Geant 4

# Validation/Verification Activities in Geant4

11th Geant4 Collaboration Workshop and Users Conference at LIP - Lisboa


SLAC/SCCS

Koi, Tatsumi


STANFORD LINEAR ACCELERATOR CENTER

# Outline

- Hadron Validation
  - From low energy to high energy
  - CHIPS
  - Low Energy Neutron Transportation
  - Ions
- EM Validation
  - Standard
  - Low Energy
- Validation of Use Cases
  - Space Applications
  - Medical Applications
- Other information

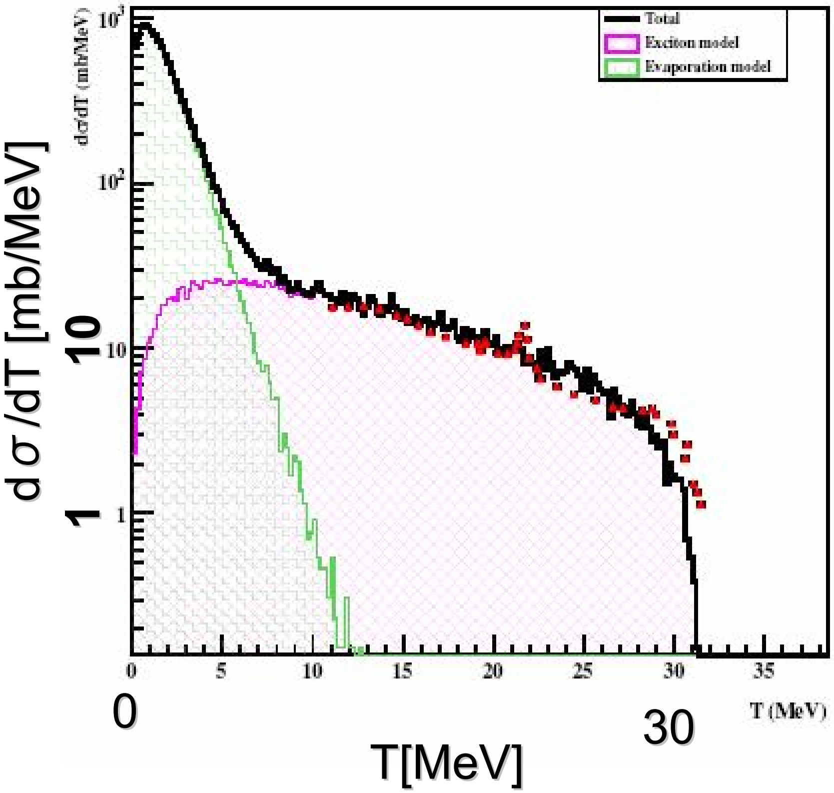
# Precompound model

- This model handles lowest energy (below 170 MeV) hadron interactions
- In following plots the Geant4 precompound model coupled with evaporation model to handle low energy de-excitation of nucleus
- Precompound is exciton model

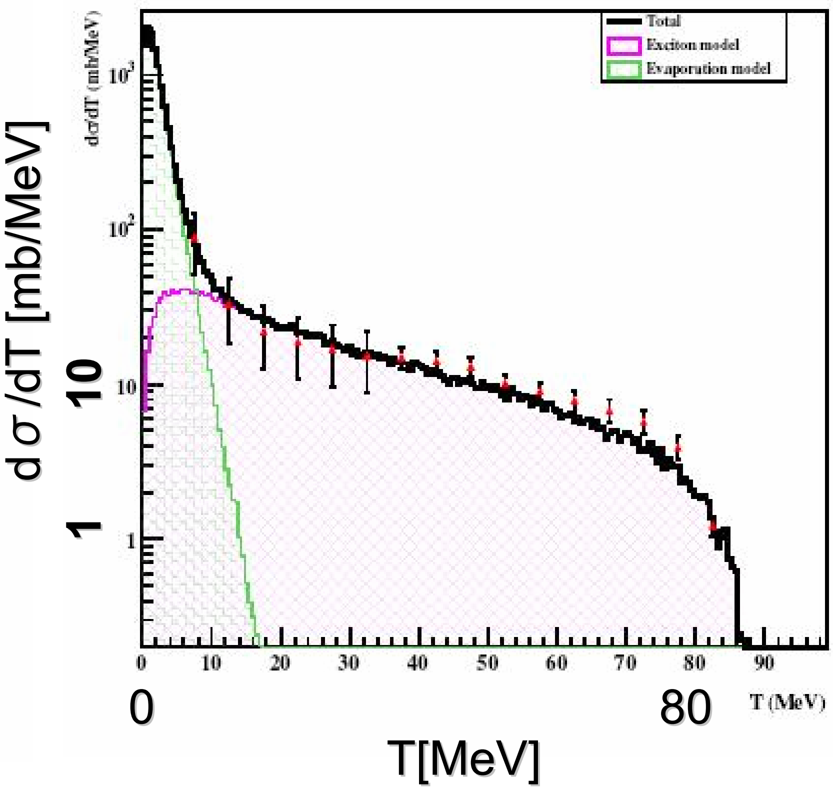
# Neutron Production Cross Section

Secondary neutrons are created in

Exciton (Precompound)    Evaporation




Sn (p, X n) 35MeV




Bi (p, X n) 90MeV

# Intermediate energies (170 MeV < E < 3.0 GeV)

Binary Cascade
Bertini Cascade
and
LEP

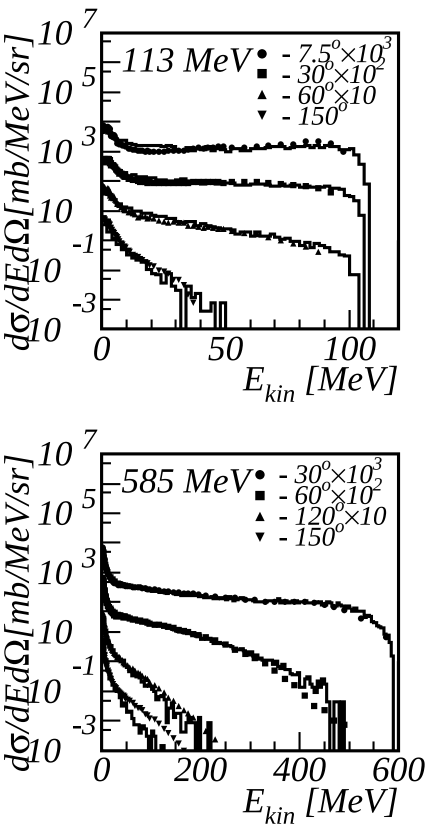
# Verification Suite for the Cascade Energy Region

- We have developed since 2002 as test30
- Neutron production by p, d, $\alpha$, $^{12}C$ with E < 3 GeV
  - P + A -> n + X
  - d + A -> n + X
  - $\alpha$ + A -> n + X
  - $^{12}C$ + A -> n + X
- Pion production
  - P + A -> $\pi^{\pm}$ + X
- 73 thin target experiments with reasonably small systematic
- Control on differential spectra (63 histograms)

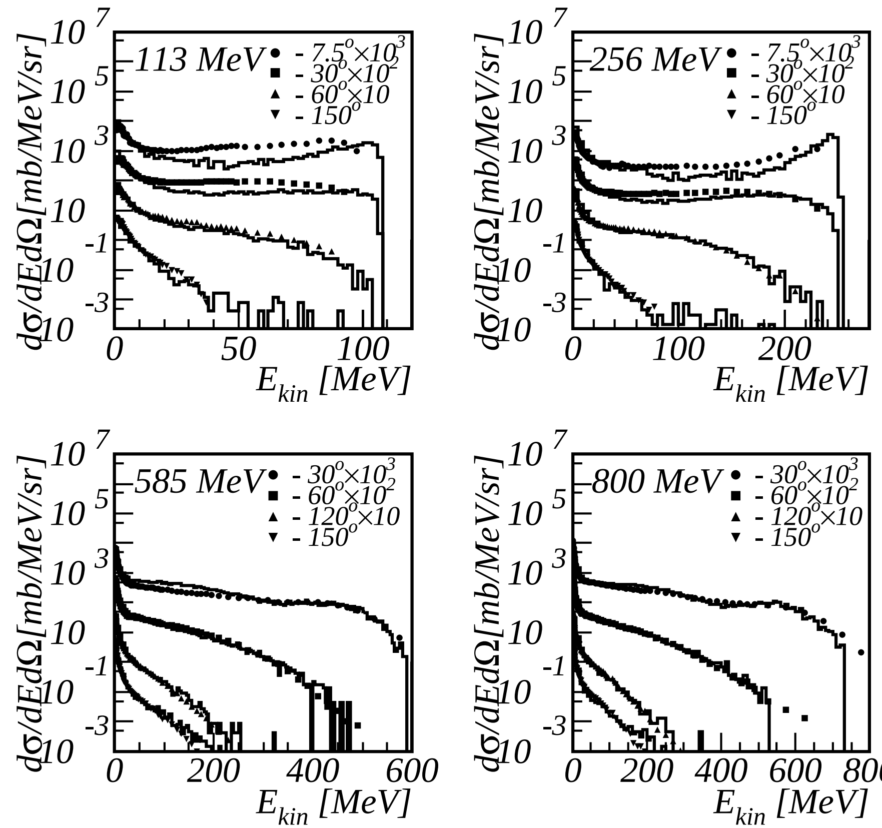
- Models under testing:
  - Binary Cascade
  - Binary Ion cascade
  - Bertini Cascade
  - Wilson-Abrasion model
  - CHIPS
  - LHEP
- Additionally to double differential spectra for comparisons with the data a set of histograms with inclusive spectra is produced

# Neutron spectra by protons in Aluminum

Binary Cascade




Bertini Cascade

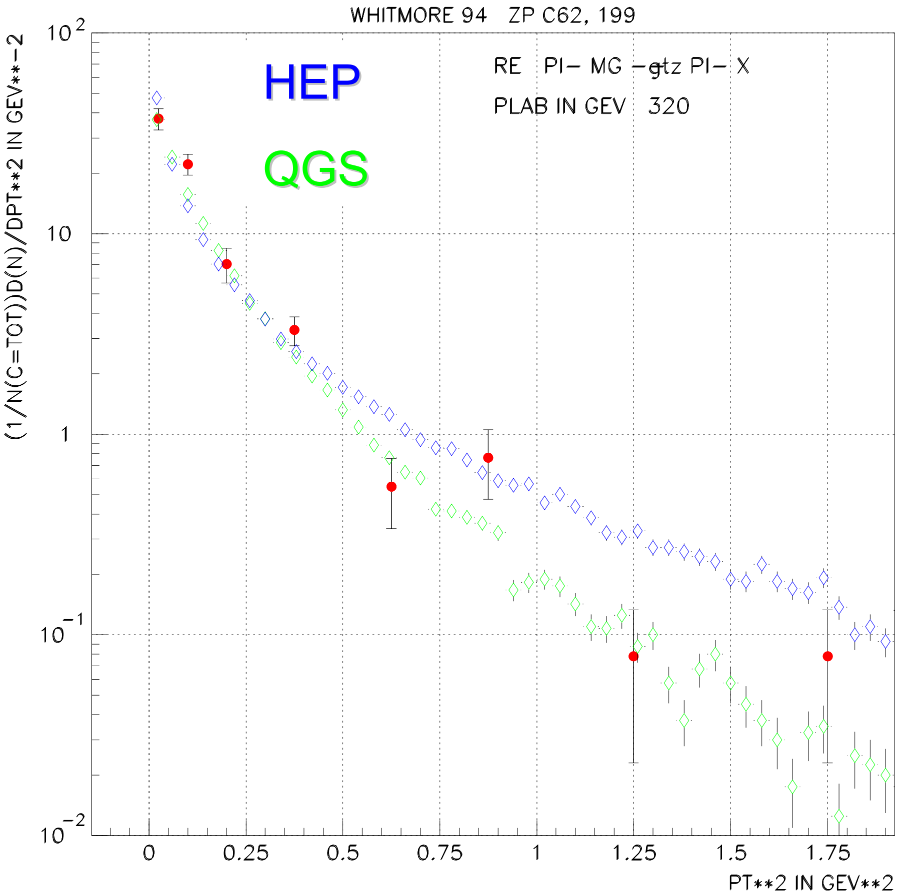


# High Energy >50GeV

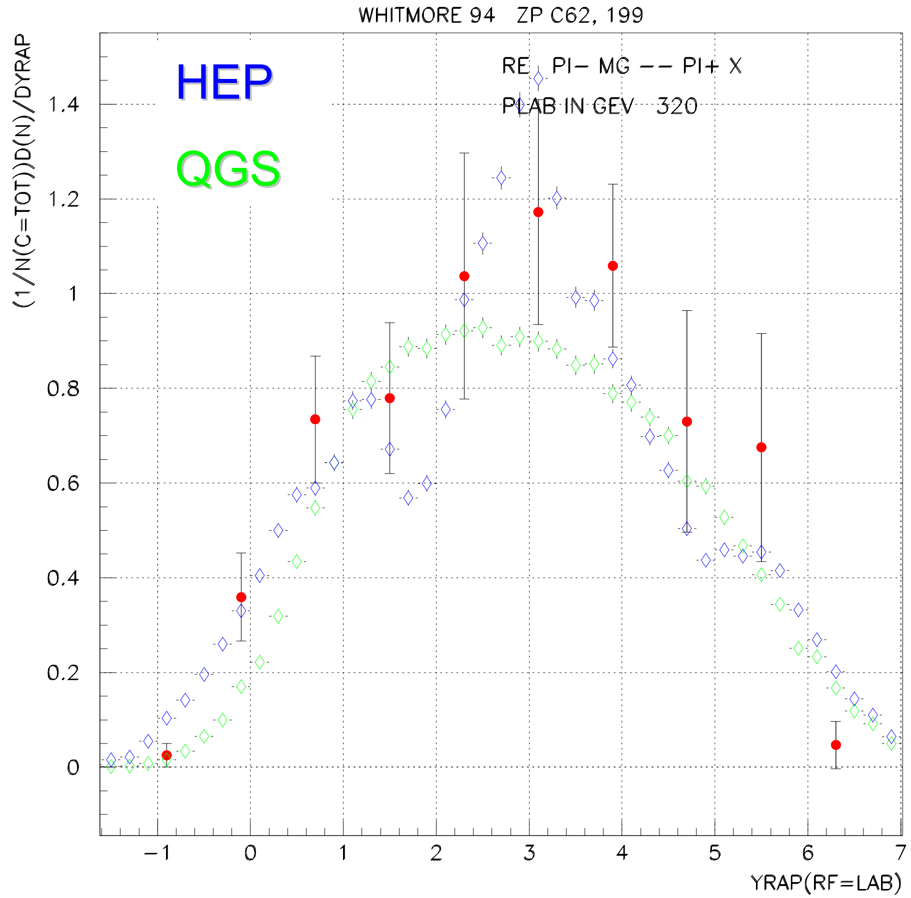
We have 3 models
(QGS, FTF and HEP)
for these energies.

