Energy-Resolved Beta Detectors for β-NMR Studies at VITO

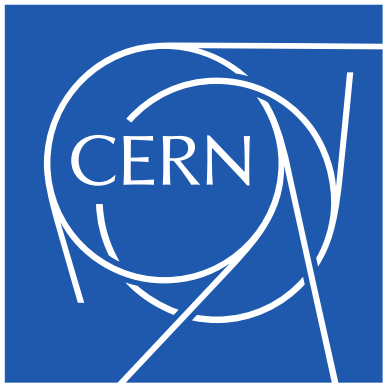
Daniel Paulitsch

on behalf of the VITO collaboration

ISOLDE Workshop and Users meeting 04.12.2025

European Research Council

Established by the European Commission

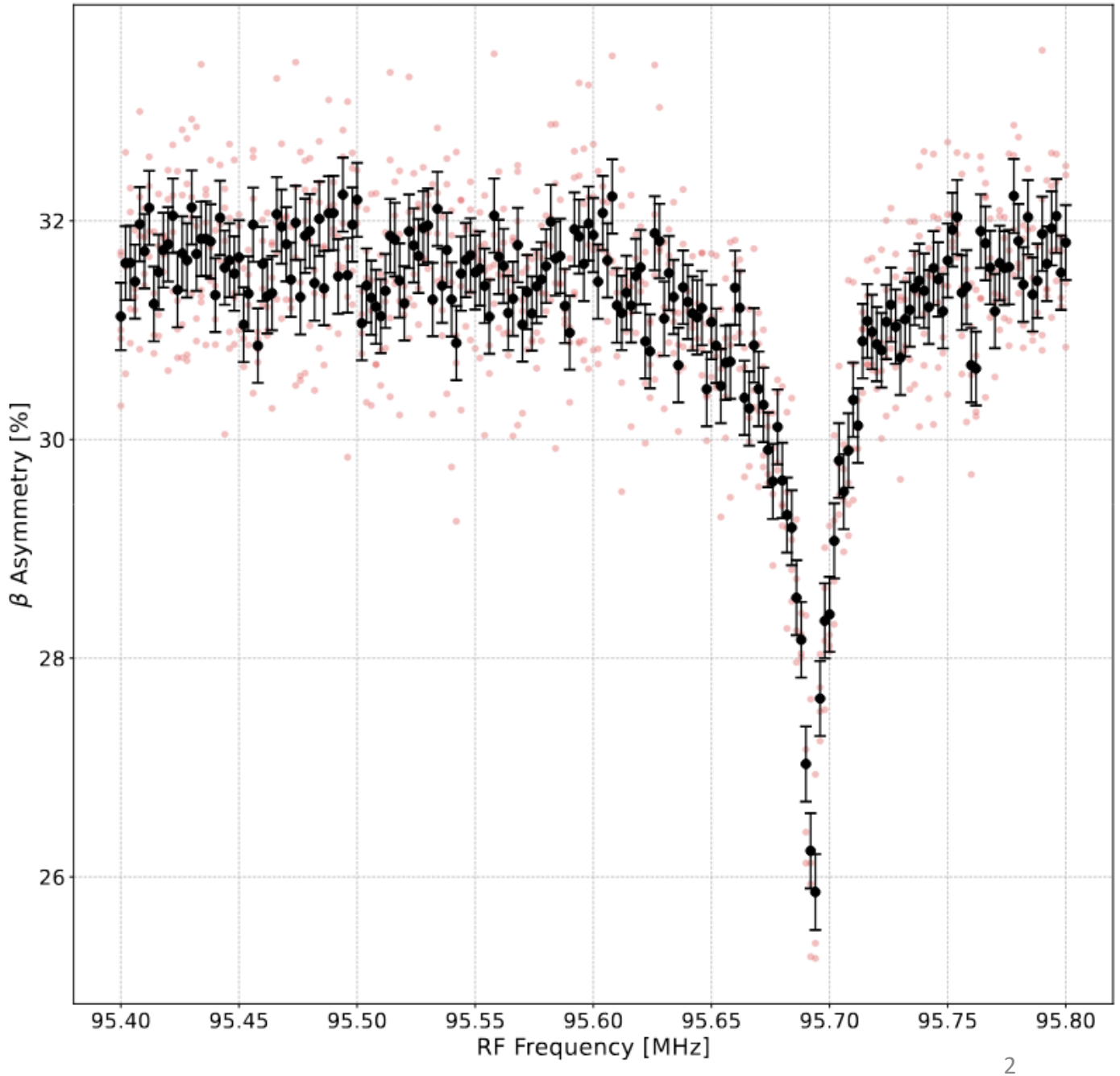


Outline

VITO Beamtime October 2025
^{47}K, ^{48}K, ^{49}K

– Upgrades that contributed to the results we got

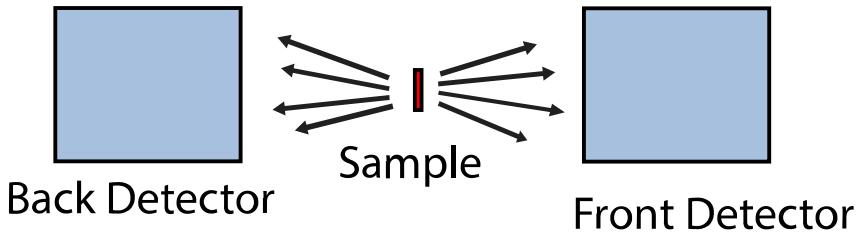
- The β-NMR measurement principle

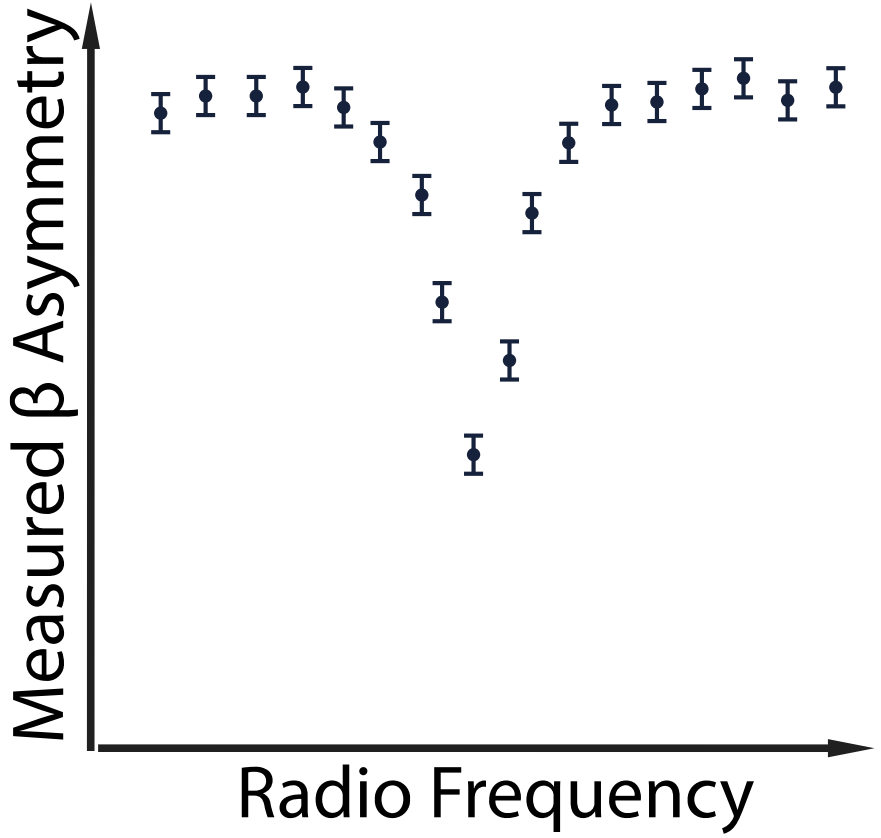


β-Detected NMR -Overview

- Nuclear spin polarization via optical pumping
- Asymmetry in β decay from ensemble of spin polarized nuclei
- Destruction of asymmetry with RF

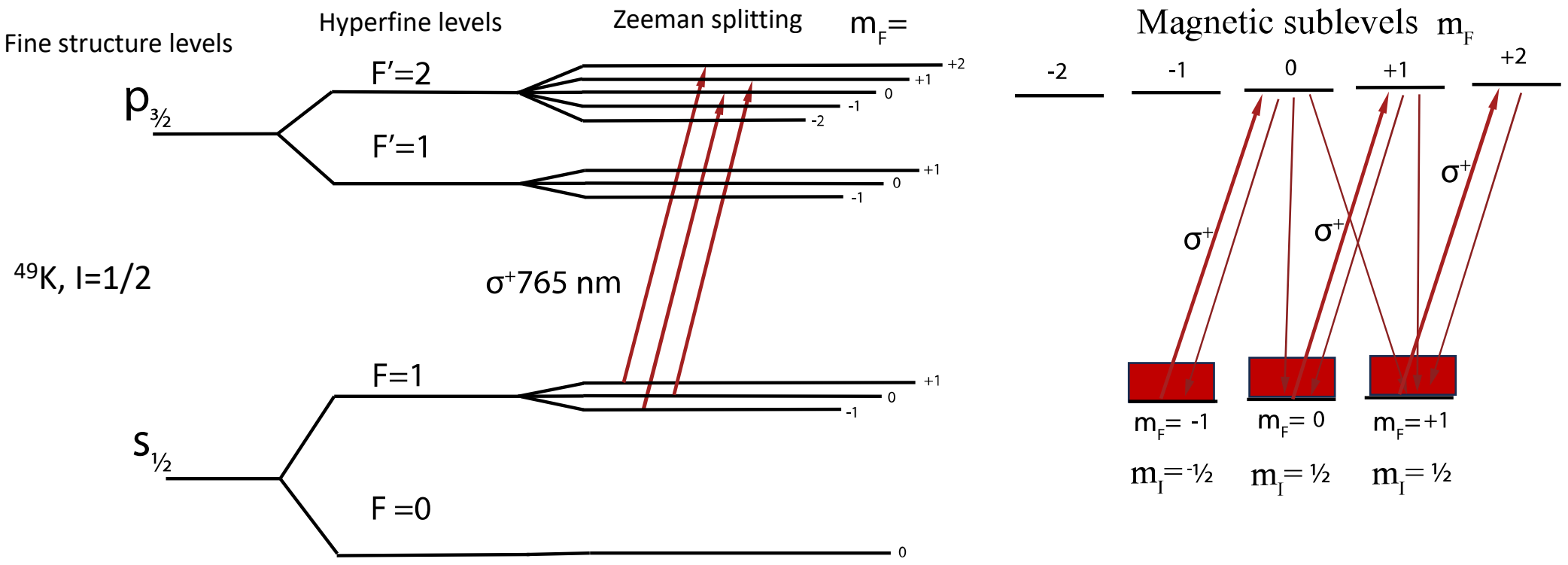
$$A_{exp} = \frac{N(0°) - N(180°)}{N(0°) + N(180°)}$$





