Geant 4

Systematic validation of electromagnetic and hadronic physics in LowE Electromagnetic and Advanced Examples Working Groups

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on behalf of the

Geant4 Low Energy Electromagnetic and Advanced Examples Working Groups

CERN

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Geant4 physics

- Wide set of physics processes and models
- Versatility of configuration according to use cases

- How to best choose the most appropriate model for my simulation?

- Provide objective criteria to evaluate Geant4 physics models
  - document their **precision** against established experimental data
  - evaluate all available Geant4 physics models **systematically**
  - **publication-quality** results, subject to peer-review process

- Geant4 Physics Book
  - validation of basic Geant4 physics quantities (cross sections, final state distributions etc.)
  - demonstration of Geant4 validation in some typical use cases

Lines of activity

- Basic physics quantities of Geant4 models
  - Cross sections, angular distributions, final state spectra etc.
  - In progress: Bremsstrahlung, Atomic Relaxation

- Experimental use cases
  - Related to the assessment of basic physics quantities
  - In progress: Bragg peak of protons, LHC radiation monitors

- LowE Electromagnetic specific models
  - Models with no other counterpart in Geant4
  - e.g. new Geant4-DNA models at the eV scale

Statistical Toolkit

http://www.ge.infn.it/statisticaltoolkit

- Satellite project: rigorous mathematical tools for the comparison of data distributions

- Recent release 2: April 2006, new minor release end July 2006
- New tests
  – Girone (generalised algorithm)
  – Watson
  – Weighted Kolmogorov-Smirnov, Creamer-von Mises
- Improved tests
  – Anderson-Darling, Cramer-von Mises: asymptotic distributions
  – χ^2, Goodman, Tiku: significantly improved CPU performance
- ROOT User Layer component added
- Use GNU AutoTools
- Performance analysis of all goodness-of-fit tests
- Publication submitted to IEEE Trans. Nucl. Sci. last week

Electromagnetic Physics

K. Amako et al.,
Comparison of Geant4 electromagnetic physics models against the NIST reference data
IEEE Trans. Nucl. Sci., Vol. 52, Issue 4, Aug. 2005, pp. 910-918

- Systematic approach
  - cover ALL available models
- Quantitative validation
  - rigorous statistical methods for the comparison of simulated and experimental data distributions

- Adopt the same method also for hadronic physics validation
  - address all modelling options
  - start from the bottom (low energy)
  - progress towards higher energy based on solid ground of previous assessments
  - statistical analysis of compatibility with experimental data

- Guidance to users based on objective ground
  - not only "educated-guess" PhysicsLists

Validation of EM physics

An example of activity: **ALL** Geant4 Bremsstrahlung models

The sets of cross section models for γ have already been extensively and successfully validated

K. Amako et al., published in IEEE Trans. Nucl. Sci.

Now **e^-/e^+ EM processes** to be taken into account

more difficult to find reference data and to disentangle effects (because of the continuous part)

For **Bremsstrahlung**, 3 sets of models:

- G4eBremsstrahlung
- G4LowEnergyBremsstrahlung
- G4PenelopeBremsstrahlung

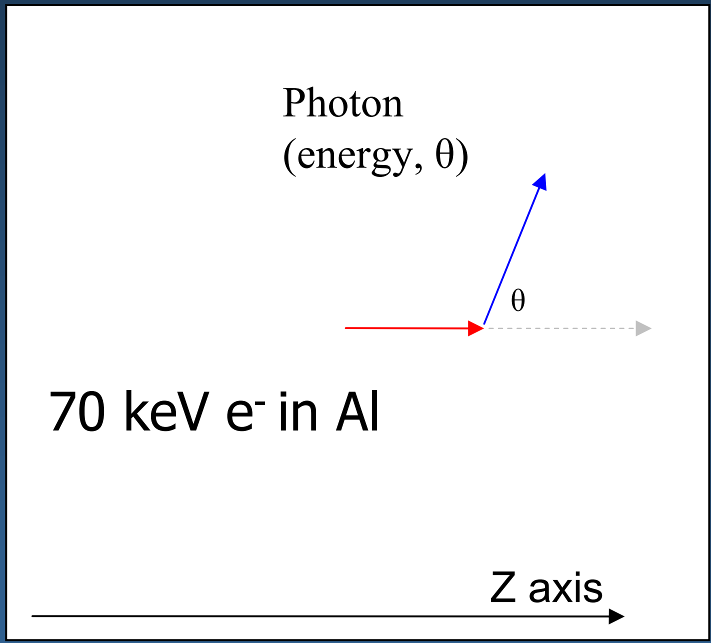
→ 3 alternative angular distributions:

Tsai, 2BS, 2BN

Preliminary test
Comparison of final states

Check the **final state** (= energy and angular distribution) generated by the different Bremsstrahlung models

Create an e^- of given energy (70 keV) in a given material (Al) → **force the Bremstrahlung interaction**

