Minidex

Muon-induced neutrons indirect detection experiment

Measurement of muon-induced neutrons

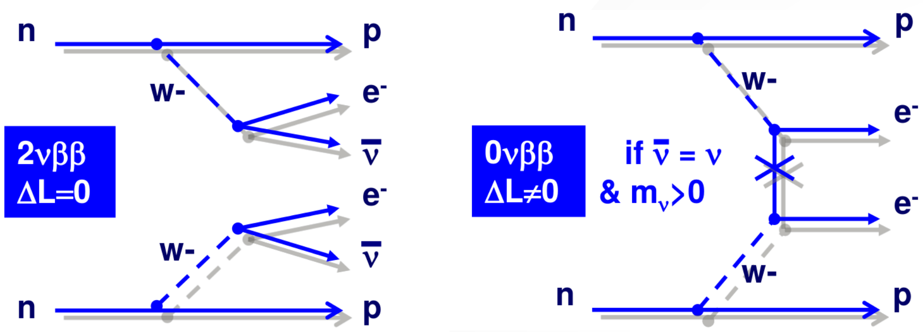
IMPRS colloqium - 08/04/2016

Raphael Kneißl

Outline

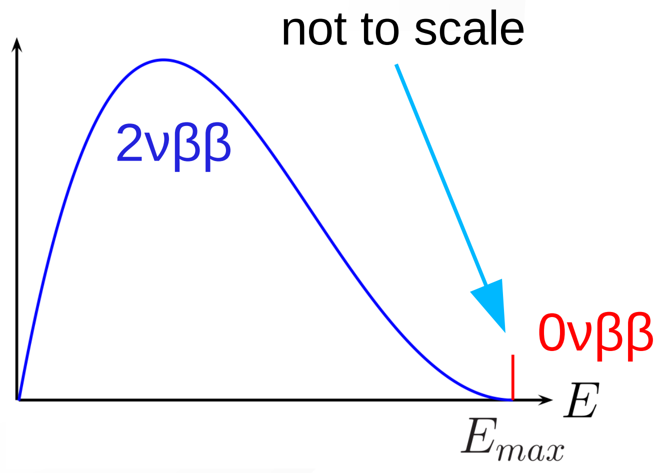
1. 0νββ, muon-induced neutrons and motivation of Minidex
2. Working principle and general analysis strategy
3. Minidex Run 1
4. Minidex Run 2 and fast neutron detector
5. Summary and outlook

0νββ



Experiments (e.g. GERDA) are searching for the 0νββ, if exists:

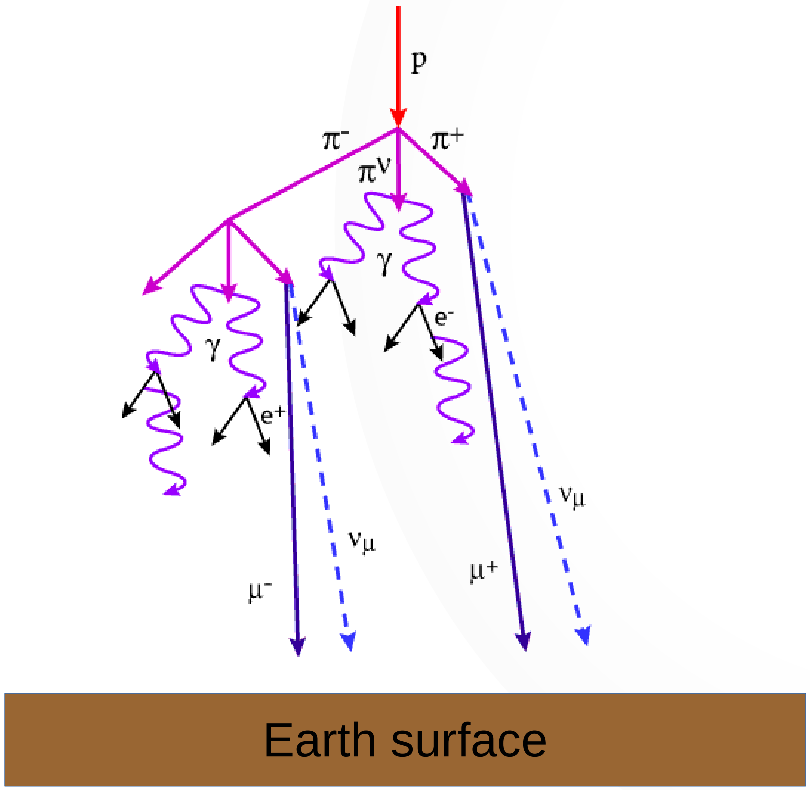
→ determines nature of ν (Dirac or Majorana)
→ gives information on absolute neutrino mass / mass hierarchy
→ implies lepton number violation



Low backgrounds are required to measure 0νββ !!!

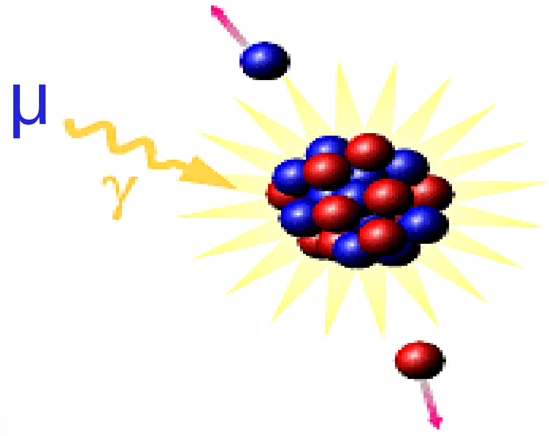
1.1 Muon-induced neutrons

Muons



Muon-induced neutrons

Neutron production via different processes: photo-nuclear interactions (dominant at ~10GeV), muon capture, ...



1.2 Motivation for Minidex

Muon-induced neutrons as background source for low-background experiments

Direct background:
Generation of signals in the detectors

Indirect Background:
Production of long-lived radioactive isotopes

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Muon-induced neutrons as background source for low-background experiments

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Generation of signals in the detectors

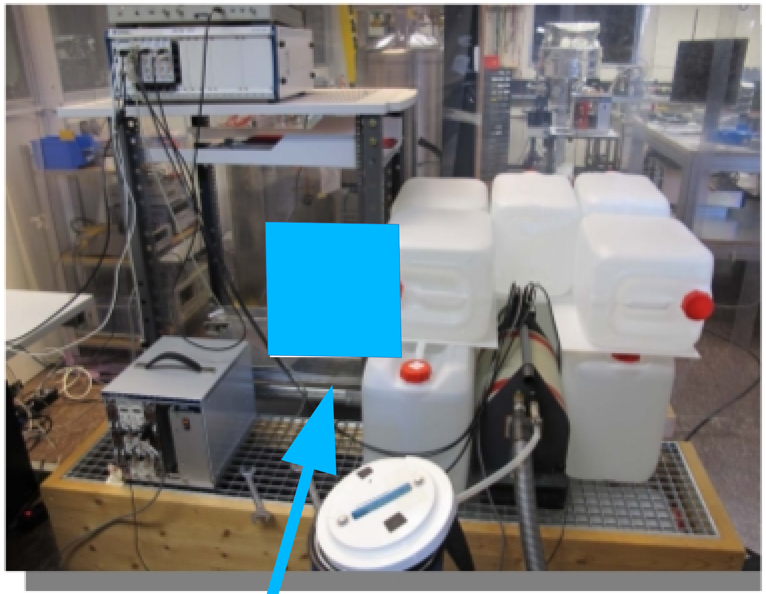
Indirect Background:
Production of long-lived radioactive isotopes

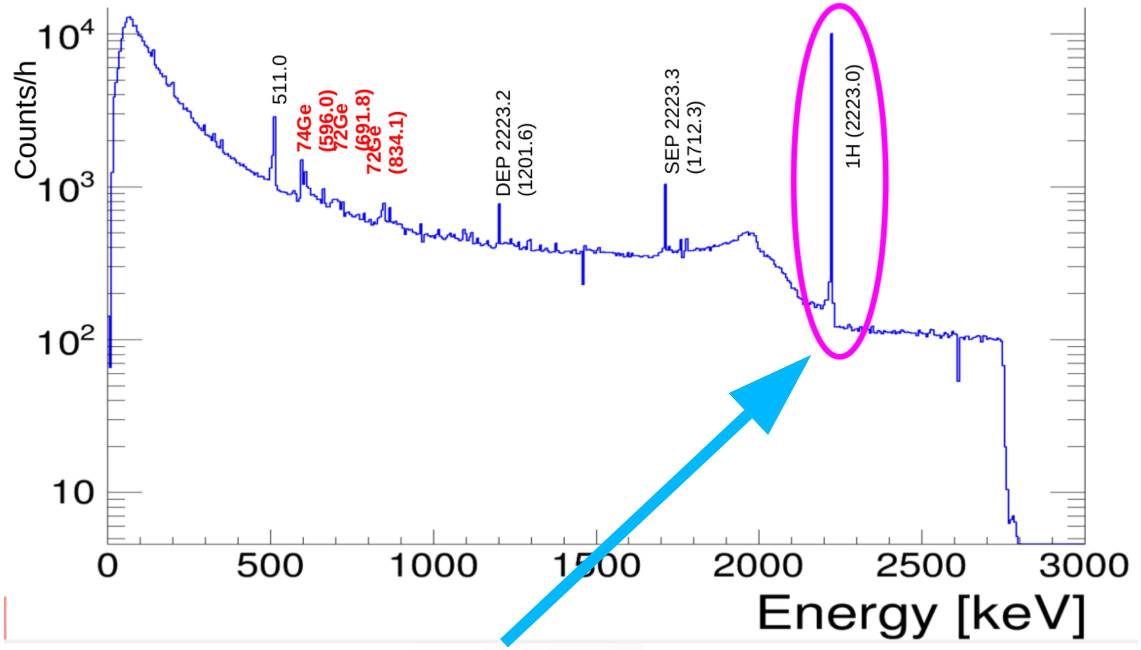
Problem: Neutron production rates as **function of muon energy and material** are not well known

Experiment for MC validation → Improve numbers → Tune MC → Optimize shielding, positioning, ...

1.3 Origin of Minidex idea

Original research project: Investigate neutron capture on germanium detectors





AmBe neutron source

Thermal neutron capture on hydrogen with 2.223 MeV gammas

Use this idea to investigate muon-induced neutrons

1.4 Minidex project

Experiment

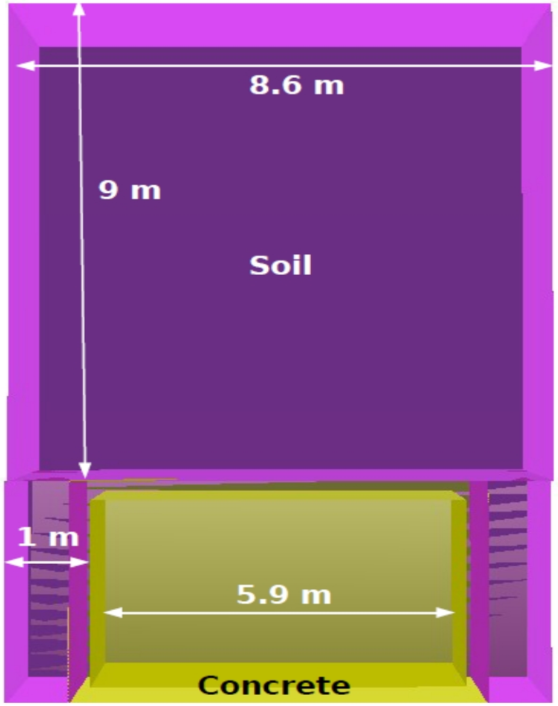
Built up experiment in shallow underground lab (~16m.w.e.):

- Suppress cosmic neutron flux (at sea level)
- Still high muon flux
- Good accessibility

Compare

Monte Carlo

Monte Carlo of lab and Mindex setup (Geant4 9.6.2 interfaced with Mage)



