health pyhsics division
risk and safety

Microdosimetric GEANT4 and FLUKA Monte-Carlo Simulations and Measurements of Heavy Ion Irradiation of Silicon and Tissue

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Outline

- Simulation of radiation effects
- Code validation by using microdosimetric quantities
- Comparison of measurements and simulations
  - heavy ion irradiation (silicon & tissue)
  - microdosimetric measurements (2µm sensitive volume)
  - Monte Carlo simulation (FLUKA, GEANT4)

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Why Radiation Simulation?

Simulation supports…

- understanding radiation interaction mechanism
- irradiation test measurements
- design radiation hard semiconductor
- optimize shielding

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Validation Approach

- Validation of Monte Carlo high energy particle transport
- Using microdosimetric methods
- Compare measurements with simulations
  - absorbed dose
  - lineal energy spectra
  - dose mean lineal energy

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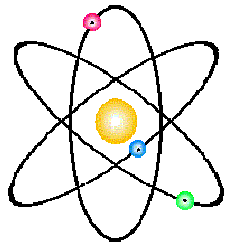
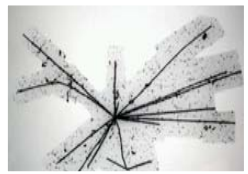
Monte Carlo Simulation with FLUKA & GEANT4

- Transport of
  - electromagnetic particles
  - hadronic particles
  - heavy ions
- Energy: 20 TeV to …
  - 10keV (all particles)
  - thermal neutrons (~ 0,1 eV)
  - 1 keV (ph, e^-) / FLUKA
  - 250eV (ph, e) / GEANT4
- Score energy deposition
  - event by event
- Simulation of microdosimetric spectra





FLUKA official FLUKA site Milano

http://www.fluka.org/index.html

GeantA

http://geant4.web.cern.ch/geant4/

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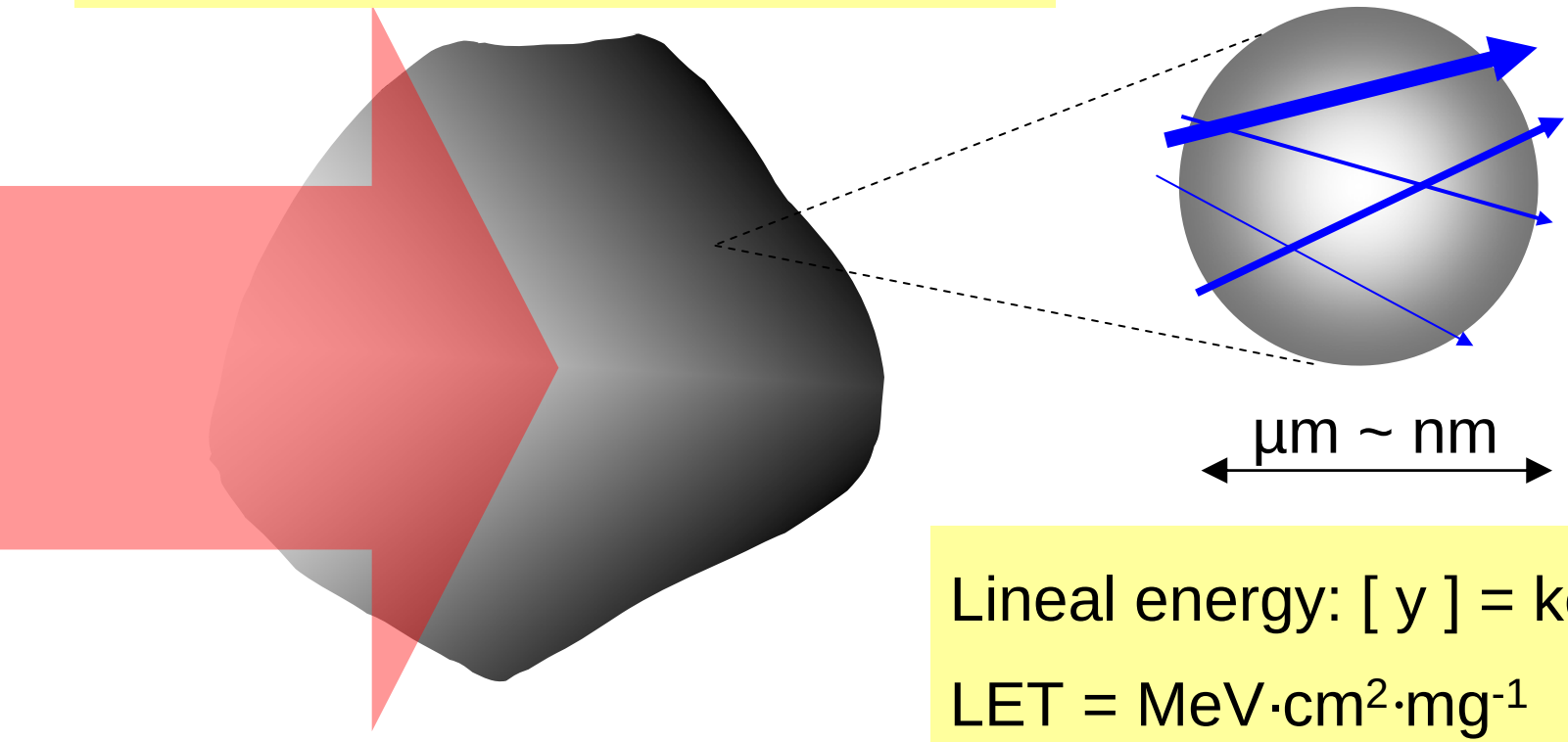
Dosimetry - Microdosimetry

