Internal Bremsstrahlung in beta decays

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Summary

In standard beta decay calculations, the internal Bremsstrahlung process is included in the radiative corrections. When compared to measurements, the emitted soft photons are assumed to be lost in the detection process or totally absorbed by the apparatus. This work aims at estimating the influence on the beta spectrum shape of a partial absorption of these photons, which corresponds to the real situation. A custom code was developed with the oldest and the most recent formalisms, and validated against high-quality measurements. Two realistic devices were simulated with Geant4: a 4π Si(Li) spectrometer measuring ^{32}P decay, and a metallic magnetic calorimeter measuring ^{99}Tc decay. As a result, high statistics (> 10^8 and > 10^9 counts, respectively) would be necessary to be sensitive to internal Bremsstrahlung, dominantly in the endpoint region.

Theory

The process

Internal Bremsstrahlung refers to the emission of soft photons by a β particle leaving the atom, thus accelerated or decelerated in the nucleus field. These photons can have all energies up to the endpoint energy of the β spectrum.

The first model from Knipp, Uhlenbeck and Bloch (KUB) [1,2]

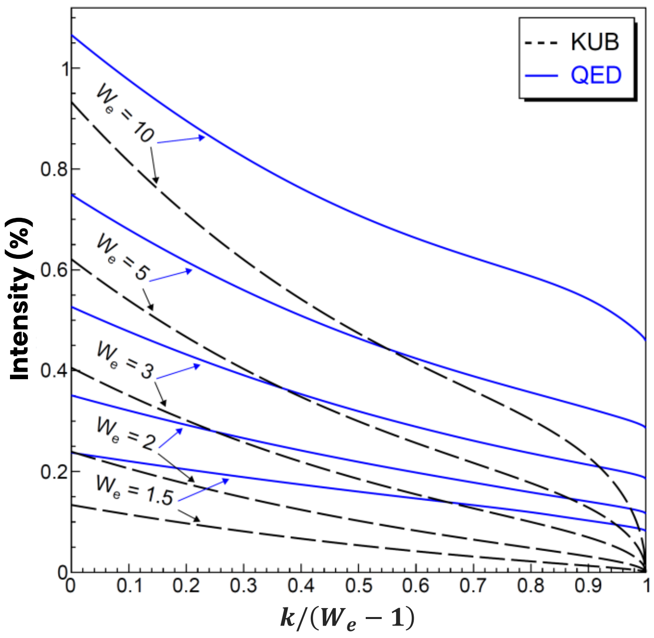
Established with plane waves and ignoring Coulomb effects, the formalism assumes a two-independent-step process: 1) β particle emission, and 2) soft photon emission. The number of photons $S(k)$ emitted with an energy k is then:

$$S(k) = \int_{1+k}^{W_0} P(W_e)\,\phi(W_e,k)\,\mathrm{d}W_e \qquad \text{where} \qquad \phi(W_e,k) = \frac{\alpha}{\pi k}\cdot\frac{p}{p_e}\left[\frac{W_e^{\,2}+W^2}{W_e p}\ln(W+p) - 2\right]$$

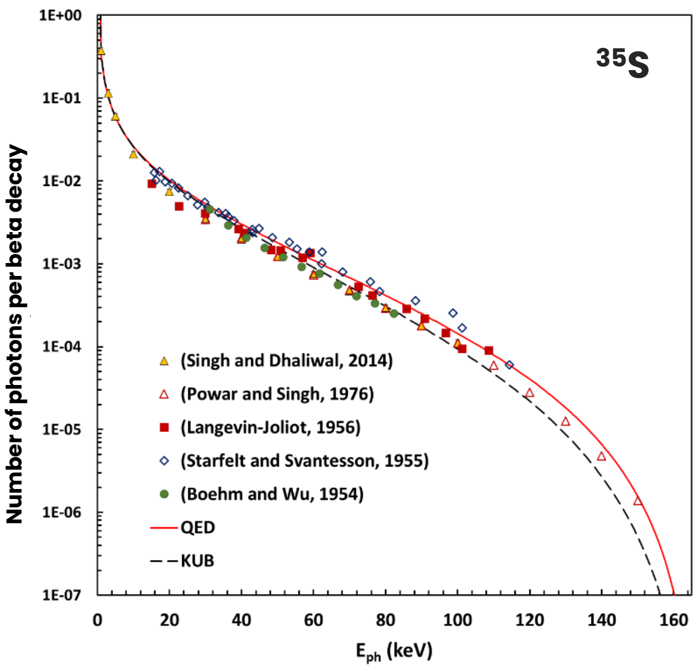
is the conditional probability that a β particle emitted with an energy W_e radiates a photon. $P(W_e)$ may come from a measured beta spectrum or from any theoretical model.

