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Investigation of gamma emission in experimental modeling of hadron therapy

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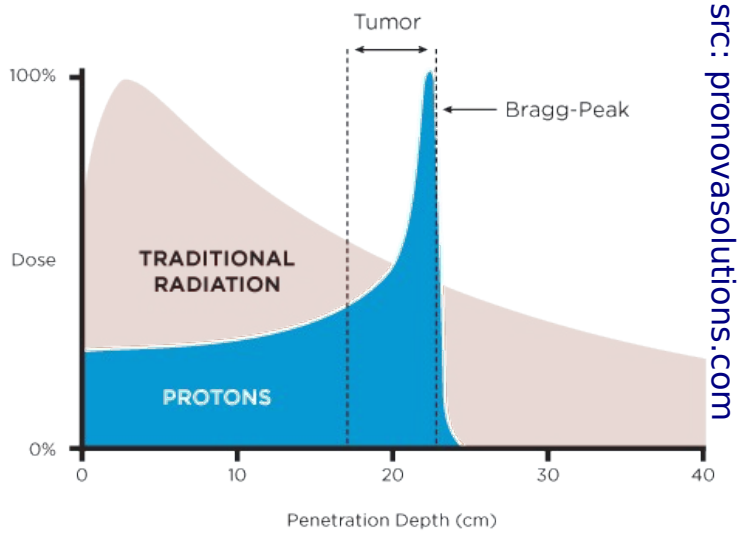
Context:

- Hadron therapy
- Quality assurance
- Alternative (to PET) imaging methods



Physics goals:

Future Prompt Gamma (PG) imaging devices based on Compton cameras will need precise data on the correlation between the Bragg Peak Position (BPP) and the characteristics of the gamma spectra

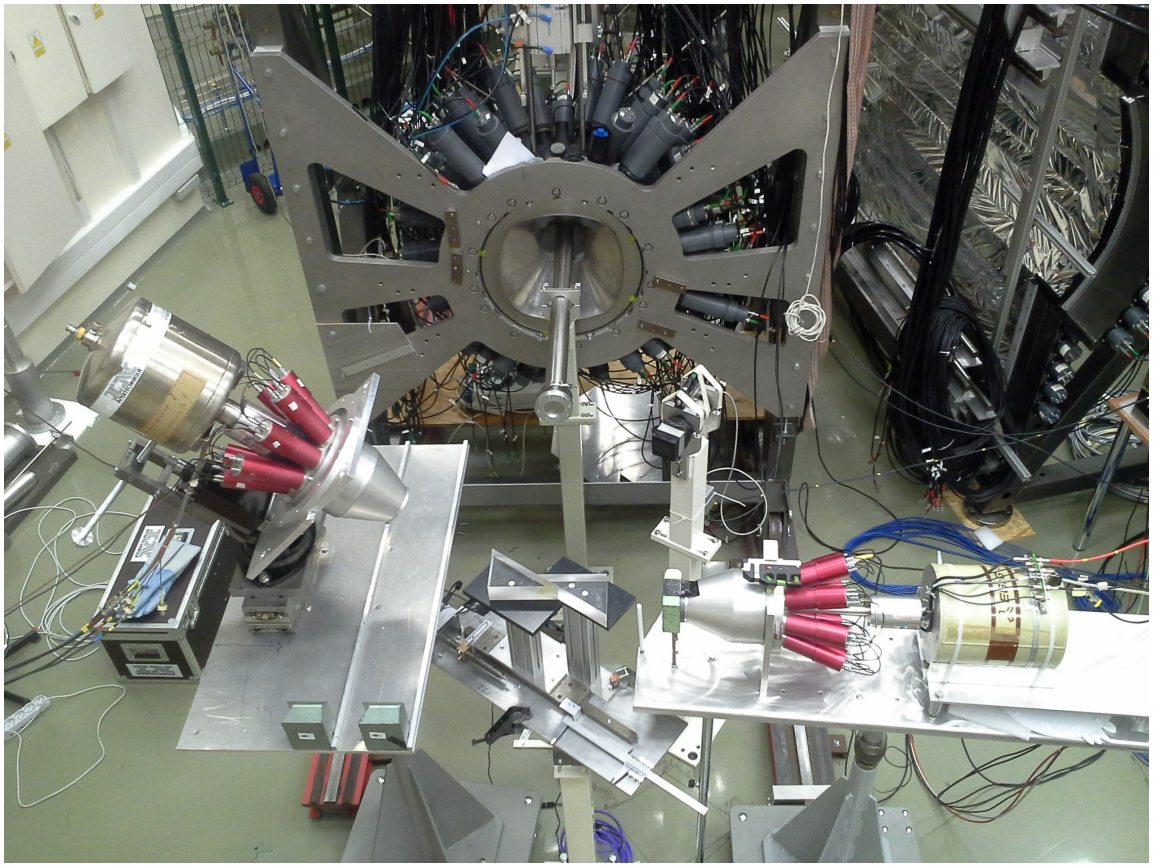
- Measure gamma yield in phantom per unit of depth as function of depth
- Extract such dependencies for discrete transitions in C (4.44 MeV) and O (6.13 MeV), as well as for the continuum in energy intervals
- Use different phantom materials to vary O/C content
- Repeat measurements for different detection angles to find optimal conditions
- Use our smart target setup to extract clean information (no effect of collimator)
- Develop algorithms to determine BPP by measuring PG radiation from an irradiated object

Proteus C-235 cyclotron (IBA).

src: http://www.ifj.edu.pl/ccb/index.php

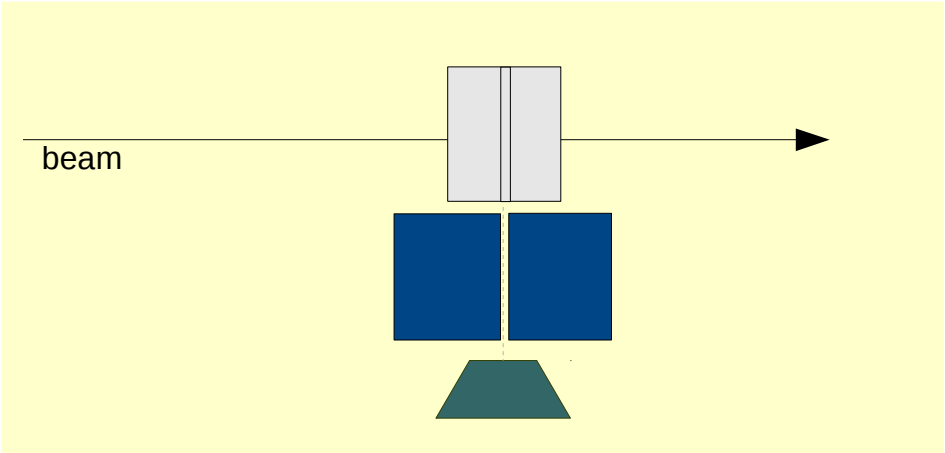
Gantry – part visible to patients.

