Optical Properties of the Double Chooz scintillators

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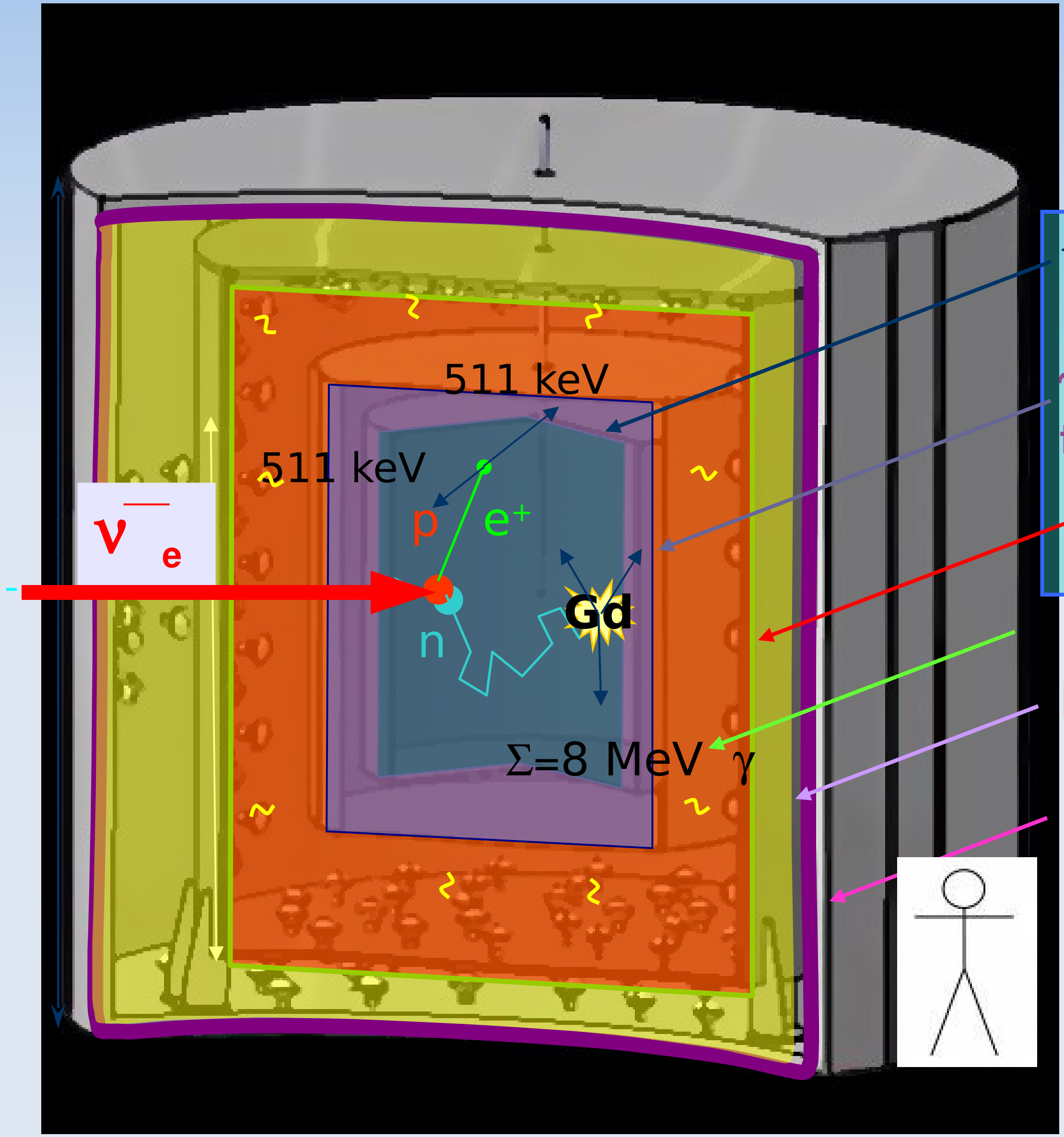
Outline

- Introduction: Double Chooz detector
- Scintillator requirements
- Measurements of the optical properties
  - Light Yield measurements and Model
  - Time profile measurements
  - α quenching
  - Low energy electron quenching
- Summary
- Outlook

The Double Chooz detector



ν target : Detection of e^+, n

γ -catcher: Converts γ escaping from target to visible light

Buffer: Shielding of the inner two volumes

Buffer steel tank + 390 PMTs

Muon VETO: Detection of myons (72 PMTs)

