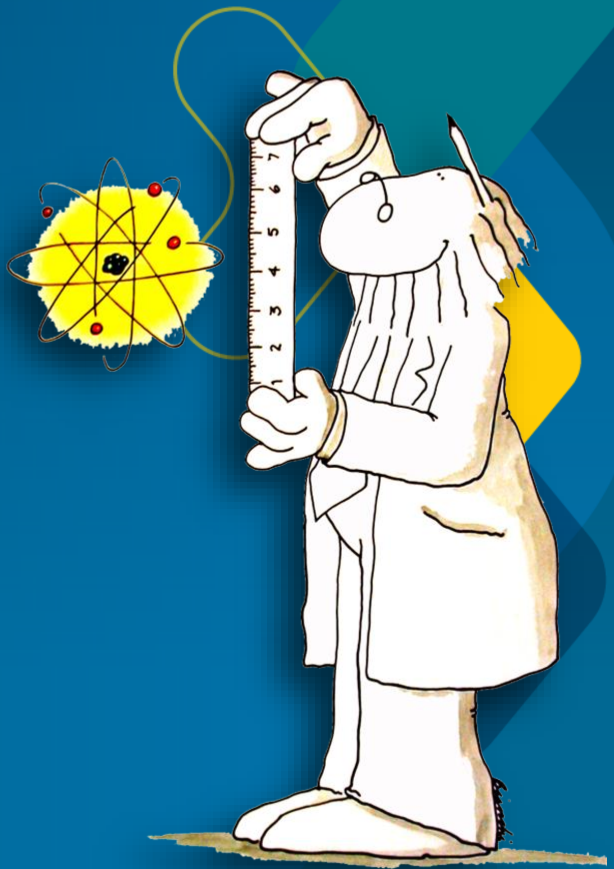
NRC·CNRC

EGSnrc update and Monte Carlo simulation verification



Frédéric Tessier

Measurement Science and Standards
National Research Council Canada

NRC·CNRC

EGSnrc update and Monte Carlo simulation verification

Ernesto Mainegra-Hing

Atomic relaxation and PE cross sections

Frédéric Tessier

Reid Townson

Radionuclide decay modelling

Dave Rogers

Improved kerma calculations

Measurement Science and Standards
National Research Council Canada

"This talk is almost, but not quite, entirely unlike a scientific presentation."

— paraphrasing Douglas Adams

Team

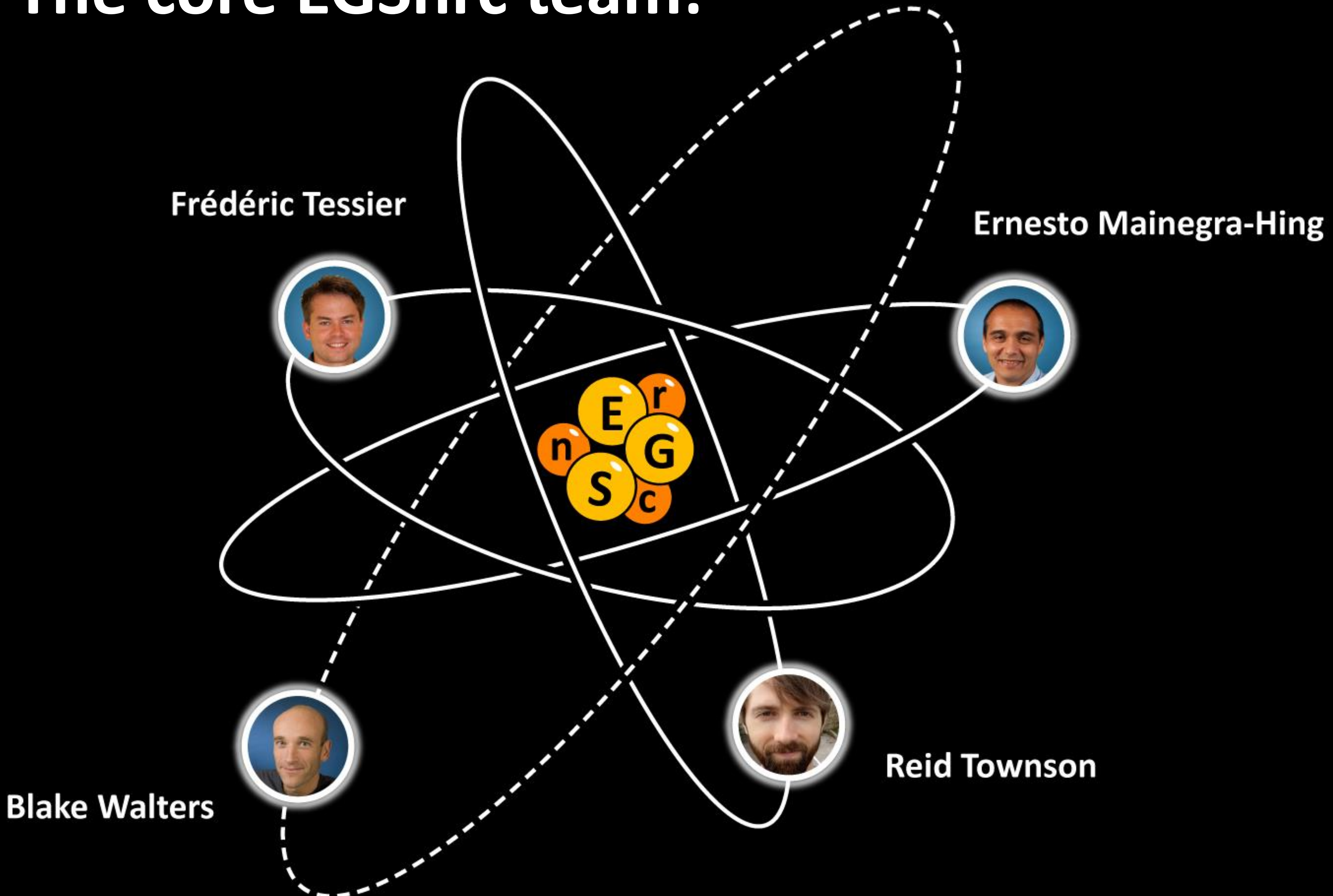
Code

News

Bugs

Test

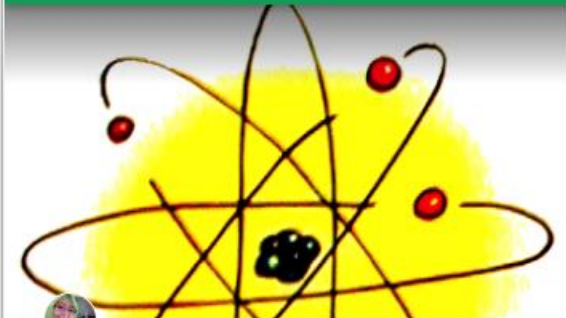
The core EGSnrc team:



EGSnrc - Google+

Secure | https://plus.google.com/communities/106437507294474212197

Google+ Search Google+ Sign in



807 members - Public

EGSnrc

Monte Carlo simulation of radiation transport

JOIN

Search Community

About Community

EGSnrc is a software package for the Monte Carlo simulation of coupled electron and photon radiation transport. Its current range of applicability in energy is 1 keV to 10 GeV.

EGSnrc

Filter

Frederic Tessier Moderator ▸ Course

Wrapping up a successful two-week EGSnrc course at ICTP in Trieste, Italy. Congratulations to all the students! Thank you to the organizers and sponsors, on behalf of all lecturers. +1 if you enjoyed the course!

Grignano

+1 17

Marc Chamberland: Great group of students! It was a blast and I can't wait to hear what y...

55karlpdf ▸ Discussion 2d

Hi all, Where can I find download EGS_WINDOWS? I'm n o t looking for the

---

dian kurniawati ▸ Discussion 18h

Hi all,
i have problem, how to combine *.3ddose data on phyton or matlab (CERR) ?
please help me.
thanks

+1 1

Oanh Oanh: Hi,
You have downloaded and run the CERR on...

Pete Watson ▸ Bug report 4d

I had been noticing some infinite loop behaviour when using a beam shared library as source in egs_chamber (see: https://plus.google.com/100288585807196289271/posts/hPgndfQjMw5).

With the help of Marc-Andre Renaud, we determined that the cause was in egs_beam_source.cpp, where particles in the source were being rejected beca ...

Hi all, I have an electron beam model for which I have built, compiled and...

Hi all, I have an electron beam model for which I have built, compiled and made a shared library in $EGS_HOME. Whenever I use this beam model as a beam ... - Julien...

plus.google.com

Team.

Code

EGSnrc is now in the public domain

Since 2016, the EGSnrc software is distributed under the **GNU Affero GPL v3.0** open source licence.

BEAMnrc is now integrated in the EGSnrc installation.

Permissions

- ✓ Commercial use
- ✓ Modification
- ✓ Distribution
- ✓ Patent use
- ✓ Private use

Limitations

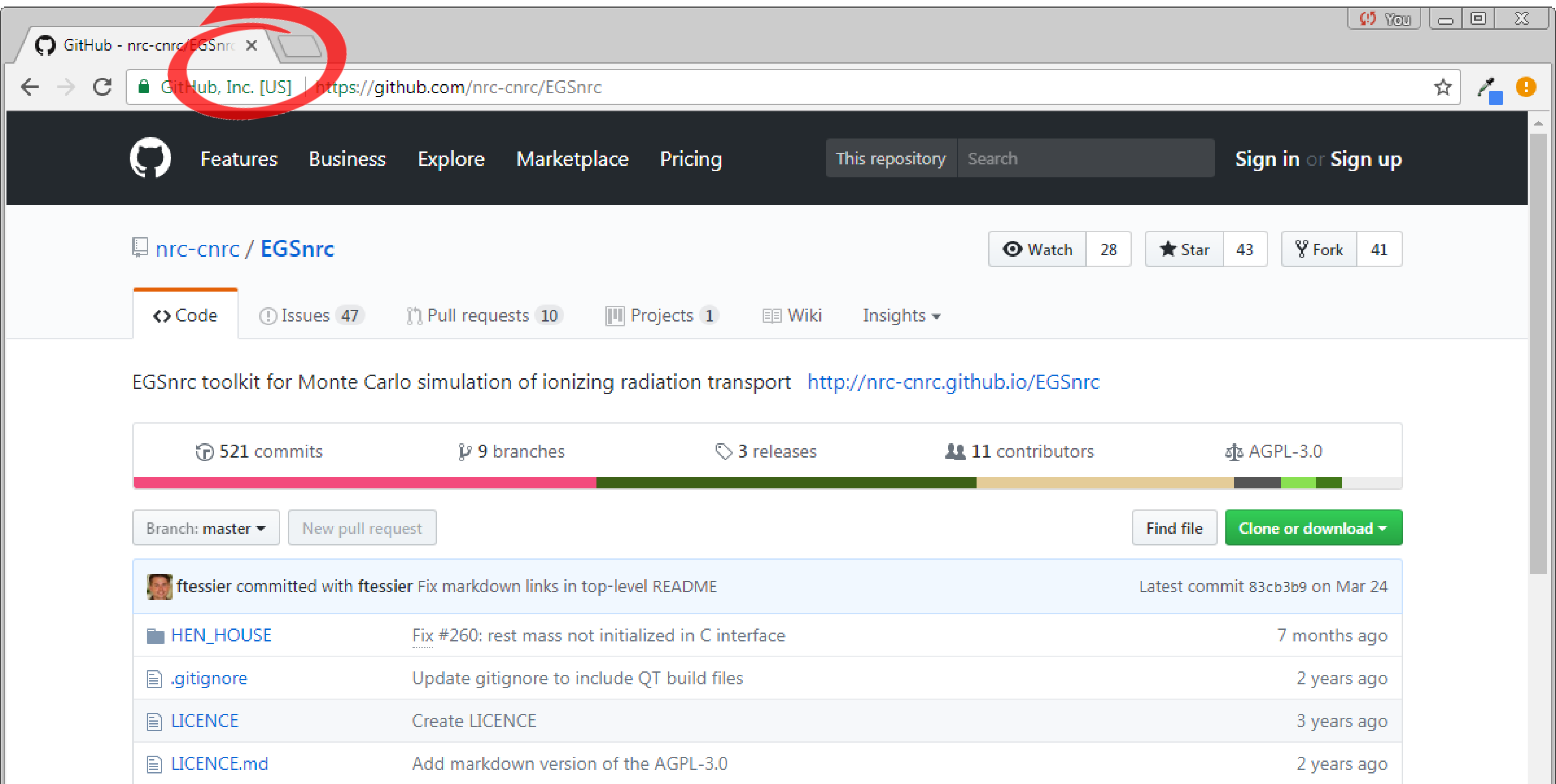
- ✗ Liability
- ✗ Warranty

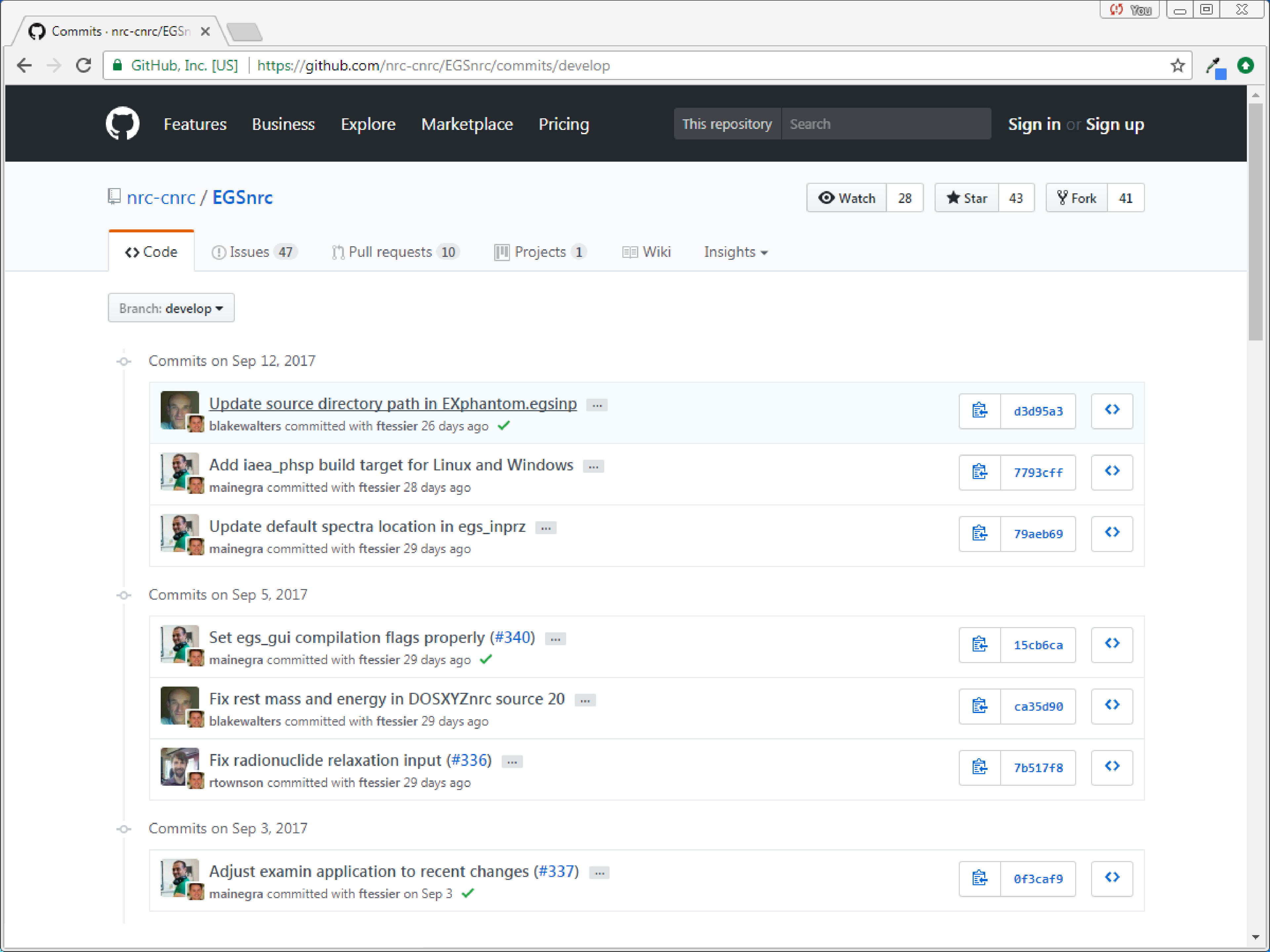
Conditions

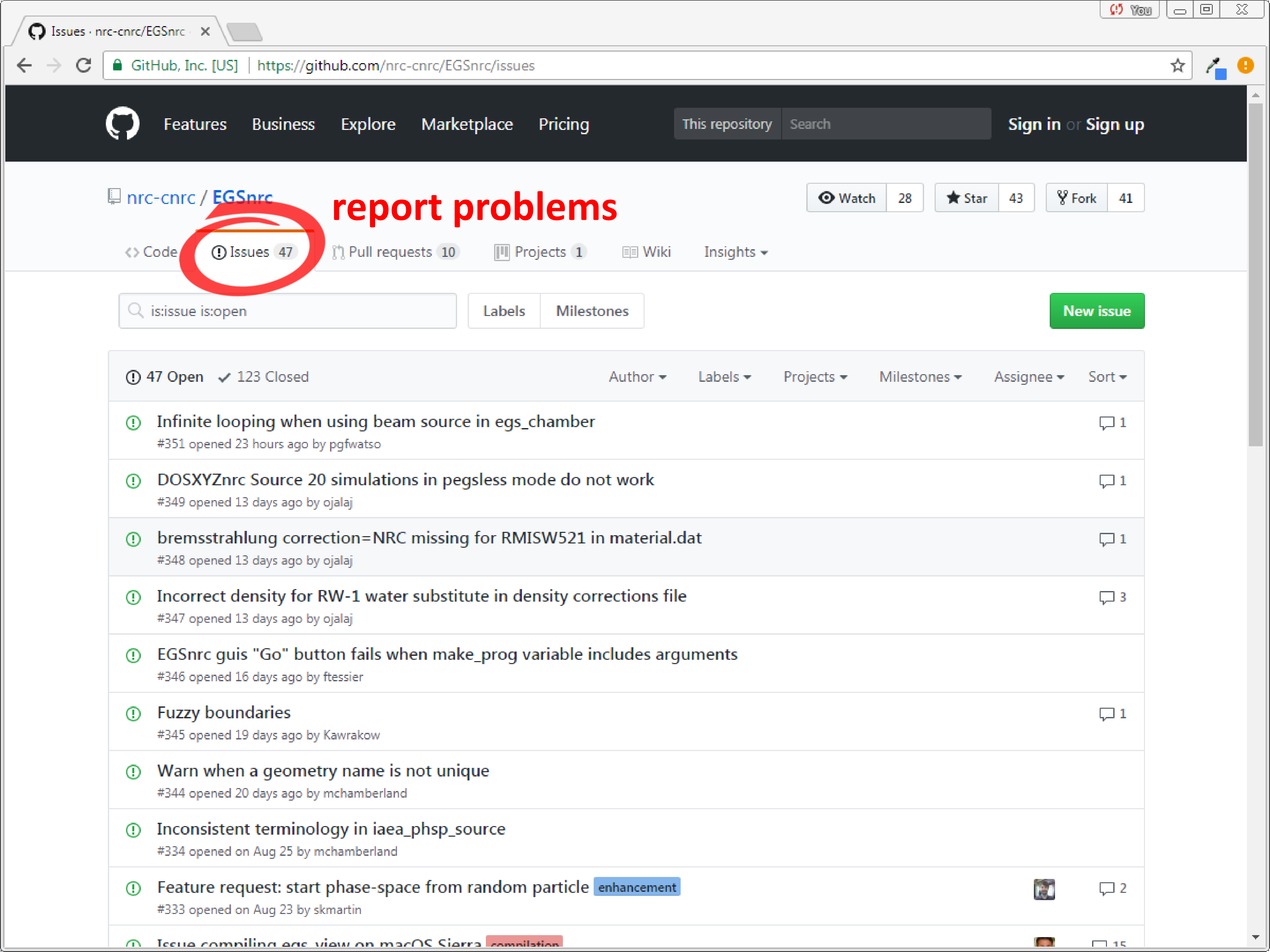
- ⓘ License and copyright notice
- ⓘ State changes
- ⓘ Disclose source
- ⓘ Network use is distribution
- ⓘ Same license

