BetaShape Status

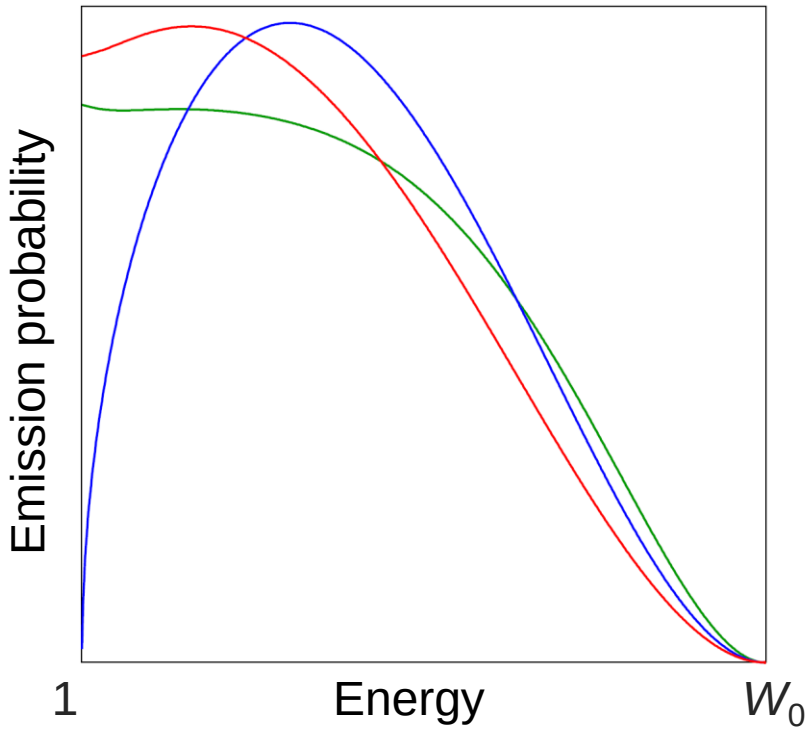
X. Mougeot, CEA-LNHB (France)

USNDP meeting 2025

Beta spectrum shape

Phase space Fermi function Shape factor

$$\frac{\mathrm{d}P}{\mathrm{d}W} \propto \boxed{pWq^2} \cdot \boxed{F(Z,W)} \cdot \boxed{C(W)}$$



W electron energy, W_0 transition energy

p electron momentum, q neutrino momentum

Allowed	$C(W) = 1$
First forbidden unique	$C(W) = q^2 + \lambda_2 p^2$
Second forbidden unique	$C(W) = q^4 + \lambda_2 q^2 p^2 + \lambda_3 p^4$
Third forbidden unique	$C(W) = q^6 + \lambda_2 q^4 p^2 + \lambda_3 q^2 p^4 + \lambda_4 p^6$
	Etc.

- ✓ The BetaShape program (version 2.4) now replaces the LogFT code. Electron captures also treated.
- ✓ $F(Z,W)$ and λ_k parameters determined from the relativistic electron wave functions, obtained by numerical solving of the Dirac equation.
- ✓ Included: extended nucleus; atomic exchange, overlap and screening; radiative corrections; database of experimental shape factors.

For forbidden non-unique transitions, coupling with nuclear structure is necessary.

→ ξ-approximation possible but accuracy is questionable.

Version 2.3 (September 2023)

Technical

- ✓ Rounding limit can be changed via a simple option.
- ✓ Provision of *f*-values and average energy of emitted neutrinos (B and EC).
- ✓ Handling of branching ratios (BR and NB from N and PN records) and propagation of their uncertainties.
- ✓ Modification of forbiddenness assignment when J^{π} are ambiguous.

Physical model

- ✓ Tabulation of atomic screening and exchange effects from full numerical calculations.
- ✓ Inclusion of the atomic overlap correction in beta decays. Negligible influence except close to the end-point energy, which can appear lower by hundreds of eV.

Uncertainties

- ✓ Treatment of non-numeric uncertainties (AP, SY, GT, etc.). Up to version 2.2, treated as null.
- ✓ Treatment of asymmetric uncertainties. Important for large uncertainties on intensities and transition energies.

Developments for the recent versions

✓ Feedbacks at 2023 USNDP meeting → **Version 2.3.1** in December 2023.

- A few bugs fixed in generated CSV files. Description of CSV format in a separate Microsoft Office Excel file.
- Insertion of a comment line with the code version in updated ENSDF files.

✓ Feedbacks at 2024 NSSD meeting → **Version 2.4** in June 2024.

