Simulation of Prompt Gamma Imaging in Hadron Therapy

NEMNYUGIN S.A., GOLUBEVA P.A., PRIMAK K.A.

SAINT-PETERSBURG STATE UNIVERSITY

LXXI INTERNATIONAL CONFERENCE NUCLEUS 2021

Outline

- Hadron therapy
- Image guided hadron therapy
- Computational model
- Results
- Conclusion

Hadron therapy

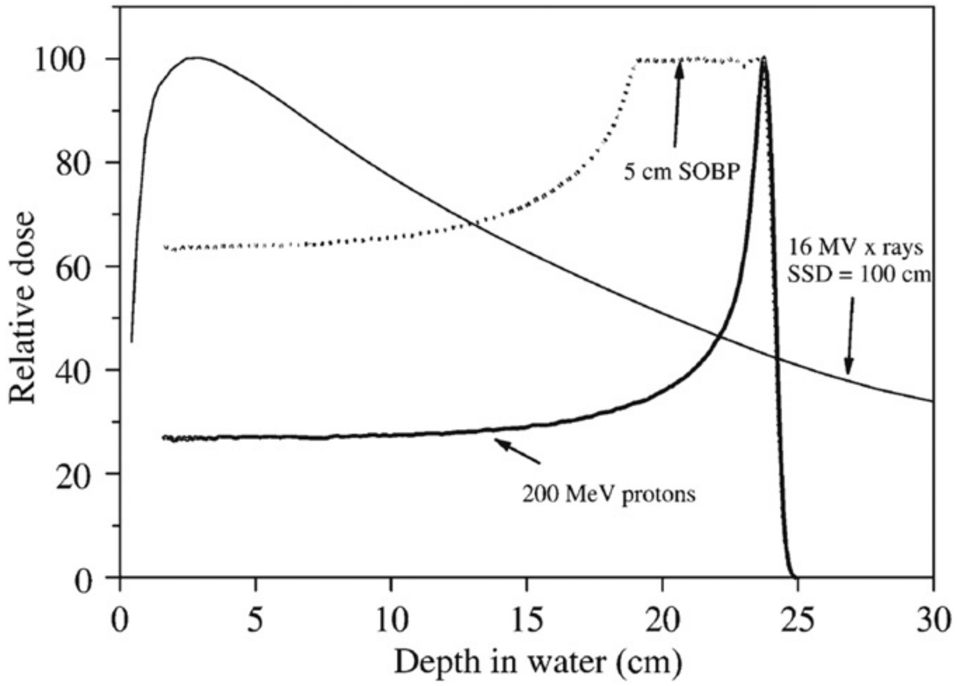


Fig. 1. Depth-dose distributions. Water phantom.
SOBP – Spread Out Bragg Peak radiotherapy.

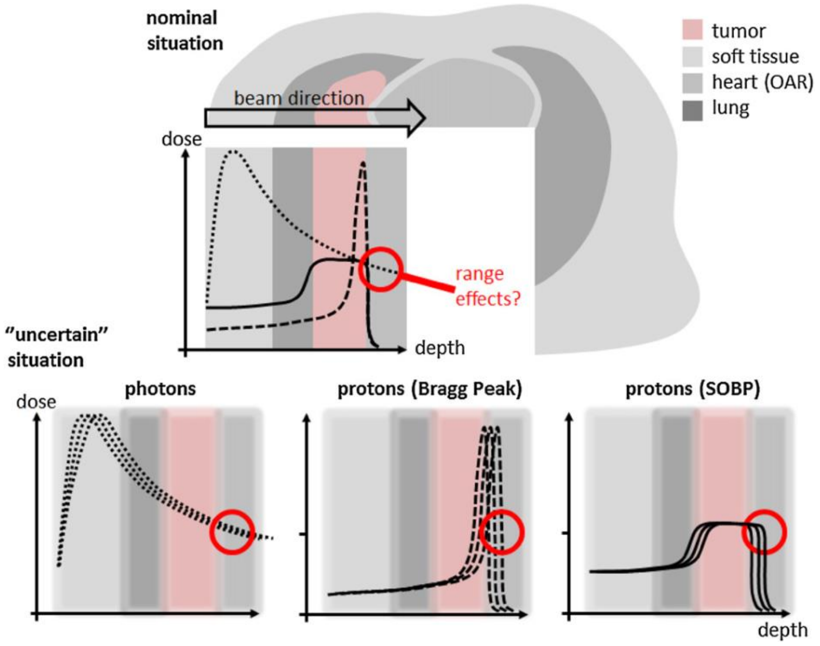


Fig. 2. Influence of uncertainties on depth-dose profile.

