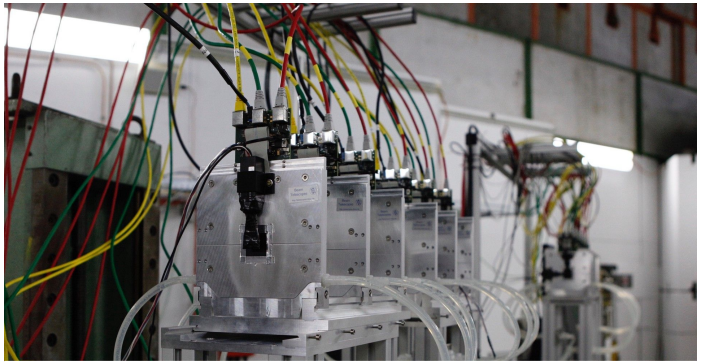
A New High Rate Electron Beamline at DESY II

Dohun Kim

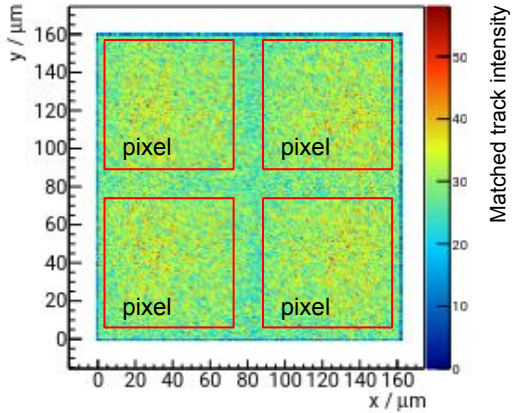
DPG Session T 94.7
Mar. 24. 2022

Testbeam

- Testbeam
  - To verify the performance of sensors or devices using high energetic particle beam
  - Tracking using beam telescope
    - Enable to distinguish particle and noise
- Pixel sensor study as an example
    - Tracking efficiency & timing
    - Charge deposition
    - Charge sharing & cross-talk
    - etc.
- A lot of tracks are required for precise measurement
  - E.g. Efficiency in a single-pixel



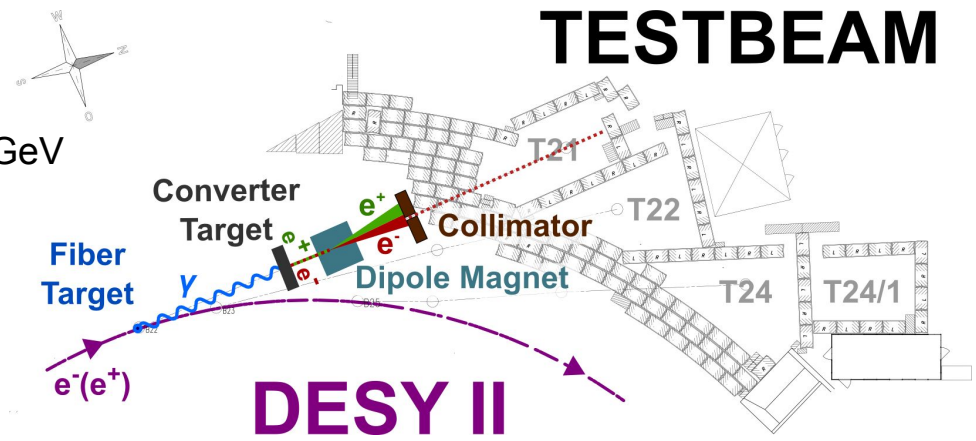
MIMOSA Telescope at one of DESY Testbeam areas



A High Rate Testbeam Data Acquisition System and Characterization of High Voltage Monolithic Active Pixel Sensors

The DESY II Testbeam Facility

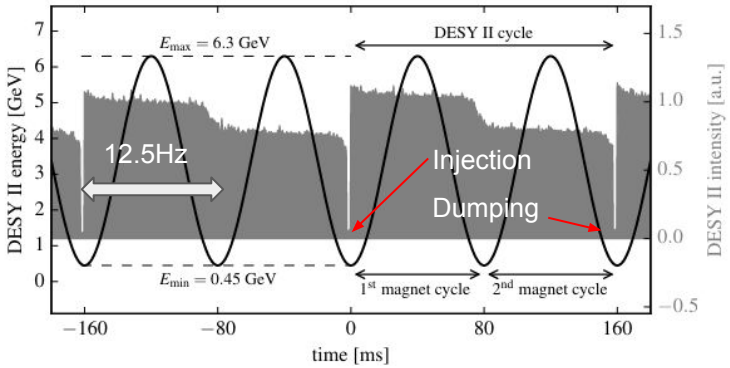
- DESY provides three testbeam lines (T21, T22 and T24) with single electrons
- Beam is generated by two targets
- Enables choice of momentum between 1 and 6 GeV
- Limits rate to a few 10 kHz
- Why to require high rate beam?
  - A lot of tracks for precise measurement
  - To irradiate sensors
  - To verify readout performances of sensors with high rate beam
    - E.g. beam monitor, beam counter
- How to increase the rate?

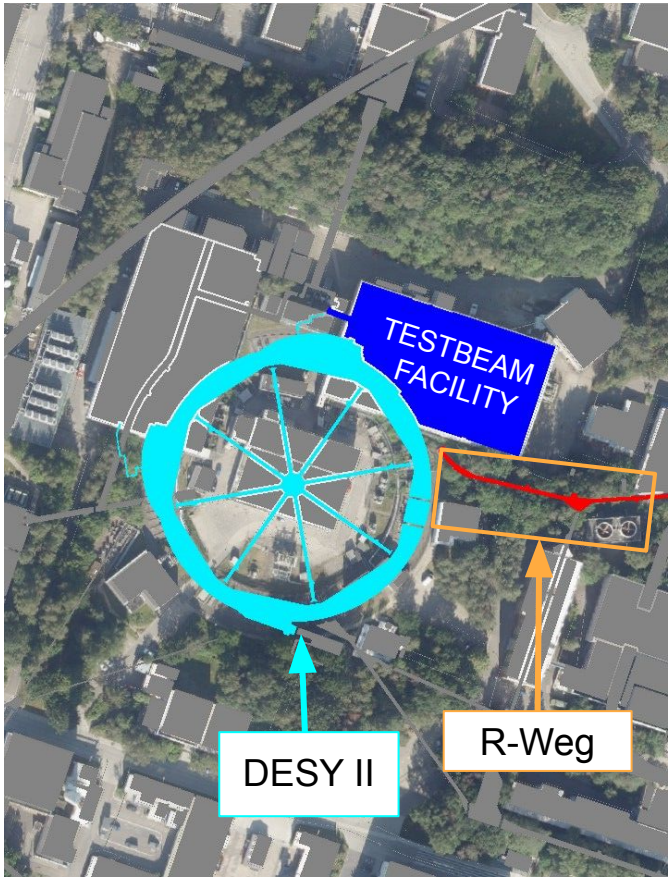


arXiv:1807.09328v2

The R-Weg

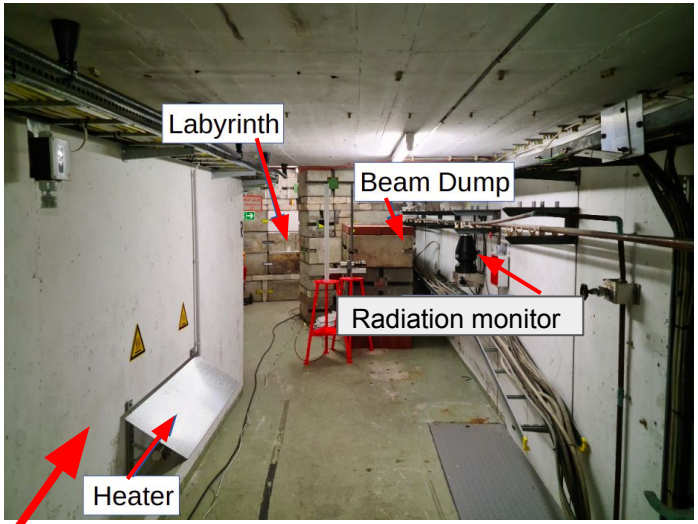
- Former transfer beamline from DESY II to DORIS
- Beam is transferred to PETRA or
- dumped after 2nd magnet cycle in DESY II
- Feasibility studies in order to test usability as a new test beam line with high rates
- Installation of equipment in 2021

