This project has been funded by the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 657751

Started on 4 May 2015

Identification of Dark Matter 2016

Cutlers' Hall, Sheffield, UK

NITEC

a Negative Ion Time Expansion Chamber for directional Dark Matter searches

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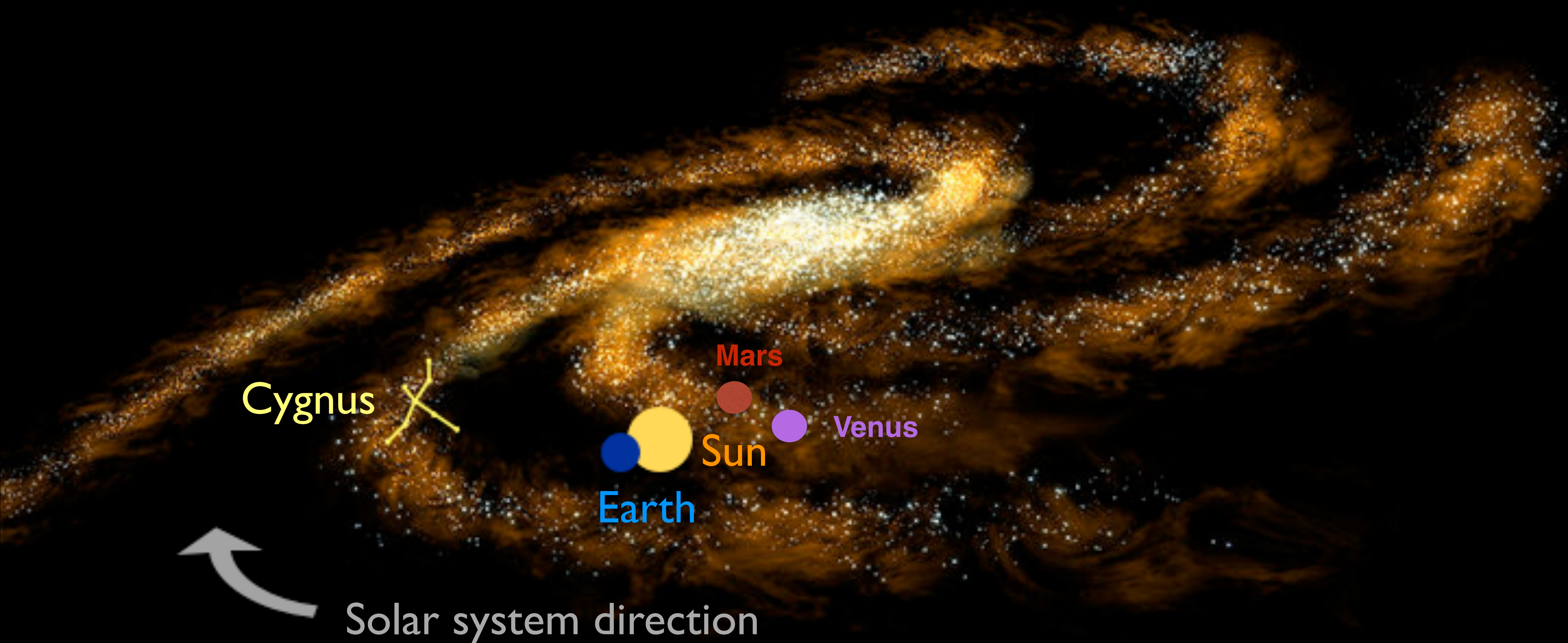
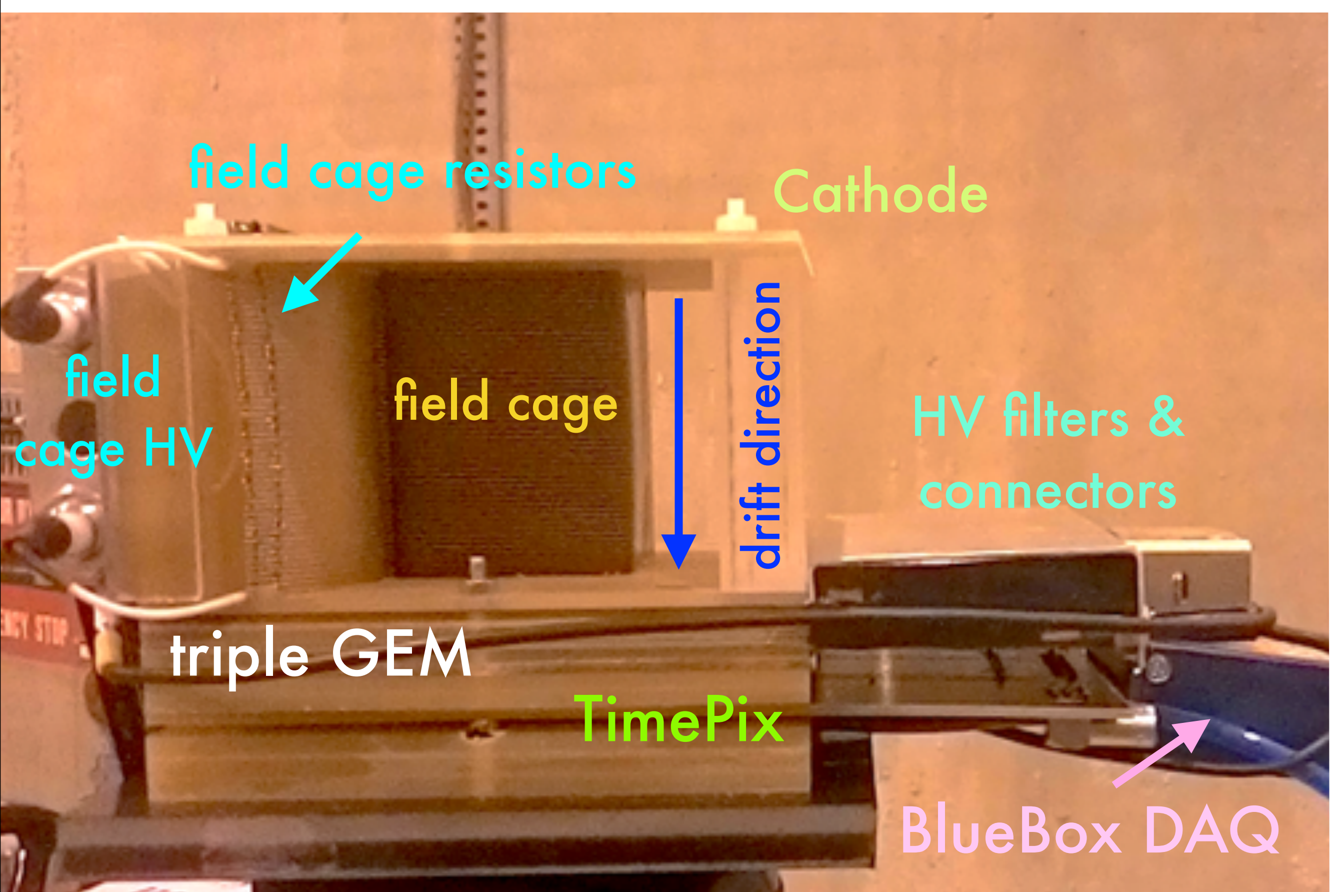
In collaboration with G. Bencivenni, G. Cavoto, G. Mazzitelli, F. Murtas, F. Renga, D. Tagnani

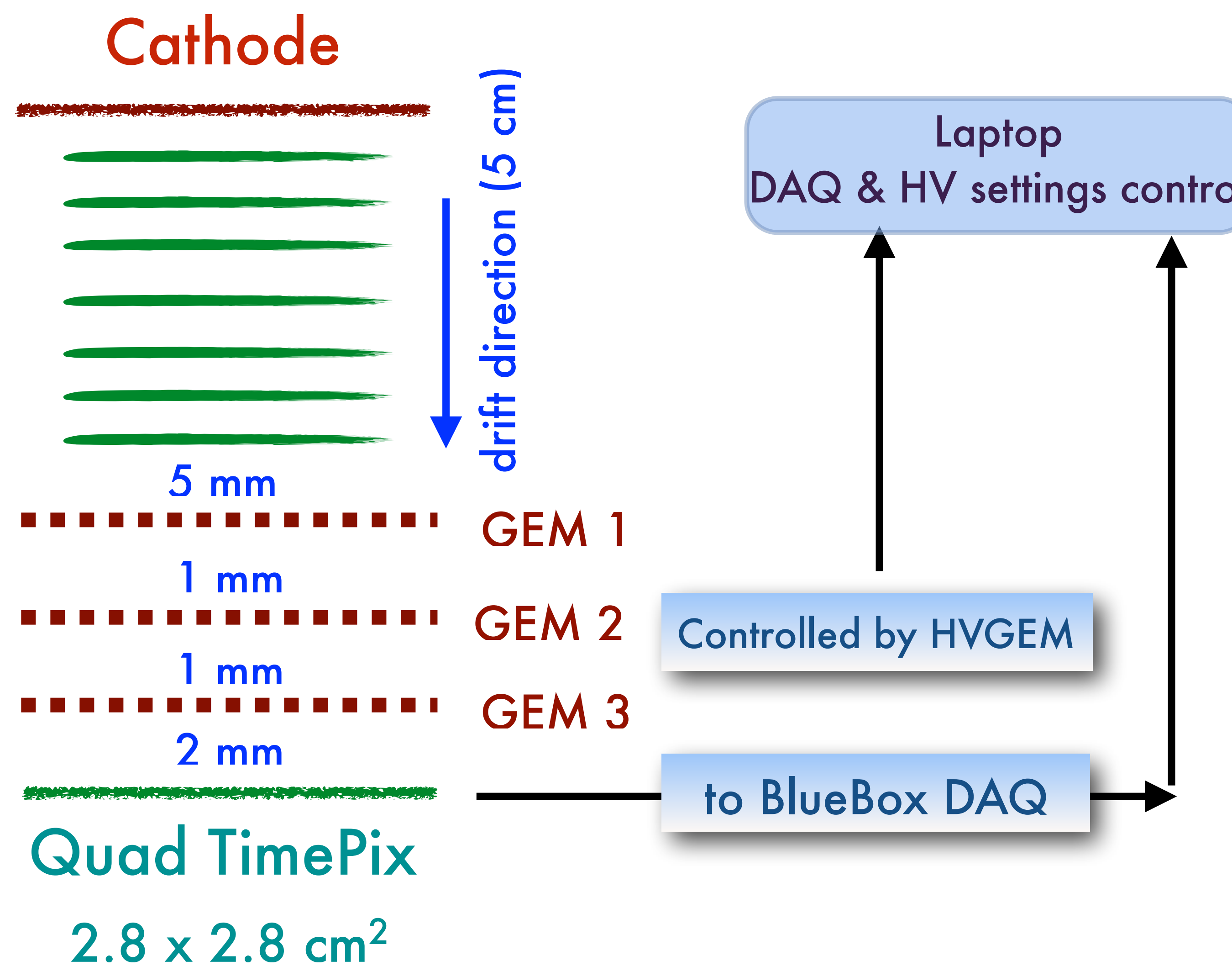


Men are from Mars, Women are from Venus
.....and WIMPs are from Cygnus :)

Small NITEC prototype

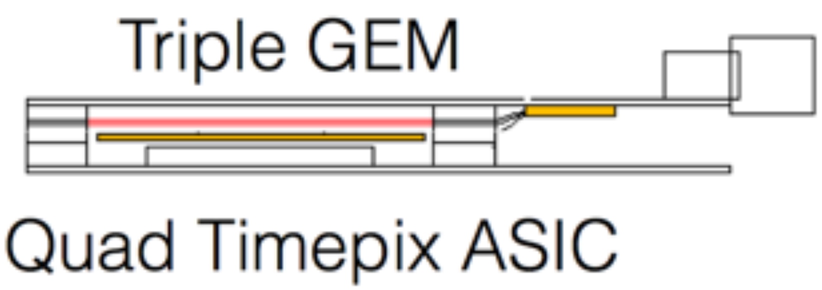
This is the first 5 cm drift distance TPC ever realized with GEMPix readout





GEMPix

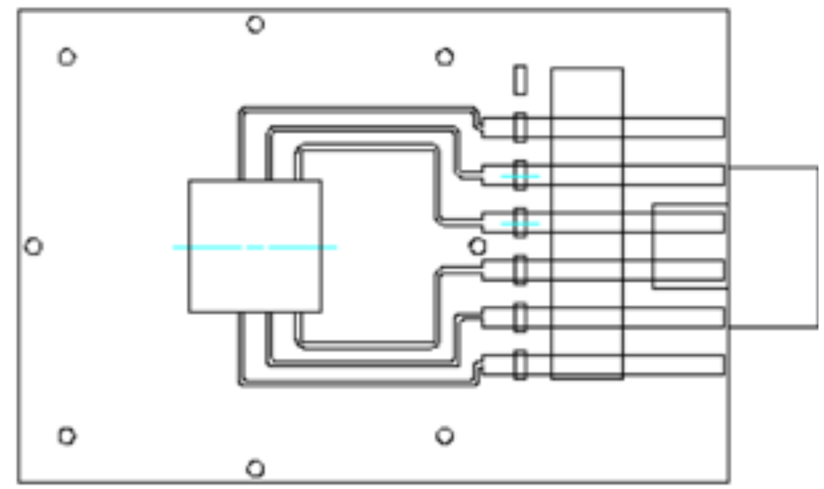
Triple GEM detector with HV filters and connector



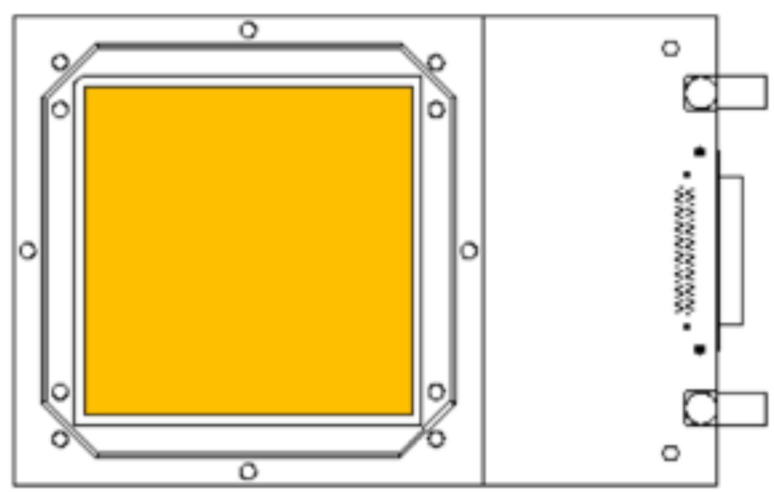
Quad Timepix ASIC board with naked devices (i.e. no silicon)