# HEP Model

## pi- Scattering on Mg, Plab 320 GeV/c




$P_t^2$ [GeV$^2$]

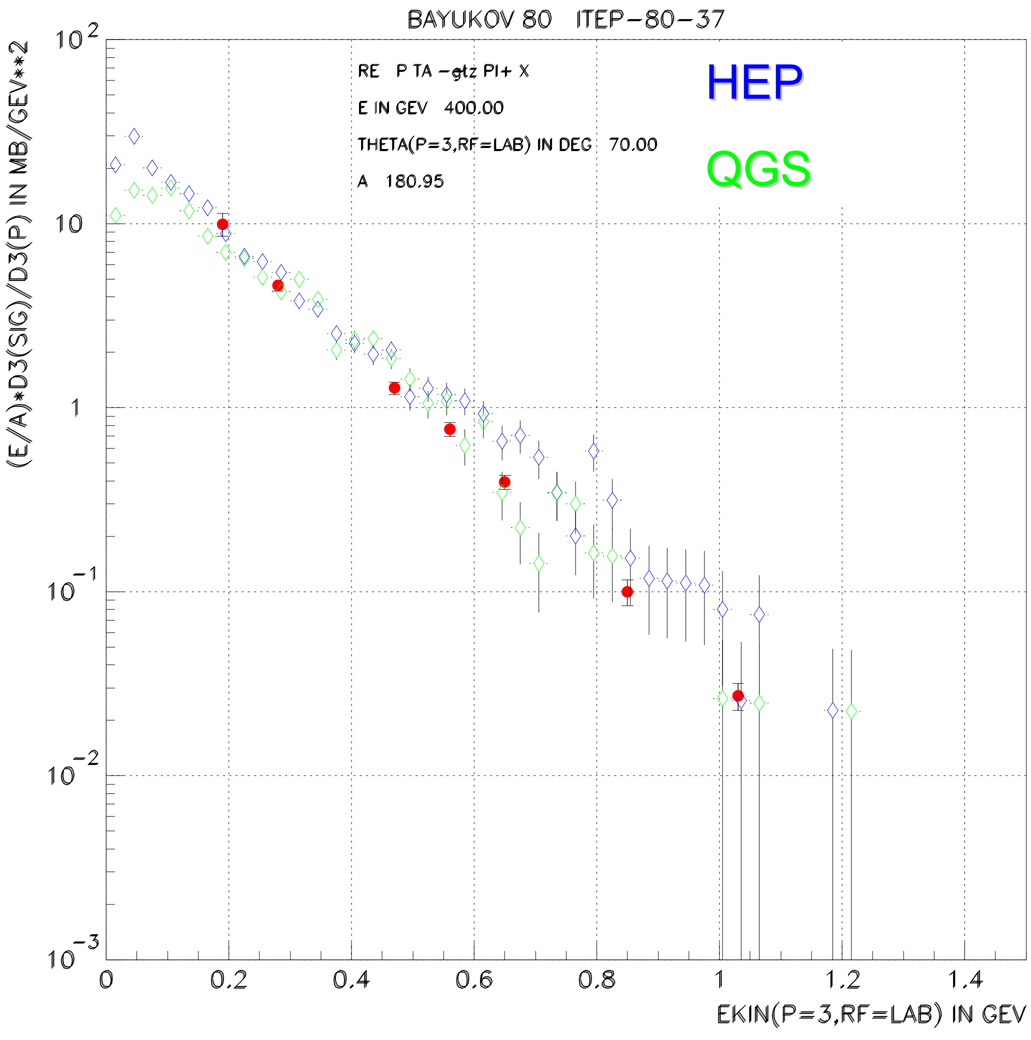



Rapidity $\eta = \frac{1}{2}\ln\left(\frac{E+p_z}{E-p_z}\right)$

Z.Phys.C62(1994)199

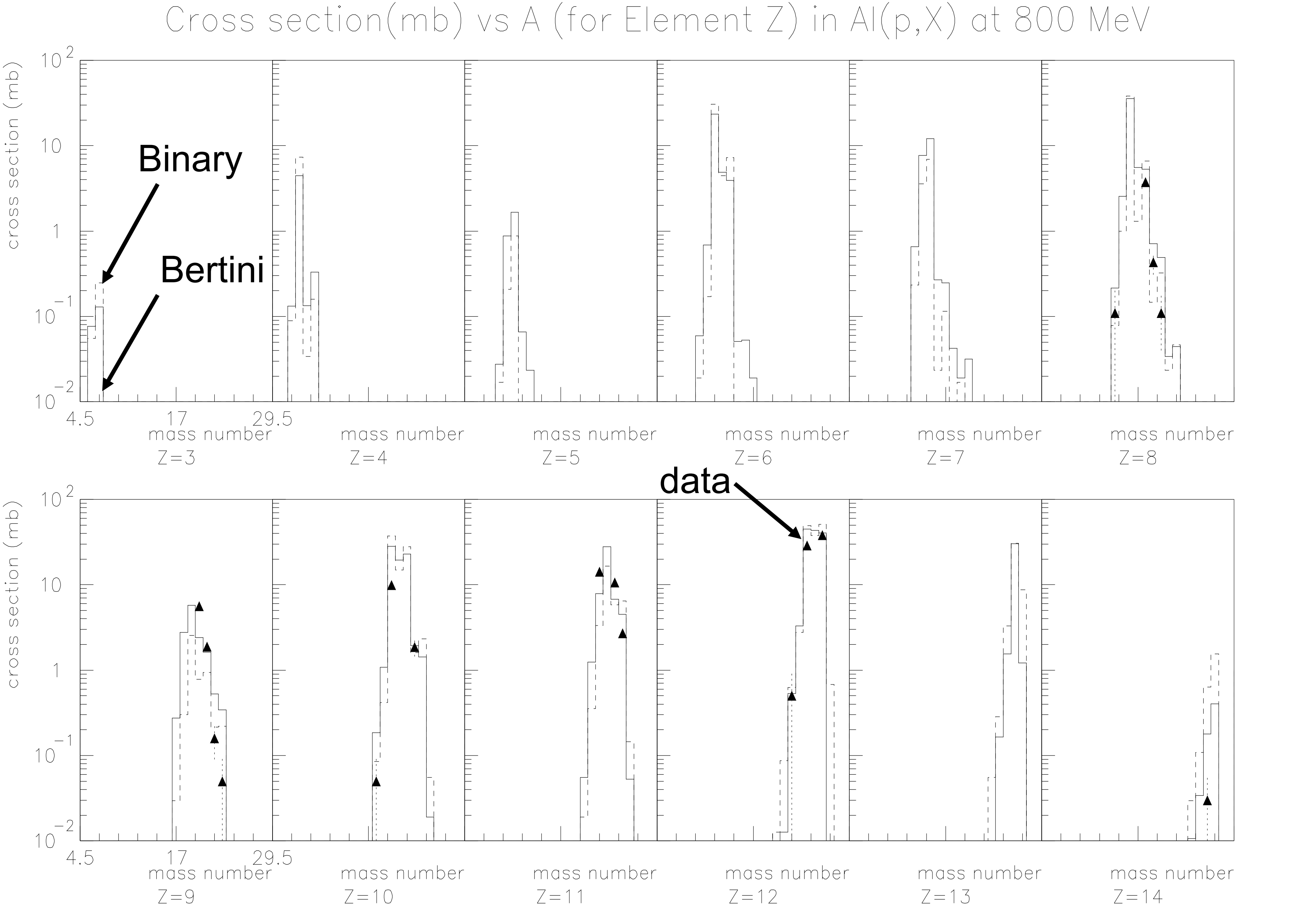
# *HEP Model*

# pi+(70deg) from proton (400GeV) on Ta



# Isotope production by precompound models

- We have two precompound models.
  - One is currently integrated within Bertini Model
  - Another is implemented independently, so that it can be used by itself or coupled to Binary Model
- The range of nuclear excitation energies handled by these precompoud models are most important to isotope production
- Next slide compare the two models to data.

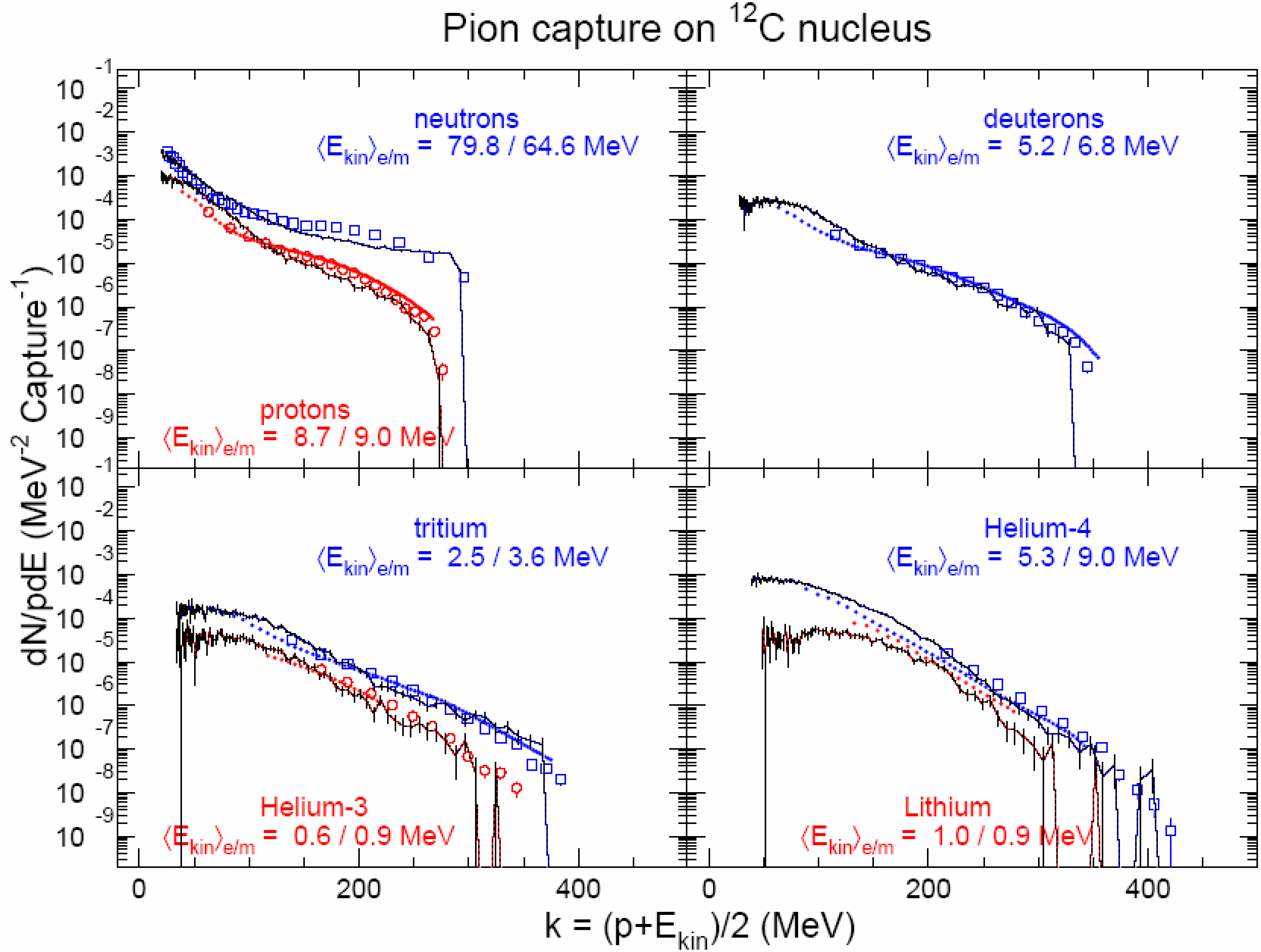



Data: H. Vonach et al., Physical Review C, 55, 2458, 199705

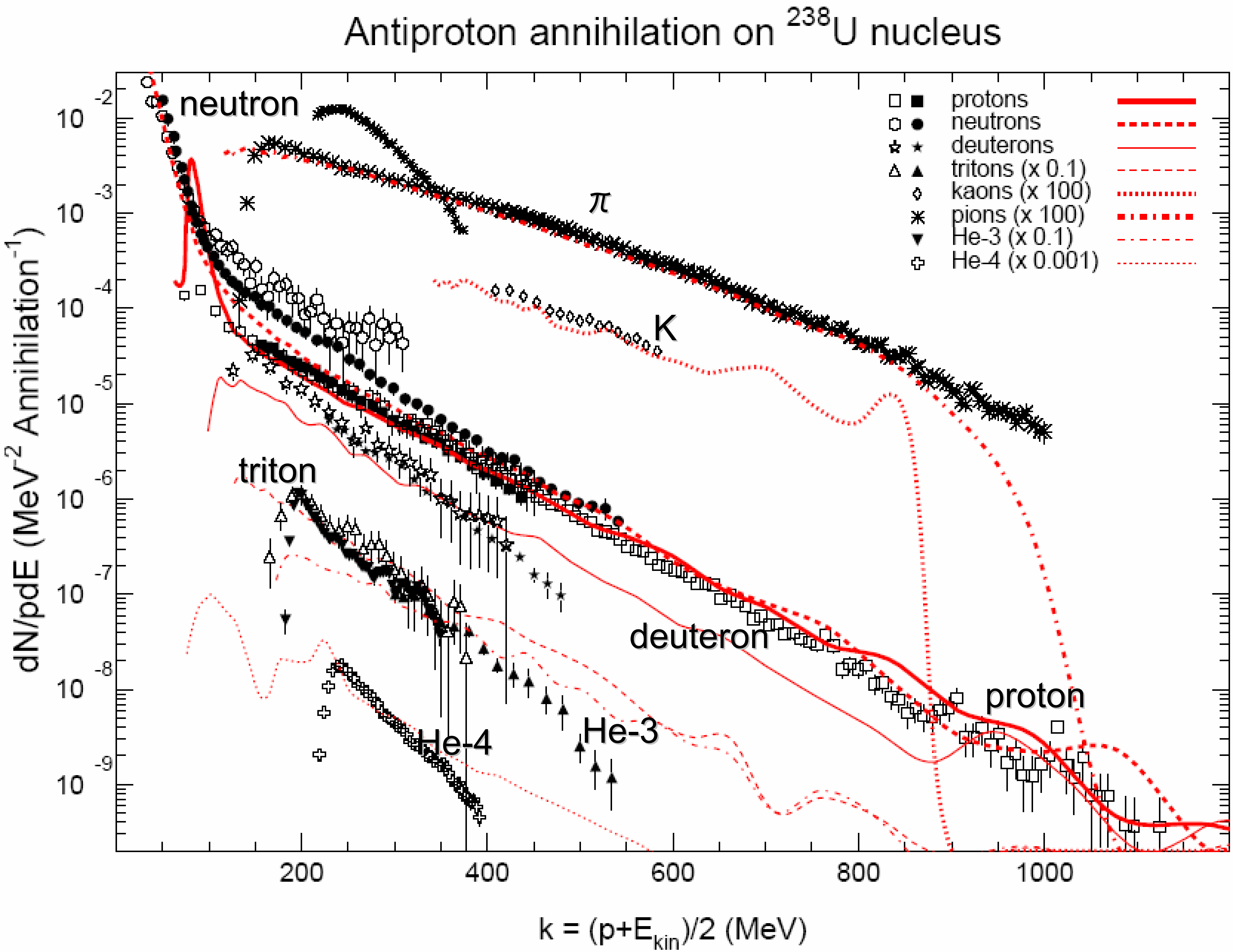
# Validation of Chiral Invariant Phase Space decay (CHIPS) model