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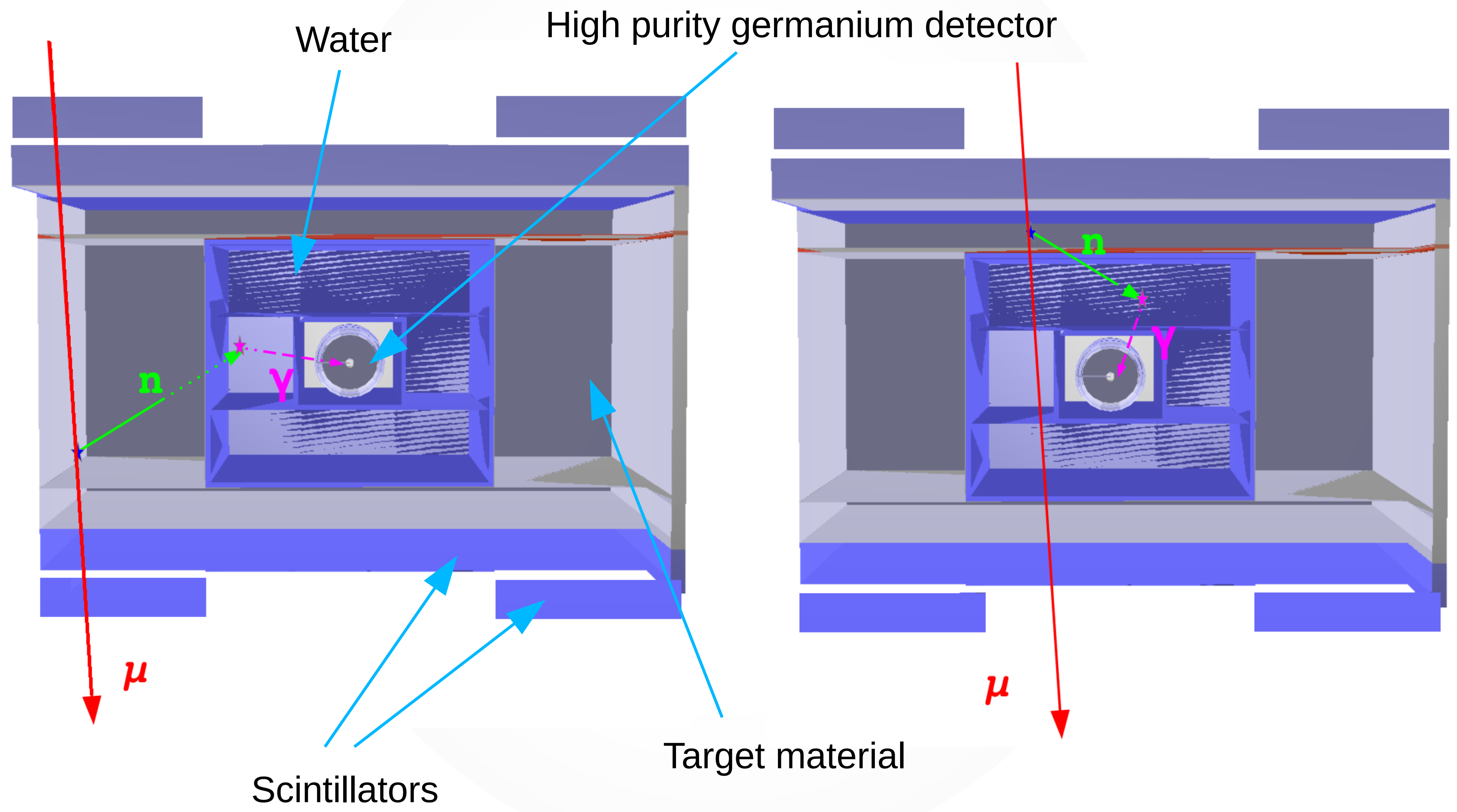
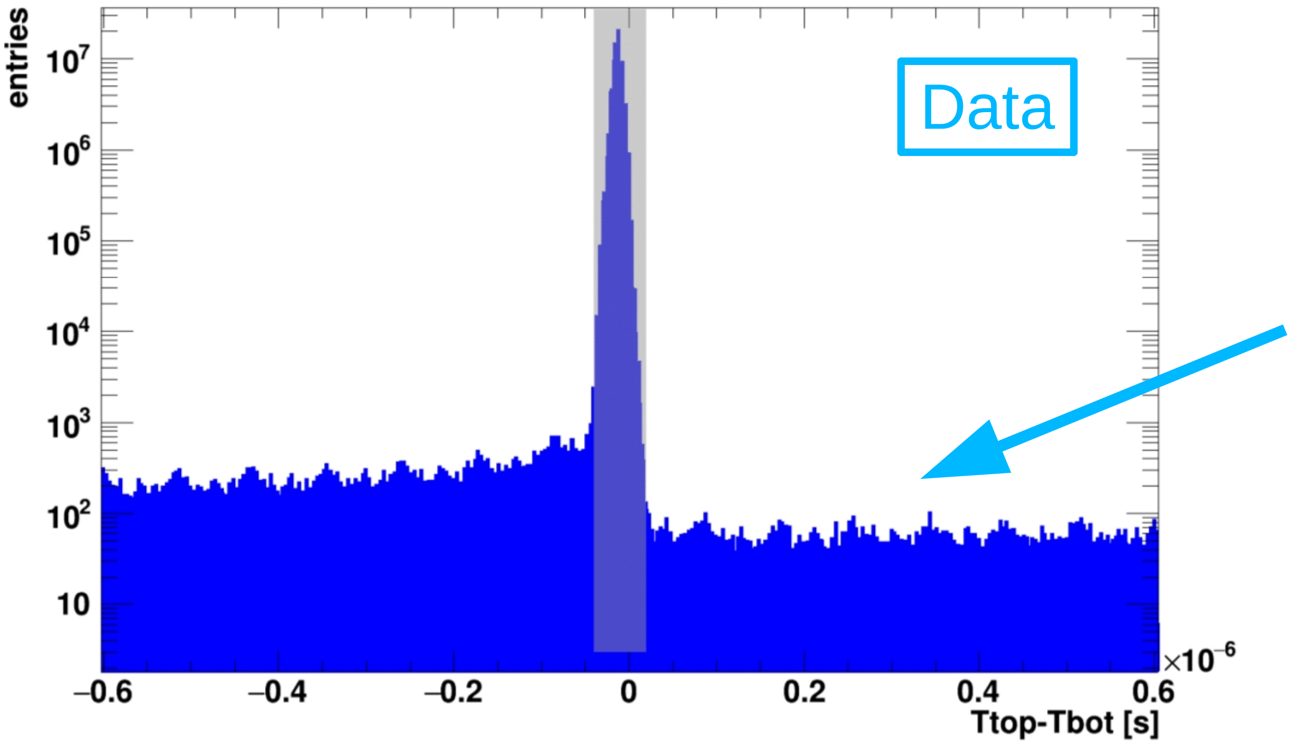
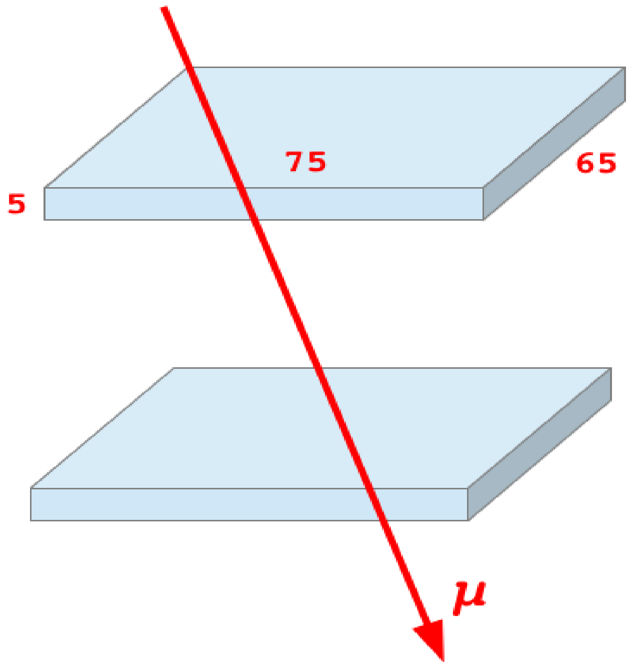
2.1 Working principle of Minidex



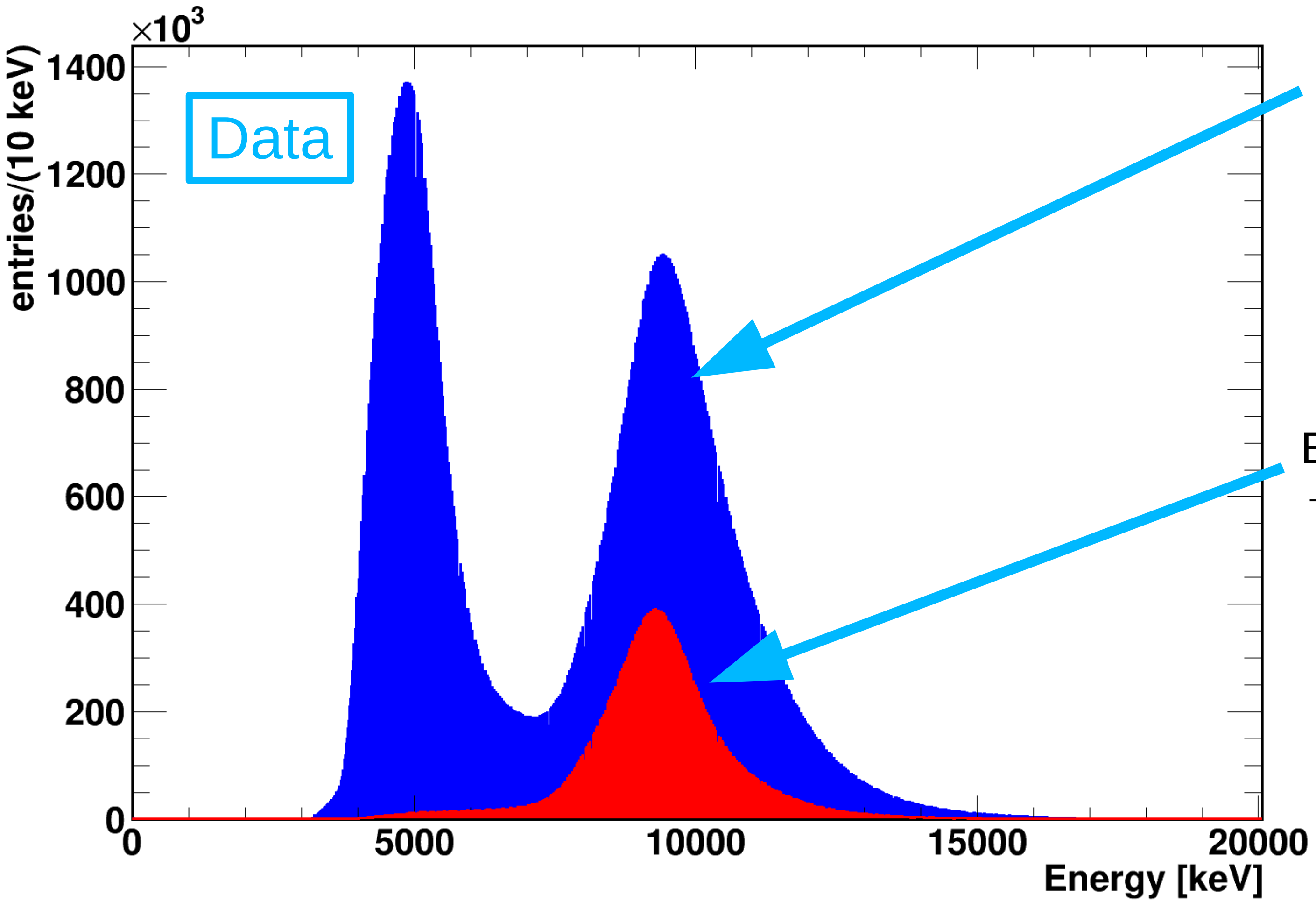
2.2 General analysis strategy





Define a trigger: Allowed time difference between the panels is -40ns to +20ns

2.2 General analysis strategy

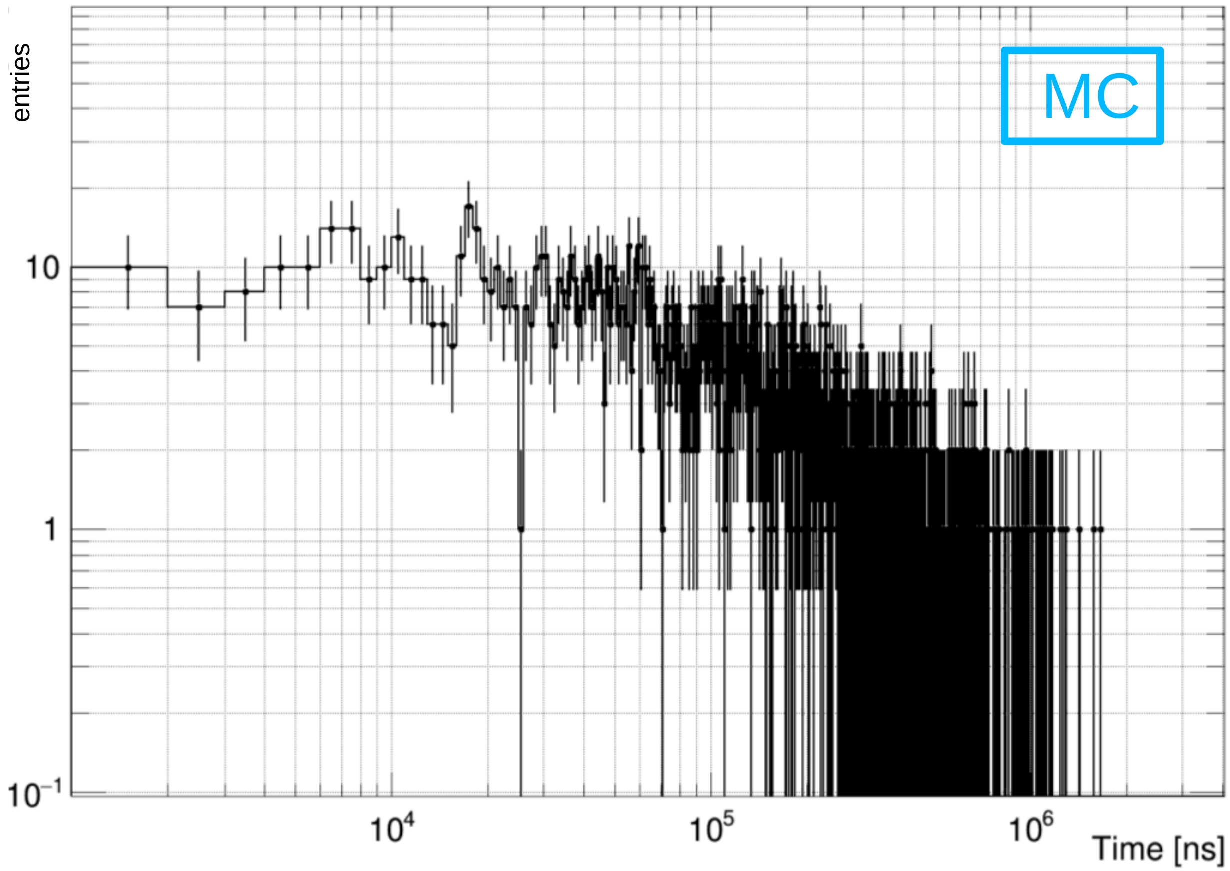


Energy spectrum of top scintillator without time cut

Energy spectrum with time cut
→ trigger rate: ~(8-10)Hz

2.2 General analysis strategy

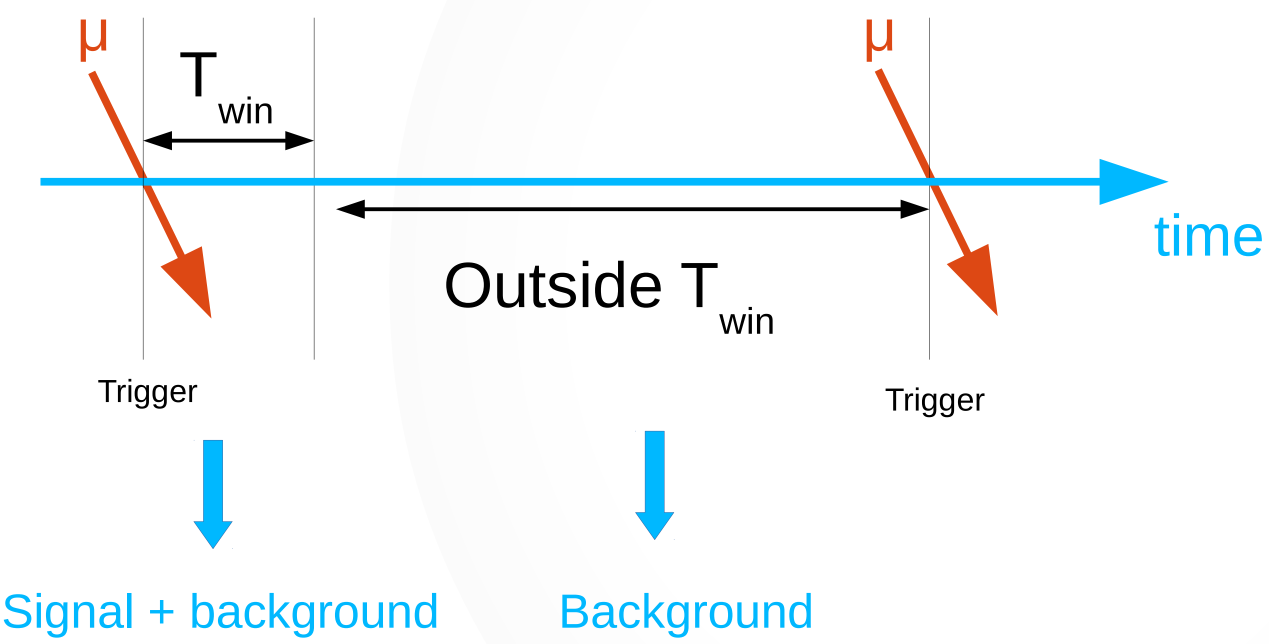
Time distribution between trigger and a detected 2.2MeV gamma



All muon-induced 2.2Mev gammas are detected before ~2ms

2.2 General analysis strategy

Look for 2.2MeV gamma's in the germanium detectors



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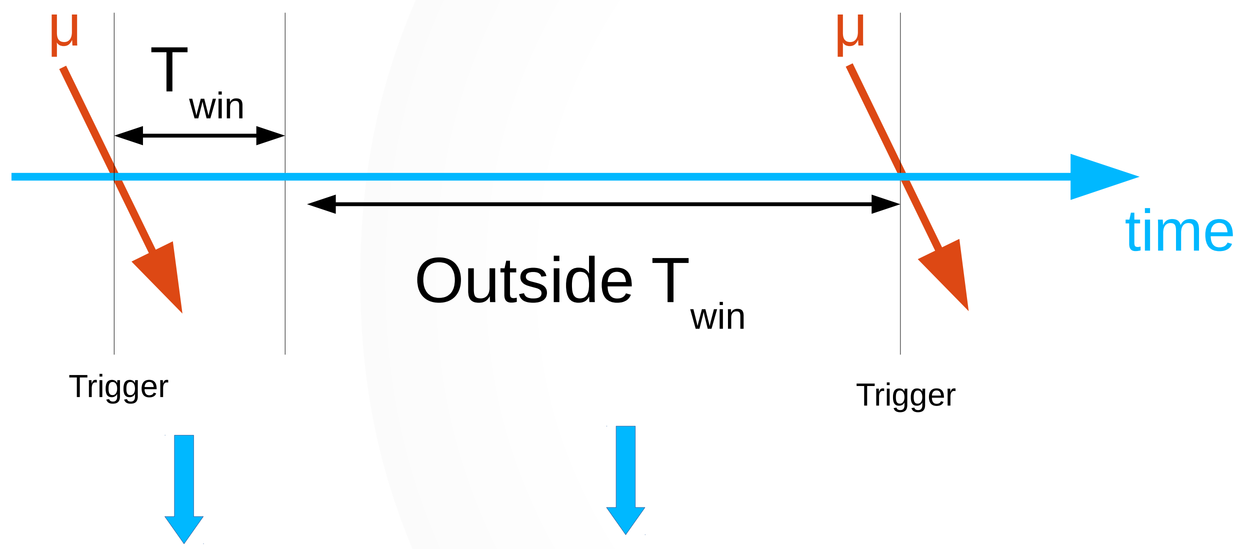


