Westfälische Wilhelms-Universität Münster

The Dual-Phase Liquid Xenon Time Projection Chamber (TPC) of Münster

Calibration and Safety Aspects

Schule für Astroteilchenphysik 2017

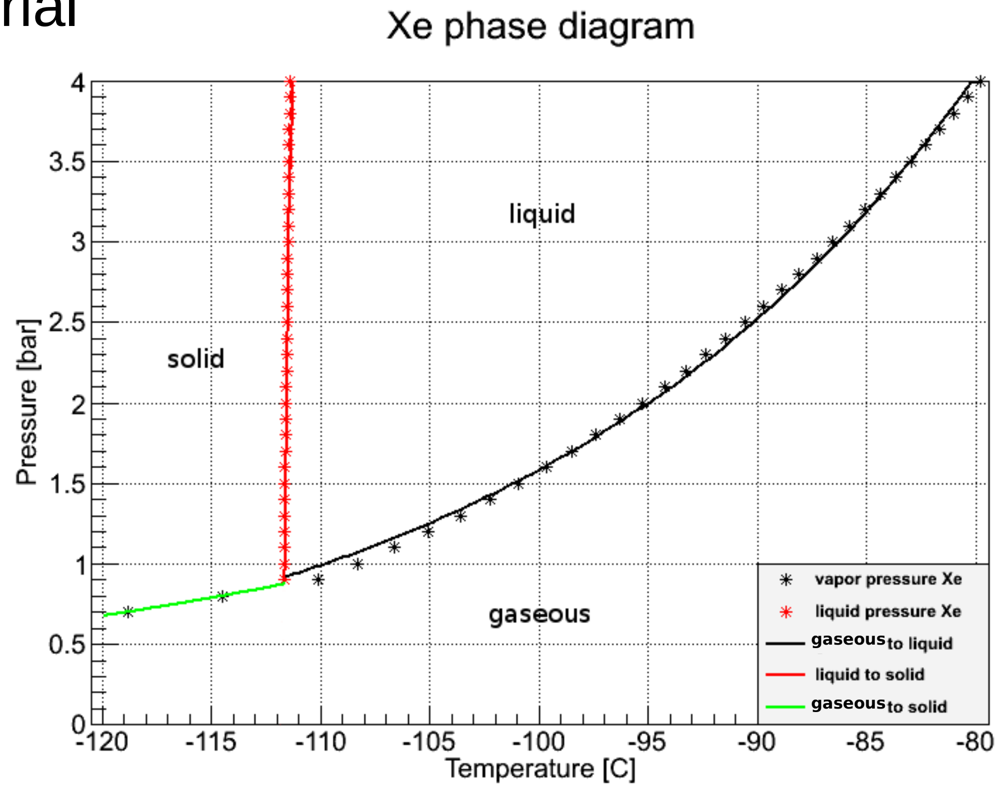
Kevin Gauda – 10.10.2017

wissen.leben
WWU Münster

Properties of Xenon as Detector Material

- Noble gas characterized by:
  - High atomic number **Z = 54**
  - Atomic weight **Ā = 131.30 u**
  - Density (liquid xenon) $\boldsymbol{\rho_{LXe}}$ **= 3 g/cm³**
  - Boiling point -108.1 °C (1 bar)
  - Freezing point -111.8 °C (1 bar)

    → **Operation at -100 °C, 2 bar**
- Transparent to own scintillation light
- Self-shielding
  (absorption of higher energy photons)
- Bad news: Xenon is expensive!



Signal Generation with Xenon

- Processes after interaction:
  - **Excitation**
  - **Ionization**
    - Generation of ions and **free electrons**
  - Heat
- Emission of 178 nm scintillation light

Excitation process:

$$Xe^{*} + Xe + Xe \rightarrow Xe_2^{*} + Xe$$

$$Xe_2^{*} \rightarrow 2\,Xe + h\nu$$

Ionization process:

$$Xe^{+} + Xe \rightarrow Xe_2^{+}$$

$$Xe_2^{+} + e^{-} \rightarrow Xe^{**} + Xe$$

$$Xe^{**} \rightarrow Xe^{*} + heat$$

$$Xe^{*} + Xe + Xe \rightarrow Xe_2^{*} + Xe$$

$$Xe_2^{*} \rightarrow 2\,Xe + h\nu$$

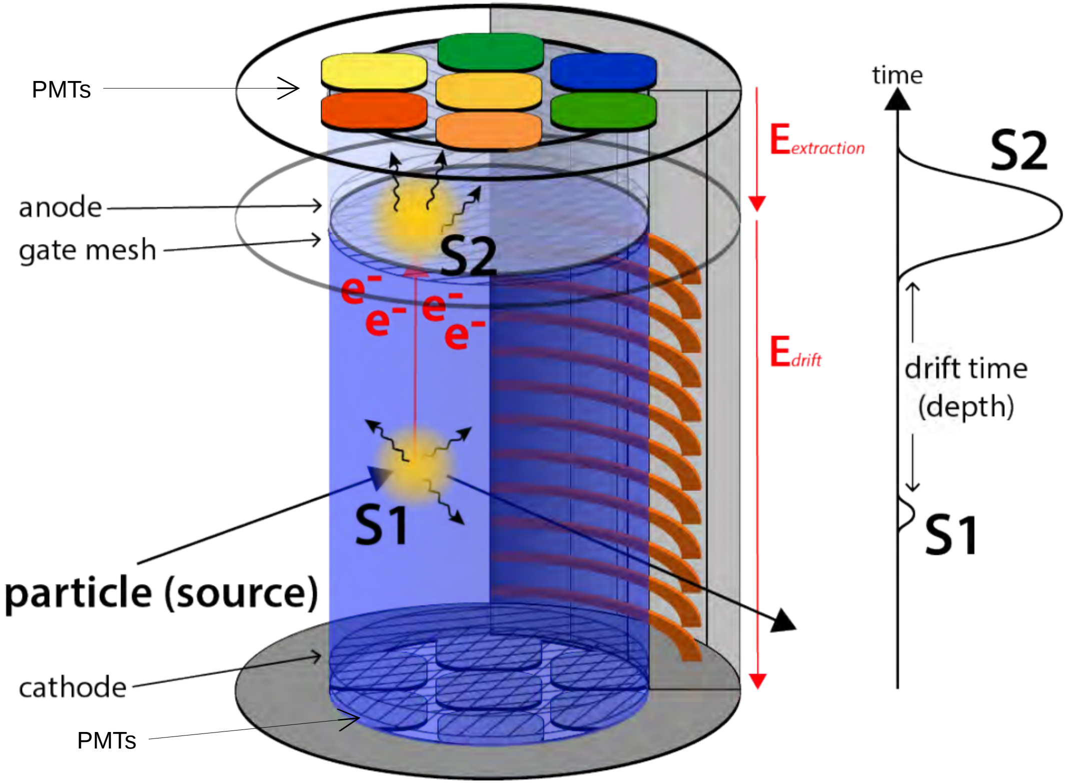
Working principle of Dual-Phase Liquid Xenon TPCs

- Two electric fields between cathode, gate and anode
- Top and bottom PMTs detect light
- Signal generation:

→ Incoming particle

→ S1 signal:
Xe-dimers are created via **excitation and ionization → light emission**

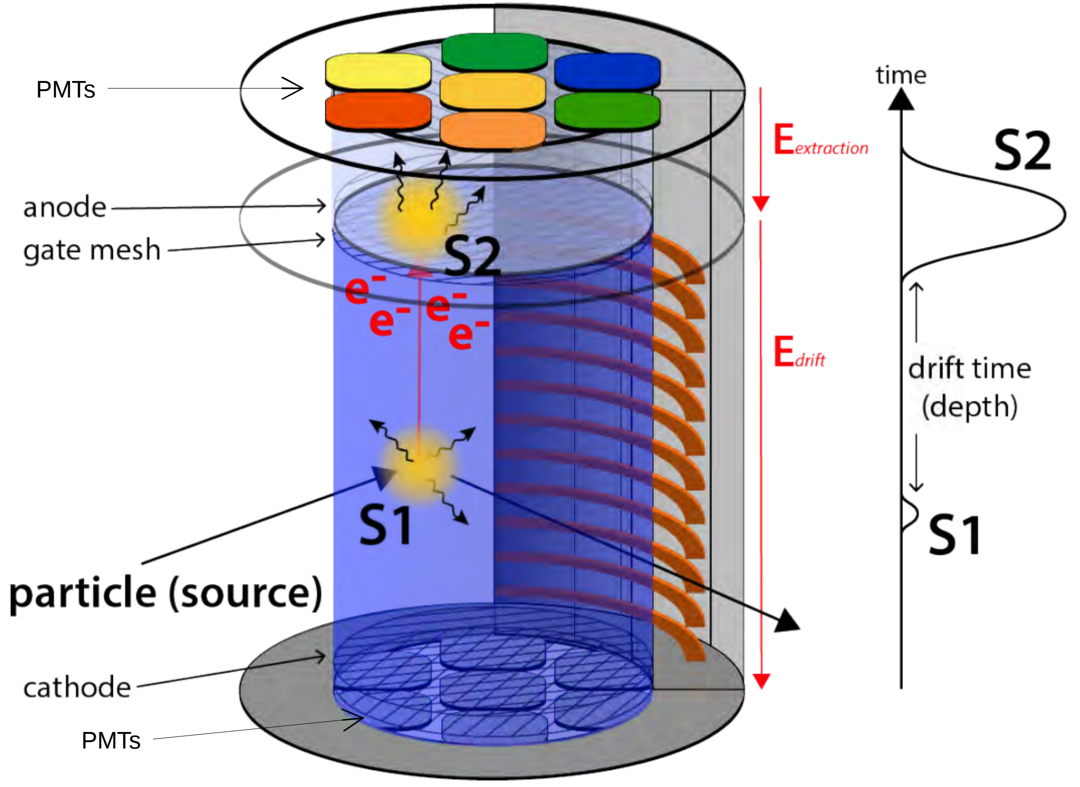
→ S2 signal:
Electrons are drifted to gate via E_{drift} and extracted via $E_{extraction}$ → **light emission via electrolumniscence**



L. Althüser, *GEANT4 simulations of the Muenster dual phase xenon TPC*, Bachelor thesis, 2015

Working principle of Dual-Phase Liquid Xenon TPCs

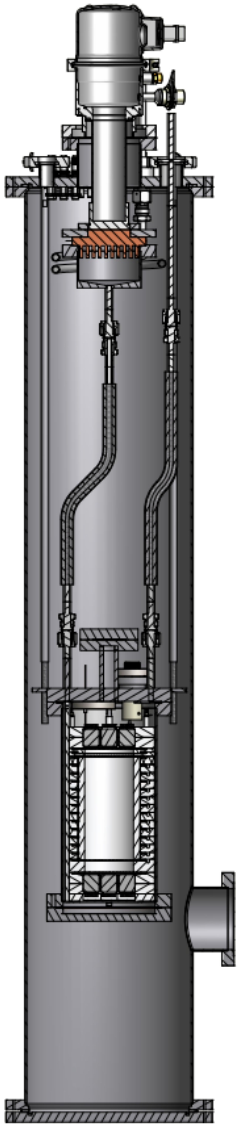
- S1: mainly seen by bottom PMTs
- S2: mainly seen by top PMTs
- Energy reconstruction by using anti-correlated S1 and S2
  - Coincidence determination & correct energy estimation only with low concentration of e.g. O_2, H_2O, ...
- **3d position reconstruction**
  - z: S1-S2 time difference & electron drift velocity → drift length
  - xy: hit pattern of PMTs



