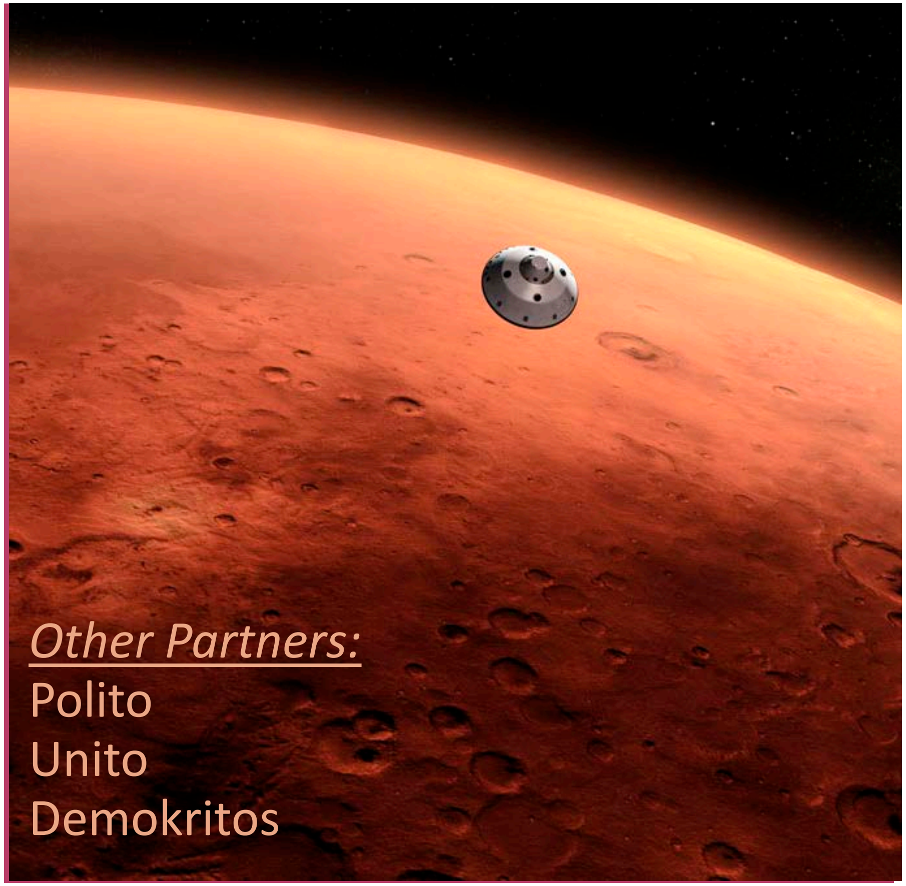
Recent validation results from the ESA ROSSINI2 project

Slides prepared by Martina Giraudo on work performed for ESA by Thales Alenia Space Italy

Adapted by Giovanni Santin for the purpose of this talk focussing on Geant4 validation

- Context: ROSSINI 2, material selection
- Experimental test set-up
- Simulation set-up
- Comparison with test results



Other Partners:
Polito
Unito
Demokritos

ROSSINI2

Radiation Shielding by ISRU and/or Innovative Materials for EVA, Vehicle and Habitat

Martina Giraudo
Thales Alenia Space Italia

ROSSINI2

- **A 2 YEAR PROJECT FUNDED BY ESA STARTED IN 2015**

- **Prime contractor:** Thales Alenia Space Italia
- **Radiation Test – Data analysis:** GSI & INFN
- **Simulations:** Thales Alenia Space Italia
- **Materials:** TAS-I, with Demokritos, Polito and Unito

Main goals

- **Select** promising shielding structures
  - Including innovative materials and systems
- **Test** under protons and heavy ions beams the proposed targets to prove shielding behavior and layering effect
  - @ GSI & NSRL
- Monte Carlo **simulations** with Geant4 & PHITS
- Inhabited **habitat** design
- Give **recommendations** and guidelines for the design and use of transfer habitat implementing the ALARA principle

Space habitat: shielding

Integrated approach:

- Research for novel/innovative shielding materials
- Using multifunctional materials
- Considering the internal mass distribution (~15 g/cm2)
- Using ISRU materials when available

Material Selection

Bethe-Bloch → ~ Z A^{-1}

$$-\frac{dE}{\rho dx}=k\frac{Z}{A}\cdot\frac{z^{*2}}{\beta^{2}}\left(\log\frac{2\gamma^{2}\beta^{2}m_{e}c^{2}}{I}-\eta\right)$$

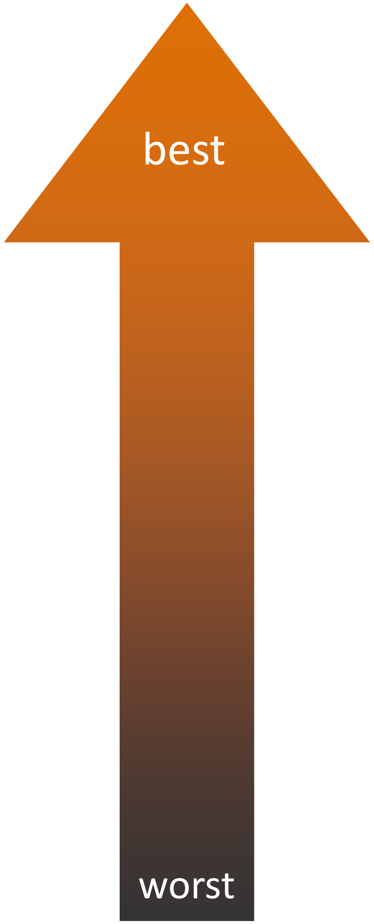
Bradt-Peters ~ $A^{1/3}$

$$\sigma=\pi r_{0}^{2}\left(A_{T}^{1/3}+A_{P}^{1/3}-b\right)^{2}$$

Material Index = $Z\rho^{-1}A^{-2/3}$

Analytic hierarchy process

Material index, Multifuctionality, External-Internal-Launch environment compatibility, Safety, Availability, TRL



RANGE OF INTEREST

Liquid H_2

Magnesium alloy

Polypropilene

Polyethylene

Water

Aluminum

Lead

ISRU materials

In Situ Resource Utilization - ISRU Materials

- Mars Regolith Simulant → Orbitec JSC Mars1A <1mm
- Moon Regolith Simulant → Orbitec JSC Lunar-1A <1mm
- Moon Concrete → Dinitech D-NA-1