Steel Shielding

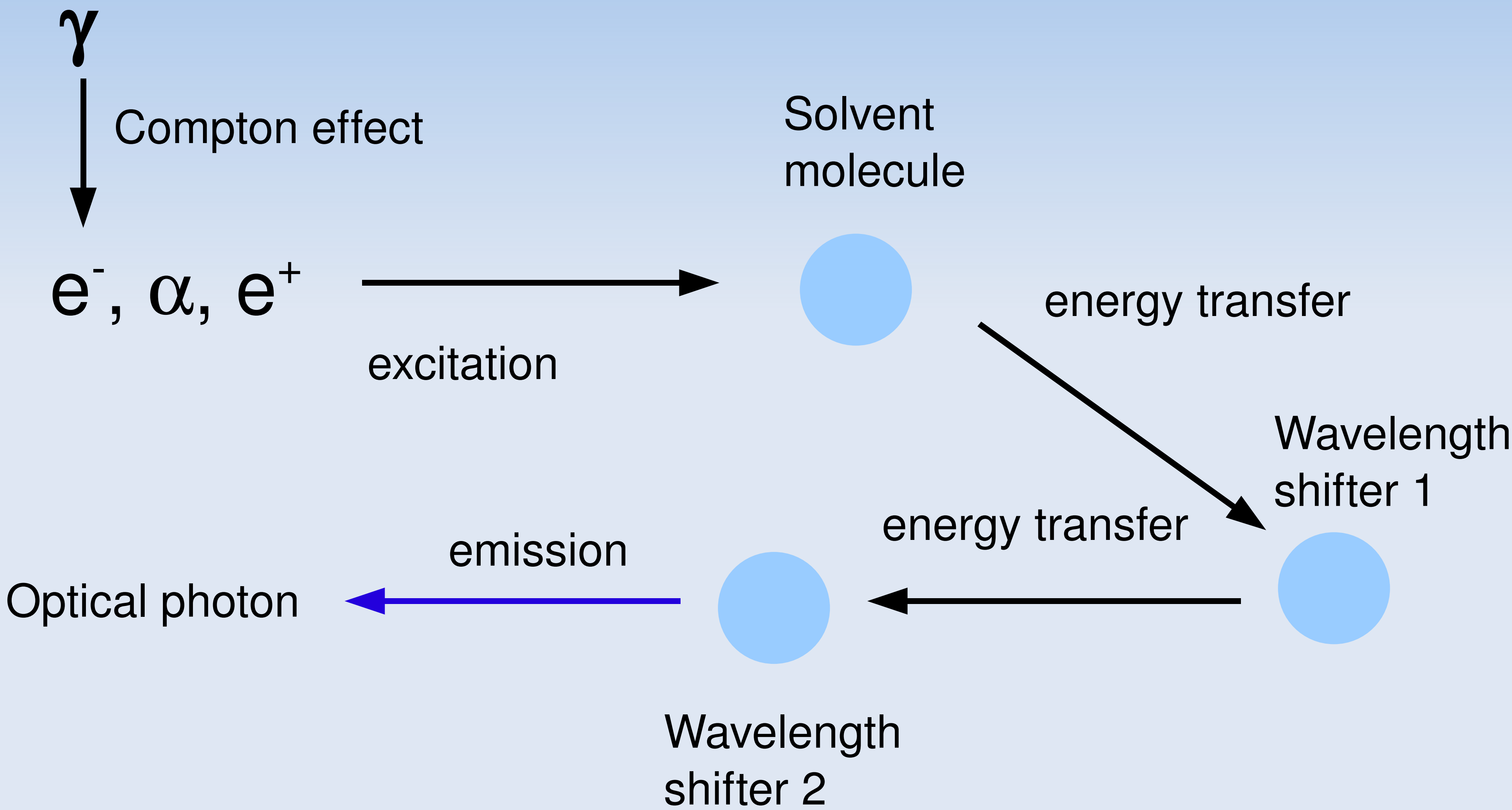
Detection of ν : inverse β decay

$$\bar{\nu}_e + p \rightarrow n + e^+$$

n – capture on Gd

→ background suppression

How does a scintillator work?



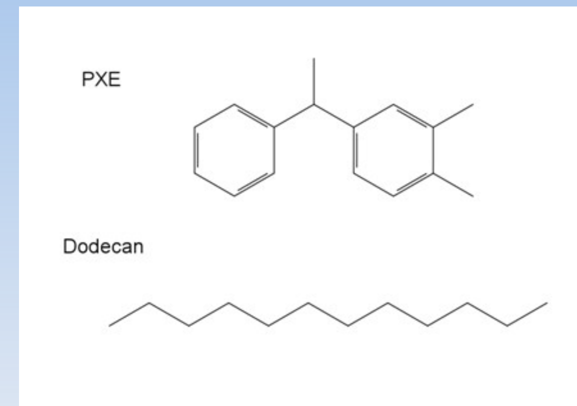
Scintillator Characteristics

- Efficient neutron capture → Gd , solubility of Gd
- Optical and chemical stability on a timescale of years
- Material compatibility
- Radiochemical purity
- **High light yield (photons/MeV) in the Target (→ energy resolution)**
- **Same light yield in Target and γ catcher**
- **Same density in Target and γ catcher (and the other volumina)**
- **Time probability density function (pdf) for scintillator emission can be tuned (→ pulse shape discrimination)**
- **Determination of alpha quenching and low energy electron quenching (→ alpha background and energy scale)**

Choice of components

- Solvents
  - High transparency and light yield
  - Material compatibility with the acrylic tanks
  - Flexibility to adjust light yield, density and time pdf

  → PXE/Dodecane mixture

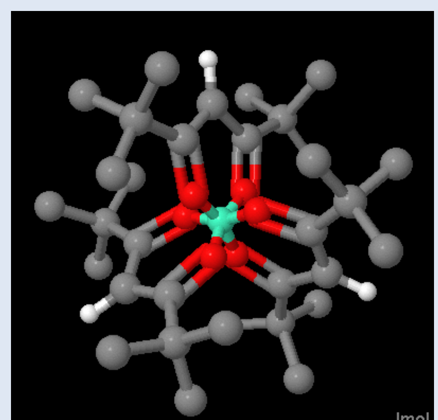


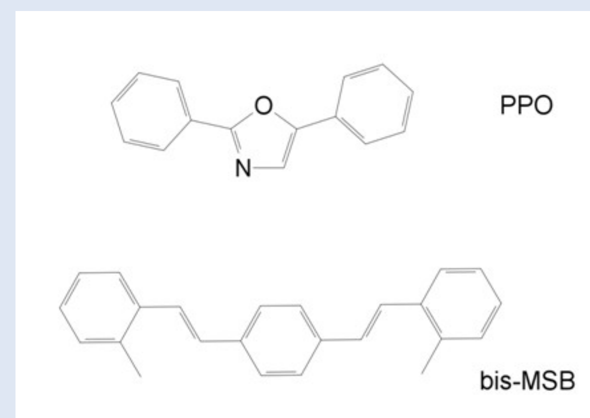
- Solutes: Wavelength shifters (Fluors)
  - Sufficient overlap of absorption spectra of acceptor (e.g. primary fluor) and emission spectrum of donor (e.g. solvent molecule)

  → effective energy transfer and wavelength shift to more transparent region
  - High quantum efficiency and purity

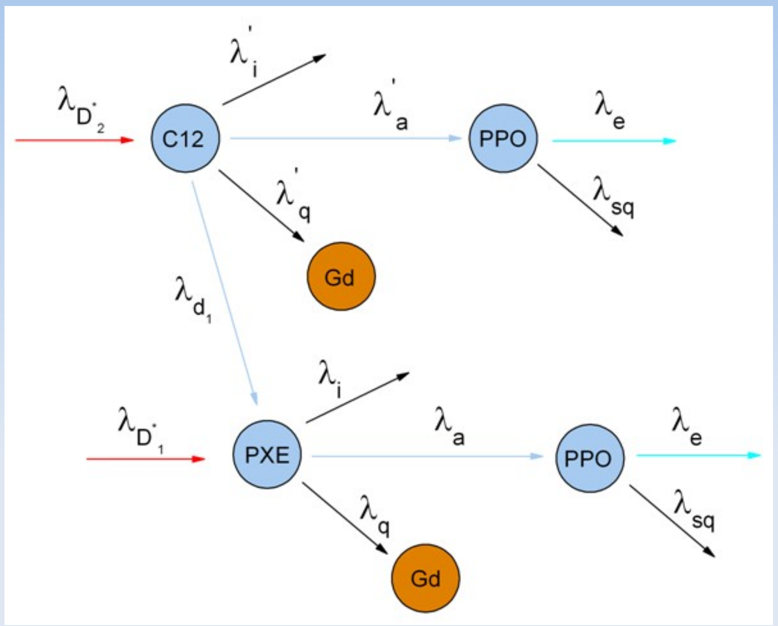
    → PPO and bis-MSB
- Solutes: Gadolinium-complex
  - Stability (data for 4.5 years)
  - Radiochemical/optical purity
  - High solubility

