22nd Geant4 Collaboration Meeting

[Link to Scientific Program]

Geant 4

Geant4 Status & Overview

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for the Geant4 Collaboration

25-29 September 2017

University of Wollongong, Australia

Centre for Medical Radiation Physics

Meeting goals

- Validation / quality assurance in particular in MT mode and large event samples
  - Critical for both physics and non-physics
  - Examine the test coverage : do we cover all functionalities / phase space?
  - Collaboration-wide effort
- Familiarize with new (and current) tools
  - Drupal, Git
  - Coverity, performance monitoring, Cdash, physics validation DB, etc.
- Documentation overhaul
  - Join the discussion at plenary session / parallel session on Thursday
  - Again, collaboration-wide effort
- Update user requirements
  - New requirements, forgotten requirements
  - Emerging user domains, e.g. material science, radiation security, …

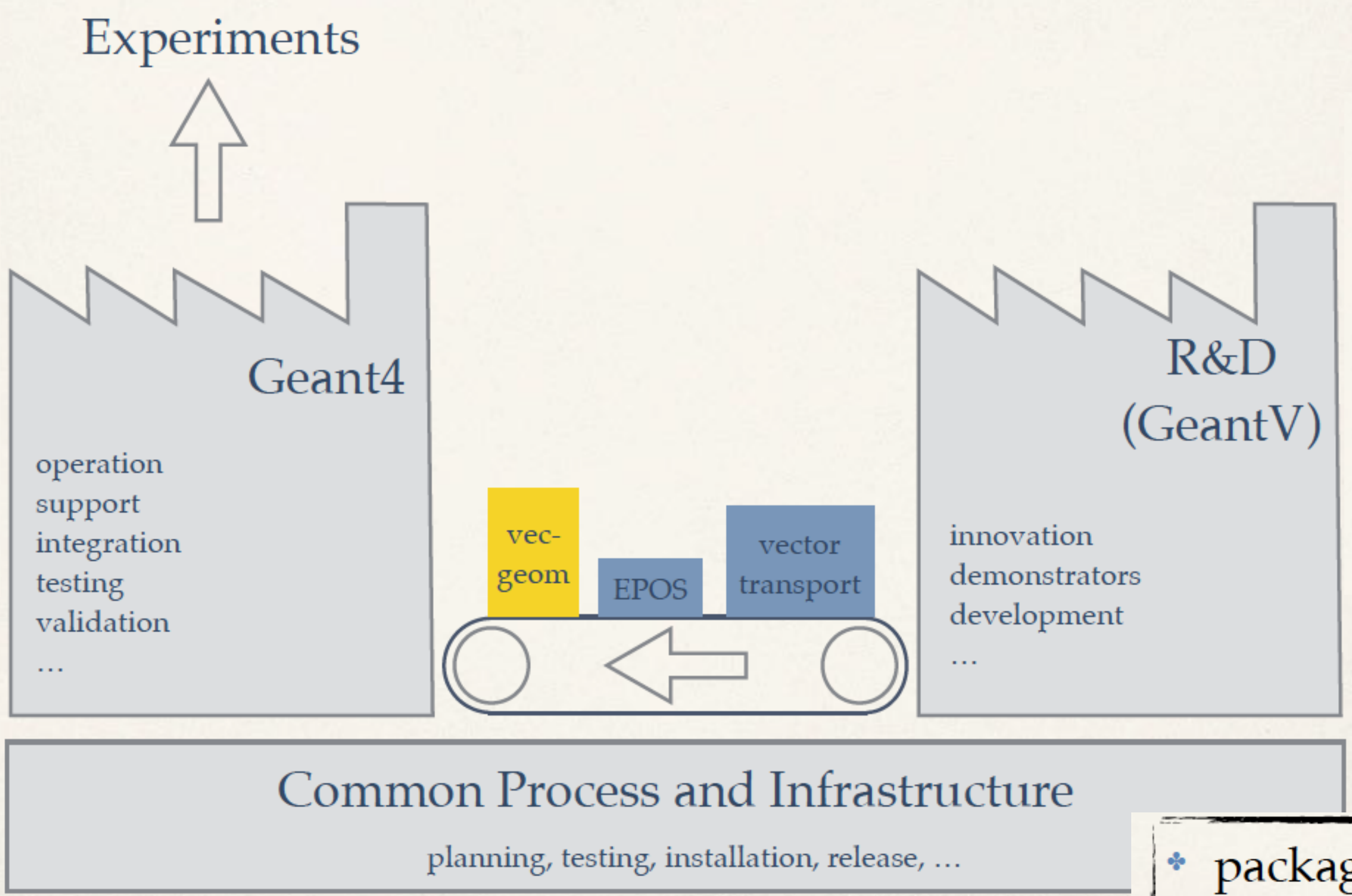
M. Asai

Let's discuss

- Geant4 version 10 series is not our ultimate goal. It's a solid milestone we have made, and it's the beginning of our new era.
  - We will keep improving Geant4, maintaining it and supporting our customer users for foreseeable future.
  - Robust and achievable longer term strategic plan can only be made with brainstorming discussions.
- Let's start shaping Geant4 version 11
- The third general paper is out!! Thank you all for your contribution!!
  - What's next?
  - Web pages, documentation, movie, etc.

M. Asai

SFT simulation meeting – 19.09.2017



Operation

- responsive user support
- new experiment needs
- agility to integrate new components
- aggressive evolution and modernization
- improve work efficiency by using new soft dev tools

R&D

- feasibility study before full development
- versatile architecture
- multi-interface support (vector, sequential)
- quality implementations
- discontinuation of non successful investigations

- packaging of components
- automation of procedures
- solid testing and validation

- LHC experiments (and others) will base their simulation applications on the Geant4 toolkit for the next 5-10 years

- GeantV review recommended to incorporate/integrate the R&D 'goodies' as soon as possible into the Geant4 toolkit

P. Mato

Infrastructure

Draft Geant4 Website in Drupal

- new-geant4-dev.web.cern.ch
- Completed migration of existing site
  - Public pages
  - Internal and SB pages
- Used Importer tool
    - Based on original tool by summer student
  - Crawl existing site
  - parse pages to extract
    - links to other pages and files
    - content like title and body of page
      - Difficulty: wide range of page formats of G4 pages, down to plain text
  - Upload files
  - Create nodes, one node per page parsed
  - Correct links
  - Create alias and menu

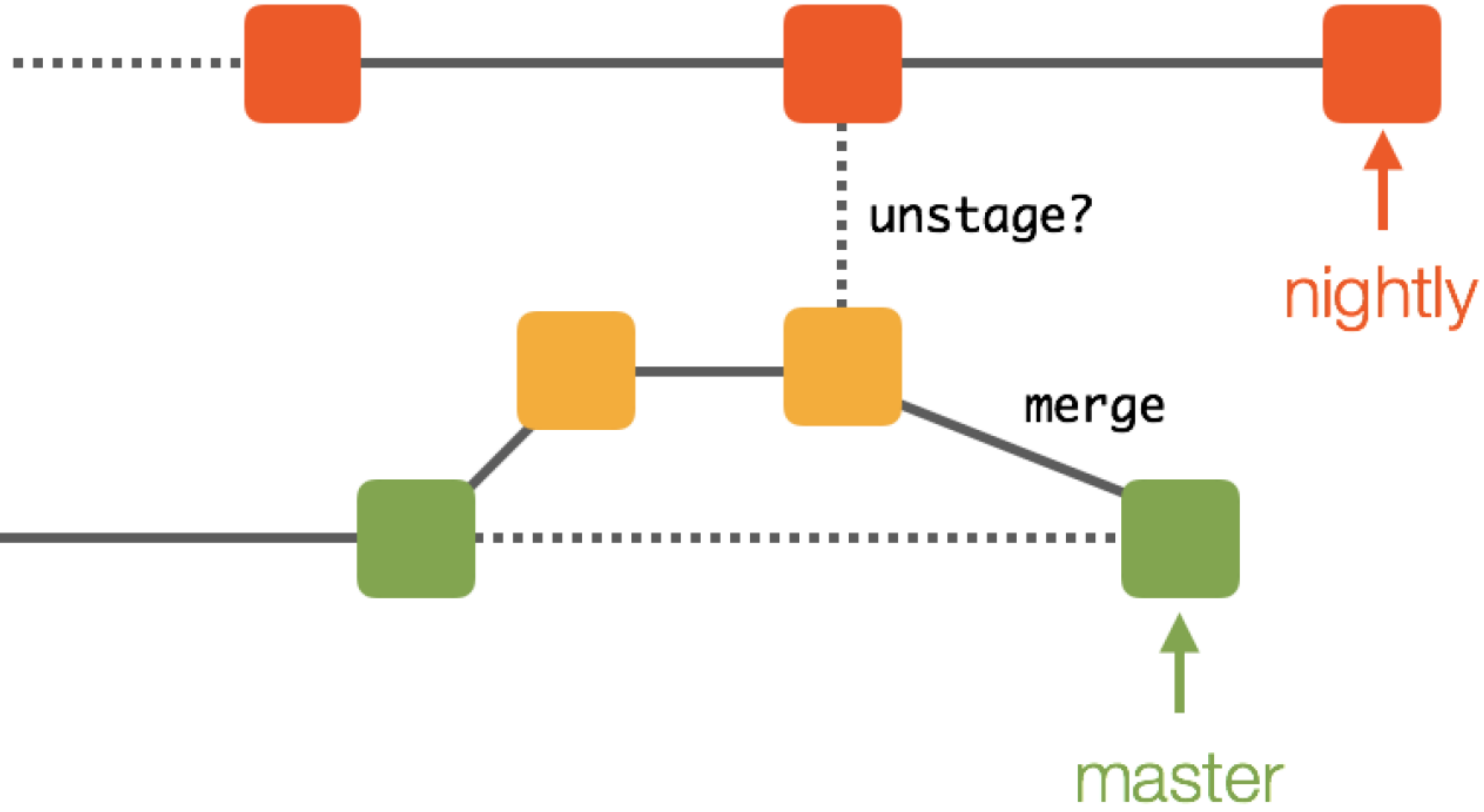
Timescale for Switching http://cern.ch/geant4 to Drupal site

- Rather short timescale for switch to new site
  - Maintaining two sites in sync is difficult
- Freeze existing site this week?
- Evaluate new site, identify and fix problems
- Re-check that mirror for geant4.org as expected
- Switch cern.ch/geant4 to Drupal site within a month
  - And disable geant4.cern.ch
    - Or forward to Drupal site

G. Folger

Geant4 GIT Migration

Workflow proposed



- MR tested in isolation in Continuous testing; automatic 'almost' immediate response from testing
- MRs passing Continuous and code review (by shifter & coordinators) tested on 'stage' branch for nightlies
- Faulty MR unstaged and back to Continuous/review; others merged to Master (accepted)

G. Cosmo, G. Folger, B. Morgan

Points of discussion addressed

- Generation of tags for 'accepted' merge requests
  - To be verified how this can be automated, based on MR description
- Testing cycle time for Continuous builds to be effective
  - Incremental builds and exploring ccache solution also adopted in Root
- Timescale and transition
  - To be done in 2018 during 'quiet' period (after a reference-tag or Beta release)
  - Switch to Git to be done as sharp cutoff with Master cloning last reference tag (Master always stable and working) and SVN repository switched to read-only mode
  - Proper documentation for developers to be provided before that with 'essential' Git commands (and examples) to use for implementing the process
- Addition of automatic formatting checks and Coverity analysis/reports
  - To be explored and eventually added in a later stage

G. Cosmo, G. Folger, B. Morgan

Documentation and Publication comments

- It is often difficult to find information quickly in our documentation
- Physics Reference Manual is often not very helpful
  - first time reader/user is often lost
  - overall meaning of a given topic can be buried in the technical aspect
  - information is often missing
- Toolkit Developers Guide has inconsistent UML formats, colors
- Publications
  - we in Geant4 do not publish enough
  - if you have a new development, don’t wait for next general paper to publish it

D. Wright, A. Howard

Documentation and Publication comments

- In-code documentation
  - Mihaly has done a lot of it; will talk to Alex about automatic extraction into documentation manuals
- New EM code descriptions (for physics list descriptions) coming soon
  - Farah will write brief description of bremsstrahlung and pair-production
  - Mihaly will do the same for multiple scattering
  - Sebastien and Vladimir have provided names of EM model developers – they should write brief descriptions as well
- Time was spent scanning re-formatted documentation
  - please send comments to Alex

D. Wright, A. Howard

Geometry

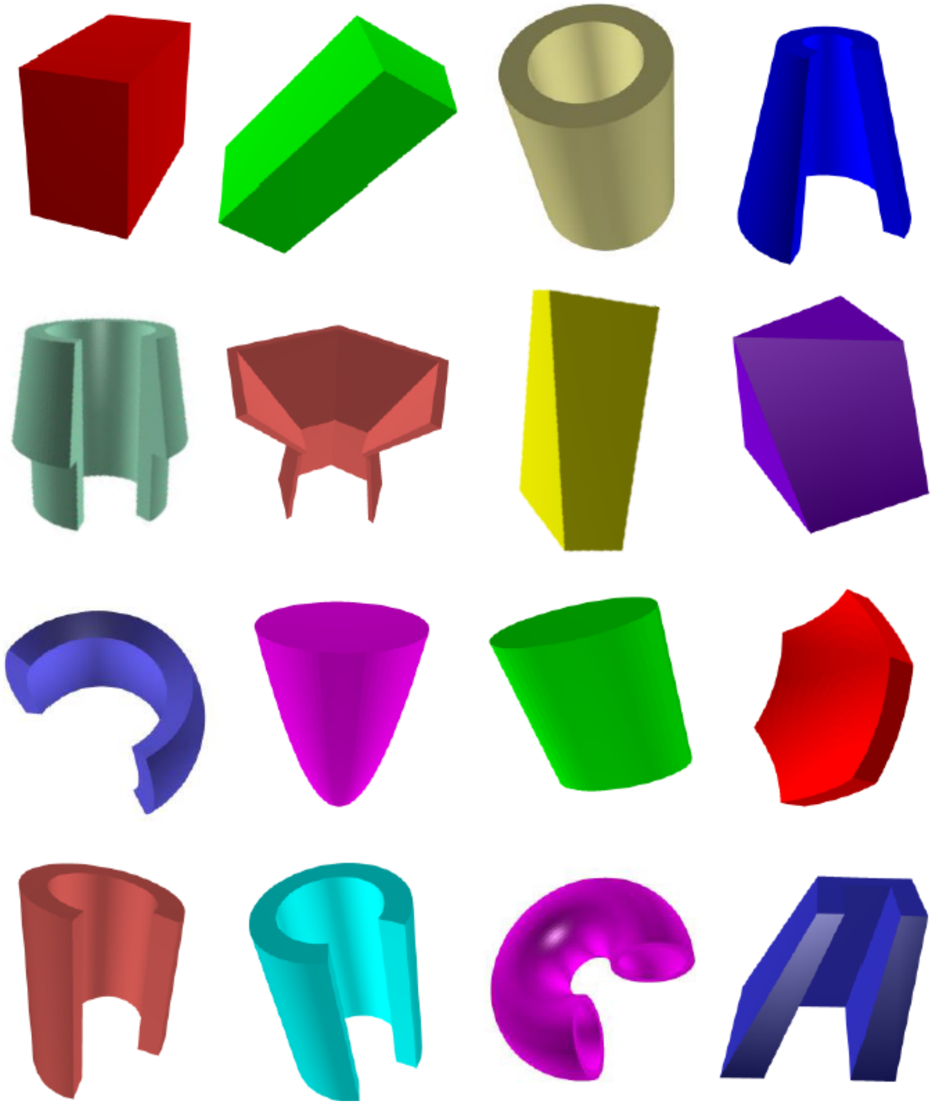
Shapes implementation status

- Available in VecGeom:
  - Box, Orb, Trapezoid (Trap), Simple Trapezoid (Trd), Sphere (+ sphere section), Tube (+ cylindrical section) , Cone (+ conical section), Generic Trapezoid (Arb8), Polycone, Polyhedron
  - Paraboloid, Parallelepiped (Para), Hyperboloid, Ellipsoid, Torus (+ torus section), Scaled Solid, Boolean (addition, subtraction, intersection), Cut Tube, Simple Extruded Solid (SExtru), Tessellated Solid
- Only in USolids:
  - Tetrahedron (Tet), Multi-Union, Generic Polycone
  - Extruded solid

    expressed as specialization of Tessellated Solid
- Missing:
  - Elliptical Cone, Elliptical Tube