- Capture
- Anti Proton Annihilation
- Gamma-Nucleus
- Elastic Scattering

# Verification of nuclear capture at rest
# CHIPS Model



# CHIPS Model

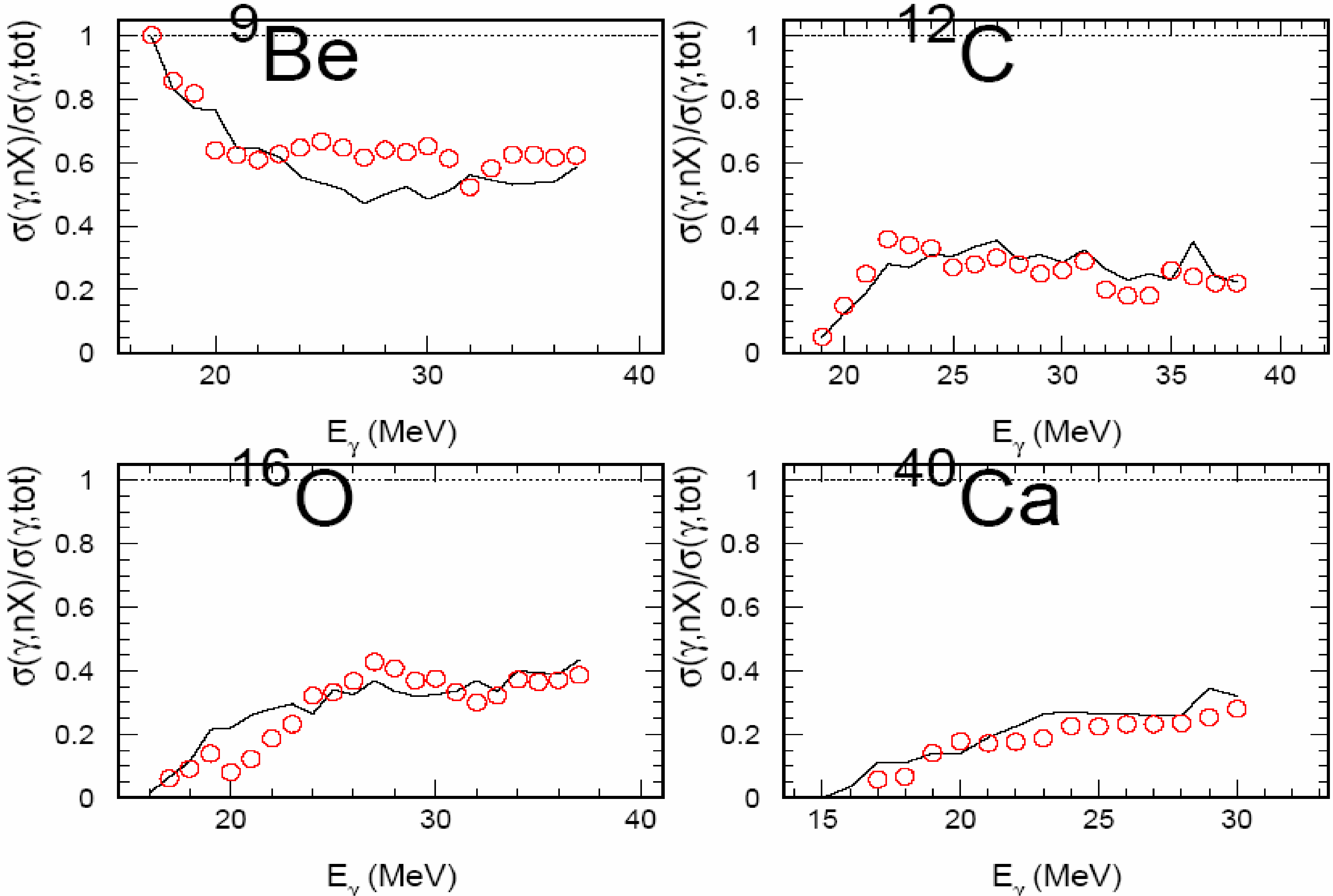


Antiproton annihilation on 238U nucleus
dN/pdE (MeV-2 Annihilation-1)
k = (p+Ekin)/2 (MeV)
200
400
600
800
1000
10-2
10-3
10-4
10-5
10-6
10-7
10-8
10-9
protons
neutrons
deuterons
tritons (x 0.1)
kaons (x 100)
pions (x 100)
He-3 (x 0.1)
He-4 (x 0.001)
neutron
π
K
triton
deuteron
proton
He-4
He-3

# Verification of gamma-nuclear reactions

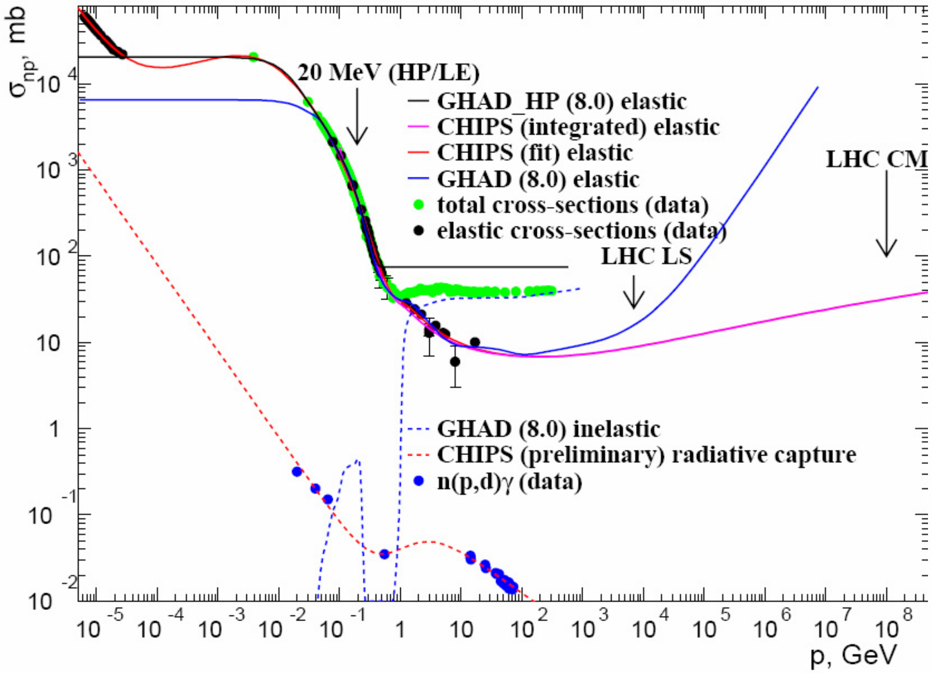
## CHIPS Model

Photoneutron production part of total photonuclear cross section

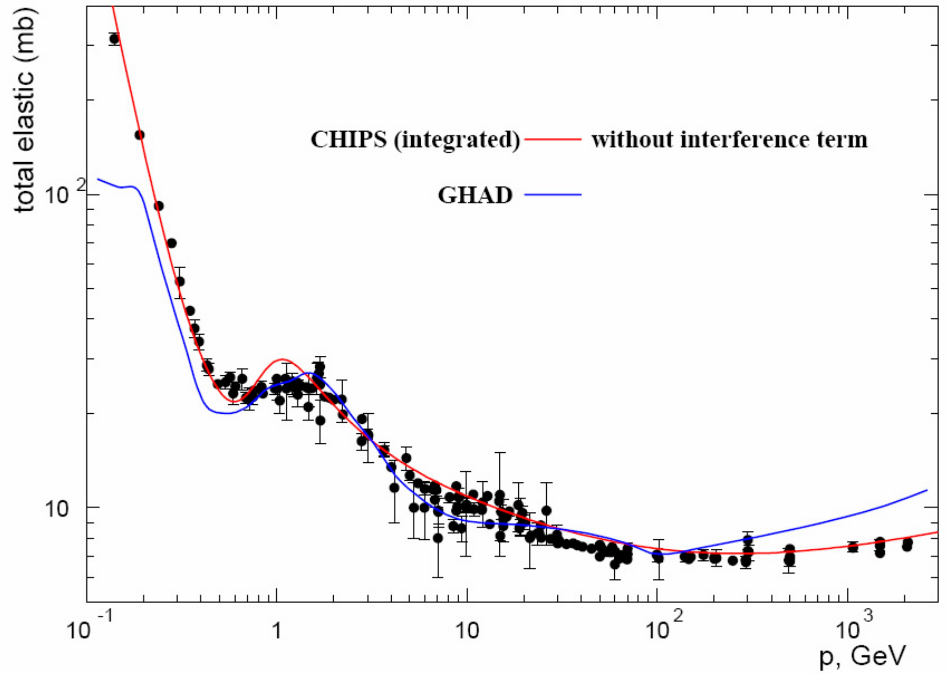


# np and pp Elastic Cross Section

np




pp

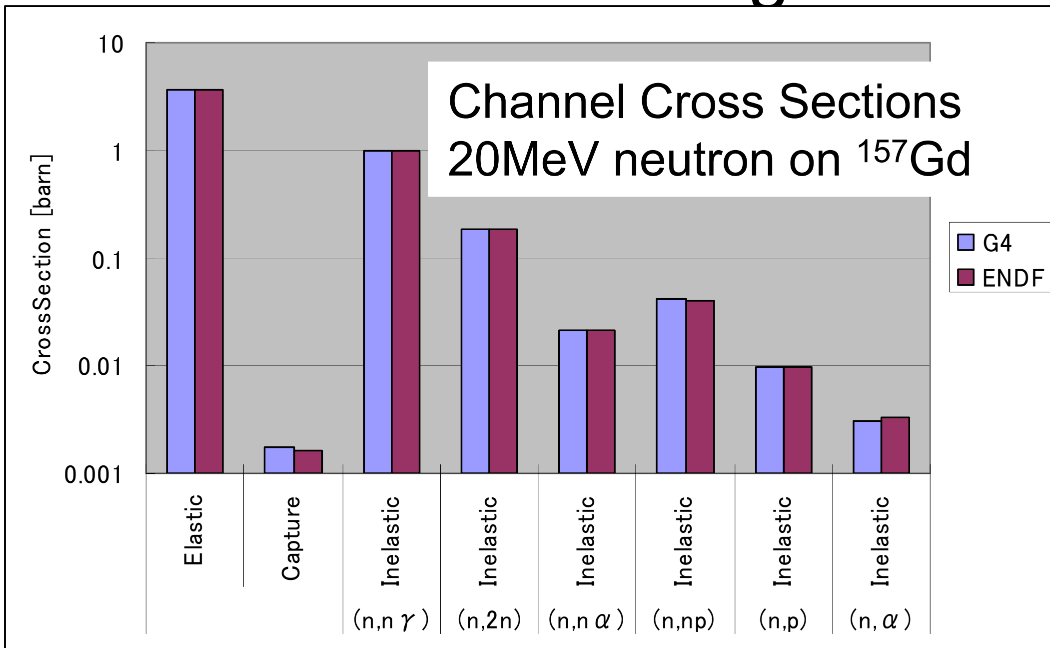


# Low Energy (<20MeV) Neutrons

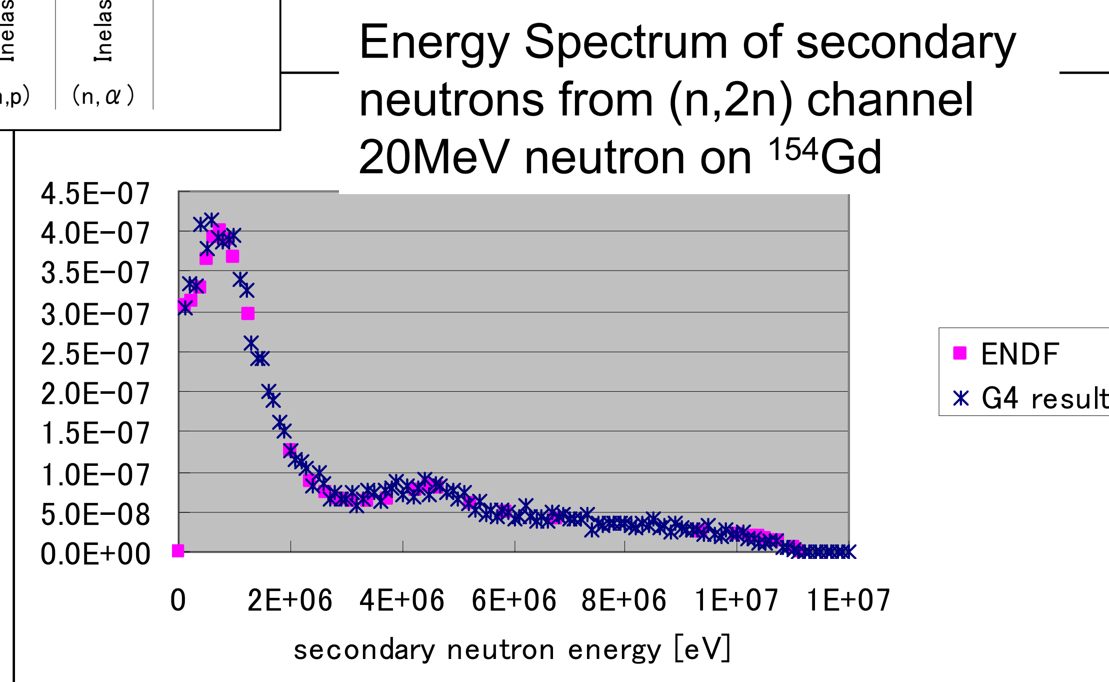
Neutron High Precision Models and Data Sets

These are data driven models, therefore comparison results to the ENDF data should be very close.

