Uncertainty Assessment in Computational Dosimetry:

A comparison of Approaches

Euratom VI Framework Programme

Microdosimetric distributions and pulse-height spectra for a mini-TEPC due to photon radiation

Elisabetta Gargioni, Sofia Rollet, Bernd Grosswendt

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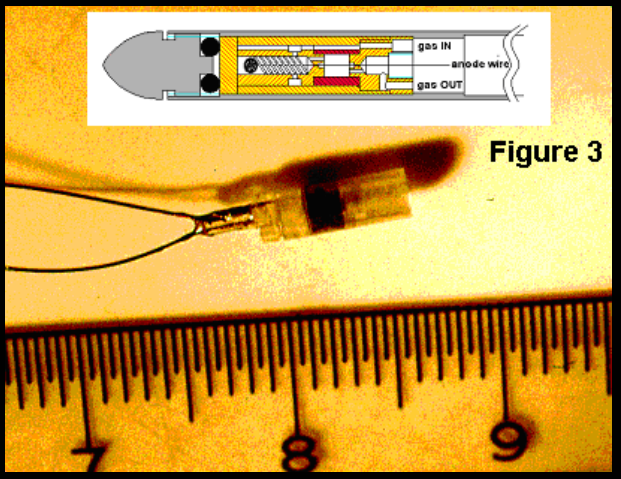
PTB

mini-TEPC developed at INFN-LNL (Paolo Colautti's group)

calibration with external source



INFN

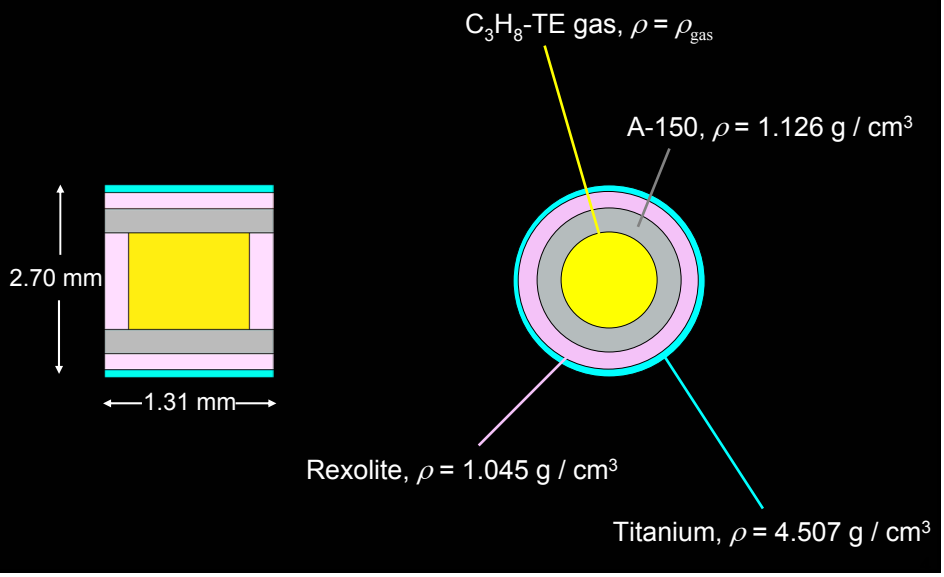
Main characteristics of mini-TEPCs

They are reliable detectors which can work in highly intense fluxes

use in clinical dosimetry

different site diameters:
$2\mu m \leq D \leq 0.3\ \mu m$

Simplified geometry of the mini-TEPC (courtesy of Paolo Colautti)



Monte Carlo study

Calculation of

pulse-height spectra

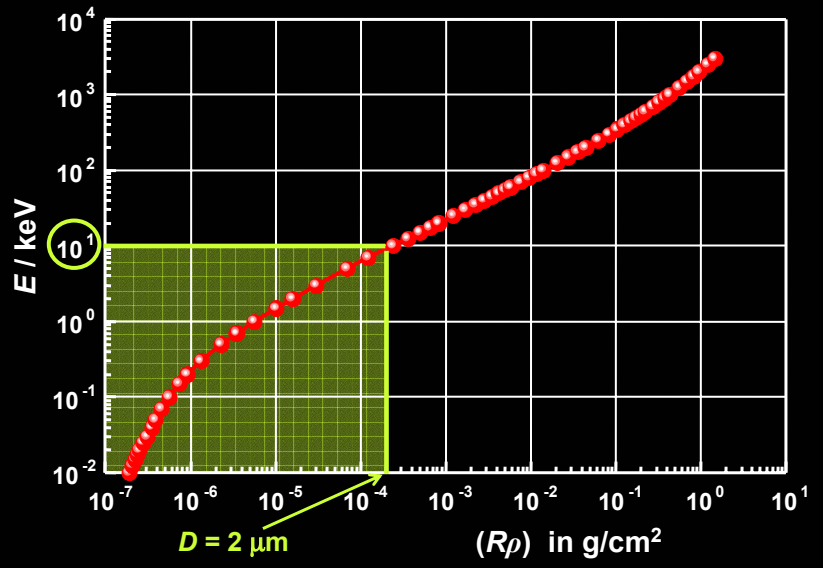
due to

250-kV X-rays, ^{137}Cs, ^{60}Co

using three codes:

"MINI-TEPC", MCNP, and FLUKA

Electron CSDA-range in propane-based TE-gas



Problematic aspects in the MC calculation

low-energy electrons play
the most important role

→ energy threshold, energy deposition

small sensitive volume

→ statistics

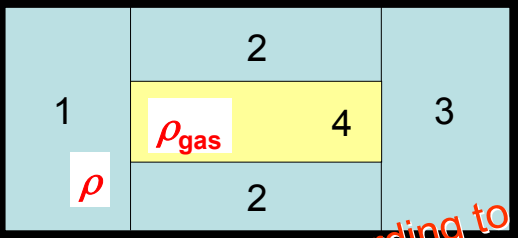
MC code: "MINI-TEPC.FOR"
(developed by B. Grosswendt)

event-by-event simulation for electrons down to 10 eV
(FLUKA, MCNP: 1 keV)

ad-hoc geometry specification

ad-hoc application of variance reduction techniques

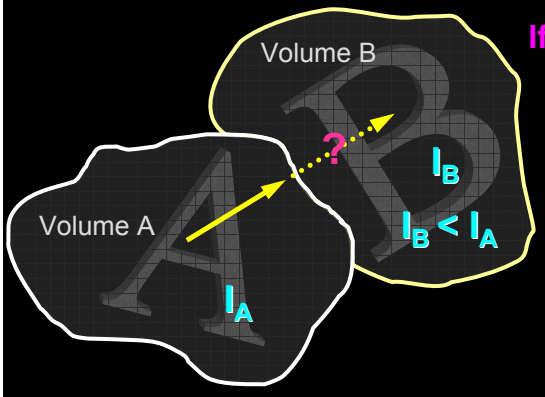
Detector model in "MINI-TEPC": first approximation



scaling according to the density

simplified geometry with one material (propane-TE)