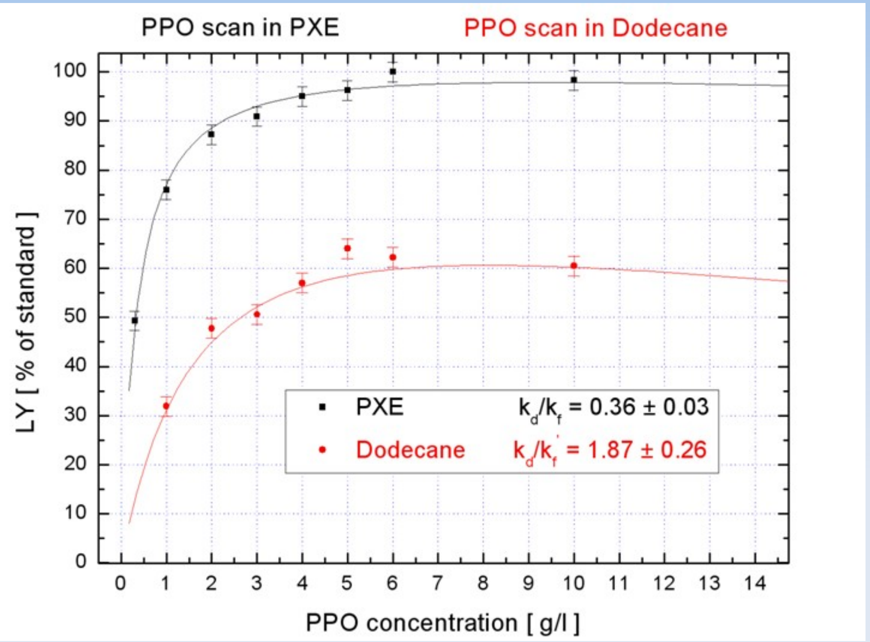
  → Betadiketones

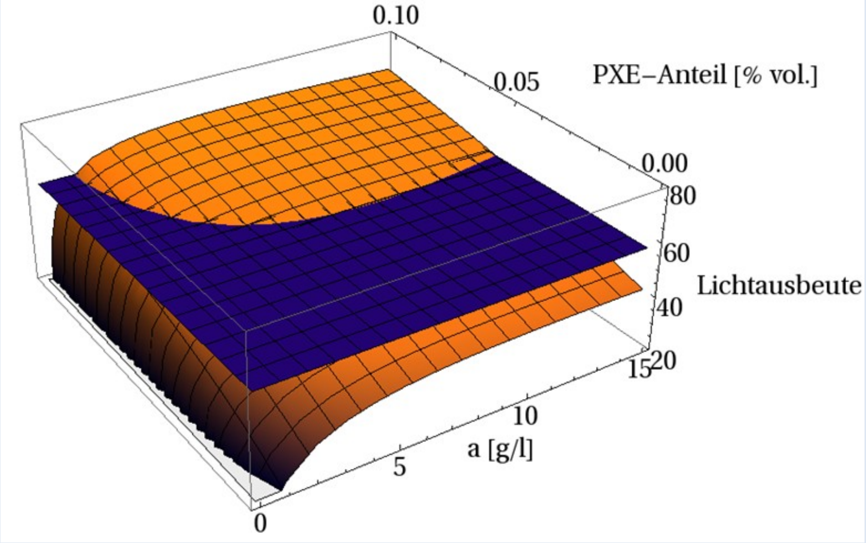




Light Yield Measurements and Modeling





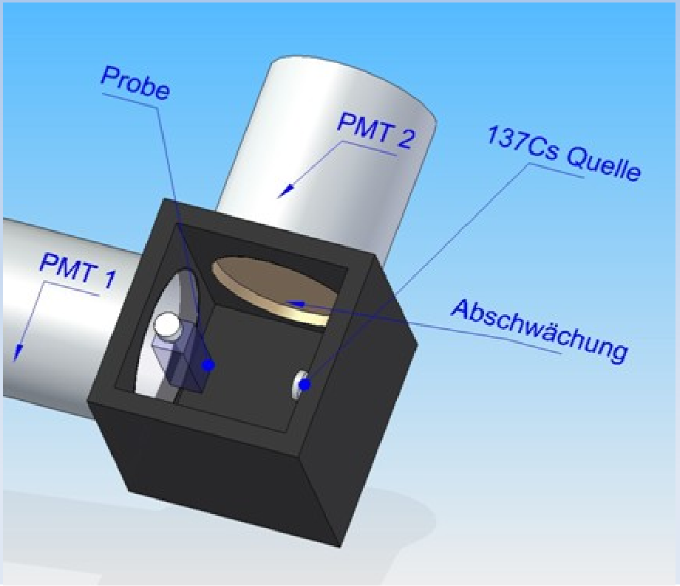


- Measurement of Light Yield for different scintillator compositions → fit data to determine the energy transfer time constants used in the model
- Model predictions used to optimize the composition and match the LY of Gamma Catcher and Target scintillator

C.Buck, F.X. Hartmann, D.Motta. S.Schönert, CPL, 435 (2007) 252 – 256, C. Aberle: Diplomarbeit (2008)

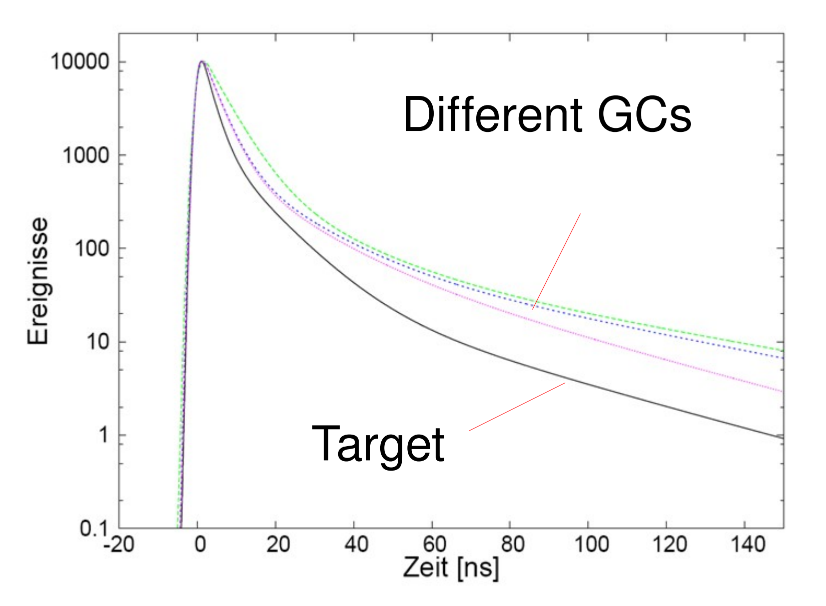
Time profile

- The time pdf for light emission can be measured directly
  - PMT 1 : hundreds of photons/event → Start
  - PMT 2 : << 1 photon/event → Stop
  - Coincidence of PMT1 and PMT2
  - t(Stop)-t(Start)-distribution = time pdf



- With the light yield model we are able to understand differences in the time pdfs for different scintillator compositions (the energy transfer paths have different time constants).

