Investigation of the prompt gamma ray emission for on-line monitoring in ion therapy

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Outline

- Introduction
- Physical priciples
- Tools and Setup
- Simulations and Results
- Improvements
- Outlook

Introduction

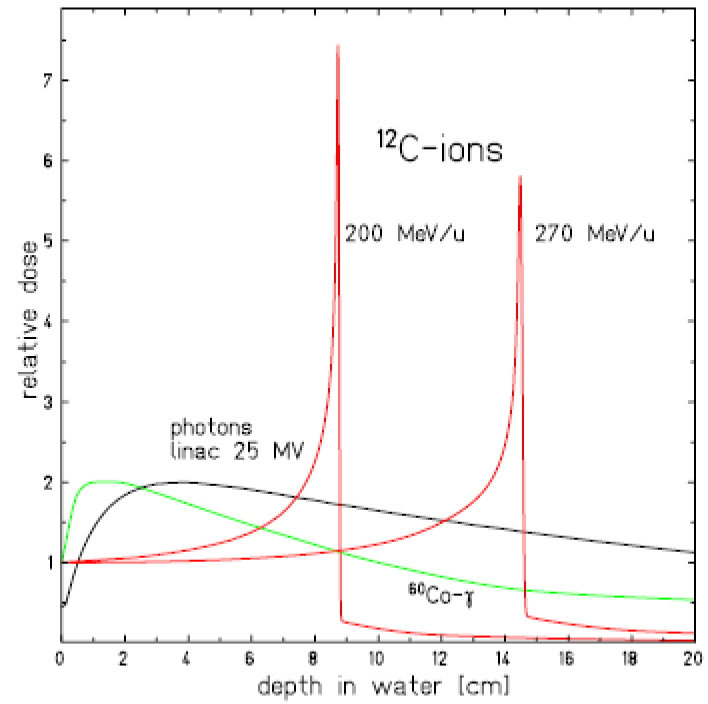
- Increasing treatment of cancer by radiotherapy with ions
- Med Austron will start 2015 with C^{12} and p^{+} beams
- No satisfying method for online monitoring
- Investigate the possibility of prompt gamma based monitoring

Physical principles

- Bethe-Bloch-formula

$$\frac{dE}{dx} \approx \frac{Kn_0(Z_{eff})^2}{\beta^2} * \ln[\frac{2m_e c^2 \beta^2}{I(1-\beta^2)}]$$

  - Maximum energy loss at about 350 keV/u for C^{12}
  - Depth of the Bragg peak linked to the primary energy



D. Schardt et al. Heavy-ion tumor therapy: Physical and radiobiological benets. Reviews of modern physics, 82(1):383{425, 2010.

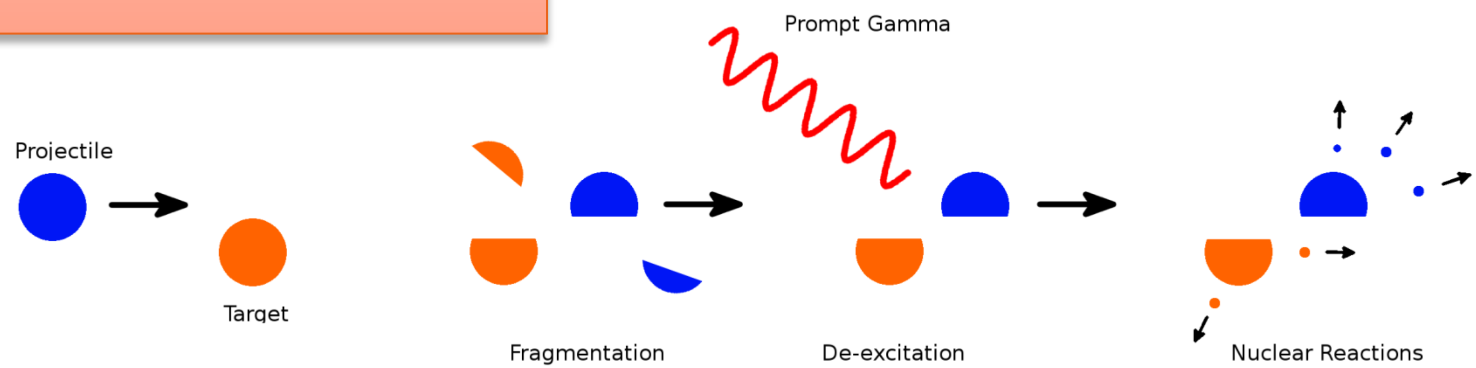
Physical principles

PET monitoring

- Prompt background radiation
  - Only between pulses or after treatment feasible
- Wash out effects
  - Economical Offline-PET inaccurate

