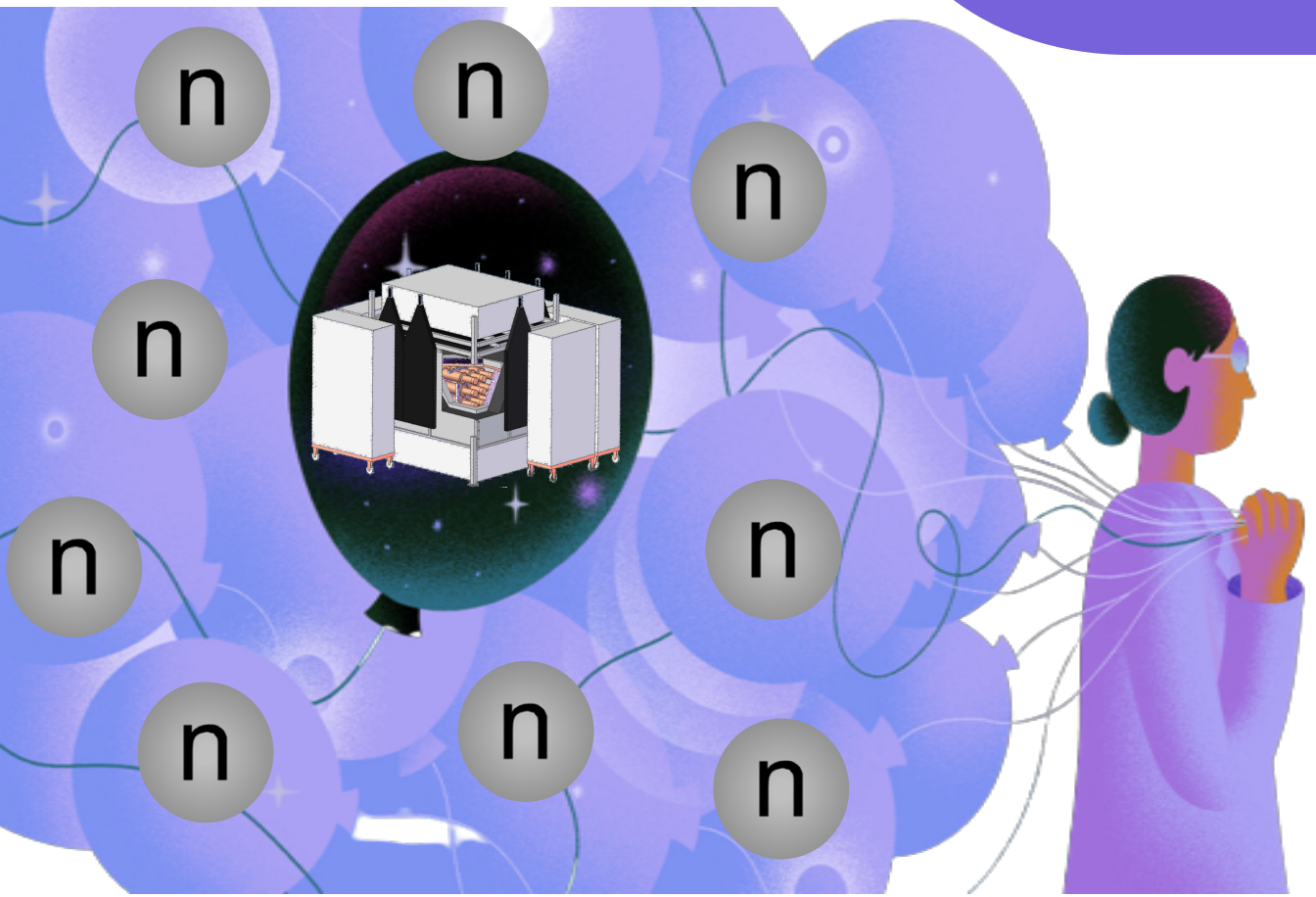
20th Multidark Consolider Workshop
25th-27th October – UPV Campus de Gandia

Neutron calibrations in dark matter searches: the ANAIS-112 case



Tamara Pardo on behalf of the ANAIS research team

J. Amaré, J. Apilluelo, S. Cebrián, D. Cintas, I. Coarasa, E. García, M. Martínez, M.A. Oliván, Y. Ortigoza, A.Ortiz de Solórzano, **T. Pardo**, J. Puimedón, A. Salinas, M.L. Sarsa, P. Villar

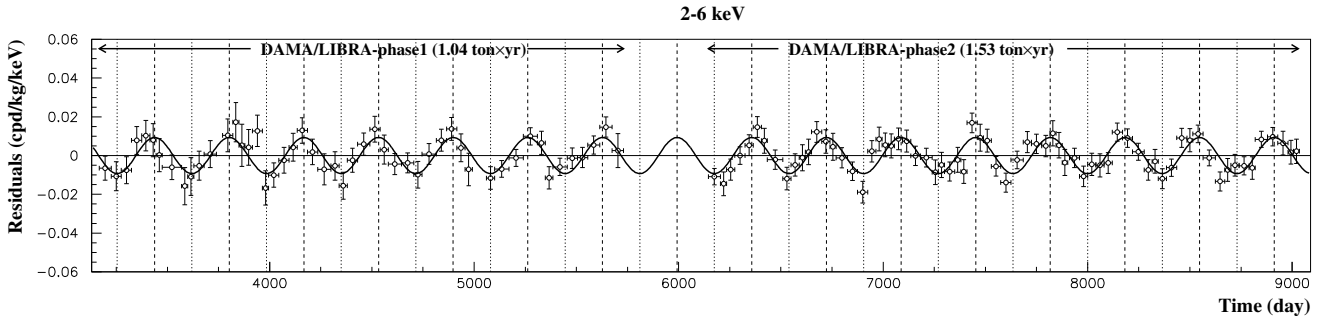
20th Multidark Consolider Workshop, Gandia
25th-27th October 2023

MINISTERIO DE CIENCIA E INNOVACIÓN
UNIÓN EUROPEA Fondo Social Europeo
AGENCIA ESTATAL DE
Centro de Astropartículas y Física de Altas Energías
Universidad Zaragoza
MultiDark Multimessenger Approach for Dark Matter Detection
Universidad Zaragoza

THE ANAIS-112 EXPERIMENT

Universe 4, 116 (2018), 1805.10486
Progress in Particle and Nuclear Physics 114 (2020)

DAMA/LIBRA experiment at LNGS uses ~250kg **NaI(Tl)** as target and it has been taking data for more than 20 years



DAMA/LIBRA data favor the presence of a modulation with proper features at **13.7σ** CL in the **2-6 keV** & **11.8σ** CL in the **1-6 keV**

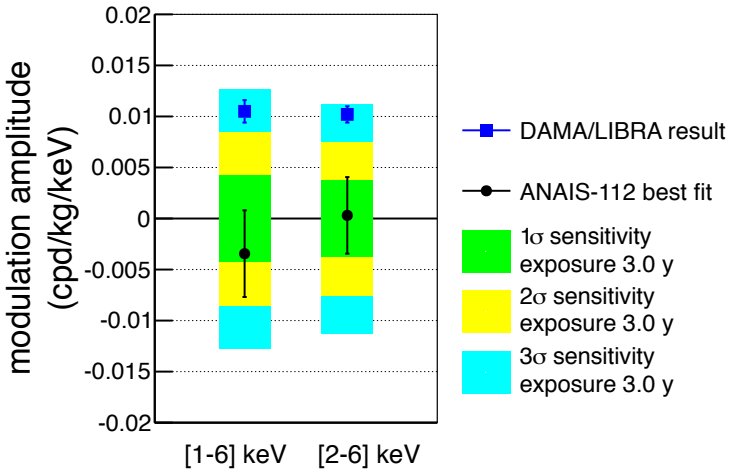
ANAIS' goal is to **confirm or refute** in a model independent way the DAMA/LIBRA positive annual modulation result with the same target and technique (but different experimental approach and environmental conditions) at the Canfranc Underground Laboratory (@Spain) with 112.5 kg of NaI(Tl)

More details on the ANAIS-112 set-up here:

J. Amaré et al., EPJC79 (2019) 228

THE ANAIS-112 EXPERIMENT

3 years of analyzed data are compatible with absence of modulation and incompatible with DAMA/LIBRA with a sensitiviy **>2.5σ** in [1-6] & [2-6] keV



J. Amaré et al. Physical Review D 103 (2021) 102005
Phys. Rev. Lett. 123 (2019) 031301

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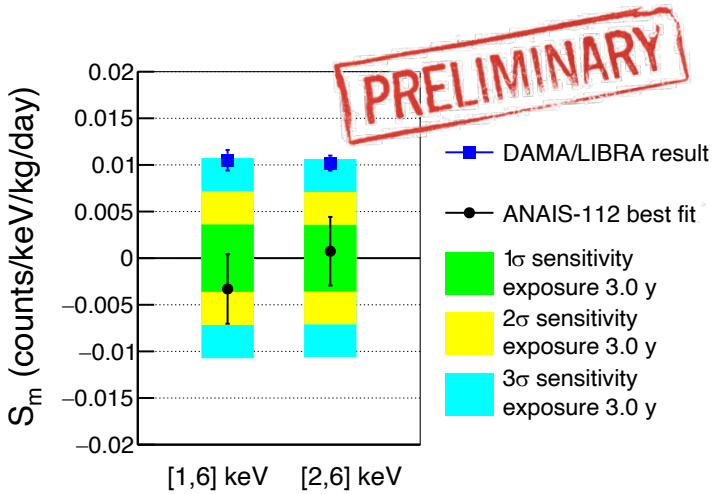

I. Coarasa et al, JCAP11(2022)048
I. Coarasa et al, JCAP06(2023)E01

The reanalysis of the 3-year exposure after applying **machine learning** for data filtering provides a better sensitivity of **2.9σ !!**

ANAIS' goal is to **confirm or refute** in a model independent way the DAMA/LIBRA positive annual modulation result with the same target and technique (but different experimental approach and environmental conditions) at the Canfranc Underground Laboratory (@Spain) with 112.5 kg of NaI(Tl)

THE ANAIS-112 EXPERIMENT

3 years of analyzed data are compatible with absence of modulation and incompatible with DAMA/LIBRA with a sensitiviy **>2.5σ** in [1-6] & [2-6] keV

Could DAMA/LIBRA still be interpreted as DM if ANAIS-112 does not see any modulation?

ANAIS' goal is to **confirm or refute** in a model independent way the DAMA/LIBRA positive annual modulation result with the same target and technique (but different experimental approach and environmental conditions) at the Canfranc Underground Laboratory (@Spain) with 112.5 kg of NaI(Tl)

Is it really a direct comparison?

ANAIS & DAMA use the same target material, **NaI(Tl)**, and are calibrated with gamma sources → direct comparison in **keVee(*)**

(*) keVee: electron-equivalent keV

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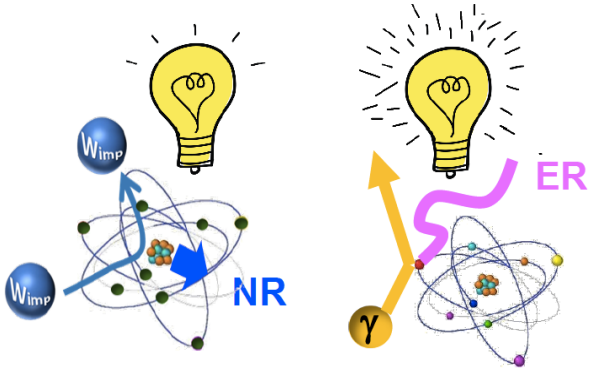

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$$QF = \frac{L_{NR}}{L_{ER}}$$

In a scintillator, an **electron recoil** (ER) produces much more light than a **nuclear recoil** (NR) of the same energy

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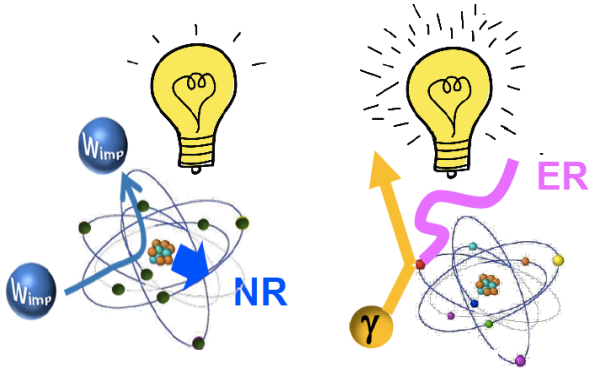
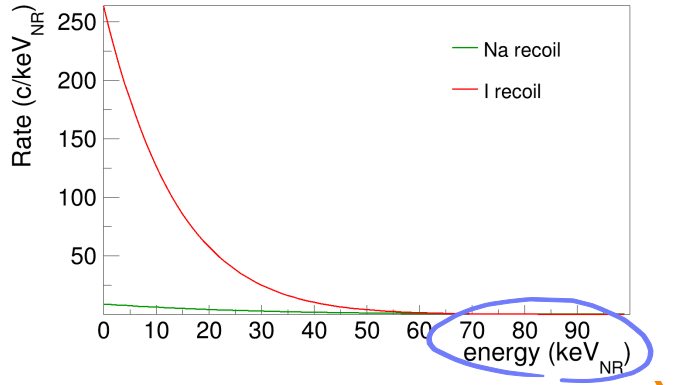
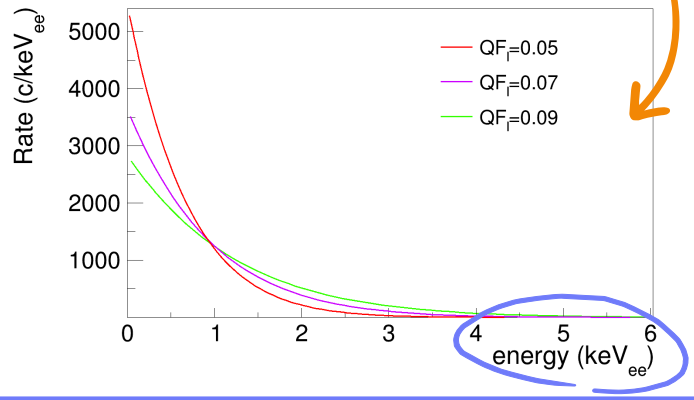
In most of the models, DM is supposed to produce NR

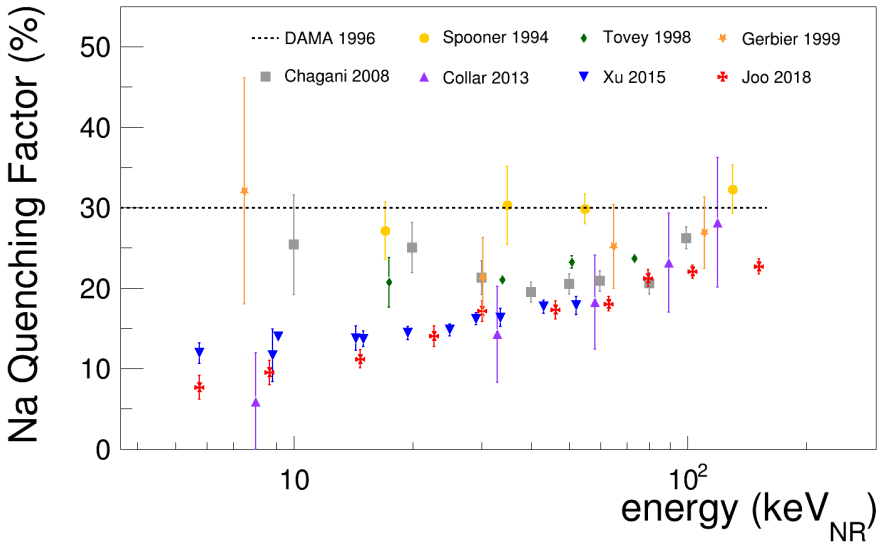
→ Experiments must be compared in the **NR**-energy scale, which requires a precise knowledge of the **QFs**







Current status of QF measurements in NaI



A large number of **experiments** have been performed to measure the QFs of NaI detectors

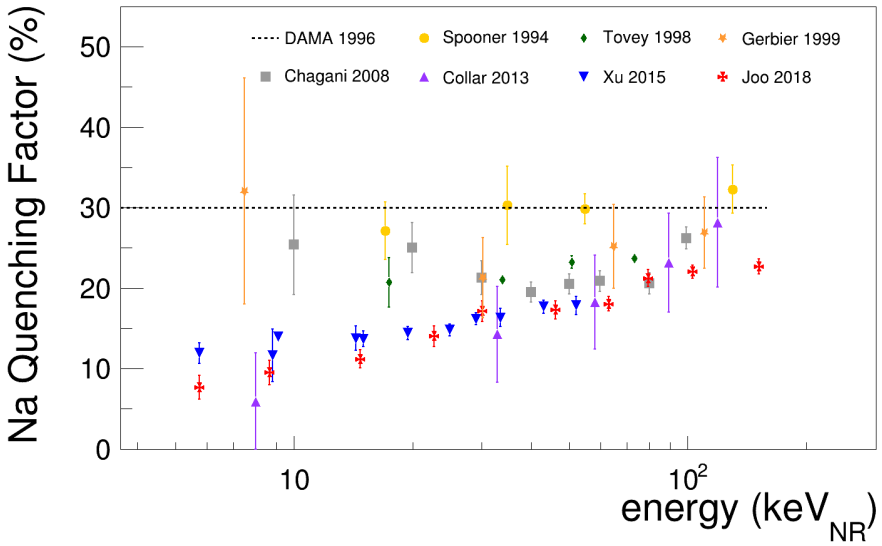
Still too many uncertainties in the QF values and energy dependences for NaI

Q_{Na} DAMA = 0.3
Q_I DAMA = 0.09

Constant QF? **1**

2 Decreasing with energy QF @ low energies?

Current status of QF measurements in NaI



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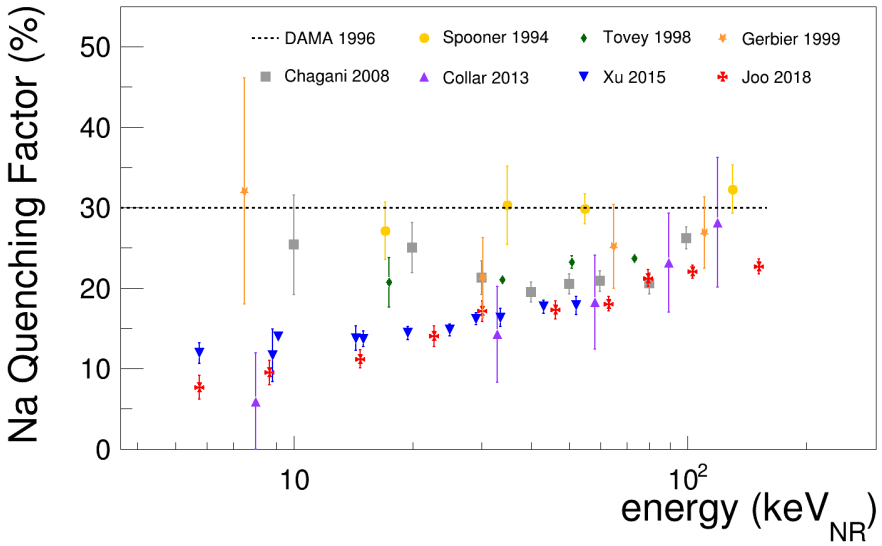

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Differences in **experimental procedures** have introduced systematic differences

QF is an **inherent** property of NaI(Tl)

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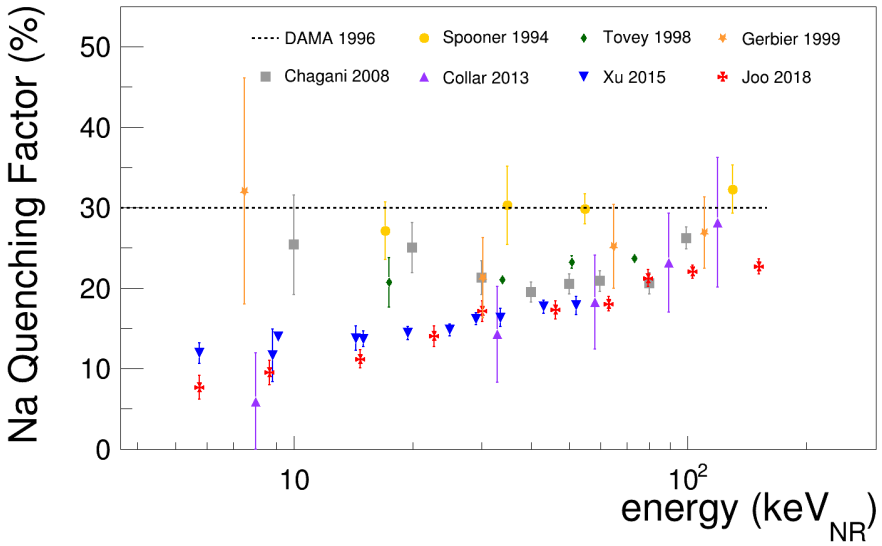

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Still too many **uncertainties** in the QF values and energy dependences for NaI

Why?