→ Possible Application: pulse shape analysis in Double Chooz to distinguish between events in the Target and events in the GC



C. Aberle: Diplomarbeit (2008)

α quenching: Motivation

- Light Yield is lower for α –particles than for e^-
- Reason: dE/dx higher for α → ionisation density is higher → more quenching processes
- Definition of the quenching factor: $QF=E(\alpha)/E(e^-)$ at $LY(\alpha) = LY(e^-)$
- The α quenching factors of the scintillators determine the visible energy of α -background in Double Chooz
- Example: QF=10 at 5 MeV

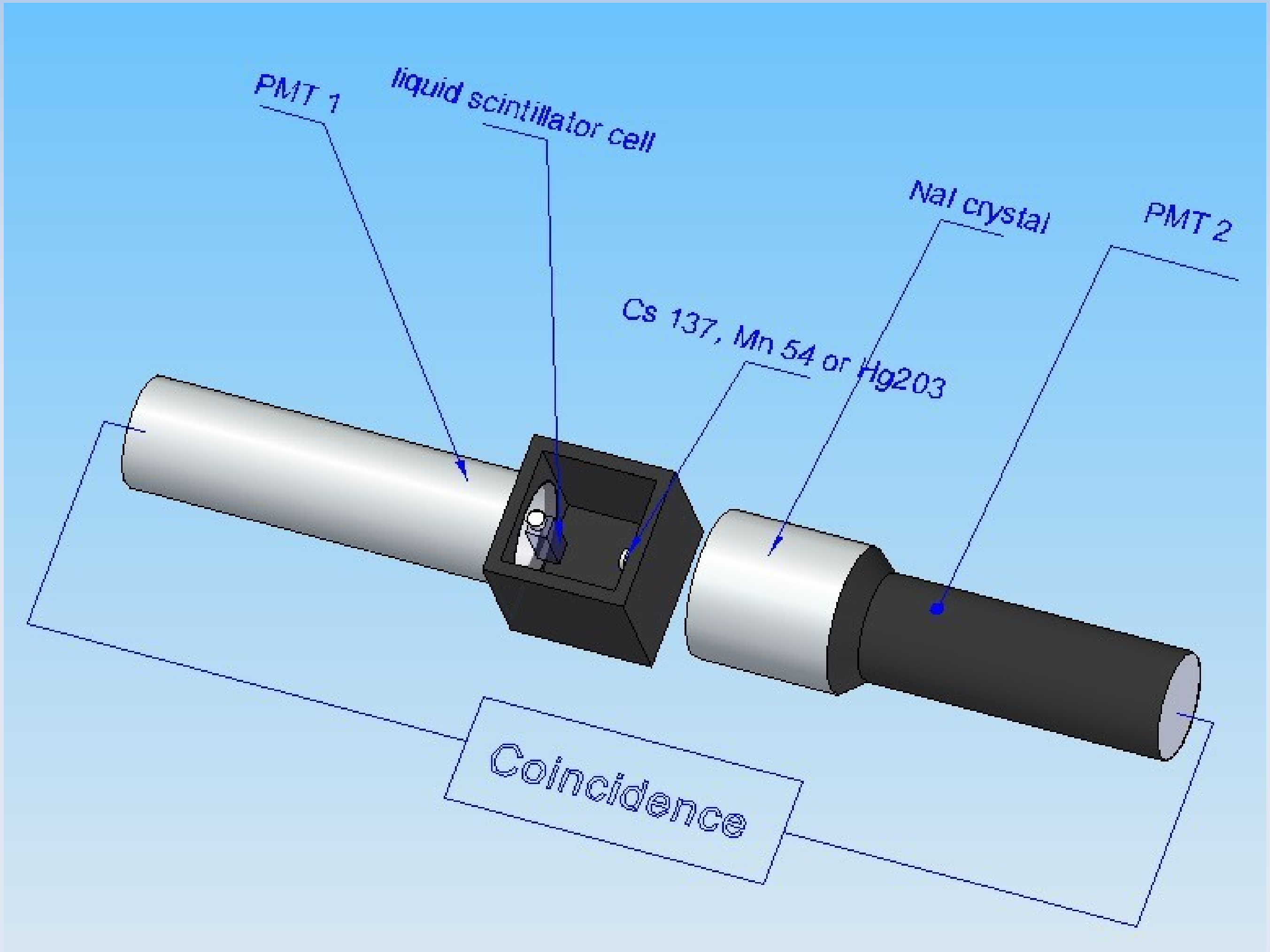
→ 5 MeV α create as much light as electrons with 500 keV

- We measure the LY for electrons and α particles.

α quenching: Setup

γ sources

- Compton scattering dominant. Scattered e^- excites scintillator.
- PMT 1 measures signal and opens coincidence gate
- If the photon is backscattered with 180° it can be detected by the NaI-PMT2 system
- Coincidence → scattering angle = 180°
→ Fixed energy of e^- and corresponding LY in PMT1



α quenching: Sources

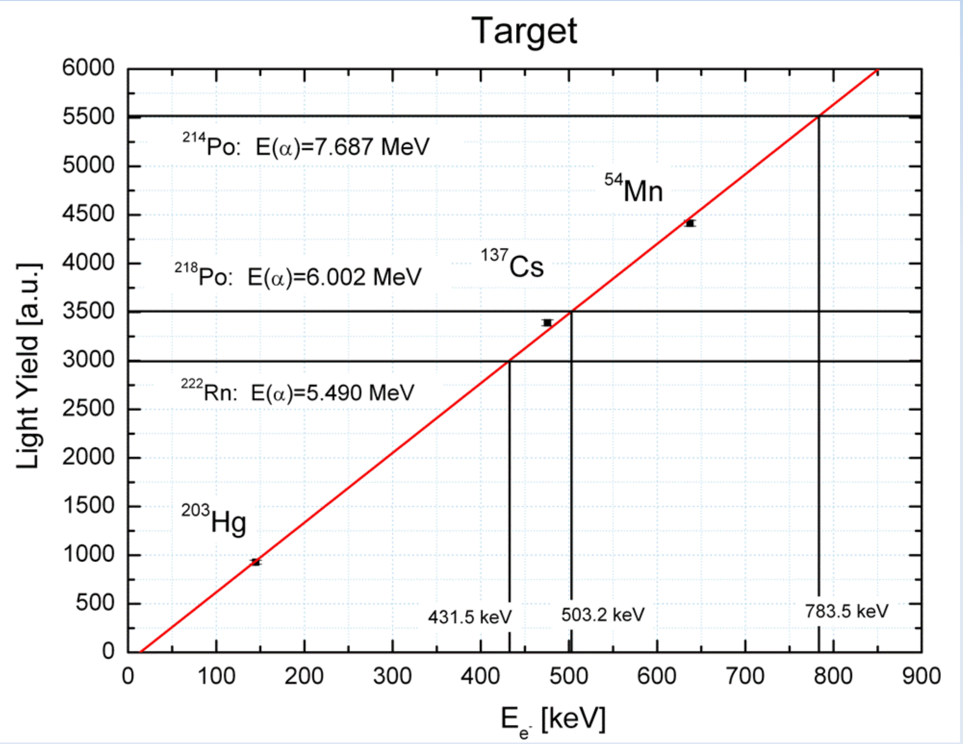
α source #1:

- ^{222}Rn emanating from Uranium salt is purged through PPO powder
- ^{222}Rn decays within days to ^{210}Pb (0.5 years to grow in ^{210}Pb ($t_{1/2}$=22.3 y)) which is in equilibrium with ^{210}Po (5.3 MeV α)

→ PPO is dissolved in the scintillator, the α decay inside the scintillator

α source #2:

- Emanating ^{222}Rn from a Radium solution (25.6 Bq) is purged with N_2 directly through the scintillator
- ^{222}Rn decays inside the scintillator to ^{210}Pb via ^{218}Po and ^{214}Po emitting three α (5.5 MeV, 6.0 MeV and 7.7 MeV).

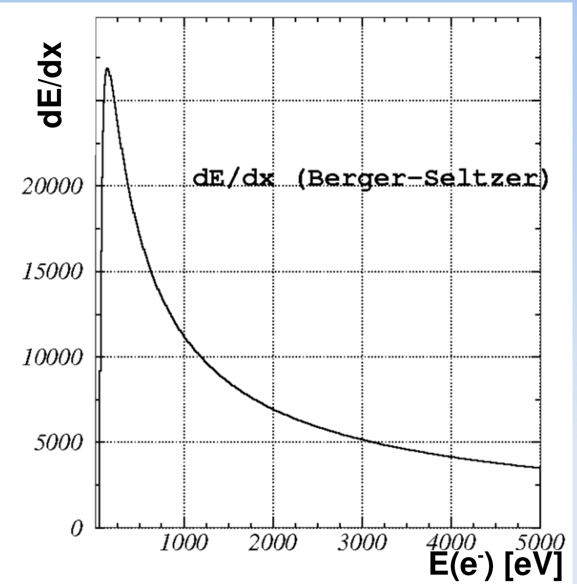


α quenching: Results

Scintillator	QF(5.3 MeV)	QF(5.5 MeV)	QF(6.0 MeV)	QF(7.7 MeV)
Target	13.3 ± 0.3	12.7 ± 0.4	11.9 ± 0.4	9.8 ± 0.5
GC (5 g PPO/l)	15.4 ± 0.5	14.4 ± 0.3	13.7 ± 0.3	11.1 ± 0.3
GC (2 g PPO/l)	17.4 ± 0.5	16.2 ± 0.4	15.3 ± 0.4	12.6 ± 0.4
Veto	13.7 ± 0.5	13.0 ± 0.4	12.2 ± 0.4	10.0 ± 0.4

Example: 7.7 MeV α in Target <-> 786 keV e^-

Low energy electron quenching: Motivation



- dE/dx is high for slow electrons

→ high ionisation density and increased quenching expected

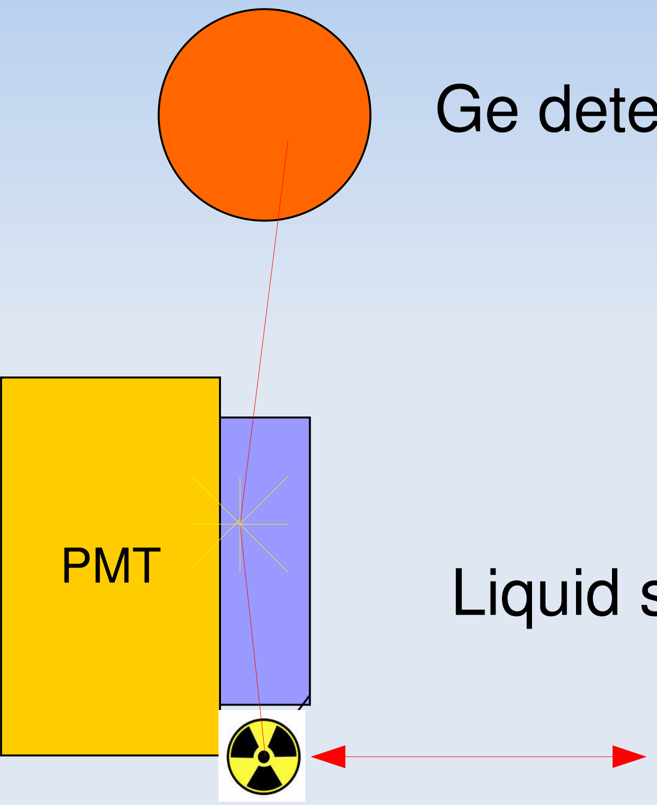
- We measure the light yield for low energy electrons directly
- Use γ source: Compton scattering with small scattering angles → e^- with low energies excite the scintillator
- **Germanium detector** used to measure the energy of the scattered γ **precisely**, energy of electrons not determined by angle but by energy deposition in the Ge crystal

Why is this important for Double Chooz?

„gamma quenching": e.g.: e^+ => 2 x 511 keV gammas lead to energy deposition via multiple Compton scattering with low energy recoil electrons => visible energy of e^+ smaller than e^- with equivalent energy

=> Energy scale of prompt events („spectral analysis")

Low energy electron quenching: Setup



Ge detector

Liquid scintillator

^{137}Cs source (mounted on a movable rail)

- Coincidence set up between Ge detector and PMT attached to the liquid scintillator
- Compton scattering angle from 0° to 50°

→ Scattered e^- with energies 8-200 keV

(E_{e-}=662 keV – E_{Ge})

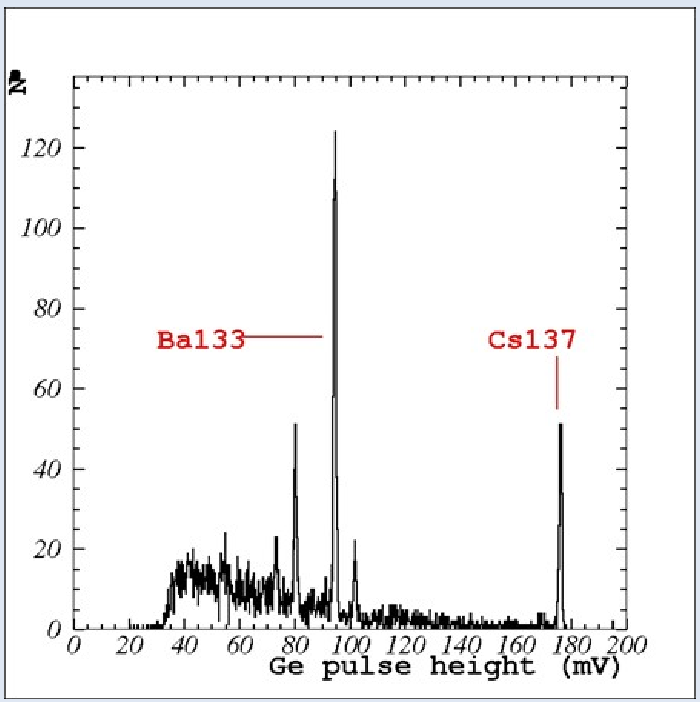
Work done together with Stefan Wagner and Stefan Schönert

