Geant 4

Simulation for LHC Radiation Background

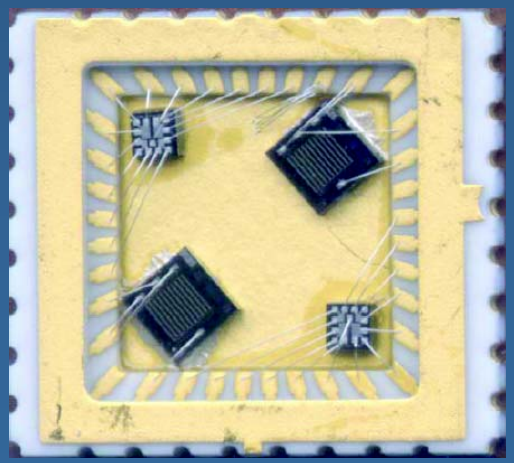
Optimisation of monitoring detectors and experimental validation

M. Begalli[1], S. Fonseca[1], M. Glaser[2], S. Guatelli[3], B. Mascialino[3], M. Moll[2], M.G. Pia[3], F. Ravotti[2]

[1]Universidade do Estado do Rio de Janeiro, Brazil

[2]CERN, Geneva, Switzerland

[3]INFN Genova, Italy



IPRD 06
10th Topical Seminar
on Innovative Particle and Radiation Detectors
1 - 5 October, 2006
Siena, Italy

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

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

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

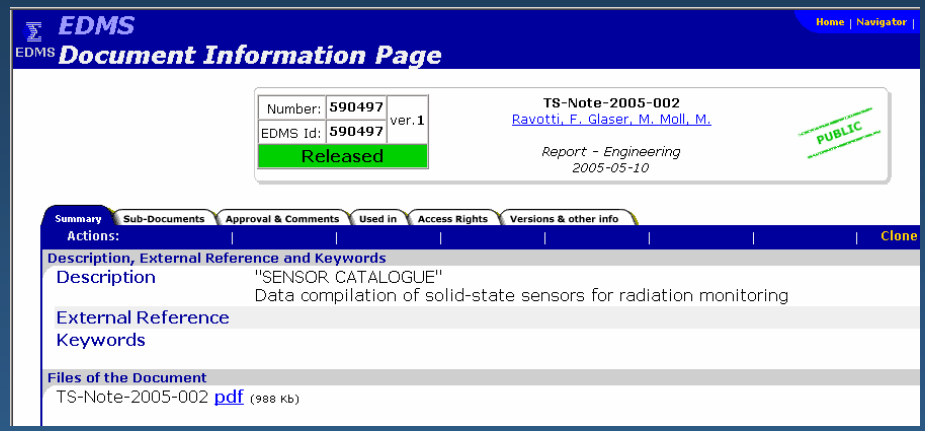
Evaluation of various radiation monitoring detectors

Optimisation ⇒ Experimental measurements + Geant 4 simulation

Sensor Catalogue
(www.cern.ch/lhc-expt-radmon/)

Specifies sensors suitable for dosimetry in the LHC experiments environment

- Mixed-LET radiation field
- ~5 orders of magnitude in intensity
- Many devices tested, only a few selected



2 x RadFETs (TID)	[REM, UK and LAAS, France]
2 x *p-i-n* diodes (1-MeV Φ_{eq})	[CMRP, AU and OSRAM BPW34]
1 x Silicon detectors (1-MeV Φ_{eq})	[CERN RD-50 Mask]

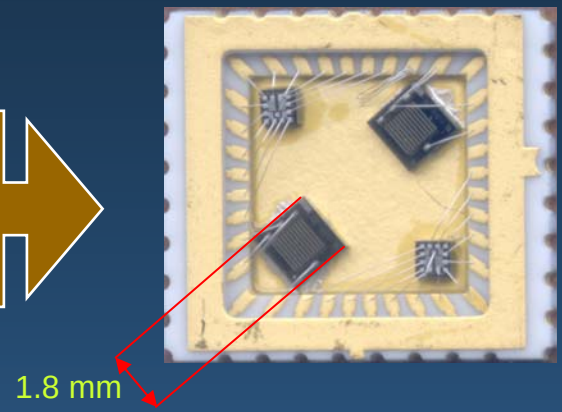
Further devices under investigation, on-going activity

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



~10 mm² 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

Radiation Transport Characteristics (0.4 mm Al_2O_3):

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

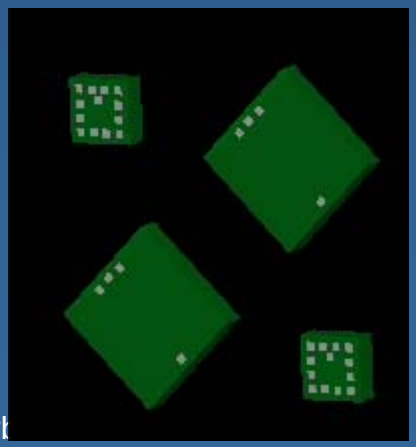
Geant4 Radmon Simulation

- 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, Villigen, Switzerland
  - experimental data: neutrons (Ljubljana TRIGA reactor), *in progress*