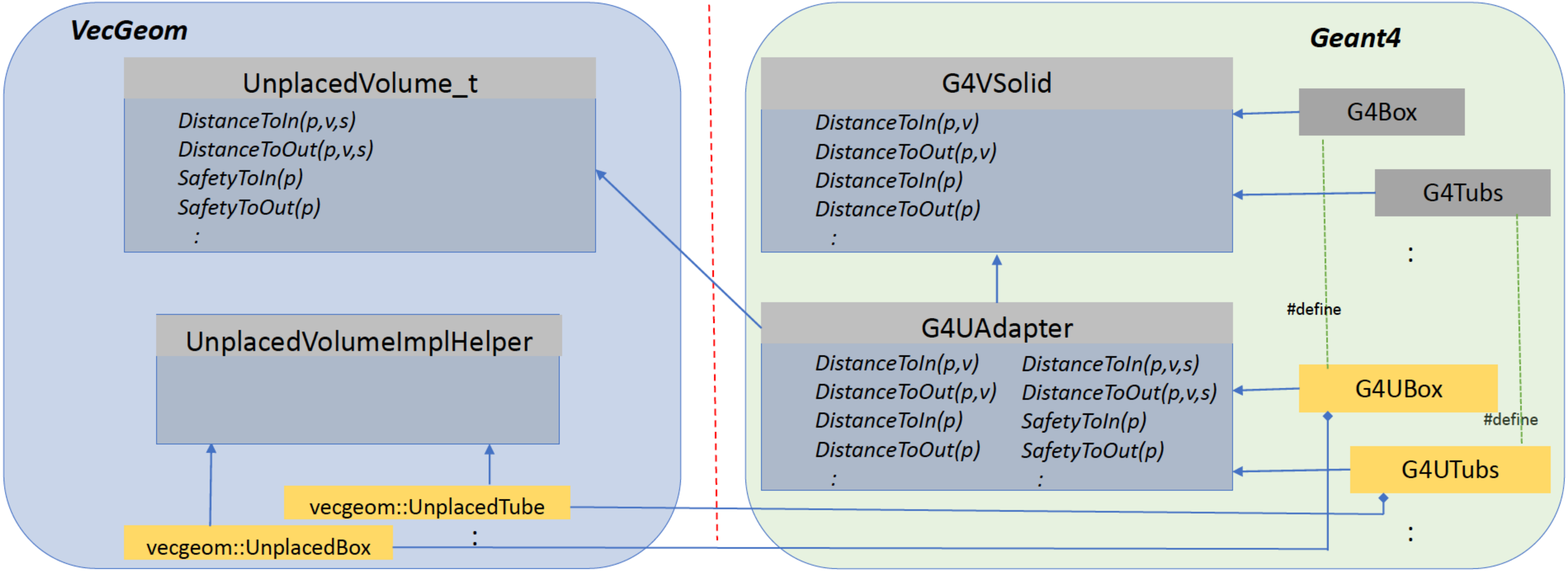
    can be composed through scaling
  - Half-spaces/planes
  - Twisted shapes (box, trap, tube)

    Complex and infrequent use



G. Cosmo

Interfacing VecGeom Solids in Geant4



- Wrappers in Geant4 making VecGeom shapes look like native Geant4 solids types
- Adapter in Geant4 wrapping VecGeom implementations (improved design expected in release 10.4)
- Completely transparent to users – i.e. requiring no changes in users code

G. Cosmo

Revision of Geant4 Solids

The revision has been inspired by the following factors:

- Most of the Geant4 solids were implemented a long time ago. We now have better hardware and software:
  - better compilers with more stable and advanced optimizers
  - better implementation of math functions, for example, std::min(a,b), std::max(a,b) are not anymore templates but processor instructions

- Several places where code could be improved, for example:
  - G4Trd was slower than G4Trap
  - use of std:atan2(y,x) in solids with a cut in Phi
  - G4Polycone and G4Polyhedra not optimized

- Particularities in the shapes used in the geometry setup of the CERN experiments
  - CMS: >90% of G4Trap shapes have rectangular YZ cross section
  - ALICE & ATLAS: 100% of G4ExtrudedSolid shapes are right prisms

E. Tcherniaev

“Trapezoid like” solids

Measurements were done for 100 million calls on McBook Pro, 2.7 GHz Intel Core i5

	G4Box		G4Trd		G4Para	
	old	new	old	new	old	new
Inside						
kInside	0.39 s	0.39 s	0.58 s	0.51 s	0.48 s	0.59 s
kSurface	1.09 s	0.39 s	1.51 s	0.51 s	1.27 s	0.60 s
kOutside	0.77 s	0.32 s	0.89 s	0.40 s	0.78 s	0.50 s
Safety to In	0.35 s	0.31 s	2.13 s	0.42 s	0.94 s	0.50 s
Safety to Out	0.52 s	0.34 s	1.16 s	0.45 s	0.91 s	0.52 s
Distance To In	2.96 s	1.15 s	3.21 s	2.07 s	2.26 s	2.15 s
Distance To Out	3.61 s	1.79 s	4.53 s	2.59 s	4.06 s	2.75 s
Surface Normal	1.62 s	0.60 s	3.22 s	1.59 s	2.27 s	1.71 s

E. Tcherniaev

Plans for G4 Solids

- Current results give confidence that it is possible to achieve noticeable speed-up by revising the Geant4 shapes code and therefore provide immediate benefit to users and experiments simulations.

- Future plans:
  - Complete revision of G4Tubs, adopt its code for G4CutTubs
  - Add specialized implementation for *concave right prism* into G4ExtrudedSolid
  - Revise G4Polycone and G4Polyhedra
  - Feed back ideas/improvements to corresponding VecGeom shapes algorithms where possible
  - Keep using Geant4 geometry as reference for validation

E. Tcherniaev

Validation Tools

DoSSiER

- DoSSiER: **D**atabase **o**f **S**cientific **Si**mulation and **E**xperimental **R**esults is actively being developed with participation by Geant4 groups at Fermilab and SLAC. https://g4devel.fnal.gov:8181/ (https protocol; for end to end encryption)
- We already identified features in Geant4 that needed fixing.
- GENIE group is providing input and requirements.
- Experimental data and results from simulation (Geant4, GENIE/GeantV (soon)) are stored in a relational database.
- Data can be imported and exported using json/xml formats. (python scripts are provided to extract data from root files or ASCII tables and convert to json/xml.)
- Web application:
  - allows to select and search.
  - allows to overlay experimental and simulated data.
  - authentication is necessary to have access to internal data and functions (e.g. upload, edit, delete).
- Web service: allows to programmatically access the repository(read only).

H. Wenzel

Geant Validation Portal

- the main purpose is to facilitate “hadronic physics” validation for Geant4
- predecessor “g4-val” was created in 2013 by George Lestaris (CERN technical student)
- the initial design was not scalable enough and slow
- In 2016 CERN summer student (*) developed a prototype based on Node.js as “interface” to DOSSIER database.

What “geant-val” can do

- plot MC and experimental data
- create overlaying and ratio plots
  - Release with release
  - Release with experimental data
- produce chi2 table

- consistent storage of test results
- production of overlaying plots and ratio plots for regression testing
- possibility for comparison with experimental data
- simple statistical evaluation for regression testing

short-term plans:

- continue integration of new tests
- continue our work towards more sophisticated statistical analysis

D. Konstantinov, G. Latyshev, W. Pokorski

Electromagnetic Physics

Standard EM update

- Improved version of Urban msc model (L.Urban)
  - Including fix for low-energy antiproton transport (H. Holmestad)
- Mott corrections to the GS model of multiple scattering (M.Novak)
- Updated implementation of Mott corrections to single scattering model (M.Tacconi)
- Restored functionality of G4WentzelVIRelModel (V.Ivanchenko)
- New interface to triplet production for bremsstrahlung (A.Bagulya), gamma conversion, positron annihilation (V.Ivanchenko)
- Nuclear stopping fixed (HyperNews #1595) (V.Ivanchneko)
- Fixed gamma conversion sampling below 50 MeV (V.Ivanchenko)
- Low-energy limit for cut for PAI models for precise simulation of gaseous detectors (D.Pfeiffer)
  - We know better now the limitations of the PAI model
- Review and update of gamma->mumu process (A.Sokolov)
- Theoretical review & updated gamma pair-production model (F. Hariri)

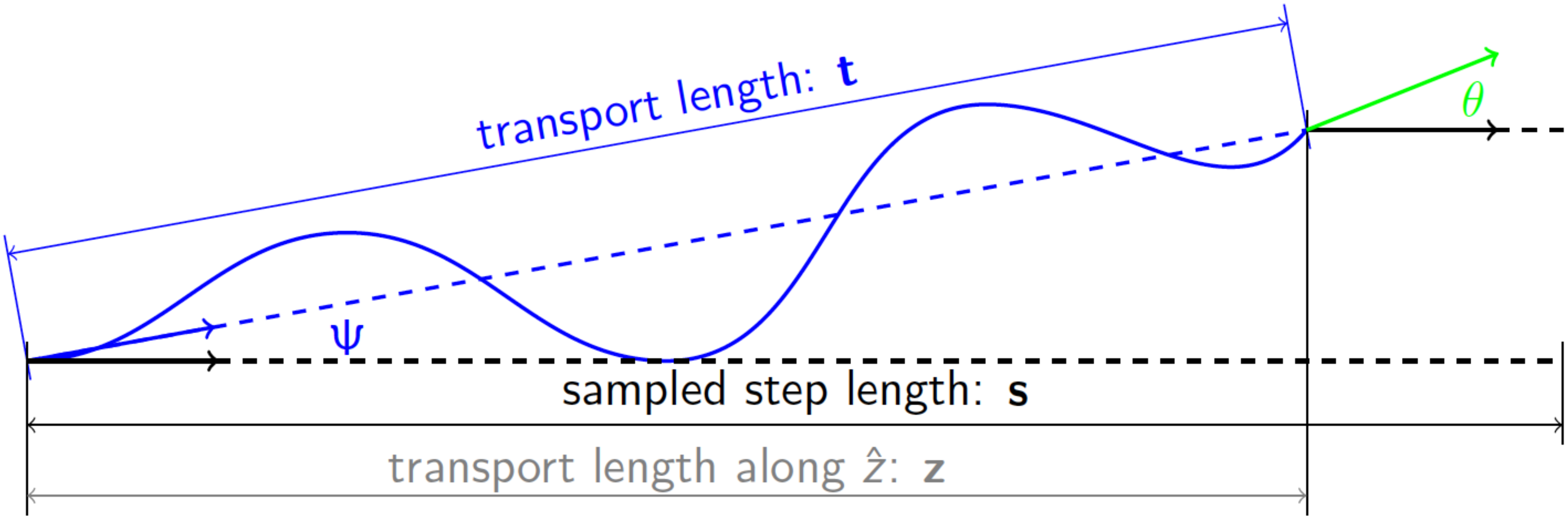
V. Ivanchenko

Few remarks

- For many years experts were saying that the golden standard for electron/positron MC simulation are EGS and Penelope
  - The work made by Mihaly and reported at the parallel session also demonstrate that EGS and Penelope high quality results are obtained in specific conditions with special options enabled
    - Very small steps and detailed algorithms of scattering
    - These regimes are far from the default and needs huge CPU
- Long ago we started Opt4 as a configuration which «the most accurate EM physics»
  - With the recent Mihaly result we can start to speak about Geant4 «golden standard» simulation
- Few words about history:
  - GS work has been introduced by Omrane Kadri for Geant4 9.3 and published in 2009
  - Mihaly completely revised the model for 10.2
  - Now Mihaly provides this new update for 10.4
  - GS needs to be tuned not only for «most accurate» simulation but also for HEP users
    - This should be a part of 2018 work plan
- One can see that Geant4 is mature enough and any real improvement of physics requires big efforts, accumulation of expertise and time
  - We need to have this in mind when plan our activity
  - We need explain this fact to management (finding agencies)
  - This is valid not only for EM but also for other physics

V. Ivanchenko

Multiple scattering



M. Novak

Multiple scattering

The Goudsmit-Saunderson multiple scattering model:

- exact Goudsmit-Saunderson angular distributions
- based on (relativistic) screened-Rutherford elastic DCS (DCS_{SRF}): scattering of **spinless** e- on exponentially screened, point like Coulomb potential
- solution of the relativistic Schrödinger equation (Klein-Gordon equation) for spinless e- under the first Born approximation
- simple analytical DCS with only one screening parameter

Spin relativistic corrections to the GS Multiple scattering model

Spin relativistic correction (still under development but close to its "final" form):

- Mott DCS (DCS_{Mott}): scattering of e^-/e^+ **with spin** on a point like, unscreened Coulomb potential (the spinless correspondence is the unscreened Rutherford)
- solution of the Dirac equation with a point like, unscreened scattering potential: relativistic Dirac-Coulomb partial wave calculation
- the DCS used is

$$\frac{d\sigma}{d\Omega} \equiv \frac{d\sigma}{d\Omega}(Z, E_{kin}, \theta) = \left[\frac{ZZ'e^2}{pc\beta}\right]^2 \frac{R_{Mott}(Z, E_{kin}, \theta)}{[1-\cos(\theta)+\eta']^2} \equiv DCS_{SRF\times Mott} \quad (1)$$

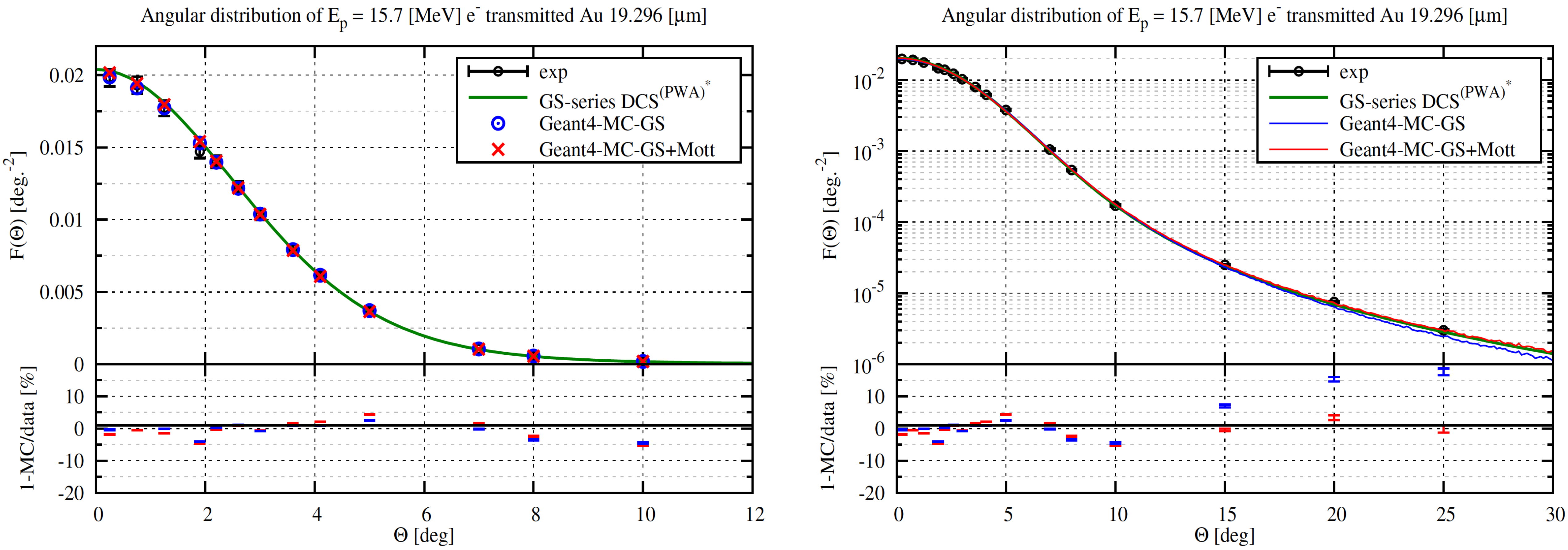
  - where $R_{Mott}(Z, E_{kin}, \theta) = DCS_{Mott}/DCS_{RF}$ with DCS_{RF} being the unscreened, relativistic Rutherford DCS
  - η' is a modified screening parameter such that the most accurate PWA first transport cross section (that determines the mean of the GS angular distribution) is reproduced by $DCS(\eta')_{SRF\times Mott}$ i.e. the solution of

$$2\pi\int_0^{\pi}[1-P_{l=1}(\cos(\theta))]\frac{d\sigma}{d\Omega}\sin\theta d\theta = 2\pi\int_0^{\pi}[1-P_{l=1}(\cos(\theta))]\frac{d\sigma}{d\Omega}^{PWA}\sin\theta d\theta \quad (2)$$