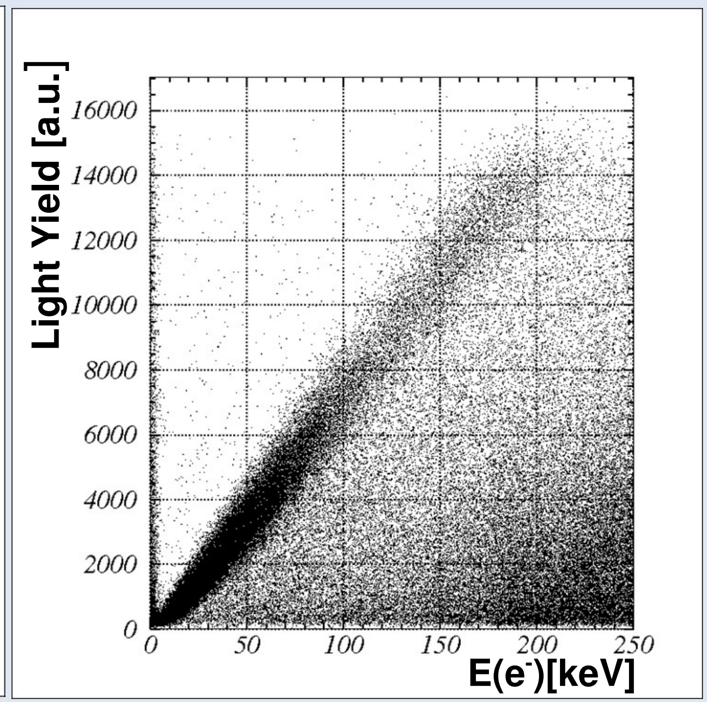
Low energy electron quenching: Data

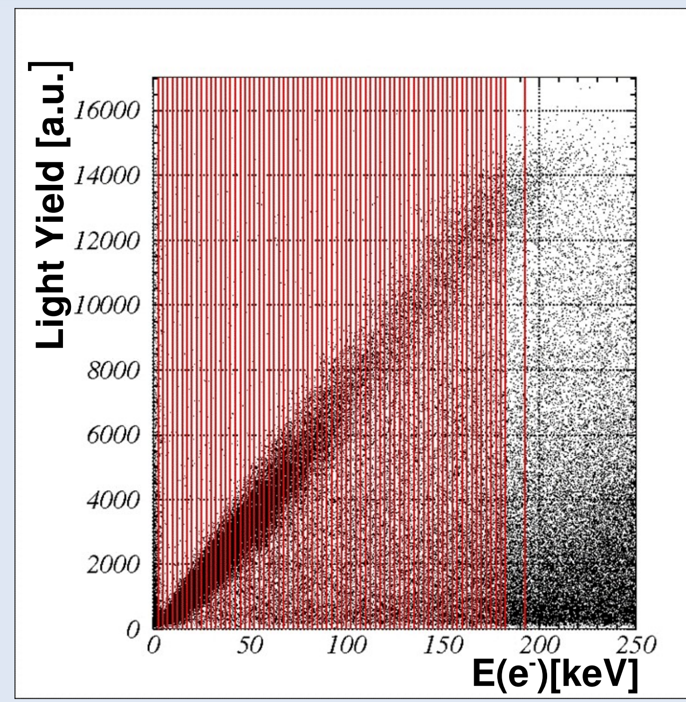
Calibration of Ge detector (± 0.5 % resolution)

Scatter plot: each point represents one event with energy depositions in the liquid scintillator and the Ge detector

Cut the interesting region in 80 energy bins (Ge):
Calculate Ee-=662 kev-E(Ge) for each bin
Analyse the light yield in the liquid scintillator for each bin

