The Münster TPC – design, DAQ and processing of a dual-phase TPC

Institut für Kernphysik
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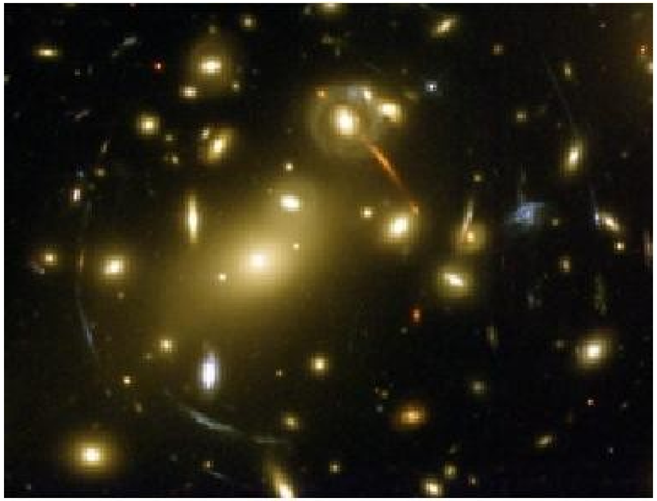
- Functionality of a dual phase TPC
- Setup of the Münster TPC
- Calibration of the photomultiplier tubes (PMTs)
- Conclusion and outlook

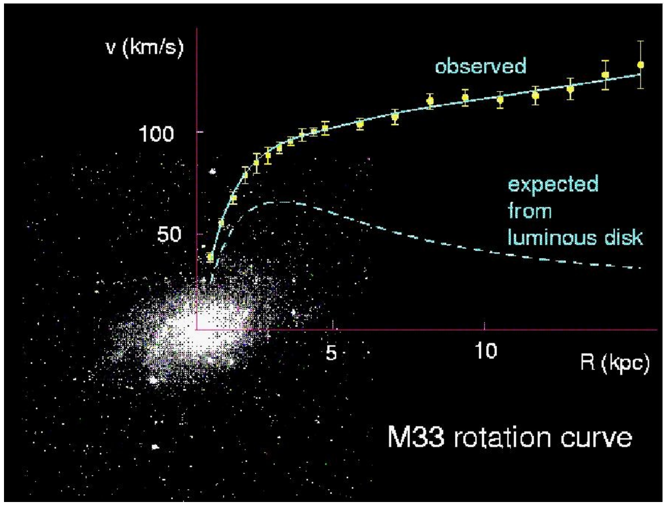
Westfälische Wilhelms-Universität Münster

Motivation of direct dark matter detection and to build an institutional TPC

- WIMP (weakly interacting massive particle) as a candidate for dark matter
- Research on direct dark matter detection in various experiments (XENON, LUX, CDMS, EDELWEISS, CRESST, ...)



Xe
XENON
Dark Matter Project

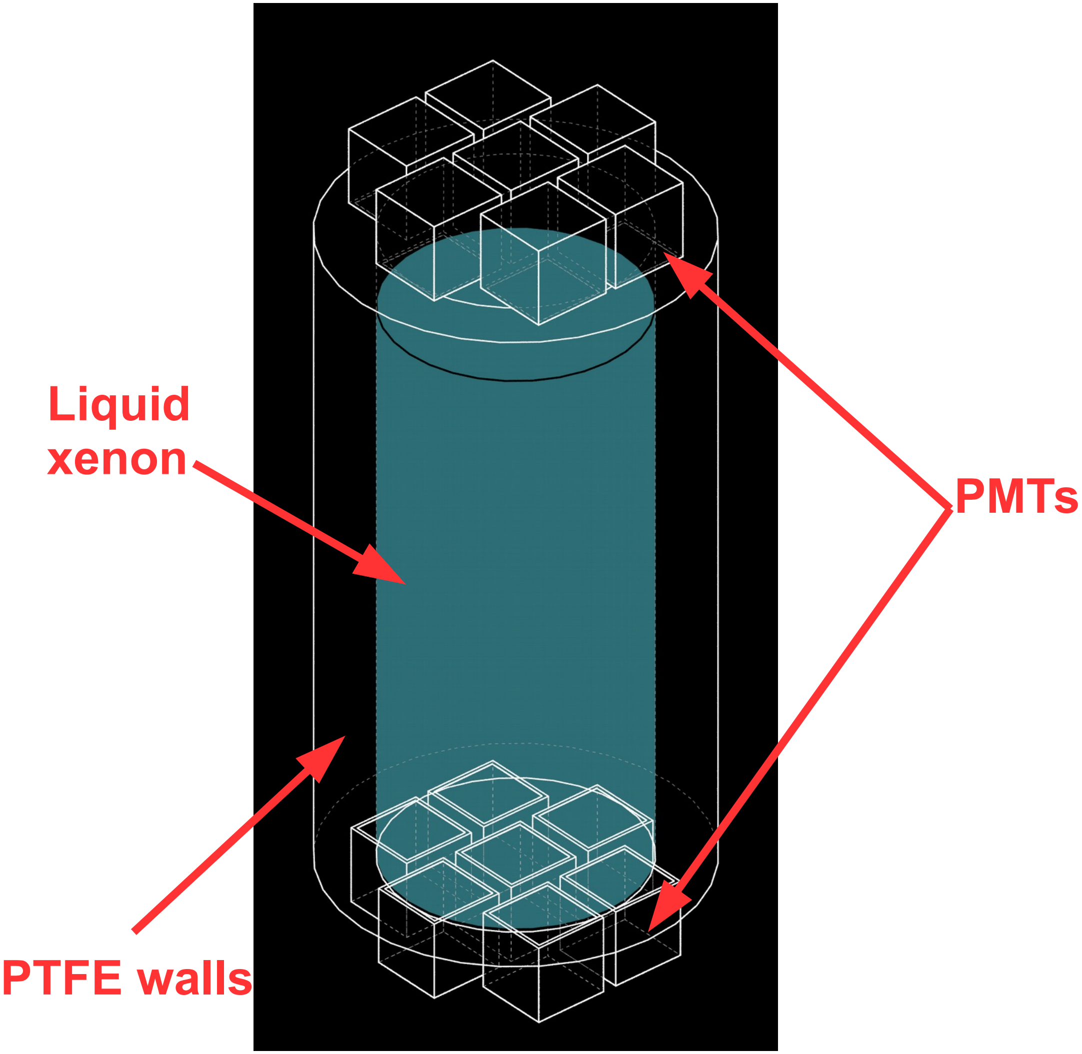


Functionality of a dual phase time projection chamber (TPC)

- Liquid and gaseous xenon in a cylindrical detector

  → Dual phase TPC

- Arrays of photomultipliers (PMTs) at top and bottom
- Surface of liquid xenon 1-2 centimeters below top PMTs



Functionality of a dual phase TPC

- Scintillation on electronic or nuclear recoil

  → S1 signal (short)