- GS angular distributions were computed based on this form of the DCS and the corresponding rejection functions are stored in files (note that there is a Z and particle type dependence of the angular distributions)
- no more details on theory today let's focus on the results

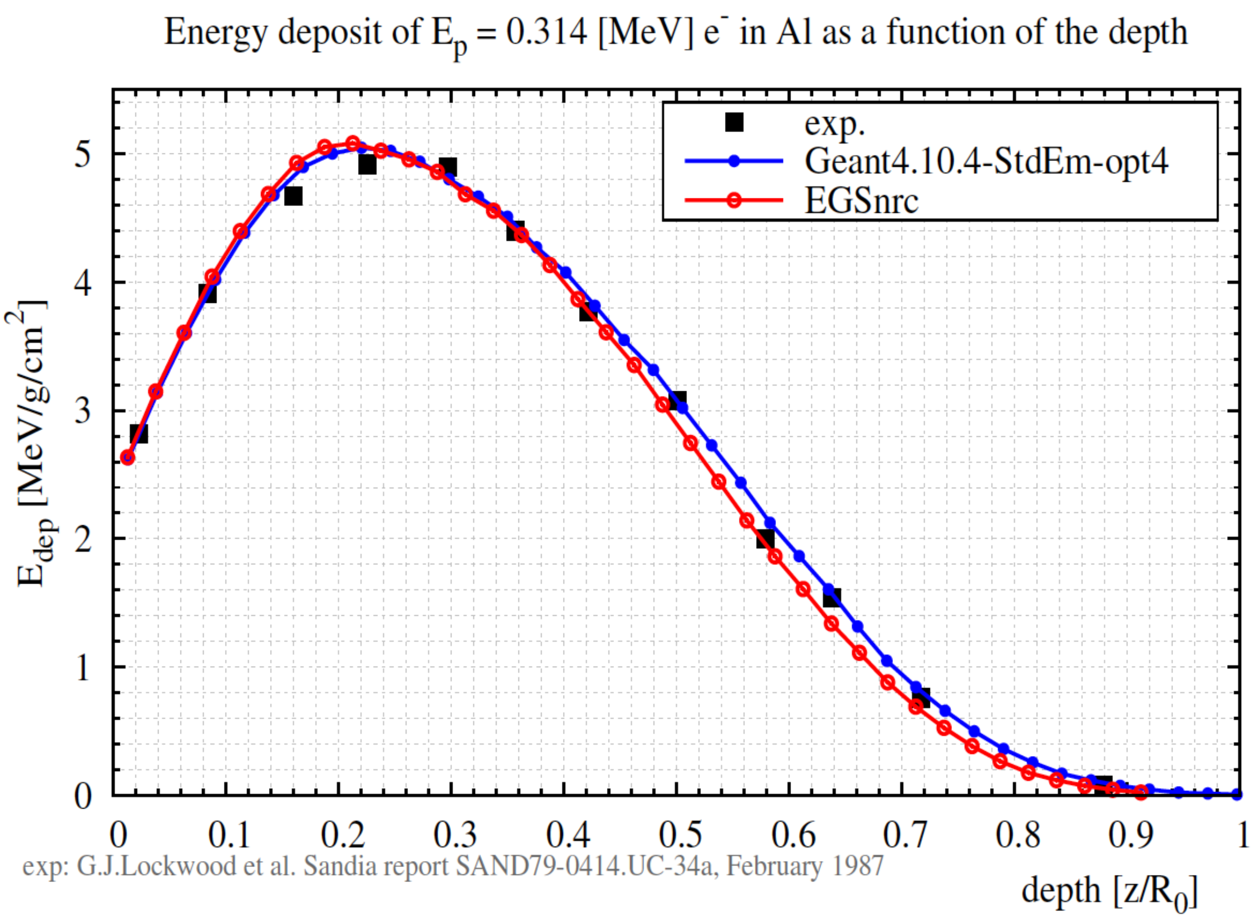
M. Novak

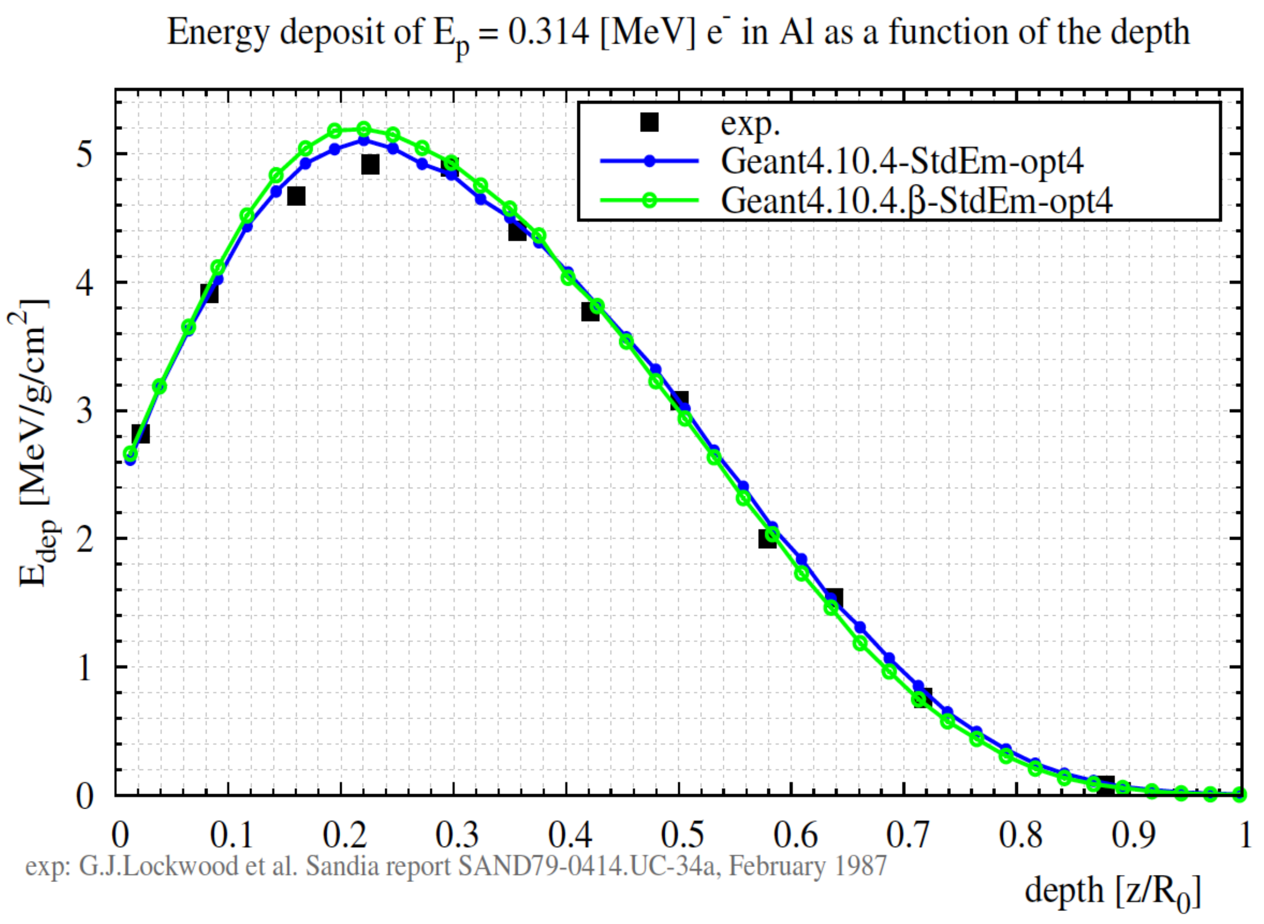
Angular distributions



M. Novak

Energy deposit in semi-infinite Al target as a function of depth
Using SANDIA experimental data





M. Novak

Depth dose in Silicon

- experimental data: U. Werner, F. Koch, G. Oelgart, J. Phys. D: Appl. Phys. 21 (1988) 116.
- Geant4 test37 simulation results with the new GS-model with Mott-correction: **Geant4.10.4-StdEm-opt4**
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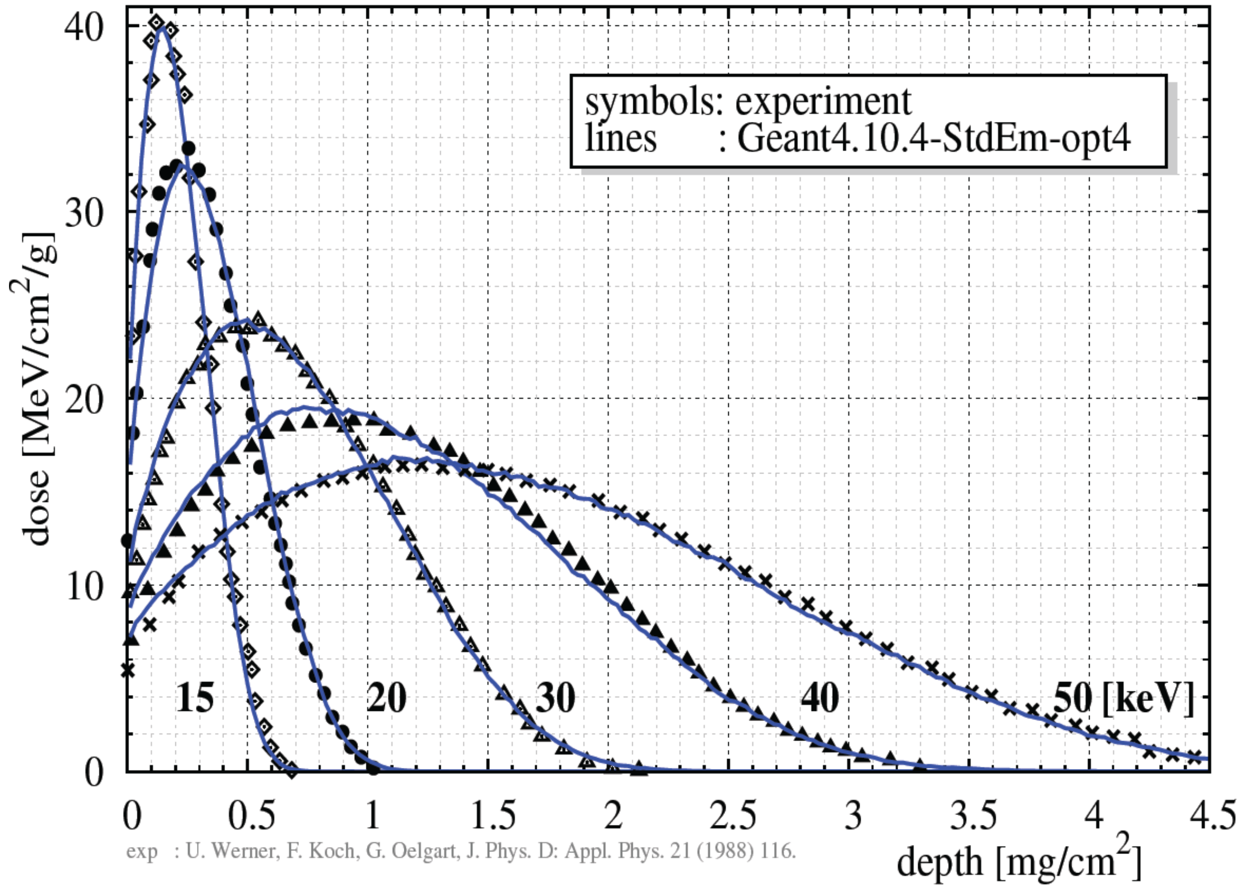