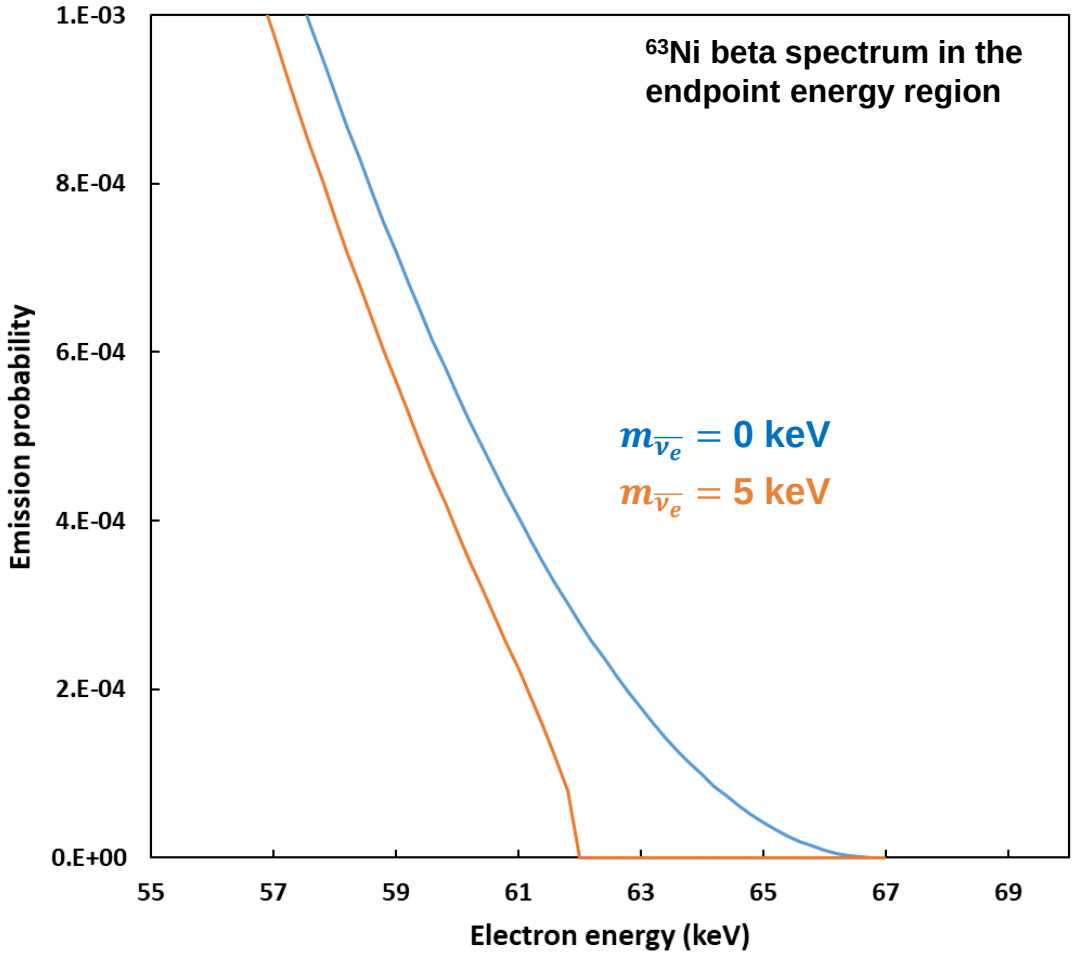
- Acceleration of electron capture calculations by a factor of 50 via an extensive tabulation of wave function overlaps.
- An environment variable (**`BSINSTALL`**) can be defined to run the code from any directory.
- Validation of the code on the entire ENSDF database, archived version of January 2024.

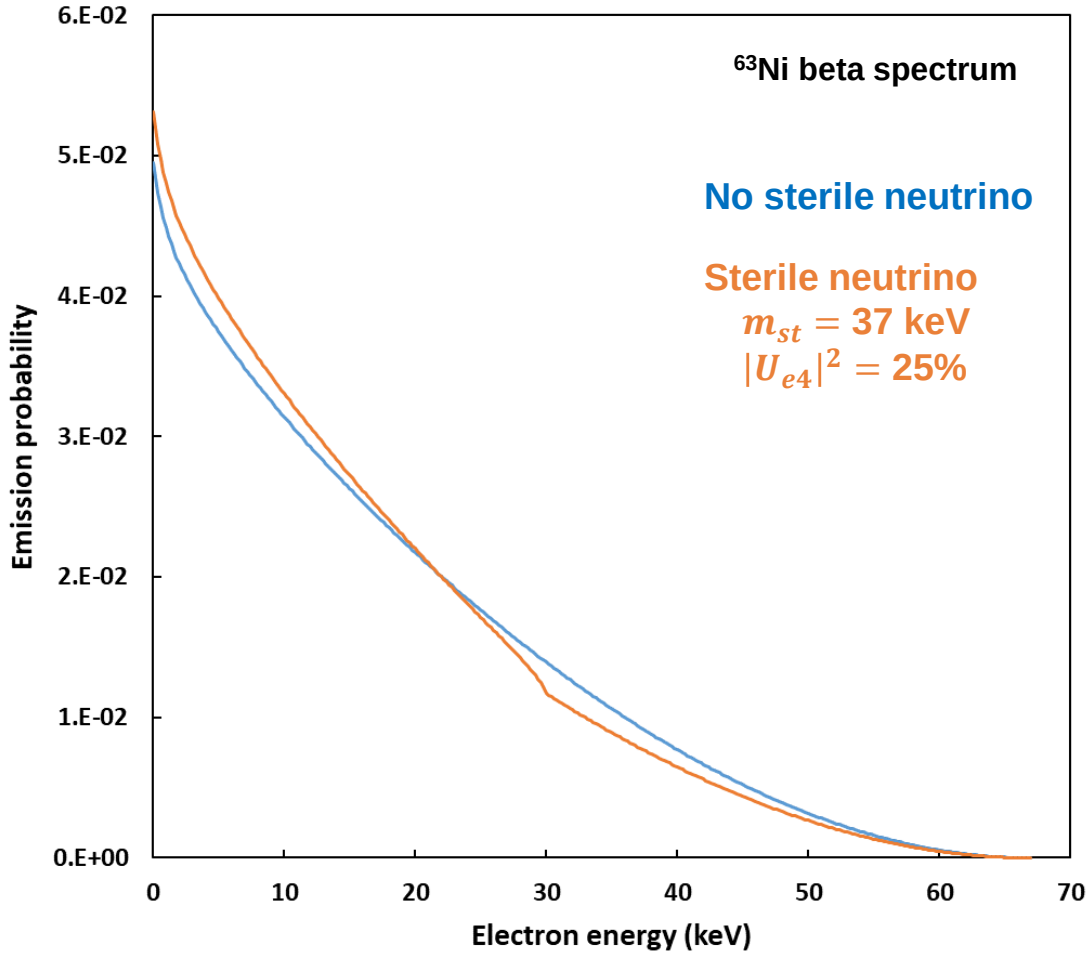
➢ **Version 2.5** (in preparation)

