Radiation field representativeness, homogeneity and penetration requirements

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Outline

- Radiation field homogeneity for system-level testing
- Radiation field penetration for system-level testing
- Radiation field representativeness for system-level testing
- Conclusions

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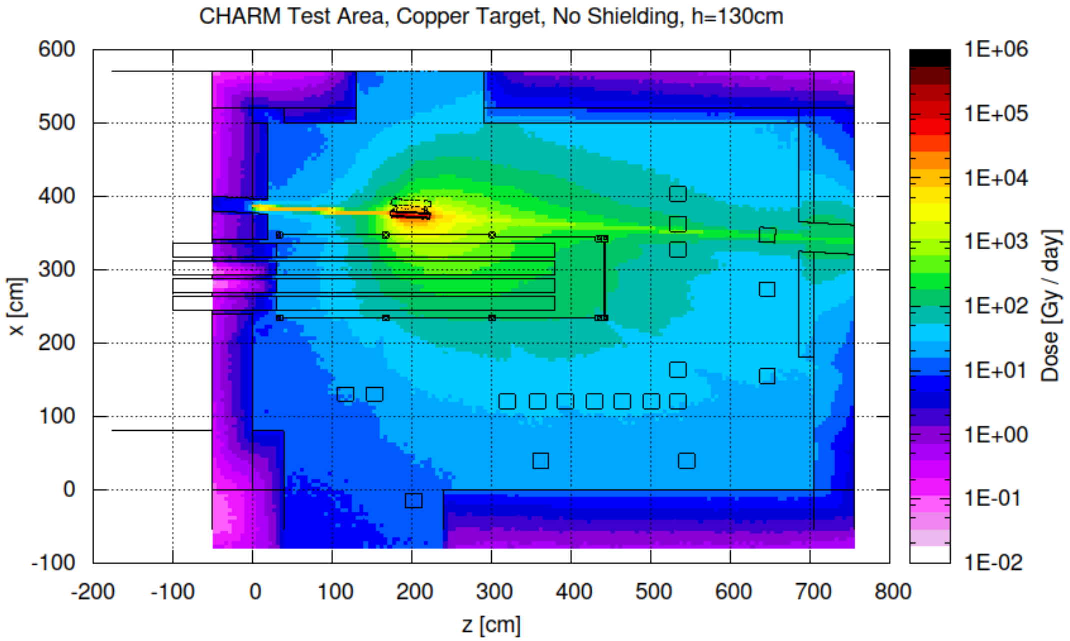
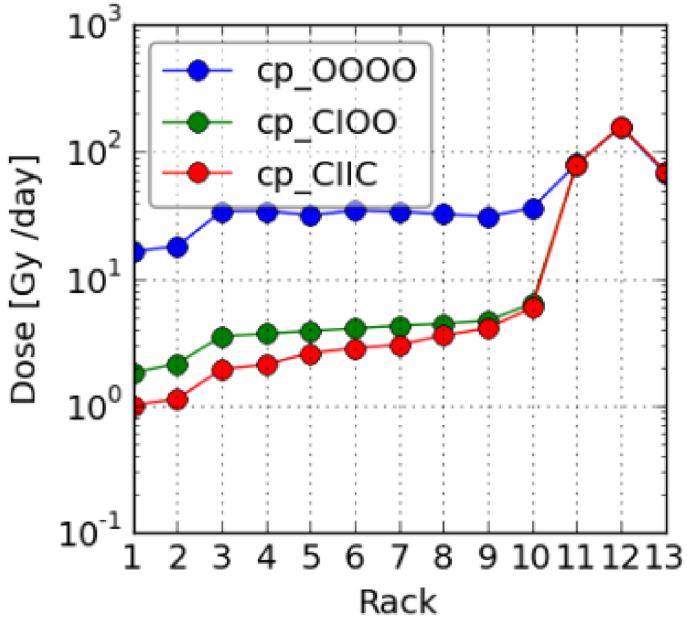
Homogeneity: Collimated beams versus mixed field

- Examples of “large” beams (up to ~60 x 60 cm^2) covered in Daniel’s presentation
- CHARM: mixed-field facility in which very large areas (several meter range) are covered with homogeneous radiation levels