EGSnrc is now hosted on github.com

https://github.com/nrc-cnrc/EGSnrc




Commits · nrc-cnrc/EGSn
GitHub, Inc. [US] | https://github.com/nrc-cnrc/EGSnrc/commits/develop
Features
Business
Explore
Marketplace
Pricing
This repository
Search
Sign in or Sign up
nrc-cnrc / EGSnrc
Watch 28
Star 43
Fork 41
Code
Issues 47
Pull requests 10
Projects 1
Wiki
Insights
Branch: develop
Commits on Sep 12, 2017
Update source directory path in EXphantom.egsinp
blakewalters committed with ftessier 26 days ago
d3d95a3
Add iaea_phsp build target for Linux and Windows
mainegra committed with ftessier 28 days ago
7793cff
Update default spectra location in egs_inprz
mainegra committed with ftessier 29 days ago
79aeb69
Commits on Sep 5, 2017
Set egs_gui compilation flags properly (#340)
mainegra committed with ftessier 29 days ago
15cb6ca
Fix rest mass and energy in DOSXYZnrc source 20
blakewalters committed with ftessier 29 days ago
ca35d90
Fix radionuclide relaxation input (#336)
rtownson committed with ftessier 29 days ago
7b517f8
Commits on Sep 3, 2017
Adjust examin application to recent changes (#337)
mainegra committed with ftessier on Sep 3
0f3caf9


Issues · nrc-cnrc/EGSnrc
GitHub, Inc. [US] | https://github.com/nrc-cnrc/EGSnrc/issues
Features
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Explore
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This repository
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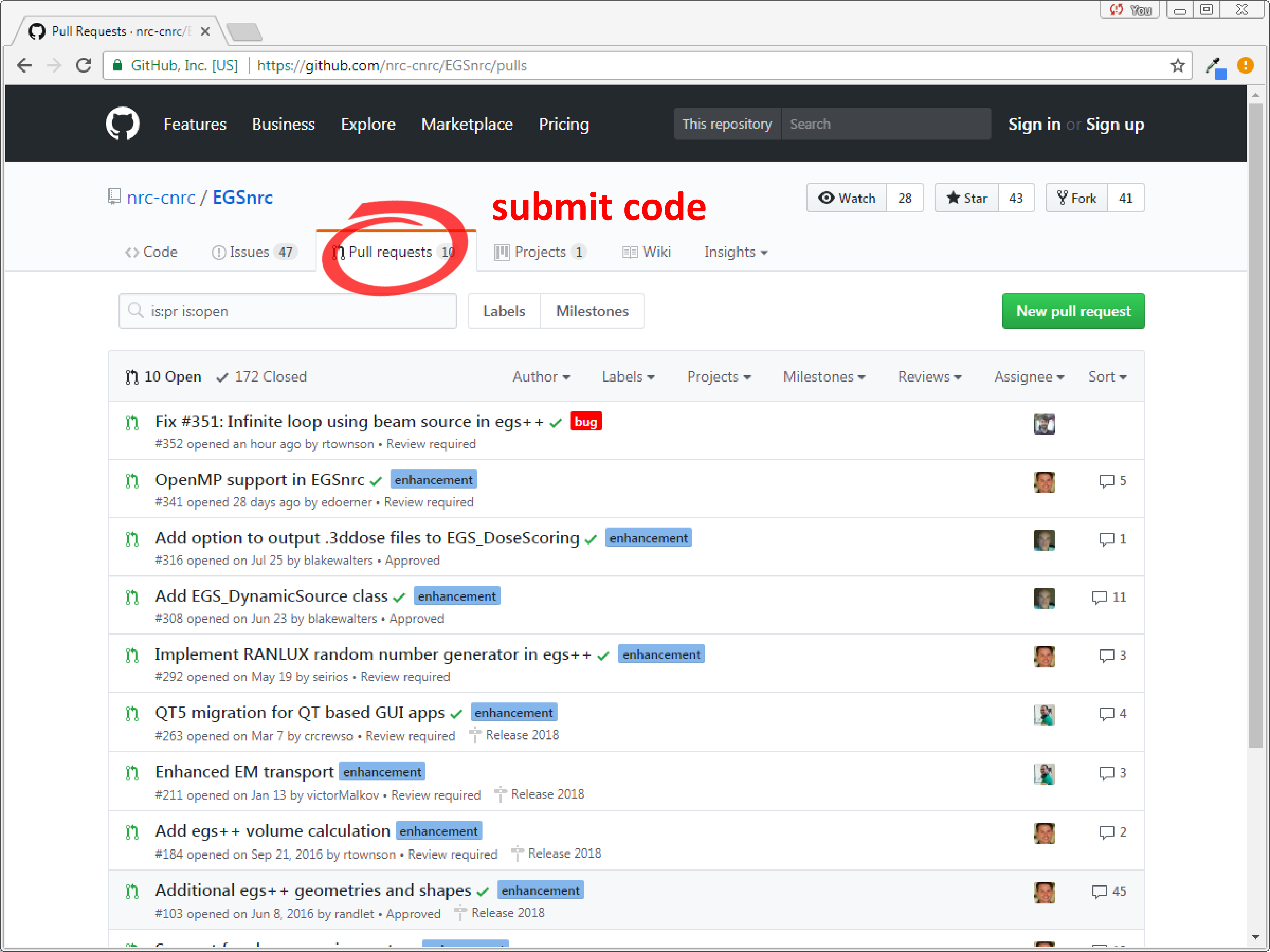
nrc-cnrc / EGSnrc
report problems
Watch 28
Star 43
Fork 41
Code
Issues 47
Pull requests 10
Projects 1
Wiki
Insights
is:issue is:open
Labels
Milestones
New issue
47 Open
123 Closed
Author
Labels
Projects
Milestones
Assignee
Sort
Infinite looping when using beam source in egs_chamber
#351 opened 23 hours ago by pgfwatso
1
DOSXYZnrc Source 20 simulations in pegsless mode do not work
#349 opened 13 days ago by ojalaj
1
bremsstrahlung correction=NRC missing for RMISW521 in material.dat
#348 opened 13 days ago by ojalaj
1
Incorrect density for RW-1 water substitute in density corrections file
#347 opened 13 days ago by ojalaj
3
EGSnrc guis "Go" button fails when make_prog variable includes arguments
#346 opened 16 days ago by ftessier
Fuzzy boundaries
#345 opened 19 days ago by Kawrakow
1
Warn when a geometry name is not unique
#344 opened 20 days ago by mchamberland
Inconsistent terminology in iaea_phsp_source
#334 opened on Aug 25 by mchamberland
Feature request: start phase-space from random particle
enhancement
#333 opened on Aug 23 by skmartin
2


Pull Requests · nrc-cnrc/E
GitHub, Inc. [US] | https://github.com/nrc-cnrc/EGSnrc/pulls
Features
Business
Explore
Marketplace
Pricing
This repository
Search
Sign in or Sign up
nrc-cnrc / EGSnrc
submit code
Watch 28
Star 43
Fork 41
Code
Issues 47
Pull requests 10
Projects 1
Wiki
Insights
is:pr is:open
Labels
Milestones
New pull request
10 Open
172 Closed
Author
Labels
Projects
Milestones
Reviews
Assignee
Sort
Fix #351: Infinite loop using beam source in egs++ bug
#352 opened an hour ago by rtownson • Review required
OpenMP support in EGSnrc enhancement
#341 opened 28 days ago by edoerner • Review required
5
Add option to output .3ddose files to EGS_DoseScoring enhancement
#316 opened on Jul 25 by blakewalters • Approved
1
Add EGS_DynamicSource class enhancement
#308 opened on Jun 23 by blakewalters • Approved
11
Implement RANLUX random number generator in egs++ enhancement
#292 opened on May 19 by seirios • Review required
3
QT5 migration for QT based GUI apps enhancement
#263 opened on Mar 7 by crcrewso • Review required
Release 2018
4
Enhanced EM transport enhancement
#211 opened on Jan 13 by victorMalkov • Review required
Release 2018
3
Add egs++ volume calculation enhancement
#184 opened on Sep 21, 2016 by rtownson • Review required
Release 2018
2
Additional egs++ geometries and shapes enhancement
#103 opened on Jun 8, 2016 by randlet • Approved
Release 2018
45

Installing EGSnrc in a nutshell

(but preferably in a Linux shell)

```
$ git clone https://github.com/nrc-cnrc/EGSnrc.git
$ cd EGSnrc
$ HEN_HOUSE/scripts/configure
```

Installing EGSnrc in a nutshell

(but preferably in a Linux shell)

```
$ git clone https://github.com/nrc-cnrc/EGSnrc.git
$ cd EGSnrc
$ git checkout develop  # use the develop branch
$ HEN_HOUSE/scripts/configure
```

There are two main branches:

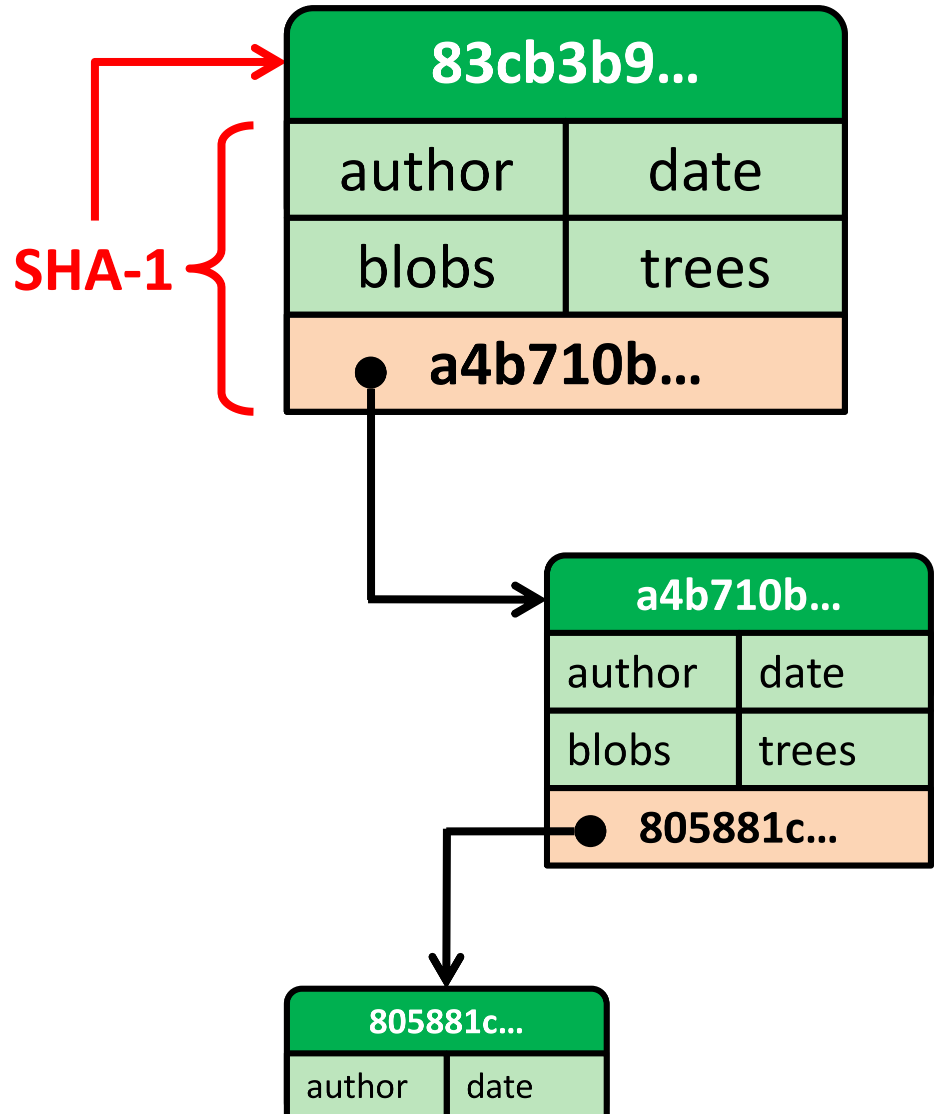
1. master: updated yearly, versioned by **year** (EGSnrc 2017).

2. develop: ongoing changes, versioned by **commit** (d3d95a3).

Cloning provides the entire commit history (try `git log`)

git is a robust version control system

- commit hashes
- distributed, decentralized
- offline repository
- no repository setup
- atomic commits
- commit staging
- fast, efficient
- flexible and safe
- lighthweight branches
- github, bitbucket, etc.



Code.

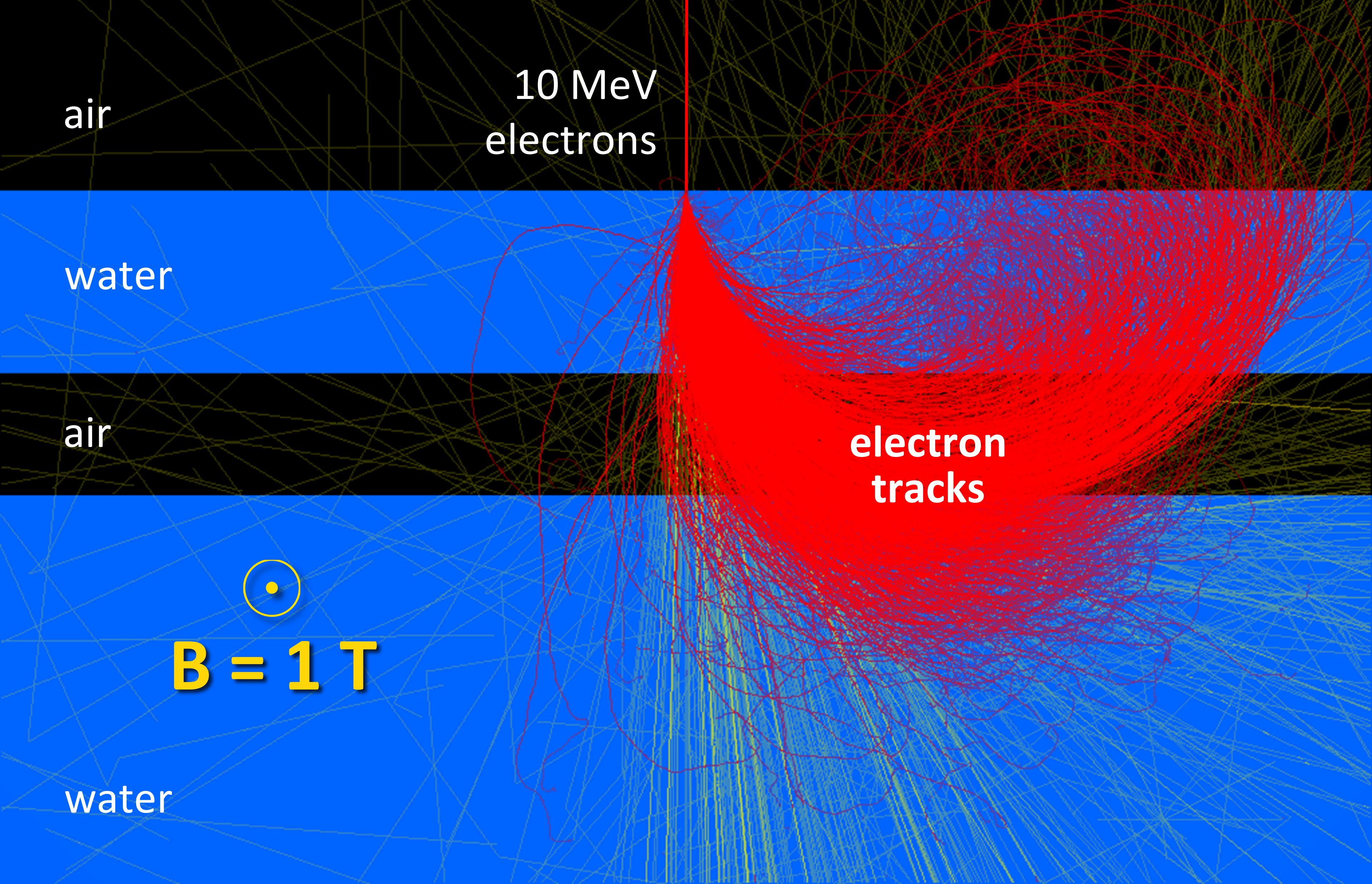
Ernesto Mainegra-Hing
Atomic relaxation and PE cross sections

Reid Townson
Radionuclide decay modelling

Dave Rogers
Improved kerma calculations

News

EGSnrc can model magnetic fields, *again!*



EM fields requires `emf_macros.mortran`

Electromagnetic fields are not included by default; you have to include the EMF macros in the compilation chain, e.g.,

```
EGSPP_USER_MACROS = cavity.macros \
      $(EGS_SOURCEDIR)emf_macros.mortran
```

Fields are defined in the input file:

```
:start MC transport parameter:

      Magnetic Field = 0 0 1   # Bx By Bz (in T)
      Electric Field = 0 0 0   # Ex Ey Ez (in V/cm)
      EM ESTEPE      = 0.02

:stop MC transport parameter:
```

(EM ESTEPE = 0.02 ← ϵ_B)

Malkov proposed a higher-order method

Charged particle transport in magnetic fields in EGSnrc

V. N. Malkov[a] and D. W. O. Rogers[a]
Carleton Laboratory for Radiotherapy Physics, Physics Department, Carleton University, Ottawa, Ontario K1S 5B6, Canada

(Received 7 January 2016; revised 30 May 2016; accepted for publication 8 June 2016; published 29 June 2016)

Purpose: To accurately and efficiently implement charged particle transport in a magnetic field in

Sensitive volume effects on Monte Carlo calculated ion chamber response in magnetic fields

Victor N. Malkov[a] and D. W. O. Rogers
Department of Physics, Carleton Laboratory for Radiotherapy Physics, Carleton University, Ottawa, ON, Canada

(Received 17 May 2017; revised 8 June 2017; accepted for publication 13 June 2017; published 19 July 2017)

Purpose: The development of magnetic resonance-guided radiation therapy (MRgRT) necessitates accurate Monte Carlo (MC) models of ion chambers for computing ion chamber corrections to compensate for the presence of the magnetic field. This study evaluates the sensitivity of the ion chamber dose response in a magnetic field on the collection volume used in the MC simulation.
Methods: The EGSnrc system's egs_chamber application is used with a recently developed and validated magnetic field transport code. The calculated dose to the sensitive volume of the chamber per unit incident photon fluence, normalized to that at 0 T, is evaluated as a function of magnetic field for the PTW 30013, PTW 31006, PTW 31010, Exradin A12S, and Exradin A1SL chambers. The sensitive region is varied by excluding the volume corresponding to either 0, 0.5, or 1 mm of distance

News.