Signal + background

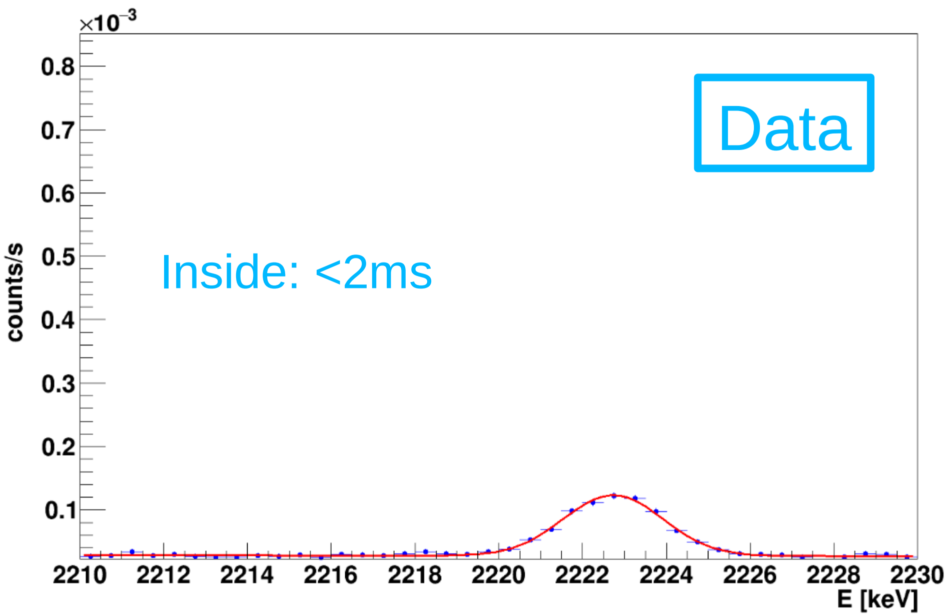
Background

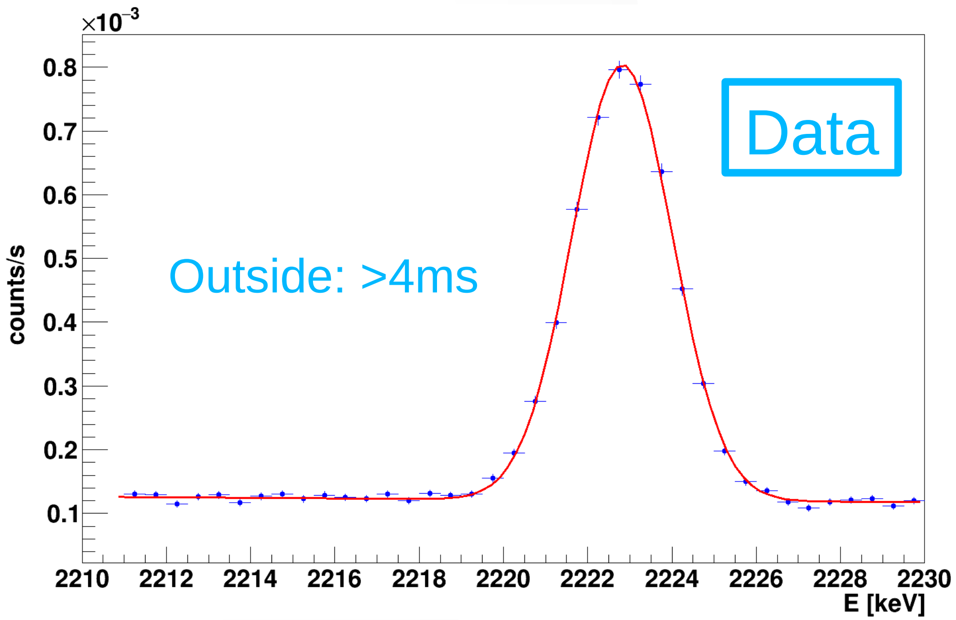
Determine the S/B ratio for different time windows (10μs to 50ms)
→ investigate the time behavior of our MC for muon-induced neutrons in our setup

2.2 General analysis strategy

Inside T_{win} - to collect the whole signal: <2ms

Outside T_{win} – to collect the background: >4ms





Fit: Gaus + pol1 → Determine the signal and background

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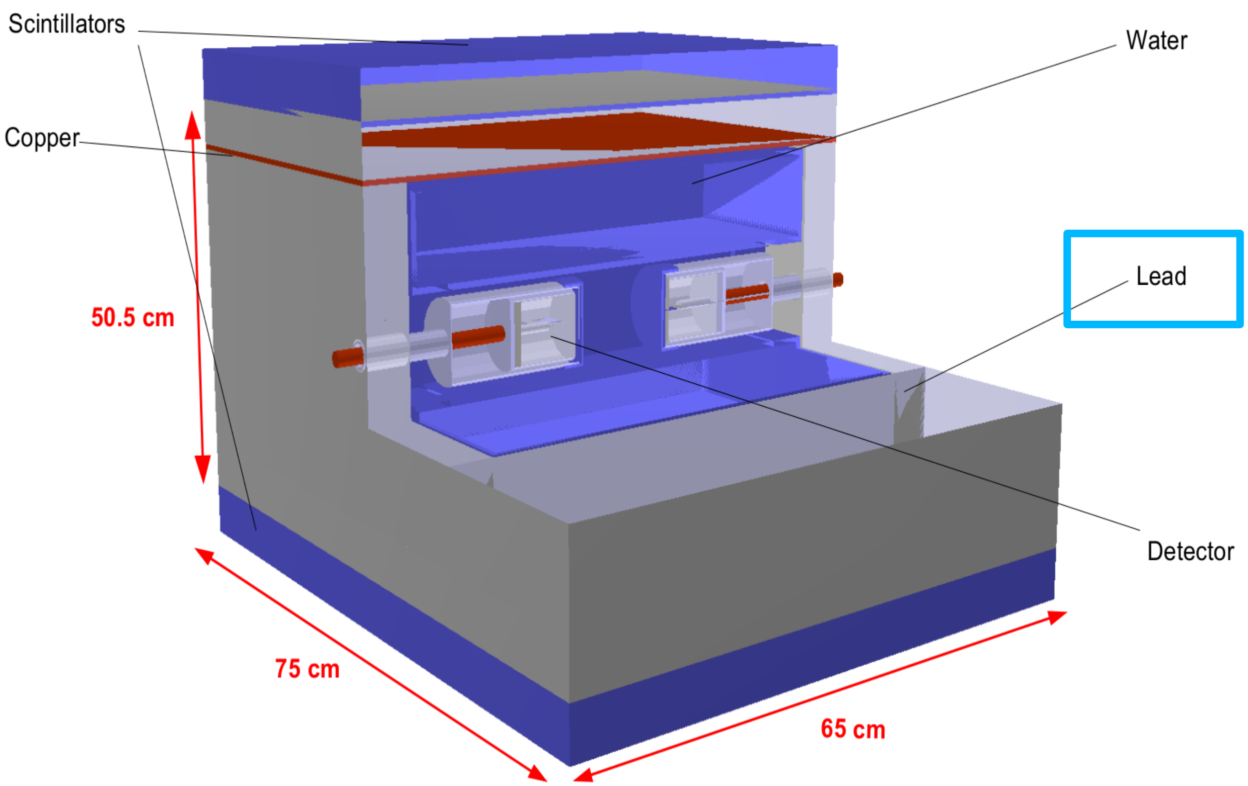
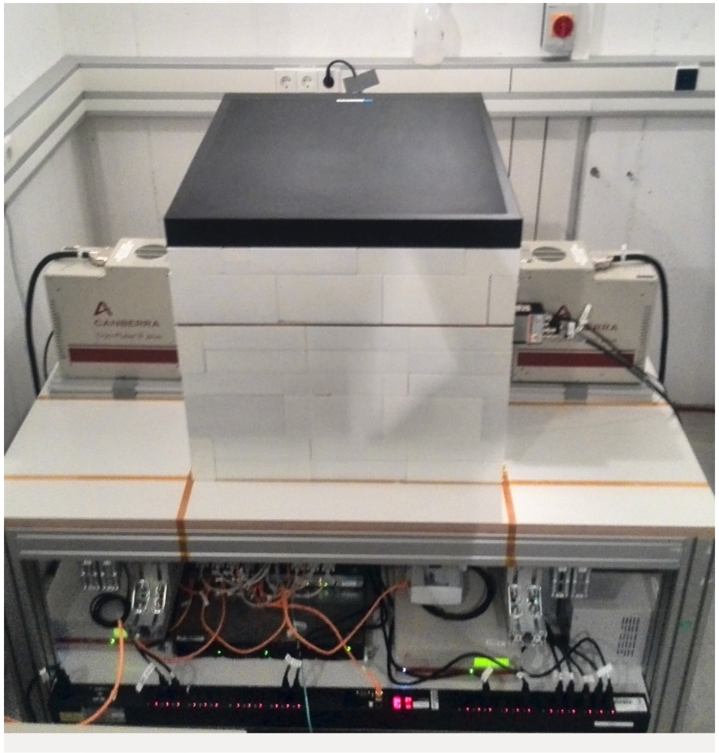
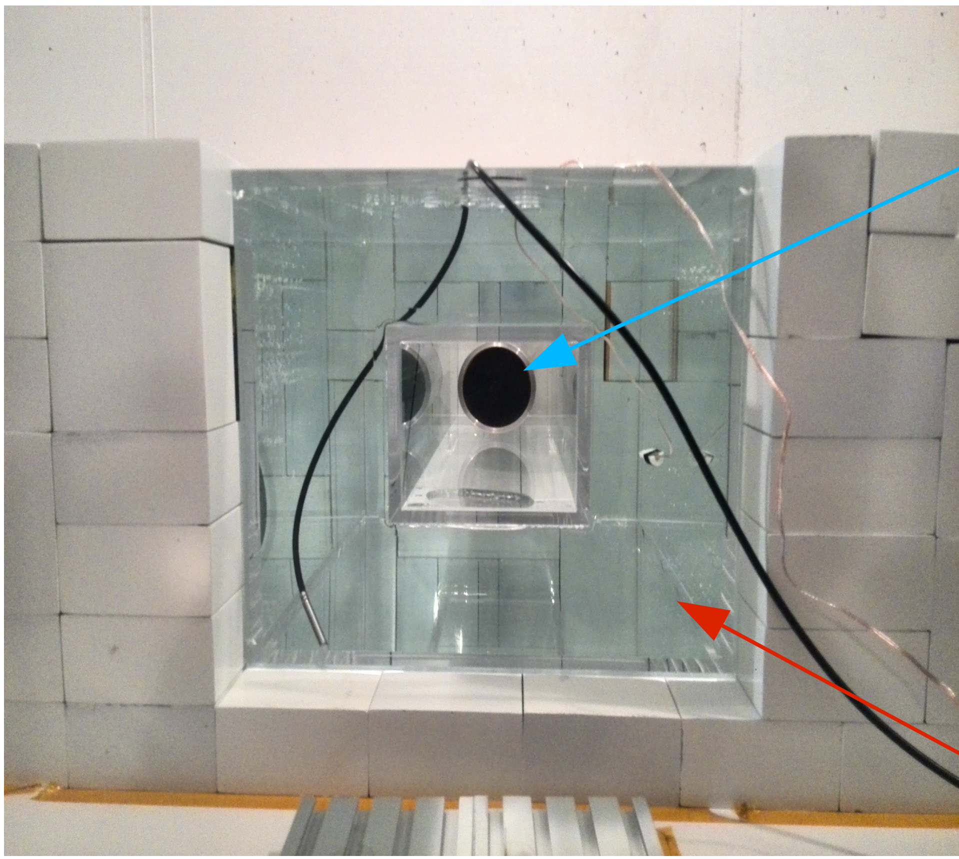
3.1 Minidex run 1 setup

