Geant4 Hadronics Overview (DRAFT 070417)

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Outline

- Geant4 Hadronic Physics Working Group
- Hadronic model inventory
- Hadronic framework
  - Theory driven models
  - Data driven models
  - Parametrization driven models
  - Physics lists
- Recent developments
- Future plans

Following items are not discussed here:

- Hadronic physics validation (covered by Dennis Wright)
- Phycisc lists (Gunter Folger)
- Shower shape issue (Alberto Ribon)
- CHIPS (Mikhail Kossov)

Group Members

- Aatos Heikkinen (Helsinki Institute of Physics) - coordinator
- Dennis Wright (SLAC) - coordinator
- Makoto Asai (SLAC)
- Gunter Folger (CERN)
- Alexander Howard (CERN)
- Vladimir Ivantchenko (ESA, CERN)
- Tatsumi Koi (SLAC)
- Mikhail Kossov (CERN)
- Fan Lei (Qinetiq)
- Maria Grazia Pia (INFN, CERN)
- Alberto Ribon (CERN)
- Nikolai Starkov (CERN)
- Peter Truscott (Qinetiq)

(Hadronic Physics Working Group web-page http://geant4.web.cern.ch/geant4/collaboration/working_groups/hadronic/)

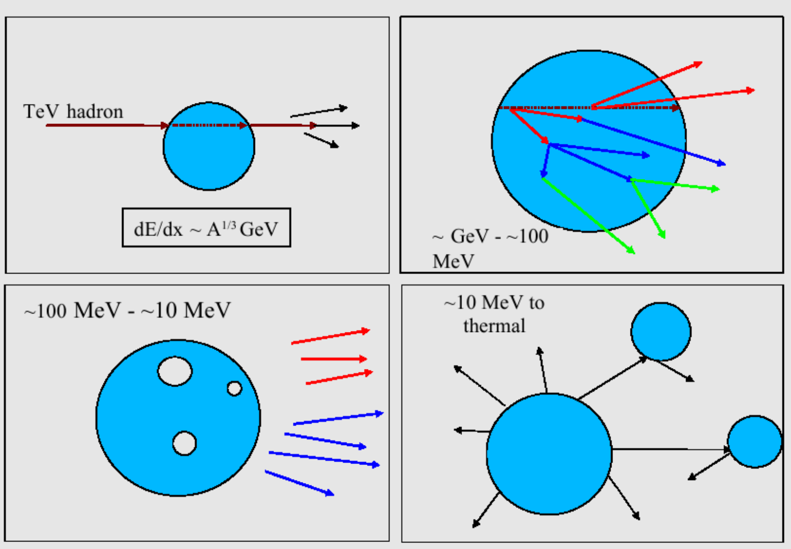
New Group Members

- Giacomo Cuttone (Researche Chief at Laboratori Nazionali del Sud, INFN Catania)
- Pablo Cirrone (INFN Catania)
  - Medical applications and measurements of nuclear fragment production for C ion on different targets (0-400 AMeV)
  - Participates on behalf of Geant4 to IAEA initiative to standardize the use of nuclear data for simulating nuclear interactions in charged particle radiation therapy applications
- Alain Boudard (CEA Saclay) - Original developer of Liegé cascade

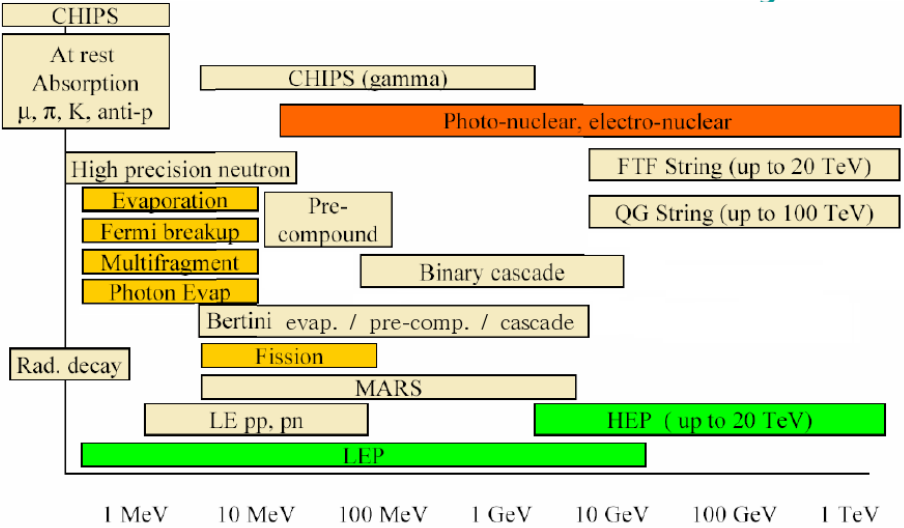
PhD students starting this summer 2007:

- Pekka Kaitaniemi (HIP, CEA) - INCL/ABLA models in Geant4
- Francesco Romano (INFN Catania)
  - Ligh evaporated particles with Geant4 pre-equilibrium and evaporation models
  - Implications to hadronic treatment

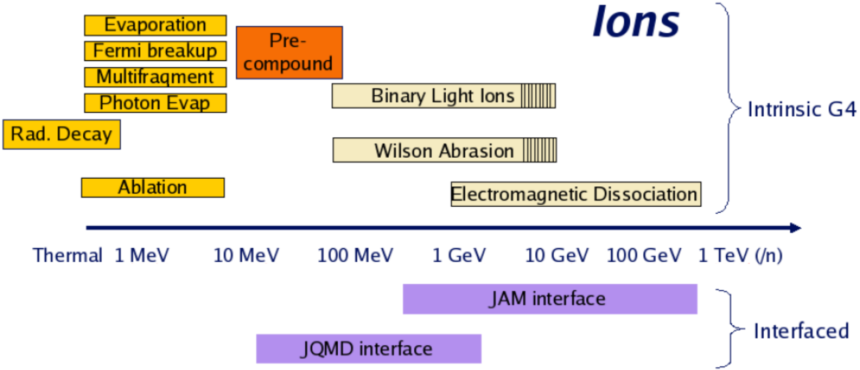
Modelling hadronic physics in keV – TeV energy range



Hadronic model inventory



Existing Geant4 Nuclear-Nuclear Final State Models



EPAX model also compared with above but not interfaced (REAT-MS)

(from T Koi, 28/07/06)

Model details are decumented in Geant4 Reference Manual

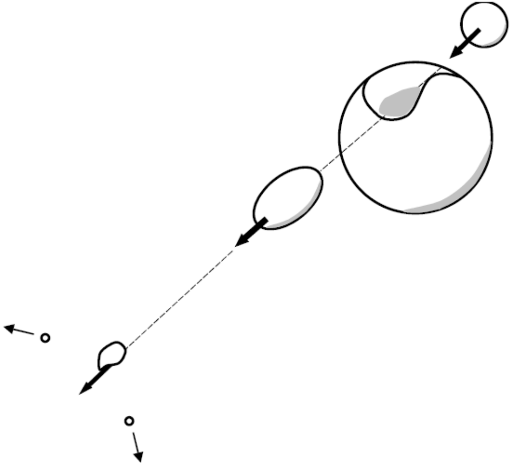


Figure 26.1: In the abrasion process, a fraction of the nucleons in the projectile and target nucleons interact to form a fireball region with a velocity between that of the projectile and the target. The remaining spectator nucleons in the projectile and target are not initially affected (although they do suffer change as a result of longer-term de-excitation).

Wilson abrasion model. (http://geant4.web.cern.ch/geant4/UserDocumentation/UsersGuides/PhysicsReferenceManual/html/index.html)

Modular structure of Geant4 hadronic interactions

- Pure hadronic processes valid from 0 to 100 TeV range
- γ μ e - nuclear processes valid from 10 MeV to TeV
- Hadron ionization for charged hadrons
- At rest
  - Stopped μ, π K, anti-proton
  - Radioactive decay
- Elastic
  - Same process for all long-lived hadrons (but different models)
- Inelastic
  - Different process for each hadron
  - Photo-nuclear, electro-nuclear, muon-nuclear
  - Ions
- Capture
  - Example: neutron capture
- Fission
  - Neutron-induced