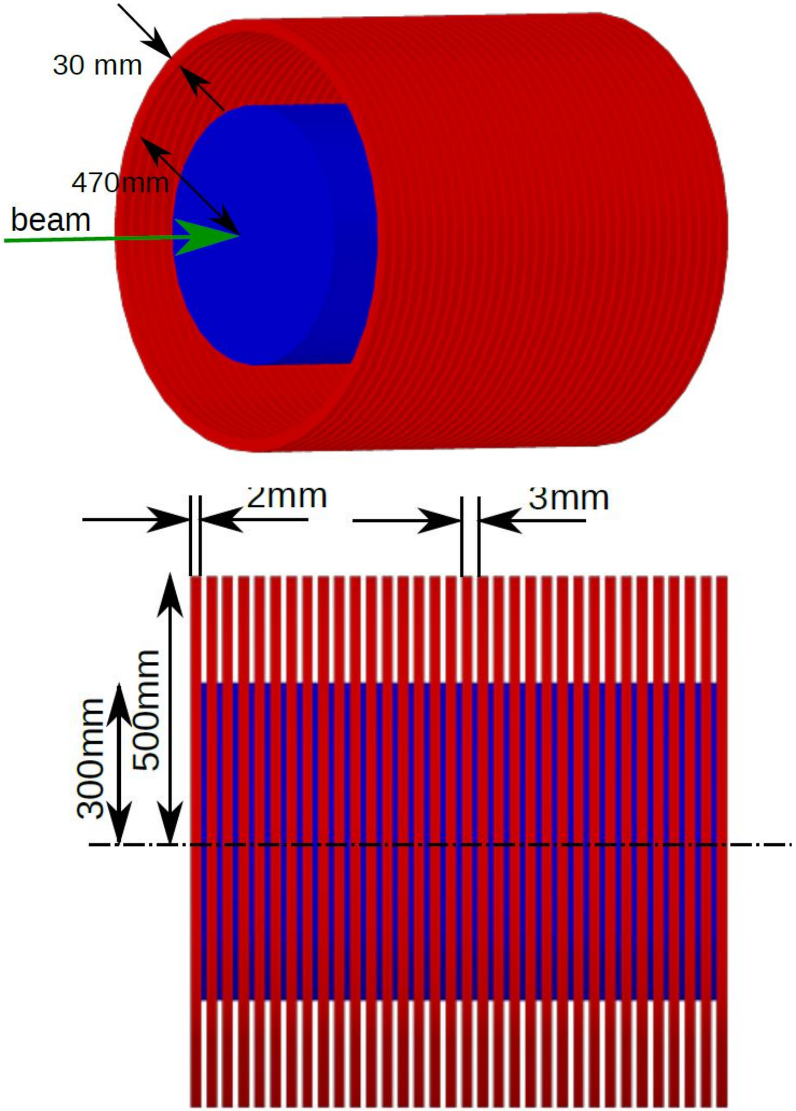
Prompt gamma monitoring

- Emitted by excited nuclei
- < 1 ns
  - Online monitoring
- No radiation background
- No wash out effects

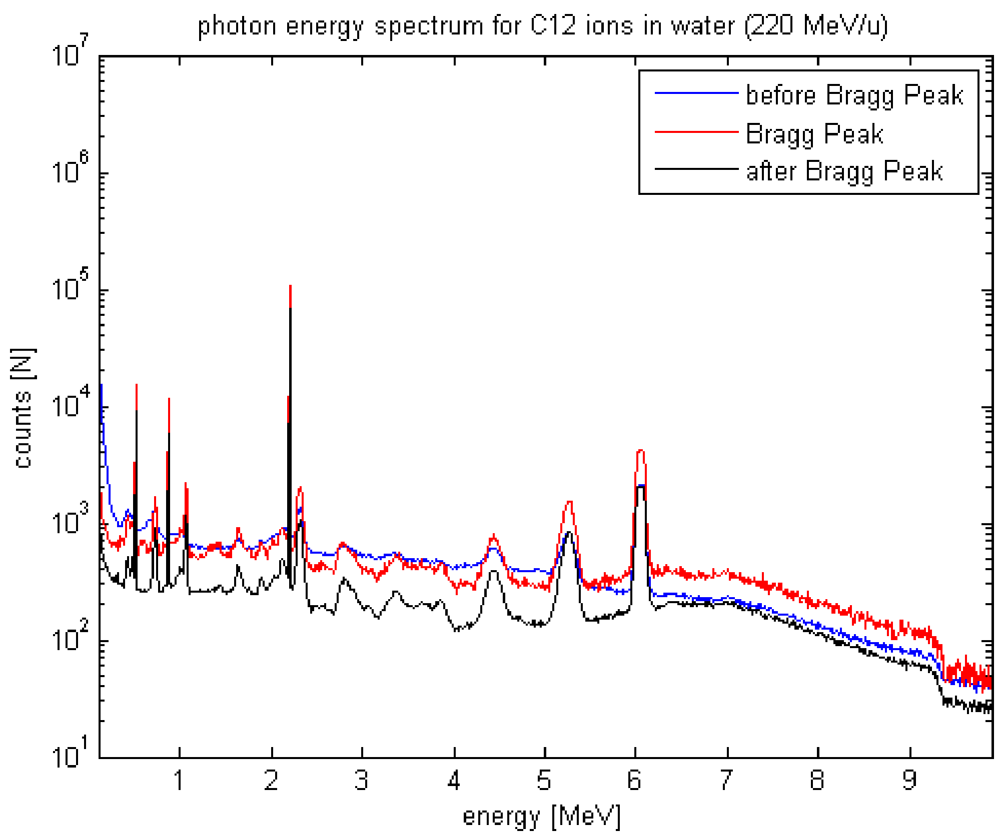


Tools and Setup

- Investigations based on Monte Carlo simulations
  - Gate
    - Geant4 Application for Topographic Emission based on Geant4
    - Simulation environment for medical purpose
- Task
  - Link production parameters of prompt photons to the Bragg peak position



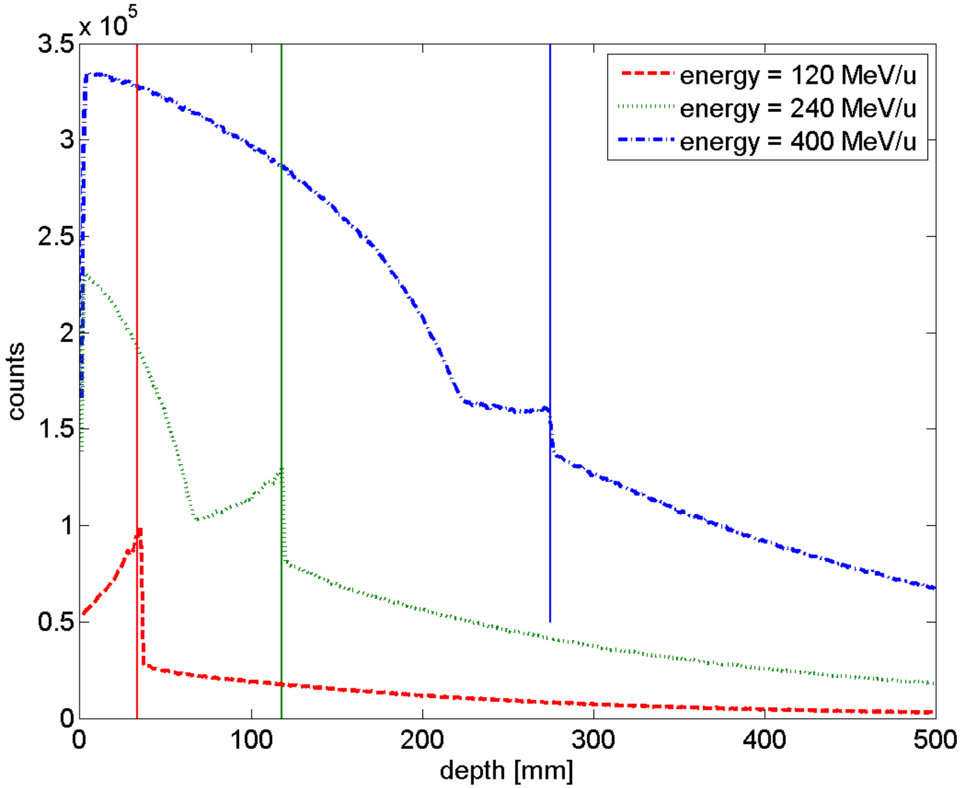
Simulation



- Energy spectrum
  - Prominent peaks independent from primary energy
  - Also independent from the penetration depth
  - Beside count rate no significance