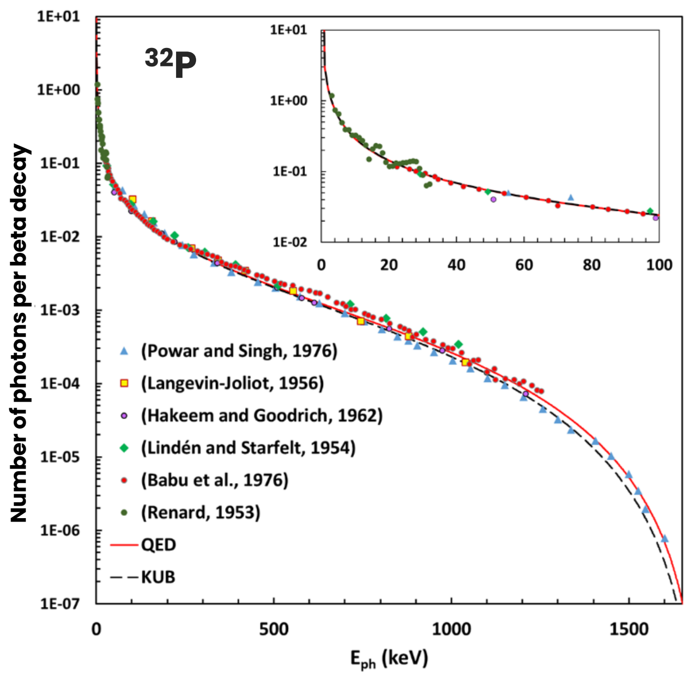
The most recent model derived from quantum electrodynamics (QED) [3]

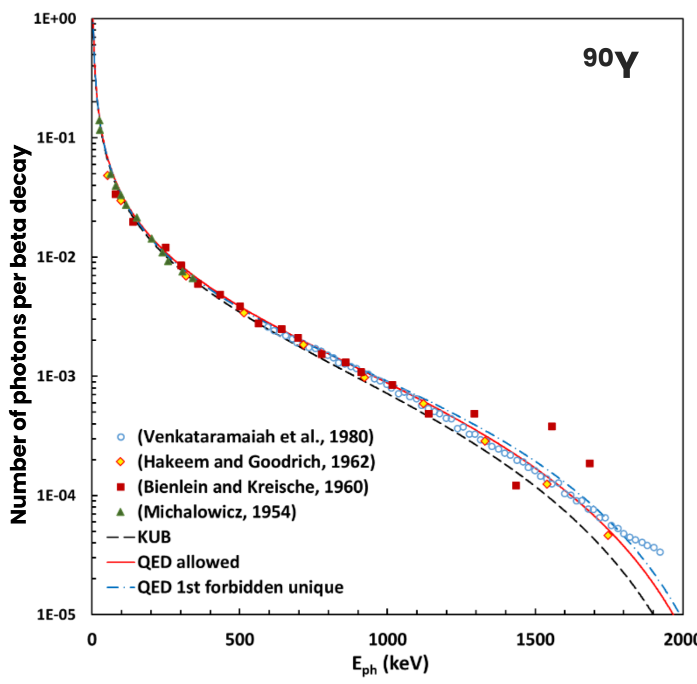
The formalism was revisited with a consistent QED analysis including Coulomb effects and daughter nucleus recoil. The equivalent of $\phi(W_e,k)$ depends on the beta spectrum shape, calculated with BetaShape [4]. The figure on the right presents intensity distribution curves for different initial beta energies, with dominant emission of low-energy photons.



