G4MSBG: recent developments

P. Arce[1], D. Bolst[2], M-C. Bordage[3], P. Cirrone[4], M.A. Cortes-Giraldo[5], D. Cutajar[2], G. Cuttone[4], L. Desorgher[6], P. Dondero[7], A. Dotti[8], B. Faddegon[9], C. Fedon[10], S. Guatelli[2], S. Incerti[11], V. Ivanchenko[12], D. Konstantinov[13], I. Kyriakou[14], G. Latyshev[13], A. Le[2], C. Mancini-Terracciano[15], A. Mantero[7], M. Maire[16], M. Novak[17], C. Omachi[18], L. Pandola[19], A. Perales[20], Y. Perrot[21], G. Petringa[4], J.M. Quesada[5], J. Ramos-Méndez[9], F. Romano[22], D. Sakata[2], L.G. Sarmiento[23], T. Sasaki[24], I. Sechopoulos[10], E. Simpson[25], T. Toshito[18], D. Wright[26]

[1]CIEMAT, Spain, [2]CMRP, University of Wollongong, Australia, [3]CRCT (INSERM and Paul Sabatier University), France, [4]INFN LNS Catania, Italy, [5]Universidad de Sevilla, Spain, [6]Radiophysics Institute, Switzerland, [7]SWHARD srl, Italy, [8]Former SLAC, USA,[9]University of California San Francisco, USA, [10]Radboud University Medical Center, The Netherlands, [11]CENBG, France, [12]Tomsk State University, Russian Federation, [13]IHEP, Protvino, Russian Federation, [14]Ioannina University, Greece, [15] Roma 1, INFN, Italy, [16]LAPP, IN2P3, France, [17]CERN, Switzerland, [18]Nagoya Proton Therapy Center, Japan, [19]INFN Gran Sasso, Italy, [20]Clínica Universidad de Navarra, Spain, [21]IRSN, France, [22]NPL, UK, [23]Lund University, Sweden, [24]KEK, Japan, [25]ANU, Australia, [26]SLAC, USA

Geant4 Collaboration Meeting, Jefferson Lab, US, 23-27 September 2019

Motivation & Goals

- Geant4 medical users community is large and very well established.
- Geant4 offers many **pre-built physics lists**. Which one is more adequate for a specific medical physics application scenario?
- The **Geant4 Medical Simulation Benchmarking Group (G4MSBG)** was created to:
  - Collect tests to benchmark Geant4 pre-built physics lists for medical physics applications
  - Include these benchmarks into regression tests
  - Provide physics list recommendations for medical physics applications

Tested Geant4 Physics Constructors and Lists

Electromagnetic Physics Constructors

- **G4EmStandardPhysics** (a.k.a. “option0”)
  - Usually used as reference by Geant4 physics developers for high-energy physics.
- **G4EmStandardPhysics_option3** (“**EMY**” suffix in physics list naming convention)
  - Based of G4EmStandardPhysics with more accurate settings to model dE/dx, nuclear stopping & fluorescence.
- **G4EmStandardPhysics_option4** (“**EMZ**” suffix)
  - Deemed to be the most accurate combination of Geant4 models, regardless of CPU efficiency.
- **G4EmLivermorePhysics** (“**LIV**” suffix)
  - Includes data-driven low-energy models for e^- ionization and γ based on the Livermore evaluated data libraries.
- **G4EmPenelopePhysics** (“**PEN**” suffix)
  - Includes low-energy models for e^-, e^+ & γ re-engineered from PENELOPE code

Geant4 EM Physics Lists

Geant4	*Opt0*	*Opt3*	*Opt4*	*Livermore*	*Penelope*
Rayleigh scattering and photoelectric effect	Livermore				Penelope
Compton scattering	Standard	G4KleinNishinaModel	*G4LowEPComptonModel*[18] for $E < 20MeV$ *	Livermore for $E < 1GeV$ *	Penelope for $E < 1GeV$ *
Gamma conversion	Standard	Standard	Penelope for $E < 20MeV$ Standard for $E > 20MeV$	*G4BetheHeitler5DModel* [19], for $E < 1GeV$, Standard for $E > 1GeV$	Penelope for $E < 1GeV$, Standard for $E > 1GeV$
e^- and e^+ ionisation	Standard	Standard	Livermore for e^- for $E < 100keV$, Penelope for e^+ for $E < 100keV$, Standard for $E > 100keV$	Livermore for $E < 100keV$ Standard for $E > 100keV$	Penelope
e^- and e^+ bremsstrahlung	Standard	*G4SeltzerBergerModel* for $E < 1GeV$, *G4eBremsstrahlungRelModel* for $E > 1GeV$			Penelope
e^+ annihilation	Standard				Penelope
e^- and e^+ multiple scattering	Urban model [20] for $E < 100MeV$, Wentzel for $E > 100MeV$	Default model	Goudsmit-Saunderson model [21], [22] for $E < 100MeV$		
Coulomb Scattering	on	off	on		
MscStepLimiting Type	*fUseSafety*	*fUseDistanceToBoundary*	*fUseSafetyPlus*	*fUseSafetyPlus*	*fUseSafetyPlus*
Bremsstrahlung angular distribution	*ModifiedTsai*	*2BS*			*Penelope*

