i-TED (prototype) Commissioning 2018: The challenge and the motivation

Víctor Babiano Suárez

Javier Balibrea, Luis Caballero, David Calvo, Cesar Domingo, Ion Ladarescu, Jorge Lerendegui, Pablo Olleros, José Luis Taín
IFIC (Universitat de València – CSIC)

Francisco Calviño, Adria Casanovas, Ariel Tarifeño (UPC)

Victor Alcayne, Daniel Cano (CIEMAT)

Carlos Guerrero, Mª Ángeles Millán, Mª Teresa Rodríguez (US)

n_TOF local team and the n_TOF Collaboration

Preview

- This presentation summarizes some preliminary results from the 2018 commissioning of an **i-TED prototype**. Data from C_6D_6 detectors will be used as a benchmark.
- Two parts:
  - The challenge, related to the temporal response of i-TED.
    - Check the neutron energy spectra.
    - Reveal the **difficult of determining t_0**.
    - Preliminary solution based on software TOF corrections.
  - The motivation, related to the **first empirical background reduction results** obtained with iTED with respect to C_6D_6 by using gamma-ray imaging cuts.

The challenge

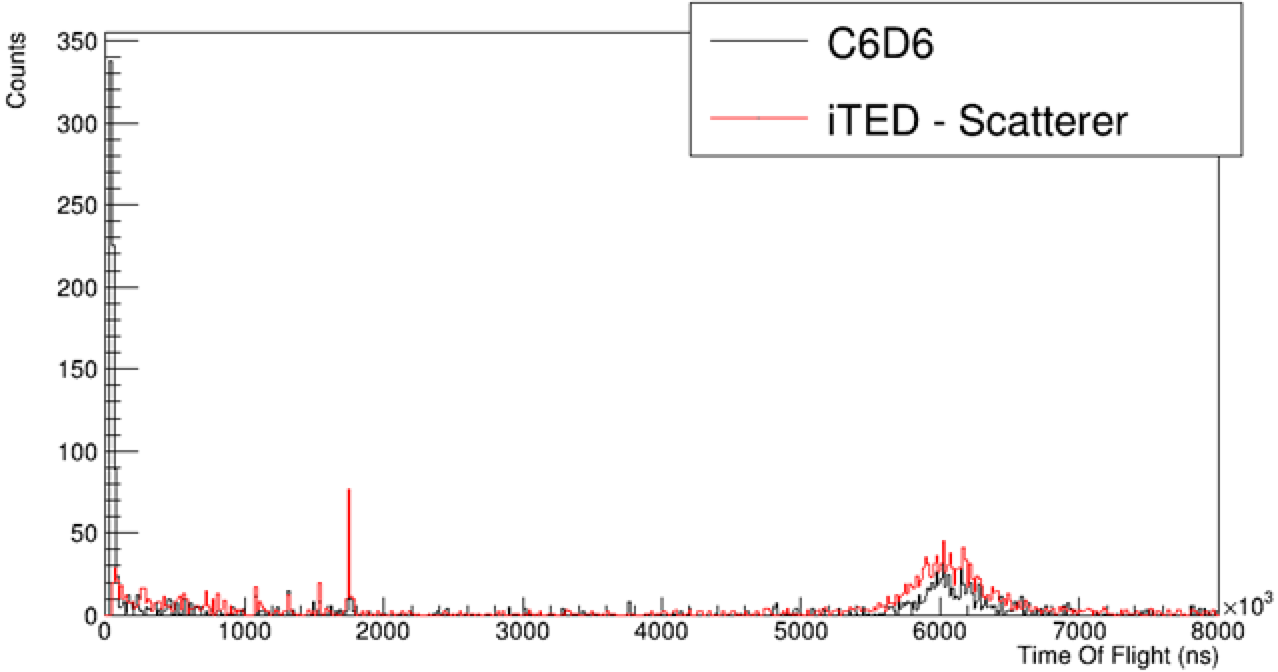
One of the main challenges with i-TED until now is to reconstruct the **time of flight** (neutron energy) spectra with sufficient time (energy) **precision**.

Time of flight spectra

^{197}Au

The challenge

One of the main challenge with i-TED until now is to reconstruct the **time of flight** (neutron energy) spectra with sufficient time (energy) **precision**.



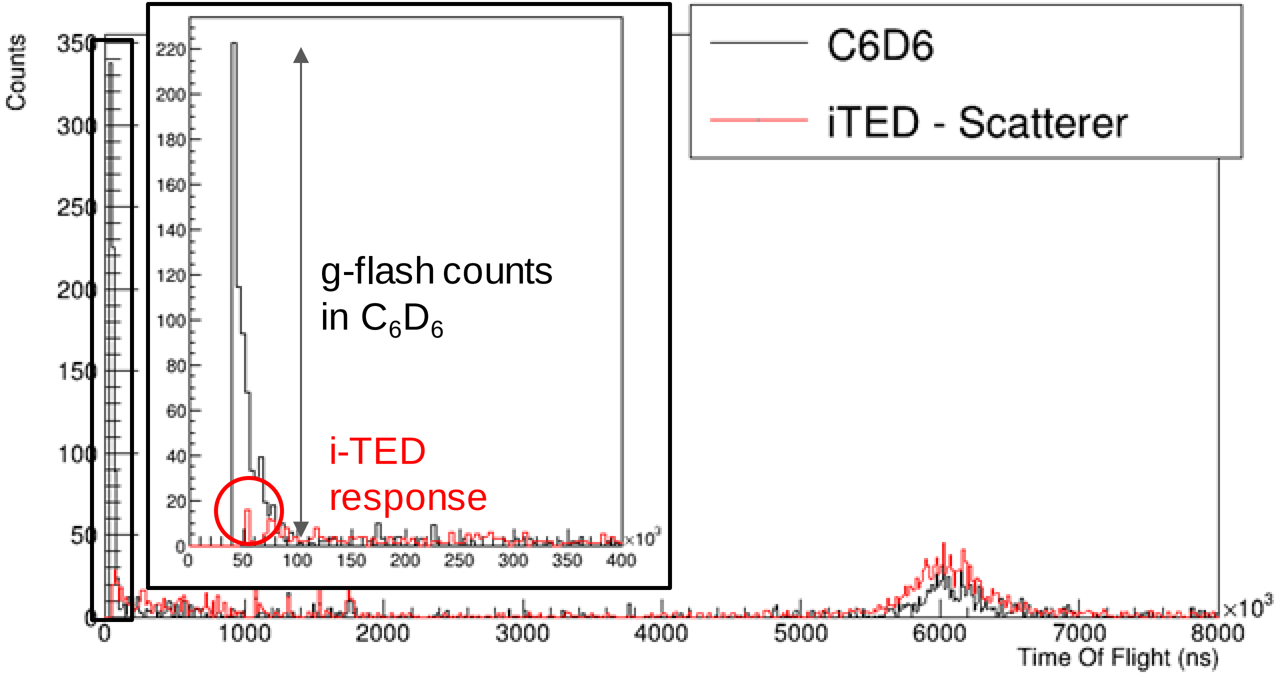
Just one bunch of protons!

Time of flight spectra

^{197}Au

The challenge

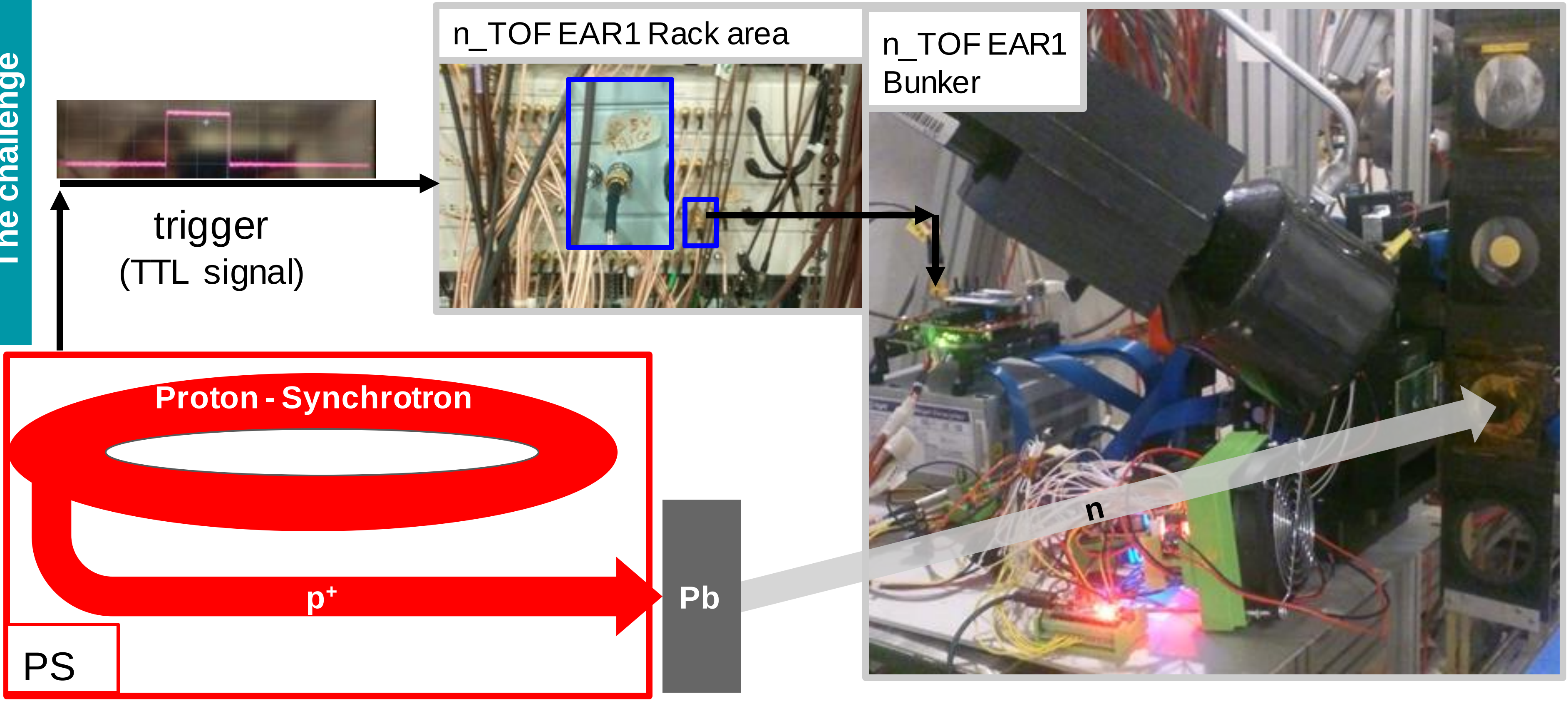
One of the main challenge with i-TED until now is to reconstruct the **time of flight** (neutron energy) spectra with sufficient time (energy) **precision**.



Just one bunch of protons!

