Muon radiations at ILC main beam dump

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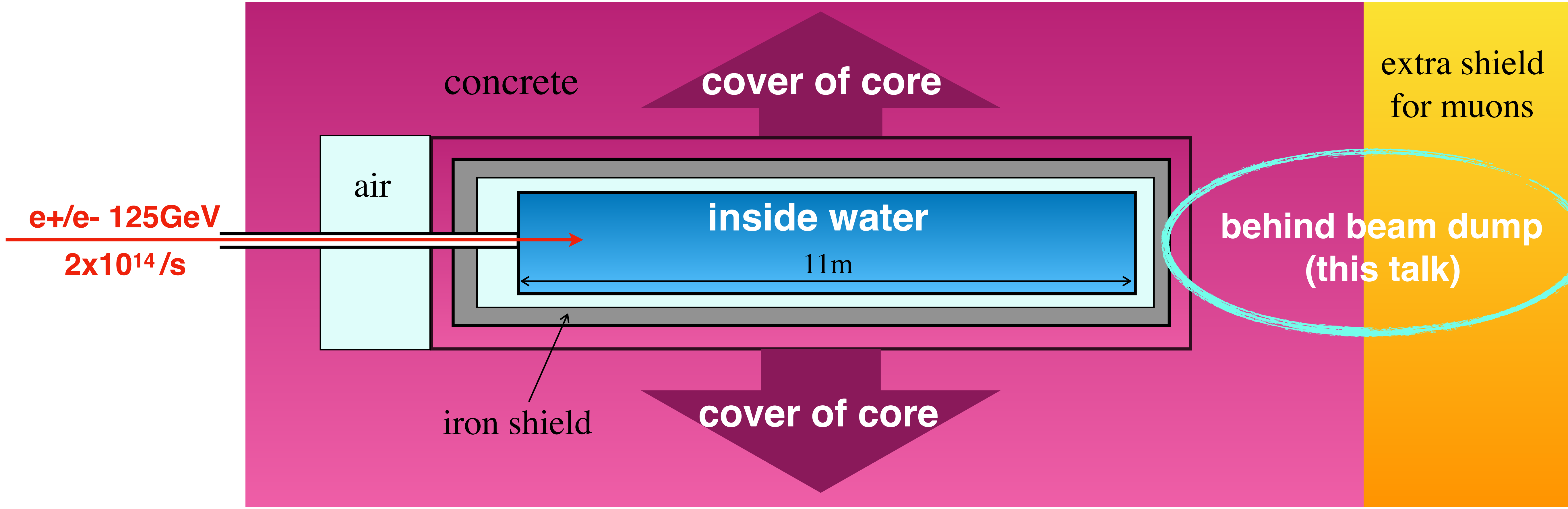
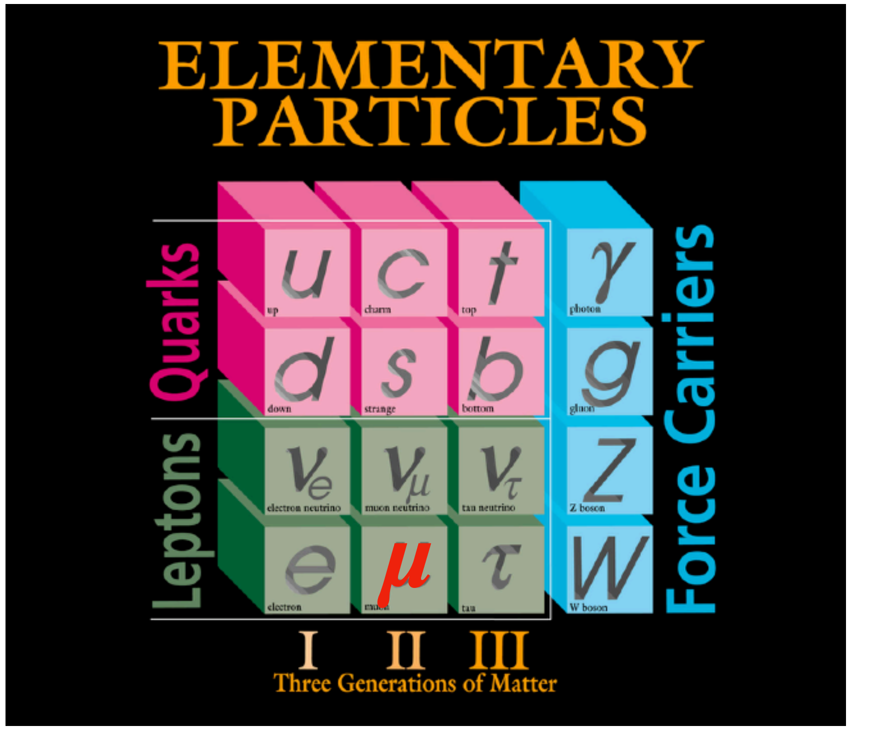
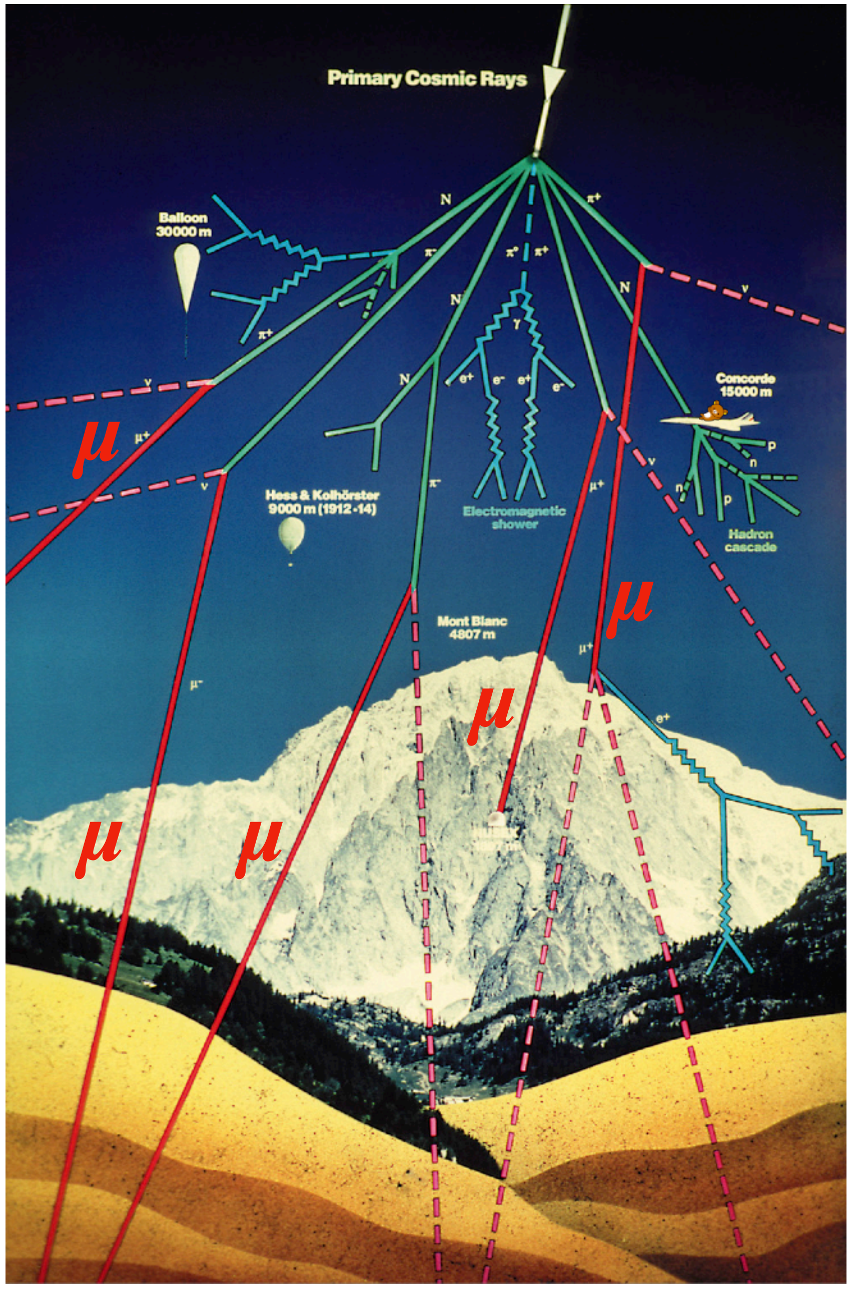
Introduction