L. Althüser, *GEANT4 simulations of the Muenster dual phase xenon TPC*, Bachelor thesis, 2015

Design of the Münster TPC

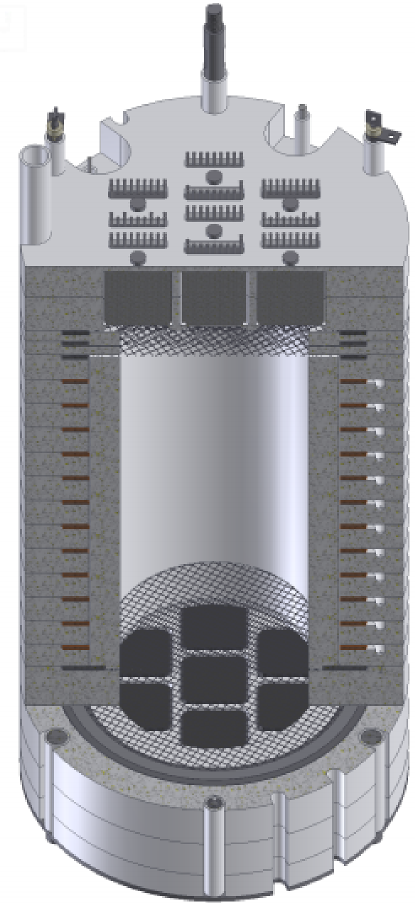
- Designed originally for monitoring purity of XENON1T
- **Xenon filling** by guiding xenon gas slowly into cryostat
  - Gaseous xenon cooled to -100°C by coldhead → **liquefaction**
- Vacuum vessel for **thermal insulation** (high vacuum)
- **Gas circulation** through hot zirconium **getter** by **pump** → reduce electronegative impurities



J. Schulz, *Design of a 2-Phase Xenon Time Projection Chamber for Electron Drift Length Measurement*, Diploma thesis, 2011

Design of the Münster TPC – Basic Design

- **Diameter 8 cm**,
  height 17 cm (i.e. drift length)
- Maximum **mass of 2.6 kg xenon**
- Cylindrical polytetraflourethylene (**PTFE**) container
  - Highly reflective
  - Fitting high purity demands
  - Low electric field distortion by PTFE ($\varepsilon_{r,\ LXe} = 1.88$; $\varepsilon_{r,\ PTFE} = 2.1$)
- 14 Hamamatsu R8520-06-Al 1 **PMTs** (same as XENON100)



J. Schulz, *Design of a 2-Phase Xenon Time Projection Chamber for Electron Drift Length Measurement*, Diploma thesis, 2011

Design of the Münster TPC – Basic Design

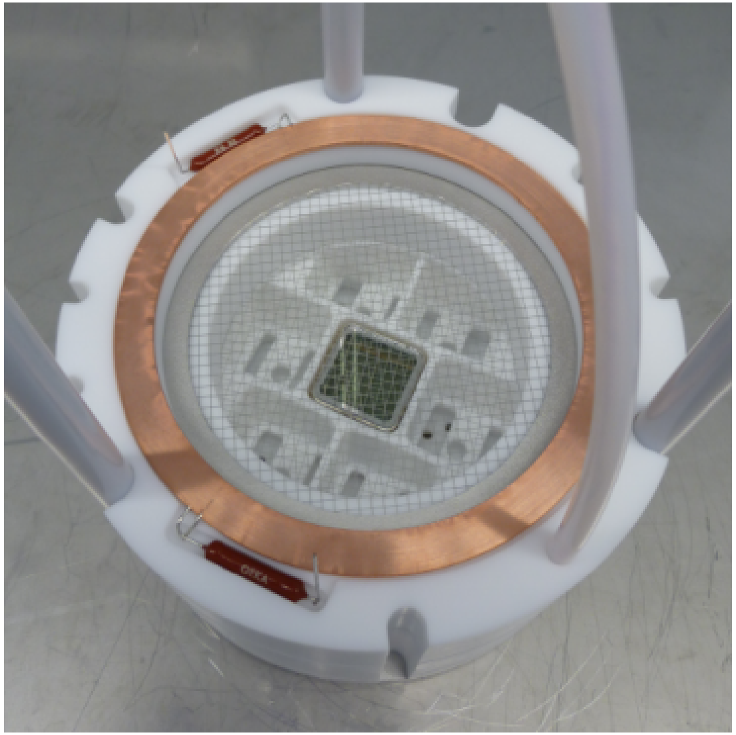
- **Diameter 8 cm**,
  height 17 cm (i.e. drift length)
- Maximum **mass of 2.6 kg xenon**
- Cylindrical polytetraflourethylene (**PTFE**) container
  - Highly reflective
  - Fitting high purity demands
  - Low electric field distortion by PTFE ($\varepsilon_{r,\ LXe}$ = 1.88; $\varepsilon_{r,\ PTFE}$ = 2.1)
- 14 Hamamatsu R8520-06-Al 1 **PMTs** (same as XENON100)

J. Schulz, *Design of a 2-Phase Xenon Time Projection Chamber for Electron Drift Length Measurement*, Diploma thesis, 2011

Design of the Münster TPC – Electric Field Design

- High Voltage:
  - Cathode: -8.5 kV (i.e. E_{drift} = 0.5 kV/cm)
  - Anode: 2.5 kV (i.e. $E_{extraction}$ = 5 kV/cm)
  - Annular electrodes for improved field homogenity
- Electric fields in xenon:
  - **Electron extraction yield** dependent on field strength (Münster TPC: ~70 %)
  - **Electron drift velocity** dependent on field strength (Münster TPC: < 2 mm/μs)

→ Increased electric field feasible!



