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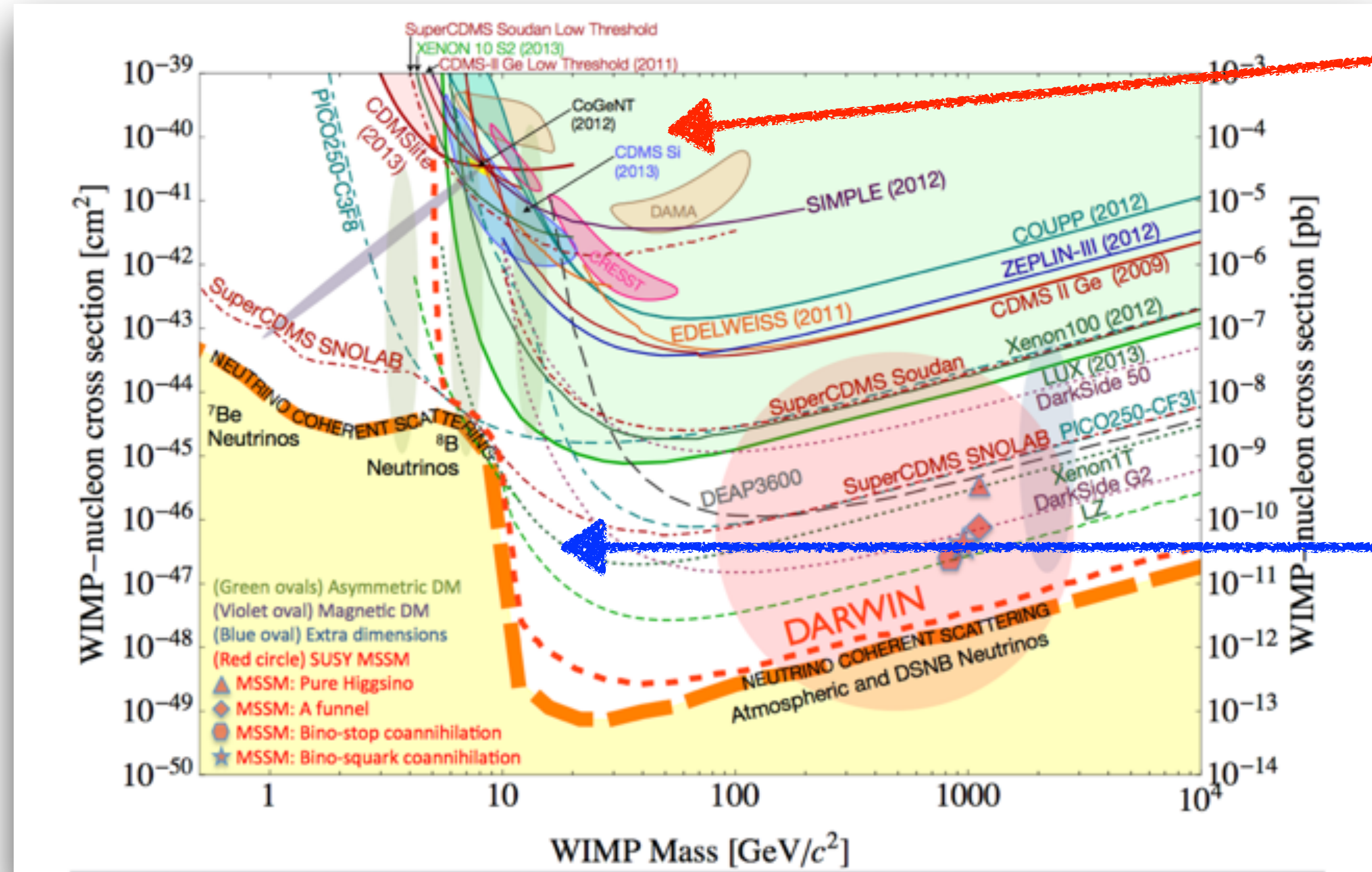
NITEC

a Negative Ion Time Expansion Chamber for directional Dark Matter searches

Consiglio di Laboratorio - Preventivi per il 2016

Direct Dark Matter Searches



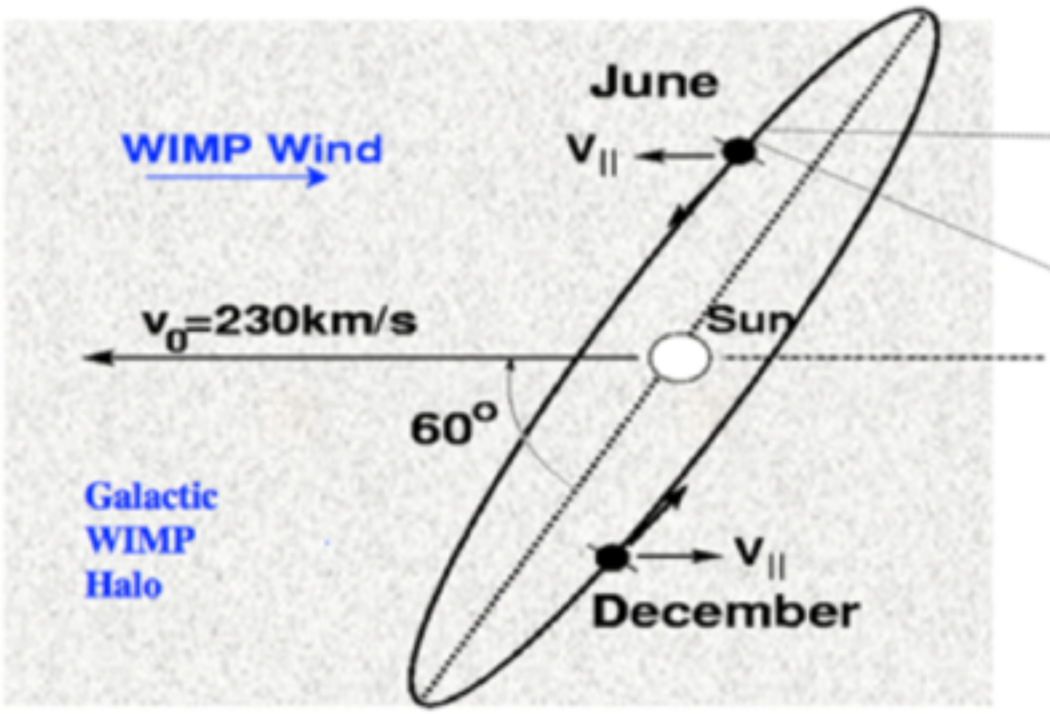
- Claims for detection inconsistent with exclusions limits
- Neutrino Floor: DM experiments sensitive to solar and diffuse neutrinos background, that gives EXACTLY same response as signal

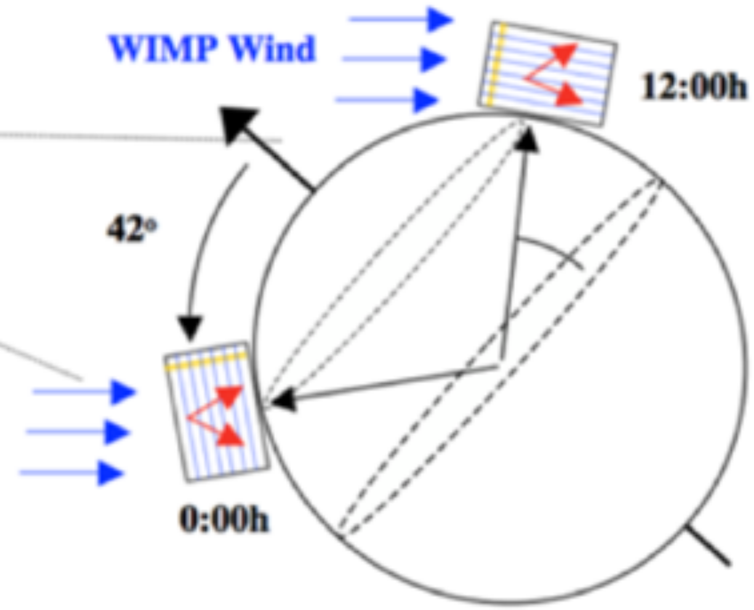
Next generation experiments will need an additional handle on top of rate and energy to discriminate signal from background: DIRECTIONALITY

The power of direction

- *Annual Modulation:* as a result of Earth motion relative to WIMP halo; rate modulation with a period of 1 year and phase ~2 June; large mass required (~2% effect)

- *Diurnal Direction Modulation:* Earth rotation about its axis, oriented at angle w/respect to WIMP "wind", change the signal direction by 90 degree every 12 hrs. ~30% effect.