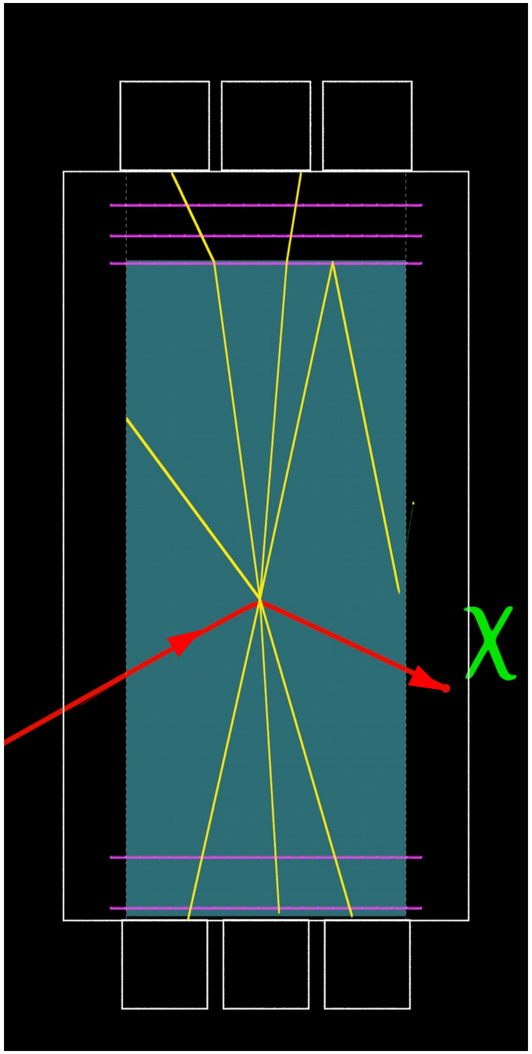
- More efficient light collection at the bottom due to (total) reflection at the surface of the liquid xenon

- PTFE (Teflon™) walls with high reflection properties in the VUV spectrum (178nm scintillation wavelength)

$$\chi + \mathrm{Xe} \rightarrow \chi + \mathrm{Xe}^*$$

$$\mathrm{Xe}^* + \mathrm{Xe} + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^* + \mathrm{Xe}$$

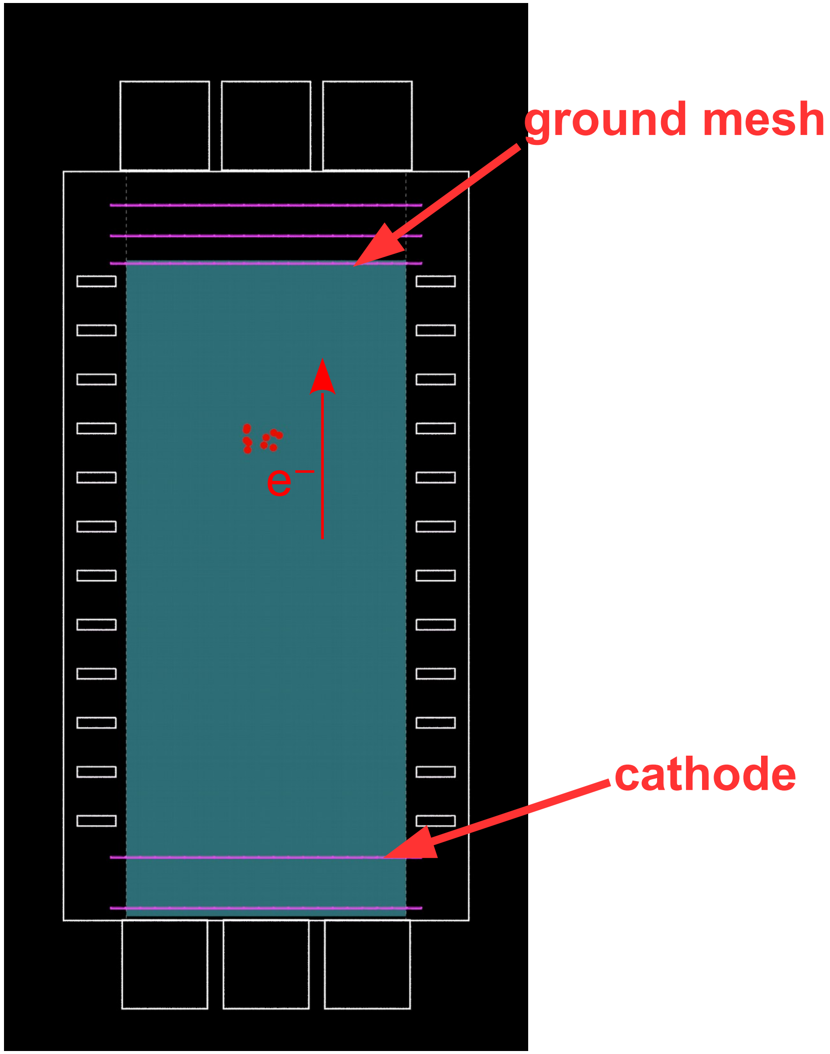
$$\mathrm{Xe}_2^* \rightarrow 2\mathrm{Xe} + h\nu$$



Creation of secondary signal S2

- Ionization of Xe emits electrons
- Electrons drift with constant velocity of ~1.7mm/µs @ 1kV/cm towards surface due to high electric field
- Cathode potential: ~ -17kV
- Drift time → z position

$$\chi + \mathrm{Xe} \rightarrow \mathrm{Xe}^{+} + \mathrm{e}^{-} + \chi$$
$$\mathrm{Xe}^{+} + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^{+}$$
$$\mathrm{Xe}_2^{+} + \mathrm{e}^{-} \rightarrow \mathrm{Xe}^{**} + \mathrm{Xe}$$
$$\mathrm{Xe}^{**} \rightarrow \mathrm{Xe}^{*} + \mathrm{heat}$$