Bugs

Zero electron rest mass for 30 days!

Closed **ftessier** opened this issue on Mar 1 · 0 comments

Thank you to **Shahid Naqvi**

ftessier commented on Mar 1 • edited

Owner

Description

A critical bug has been uncovered in EGSnrc which causes the electron energy to be offset by the value of the electron rest mass in some applications. This bug was introduced in commit `1eaf898` and is caused by the `prm` variable (precise rest mass) being used before it is initialized via `call hatch`.

Scope

Affects versions of EGSnrc downloaded between **3 February 2017 and 2 March 2017, inclusively.** For those working off the `develop` branch, the corrupted date range is 24 January to 2 March.

Remediation

The fix involves patching three source files, as detailed in commit `805881c`. The EGSnrc repository has been patched accordingly as of **1 March 2017,** on both branch `master` (commit `805881c`) and branch `develop` (commit `1c1cdb2`).

Wrong MS coefficients for 17 *years!*

Closed **jantolak** opened this issue on Jun 24, 2016 · 1 comment

Thank you to John Antolak

jantolak commented on Jun 24, 2016 • edited by ftessier

Contributor

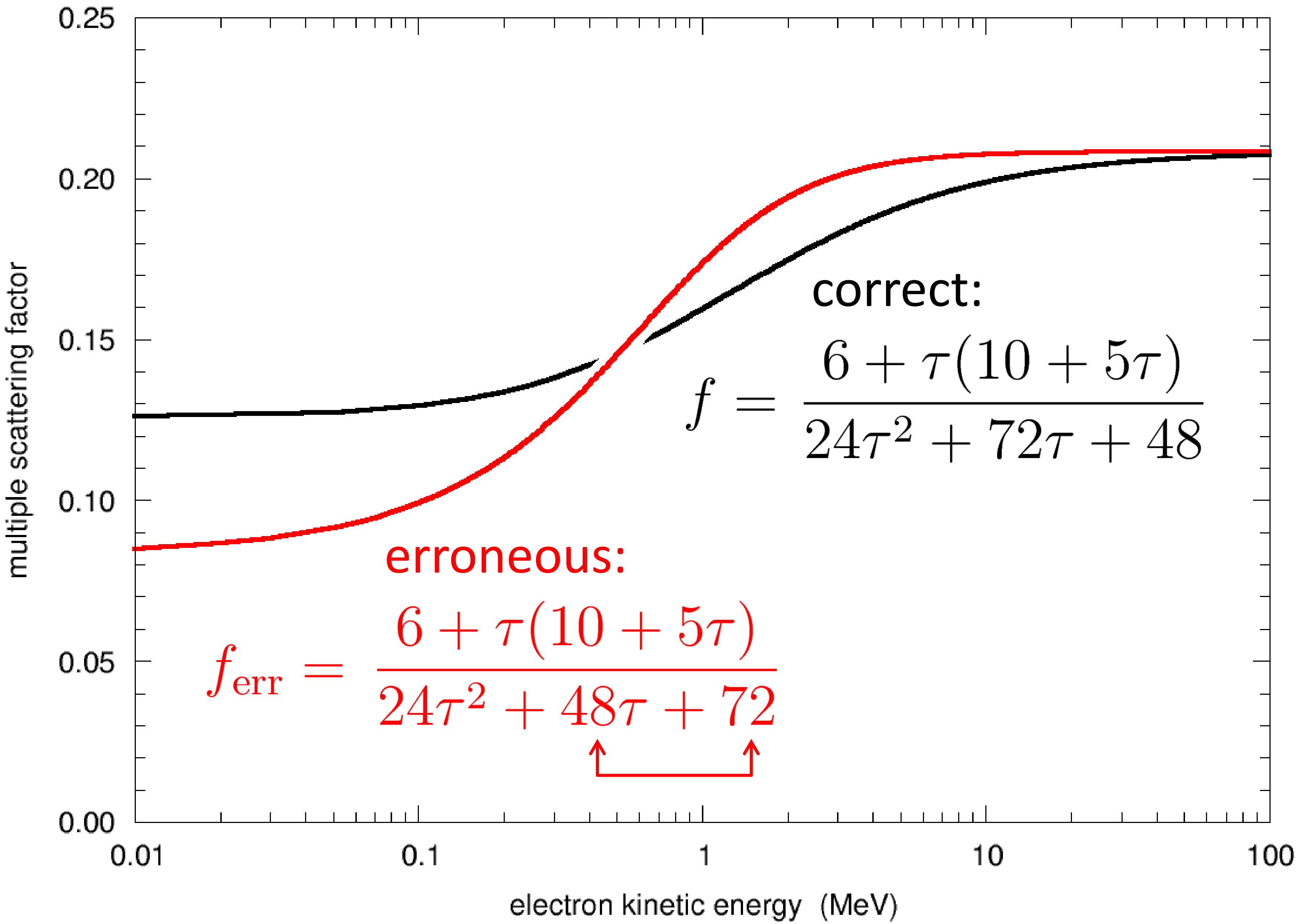
In `egsnrc.mortran`, subroutine `msdist_pII` at line 4092, it appears that the polynomial in the denominator is incorrect. Here is the current code at those lines.

```
4091    "e       = e * (1 - epsilonp*epsilonp*((6+tau*(10+5*tau))/(tau+1)/(tau+2))/24);
4092    e       = e * (1 - epsilonp*epsilonp*(6+10*tau+5*tau2)/(24*tau2+48*tau+72));
```

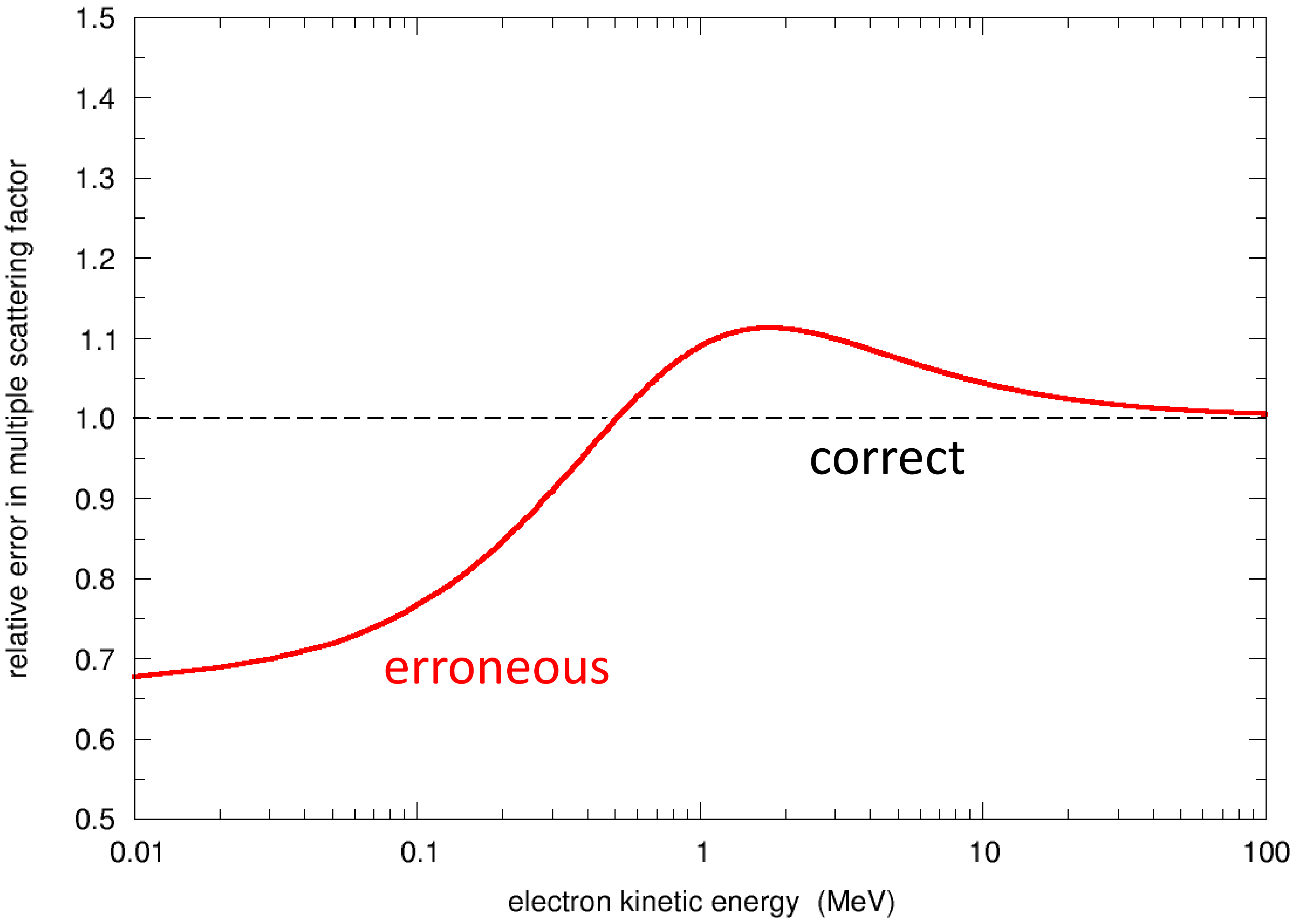
Assuming that the expression on line 4091 is correct, the denominator in the last term should be `24*(tau+1)*(tau+2) = 24*(tau2+3*tau+2) = (24*tau2+72*tau+48)`: the 72 and 48 are not in the right place in the code. Therefore, line 4092 should read

```
4092    e       = e * (1 - epsilonp*epsilonp*(6+10*tau+5*tau2)/(24*tau2+72*tau+48));
```

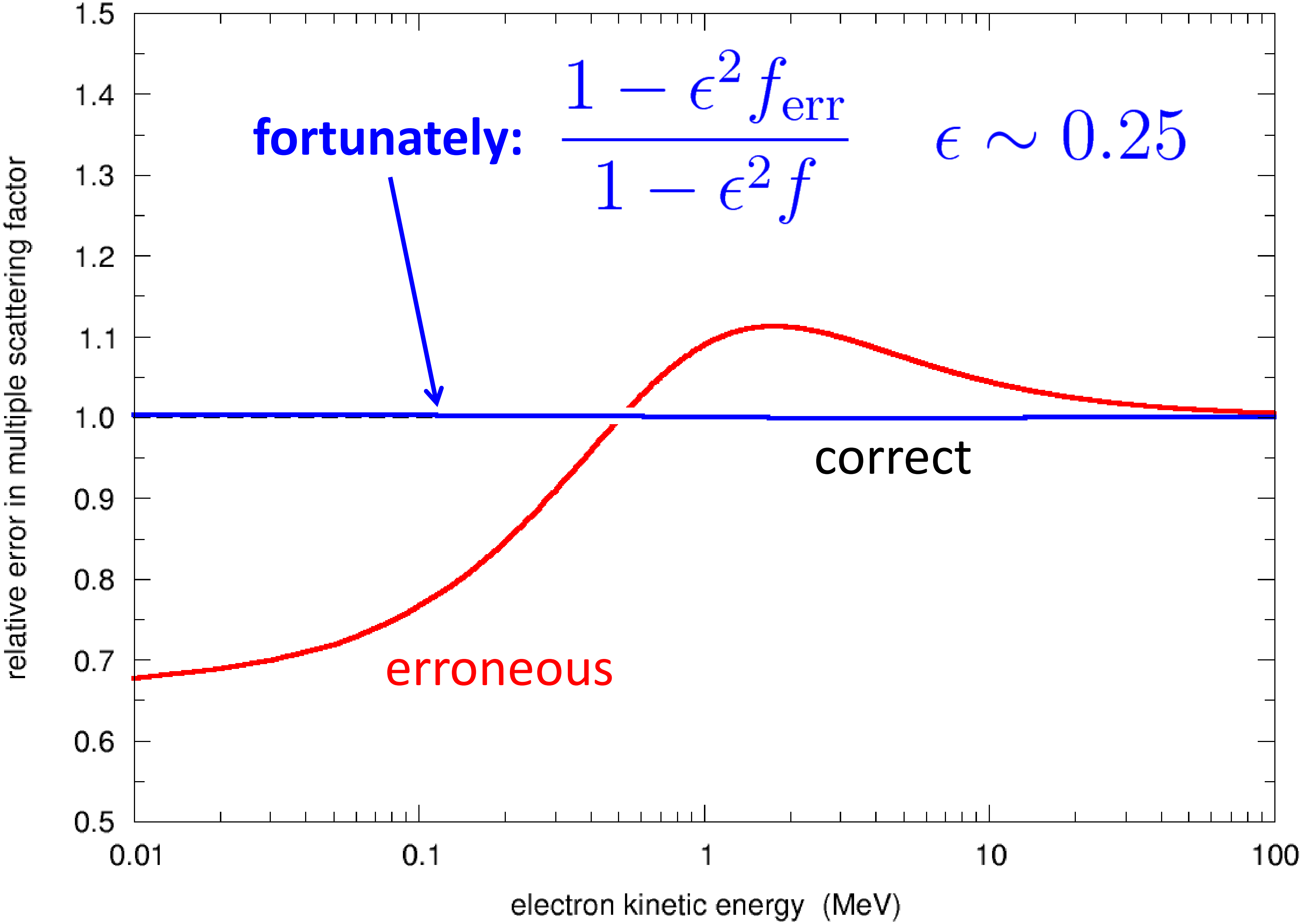
It appears that this error makes very little difference, which is likely why it has not been noticed. The error was actually pointed out to me by a trainee who was working on his own MC code for electron scattering and wanted to compare to an existing code as a baseline.



