

Design of the Cherenkov Full-body PET Scanner with GATE Simulation

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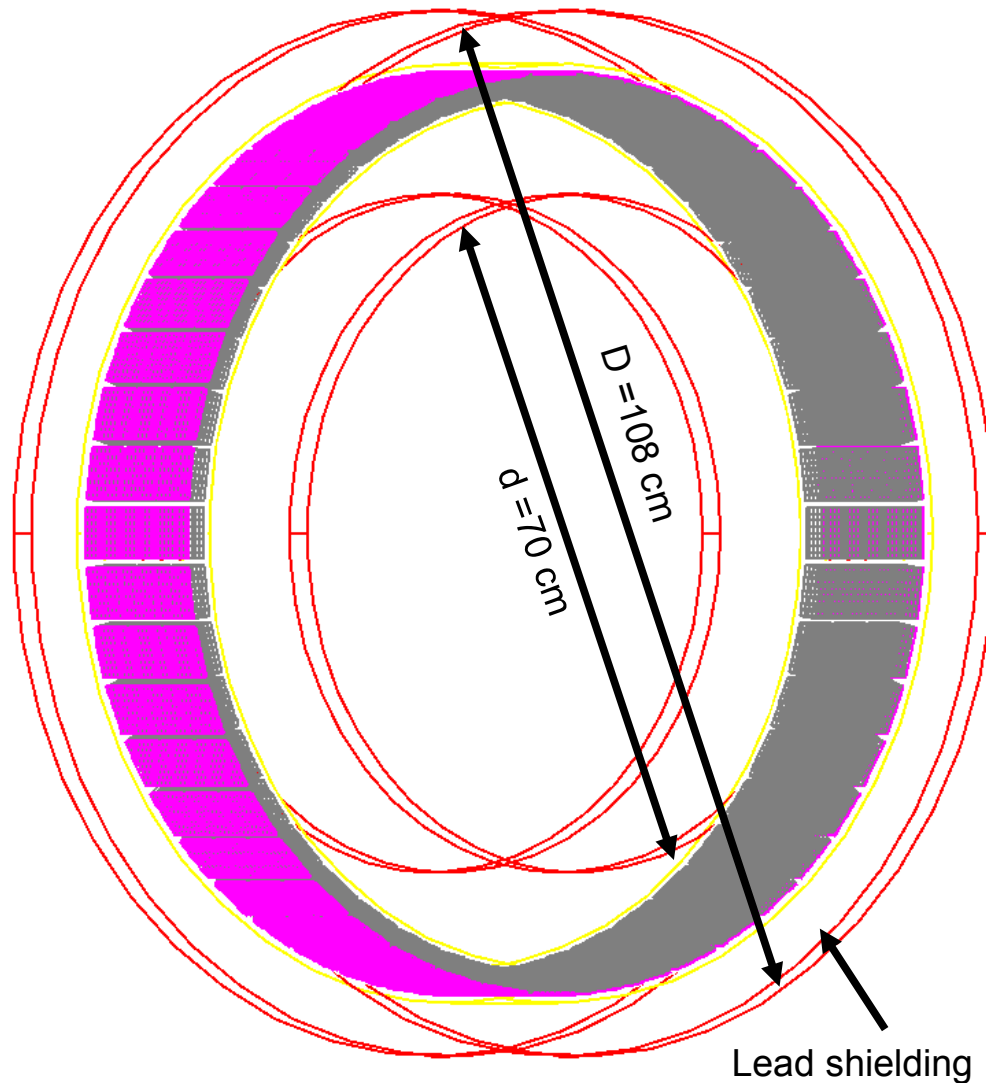
Group CaLIPSO



PECHE project

- Goal of the project: design a detector with the excellent time resolution and high efficiency.
- Main idea: use Cherenkov light instead of scintillation. Will compare two approaches: use of lead fluoride / lead tungsten crystals.
- PbF_2 crystal + MCP-PMT + Fast flash ADC (SAMPIC)
 - Excellent time resolution, low dark count rate.
 - High price.
- PbWO_4 crystal + Si PM + Fast flash ADC (SAMPIC)
 - Good timing performance, not expensive.
 - High dark count rate in the single-photon detection mode.

PECHE project



Gray - PbF₂ crystal:

- * transparency range $\lambda > 245 \text{ nm}$,
- * photon interaction length 9 mm,
- * density 7.77 g/cm³

Magenta – photocathode.

Crystal size is 6.5 mm x 6.5 mm.

Thicknesses are from 10 to 20 mm.

Matrix consists of 1 x 8 x 8 PbF₂ crystals.

We plan to construct PET scanner with 1 ring of detectors but we are modeling 3 rings for comparison with real scanner Discovery D-690.

Simulation Strategy

Approach: tracking of all optical photons in the GATE package

Parameters to study:

- spatial resolution
- TOF precision
- NECR (noise equivalent count rate)
- NEMA Phantom image (reconstruction)

Activity in the phantom shall be 5.3 kBq/cc or 75 Mbq for 14000 cc

We plan to use cluster IRFU iclust capacity: 450 CPU x 2.5 MHz

Preliminary test

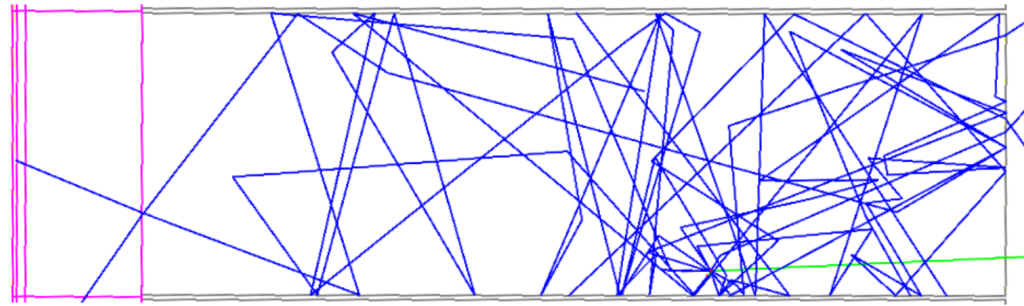
100 events/s

10^{10} ~19 days (3 min of phantom scan).