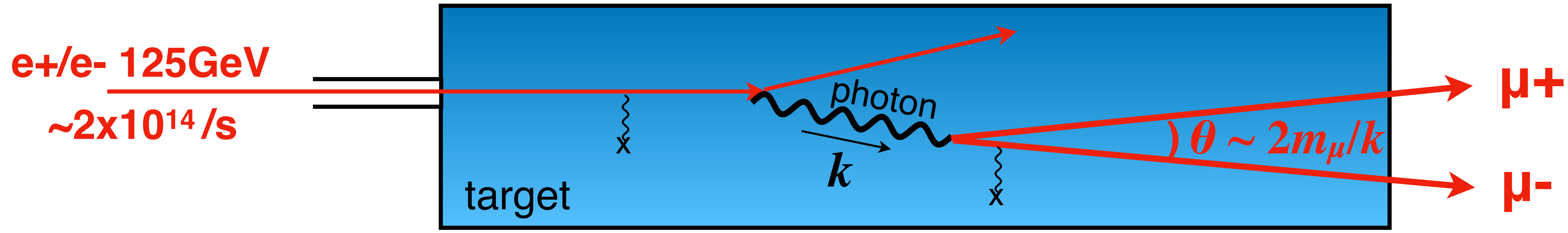
- Recent study related to muons produced behind ILC main beam dump
- 2 $\times 10^{14}$/s electrons with 125 GeV dive into main beam dumps
- Part of the energy is used for the production of radio-nuclides
  - **Inside water**: The biggest issue. How to deal with 100TBq Tritium and heat safely (well known and studied)
  - **Cover of core**: Thickness of concrete. Scattered fast neutrons and thermalized one produce large number of nuclides (see Yu's and Nobuhiro's talks)
  - **Behind beam dump**: Topic in this talk. Almost 100% phenomenon is due to **muon**

- <u>Muon</u> is a copy of electron, feel electromagnetic and weak force but not strong force
- 200 times heavier than electron ($m_\mu = 106\mathrm{MeV}$)
- Only the mass difference induces followings:
  - Charged pion mostly decays into muon, not electron
  - Photon mostly decays into electron pair, not muon pair
- It seems that muon radiation make problems at only "hadron" accelerators in which a ton of pions are produced
- However, we cannot ignore muon radiation at ILC since most of the beams are not stored in rings and discarded in dumps → A lot of chances to produce muons