Geant4 EM parameter	*Opt0*	*Opt3*	*Opt4 Livermore Penelope*	*SS*	*GS*	*WVI*
Minimum energy (eV)	100.	10.	10.	100.	100.	10.
Lowest electron energy (keV)	1.	0.1	0.1	0.01	1.	0.01
Number of bins per decade	7	20	20	7	7	20
Angular generator	false	true	true	false	false	true
Mott corrections	false	true	true	false	false	true
dRoverRange (mm) for e^- and e^+	0.2	0.2	0.2	0.2	0.2	0.2
finalRange for e^- and e^+ (mm)	1.	0.1	0.1	1.	1.	0.1
dRoverRange (mm) for muons and hadrons	0.1	0.05	0.05	0.1	0.1	0.05
Lateral displacement for muons and hadrons	false	true	true	false	false	true
Skin	1	1	3	1	1	0
Range factor	0.04	0.04	0.08	0.04	0.06	0.04
Theta (rad)	π	π	π	0.	π	0.15
Fluorescence	off	on	on	on	off	on
Auger electrons and PIXE modelling	off	off	off	on	off	off

Tested Geant4 Physics Constructors and Lists

Hadronic Physics Constructors

For proton therapy

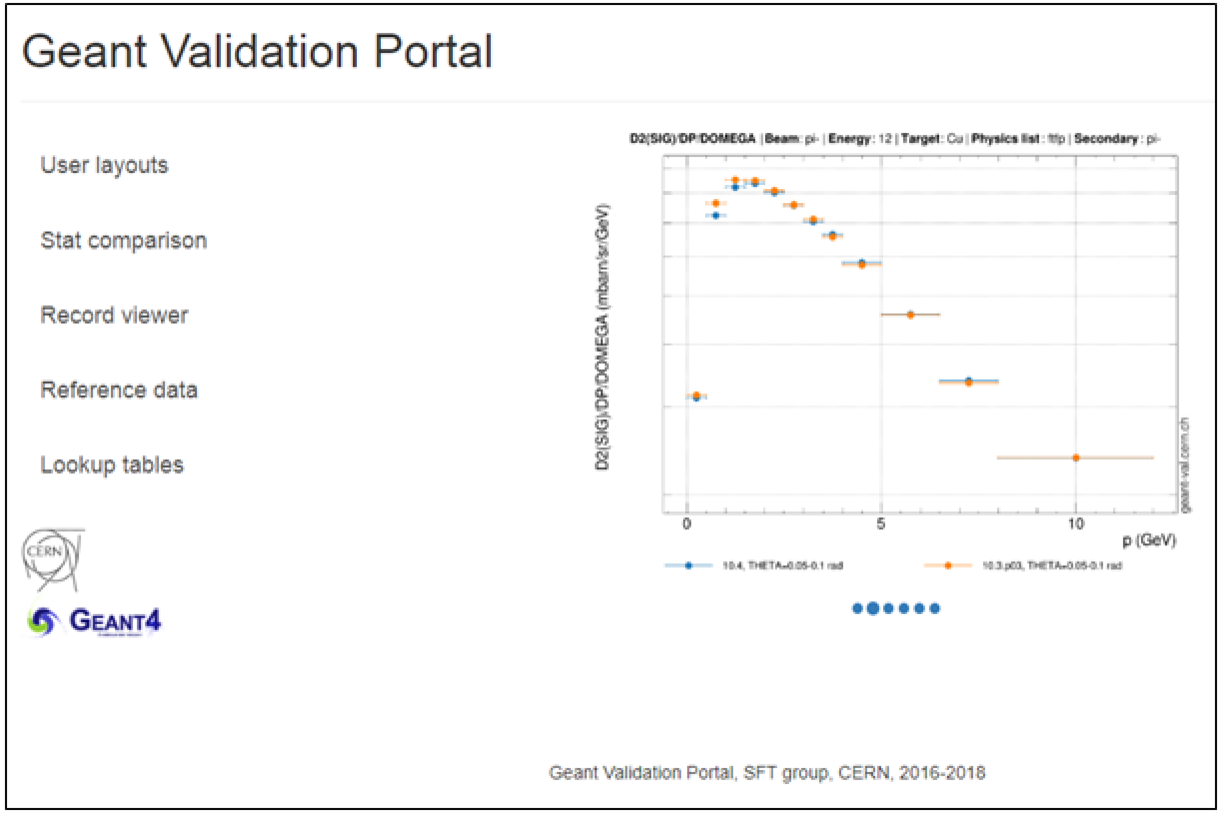
- **QGSP_BIC_HP**
  - **G4EmStandardPhysics_option4** is used by default since Geant4-10.5.
- **QGSP_BIC_EMY** is same as previous, but…
  - **No HP libraries** for neutrons.
  - G4EmStandardPhysics_**option3** is used.
- **QGSP_BERT_HP** differs from QGSP_BIC_HP in:
  - EM interactions are modeled with "**option0**".
  - For incident **p** & **n**, Bertini model (own Precompound+Evaporation) is used for hadronic inelastic scattering.

