Calibration Measurements with Liulin and TEPC Hawk in HIMAC BIO, and related calculations with PHITS

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Introduction

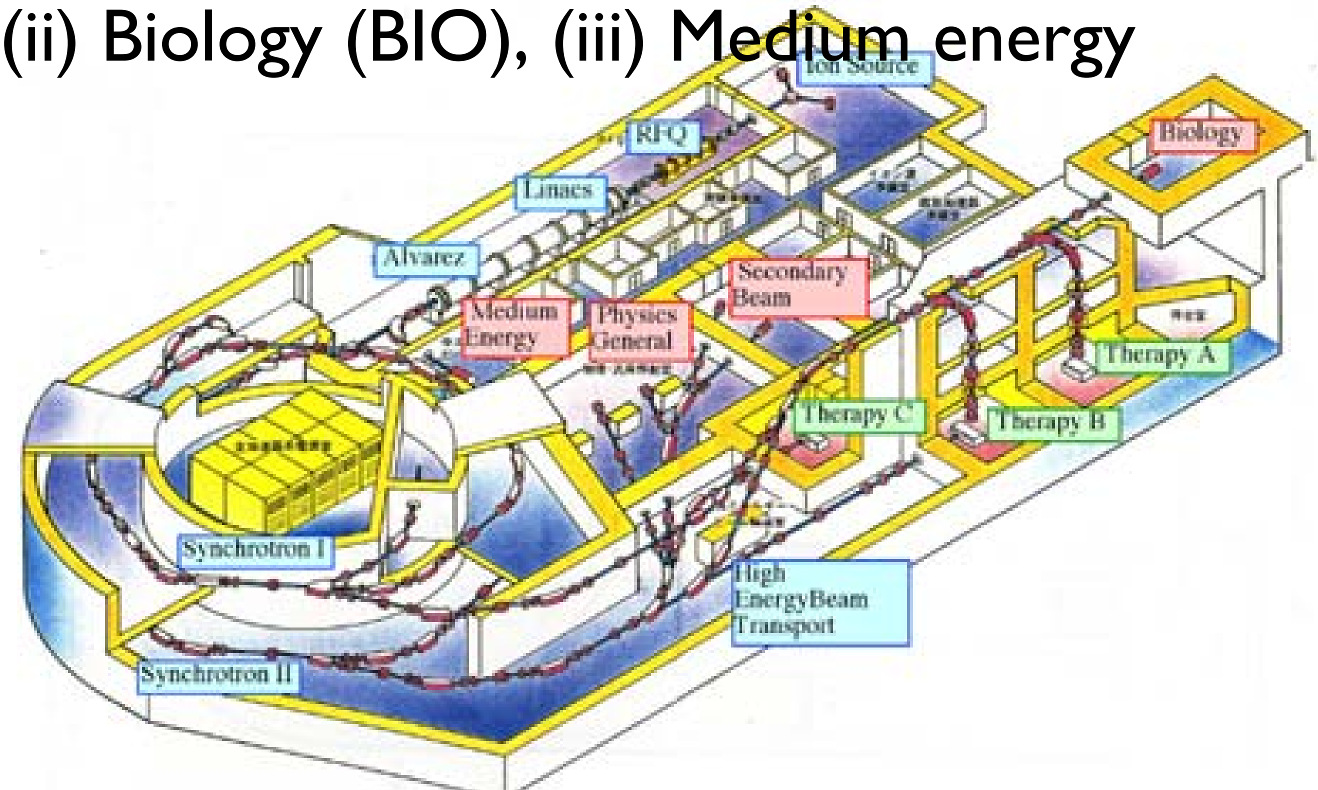
- Silicon detectors and TEPCs are often used to describe the radiation field onboard aircrafts and spacecrafts (MIR, ISS, Chandrayaan1, Foton)
- Goals
  - to describe the potential of silicon detector Liulin and TEPC Hawk for measurement of low and high LET ions
  - To compare LET spectra measured with Liulin and Hawk, and calculated with PHITS for several HIMAC beams
  - To explore the capability of Liulin and Hawk to evaluate fragments created in front of the detector

Introduction

- We expose Hawk and several types of Liulins in several HIMAC beams, measured spectra differ, the reasons are:
  - "Not perfect" calibration of Liulins for heavy ions
  - Different thicknesses in front of active volumes
- Objectives
  - Fluence and absorbed dose evaluation
  - Calculation of the real energy in HIMAC BIO
  - Recalibration of Liulins
  - Study of influence of different thicknesses and materials in front of silicon detectors
  - Comparison of LET spectra measured with silicon detectors and TEPC and calculated with PHITS

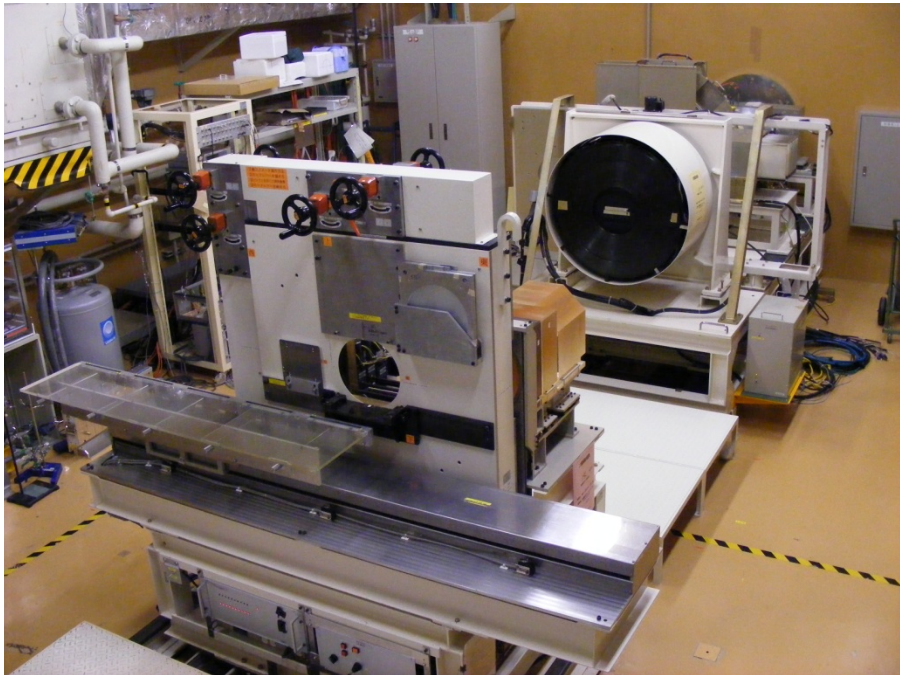
HIMAC

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



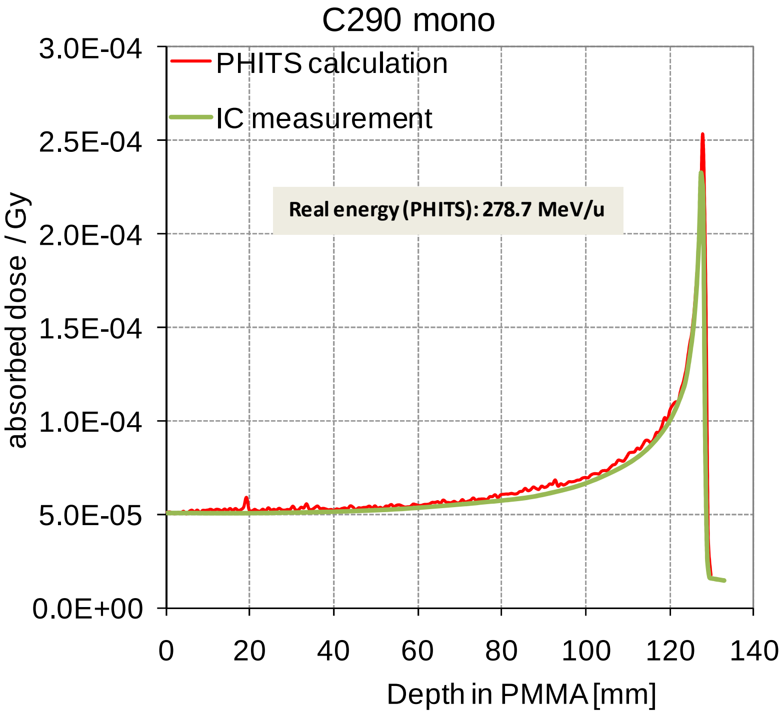
HIMAC BIO

- *Advantage:*
  - Bragg curve is well defined
  - Broad parallel beam (ϕ 10cm)
- *Disadvantage:*
  - Beam goes through scatter filter (different for different ions) and over 7m of air
- Ion+nominal energy in MeV/u: **He 150**, **C 135**, C 290, **C 400**, Si 490, **Ne 400**, 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

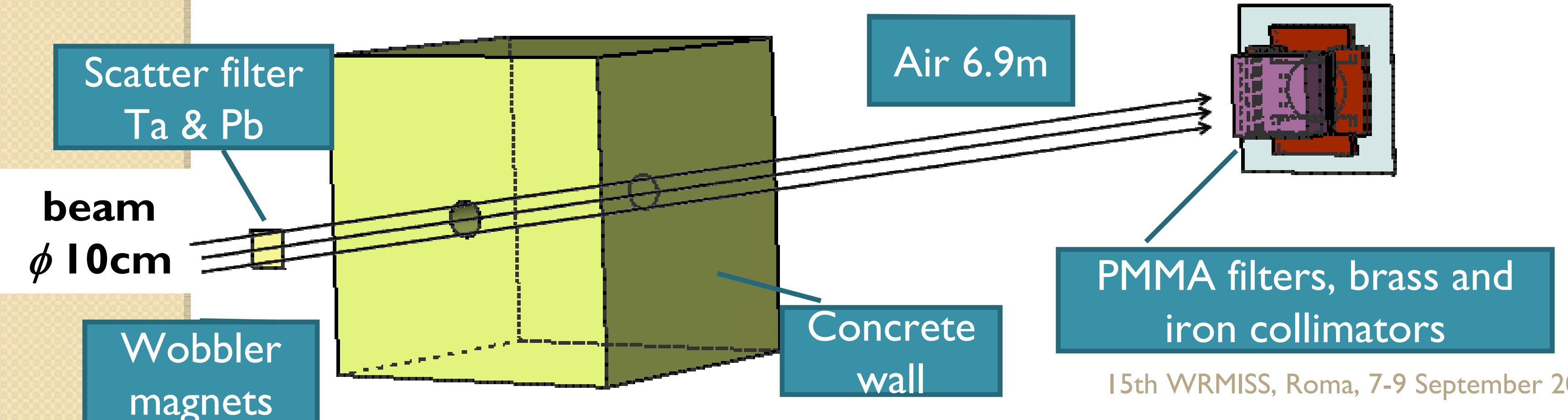


Measured and calculated Bragg curves

- Measurement with Markus ionization chamber behind different thicknesses of PMMA filters



