NoAmpTPC: study on a direct readout of ionization electrons for TPC

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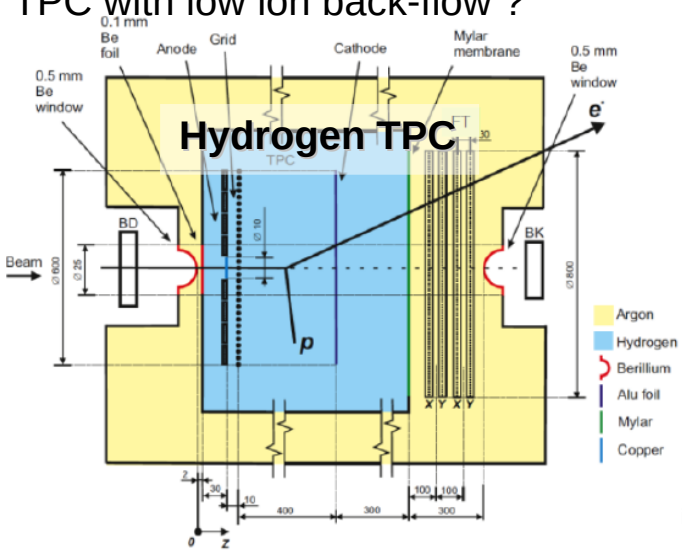
Motivation for the NoAmpTPC read-out project

Interest of direct read-out of ionization electrons

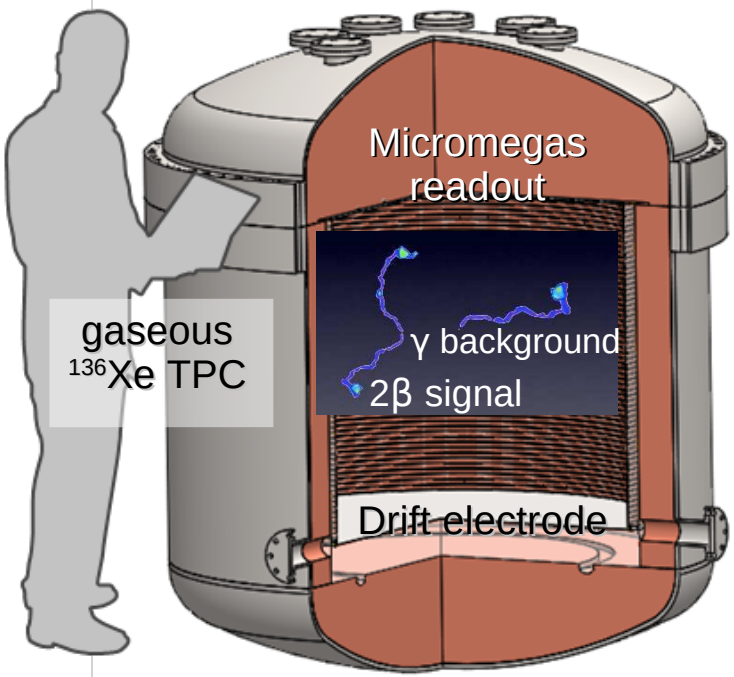
- Better energy resolution expected compared to gaseous amplification methods, if very low noise level compared to amount of primary electrons
- Less constraints on choice of the gas mixture
- Simplified read-out → robust TPC
- No ion production
- Large segmentation of the read-out → rather good spatial resolution (1-2 mm)

Possible applications

- Search for neutrinoless double-beta decay in high pressure Xenon 136 gaseous TPC → PandaX-III experiment
- High pressure hydrogen TPC as target for tracking of low momentum recoil protons
- TPC with low ion back-flow ?



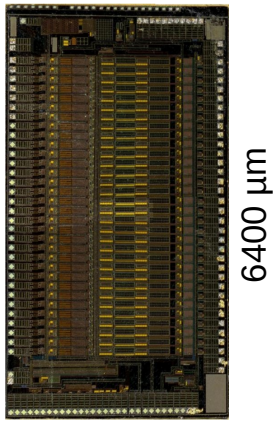
PandaX-III experiment



The NoAmpTPC read-out project

Principle of the read-out

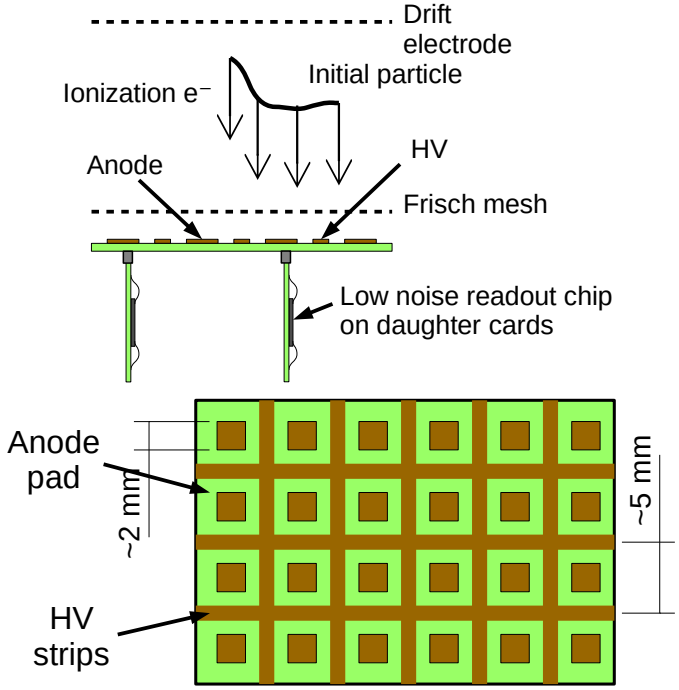
- Read-out board with large segmentation and very low-noise electronics
- Small read-out pads with Frish grid + focusing by polarized strips
- Very low-noise front-end chips → IDeF-X LXE (100 e^- with 10 pF capacitance) mounted on board or on daughter cards on the back side
- Electronics readout chain based on DREAM chip



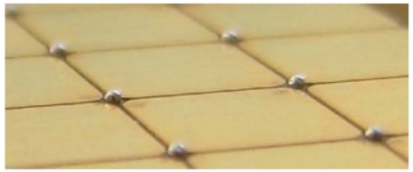
2800 µm

IDeF-X HD LXe chip
32 channels
Configurable peaking time:
1 – 13 µs

Principle of the detection

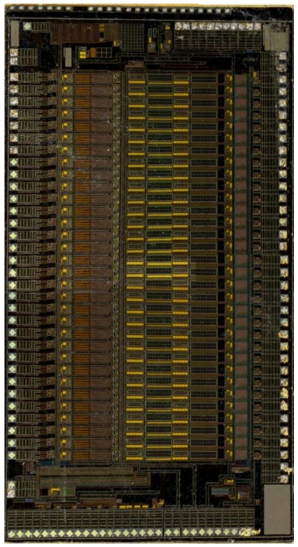


Idea from XEMIS project (liquid Xe TPC)



MIMELI project
D. Thers (Subatech)