Optical Pumping

First step: creation of the polarized beam via optical pumping



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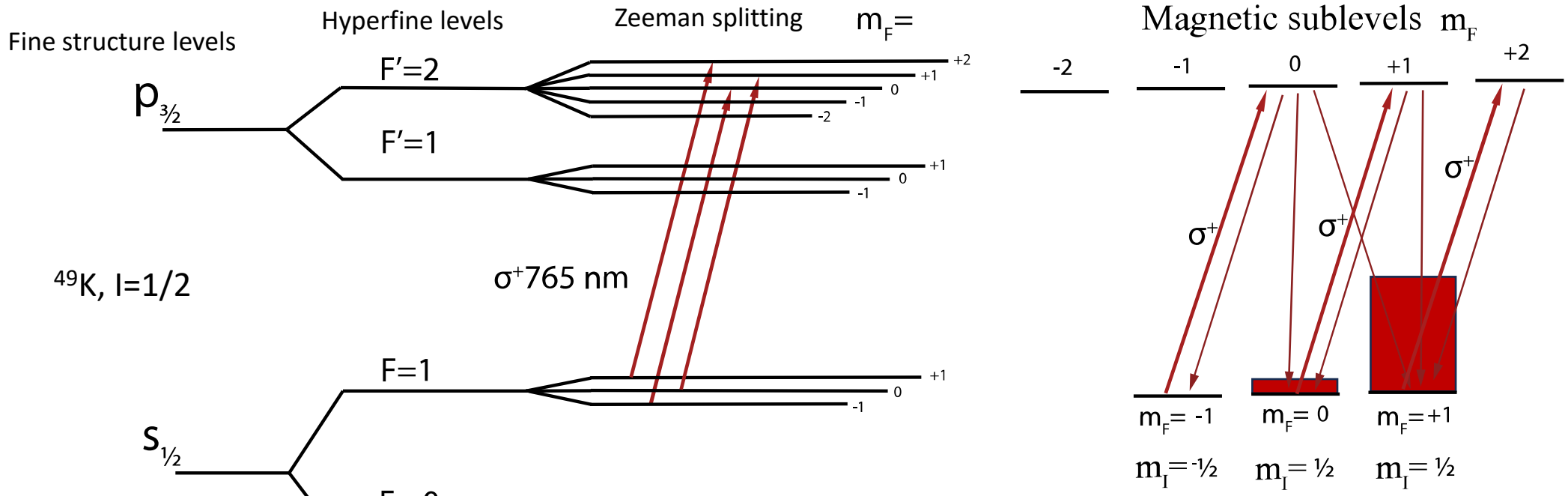
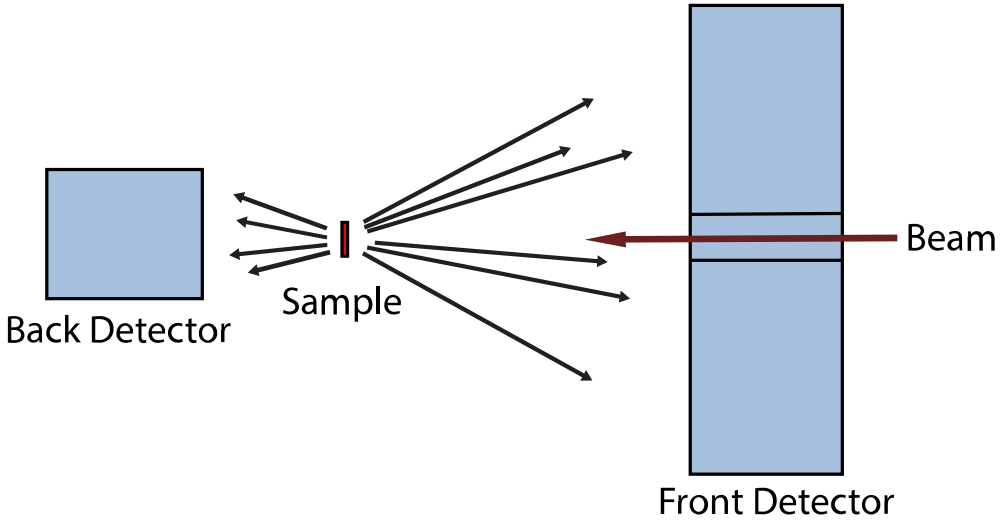
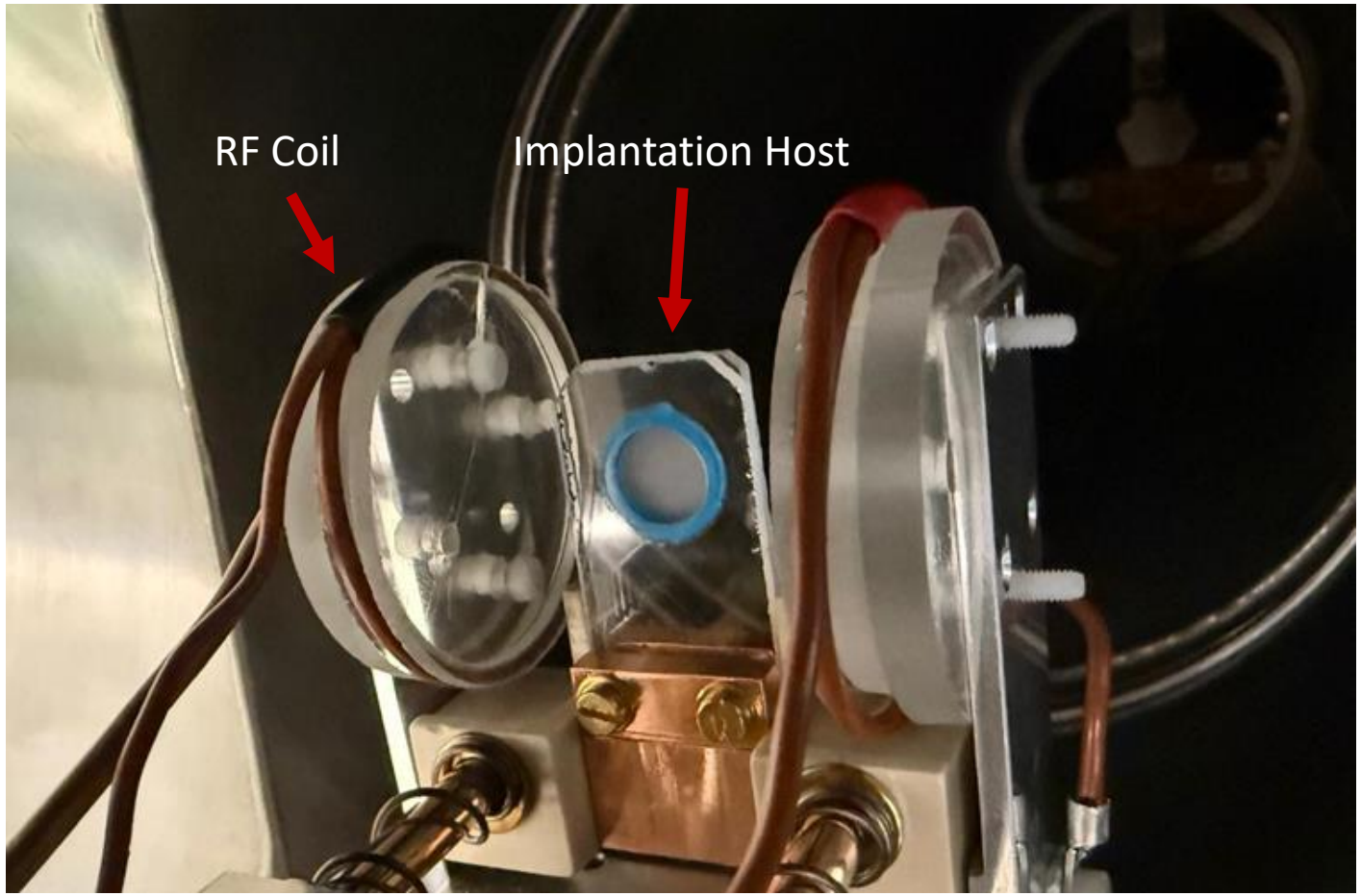


Magnetic field increases –>decouples spins ->polarized nuclei

β-NMR

- Beam is implanted in the sample
- Polarization is confirmed -asymmetry between both detectors

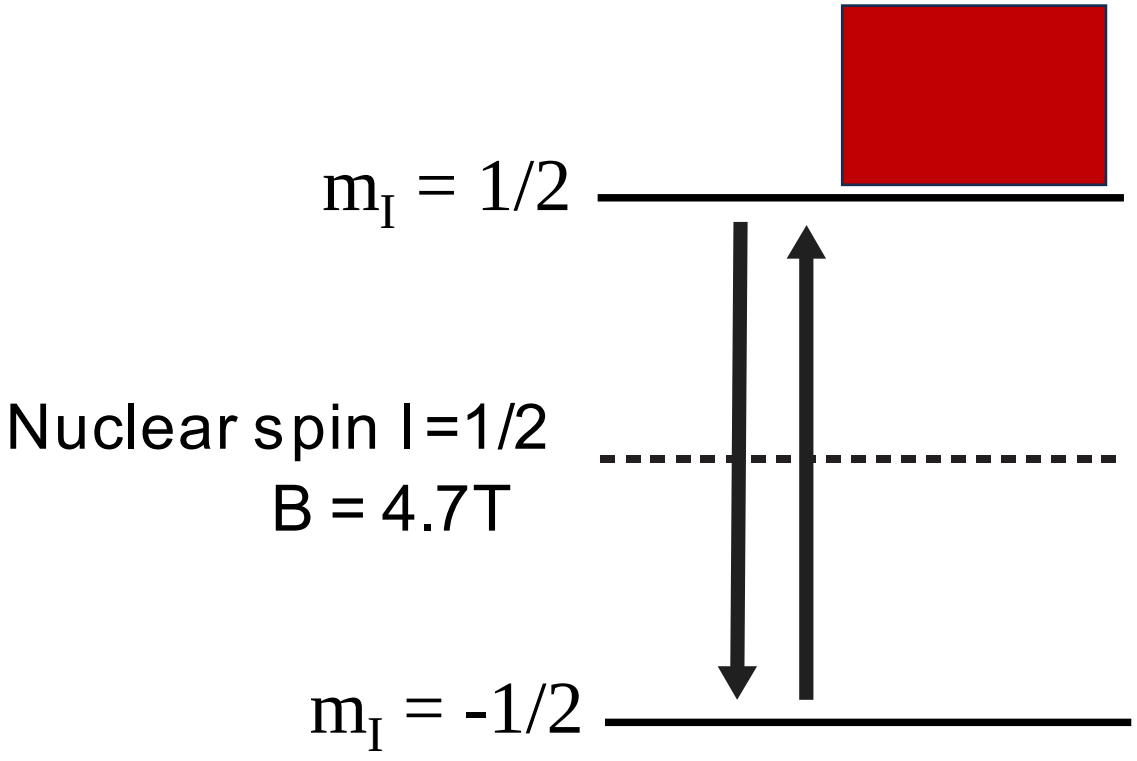


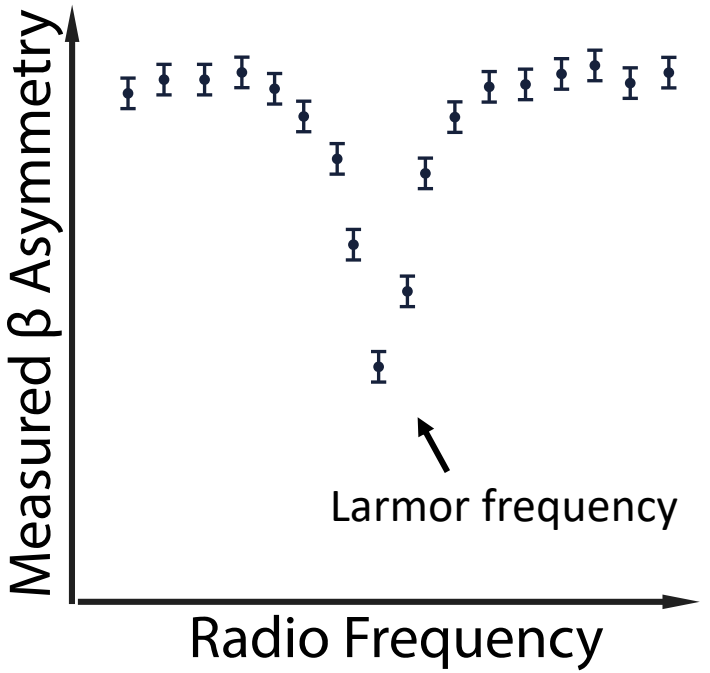


β-NMR

- Nuclei in a specific magnetic substate
- Strong magnetic field
- RF at Larmor Frequency ->Transfer population between two states-> decrease in asymmetry

