DFG Deutsche Forschungsgemeinschaft

GEFÖRDERT VOM
Bundesministerium
für Bildung
und Forschung

SFB 1258 Neutrinos
Dark Matter
Messengers

TUM Technische Universität München

# Measuring the Fluorescence Decay-time Constants of the JUNO Liquid Scintillator using Gamma Radiation and a Pulsed Neutron Beam

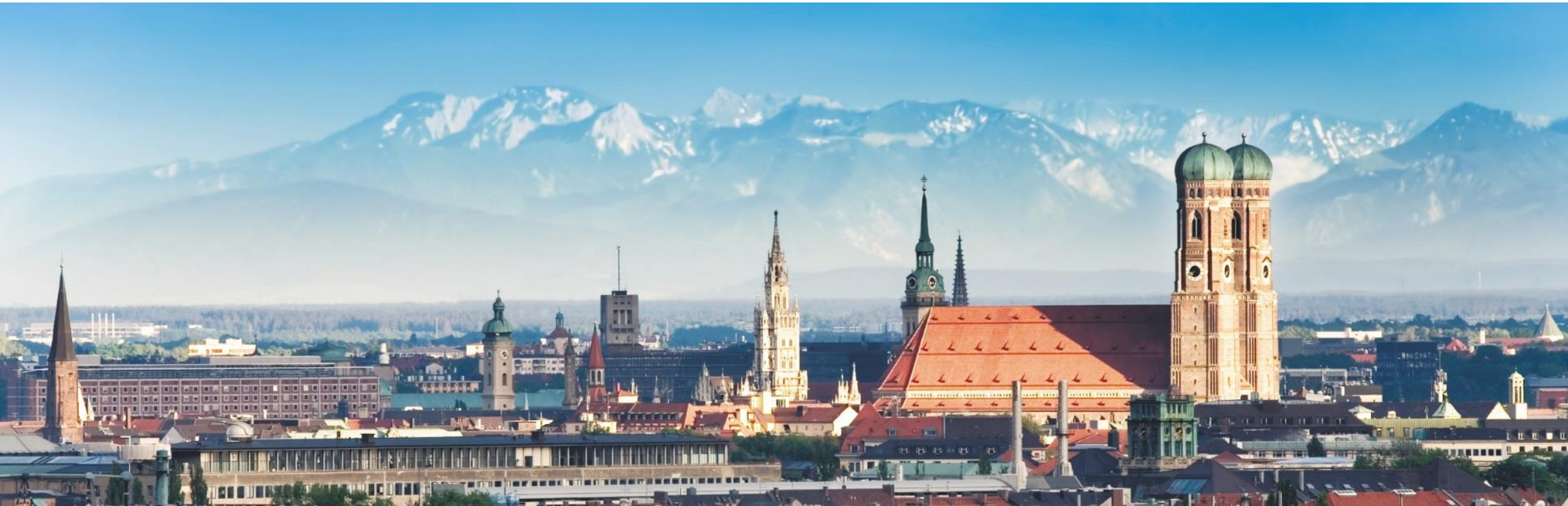
JUNO

## ***Raphael Stock***

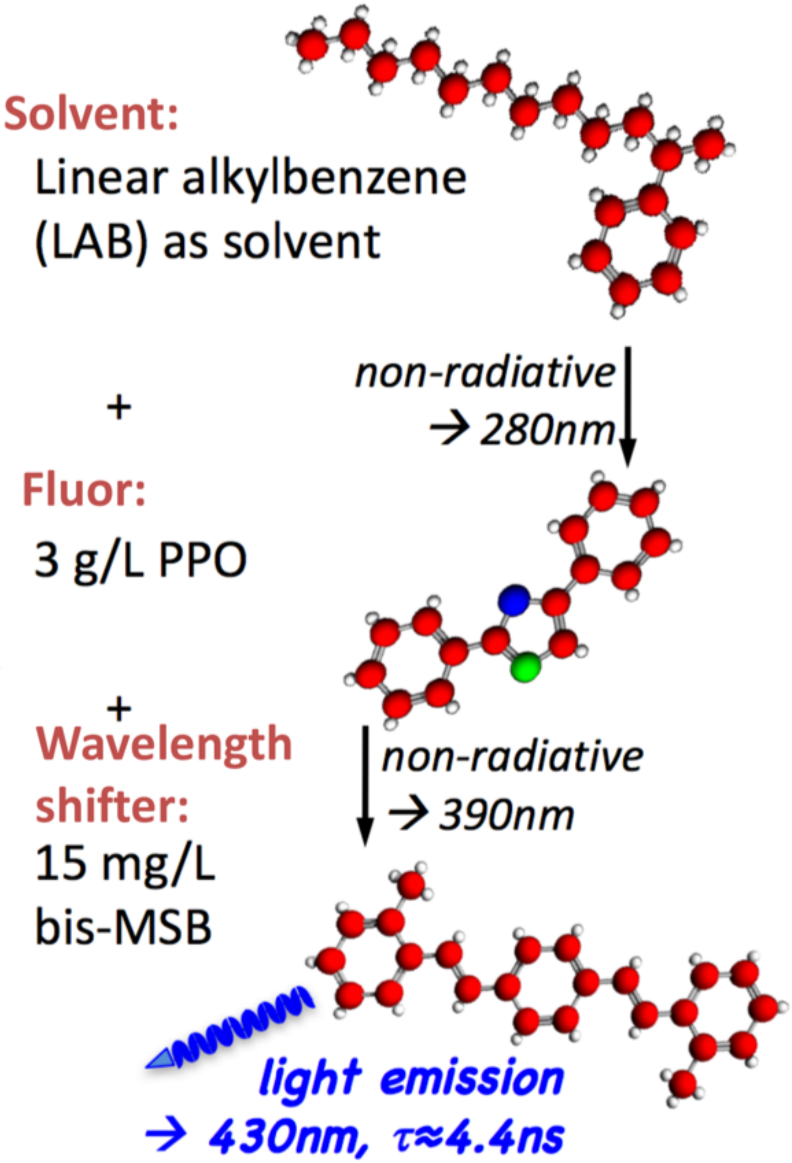
***with Hans Steiger & Lothar Oberauer***

**Baikal Summer School 2019**

MLL
Maier-Leibnitz-Laboratorium
für Kern-, Teilchen- & Beschleunigerphysik



# Scintillation Process in JUNO‘s Mixture



**Solvent:**
Linear alkylbenzene (LAB) as solvent

*non-radiative → 280nm*

\+

**Fluor:**
3 g/L PPO

*non-radiative → 390nm*

\+

**Wavelength shifter:**
15 mg/L bis-MSB

***light emission → 430nm, τ≈4.4ns***

**Energy hopping:**

- Molecular collisions with neighbouring solvents, spatial propagation of excitation energy

**Förster mechanism:**

- Dipole-dipole interaction,
- fast (depending on concentration) and local transfer of energy

**Lifetimes of molecular excited states:**

- depend on the concentration of solvent, fluor and wavelength-sifters
- influence pulse shape of events