Reasons of uncertainties in Bragg peak localization:

✓Physical and biological processes that are not taken into account.

✓Modelling errors.

Goal of this study is evaluation of applicability of secondary prompt gamma radiation for real-time measurement of Bragg peak position.

- Computational model of experimental setup has been proposed.
- Spectrum and depth-dose profiles are calculated.
- Dependence of Bragg peak parameters on spectrum of prompt gamma were analyzed.

Image guided hadron therapy

Steps of treatment:
1. Preparation of treatment plan.
2. Treatment session.
3. Getting results of visualization.
4. Correction of treatment plan.
5. Next part of treatment session.

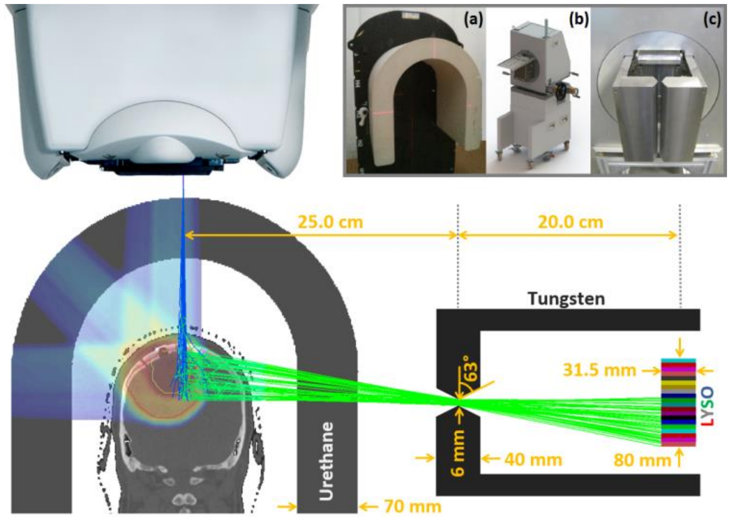


Fig. 3. PGI device.

Visualization methods

- Pointwise measurements of absorbed dose (direct).
- Proton radiography/tomography (direct).
- Computer tomography (indirect).
- Magnetic resonance tomography (indirect).
- Positron emission tomography (indirect).
- Prompt gamma imaging (PGI, indirect).

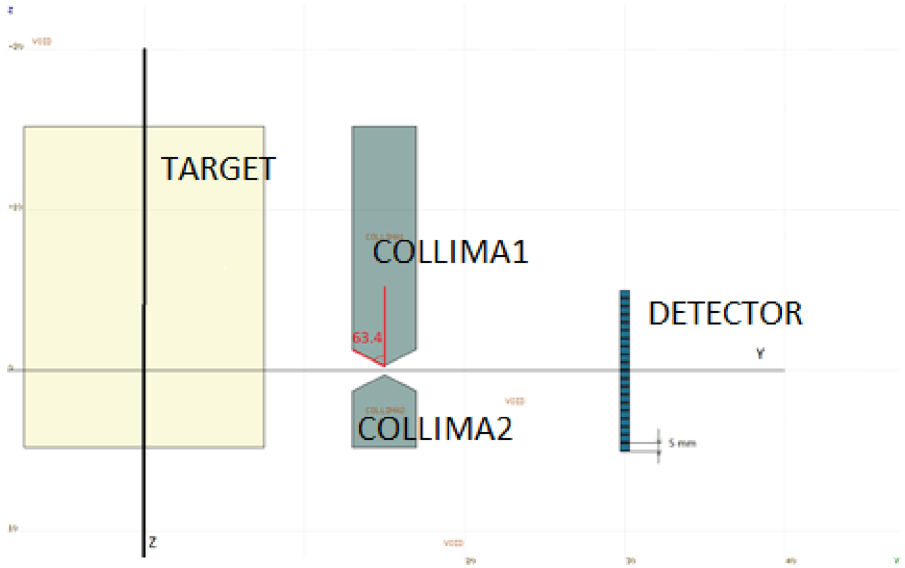
Peak energy (MeV)		Interpretation
Measured	Tabulated	
0.73	0.718	$^{12}C(p,x)^{10}B^*$
		$^{16}O(p,x)^{10}B^*$
1.02	1.022	$^{12}C(p,x)^{10}B^*$
		$^{16}O(p,x)^{10}B^*$
1.98	2.000	$^{12}C(p,x)^{11}C^*$
2.20	2.223	$^{1}H(n,\gamma)^{2}H$
2.74	2.742	$^{16}O(p,p^*)^{16}O^*$
3.36	$3.42 = 4.44 - 2 \times 0.511$	$^{12}C(p,p^*)^{12}C^*$
3.89	$3.93 = 4.44 - 0.511$	$^{16}O(p,x)^{12}C^*$
4.37	4.44	$^{12}C(p,2p)^{11}B^*$
5.15	$5.107 = 6.129 - 2 \times 0.511$	
5.58	$5.618 = 6.129 - 0.511$	$^{16}O(p,p^*)^{16}O^*$
6.02	6.129	