IDeF-X HD (LXE) performance

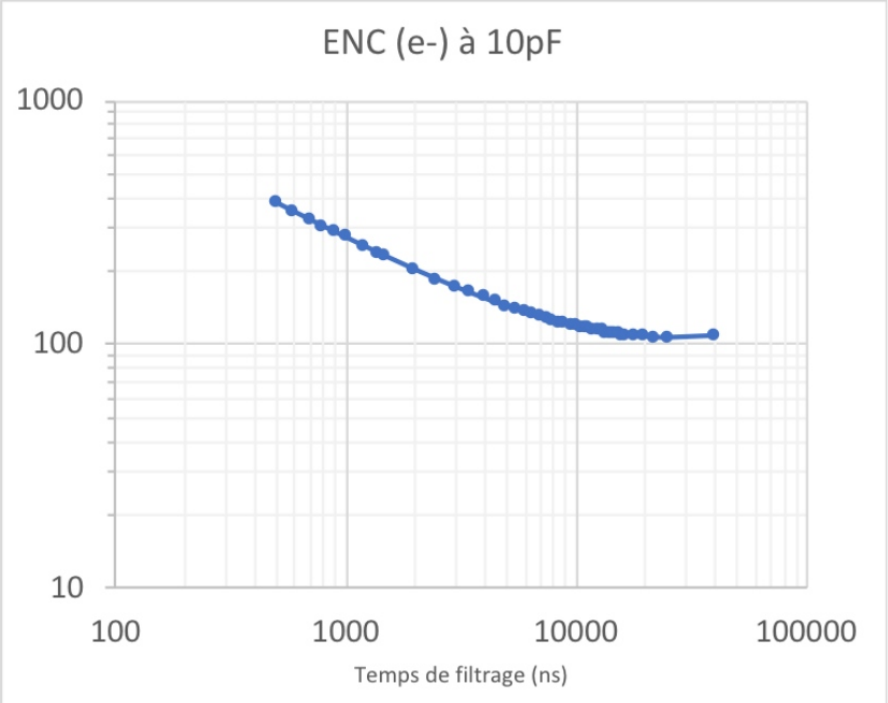


6400 µm

2800 µm

IDeF-X chip family designed at CEA Saclay IRFU to read CdTe solid detectors

LXE version used for XEMIS project (liquid Xenon TPC, D.Thers, Subatech) for 3 gammas medical imaging, 32 channels, amplification + shaping



Noise levels :

- 80 e^- + 15 e^-/pF with 1 µs peaking time
- 33 e^- + 6 e^-/pF with 12 µs peaking time

Remaining of the read-out chain

Constraints

IDeF-X LXE chips only do amplification and shaping

Triggering, sampling, digitization and recording to be done by other electronics + DAQ

Need to record signal amplitude, time, optionally signal shape

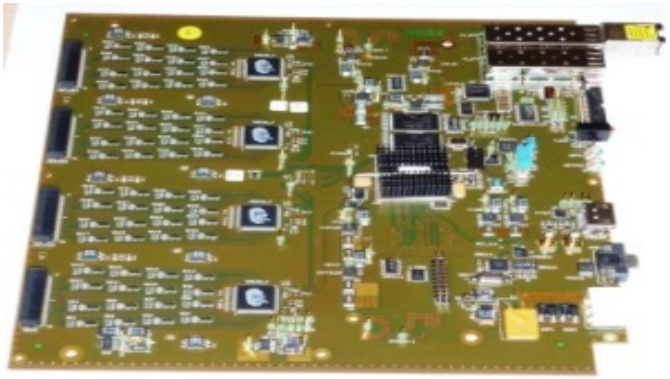
Possible electronics chain

Several front-end chips could be used to read signals from IDeF-X like DREAM or AGET (also VMM or SAMPA ?), with deactivated front-end

AGET and DREAM (IRFU + others): 64 channels, auto-triggable, analog sampling on SCA capacitor array (512 samples 1 to 50MHz), to be combined with ADC, front-end stages can be by-passed

Preliminary tests at Saclay

Using DREAM "FEU" (front-end unit) card with 8 chips (512 channels), 8-channel ADC chip integrated to the card, standalone DAQ

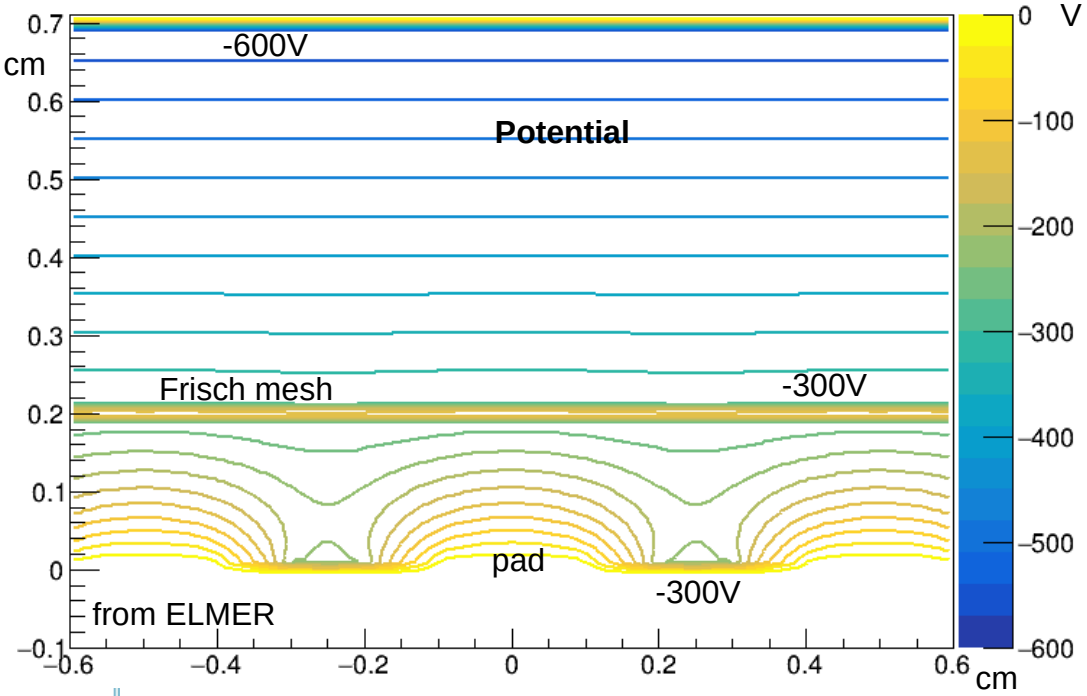


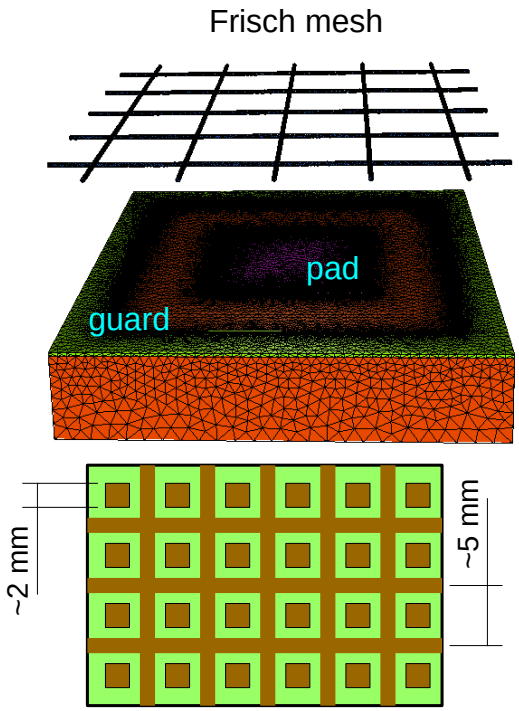
Garfield++ simulation of the read-out plane