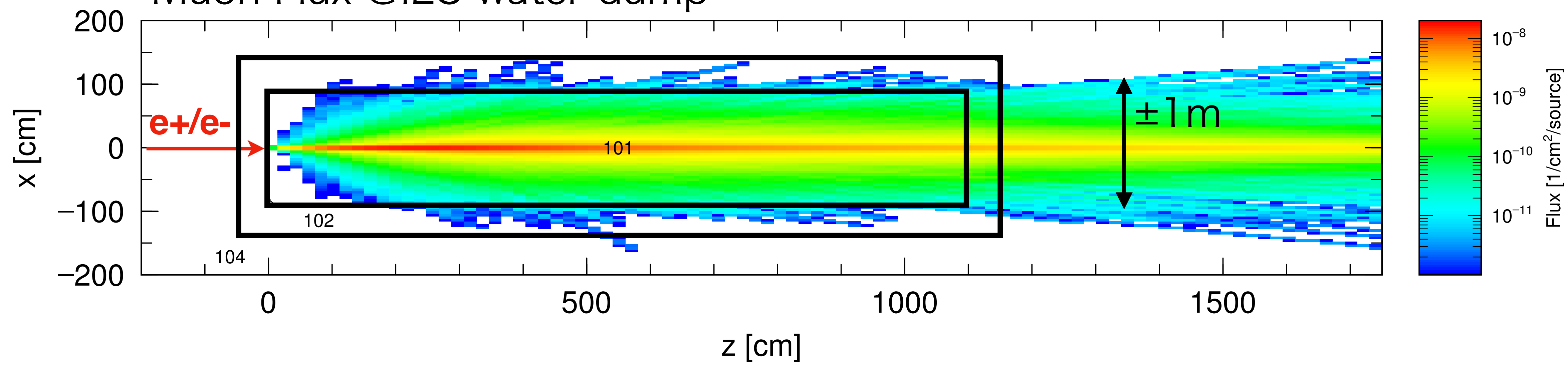




Muon production at electron accelerators

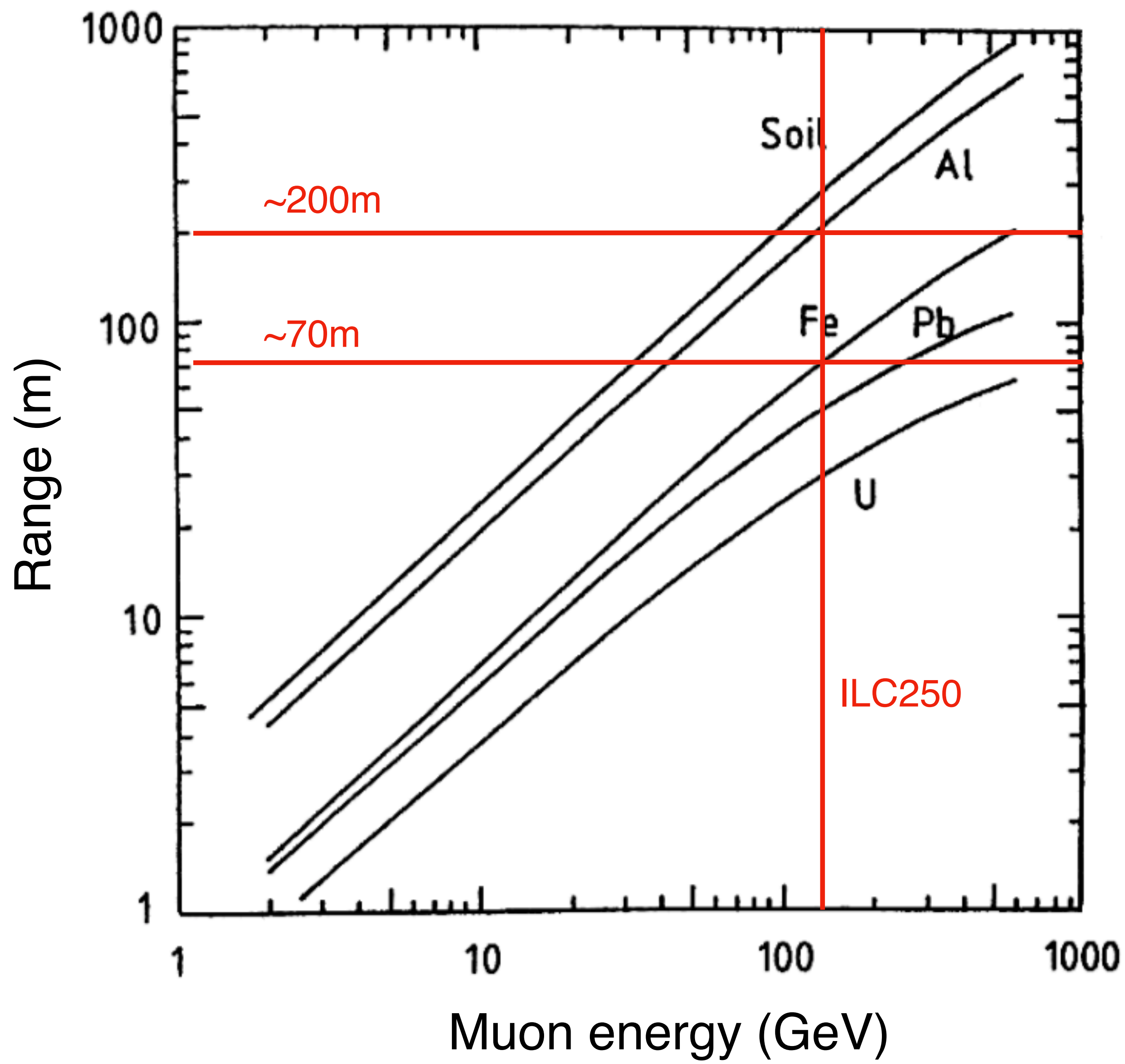


Muon Flux @ILC water dump



- Muons are mainly produced by pair production via bremsstrahlung in target
- extremely forward direction: $\theta \sim m_\mu / k$
- smaller cross section: $\sigma(\mu\mu) \sim \sigma(ee)/40000 \sim 0.1\, Z^2\, \mu\mathrm{b}$
  - 10^(10-11) muons/s (ILC, E_{max}~100GeV)
  - 10^(6-7) muons/s (J-PARC. MLF)
  - 10^(10-11) muons/s (J-PARC. Neutrino Experimental Facility, E_{max}~20GeV)