Absorbed dose: [D] = Gy = J · kg^{-1}



Lineal energy: [y] = keV · µm^{-1}

LET = MeV·cm^{2}·mg^{-1}

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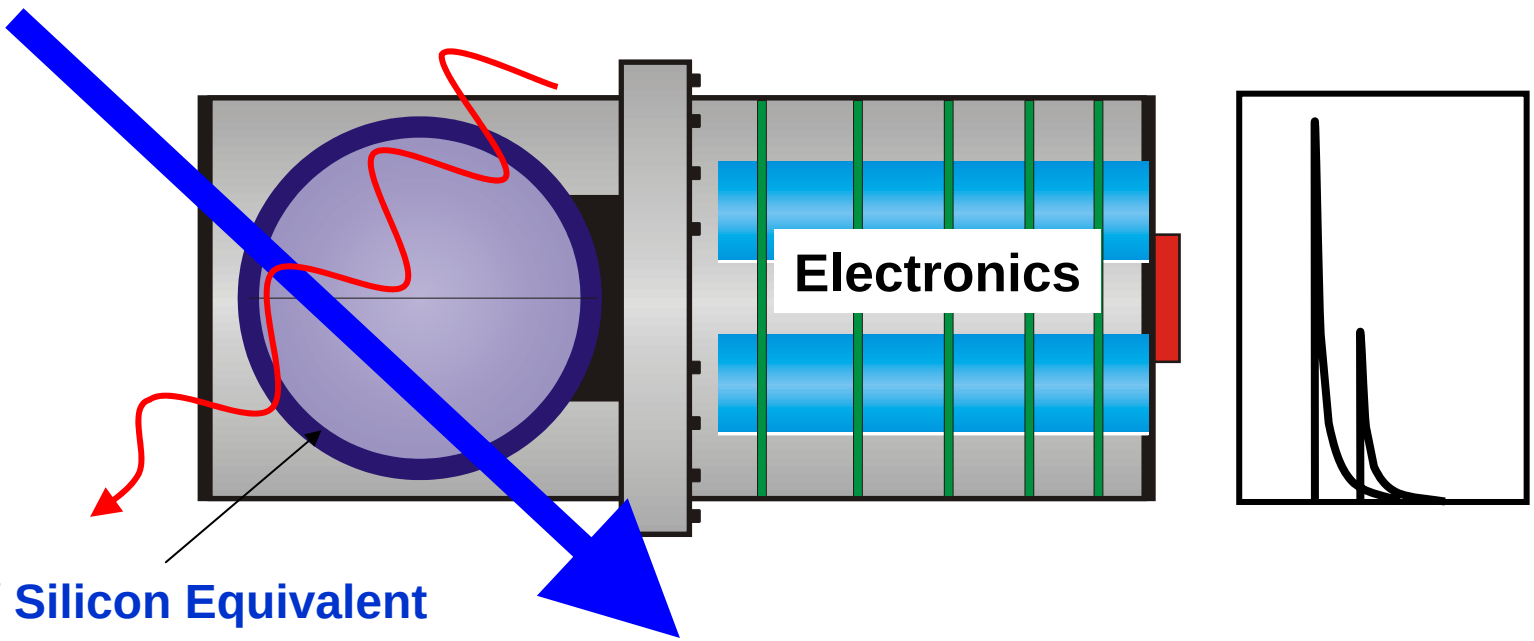
Micro-Dosimeter (Rossi-Type)