- Phase I - measurements started in the Cyclotron Centre Bronowice in Kraków (launched 2013)
- Experimental conditions designed to simulate course of hadron therapy



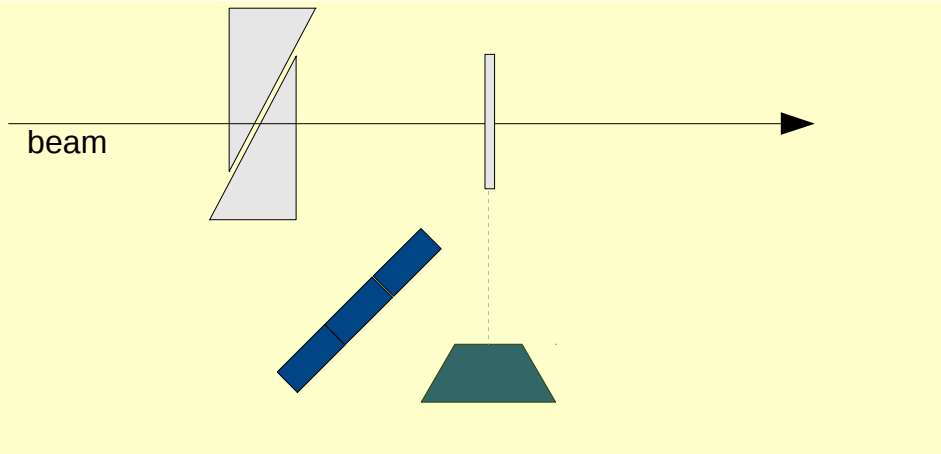
Top view of the experimental setup.