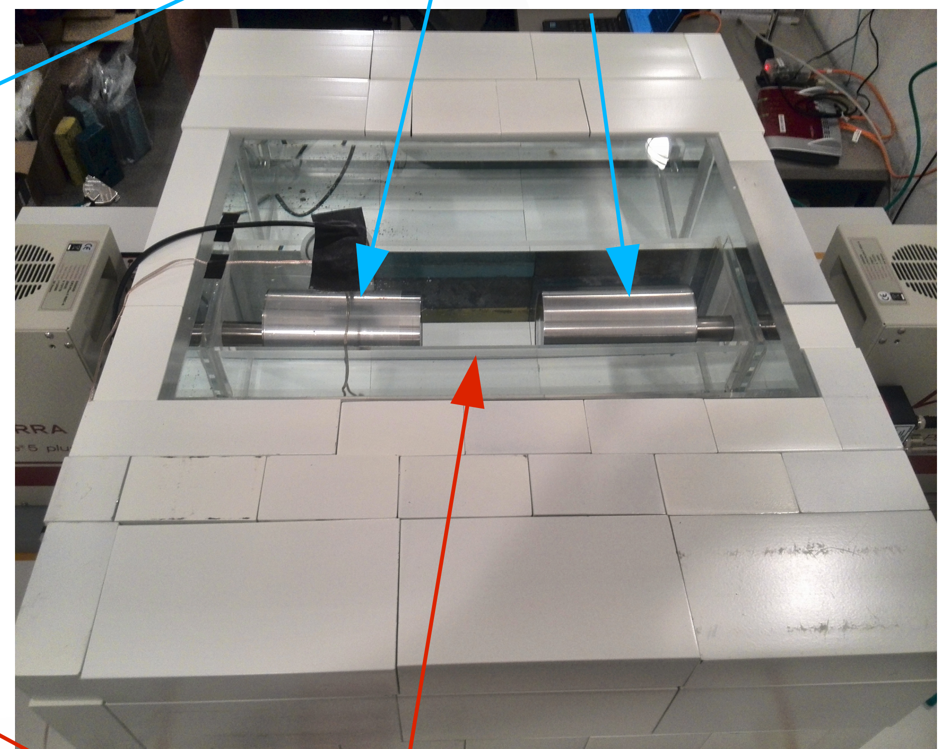




3.1 Minidex run 1 setup

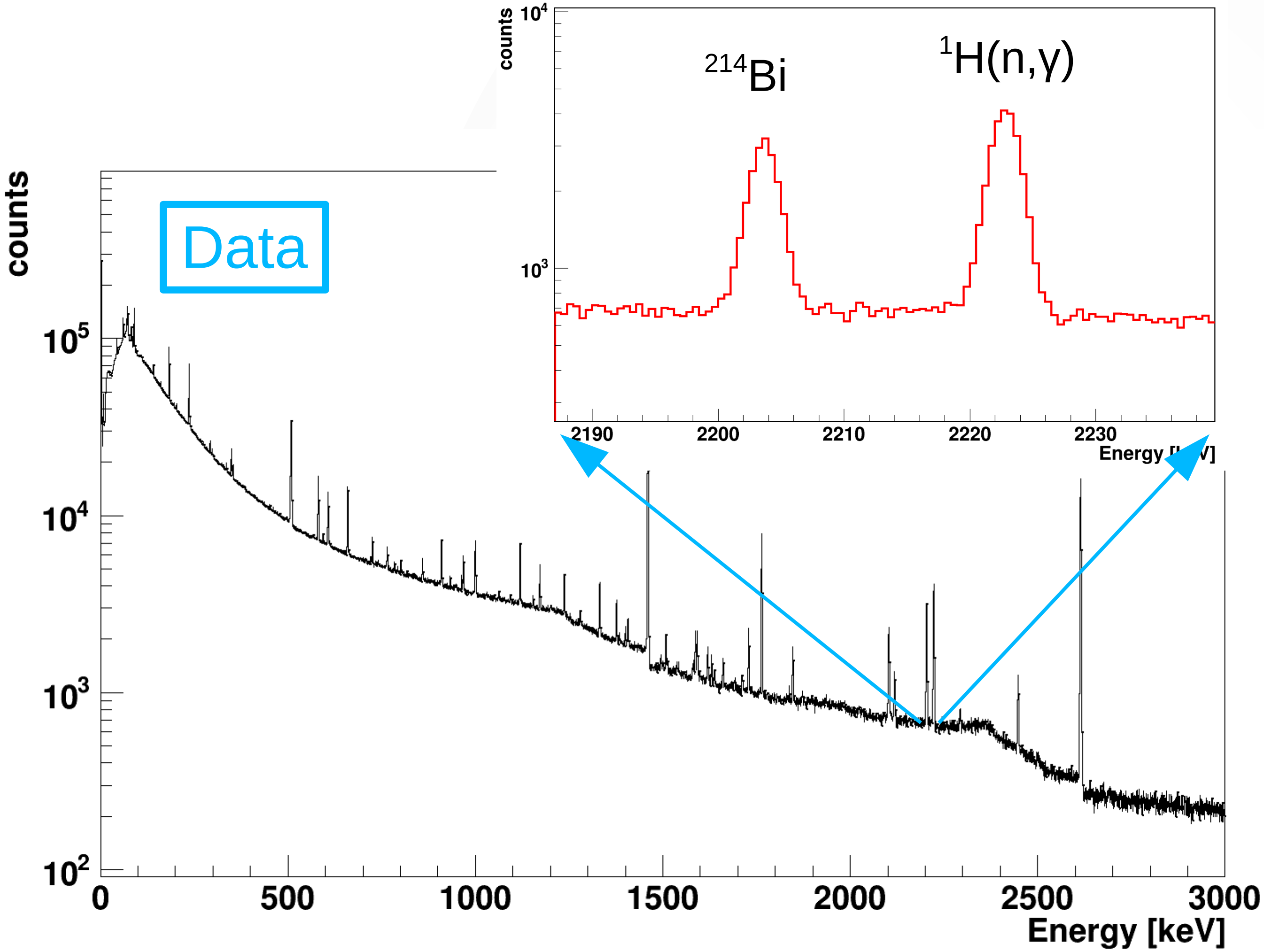
High-purity germanium detectors





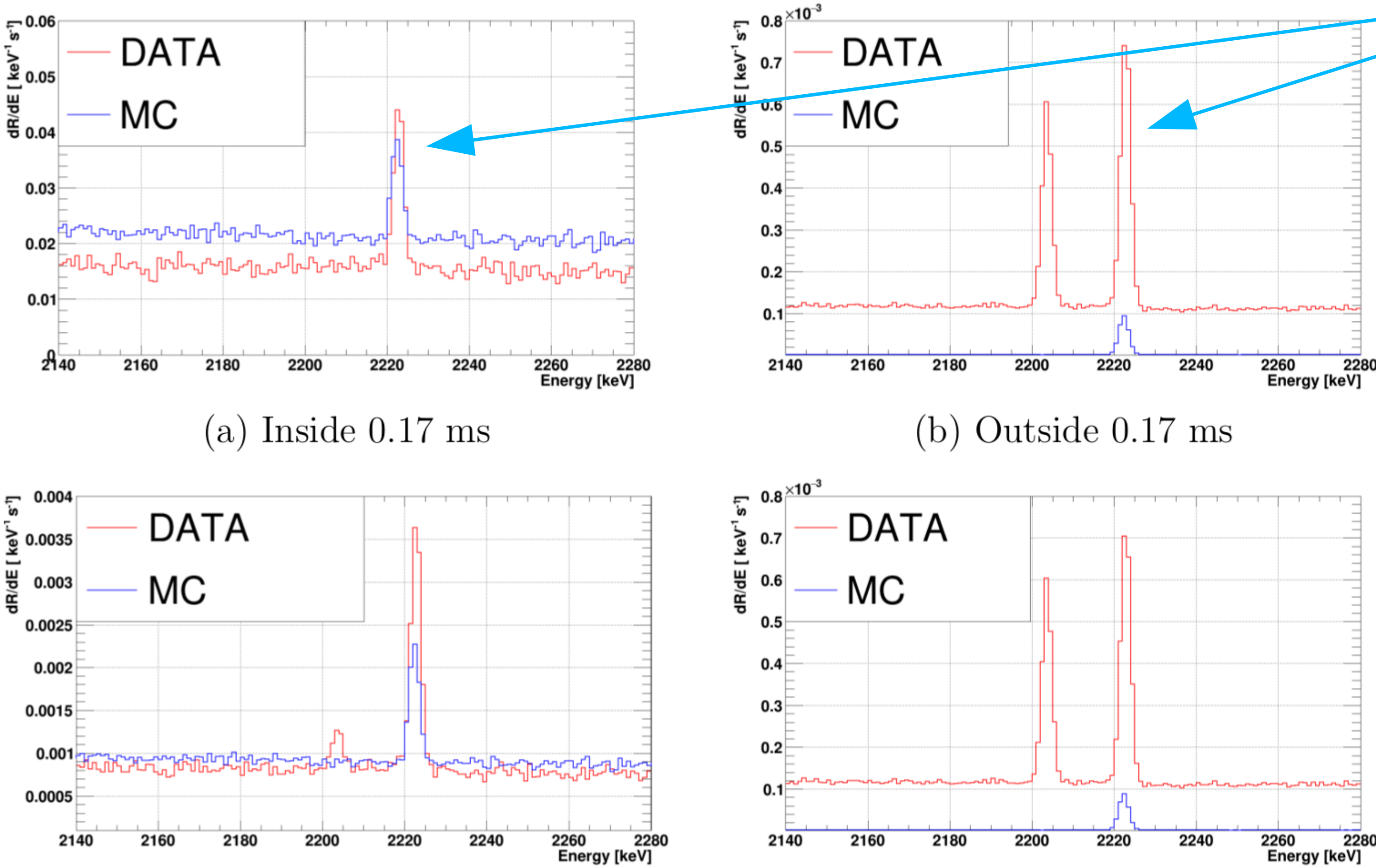
Plastic container with water

3.2 Minidex run 1 energy spectrum



- Commissioning run (July 2015 to Jan. 2016)
  → ~100 days of data
- Efficiencies of scintillator panels only 80-90 %
- No small scintillator panels installed
  → lead signal contaminated by water
- Energy resolution (FWHM) at 2.2MeV: ~2.8keV

3.3 Data MC comparison



(a) Inside 0.17 ms

(b) Outside 0.17 ms

(c) Inside 4 ms

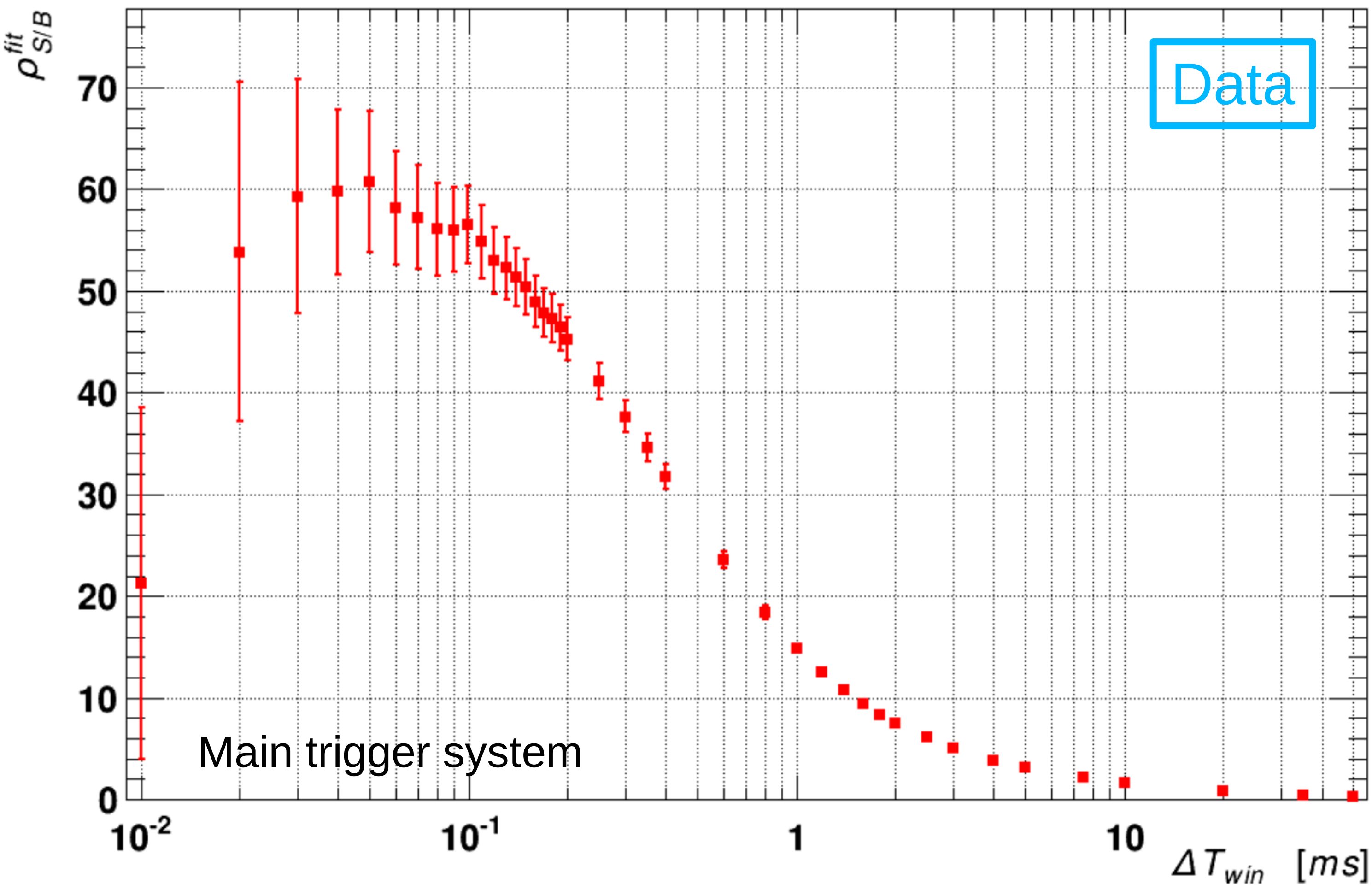
(d) Outside 4 ms

Neutron peak

- MC produces to less signal
- Missing background in MC

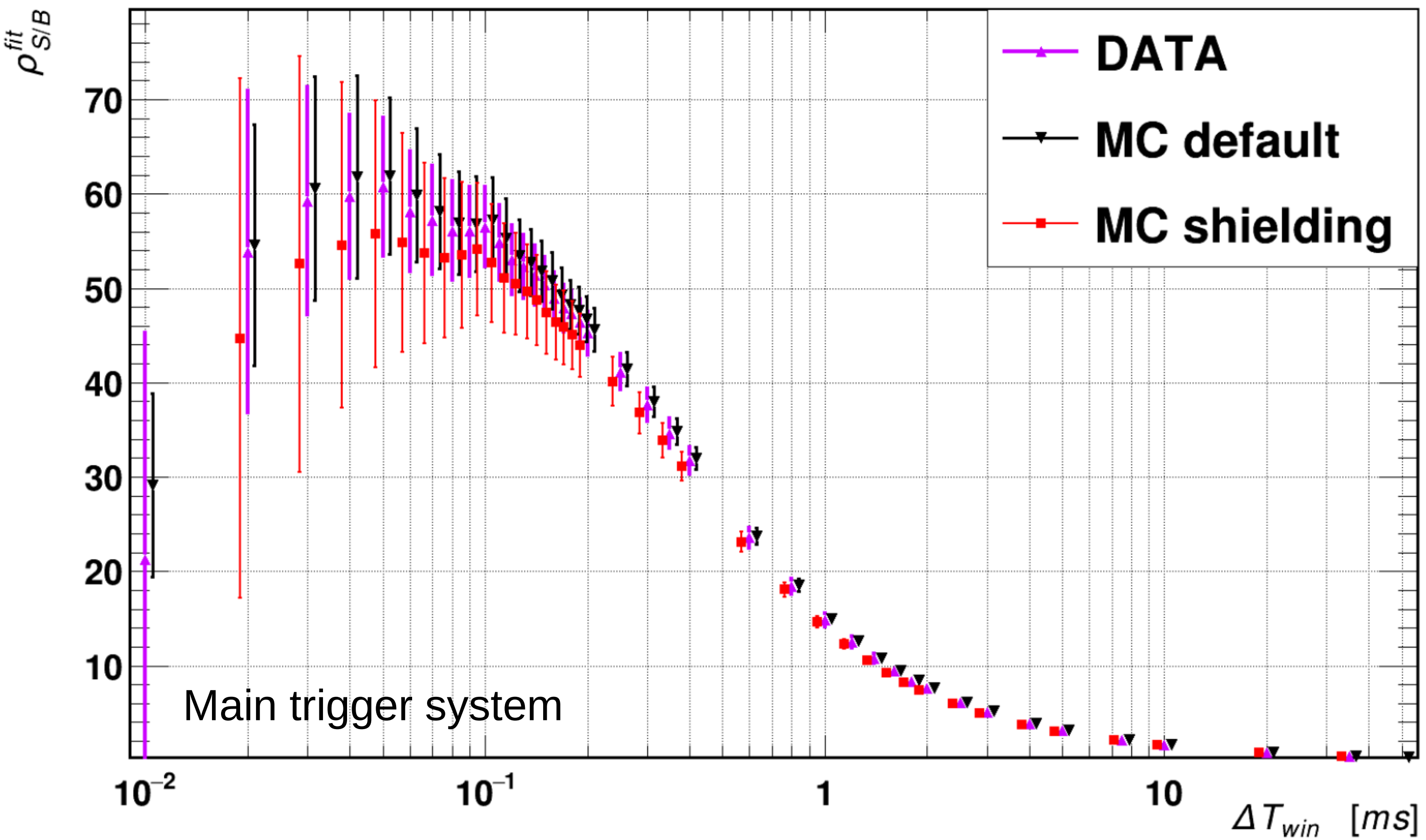
Scale MC to data

3.3 Signal to background ratio



- Only the two big panels generate the trigger
- Efficiency of panels are taken into account
- T_{win} = 2ms → S/B~7
- T_{win} ≤ 0.1ms → S/B~60

3.3 Signal to background ratio



Good time behavior reconstruction of our MC for the detection of muon-induced neutrons in our setup