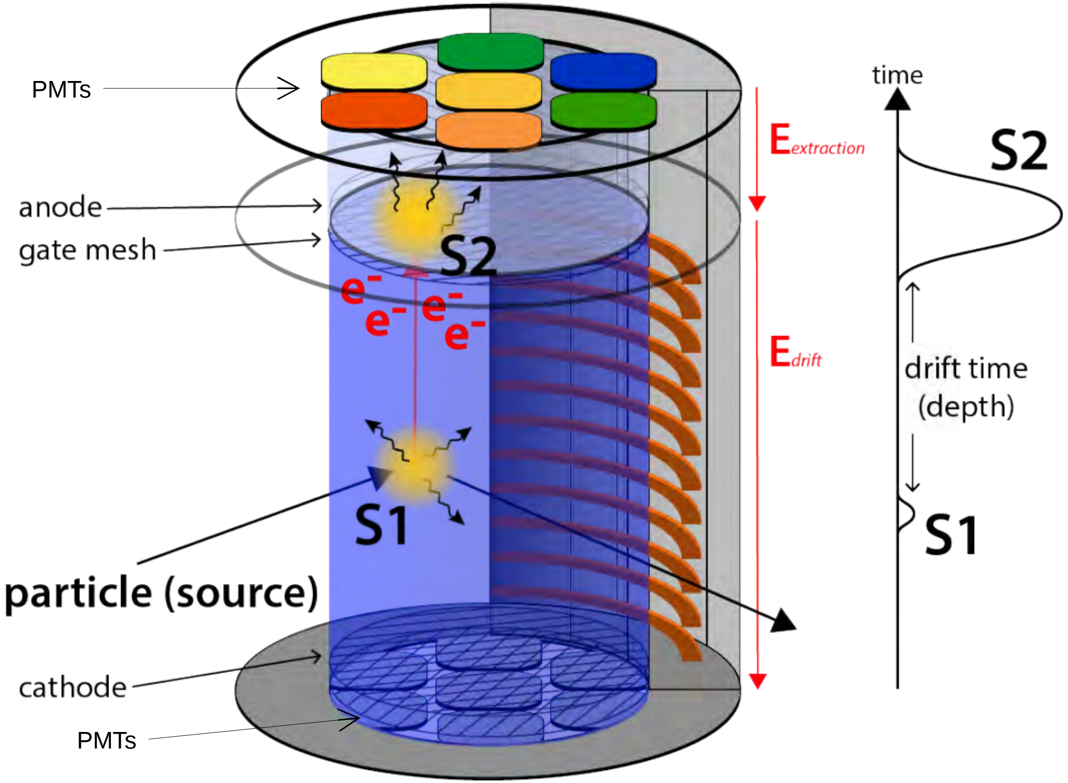
J. Schulz, *Design of a 2-Phase Xenon Time Projection Chamber for Electron Drift Length Measurement*, Diploma thesis, 2011

Design of the Münster TPC – Filling Height

- Importance of **liquid level**:
  - Electron extraction efficiency dependent on field strength
  - Field strength highest between gate and anode

    → **Highest signal rate there!**

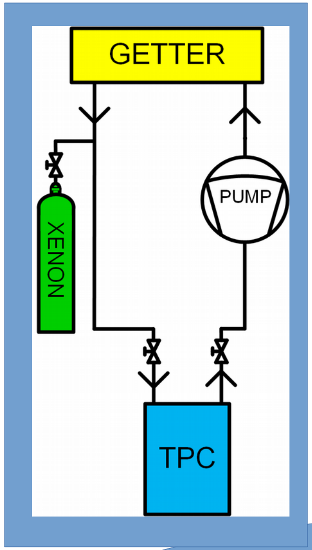
    → Current project!
- Level meters
  - Cylindrical capacitors from bottom to top of TPC
  - Change of filling height
    → change of capacity: $\Delta C \propto \Delta \epsilon_r$



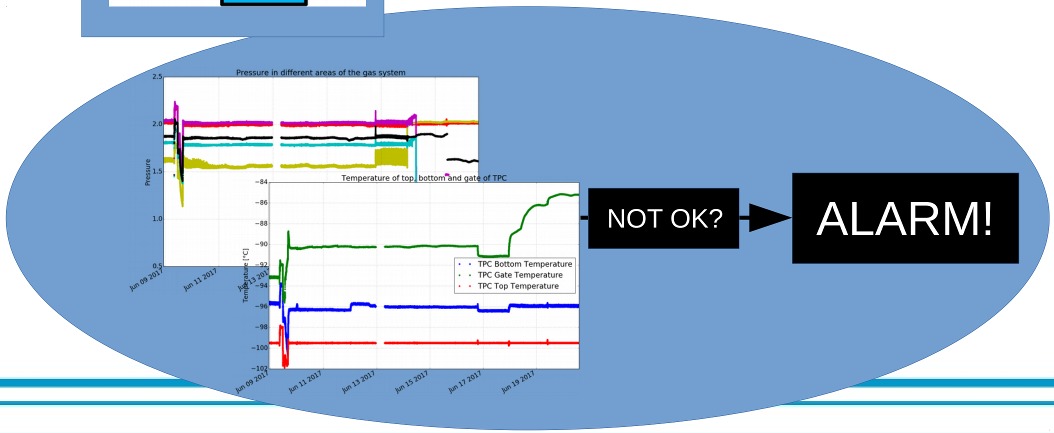
D. Schulte, *Capacitance-Based Levelmeter Read-Out for the Münster Dual Phase Xenon Time Projection Chamber*, Bachelor thesis, 2016