Variance reduction: Russian roulette



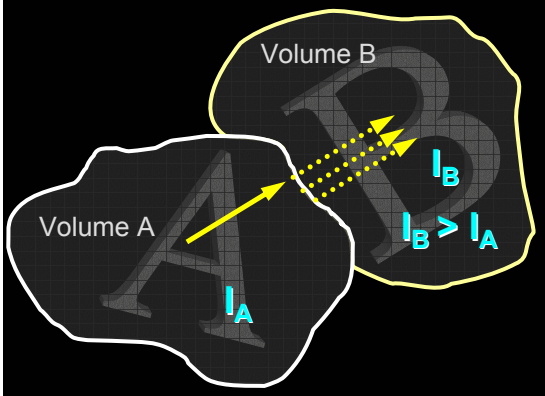
If *r* < 1 play Russian roulette:

with probability ***r***, **keep** the particle and alter its weight to (***wgt / r***)

with probability **(1-*r*)**, **kill** the particle
→ weight set to **0**

total particle weight is only statistically conserved

Geometry splitting

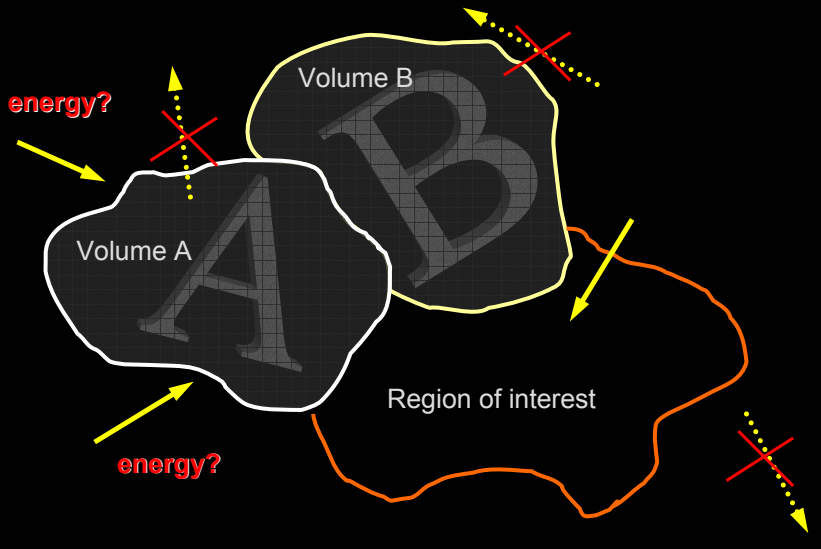


$r = l_B / l_A$

$n = \text{int}(r)$

All *n* particles emerging from splitting have the same attributes, including *wgt‘ = wgt / n*

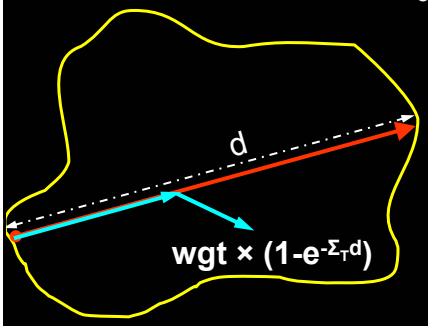
Truncation



Remove particle from part of phase space that do not contribute to the final results

Forced collisions

Particles entering specified cells are split into collided and uncollided parts:



For distance-to-boundary *d*:

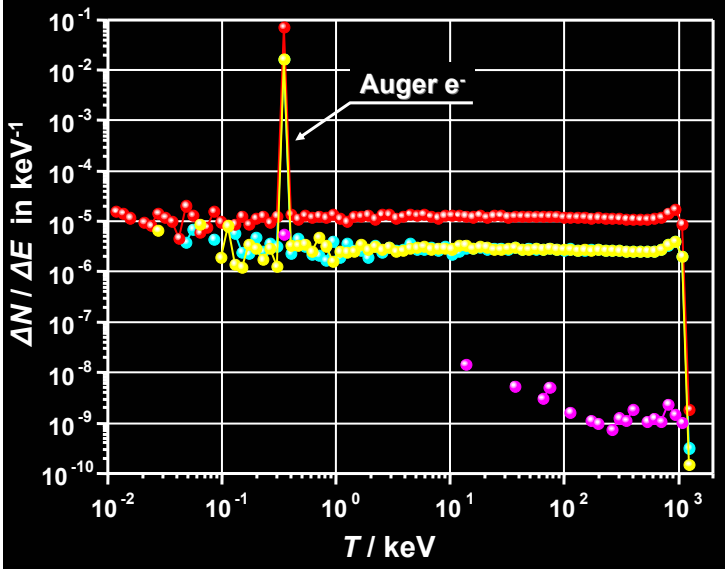
probability(no-collision) = $\exp(-\Sigma_T)d$

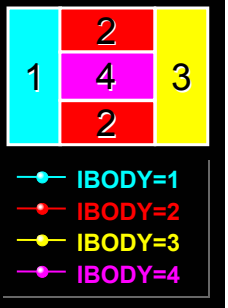
probability(collision) = $1-\exp(-\Sigma_T)d$