- Implementation of a “help” option to facilitate use.
- EC decays: Provision of the atomic orbital energies and of the neutrino energies.
- B decays: Possibility to define a non-zero mass to the neutrino, and to add a sterile neutrino (mass, amplitude).
- Implementation ongoing: improved uncertainty propagation on BR and NB from N and PN records (following Jun Chen’s recommendations).

→ Feel free to send me any bug report or suggestion of improvements.

Massive neutrinos in beta decays

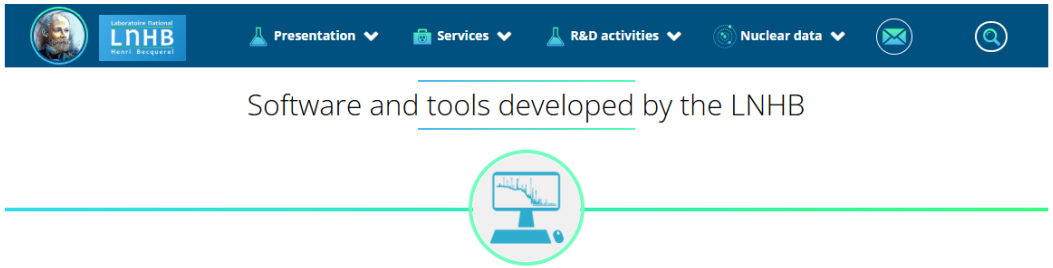




Where to get BetaShape

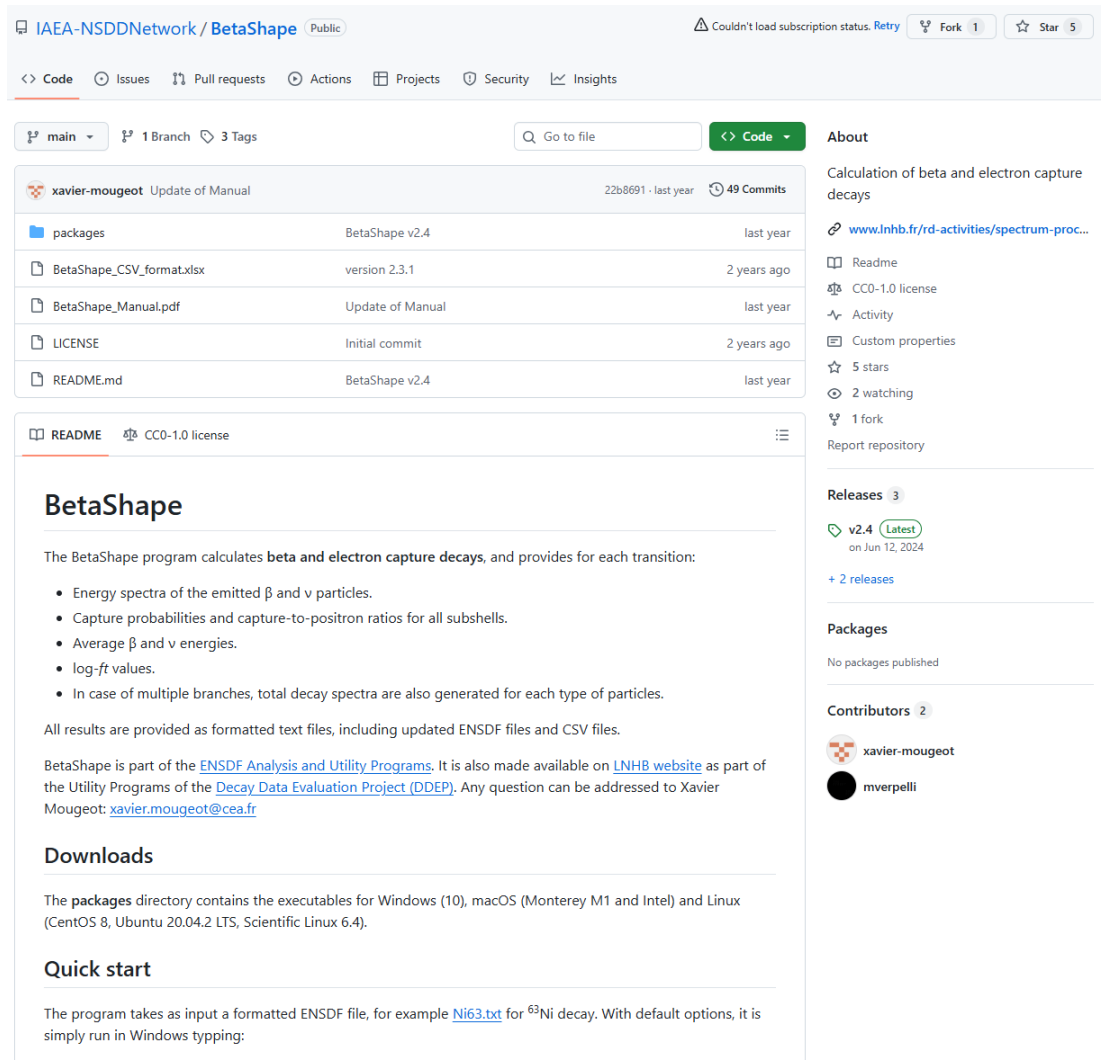
LNHB website

http://www.lnhb.fr/rd-activities/spectrum-processing-software/



IAEA-NSDD GitHub Repository

https://github.com/IAEA-NSDDNetwork



ICRM2025 Conference

The CEA-LNHB organized the 24th International Conference on Radionuclide Metrology and its applications (ICRM2025).

This biannual conference is very structuring for our metrology community.

- ✓ > 220 participants from 33 countries of all the continents.
- ✓ Scientific Committee decision:
  - 43 Orals and 106 Posters.
  - 113 abstracts selected for an article in a Special Issue of Applied Radiation and Isotopes.
  - 16 abstracts as ICRM Technical Series.
- ➢ Edition part is not over yet. Still some articles under review.

CONFERENCE TOPICS

- Aspects of international metrology
- Intercomparisons
- Measurement standards and reference materials
- Radionuclide metrology techniques
- Alpha-particle and beta-particle spectrometry
- Gamma-ray spectrometry
- Liquid scintillation counting techniques
- Nuclear decay data
- Low-level measurement techniques
- Radionuclide metrology in life sciences
- Source preparation techniques
- Quality assurance and uncertainty evaluation in radioactivity measurements

