Time-of-flight Low Energy Neutron Detector

For low energy recoil calibration

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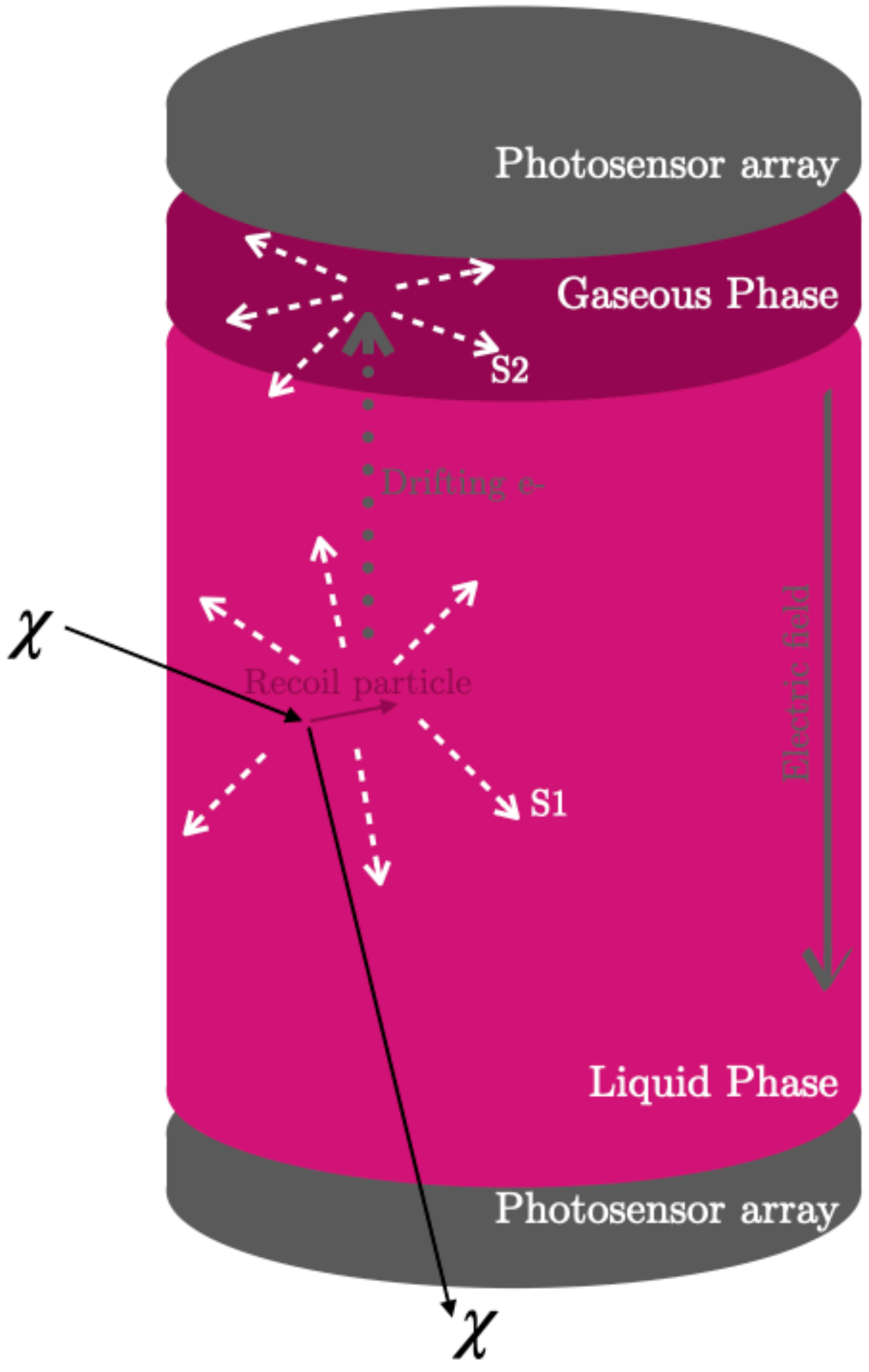
Noble Liquids Responses At Low Energy

For dark matter search and neutrino physics



Noble liquids dual phase TPC provides access to **ionisation** and **scintillation** channels.

Dropping scintillation signal allows to **lower recoil energy threshold**, crucial for:

- Dark matter search in the O(1 GeV/c^2) regime.
- Supernova neutrino burst through CEνNS.

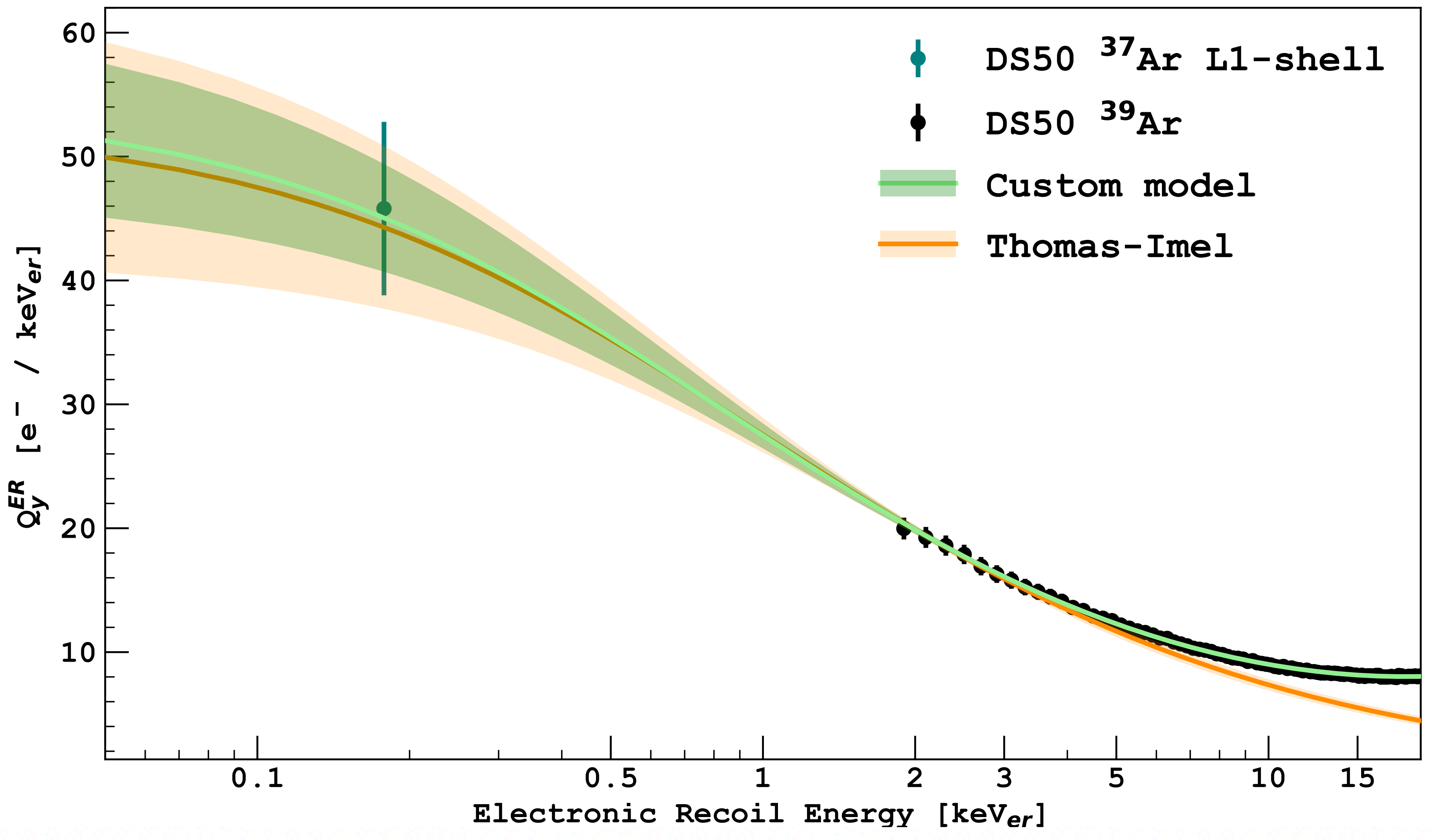
Need of ionisation response down to sub-keV