Σ_T = total scattering cross section

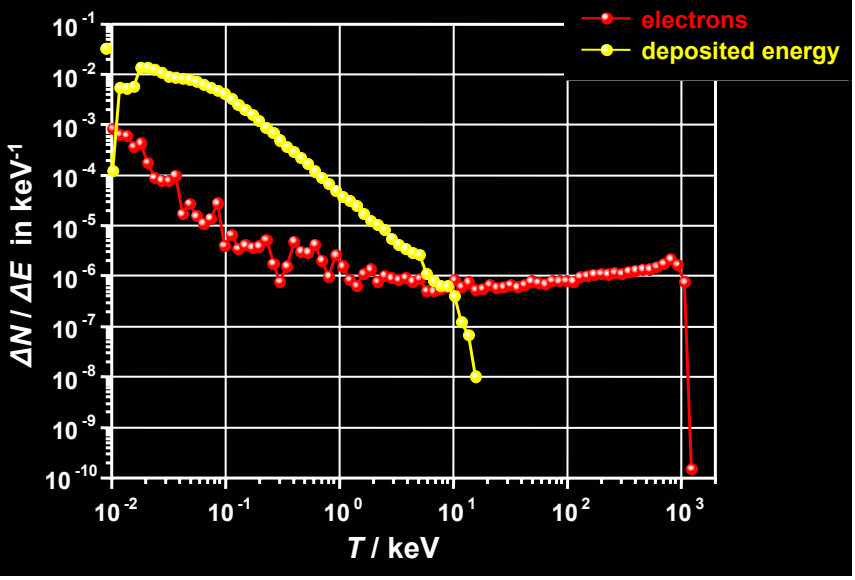
Secondary electron distribution for ^{60}Co-photons

Greatest contribution from the wall!



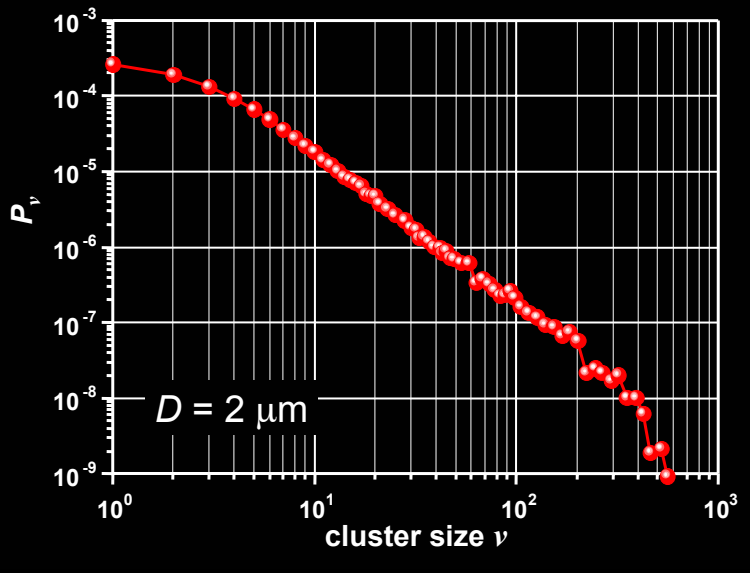


Pulse-height spectrum for ^{60}Co-photons in the gas cavity (D = 2 μm)

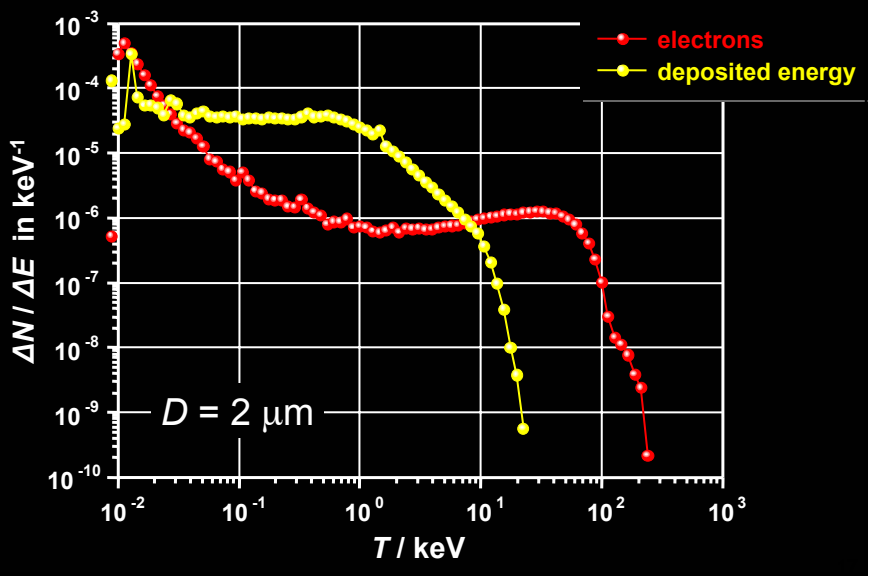


Cluster-size distribution for ^{60}Co-photons

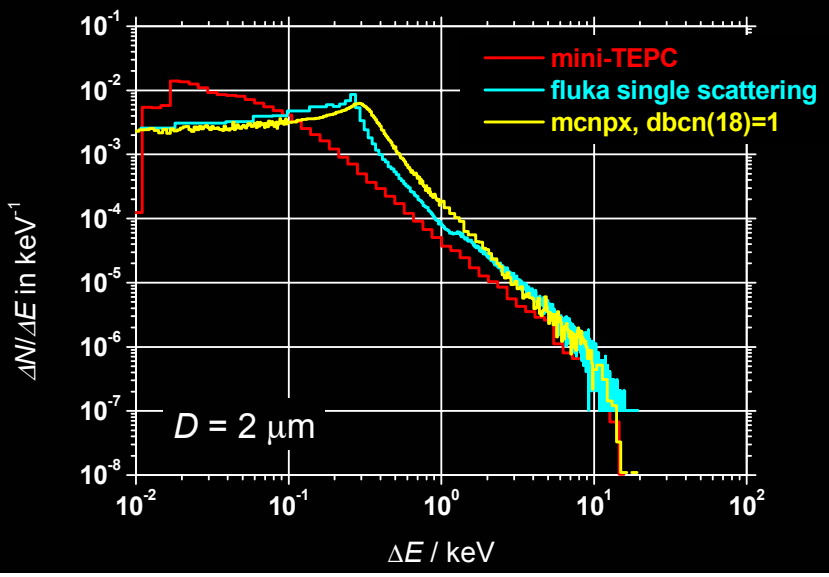
used variance reduction: russian roulette + electron splitting