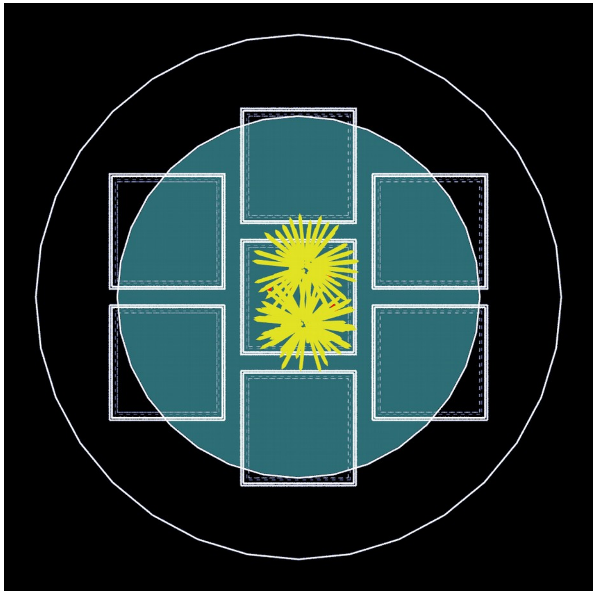
Creation of secondary signal S2

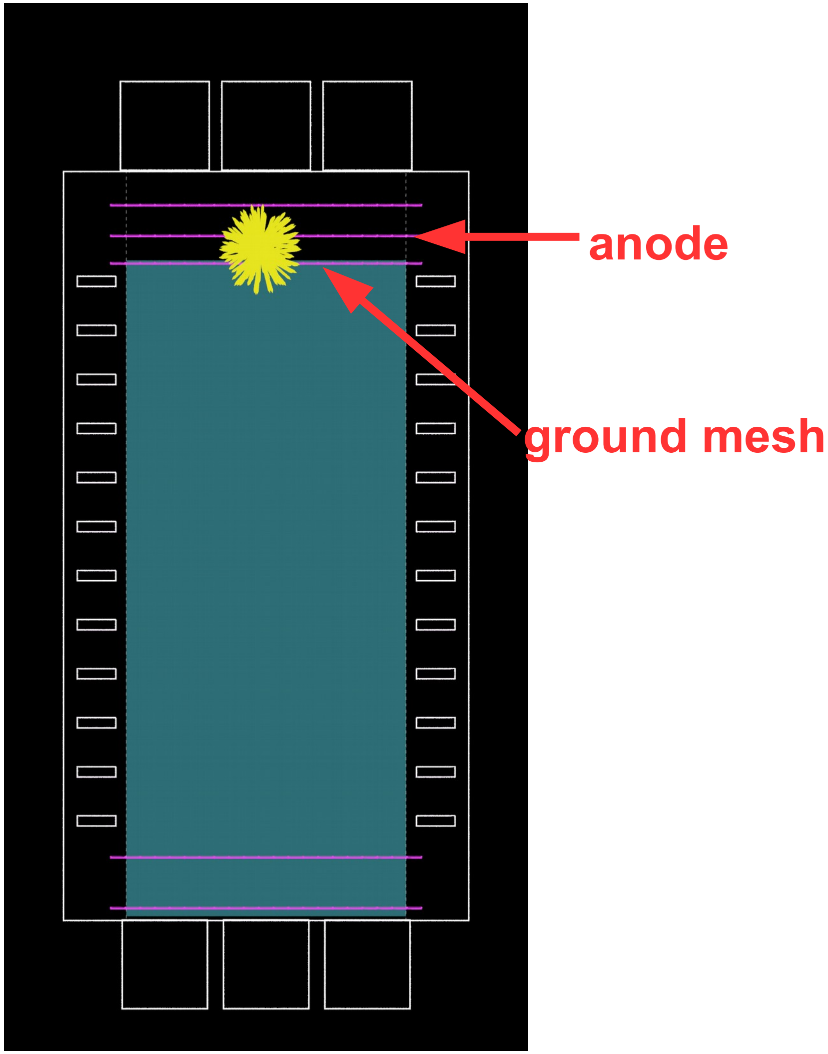
- Within gaseous phase secondary scintillation of Xe due to stronger electric field (~10 kV/cm) and accelerated electrons

  → S2 signal (wide)

- Hit pattern → xy position
- 3D position reconstruction
- Anode potential:

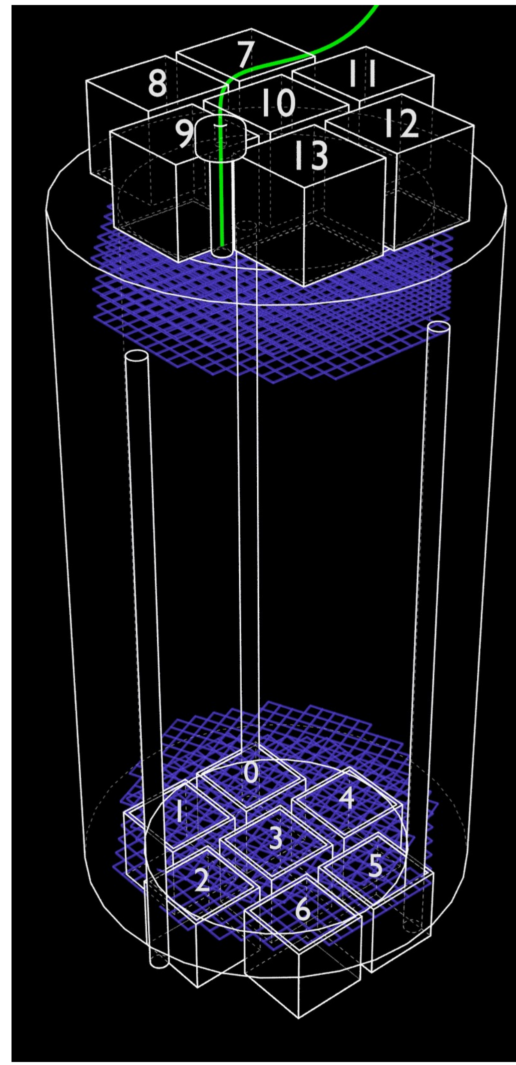
  ~ +4kV





The Münster time projection chamber (TPC)

- Internal components
  - – 14 photo multiplier tubes
  - – glass fiber for LED calibration
- Dimensions:
  - – inner diameter: 80 mm
  - – maximum drift length: 170 mm
  - – Total xenon amount: ~3kg



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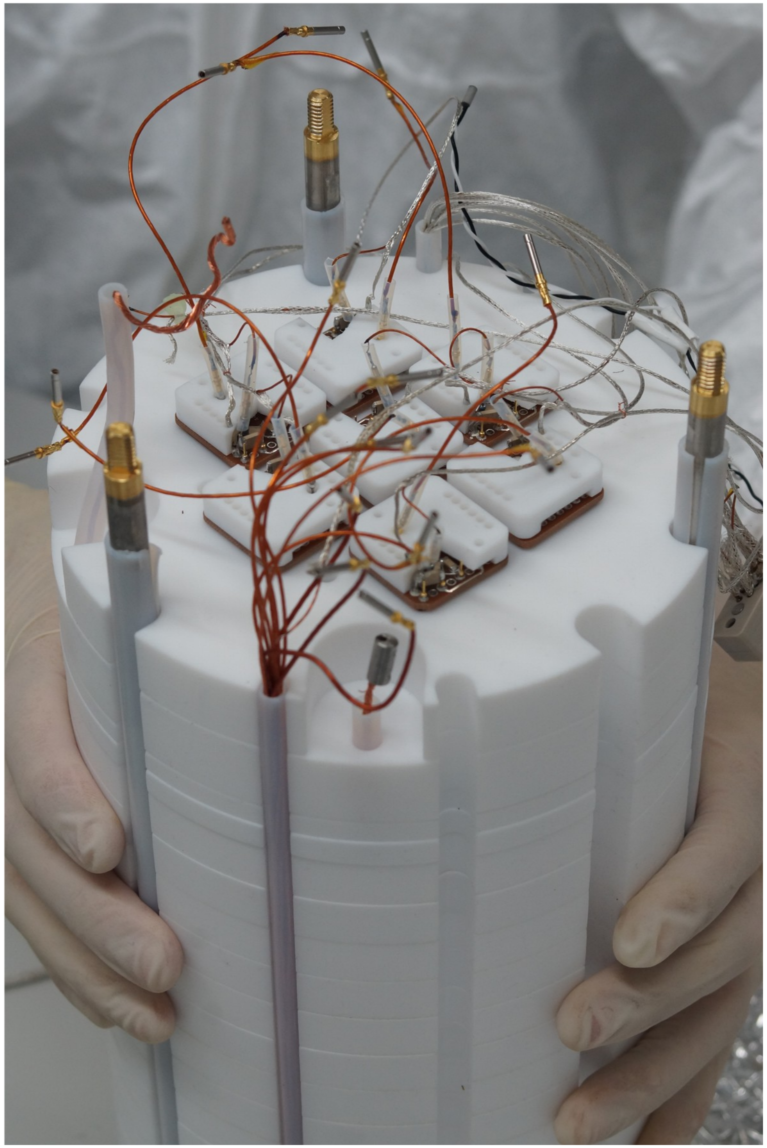