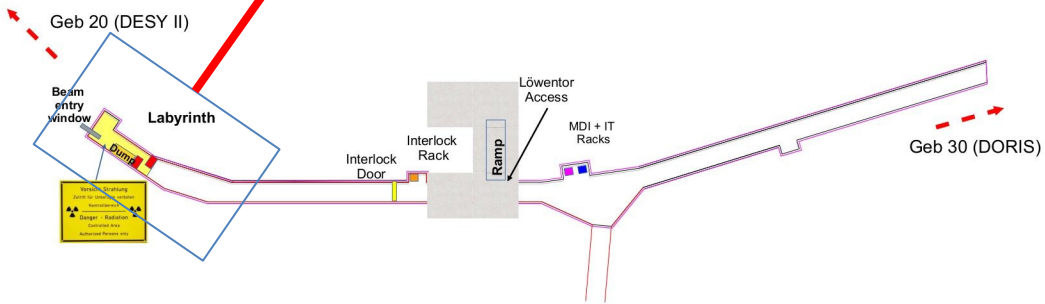




Installed Instrumentation

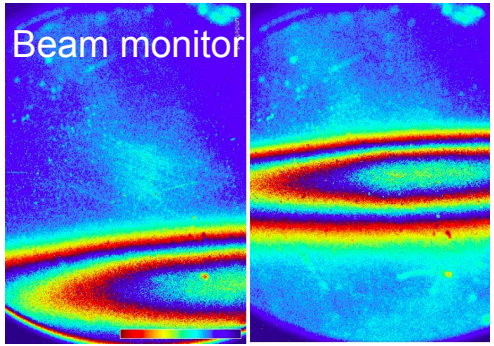
- Radiation safety calibrations
  - Interlock door is located far from beam dump
  - Heater removes humidity
  - Labyrinth with two walls
  - Radiation monitors

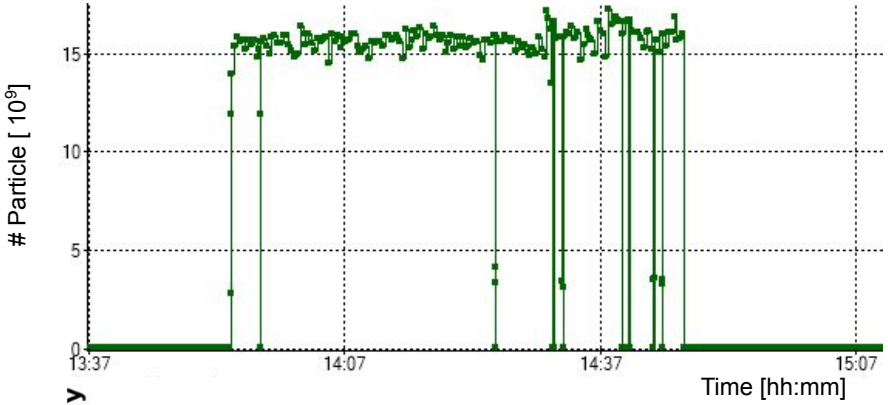


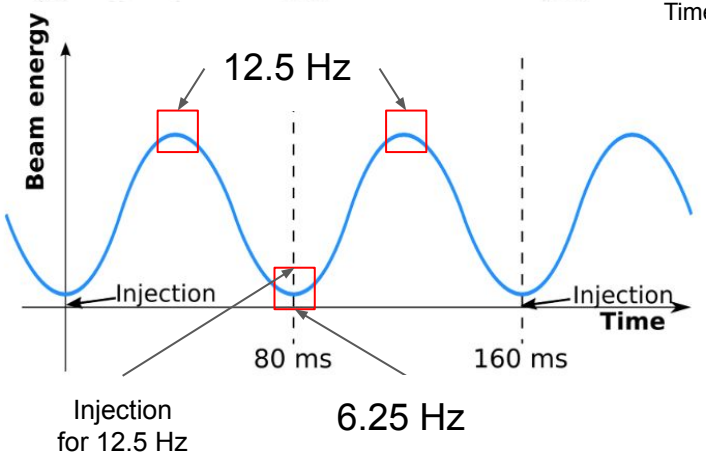


Beam Operation at the R-Weg

- # Particles
  - Min. : 1x10^{8} e / bunch
  - Max. : 3x10^{10} e / bunch
- Bunch length < 100 ps
- Rate of extraction : 6.25 Hz or 12.5 Hz
  - Current : 6.25 Hz
  - Concerns of stability for 12.5 Hz
- Energy of beam between 0.45 GeV and 6.3 GeV
- Current beam shape and beam position are unstable

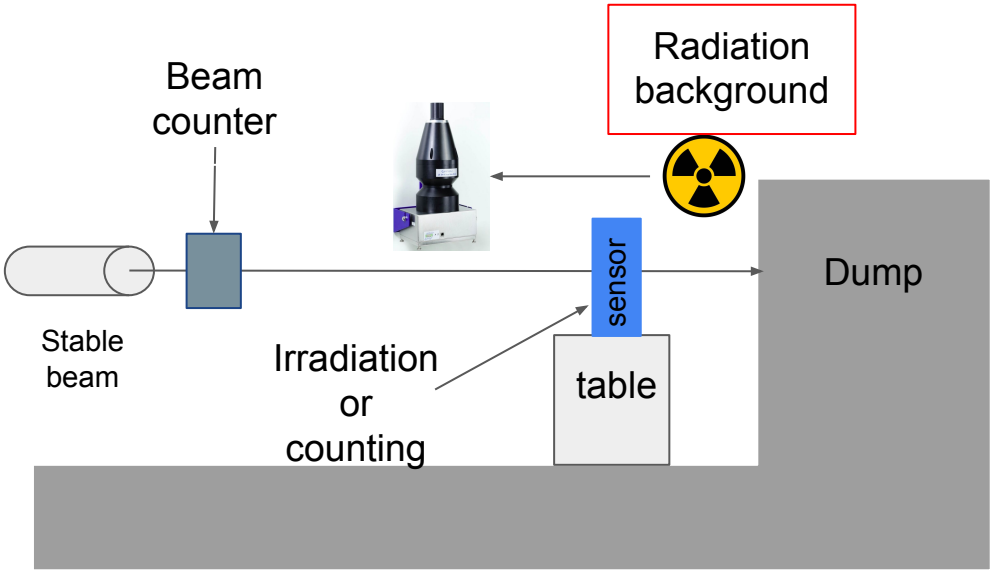






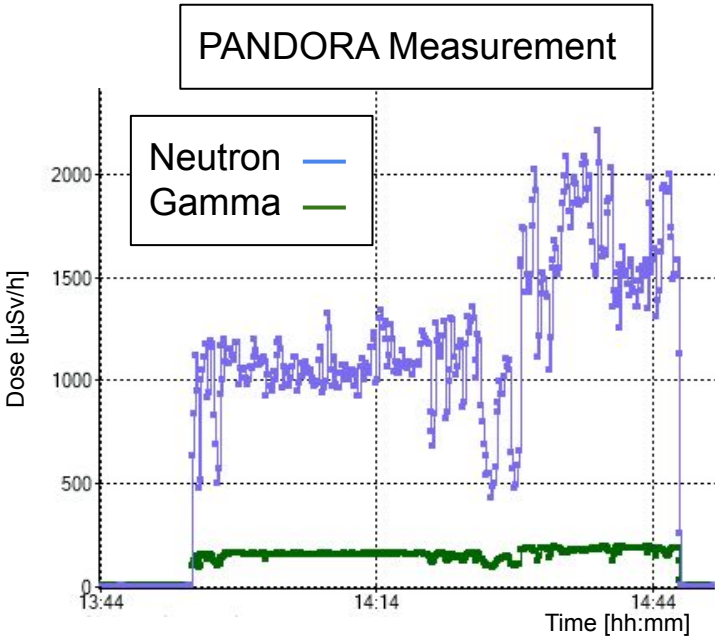
How to transform the R-Weg from an expert into a user facility?