A dedicated GEM HV

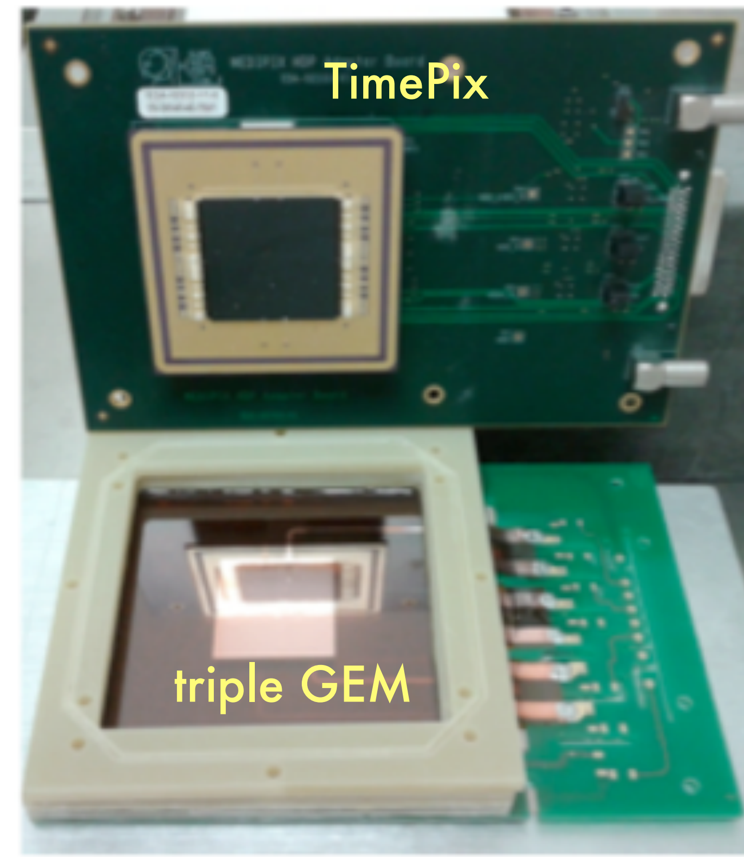
Developed by LNF in collaboration with CERN



top view



side view

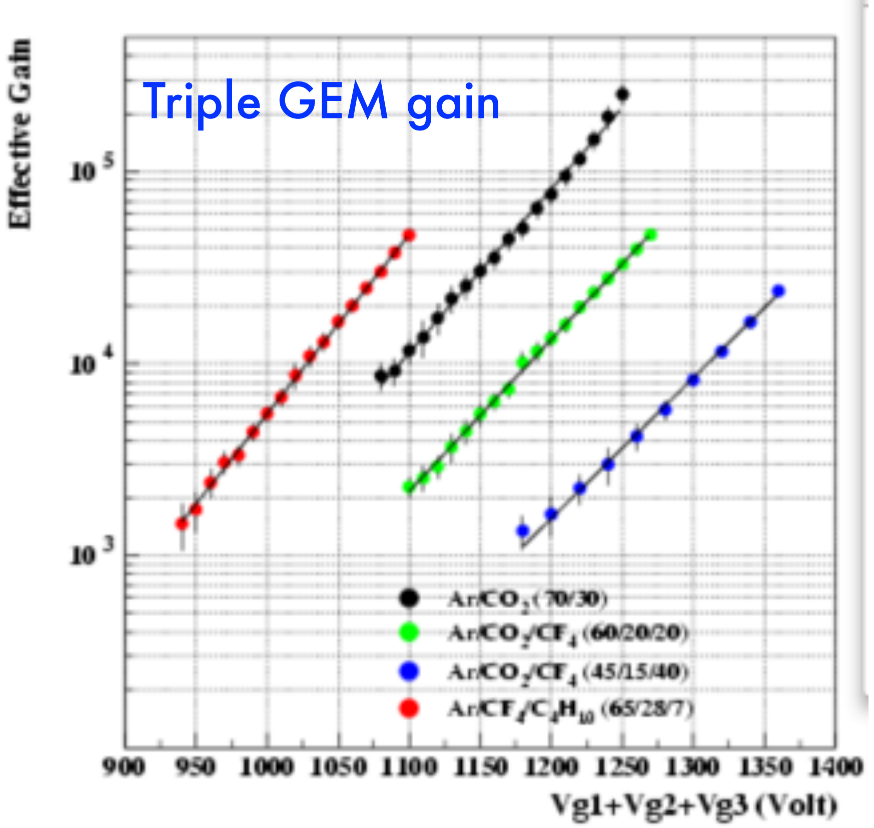


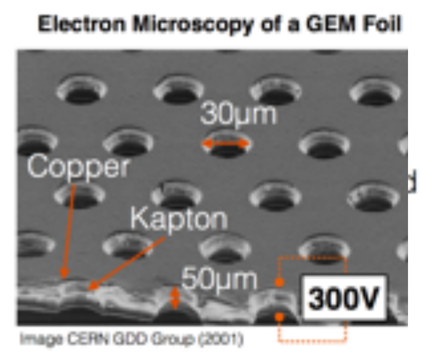
pixel size 55 x 55 um

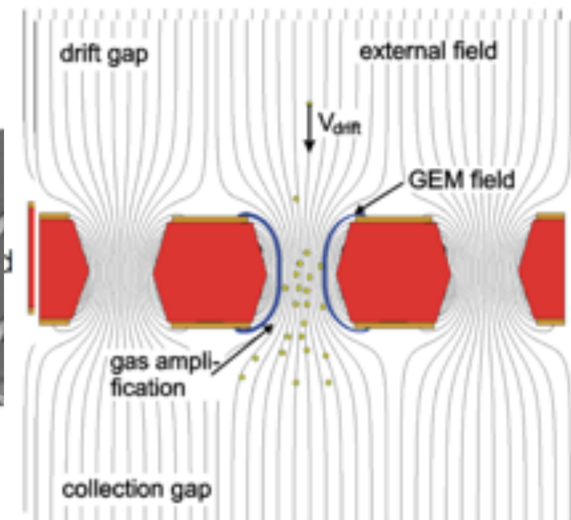
Quad Timepix (512 x 512 pixels) = 4 Timepix chips

2.8×2.8 cm^2

GEM Amplification

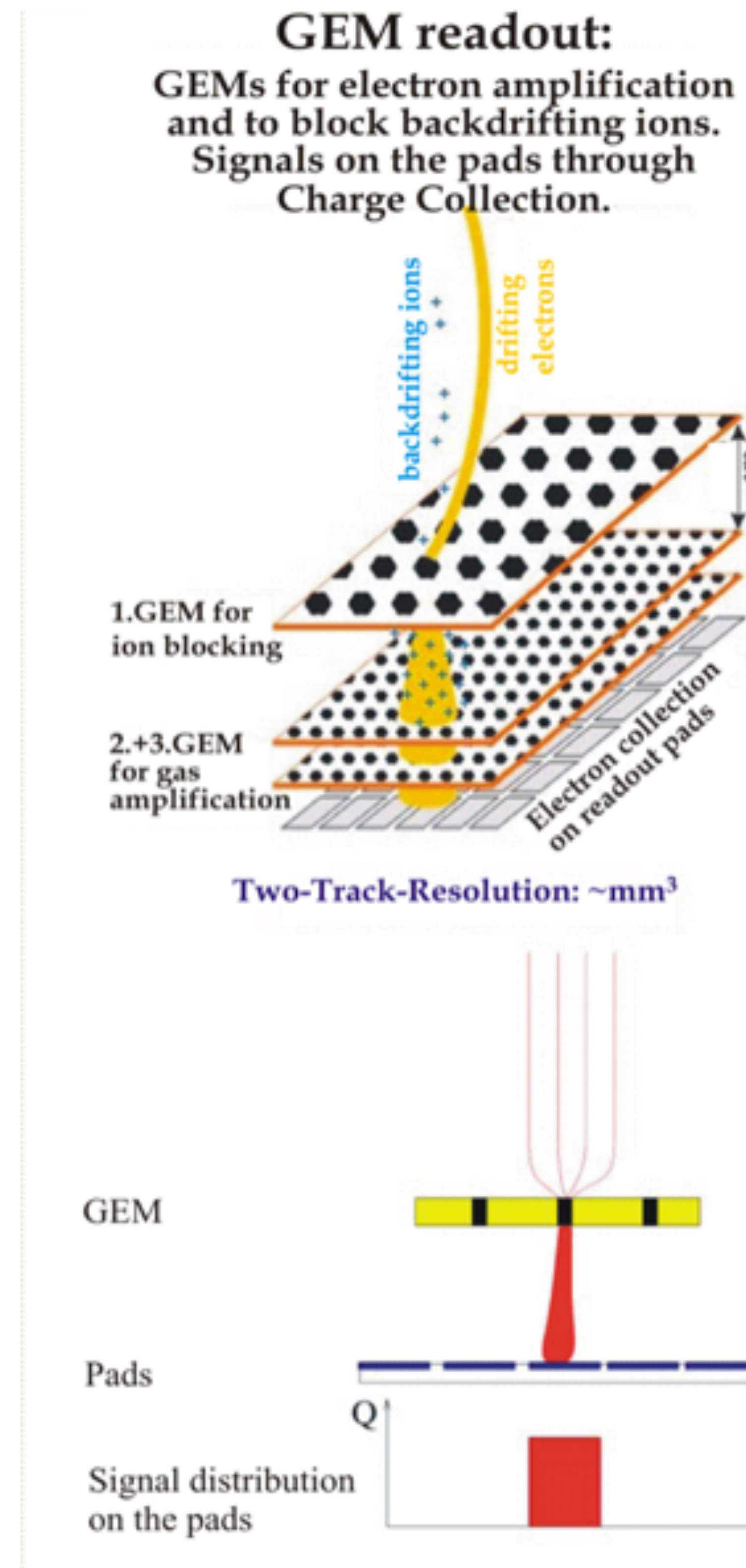






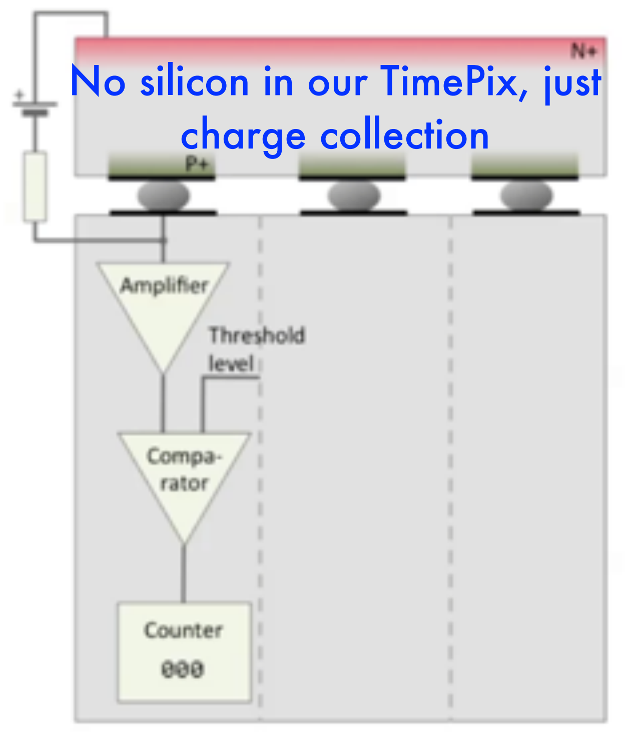
- Particle conversion, charge amplification and signal induction zones are physically separated
- Large dynamic range: from 1 to 10^8 particle/cm^2 /s
- <u>Gain up to > 10^4</u>
- <u>High stability/granularity</u>

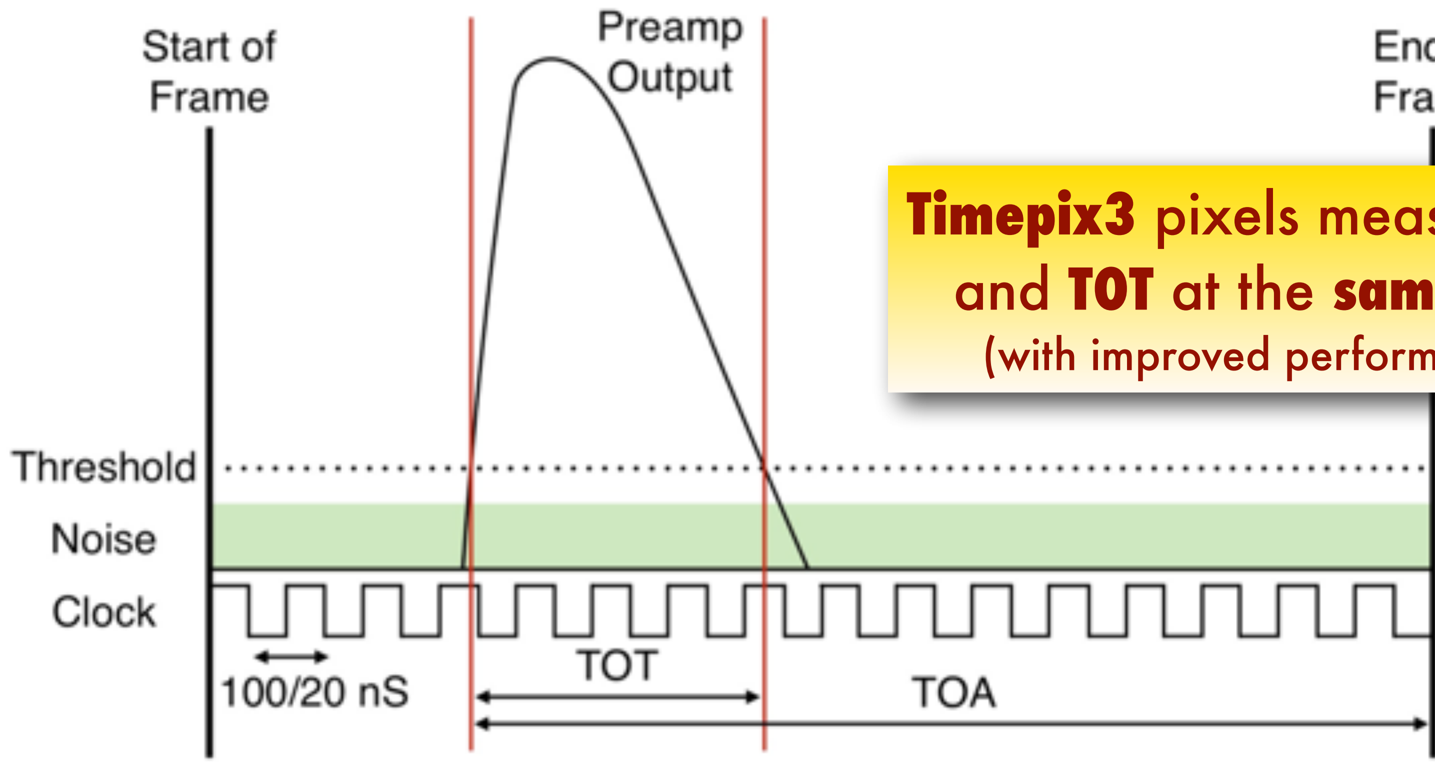
- Micro pattern gas detector
- Thin holes are etched in a metallised kapton foil and a potential is placed across it
- Very large electric field around the holes (40 kV/cm) which creates a localised electron avalanche



TimePix

- TimePix is a pixelated silicon detector developed by MediPix2 collaboration
- We use a 2x2 array for a total of 512x512 pixel of 55 um side WITHOUT silicon sensors
- Processing electronics, including preamplifiers, discriminator threshold and pseudo-random counter fit inside the footprint of the overlying semiconductor pixel.
- Can be operated in counting TOA, TOA and TOT mode but also *TOA/TOT MIXED mode*





Timepix3 pixels measure **TOA** and **TOT** at the **same time** (with improved performances)

- Timepix clock can run from <1 MHz up to 100 MHz
- Timepix counter depth is 11810 —> limits total acquisition time —> ok for negative ion slow drift as well

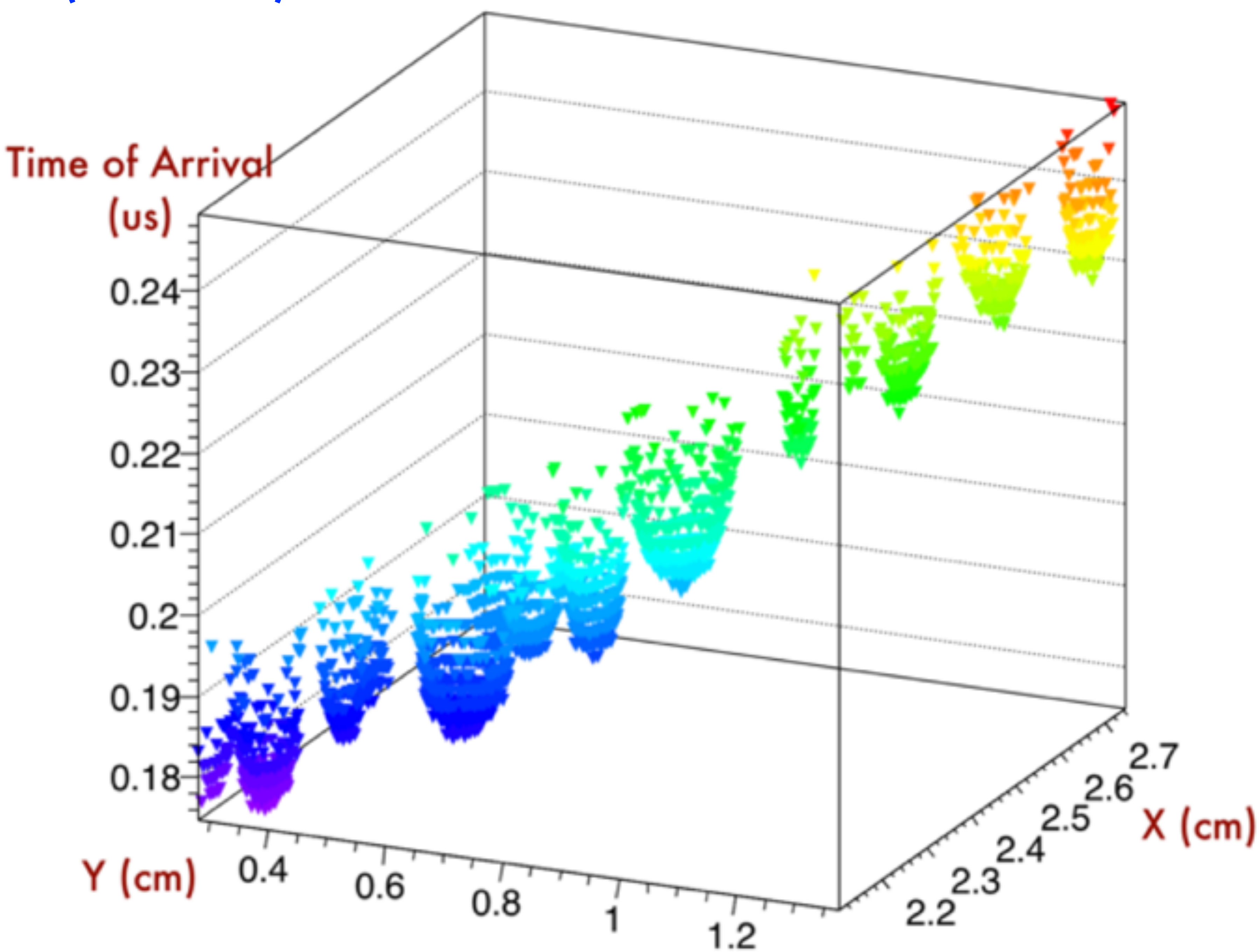
GEMPix + NITPC: A Time Expansion Chamber