1 Differences in **experimental procedures** have introduced systematic differences

QF is an **inherent** property of NaI(Tl)

2 QF can **vary** between individual NaI(Tl) detectors

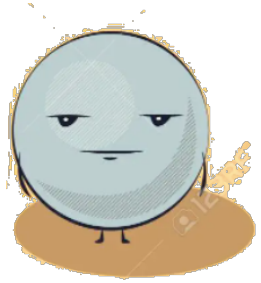
- Impurities
- Doping concentration
- …

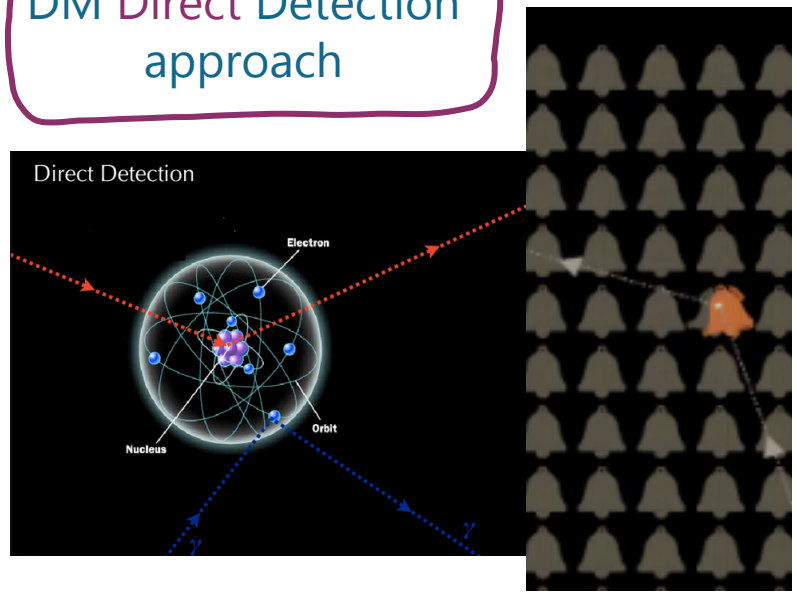
Neutron calibration program

Determining the QF is crucial to support the direct model independent testing of DAMA-LIBRA; **systematic**

Neutron interactions are relevant for a DM experiment because they produce NR of the target nuclei as WIMPs do

DM Direct Detection approach





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Determining the QF is crucial to support the direct model independent testing of DAMA-LIBRA; **systematic**

QF determination for ANAIS-112 crystals is ongoing: **two approaches** are followed in parallel

small size

not ANAIS crystals

Monochromatic neutron source

^{252}Cf source

ANAIS crystals

greater reliance on MC model

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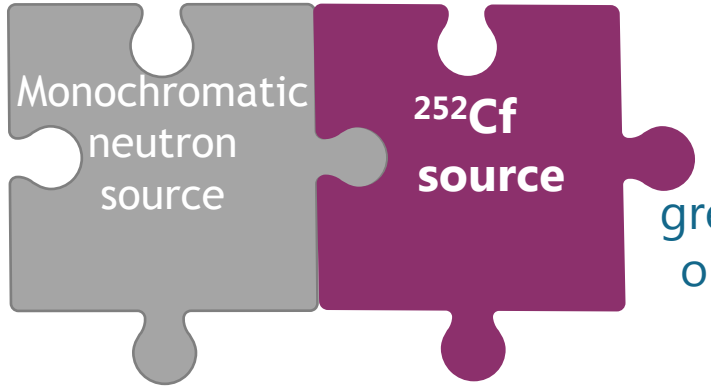


ANAIS crystals

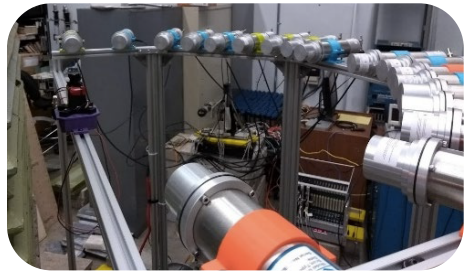
greater reliance on MC model

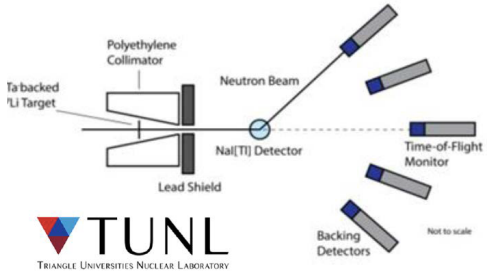
Multiple scattering is one of the most relevant differences

Both approaches are **complementary** and **should be consistent**

Neutron calibration program

Monochromatic neutron source





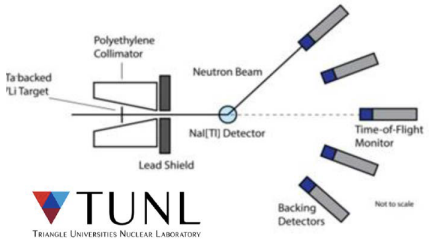
In collaboration with Yale (from COSINE collaboration) and Duke researchers @ TUNL

Neutron calibration program

Monochromatic neutron source

Analysis of **systematic** effects

2 different linear **energy calibrations**



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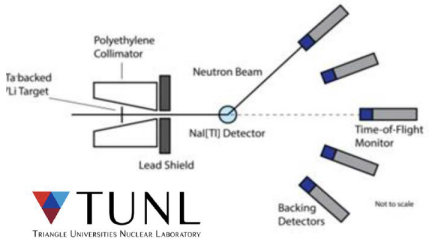
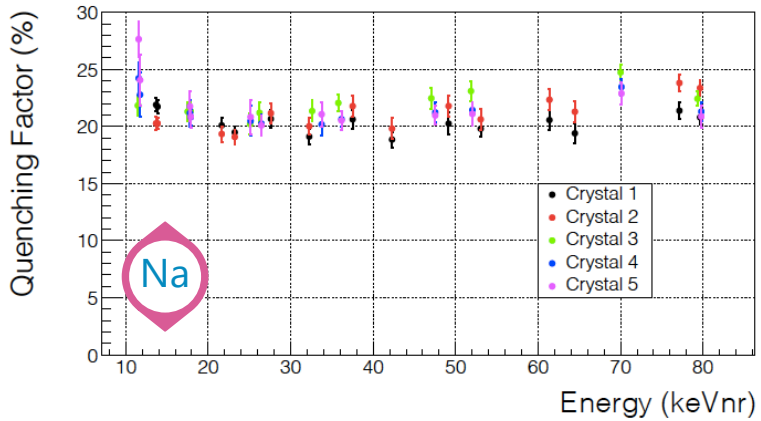


133Ba

Non-proportional 1

6.6, 30.8, 35.1 keV



No clear dependence with energy

QFNa =(21.2 ± 0.8) %

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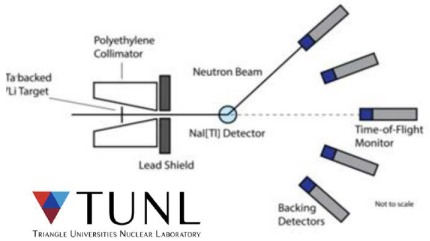

133Ba → Non-proportional (1)

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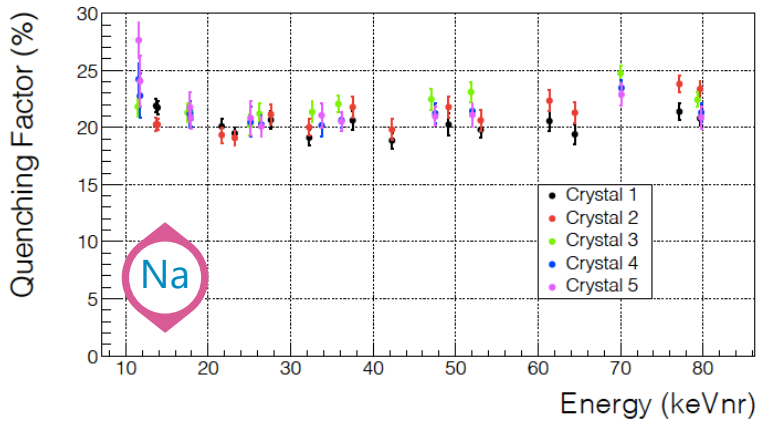

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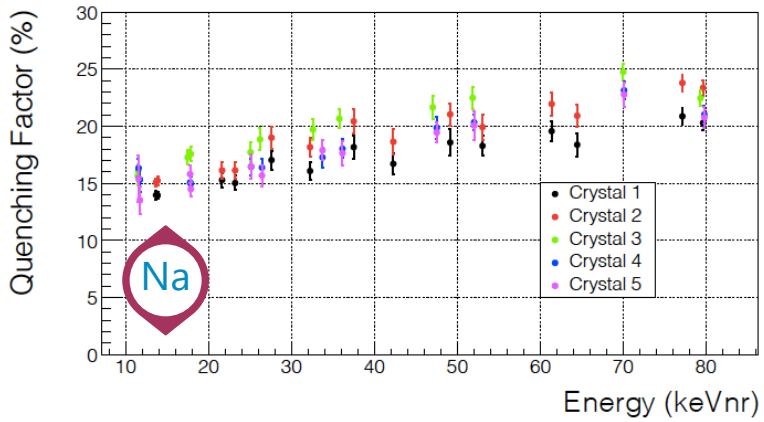
57.6 keV inelastic peak



Decreasing with energy QFNa @low energies

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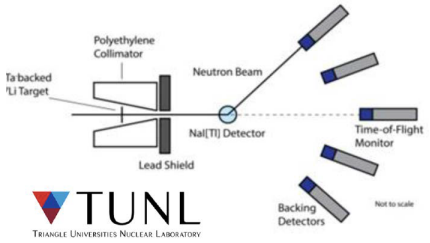

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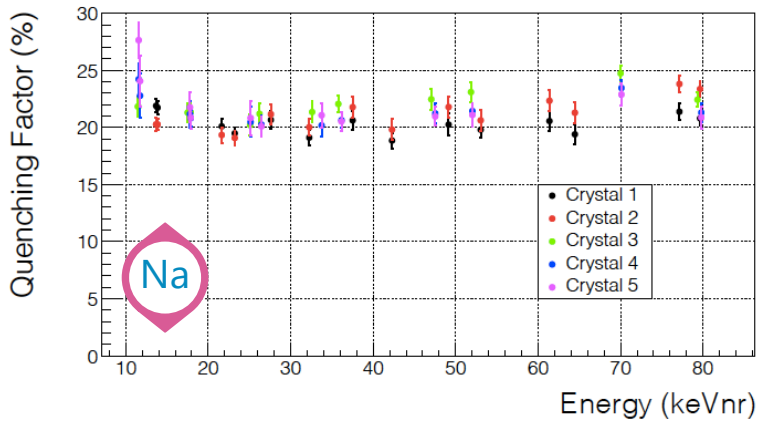

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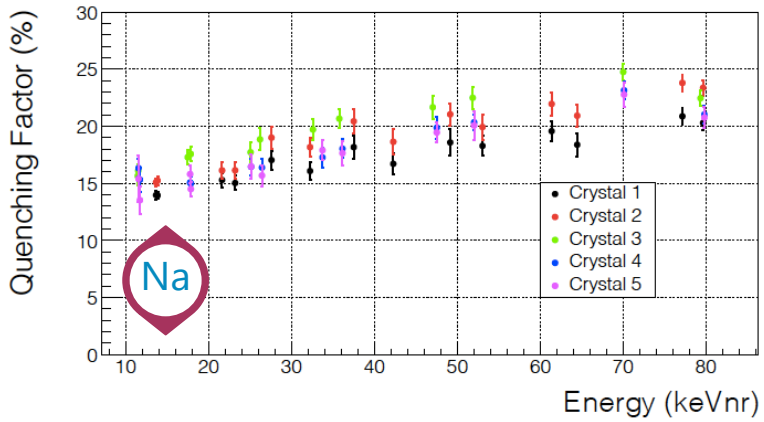

Decreasing with energy QFNa @low energies

Compatible values for the 5 crystals

Both procedures are **not compatible** among them <50 keV

Neutron calibration program

Monochromatic neutron source

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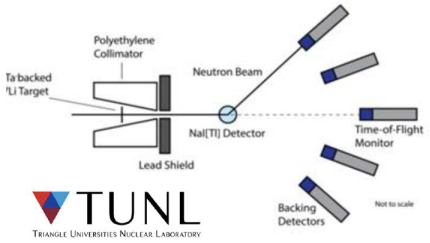

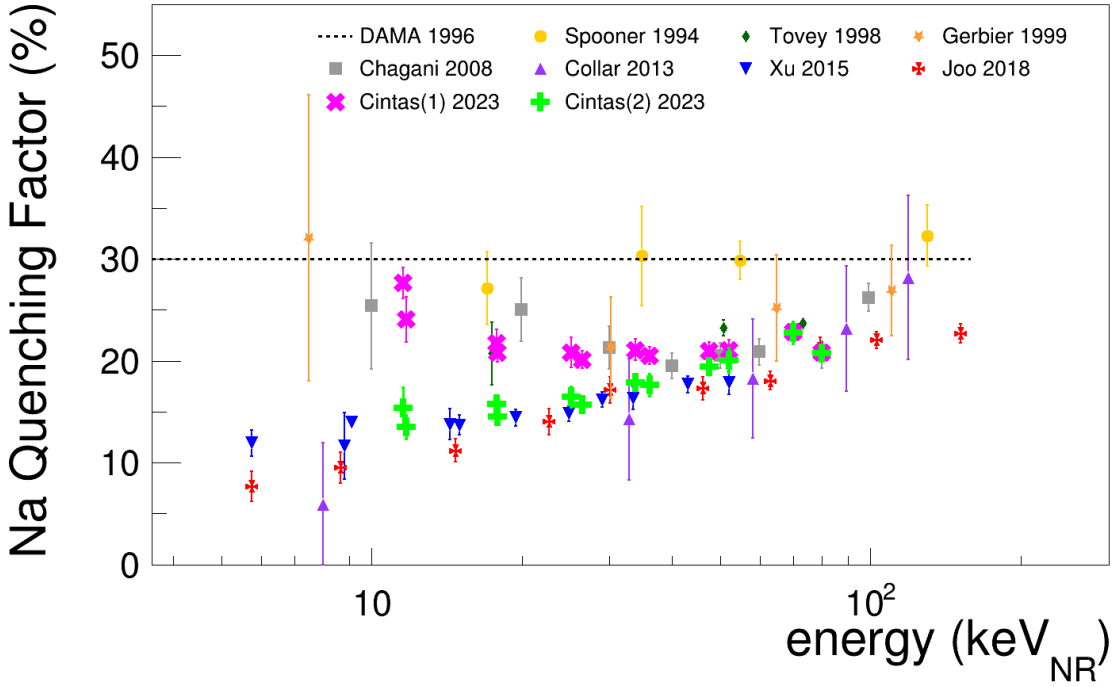

Fully **compatible** with previous measurements

D. Cintas et al 2021 J. Phys.: Conf. Ser. 2156 012065

D. Cintas. *New strategies to improve the sensitivity of the ANAIS-112 experiment at the Canfranc Underground Laboratory*. PhD Thesis. Universidad de Zaragoza, 2023

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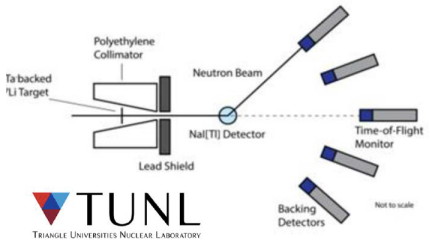

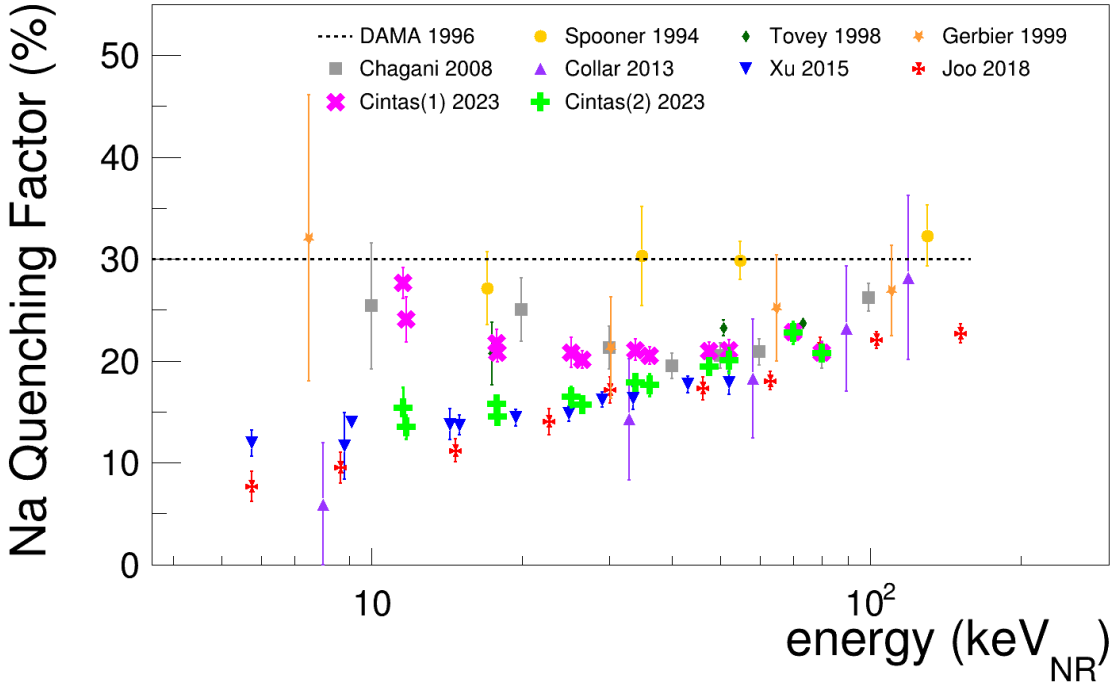

Fully **compatible** with previous measurements

Both procedures are **not compatible** among them

Systematics play a relevant role in the comparison of results

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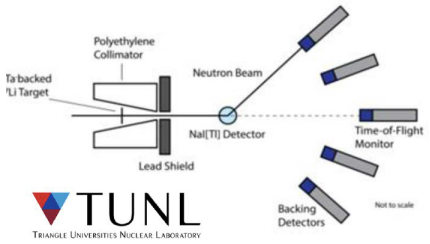

