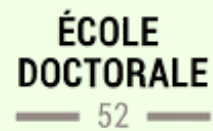




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52



RICOCCHET
A Coherent Neutrino Scattering Program



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cnrs



NUCLEI &
PARTICLES

Preliminary measurement of the germanium ionization yield

First studies of the new silicon crystal detectors

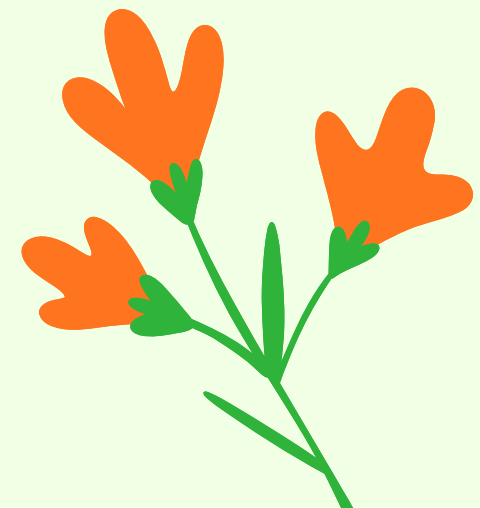
Ricochet experiment

PhD day – 23/04/2026

Tatiana Le Bellec under the supervision of Corinne Augier and Julien Billard



Let's start with some context



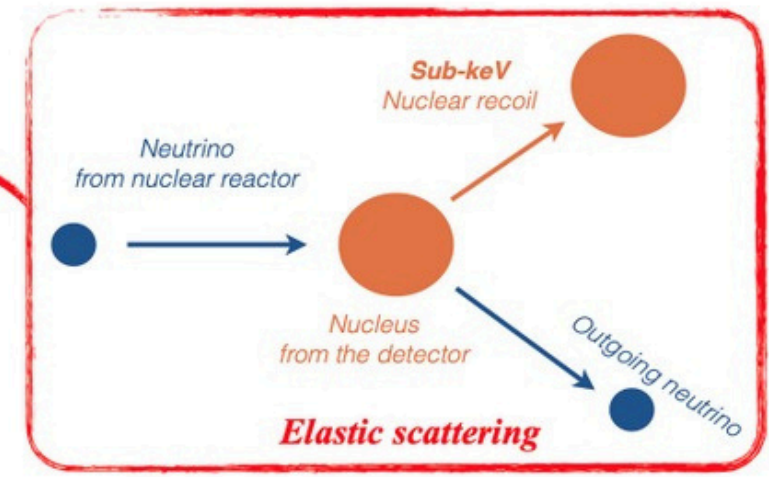
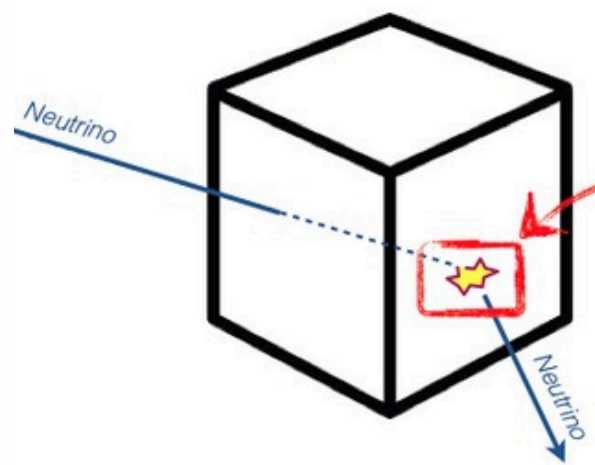


The CENNS

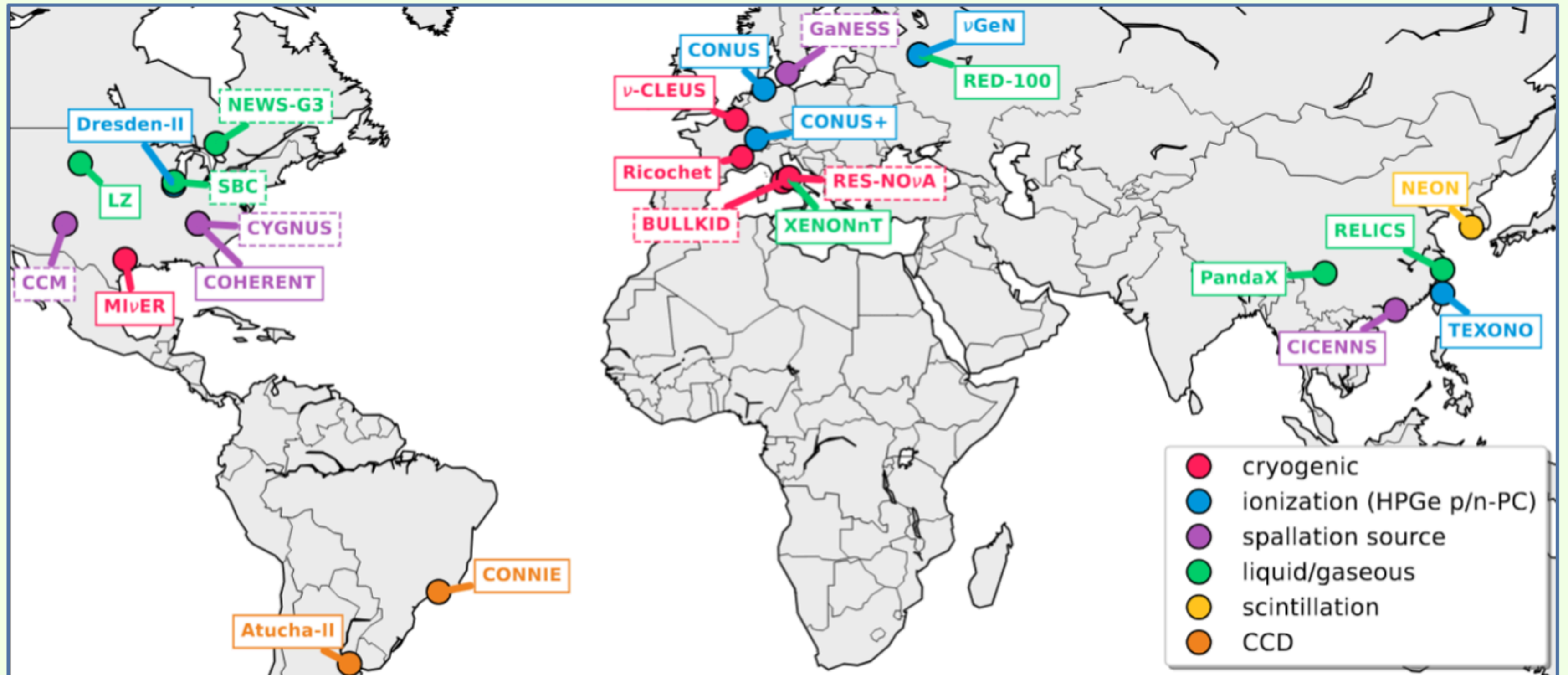
(Coherent Elastic Neutrino-Nucleus Scattering)

For the coherence we use **neutrinos from nuclear reactors**

$$E_\nu \approx 3 \text{ MeV}$$



CENNS experiments map

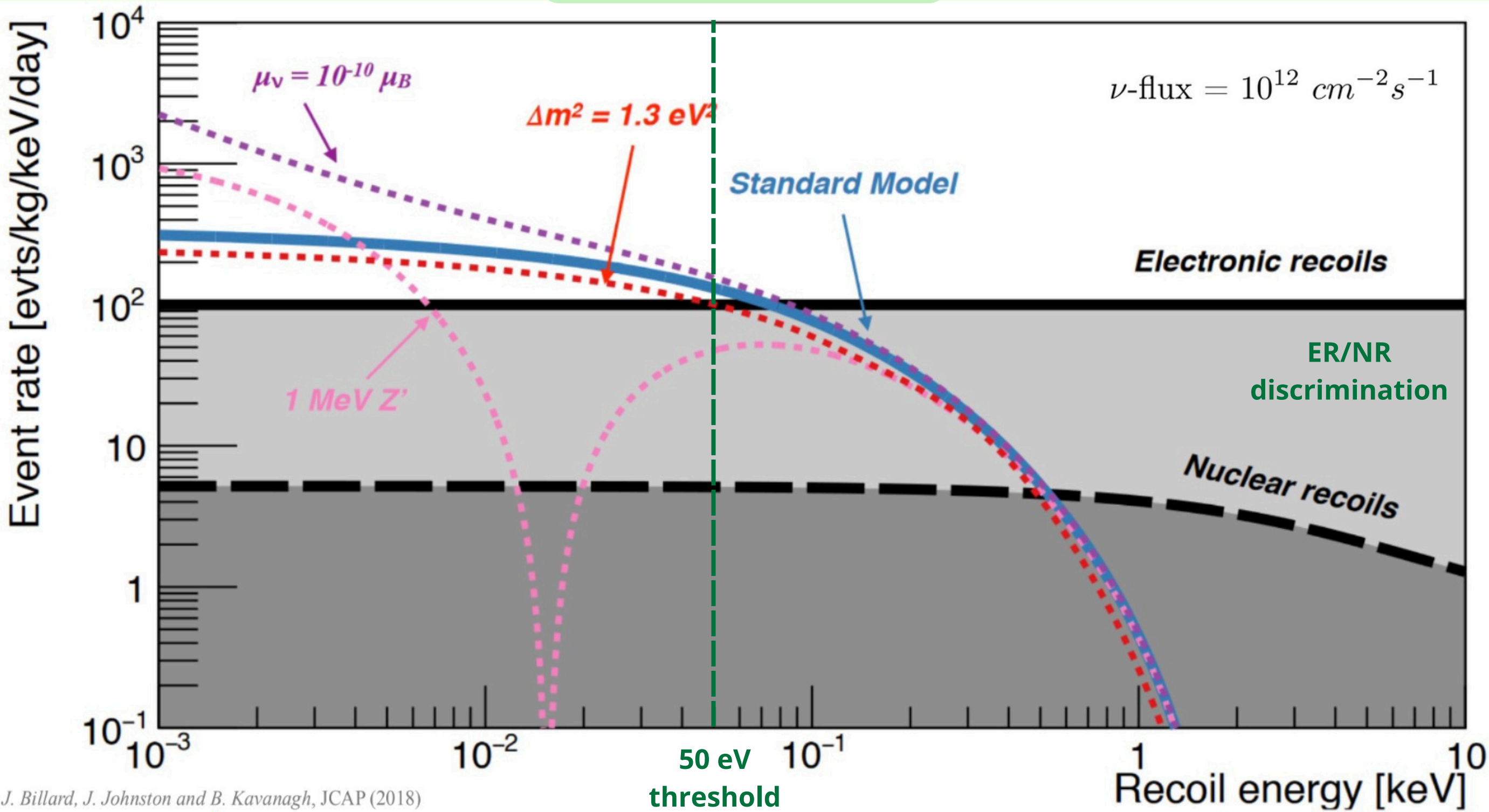


First CENNS detection by the COHERENT collaboration in 2017

A door towards new physics



CENNS spectrum

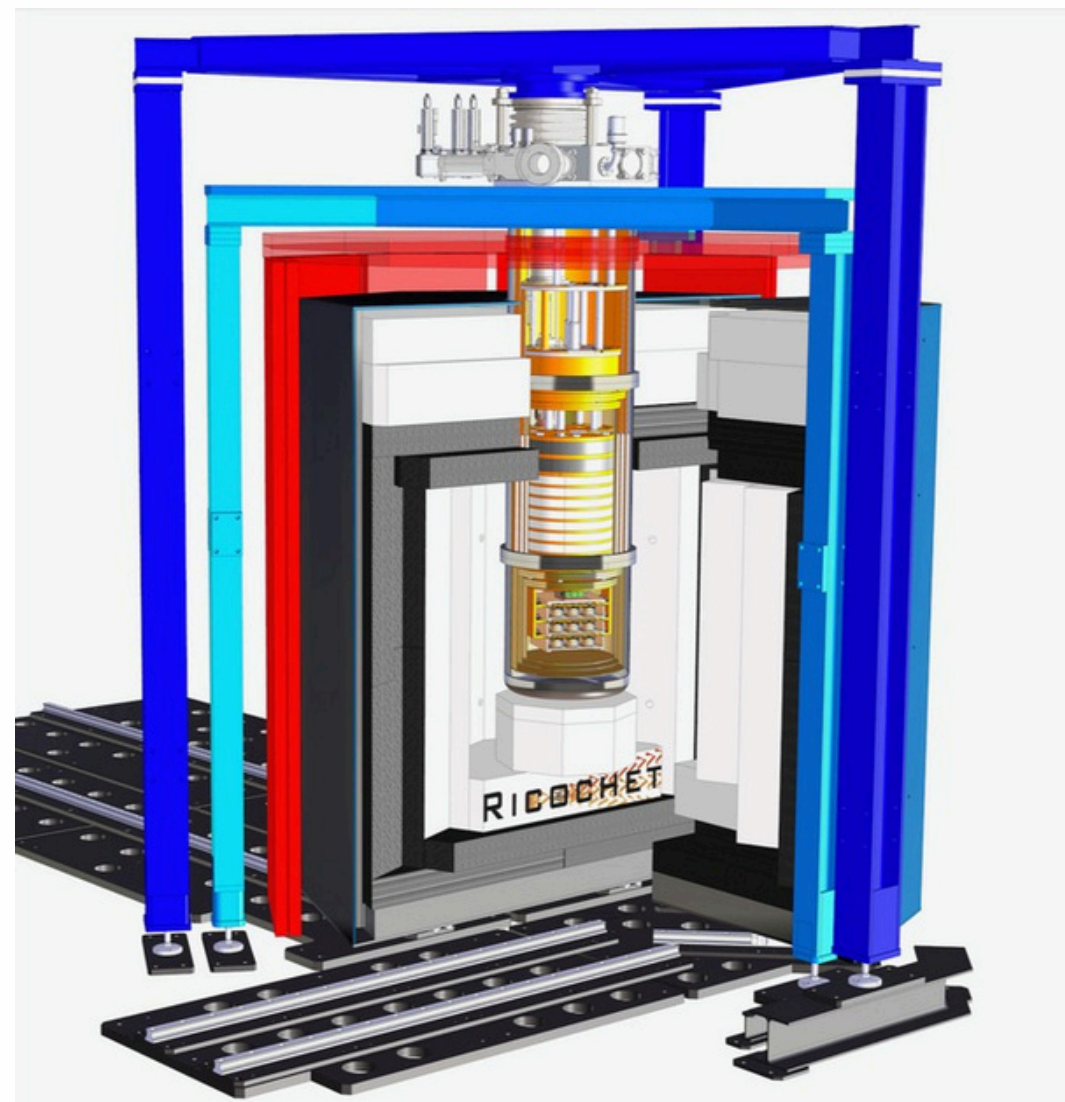


J. Billard, J. Johnston and B. Kavanagh, JCAP (2018)

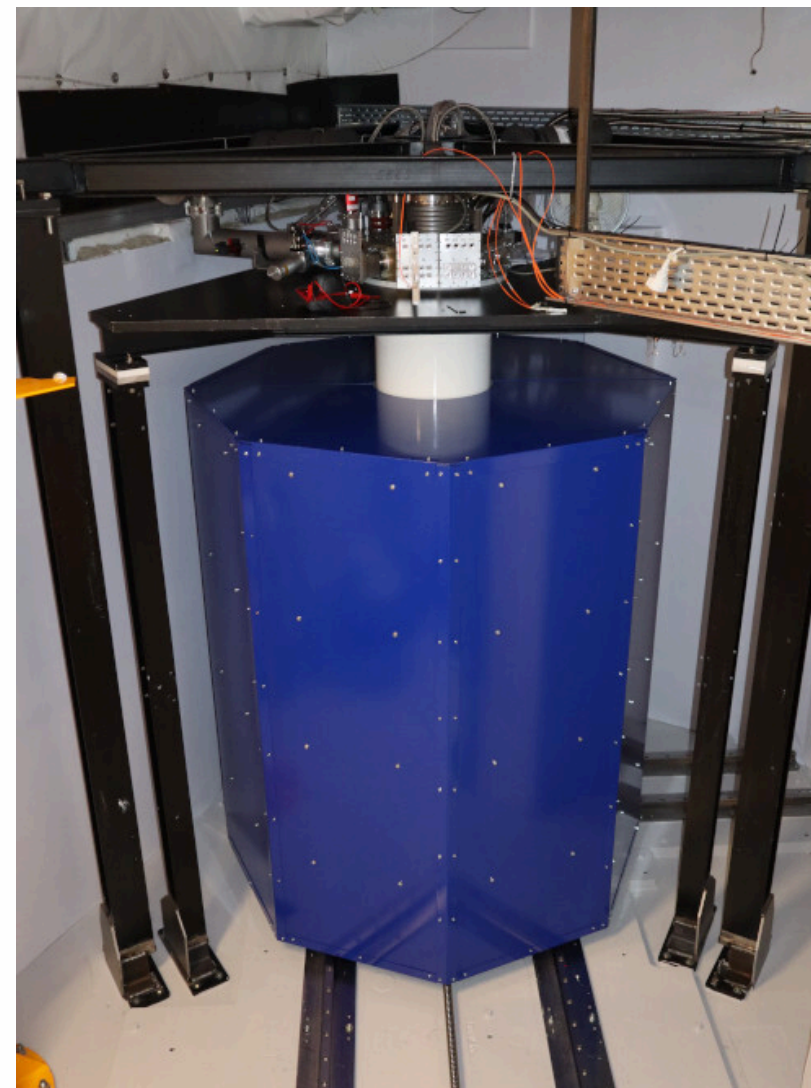
Ricochet experiment



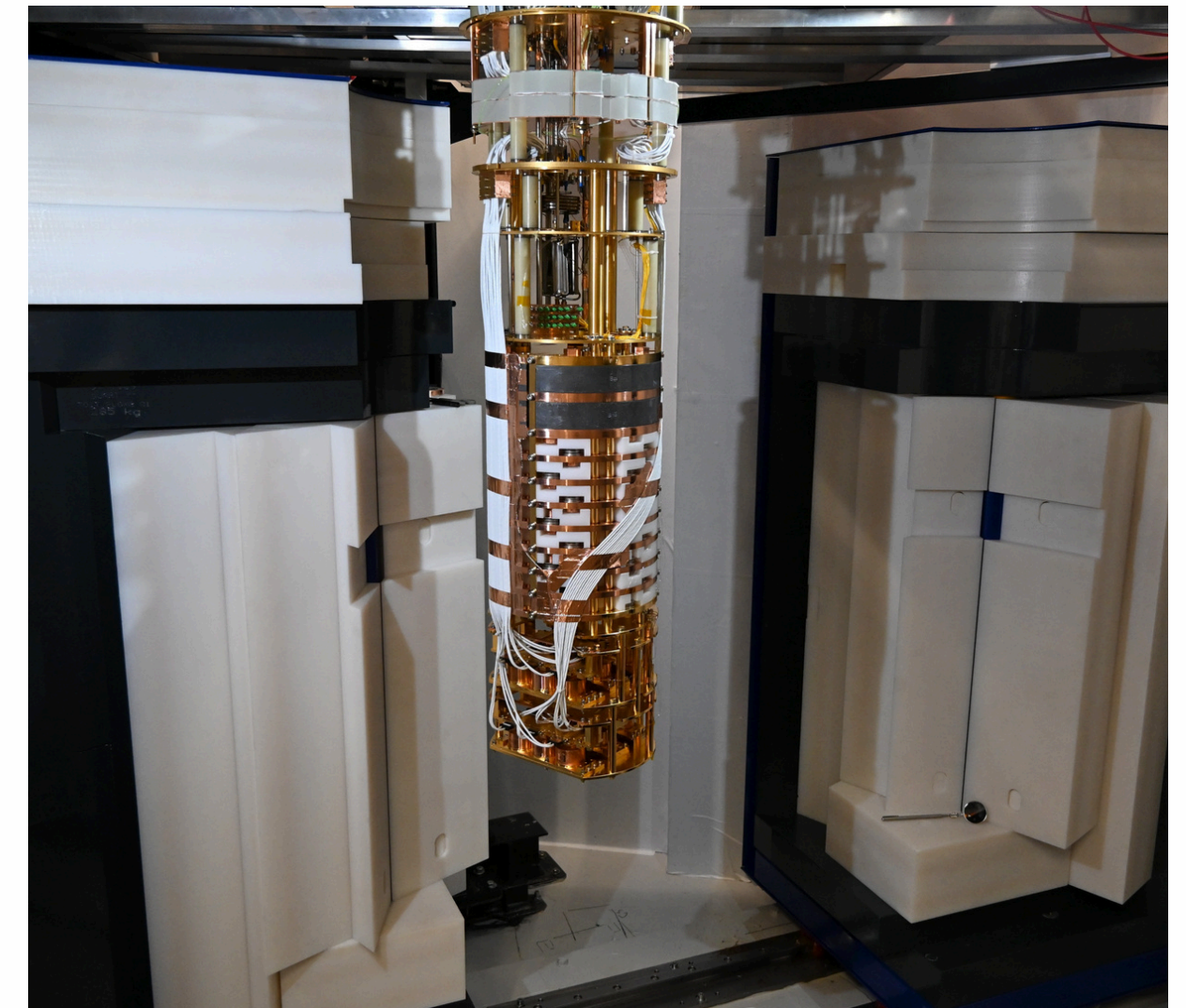
Ricochet is a **cryogenic experiment** aiming at **detecting the CENNS signal at keV scale energies**. It is located at **8.8 m from the nuclear core** of the **Laue Langevin Institute in Grenoble**.