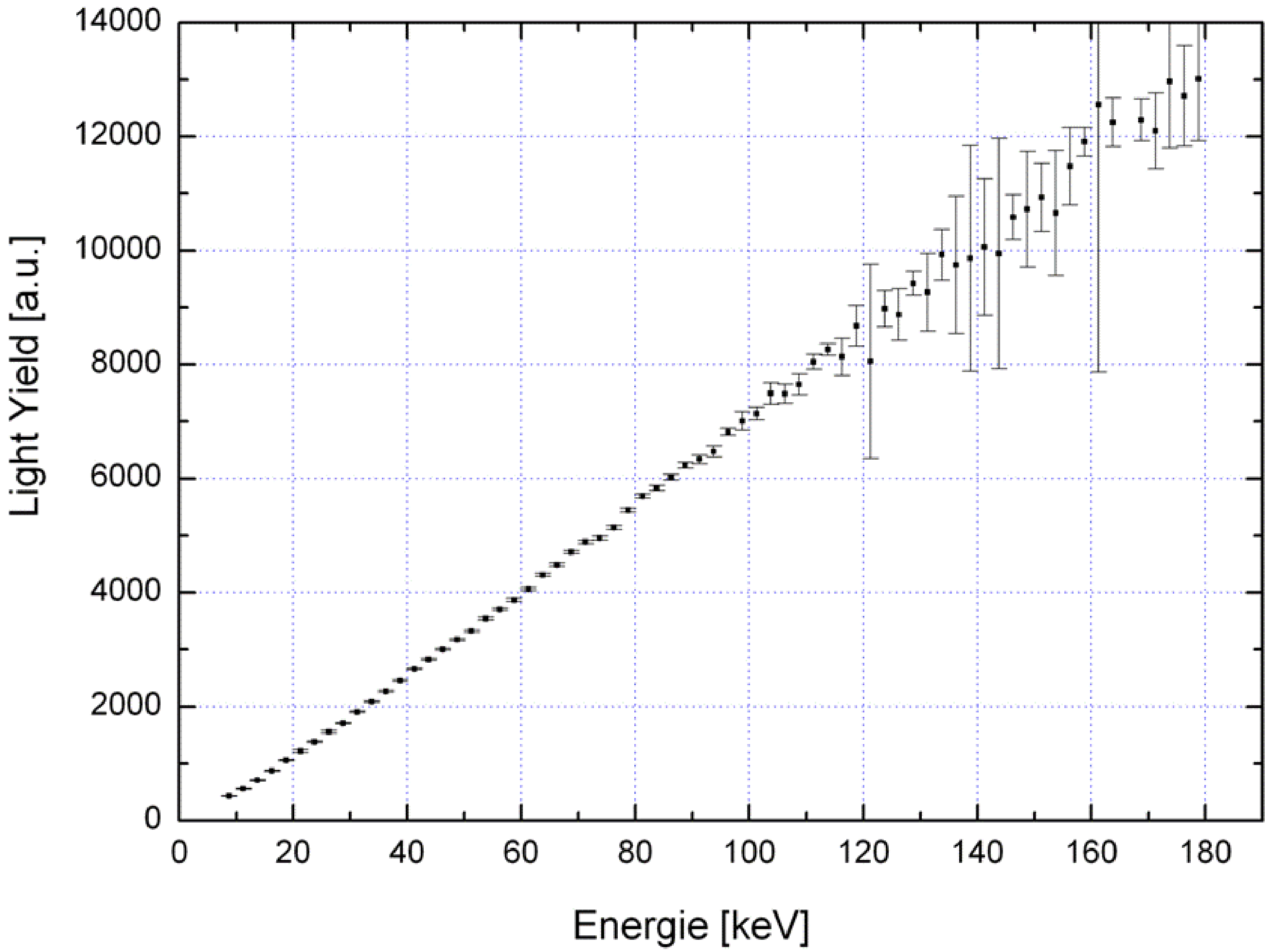






Low energy electron quenching: Results

Scintillator: PC (Pseudocumene) + PPO



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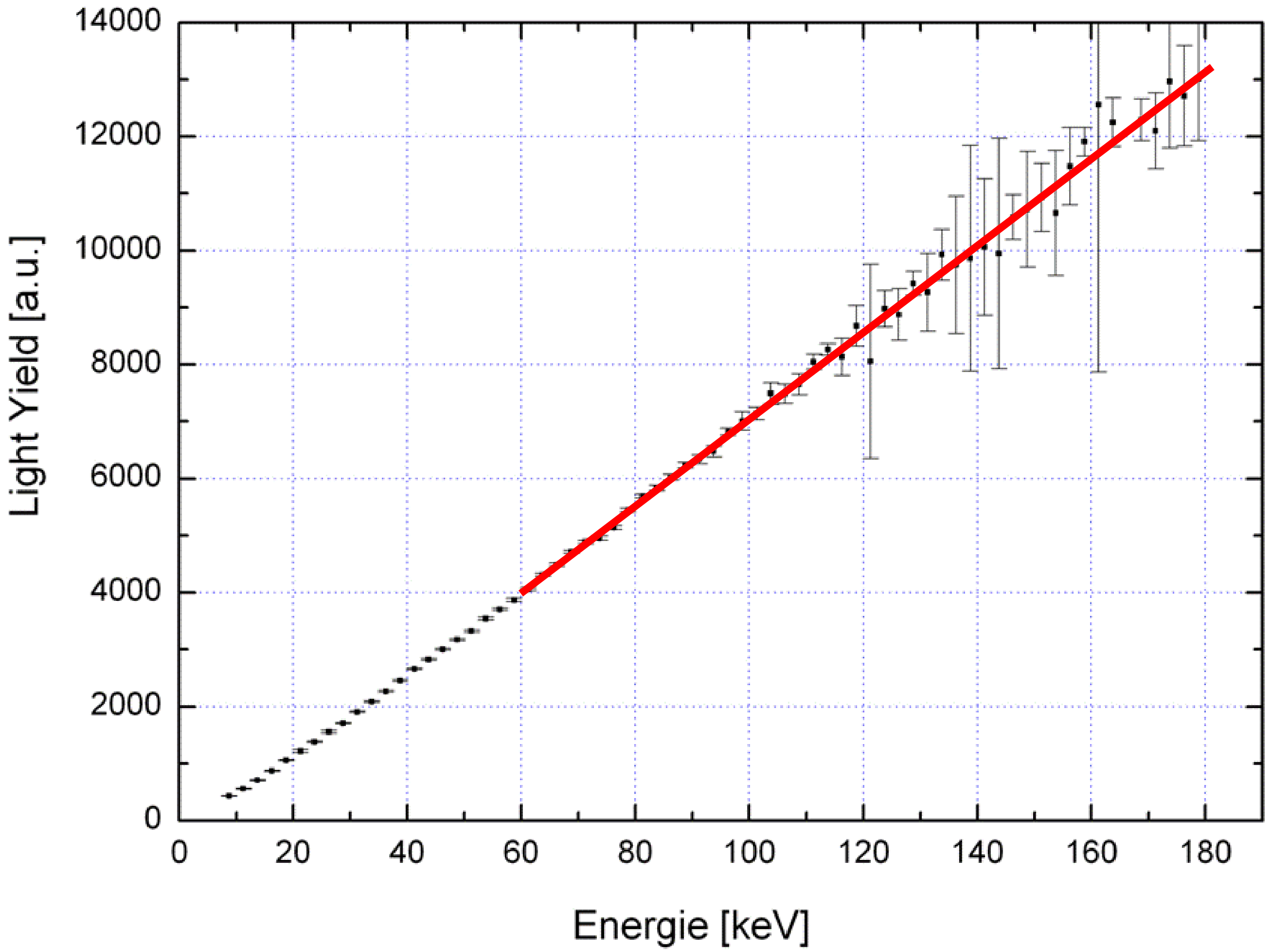