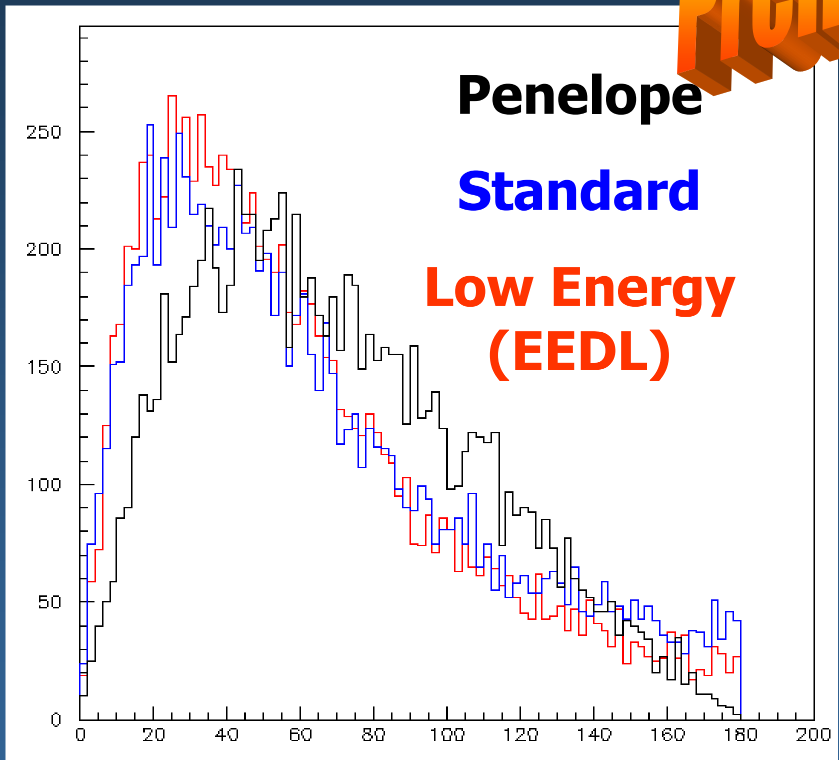


energy and polar angle of the emitted photon

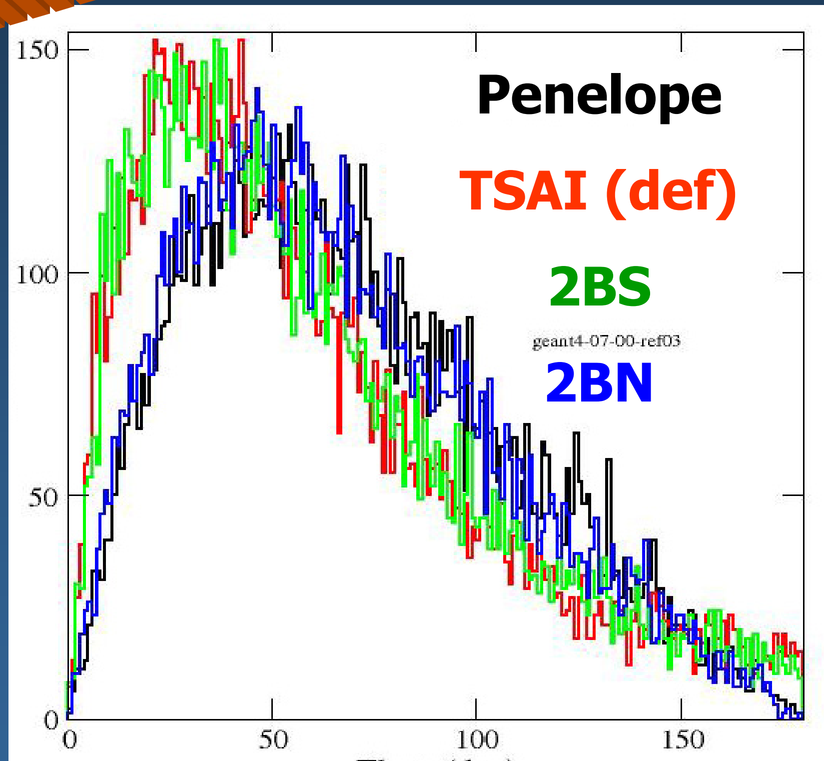
Notice: test of the **shape of dσ/dθdW**, not of the absolute value

Angular distributions

Preliminary



Angle (deg)



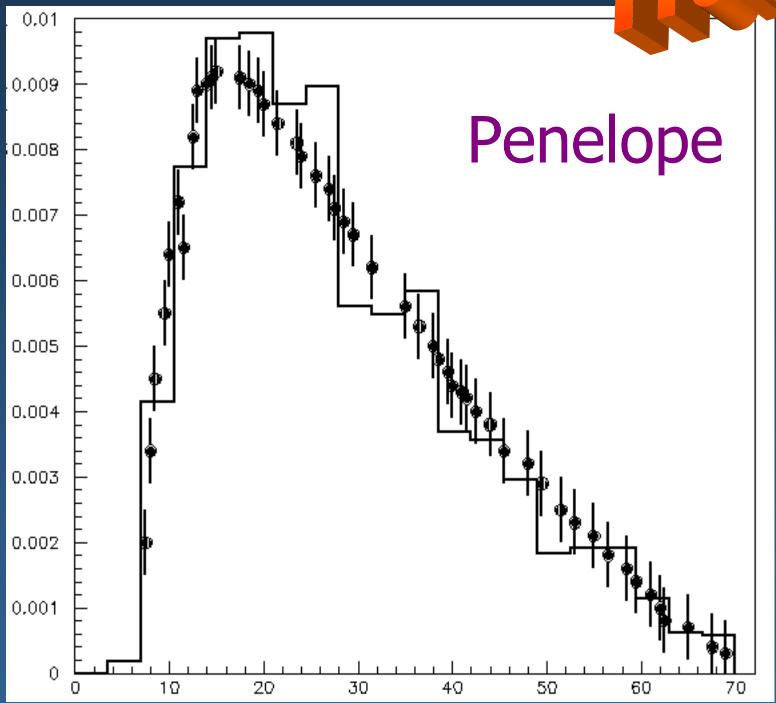
Angle (deg)