ICRM 2025

24th International Conference on Radionuclide Metrology and its applications

19-23 May 2025
Paris
France

https://icrm2025.org/

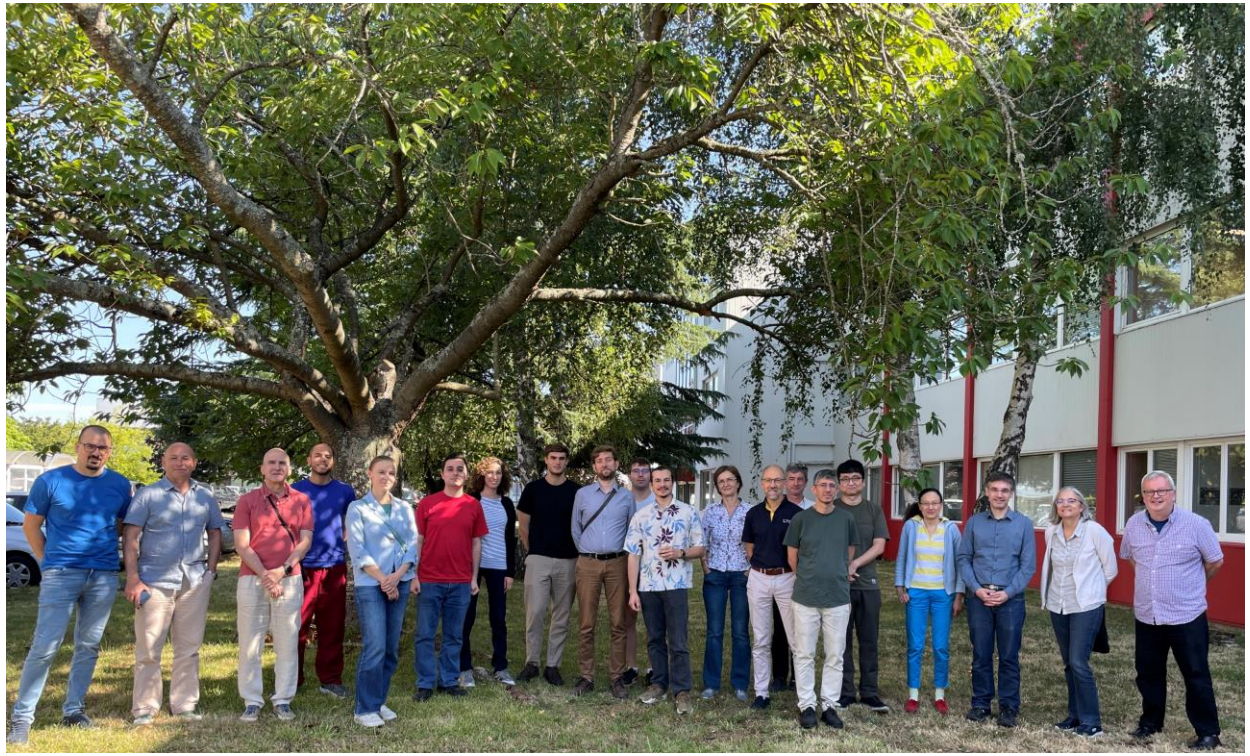
ESNT Workshop

Organization of workshop within the Theoretical Nuclear Structure and reaction framework of CEA/Irfu (Fundamental Research Division).

Probing nuclear structure with beta-decay energy spectra

CEA Saclay, 7-10 July 2025

- ✓ Scientific organization with B.C. Rasco from ORNL.