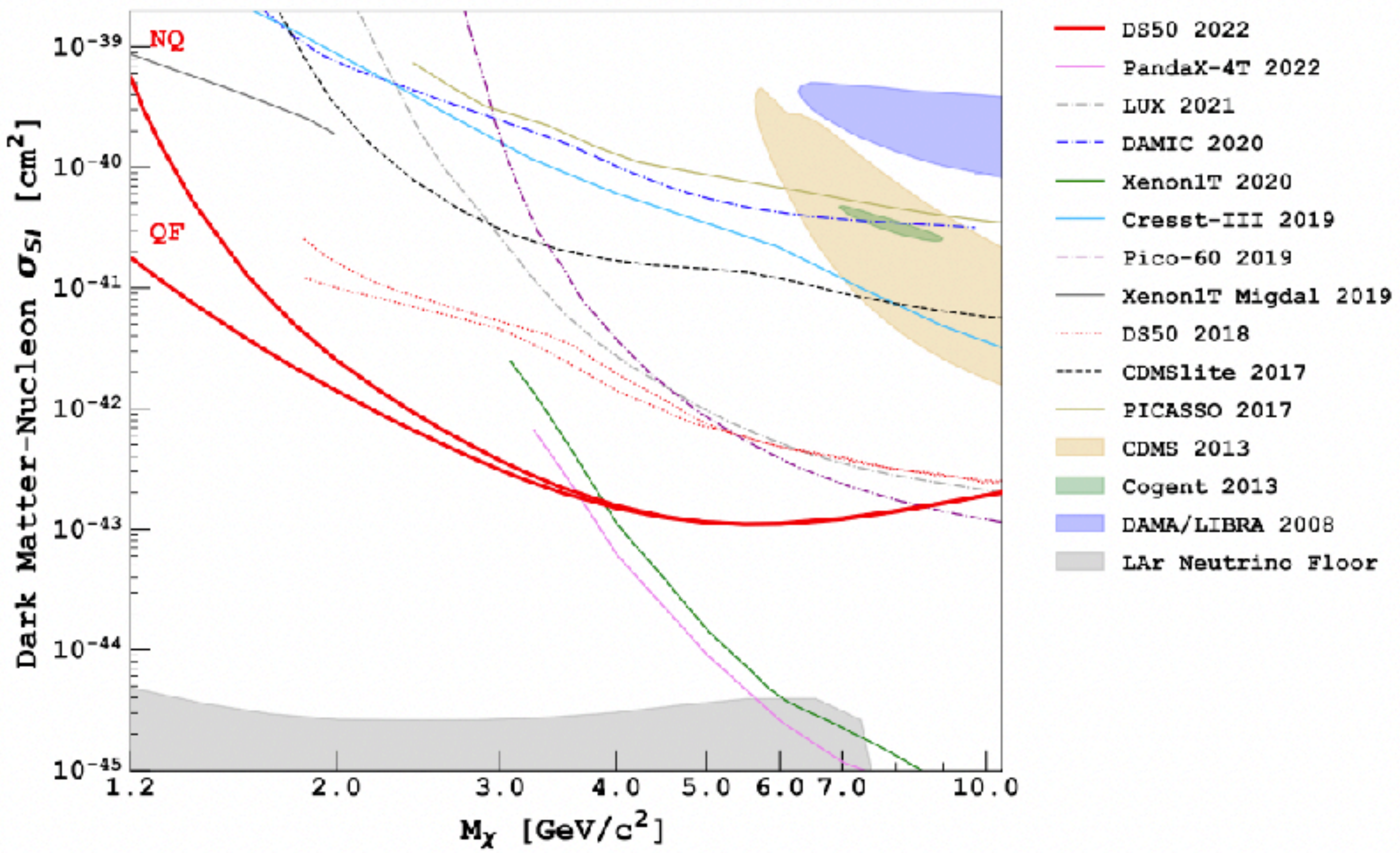
Low energy response model

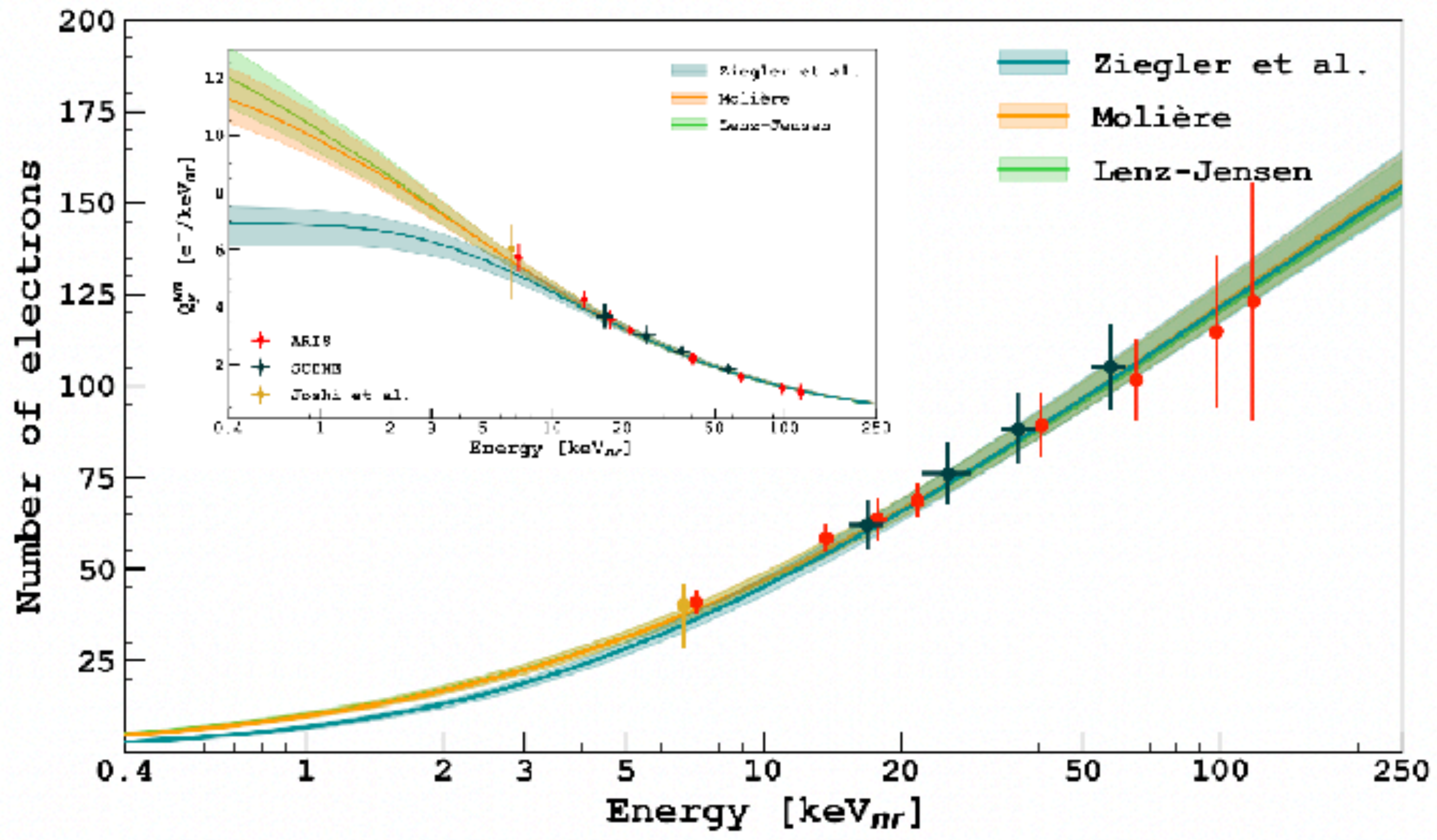
Low mass analysis in DarkSide-50

The high mass response model can be extend to lower energy under large uncertainties.

This gave the best limits on ~1 GeV/c² WIMP mass in DarkSide-50.

