Part of 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

CAASTRO-CoEPP Joint Workshop

University of Melbourne, Australia

TPC GEMs R&D for directional DM search

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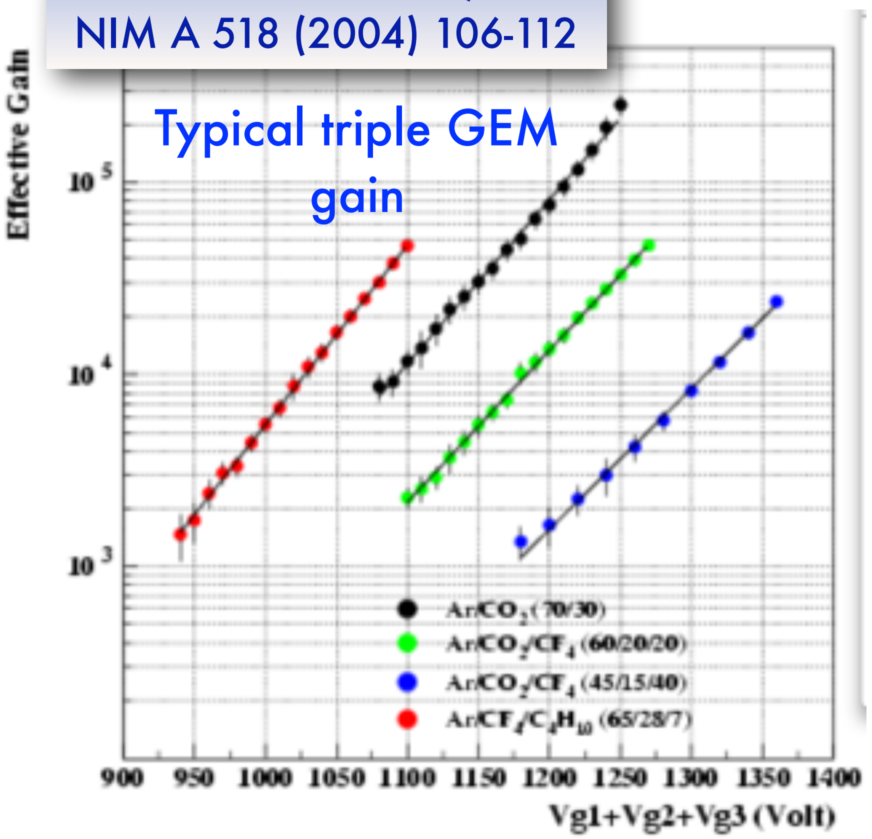
Projects & Concepts

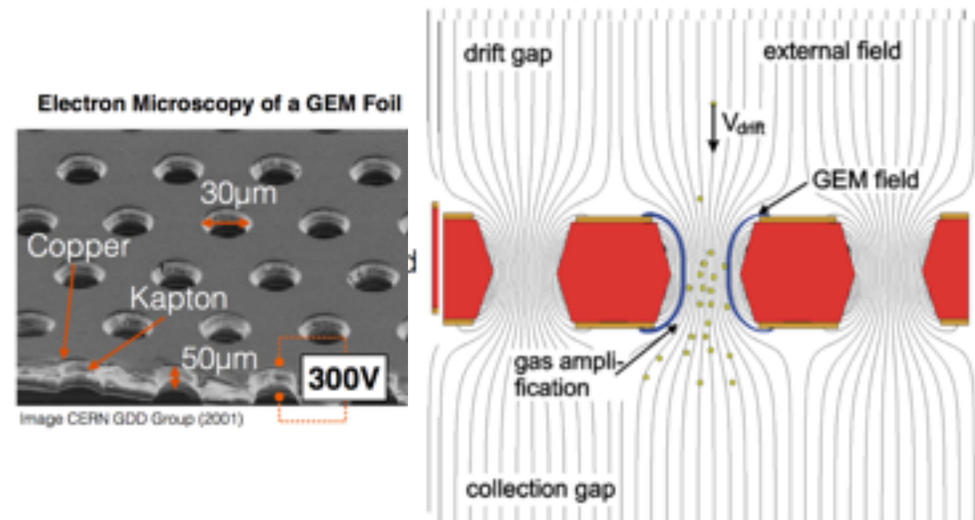
- **NITEC** EU HORIZON 2020 May 2015- May 2017
  - Triple thin GEM amplification (3 x 3 cm^2) + pixel charge/time readout
- **DCANT** INFN CSN5 2014-2016
  - Carbon nanotubes with anisotropic directional response
- **CYGNUS-RD** INFN CSN5 2017-2018
  - Triple thin GEM amplification (10 x 10 cm^2) + CMOS optical readout

Thin GEM Amplification

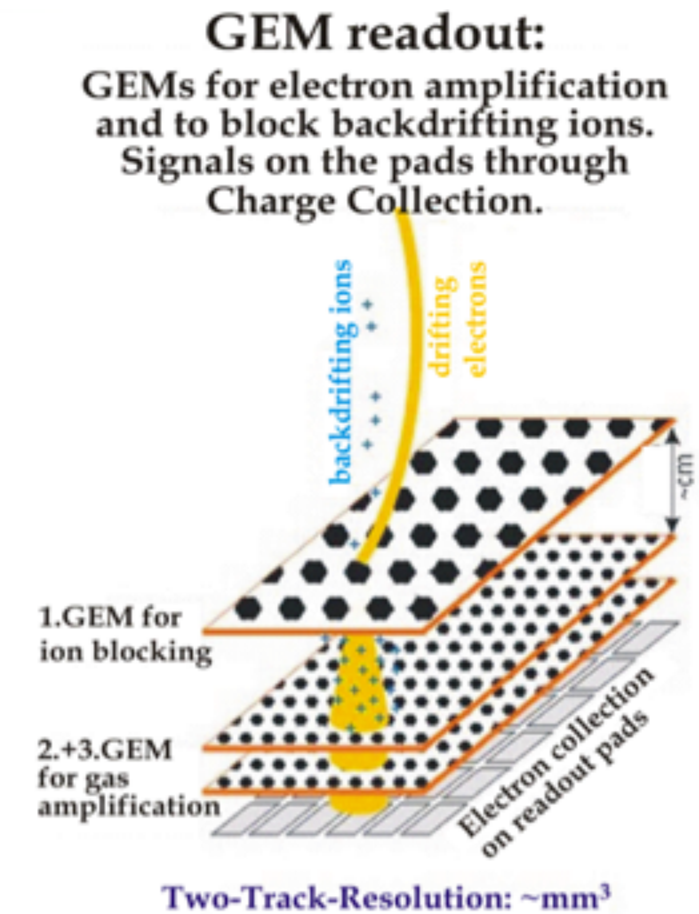
M. Alfonsi et al.,
NIM A 518 (2004) 106-112

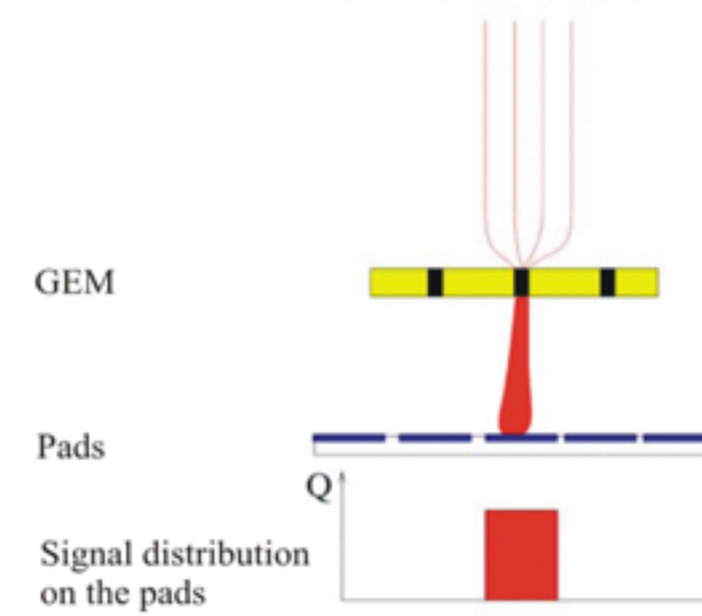


- Particle conversion, charge amplification and signal induction zones are physically separated
- Large dynamic range: from 1 to 10^8 particle/cm^2 /s
- <u>Gain up to > 10^4</u>
- <u>High stability/granularity</u>



- 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

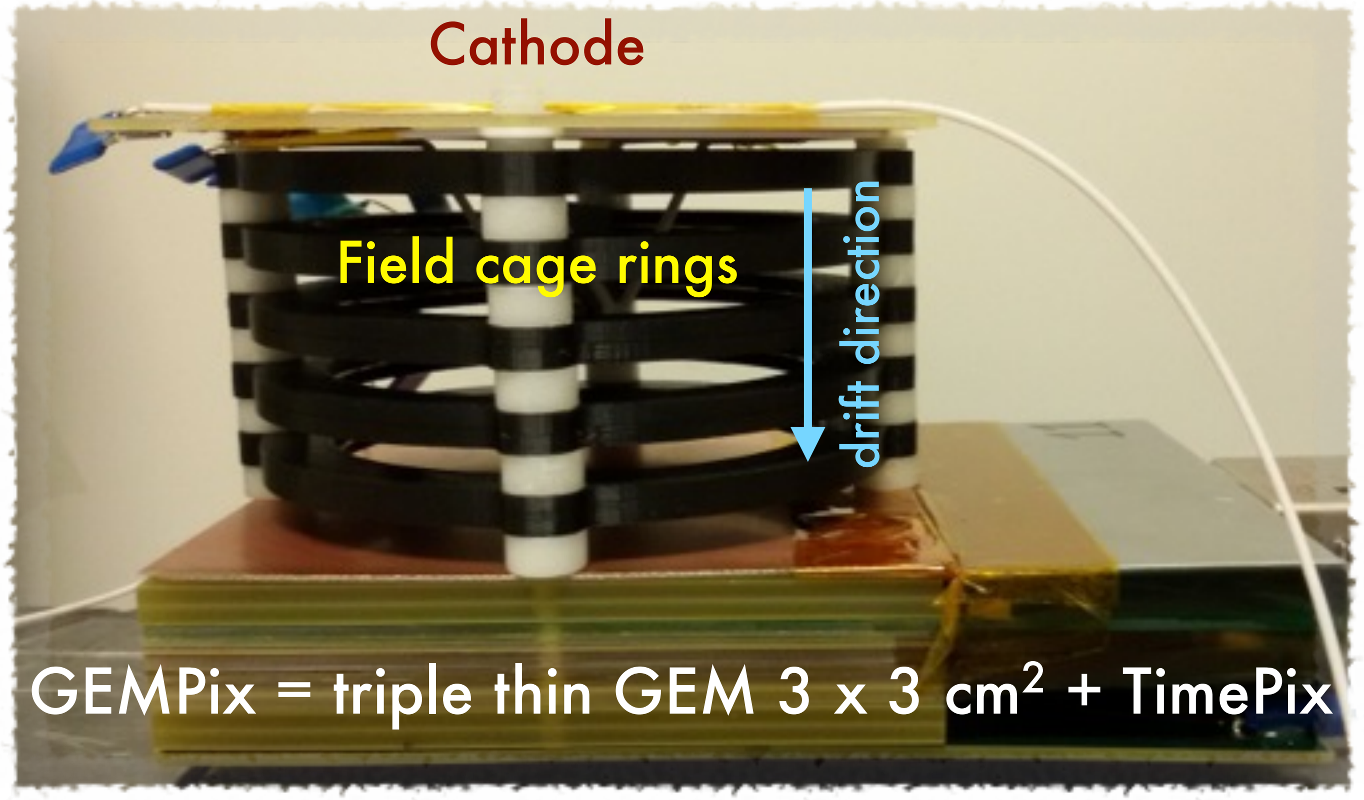


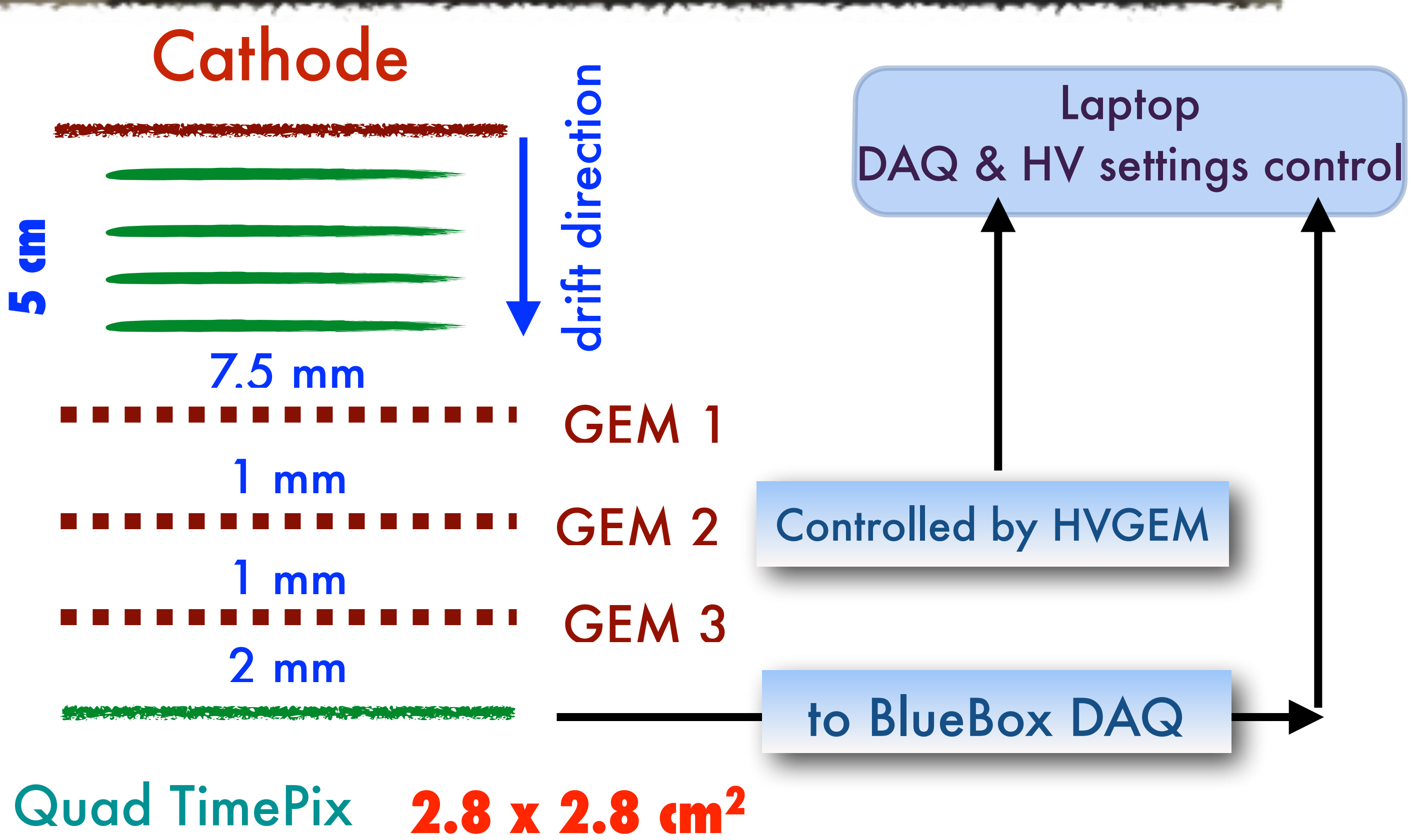


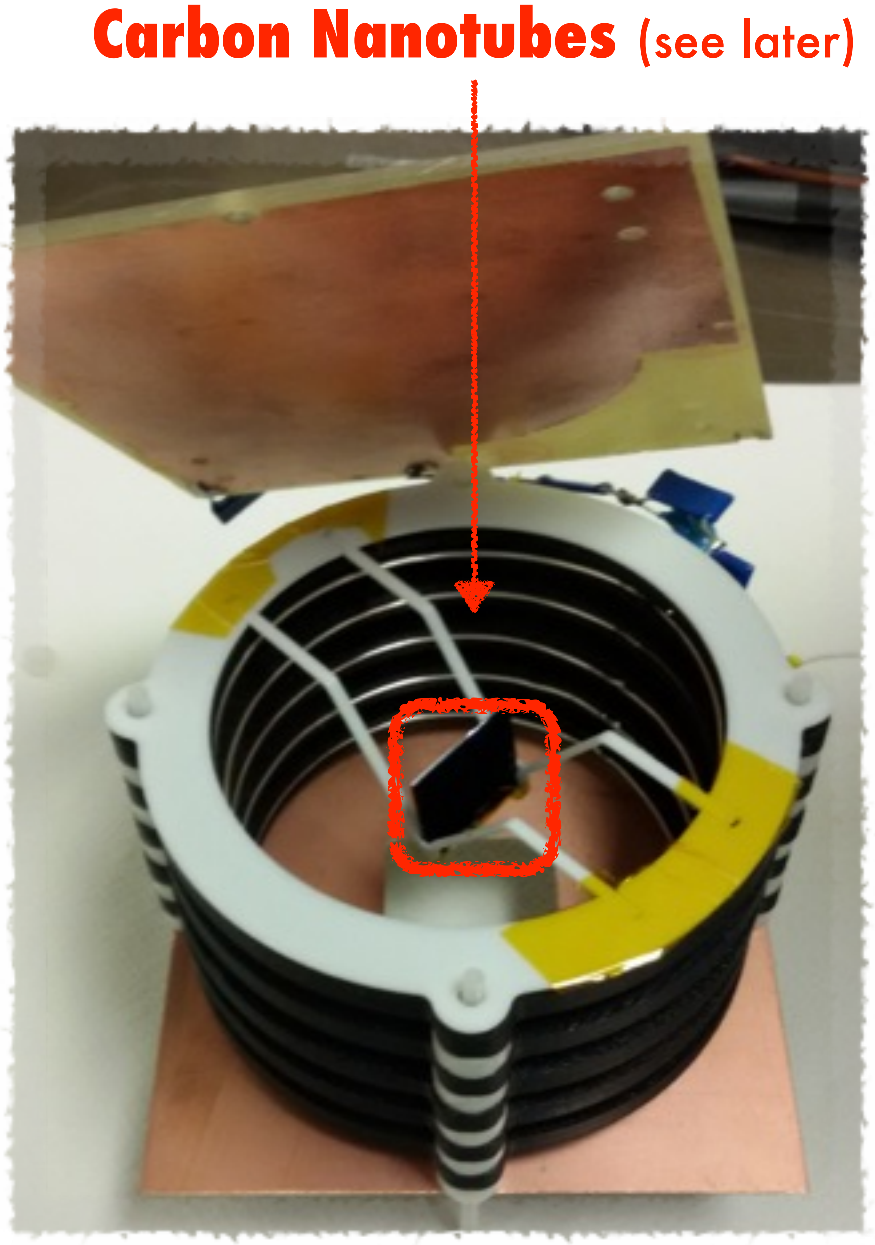
NITEC

a Negative Ion Time Expansion Chamber for directional Dark Matter searches

NITEC detector





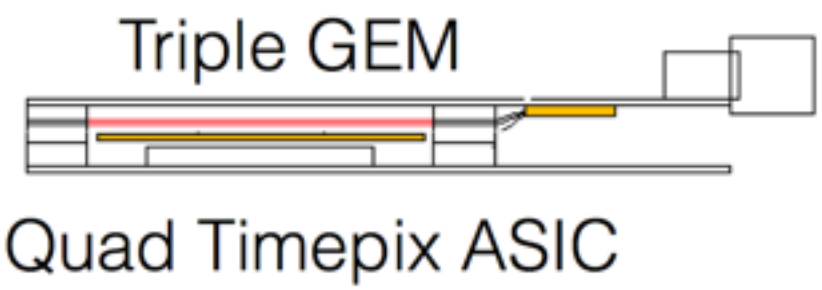


New field cage: rings support structure (in black in the picture) manufactured with 3D printer

