Geant4 Physics: Status and Plans

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Outline

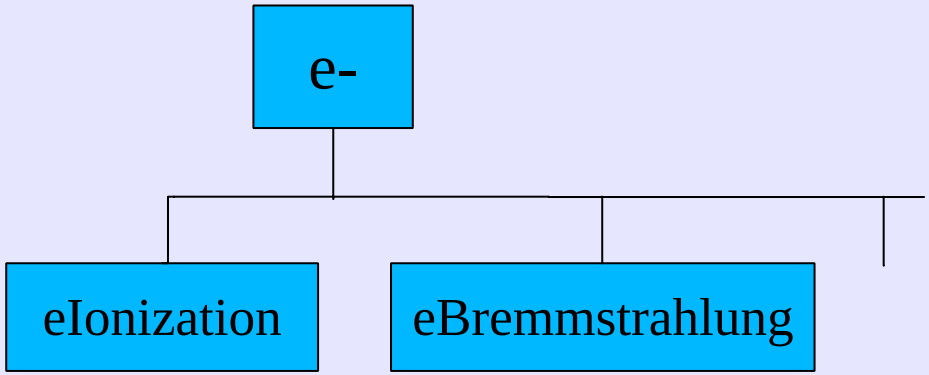
- Electromagnetic physics
  - standard
  - low energy
  - optical
  - parameterized showers
  - validation
- Hadronic physics
  - hadronic models/processes organization
  - high precision neutrons
  - neutrino scattering
  - ion physics
  - physics lists
  - validation

Model Approach to EM Processes

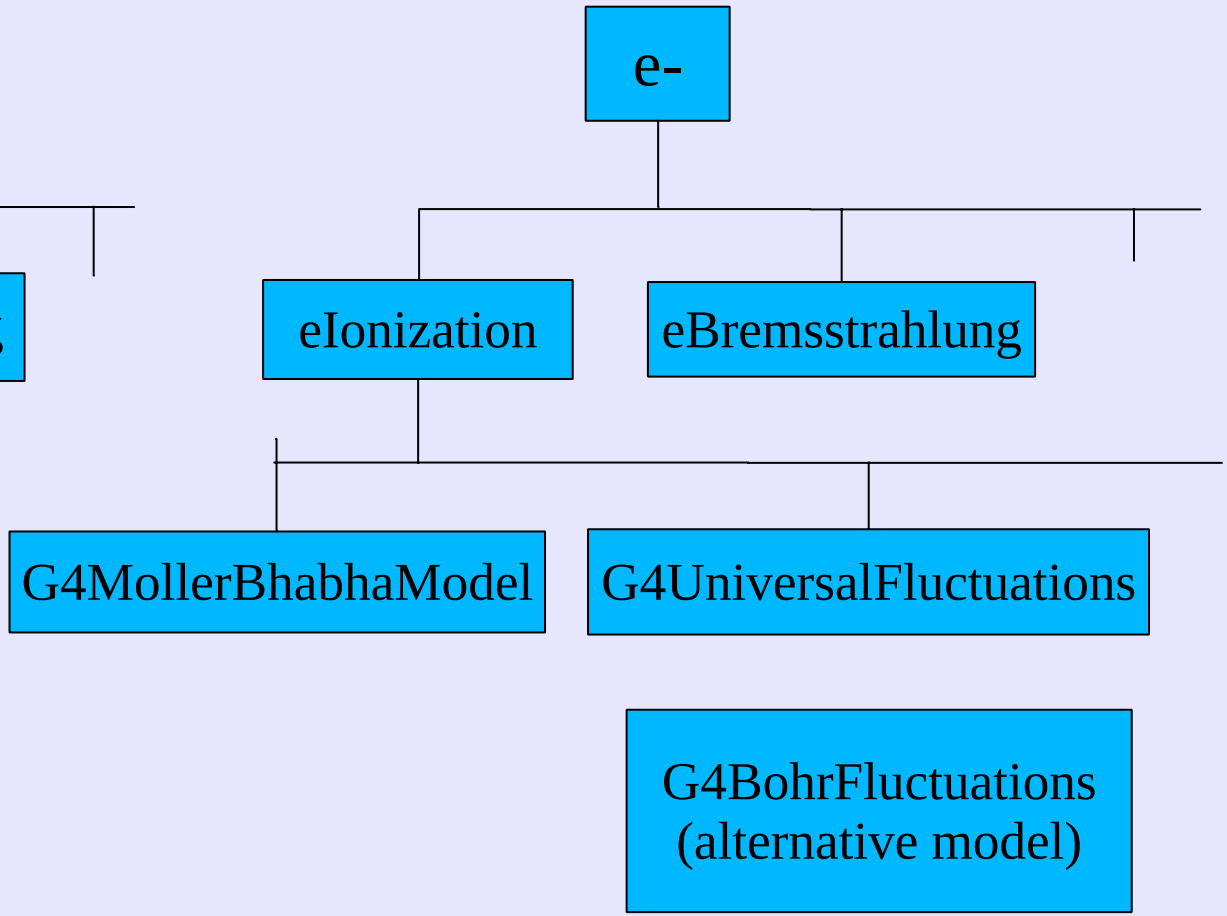
- Past approach: for each physics process there was only one physics model hardwired into the code
- Current approach: one physics process => possibly several physics models which can be interchanged
  - more object-oriented, easier to maintain
- Plan: almost all EM physics processes will have models that can be assigned to the process
  - however, this is currently invisible to the user
  - developers decide for now which model is best