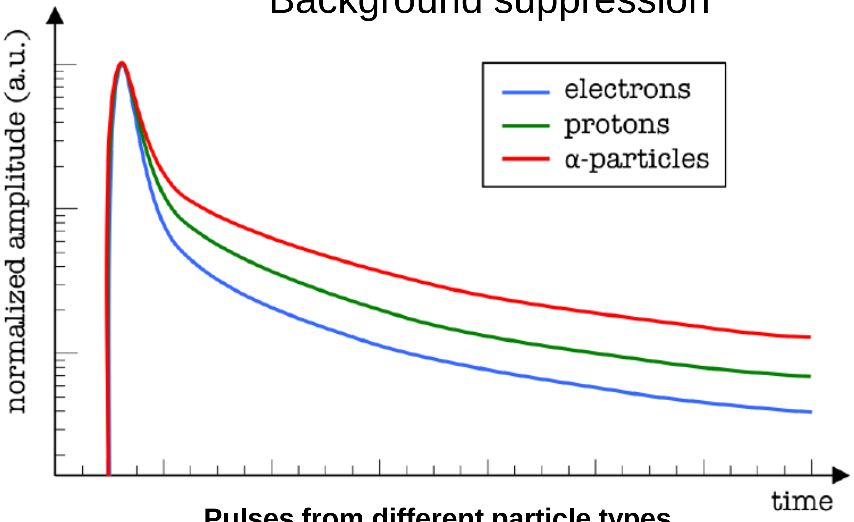
# Event Reconstruction & Pulse Shape Analysis

**Particle identification**

α-events produced by natural activity

Neutrino-induced β-events

Background suppression

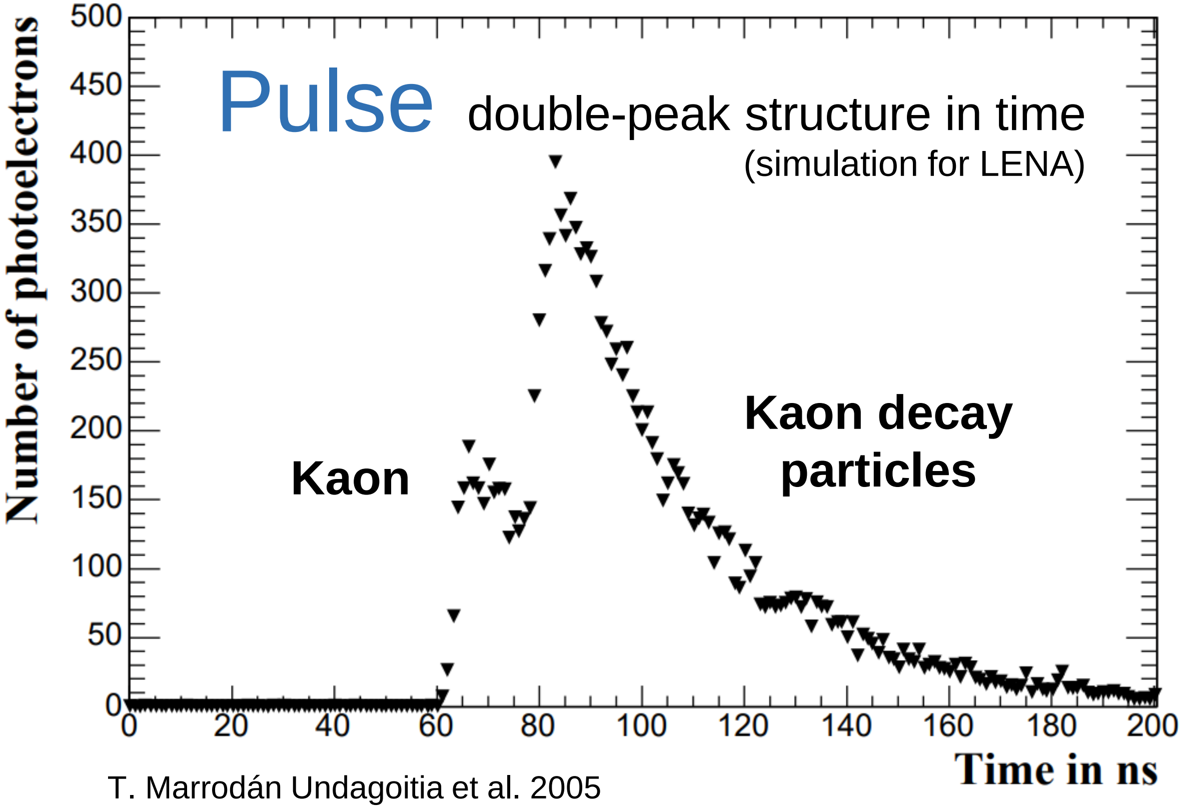


**Pulses from different particle types**
(Vinzenz Zimmer‘s PhD Thesis)

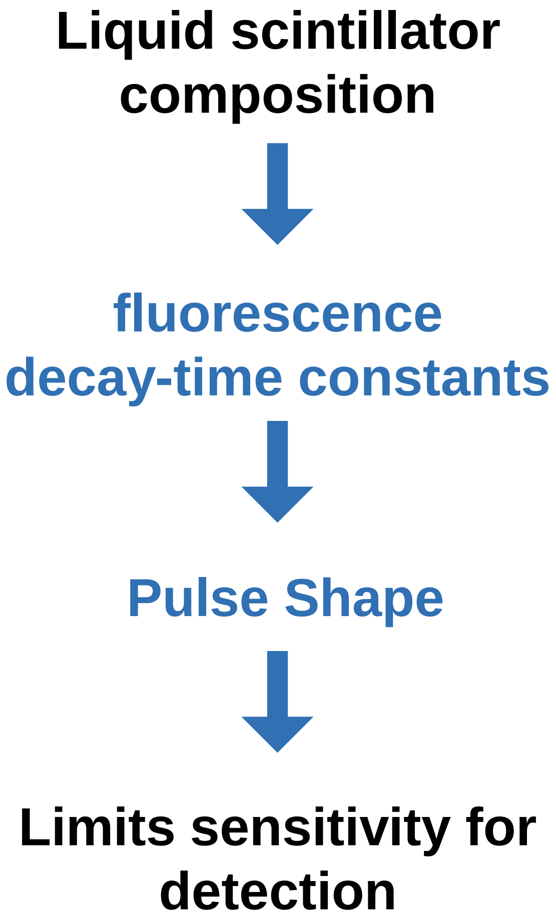
- Emission of initial photons smeared out in time
- Fluorescence decay-time constants have to be considered for the reconstruction algorithms of position and timing
- Global Monte Carlo Simulation (photon emission and propagation model) of the entire JUNO detector
- Parametrization of pulses from different particle types helps to discriminate certain events from background