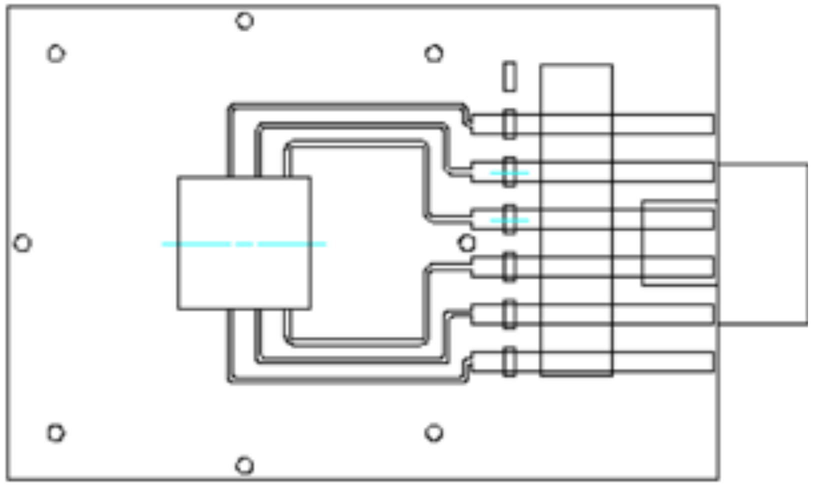
GEMPix

Developed by LNF in collaboration with CERN

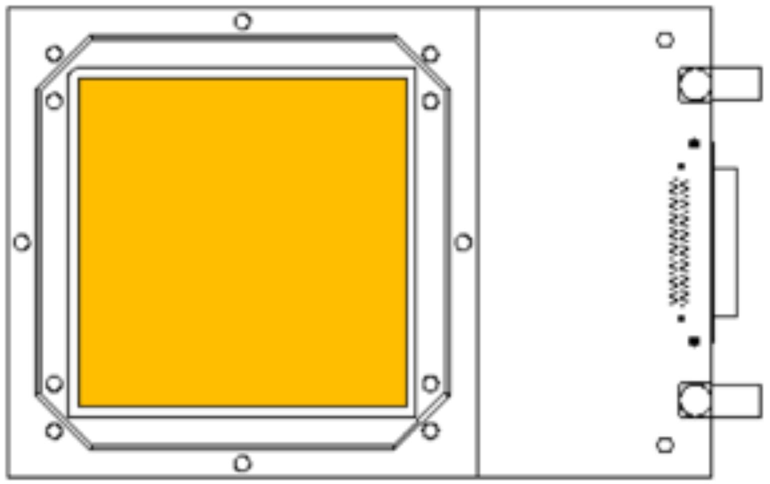
Triple GEM detector with HV filters and connector



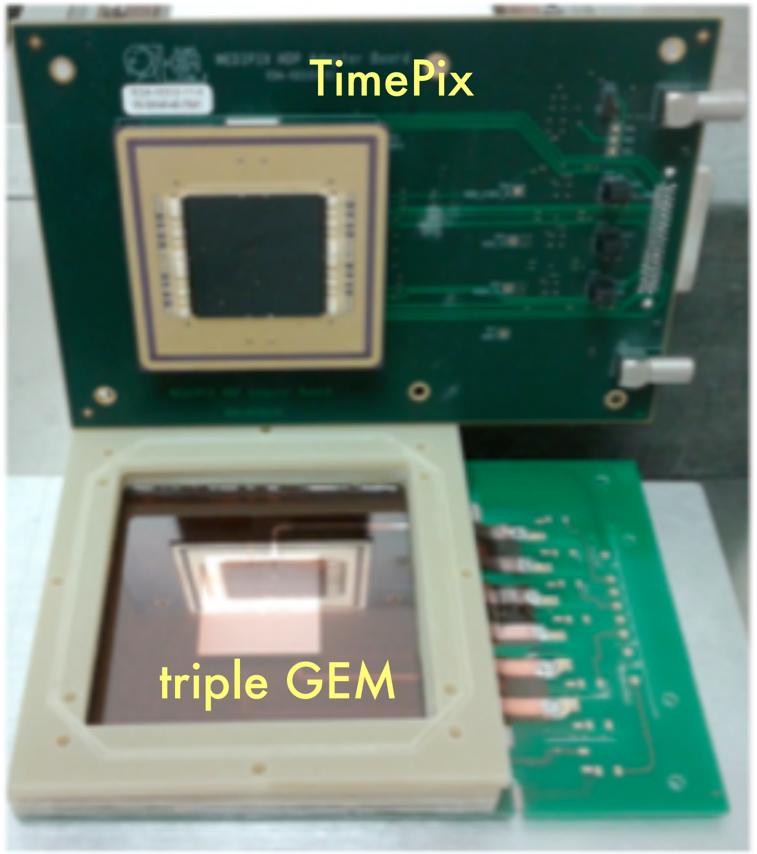
Quad Timepix ASIC board with naked devices (i.e. no silicon)



top view



side view



A dedicated, very stable GEM HV up to <u>700 V per GEM fully developed at LNF</u>

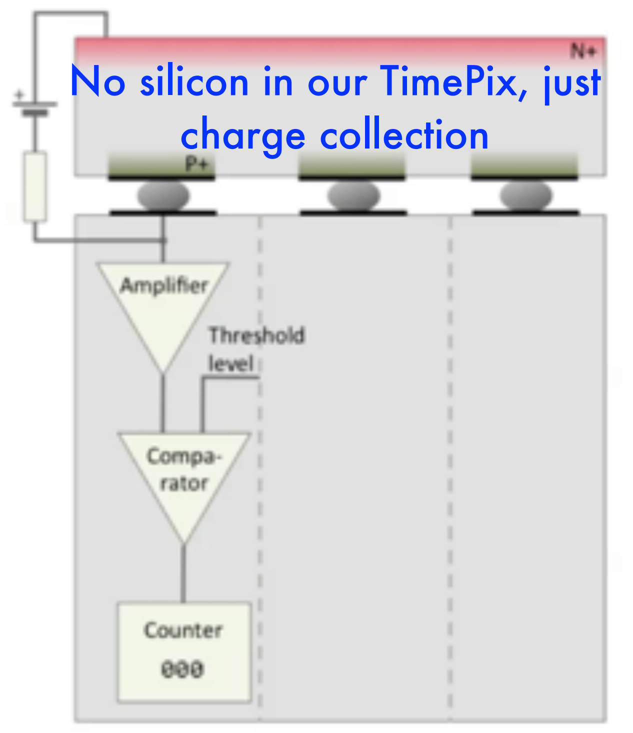
pixel size 55 x 55 um

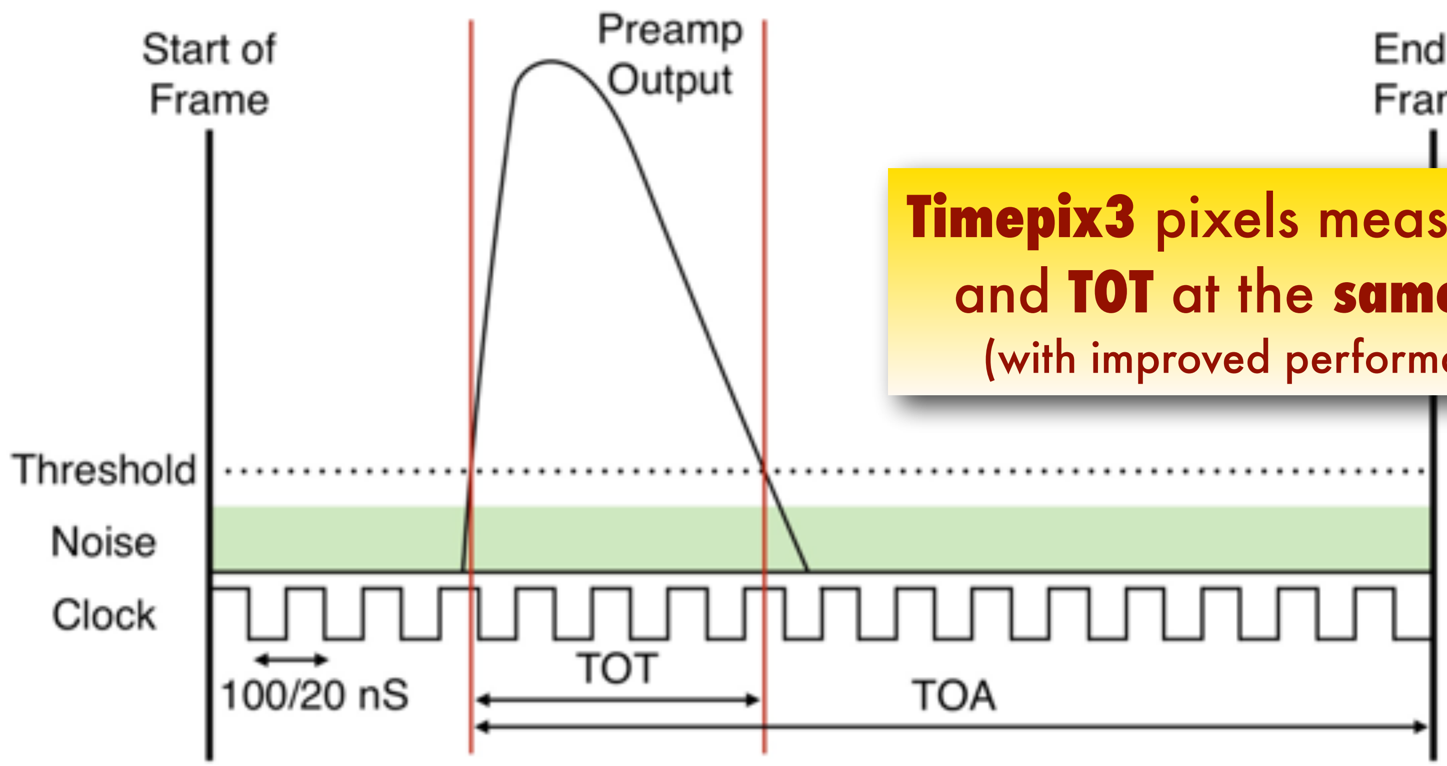
Quad Timepix (512 x 512 pixels) = 4 Timepix chips

2.8 x 2.8 cm^2

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, **SUITED FOR BOTH ELECTRONS and NEGATIVE IONS DRIFT**

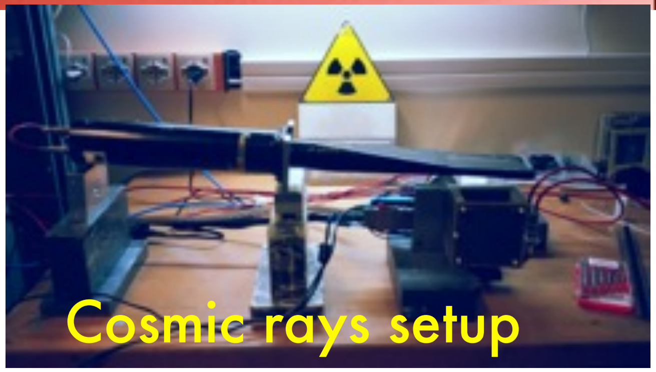
NITEC activities 2015-2016

- Characterization of old 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

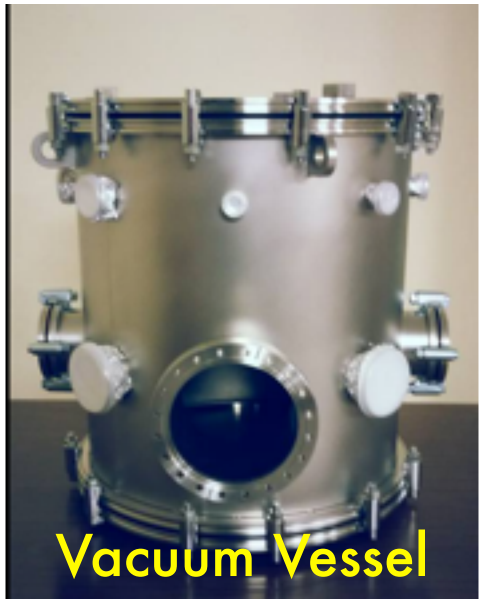
Jul-Sep 2015

Oct 2015/Apr 2016



- Design and procurement of vacuum vessel to operate below atmospheric pressure, design of new field cage

Nov 2015 - Apr 2016



- Old prototype tests with SF_6 negative ion mixtures
  - pure SF_6, $Ar:CO_2:SF_6$ (high pressure)

May 2016

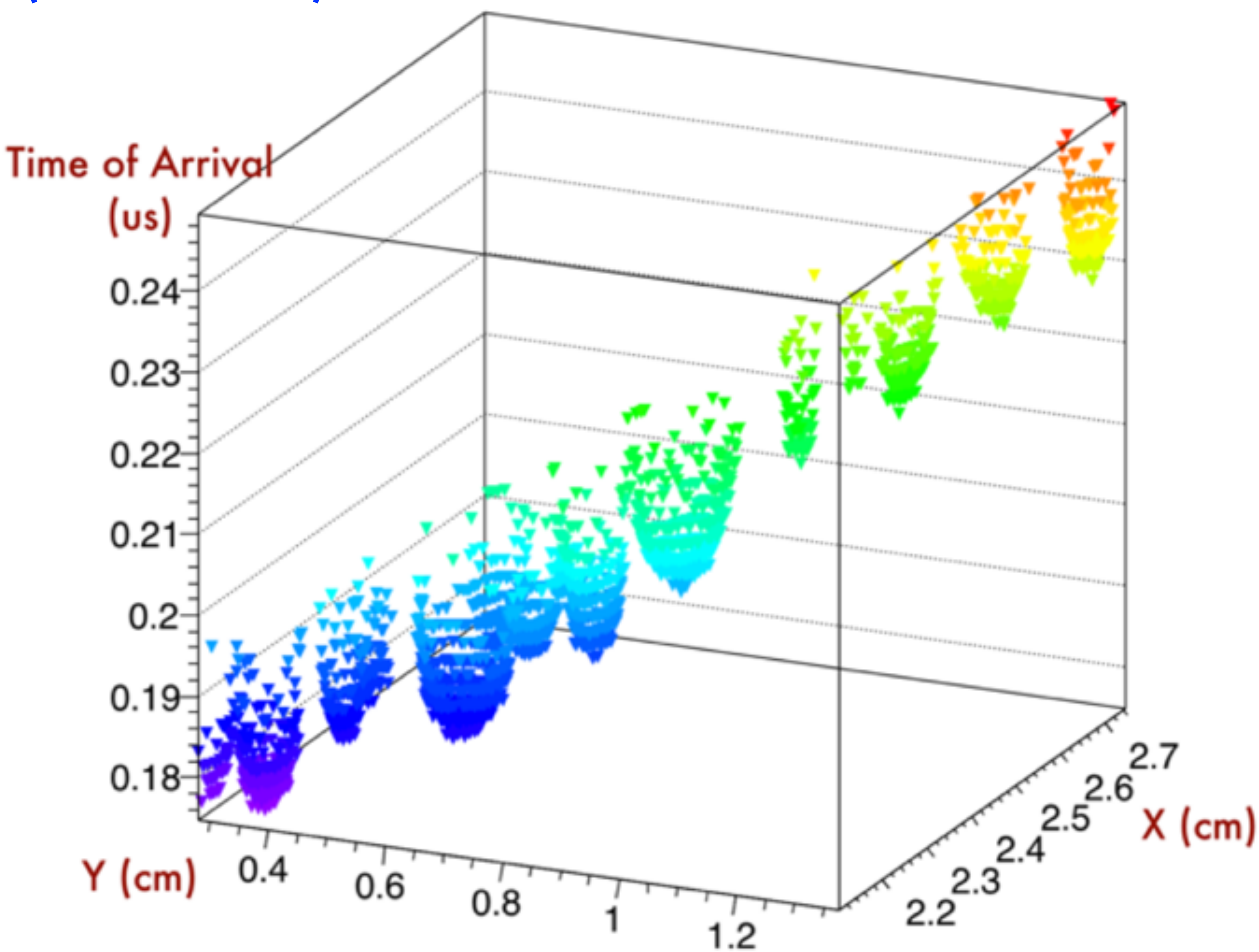
- New prototype tests with SF_6 negative ion mixtures
  - pure SF_6, $He:CF_4:SF_6$ (low pressure)

Dec 2016

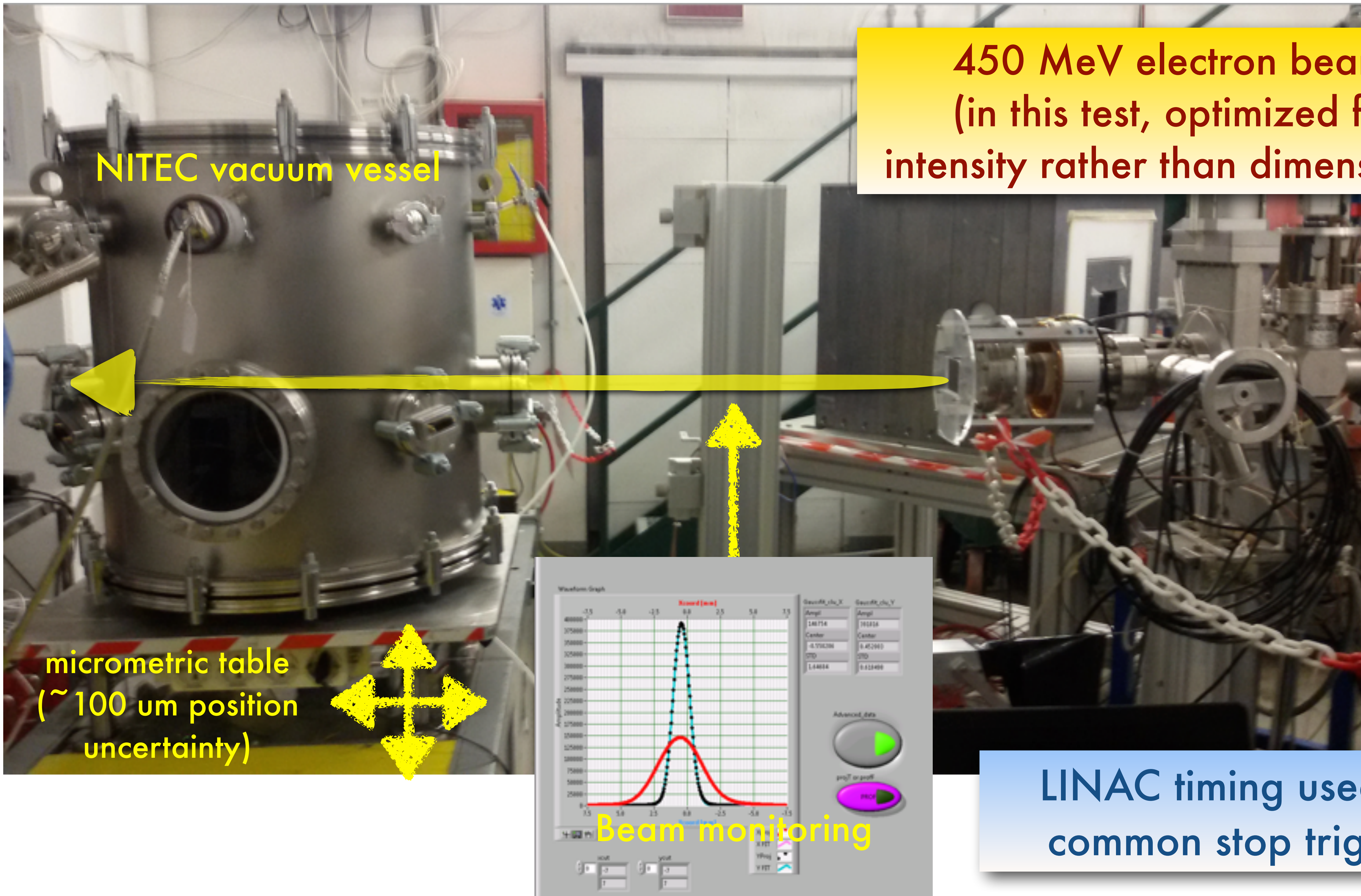
Data analysis still on going

A NITEC event

A cosmic ray recorded track in Ar:CO_2
(electron drift)



Measurement @ Beam Test Facility



450 MeV electron beam
(in this test, optimized for
intensity rather than dimensions)

LINAC timing used as
common stop trigger

Time measurements (TOA)