Design of the Münster TPC – Critical Devices

- Gas system
  - Pressure in TPC limited by **rupture disc**
  - Prevent **blocking of pump**
- Slow Control
  - Monitoring **temperature, pressure, high voltage, gas flow** cia LabView cRIO system
  - Sends out **mail and SMS alarms**, if certain parameters out of range
  - Shifters: Manual protocolling of certain parameters and device states
- Emergency prevention
  - Uninterruptible power supply

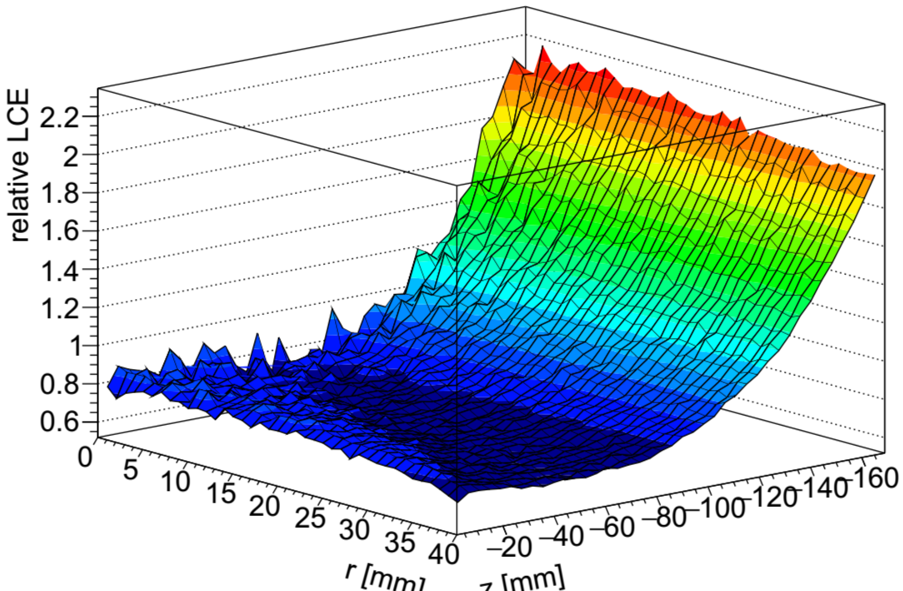


Shifter	Date	Stability	Liq N2	…	Sign
Michael	2017-10-02	ok	ok		mm
Alex	2017-10-09	P2 oscill.	ok		af
Kevin	2017-10-16	ok	Refill!		kg
…					



Light Collection Efficiency (LCE), Electron Lifetime (EL), Light Yield (LY)

- **LCE**: S1 generation not homogenous, as shown by LCE map
  - Deeper generated S1 are bigger
- **EL:** Electrons catched by impurities (e.g. O_2)
  - S2 from deeper S1 events are smaller
- **LY**: Assigned energy per *pe*
- Use **Kr-83m** source for calibration
  - Energy of 32.2 keV and 9.4 keV (with 156 ns delay) → see talk of M. Wigard (4e)



Simulated LCE map for 7 eV photons measured with bottom PMTs

L. Althüser, *GEANT4 simulations of the Muenster dual phase xenon TPC*, Bachelor thesis, 2015

Outlook

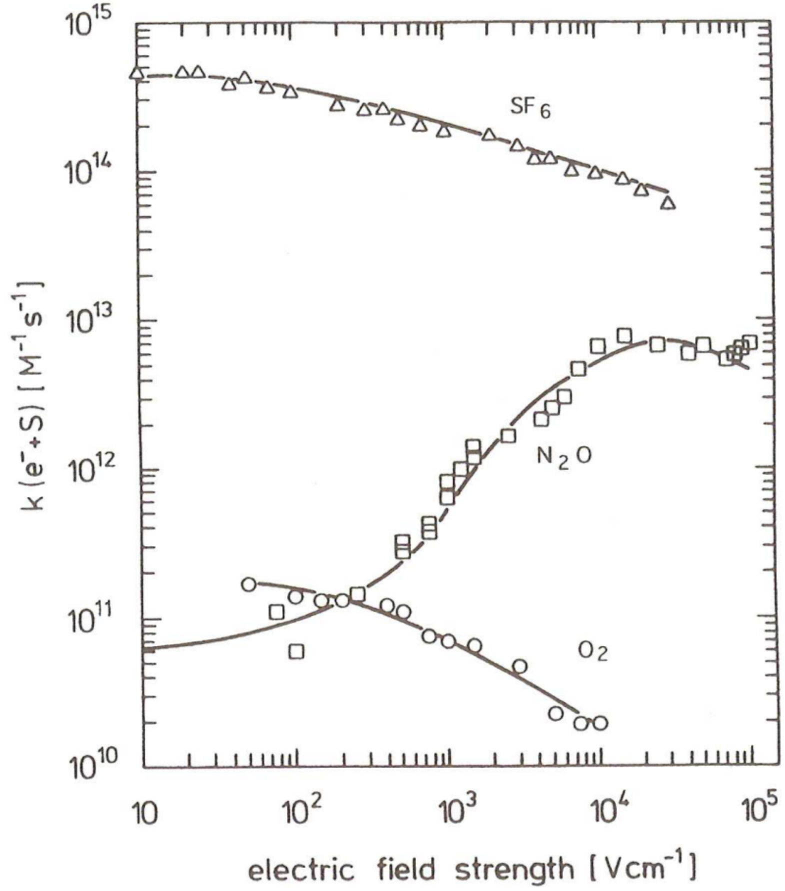
- Safety enhancement
- Liquid level adjustment
- Energy calibration with Kr-83m
  - Light collection efficiency
    → S1 correction
  - Electron lifetime
    → S2 correction
  - Light yield
    → Corrected energy estimation
  - Use other sources (e.g. Cs-137 with 662 keV photons)

Thank you for your attention!