Ricochet experiment scheme



outer shielding made of lead and polyethylene

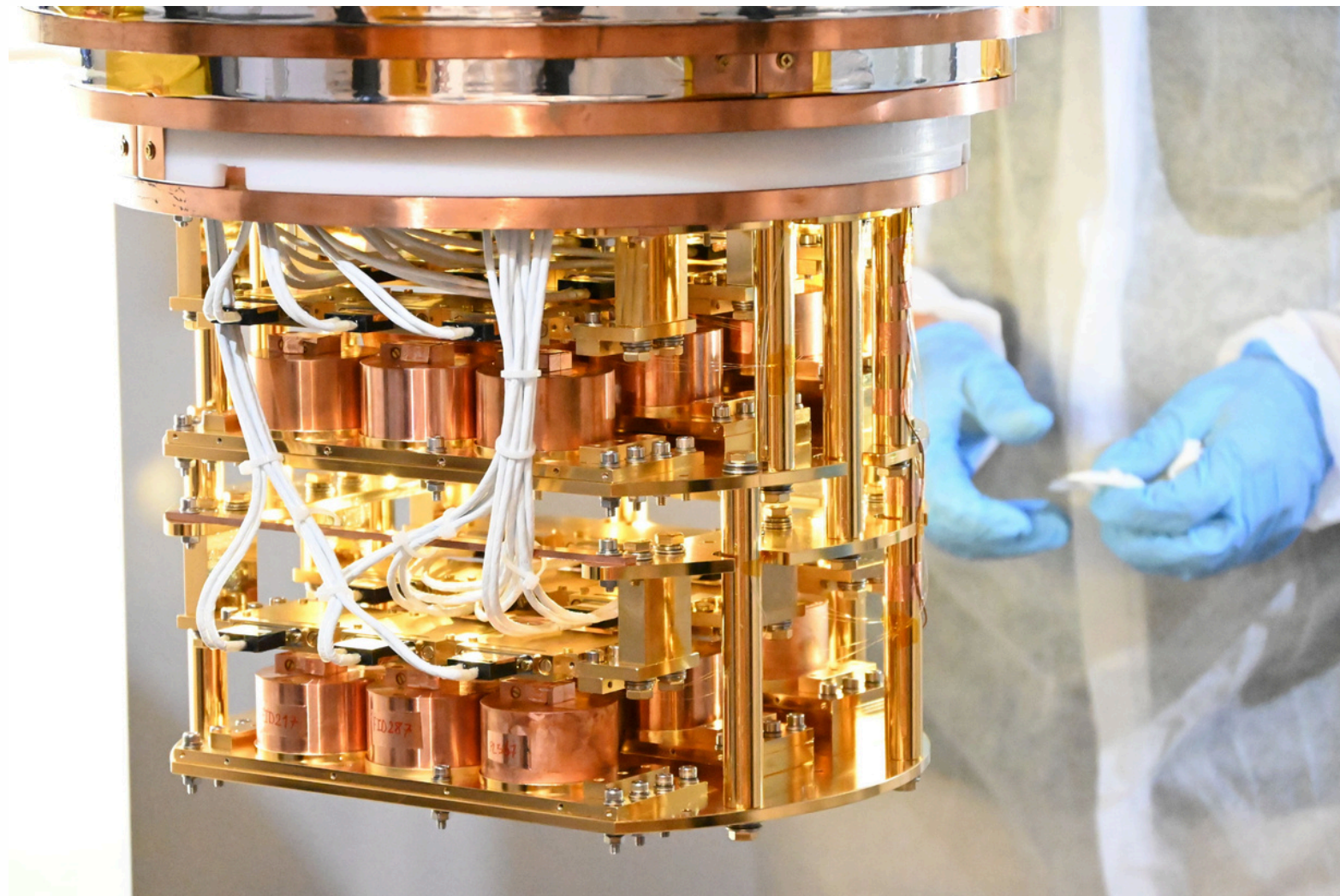


the **cryostat** with its 150kg inner shielding and the first stage where the **CryoCube** is cooled to **15 mK**

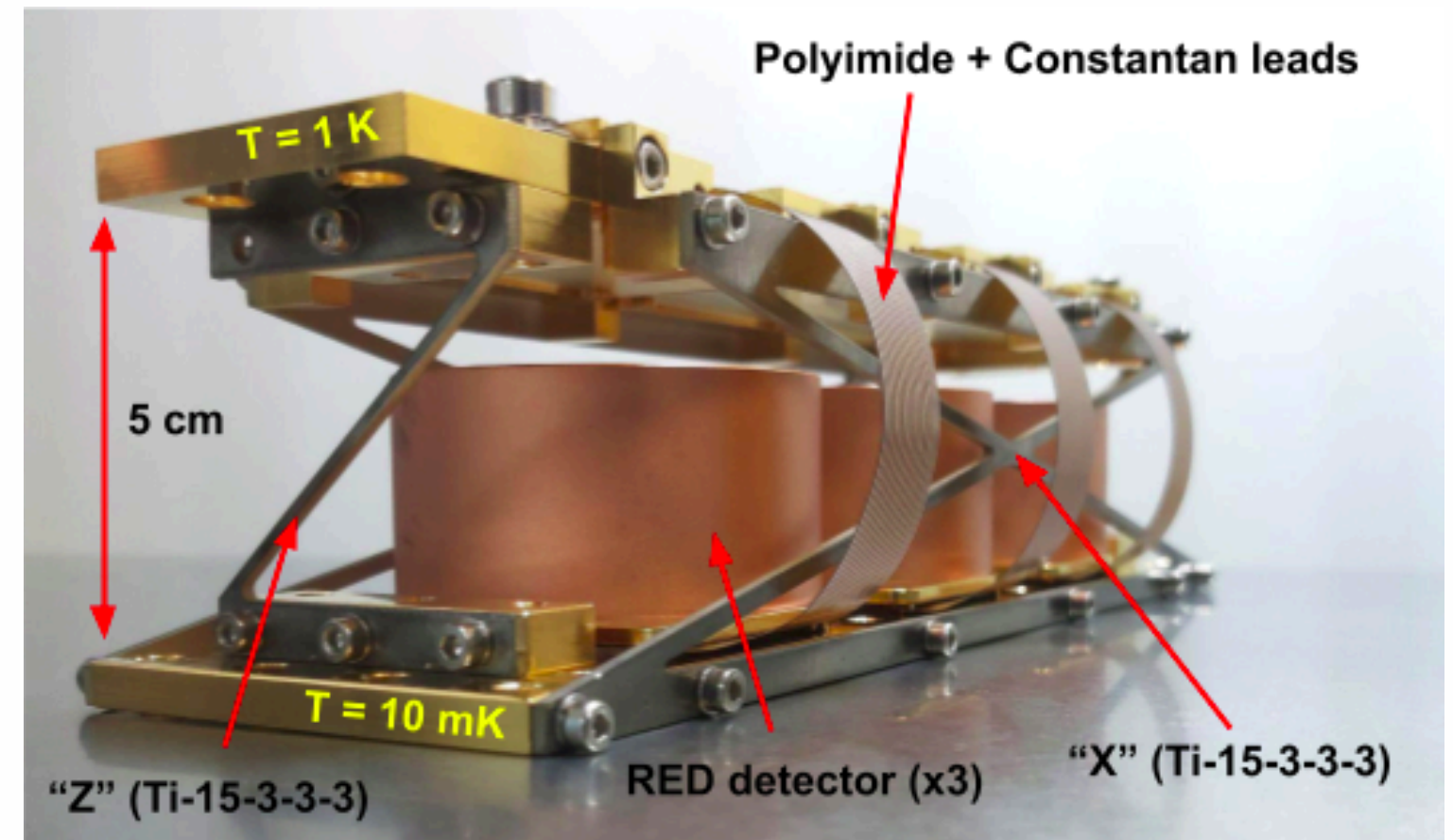


different backgrounds: cosmogenic, reactogenic, radiogenic

Ricochet experiment



The **CryoCube** in the RUN016: 6 MiniCryoCubes
→ 18 detectors in total



A **MiniCryoCube** (3detectors)

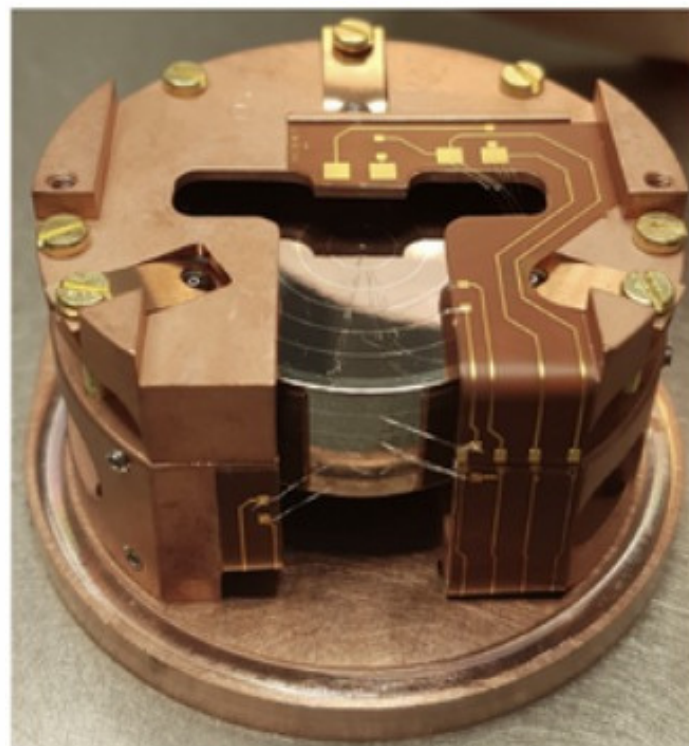
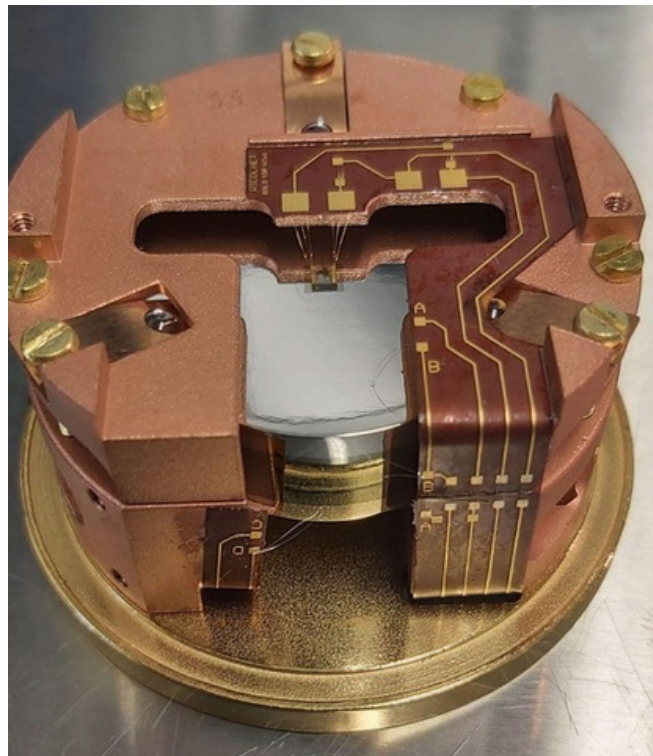
→ Ricochet's current run is the RUN17



The detectors

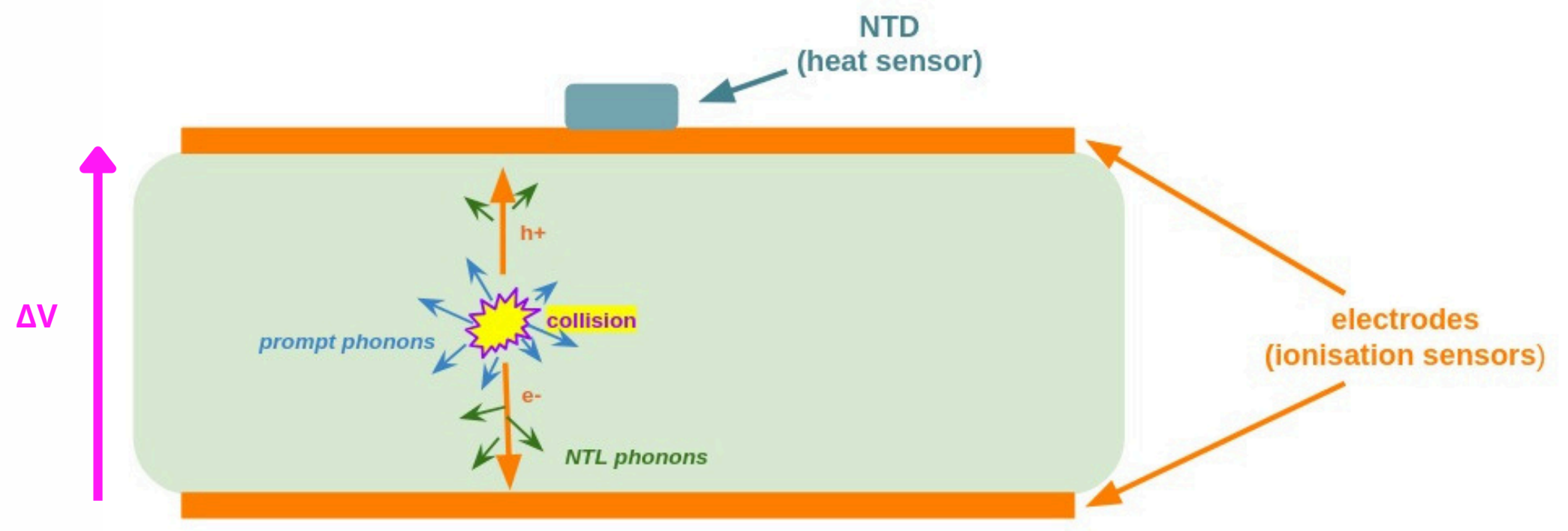


The detectors are **42g Germanium crystals** equipped with a **thermal sensor (NTD in Germanium)** and aluminum **electrodes**. The NTD and the electrodes help us to make a **double measurement of the heat energy (Eh) and the ionization energy (Ei)**.