Model Approach to EM Processes

- old way



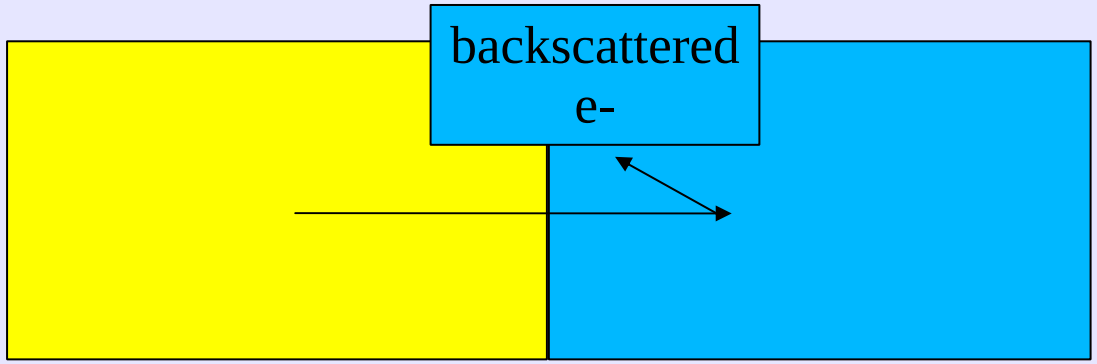
- new way



Range Cut and Stability of Energy Deposit

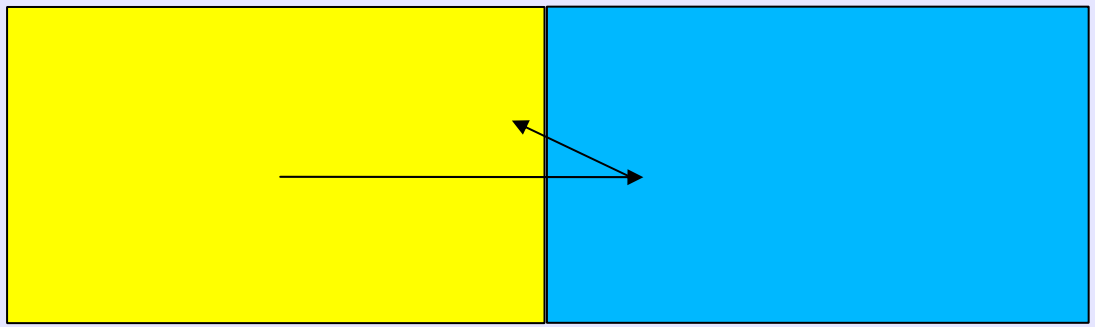
- It was recently discovered that energy deposit in sampling calorimeters was not stable as the range cut was decreased to very small values (100 nm)
- Problem due to insufficient backscattering of low energy electrons
- Problem fixed in Geant4 8.0 by making step size much smaller after a material boundary is crossed