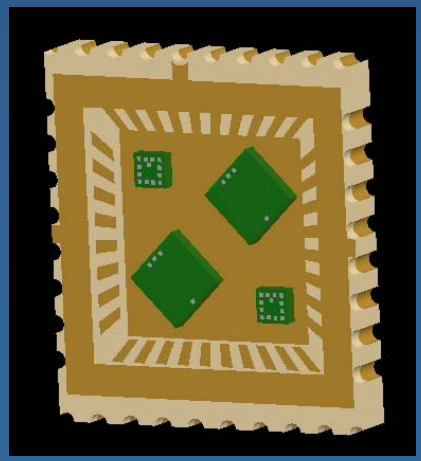
Study of packaging effects

- 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

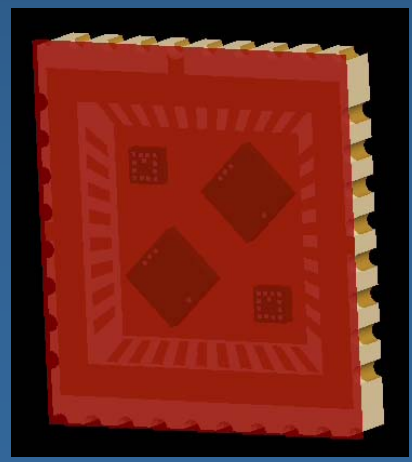
No packaging



With packaging



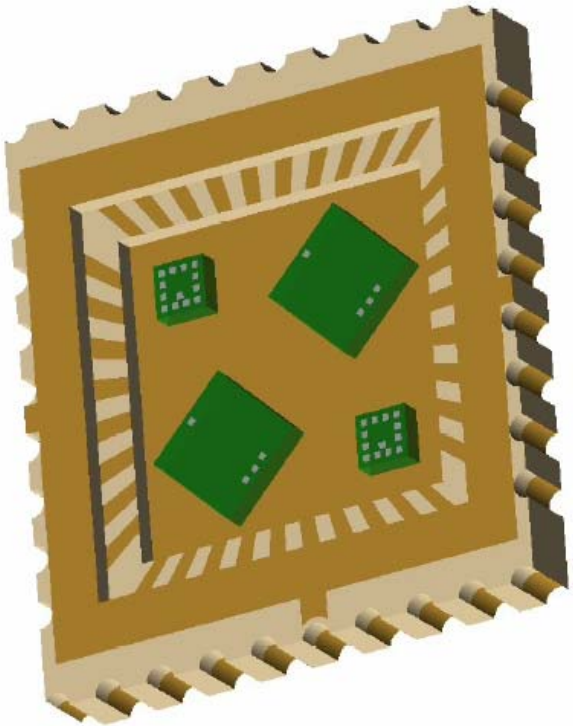
With a ceramic or FR4 lid



Part Dimensions
36 pin square Ceramic Chip Carrier
MIL-STD-105 D

Part bounding (Model 0)

01-C1-D3-K	19-C3-D3-K
02-C1-S2-K	20-C3-S2-K
03-C1-G2-K	21-C3-G2-K



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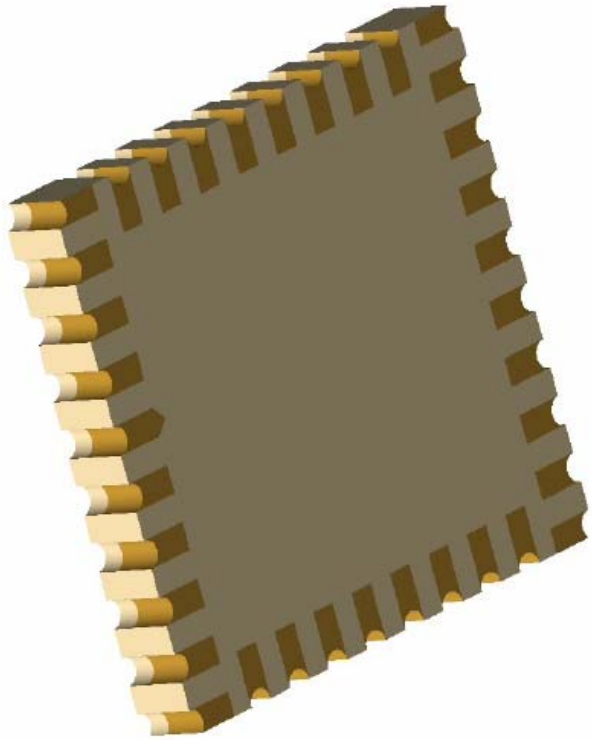
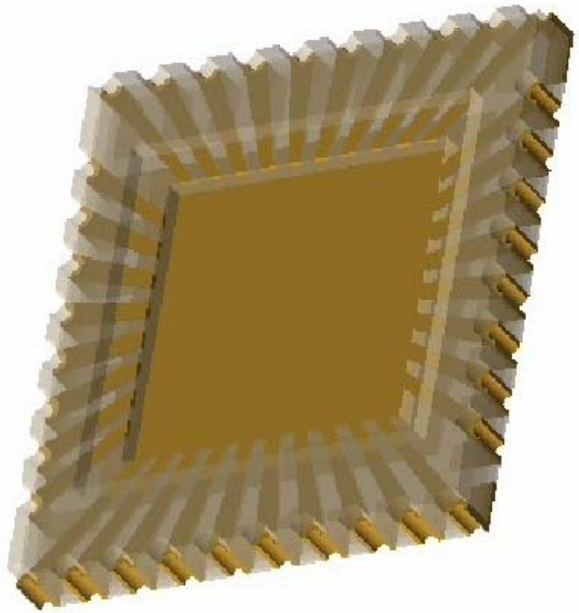
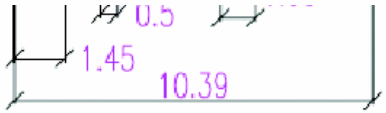




