Hybrid Detector for Microdosimetry (HDM) readout and experimental results

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TWEPP 2023

UNIVERSITY OF TRENTO

FONDAZIONE BRUNO KESSLER

TIFPA
Trento Institute for Fundamental Physics and Applications

Why proton therapy?

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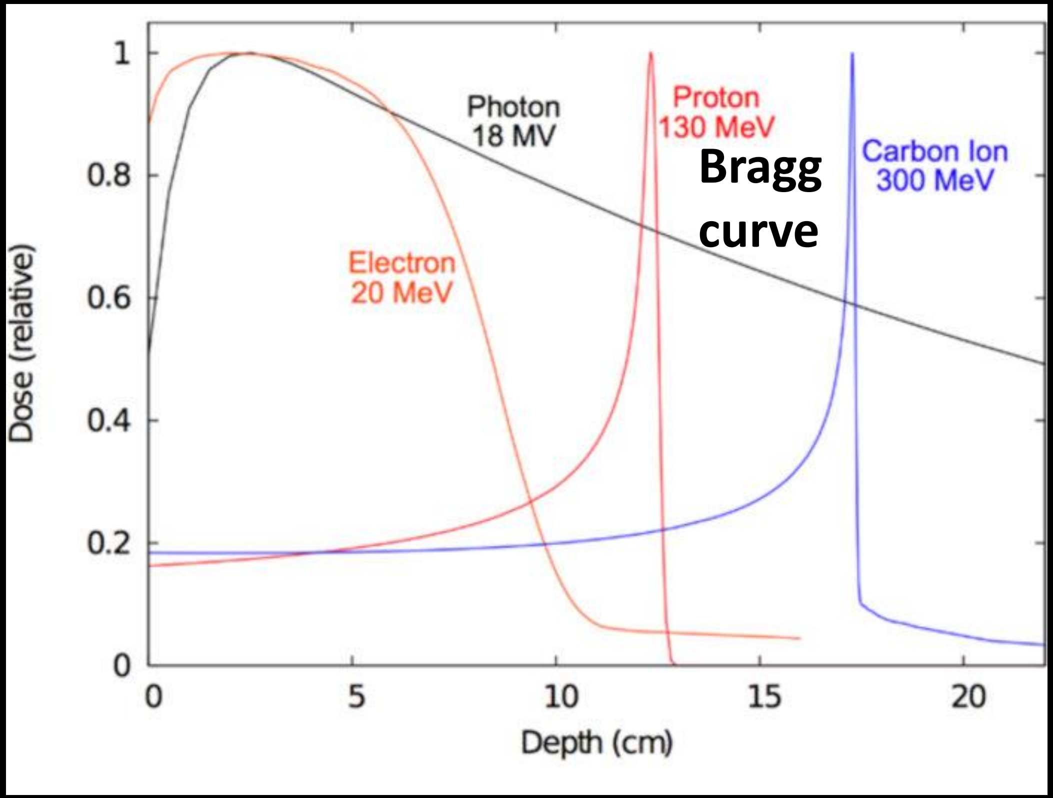
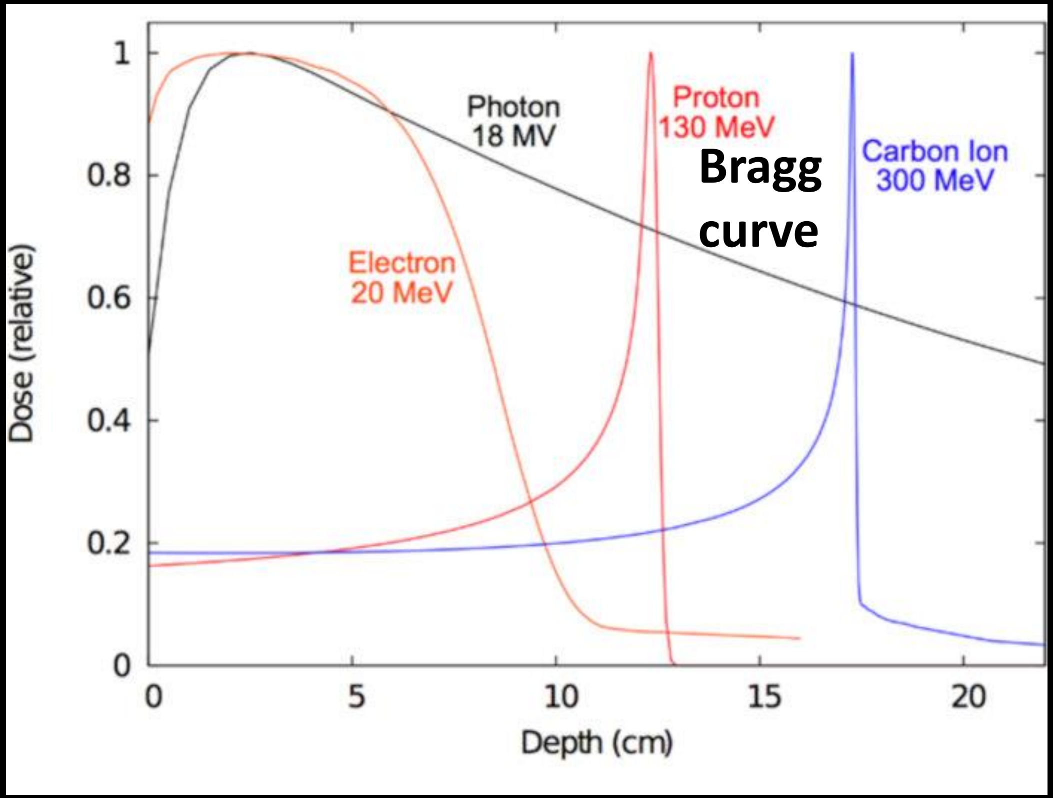


Kaiser, Adeel et al. 10.3791/58372.

Why proton therapy?

- Very localized dose deposition



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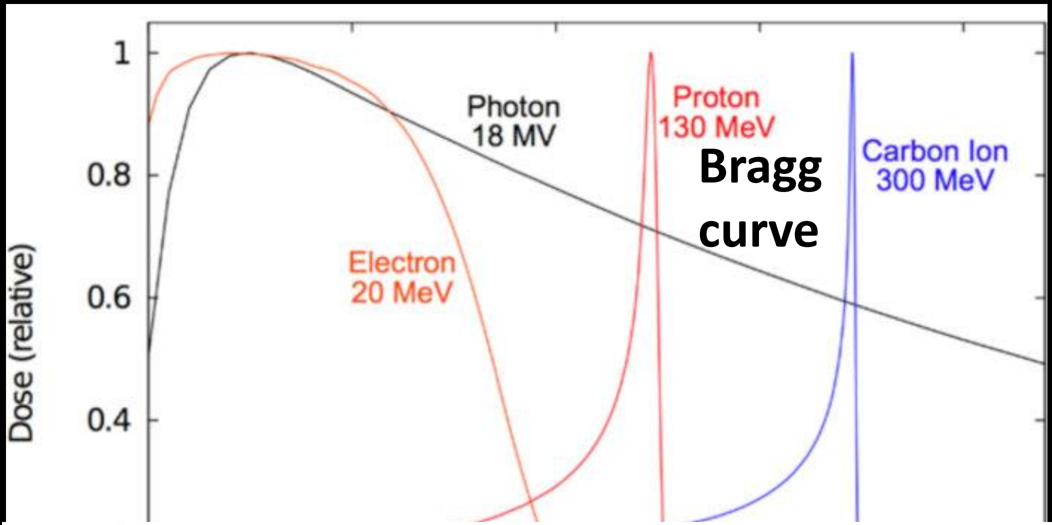
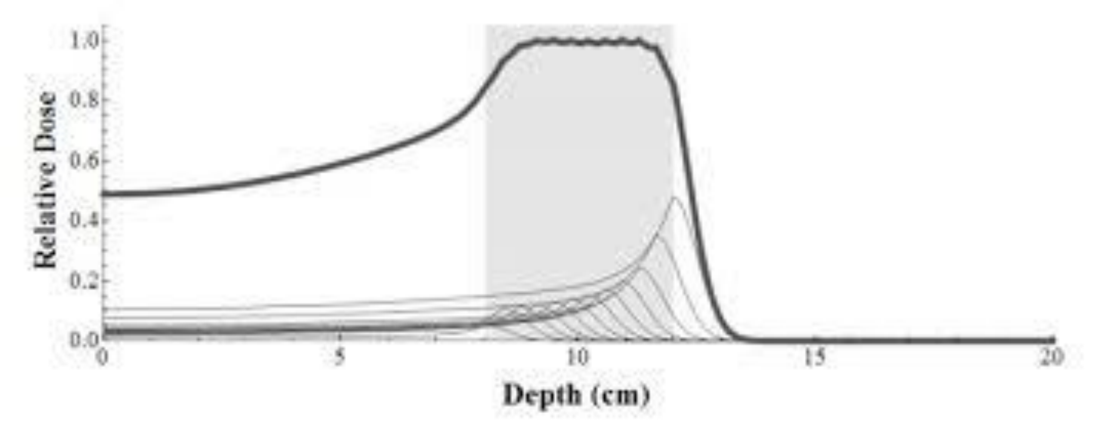
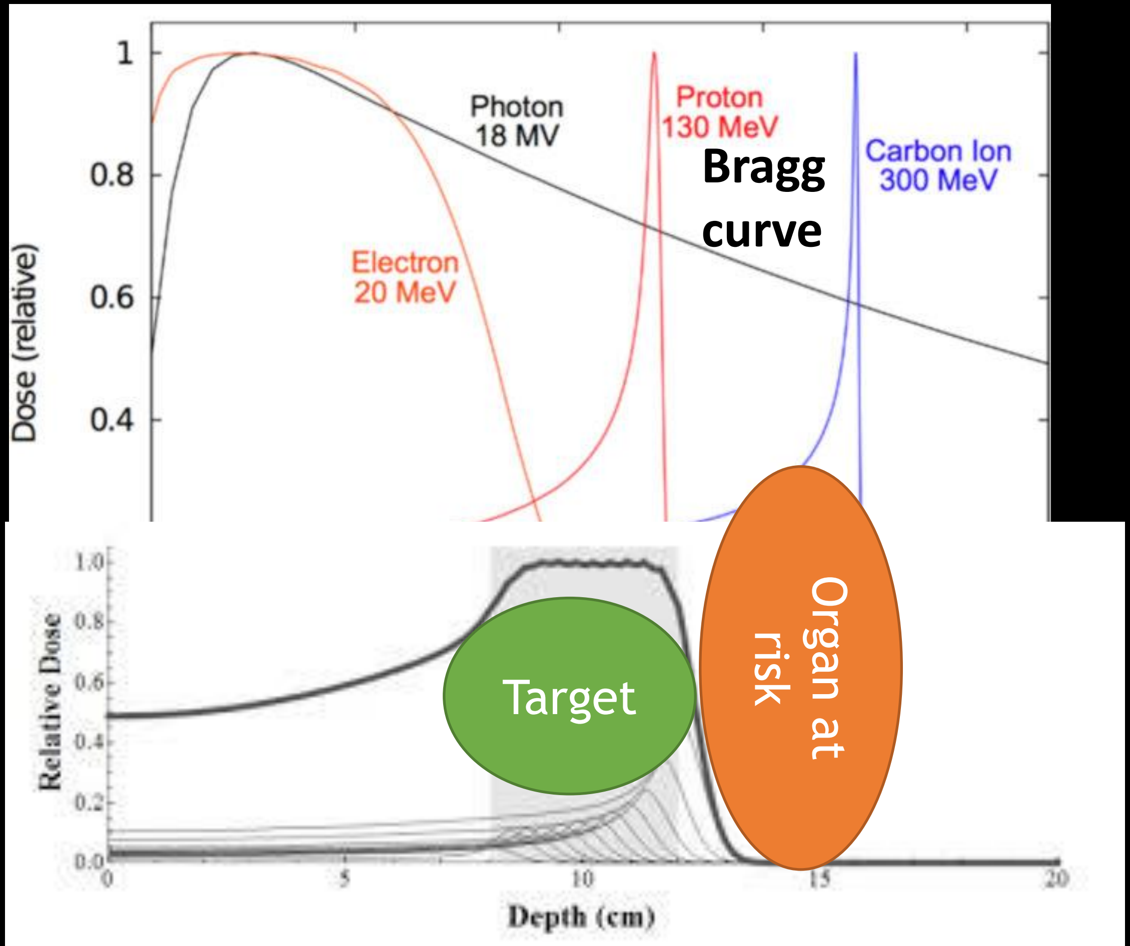
- It is possible to create a uniform dose as sum of Bragg peaks





Why proton therapy?

- Very localized dose deposition
- It is possible to create a uniform dose as sum of Bragg peaks
- Ideal when a sensitive target is on the edge



Proton therapy - goals

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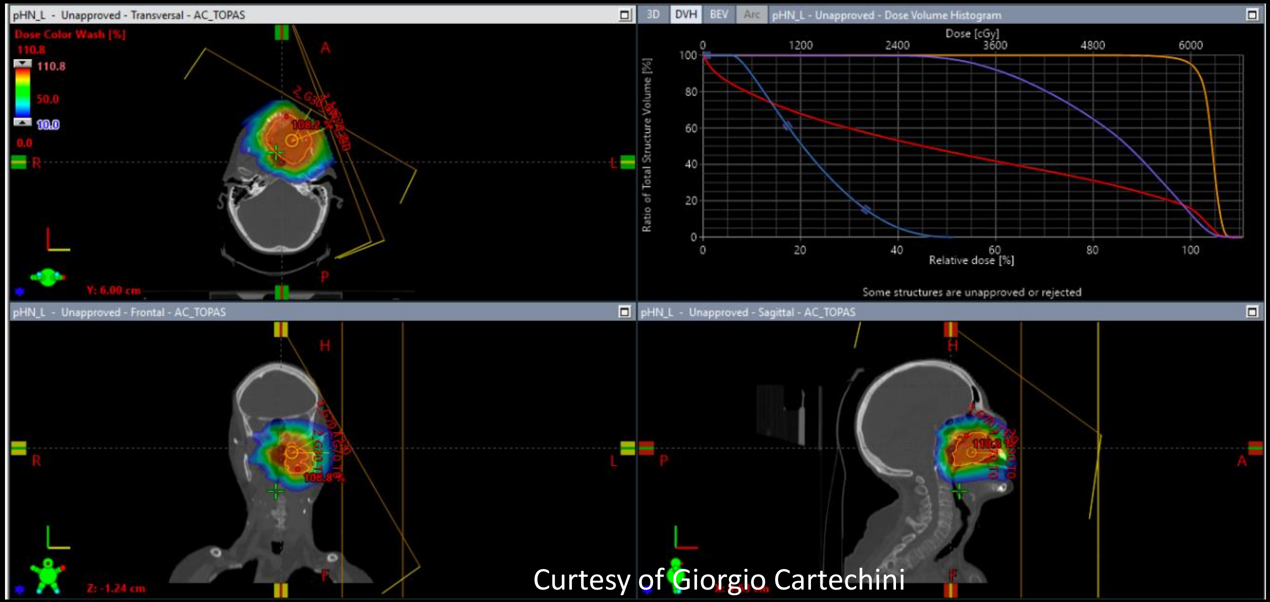
- The dose delivery is planned with the help of a software: the Treatment Planning System (TPS)



Curtesy of Giorgio Cartechini

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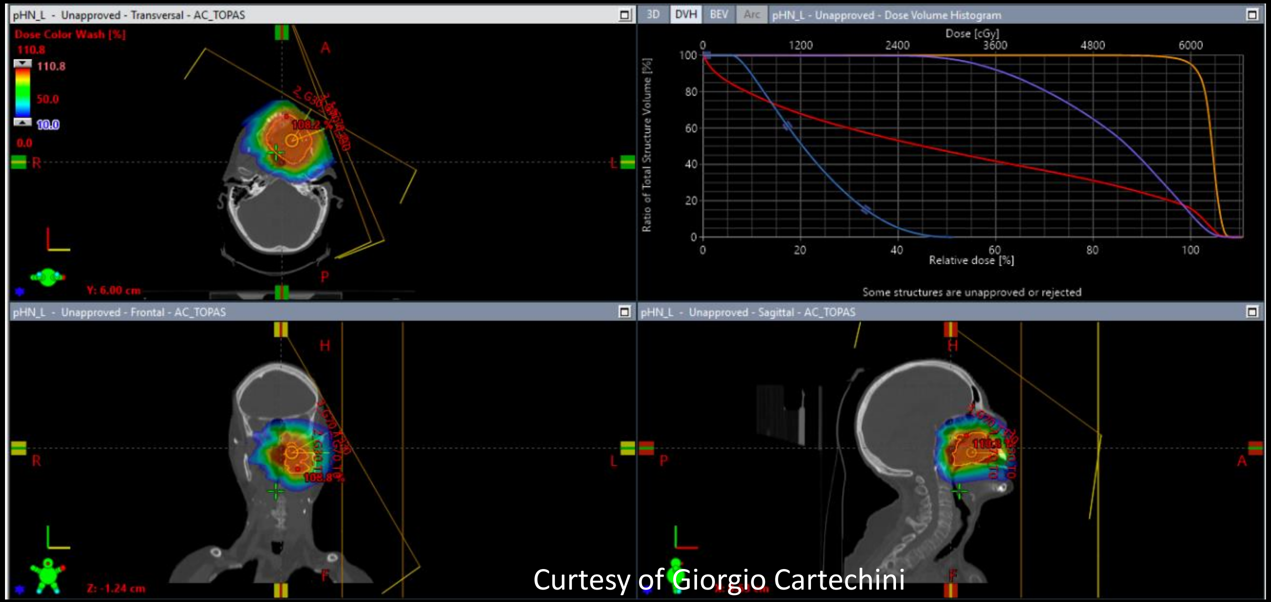

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- TPS requires information particle specie and energy - **radiation quality**

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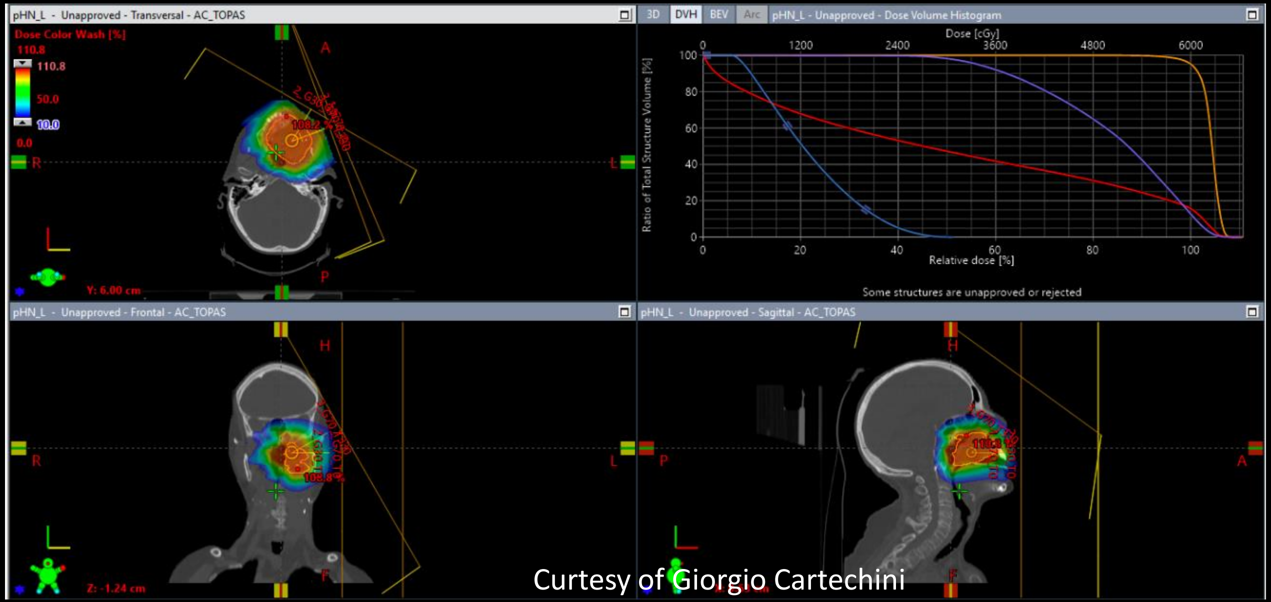

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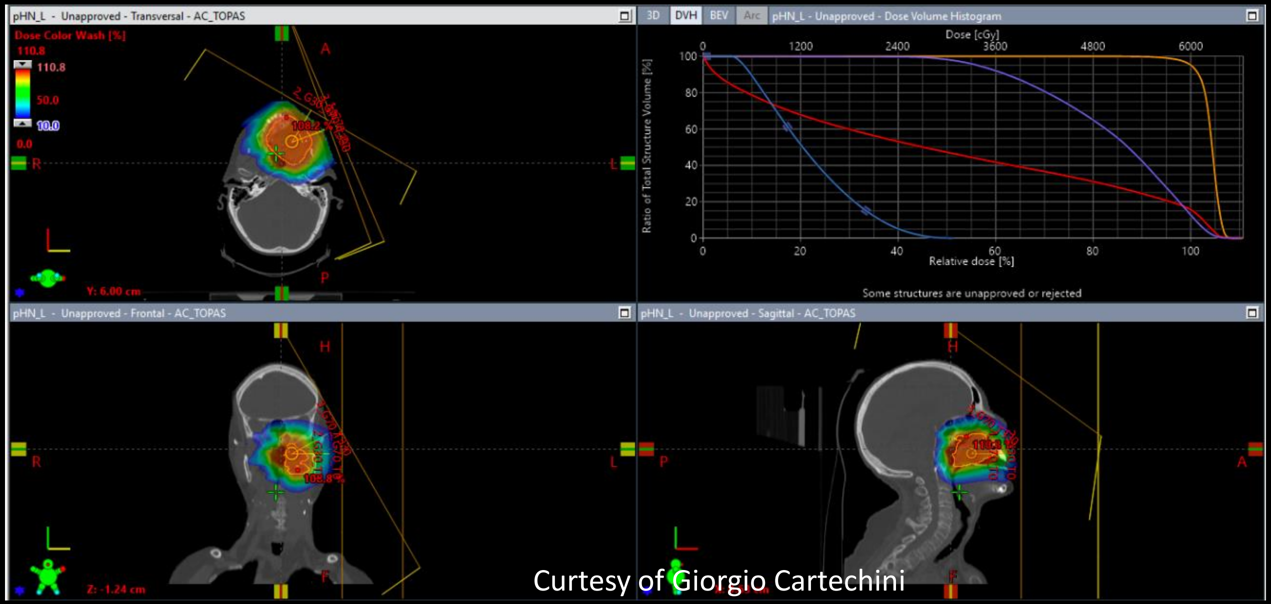
  - Particle type
  - Particle energy

Proton therapy - goals



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- The dose delivery is planned with the help of a software: the Treatment Planning System (TPS)

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  - Particle type
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- **Good description** of the radiation quality will result in a **better TPS plan**

How radiation damage occurs

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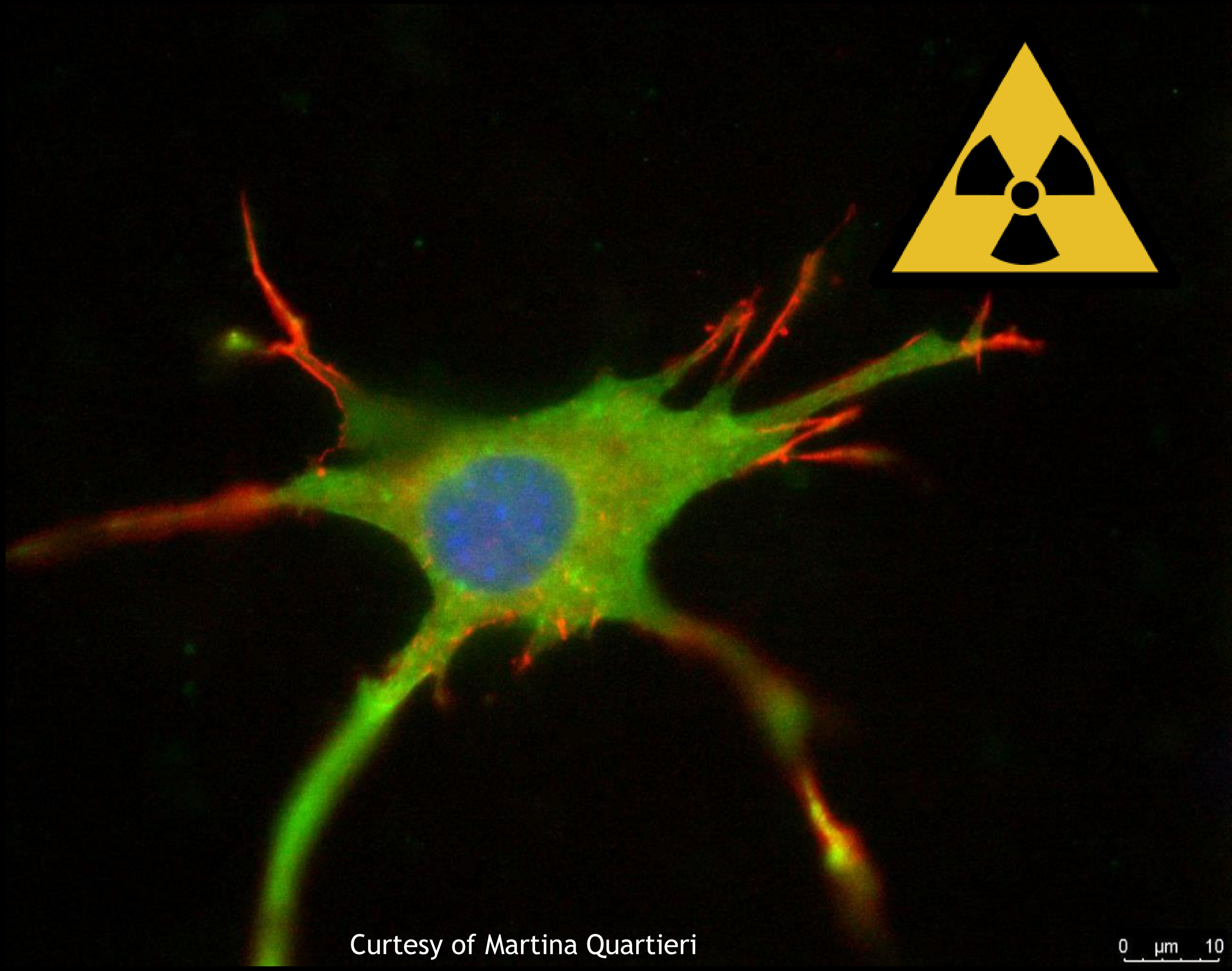
- Radiation damages occurs at cellular level



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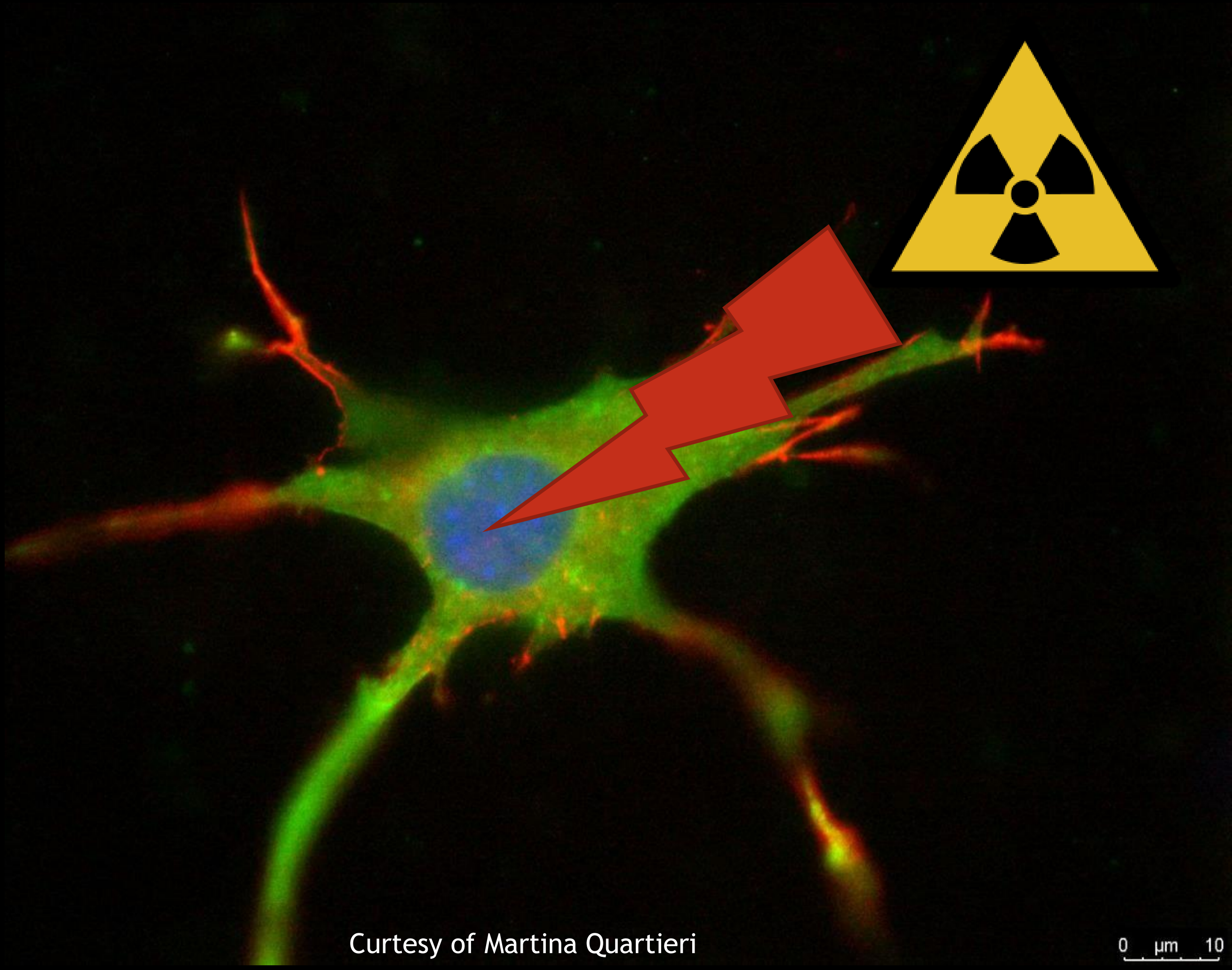

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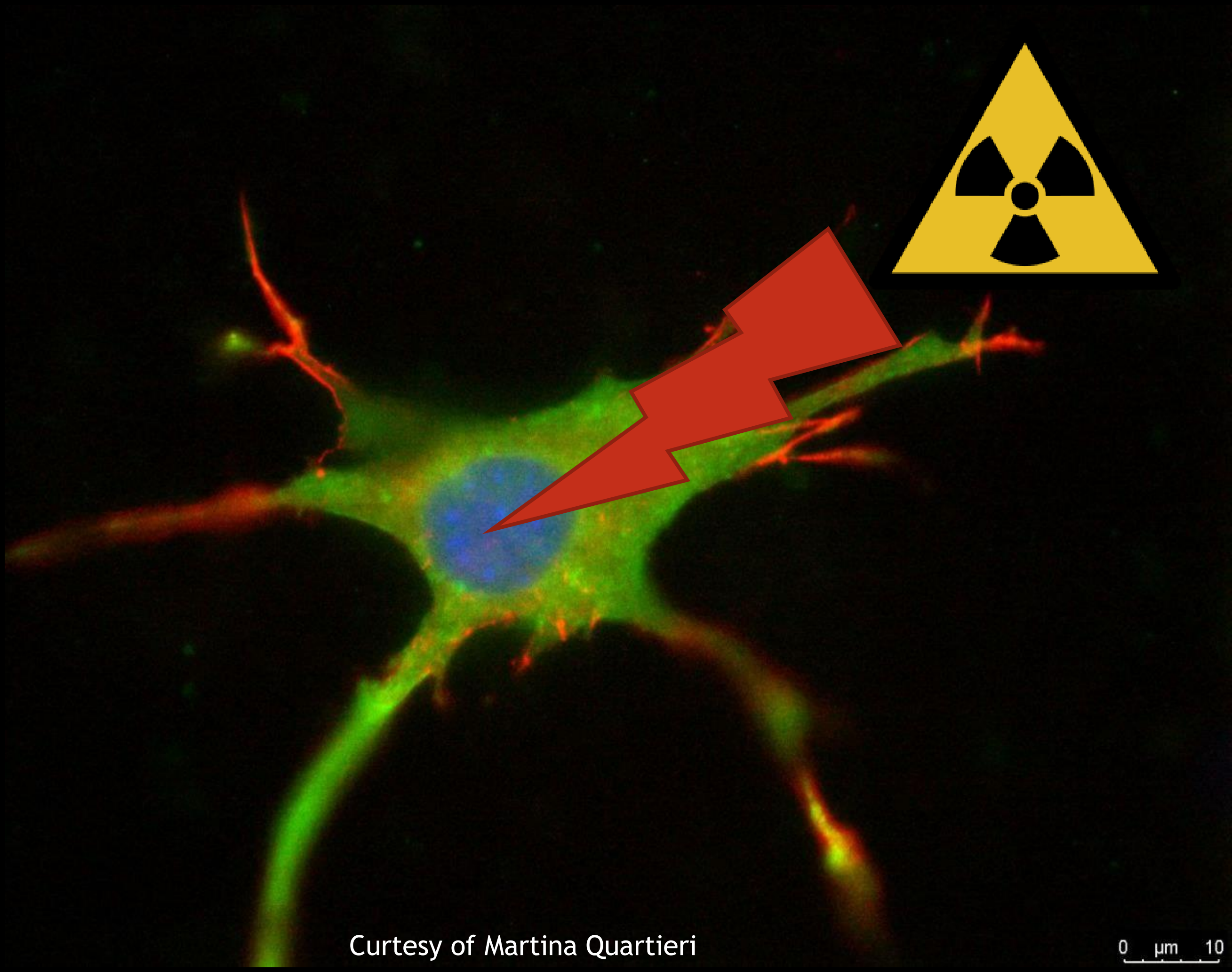

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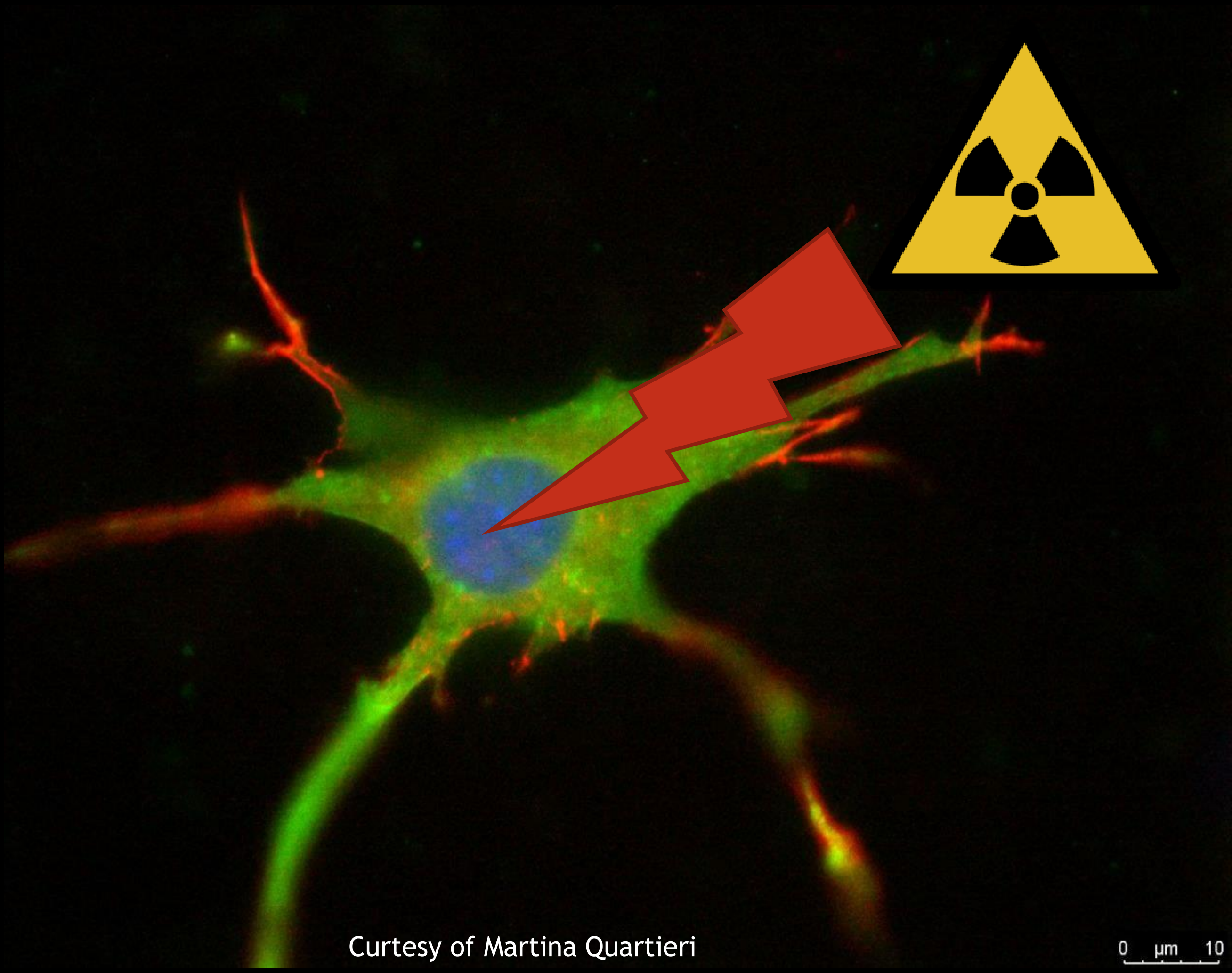

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MICRODOSIMETRY

Tissue equivalent proportional counter (TEPC)

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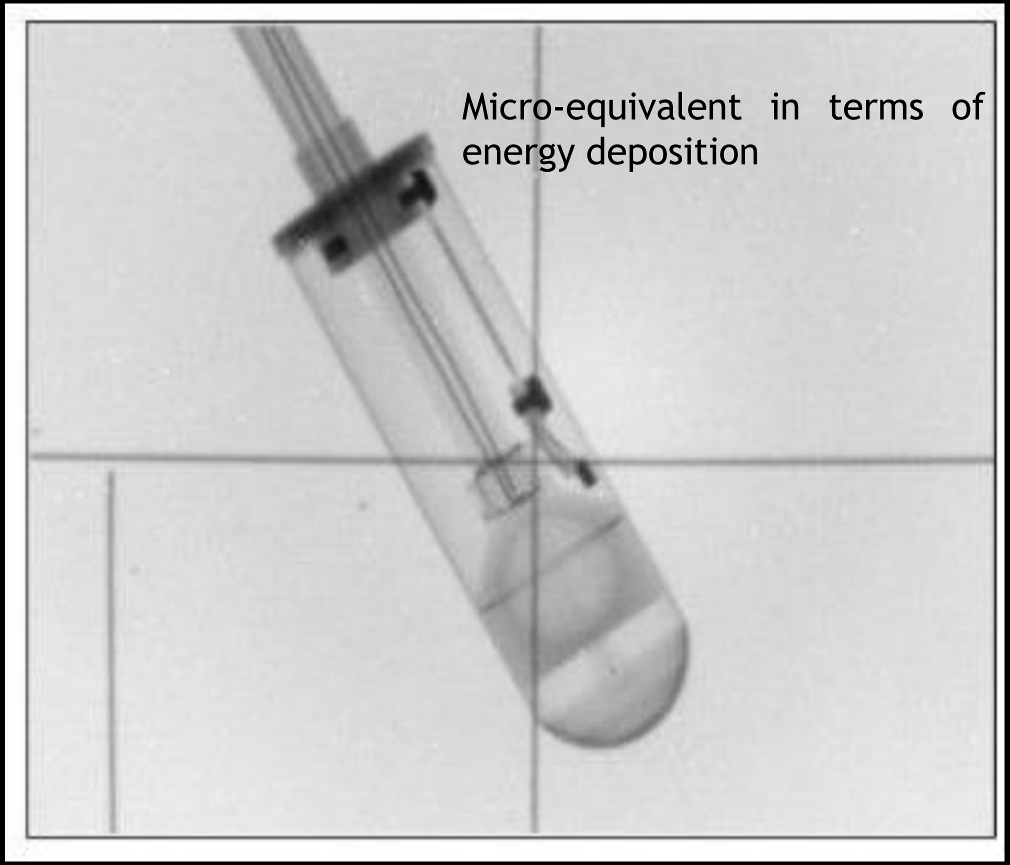
Reference microdosimeter according to ICRU36



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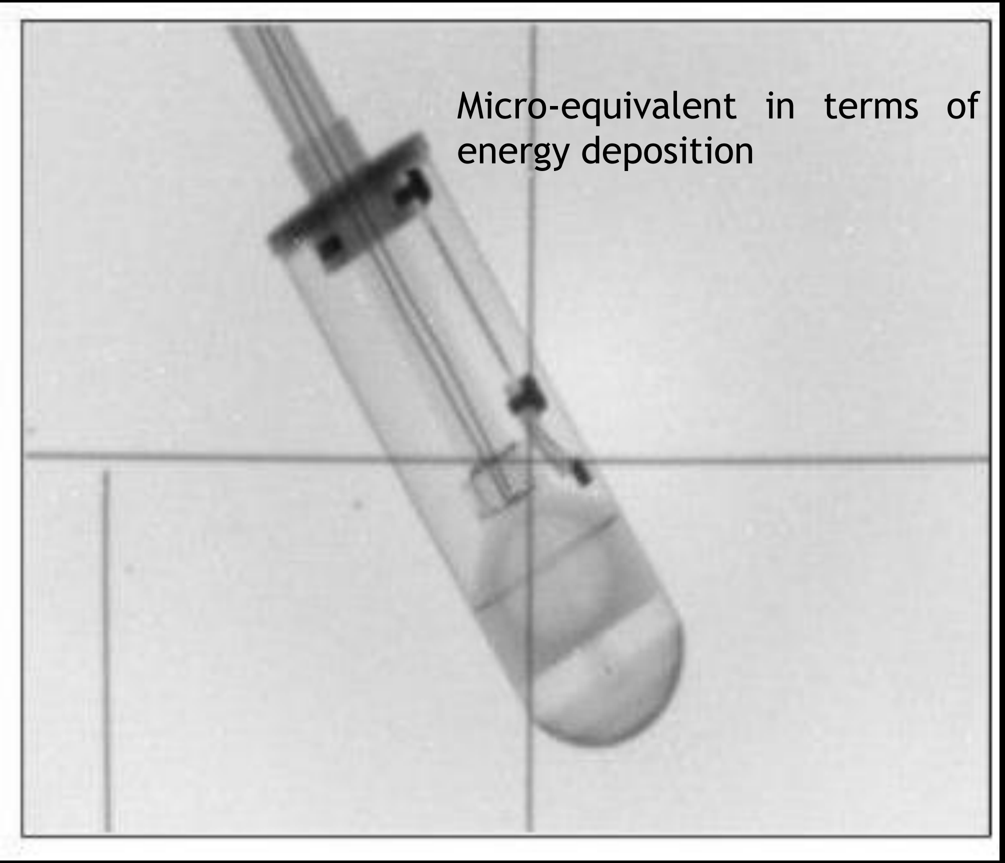

