PHITS calculation of the radiation field in HIMAC BIO

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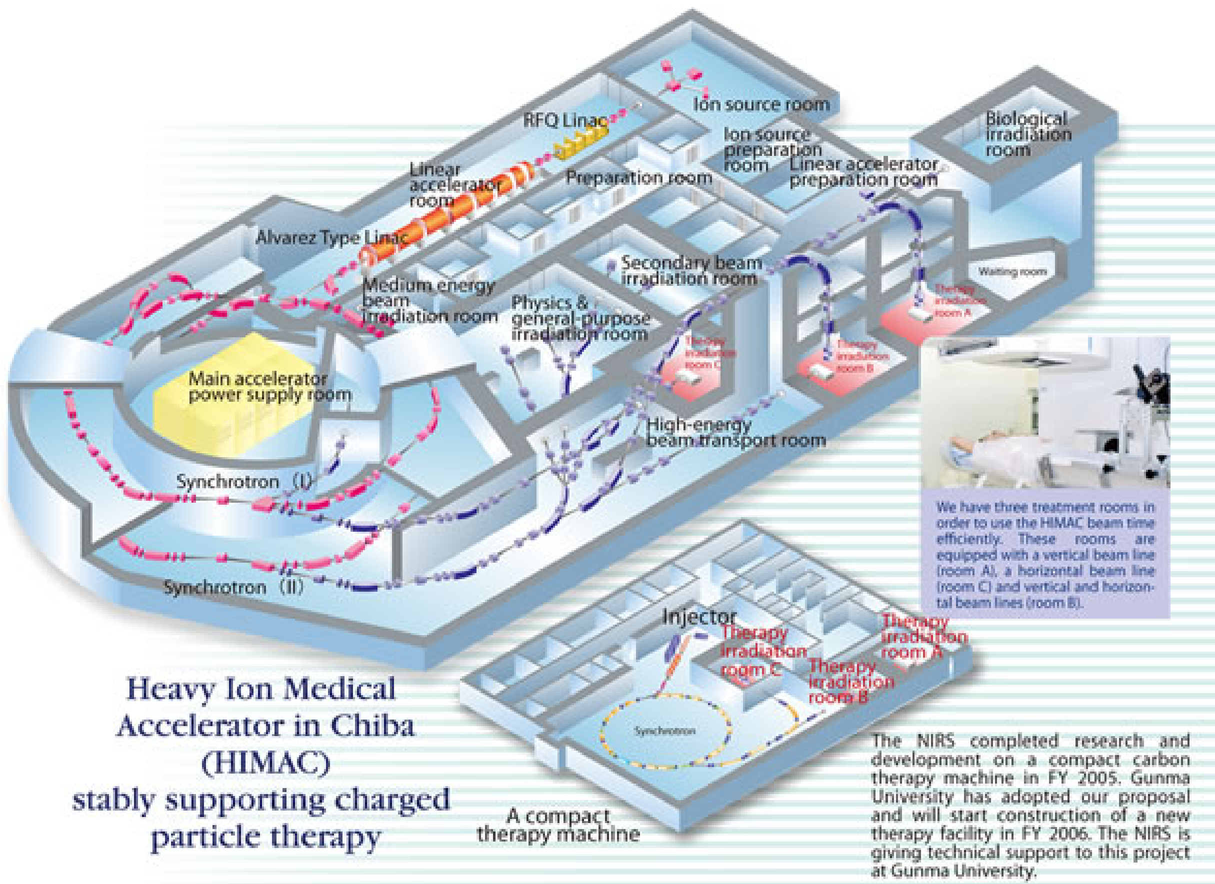
Outline

- Introduction
- Beam-line description
- Depth-dose curves
- Beam profile
- Example of application
  - Silicon detector calibration using only one heavy ion beam
  - Fragments contribution
  - LET spectra
- Conclusions

Introduction

- HIMAC - Heavy Ion Medical Accelerator in Chiba
  - Three irradiation rooms for experiments: (i) General Physics, (ii) Biology (BIO), (iii) Medium energy



http://www.nirs.go.jp/ENG/research/charged_particle/index.shtml

Introduction

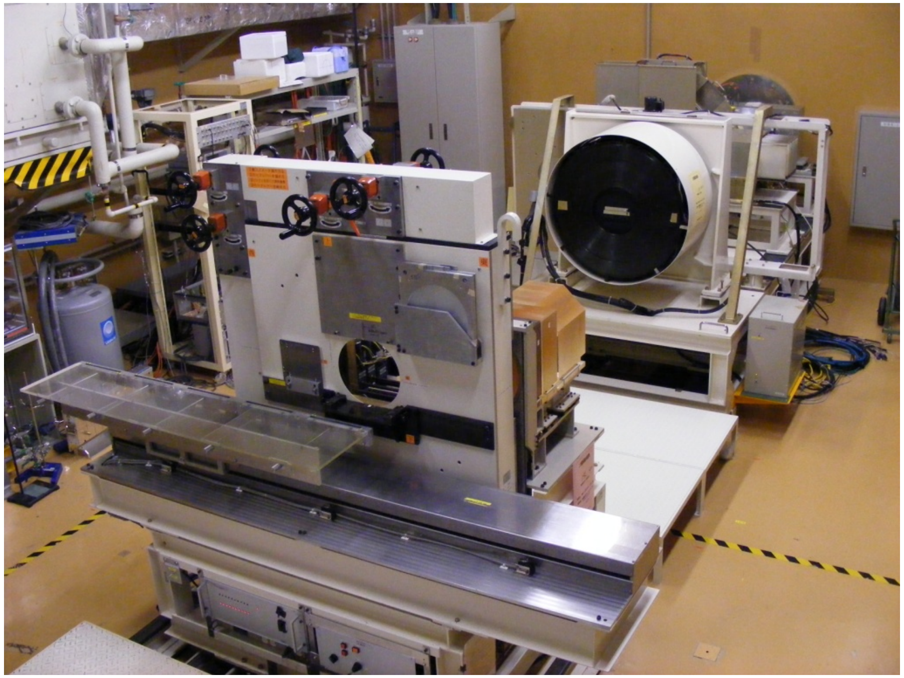
- HIMAC BIO is an irradiation room used for heavy ion experiments related to biology and physics
- Goals
  - to provide detailed information about the components of the beam line at HIMAC BIO
  - to express the exact beam composition via fragment contribution to absorbed dose calculated by PHITS at the location of irradiated samples
  - To compare PHITS simulations with measurements using a semiconductor detector Liulin

HIMAC BIO

- *Advantage*:
  - Bragg curve is well defined
  - Broad parallel beam (ϕ 10cm)
  - Flat beam profile

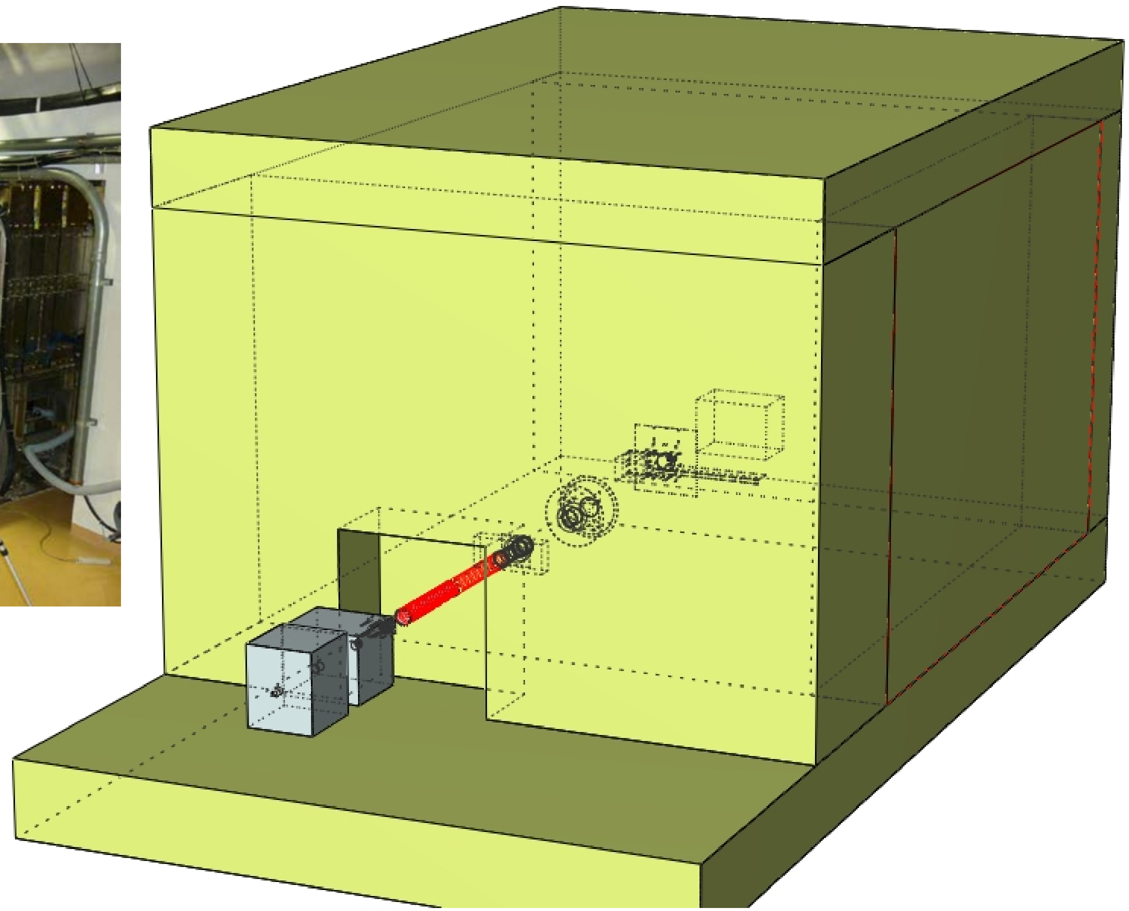
- *Disadvantage*:
  - Fragments and secondary particles because beam goes through scatterer (different for different ions) and 6.7m of air

- Ion+nominal energy in MeV/u: He 150, C 135, C 290, C 400, Ne 400, Si 490, Fe 500
- Measurements performed behind different thicknesses of PMMA filters
  - 9 filters are available (in mm): 0.5, 1, 2, 4, 8, 16, 32, 64, 128