- At moderately high reduced fields, anions drift at about 100 m/s, compared to about 10^4 m/s for electron in typical atmospheric pressure drift chamber conditions
- Excellent GEMPix time, energy and spatial resolutions
- Slow anions speed + typical separation of primary ionization clusters in gas + GEMPix performances = Time Expansion Chamber
    - Single ionization clusters drift slowly and could be individually observed with high precision: a relative time expansion between ionization process and signal readout has effectively been achieved
- Single ionization cluster observation can provide excellent dE/dx information, improved position resolution and possibility of superior energy resolution for low energy radiation

"The Time Expansion Chamber and single ionization measurement" (A.H.Walenta, IEEE TNS 26 73)
"Suppressing drift chamber diffusion without magnetic field" (C.J.Martoff et al, NIM A 440)

A NITEC event

A cosmic ray recorded track in Ar:CO_2
(raw data)



SF_6: a new player in the game

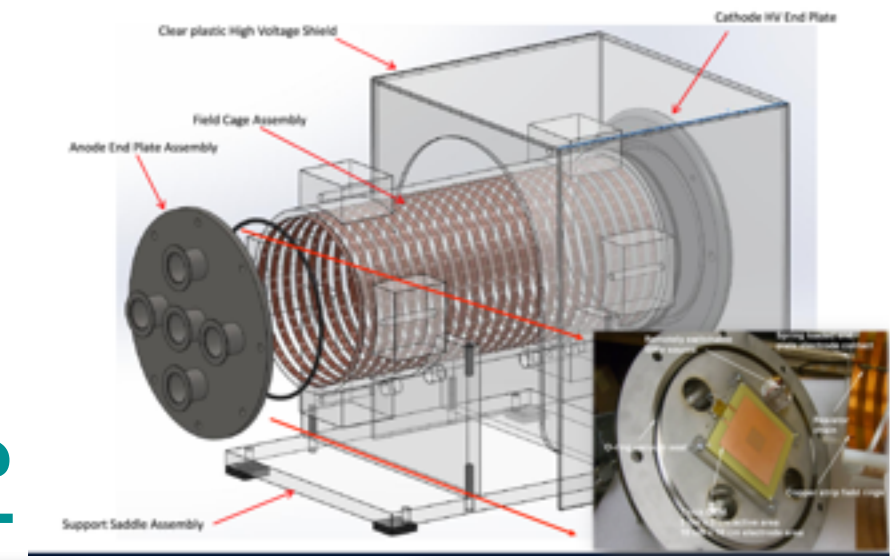
electron gas features

- Example: CF_4
  - Larger diffusion -> smaller detector length
  - Spin target -> no sacrifice of volume -> higher target density at same pressure -> can operate at shorter drift lengths.
  - Benign
  - Good scintillator -> allows for optical readouts
  - Fiducialization?

negative ion gas features

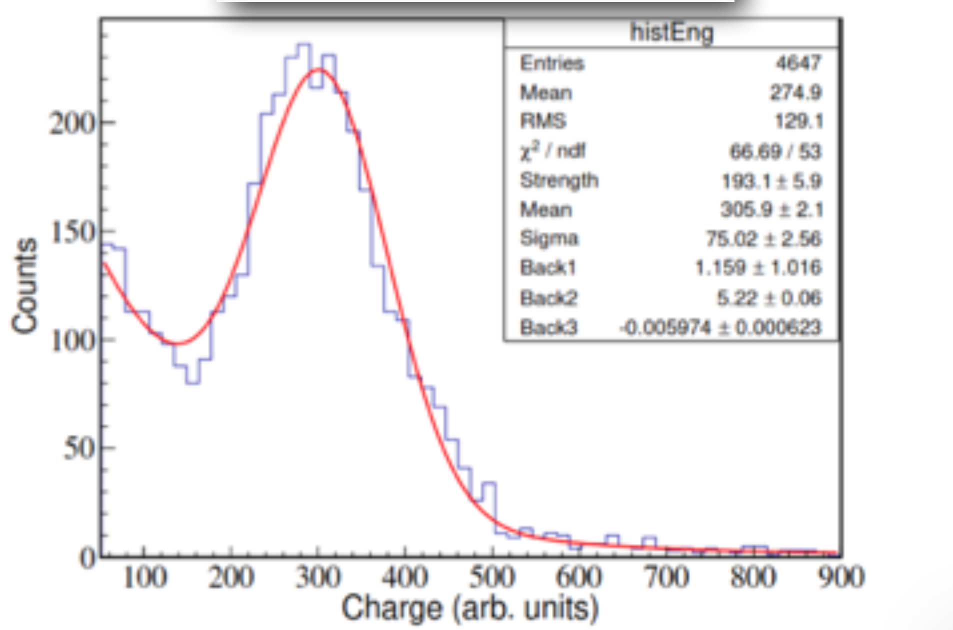
- Example: CS_2
  - Low diffusion -> large detector length
  - Good high voltage operation at low pressures
  - Demonstrated fiducialization
  - Lack spin-dependent content -> sacrifice detector volume to enable negative ion operation with a spin target
  - Toxic **TOXIC**

Measured with thick GEMs



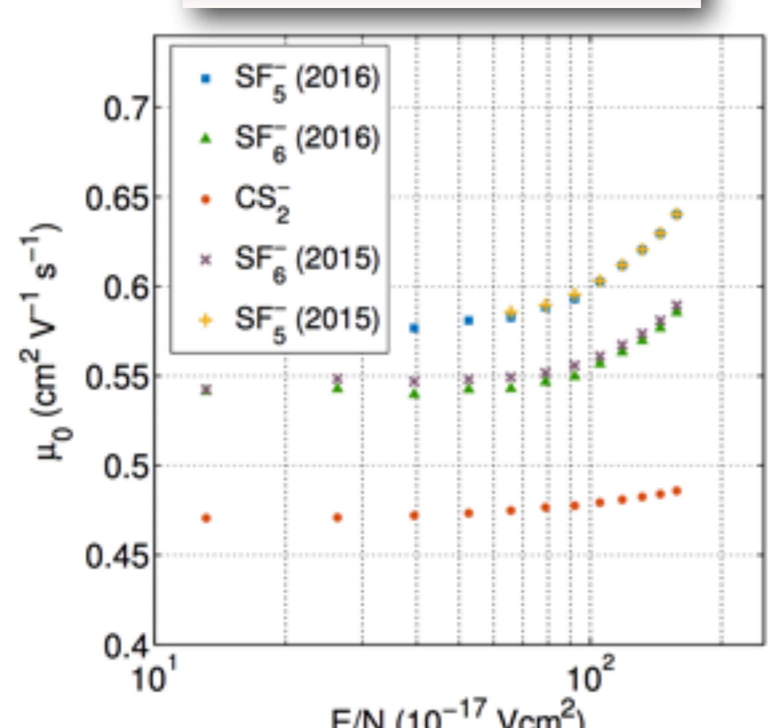
Could SF_6 have only nice features of both???

Gas gain proved

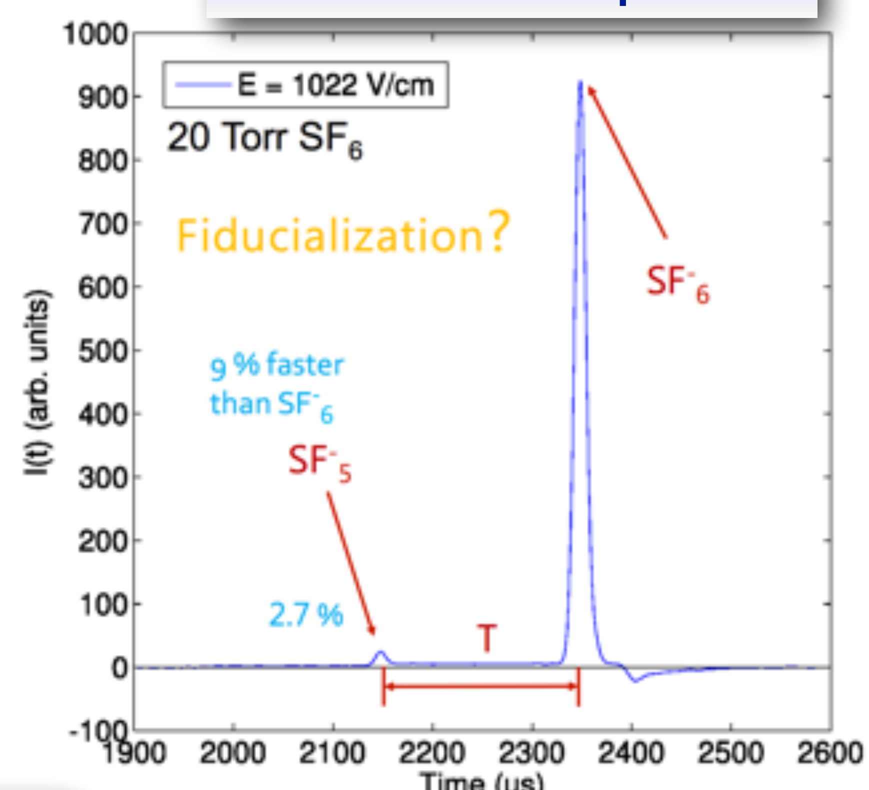


(a) ^{55}Fe energy spectrum in 30 Torr SF_6 using 0.4 mm THGEM

Mobility



Fiducialization proved



From D. Loomba talks (2015-2016)

NITEC activities

- Characterization of the small prototype with Ar:CO_2 and Ar:CO_2:CF_4 mixtures in traditional electron carrier configuration with:
  - Cosmics
  - ^{55}Fe spectrum
  - 450 MeV electrons at beam line (BTF)

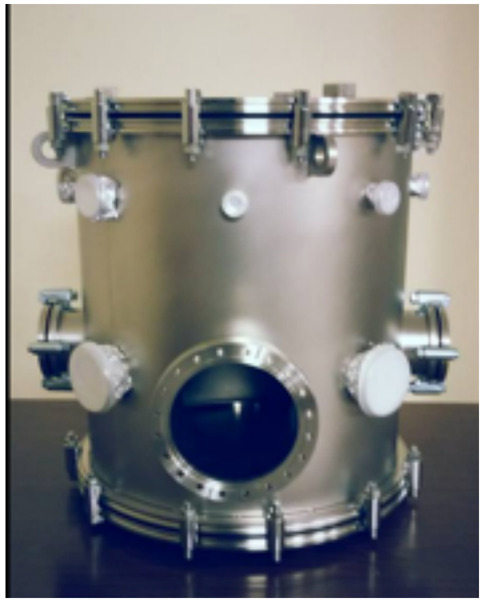
On going work on single ionization cluster detection with electron drift

Jul-Sep 2015

Oct 2015/Apr 2016

- Design and procurement of vacuum vessel to operate below atmospheric pressure

Nov 2015 - Apr 2016

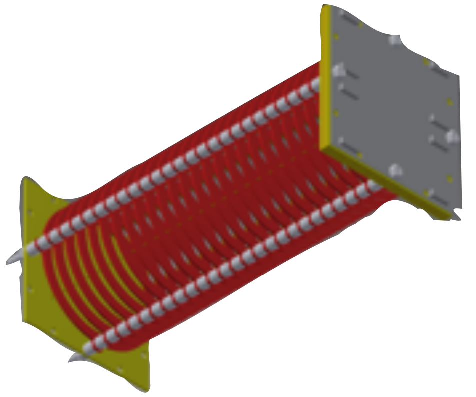


- First tests of the small prototype with SF_6 mixtures
  - 450 MeV electron beam test with Ar:CO_2:SF_6
  - ^{55}Fe data with pure SF_6

May 2016

- Design, development and manufacturing of large prototype (~15-20 cm drift distance)

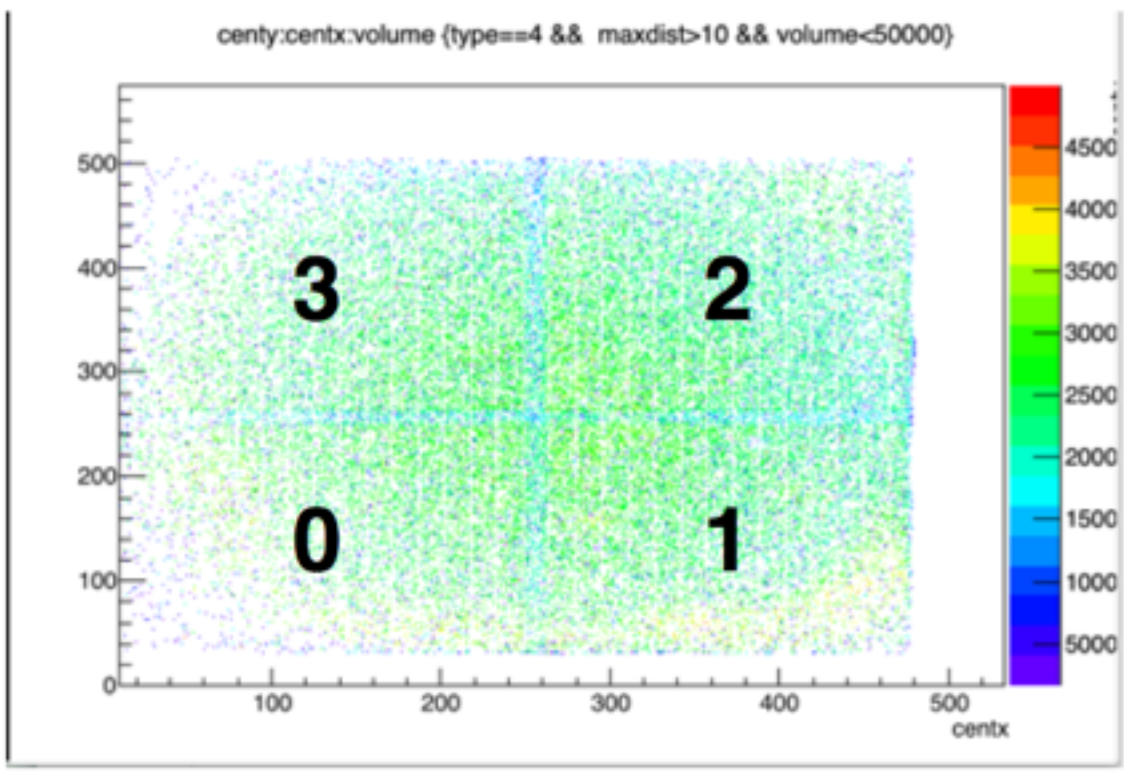
May 2016 - Nov 2016(?)

