



**Low-energy EM group :**  
**validation of low energy EM models**

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**Geant Low Energy EM Physics working group**

**19-20 January 2009**  
**CERN**



# Content

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- Recent validation results
- Future strategy



# Summary of recent validation results

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- Validation of **ionisation cross sections** for PIXE with protons and alphas (K and Li atomic sub-shells)
- Validation of **Geant4-DNA** processes
- Validation for **therapeutic** applications
  - e-/photons
  - hadrons

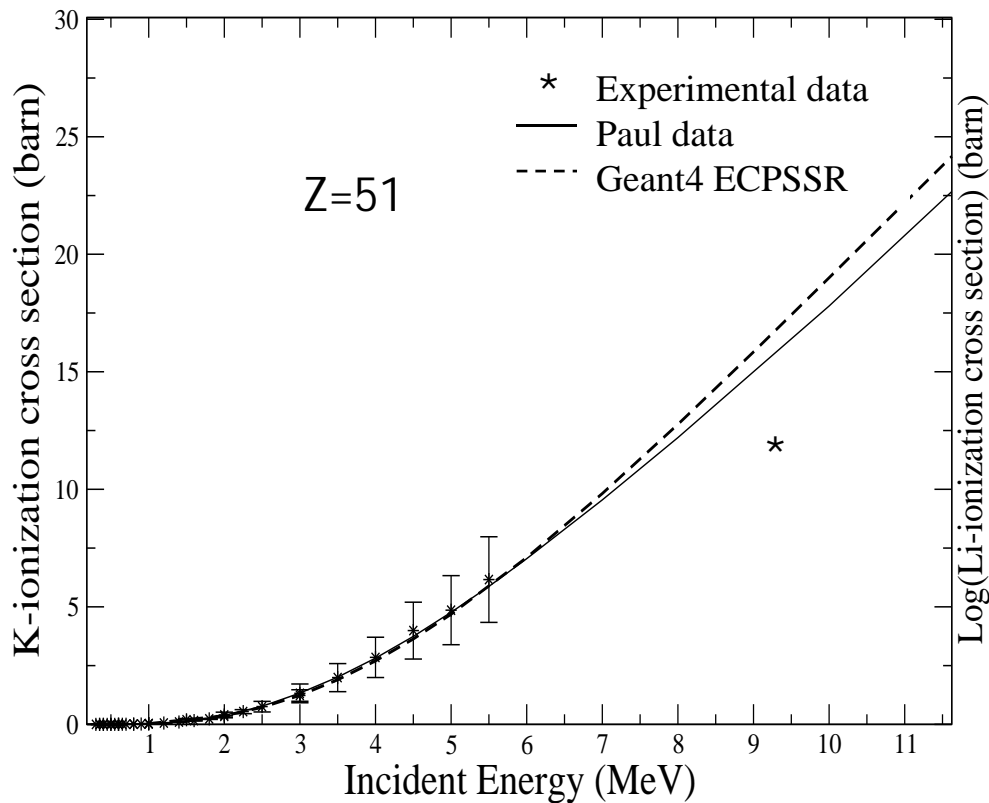


# New PIXE models

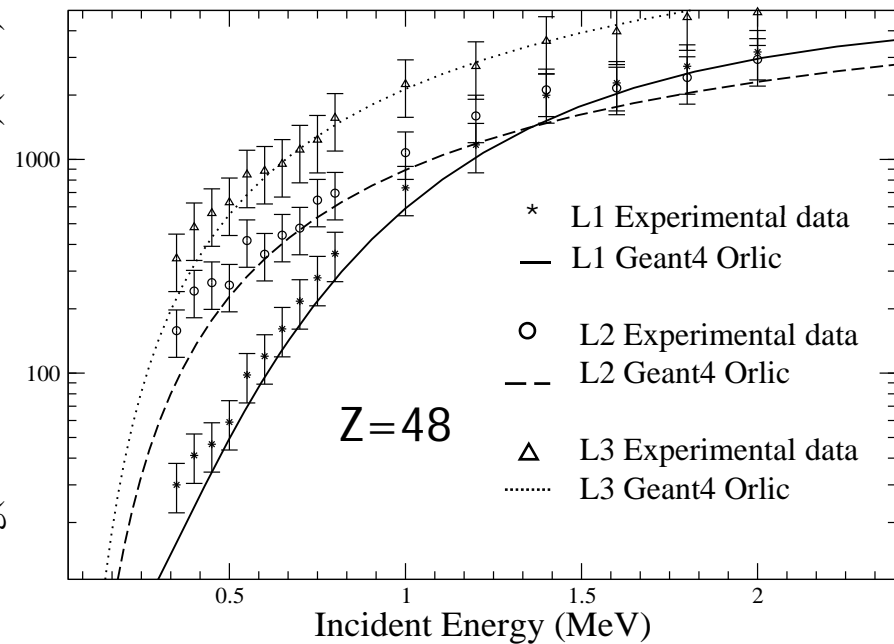
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# Comparison with experiment

