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Comparison of Various Codes for Particle Interaction with Material

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CERN Accelerator School
Thessaloniki, Greece
November 11-23, 2018

This Course at CAS-Thessaloniki / Nov. 2018

- Nov. 20: Simulation of Particle-Material Interactions:
  1. Basics
- Nov. 20: Simulation of Particle-Material Interactions:
  2. Advanced Implementation in the Monte-Carlo Codes
- **Nov. 22: Comparison of Various Codes for Particle Interaction with Material**

Outline

- Input Files
- Rules-of-Thumb
- A “Dream Code” Features
- Code Benchmarking: Microscopic and Macroscopic Levels
- Code Intercomarison Campaigns
- Participant’s Experience: Short Stories & Feedback

Input Files

The user creates input files that are subsequently read by the code. These files contain info about the problem in areas such as:

1. Geometry specification with material assignment to the regions
2. Description of materials
3. Scoring/tallying definition - “sensitive region” assignment in item (1) or/and geometry-independent mesh/histograms with corresponding lists of functionals
4. Possible assignment of magnetic and electric fields and other properties affecting particle transport in regions of item (1)
5. The source term either in a simple parametric form or as an external file
6. The cutoff energies or/and time of flight (TOF) for particle classes, materials and regions
7. Possible material/region spatial resolution and pilot steps
8. Any variance reduction techniques to be applied for various interaction classes, regions, materials etc.

Rules-of-Thumb for MC Code Users

1. Define and sample the geometry and source well
2. You cannot recover lost information
3. Question the stability and reliability of results
4. Be conservative and cautious with variance reduction biasing
5. The number of histories run is not indicative of the quality of the results; rather aim at a RMS statistical error less than a few % in the regions of interest
6. In short runs, try to understand what a combination of variance reduction techniques provides the highest computing efficiency and estimate required total number of histories
7. Use biasing in particle-, cutoff energy-, space- and material--dependent manner
8. Minimize the number of unneeded regions and histograms

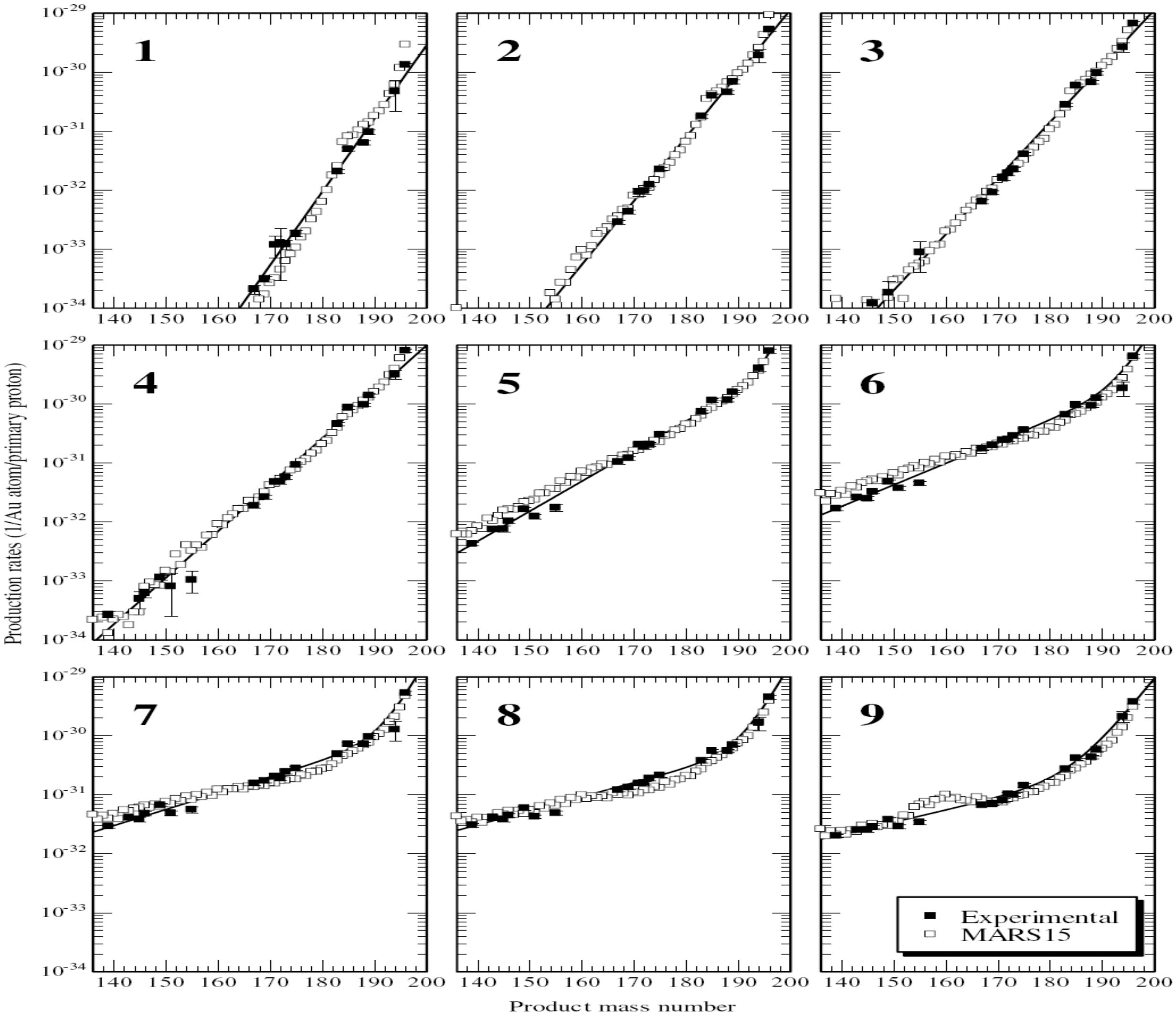
"A Dream Code" Features

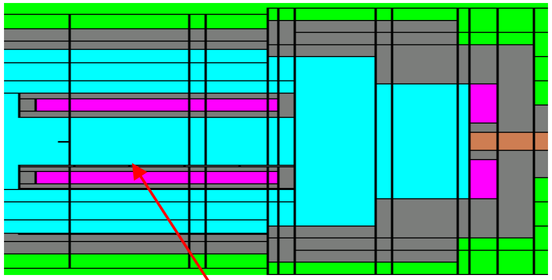
- Reliability
- Predictive power
- Best performance in benchmarking campaigns
- Geometry module capabilities in complex accelerator environment with automated beamline and ring lattice creation and implementation in the model (Beamline Builders in MARS15 and FLUKA), with detailed magnet & RF description along with their EM-fields
- Particle tracking capabilities, including arbitrary magnetic fields and multi-turn tracking with accelerator codes (PTC, SixTrack, etc)
- User friendliness, first of all in geometry model building, but also in a choice of key input parameters (physics list, biasing options, cutoff energies etc.)
- Good CPU performance; MPI readiness
- Import/export in GDML format; CAD reader

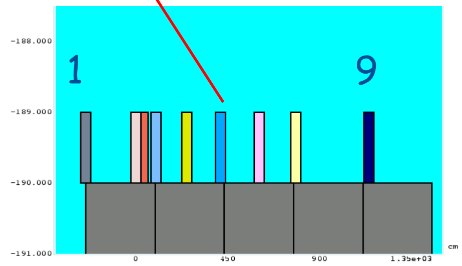
Code Benchmarking

- **Debugging:** The code should calculate what is supposed to calculate
- **Validation:** Results should agree with established (analytic) result for the specific case
- **Inter-comparison:** Two codes should agree if the model is the same
- **Verification:** The code should agree with (reliable) measurements

Nuclide Production at 12-GeV K2K Target Station

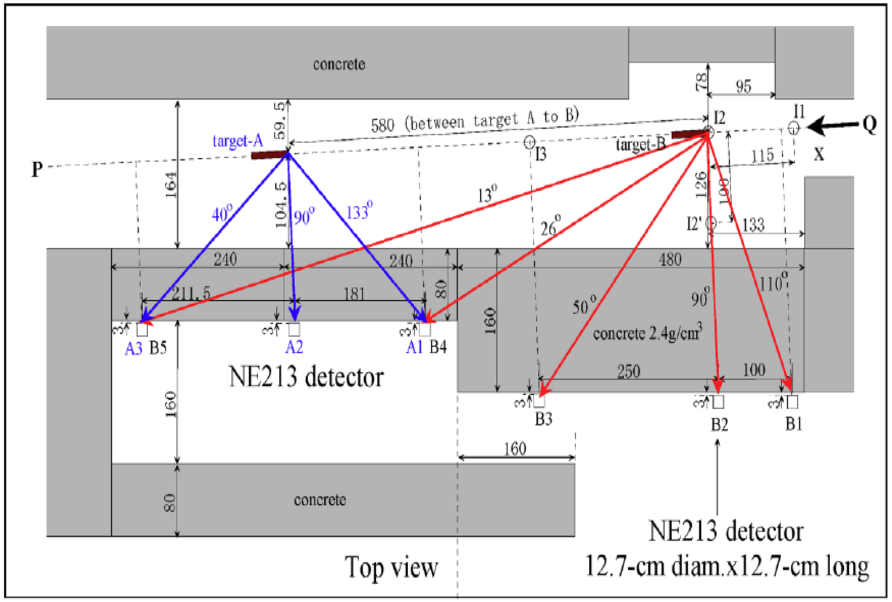


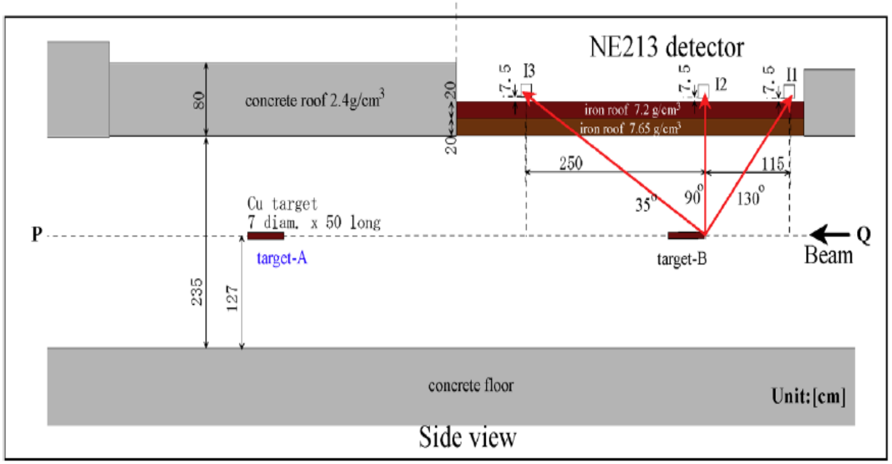




Nine gold foil samples over 12 meters

CERF 120 GeV/c Hadron Beam Facility (1)





102 N. Nakao et al. / Nucl. Instr. and Meth. in Phys. Res. B 266 (2008) 93–106

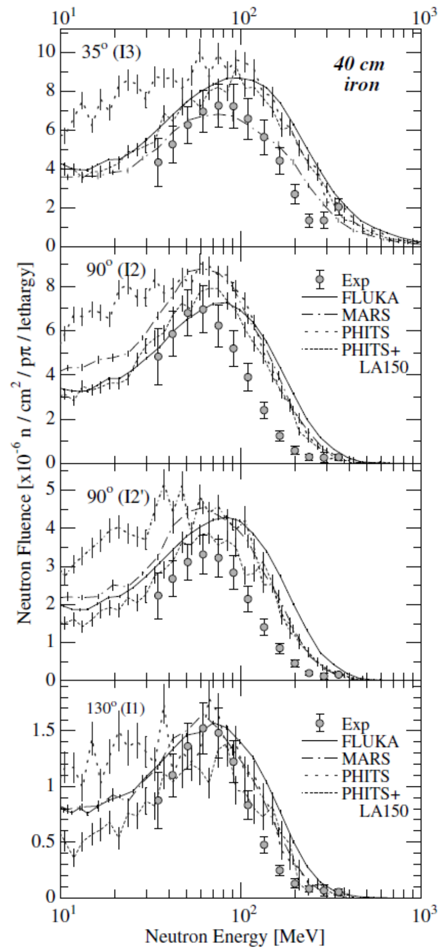


Fig. 11. Neutron energy spectra above the 40 cm thick iron shield roof, compared between measurement and simulation results. Note that position I2' is at 90° with respect to the beam direction but displaced laterally by 1 m.