Range of muon



Muon mainly lose energy by ionization loss

$\rho(Al) = 2.7\ g/cm^3$

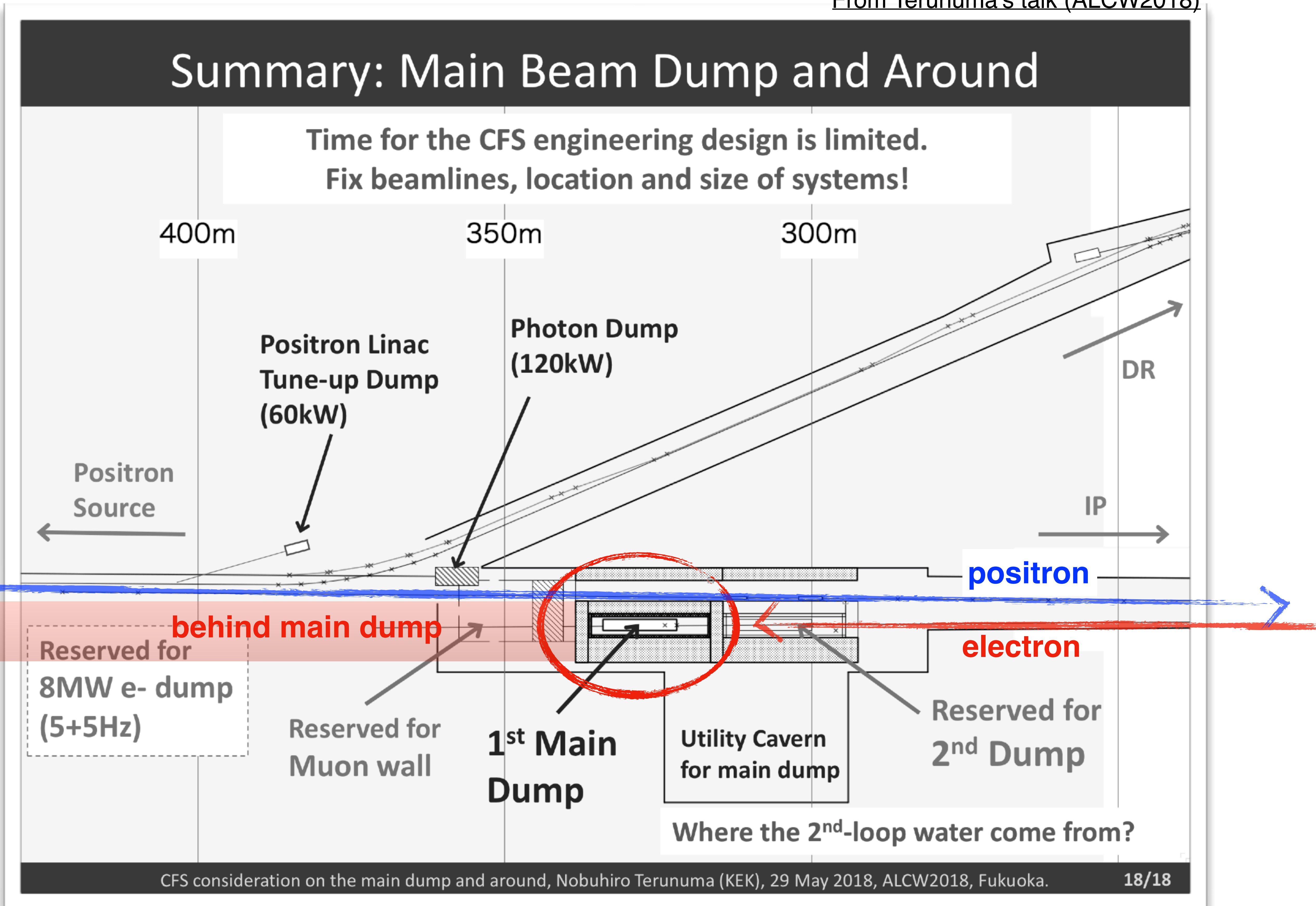
$\rho(concrete) \sim 2.3\ g/cm^3$

$\rho(rock) \sim 2.7\ g/cm^3$

- Need long shield to stop muons due to its strong penetrating power
  - Muons don't feel strong force and bremsstrahlung cross section is suppressed by the heavy muon mass

The region where muons penetrate

From Terunuma's talk (ALCW2018)



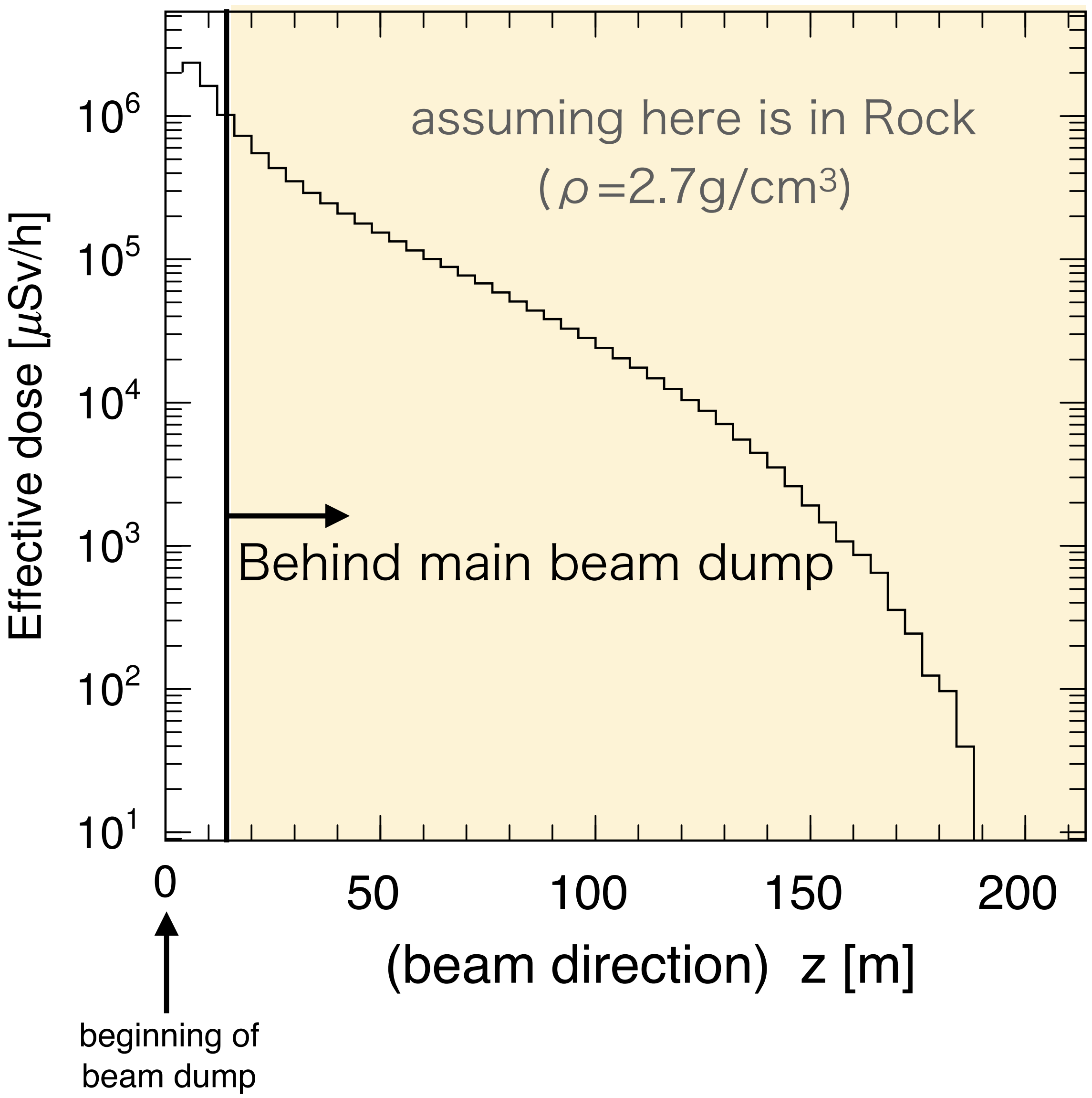
Muon shielding

- Two concerning things:

  (1) Radiation exposure by muons

  (2) Radionuclide production and its effect to environment

(Muon dose along beam axis. Area of surface is 1m²)



- High dose for a long interval
- Need good predictions of the intensity and spread of muons for an adequate design of muon shielding
- Need Monte Carlo code that correctly calculate muon pair production, muon transportation