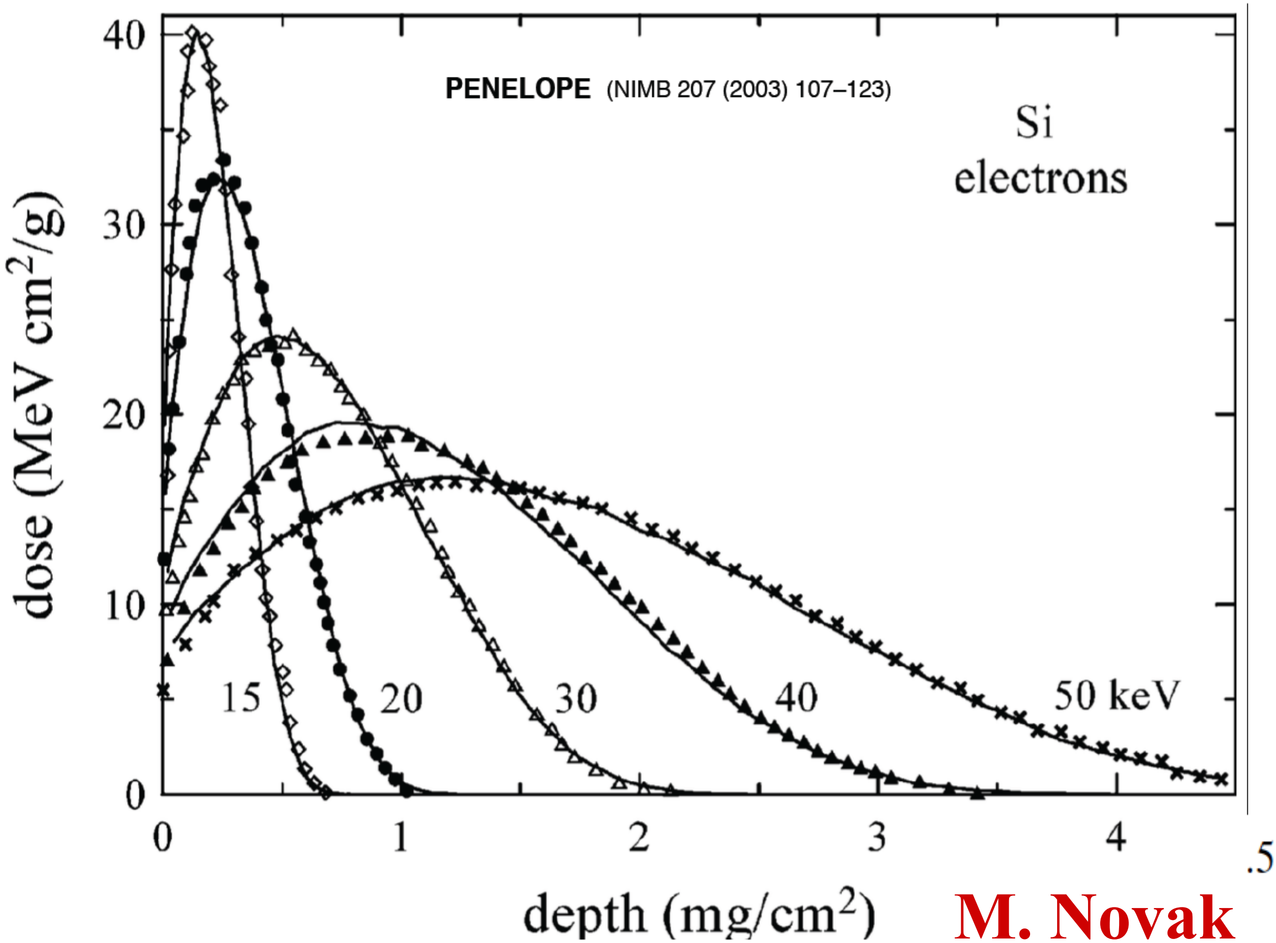

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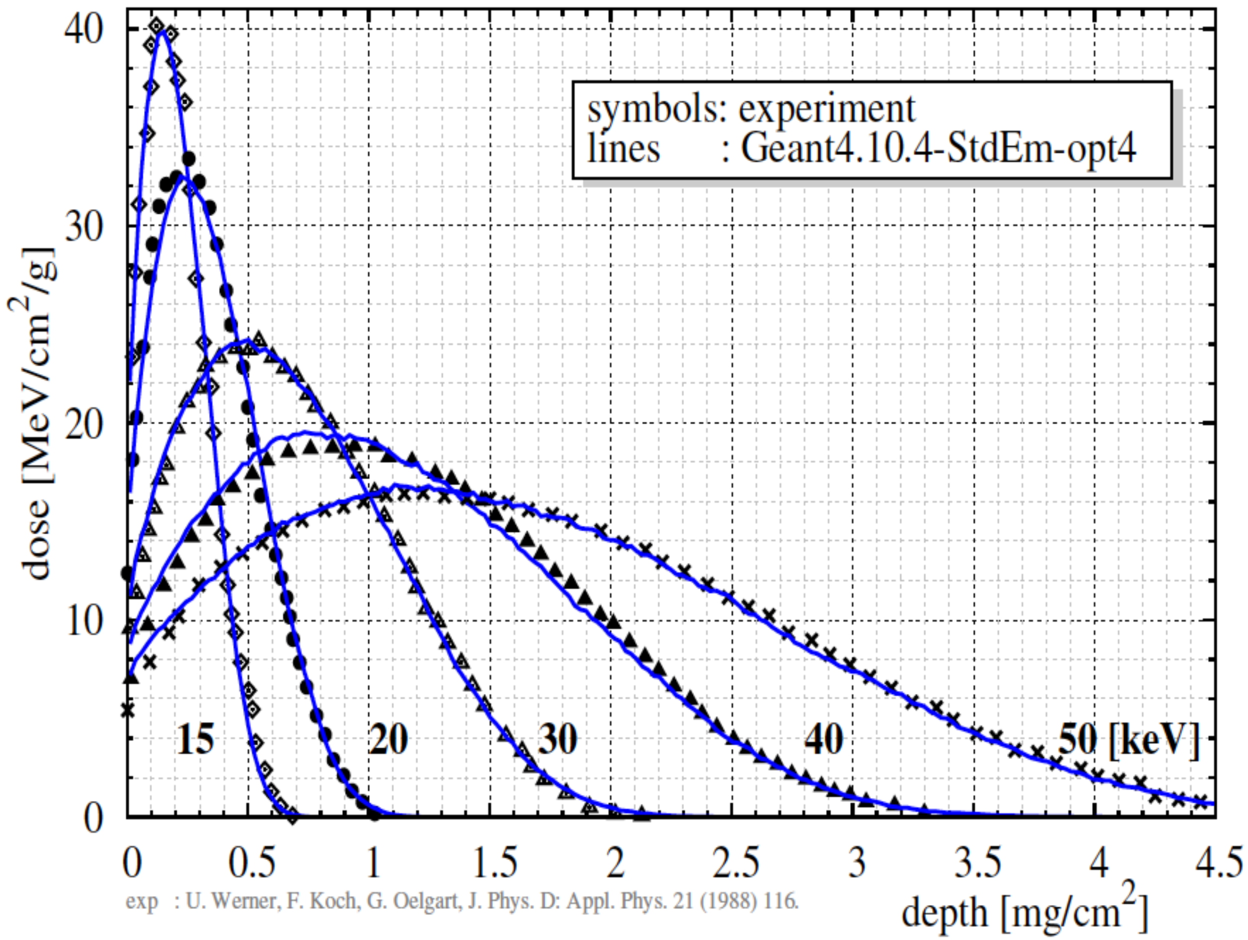
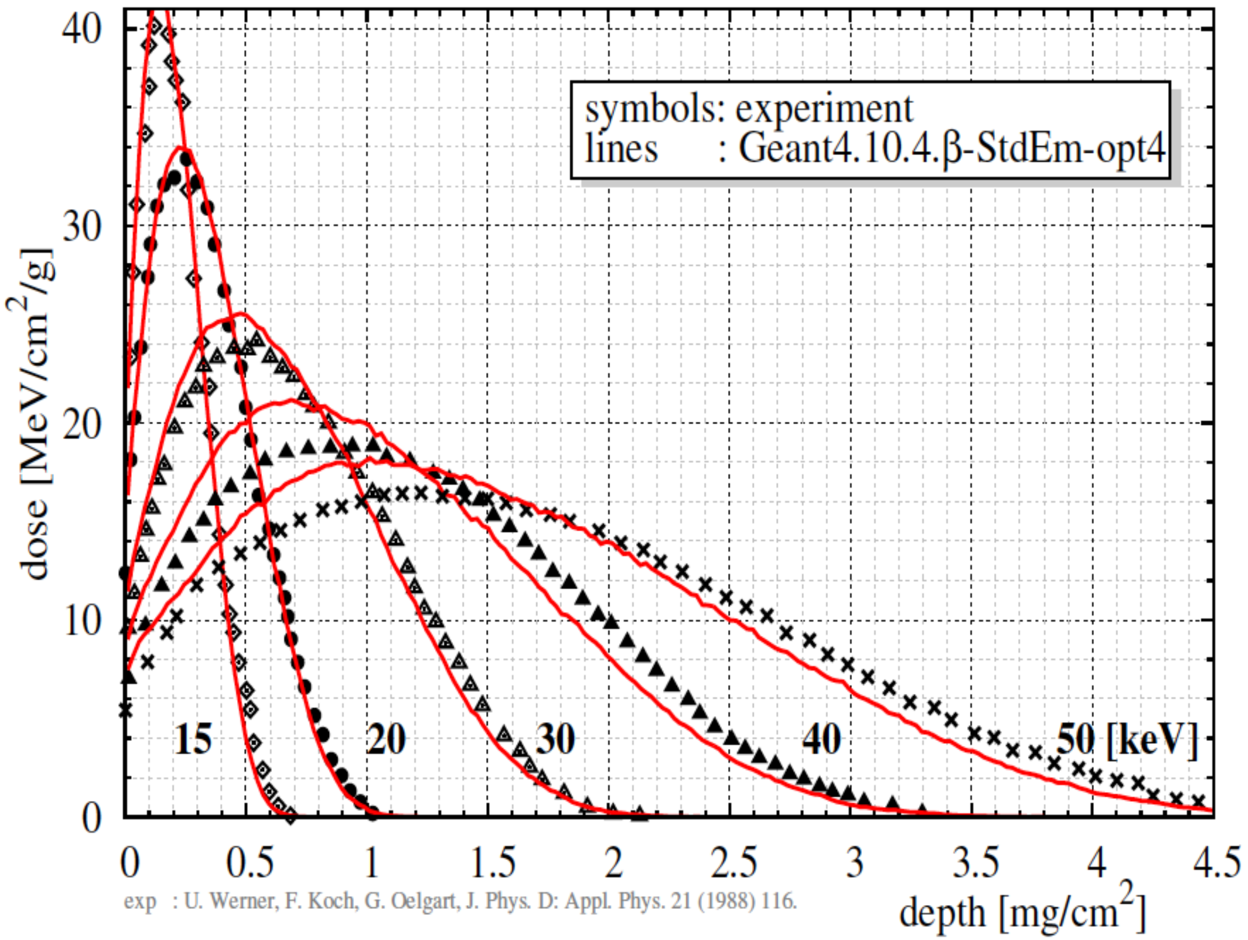
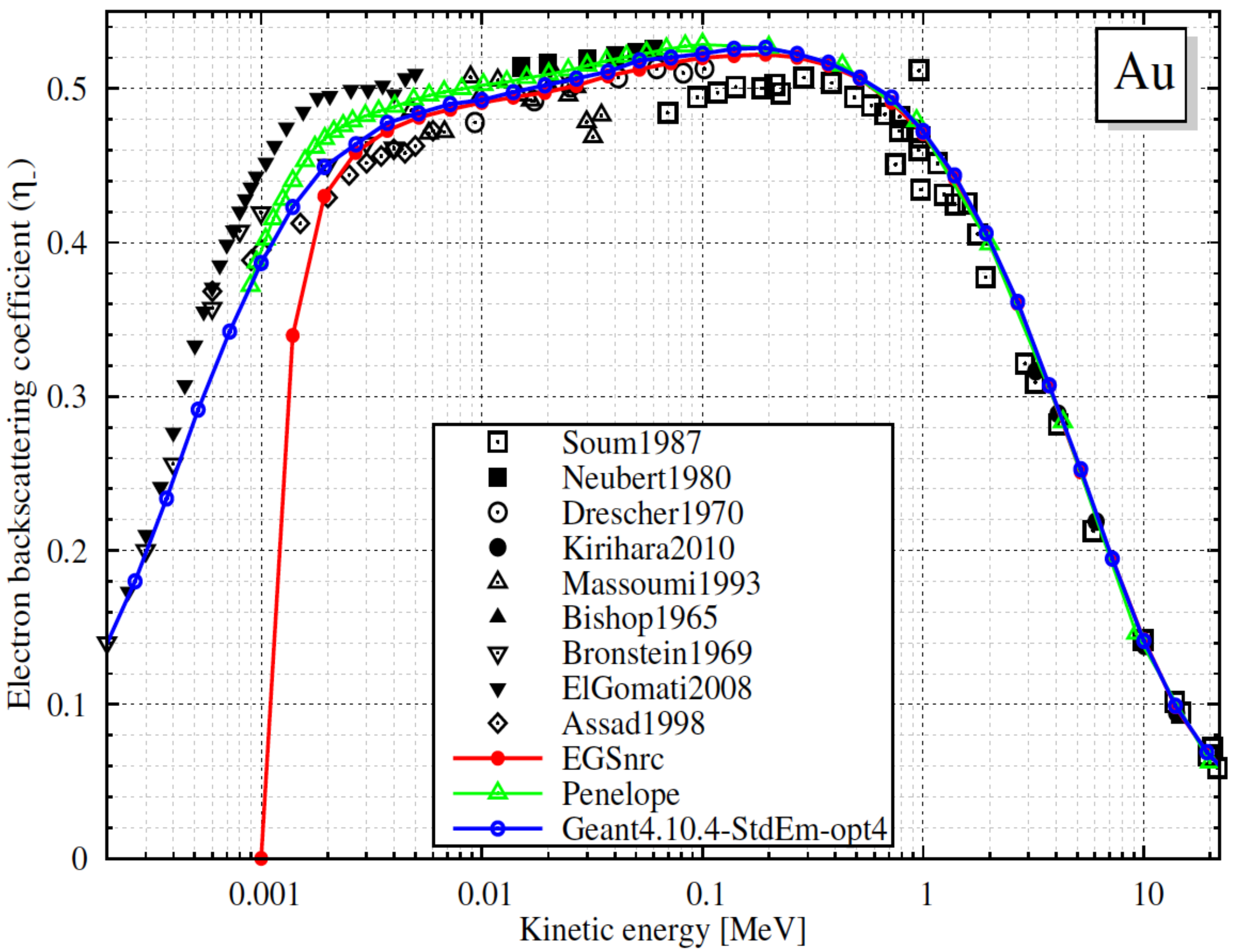
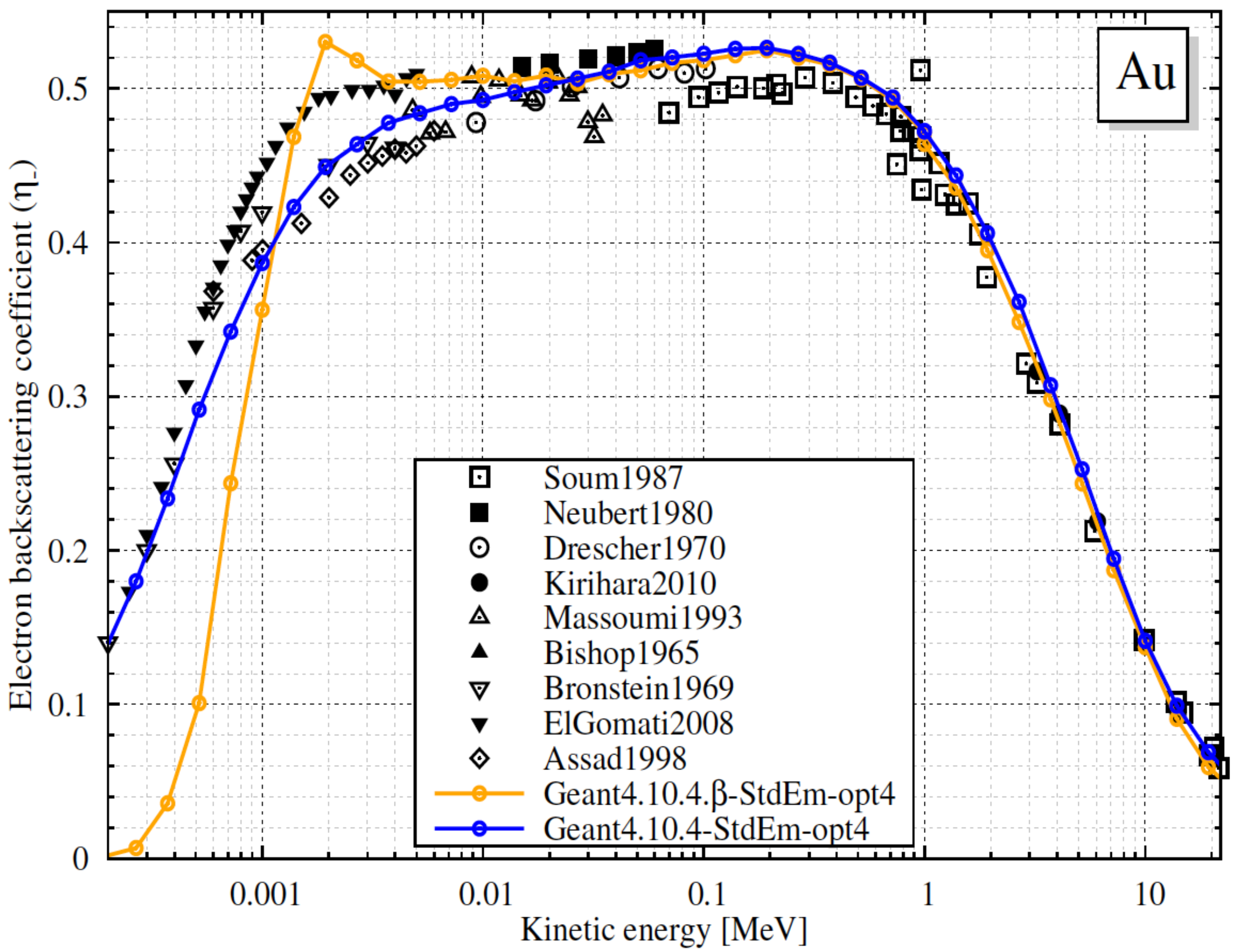