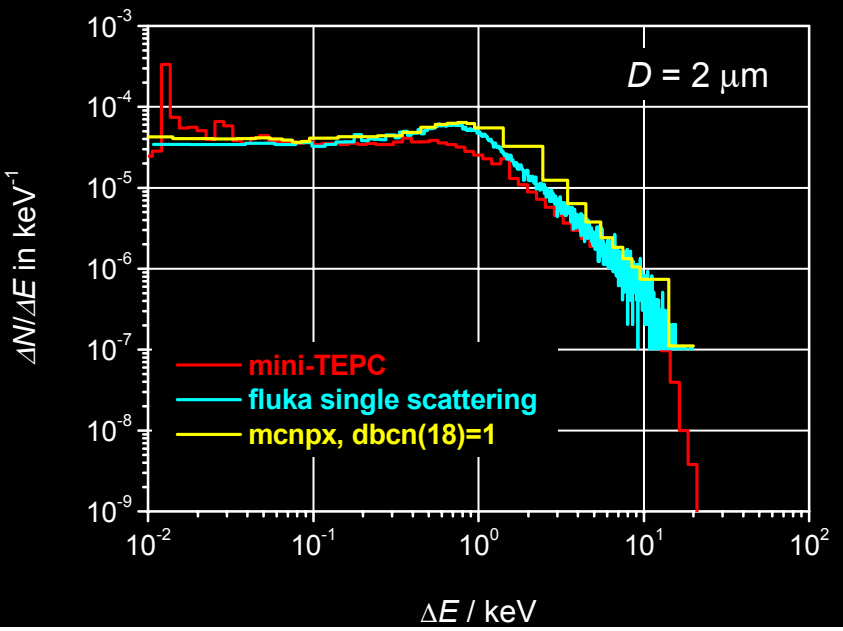
Pulse-height spectrum for 250-kV photons in the gas cavity