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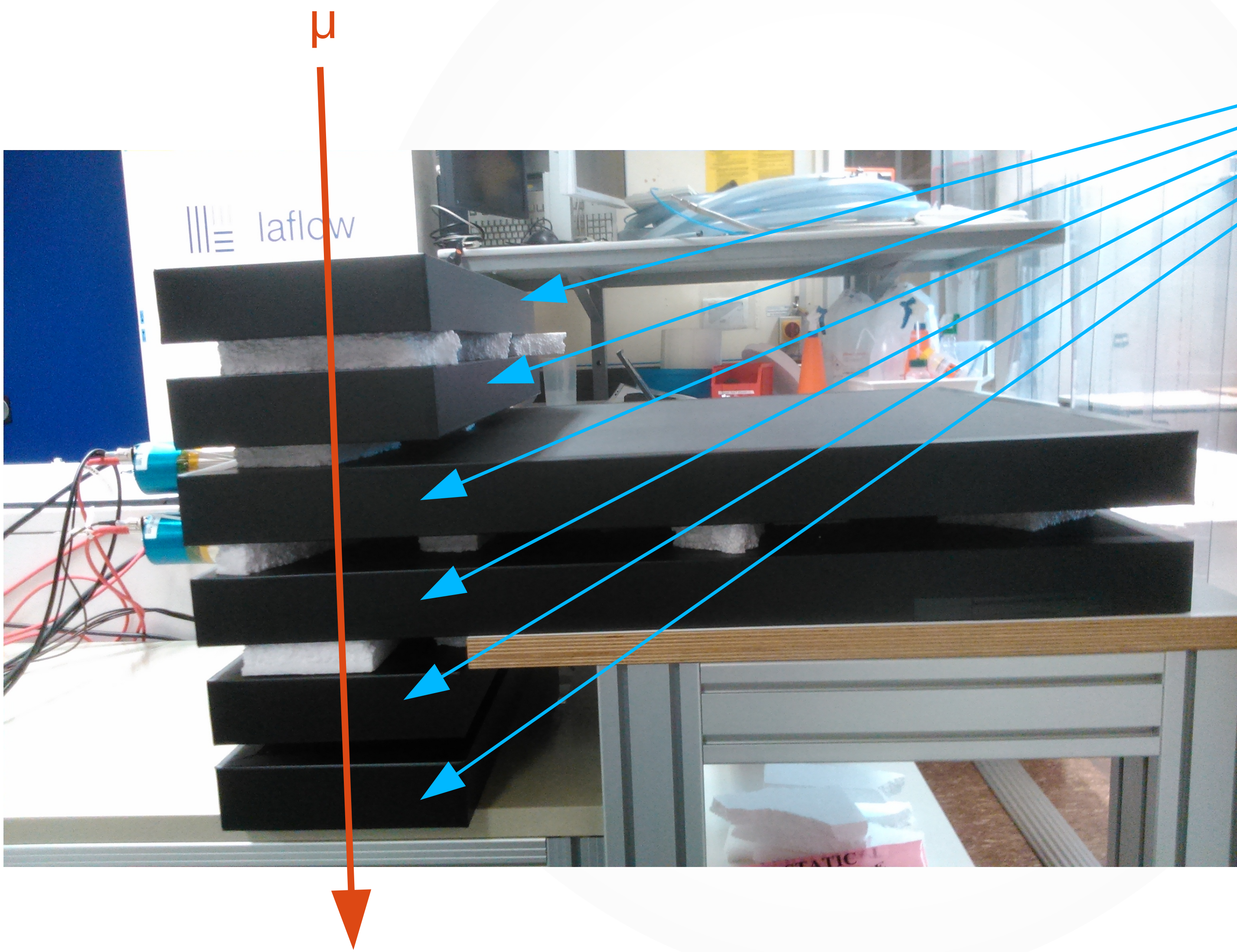
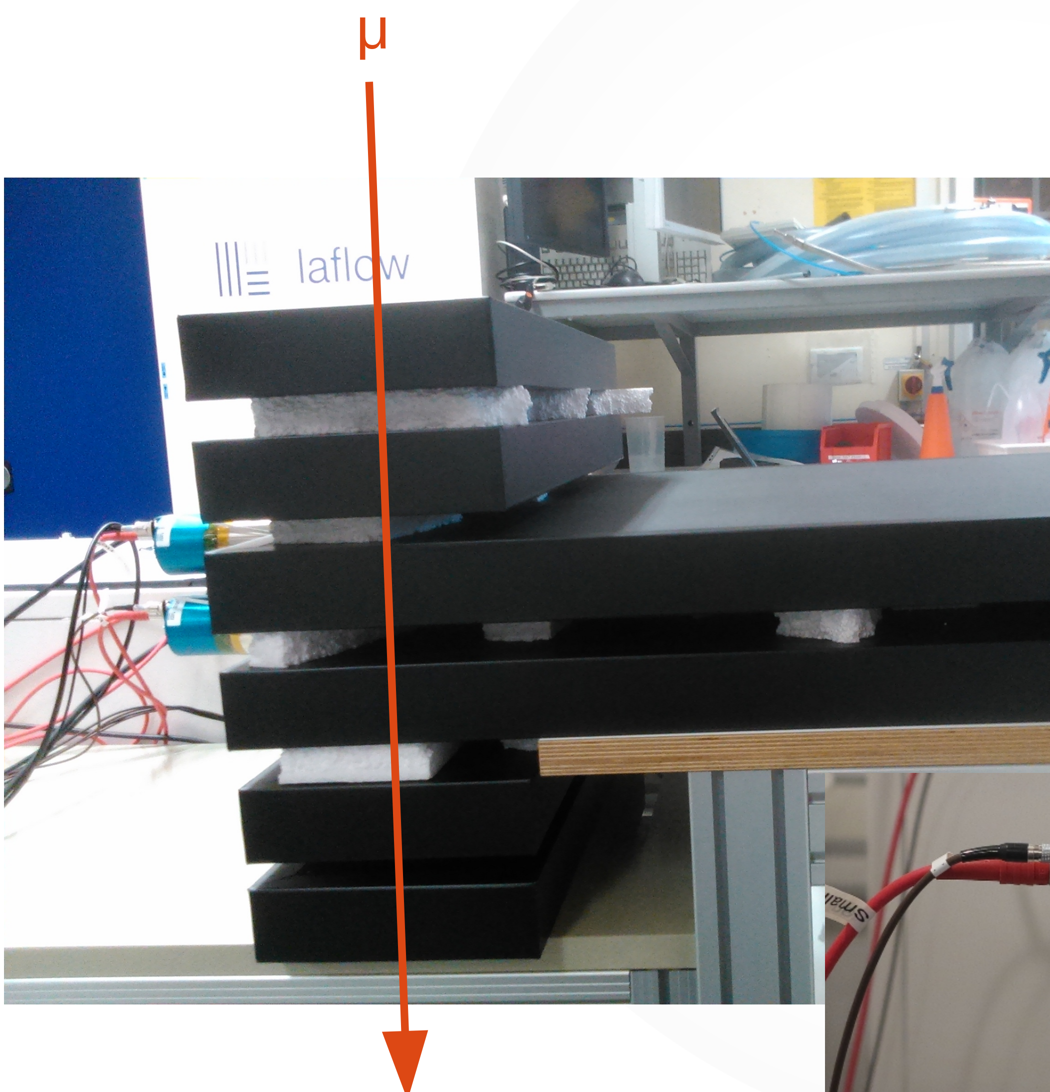
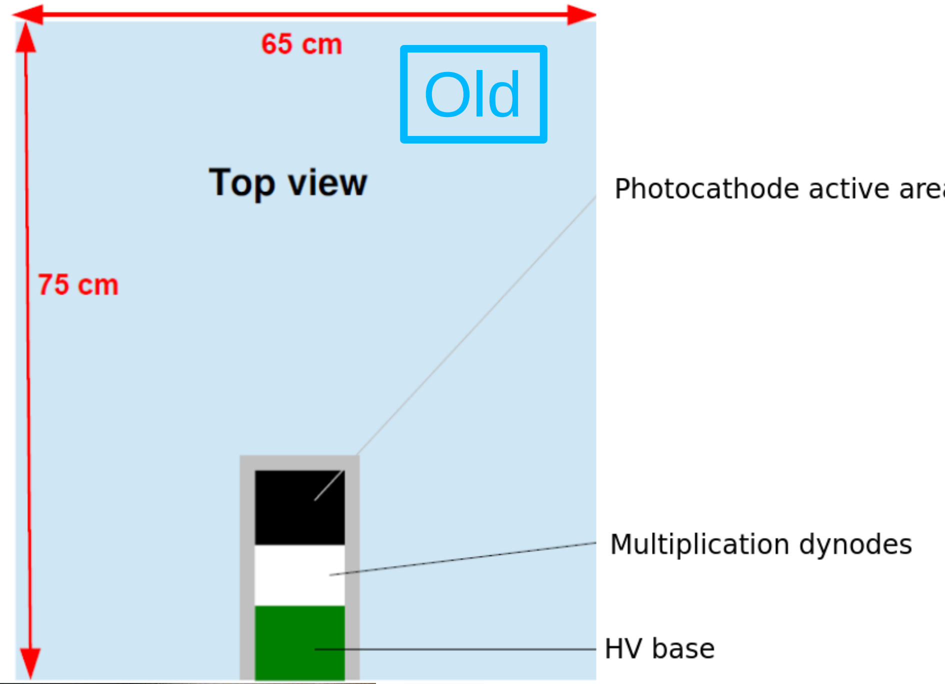
4.1 Minidex run 2 - new panels