- Calculation with PHITS
  - Geometry of HIMAC BIO



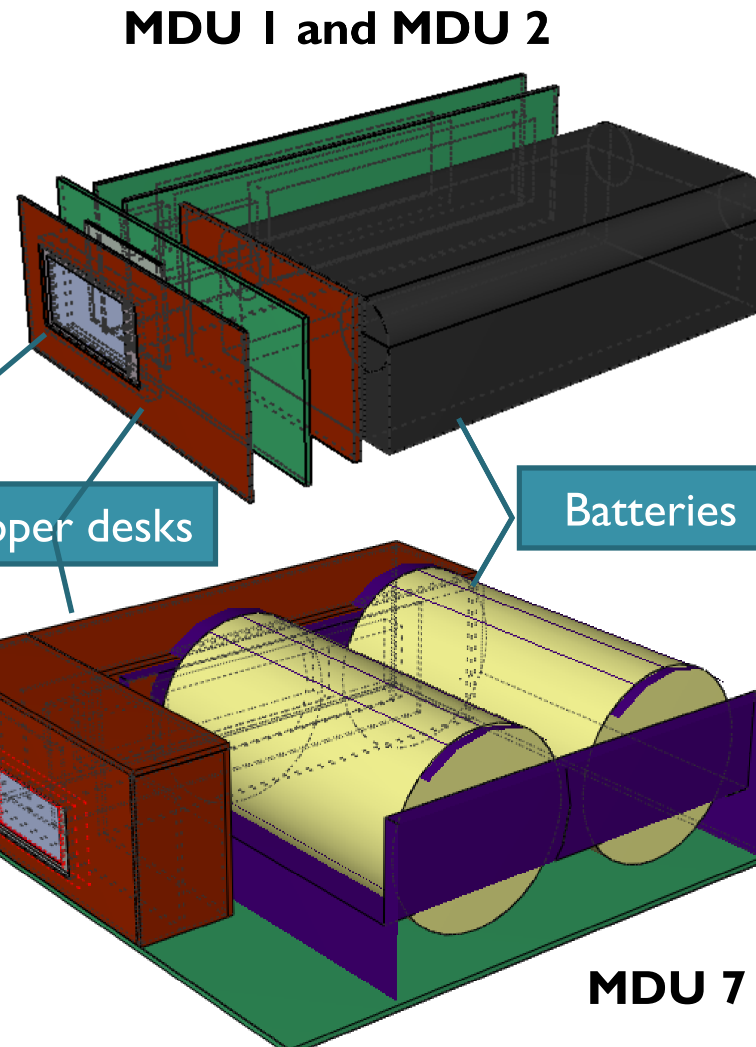
Range and energy of beams in HIMAC BIO

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%

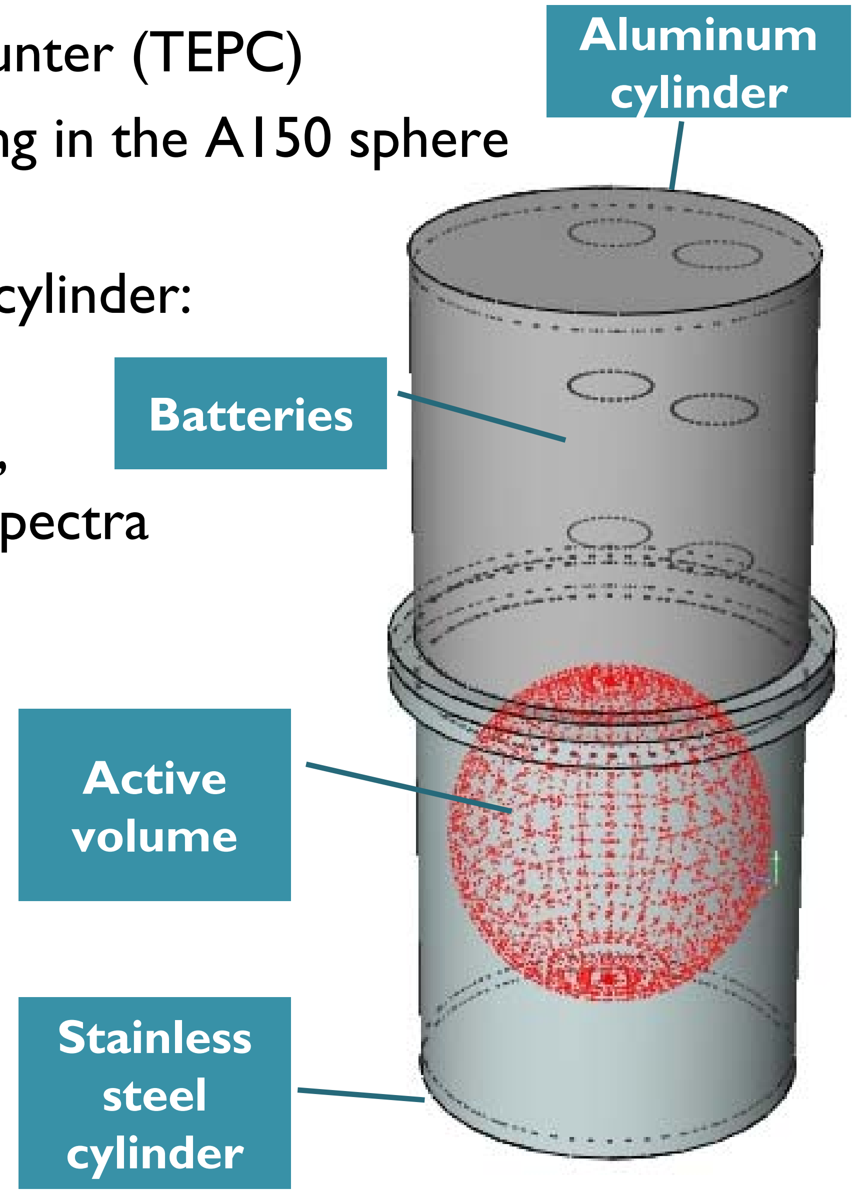
Materials and Methods: Liulin

- 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)
- Fluence, absorbed dose
- Dose equivalent (Kubančák)



Materials and Methods: Hawk

- Tissue equivalent proportional counter (TEPC)
- Active volume: propane gas housing in the A150 sphere (12.5cm in diameter)
- Size: stainless steel and aluminum cylinder: 15.5cm diameter, 33cm long
- Number of events, absorbed dose, dose equivalent, lineal energy (y) spectra



Particle fluence estimated with Liulin and Hawk

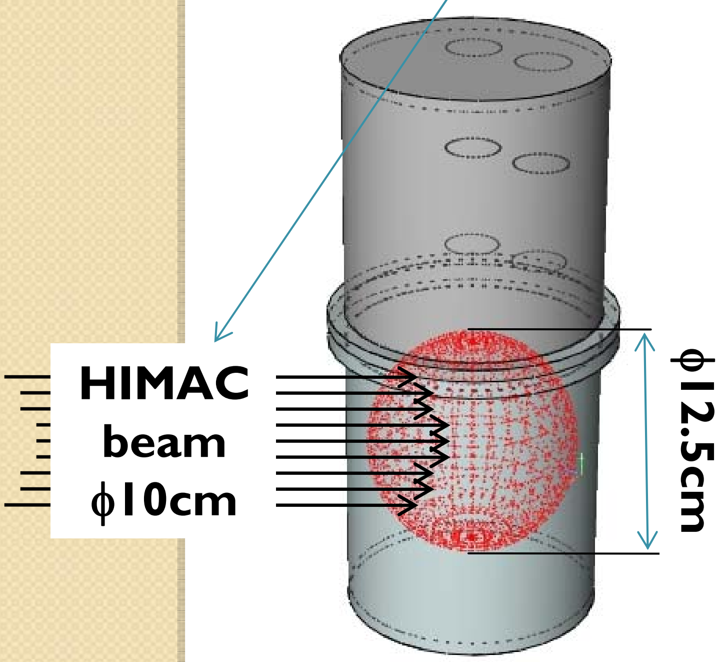
- Broad parallel beam:

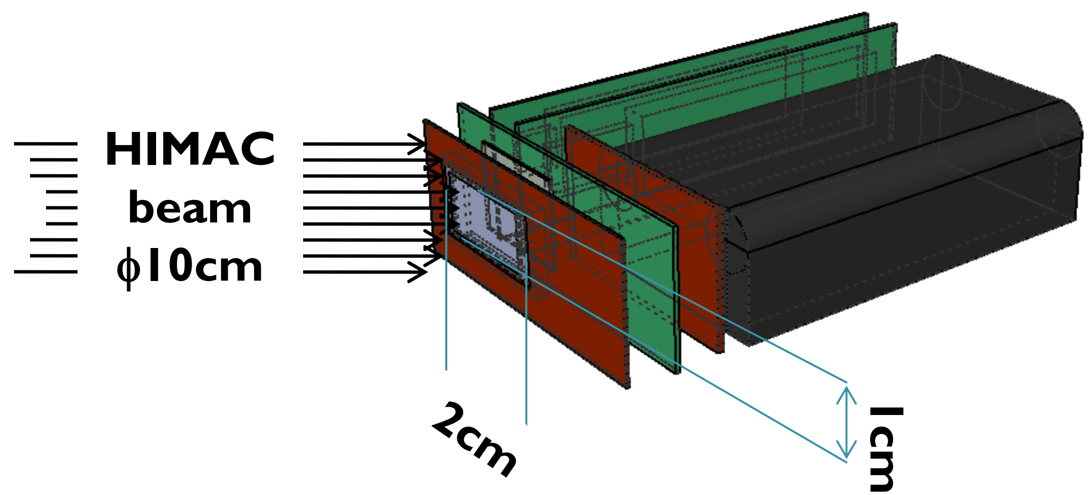
$$\Phi = \frac{N}{a}$$

- N … number of events
- a …area of entrance surface of the active volume

Hawk: $a=\pi r^2=78.5cm^2$

Liulin: $a=2cm^2$





Particle fluence estimated with Liulin and Hawk

- Isotropic radiation field:

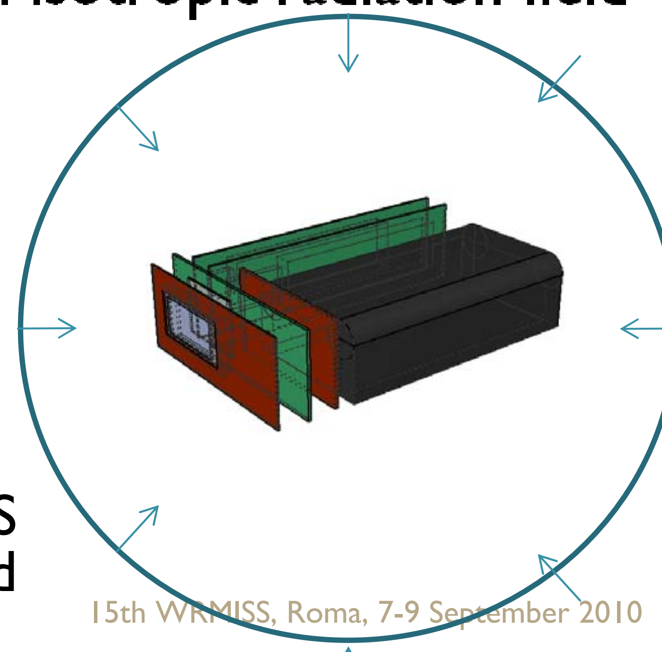
$$\Phi = \frac{1}{V}\sum_j l_j = \frac{N \cdot \bar{l}}{V} = \frac{N}{A/4}$$

- $\sum_j l_j$… sum of all chord lengths inside the active volume *V*
- $\bar{l} = \sum_j l_j / N$…mean chord length
- *A* … area of the body's surface

$$\bar{l} = 4V / A$$

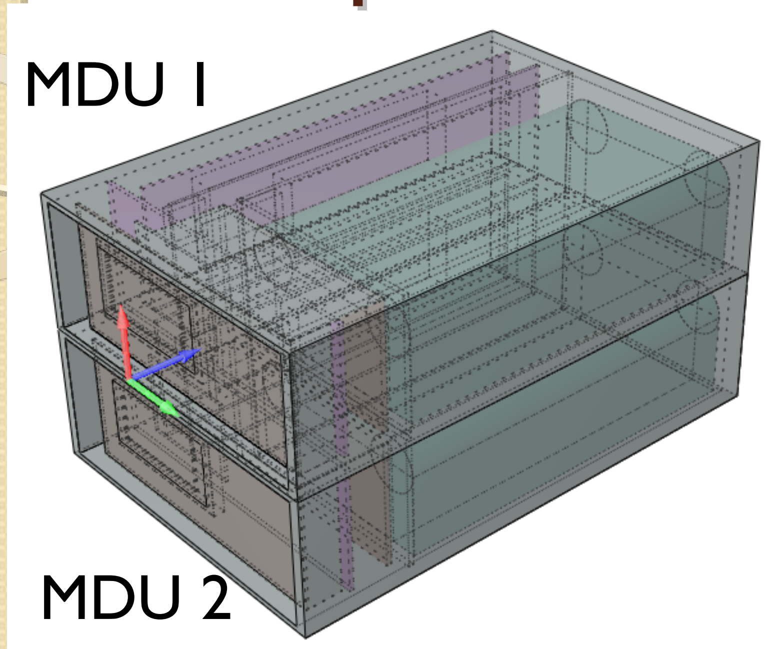
… came from The Cauchy's Mean Value Theorem, valid for convex objects in isotropic radiation field

	Φ / cm^{-2}	
	Isotropic r.f.	Parallel beam
Liulin	N / 1.045	N / 2
Hawk	N / 122.7	N / 78.5