Apr 2016

- $Ar:CO_2:SF_6$ 192:85:93 Torr

  GEM gain 1480 V

- Pure SF_6 at 75 Torr, 100 Torr, 150 Torr

  GEM gain 1140 V 1240 V 1440 V

Dec 2016

- $He:CF_4:SF_6$ 60:40:120 Torr, 360:240:10 Torr

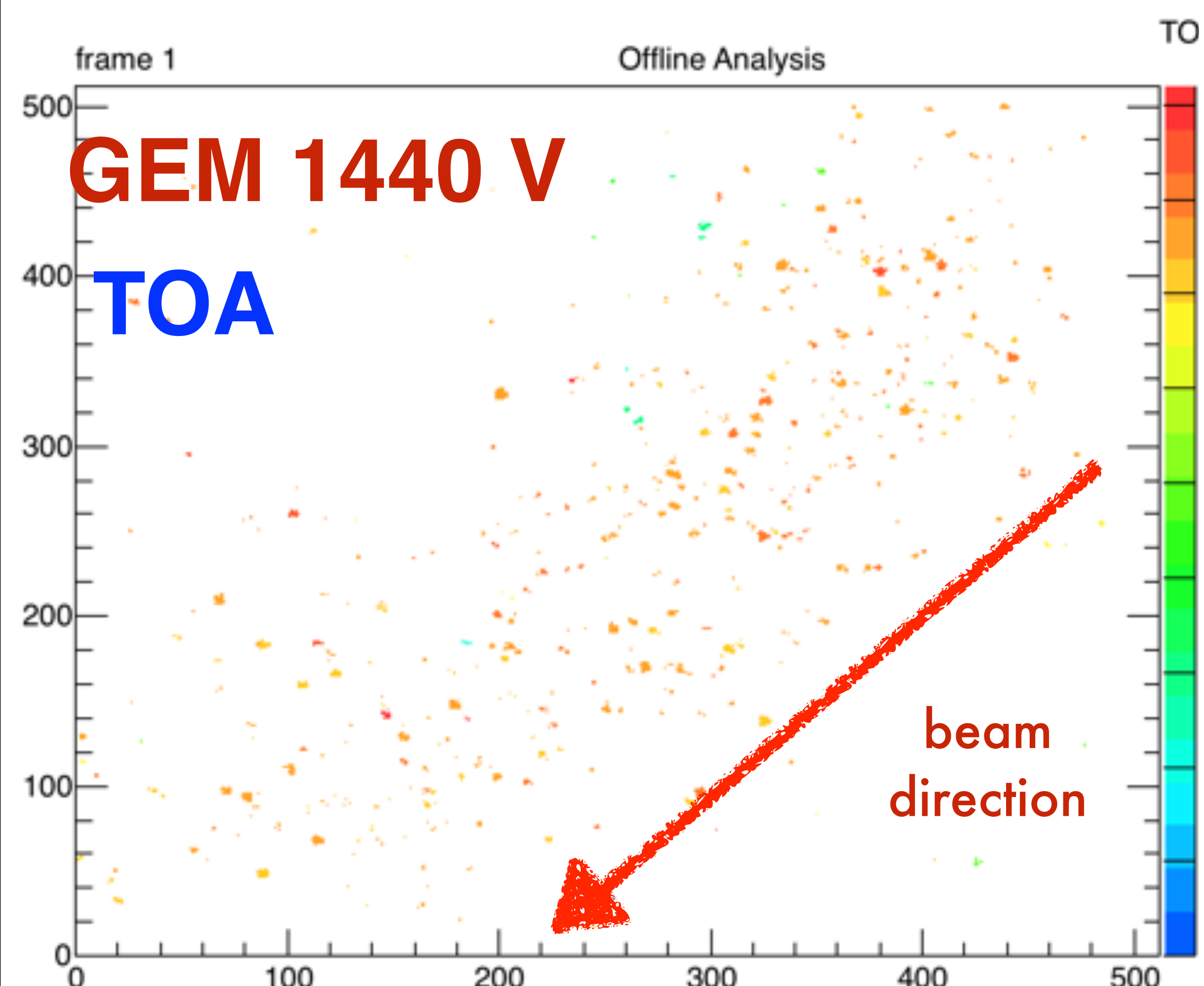
  GEM gain 1460 V 1640 V

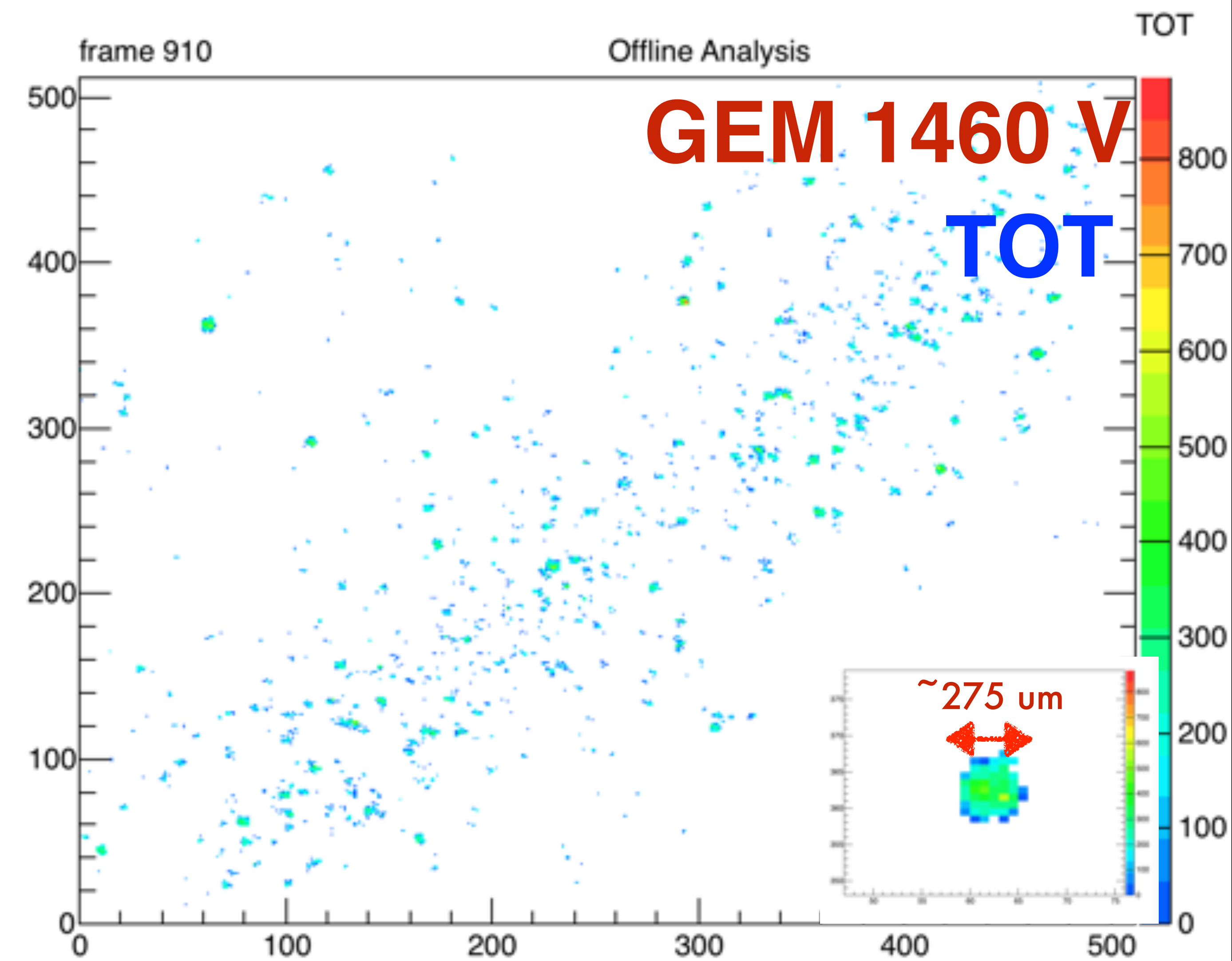
We measured the Time Of Arrival for 5 different drift distances @ 250, 530, 640, 750 and 860 V/cm for each configuration

(less points in Apr 2016 data)

SF$_6$ @ 150 Torr

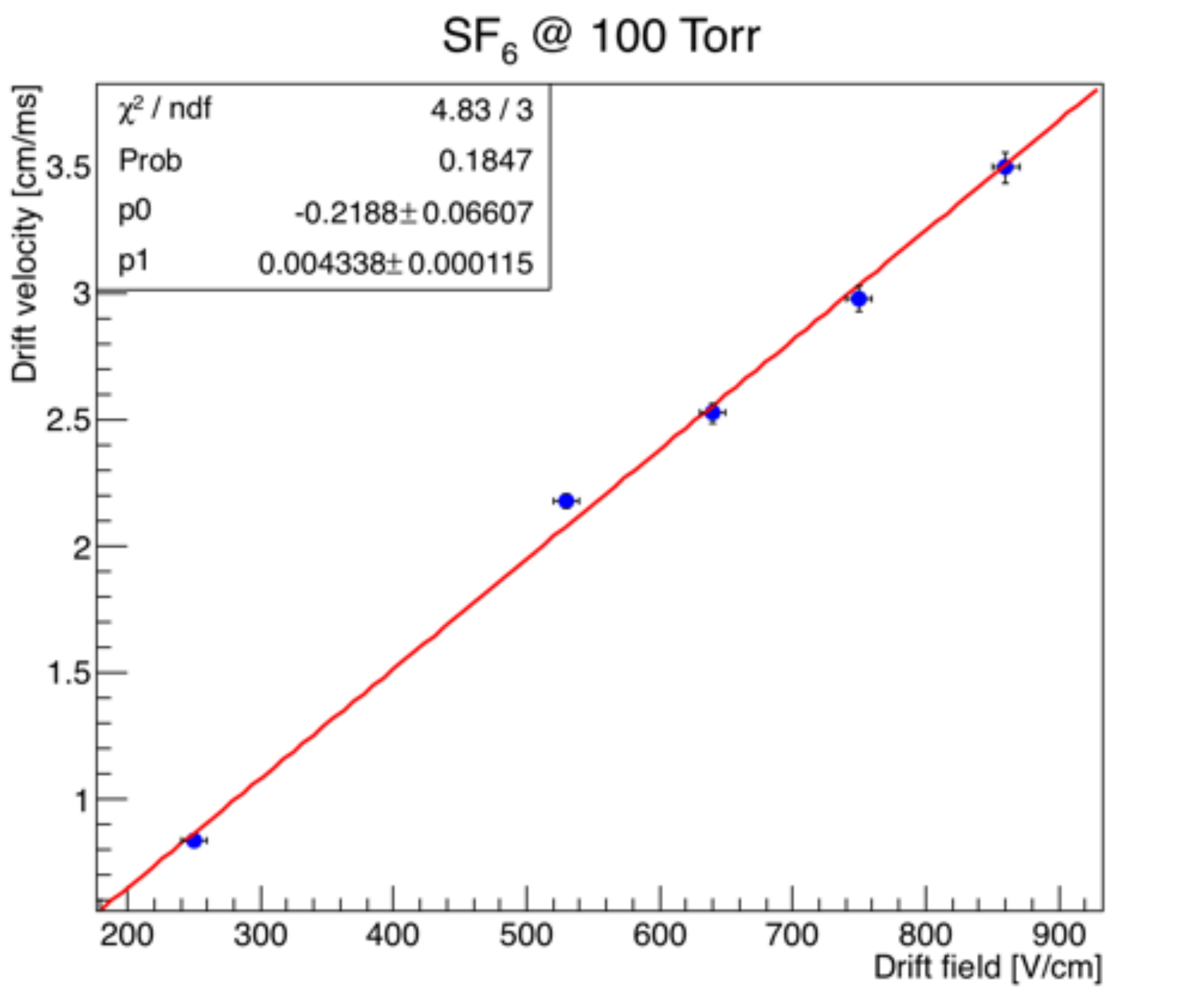
Dec 2016





Global quantities analysis shown in this talk. On going work on single track analysis.

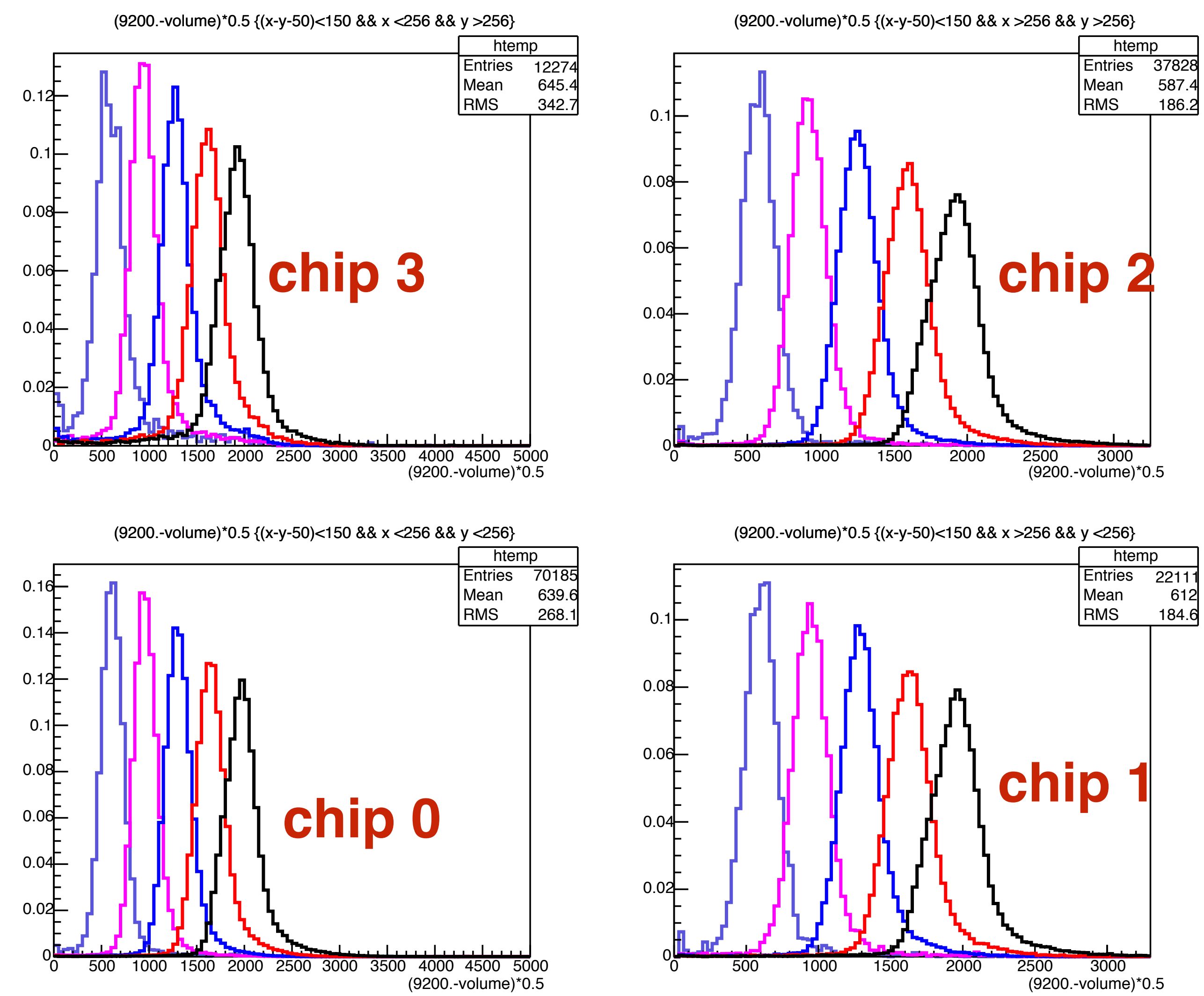
SF_6 @ 100 Torr TOA analysis



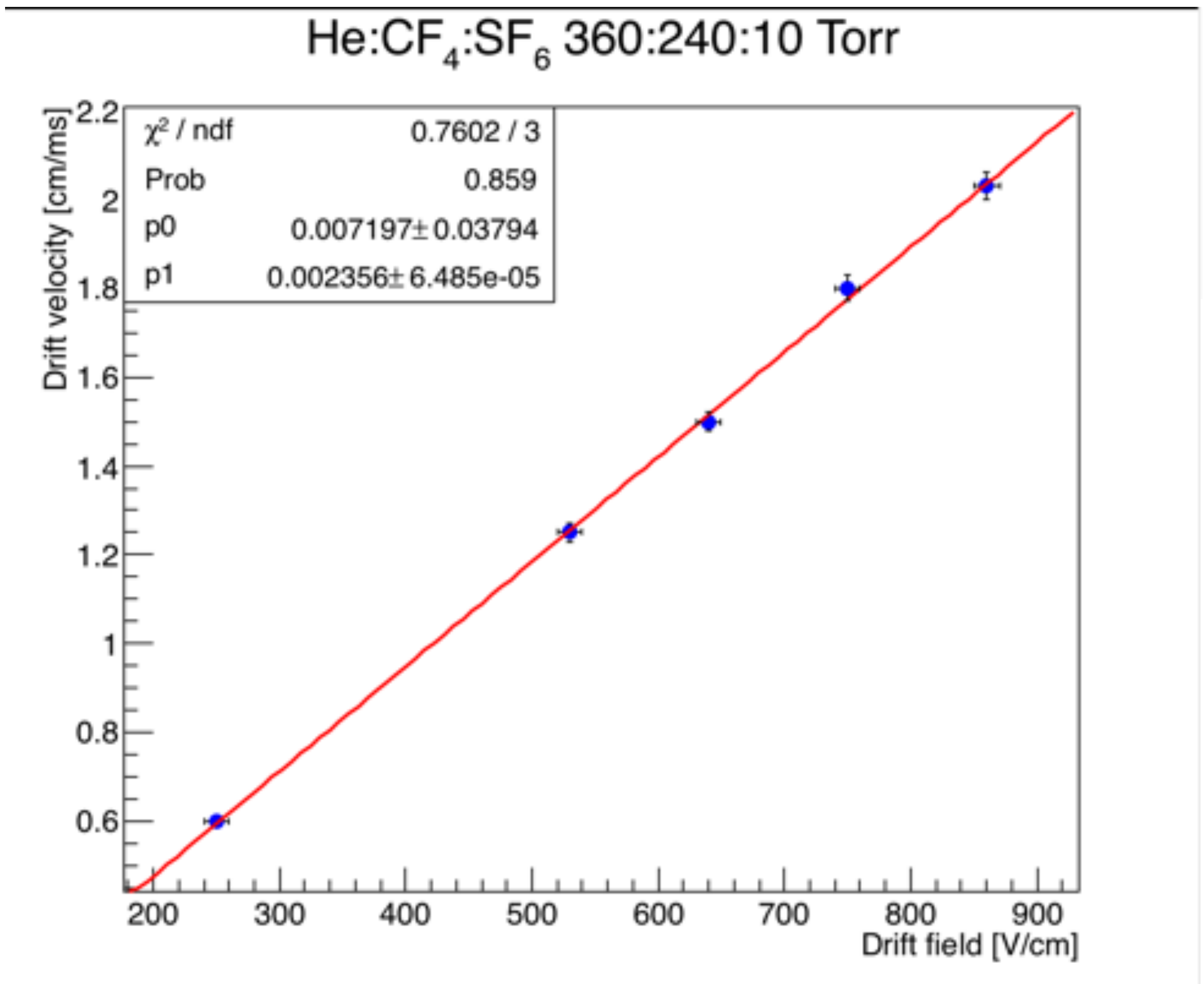
750 V/cm

```
vdrift chip 0 is 0.00295763 +/- 9.35414e-05
vdrift chip 1 is 0.00296488 +/- 9.37884e-05
vdrift chip 2 is 0.00299155 +/- 9.46174e-05
vdrift chip 3 is 0.00299736 +/- 9.48585e-05
```

Drift times



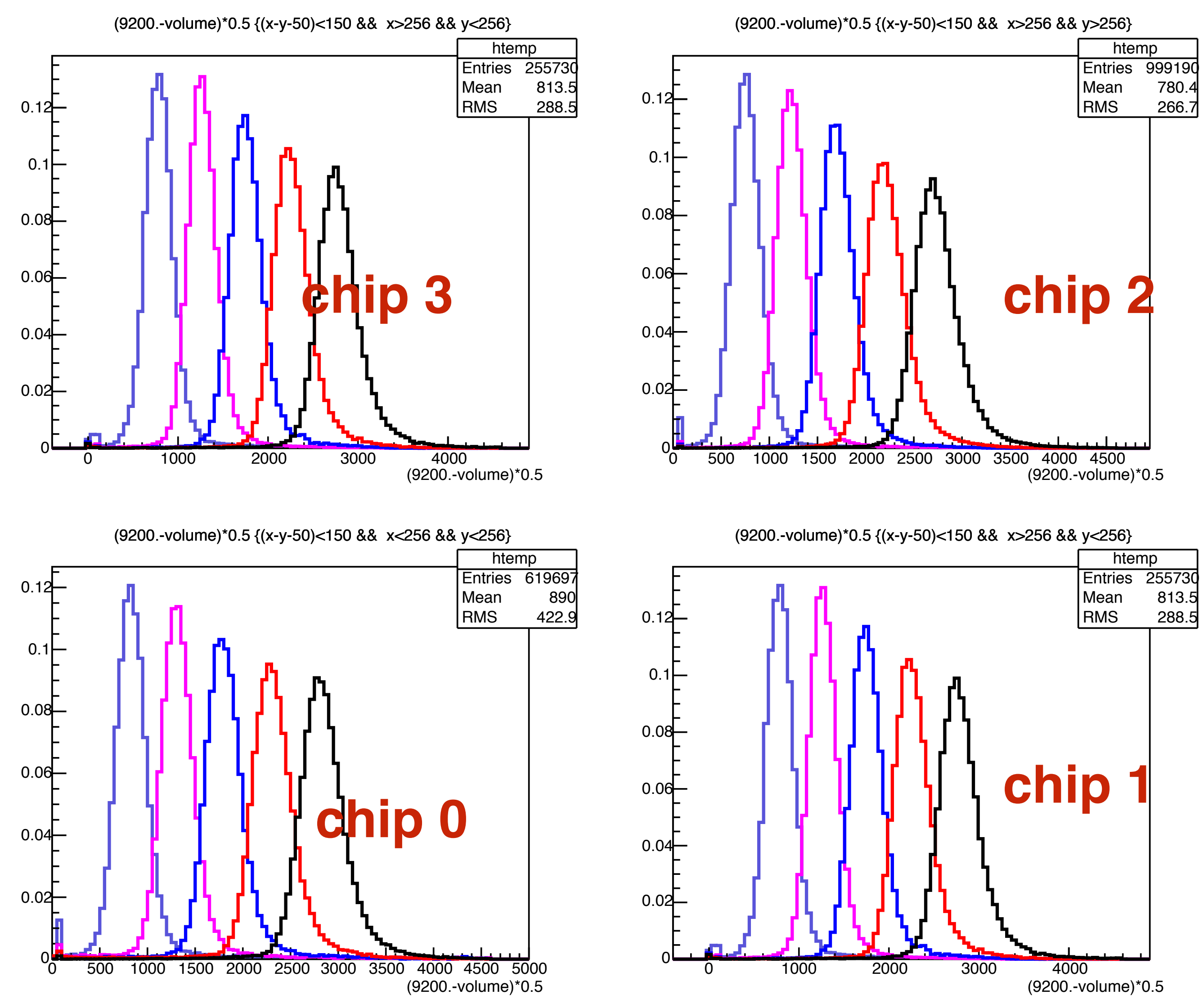
He:CF_4:SF_6 360:240:10 Torr TOA analysis