Planar detector

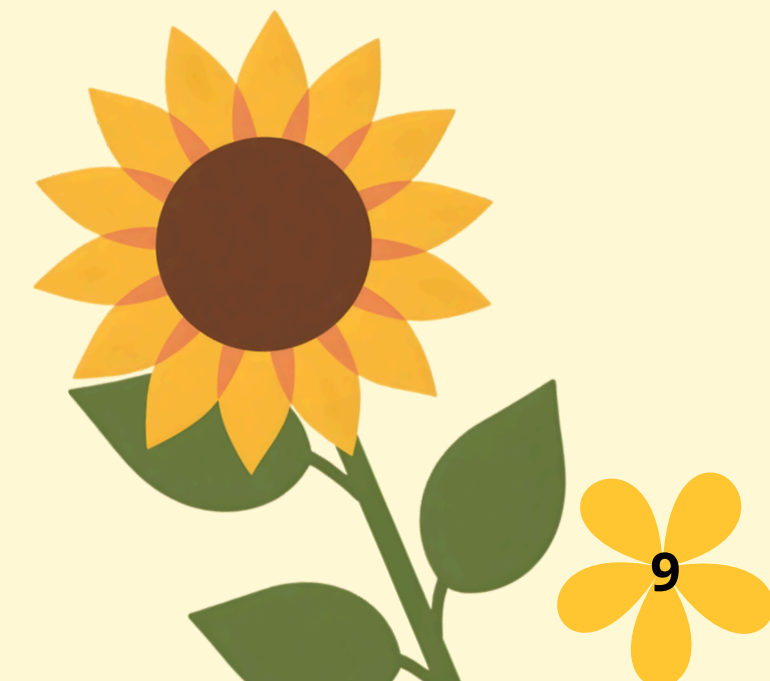
FID detector



working principle of a planar detector



About Quenching (ionization yield)



Goal of the study

Measure the **Quenching on Germanium**

$$Q_{NR} = \frac{E_{i,NR}}{E_{r,NR}}$$

Strategy

we have **E_i** and **E_h**

we have **E_r**

we have **Q!**

Method

We use **RUN014 Cf data** (a lot of NR)

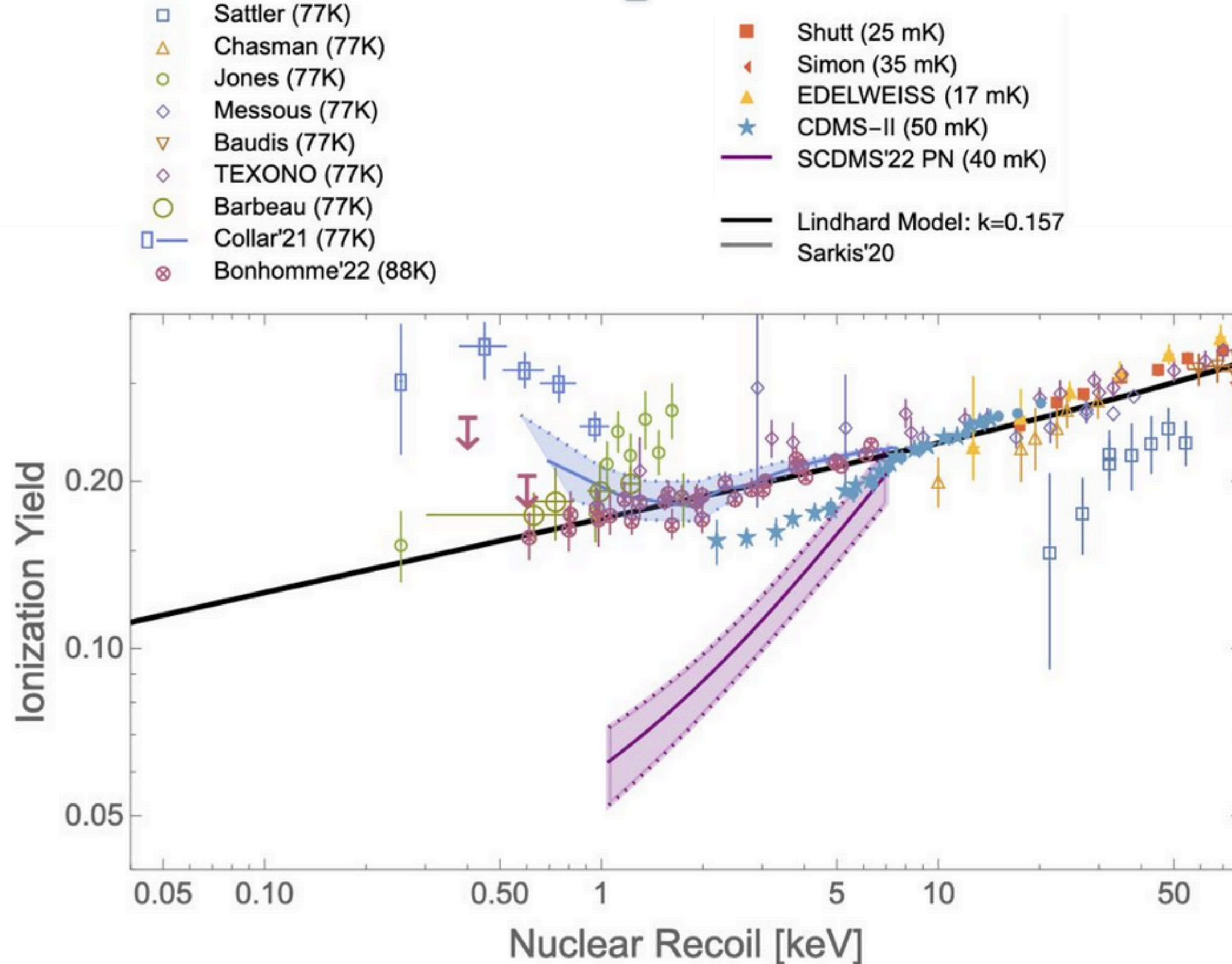
We do **Er slices** and look at the data histogram on each slice

Be careful of...

We must take into account:

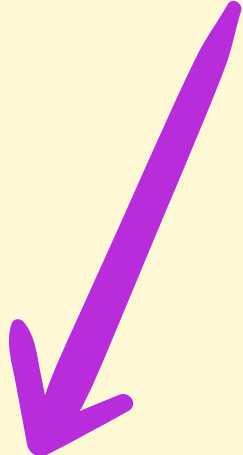
Heat Only (HO), Nuclear Recoils (NR), Surface events (betas), multiple scattering!

State of the art of the Quenching measurement





Two approaches



①

Analytical model

Summing the **contributions**
(HO, NR, betas)

②

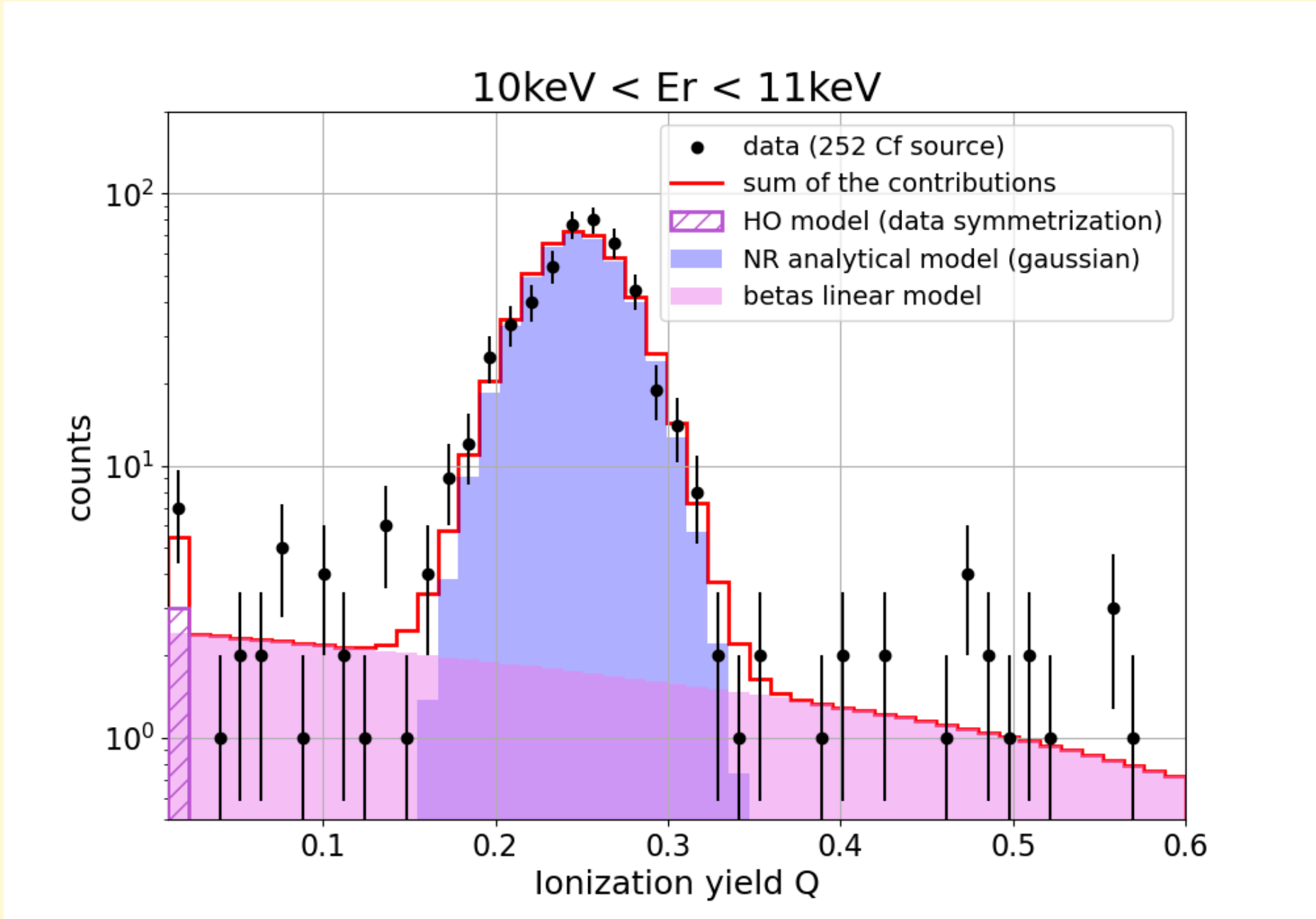
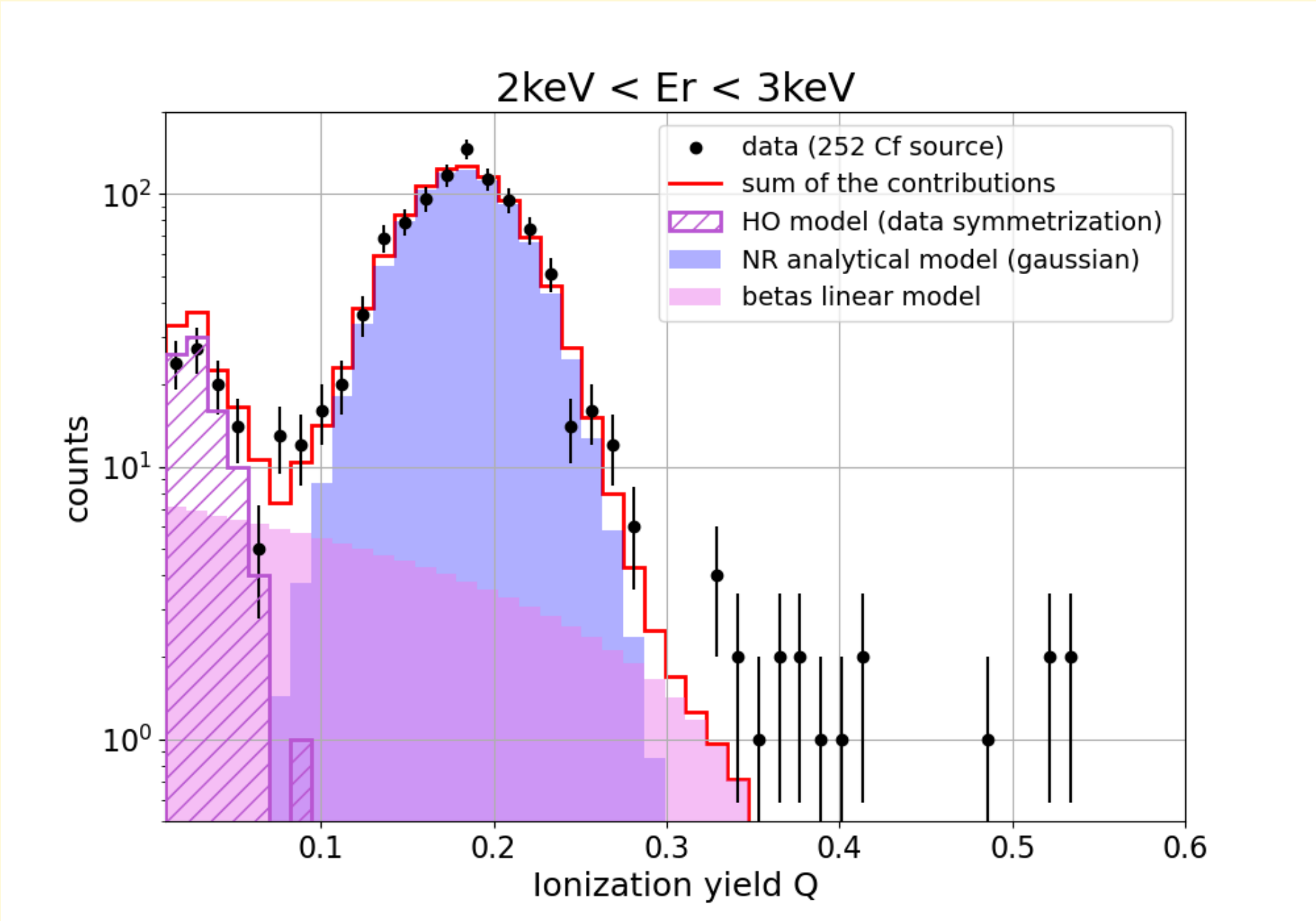
Model running simulations

Using an algorithm called **MPS**
developed by the group



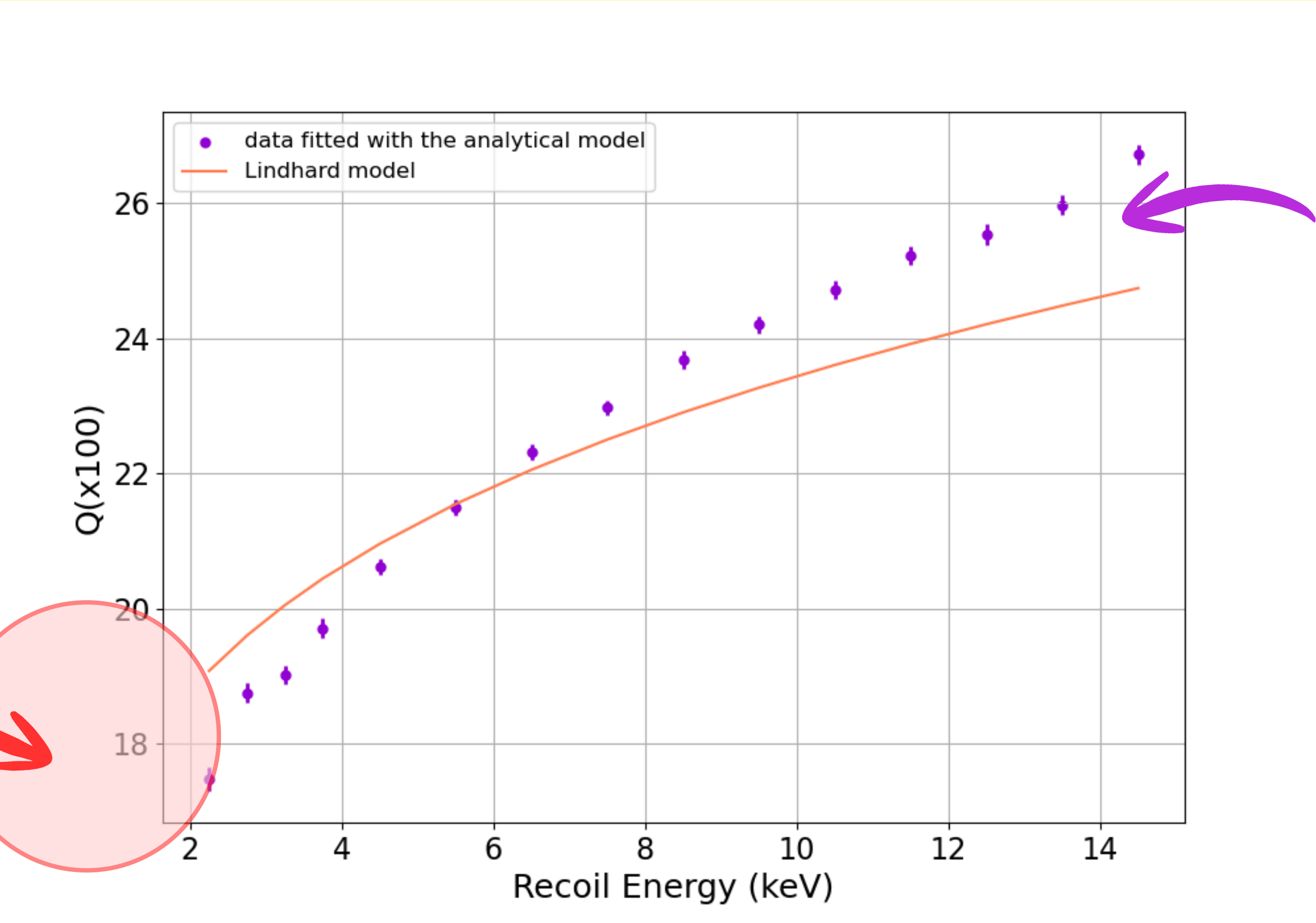
Analytical model

$$N_{tot} = Gauss(A_G, \mu, \sigma) + HO + Lin(A_L, \alpha)$$



Minimizing a Poissonian **Likelihood**, we find the **Q value that fits better the data**