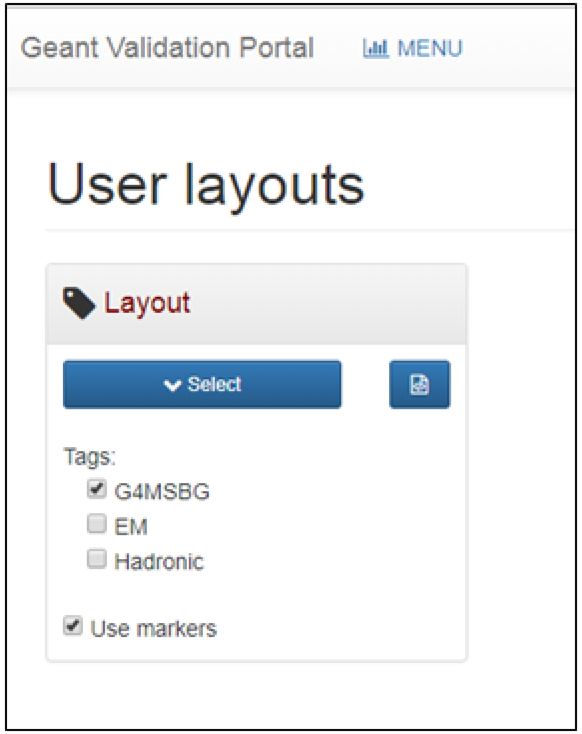
For carbon ion therapy:

- **G4IonBinaryCascade -** LightIonBinaryCascade model.
- **G4IonQMDPhysics -** Quantum Molecular Dynamics (QMD) model.
- **G4IonINCLXXPhysics -** Liège Intranuclear-Cascade model (INCL).

Integration in *geant-val* for Automatized Regression Tests

By D. Konstantinov and G. Latyshev
IHEP, Protvino, Russian Federation





https://geant-val.cern.ch/

G4_Med is integrated in ***geant-val*** to execute regularly automatized regression tests on the CERN computing infrastructure

Tests included in G4-Med

https://twiki.cern.ch/twiki/bin/view/Geant4/G4MSBG

Jump | Search
Geant4 All webs

Log In
Geant4

Geant4 Web
Create New Topic
Index
Search
Changes
Notifications
Statistics
Preferences

TWiki > Geant4 Web > G4MSBG (2019-04-23, LucianoPandola)

Edit Attach PDF

Welcome to the Twiki web page of the G4MSBG initiative: G4-Med

Purpose

The aim of the Geant4 Medical Physics Benchmarking Group (G4MSBG) is to develop a fully automatised Geant4 benchmarking and regression testing system for medical physics applications, called G4-Med. A set of Geant4 Physics Constructors and Lists of interest for medical physics applications are tested. The tests are integrated in the geant-val test system to be executed for benchmarking and regression testing. The test are executed using the CERN computing infrastructure.

List of current tests

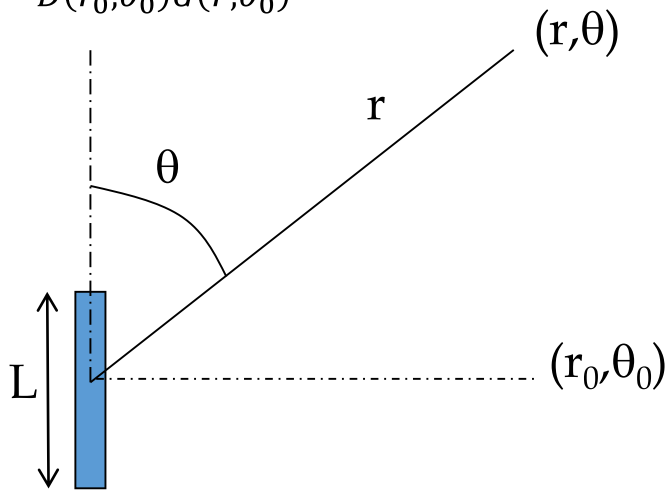
Currently the G4-Med system includes 18 tests.