Pulse-height spectrum for ^{60}Co: Comparison of codes



Comparison of codes: 250-keV photons



Disagreement possibly due to…

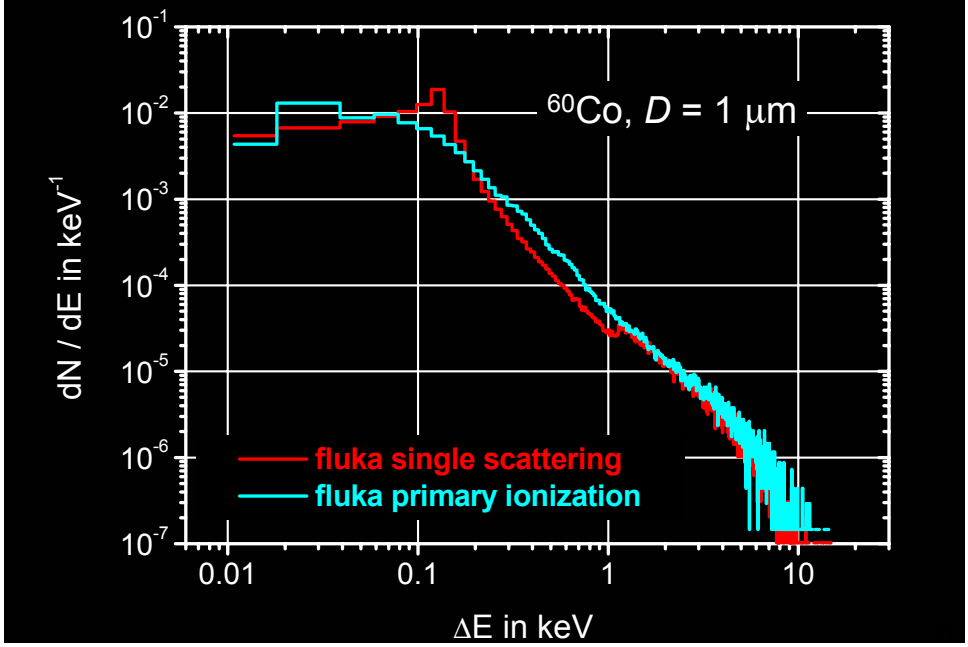
… particle-track description

… energy threshold for electron transport

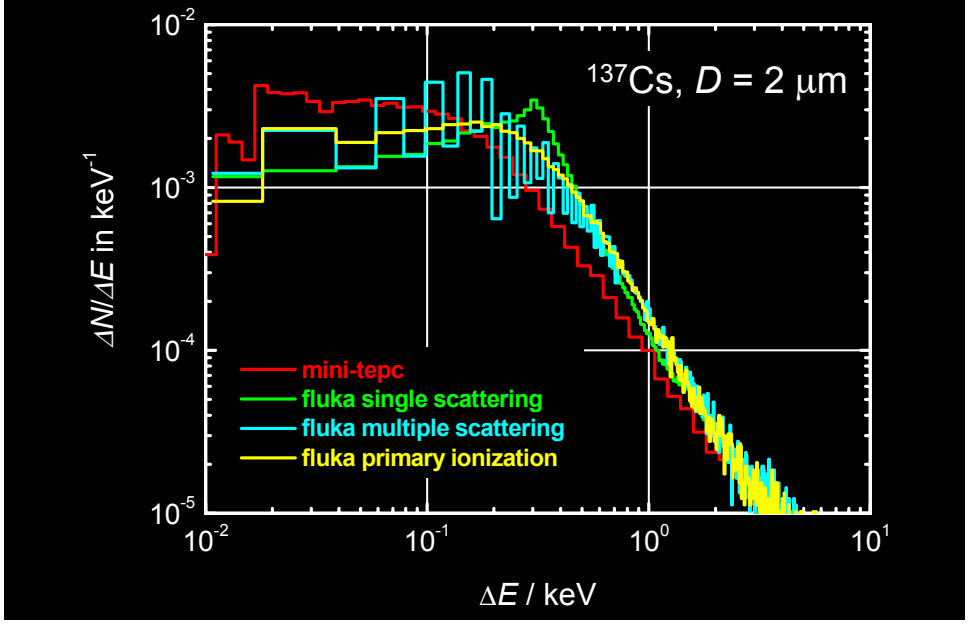
… sampling of energy straggling

… different cross-section data

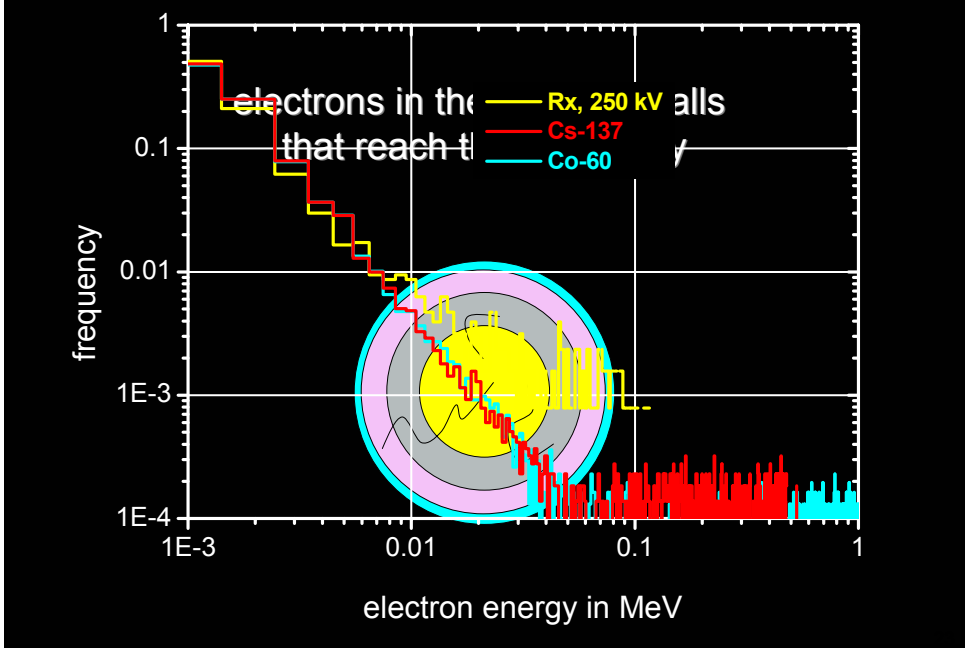
Different straggling algorithms in FLUKA



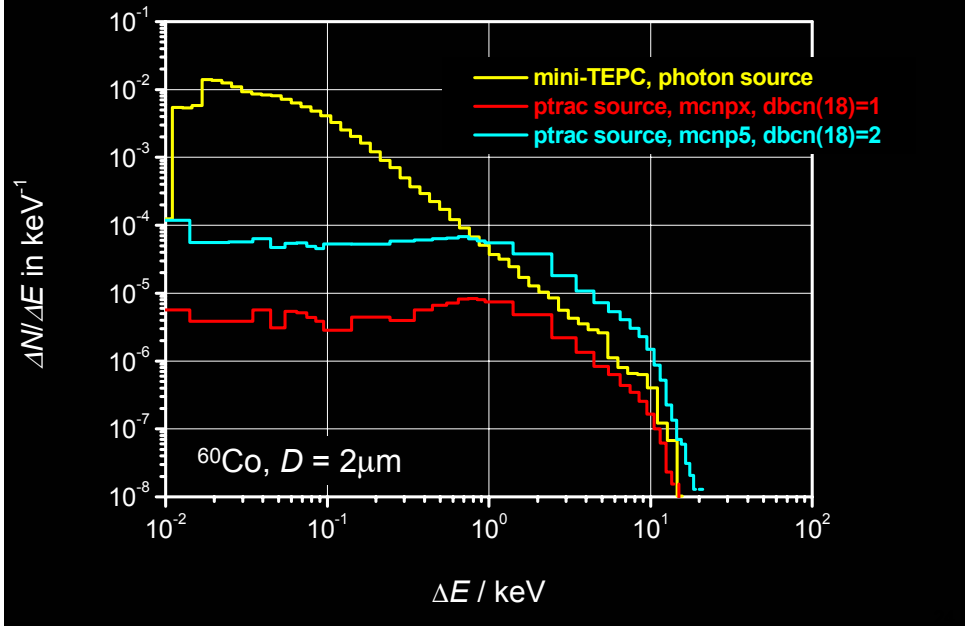
Different straggling algorithms in FLUKA