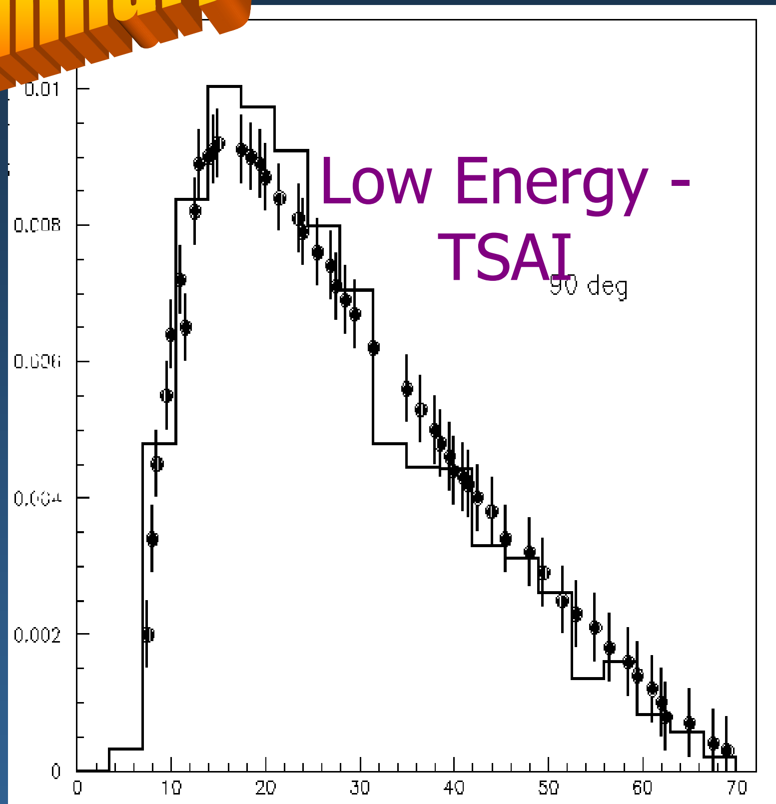
Angular distribution of photons is **strongly model-dependent**

Comparison

Preliminary

Intensity/Z (eV/sr keV)





Photon energy (keV)

Photon energy (keV)

Relative comparison (90 deg dir). The shapes ~**agree** →

More work in progress

Statistical analysis to be done

Advanced Examples

Document Geant4 application in real-life use cases

Collect and analyse requirements
Verify Geant4 capabilities to address experimental domains

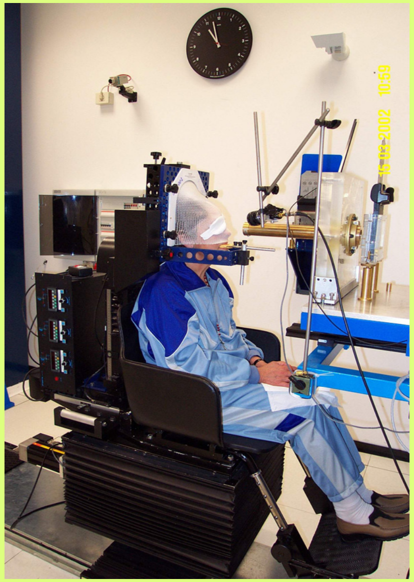
Goal:
Document **quantitatively** Geant4 **validation** for most Advanced Examples

Proton Bragg peak

Space Science

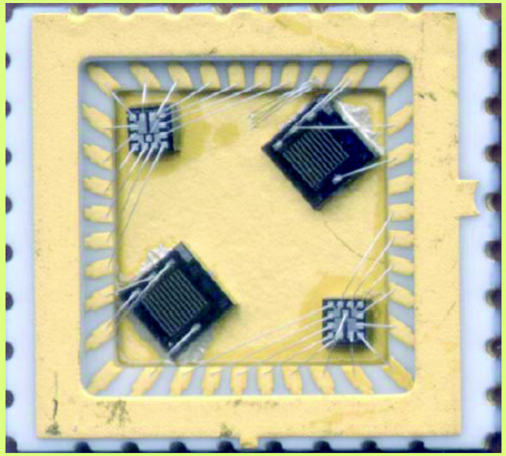
Astronauts' radiation protection

Medical Physics



Oncological radiotherapy

High Energy Physics



LHC Radiation Monitors

- Assess lowest energy range of hadronic interactions
  - pre-equilibrium + nuclear deexcitation

  to build further validation tests on solid ground
- Results directly relevant to various experimental use cases
  - see also talk on Simulation for LHC Radiation Background

Relevant Geant4 models

Electromagnetic

- Standard
- Low Energy – ICRU 49
- Low Energy – Ziegler 1977
- Low Energy – Ziegler 1985
- Low Energy – Ziegler 2000
- New “very low energy” models

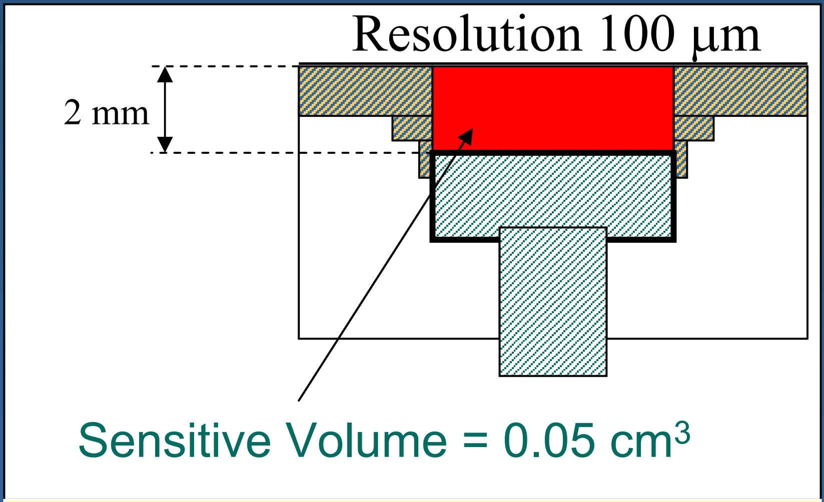
Hadronic

- Parameterized (à la GHEISHA)
- Nuclear Deexcitation
  - Default evaporation
  - GEM evaporation
  - Fermi break-up
- Pre-equilibrium
  - Precompound model
  - Bertini model
- Intra-nuclear cascade
  - Bertini cascade
  - Binary cascade
- Elastic scattering
  - Parameterized
  - Bertini