- Precise references for
  - Radiation backgrounds
  - Beam stability
  - Electron dose over time
  - Beam counter



Radiation

- Radiation background
  - How many neutrons and gammas
    - Resonance of photonuclear reaction
    - Mostly from beam dump
  - Measurement
    - Radiation monitor : PANDORA
- PANDORA
  - Scintillator
    - Gamma > 50 keV
    - Low energetic neutron < 20 MeV
  - Moderated ^{3}He tube
    - High energetic neutron > 20 MeV
- Simulation : FLUKA



Time structure / Type of radiation	Continuous Total response, no pileup	Burst Delayed response only
High energy neutrons > 20 MeV	Scintillator: H(n,n)H → recoil protons	Scintillator: $^{12}C(n,p)^{12}B \rightarrow {}^{12}C + \beta + \nu$
Low energy neutrons < 20 MeV	Moderated ^{3}He – tube: $^{3}He(n,p)^{3}T$	Moderated ^{3}He – tube: $^{3}He(n,p)^{3}T$ delayed by TOF

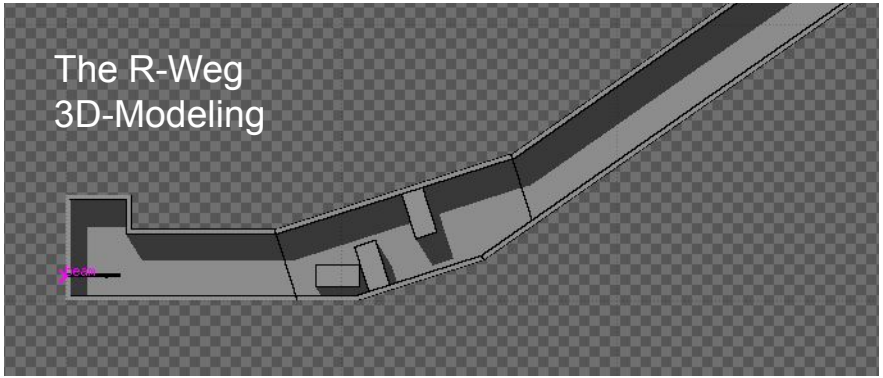
Table 1 – Overview of the LB 6419 responses due to neutron radiation.

Nuclear Science Symposium Conference Record, 2007.
Volume: 3, Pages: 1982 - 1983

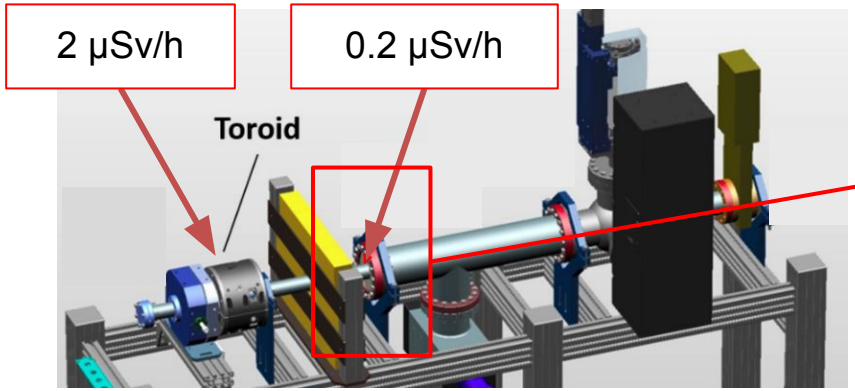
Simulating the R-Weg

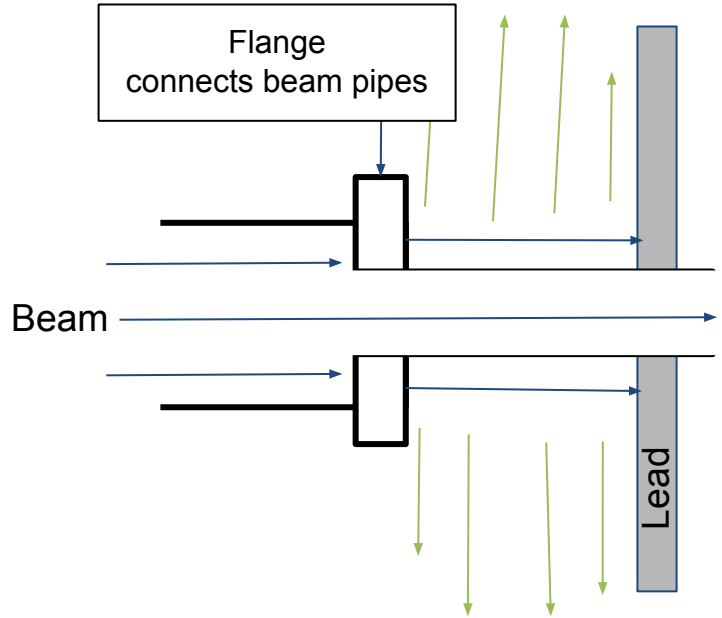
https://fluka.cern

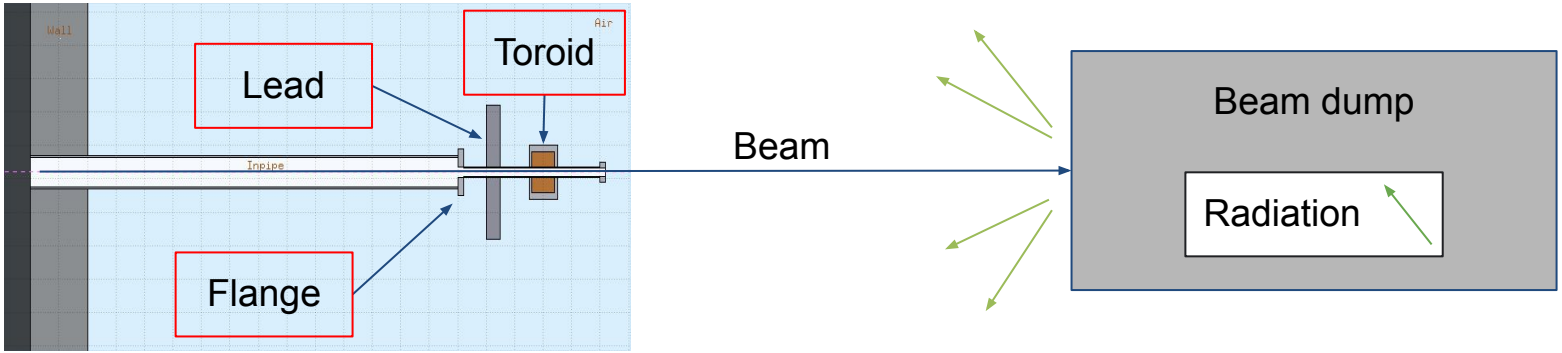
- MC framework for the interaction and transport of particles in materials
  - Based on card system
  - Photon interactions > 100eV
  - Electron interactions > 1 keV
  - Thermal and high energy neutron interaction
- Using FLUKA
  - Radiation protection to measure dose
  - Magnetic field to study beam stability
  - Radiation damage to estimate irradiation