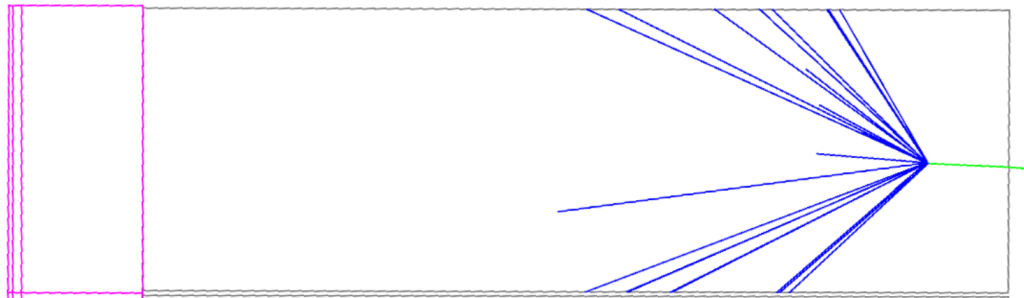
Possibility to speed up

- 1) optimization cuts of particle tracking in GEANT4
- 2) separated simulation for phantom and detectors

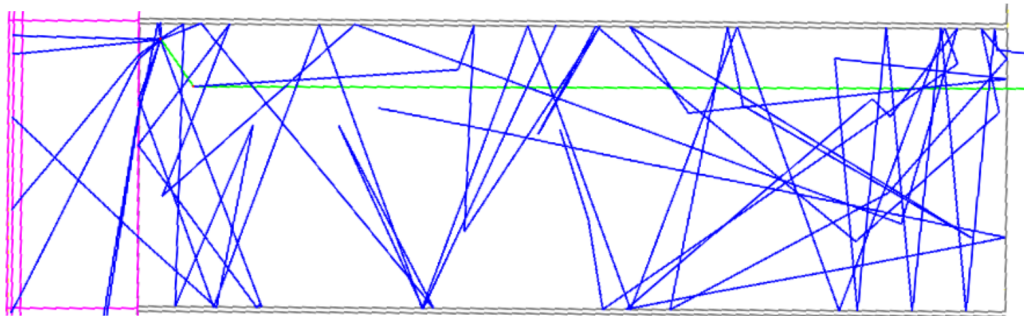
Surfaces of the PbF_2 crystals