Typical target setup with collimator



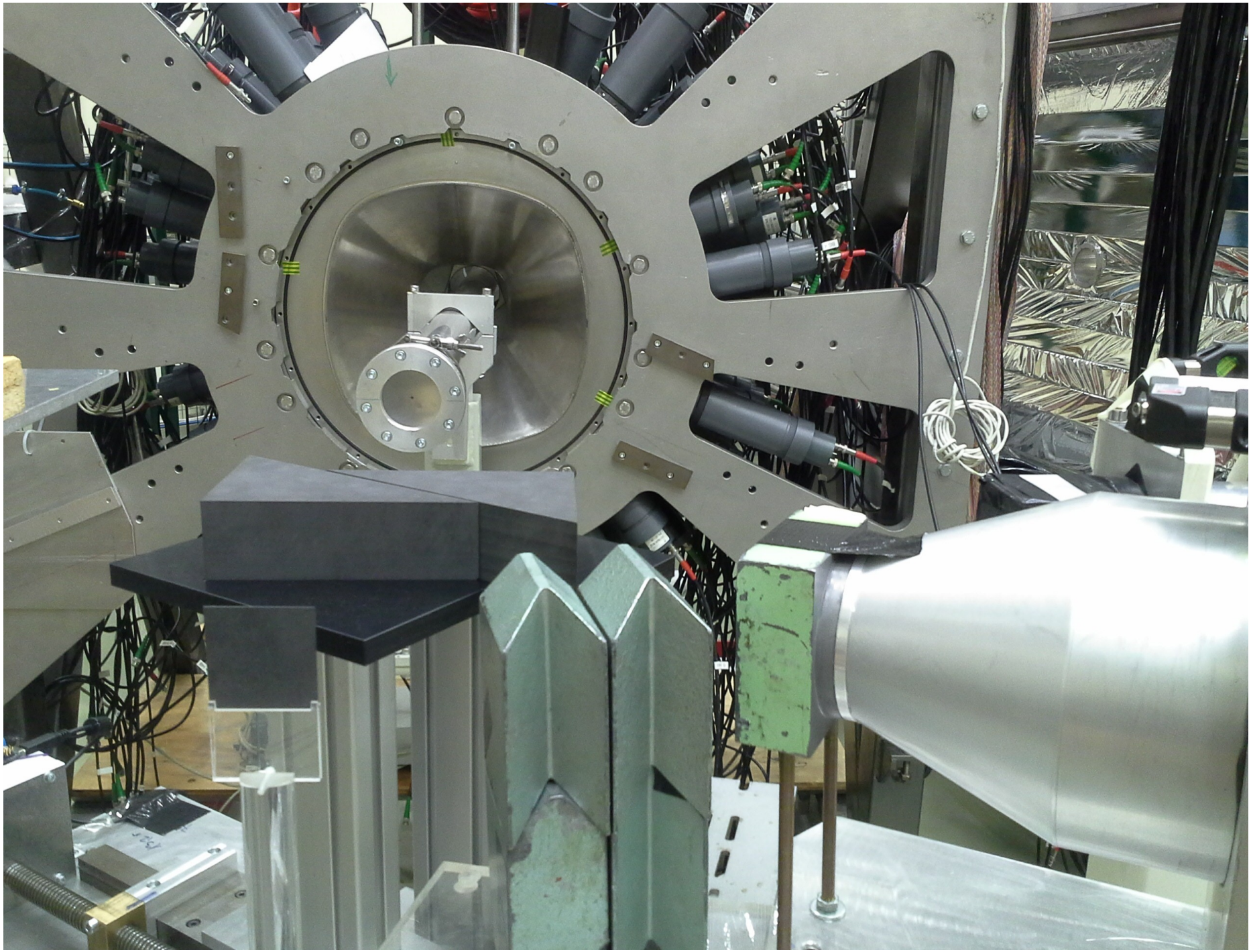
vs

Our setup with spatial separation of phantom parts

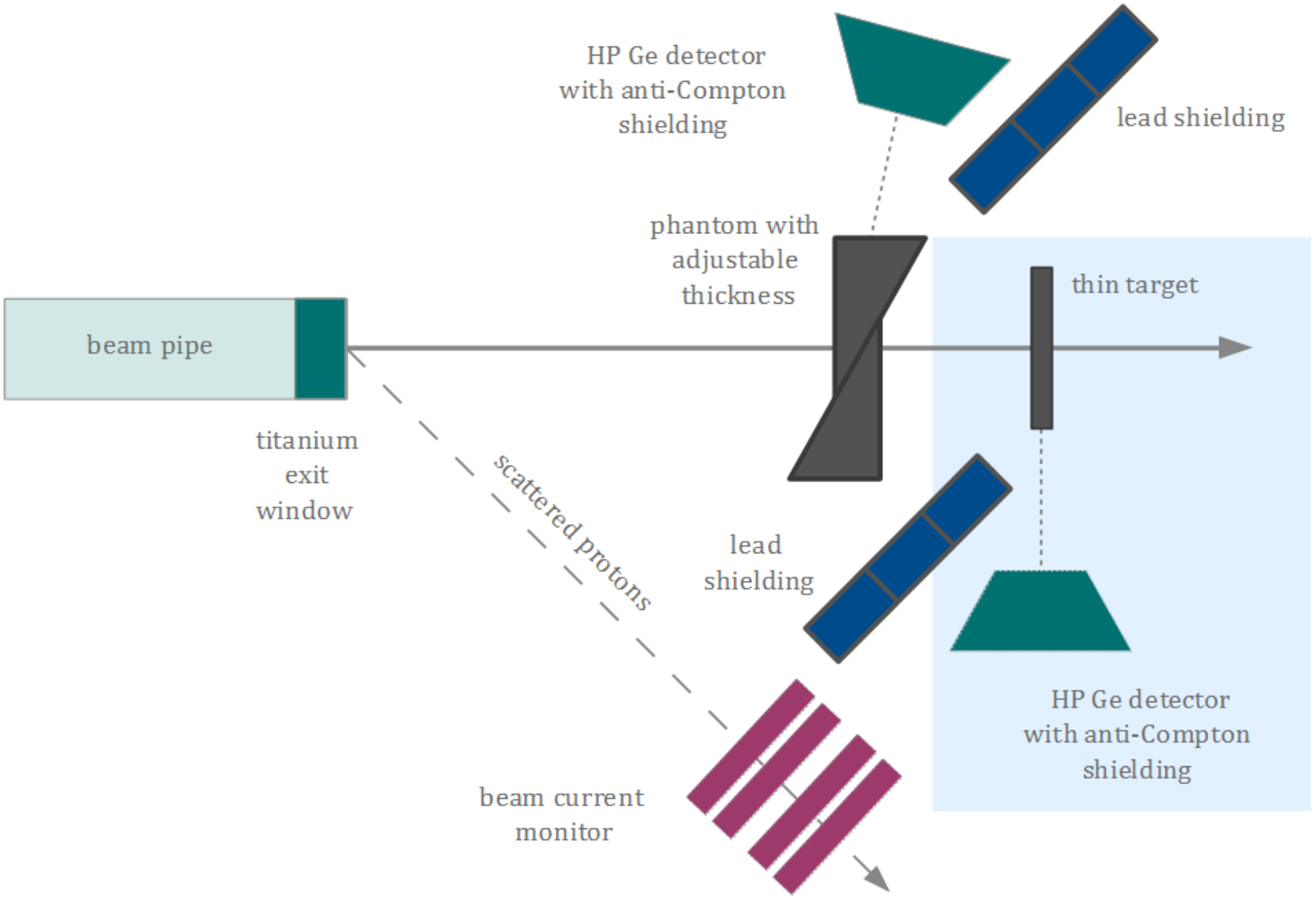


- Phantom construction enables integrated or differential measurement (γ emitted from all phantom parts in the acceptance or only from a thin slice)
- Target thickness remotely controlled – no need to access the experimental hall during one measurement series

Experimental setup – the phantom



Experimental setup



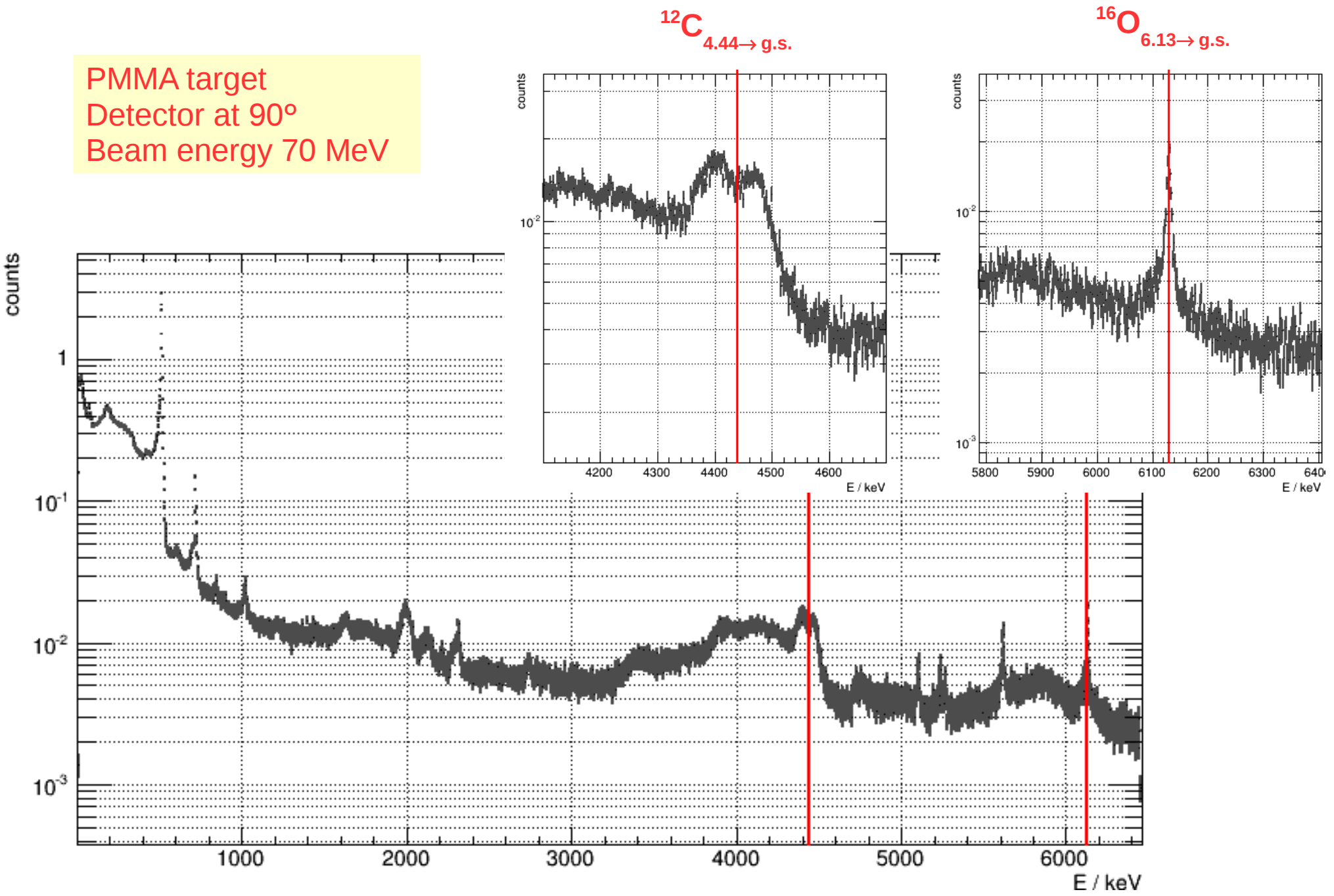
A measurement series:

Fix: beam energy, detection angle, phantom material

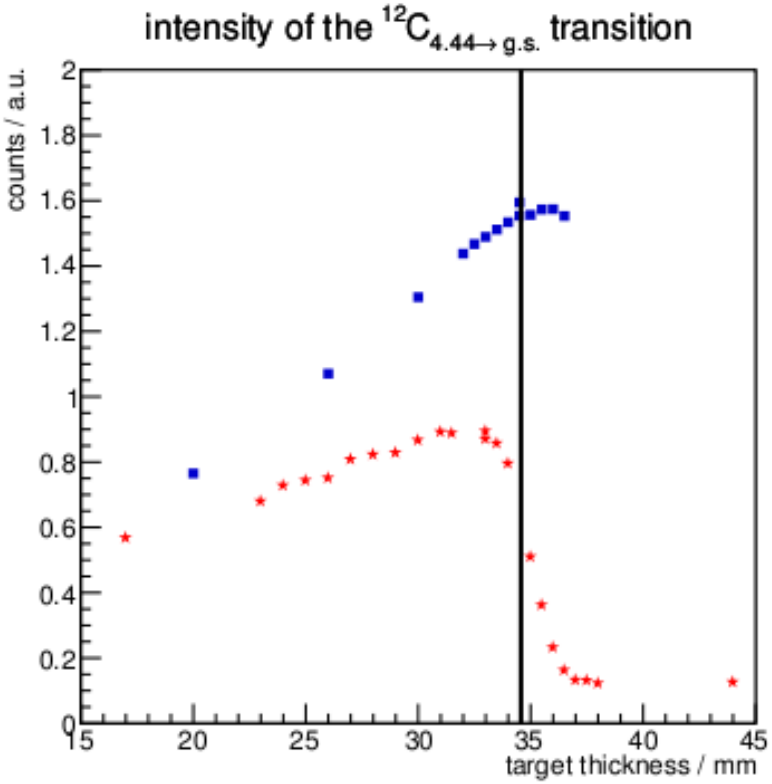
Vary: phantom thickness

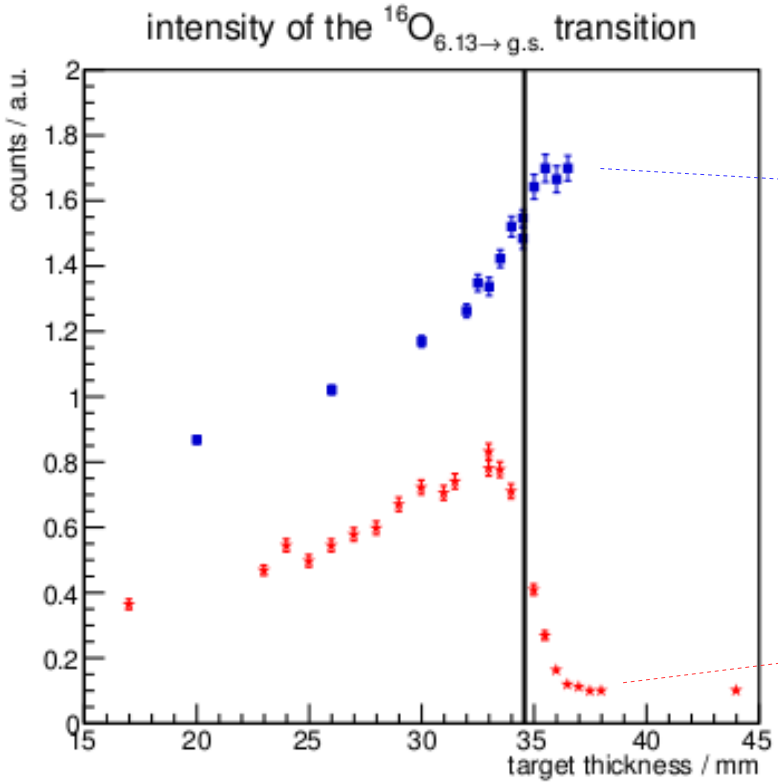
Measure: N(E_γ, target thickness)

PMMA target
Detector at 90°
Beam energy 70 MeV



Energy / Material	Graphite	PMMA
70 MeV	90° thick 90° thin 60° thick	90° thick 90° thin + bg