860 V/cm

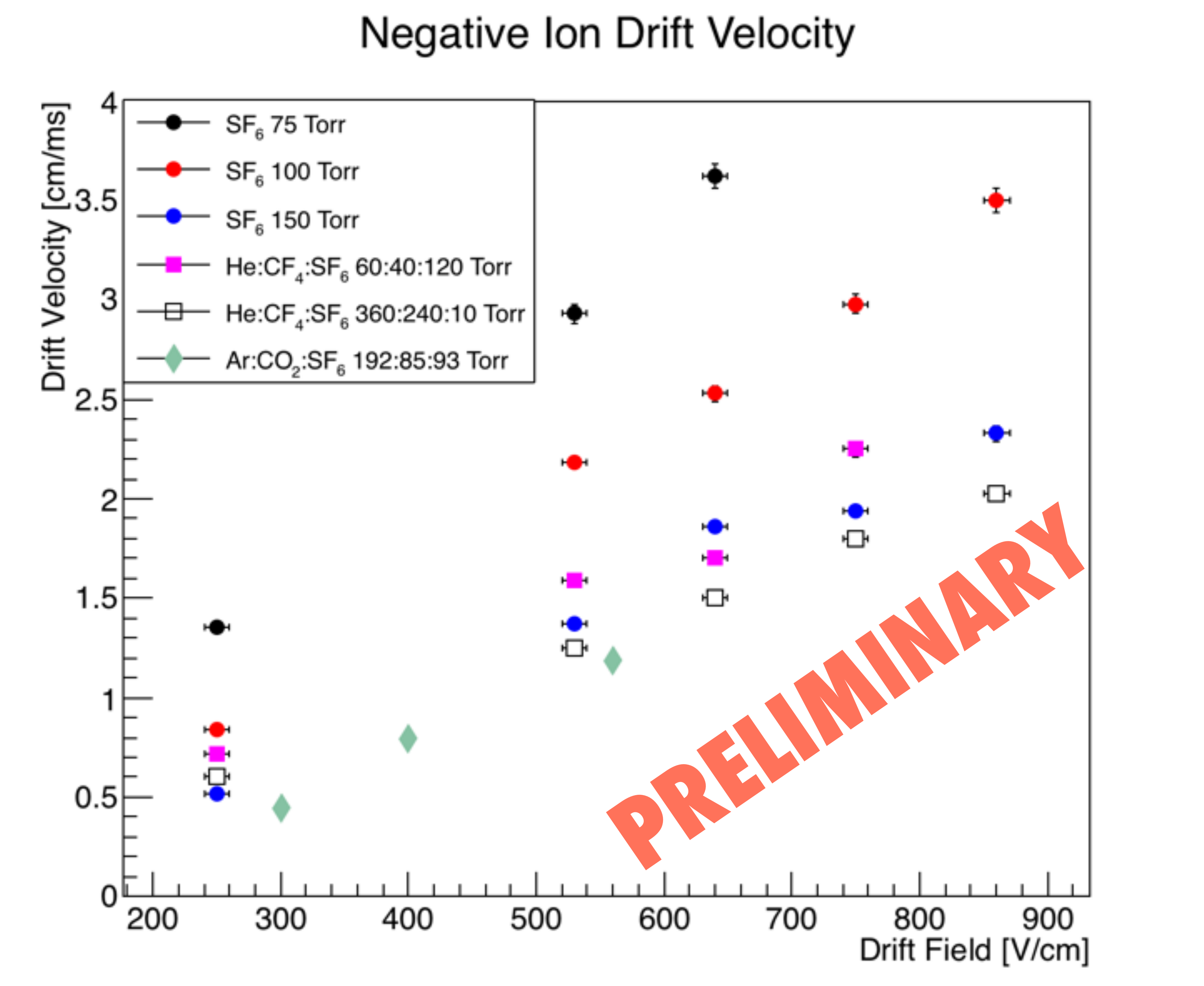
```
vdrift chip 0 is 0.0020193 +/- 6.38648e-05
vdrift chip 1 is 0.00203158 +/- 6.42549e-05
vdrift chip 2 is 0.00205442 +/- 6.49827e-05
vdrift chip 3 is 0.00203158 +/- 6.42549e-05
```

Drift times

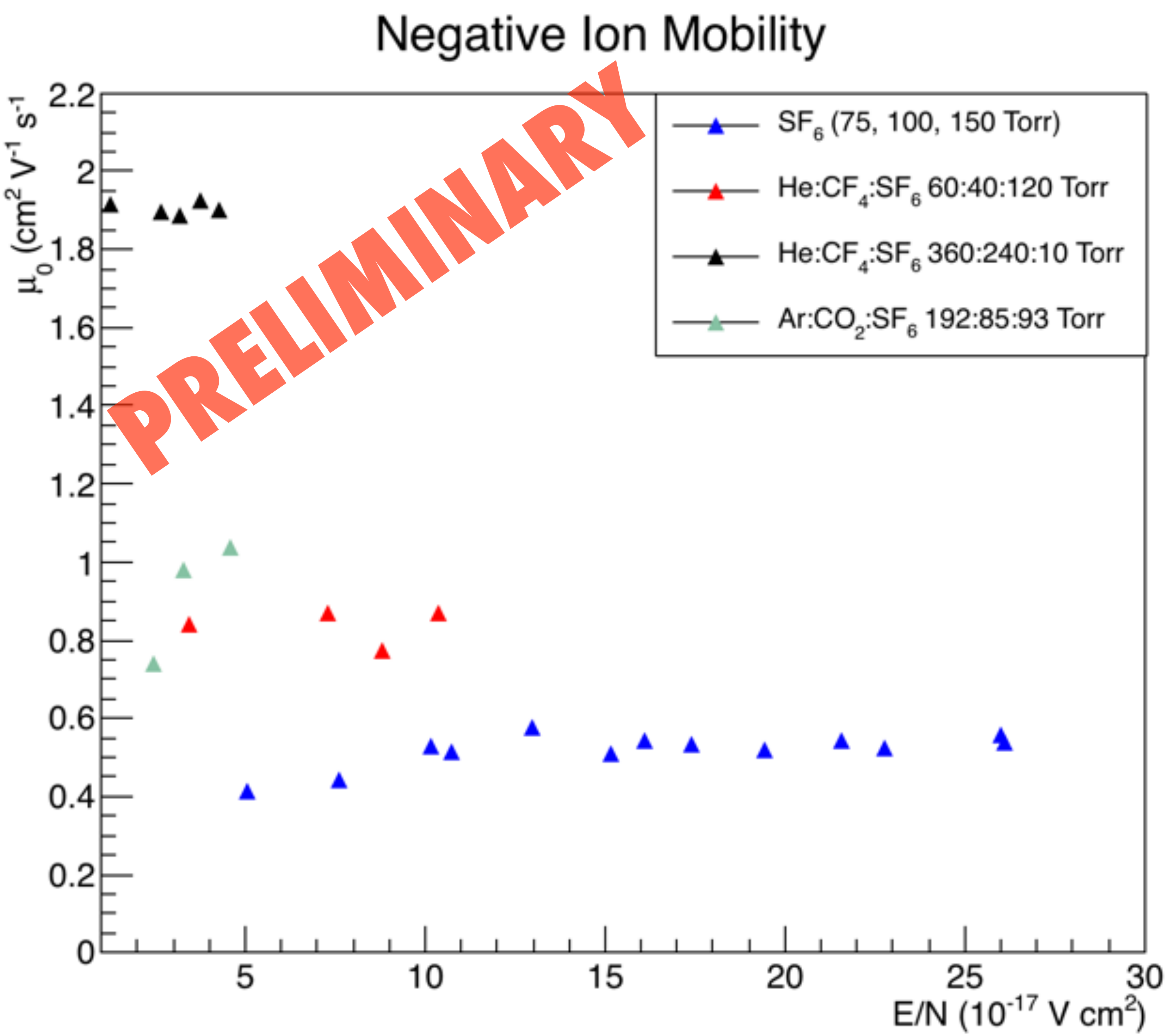


Nearly atmospheric operation!

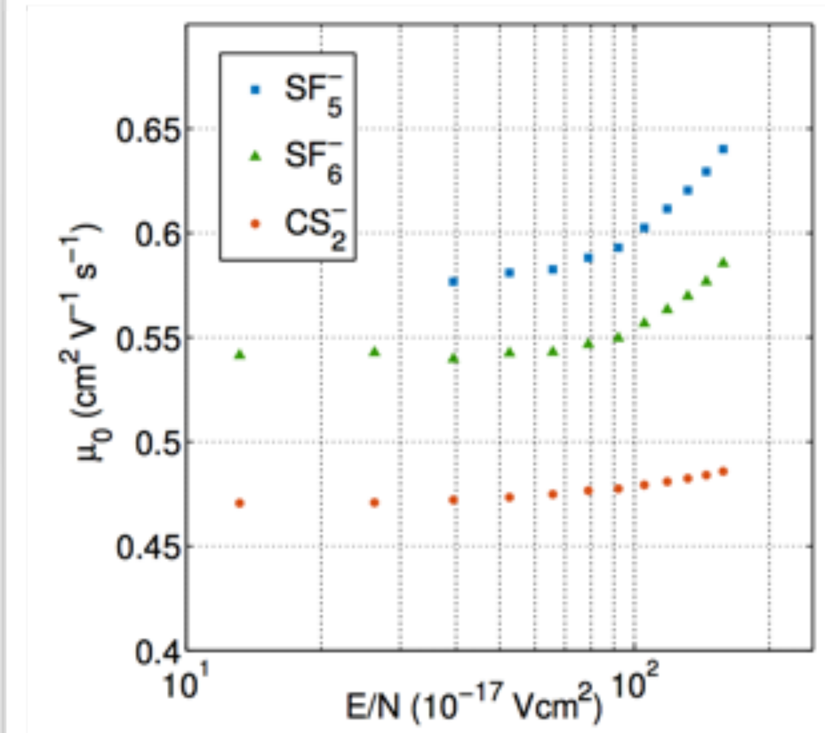
Drift Velocity Measurements



Mobility Measurements



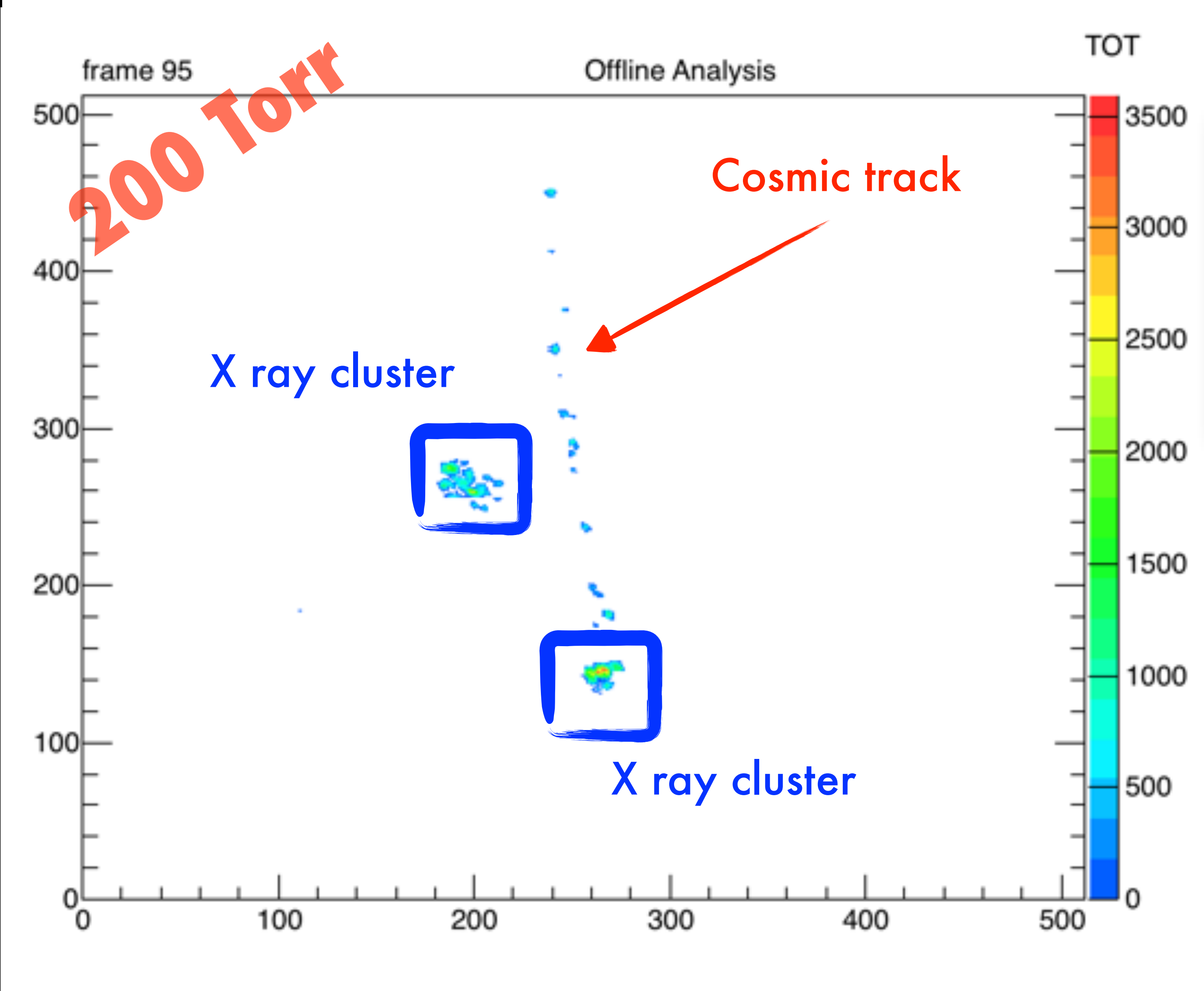
Pure SF_6 results in agreement with published data

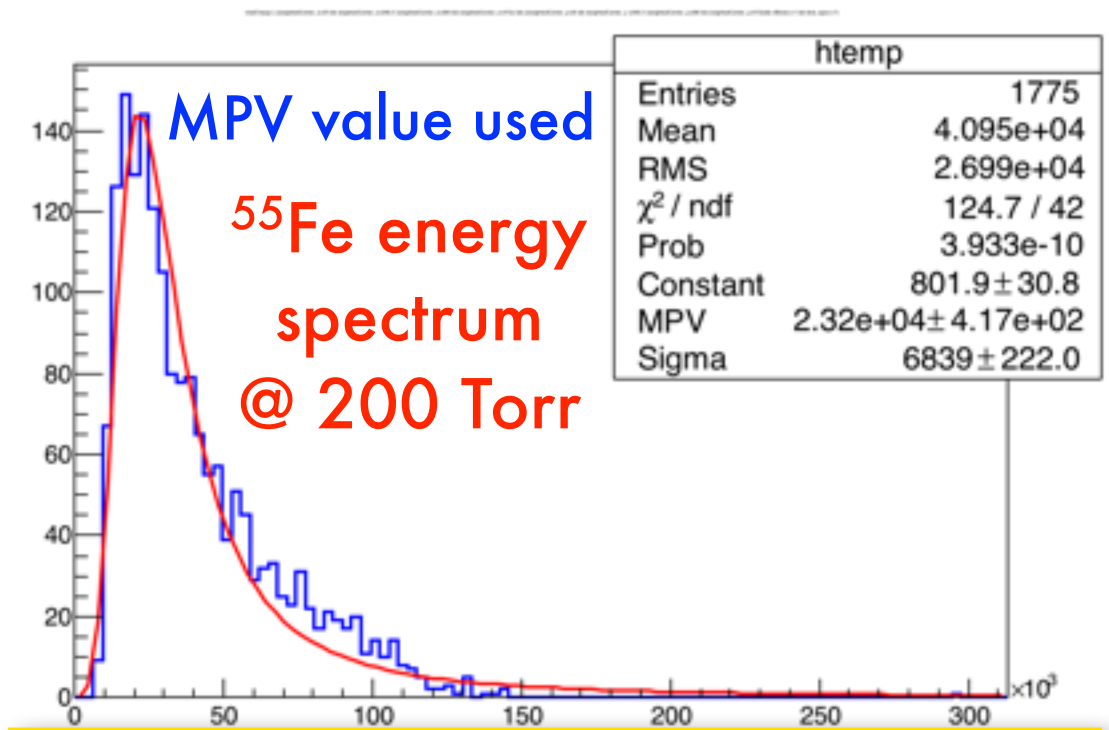


N.S.Phan et al, arXiv:1609.05249

NITEC gain (TOT) measurements in pure SF_6

^{55}Fe radioactive source





CAVEAT: <u>**not completely understood**</u> energy spectrum

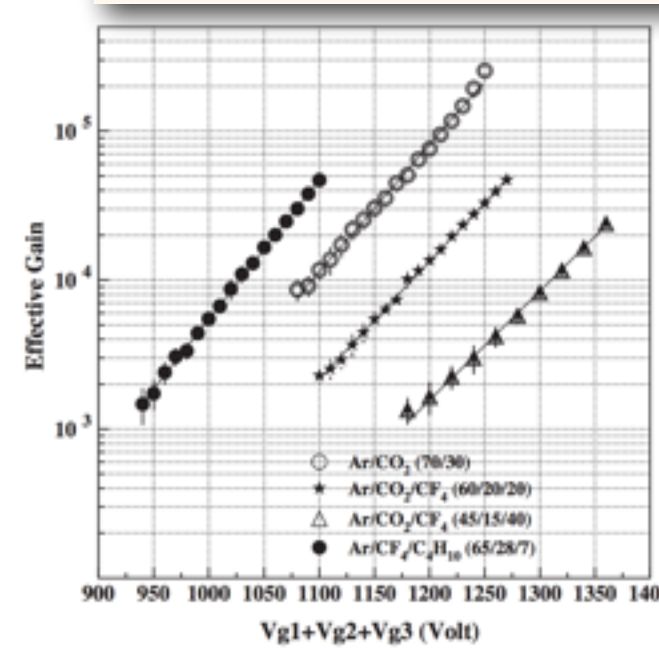
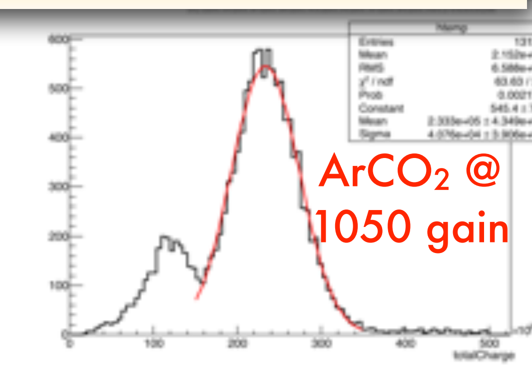


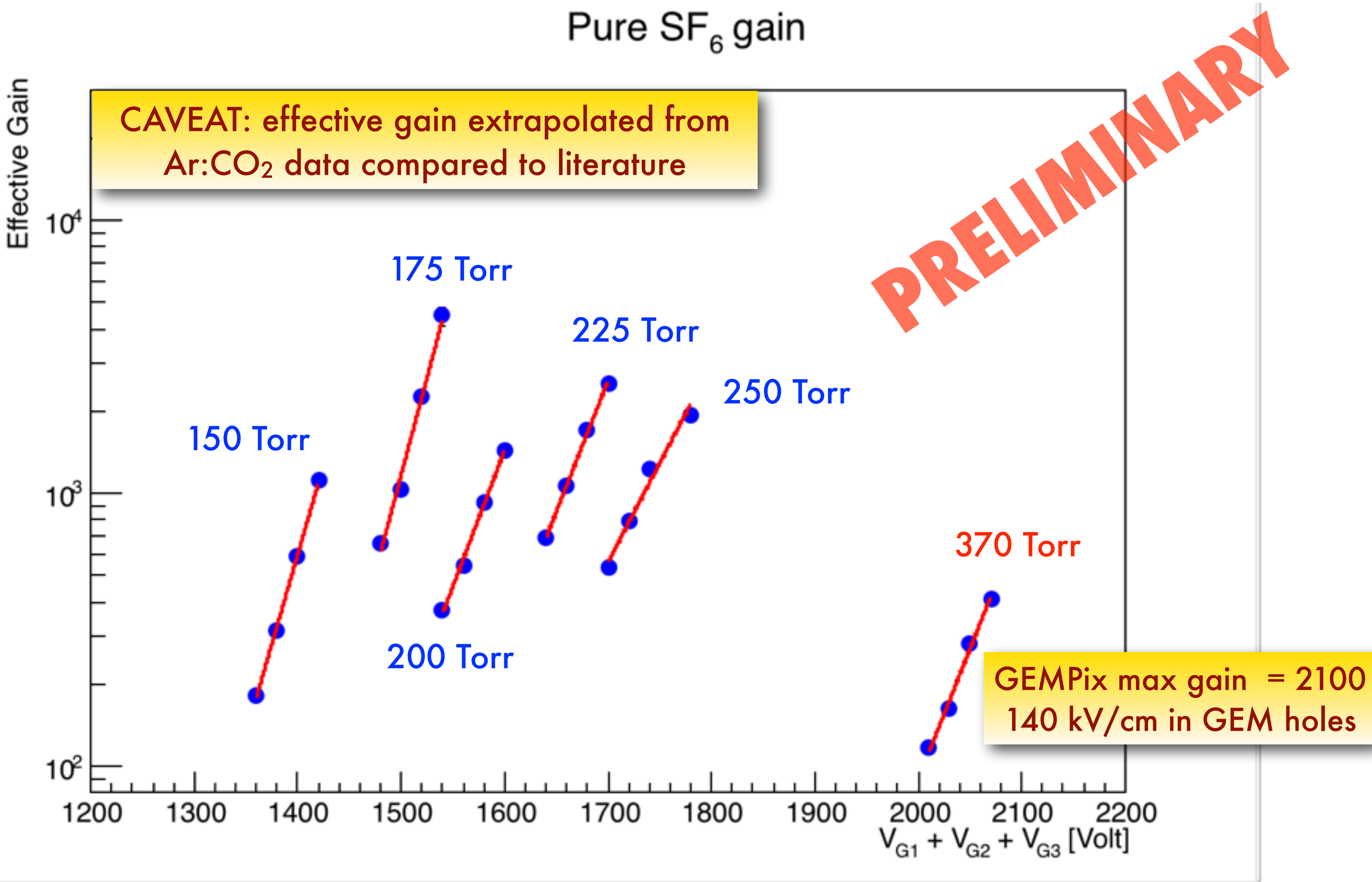
Fig. 3. Gas gain for the tested gas mixtures.