Diffuse white

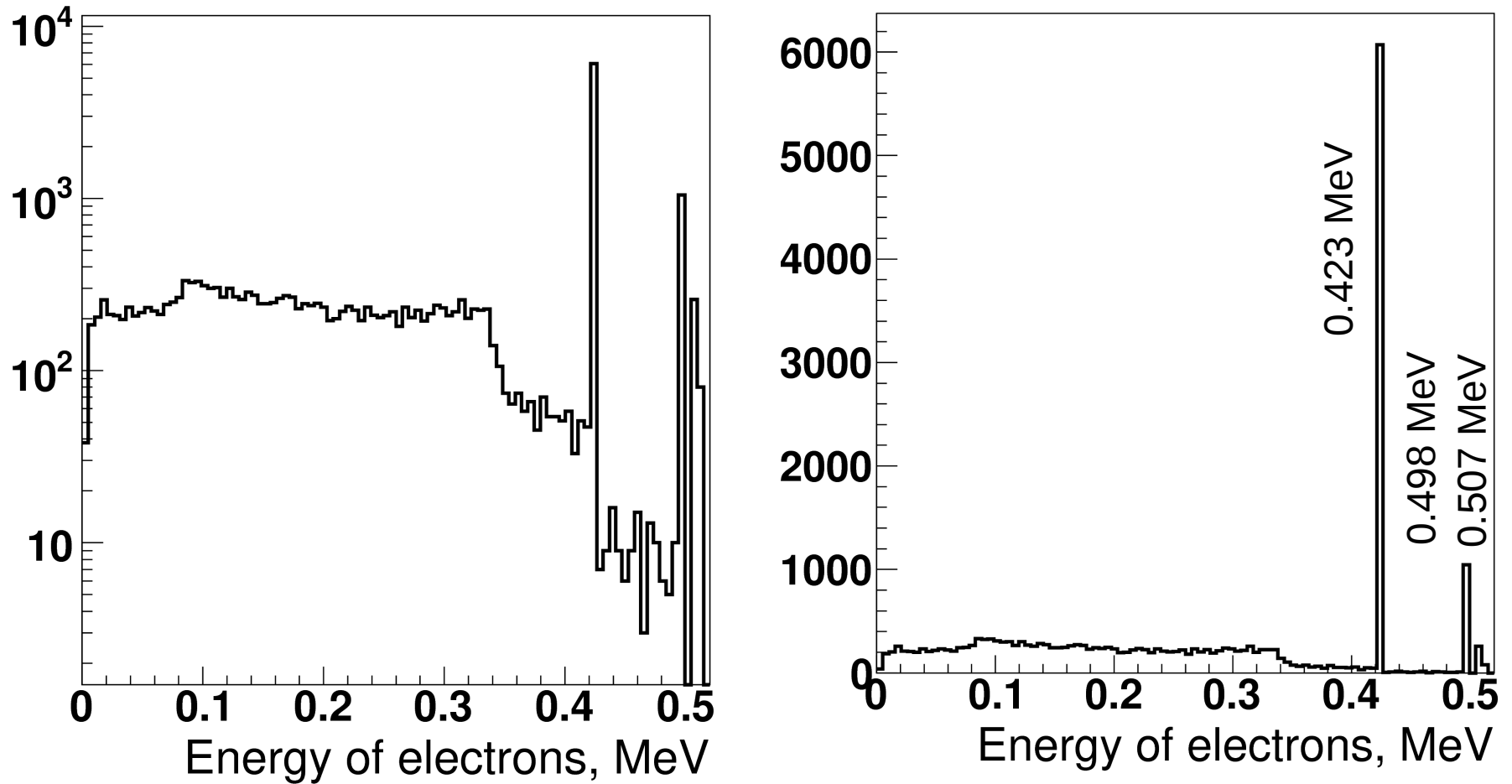


Black



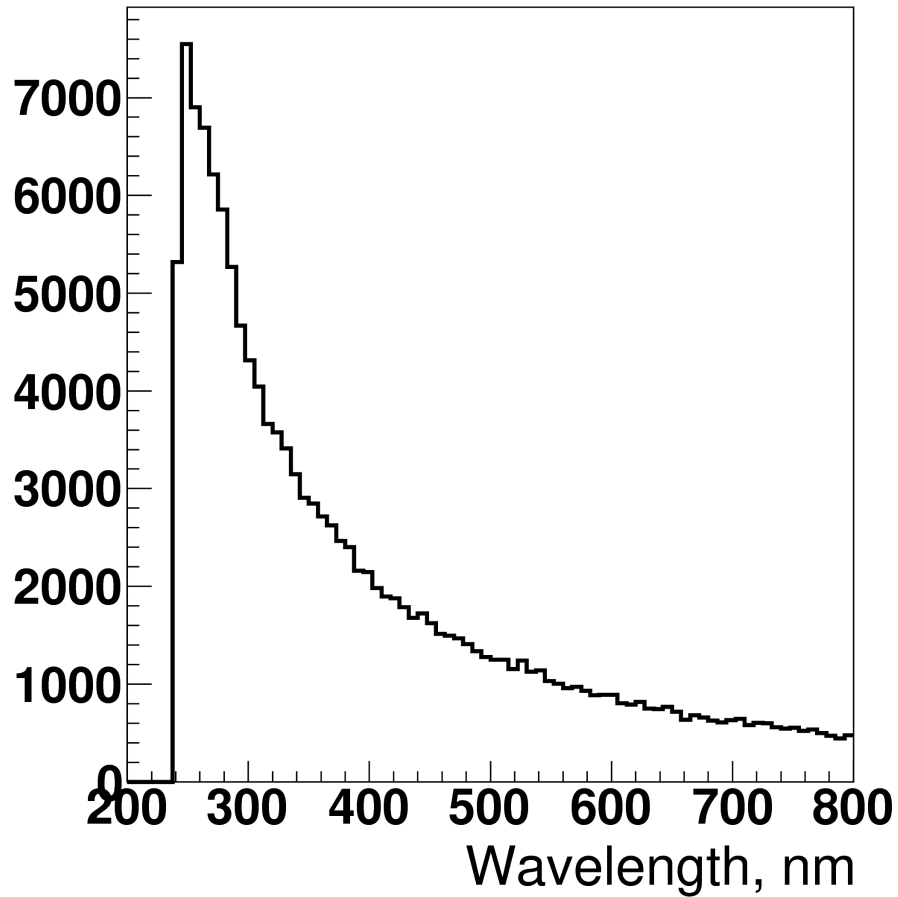
Polished

Results

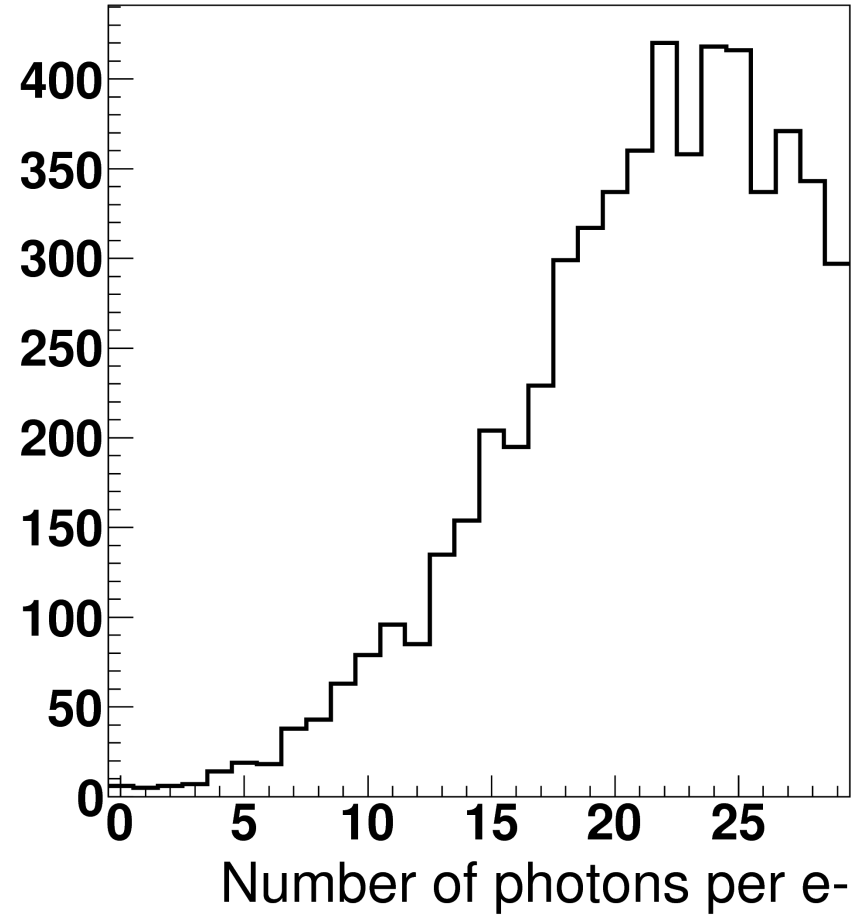


Electrons distribution in PbF_2 logarithmic scale (left) and linear scale (right)