- TEPC (*tissue equivalent proportional counter*)
- SEPC (*silicon equivalent proportional counter*)

Source: Columbia University



Tissue / Silicon Equivalent Chamber (10 µm ~ 100nm)

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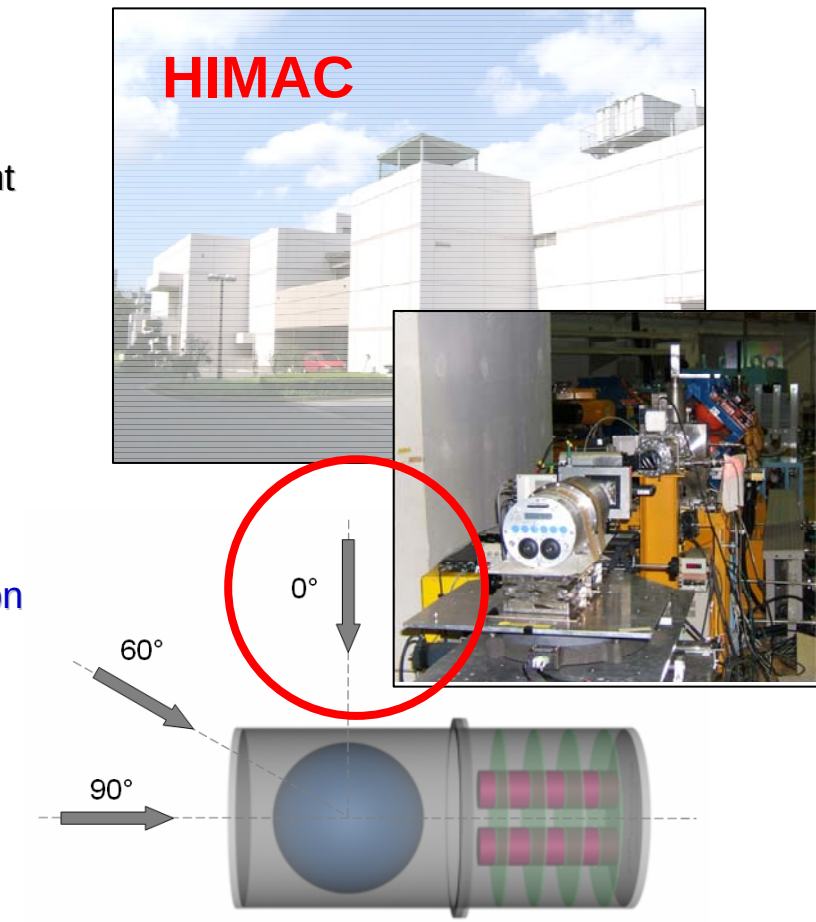
HIMAC - Heavy Ion Medical Accelerator, Chiba, Japan