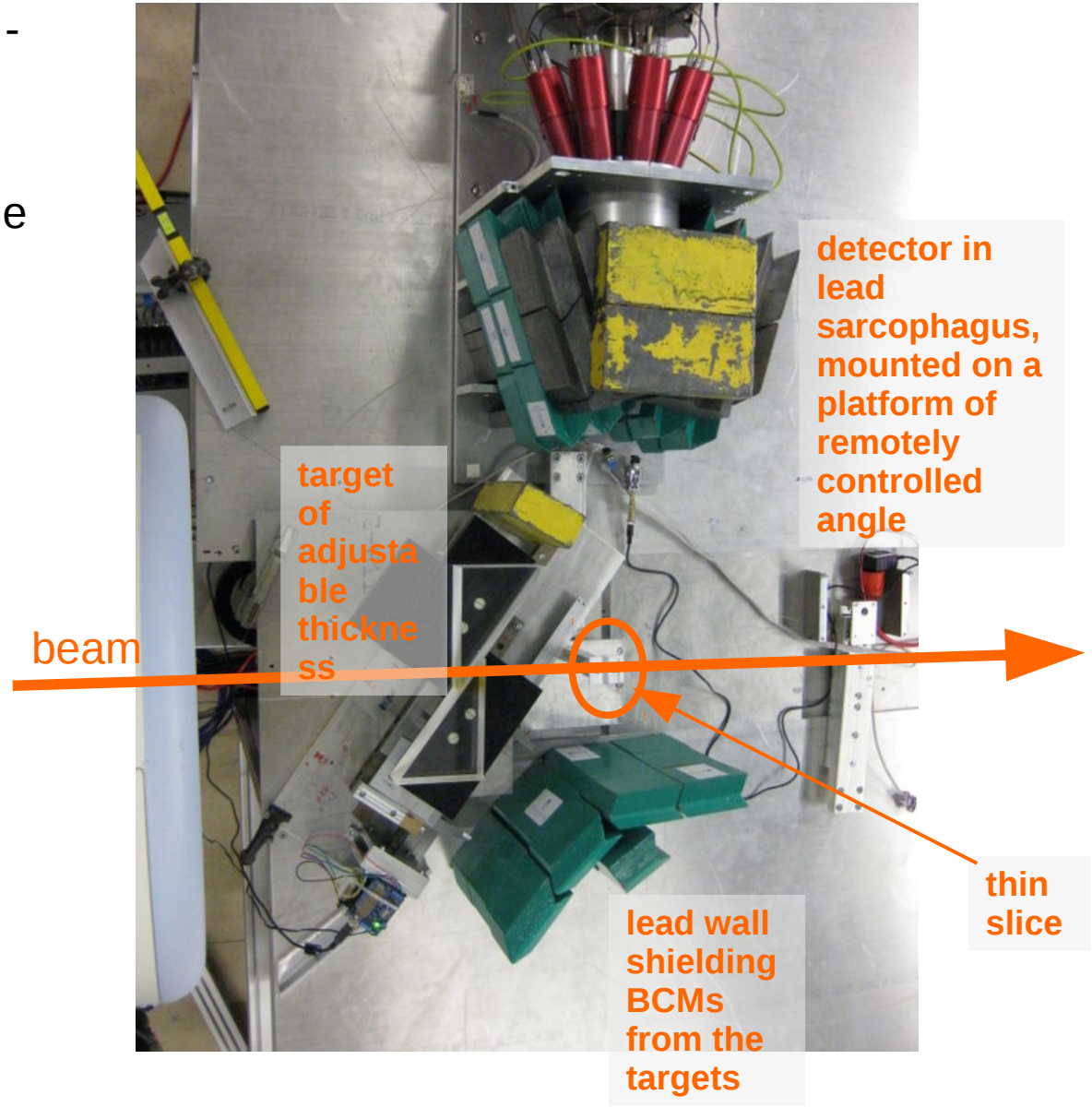


Thick target data (intergrated)

Thin target data (differential)

Anticipated accuracy of BPP determination ~1 mm

- Phase II (July/August 2015) - measurements continued in HIT
- Setup as before, but only one detector and only thin target (differential) measurements
- Very good and stable experimental conditions
- Measurements for more angles, also at higher beam energy (130 MeV)



Summary of measurements performed at CCB

CCB 2014

Energy / Material	Graphite	PMMA
70 MeV	90° thick 90° thin 60° thick	90° thick 90° thin + bg

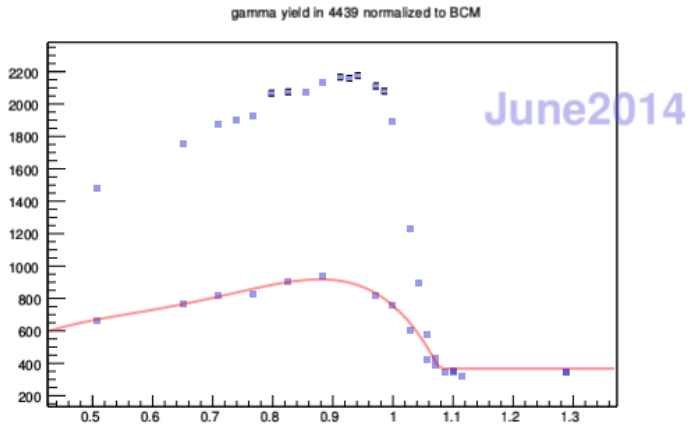
HIT 2015

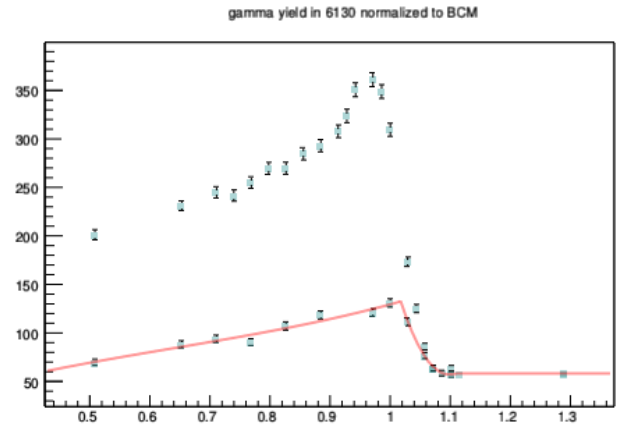
Energy / Material	Graphite	PMMA	POM
70 MeV	90°, 120°	90°, 120°	90°
130 MeV	120°	90°, 120°, 120° with RiFi	