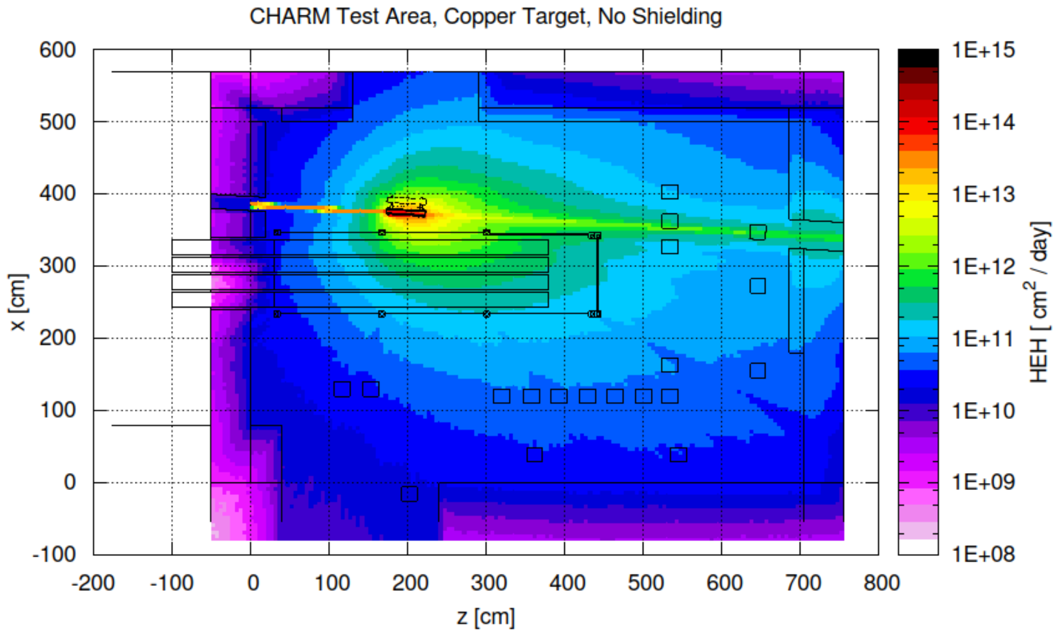


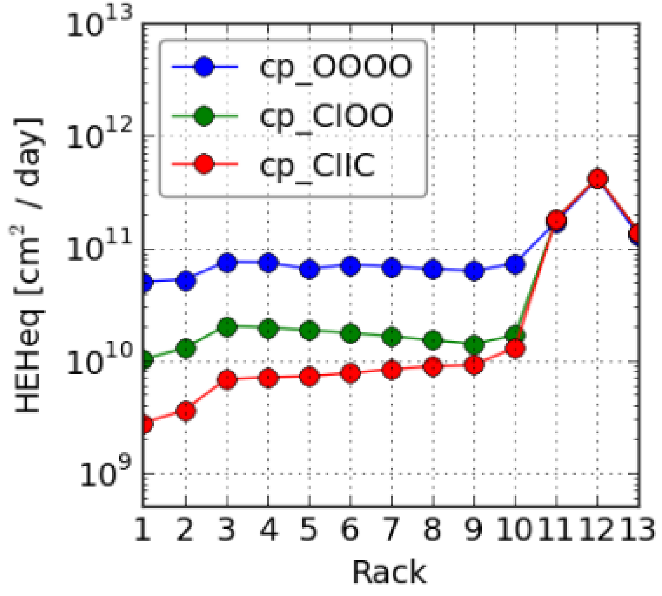


FLUKA simulation of CHARM TID map [A. Thornton, ATS Note 2016]

Homogeneity: Collimated beams versus mixed field

- Similar situation for high-energy hadron fluence



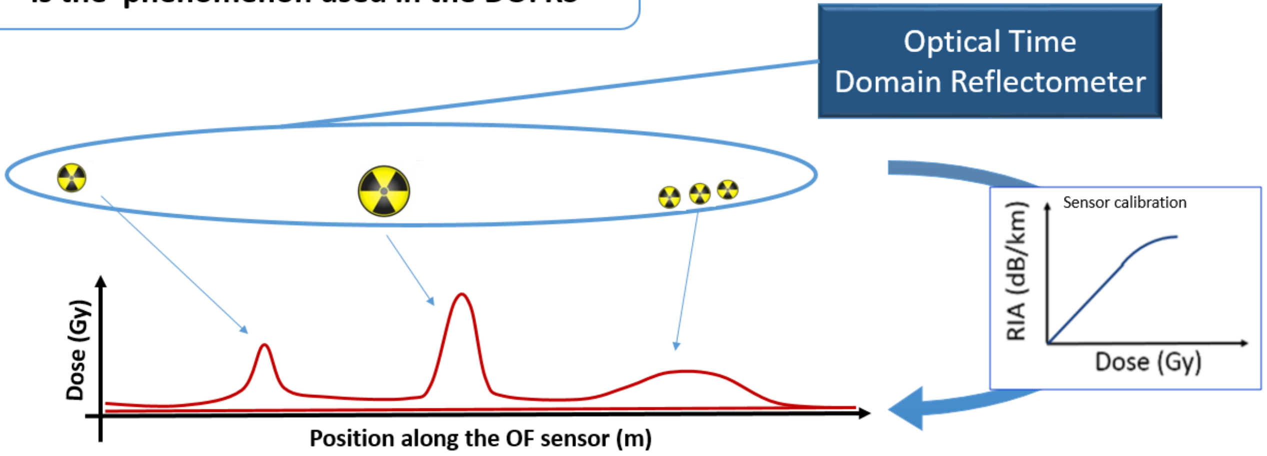


FLUKA simulation of CHARM High-Energy Hadron (HEH) map [A. Thornton, ATS Note 2016]

Homogeneity: Collimated beams versus mixed field

D. Di Francesca (NSREC and IEEE TNS, 2018)

The Radiation Induced Attenuation (RIA) is the phenomenon used in the DOFRS



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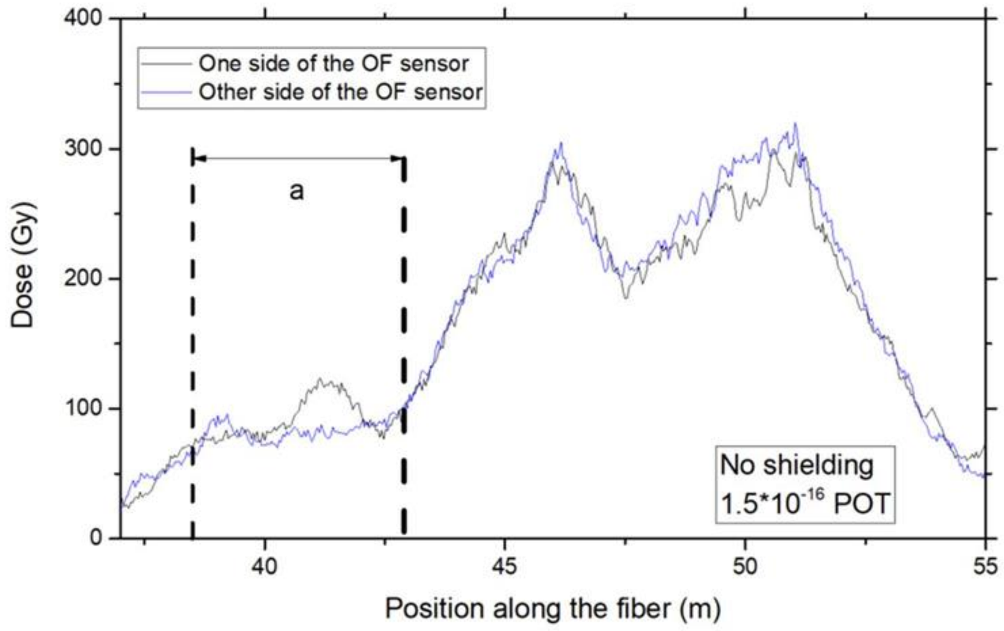