Simulated design

- Read-out plane with electrode pads and focusing HV guard strips
- Amplitude of signal, electrons lost on Frisch mesh and on FR4
- Goal: optimization of pads/focusing guard strips geometry, evolution vs electrodes HV
- Method: GMSH (geometry, 2D/3D meshing) + ELMER (electric field) + Garfield++ (electron and ion drift), Ar+5% isobutane gas mixture 1 bar

from GMSH





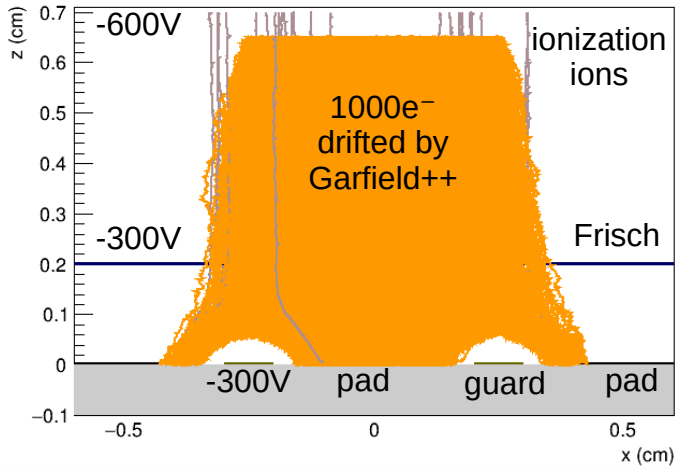
Garfield++ simulation of the read-out plane

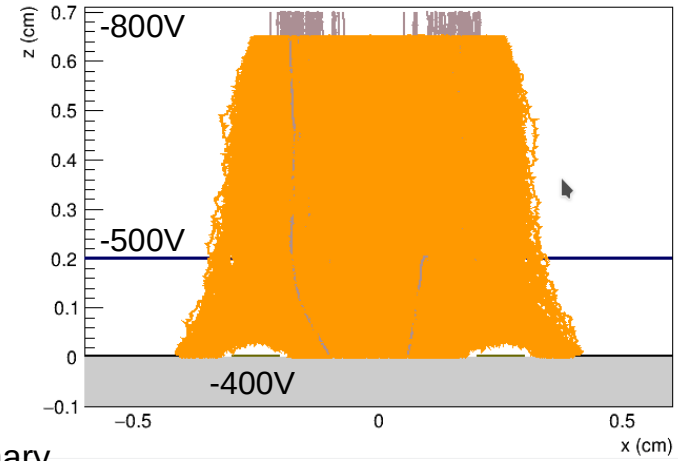
Dependence to the electrode voltage

Capture of electron by the Frisch mesh

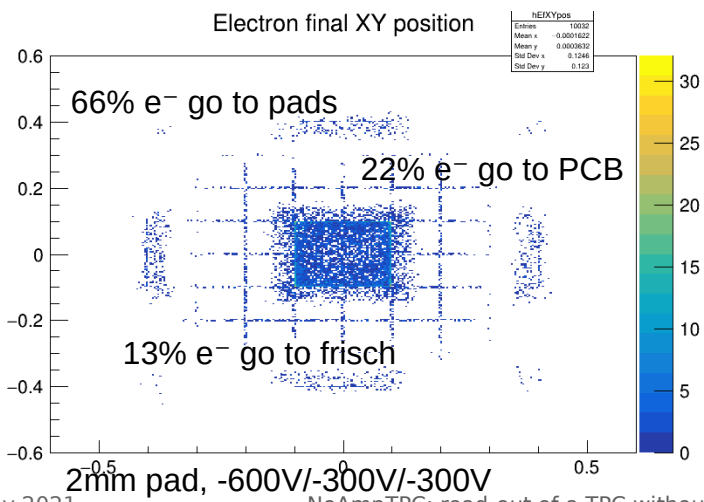
Efficiency of the guard electrodes to avoid e^- going to PCB insulator

Ion production at larger HV

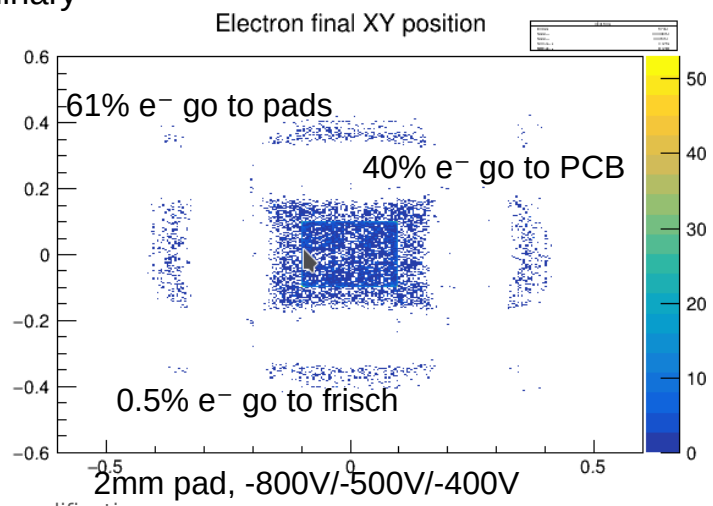




Preliminary



2mm pad, -600V/-300V/-300V



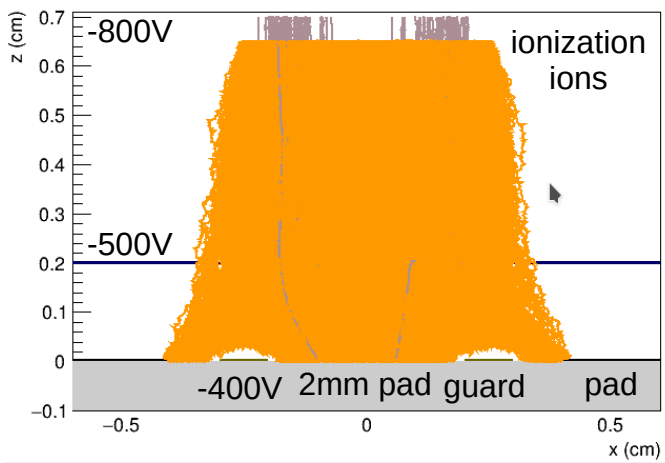
2mm pad, -800V/-500V/-400V

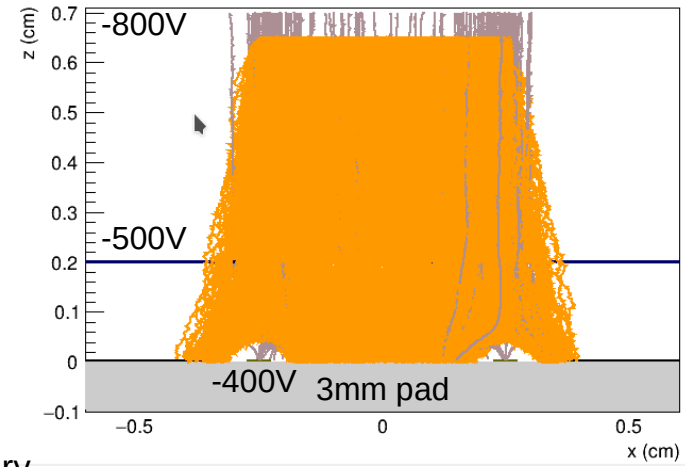
Garfield++ simulation of the read-out plane