$$\nu_L = \frac{\gamma B}{2\pi} = \frac{\mu B}{hI}$$





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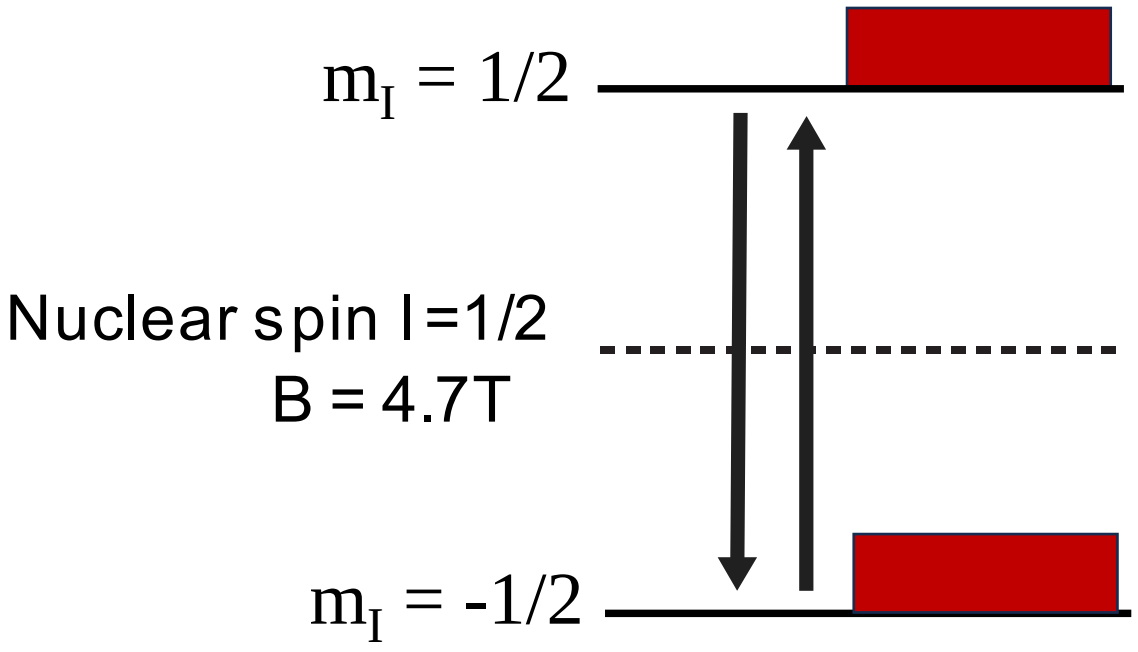
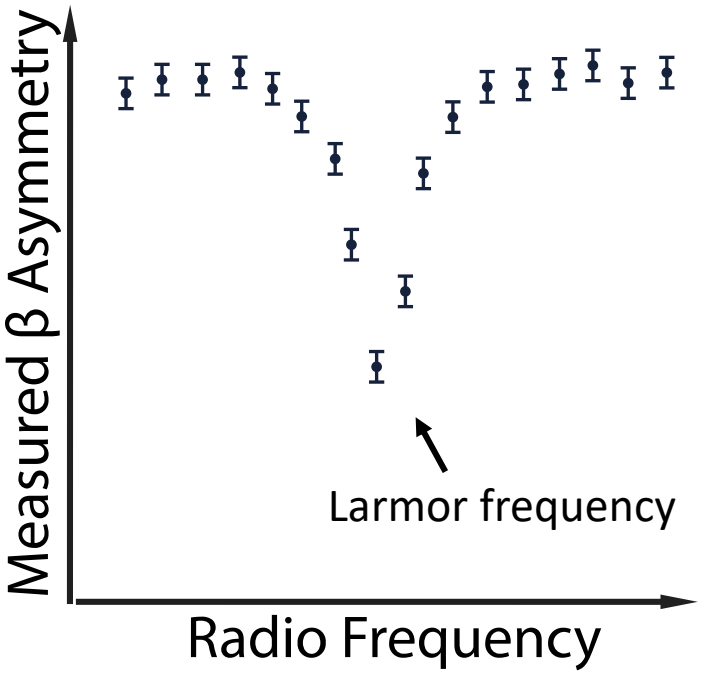




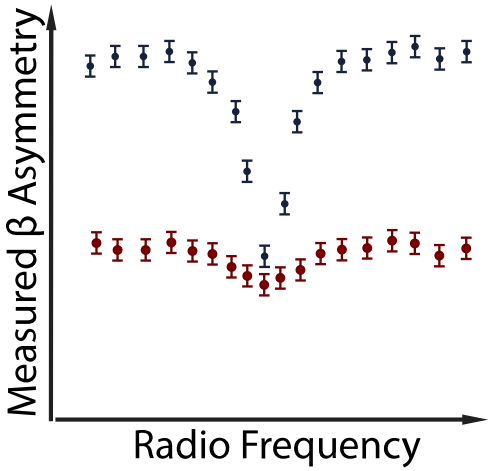
β-Decay Asymmetry

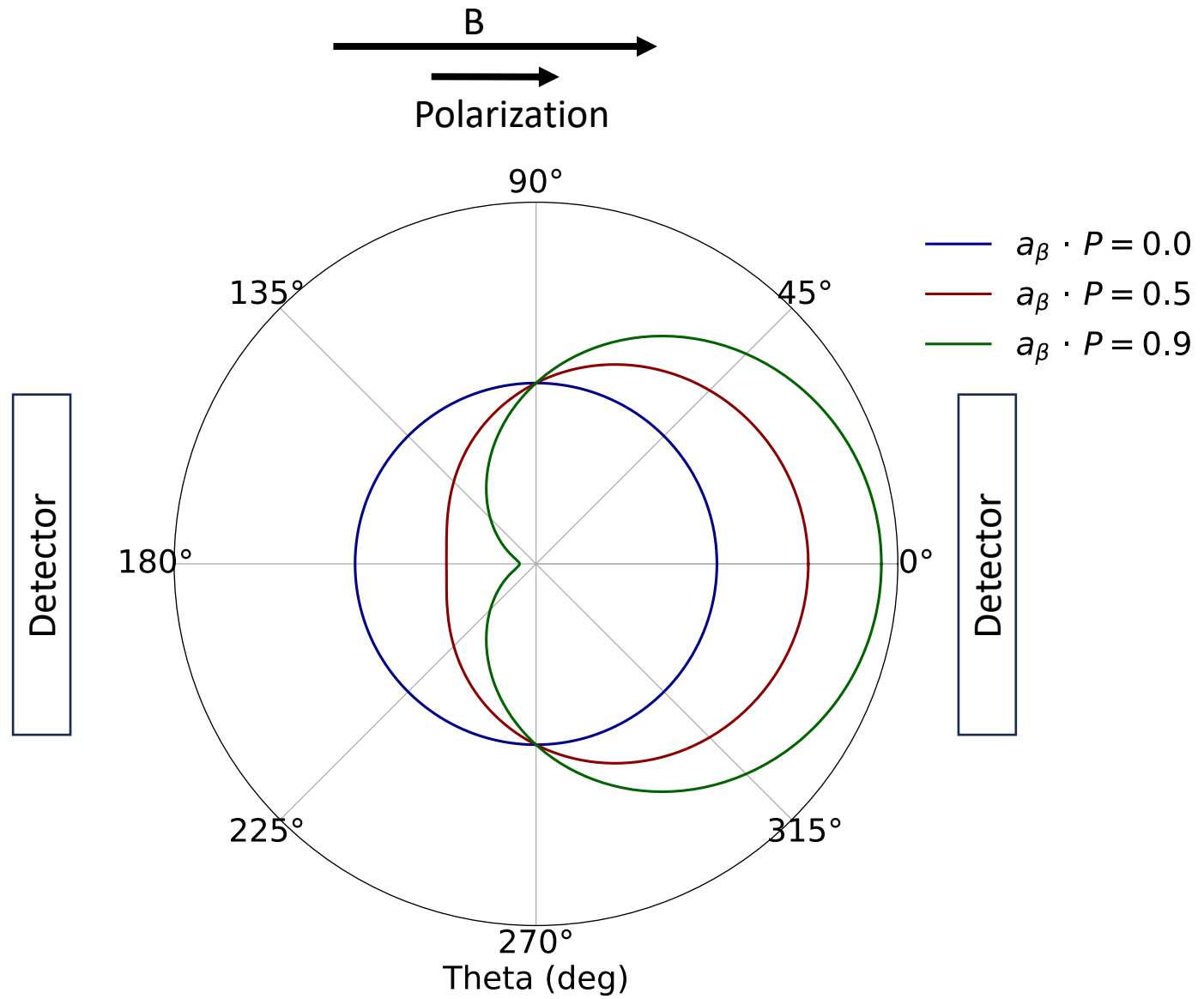
- Weak interaction non parity conserving
- Only acts on particles with left-handed chirality