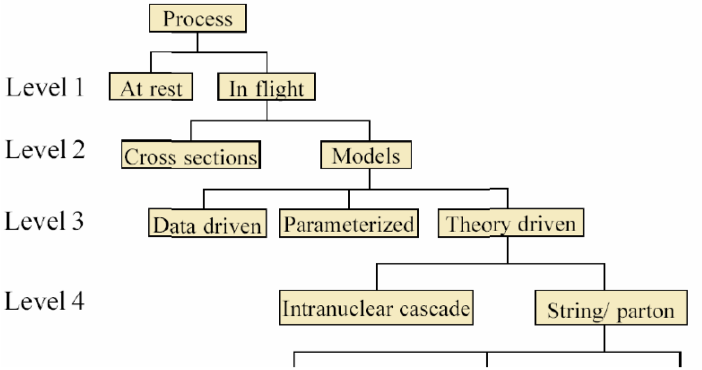
Cross sections – Hadronic framework

- Default cross section sets are provided for each type of hadronic process:
  - Fission, capture, elastic, inelastic
  - Hadronic framework provides mechanism to override or replace these data sets
- Different types of cross section sets:
  - Some contain only a few numbers to parametrize cross section
  - Some represent large databases (data driven models)
  - Some are not yet fully exposed to framework (such as Bertini data)

Alternative cross sections:

- Low energy neutrons
- Neutron and proton reaction cross sections
  - 20 MeV $<$ E $<$ 20 GeV
- Ion-nucleus reaction cross sections

Hadronic framework - levels



(J.P. Wellisch, Hadronic shower models in GEANT4 – the frameworks, Comput. Phys. Commun. 140 (2001) 65–75)

Theory driven models

- Dominated by theory
  - QCD
  - strings
  - chiral perturbation theory
- Data used mainly for normalization and validation
- Final states determined by sampling theoretical distributions
- Theory driven models are ofte CPU intensive

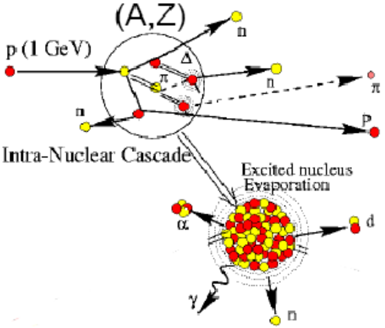
Physics lists

Geant4 philosophy implies the usage of physics lists.
Physics lists provide wanted collection of models such as:

- Parton string models at high energies
- Intra-nuclear transport models at intermediate energies
- Statistical break-up models for de-excitation

Bertini intra-nuclear cascade as an example of theory driven model

Bertini provides a collection of theory driven models with parametrization features $E < 3 GeV$



Models included:

- Bertini INC model with exitons
- Internal pre-equilibrium model
- Nucleus explosion model
- Fission model
- Evaporation model

(Bertini models are provided in physics lists: LHEP_BERT, LHEP_BERT_HP, QGSP_BERT, and QGSP_BERT_HP).

Parametrization driven models

- Depends on both data and theory:
  - Enough data to parametrize cross sections, multiplicities, angular distributions
- Final states determined by theory, sampling:
  - Use conservation laws to get charge, energy, etc.
- Examples:
  - Fission
  - Capture
  - GEISHA based models LEP, HEP

GEISHA as an example of parametrization driven model

- Based on GHEISHA package of Geant3.21, two sets of models exist for inelastic scattering of particles in flight:
  - Low energy models:
    - E $<$ 40-50 GeV
- High energy models:
  - 50 GeV $<$ E $<$ O(TeV)
- Original approach to primary interaction, nuclear excitation, intra-nuclear cascade and evaporation is kept
- Fission, capture and coherent elastic scattering are also modeled through parametrized models

Data driven models

- Characterized by lots of data:
  - Cross section (data tables in code)
  - Angular distribution
  - Multiplicity
- To get interaction length and final state, models simply interpolate data:
  - Usually linear interpolation of cross section, and Legendre polynomials
- Examples:
  - Coherent elastic scattering (pp, np, nn)
  - Radioactive decay
  - Neutrons ($E < 20$ MeV) (separate database is provided)

Recent developments in Geant4 hadronics

[TO BE DONE: add material from slac-pub-12348]