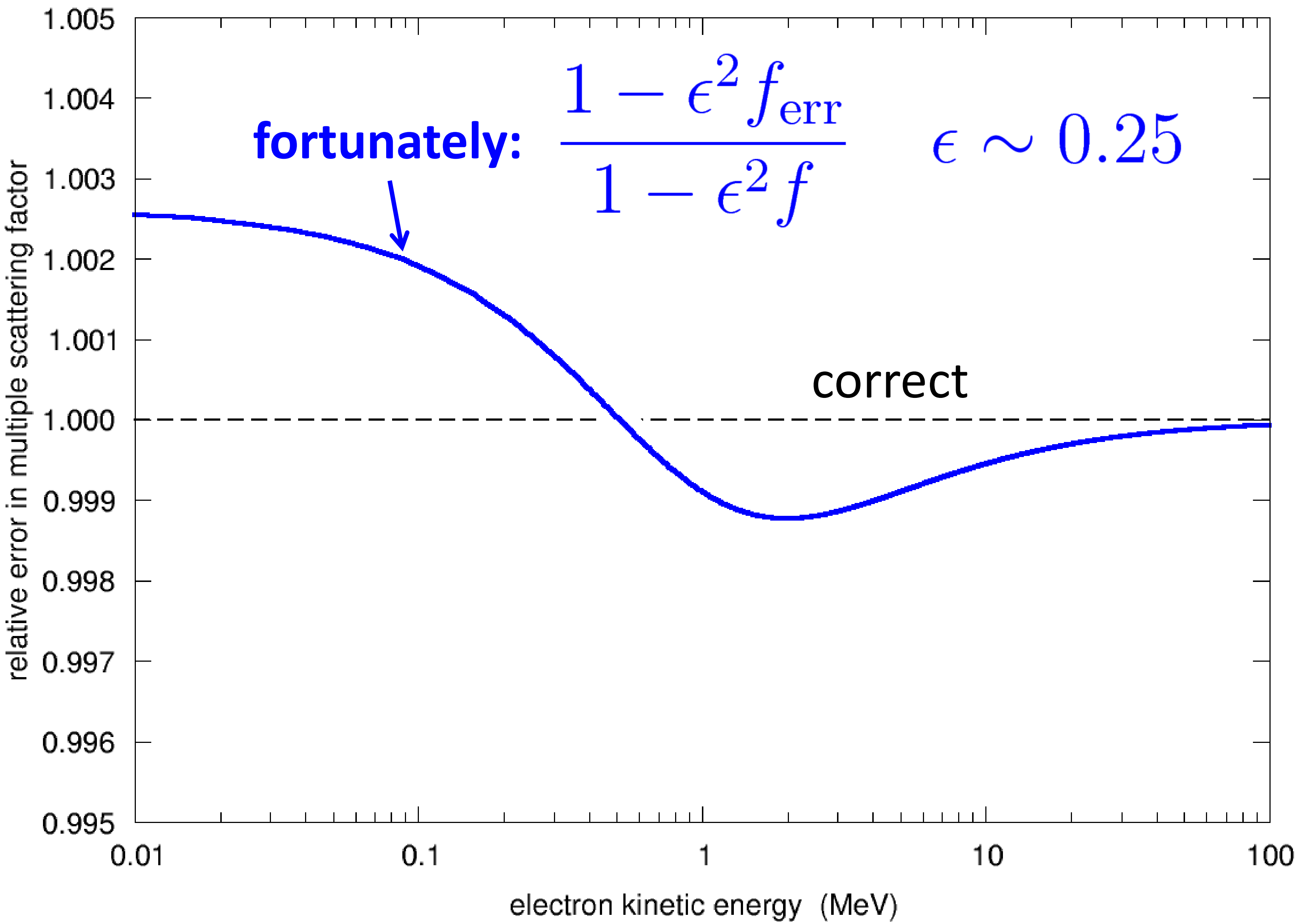
0.25
0.20
0.15
0.10
0.05
0.00
0.01
0.1
1
10
100
multiple scattering factor
electron kinetic energy (MeV)
correct:
$f = \frac{6 + \tau(10 + 5\tau)}{24\tau^2 + 72\tau + 48}$
erroneous:
$f_{\mathrm{err}} = \frac{6 + \tau(10 + 5\tau)}{24\tau^2 + 48\tau + 72}$



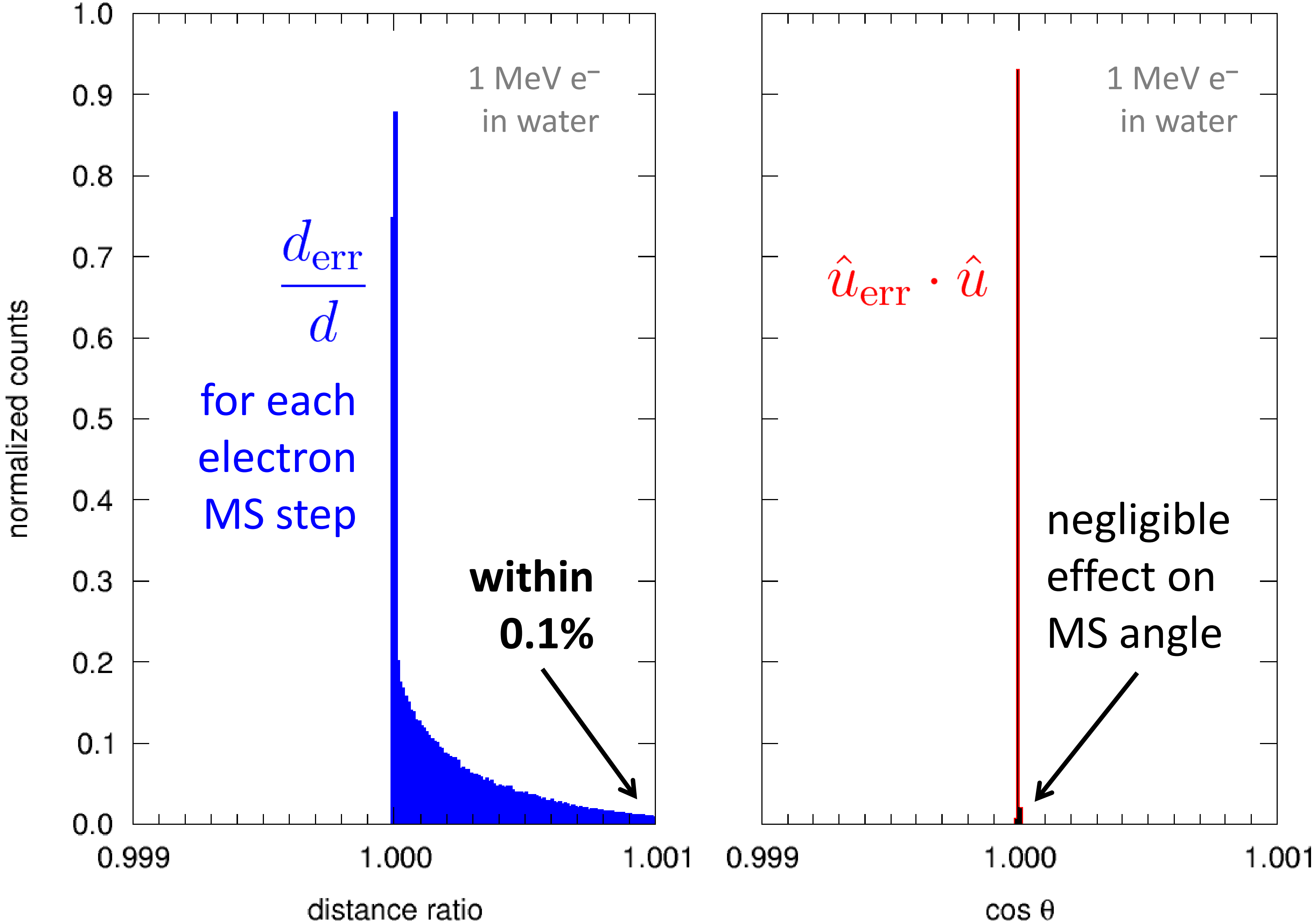
relative error in multiple scattering factor
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
correct
erroneous
0.01
0.1
1
10
100
electron kinetic energy (MeV)



fortunately:
$\frac{1-\epsilon^2 f_{\rm err}}{1-\epsilon^2 f}$
$\epsilon \sim 0.25$
correct
erroneous
relative error in multiple scattering factor
electron kinetic energy (MeV)
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.01
0.1
1
10
100

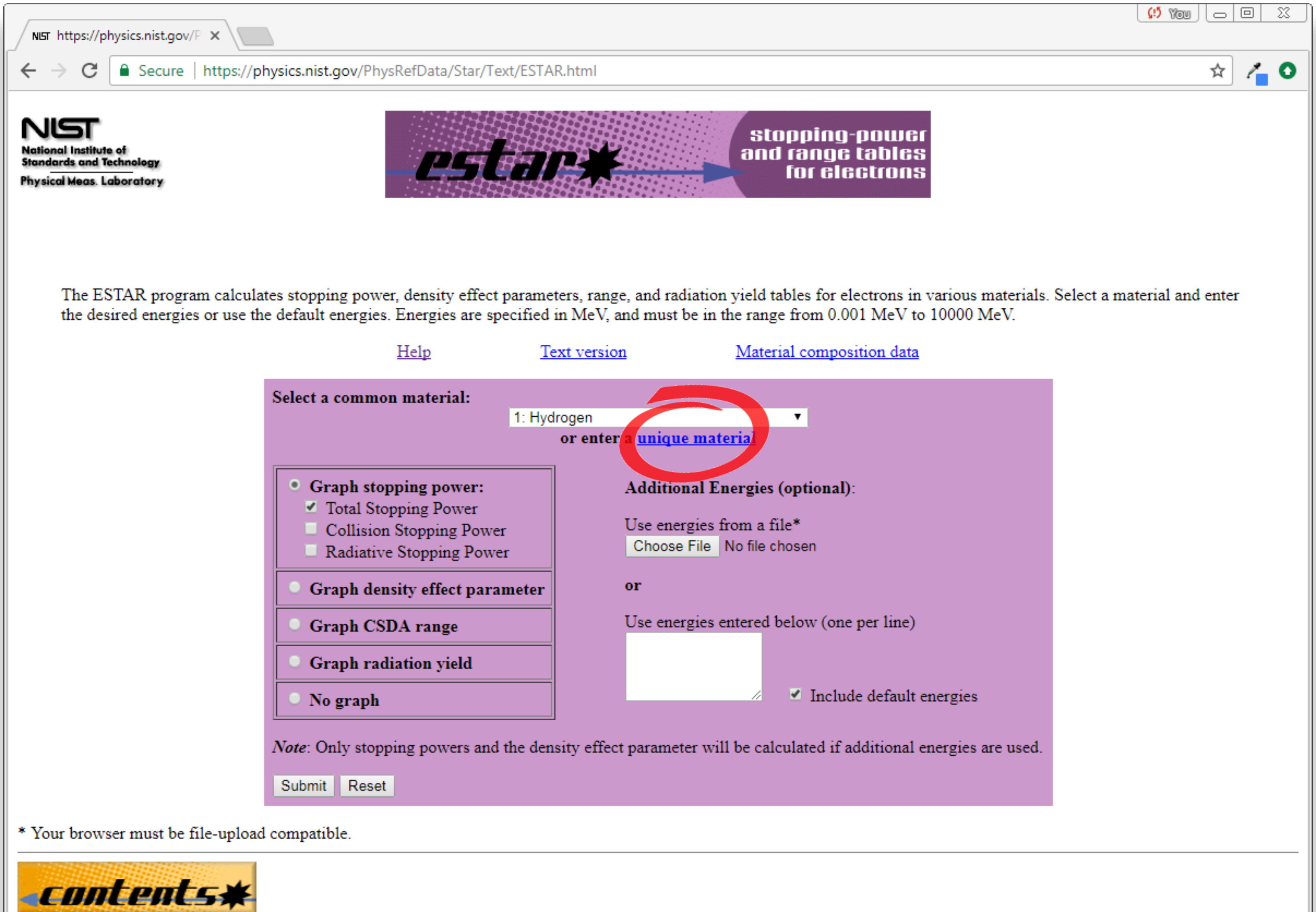


fortunately:
$$\frac{1-\epsilon^2 f_{\rm err}}{1-\epsilon^2 f}$$
$\epsilon \sim 0.25$
correct
relative error in multiple scattering factor
1.005
1.004
1.003
1.002
1.001
1.000
0.999
0.998
0.997
0.996
0.995
0.01
0.1
1
10
100
electron kinetic energy (MeV)

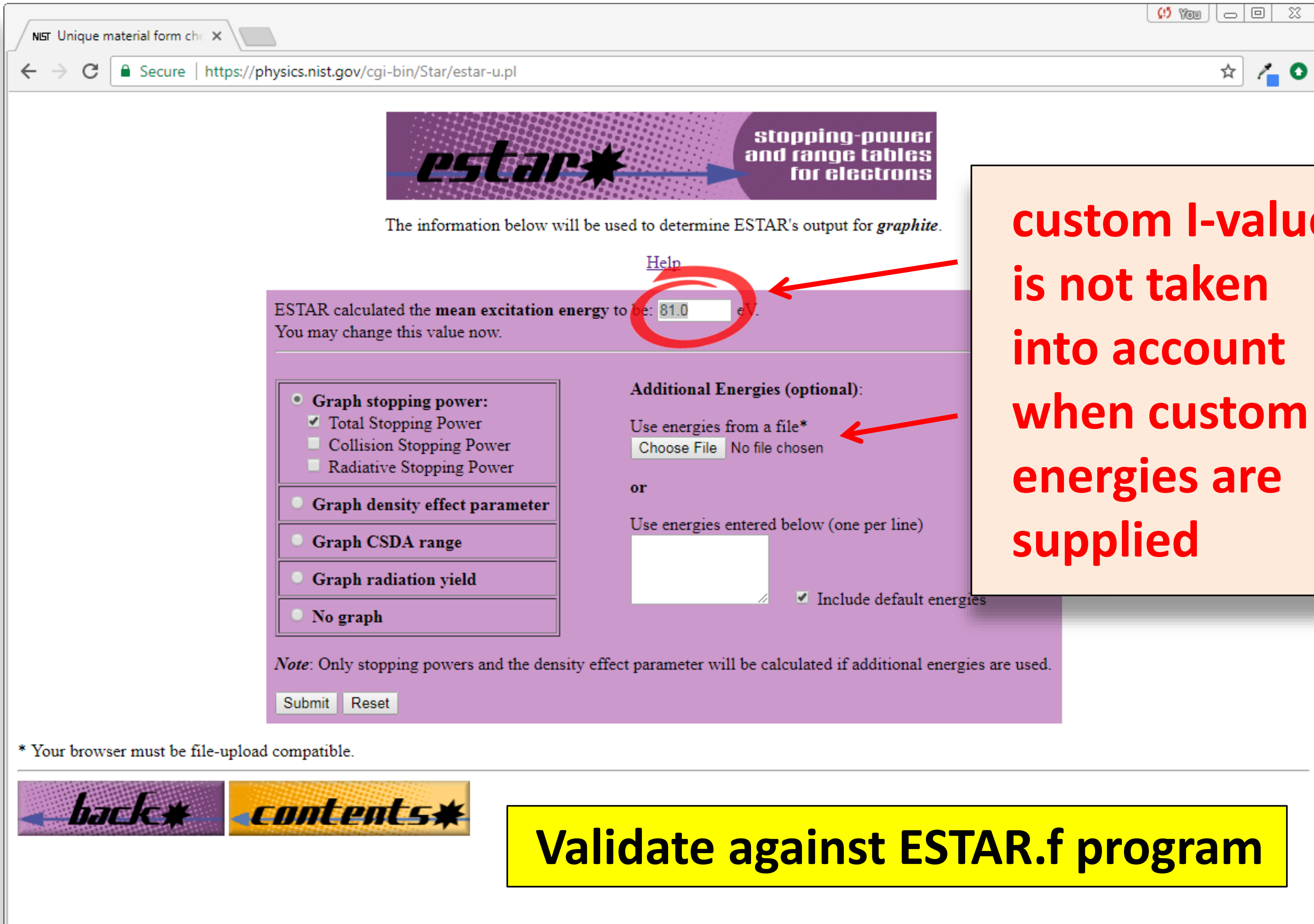


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
normalized counts
1 MeV e⁻
in water
$\frac{d_{\mathrm{err}}}{d}$
for each
electron
MS step
within
0.1%
0.999
1.000
1.001
distance ratio
1 MeV e⁻
in water
$\hat{u}_{\mathrm{err}} \cdot \hat{u}$
negligible
effect on
MS angle
0.999
1.000
1.001
cos θ

Someone else's bug: ESTAR I-value



Someone else's bug: ESTAR I-value



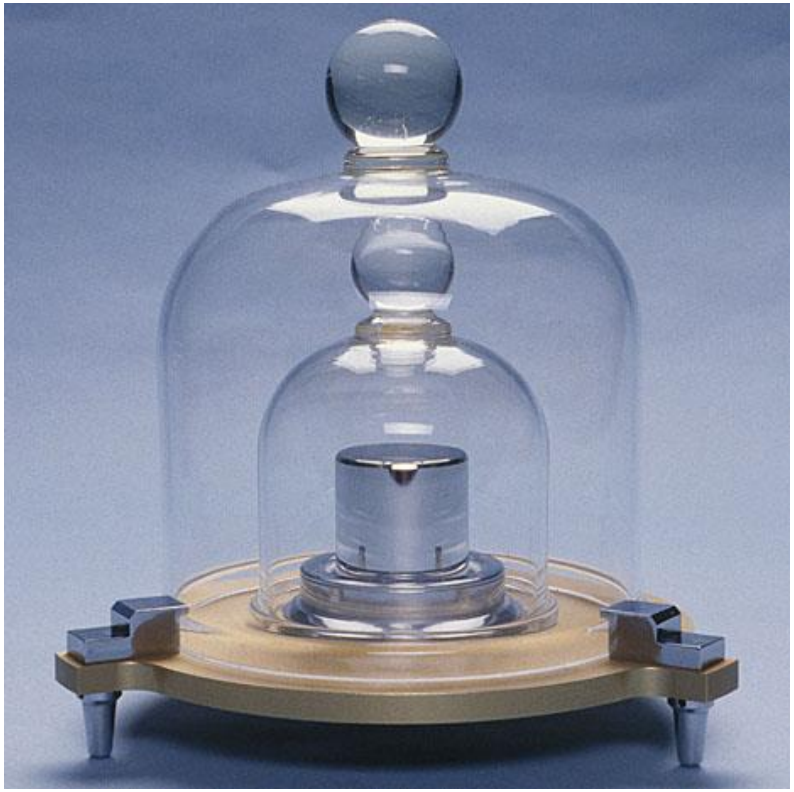
custom I-value is not taken into account when custom energies are supplied

Validate against ESTAR.f program

Bugs.

Test

Are Monte Carlo simulations *traceable?*



Mass measurements are in principle traceable to the BIPM kilogram in Paris (until 2018).

Are we doing everything we can to ensure the validity of Monte Carlo simulation?