Dependence to the read-out plane geometry

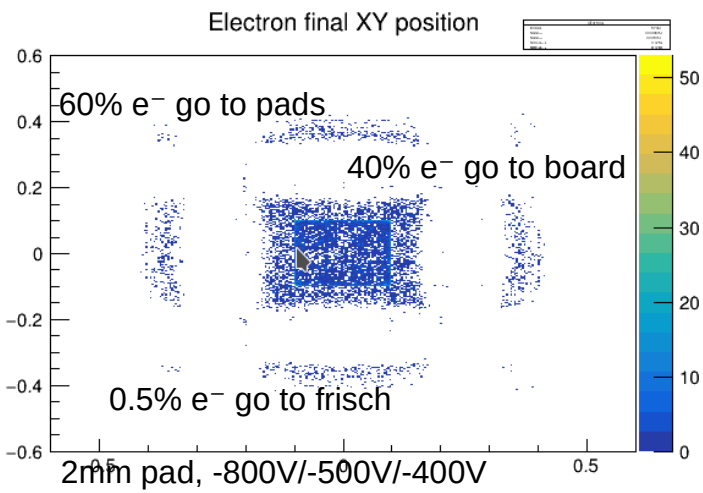
Larger pads to collect more electrons

But also larger capa → more noise ?

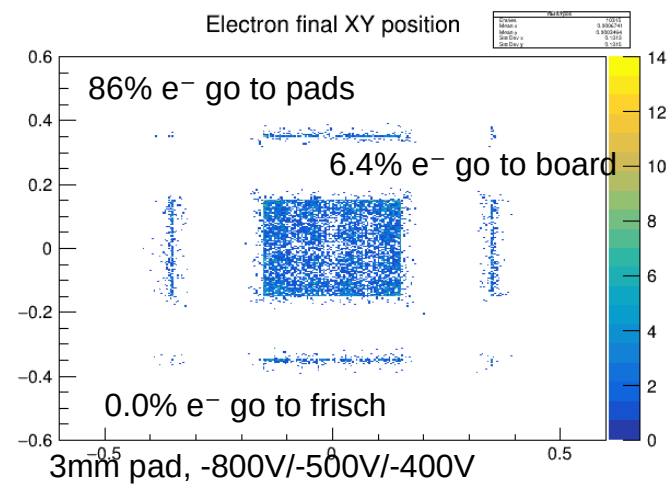




Preliminary



2mm pad, -800V/-500V/-400V



3mm pad, -800V/-500V/-400V

Garfield++ simulation: overview of performance

Several pad sizes tested

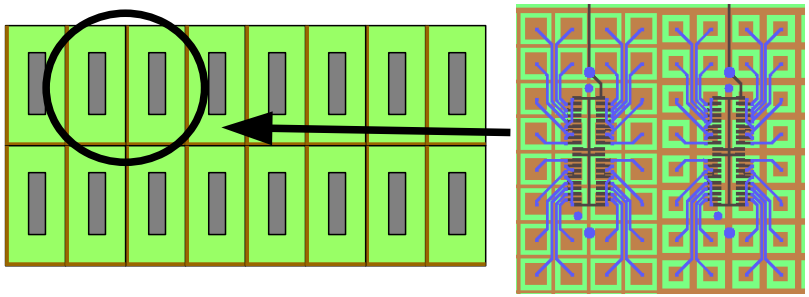
- Better electron collection with larger sizes
- Not clear effects of Frisch vs guard voltages
- Further studies needed

Geometry (5mm pitch)	Voltages drift/frisch/ guard	% e^- on pad	% e^- on board	% e^- on Frisch	% event with signal integral = 1	% events with 1 ion or more	% event with signal integral < 1
2mm pads 1mm guard	600/300/300	66 %	22 %	13 %	65 %	0,3 %	34 %
	800/500/400	61 %	41 %	0.4 %	57.9 %	1.3 %	40.8 %
	700/400/500	83 %	3.6 %	16 %	80 %	1.3 %	19 %
2mm pads 2mm guard	600/300/300	74 %	0.1 %	27 %	72.5 %	0.7 %	26.7 %
	800/500/400	107 %	1.6 %	4.3 %	82.1 %	9.4 %	8.4 %
	800/500/500	100 %	0 %	10.5 %	82.6 %	6.8 %	10.6 %
3mm pads 0.5mm guard	600/300/300	88 %	1.5 %	6.3 %	92 %	0.2 %	7.4 %
	800/500/400	86 %	6.4 %	0 %	91.8 %	2.5 %	5.7 %
	700/400/400	93 %	1.1 %	1.4 %	96.9 %	0.8 %	2.2 %
3.5mm pads 0.5mm guard	600/300/300	96 %	0 %	4.1 %	95.7 %	0.1 %	4.1 %
	800/500/400	100 %	0 %	0 %	98 %	1.9 %	0 %
	700/400/300	98 %	0.2 %	0.2 %	98.9 %	0.8 %	0.3 %