Results

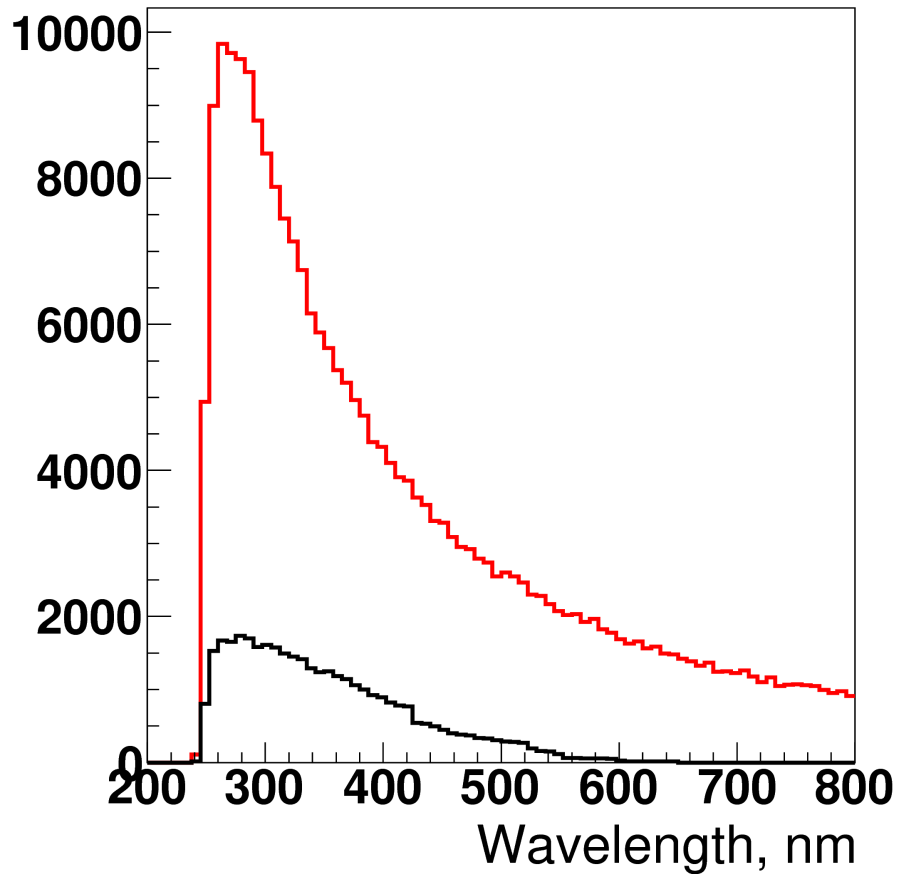


Cherenkov photons wavelength in PbF_2

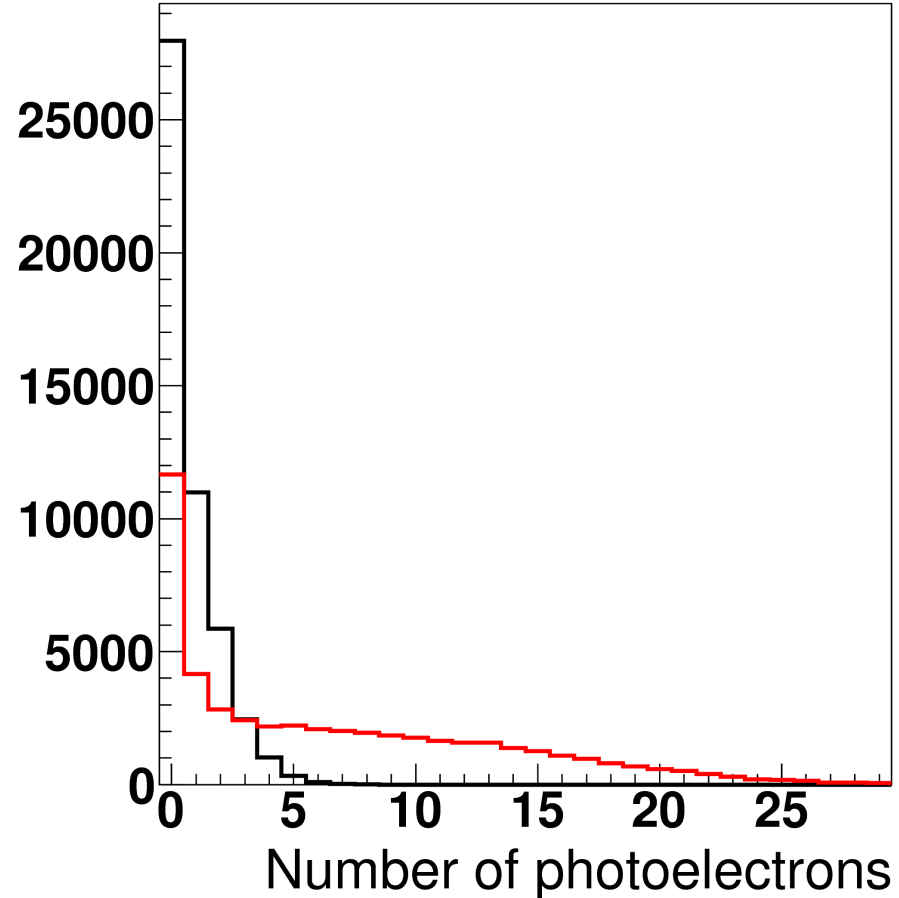


Number of Cherenkov photons emitted per electron (only for the photoionization electrons) in PbF_2