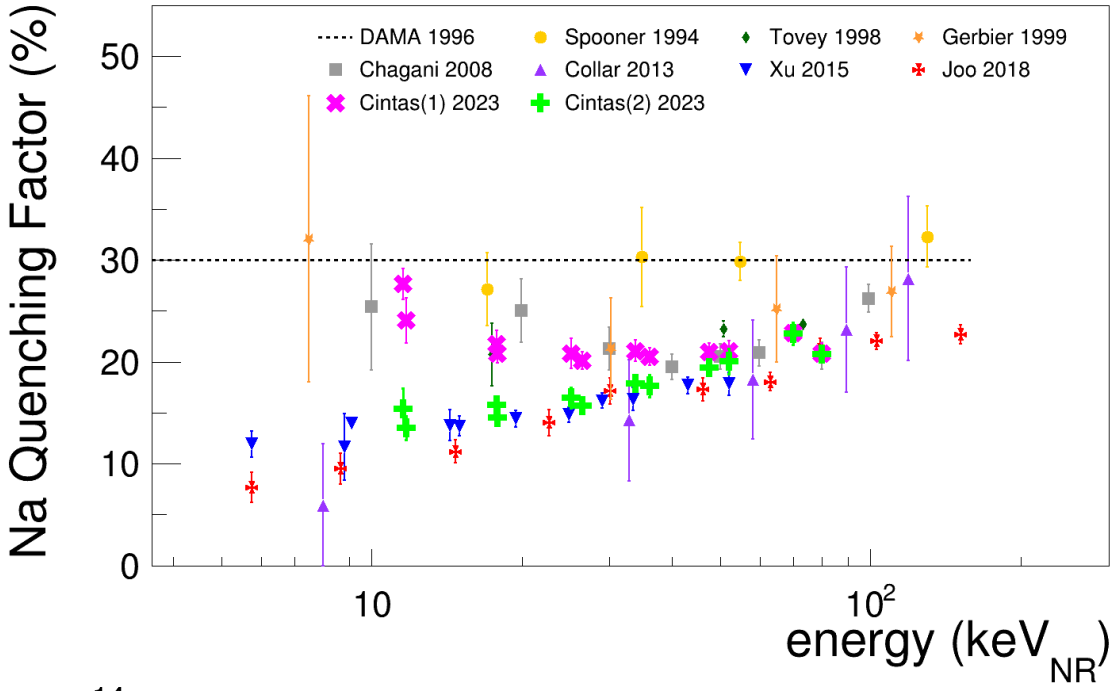

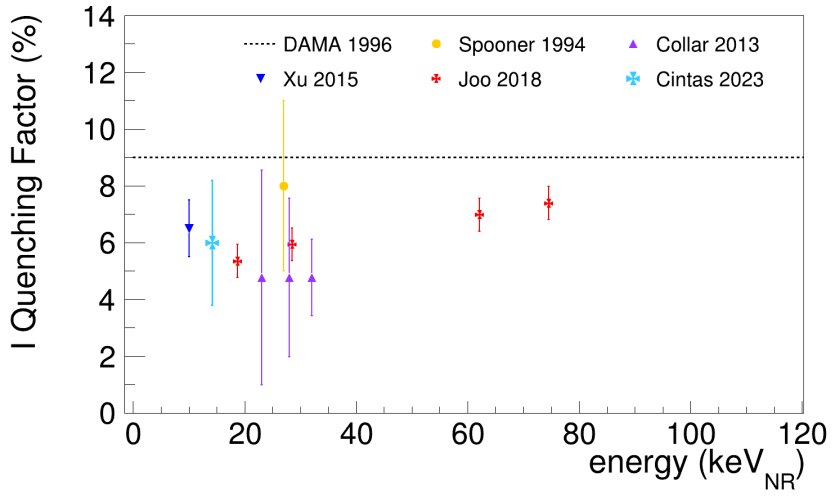

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I **QFI=(6.0 ± 2.2)%** (combining data from 2 crystals)

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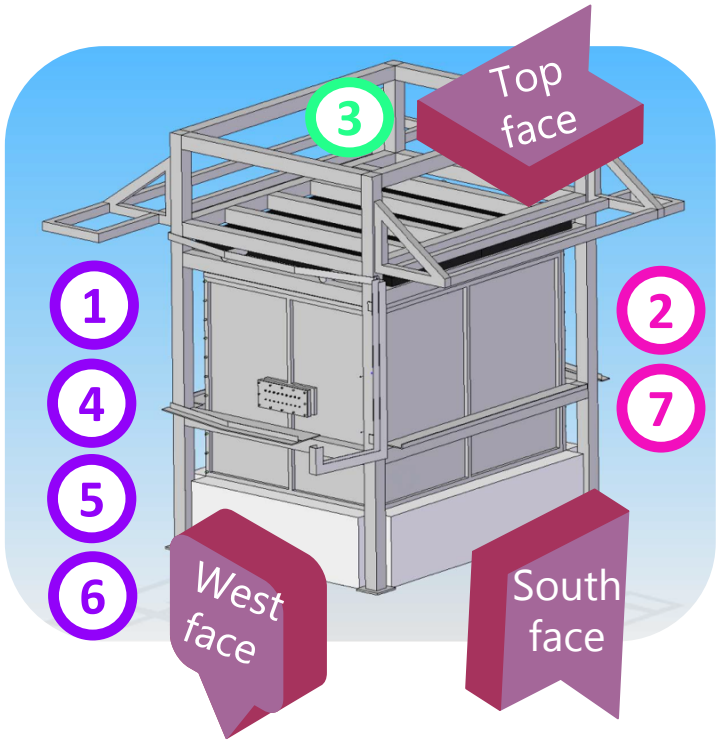
Neutron calibration program

^{252}Cf source

Seven calibration runs since April 2021 using a **252Cf neutron source** at different positions in the ANAIS-112 set-up



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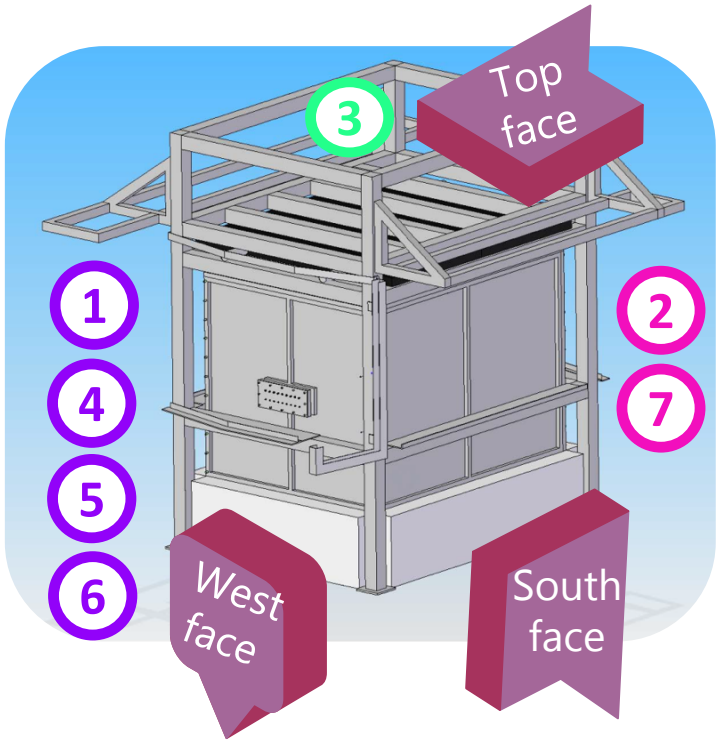

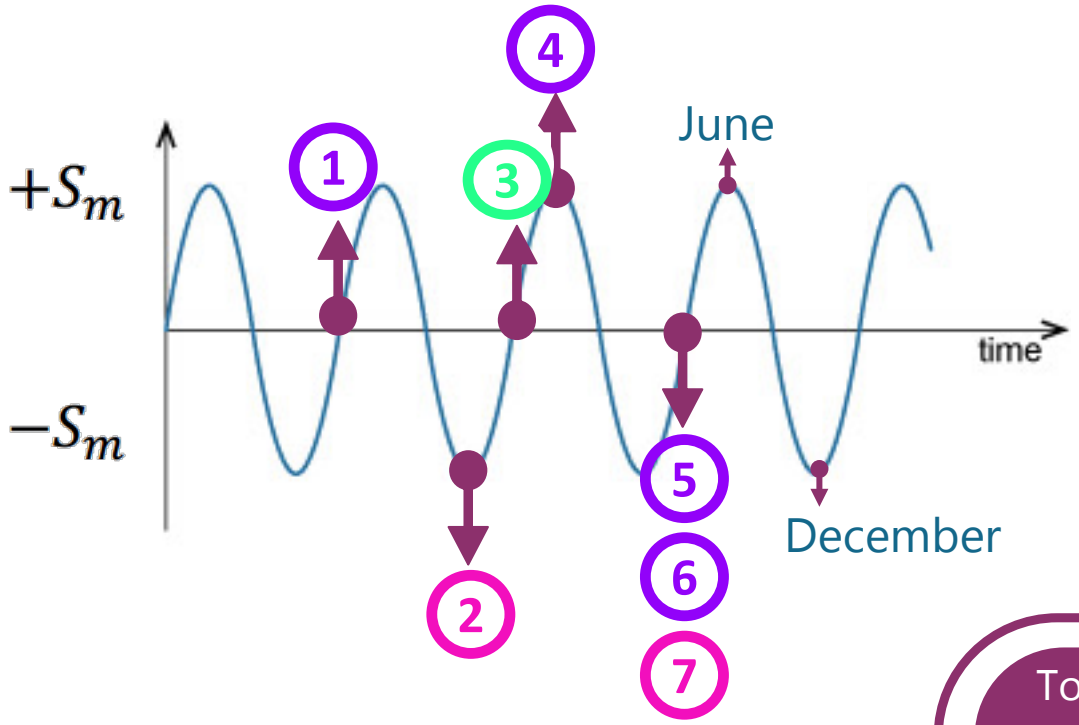

To evaluate the stability of the efficiencies for selecting NR along time

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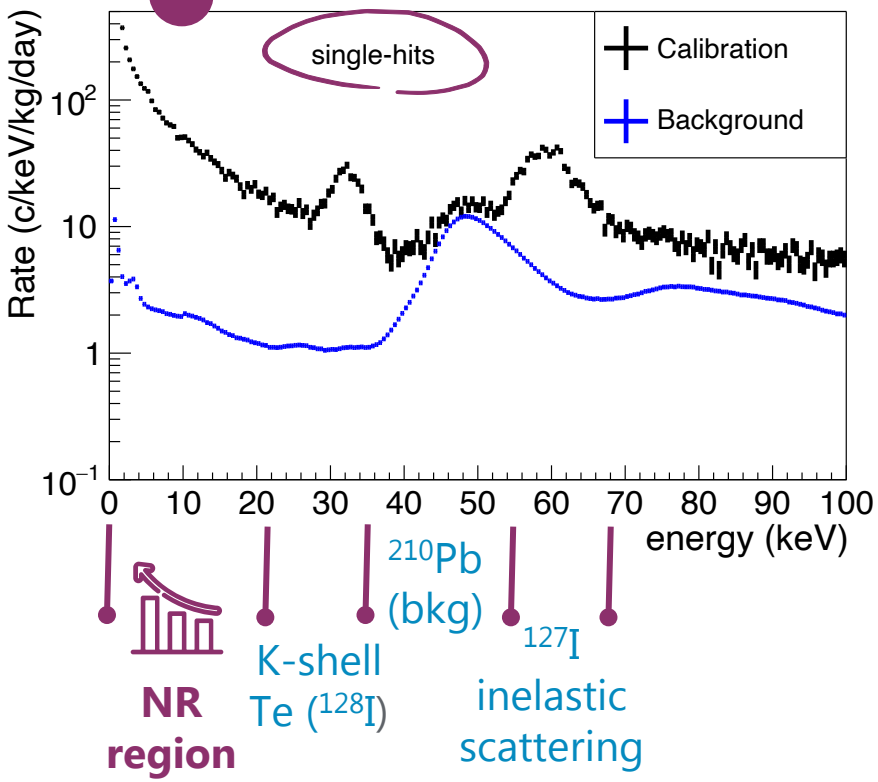

clean population of **bulk** scintillation events

large number of events in the ROI ([1-6] keV)

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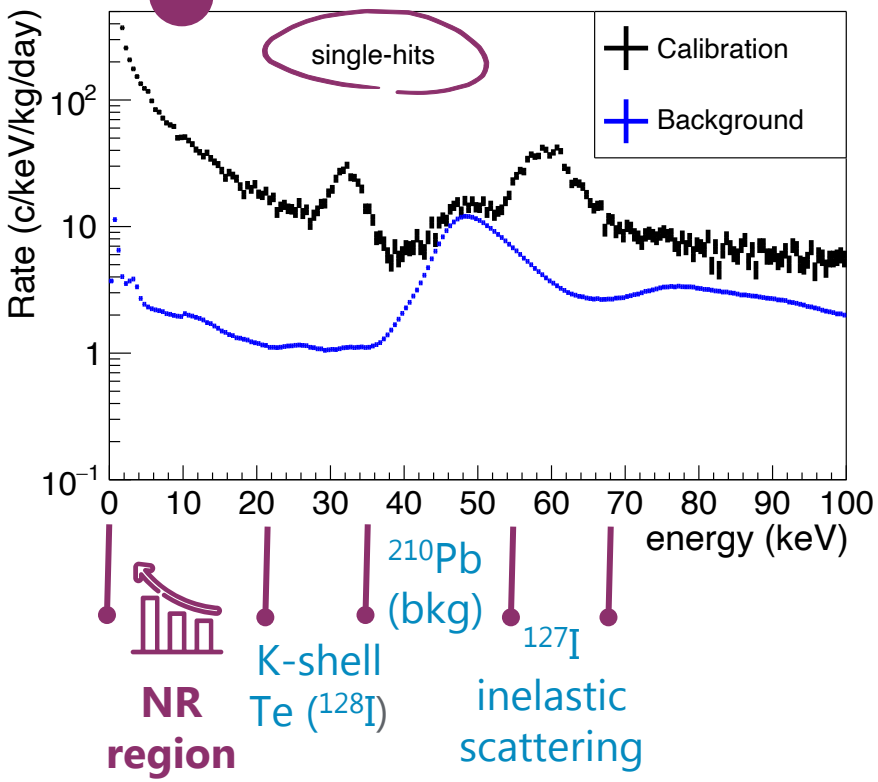

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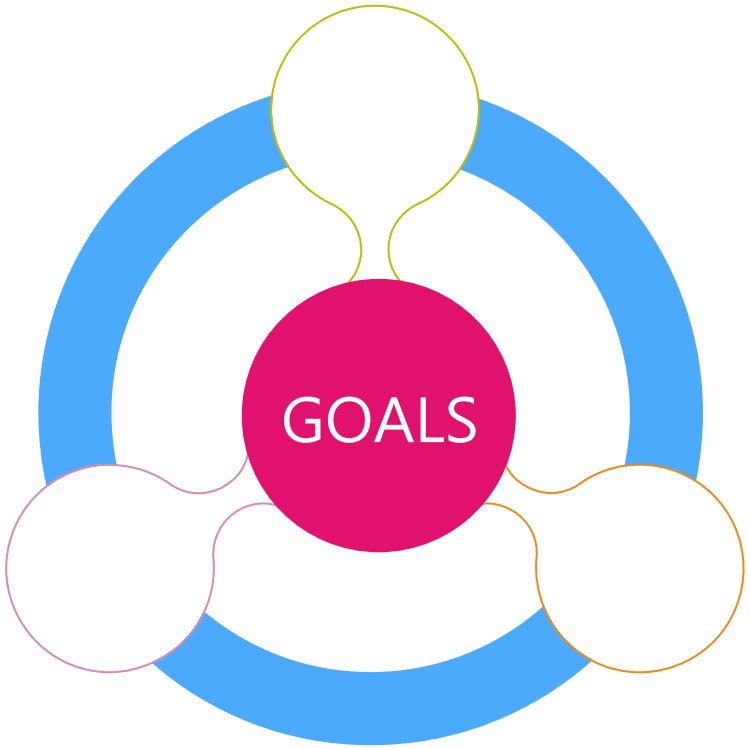

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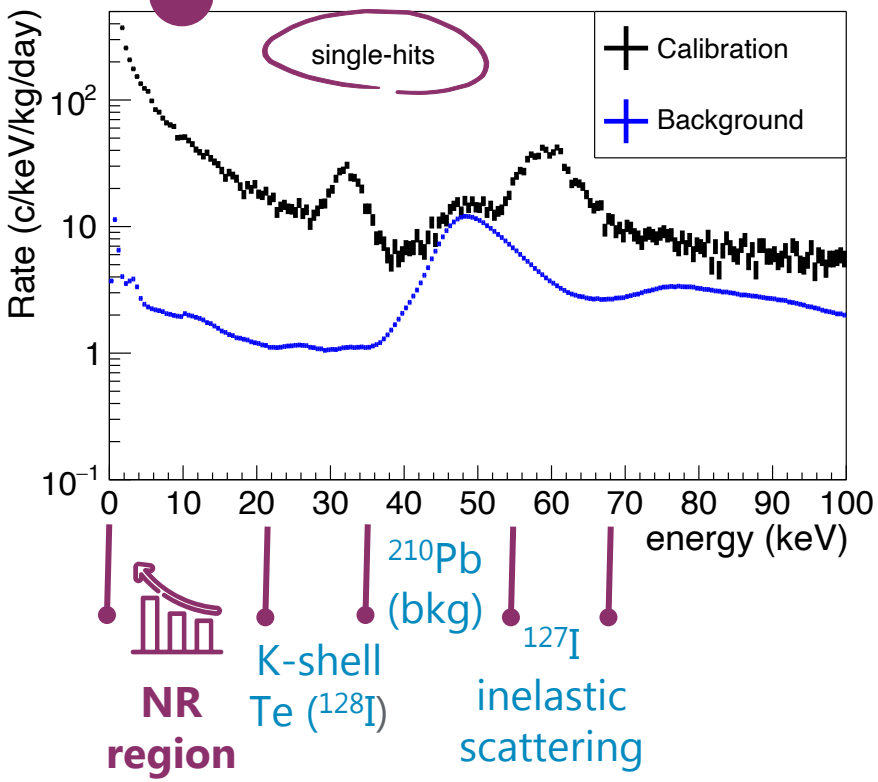
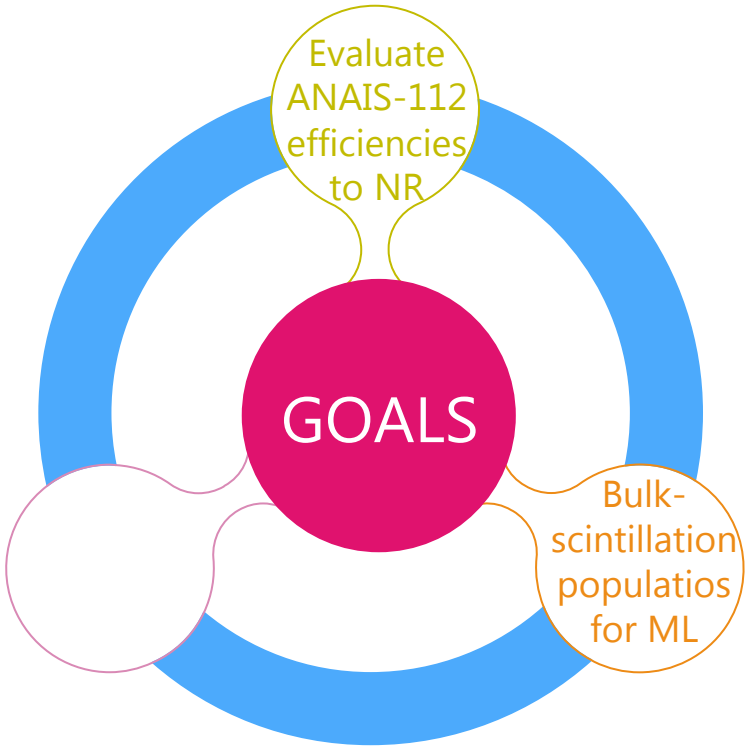
I. Coarasa et al, JCAP11(2022)048
I. Coarasa et al, JCAP06(2023)E01