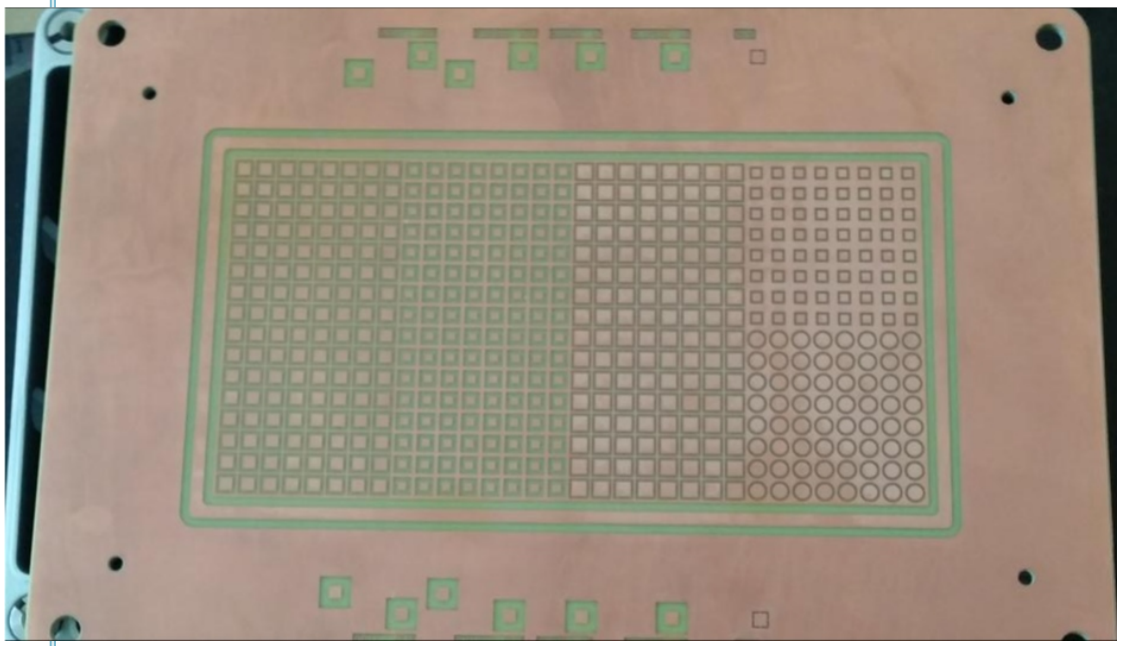
NoAmpTPC prototype design

Read-out board

- 512 pads within 8x16cm active area
- 5mm pitch, several pad sizes
- HV guard strips to focus electrons on pads
- Pad geometry based on Garfield++ simulation
- Production with low ε_R PTFE material failed, tentative in progress with new producers
- Present board in FR4 material, with $\varepsilon_R > 4$ (vs ε_R~2.2 and Df~0.0009 for typical PTFE materials)



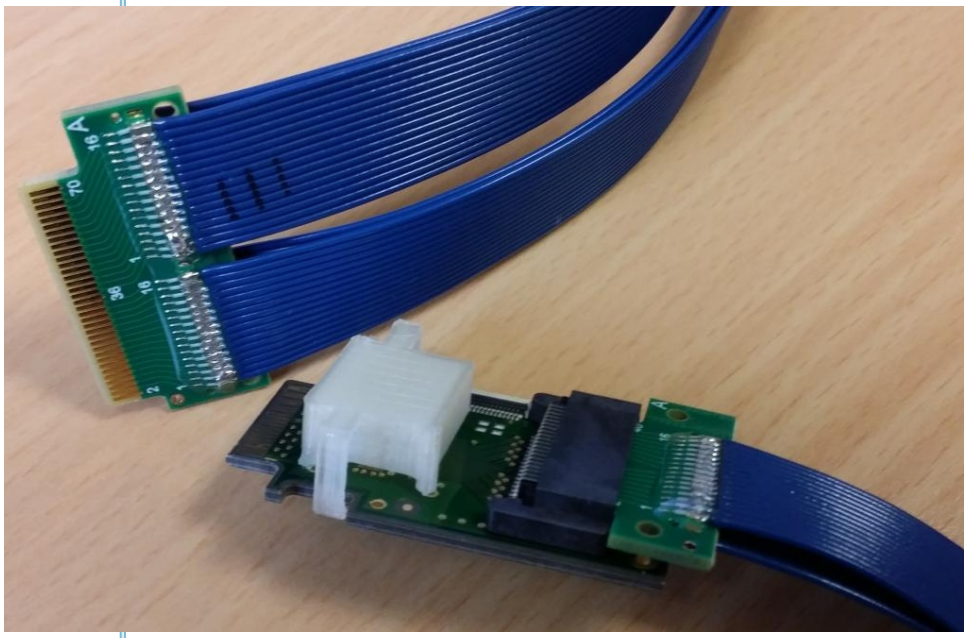
Pad to connector strips



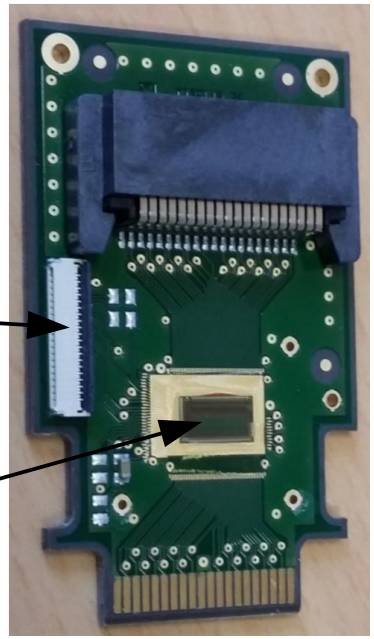
NoAmpTPC prototype design

IDeF-X daughter cards

- Holding the IDeF-X chip
- Samtec HSEC8 connectors
- Powered and controlled by a service card through FPC cable
- Connected to DREAM FEU card by micro-coax flat cables
- 20 cards produced with low ε_R material (RT5880)