t_0 determine - External trigger

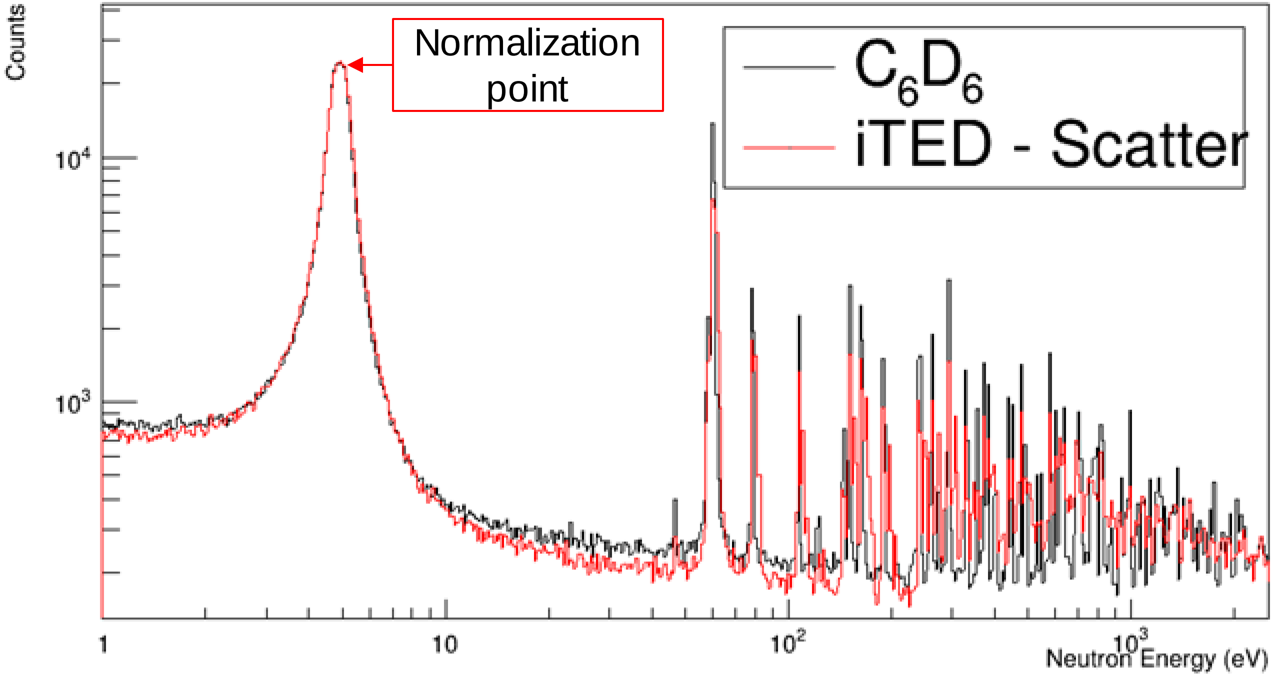
The challenge



Neutron energy spectra

^{197}Au

The challenge

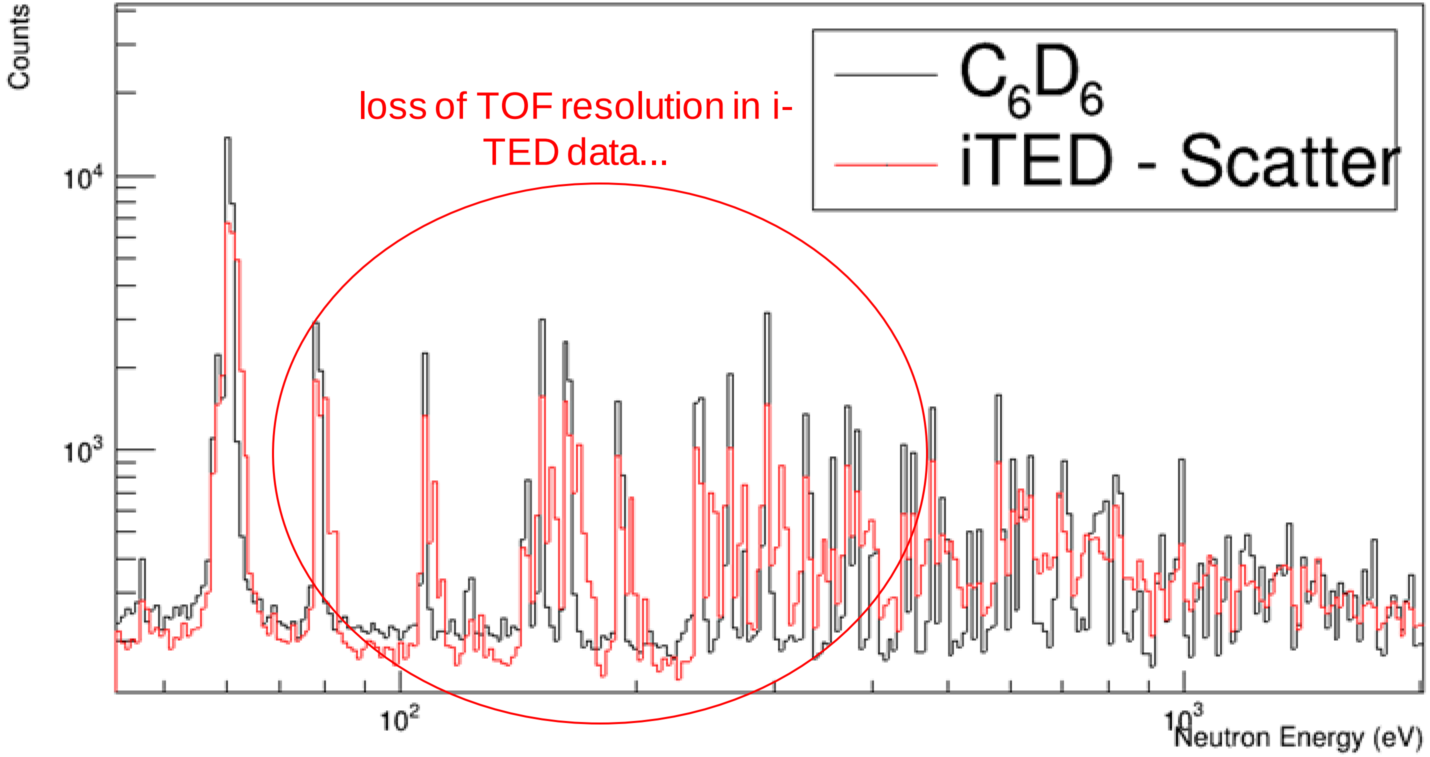


At first sight both TOF spectra look similar, however if we look in more detail in the high neutron-energy range a splitting and broadening of the narrow resonances can be observed in the i-TED data (next slide)

Neutron energy spectra

^{197}Au

The challenge

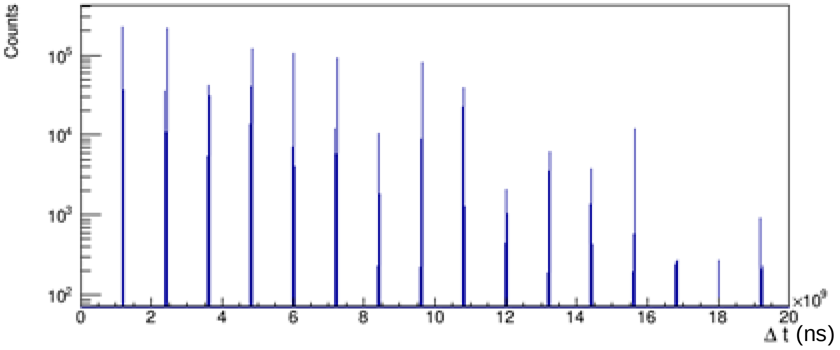


Origin of the problem: time-jitter in i-TED triggers

[197]Au

The challenge

Creating histograms with the delta time between consecutive triggers we appreciate some splits:

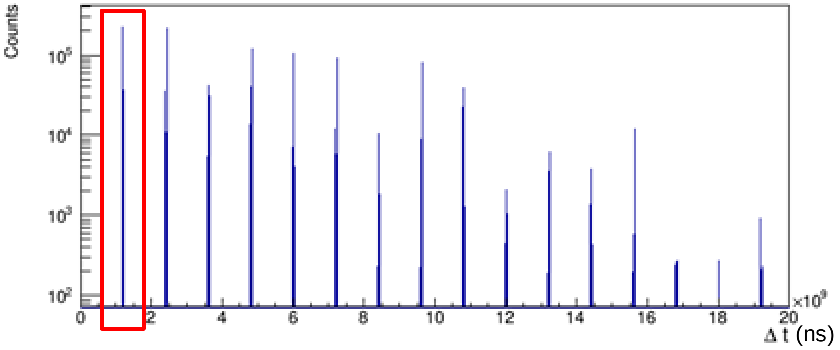


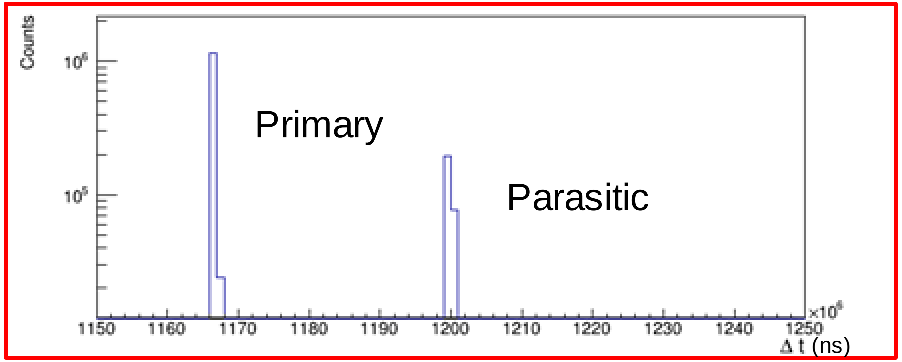
Origin of the problem: time-jitter in i-TED triggers

^{197}Au

The challenge

Creating histograms with the delta time between consecutive triggers we appreciate some splits:



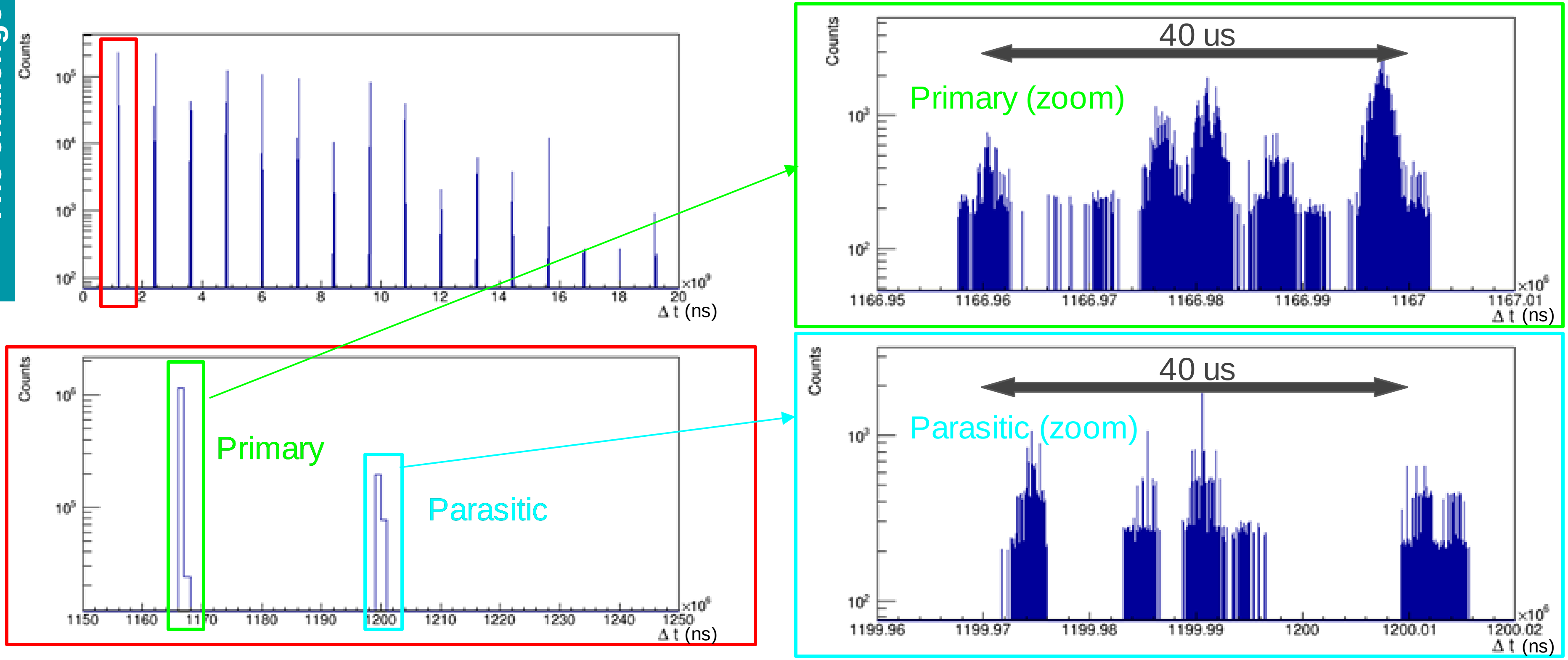


Origin of the problem: time-jitter in i-TED triggers

^{197}Au

The challenge

Creating histograms with the delta time between consecutive triggers we appreciate some splits:



Software method to correct the i-TED trigger-tof

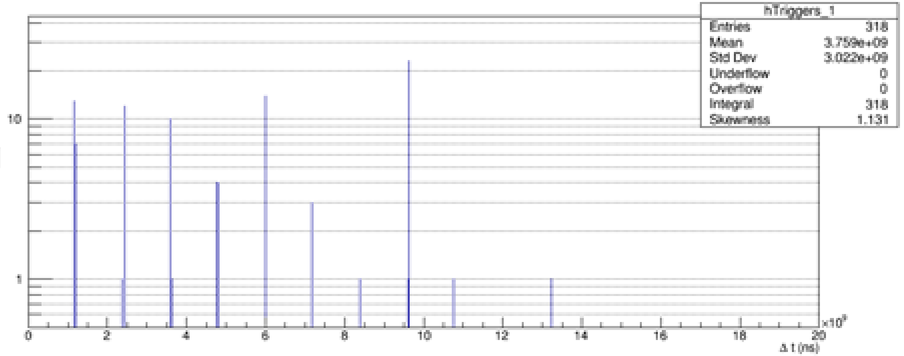
^{197}Au

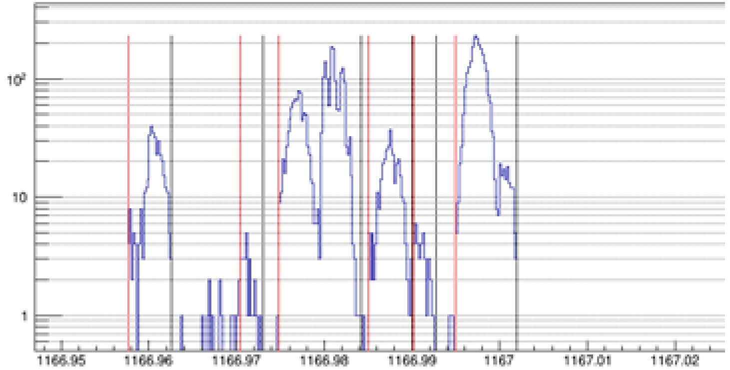
The challenge

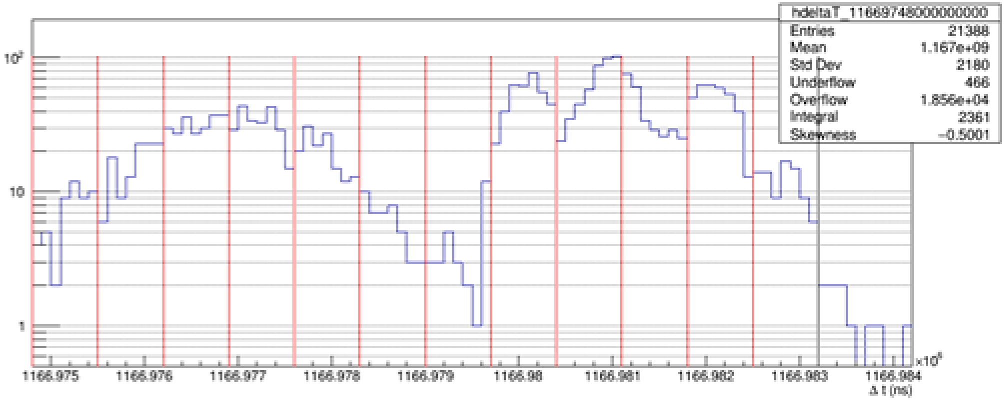
Method:

- Calculate Delta time between triggers.
- Group bunches by their delta trigger time.
- Calculate time differences between groups using tof spectra and chi2 minimization.
- Correct tof and recalculate neutron energy.