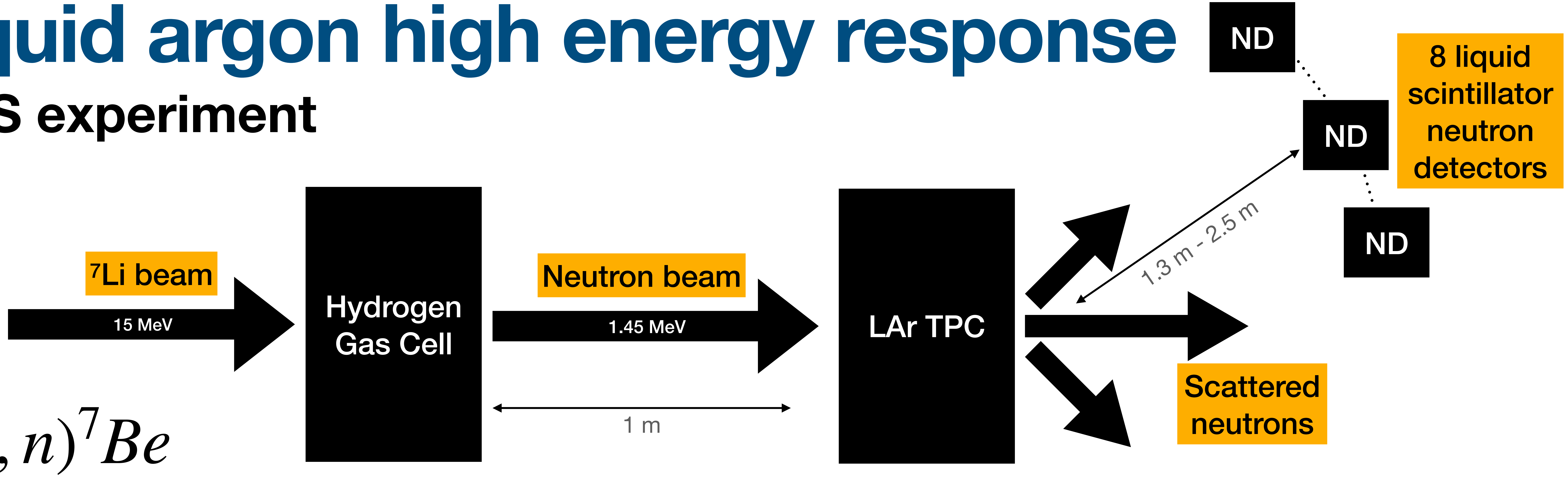






Liquid argon high energy response

ARIS experiment



ND

ND

ND

8 liquid scintillator neutron detectors

^{7}Li beam

15 MeV

Hydrogen Gas Cell

Neutron beam

1.45 MeV

1 m

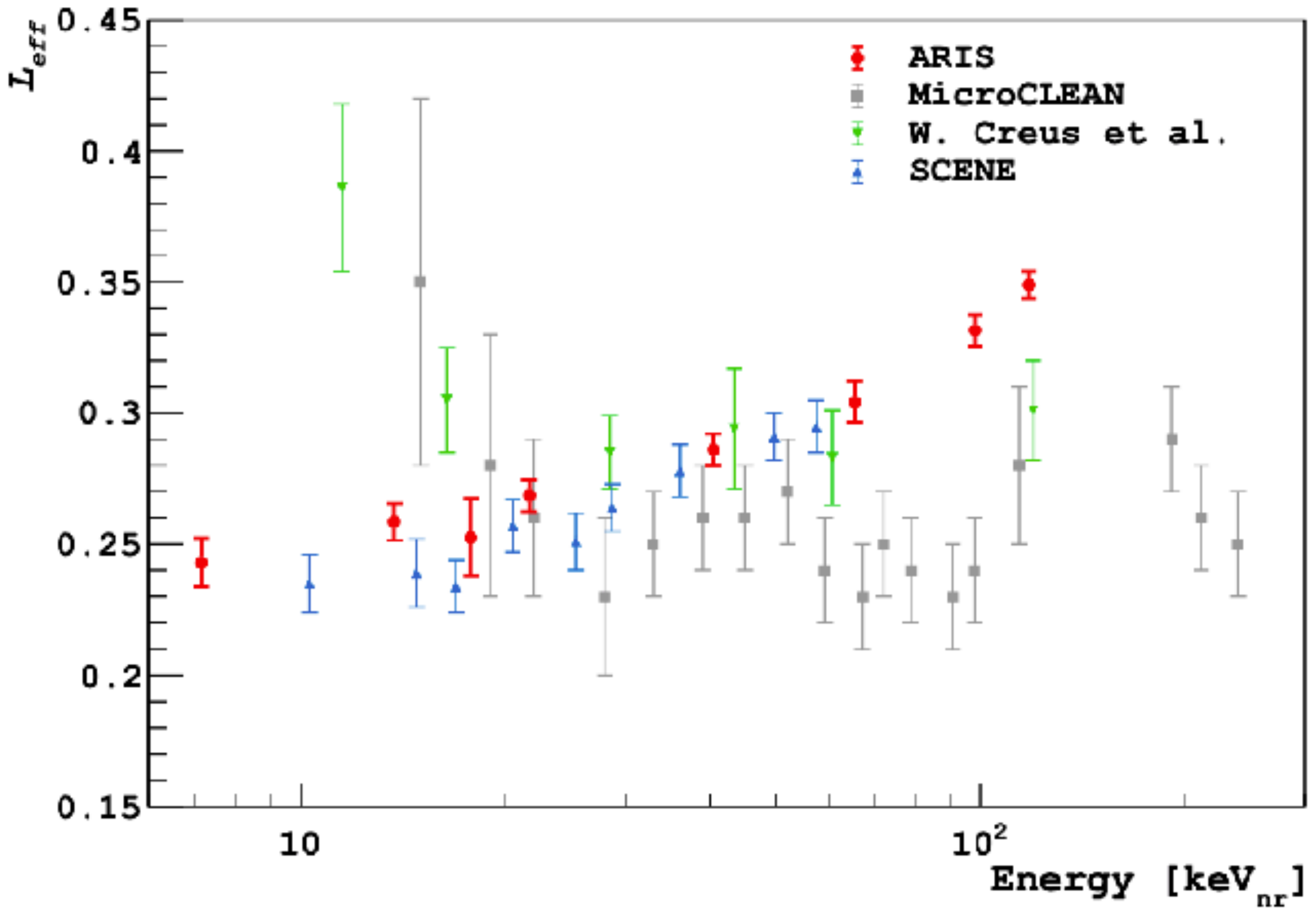
LAr TPC

1.3 m - 2.5 m

Scattered neutrons

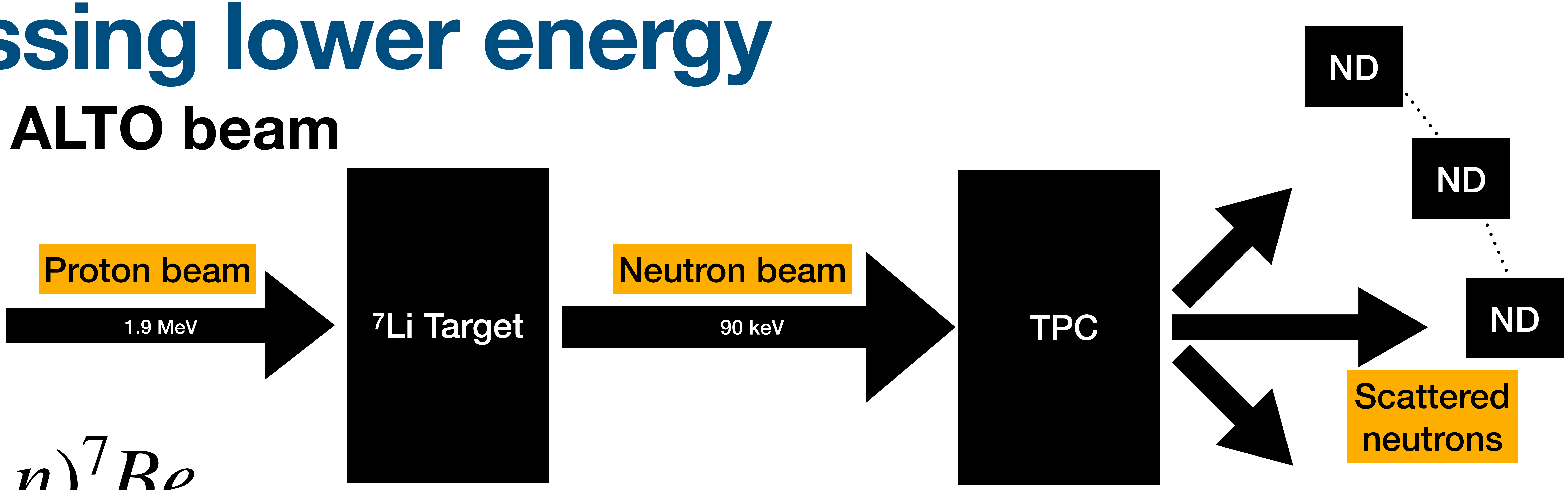
$$p(^7Li,n)^7Be$$

- The **recoil energy** is related to the scattered neutron energy which is related to the **scattering angle**.
- The lower is the angle, the lower is the NR energy.
- At a minimum of 25.5°, a **7.1 keV NR** energy is accessible.