Effective gain extrapolated from Ar:CO_2 data compared to literature

June 2016

NITEC gain measurement in pure SF_6

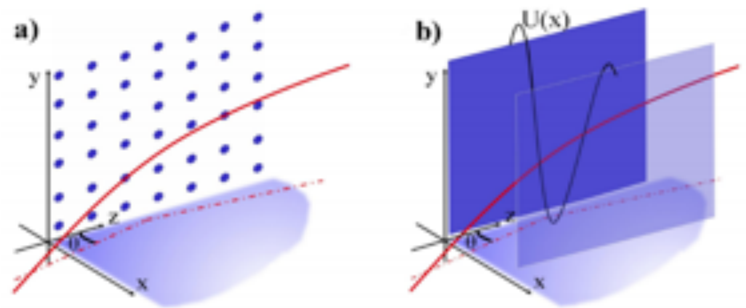


DCANT

Carbon Nanotube for
for Dark Matter directional searches

DCANT Concept

Channelling concept



Critical (Lindhard's) angle

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

Potential well depth

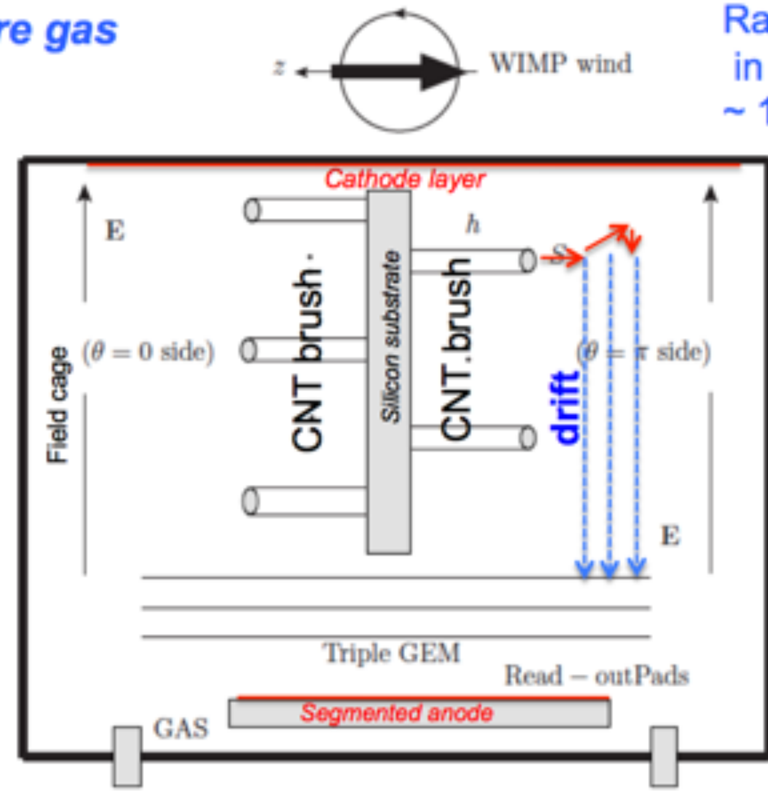
Particle energy

~ 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

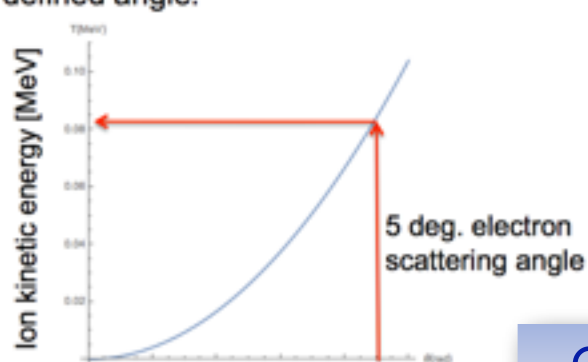
Drift distance can be 10 cm

Carbon ions **ranging out** In the gas

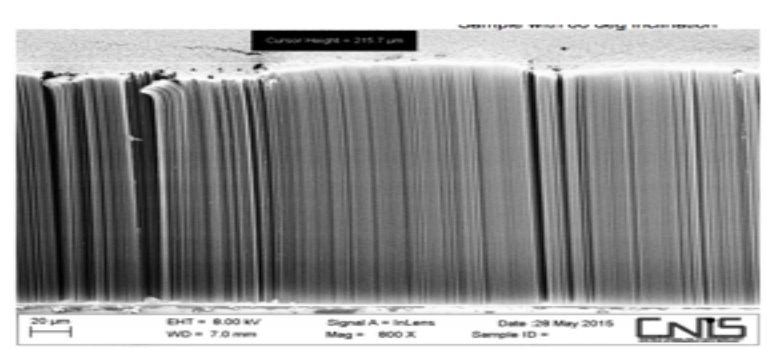
Electrons from ionized gas atom **drift** towards anode

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



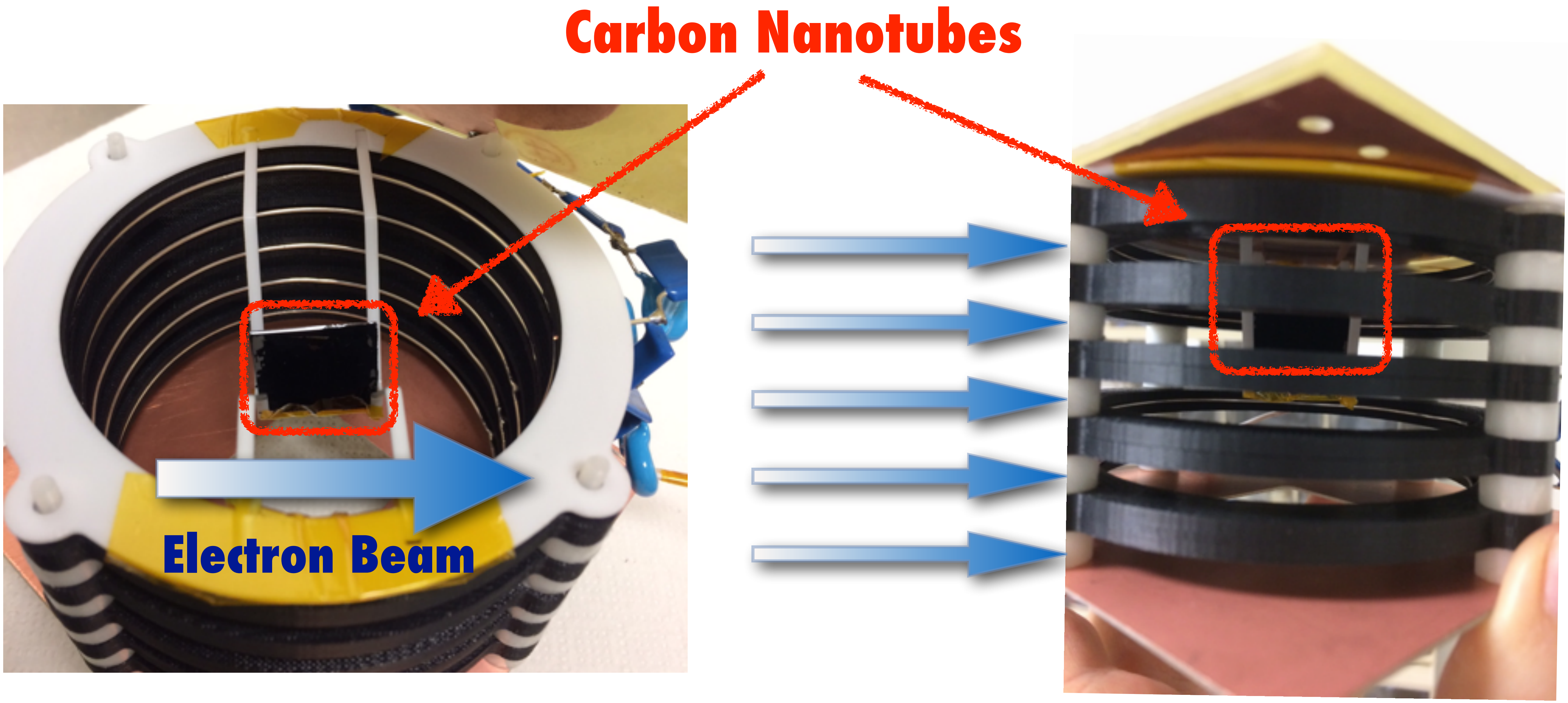
- About 10^{16} 1nm diameter SWCNT can fit on a 10x10 cm^2 substrate
- Surface density of a graphene layer: 1/1315 g/m^2
- About 2 g CNT on 100cm^2

CNT ropes?

C. Capparelli et. al, Phys. Dark Univ. 11, 79 (2016)

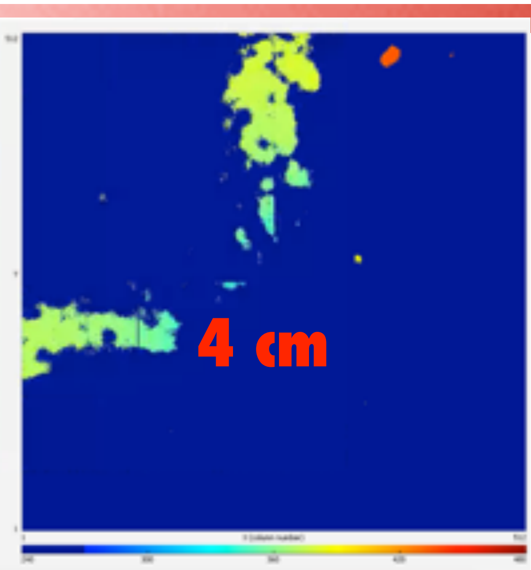
G. Cavoto et. al, Eur. Phys. J C 76 (2016) no.6, 349

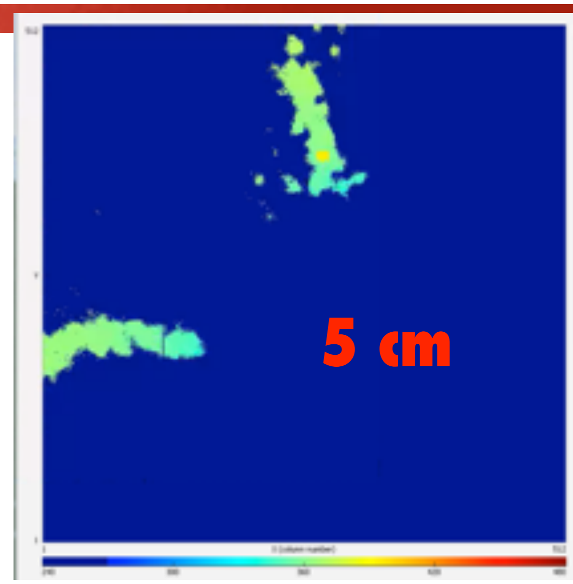
NITEC tests with carbon nanotubes

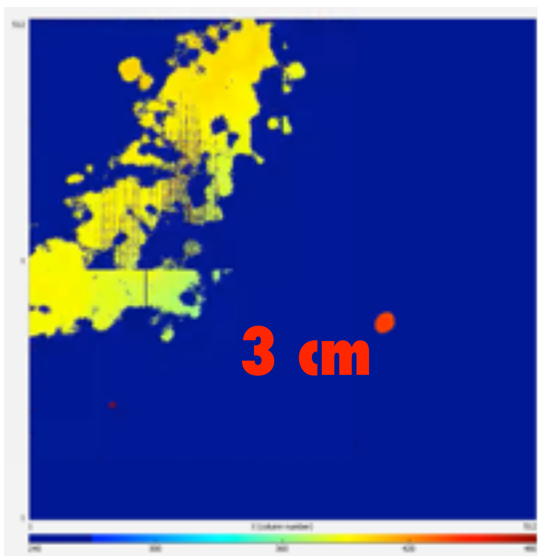


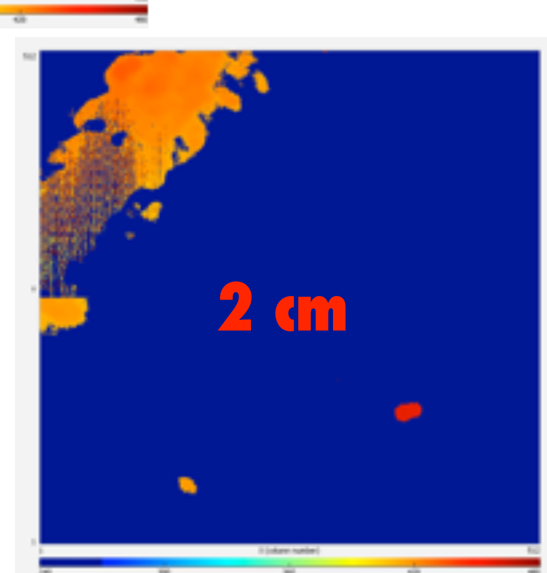
Beam on the side of nanotubes at various heights to study modification of the drift field