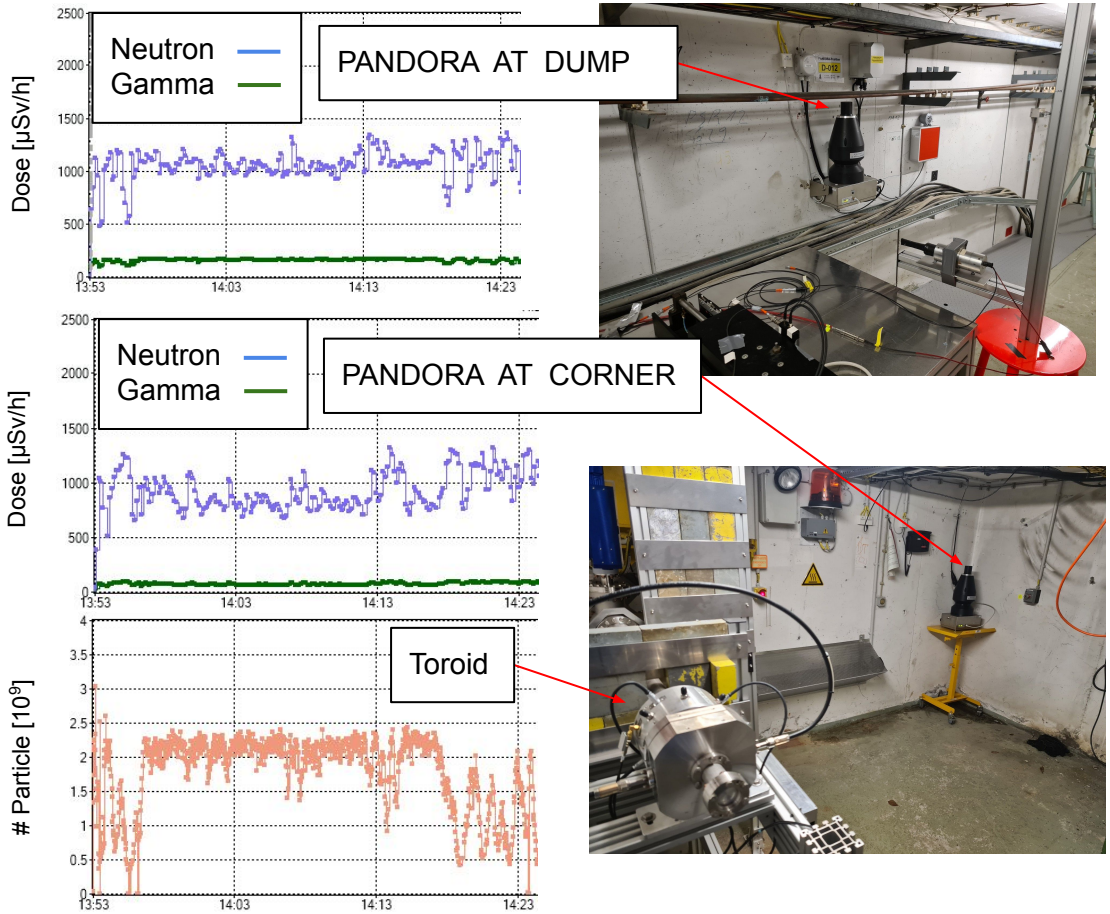
Simulated Beam Line







Compare to Doses During Beam Time



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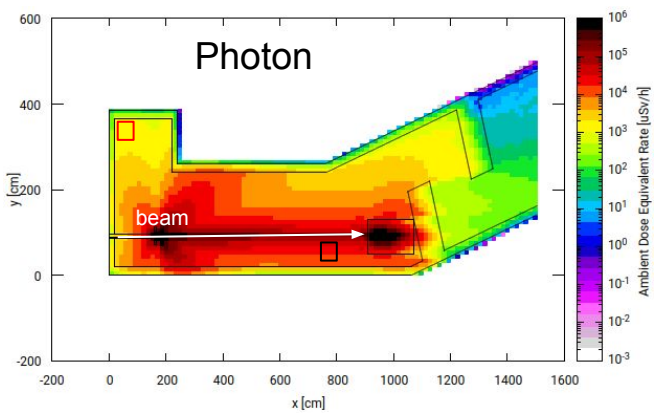

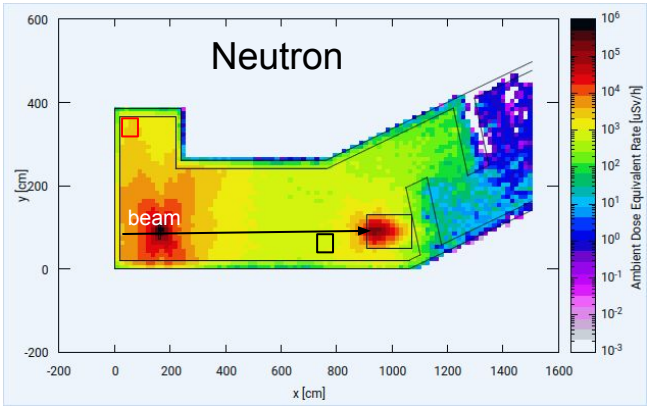

		□At the corner	□At the Dump
Simulated Dose [μSv/h]	Photon	880 ± 20	10250± 50
	Neutron	1750 ± 100	900 ± 100
Measured Dose [μSv/h]	Photon	~70	~160
	Neutron	~800	~1000

Summary

- R-Weg provides a high rate e-beam
  - High potential utility
  - Precise measurement & irradiation campaign
  - Ongoing study of radiation & beam stability
    - FLUKA simulation

- Simulation & measurement
  - Simulation results in an overestimation of photons
    - Working in progress
  - A lot of neutron at the corner

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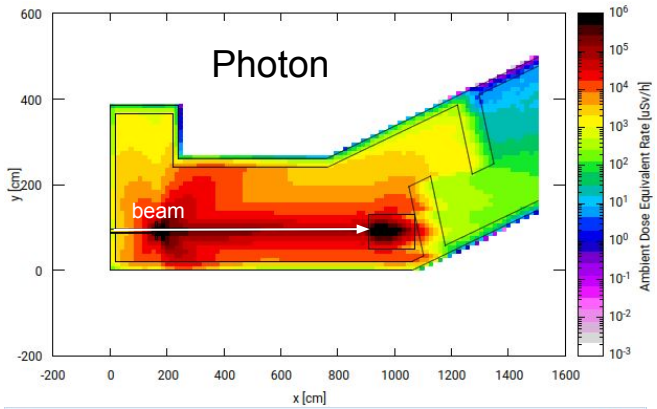
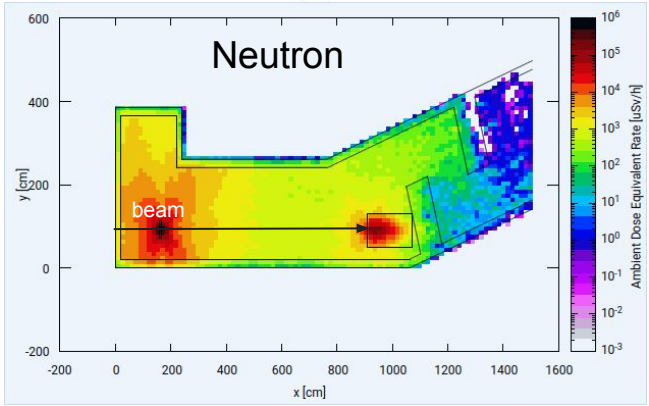
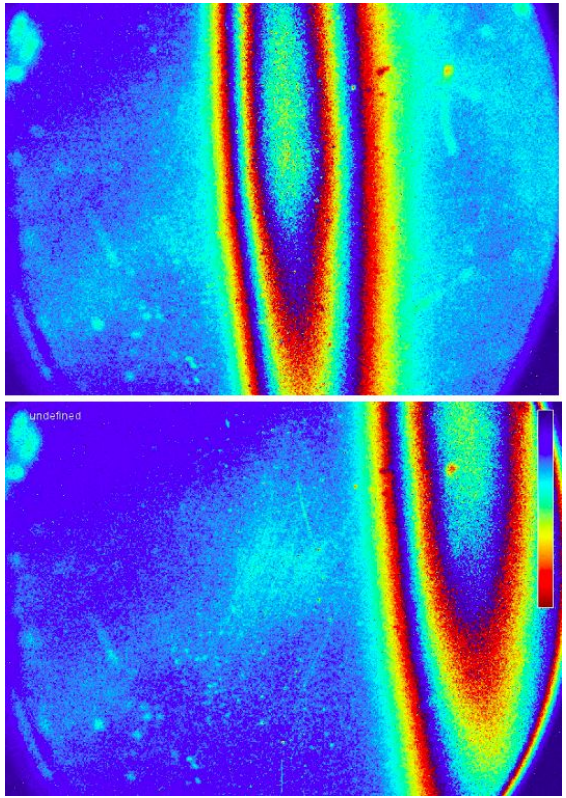