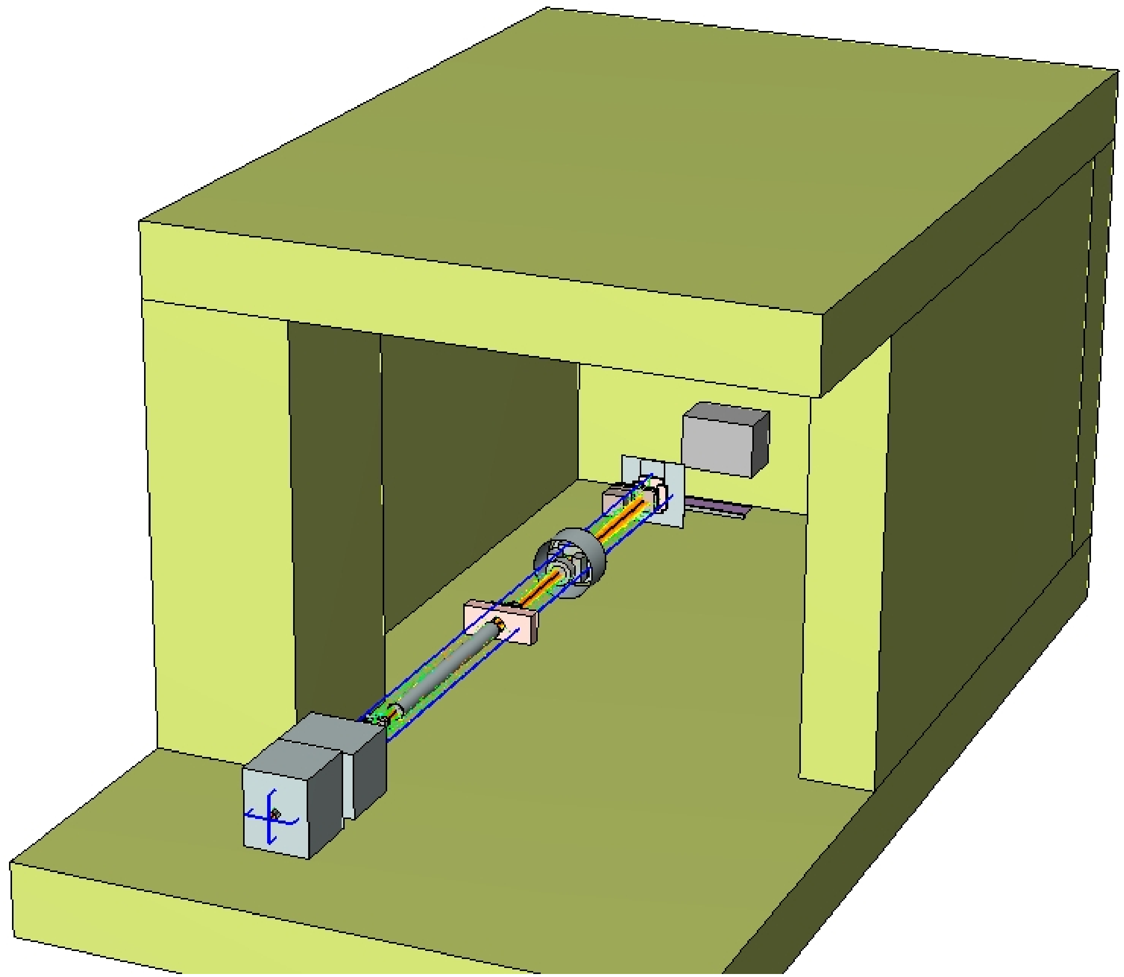


HIMAC BIO geometry used for PHITS calculations

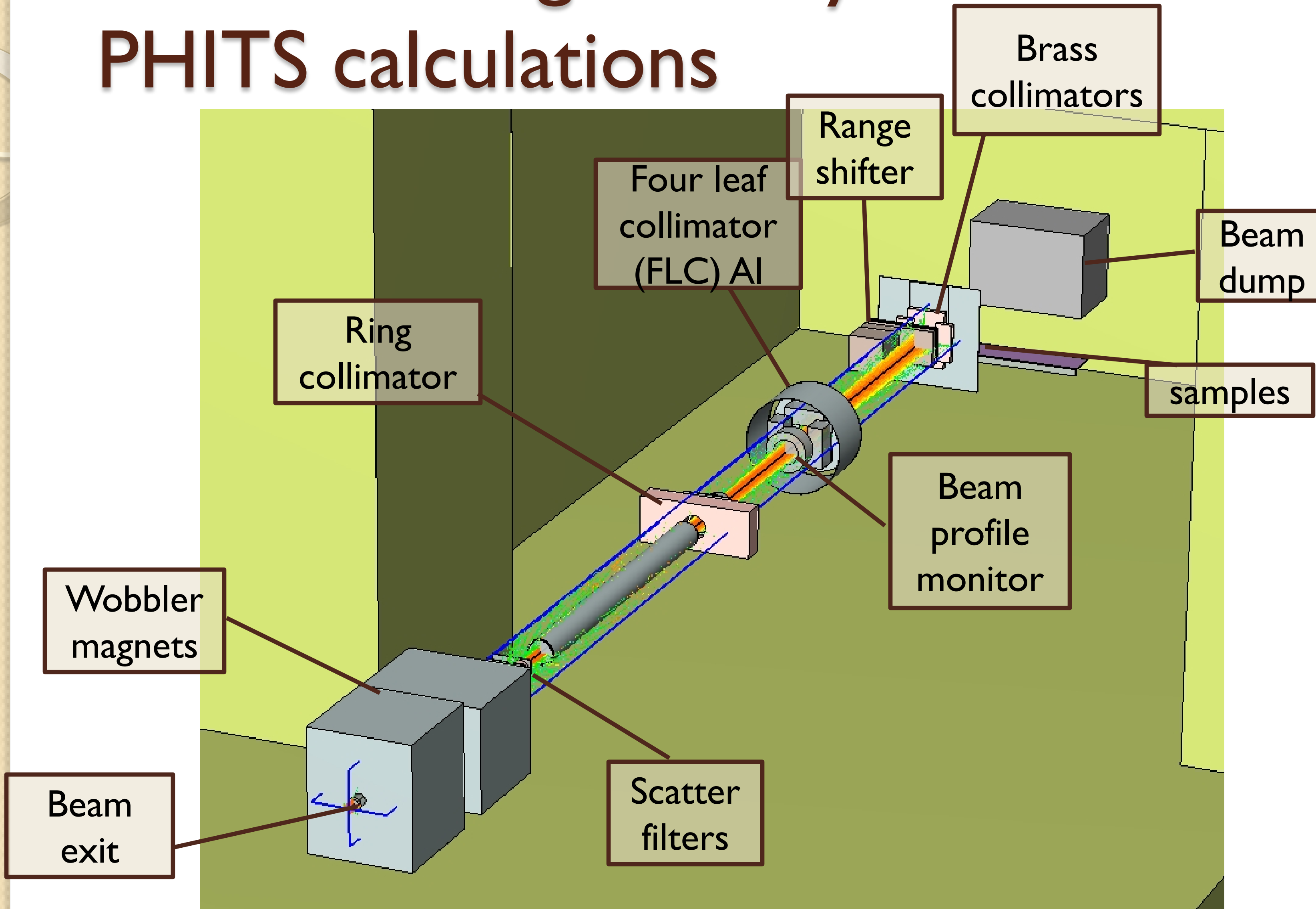
Synchrotron room



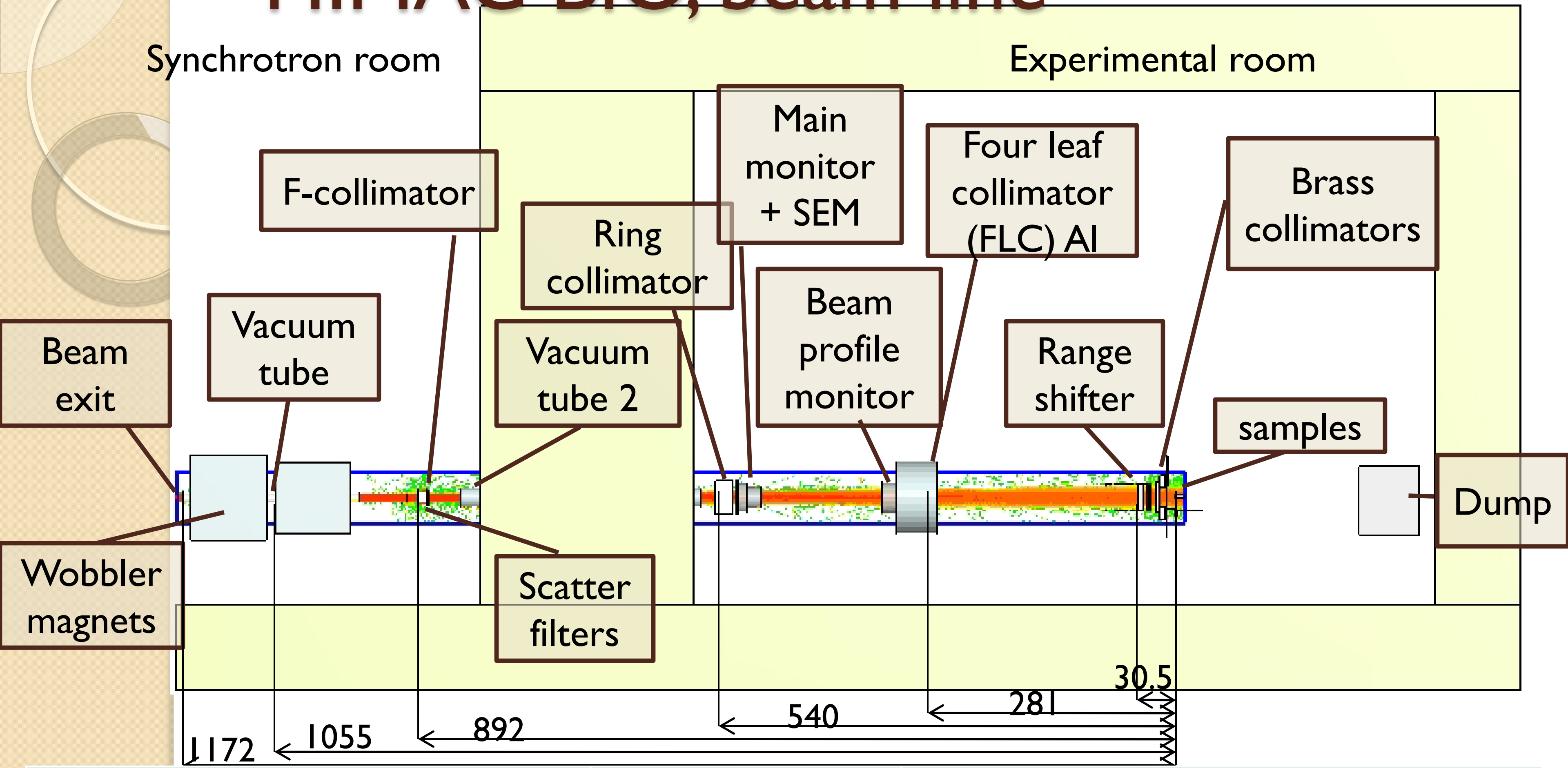
HIMAC BIO geometry used for PHITS calculations



HIMAC BIO geometry used for PHITS calculations

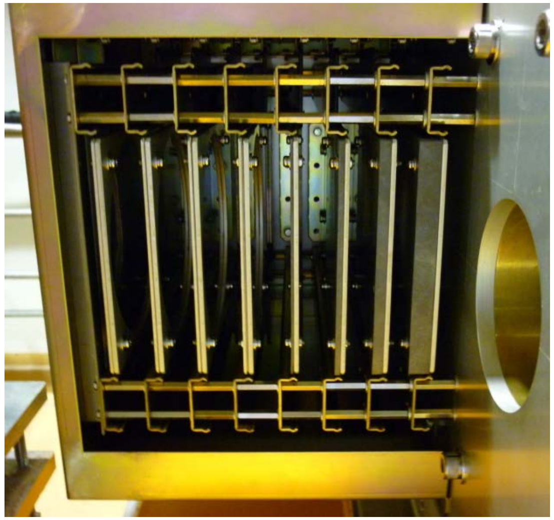


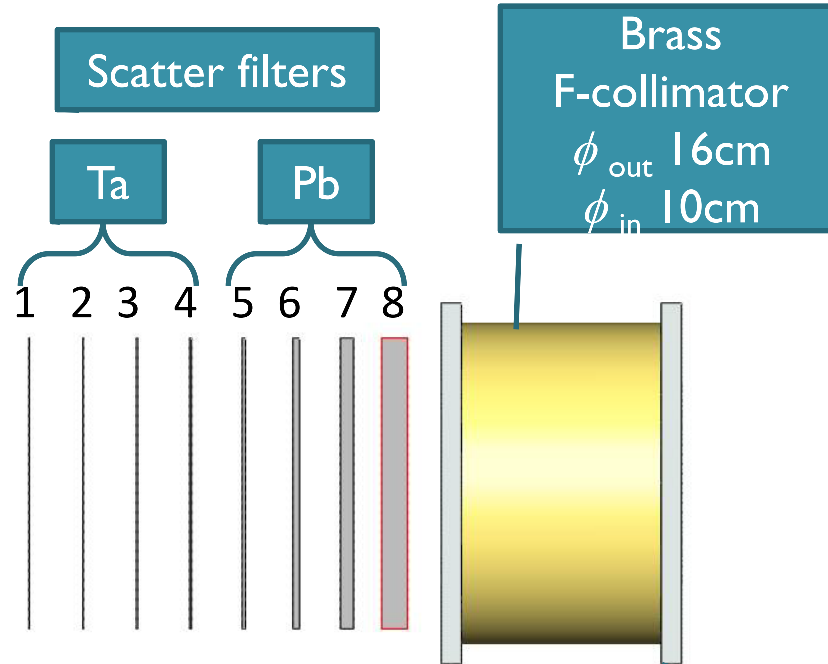
HIMAC BIO, beam line



Materials on the beam line	Thickness / cm	Water equivalent thickness / cm
Air	668.8	0.8
Aluminum windows (11)	0.011	0.03
Scatter filters (Ta or Pb)	Variable, depends on ion and energy	
Range shifter (PMMA)	Variable	