Introduction and material selection

Experimental test set-up

Simulation set-up

Comparison with test results

- Dose reduction, Microdosimetry, Characterization of Fragments

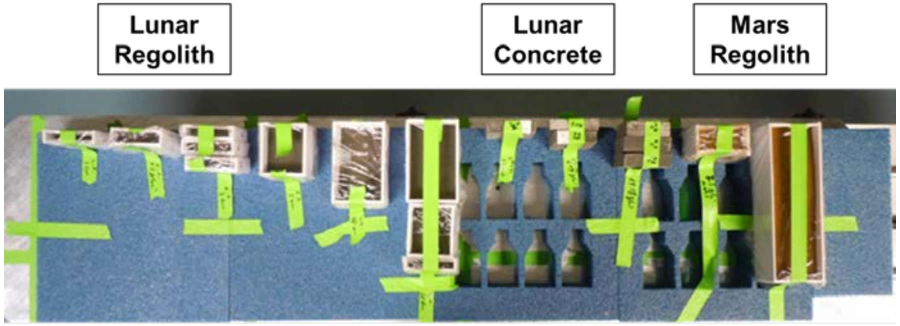
Dose reduction and microdosimetry

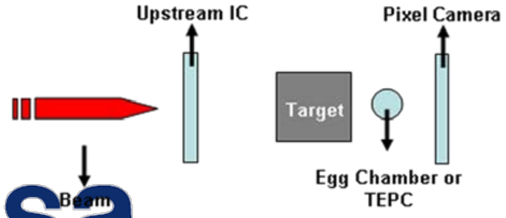
Dose Reduction

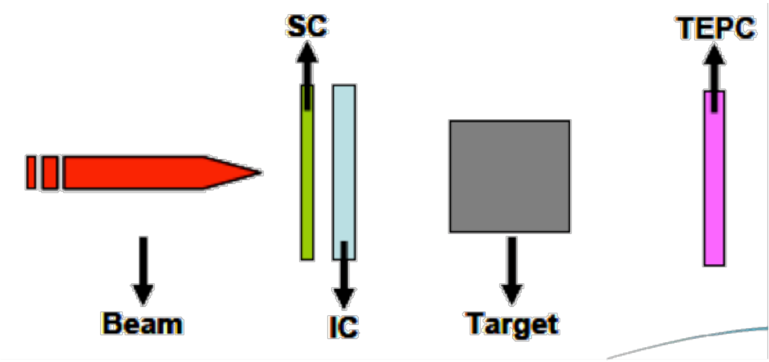
- EGG counter
- Exit window - end of target 234 inches

Microdosimetry

- Tissue Equivalent Proportional Chamber → equivalent to a tissue volume of 2 µm diameter

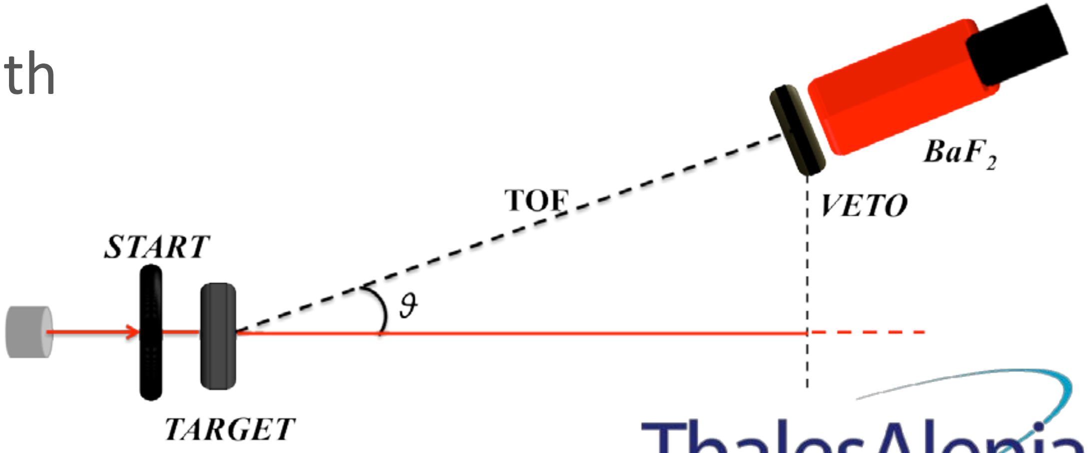






Fragments characterization

- Yield and kinetic energy spectrum of secondary particles
- Energy loss information by a ΔE-E telescope
- ΔE-E telescope: 9 mm thick plastic scintillator (VETO) for measuring the energy loss ΔE + 14 cm BaF_2 crystal for acquiring the residual energy E
- Kinetic energy spectra with the Time-of-Flight (TOF) method



Introduction and material selection

Experimental test set-up

Simulation set-up

Comparison with test results

- Tools, physics

Simulations Summary

- ROSSINI 1 study Bragg Peak PHITS simulations
- ROSSINI 2 validation against experimental BNL data
- Trade-off simulations for material selection
  - GCR shielding efficiency
  - SPE shielding efficiency
- Test set up simulations and comparisons
- 3D inhabited habitats simulations on the Moon and in deep space

Simulations: Methods and tools

- 2 different Monte Carlo codes:
  - Geant4
    - GRAS interface developed by ESA
  - PHITS

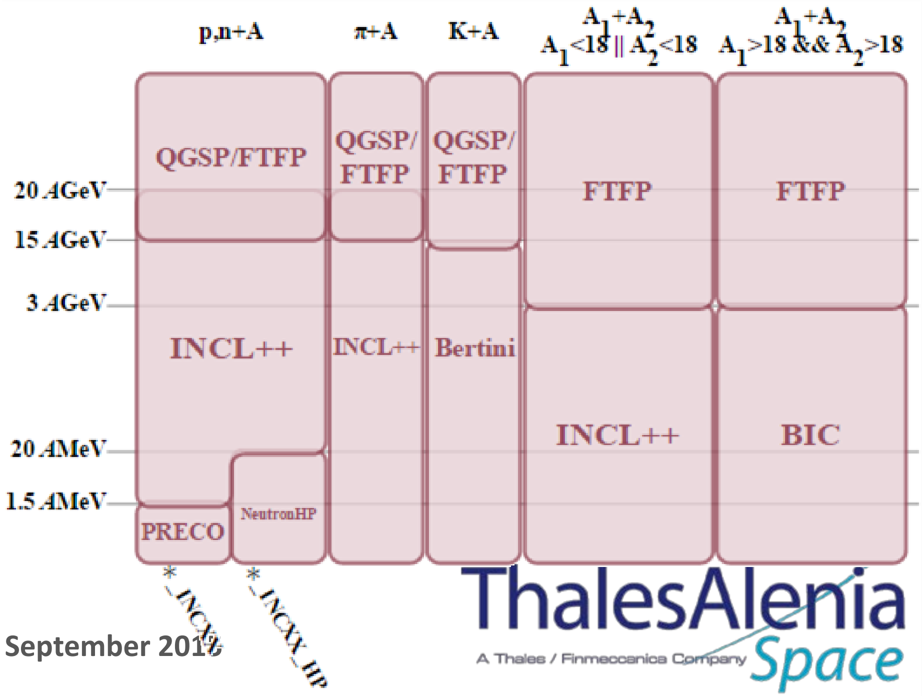
- ICRP 123 fluence to dose conversion factors used for 3D habitat simulations
  - Sato et al., PHITS