Backup

Purity Aspects – Electron lifetime

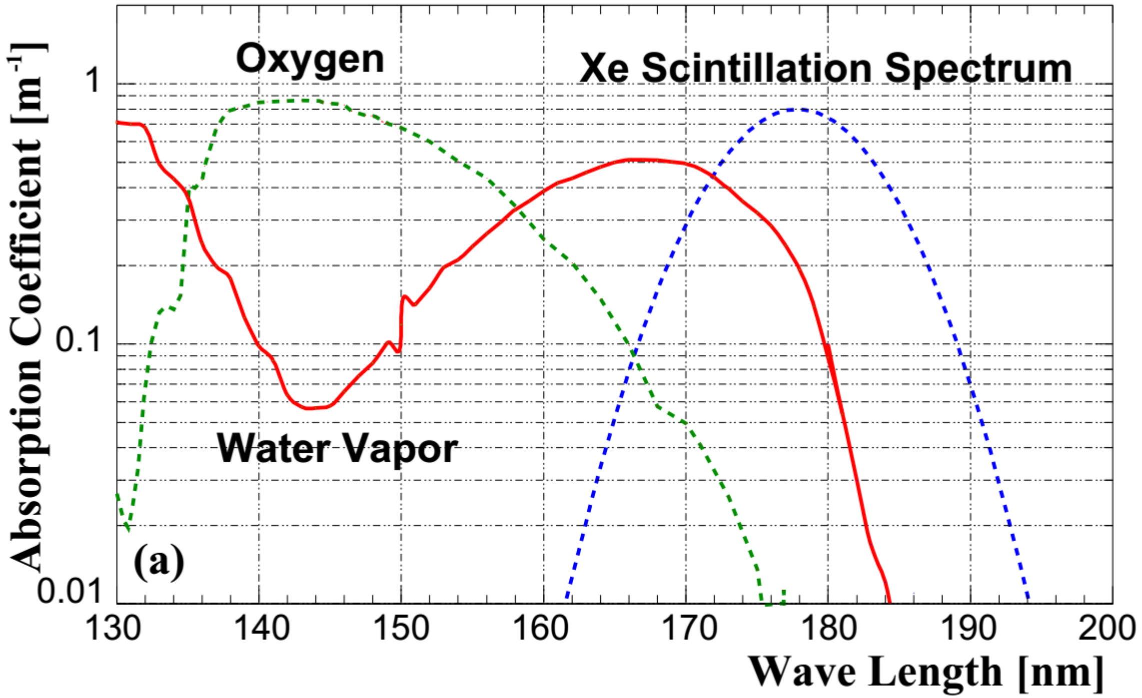
- Electron lifetime τ: mean time before attachement
- Electron attachement rate constant k dependent on field strength and impurity
- Exponential electron reduction by impurities: electronegative molecules, e.g. N_2O, O_2, ...
  - Purification by hot metal getter
  - XENON1T: $\tau \approx 450$ µs (mean)
  - Münster: electron lifetime not yet measured



E. Aprile, T. Doke, *Liquid Xenon Detectors for Particle Physics and Astrophysics*, 10.1103/RevModPhys.82.2053, 2009

wissen.leben WWU Münster

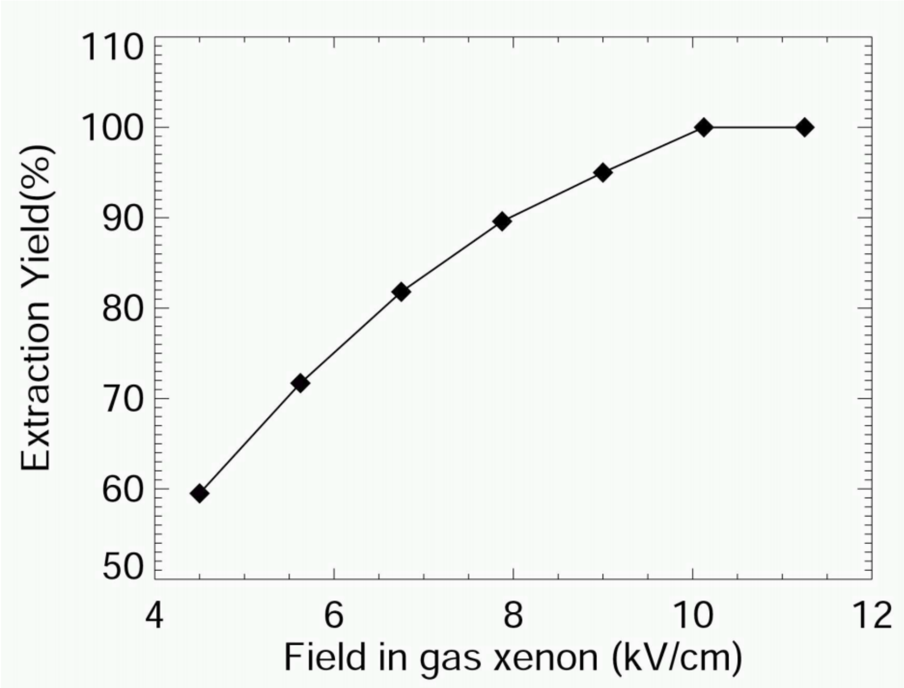
Purity Aspects – Photon absorption by impurities