To improve: group selection.







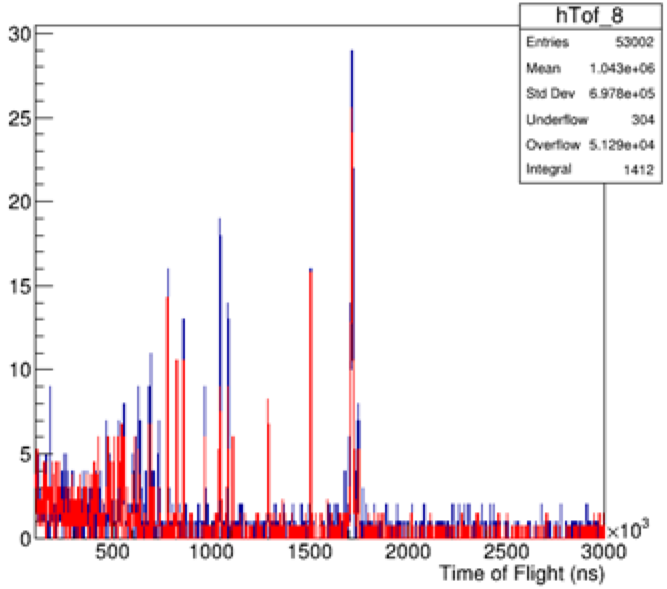
Software method to correct the i-TED trigger-tof

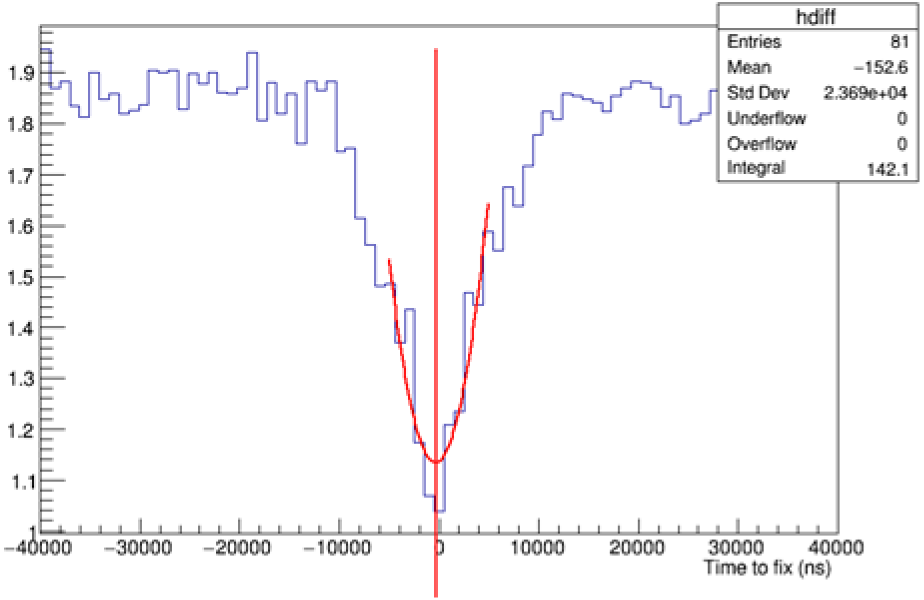
^{197}Au

The challenge

Method:

- Calculate Delta time between triggers.
- Group bunches by their delta trigger time.
- Calculate time differences between groups using tof spectra and chi2 minimization.
- Correct tof and recalculate neutron energy.





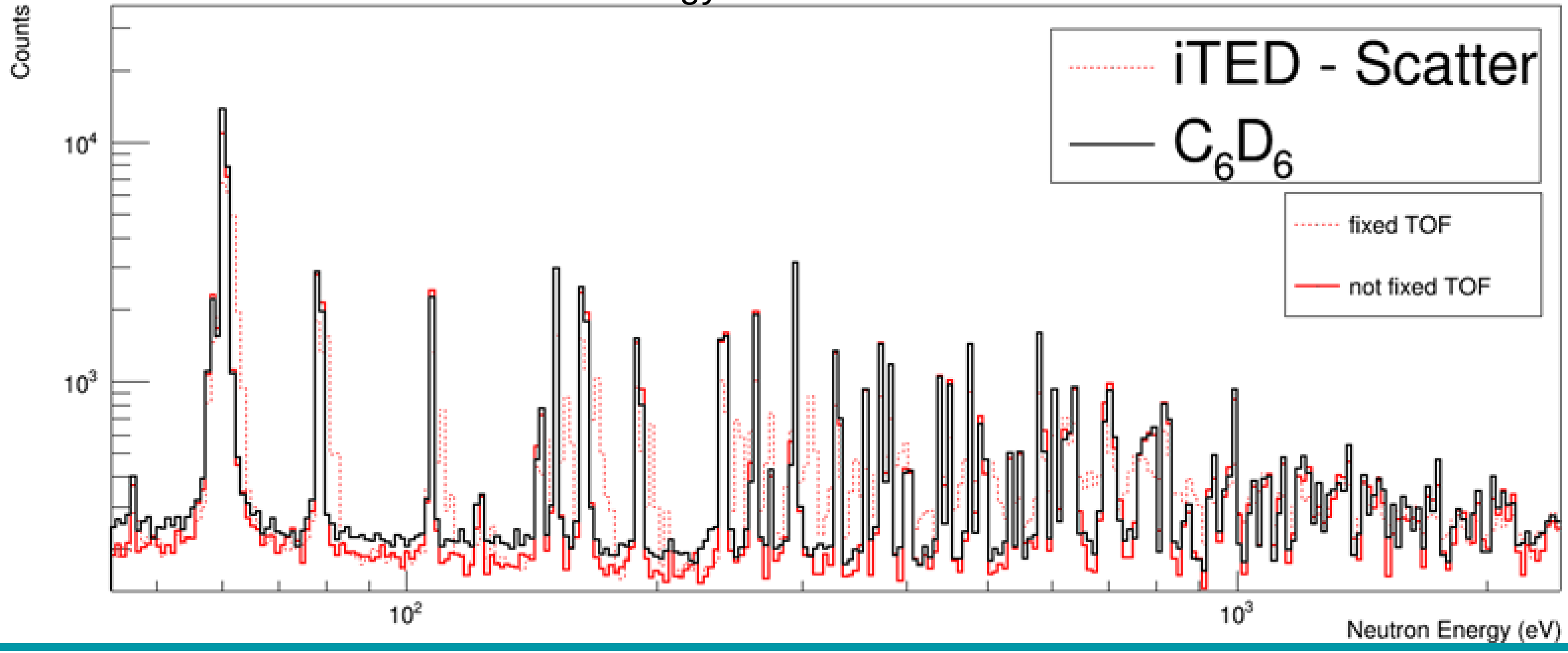
Fixed i-TED tof by software method

^{197}Au

The challenge

Method:

- Calculate Delta time between triggers.
- Group bunches by their delta trigger time.
- Calculate time differences between groups using tof spectra and chi2 minimization.
- Correct tof and recalculate neutron energy.



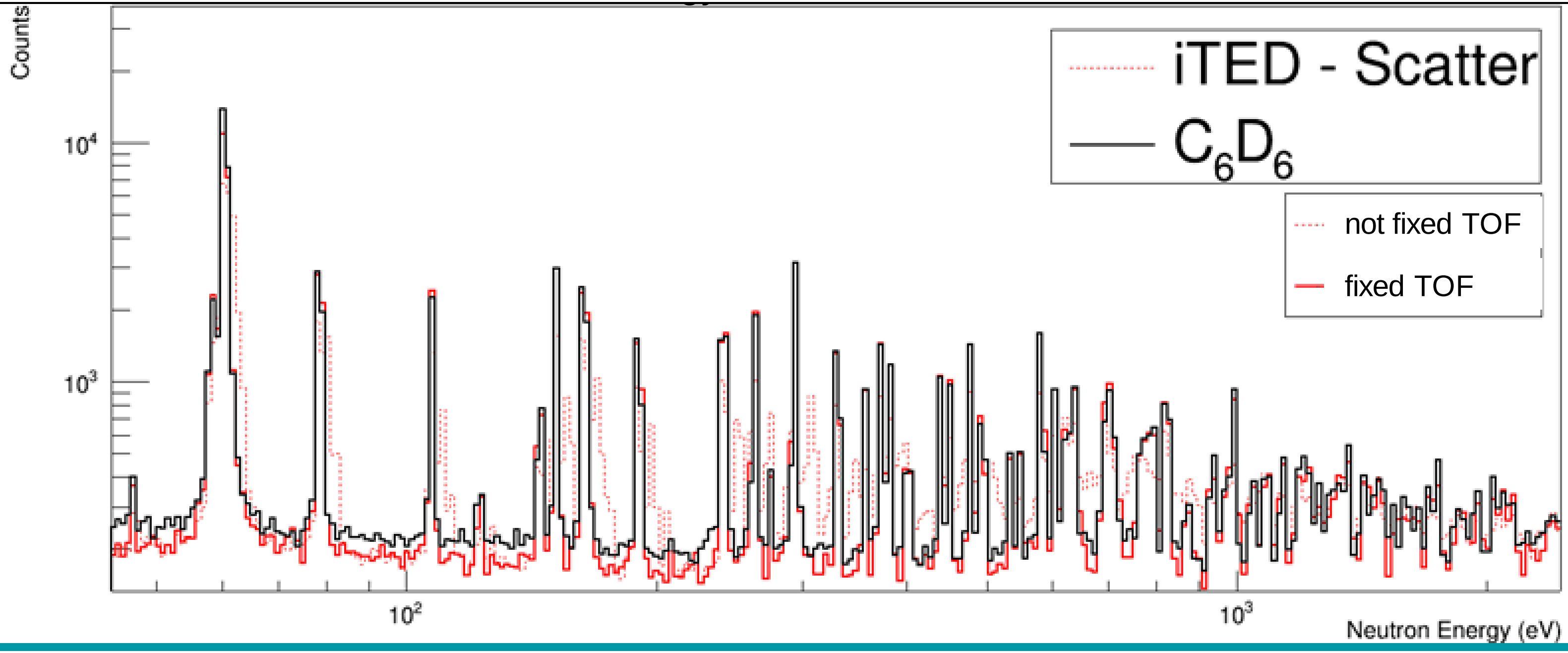
Fixed i-TED tof by software method

^{197}Au

The challenge

Once the trigger-jitter issue is solved, each **i-TED Scatterer** detector becomes **fully equivalent to** one **C_6D_6 detector** both in terms of:

- TOF Resolution
- g-ray Efficiency



i-TED detector: not only a C_6D_6

Once the trigger-jitter issue is solved, each i-TED Scatterer detector becomes fully equivalent to one C_6D_6 detector both in terms of:

- TOF Resolution
- g-ray Efficiency

In addition, i-TED has two features, which one can try to exploit further:

- **high energy resolution** ($LaCl_3$) → to gain valuable information on the nuclear structure aspects
- **g-ray imaging capability** → to reduce neutron induced backgrounds and enhance S/B-ratio

The motivation: i-TED capability for background rejection

Once the trigger-jitter issue is solved, each i-TED Scatterer detector becomes fully equivalent to one C_6D_6 detector both in terms of:

- TOF Resolution
- g-ray Efficiency

In addition, i-TED has two features, which one can try to exploit further:

- high energy resolution ($LaCl_3$) → to gain valuable information on the nuclear structure aspects
- **g-ray imaging capability** → to **reduce** neutron induced **backgrounds** and enhance S/B-ratio

With **the motivation of exploring the i-TED capability for background rejection**, in the next slides we will see first preliminary tests to see how to exploit g-ray imaging capability aiming at a background reduction.