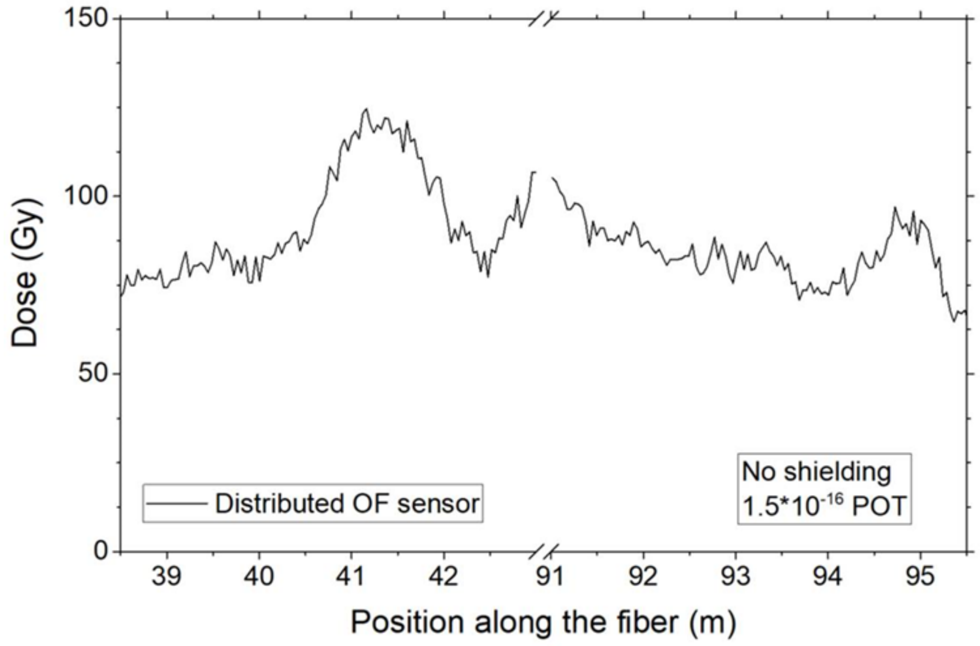

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- Radiation field homogeneity for system-level testing
- Radiation field **penetration** for system-level testing
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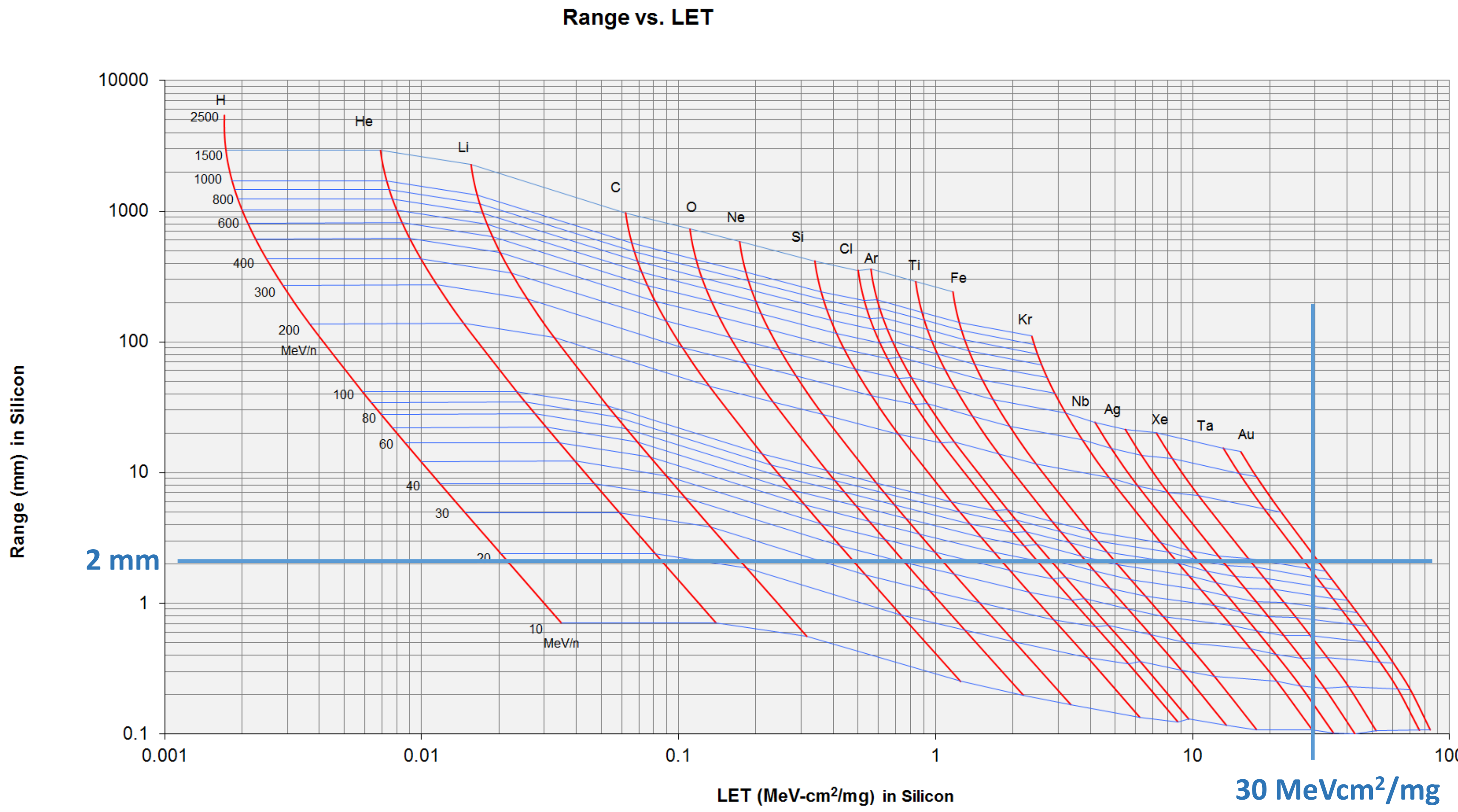
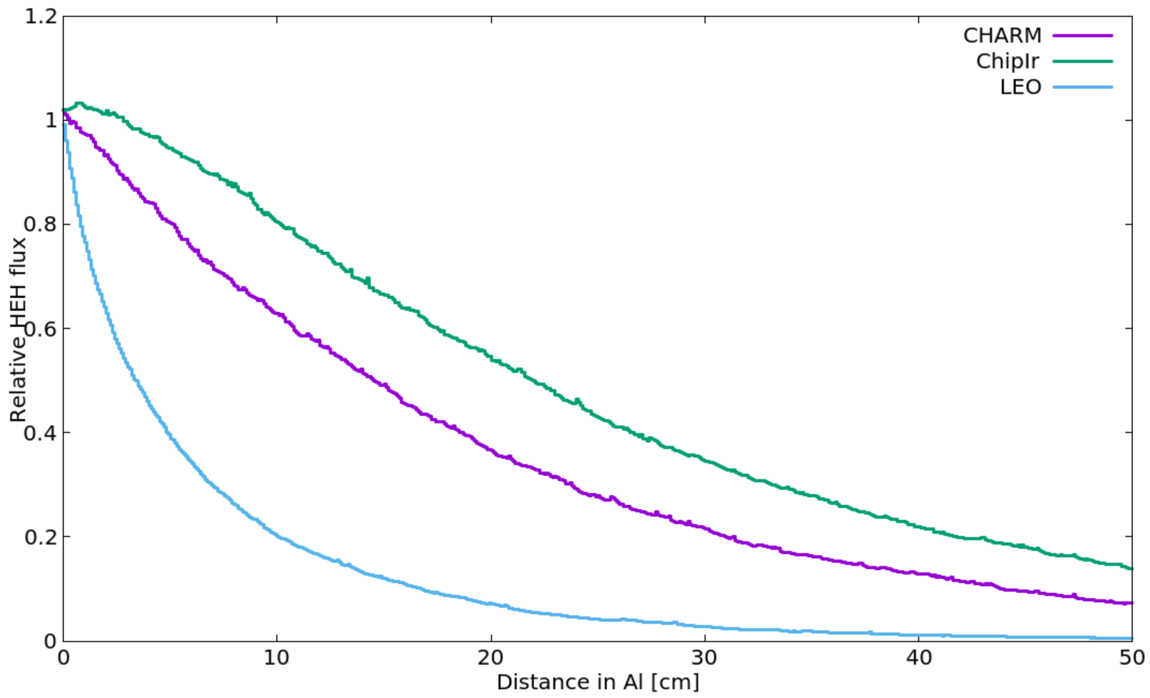
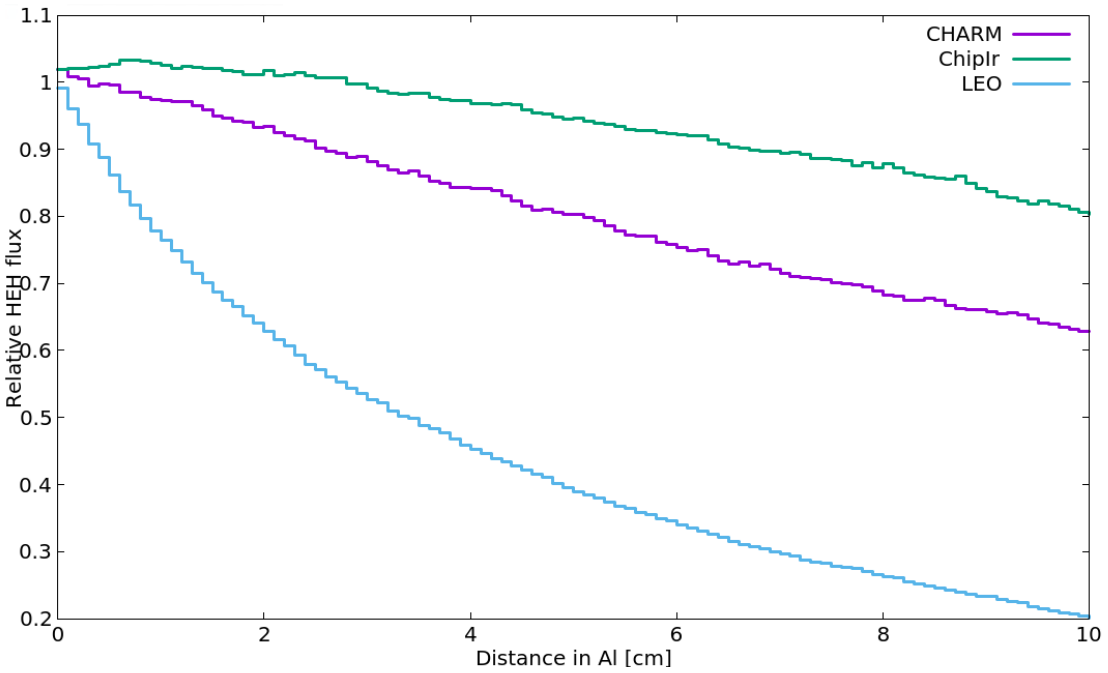
Penetration: Ranges in silicon – trade-off versus LET

- “Low” LET:
  - 1 GeV/n Fe: 14.7 cm(Si) range
- Indirect energy deposition:
  - 200 MeV proton: 13.9 cm(Si) range
- “High” LET (>30 MeVcm^2/mg) involves penetration bellow 2 mm (for “heavy” gold ion)
- Optimized LET and range working points need to be identified for each component/board/system