Simulation tool framework

- Software/codes versions for ROSSINI2:
  - Geant4.10.01 / GRAS v3.03
  - Root 5.34/23
  - Python 2.6.6
  - PHITS v2.64
  - Angel v4.31
  - SimpleGeo 4.3.3

Geant4 physics

- Considered Geant4 physics lists:
  - QGSP_INCLXX and QGSP_INCLXX_HP
  - FTFP_INCLXX and FTFP_INCLXX_HP
  - FTFP_BERT and FTFP_BERT_HP
  - QGSP_BERT and QGSP_BERT_HP
  - QGSP_BIC and QGSP_BIC_HP
  - QBBC_EMY (EM opt3)
  - Shielding
- Driven via Command Line arg. (bypassing GRAS physics lists) to avoid ambiguities
  - However, limited in EM choice to opt0 for most cases, while opt4 is recommended for high accuracy dosimetry



Introduction and material selection

Experimental test set-up

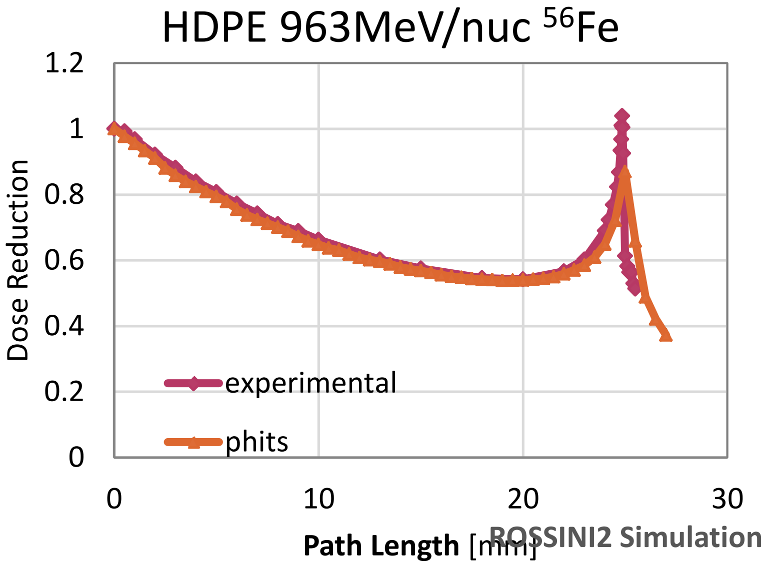
Simulation set-up

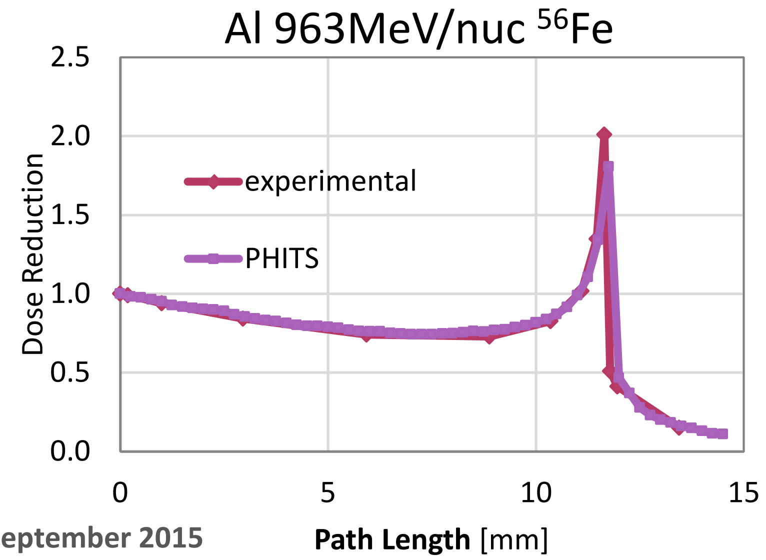
Comparison with test results

- PHITS and Geant4
  Protons and ions
  Energy from 89 to 983 MeV/nuc

ROSSINI1 study
PHITS simulations - experimental data

- Simulations carried out to compare rad test results of ROSSINI1 with PHITS simulation
- Good agreement for Al and HDPE
- Bad agreement for ISRU Materials, probably due to material modeling