Q vs Er



Results include only statistical uncertainties

0-2 keV region: ongoing study

MPS model running simulations



★ We simulate events following Lindhard model

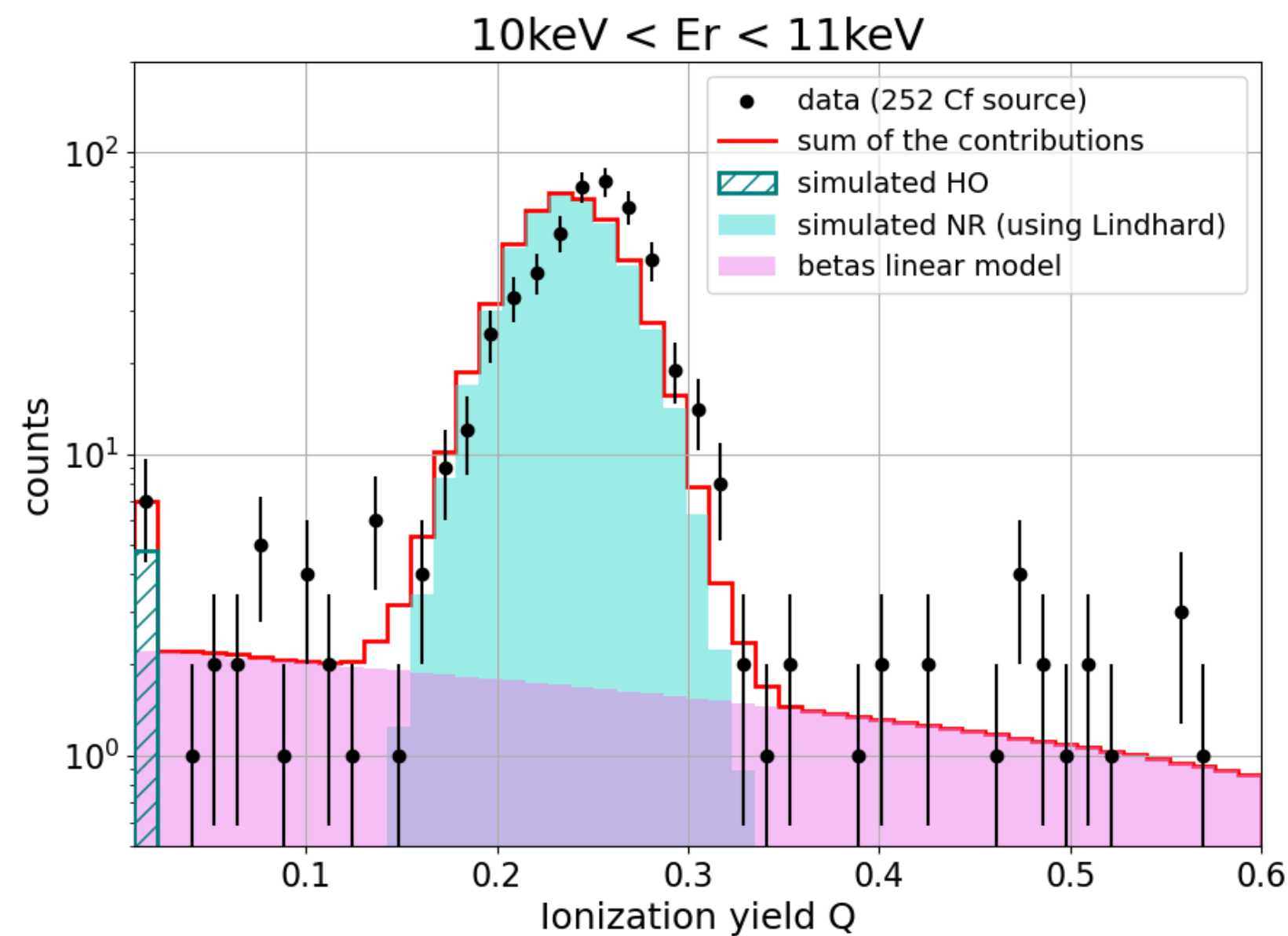
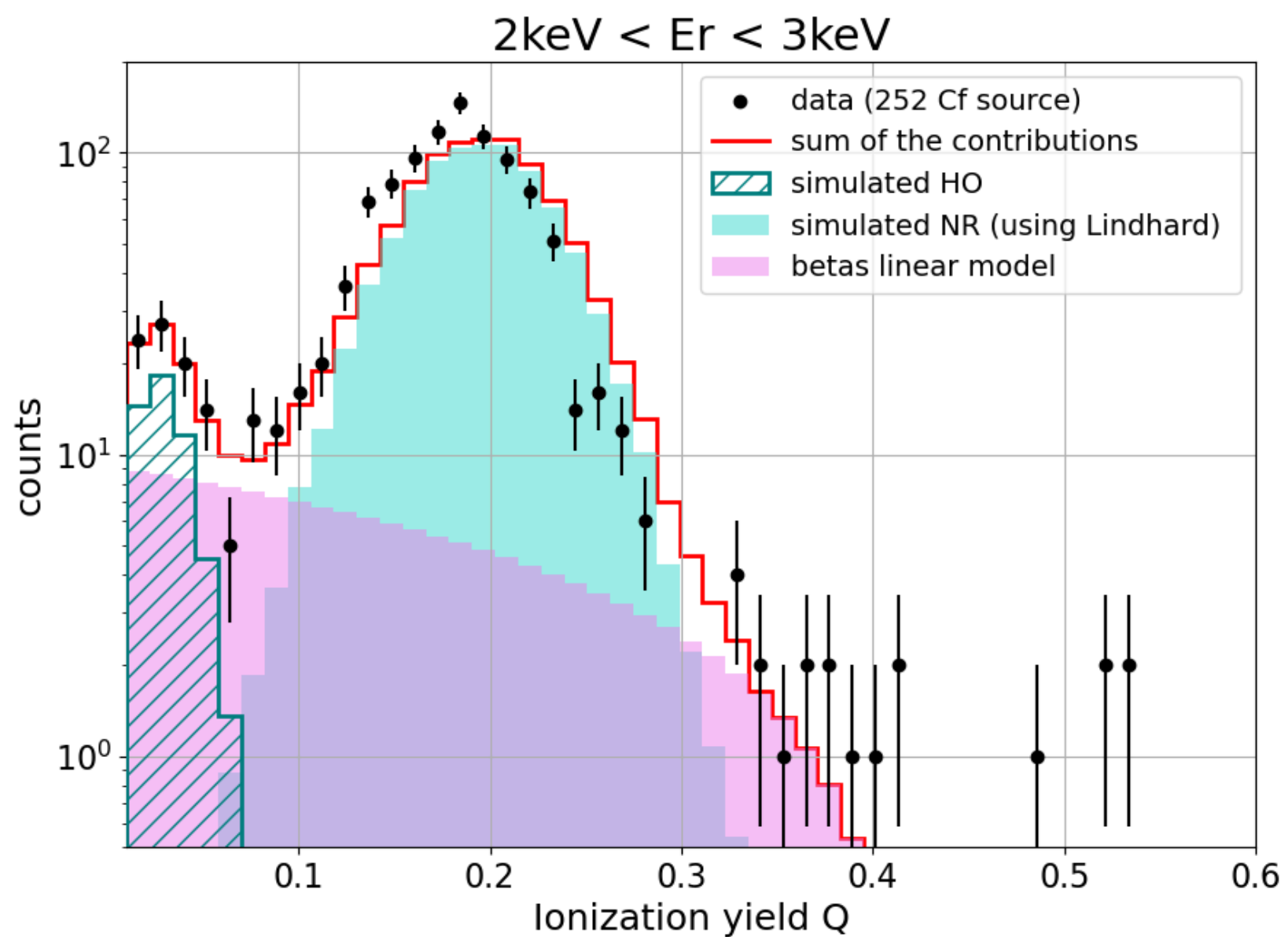
★ We make a **Q scan** in order to find **the best fitting Q value**

★ We may include **multiple scattering**

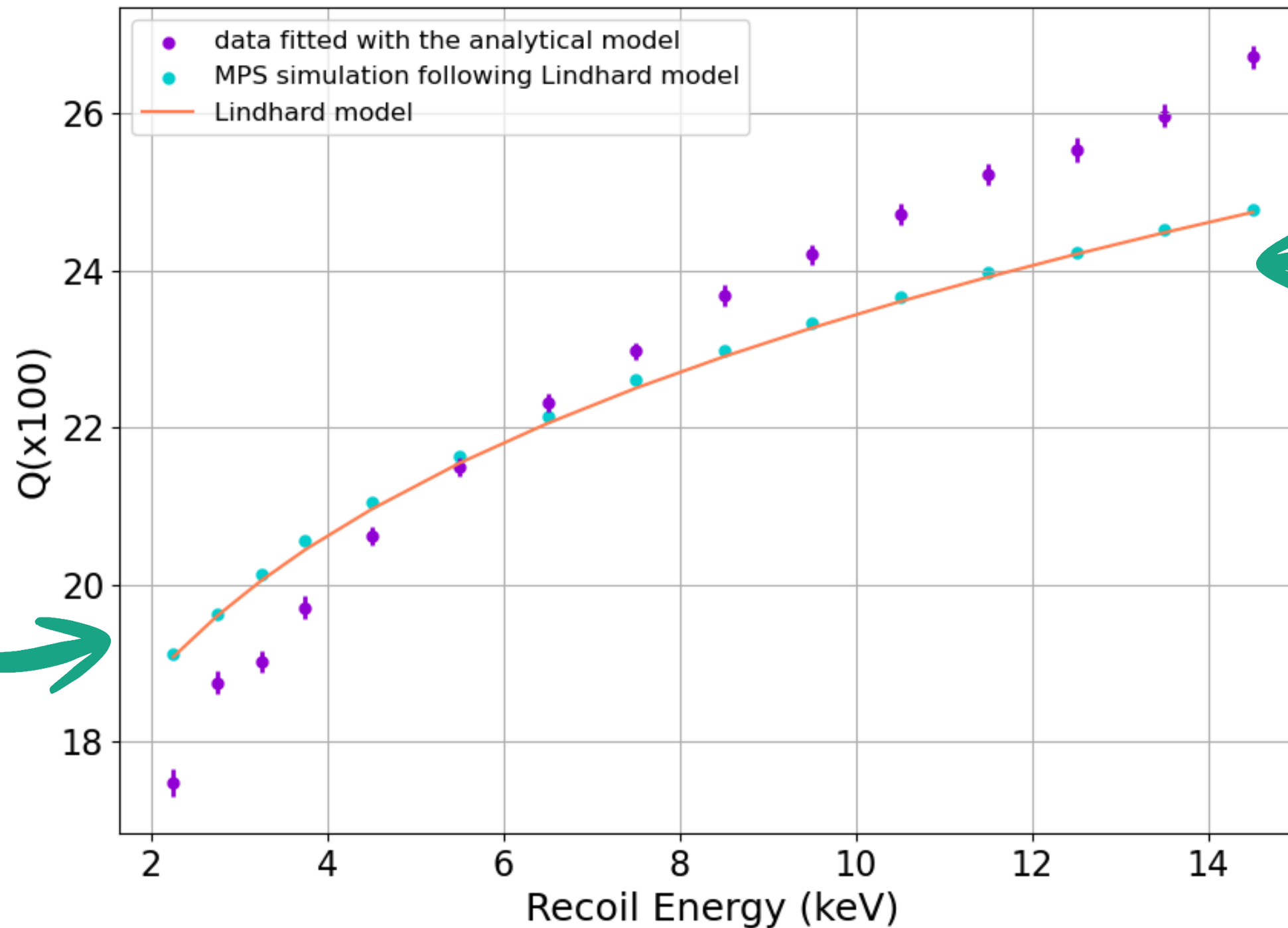
MPS simulations following Lindhard



simulated NR, simulated HO, linear model for betas



Q vs Er



The simulated events follow the Lindhard model: **there is no reconstruction bias at these recoil energies**

MPS simulation with Lindhard are **not fitting well the data**

let's do a scan over Q values for Er each slice!

MPS model running simulations



★ We simulate events following Lindhard model

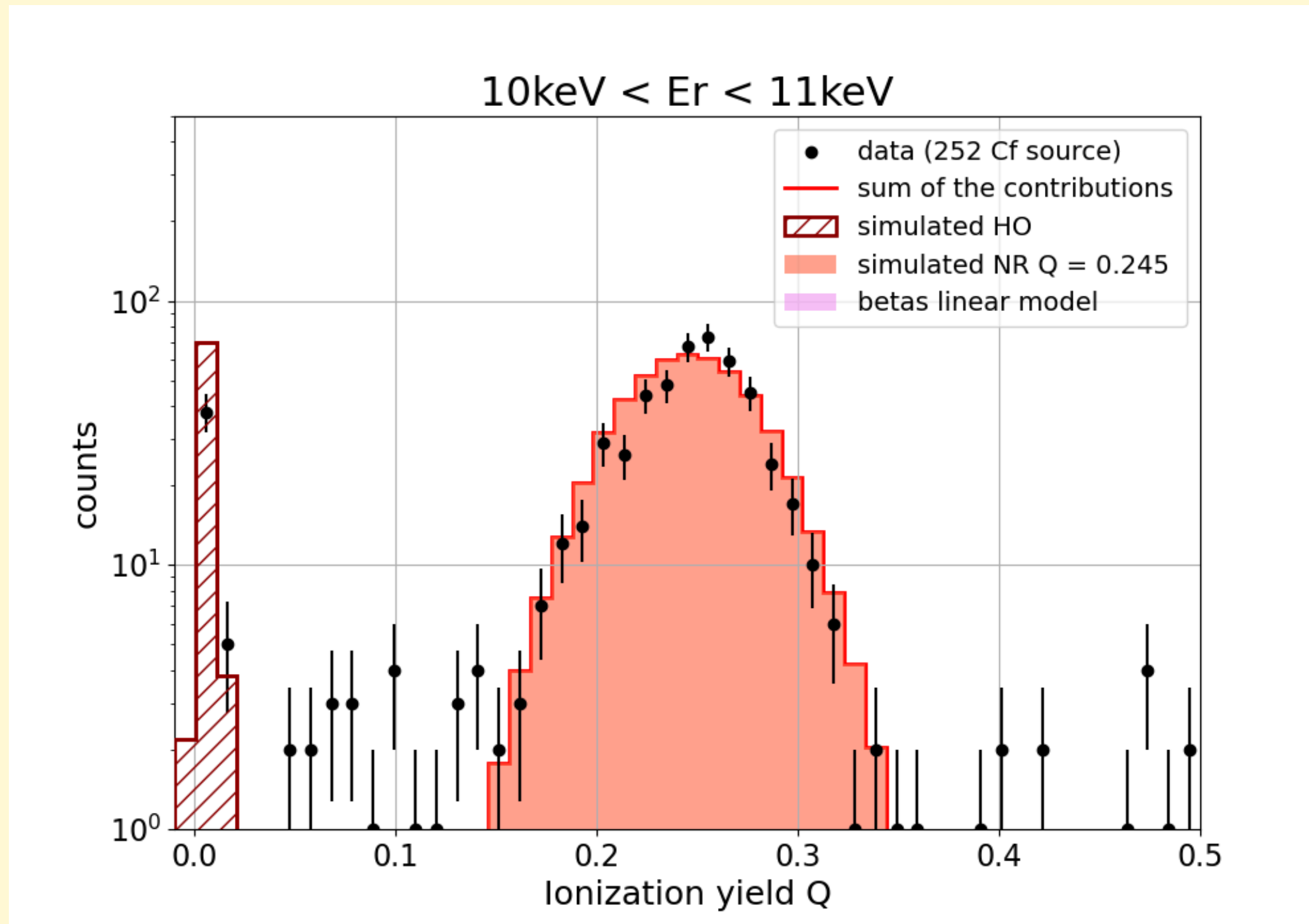
★ We make a **Q scan** in order to find **the best fitting Q value**

★ We may include **multiple scattering**

Example of the 10-11 keV slices



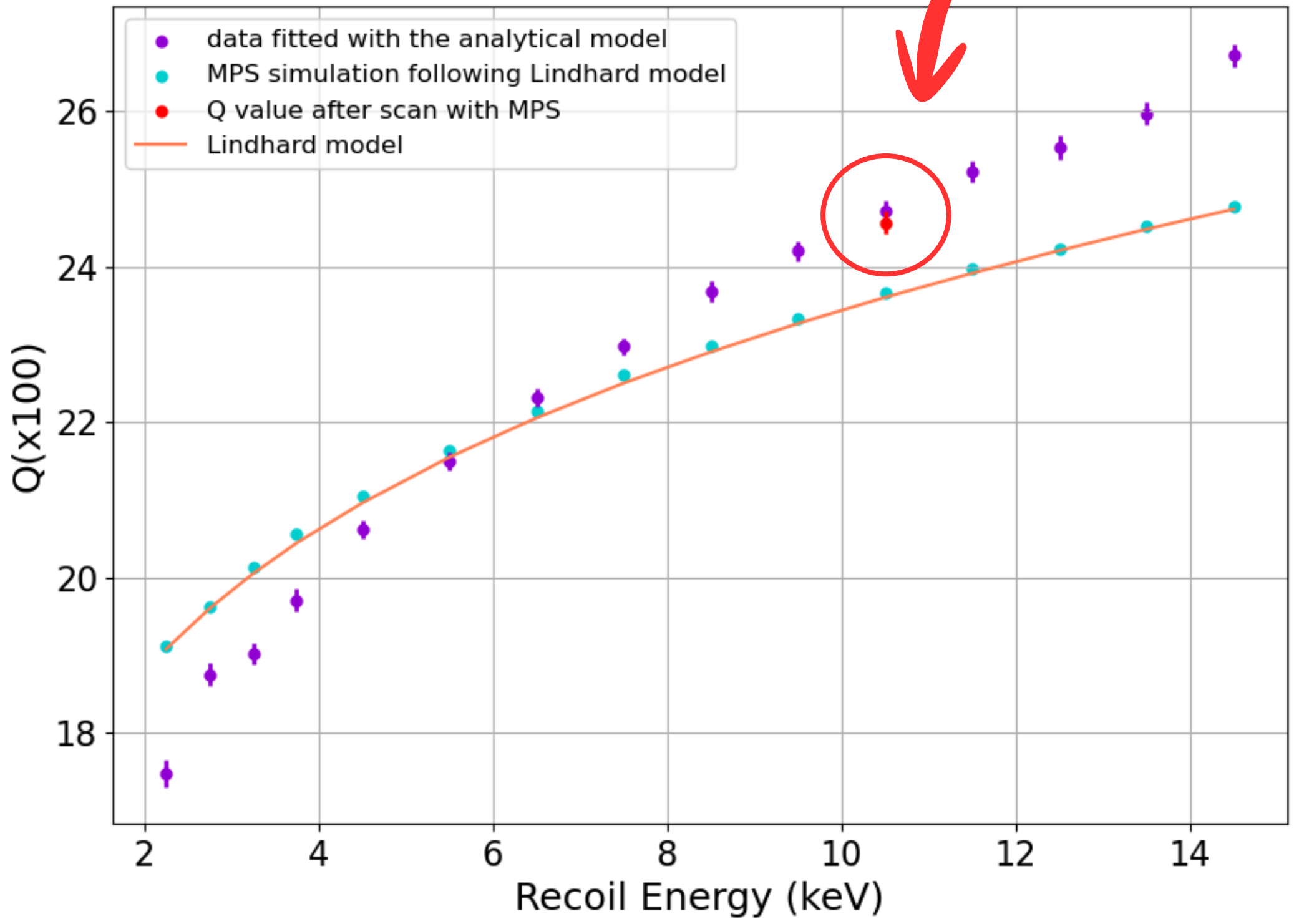
For each Er slice, we simulate events with MPS **fixing the Q value** and we do that **for a set of Q values**



$$Q(10-11) = 0.244 \pm 0.002$$

Q vs Er

A new point!
fitting better the
data





MPS model running simulations

★ We simulate events following Lindhard model

★ We make a **Q scan** in order to find **the best fitting Q value**

★ We may include **multiple scattering**

Now what about the multiple scattering contribution?



In a detector, a particle can sometimes do **more than one recoil**.

But **the detector is not able to record separately the energies** coming from different recoils (not enough time between the collisions)...

Then we get just **one E_r for a multiple recoil event**.

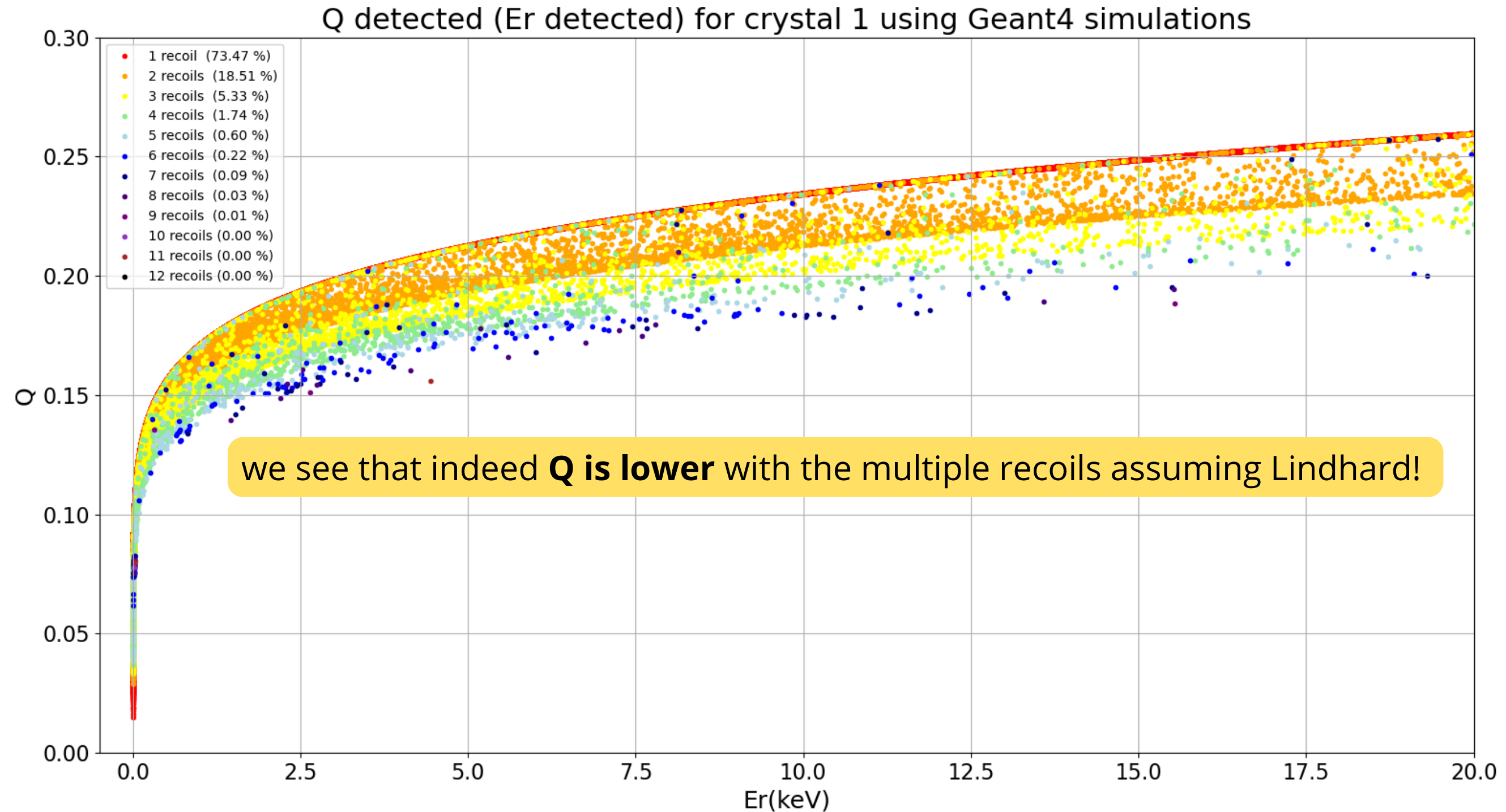
The **quenching computed with the energies coming from multiple scattering is lower** than the one we would have for a single collision.