Simulations

Photon production
10^7 C^{12} impinging a water target

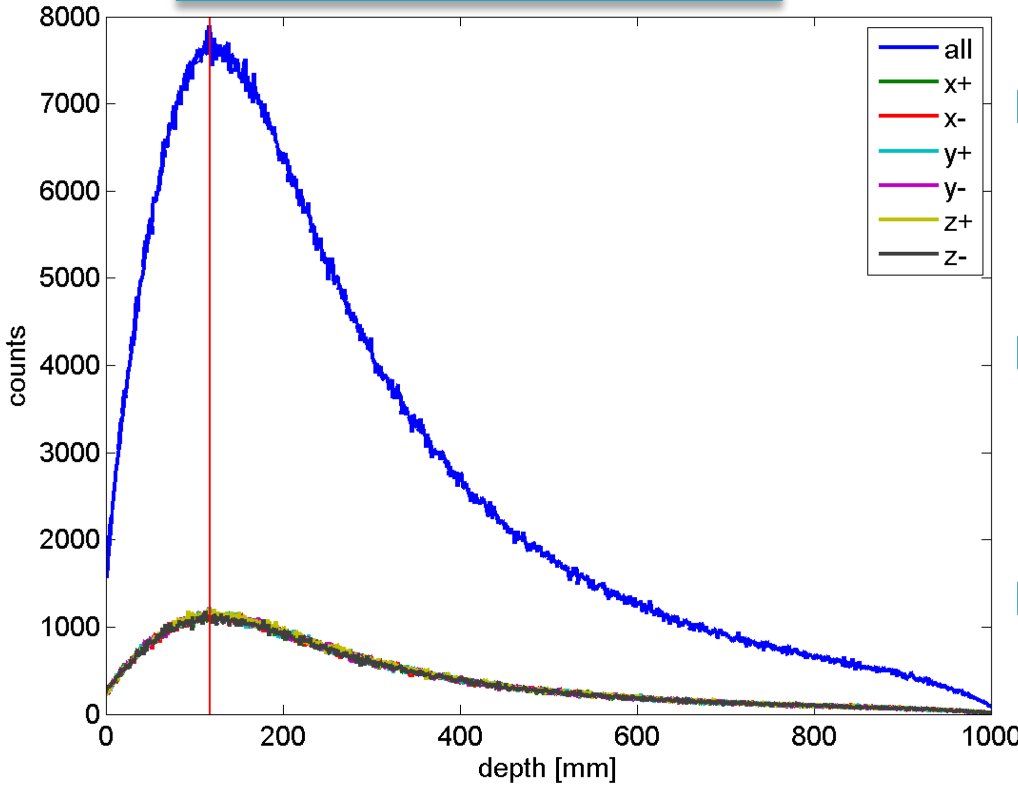


- Signal at the Bragg peak
  - Less significance for higher primary energy
- High signal before Bragg peak
  - Mainly produced by photons < 500 keV
- Searching for an optimal energy range

Simulations

2.2 MeV Photon production
10^7 C^{12} impinging a water target

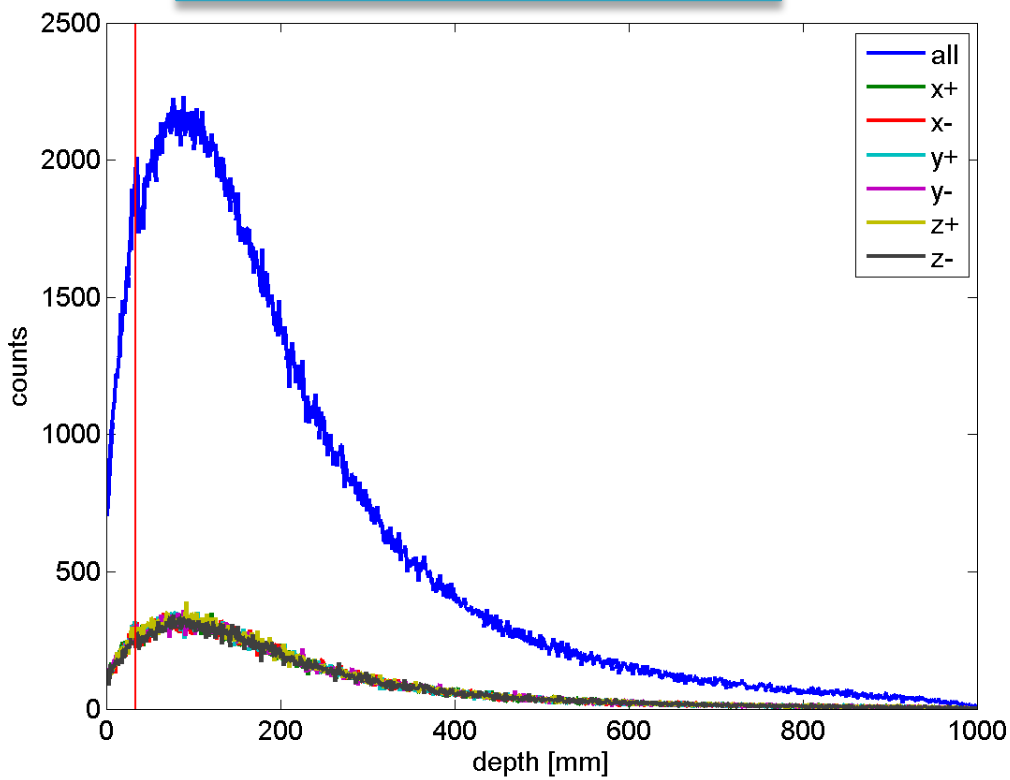
240/u MeV primary energy



- typical example for prominent peaks
- No significance at the Bragg peak
- Produced by the neutron capture of hydrogen