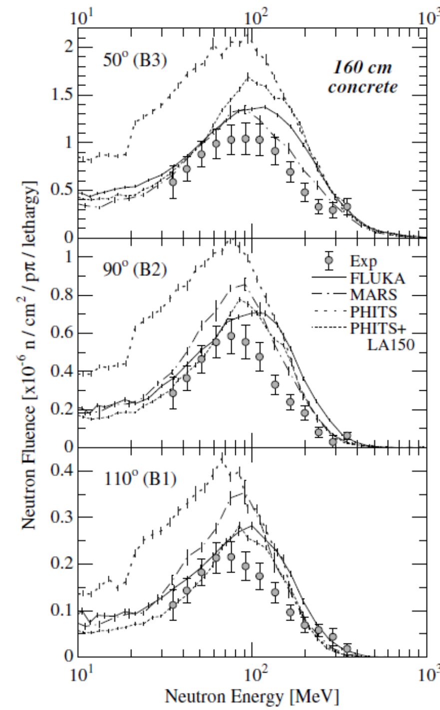


Fig. 12. Neutron energy spectra behind the 160 cm thick concrete shield, compared between measurement and simulation results.

not negligible and contribute to the results of the maximum energy group in the unfolding process. For the results in the other lateral locations, neutron fluxes above 380 MeV are negligible, and no significant bump can be seen. Improved neutron spectra are expected to be obtained when extended response functions with wider neutron energy range are available in the future.

6.2. Discussions for measurement

The measurements above the iron roof have been car-

CERF 120 GeV/c Hadron Beam Facility (2)

N. Nakao et al. / Nucl. Instr. and Meth. in Phys. Res. B 266 (2008) 93–106 103

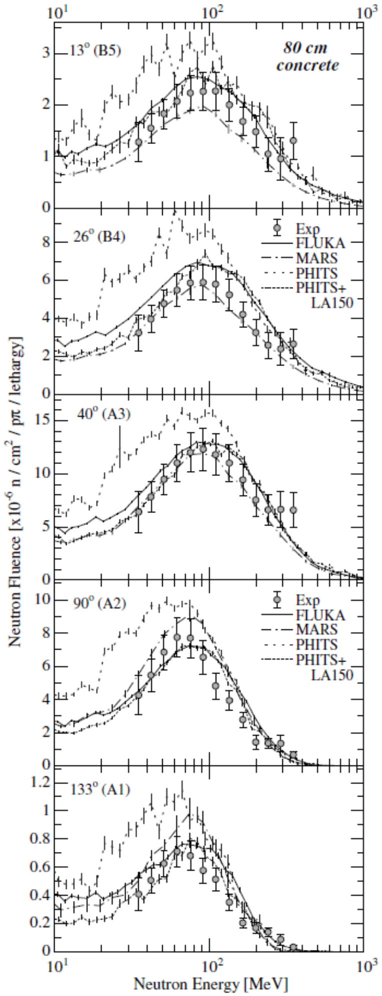


Fig. 13. Neutron energy spectra behind the 80 cm thick concrete shield, compared between measurement and simulation results.

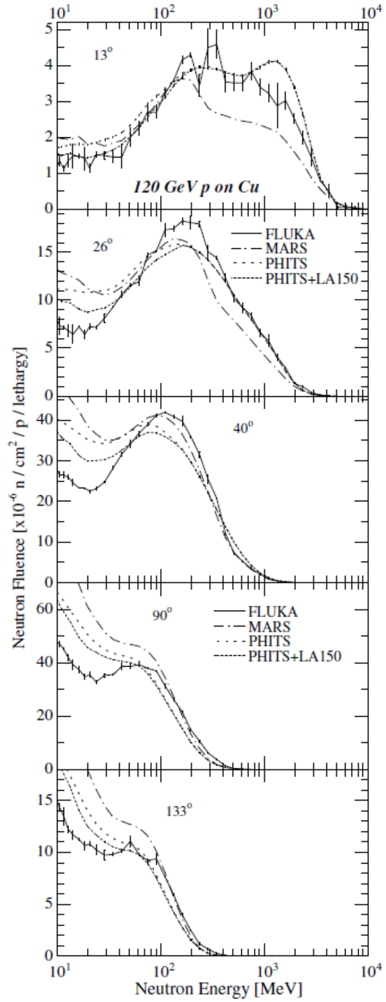


Fig. 14. Simulated results of neutron energy spectra from a copper target (7-cm diameter by 50-cm long) impacted by 120 GeV protons.

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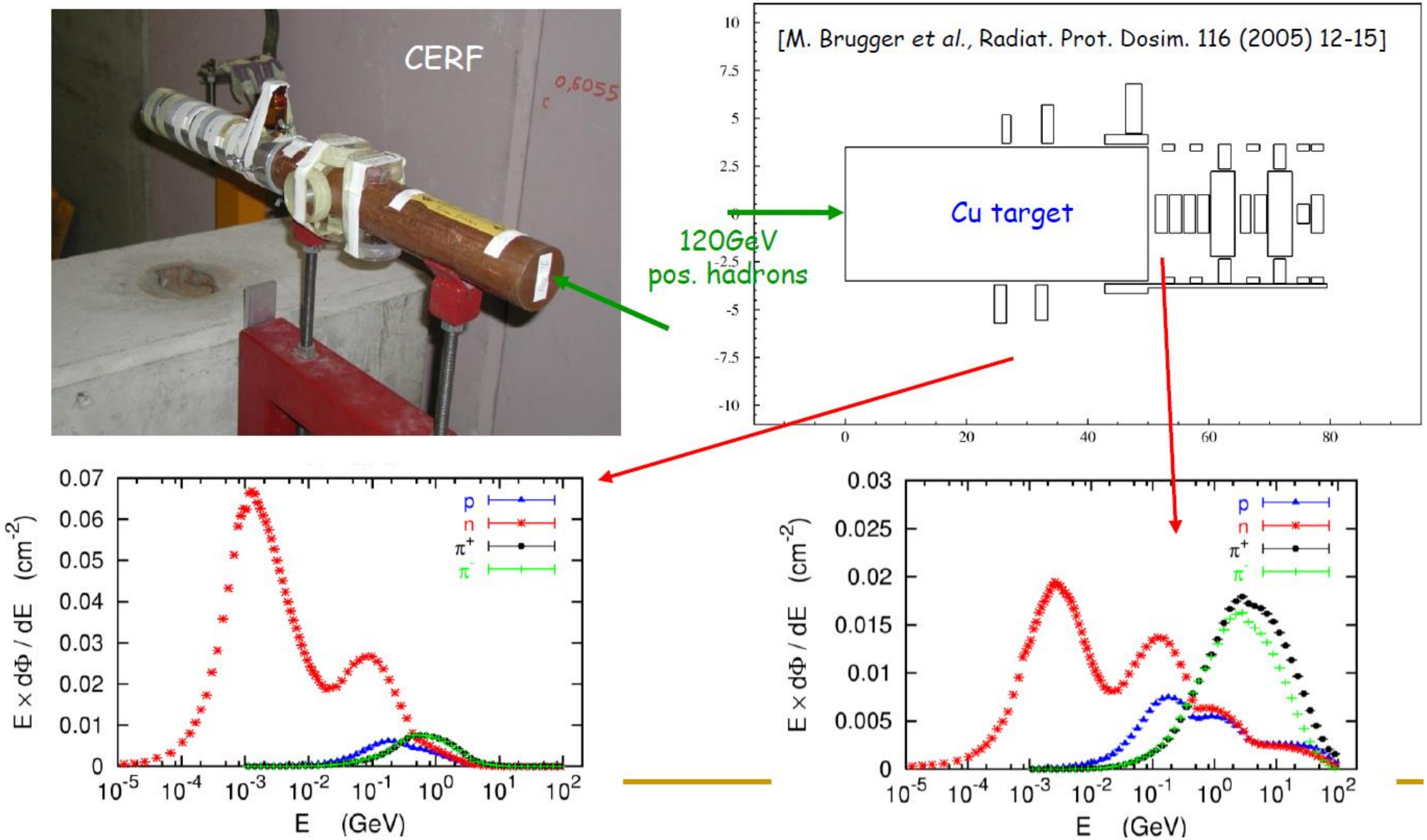
CERF Residual Dose Benchmarking (2005)

Irradiation of samples of different materials to the stray radiation field created by the interaction of a 120 GeV positively charged hadron beam in a copper target



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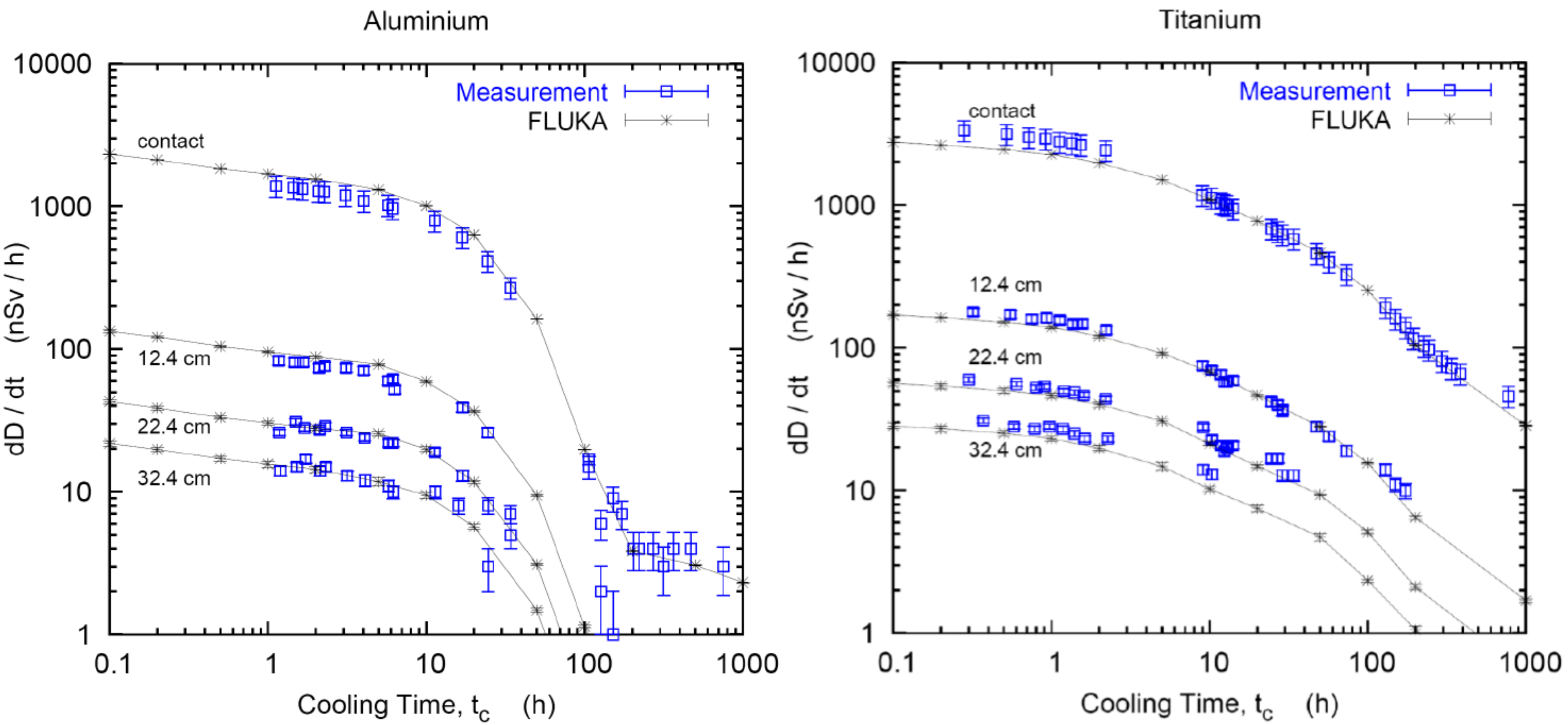
CERF Residual Dose Benchmarking (2005)