Fig. 4. Prompt gamma spectrum (see next slide).

Modelling tool

FLUKA 4.1.1 (CERN, INFN)
+
FLAIR 3.1-13GUI

Computational model



Incoming beam: protons, 160 MeV, directed along Z-axis.

Target: cylinder, R = 7.5 cm, h = 20 cm, shift along Z 4.8 cm, PMMA.

Collimator: slot width 6 mm, angle 63.4 degrees, thickness 4 cm, tungsten.

Detector: plates width 5 mm, total width 10 cm, NaI(Ti).

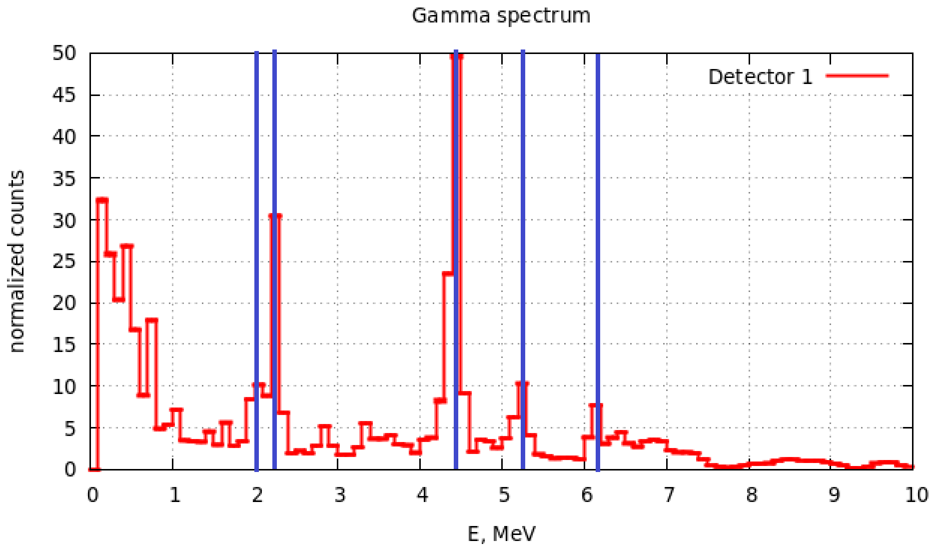


Fig. 5. Spectrum of prompt gamma, modelling results.