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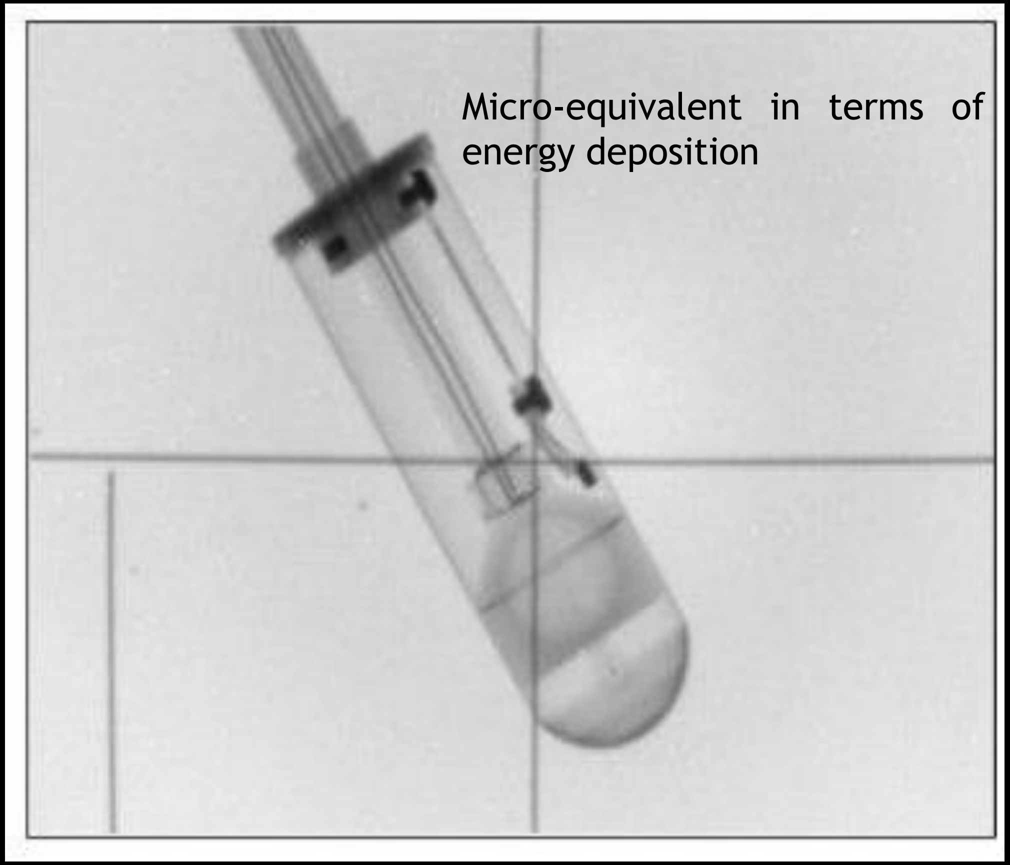

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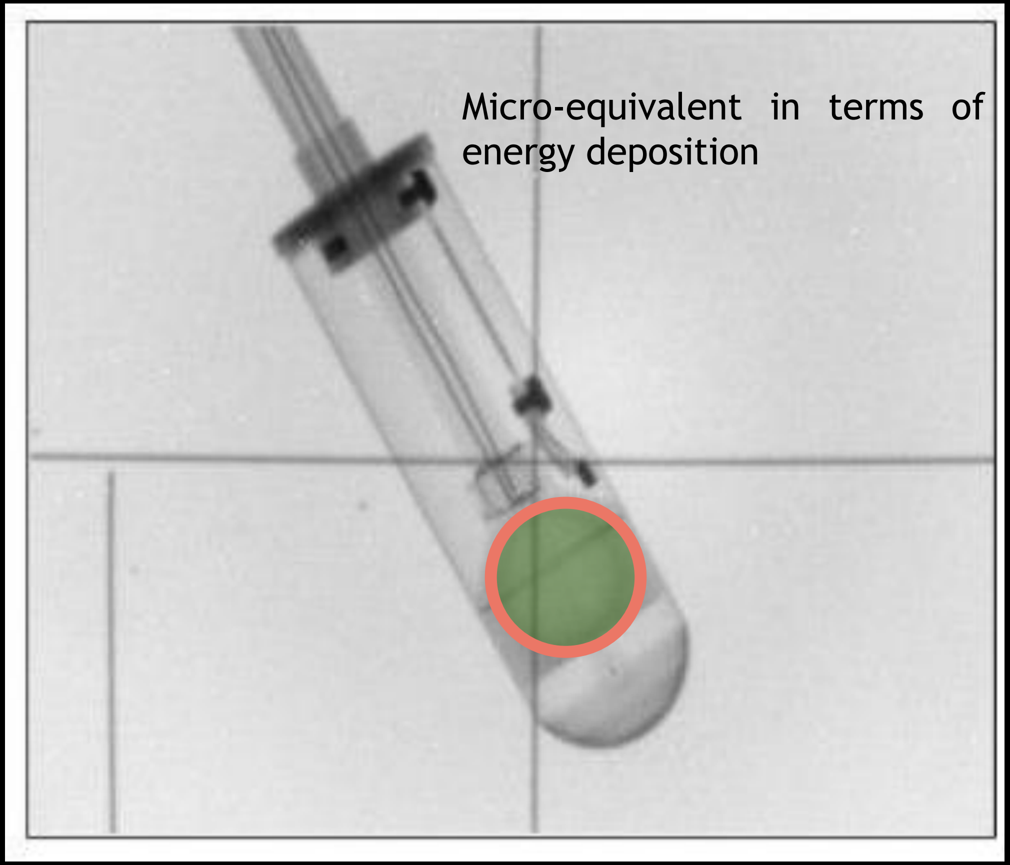

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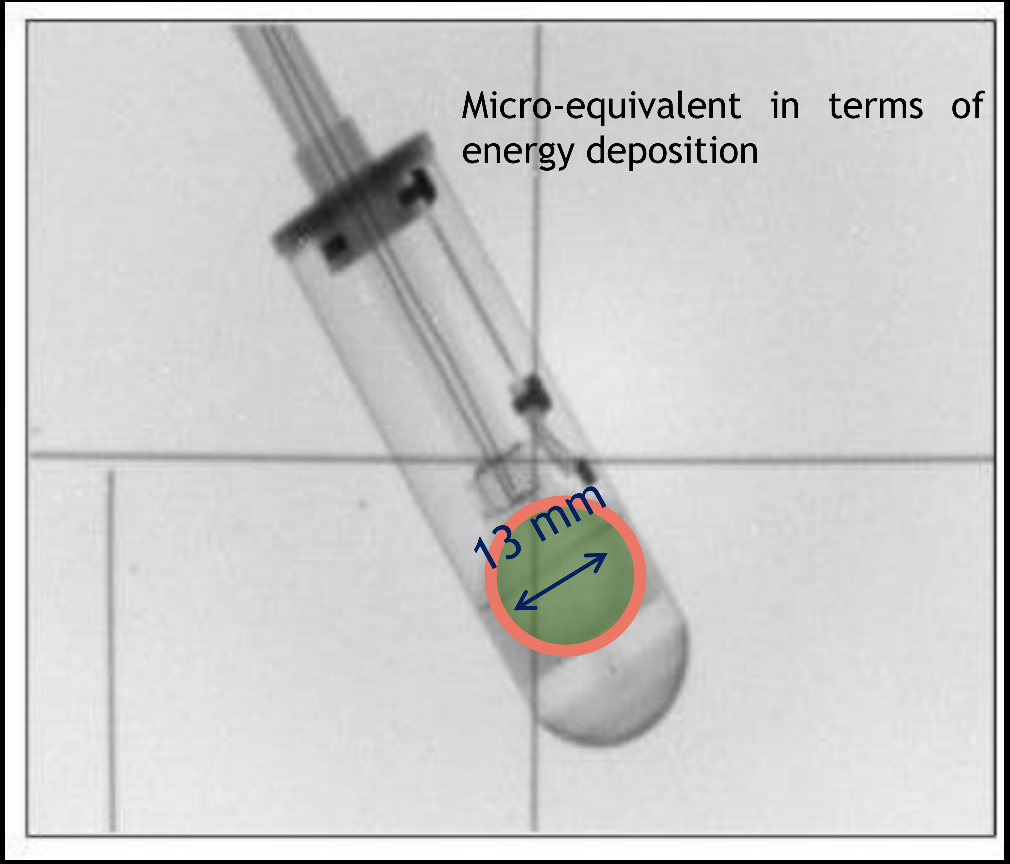

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Microdosimetry main quantity

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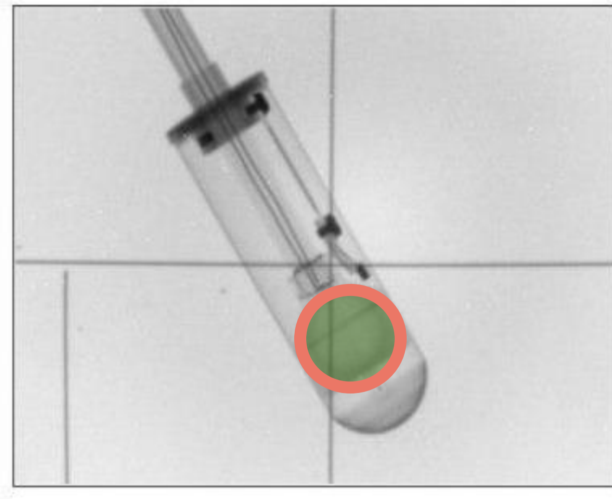

Energy recorded in the detector

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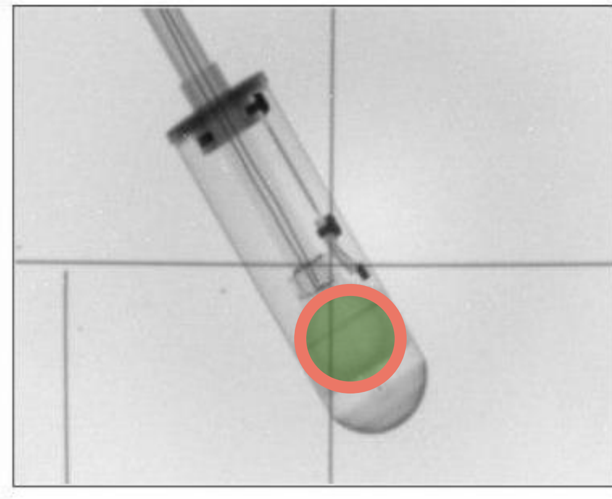

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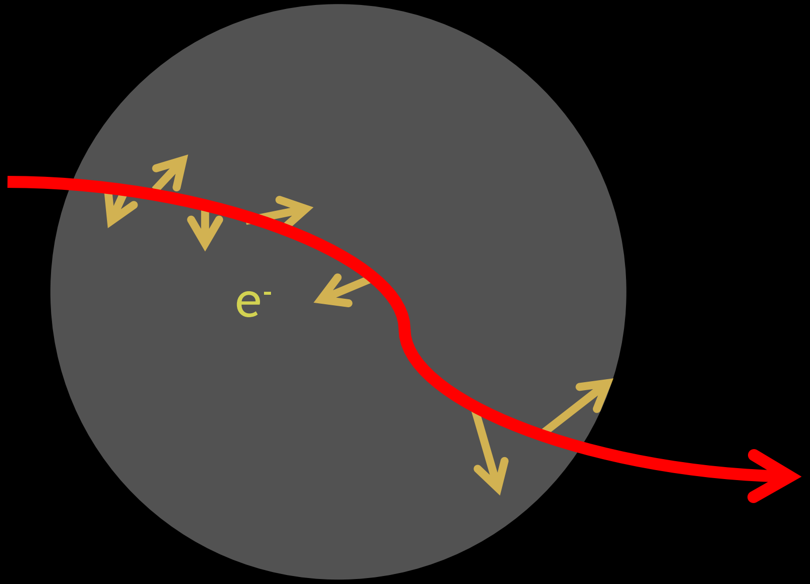

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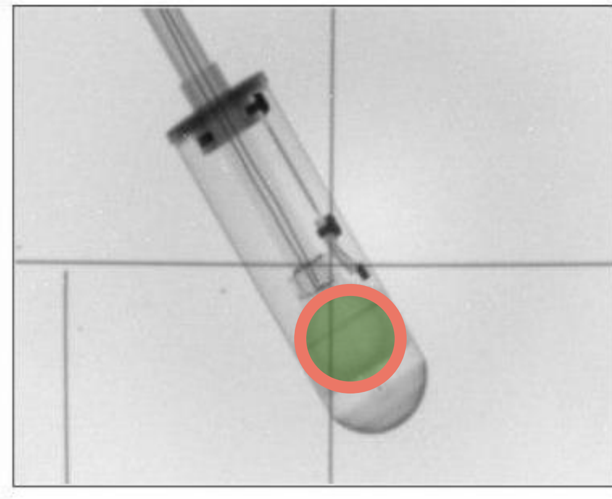

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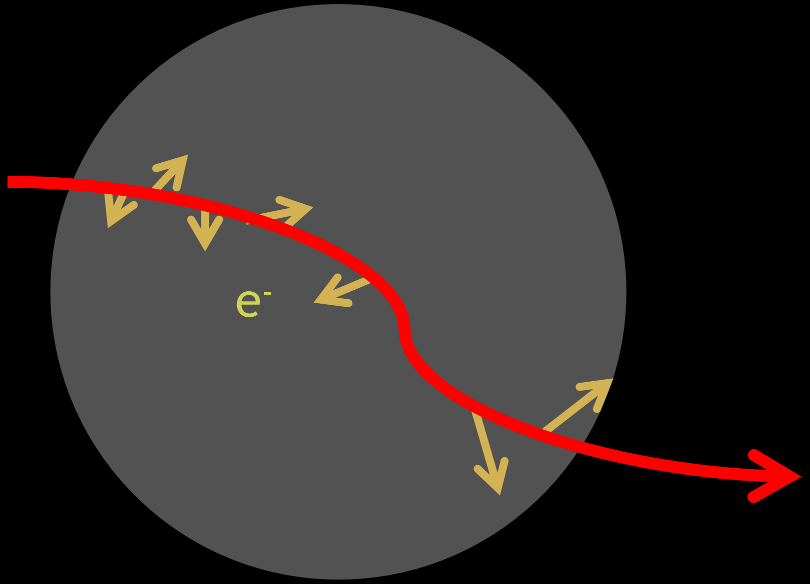

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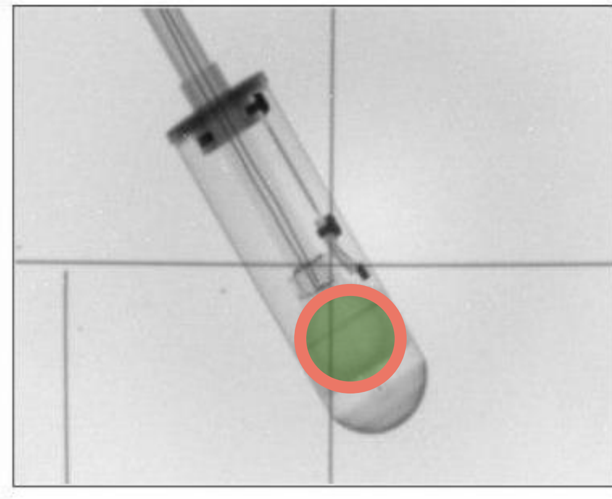

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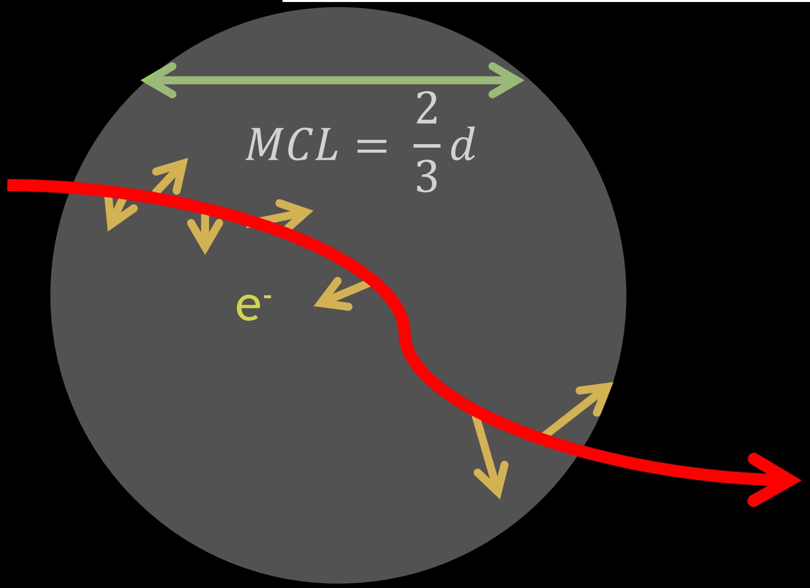

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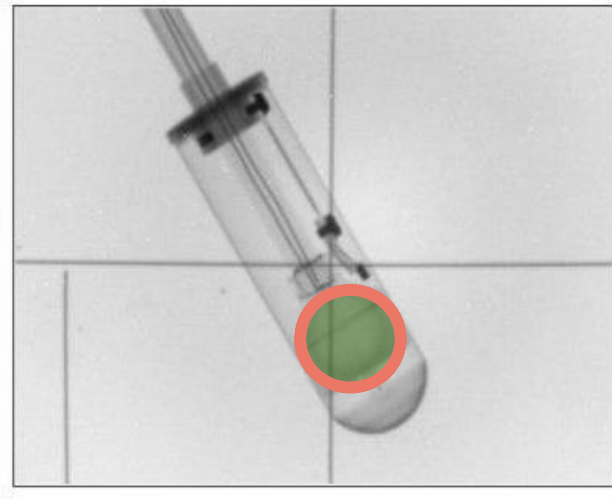

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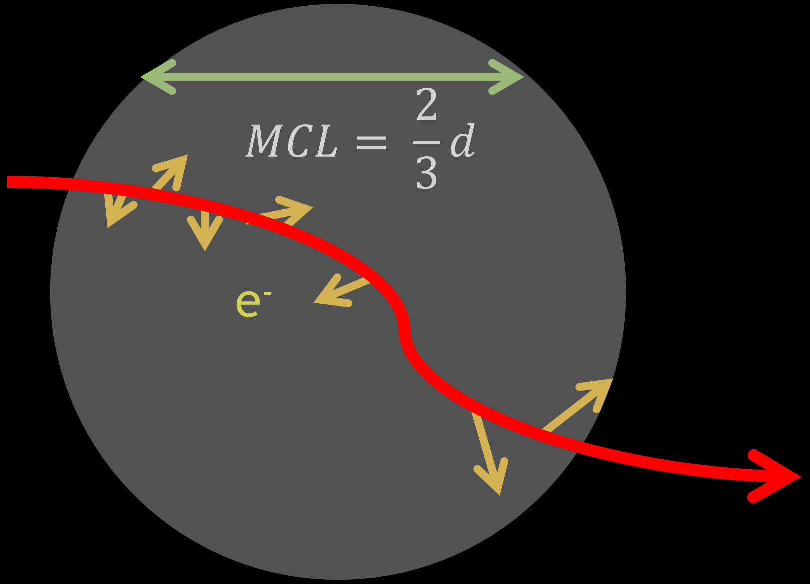

All particles are assumed to travel the same distance

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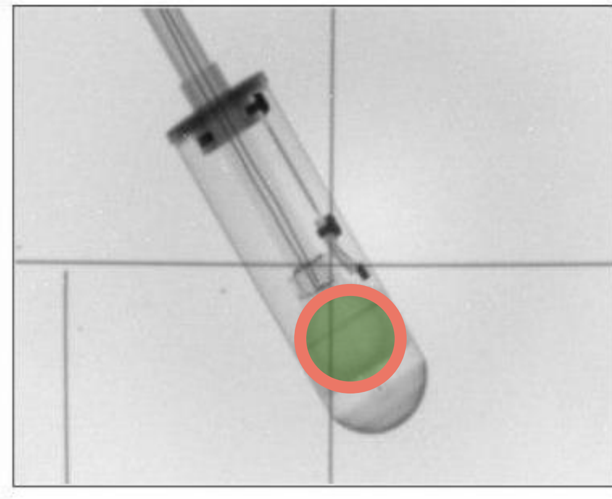

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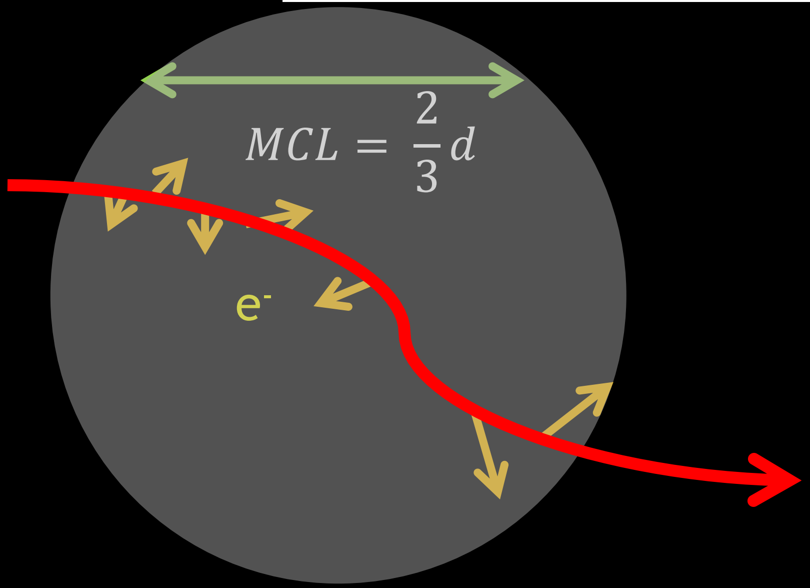

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To provide a better radiation quality description

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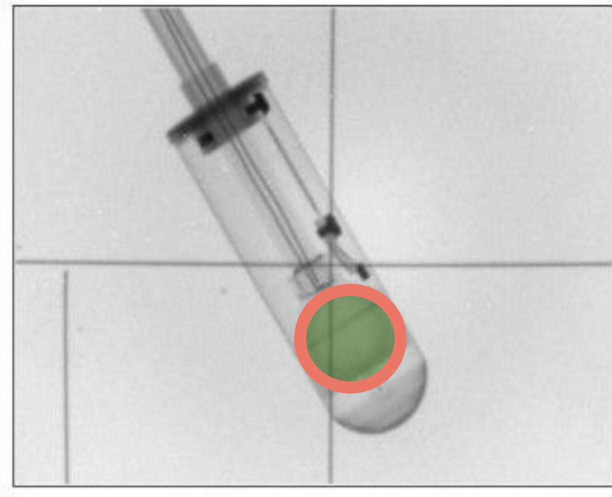

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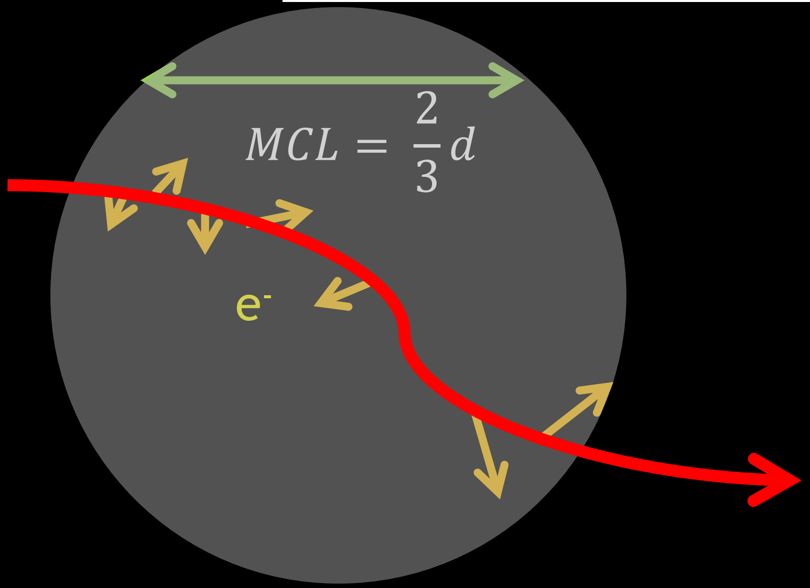

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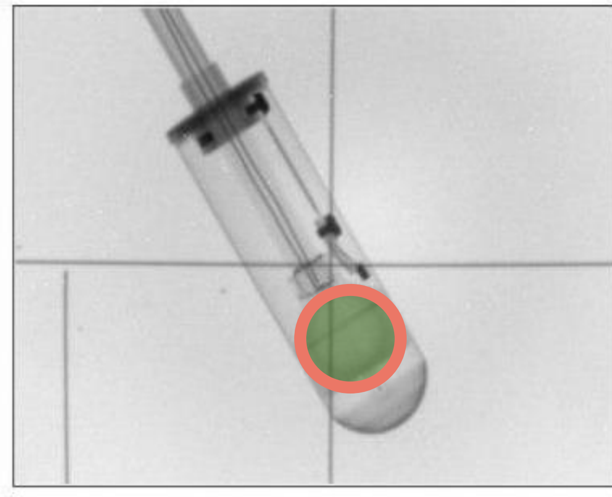

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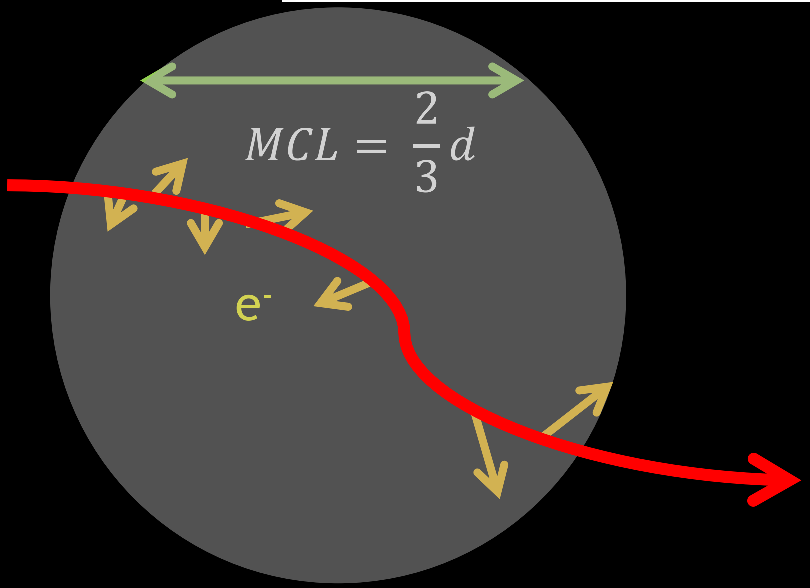

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A tracker is needed

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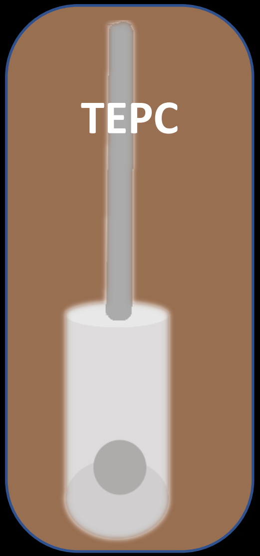

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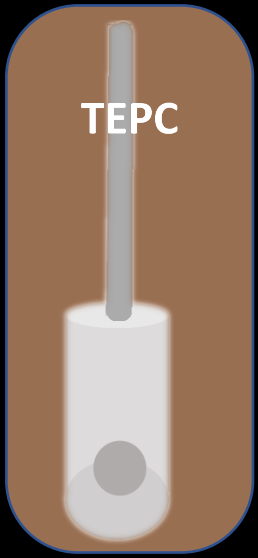

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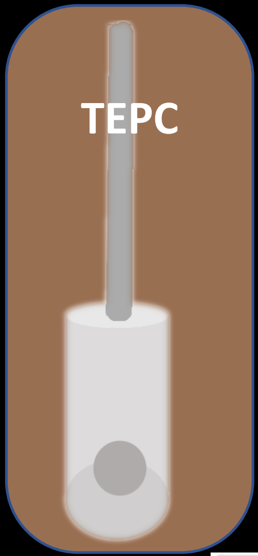
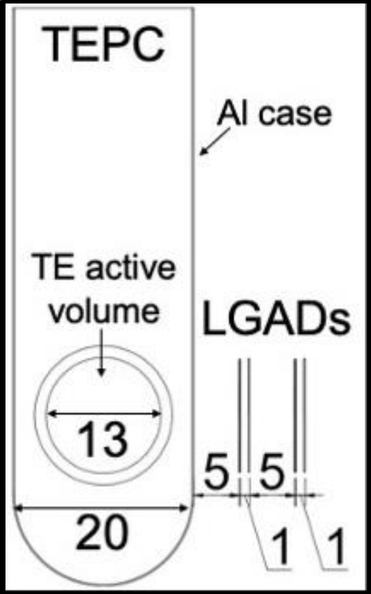


Low Gain Avalanche Detectors



Units in mm

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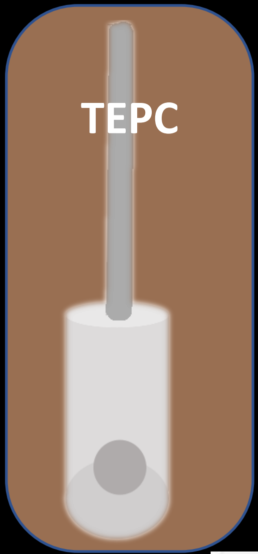
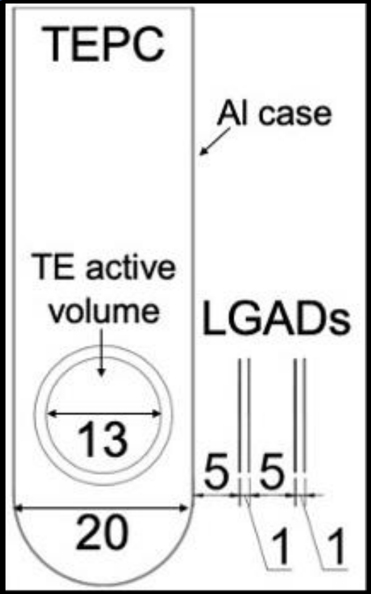
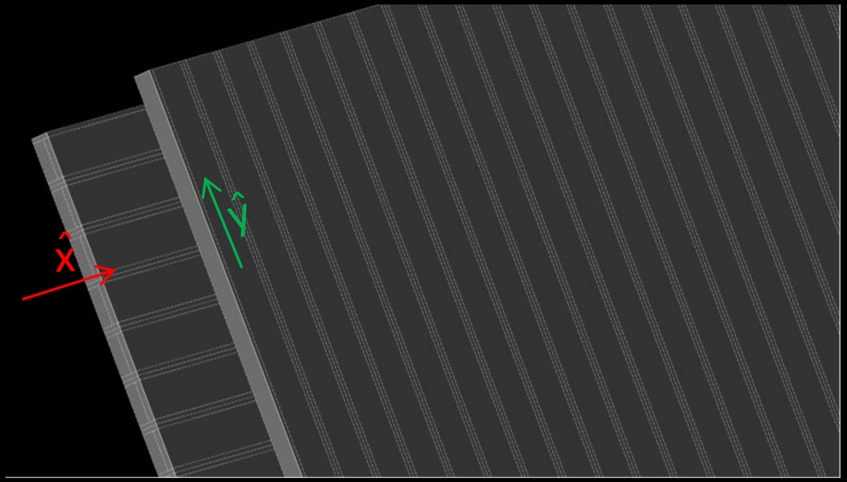




Units in mm

Strip is activated



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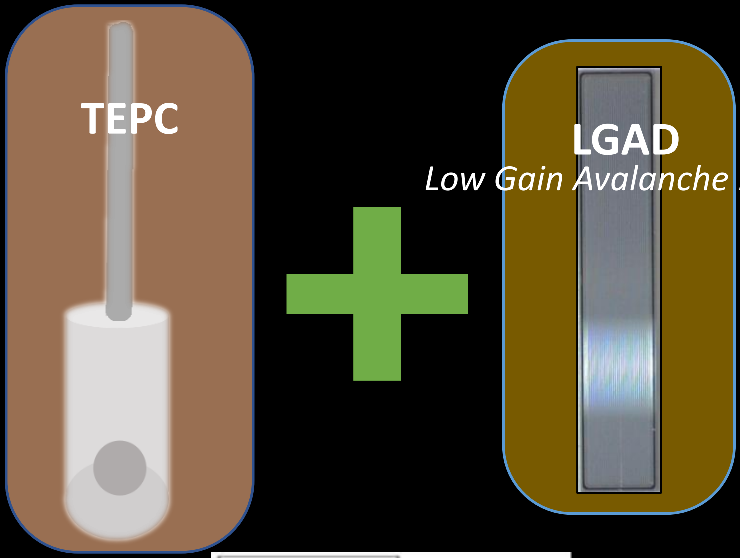

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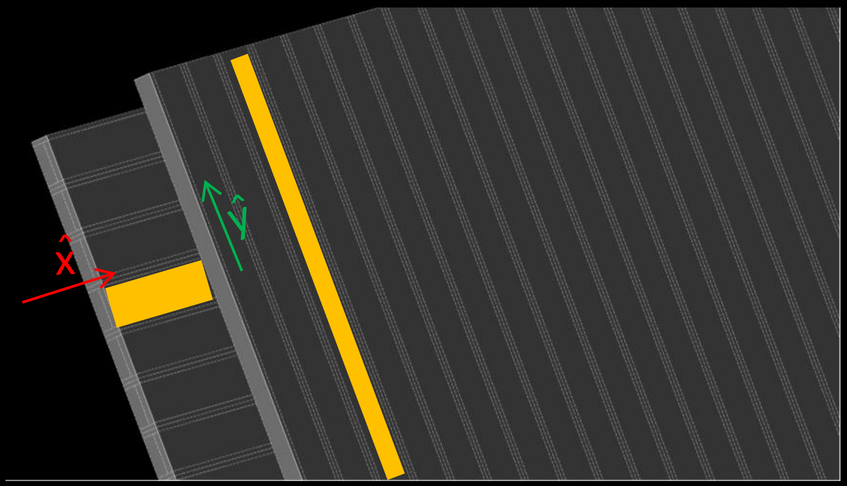

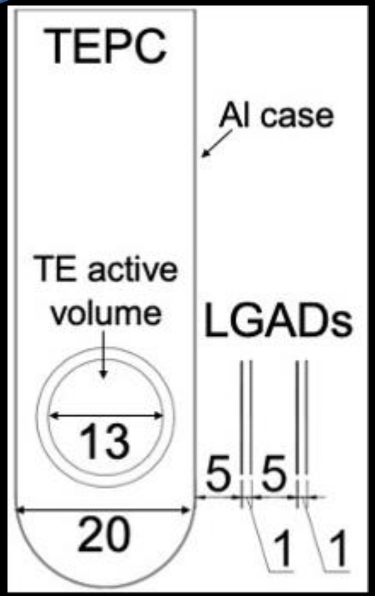

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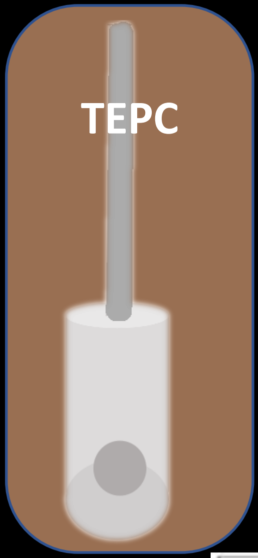

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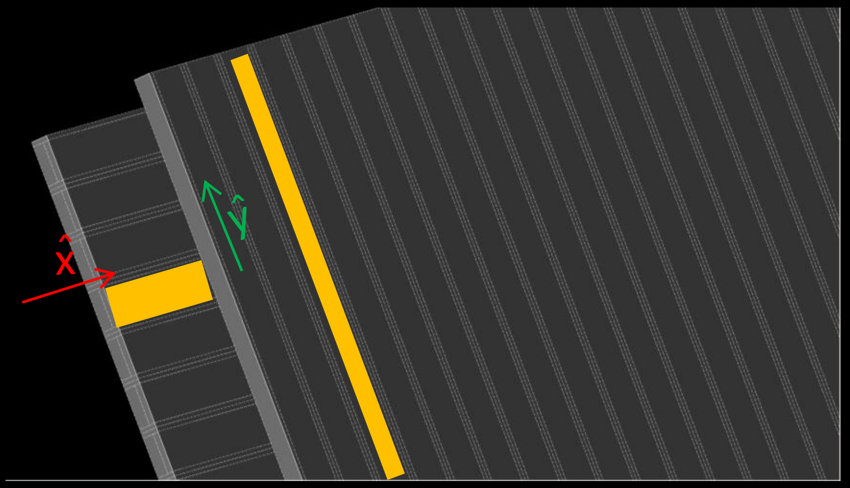
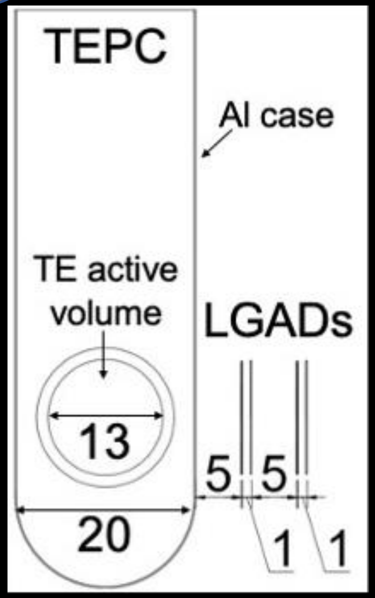
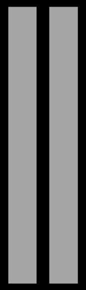




Units in mm

Tissue equivalent proportional counter



Low Gain Avalanche Detector

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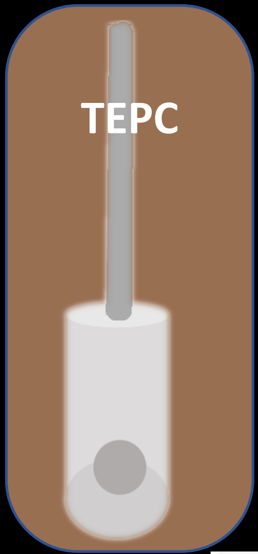

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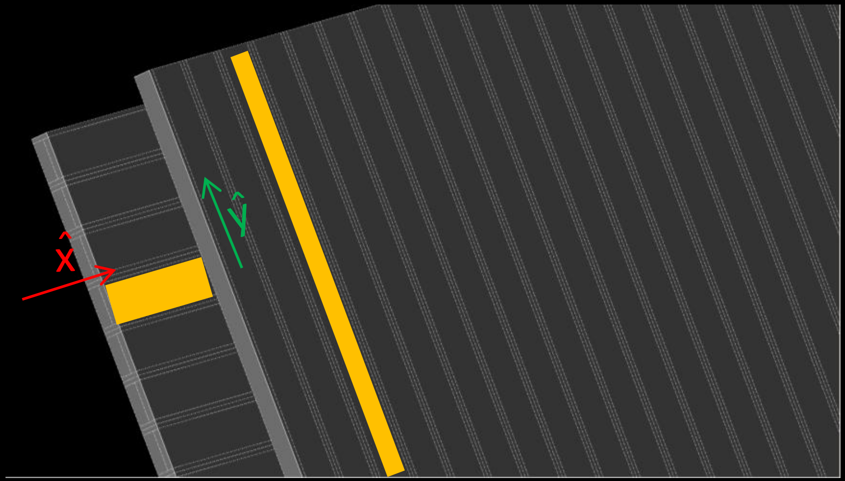
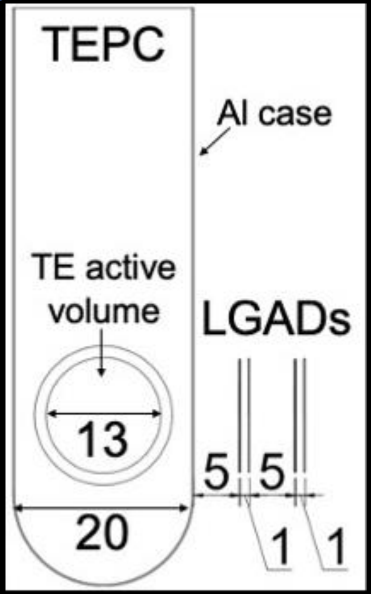


4 Planes (2-x̂, 2-ŷ) to reconstruct the track



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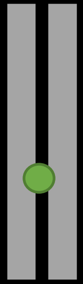

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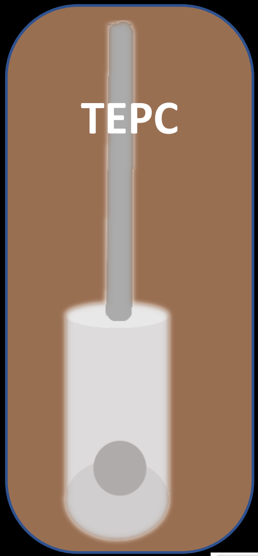

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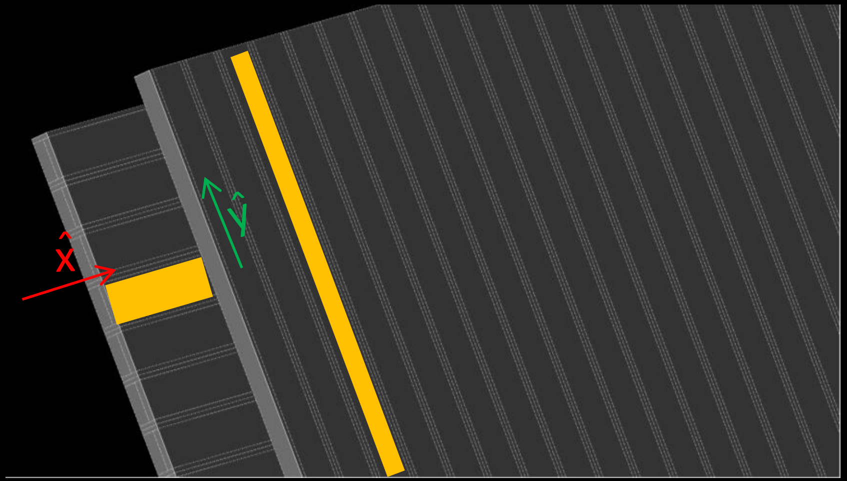