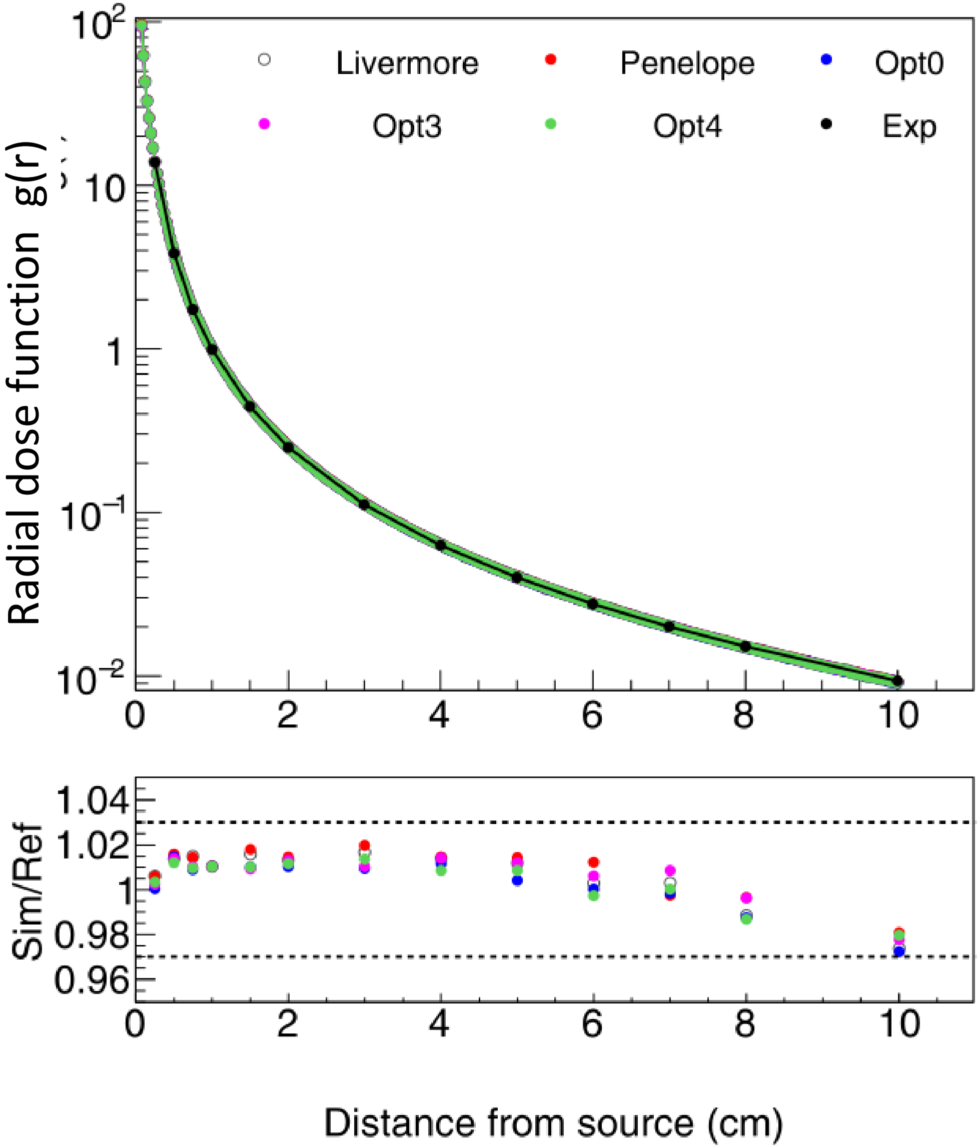
Test	geant-val layout	Authors
Photon attenuation coefficients	PhotonAttenuation	S. Guatelli, L. Pandola
Electron stopping powers	ElectronDEDX	V. Ivanchenko
Low energy electron backscattering	ElectronBackScat	P. Dondero, A. Mantero,V. Ivanchenko, M. Novak
Electron scattering from foils at 13-20 MeV kinetic energies	ElecForwScat	B. Faddegon, J. Ramos-Méndez
Bremsstrahlung yield	Bremsstrahlung	B. Faddegon,J. Ramos-Méndez
Fano cavity	Fano cavity	P. Arce , M. Maire, M. Novak
Electron Dose Point Kernel	LowEElecDPK	S. Incerti, M.-C. Bordage, I. Kyriakou, Y. Perrot
Microdosimetry	Microyz	S. Incerti, I. Kyriakou
Brachytherapy - dose rate	Brachy-ir	S. Guatelli, D. Cutajar
Dosimetry - clinical 5-6 MeV electron beam	To be added	L. Desorgher
Dosimetry for mammography	Mammo	C. Fedon, I. Sechopoulos
Hadronic nucleus-nucleus inelastic cross section	NucNucInelXS	D. Sakata, S. Guatelli, E. Simpson
Bragg curves in water for 67.5 MeV protons	LowEProtonBraggPeak	B. Faddegon, J. Ramos-Méndez
Absolute neutron yield for protons	ProtonC12NeutronYield	B. Faddegon, J. Ramos-Méndez
Production cross sections of different fragments	C12FragCC	C. Omachi, T. Toshito, T. Sasaki
62 MeV /n C-12 fragmentation on Carbon target	LowEC12Frag	C. Mancini-Terracciano
400 MeV/n C-12 fragmentation	C12Frag	D. Bolst, S. Guatelli, F. Romano
Estimation of proton radiobiological damage	LowEProtonRBE	G. Petringa, GAP Cirrone L. Pandola, G. Cuttone
Light ion (proton, 3He, carbon) range and depth dose curves in water	LightIonBraggPeak	M. Cortes-Giraldo, A. Perales, J. M. Quesada Molina

Brachytherapy test

S. Guatelli, A. Le and D. Cutajar, University of Wollongong

- Based on the Advanced Example *brachytherapy*
- ^{192}Ir Flexisource (HDR brachytherapy)
- $g(r) = \frac{\dot{D}(r,\theta_0)G(r_0,\theta_0)}{\dot{D}(r_0,\theta_0)G(r,\theta_0)}$ (Task Group 43)