Monte Carlo simulation

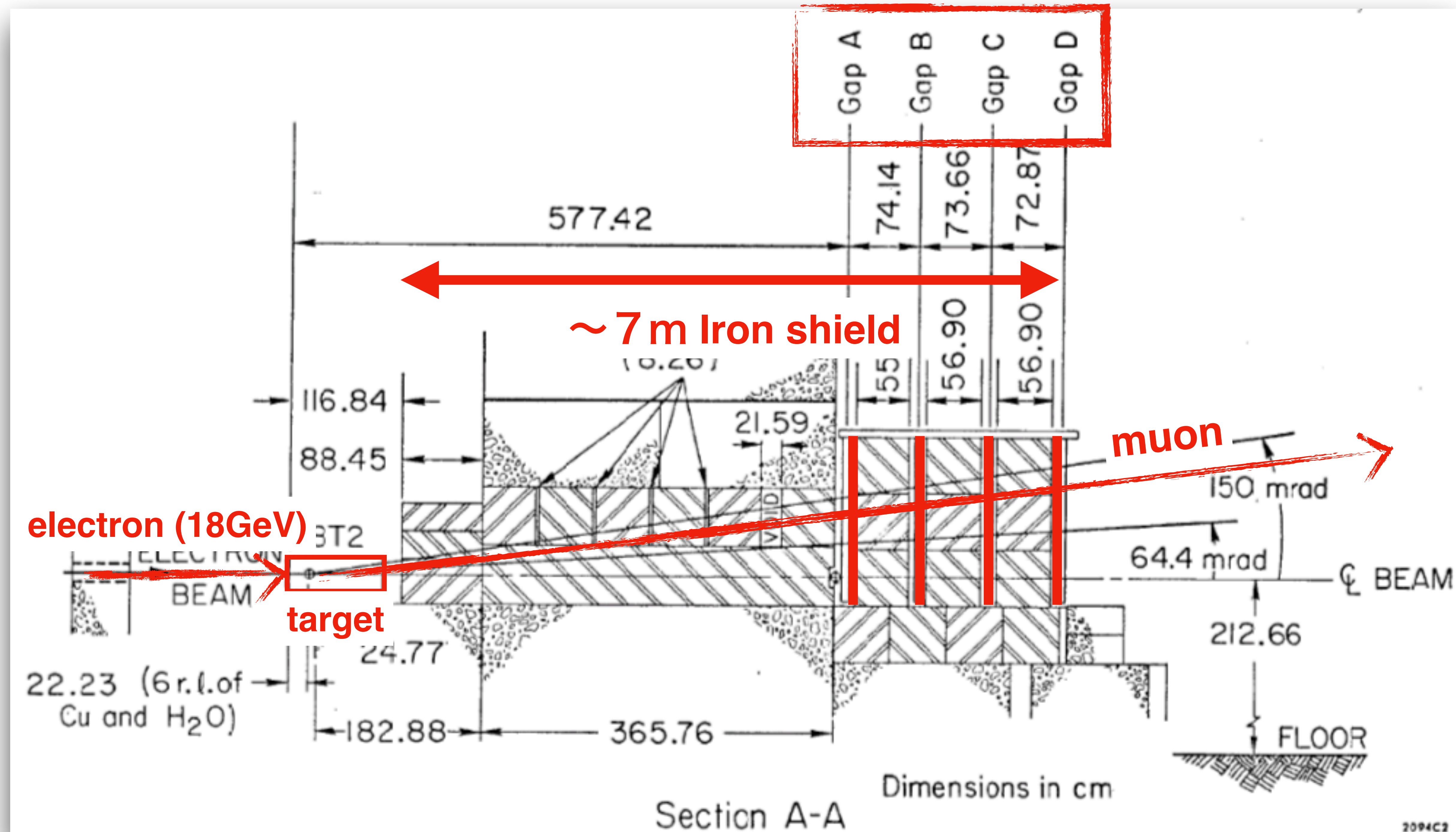
- We use PHITS and FLUKA (in this talk mainly PHITS)
- PHITS is a general-purpose Monte Carlo particle transport simulation code mainly developed in JAEA. KEK is also contributing to the development of EM shower (EGS5) and implementing models of high energy physics
- Recent developments on PHITS allow it to use for the shield design of high energy accelerator
- User friendly. Especially visualization is very easy.

Muon fluence induced by electron beam

- Comparison to data regarding muon shielding at SLAC using 18GeV electron

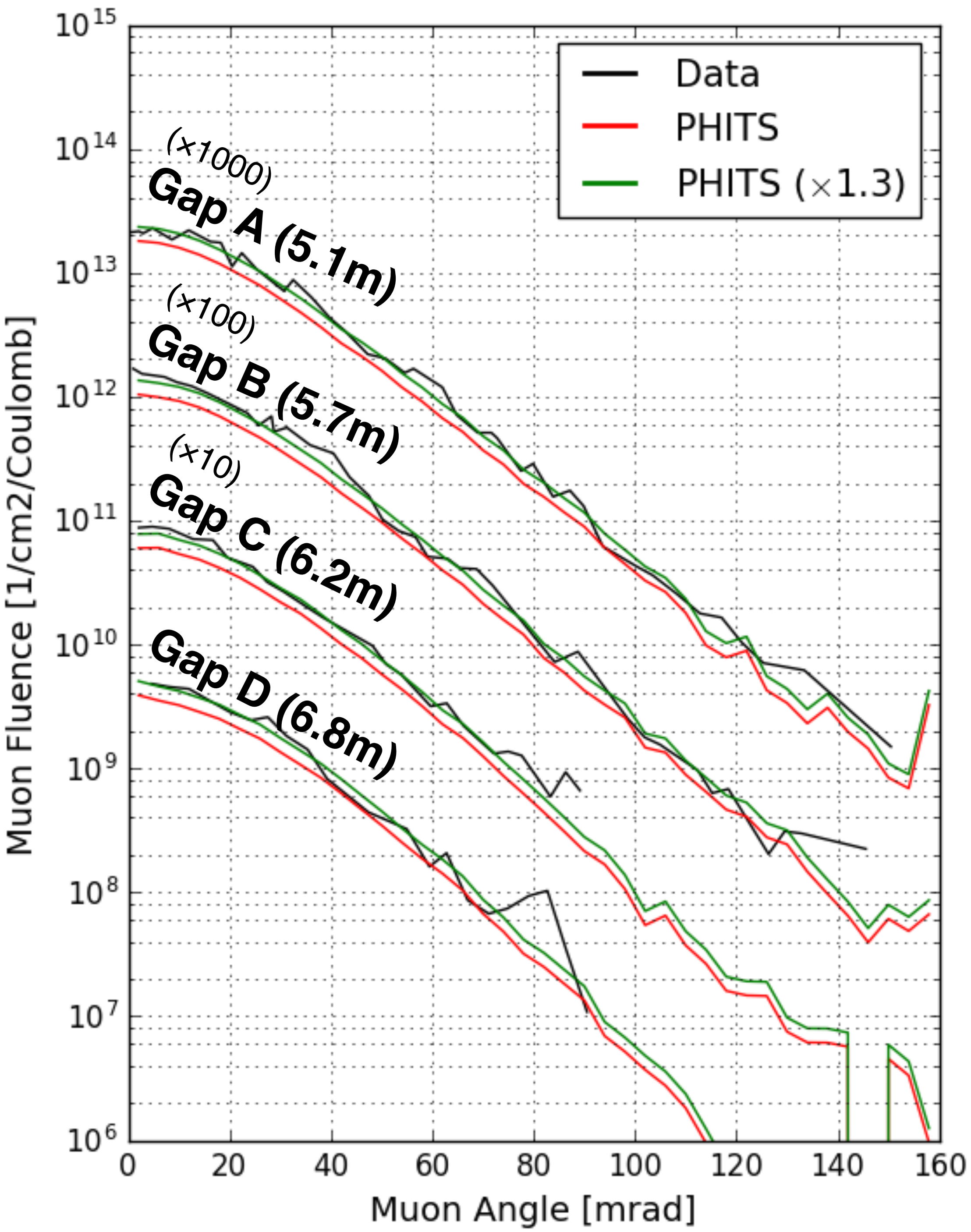
W.R.Nelson, et.al., Nucl. Instr. and Meth. 120 (1974), 413-429