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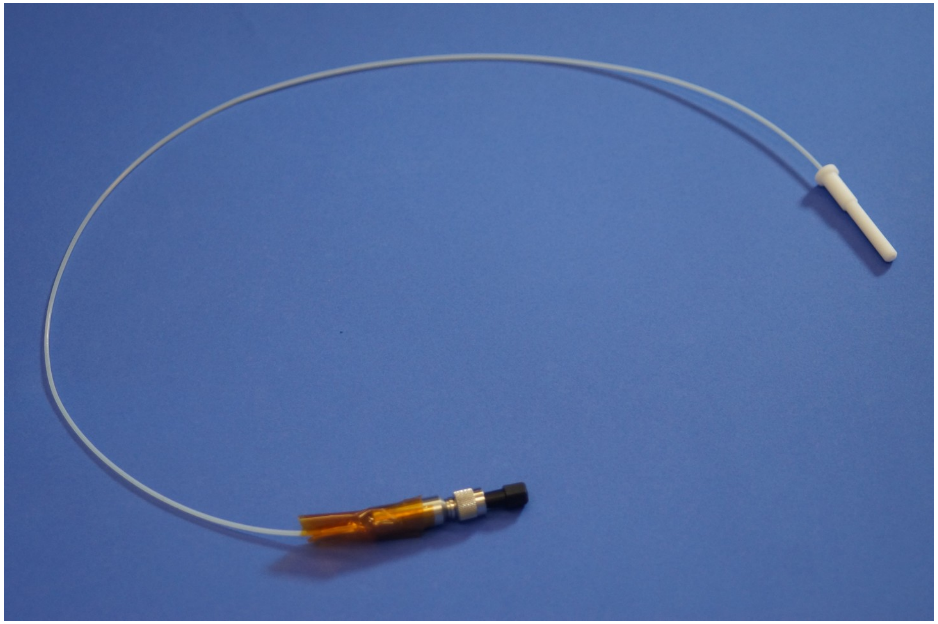


Photomultiplier tube (PMT)

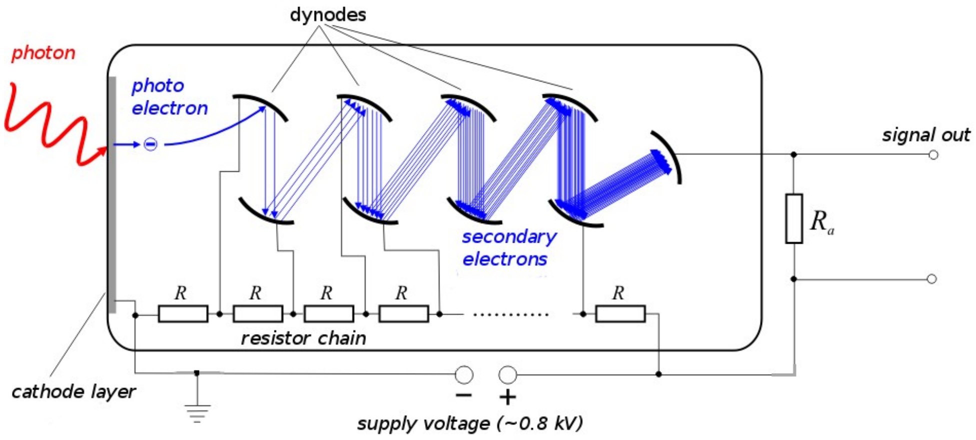
- Emission of electrons due to the photoelectric effect
- Bialkali compounds as cathode material for high quantum efficiency (30% at 175nm)

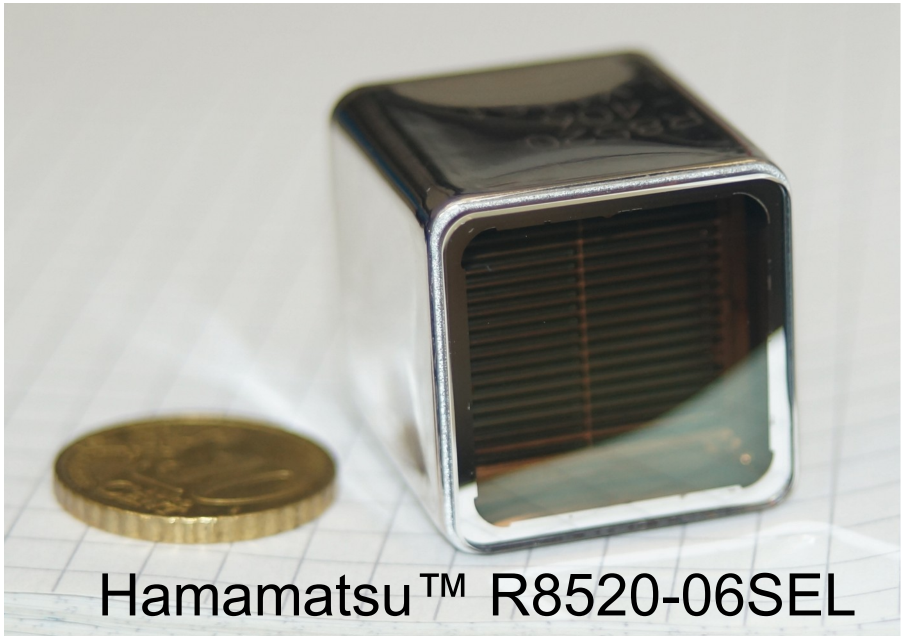
$$\text{Q.E.} = \frac{n_{\text{detected photons}}}{n_{\text{incoming photons}}}$$

- Multiple dynodes (10) with high secondary electron emission coefficient (gain)