Backup

Beam Stability

- Beam stability
  - Fluctuation of mains frequency
    which synchronizes Magnetsystem
    - Fluctuation in the beam position
    - Deformation of the beam shape
  - Beam structure
  - Avoid impact on normal operation stability
  - Beam only for a few hours per day currently



Idea

- **Uncertainty of angle**

$$B[T] = \frac{E[GeV]}{0.3L[m]} = \frac{E}{0.3S}\theta \rightarrow \frac{\Delta\theta}{\theta} = \frac{\Delta E}{E}$$

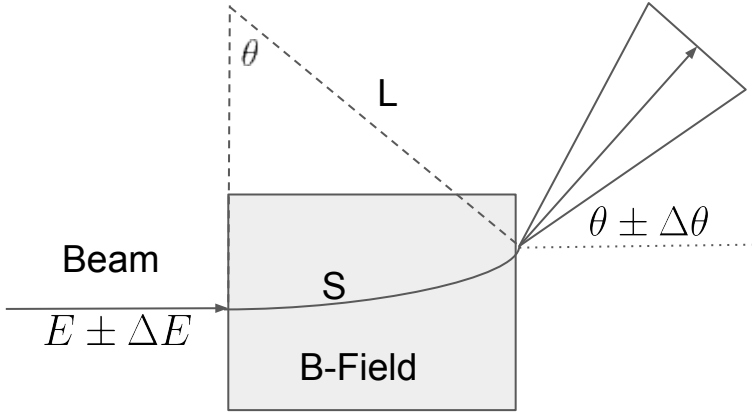
- **Uncertainty of extraction time and energy**

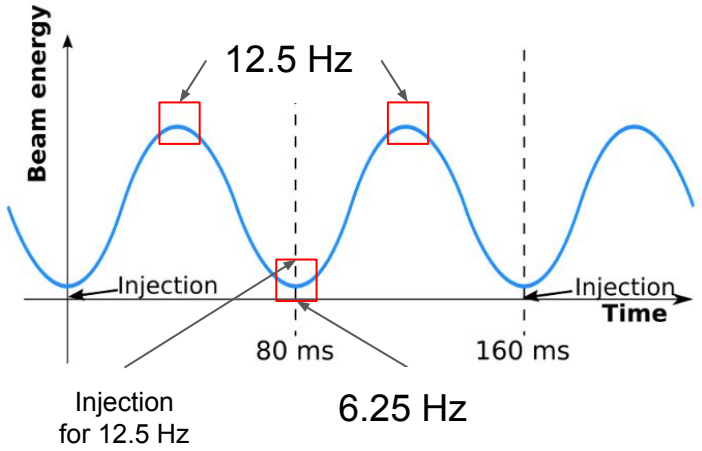
$$E(t) = Asin(2\pi f_{inj} t) + B$$

Where A, B are constant and f_{inj} is injection frequency

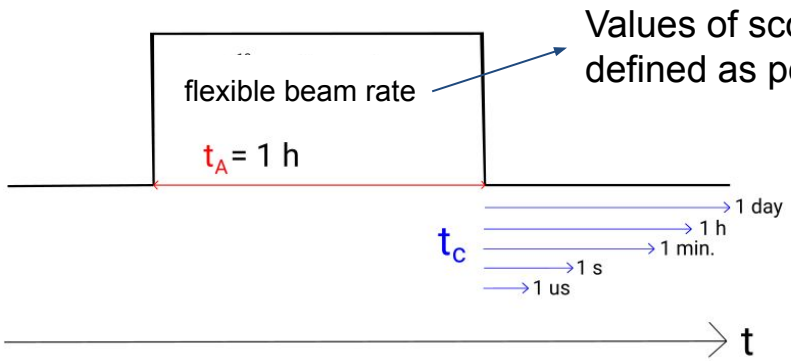
$$t_{ex} = \frac{N}{f_{net}} \rightarrow \frac{\Delta t_{ex}}{t_{ex}} = \frac{\Delta f_{net}}{f_{net}}$$ where N is cycle of magnet per sec.

$$\Delta[sin(x)] = sin(x + \Delta x) - sin(x)$$

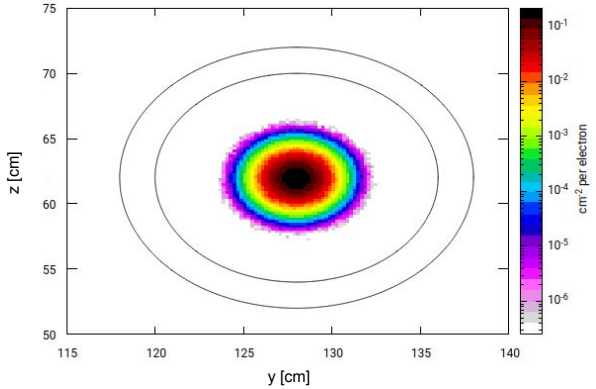


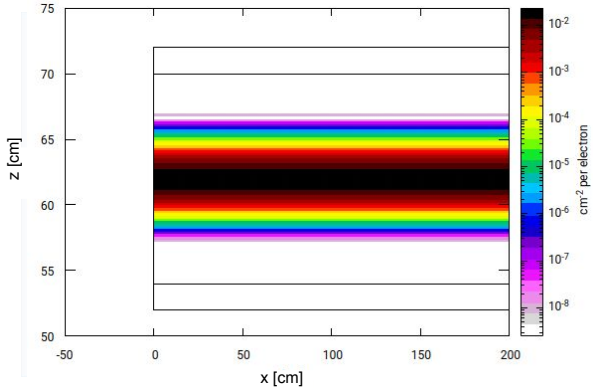


Beam-Parameters

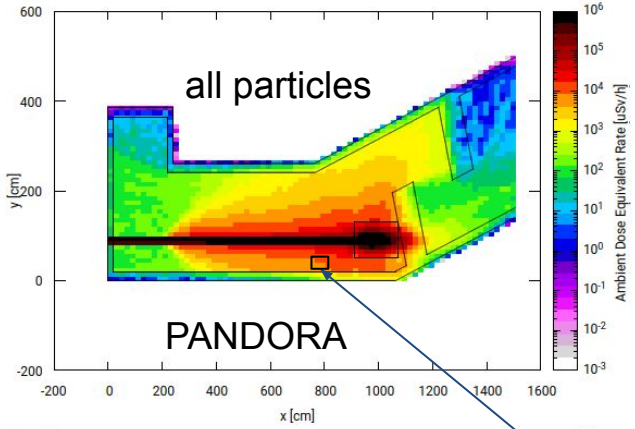


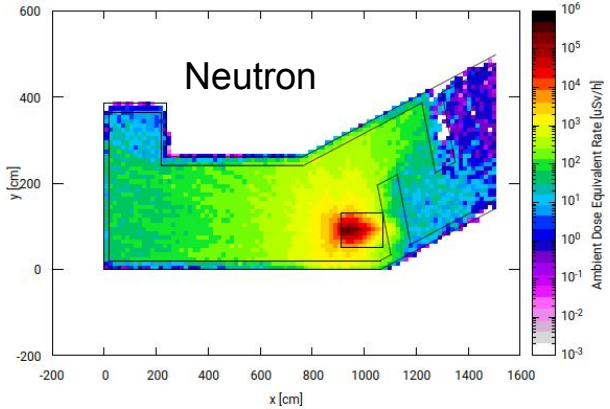
- Electron-Beam
- Energy : 500 MeV
- Gaussian Distribution
  - FWHM in x-, y-axis : 2cm
- Beam times : 1 h
- Several different cooling times