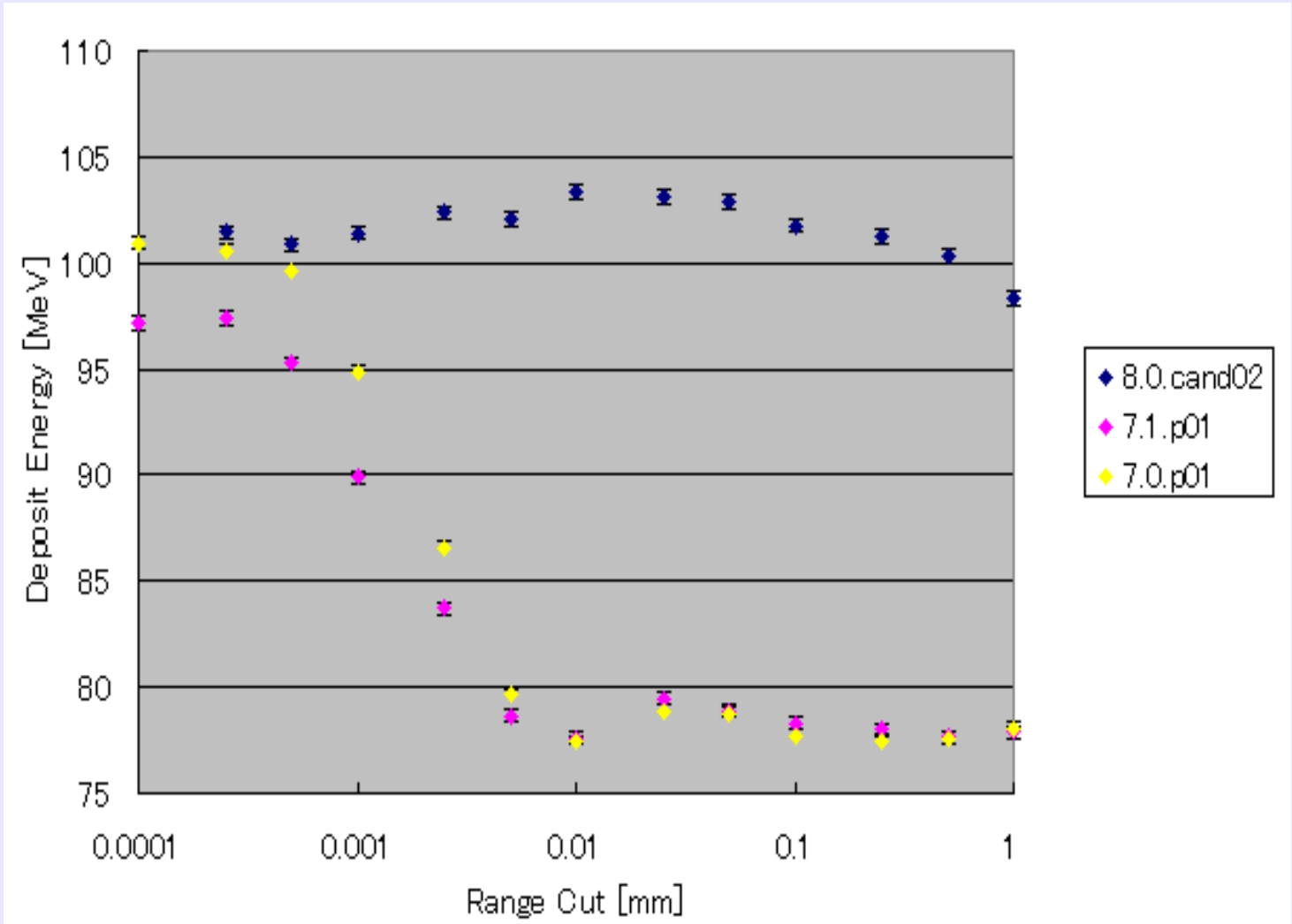
before



low density material high density material

now




110
105
100
95
90
85
80
75
Deposit Energy [MeV]
0.0001
0.001
0.01
0.1
1
Range Cut [mm]
8.0.cand02
7.1.p01
7.0.p01