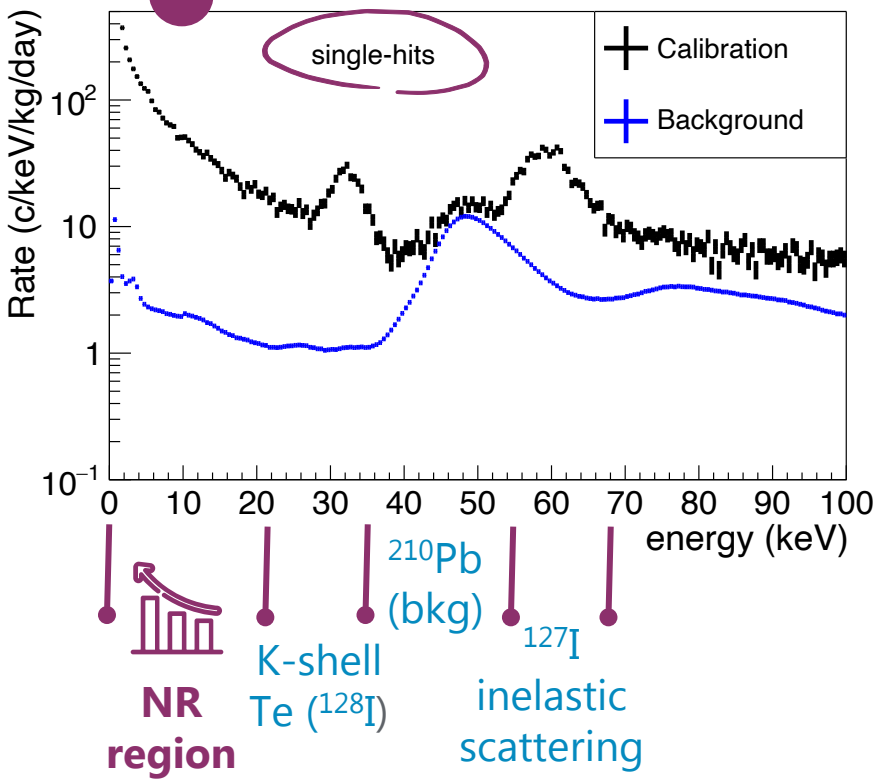
- clean population of **bulk** scintillation events
- large number of events in the ROI ([1-6] keV)



Neutron calibration program

^{252}Cf source

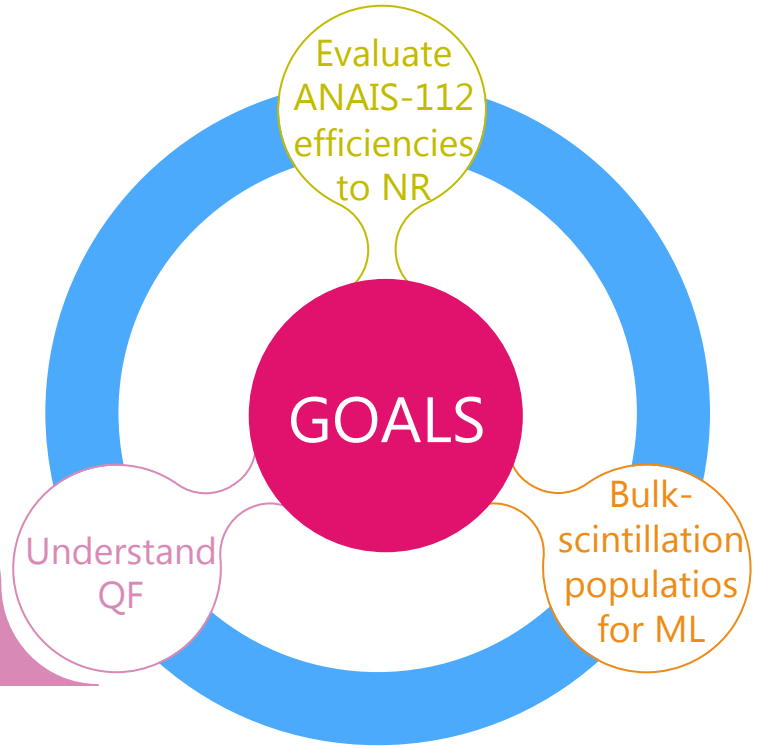
Seven calibration runs since April 2021 using a **252Cf neutron source** at different positions in the ANAIS-112 set-up



clean population of **bulk** scintillation events

large number of events in the ROI ([1-6] keV)

On-site neutron calibrations can be an important cross-check!!



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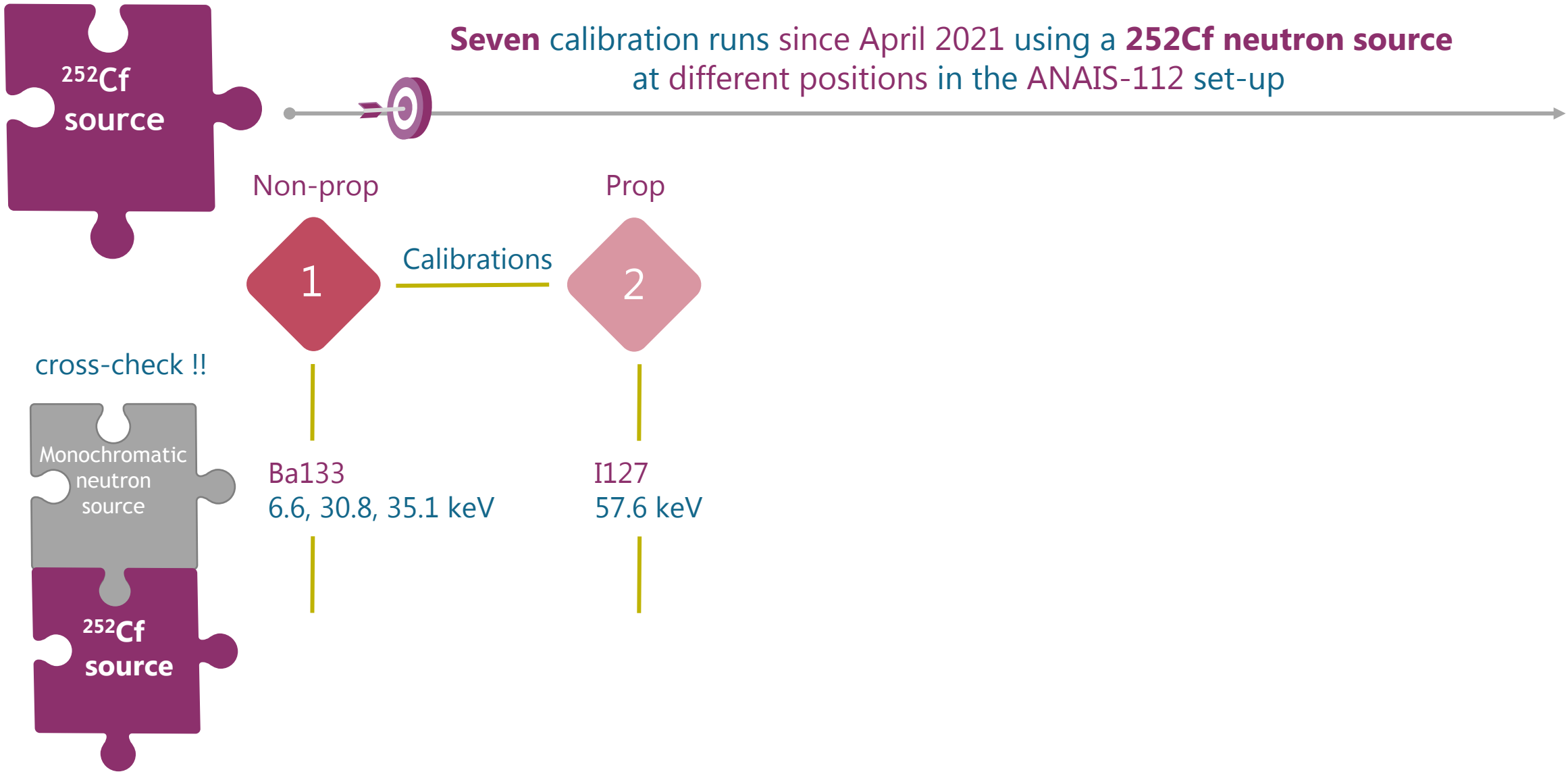

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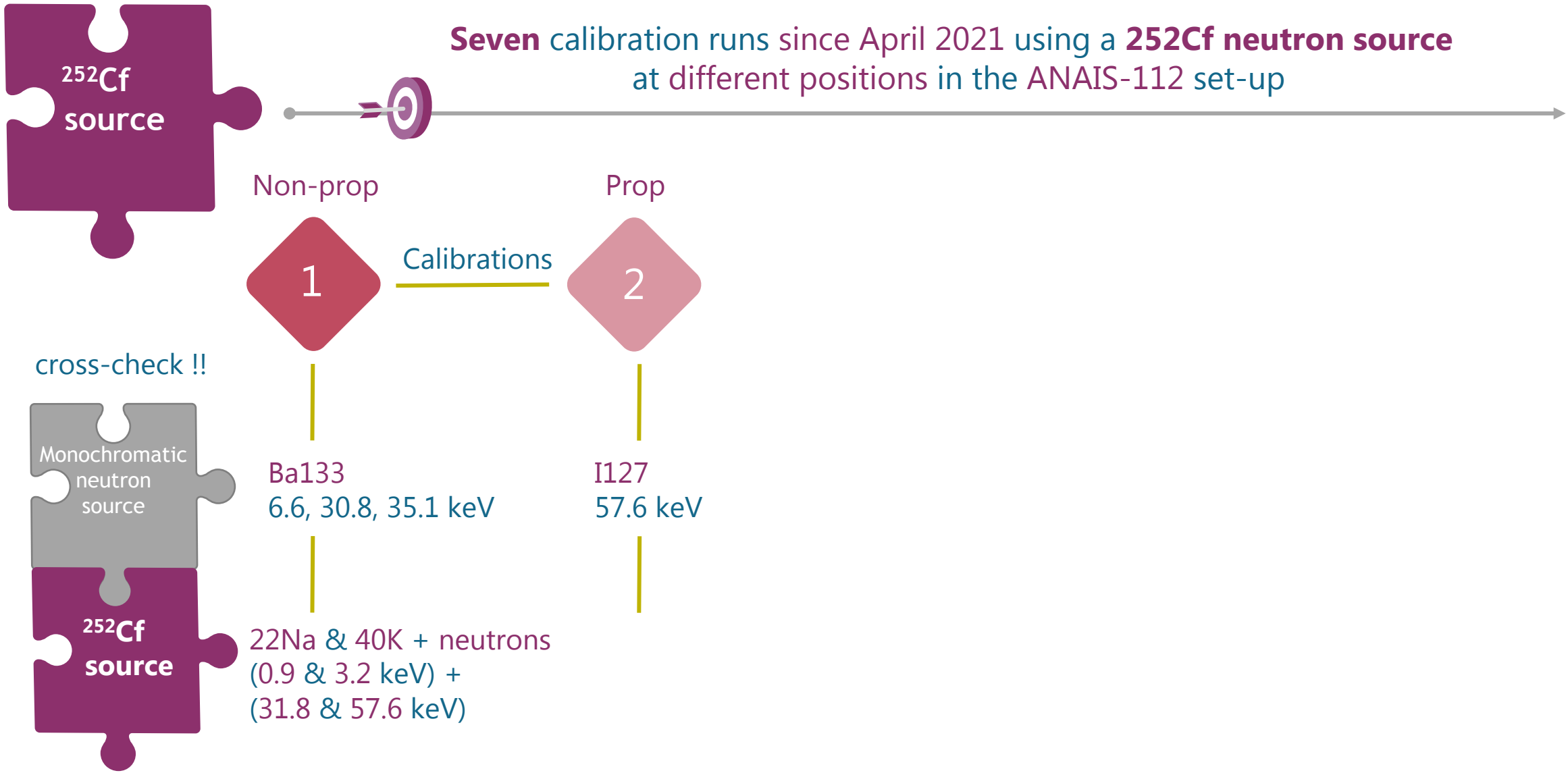

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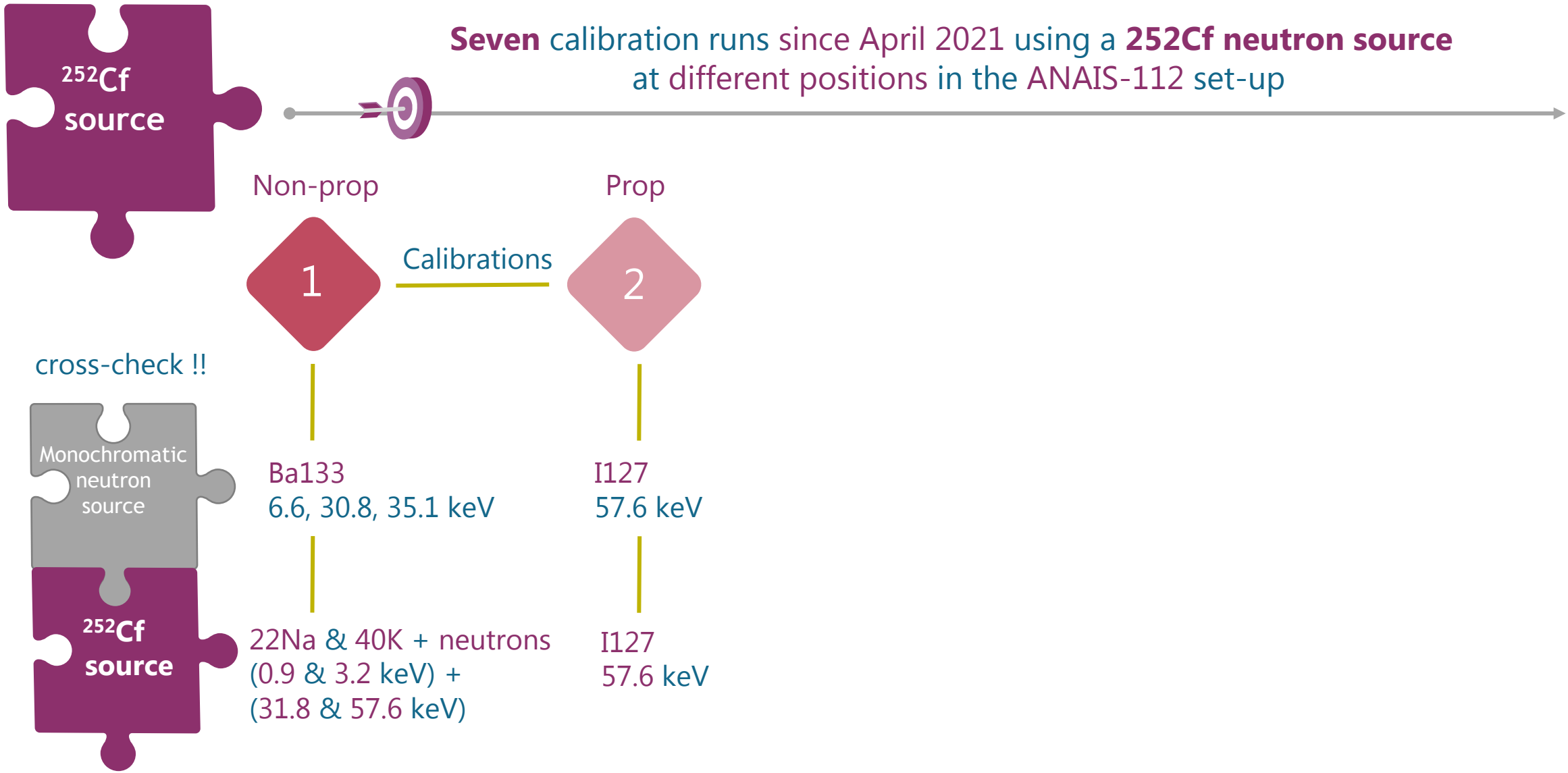

Neutron calibration program

Seven calibration runs since April 2021 using a **252Cf neutron source** at different positions in the ANAIS-112 set-up

^{252}Cf source

Non-prop | Prop

1 — Calibrations — 2

cross-check !!

Monochromatic neutron source

^{252}Cf source

Ba133
6.6, 30.8, 35.1 keV

22Na & 40K + neutrons
(0.9 & 3.2 keV) +
(31.8 & 57.6 keV)

I127
57.6 keV

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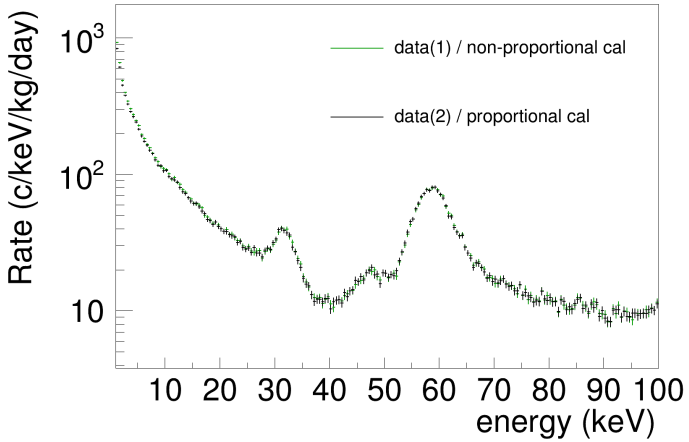
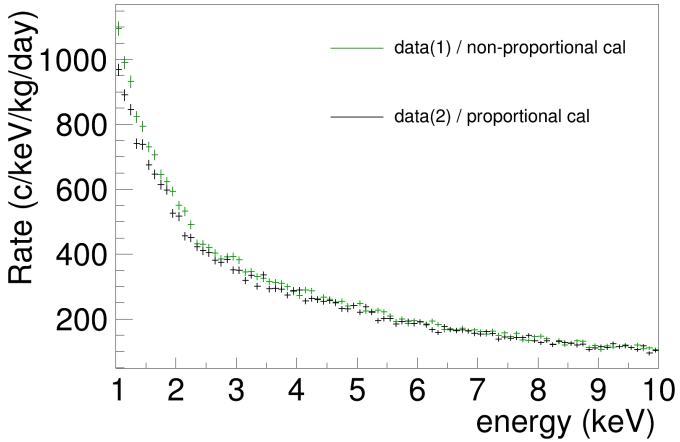
57.6 keV





Neutron calibration program

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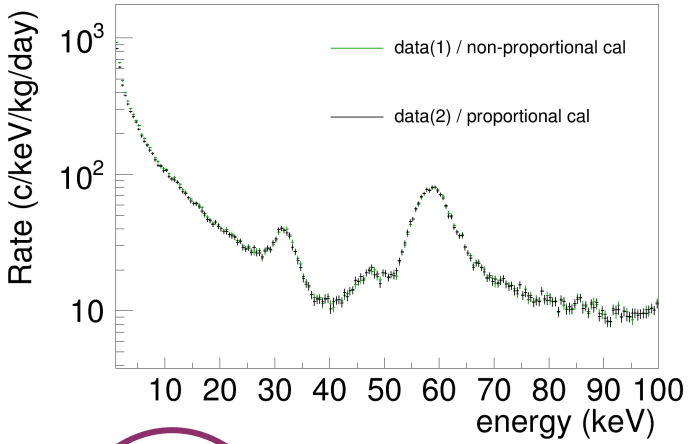
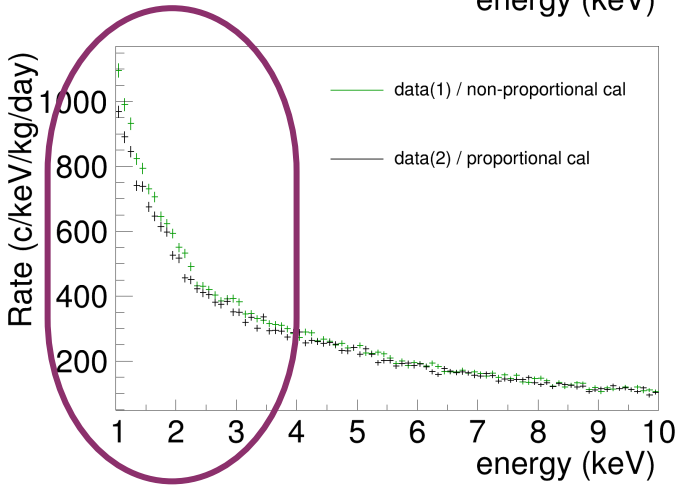




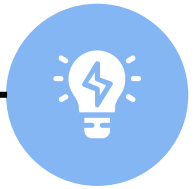
We will show **non-proportional** calibration

Bulk calibration

Results on the quenching factor

Our aim

Determine the **QF** for **our crystals** by a precise quantitative comparison between measurement and simulation