Results

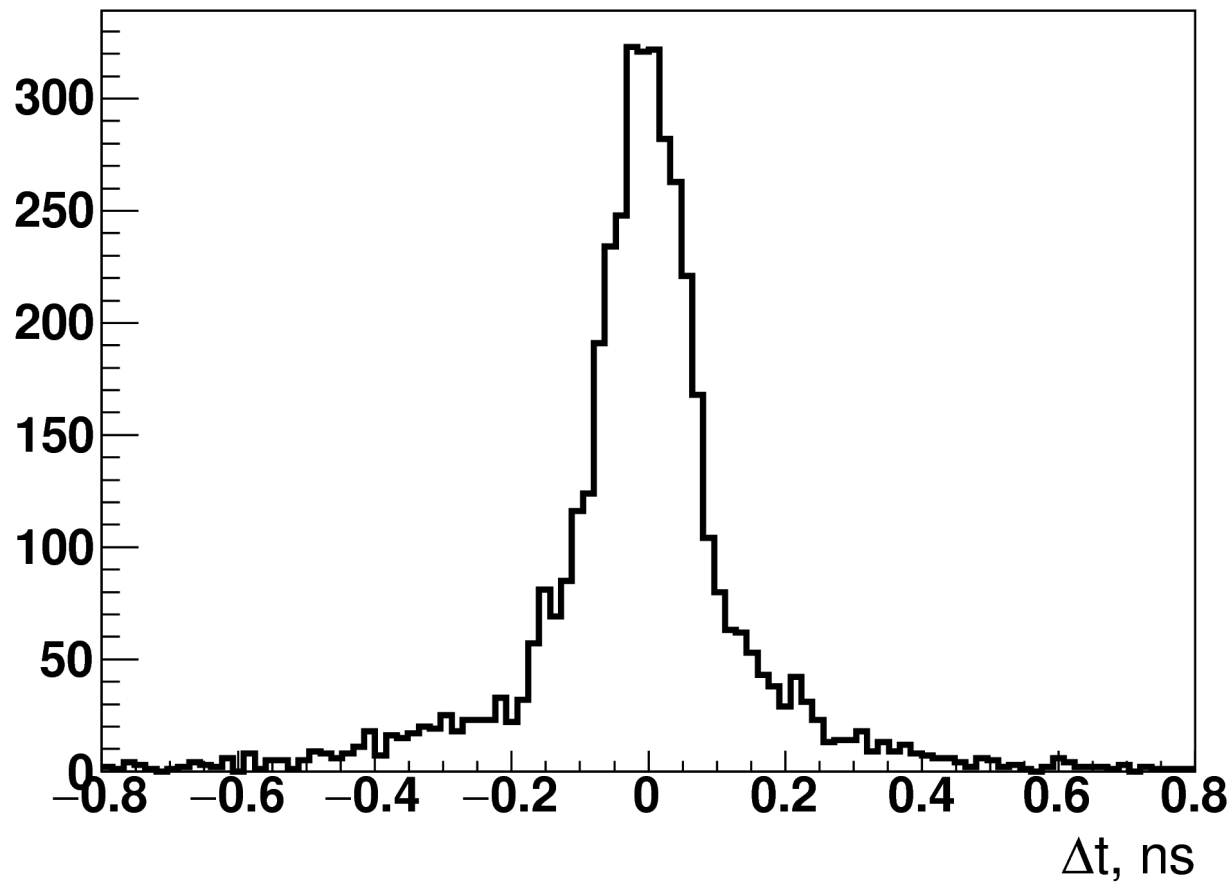


Cherenkov photon wavelength distribution at the photocathode. Red curve: efficiency 100%, Black curve: realistic photocathode quantum efficiency



Number of photoelectrons registered at photocathode. Red curve: efficiency = 100%, Black curve: with realistic photocathode quantum efficiency

Results



Coincidence resolving time distribution

Noise Equivalent Count Rates (NECR)