7.11

0.45



ENS/ASS
S.ENS/S.ASS
Chip carrier for REM-LAAS MOSFET dosimeters
ECHELLE SCALE 10:1
RADMON
36LD Chip Carrier
NOM/NAME | DATE
DES/DRA. M.Glaser 17/06/2005
CONTROL.
APPRO.
PH-DT2-SD
REMPLACE/REPLACES 30/05/2005
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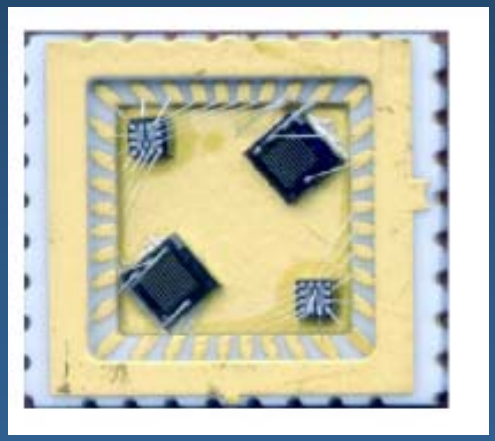
Geometry

- Geant4 offers advanced functionalities to model the geometry

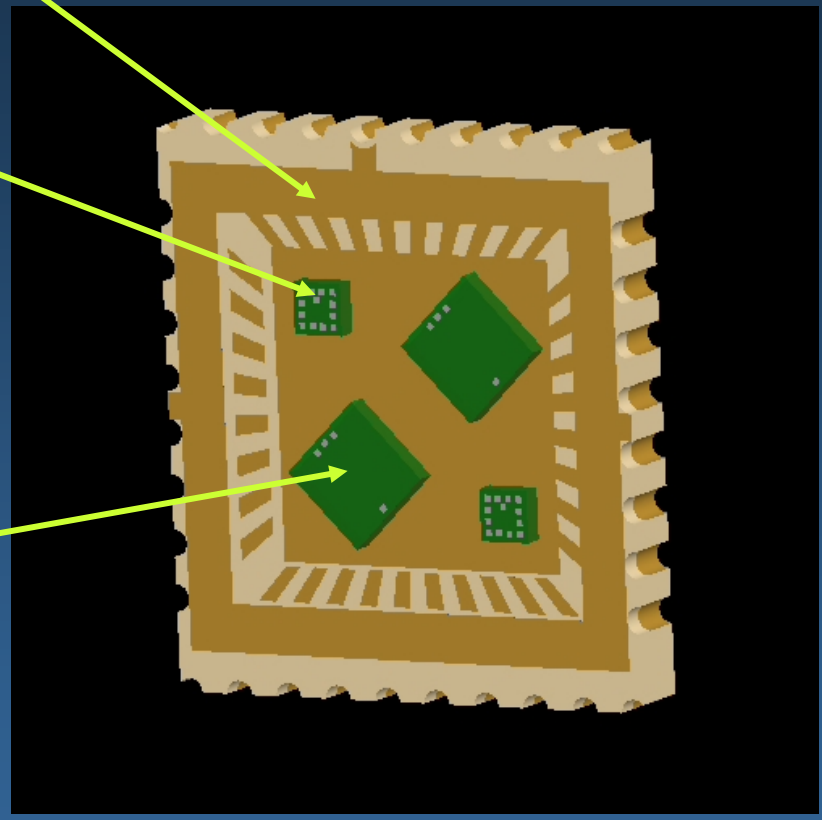


Packaging

REM-TOT-500

LAAS

Geant4 simulation



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

Physics

Electromagnetic validation

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, 910-918

Hadronic validation

In progress

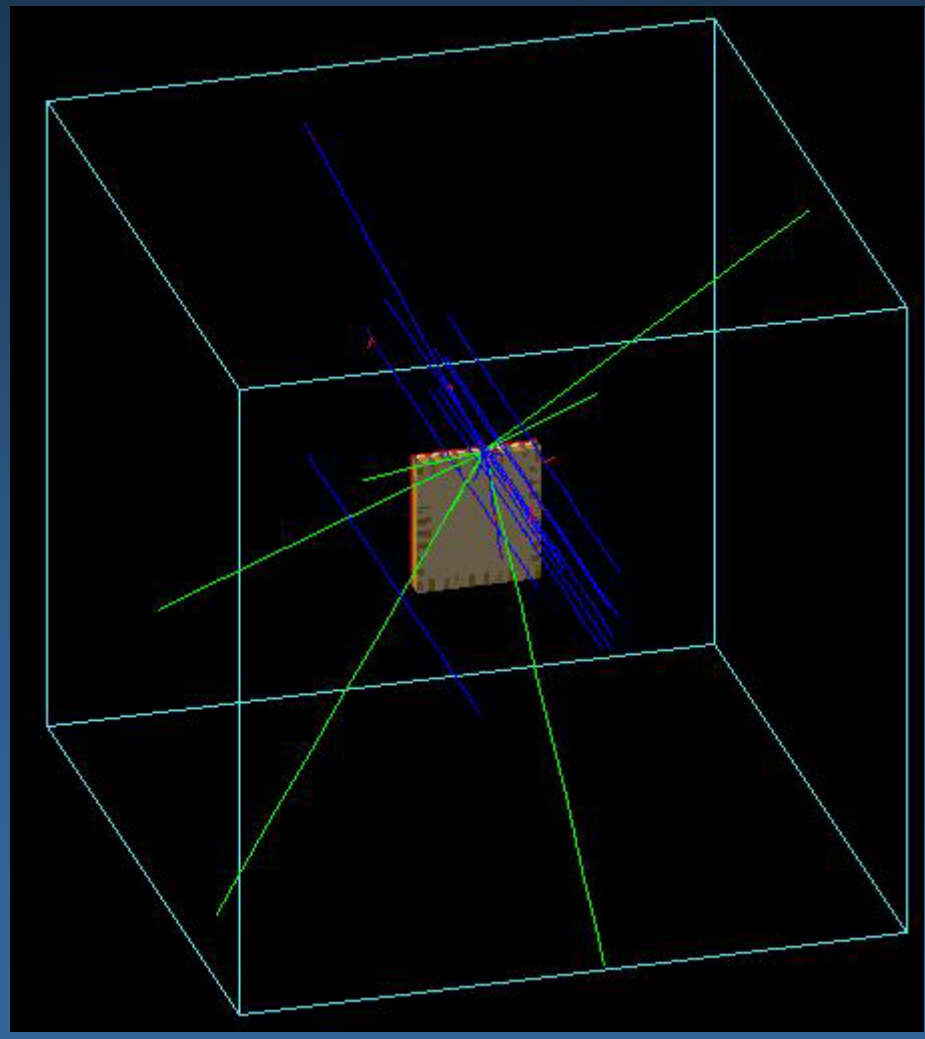
See "Systematic validation of Geant4 electromagnetic and hadronic models against proton data" at CHEP06