K-shell ionisation cross sections :  
G4ECPSSRCrossSection VS Paul data  
fitting VS experimental data



Li-subshell ionisation cross sections :  
G4OrlicCrossSection VS recent  
tabulated experimental data (1994)

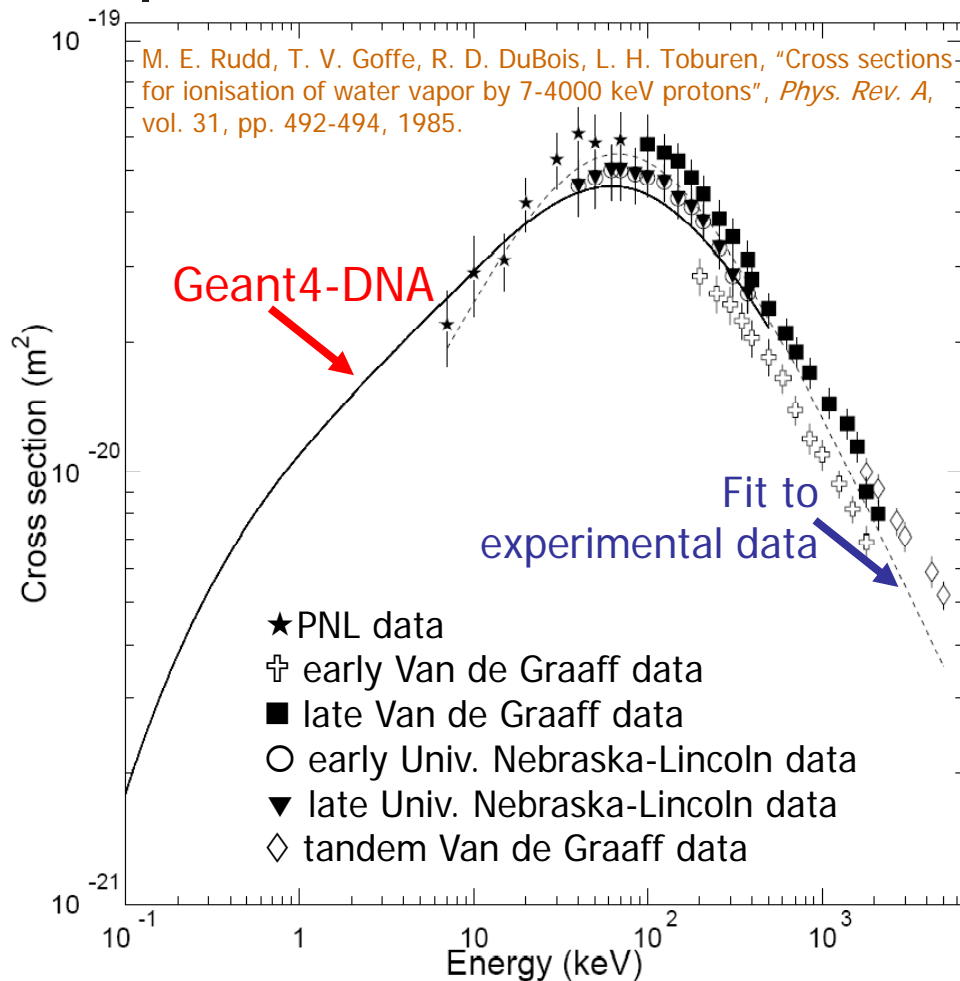




# The Geant4 DNA project

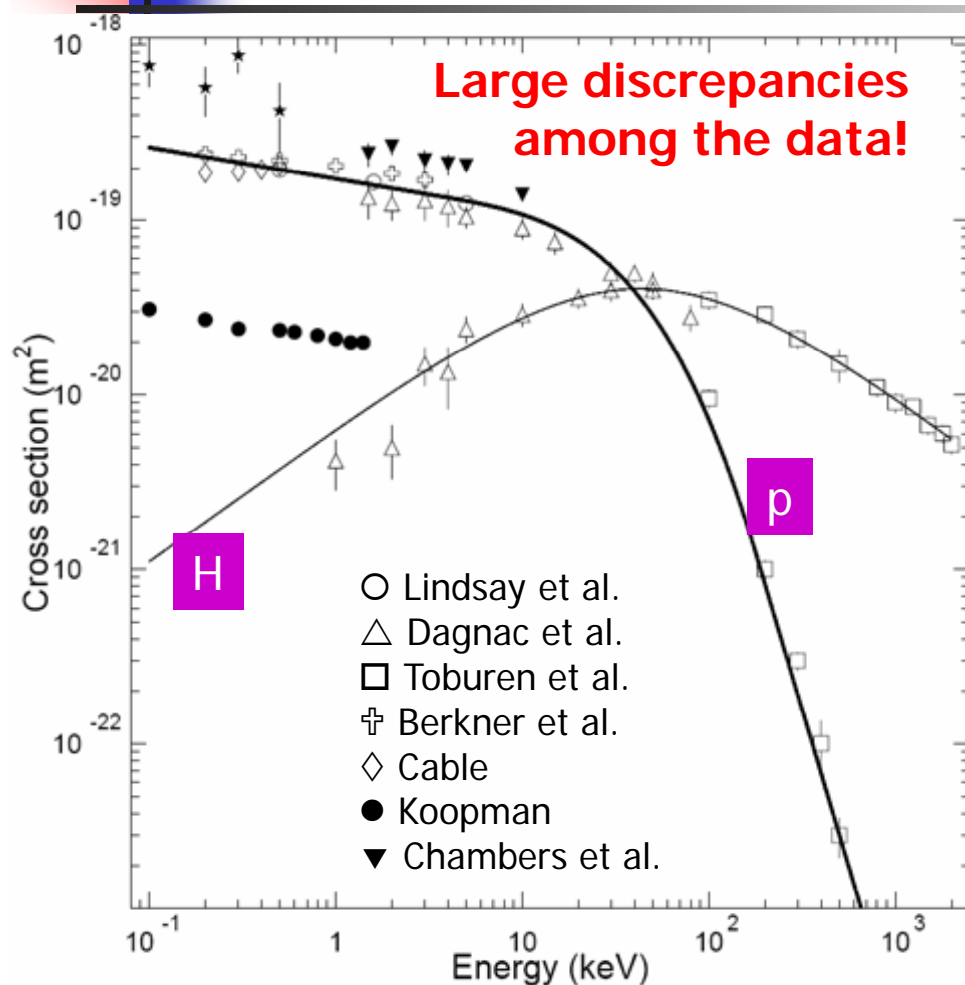
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# Proton ionisation: total cross section



- Cross section based on two complementary models
  - a semi-empirical analytical approach for  $100 \text{ eV} < E < 500 \text{ keV}$  with parameters specifically calculated for liquid water
  - a model based on the Born theory for  $500 \text{ keV} < E < 10 \text{ MeV}$
- Note :
  - Geant4-DNA model: liquid water
  - Experimental data: vapour
- All measurements performed by the same team at different accelerators and time

# Charge change cross section: proton and hydrogen



- Cross section based on a semi-empirical approach
  - Described by an analytical formula
  - With parameters optimized from experimental data in vapour
- Note :
  - Geant4-DNA model: liquid water
  - Experimental data: vapour