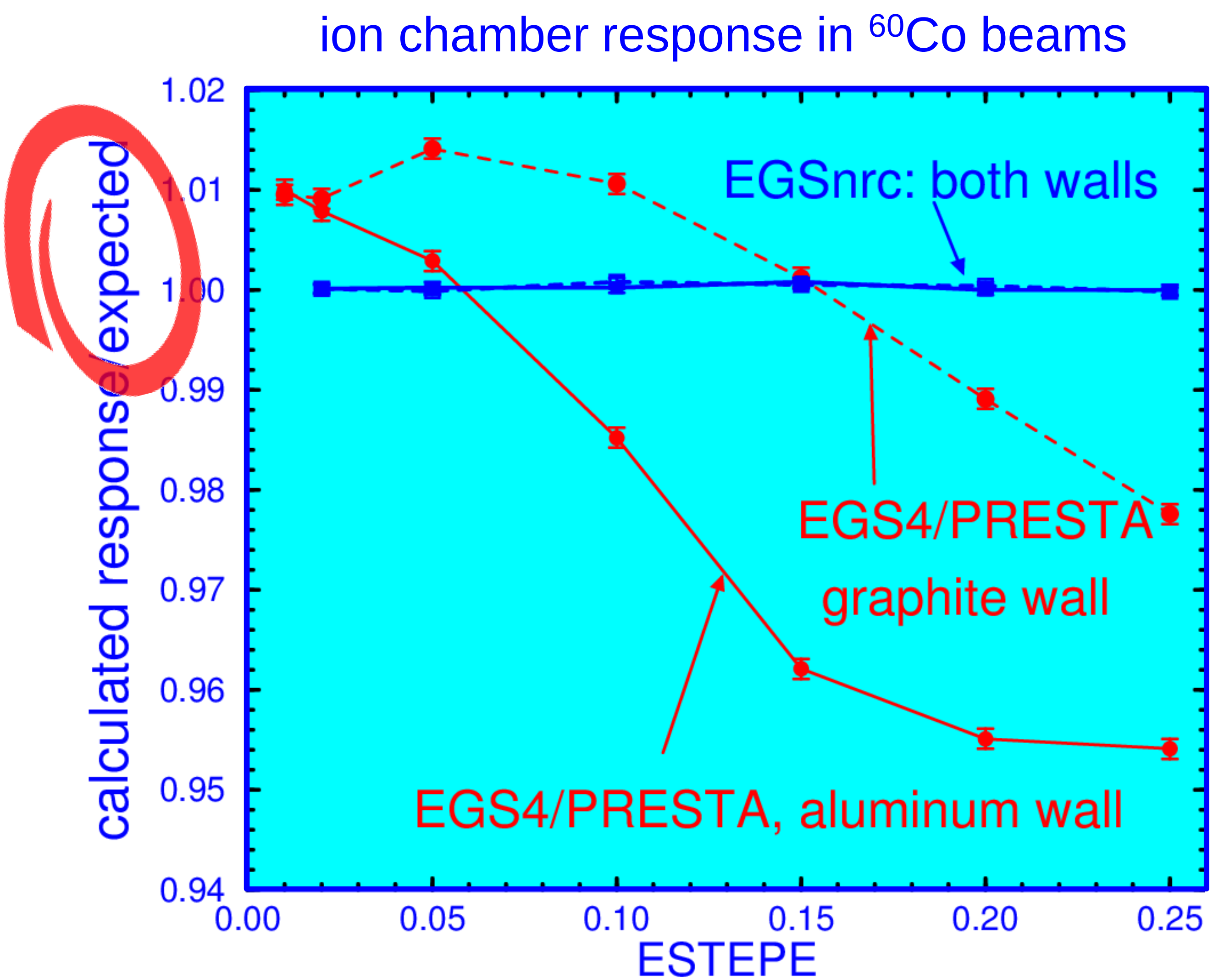
Monte Carlo simulation results are widely trusted, for example in dosimetry protocols.

Clients have started to ask for official Monte Carlo simulation calibration certificates!

What is software traceability anyway?

1. **robust versioning, robust source code**
   - migrate to git version control system ✓
   - port the EGSnrc core code to C++
2. **automated, continuous integration testing**
   - compilation test on every commit (Travis CI) ✓
   - run standard simulation set for numerical comparison
3. **automated, ongoing key comparisons between codes**
   - agree on key data and key scenarios
   - develop a common simulation description language?
4. **Monte Carlo simulation verification**

Kawrakow's famous Fano test graph



"EGSnrc is accurate to within 0.1%, with respect to its own cross sections."

This remains a distinguishing feature of EGSnrc today!

Fano theorem provides a rigorous test

A Monte Carlo simulation algorithm is essentially solving the Boltzmann transport equation, numerically:

$$\mathbf{u} \cdot \nabla_r \phi = \rho \left(s + I[\phi] \right)$$

$$0 = \rho \left(s + I[\phi] \right)$$

change in fluence **source** **atomic interactions**

per unit mass

If the atomic properties are identical everywhere, **a uniform fluence implies a uniform source (per unit mass).**

Since the solution to the Boltzmann equation is presumed unique: **turn this around to verify the Monte Carlo algorithm.**

IOP Publishing | Institute of Physics and Engineering in Medicine Physics in Medicine & Biology

Phys. Med. Biol. **60** (2015) 6639–6654 doi:10.1088/0031-9155/60/17/6639

Reference dosimetry in the presence of magnetic fields: conditions to validate Monte Carlo simulations

Hugo Bouchard[1], Jacco de Pooter[2], Alex Bielajew[3] and Simon Duane[1]

[1] Acoustics and Ionising Radiation Team, National Physical Laboratory, Hampton Road, Teddington TW11 0LW, UK
[2] VSL B.V., Thijsseweg 11, NL-2629 JA Delft, The Netherlands
[3] Department of Nuclear Engineering and Radiological Sciences, The University of Michigan, Ann Arbor, MI 48109, USA

E-mail: hugo.bouchard@npl.co.uk

Received 3 February 2015, revised 22 June 2015
Accepted for publication 26 June 2015
Published 13 August 2015

Abstract

With the advent of MRI-guided radiotherapy, reference dosimetry must be thoroughly addressed to account for the effects of the magnetic field on absorbed dose to water and on detector dose response. While Monte Carlo plays an essential role in reference dosimetry, it is also crucial for determining

Fano theorem within a magnetic field

The magnetic field adds a Lorentz force term in the Boltzmann transport equation:

$$\mathbf{u}\cdot\nabla_r\phi = \rho\left(s + I[\phi]\right) - quB(\hat{\mathbf{u}}\times\hat{\mathbf{b}})\cdot\nabla_p\phi$$

There are **two choices** to recover a testable *Fano condition:*

1. scale the magnetic field with density $B \to B/\rho$

2. make this gradient parallel to velocity

The condition $\nabla_p\phi \sim \hat{\mathbf{u}}$ implies that the magnetic term vanishes: *a **uniform isotropic source** yields a uniform fluence!*

Fano testing requires 3 ingredients

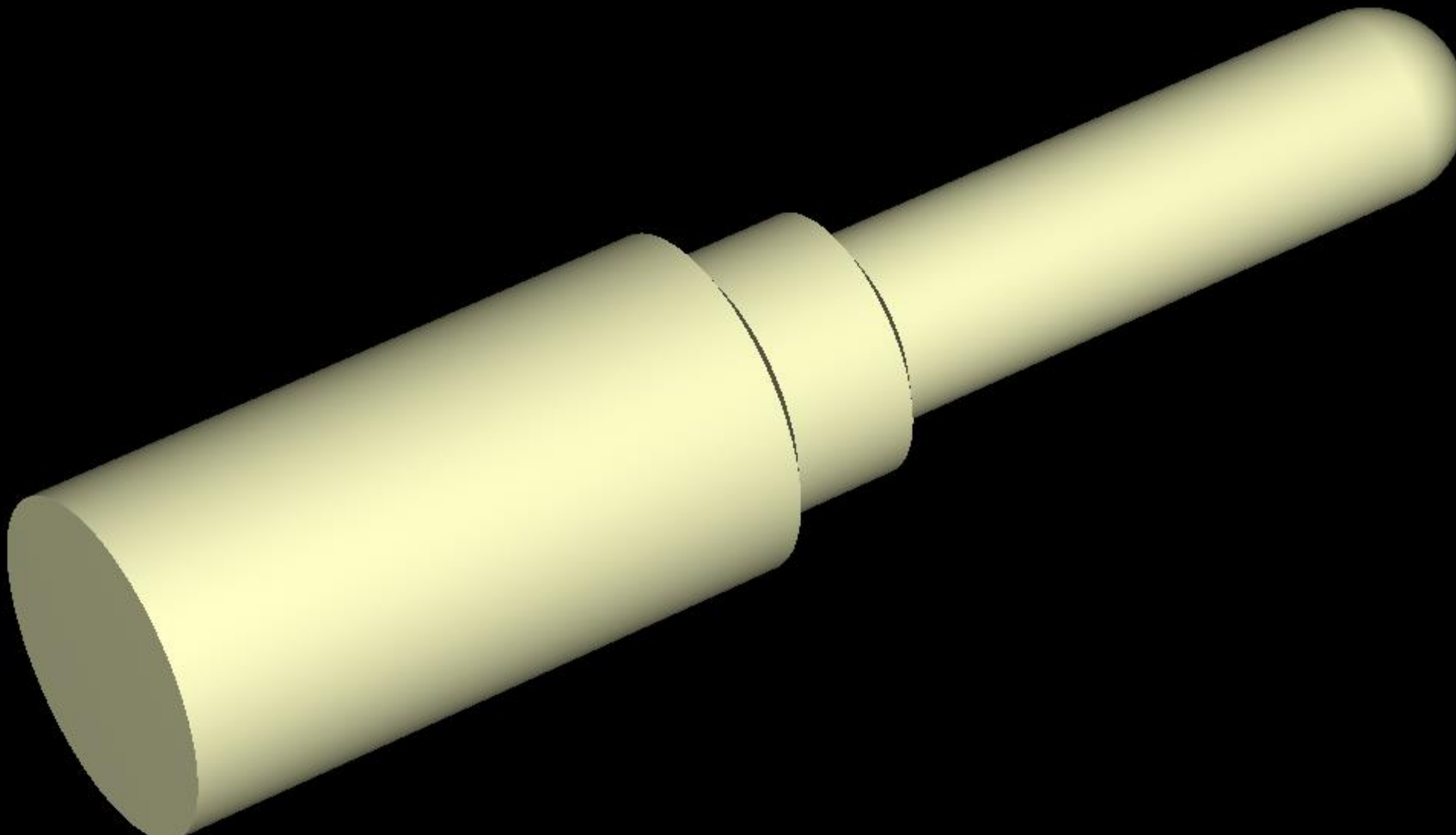
1. **uniform atomic interaction cross sections:**
   set all regions to the same material, vary the density.

2. **a uniform, isotropic, density-scaled source of particles:**
   before: parallel photon beam, regenerate photons.
   now: use the `egs_fano_source` class.

3. **an infinite simulation space:**
   before: discard photon, worry about electron range...
   now: use an *infinite* simulation space!