In this case, ^{197}Au(n,γ) is not suitable because the capture yield is very high and, therefore, a ^{56}Fe sample was measured during the 2018 commissioning of the first i-TED prototype

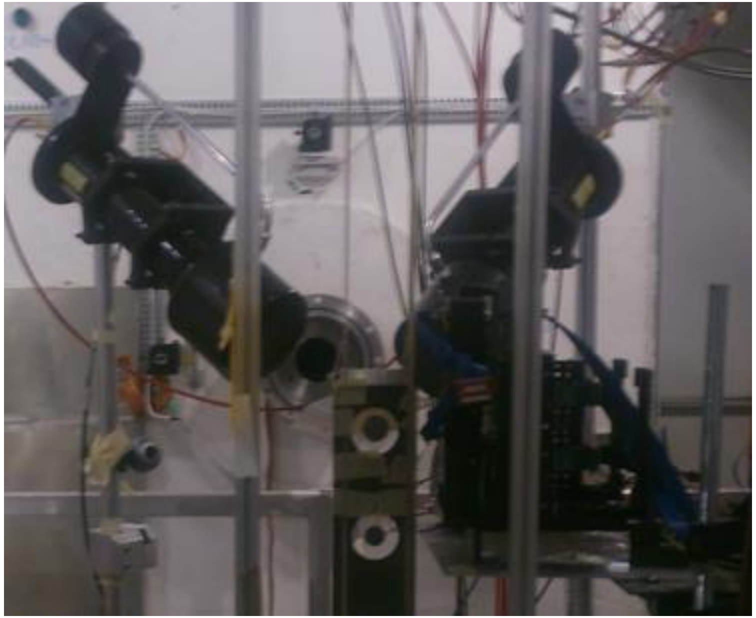
The motivation

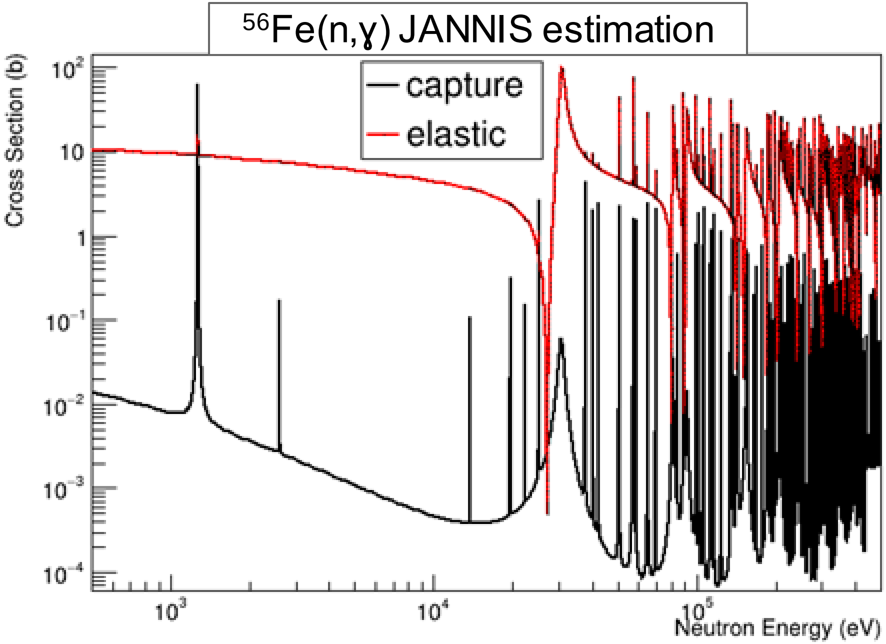
^{56}Fe(n,γ) capture data: playground for i-TED tests

^{56}Fe

^{56}Fe, the first candidate:

- Large ratio between elastic and capture cross section.
- Available data from i-TED (prototype) Commissioning 2018 @EAR1.