Dose rate as function of cooling time for different distances between sample and detector

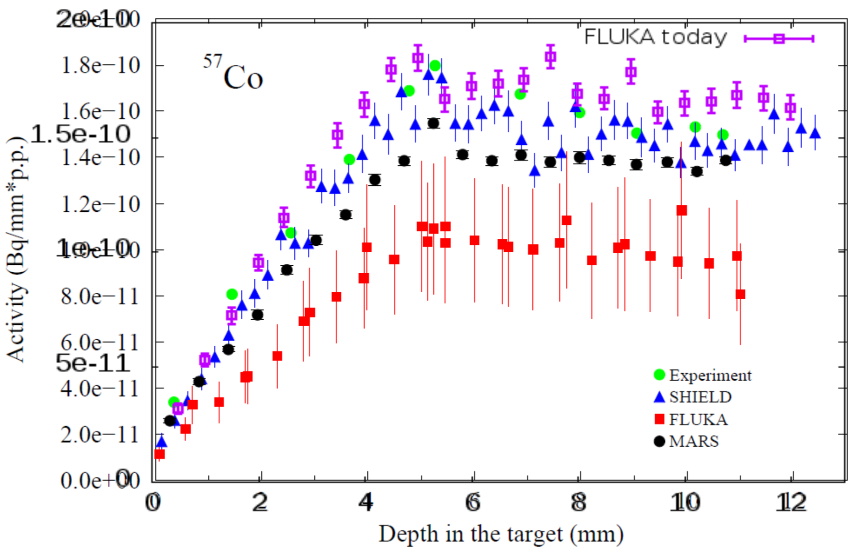


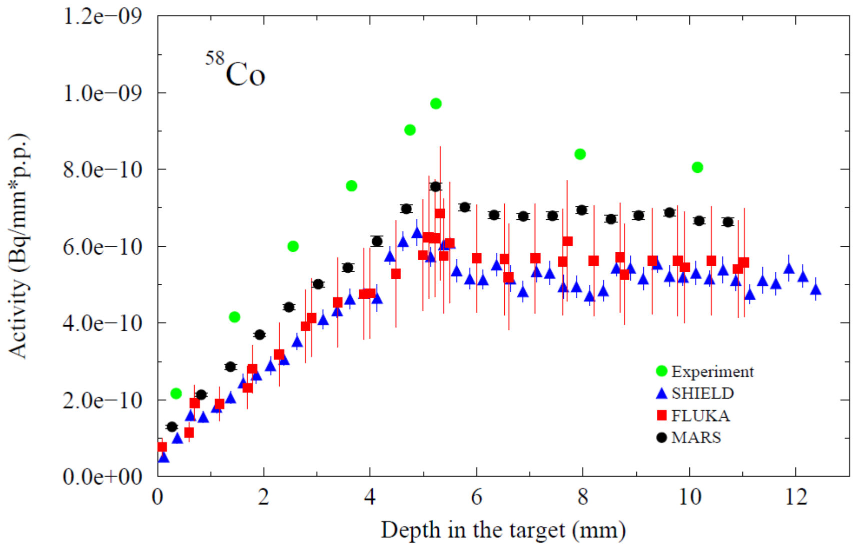
[M. Brugger *et al.*, Radiat. Prot. Dosim. 116 (2005) 12-15]

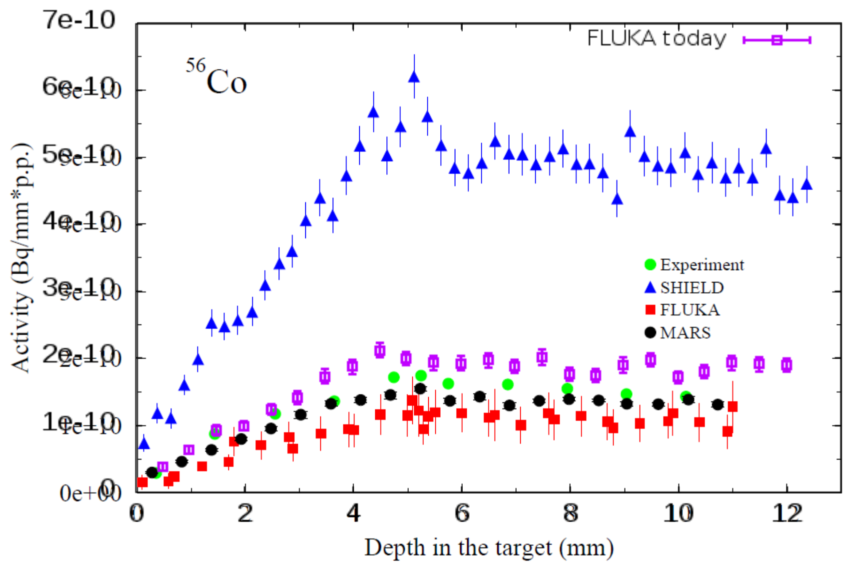
Activity Benchmarking at GSI

500 MeV/n ^{238}U beam on Cu

[E. Mustafin *et al.*, EPAC 2006, TUPLS141, 1834]







CERN CHARM Facility at 24 GeV/c

T. Oyama et al. — *Nuclear Inst, and Methods in Physics Research B 434 (2018) 29–36*

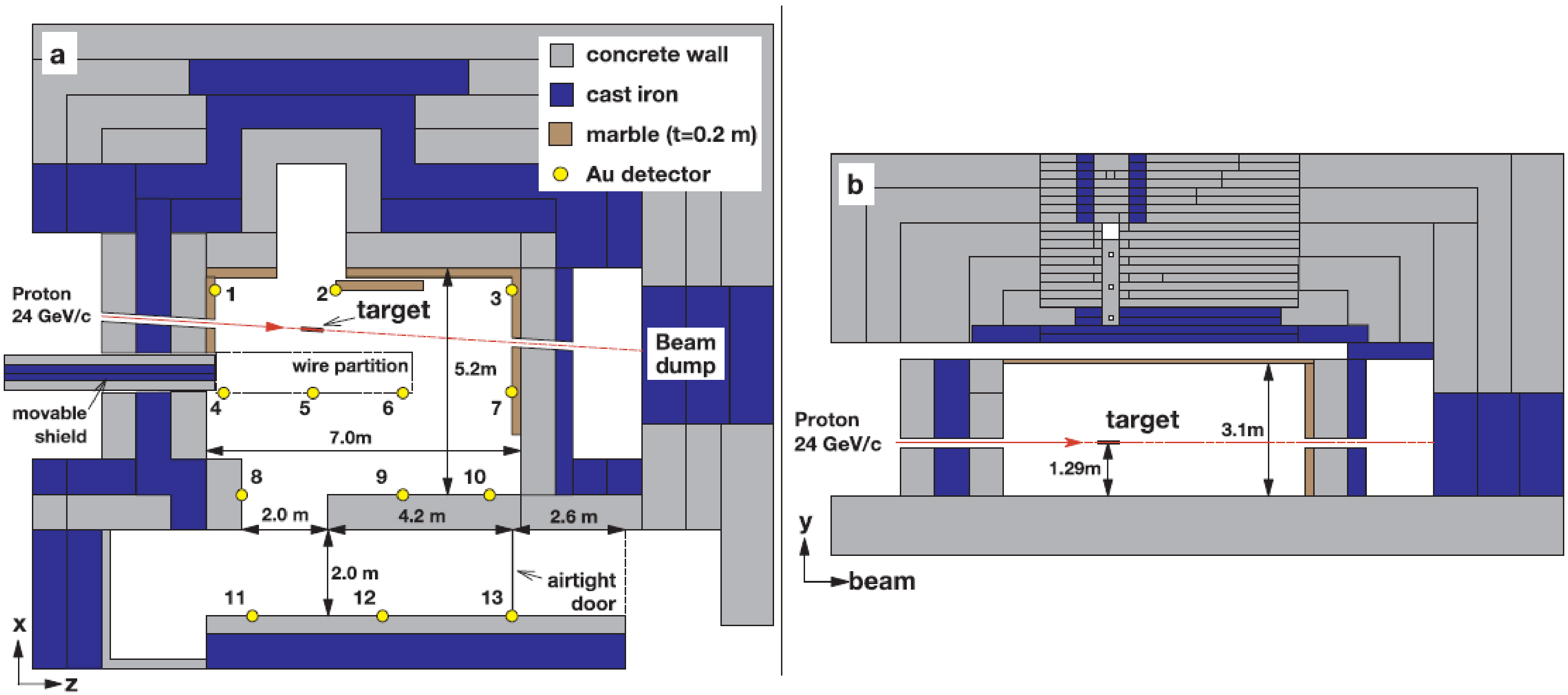
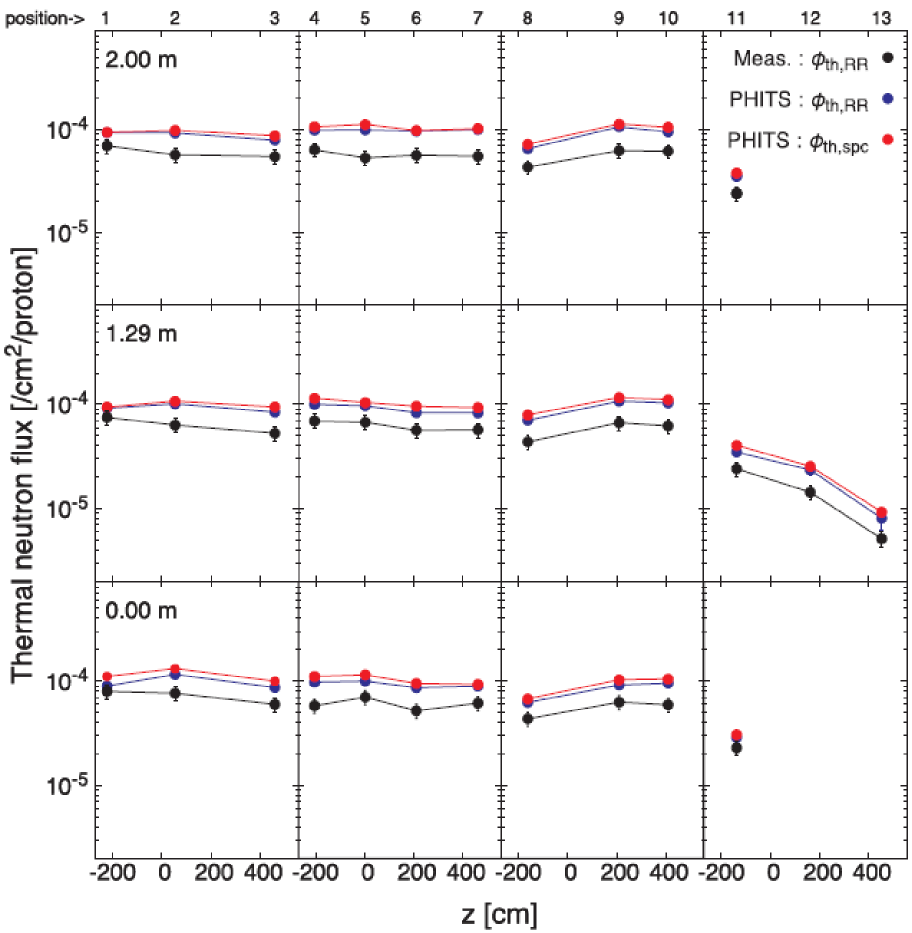
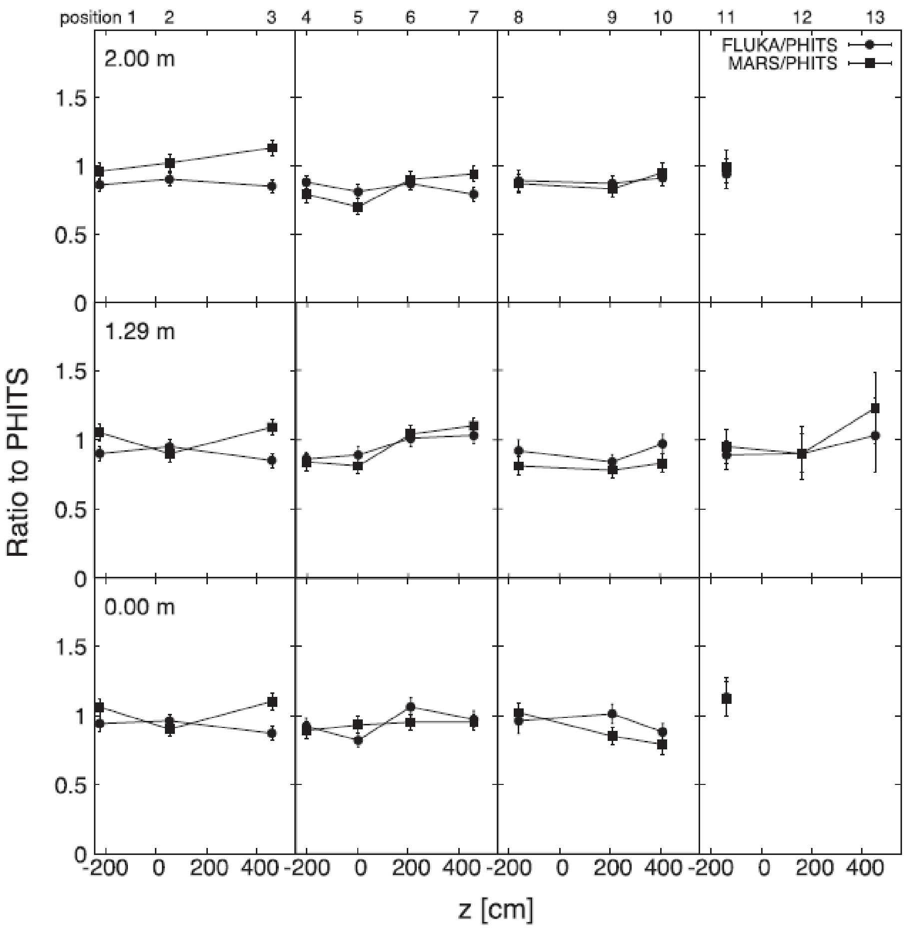