Values were verified with PHITS in a simple isotropic radiation field

Comparison of two identical Liulins

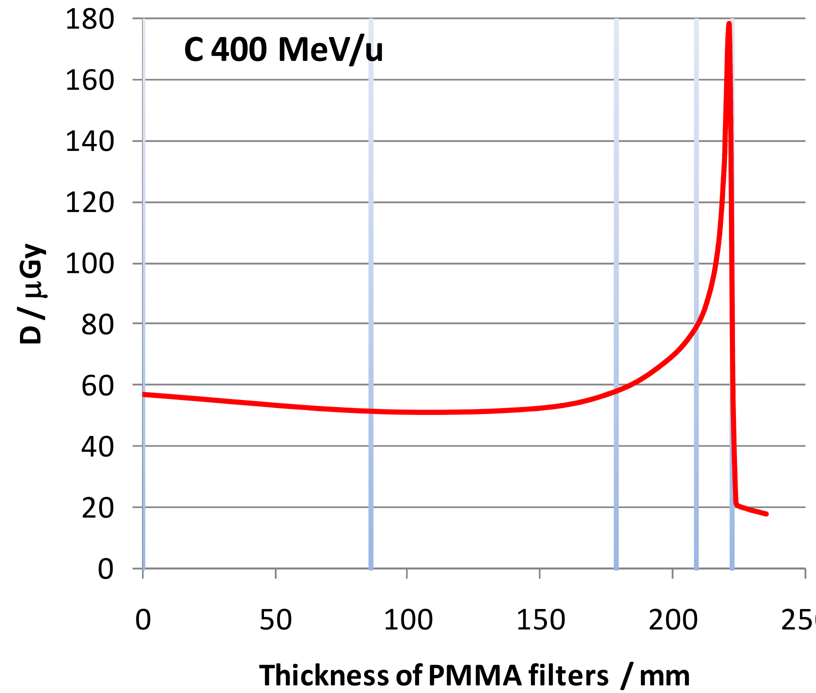


- Front aluminum cover removed from both Liulins
- PE desk removed from MDU 1

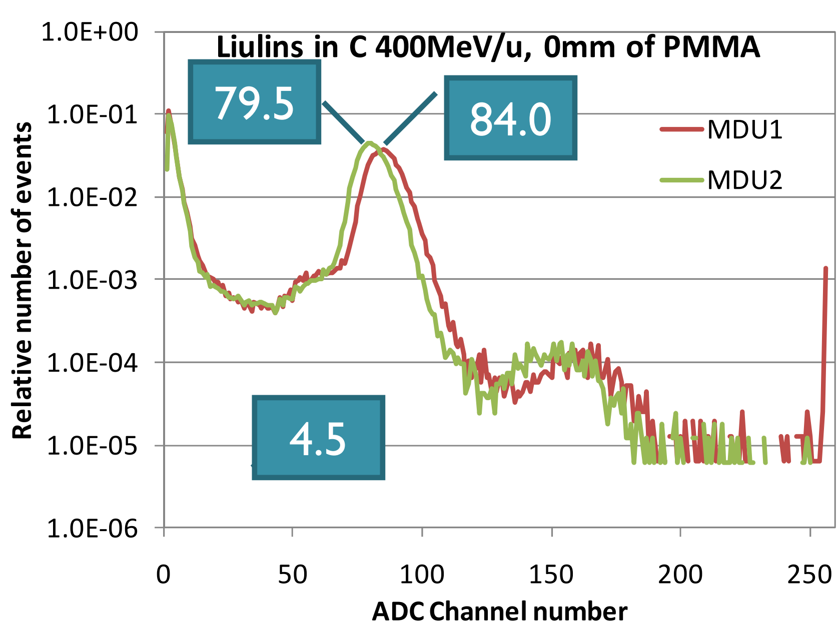
Beam: **C 400** MeV/u

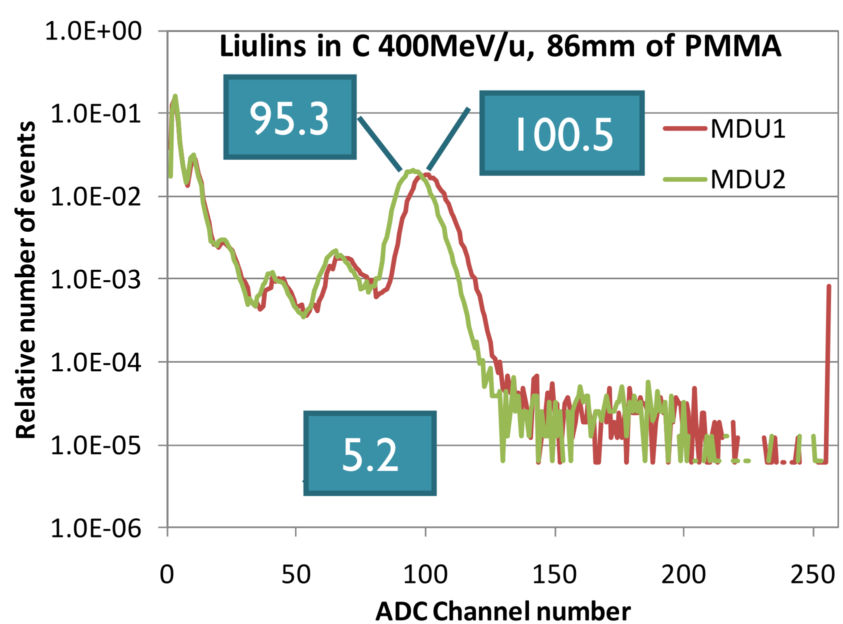
PMMA:

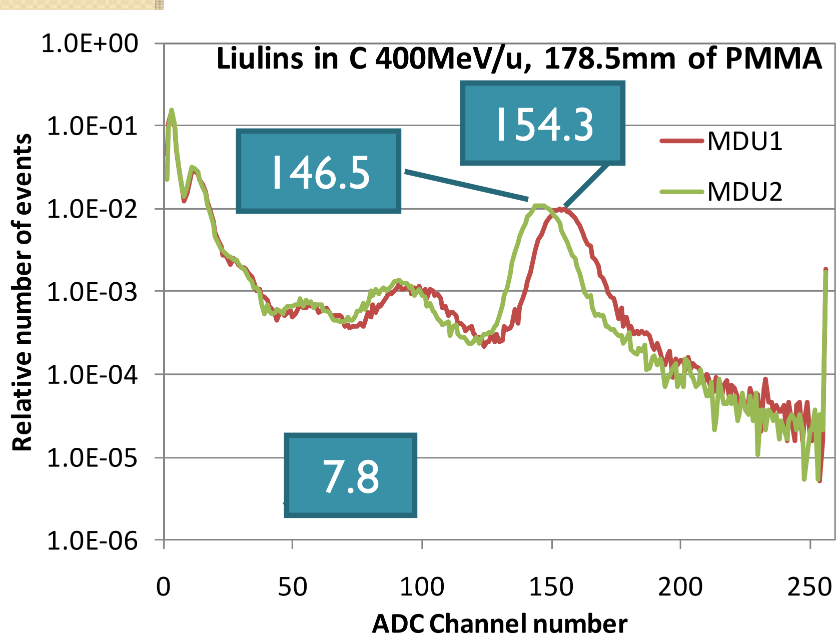
0.0 mm
86.0 mm
178.5 mm
208.5 mm

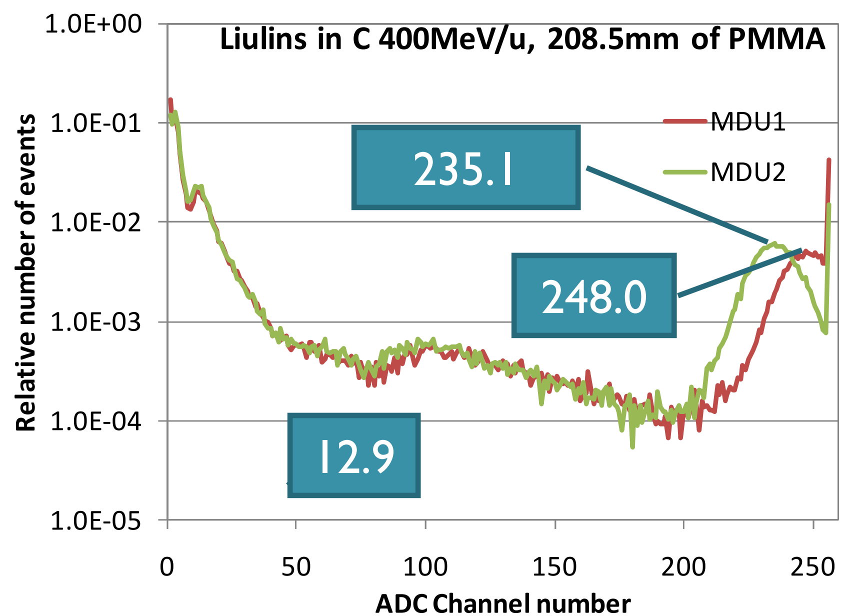


Identical Liulins in C 400MeV/u

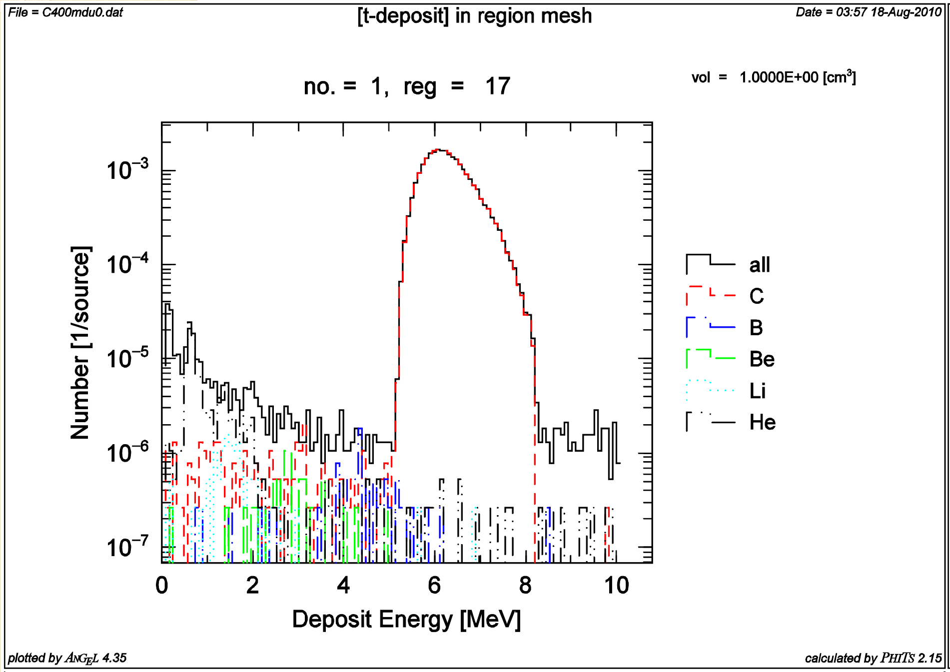


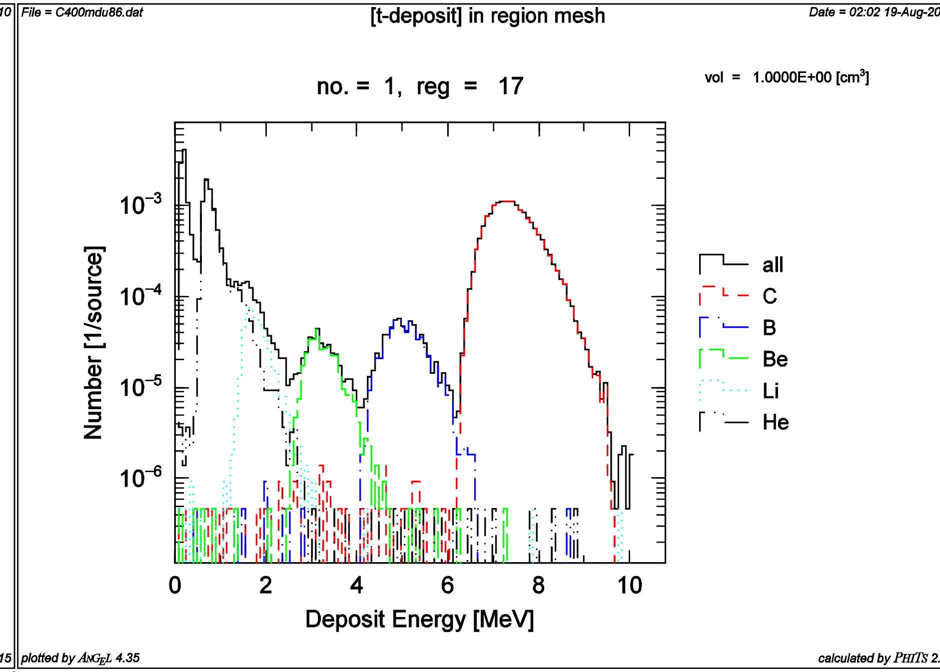


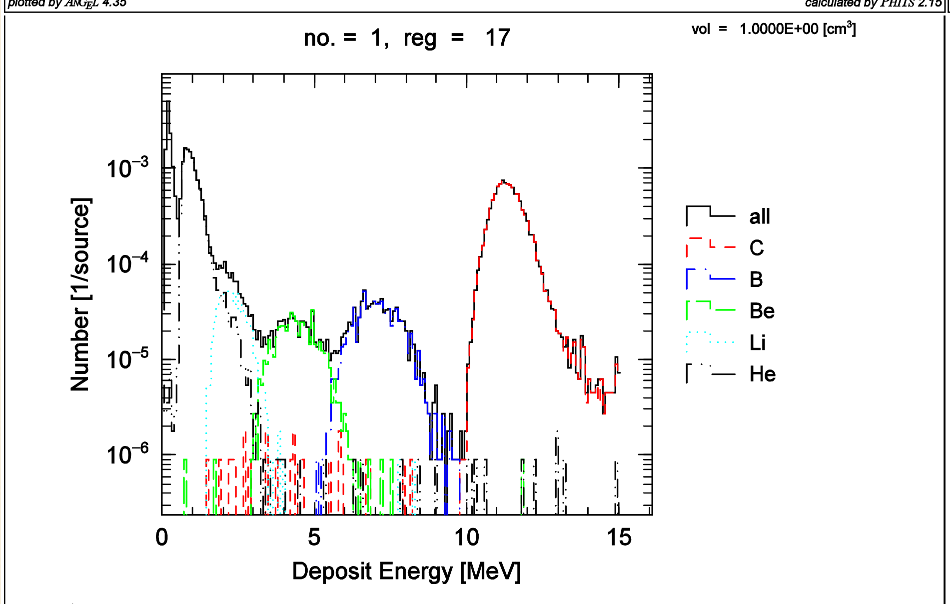


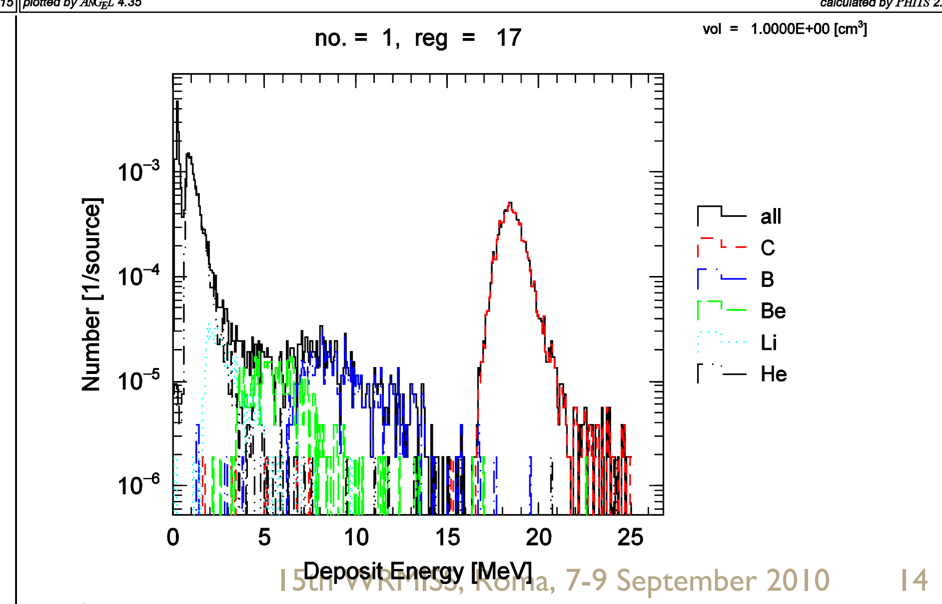


Recalibration of Liulin using PHITS



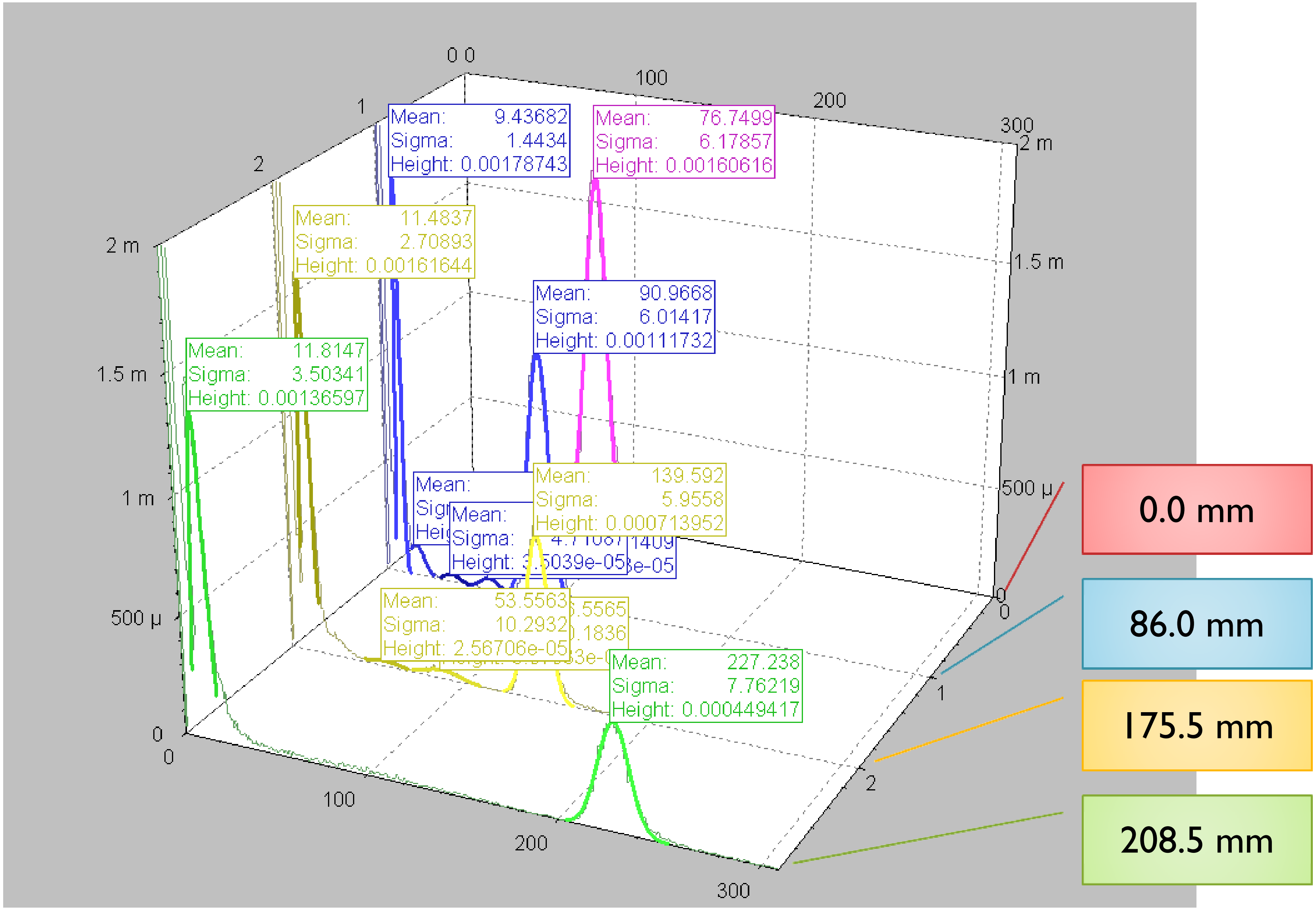




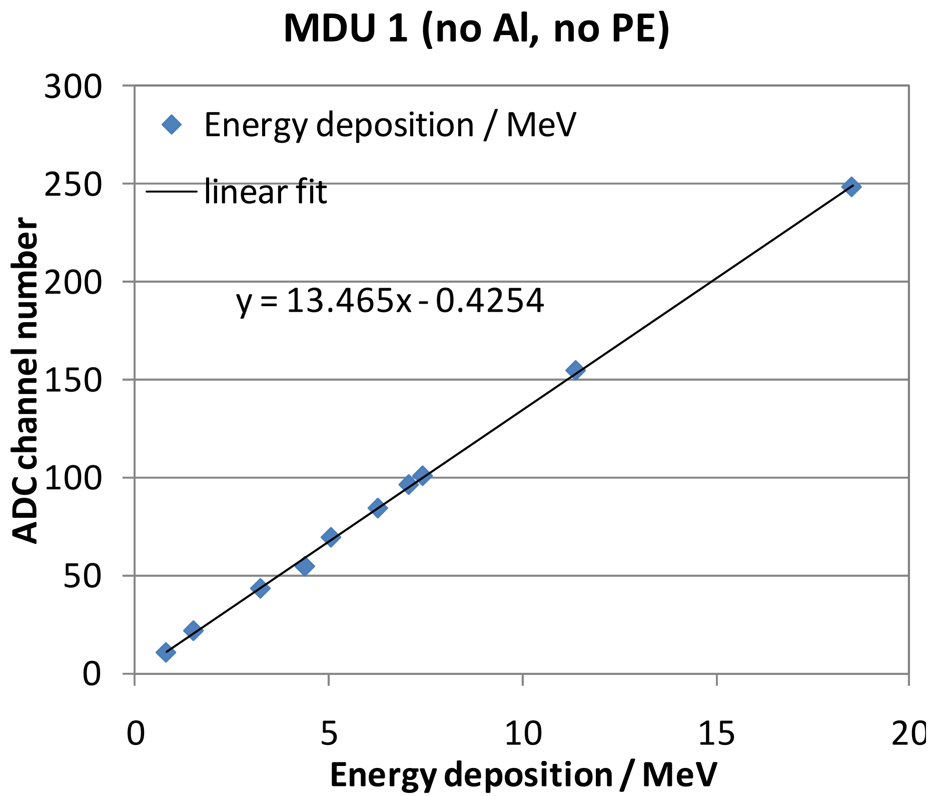


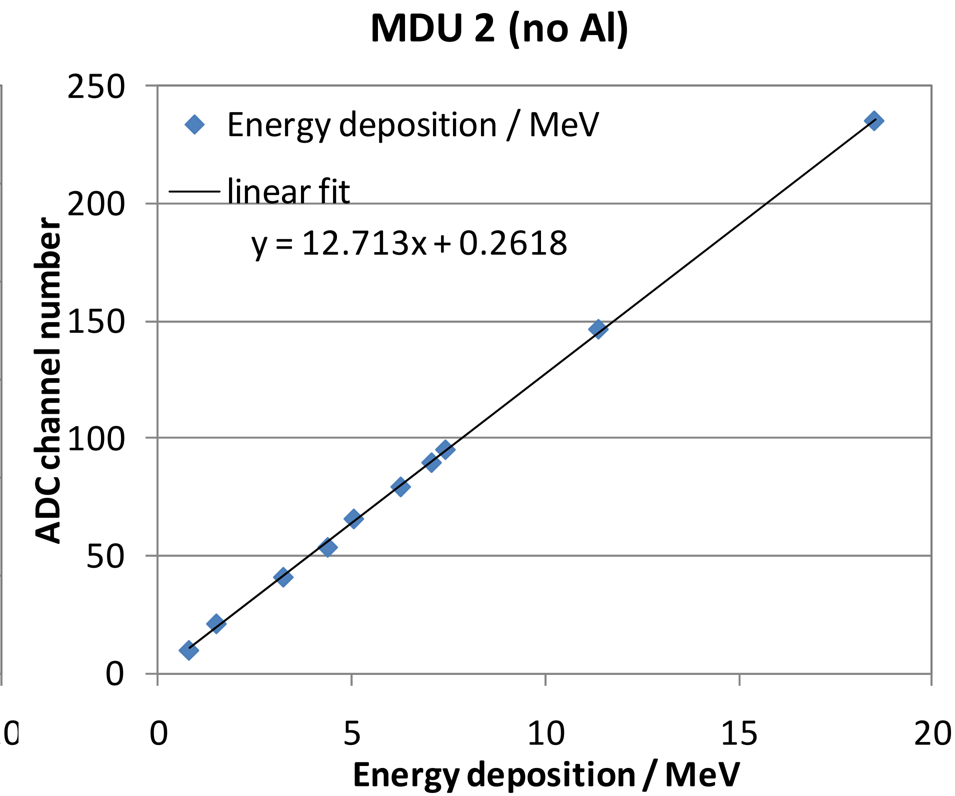
Recalibration of Liulin using PHITS

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