# Verification of High Precision Neutron models



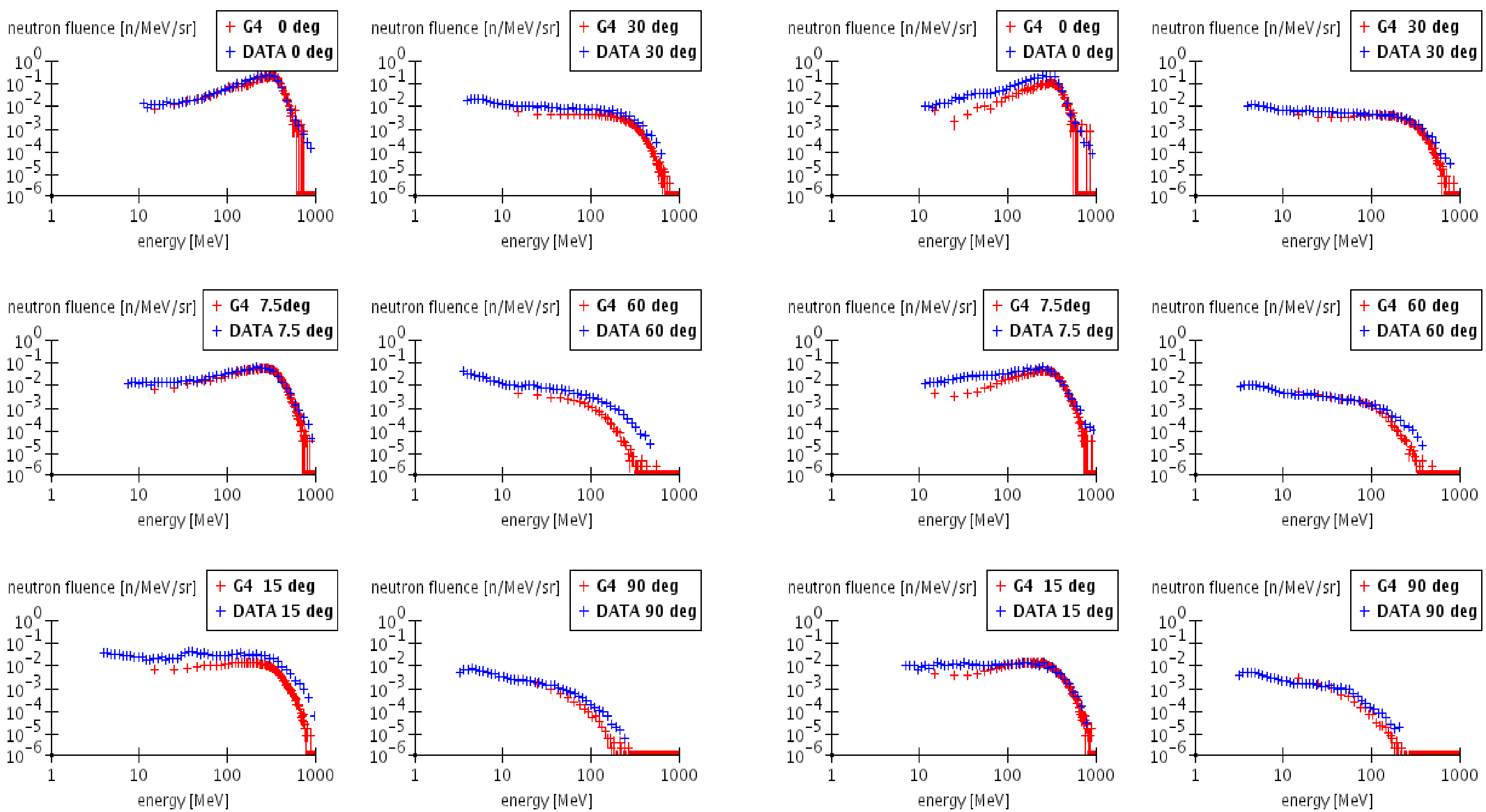

**Geant4 results are derived from thin target calculations**



# Ions
# Binary Light Ions Cascade
# Wilson Abrasion Ablation
# Electromagnetic Dissociation

# Neutron Yield  Fe 400 MeV/n beams

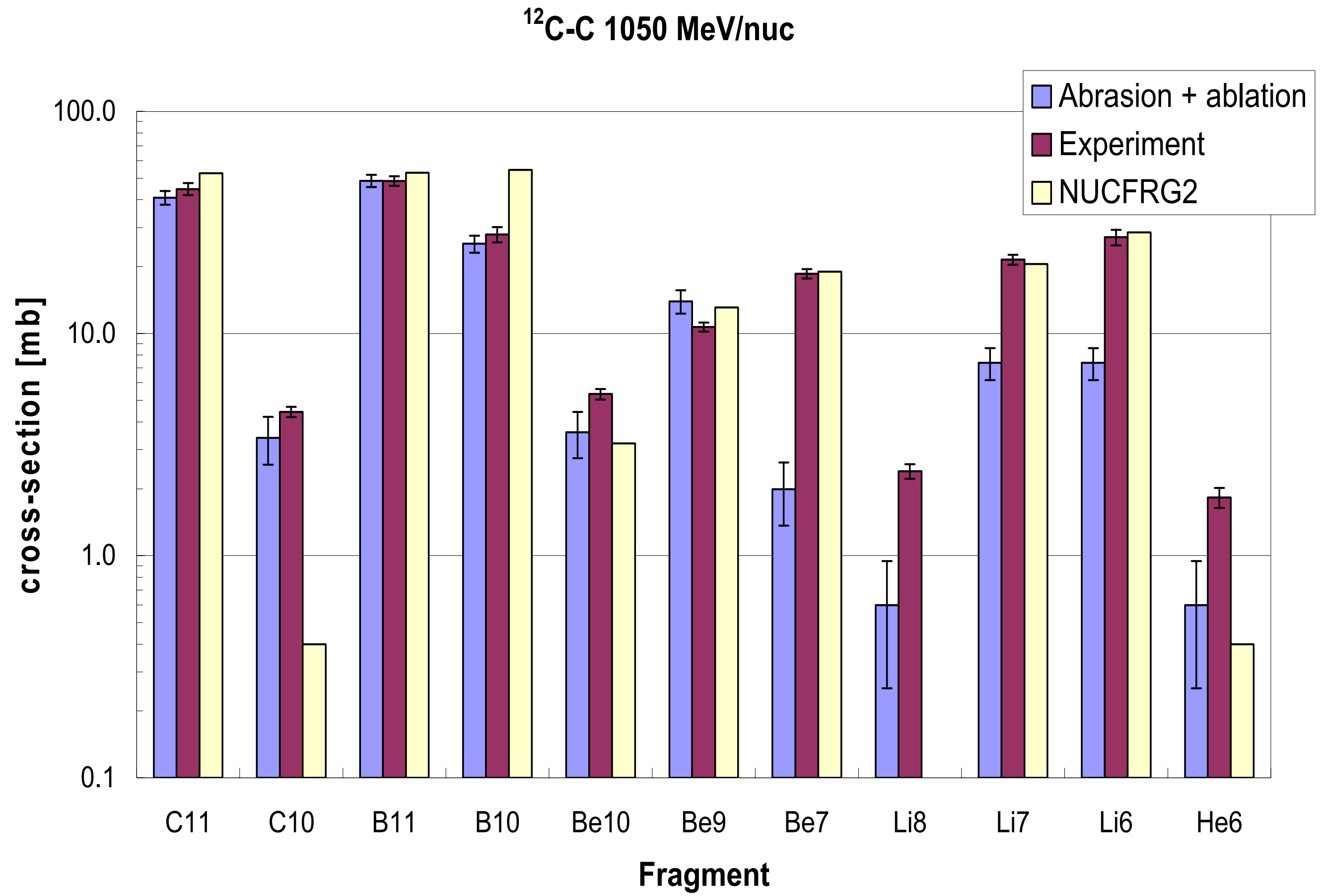
Carbon | Aluminum




Binary Light Ions Cascade

T. Kurosawa et al., *Phys. Rev. C62* pp. 04461501 (2000)

# Validation of Wilson Abrasion Ablation Model




J W Wilson et al., “NUCFRG2: An evaluation of the semi-emperical nuclear fragmentation database,” NASA Technical Paper 3533, 1995.

# Validation of G4EMDissociaton Model and Cross Section

Target Emulsion nuclei: Ag 61.7%, Br 34.2%, CNO 4.0% and H 0.1%

| Projectile | Energy [GeV/nuc] | Product from ED | G4EM Dissociation [mbarn] | Experiment [mbarn] |
|---|---|---|---|---|
| Mg-24 | 3.7 | Na-23 + p | 124 ± 2 | 154 ± 31 |
| Si-28 | 3.7 | Al-27 + p | 107 ± 1 | 186 ± 56 |
| | 14.5 | Al-27 + p | 216 ± 2 | 165 ± 24† <br> 128 ± 33‡ |
| O-16 | 200 | N-15 + p | 331 ± 2 | 293 ± 39† <br> 342 ± 22* |

M A Jilany, "Electromagnetic dissociation of 3.7 A GeV 24Mg and 28Si projectiles in nuclear emulsion," *Nucl Phys*, **A705**, 477-493, 2002.

# Validation of EM Standard Physics

# Validation of Standard EM Physics

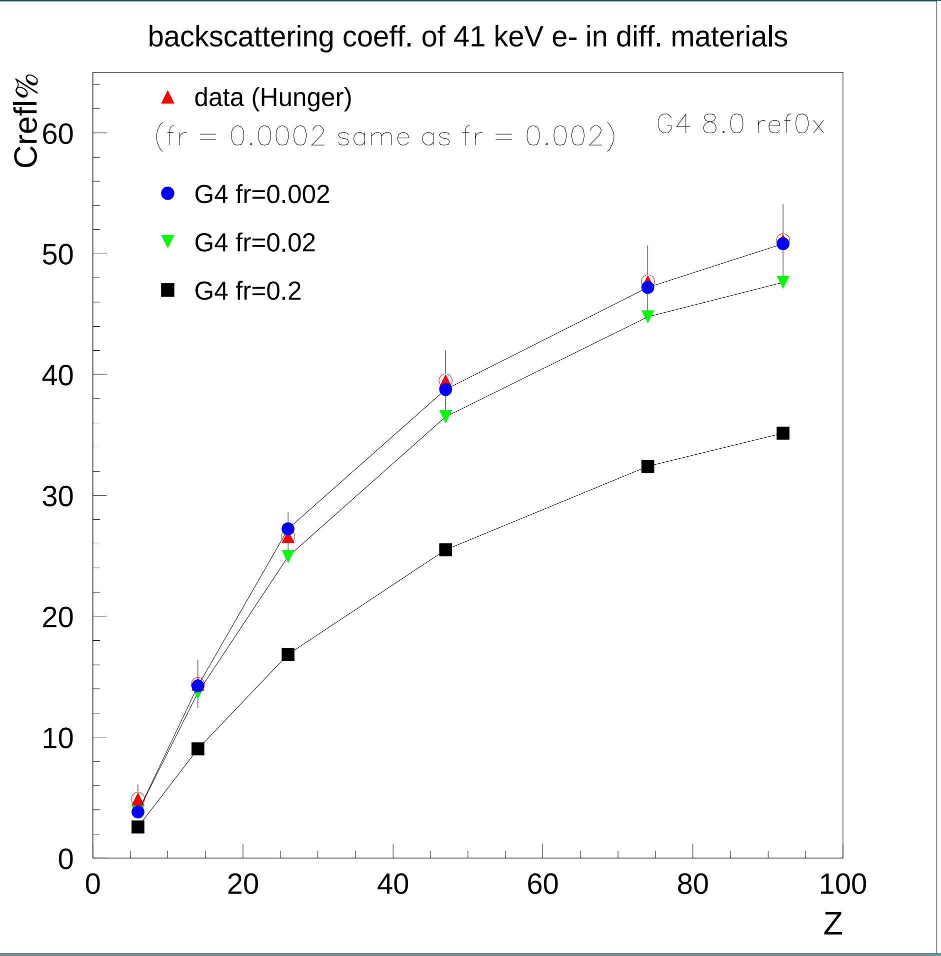
- Unit tests by developers
- Comparisons with Geant3
- Comparison against theoretical predictions
- Comparison against evaluated data
- Testing suite:
  - About 20 G4 examples are used for different tests
  - More than 100 macro files
  - Limited statistic is regularly executed by sst
  - Large statistic tests are executed by the EM group
  - Results for each reference version of G4 are archived
- User validation

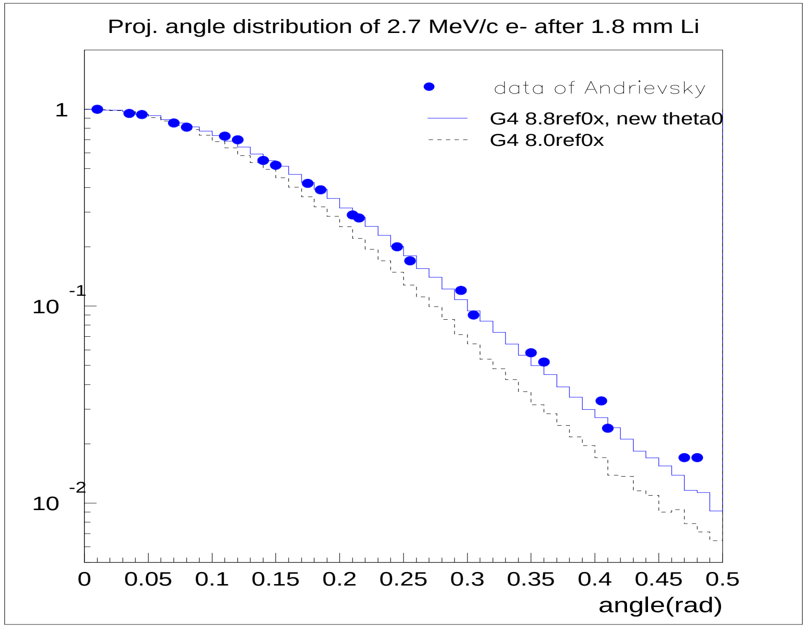
# EM standard test suite examples/extended/electromagnetic

| Test | Purpose | Responsible | N macro | G3 |
|---|---|---|---|---|
| TestEm0 | G4EmCalculator | M.Maire | 5 | |
| TestEm1 | Tracking/EM physics in infinite media | M.Maire | 15 | + |
| TestEm2 | EM shower in homogeneous media | M.Maire | 7 | + |
| TestEm3 | Sampling calorimeter | M.Maire | 23 | + |
| TestEm4 | Gamma interactions | M.Maire | 3 | + |
| TestEm5 | Multiple scattering | L.Urban | 18 | + |
| TestEm6 | High energy muons | H.Burkhardt | 6 | |
| TestEm7 | Bragg peak | M.Maire | 6 | |
| TestEm8 | PAI models | V.Grishine | 2 | |
| TestEm9 | Crystal Calorimeter | V.Ivanchenko | 5 | |
| TestEm10 | TRD models | V.Grichine | 2 | |

| | | | | |
|---|---|---|---|---|
| TestEm11 | Deep dose profile (plane) | M.Maire | 5 | + |
| TestEm12 | Deep dose profile (spherical) | M.Maire | 4 | |
| TestEm13 | Gamma interactions | M.Maire | 6 | + |
| TestEm14 | Cross sections and mfp | M.Maire | 5 | + |
| TestEm15 | Multiple Scattering | M.Maire | 4 | |
| TestEm16 | Synchrotron radiation | H.Burkhardt | 3 | |
| TestEm17 | Muon processes | R.Kokoulin, A.Bogdanov | 6 | |
| GammaTherapy | Bremsstrahlung beam | V.Ivanchenko | 5 | |
| test31 | Sliced media | V.Ivanchenko | 5 | |

# Multiple Scattering Update for the release 8.1 (CHEP'06)

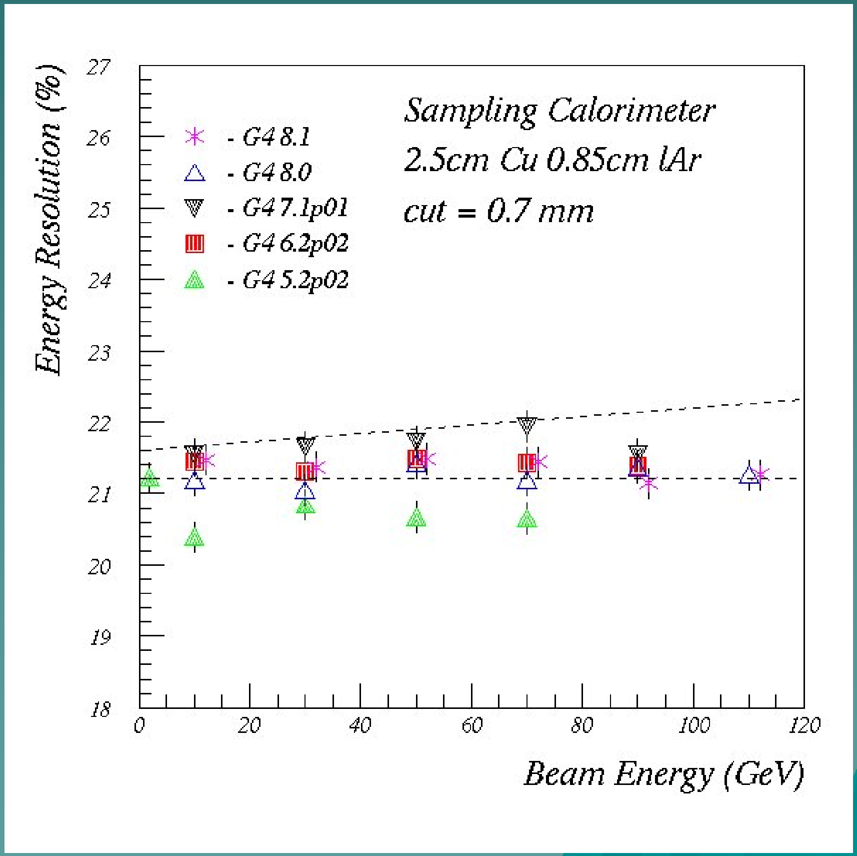


# Atlas HEC Calorimeter (Monte Carlo' 2005)

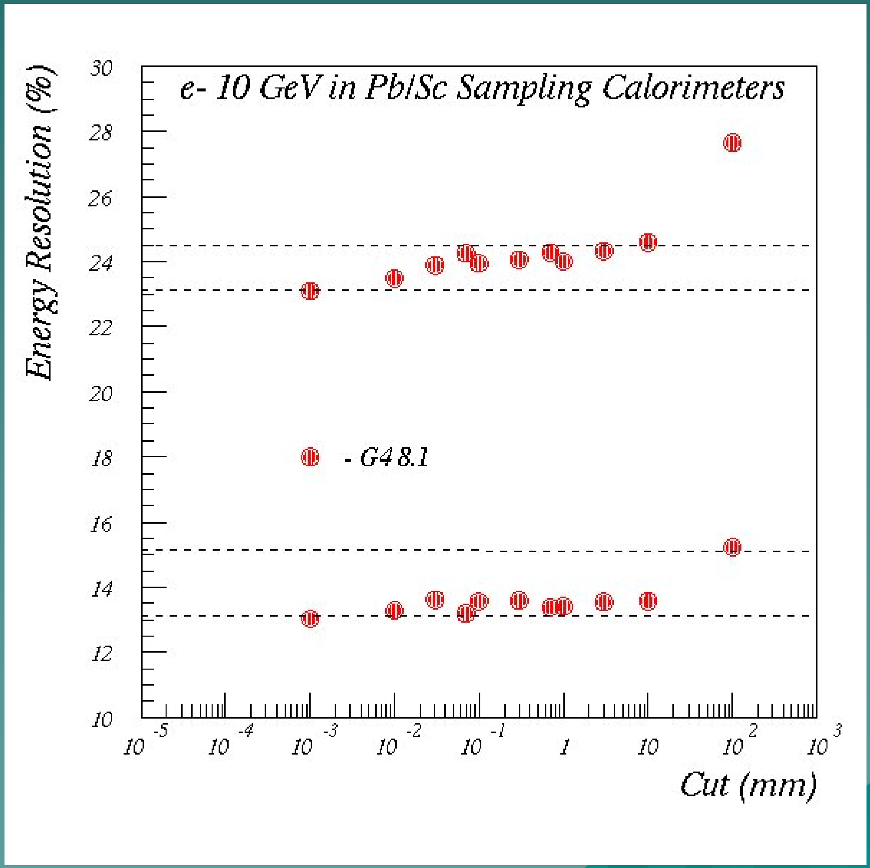
- The first setup for the suite
- ATLAS HEC structure is used as a reference since release 5.2
- Based on TestEm3
- Resolution is compared with the data
- 30 GeV $e^-$ were chosen (Gaussian spectrum)