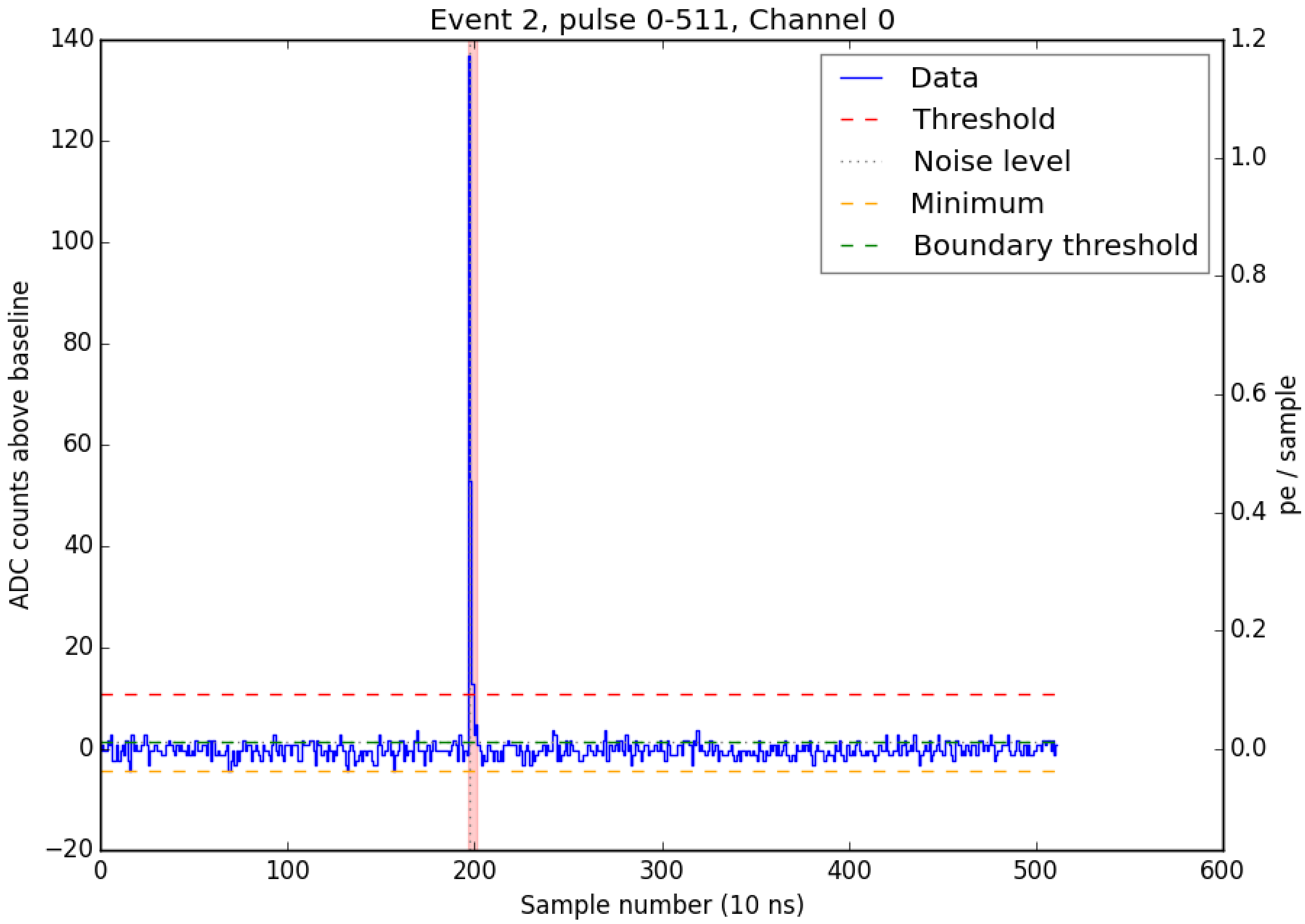
$$\text{gain} = \frac{N \cdot e_{\text{detected}}}{e_{\text{photo}}} \approx 2 \cdot 10^6 \text{ @ } 800\,\text{V}$$

- High time resolution (O(1ns))