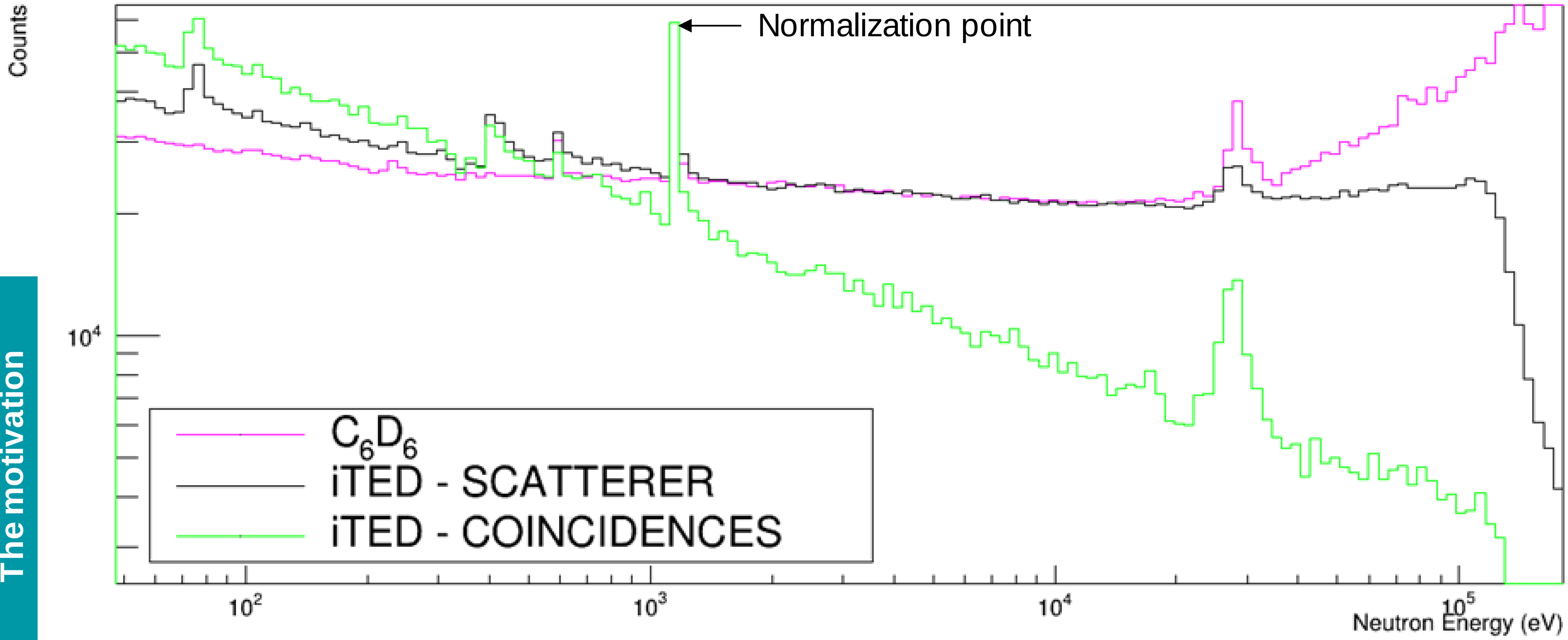
The motivation

Neutron energy spectra from $^{56}Fe(n,\gamma)$

^{56}Fe

The motivation

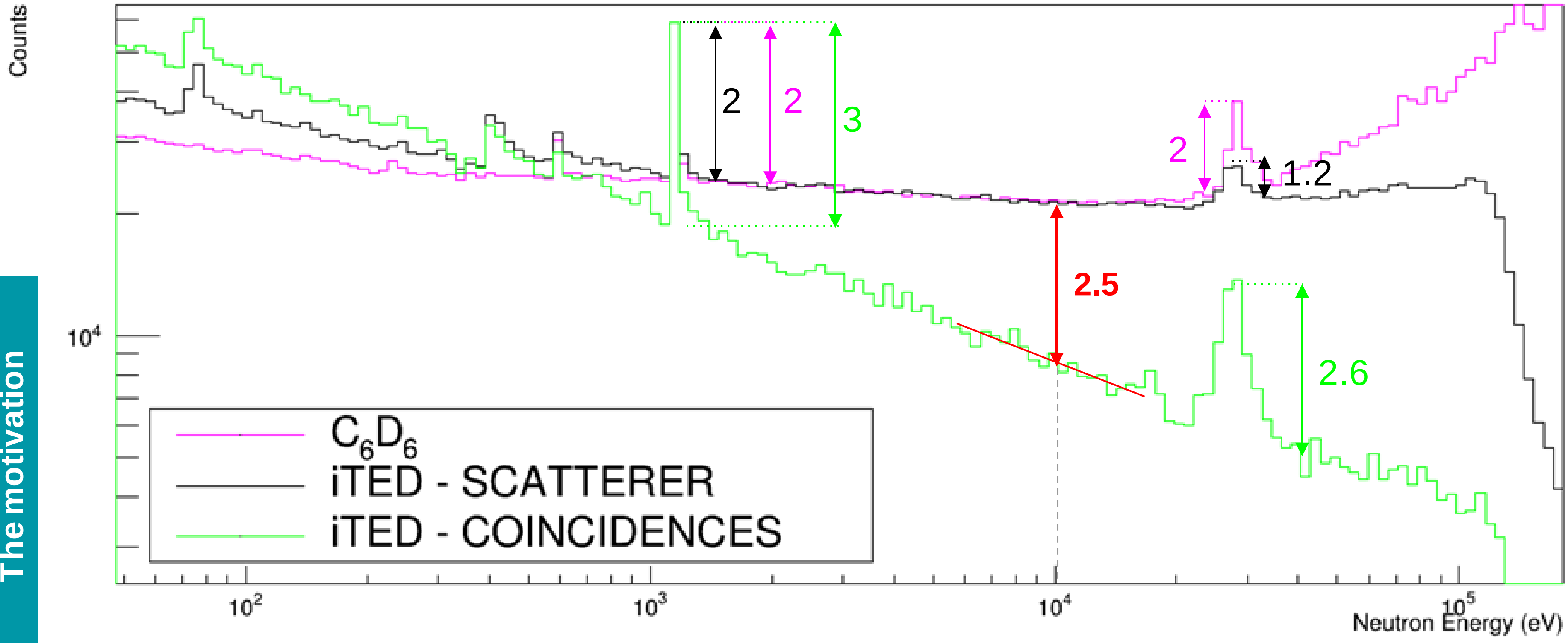
i-TED vs C_6D_6



Neutron energy spectra from $^{56}Fe(n,\gamma)$

^{56}Fe

i-TED vs C_6D_6



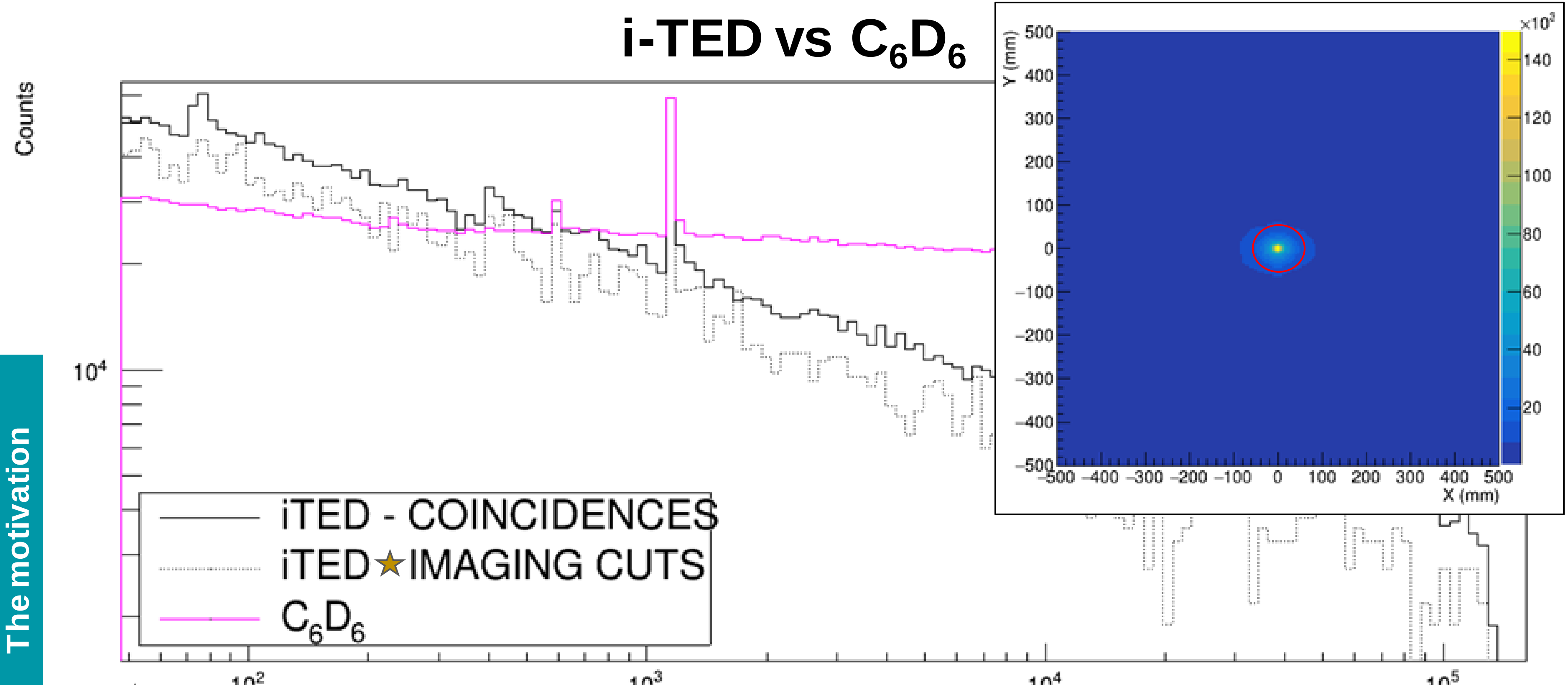
The motivation

Neutron energy spectra from $^{56}Fe(n,\gamma)$

^{56}Fe

The motivation

i-TED vs C_6D_6

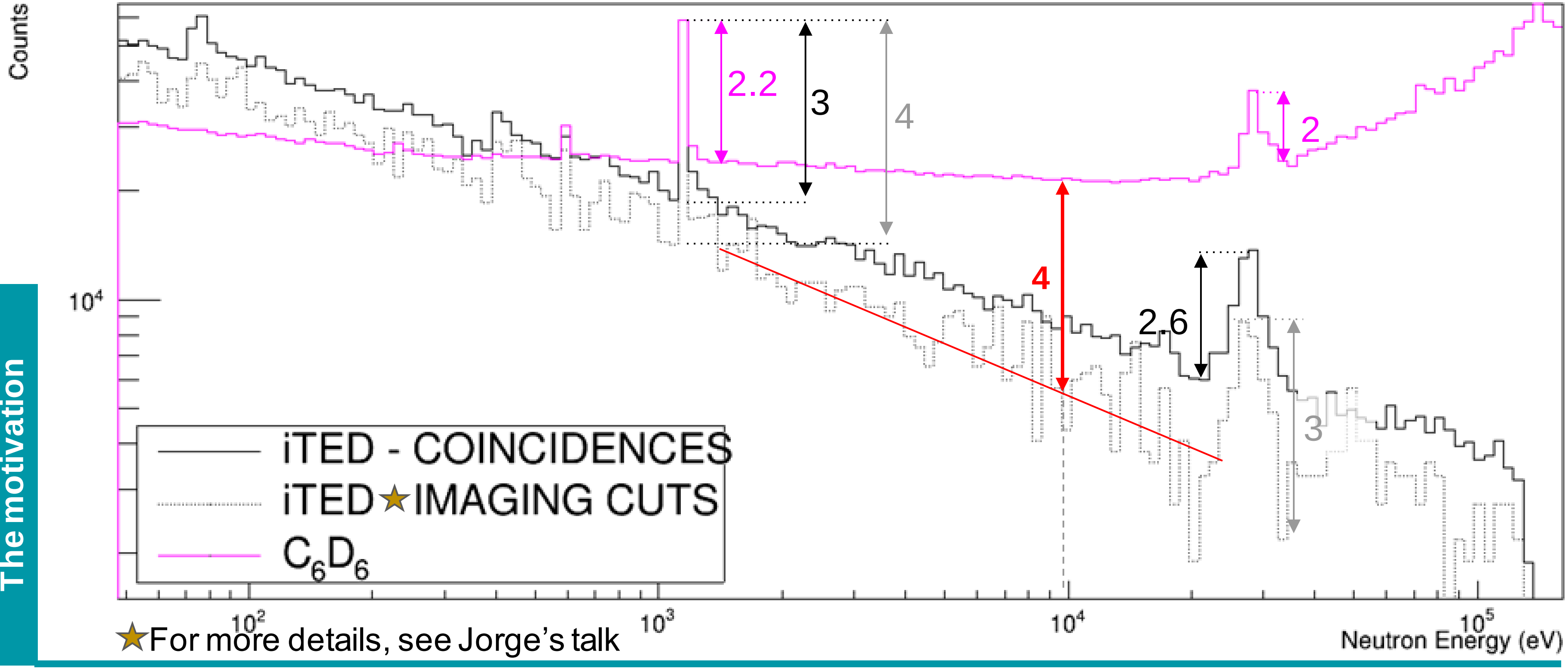


★For more details, see Jorge's talk

Neutron energy spectra from $^{56}Fe(n,\gamma)$

^{56}Fe

i-TED vs C_6D_6



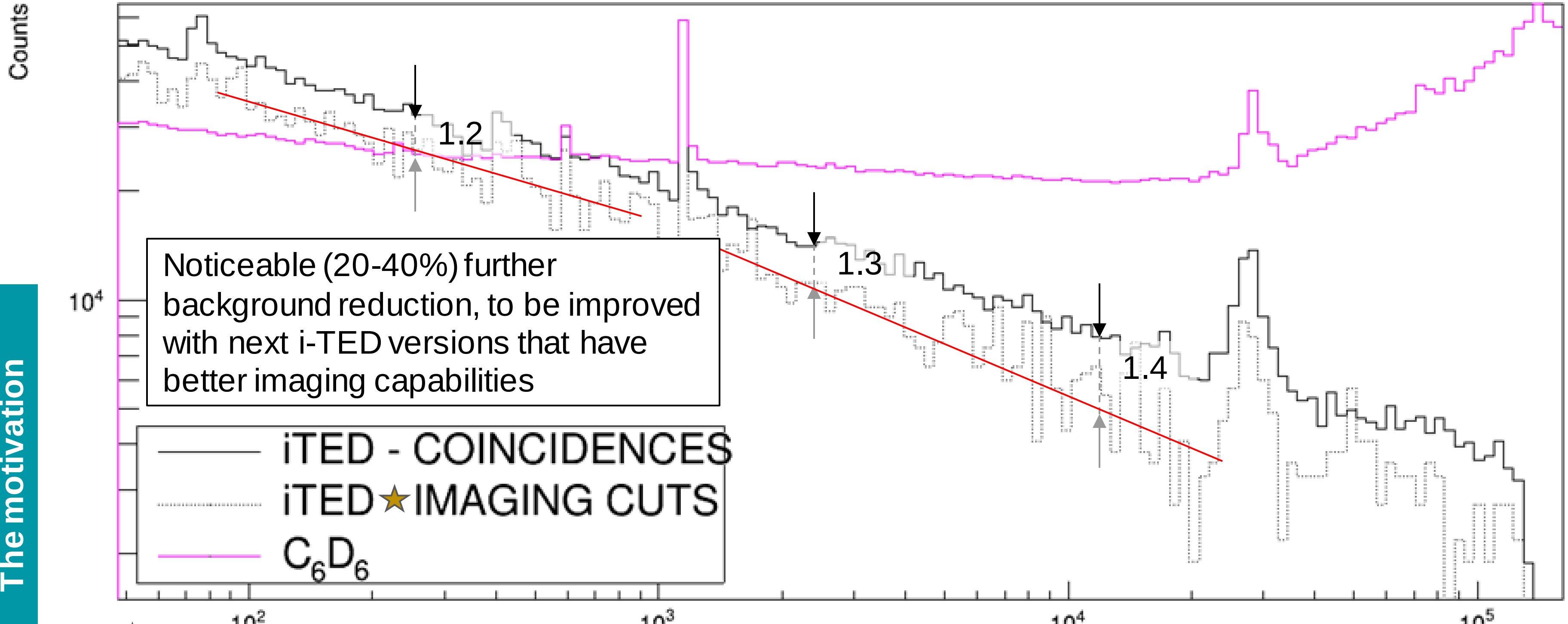
★For more details, see Jorge's talk

The motivation

Neutron energy spectra from $^{56}Fe(n,\gamma)$

^{56}Fe

i-TED vs C_6D_6



★For more details, see Jorge's talk

The motivation

Summary and outlook

The challenge

One of the main challenges in the first analysis of the 2018 commissioning data was due to inaccuracies in the trigger signal, which led to a loss of TOF resolution:

- Since g-flash cannot be time-stamped with i-TED, an external trigger (PS-signal) was used to determine the t_0.
- A jittering appears in the trigger time-distributions, which is also reflected in a splitting of the narrow resonances at high neutron energy.
- Some possible causes for the observed jitter are the following:
  - Something (the g-flash?) is triggering the system apart from the PS-signal in a window of about 40 us.
  - Jittering in the trigger signal of the PS.
- A software method has been developed to correct for this jitter. This is, however, a **preliminarily patch**, and a **hardware solution will be implemented in next i-TED measurements**.

Summary and outlook

Tests with the ^{56}Fe(n,g) capture data taken in 2018 at EAR1 using a small-prototype of i-TED show interesting preliminary results:

- In the 1 keV - 100 keV neutron energy range, a significant background reduction is obtained simply by the time-coincidence method used.
- Applying g-ray Compton imaging cuts in order to select g-rays coming from the sample, allow one to reduce a bit further the background and increase the signal-to-background ratio, particularly when compared to a C_6D_6 in the keV energy range (factor 4 lower background level at 10 keV for i-TED with imaging compared to C_6D_6).
- One has to keep in mind that, these **tests were made with a small prototype of only 3 crystals** with rather limited imaging capability, when compared to the **20 crystals final version of i-TED foreseen for 2021**.
- Very promising results are expected also from alternative analysis techniques, which instead of Compton backprojection rely on ML-algorithms (please **see Jorge's talk!**)
- After completing the analysis of ^{56}Fe(n,g) with i-TED at EAR1, a similar analysis will be made with the ^{93}Nb(n,g) data measured at EAR2 (even more challenging).

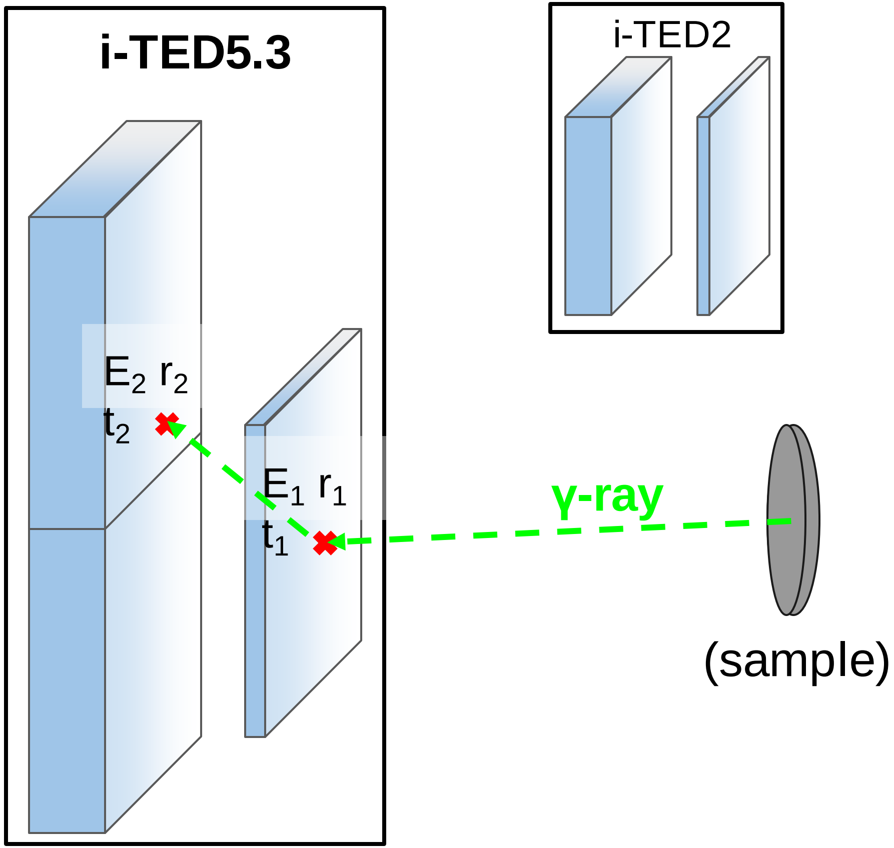
The motivation

BACKUP

The i-TED Concept and 2018 prototypes

- Two detection planes operating in time coincidence:
  - Scatterer (1 PSD)
  - Absorber (1 or 2 PSDs)

- Energy, position and time of every gamma-ray hit are measured at each stage:
  - One can select data from only one stage (singles).
  - Or select events in temporal coincidence in the two stages, which allows to apply Compton imaging.

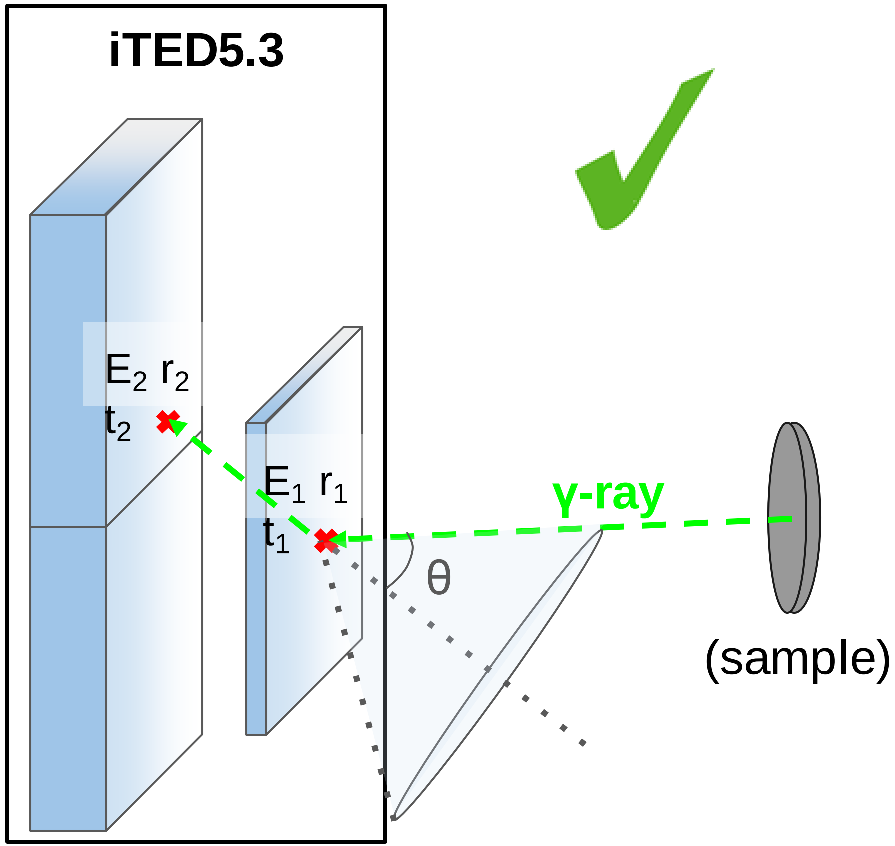


The i-TED Concept and 2018 prototypes

- Two detection planes operating in time coincidence:
  - Scatterer (1 PSD)
  - Absorber (1 or 2 PSDs)
- Energy, position and time of every gamma-ray hit are measured at each stage.
- Using data in coincidences, a cone can be traced with the calculated Compton angle:

$$\theta = arcos\left(1 - m_e c^2\left(\frac{1}{E_2} - \frac{1}{E_1 + E_2}\right)\right)$$

which determines the possible directions of the incoming γ-ray.

