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

Hydrogen TPC

Micromegas readout

γ background

2β signal

Drift electrode

gaseous Xe TPC
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

**Principle of the detection**

- Initial particle
- Ionization e⁻
- Drift electrode
- Anode
- HV
- Frisch mesh
- Low noise readout chip on daughter cards
- 2800 µm

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

Idea from XEMIS project (liquid Xe TPC)

MIMELI project
D. Thers (Subatech)
IDeF-X HD (LXE) performance

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
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

![Diagram of simulated design](image)
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
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?

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**Preliminary**

**Electron final XY position**

- 2mm pad, -800V/-500V/-400V
  - 60% e⁻ go to pads
  - 40% e⁻ go to board
  - 0.5% e⁻ go to frisch

- 3mm pad, -800V/-500V/-400V
  - 86% e⁻ go to pads
  - 6.4% e⁻ go to board
  - 0.0% e⁻ go to frisch
## 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

<table>
<thead>
<tr>
<th>Geometry (5mm pitch)</th>
<th>Voltages drift/frisch/guard</th>
<th>% e⁻ on pad</th>
<th>% e⁻ on board</th>
<th>% e⁻ on Frisch</th>
<th>% event with signal integral = 1</th>
<th>% events with 1 ion or more</th>
<th>% event with signal integral &lt; 1</th>
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<tr>
<td>2mm pads 1mm guard</td>
<td>600/300/300</td>
<td>66 %</td>
<td>22 %</td>
<td>13 %</td>
<td>65 %</td>
<td>0.3 %</td>
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<td>800/500/400</td>
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<td>700/400/500</td>
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<td>80 %</td>
<td>1.3 %</td>
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<td>100 %</td>
<td>0 %</td>
<td>10.5 %</td>
<td>82.6 %</td>
<td>6.8 %</td>
<td>10.6 %</td>
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<td>92 %</td>
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<td>93 %</td>
<td>1.1 %</td>
<td>1.4 %</td>
<td>96.9 %</td>
<td>0.8 %</td>
<td>2.2 %</td>
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<td>96 %</td>
<td>0 %</td>
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<td>95.7 %</td>
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<td>0 %</td>
<td>98 %</td>
<td>1.9 %</td>
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<td>0.2 %</td>
<td>98.9 %</td>
<td>0.8 %</td>
<td>0.3 %</td>
</tr>
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</table>
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 $\varepsilon_R$ PTFE material failed, tentative in progress with new producers

Present board in FR4 material, with $\varepsilon_R > 4$ (vs $\varepsilon_R \sim 2.2$ and $Df \sim 0.0009$ for typical PTFE materials)
**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 $\varepsilon_R$ material (RT5880)
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

Service card
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
- ~122 e⁻
- ~88 e⁻ (bad connector solder)

7.4 µs peaking time
- ~146 e⁻
- ~109 e⁻
- ~81 e⁻ (with common mode noise (CMN) correction)
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 ~ 10³ Bq, not very visible
Data analysis done in REST-for-physics environment (Rare Event Search Toolkit)
Max ADC channel per event for each channel

Max sample spectrum vs Channel

7.4 µs peaking time

Am-241 source

Broken IDeF-X card

Not in trigger

Very preliminary

No source

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 $\varepsilon_R$ 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 ?