- 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

Primary particle generator

- Monocromatic protons beams
  - 254 MeV (experimental)
  - 150 MeV
  - 50 MeV
- Protons are generated randomly on a surface of 1.2 cm x 1.2 cm



Geometrical acceptance ≅ 7%

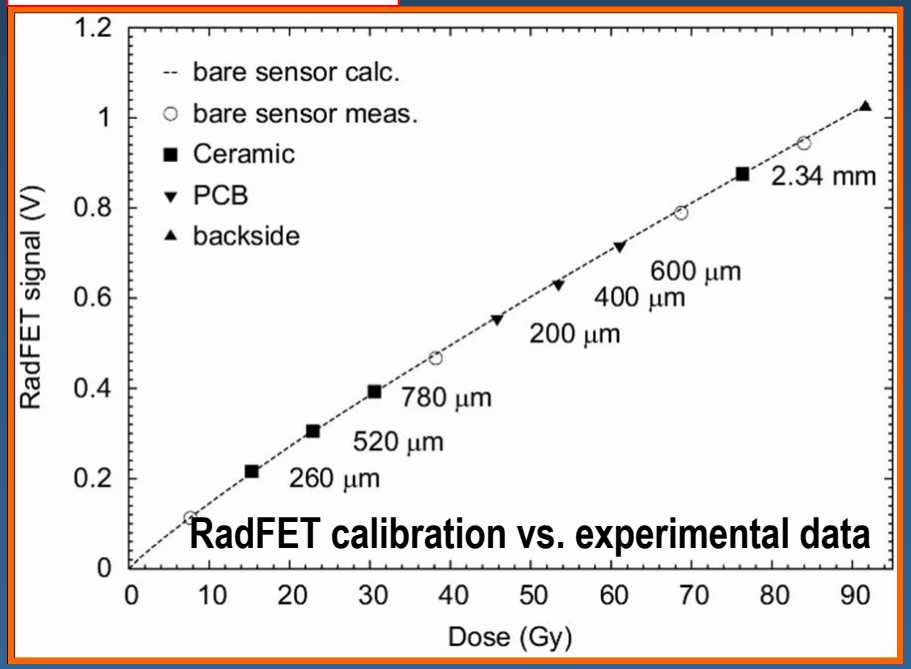
fraction of primary particles hitting the sensors

254 MeV protons at PIF facility (PSI)

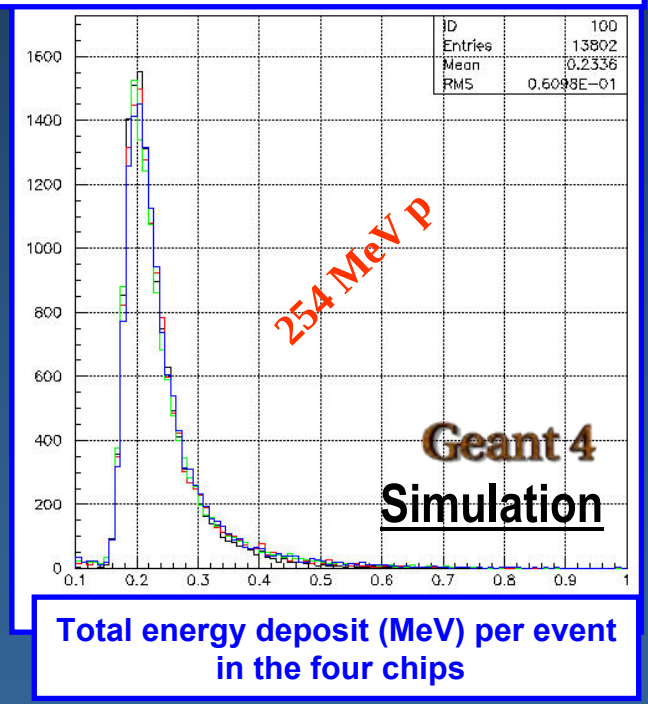
254 MeV proton beam incident on the sensors
Various material type and thickness, front/back
Measurement: dose

Front incident p – No packaging
Front incident p - Packaging + 520 μm Alumina
Front incident p - Packaging + 780 μm Alumina
Front incident p - Packaging + 2340 μm Alumina