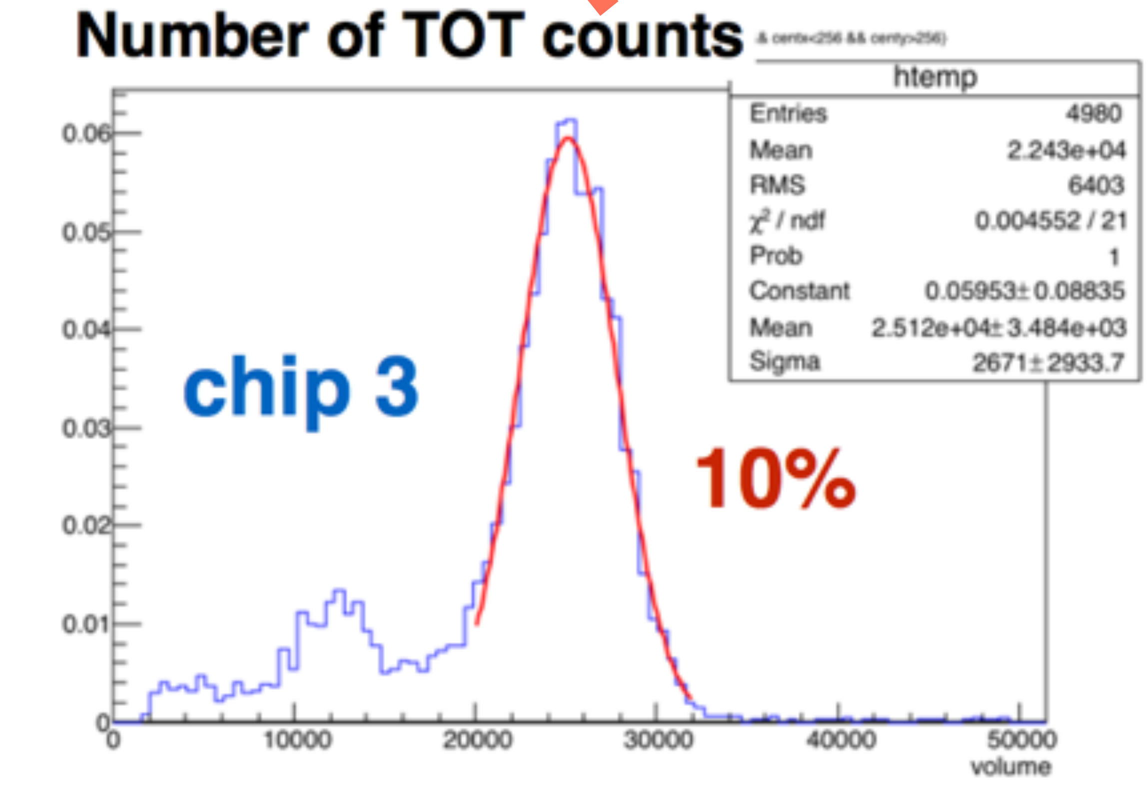


NITEC characterization with $Ar:CO_2:CF_4$

PRELIMINARY

^{55}Fe radioactive source





10% - 12% energy resolution with non-optimized calibrations

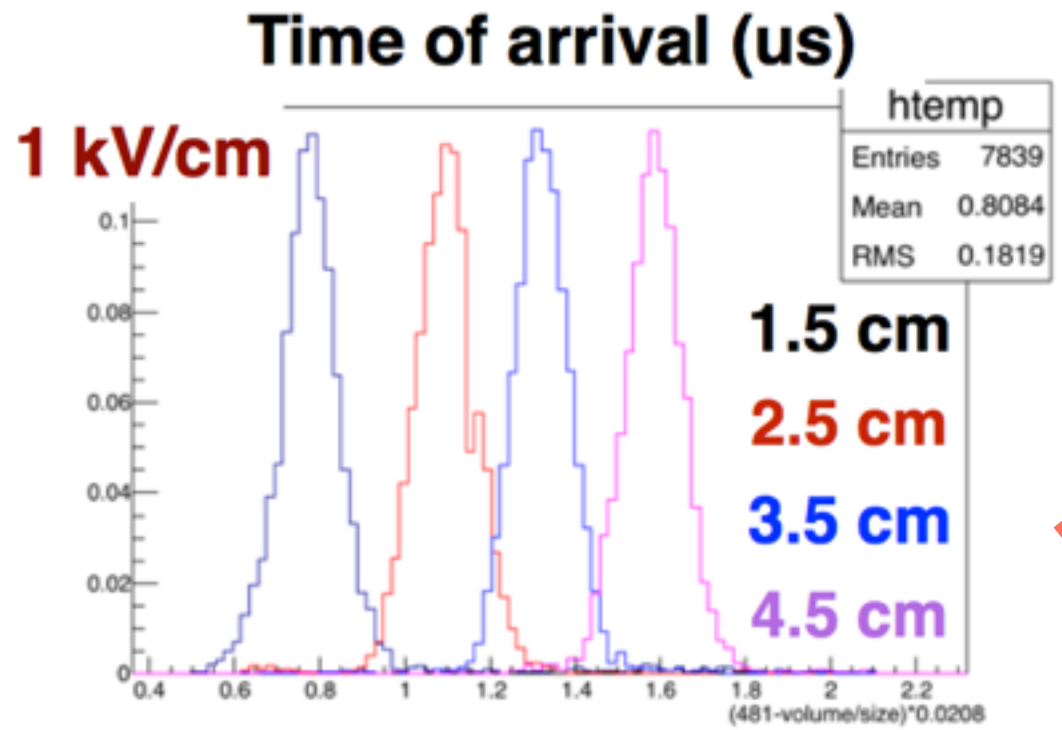
Measurement @ Beam Test Facility

450 MeV
electron beam down
to single particle
(< 1 mm^2 beam spot)

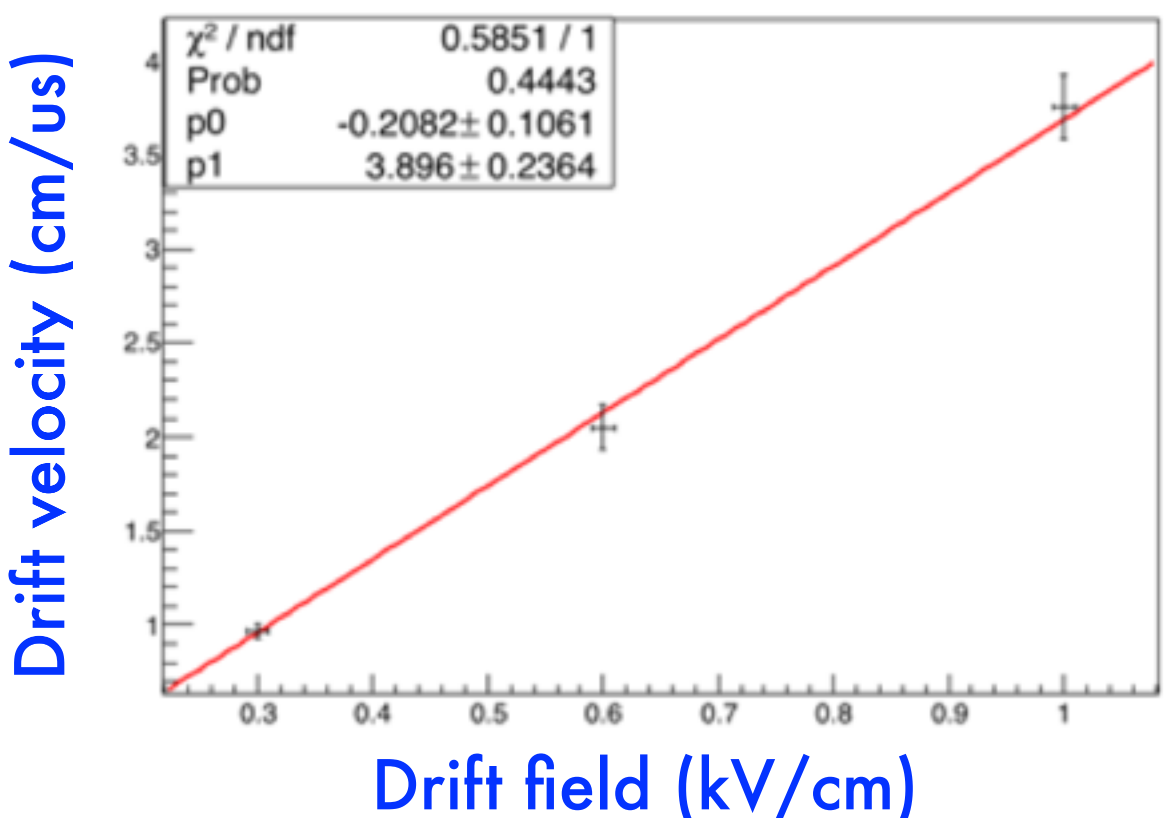
micrometric table
(~100 um position
uncertainty)

NITEC characterization with $Ar:CO_2:CF_4$

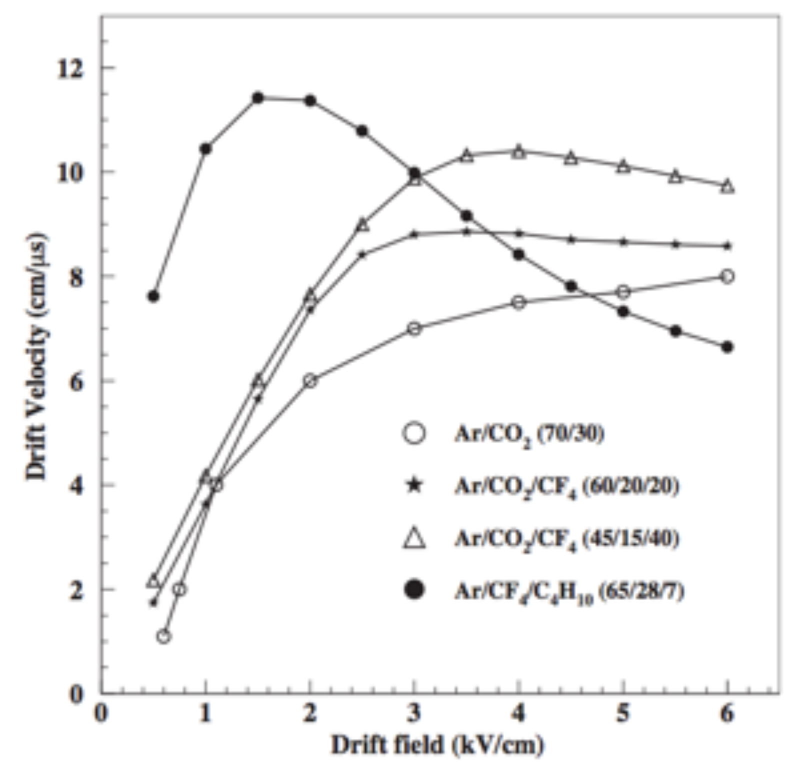
450 MeV electron beam data @ BTF



PRELIMINARY

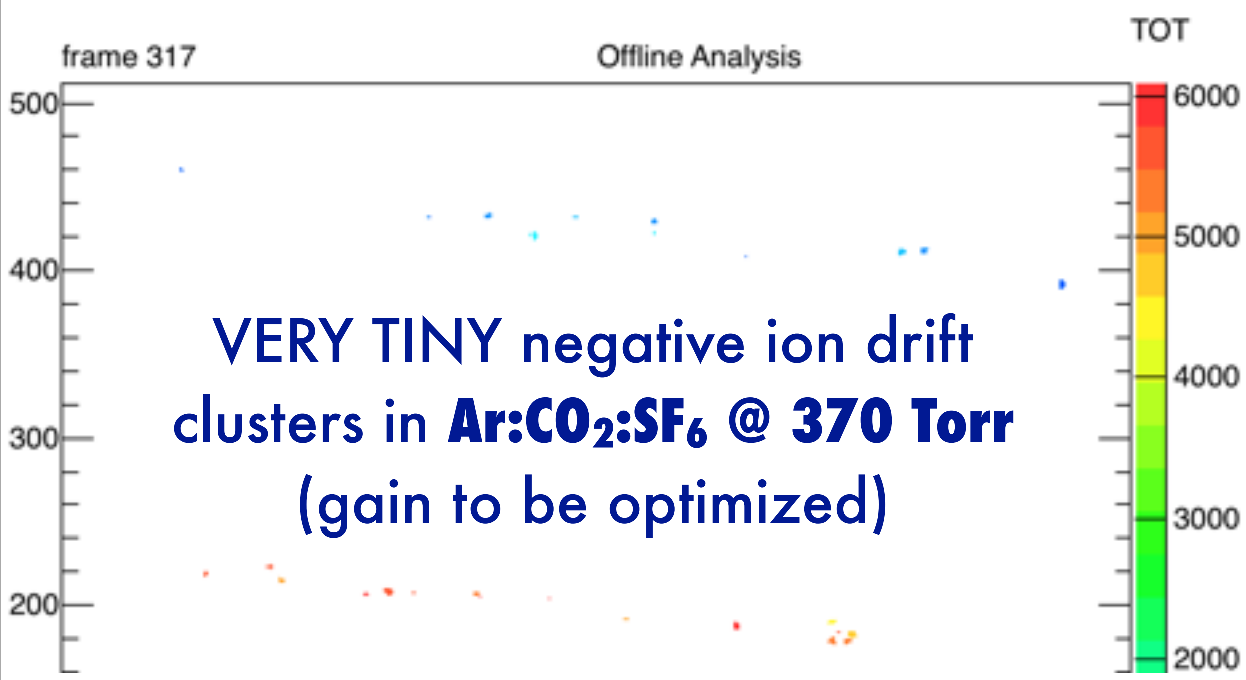


Consistent with published measurements



NITEC negative ion operation $Ar:CO_2:SF_6$

Negative ion operation with $Ar:CO_2:SF_6$ mixture 52:23:25 @ 370 Torr



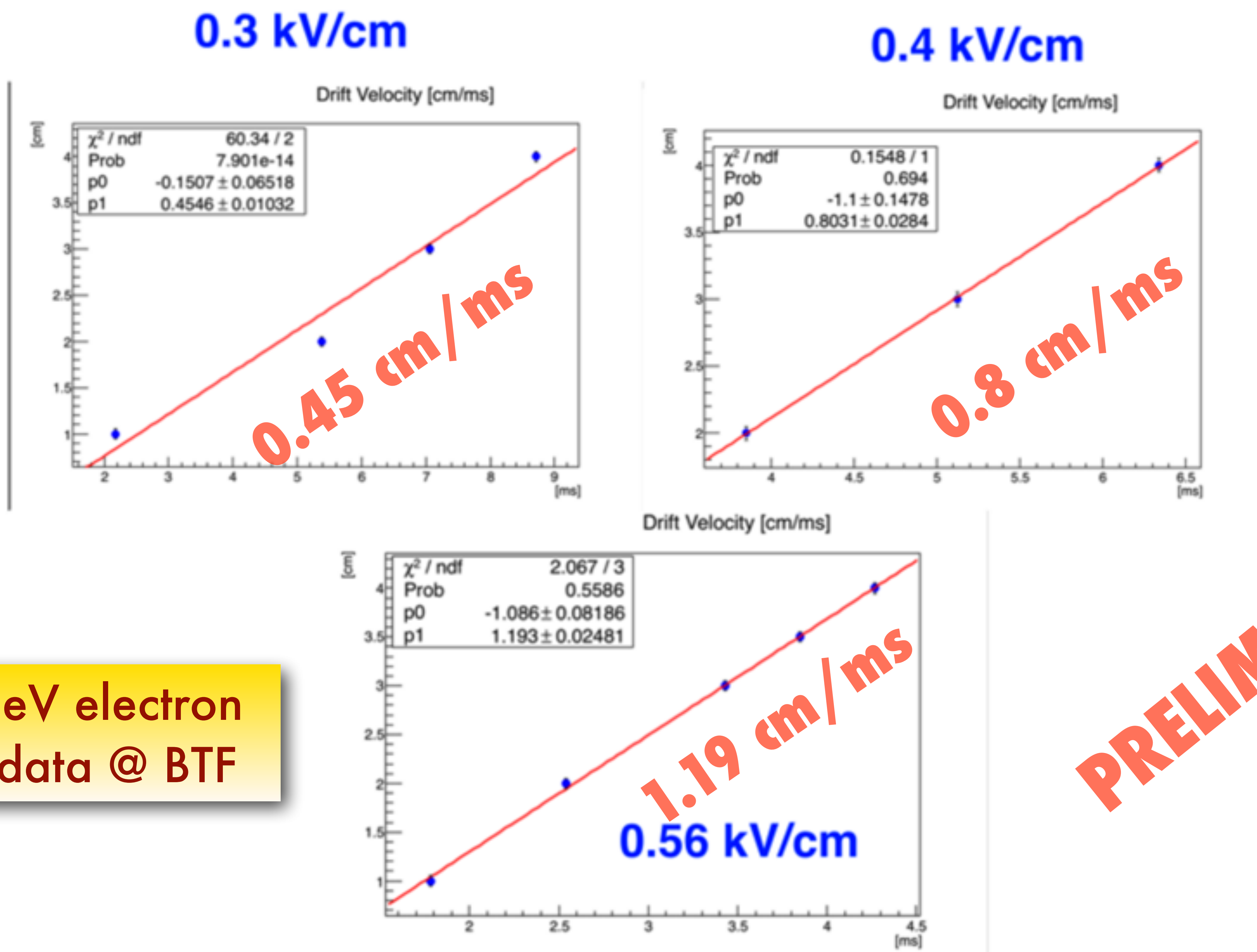
VERY TINY negative ion drift clusters in **$Ar:CO_2:SF_6$ @ 370 Torr** (gain to be optimized)

electron drift clusters in **$Ar:CO_2$ @ 740 Torr**

- Encountered several operating issues for the TPC due to the low pressure regime
  - Field cage built by Nikhef before the NITEC start for proton tomography and to be operated at atmospheric pressure
- Pressure and drift field strongly limited by this
  - Data taken at 370 Torr with ~0.3-0.6 kV/cm drift field
- Thanks to this experience, we are carefully designing the large prototype and performing preliminary tests on each component in order to solve all these issues