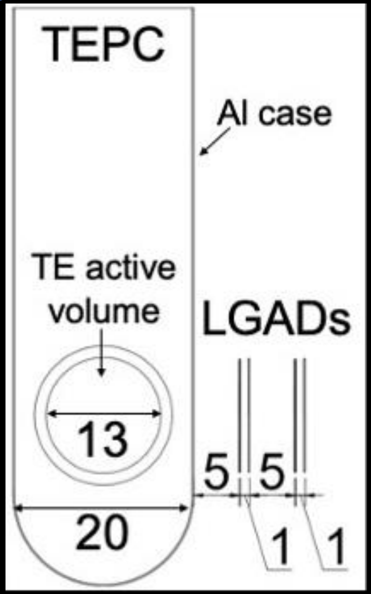

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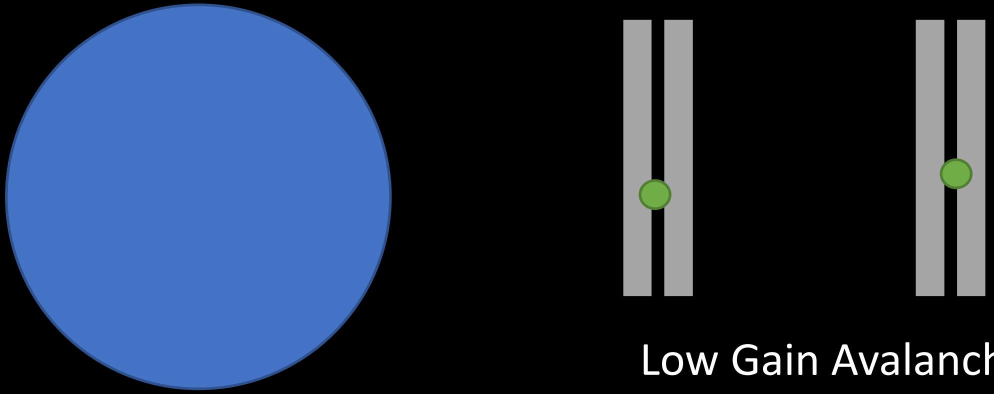

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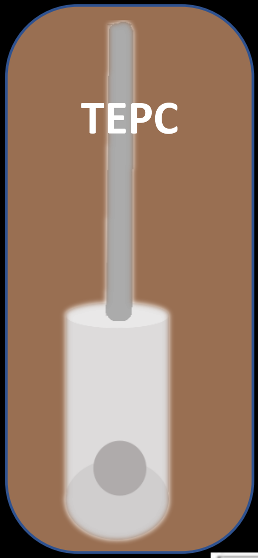

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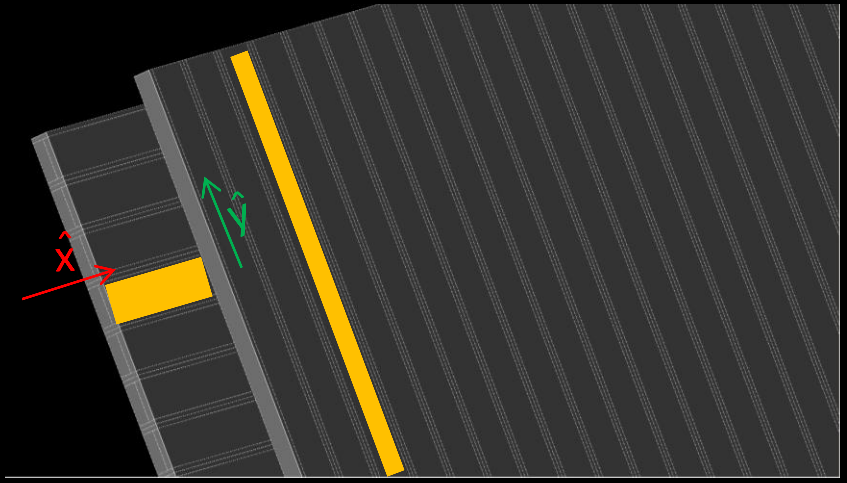

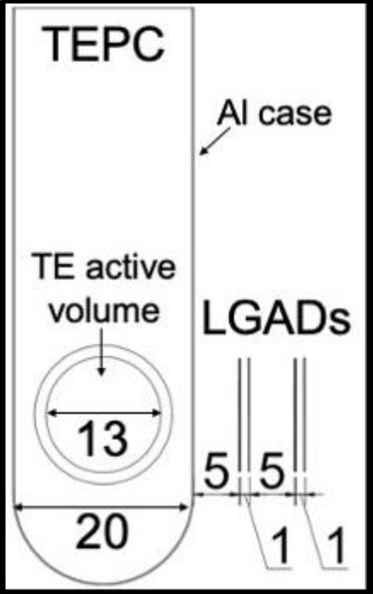

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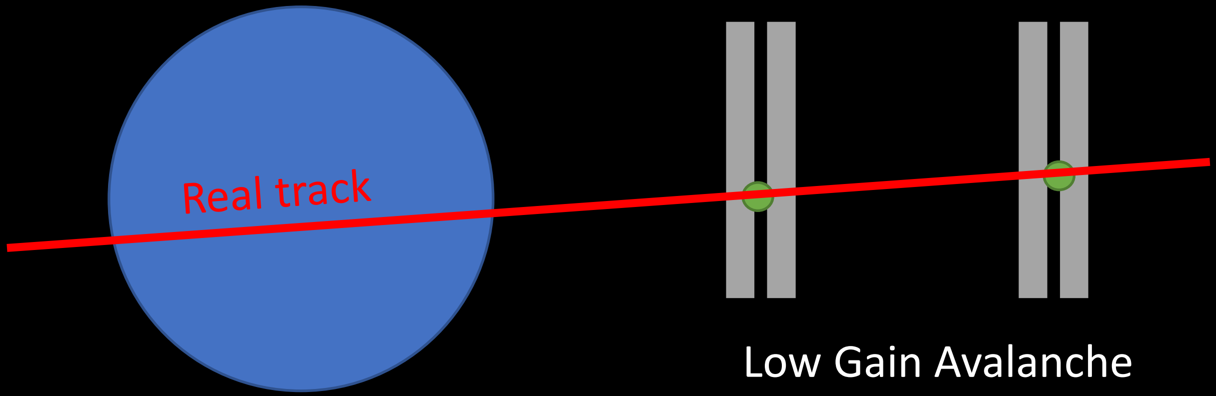

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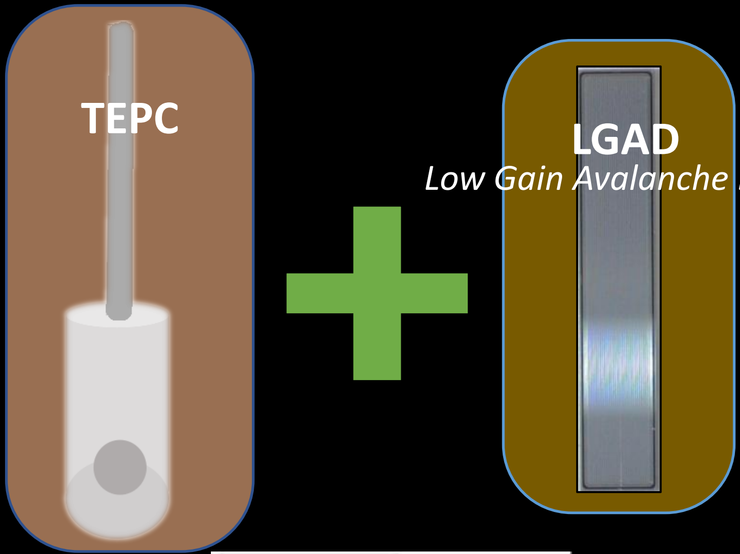

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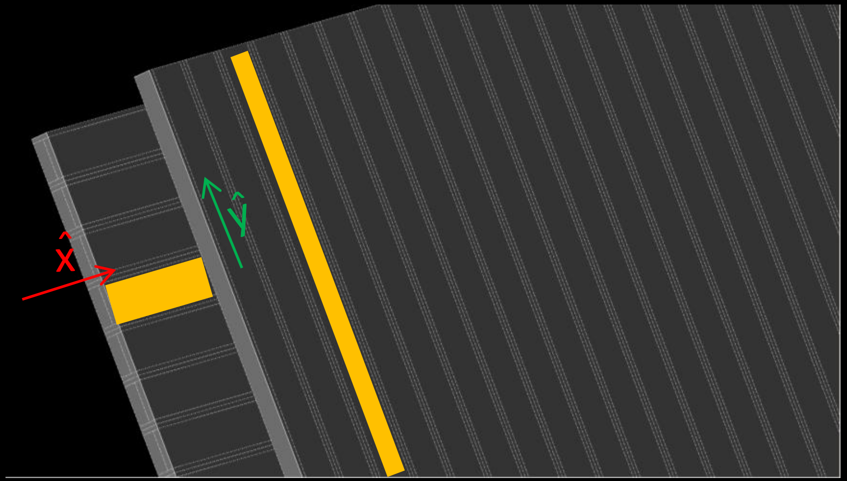
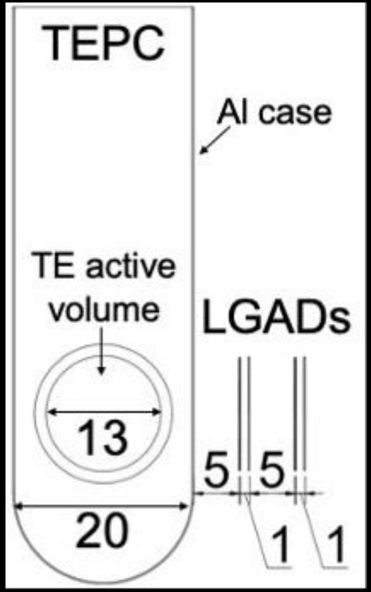
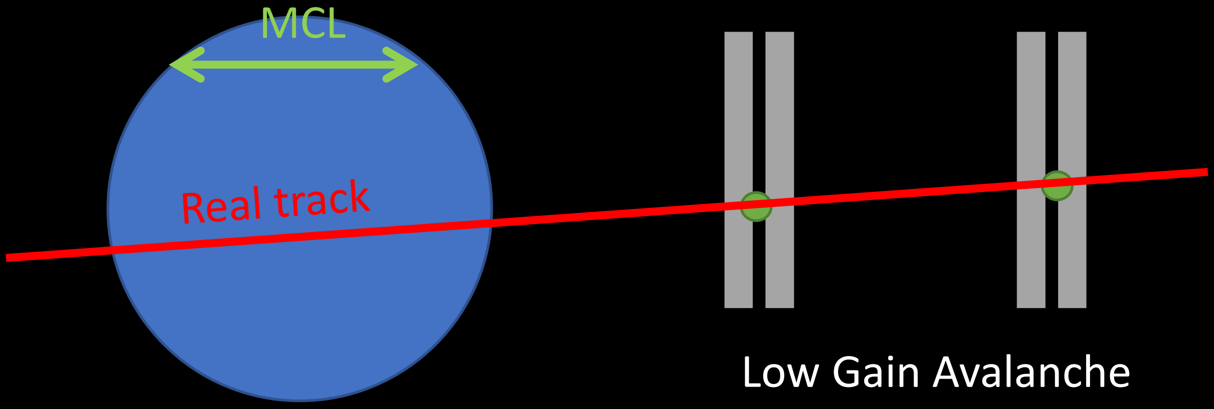


4 Planes (2-x̂, 2-ŷ) to reconstruct the track



Units in mm

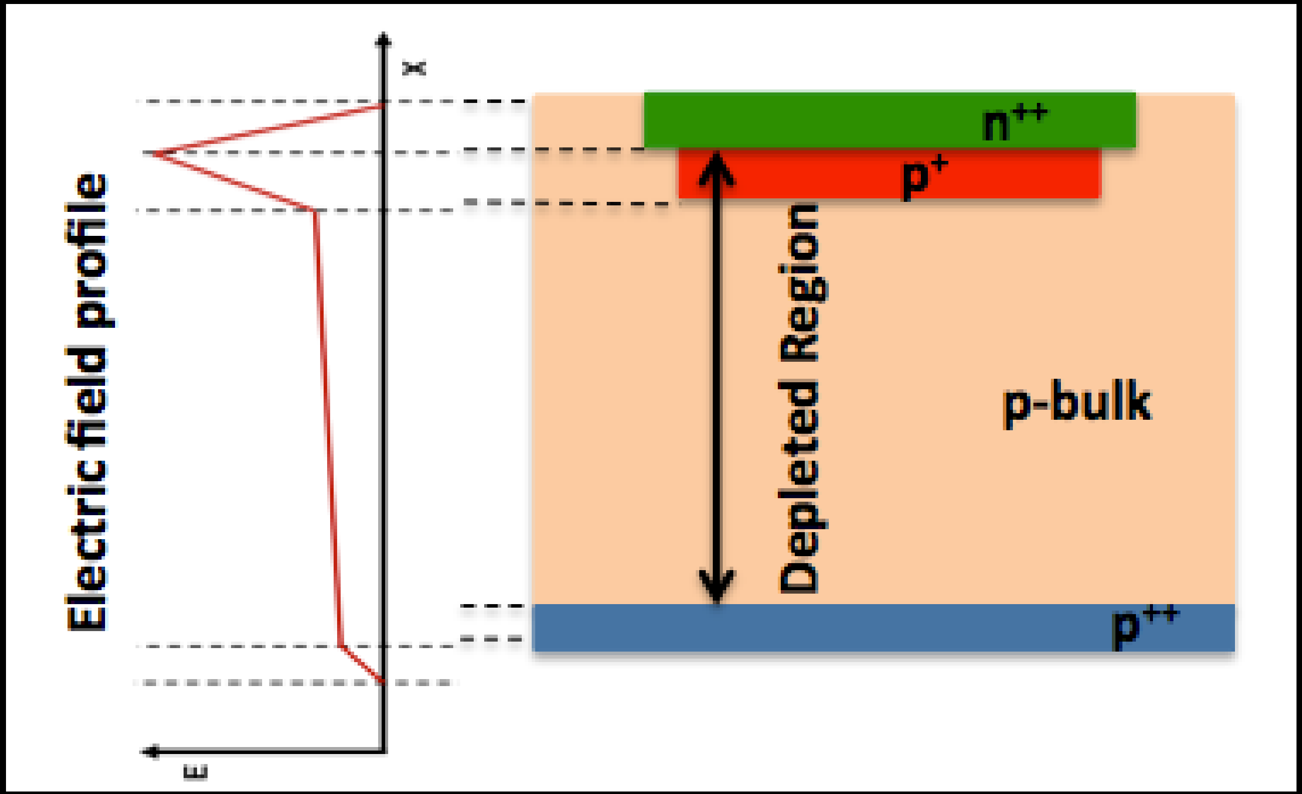


Tissue equivalent proportional counter

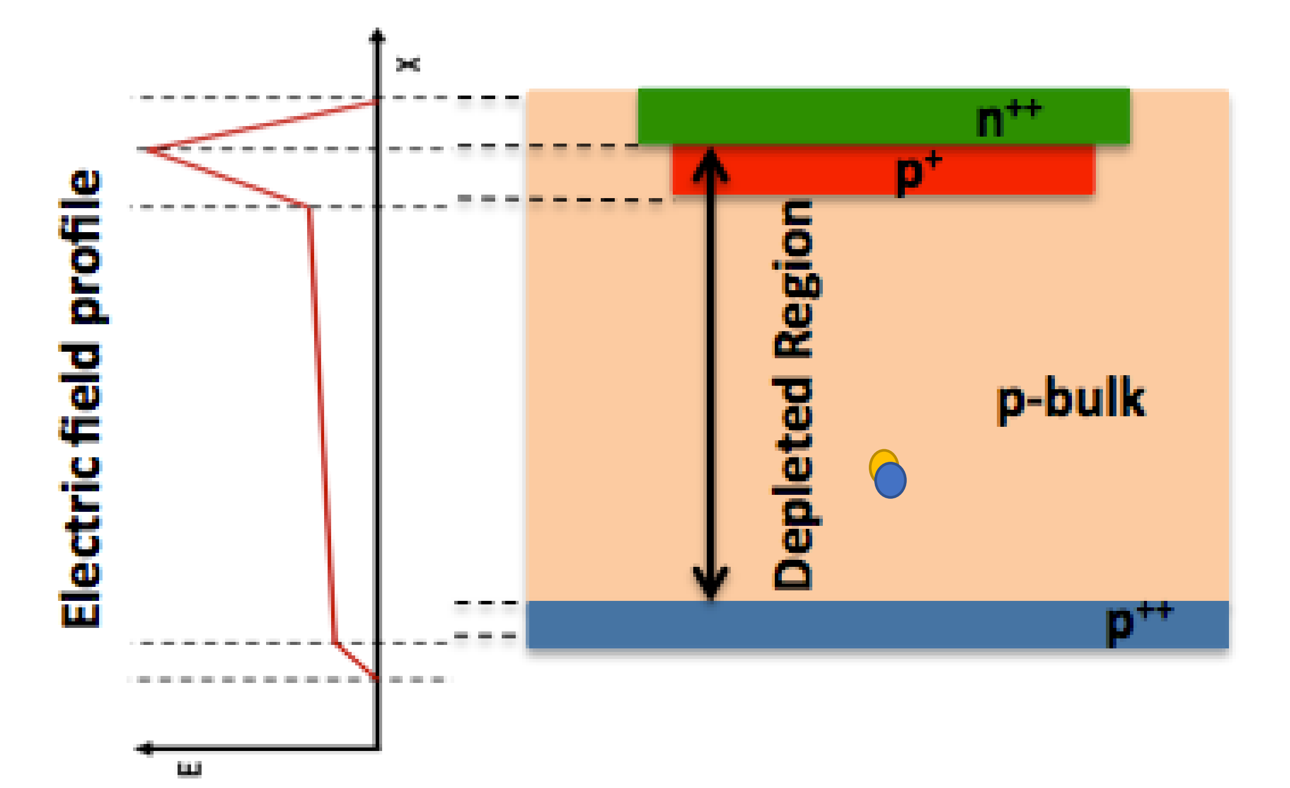
Low Gain Avalanche Detector

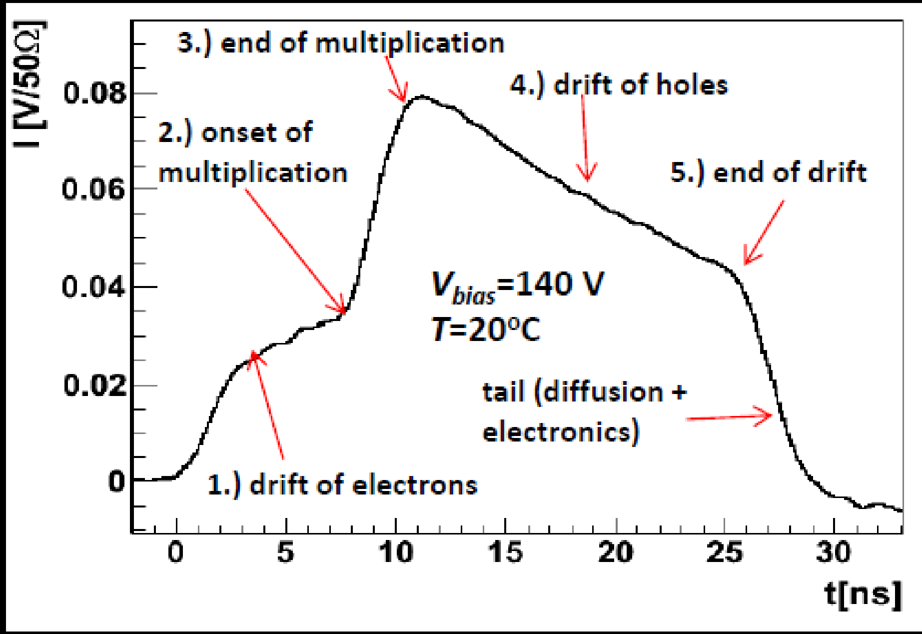
Low Gain Avalanche Diode (LGAD) detectors

Low Gain Avalanche Diode (LGAD) detectors

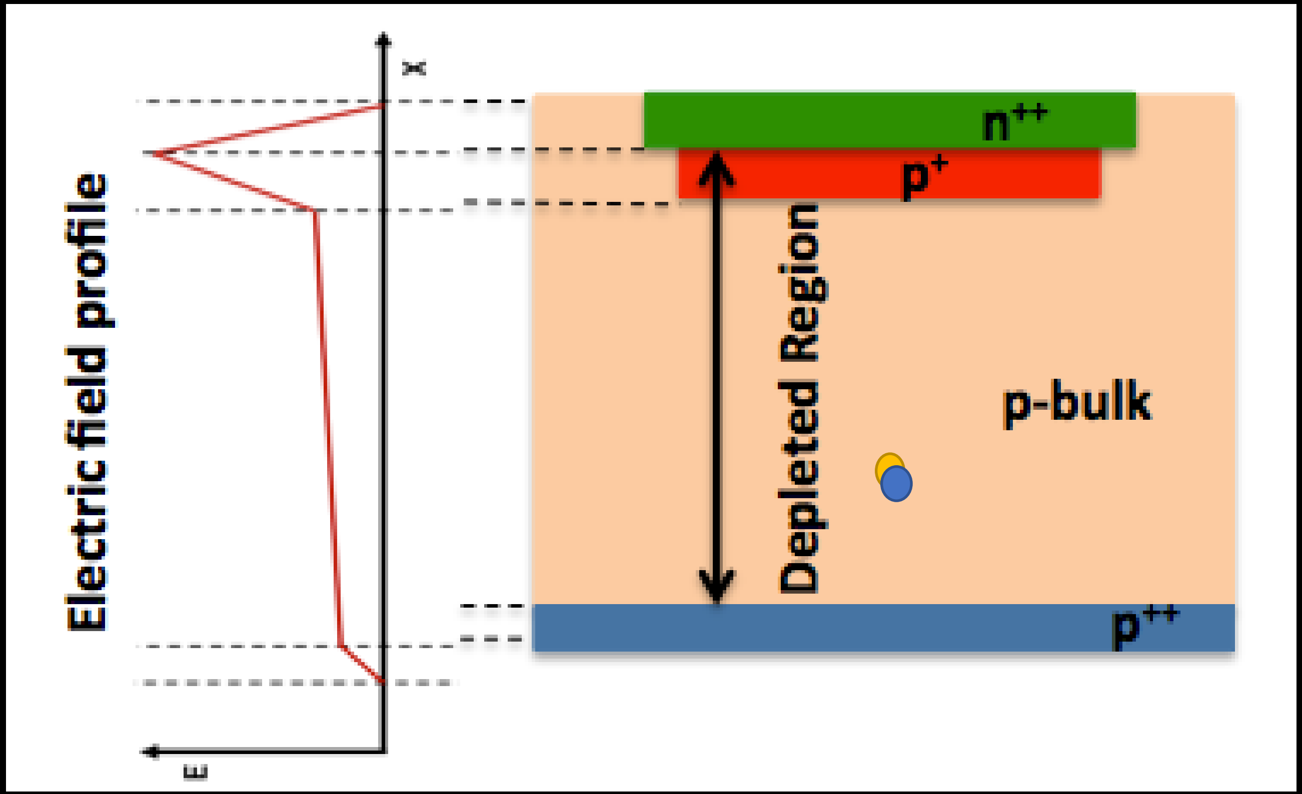


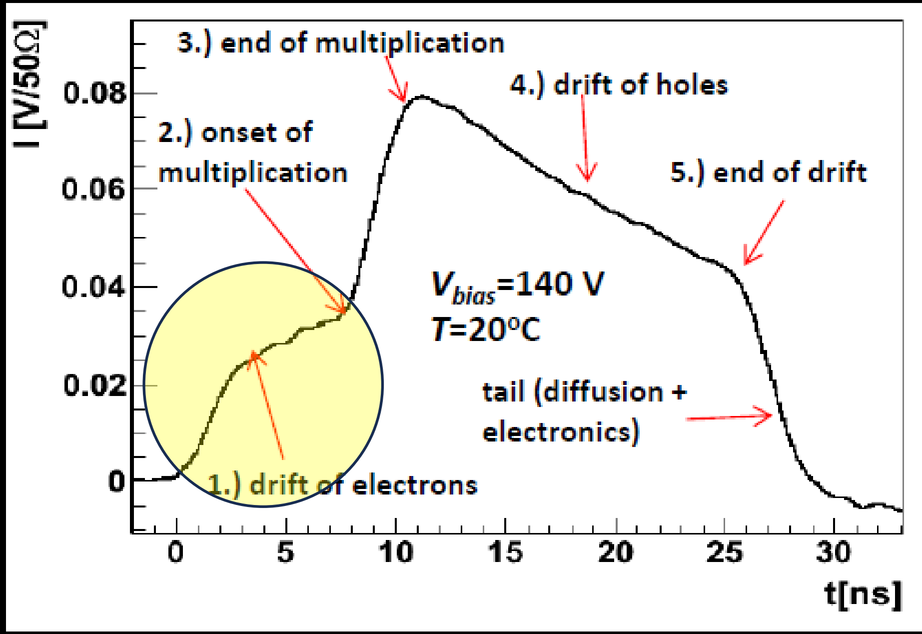
Low Gain Avalanche Diode (LGAD) detectors



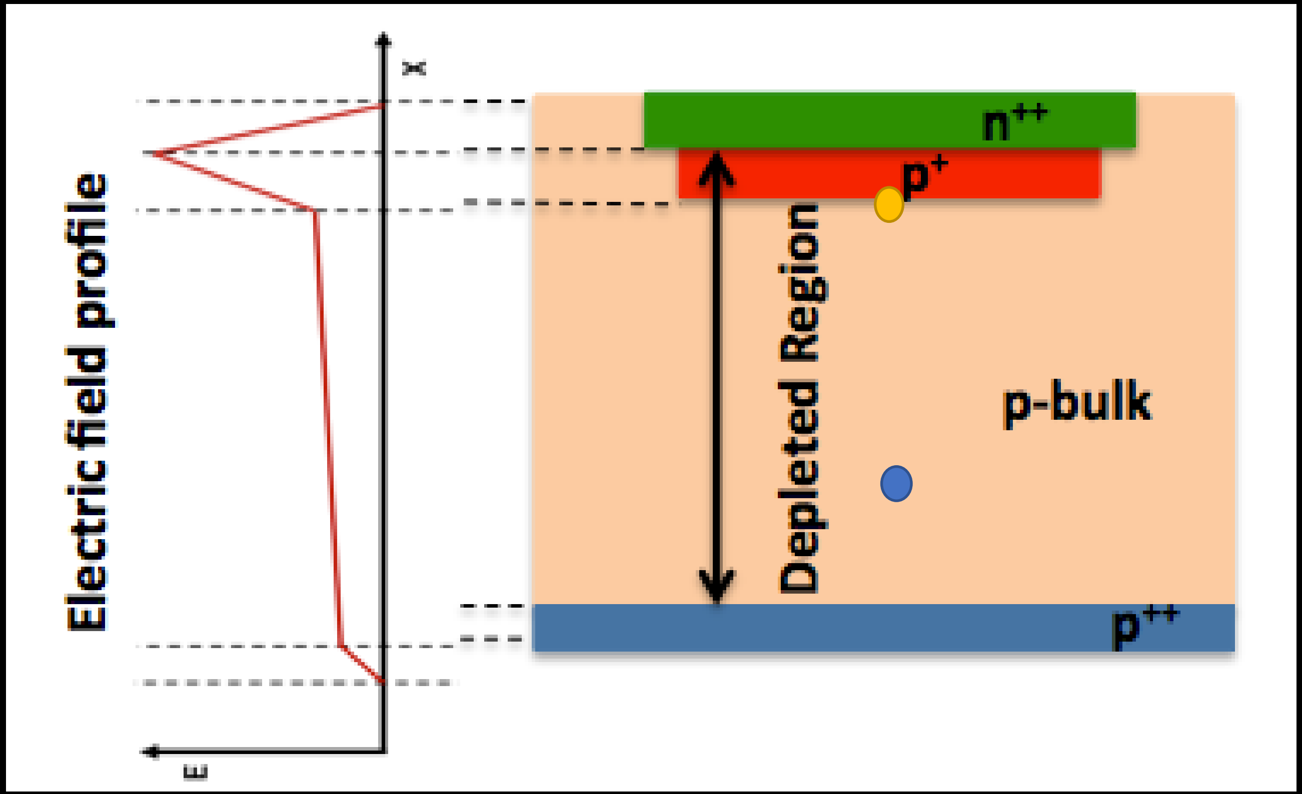


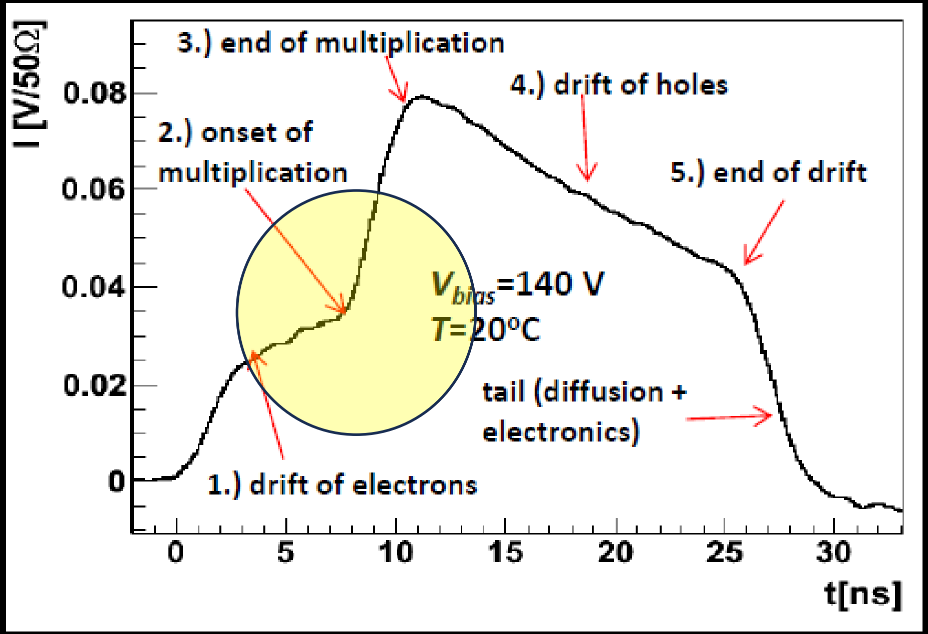
Low Gain Avalanche Diode (LGAD) detectors



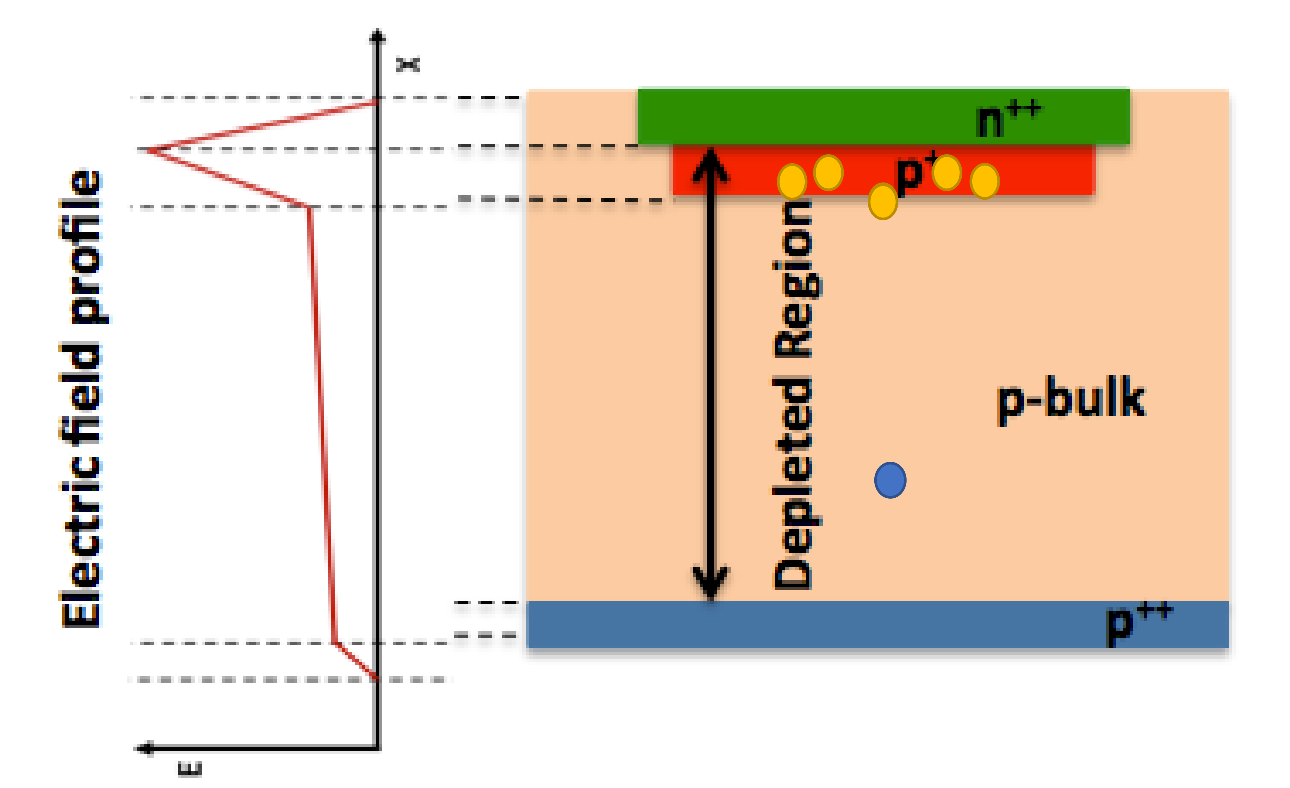


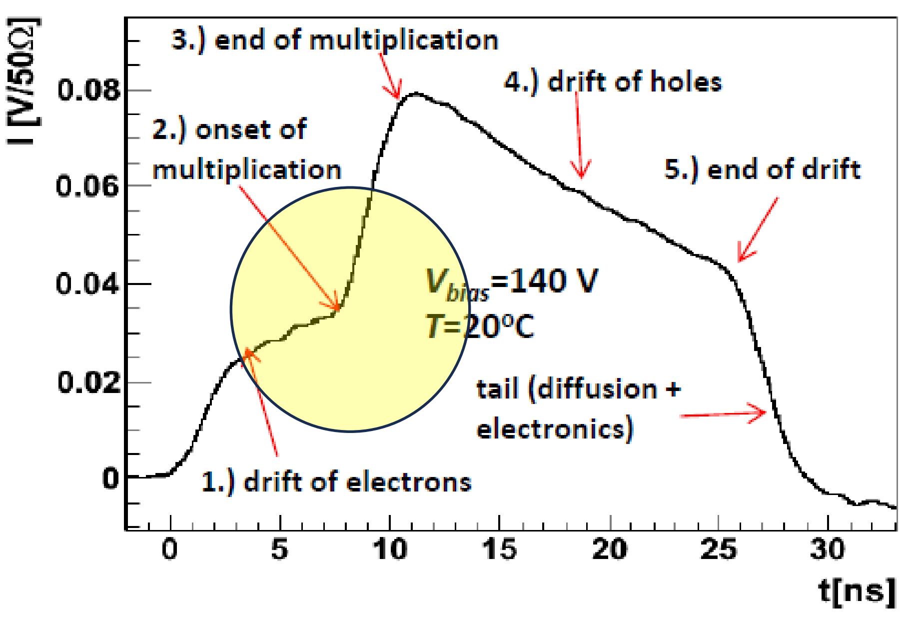
Low Gain Avalanche Diode (LGAD) detectors



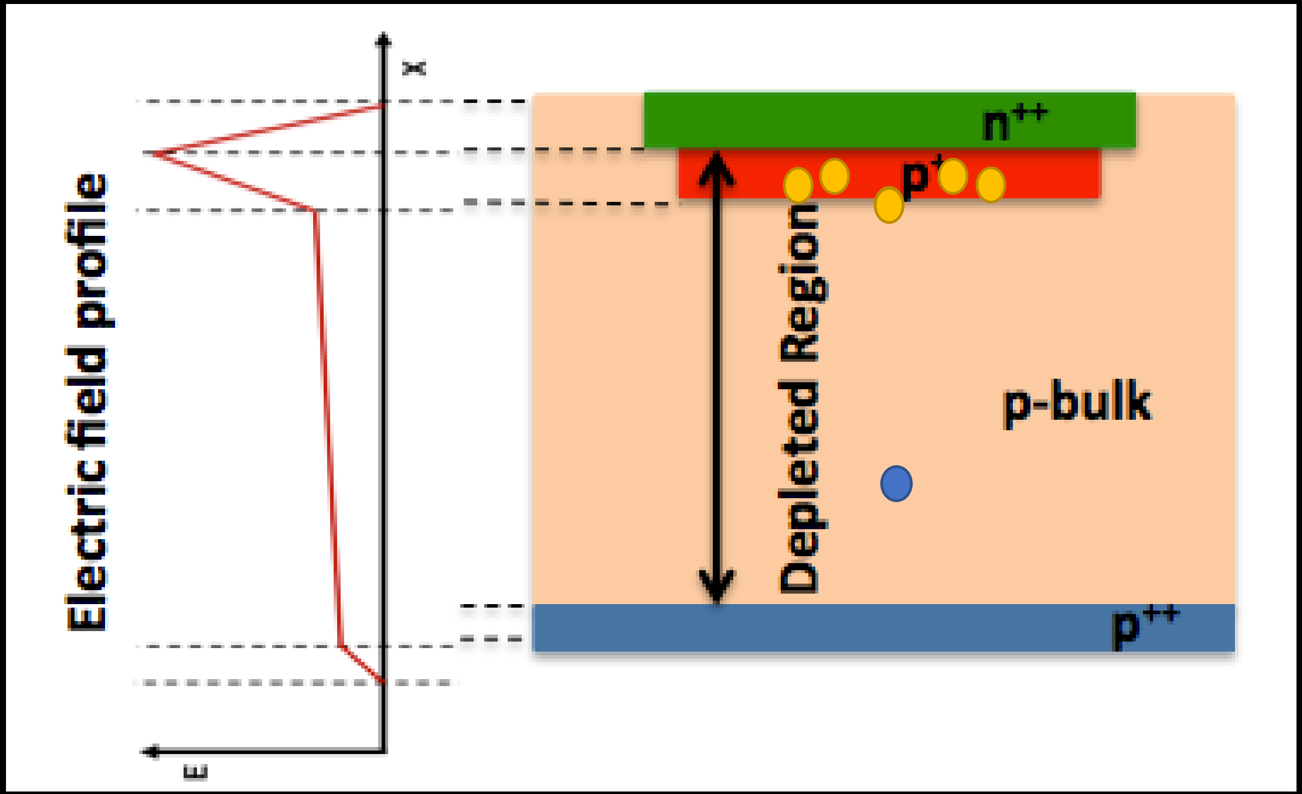


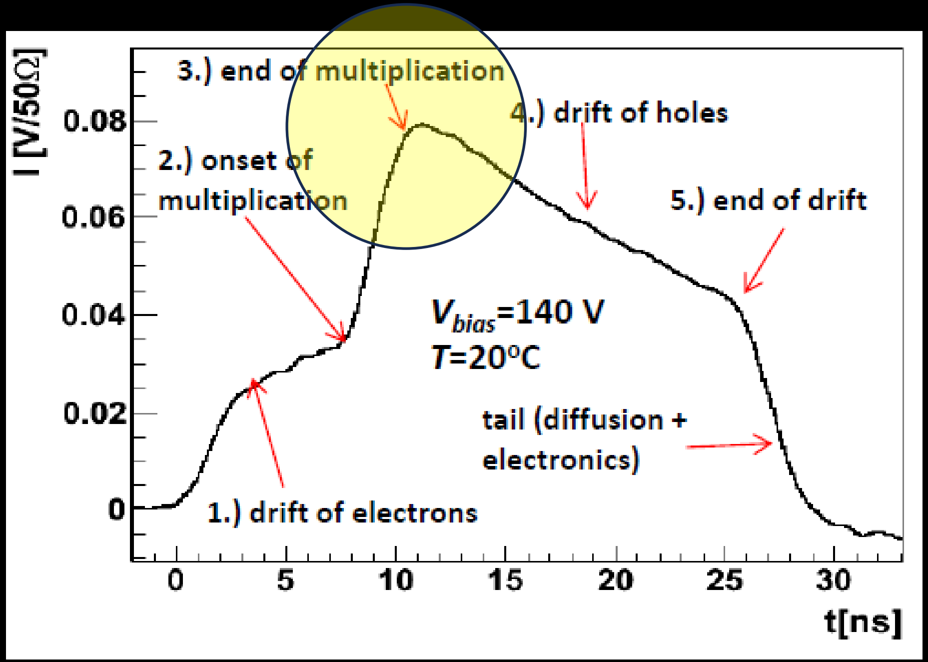
Low Gain Avalanche Diode (LGAD) detectors