Scatter filters

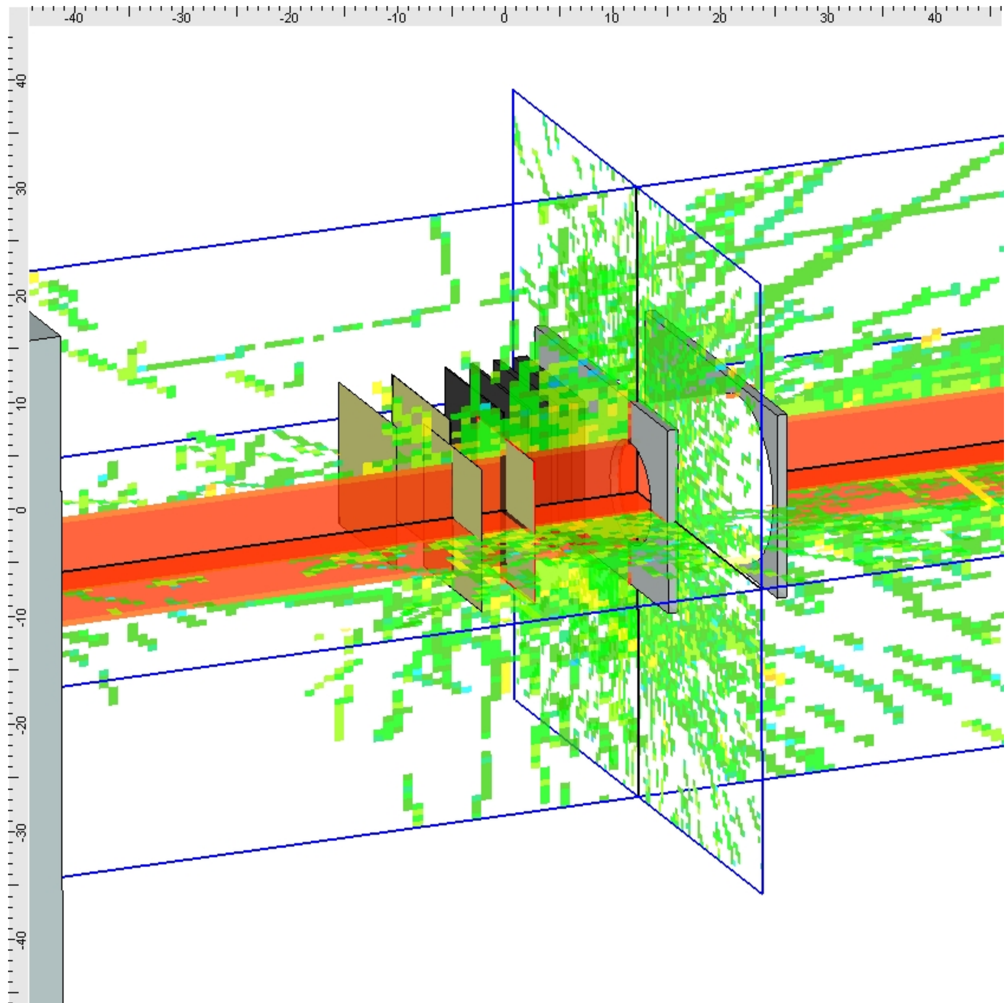




Ion and energy / MeV/u	Ta / mm	Pb / mm	Water eq. / mm
He 150 mono	0.215	0	3.57
C 135 mono	0.215	0	3.57
C 290 mono	0.434	0	7.20
C 290 SOBP	0.649	0	10.77
C 400 mono	0.754	0	12.52
Ne 230 mono	0.539	0	8.95
Ne 400 mono	1.02	0	16.93
Si 490 mono	0.434	1.6	25.35
Fe 500 mono	0.215	1.6	21.72

Scatter filters

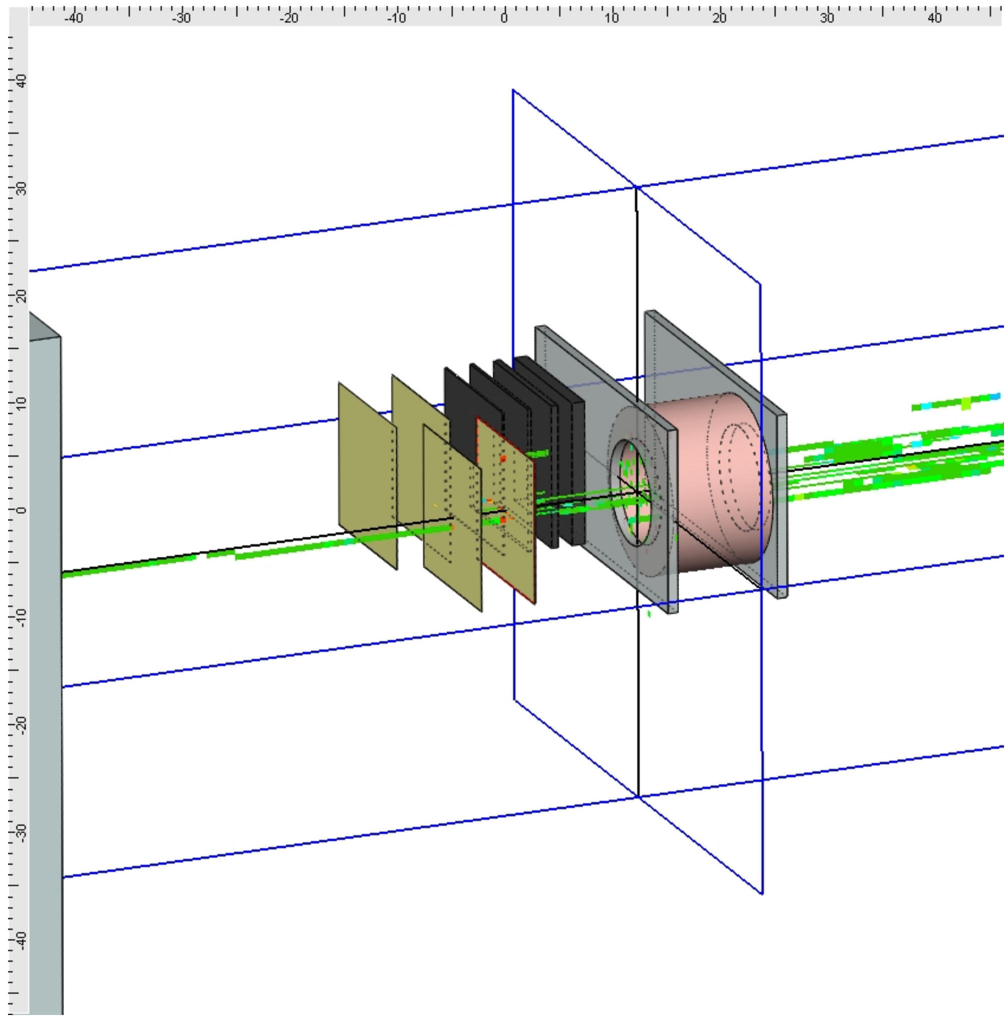
Configuration for Ne 400 MeV/u, all charged particles



The density of energy distribution is visibly higher behind the scatter filters

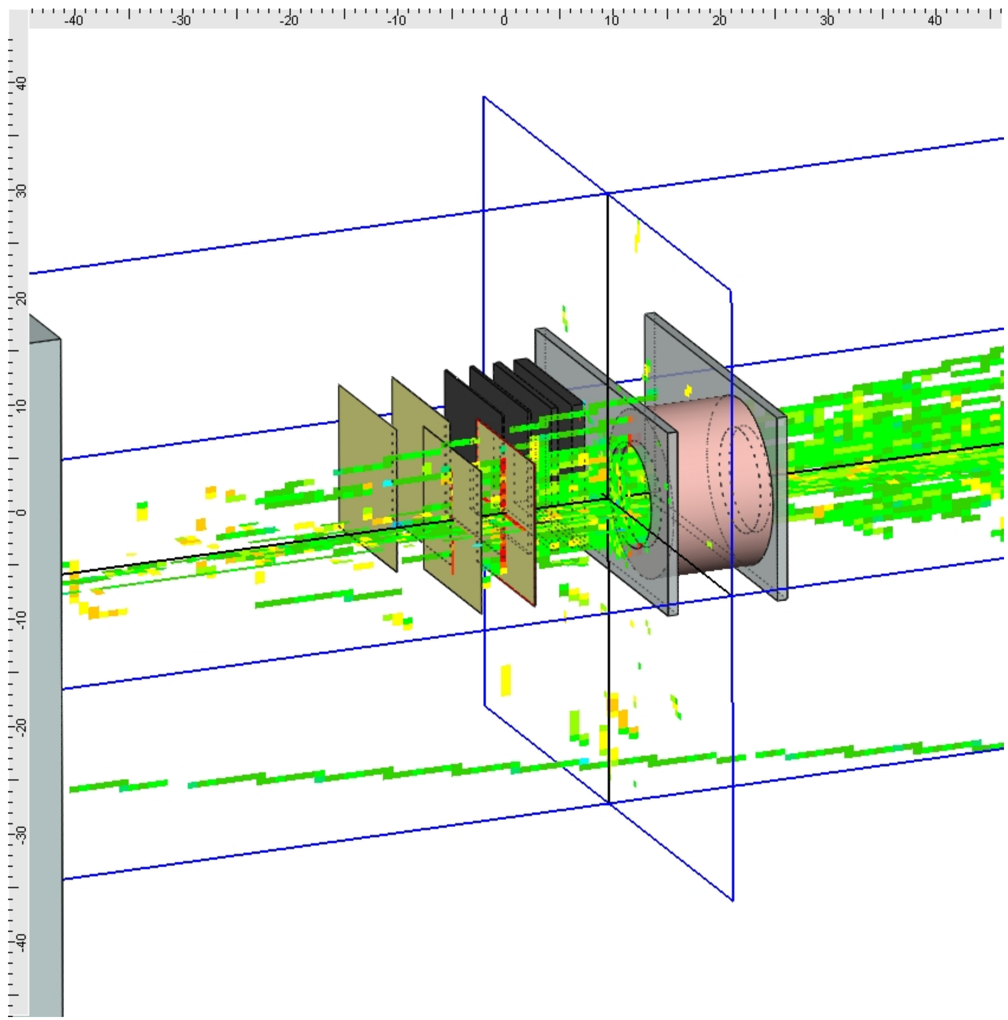
Scatter filters

Configuration for Ne 400 MeV/u, Oxygen ions only



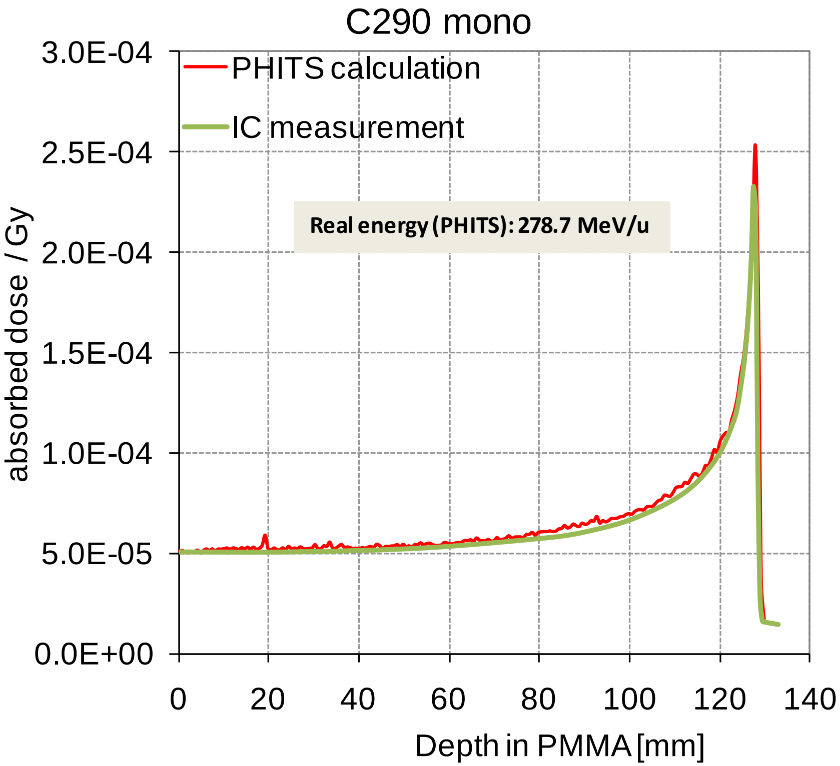
Scatter filters

Configuration for Ne 400 MeV/u, He only



Measured and calculated Bragg curves

- Measurement with Markus ionization chamber behind different thicknesses of PMMA



- Calculated Bragg curves fitted well to the measured ones => well designed geometry was confirmed

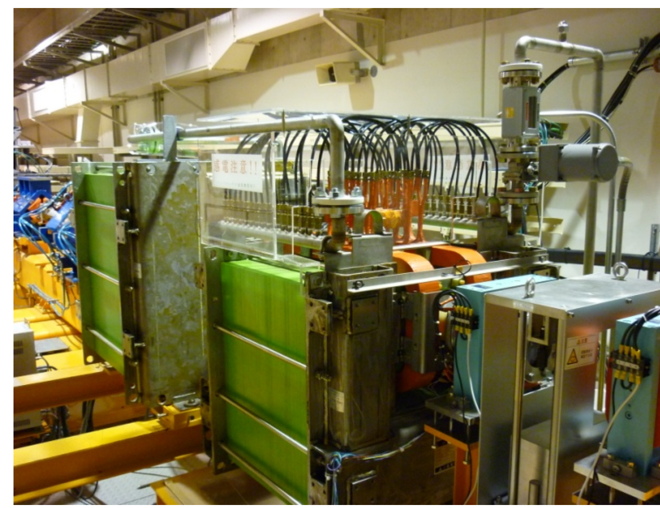
Range and beam energies in HIMAC BIO

Ion	Nominal energy / (MeV/u)	Range in PMMA / cm		Beam energy in front of PMMA filters / (MeV/u)	
		Measured with IC	Calculated with PHITS	SRIM	PHITS
He	150	12.63	12.58	145.35	145.5
C	135	2.73	2.91	112.54	114.0
C	290	12.83	12.61	274.43	278.7
C	400	22.23	22.01	382.85	389.7
Ne	400	12.48	12.48	370.05	373.8
Si	490	11.88	11.77	445.68	447.0