Standard EM Processes: Plans

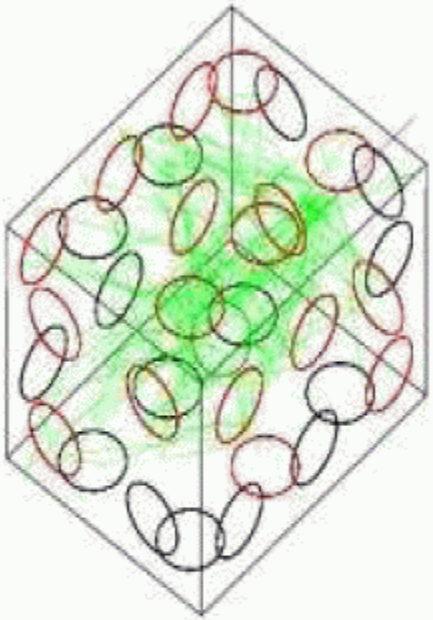
- Further improvement of ionization processes
  - spin and mass effects for muons, pions, kaons
  - tune and verify corrections to hadron and ion ionization
  - allow user to plug in stopping power data
- Alternative multiple scattering processes for different particle types
  - e-, e+, muons, hadrons, ions
- Introduce K-L shell x-rays to photo-electric effect

Low Energy EM Processes

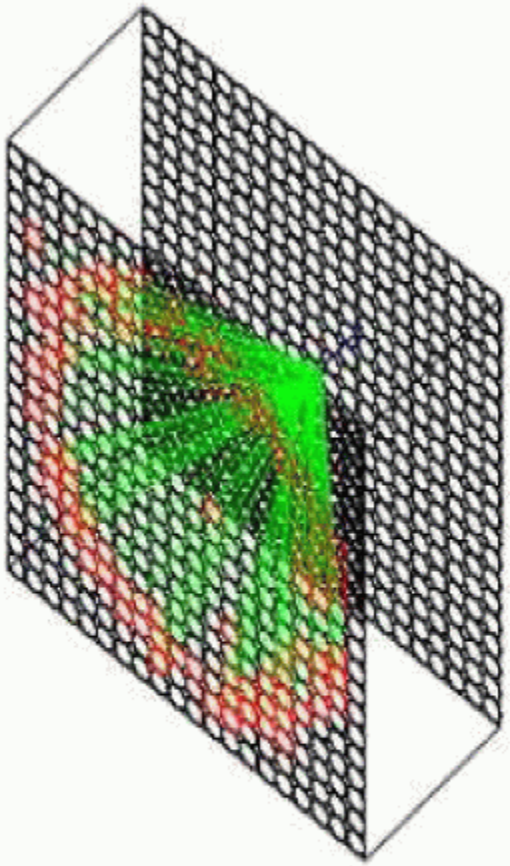
- New process: G4LowEnergyPolarizedRayleigh
  - given initially polarized photon, produces final state polarization
- Plans:
  - Penelope multiple scattering (a low energy alternative to standard multiple scattering)
  - improved angular distribution for photo-electric effect (new model based on Gavrila theory)
  - extension below 250 eV (down to eV scale in water, and other materials if manpower is available)

Optical Photons

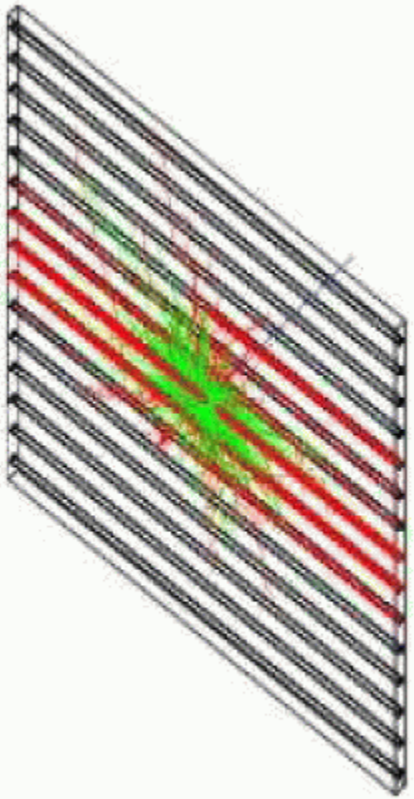
- Available processes:
  - reflection/refraction, bulk absorption, Rayleigh scattering, wavelength shifting
- New examples:
  - Fresnel lens (examples/advanced/air_shower)
  - Cerenkov light, wavelength shifting, scintillation (examples/extended/optical/LXe)