Fig. 1. Cross-sectional view (a) and longitudinal-sectional view (b) taken along the Cu target plane of the CHARM facility, together with important dimensions. The numbers 1–13 indicate the experimental location of the gold foils.

PHITS, FLUKA & MARS *vs* CHARM 24 GeV/c Data



PHITS & Exp within 50%



FLUKA, PHITS & MARS within 30%

T. Oyama et al., NIM, **B434** (2018) 29-36

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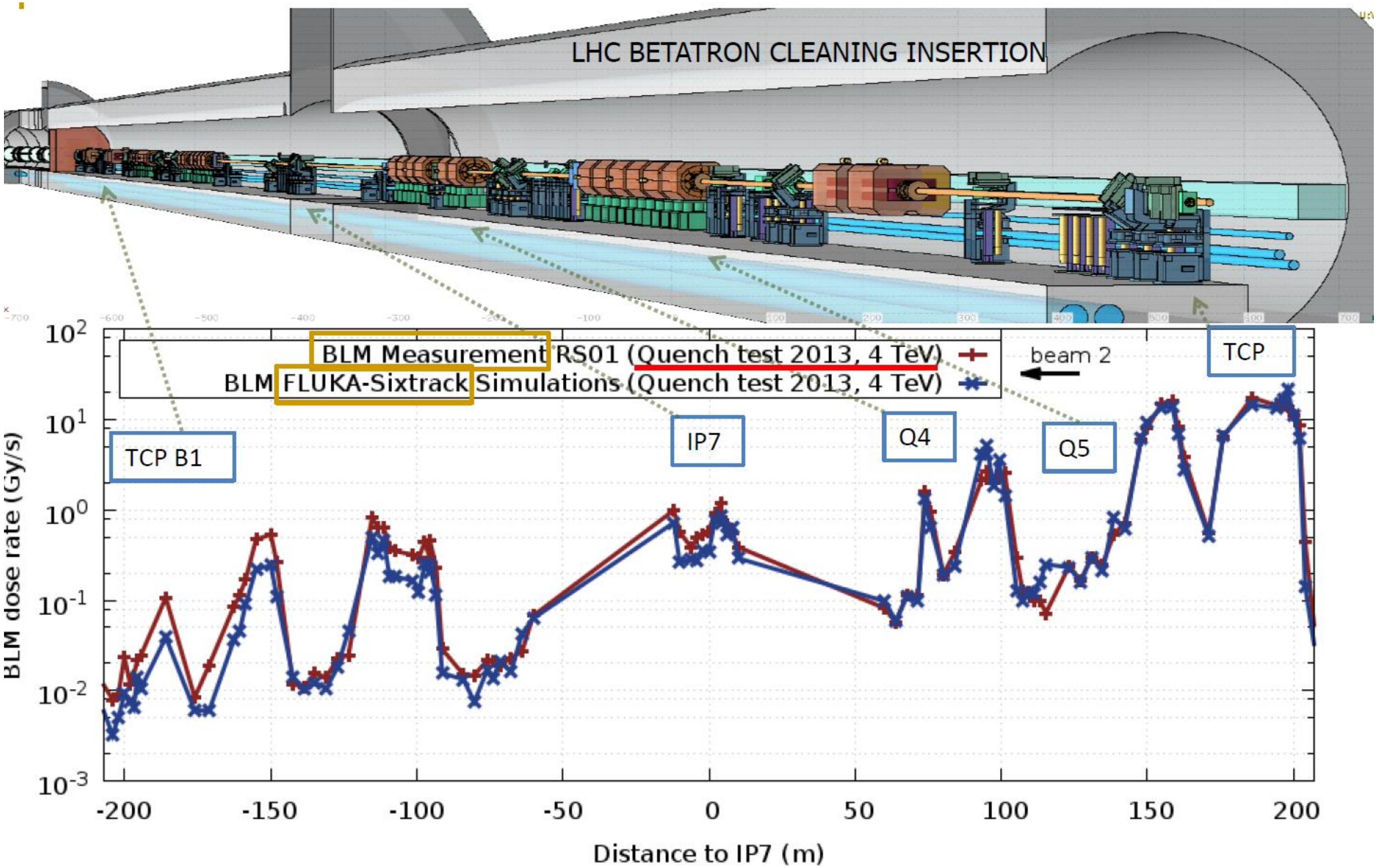
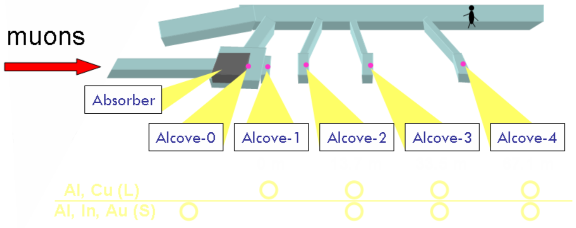
FLUKA Verification at LHC Betatron Cleaning

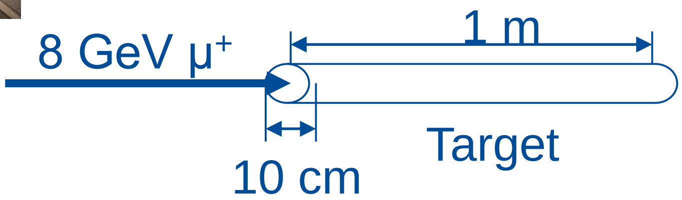


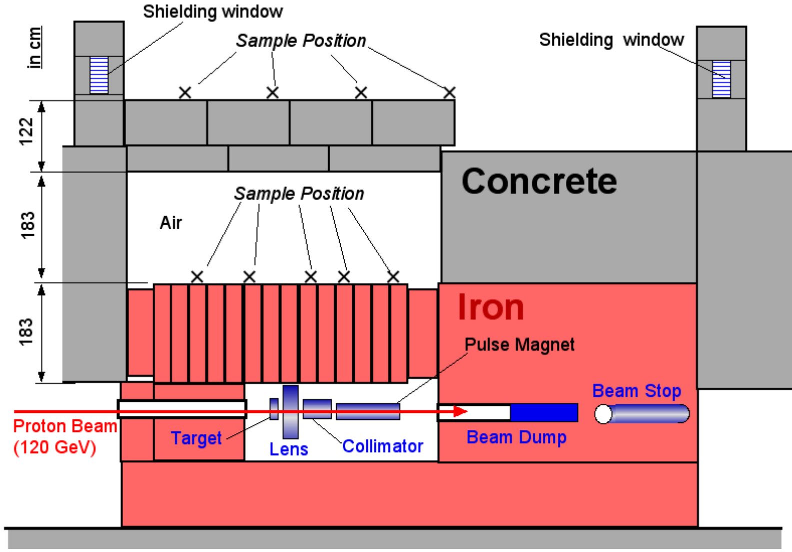
Shielding and Radiation Effect Experiment

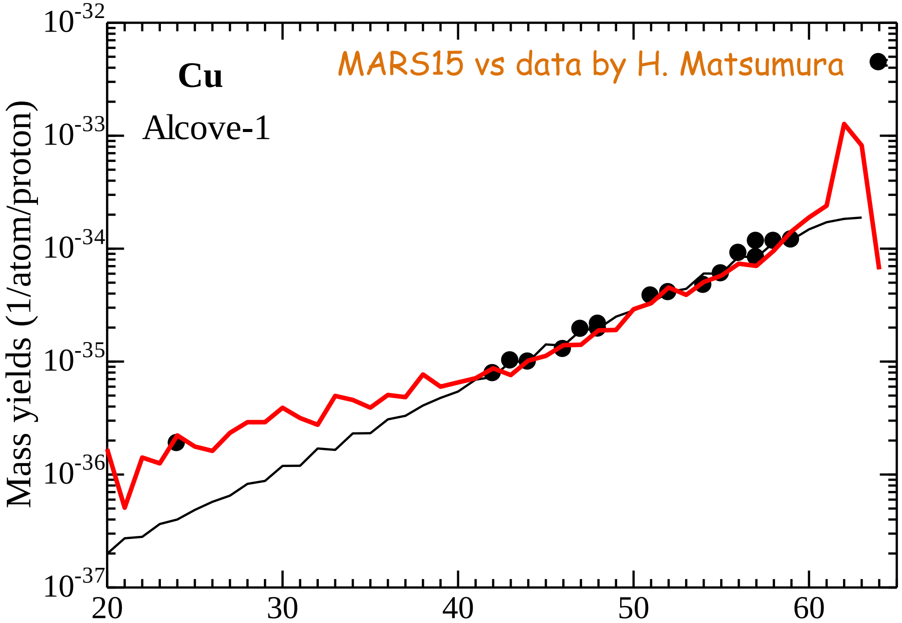
JASMIN Japan-FNAL Collaboration:
<u>Shielding and Radiation Effect Experiments at FNAL</u>
T-972 (2007-2009)
T-993 and T-994 (2009-2012)
Shielding data and code benchmarking; targets, collimators and thick shields; radiation effects on instruments and materials

Example: Muon-induced nuclide production









Air Activation at NuMI Neutrino Production Facility

To get more confidence in the MARS15-based LBNF target station design, a benchmarking campaign on air activation has been recently undertaken at the Fermilab NuMI target station for 120-GeV beam on target

NIM **B414** (2018) 4-10

Measured and calculated production rate density (cm^{-3} POT^{-1} s^{-1}) for the most important radionuclides generated in the air in the beam enclosure of the NuMI target chase.