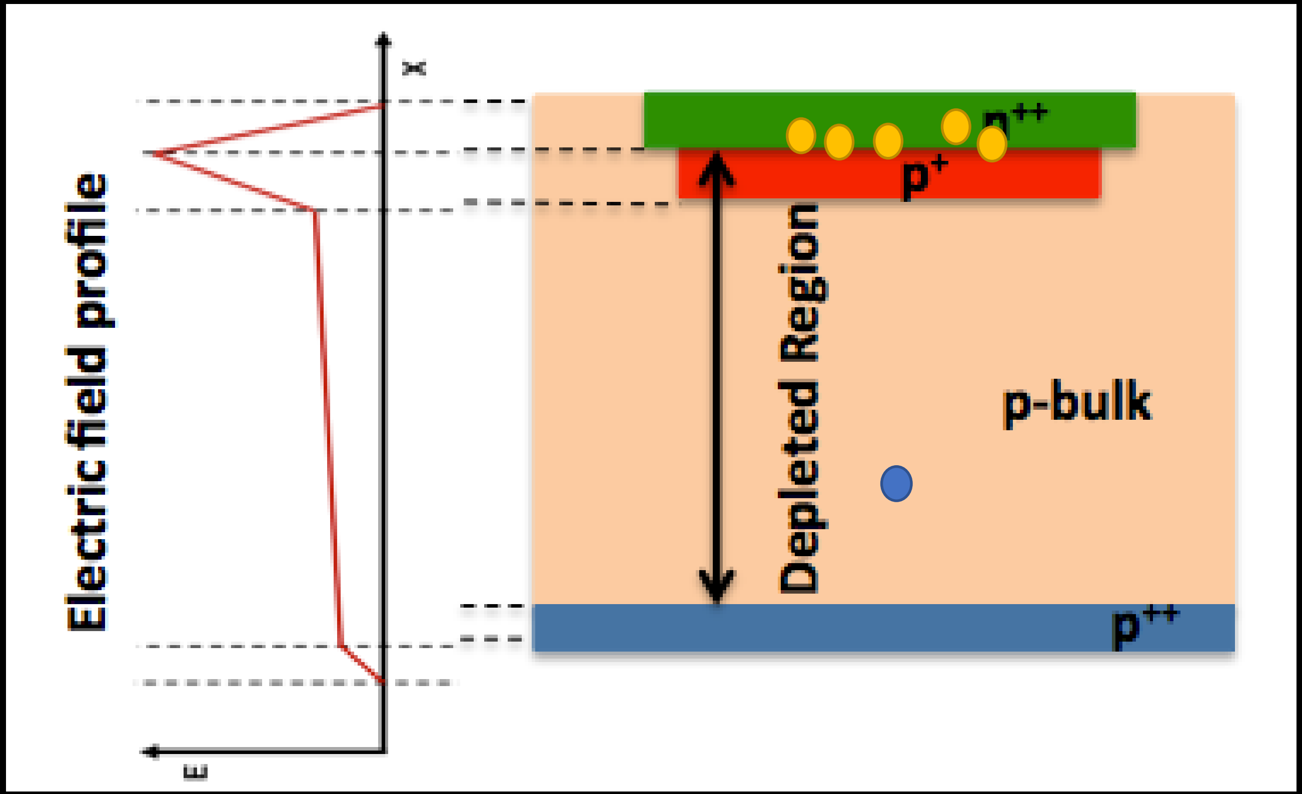


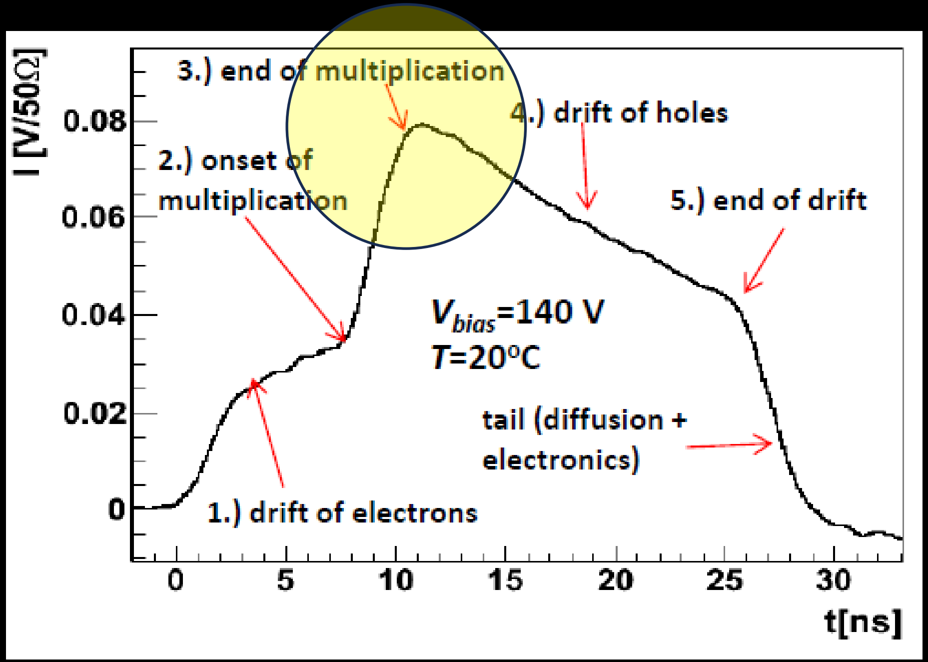
Low Gain Avalanche Diode (LGAD) detectors





Low Gain Avalanche Diode (LGAD) detectors





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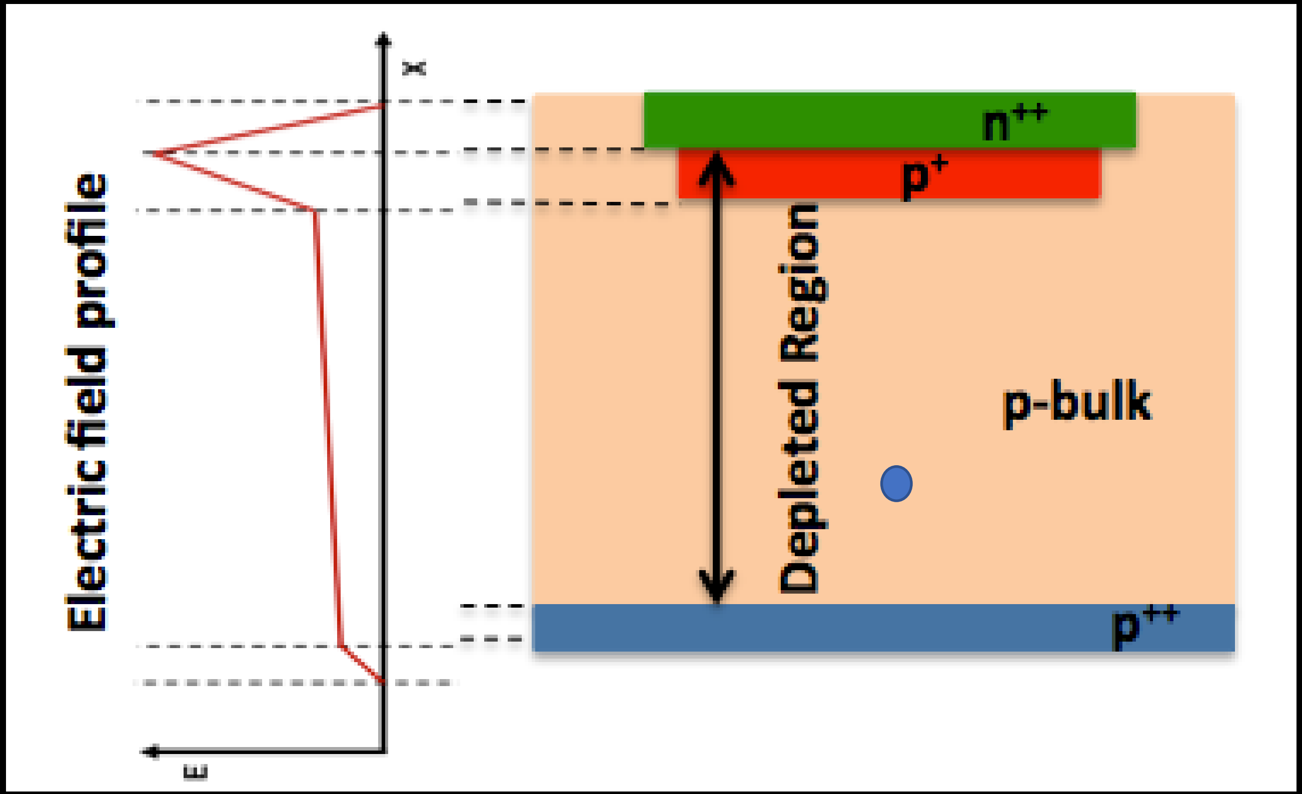
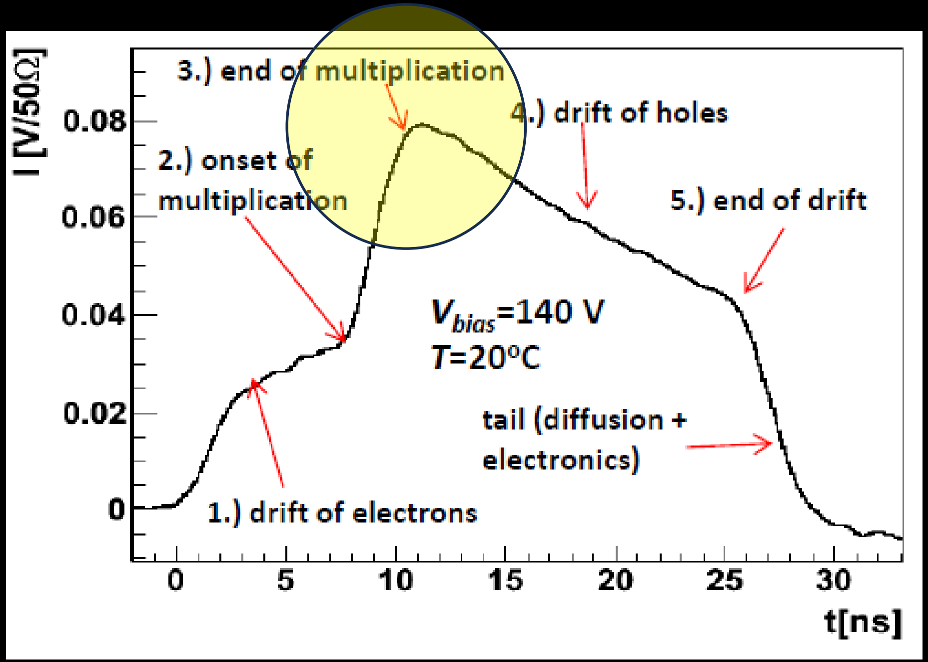
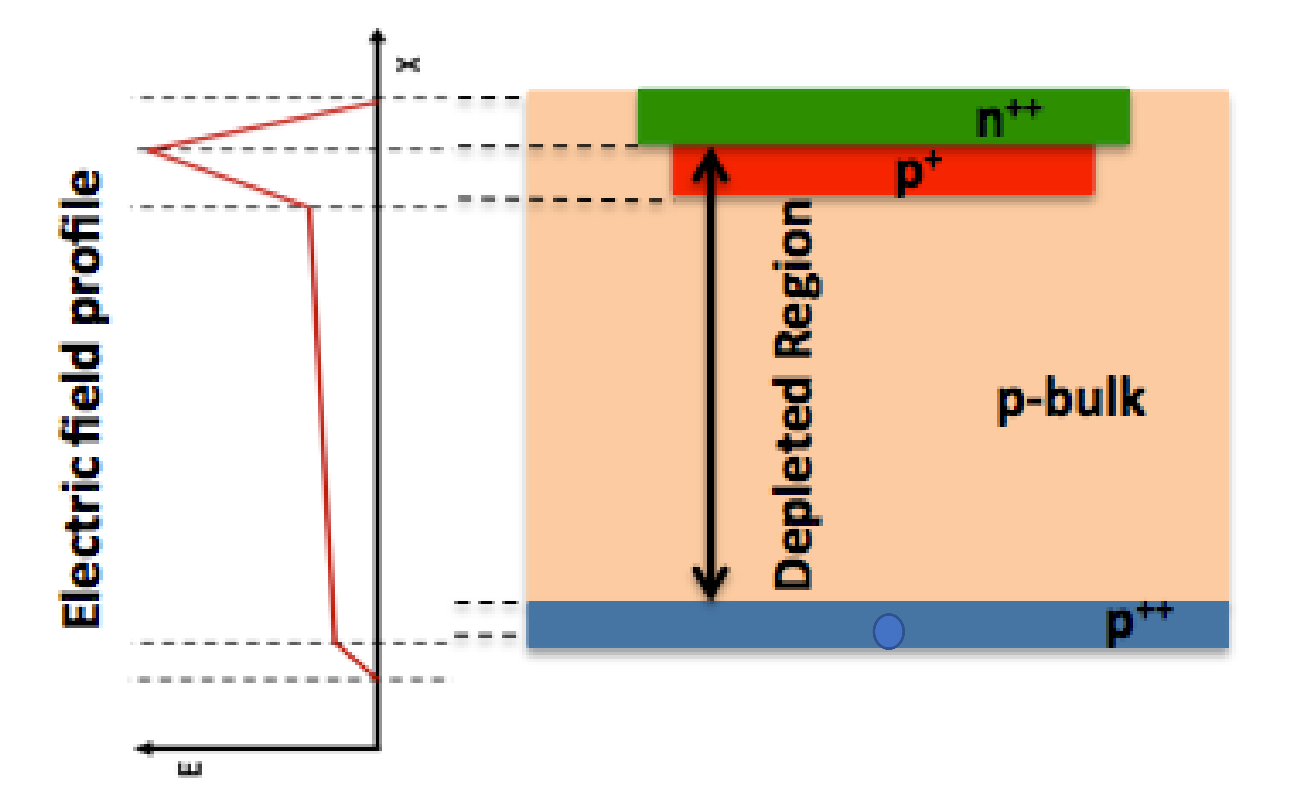
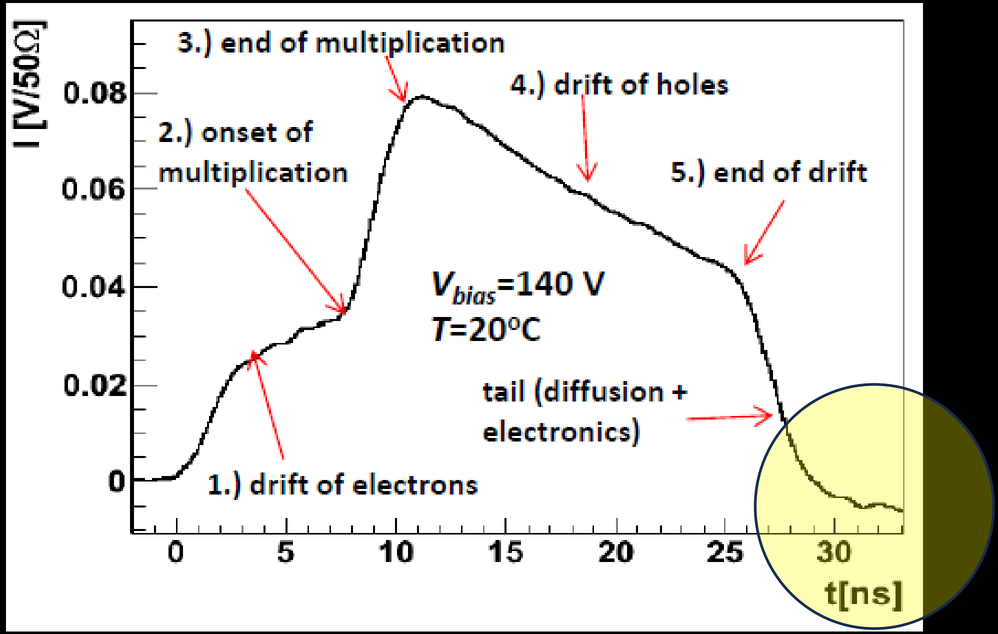




Low Gain Avalanche Diode (LGAD) detectors





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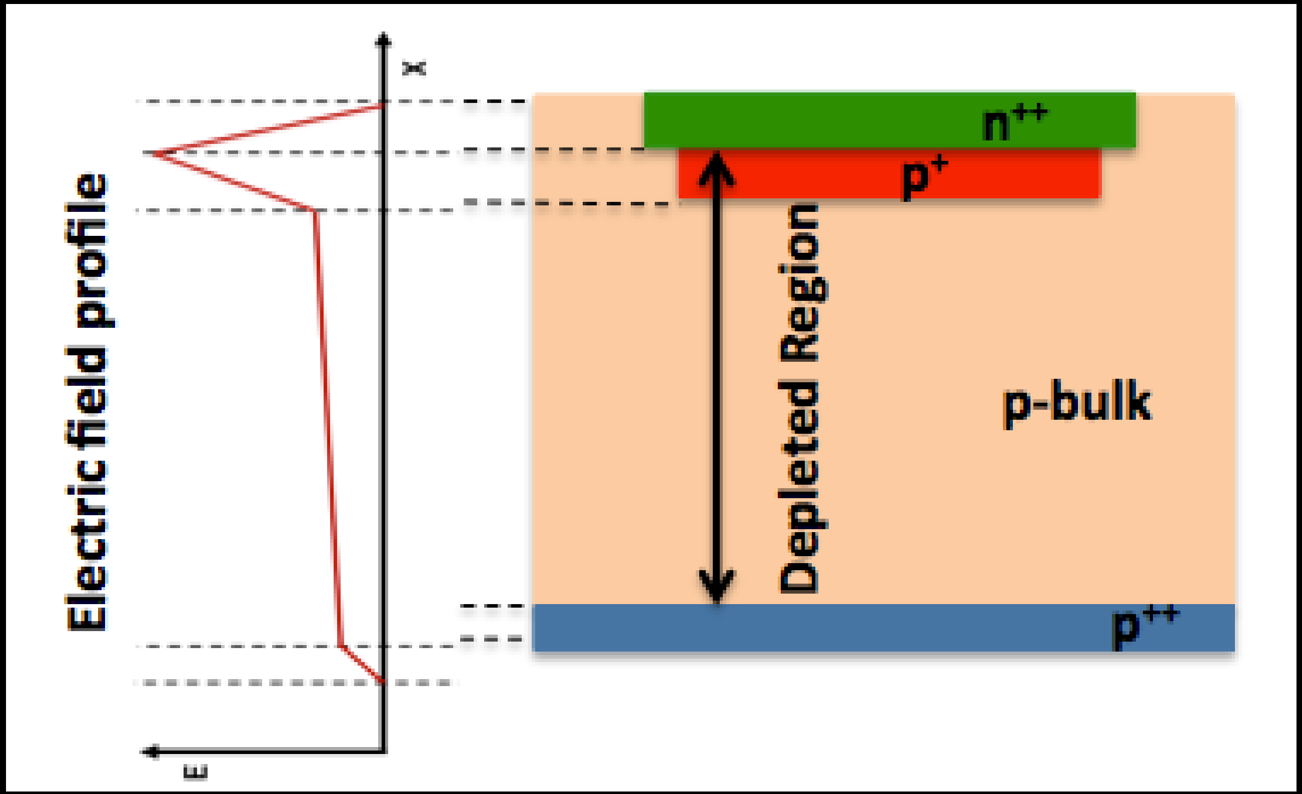

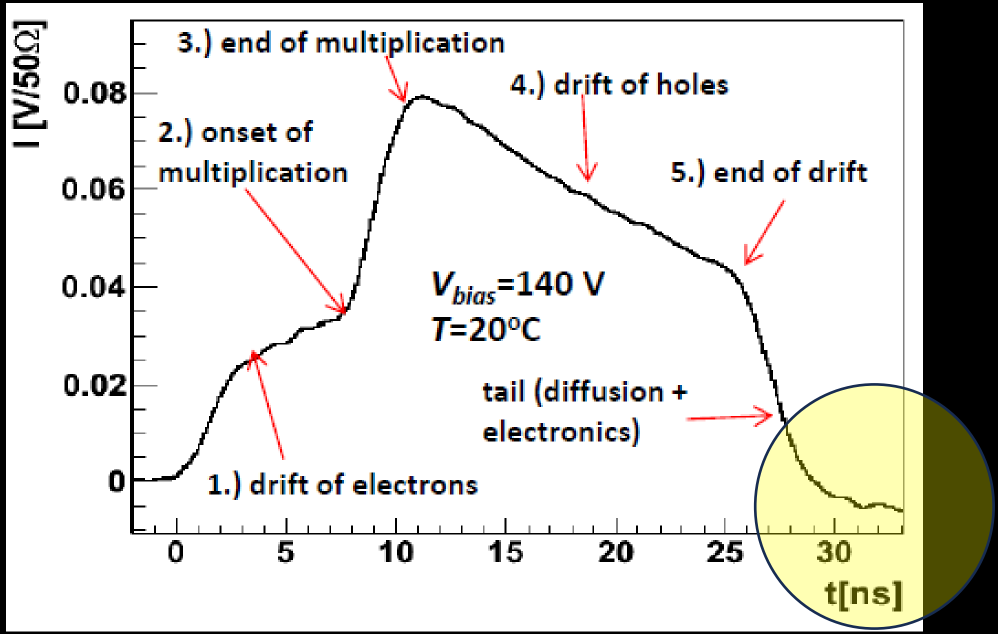

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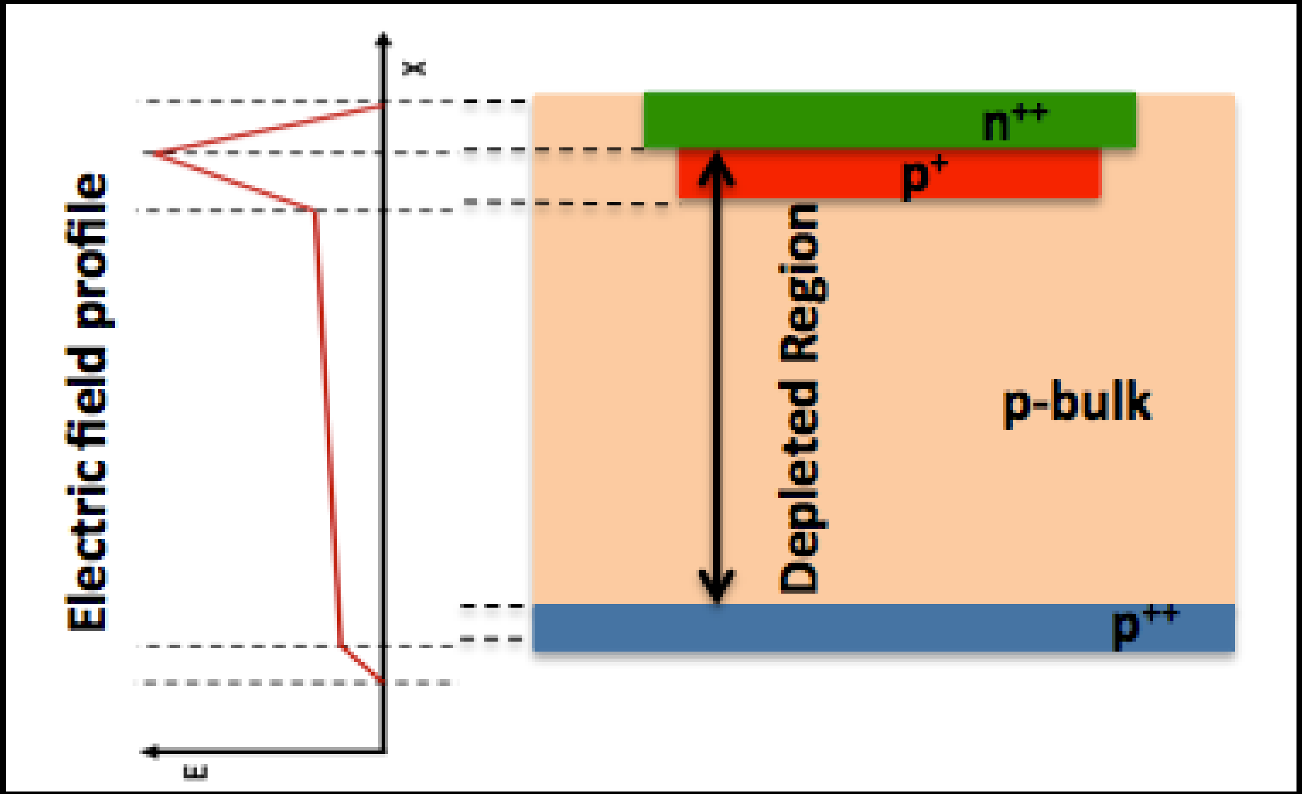
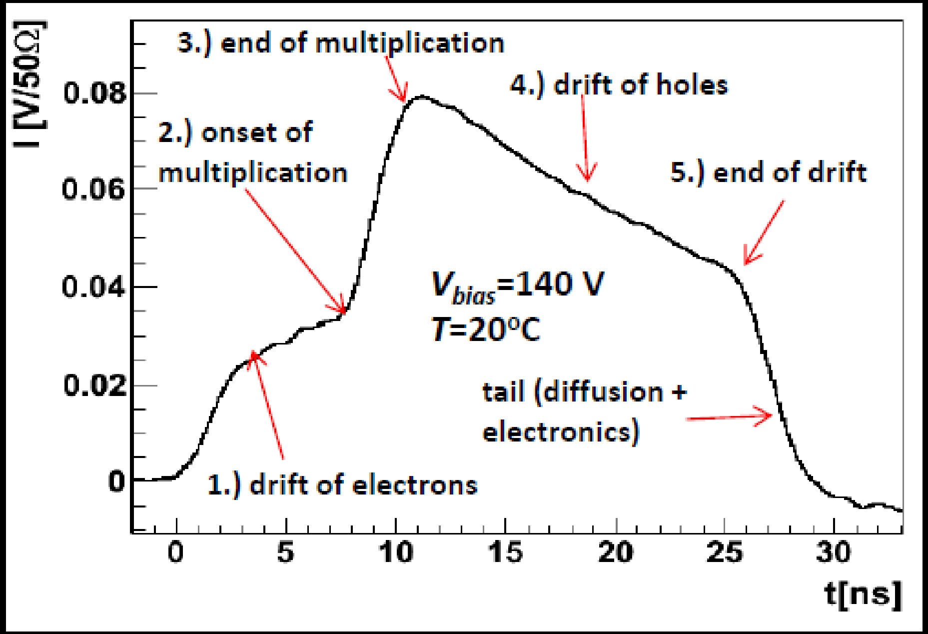
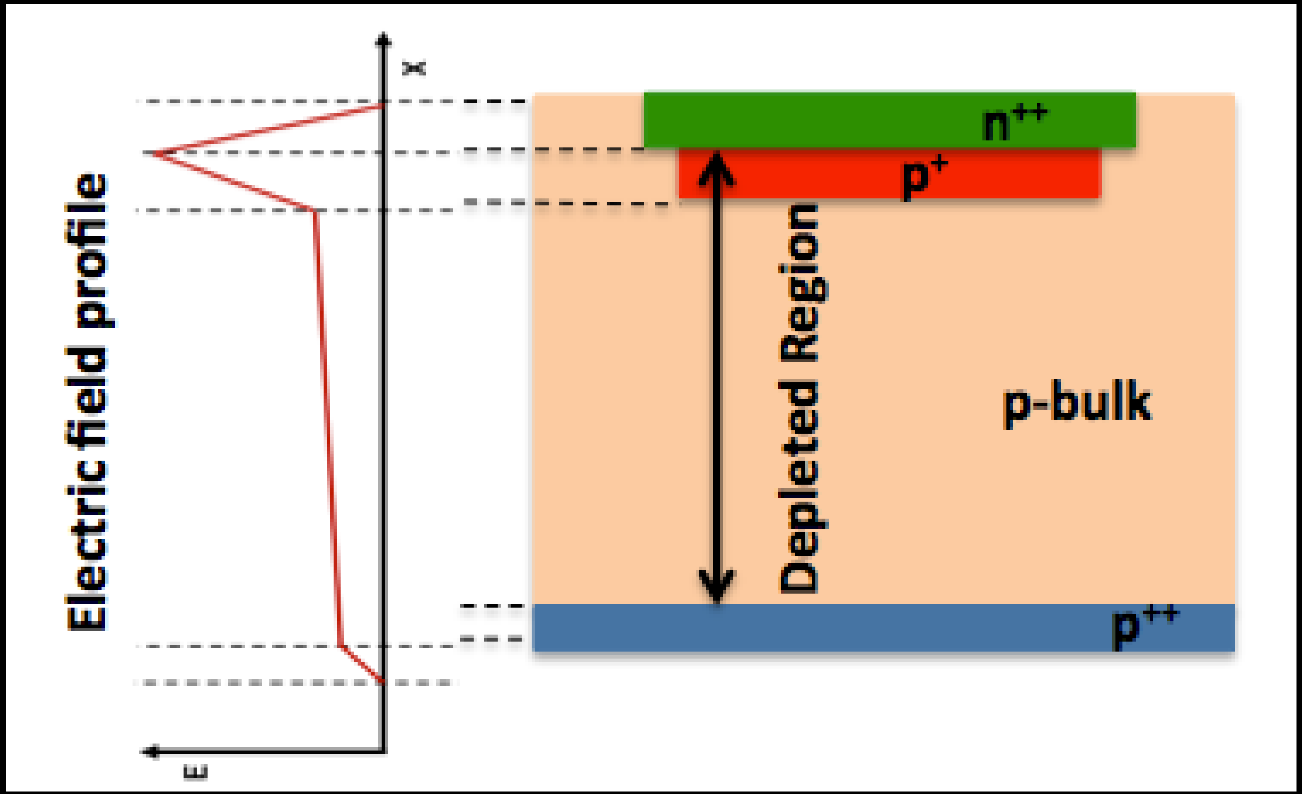
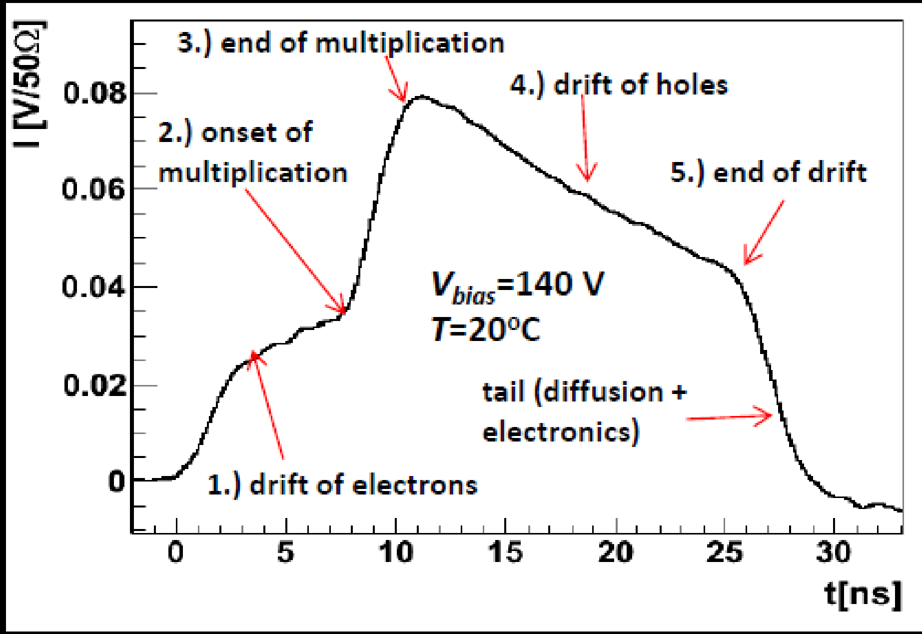




- Strip detector

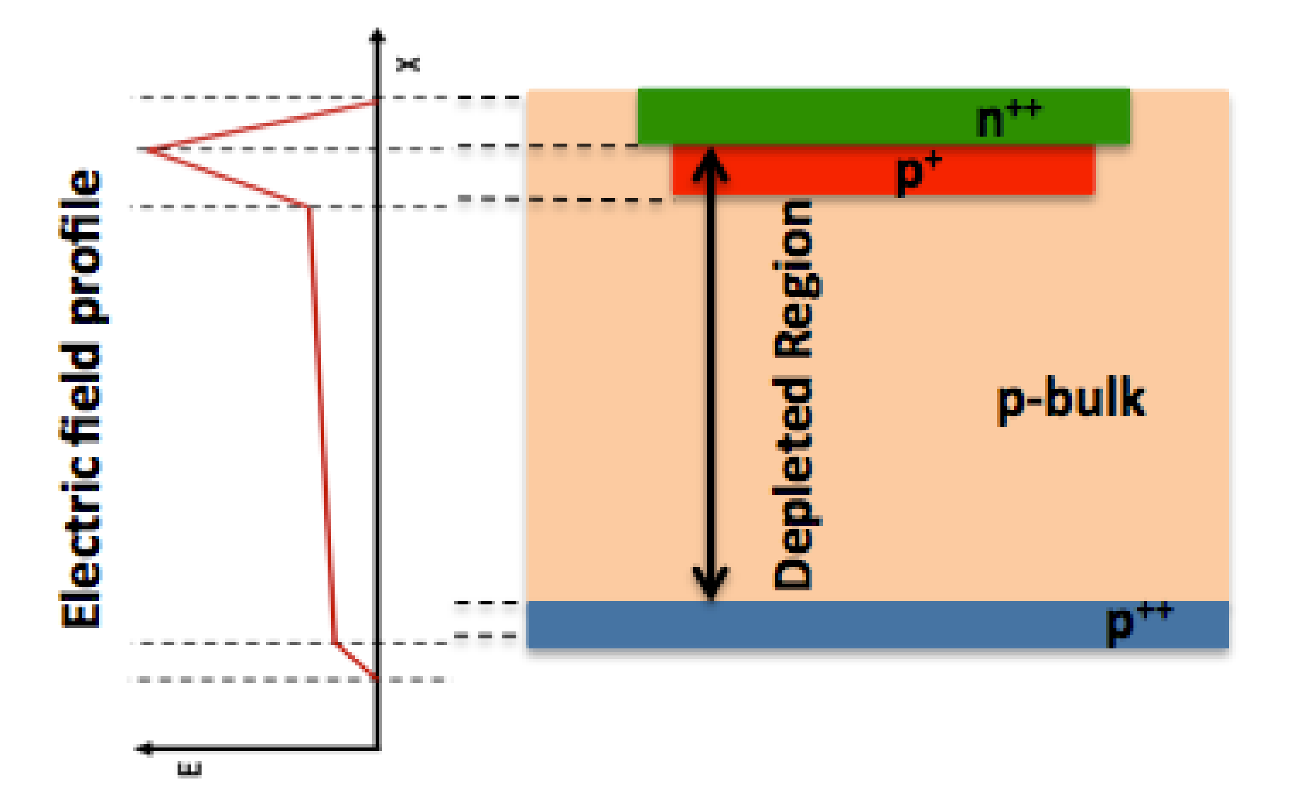
Low Gain Avalanche Diode (LGAD) detectors

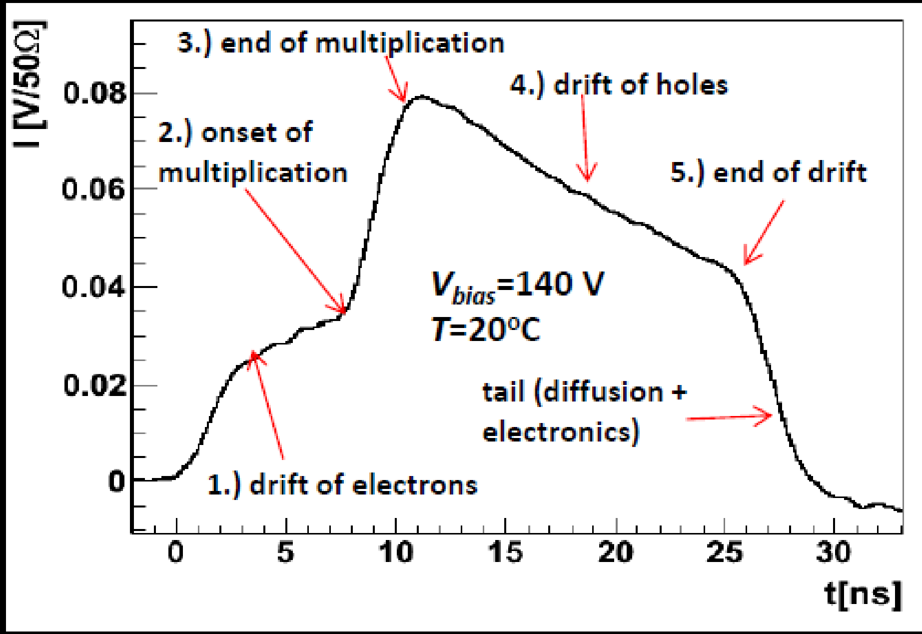




- Strip detector
- Low (1-100) gain is customizable depending on the doping

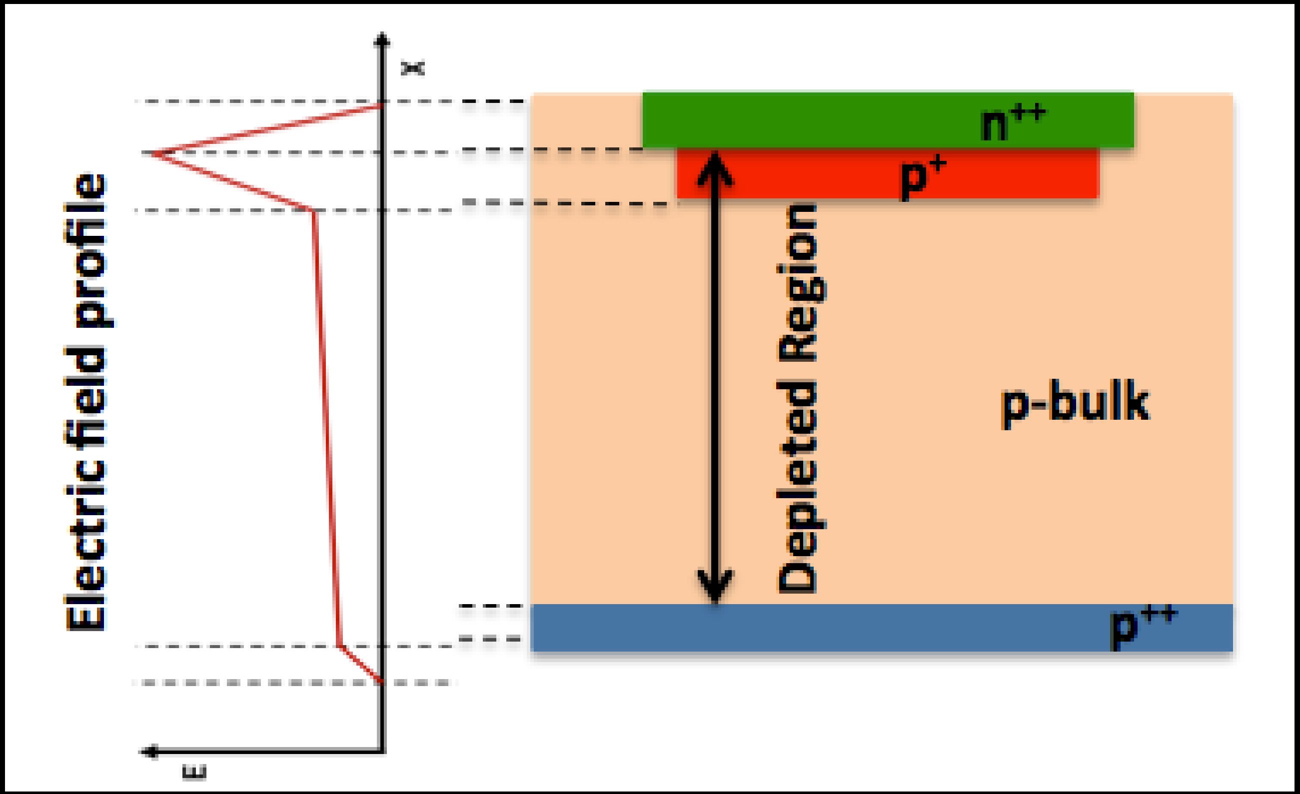
Low Gain Avalanche Diode (LGAD) detectors

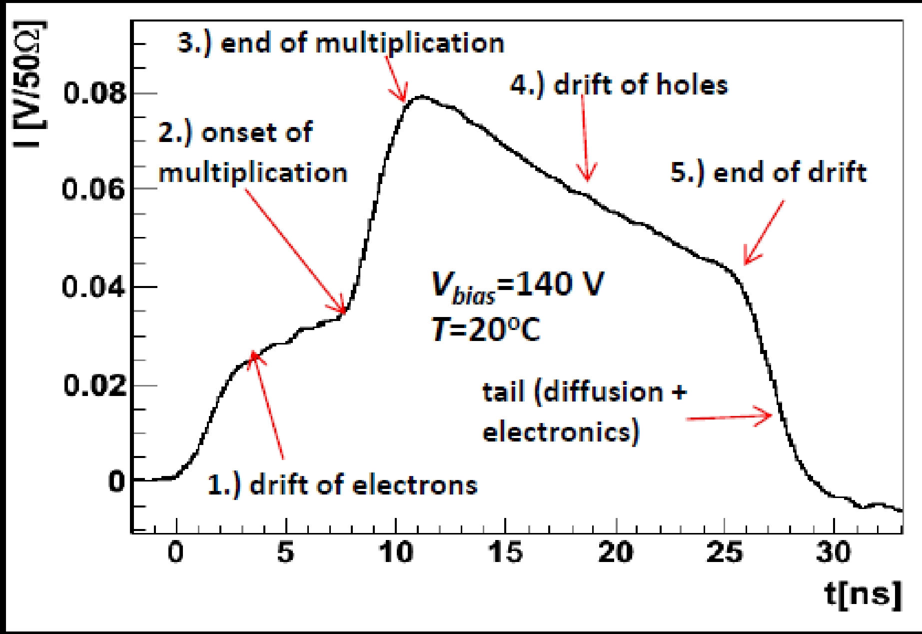




- Strip detector
- Low (1-100) gain is customizable depending on the doping
- Thin sensor down to 70 um. High radioresistence

Low Gain Avalanche Diode (LGAD) detectors



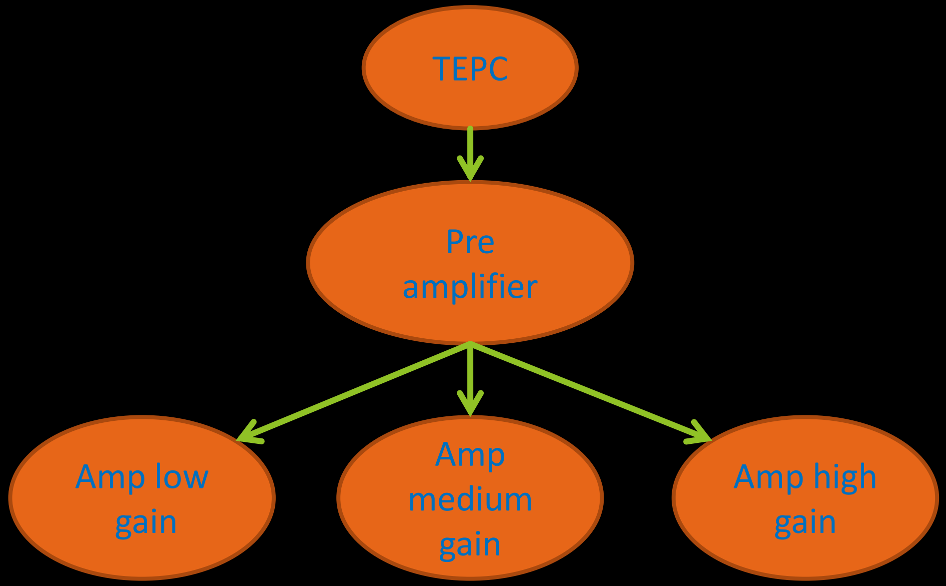


- Strip detector
- Low (1-100) gain is customizable depending on the doping
- Thin sensor down to 70 um. High radioresistence
- Fast sensor: signal pulse ≃ 1 ns