ROSSINI1 study
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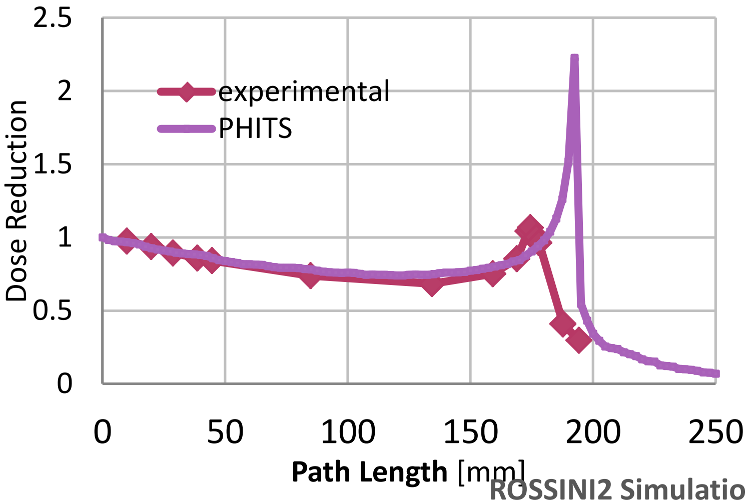
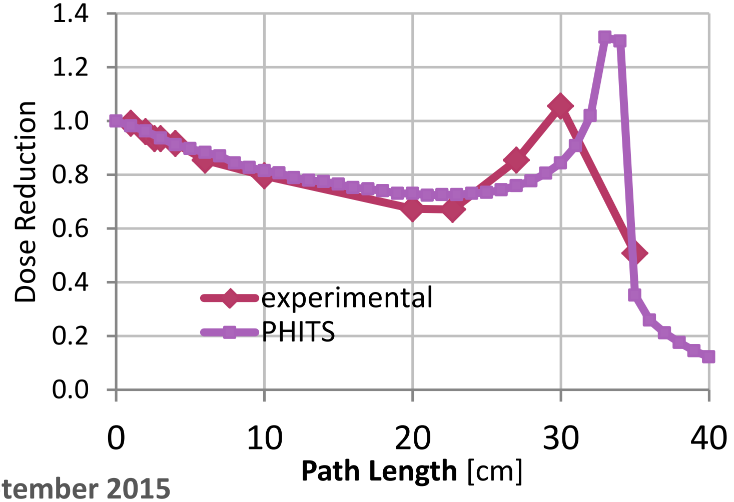
Moon Concrete 963MeV/nuc ^{56}Fe