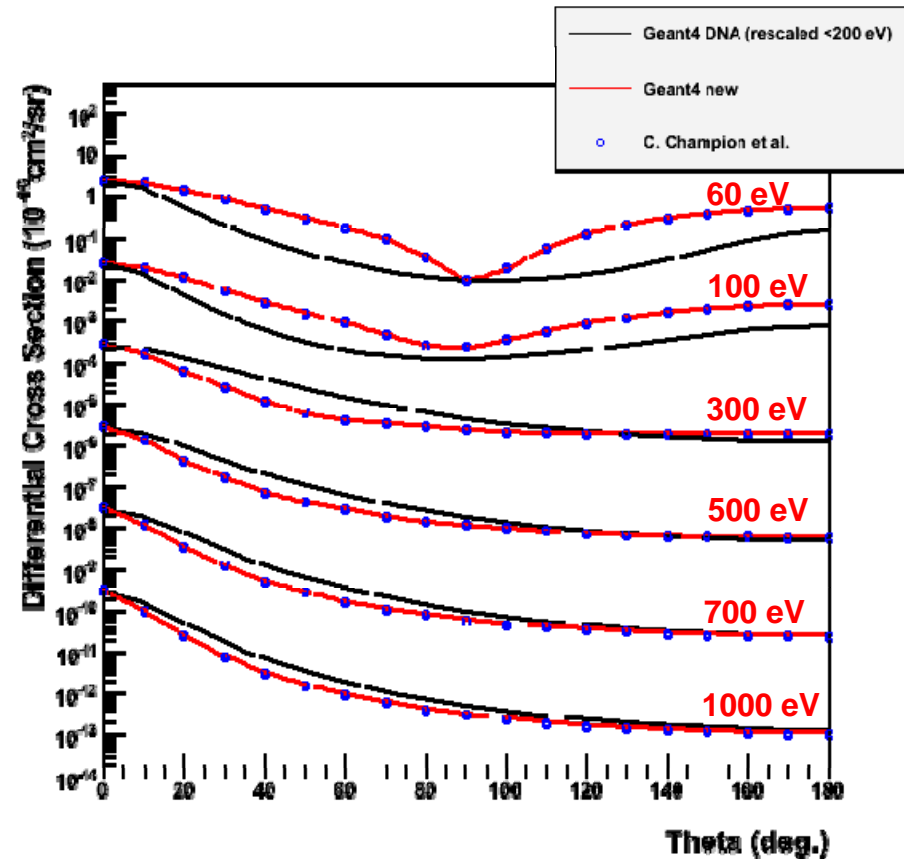
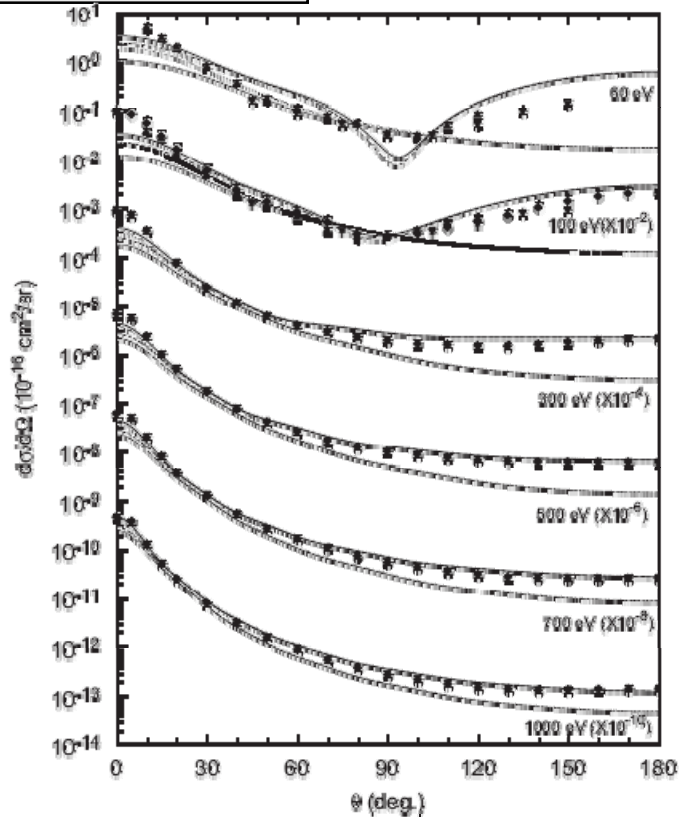
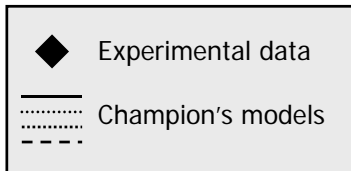
# Recent developments: improving e- elastic scattering

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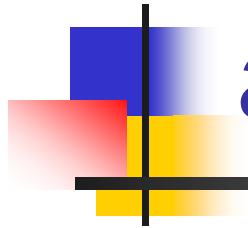
- Example of collaboration between low energy working group and **external collaborators**
- **Two complementary models** were available in Geant4 DNA models
  - Brenner Zaider (7.5 eV - 200 eV): semi empirical
  - Screened Rutherford (>200 eV): screening correction
- A **new theoretical model** developed by C. Champion is now available in Geant4 9.2
  - 10 eV - 10 keV
  - Complex potential including static contribution and multiple effects like correlations, polarization, exchange