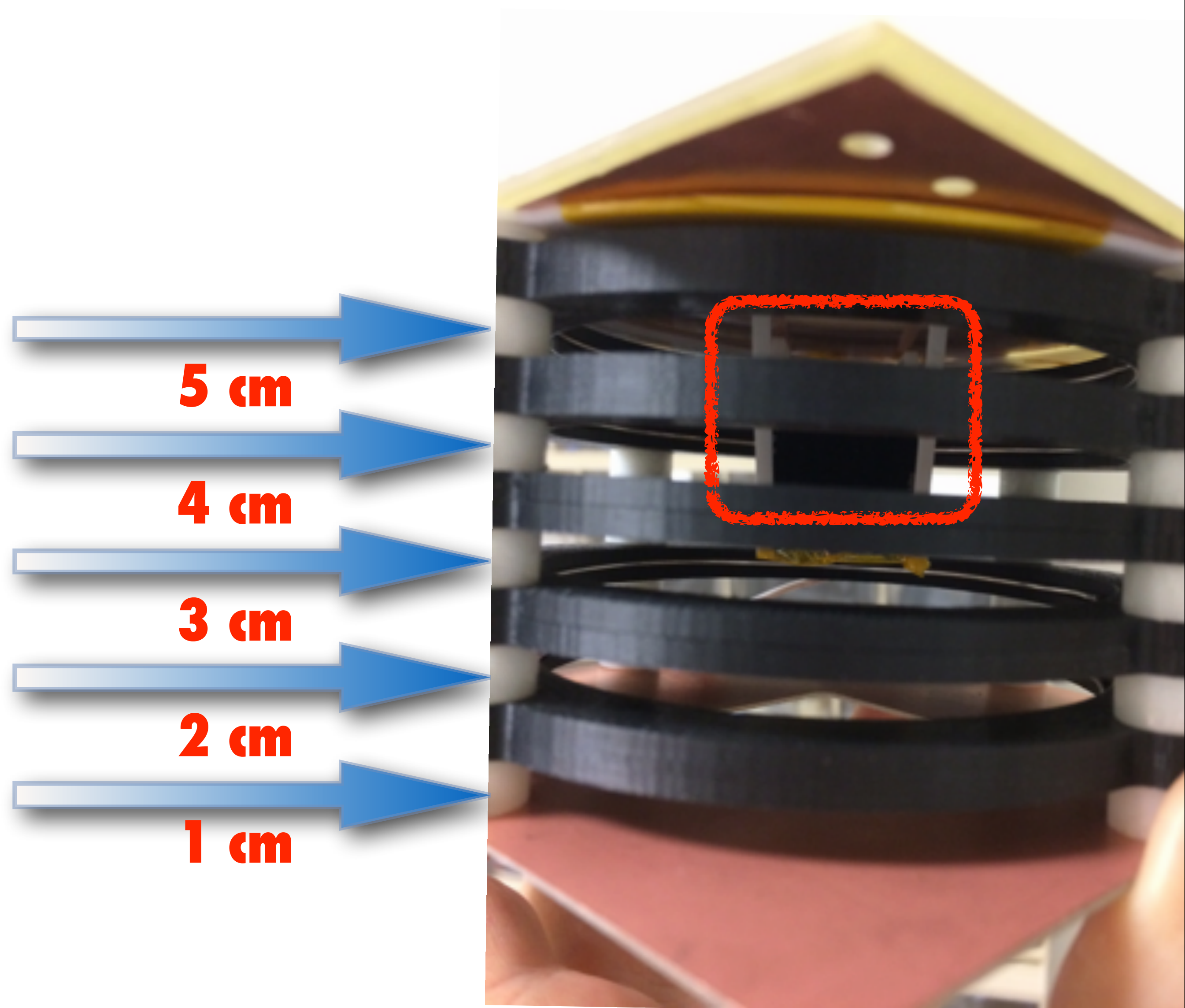
NITEC tests with carbon nanotubes





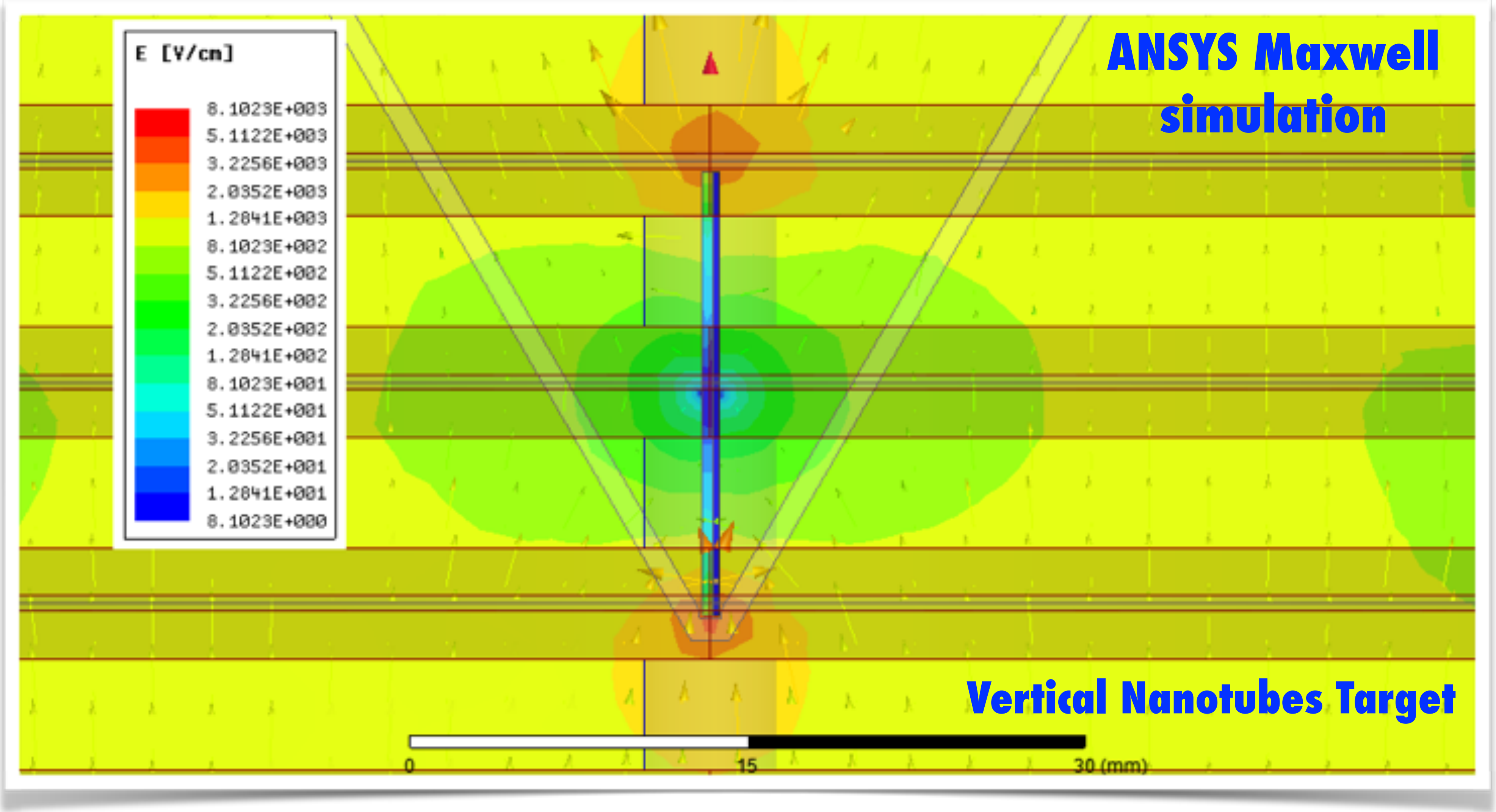




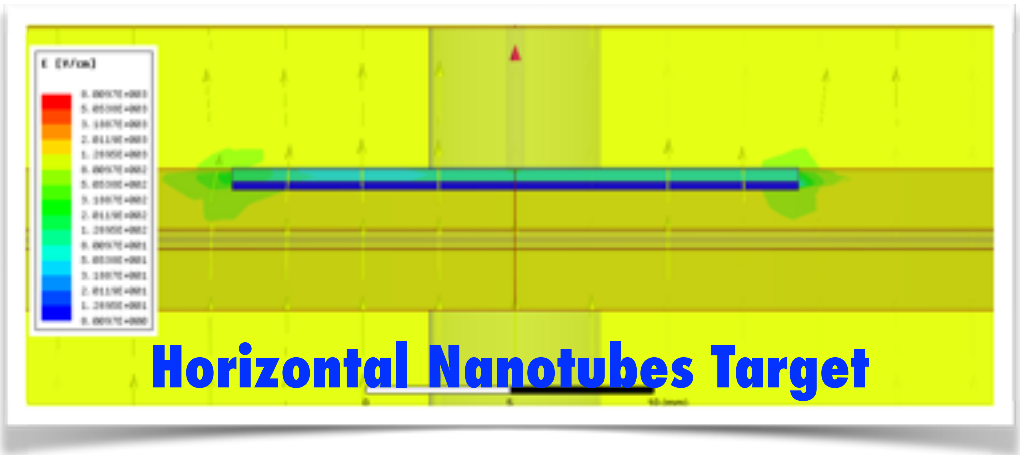


$Ar:CO_2:CF_4$ TOA data @ 300 Torr
(confirmed with pure SF_6 @ 150 Torr)

NITEC with carbon nanotubes



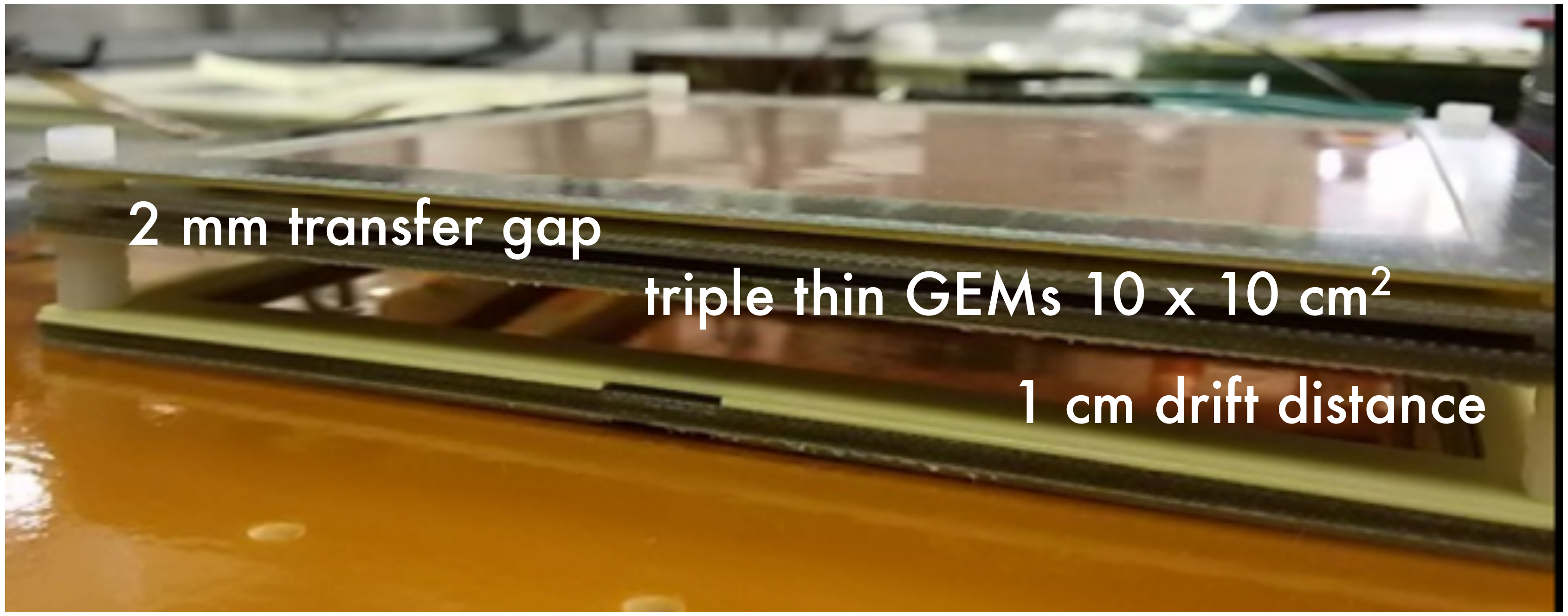
- **We observe a consistent modification of the drift field due to the introduction of nanotubes structure AND support**
  - Support, kapton scotch and nanotube get polarized
  - ANSYS simulation confirms observed results
  - On going work to develop suitable support and substrate

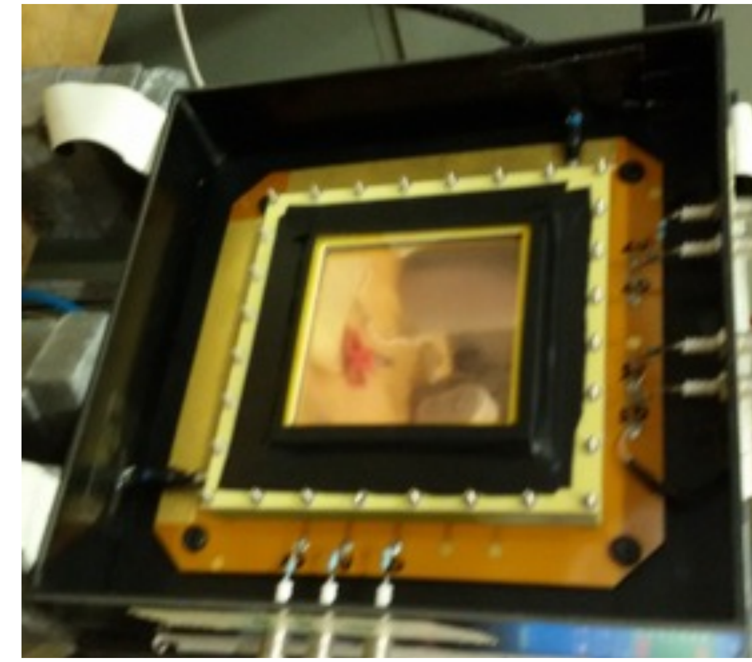


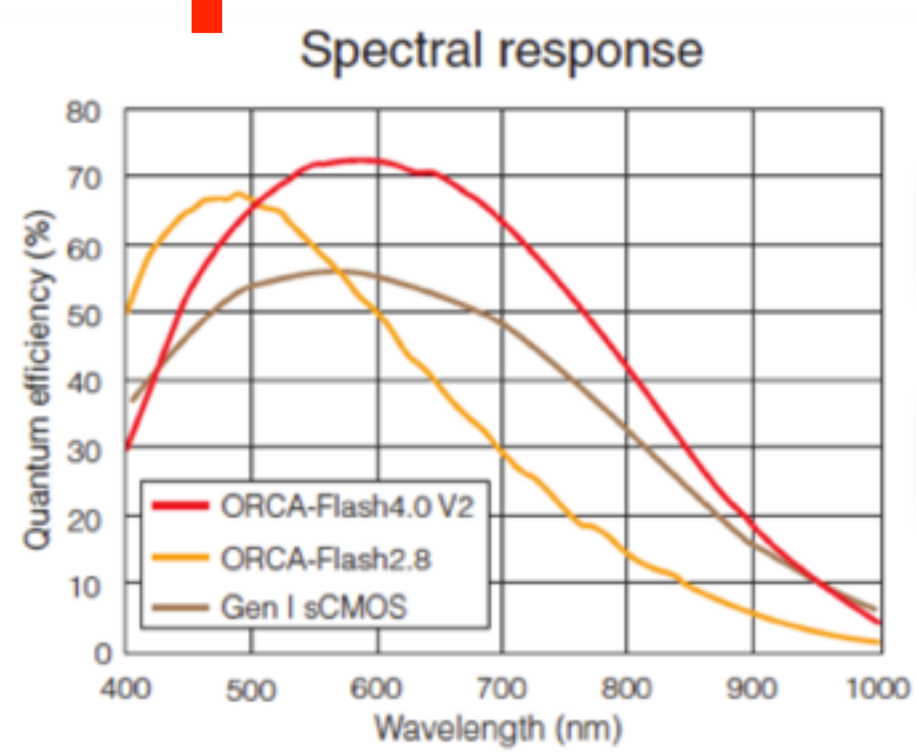
CYGNUS-RD

Optical readout for a Negative Ion Time Projection Chamber

CYGNUS-RD Detector



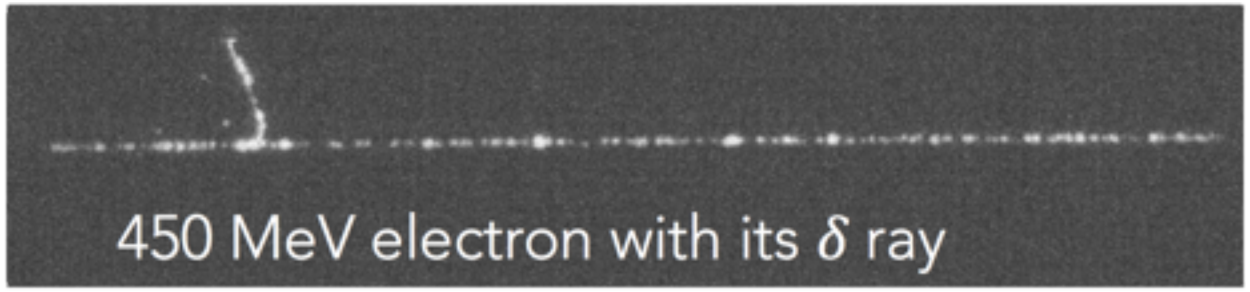


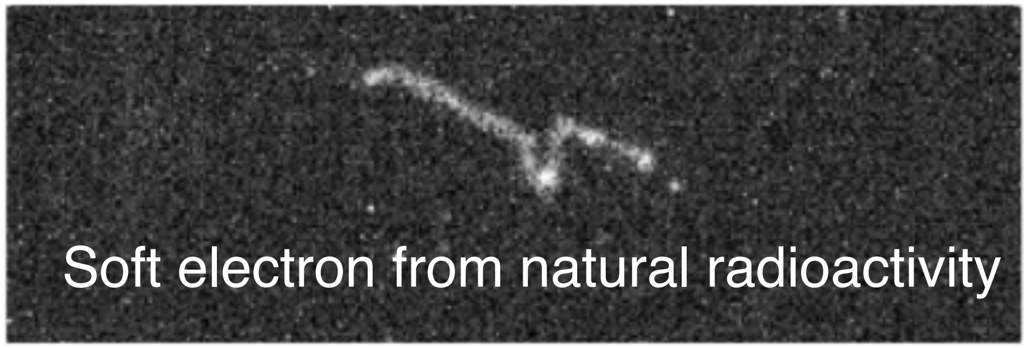


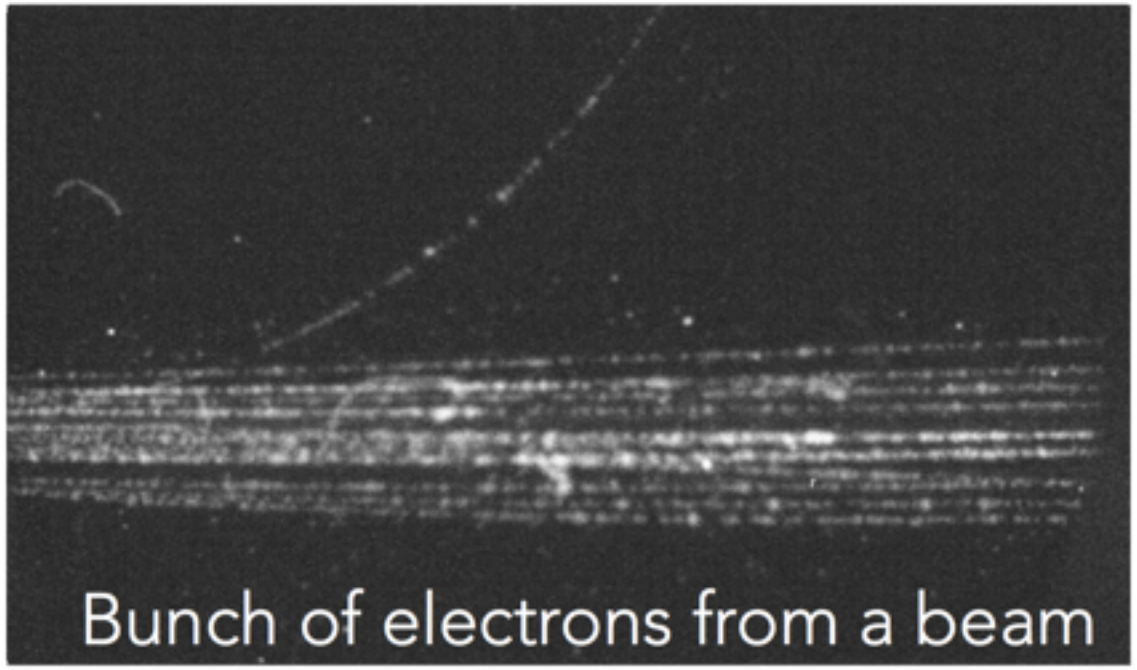
M. Marafini et al., JINST 10, P12010 (2005)

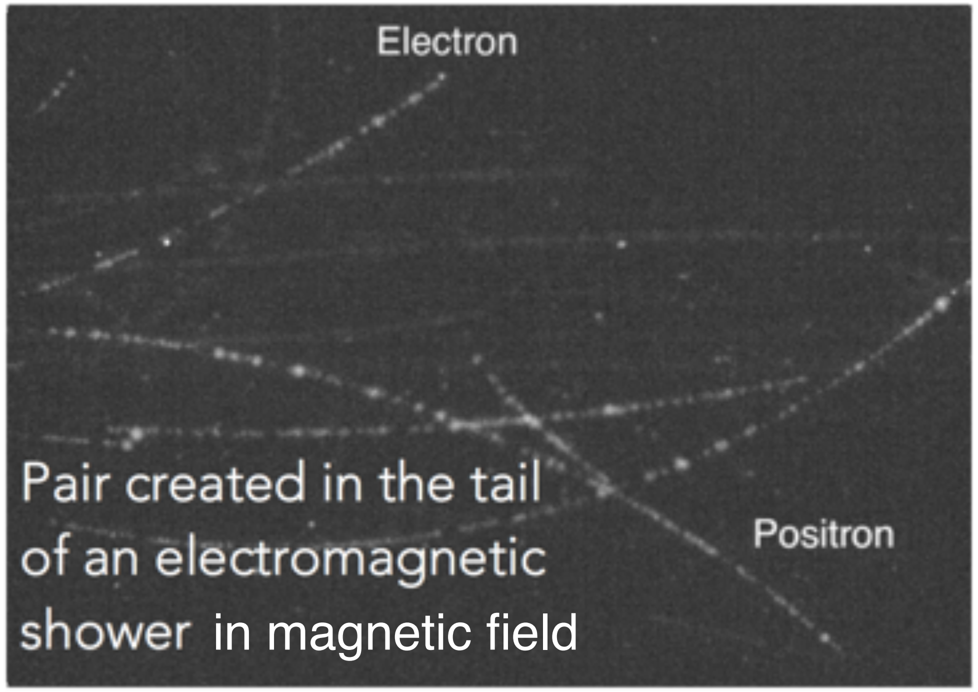
M. Marafini et al., NIM A 824 (2016) 562

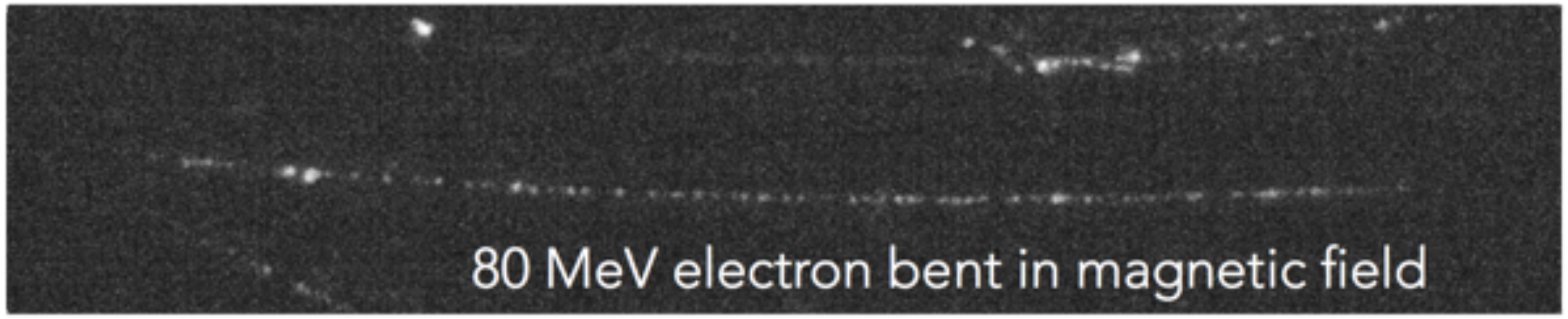
CYGNUS-RD events (with electron drift)