Production rate	^{41}Ar	^{11}C	^{13}N	^{15}O
Measurement	1.98×10^{-12}	6.38×10^{-11}	4.07×10^{-11}	3.50×10^{-11}
Standard methodology	6.85×10^{-12}	2.22×10^{-10}	5.22×10^{-11}	9.16×10^{-11}
MARS15	1.08×10^{-12}	4.44×10^{-11}	3.71×10^{-11}	4.16×10^{-11}
MARS15/data	0.55	0.70	0.91	1.19

50%

10-30%

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120-GeV Muon Range-out Distance in Dolomite (m)

LBNF 120 GeV

	All dolomite	Dolomite after absorber
MARS15	223.7	214.5
FLUKA	223	218

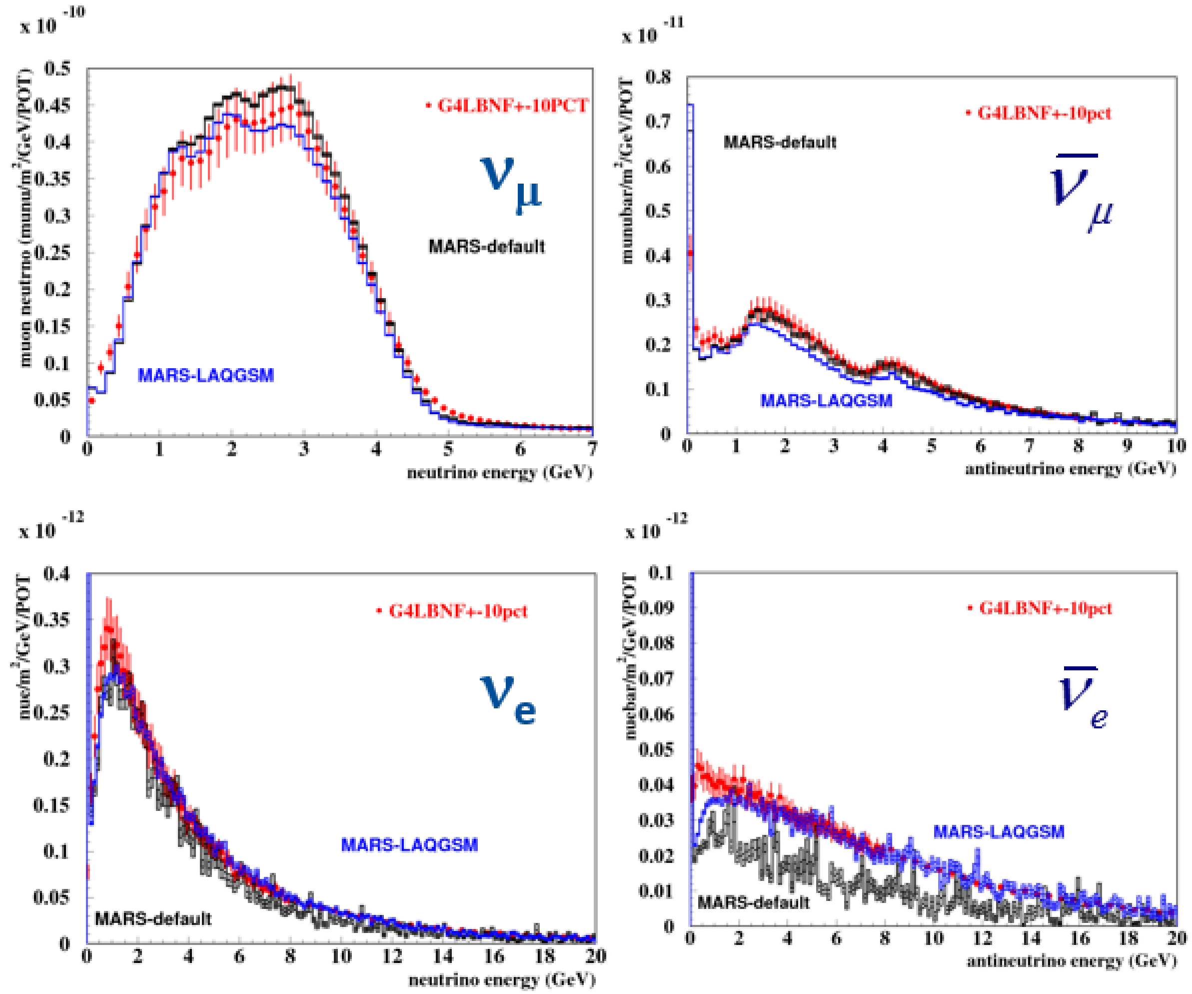
Notes:

1. All-dolomite FLUKA and MARS models are identical;
   MARS statistics 40M muons (8 decades), FLUKA …
2. Absorber model in FLUKA ?
   MARS statistics 80M muons (9 decades), FLUKA …

Neutrino Fluxes at Far Detector (1300 km)

Thorough search and elimination of differences in MARS15LBNF and G4LBNF models were performed on the optimized ν-flux: geometry, materials, magnetic fields etc.

ν-fluxes at the Far Detector calculated with MARS15 and Geant4 now agree within 10%. The code related uncertainties were reduced to the differences in the event generators, especially for K^- and K^0 mesons (need data!)



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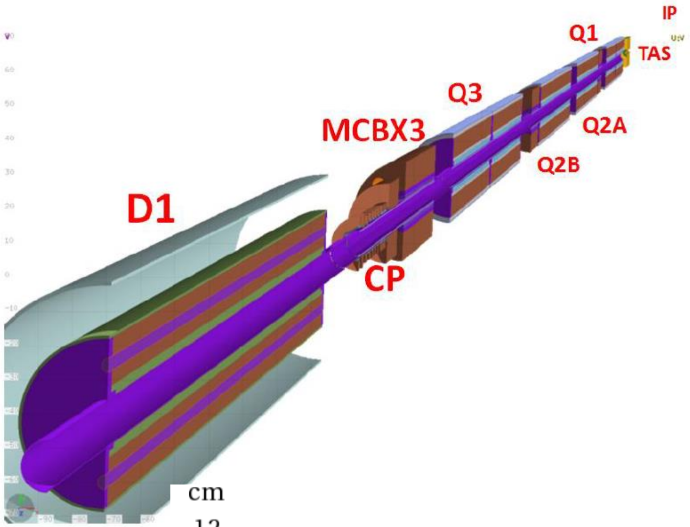
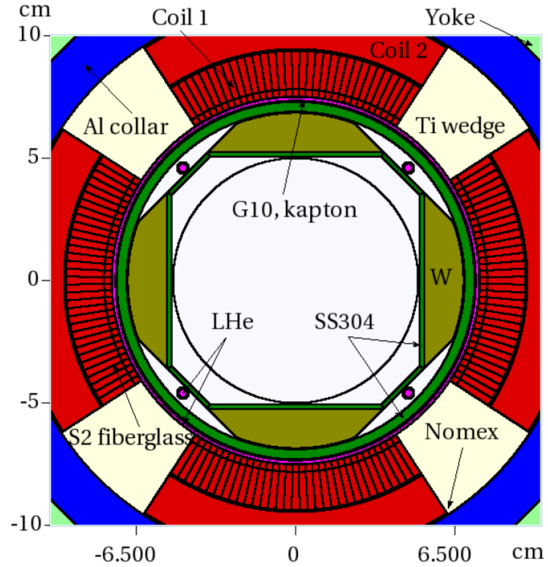
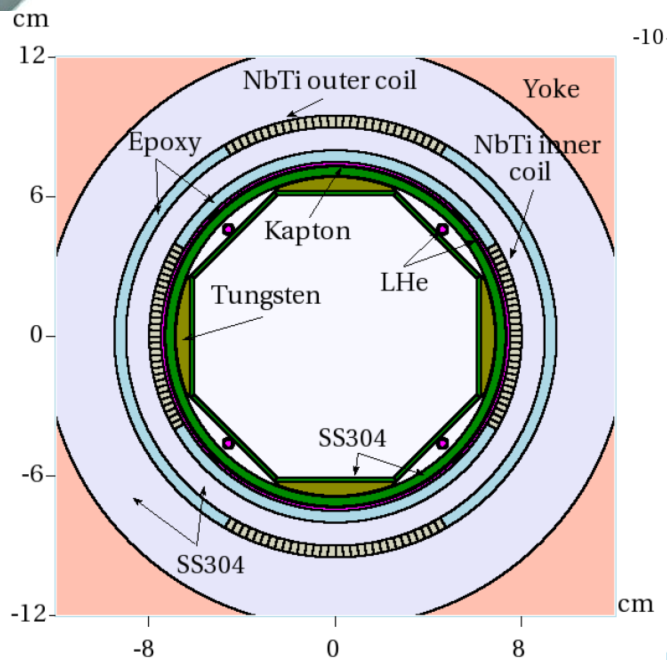
HL-LHC IT FLUKA-MARS Study and Intercomparison



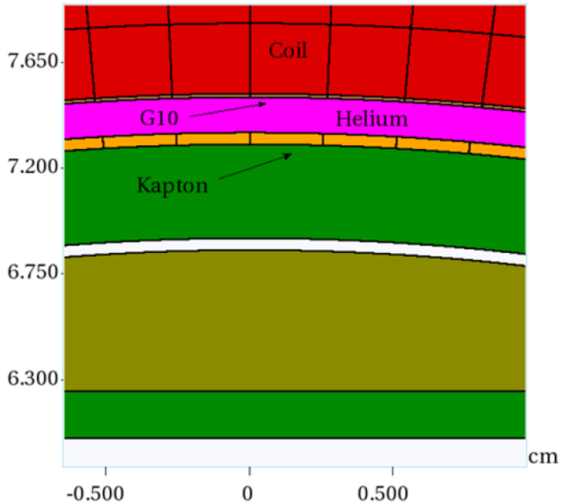


Q1



MCBX

Q1-Q3 details



PRAB (2015)