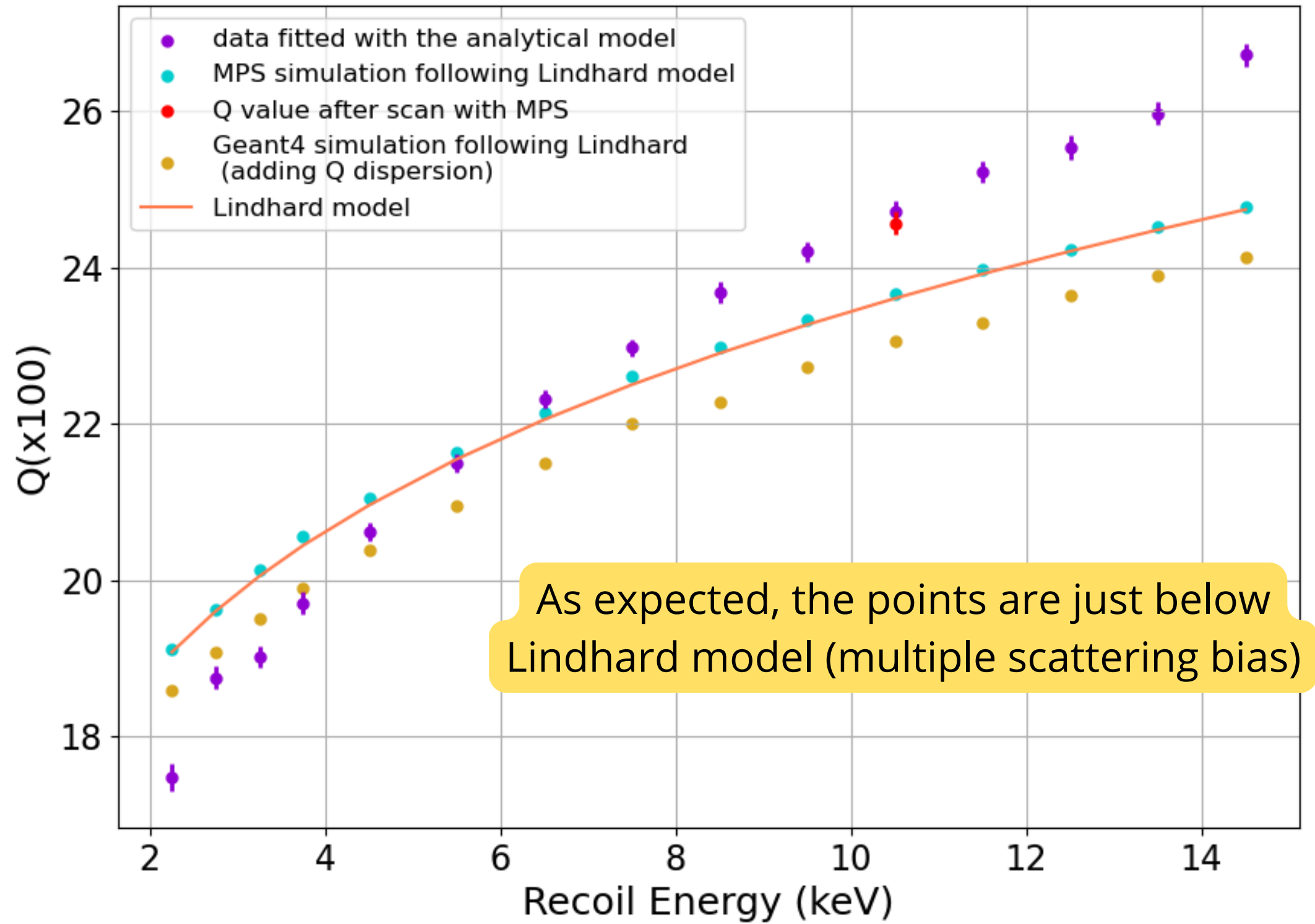
Multiple scattering effect



We can run **simulations with Geant4** (from M. De Jésus)



Q vs Er





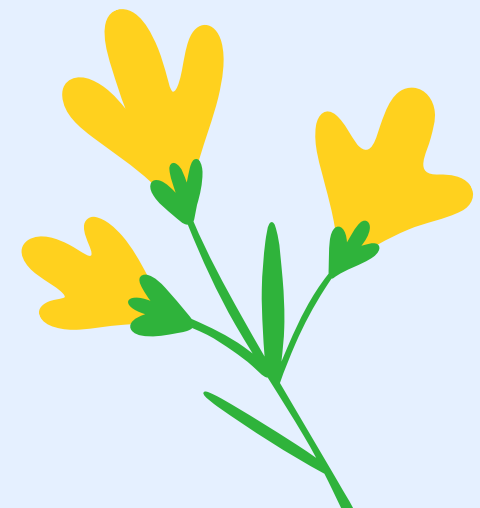
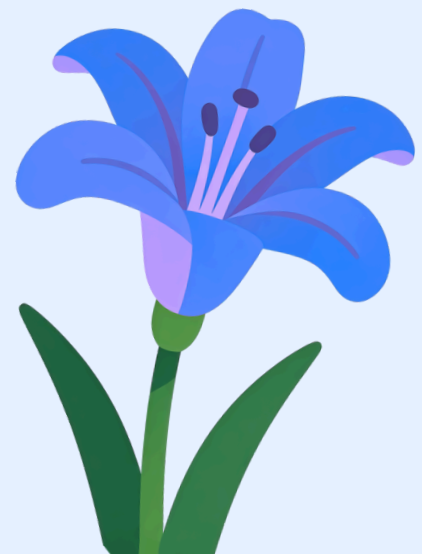
More exciting things to come!

→ The goal is to have a **full model simulated with MPS including the multiple recoils without assuming Lindhard!**

→ The region **below 2 keV is an ongoing study** (maybe the most interesting part!)



Development of new detectors in Silicon and preliminary analysis





Why do we want to use Silicon?



How do we use Silicon?



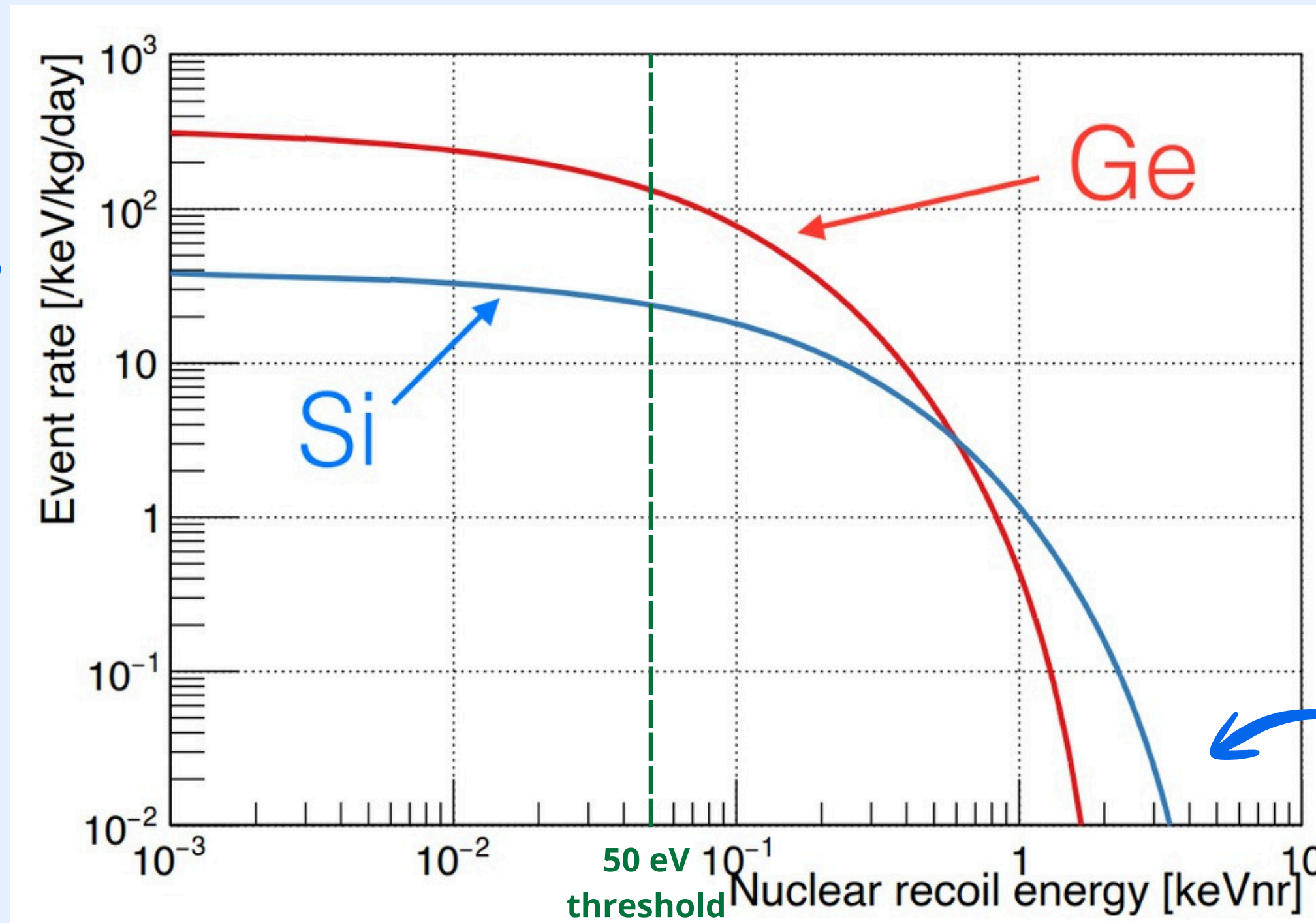
A little bit of analysis with the first data



Why do we want to use Silicon?



Standard model CENNS spectra for Ge and Si



lower rate than Ge

but higher maximum Er than Ge

→ Possible **comparison of the 2 materials** to crosscheck the results: $\sigma \propto N^2$



How do we use Silicon as a new material for our detectors?

We want to operate the new detectors similarly as the Ge ones

We might take into account some **differences between Si and Ge**





How do we use Silicon as a new material for our detectors?

We want to operate the new detectors similarly as the Ge ones

We might take into account some **differences between Si and Ge**

①

Si density < Ge density

For the same crystal size: $m_{Ge} \simeq 40 \text{ g}$ / $m_{Si} \simeq 17 \text{ g}$

②

The pair creation energies are not the same:

$$\epsilon_{Ge} = 3 \text{ eV} / \epsilon_{Si} = 3.8 \text{ eV}$$

③

Calibration: we can't activate Si as we do with Ge!

We use sources put in the copper holder next to the crystal with defined peaks:

→ **Fe(55) source** = a doublet (**5.89 keV, 6.4 keV**)

→ **Am(241) source** = **60 keV**

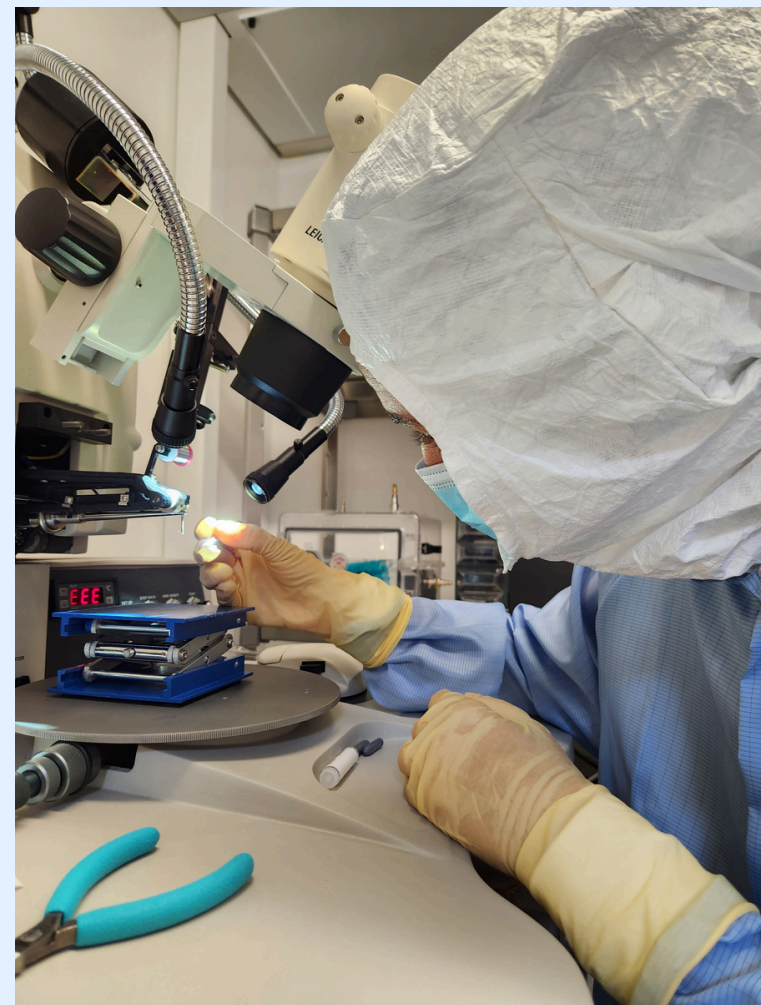


Fe source produces surface events (problem of charge collection)! not so good for calibration



We use 2 Si planar detectors

Some pics about the development of our new detectors

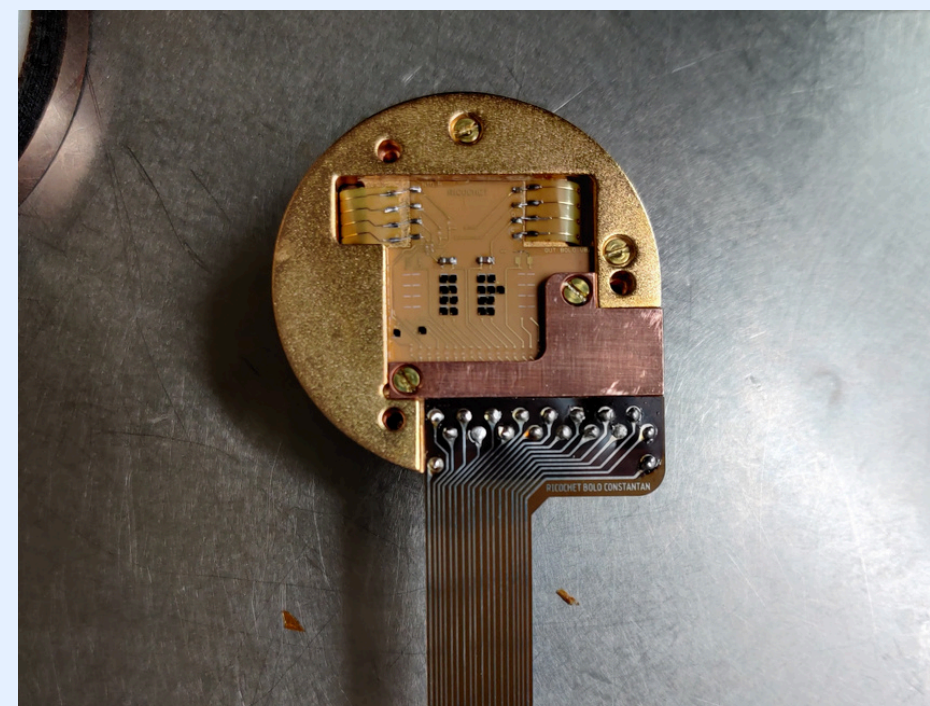


Working hard to make them perfect...

So bright and beautiful!



Here is PLSI01 (Sidonie)!



Now let's go into more details...

And PLSI02 (Simone) is over there!