$$W(\theta) = 1 + a_\beta P \frac{v}{c} \cos(\theta)$$

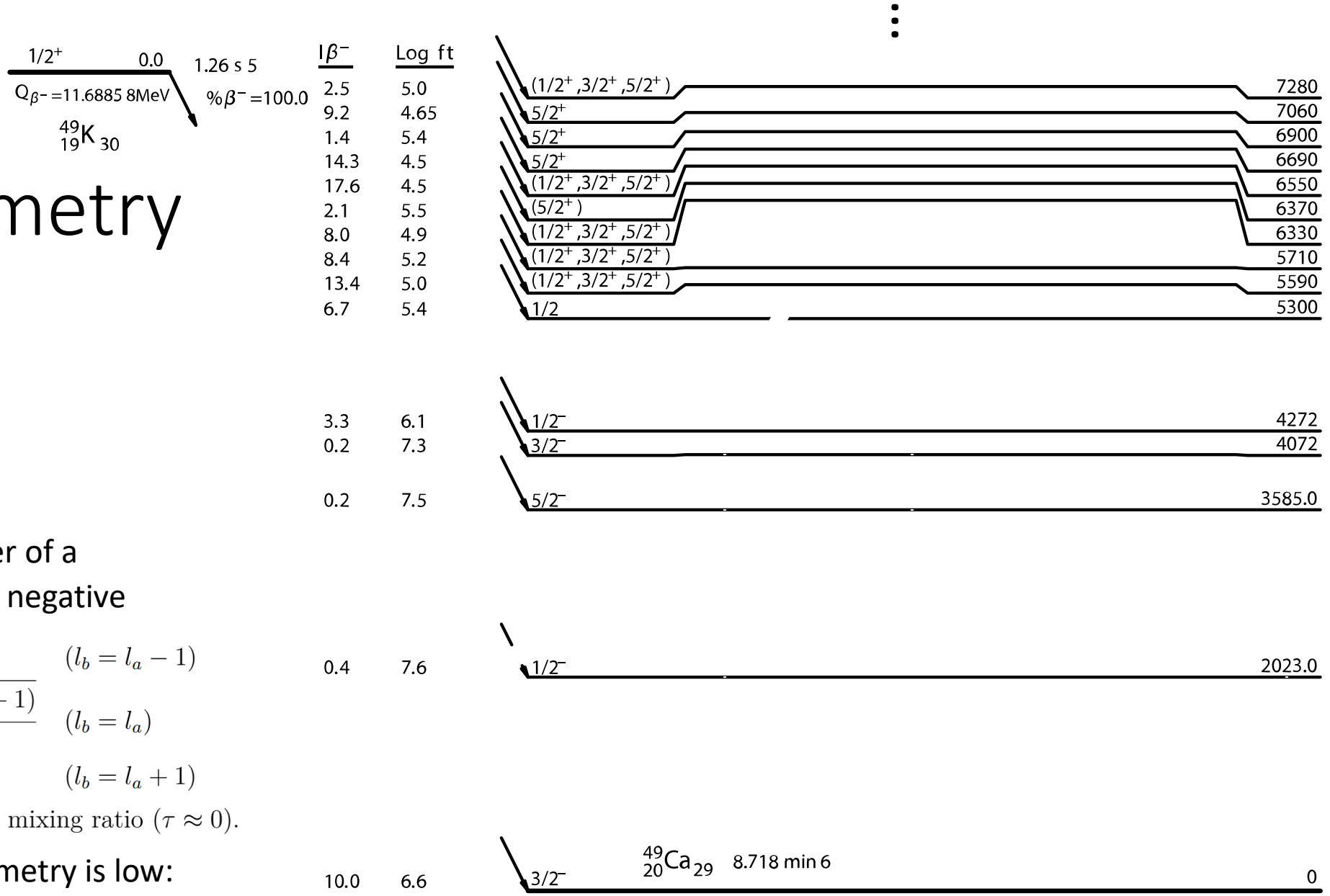
v … velocity of the emitted beta-particle,
P… nuclear polarization,
a_β… total beta asymmetry parameter

- a_β P …Determines the amplitude of the signal





a_β… β Asymmetry Parameter



$$a_\beta^{(\mathrm{tot})} = \frac{\sum_i I_{\beta,i}\, a_{\beta,i}}{\sum_i I_{\beta,i}}$$

$a_{\beta,i}$… β asymmetry parameter of a transition -can be positive or negative

$$\mathrm{a}_{\beta,i}(l_a, l_b) = \begin{cases} -1 & (l_b = l_a - 1) \\ \dfrac{-1/(l_a+1) - 2\tau\sqrt{l_a/(l_a+1)}}{1+\tau^2} & (l_b = l_a) \\ \dfrac{l_b}{l_a+1} & (l_b = l_a + 1) \end{cases}$$

where τ is the Fermi and Gamow-Teller mixing ratio ($\tau \approx 0$).

For some nuclei the total asymmetry is low: ^{11}Be, ^{49}K

β Spectrum of ^{49}K

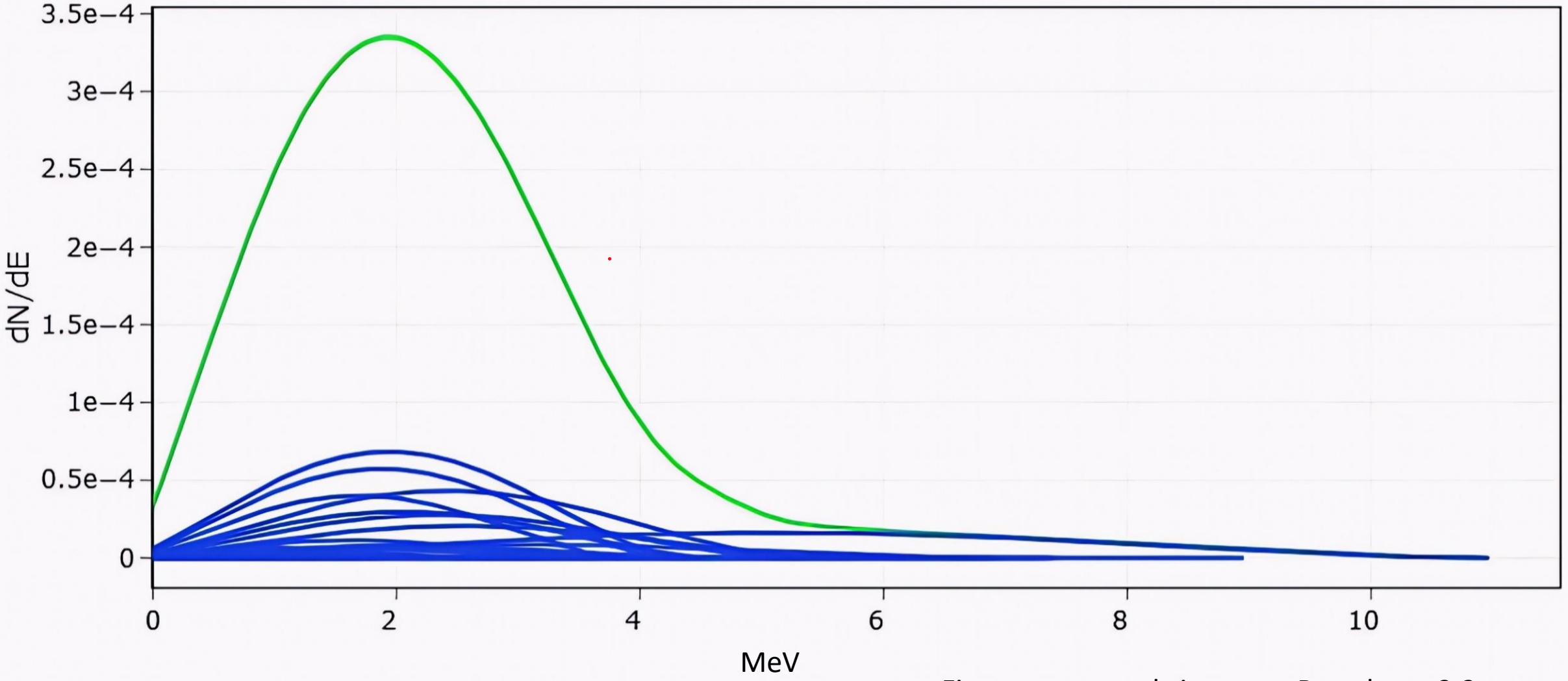


Figure: source nds.iaea.org, Betashape 2.2

β Spectrum of ^{49}K

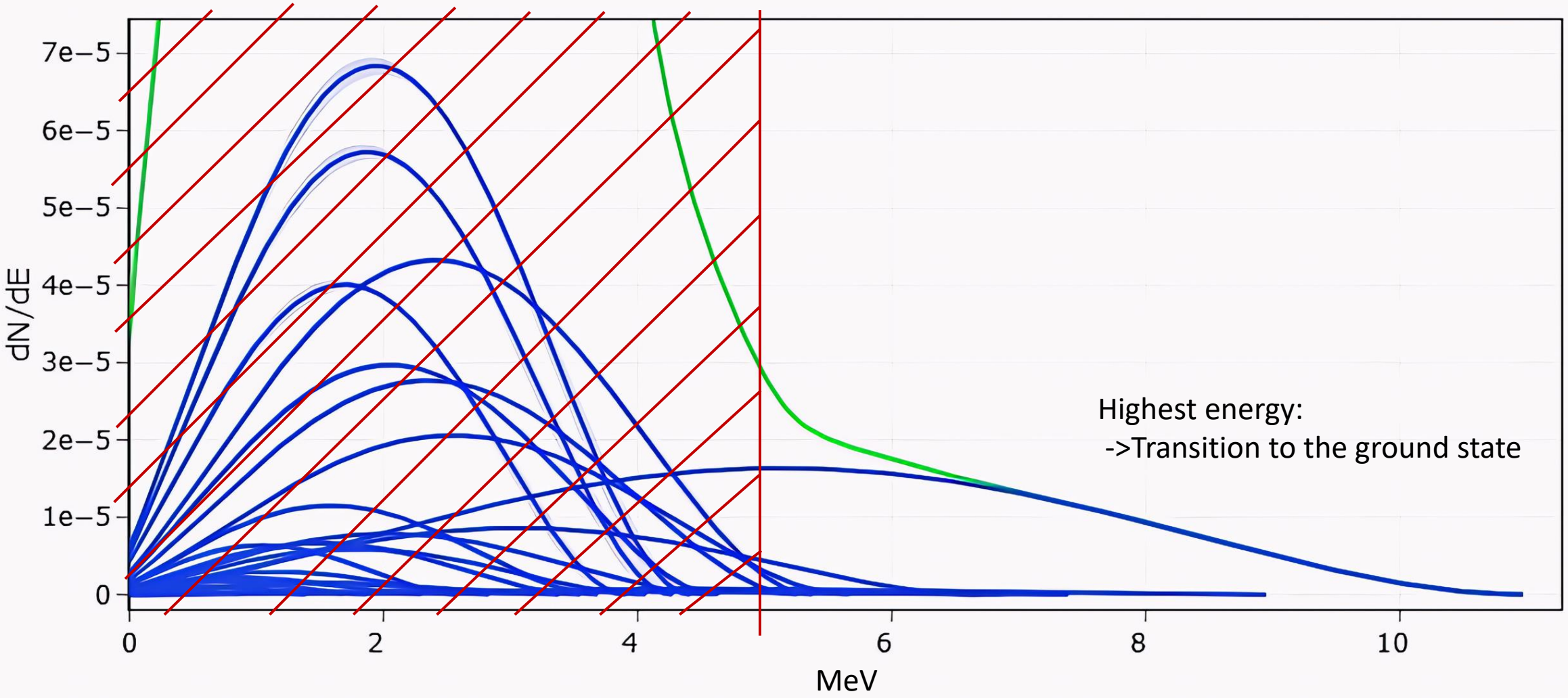
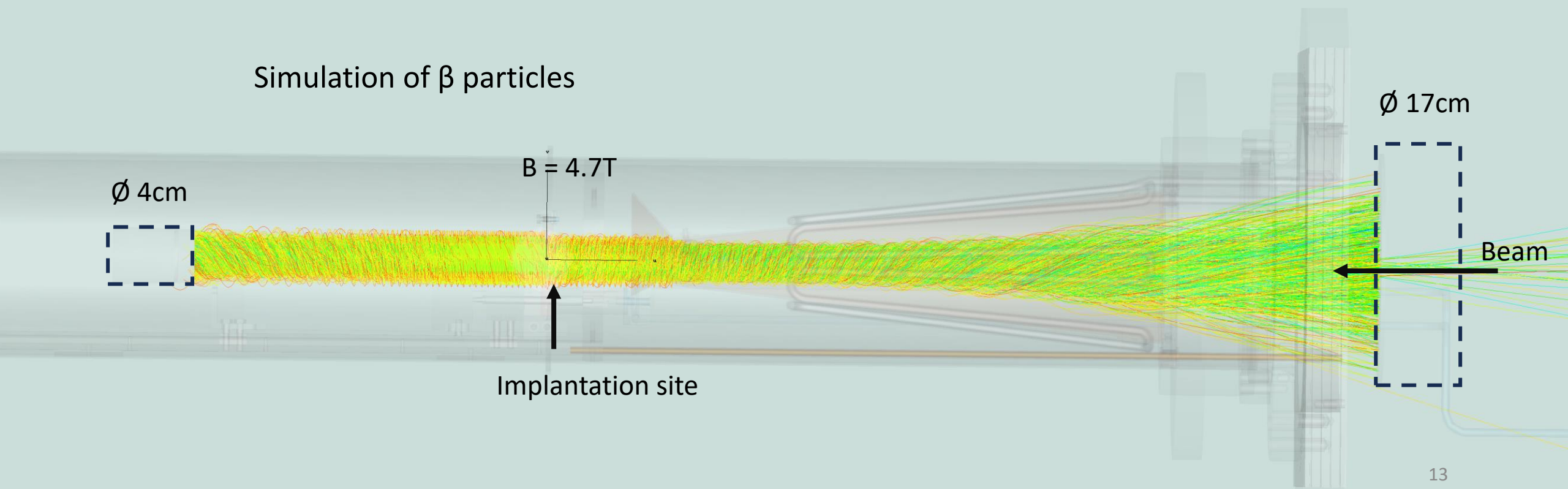