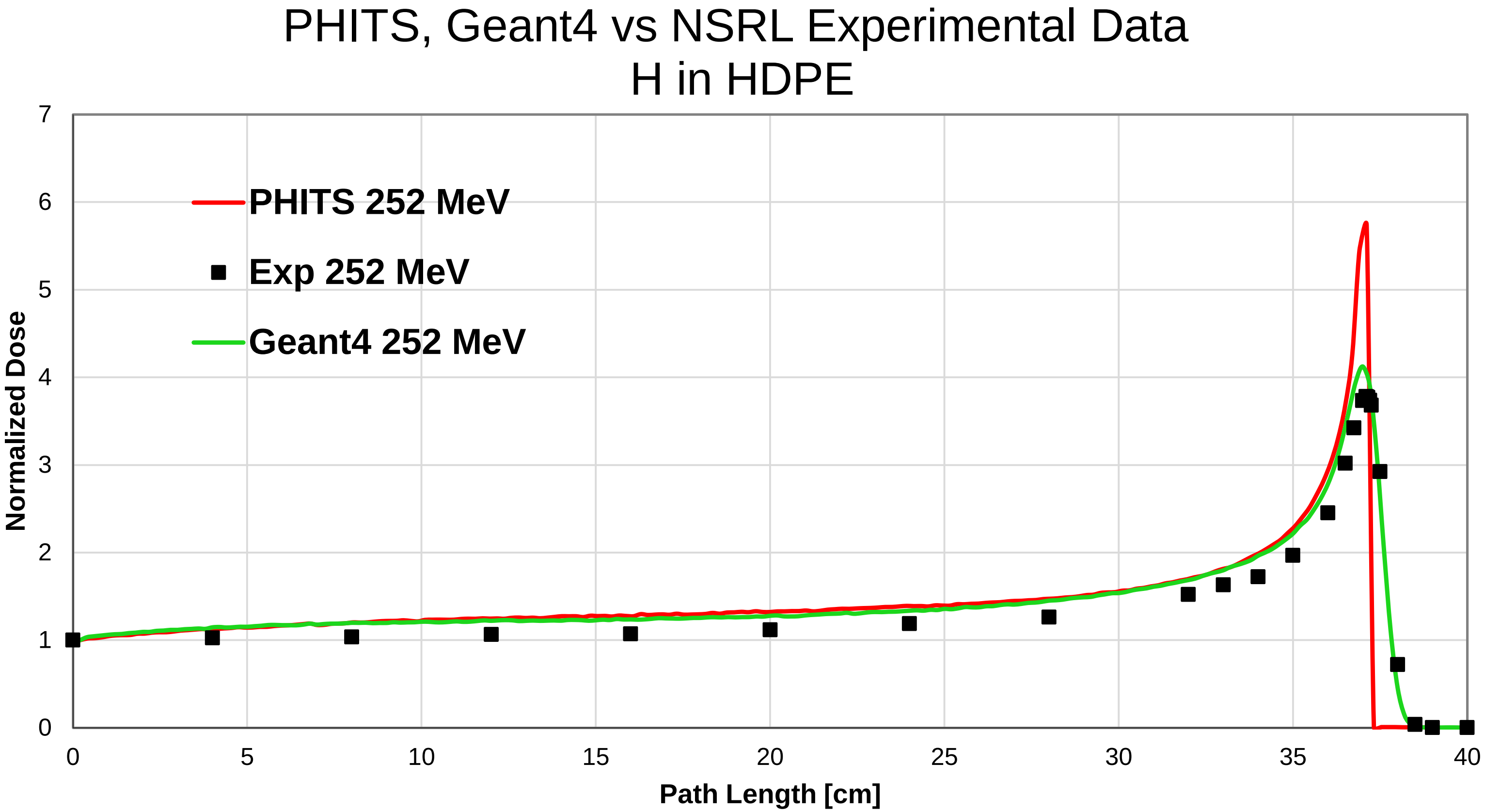


Mars Regolith 963MeV/nuc ^{56}Fe



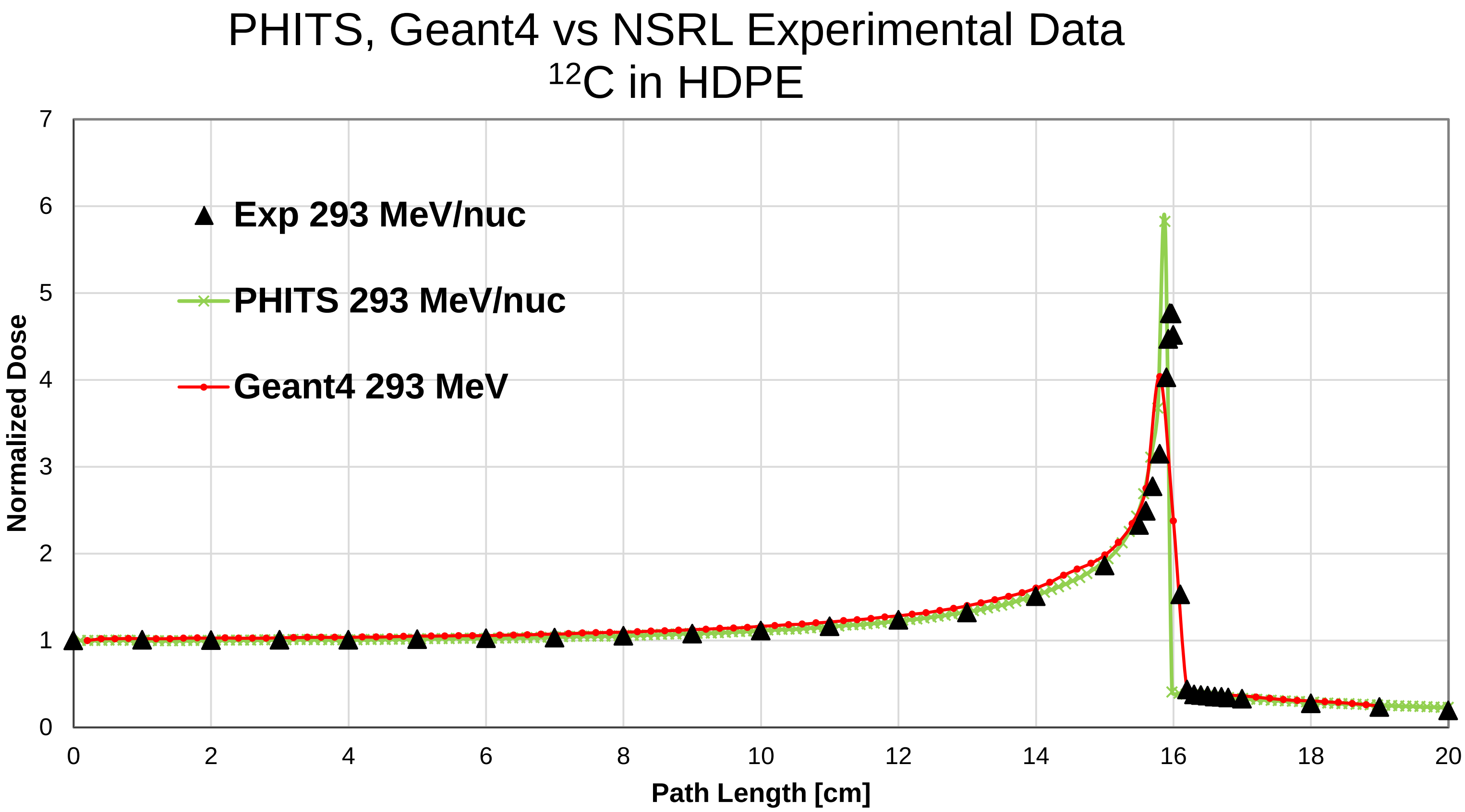
+ ROSSINI 2 Comparisons against BNL data