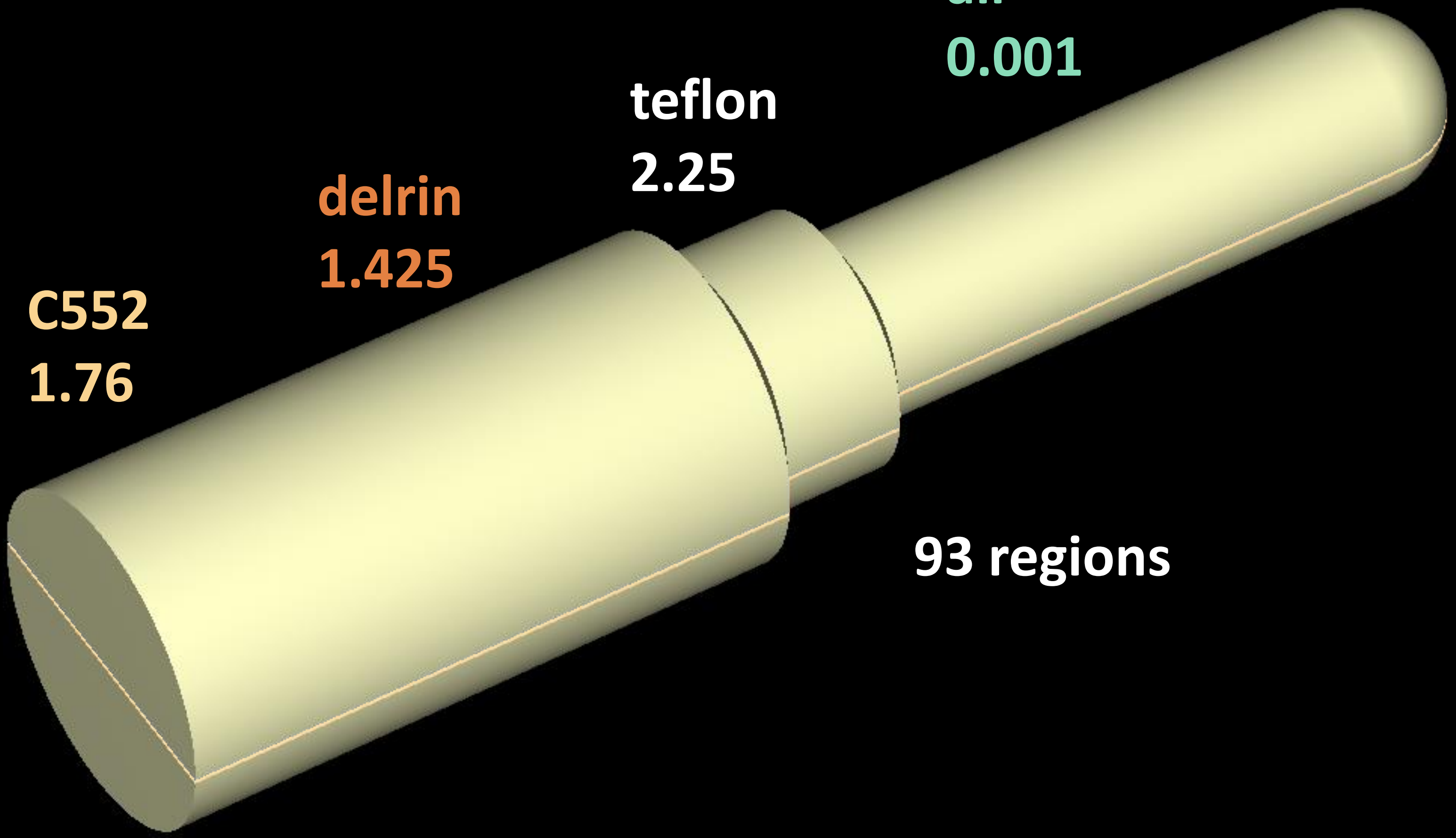
Fano testing an ion chamber

Exradin A12, 0.6 cm3 chamber



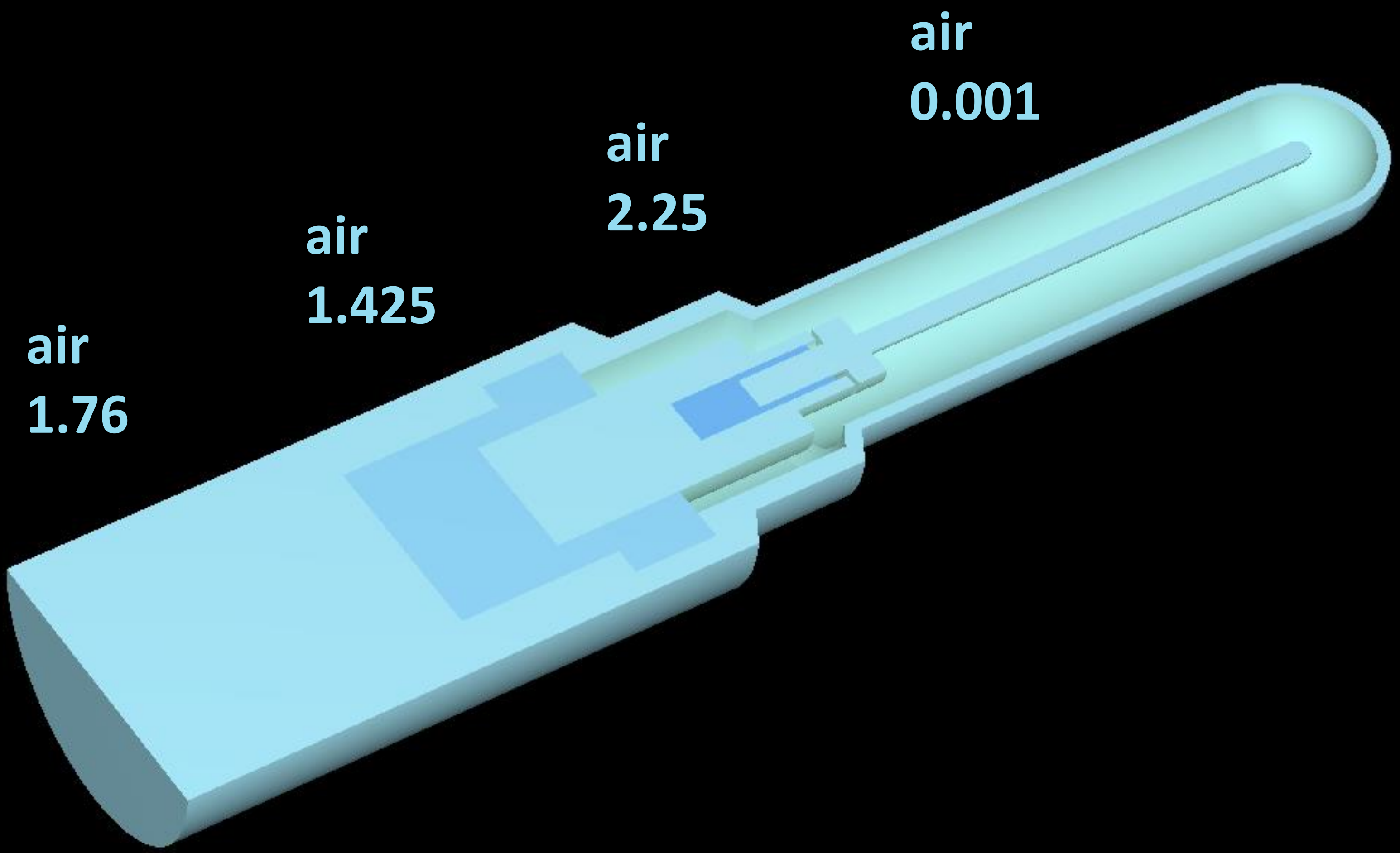
Fano testing an ion chamber

Exradin A12, 0.6 cm3 chamber



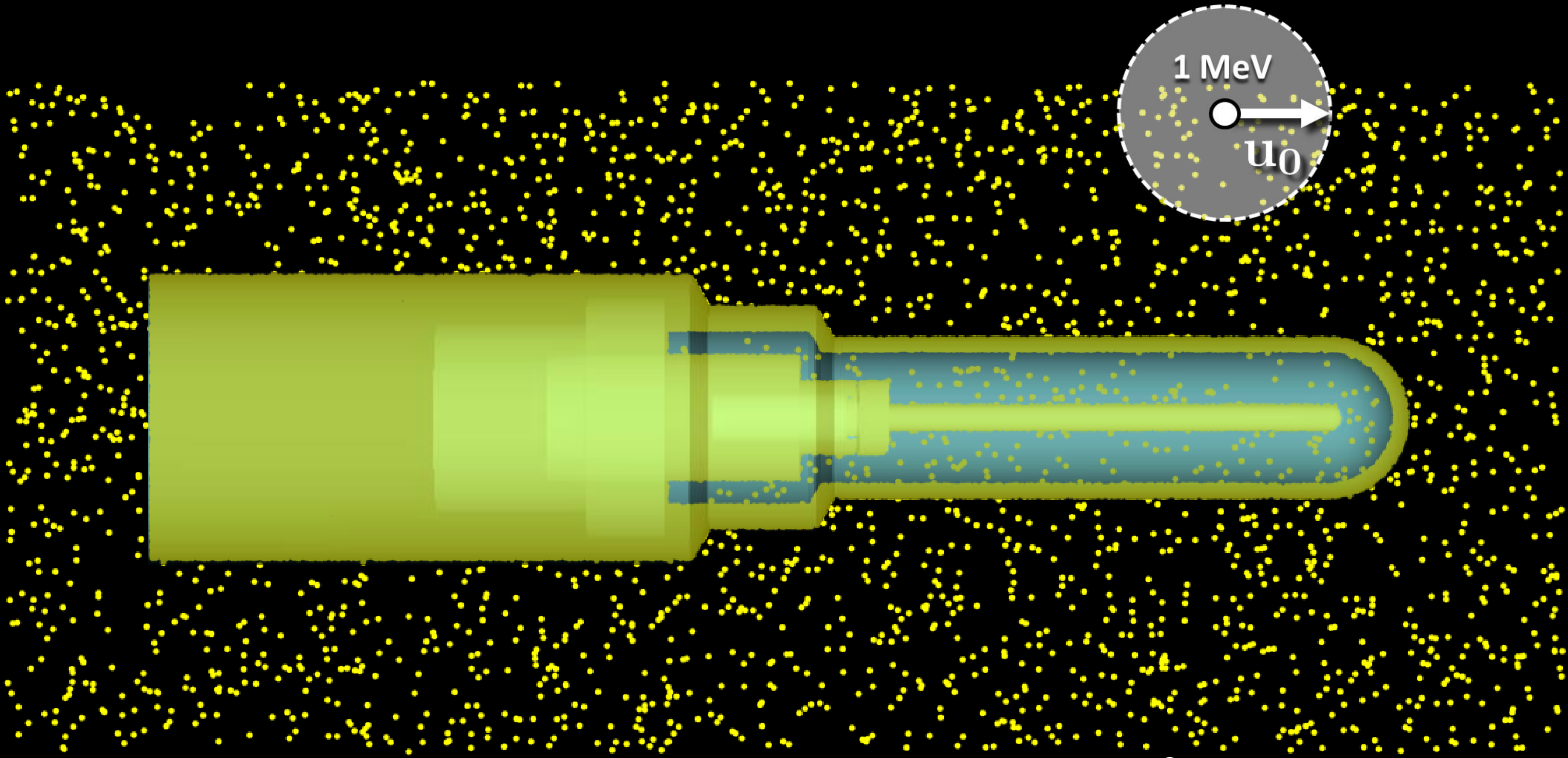
Fano testing an ion chamber

1. uniform atomic interaction cross sections



Fano testing an ion chamber

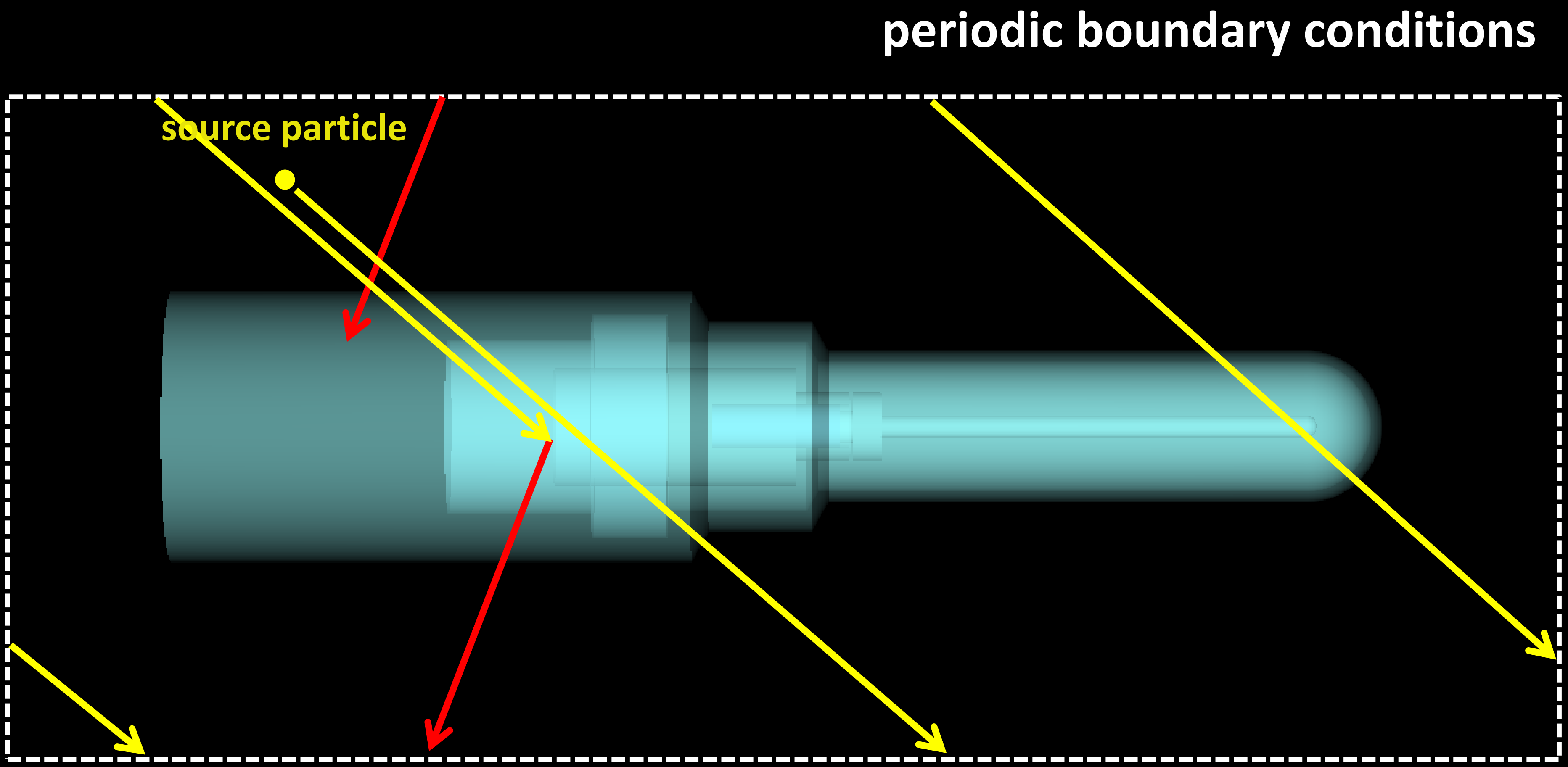
2. a uniform, isotropic, density-scaled source of particles