450 MeV electron beam data @ BTF

Negative ion drift velocity measurement in $Ar:CO_2:SF_6$



450 MeV electron beam data @ BTF

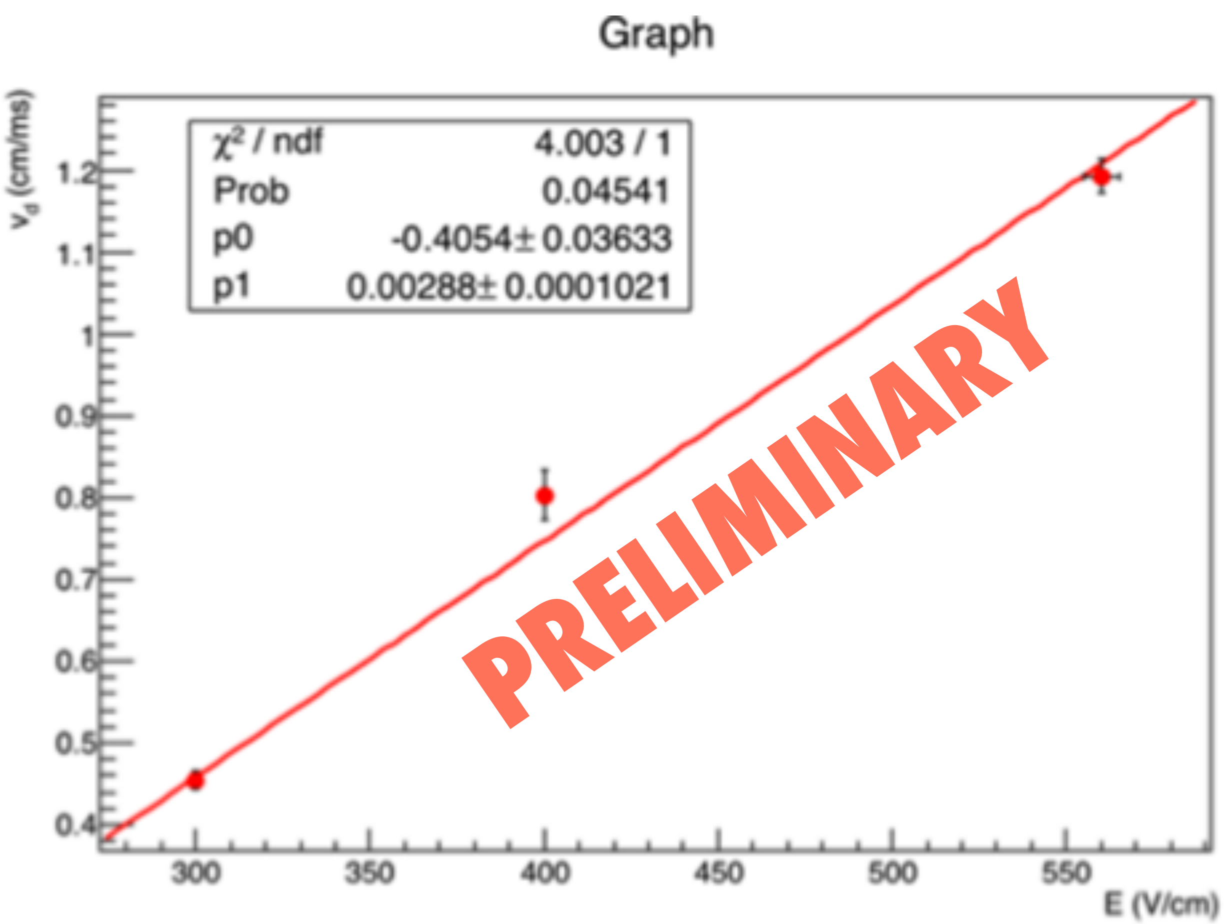
PRELIMINARY

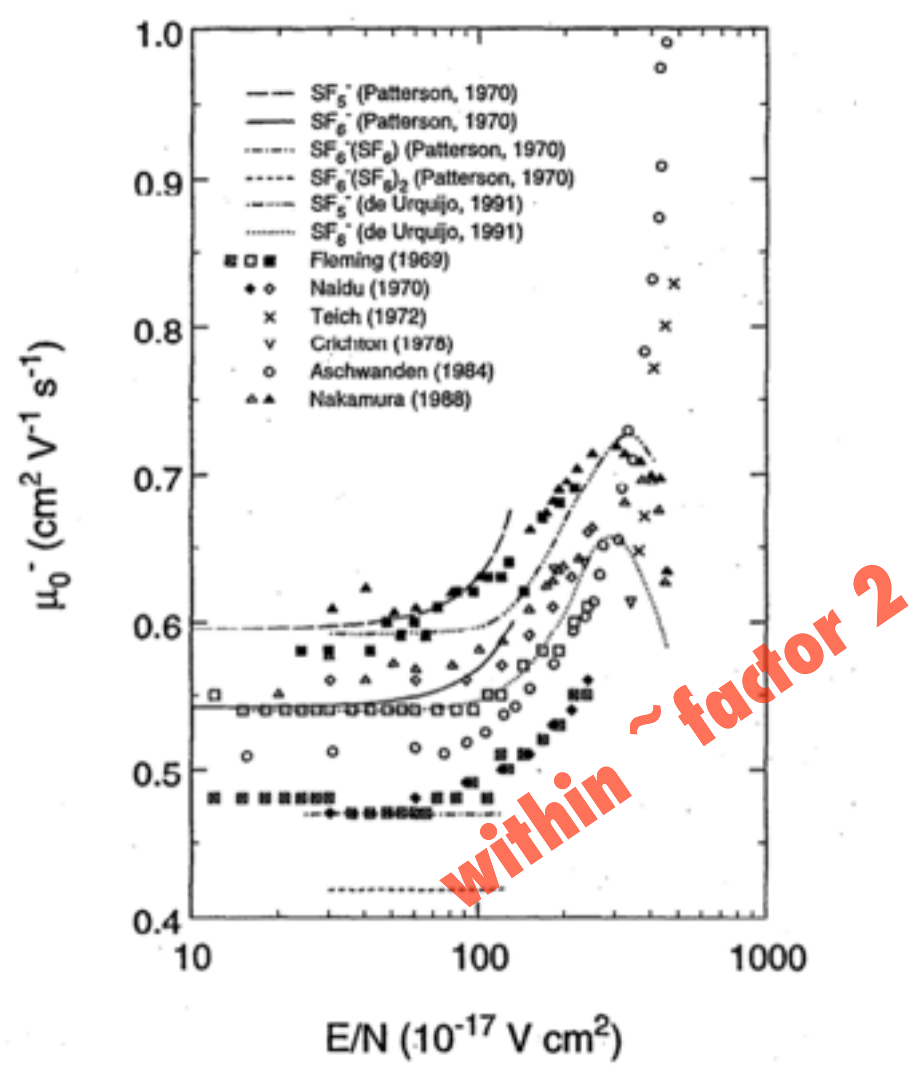
Negative ion drift velocity measurement in $Ar:CO_2:SF_6$

Drift velocity compatible with negative ions
(need to understand and prove which ion species is drifting)

L. Christophorou & J. Olthoff
J. Phys. Chem. Ref. Data, Vol 29, No. 3, 2000

BTF measurement of "allegedly" SF_6^- drifting in $Ar:CO_2:SF_6$ (52:23:25)



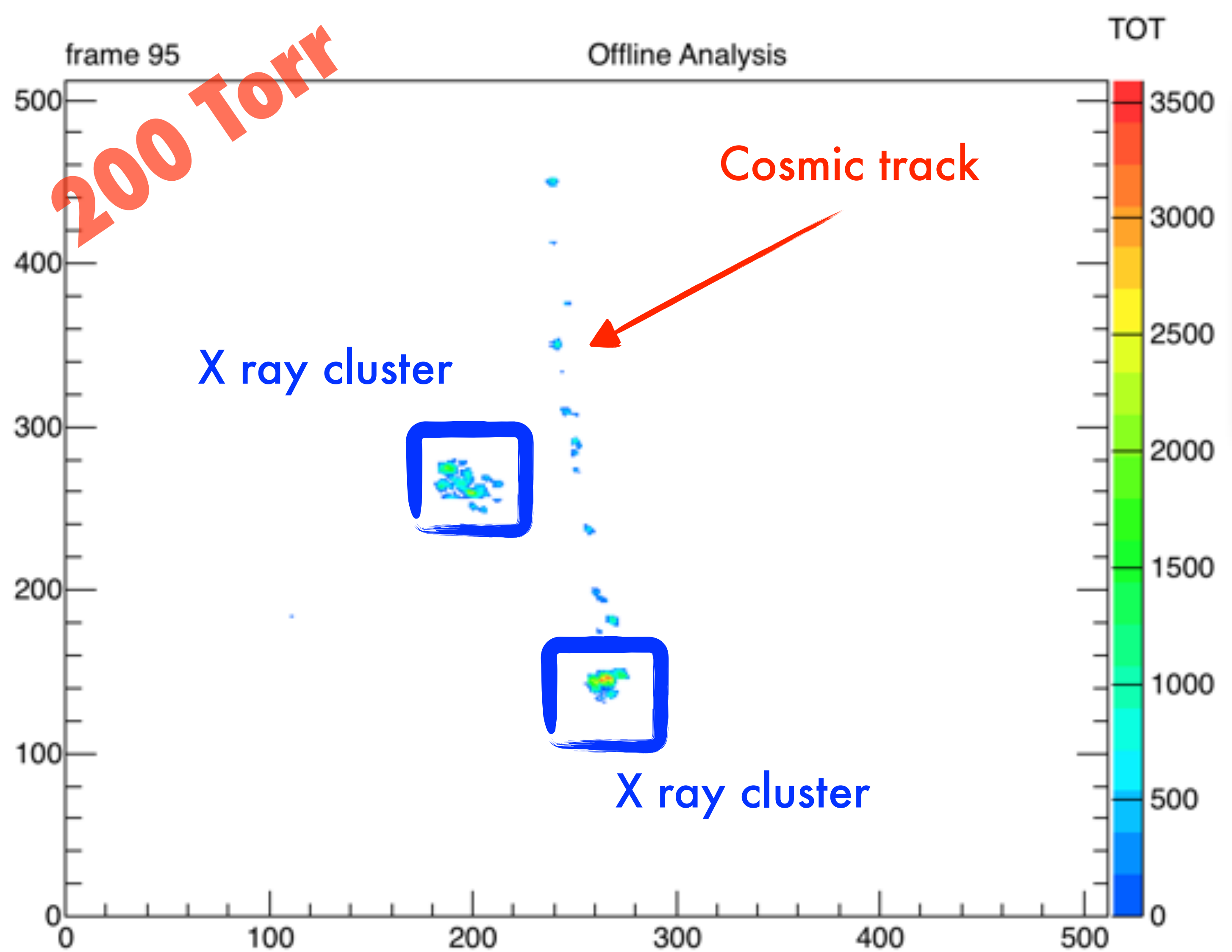


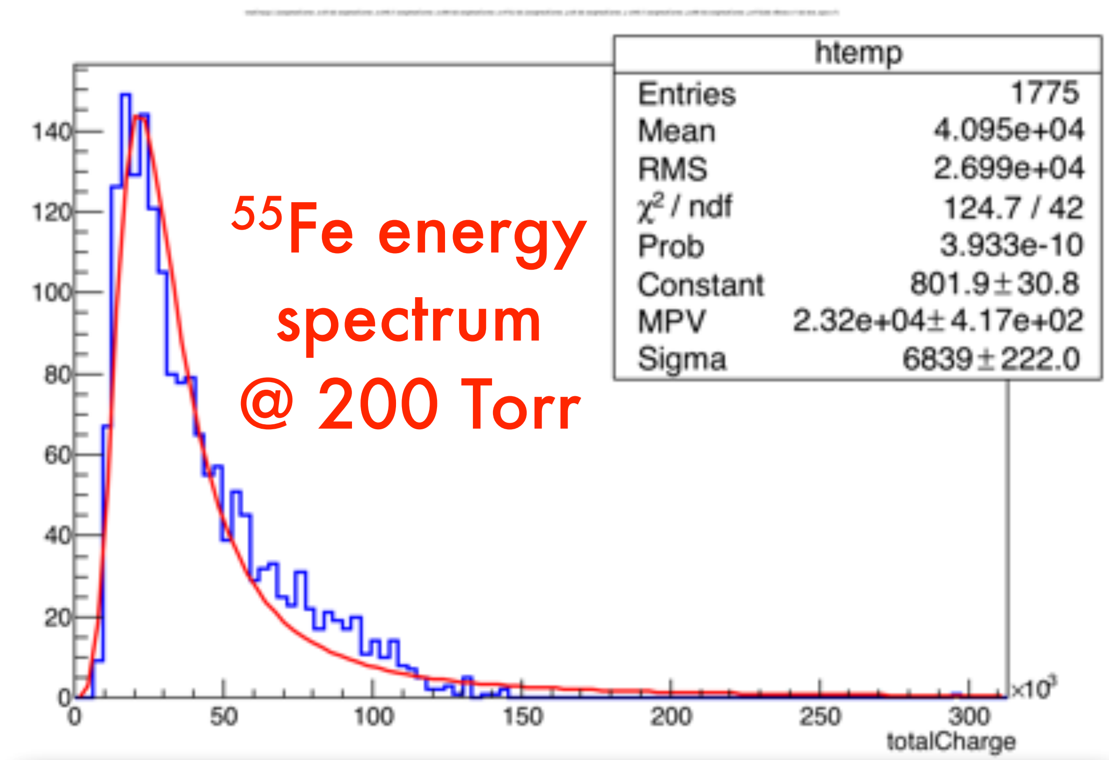
with the large prototype we are designing we will be able to test lower pressures and higher drift fields

~ 0.5 cm/ms @ 0.3 kV/cm @ 220 Torr for SF_6^- drifting in SF_6 (expected higher in lower density gases)

NITEC gain measurement in pure SF_6

^{55}Fe radioactive source





CAVEAT: **not understood** energy spectrum

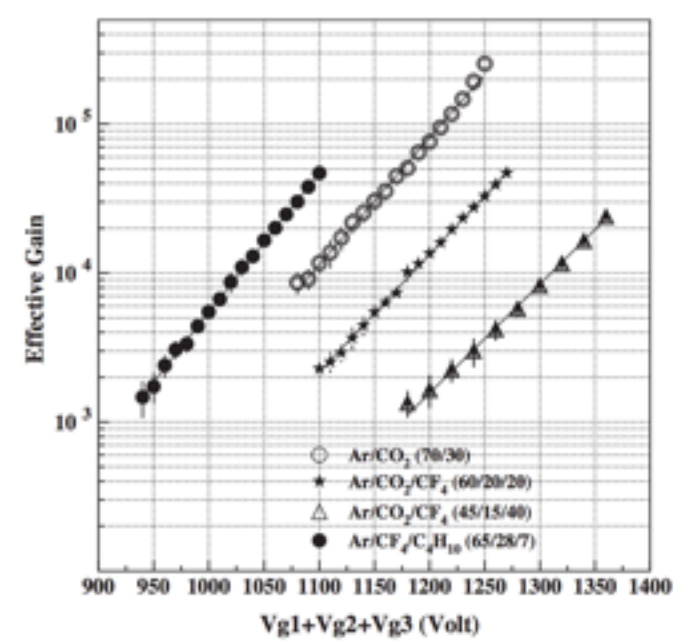
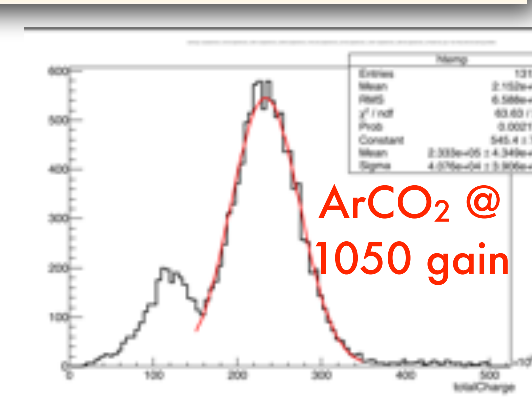