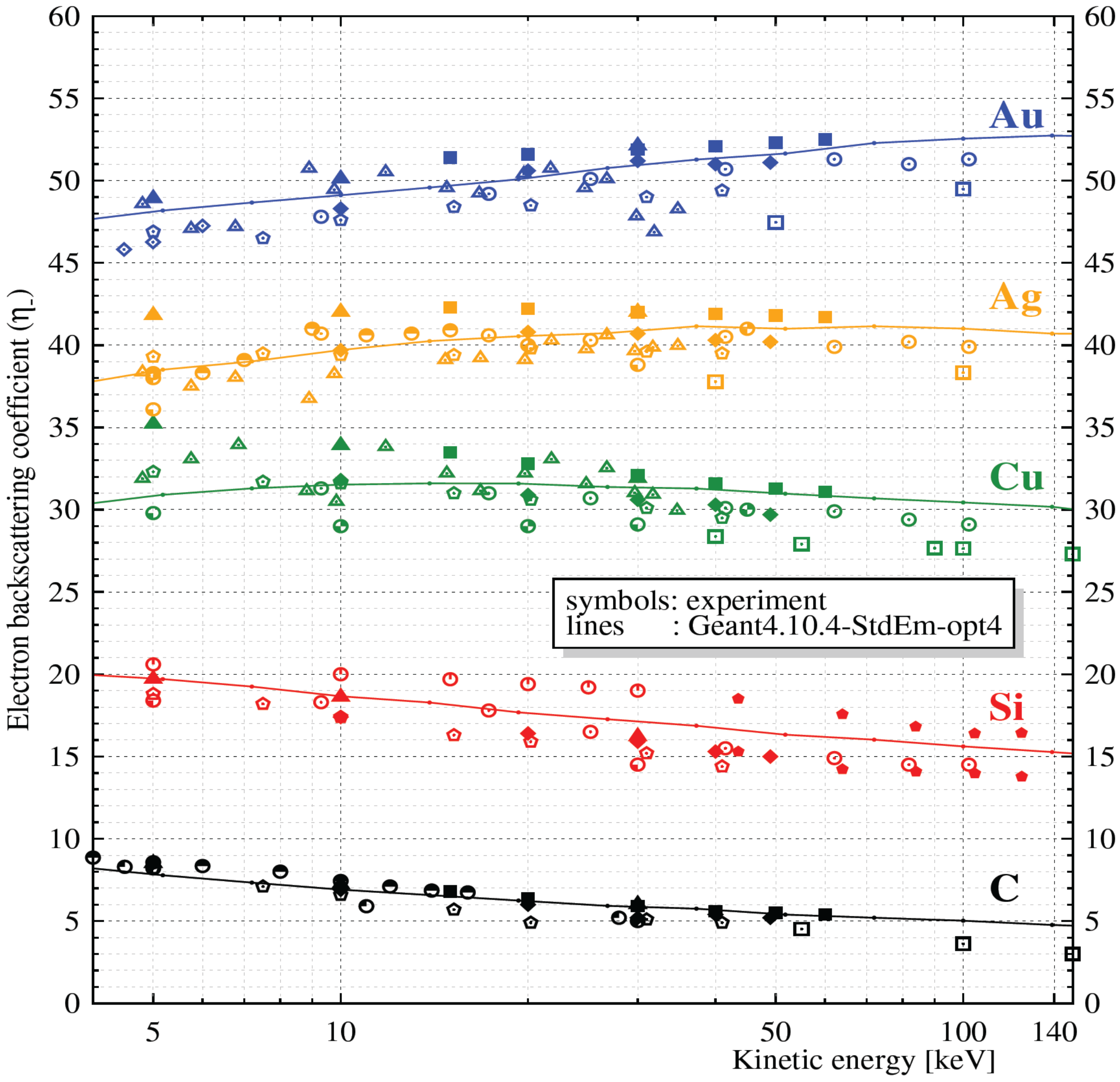
Electron backscattering in Au

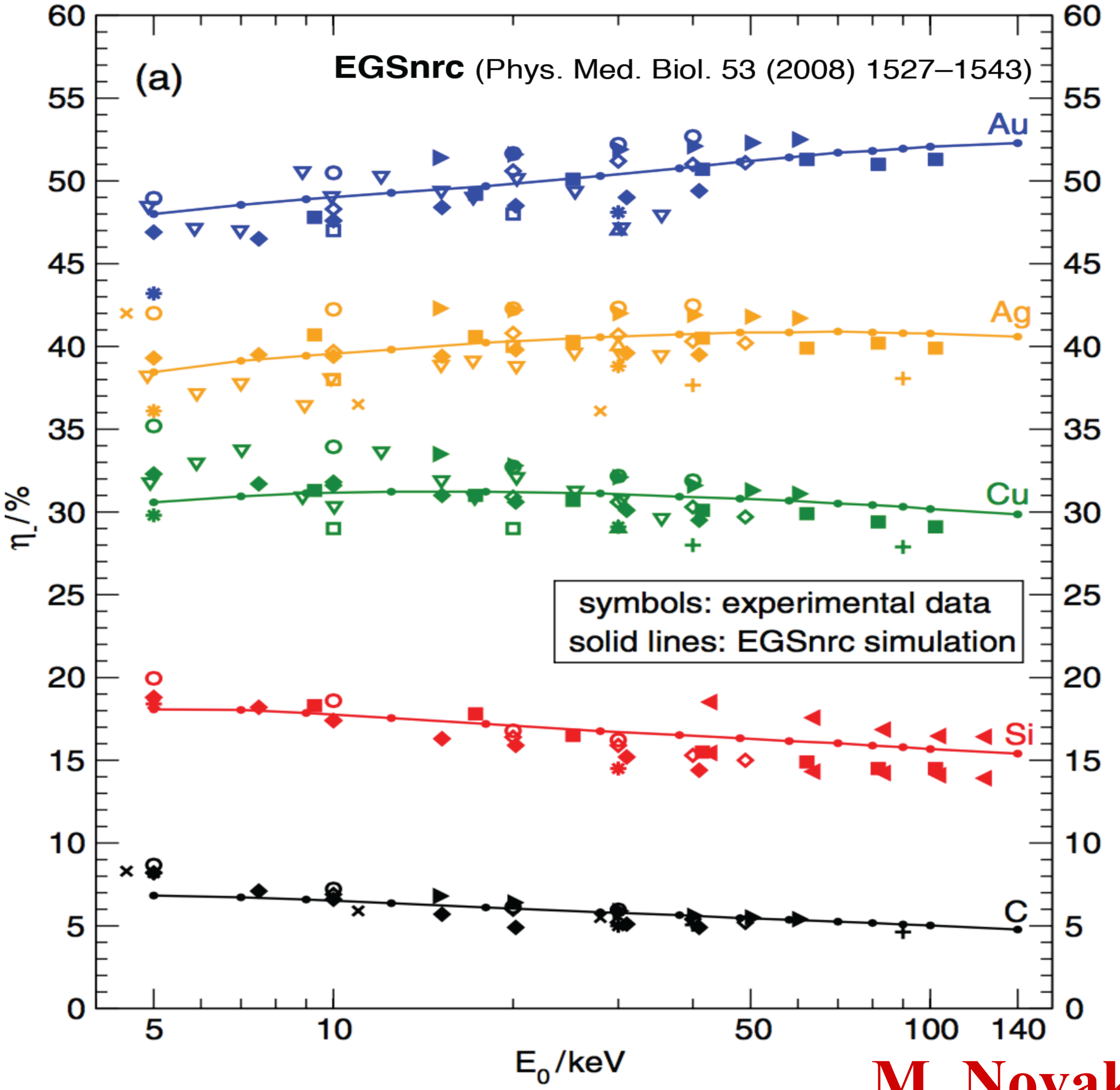




M. Novak

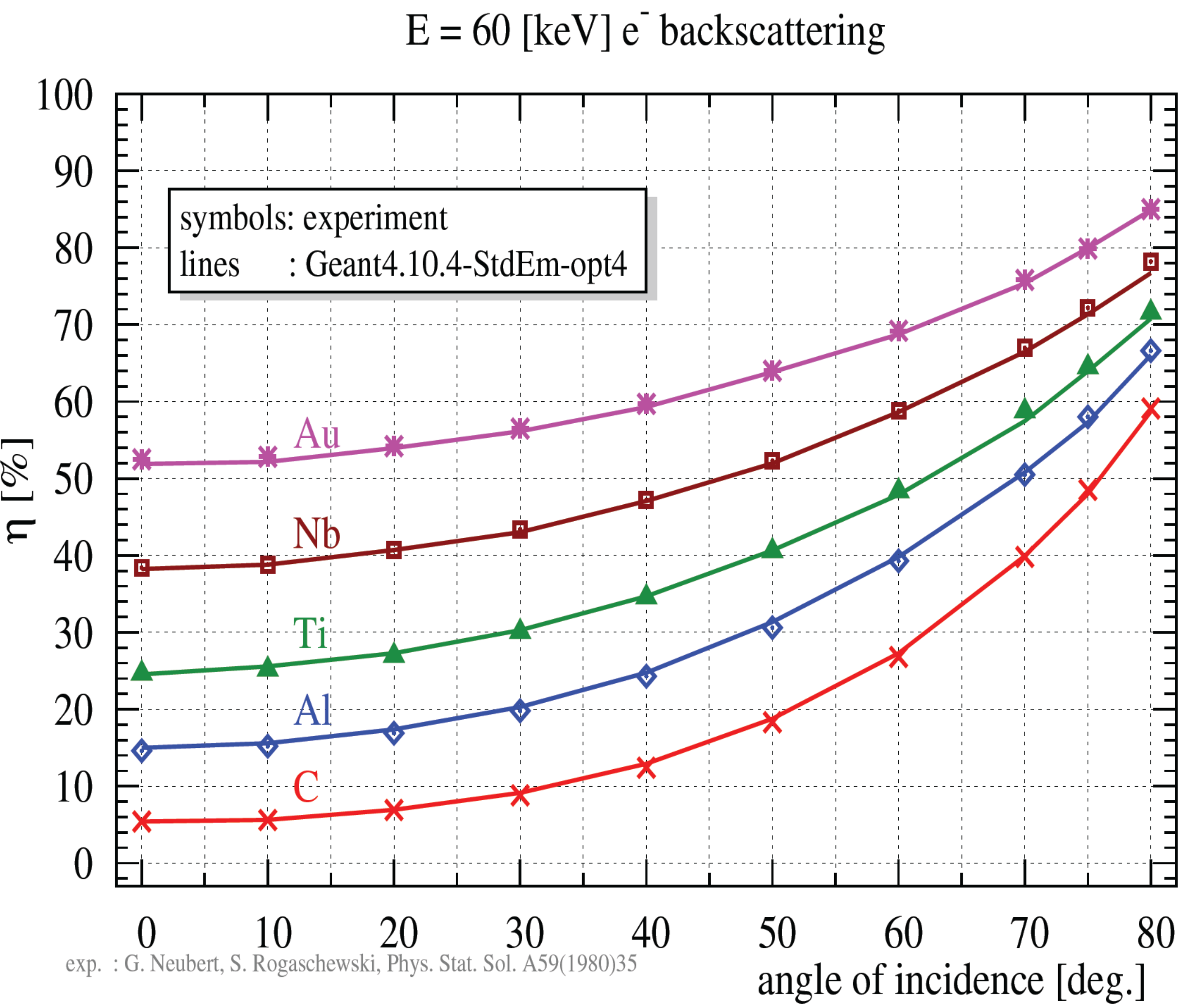
Low energy electron backscattering: normal incidence, function of primary energy, target Z

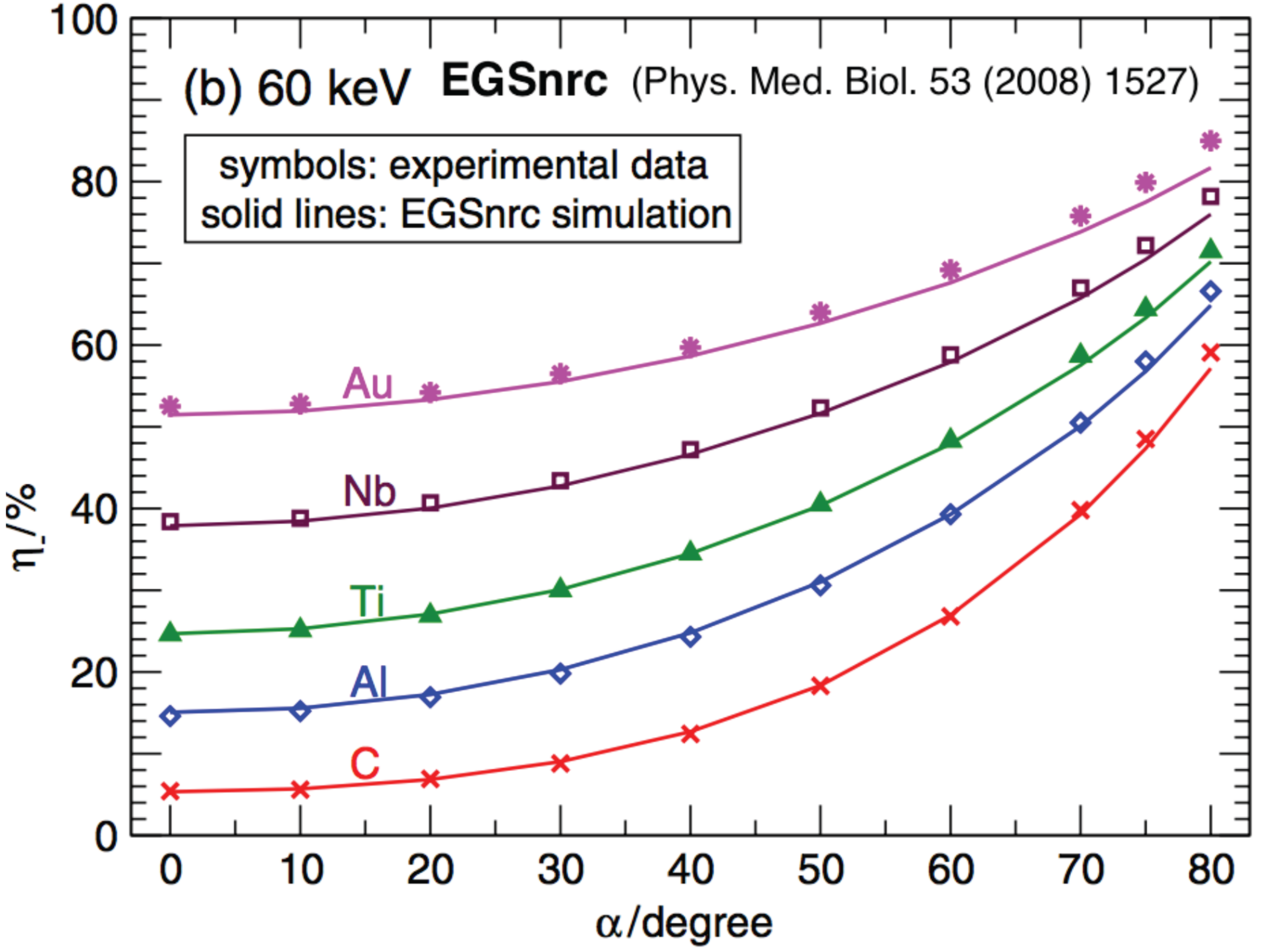




M. Novak

Low energy electron backscattering: function of angle of incidence, target Z





M. Novak

The Landau-Pomeranchuk-Migdal Effect

For simplicity, let us consider the bremsstrahlung process:

- Ultrarelativistic electron emits a low-energy photon $\Longrightarrow q_{//}$ can be very small
- Uncertainty principle $\rightarrow$ interaction takes place over a long distance, called *formation length*
- If anything happens to the electron or photon along this distance that disturbs their coherence, the emission of the photon will be suppressed
- The *Landau-Pomeranchuk-Migdal (LPM)* effect first discussed in [3] and slightly later in [4] is the suppression due to *multiple scattering*

θ_{ms}: the mean deflection angle due to multiple scattering along the formation length and θ_r: the mean emission angle

$$s \sim \frac{\theta_r}{\theta_{ms}} \quad \textbf{LPM is effective} \text{ when } \quad s \lesssim 1$$

suppression is important when:

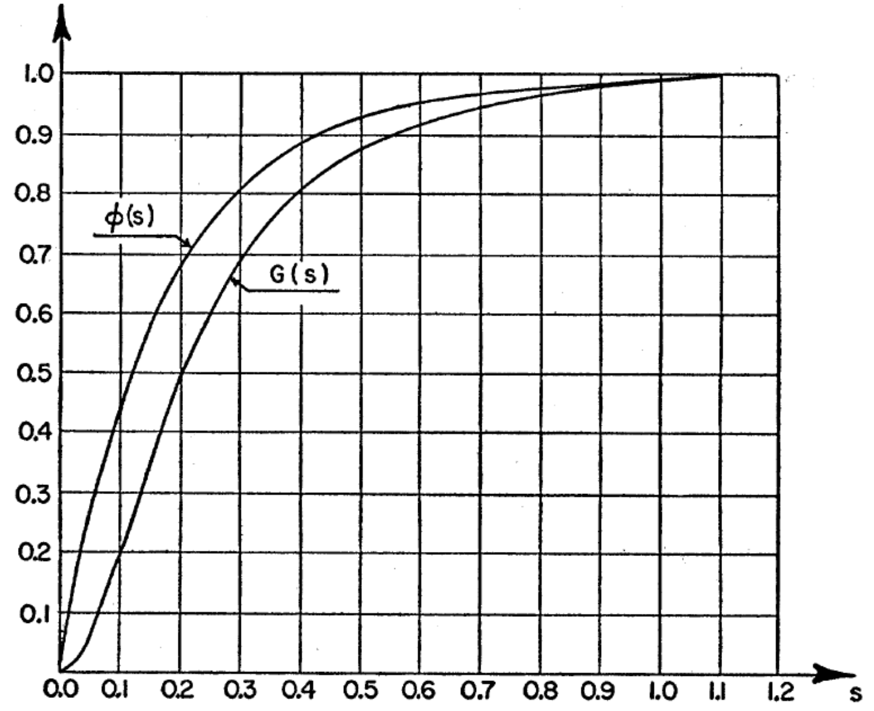
$\theta_{ms} > \theta_r \rightarrow s < 1$

$\Longrightarrow G(s) \rightarrow 0$ and $\phi(s) \rightarrow 0$

absence of suppression when:

$\theta_{ms} < \theta_r \rightarrow s > 1$

$\Longrightarrow G(s) \rightarrow 1$ and $\phi(s) \rightarrow 1$



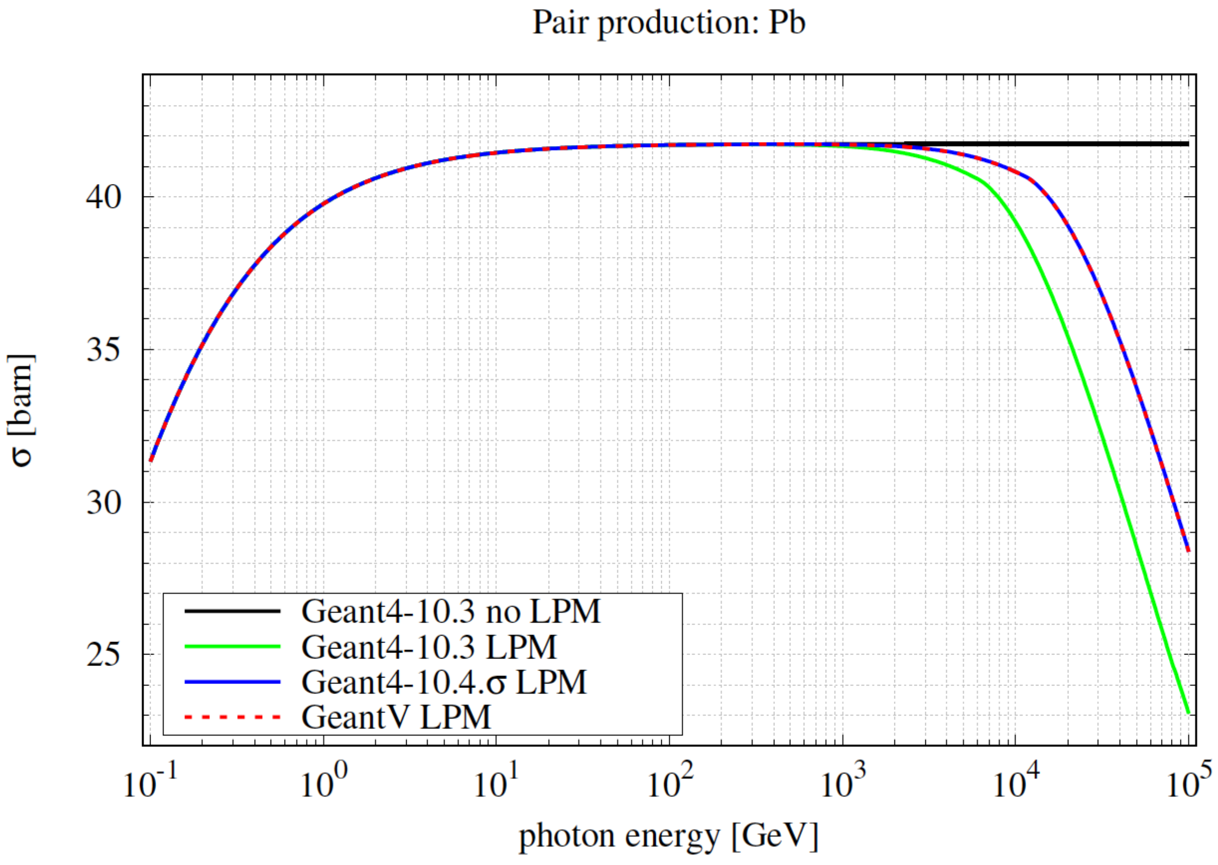
F. Hariri

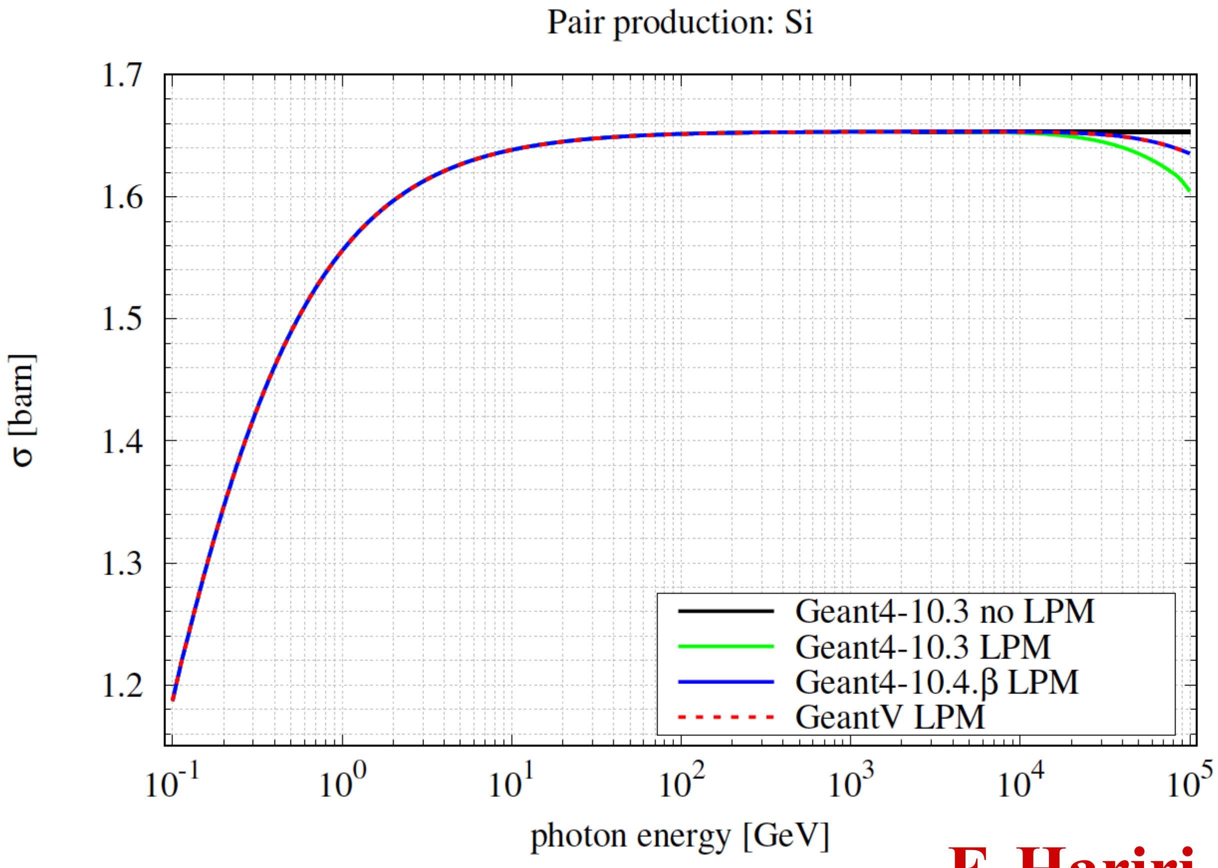
➠ Reviewing the pair production model including LPM suppression showed an inconsistent calculation of the LPM suppression variable and the material dependent LPM energy in the model used by *Geant4* $\leq$ *10.3*

- **Pair-production** differential cross-section including LPM:

$$\frac{d\sigma}{d\epsilon} = 4\alpha r_e^2 Z(Z+\eta(Z))\,\xi(s) \times \left\{ \left[\frac{1}{3}G(s)+\frac{2}{3}\phi(s)\right]\left[\epsilon^2+(1-\epsilon)^2\right]\left[\frac{1}{4}\phi_1-\frac{1}{3}lnZ-f_c\right] + \frac{2}{3}G(s)\,\epsilon(1-\epsilon)\left[\frac{1}{4}\phi_2-\frac{1}{3}lnZ-f_c\right]\right\}$$