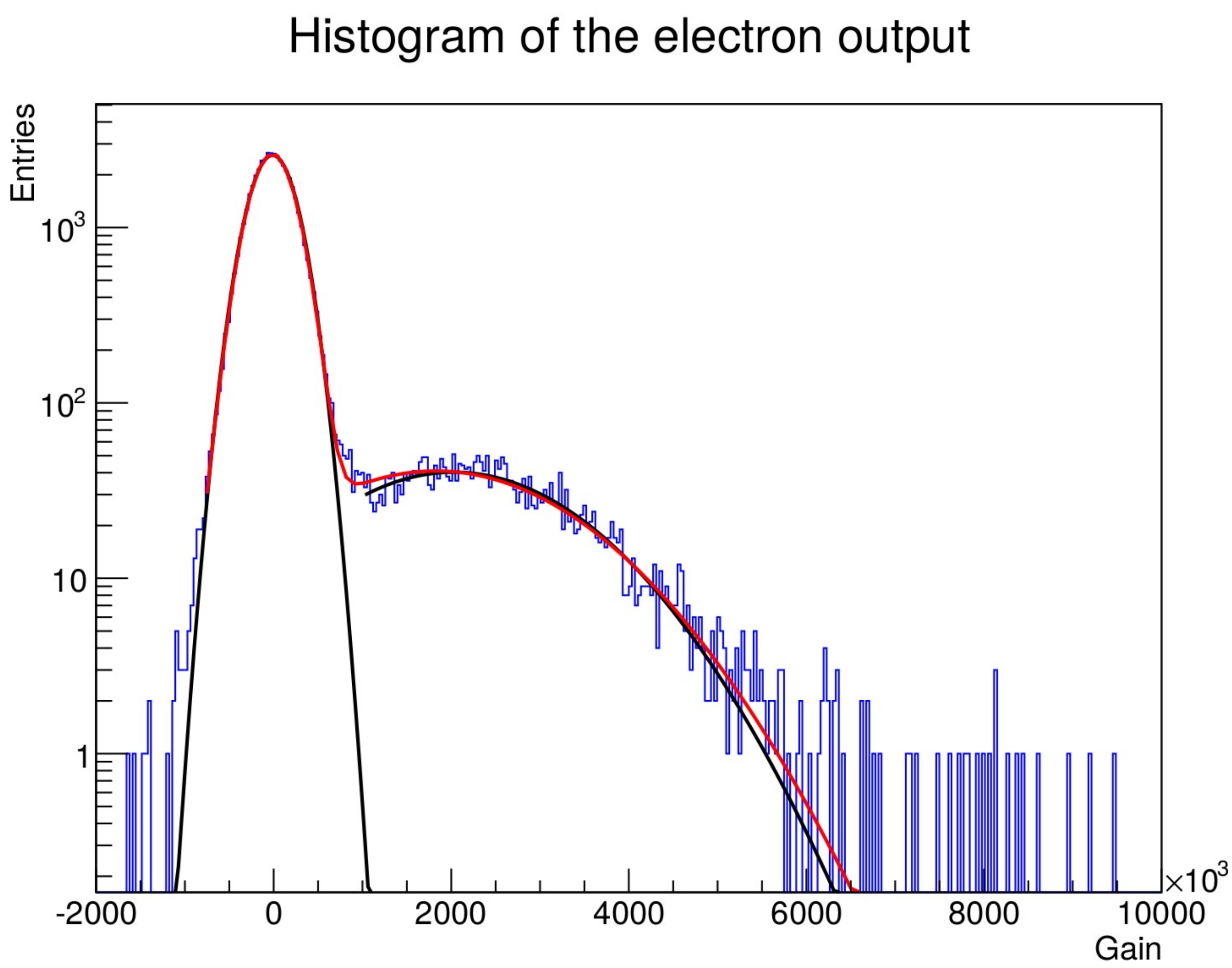




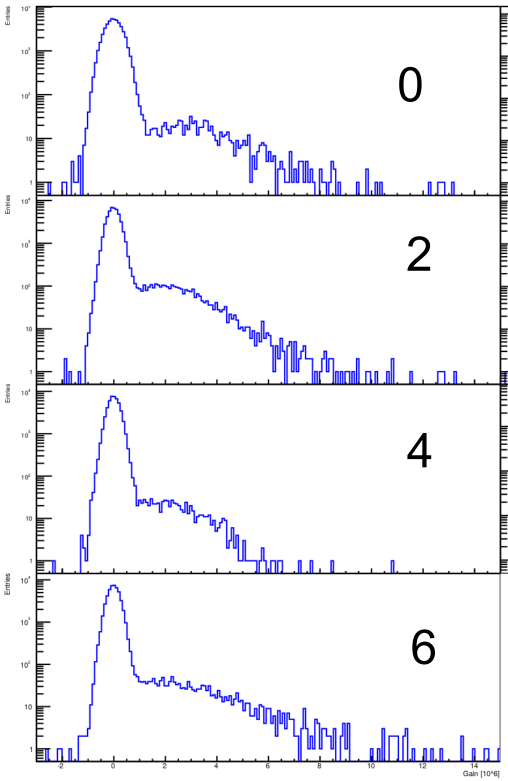
Gain calibration

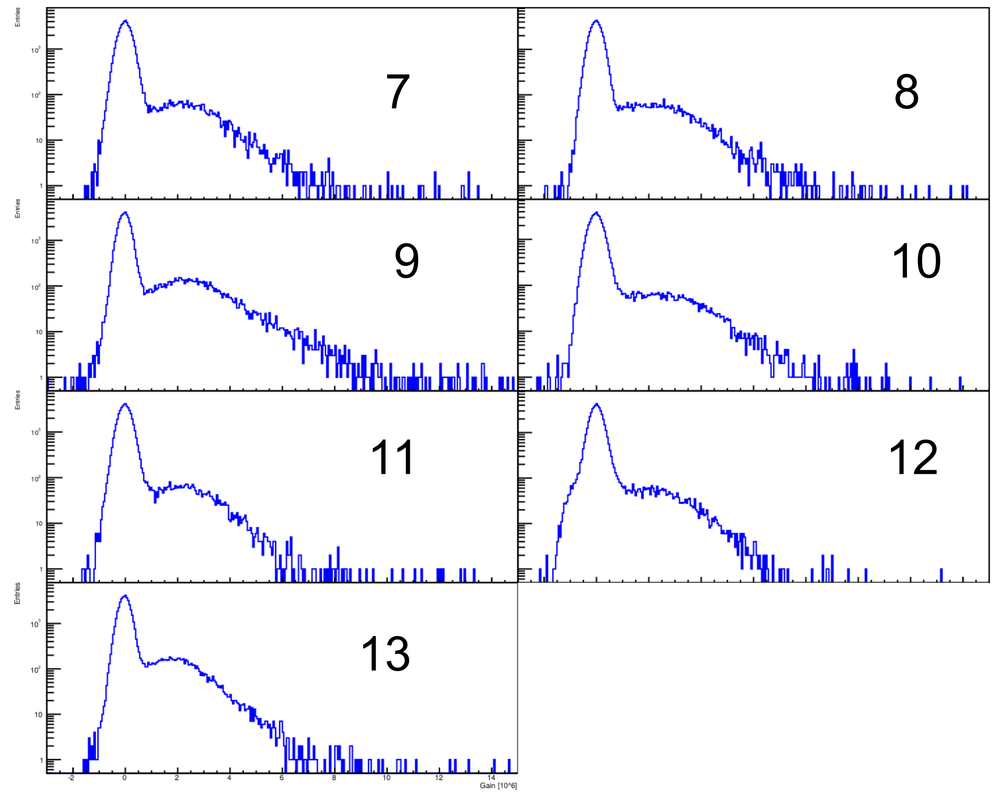


Gain calibration



Credit: Julian Blanke





Credit: Julian Blanke

Conclusion and outlook

- Experimental TPC in Münster for developing new techniques large TPCs might benefit from
- Gain calibration of PMTs at room temperature with external LED

Outlook:

  - Refill the TPC after upgrade

→ Measurements and analysis:

  - Investigate S2/S1 signal ratio with different drift fields
  - 3D reconstruction
  - Characterize detector and compare it to Monte Carlo simulation (GEANT4)
  - Internal and external energy calibration

Thanks for your attention

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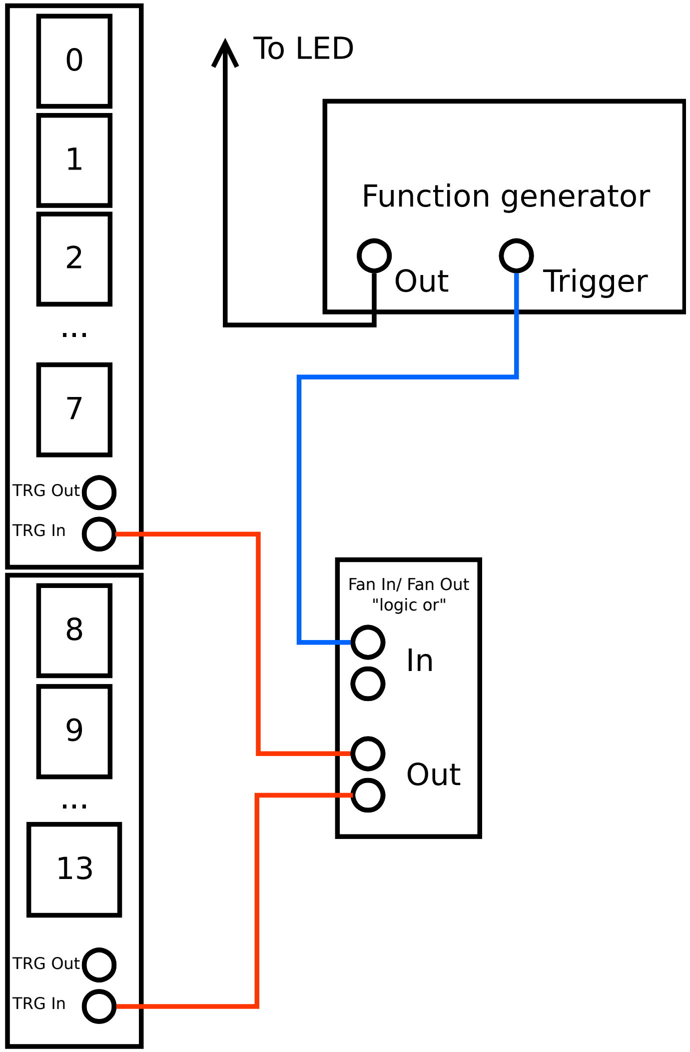
Data Acquisition (DAQ)