Experimental data

- CATANA hadrontherapy facility in Catania, Italy
  - high precision experimental data satisfying rigorous medical physics protocols
  - Geant4 Collaboration members

Markus Ionization chamber



Markus Chamber

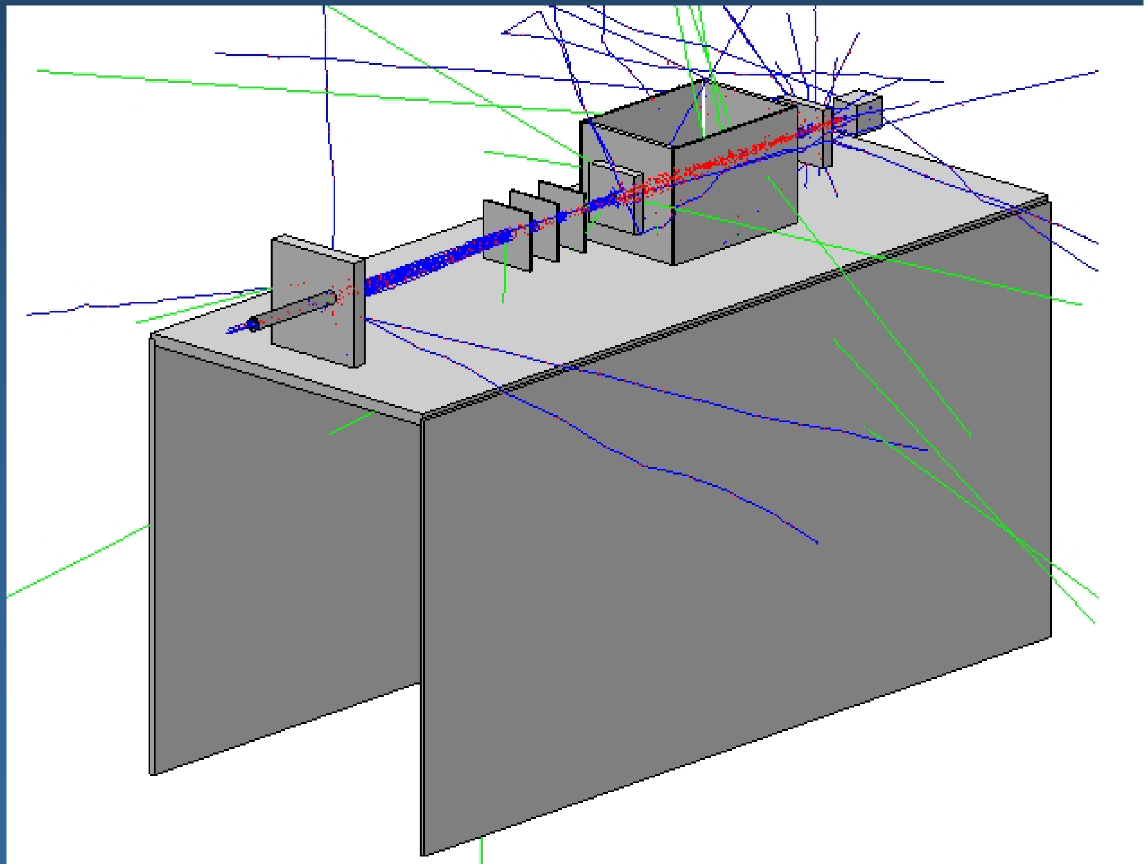
Geant4 test application

Accurate reproduction of the experimental set-up in the simulation

This is the most difficult part to achieve a ***quantitative*** *Geant4 physics validation*

Geometry and **beam** characteristics must be known in detail and with high precision