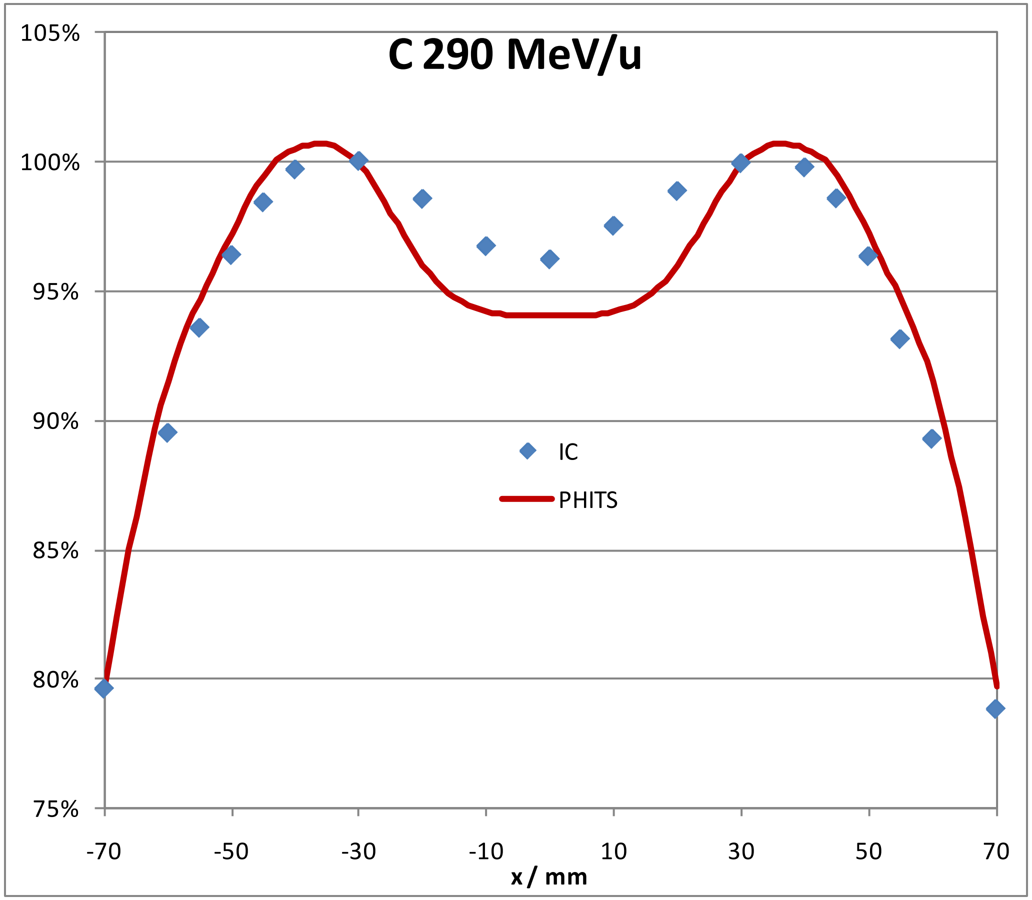
Differences in range < 2 mm and in energies 2%

Beam profile

- Experiments: by Hisashi Kitamura 2003-2007
  - Markus ionization chamber
  - He, C, Ne, Si, Ar, Fe, Kr, Xe
    - Several energies, diameters, binary filters for each ion
- PHITS calculations:
  - Scatterers as described above
  - Wobbler magnets
    - 2 dipole electromagnets to change the beam diameter in x and y axis
    - Magnetic field intensity: 0.5 kG
    - Radius of gap: 10cm



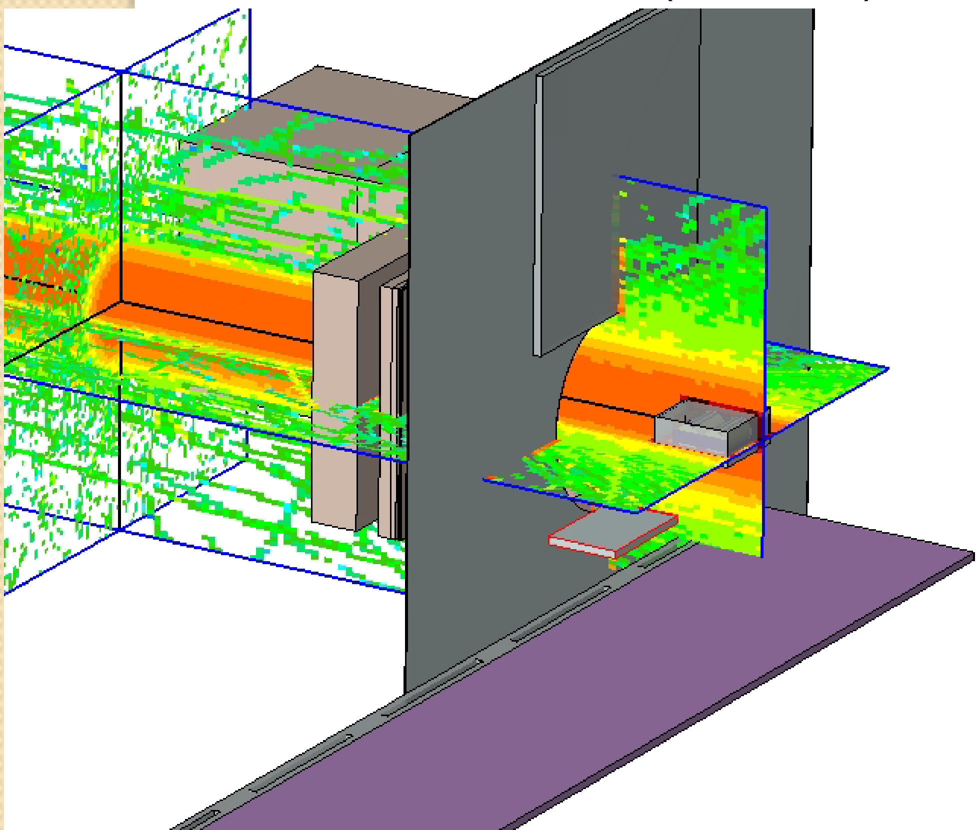
Beam profile



PHITS simulation: transverse dose distribution at the front surface of water column

Liulin

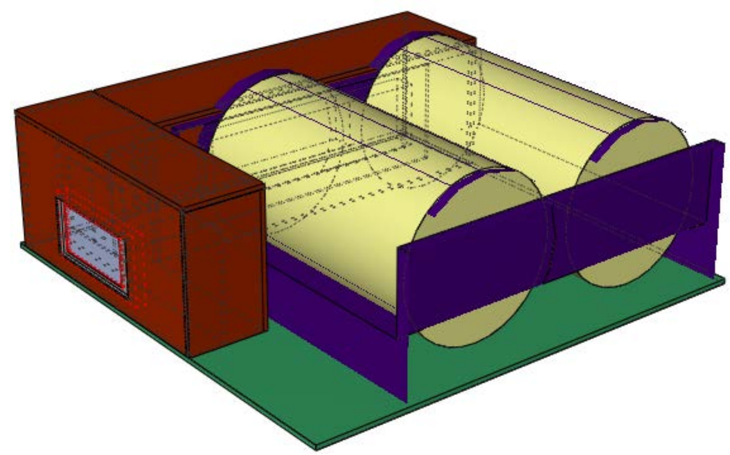
- Energy deposition spectrometer
- Active volume: silicon diode (2 × 1 × 0.03 cm^3)
- Size: 98×65×25 mm^3 (MDU01&02)
  103×103×47 mm^3 (MDU07)



- Absorbed dose calculation

$$D_{Si} = \frac{1}{m}\sum_{i=1}^{256} N_i \varepsilon_i$$

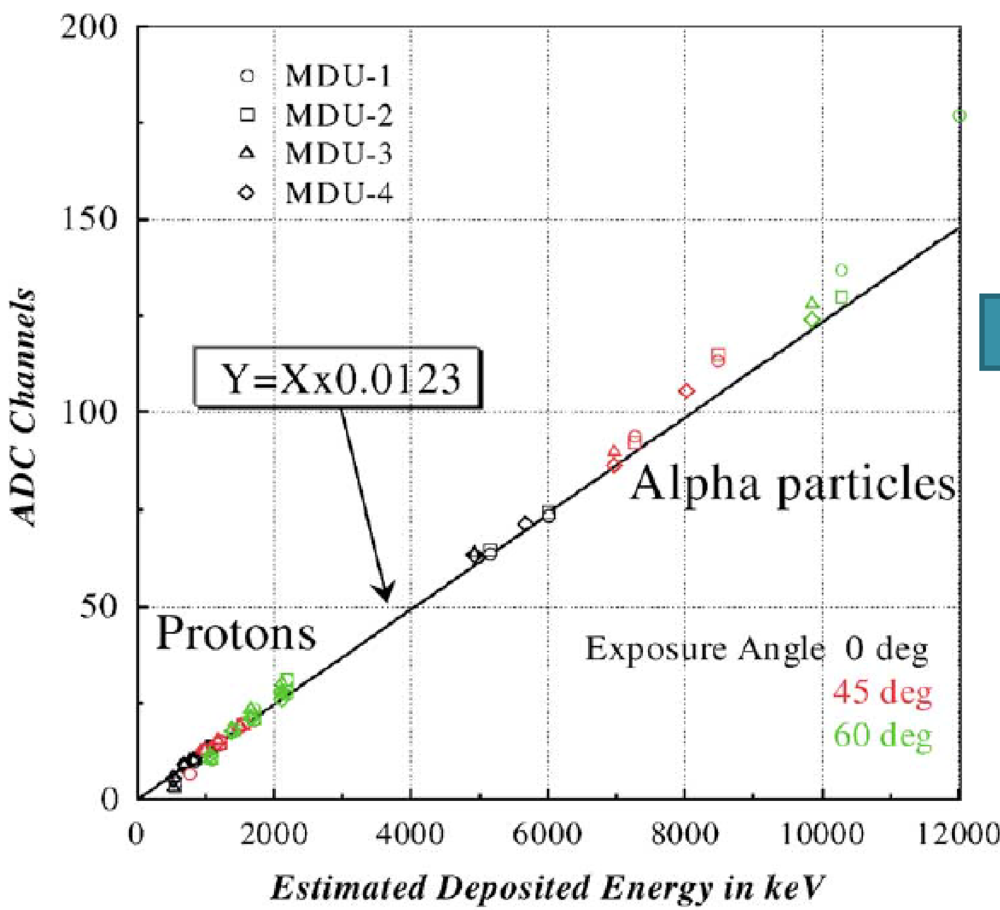
ε_i is energy deposition



Energy deposition calibration of Liulin

- Original method:

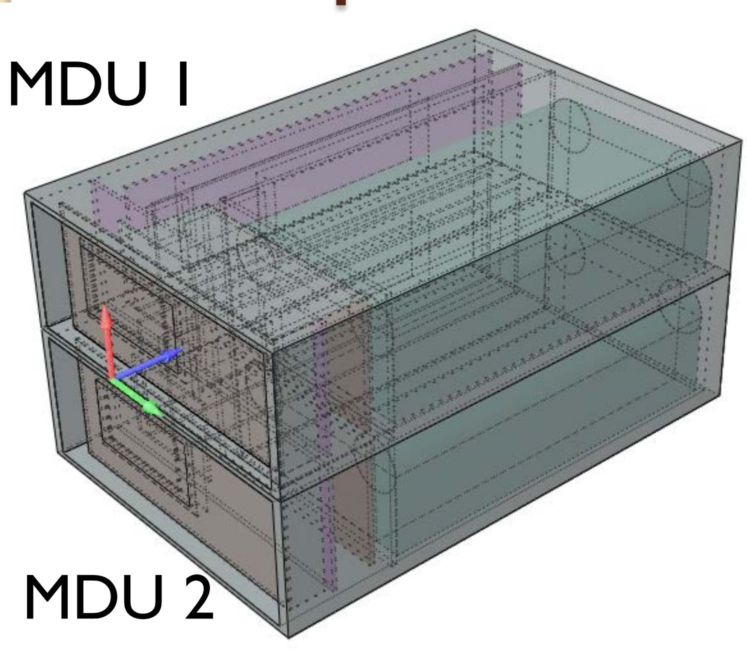
Y. Uchihori et al. / Radiation Measurements 35 (2002) 127–134