Penetration: proton and neutron spectra

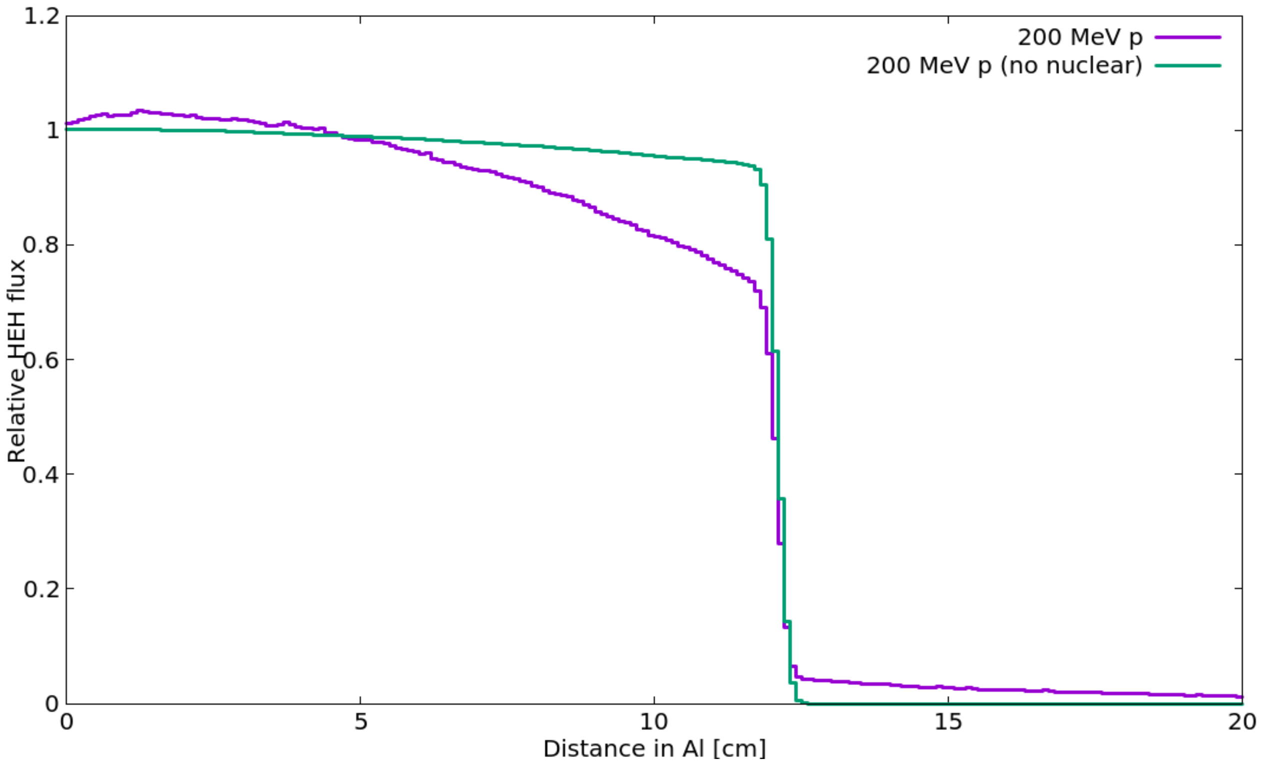




- Protons in trapped belts are highly penetrating in the mm aluminum range (e.g. 0.8 relative value after 7mm - shielding is much less efficient than for TID)
- CHARM and ChipIr have much larger penetrations (e.g. 0.8 relative value reached at 5 and 10 cm respectively) due to larger energies and strong neutron presence