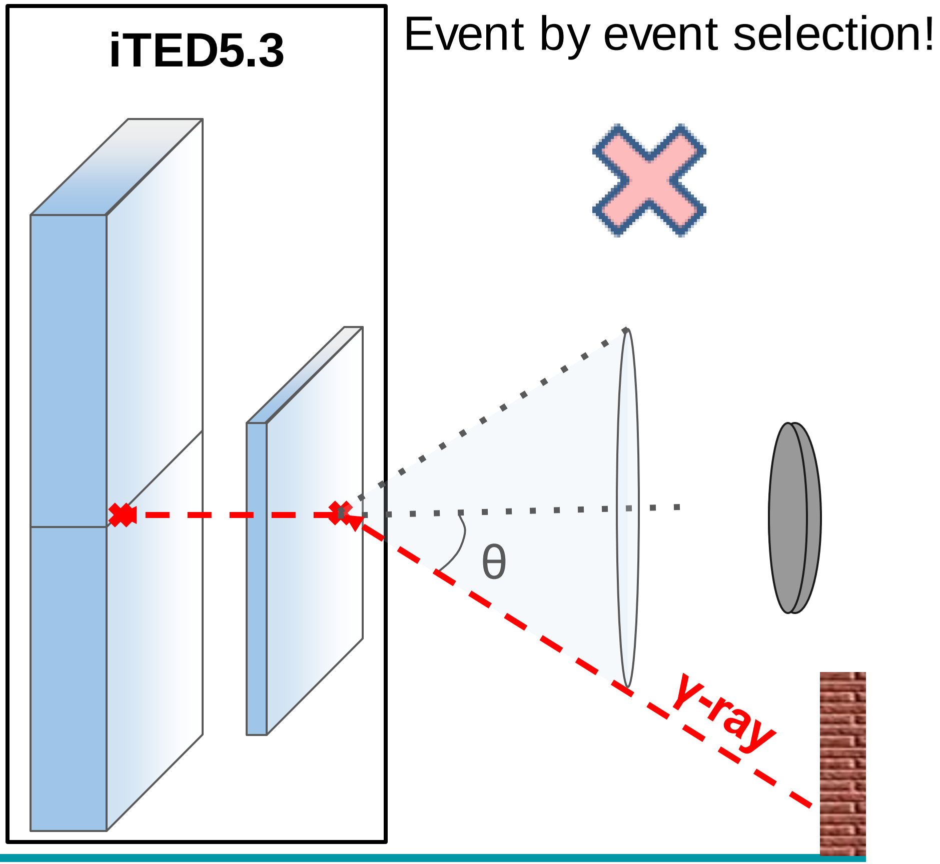


The i-TED Concept and 2018 prototypes

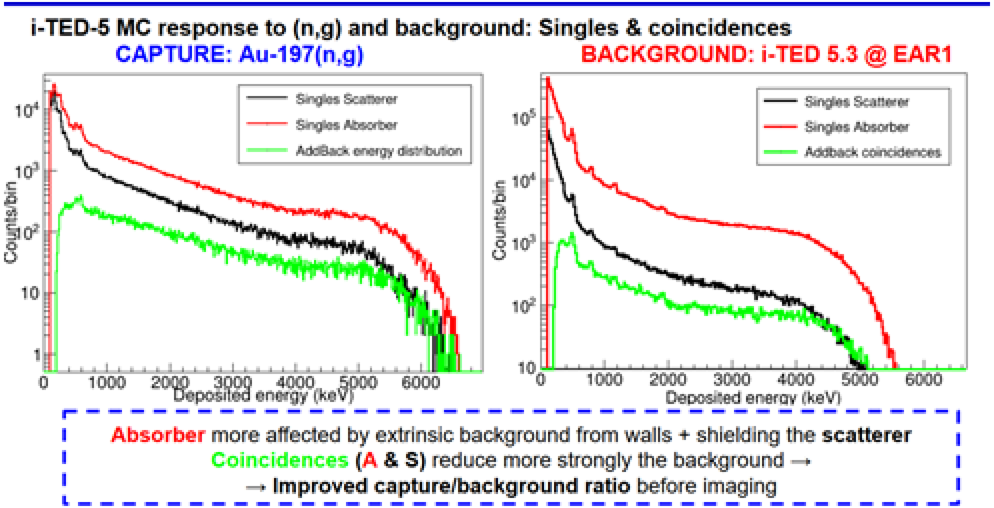
- Two detection planes operating in time coincidence:
  - Scatterer (1 PSD)
  - Absorber (1 or 2 PSDs)
- Energy, position and time of every gamma-ray hit are measured at each stage.
- Using data in coincidences, a cone can be traced with the calculated Compton angle:

$$\theta = arcos\left(1 - m_e c^2 \left(\frac{1}{E_2} - \frac{1}{E_1 + E_2}\right)\right)$$

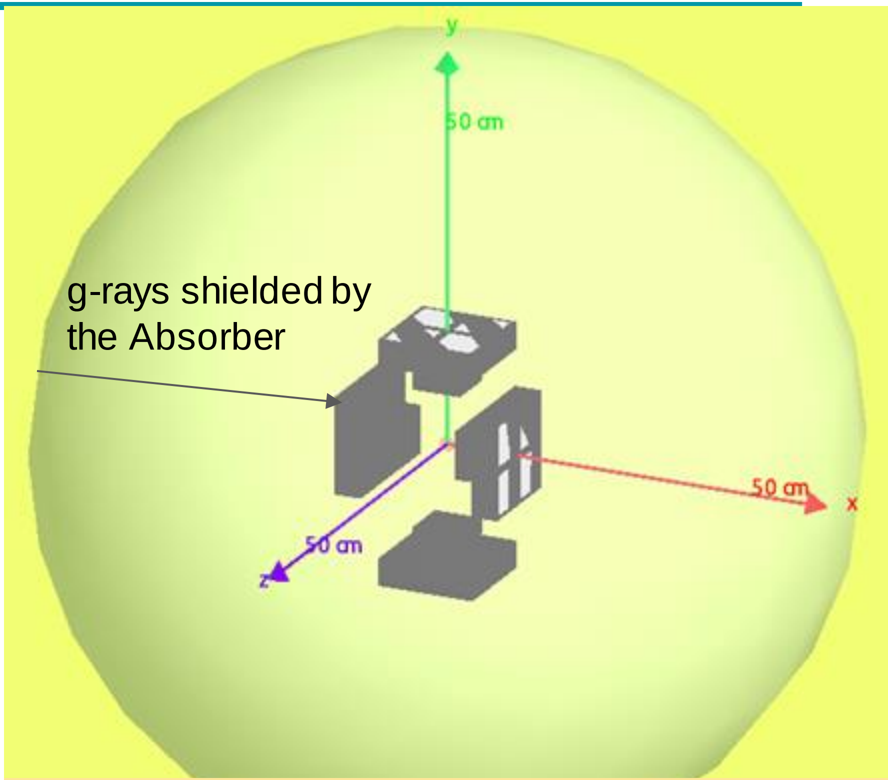
which determines the possible directions of the incoming γ-ray.



Time-Coincidence background rejection



Soft spectra measured with i-TED5.3 prototype (GREEN/IN COINCIDENCES) during 2018 Commissioning at EAR1.



sphere as a representative background from capture in the surrounding of the exp. area.

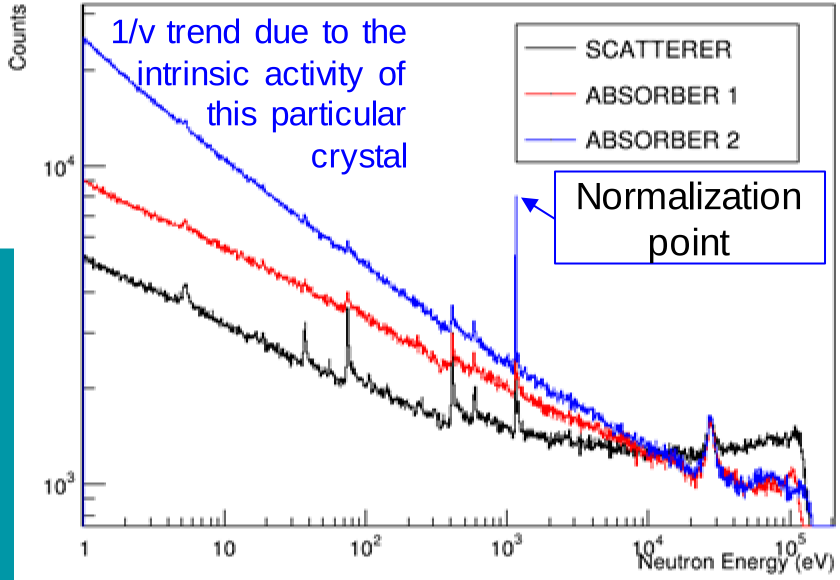
Neutron energy spectra from $^{56}Fe(n,\gamma)$

^{56}Fe

The motivation

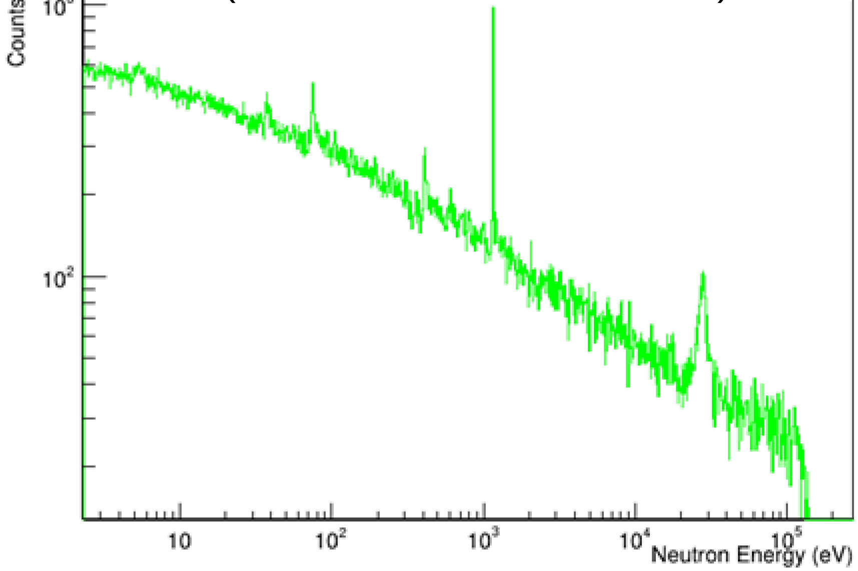
i-TED

Singles



Coincidences

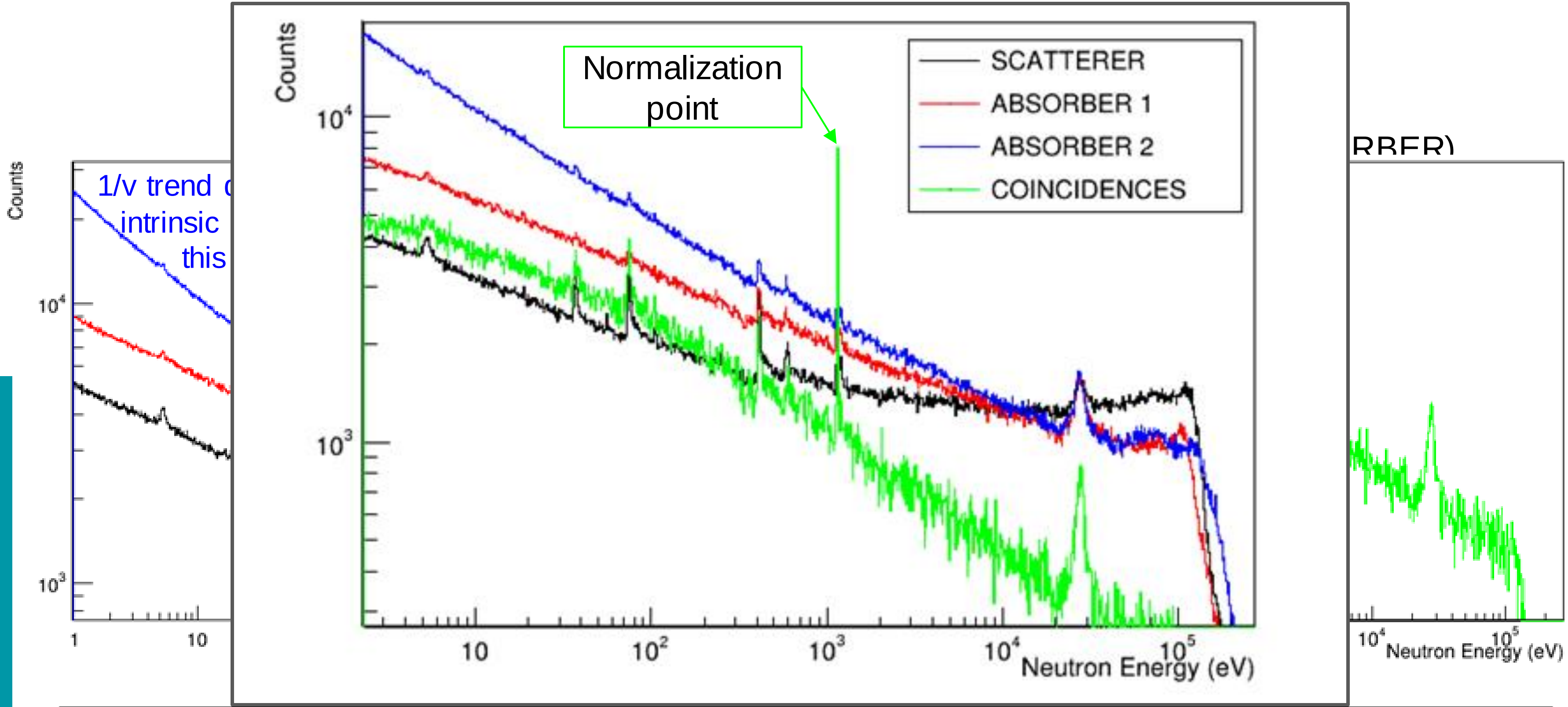
(SCATTERER + ABSORBER)