# Search for Proton Decay

$$p \rightarrow K^+ + \bar{\nu}$$



T. Marrodán Undagoitia et al. 2005



**Liquid scintillator composition**

**fluorescence decay-time constants**

**Pulse Shape**

**Limits sensitivity for detection**

# Distribution of Light Emission in the Fluorescence Process

▬ Cherenkov radiation

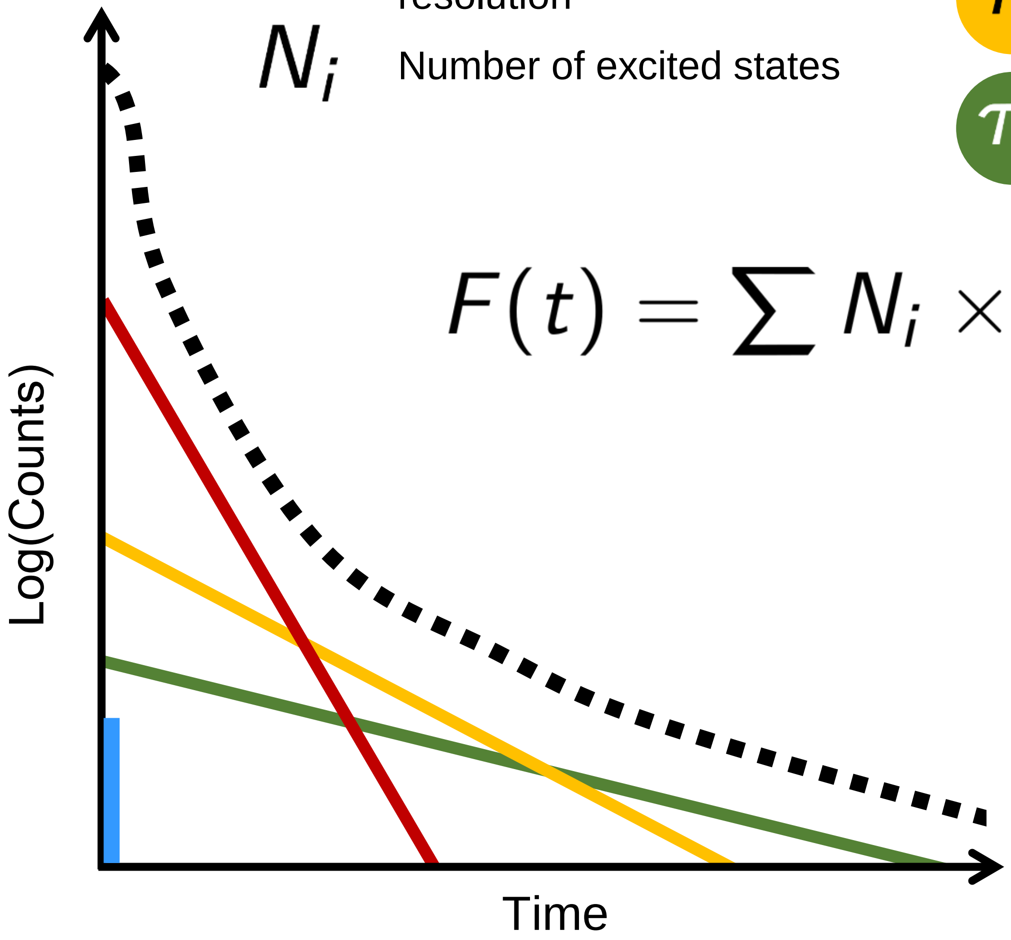
■ ■ ■ ■ Total distribution with time resolution

$N_i$ Number of excited states

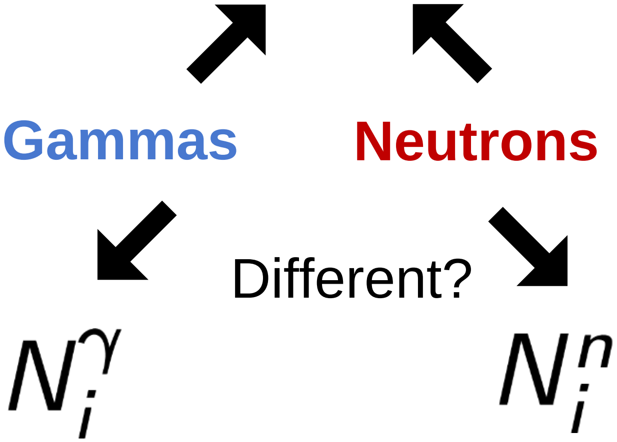
$\tau_1$ Short decay-time constant

$\tau_2$

$\tau_3$ Long decay-time constants



$$F(t) = \sum N_i \times \exp\left(-\frac{t-t_0}{\tau_i}\right) * R(t)$$



**Gammas**

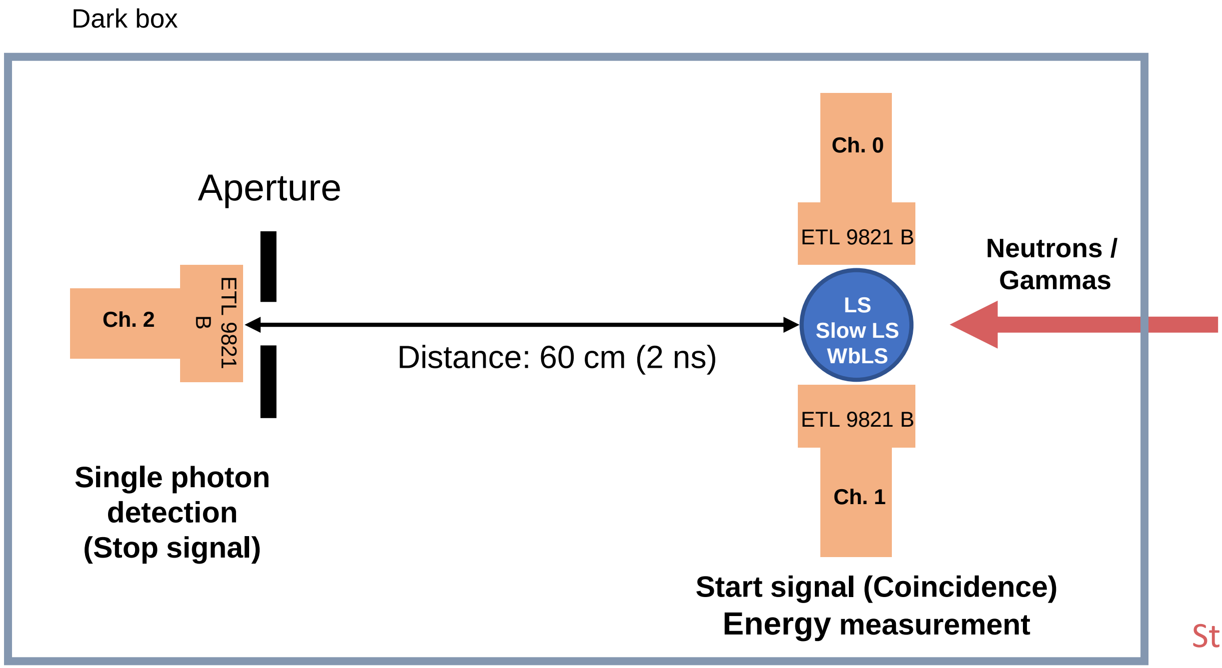
**Neutrons**

Different?

$N_i^{\gamma}$

$N_i^{n}$

# Experimental Setup



Dark box

Aperture

Ch. 2

ETL 9821 B

Distance: 60 cm (2 ns)

Ch. 0

ETL 9821 B

LS
Slow LS
WbLS

ETL 9821 B

Ch. 1

**Neutrons / Gammas**

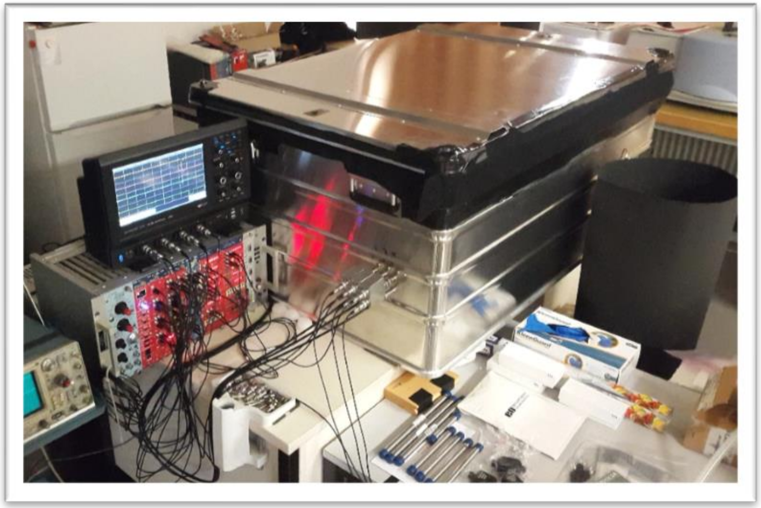
**Single photon detection (Stop signal)**