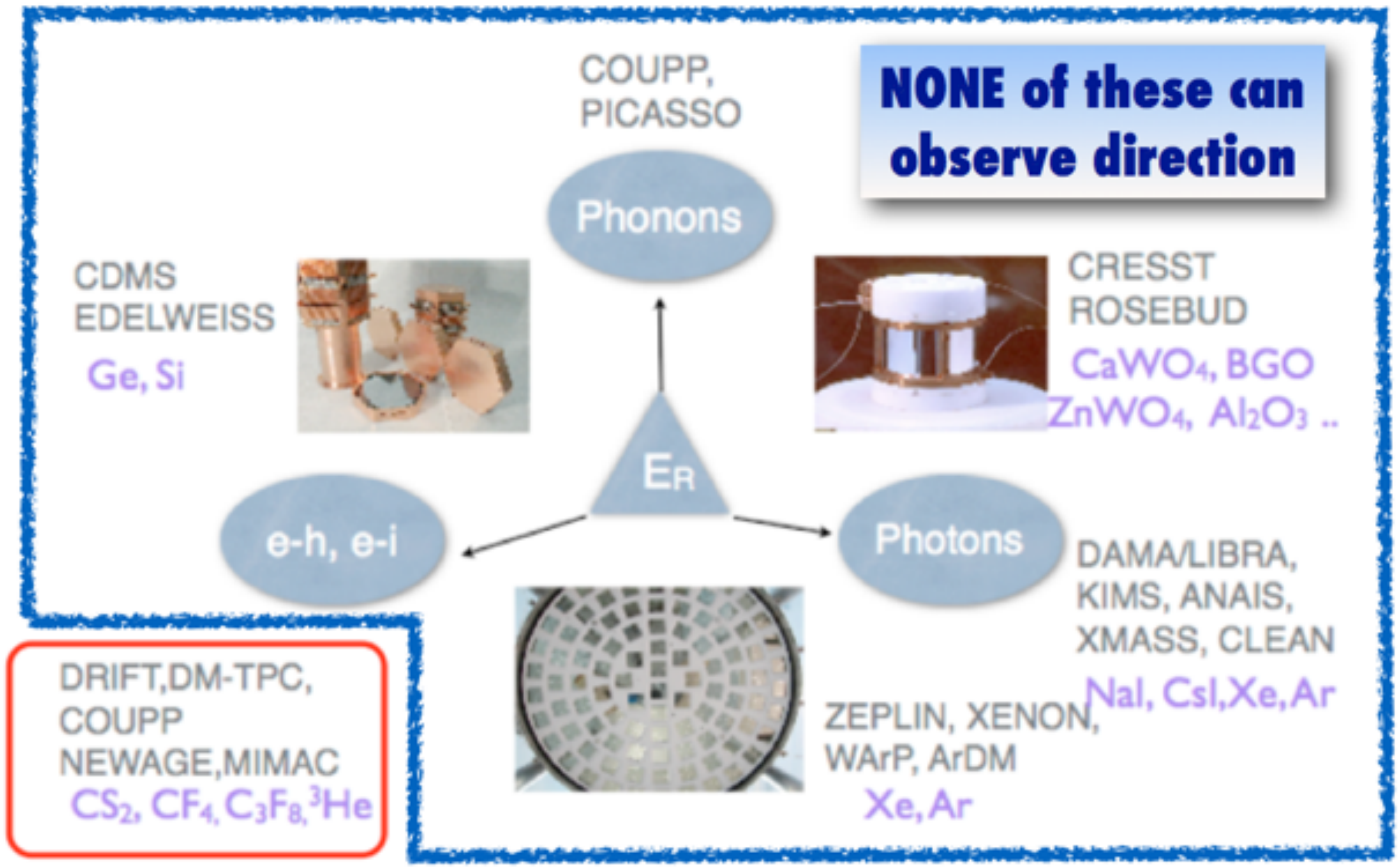




No background <u>whatsoever</u> can mimic a directional correlation with an astrophysical source

<u>PLUS: directionality is the only tool that allows to reject the neutrinos background from the Sun</u>

DM Direct Detection Experiments



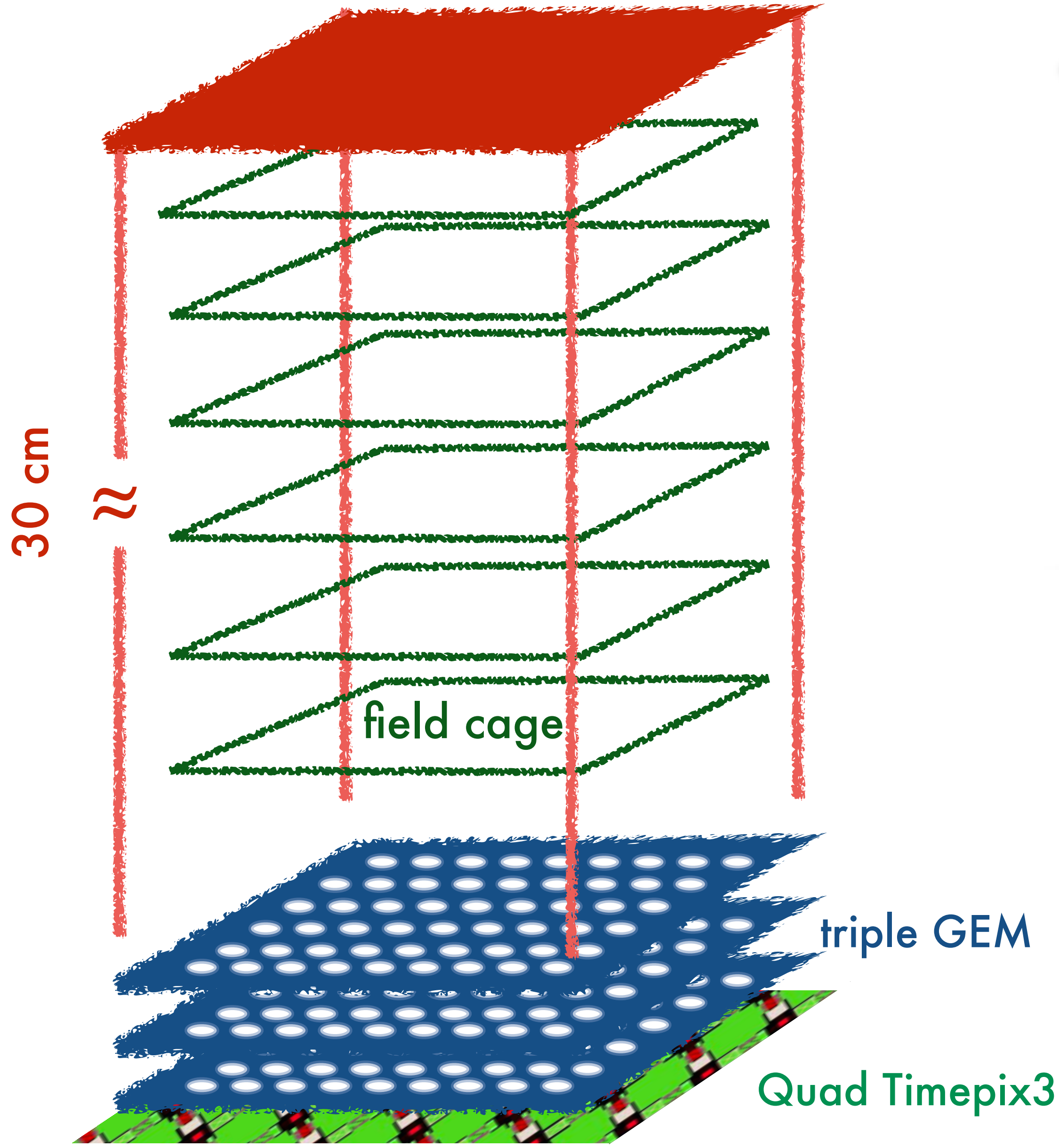
DRAWBACK: small masses

Low pressure gas detector in order to observe direction at these energies

- Directional gaseous detectors potentially provide the best observables of any DM experiment:
  - total charge collected indicates energy of the recoil
  - comparison b/w track path and energy provide excellent rejection of alphas and electrons
  - the track itself indicates the axis of the recoil
  - measurement of charge (and dE/dx) along the path allows to infer the sense of direction

All these information offer much more efficient means to actively suppress background than any other experimental approach

NITEC project



3 x 3 cm^2

Started on 4/5/2015

MARIE SKŁODOWSKA-CURIE ACTIONS

 # 657751

Individual Fellowships (IF)