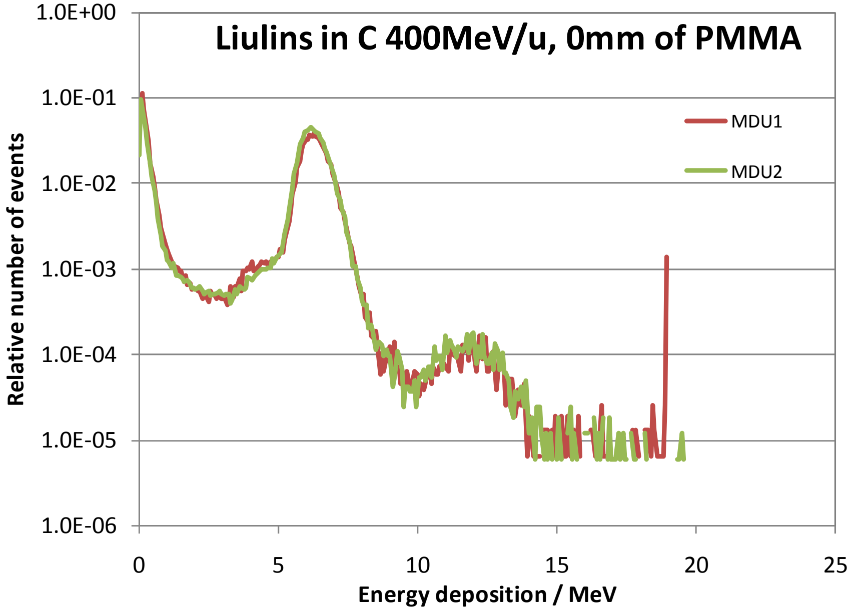


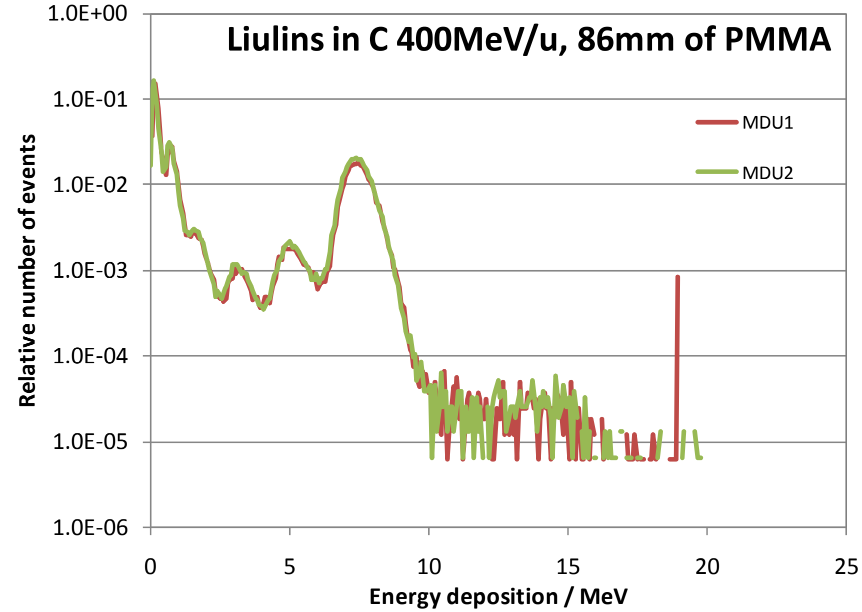
Recalibration of Liulin using PHITS

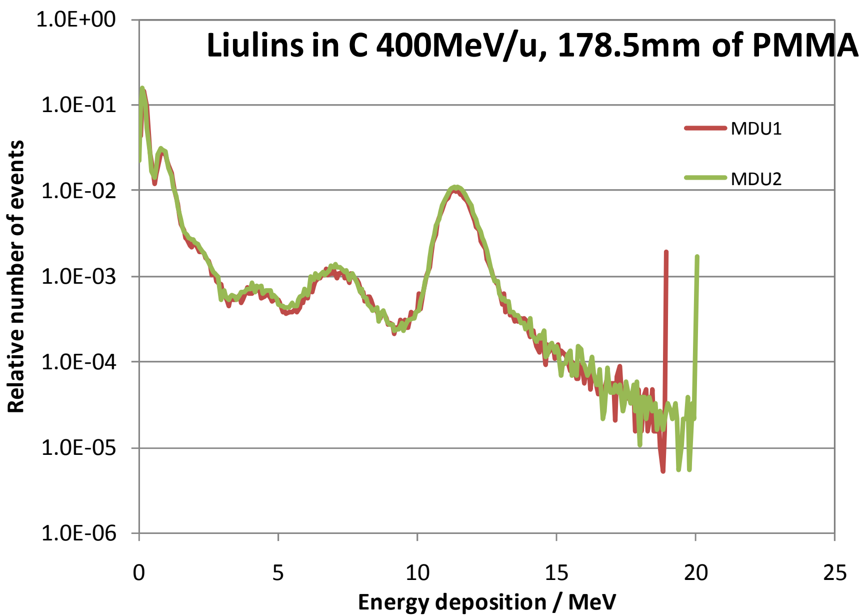


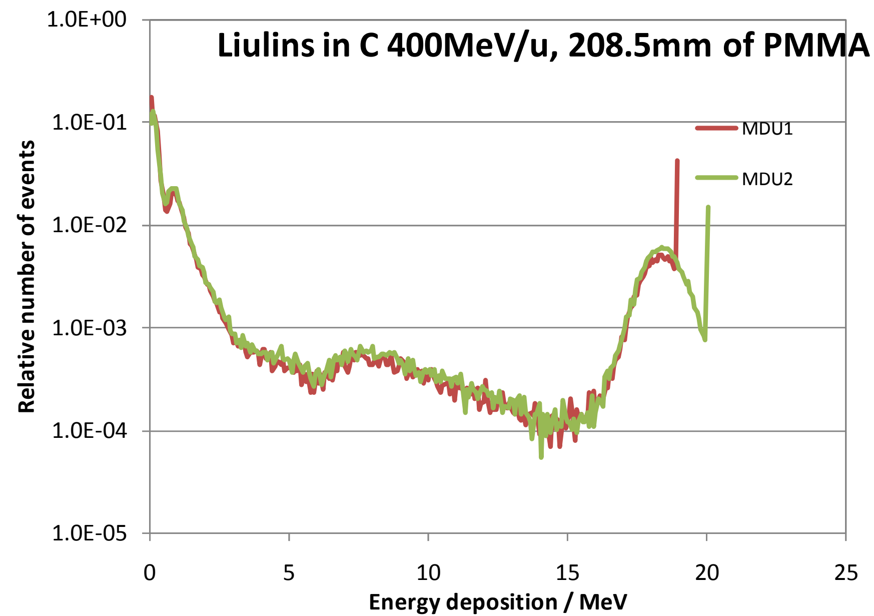


Comparison of two identical Liulins

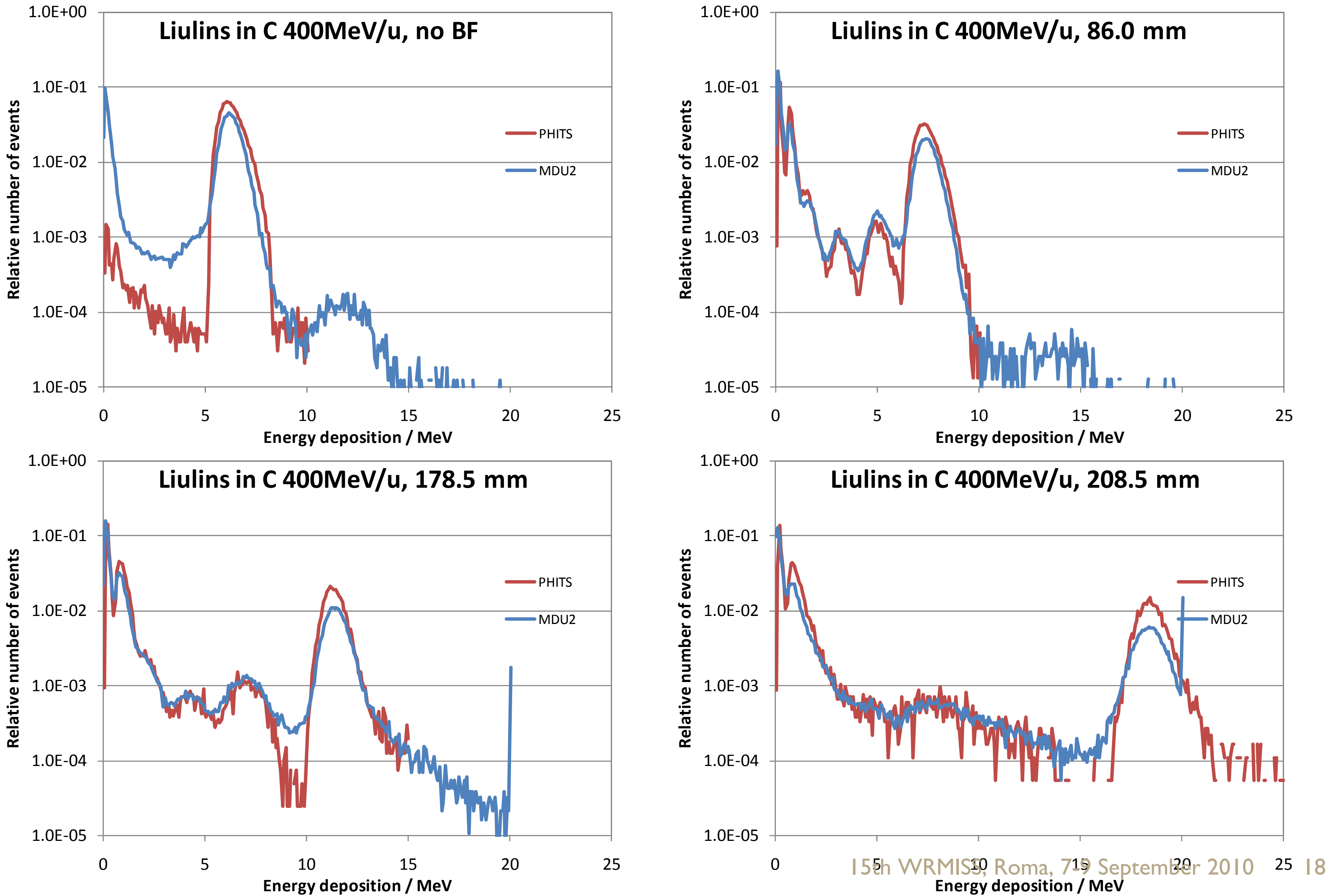






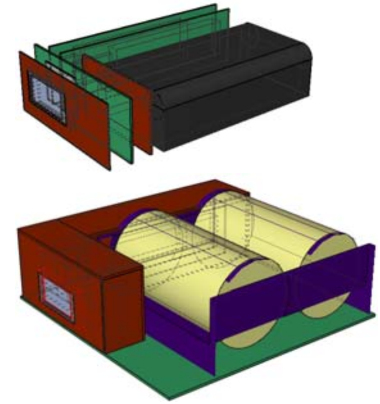


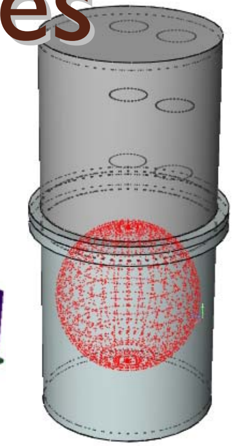
Comparison of Liulin spectra with PHITS



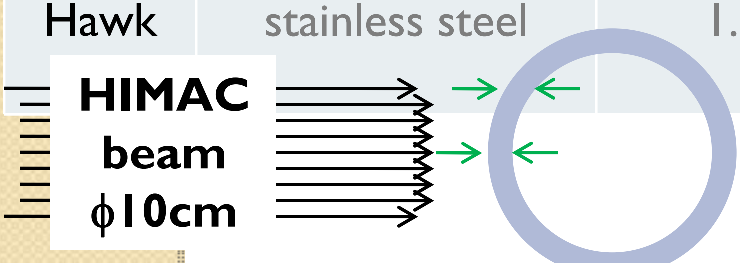
Influence of different thicknesses

- MDU 1 and MDU 2 in He150 MeV/u
- MDU 2 and MDU 7 in Ne400 MeV/u
- MDU 7 and Hawk in C135 MeV/u