Readout

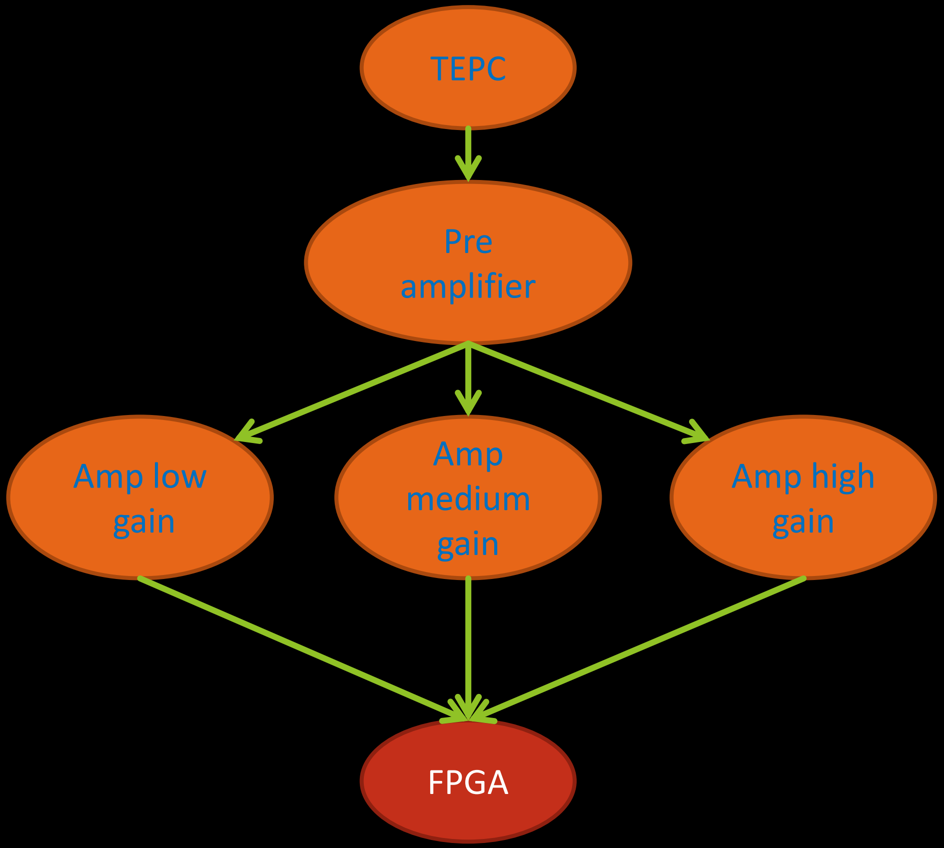
TEPC – readout FPGA

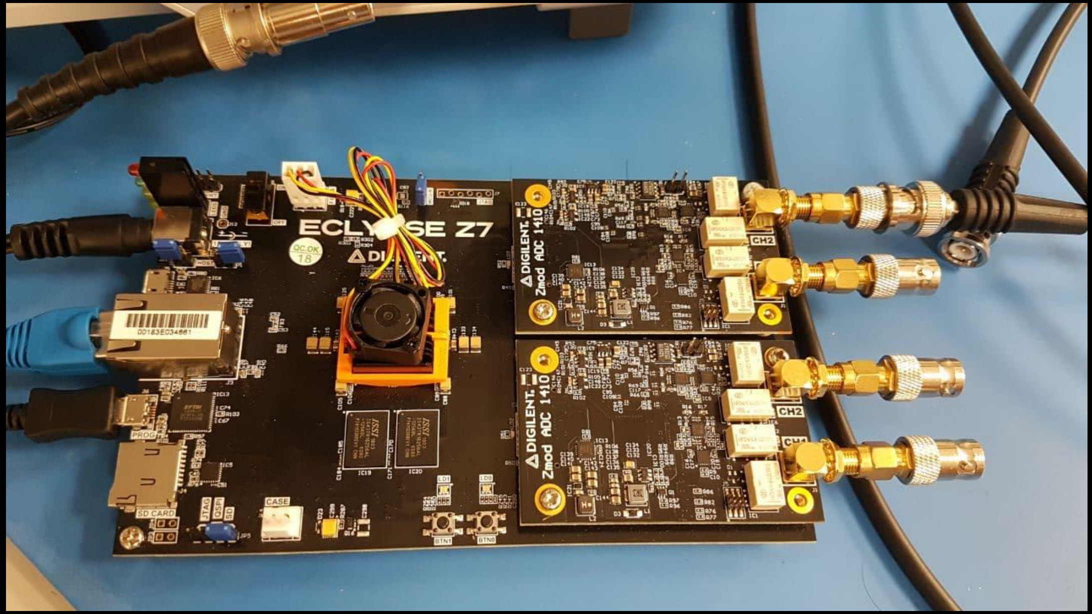
Tissue equivalent proportional counter



TEPC – readout FPGA

Tissue equivalent proportional counter





TEPC – readout FPGA

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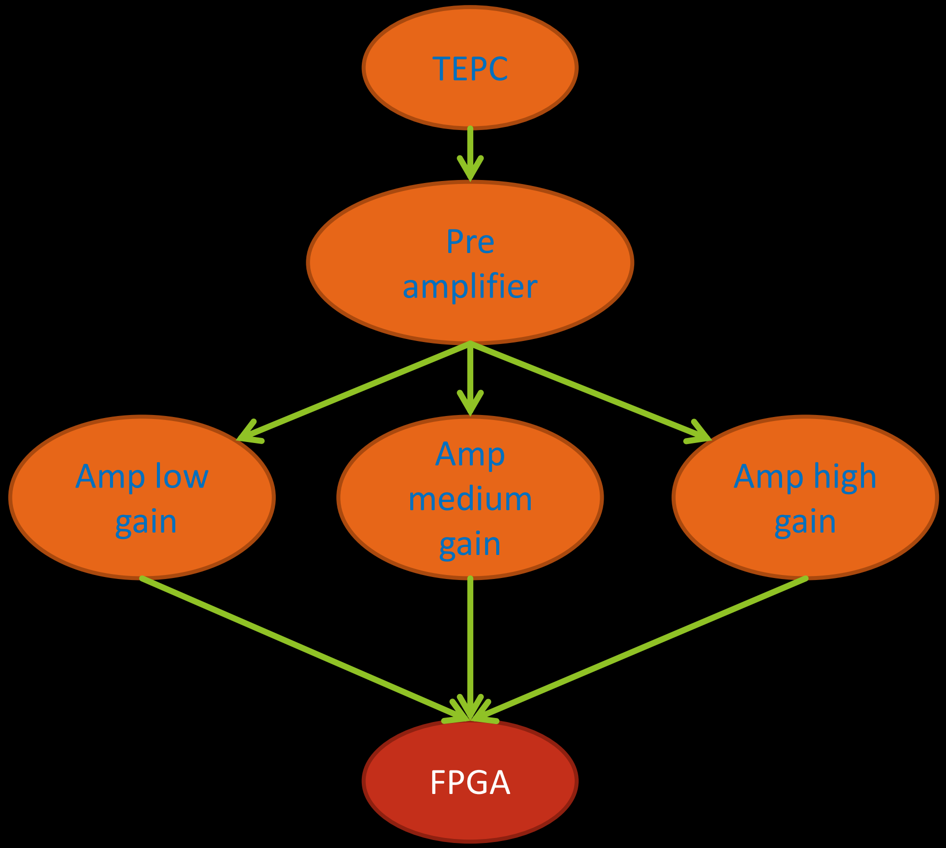

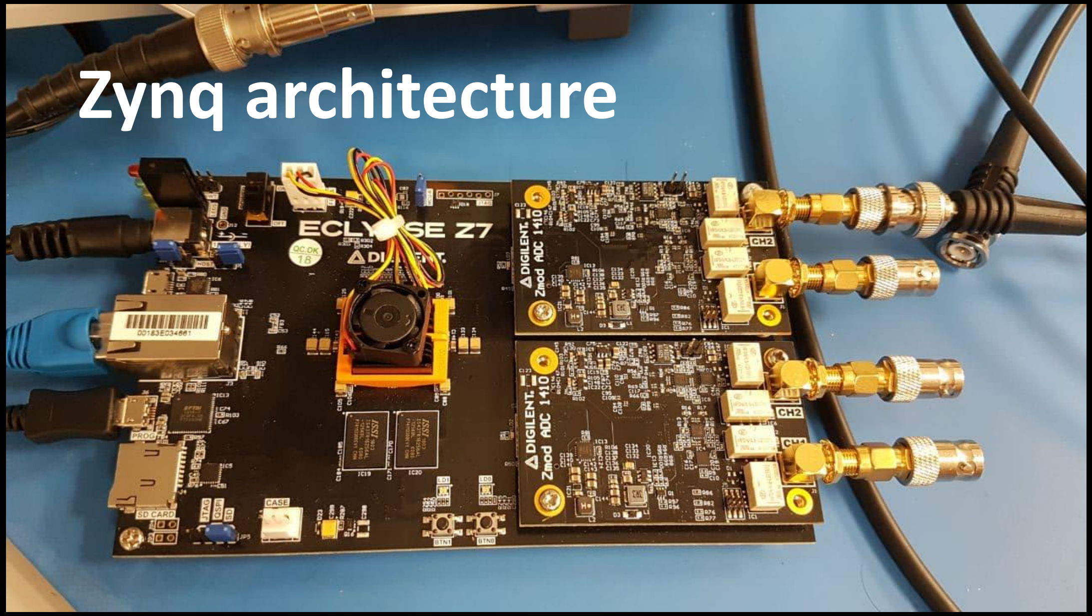

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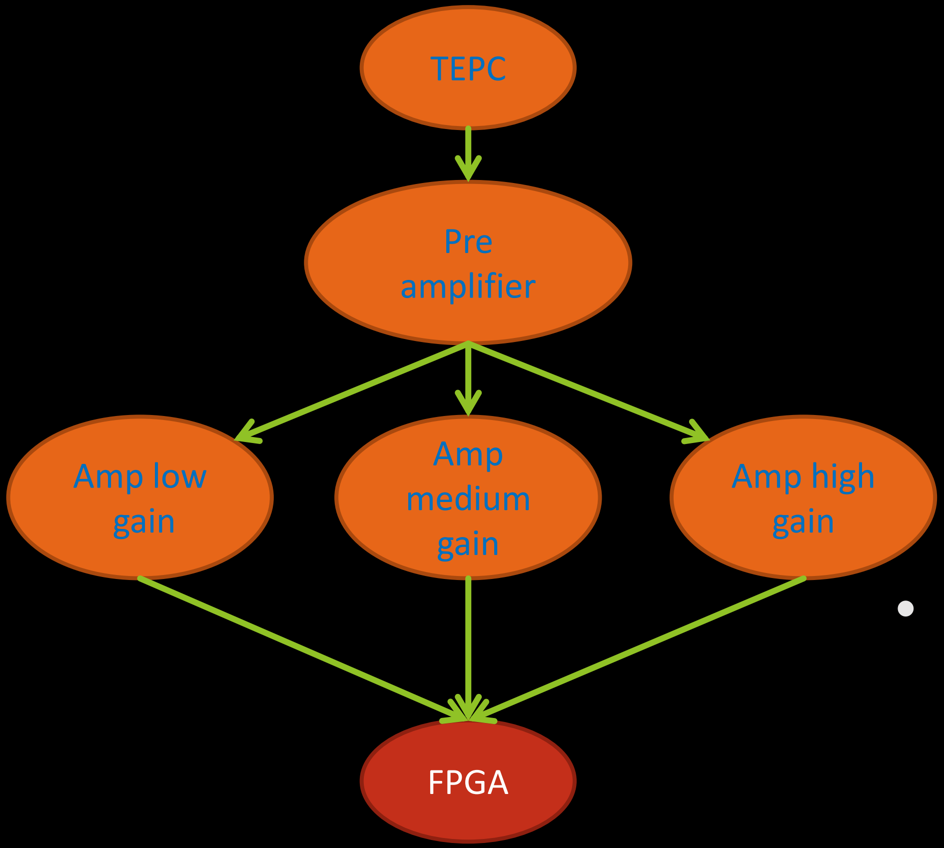
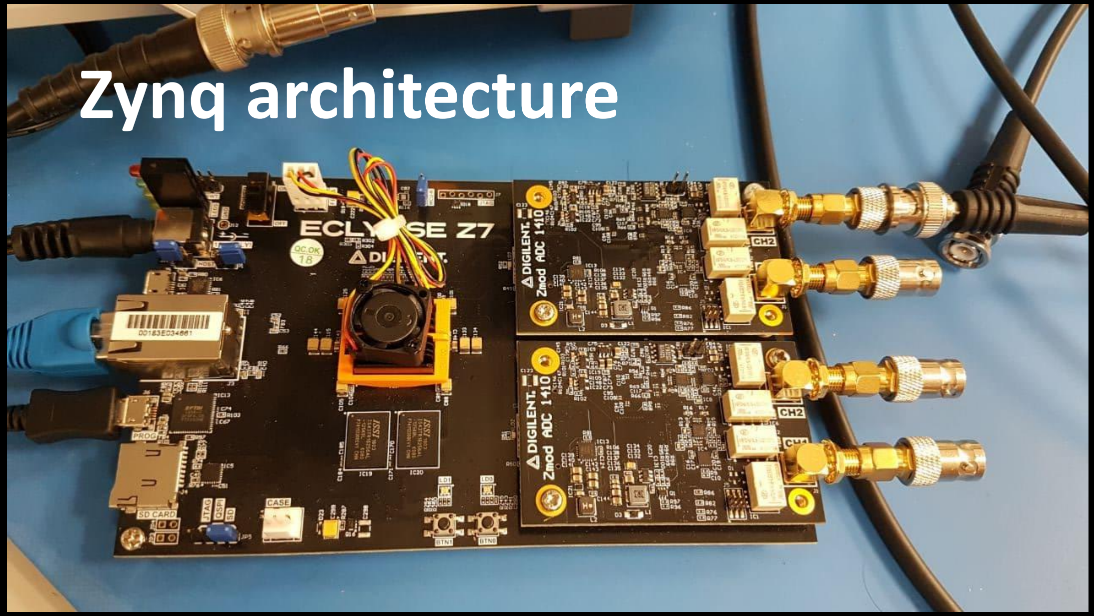
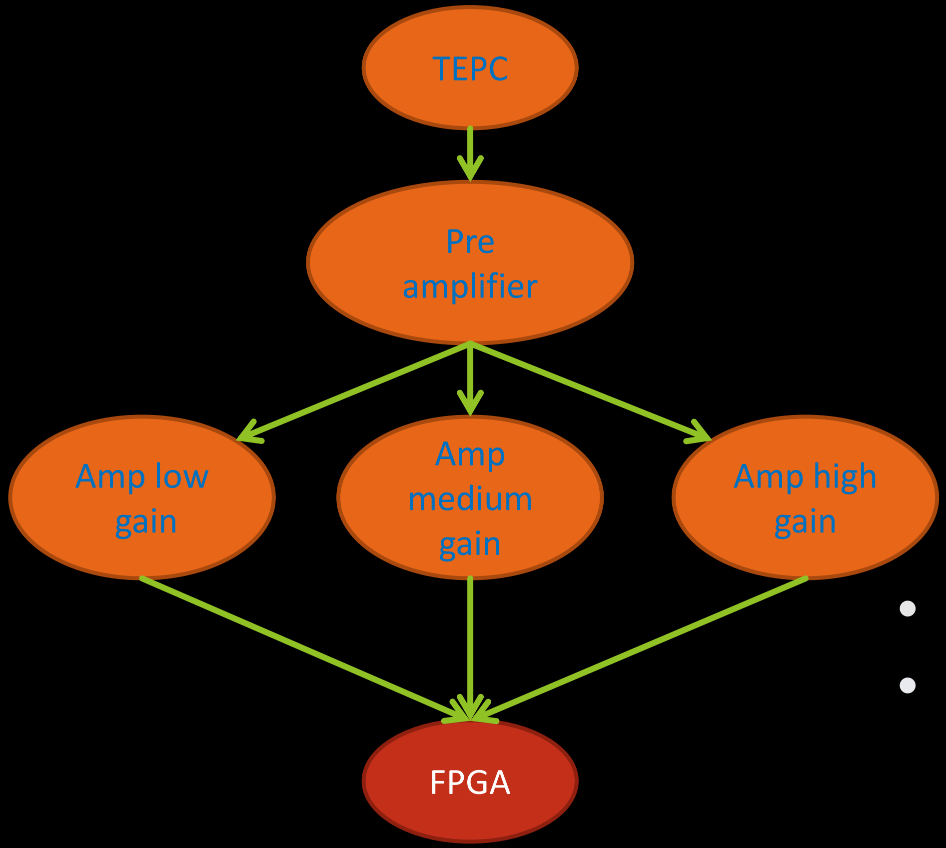


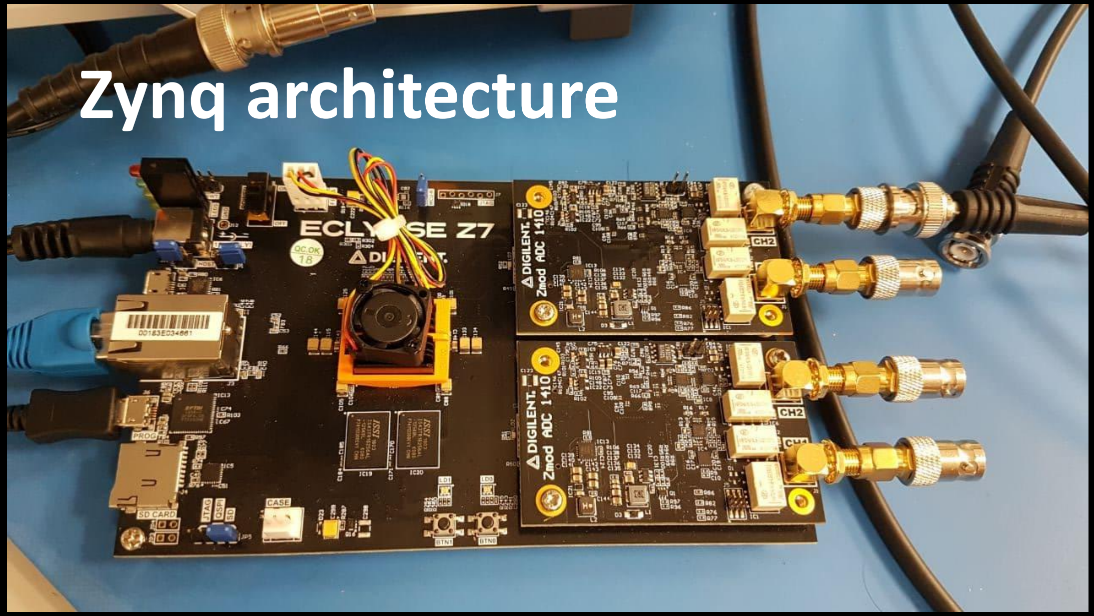


- 2 x Zmod ADC 1410; 14 bits resolution, ± 25V

TEPC – readout FPGA

Tissue equivalent proportional counter

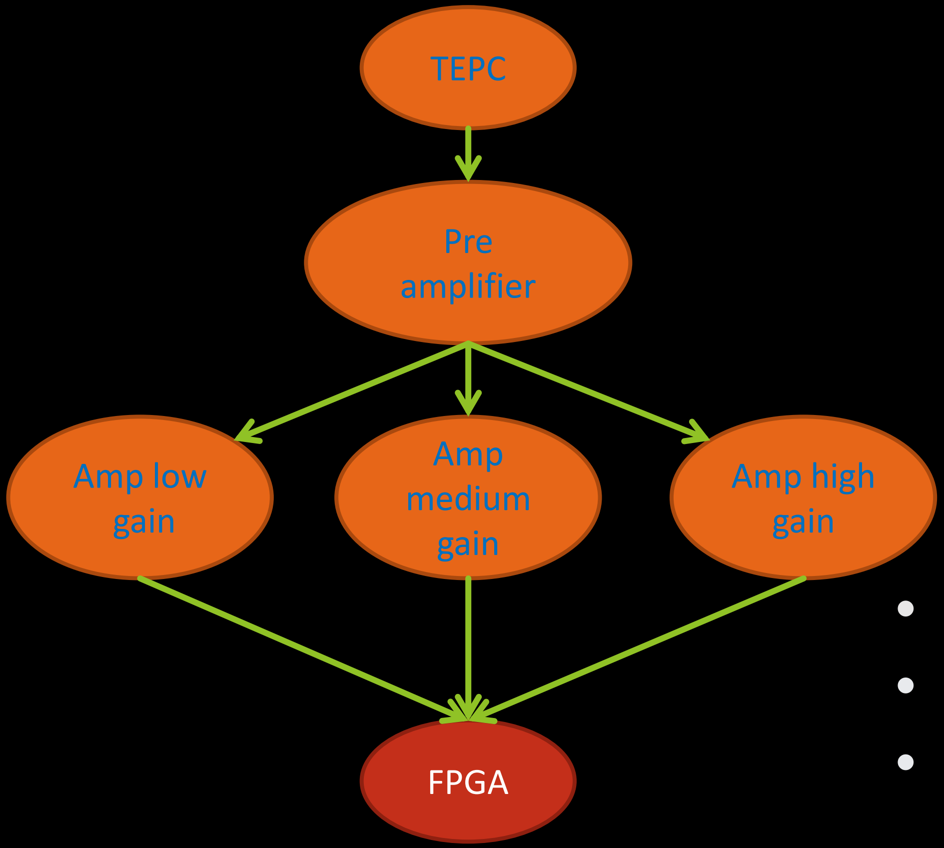


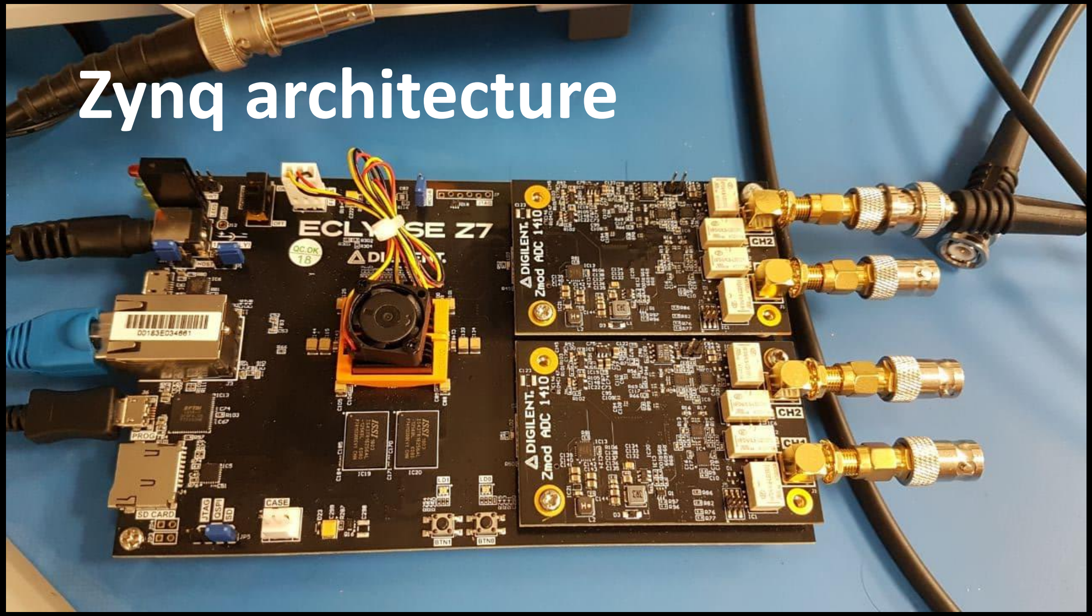


- 2 x Zmod ADC 1410; 14 bits resolution, ± 25V
- Fully customizable system

TEPC – readout FPGA

Tissue equivalent proportional counter





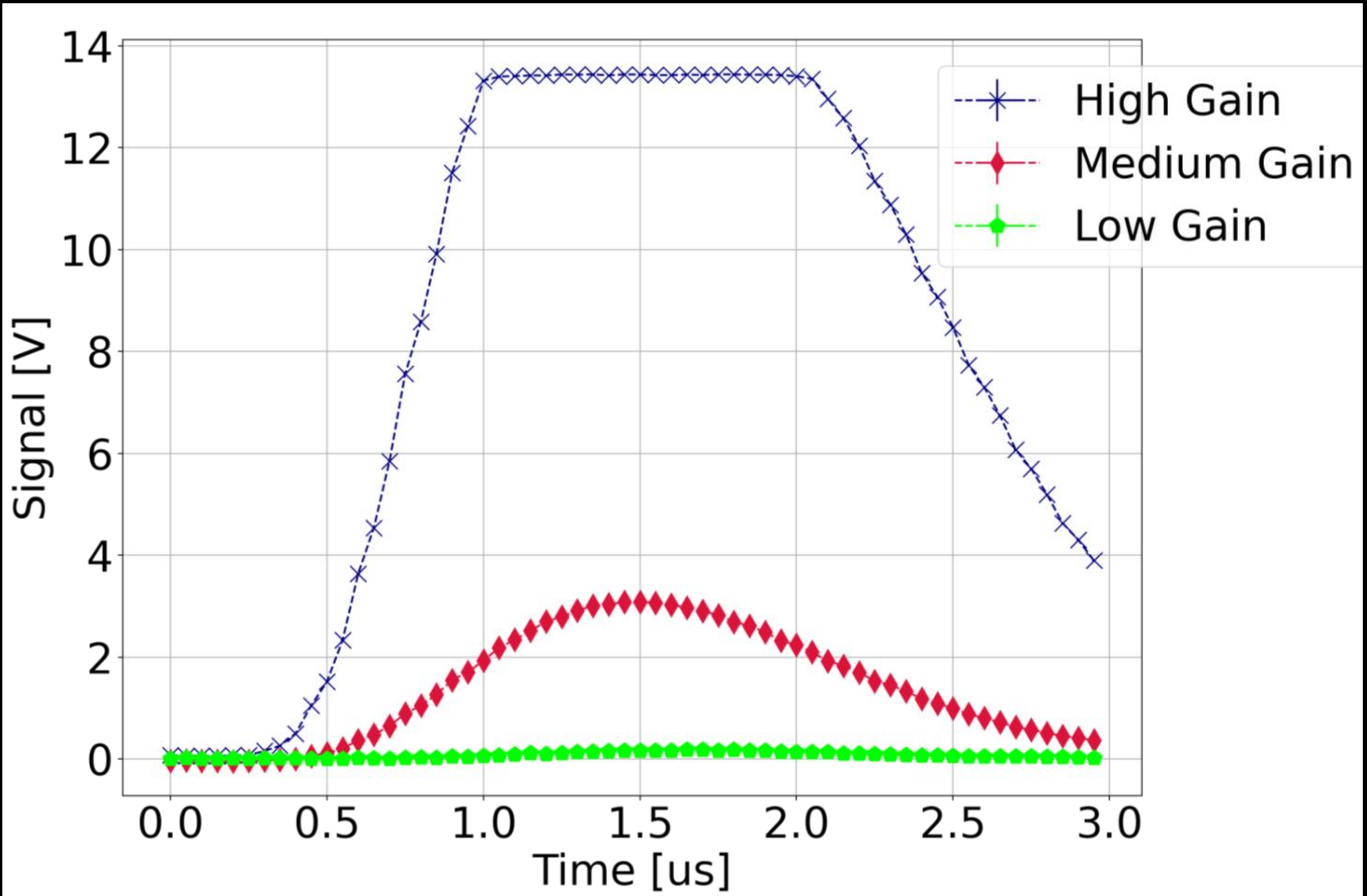
- 2 x Zmod ADC 1410; 14 bits resolution, ± 25V
- Fully customizable system
- Extra channel available

TEPC - readout

Tissue equivalent proportional counter

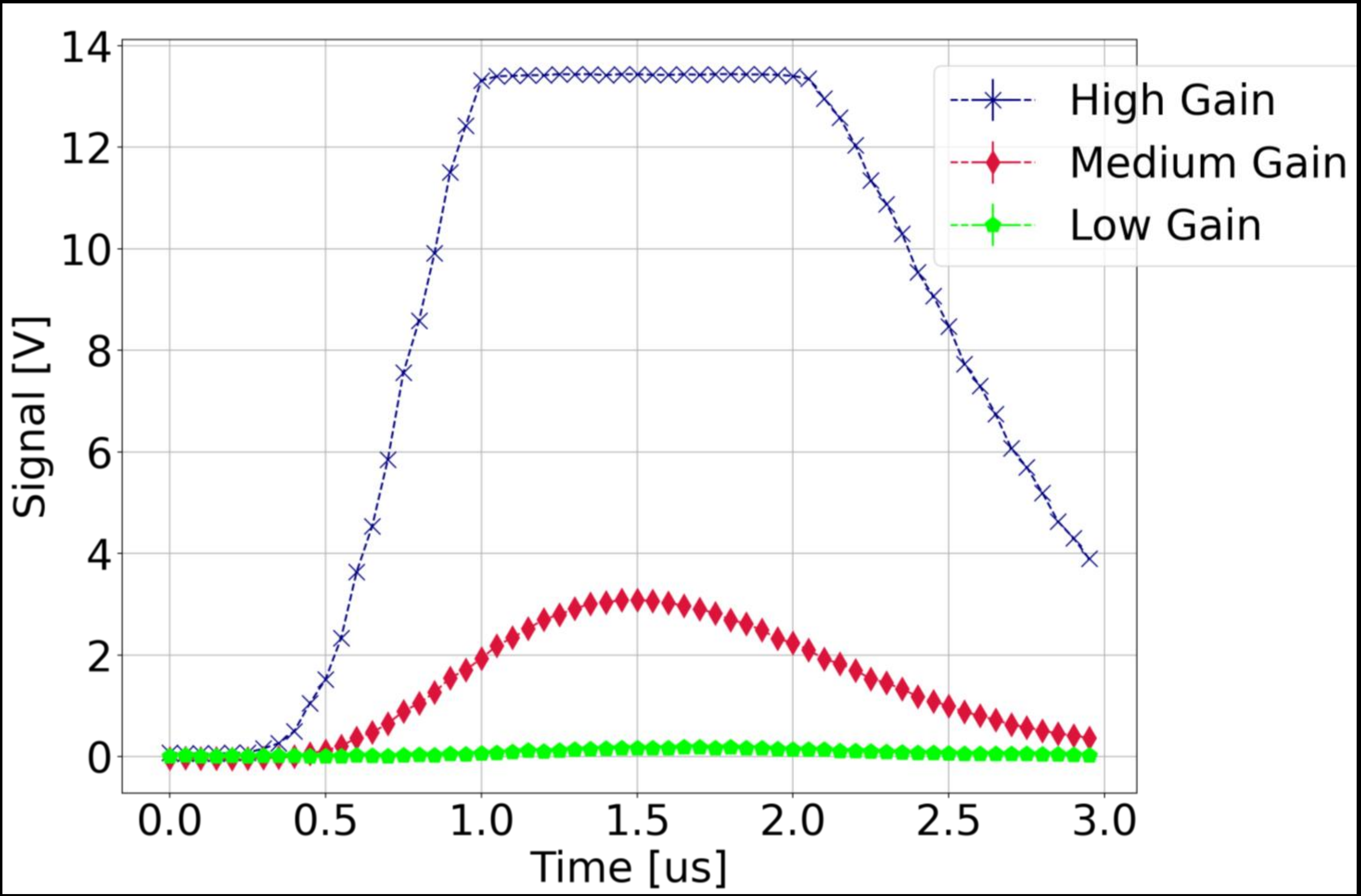
TEPC - readout

Tissue equivalent proportional counter



TEPC - readout

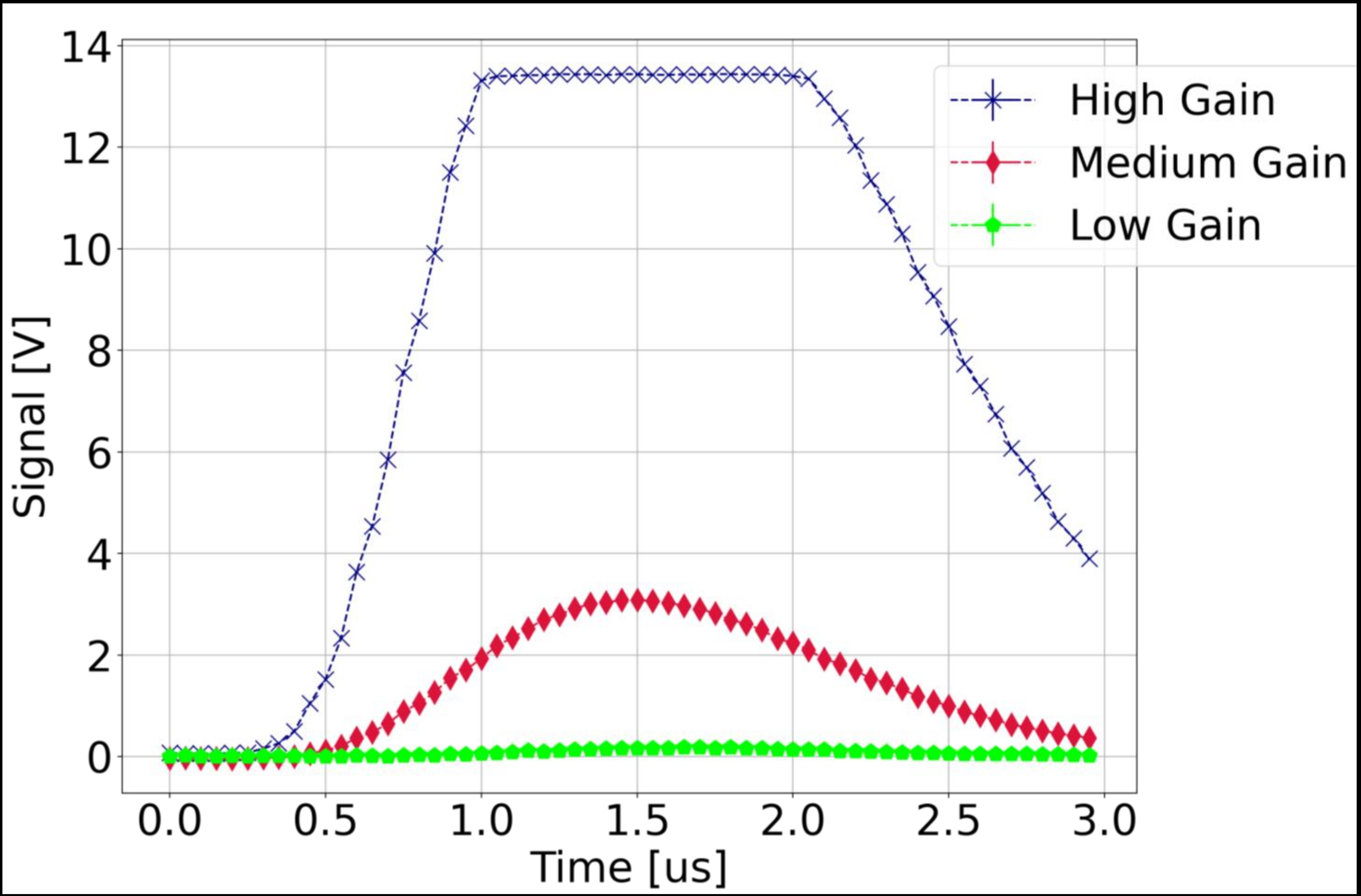
Tissue equivalent proportional counter



- Direct Memory Access (DMA) from the ADCs to an embedded Linux OS.

TEPC - readout

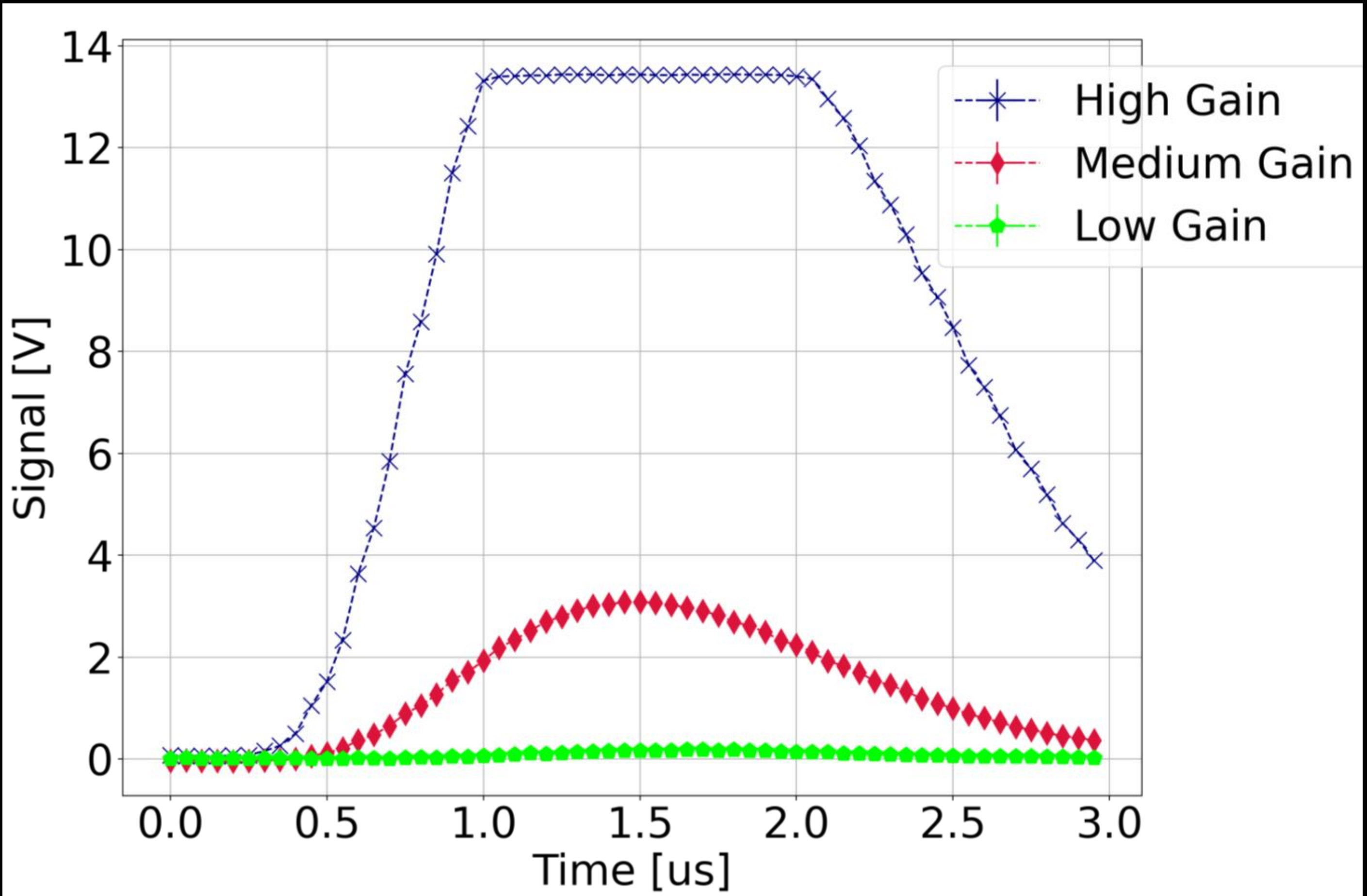
Tissue equivalent proportional counter



- Direct Memory Access (DMA) from the ADCs to an embedded Linux OS.
- Each trigger event is saved and can be sent via TCP-IP

TEPC - readout

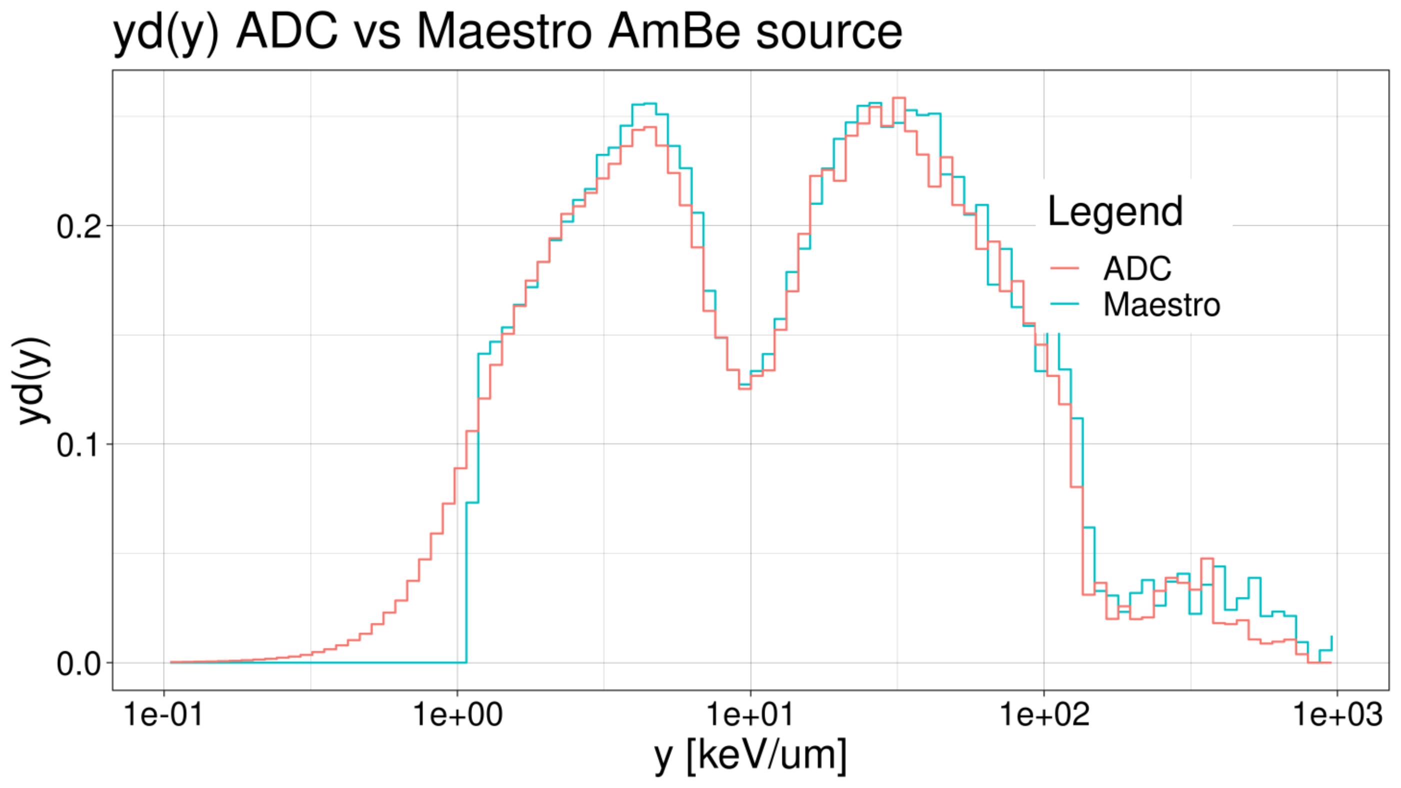
Tissue equivalent proportional counter



- Direct Memory Access (DMA) from the ADCs to an embedded Linux OS.
- Each trigger event is saved and can be sent via TCP-IP
- External trigger pulse for dead time estimation and possible synchronization with other devices

TEPC - readout

Tissue equivalent proportional counter



- Direct Memory Access (DMA) from the ADCs to an embedded Linux OS.
- Each trigger event is saved and can be sent via TCP-IP
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TEPC - readout

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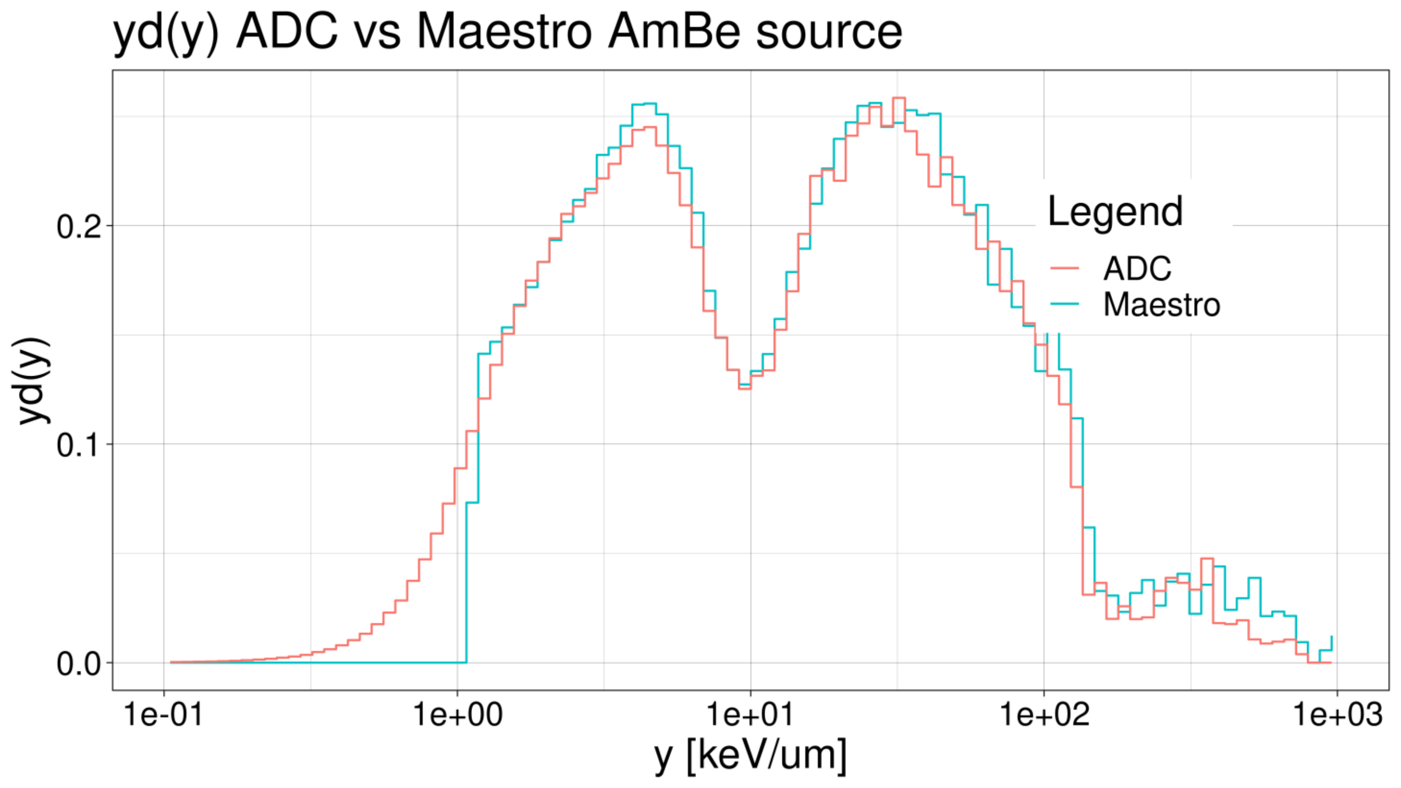


- Direct Memory Access (DMA) from the ADCs to an embedded Linux OS.
- Each trigger event is saved and can be sent via TCP-IP
- External trigger pulse for dead time estimation and possible synchronization with other devices
- Spectra overlaps. Good.