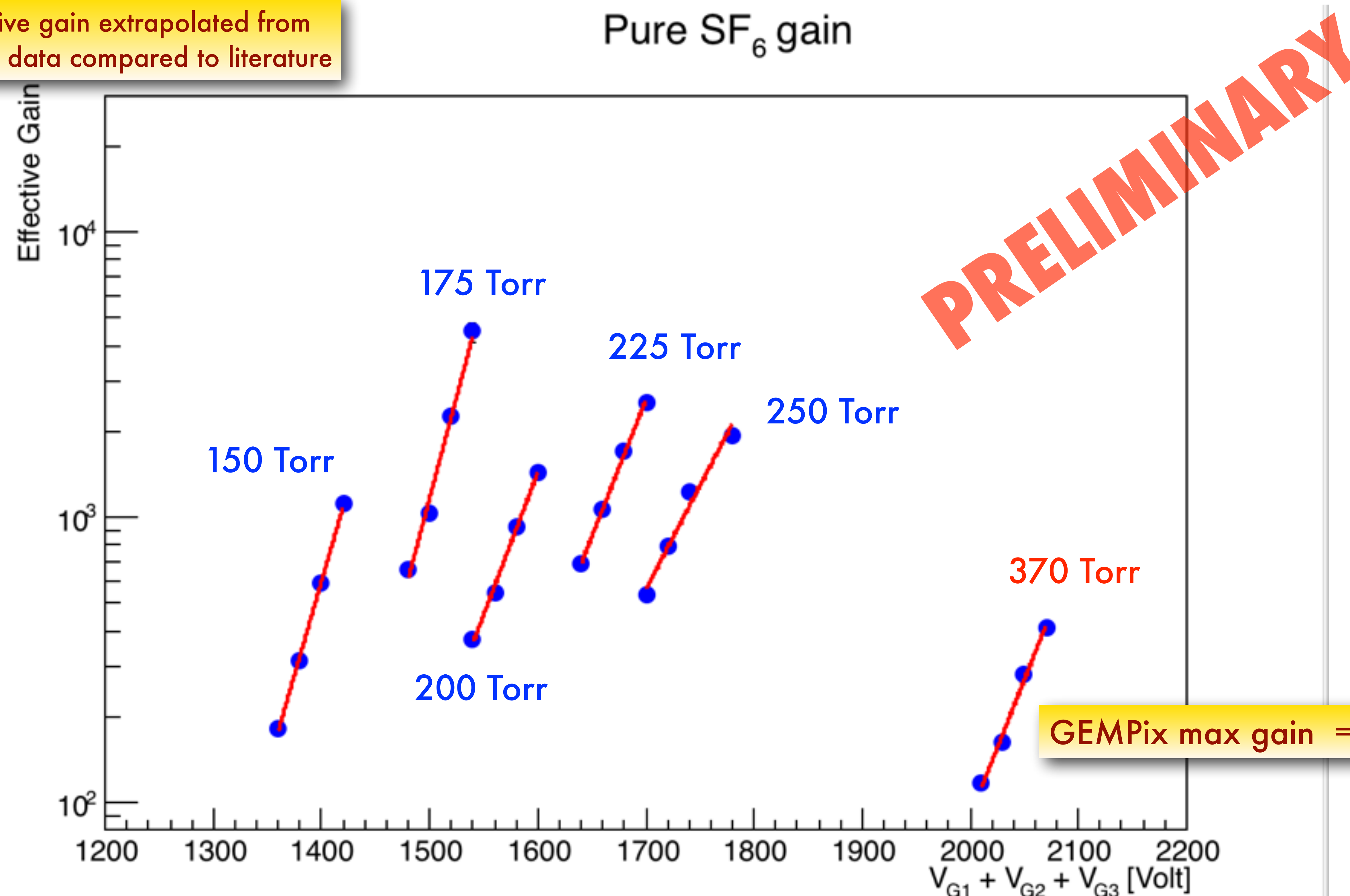
Fig. 3. Gas gain for the tested gas mixtures.



Effective gain extrapolated from Ar:CO_2 data compared to literature

NITEC gain measurement in pure SF_6

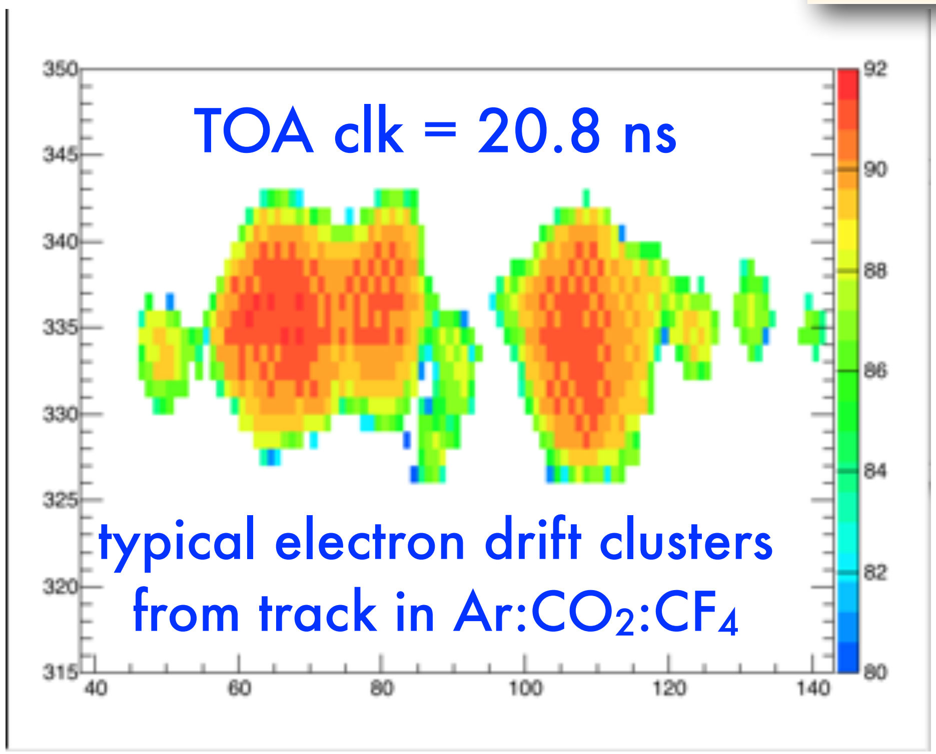
Effective gain extrapolated from $Ar:CO_2$ data compared to literature



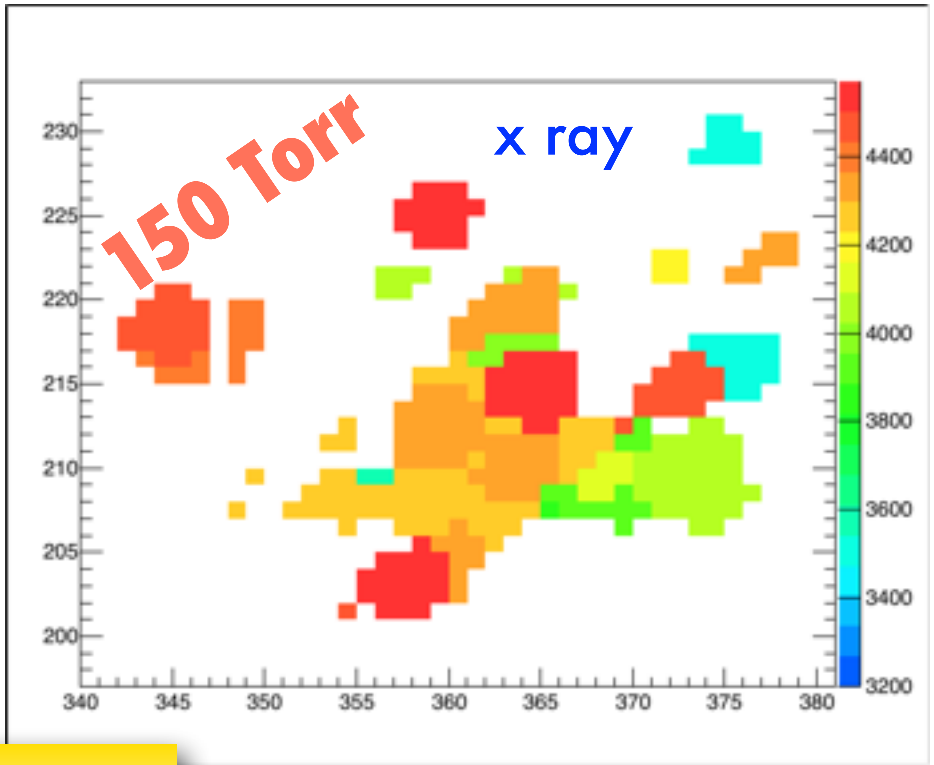
GEMPix max gain = 2100

NITEC minority carriers indication in pure SF_6

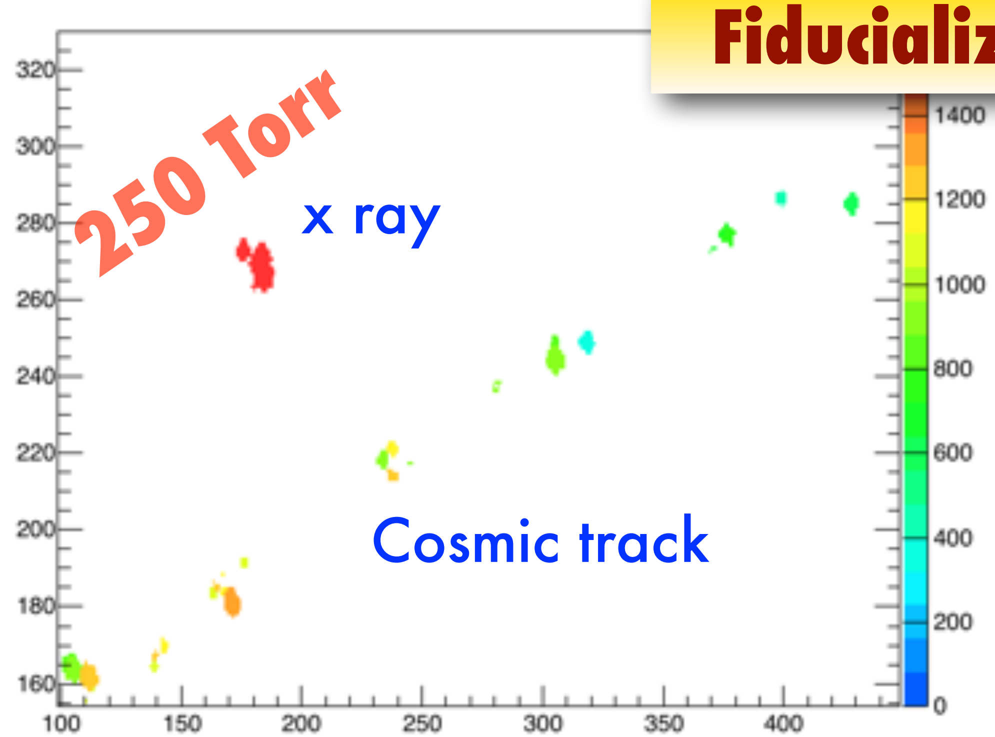
Quantitative analysis on going

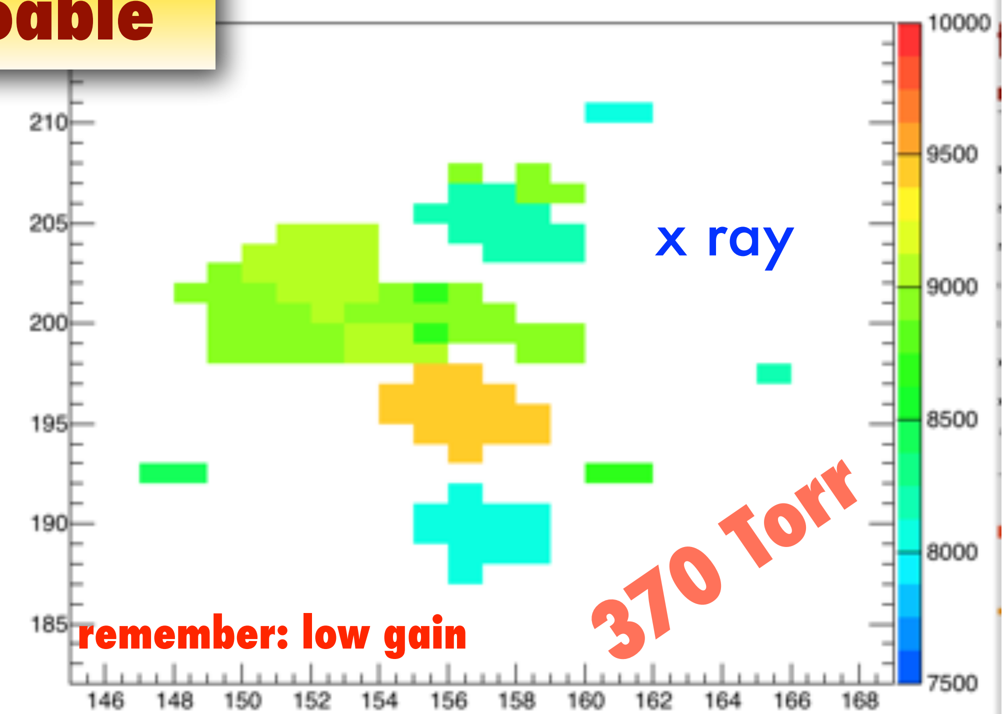


TOA clk = 1.3 us



Fiducialization seems doable





Conclusions & Outlook

- **NITEC is a Negative Ion Time Expansion Chamber with which in one year we manage to:**
  - Measure negative ion **drift velocity** in $Ar:CO_2:SF_6$ **at 370 Torr**
  - Measure **gain** in pure SF6 **up to 370 Torr**
  - Have indication of the presence **minority carriers** for fiducialization
  - Identify ~ 20 **ionization cluster/cm** in conventional electron carrier configuration (not shown due to lack of time)

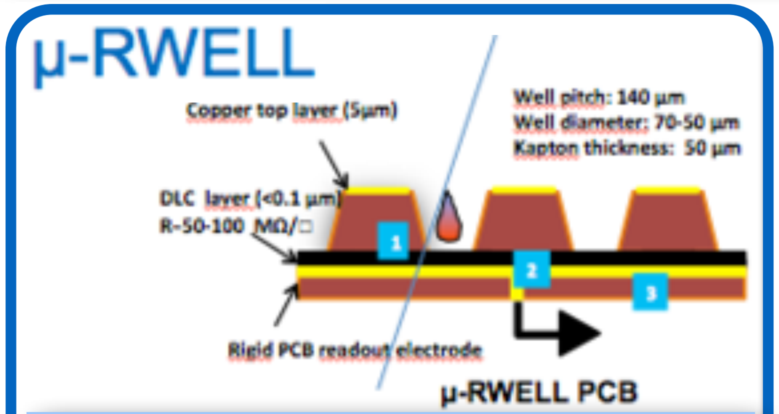
To do (on going):

- **With the small prototype:**
  - Measure gain in $Ar:CO_2:SF_6$ with ^{55}Fe radioactive source
  - Quantitative analysis of minority carriers
  - Test with alphas and neutron radioactive source
  - Improve single ionization cluster identification and measurement
- **With the large prototype (estimated by end of the year):**
  - Gain and drift velocity measurements of pure and mixtures of SF_6 at lower pressure and higher drift fields
  - Alphas and neutrons measurements (possibly at a n beam facility?)
  - Test of carbon nanotubes anysotropic response at the BTF
  - Identification of the minority carriers for fiducialization
  - Gain and drift velocity measurements of pure and mixtures of CS_2 at DRIFT colleagues lab in Sheffield University

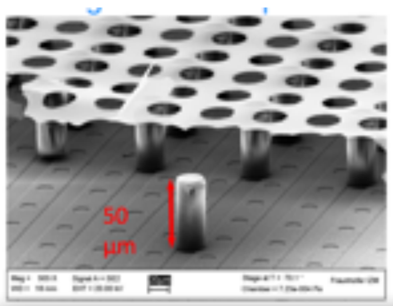
..all before the end of the Marie Curie Individual Fellowship **(4th May 2017)**

NITEC possible future: CYGNUS-RD

CYGNUS-RD: development and characterization of a Negative Ion TPC with MPGDs readouts (charge/optical)