GEANT4 simulation

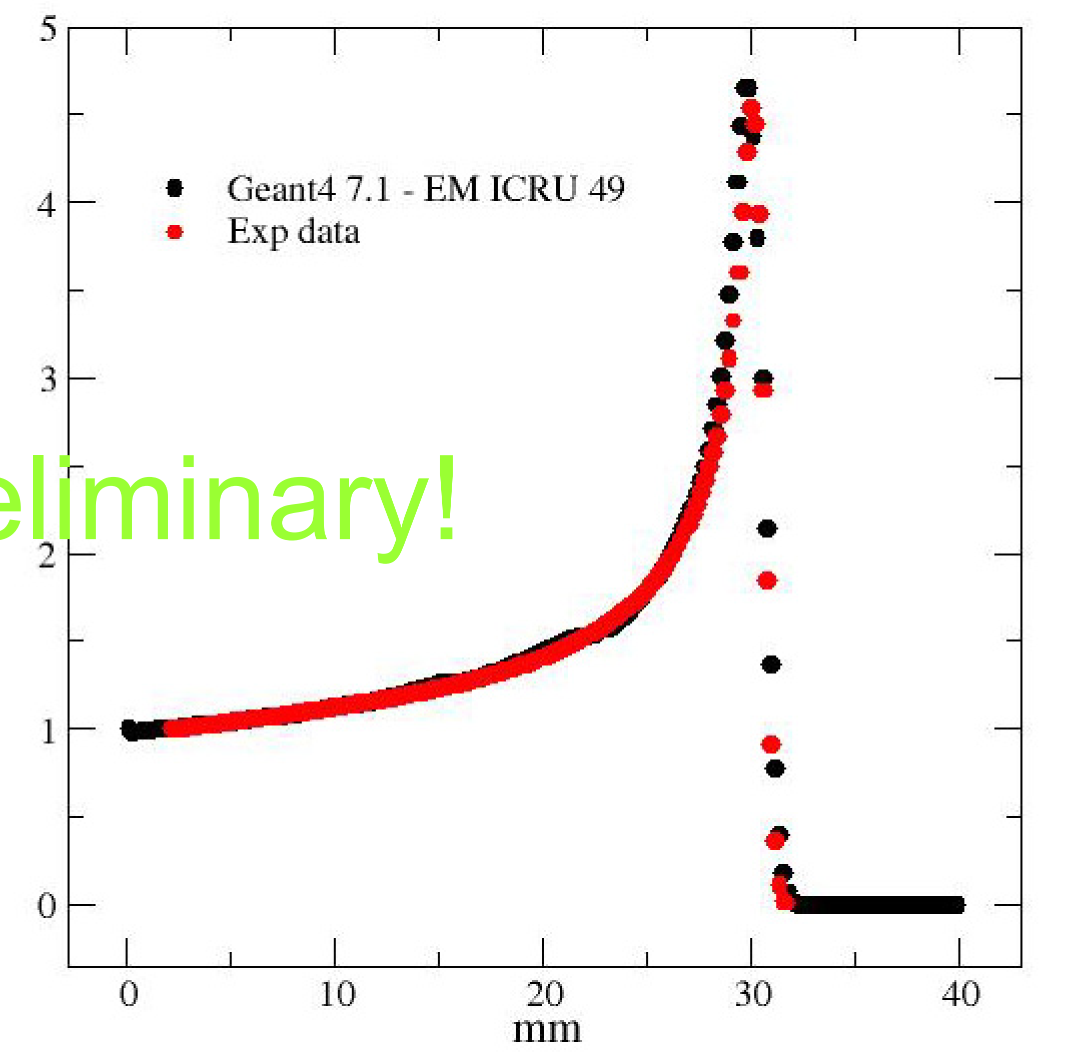


Geant4 *hadrontherapy*
Advanced Example

Maria Grazia Pia

EM – ICRU 49 + Elastic + Precompound + default Nuclear Deexcitation

ENTIRE PEAK	Exp	G4
S	2.89	3.39
T	3.26	3.46
GoF test	CVM-AD	



N_E=149 N_{G4}=150	Test statistics	p
KS	0.0368	0.999944
CVM	0.0131	0.999887
AD	0.0993	0.999974

Radiation monitoring at LHC

- The LHC experiments have considered as a major problem the effect of radiation on installed equipment from the outset
- Necessary to monitor radiation fields during early LHC commissioning to prepare for high intensity running and to prepare appropriate shielding or other measures
- A lot of interesting work is in progress to ensure that radiation effects do not make LHC commissioning even more difficult than expected

Critical issue

It is essential to have a radiation monitoring system adapted to the needs of radiation tolerance understanding from the first day of LHC operation

LHC Experiment Radiation Monitoring Working Group - Microsoft Internet Explorer provided by CERN

File Edit View Favorites Tools Help

Address http://lhc-expt-radmon.web.cern.ch/lhc-expt-radmon/

LHC Experiment Radiation Monitoring (RADMON)

Solid-State Radiation Sensor Group

Publications

Link to LHC Machine (RADWG)

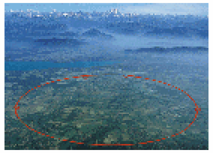
Link to Tevatron (CDF, D0)

Link to HERA (H1, HERMES, ZEUS)

Home

LHC Experiment Radiation Monitoring Working Group

RADMON



- Minutes of the Meetings and Presentations
- Joint Radiation Working Group (RADWG) & LHC Experiment Radiation Monitoring Working Group (RADMON) Workshop (04 December 2003)
- 4th RADWG-RADMON Radiation Workshop at CERN (01 December 2004)
- Sensor Catalogue (DATA COMPILATION OF SOLID-STATE SENSORS FOR RADIATION MONITORING)
- Meetings Related to RADMON Activities
- 5th LHC Radiation Workshop at CERN (29 November 2005) NEW

Last Meeting held on on Tuesday, 27 September 2005;

Next Meeting: not scheduled yet.

Solid State Radiation Sensor Group

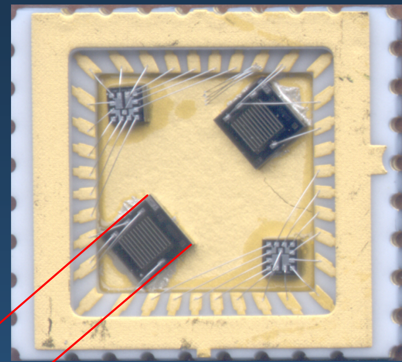
Evaluation of various radiation monitoring detectors

Optimisation → Experimental measurements + **Geant 4** simulation

RadFETs Packaging

The configuration of the packaging of the sensors can modify the chips response, inducing possible errors in the measurements

Commercial packaging cannot satisfy all the experiments requirements (size/materials) → Development & study in-house at CERN →



1.8 mm

~10 mm^2 36-pin Al_2O_3 chip carrier

- High Integration level:
  up to 10 devices covering from mGy to kGy dose range
- Customizable internal layout
- Standard external connectivity