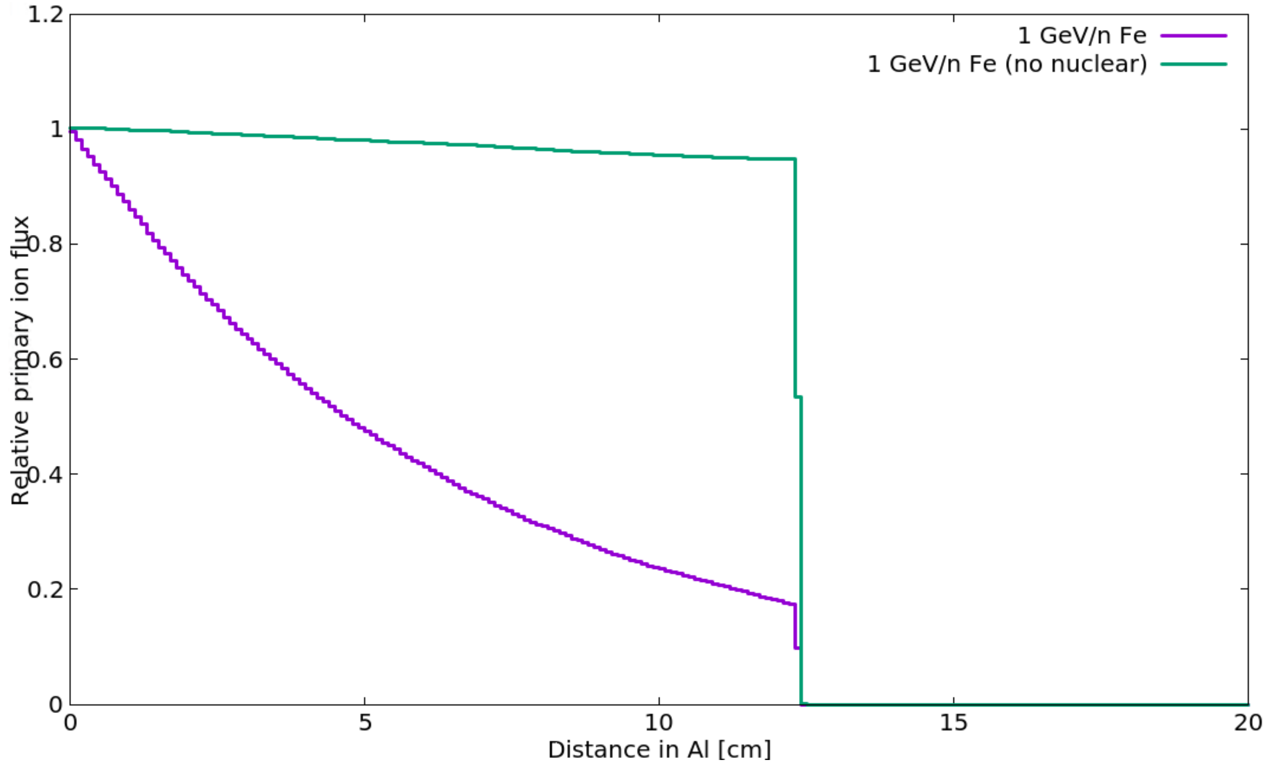
Penetration: mono-energetic protons

- For 200 MeV protons, inelastic interaction length (e.g. 50cm in silicon) is significantly larger than range (e.g. 14cm in silicon) therefore the effect of the interaction with the material is dominated by dE/dx losses (i.e. efficient degradation)
- Nuclear events however still have a visible impact on the HEH penetration



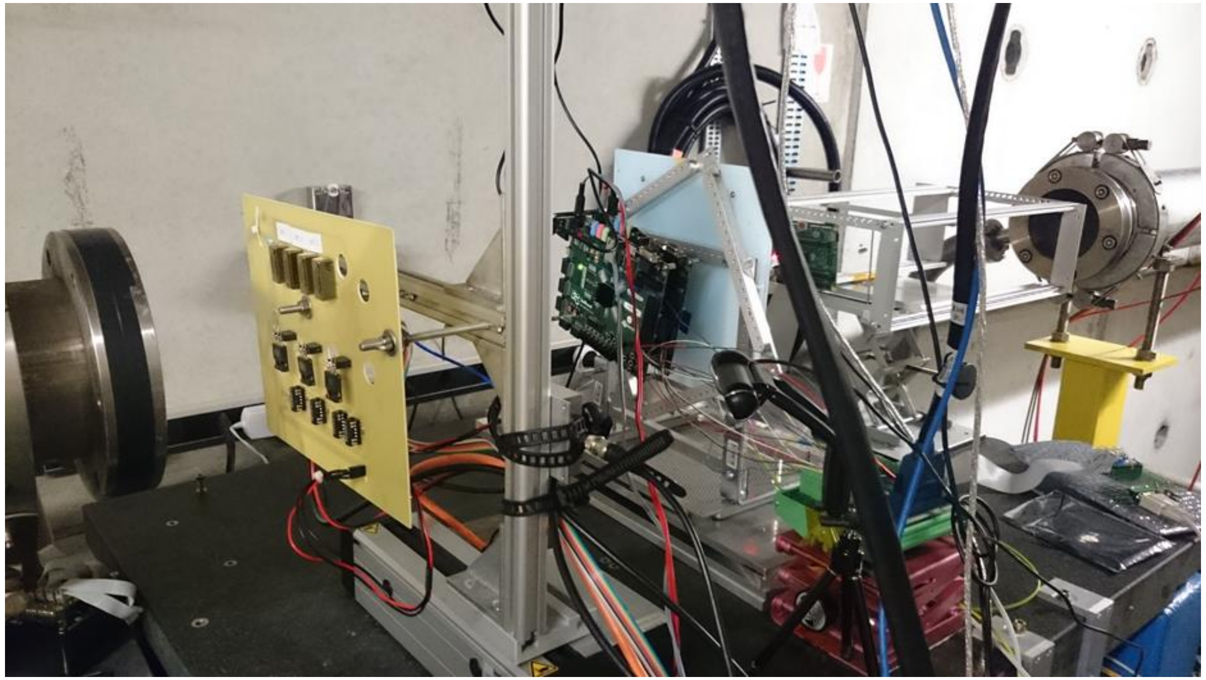
Penetration: mono-energetic heavy ions

- For 1 GeV/n ions, inelastic interaction length in silicon (8.3 cm) is shorter than range (14.7 cm)
- Hence, interaction with matter is dominated by nuclear fragmentation, and (though not represented in the figure) a significant amount of light secondaries are produced, effectively changing the nature of the radiation field



Penetration: mono-energetic heavy ions

- Ultra-high energy test campaigns at CERN, with heavy RADSAGA involvement (both as test campaign support and users)
- Possibility of testing in air, with packaged parts and multiple boards in parallel
- Main limitations:
  - Beam fragmentation (beam instrumentation, boards under test…)
  - Low effective LET value (~10 MeVcm^2/mg for 150 GeV/n lead beam)



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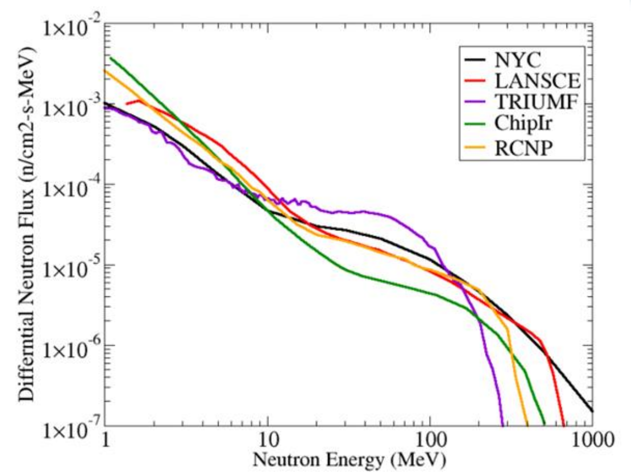
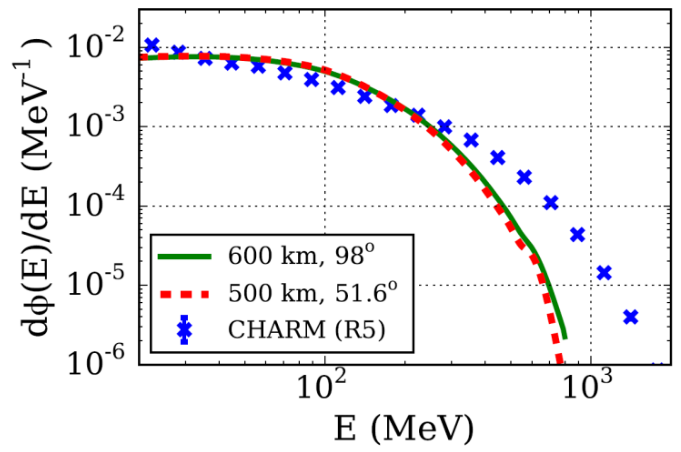
Representativeness: spectral acceleration factor