protons in HDPE, 252 MeV



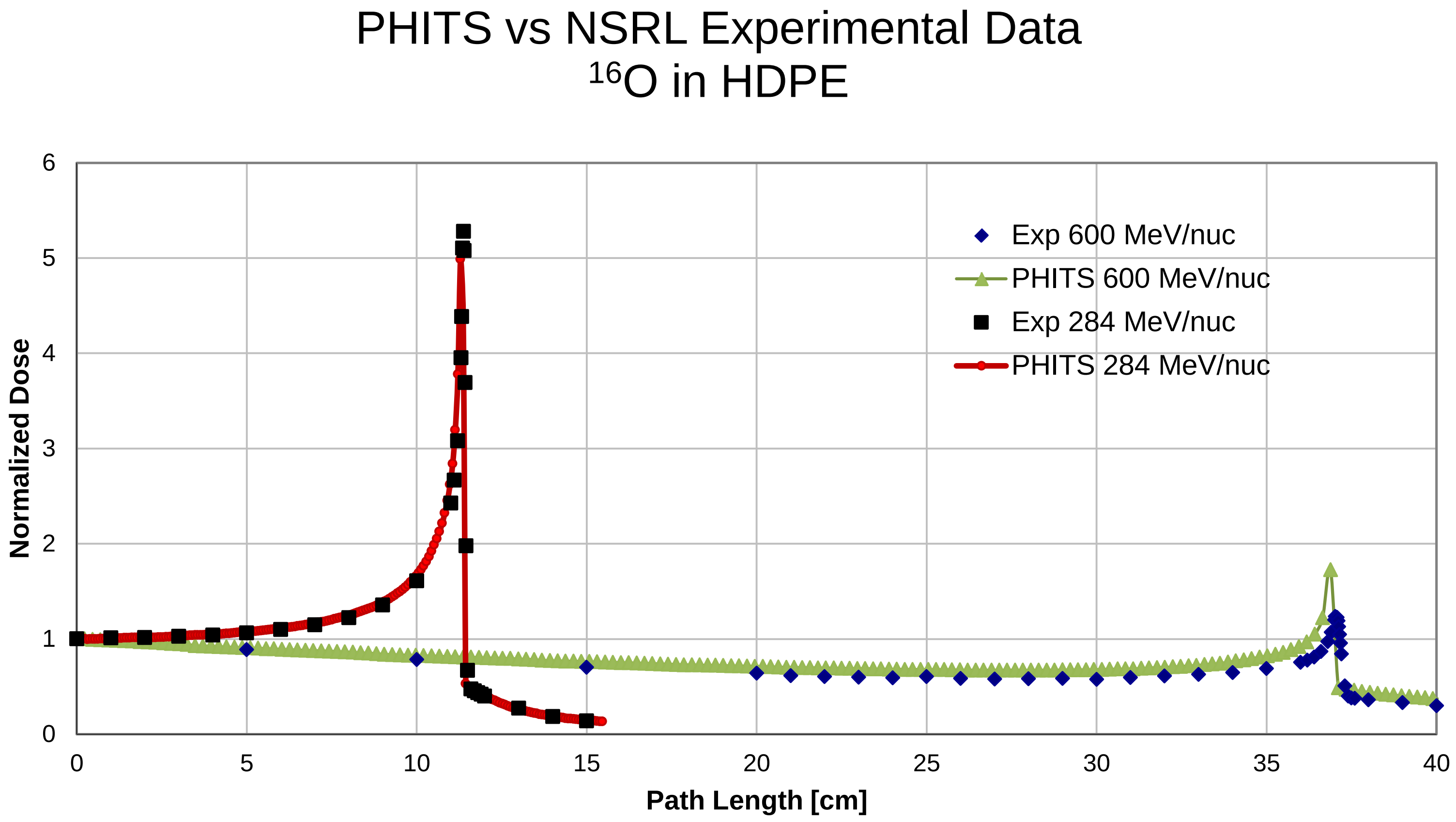
Comparisons against BNL data

^{12}C ions in HDPE, 293 MeV/nuc



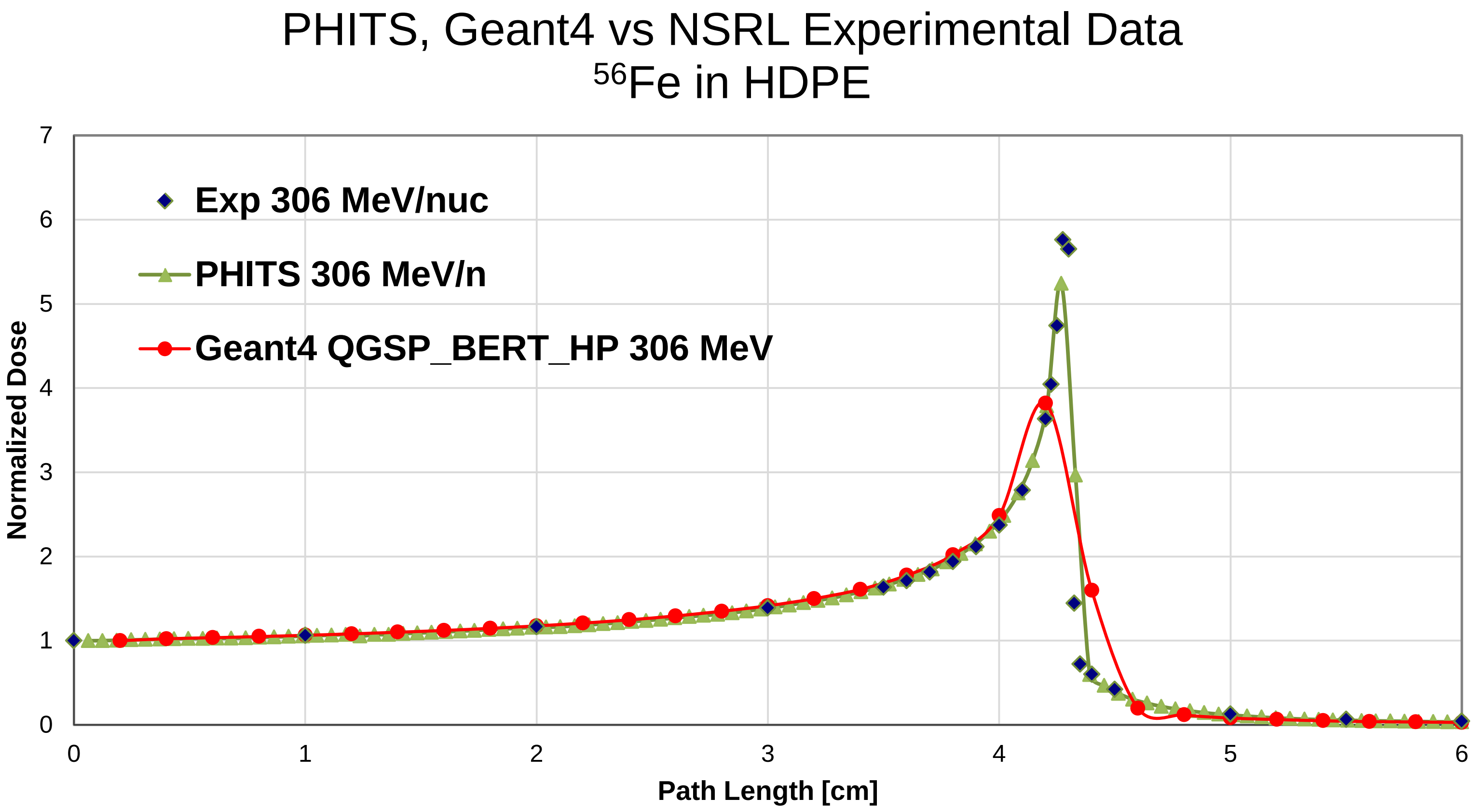
Comparisons against BNL data

^{16}O ions in HDPE, 284 and 600 MeV/nuc



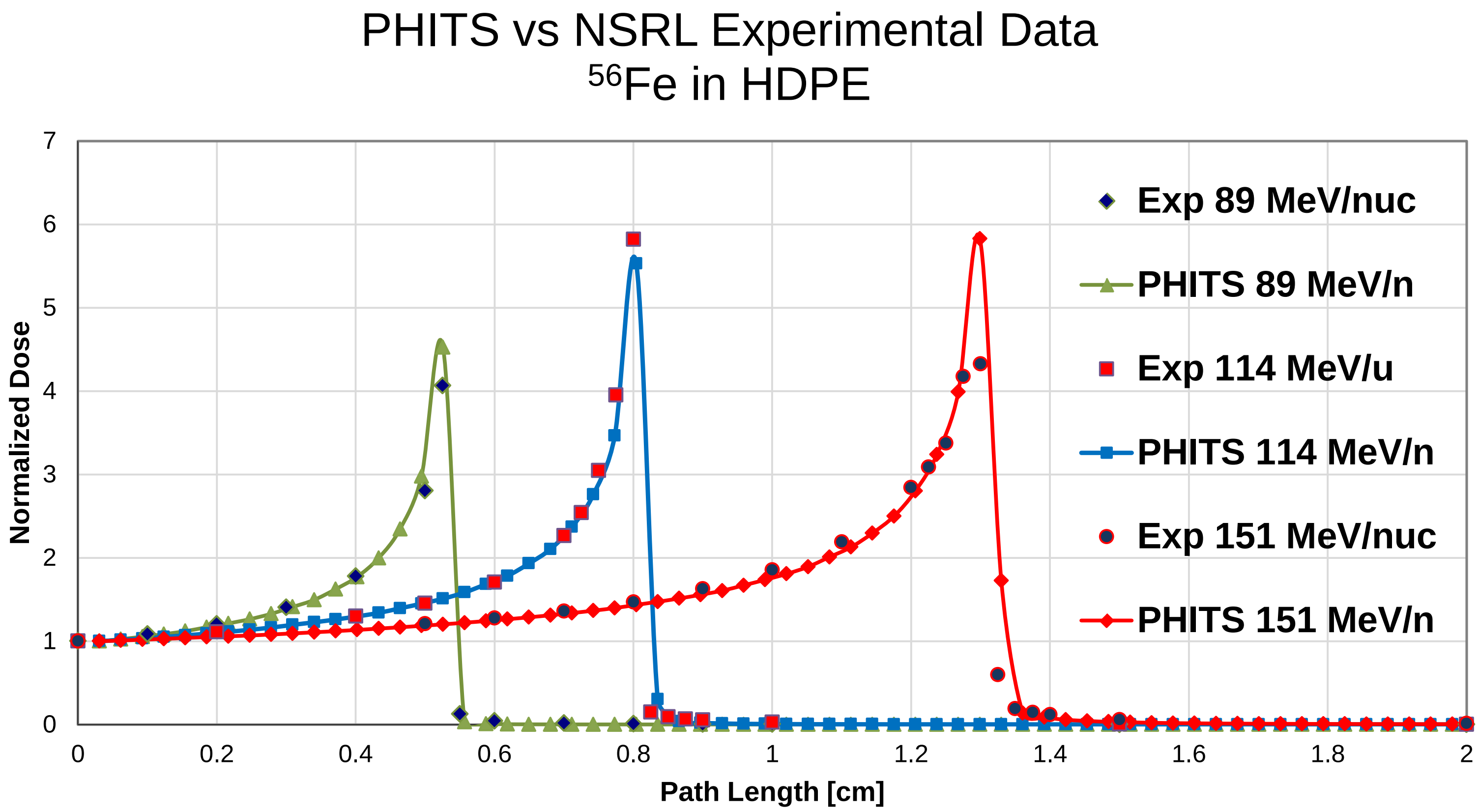
Comparisons against BNL data

^{56}Fe in HDPE, 306 MeV/nuc



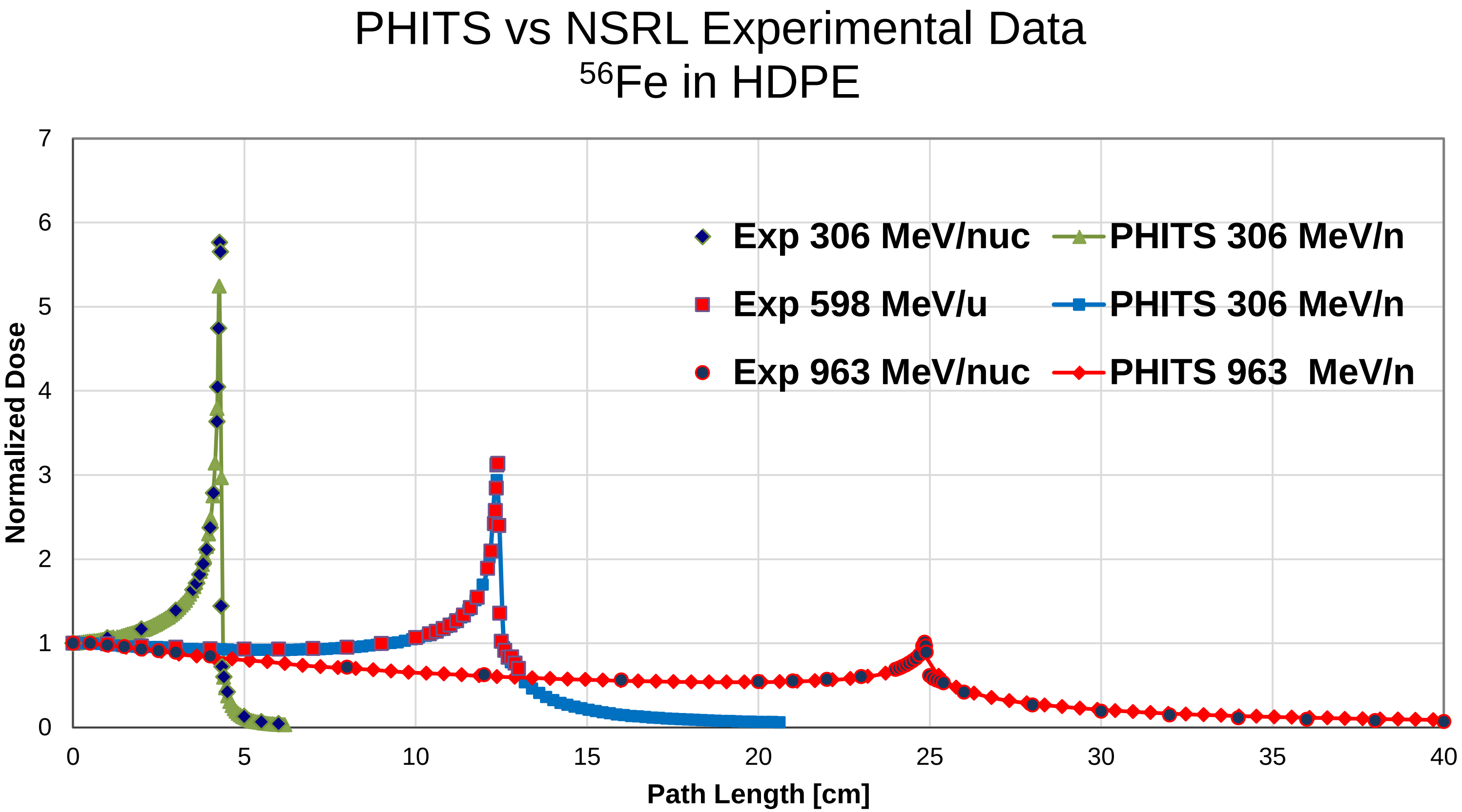
Comparisons against BNL data

^{56}Fe in HDPE, 89, 114, 151 MeV/nuc



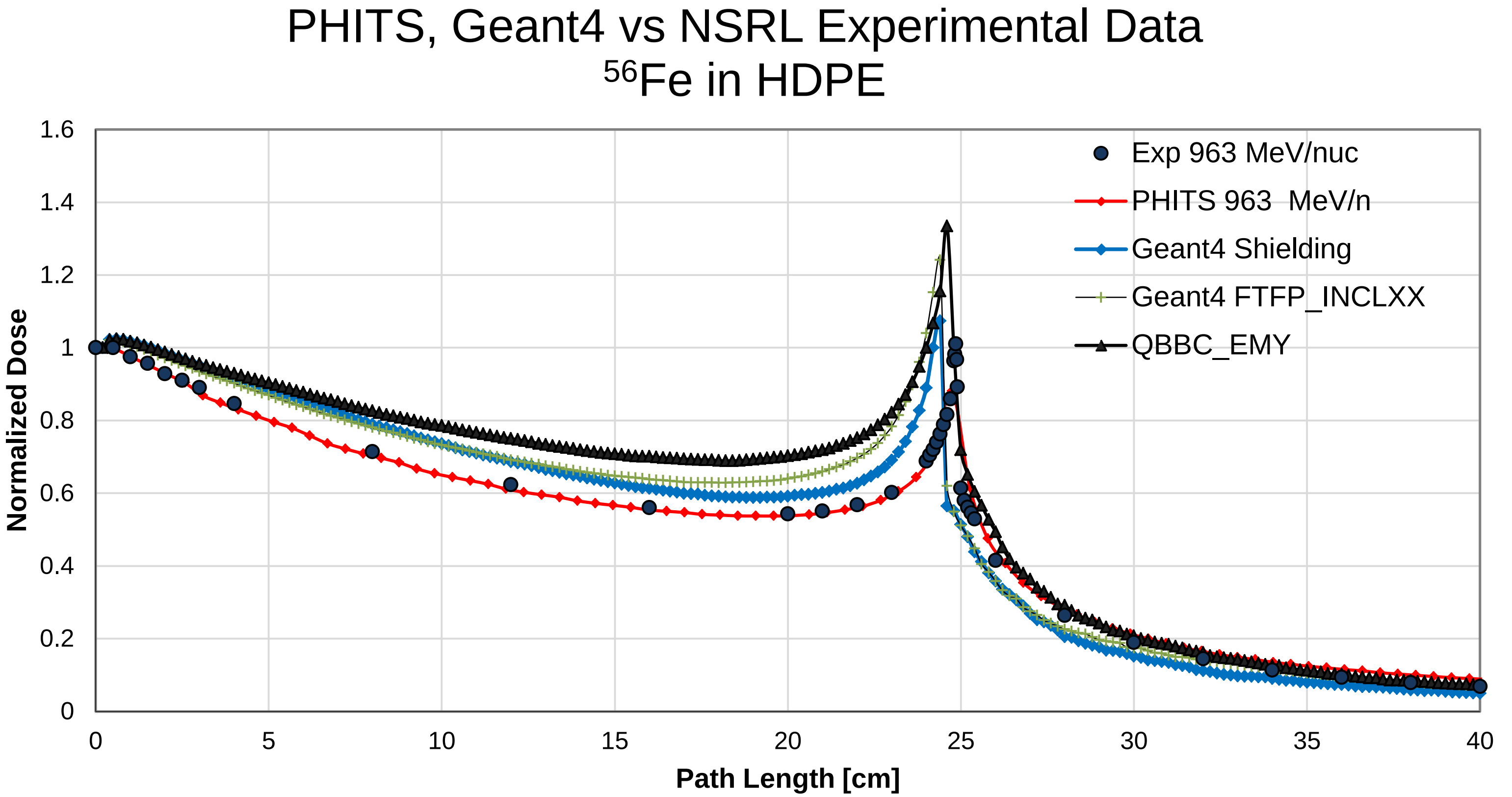