Scintillation



Cerenkov



WaveLengthShifting

Optical Photons: Plans

- New member functions for G4OpBoundaryProcess:
  - allow both specular and diffuse components for transmitted photon
- Micro-facet extension
  - sophisticated surface roughness model
  - reads from a map and decides whether reflection or refraction should occur
- Attached surfaces
  - allow volumes with different optical treatments on different surfaces

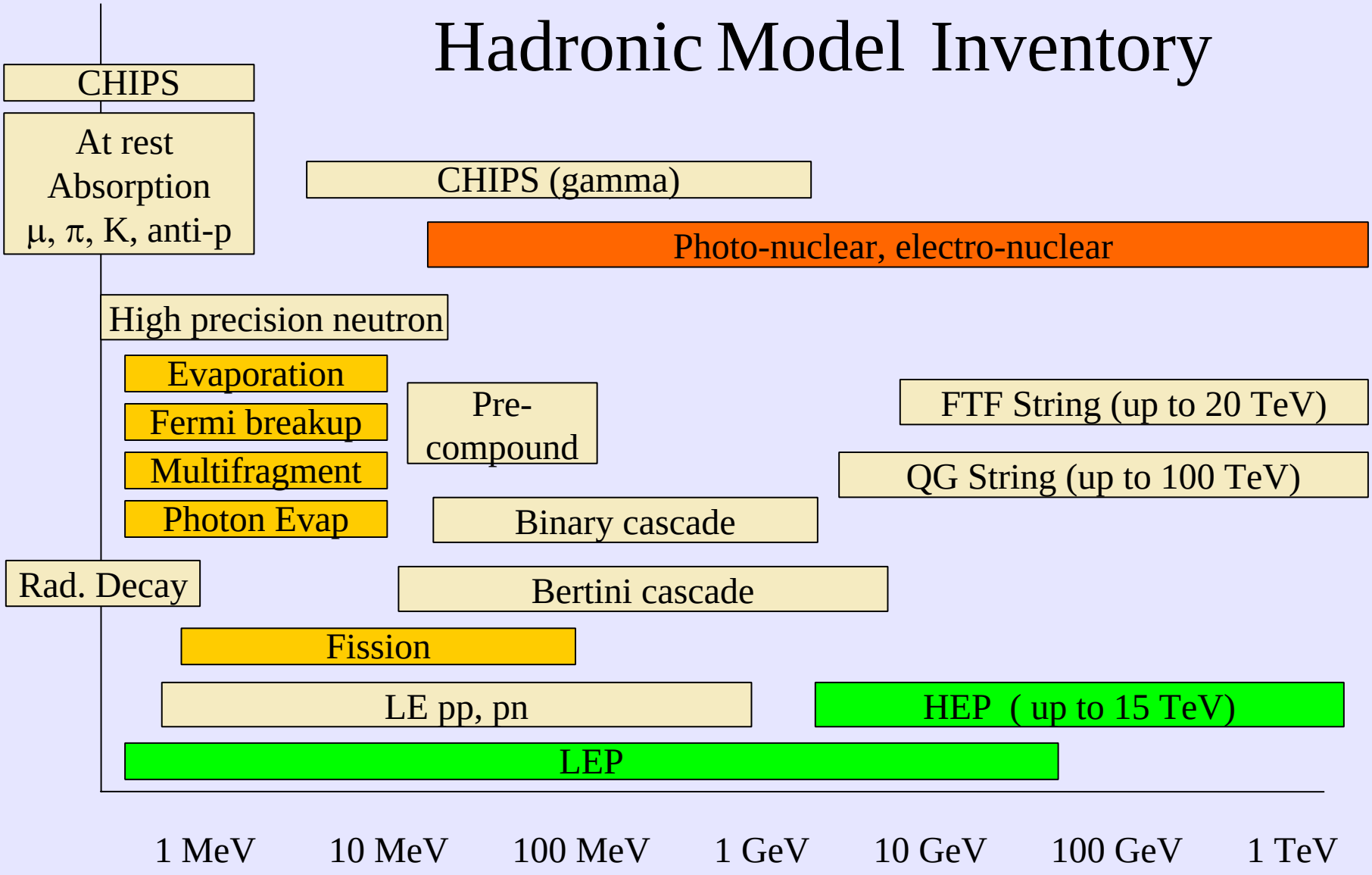
Parameterized Showers

- Detailed simulations of EM showers are very time consuming – try parameterized showers
- New concrete implementation of parameterized EM showers: Gflash
  - uses Grindhammer-Peters method of parameterization
  - energy distribution of a shower can be factorized into single-variable functions of shower depth, distance from shower axis and azimuthal angle
  - actual parameters taken from a full Geant3 simulation
- Results:
  - two orders of magnitude faster for simple geometries
  - < 5 times faster for realistic geometries