- Data Acquisition by 2 CAEN1724© flash ADCs with FPPDAQ
- Trigger via external function generator or internal threshold
- Zero length encoding (ZLE) limits the amount of raw data
- Data structure:
  - – Event: contains for each channel one waveform
  - – Waveform: list of ADC samples



Scintillation of xenon

- Excitation or ionization of Xe atoms

Excitation:

$$\chi + \mathrm{Xe} \rightarrow \chi + \mathrm{Xe}^*$$
$$\mathrm{Xe}^* + \mathrm{Xe} + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^* + \mathrm{Xe}$$
$$\mathrm{Xe}_2^* \rightarrow 2\mathrm{Xe} + h\nu$$

Ionization:

$$\chi + \mathrm{Xe} \rightarrow \mathrm{Xe}^+ + \mathrm{e}^- + \chi$$
$$\mathrm{Xe}^+ + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^+$$
$$\mathrm{Xe}_2^+ + \mathrm{e}^- \rightarrow \mathrm{Xe}^{**} + \mathrm{Xe}$$
$$\mathrm{Xe}^{**} \rightarrow \mathrm{Xe}^* + \mathrm{heat}$$
$$\mathrm{Xe}^* + \mathrm{Xe} + \mathrm{Xe} \rightarrow \mathrm{Xe}_2^* + \mathrm{Xe}$$
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S1 signal

Not available due to extraction!
→ S2 signal

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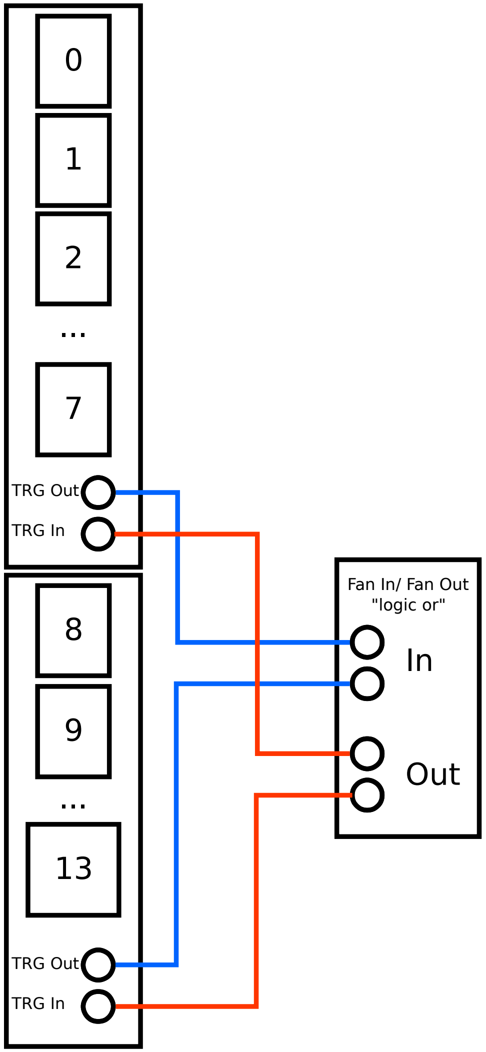
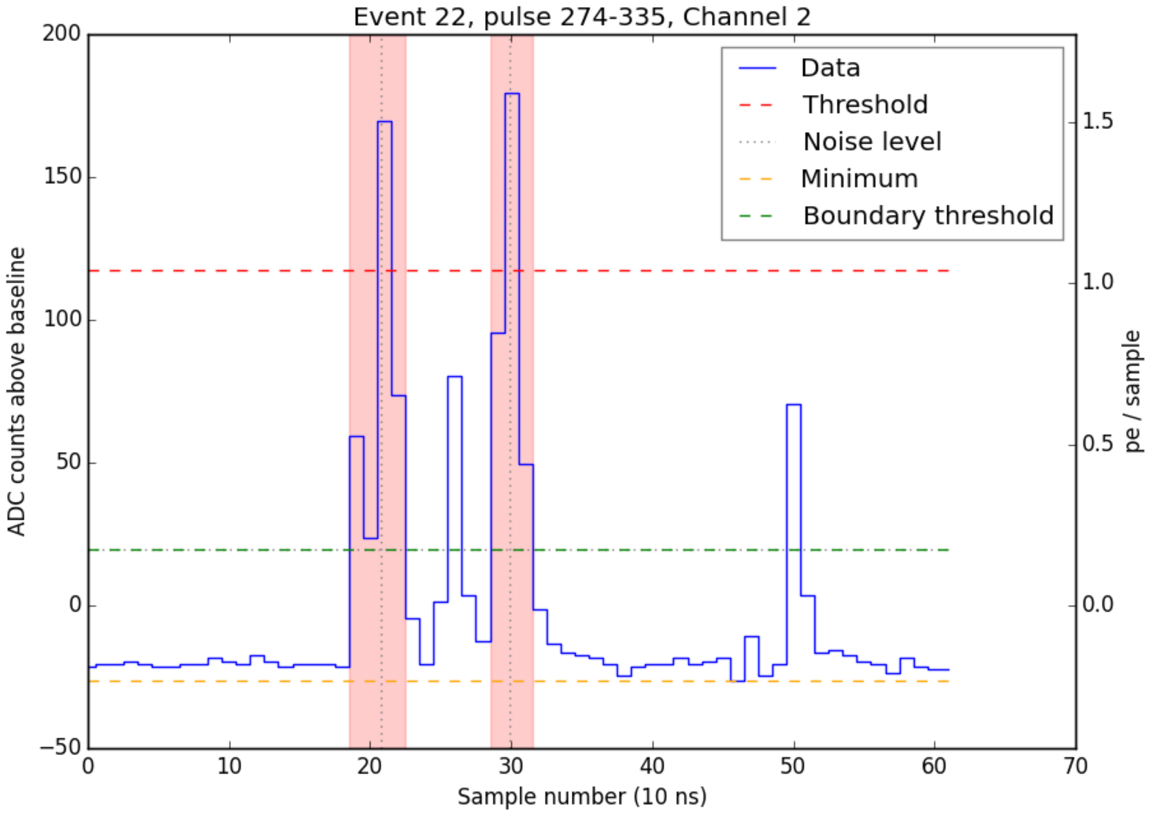