Packaging under validation

- Type of materials
- Thickness
- Effects of lids

Geant 4

Calculated Radiation Transport Characteristics (0.4 mm Al_2O_3):

- $X = 3\text{-}4\ \%\ X_0$
- *e* cut-off ≅ 550 KeV
- *p* cut-off ≅ 10 MeV
- photons transmission ≥ 20 KeV
- *n* attenuation ≅ 2-3 %

Geant4 Radmon Simulation

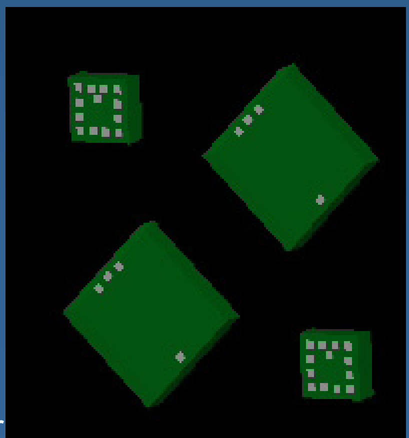
- A Geant4 application has been developed to study the effects of different packaging configurations
  - Collaboration between Radmon Team (CERN PH/DT2 + TS/LEA) and Geant4 Advanced Examples Working Group
- Main objectives:
  - A quantitative analysis of the energy cut-off introduced by the packaging as a function of particle type and energy
  - A quantitative analysis on how materials and thickness affect the cut-off thresholds
  - A quantitative analysis of the spectrum of particles (primaries and secondaries) hitting the dosimeter volume as a function of the incoming spectrum
- Rigorous software process
  - in support of the quality of the software results for a critical application
- Validation of the simulation
  - experimental data: p beam at PSI
  - experimental data: neutrons (Ljubljana), *in progress*

Released as Geant4 Advanced Example June 2006

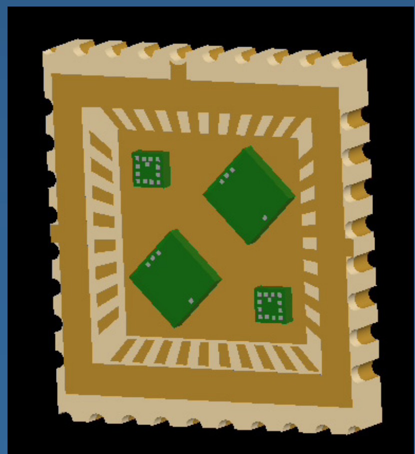
Study of packaging effects

- Experimental test
  - 254 MeV proton beam
  - various configurations: with/without packaging, different covers
  - dose in the 4 chips
- Simulation
  - same set-up as in the experimental test (for validation)
  - also predictive evaluations in other conditions