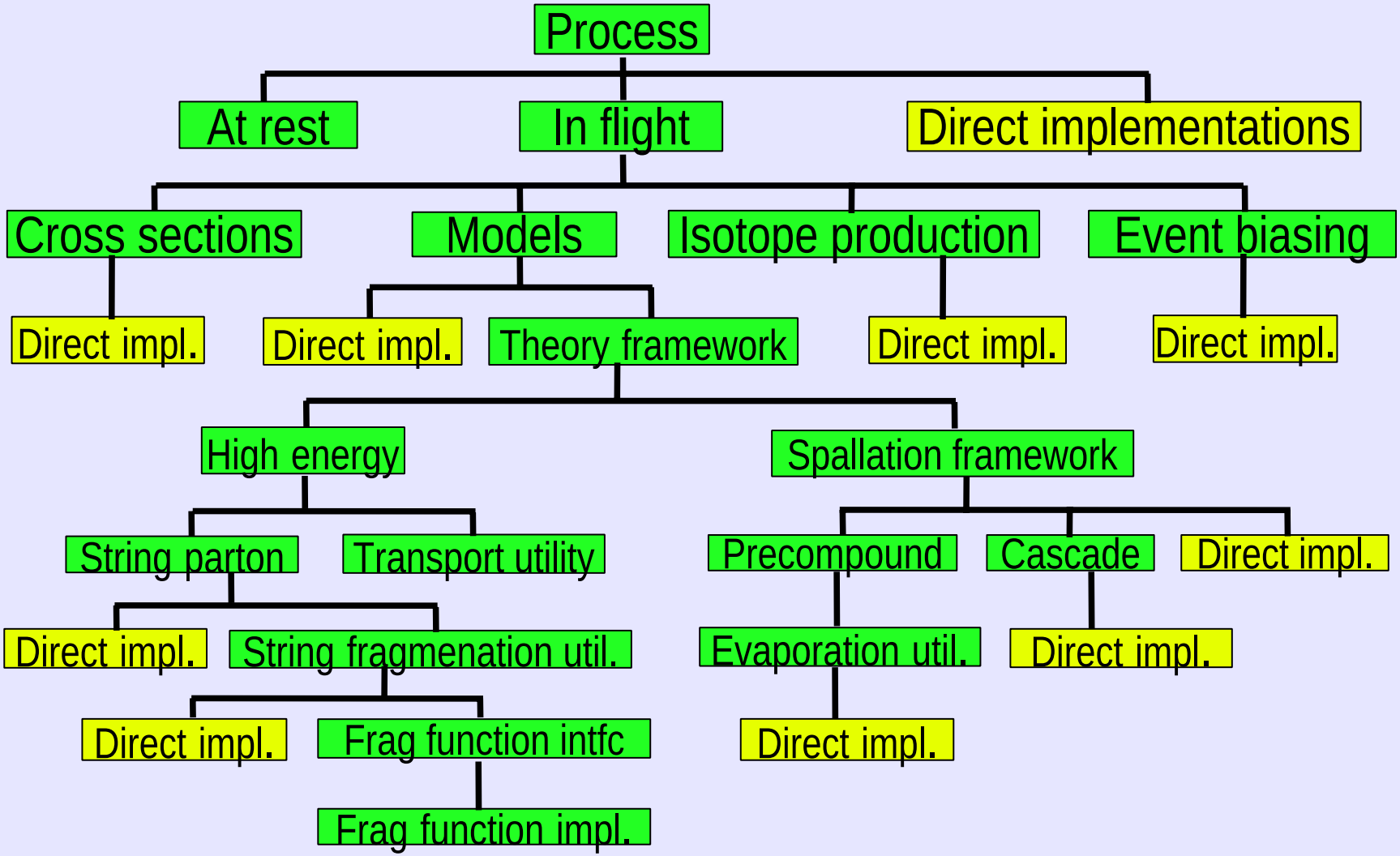
EM Validation

- Validation of electromagnetic processes is the first priority of EM working group this year
- Extensive testing and validation of multiple scattering
  - important due to recent improvements in msc and backscattering
  - multiple scattering regression tests already carried out for each release
- Plan to atomize and systematize existing validation suite
- New web page for verification results

Hadronic Model Inventory



Hadronic Model Organization



High Precision Neutrons

- Data-driven model for neutrons of 20 MeV down to thermal energies:
  - elastic, inelastic, capture, fission available
- Best models to use at low energies, but:
  - slower than other models
  - not all elements are covered, due to lack of data
- Second problem has been fixed => new models:
  - G4NeutronHPorLE
    - when sufficient data exist, NeutronHP models used
    - when insufficient data exist, Low Energy Parameterized models are used

Plans for High Precision Neutrons

- Data files which NeutronHP models use are in G4NDL (G4 Neutron Data Library)
  - it does not contain all elements
  - recently, key element Gd has been added and still more are to be added in near future (at the request of users)
- Extend up to 150 MeV
  - perhaps even extend to protons
- Re-write G4NDL in simpler format
  - depend more heavily on ENDF database
- Documentation of format and users guide planned

Neutrino Physics with CHIPS

- Chiral Invariant Phase Space (CHIPS) model can be applied to many physics processes
  - currently used in Geant4 for photo- and electro-nuclear processes, capture reactions, nuclear de-excitation
- Soon to be applied to neutrino interactions
  - important for many existing and planned neutrino experiments
  - (ν,A) cross section classes are complete for ν_μ , ν_μ -bar
  - already better than V-A fits to data
  - processes available this year