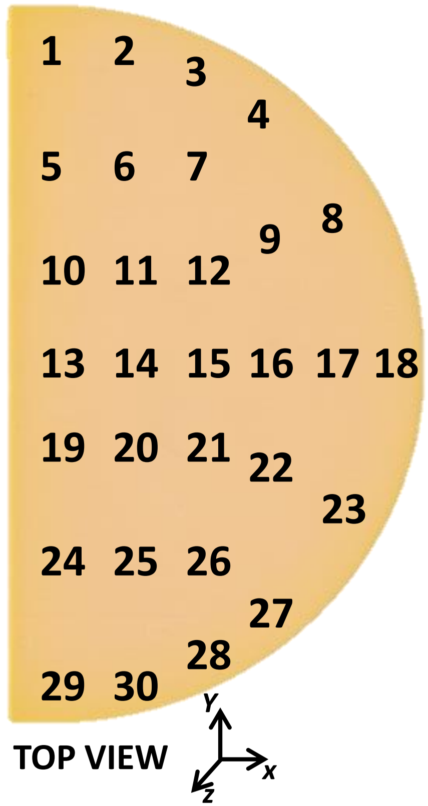


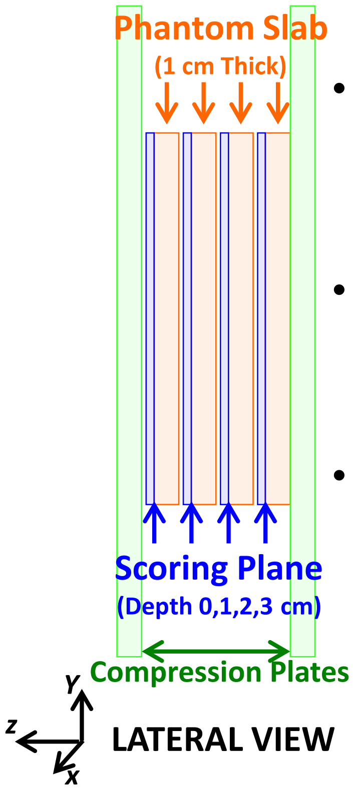


- Comparison against D. Granero, et al, (2006) Med. Phys. 33 (12), pp: 4578-82.
- Agreement within 3σ with reference data for all EM constructors