- HIMAC
  - is used for cancer therapy
  - is available for scientific experiments during night time and weekends
- ICCHIBAN -8
  - Measurements in the framework of *Inter Comparison for Cosmic-ray with Heavy Ion Beams at NIRS*
  - Radiation study at the International Space Station
- Tissue & Silicon irradiation measurements
  - O 400 MeV/u
  - Fe 300 MeV/u



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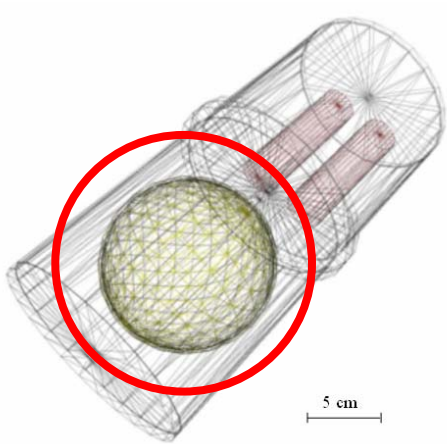
High Energy Particle Transport Simulation

- Detector geometry and material
- Source: heavy ions
  - O 400 MeV/u
  - Fe 300 MeV/u
- Analysis of beam characteristics (shape, divergence, etc.)
- High energy particle Monte Carlo transport codes
  - FLUKA-2005
  - GEANT4



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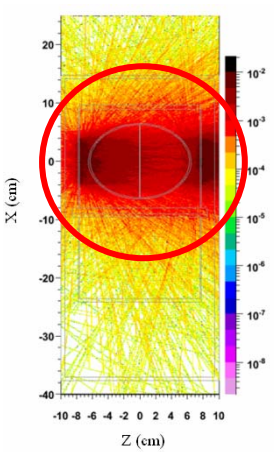
Simulation Results: Particle fluence density

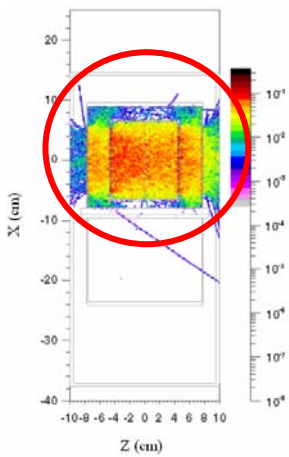
(particle ·cm^{-3} per unit source)

Oxygen 400 MeV/u
broad beam

- Neutron fluence rate
- Inside tissue

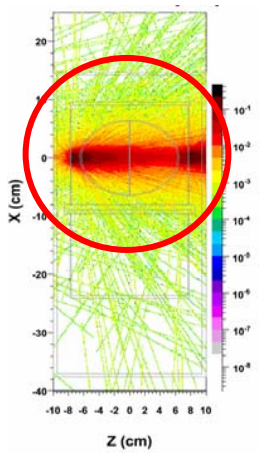


- Electron fluence rate
- Inside silicon

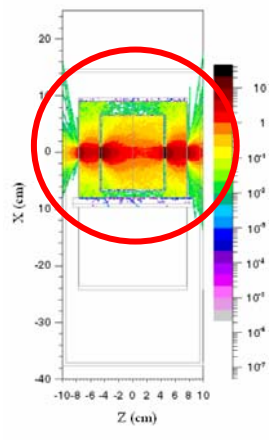


Iron 300 MeV/u
small beam

- Neutron fluence rate
- Inside tissue



- Electron fluence rate
- Inside silicon



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Total absorbed dose in 2µm sensitive silicon & tissue volume due to heavy ion irradiation

Instrument	Beam	Measurement	FLUKA	Geant 4
	MeV/u	(Gy / source particle × 10^{-10})		
TEPC	O 400	2.3 ± 0.3	2.9 ± 0.3	2.7 ± 0.3
	Fe 300	47.0 ± 7.0	45.8 ± 4.6	43.3 ± 4.3
SEPC	O 400	2.1± 0.3	2.8 ± 0.3	2.7 ± 0.3
	Fe 300	44.4 ± 6.7	45.8 ± 4.6	42.3 ± 4.2