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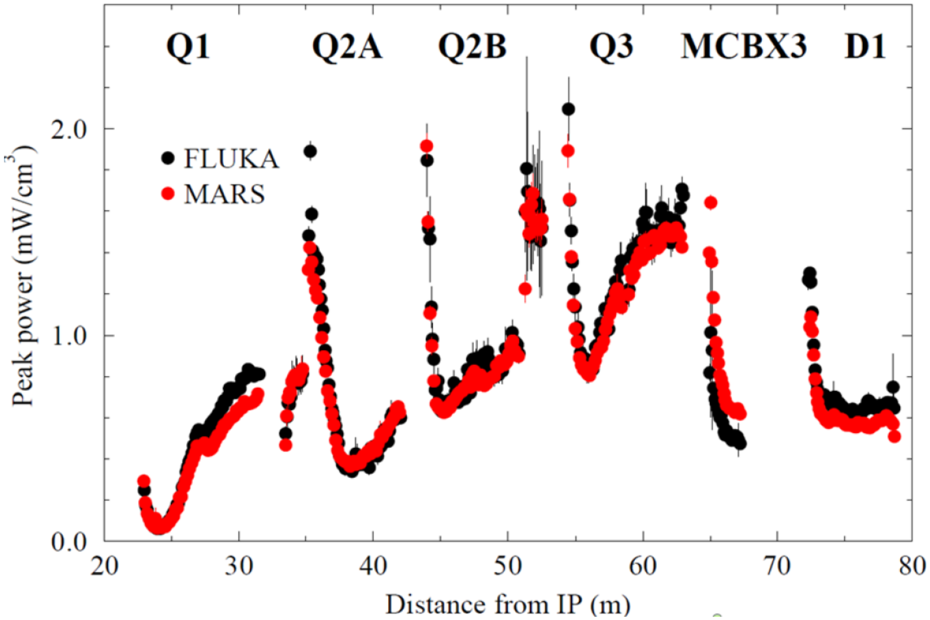
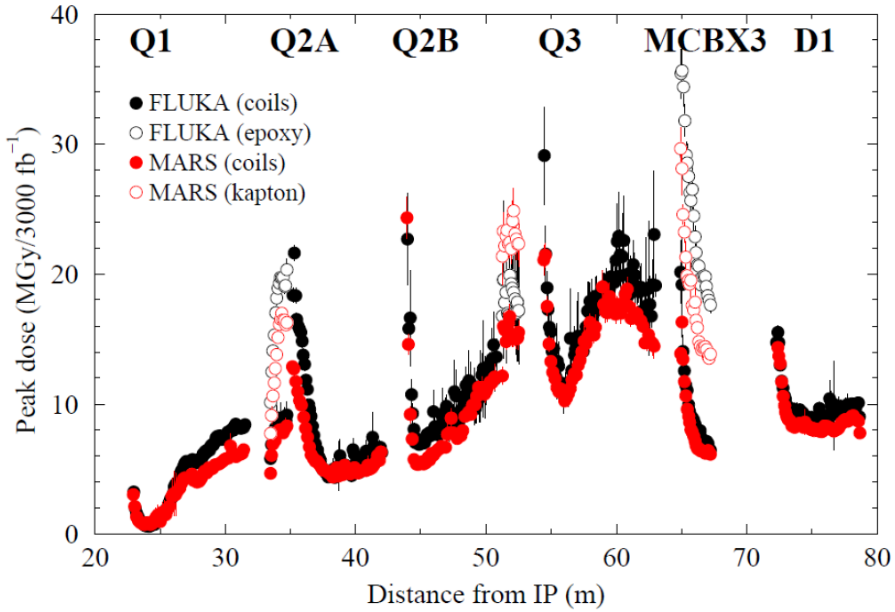
HL-LHC IT FLUKA-MARS Study and Intercomparison





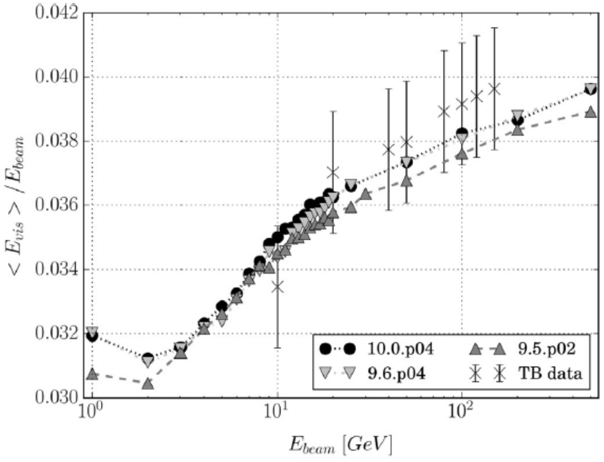
HL-LHC IT FLUKA-MARS Study and Intercomparison

TABLE I. Integral power dissipation (W) in components of inner triplet calculated with FLUKA and MARS codes for two different interconnect (IC) gap lengths.

Component	FLUKA				MARS	
	10 cm gap in ICs		50 cm gap in ICs		50 cm gap in ICs	
	Magnet cold mass	Beam screen	Magnet cold mass	Beam screen	Magnet cold mass	Beam screen
Q1A+Q1B	100	170	100	170	95	170
Q2A+orbit corrector	95	60	100	65	100	65
Q2B+orbit corrector	115	80	120	80	115	80
Q3A+Q3B	140	80	140	80	135	75
Corrector package	55	55	60	55	60	65
D1	90	60	90	60	90	55
Interconnects	20	140	20	105	15	85
Total	615	645	630	615	615	600

GEANT4 vs Data

Cu-Lar ATLAS HEC Calorimeter



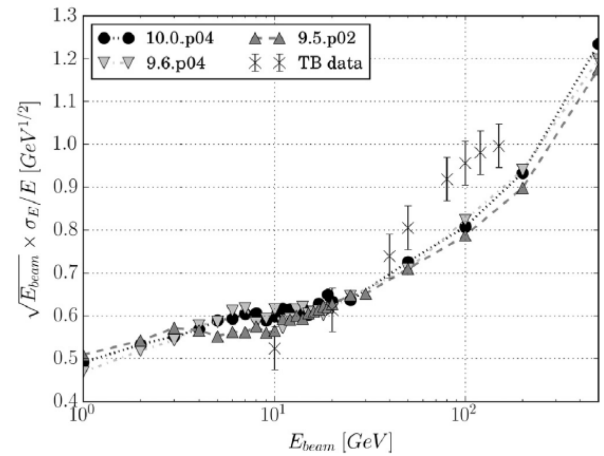
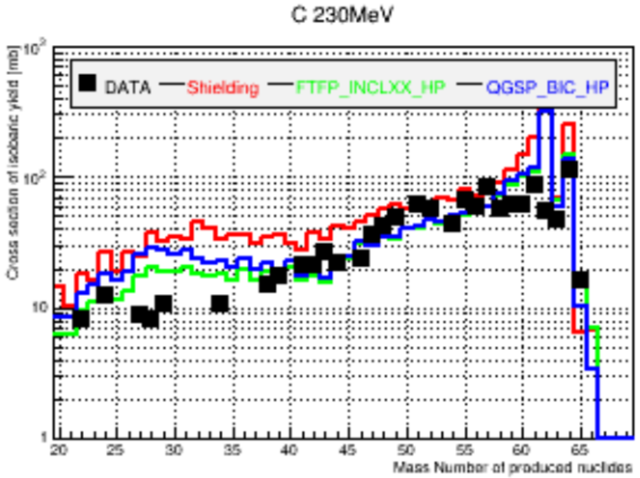
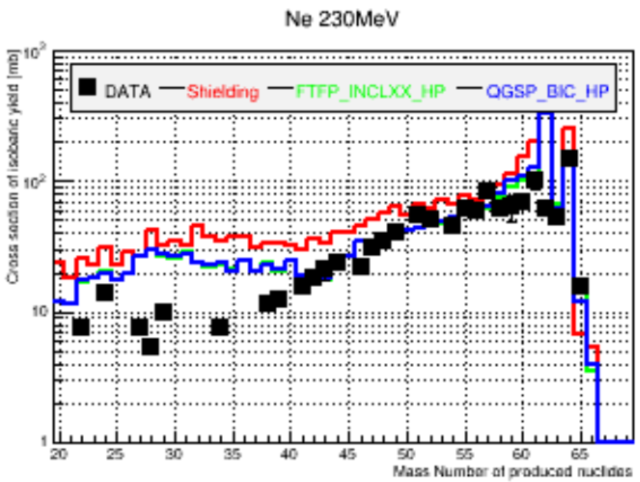


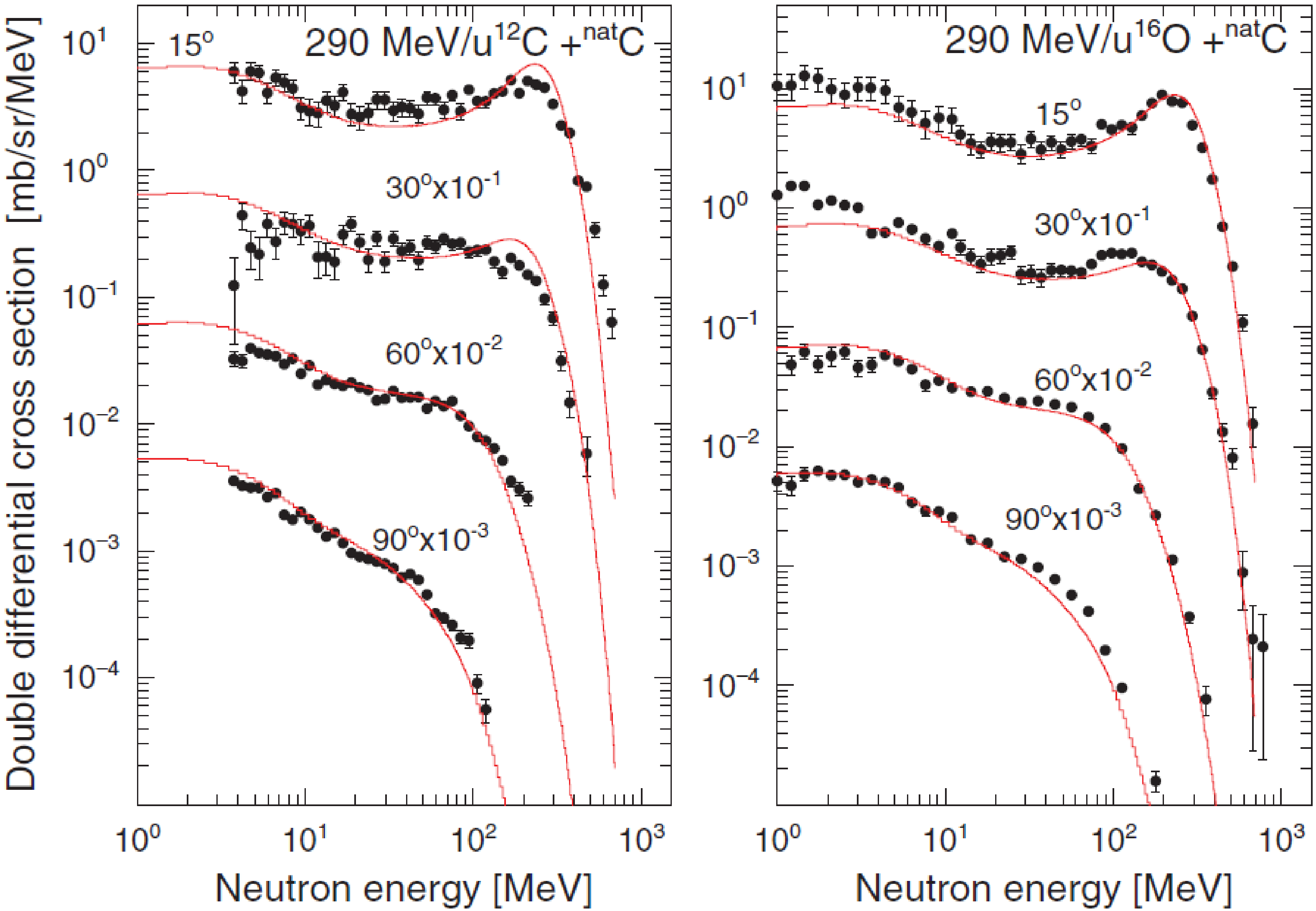
Fig. 21. Comparison of recent GEANT4 versions with test beam data for the response (top) and resolution (bottom) of the copper/liquid argon simplified calorimeter (ATLAS HEC).