Default EM physics



# Comparison with Published Data (preliminary)

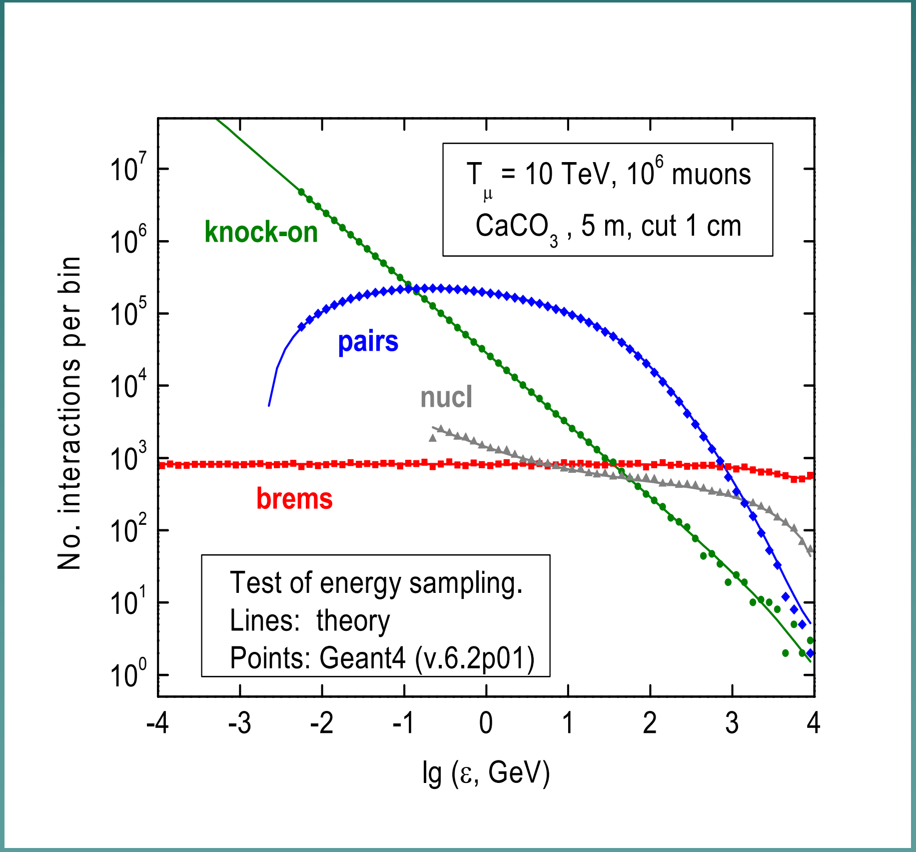
- ZEUS calorimeter test beam data
  - NIM A262 (1987) 229
  - NIM A274 (1989) 134
  - E.Bernardi thethis
  - PS CERN measurements
- Two calorimeter structures:
  - 5mm Pb/5mm Sc
  - 10 mm Pb/2.5 mm Sc
- Accurate description of sizes and materials was needed

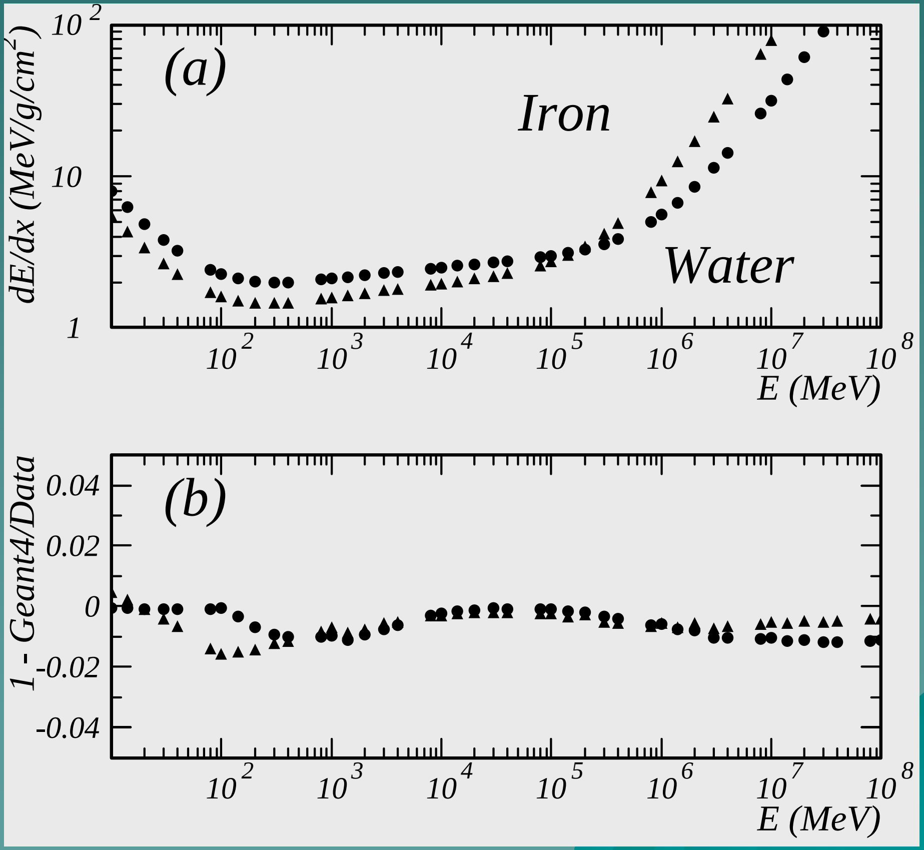


# Verification theory/Geant4
## (IEEE Trans. Nucl. Sci. 53(2006)270)

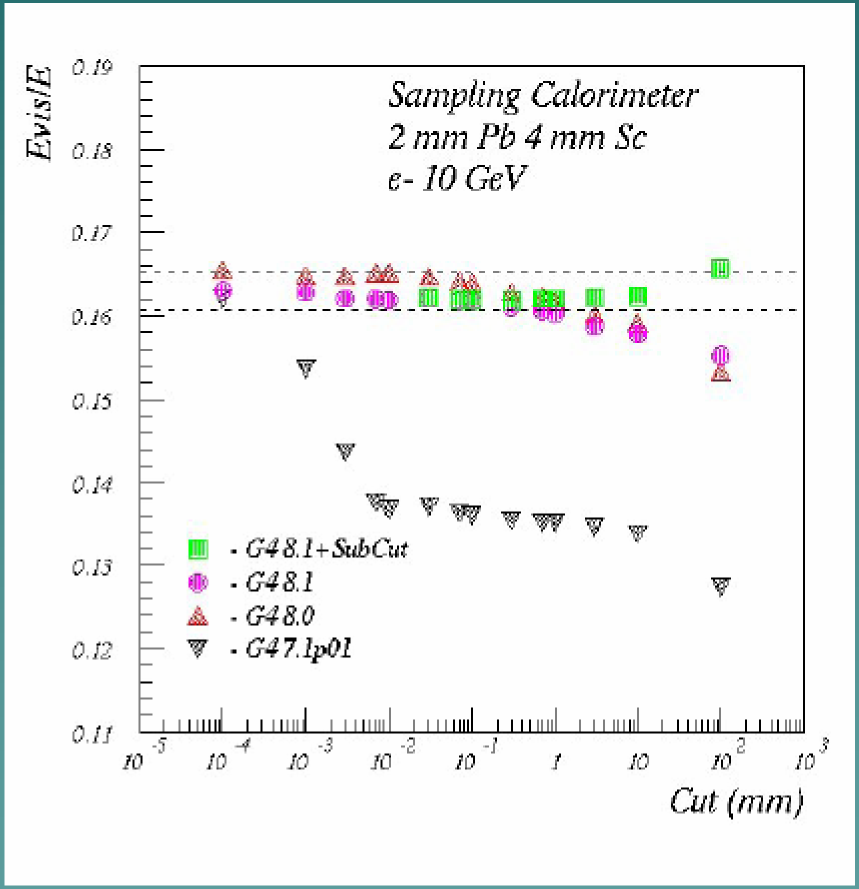
Differention cross sections
precision better 5%

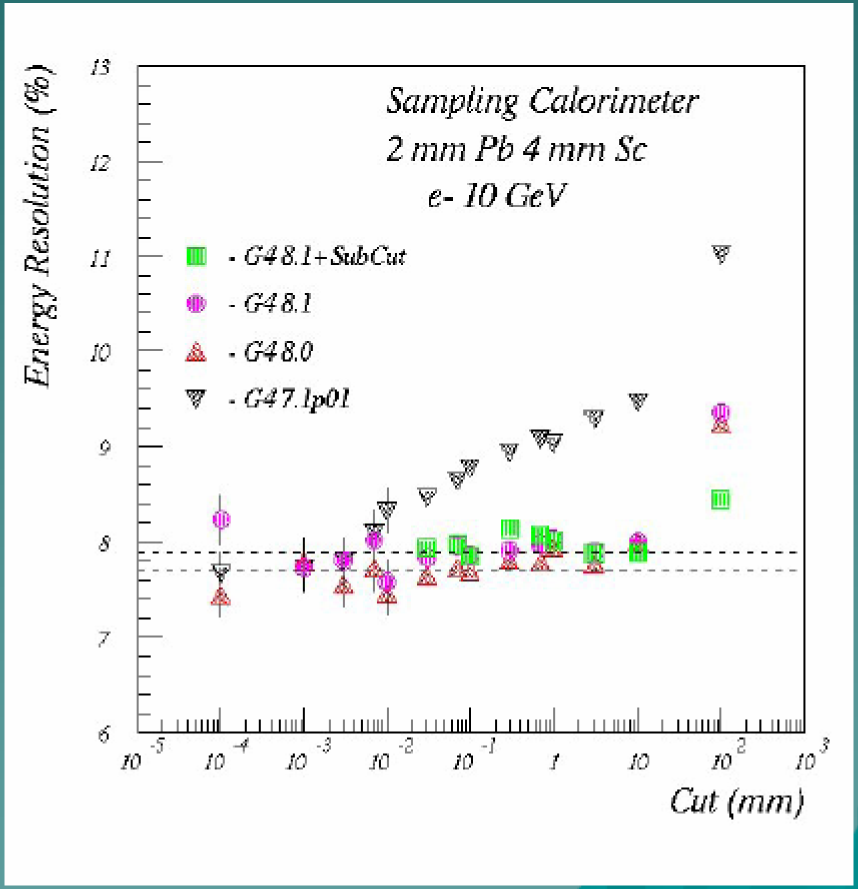
Muon stopping power
Precision about 2%



# LHCB Type Calorimeter



# Validation Activities
# of
# Low Energy EM group

# 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

# Validation of EM physics

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

The sets of cross section models for $\gamma$ 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:

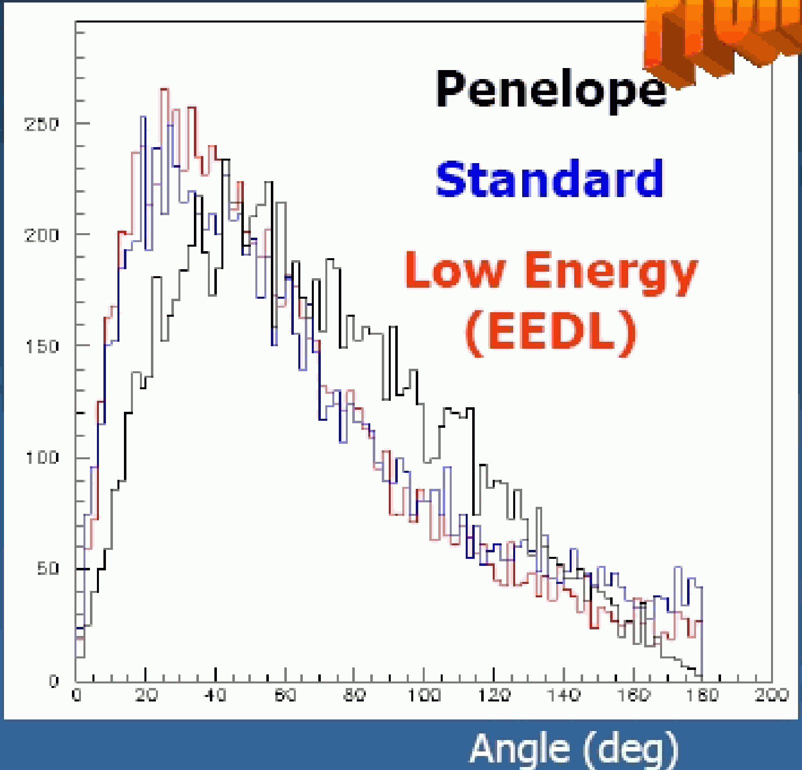
- G4eBremsstrahlung
- G4LowEnergyBremsstrahlung
- G4PenelopeBremsstrahlung

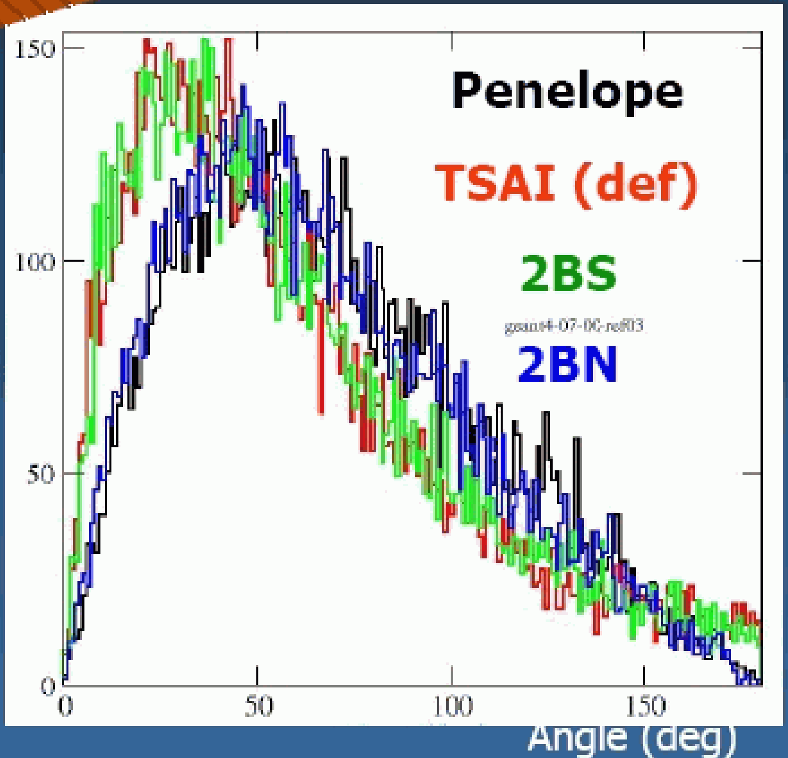
→ 3 alternative angular distributions:

**Tsai, 2BS, 2BN**

# Angular distributions

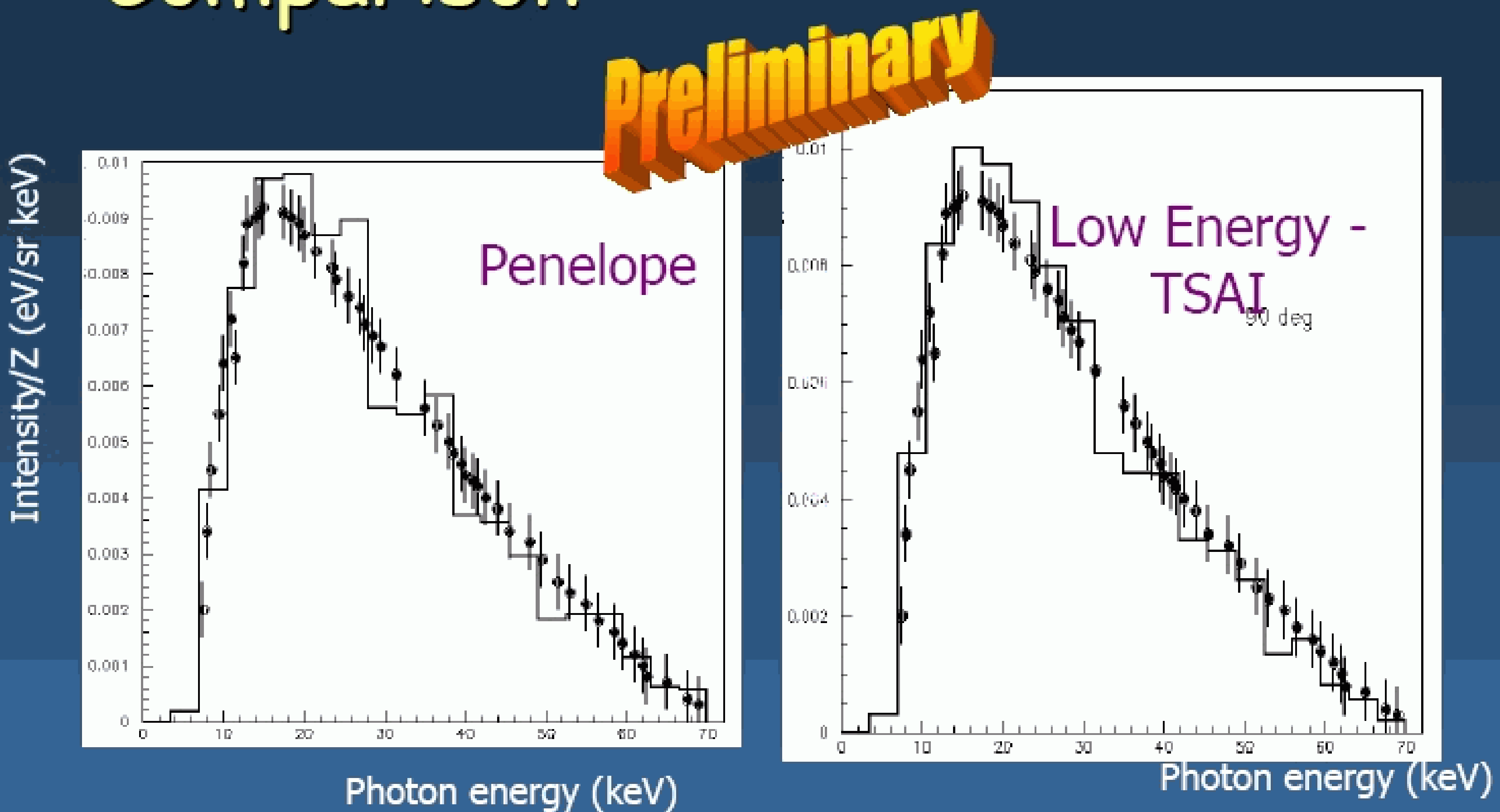
Preliminary




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

# Comparison



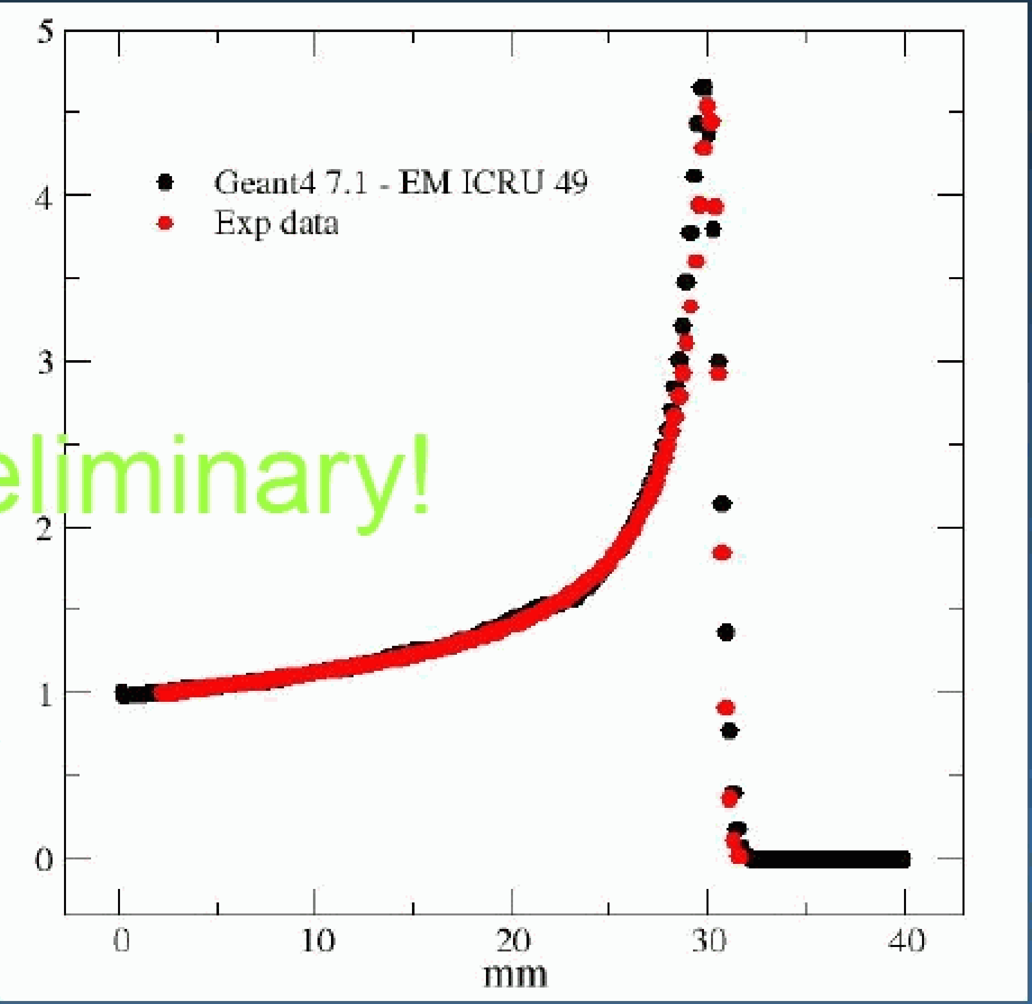

**Relative comparison** (90 deg dir). The shapes ~**agree** →

**More work in progress**

**Statistical analysis to be done**

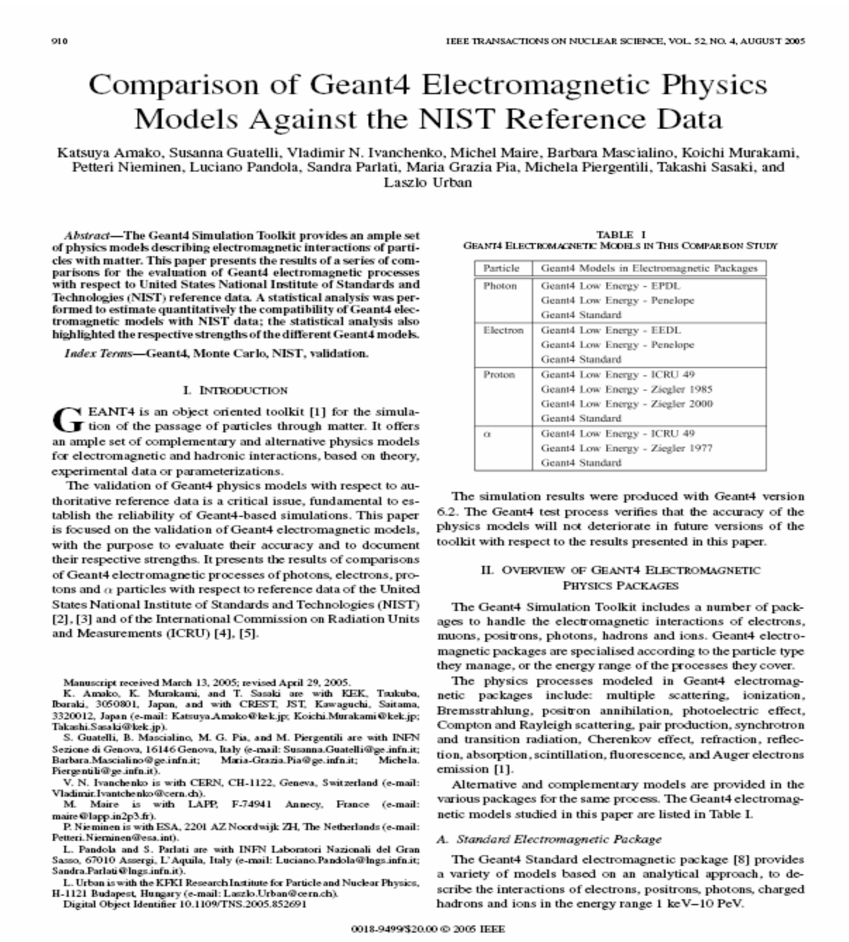
# EM - ICRU 49 + Elastic + Precompound + default Nuclear Deexcitation

| 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 |

# Comparison of Geant4 Electromagnetic Physics Models Against the NIST Reference Data





## Comparison of Geant4 Electromagnetic Physics Models Against the NIST Reference Data

Katsuya Amako, Susanna Guatelli, Vladimir N. Ivanchenko, Michel Maire, Barbara Mascialino, Koichi Murakami, Petteri Nieminen, Luciano Pandola, Sandra Parlati, Maria Grazia Pia, Michela Piergentili, Takashi Sasaki, and Laszlo Urban

*Abstract*—The Geant4 Simulation Toolkit provides an ample set of physics models describing electromagnetic interactions of particles with matter. This paper presents the results of a series of comparisons for the evaluation of Geant4 electromagnetic processes with respect to United States National Institute of Standards and Technologies (NIST) reference data. A statistical analysis was performed to estimate quantitatively the compatibility of Geant4 electromagnetic models with NIST data; the statistical analysis also highlighted the respective strengths of the different Geant4 models.

*Index Terms*—Geant4, Monte Carlo, NIST, validation.

### I. Introduction

GEANT4 is an object oriented toolkit [1] for the simulation of the passage of particles through matter. It offers an ample set of complementary and alternative physics models for electromagnetic and hadronic interactions, based on theory, experimental data or parameterizations.

The validation of Geant4 physics models with respect to authoritative reference data is a critical issue, fundamental to establish the reliability of Geant4-based simulations. This paper is focused on the validation of Geant4 electromagnetic models, with the purpose to evaluate their accuracy and to document their respective strengths. It presents the results of comparisons of Geant4 electromagnetic processes of photons, electrons, protons and $\alpha$ particles with respect to reference data of the United States National Institute of Standards and Technologies (NIST) [2], [3] and of the International Commission on Radiation Units and Measurements (ICRU) [4], [5].

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Digital Object Identifier 10.1109/TNS.2005.852691

TABLE I
Geant4 Electromagnetic Models in This Comparison Study

| Particle | Geant4 Models in Electromagnetic Packages |
|---|---|
| Photon | Geant4 Low Energy - EPDL<br>Geant4 Low Energy - Penelope<br>Geant4 Standard |
| Electron | Geant4 Low Energy - EEDL<br>Geant4 Low Energy - Penelope<br>Geant4 Standard |
| Proton | Geant4 Low Energy - ICRU 49<br>Geant4 Low Energy - Ziegler 1985<br>Geant4 Low Energy - Ziegler 2000<br>Geant4 Standard |
| $\alpha$ | Geant4 Low Energy - ICRU 49<br>Geant4 Low Energy - Ziegler 1977<br>Geant4 Standard |

The simulation results were produced with Geant4 version 6.2. The Geant4 test process verifies that the accuracy of the physics models will not deteriorate in future versions of the toolkit with respect to the results presented in this paper.

### II. Overview of Geant4 Electromagnetic Physics Packages

The Geant4 Simulation Toolkit includes a number of packages to handle the electromagnetic interactions of electrons, muons, positrons, photons, hadrons and ions. Geant4 electromagnetic packages are specialised according to the particle type they manage, or the energy range of the processes they cover.

The physics processes modeled in Geant4 electromagnetic packages include: multiple scattering, ionization, Bremsstrahlung, positron annihilation, photoelectric effect, Compton and Rayleigh scattering, pair production, synchrotron and transition radiation, Cherenkov effect, refraction, reflection, absorption, scintillation, fluorescence, and Auger electrons emission [1].

Alternative and complementary models are provided in the various packages for the same process. The Geant4 electromagnetic models studied in this paper are listed in Table I.

*A. Standard Electromagnetic Package*

The Geant4 Standard electromagnetic package [8] provides a variety of models based on an analytical approach, to describe the interactions of electrons, positrons, photons, charged hadrons and ions in the energy range 1 keV–10 PeV.