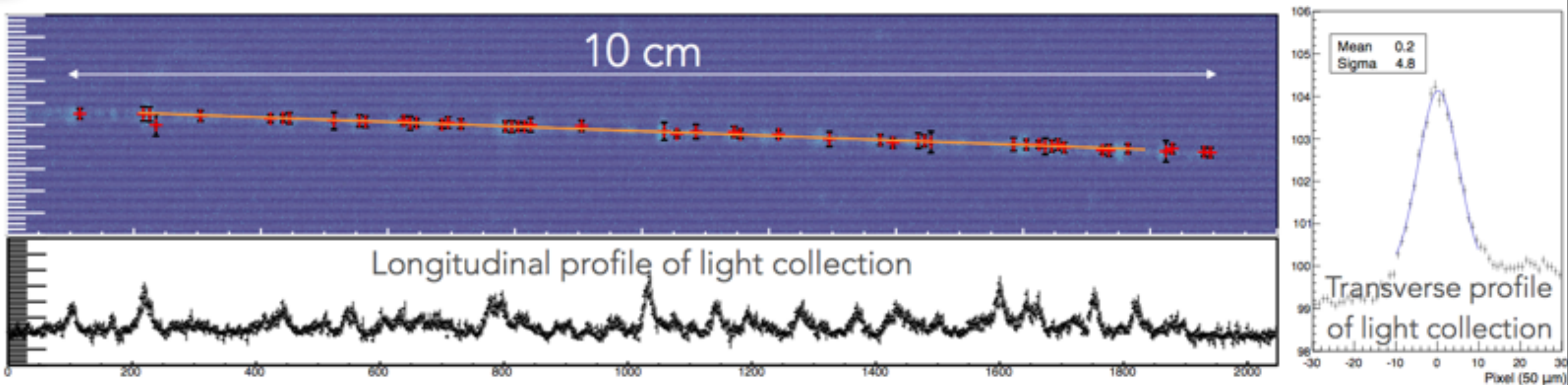




CYGNUS-RD potentialities

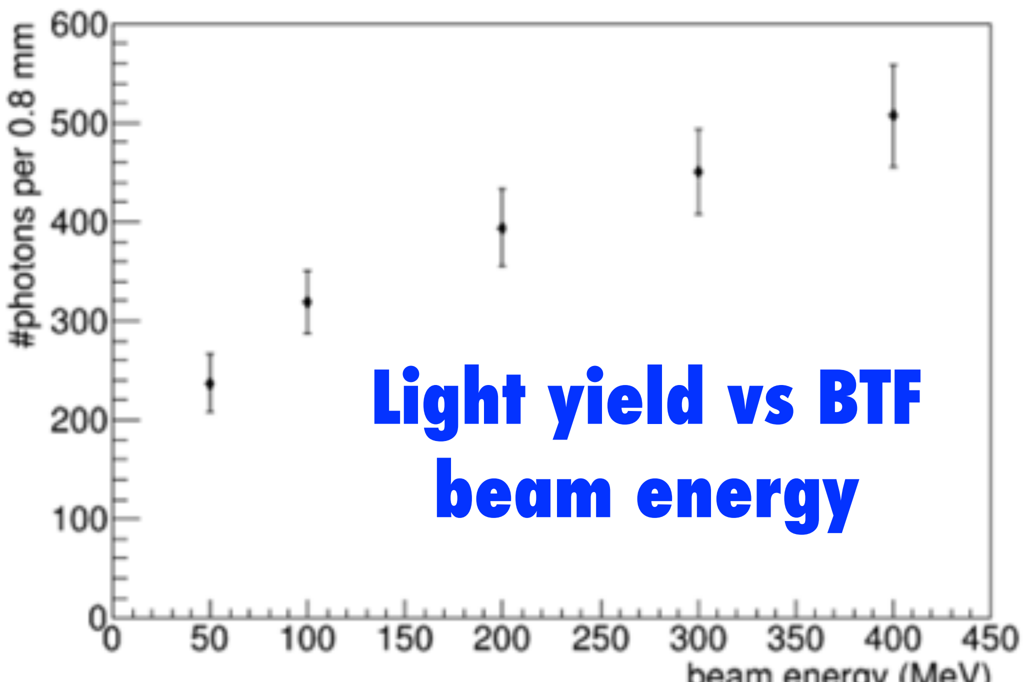
May 2016, electron drift

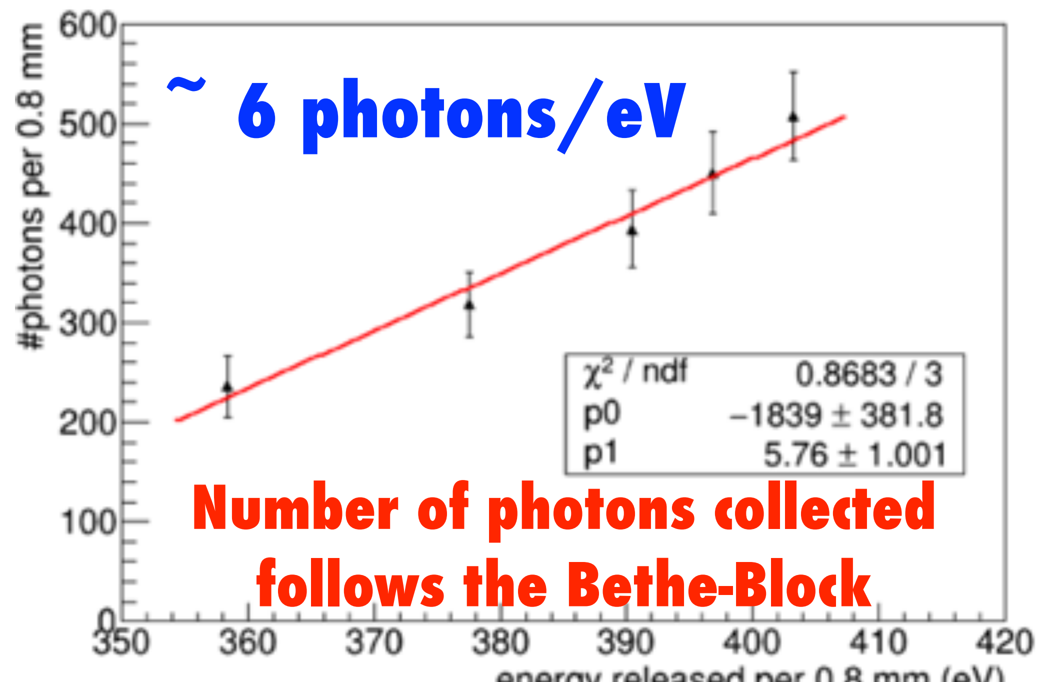
1) Tracking



~ 1000 photons/track mm, ~70 um track residuals, cluster structures visible

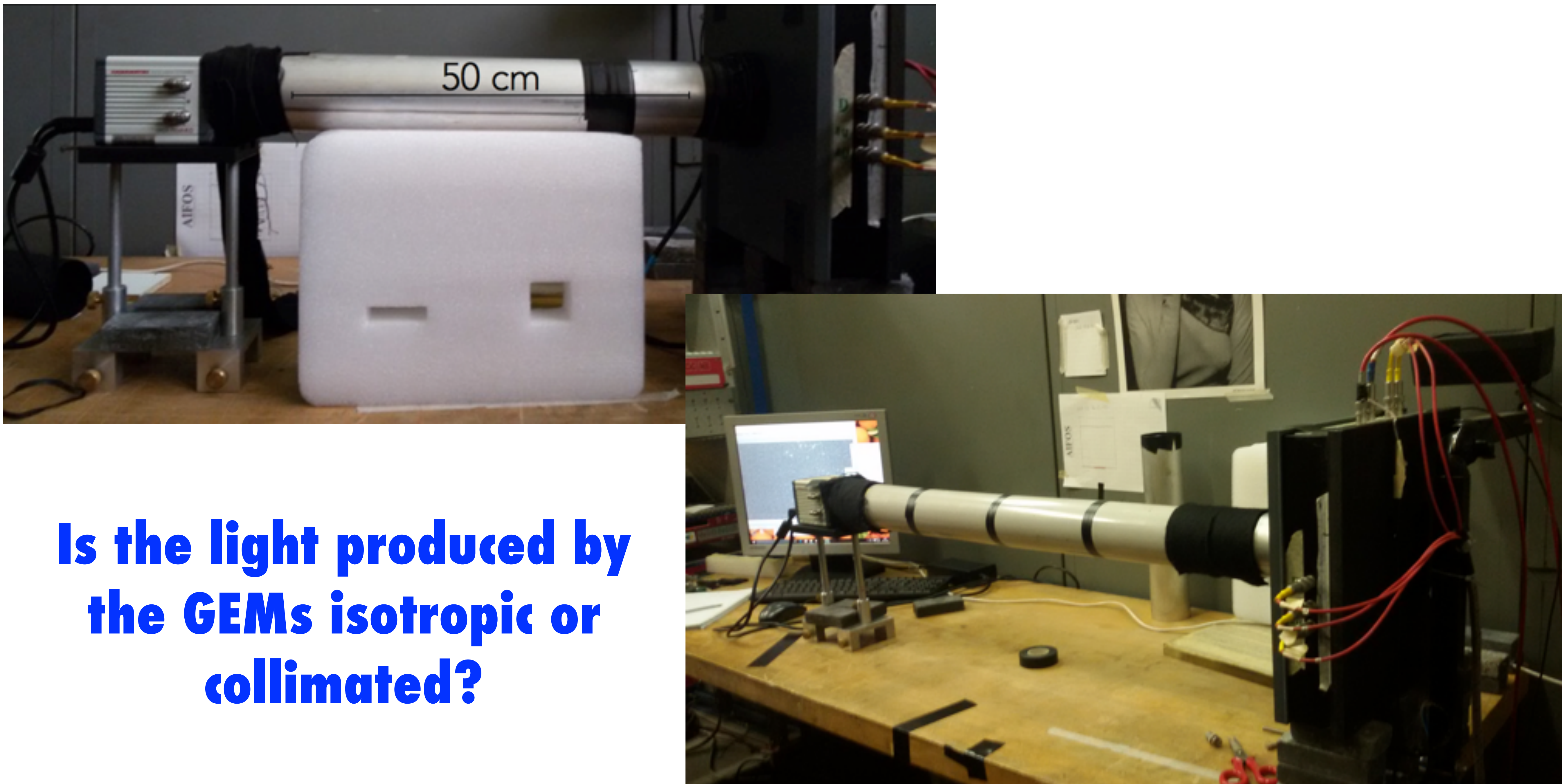
2) Ionization density (can be used to extrapolate track direction/sense)





Light vs Distance Study

How far can we go and still see light?
i.e. how large area can we cover with one CMOS camera?

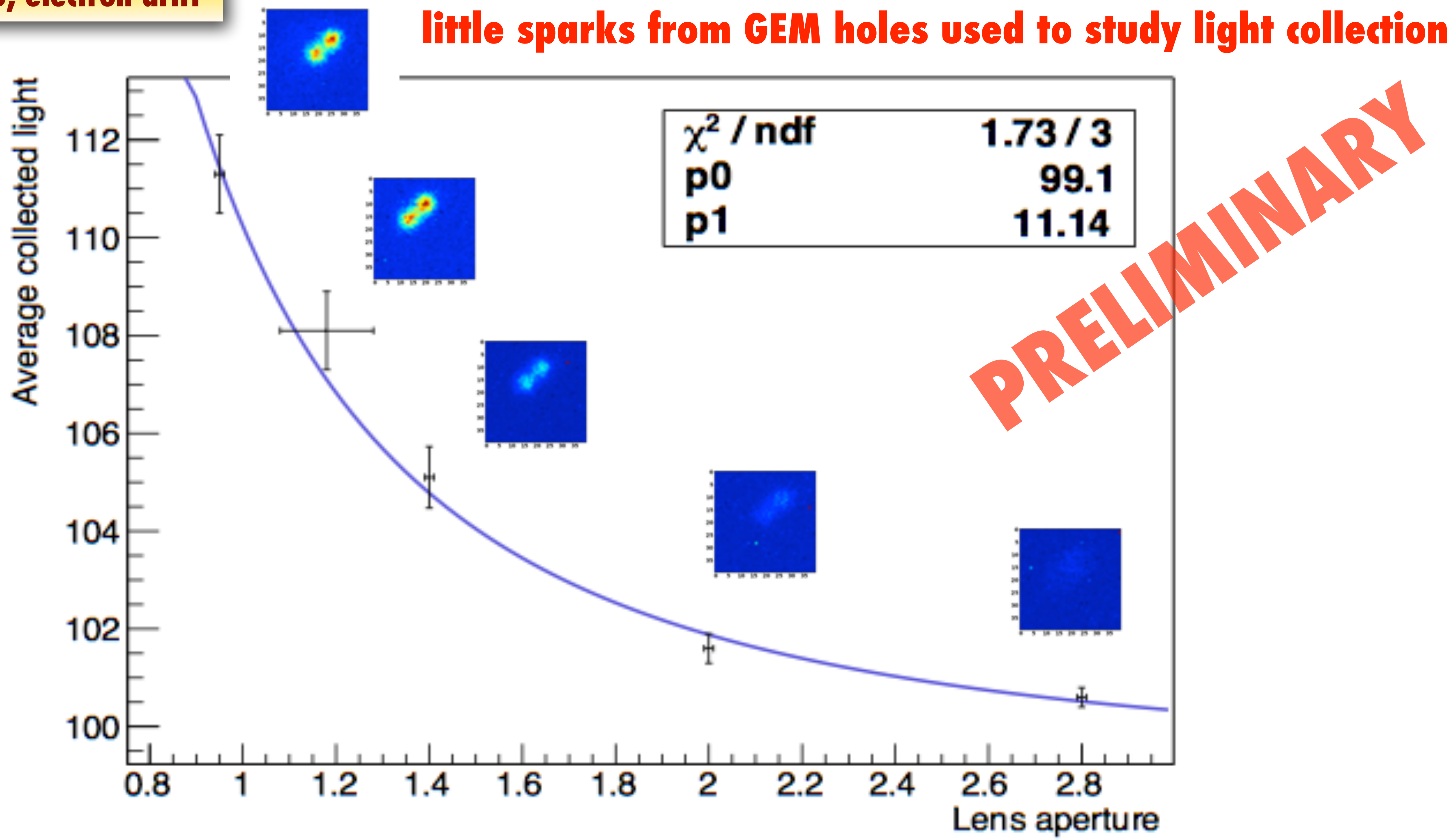


Is the light produced by the GEMs isotropic or collimated?

Light vs Lens Aperture

Dec 2016, electron drift

little sparks from GEM holes used to study light collection

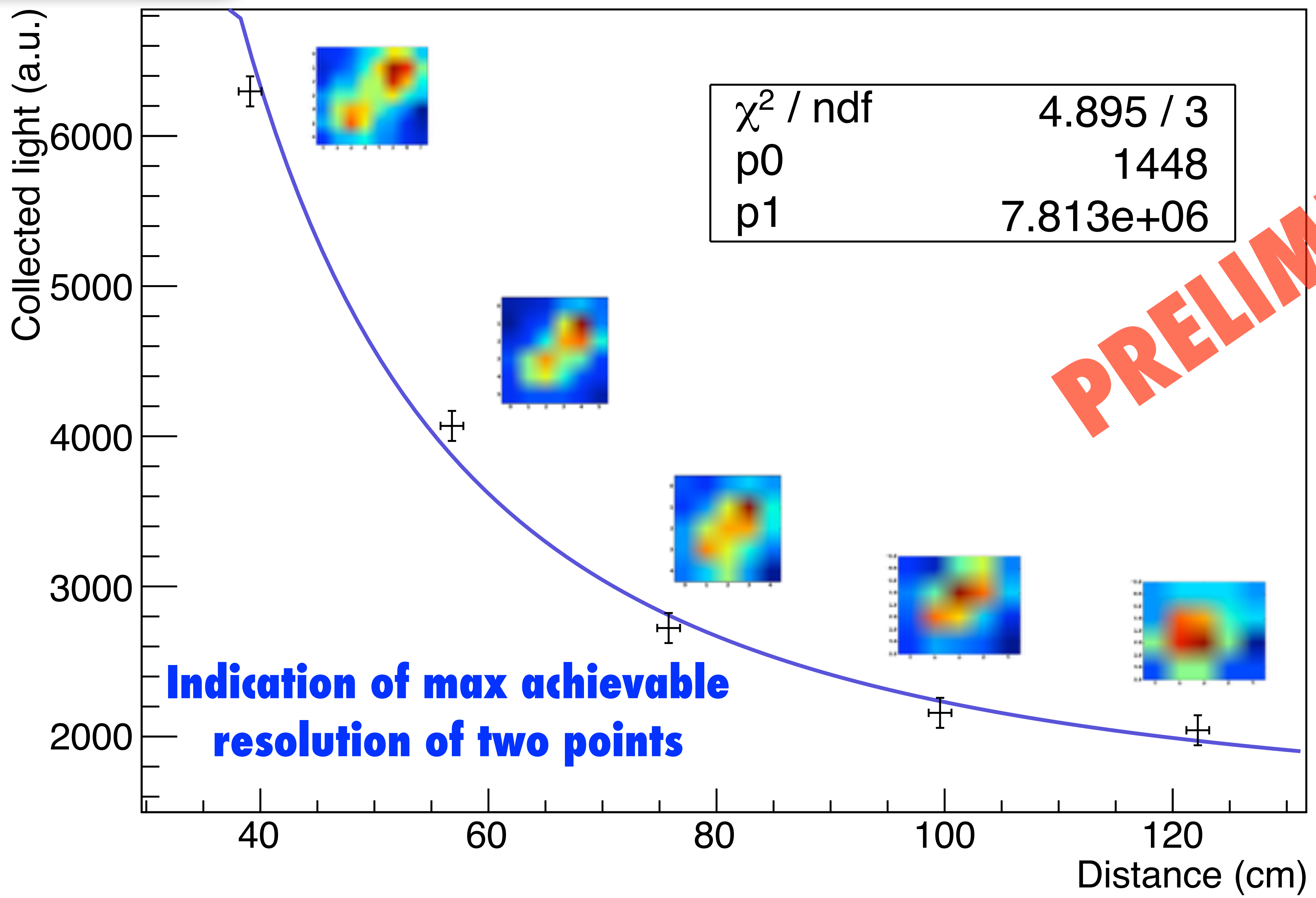


@ 20 cm distance 50 um pixels equivalent

Light vs Distance

Dec 2016, electron drift

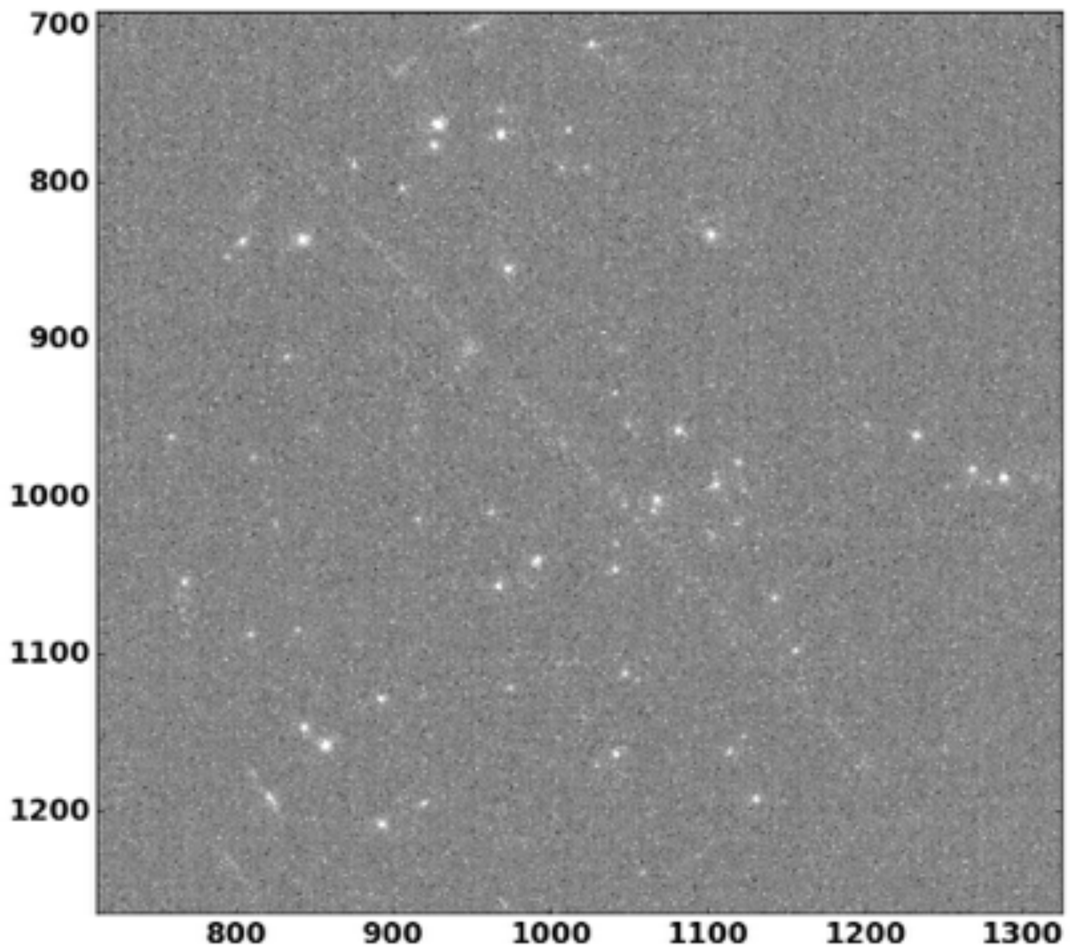
@ 60 cm we cover a 30 x 30 cm^2 area



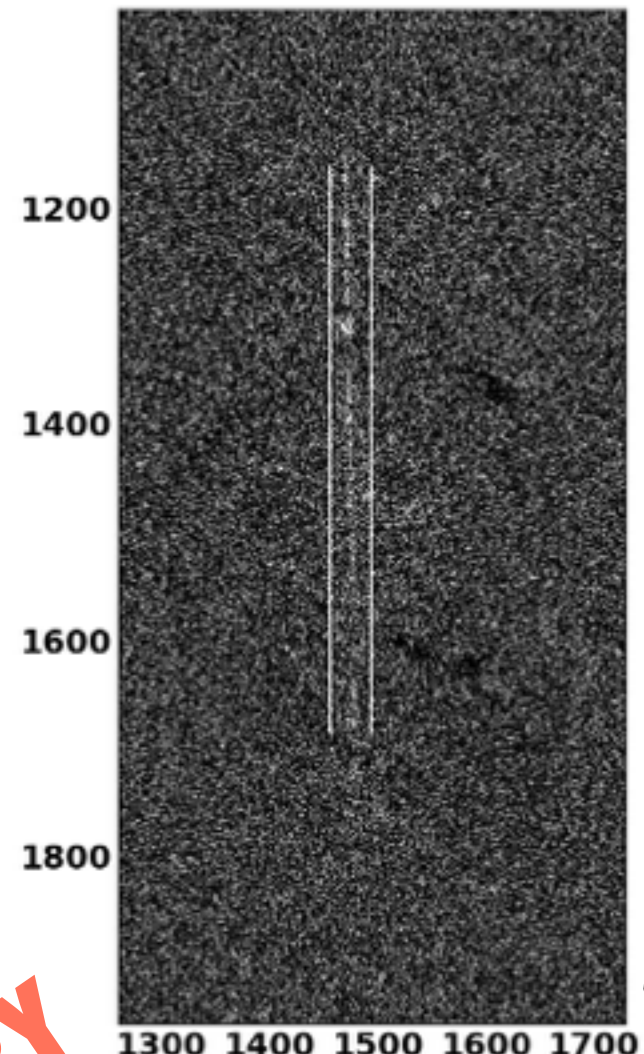
Both light vs lens aperture and light vs distance indicate isotropic light production