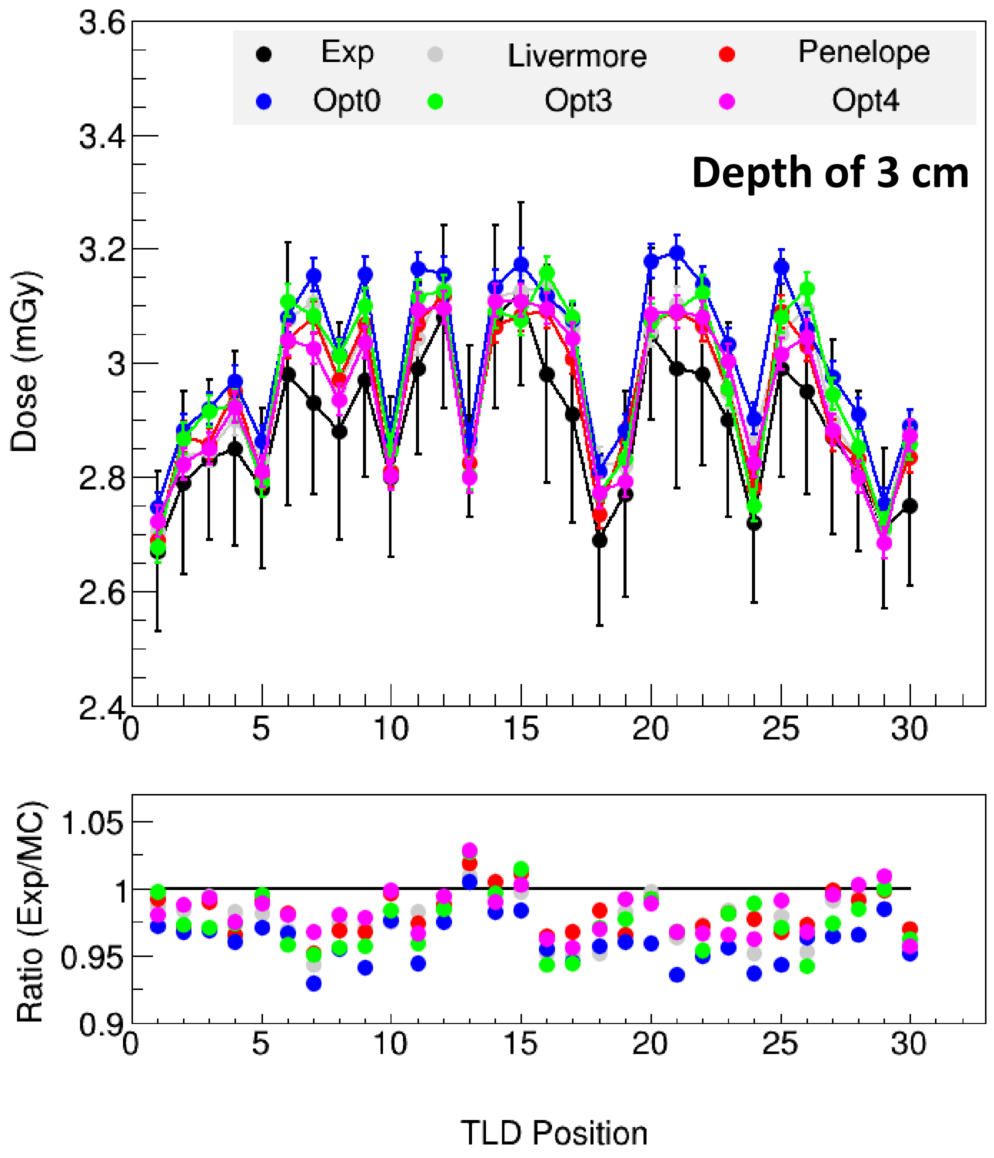
Internal breast dosimetry

C. Fedon and I. Sechopoulos, Radboudumc (NL)





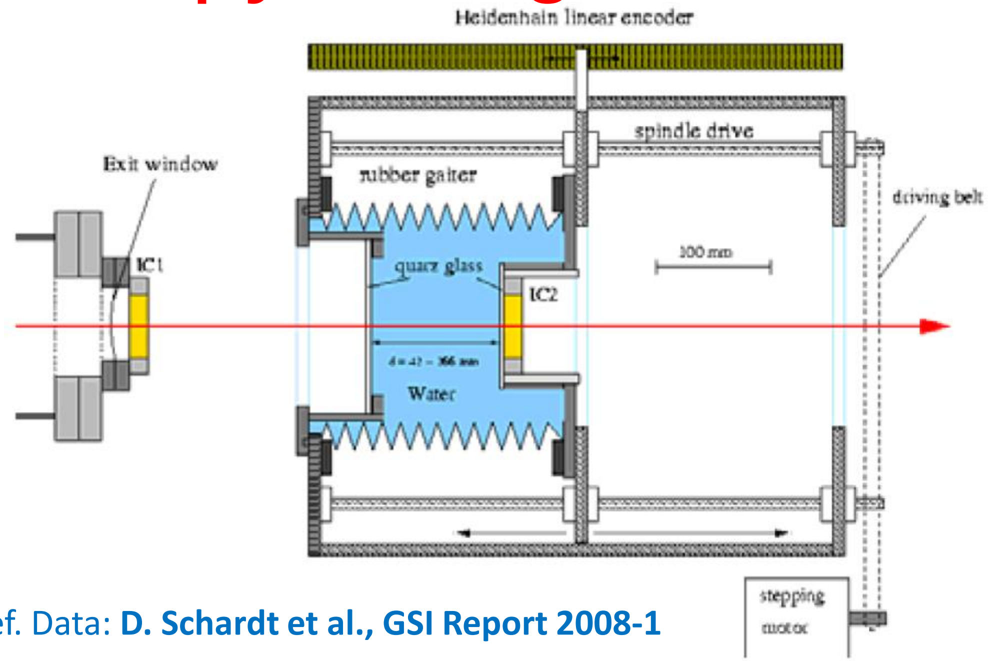
- Typical breast phantom (50% glandular 50% adipose)
- Dose scored in 30 positions at 4 different depths
- Comparison with experimental measurements (TLDs) at 20 keV



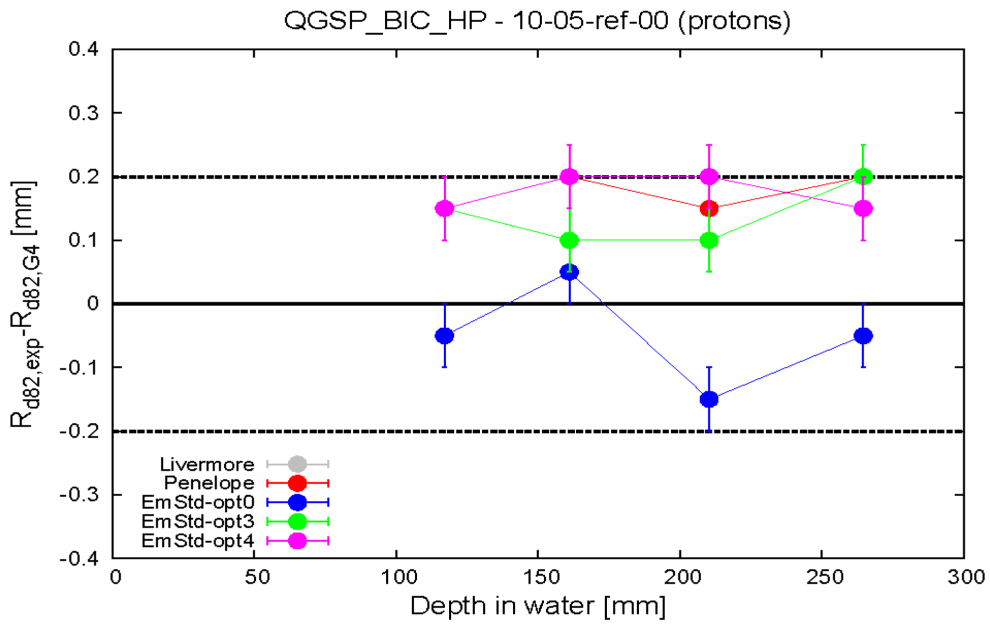
- Agreement within 1σ with the experimental measurements
- Best performance (on average) with ***"Opt4"***
- Performance of ***"Opt 0"*** worsens with increasing depth