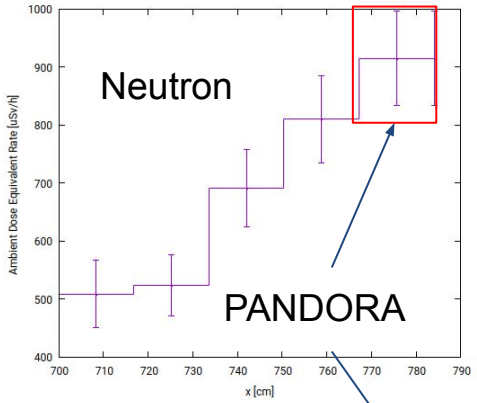


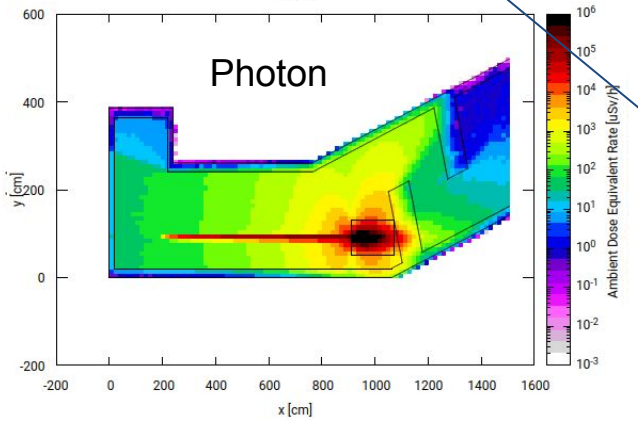


Compare to Doses during Beam time

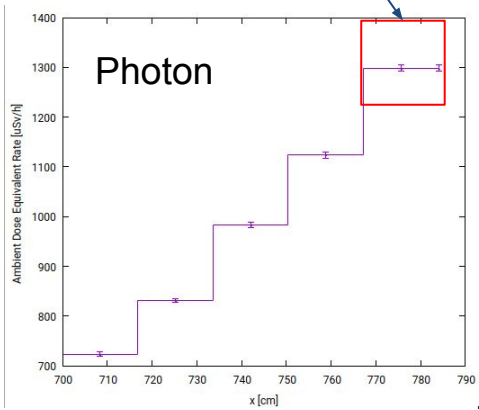








- The mean of dose
  - between z = 120cm and z = 140cm
- Measured dose from PANDORA (07.02.2021)
  - Photon ~ 160 uSv/h
  - Neutron ~1000 uSv/h
- Simulated dose
  - Photon : 1300 ± 20 uSv/h
  - Neutron : 900 ± 100 uSv/h



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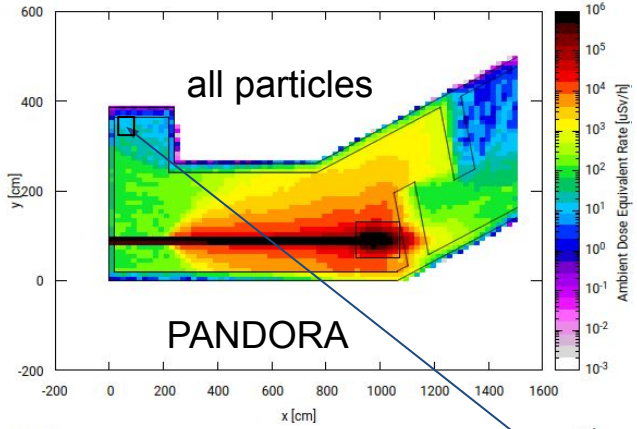
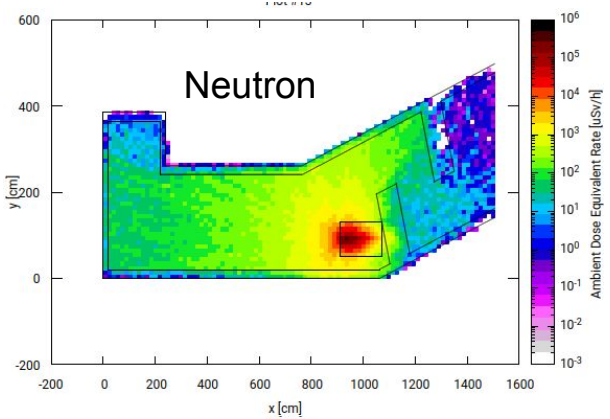
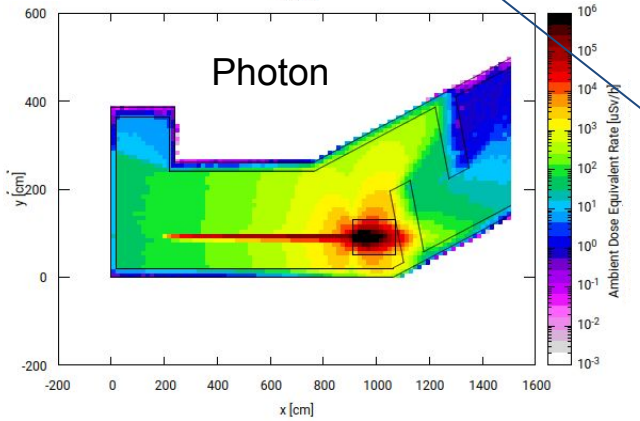


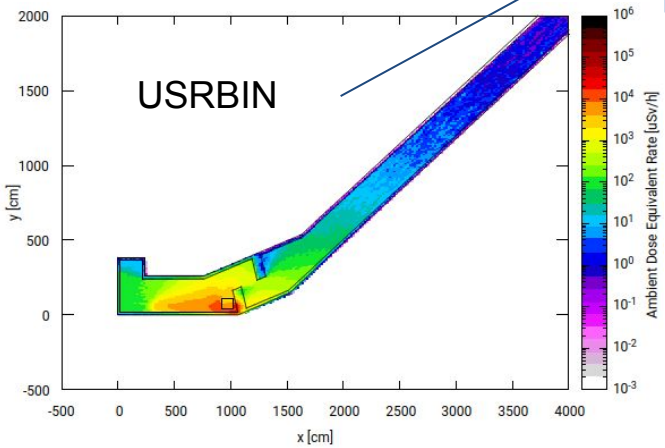




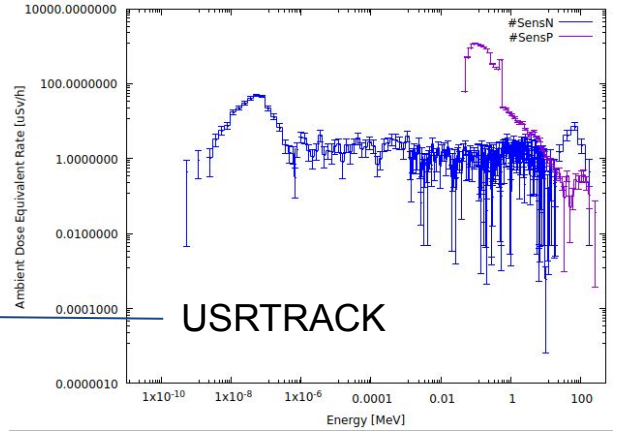
- The mean of dose
  - between z = 120cm and z = 140cm
- Measured dose from PANDORA at the corner (07.02.2021)
  - Photon ~ 70 uSv/h
  - Neutron ~ 800 uSv/h
- Simulated dose
  - Photon : 6 ± 0.5 uSv/h
  - Neutron : 12 ± 10 uSv/h

Extracting the Dose

- Total fluence
- Small bin size (21-24)
- (x,y,z) and Dose



- Differential fluence
- Large bin size (30-35)
- Energy and Dose



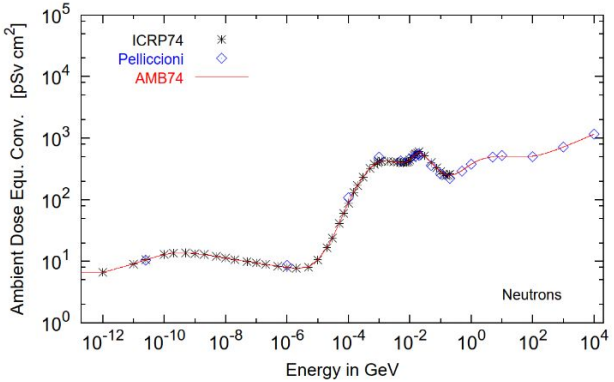
Definition of PANDORA in GEO & Sensitivity of PANDORA

- Distance between Dump & PANDORA
  - ~1.6m
- Volume
  - 10^3 cm^2
- Defined material in FLUKA
  - Air
  - Possible : scintillator