Figure: source nds.iaea.org, Betashape 2.2

Requirements for the Detectors

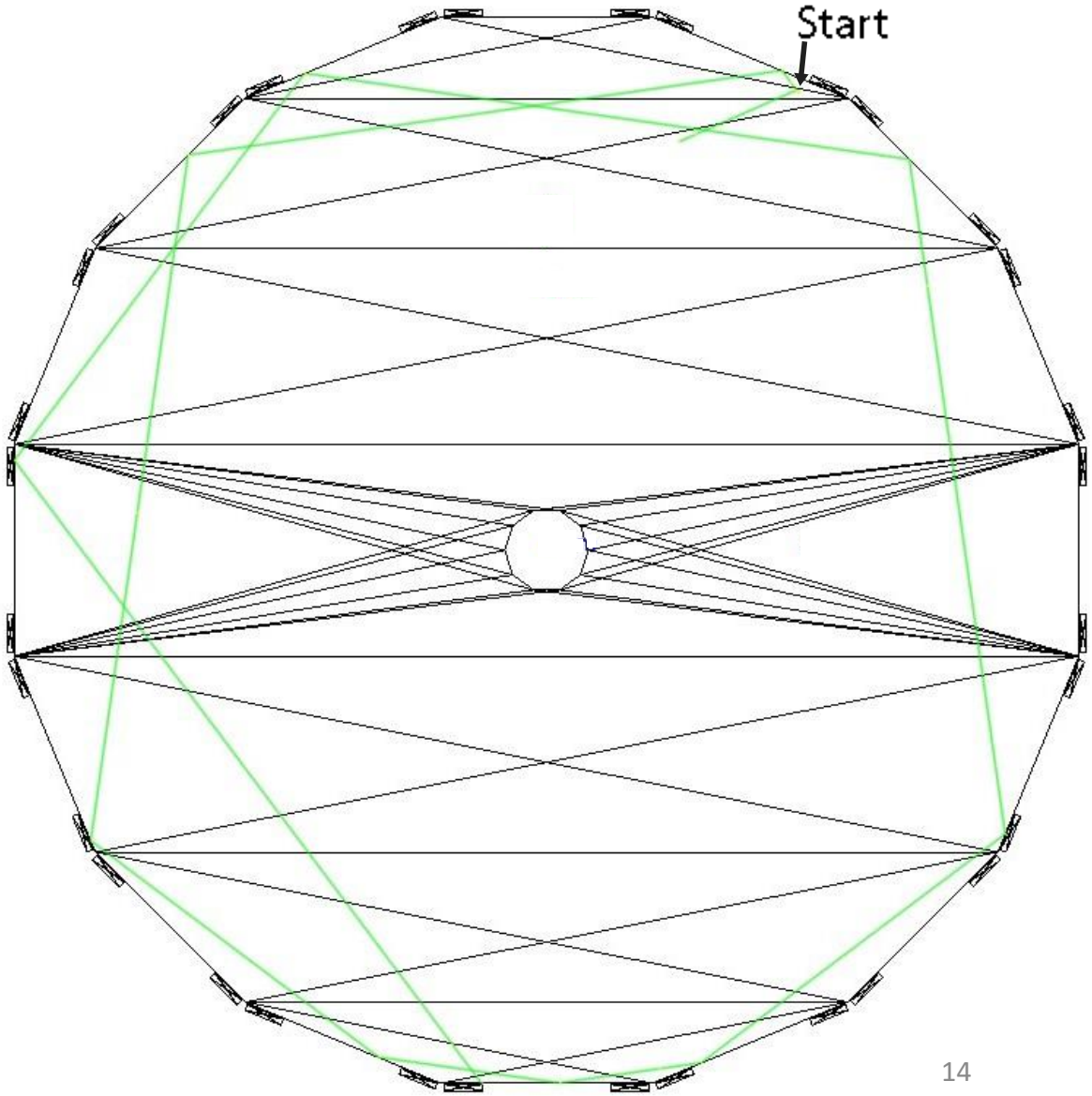
Thickness 6 cm -Plastic Scintillator
In magnetic field ->Silicon Photomultipliers

Simulation of β particles



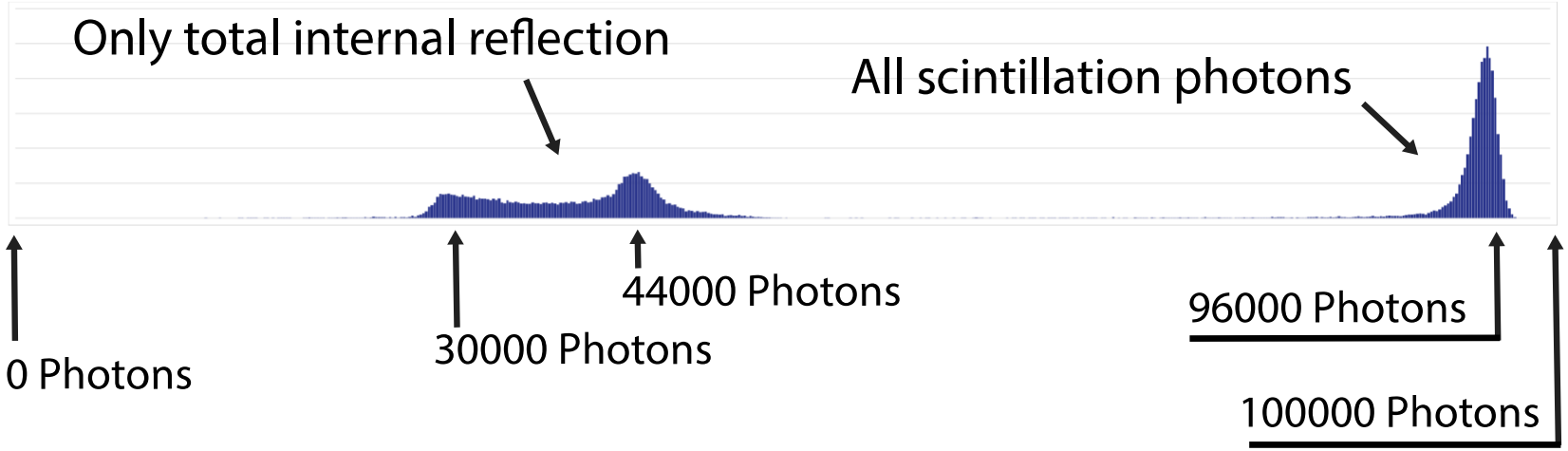
Light Transport Simulations -Geant4

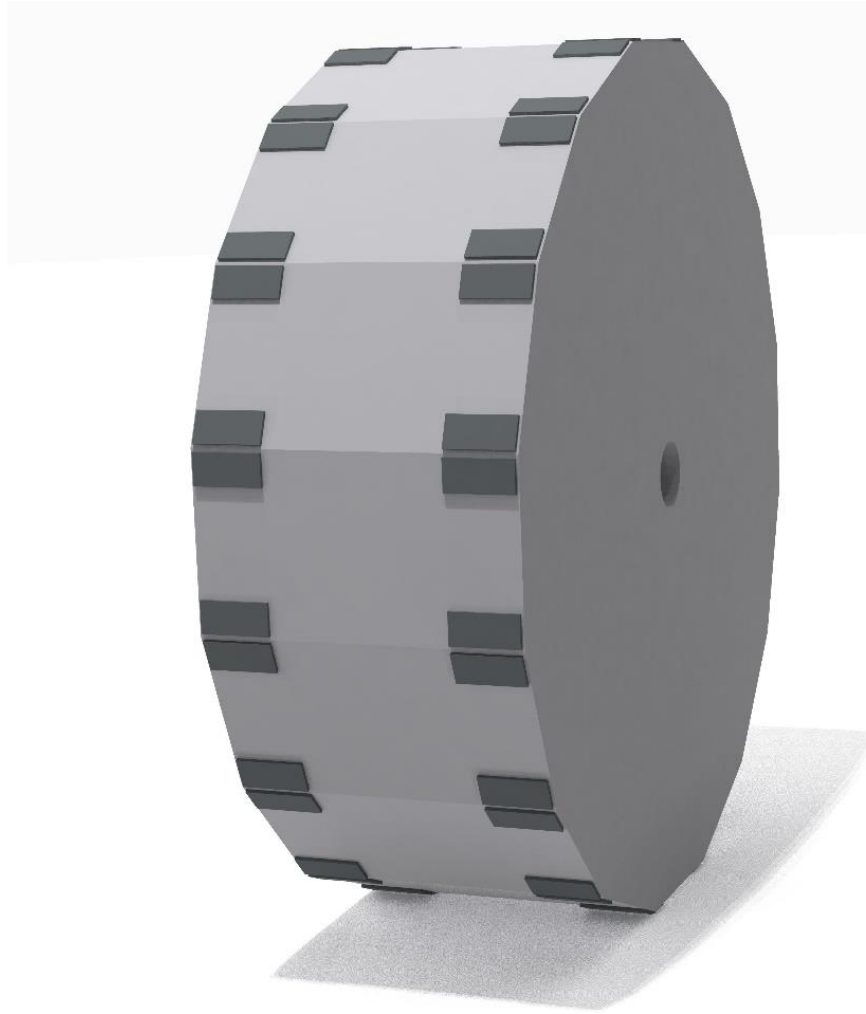
-Simulations in Geant4 with ‘optical‘ photons -optics package
-β particle hits the scintillator at a random position.
-The number of ‘optical‘ photons that are detected by the silicon photomultipliers is recorded.