**Start signal (Coincidence)**
**Energy measurement**

**LS Vessel**

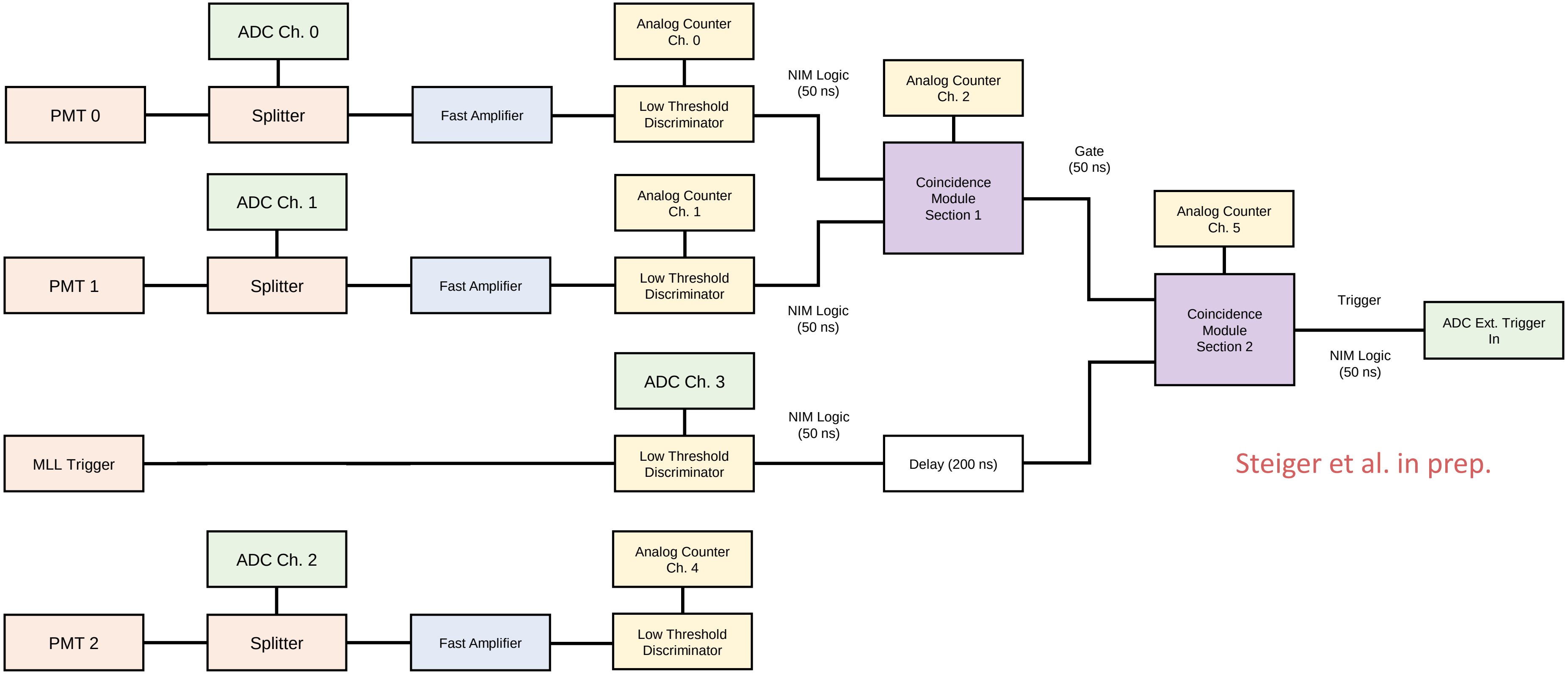
Steiger et al. in prep.

**PMTs with Mu-Shield (3x ETEL 9821, 3inch)**



**Setup during Commissioning Phase**

# Readout Electronics and Trigger Logic for Pulsed Neutron Beam

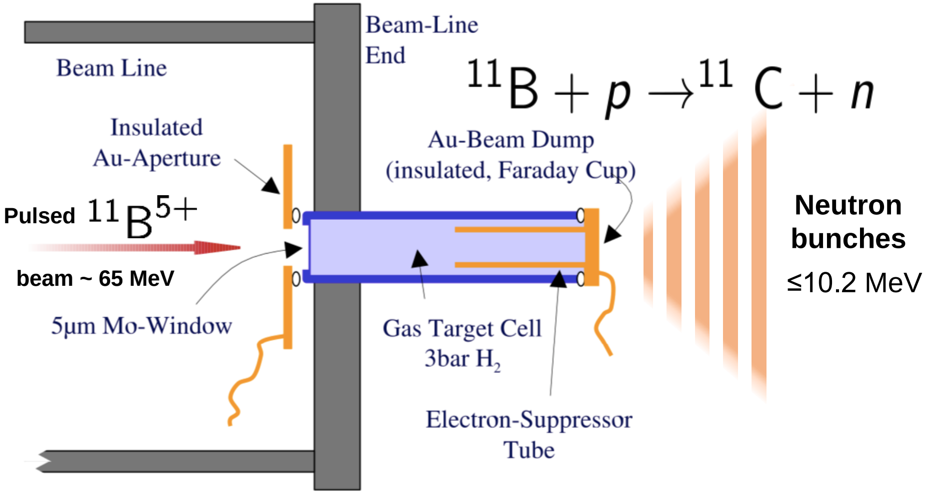


Steiger et al. in prep.

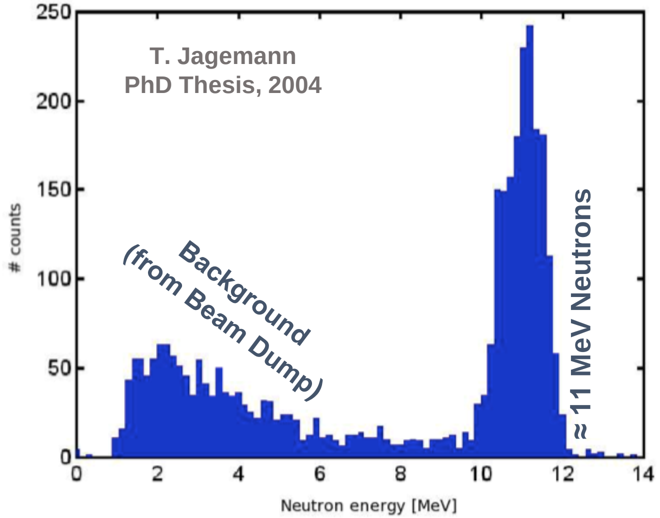
- ADC triggered on the coincidence of the beam chopper signal and the two close PMTs
- Searching for single photon electron events in the far PMT by offline analysis
- Rates are adjusted with analog counters (~3% of the triggers contain 1 PE in PMT 2), constantly cross-checked during beam time

# Heavy Ion Beam driven pulsed Neutron and Gamma Generation

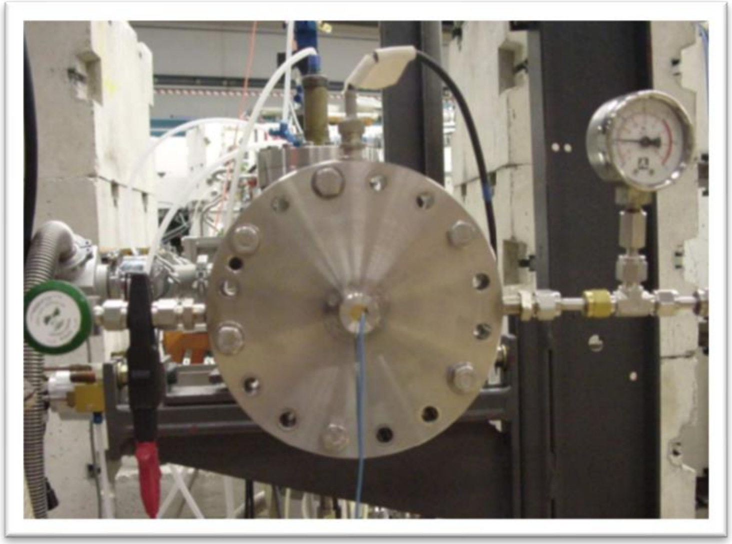
The MLL Tandem Laboratory (Hall II Beamline -10°)