G. Bencivenni et al., JINST 10 P0 2008



GridPix

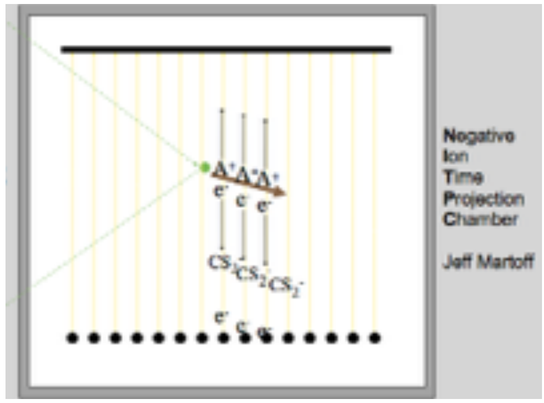
W. Koppert et al., NIM A 732, 245-249

Orange

M. Marafini et al, JINST 10 No 12 P12010

+

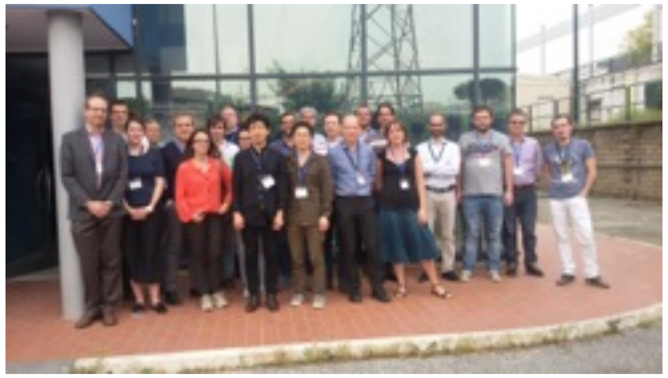
Negative Ions (SF6)



Total budget asked:
~50k EUROS / 2 years
(answer by Sep 2016)

Team ~ 3 FTE
(LNF + Roma1)

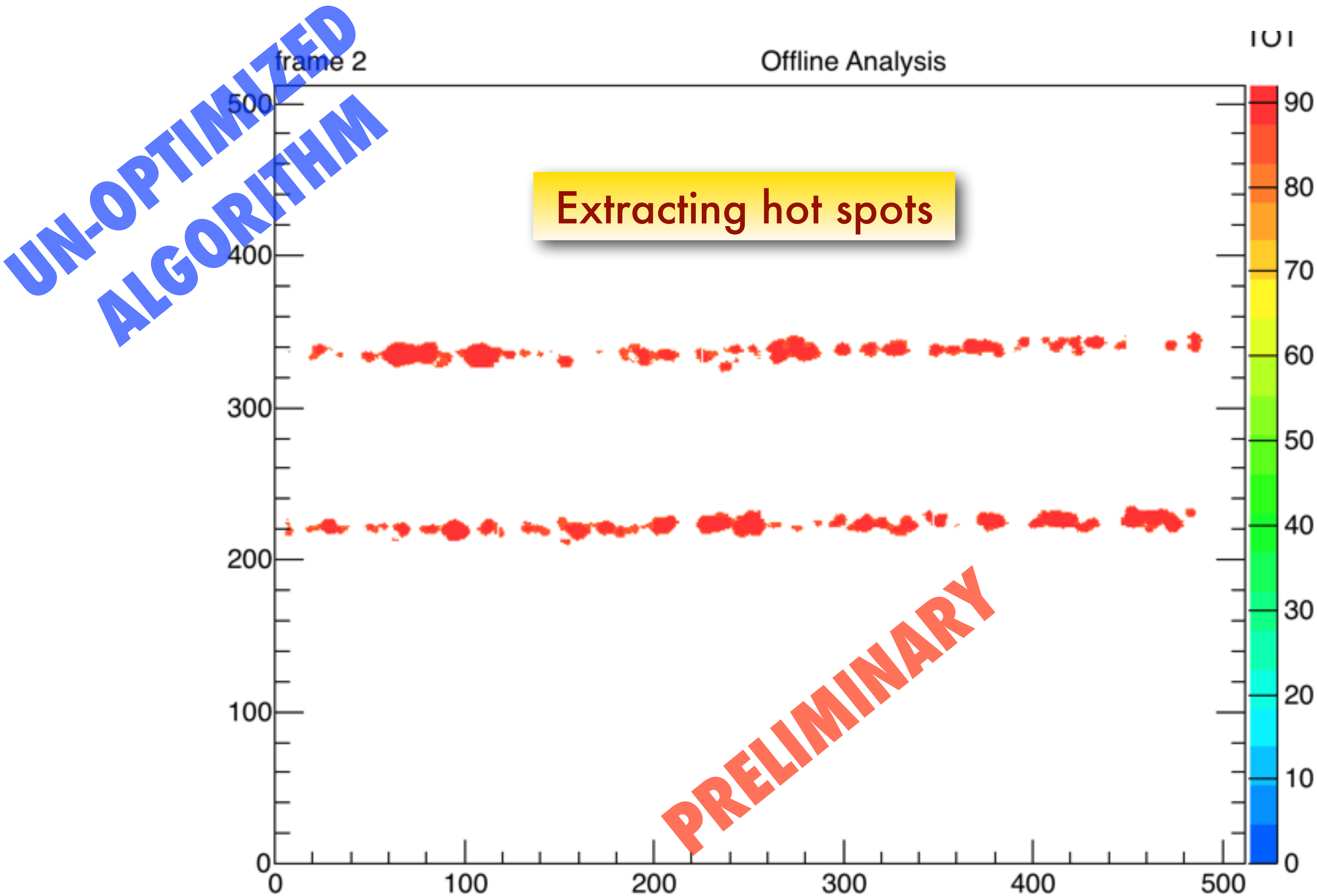
In the context of the
CYGNUS-TPC project



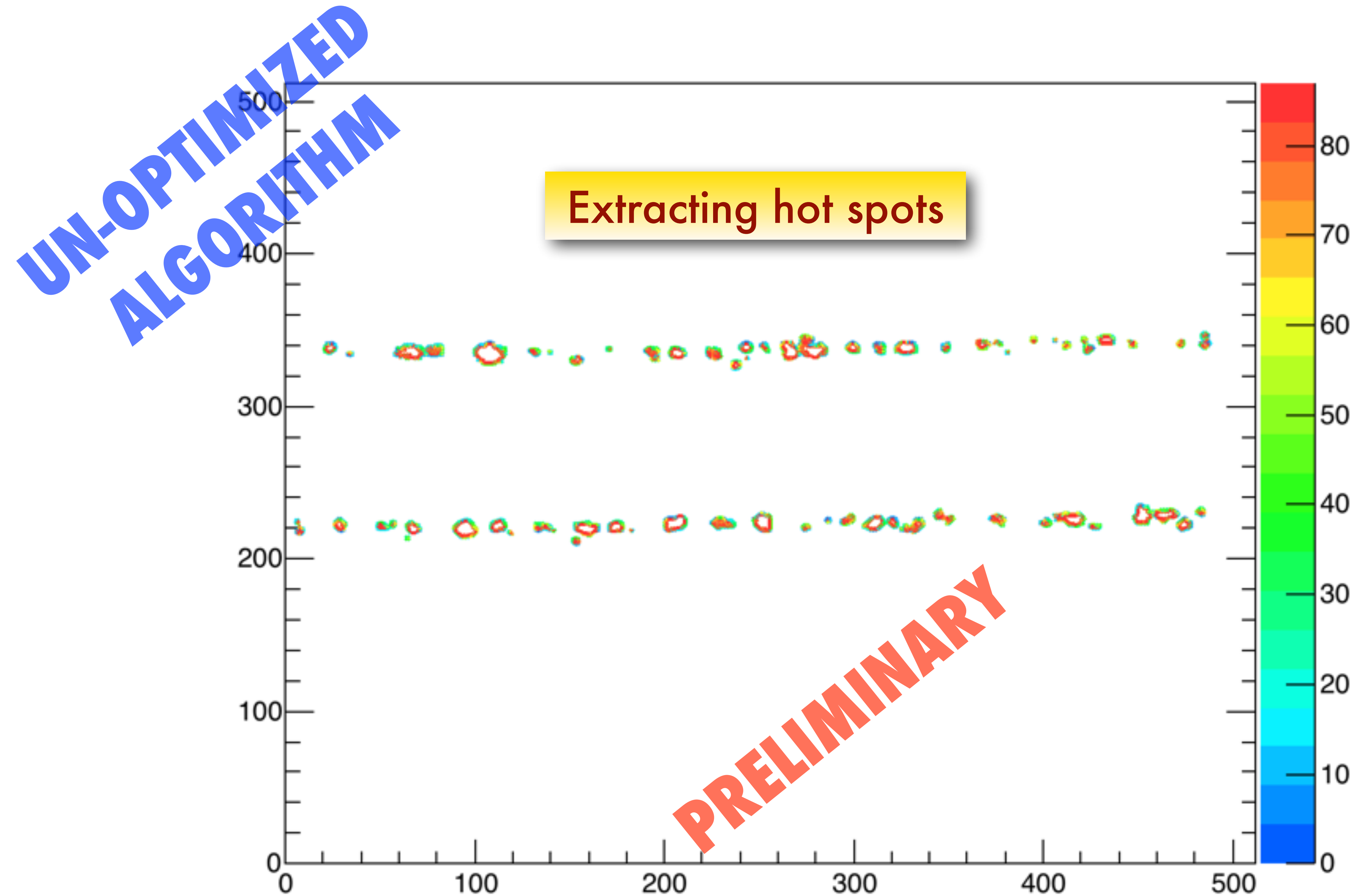
...CAVEAT me finding a position (my contract ending 05/17)