Simulated how many Particles with which energy pass through this volume

Using convert factor
the ambient dose is calculated

Using python code:
sensitivity * ambient dose
= expected ambient dose from PANDORA



[A FLUKA user-routine converting fluence into effective dose and ambient dose equivalent]

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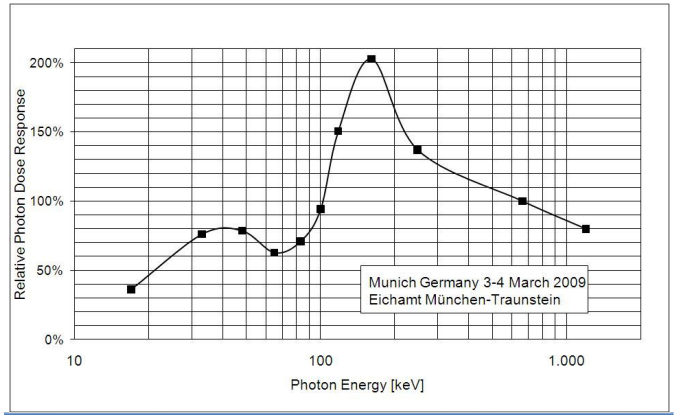
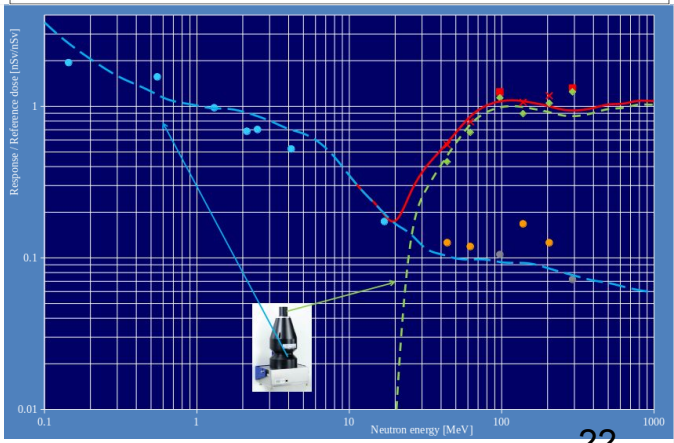
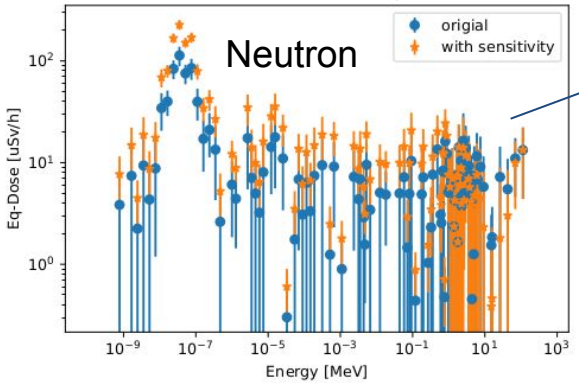




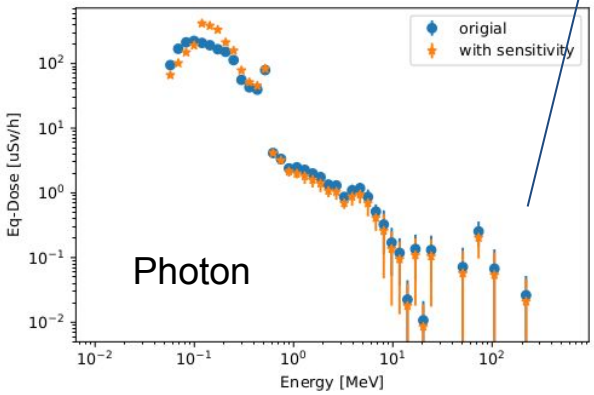
Energy vs Ambient Dose & Sensitivity

At the dump



Original simulated Dose : 1098.9 uSv/h
Corrected Dose : 1884.7 uSv/h
Error : 76.5 uSv/h

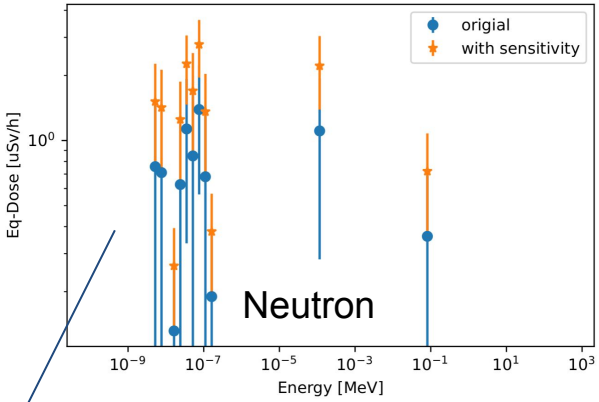
Original simulated Dose :1775.2 uSv/h
Corrected Dose :2291.1 uSv/h
Error :10.6 uSv/h

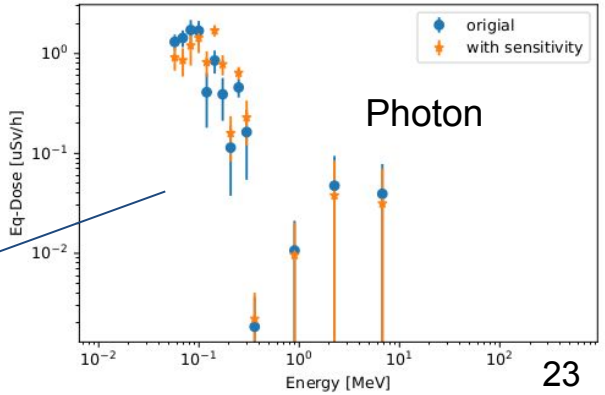


Original simulated Dose : 7.9 uSv/h
Corrected Dose : 15.9 uSv/h
Error : 2.2 uSv/h

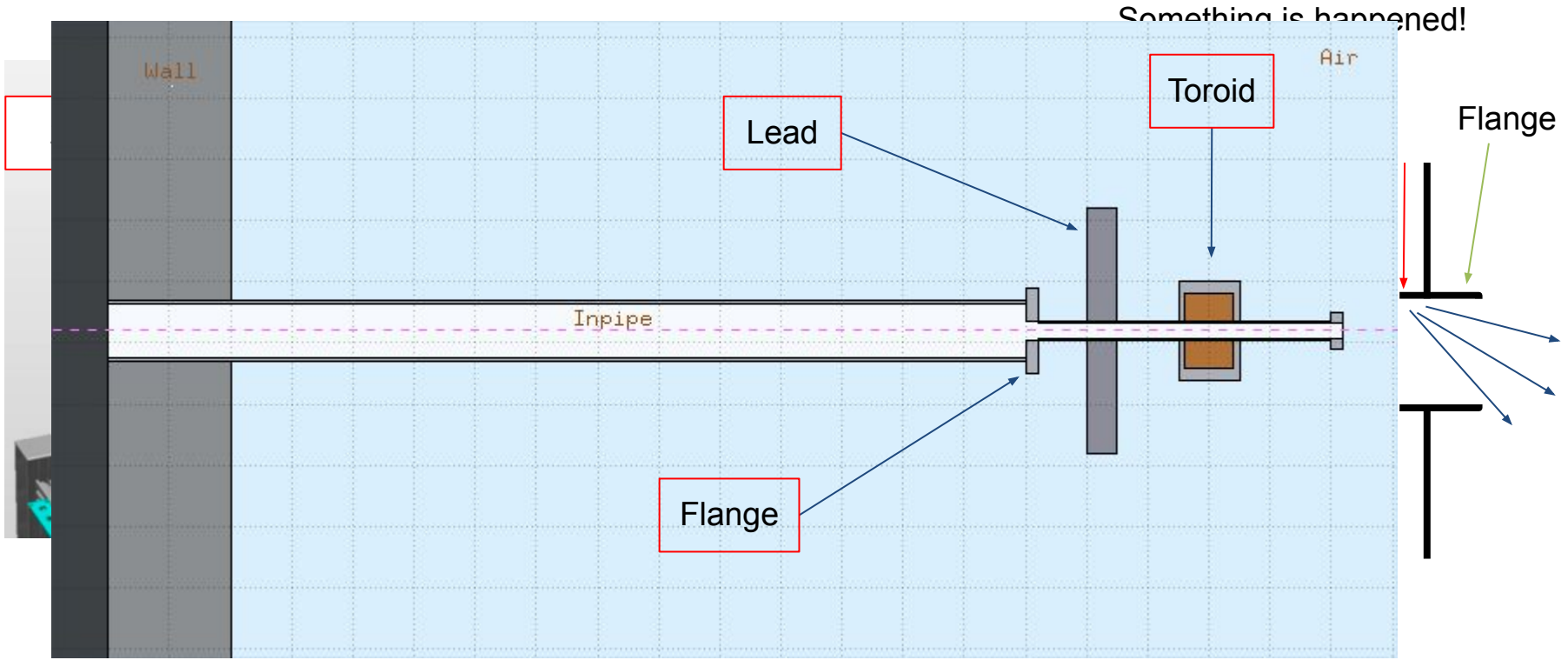
Original simulated Dose : 8.6 uSv/h
Corrected Dose : 8.8 uSv/h
Error : 0.8 uSv/h