Schematic Drawing of the Hydrogen Target

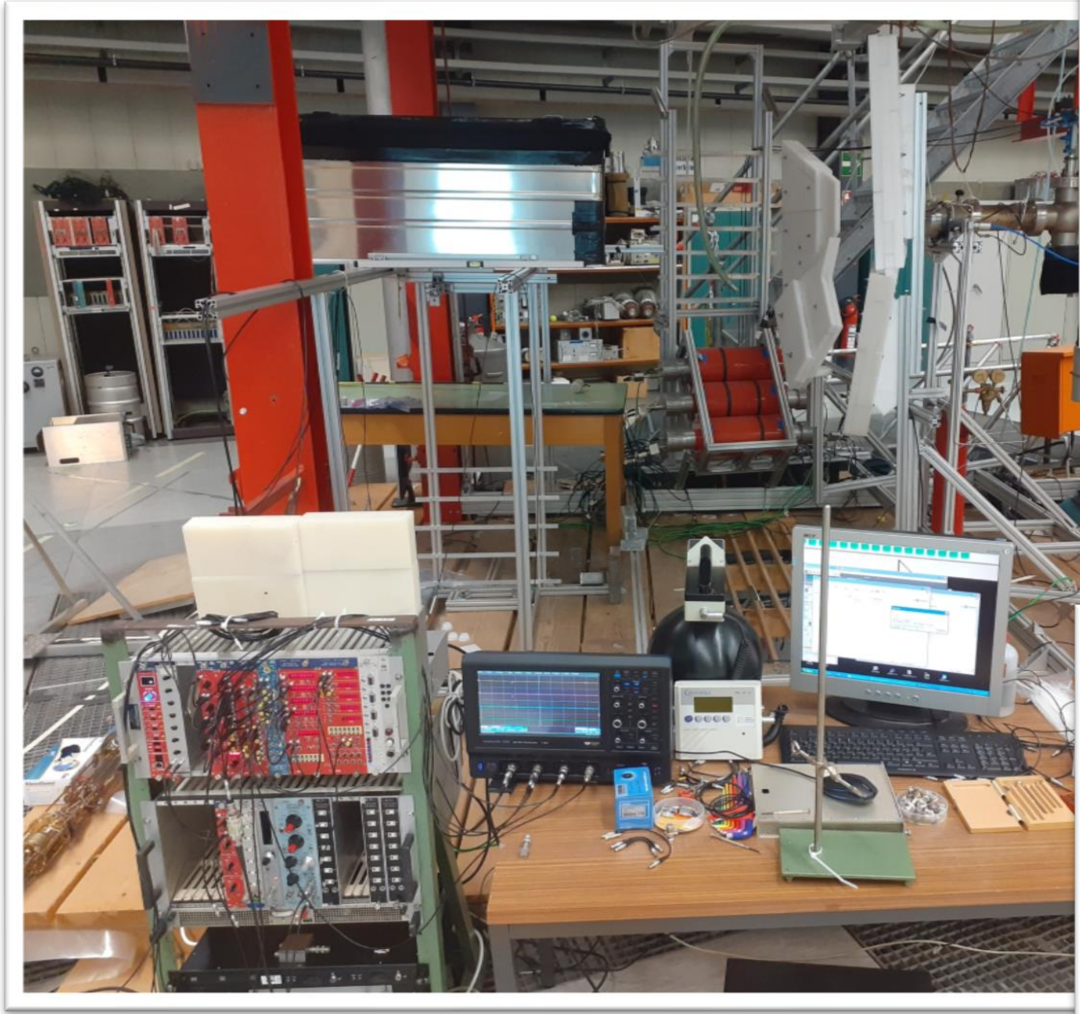


Energy Spectrum of the produced Neutrons



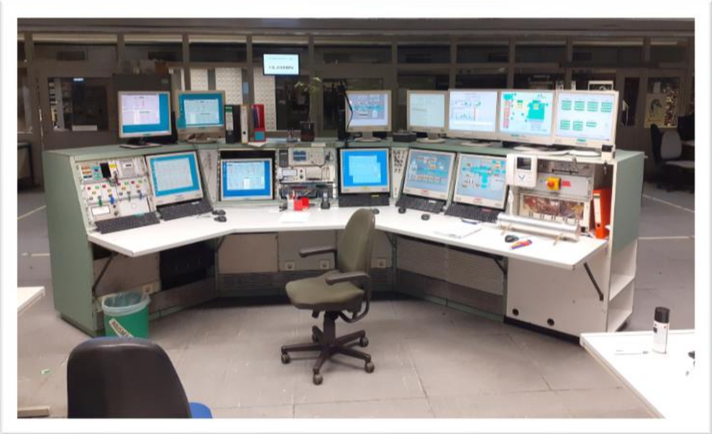
Hydrogen Cell with Beam Dump

# Beam Time in April/May



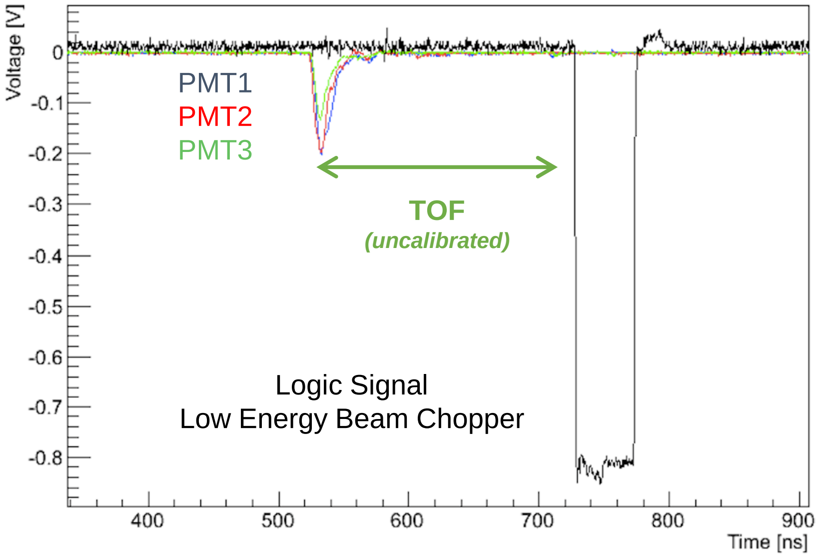
Setup during Beam time at the MLL in Hall 2