230 MeV C and Ne on Cu-target





PHITS: 290 MeV/u ^{12}C and ^{16}O on ^{nat}C



PHITS: Neutron Production for 256 MeV p on Thick Targets

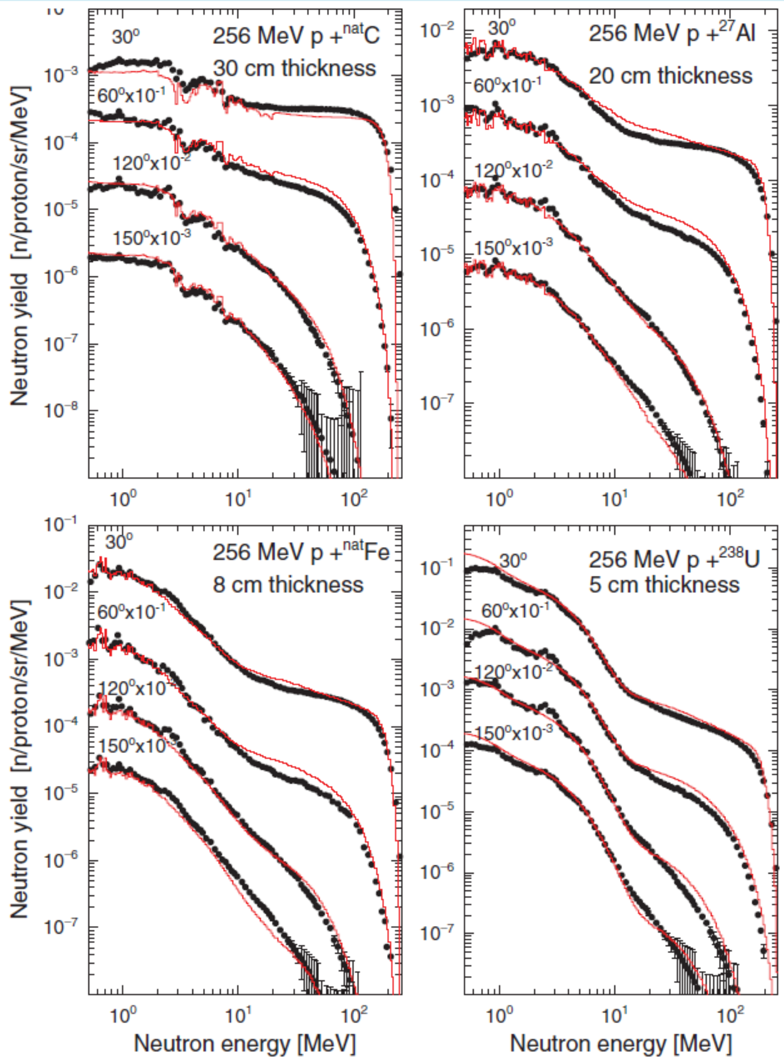
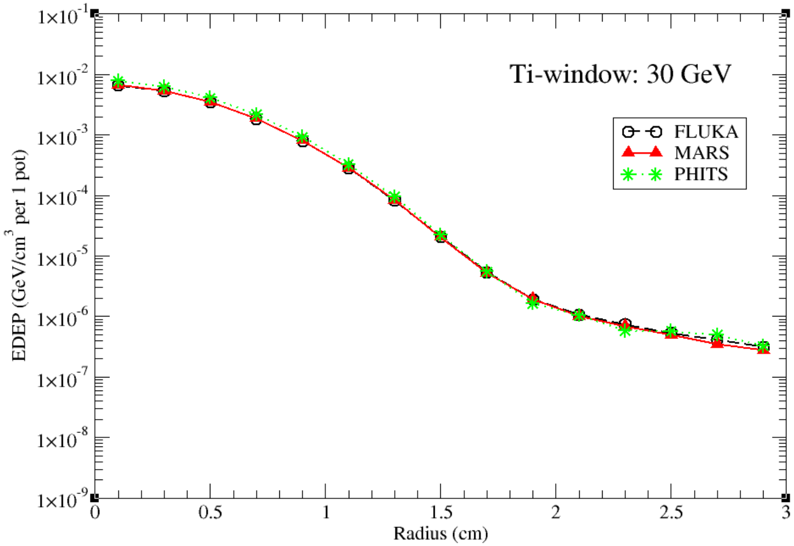
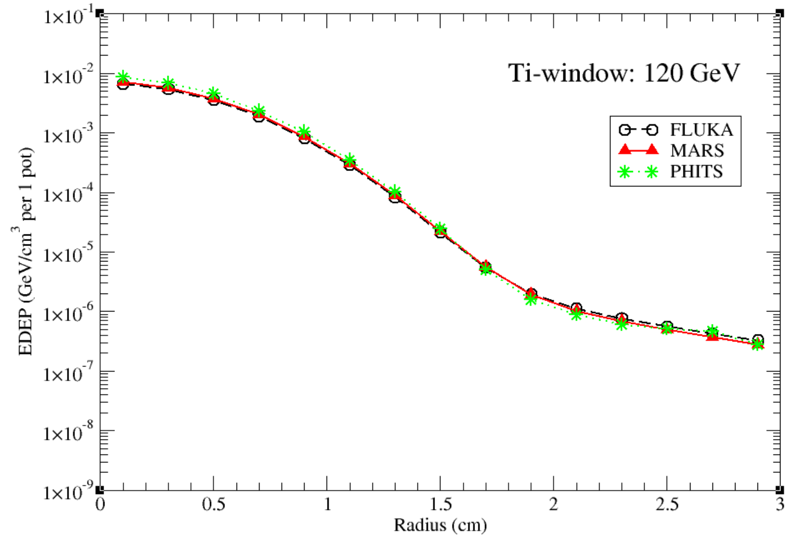
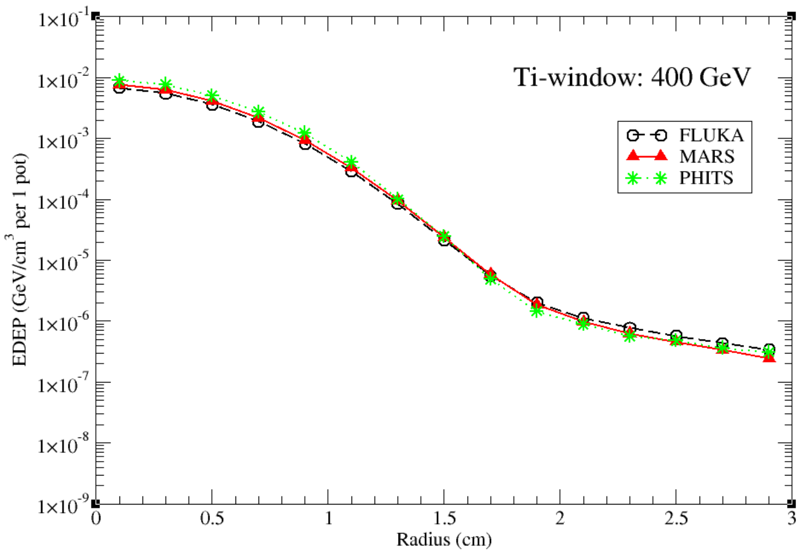


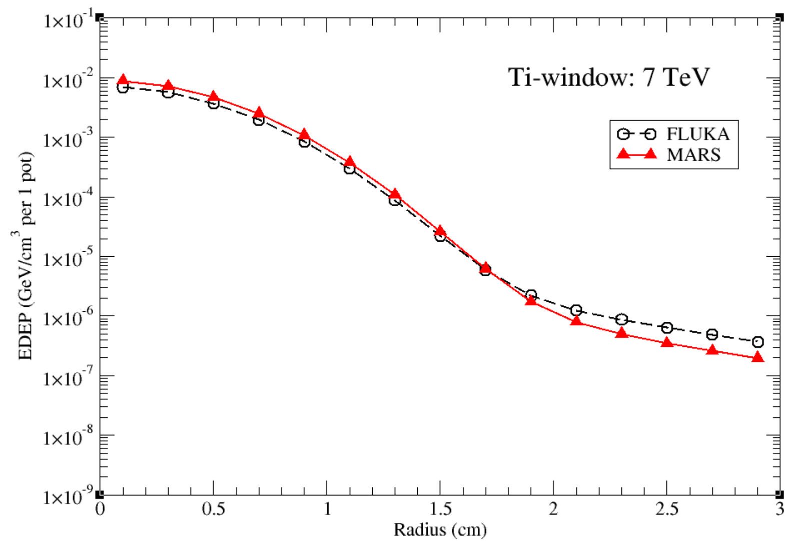
Figure 11. Differential neutron production yields at scattering angles of 30°, 60°, 120°, and 150° for an incident proton energy of 256 MeV on stopping lengths of C, Al, Fe, and U targets [33].