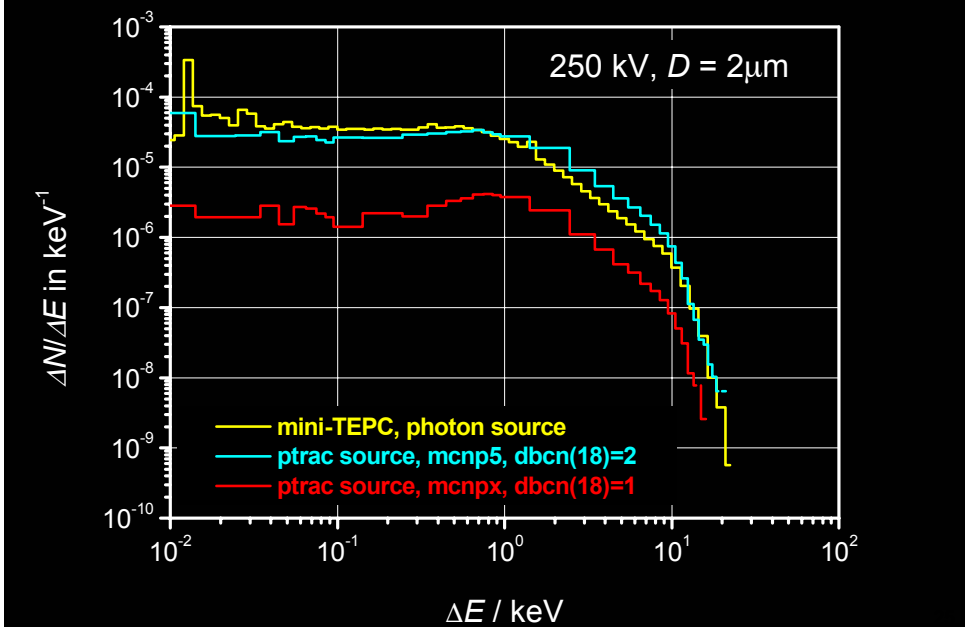
Tracking electrons with MCNP: PTRAC



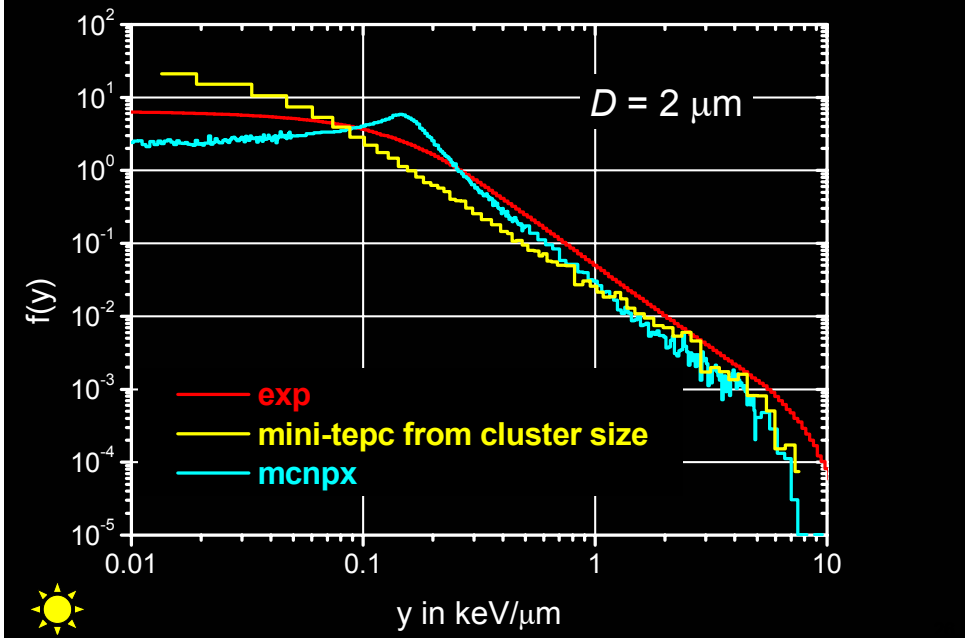
Different straggling algorithms in MCNP



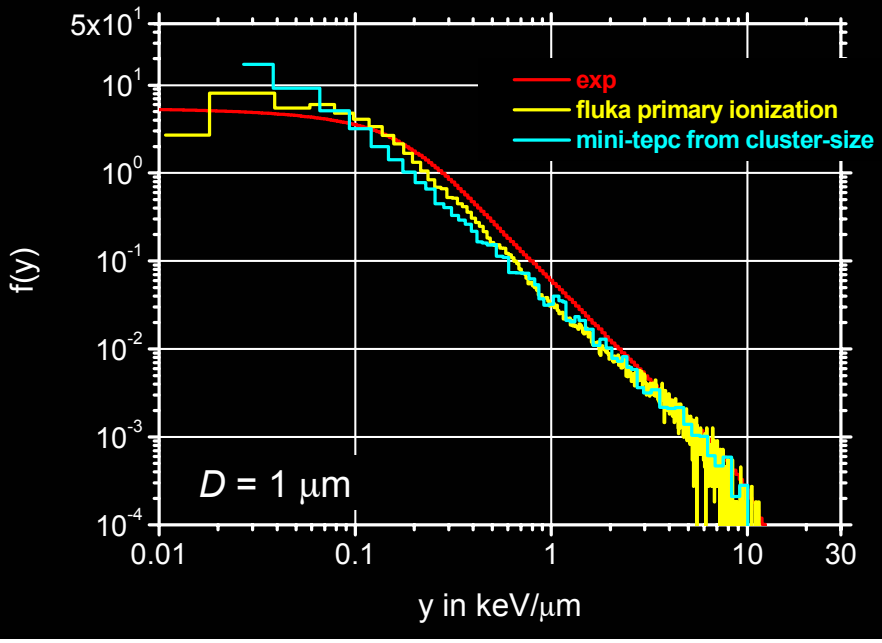
Different straggling algorithms in MCNP



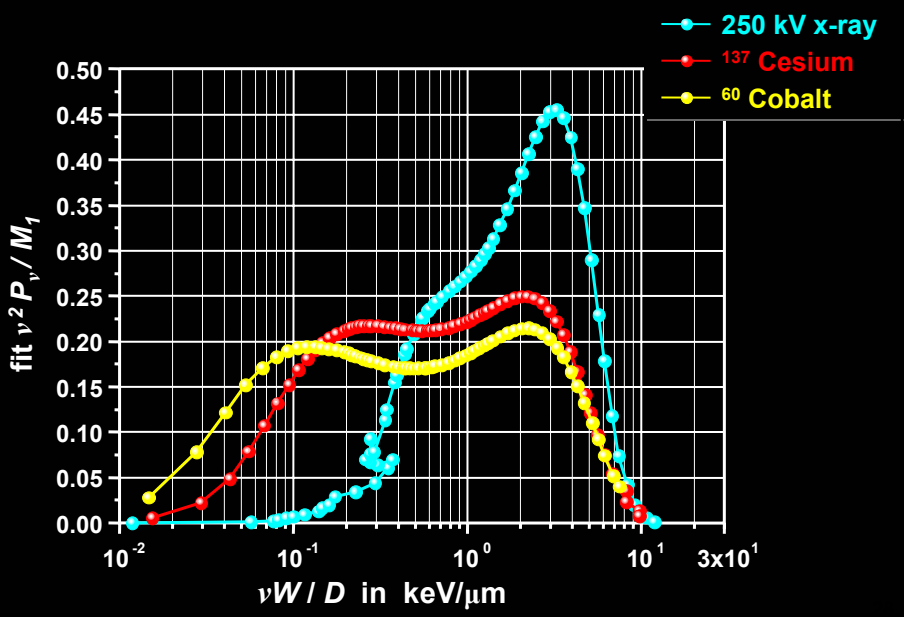
Comparison with experiments: ^{60}Co



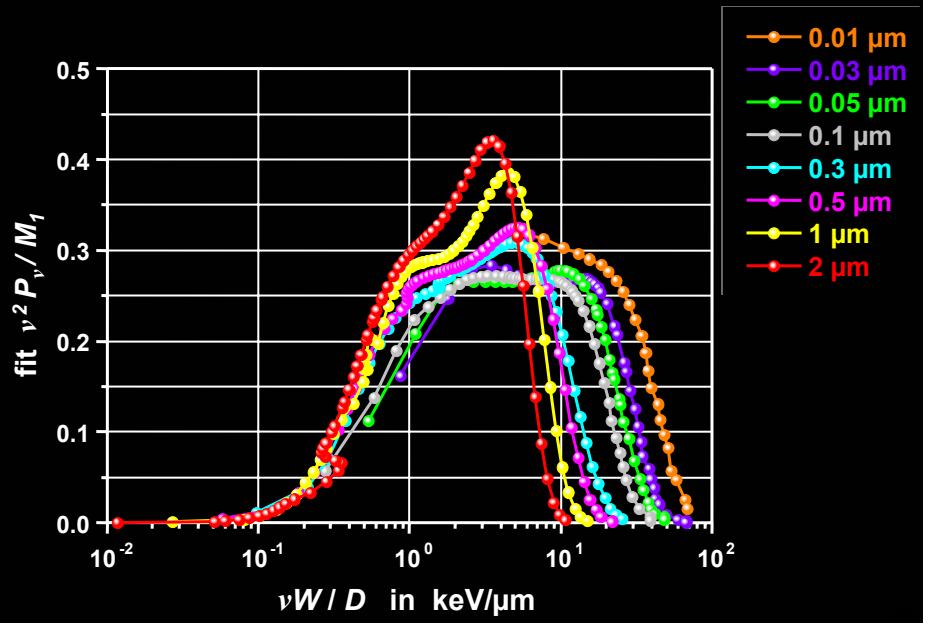
Comparison with experiments: ^{60}Co



Microdosimetric spectra for D = 2 μm