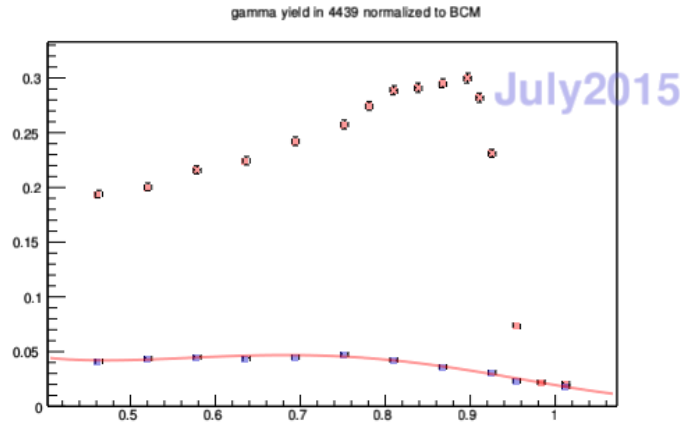
Consistency check for two data sets

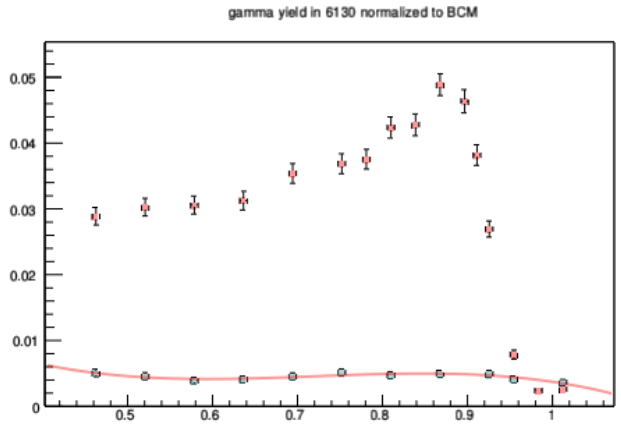
Way of comparing the data:

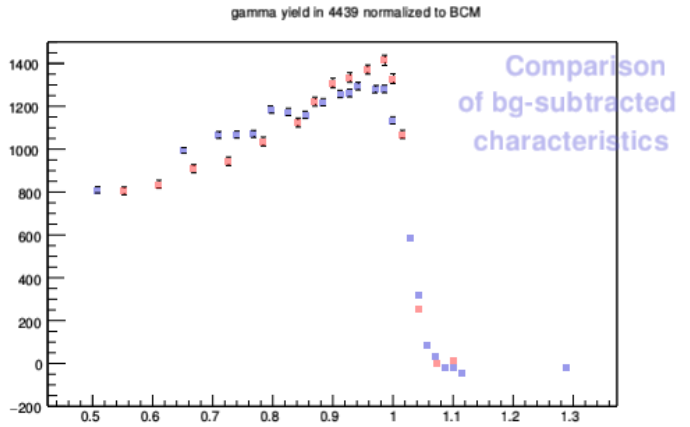
- Analysis performed on all series (PMMA, 90 deg, thin slice, plus empty-target measurements for bg study)
- Characteristics built for June2014 and July2015, on x-axis reduced target thickness (divided by range)
- For each characteristics, corresponding bg characteristics was subtracted
- The June2015 data were scaled by a certain factor – the same for C- and O-lines