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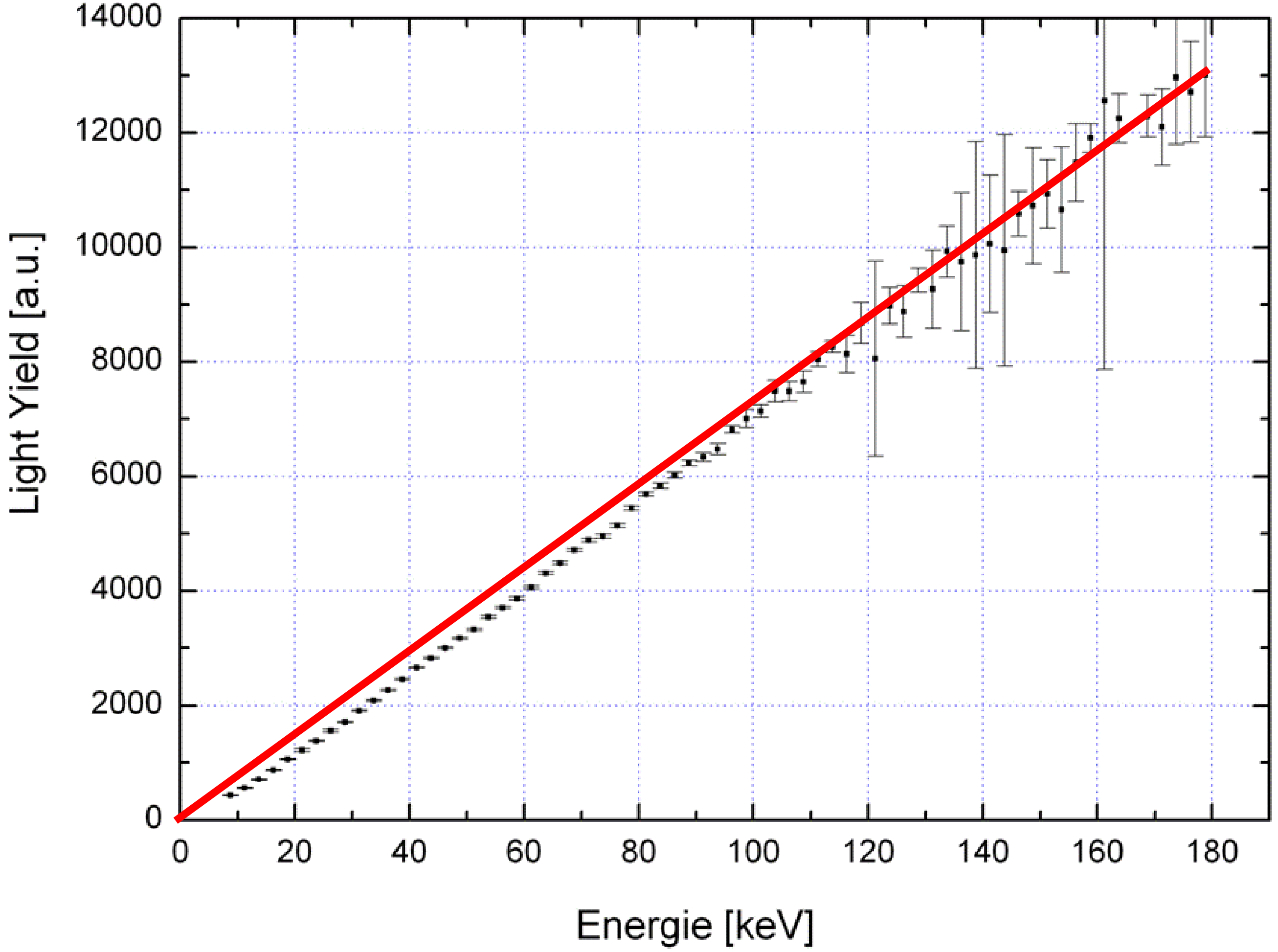
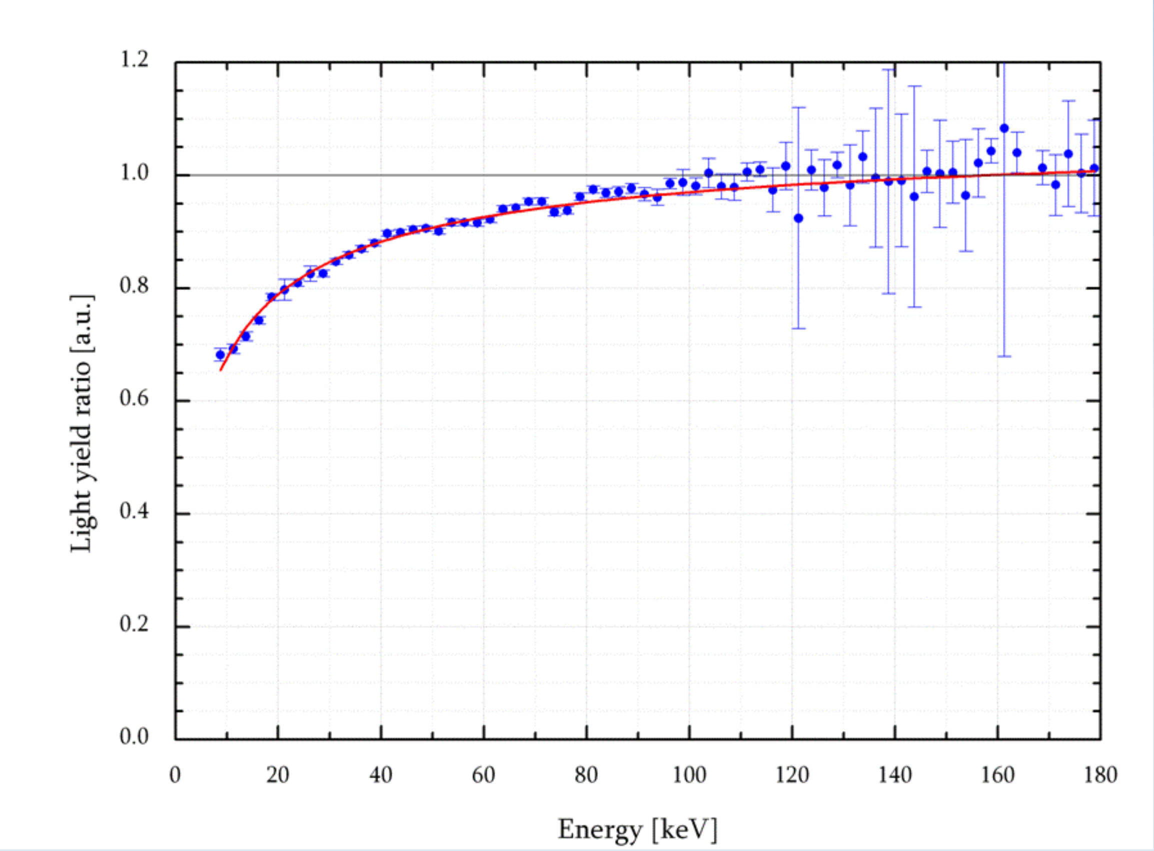


Low energy electron quenching: Results

- Fit with Birks model:

$$dL/dx = \frac{S_0 * dE/dx}{1 + kB * dE/dx}$$

- dE/dx calculated with Berger-Seltzer equation
- Program written to do the χ^2 fit numerically with small steps dx



Preliminary Result: kB=0.0145 ± 0.0020 cm/MeV (PC+PPO scintillator)

Summary

- The scintillators for Double Chooz have to meet several requirements at the same time
- Suitable components have been chosen
- Lab measurements/models to optimize the compositions
  - LY measurements → optimize the Target LY
    → match Target and GC light yield
  - Measurement of time pdf of light emission
    → pulse shape discrimination
- Alpha quenching → study alpha background
- Low energy electron quenching → energy scale
- Microphysics of the scintillator studied

Outlook

- Low energy electron quenching for the Double Chooz scintillators
- Adjust kB in the Double Chooz simulation software
- New lab measurements planned, e.g. neutron capture on Gd
- Simulation of detector response with respect to scintillator properties
- Work on Double Chooz Data Analysis