Simulations

120/u MeV primary energy



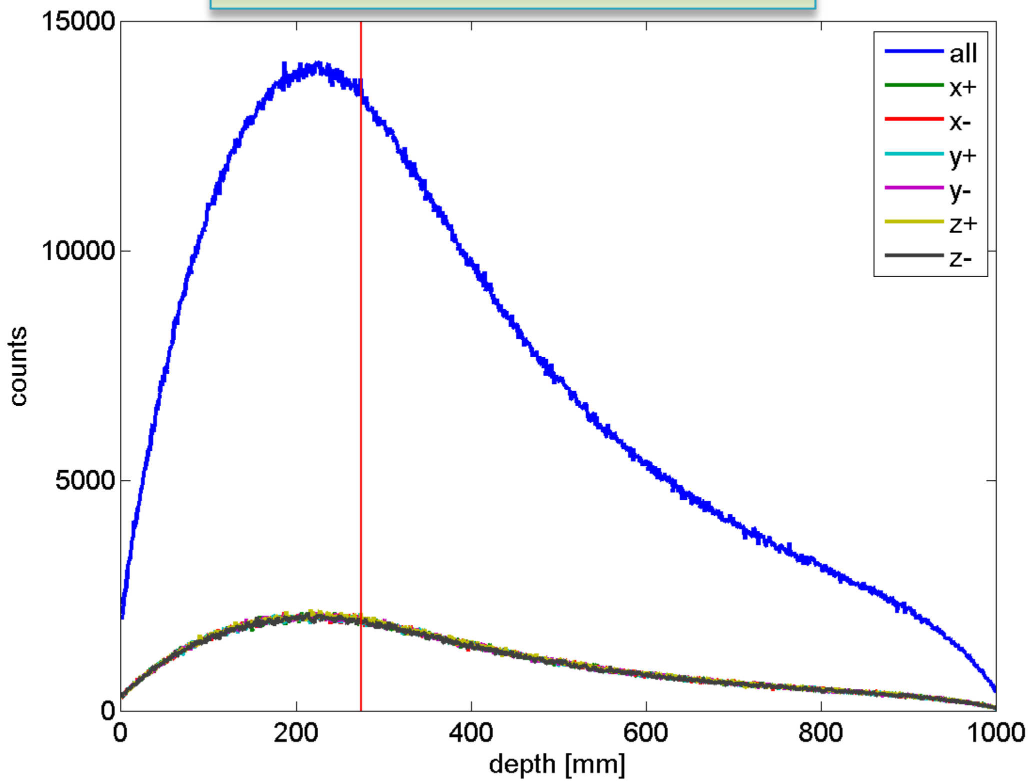
2.2 MeV Photon production
10^7 C^{12} impinging a water target

- typical example for prominent peaks
- No significance at the Bragg peak
- Produced by the neutron capture of hydrogen

Simulations

2.2 MeV Photon production
10^7 C^{12} impinging a water target

400/u MeV primary energy

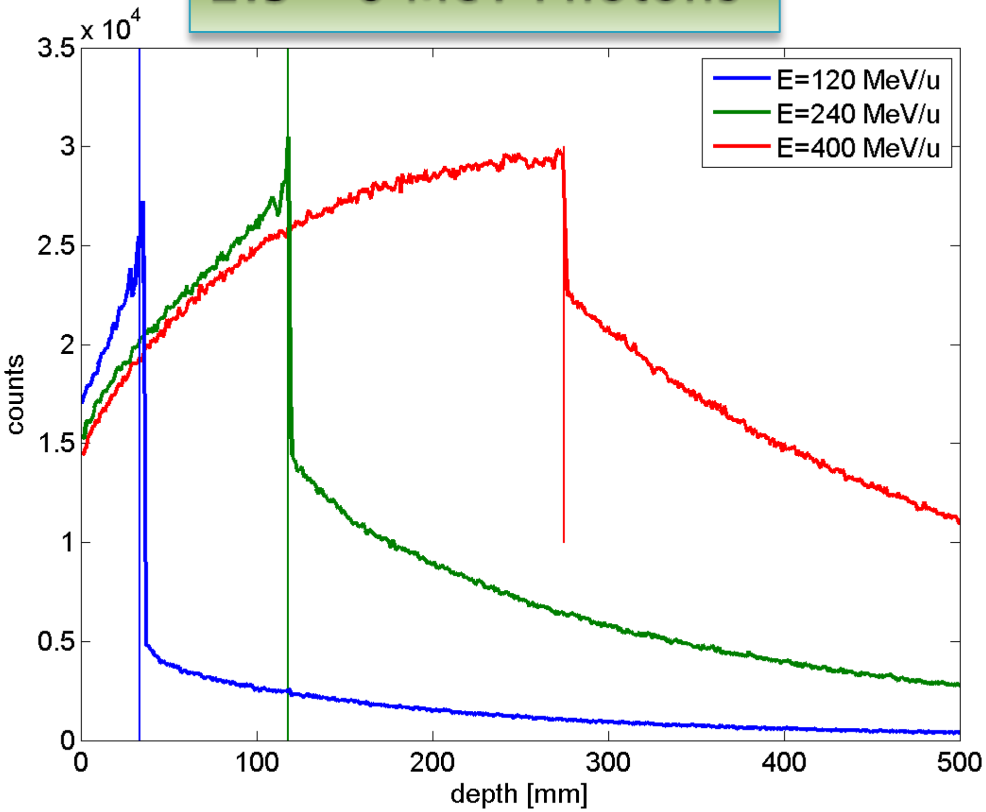


- typical example for prominent peaks
- No significance at the Bragg peak
- Produced by the neutron capture of hydrogen

Simulation

Photon production
10^7 C^{12} impinging a water target

2.3 – 6 MeV Photons

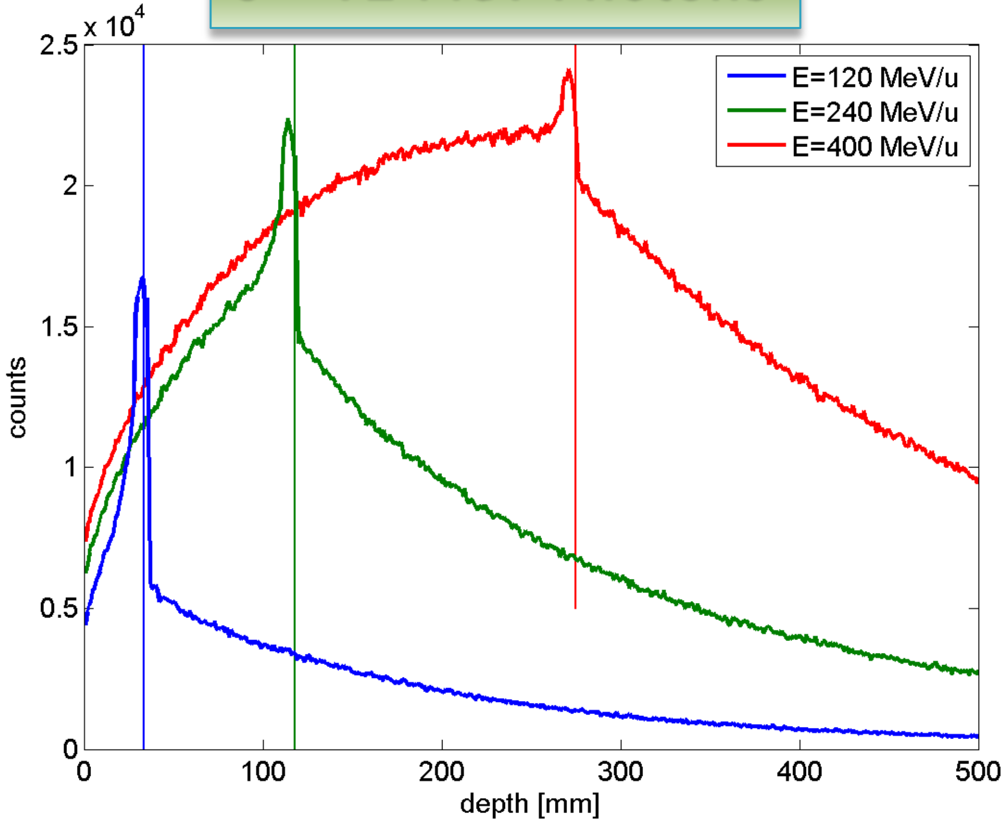


- Most promising energy region
- Compromise between count rate and significance
- No strong significance in angle distribution