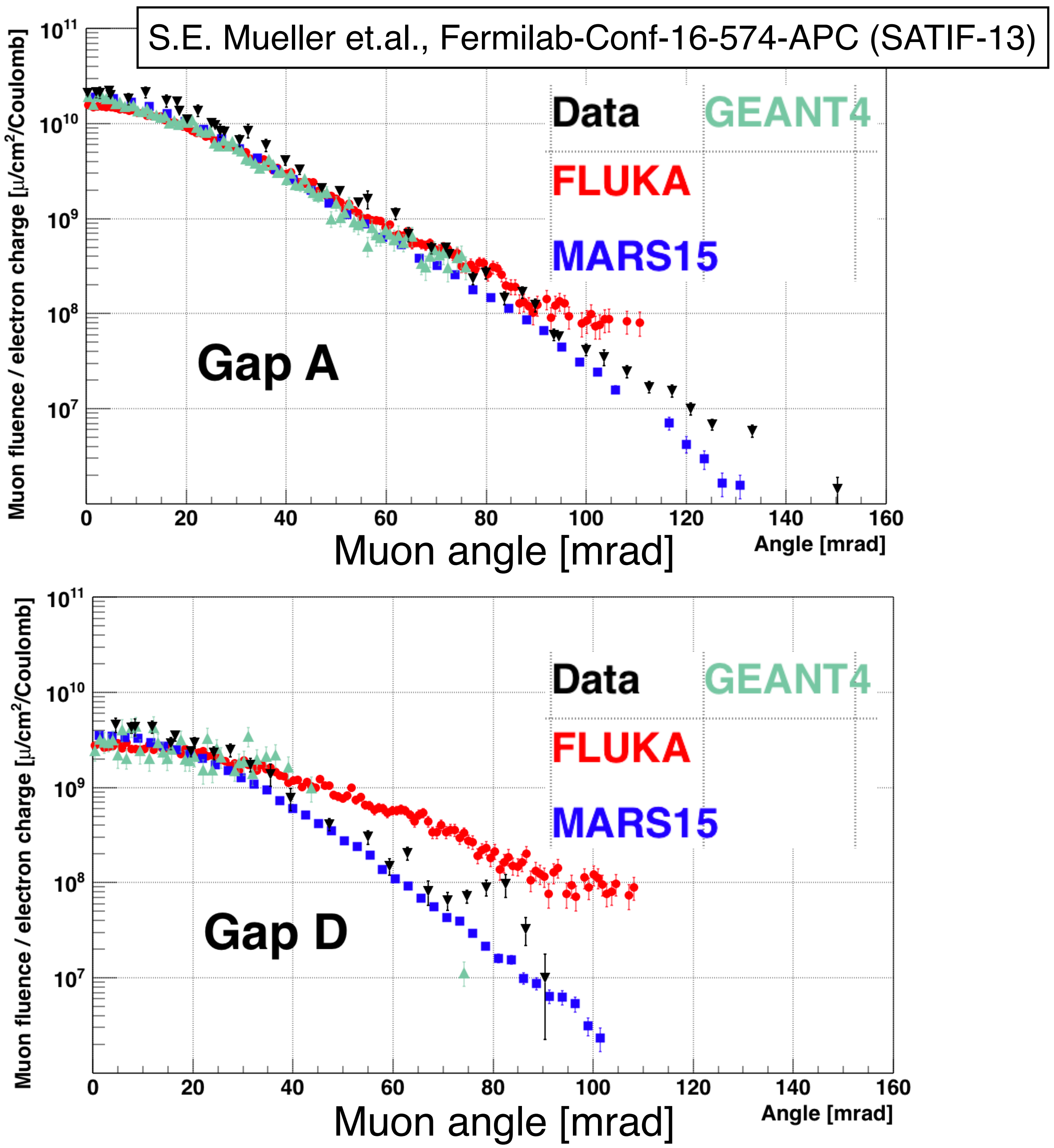
- Muon angular distributions at 4 Gaps



Muon fluence induced by electron beam

- PHITS and MARS seem to give good predictions of muon flux





Nuclide production

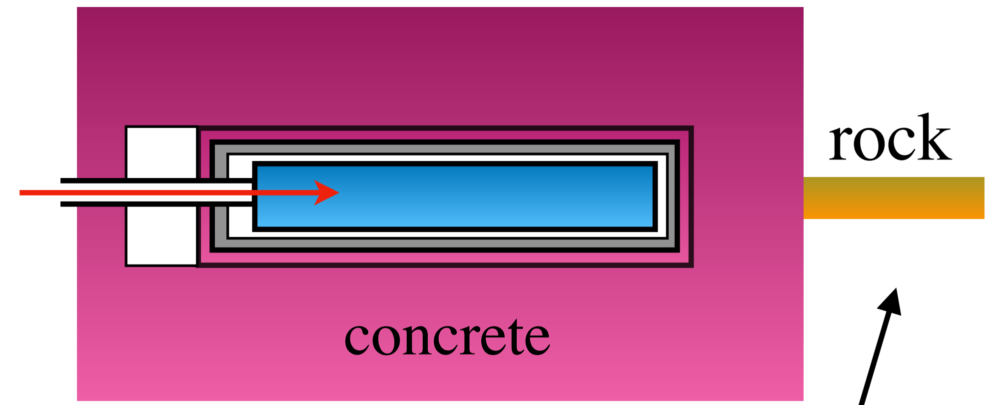
- 4 processes of radionuclide:

  (1) negative muon capture $(\mu\text{-} + p \rightarrow n + \nu_{\mu})$

  (2) EM interaction between muon and nuclear/nucleon

  (3) Secondary neutron interactions (spallation, capture)

  (4) Secondary photon interactions (photo-nuclear)