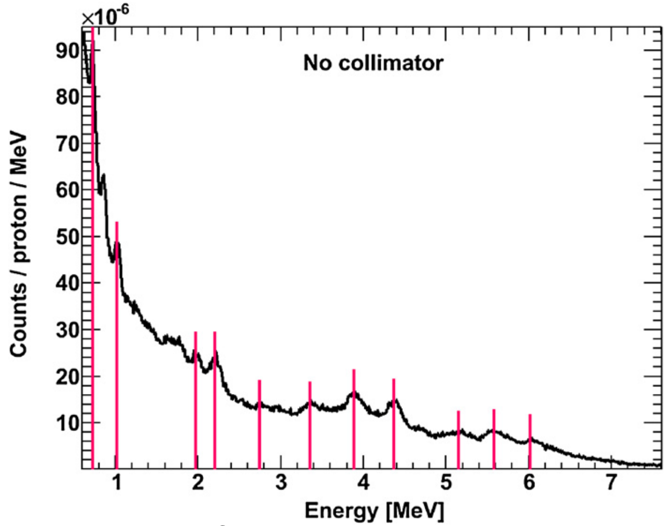
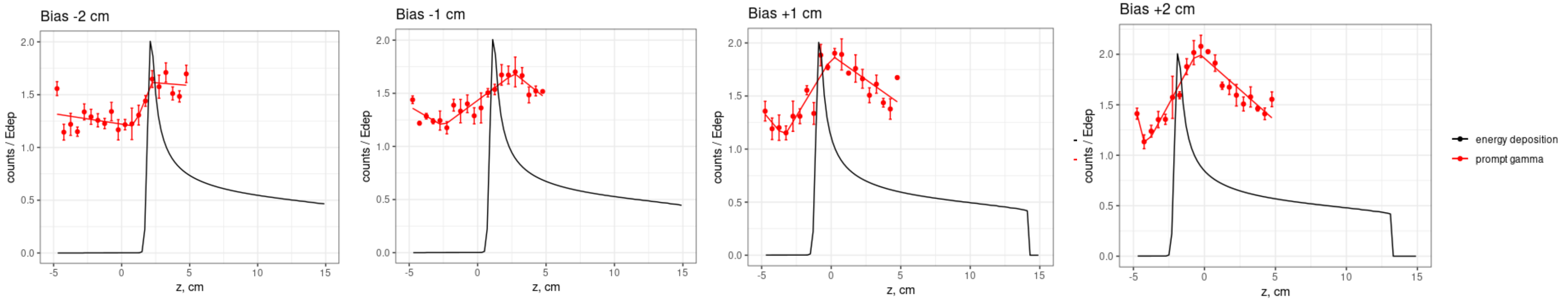
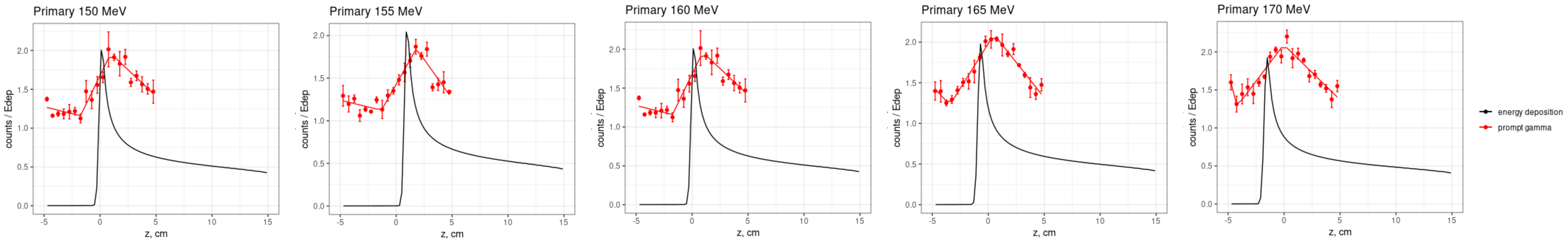


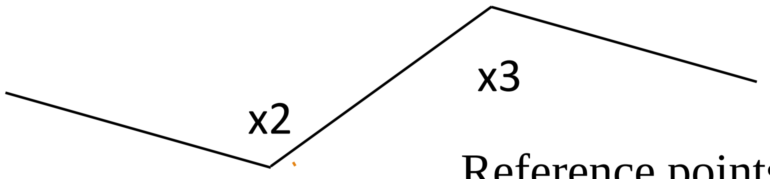
Fig. 6. Spectrum of prompt gamma, experiment

[J Smeets, F Roellinghoff, et al. *Prompt gamma imaging with a slit camera for real-time range control in proton therapy*. Phys. Med. Biol., 2012, 57, 3371-3405].