Microdosimetric spectra at different D



Thank you to…

Gianfranco Gualdrini

Paolo Colautti & Davide Moro

Los Alamos

Grady Hughes

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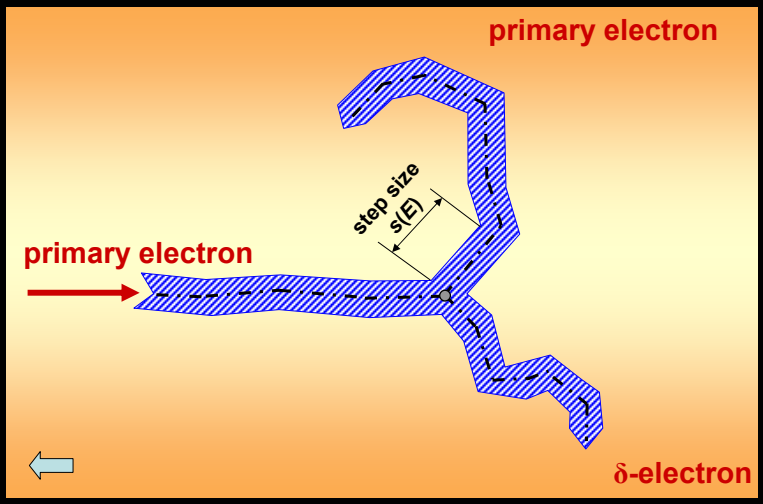
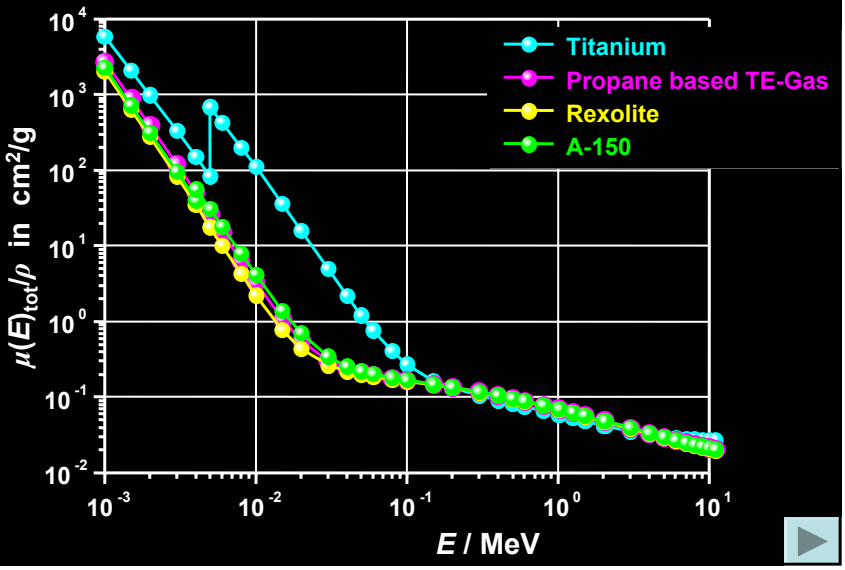
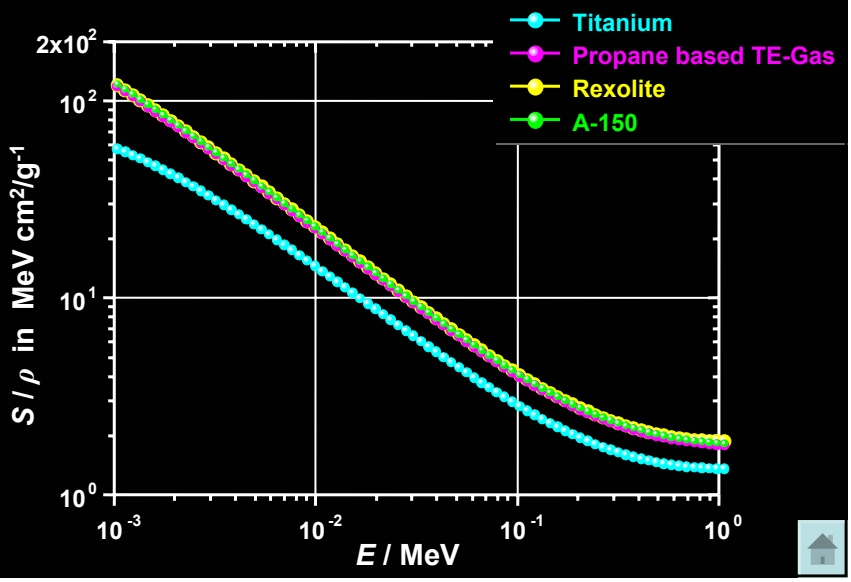
The traditional model of particle tracks based on condensed histories: MCNP, EGS, GEANT, FLUKA, …