Energy deposition
$\varepsilon_i = i \times 81.3\text{keV}$

i… ADC channel number

Comparison of two identical Liulins



- Front aluminum cover removed from both Liulins
- PE desk removed from MDU 1

Beam: **C 400** MeV/u

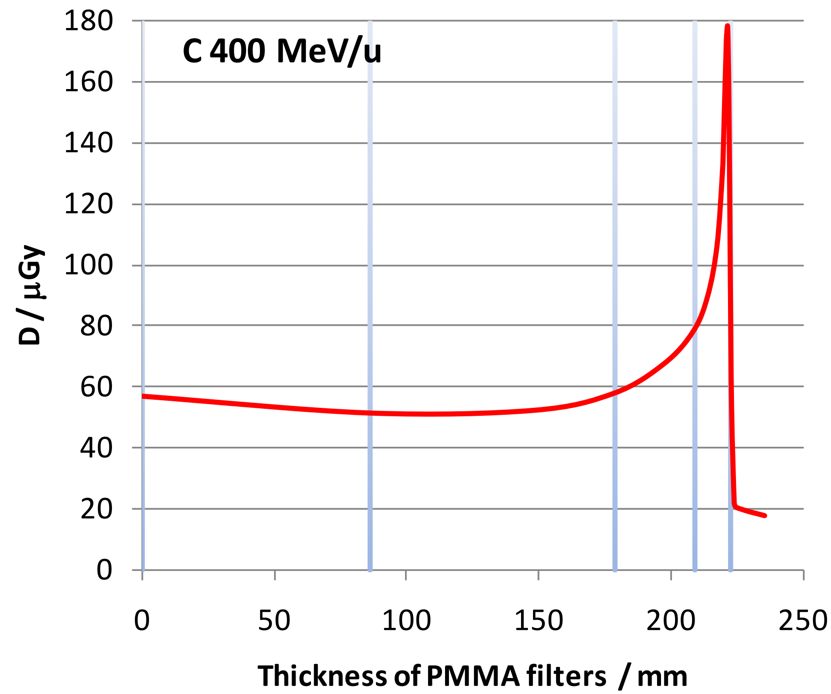
PMMA:

0.0 mm

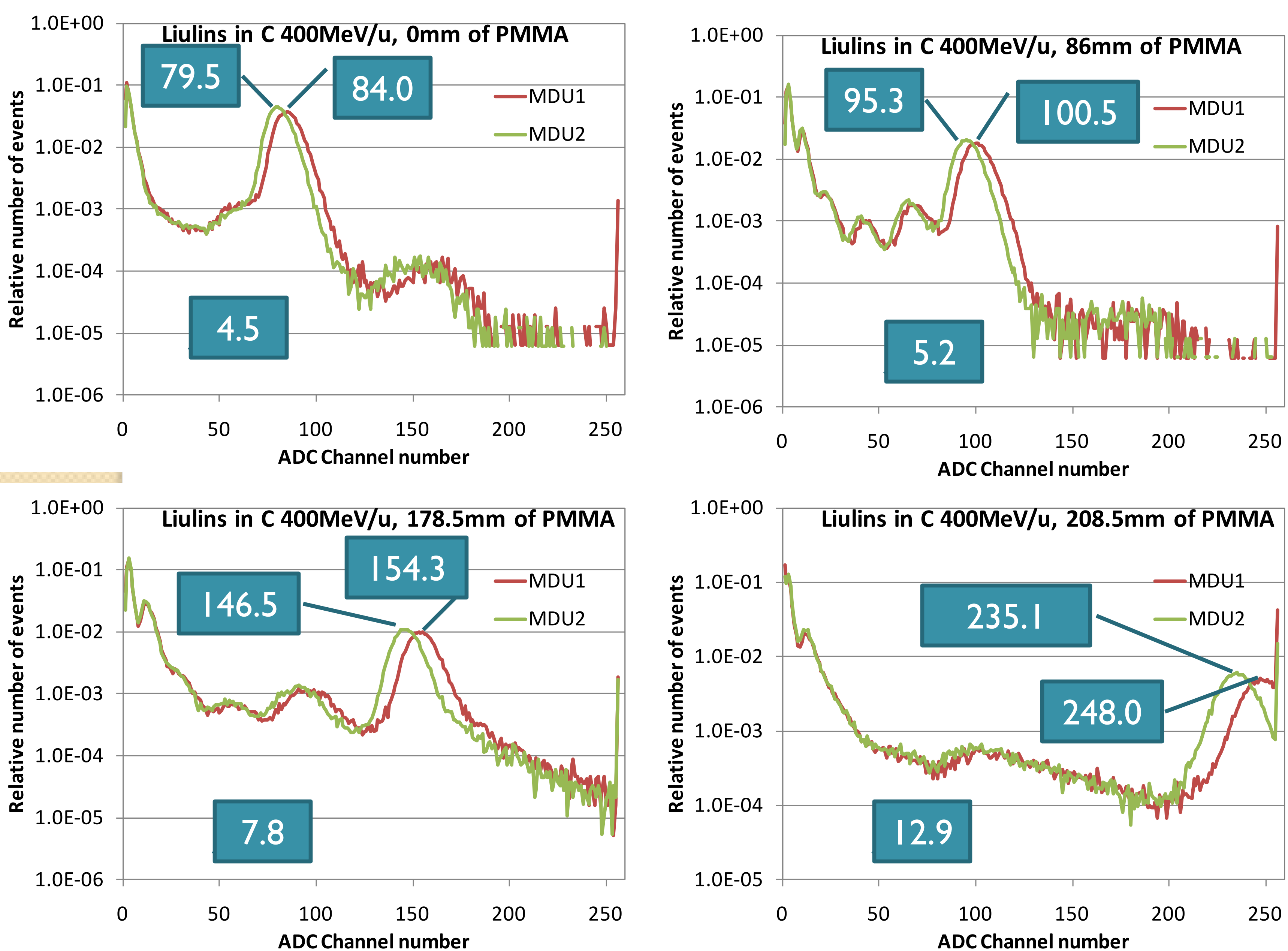
86.0 mm

178.5 mm

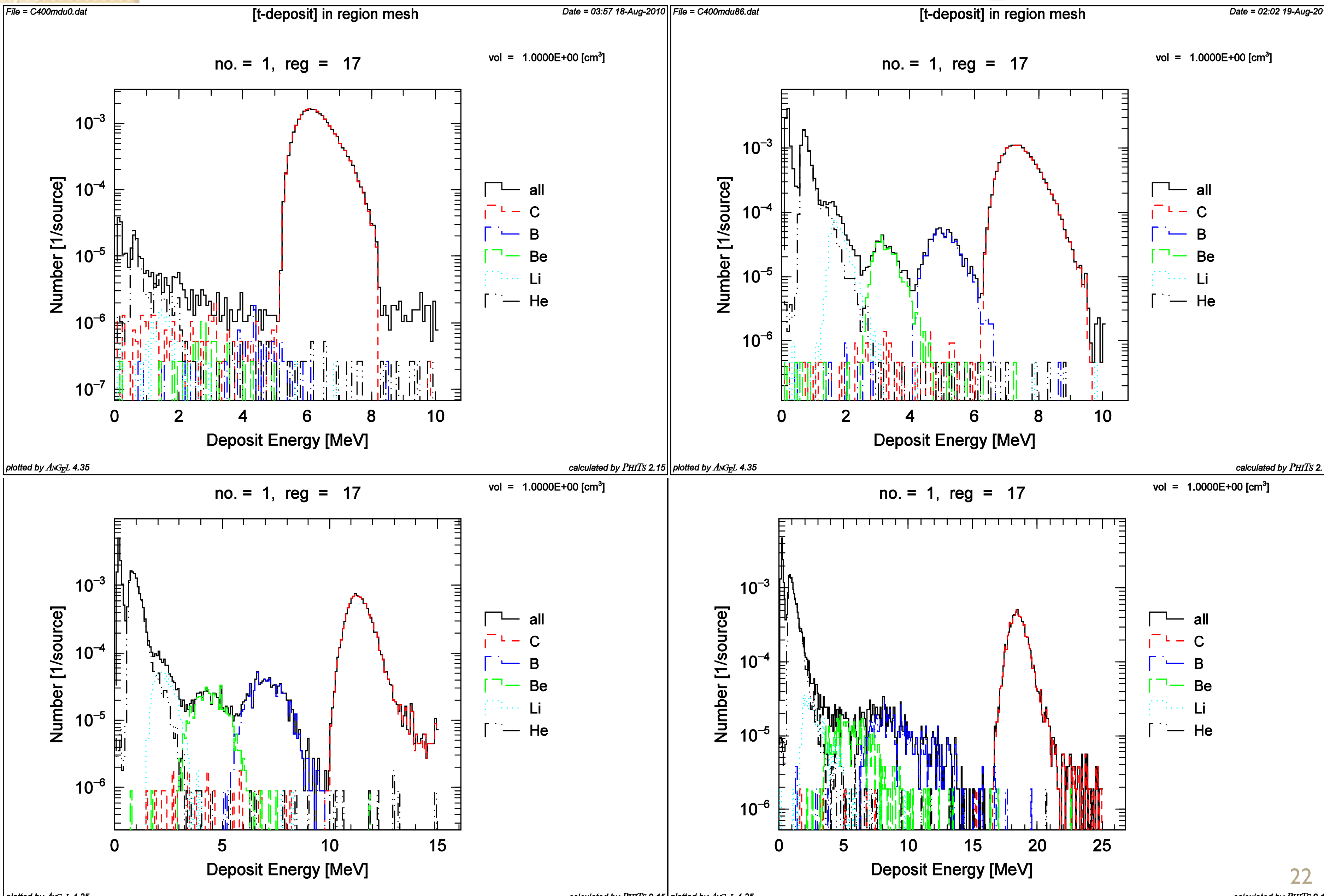
208.5 mm



Identical Liulins in C 400MeV/u

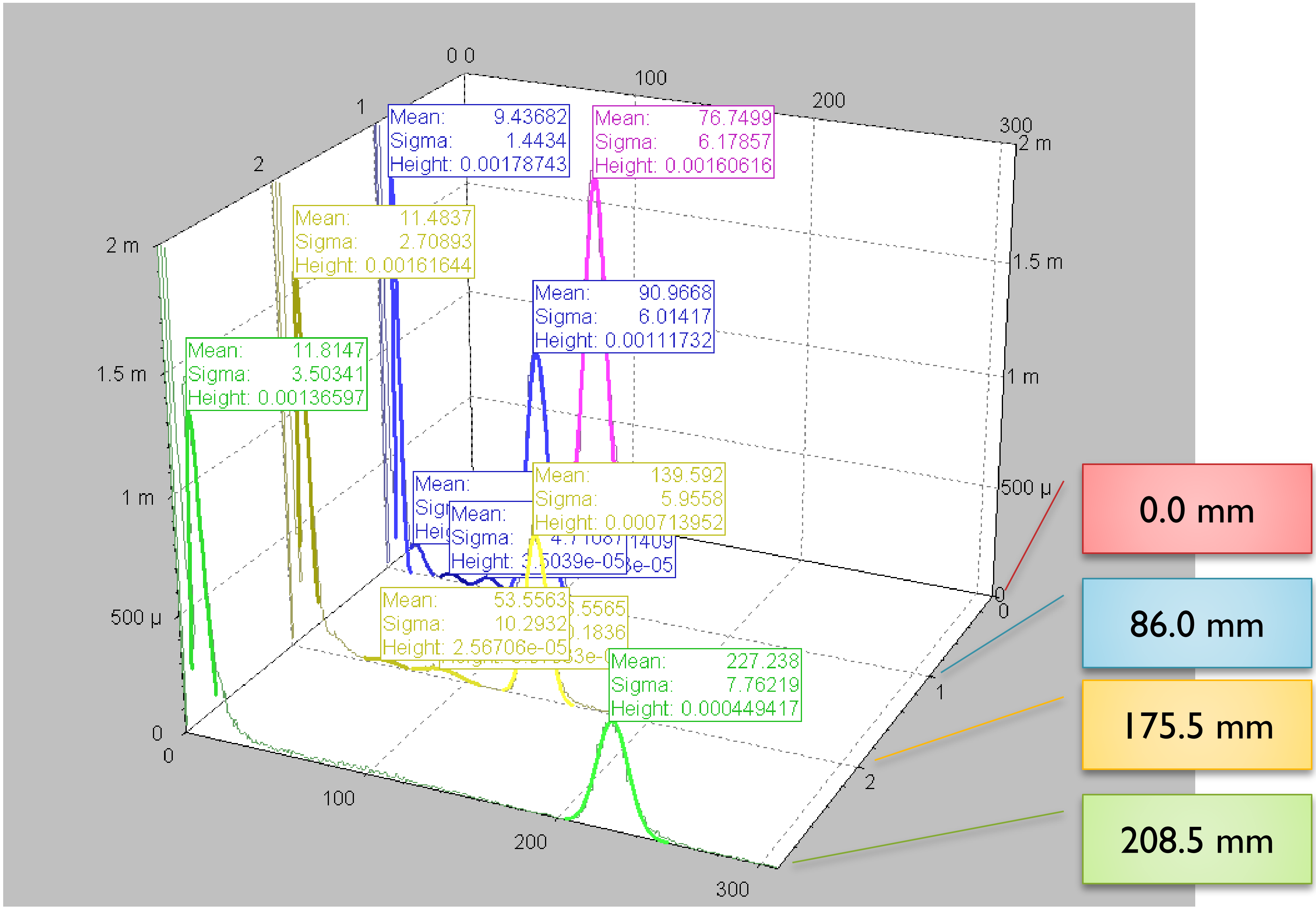


Recalibration of Liulin using PHITS

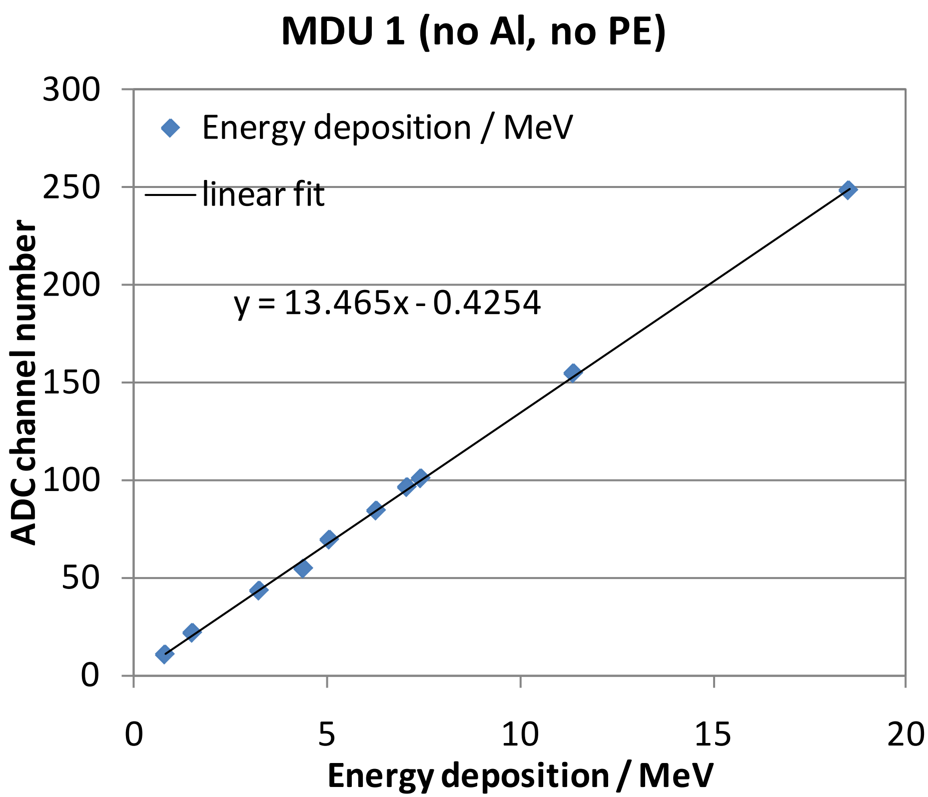


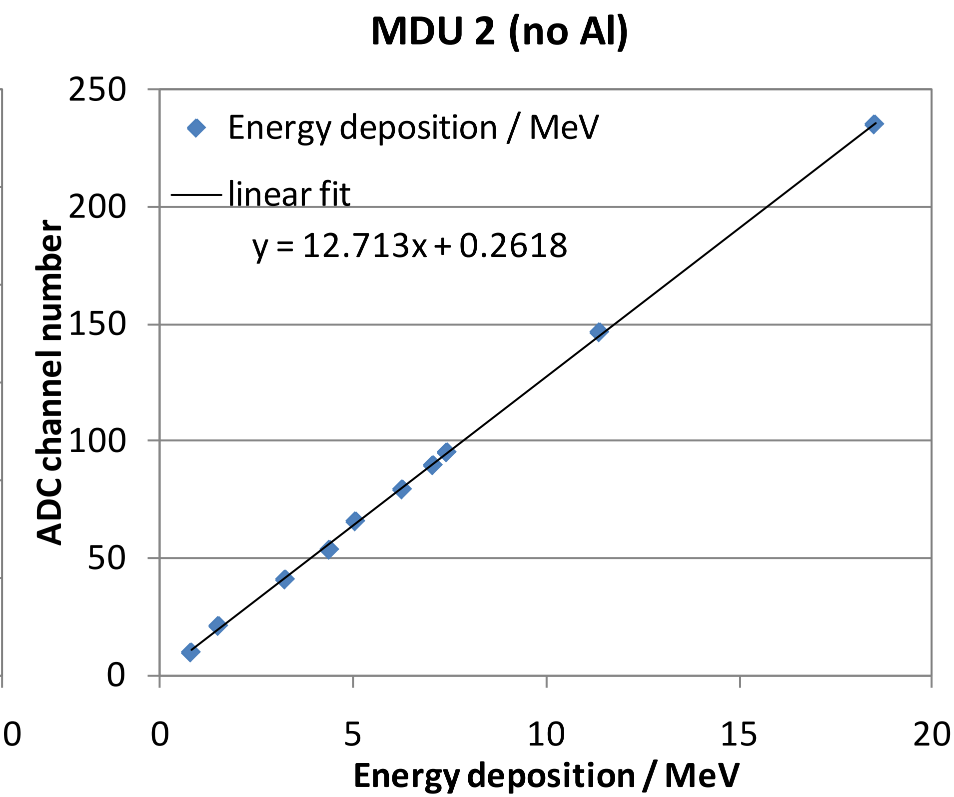
Recalibration of Liulin using PHITS

- Gaussian fits of all peaks (primary C, fragments)