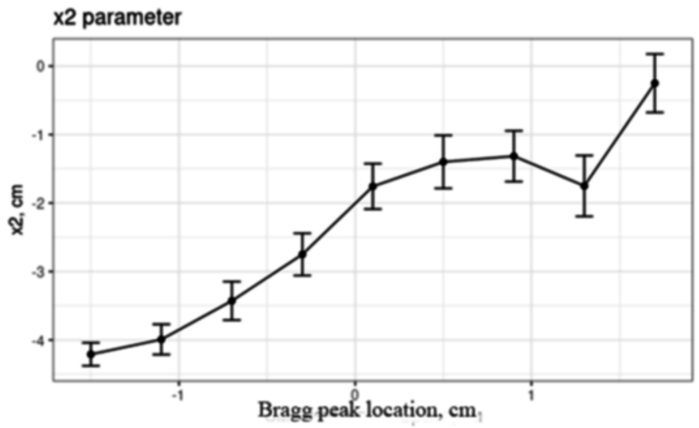
Depth-dose and prompt gamma distributions

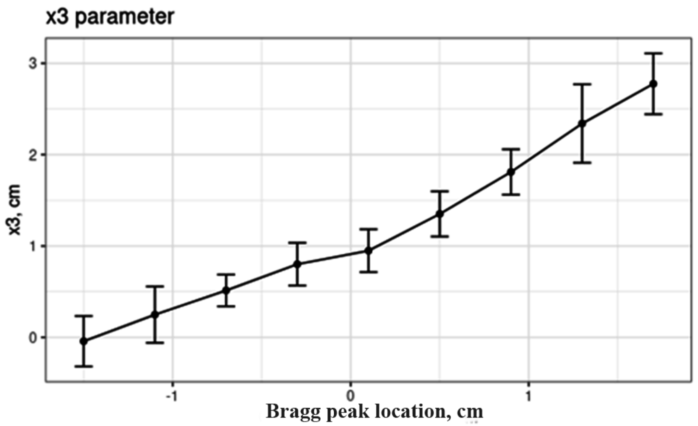






Reference points





Carbon beam

Particles	Fraction, %
p^+	38.5
^4He	28.1
n^0	17.5
γ	9.3
^2H	3.5
^3He	2.0
^3H	1.0

Fig. 8. Composition of secondary radiation.

Particles	Fraction, %
p^+	0
n^0	37.1
γ	14.4

Fig. 9. Fraction of secondary particles passed through collimator.

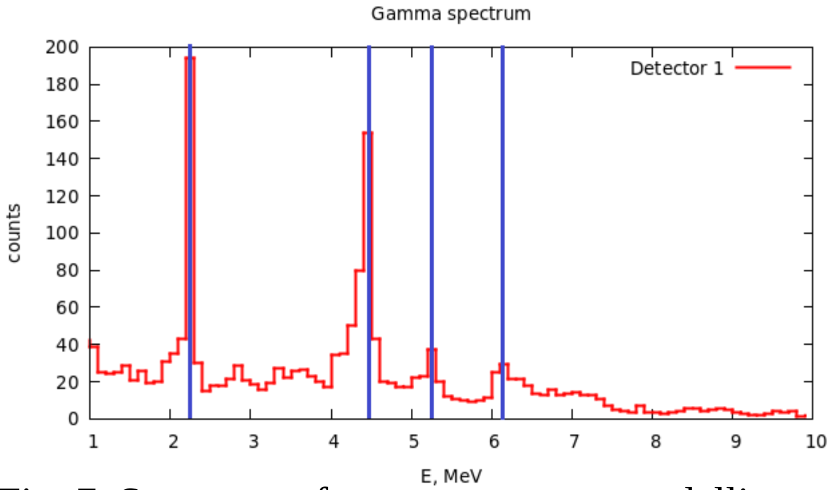


Fig. 7. Spectrum of prompt gamma, modelling and experimental results.

Modelling (MeV)	Experiment (MeV)	Reaction
2.0	2.000	$^{12}C(p,x)^{11}C^*$
2.2	2.223	$^1H(n,\gamma)^2H$
4.4	4.44	$^{12}C(p,2p)^{11}B^*$
5.2	5.107	$^{16}O(p,p^*)^{16}O^*$
6.1	6.129	$^6O(p,p^*)^{16}O^*$

Conclusion

- Numerical results for spectrum of prompt gamma agree with experimental results.
- Proposed parameters of secondary radiation distribution allow localize Bragg peak experimentally.
- Fraction of secondary particles passed through collimator other than gamma should be minimized.
- Results for carbon beams are also obtained with Geant4 framework.

Thank you for attention!