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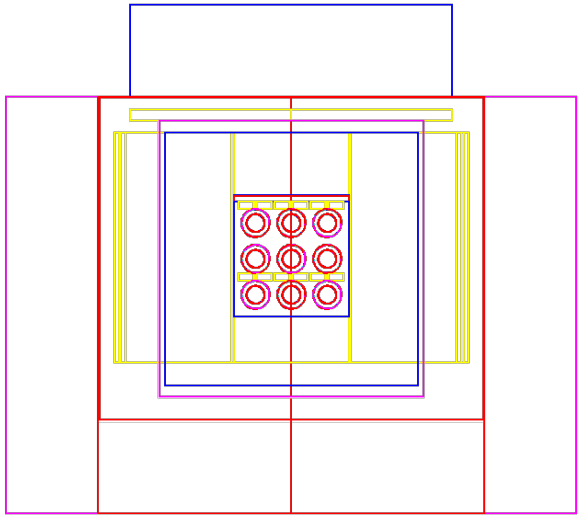
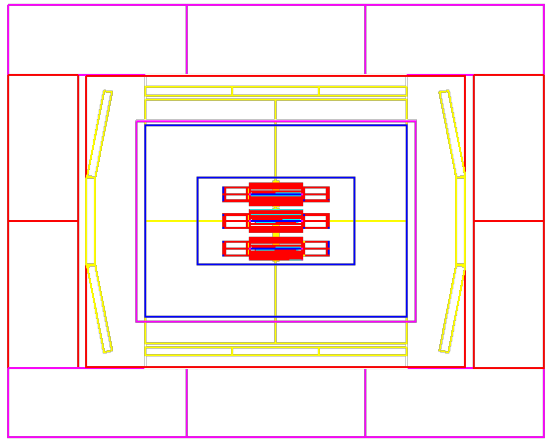
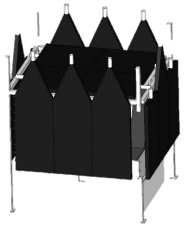
The ANAIS-112 Geant4 model has been extended for simulating the neutron calibration

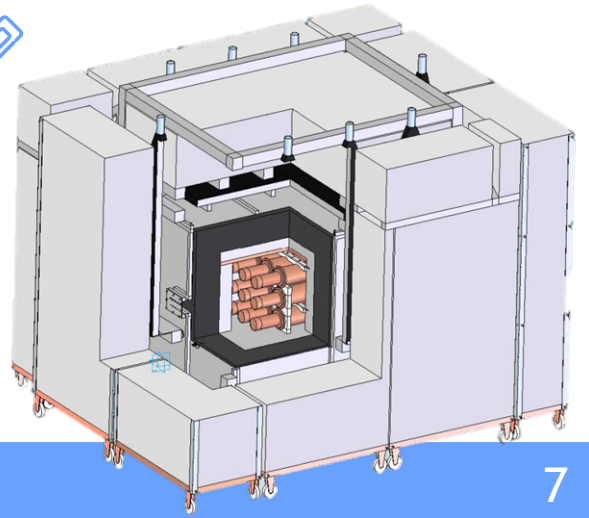
J. Amaré et al., EPJC79 (2019) 412





- 3x3 matrix of 12.5 kg NaI(Tl) cylindrical modules + PMTs
- 30 cm lead
- Anti-Radon box
- 40 cm PE/water
- 16 anti-muon vetoes





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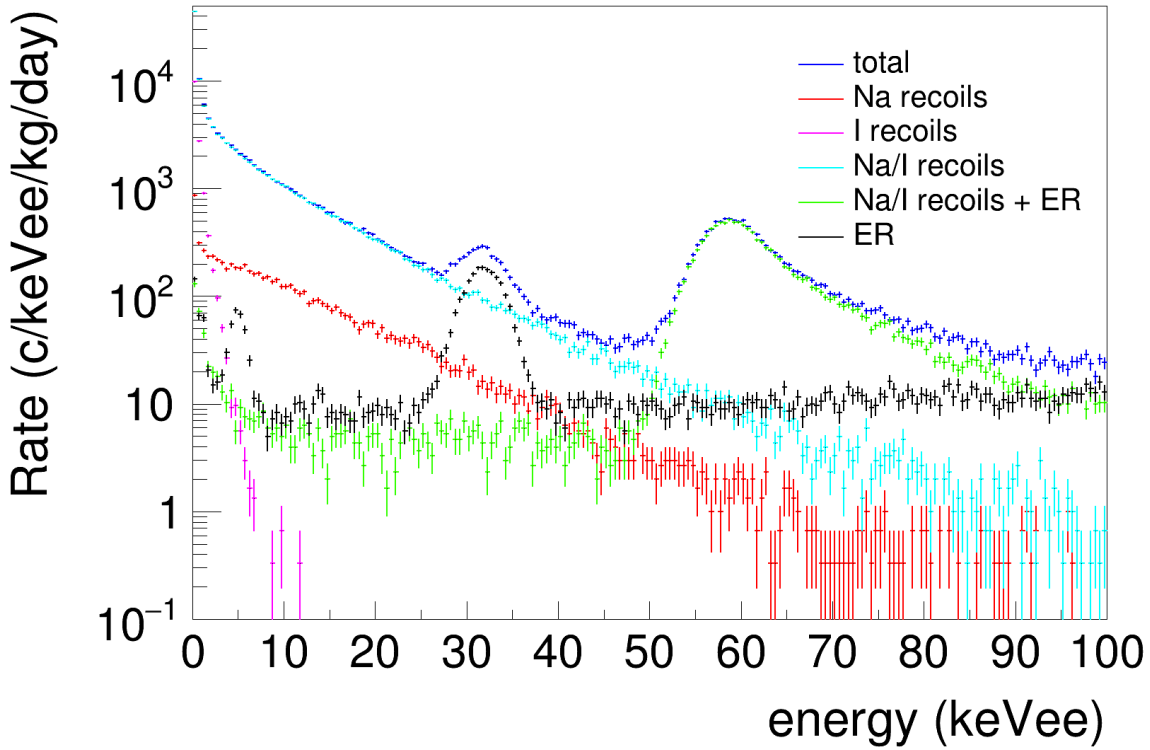
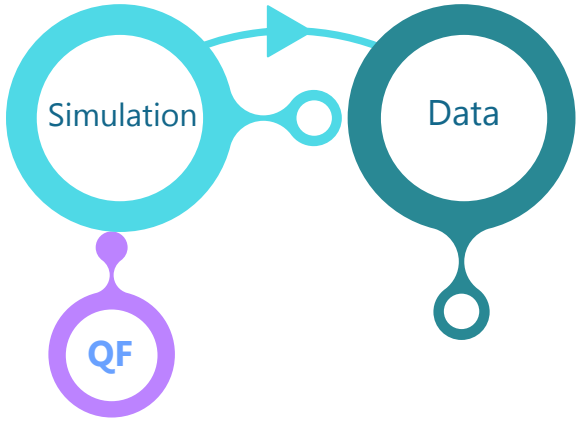


$E_{ee} = QF \times E_{NR}$

Large ANAIS-112 crystals exposed to fast neutrons show rates at low energy dominated by **multiple scattering**

Nuclear recoils are dominant up to 50 keVee

Results on the quenching factor



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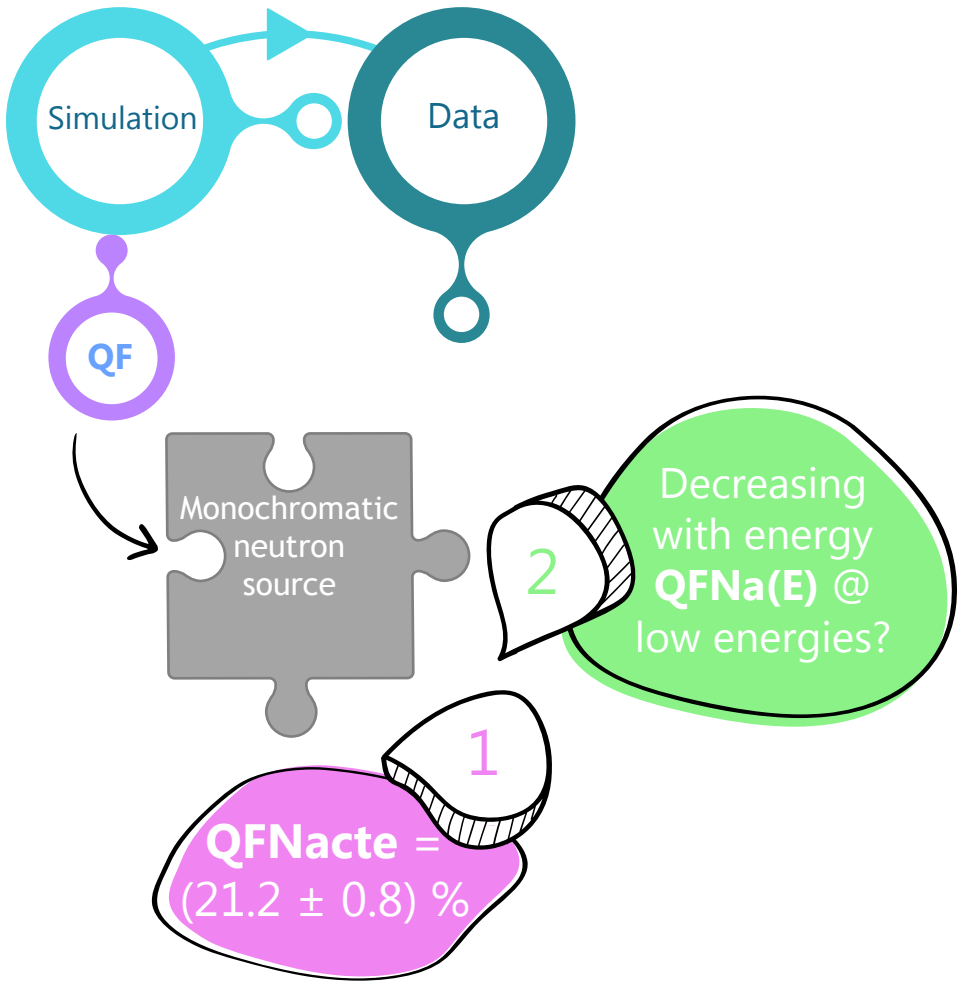

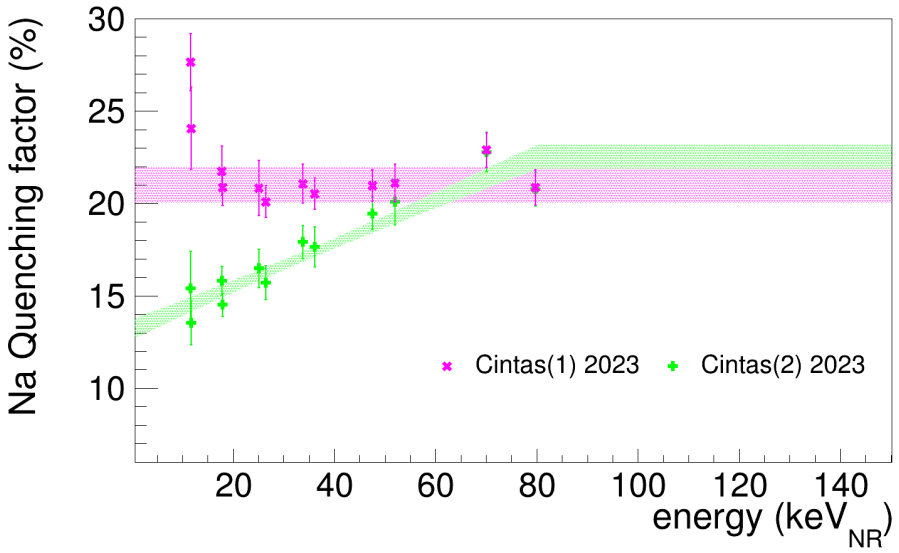

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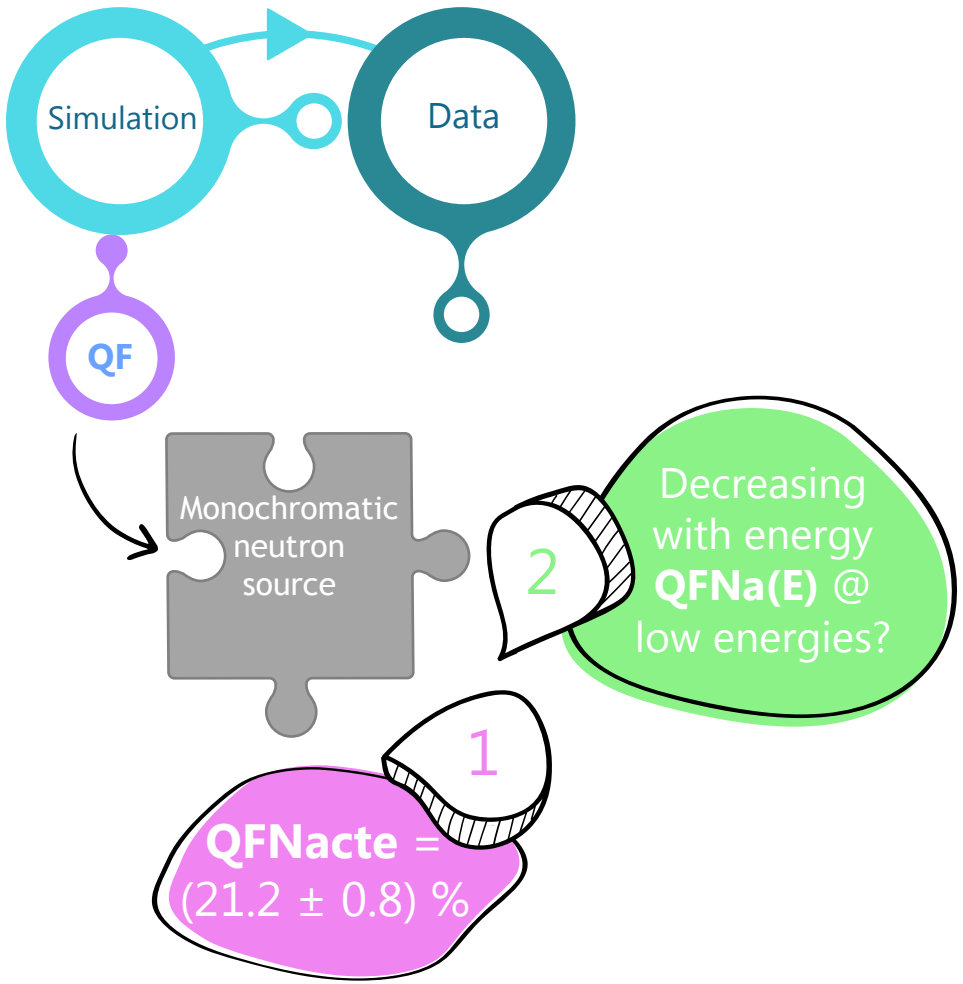
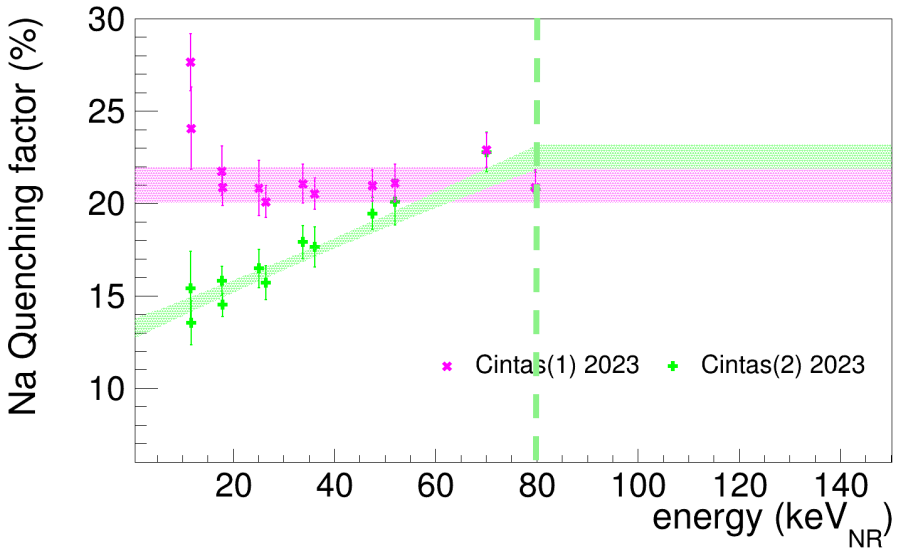
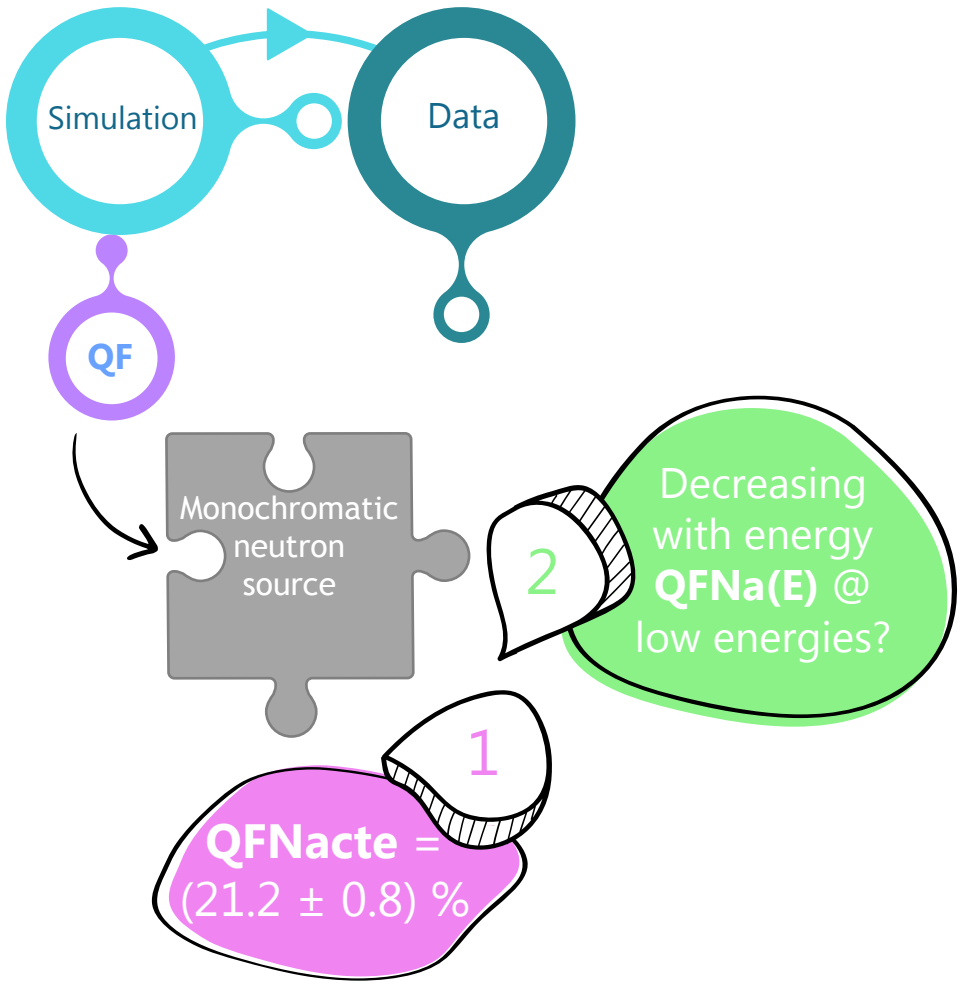
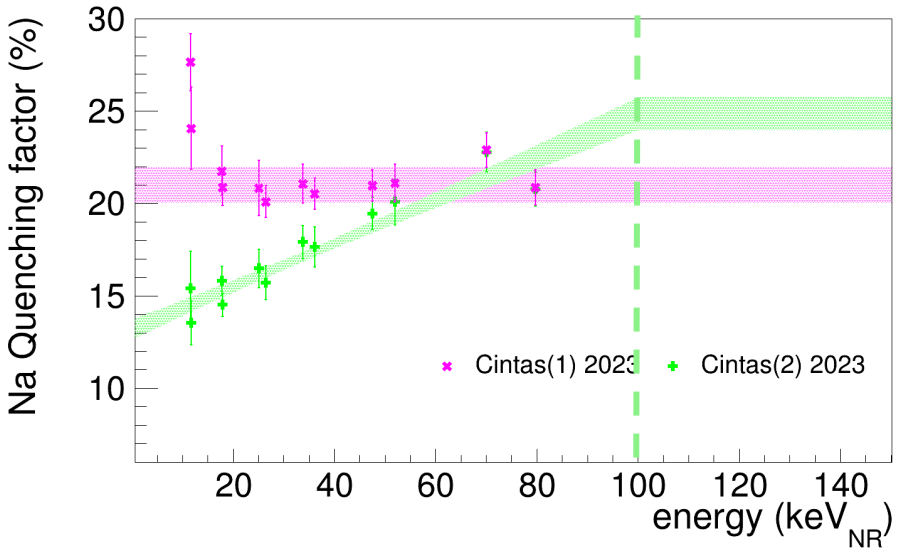