Example of cosmic track @ 60 cm

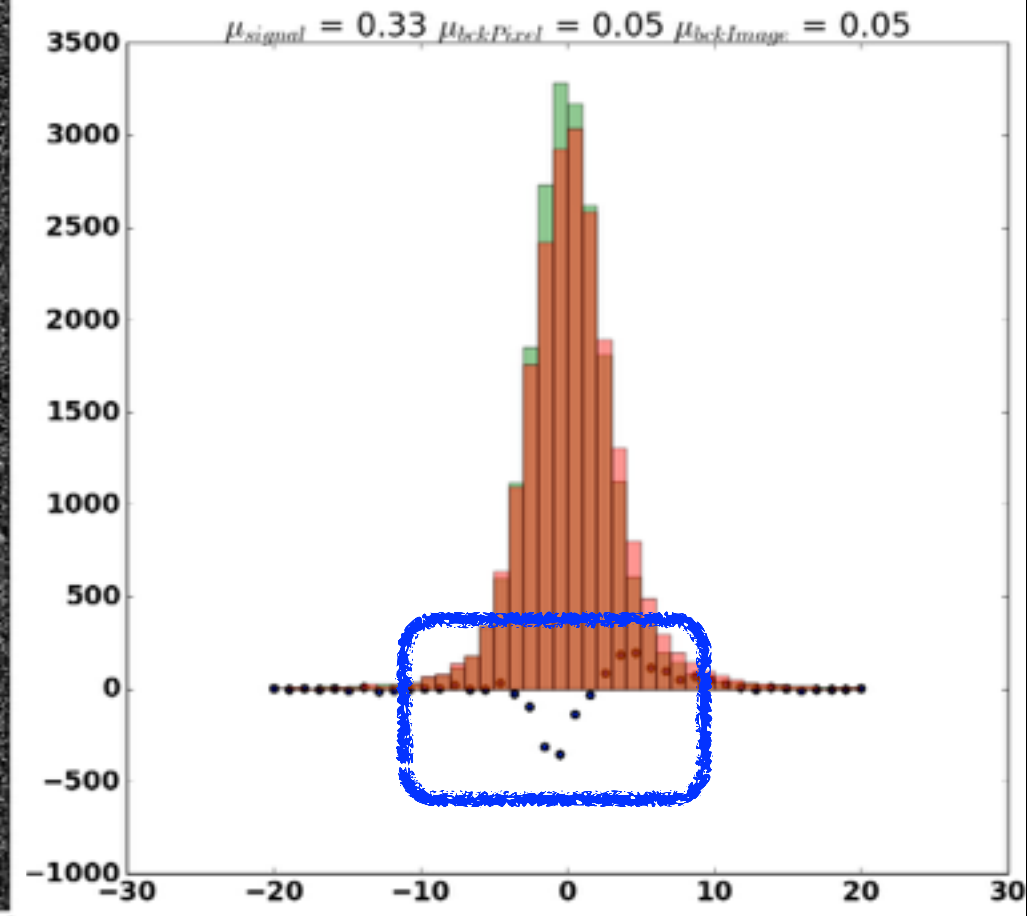
Cosmic track raw data as seen by the CMOS



Background subtracted & rotated



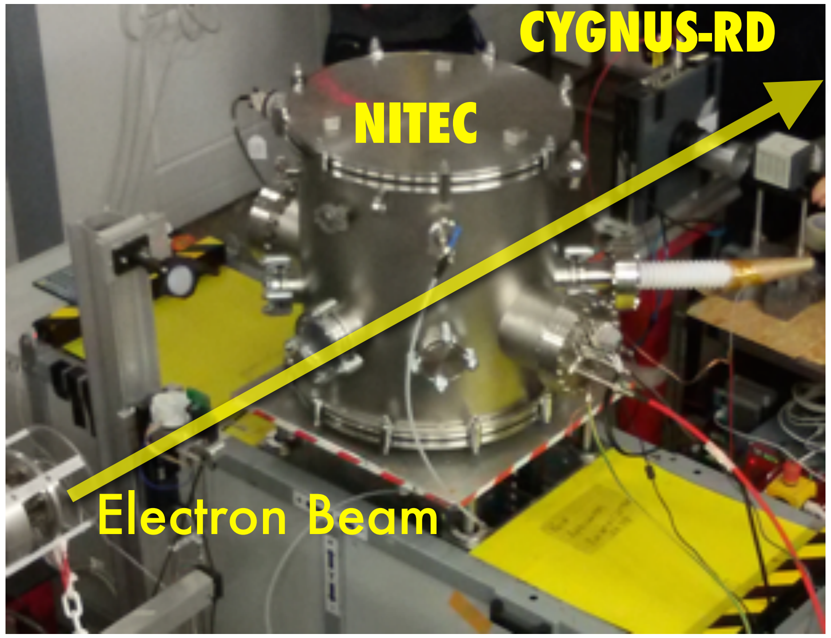
Signal (red)/ noise (green) comparison

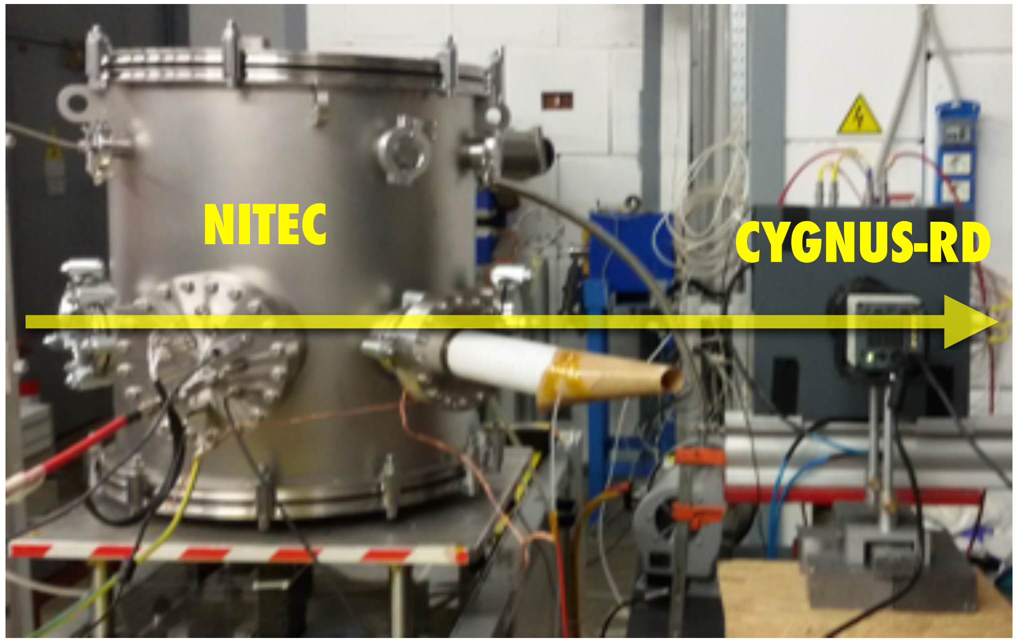


PRELIMINARY

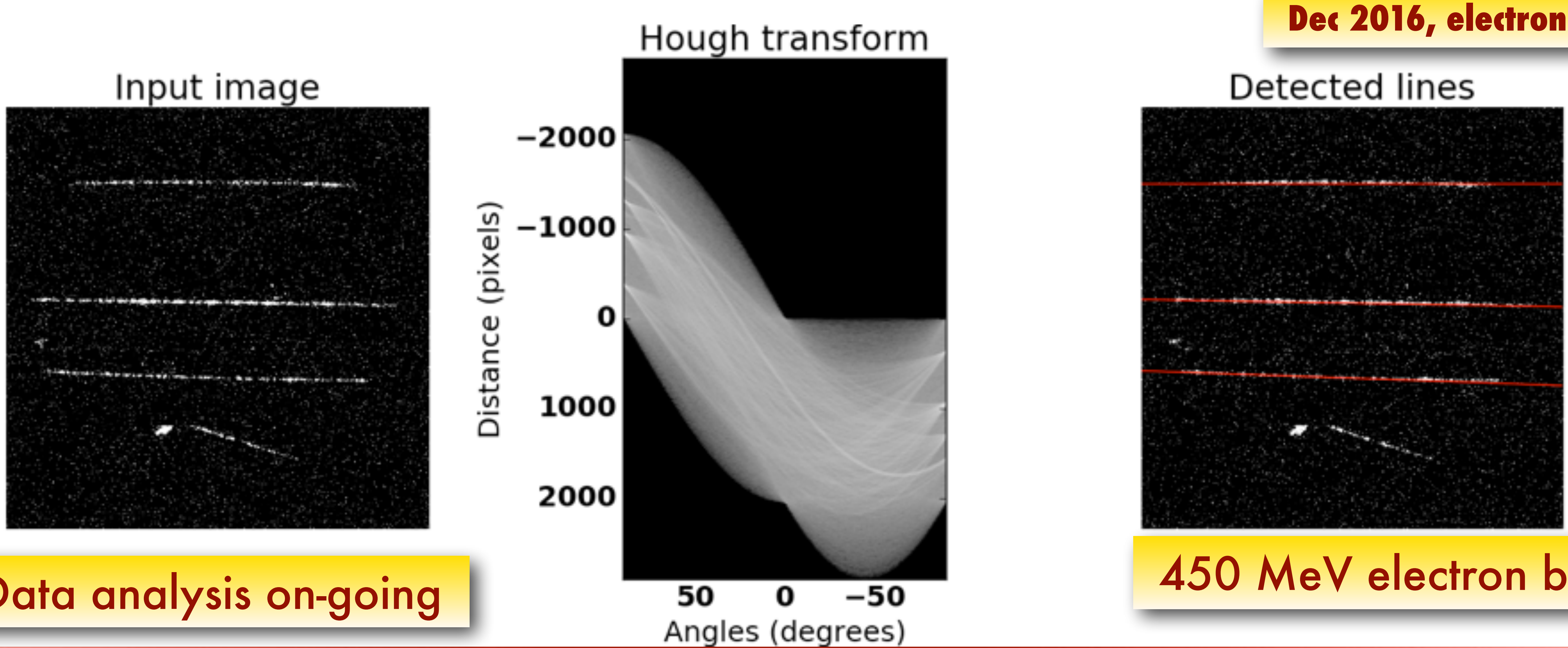
After noise subtraction, signal is clearly visible

CYGNUS-RD @ BTF





Dec 2016, electron drift



Data analysis on-going

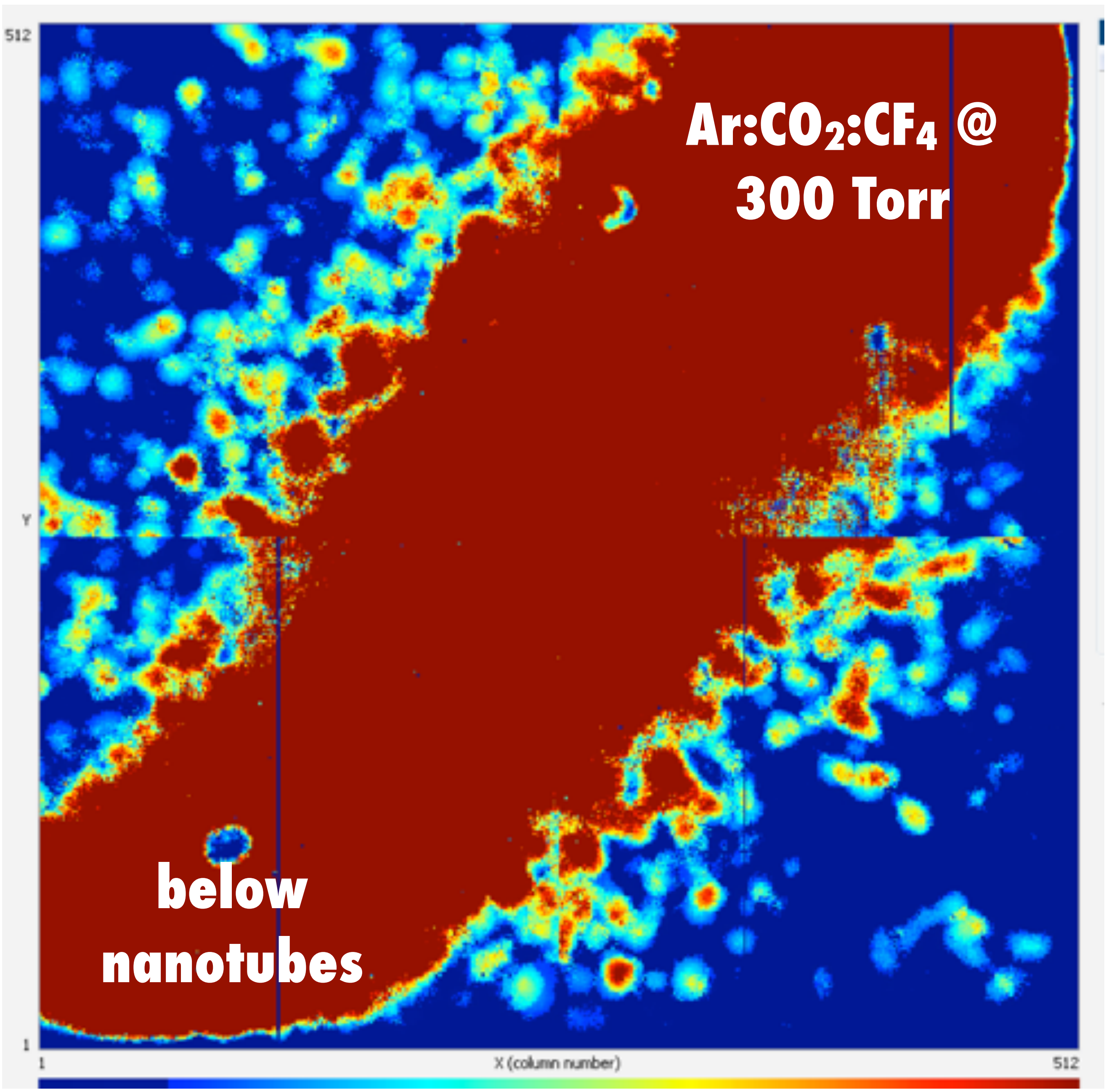
450 MeV electron beam

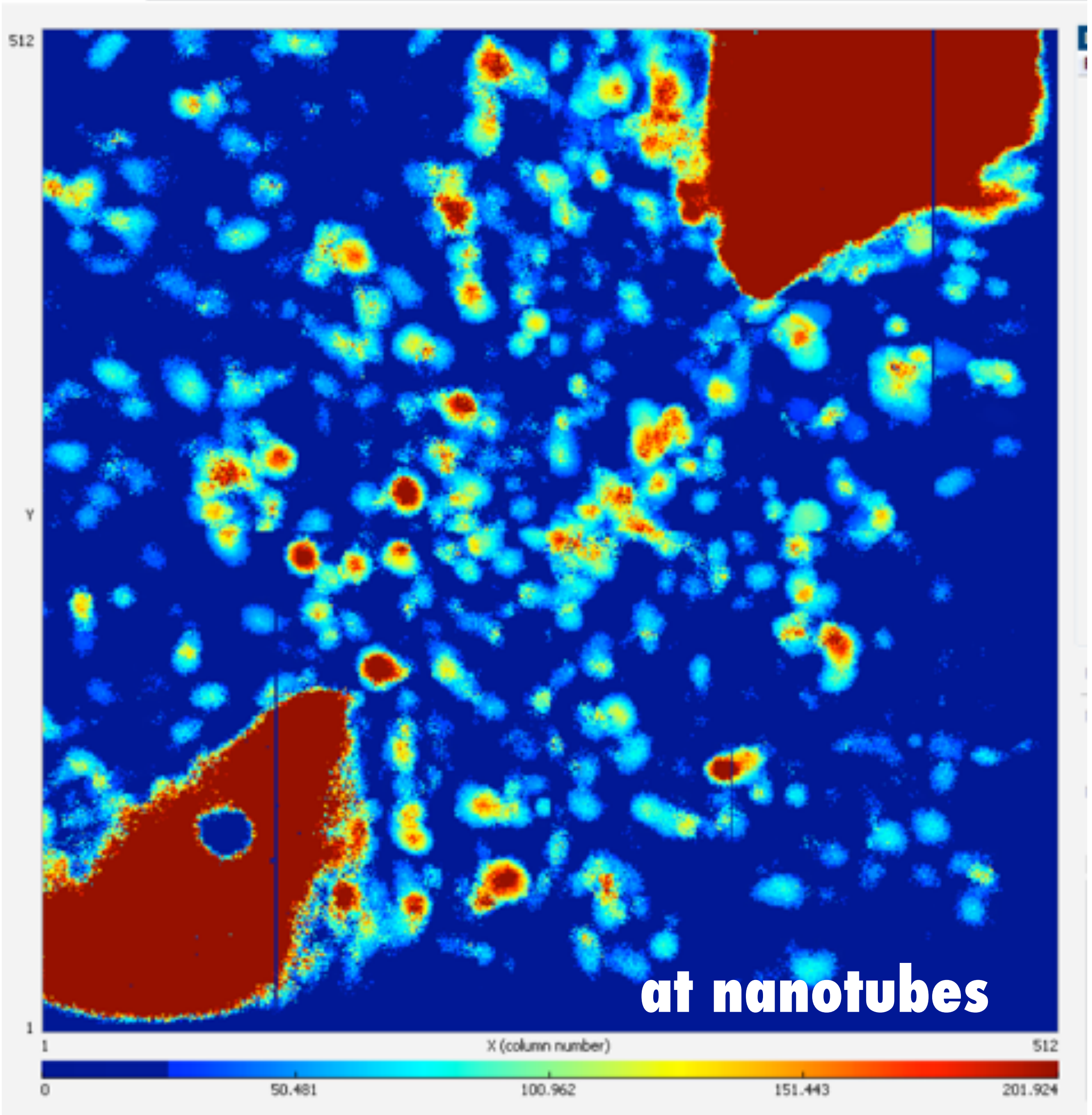
Conclusions & Outlooks

- **NITEC**
  - Innovative SF_6 based negative ion gas mixtures tested and operated nearly atmospheric pressure (610 Torr) with triple thin GEMs at electron beam line
  - Perform gain study with ^{55}Fe with the tested mixtures and explore new ones with higher He content (i.e. lower density)
  - Perform neutron run at the ENEA facility (under discussion)
- **DCANT**
  - Support and nanotubes observed to modify drift field
  - On going study to develop suitable support and substrate
- **CYGNUS-RD**
  - Verified isotropic emission of photons by the GEMs, implying that collected light follows optical rules (one over distance squared)
  - Cosmic tracks easy identified at 60 cm distance (i.e. 30 x 30 cm^2 area covered)
  - New beam test beginning Feb with attempt of atmospheric negative ion operation following gas mixtures tested by NITEC
  - Test of PMT inside TPC volume to measure times (minority carriers)

Backup

Carbon Nanotubes





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)