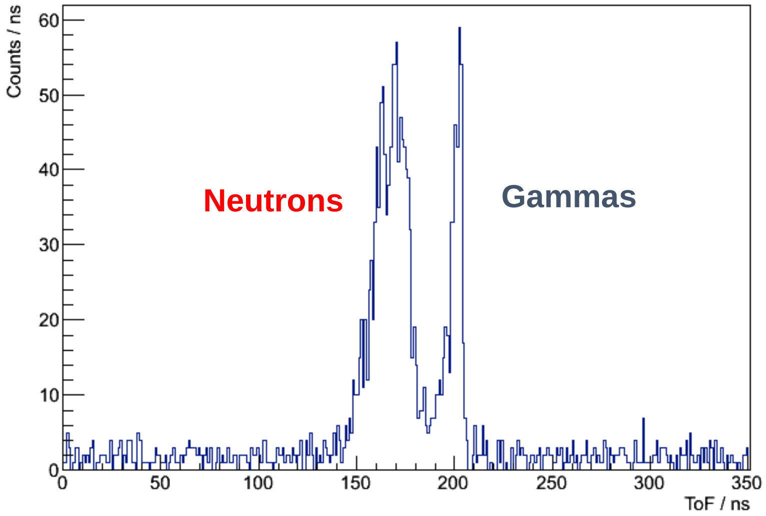
CCTV



MLL Control Room

# Time of Flight Spectrum of Neutrons and Gammas





**Test Example Event of all three PMTs with the Beam Chopper**

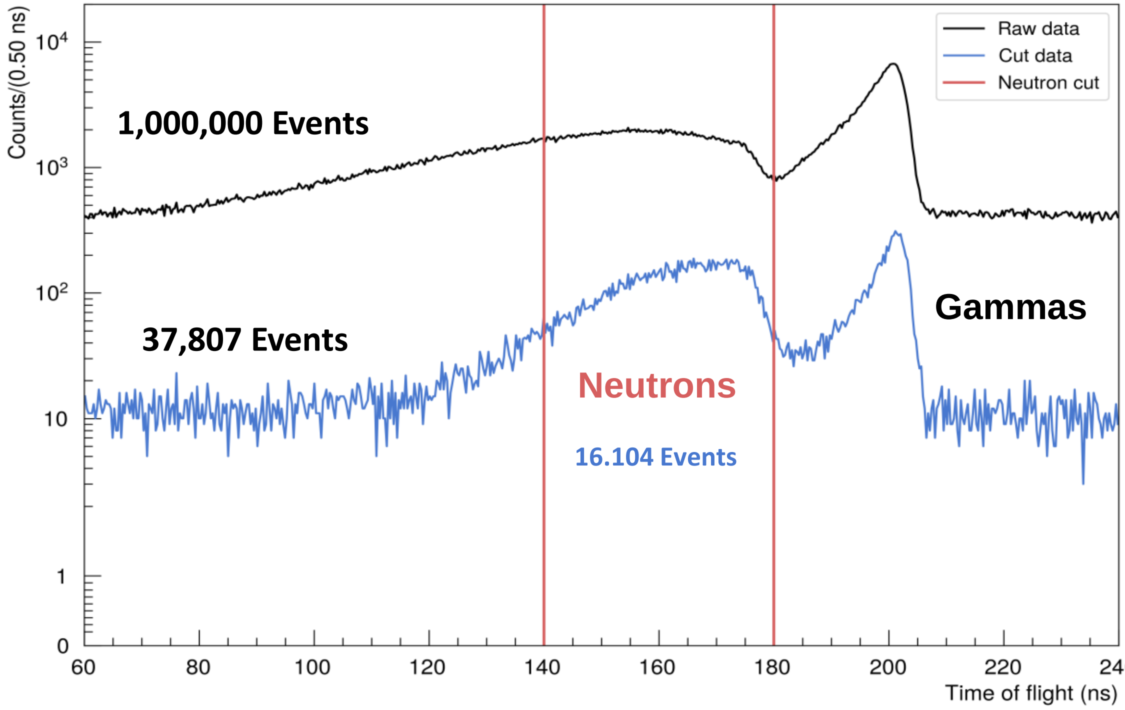
**TOF Spectrum of Neutrons and Gammas**

- $^{11}$B beam is chopped and bunched on the low energy part of the beamline directly after the injector
- Ion bunch of 10 ns width is hitting the hydrogen gas target **every 1250 ns**
- Since the detector is placed ≈ 1.5 m away from the hydrogen cell, the TOF can be used for particle identification.
- TOF of neutrons is smeared due to $^{11}B^{5+}$ energy losses caused by non homogeniously sputtered gold (from the beam stop) onto the inside of the target vessel foil (less $^{11}B^{5+}$ energy → less neutron energy → longer TOF).

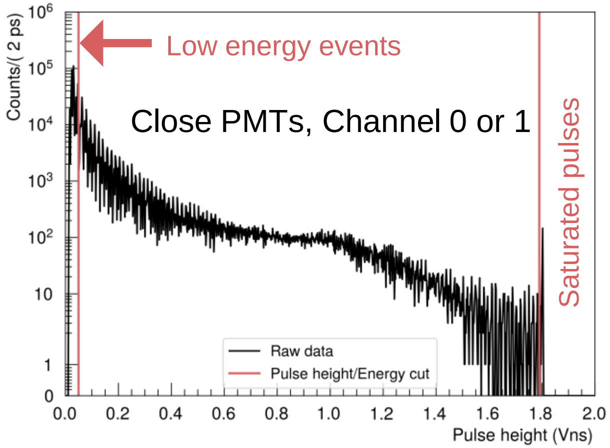
# Preliminary Data Analysis

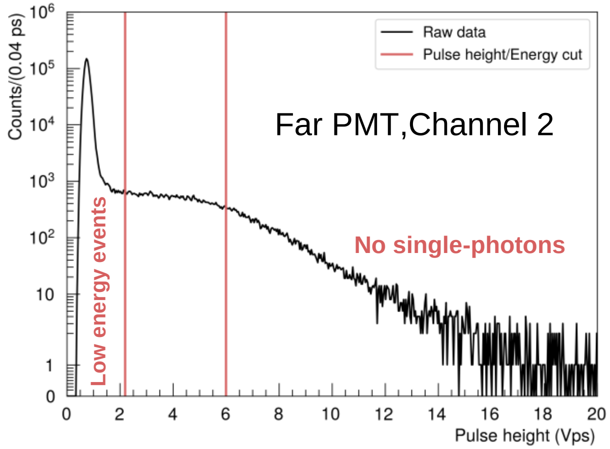
***Example:** first data of Friday night*