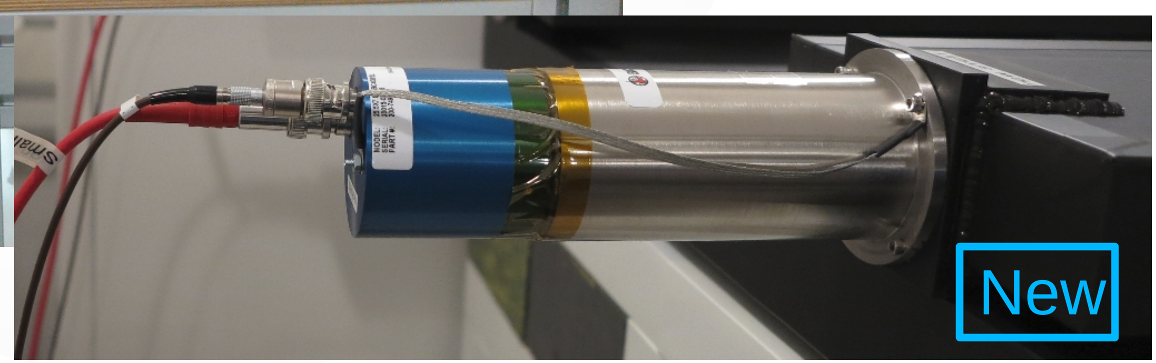


New scintillators
→ efficiencies >99 %

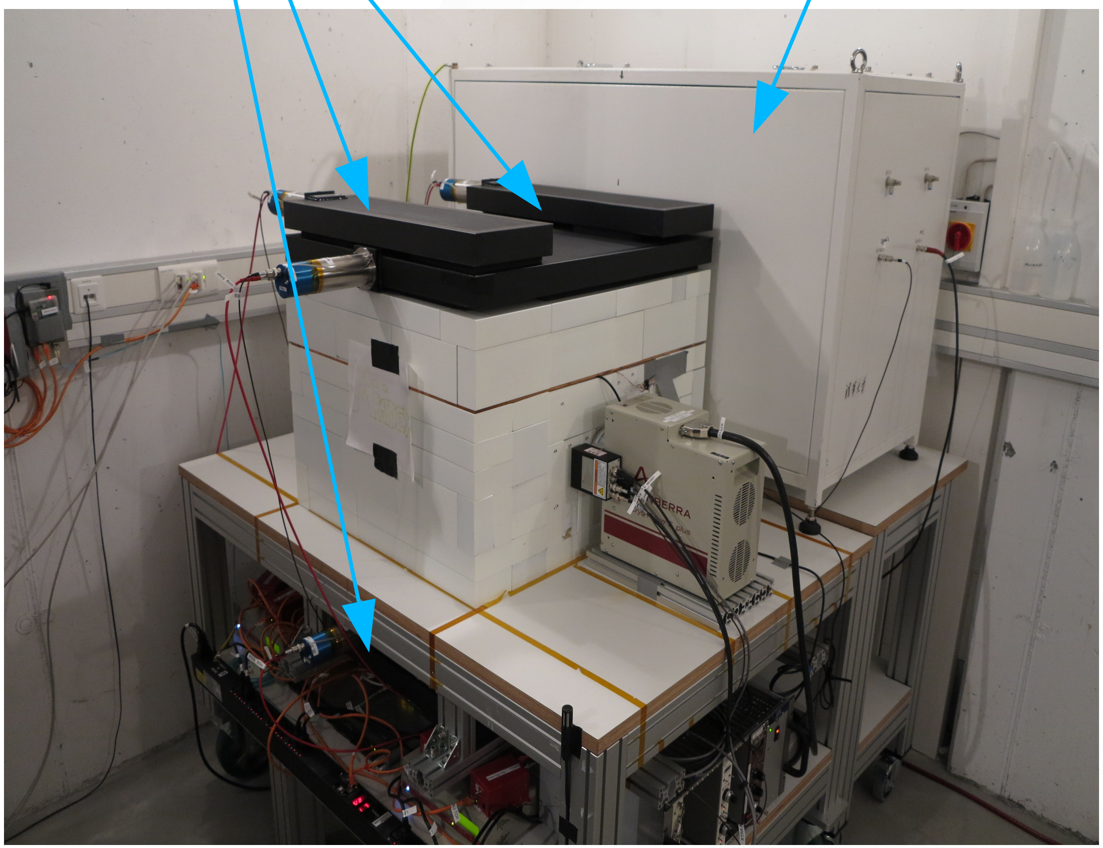
4.1 Minidex run 2 - new panels





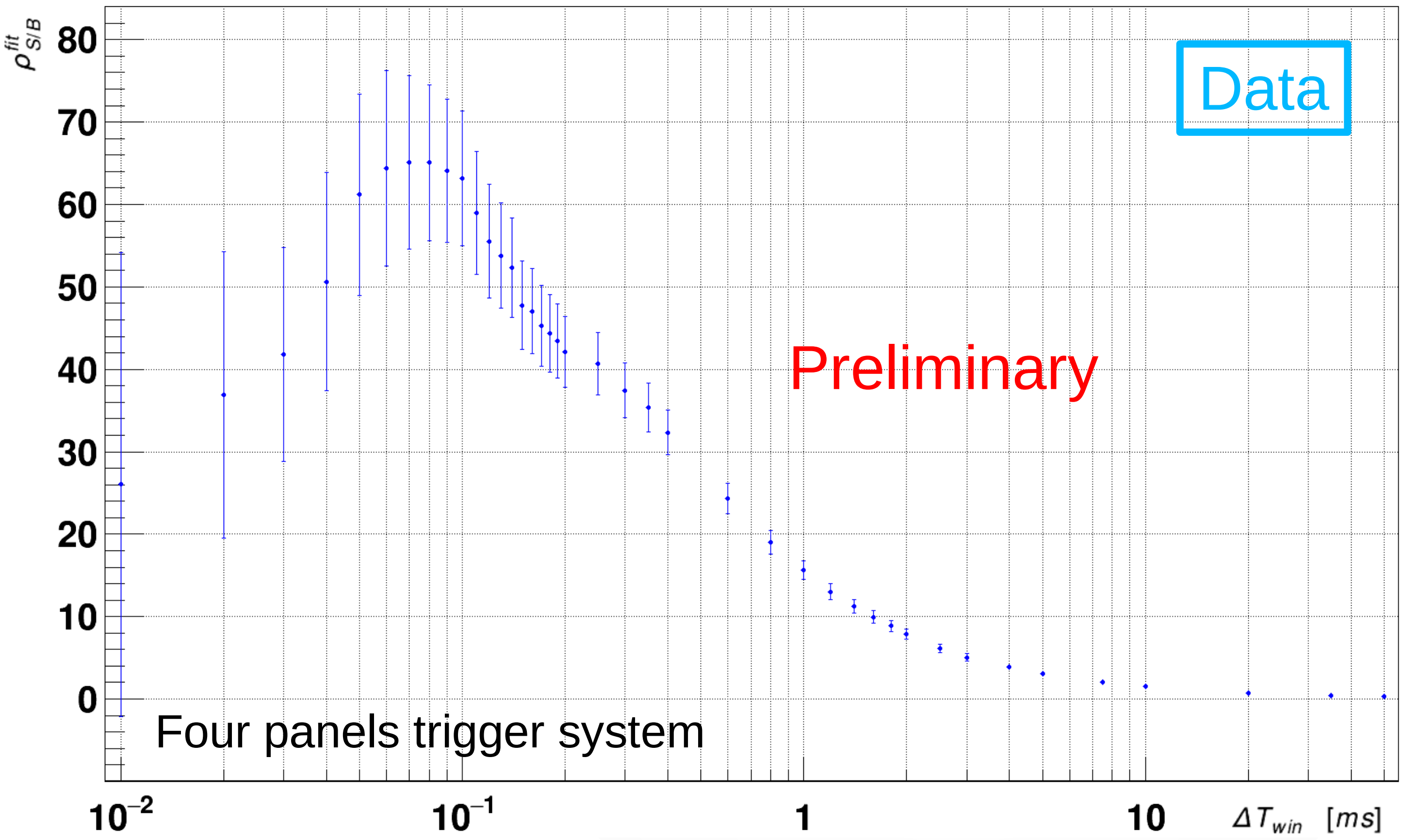


4.2 Minidex run 2 setup



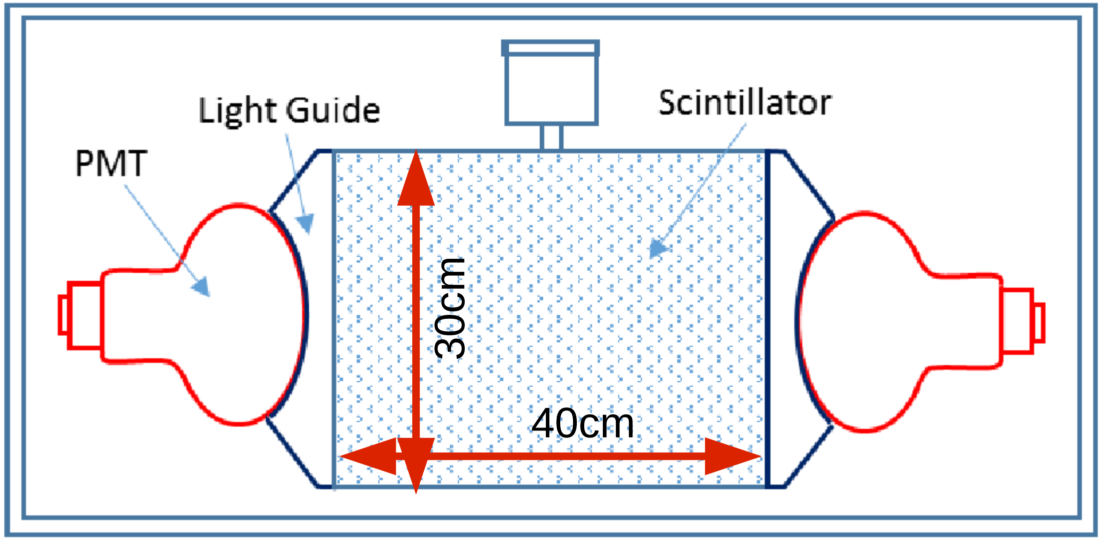
- Six new scintillator panels installed → different trigger settings possible
- Additional fast neutron detector (FND), Gd-loaded liquid scintillator, from Tsinghua University -> crosscheck
- Run 2 started Jan. 2016 (data taking ongoing) → ~60 days of data

4.3 Signal to background ratio



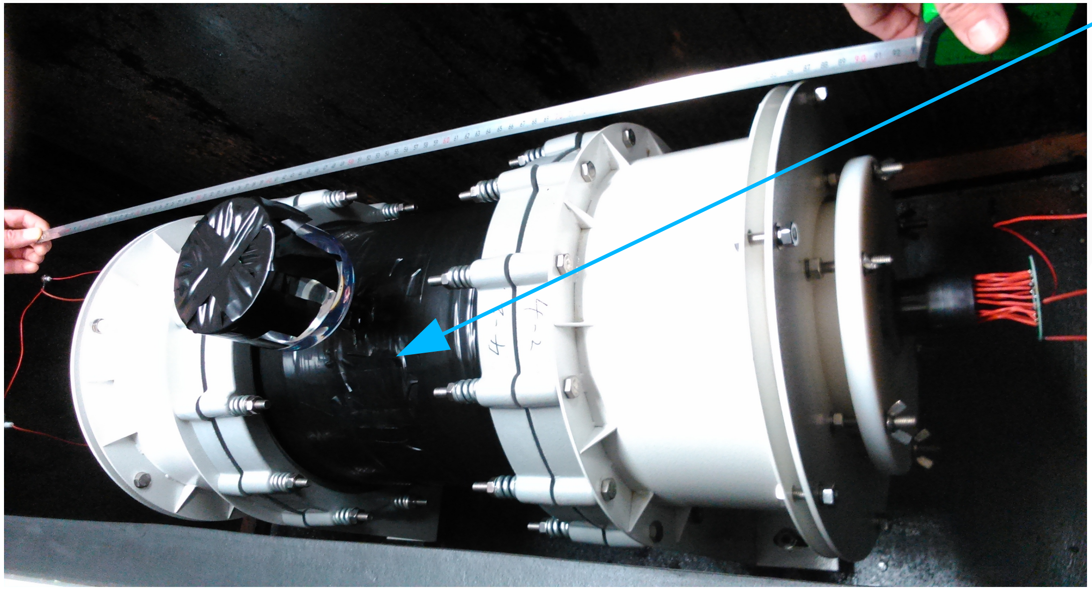
- Two big and two small panels generate the trigger
  → clean lead signal
- T_{win} = 2ms → S/B~8
- T_{win} ≤ 0.1ms → S/B~65
  → higher values than run 1 and no efficiency correction involved
- No fully integrated simulation for run 2 up to now

4.4.1 Fast neutron detector



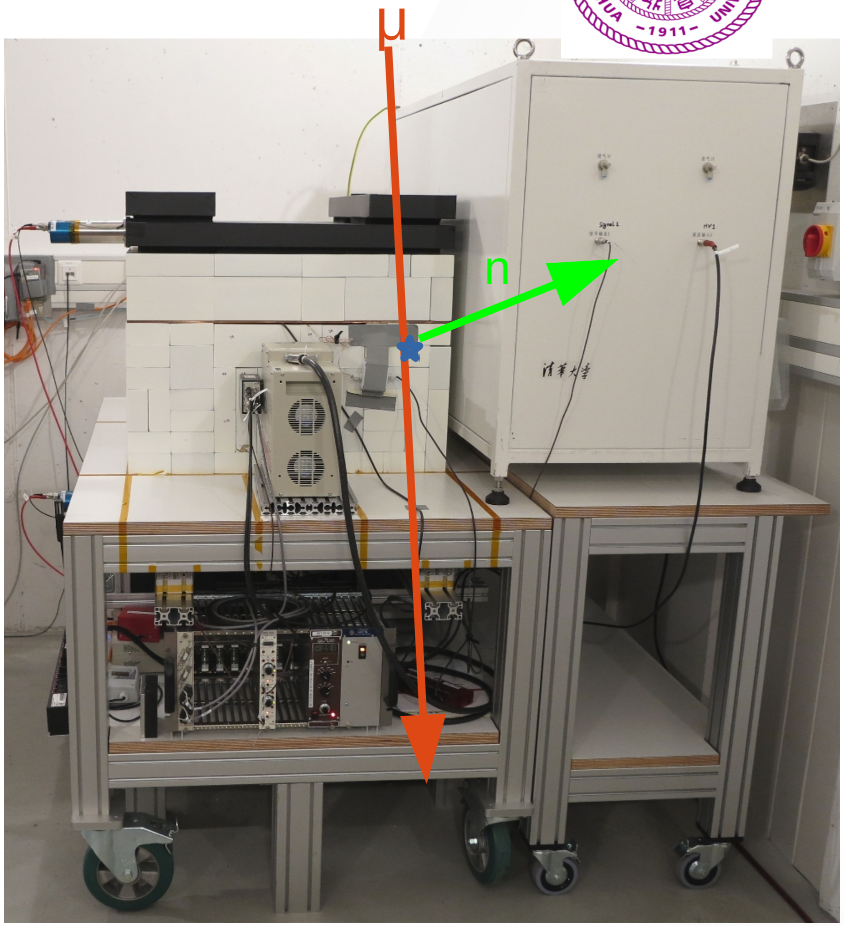
Side view

28l of liquid scintillator

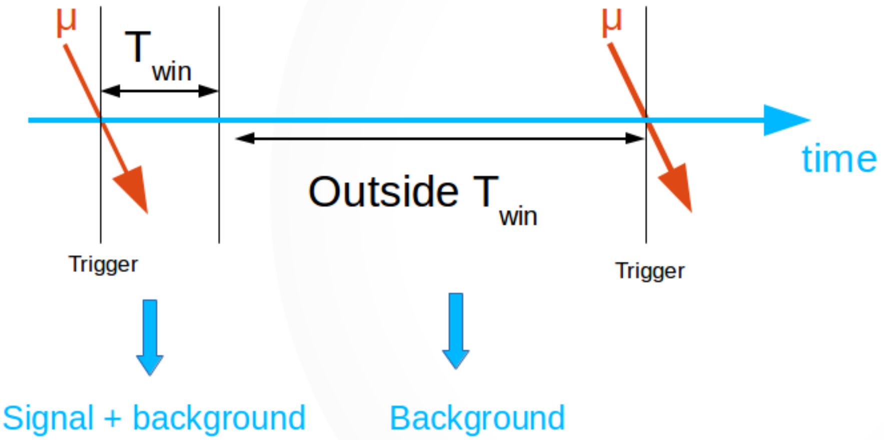


Top view

4.4.2 Analysis strategy for FND

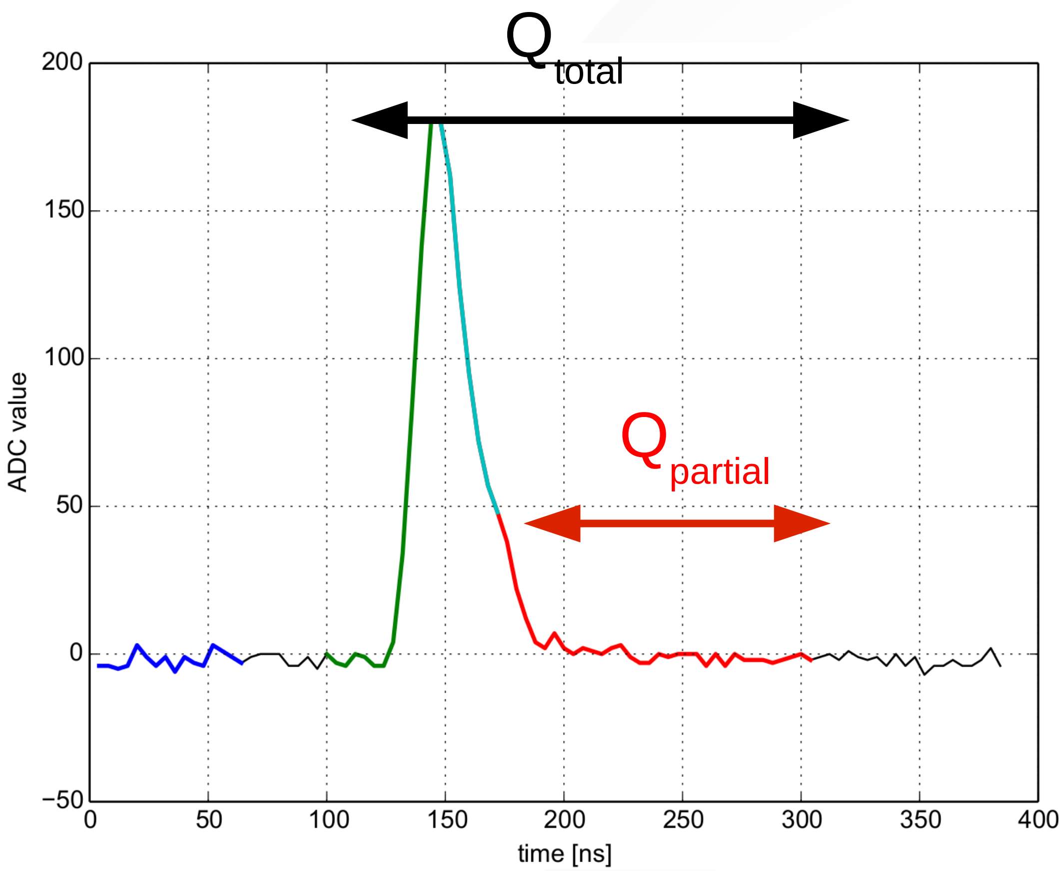


- Same goal and similar analysis as for the germanium detectors:
  Investigate the time behavior of our MC for muon-induced neutrons in our setup
  → Look for signals in FND after trigger



- Different trigger settings possible
  → E.g. choose only panels next to neutron detector
- Analysis just started
  → Only first preliminary results are shown

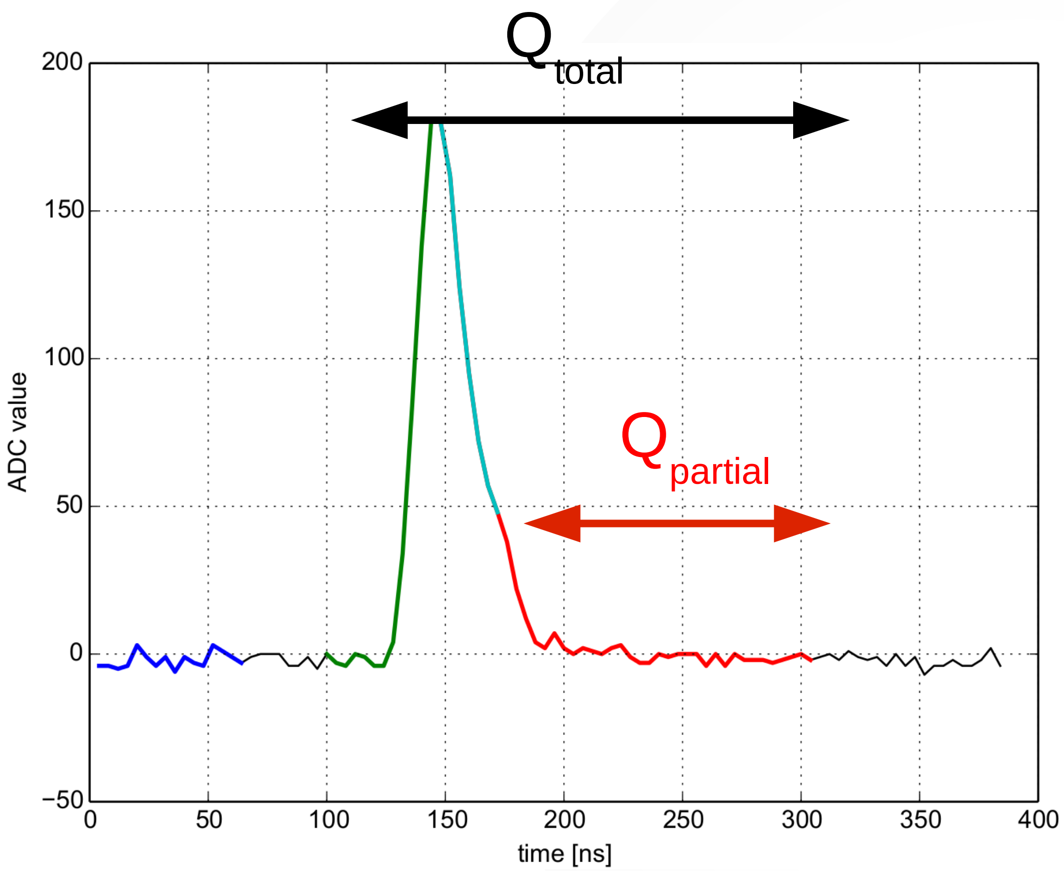
4.4.2 Analysis strategy for FND



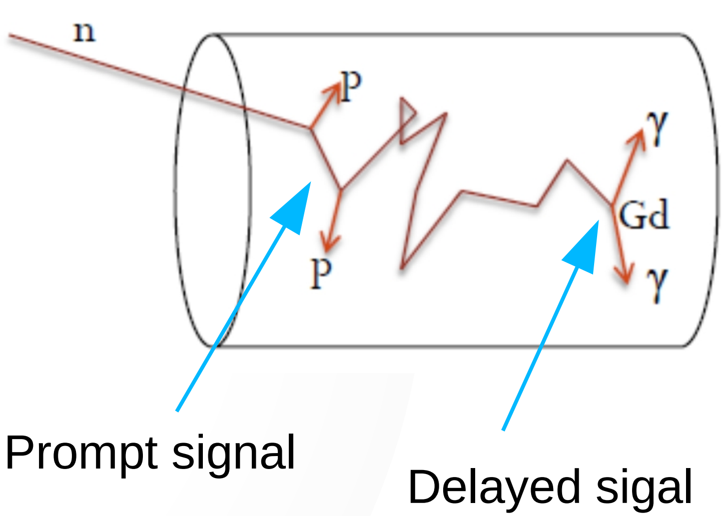
Different pulse shapes for neutrons and gammas/betas in liquid scintillator
→ Pulse shape discrimination

$$DF = \frac{Q_{part,pmt\,1}}{Q_{total,pmt\,1}} + \frac{Q_{part,pmt\,2}}{Q_{total,pmt\,2}}$$