- IEEE Trans. Nucl. Sci. 52- 4 (2005) 910-918
- Covering all available EM models of Geant4
- Rigorous statistical methods for the comparison of simulated and experimental data distributions

# Validations activities
# in
# Space Applications

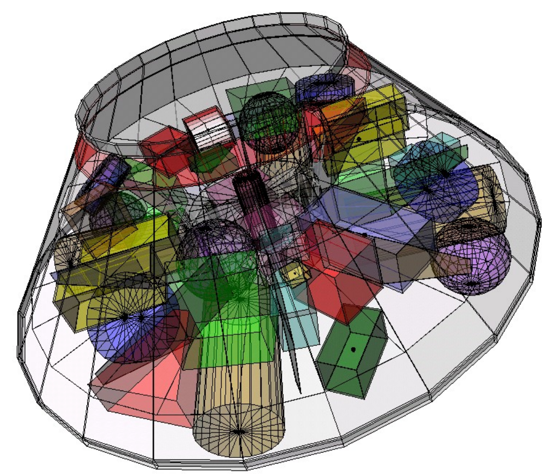
# Comparison of Geant4 Sector-shielding and Monte Carlo Analyses for Space Applications[1]

R. Lindberg, G. Santin, P. Nieminen, H. Evans, E. Daly, June 2006

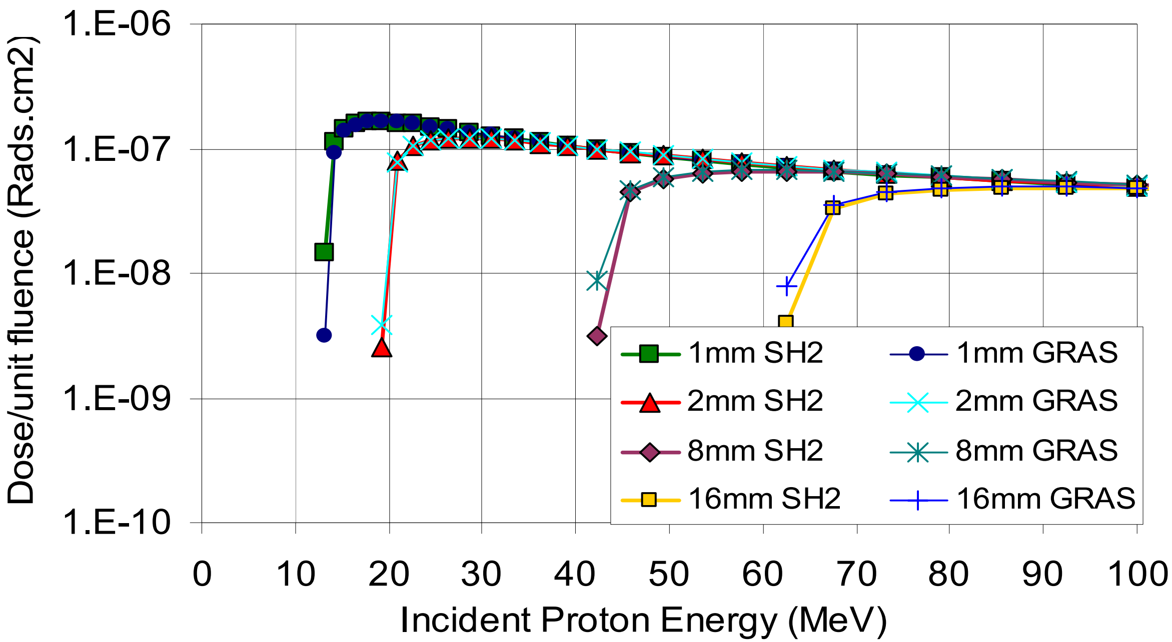
- Compared Total Ionising Dose using Sector-shielding method (SSAT[*,2]) and Monte Carlo method (GRAS[**,3]).
- Geant4 version: 8.0.p01 using standard and hadronics physics
- Comparisons performed on geometries with increasing complexity:
  - Slab
  - Solid Sphere
  - Hollow Box.
  - Realistic Satellite Geometry (ConeXpress ~100 volumes)

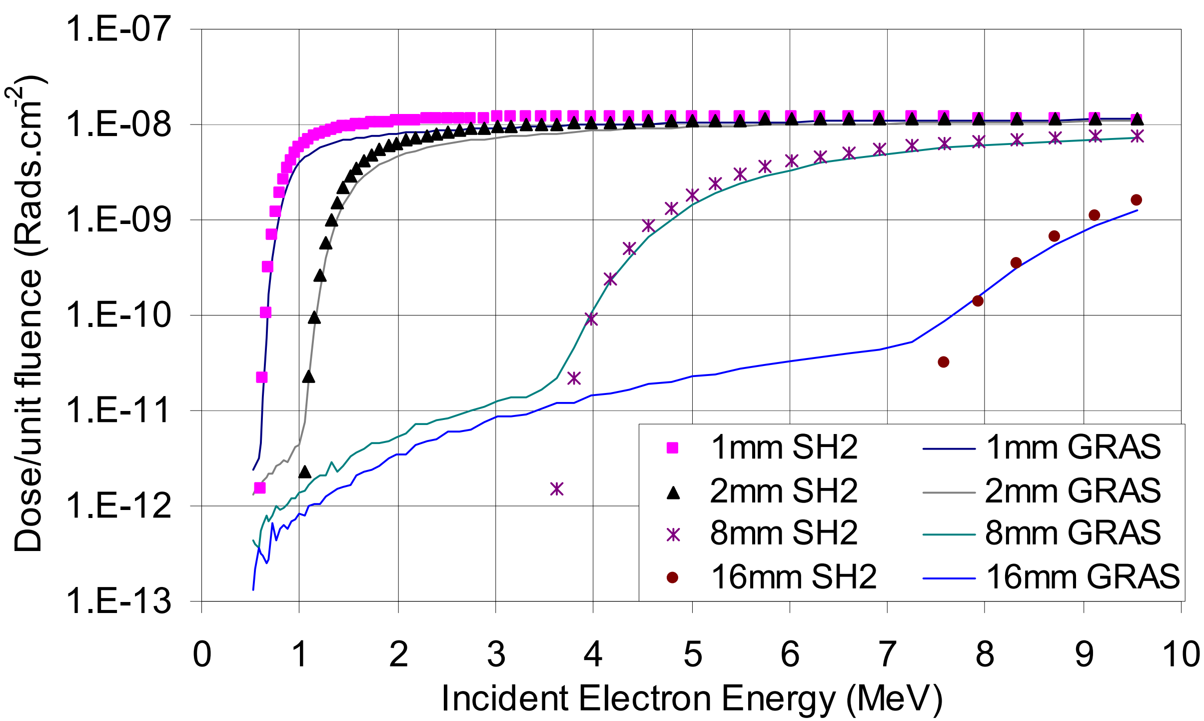
[*] Sector Shielding Analyses Tool (SLANT method)
[**] Geant4 Radiation Analyses for Space.ver 1.3

- Space environment based on 200-day geostationary transfer orbit and ~12 year geostationary orbit.
  - Trapped protons: < 400 MeV
  - Solar protons: < 200MeV
  - Trapped Electrons: < 7 MeV



ConeXpress satellite, modelled in GDML.




- Compared results from mono-energetic particles between GRAS and Shieldose2 (used as dose-depth curve in SSAT)
- Detector is 2 mm Si slab behind 3 mm Aluminium slab.
- As would be expected, protons show very good agreement to within 3%
- For electrons, as incident particle energy increases, agreement is better. Shieldose2 predicting higher dose.

RATIO OF GRAS/SSAT FOR SIMPLE GEOMETRIES IN GTO

| | Thickness | Tr. p (%) | Tr. e (%) | Solar p (%) | Total dose (%) |
|---|---|---|---|---|---|
| **Slab** | 2 mm | 92±0.3 | 60±0.2 | 101±0.1 | 62±0.3 |
| | 7 mm | 81±0.6 | 63±2 | 102±0.2 | 74±2 |
| | 20 mm | 82±0.8 | 61±3 | 102±0.3 | 75±4 |
| **Sphere** | 2 mm | 110±0.7 | 100±0.9 | 111±0.3 | 85±3 |
| | 7 mm | 75±1 | 114±11 | 89±0.5 | 86±11 |
| | 20 mm | 86±2 | 82±39 | 110±1 | 72±12 |
| **Box** | 2 mm | 77±2 | 34±1 | 91±1 | 36±2 |
| | 7 mm | 85±6 | 31±5 | 97±2 | 59±18 |
| | 20 mm | 83±8 | 57±15 | 103±4 | 85±28 |

TOTAL DOSES ON CONEXPRESS SUBSYSTEMS IN GTO

| Subsystem | GRAS TID [rad] | SSAT TID [rad] | Difference (%) (Dssat-Dgras)/Dgras |
|---|---|---|---|
| PCDU | 398 | 824 | 110 |
| DHS Master | 330 | 655 | 100 |
| PPU1 | 637 | 1602 | 150 |
| PPU3 | 473 | 1598 | 240 |
| Star-Tracker1 | 1077 | 5838 | 440 |
| Star-Tracker2 | 1243 | 5871 | 370 |
| DockCamera1 | 470 | 1639 | 250 |
| CaptureTool | 272 | 2539 | 830 |
| Sun-Sensor | 29632 | 47113 | 60 |

Simple 3D geometries:

- Reasonable correlation – between a few per cent (solar protons) to a factor 3 (trapped electrons).

ConeXpress:

- Difference of up to factor 8 for most heavily shielded subsystems

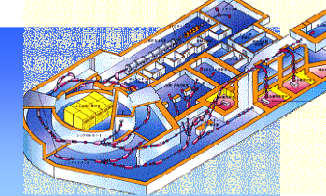
General remarks:

- Protons show better results than electrons → electrons scatter in a more irregular way
- Trend can be seen where higher shielding increases differences
- Largest influence on results seem to be geometry complexity

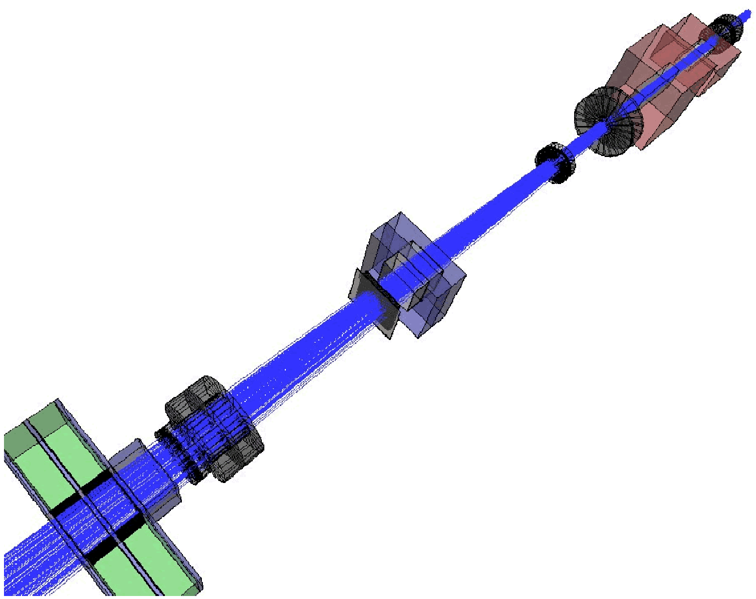
References:

1. R. Lindberg et al., "Detailed Comparison of Monte Carlo Sector-Shielding Analyses for Space Applications", IEEE Trans. Nucl. Sci., accepted for publication.
2. G. Santin et al., "GRAS: A general purpose 3D simulation tool for space environment effects analysis", IEEE Trans. Nucl. Sci. 52, Issue 6, 2005, pp. 2294 – 2299
3. G. Santin et al., "New Geant4 based simulation tools for space radiation shielding and effects analysis", Nuclear Physics B (Proc. Suppl.) 125, pp. 69-74, 2003

# Validation Activities
# in
# Medical Applications



# Results from the recent carbon test beam at HIMAC



Koichi Murakami
Statoru Kameoka

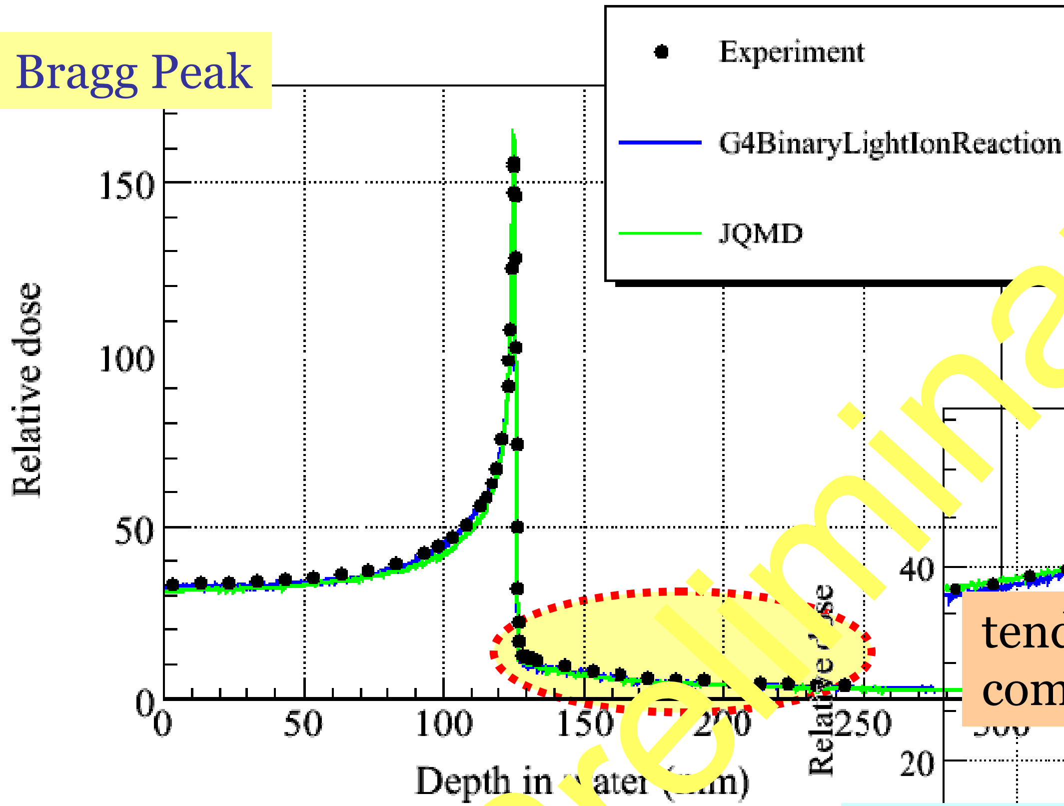
KEK CRC

# Introduction

- A joint project among Geant4 developers, astro-physicists and medical physicists in Japan
  - ✓ *Development of software framework for simulation in radiotherapy*
    - ≫ funded by the Core Research for Evolutional Science and Technology (CREST) program organized by Japan Science and Technology Agency (JST) from 2003 to 2008
- The project goal
  - ✓ provides a set of software components for simulation in radiotherapy (especially hadrontherapy),
    - ≫ well designed general purpose software framework
    - ≫ DICOM/DICOM-RT interface
    - ≫ application of GRID computing technology
    - ≫ visualization tools
  - ✓ In addition, physics validation is one of key issues.

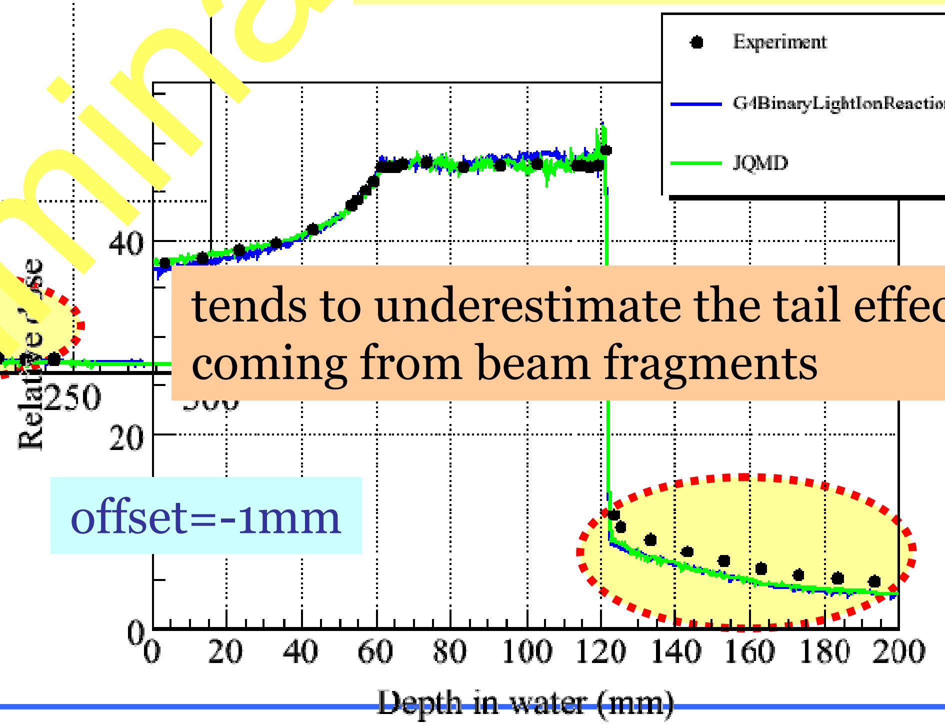
# Comparison between Experiment and Simulation (290 MeV/u)

Bragg Peak




offset=-0.8mm

SOBP
(Spread-Out Bragg Peak)
w/ Ridge Filter

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tends to underestimate the tail effect coming from beam fragments

Many validations are also done by HEP peoples and presented in CHEP06, Calor06, Hadron Shower Simulation Workshop and so on.