Accessing lower energy

With the ALTO beam



Proton beam

1.9 MeV

^{7}Li Target

Neutron beam

90 keV

TPC

ND

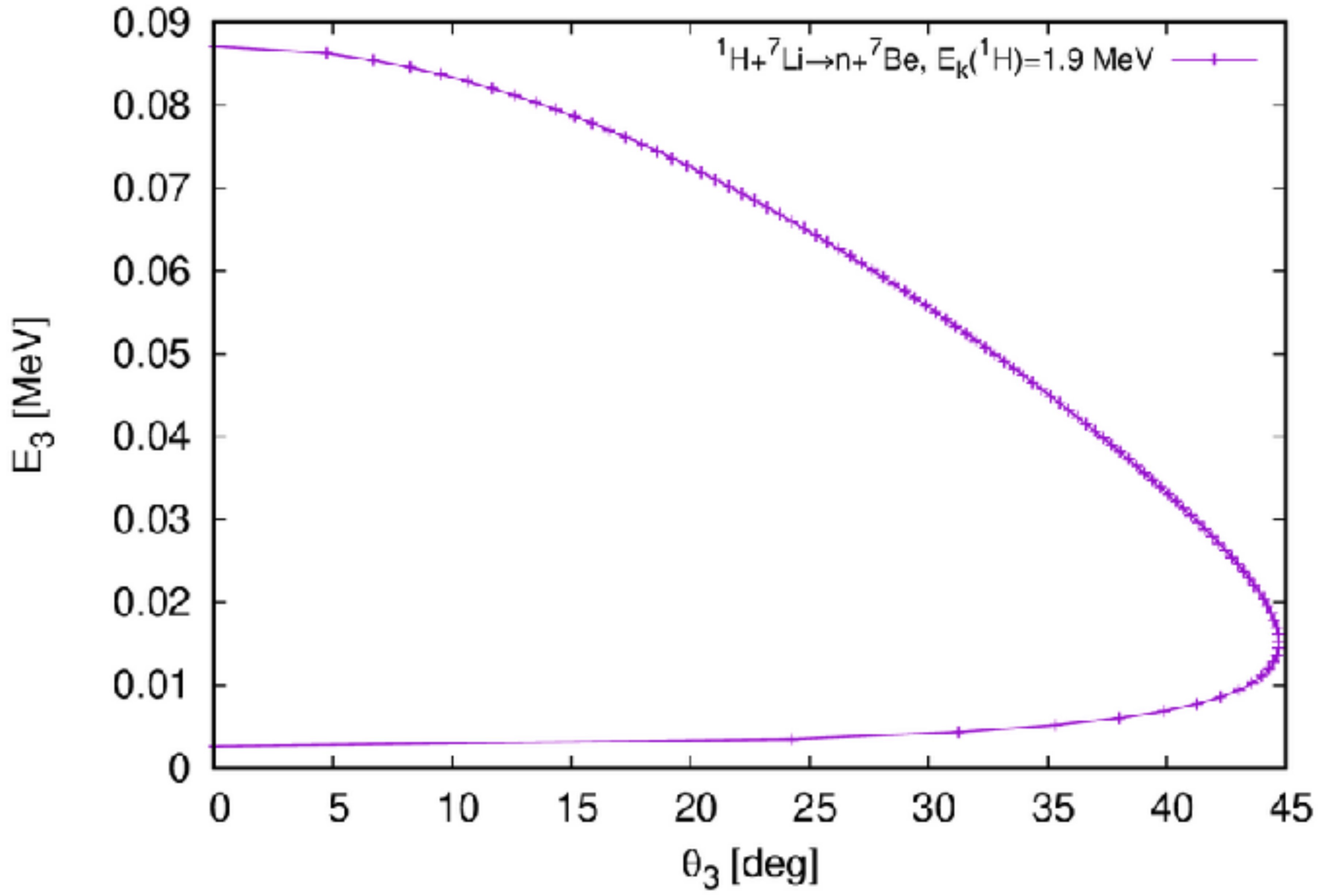
ND

ND

Scattered neutrons

$$^7Li(p,n)^7Be$$

- At 1.9 MeV, produces ~90 keV neutrons naturally collimated.
- Giving access to **sub-keV NR**.
- Requires a detector sensitive to such low energy neutrons.



O(100 keV) neutron detection

Need of time coincidence

- The $^{7}Li(p,n)^{7}Be$ produces a 478 keV γ emission background that has to be rejected by **time coincidence** cut between **beam**, **TPC** and **neutron detector**.

- Current neutron detection technology at this energy require **thermalisation** which is too slow to make the coincidence possible.

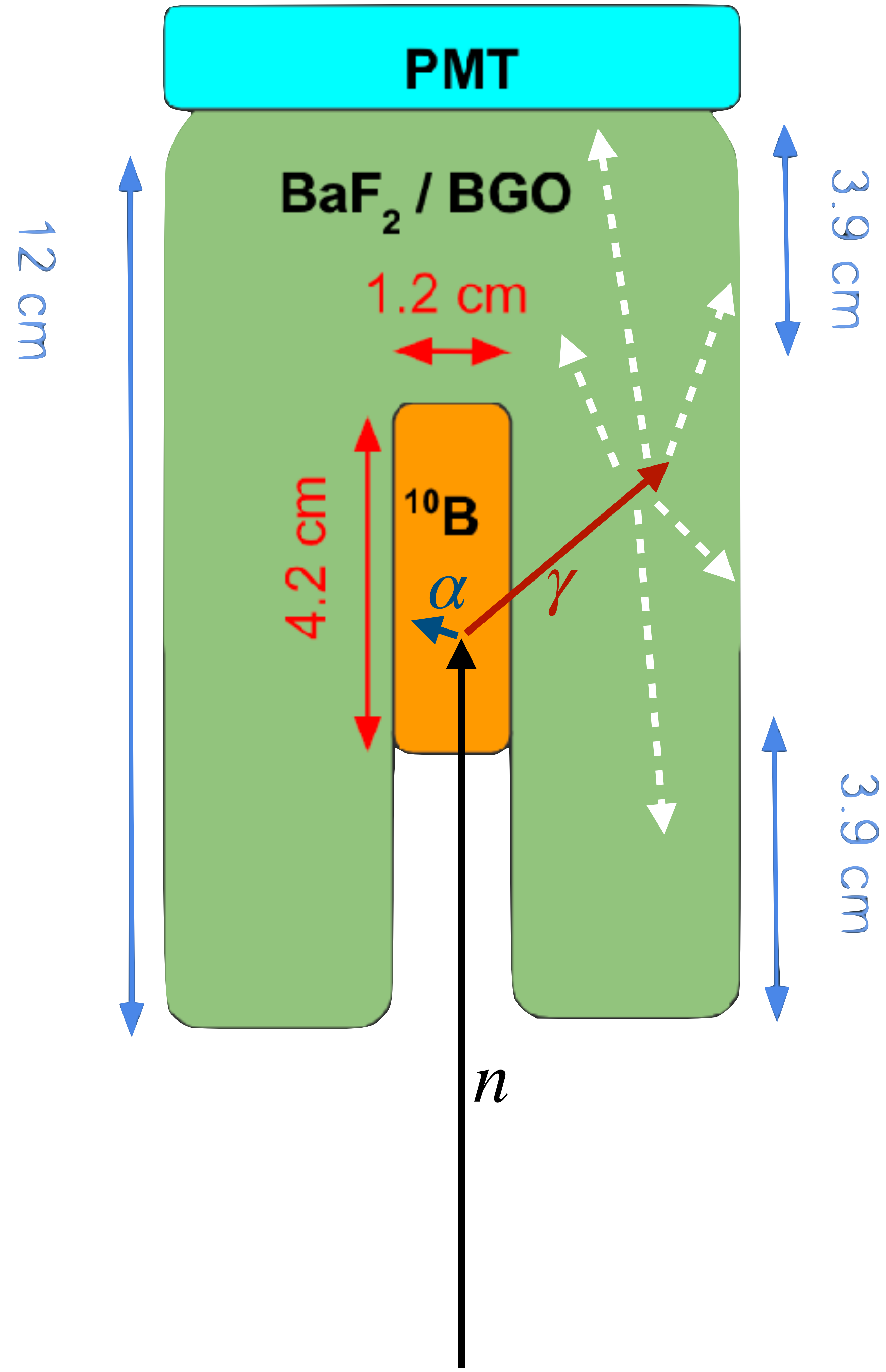
- We propose a **detector based on the boron-10 high neutron capture cross-section** (2 barn).

Novel time-of-flight neutron detector

BoND (Boron Neutron Detector)

$$n + {}^{10}B \rightarrow {}^{7}Li + \alpha + \gamma$$

- Neutron is captured **without thermalisation**, without loosing coincidence
- Emitted 478 keV γ absorbed in inorganic crystals.
- Target can be remove for blank measurement of the beam background.