Experimental data



Comparison



Total energy deposit (MeV) per event in the four chips

No significant effects observed with different packaging

Geant4 simulation in agreement with experimental data

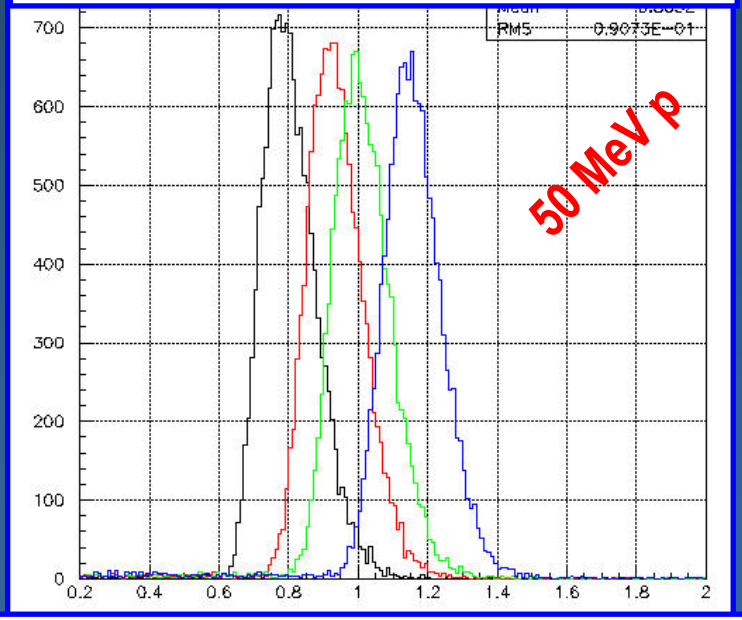
Complementary validation studies

- Validation of the proton Bragg peak
  - Reference data from CATANA (INFN-LNS Hadrontherapy Group)
  - Systematic and quantitative validation of Geant4 electromagnetic and hadronic physics
- Systematic validation of Geant4 electromagnetic physics
  - *Amako, S. Guatelli, V. Ivanchenko, M. Maire, B. Mascialino, K. Murakami, L. Pandola, S. Parlati, M. G. Pia, M. Piergentili, T. Sasaki, L. Urban*, "Validation of Geant4 electromagnetic physics versus the NIST databases", IEEE Transactions on Nuclear Science, vol. 52 (4), 2005, pp. 910-918
- And others in progress

Effects predicted at various proton energies

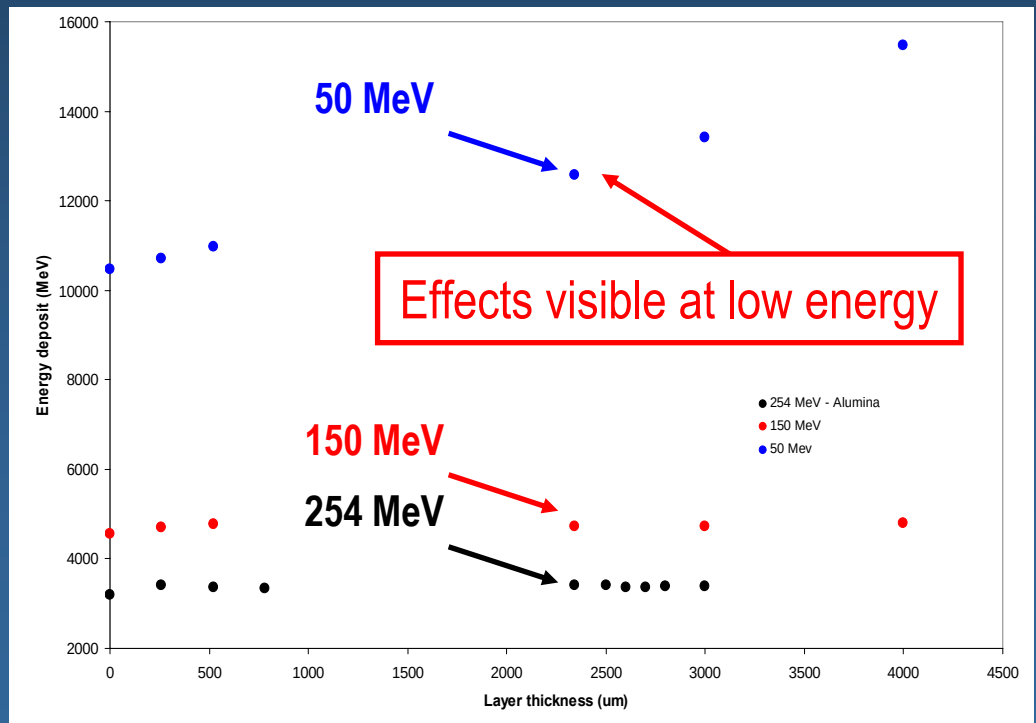
- Predictive power of the simulation to investigate the effects of the packaging for different proton beams
- Study the effect for 50 MeV, 150 MeV proton beams
- Study of the effect of the front lid

Front incident p - Packaging + 520 μm Alumina
Front incident p - Packaging + 2340 μm Alumina
Front incident p - Packaging + 3000 μm Alumina
Front incident p - Packaging + 4000 μm Alumina



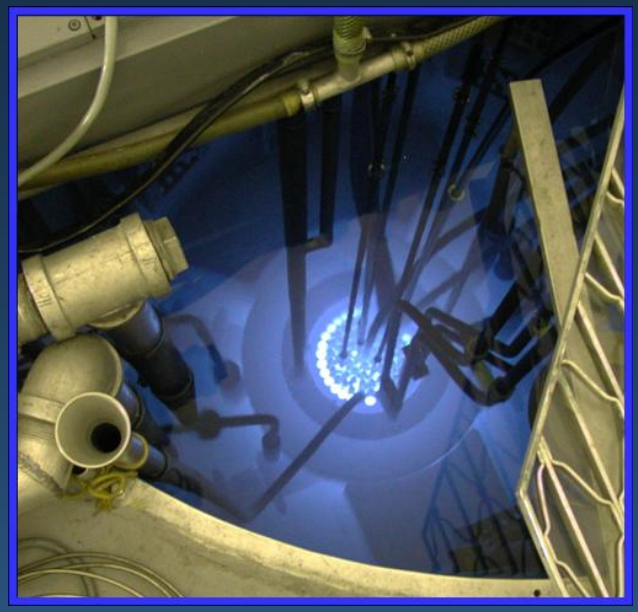
Total energy deposit (MeV) per event in the four chips