Simulation

Photon production
10^7 C^{12} impinging a water target

6 – 12 MeV Photons

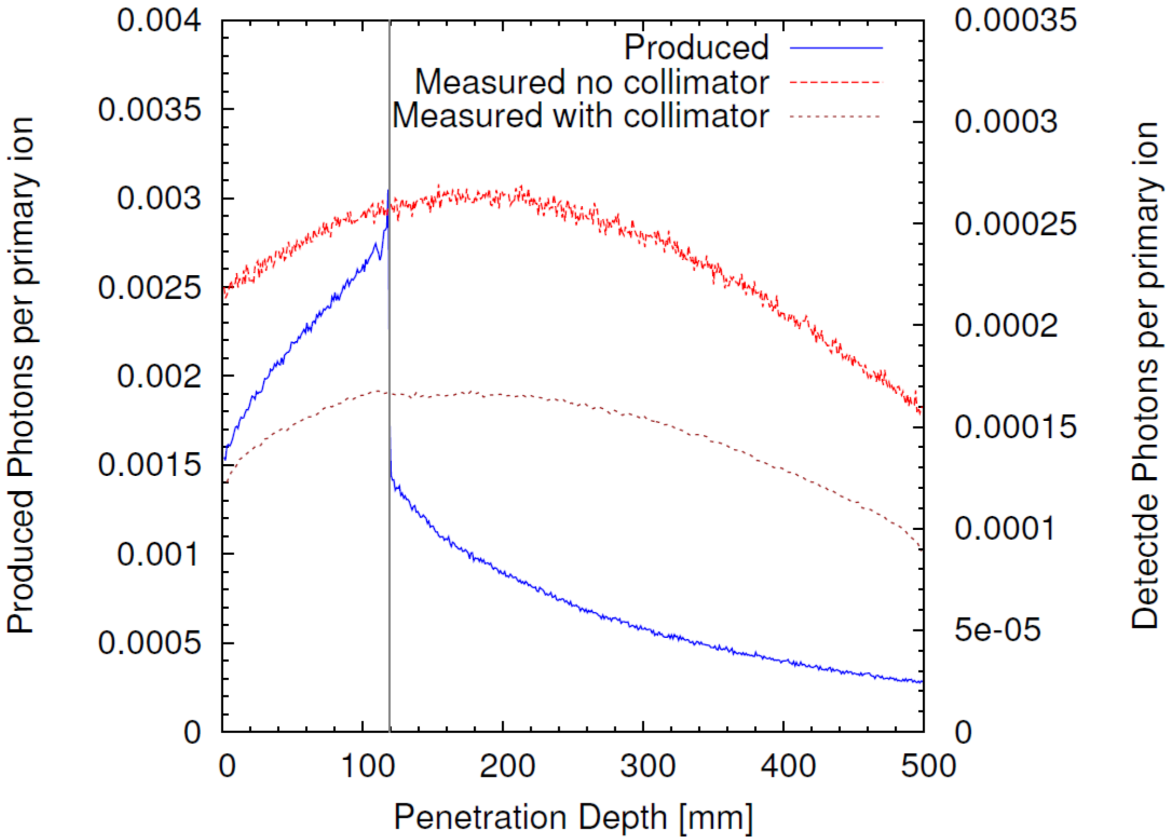


- Worse detector efficiency
- Worse ratio between production rate and significance