Call: H2020-MSCA-IF-2014

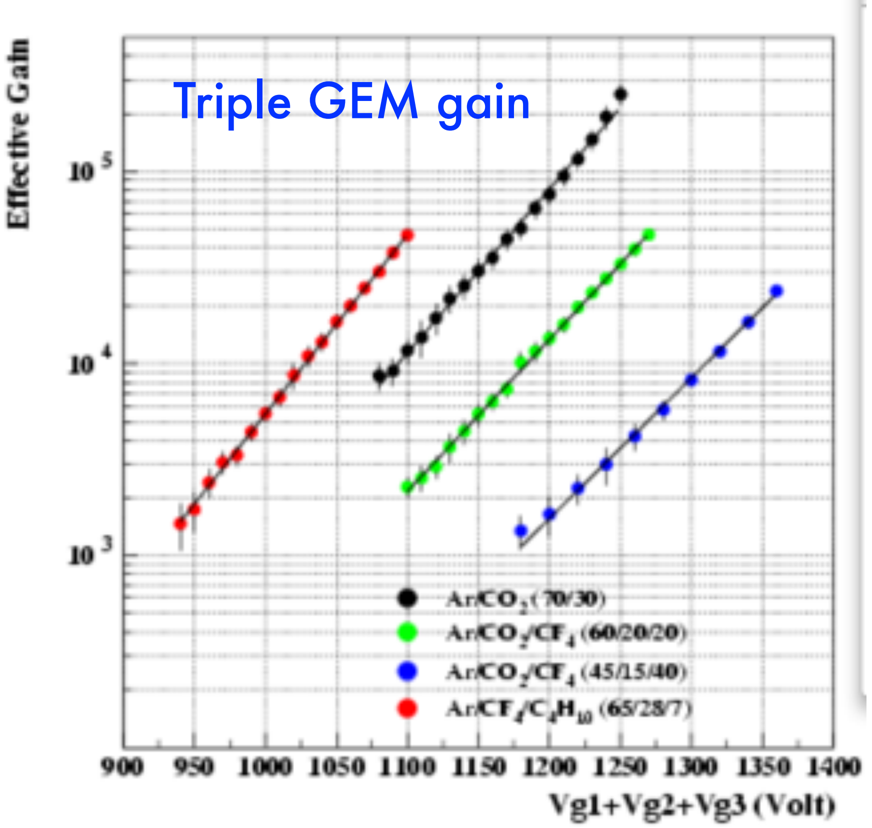
- A Negative Ion Time Expansion Chamber for very rare event searches
  - Negative ions as image carrier
  - 30 cm drift distance
  - Triple GEM amplification
  - CMOS pixel readout

GEMPix

Innovation: first combination of negative ion concept with GEM amplification and CMOS pixel readout

- Prove capability of:
  - 3D reconstruction of the recoiling track with O(200) um spatial resolution
  - Low energy threshold with signal/background discrimination below 50 keV
  - Sense ("head-tail") discrimination down to about 50 keV
  - 30 cm drift distance with very small disruption of performances due to diffusion

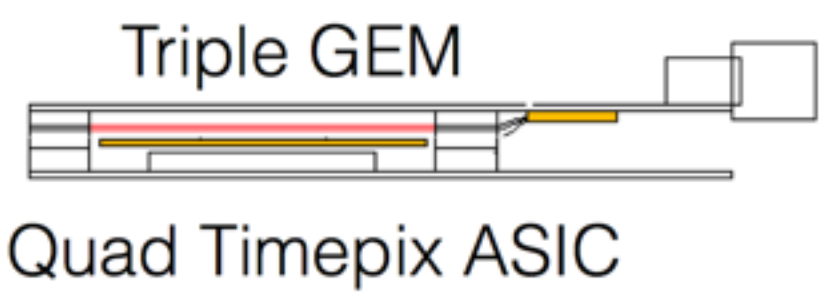
GEMPix



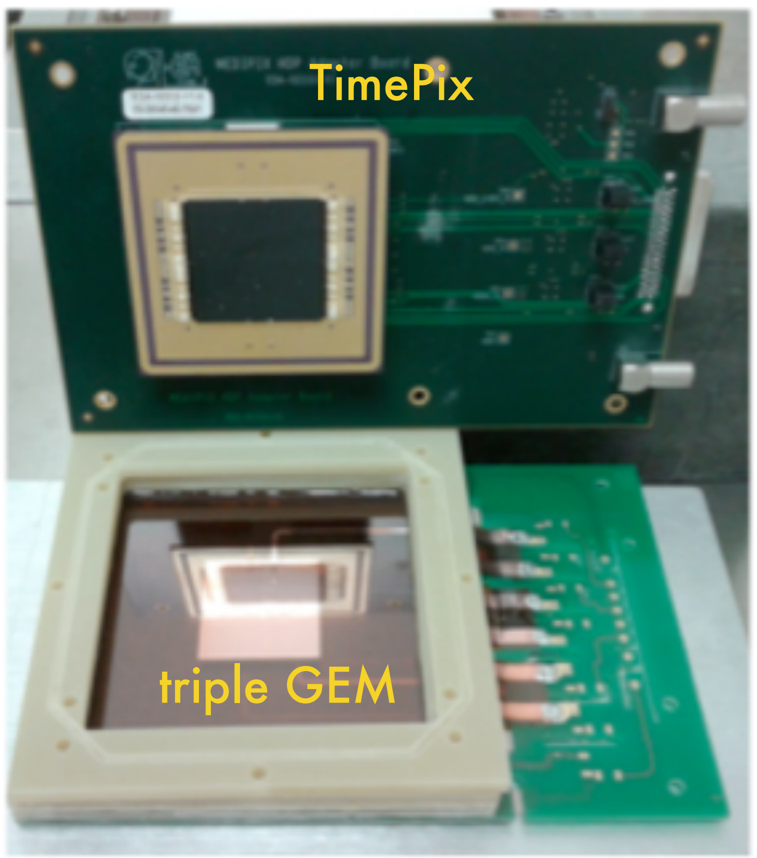
GEM amplification gives:

- 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>

Triple GEM detector with HV filters and connector



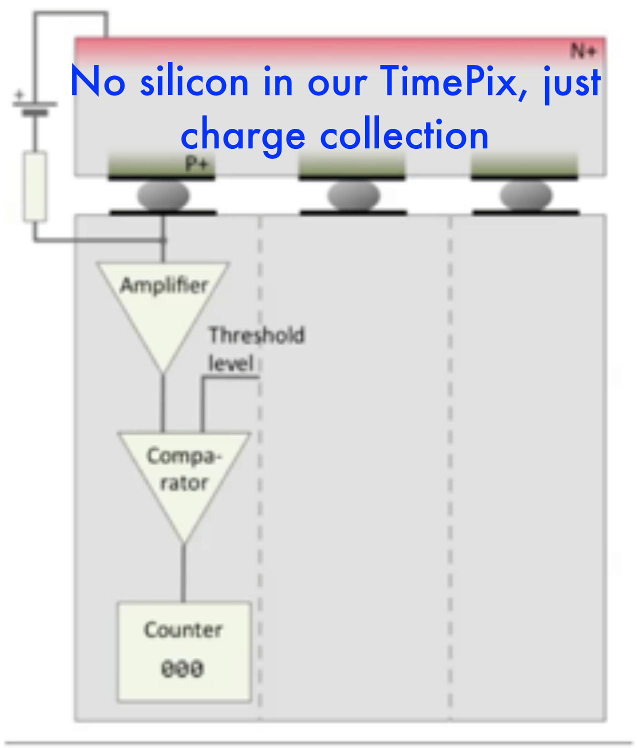
Quad Timepix ASIC board with naked devices (i.e. no silicon)