Energy Resolution, Detectors

- Early design
- Total internal reflection only

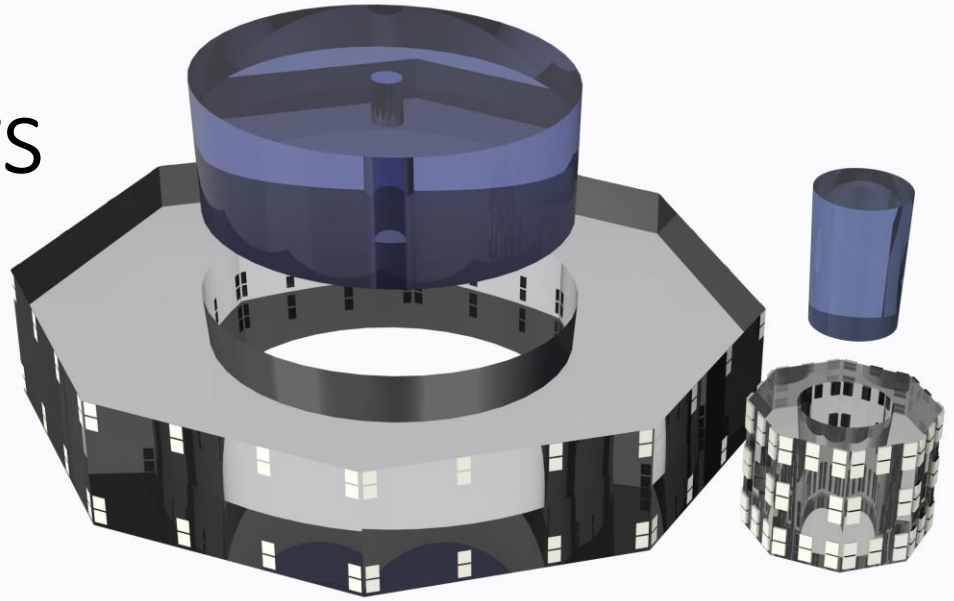


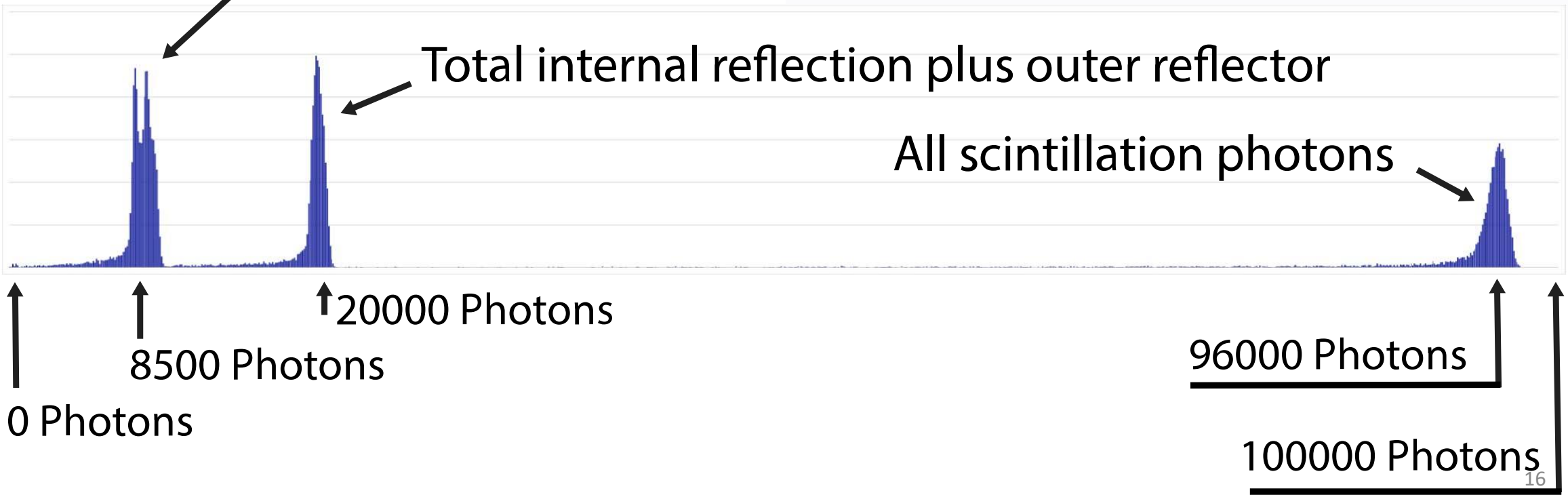


Energy Resolution, Detectors

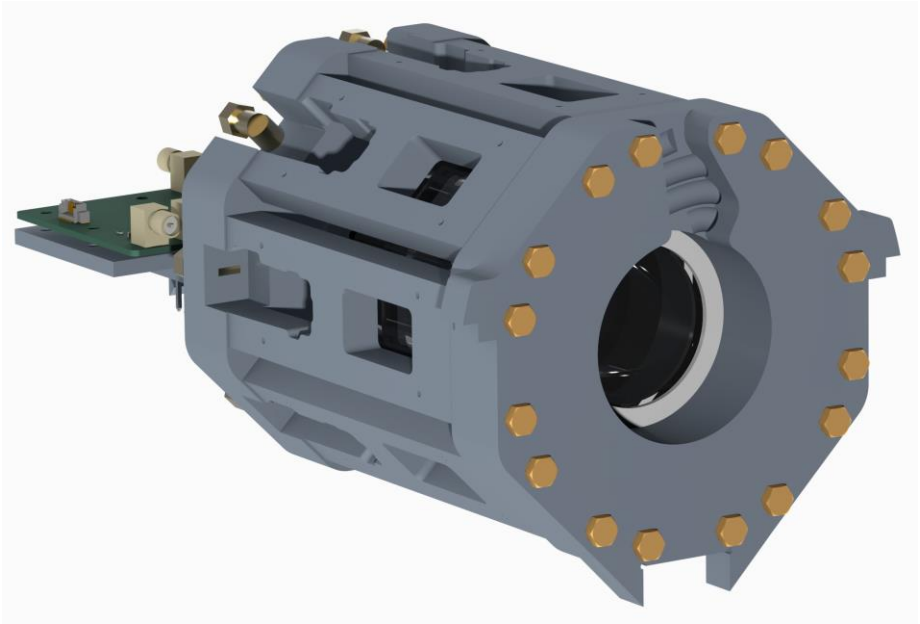
- Optimized design ->light guide/diffuser