Total energy deposit (MeV) in the four chips

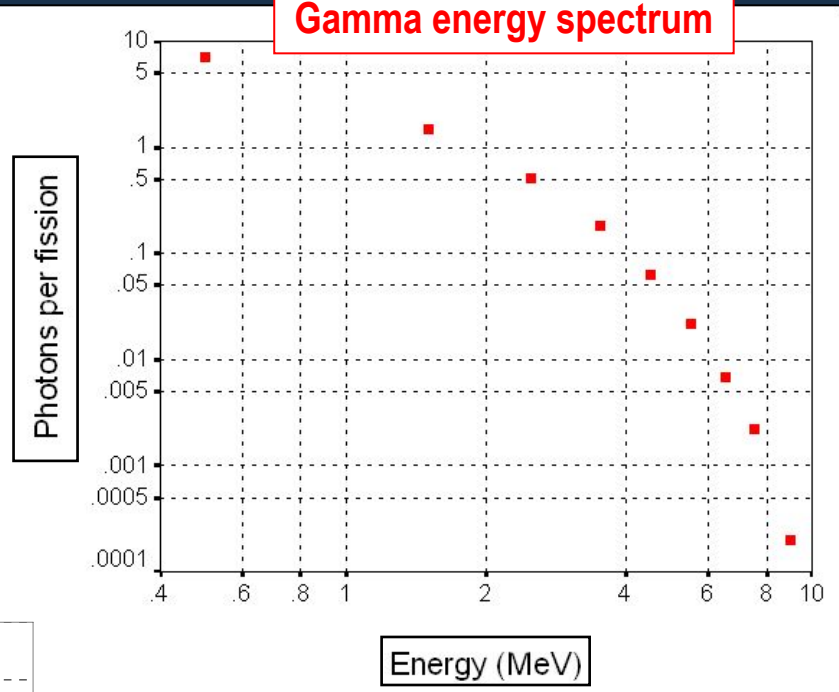


Al2O3 thickness in front of the packaging (μm)