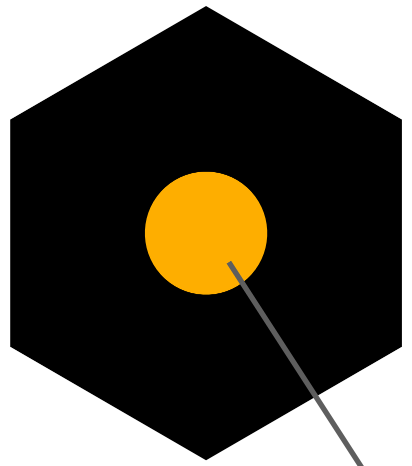
Scintillation crystal and PMTs

Geometry options

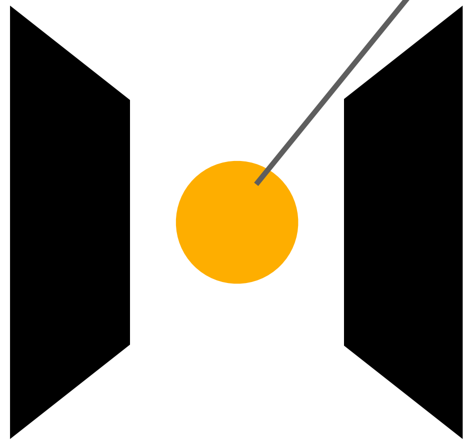
BaF2

- Very fast scintillation response (~1 ns)
- Low light yield (~10 photon/keV)

From IJCLab



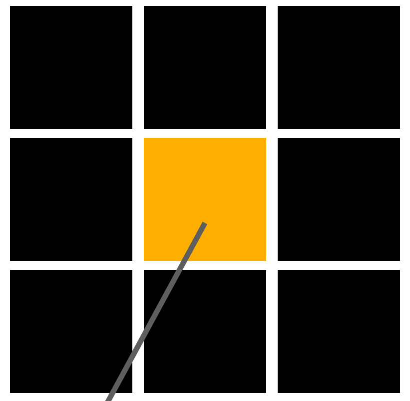
From APC



Boron target

BGO

- Slow scintillation (300 ns)
- Low light yield (~10 photon/keV)



NaI(TI)

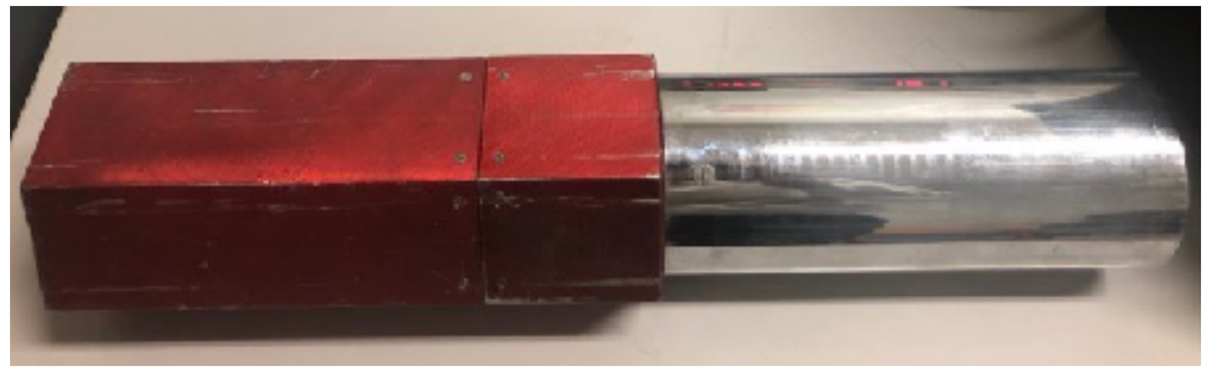
- Slow scintillation (250 ns)
- High light yield (38 photon/keV)

Already including a 8 mm radius well.