### Time-Of-Flight Spectrum of Neutrons and Gammas

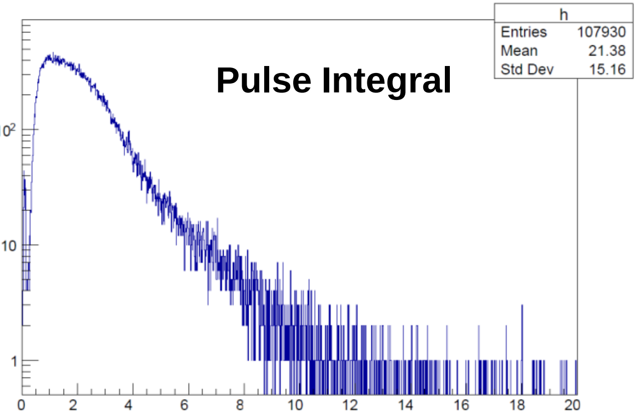


### Pulse Heights





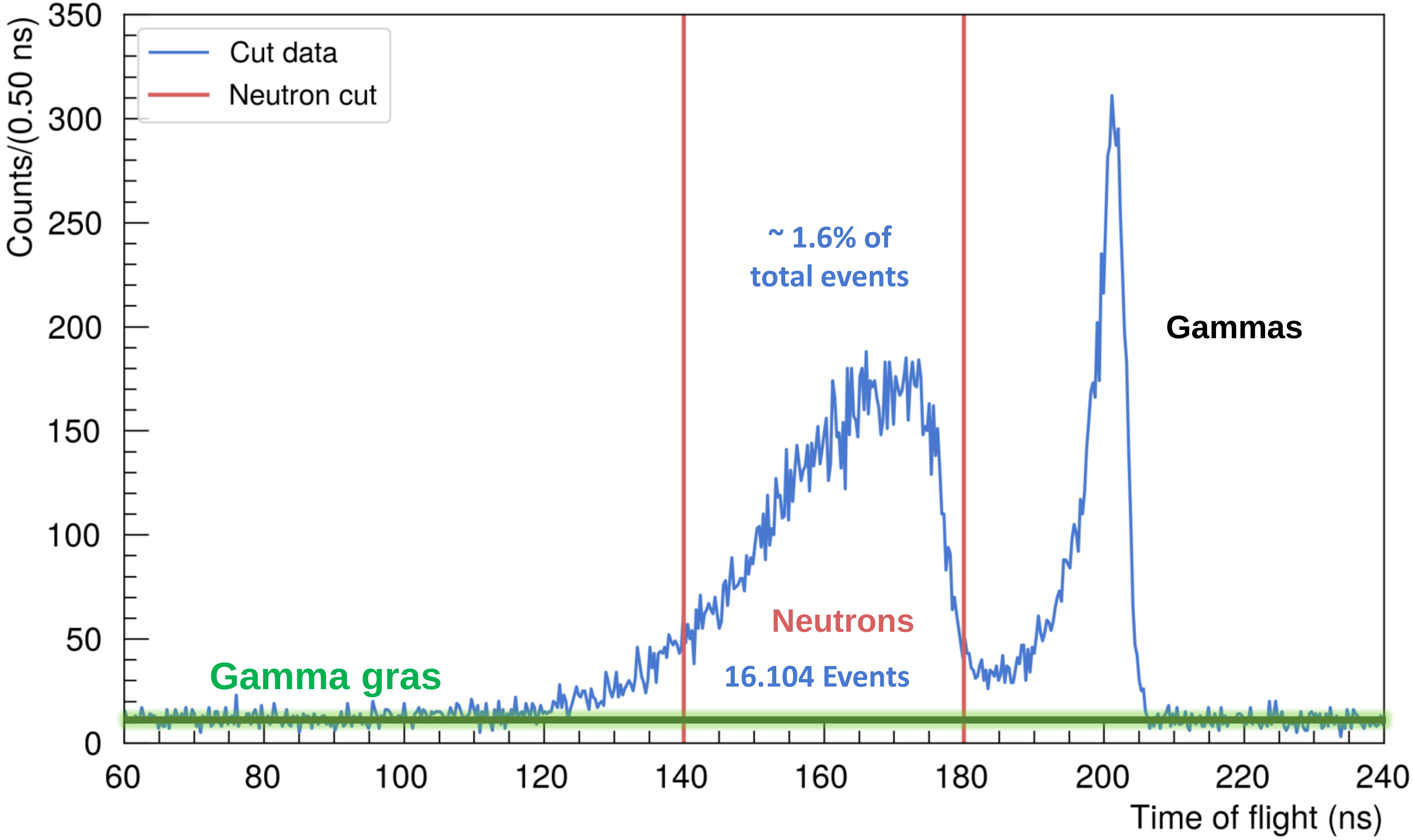
### Pulse Integral



# Preliminary Data Analysis

***Example:** first data of Friday night*

Time-Of-Flight Spectrum of Neutrons and Gammas



~ 1.6% of total events

Gammas

Neutrons

16.104 Events

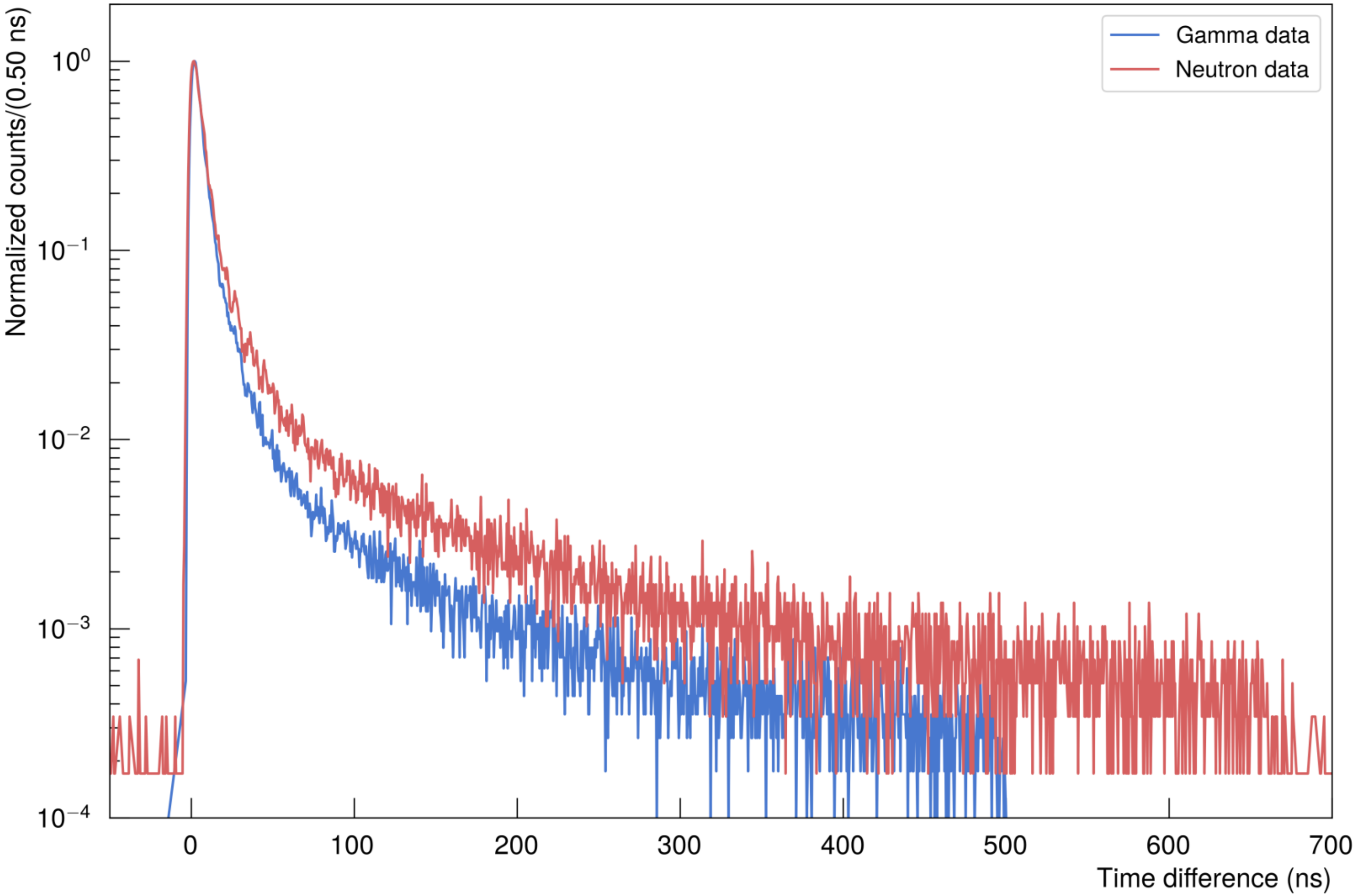
Gamma gras

**Around 5 % Gammas in our Neutron sample**

# Preliminary Data Analysis

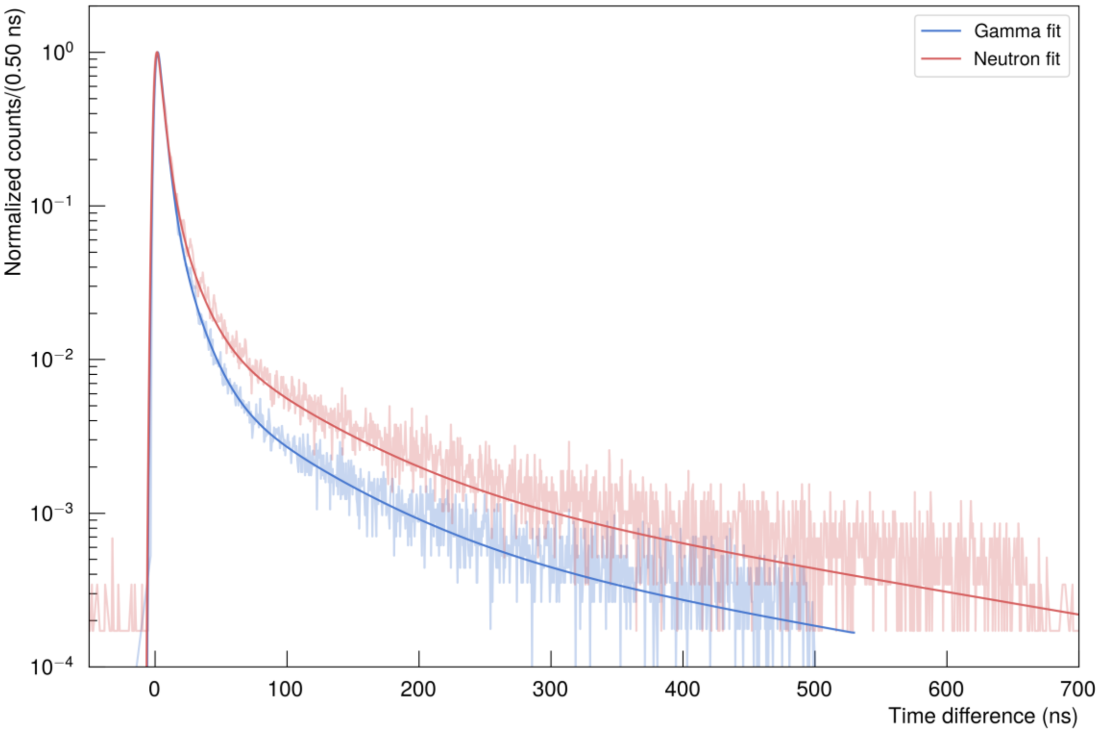
| Beam Time Data Runs | Total Events | Neutron Events after Cuts |
|---|---:|---:|
| Friday 1 | 1,000,000 | 16,104 |
| Friday 2 | 816,600 | 14,030 |
| Run 1 | 2,000,000 | 33,318 |
| Run 2 | 2,000,000 | 32,160 |
| Run 3 | 2,000,000 | 32,605 |
| Run 4 | 500,000 | 8,611 |
| **Total Beam time** | **8,316,600** | **136,828** |

# Preliminary Results

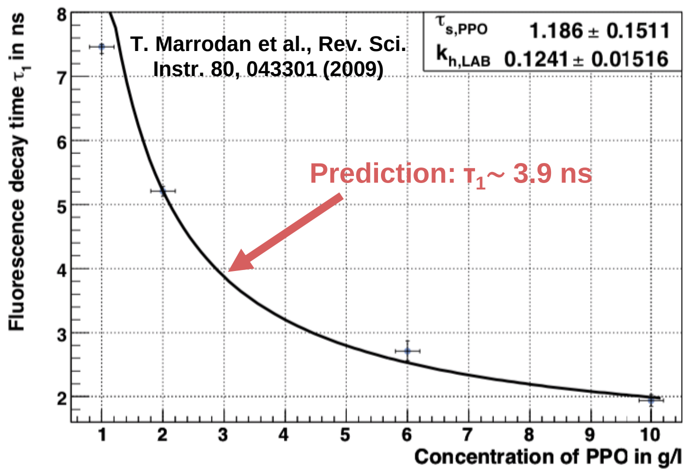


# Preliminary Results of the Beam Time

- **Simultaneous fitting** of gamma and neutron data with same decay-time constants for both curves but different probabilities



**Prediction of the shortest time constant prediction as function of the PPO concentration**



| | | |
|---|---|---|
| $\tau_1$ = 4.13 ± 0.04 ns | $p_{1G} \approx 90.67$ % | $p_{1N} \approx 85.93$ % |
| $\tau_2$ = 13.63 ± 0.37 ns | $p_{2G} \approx 8.82$ % | $p_{2N} \approx 12.96$ % |
| $\tau_3$ = 67.73 ± 4.11 ns | $p_{3G} \approx 0.46$ % | $p_{3N} \approx 0.98$ % |
| $\tau_4$ = 363.62 ± 30.33 ns | $p_{4G} \approx 0.06$ % | $p_{4N} \approx 0.14$ % |