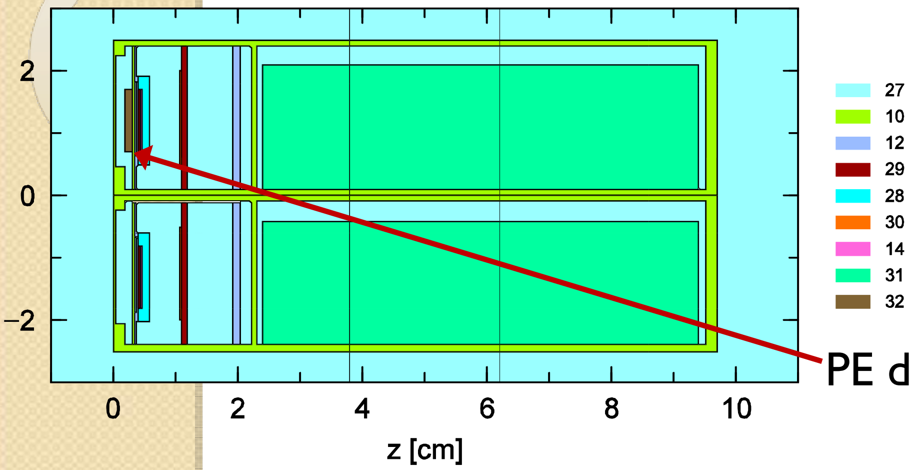


Device	Materials	Thicknesses / mm	Water equivalent / mm	PMMA equivalent / mm
MDU 1	Epoxy, Cu, Al, PE, Al	0.3, 0.07, 0.12, 1.2, 0.3	0.35+ 0.63+ 0.32 +1.12+ 0.81 = **3.23**	**2.69**
MDU 2	Epoxy, Cu, Al, Al	0.3, 0.07, 0.12, 0.3	0.35+ 0.63+ 0.32 + 0.81 = **2.11**	**1.76**
MDU 7	Epoxy, Cu, Al, Al	0.3, 0.07, 0.12, 2.0	0.35+ 0.63+ 0.32 + 5.4 = **6.70**	**5.59**
Hawk	A150, stainless steel	2.1– 3.4, 1.2 – 1.5	2.37– 3.84, 8.0 – 10.53 **11.97 – 16.47**	**9.97 – 13.73**



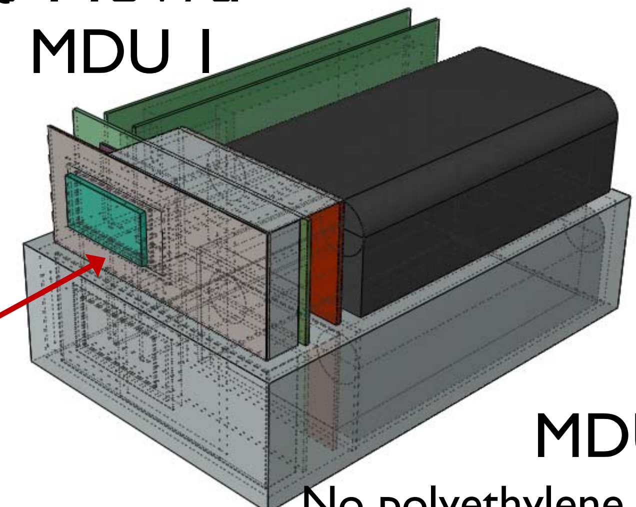
Influence of different thicknesses

- MDU 1 and MDU 2 in He 150 MeV/u



PE desk (1.2mm)

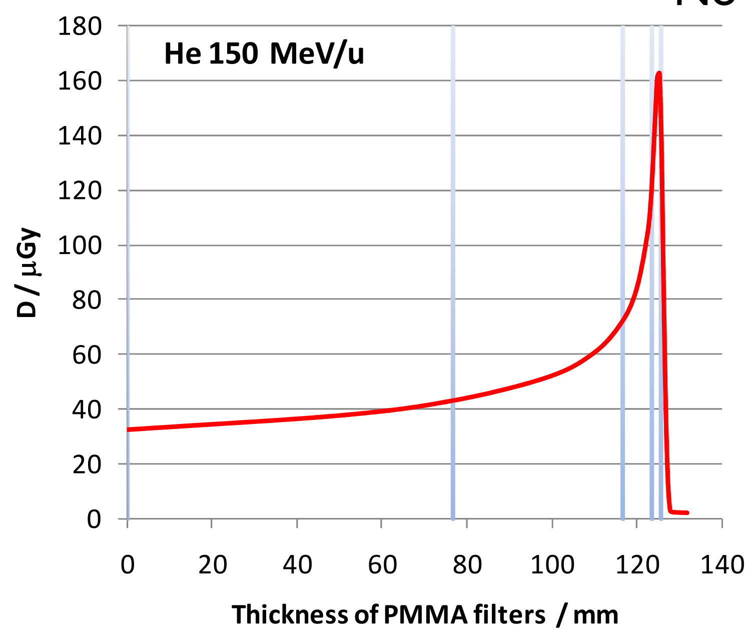
MDU 1



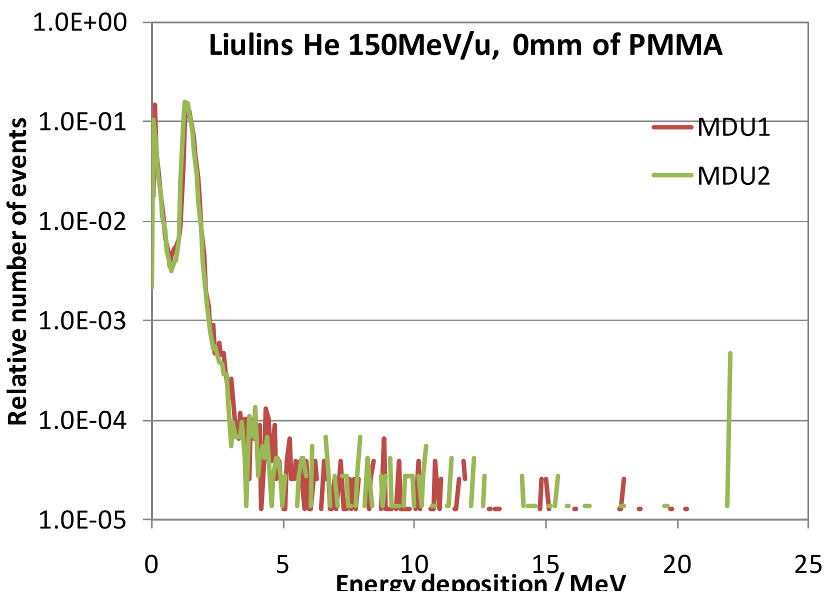
MDU 2

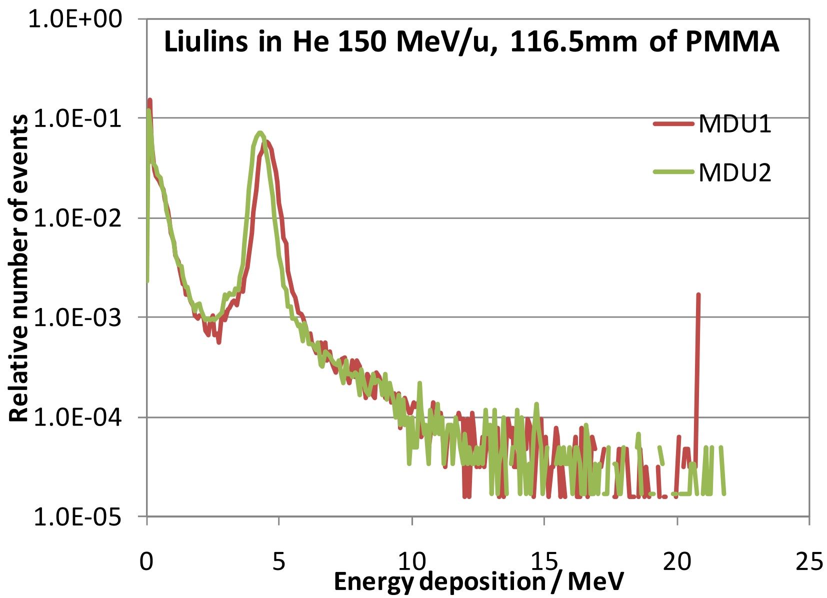
No polyethylene desk

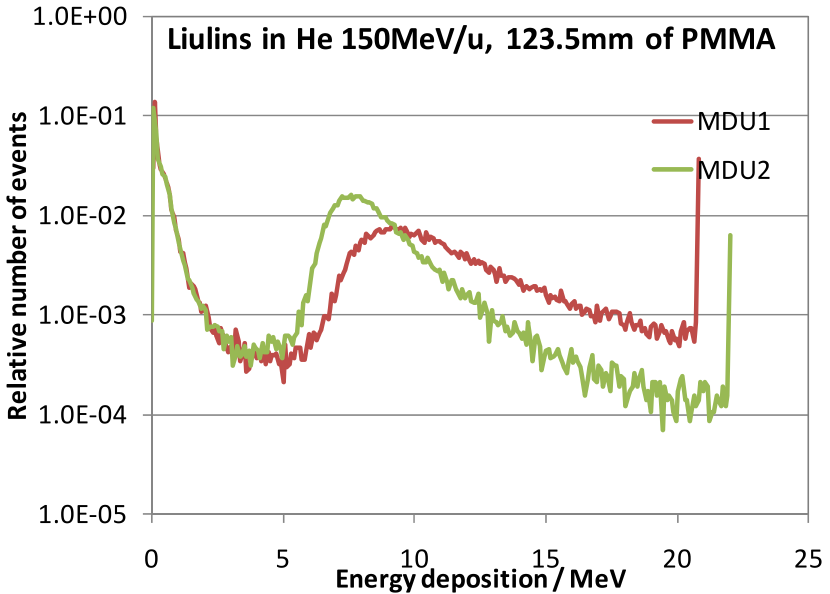
- PMMA:
  - 0mm
  - 116.5mm
  - 123.5mm
  - 125.5mm