Measured during the 2018 commissioning with the i-TED5.3 prototype at EAR1

Neutron energy spectra from $^{56}Fe(n,\gamma)$

^{56}Fe



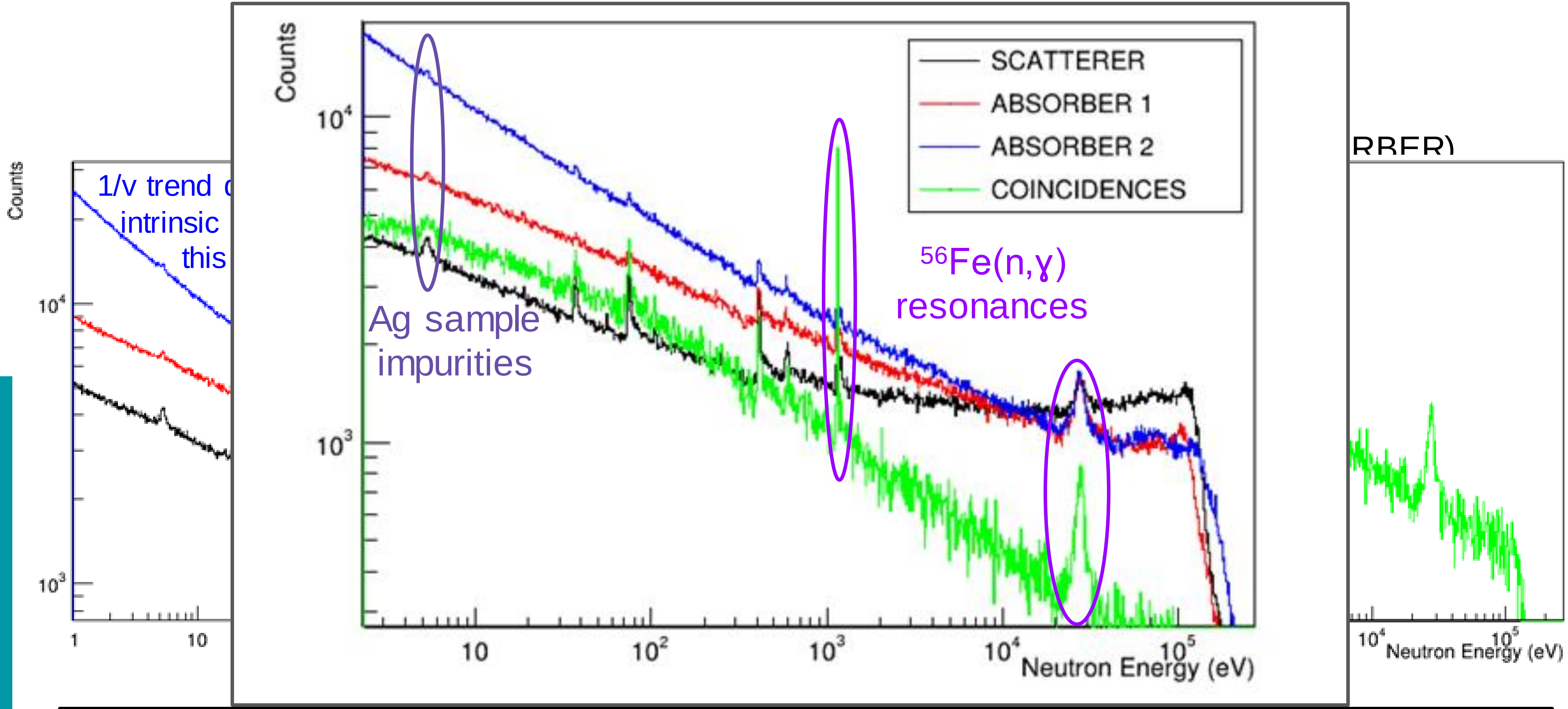
Measured during the 2018 commissioning with the i-TED5.3 prototype at EAR1