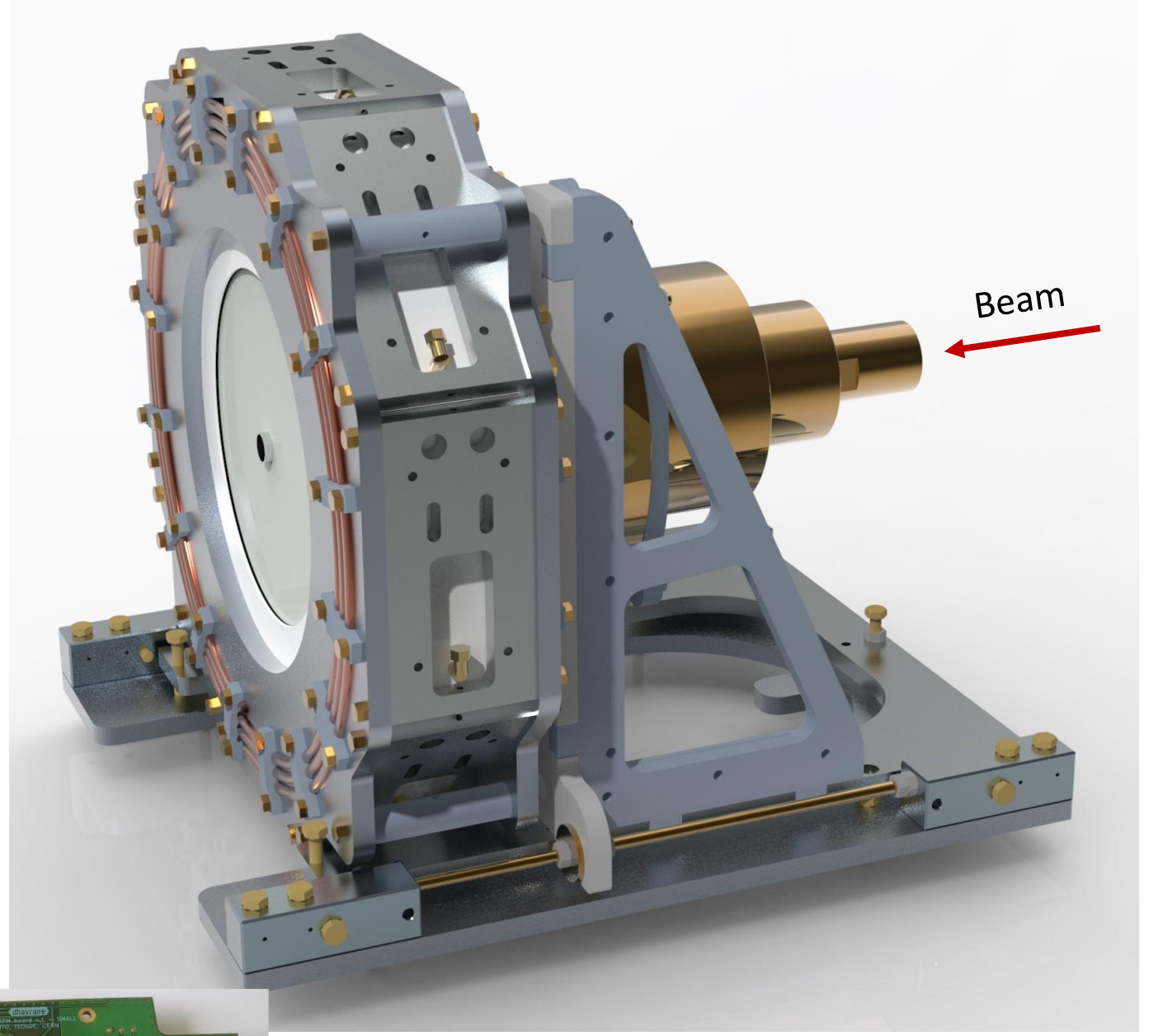
PMMA light guide/diffuser



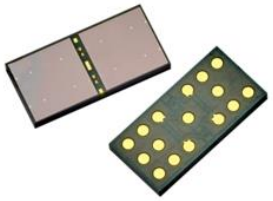


Detector Setup

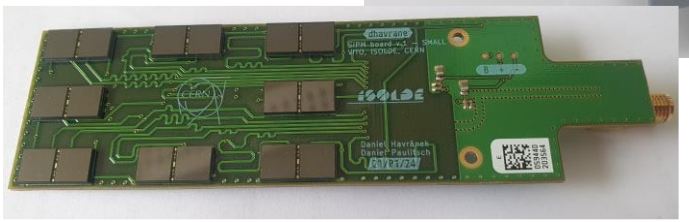




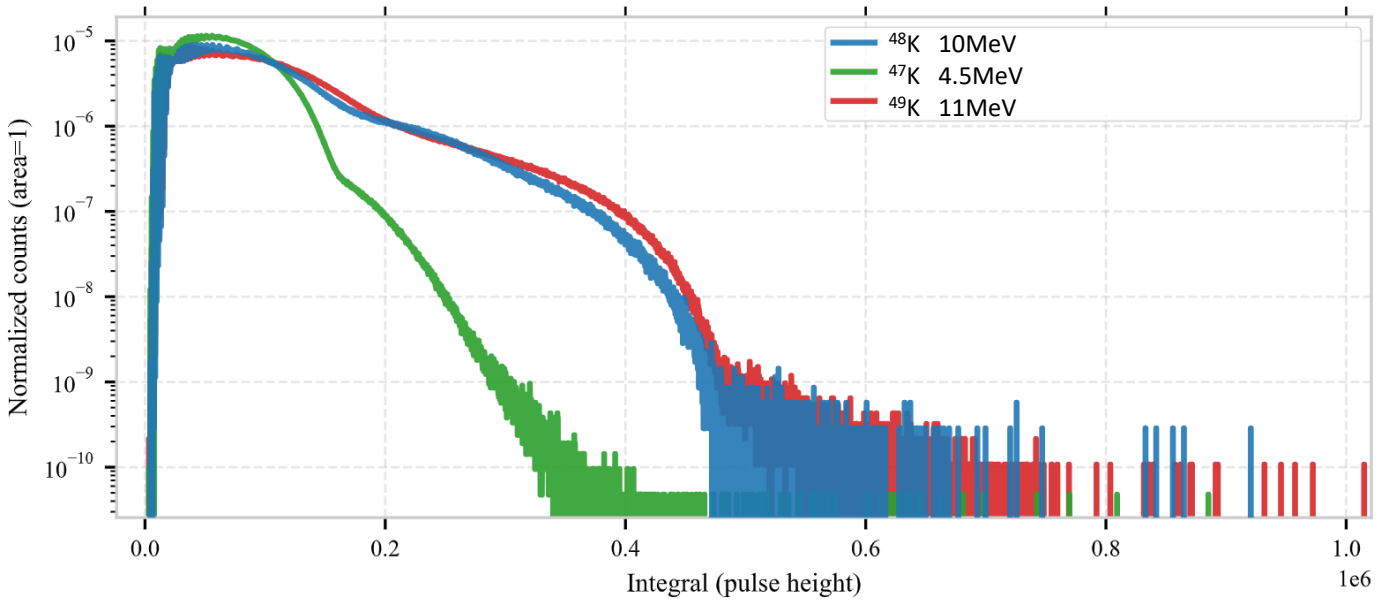
- Plastic scintillator ELJEN TECHNOLOGY 200,
- PMMA light guide,
- 64 6x6mm silicon photomultipliers
- surrounded by a diffuse reflector –optical Teflon



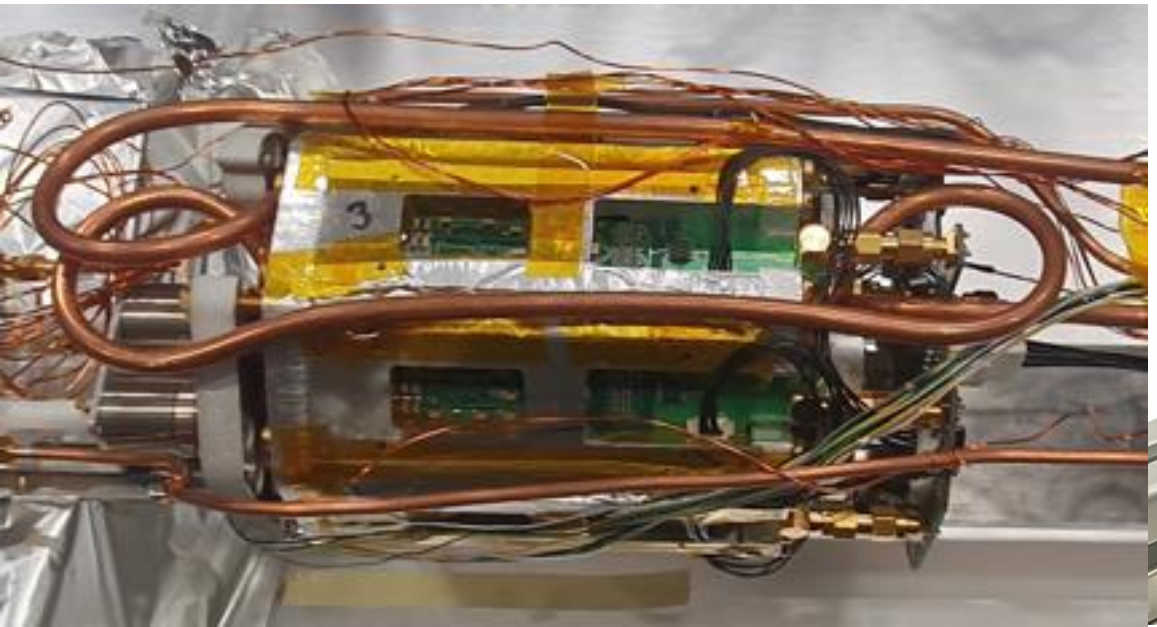
(Broadcom AFBR-S4N66P024M 2×1 NUV-MT)