- The Bertini-INUCL cascade is extended to projectiles with strangeness
- New, better CHIPS models for stopping particles
- As usual, improved physics models, have been made available in physics model configurations (physics lists)

(D. Wrigth et al.: *Recent Developments and Validations in Geant4 Hadronic Physics*, SLAC-PUB-12348. http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-12348.pdf)

Hadronic physics plans

Priorities for Geant4 hadronic physics development are:

- Inclusion of new Fritiof fragmentation (FTF) diffraction model
- Releasing INCL4/ABLA models
- Improved coupling of binary cascade to precompound model
- Completion of Glauber-Gribov cross-sections
- Bertini
  - Improvement to Coulomb barrier treatment
  - Sub-model interfaces provided
- Charge exchange process relase
- New parameterized model using HARP data

Hadronic physics plans (cont.)

- CHIPS
  - Low energy simulation of antiproton-nuclear interactions
  - Upgrade of photo- and lepto-nuclear single nucleon production
- Coherent elastic hadron scattering from nuclei:
  - prepare a generator of quasi-elastic hadron-nucleus scattering
- Extend pion cross sections
  - Include more pions and kaons in final state
- Error reporting capability based on hadronic whiteboard to be completed

Hadronic physics plans (cont.)

Moreover Geant4 hadronic physics working group will:

- Continue participating HSSW benchmarking and code comparisons
- Stregthenthe treatment of choosing optimal submodel from various available options
  - Workshop in June 2007 for pre-equilibrium and evaporation models
- Participation IAEA standardisation initiative
- Improve hadronic framework usage (Bertini) and increade code reuse of submodels (INCL)
- Optimize the code speed
  - For example we gain factor ≈ 2 speedup of Bertini INC after optimization performed by computer specialists at High Performance Computing Unit, Abo Akademi University, Finland

Future Geant4 hadronics attractions: INCL-ABLA (Liége cascade)

INCL4-ABLA Range of application
Beams: π,p,n,d,t,3He,4He
Energies: ~100 MeV- 3 GeV
Targets: Al (C?) - U

Precisions: 10%-20% except identified defects
((p,n) quasielastic, π production, light nuclei…)

Already in transport codes (LAHET-MCNPX-Hermes)

INCL5-NewABLA Improvements
Low energy (down to 50 MeV?)
π production, π beams
Light evaporation residues, light nuclei

All parts separately tested, to be assembled soon
(International Comparison of Spallation Models; late 2007)

Future
Extension up to ~10 GeV
Beams of light ions

Note: (Models to be complemented by coherent scattering (Glauber type) and nuclear structure at low energy)

As experimentalists, a real will (or wish) to have it in GEANT-4

(A. Boudard)

Potential of INCL5 for light nuclear-nuclear physics

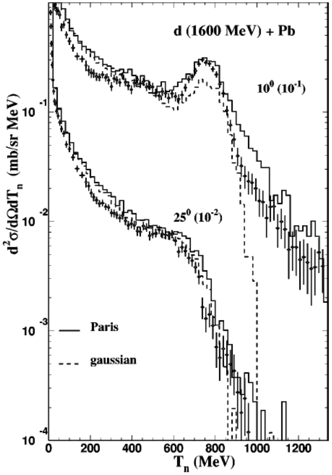
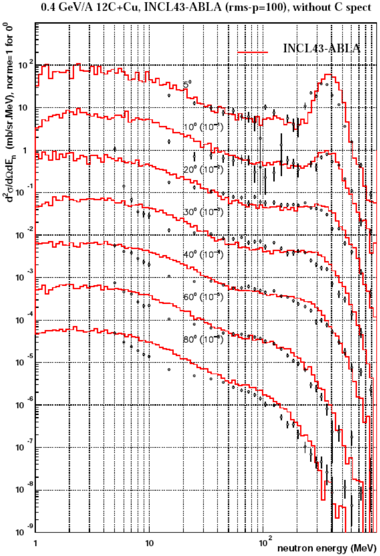


FIG. 22. Neutron double differential cross sections for deuteron-induced reactions on a Pb target at 800 MeV per nucleon incident energy, plotted with a linear energy scale. The predictions of the INCL4 + KHSv3p model are given by the histograms. Two mo-



(A. Boudard et al.)