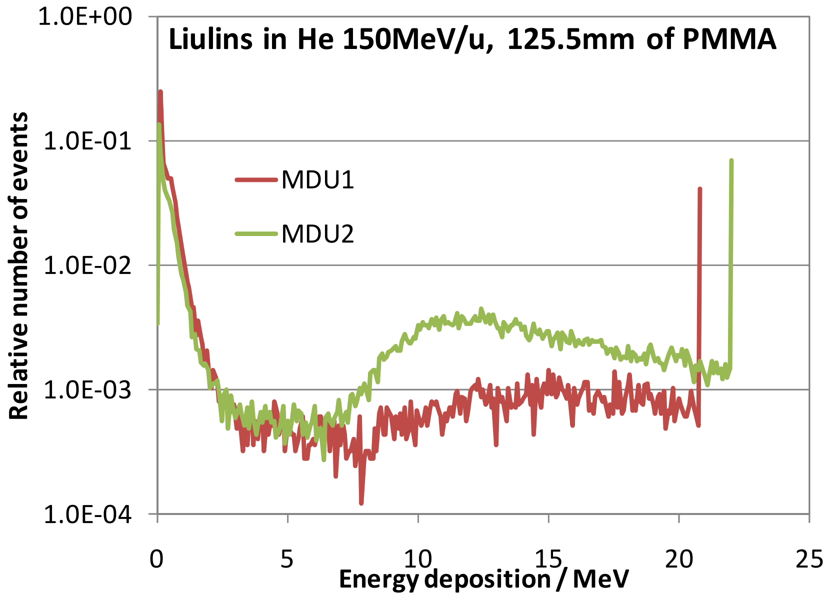


Influence of different thicknesses: MDU 1 and MDU 2



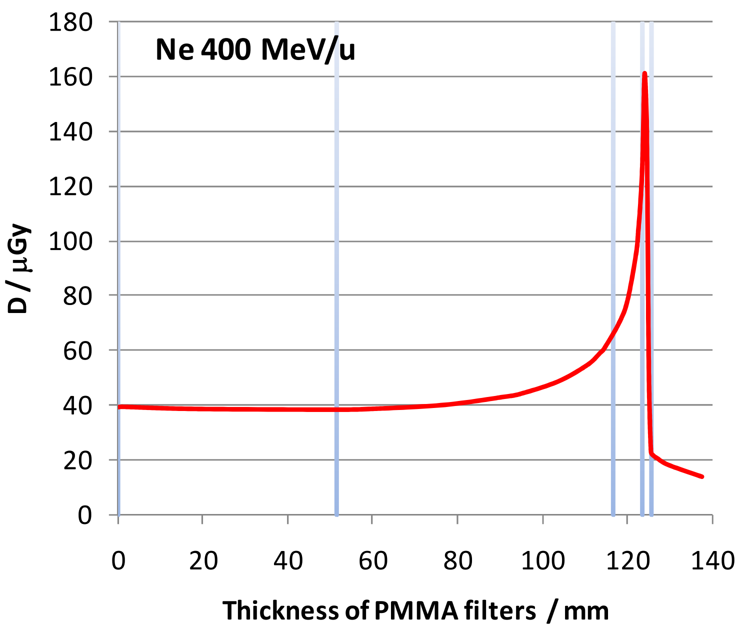


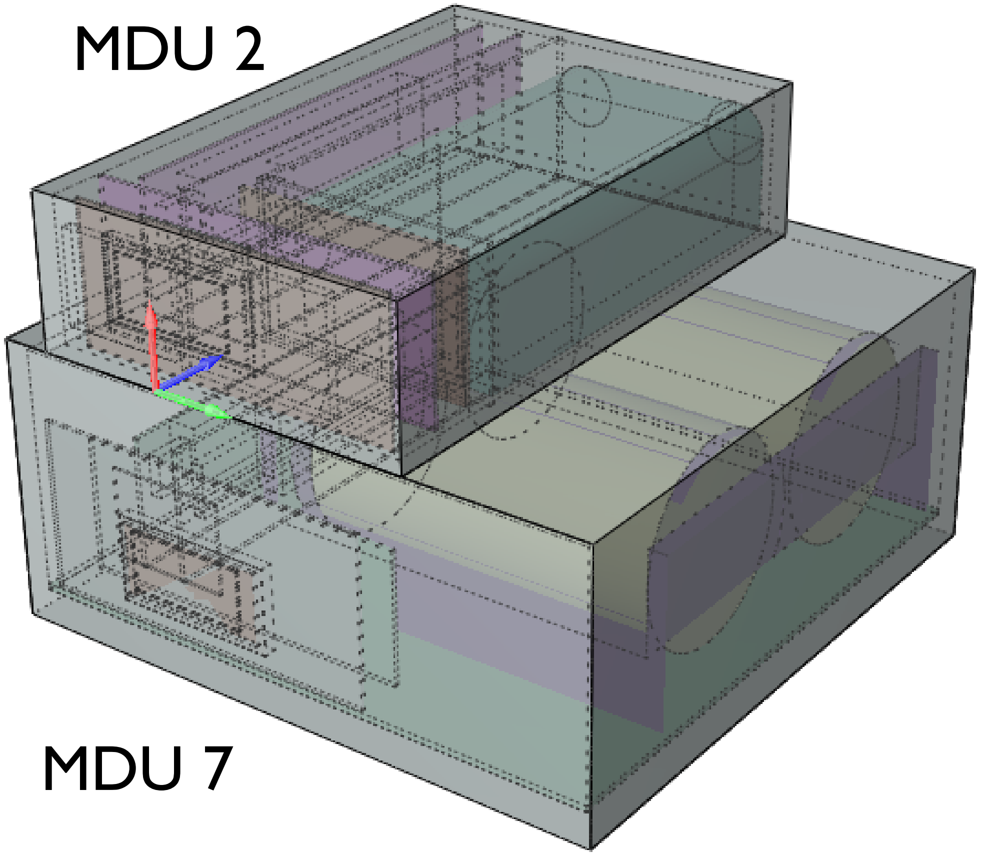




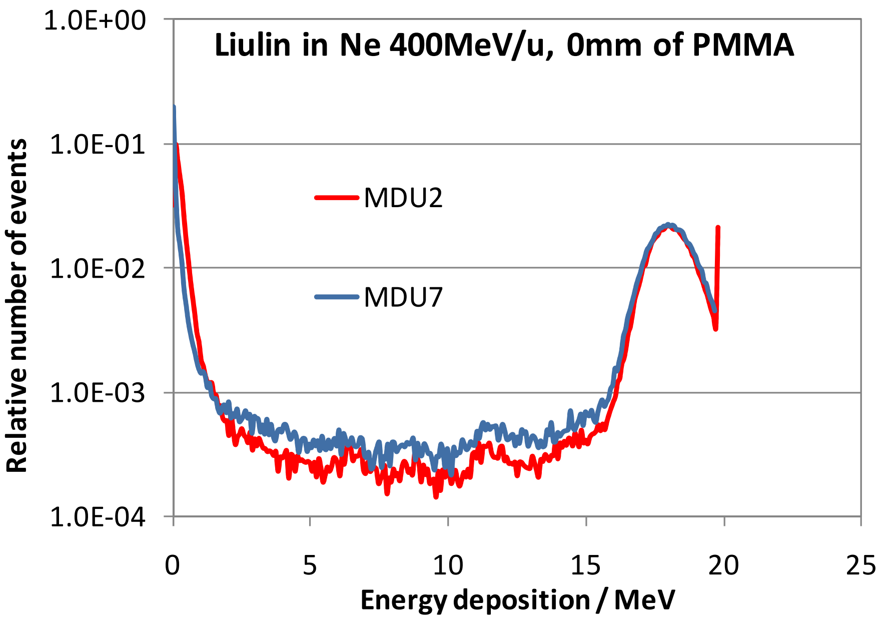
Influence of different thicknesses:

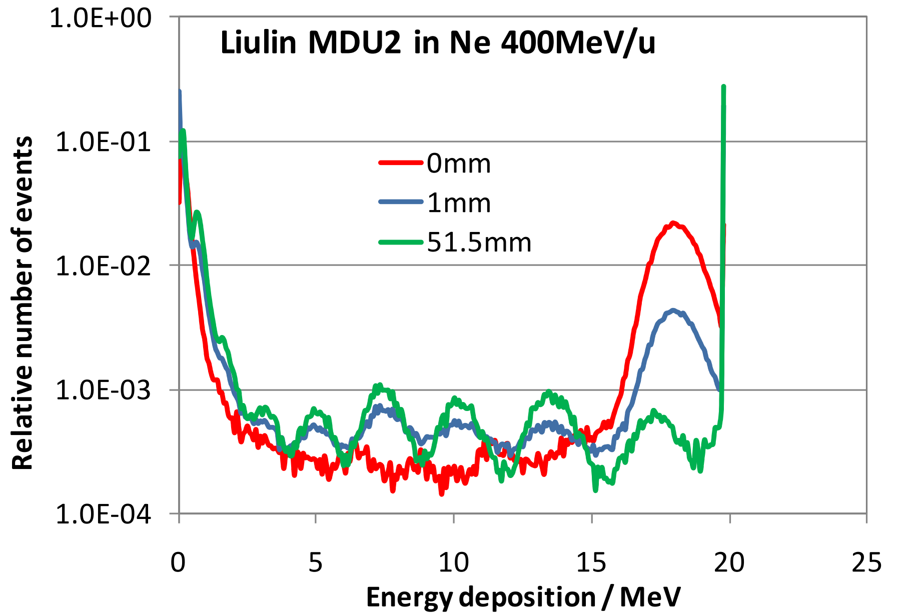
- MDU 2 and MDU 7 in Ne 400 MeV/u
  - PMMA:
    - 0.0 mm
    - 1.0 mm
    - 51.5mm