2 Si planar detectors for the RUN141: PLSI01, PLSI02



PLSI01: ★ T=21 mK

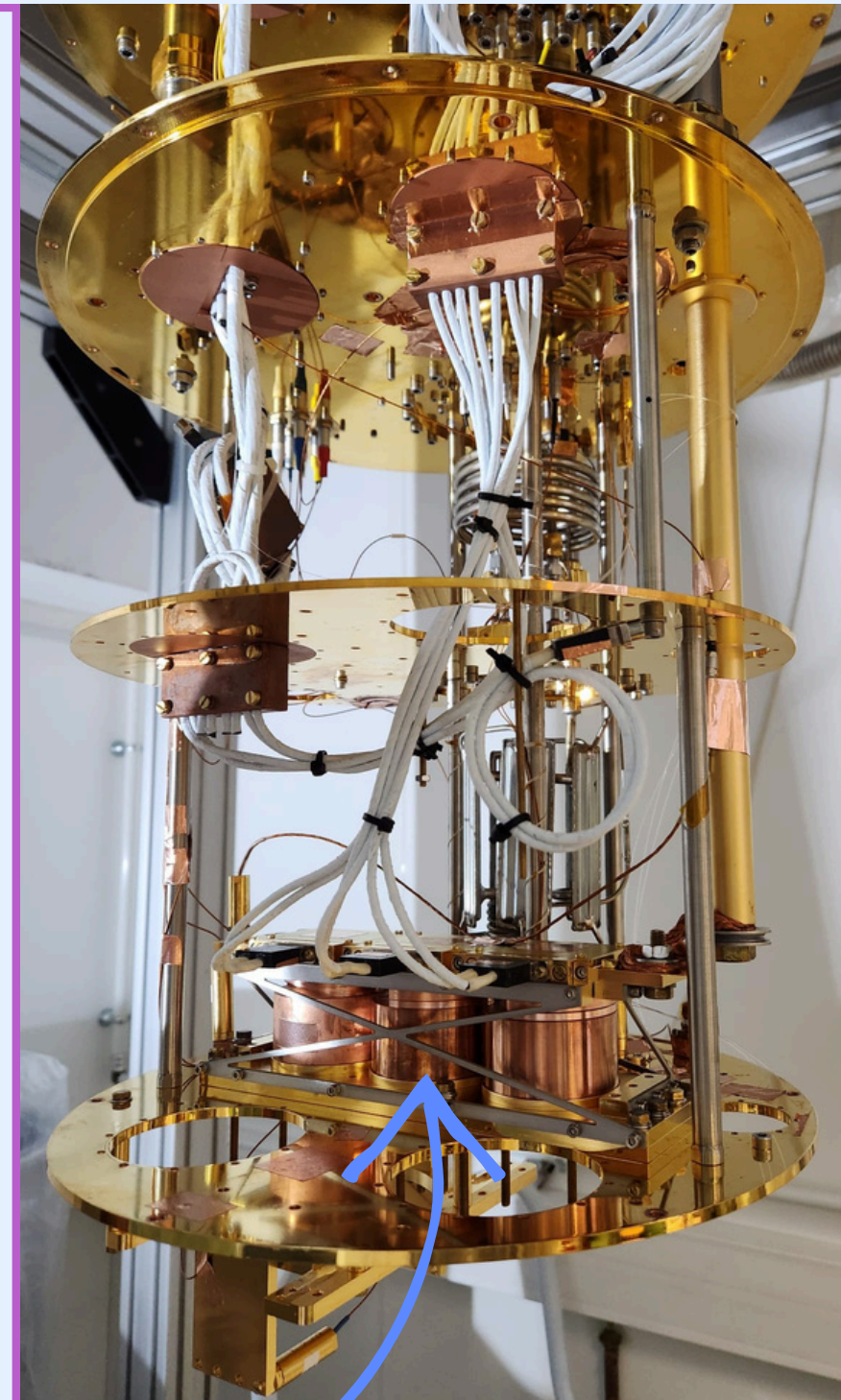
★ heat channel ✓ reso = 150 eV

★ two ionization channels ✓ reso = 80 eV

PLSI02: ★ T=21 mK

★ heat channel ✓ reso = 150 eV

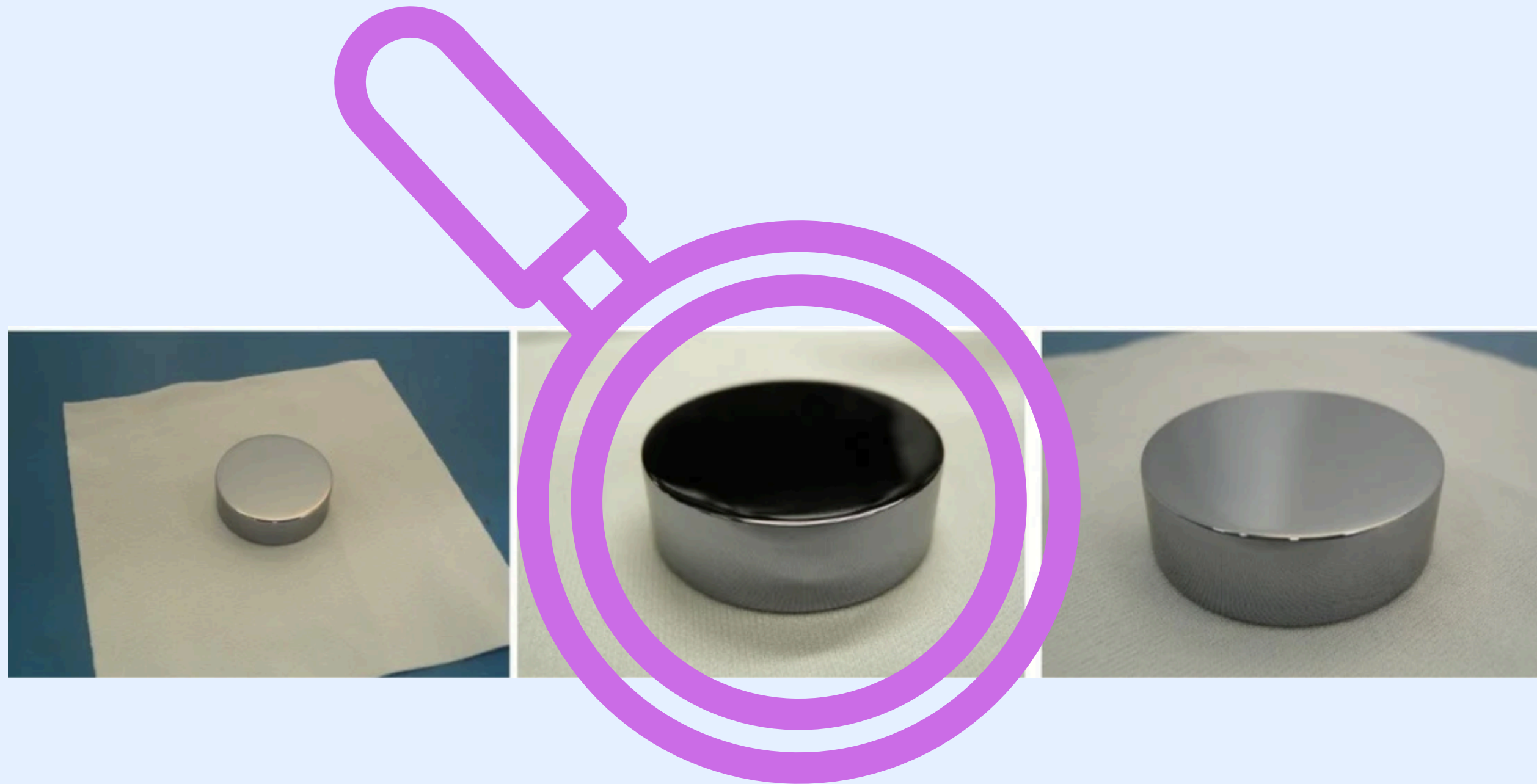
★ two ionization channels but less performant ✓ reso = 130 eV



PLSi01 and PLSi02 were put in the LIO cryostat in Lyon

+ a laser!

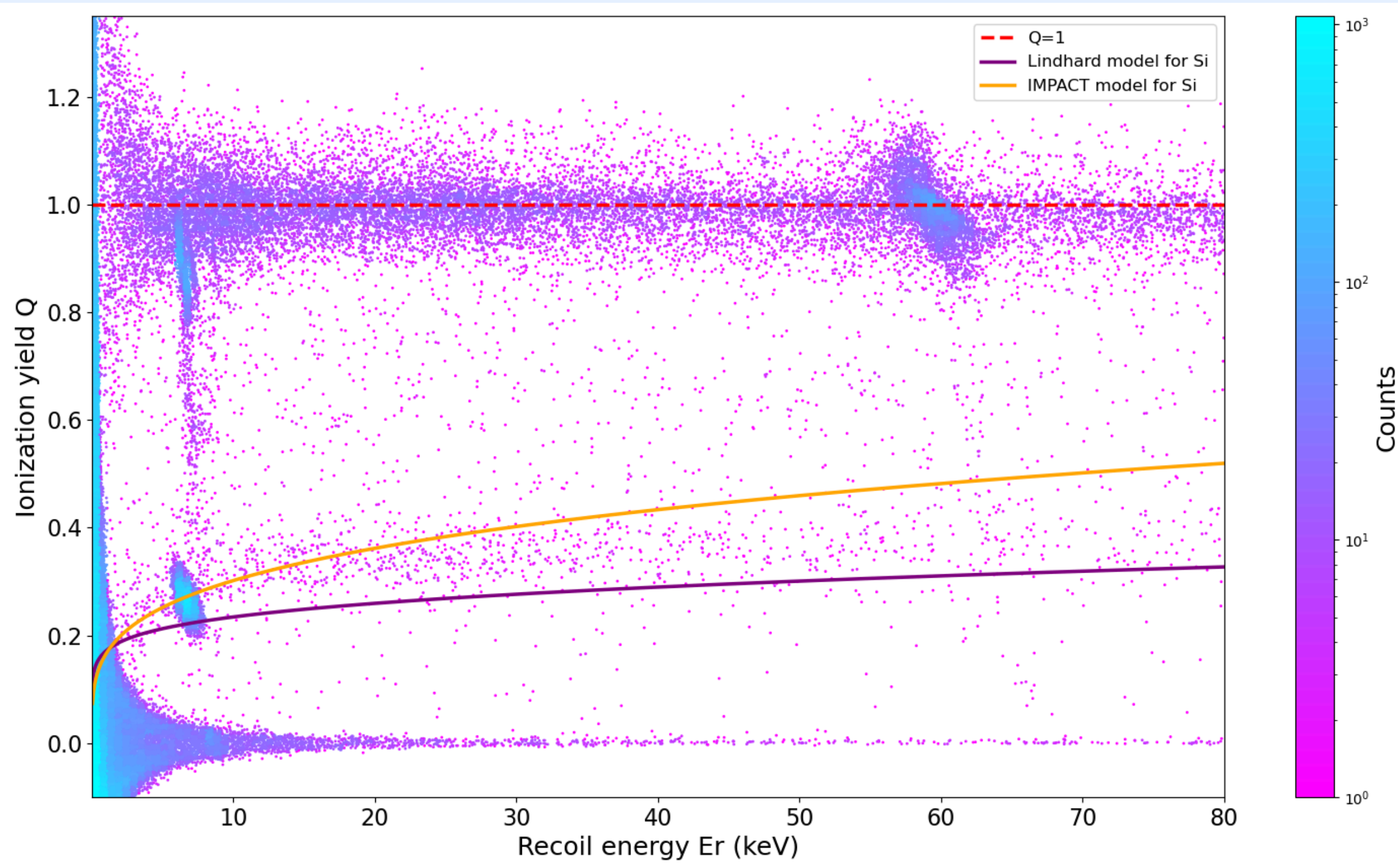
PLSI01 preliminary analysis on RUN141



Choosing the bias between the electrodes $V = -7$ V



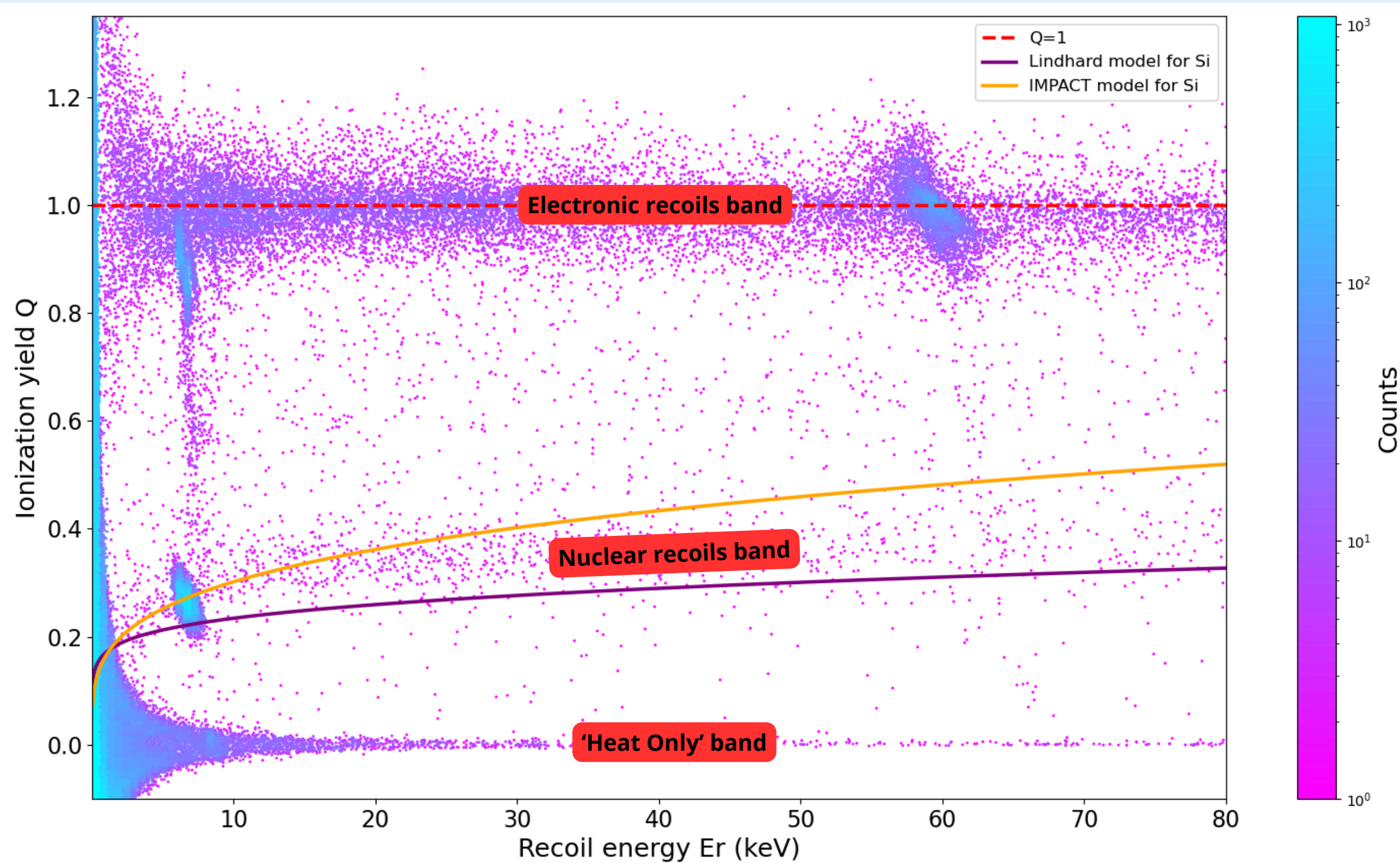
'Q vs Er' plot



Choosing the bias between the electrodes $V = -7\text{ V}$



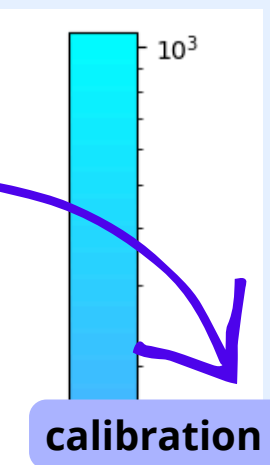
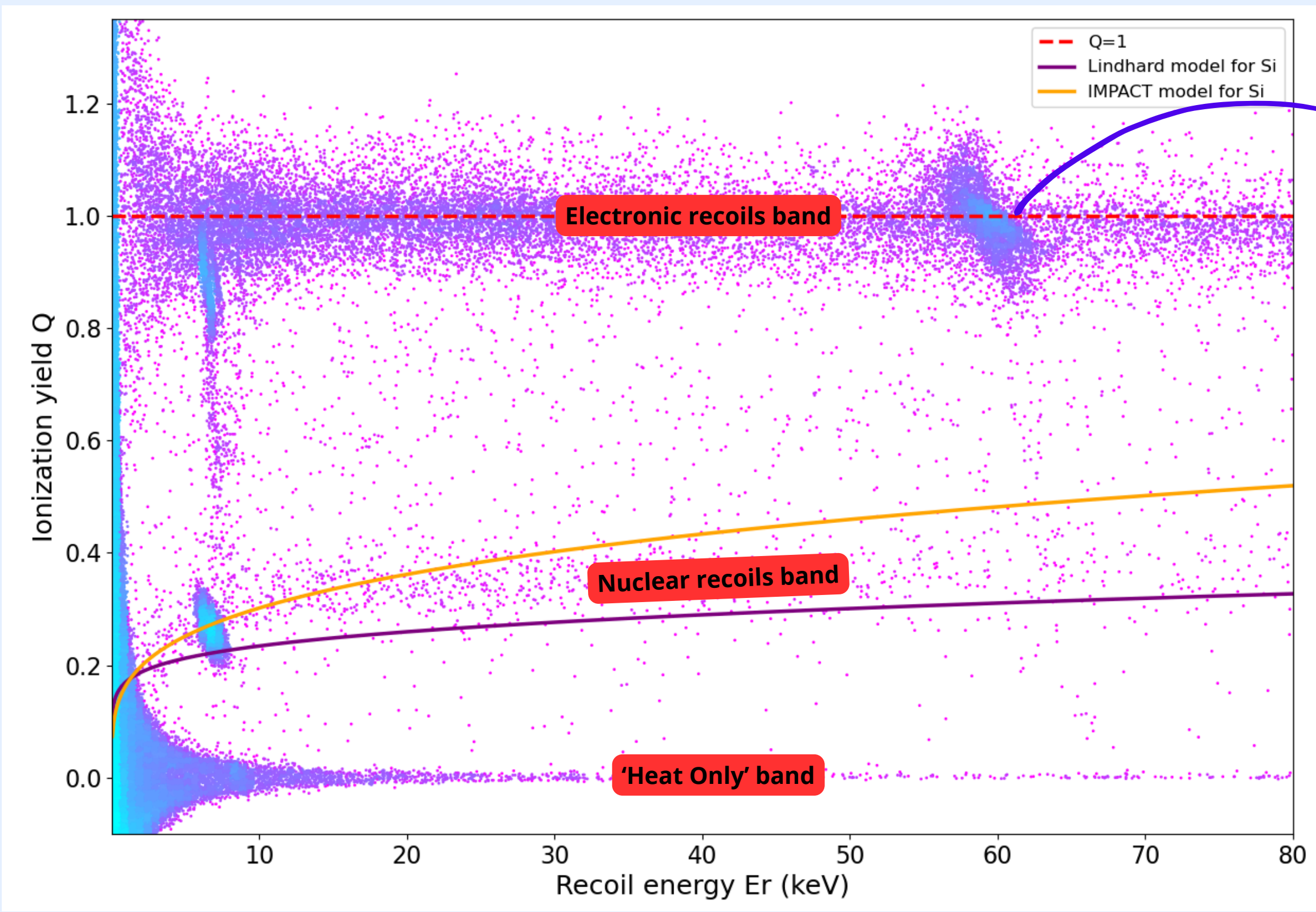
'Q vs Er' plot