E. Aprile, T. Doke, *Liquid Xenon Detectors for Particle Physics and Astrophysics*, 10.1103/RevModPhys.82.2053, 2009

Electric Fields in Xenon

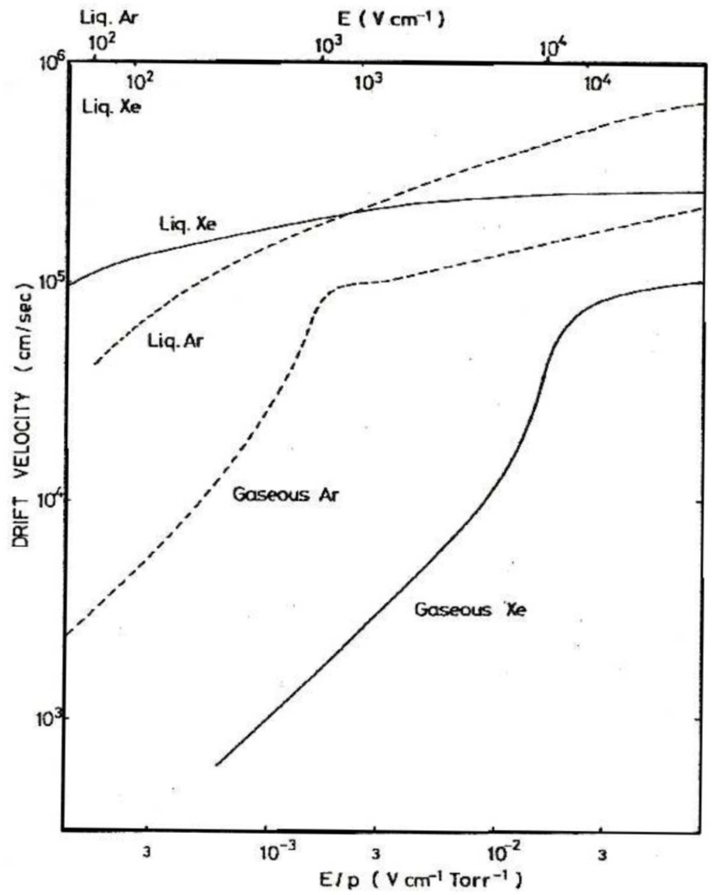
- Extraction yield of generated electrons from liquid to gaseous xenon dependent on field strength
  - 100 % at $E_{extraction} > 10$ kV/cm
- Electron drift velocity dependent on field strength
  - Saturation at 3-10 kV/cm



E. Aprile, T. Doke, *Liquid Xenon Detectors for Particle Physics and Astrophysics*, 10.1103/RevModPhys.82.2053, 2009

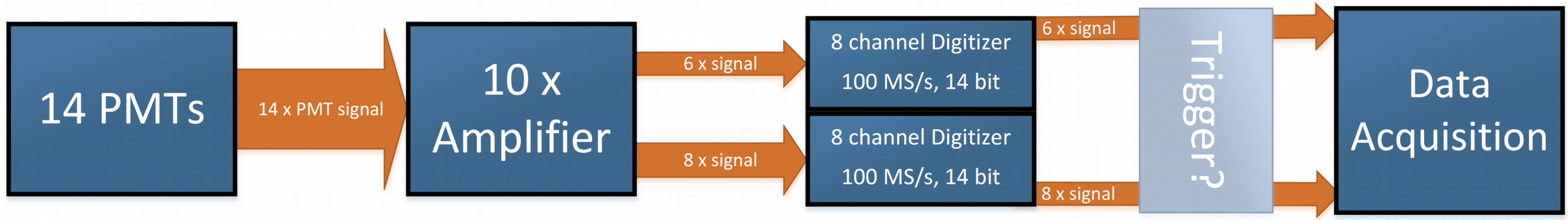
Electric Fields in Xenon

- Extraction yield of generated electrons from liquid to gaseous xenon dependent on field strength
  - 100 % at $E_{extraction} > 10$ kV/cm
- Electron drift velocity dependent on field strength
  - Saturation at 3-10 kV/cm