egs_fano_source

Fano testing an ion chamber

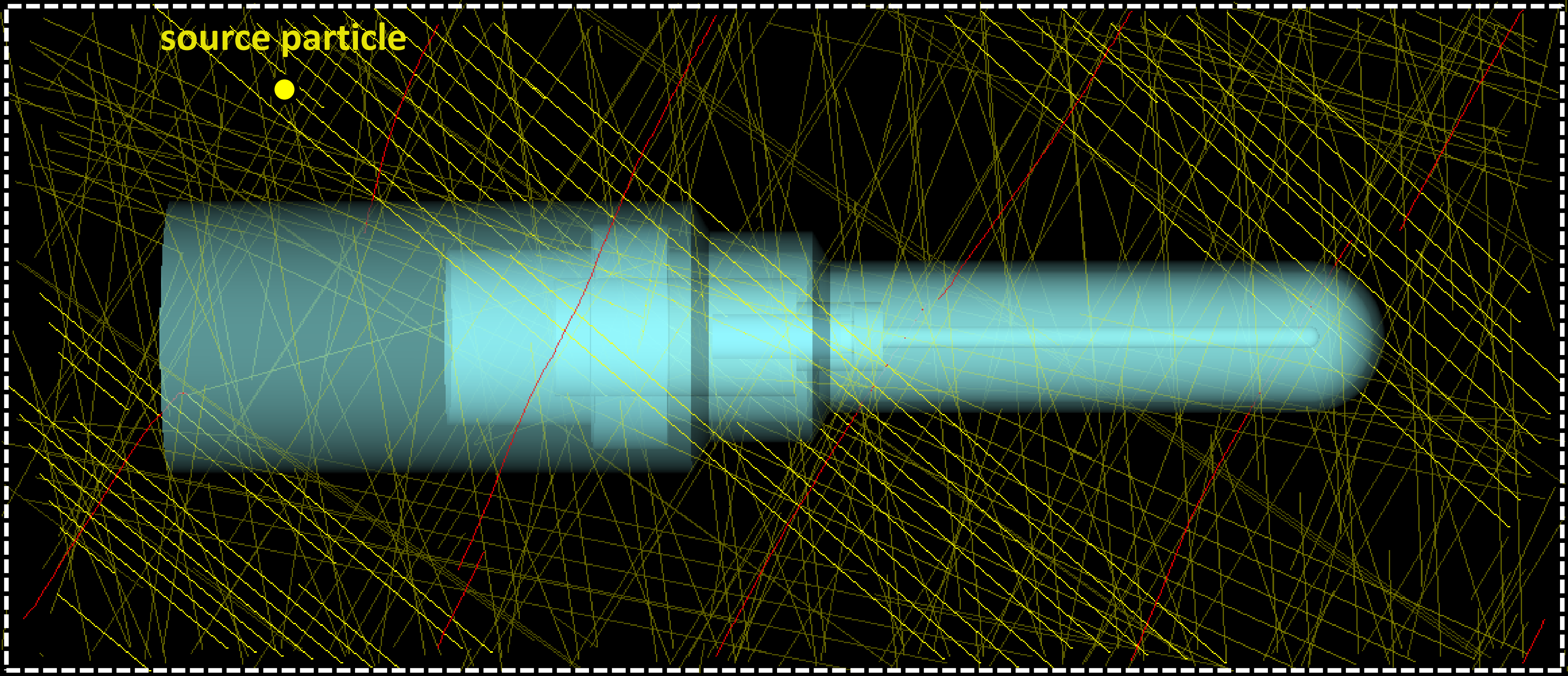
3. an infinite simulation space



Fano testing an ion chamber

3. an infinite simulation space

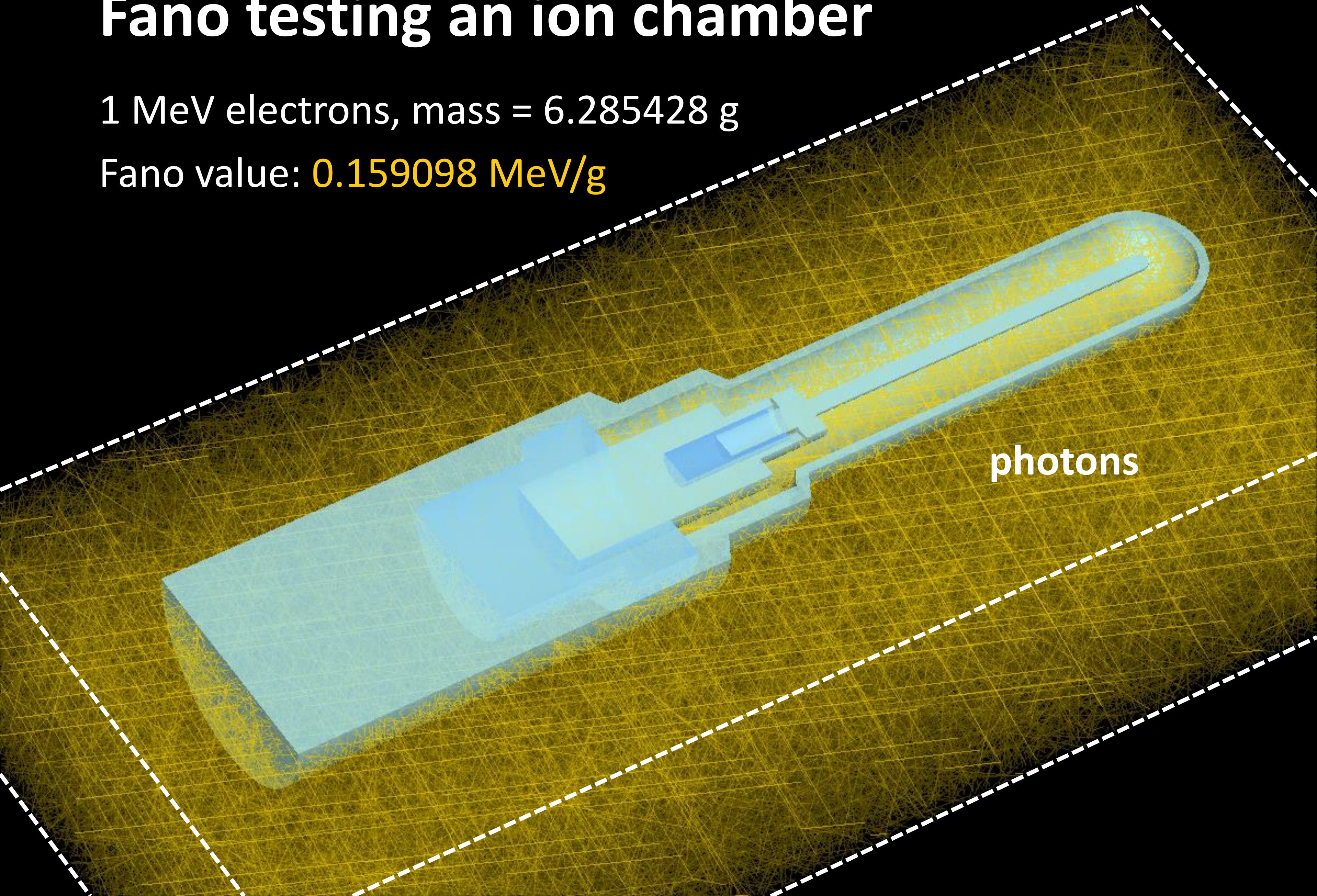
periodic boundary conditions



Fano testing an ion chamber

1 MeV electrons, mass = 6.285428 g

Fano value: 0.159098 MeV/g



Fano testing an ion chamber

1 MeV electrons, mass = 6.285428 g

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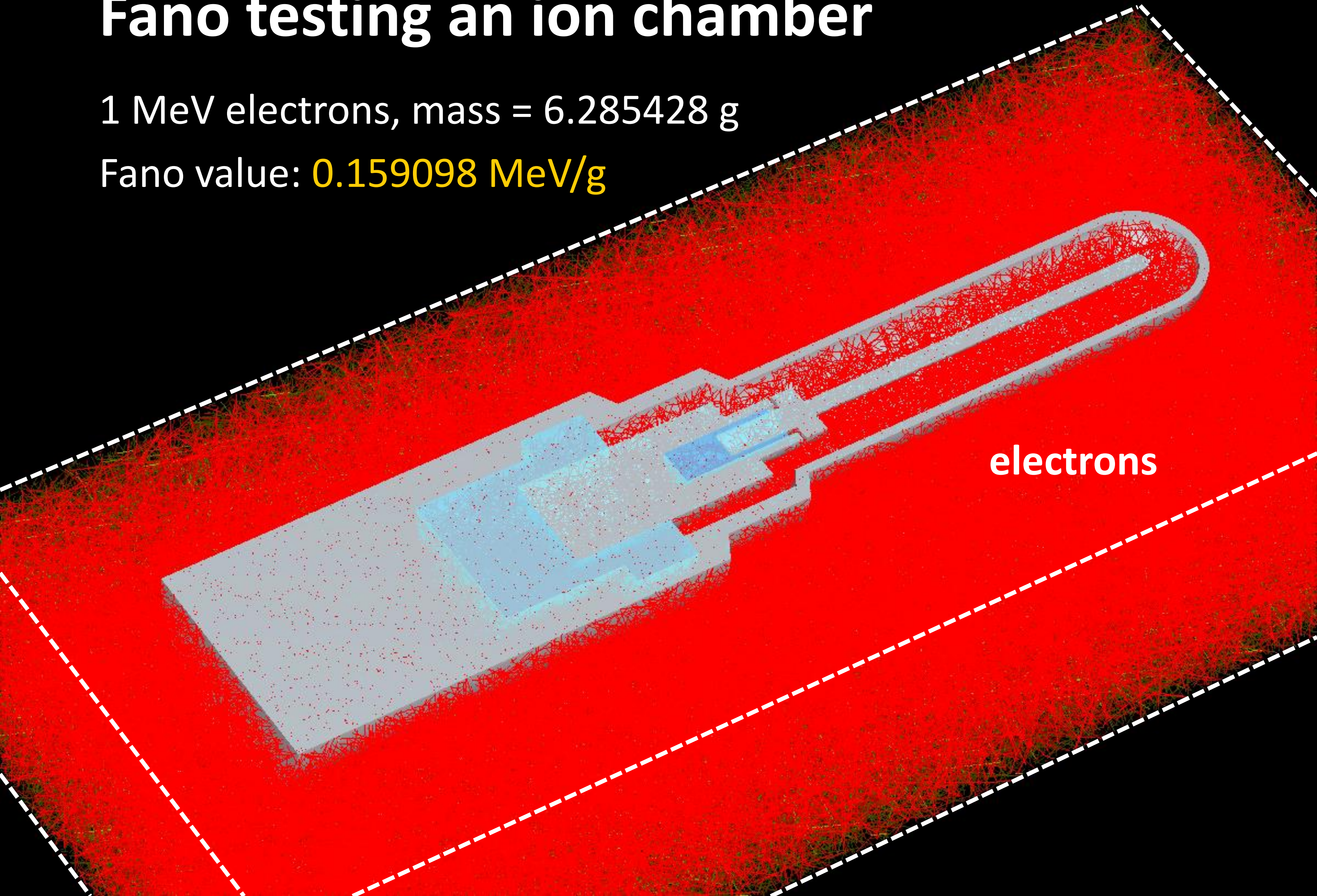
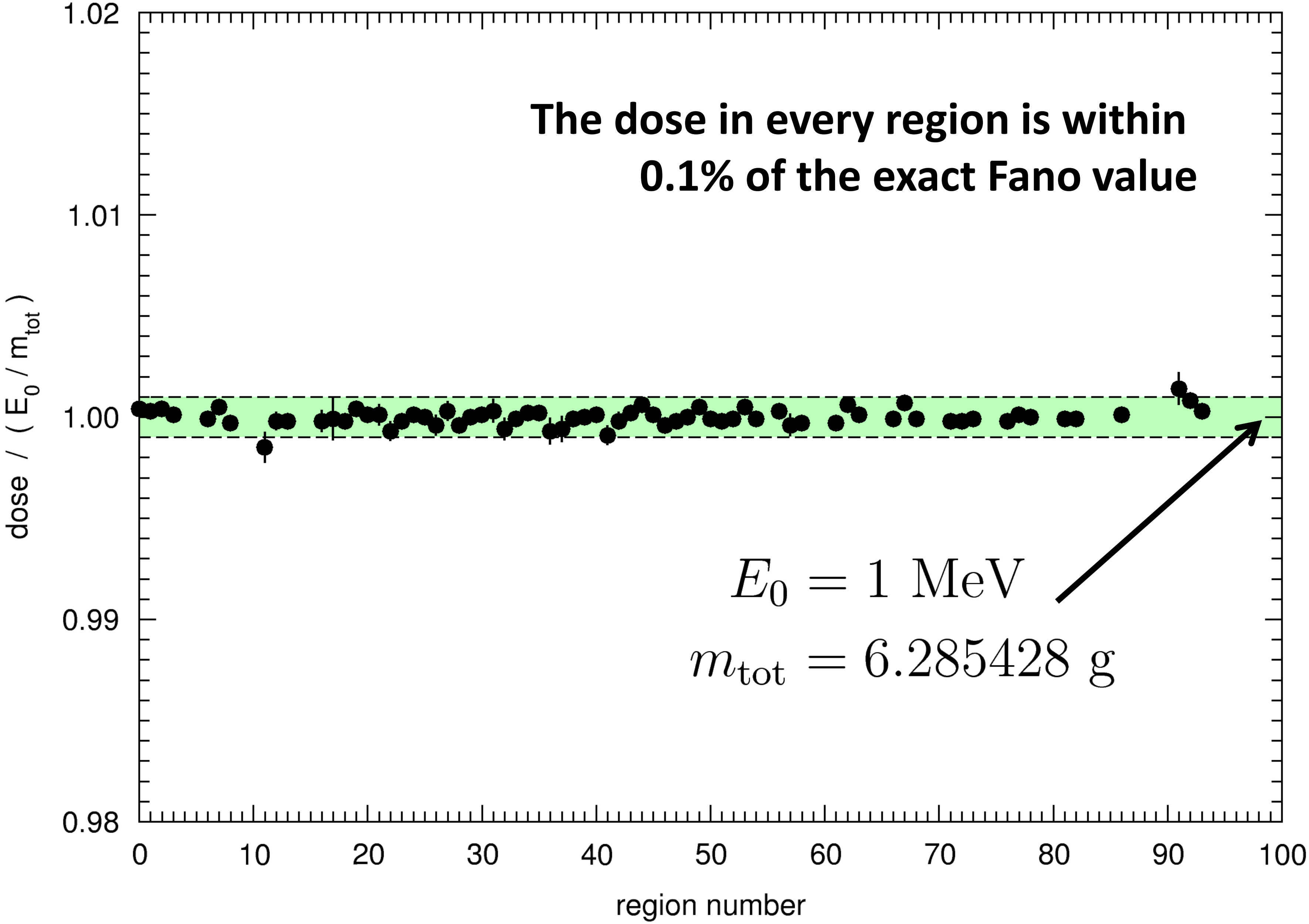
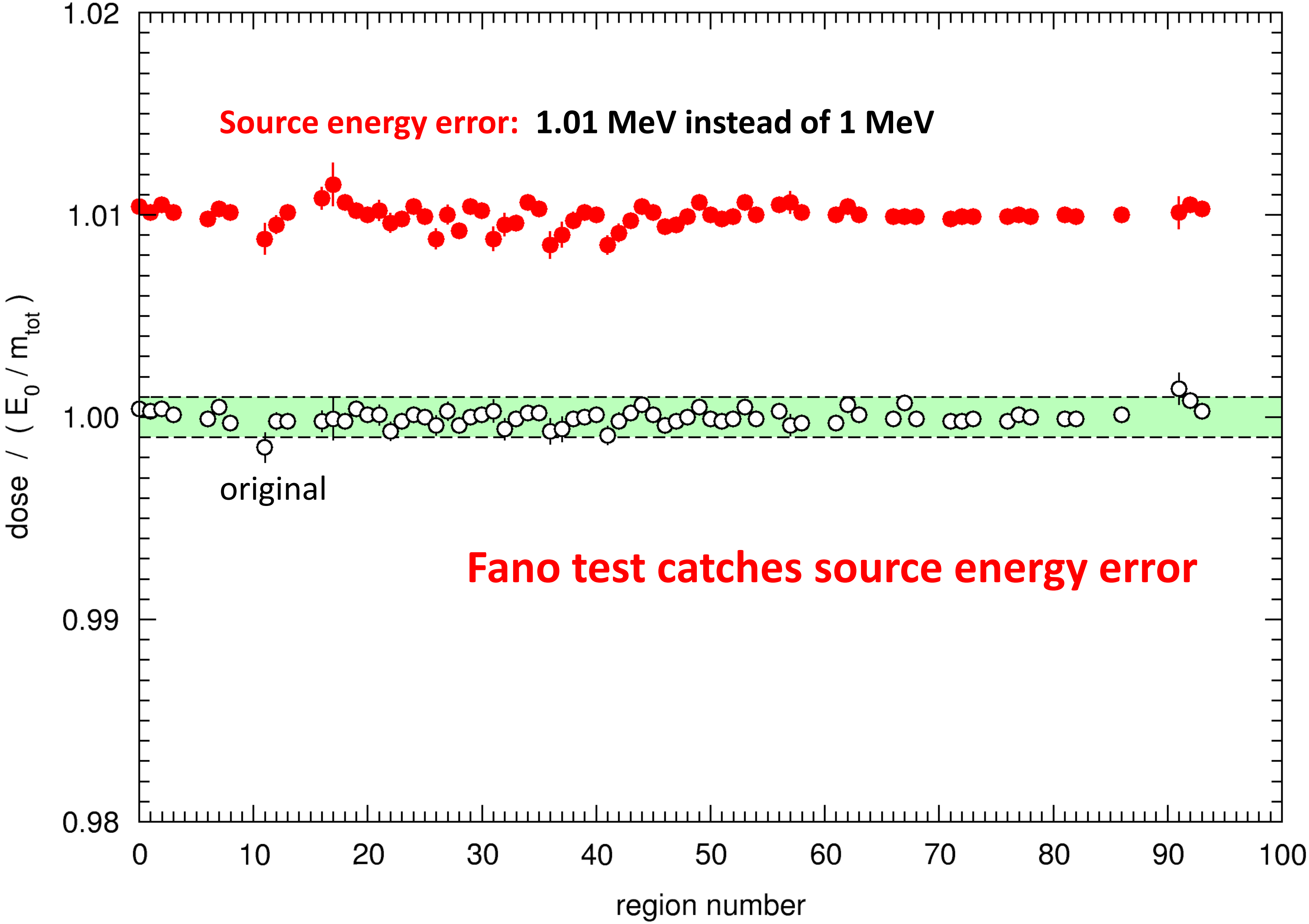
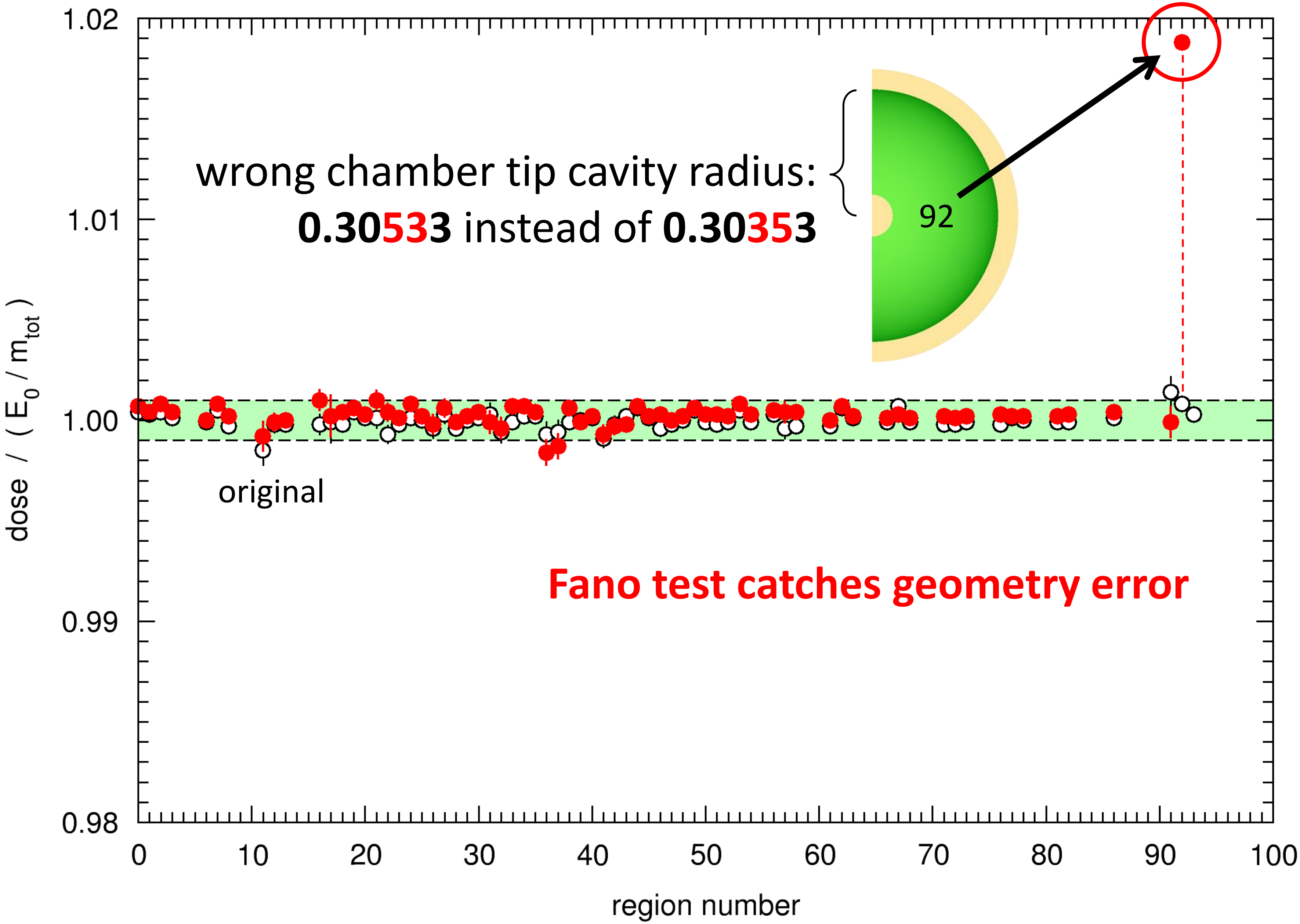


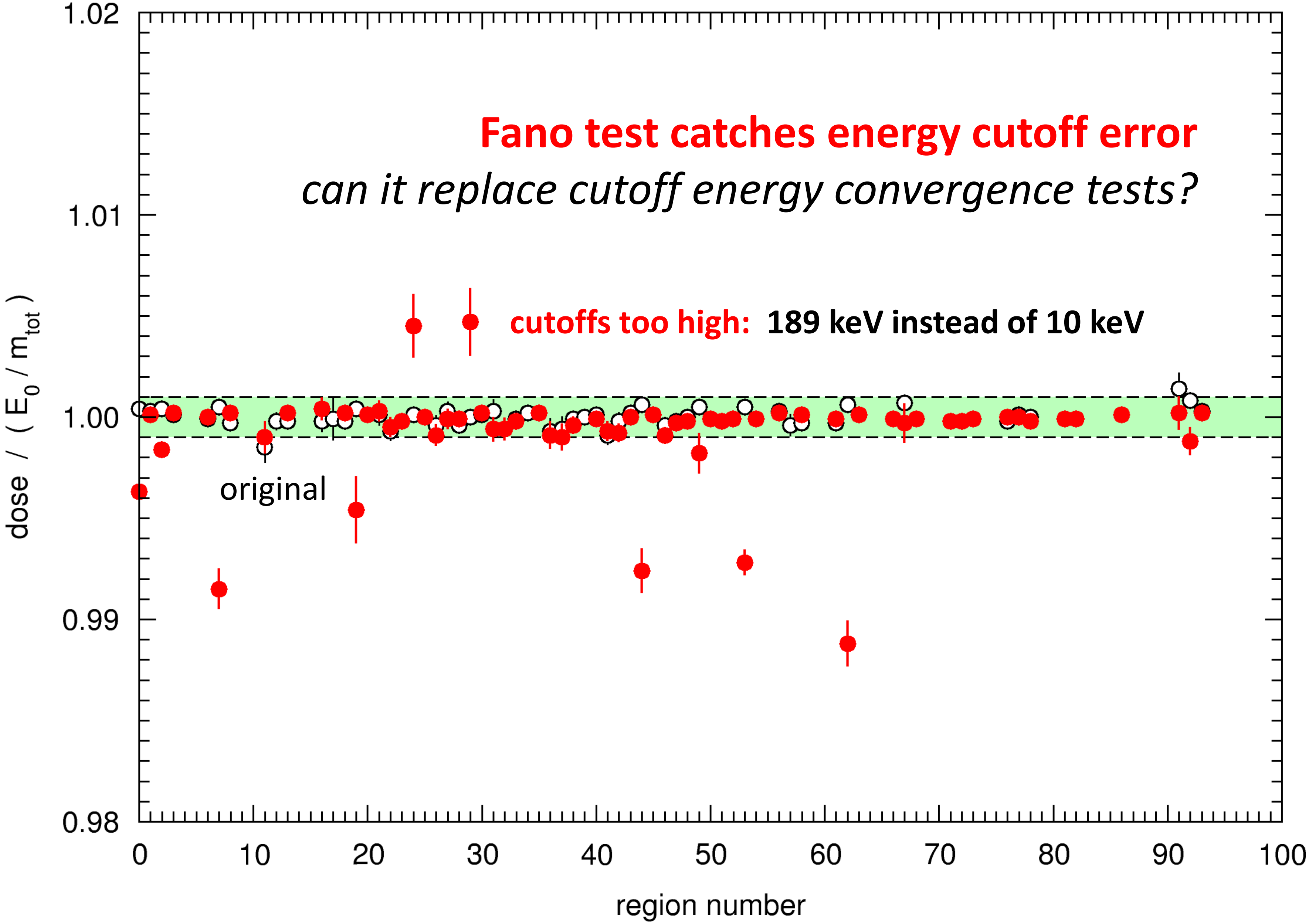


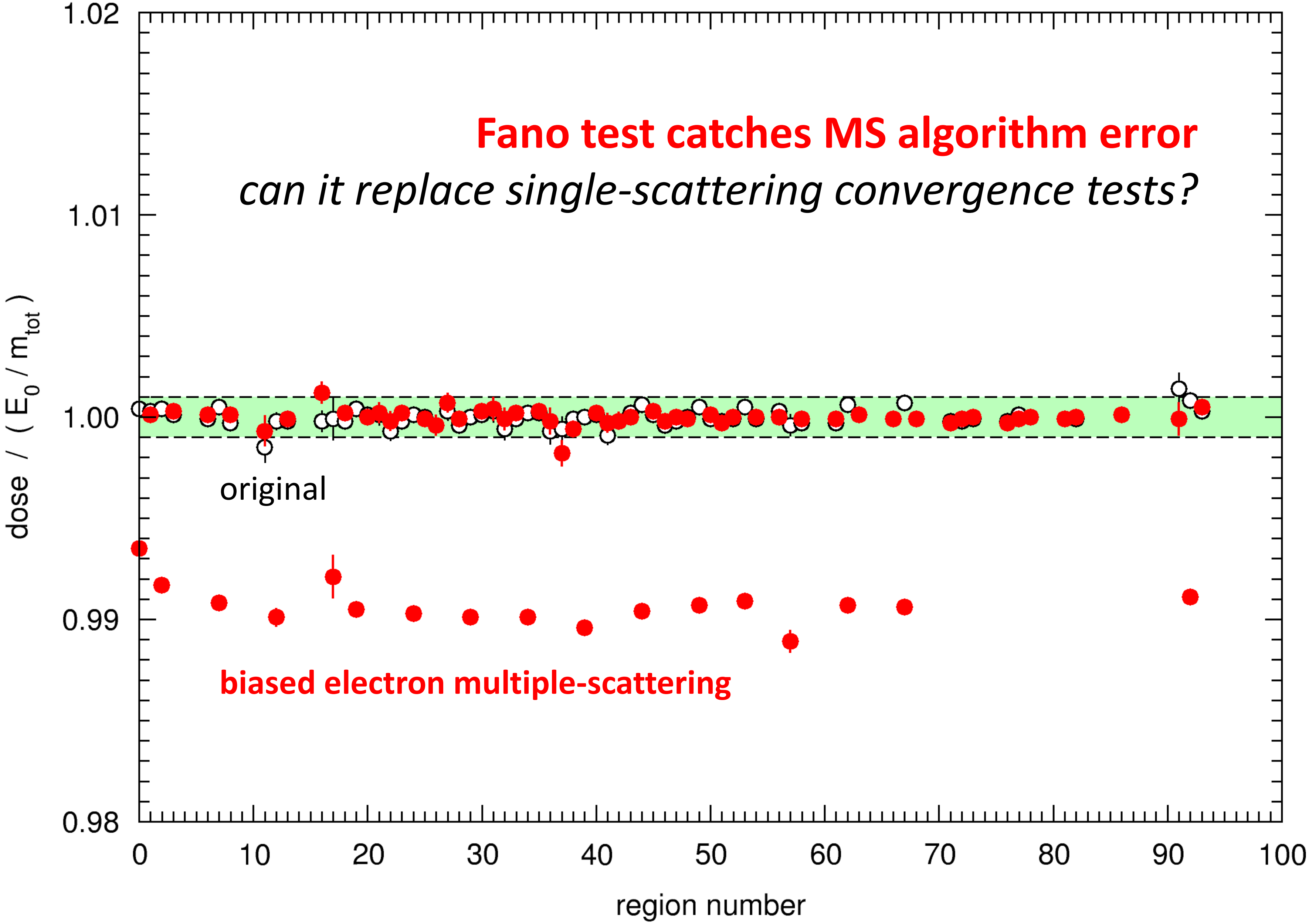
The dose in every region is within 0.1% of the exact Fano value
$E_0 = 1$ MeV
$m_{\rm tot} = 6.285428$ g
dose / (E_0 / m_{tot})
region number
1.02
1.01
1.00
0.99
0.98
0
10
20
30
40
50
60
70
80
90
100