Uncertainty in QFNa(E) modelling

Results on the quenching factor





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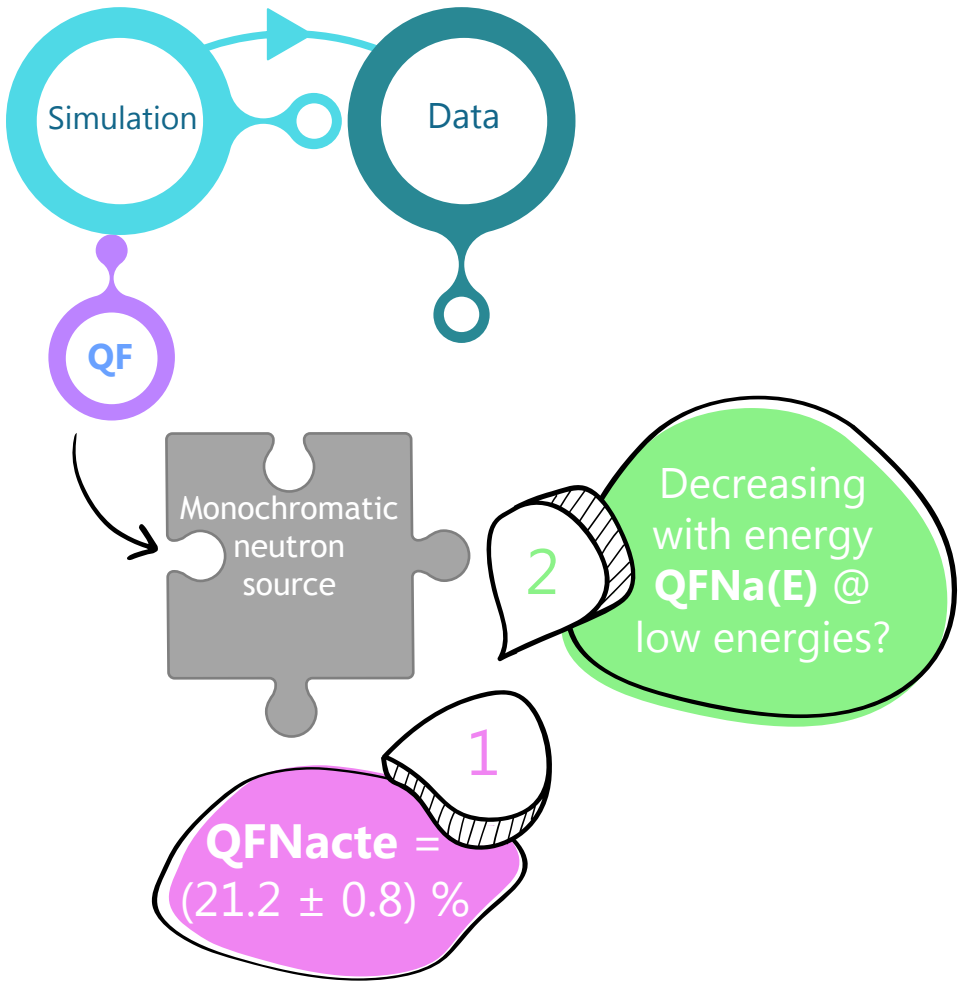

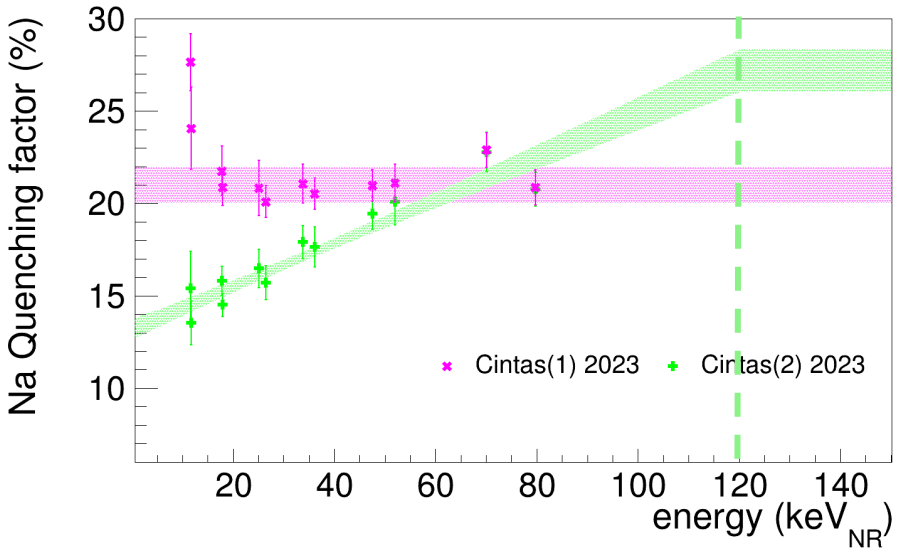

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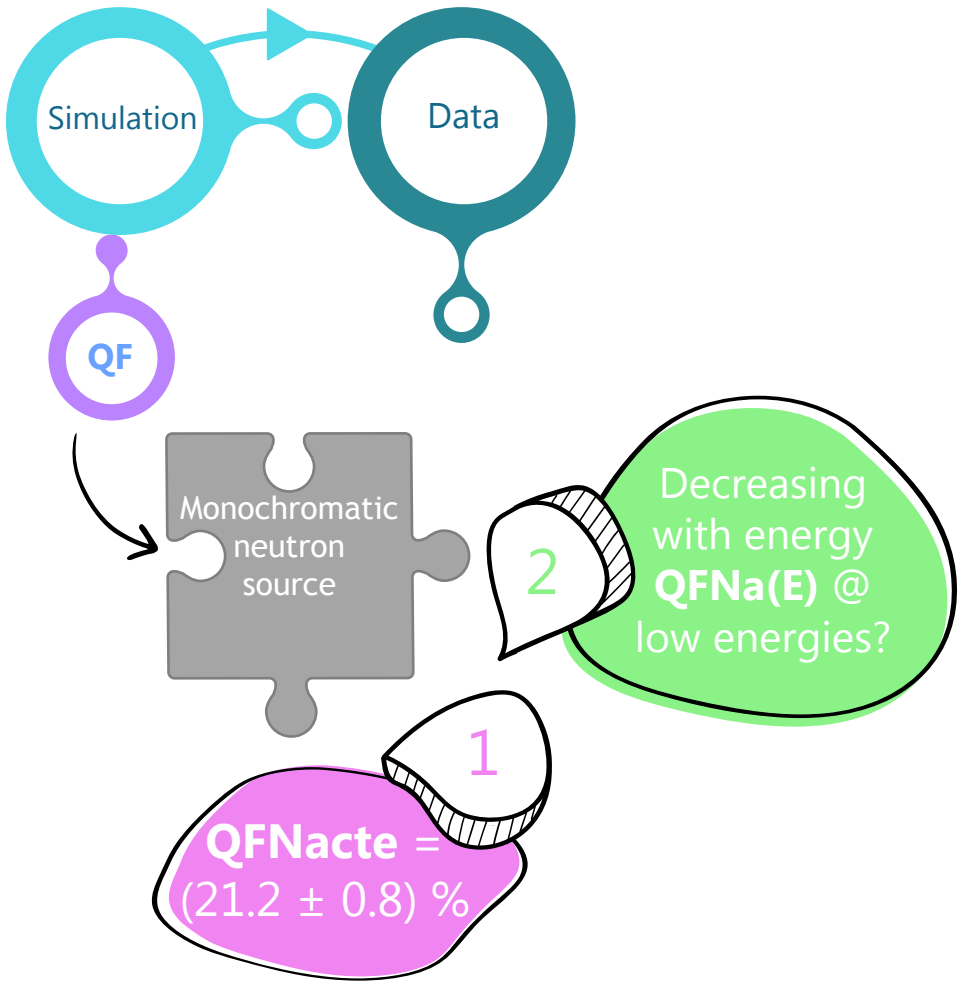

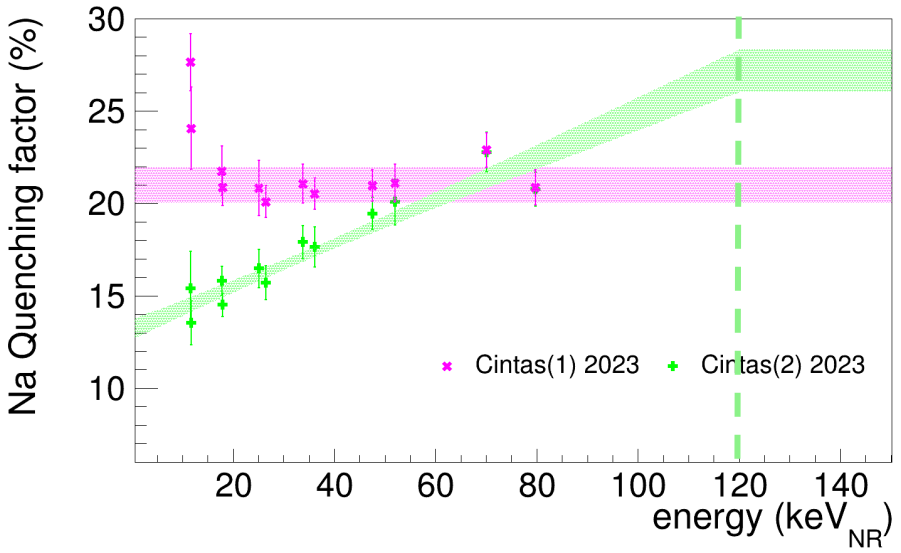

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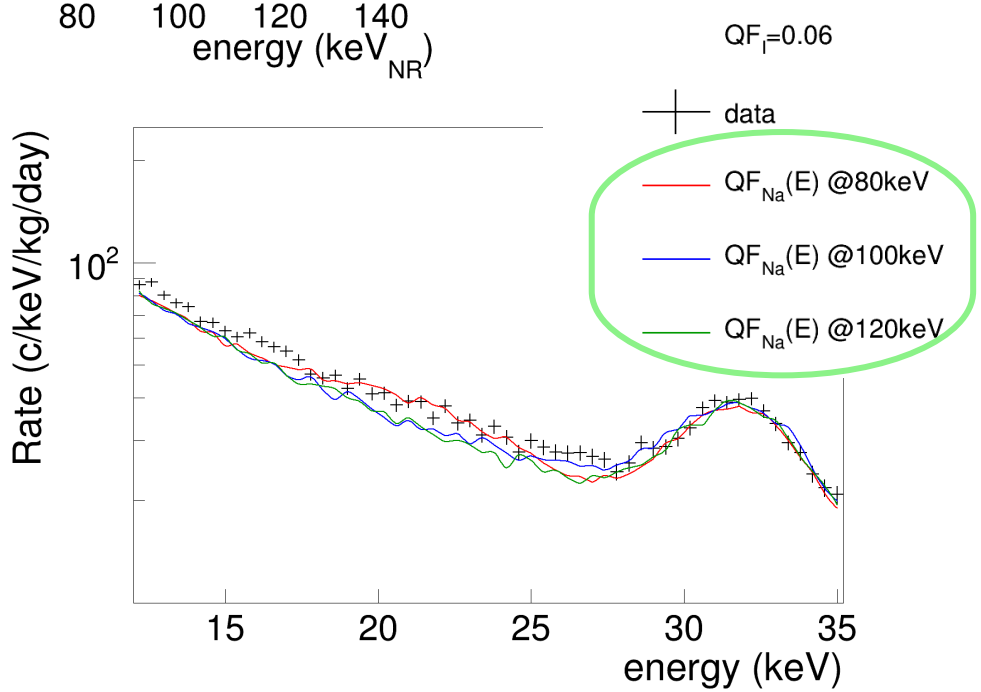

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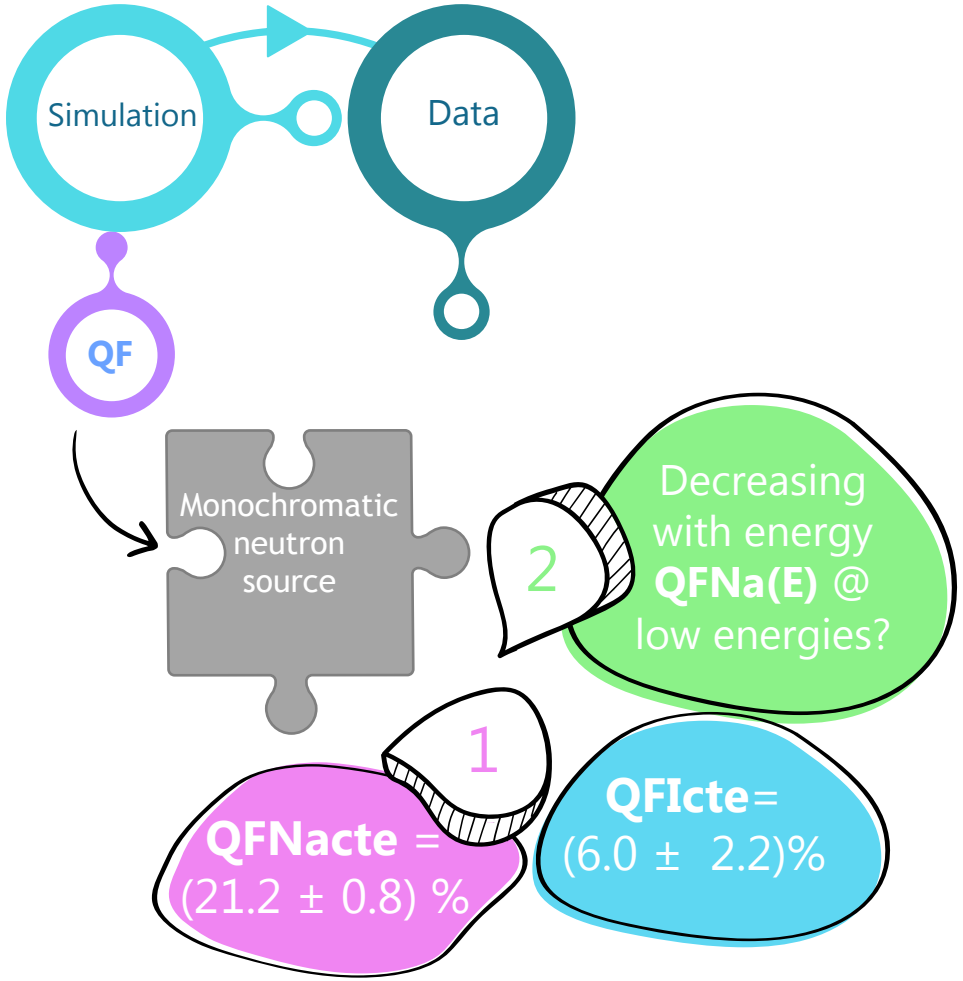
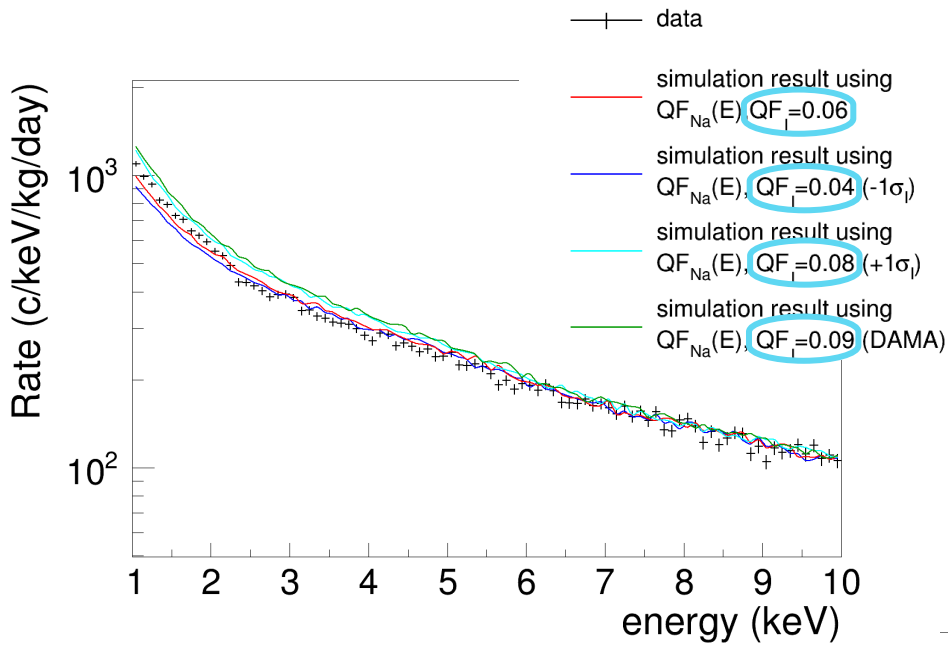
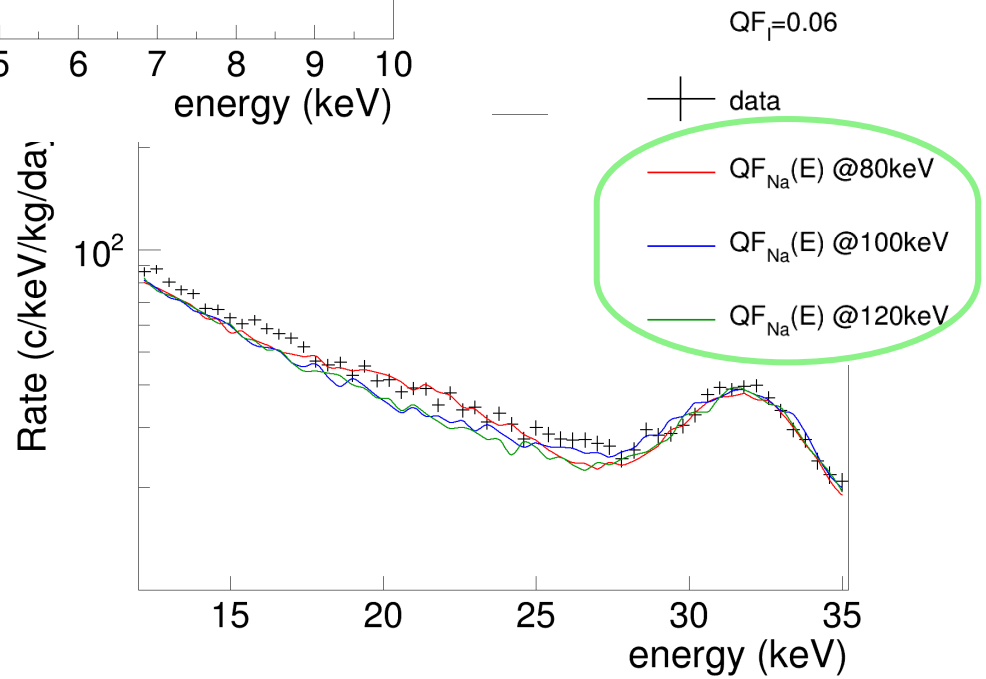