- ✓ 21 participants from Canada, Germany, Italy, Spain, UK, USA, and France (Metrology, Strasbourg University, IJCLab, CEA/Irfu, CEA/DAM).
- ✓ Half theorists, half experimentalists.
- ✓ Very interesting for all the participants. Another edition is in preparation, most probably in September 2026.



Program and presentations available on the ESNT website:

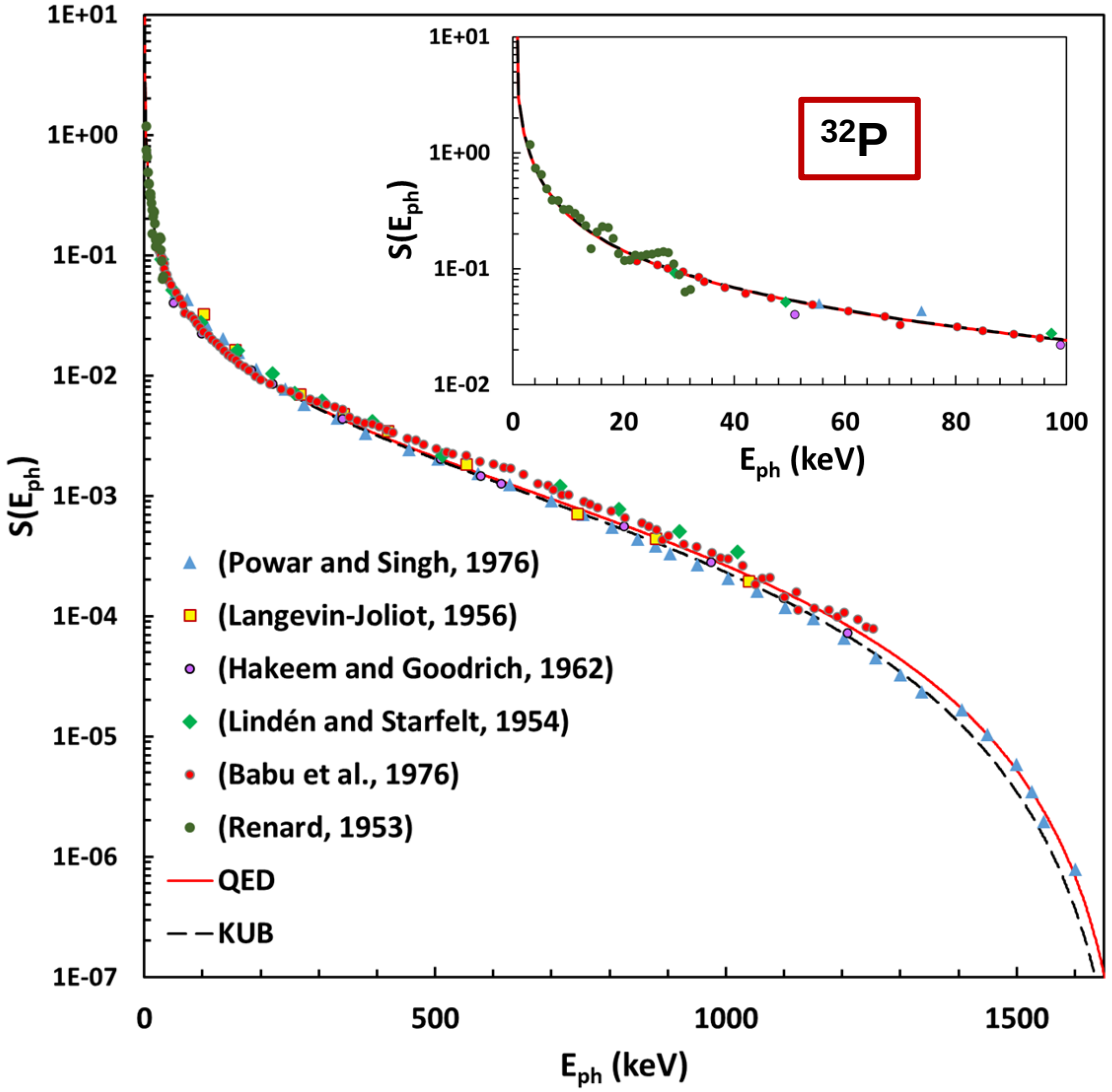
https://esnt.cea.fr/Phocea/Page/index.php?id=129