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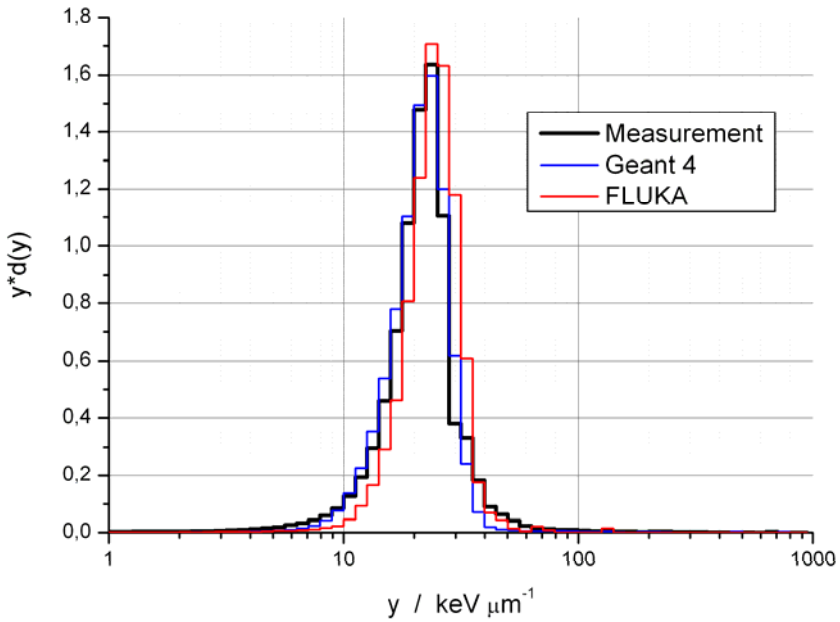
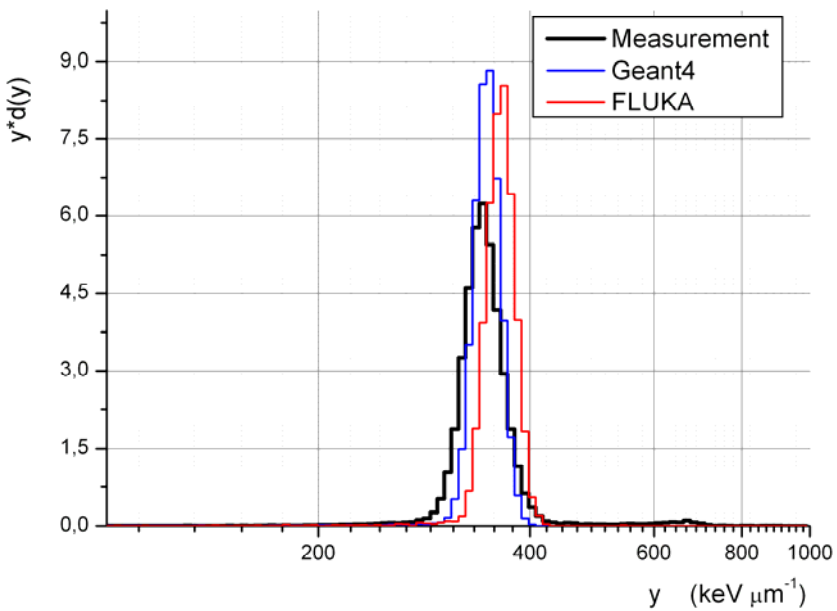
Microdosimetric absorbed dose spectra in *tissue* Measurements, FLUKA, GEANT4