Simulations

Photon detection
10^7 C^{12} impinging a water target

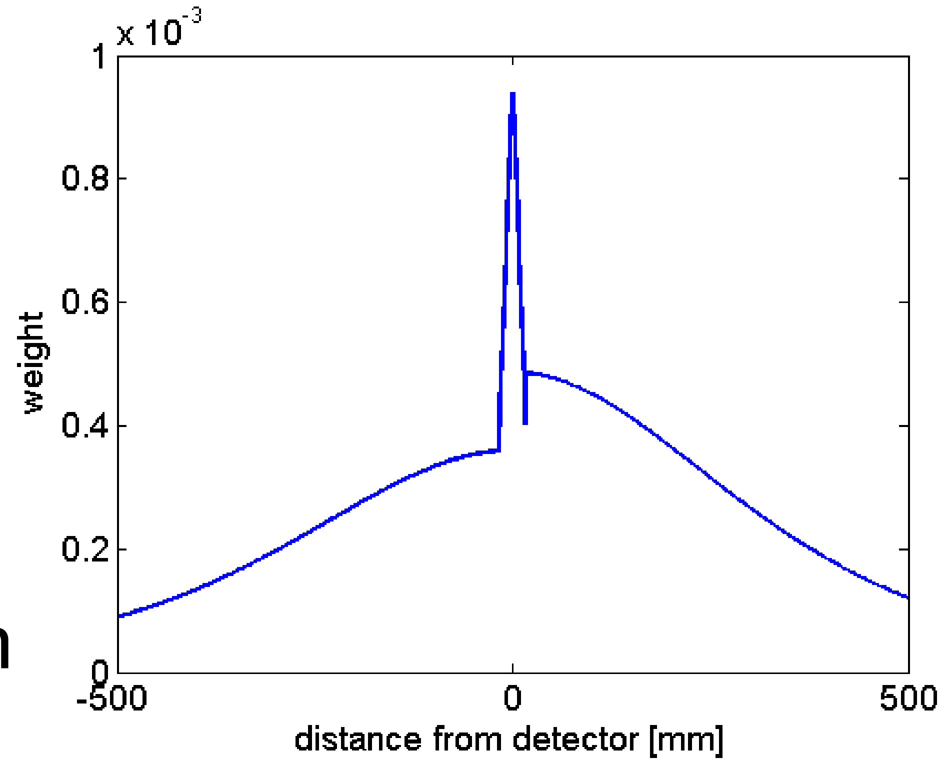
2.3 – 6 MeV Photons



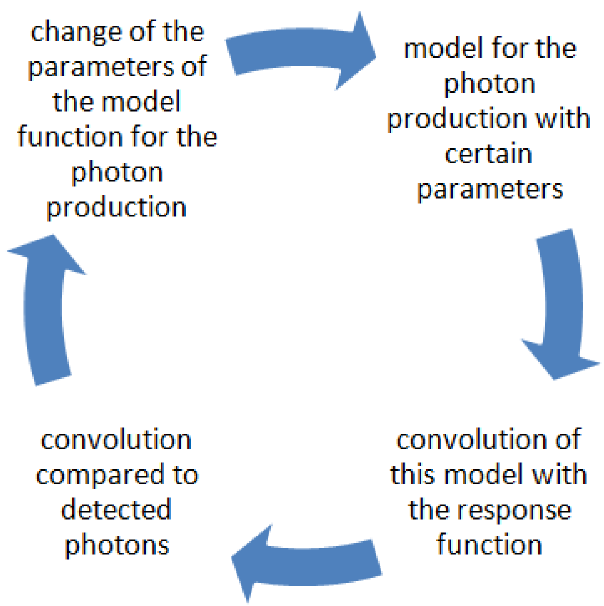
- Ideal Detectors
- 3 cm lead Collimators
- 1mm gabs every 3 mm

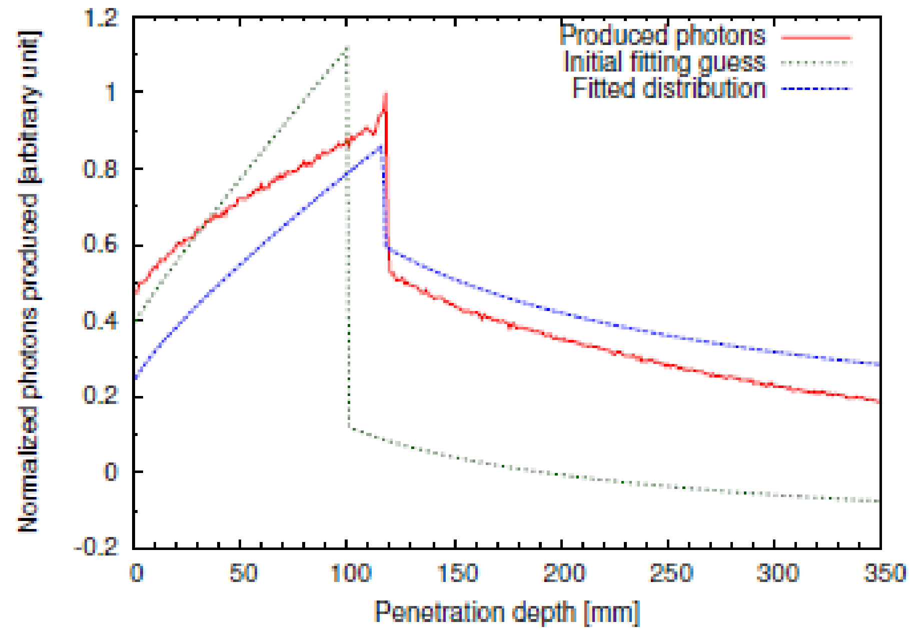
Recalculation

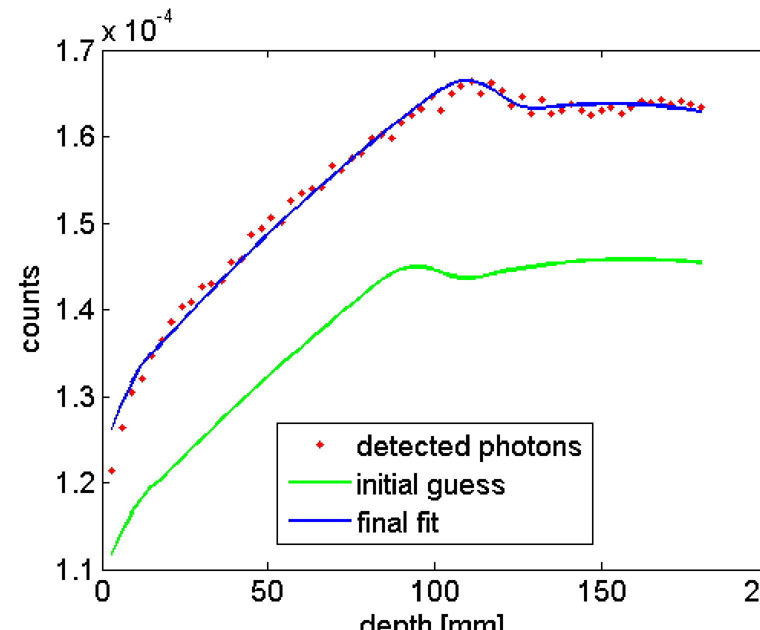
- Calculate the system response function
- Define simple model of the production function



Recalculation







Recalculation

120/u MeV primary energy

Bragg peak at 35 mm

primary ion number	fitted Bragg depth [mm]	standard error [mm]
$8\ 10^7$	38	2.15
$1.6\ 10^8$	36	1.65
$2.4\ 10^8$	37	1.42
$3.2\ 10^8$	37	1.3
$4\ 10^8$	37	1.26

240/u MeV primary energy

Bragg peak at 118 mm

primary ion number	fitted Bragg depth [mm]	standard error [mm]
$8\ 10^7$	116	3.25
$1.6\ 10^8$	116	1.96
$2.4\ 10^8$	117	2.02
$3.2\ 10^8$	117	1.53
$4\ 10^8$	118	1.52