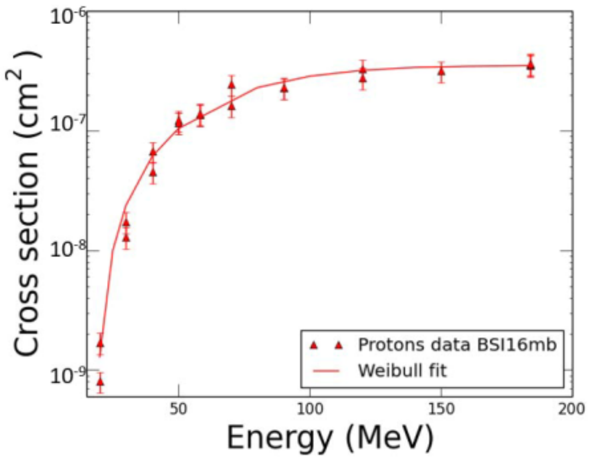
- Typically, SEE cross sections for space applications are expressed as a function of energy (protons) or LET (ions) and folded with the respective spectra in the operation application
- Directly comparing the particle energy spectra of testing and application environments via an acceleration factor is also an option (e.g. as is done in ground level applications with atmospheric-like neutron spallation sources)
  - Similar can be done in CHARM for LEO orbit, considering high-energy hadrons versus protons, under the assumption that different hadrons (protons, neutrons, pions) have equivalent SEE cross sections (high-energy hadron approximation)
- (More on mixed-field representativeness of TID and DDD in Rudy’s talk)

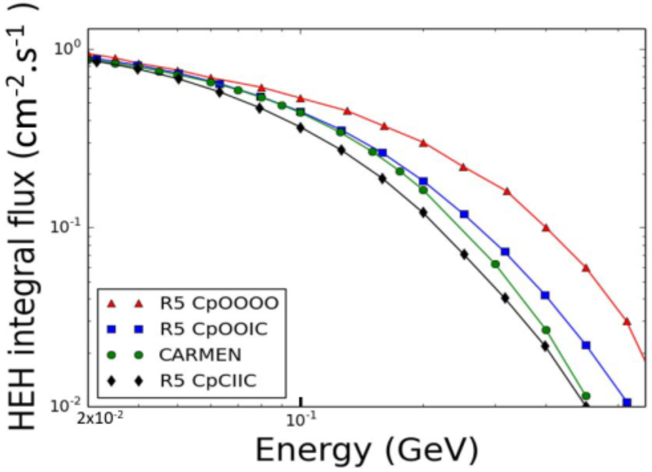


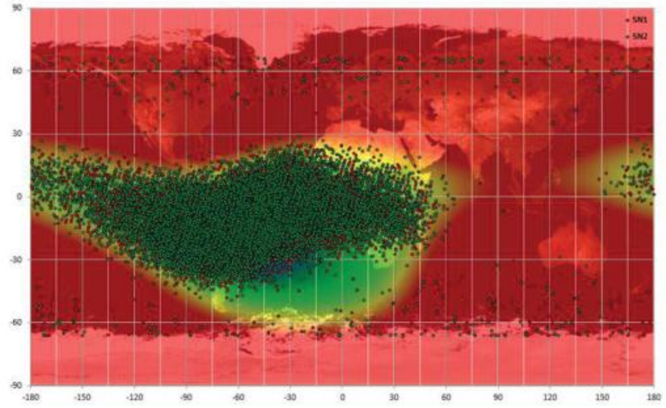


Representativeness: spectral acceleration factor

- Example of application of CHARM mixed-field data to in-obit SEL rate prediction (N. Kerboub, RADECS 2018 and IEEE TNS)





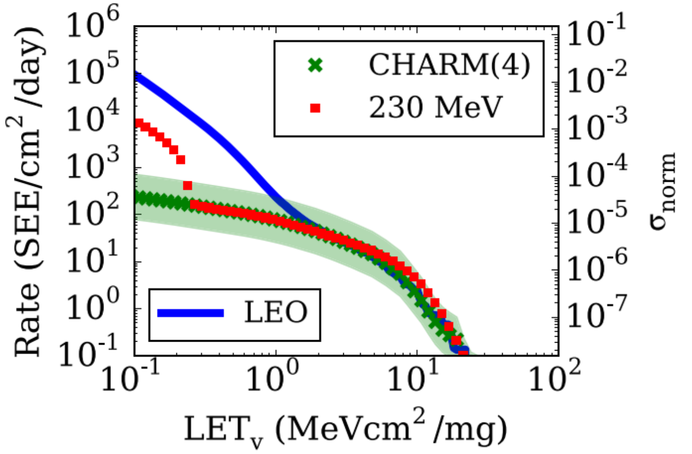


Quantity	BSI 1	BSI 2	Relative Error
SELs during mission	6882	7279	-
SELs per day	12.5	13.3	
Monoenergetic estimation	14.7 SEL/day		10-17%
CHARM estimation	20 SEL/day		51-60%