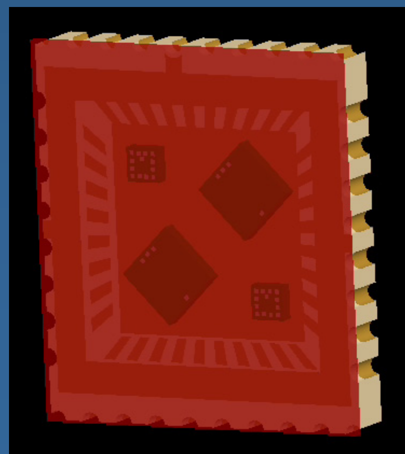
No packaging



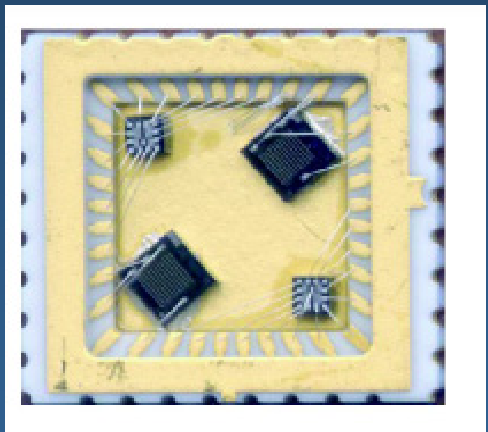
With packaging



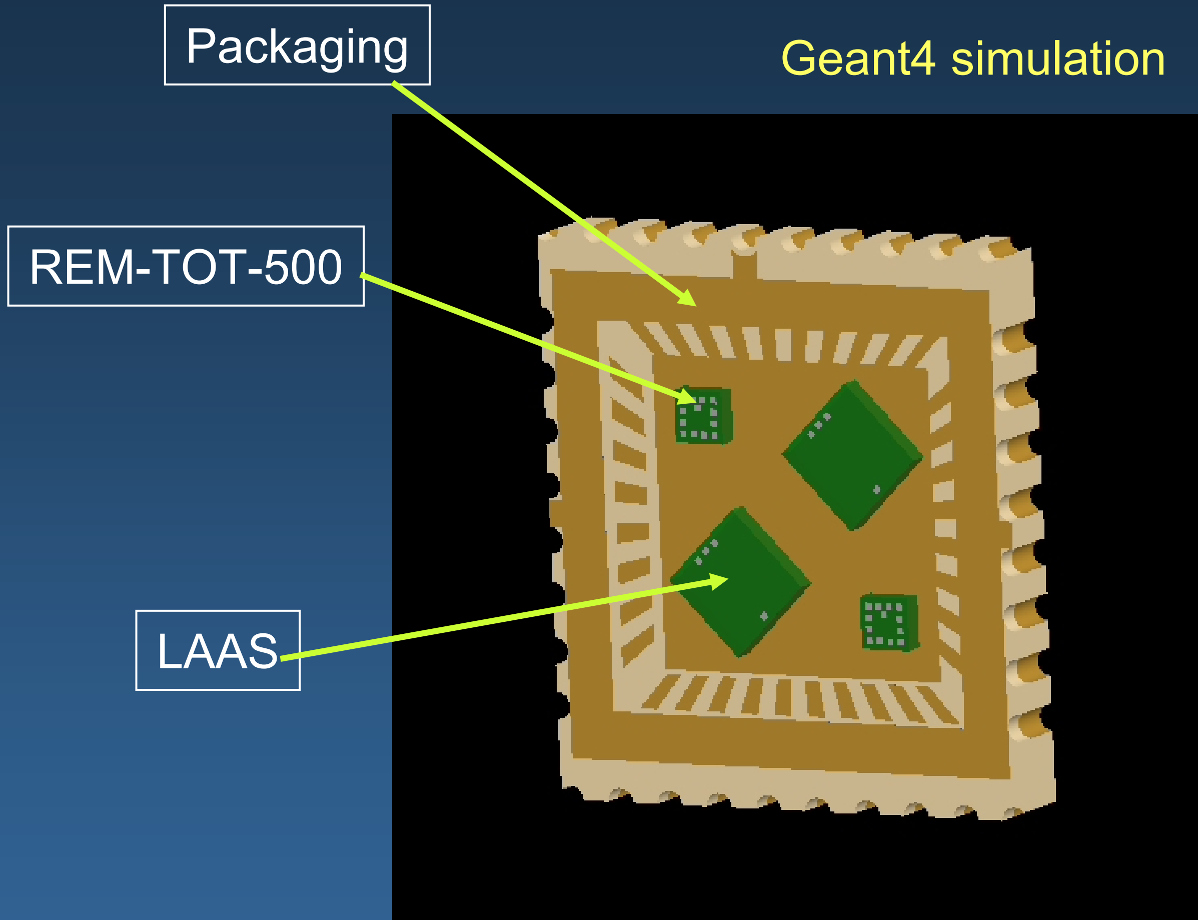
With a ceramic or FR4 lid



Geometry



Geant4 simulation



The full geometry has been designed and implemented in detail in the Geant4 simulation

Physics

Electromagnetic validation

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Hadronic validation

In progress

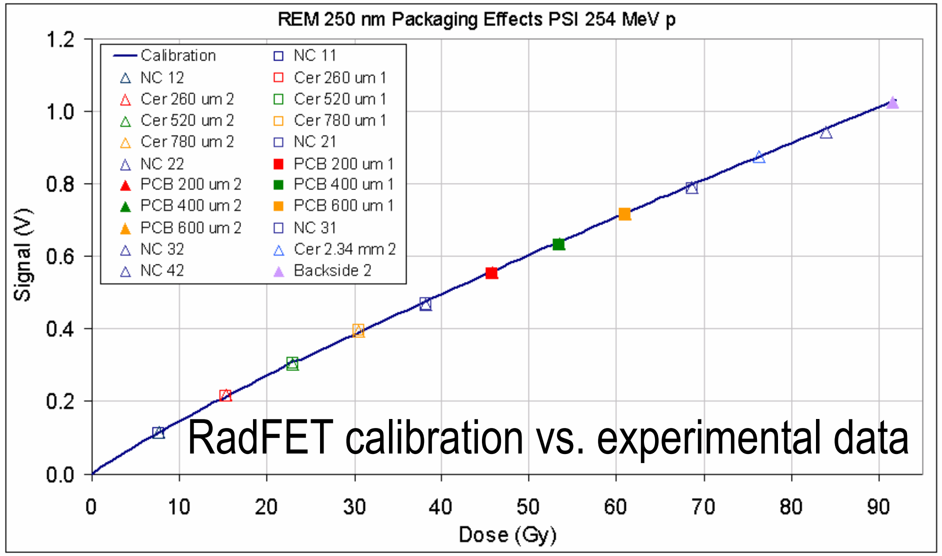
See "Systematic validation of Geant4 electromagnetic and hadronic models against proton data" at CHEP06

- Electromagnetic physics
  - Low Energy Livermore for electrons and photons processes
  - Standard model for positron processes
  - Low Energy ICRU 49 parameterisation for proton & ion ionisation
  - Multiple scattering for all charged particles
- e/γ nuclear physics
  - Electron Nuclear Reaction for electrons and positrons
  - Gamma Nuclear Reaction for photons
- Hadronic interactions
  - Neutrons, protons and pions:
    - Elastic scattering
    - Inelastic scattering
      - Nuclear de-excitation
      - Precompound model
      - Binary Cascade up to E = 10 GeV
      - LEP model between 8 GeV and 25 GeV
      - QGS Model between 20 GeV and 100 TeV
      - Neutron fission and capture
  - Alpha particles:
    - Elastic scattering
    - Inelastic scattering based on Tripathi, IonShen cross sections:
      - LEAlphaIneslatic model up to 25 GeV
      - BinaryIonModel between 80 MeV and 10 GeV
- Decay