LGAD Readout - overview

Low Gain Avalanche Detector

LGAD Readout - overview

Low Gain Avalanche Detector

LGADs

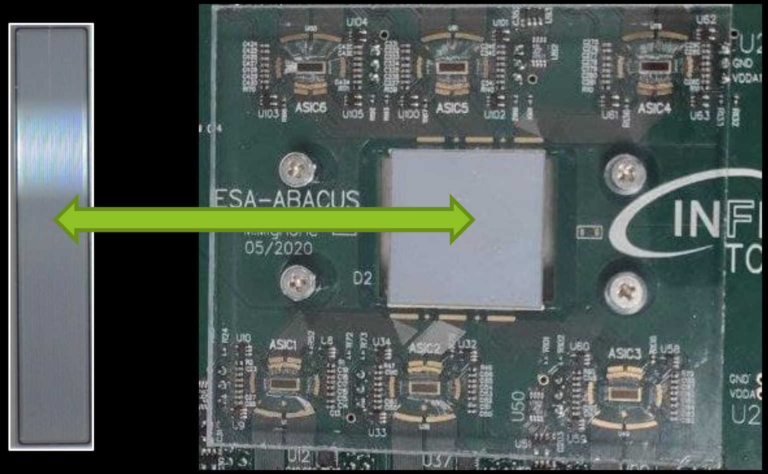
71 channels

LGAD Readout - overview

Low Gain Avalanche Detector

LGADs

ABACUS ASIC



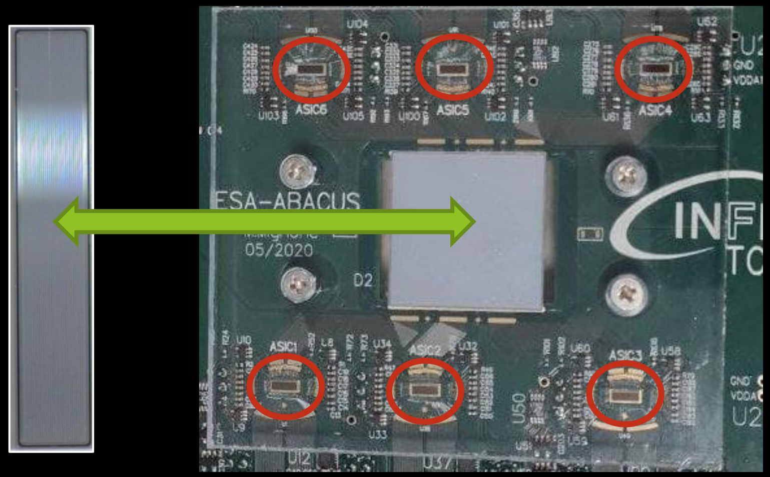
71 channels

LGAD Readout - overview

Low Gain Avalanche Detector

LGADs

ABACUS ASIC



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LGAD Readout - overview

Low Gain Avalanche Detector

LGADs

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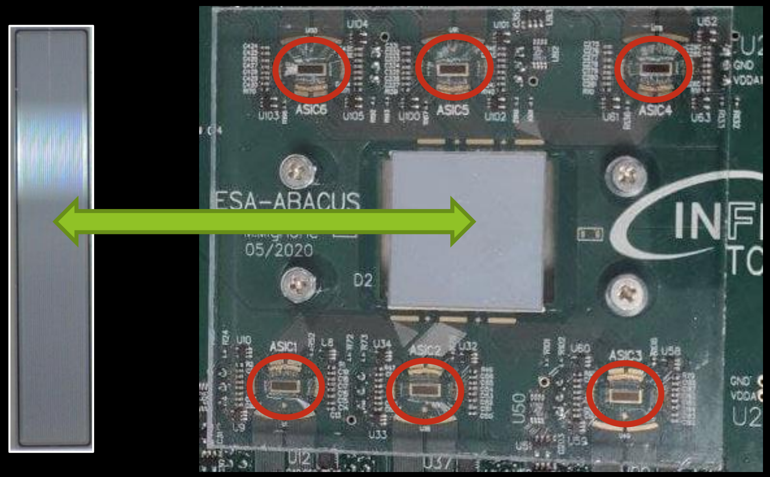


71 channels

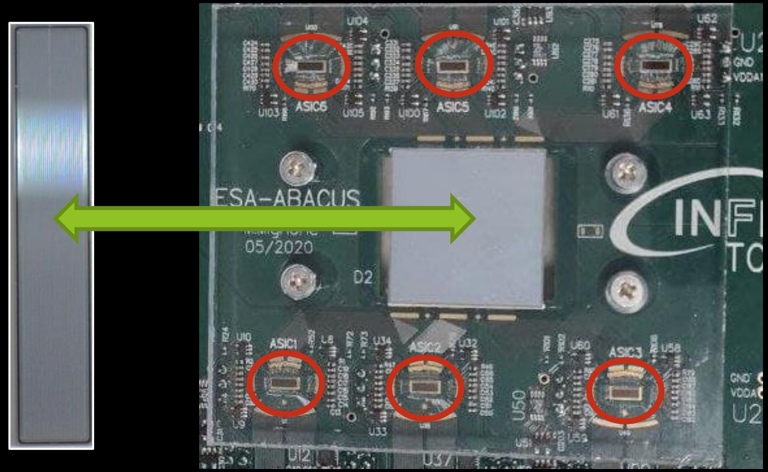
Each chip read a maximum of 24 LGADs

LGAD Readout - overview

Low Gain Avalanche Detector

LGADs

ABACUS ASIC



71 channels

Each chip read a maximum of 24 LGADs

- Adjust thresholds levels
- Signal processing

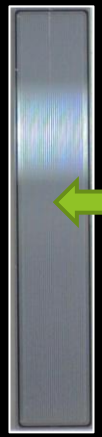
LGAD Readout - overview

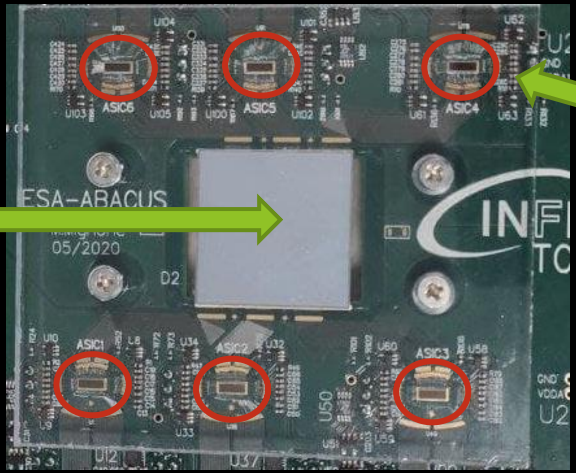
Low Gain Avalanche Detector

Readout based on
ESA_ABACUS and ABACUS
chip developed by INFN-TO
for MoVe IT

LGADs

ABACUS ASIC





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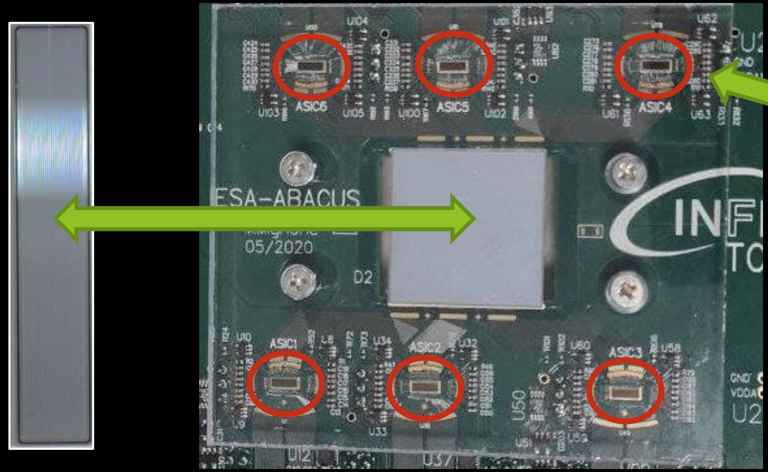
LGAD Readout - overview

Low Gain Avalanche Detector

LGADs

ABACUS ASIC



71 channels

Each chip read a maximum of 24 LGADs

- Adjust thresholds levels
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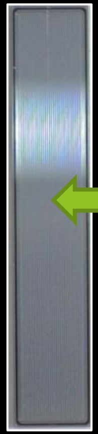
Readout based on ESA_ABACUS and ABACUS chip developed by INFN-TO for MoVe IT

- Physical support
- Power and connections

LGAD Readout - overview

Low Gain Avalanche Detector

LGADs



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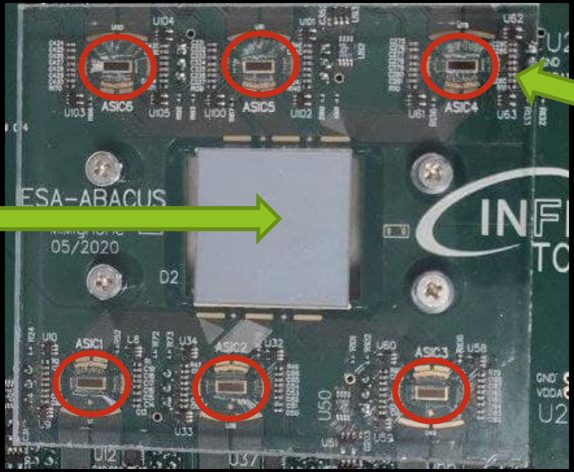
ABACUS ASIC



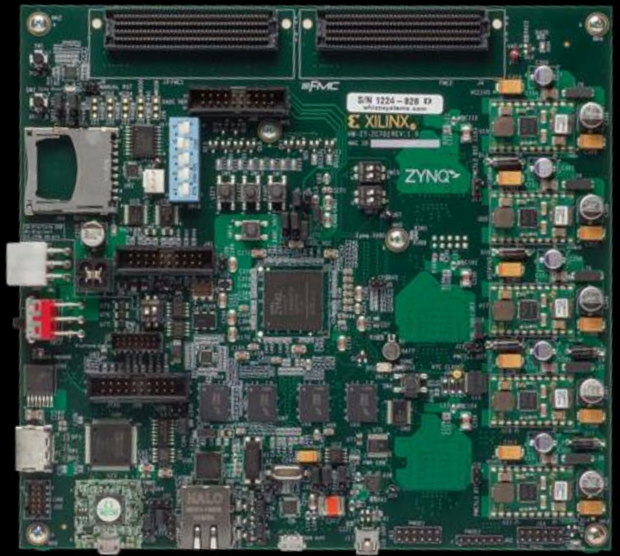
Each chip read a maximum of 24 LGADs

- Adjust thresholds levels
- Signal processing

Readout based on ESA_ABACUS and ABACUS chip developed by INFN-TO for MoVe IT

- Physical support
- Power and connections

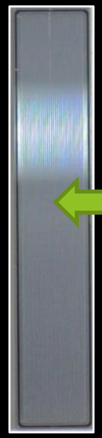
Digital signal from ESA_ABACUS is processed thanks to FPGA Xilinx model zc702



LGAD Readout - overview

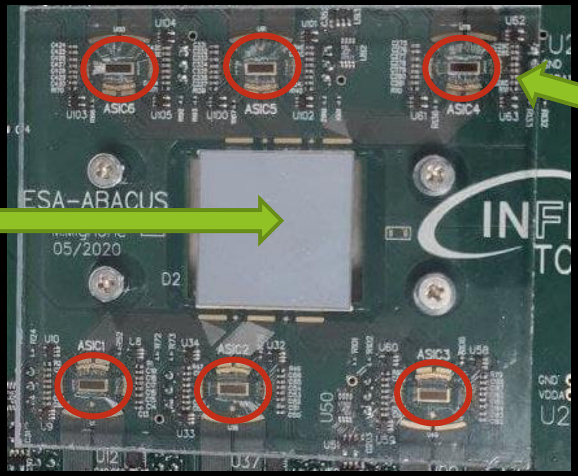
Low Gain Avalanche Detector

LGADs



71 channels

ABACUS ASIC



Each chip read a maximum of 24 LGADs

- Adjust thresholds levels
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Readout based on ESA_ABACUS and ABACUS chip developed by INFN-TO for MoVe IT

- Physical support
- Power and connections

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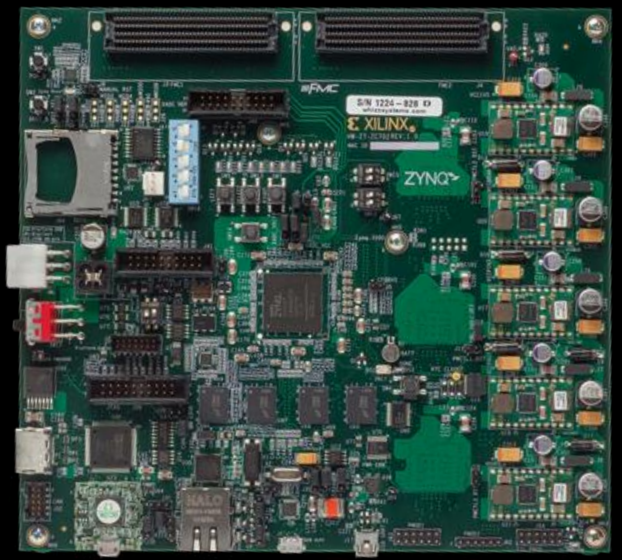


- Thresholds controls
- Signals from ASICs

LGAD - FPGA

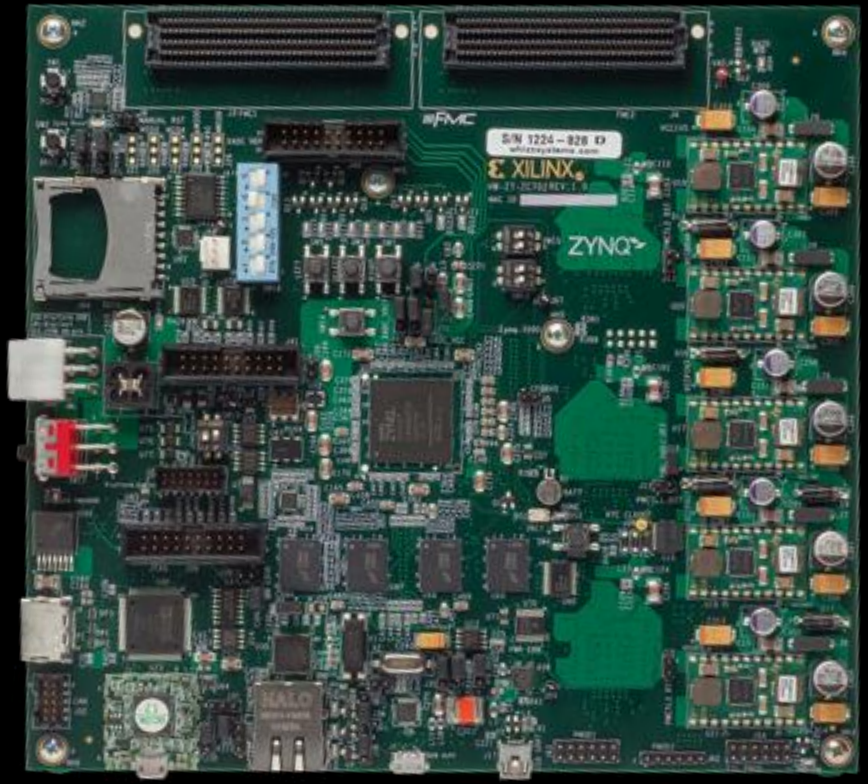
Low Gain Avalanche Detector

LGAD - FPGA

Low Gain Avalanche Detector

Xilinx model zc702

Zynq

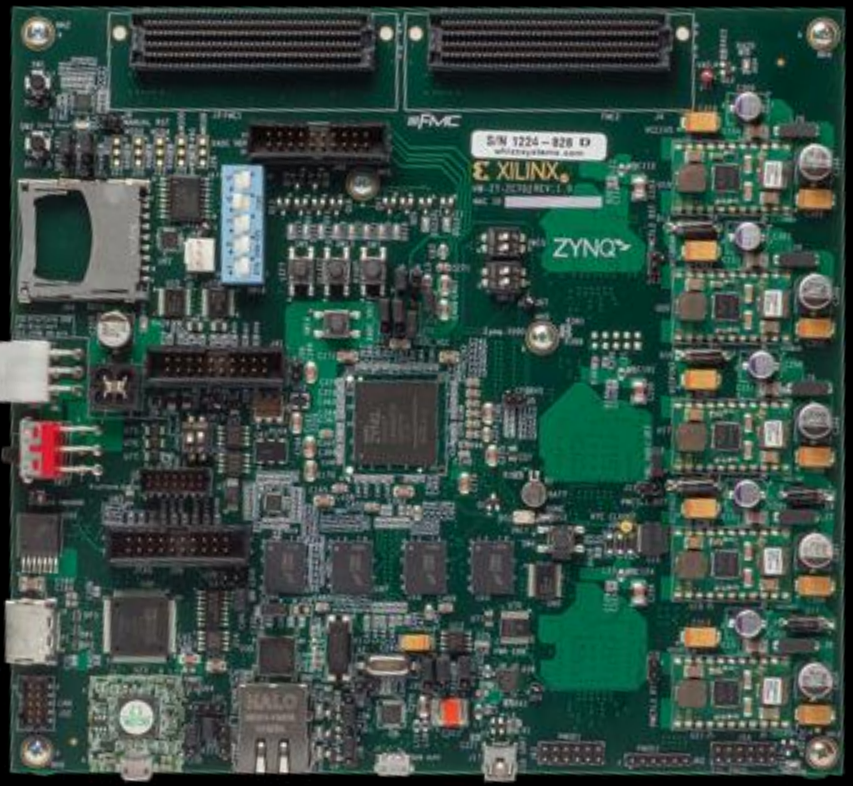


LGAD - FPGA

Low Gain Avalanche Detector

Xilinx model zc702

Zynq



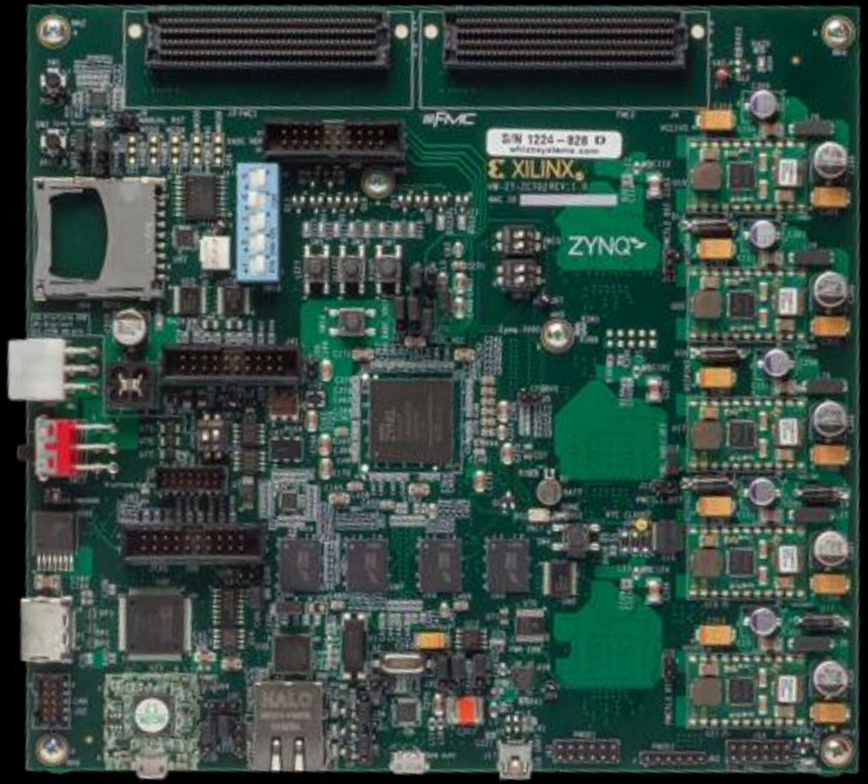
- Counts the digital signal from the ABACUS ASICs

LGAD - FPGA

Low Gain Avalanche Detector

Xilinx model zc702

Zynq



- Counts the digital signal from the ABACUS ASICs
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LGAD - FPGA

Low Gain Avalanche Detector

Xilinx model zc702

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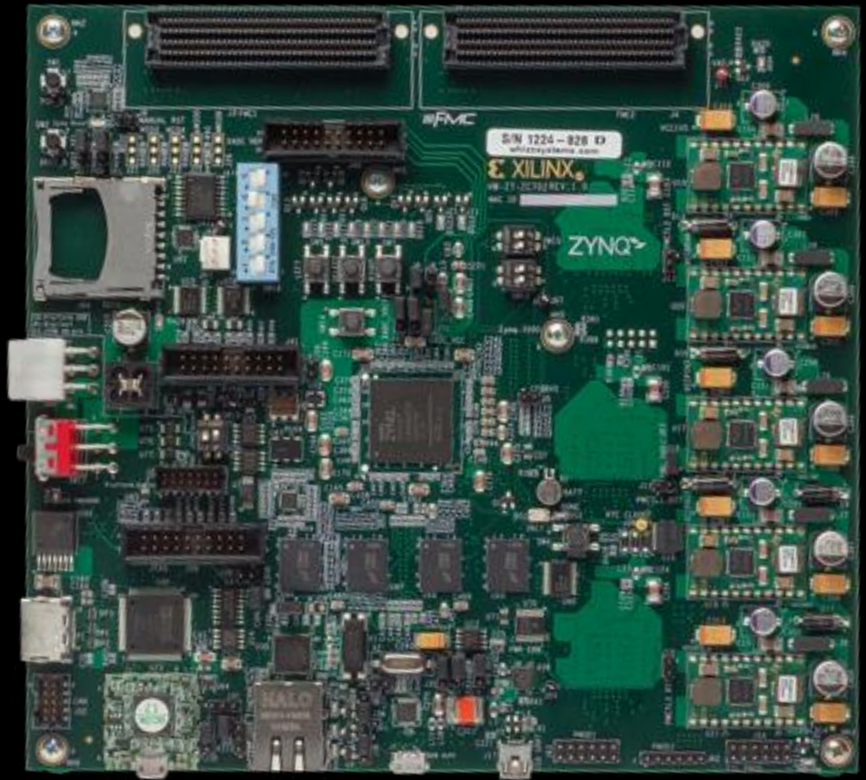

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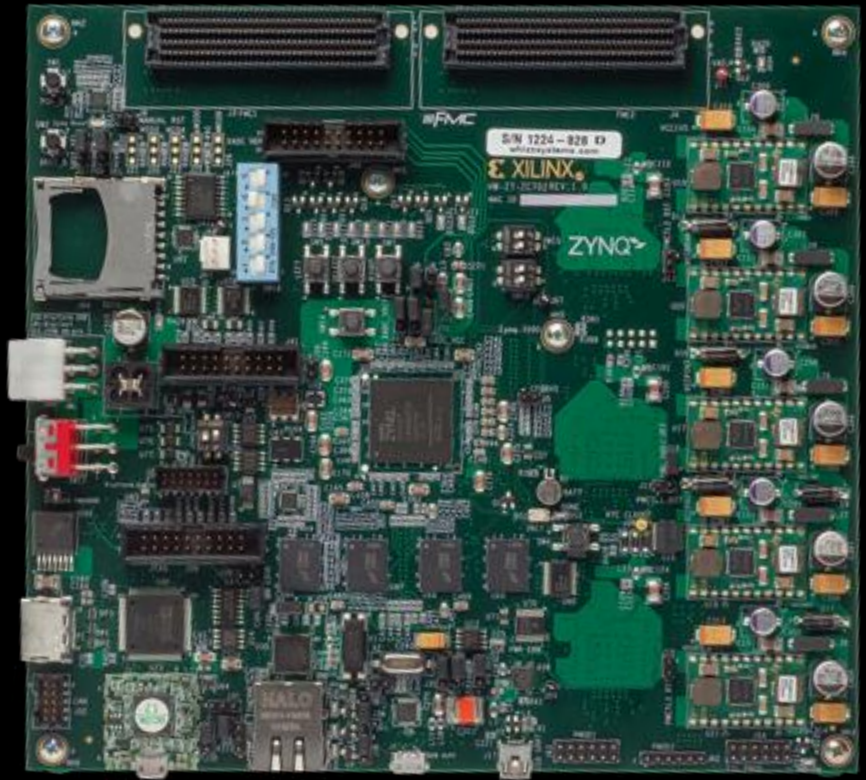

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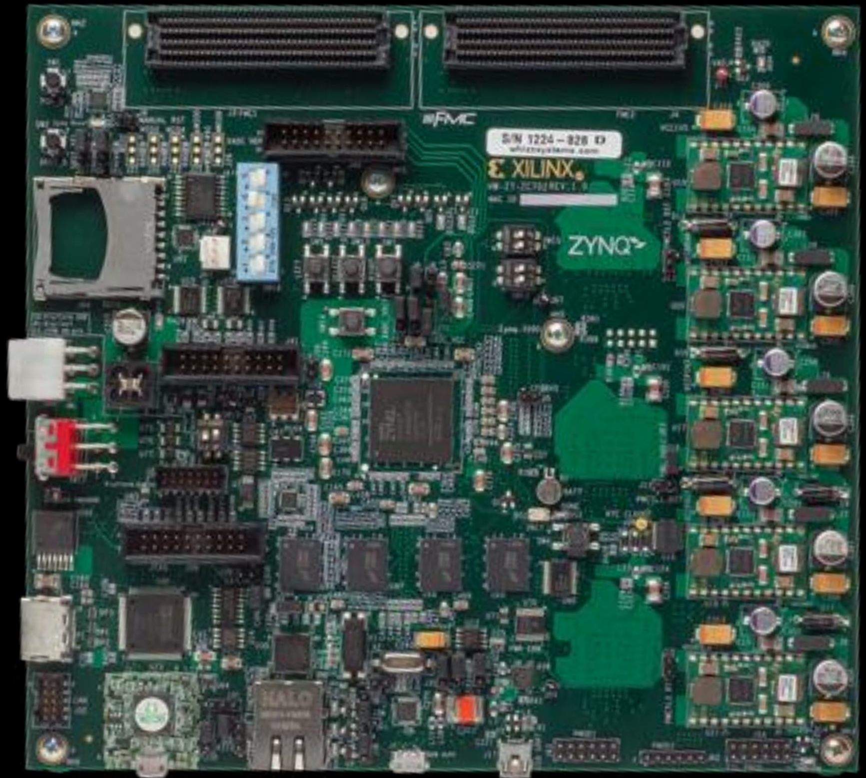

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LGAD - Experimental results (Threshold scans)

Low Gain Avalanche Detector

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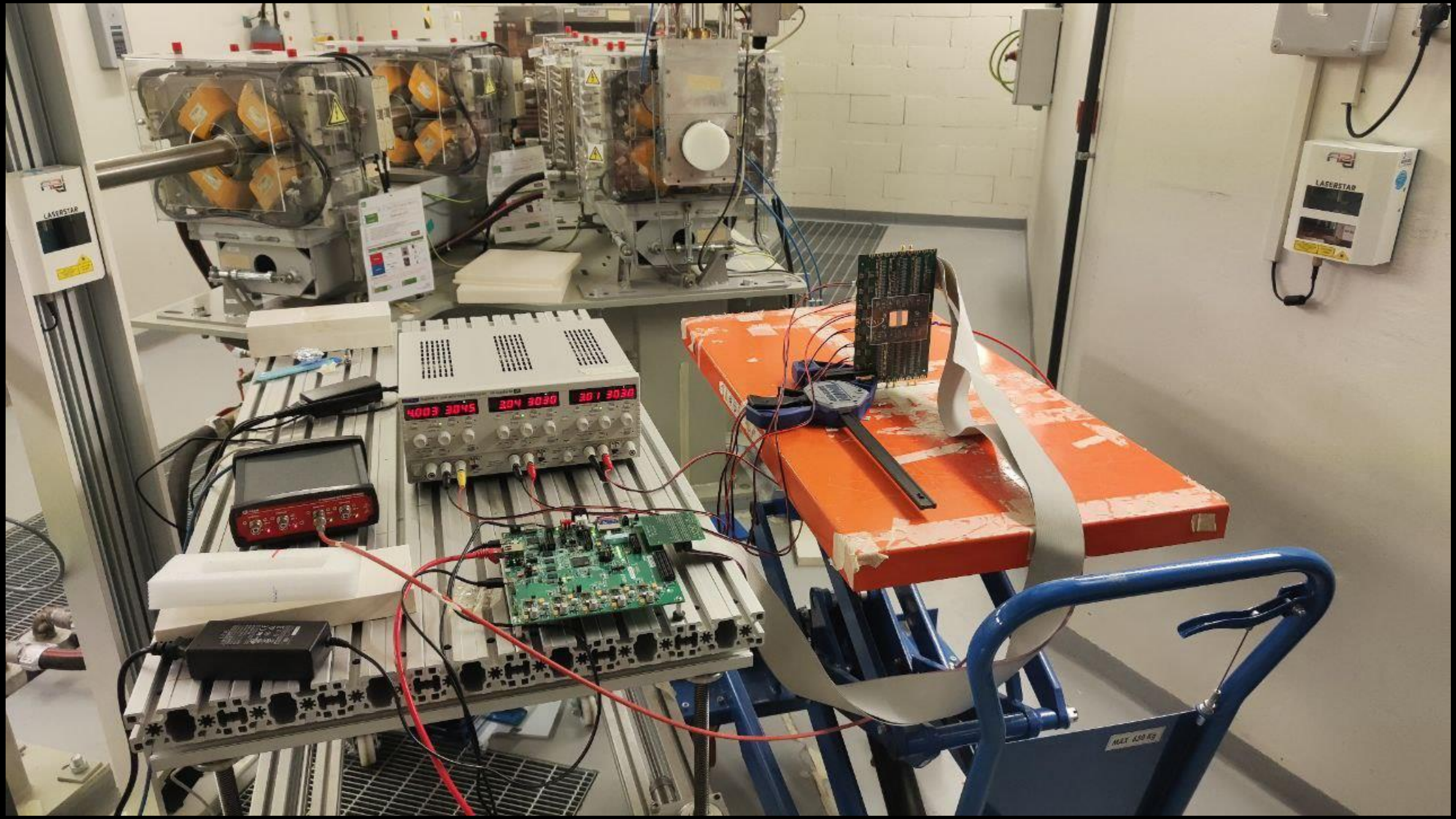
Low Gain Avalanche Detector



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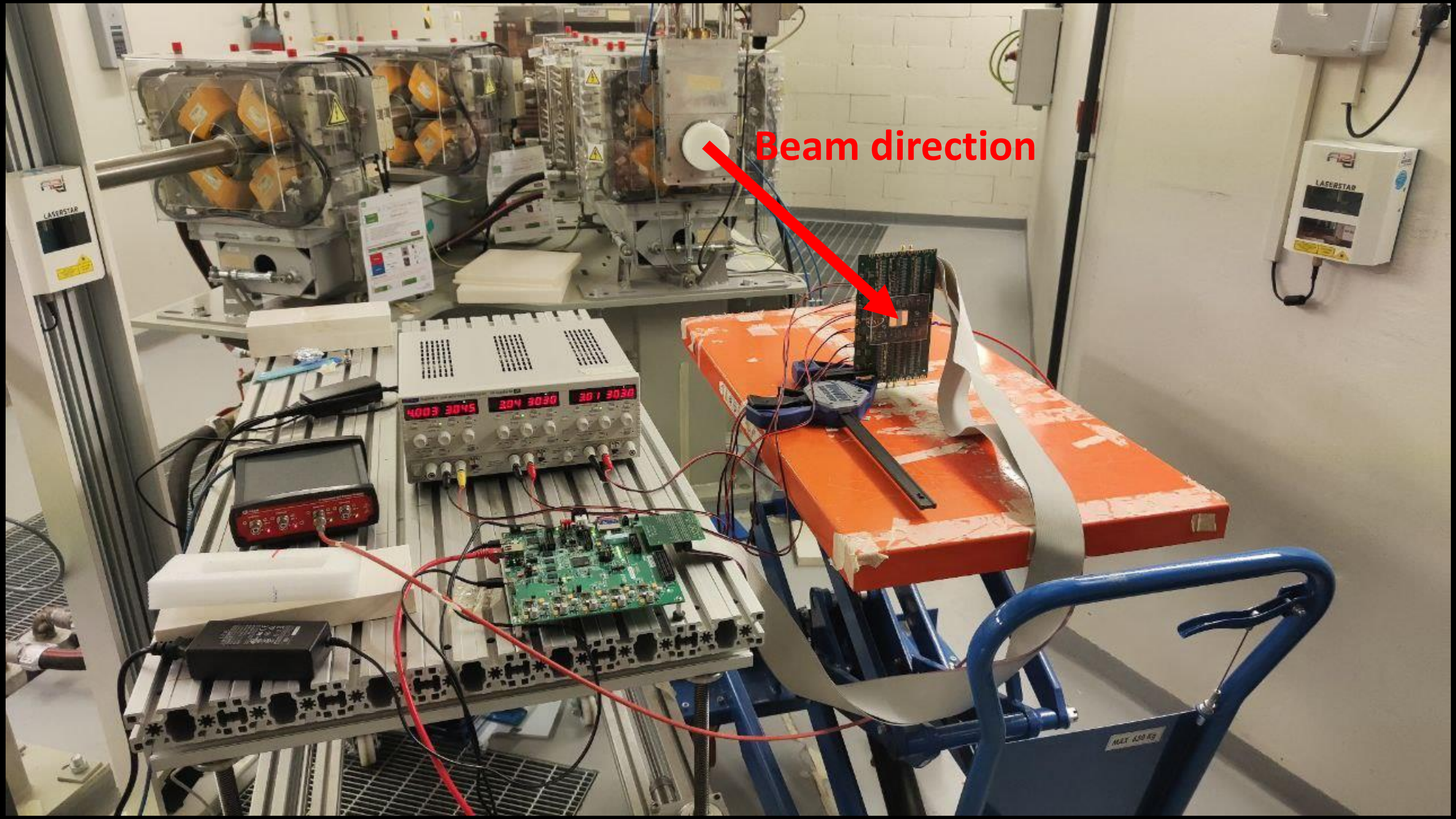

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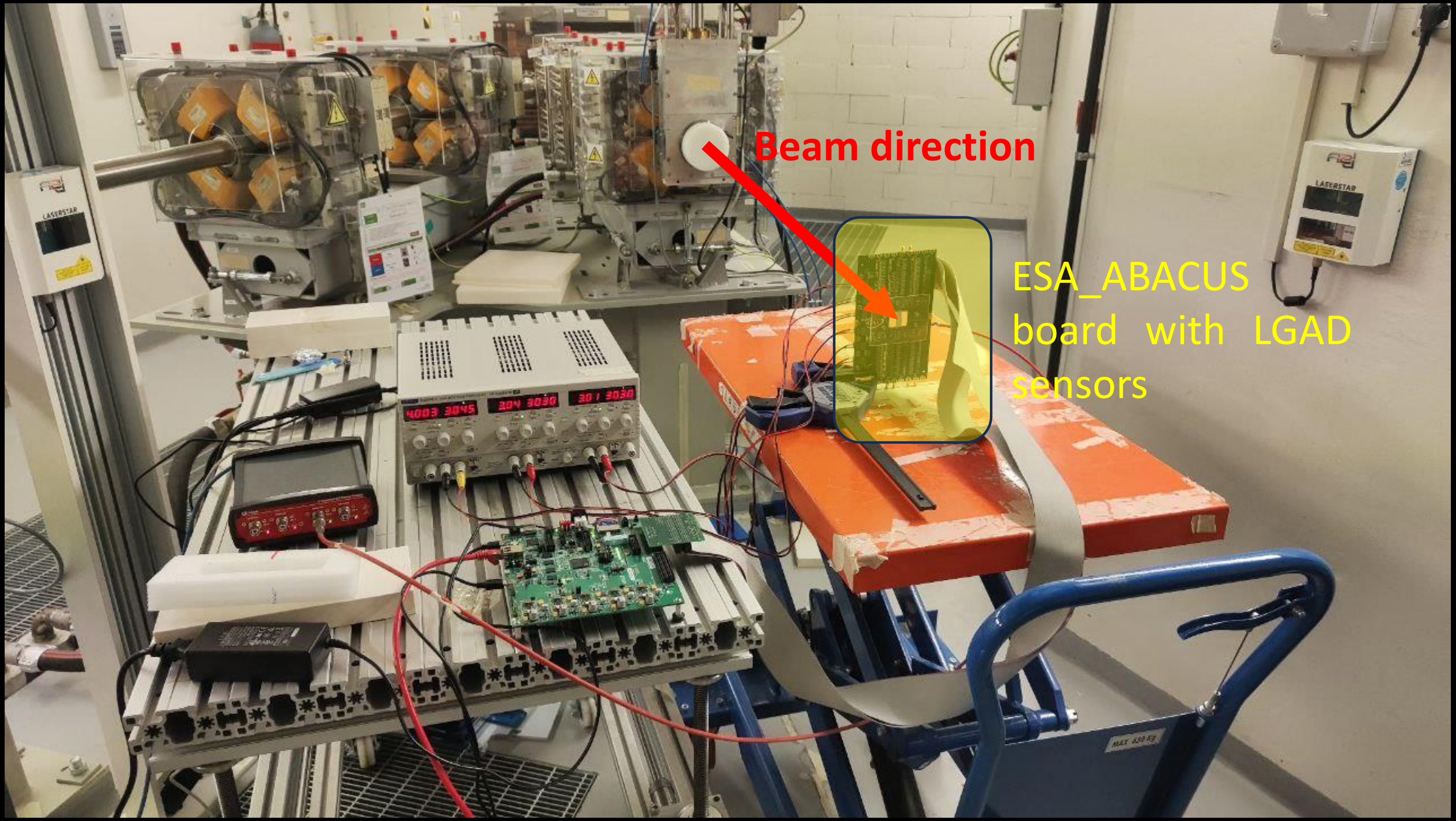