At the corner



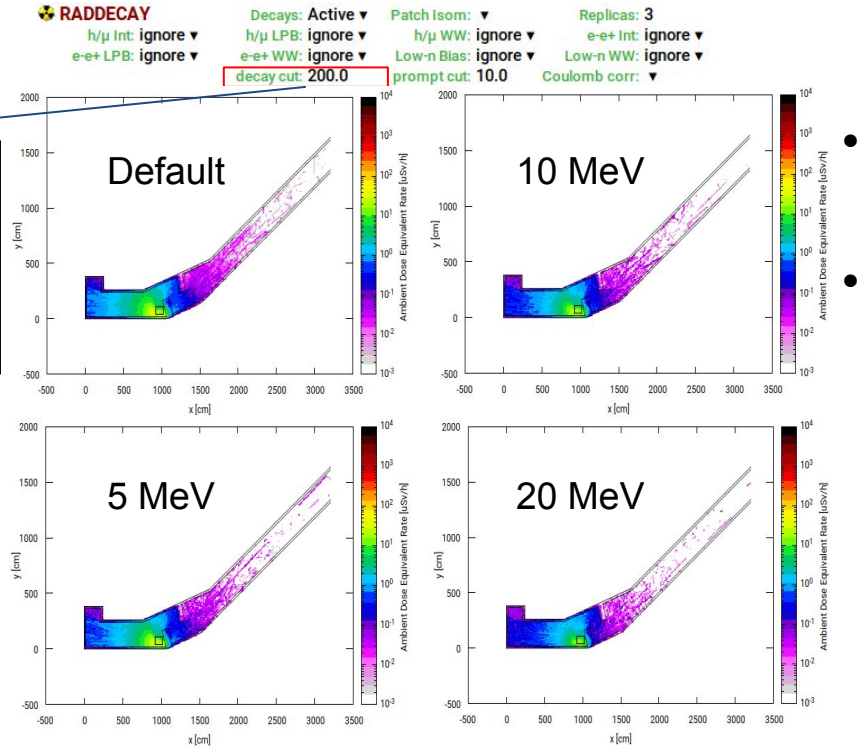


Beam Line in FLAIR



Decay Cut for Residual Decay

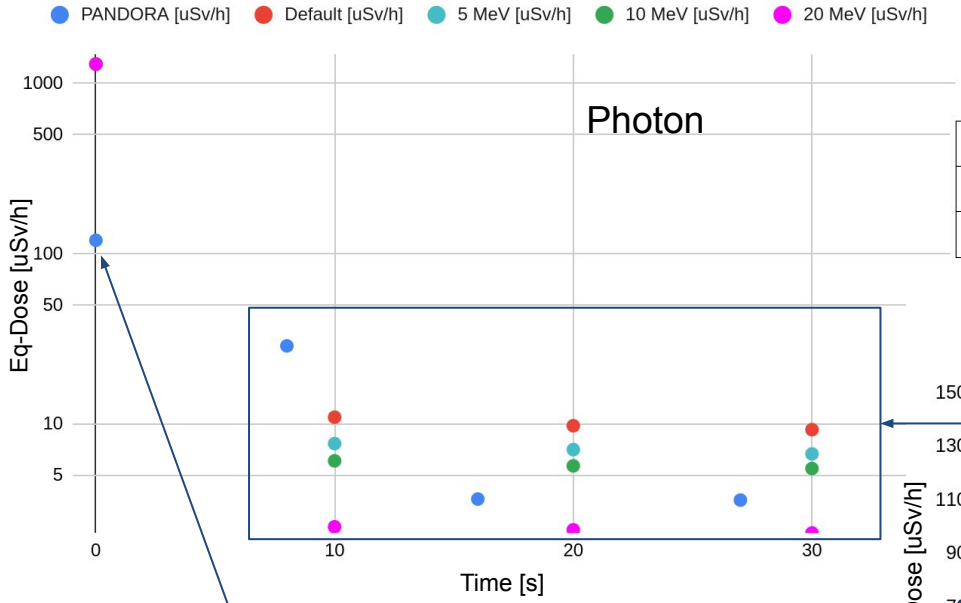
Cut energy of Residual Decay
1. Default : 1 MeV
2. 5 MeV
3. 10 MeV
4. 20 MeV



t_c = 10s

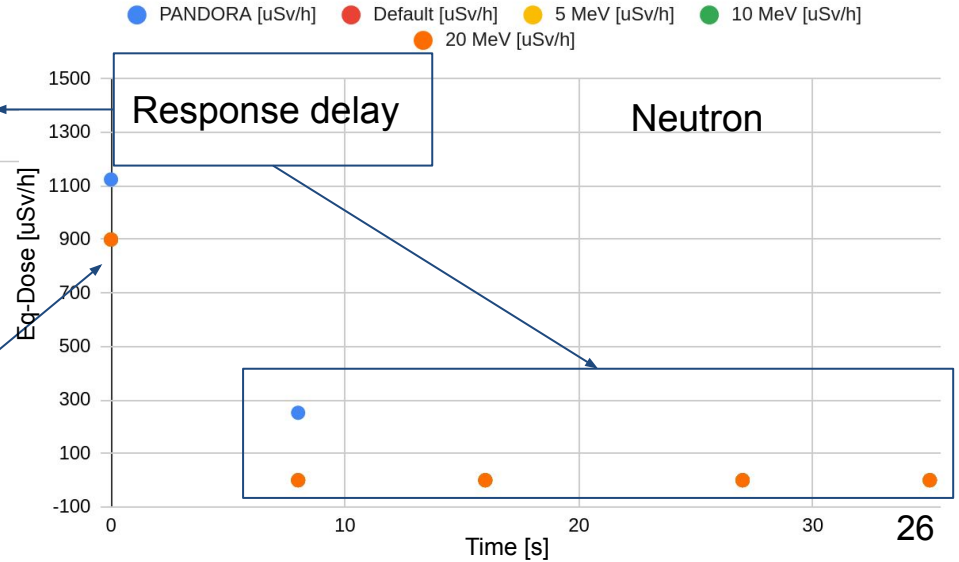
- Several different values of decay cut
  - Generated number of photons by the high value of decay cu are smaller
- Neutrons disappear immediately afte extraction stops beam

Compared Doses During Cooling Down



Type of radiation \ Time structure	Continuous Total response, no pileup	Burst Delayed response only
High energy neutrons > 20 MeV	Scintillator: H(n,n)H → recoil protons	Scintillator: $^{12}C(n,p)^{12}B \rightarrow {}^{12}C + \beta + \nu$
Low energy neutrons < 20 MeV	Moderated ^{3}He – tube: $^{3}He(n,p)^{3}T$	Moderated ^{3}He – tube: $^{3}He(n,p)^{3}T$ delayed by TOF

Table 1 – Overview of the LB 6419 responses due to neutron radiation.



Beam off after this time