Oxygen 400 MeV/u irradiation



Iron 300 MeV/u irradiation



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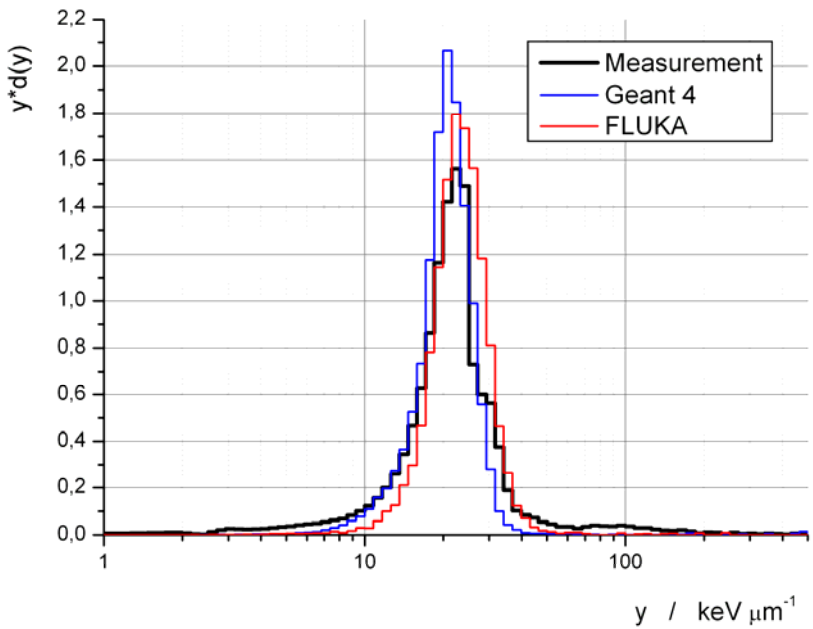
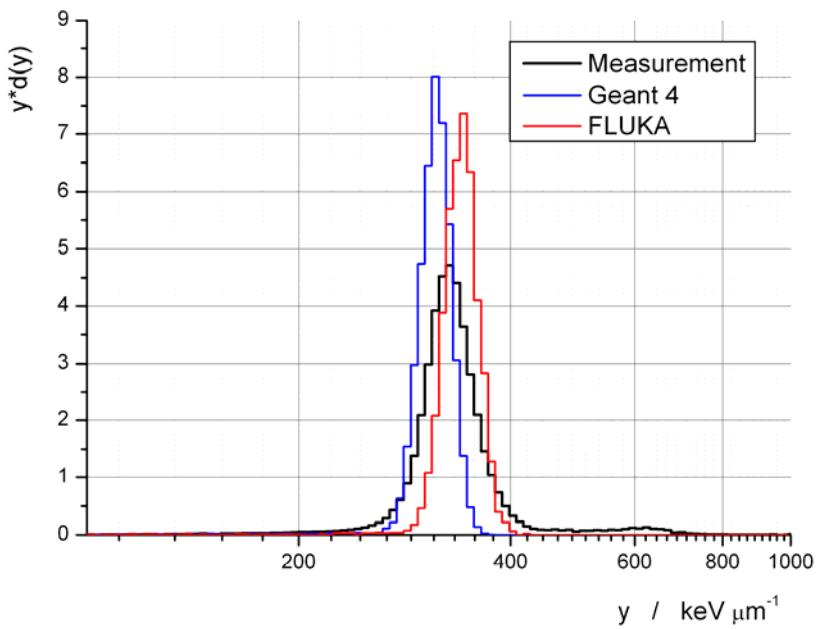
Microdosimetric absorbed dose spectra in *silicon* Measurements, FLUKA, GEANT4

Oxygen 400 MeV/u irradiation



Iron 300 MeV/u irradiation



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Ratios of Dose Mean Lineal Energy $\bar{y}_D$

Instrument	Beam (MeV/u)	FLUKA/Meas.	Geant 4/Meas.
TEPC	O 400	1.04 ± 0.16	0.97 ± 0.15
	Fe 300	1.05 ± 0.16	1.00 ± 0.15
SEPC	O 400	0.89 ± 0.13	1.22± 0.18
	Fe 300	1.01 ± 0.15	0.93± 0.14