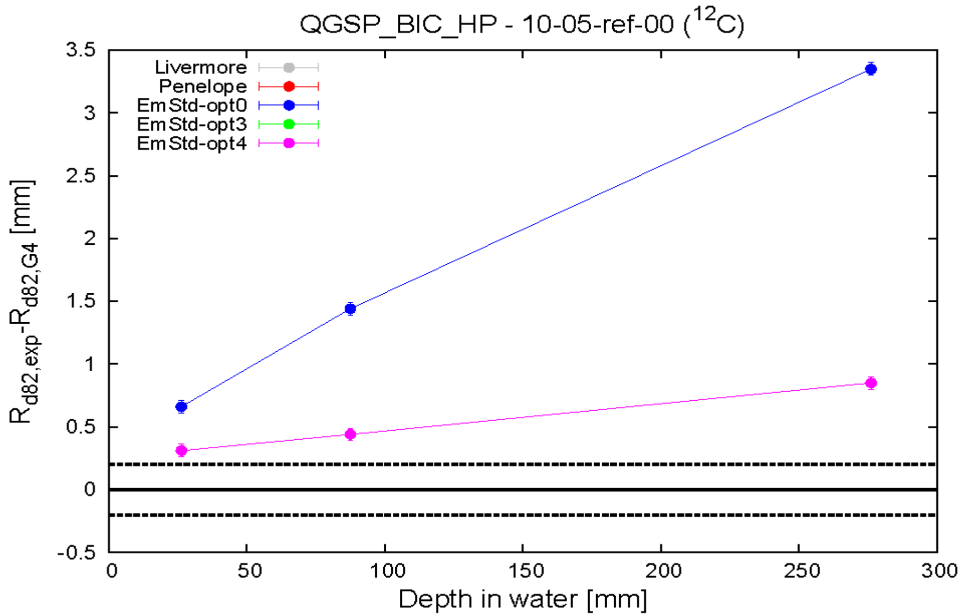
C. Fedon et al., "Internal breast dosimetry: monoenergetic" **Med. Phys. 45 (2018)**
C. Fedon et al., "Internal breast dosimetry: spectrum" **Med. Phys. 45 (2018)**