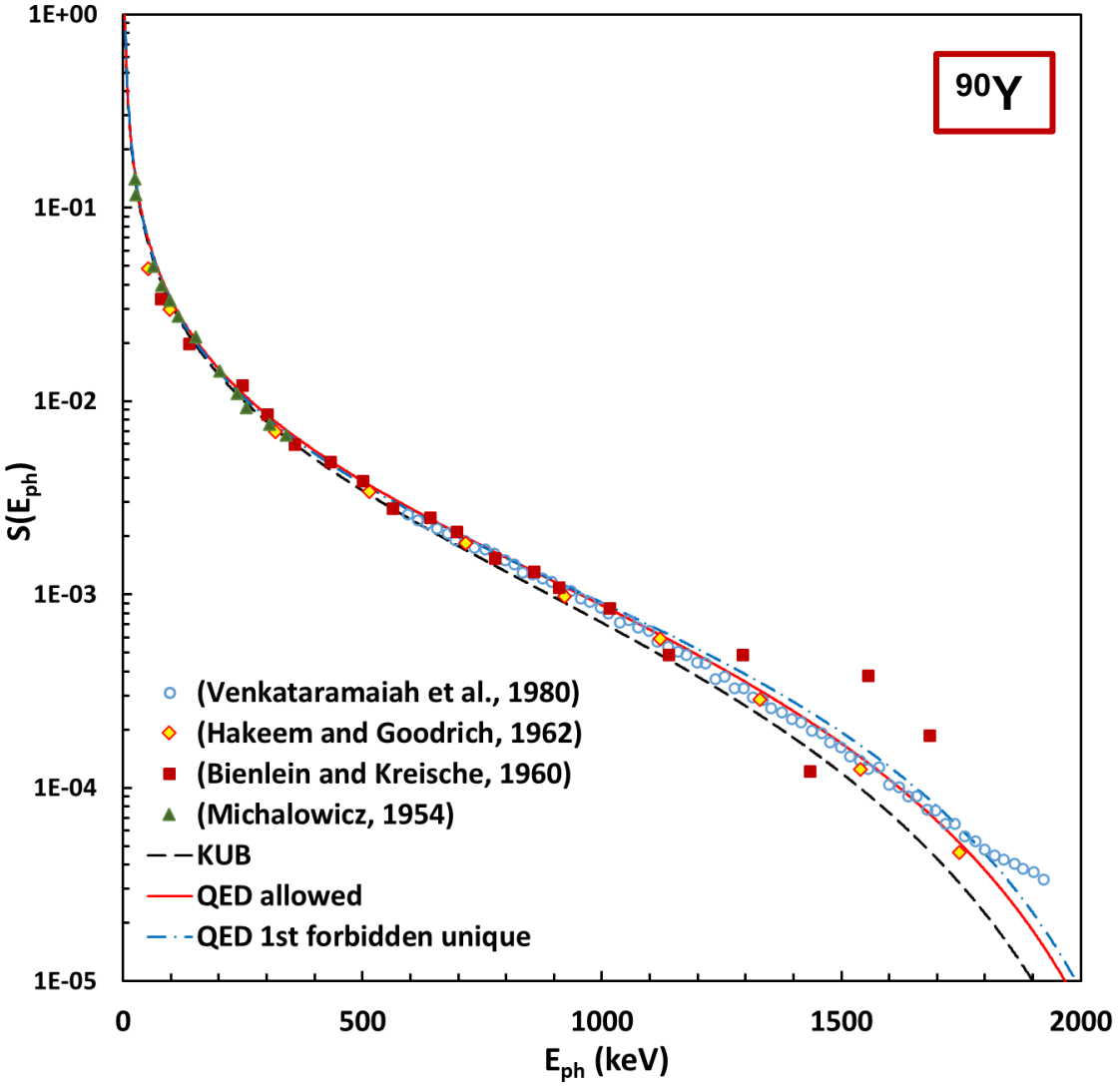
Internal bremsstrahlung

This process is part of the radiative corrections, in which the **emitted soft photons** are assumed lost for the detection. In reality, these photons are **partially reabsorbed in the measurement**.