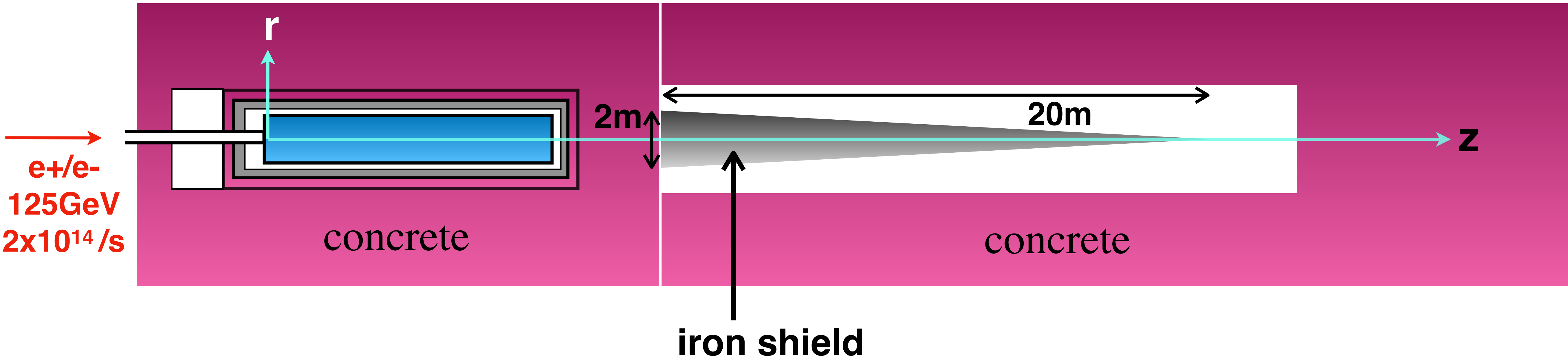
here
most activated region by muon

Nuclide	Half-life(y)	Activity(Bq/g) (After 20 years run)	μ-/μ+	process
3H	12.3	3.8	2.8	(1)>(2)~(3)
22Na	2.6	1.8	6.2	(1)>(3)>(2)
54Mn	0.9	3.5	120	(1)>>(3)>(2)
60Co	5.3	0.091	9.5	(3)
152Eu	13.5	0.11	11	(3)

- Evaluation of the number of nuclides depends on rock composition
- <u>We are planning to take more detailed data on the composition of on-site rock</u>

A case of muon shield

- Possible to decrease activation level even down to "**Clearance Level (CL)**" with 20m iron shield for muon

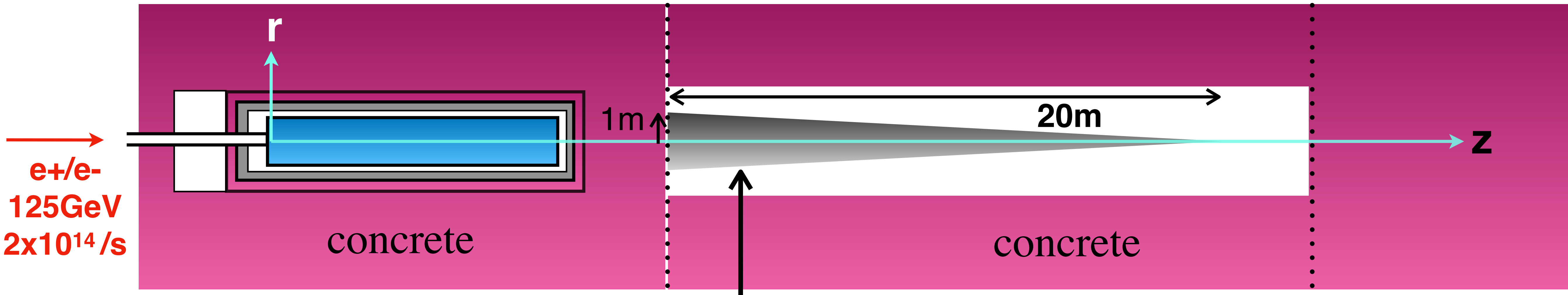


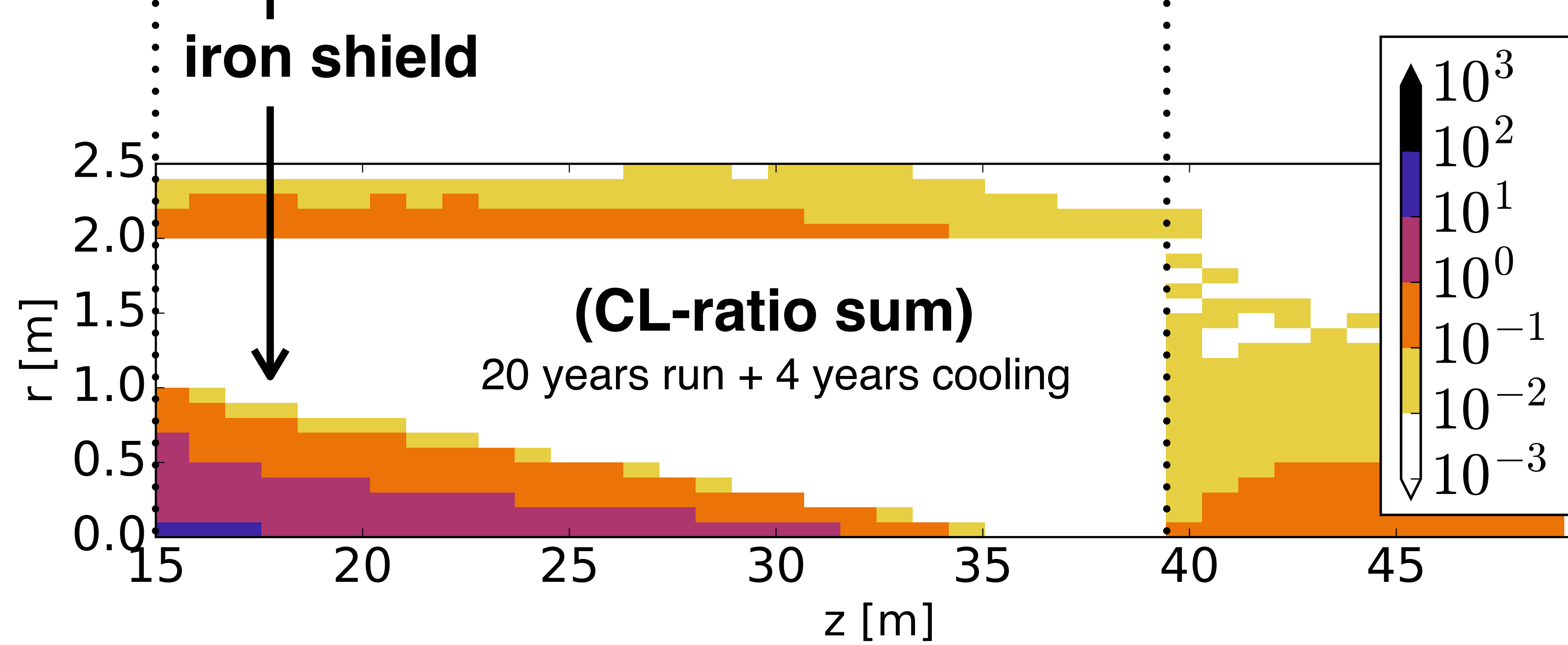
- **Clearance Level (CL)** is a level at which health damage from produced nuclides can be ignored.
  - Exposure from a material satisfying CL is less than 0.01mSv/y, which is 100 times smaller than the natural averaged dose (2.4mSv/y).