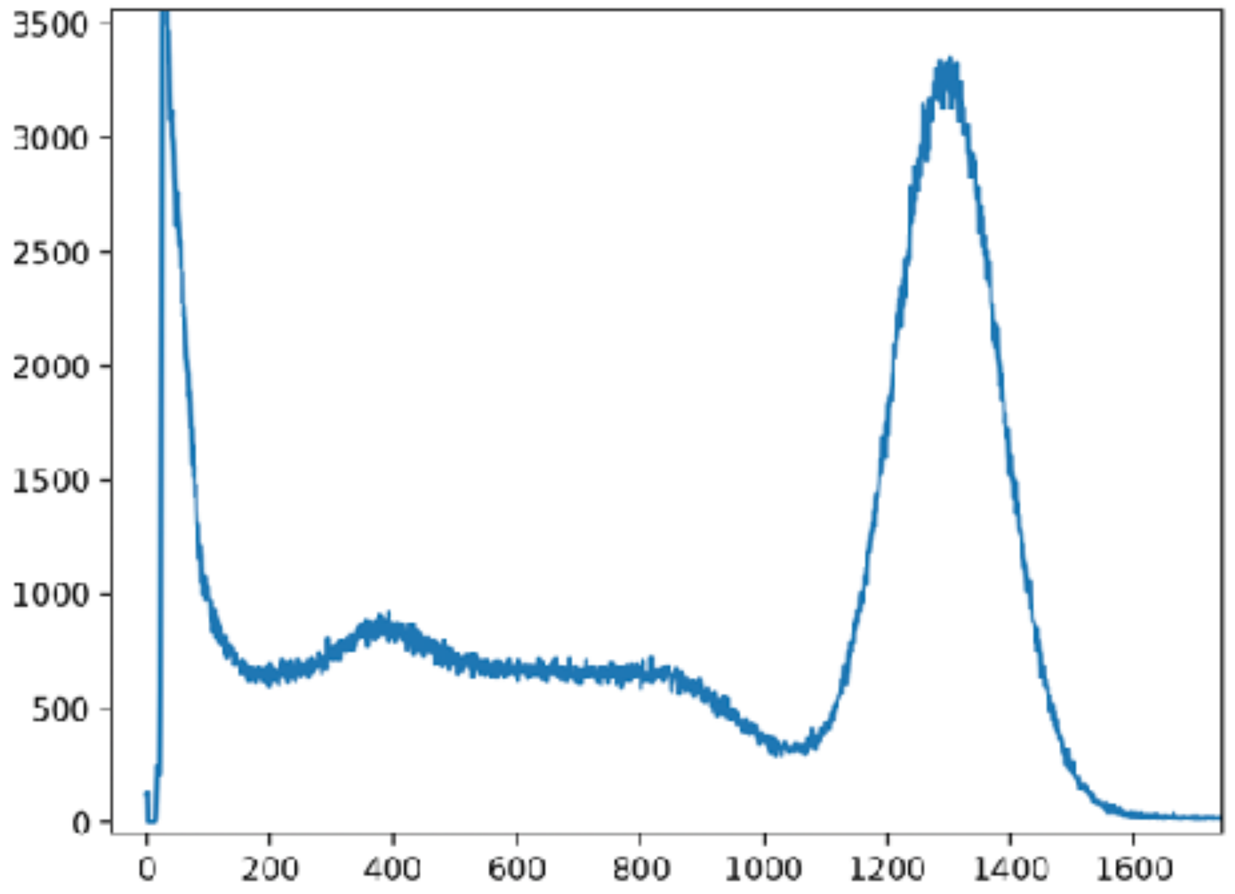
From Virginia Tech

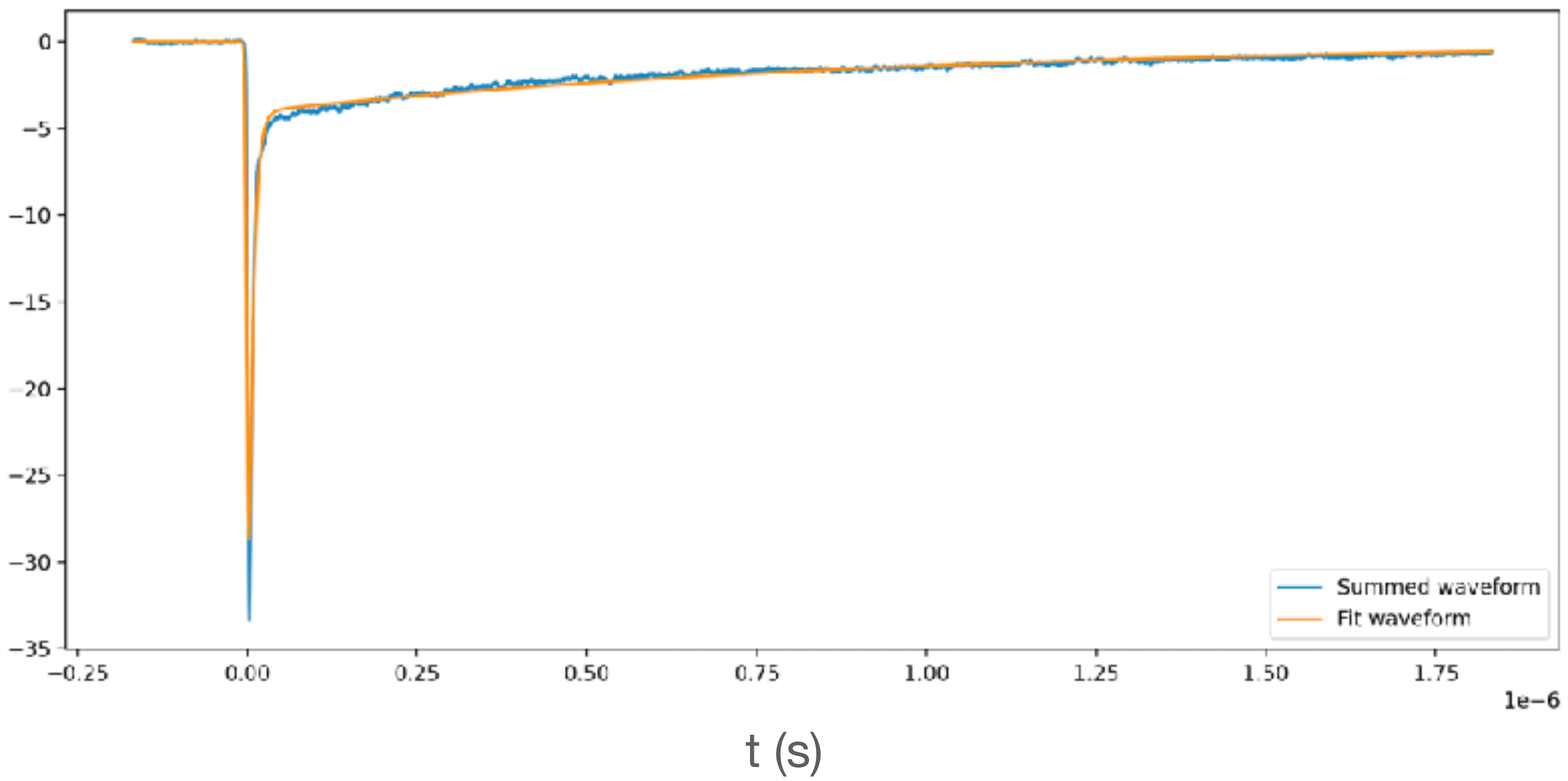
BaF2 tests

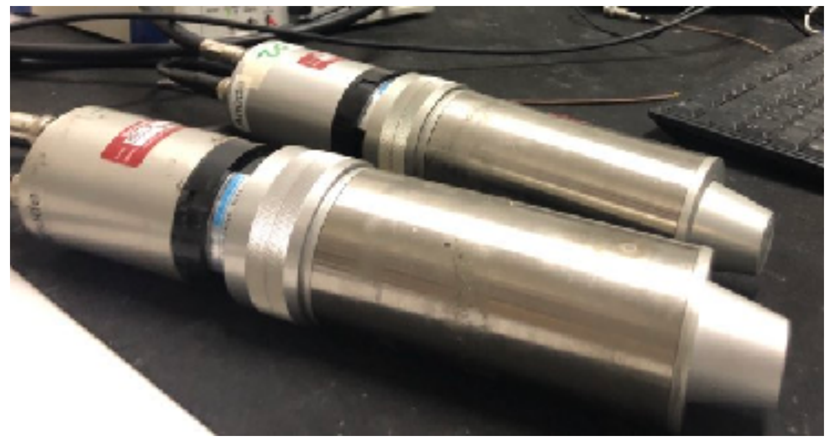
With 137Cs source



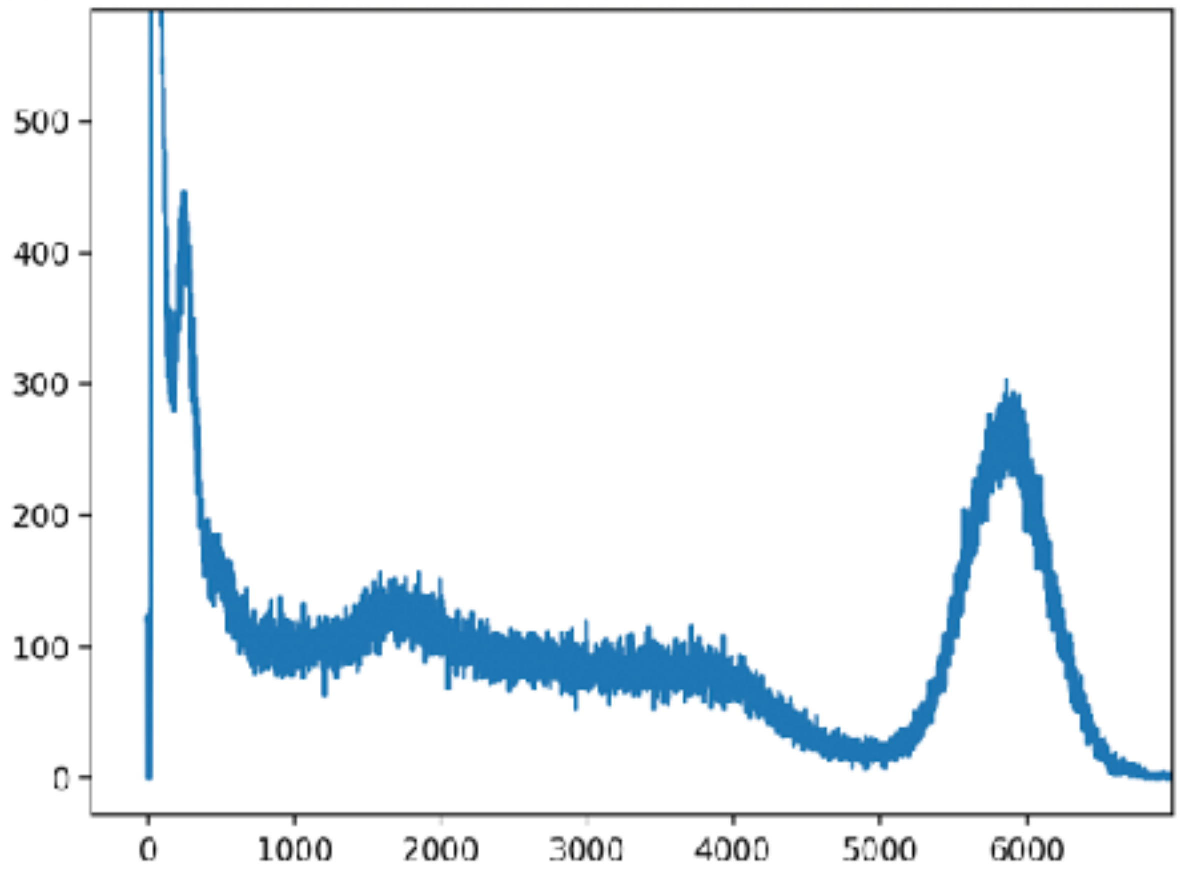
Fast component : 7.01 ns
Slow component 935 ns
FMHM/Peak = 0.155

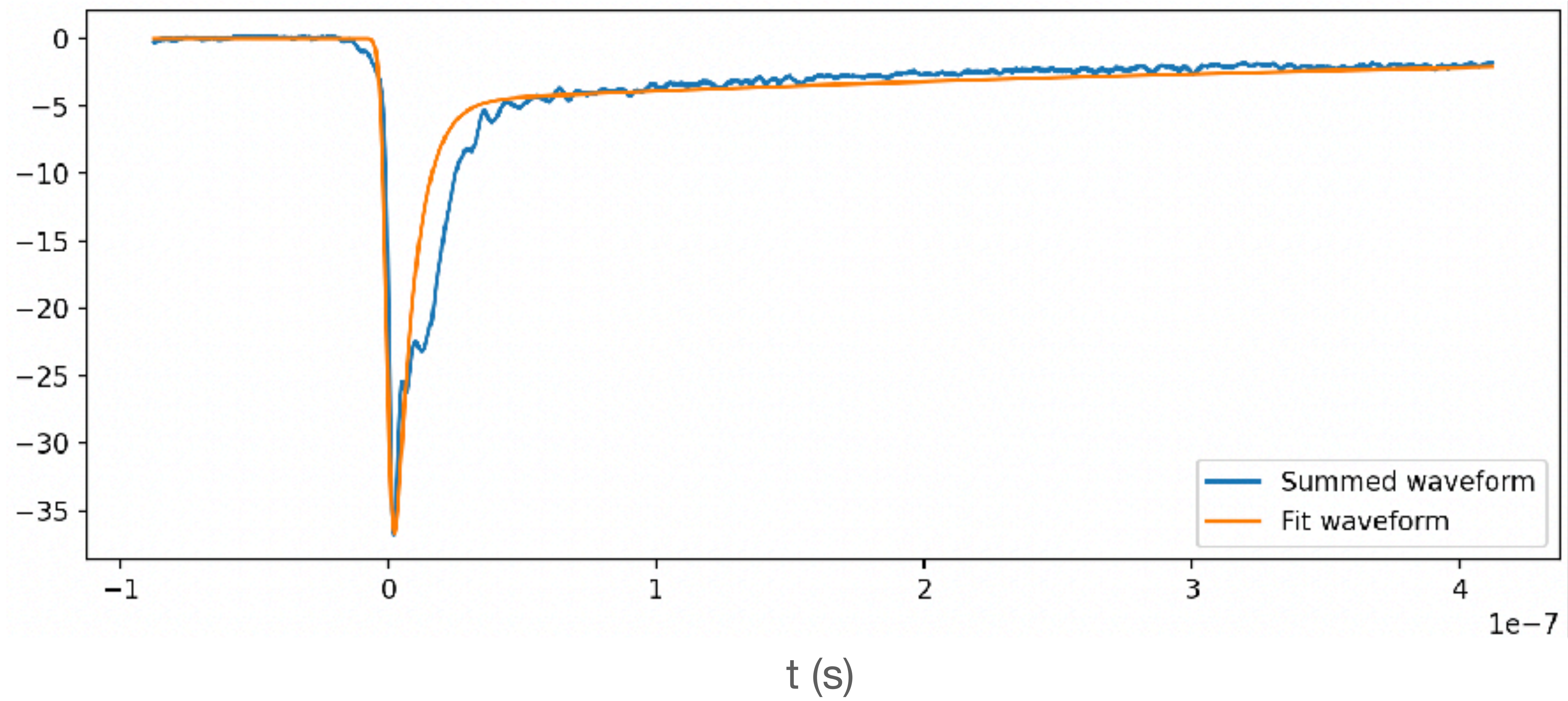






Fast component : 7.12 ns
Slow component : 500 ns
FMHM/Peak = 0.102





Other materials

Boron-10 and digitizer

Boron powder

- 25g of enriched ^{10}B powder (96% enrichment)
- Natural boron as a cheap solution (20% ^{10}B abundance)

Caen Desktop Digitizer

- 8 channel
- 500 MS/s (2 ns rate)

Next steps

In view of the 3 days of beam

Before the beam:

1. Measuring time-of-flight resolution of the photo-detectors.
2. Complete Geant4 Monte Carlo simulations.
3. Optimise geometry of the boron target and capsule.
4. Drill crystals and encapsulate boron powder.

With the beam (end of 2023):

1. Validate the principle of the neutron detector
2. Characterise the neutron beam profile

Toward low energy response measurements of LAr, LXe, mixtures…