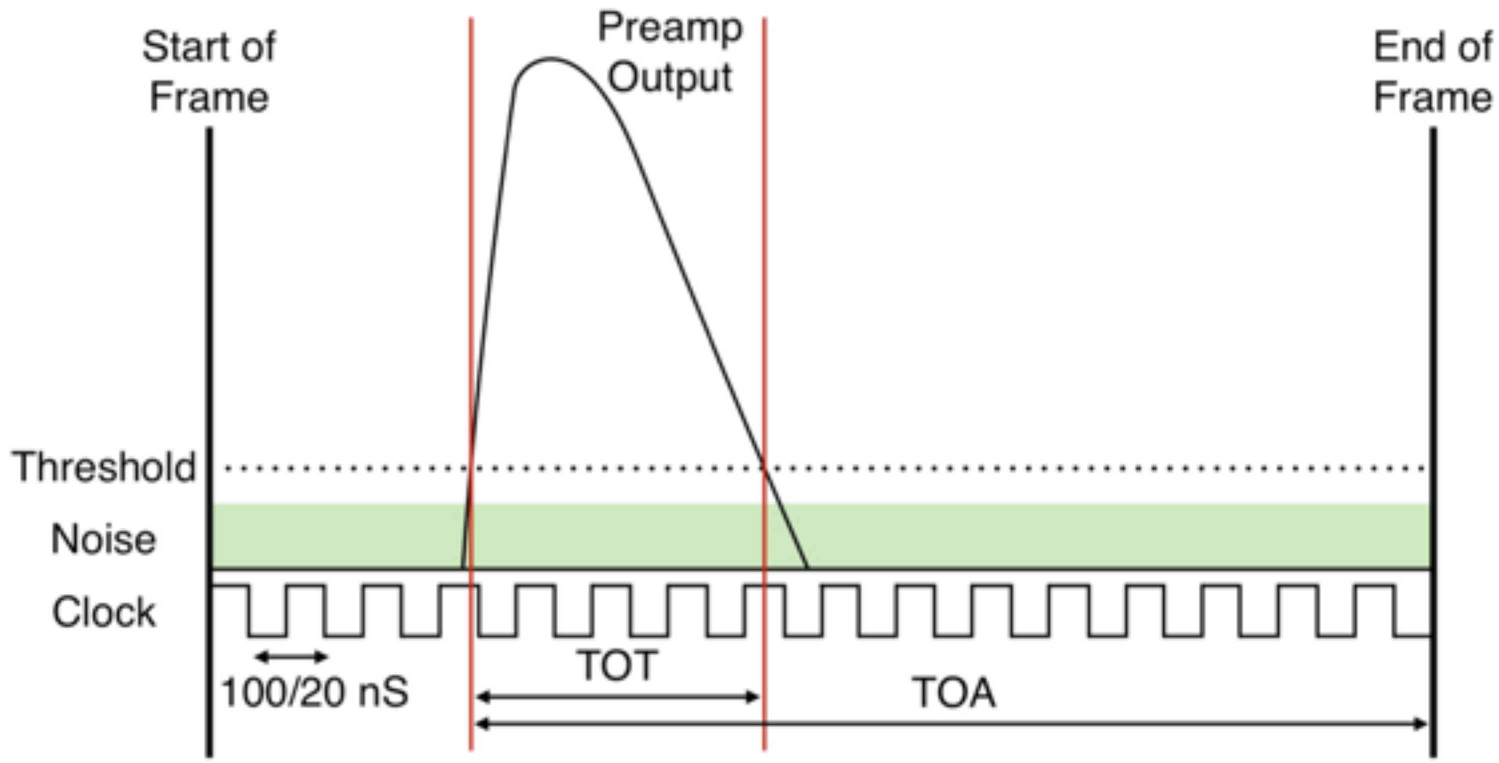


Developed by LNF in collaboration with CERN

TimePix

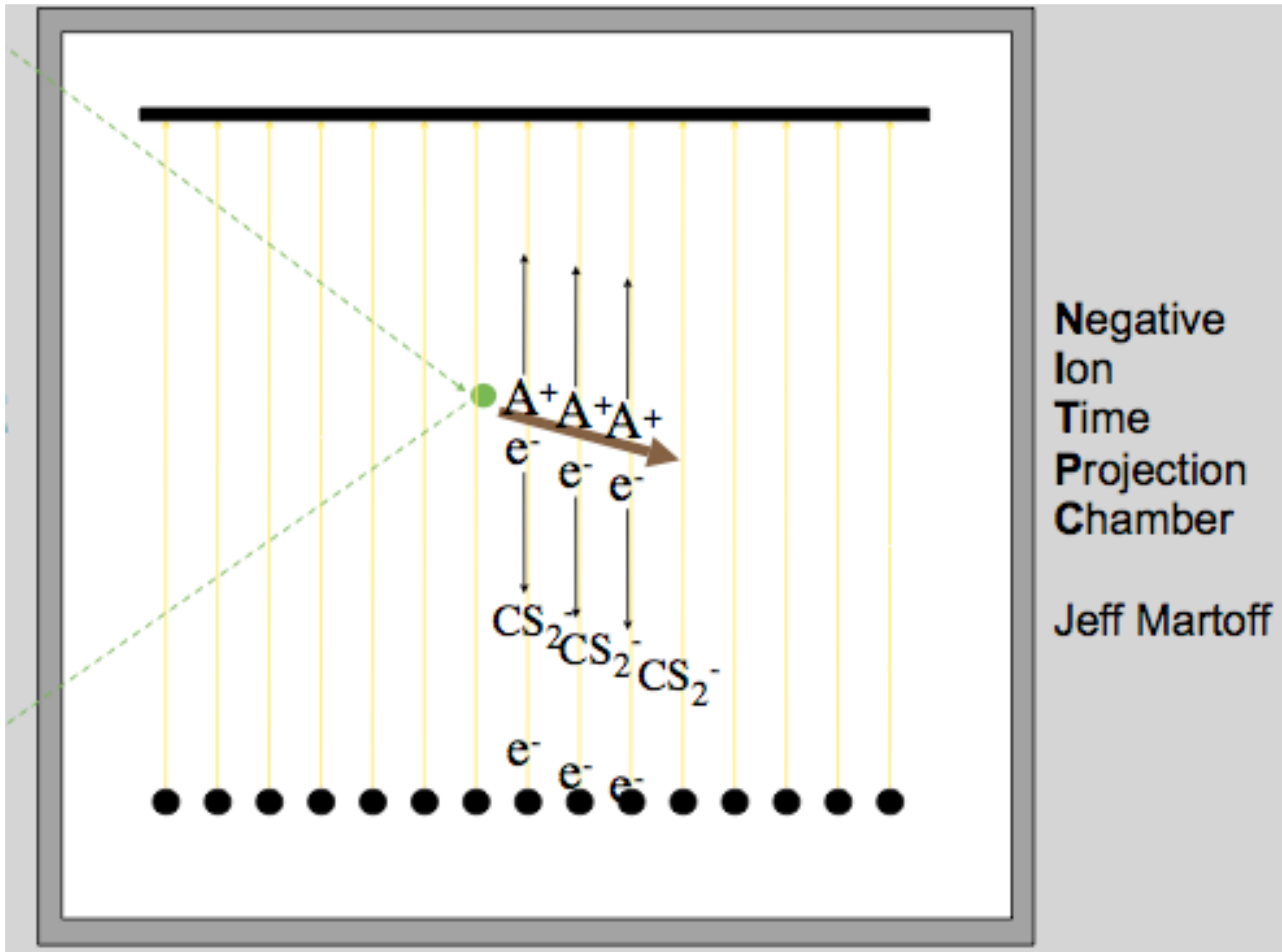
- TimePix is a pixelated silicon detector developed by MediPix2 collaboration
- We use a 2x2 array for a total of 512x512 pixel of 55 um side WITHOUT silicon sensors
- Processing electronics, including preamplifiers, discriminator threshold and pseudo-random counter fit inside the footprint of the overlying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





- Timepix clock can run at 1, 10 or 50 Mhz (100 as well, but unstable)
- Timepix counter depth is 11810 —> limits total acquisition time —> is ok for negative ion slow drift as well

Negative Ion drift



< 0.5 mm diffusion achieved over 0.5 m drift length w.r.t. 10 mm obtained with electrons (no magnetic field)

J. Martoff et al., NIM A 440 355

T. Ohnuki et al., NIM A 463

- Mixture of target gas + electronegative gas (typically CS_2)
- Primary ionization electrons are captured by the electronegative molecules at O(100) um
- Anions drift to the anode acting as the effective image carrier instead of the electrons
- Thanks to the much higher anions mass w.r.t. electrons, longitudinal and transversal diffusion is reduced to thermal limit w/out any magnetic field
- At the anode, the electron is stripped from the anion and normal electron avalanche occurs

Address TPC typical volume limitations

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 can 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 (< 1 keV)

"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)

State of the art

Collaboration	Technology	Amplification & Readout	Target	Absolute Z	Drift distance (cm)
DRIFT	NITPC	MWPC	CS	Yes	50
DMTPC	TPC	Mesh chambers + CCD + PMT	CF	R&D	20
NEWAGE	TPC	Micro Pixel Chamber	CF	R&D	30
MIMAC	TPC	Pixelized Micromegas	CF	R&D	25
D3	TPC	Double GEM + pixel	CF	R&D	9
NITEC	NITPC	Triple GEM + pixel	CS CH	Feasible as in DRIFT	20

Current experimental challenges

- **Absolute z measurement** (available only to DRIFT thanks to negative ions minority carriers)
- **Possibility to large active mass with low costs** (all except DRIFT limited to <=25 cm drift length)
- **3D track reconstruction with sense determination** (not available to all and for most limited to >= 100 keV)
- **Lowest possible energy threshold** (typical ~ 50 keV)

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NITEC main features

- **Negative Ions Time Projection chamber** –> larger allowed drift length + possibility to measure absolute z position thanks to minority carriers
- **Triple GEM amplification + pixel readout** –> state of the art spatial, time and energy resolution, sense determination via dE/dx and time measurement along path, low energy threshold thanks to high GEM gain
- **GEMPix + negative ion** –> improved position and energy resolution and best possible dE/dx
- **Explore alternative capture agents** –> CH_3NO_2 and SF_6 for easier handling and different EA

Prospectives of Collaboration

Main actors of directional Dark Matter detection + me have started (since less than one month..) discussing the possibility of forming an international collaboration for the development, construction and operation of a "some" cubic meters directional dark matter detector

- DRIFT
- DMTPC
- NEWAGE
- MIMAC
- D3
- NITEC

Everything still to be defined (bylaws for the collaboration,physics case, readout, target, etc...) but opens interesting possibilities for the lab, if LNF & INFN interested in this collaboration

Marie Curie Philosophy

Marie Curie Individual Fellowship

“aim at enhancing the creative and innovative potential of experience researchers […] through advanced training, international and inter-sectoral mobility”

“provides financial support for individual experienced researchers who want to work in host organizations”

Marie Curie Individual Fellowship do not fund a research

Team & Budget

1 FTE + collaborators

- E. Baracchini 100% (primo ricercatore TD, art. 20)
- In collaboration with
  - G. Bencivenni (primo ricercatore)
  - F. Murtas (primo ricercatore)
  - D. Domenici (ricercatore)

MARIE SKŁODOWSKA-CURIE ACTIONS
 # 657751
Individual Fellowships (IF)
Call: H2020-MSCA-IF-2014

May 2015 - May 2017

LNF is the sole participant

Marie Curie Individual Fellowship do not require to define FTE from collaborators

Participant Number	Organisation Short Name	Country	Country Coefficient	Number of Person Months	Institutional Unit Cost	
					Research, training and networking costs	Management and Overheads
1	INFN	IT	1,067	24	19 200	15 600

for 2 years!!!