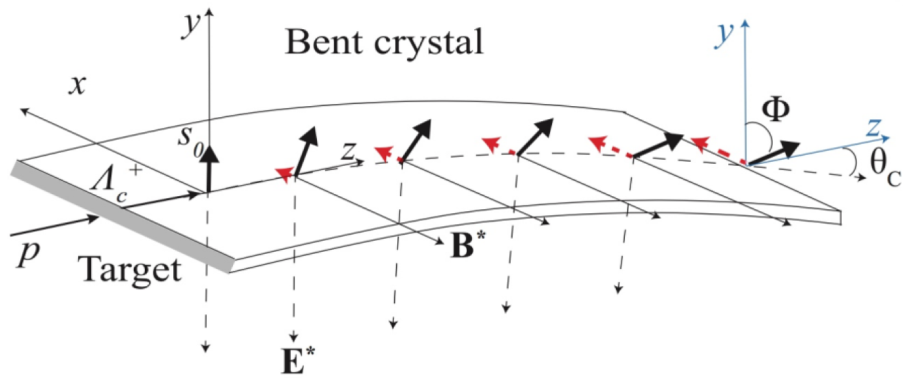
with $\epsilon \equiv E_+/E_\gamma$



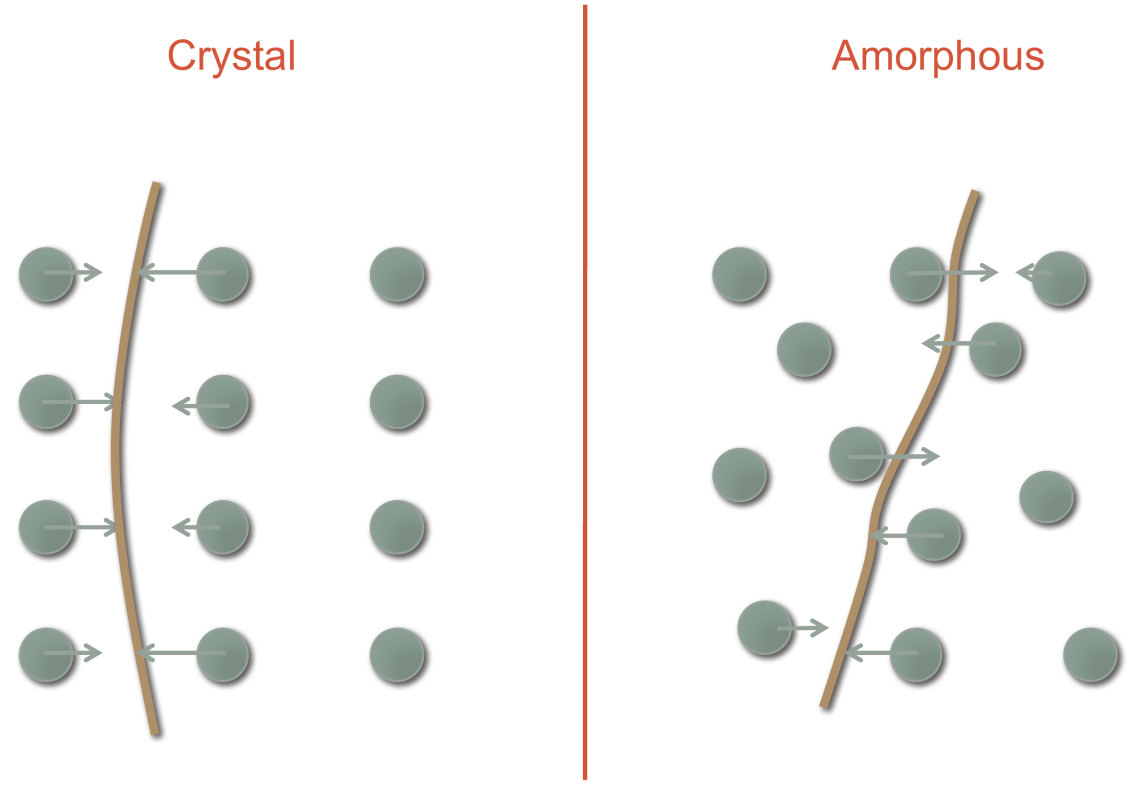


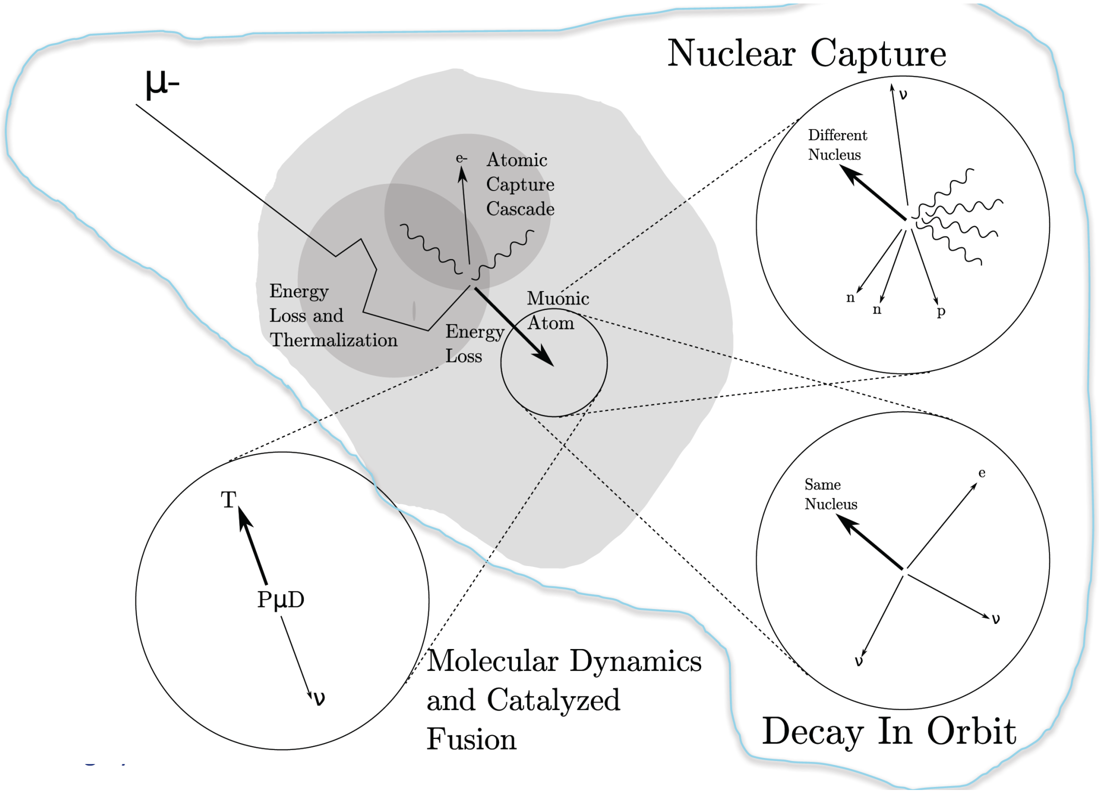
F. Hariri

Recent extensions to Geant4 capabilities

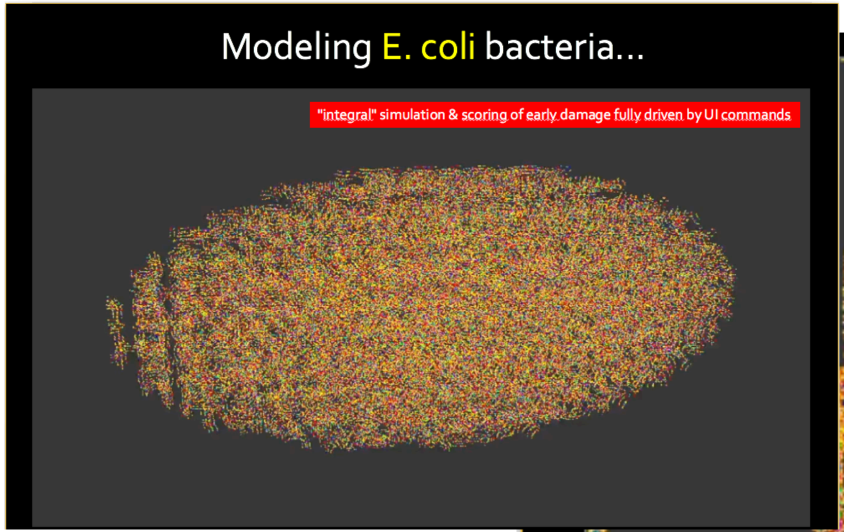


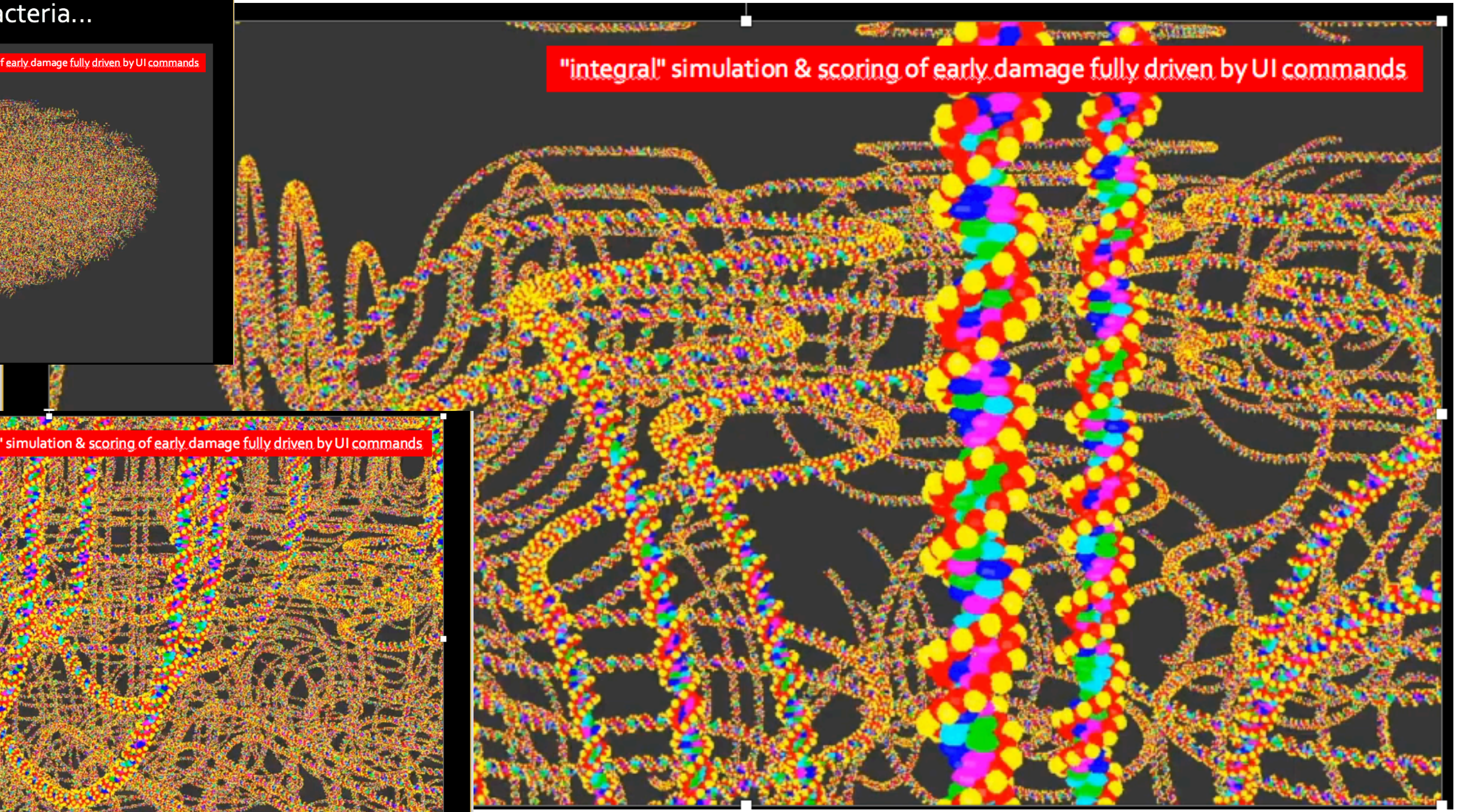
- DNA modelling (next slide)
- Crystal structure
- Muonic atoms

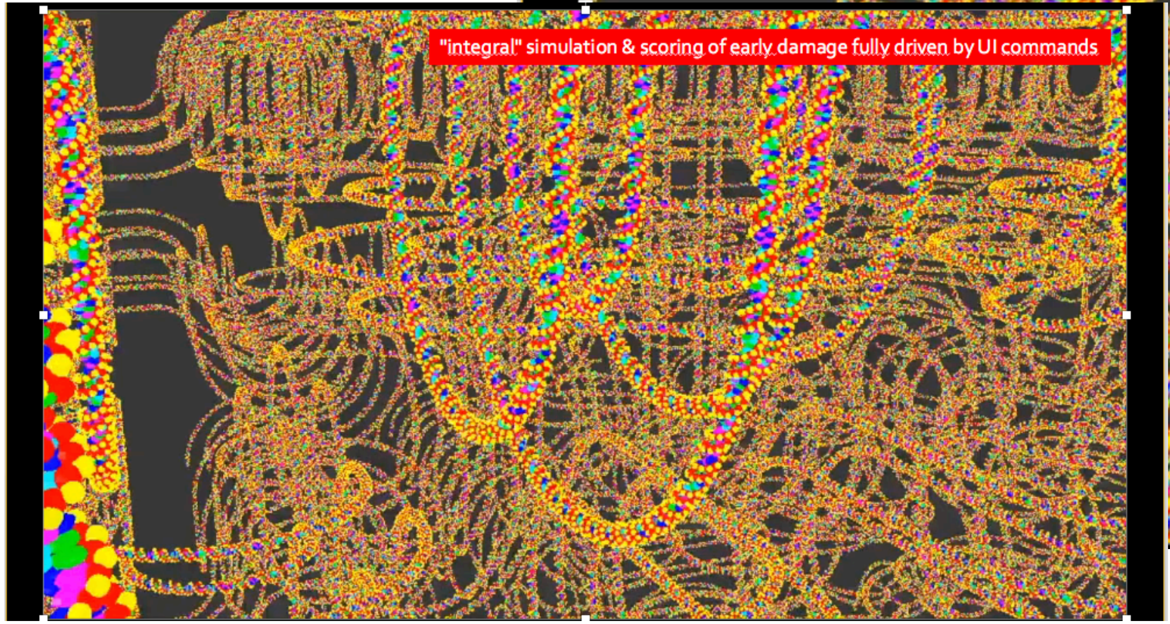




Low energy Geant4 DNA progress: DNA damage prediction







S. Incerti

Hadronic Physics

Status of **FTF** (Fritiof) Model

- Introduction of **rotating strings** in the string fragmentation
  - The standard Lund string fragmentation is unable to reproduce the <**Pt**> dependence on hadron type (mass)
  - Various ideas: for FTF, fragmenting strings rotate –> transverse mass distributions of produced hadrons
- Improved description of small-angle HARP data
  - 3-12 GeV p and $\pi\pm$ projectiles on Al, Cu, Pb
- Smearing of resonance masses (e.g. Δ and ρ)
  - Requested by Panda Collaboration

- Outcome
  - Thin-target: better at low-energies; not clear at higher energies
  - Hadronic showers: a bit higher energy response and wider showers w.r.t. G4 10.3.p02; but smaller fluctuations of energy response

A. Ribon

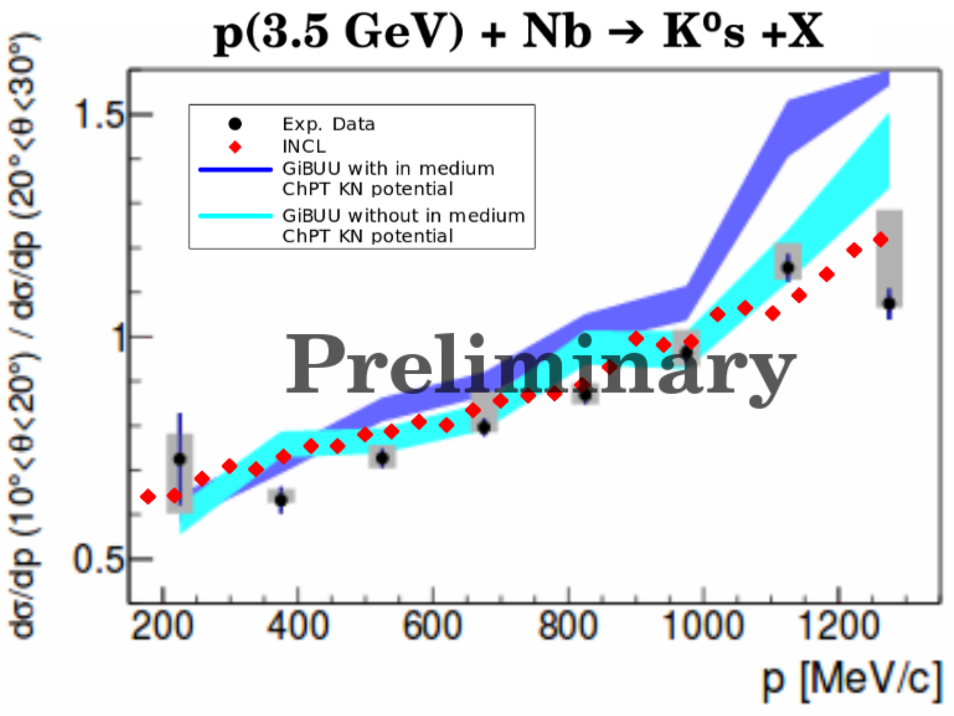
Alternative String models

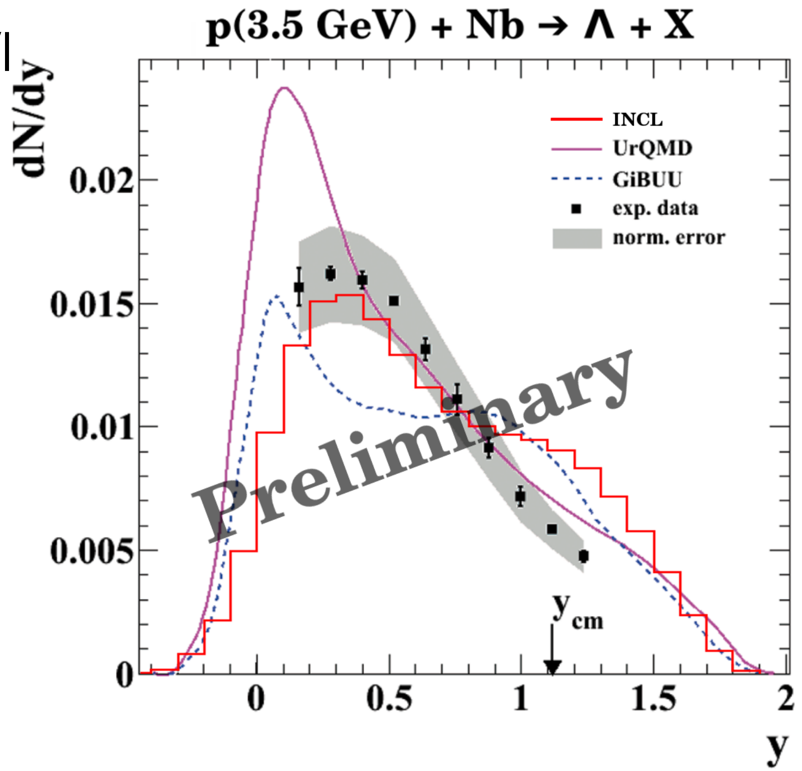
- QGS (Quark Gluon String) model is an alternative string model, used in production in Run1, but now under revision
  - More theory-based than the phenomenogical FTF model
    - For FTF, inconsistency between thin-target and hadronic showers: could be an indication that the model is reaching its limits...
  - Interesting for systematic evaluations and for applications at slightly higher energies than FTF (above few hundreds GeV up to few TeV)
- No reliable model available in Geant4 for multi-TeV hadrons
  - Starting from ~5 TeV (hadron kinetic energy in the Lab), gluon (i.e. jet) production needs to be included
  - EPOS seems the most promising model
    - Provides the best description of LHC minimum-bias data
    - Main model for ultra-high energy cosmic ray air showers
    - Contact with the leading developer (T. Pierog), and plan an interface with Fortran EPOS for next year...

A. Ribon

Intra-nuclear Cascade models

- BERT (Bertini-like) model
  - Improved the evaporation spectrum, reducing the overproduction of low-energy neutrons and protons
  - Fix on coalescence: now more fragments (d,t,He3,α) produced
- INCLXX (Liege) model
  - Originally designed up to 3 GeV; recently extended up to 15 GeV; last year included η , η' and ω
  - s & hy





J. Hirtz

Precompound / De-excitation & Radioactive Decay

- Further progress and extensions
- Consistent treatment of excited energy of nuclear fragments
- Isomer production is enable by default
- Correlated gamma emission included
- New, consistent set of data libraries

RadioactiveDecay5.1.1
Data for beta, alpha, EC, neutron, proton decay

Photonevaporation4.3.3/5.0.2
Data for de-excitation of excited nuclear level by gamma and internal conversion

ENDFSTATE2.2
Defined all ground states and excited levels with non zero lifetime

V. Ivanchenko, D. Wright

A new composite model for photo-nuclear interaction: LENDorBERTModel

- For gamma below 20 MeV, a new data-driven approach based on LEND (Low Energy Nuclear Data) has been developed by T. Koi and will be available in G4 10.4
  - LEND available for 162 isotopes from D to Pu241
- For gamma above 20 MeV and whenever LEND data is not available, the default Chips cross section and the Bertini (BERT) final-state model is used as usual
- By default, only the physics list ShieldingLEND will use this new photo-nuclear approach

T. Koi, D. Wright

$^{12}C(n,n'3\alpha)$ and $^{12}C(n,\alpha)^{9}Be$ reactions in G4ParticleHP

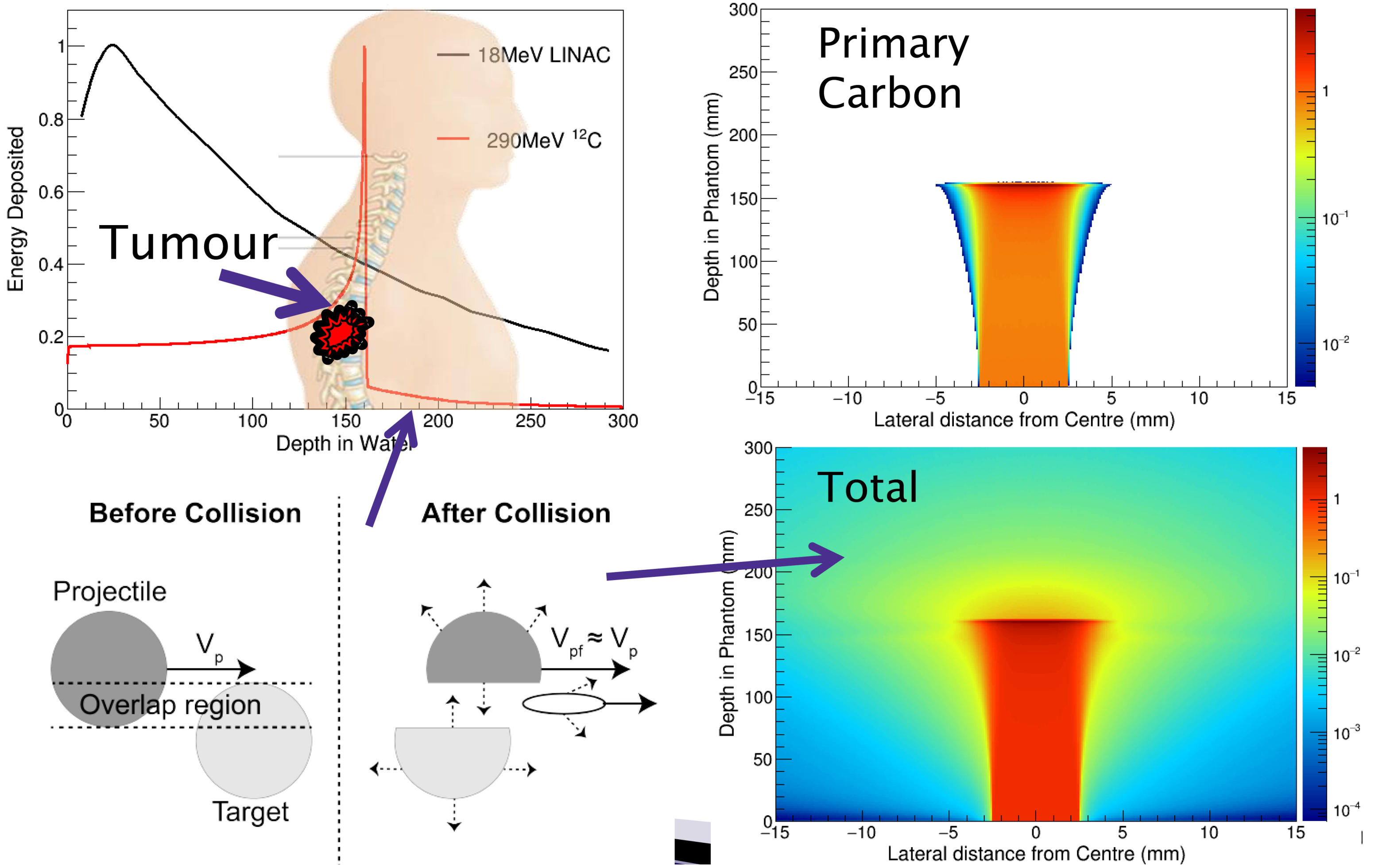
- G4ParticleHP does not always provide a complete description of multi-step breakup reactions, like $^{12}C(n, n'3\alpha)$ and $^{12}C(n,\alpha)^{9}Be$
  - Either incomplete or missing evaluated data
  - Or incomplete model implementation
- Special (rather than general !) treatment based on NRESP7 for organic scintillators and other fast neutron detectors where carbon reactions required an accurate description