Backup

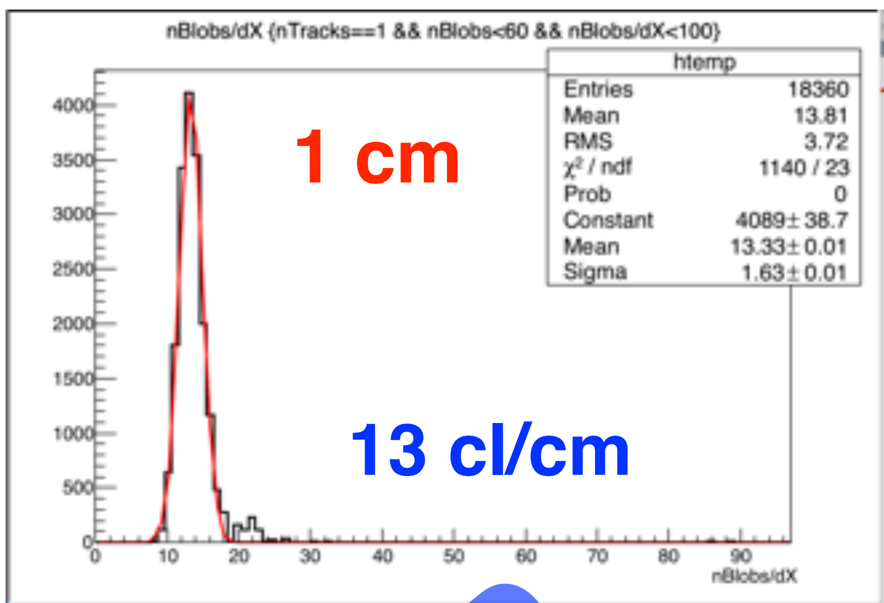
Cluster Counting with $Ar:CO_2:CF_4$

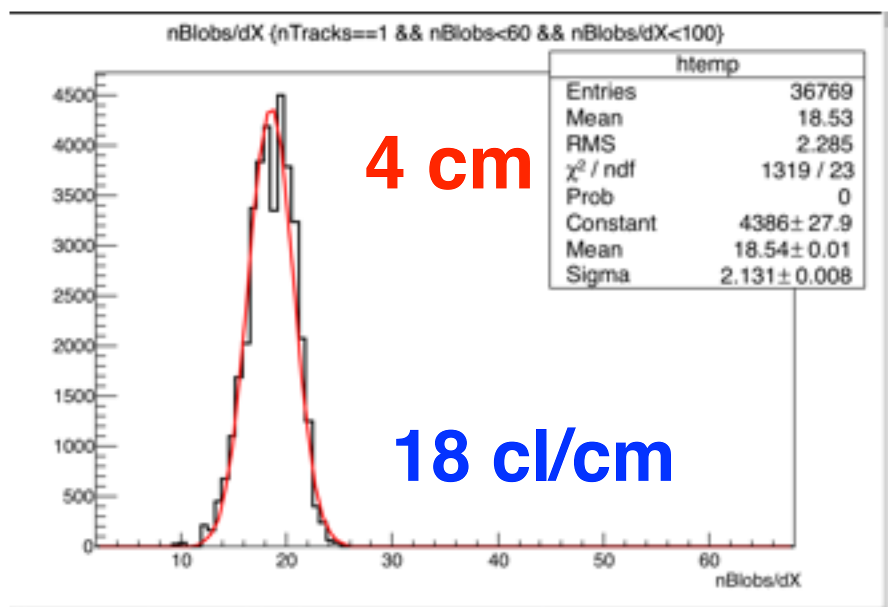


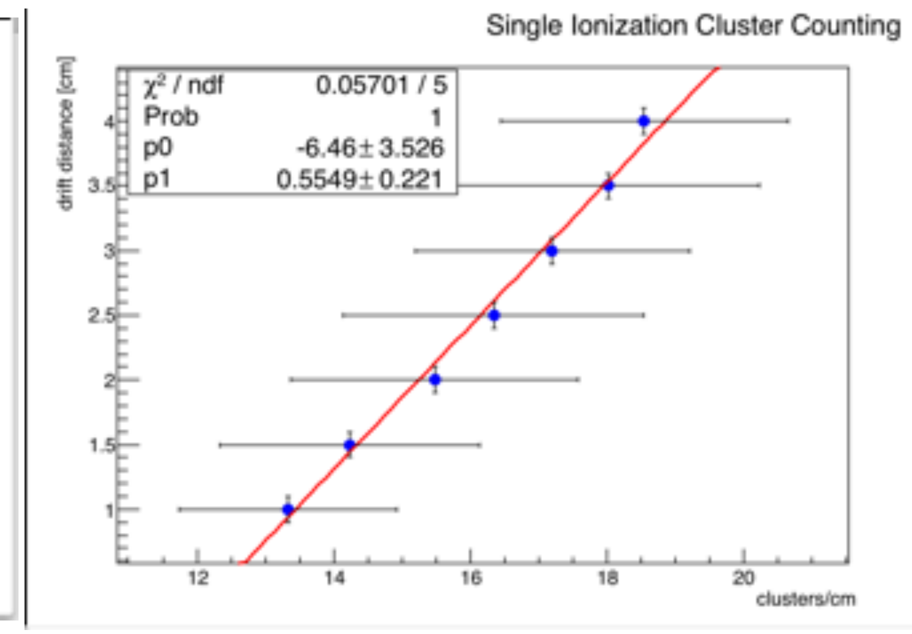
Cluster Counting with Ar:CO_2:CF_4



Cluster Counting with Ar:CO_2:CF_4

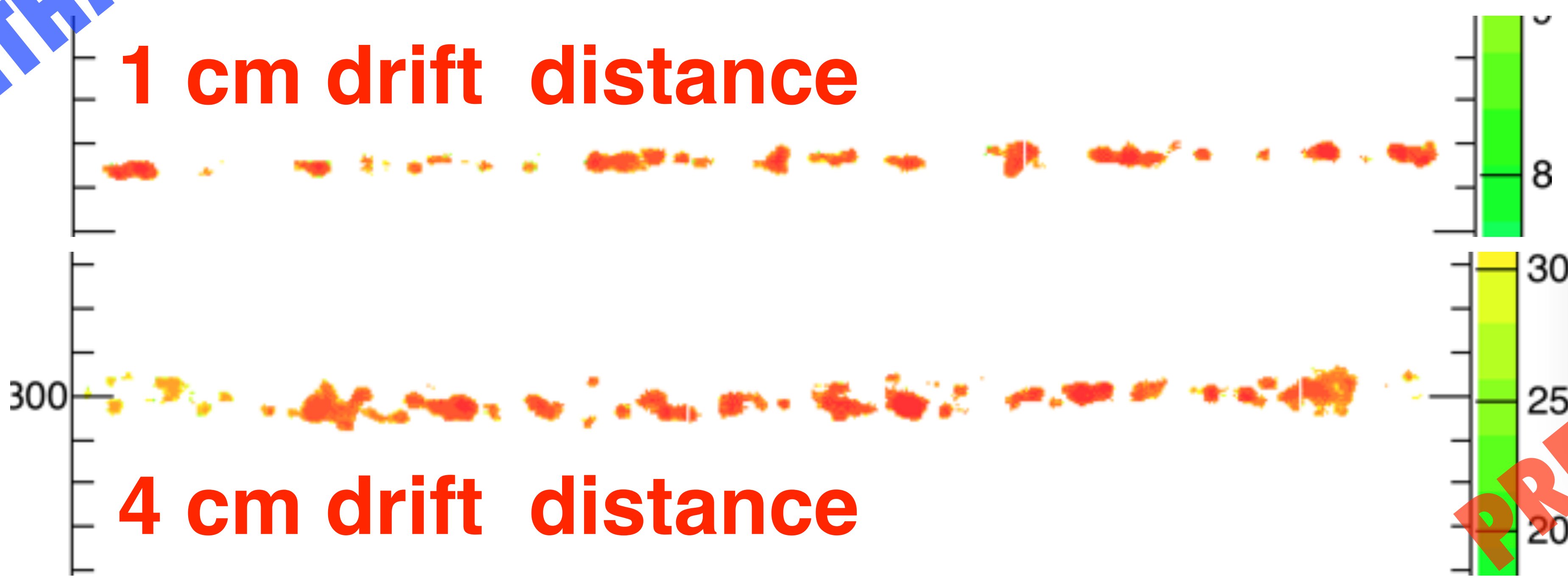






UN-OPTIMIZED ALGORITHM

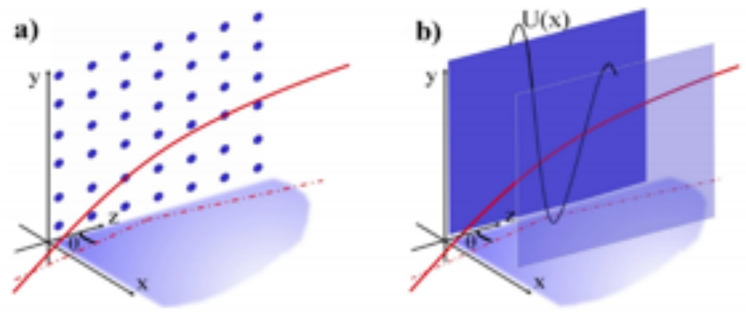
# of expected cluster/cm ~ 50



PRELIMINARY

NITEC synergy: DCANT

Channelling concept



Critical (Lindhard's) angle

$$\theta_C = \sqrt{\frac{2U_0}{E}}$$

U_0: Potential well depth

E: Particle energy

~ 8 deg for ^{6}C at 10 KeV

Detector concept

Low pressure gas (0.1 bar)

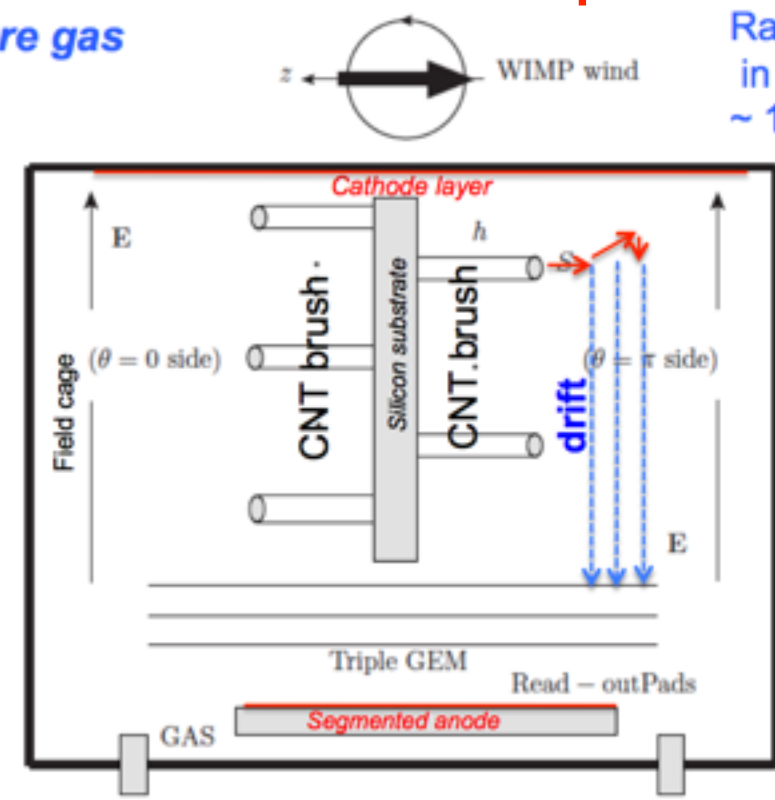
Range of 10 KeV ^{6}C in 0.1 bar Ar ~ 1mm (TRIM)

Not to scale!

h ~100 μm

S ~ $\pi(5)^2$ nm^2

Drift distance can be 10 cm

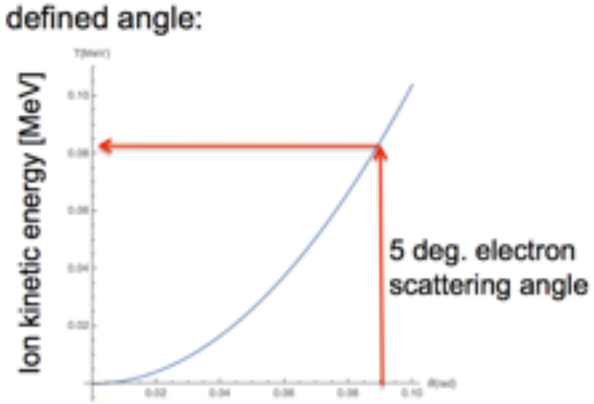


Carbon ions **ranging out** In the gas

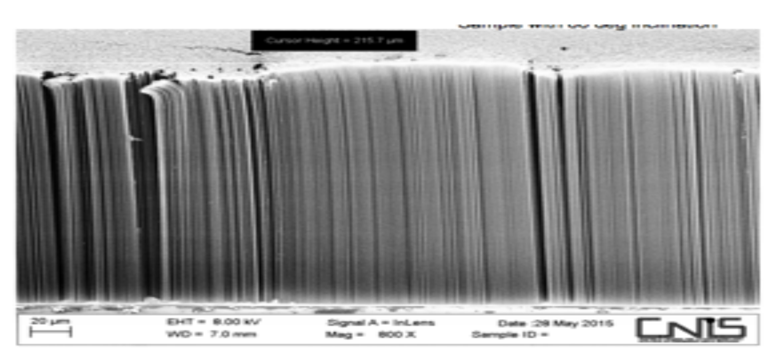
Electrons from ionized gas atom **drift** towards anode

Need to be tested:

- Use electron beam at LNF BTF to "extract" carbon ions from CNT
  - One carbon ion elastically scattered by a 500 MeV electron
    - PRO: trigger on scattered electron at well defined angle: beam clearly visible
    - CON: electron beam can induce a sizeable background into TPC



Could allow an integrated gas + solid DM target experiment WITH DIRECTIONAL SENSITIVITY



- About 10^{16} 1nm diameter SWCNT can fit on a 10x10 cm^2 substrate
- Surface density of a graphene layer: 1/1315 g/m^2
- About 2 g CNT on 100cm^2
  - ***CNT ropes?***

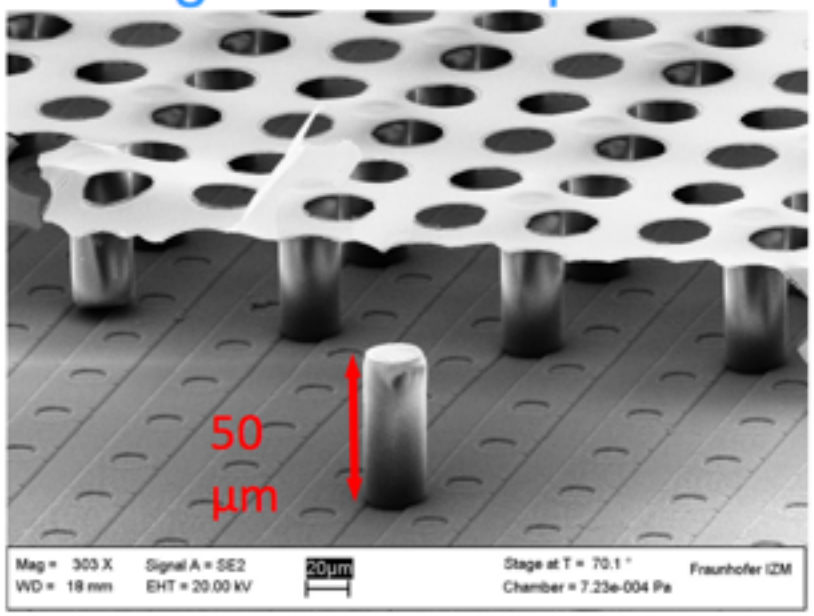
Developed an active and fruitful collaboration with DCANT group @ Roma1

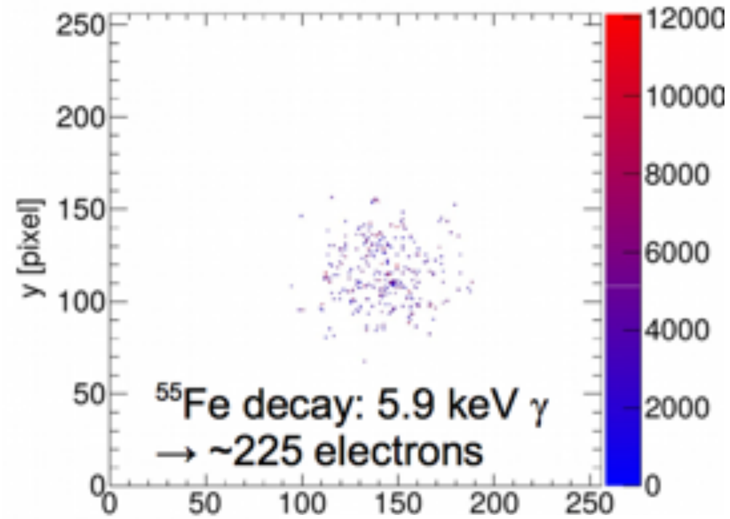
GridPix

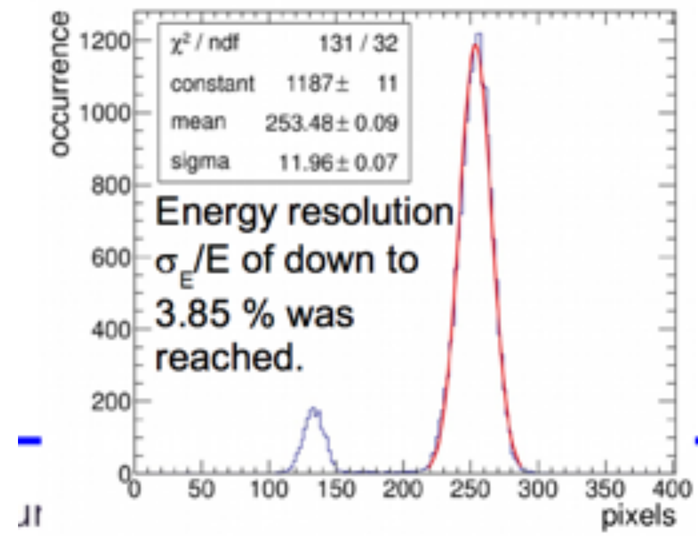
Standard charge collection:

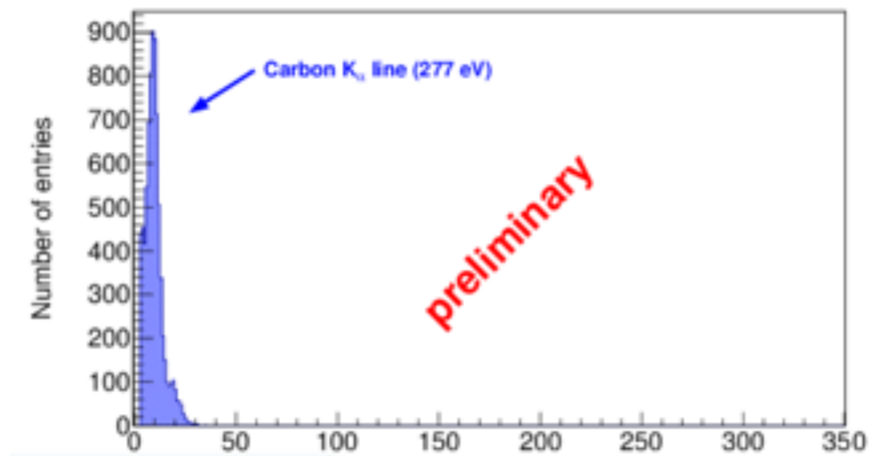
- Pads of several mm²
- Long strips (l~10 cm, pitch ~200 µm)

Instead: Bump bond pads are used as charge collection pads.



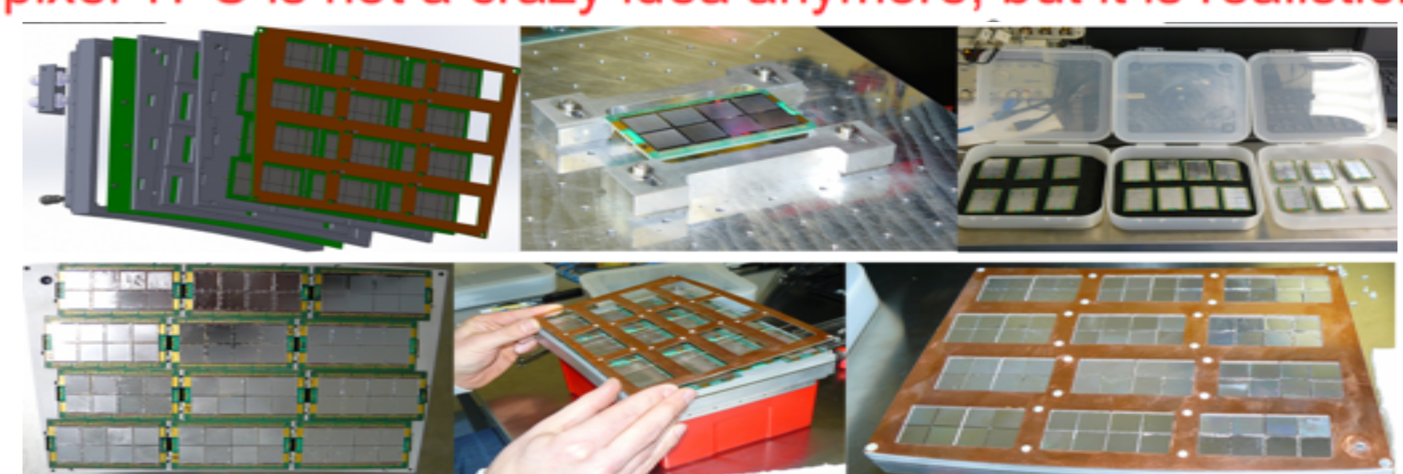






160 GridPix with an active area of 320 cm^2

pixel TPC is not a crazy idea anymore, but it is realistic.



NITEC in the context of CYGNUS-TPC

- NITEC is part of the directional DM community working for the formation of a new international collaboration for the development of a multi-ton directional DM experiment
  - CYGNUS-TPC kick-off meeting organized at LNF in April 2016
  - CYGNUS-TPC officially recognized in WhatNext white paper
  - Managed to gathered the interest of part of the italian neutrino community
- NITEC SF_6 studies and measurement will be fundamental for the development of CYGNUS-TPC proposal and CDR

TimePix vs Timepix3

	Timepix (2006)	Timepix3 (2013)
Pixel arrangement	256 x 256	
Pixel size	55 x 55 μm^2	
Technology	250nm CMOS - 6Metals	130nm CMOS - 8Metals
Acquisition modes	1) Charge (iTOT) 2) Time (TOA) 3) Event counting (PC)	1) Time (TOA) AND Charge (TOT) 2) Time (TOA) 3) Event counting (PC) AND integral charge (iTOT)
Readout Type	1) Full-Frame	1) Data driven (DD) 2) Frame (FB)
Zero suppressed readout	NO	YES
Dead time per pixel	> 300µs readout time of one frame	> 475ns ~600x Pulse measurement time + packet transfer time
Minimum timing resolution	10ns	1.562ns 6.4x
On-chip Power pulsing (PP)	NO	YES
Minimum detectable charge	~750e-	>500e- 1.5x
Output bandwidth	1 LVDS ≤200Mbps 32 CMOS ≤3.2Gbps	1 to 8 SLVS @640Mbps DDR ≤5.2Gbps 1.6x