Effect of material approximation on photon physics



Effect of material approximation on electron physics



Sampling the flight distance in forced collisions

if *s* is the flight distance and *d* the max. flight distance:

$$f(s) = \Sigma_T \frac{e^{-\Sigma_T s}}{1 - e^{-\Sigma_T d}} = \Sigma_T F(s)$$

$$\xi = F(s)$$

$$s = \frac{-\ln\left\{1 - \left(1 - e^{-\Sigma_T d}\right)\xi\right\}}{\Sigma_T}$$

Microdosimetric quantities:

lineal energy: $y = \varepsilon / \ell$ (keV/μm)

its distribution: $f(y)$

differential dose distribution:

$$d(y) = y * f(y)$$

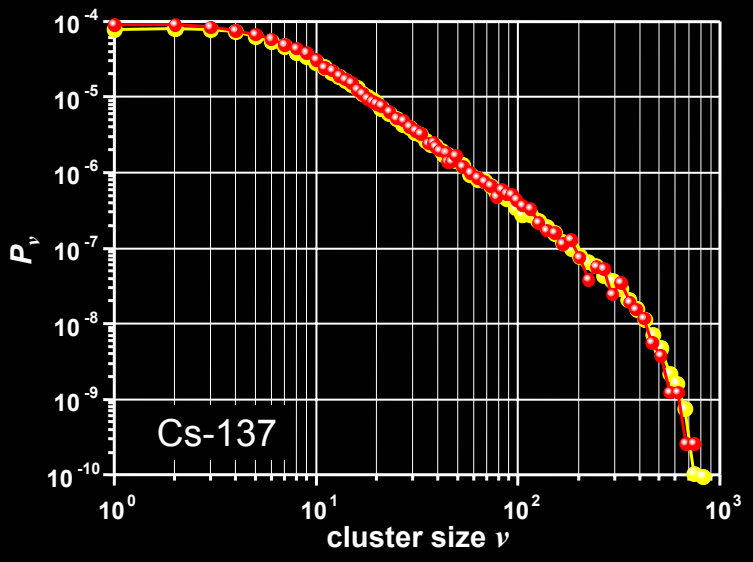
From cluster size to lineal energy

W:

$$W = \frac{\Delta E_\nu}{\nu}$$

ΔE_ν = energy absorbed for generating an ionization cluster of size ν

With / without variance reduction techniques: test

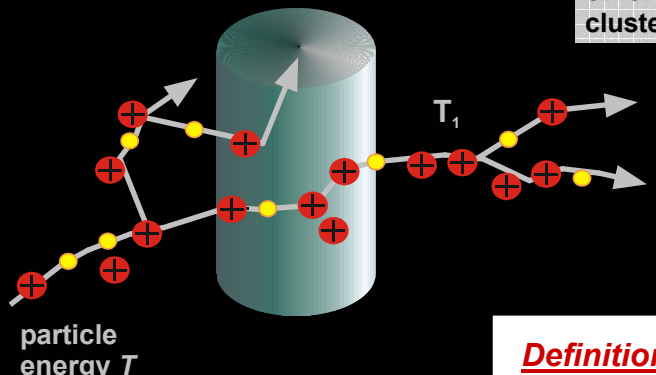


Russian roulette and electron splitting (10^6 photon)

without variance reduction techniques (10^7 photon)

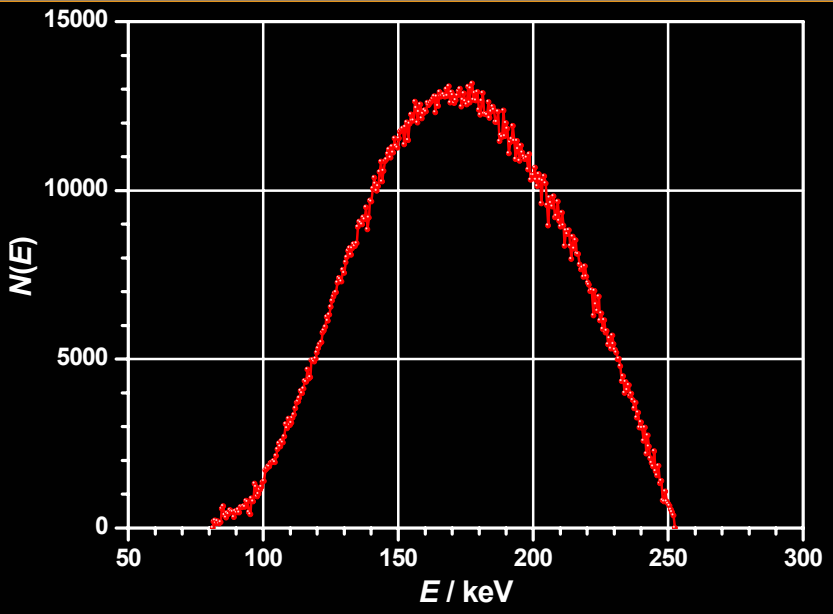
Concept of cluster size distribution

$P_\nu(T)$ is the probability of forming an ionization cluster of size ν



Definition: The cluster size is exactly the number ν of ionizations produced by a particle in a specified piece of matter

Spectral distribution of 250-kV X-rays



(Courtesy of Gianfranco Gualdrini, ENEA, Bologna)