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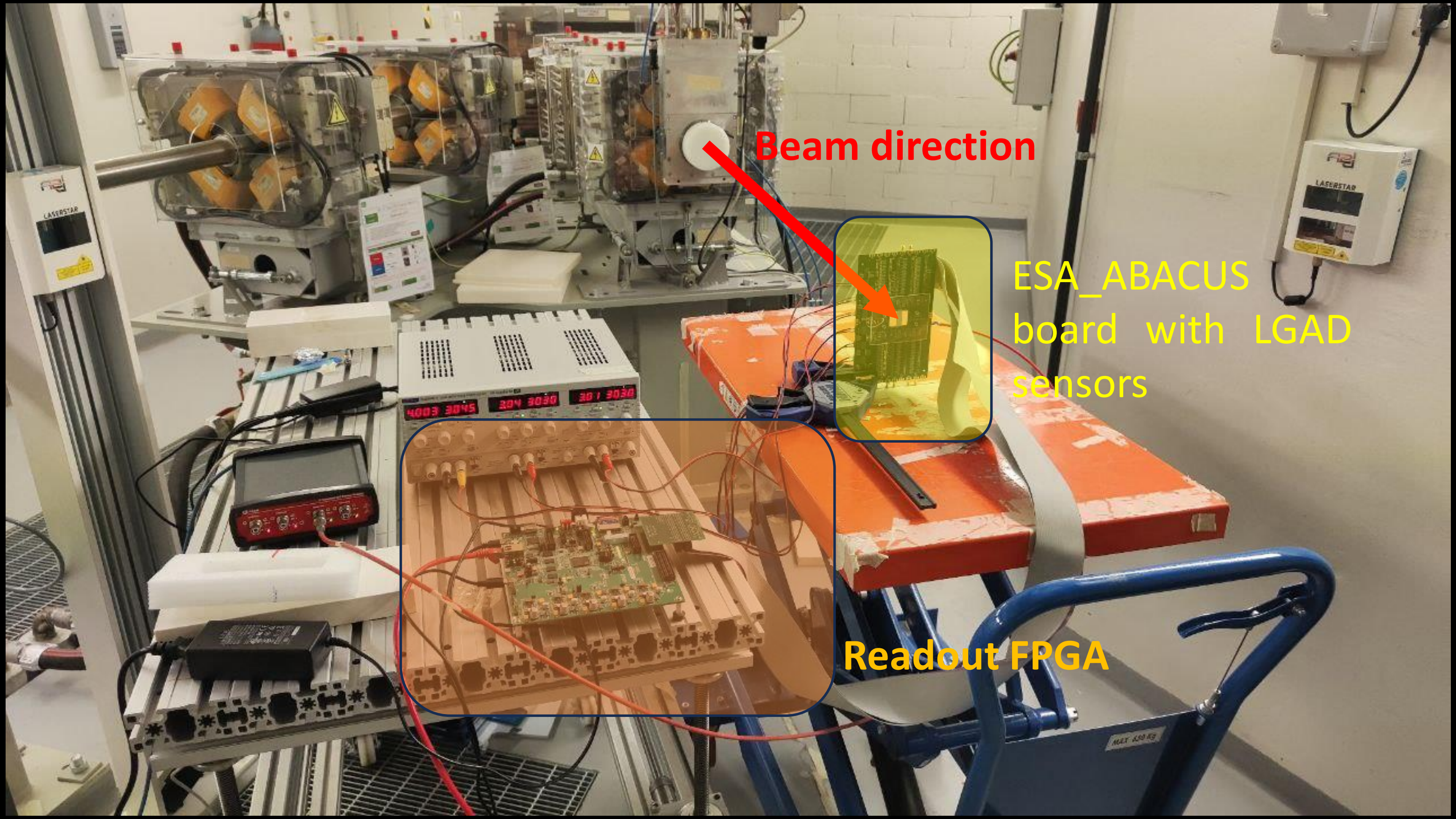

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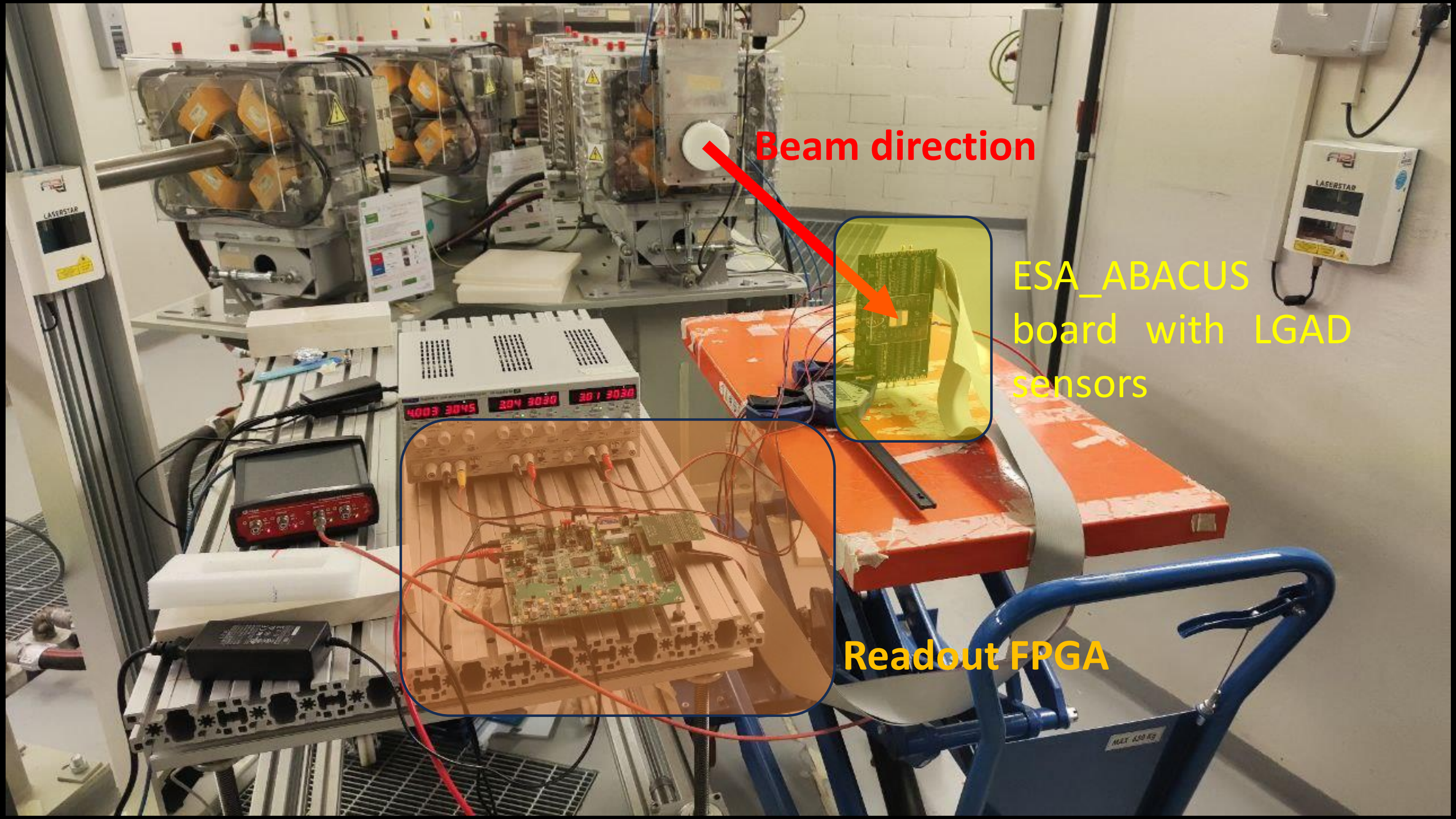

Beam test conducted at the Proton Therapy Center in Trento to answer:

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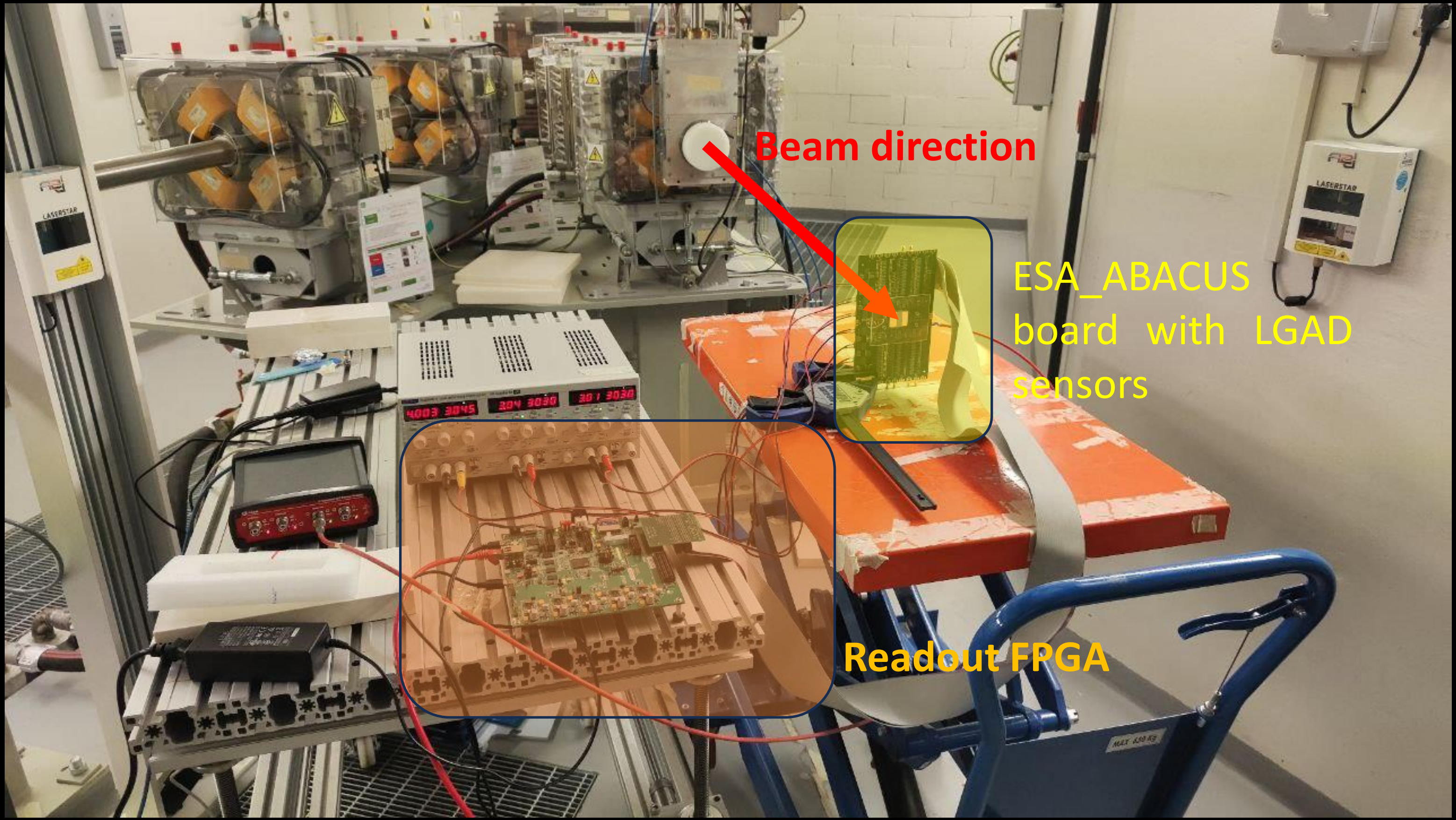


Beam test conducted at the Proton Therapy Center in Trento to answer:

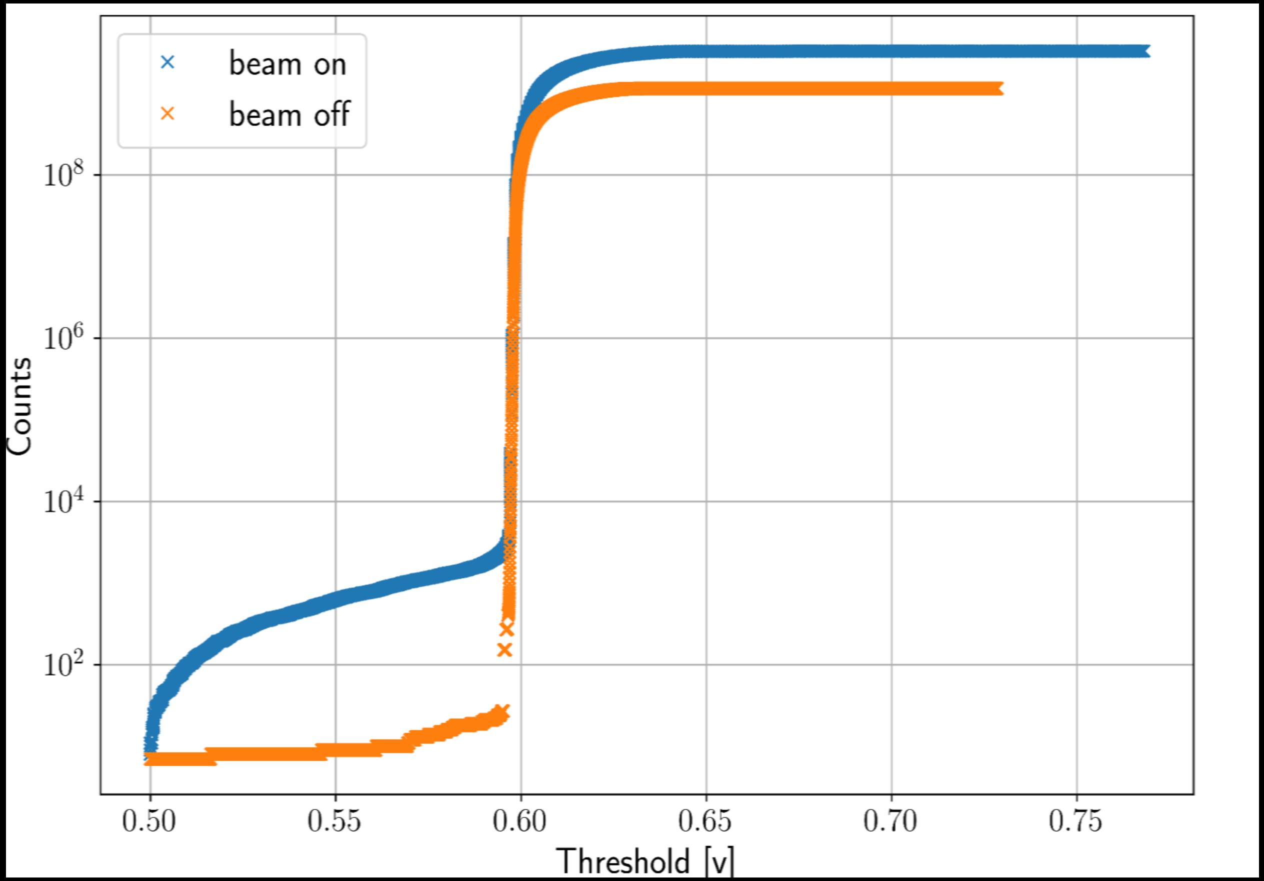
- are the LGADs sensors capable of detecting protons with energy up to 228 MeV?

LGAD - Threshold scan profile

Low Gain Avalanche Detector

LGAD - Threshold scan profile

Low Gain Avalanche Detector



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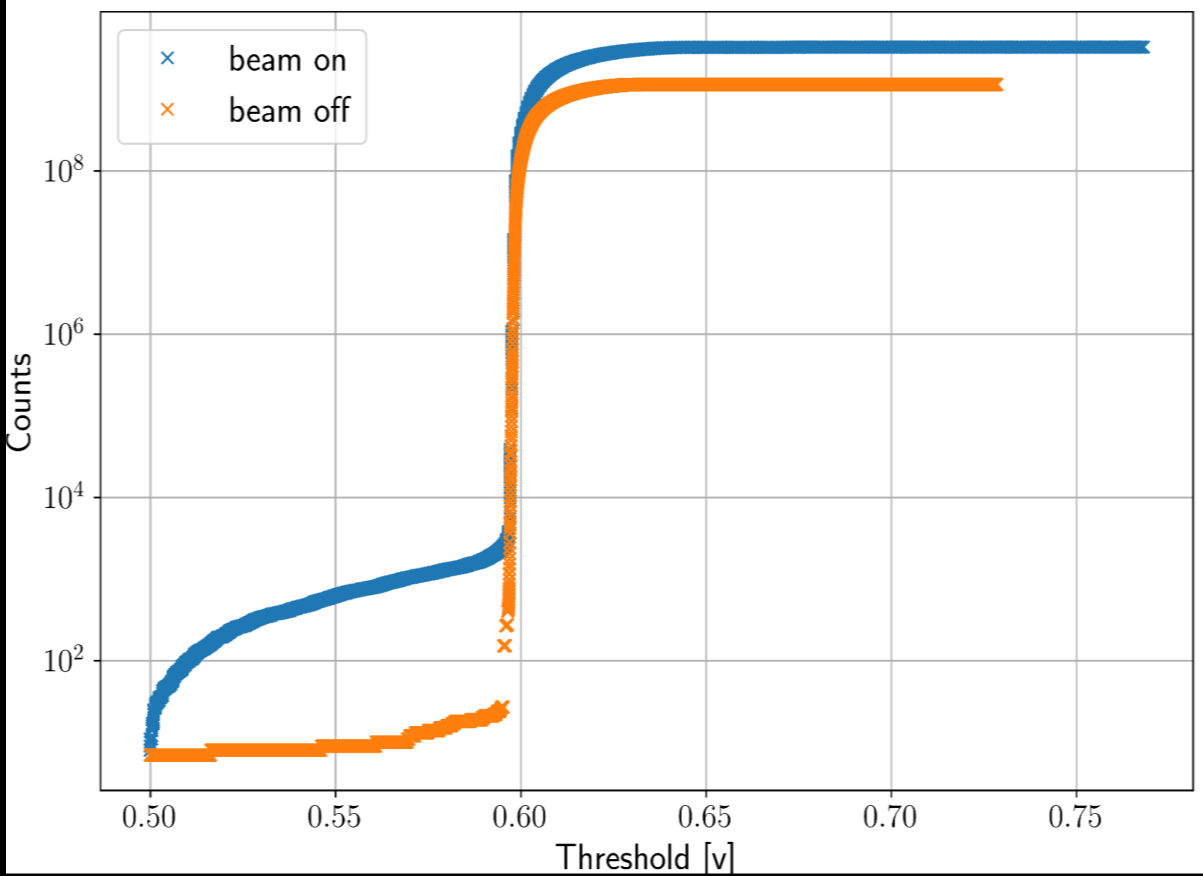

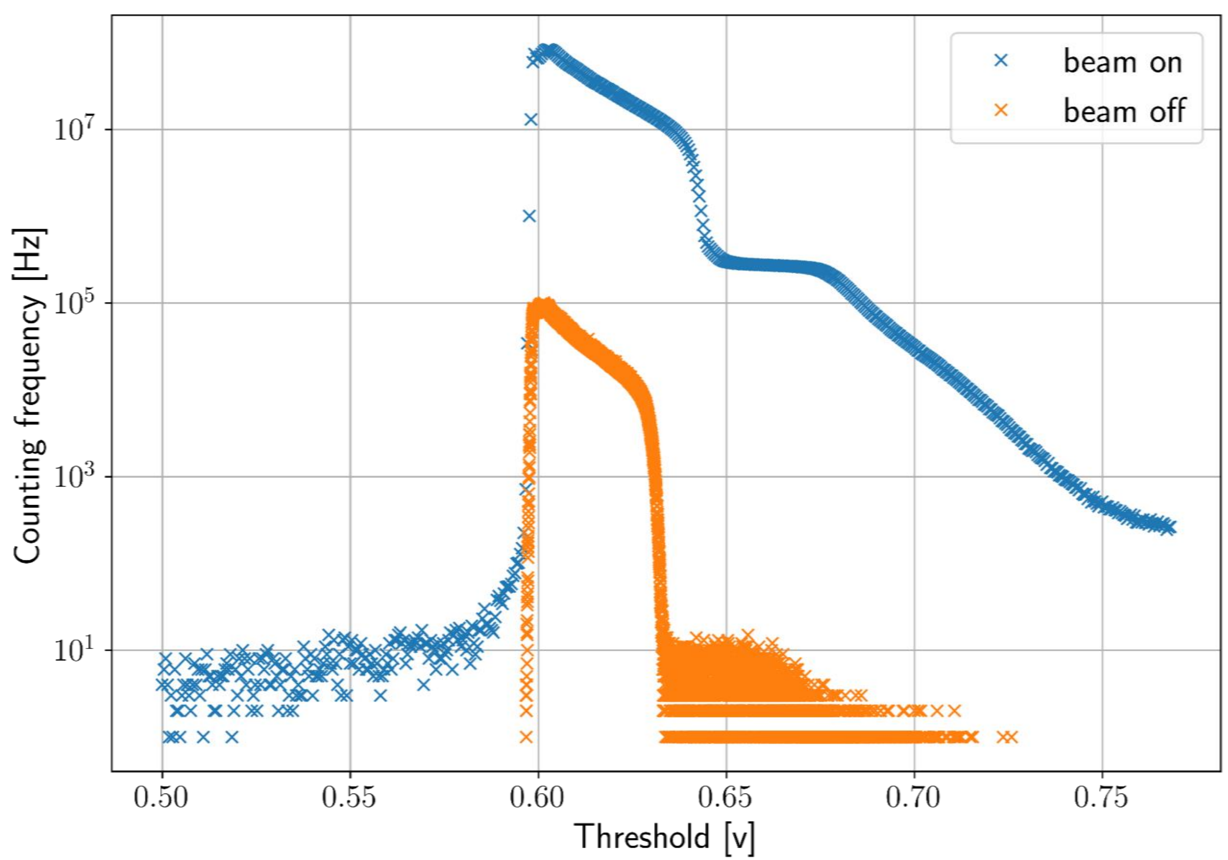

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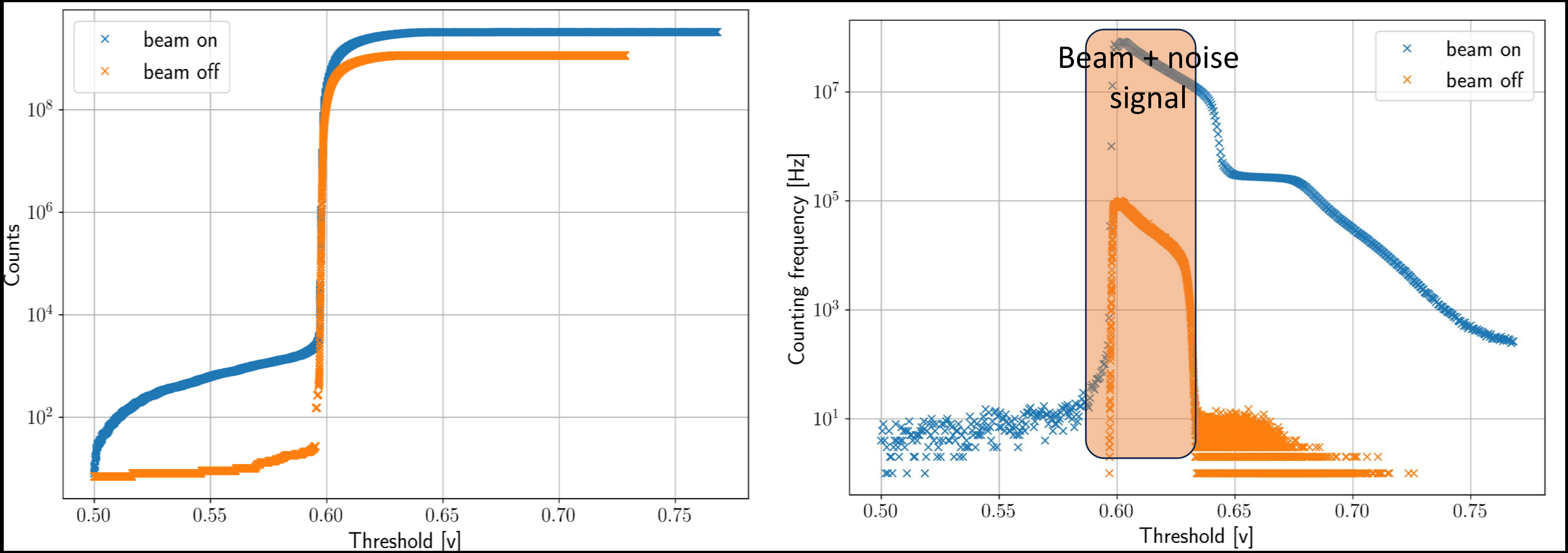

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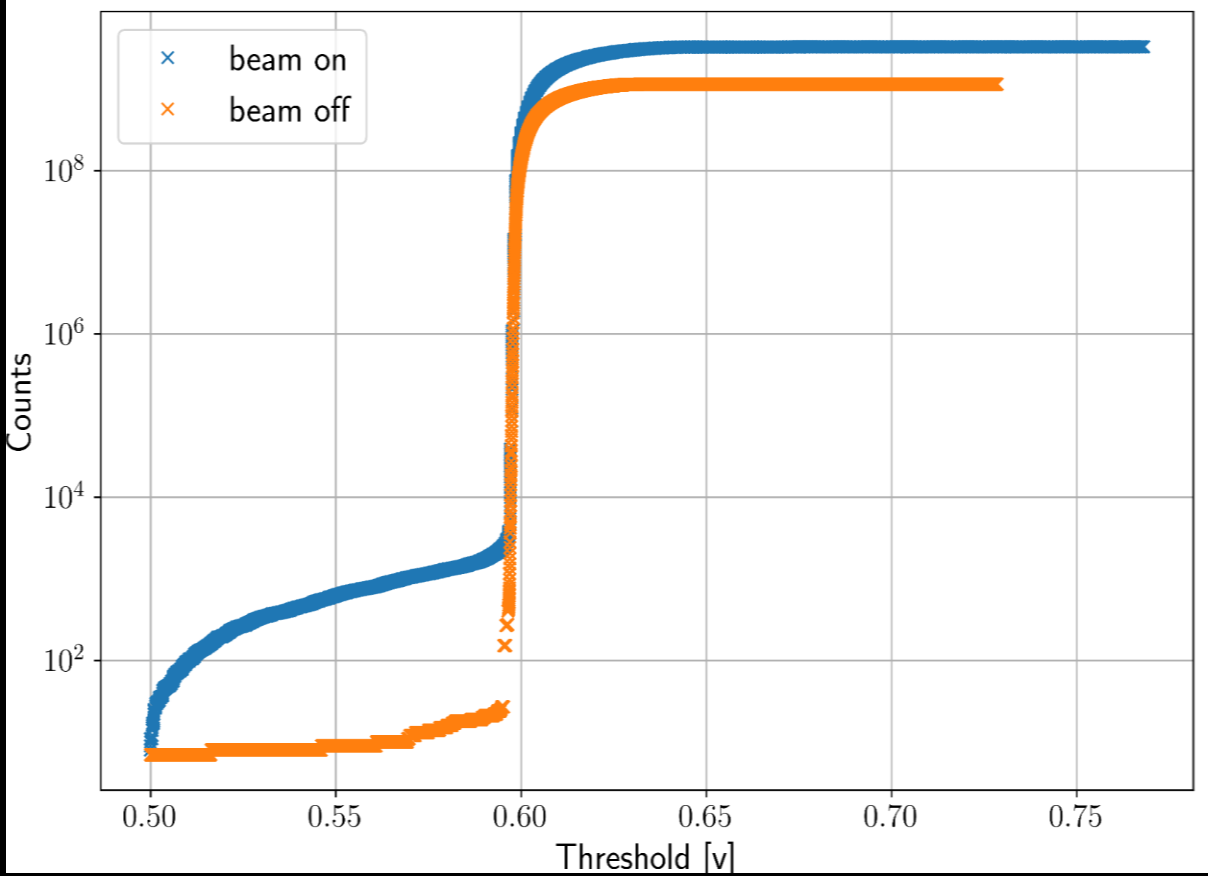

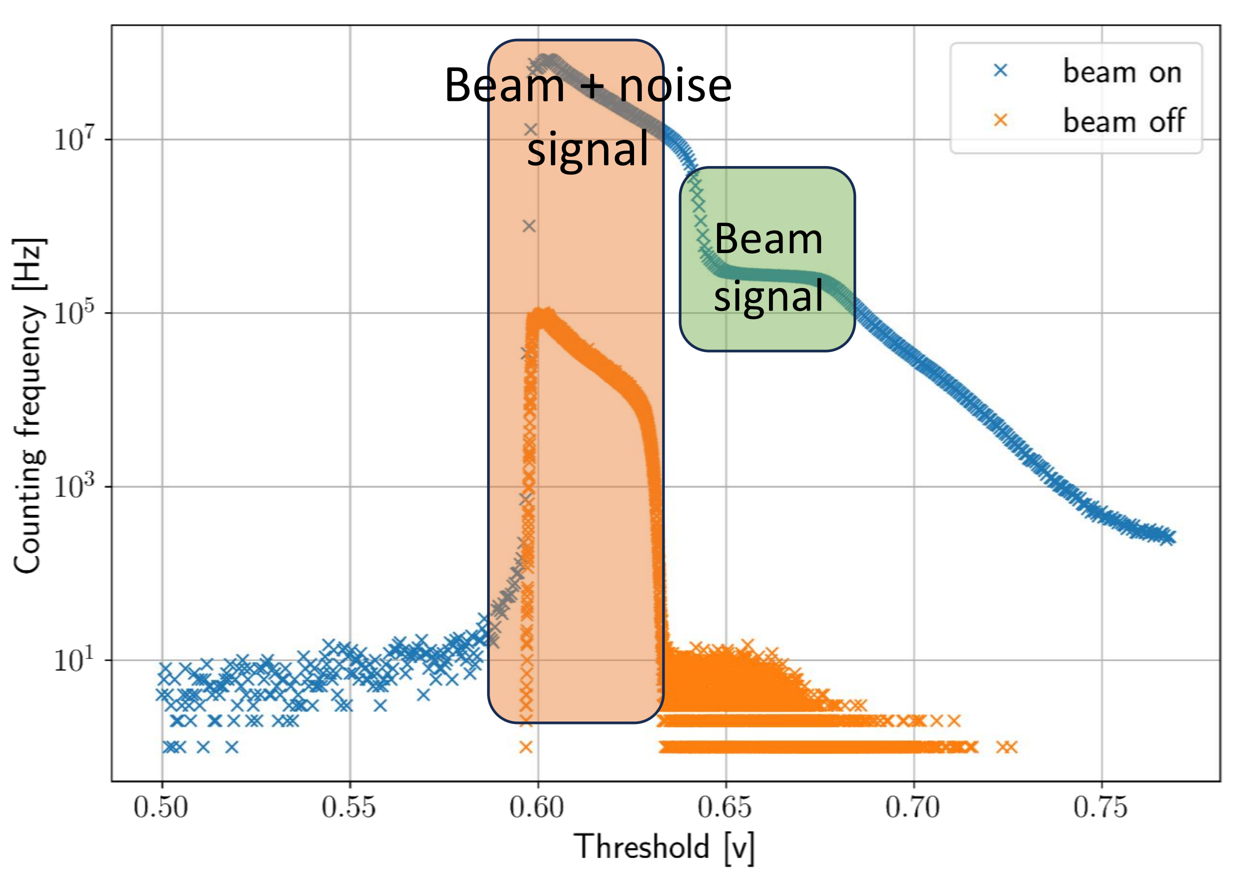

LGADs - Landau distributions

Low Gain Avalanche Detector

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Low Gain Avalanche Detector

Probability of having a signal with amplitude > $x_{\text{Threshold}}$

$$f(x \geq x_{\text{Threshold}}) = f_0 \int_{x_{\text{Threshold}}}^{\infty} p(x')d(x')$$

LGADs - Landau distributions

Low Gain Avalanche Detector

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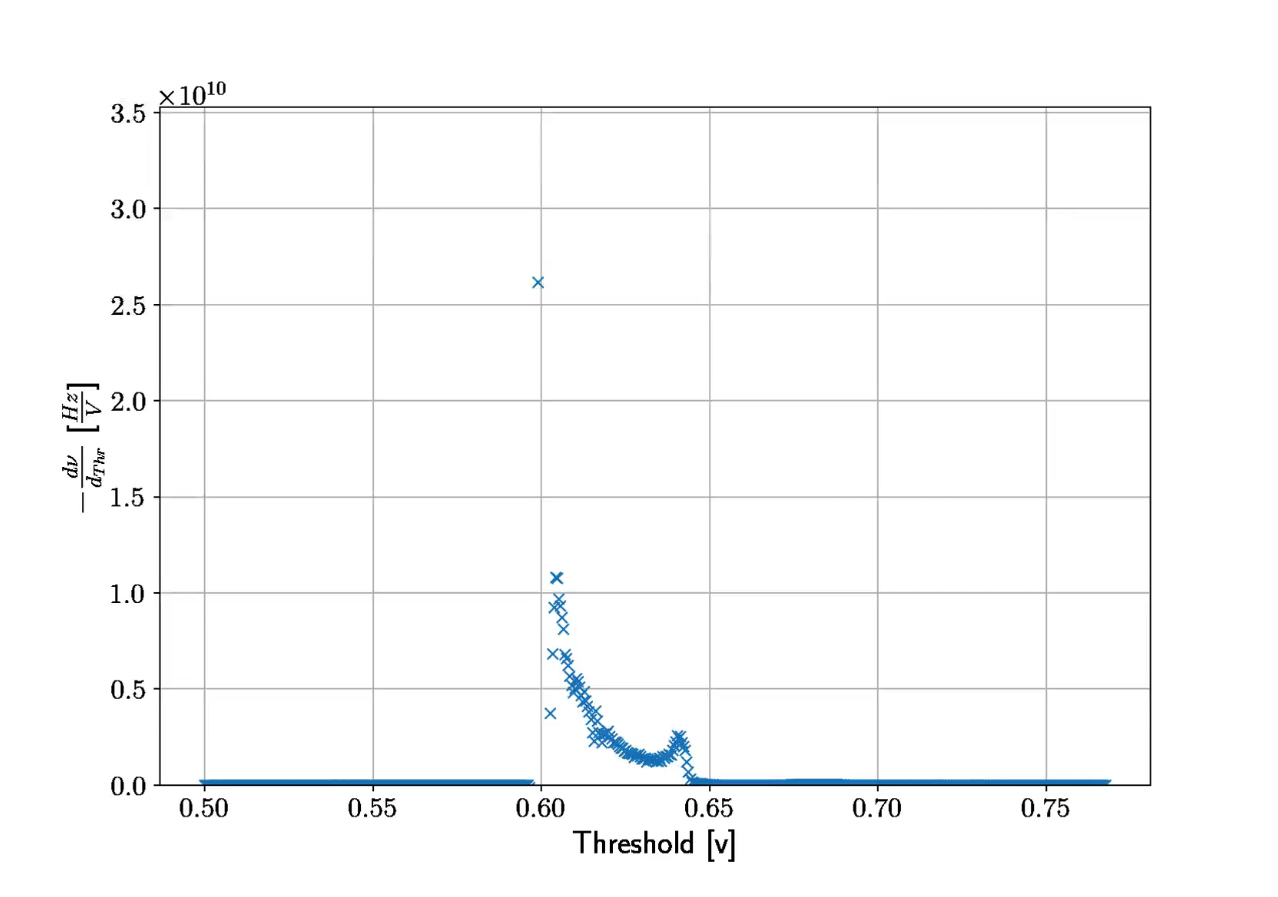

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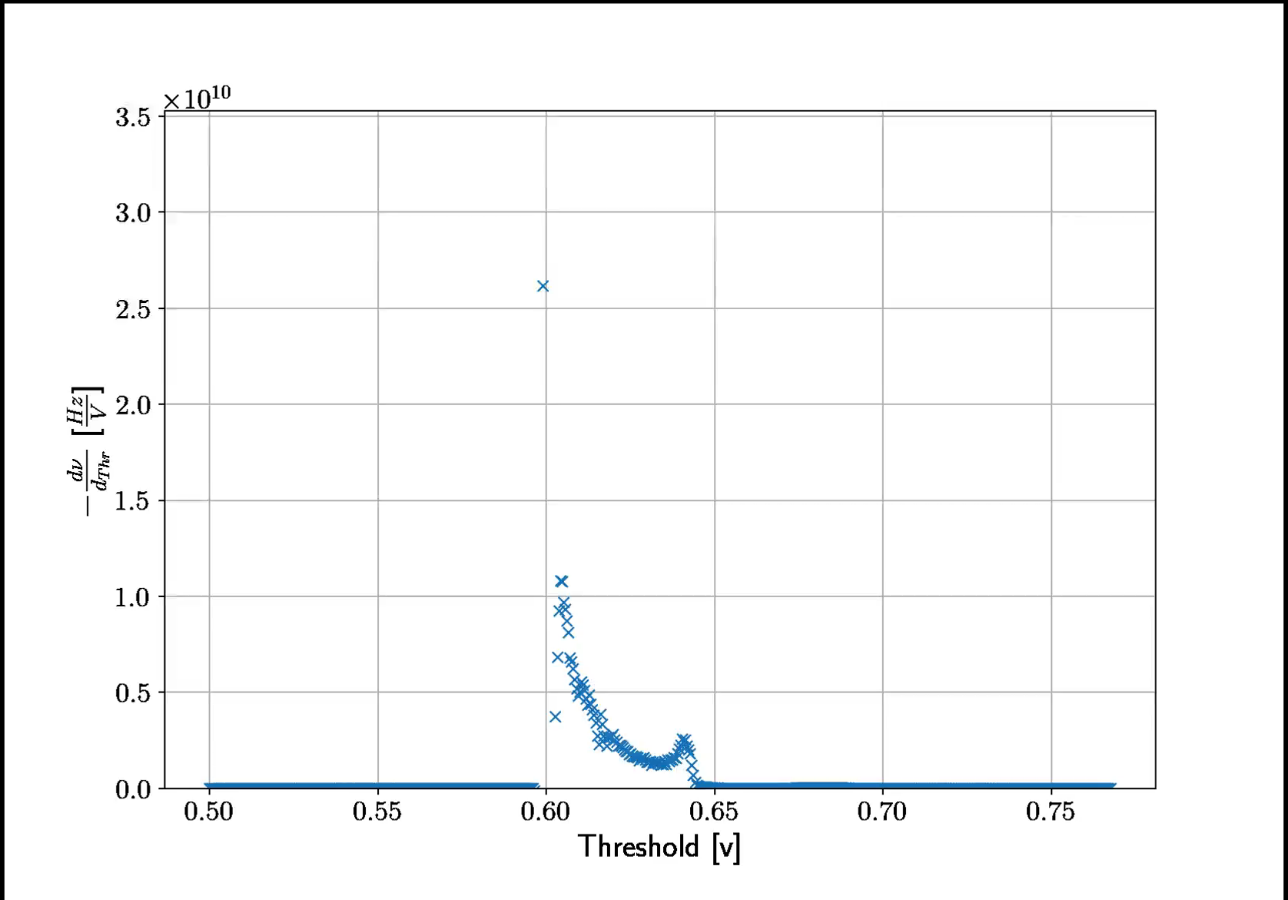

LGAD - Threshold scan results, 228 MeV

Low Gain Avalanche Detector

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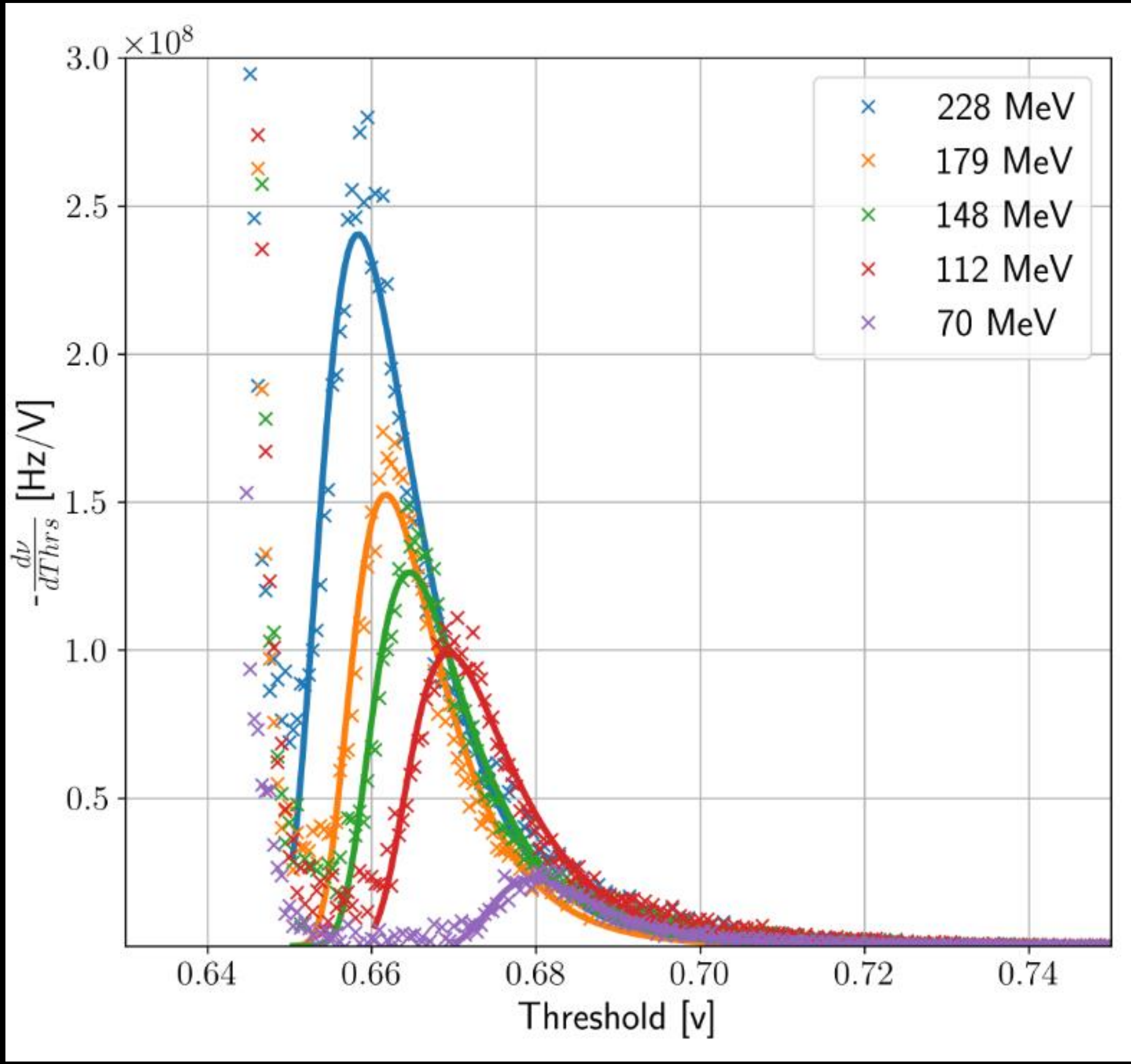