# Improving electron elastic scattering

- Differential cross section is needed for **computation of scattering angle**



# Validation for medical applications



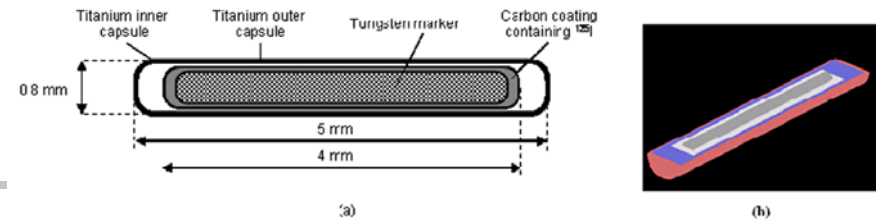


# Validation for medicine : e-/photon therapeutic beams

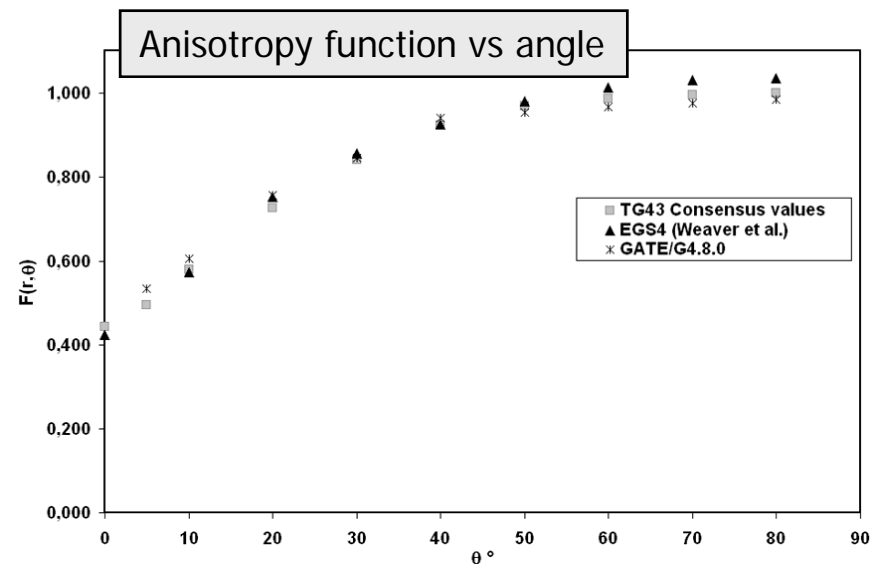
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- [LPC Clermont team](#) : V. Breton, L. Maigne, Y. Perrot
- Comparisons [GATE/Geant4](#) with
  - [EGSnrc](#) in dosimetry
  - [Dosigray](#) in treatment planning
  - Experimental data
- Deployment on grids and parallelisation, [HOPE portal](#) : [HOspital Platform for E-health](#)
- Already [two publications](#) on e- and photon validation
  - C. Thiam, V. Breton, D. Donnarieix, B. Habib and L. Maigne  
[Validation of dose deposited by low energy photons using GATE/GEANT4](#)  
[Physics in Medicine and Biology](#), 53 (2008) 3039-3055
  - L Maigne and C O Thiam, V Breton, D Donnarieix, D R Schaart  
[Improvement and validation of GATE/GEANT4 electron dose calculations at beta-ray energies](#)  
[Physics in Medicine and Biology](#) (in submission)
- [Evaluation of dose deposits by electron beams in radiotherapy in voxelized phantoms using GATE in a grid environment](#) ([PhD thesis](#) by Yann Perrot from December 2008)

# Low energy photons simulation



- $^{125}\text{I}$  brachytherapy sources
  - Best model 2301 source
  - Symmetra model I25.S06 source
  - Amersham model 6711 source
- Study
  - Air kerma strength and dose rate constant
  - Anisotropy function and radial dose function
- Comparisons:
  - G4Standard/G4LowEnergy
  - TG43 Consensus values (Monte Carlo + measurements)
- Results:
  - No high discrepancies between the 2 EM models
  - Very good agreement found between G4 Low Energy and TG43 values