4.4.2 Analysis strategy for FND



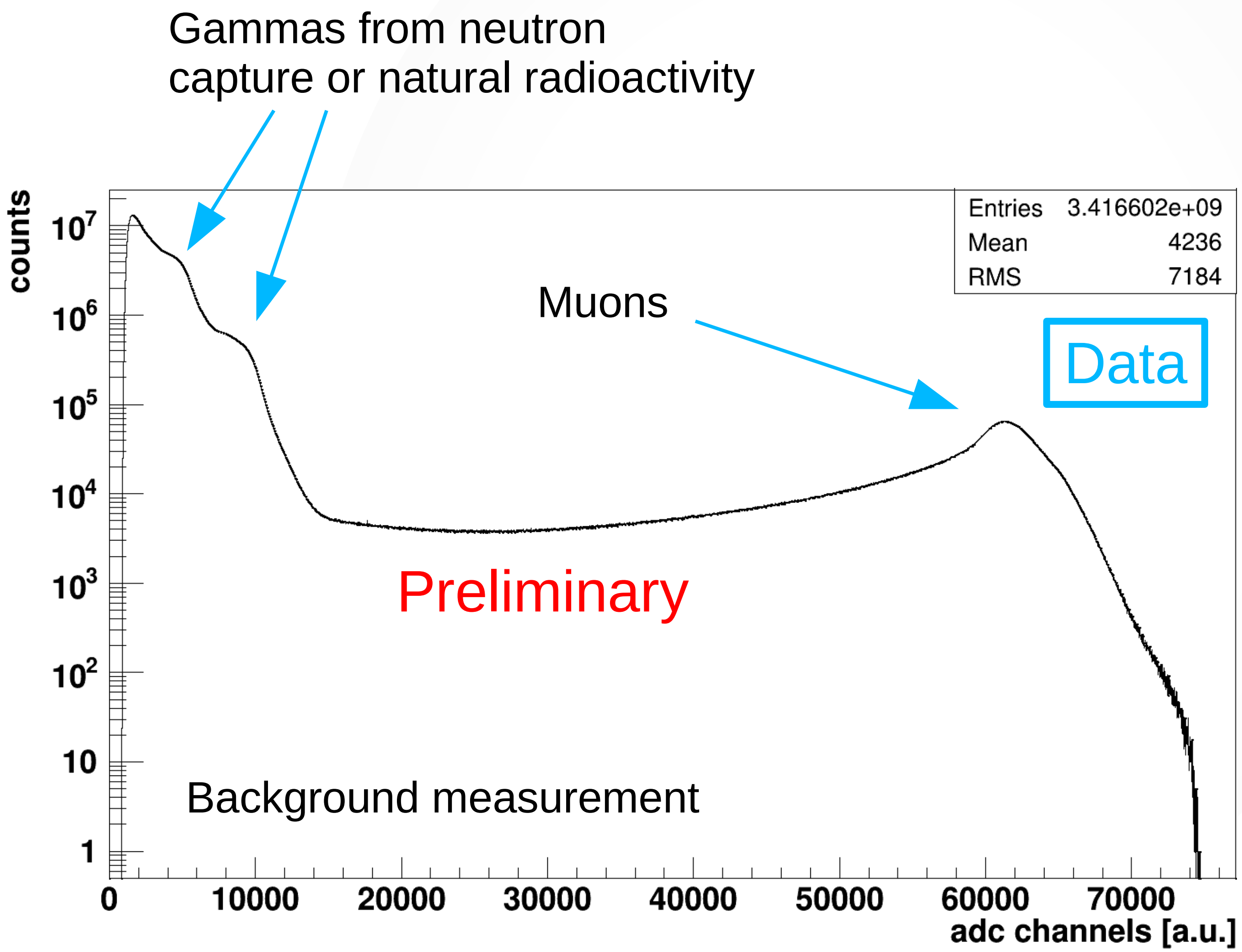
In addition for neutrons:
Fast and slow signal coincidence



Different pulse shapes for neutrons and gammas/betas in liquid scintillator
→ Pulse shape discrimination

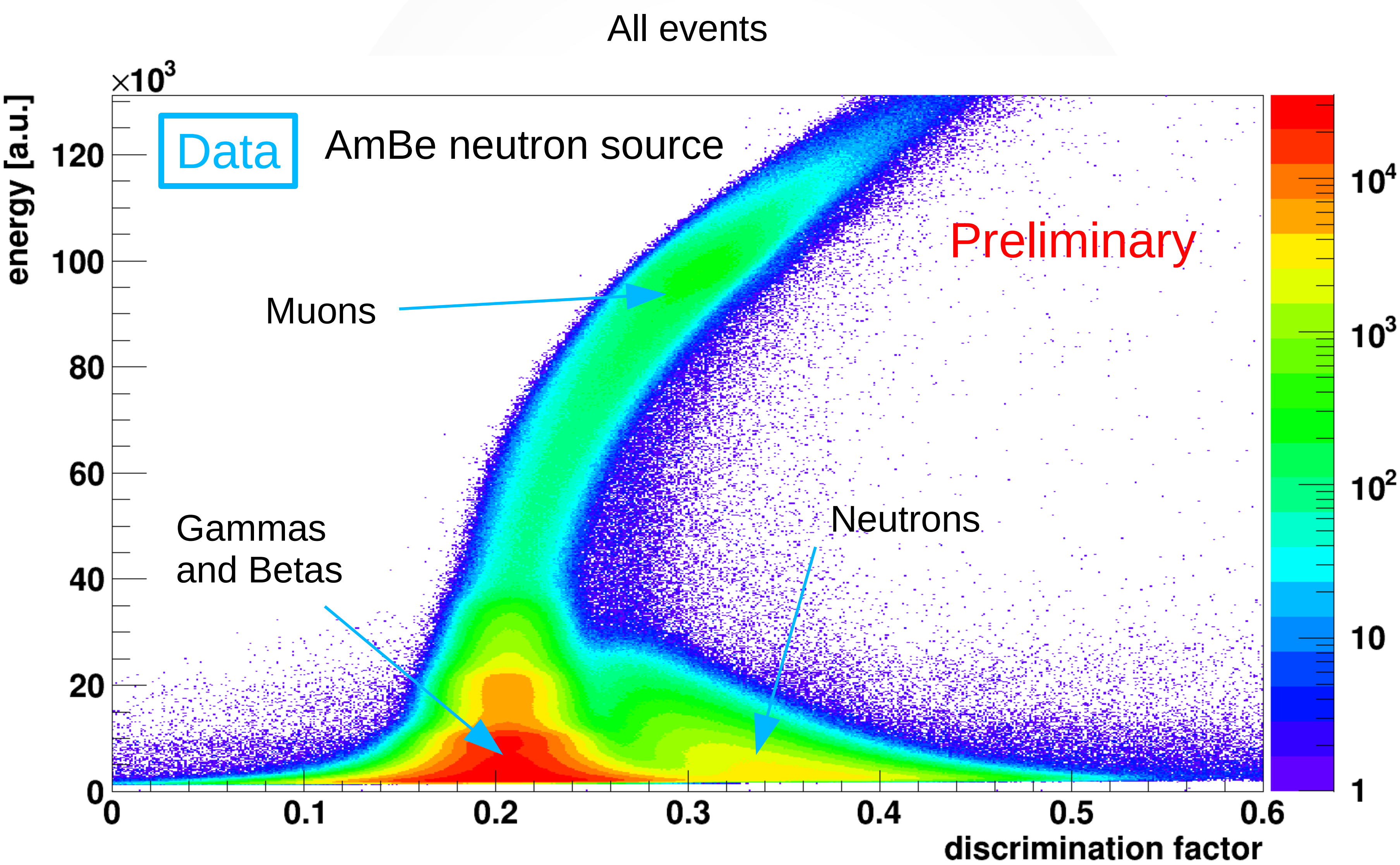
$$DF = \frac{Q_{part,pmt\,1}}{Q_{total,pmt\,1}} + \frac{Q_{part,pmt\,2}}{Q_{total,pmt\,2}}$$

4.4.3 Energy spectrum of FND



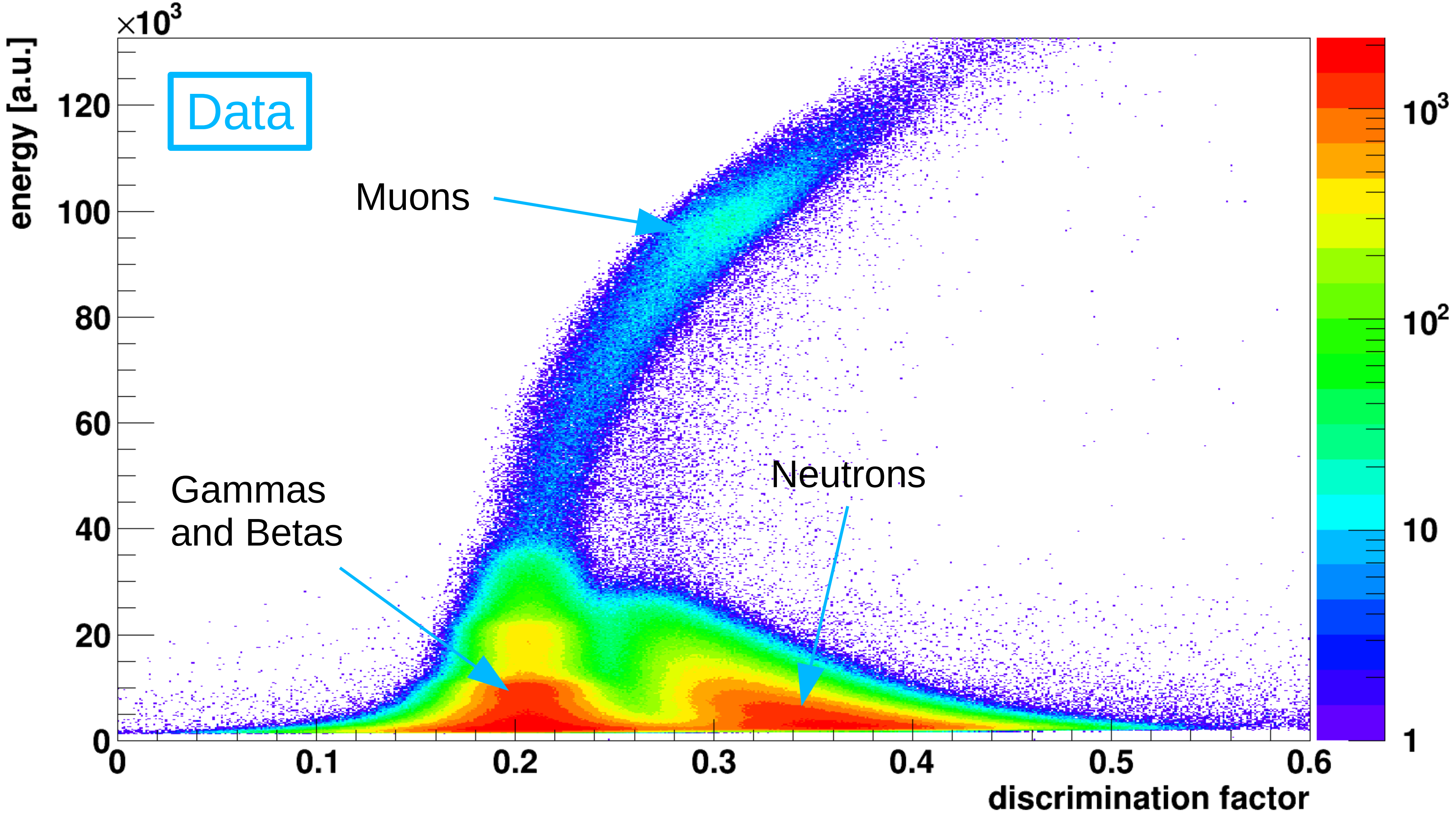
Energy resolution (FWHM) of typical liquid scintillators at 2MeV: ~400keV

4.4.4 FND data with neutron source

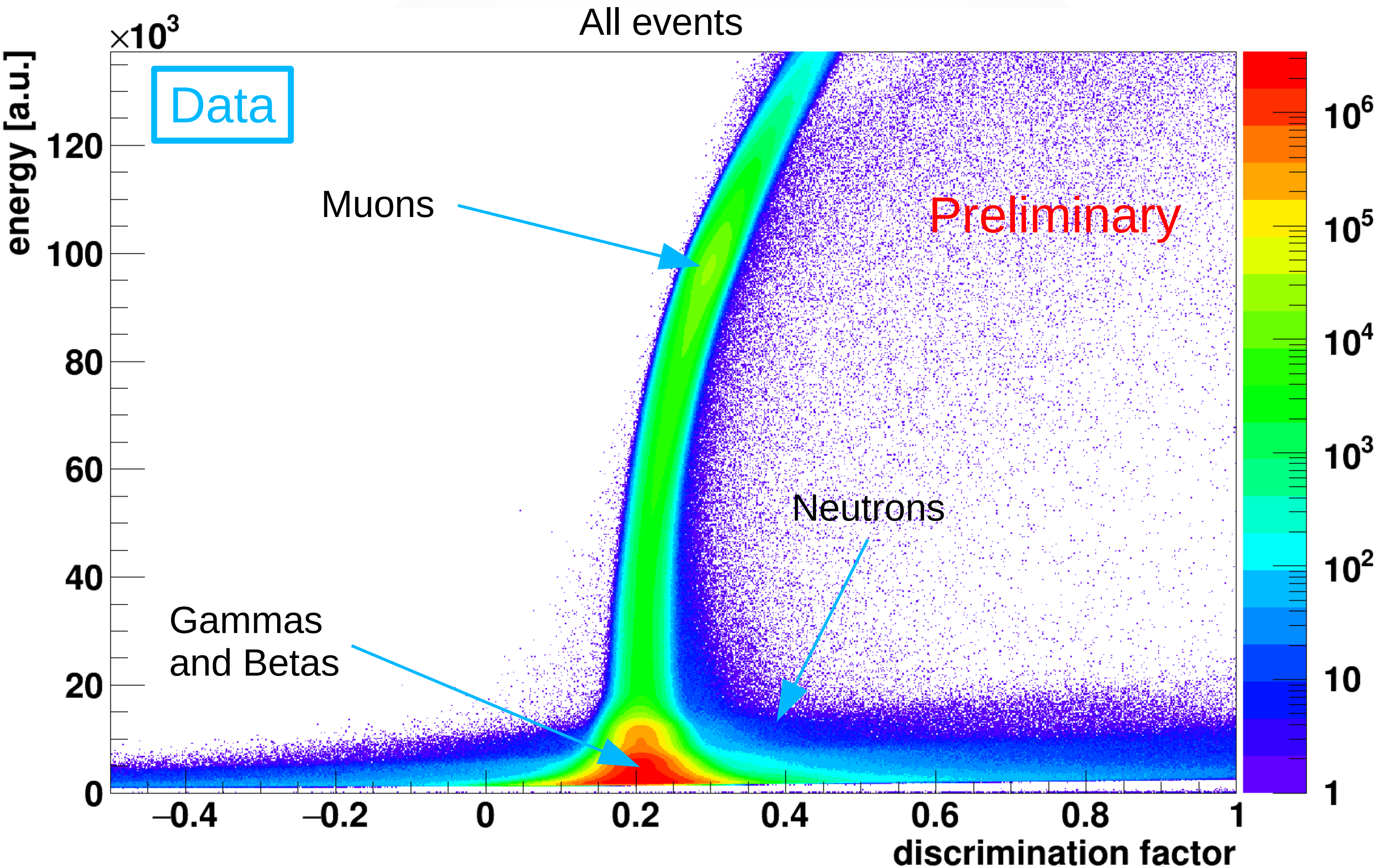


4.4.4 FND data with neutron source

Prompt-delayed time coincidence applied (here <40µs) → Only prompt events plotted