Marie Curie Individual Fellowship funds are fixed amount
independent from the proposed project

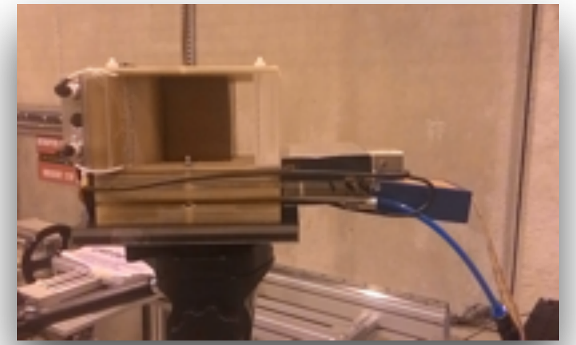
all activities are LNF activities...

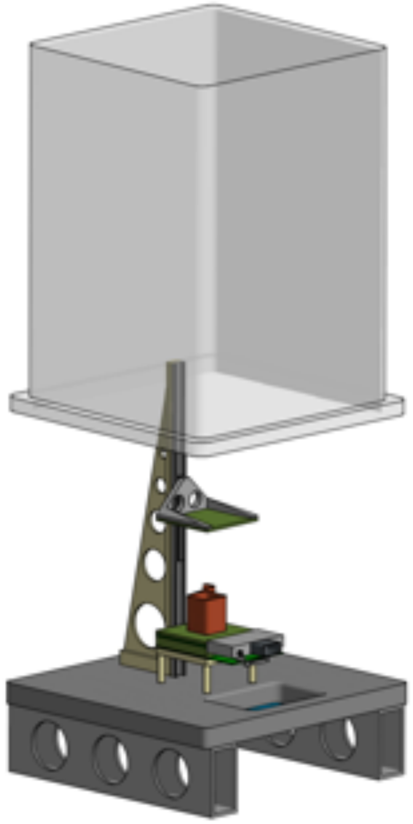
2015 Activities

Marie Curie started 4/5/2015

start test with cosmic by this/next week

- Work with an already existing 5 cm drift distance prototype (where everything is lent, including lab space, from somebody else...)
- Test conventional TPC electron-carrier configuration
- Test with laser (della sezione acceleratori)
- Design and build vessel for use with low pressure/electronegative gas mixture
  - In collaboration with Roma1: we share interest for the same kind of detector
  - Vessel construction and design provided by Roma1
  - 1 settimana FTE dal servizio di elettronica per consulenza su integrazione TPC nel vessel
- Test at BTF with low pressure/electronegative gas mixture
  - In October, again thanks to Roma1 collaborators
- Start studying and designing the gas system
  - 1 mese FTE carpenteria + 1 mese FTE officina meccanica per un miscelatore
  - CS_2 and CH_3NO_2 possess safety issues to be properly addressed, waiting for feedback from safety department to understand what the law requires
- Start acquiring material and develop design for the 20 cm prototype





all activities are LNF activities...

2016 Activities

- Setup of a lab with a proper gas system for the use of CS_2 and CH_3NO_2
  - Where? ....depends on safety issues
  - How much? ....depends on safety issues...
  - How many FTE to require to who exactly? ...depends on safety issues...
- Design and build 20-30 cm drift distance prototype
  - 1 mese FTE dal servizio di elettronica per l'integrazione dell'elettronica
  - Supporto dai collaboratori
- Build a new vessel? ..depends on how collaboration with Roma1 will continue...
- Test and characterization of long prototype at the BTF
- Measurement of ion drift properties with laser
- Test at XLAB?

Fund allocation & backup solutions

	Cost	backup solution for lower costs
Detector	3000	no solution
HV & DAQ	6700	borrow?
Vacuum Pump	6000	can borrow from sezione acceleratori for limited time
Gas system	??????	Use only SF
Gas	2000	test fewer mixtures
Laser system	10000++	use the one in sezione acceleratori
PC for DAQ	2000	use personal PC
Vessel + feedthrough ???	5000++	keep using the one built by Roma1
Travel & Conferences	4000 ??	have only video meeting

Needed 39000++++ **Funded 19200**

Fund allocation & backup solutions

There exists constraints on Marie Curie recipients for requests of additional funds to INFN commissions: we are studying a possible way out

Could it be possible to recover at least part of "Management & Overhead" funds (15600 euros)?

Needed 39000++++ Funded 19200

La piccola fiammiferaia

enough to start the project...

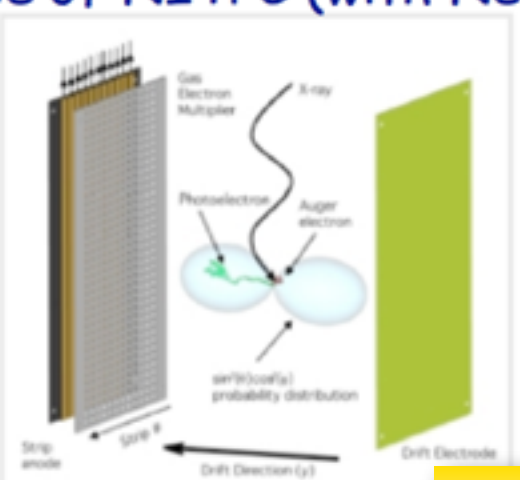
....but probably not enough matches to get to the end of the night.....

Backup

Not only DM: Alternative Applications

X ray polarimetry

- A photoelectron is emitted preferentially aligned with the electric field of the incident photon
  - Measurement of photoelectron direction provide information on photon polarization state
- Very few measurements of X ray polarization
- Can probe exotic astrophysical processes with the strongest gravitational and magnetic fields
- The community has just started to explore the use of NITPC (with Ne) [arXiv:1107.3079]



Neutrinoless double beta decay searches with light readout

- A NITEC capable of counting each primary free electron liberated in a Xe gas by an ionizing event, will approach the intrinsic fluctuations in the conversion of energy to ionization [D.Nygren, JPCS 65 012003]
- Even with counting efficiency significantly less than 100%, a 5×10^{-3} FWHM energy resolution could be achieved
- First tests with a 17 bar Xe conventional TPC show very encouraging results (1% FWHM) [A. Goldschmidt et al, IEEE NSSCR 1409]

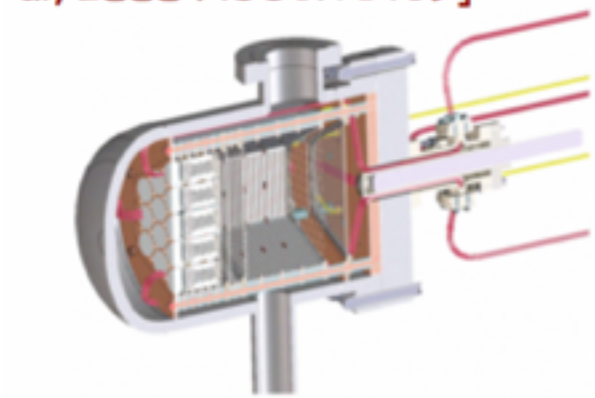
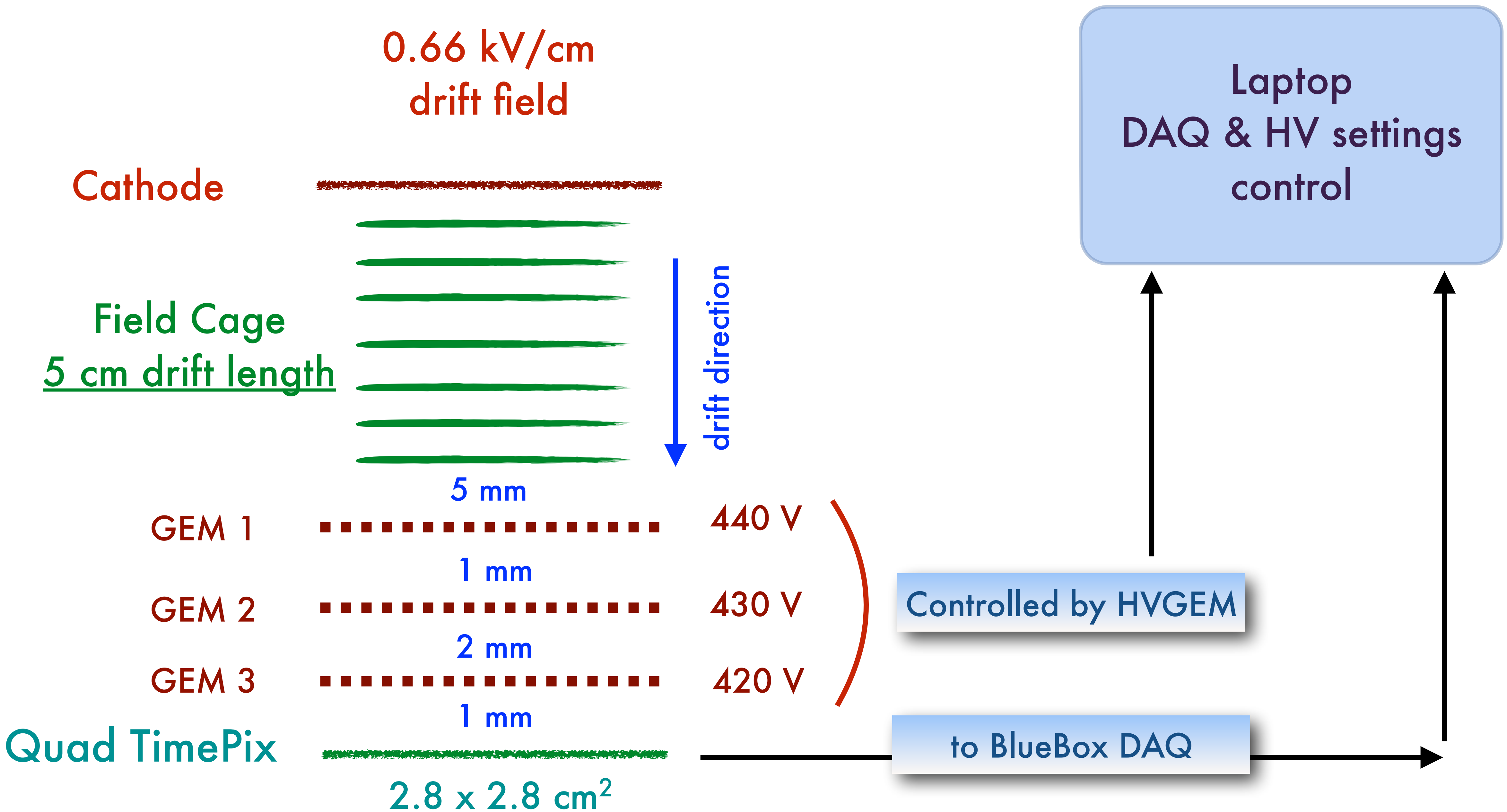