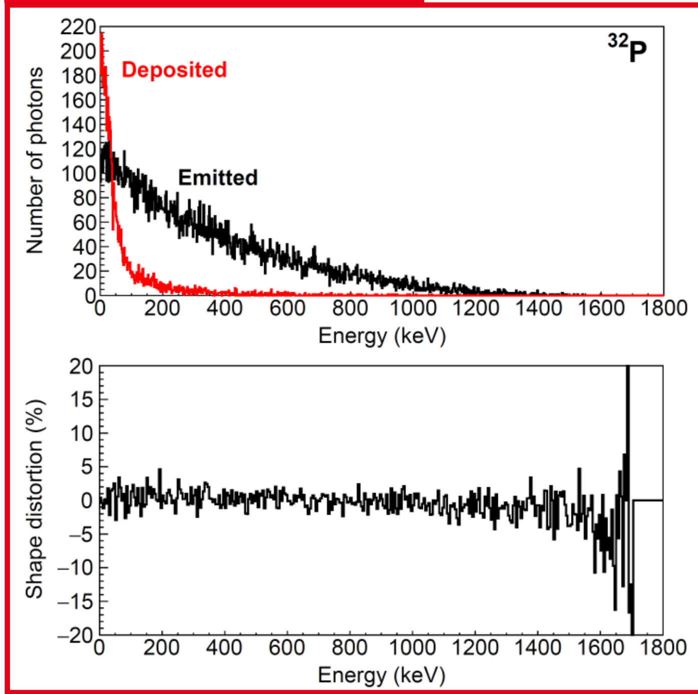
Comparison with measurements







Geant4 simulations



Geant4 11.0.3

- Standard EM physics list (option 4). 200 eV cuts for e⁻ and γ.
- Primary events: 10^7 for ^{32}P, 10^8 for ^{99}Tc. KUB model only.

4π Si(Li) spectrometer [5] measuring ^{32}P decay

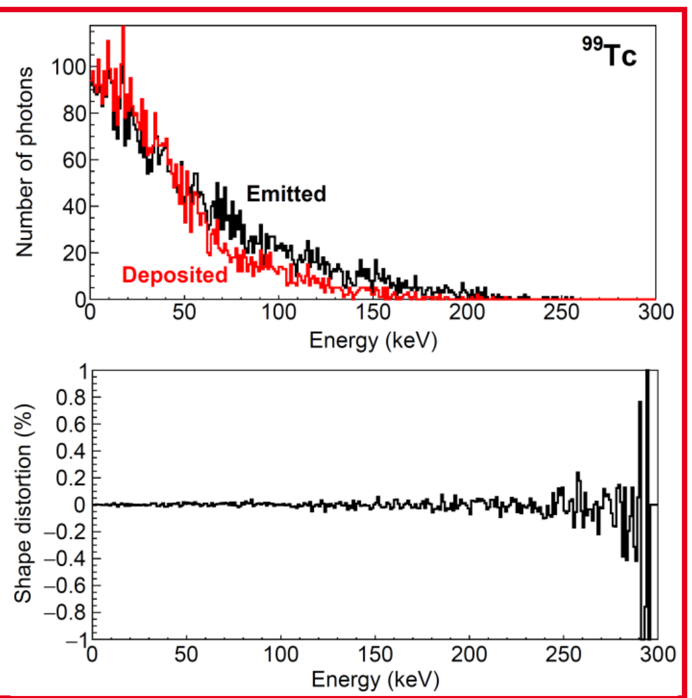
- Realistic detection geometry: two detectors, 5 mm thick and 500 mm² active area, spaced by 1.9 mm; 1 µm thick Mylar source.
- Small shape distortion in the endpoint energy region.

➢ > 10^8 events needed to be sensitive to internal Bremsstrahlung.

Metallic magnetic calorimeter measuring ^{99}Tc decay [6]

- Realistic geometry: gold cylinder, 700 µm diameter and 180 µm thick; source as cylinder, 500 µm diameter and 1 µm thick.
- Shape distortion barely visible.

➢ > 10^9 events needed to be sensitive to internal Bremsstrahlung.



[1] Knipp *et al.*, Physica 3, 425 (1936) [2] Bloch, PR 50, 272 (1936) [3] Ivanov *et al.*, PRC 90, 064608 (2014) [4] Mougeot, ARI 201, 111018 (2023) [5] Craveiro *et al.*, O-38, ICRM2025 [6] Paulsen *et al.*, PRC 110, 055503 (2024)