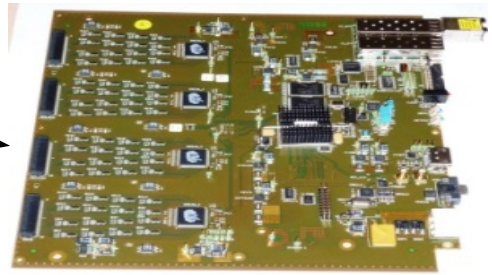


Cable to FEU



Connector to board

16 IDeF-X cards

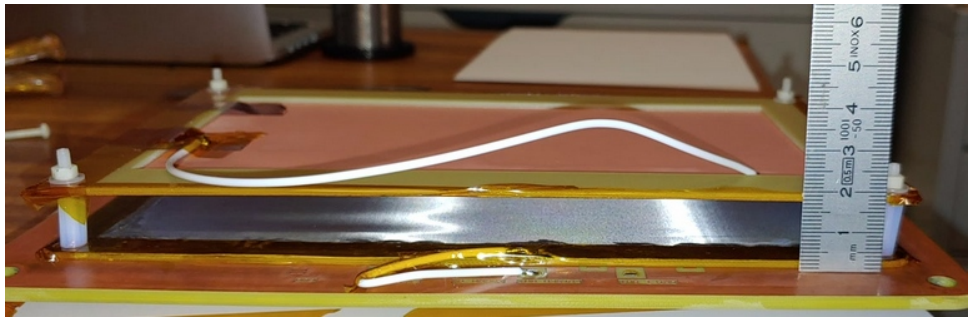


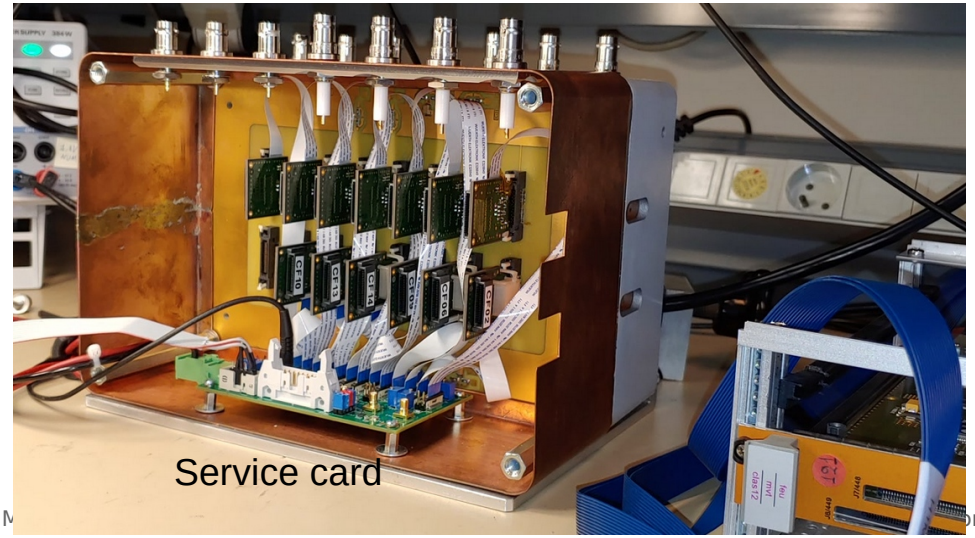
DREAM FEU card

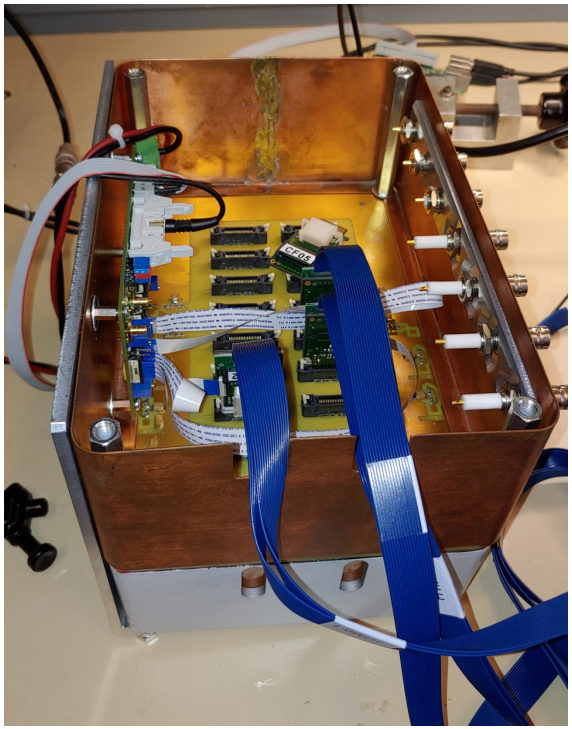
NoAmpTPC prototype test box

Test prototype

- Aluminum box for gas volume + copper cover for EM protection
- Read-out board + Frisch mesh (2mm gap) + copper clad kapton foil as drift electrode (15mm gap)
- IDeF-X chips controlled by a Raspberry card through the service card







Electronics noise level with the test box

Pedestal run

Random trigger, 500 events

2 peaking time configurations used: 1.7 µs and 7.4 µs (almost no difference at 12.9 µs)

1 ADC count ~ 6.8 e⁻ (tested with pulses on IDeF-X 50 fF capacitive test input)

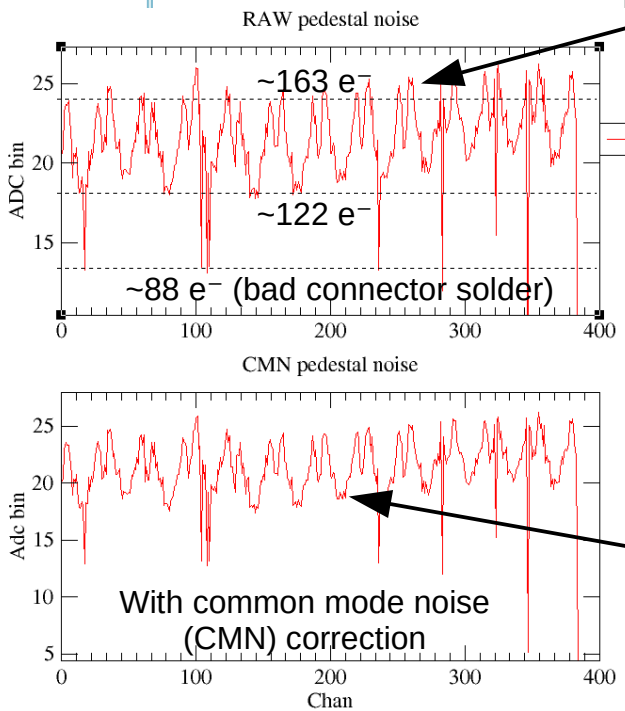
Results on pedestal RMS

Between 110 to 146 e⁻ for 7.4 µs peaking time, not far from goal noise level of 100 e⁻