Bragg Curves in Water for Proton & C-12 Beams at Therapy Energies



Ref. Data: **D. Schardt et al., GSI Report 2008-1**

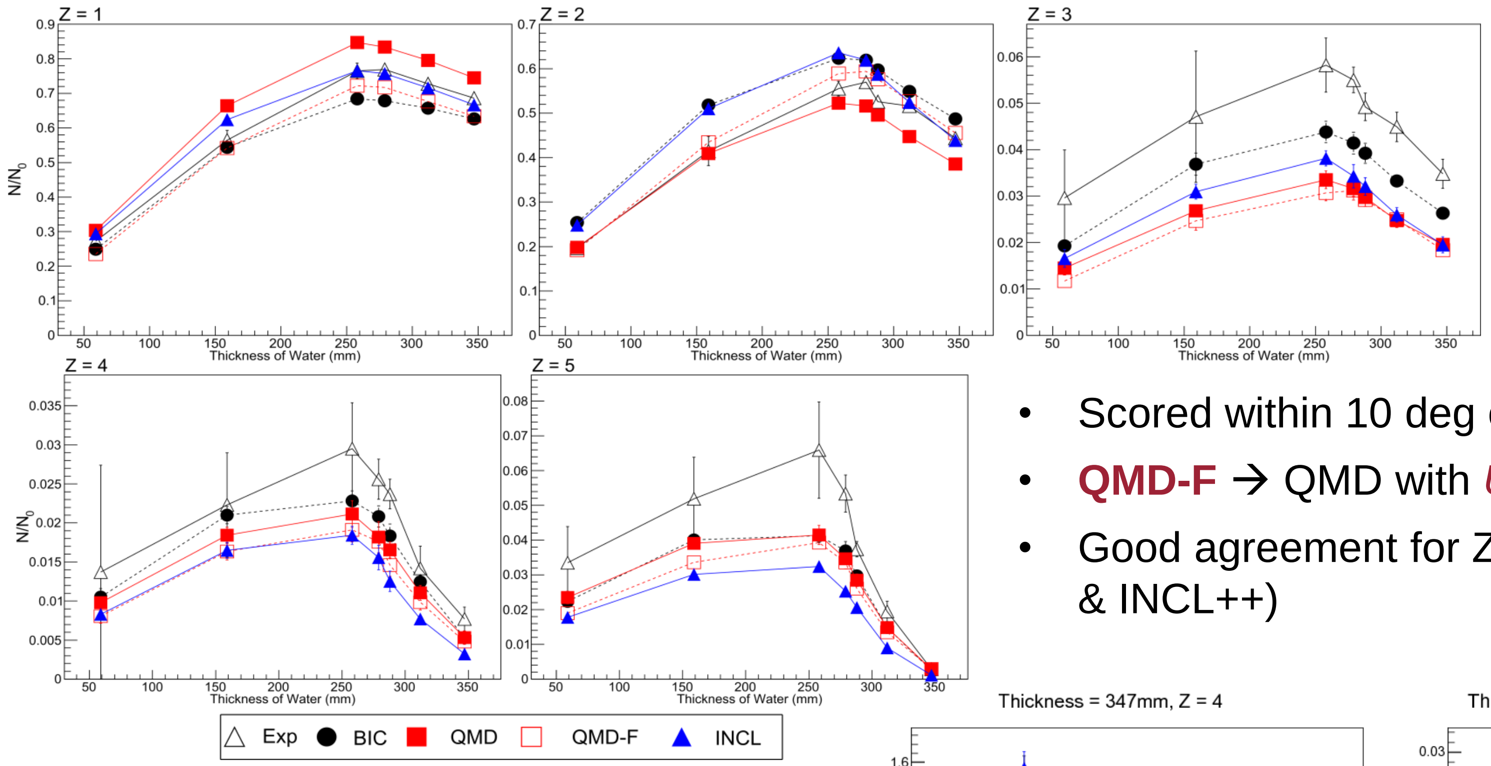


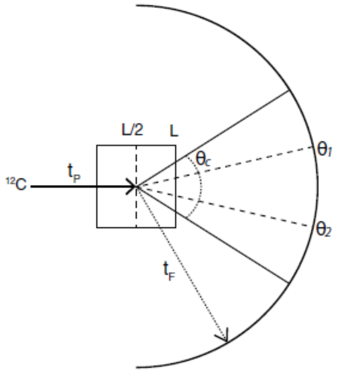


- Initial energy spread adjusted from experimental Bragg curves.
- Simplified geometry model for simulation
  - Depths of 82% distal level are compared.
- "option0" not accurate enough for ^{12}C, other EM constructors agree within 2-3 sigma.
- For proton beams, all physics constructors agree within experimental uncertainties.

M. Cortes et al, University of Seville, Spain

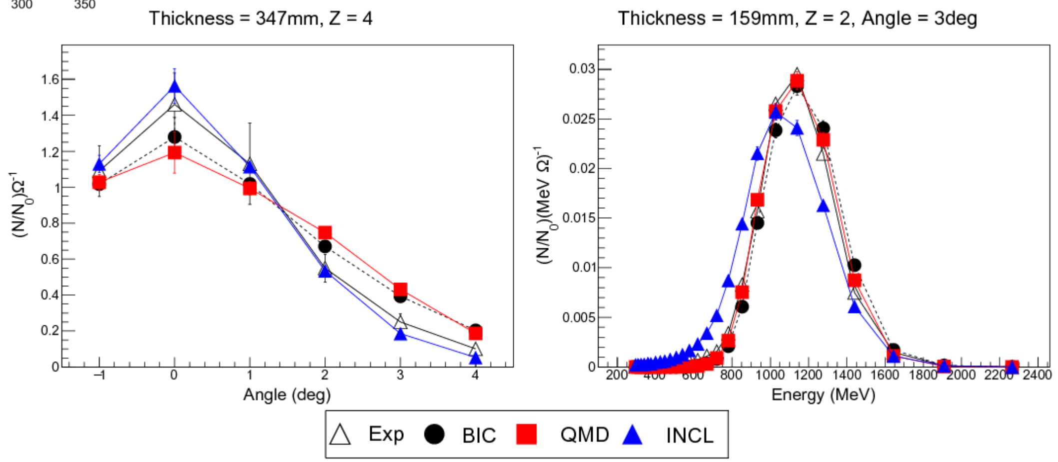
Fragment Yields for ^{12}C @ 400 MeV/u on Water Target





- Scored within 10 deg cone
- **QMD-F** → QMD with *UseFRAG* on
- Good agreement for Z < 3 (especially QMD & INCL++)

INCL++ reproduced better angular distribution, but QMD & BIC provided better energy distributions.



D. Bolst et al., NIM A 869 (2017)

Ref. Data: **E. Haettner et al., Phys. Med. Biol. 58 (2013)**

Currently integrated or in integration phase

New tests

- **I-125 source in brachytherapy** - S. Guatelli, D. Cutajar and A. Le
- **X-ray small field dosimetry** – S. Guatelli and G. Biasi, UOW (within December 2019)
- **In-vivo PET for carbon ion therapy** – S. Guatelli, A. Chacon and M. Safavi, UOW and ANSTO
- Donated by the OpenGATE Collaboration, represented by L. Maigne and D. Sarrut.

  Geant4 simulations:

  - **Test #1: simplified PET camera**
  - **Test #2: simplified SPECT camera**
- **Radioactive decay**: L. Desorgher, D. Wright and L. Sarmiento
- **Total inelastic cross section tests** should be expanded to protons and carbon ions interacting with elements up to mass ~40: E. Simpson

Conclusions & Outlook

- Currently, 18 tests have been included in *G4_Med* to benchmark EM and Hadronic physics capabilities of Geant4 for medical physics applications.
  - Some test fundamental physical quantities, others include more realistic scenarios.
- ***G4_Med*** is integrated in ***geant-val*** for regular executions on the CERN computing infrastructure.
- Overall, *G4EmStandardPhysics_option4* (**_EMZ**) is recommended for accurate simulations.
- **QGSP_BIC_HP** (_EMZ) physics list provides a good overall description for hadron therapy applications.
- TWiki page: https://twiki.cern.ch/twiki/bin/view/Geant4/G4MSBG
- Oral presentations
  - M. A. Cortes-Giraldo et al., "G4_Med, a Geant4 benchmarking tool for medical physics applications"; ENSAR2 workshop: Geant4 in nuclear physics; Madrid (Spain), April 24-26, 2019.
  - S. Guatelli et al., "G4_Med, a Geant4 benchmarking tool for medical physics applications"; MCMA 2019, Montreal, Canada, June 19-21, 2019.
- Paper submitted as a Special Report of Medical Physics accepted for publication
  - Revisions to be addressed in the manuscript

Next stage

- Introduction of new tests
- Have regression tests
  - we started the systematic benchmarking work with Geant4 10.5
- Publish a second paper documenting the two points above
- Improve documentation of Geant4 medical physics pages