The secondary production threshold is 1 μm

Experimental data

254 MeV proton beam incident on the sensors
Various material type and thickness, front/back
Measurement: dose



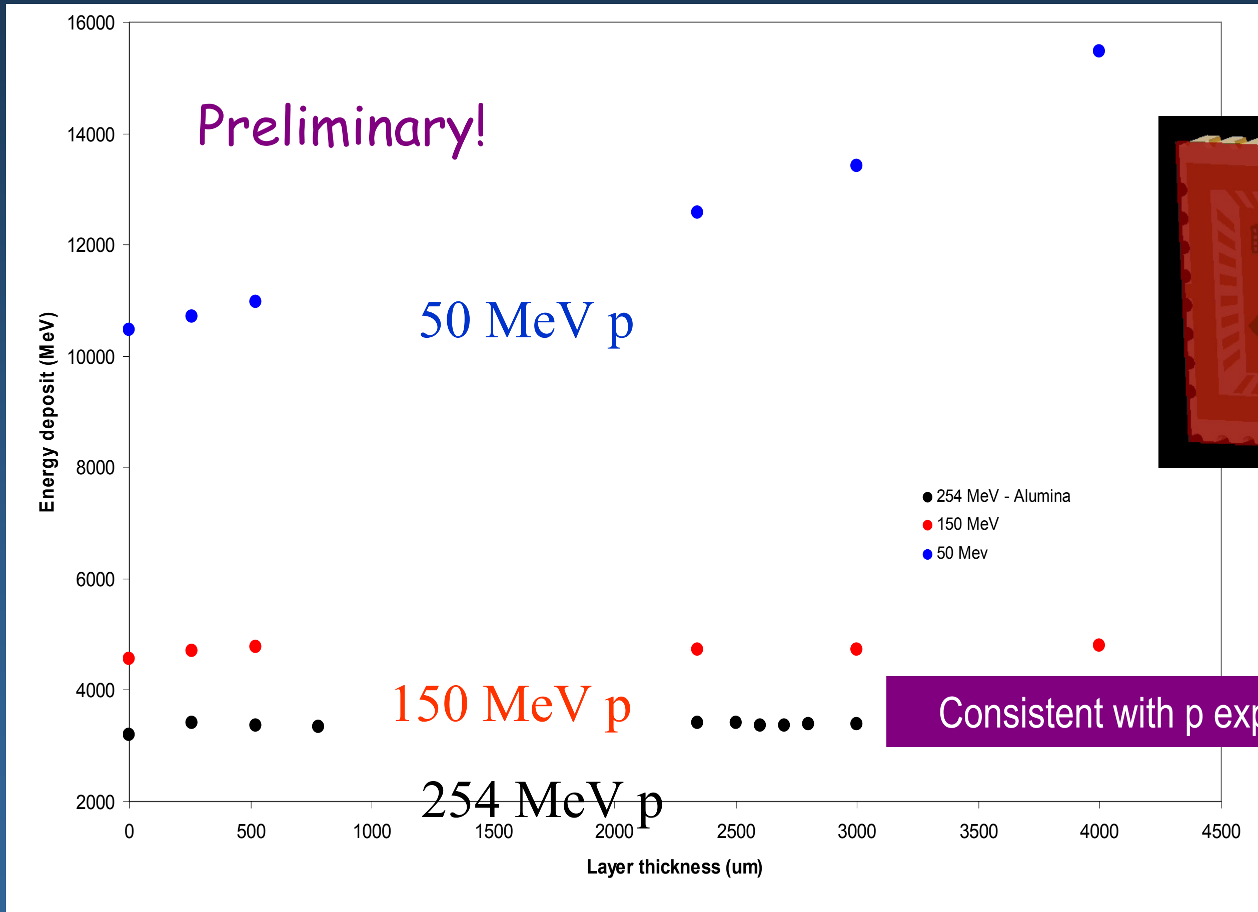
Results

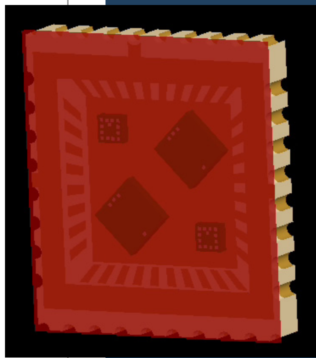
RUN	Fluence Step	Cumulated Fluence	Dose Step	Cumulated Dose	Irradiation Side	Material Type	Material Thickness
	p/cm^2	p/cm^2	Gy	Gy			um
run 10	1.51E+10	1.51E+10	7.665	7.67	Front	None	
run 11	1.50E+10	3.02E+10	7.632	15.30	Front	Al_2O_3	260
run 12	1.50E+10	4.52E+10	7.615	22.91	Front	Al_2O_3	520
run 13	1.50E+10	6.02E+10	7.629	30.54	Front	Al_2O_3	780
run 14	1.50E+10	7.52E+10	7.628	38.17	Front	None	
run 15	1.50E+10	9.03E+10	7.625	45.79	Front	FR4	200
run 16	1.51E+10	1.05E+11	7.636	53.43	Front	FR4	400
run 17	1.50E+10	1.20E+11	7.616	61.05	Front	FR4	600
run 18	1.50E+10	1.35E+11	7.63	68.68	Front	None	
run 19	1.51E+10	1.50E+11	7.657	76.33	Front	Al_2O_3	2340
run 20	1.51E+10	1.66E+11	7.647	83.98	Front	None	
run 21	1.50E+10	1.81E+11	7.615	91.60	Back	None	

No significant effects observed with different packaging

Summary of the simulation results

Packaging + ceramic front cover





Consistent with p experimental data

In progress: study of neutron data - 1st step: understand photon contamination in experimental data

Conclusion

- A systematic, rigorous validation of Geant4 physics is in progress
  - Basic physics ingredients of Geant4 models
  - Experimental use cases (Advanced Examples)

- ALL physics models pertinent to a domain
- Quantitative statistical analysis to measure "how good" Geant4 is with respect to reference data

- Main problems
  - Find reliable data
  - Get support for the activity in the Geant4 Collaboration
  - Fund the young Geant4 collaborators doing a large fraction of the work

- Conference presentations
- Publications

http://www.ge.infn.it/geant4