$$\text{NECR} = T/(T+S+2R),$$

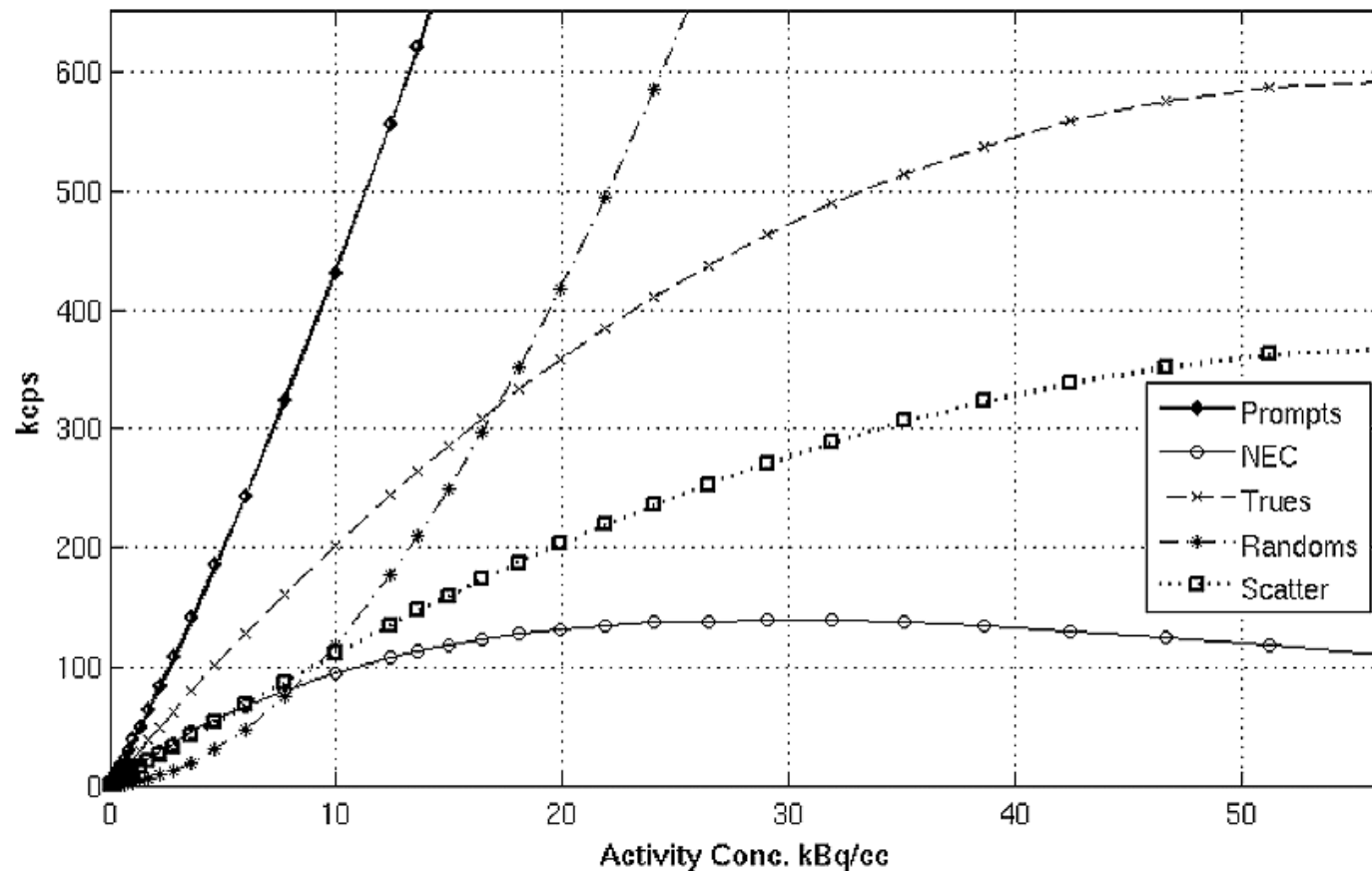
T – true coincidences

S – scatter coincidences

R – random coincidences

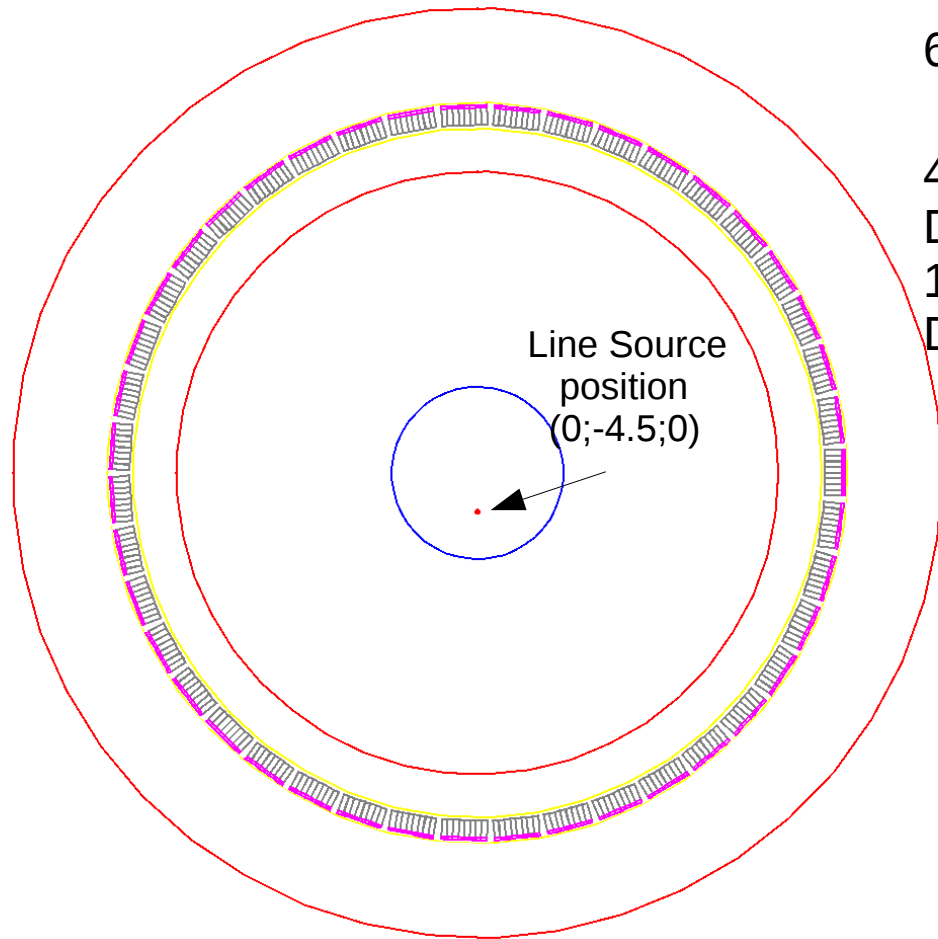
Reference point

Bettinardi et al.: Physical performance of the new hybrid PET=CT Discovery-690



4.2 x 6.3 x 25 mm³