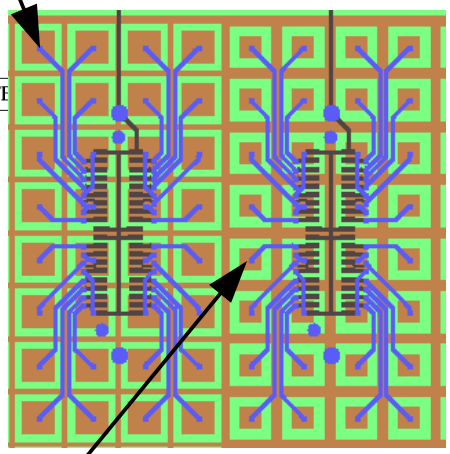
No impact from common mode noise

Strong dependence with strip length between pad and connector

1.7 µs peaking time

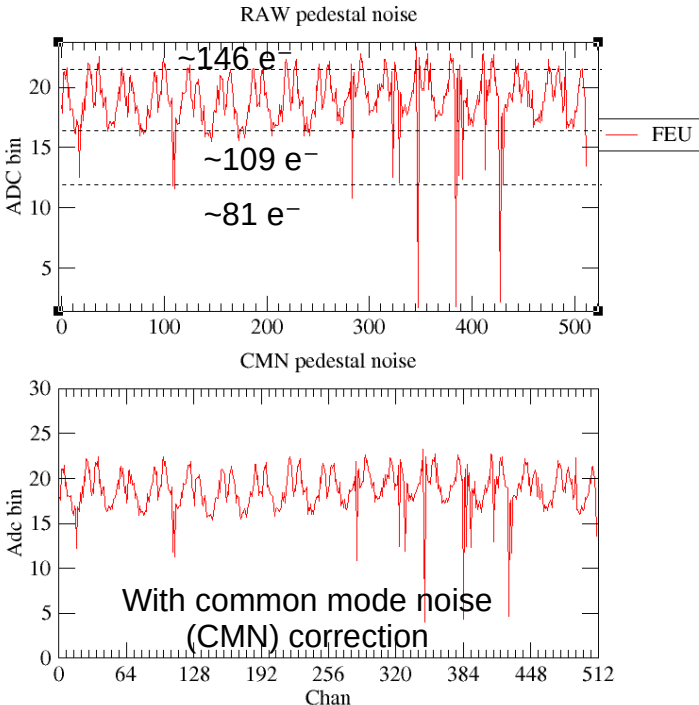


Long strips



Short strips

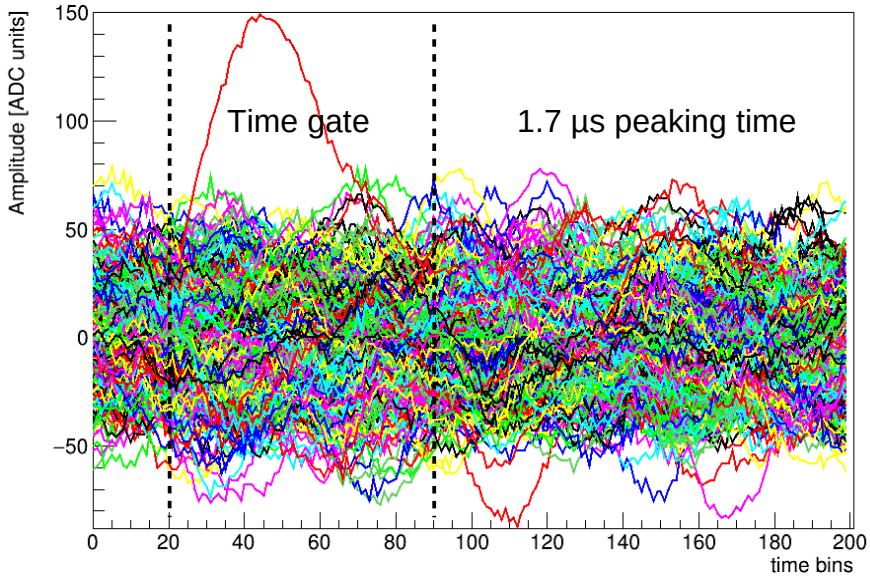
7.4 µs peaking time

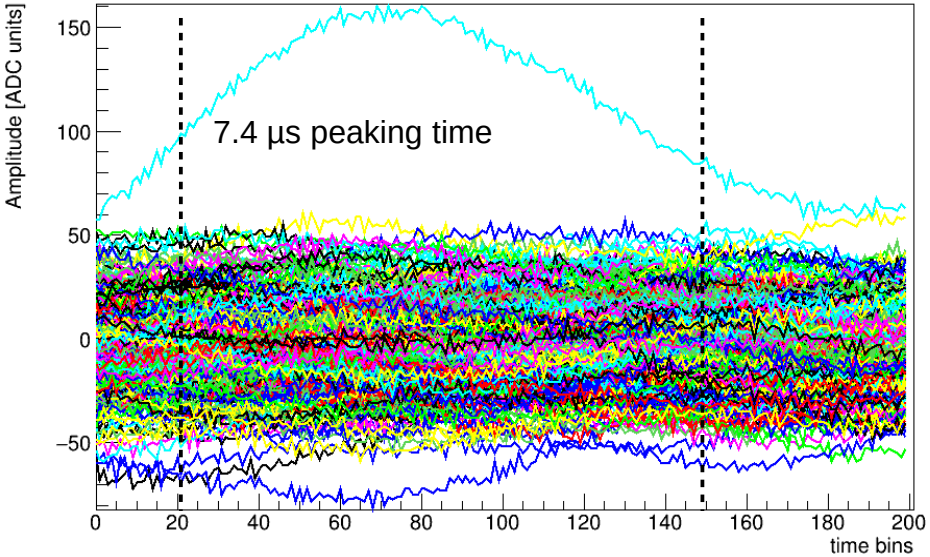


Data taking with source

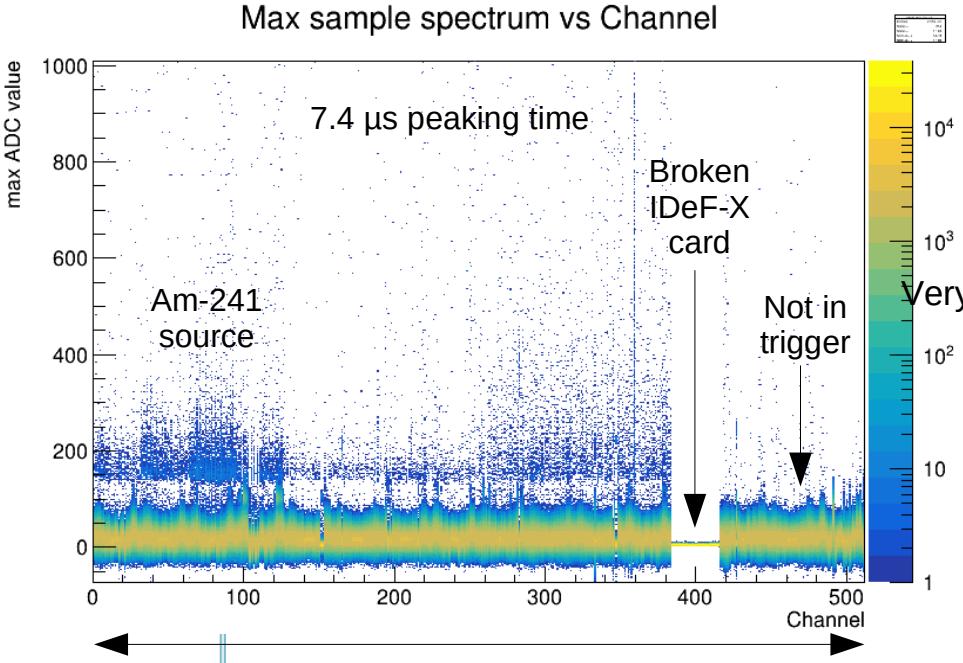
Runs with source

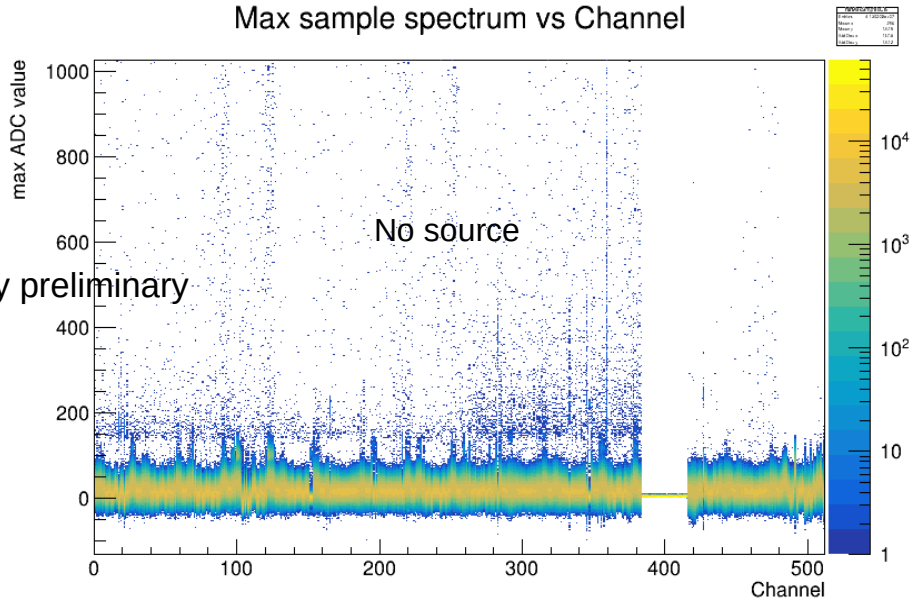
HV settings: 800V drift electrode, 500V Frisch electrode, 400V guard strips
Internal DREAM trigger, thresholds tuned to deliver < 1Hz without source
20.8 MHz sampling rate (48 ns), all channels read at each trigger
Am-241 source: photons 59.5 keV + 13.9 keV + 17 keV + 18 keV
Also used Co-57 source: photons 122 keV + 14 keV + 136 keV
But low activity sources ~ 10^3 Bq, not very visible
Data analysis done in REST-for-physics environment (Rare Event Search Toolkit)