Fig. 1. Cross section of the TPC. Wire meshes separate the 19-PMT array from several regions, beginning at the mesh in front of the PMT array, from left to right: a 5 cm buffer region, an 8 cm drift region, a 3 mm EL gap, and ... region. (Drawing by Robin LaFever.)

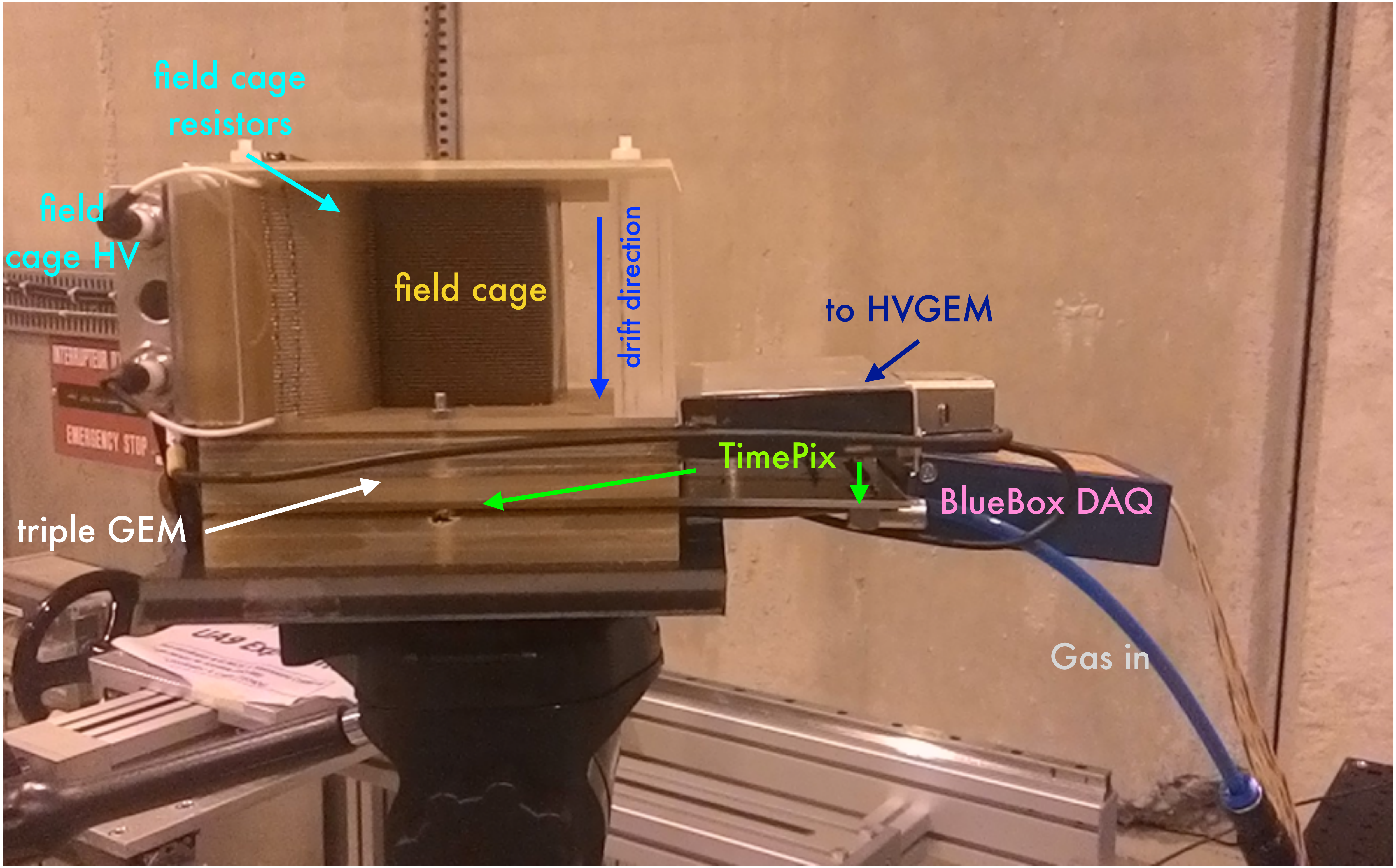
both with CH_3NO_2 as capture agent

A first prototype: schematically



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

A first prototype: for real



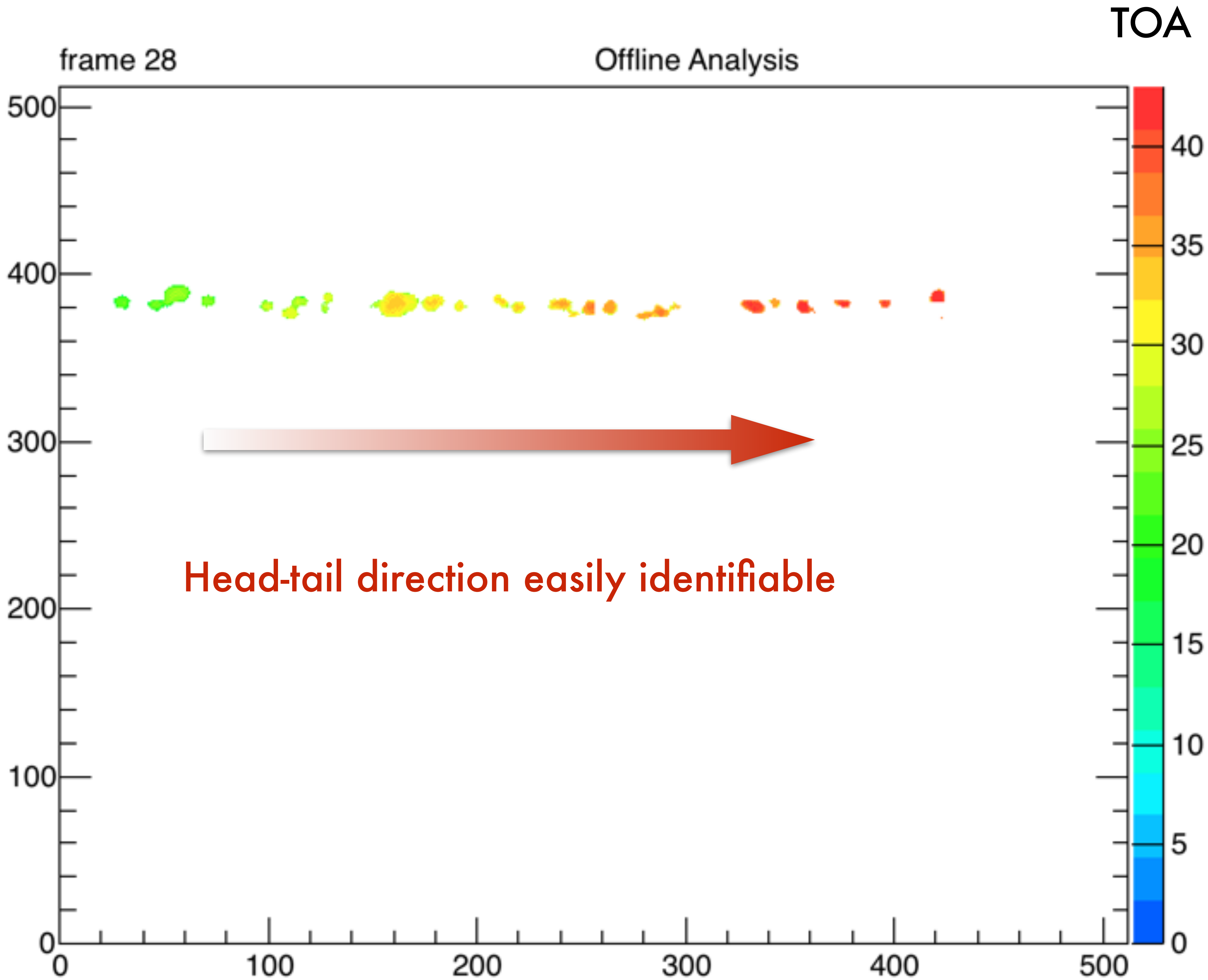
First tests and preliminary results*

Some caveats:

- $Ar:CO_2:CF_4$ mixture in 45:15:40 proportion (classical electron-carrier TPC)
- Not optimized field cage HV and GEM HV settings
- H8 beam line at CERN with ~ 400 GeV/c protons (not for DM searches...)
- Not optimal position (parassiting somebodyelse's beam test....)
- 48 MHz DAQ acquisition in TOA only (as soon as another test is available will be mixed mode) with external trigger
- FITPix system and Pixelman software to readout TimePix data, MAfalda ROOT-based framework to interface with them, but full data analysis still to be developed

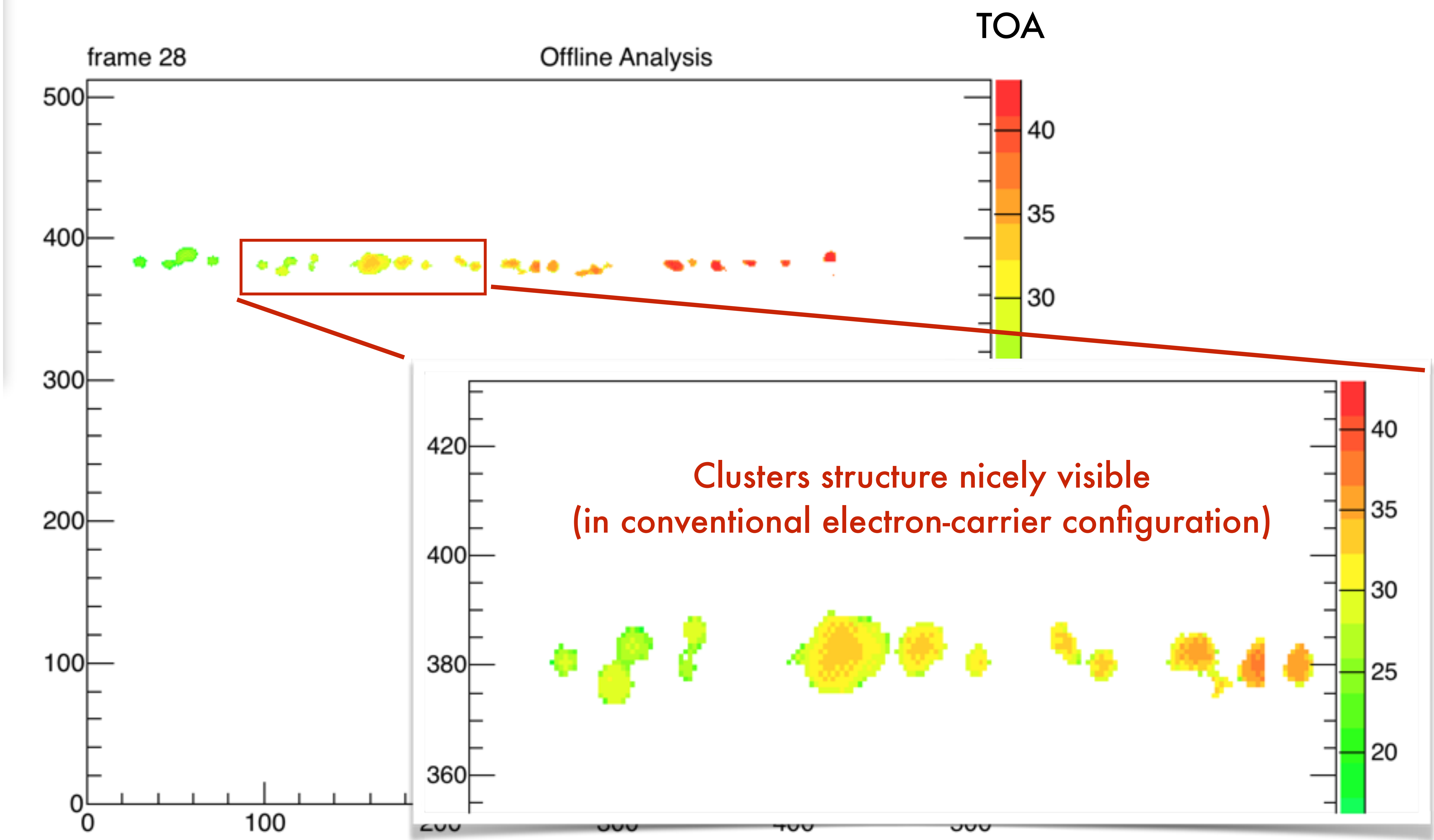
* Please note this TPC was turned on first time less than 1 month ago....

Some events



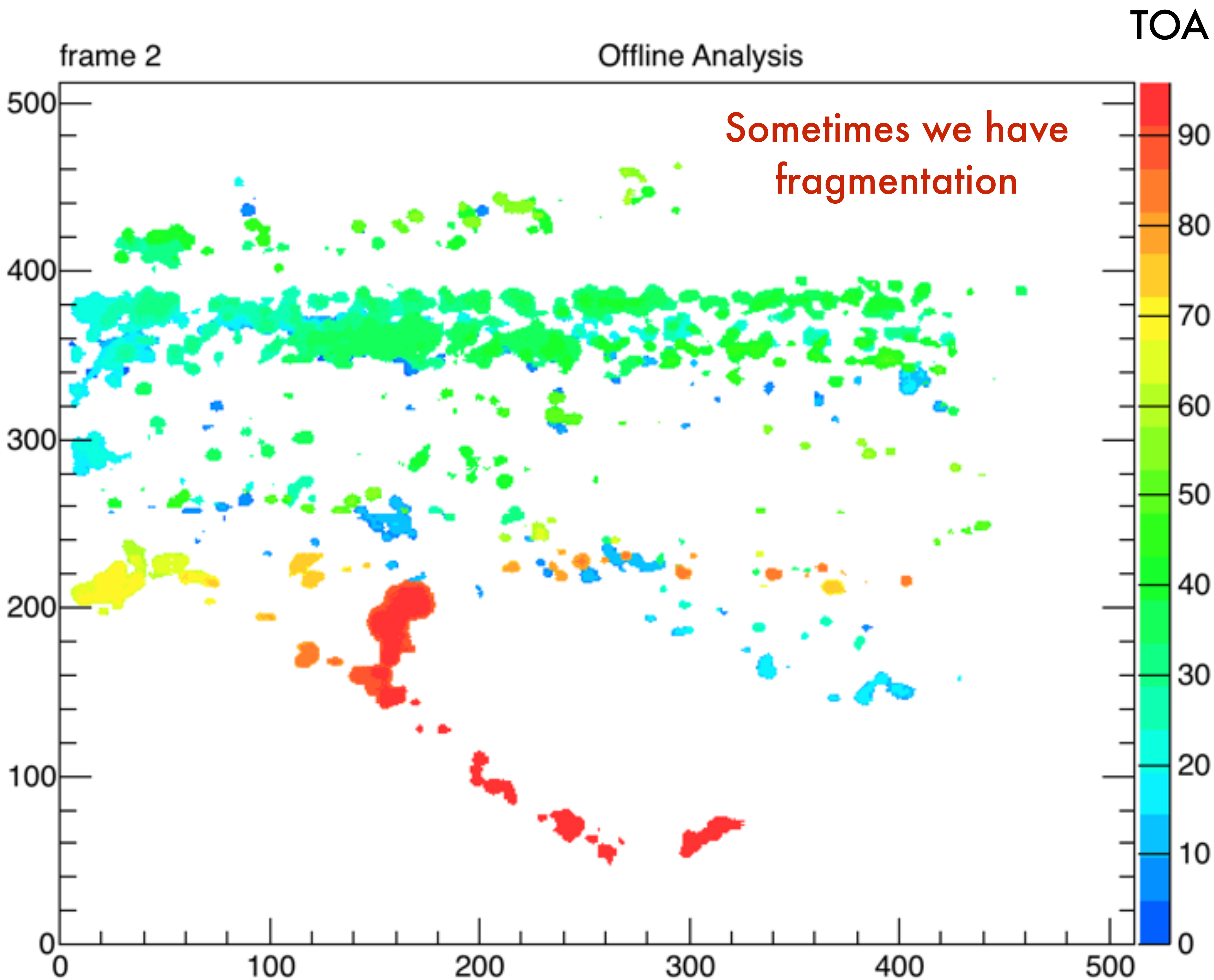
TOA
frame 28
Offline Analysis
Head-tail direction easily identifiable