LYSO
4.9 ns window
D = 81 cm
157 mm axial FOV
D_{sh} = 70 cm

Phantom for NECR counting



6.5 x 6.5 x 20 mm³
PbF₂

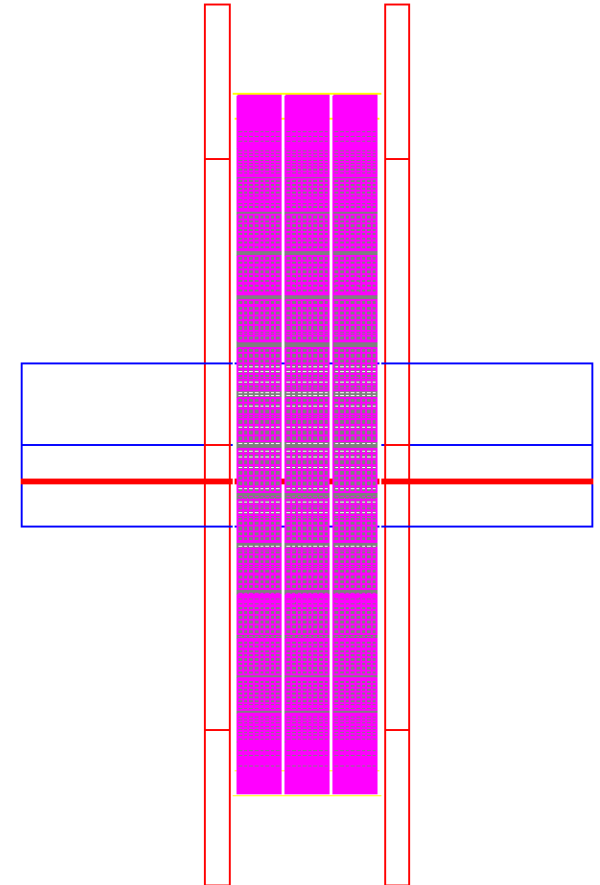
4.0 ns window

D = 91 cm

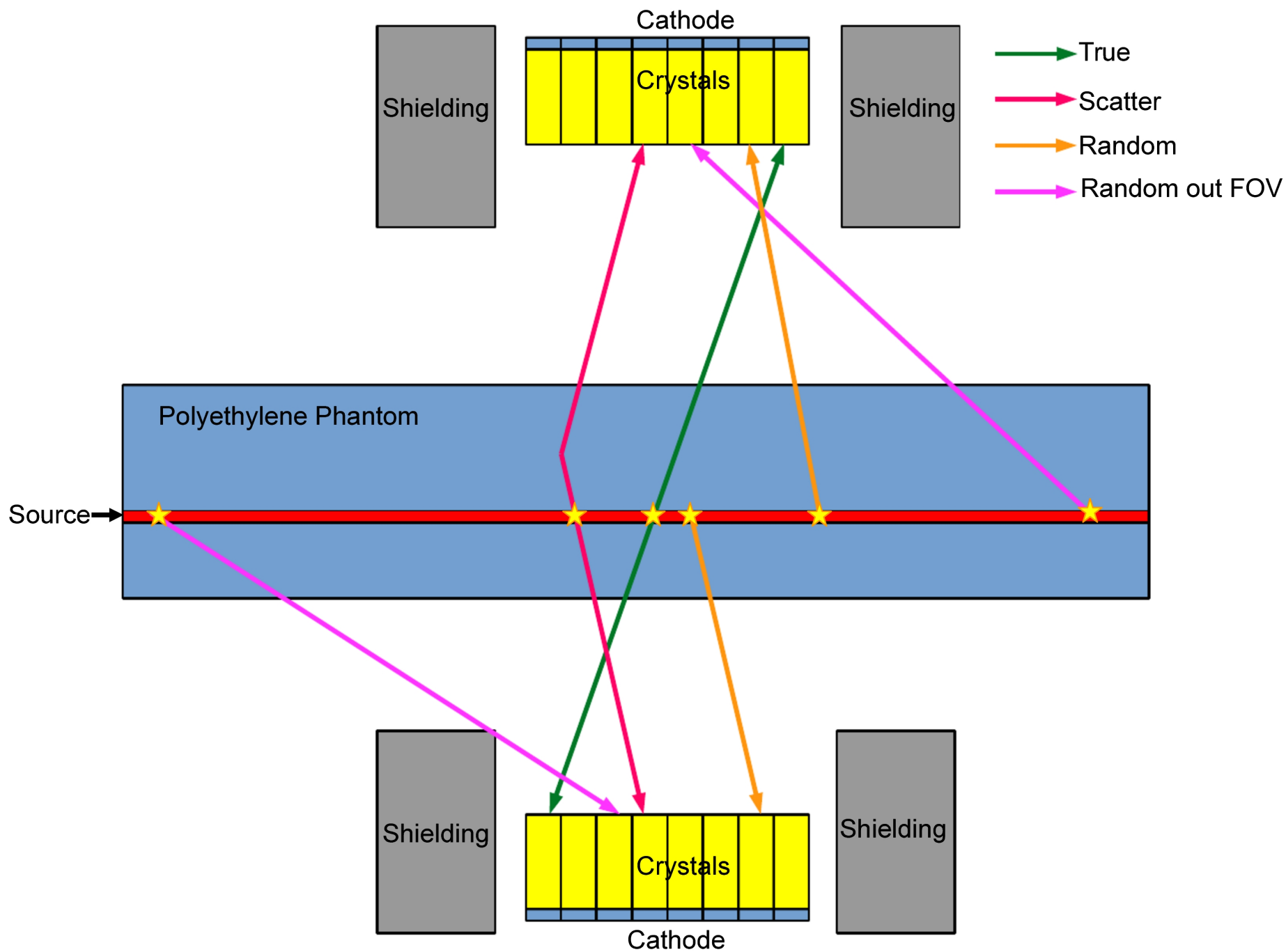
177 mm axial FOV

D_{sh} = 70 cm

Line Source
position
(0; -4.5; 0)