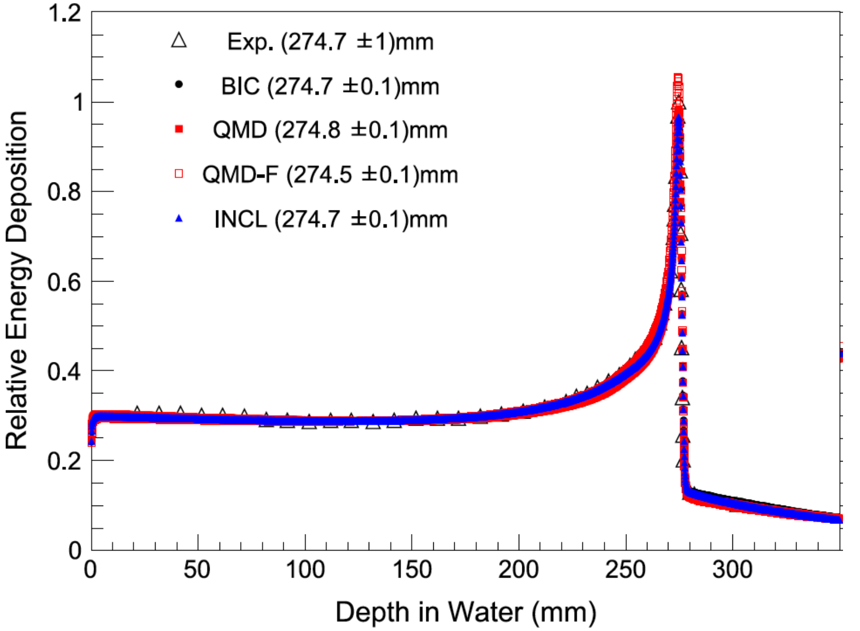
Step 1	Step 2	Step 3
$n+^{12}C \rightarrow n'+^{12}C^*$	$^{12}C^* \rightarrow \alpha+^{8}Be$	$^{8}Be \rightarrow 2\alpha$
$n+^{12}C \rightarrow \alpha+^{9}Be^*$	$^{9}Be^* \rightarrow n'+^{8}Be$	$^{8}Be \rightarrow 2\alpha$

A. R. Garcia

Validation of Geant4 fragmentation for Heavy Ion Therapy

Carbon Therapy

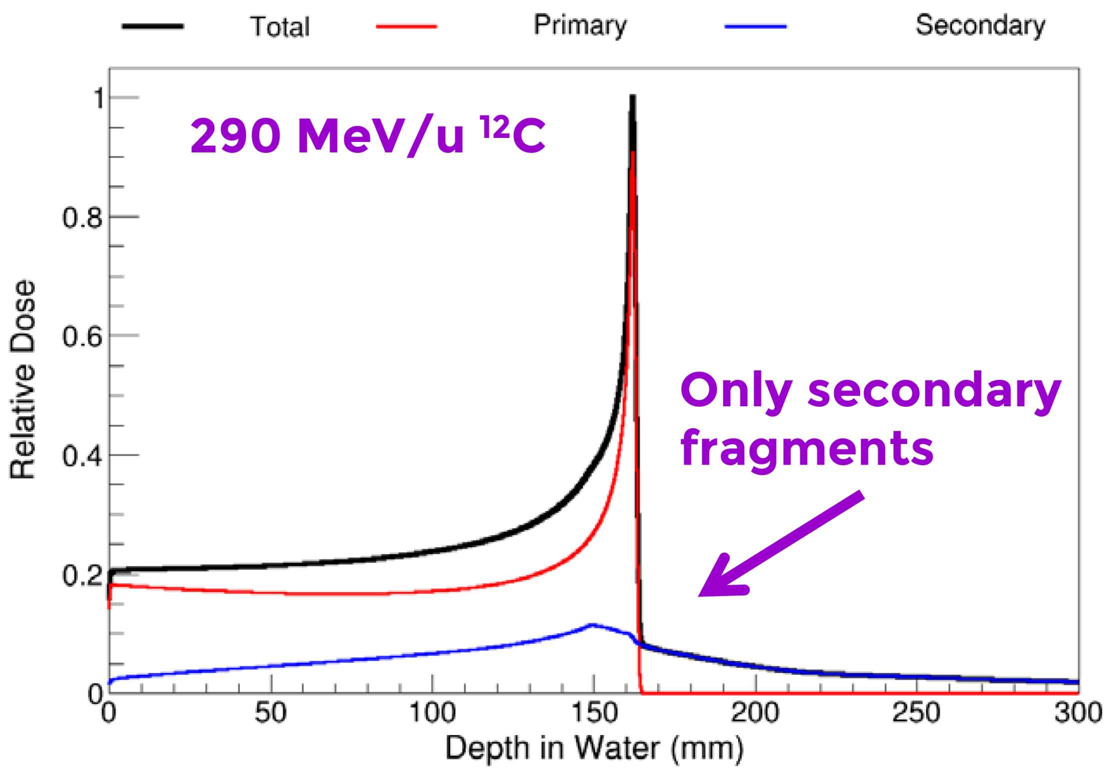




D. Bolst

Accurate Hadronic Physics needed for Heavy Ion Therapy

HIT mixed radiation field



Reference:
Francis et al, PMB, 59 (2014) 7691

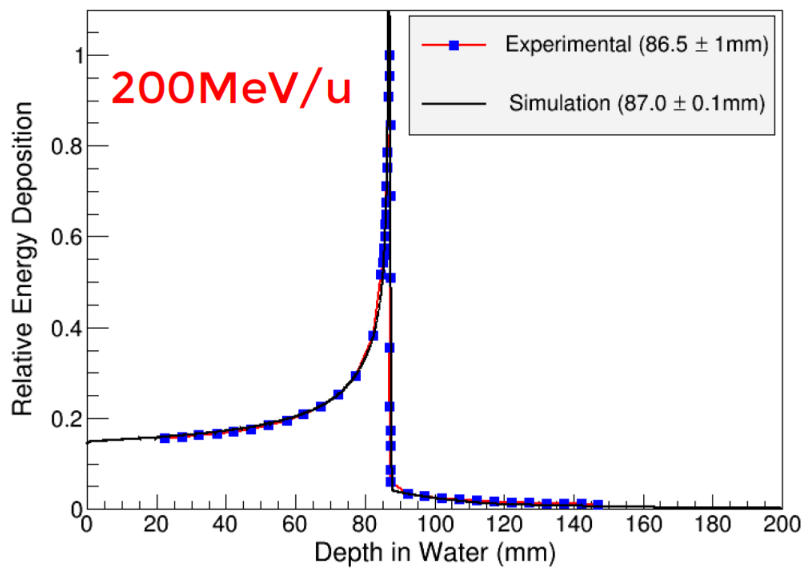
Contribution to the **dose**:

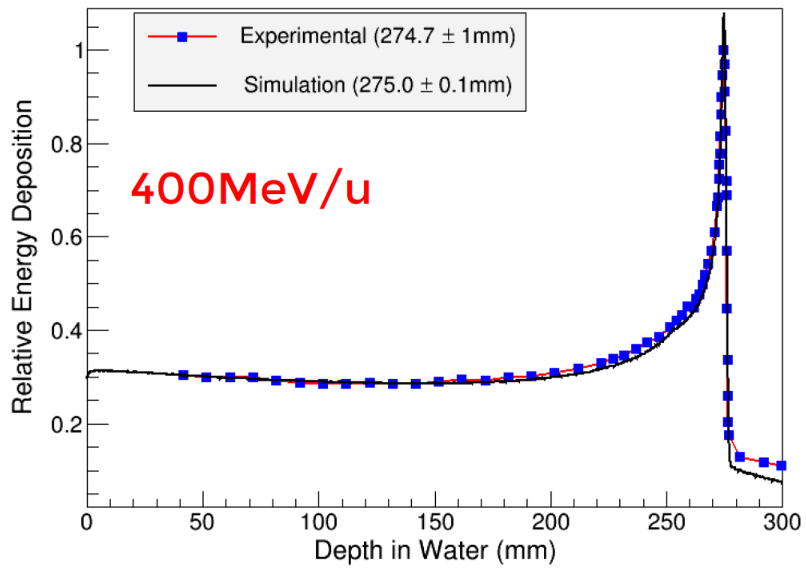
- 64% - ^{12}C ions via em interactions
- 36% - produced fragments and their secondaries
  - 14% - protons
  - 13% - alpha particles
  - 4.2 % - B ions
  - 1.7% - Li ions
  - 1.3% - Be ions

S. Guatelli

Bragg Peak validation

- Reference: E. Haettner (2006/2013) for 200MeV/u and 400MeV/u, measurements performed at GSI
- In water
- Step limit 0.05mm
- Cut size 0.1mm
- Standard EM option 3, BIC for hadronic interactions





S. Guatelli

Results

Depth in PMMA (mm) (±1)	Depth of Bragg peak in silicon (mm)	
	Experimental (±0.4)	Simulation (±0.2)
54	48.7	48.8
89	27.2	27.2
102	19.4	19.2

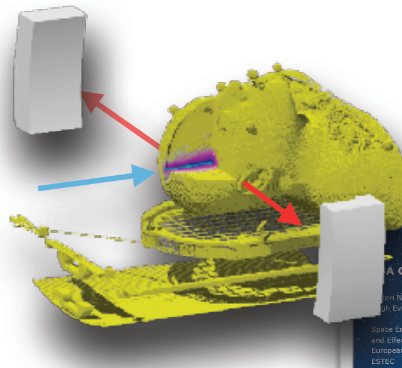
Excellent agreement between experiment and simulation with less than 1.1% difference in the Bragg Peak position.

Within 200 μm spatial resolution

S. Guatelli

Applications of low energy nuclear models

- Nuclear Physics experiments
- Hadrontherapy
- Radiobiology
- Radio-protection in space mission
- Radiation damages to electronics
- Nuclear spallation sources
- Radioactive waste



First slide of the talk "ESA Geant4 R&D Activities
from the Geant4 Space User Workshop
Hiroshima, 26 August 2015

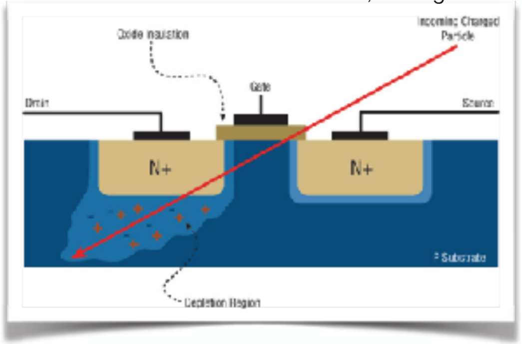


Figure from M. Sawant, COTS Journal Jan. 2012

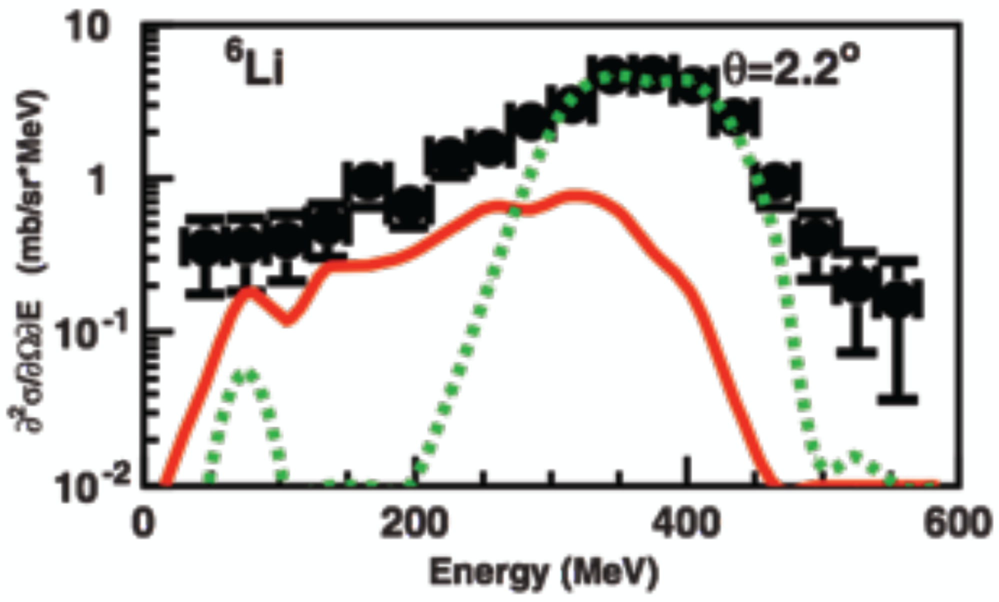
C. Mancini

- Exp. data
- BIC
- G4QMD

[Plot from De Napoli et al. Phys. Med. Biol., vol. 57, no. 22, pp. 7651–7671, Nov. 2012]

• Problems below 100 MeV

- Despite the numerous and relevant application there is no dedicated model to nuclear interaction below 100 MeV/A in Geant4



Cross section of the ^{6}Li production at 2.2 degree in a ^{12}C on ^{nat}C reaction at 62 MeV/A.

C. Mancini

GeNIALE target

- **The entrance channel model characteristics have a larger effect** on particles and fragments production as compared to the choice of the exit channel
  [J. Dudouet et al. Phys. Rev. C, vol. 89, no. 5, p. 054616, May 2014]
- The core of GeNIALE is the implementation in Geant4 of a new model for the **first stage of the interaction** between a hadron -or a nucleus- and a target nucleus
- Such a model will be coupled with the models already implemented in Geant4 for the second stage, and with the Geant4 framework in general

- Suitable models

- **Boltzmann-Uehling-Uhlenbeck (BUU)**
  - describes the time evolution of the density distribution
- **Boltzmann-Langevin (BL)**
  - BUU plus fluctuations in the nucleon-nucleon collisions
- **Antisymmetrized Molecular Dynamics (AMD)**
  - reproduce the molecular dynamics in the nuclear field

C. Mancini

Low Energy Hadronic Physics

Neutrino Scattering

- First step: Geant4-to-GENIE interface
  - use Geant4 Bertini cascade to do final state interactions in nucleus after GENIE neutrino vertex is generated
  - complete, committed to GENIE svn
  - validation underway
- Next step: GENIE-to-Geant4
  - use GENIE neutrino generators to initiate neutrino interactions in Geant4
  - need wrapper models to have GENIE models treated as Geant4 models
  - some native Geant4 neutrino cross section classes already exist (V. Grichine)

D. Wright

Summary & Outlook

We had productive discussions, we know where we're going to

- We could have lots of dense discussions and made solid progresses. We could also make solid work plan toward the version 10.4 in December.
  - Let's keep the momentum together toward our targets.
- Many collaboration-wide efforts are re-identified.
  - Git migration, Drupal migration, Documentation overhaul, etc.
  - Join these efforts.
- We could also have productive discussions on improving our credibility.
  - We reconfirmed the importance of Outreach
- We have to keep improving Geant4, maintaining it and supporting our customer users for foreseeable future.
  - Let's start shaping Geant4 version 11.
  - Let's invite new idea that would strengthen Geant4.

23rd collaboration meeting will be co-hosted by
Nuclear physics and High Energy Physics divisions of Lund University, Sweden
August 27th - 31st, 2018

M. Asai

Conclusion (personal view)

Geant4 is roughly my age, old but active and the user community is increasing and diversified from different areas. Geant4 is open to improvements both at the infrastructure and at the physics level. Ideas are already under discussion and others are of course welcome…

A personal opinion on the major points to be improved:

- **General:**
  - Development-testing-validation-integration cycle to be more streamlined, more automatic and a faster integration (with new software tools) of approved changes into production
  - Code review in all areas within Geant4 can bring non-negligible CPU speedups
  - Physics validation database to be unified and used consistently within Geant4
  - In-code documentation to be improved
  - More proactive publication and reporting of new results

- **Electromagnetic Physics:**
  - Further improvements in the description of the electromagnetic showers
  - Continue theoretical review of all electromagnetic processes
  - Extension to higher energies, in particular for FCC energies and beyond

- **Hadronic Physics:**
  - Resolve inconsistency between thin target and hadronic shower for string models to be tackled
  - First principle review of hadronic models is also needed in nearly all areas
  - Extension and development of missing models up to FCC energies and beyond