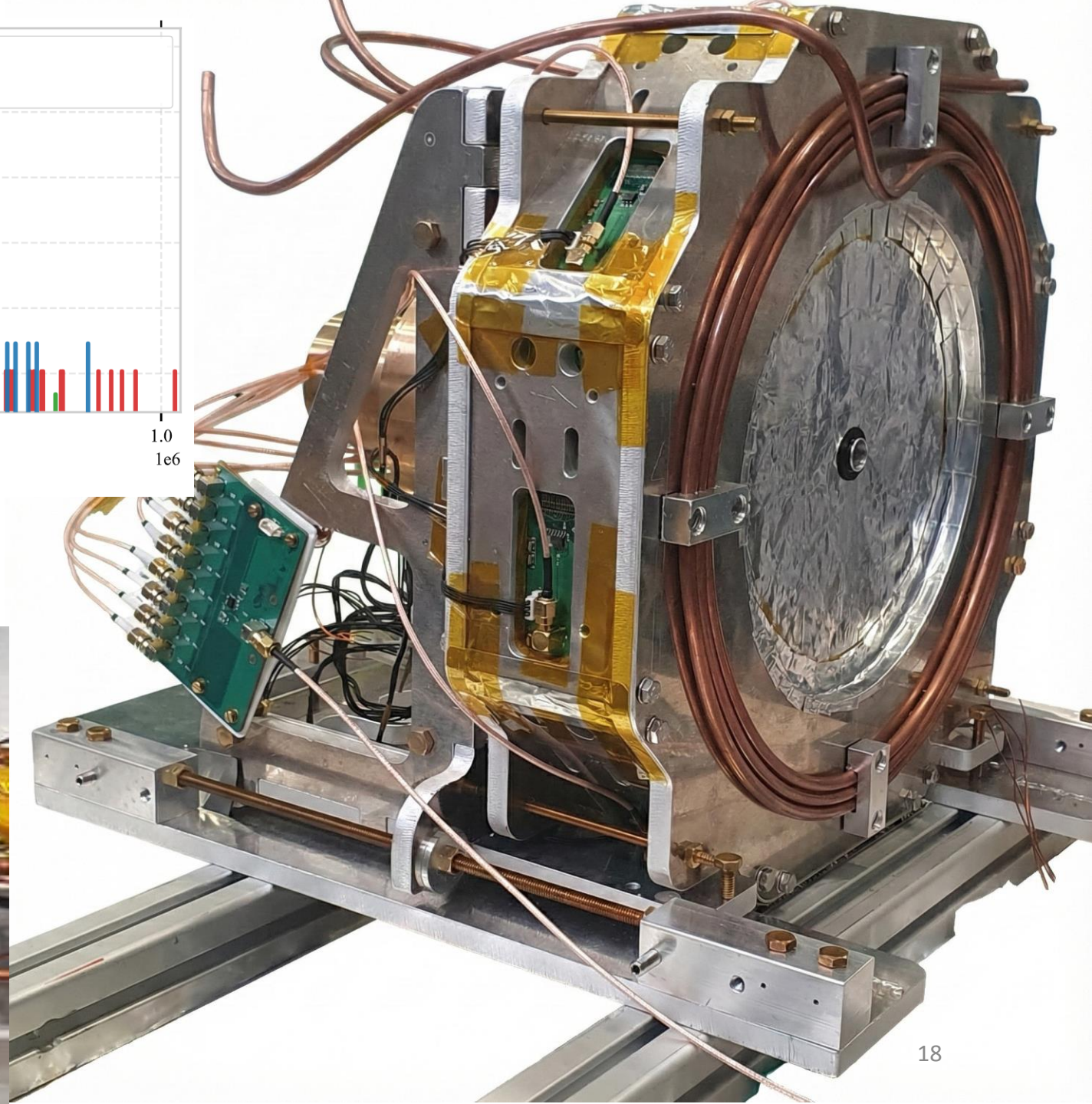


PCB -> D. Havránek DOI:10.13164/eeict.2024.109



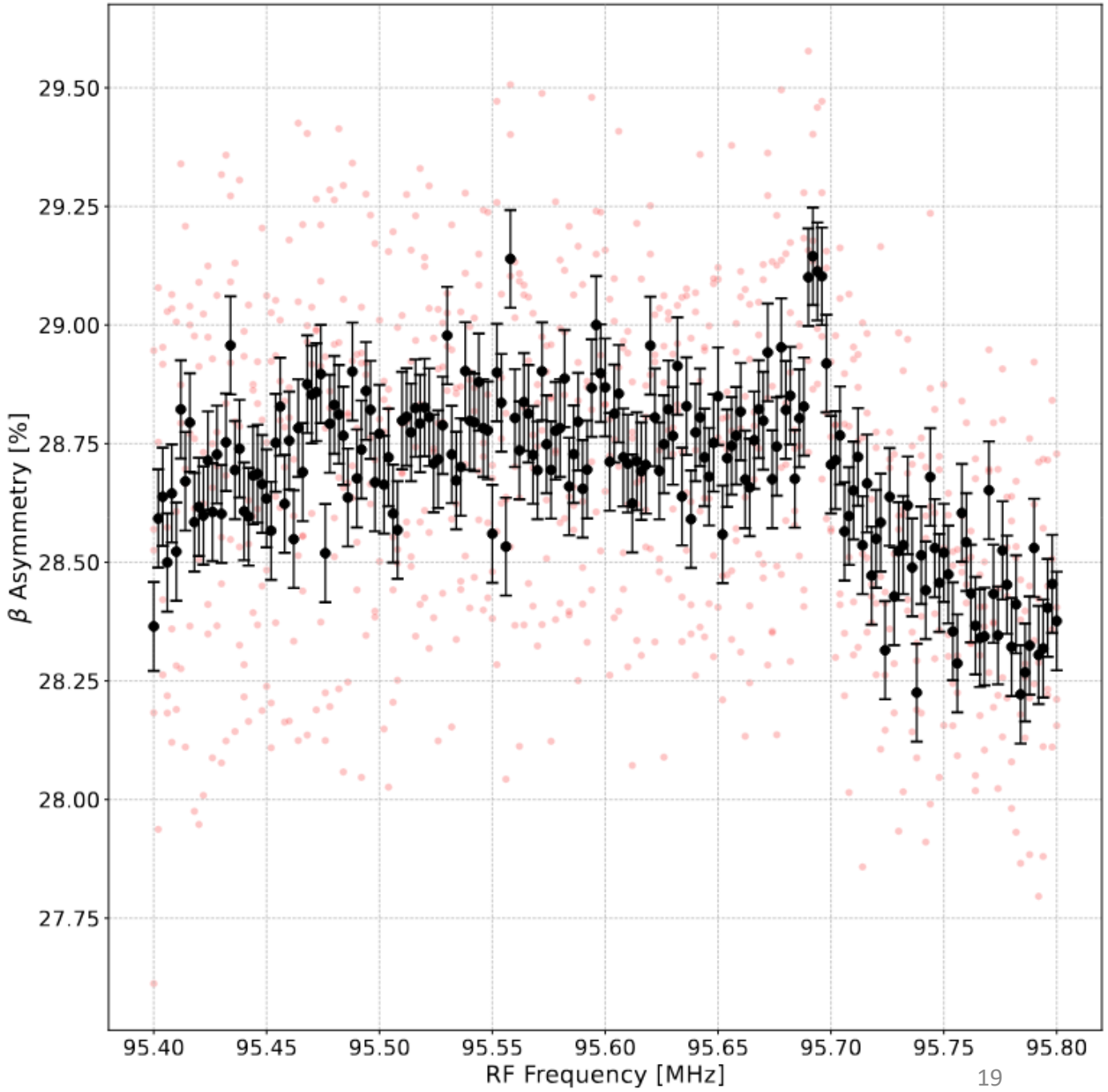
The Detectors in Reality





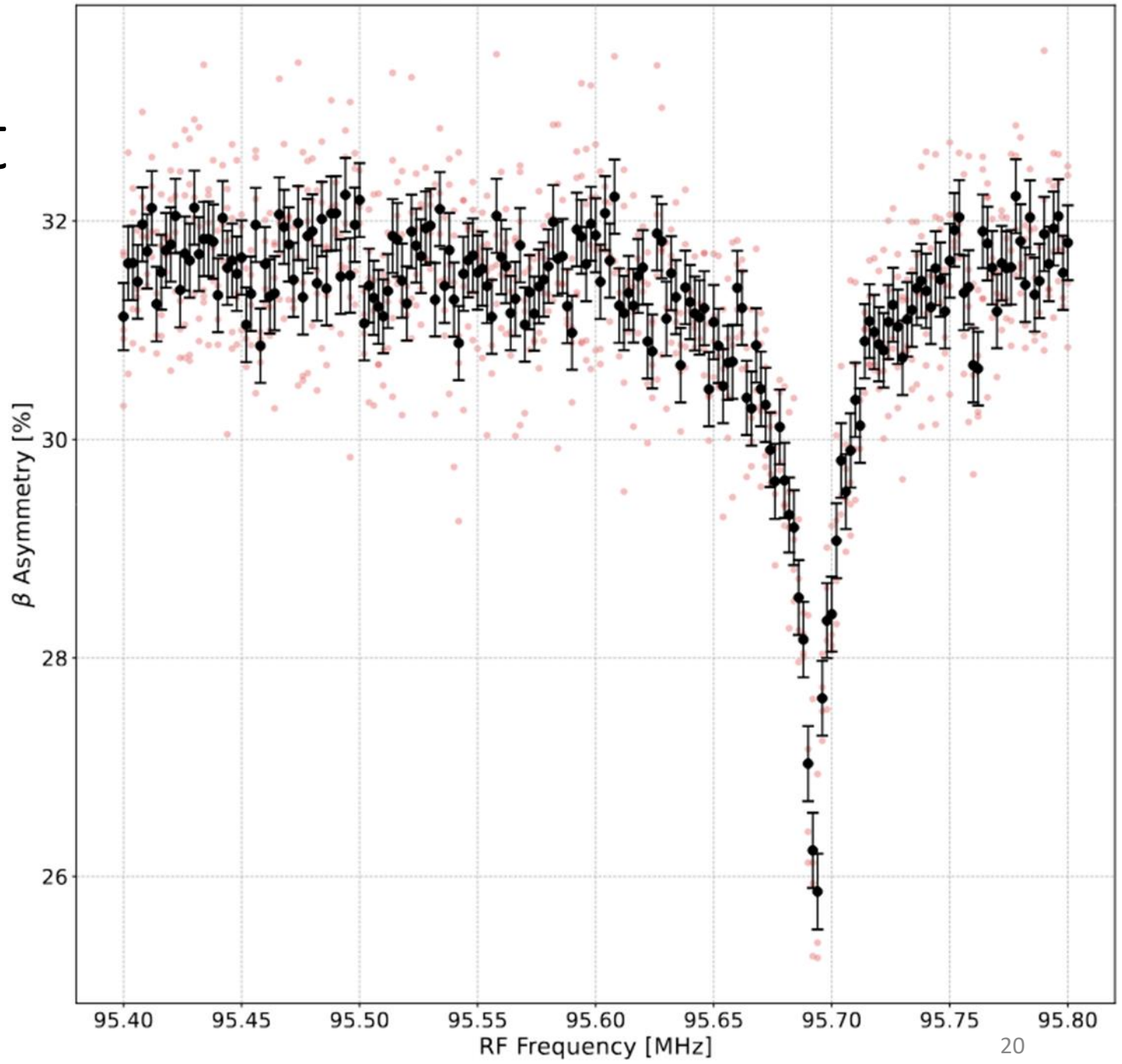
NMR Measurement of ^{49}K in KCl

Simply taking the normalized difference in counts between the detectors without considering the energy



NMR Measurement of ^{49}K in KCl

The same measurement but:
Exclude every count below an energy of 5MeV



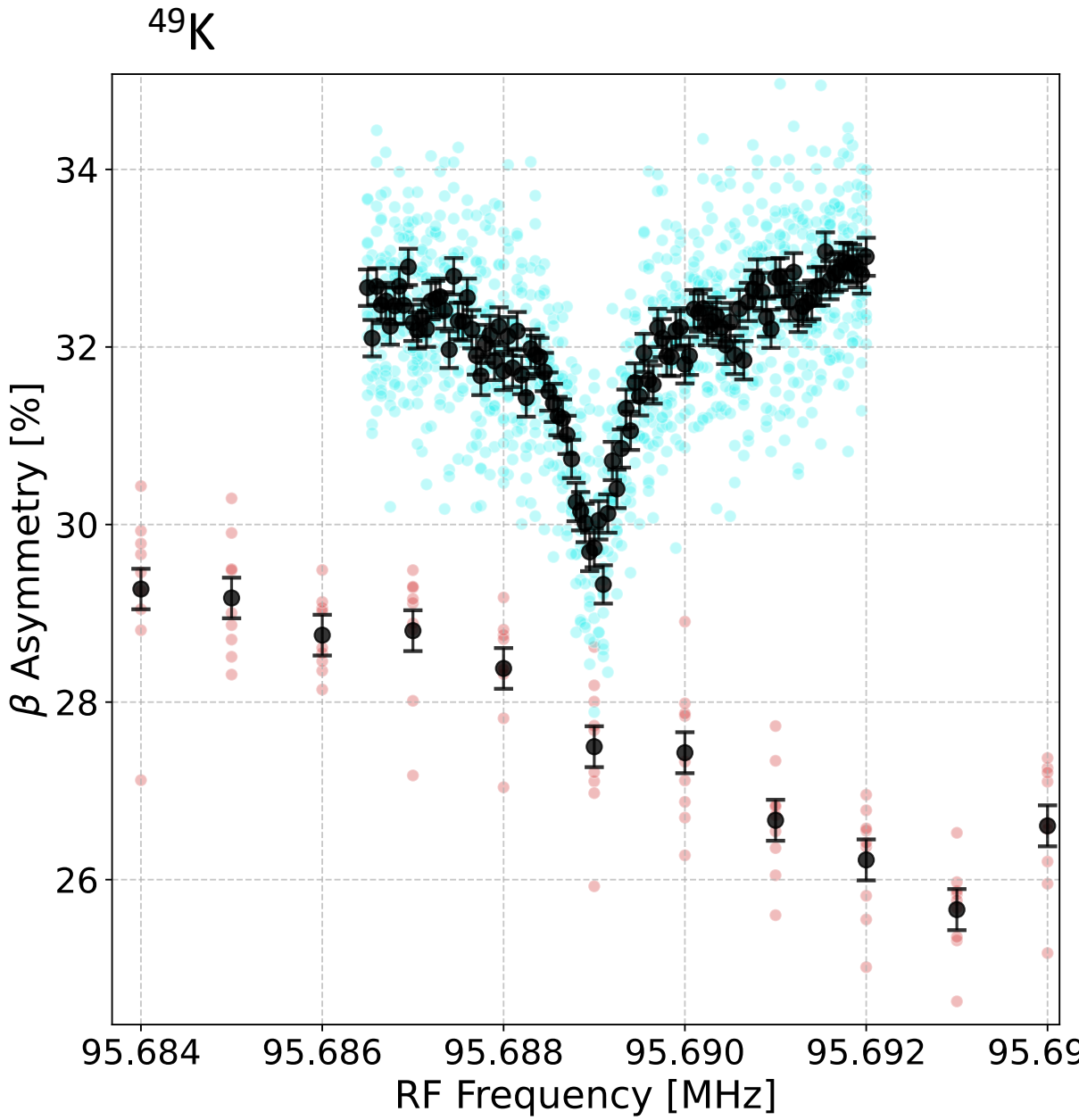
High Precision -ppm Measurements

Using a liquid host

-a low vapor-pressure ionic liquid, EMIM-DCA

- Field averaging effect
  -Molecular tumbling

ppm precision needed for: Bohr-Weisskopf effect
see talk tomorrow by A. Nagpal 11:55



Thank you,

Questions?

With funding from :

- Acknowledgements:
  - Dr. Mark Lloyd Bissell
  - ao. Univ.-Prof. Dr. Emmerich Kneringer
- **Thanks also goes to all VITO members and people associated with the experiment**:

- Mark Bissell, Anu Nagpal, Amy Sparks, Dalibor Zakoucky, Daniel Havranek, Hubert Tymoteusz Kulik, Ilaria Michelon, Jiri Jaluvka, Linus Rimpl, Marcus Jankowski, Mateusz Boleslaw Sienkiel, Michael Pesek, Michal Lupinski, Michal Mateusz Filipiak, Michal Sojka, Mikolaj Hubert Baranowski, Monika Piersa-Silkowska, Nikita Bernier, Nikolay Azaryan Ondrej Novak, Pawel Rak, Victoria Vedia, Jakub Michal Kaszowski, Magdalena Kowalska,