- Satisfying CL ⇔ (CL-ratio sum) = $\sum_{\text{for all } i} \frac{\text{Production of } i}{\text{CL of } i} < 1$

Nuclide	CL (Bq/g)
3H	100
22Na	0.1
54Mn	0.1
60Co	0.1
152Eu	0.1

A case of muon shield

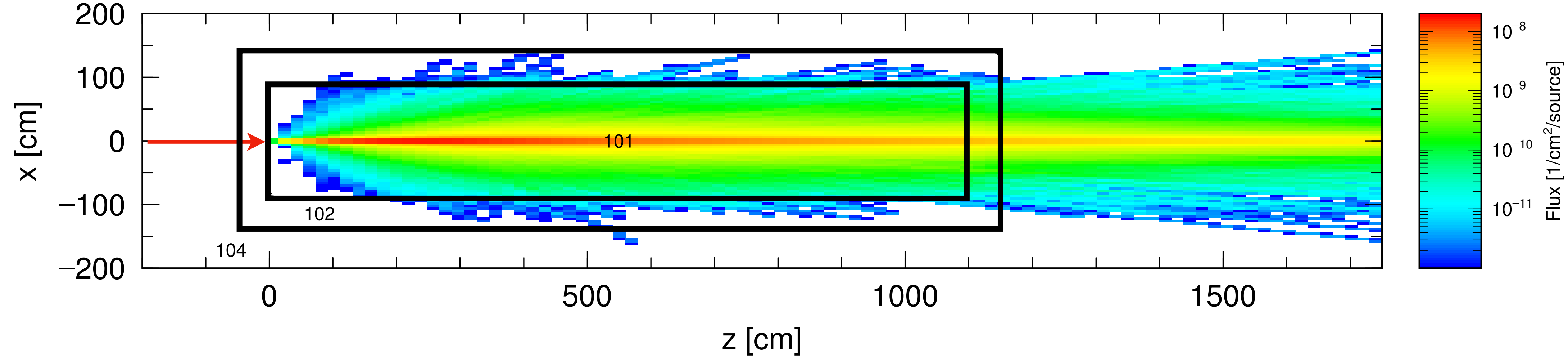




$$(\text{CL-ratio sum}) = \sum_{\text{for all } i} \frac{\text{Production of } i}{\text{CL of } i}$$

- "CL-ratio sum" becomes less than 1 except for the iron shield
- If we reduce radioactivity down to this level, radiation problems behind the beam dump at a decommissioning stage will be easier.

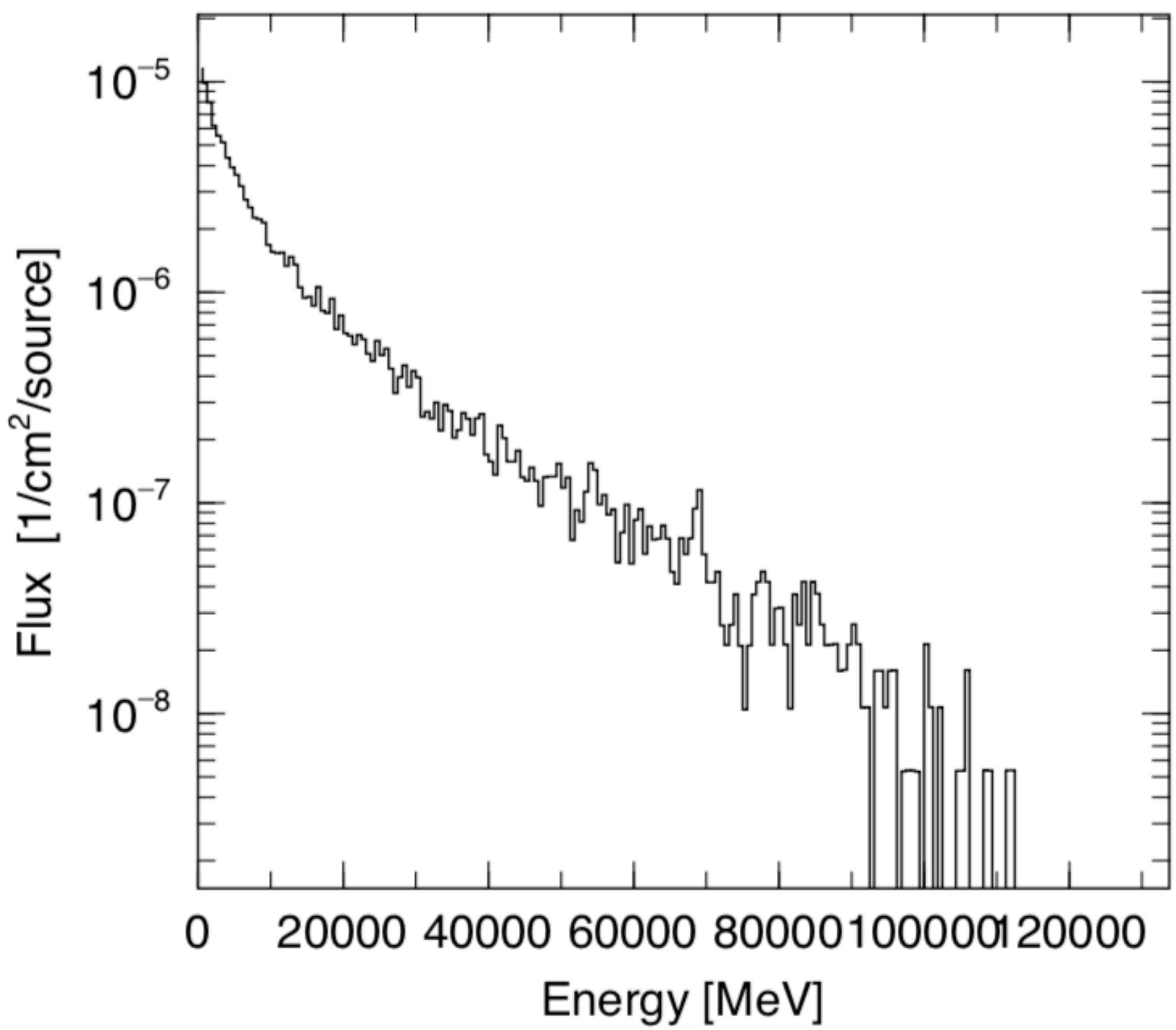
Summary



- A radiation issue related to muons at ILC main beam dump
- ~10^{10} muons/s appear behind the beam dump during the operation
- Two things to consider:
  - (1) Radiation exposure by muon
    - Strong penetrating power. Forward direction. High dose-rate for a long interval
  - (2) Radionuclide production and its effect to environment
    - Possible to reduce activation level even down to the clearance level by iron shield
- In future work, we will estimate environment effects and fix the structure of behind beam dump with a safety criteria.

extra

Muon energy distribution behind main beam dump



A long view