Comparisons against BNL data

^{56}Fe in HDPE, 306, 598, 963 MeV/nuc



+ Comparisons against BNL data

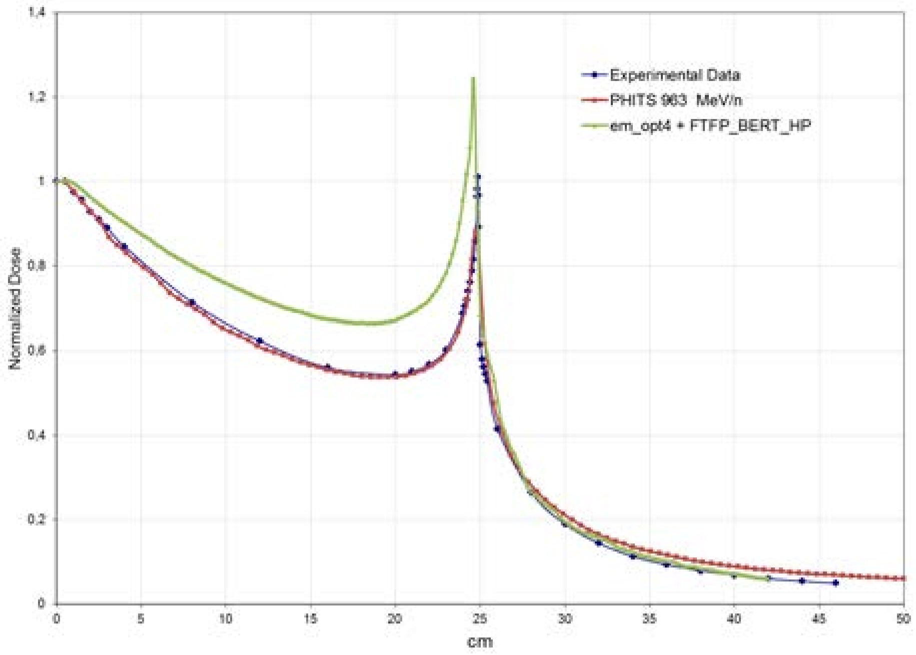
^{56}Fe in HDPE, 963 MeV/nuc



Discrepancy with simulations for high energy iron particles still under investigation

Comparisons against BNL data

^{56}Fe in HDPE, 963 MeV/nuc



Using EM option4 + FTFP_BERT_HP
(defined via GRAS interface)

Tentative summary

- Proton and ion experimental dose-depth results in HDPE up to 963 MeV/nuc @BNL
- Preliminary analysis shows relatively good agreement of Geant4 simulations up to ~300 MeV/n
- Simulations for ^{56}Fe in HDPE, 963 MeV/nuc: PHITS reproduces data very closely, while Geant4 shows significant disagreement for all tried physics options

…and request for help

- More simulations under way with refined data points in critical Bragg peak region
- Role of EM option 0 vs Option 4 being studied for a few hadronic options
- Data can be made available to Geant4 collaborators for further comparisons
- Suggestions / ideas?