Some events

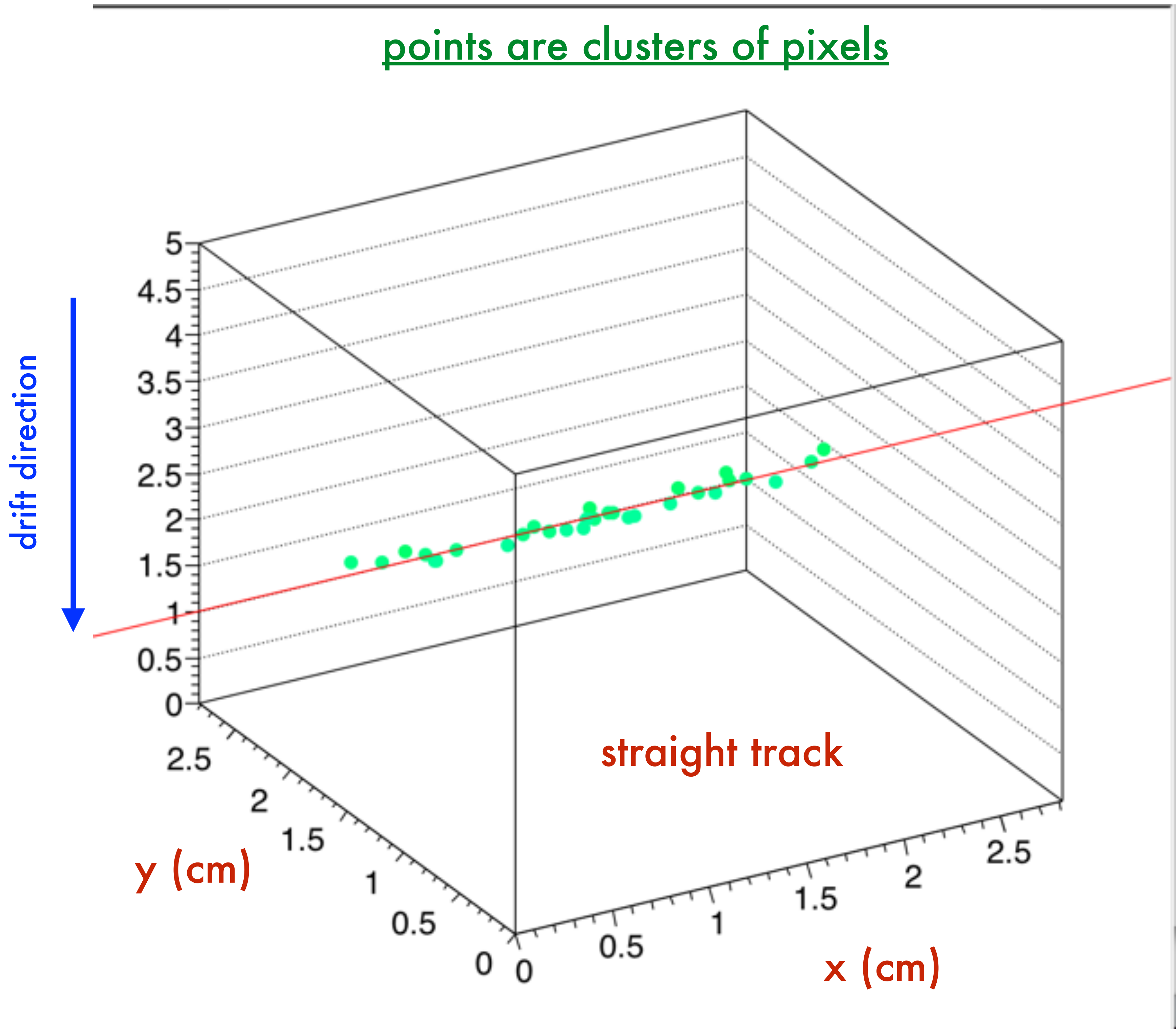


TOA
frame 28
Offline Analysis
500
400
300
200
100
0
0
100
40
35
30
420
400
380
360
40
35
30
25
20
Clusters structure nicely visible
(in conventional electron-carrier configuration)

Some events

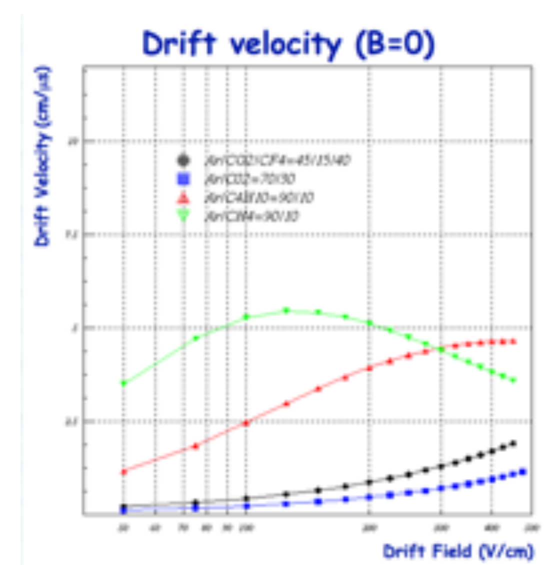

TOA
frame 2
Offline Analysis
Sometimes we have fragmentation
500
400
300
200
100
0
0
100
200
300
400
500
90
80
70
60
50
40
30
20
10
0

A preliminary 3D fit



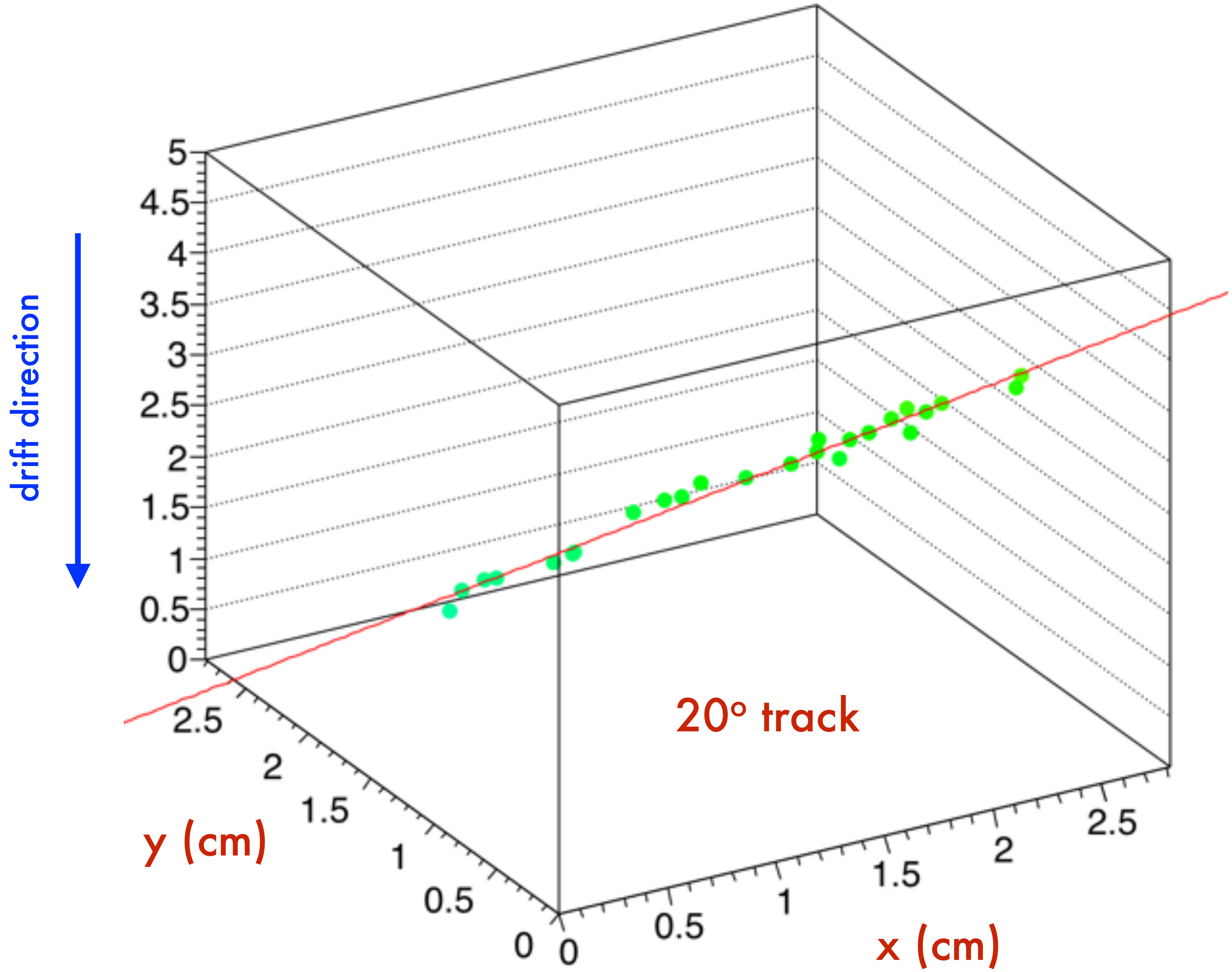
Several caveats:

- Ar:CO_2:CF_4 mixture drift velocity from literature
- Fit to centroid of clusters of pixels
- Default clustering code from Mafalda framework, to be optimized
- Completely unoptimized reconstruction & fit, only as demonstrator
- External trigger



A preliminary 3D fit

points are clusters of pixels



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