# Validation for medicine hadron therapeutic beams

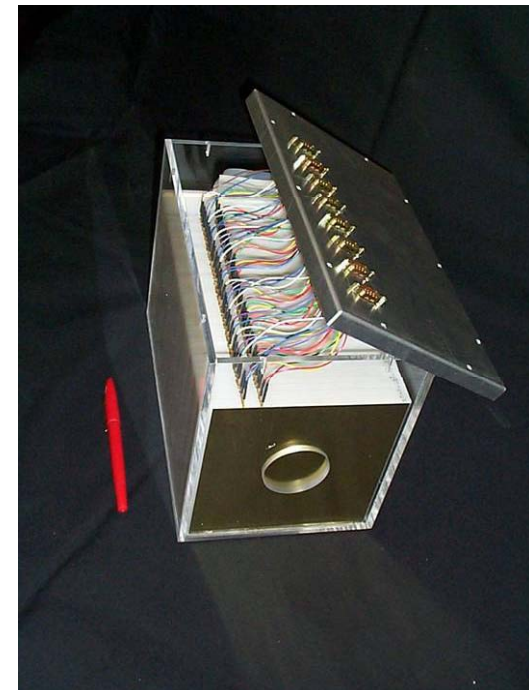
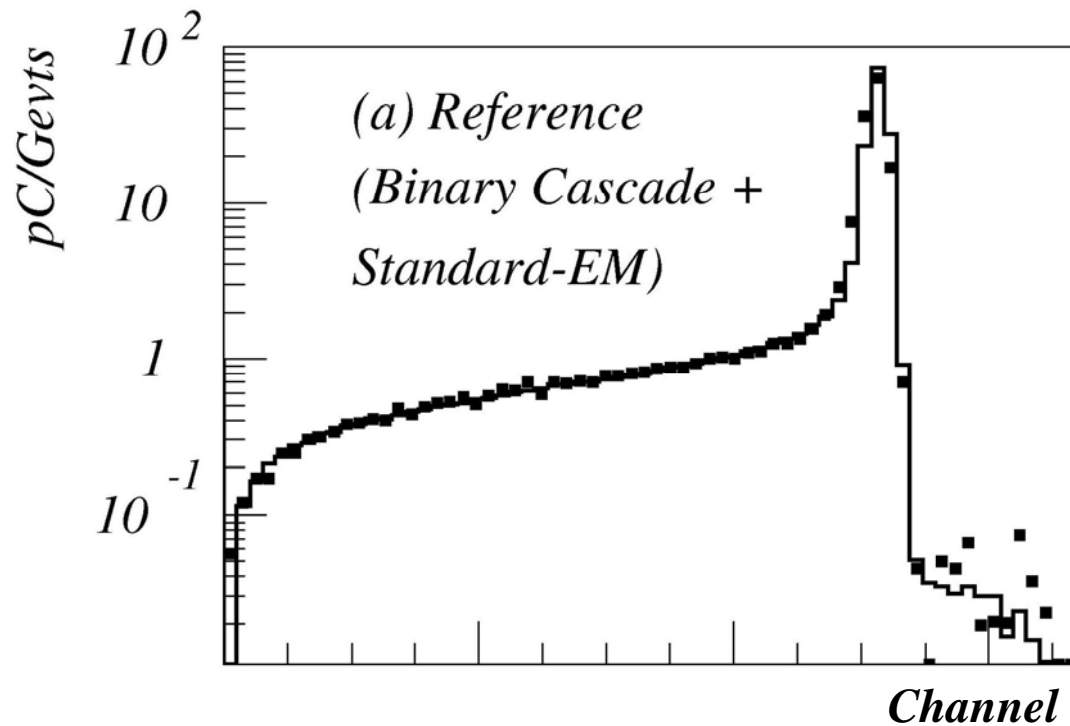
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- Several groups
  - INFN Catania team
  - Japan groups
  - MGH team : H. Pagannetti, B. Athar, B. Bednarz, B. Clasie, C. Hancox, J. Seco, C. Zacharatou
  - Sevilla team : J. M. Quesada, M. Cortes-Giraldo (Sevilla)
  - HIT, Heidelberg : K. Parodi
  - MD Anderson Cancer Center, Houston : U. Titt
  - UPenn : S. Avery
- Photons
  - EGSnrc vs Geant4 in phantoms and patients. Paper planned.
  - DPM (clinical) vs Geant4
- Proton issues
  - Extensive work
  - Large activity in [hadronics validation](#), including comparisons with FLUKA, MCNPX