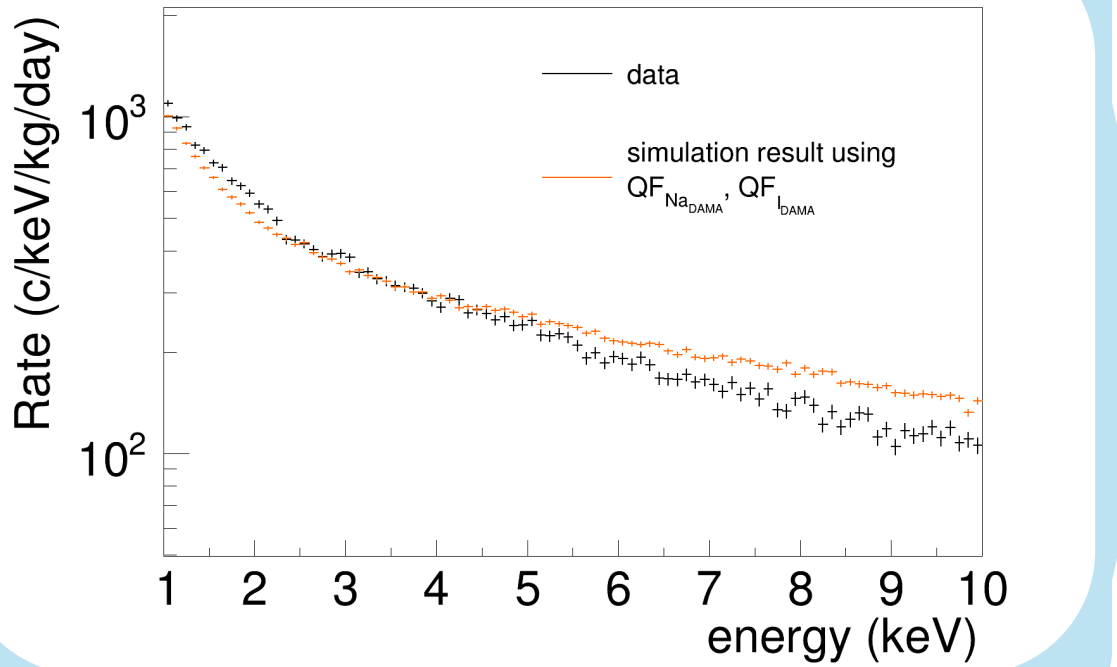
Iodine QF has influence only at very low energies (<10 keVee)

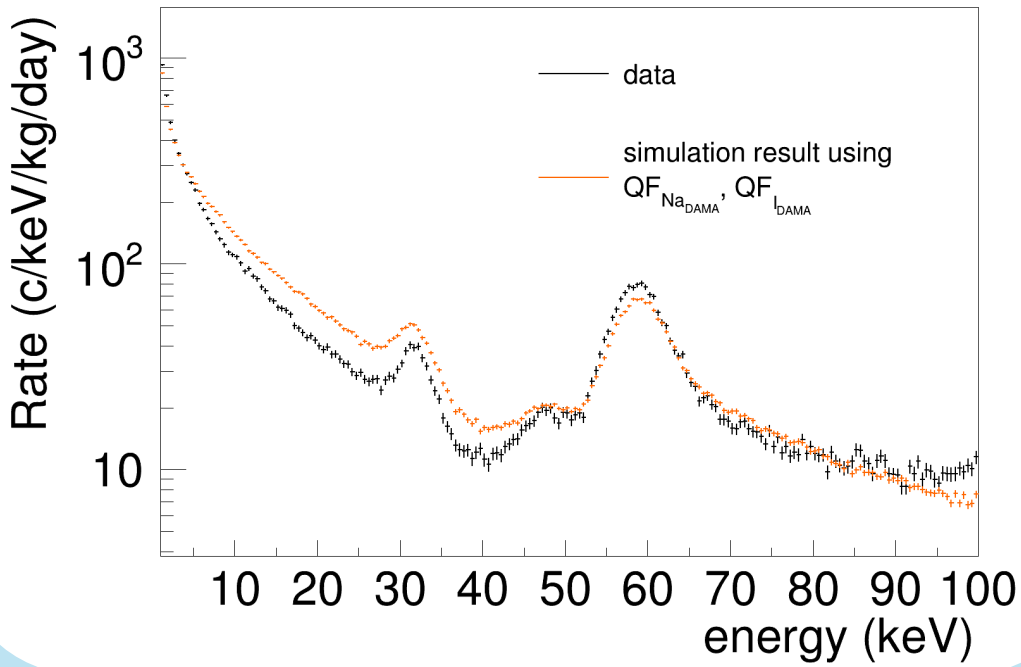


Results on the quenching factor

Comparison with **DAMA/LIBRA QFs**

Q_{Na} DAMA = 0.3
Q_I DAMA = 0.09





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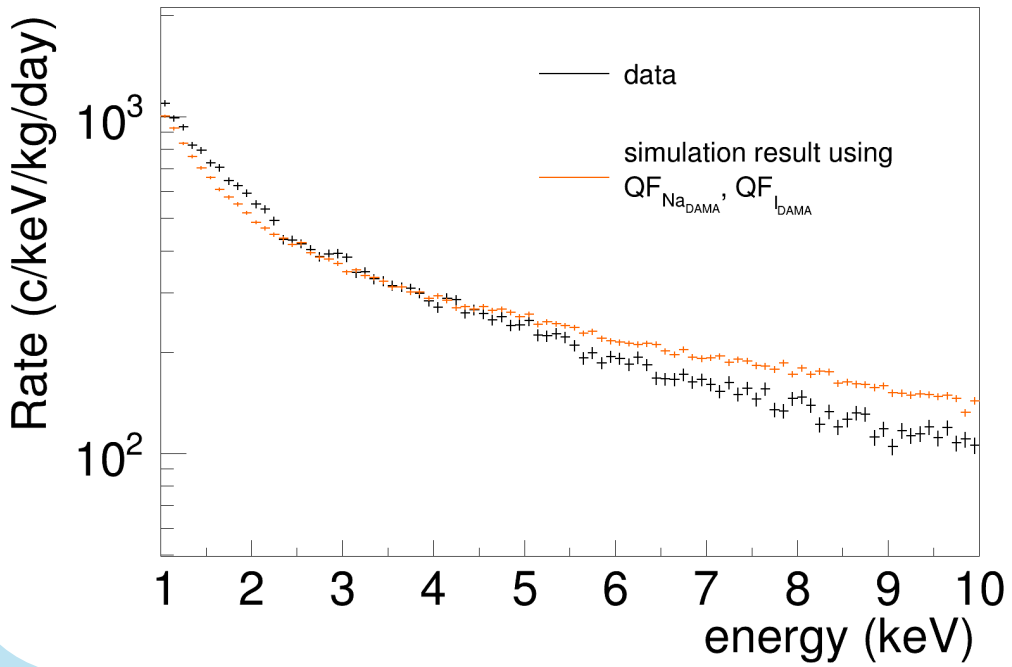
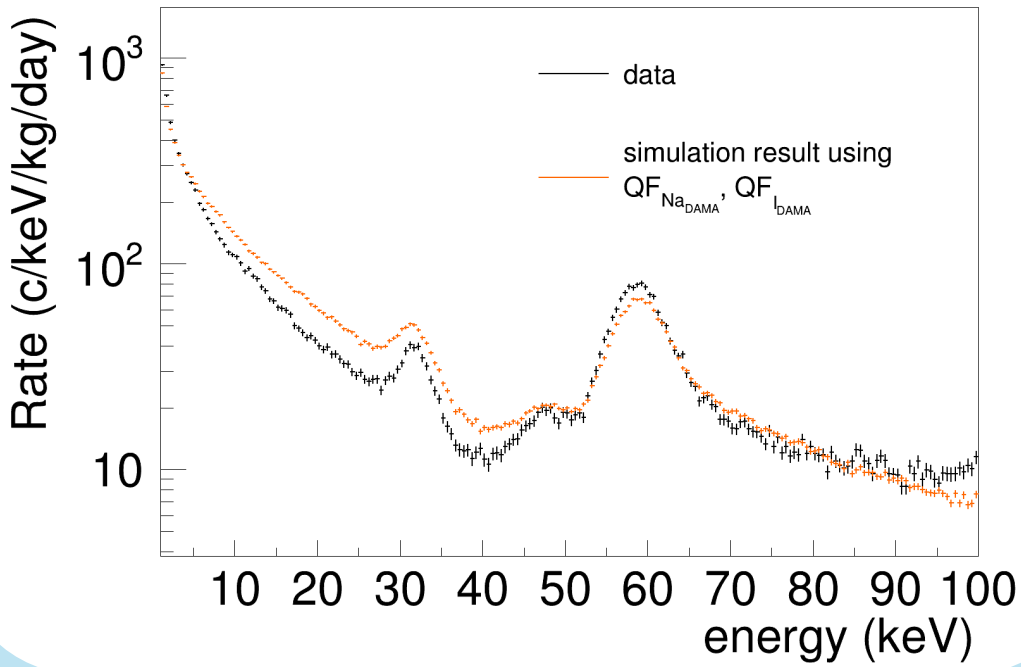
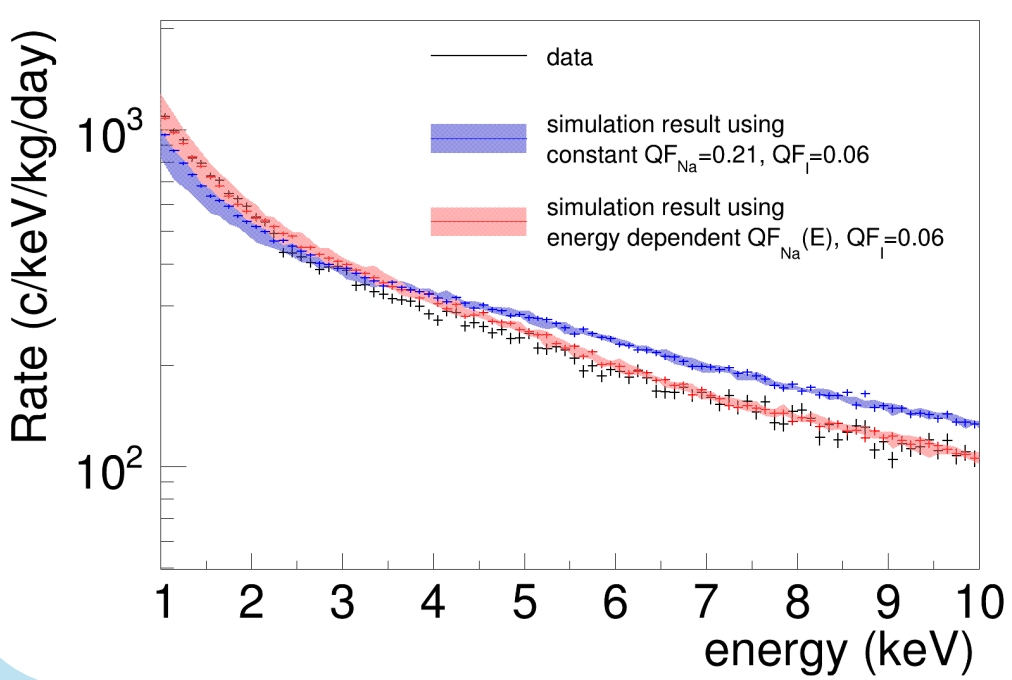


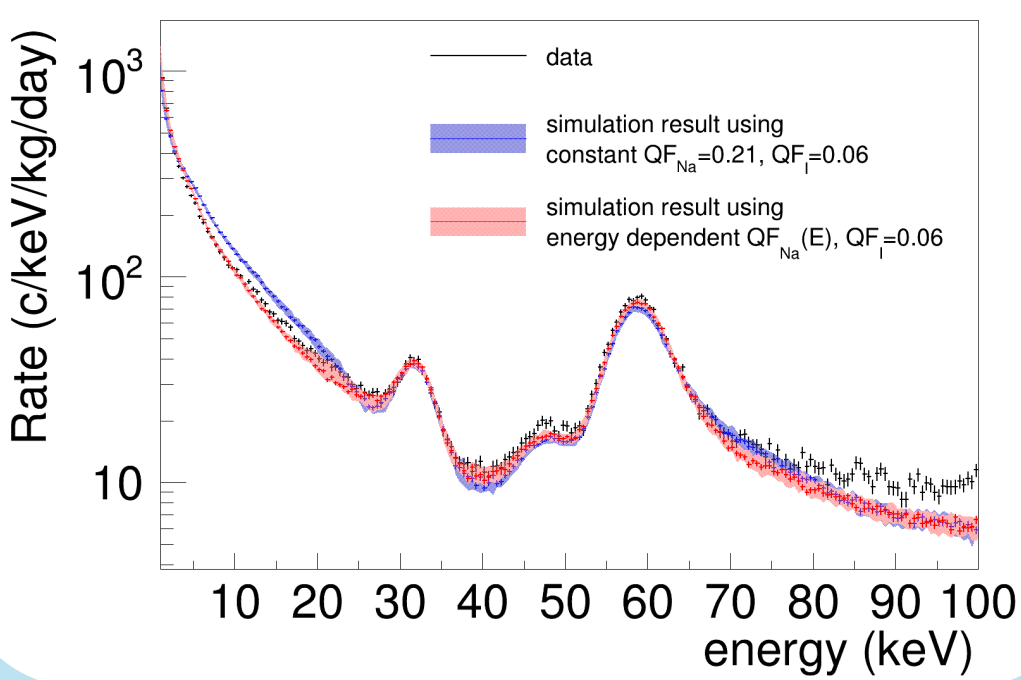


DAMA/LIBRA QFs are **not compatible** with our data

Results on the quenching factor

Comparison between **our QF models**

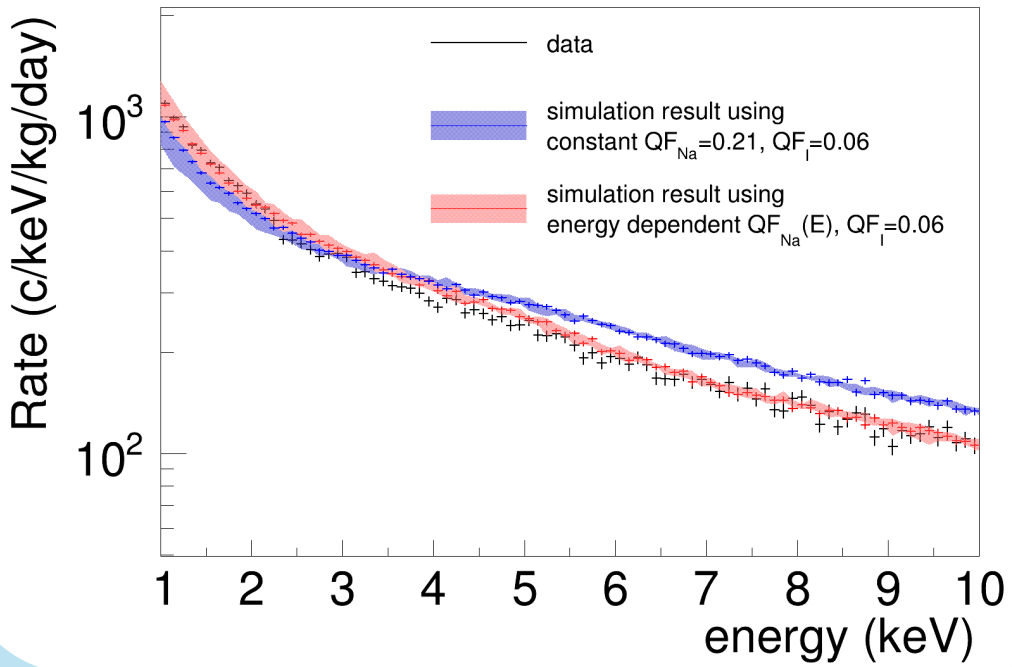


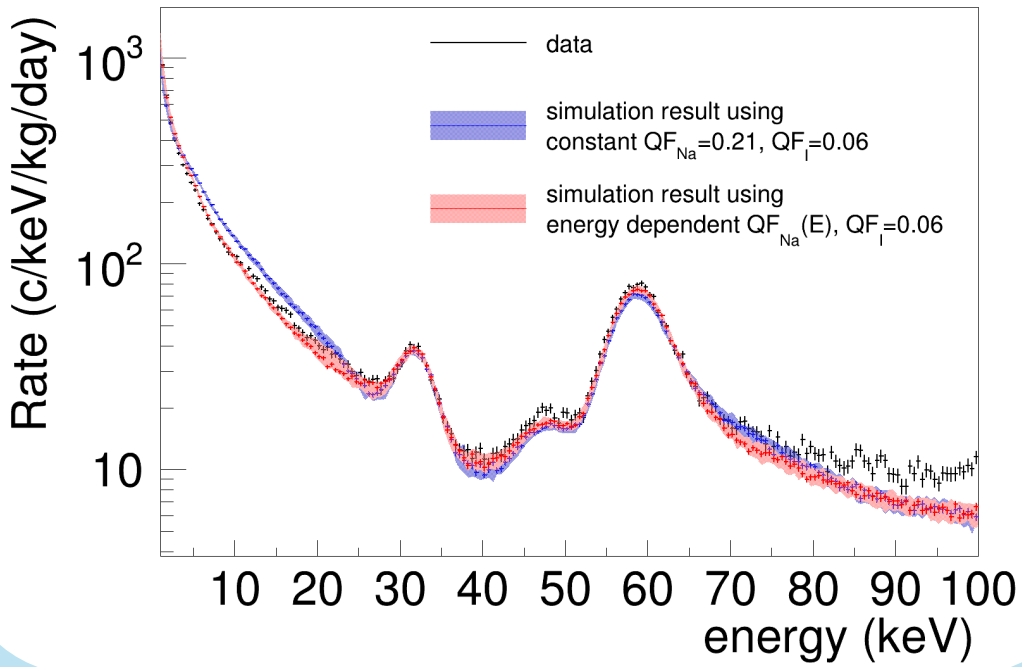


Results on the quenching factor

Comparison between **our QF models**

Fitting has **not** been **attempted** (yet)!
Spectra normalized only w/ A_{source} and tmeas and bkg added





QFNa(E) provides a robust **agreement**

QFNa(E) seems to be favoured over **QFNacte** !!!

Results on the quenching factor

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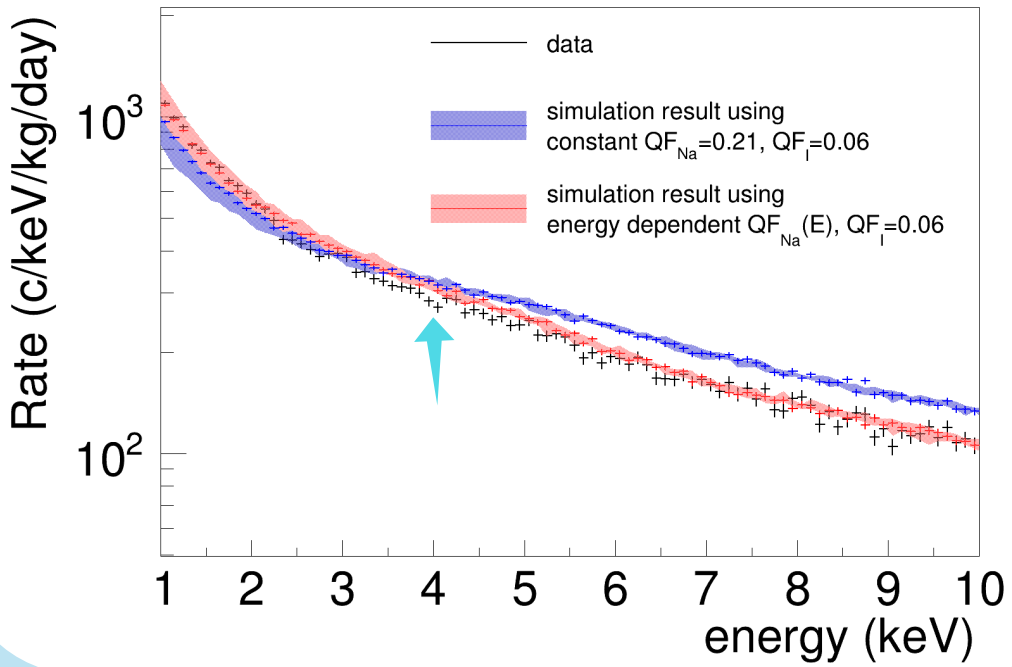