Ti-Window: EDEP @ 30, 120, 400 and 7000 GeV

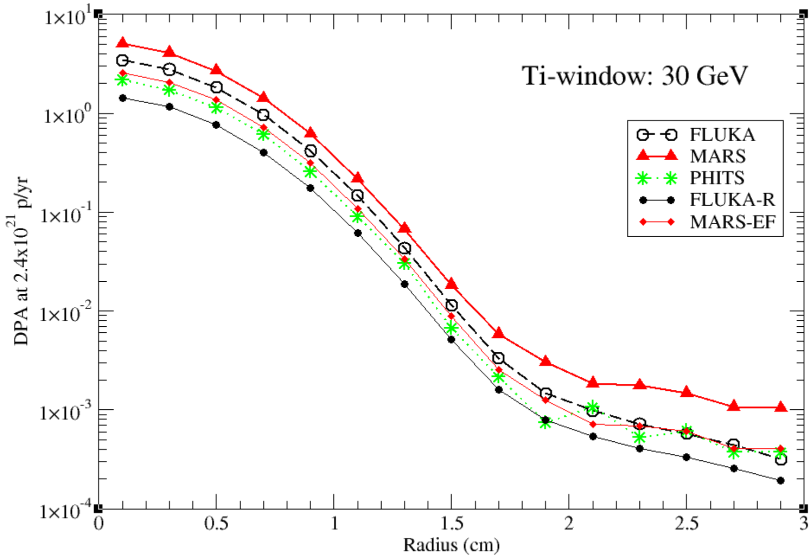


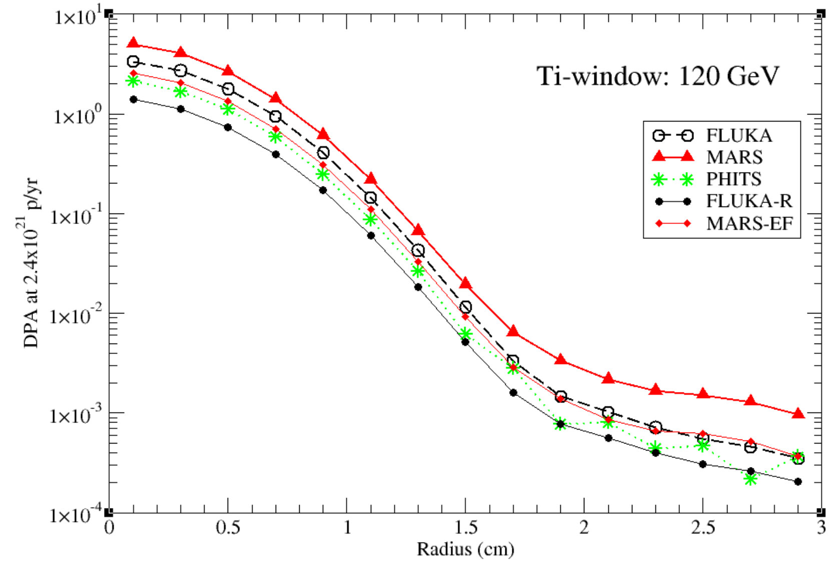


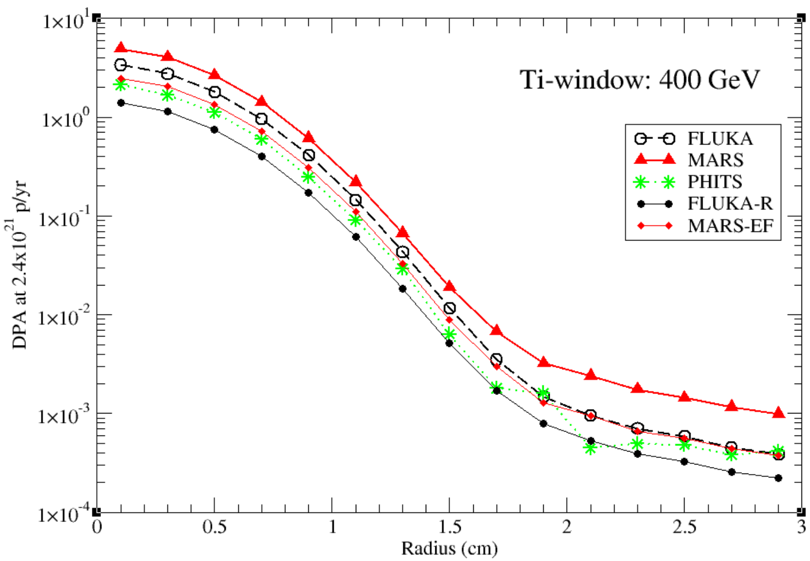


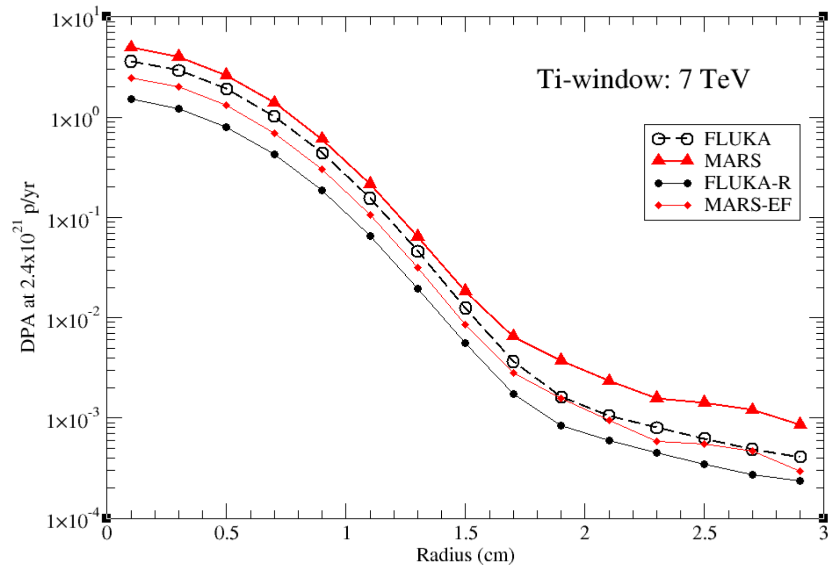


Ti-Window: DPA @ 30, 120, 400 and 7000 GeV

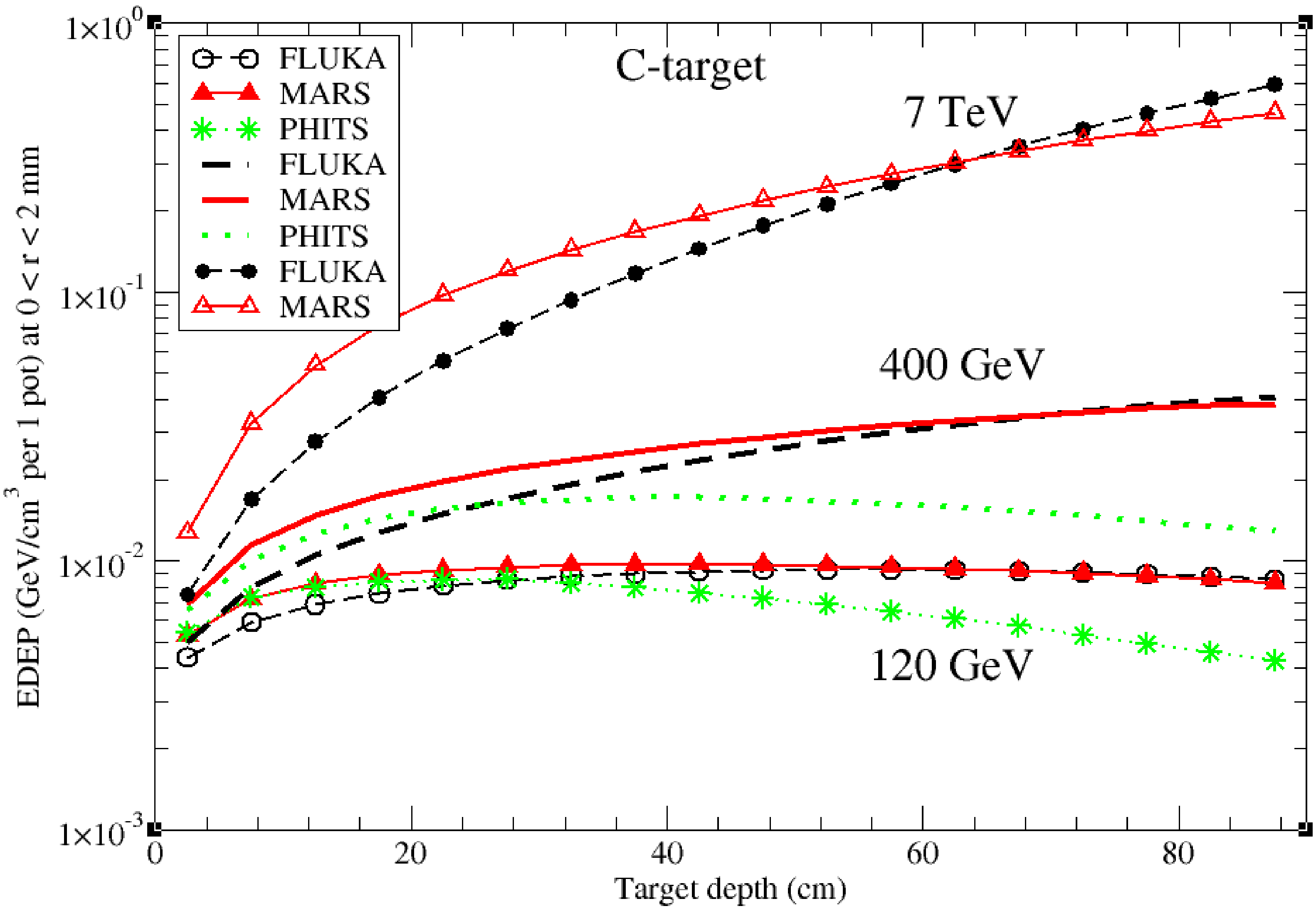




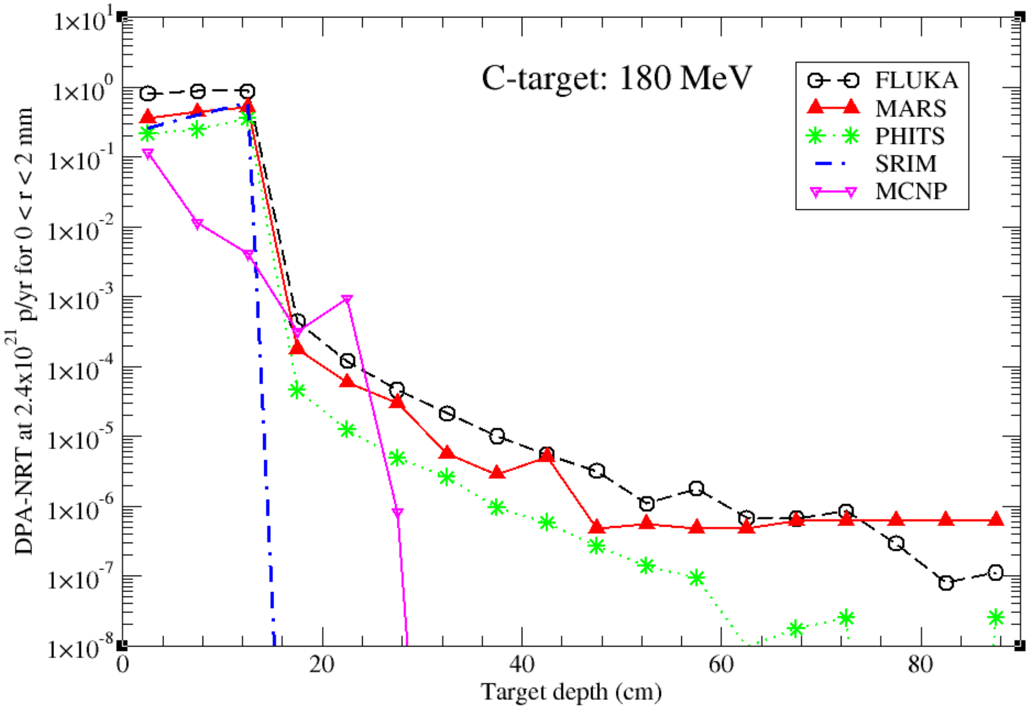


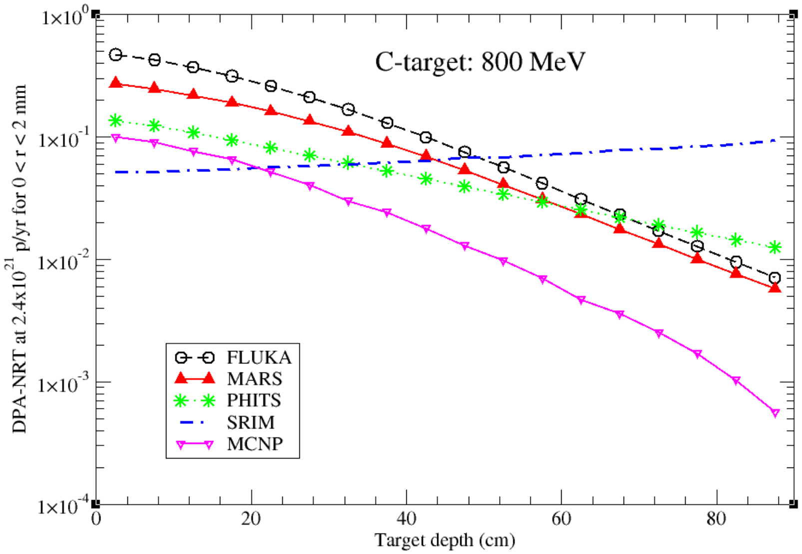


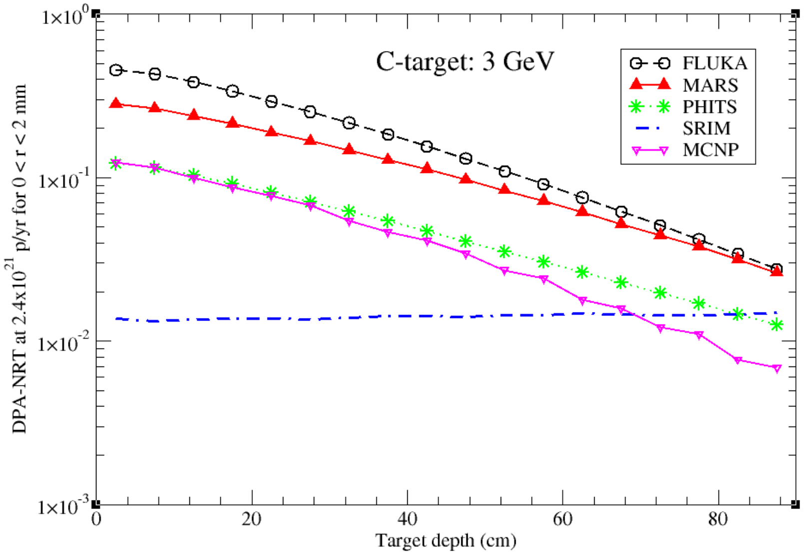
C-Target: EDEP @ 120, 400 and 7000 GeV



C-Target: DPA @ 180, 800 MeV and 3 GeV







Participant’s Experience: Short Stories & Feedback