The motivation

Neutron energy spectra from $^{56}Fe(n,\gamma)$

^{56}Fe

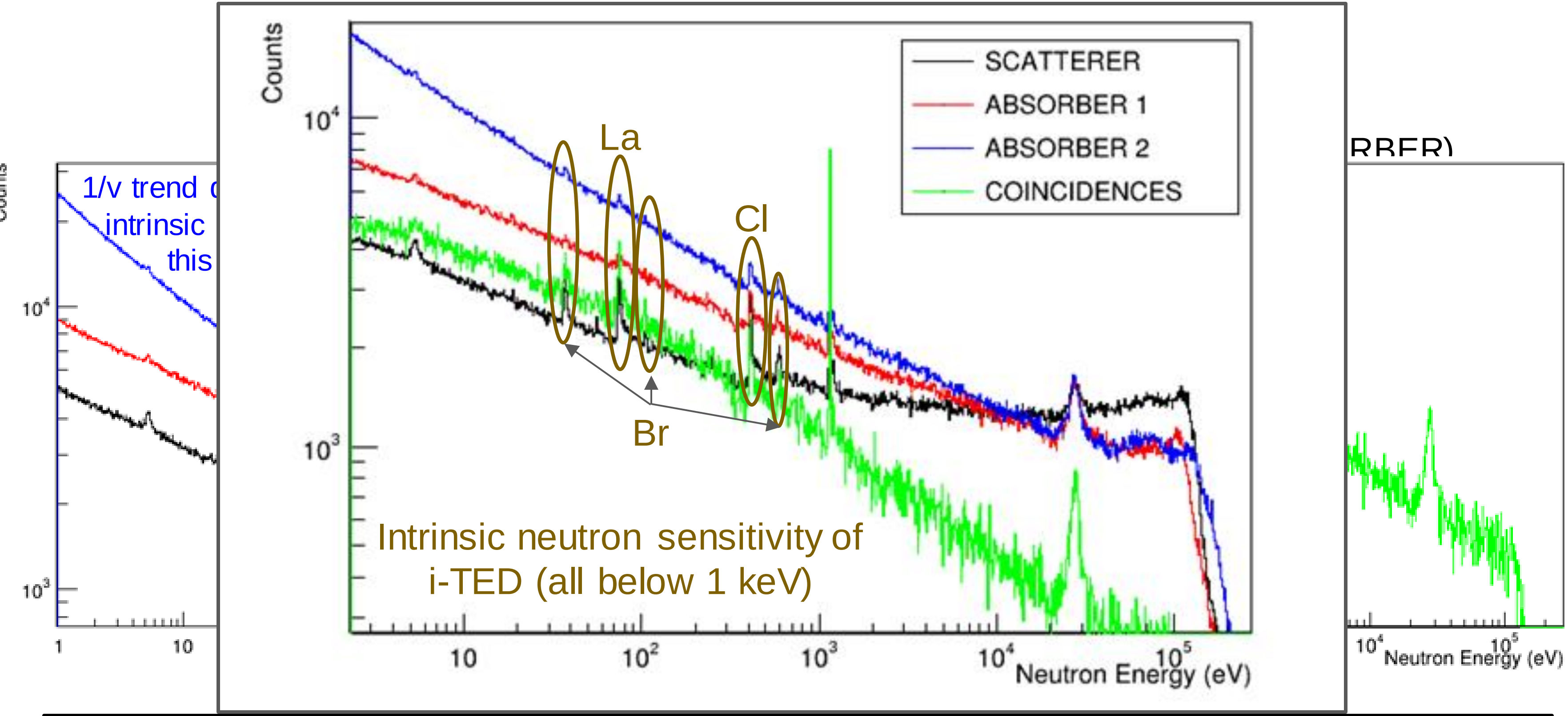
The motivation



Measured during the 2018 commissioning with the i-TED5.3 prototype at EAR1

Neutron energy spectra from $^{56}Fe(n,\gamma)$

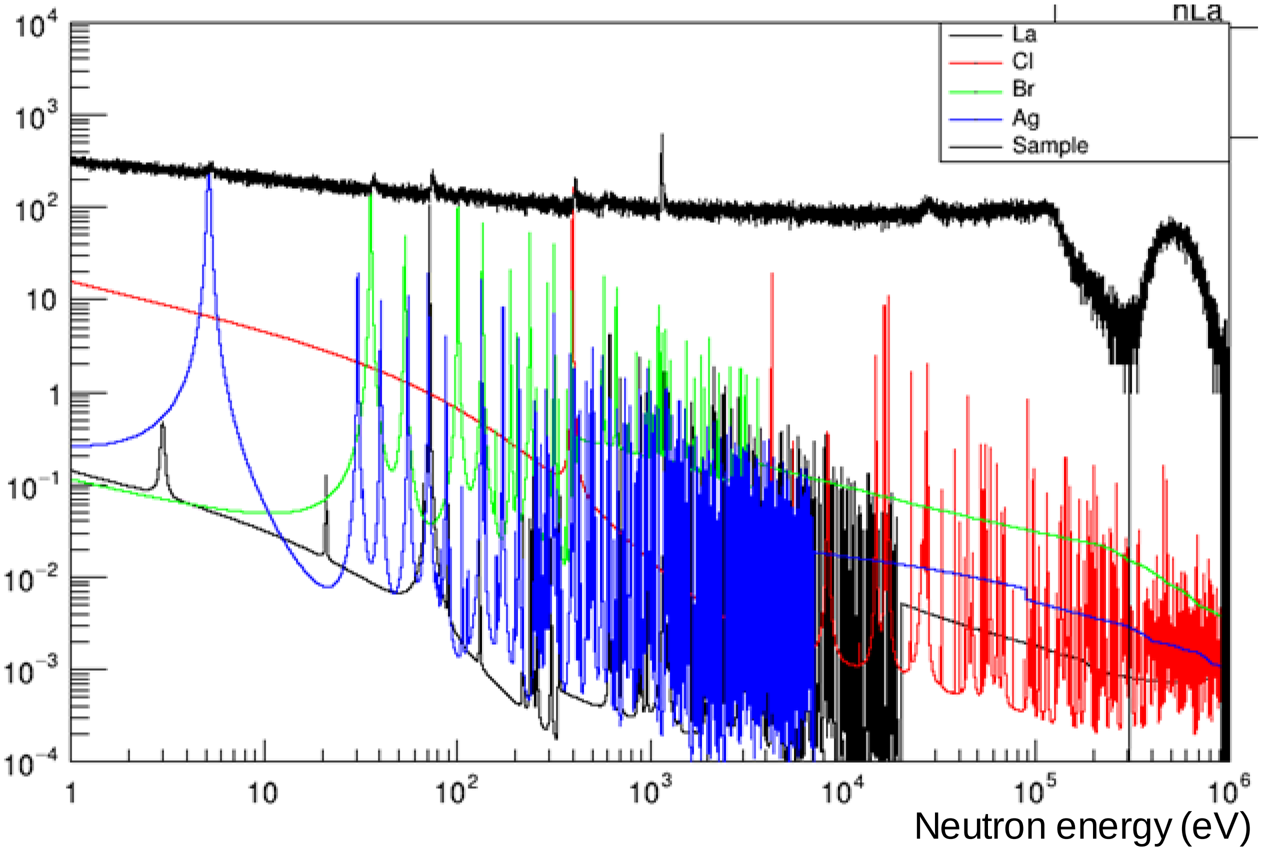
^{56}Fe



Measured during the 2018 commissioning with the i-TED5.3 prototype at EAR1

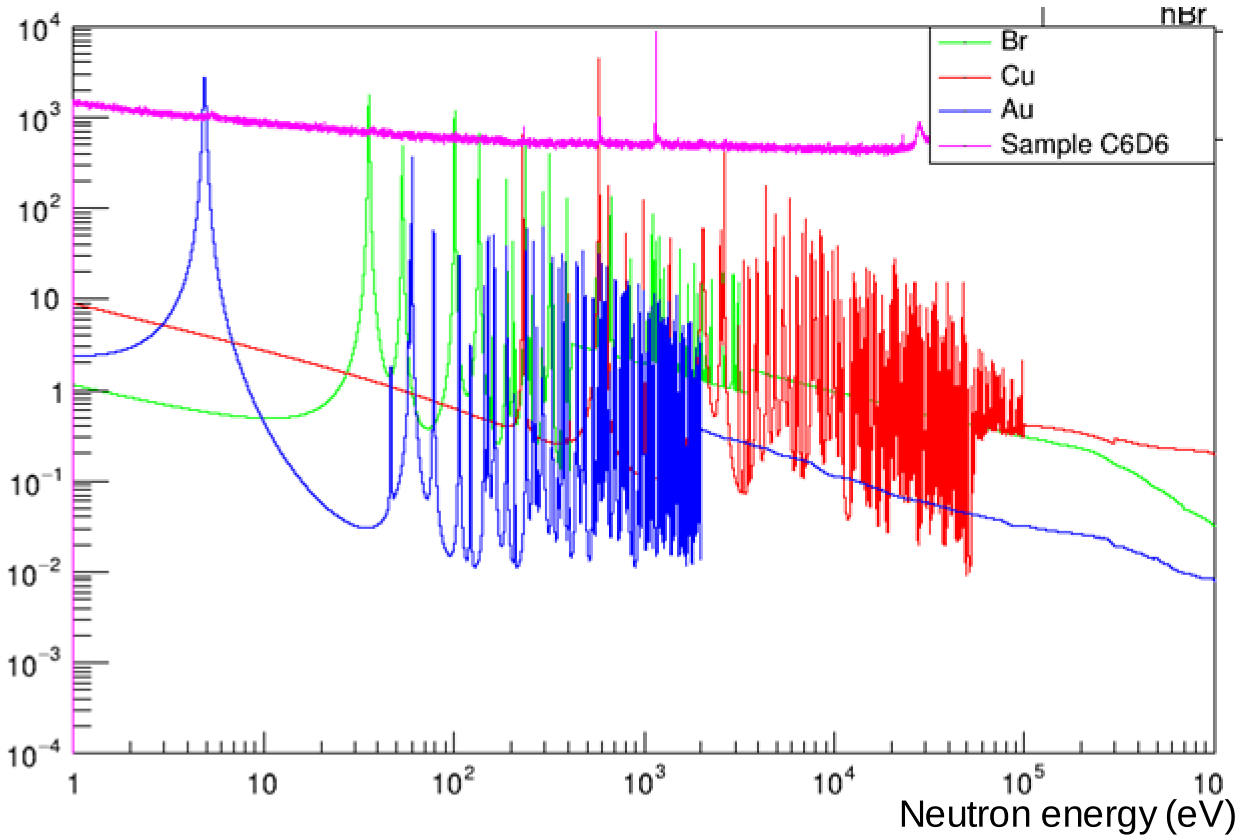
The motivation

i-TED intrinsic neutron sensitivity



The motivation

i-TED intrinsic neutron sensitivity

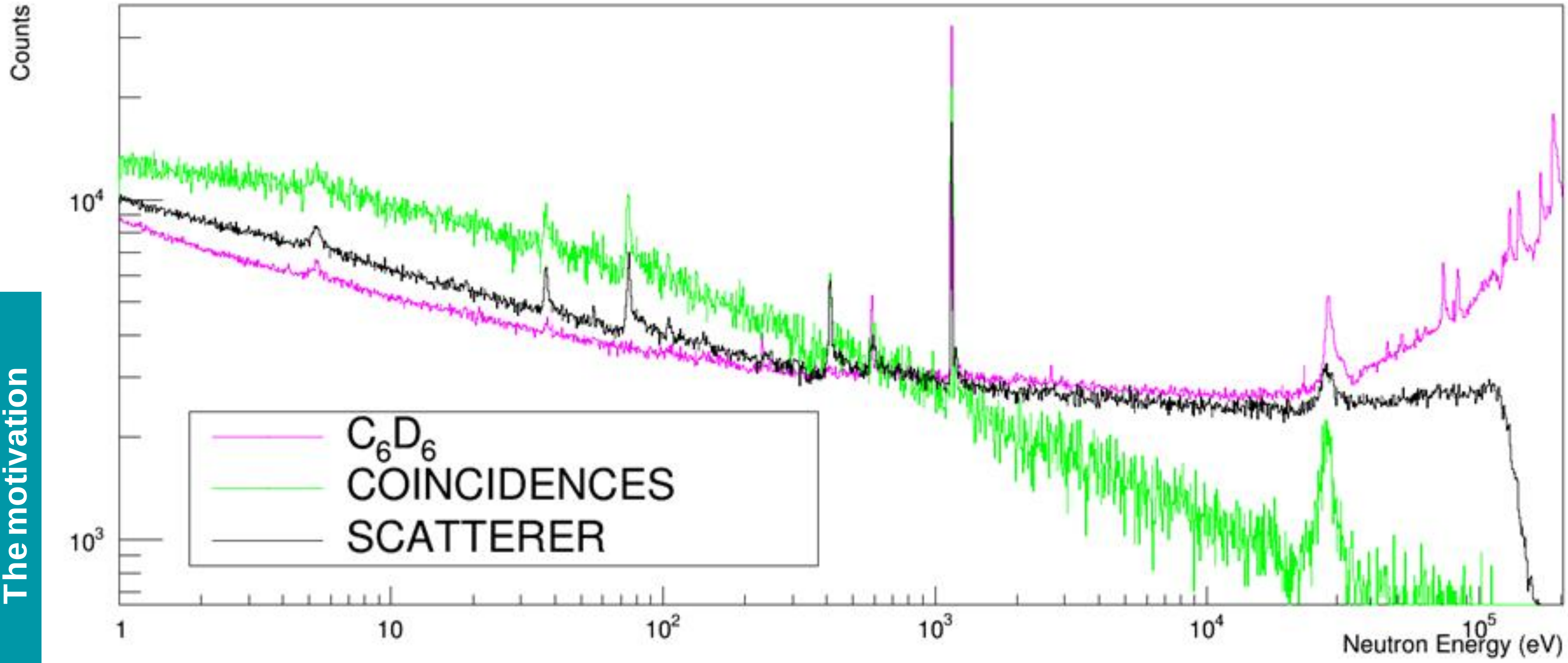


The motivation

Neutron energy

^{56}Fe

i-TED vs C_6D_6

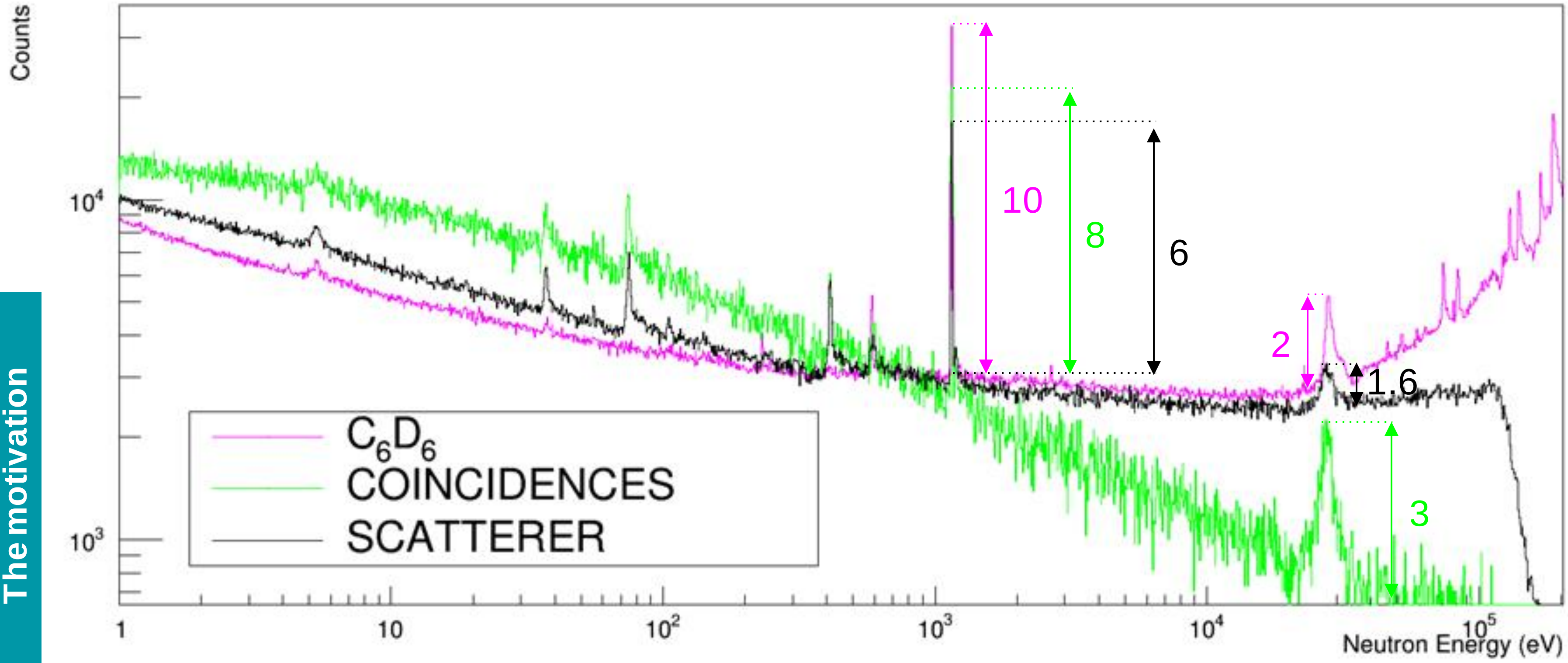


The motivation

Neutron energy

^{56}Fe

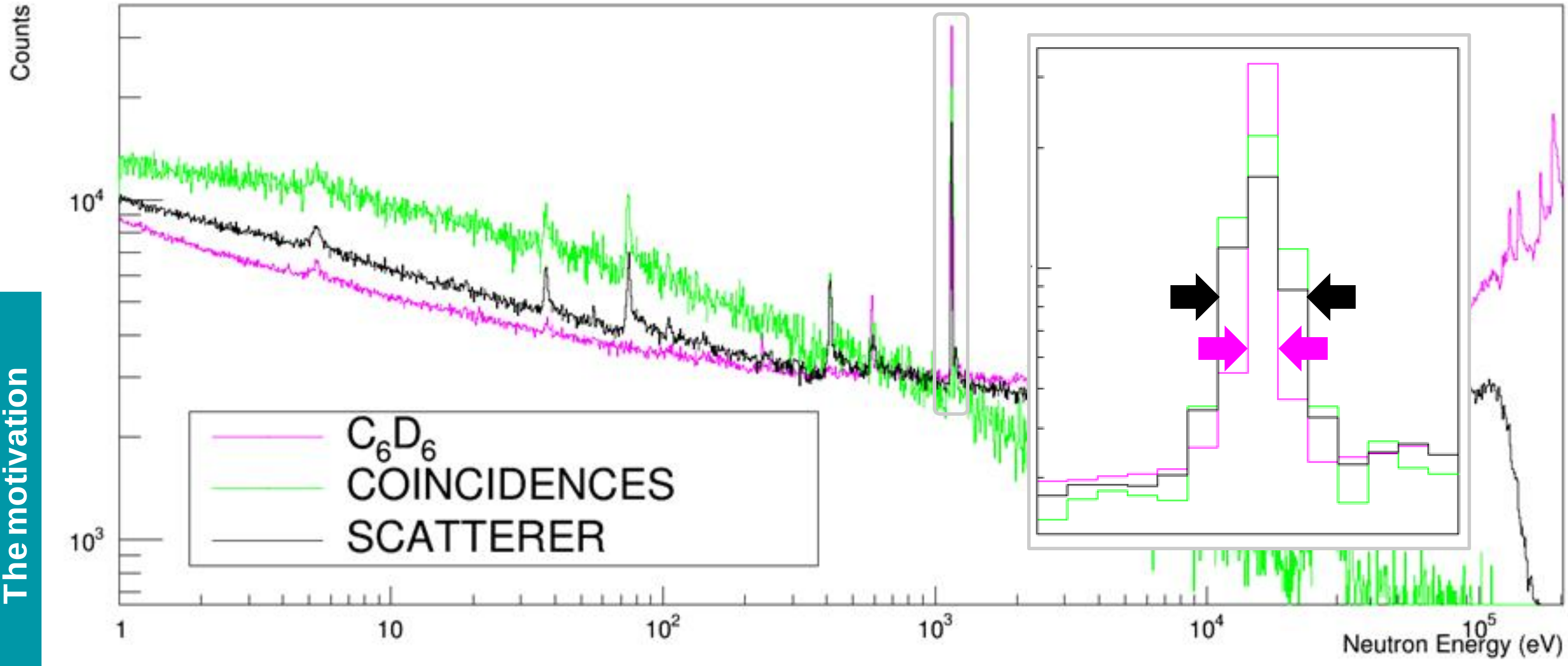
i-TED vs C_6D_6



The motivation

Neutron energy

i-TED vs C_6D_6



Some numbers from $^{56}Fe(n,\gamma)$ measurement

i-TED5.3 @EAR1

Number of runs	348
Time of measurement	116 h
Number of single events in SCATTERER (Deposited energy < 6 MeV)	**20486827**
Number of single events in ABSORBER 1 (Deposited energy < 6 MeV)	41946667
Number of single events in ABSORBER 2 (Deposited energy < 6 MeV)	149110315
Number of coincidence events (Deposited energy < 6 MeV)	**1605686 (7,8%)**
Number of coin events with valid position	1298374 (**81%**)
Number of coin events with valid position and lambda < 1000	401774 (**25%**)
Number of coin events with valid position and lambda < 500	220137 (**13.7%**)
Number of coin events with valid position and lambda < 300	140617 (**8.7%**)

The motivation