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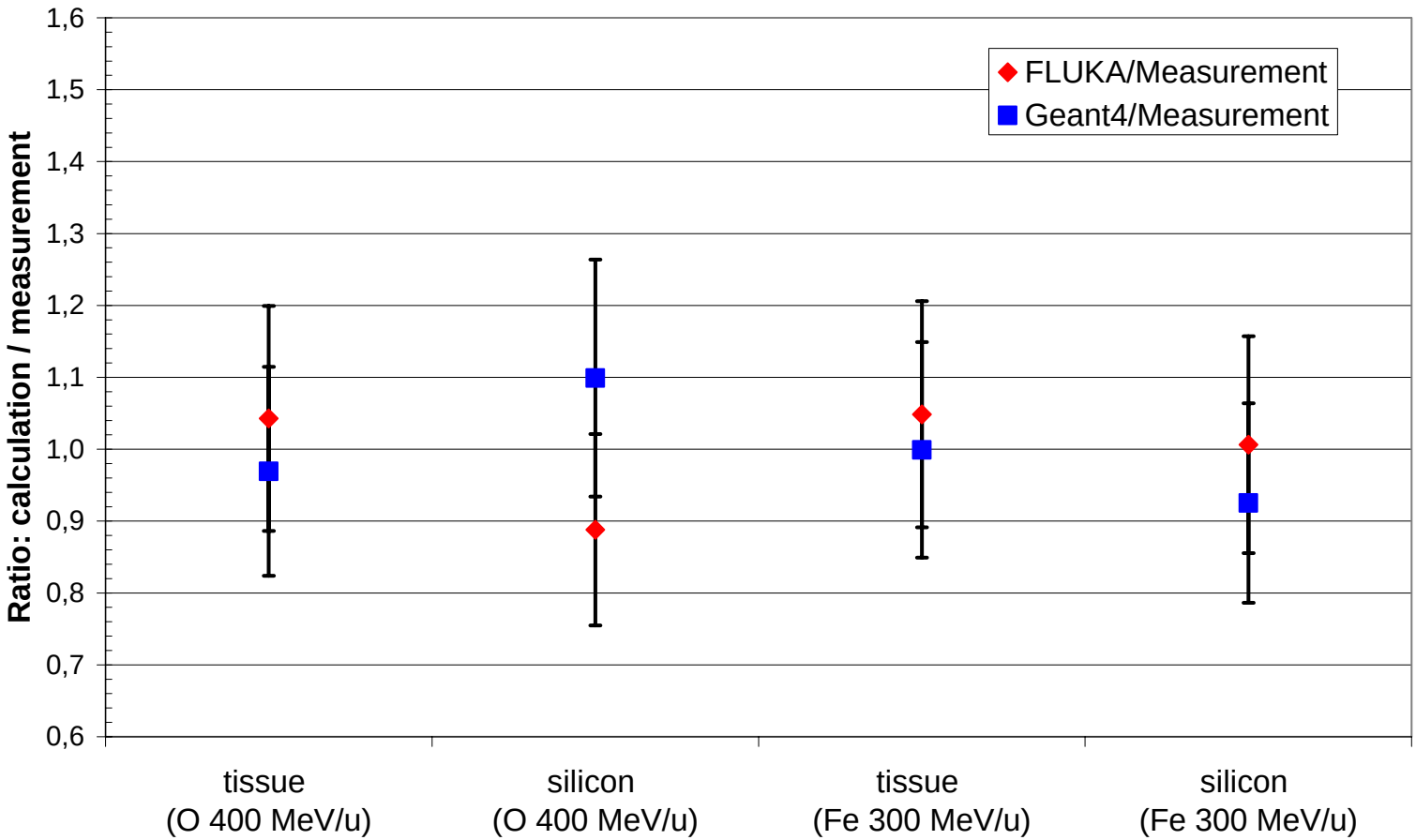
Ratios of dose mean lineal energy $\bar{y}_D$



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Conclusions

- Successful modelling of heavy ion irradiation experiments with
  - FLUKA
  - GEANT4
- Successful simulation of 2µm sizes silicon & tissue
- Ration of calculated and measured total absorbed dose between 1.3 and 0.92 (mean over all measurements 1.1).
- Agreement calculated and measured dose mean lineal energy within 10%.
- FLUKA and GEANT4 calculations agree within 5-10%

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