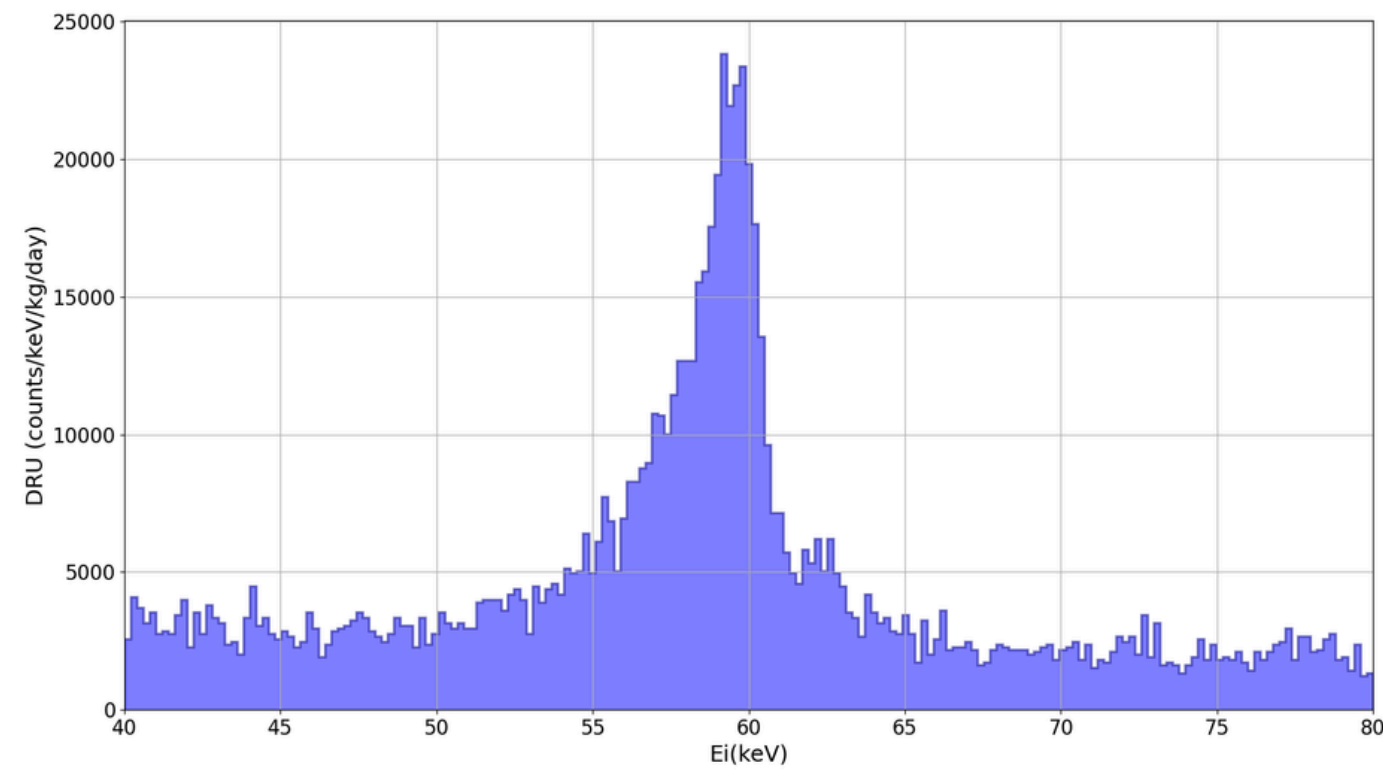
Choosing the bias between the electrodes $V = -7\text{ V}$



'Q vs Er' plot



calibration with an Am(241) source having a peak at 59.5 keV

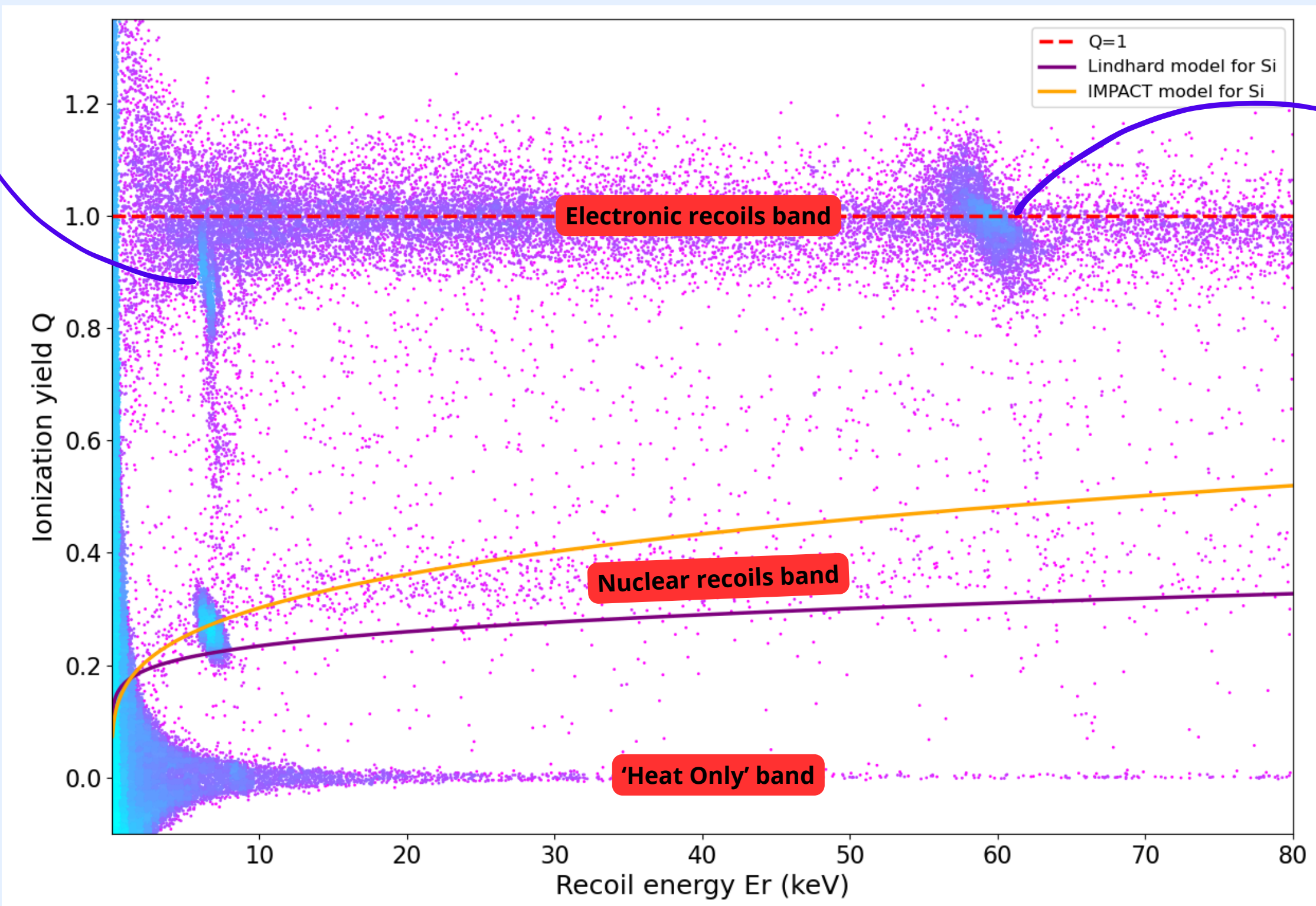


Choosing the bias between the electrodes $V = -7\text{ V}$

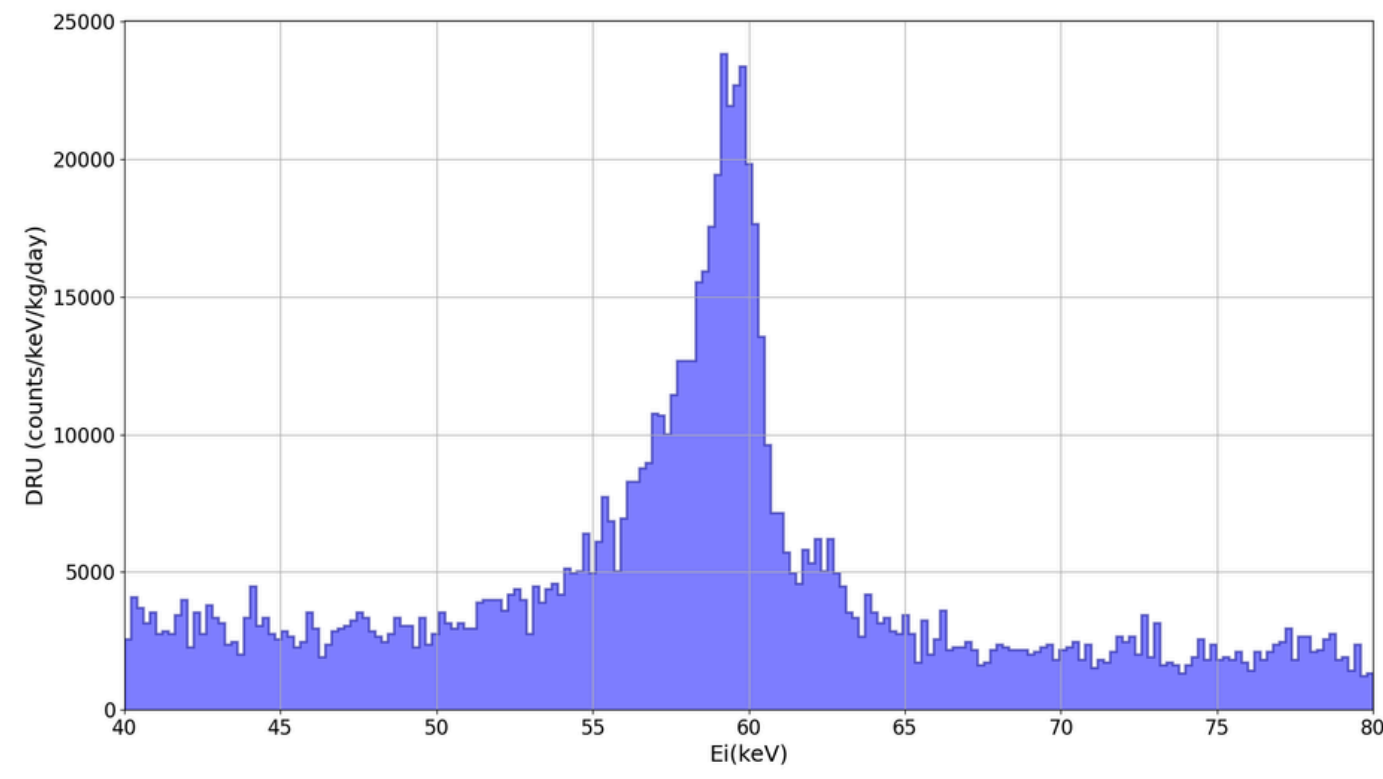


'Q vs Er' plot

Fe peak, surface events, then $Q=0.88 < 1$



calibration with an Am(241) source having a peak at 59.5 keV

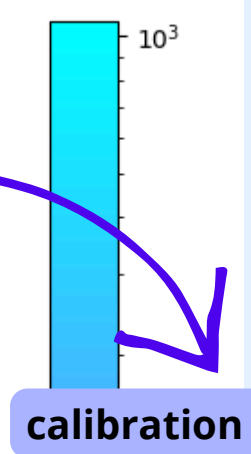
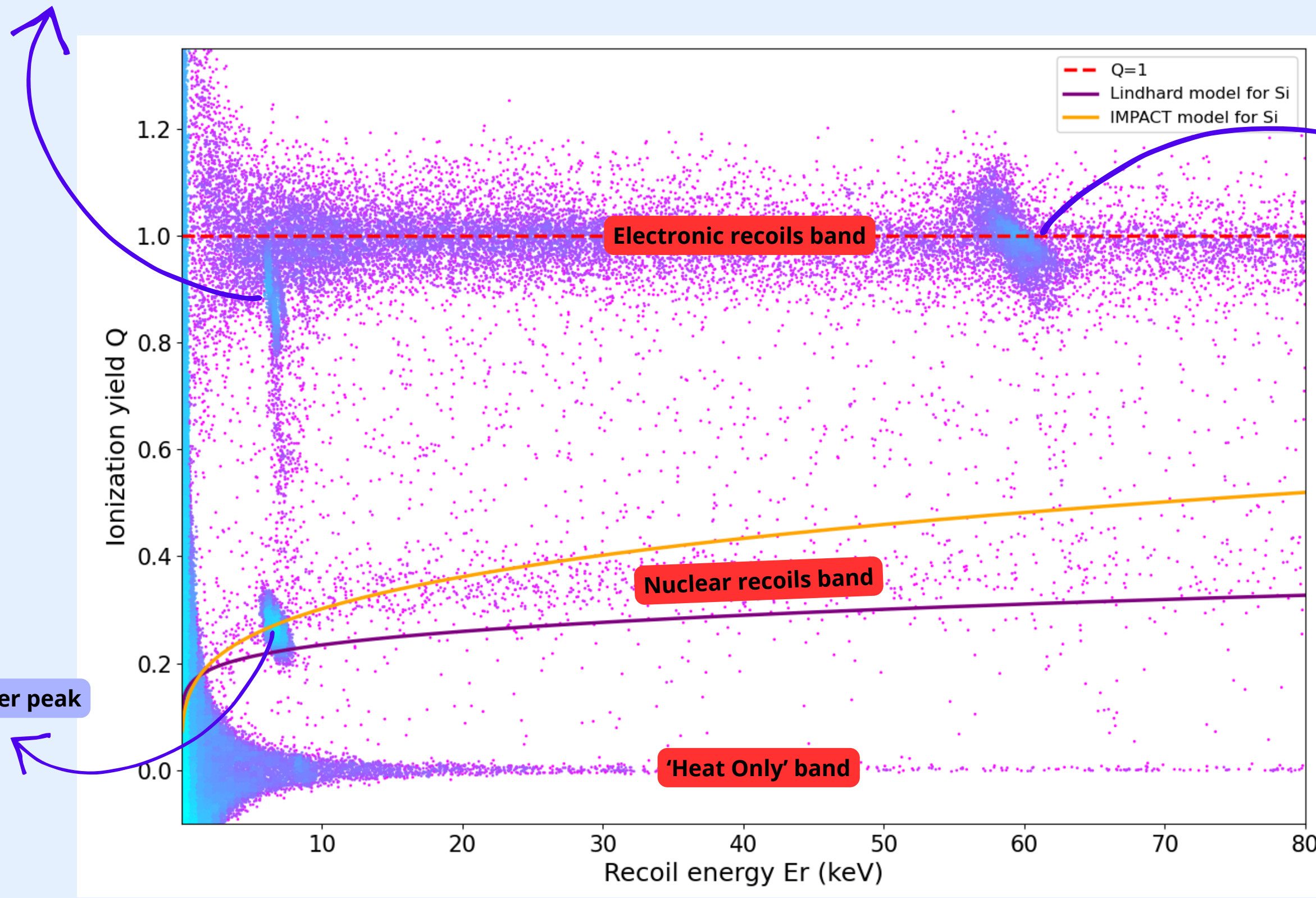


Choosing the bias between the electrodes $V = -7\text{ V}$

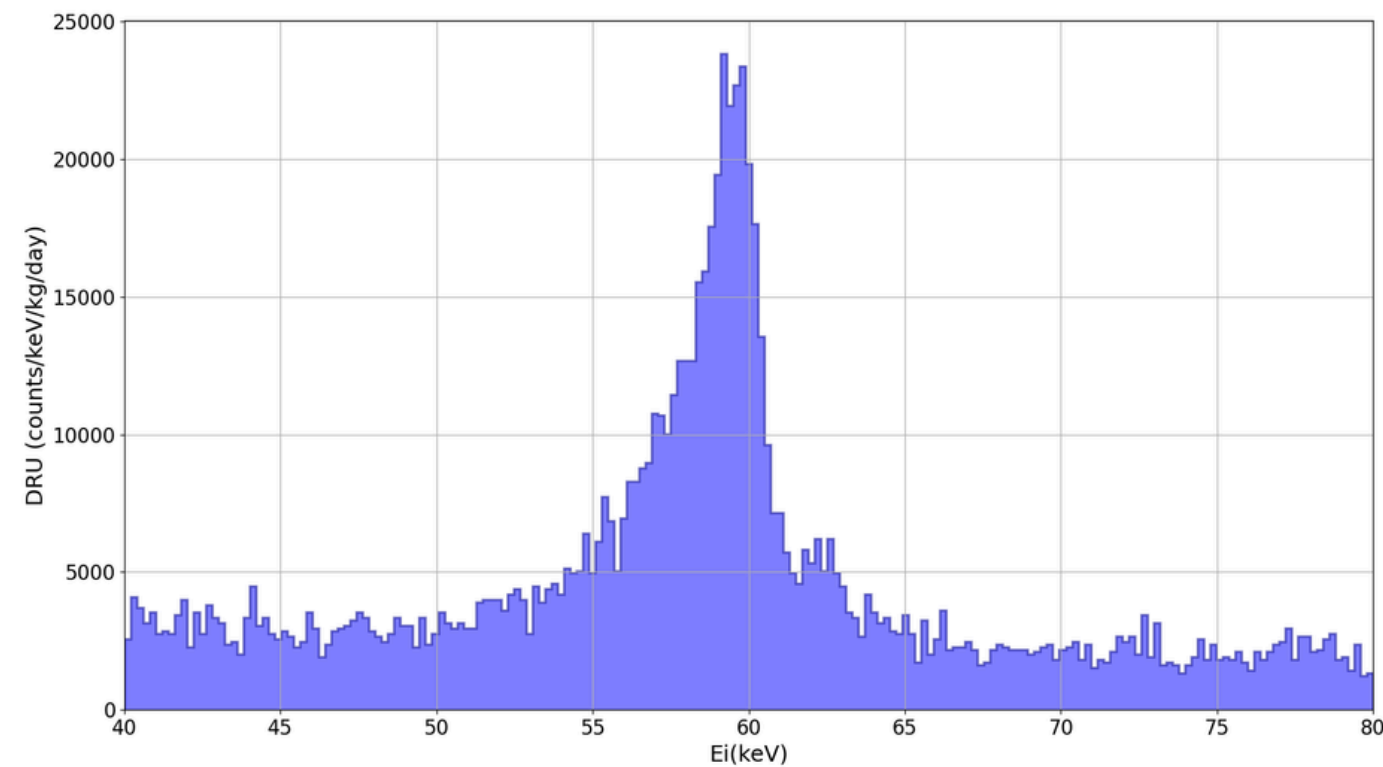


'Q vs Er' plot

Fe peak, surface events, then $Q=0.88 < 1$



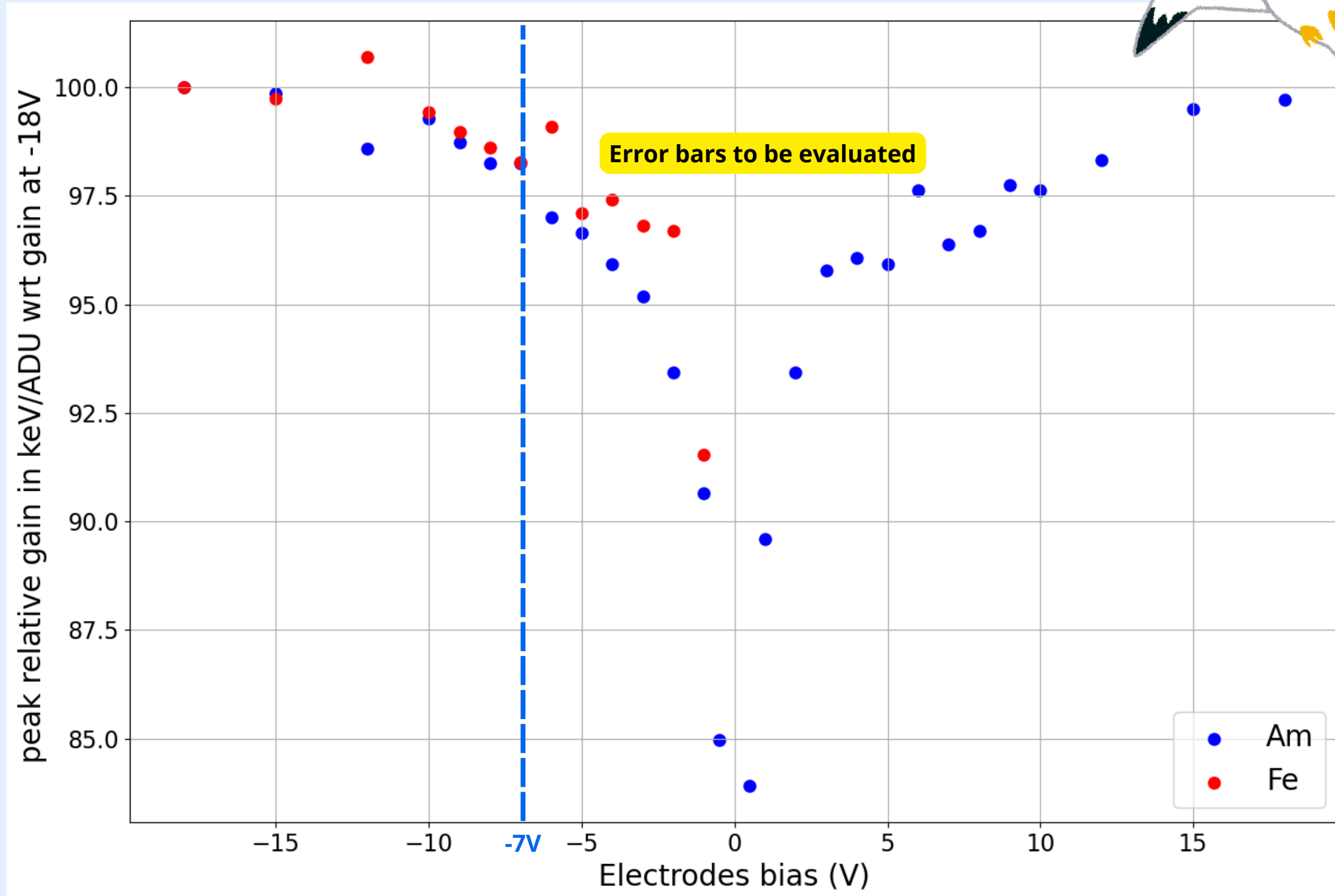
calibration with an Am(241) source having a peak at 59.5 keV