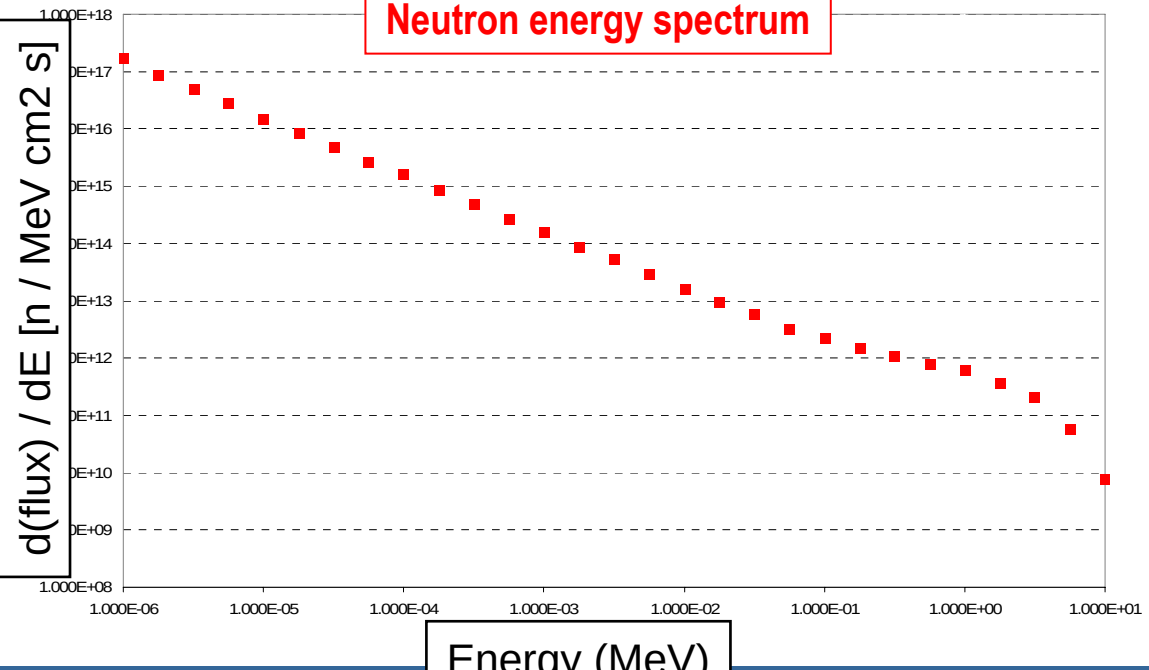
TRIGA neutron reactor facility at JSI



Gamma energy spectrum

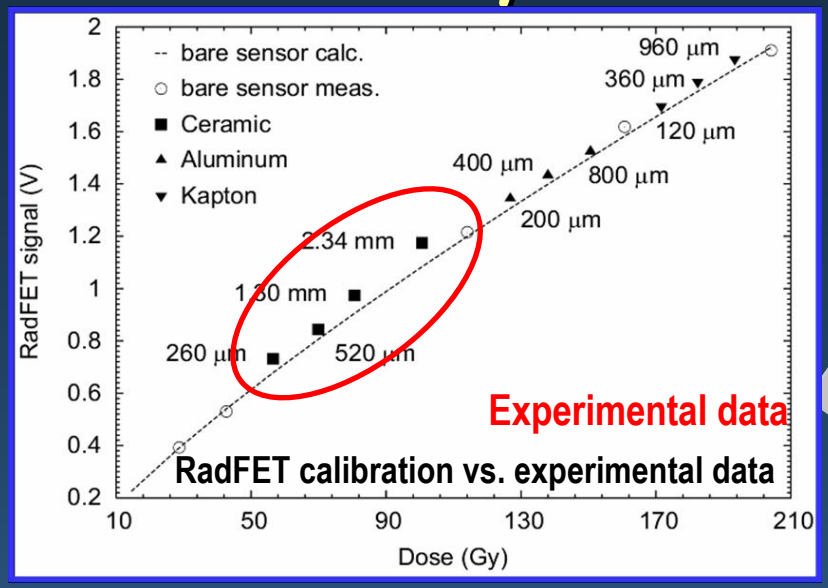


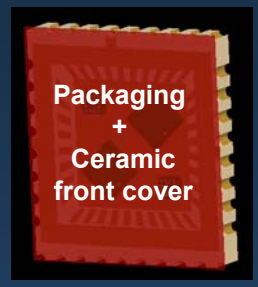
Neutron energy spectrum



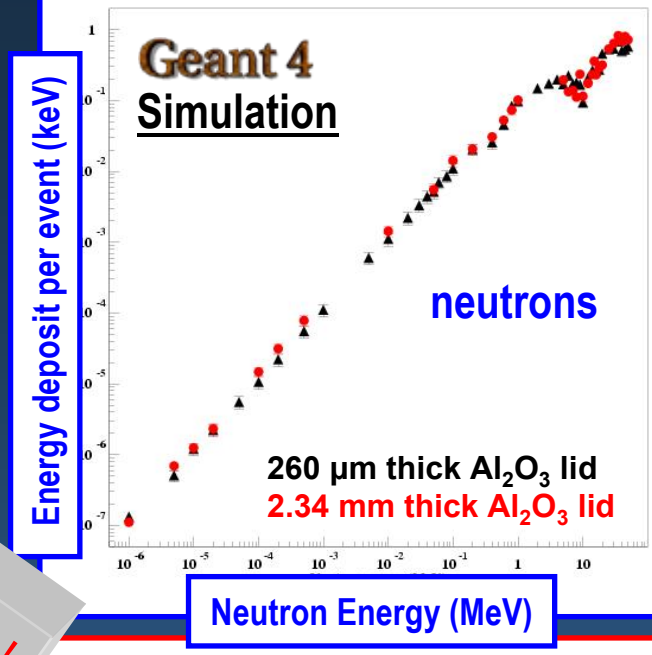
- Study the RadFET response to neutrons
- Study the contamination from photons in the JSI test data
- Comparison between experimental data and Geant4 simulation

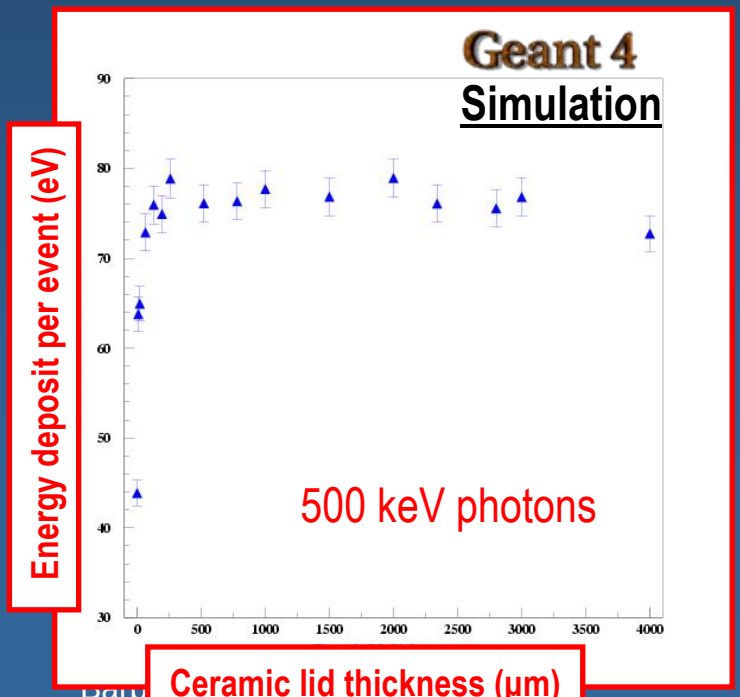
Preliminary results



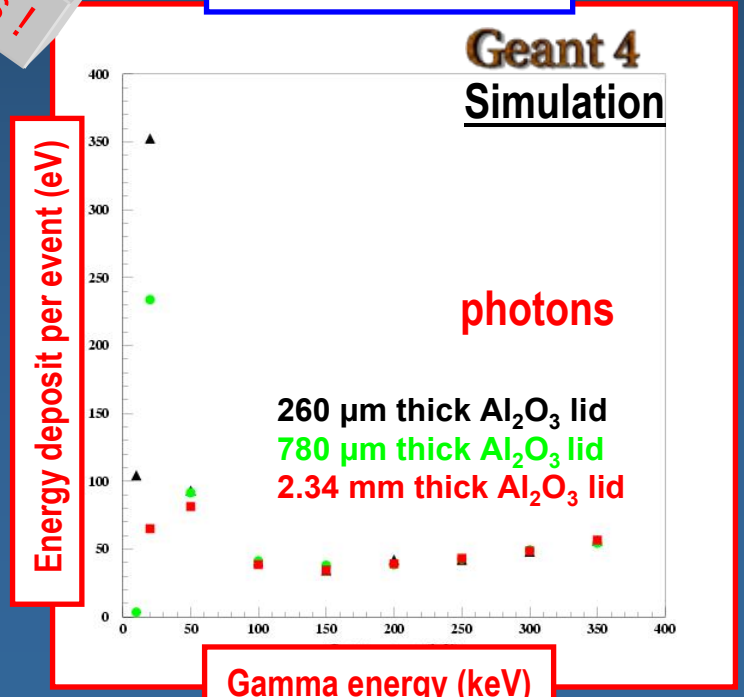


Work in progress !