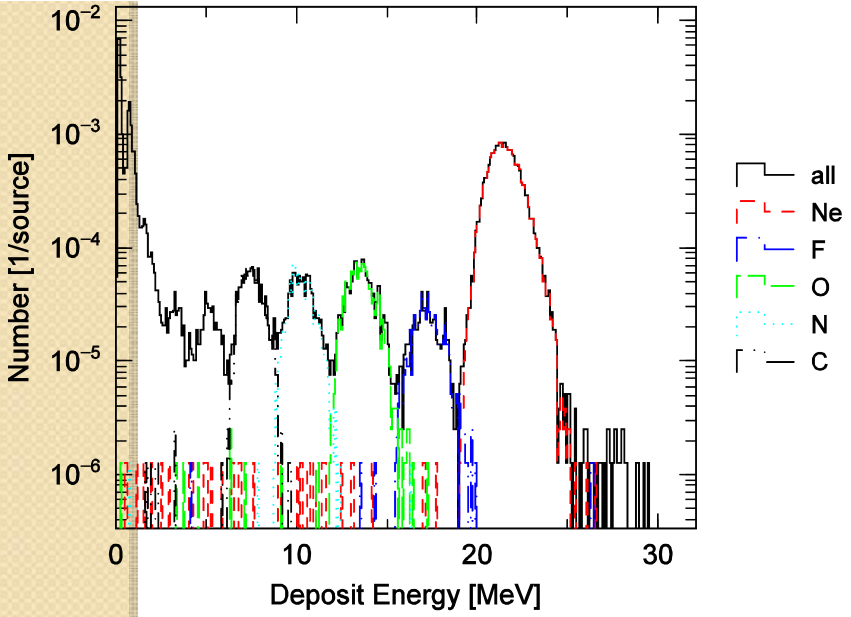


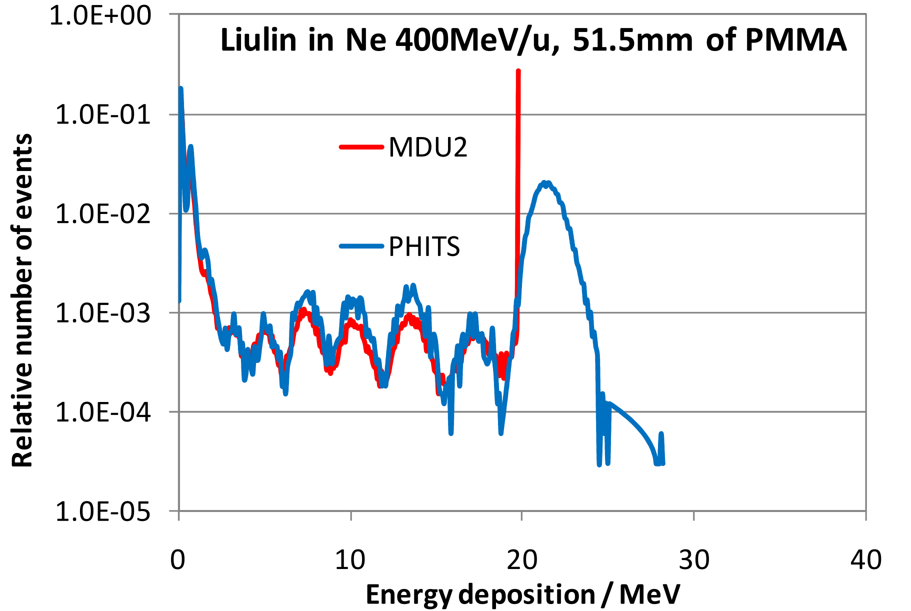


MDU 2 and MDU 7 in Ne 400 MeV/u

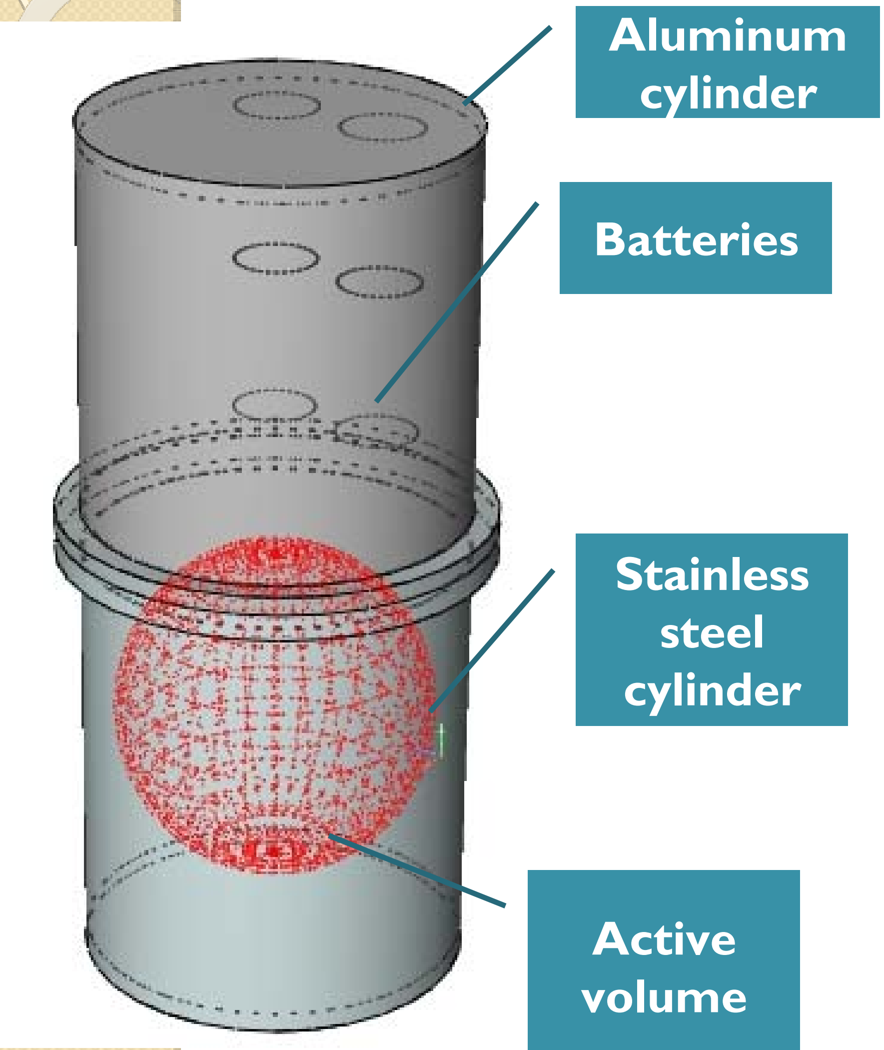


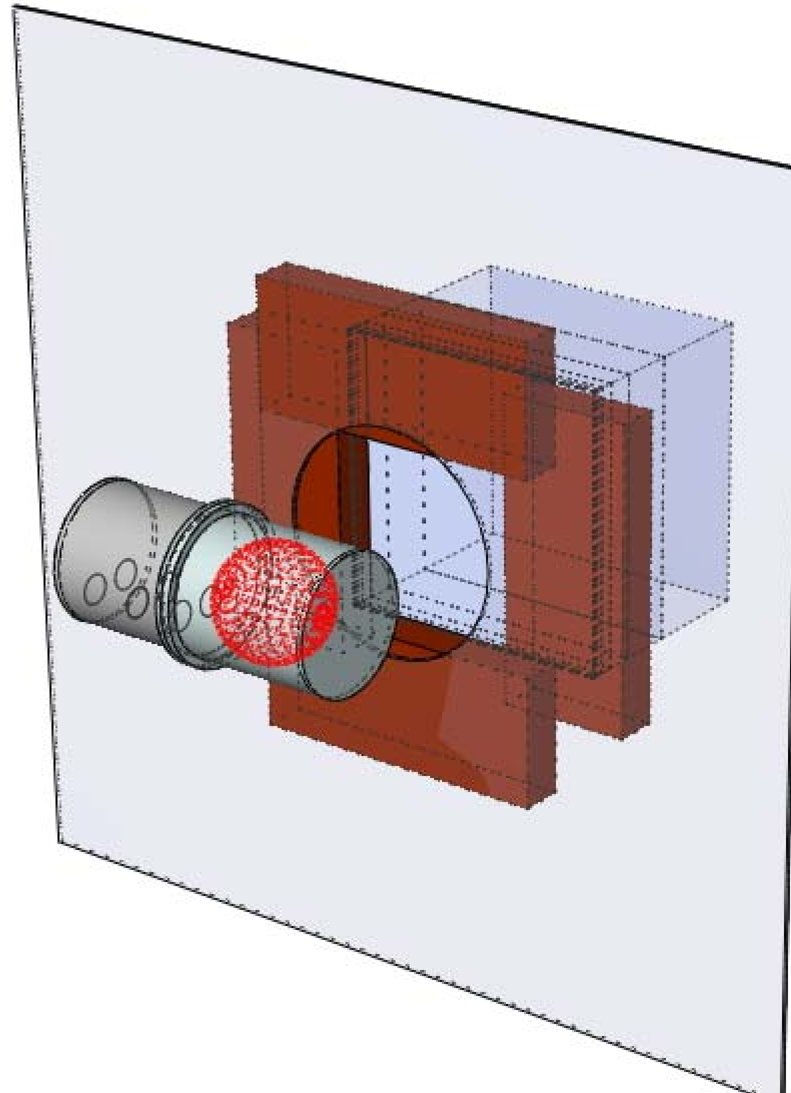






Geometry of Hawk in BIO with PHITS





Comparison of LET spectra measured with Liulin and Hawk

- Calculation of LET in water
  - Liulin: $L_w = 1.2 \times L_{Si} \times \frac{\rho_w}{\rho_{Si}}, \quad L_{Si} = \frac{\varepsilon}{d}, \quad d = 300\,\mu m$
  - Hawk: $L_w \approx y = \frac{\varepsilon}{\bar{l}}, \quad \bar{l} = \frac{4V}{A} = 1.44\,\mu m$

Energy deposition

Si to water coefficient: from ICCHIBAN, verified with PHITS

LET in silicon

Densities of water and Si

Thickness of Si diode

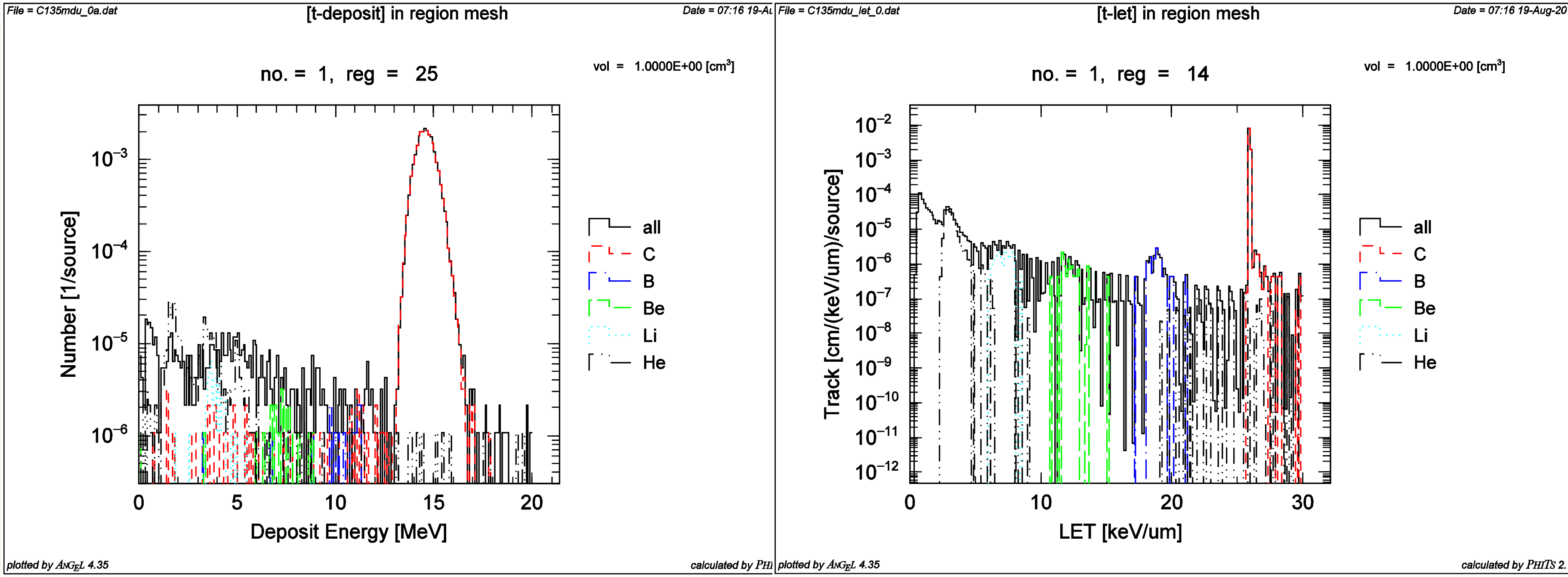
We suppose that LET in water is equal to lineal energy

Mean chord length

Came from Cauchy's Mean Value Theorem

A and V are surface area and volume, respectively, of the tissue equivalent sphere of 2μm in diameter

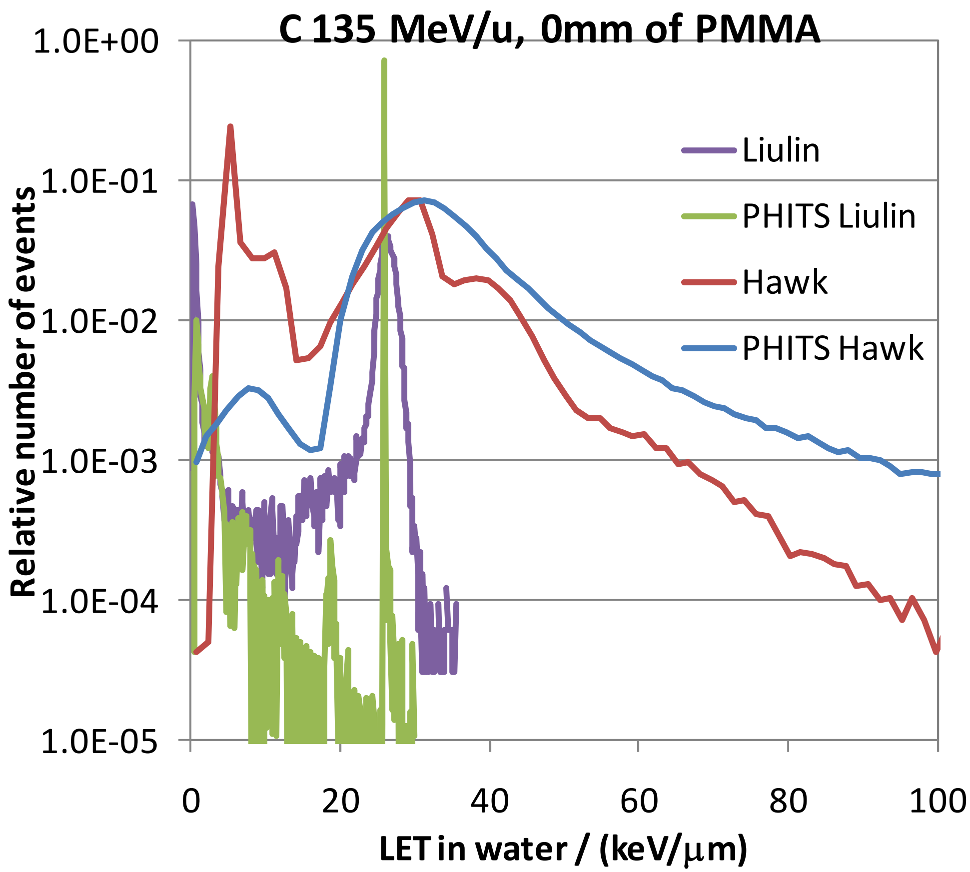
Si to water conversion coefficients



Ion	Nenergy / (MeV/u)	Si to water conv. coefficient
He	150	1.36
C	135	1.23
C	290	1.26
C	400	1.24
Ne	400	1.24

- Liulin LET spectra calculated with PHITS, (C 135 MeV/u, 0mm of PMMA)
- Water was used instead of Si-diode!

Comparison of LET spectra measured with Liulin and Hawk



Position of the peak:

L = 25.6keV/μm (Liulin) vs L = 29.3keV/μm (Hawk)

Conclusions

- Estimation of fluence with Liulin is different for different angular distribution of radiation field
- To measure heavy ions with Liulin correctly, the re-calibration should be done separately for each device, thickness of materials in front of active volume must be taken into account
- 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
- Fragments were not recognized with Hawk
- Si to water conversion coefficient estimated using PHITS code differ (1.24 – 1.36)
- Good agreement in the peak position of LET spectra measured with Liulin and Hawk when shielding thickness is taken into account, the shape is different
- Further research on calculation of TEPC spectra is needed

Acknowledgement

- ***PHITS*** developers for giving me chance to work with the code and further support, namely Tatsuhiko Sato san
- **SimpleGeo** developers, namely Chris Theis
- **ABCDview** developers, namely Jan Jakubek
- **JSPS** for support of postdoctoral fellowship

THANK YOU FOR YOUR ATTENTION!

Comparison of Liulin spectra with PHITS