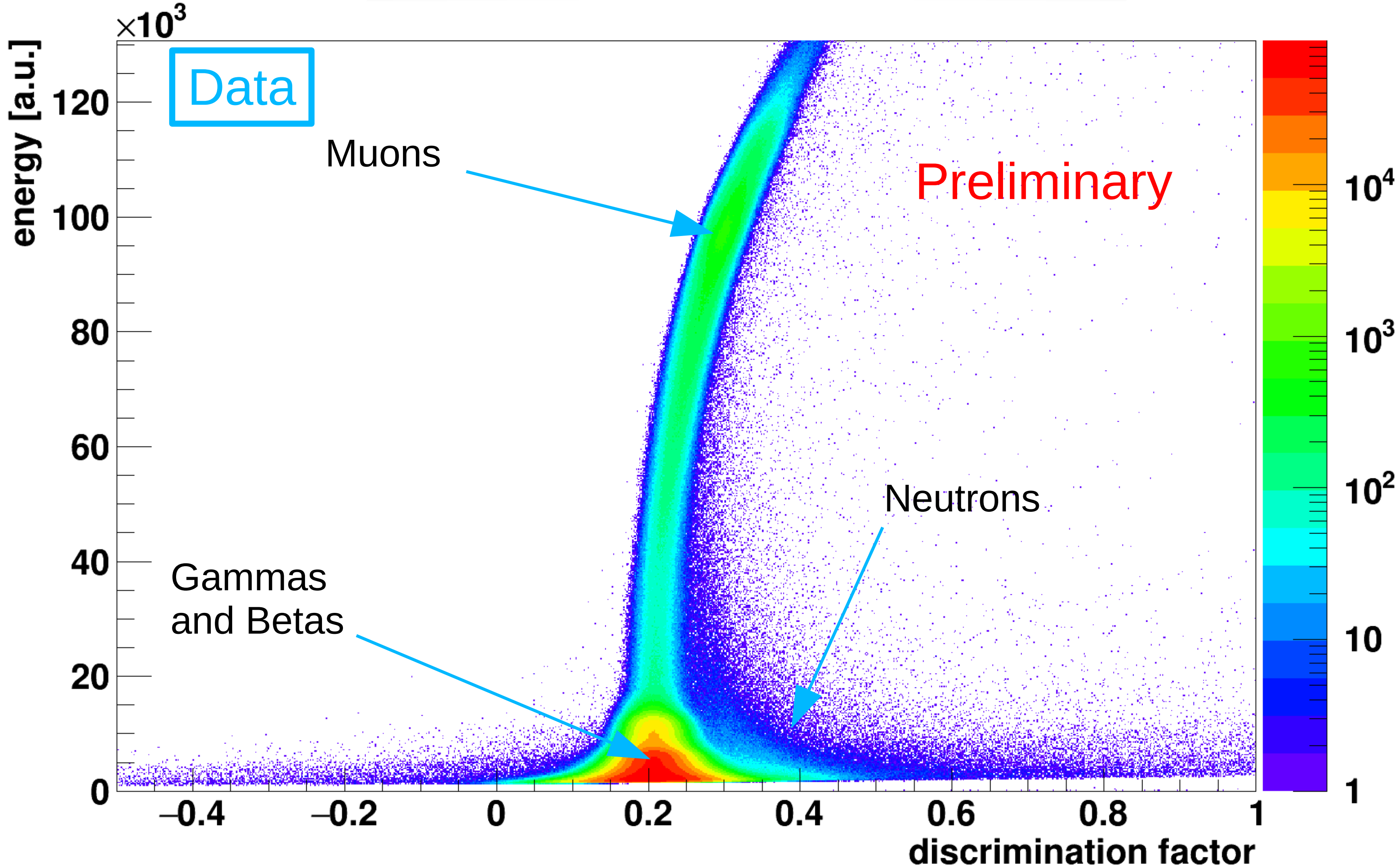
4.4.5 FND data from Minidex run 2



(For measurement with neutron source see backup slides)

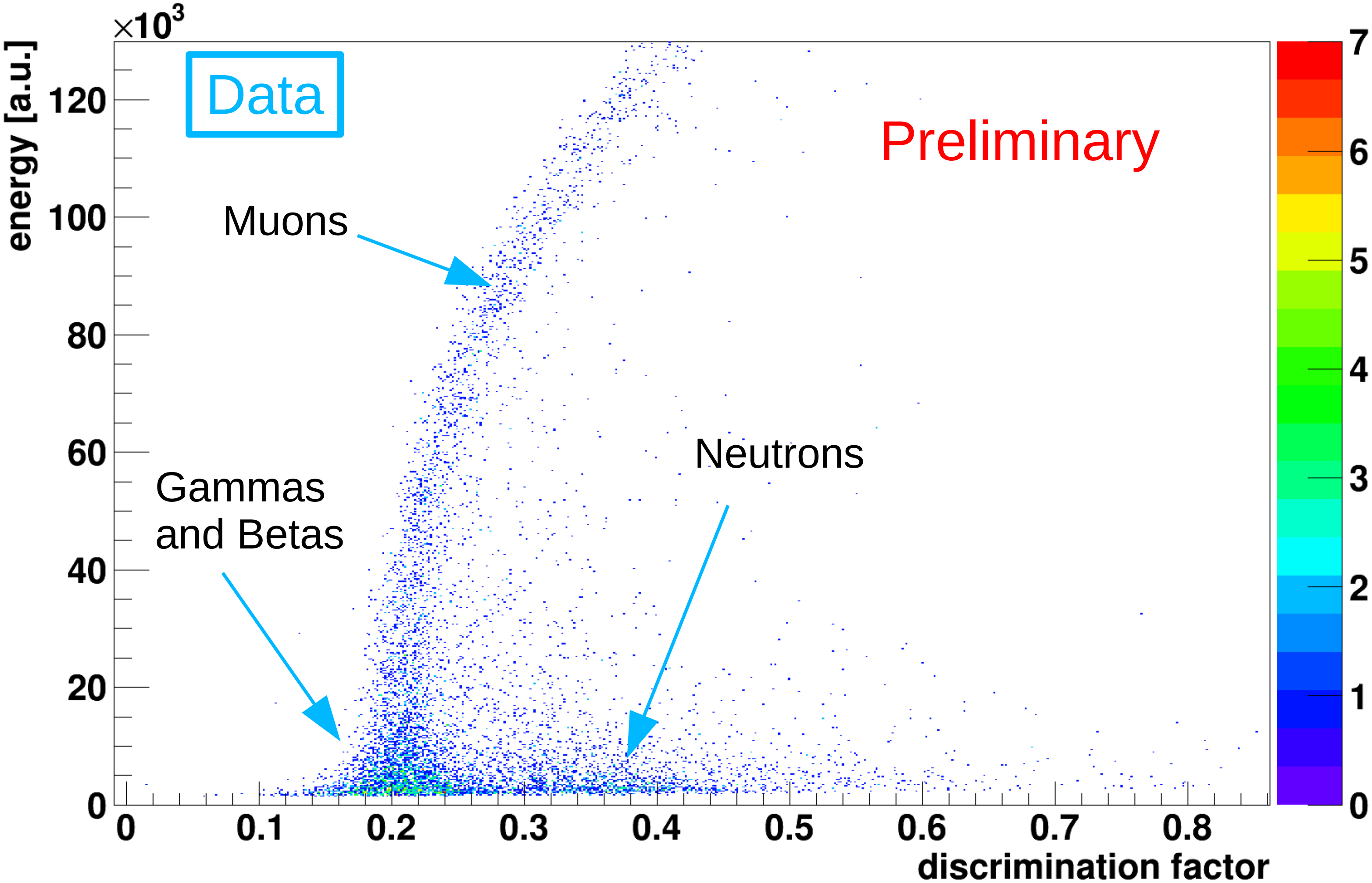
4.4.5 FND data from Minidex run 2

Prompt-delayed time coincidence applied (here <40μs) → Only prompt events plotted



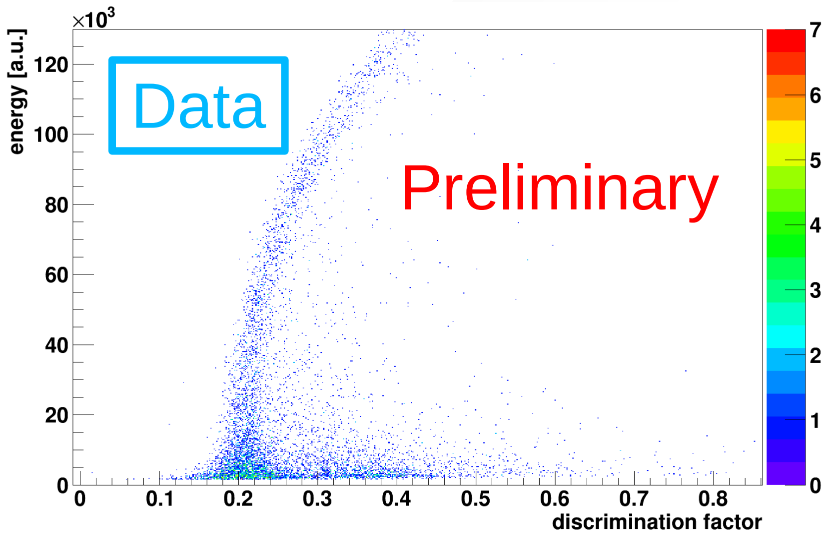
4.4.5 FND data from Minidex run 2

Prompt-delayed time coincidence applied (<40µs) and in coincidence with a scintillator panel trigger (<1µs) → Only prompt events plotted

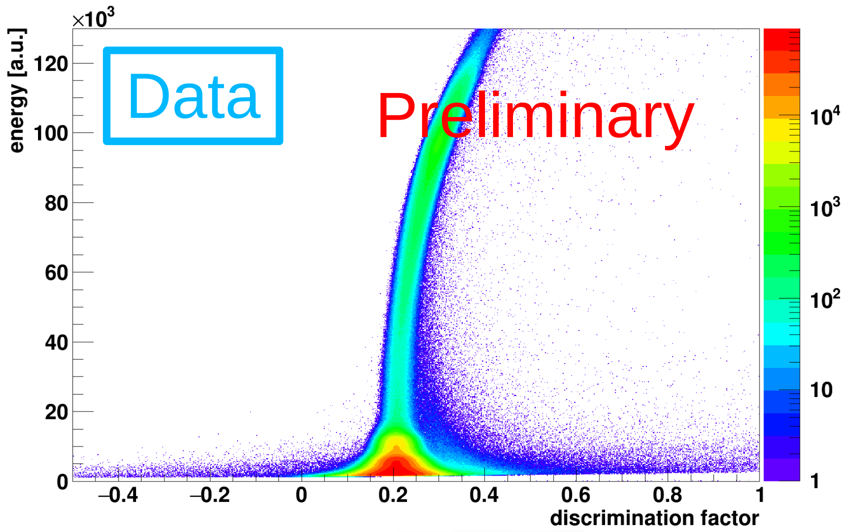


4.4.5 FND data from Minidex run 2

Coincidence with a scintillator panel trigger

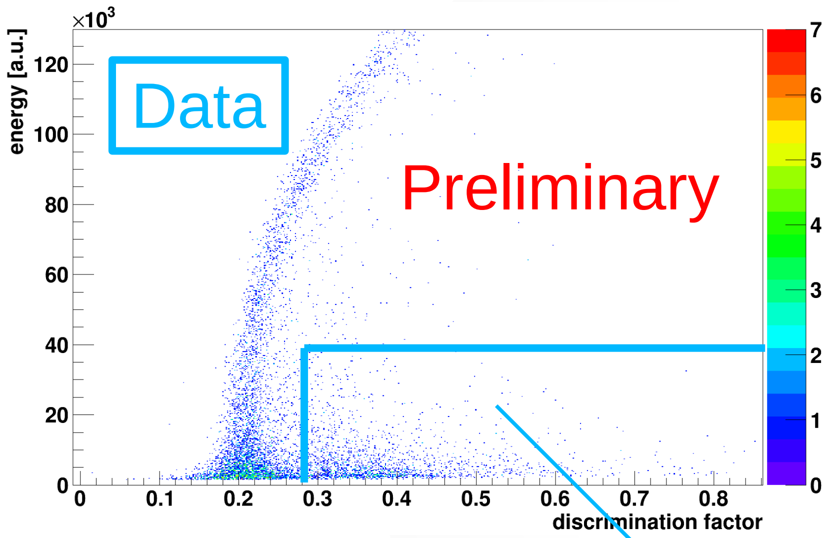


No coincidence with a scintillator panel trigger

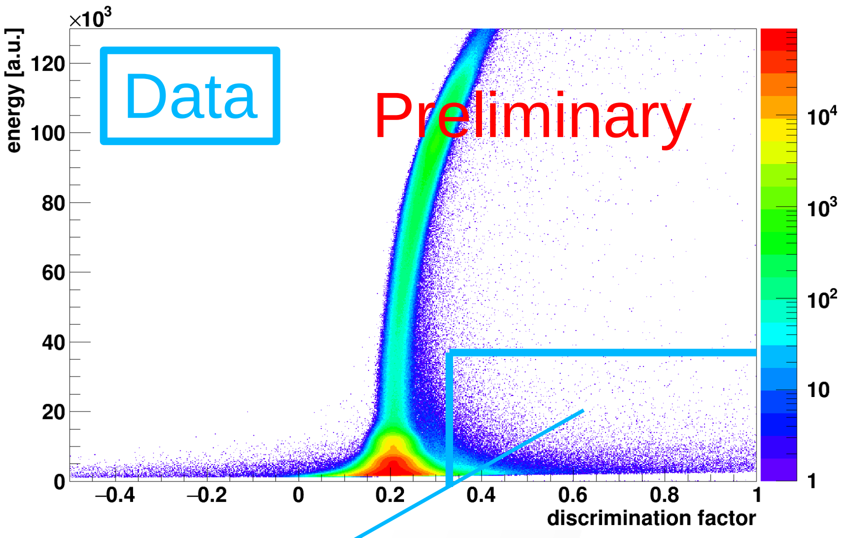


4.4.5 FND data from Minidex run 2

Coincidence with a scintillator panel trigger



No coincidence with a scintillator panel trigger



Inside time window (so after scintillation panel trigger) some orders higher neutron rate than outside time window

➡ FND sees muon-induced neutrons

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Summary

<u>Motivation for Minidex: Measure muon-induced neutrons for different muon energies and materials</u>

- Minidex run 1: Muon-induced neutrons detected in lead with maximum S/B-ratio ~60, underproduction of neutrons in MC observed

➡ Feedback to improve MC ➡ Optimize future low-background experiments

- Minidex run 2: New scintillators (+ four small scintillators) → clean lead signal and maximum S/B-ratio increased to ~65 (preliminary)
- Additional fast neutron detector installed → Muon-induced neutrons have been detected

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Outlook

- Analysis of Minidex run 2 is ongoing
- Possible tests of further materials in the future (e.g. steel)
- Possible tests at different muon energies (different underground laboratory)

Backup slide

$$R_B = \left[\frac{N_{outside}}{RT - (N_{trig} \cdot T_{win})}\right]_{T_{win}=4ms}$$