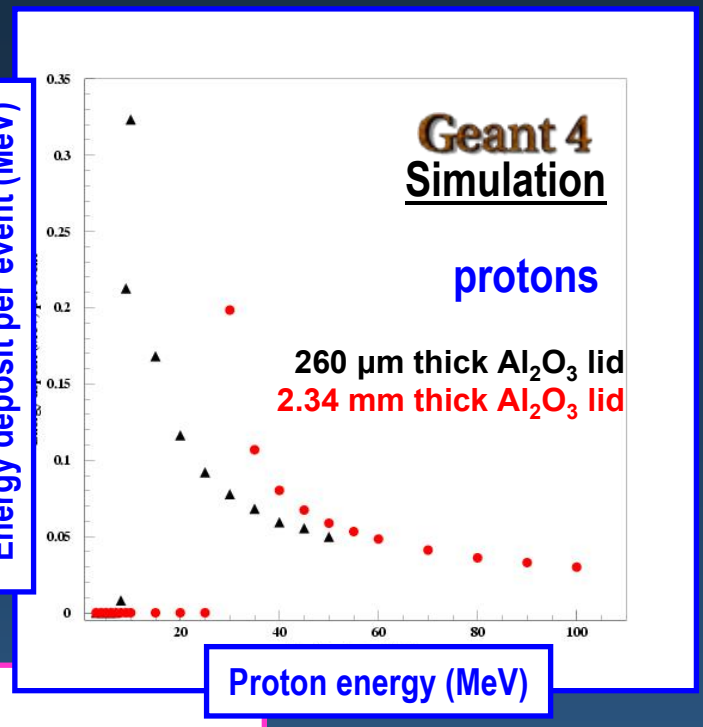
- Configuration
  - Study of the effect of the front lid
- Rigorous quantitative analysis is needed

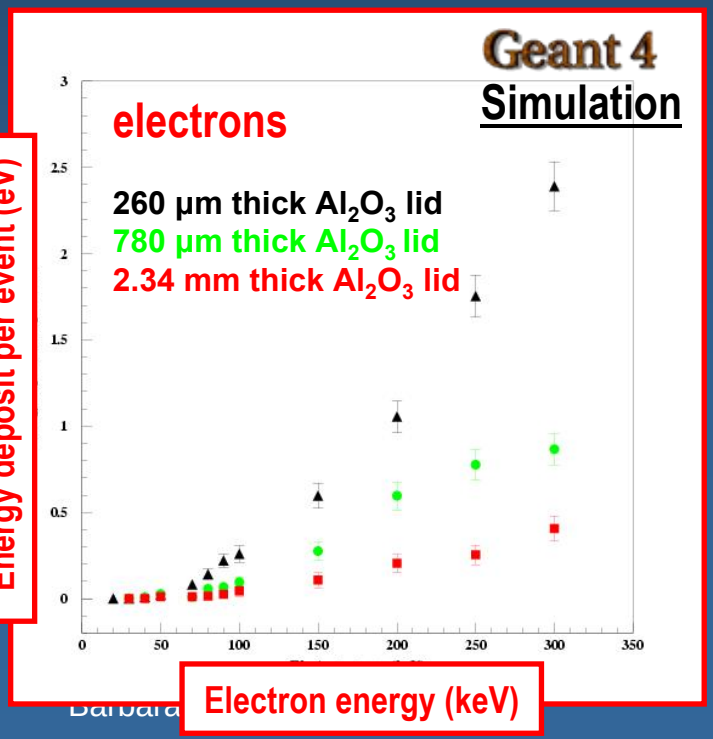


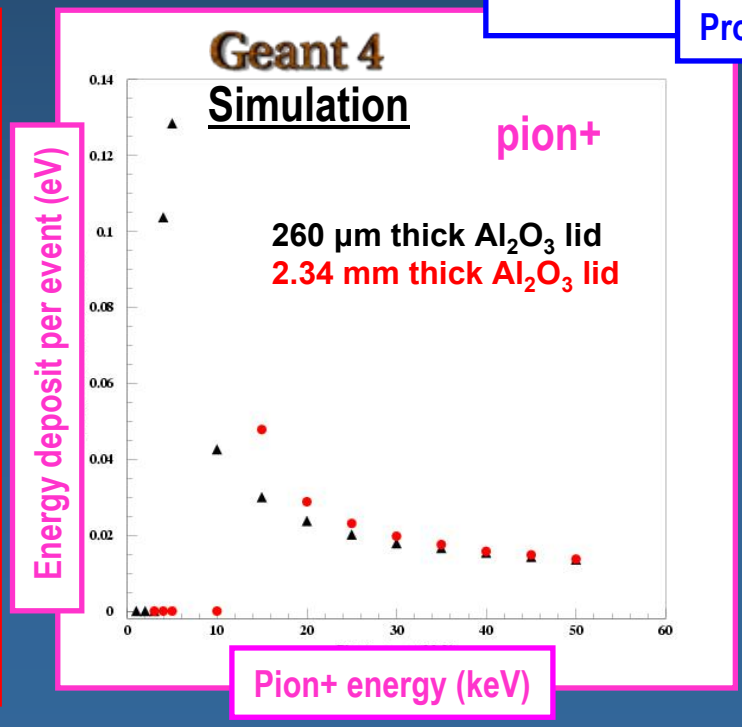
Thresholds for radiation background detection

Work in progress !

- Configuration:
  - Study of the effect of the front lid
  - Other particles







Conclusion

- Radiation monitoring is a crucial task for LHC commissioning and operation
- Optimisation of radiation monitor sensors in progress
  - packaging is an essential feature to be finalized
- Geant4 simulation for the study and optimisation of radiation monitor packaging
  - rigorous software process
  - full geometry implemented in detail
  - physics selection based on sound validation arguments
  - direct experimental validation against test beam data
- First results: proton data
  - packaging configurations: materials, thicknesses
  - no measured effects, simulation in agreement with experimental data
  - predictive power of the simulations: effects visible at low energy
- Work in progress: neutron data
  - first results available, further in depth studies to verify experimental effects
- Evaluation of particle detection thresholds
  - Predictive power of the reliable validated Geant4 simulation tool