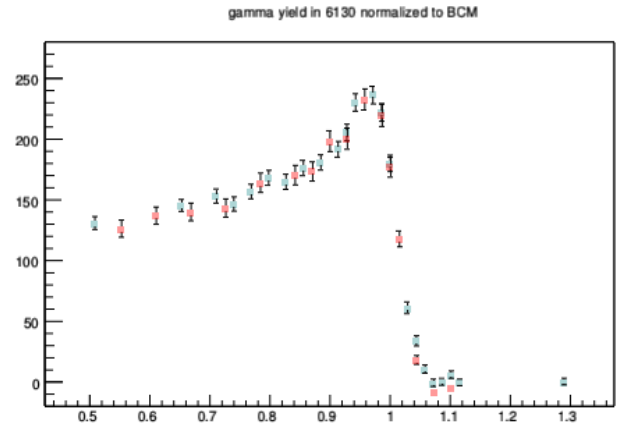








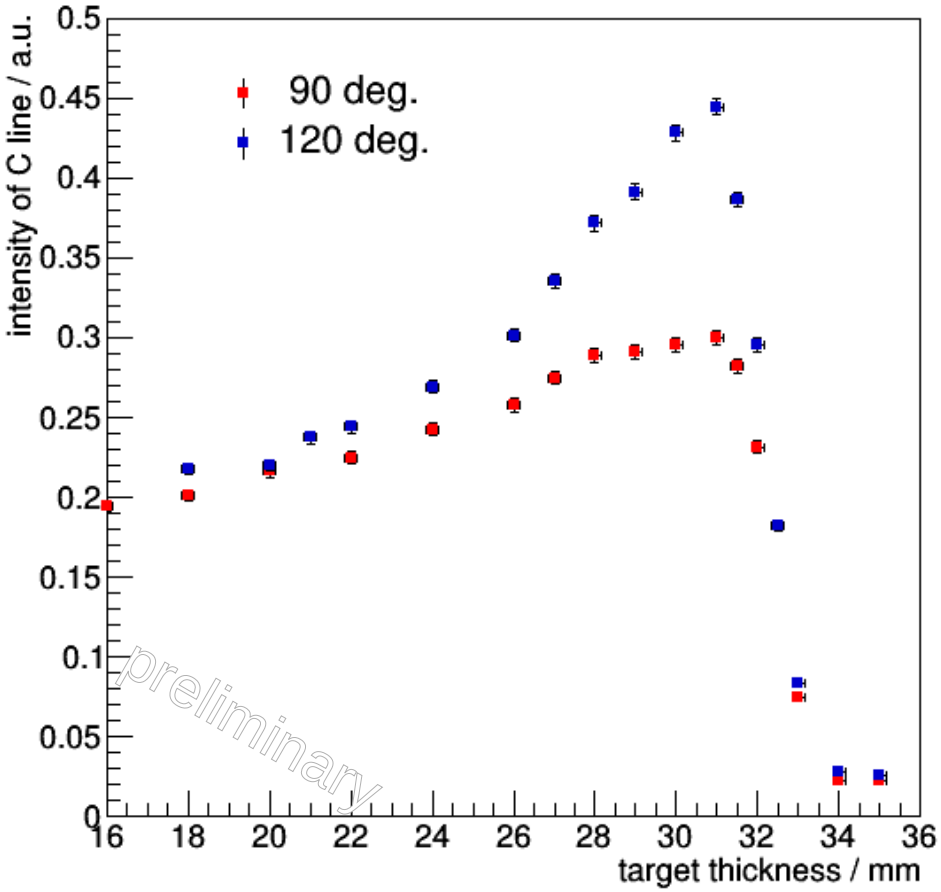




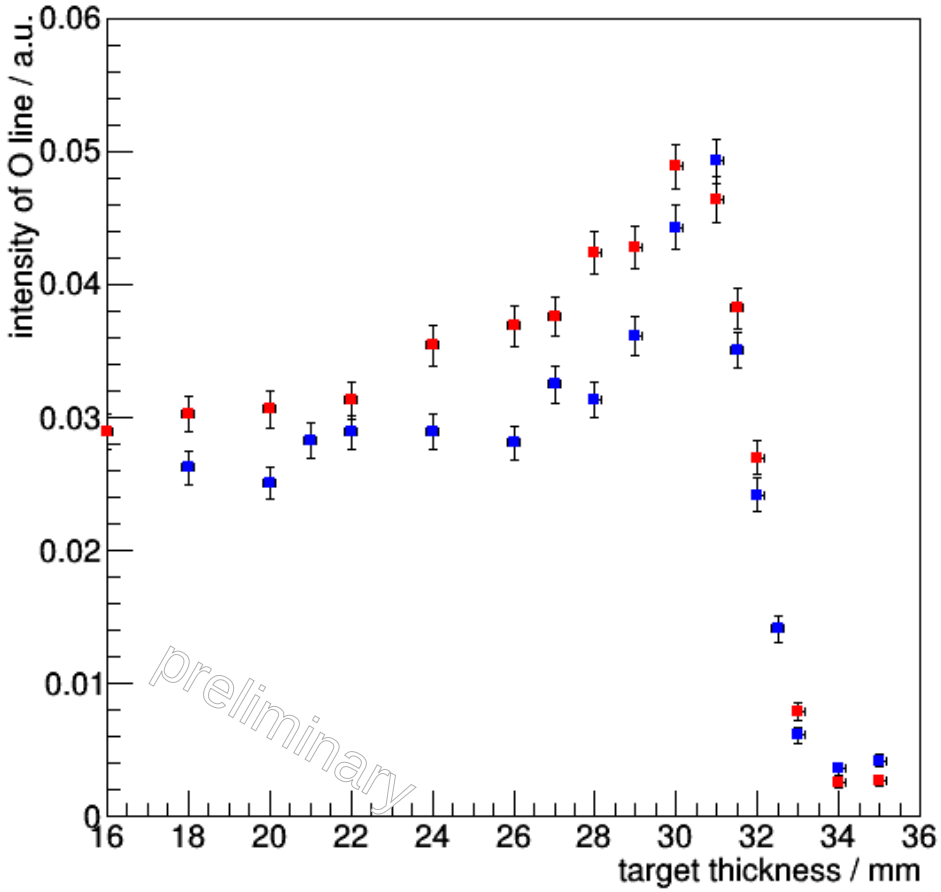
preliminary

Comparison for different detection angles

Carbon line



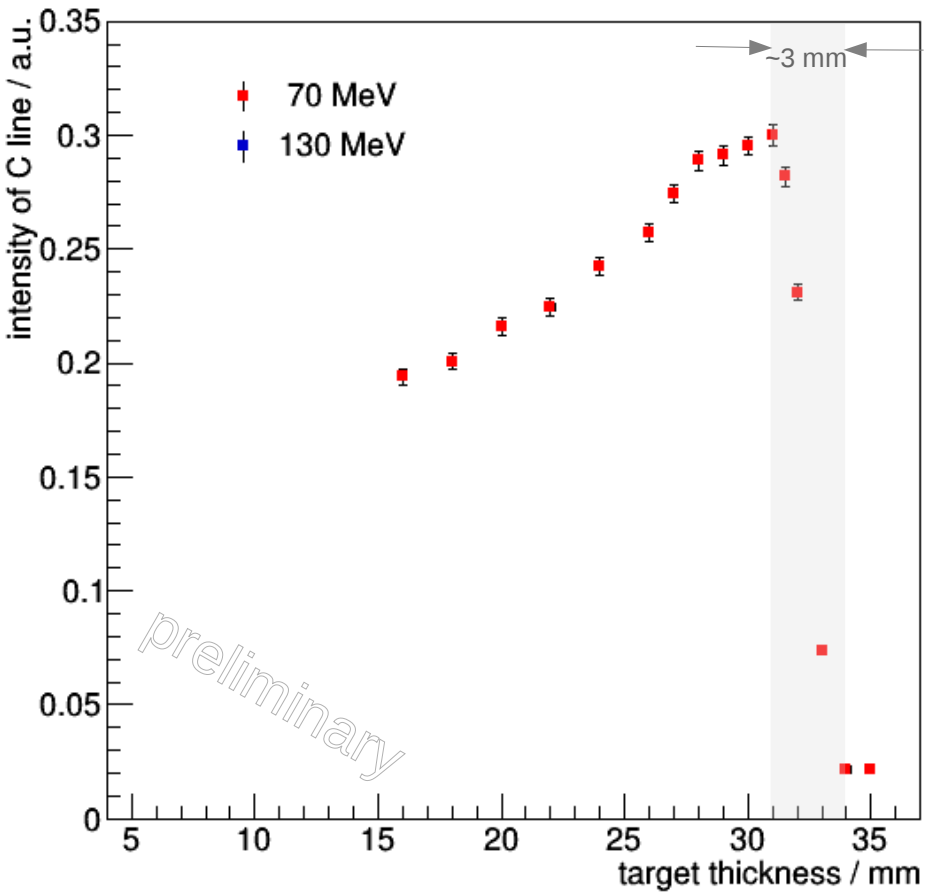
Oxygen line



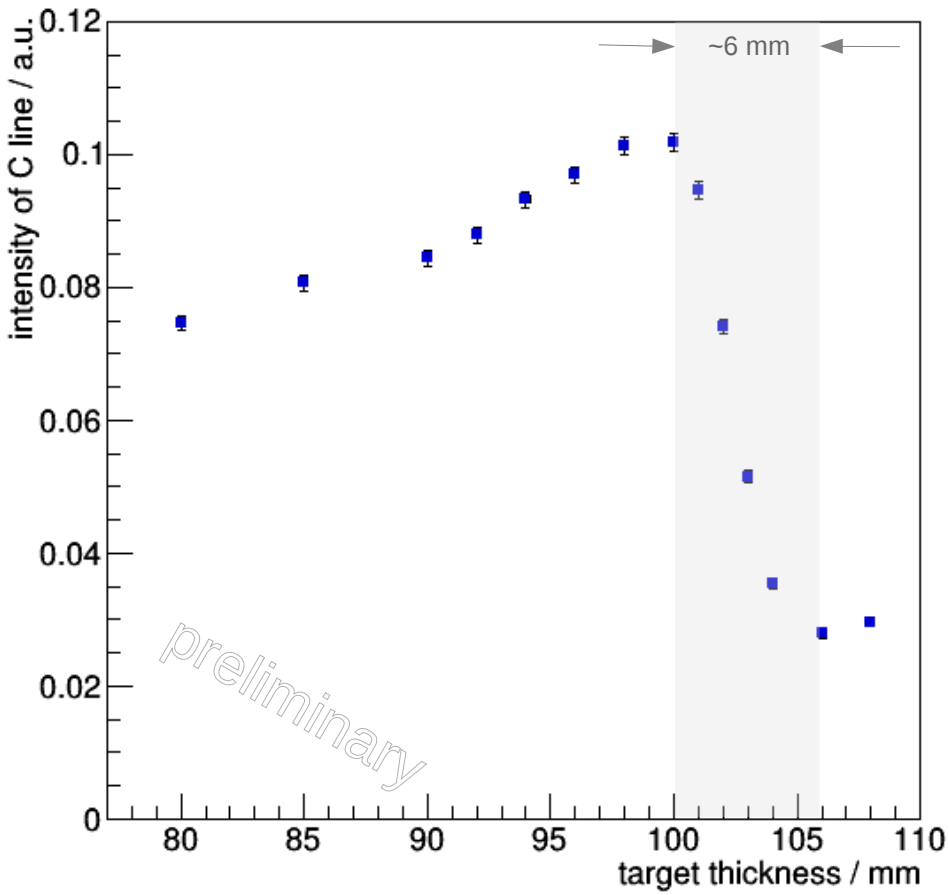
PMMA target, 70 MeV beam energy
Both structures more pronounced at 120 deg than at 90 deg.
→ **Backward angles preferred for determination of BPP**

Comparison for different beam energies

Carbon line at 70 MeV

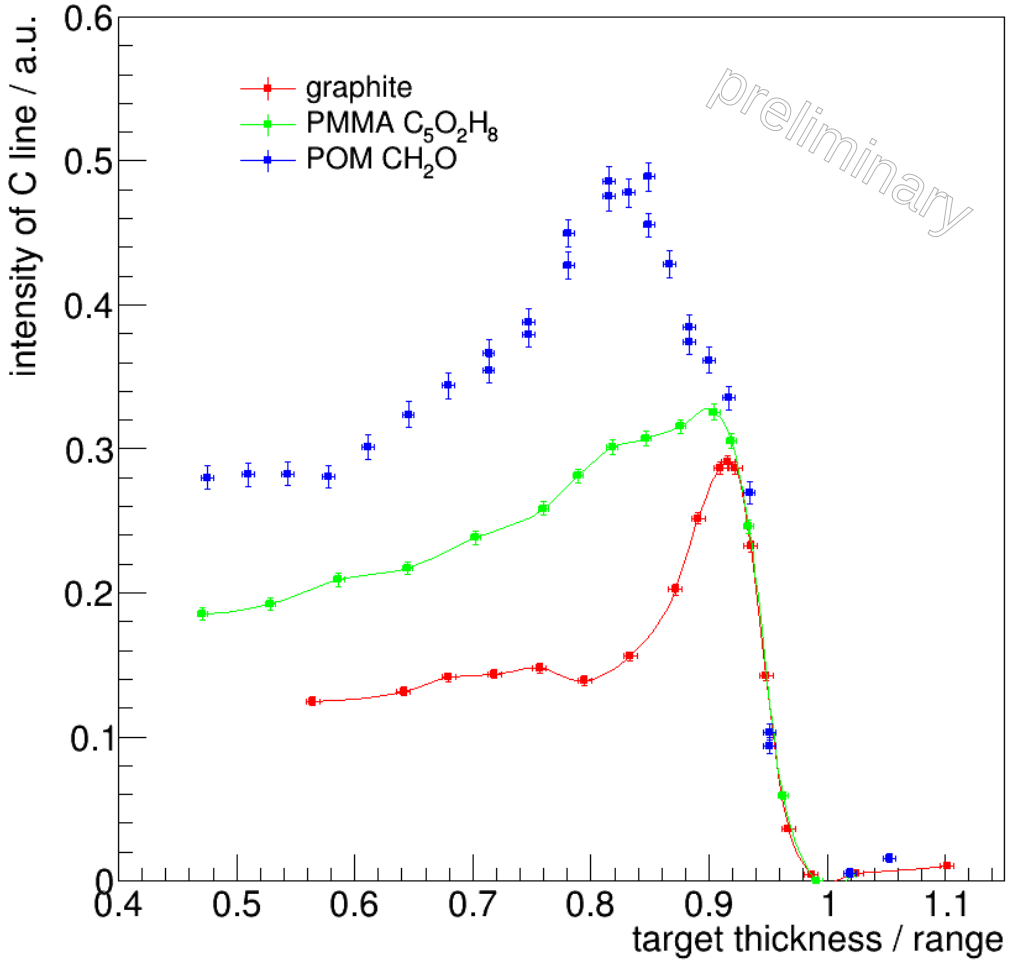


Carbon line at 130 MeV



PMMA target, 70 MeV and 130 MeV beam energy
Background level increases with beam energy
Fall-off indicating BPP smeared at higher energies due to straggling

Comparison for different phantom materials



- Beam energy 70 MeV, detection angle 90 deg.
- All presented spectra are background-subtracted and scaled by relative C content
- Excess of events in polymers is to be attributed to their oxygen contents (extited C* can be also produced by kicking off an α cluster from an O nucleus)

Summary:

- Successful beam times in CCB Kraków and HIT Heidelberg
- Good quality data on gamma emission in hadron therapy obtained
- Various phantom materials with different composition studied (graphite, POM, PMMA)
- Two proton beam energies (70 and 130 MeV)
- Three gamma detection angles (60, 90, 120 deg.)

Further research:

- Analyze obtained data also with respect to the continuum behaviour in energy intervals
- Scrutinize all corrections to have absolute normalization of data
- Take data at energies up to 230 MeV (full range of proton therapy)
- Check even more backward angles – conditions even better?
- Develop algorithms to determine BPP by measuring PG radiation from an irradiated object

Collaboration and support

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