Laser peak

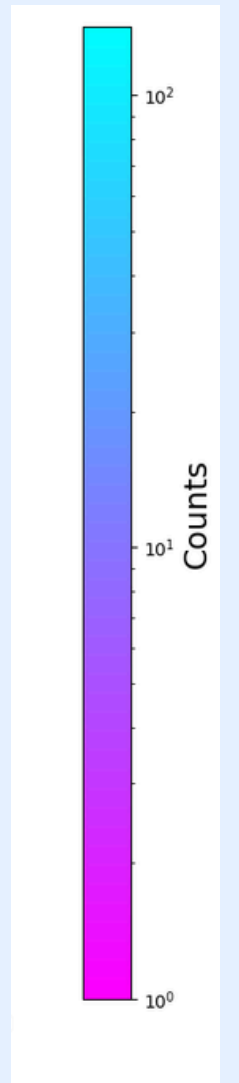
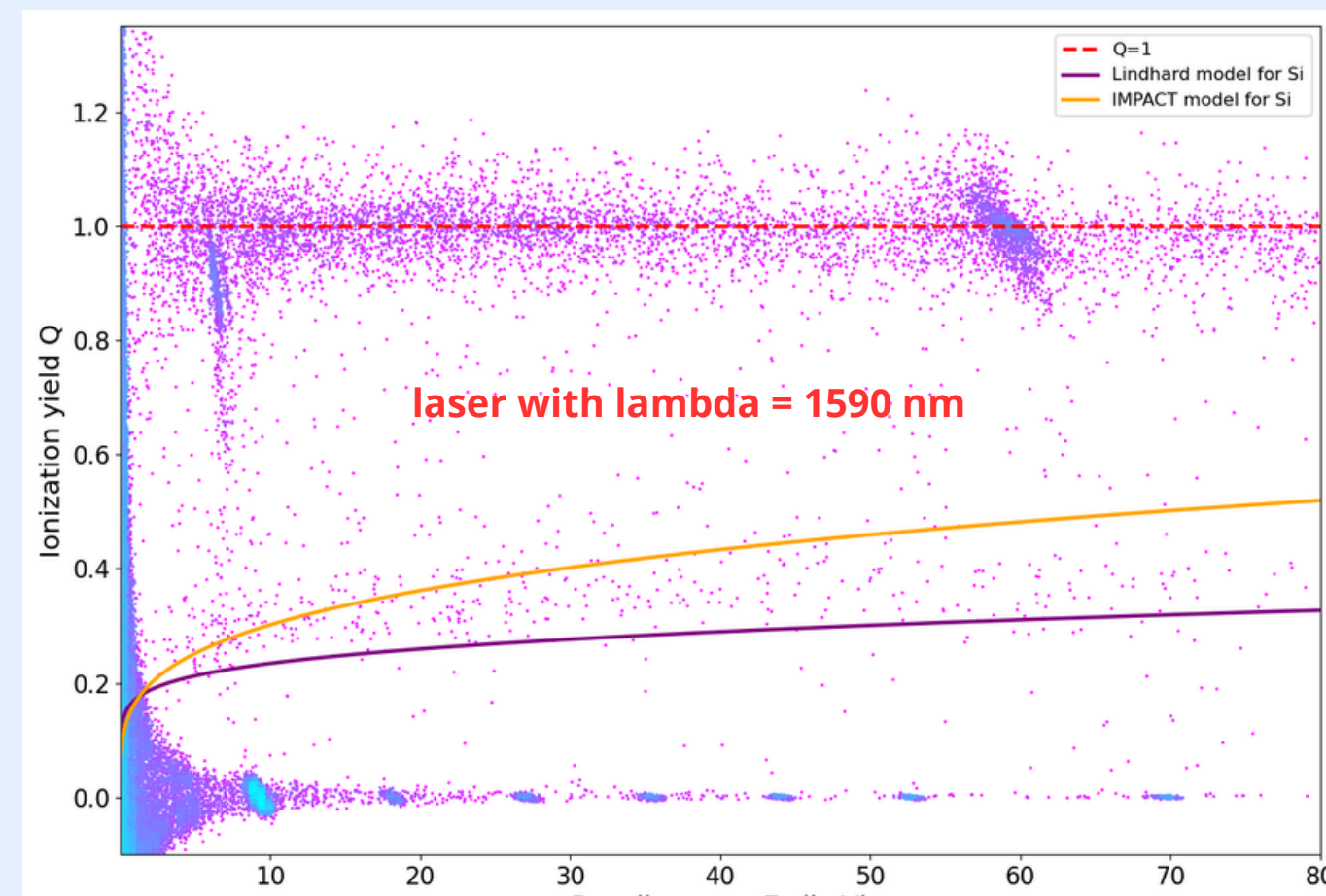
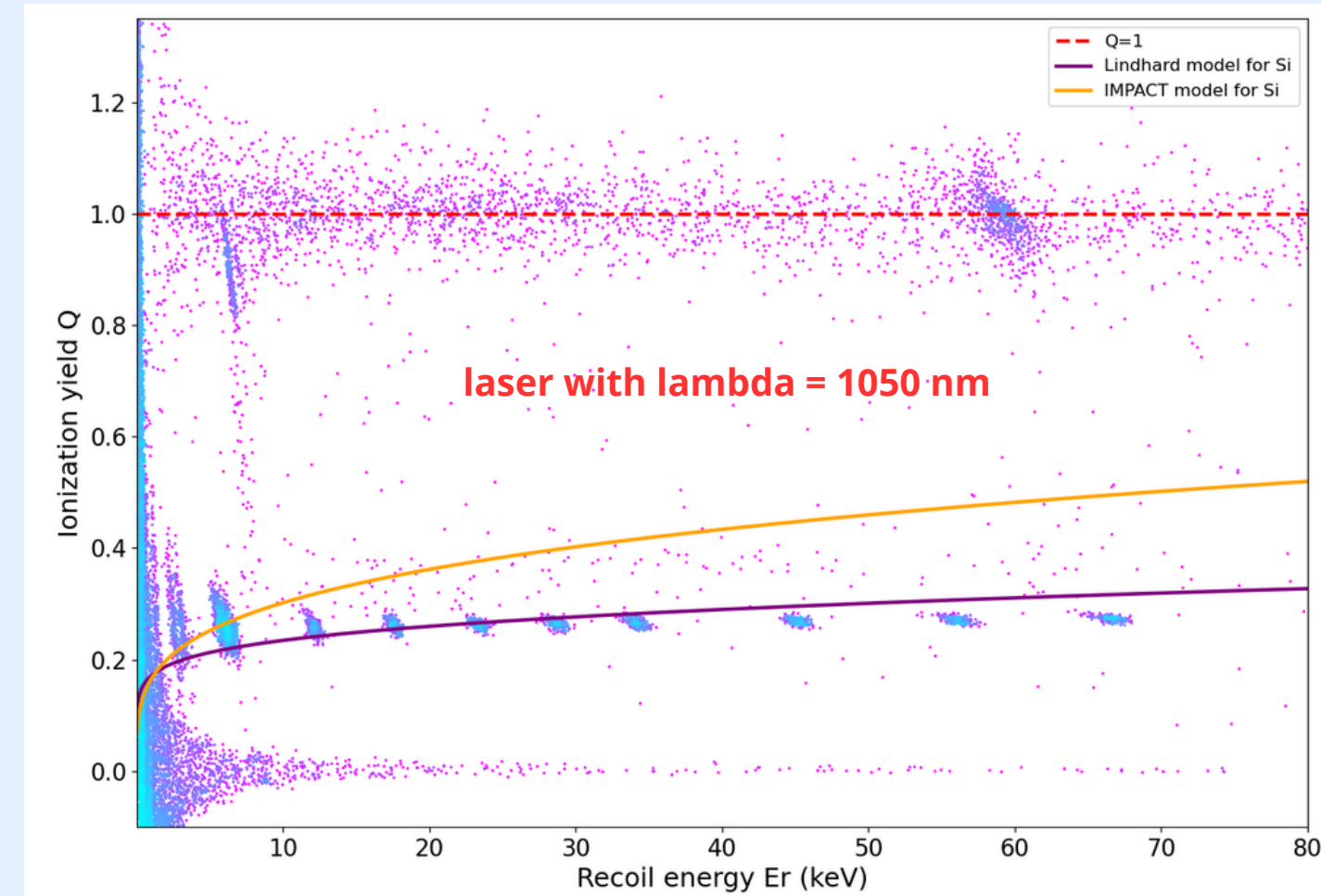
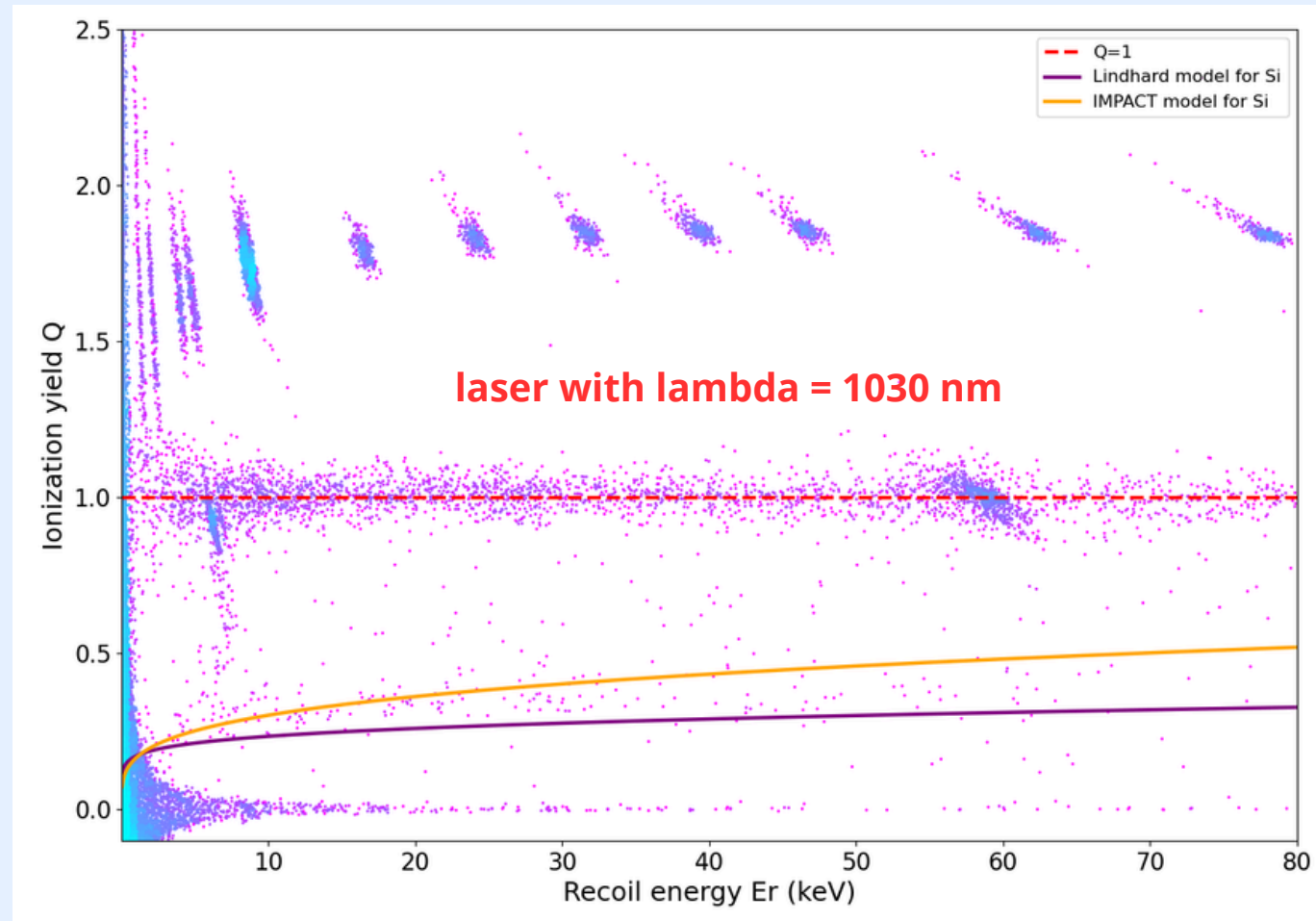
Charge collection depending on the bias between the electrodes?

The "seagull" plot



Laser scan

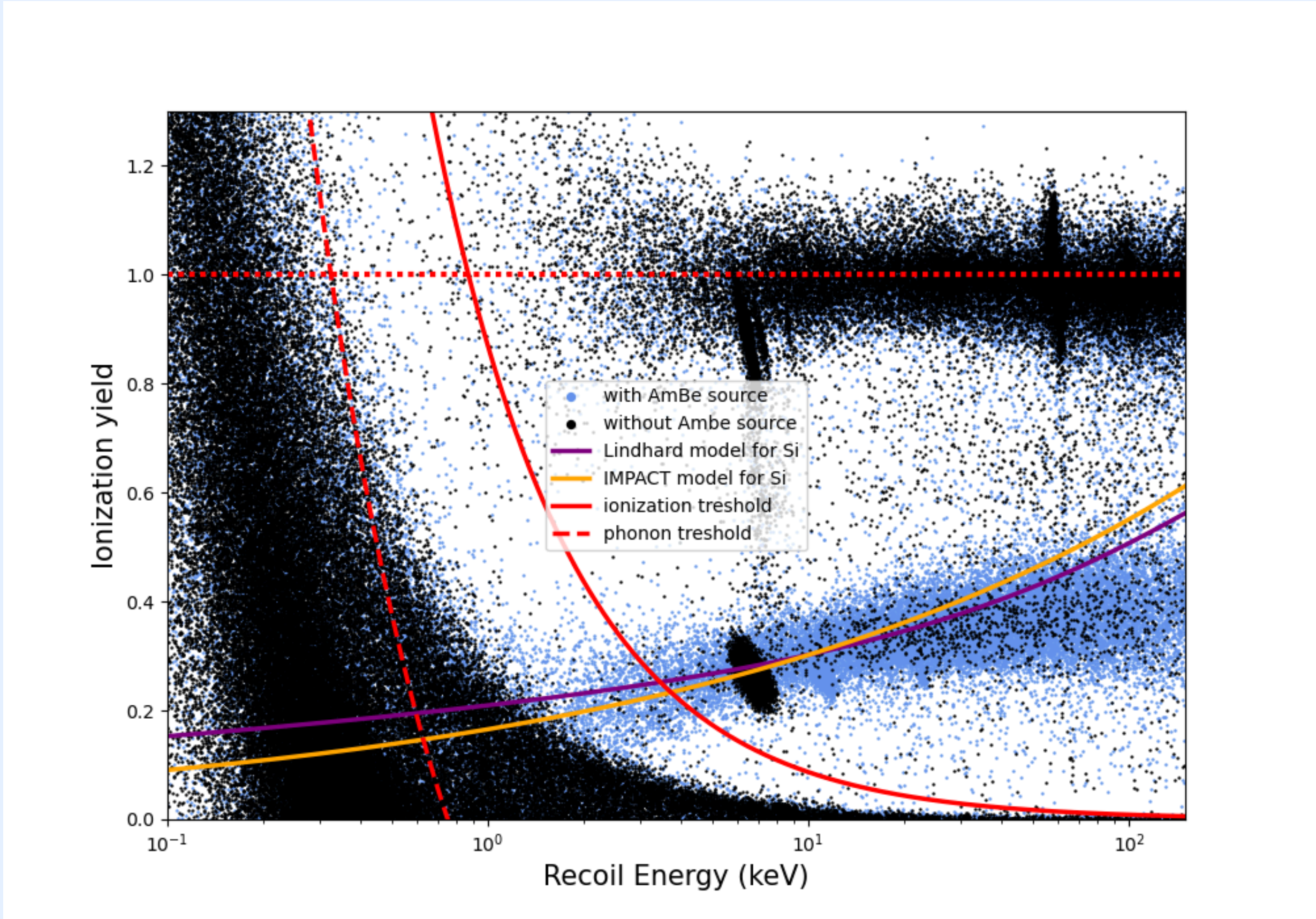
Si is a semiconductor with a gap at 1060 nm



Neutron source (AmBe) to see the nuclear recoils band

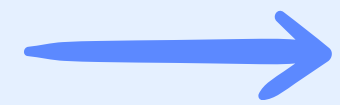


'Q vs Er' plot

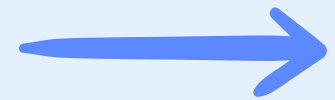




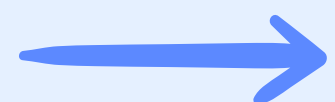
But this is just the beginning...



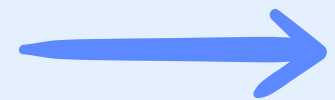
More analysis on the way, may go for a **paper** on it



4 new crystals have been ordered for FID design (Mirion Technologie)



We may go for **more massive detectors** in the future



A **future phase** for Ricochet including Germanium and Silicon crystals!

Stay tuned!



General perspectives

→ **Quenching** analysis on the way, the **region below 2 keV is under study!**

→ **More results** to come from **Silicon** analysis

→ **Successful proof of concept** of Silicon targets for Ricochet: **ANR CENNSitive**

→ **Quenching** measurement for **Silicon**

→ Focus on **new physics** with the CENNS process during the writing part of my PhD



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RICOCHET
A Coherent Neutrino Scattering Program

Thank you!

Ricochet experiment

PhD day – 23/04/2026

Tatiana Le Bellec under the supervision of Corinne Augier and Julien Billard