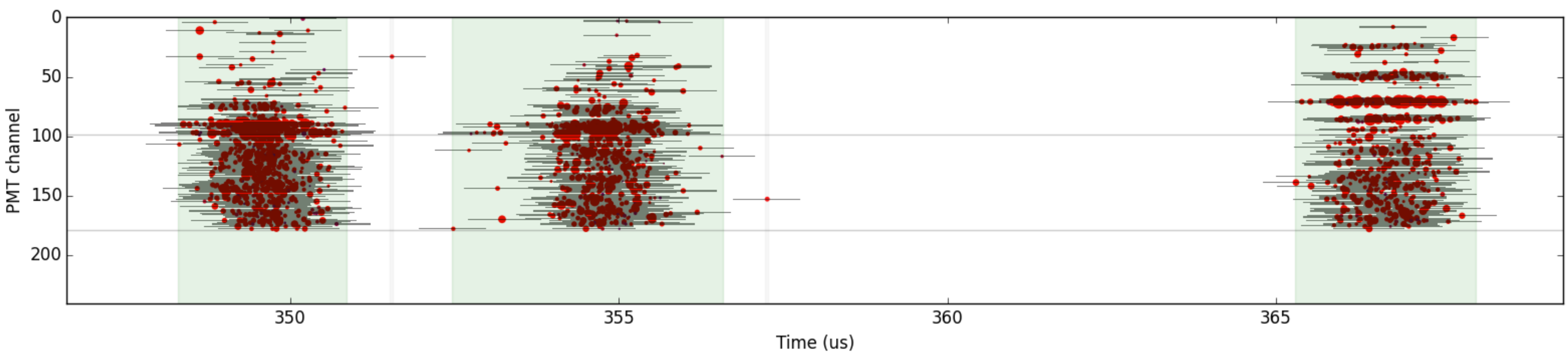
Hitfinding

- Hitfinding: a different approach as in Xerawdp
- Hit: signal over a given threshold of about 4-8 sigma above baseline for each individual channel



Clustering and Peak processing

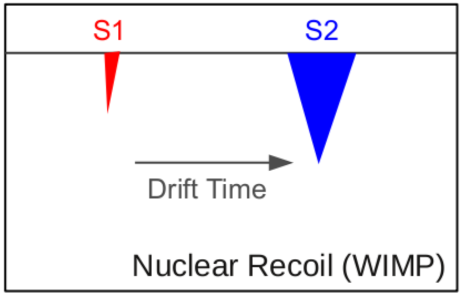
- Coincidental hits are classified into peaks via a clustering plug-in
  - Peak as a sum of all contributing hits (witness)
- Clustering is followed by calculation of peak properties (>20):
  - Height
  - Area
  - Left and right boundary
  - n_contributing_channels

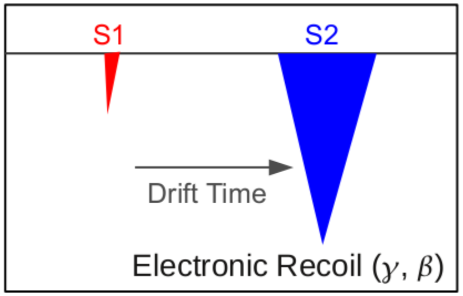


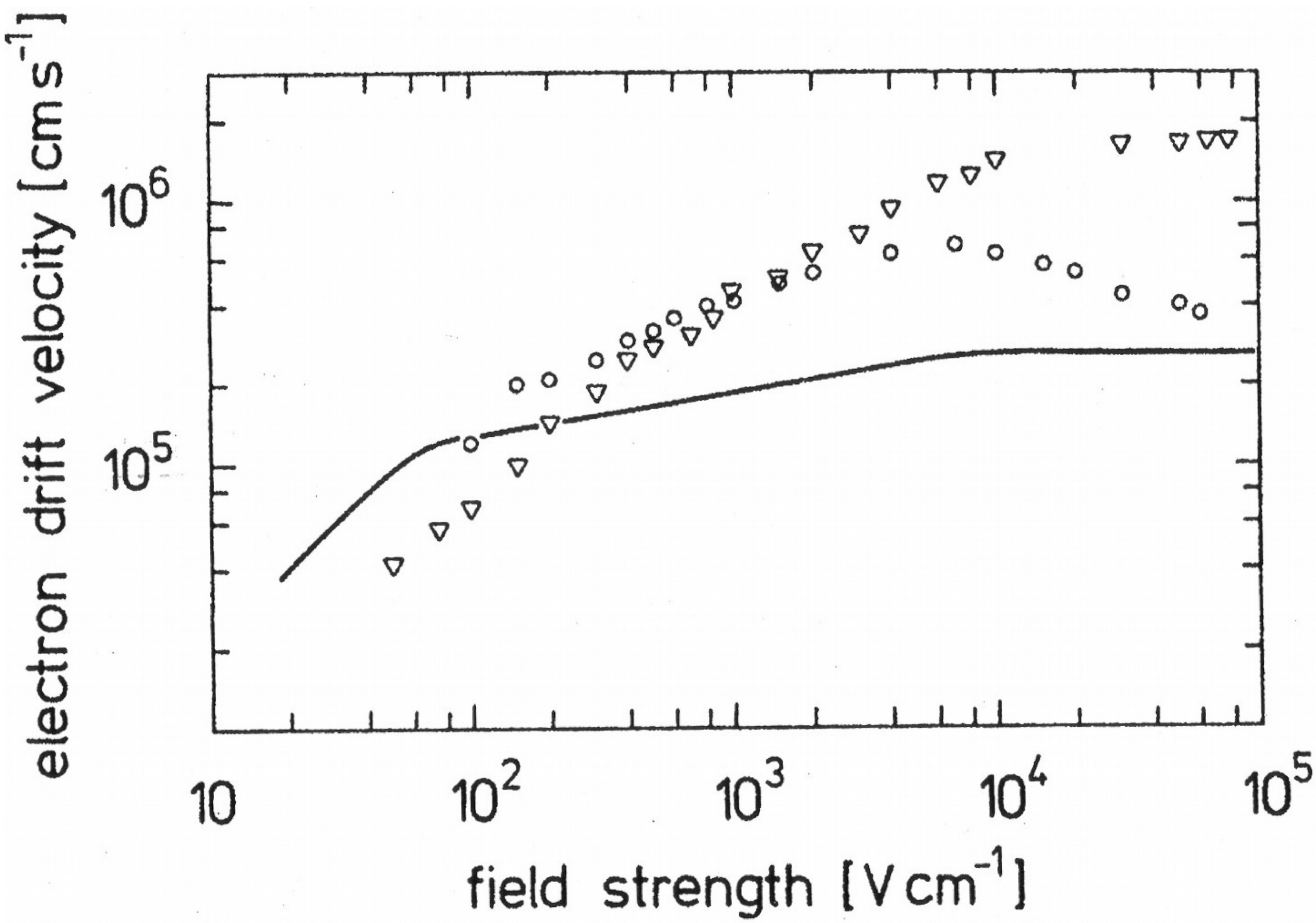
Distinction of electronic or nuclear recoil signal

- Excitation or Ionization dependent on primary signal
- Electronic recoil:
  - Relatively more Ionization → High S2/S1 signal ratio
- Nuclear recoil:
  - Less Ionization → Low S2/S1 signal ratio

→ Particle identification






electron drift velocity [cm s^{-1}]
10^6
10^5
10
10^2
10^3
10^4
10^5
field strength [V cm^{-1}]

Properties of xenon

- Xenon as liquid scintillator (178nm wavelength)
- Heaviest non-radioactive noble gas (atomic number: 54)

  $\rightarrow$ WIMP cross section increases with A^2

  $\rightarrow$ High self-shielding
- Low activity of radioactive isotopes
- Relatively equal abundance of even and odd isotopes

  $\rightarrow$ detection of spin-dependent interactions possible
- Easy cryogenics (-100° C)
- As a liquid easily scalable