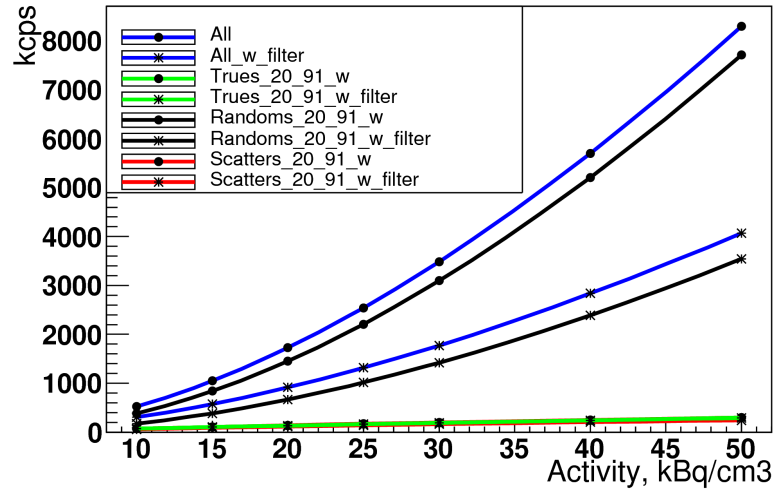
Polyethylene phantom for NECR [NEMA Standard]. Length 70 cm. Line source with activity from 5 kBq/cm³ to 50 kBq/cm³



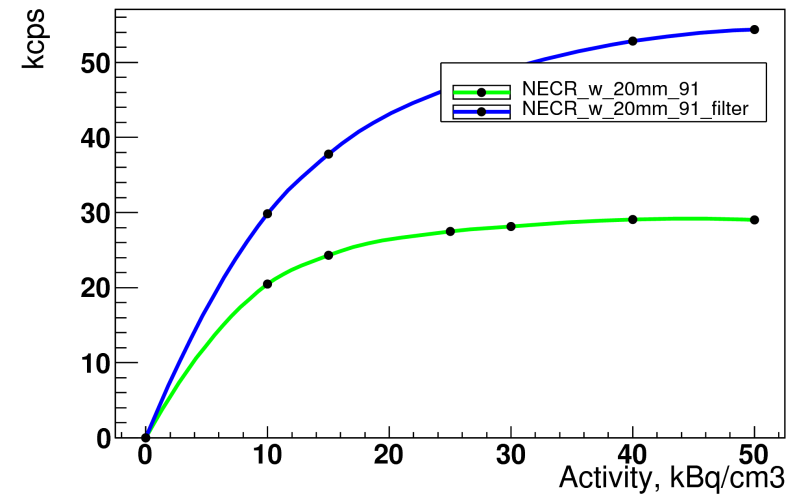
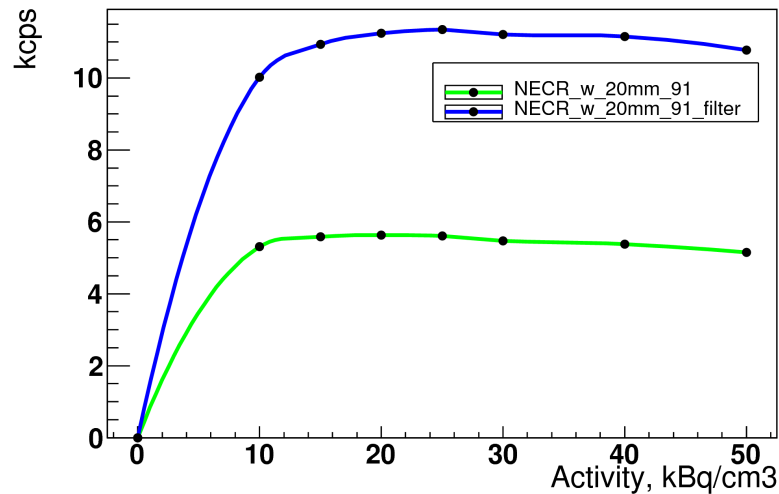
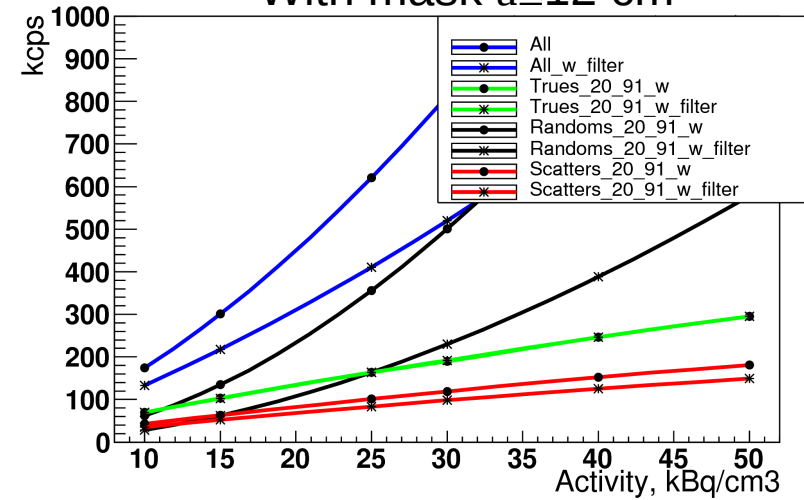
Design of the Cherenkov Full-body PET Scanner with GATE Simulation. Alokina

Results

Without mask



With mask $a \leq 12$ cm



* Filter means ideal, non-realistic case, when all activity is concentrated in the field-of-view of the scanner.

Discussion/conclusion

The first implementation of the crystal Cherenkov scanner is realized in the Gate.

The standard NECR figure-of-merit doesn't account for the TOF performance. Need to introduce the ad-hock correction to accounting for it.

The following steps will include optimization of the optical interface, crystal thickness and surfaces.

Simulation predictions will be compared with the test results ongoing at IRFU.