- ✓ Two theoretical formalisms studied, with specific work to ensure consistency of the observables:
  - The simplest from **KUB** (Knipp and Uhlenbeck, Bloch; 1936). No Coulomb effect.
  - The most accurate derived from **QED** (Ivanov et al., 2014). Coulomb effect and nucleus recoil.
- ✓ **Development of a dedicated code**, linked to BetaShape for the beta spectra.
- ✓ Review of the measurements available in the literature. Correction and selection of the most accurate.
- ✓ Validation of the theoretical predictions on ^{6}He, ^{35}S, ^{32}P, ^{90}Y. Allowed and first forbidden unique transitions.
- ✓ Realistic Geant4 Monte Carlo simulations to quantify the influence on the beta spectrum:
  - ^{32}P in an ultra-thin source measured with a 4π Si(Li) spectrometer.
  - ^{99}Tc in the gold absorber of a Metallic Magnetic Calorimeter.
- ✓ Very high statistics required for a significant effect (10^{8} and 10^{9}, respectively). Flexible method for any type of radionuclide and any type of experimental device.
- ✓ Published in Applied Radiation and Isotopes 226, 112197 (2025) within the ICRM2025 conference.

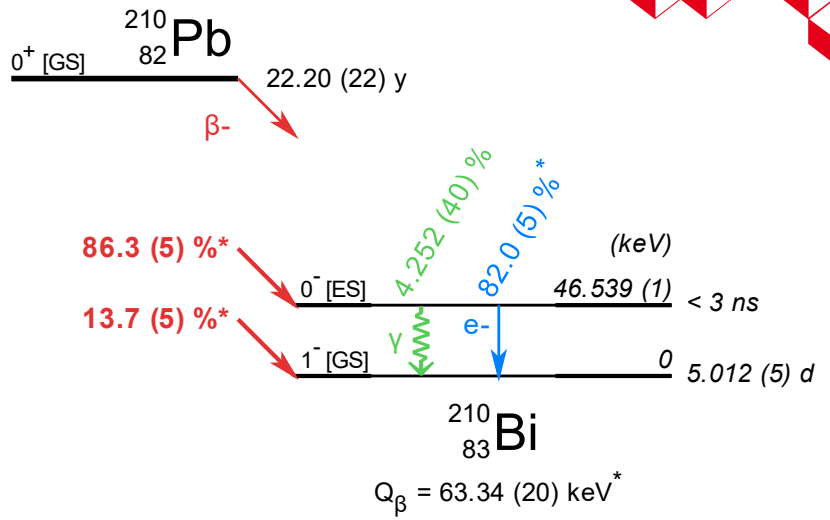
Internal bremsstrahlung

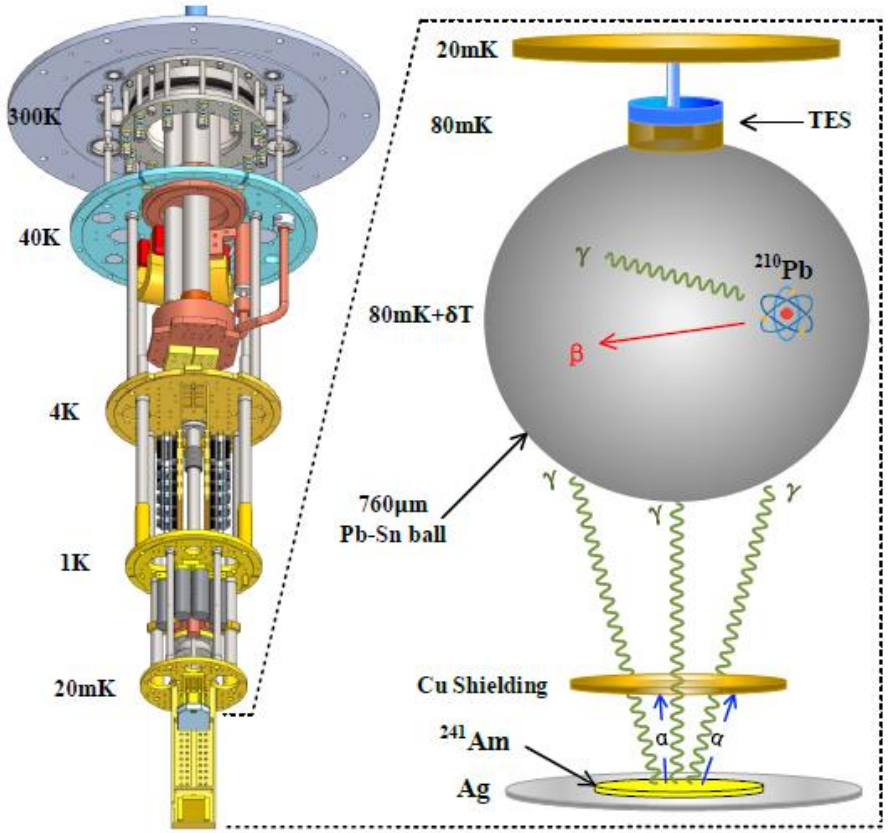




Atomic exchange effect

- ✓ High-precision measurement of the ^{210}Pb decay with a cryogenic Transition Edge Sensor at ShanghaiTech University. **Threshold-free.**
- ✓ Improvement of the atomic exchange modelling:
  - Accurate atomic model, based on RDFT and benchmarked on DF-MCDF calculations.
  - Consistent atomic and continuum electron wave functions.
- ✓ Significant influence of the atomic modelling. The one within BetaShape leads to worse agreement.
- ✓ Improved nuclear data (*): Q-value, branching ratios, and emission probability of the internal conversion electrons; γ transition admixture, $|\delta|$ and α_T deduced.
- ➢ S. Zhang et al., arXiv:2509.26390 (2025). Under review at Nature.