CHARM estimation of in-orbit SEL rate within 50% of measured value

Representativeness: energy deposition phase space

- A similar approach (of comparing test versus operation spectra through an acceleration factor or SEE "mixed-field" cross section) can be applied in the deposited energy phase space, via Monte Carlo simulations and the definition of a sensitive volume
- Not surprisingly, comparable particle energy spectra yield comparable energy deposition distributions (e.g. CHARM versus LEO, but also applicable to 230 MeV mono-energetic protons)
- Good agreement between LEO SEE rate prediction based on CHARM and that expected from traditional proton testing (mono-energetic in 20-200 MeV range)

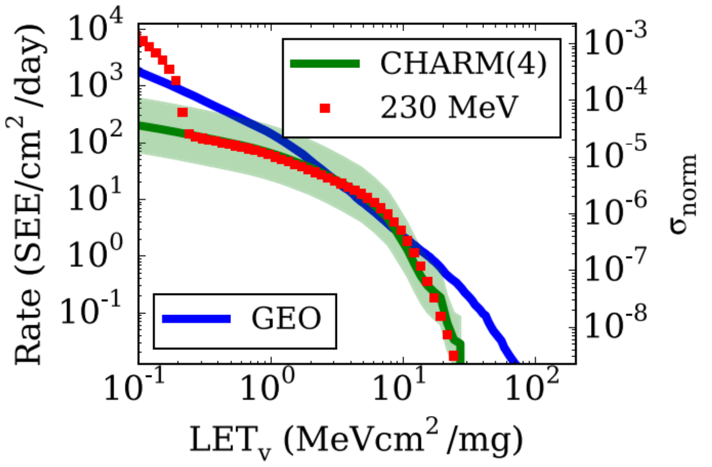


SRAM	IRPP predicted SEE rate	
	Proba-II (LEO)	Alphasat (GEO)
IS61LV5128AL-12	1.81×10^{-1} (**0.65**)	6.42×10^{-2} (**1.25**)
BS62LV8001EIP55	-	4.89×10^{-1} (**1.78**)
K6R4008V1D	2.57×10^{-3} (**0.83**)	5.63×10^{-4} (**2.58**)
AS7C34096A	1.36×10^{-3} (**1.02**)	-
AT60142F	2.8 (**1.71**)	2.7 (**1.15**)

Expected proton SEE rates (events/day/device) and obtained from CHARM and ratio with respect to standard approach

Representativeness: energy deposition phase space

- The same approach can be applied to derive the heavy ion SEE rate based on proton and/or mixed field results
- The energy deposition curves closely fit to each other up to an equivalent LET of roughly 10 MeVcm²/mg
- Therefore, protons and mixed-field can be considered as being able of both qualitatively and quantitatively representing heavy ion SEEs for components with low LET thresholds (<5 MeVcm²/mg)
- For SEE cross sections with larger LET onsets (or thicker sensitive volumes), proton/mixed-field results can only be used as upper bounds for heavy ion rate prediction



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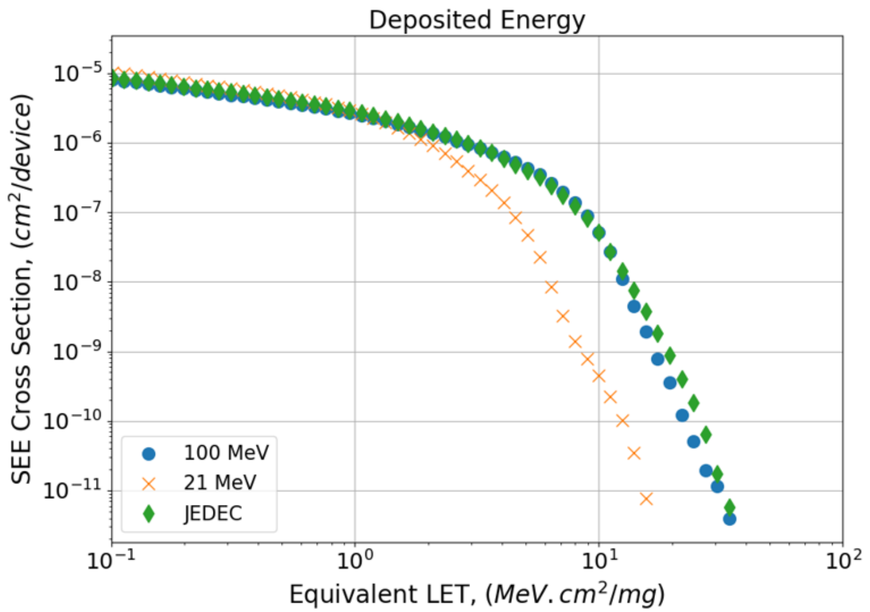
Representativeness: energy deposition phase space

- When applied to neutron SEE testing, the energy deposition description can be used to show that, for SEU (small sensitive volume, low LET onset), 14 MeV neutrons are representative of atmospheric-like neutrons, whereas for SEL (large sensitive volume and LET onset) differences of a factor 30 and above are obtained when comparing the two cross sections



A. Coronetti, RADSAGA deliverable report

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Summary and conclusions

- Homogeneity:
  - Spallation sources can provide highly homogeneous mixed radiation fields over several meter distance, enabling testing of multiple components/boards, and full systems
  - A similar experimental scenario with heavy ions instead of hadrons is not presently viable (laser-driven plasma ion acceleration?)
- Penetration:
  - For highly-energetic, neutron dominated radiation fields such as ChipIr and CHARM, very large penetration (several cm range, using a 0.8 relative value as figure-of-merit) is achieved
  - Highly-energetic ions can also have significant penetration values, but at the cm level, their interaction with matter is dominated by nuclear reactions as opposed to dE/dx
    - In addition, there is a strong tradeoff between penetration and LET
- Representativeness:
  - Describing SEEs in the deposited energy phase space can contribute to efficiently establish links between a broad variety of experimental and application environments