Following slides will introduce web pages where help users to find valuable information about Geant4 validations

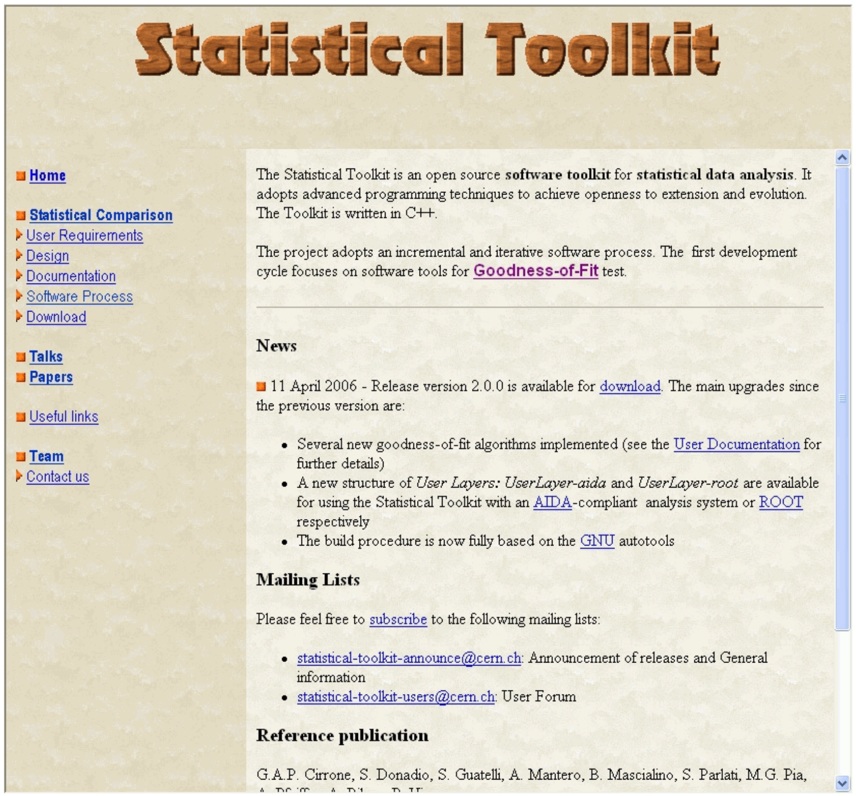
# http://geant4.web.cern.ch/geant4/results/results.shtml


- Official Testing and Validation page of Geant4 collaboration
- However most contents are
  - Out of link
  - Out of date
- Should be update soon and must be well maintained.

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

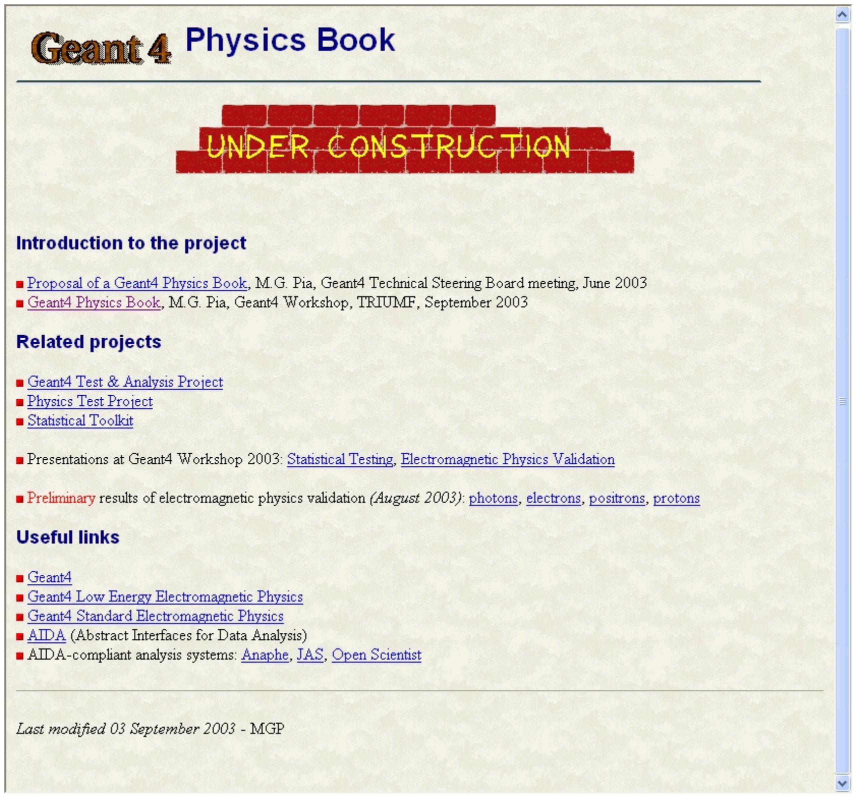

- Low Energy Electromagnetic Physics Working group web page
- Wide variety of information are available including validation results

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



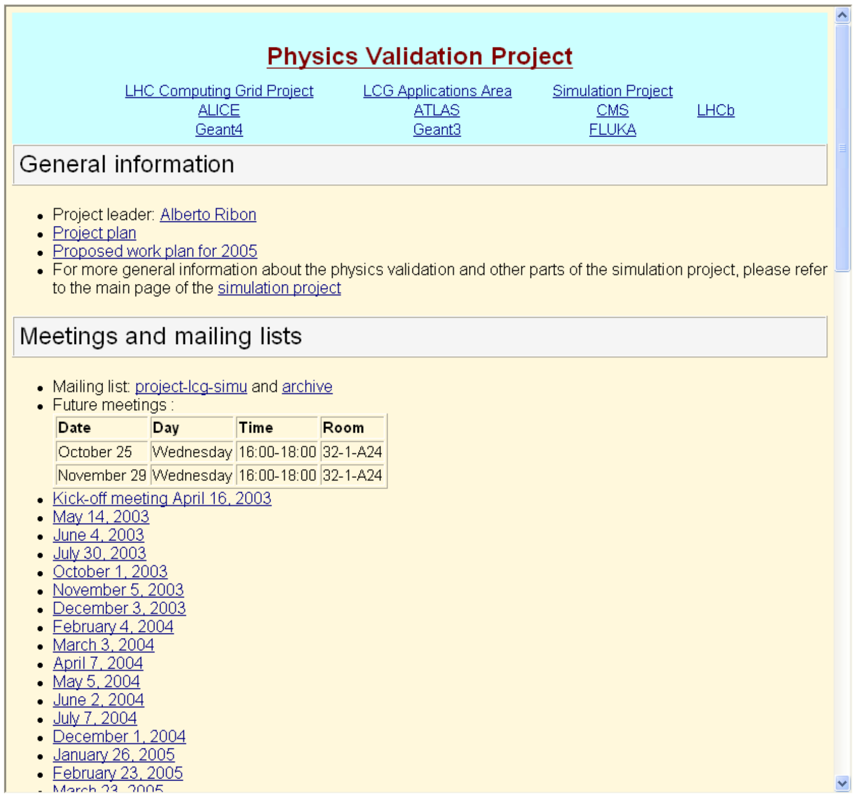

- Statistical Toolkit web page
- It is an open source software toolkit for statistical data analysis

# Geant4 Physics Book




- Provide the quality of Geant4 physics to users
- Focus to validations
- To complement Physics Reference Manual of Geant4
- Contents should have publication-level quality
- This project in progress

# http://lcgapp.cern.ch/project/simu/validation/



Physics Validation Project

LHC Computing Grid Project LCG Applications Area Simulation Project
ALICE ATLAS CMS LHCb
Geant4 Geant3 FLUKA

General information

- Project leader: Alberto Ribon
- Project plan
- Proposed work plan for 2005
- For more general information about the physics validation and other parts of the simulation project, please refer to the main page of the simulation project

Meetings and mailing lists

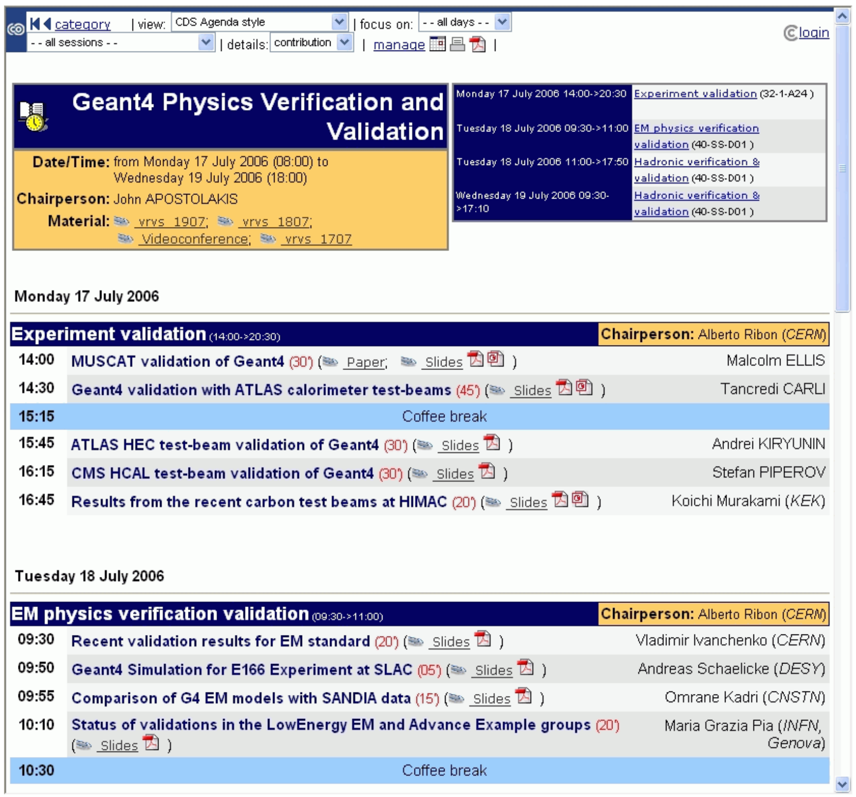
- Mailing list: project-lcg-simu and archive
- Future meetings :

| Date | Day | Time | Room |
|---|---|---|---|
| October 25 | Wednesday | 16:00-18:00 | 32-1-A24 |
| November 29 | Wednesday | 16:00-18:00 | 32-1-A24 |

- Kick-off meeting April 16, 2003
- May 14, 2003
- June 4, 2003
- July 30, 2003
- October 1, 2003
- November 5, 2003
- December 3, 2003
- February 4, 2004
- March 3, 2004
- April 7, 2004
- May 5, 2004
- June 2, 2004
- July 7, 2004
- December 1, 2004
- January 26, 2005
- February 23, 2005

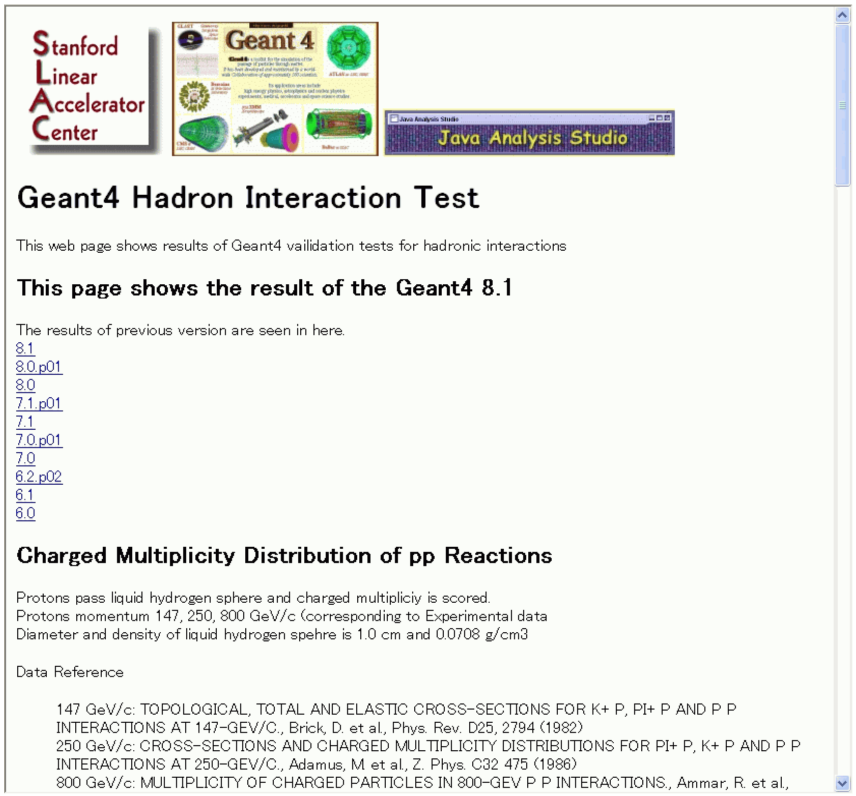
- LCD Physics Validation Project Web page
- Slides library of previous meetings is quite useful
- Also has many useful links
- HEP oriented

http://indico.cern.ch/conferenceDisplay.py?confId=4532




- Web page of “Geant4 Physics Verification and Validation Workshop” on July 2006
- Not only Geant4 developers but also several HEP experiment group presented their validations

# http://www.slac.stanford.edu/~tkoi/G4HadInt.html



Stanford Linear Accelerator Center

Geant 4

Java Analysis Studio

## Geant4 Hadron Interaction Test

This web page shows results of Geant4 vailidation tests for hadronic interactions

### This page shows the result of the Geant4 8.1

The results of previous version are seen in here.
8.1
8.0.p01
8.0
7.1.p01
7.1
7.0.p01
7.0
6.2.p02
6.1
6.0

### Charged Multiplicity Distribution of pp Reactions

Protons pass liquid hydrogen sphere and charged multipliciy is scored.
Protons momentum 147, 250, 800 GeV/c (corresponding to Experimental data
Diameter and density of liquid hydrogen spehre is 1.0 cm and 0.0708 g/cm3

Data Reference

147 GeV/c: TOPOLOGICAL, TOTAL AND ELASTIC CROSS-SECTIONS FOR K+ P, PI+ P AND P P INTERACTIONS AT 147-GEV/C., Brick, D. et al., Phys. Rev. D25, 2794 (1982)
250 GeV/c: CROSS-SECTIONS AND CHARGED MULTIPLICITY DISTRIBUTIONS FOR PI+ P, K+ P AND P P INTERACTIONS AT 250-GEV/C., Adamus, M et al., Z. Phys. C32 475 (1986)
800 GeV/c: MULTIPLICITY OF CHARGED PARTICLES IN 800-GEV P P INTERACTIONS., Ammar, R. et al.,

- Hadron Physics
  - pp interactions
  - nucleus-nucleus interactions
- EM Physics
  - Multiple Coulomb Scattering
  - Thin Layer Energy Loss
  - Multi Layer Faraday Cup
- Medical related validations
- And so on

# Summary

- Many validations are done by not only developers but also users.
- However, there is no place where are collecting those results and activities. This situation make it difficult that a user find a validation of his/her interested.
- “Testing and Validation” in Geant4 web site is the first candidate to become such a place. However it looks like left without maintenances. It should be re-organized and muse be maintained well in the future.
- The results are reasonably well in most cases, however we still discover unexpected disagreements. E.g. Visible Energy of Sampling Calorimeter.
- Future development of Geant4 should be pursed in a collaboration with these validation activities.