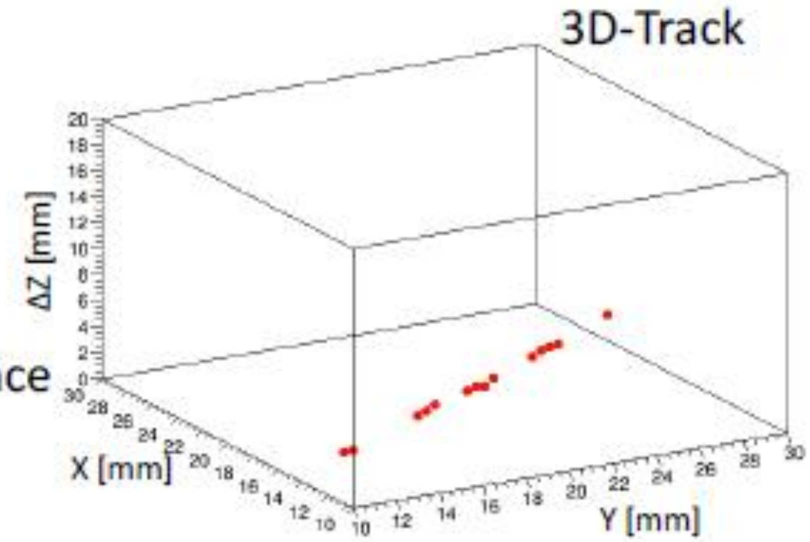
SF6 fiducializtion studies: with 3D tracks

Tomonori Ikeda (Kobe)
JPS Mar2018
paper in preparation

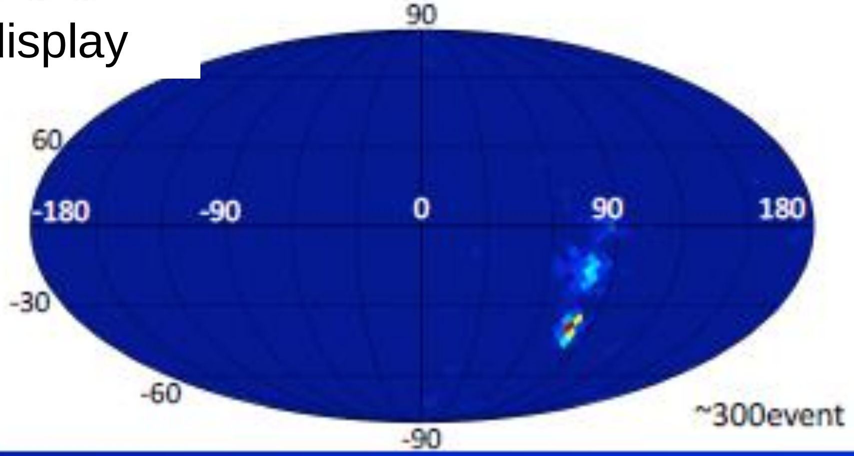
event display (waveform)



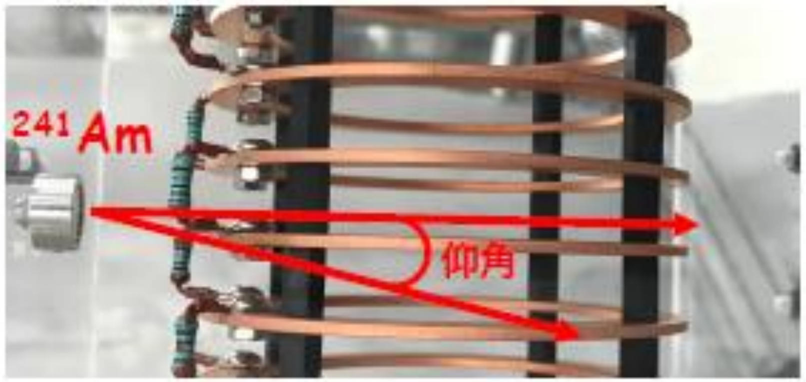
coincidence



event display



configuration



summary

Negative ion TPC for direction-sensitive DM search

small diffusion

z-fiducialization

MPGD (GEMs, micromegas, μ-PICs) performances are being studied.