E. Aprile, T. Doke, *Liquid Xenon Detectors for Particle Physics and Astrophysics*, 10.1103/RevModPhys.82.2053, 2009

Signal Chain

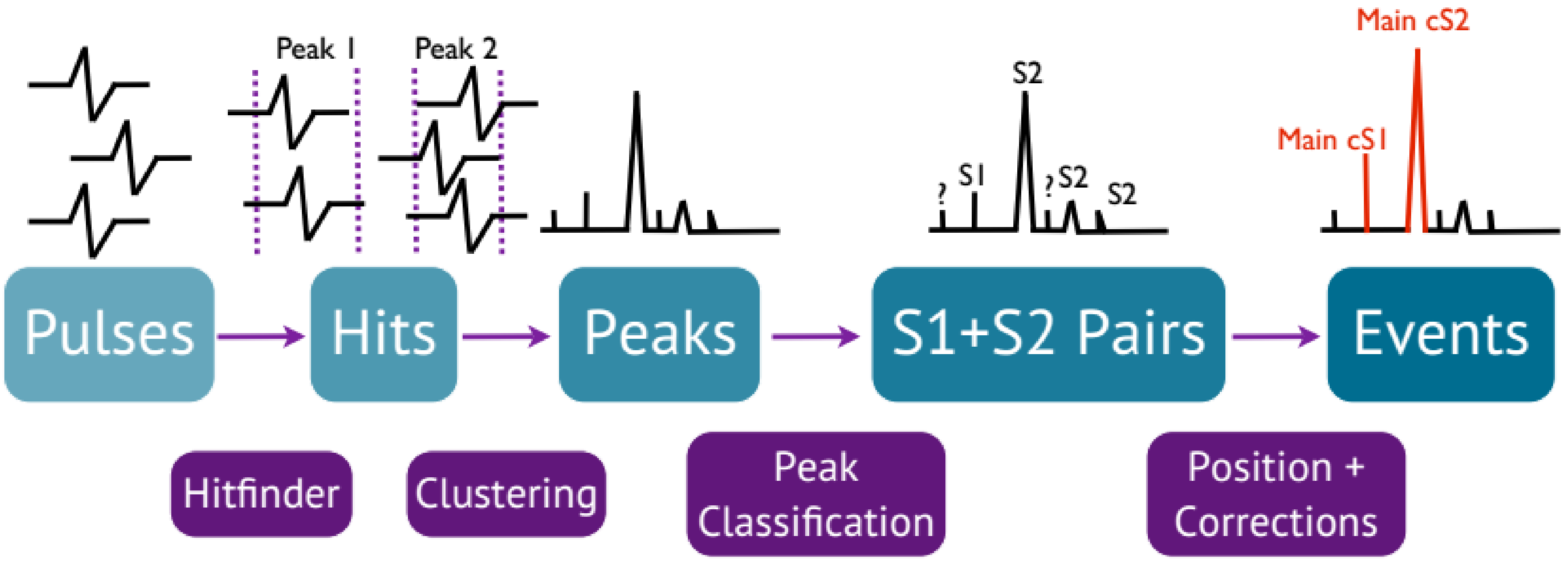


Trigger on S2-signals:

- Amplitude Threshold = 150 ADC (1.3 pe)
- Time threshold = 30 samples (300 ns)
- Recording of 2k samples after and 14k samples before trigger

Time:
1 sample ≈ 10 ns
1 Event contains 16k samples, i.e. 160 µs
Drift length: 17 cm; e^- drift velocity: 2 mm/µs
→ Maximum drift time ≈ 85 µs

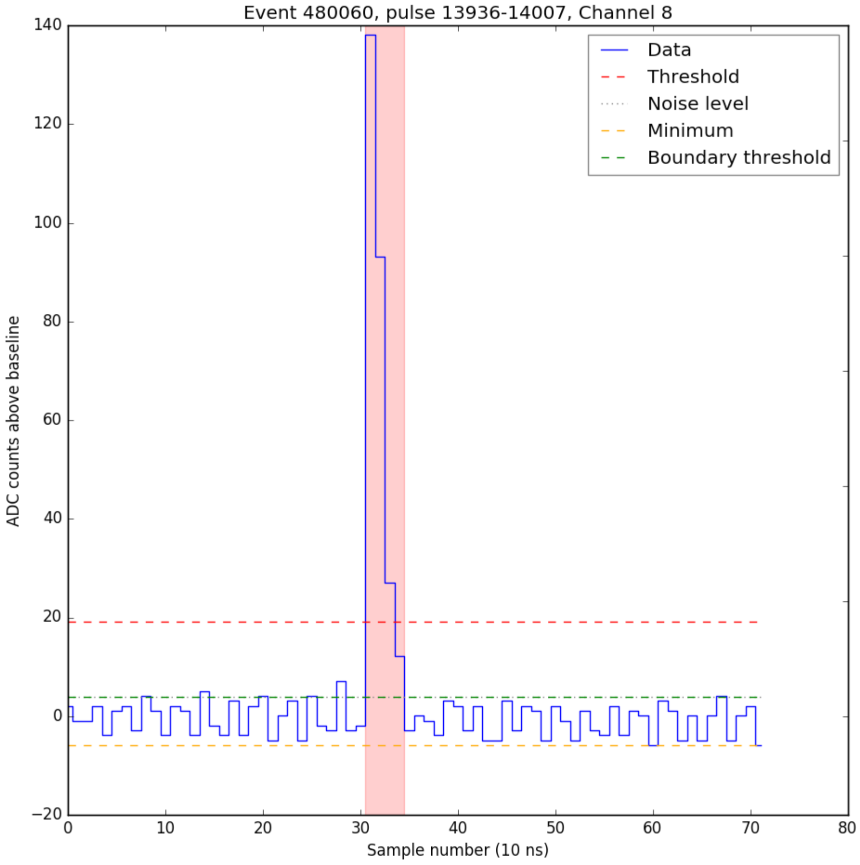
Processor for Analyzing XENON (PAX)



C. Wittweg, *XENON100 Dark Matter Search with the PAX Raw Data Processor for XENON1T*, Master thesis, 2016

Processor for Analyzing XENON (PAX)

- *Pulse* area needs 5 sigma over baseline to be declared as *hit*
- Coincident *hits* are summed to *peaks*
- If *lone hits* occur, channels are marked as suspicious (reduction of noise)
- *Peaks* are classified as
  - S1 (e.g. area < 50 pe, width < 100 ns)
  - S2 (e.g. area > 50 pe, width > 75 ns)
- S1 and S2 signals then get paired to *interactions* if S1 arrives before S2



Processor for Analyzing XENON (PAX)