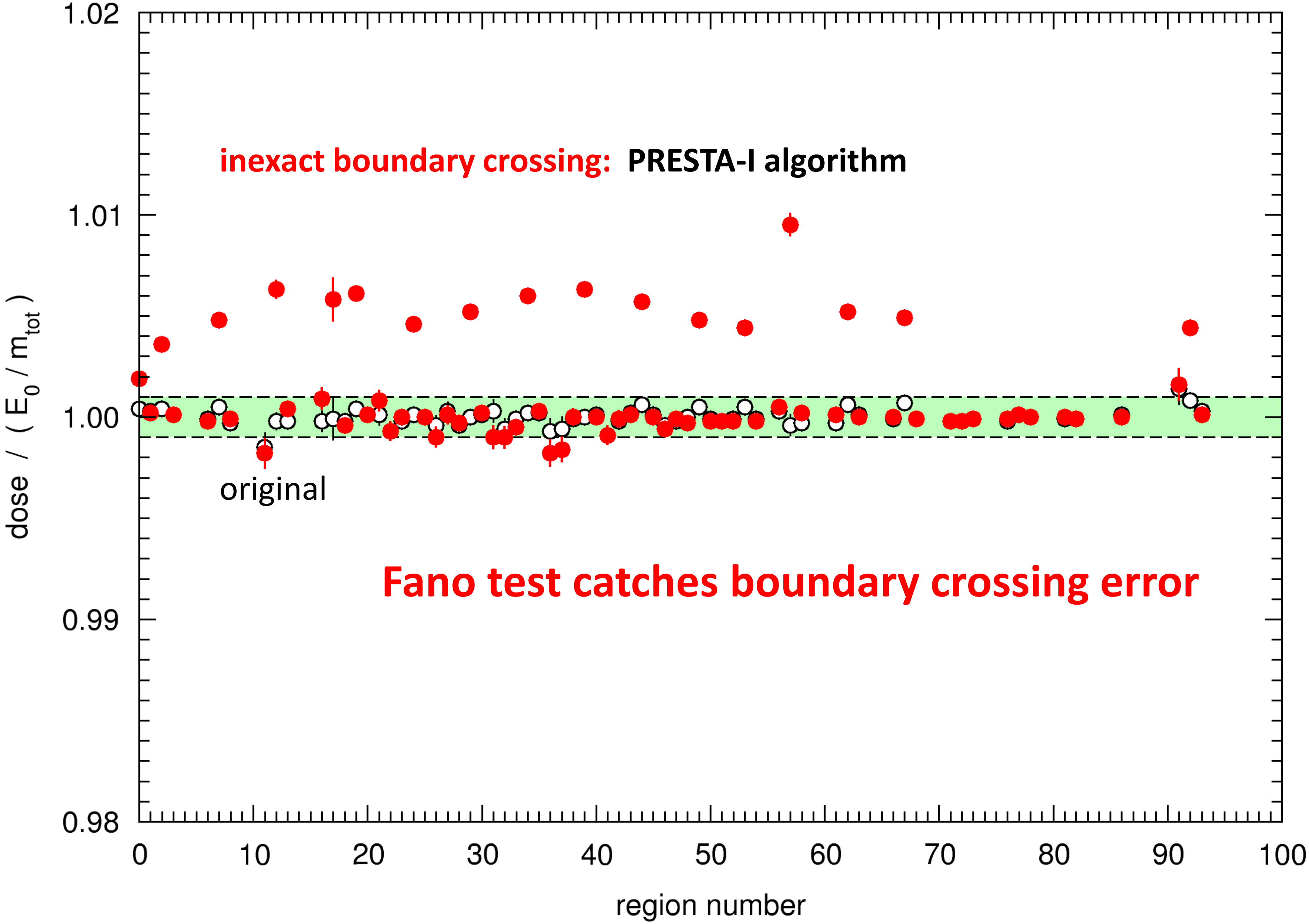
Source energy error: 1.01 MeV instead of 1 MeV
original
Fano test catches source energy error
dose / (E0 / mtot)
region number
1.02
1.01
1.00
0.99
0.98
0
10
20
30
40
50
60
70
80
90
100


wrong chamber tip cavity radius:
0.30533 instead of 0.30353
92
original
Fano test catches geometry error
dose / (E_0 / m_{tot})
region number
1.02
1.01
1.00
0.99
0.98
0
10
20
30
40
50
60
70
80
90
100

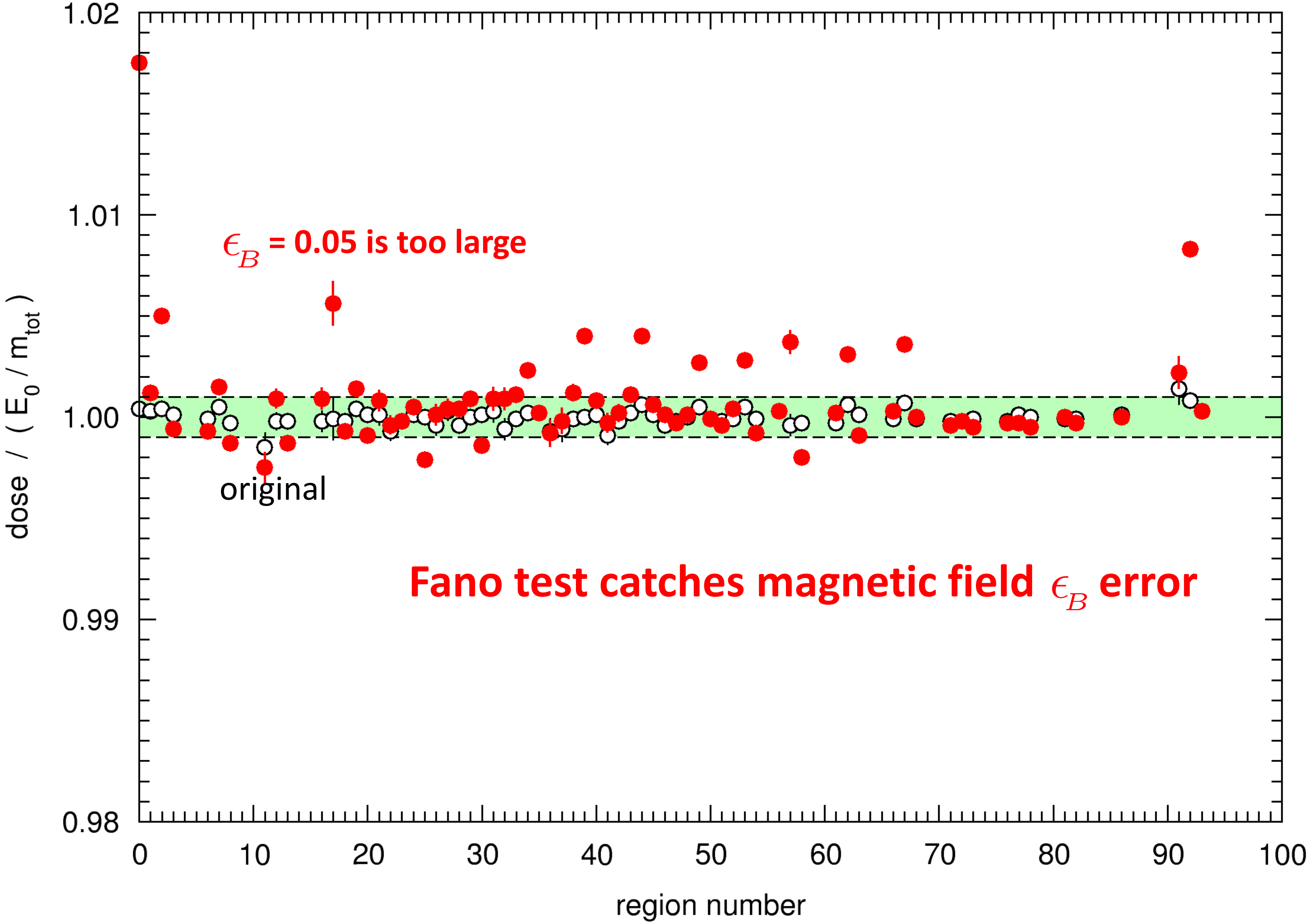

Fano test catches energy cutoff error
can it replace cutoff energy convergence tests?
cutoffs too high: 189 keV instead of 10 keV
original
dose / (E_0 / m_{tot})
region number
1.02
1.01
1.00
0.99
0.98
0
10
20
30
40
50
60
70
80
90
100

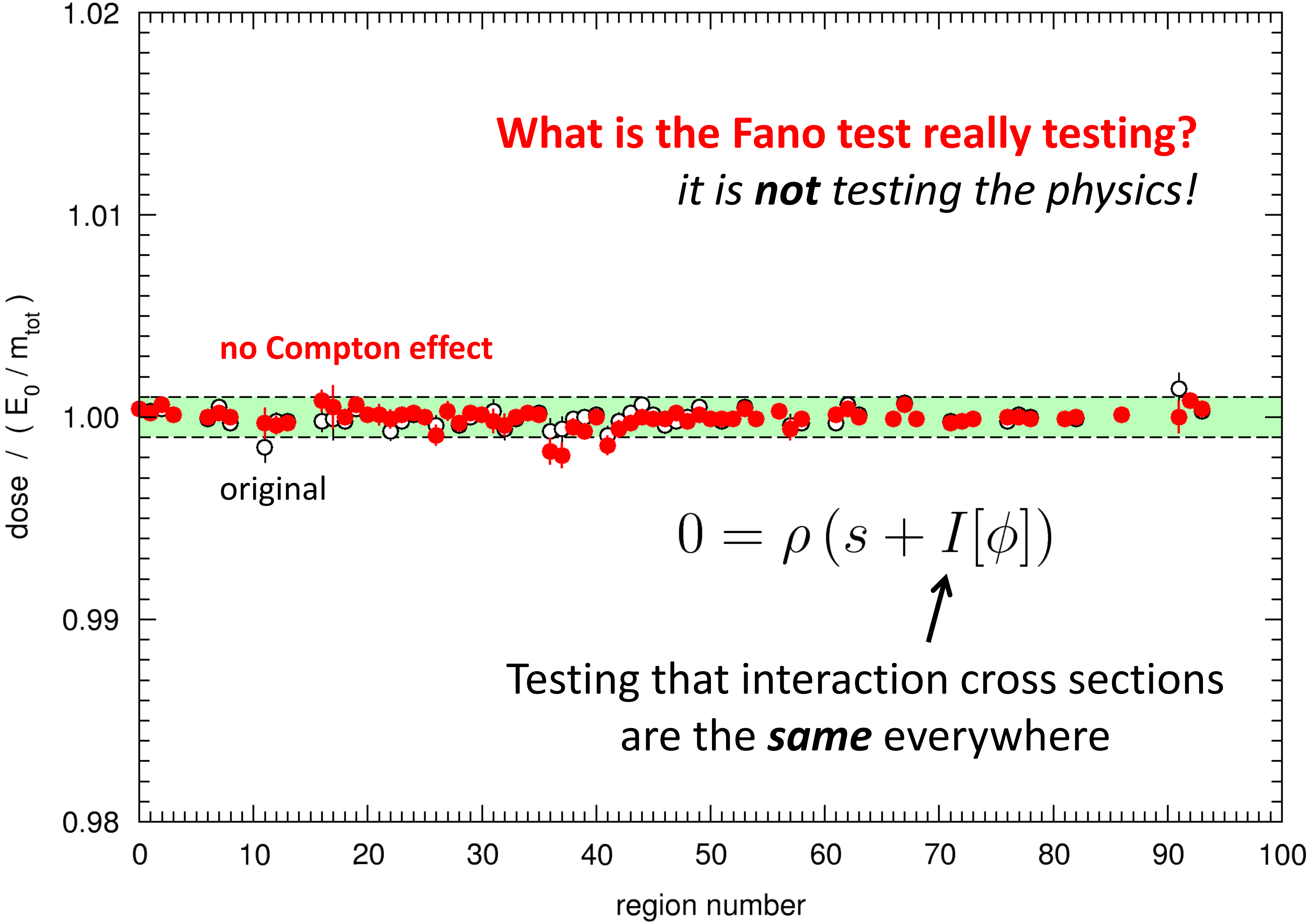


Fano test catches MS algorithm error
can it replace single-scattering convergence tests?
original
biased electron multiple-scattering
1.02
1.01
1.00
0.99
0.98
dose / (E_0 / m_{tot})
0
10
20
30
40
50
60
70
80
90
100
region number



inexact boundary crossing: PRESTA-I algorithm
original
Fano test catches boundary crossing error
dose / (E0 / mtot)
region number
1.02
1.01
1.00
0.99
0.98
0
10
20
30
40
50
60
70
80
90
100


ϵ_B = 0.05 is too large
original
Fano test catches magnetic field ϵ_B error
dose / (E_0 / m_{tot})
region number
1.02
1.01
1.00
0.99
0.98
0
10
20
30
40
50
60
70
80
90
100



What is the Fano test really testing?
*it is **not** testing the physics!*
no Compton effect
original
$0 = \rho\,(s + I[\phi])$
Testing that interaction cross sections are the ***same*** everywhere
dose / (E_0 / m_{tot})
1.02
1.01
1.00
0.99
0.98
0
10
20
30
40
50
60
70
80
90
100
region number

Leading by example:

August 2017

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Radiation dosimetry in magnetic fields with Farmer-type ionization chambers: determination of magnetic field correction factors for different magnetic field strengths and field orientations

C K Spindeldreier[1,2,4], O Schrenk[1,2], A Bakenecker[1,2], I Kawrakow[3], L Burigo[1,2], C P Karger[1,2], S Greilich[1,2] and A Pfaffenberger[1,2]

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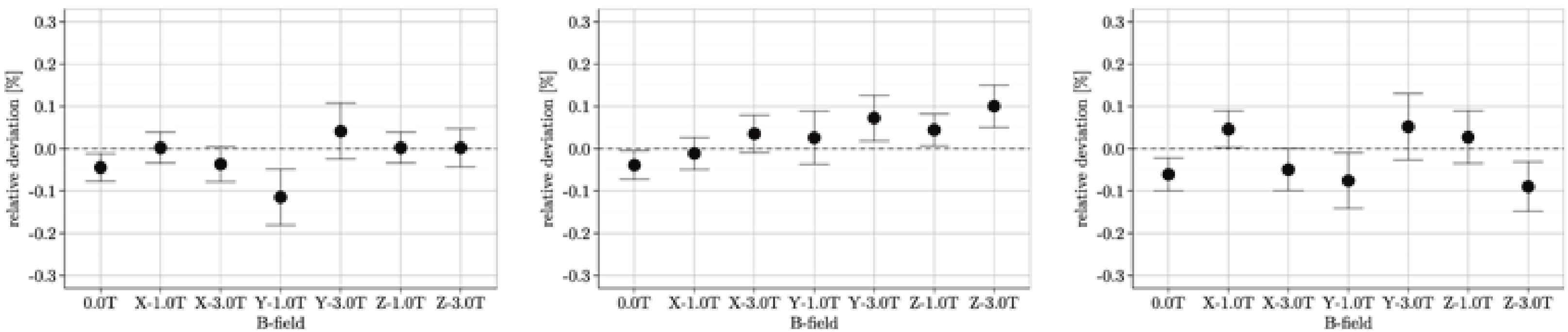
Leading by example:

August 2017

Appendix. Fano cavity test with the magnetic field macro

To test the Monte Carlo simulations with magnetic field macro for consistency, the Fano test in a magnetic field can be applied (Bouchard and Bielajew 2015, Bouchard *et al* 2015, de Pooter *et al* 2015). For this test, a primary source of 1.25 MeV electrons, isotropically distributed and



(a) (b) (c)

Figure A1. Relative deviation of cavity dose from the expected result for different media and magnetic field geometries. (a) Water. (b) PMMA. (c) Graphite.

All published Monte Carlo simulation results should to be supported by a Fano test calculation.

- Developers should **enable** Fano testing
- Authors should **report** Fano test results
- Reviewers should **request** Fano tests
- Editors should **require** Fano tests

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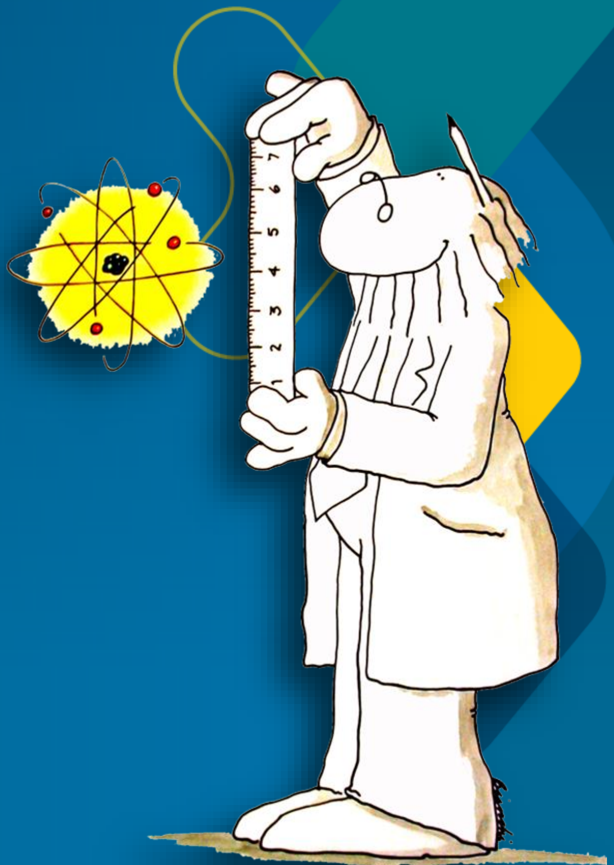
EGSnrc update and Monte Carlo simulation verification



Frédéric Tessier

Measurement Science and Standards
National Research Council Canada