400/u MeV primary energy

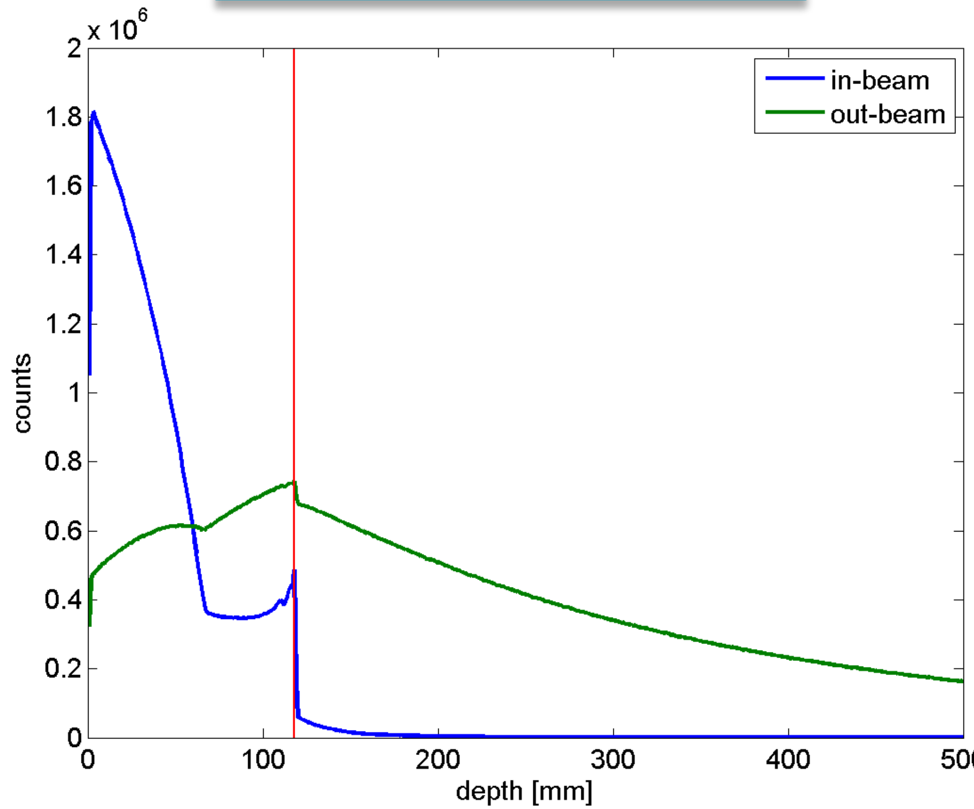
Bragg peak at 274 mm

primary ion number	fitted Bragg depth [mm]	standard error [mm]
$8\ 10^7$	263	4.26
$1.6\ 10^8$	273	3.4
$2.4\ 10^8$	267.4	4.72
$3.2\ 10^8$	267	2.24
$4\ 10^8$	269.2	2.64

Improvements

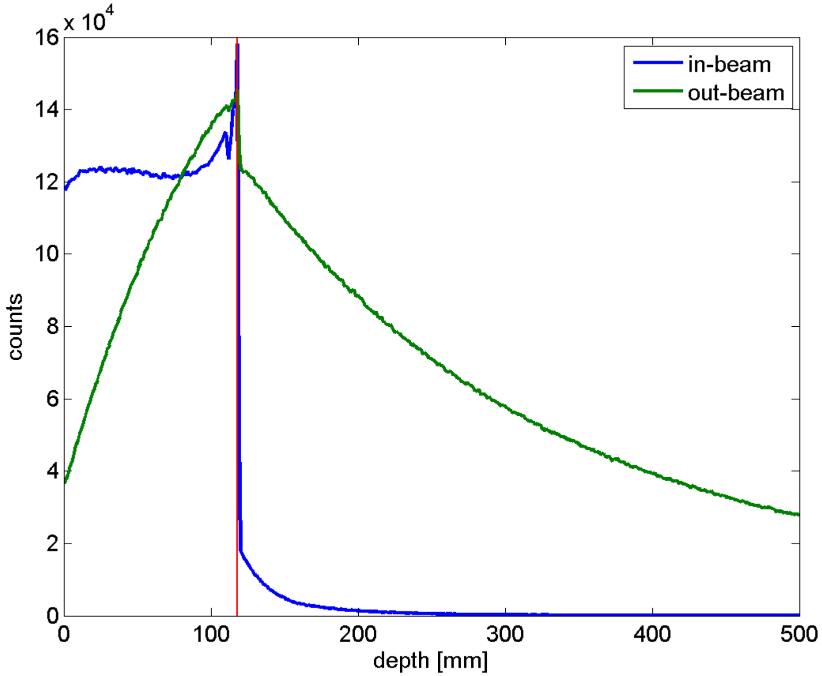
- Primary beam
  - Gaussian shaped
  - 240 MeV/u
  - Sigma of 3 mm
- Photon production divided
  - In beam
    - Radius < 6mm
  - Out beam
    - Radius > 6 mm