# Physics settings for using the Geant4 toolkit in proton therapy

C. Zacharatou Jarlskog, H. Paganetti, IEEE TNS 55 (2008) 1018 - 1025

Comparison of measured (squares) and simulated (histograms) longitudinal charge distributions in the Faraday cup for four combinations of EM physics (Standard or Low Energy) and models for p and n inelastic scattering (Bertini or binary cascade). The horizontal axes show the charge collector ('channel') number (with increasing depth) in the Faraday cup. The vertical axes show the collected charge normalized to the number of protons in the beam (160 MeV).



View of the Faraday cup consisting of 66 absorbers ( $\text{CH}_2$ ) interspaced by charge collectors (brass)



# New ion ionisation model

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# G4IonParametrisedLossModel: a new low-energy electromagnetic model for ions



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- Potential areas of application
  - **Medical** applications (ion therapy), **space** applications, ...
- Outline of future activities:
  - **Extensive validation against experimental data** in terms of reproducibility of measured dose distributions (Bragg peak), covering different ion-target combinations
  - Studying the **improvements with respect to older Geant4 models**, where the focus is particularly on medical applications (ion therapy)
  - Results will be incorporated in **PhD thesis** (A. Lechner, CERN and TU Vienna)



# Some recent validation papers

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- New Geant4 Cross Section Models for PIXE Simulation  
H. Ben Abdelouahed et al.,  
accepted in Nucl. Instrum. and Meth. B (2008) ([link](#))
- Validation of Geant4 Atomic Relaxation against the NIST  
Physical Reference Data  
S. Guatelli et al.  
IEEE Trans. Nucl. Sci., vol. 54, no. 3 (2007) 594-603 ([link](#))
- Geant4 physics processes for microdosimetry simulation: design  
foundation and implementation of the first set of models  
S. Chauvie et al.  
IEEE Trans. Nucl. Sci., vol. 54, no. 6 (2007) 2619-2628 ([link](#))



# Summary of tests

- tests of low energy processes are run on a regular basis
- coverage of tests is **being extended**

From	LowE EM process	Particle	Energy range tested
Livermore	G4LowEnergyPhotoelectric (options)	γ	10, 2, 0.6, 0.3 keV 2, 100 MeV
	G4LowEnergyCompton		
	G4LowEnergyPolarizedCompton		
	G4LowEnergyGammaConversion		
	G4LowEnergyRayleigh		
	G4LowEnergyPolarizedRayleigh	e-	600 eV, 300 eV 10, 2, 0.6, 0.3 keV
	G4LowEnergyIonisation (options)		
	G4LowEnergyBremsstrahlung (options)		
G4hLowEnergyIonisation (options)	hadrons	MeV	
Penelope	G4PenelopePhotoElectric	γ	10, 2, 0.6, 0.3 keV 2, 100 MeV
	G4PenelopeCompton		
	G4PenelopeGammaConversion		
	G4PenelopeRayleigh		
	G4PenelopeIonisation	e- e+	10, 2, 0.6, 0.3 keV
	G4PenelopeBremsstrahlung		
	G4PenelopeAnnihilation		
Geant4-DNA	ElasticScreendRutherfordLE	e-	Below MeV
	ElasticScreendRutherfordHE		
	ElasticChampion		
	ExcitationEmfietzoglou		
	IonisationBorn	e-, p	
	ExcitationMillerGreen	p, He, He+, α	
	ExcitationBorn	p	
	IonisationRudd	p, H, He, He+, α	
	ChargeDecrease	p, He+, α	
	ChargeIncrease	H, He, He+	



# Validation workplan

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- « Validation » is the purpose of **one of the 6 « mini » working groups**, coordinated by P. Cirrone (INFN/LNS)
- Activity in collaboration with Standard EM WG
- **Data collection (R18)**
  - Collect, classify and make accessible to users existing low energy validation data in the database
  - Identify and complete possible missing data
  - Make sure validation results are clearly quantified (statistical toolkit)
- Continue **comparison with other Monte Carlo codes (R19)**, including (not exactly a « validation » activity):
  - **EGSnrc** (photons)
  - **MCNPX** (protons)
  - **FLUKA** (Bragg peak)
  - **Penelope** (Compton profiles)