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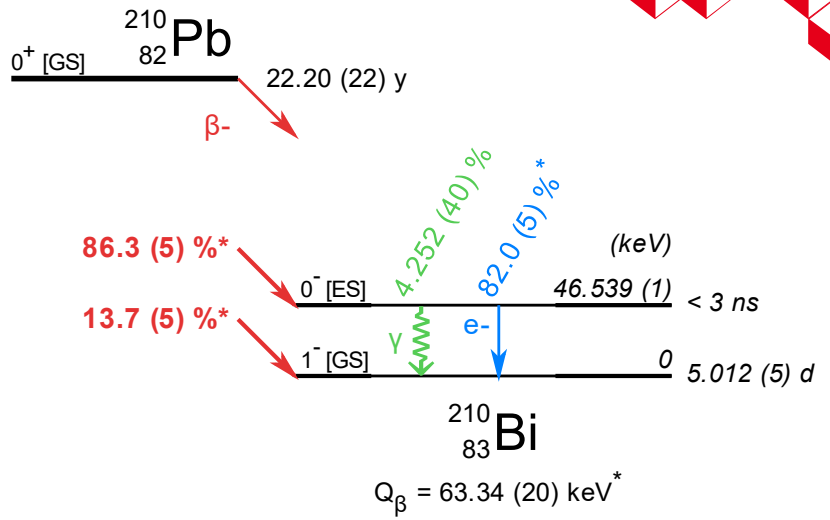

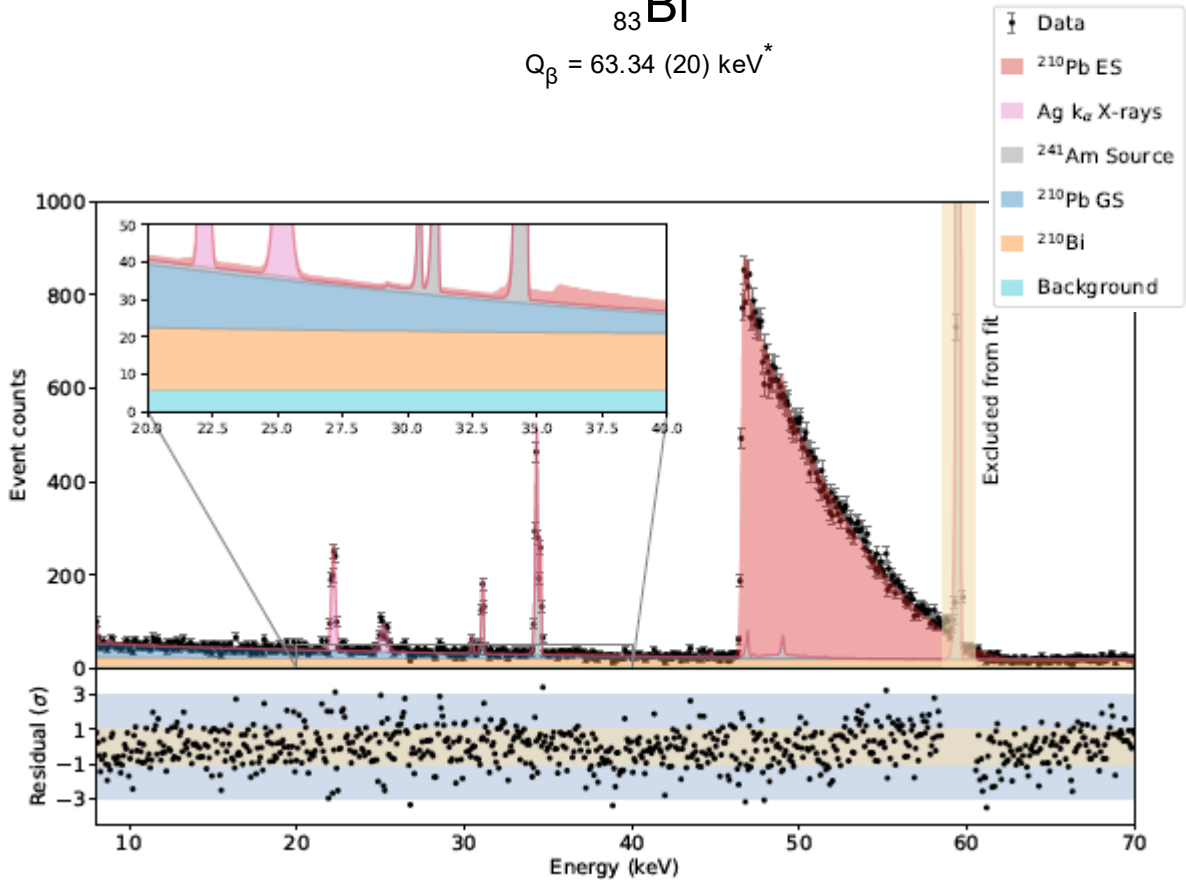

Thank you for attention