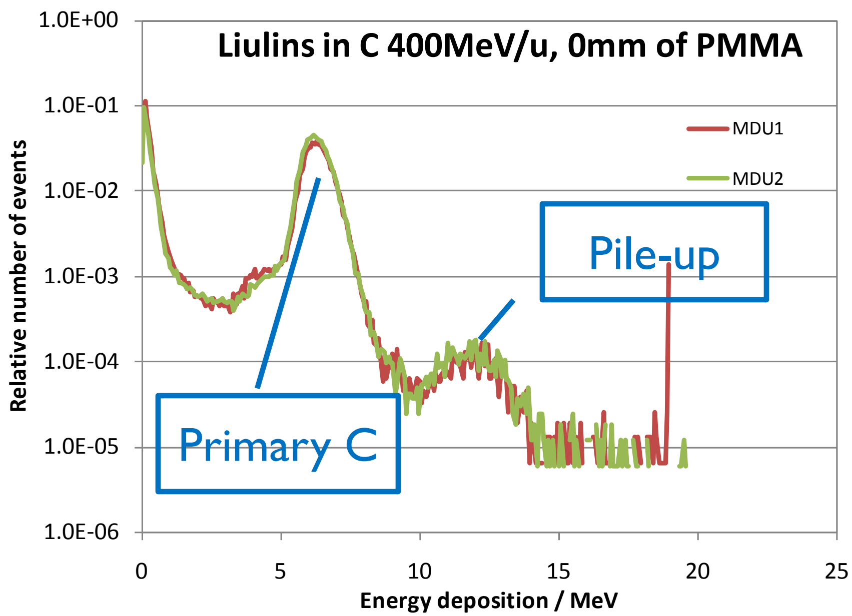


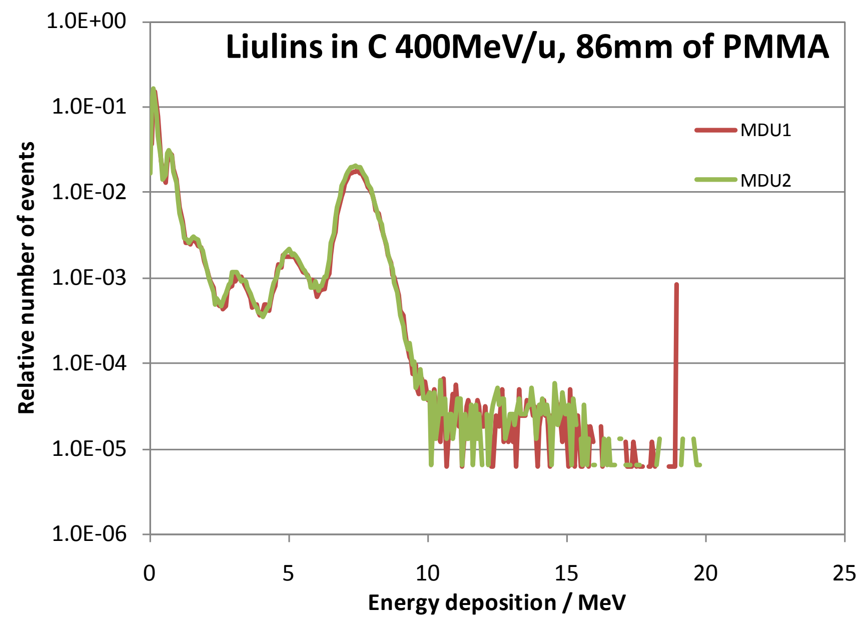
Recalibration of Liulin using PHITS

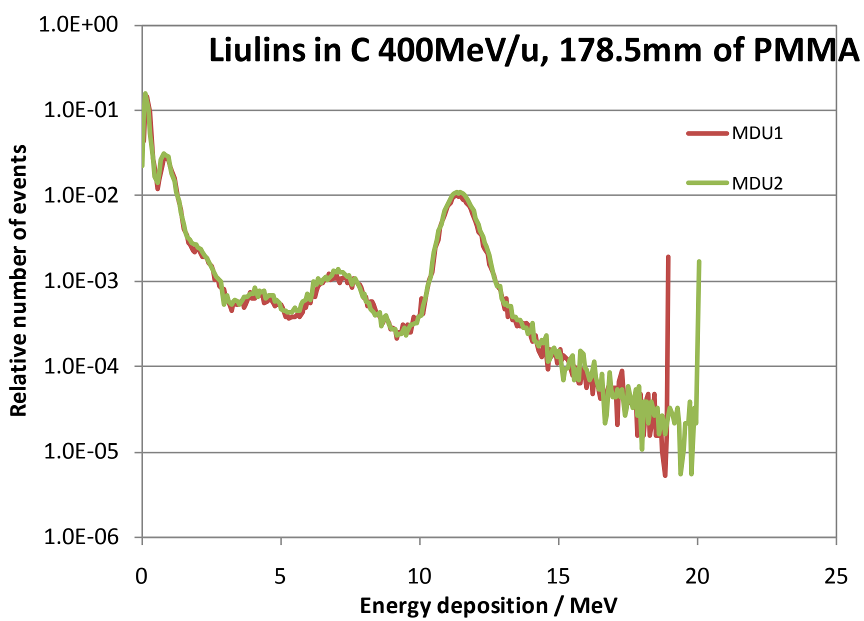


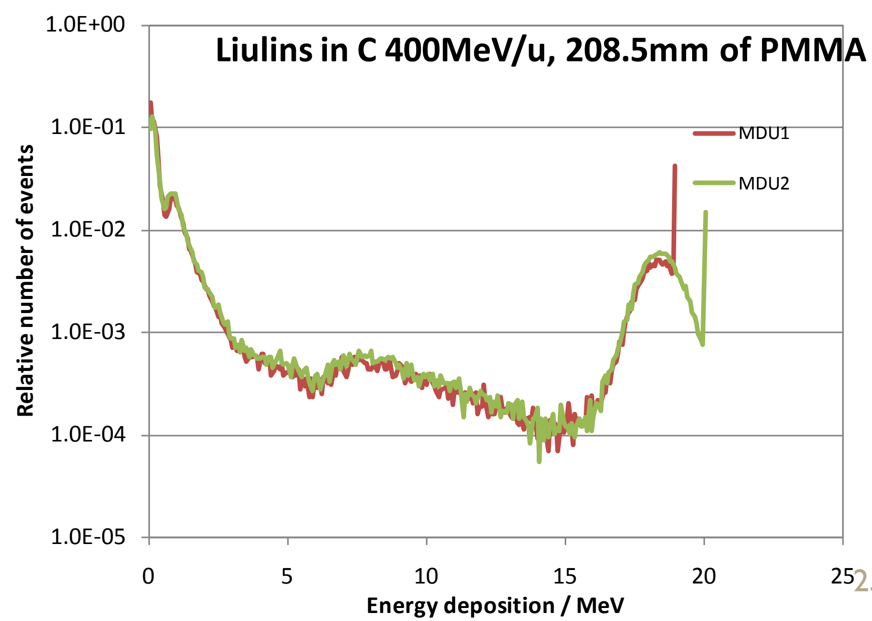


Comparison of two identical Liulins

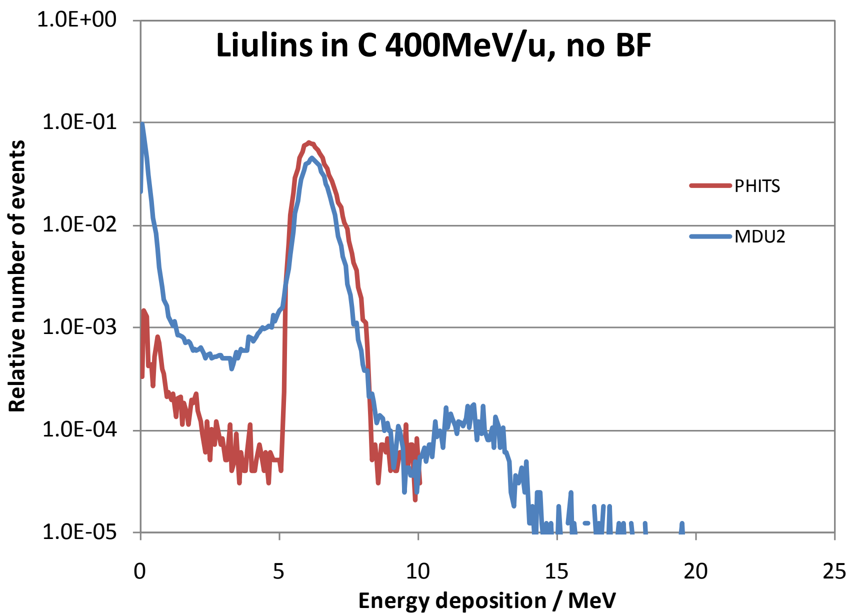


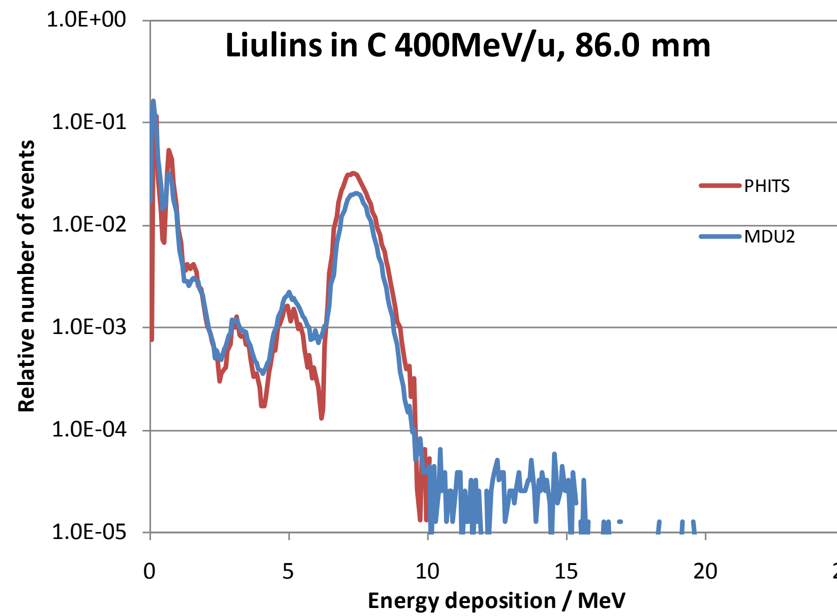


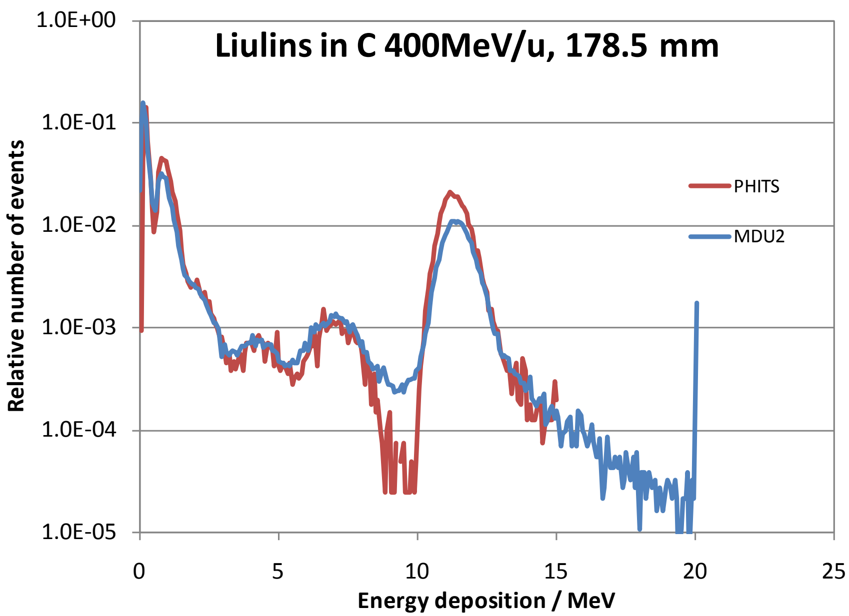


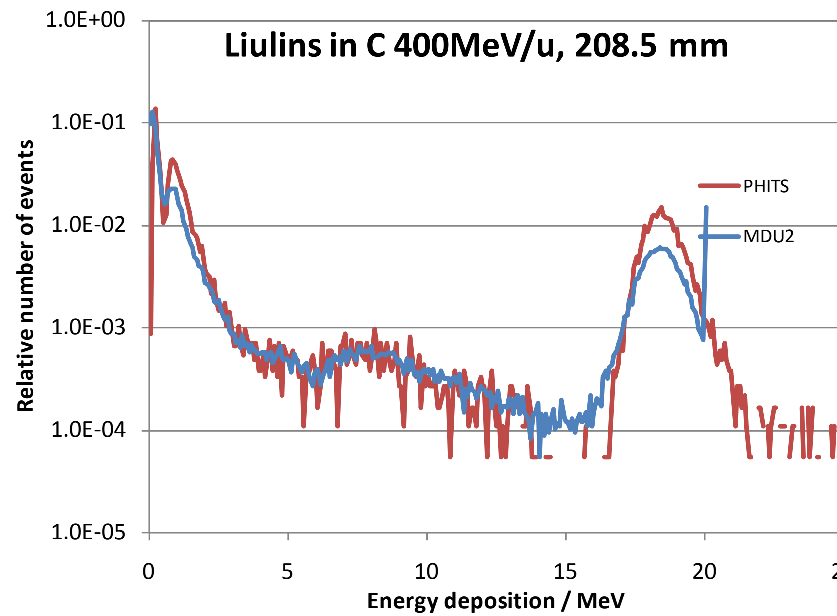


Comparison of Liulin spectra with PHITS

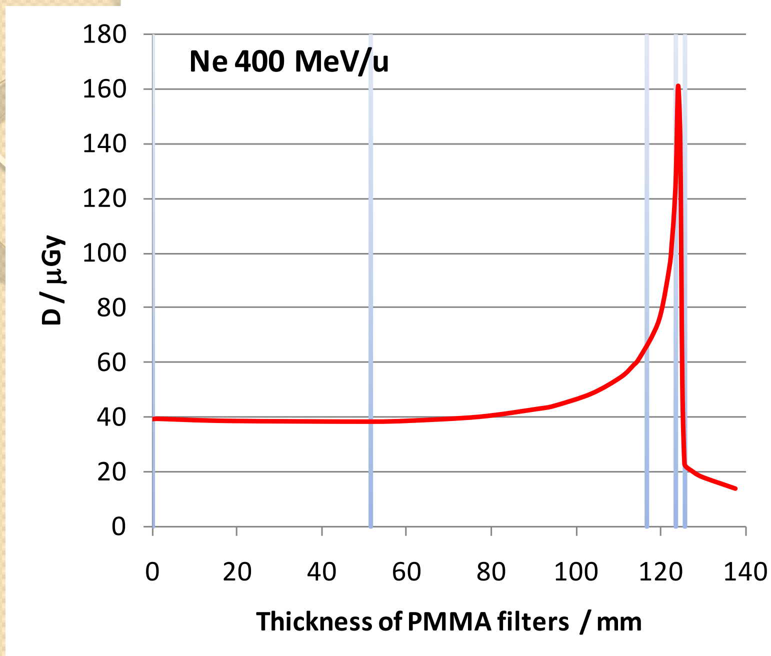


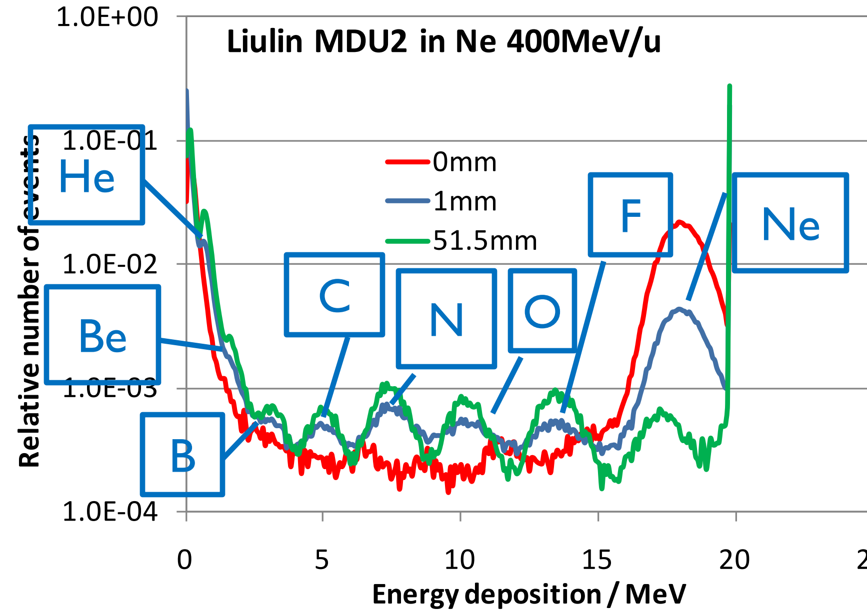


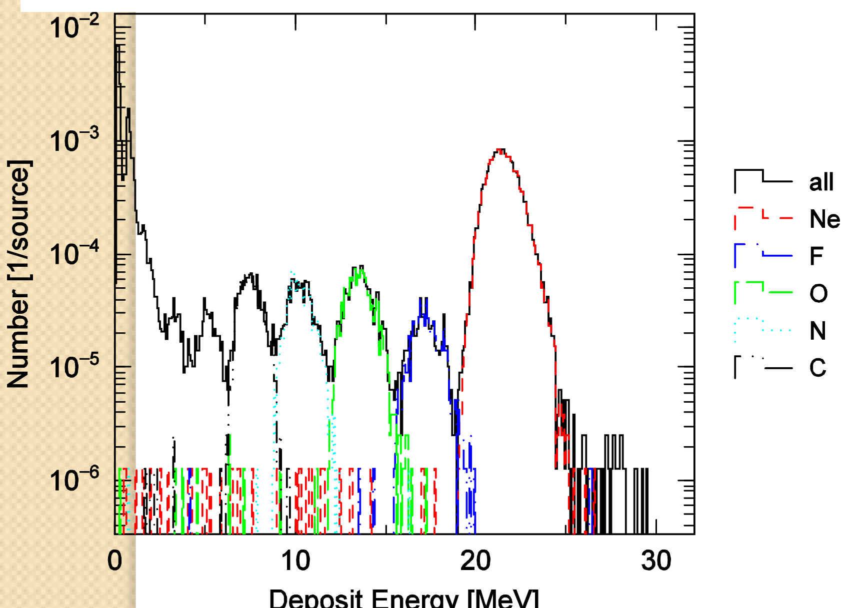


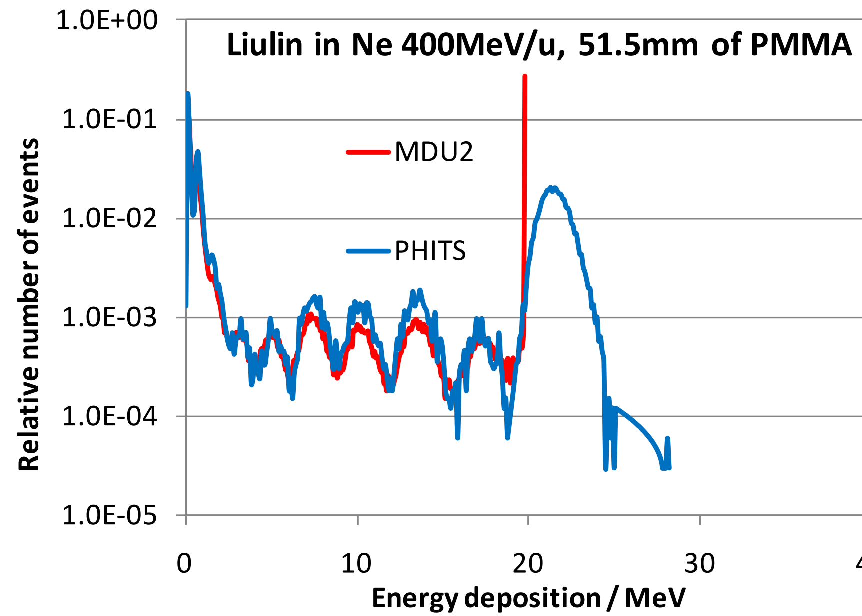


Liulin in Ne 400 MeV/u

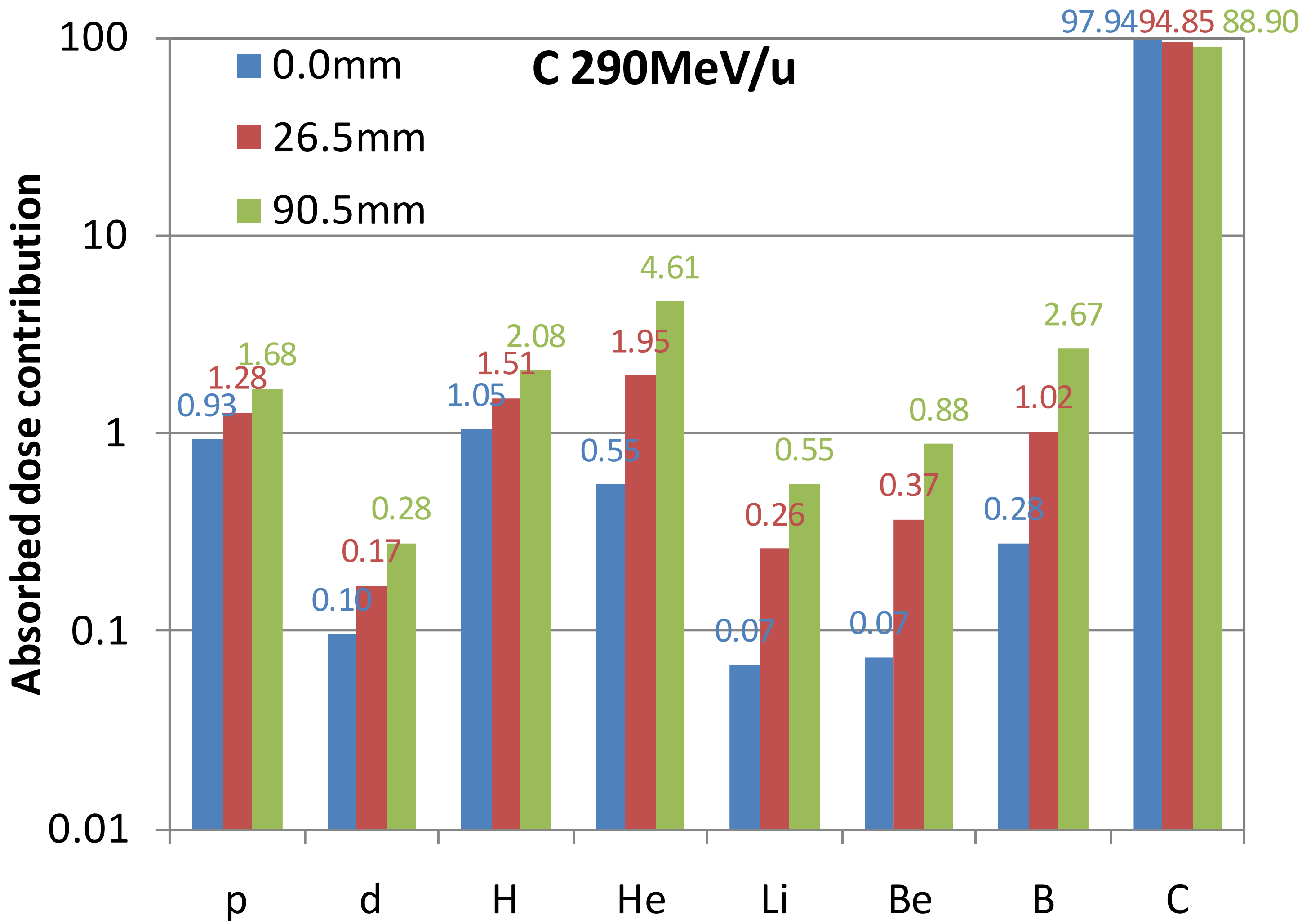








Contribution of fragments to total dose at the sample location



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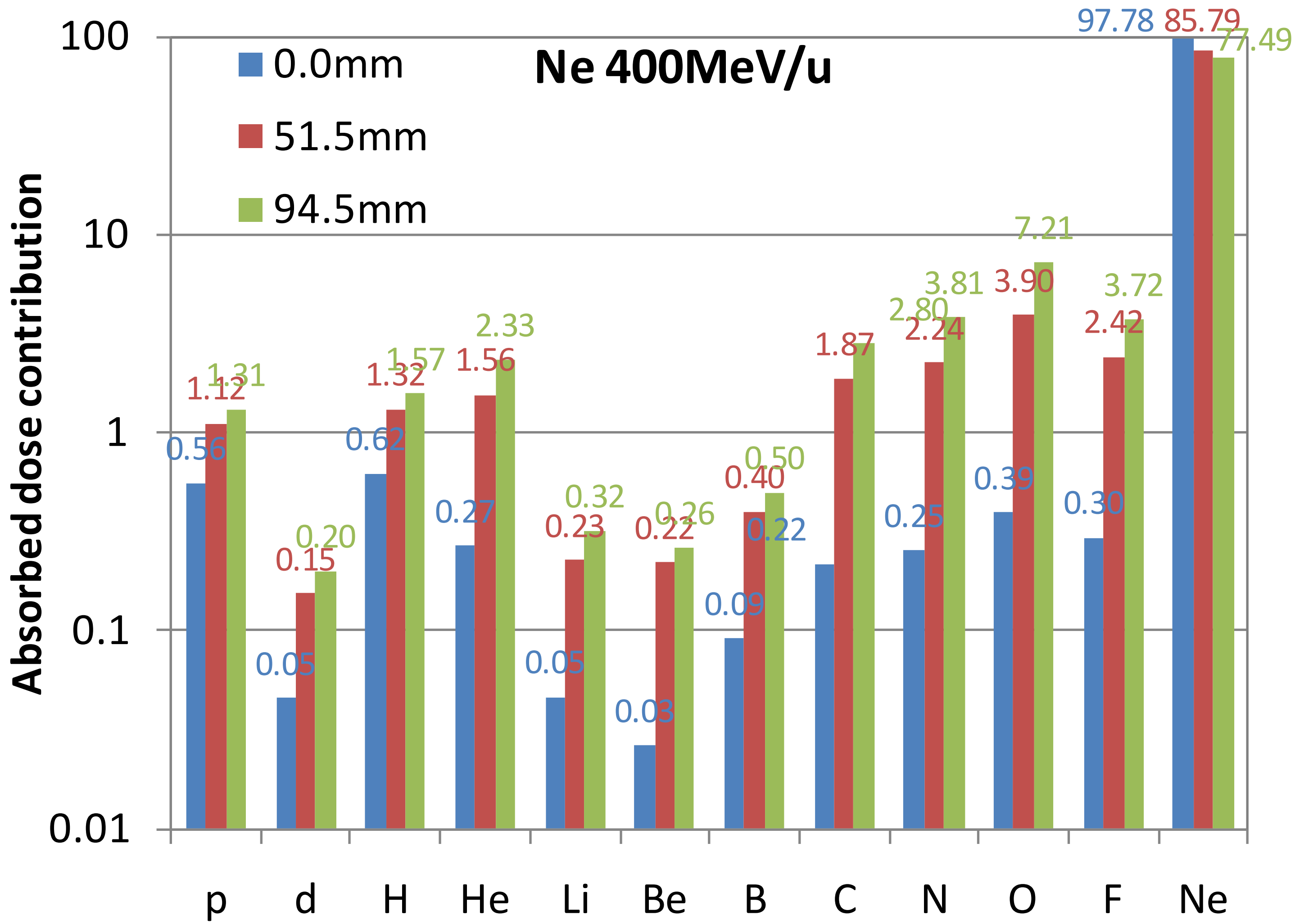


Evaluation of LET spectra with Liulin

$$L_w = k_{Si/w} \times L_{Si} \times \frac{\rho_w}{\rho_{Si}}$$

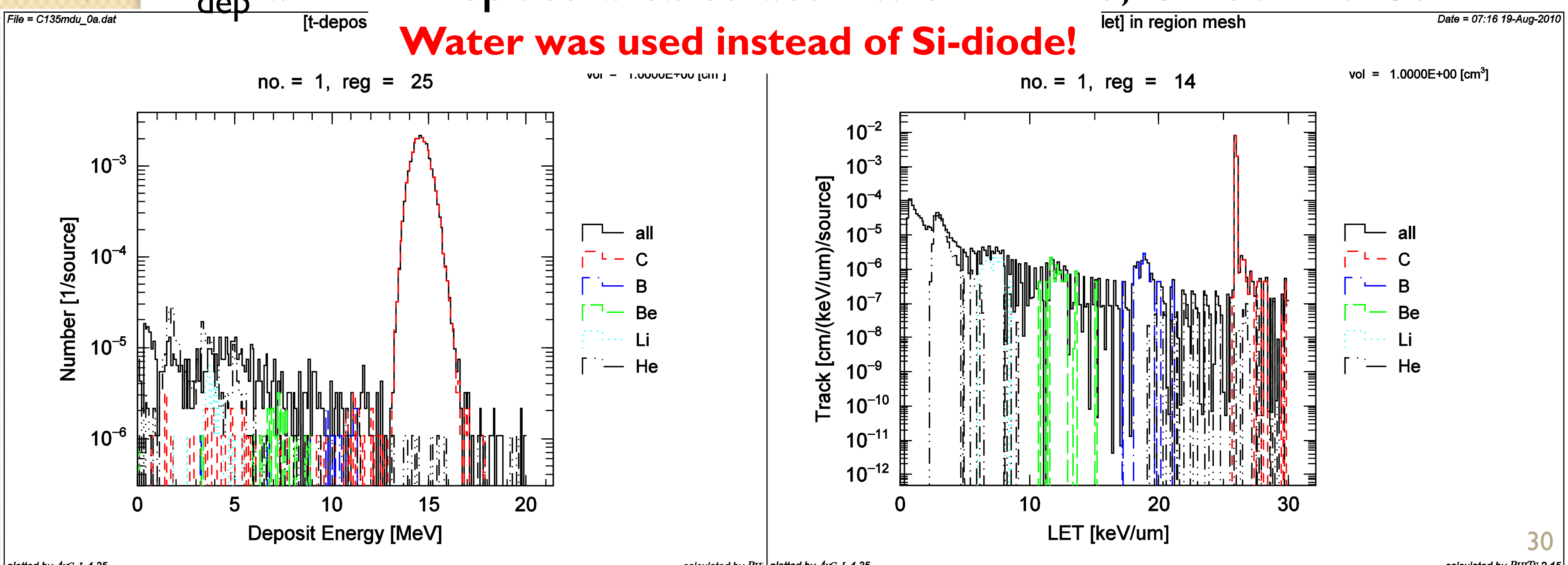
$$L_{Si} = \frac{\varepsilon}{d}$$

$$d = 300\,\mu m$$

Ion	Energy / (MeV/u)	$k_{Si/w}$ (Si to water conv. Coefficient)
He	150	1.36
C	135	1.23
C	290	1.24
C	400	1.26
Ne	400	1.24

Liulin E_{dep} and LET spectra calculated with PHITS, C 135 MeV/u

Water was used instead of Si-diode!



Conclusions

- Detail simulation of geometry of HIMAC BIO was developed
- Calibration of Liulin can be done using only one heavy ion beam
- Liulin is capable to detect fragments; the difference between measured and calculated energy deposition spectra in peaks can be important, more research on this topic is in process
- The contribution of fragments to total absorbed dose is high, from 2% to 23% depending on primary heavy ion, energy and thickness of PMMA filters
- Si to water conversion coefficient estimated using PHITS code differ depending on ion and energy (1.24 – 1.36)
- Further research on calculation of neutron contribution in the radiation field is needed

THANK YOU FOR YOUR ATTENTION!