0 – 12 MeV Photons

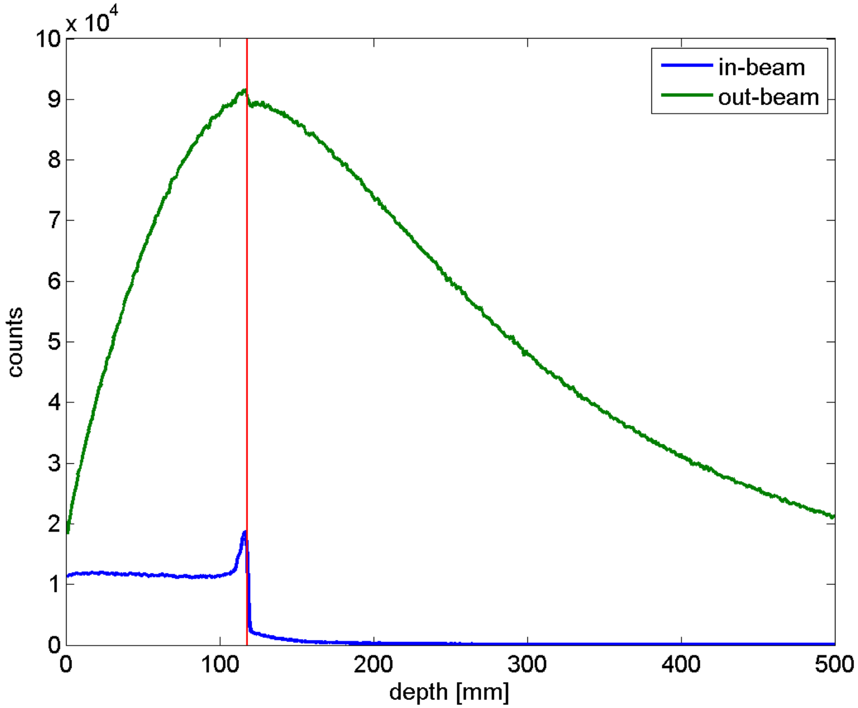


Improvements

2.3 – 6 MeV Photons

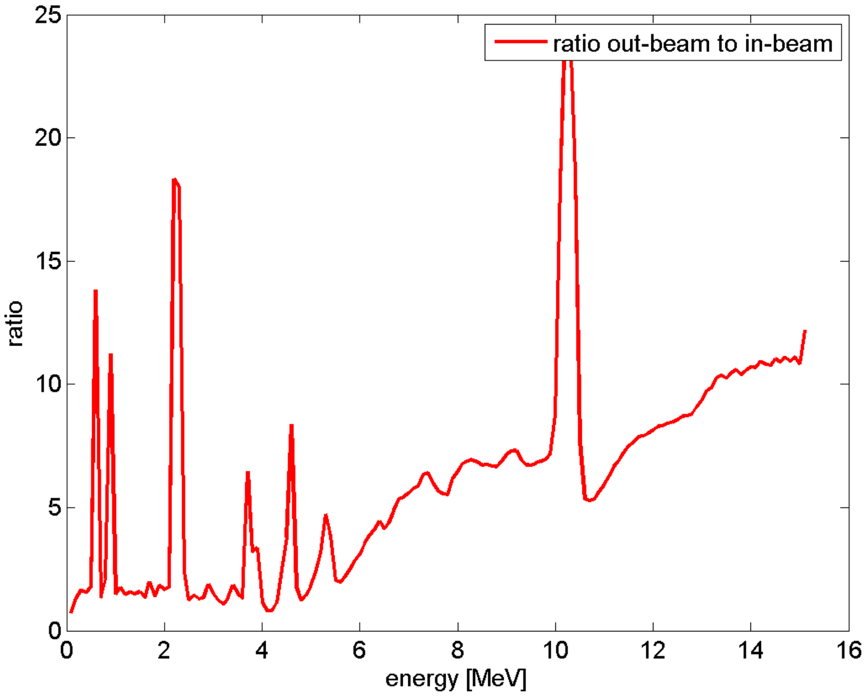


2.1 – 2.3 MeV Photons



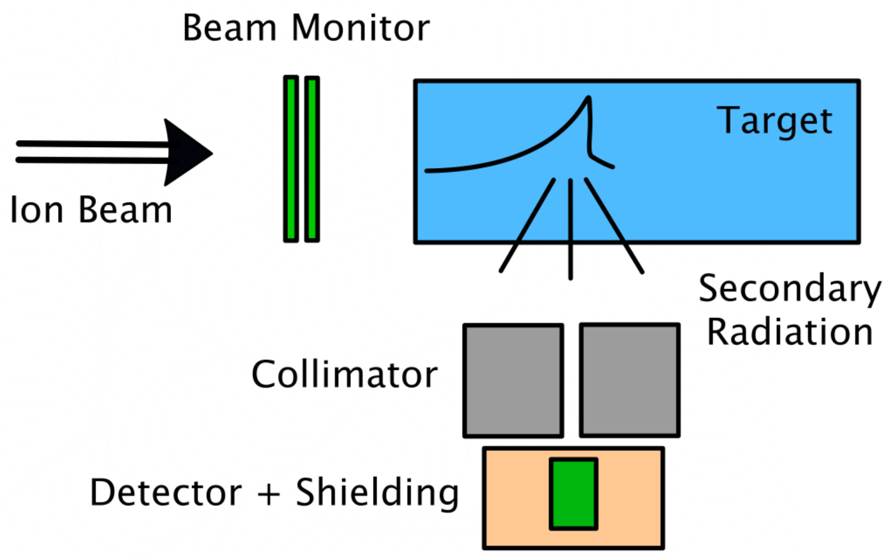
Improvements

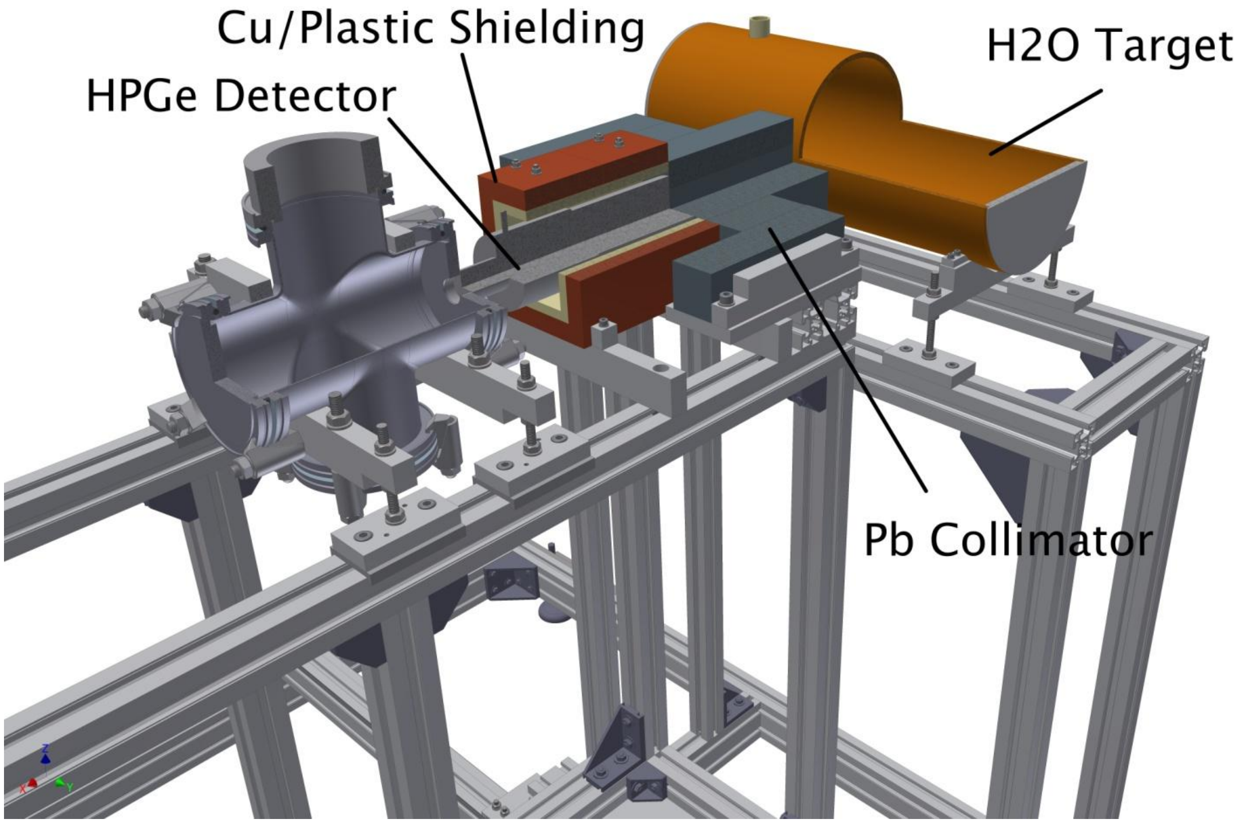
- Poor ratio for the prominent peaks
- Worse ratio above 6 MeV
- Support the most promising energy range from 2.3 – 6 MeV



Outlook

- Beamtime in October at PSI
  - proton beam
  - Energyspectra
  - Photondetection as a funtion of the depth
- Verify simulation tool and data




Cu/Plastic Shielding
HPGe Detector
H2O Target
Pb Collimator

Thank you for your attention

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