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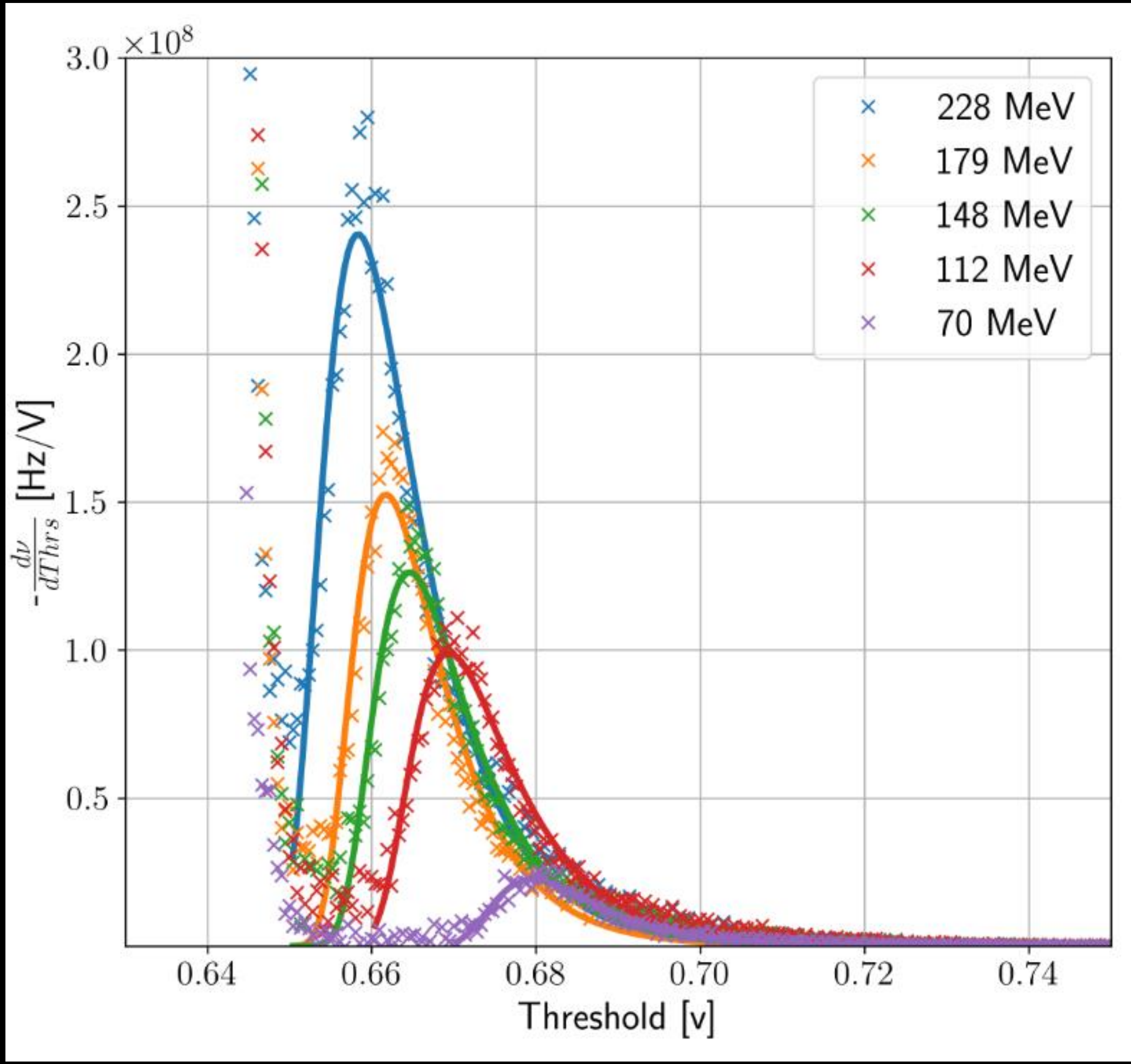
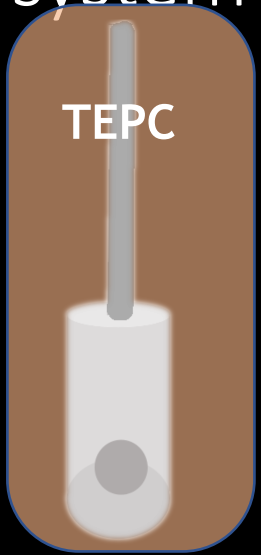
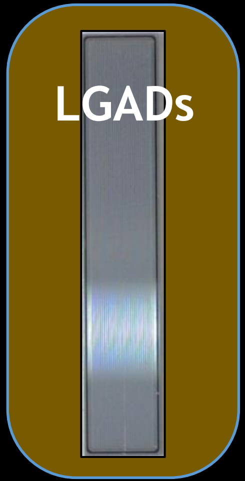


The complete readout system





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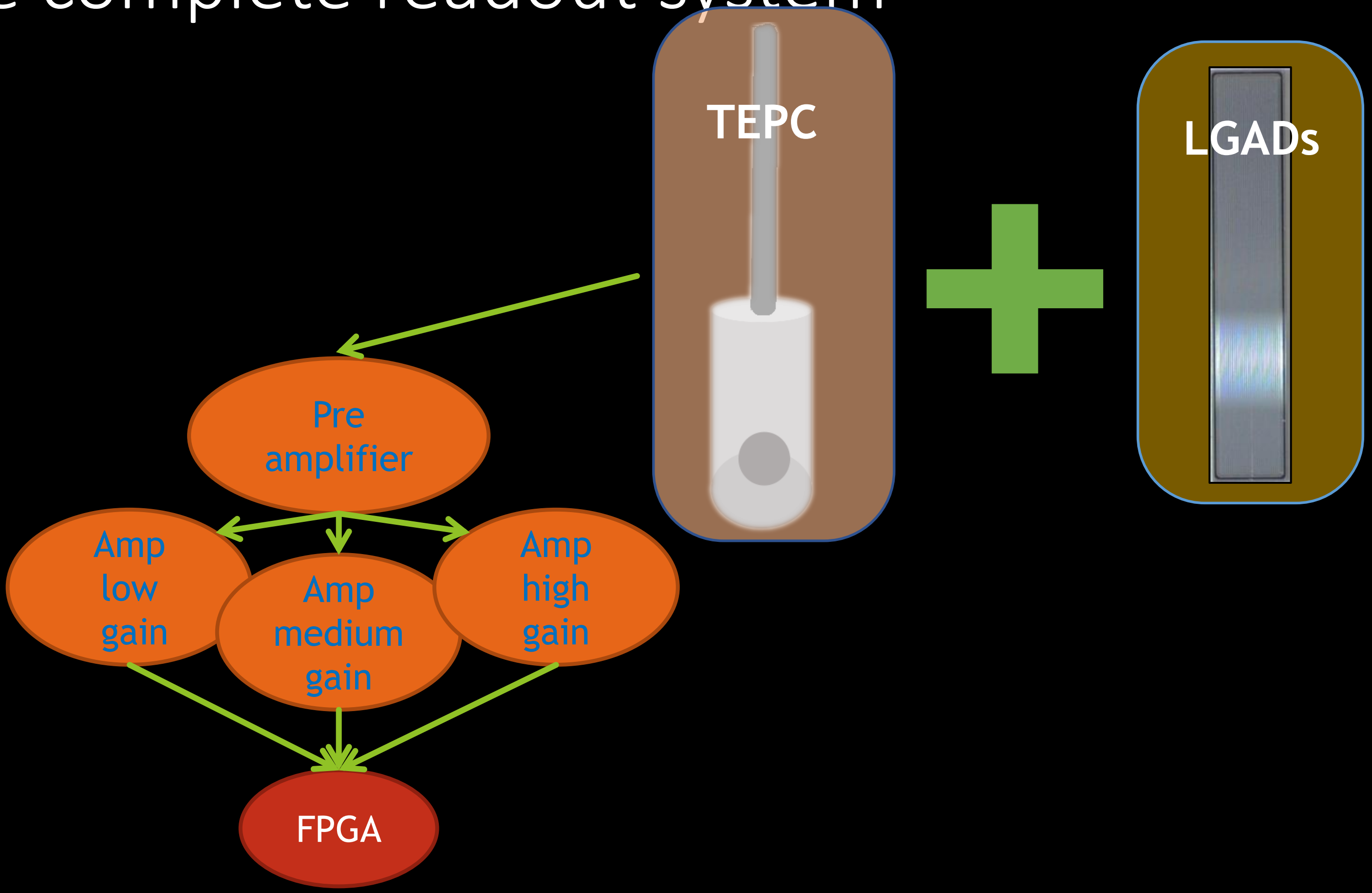

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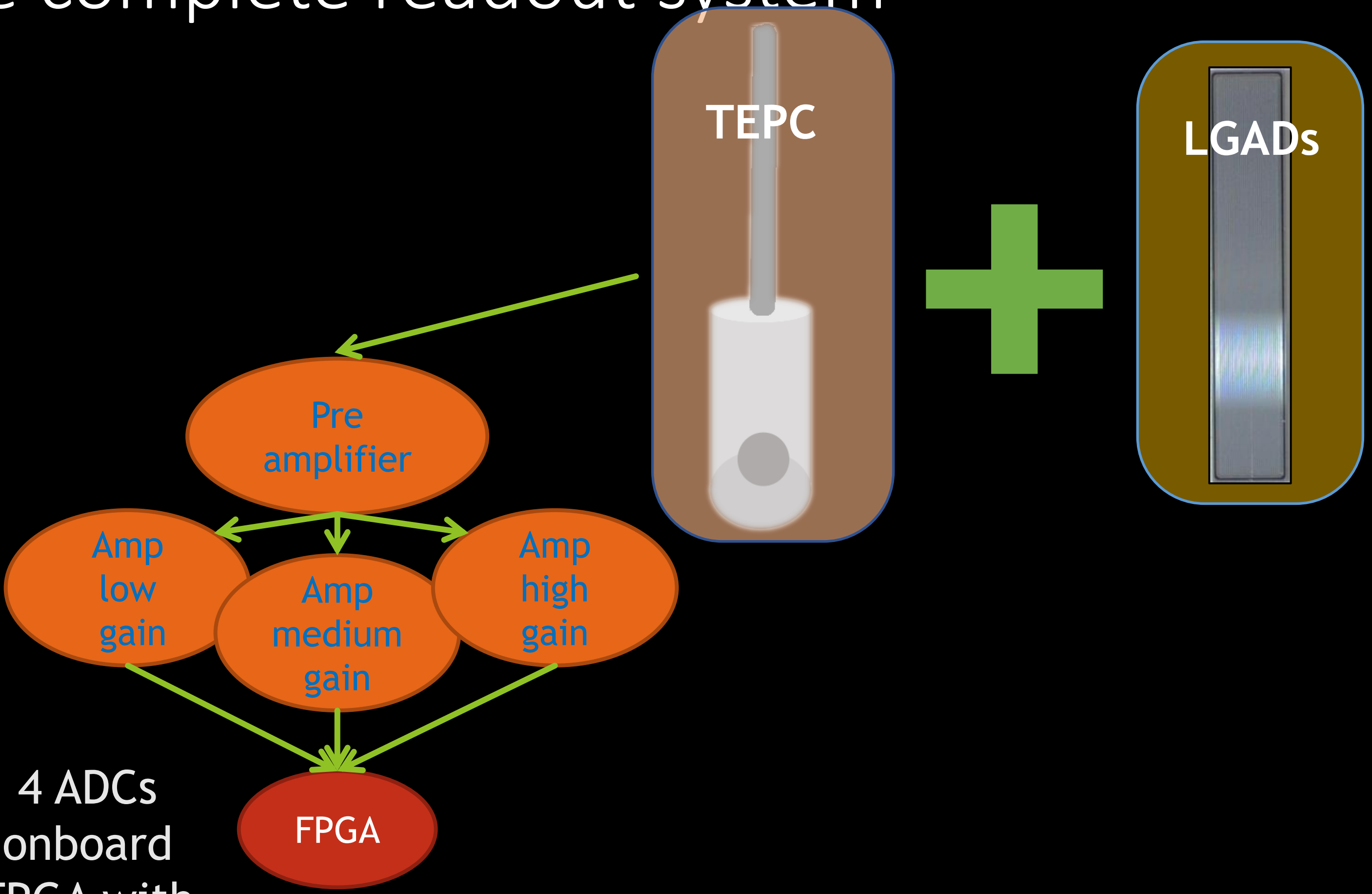

4 ADCs onboard FPGA with custom firmware

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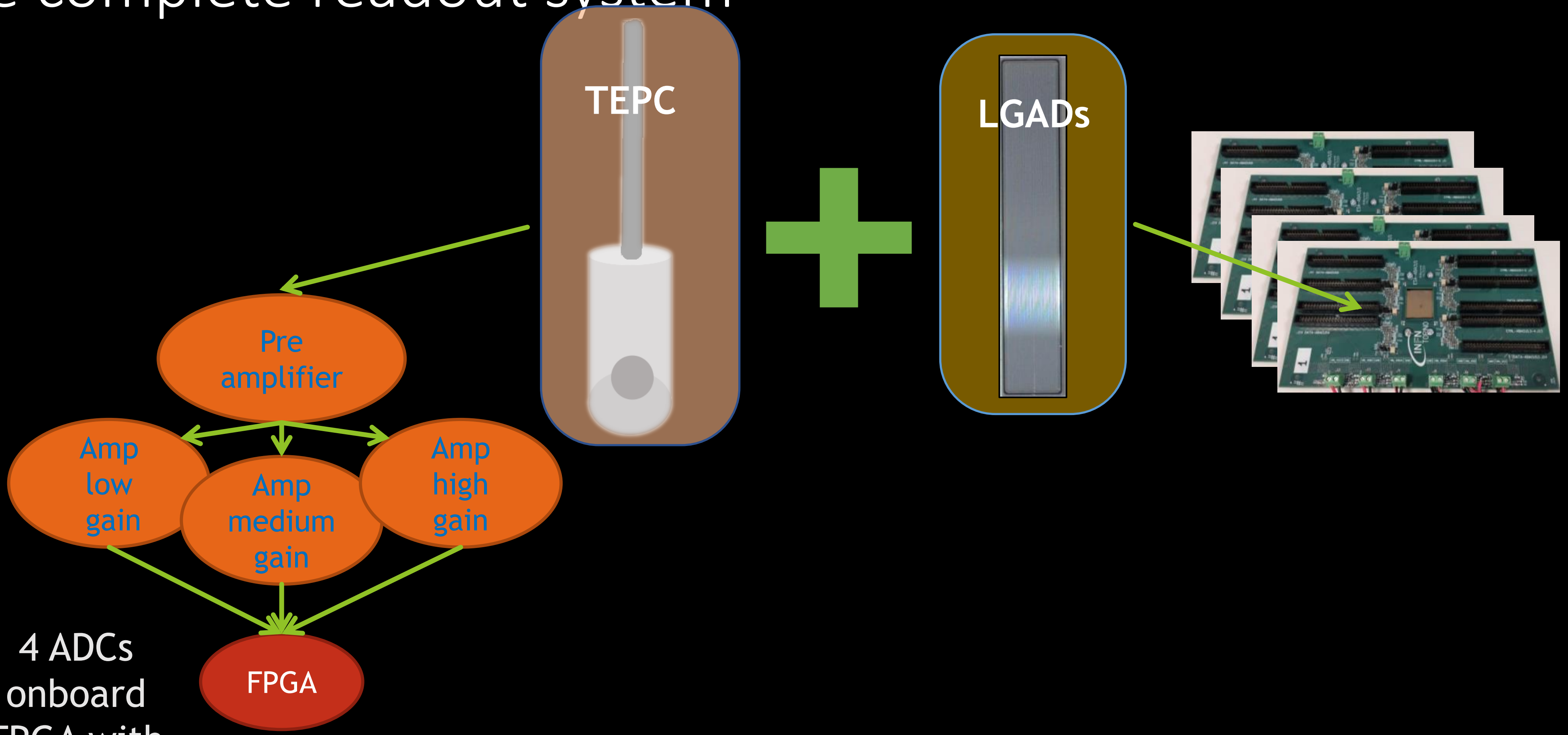

4 X ESA_ABACUS with 3 ABACUS chips each

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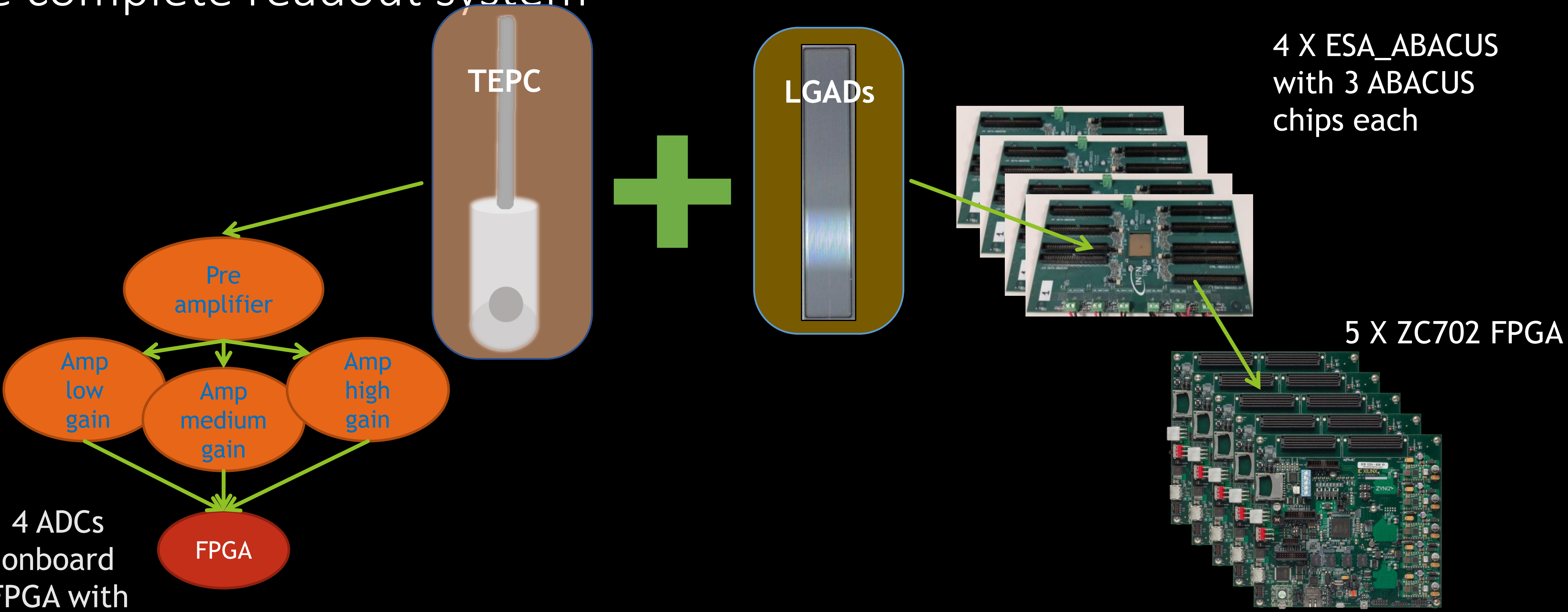

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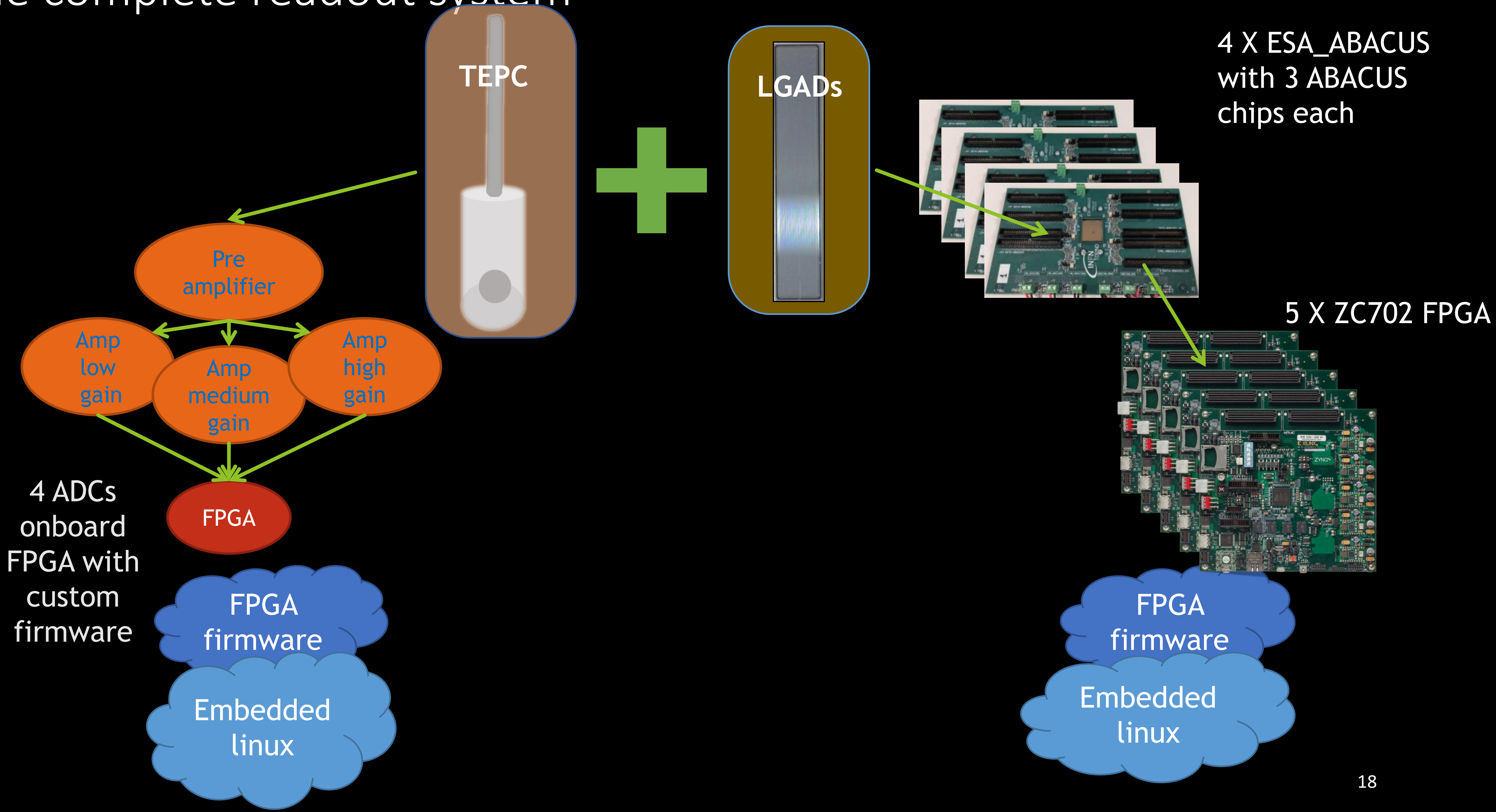

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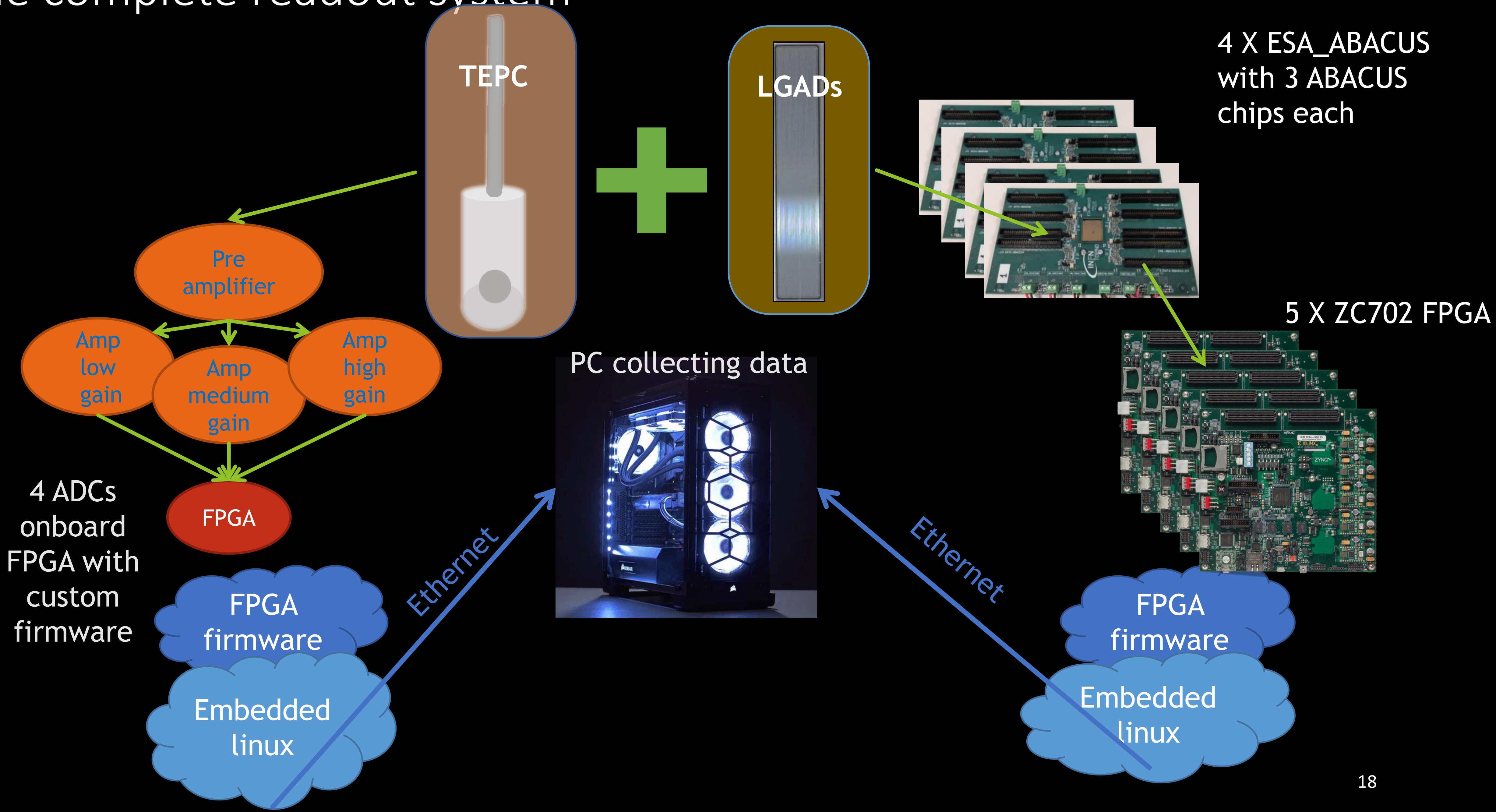

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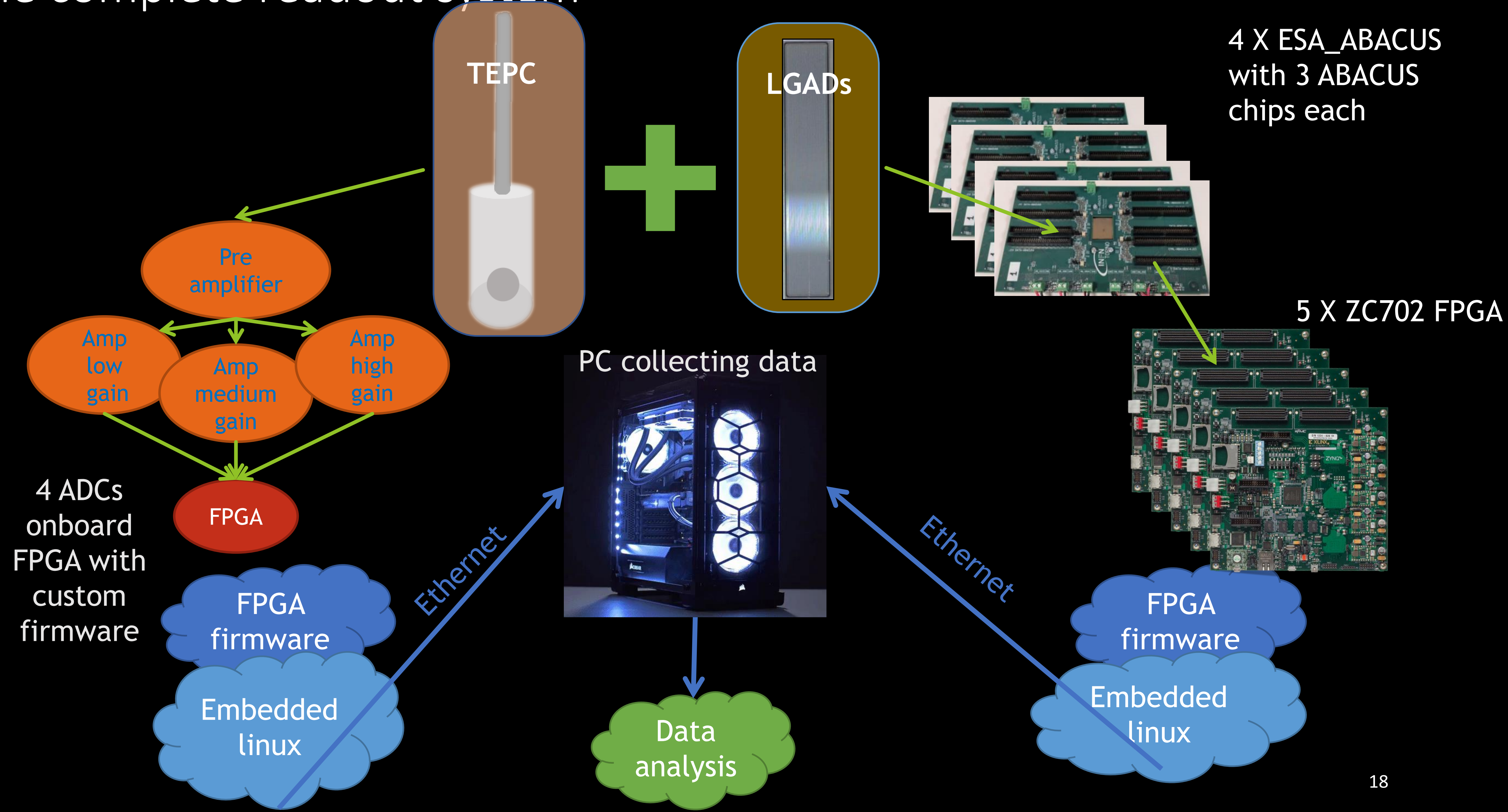

Conclusions

Work in progress

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- Data analysis

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Machine learning-based particle track reconstruction published in Physics in Medicine & Biology 10.1088/1361-6560/ac8af3

Thak you for your attentions

BiMeR

Bio—Medical Radiation physics lab

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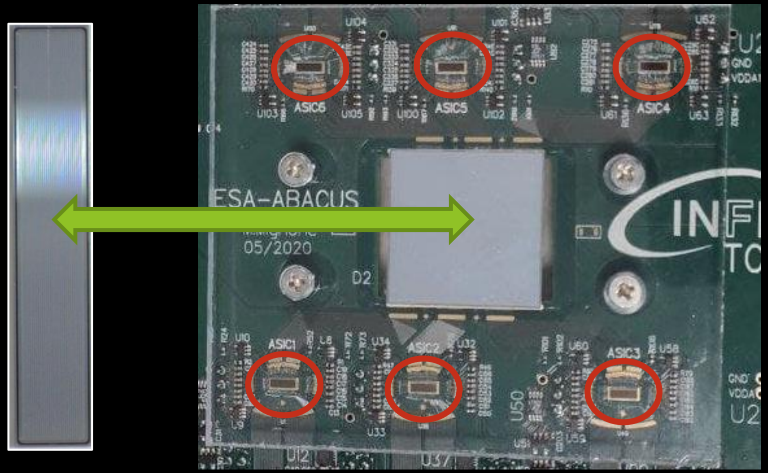
Backup slides

ABACUS ASIC

LGADs ABACUS chips

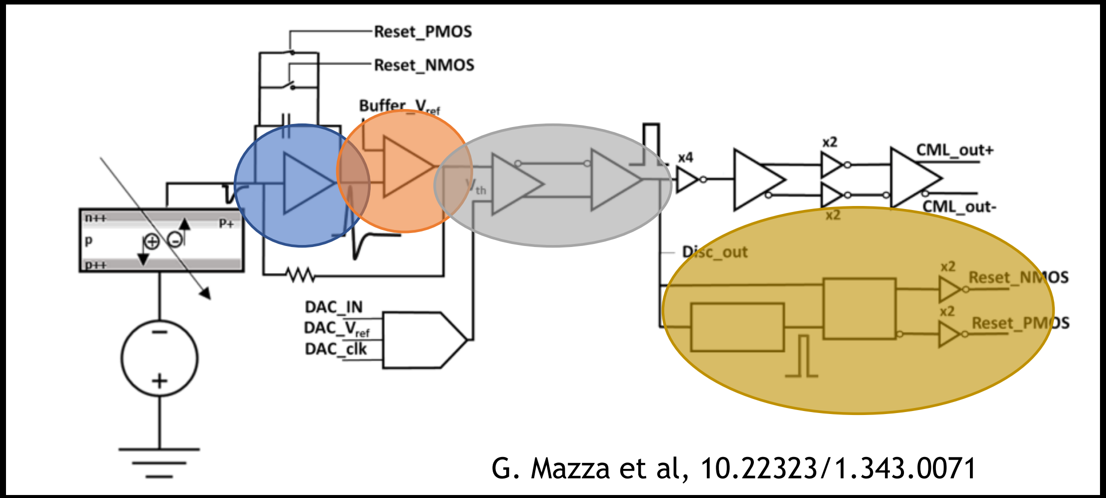


Each chip read a maximum of 24 LGADs

Sets threshold for each channel

Preamplifier Buffer

Output is in Current Mode Logic (CML)



G. Mazza et al, 10.22323/1.343.0071

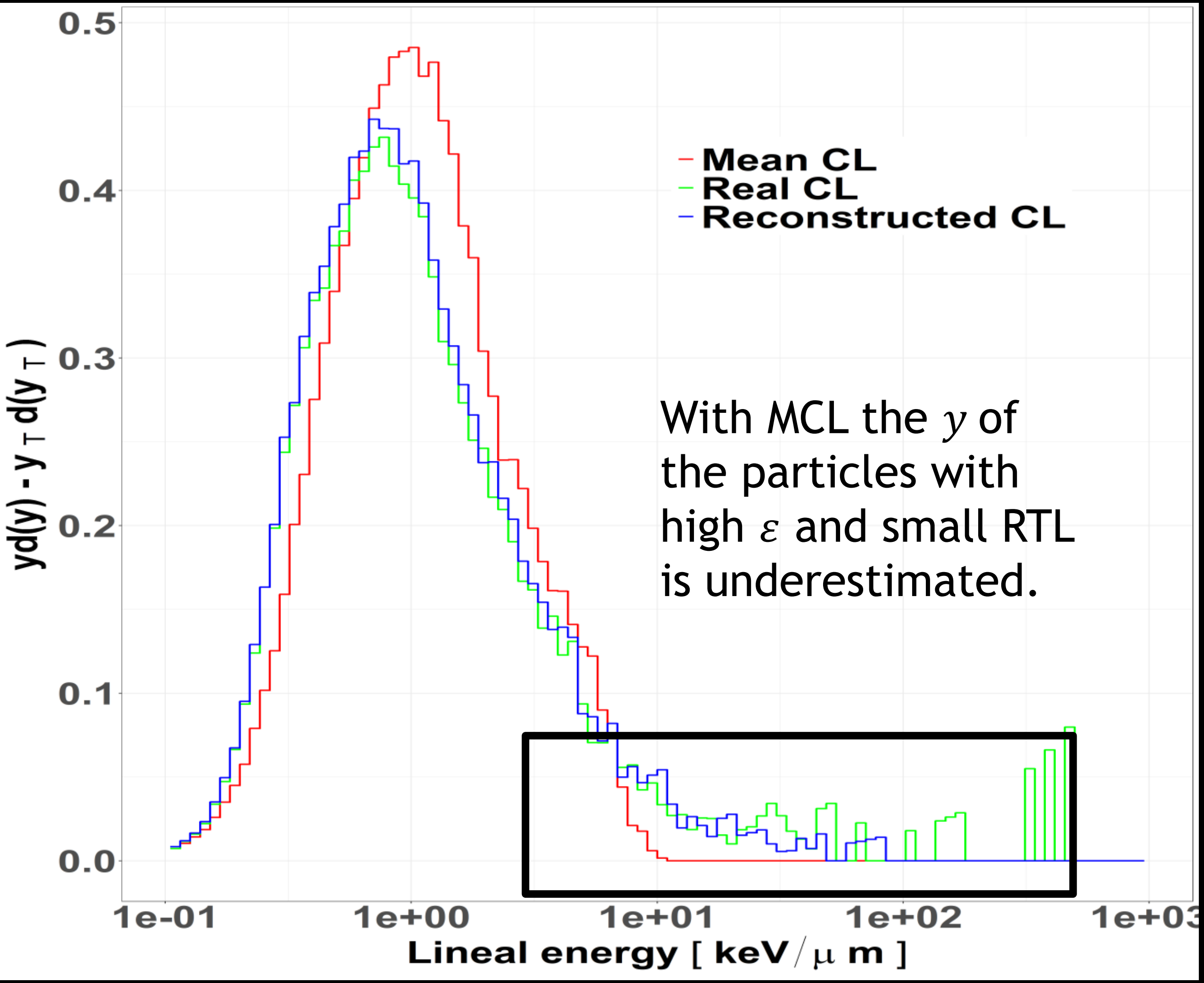
Multistage discriminator

Feedback capacitor signal reset

- Problem finding a common threshold to multiple channels due to limited range

+ New fixed version of the chip production should start within days

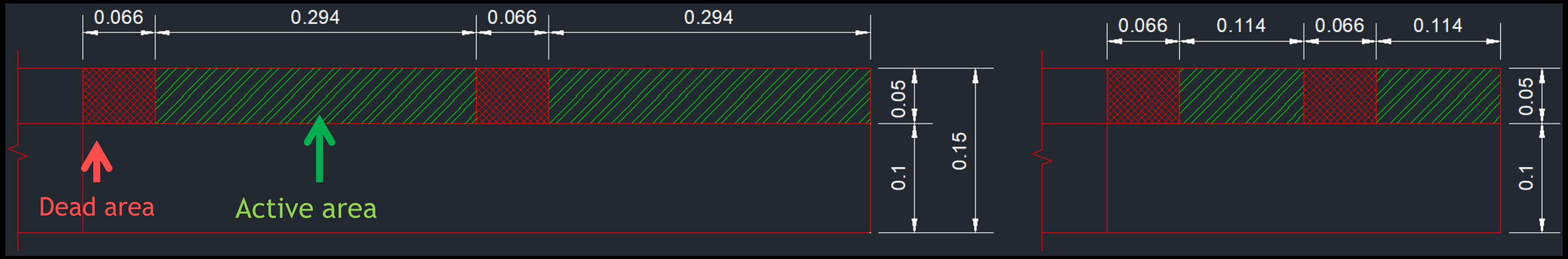
HDM: the spectrum from simulations



- HDM will improve the radiation quality description and consequentially the treatment planning
- HDM will improve the TEPC spatial resolution

LGADs geometry

34 strips per sensor



71 strips per sensor

- pitch 360 µm
- better fill factor
- less channels to read

- pitch 180 µm
- better spatial resolution

TEPC Energy deposition equivalence:

$$\Delta E_{TEPC\ gas} = \Delta E_{Tissue}$$

Mass stopping power

Diameter

Density

$$\Delta E_{TEPC} = \left(\frac{S}{\rho}\right)_{TEPC} (D\rho)_{TEPC}$$

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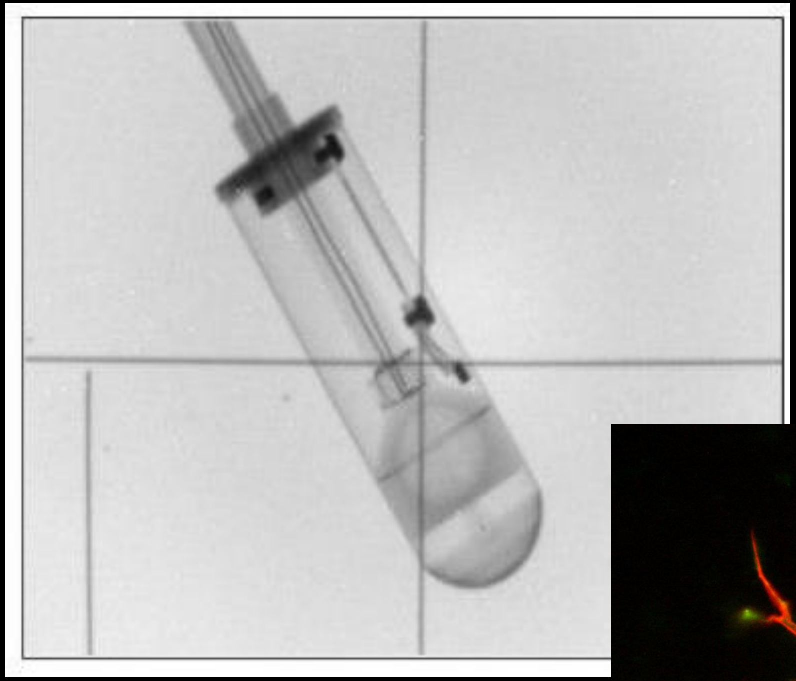

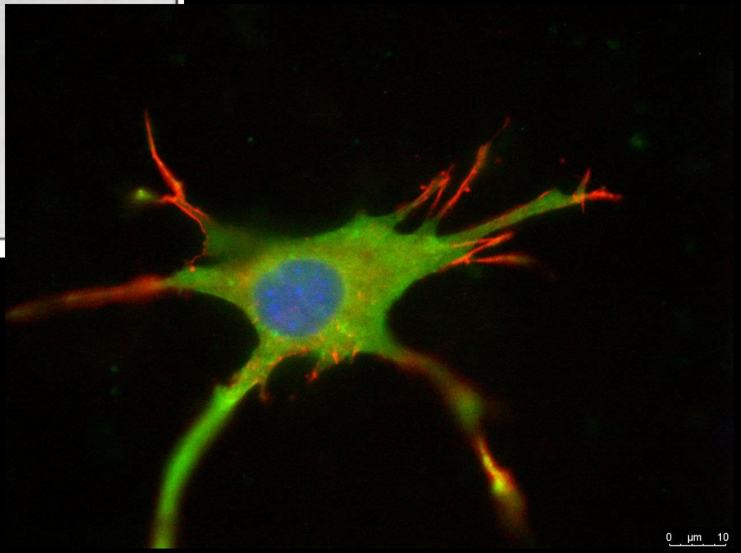

Landau distribution

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$$p(x) = -\frac{df(x)}{dx}$$