Max ADC channel per event for each channel

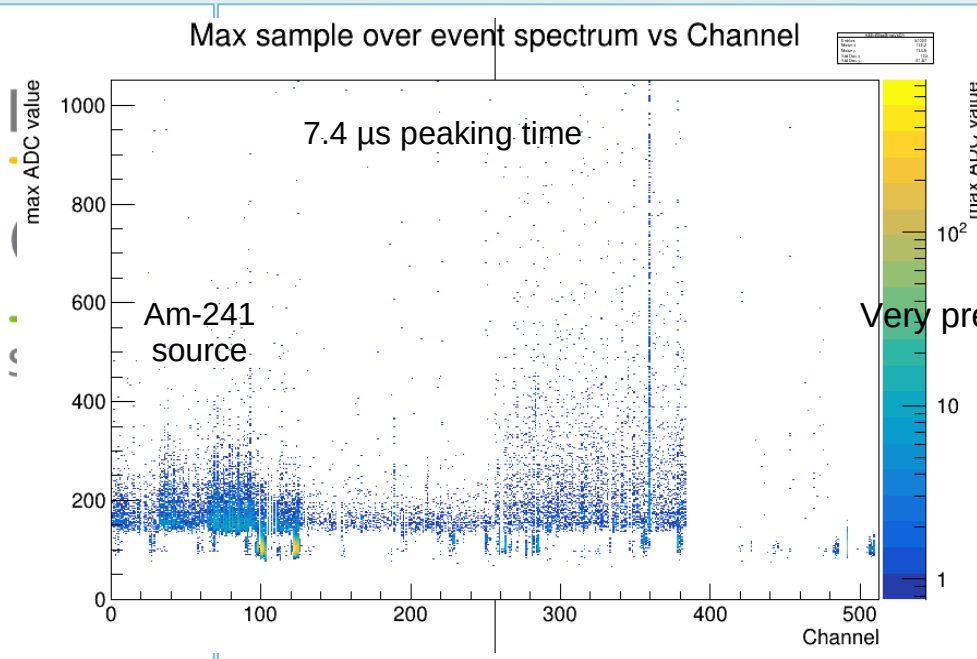


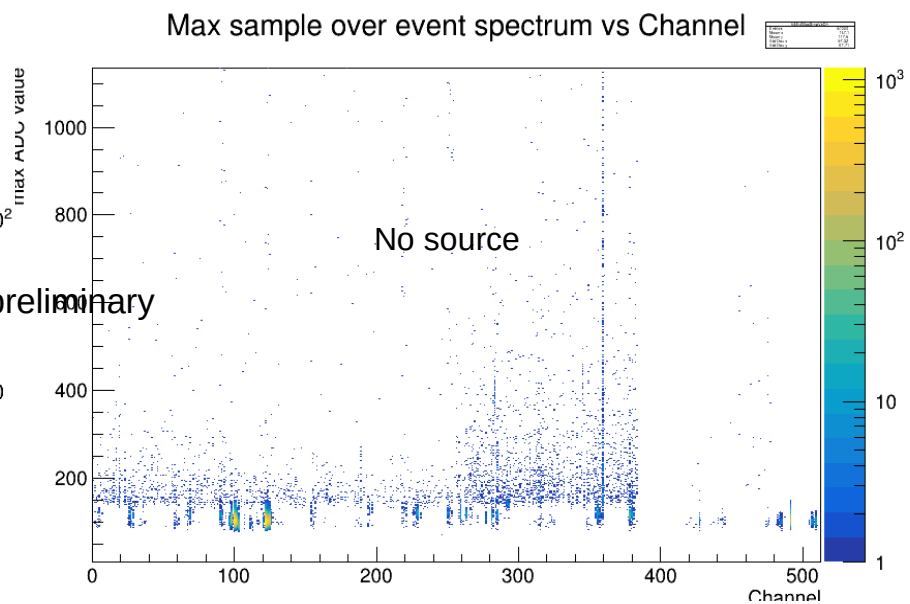


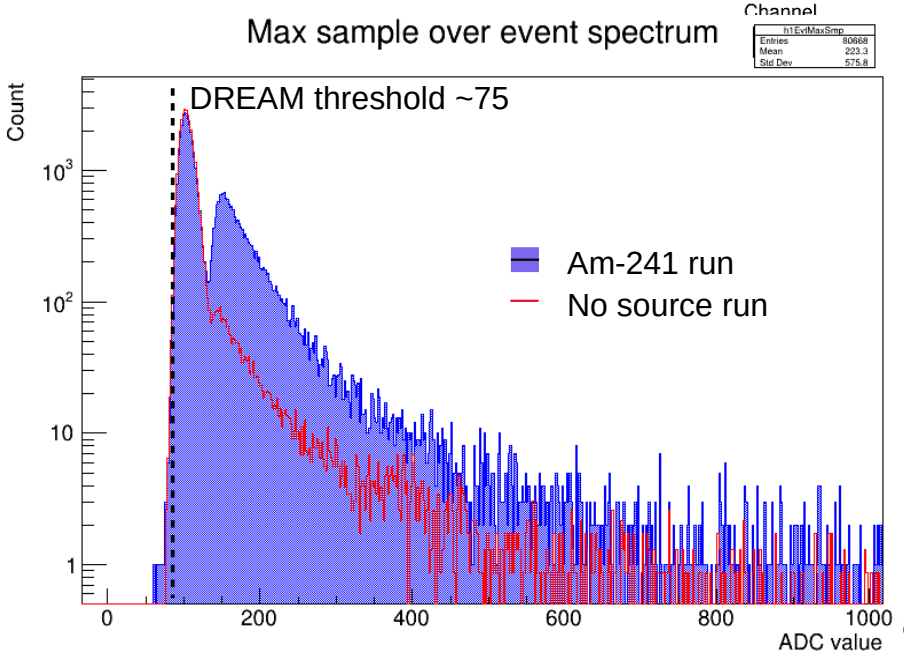
Very preliminary

16 IDeF-X cards, 32 channels each

Max ADC value per event for all channel







Source signal visible in range 900-2500 e⁻ (expected yield for 60 keV photons ~ 2300 e⁻ spread over a few pads)

Investigation on threshold effect

Data taking and analysis still ongoing (2D reconstruction, hit clusterization, fiducial selection)

Conclusion and prospects

TPC simulation with Garfield++

- Small 2x2mm pads probably not large enough to collect all electrons
- Impact of 3x3mm (or larger) pad capacitance to be studied with the real setup
- Voltage settings to be studied with the real setup

NoAmpTPC prototype

- Finalized since end of 2020
- First results promising, source signals are visible
- Requires further studies (hit clusterization, fiducial cuts, correlation with HV settings, gas mixture, pad geometry, etc...)
- Noise level could be reduced with low ε_R board, investigation ongoing to produce such board, two producers would accept to work on it

Prospects

- Performance still to be studied with the prototype with different pad and guard strip sizes: noise level, sensitivity, efficiency, energy and spatial resolutions
- Also tests with different voltages, gas mixtures, etc..
- Tests in high pressure chamber could be considered
- If successful larger TPC demonstrator ? Very low noise chip with integrated digitization ?