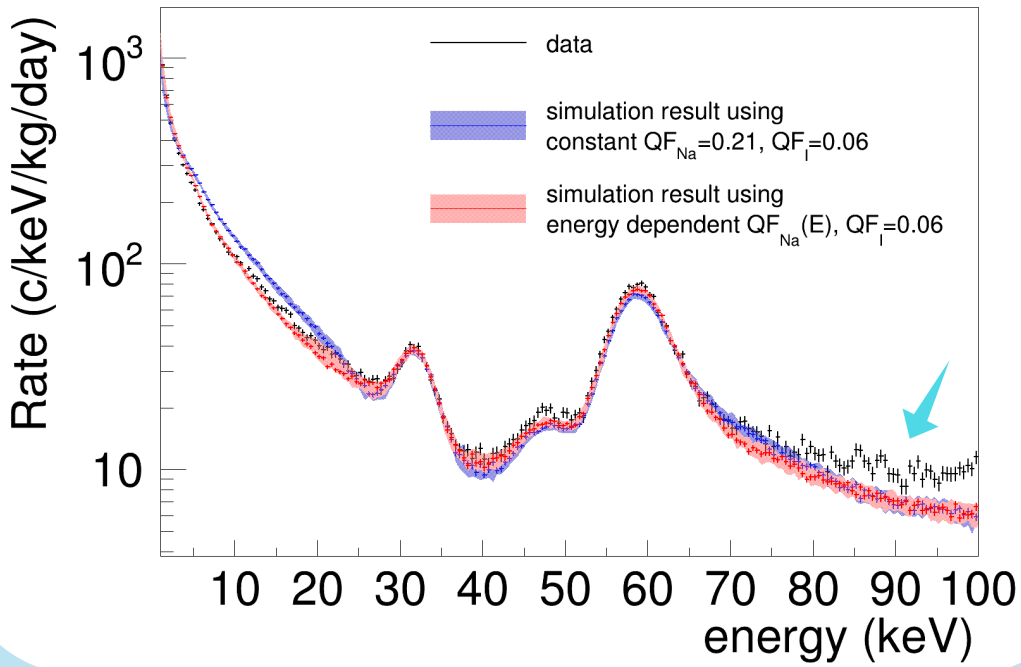

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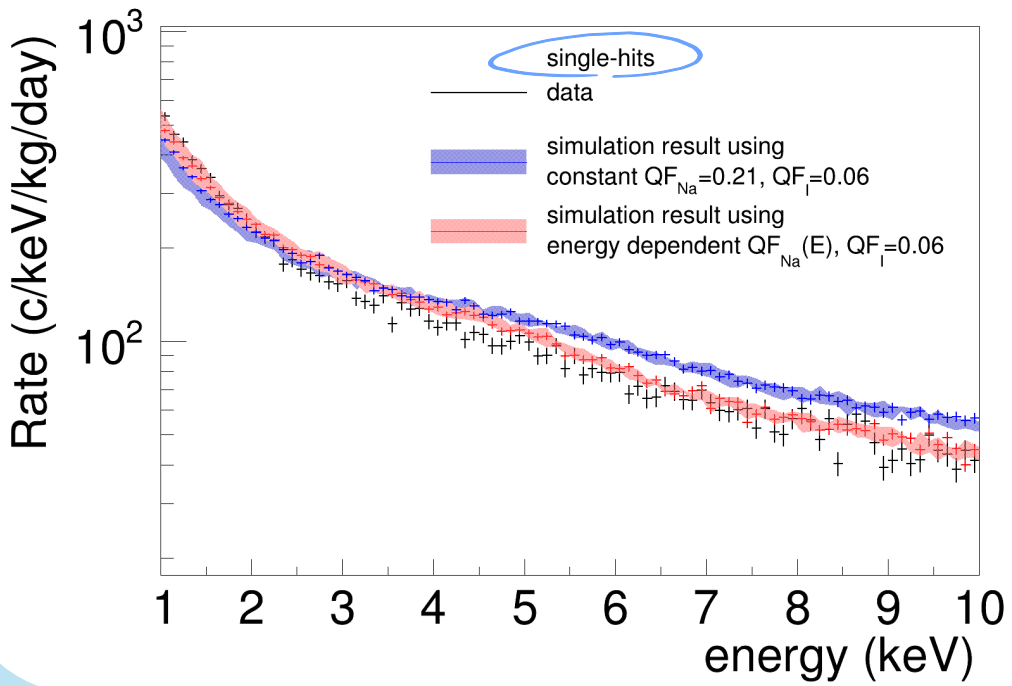

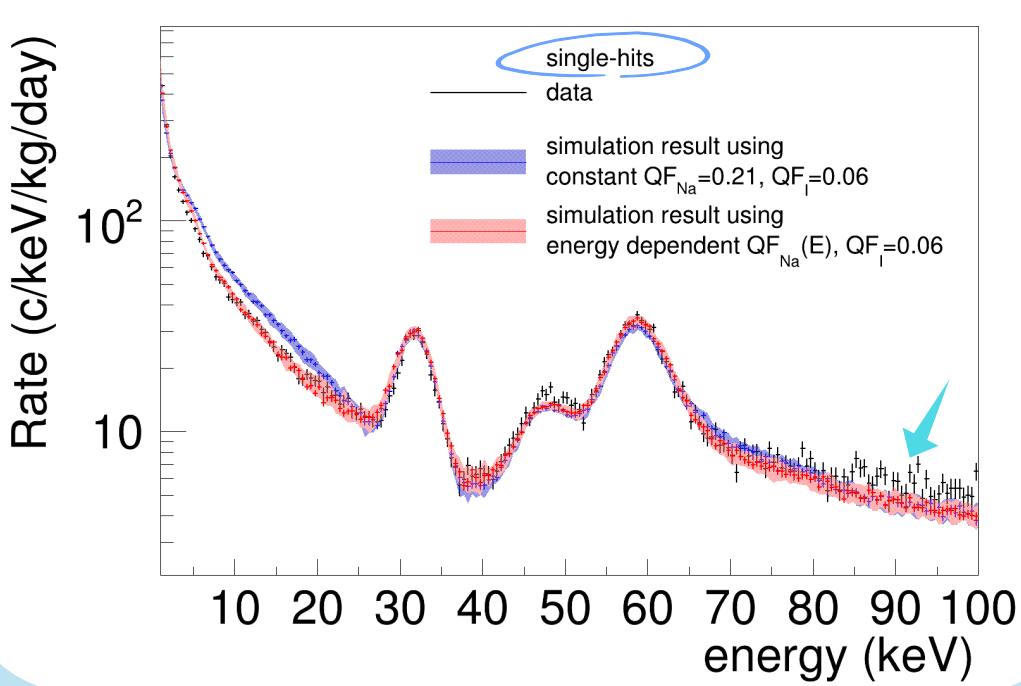

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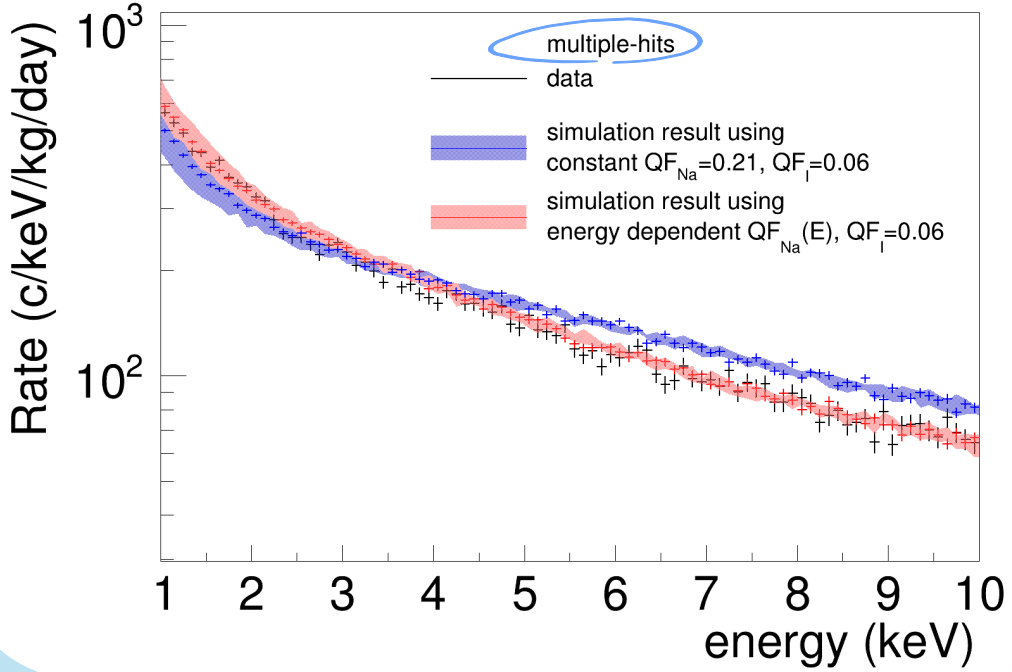
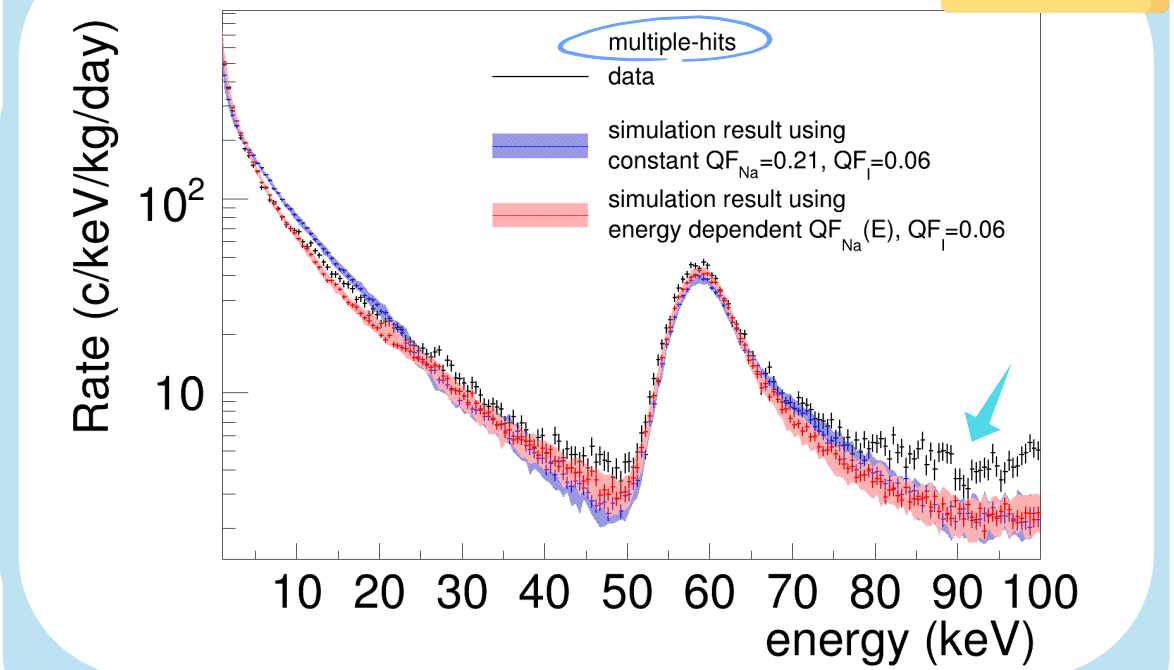
Results on the quenching factor

Comparison between **our QF models**

Further investigation is required to better understand multiple-hit events





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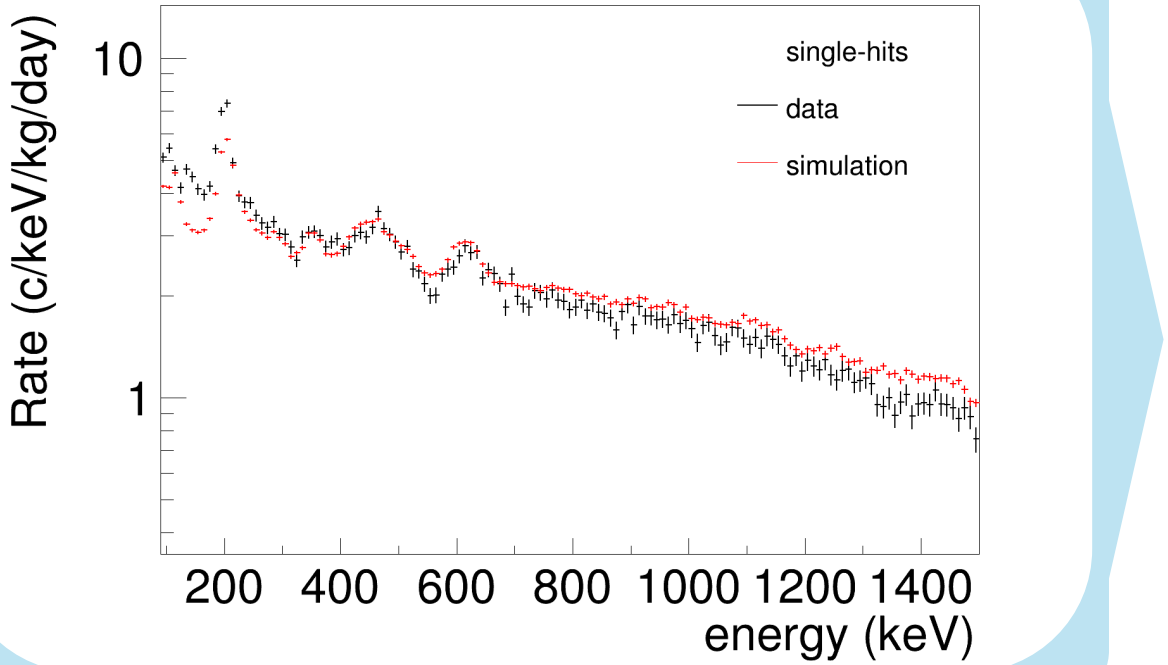
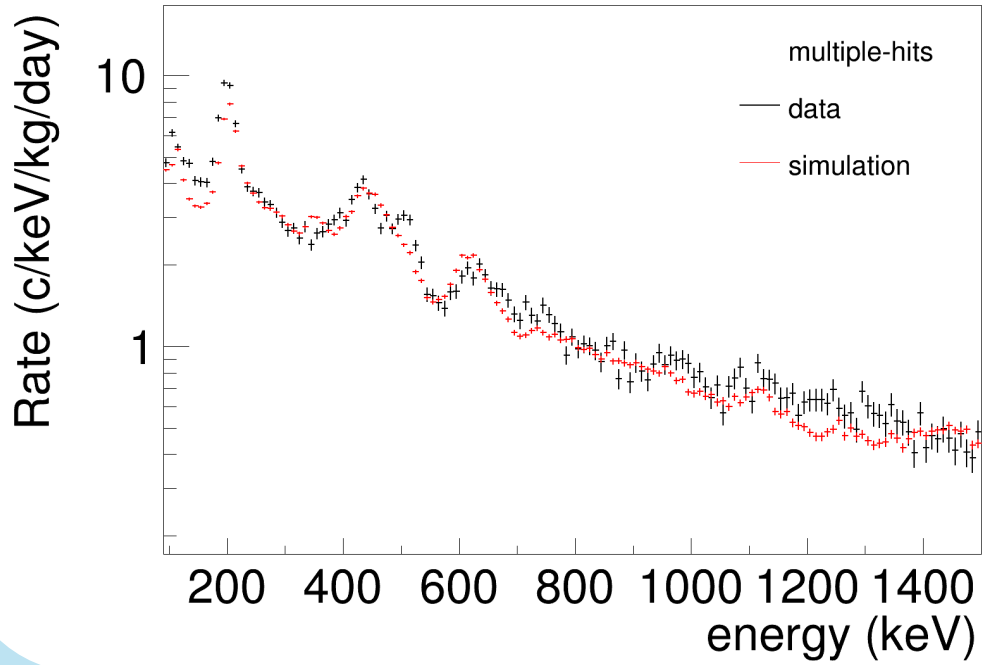
Results on the quenching factor

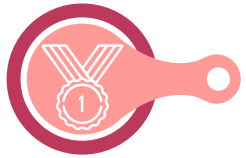
What about **HE** range?



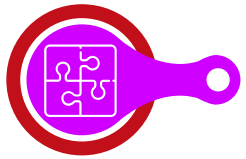


HE spectrum features are qualitatively well reproduced

TO SUM UP

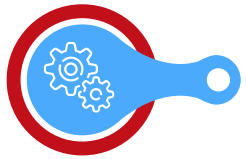


Systematics have to be taken into account for understanding a more than 20 y old-puzzling result: nuclear recoil energy conversion into visible energy could be different in ANAIS and DAMA/LIBRA detectors!



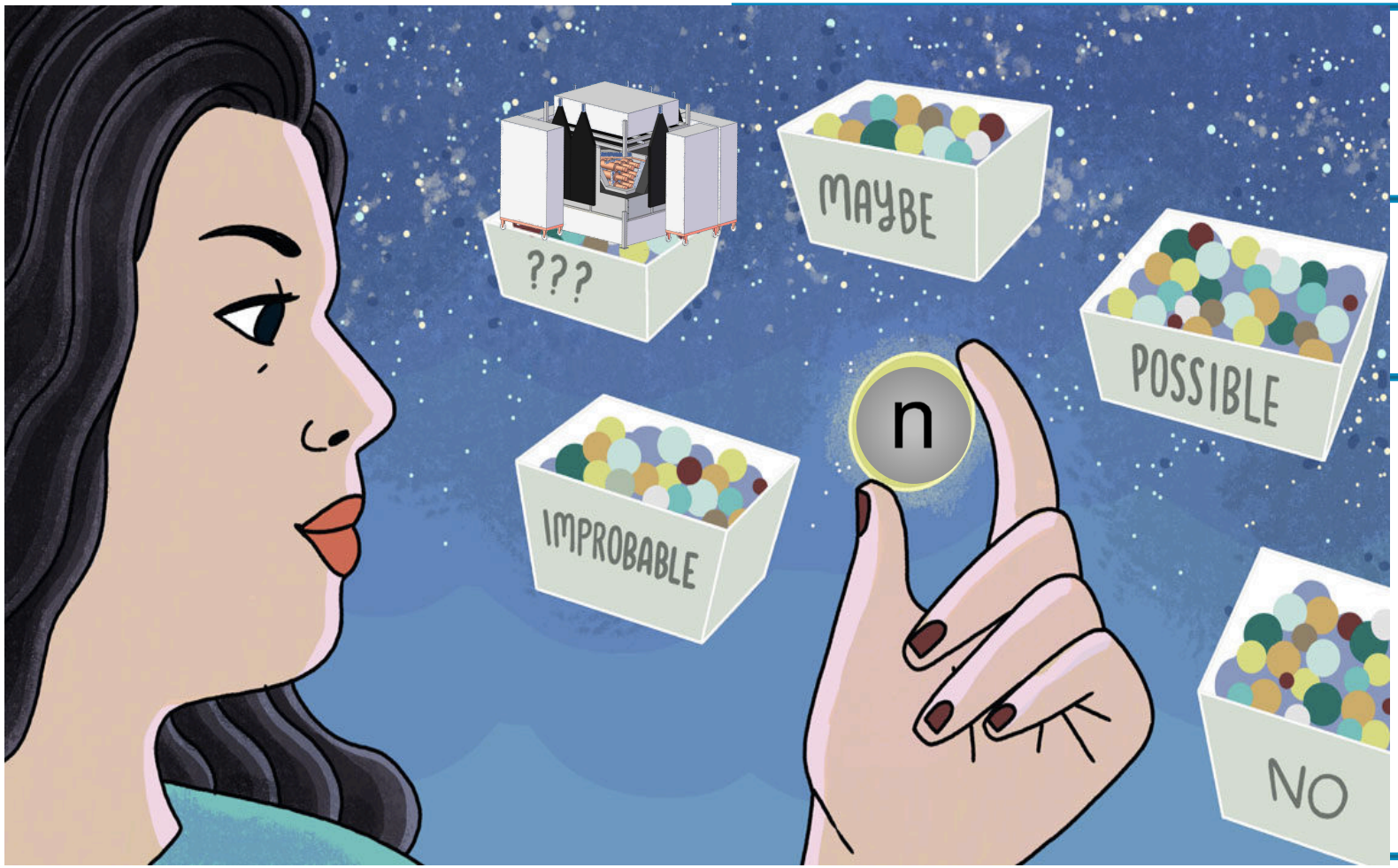
Neutron calibrations onsite have been performed using 252Cf sources at LSC, which are relevant for understanding the unnaccounted systematics behind the different QF values and energy dependences for NaI. More coordinated work from the community would be required

Our approach has proben to be truly sensitive to the QF.
QFNa(E) provides a robust agreement and seems to be favoured over constant QF. Plans to continue studying other energy dependences and to include the non-proportionality of detectors



Measurements of the QF for ANAIS detectors will be taken into account for the comparison with DAMA/LIBRA results and those from other targets

Thank you for your attention!



Tamara Pardo on
behalf of the ANAIS research team

20th Multidark Consolider Workshop, Gandia
25th-27th October 2023

Centro de Astropartículas y Física de Altas Energías
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Unanswered questions?
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