**All uncertainties purly statistical!**

- MCMC-Fitting data by a convolution of the detector resolution (Gaussian) and four exponential decays

- More long lived decays in Neutron spectrum → Matches our expectation

$$F(t) = \sum N_i \times \exp\left(-\frac{t-t_0}{\tau_i}\right) * R(t)$$

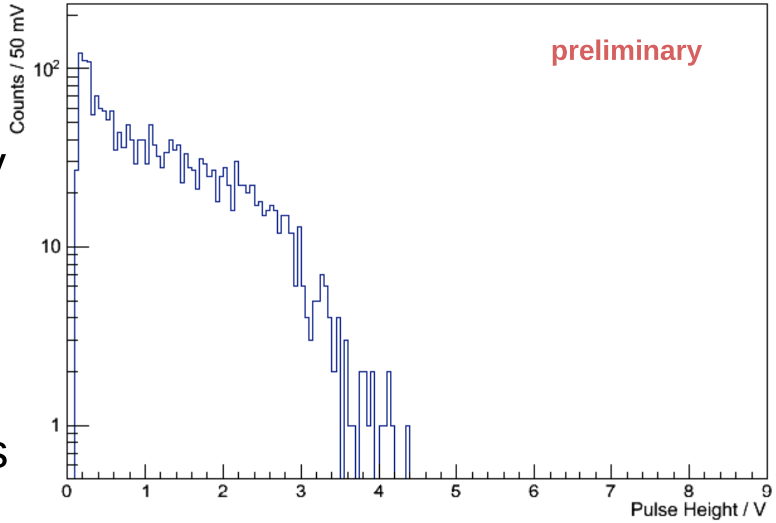
# Open Tasks

- Cross-check data analysis and perform an unbinned maximum likelihood fit with **RooFit** toolkit or **probfit** library

- Implement a **Monte Carlo simulation** of the experiment with Geant4 to study e.g. backgrounds or energy deposition by neutrons in other materials before interacting with the LS

- Sophisticated energy calibration for **Quenching factor** calculations (MC-based Compton edge reconstruction to obtain energy response of the detector for e.g. electrons, analogous to Vincenz Zimmer‘s PhD Thesis)

- Looking into the **physics** behind the fluorescence process of different particle types (e.g. working through literature)



# Outlook

**This September:** *11-day beam time at MLL*

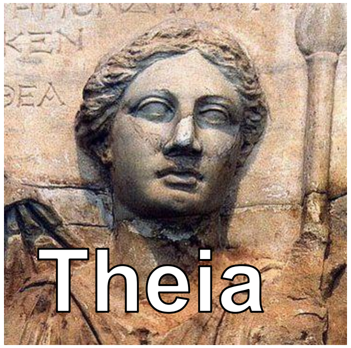
***Planned samples*:**

1. JUNO Type I (LAB + 3 g/l PPO + 20 mg/l bisMSB)
2. JUNO Type II (LAB + 2.5 g/l PPO + 15 mg/l bisMSB, Nanjing Spec. Lab)

3. Slow LS (LAB + 70 mg/l PPO, Att. Length = 25 m, Nanjing Spec. Lab)

4. US WbLS (Water + Surfactant: LAS + 5% JUNO LS)
5. Bavarian WbLS (Water + Surfactant: Triton X100 + 5% JUNO)

6. Borexino LS (PC + 1.5 g/l PPO)



# Thanks for your attention!