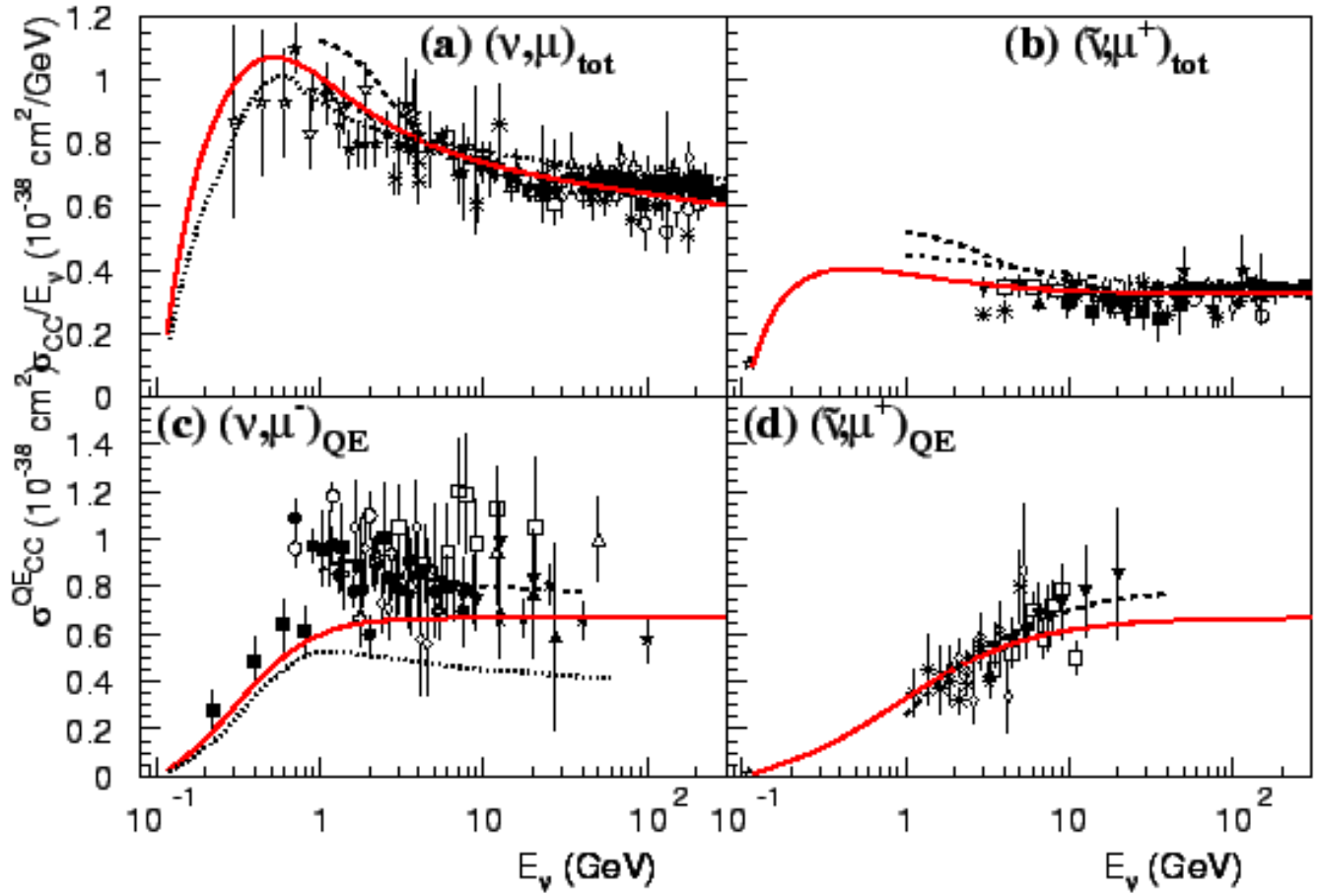


Figure 23.23: Fit of total (a,b) and quasi-elastic (c,d) cross-sections of (ν, μ) reactions (Geant4 database). The solid line is the CHIPS approximation (for other lines see text).

Ion Physics

- A growing part of Geant4 hadronics
- Began with hadronic processes for d, t, alpha at 100 MeV and below
- Now have several models for ion-ion collisions
  - G4BinaryLightIonReaction (< 5 GeV/n, A <= 12)
  - G4WilsonAbrasionModel (< 10 GeV, all A)
- Have improved ion-ion cross sections
  - Sihver, Shen, Kox, Tripathi
- Also have interfaces to JAM and JQMD models
  - for higher incident energy and A

Ion Physics: Plans

- Extend above 5-10 GeV, and to all A
- Long term project: possibly translate some high energy models to C++
- Extend Bertini cascade to use with ions

Physics Lists (1)

- A set of pre-packaged physics lists has been provided for some time by Geant4
  - purpose: to provide examples of how to build a physics list and to provide a starting point for new users
  - not intended to be the authoritative choice of the best physics (user is responsible for this)
- Number of pre-packaged physics lists has recently been reduced (to remove redundancies)
  - offered as part of the Geant4 distribution
  - instructions for using them included in README

Physics Lists (2)

- Many physics lists are available in the examples
  - ranging from simple to very detailed
  - different format than the pre-packaged lists
  - perhaps a better starting point for beginners
- Plans
  - possible re-organization of physics lists
  - validation plots for each list
  - new physics list web page

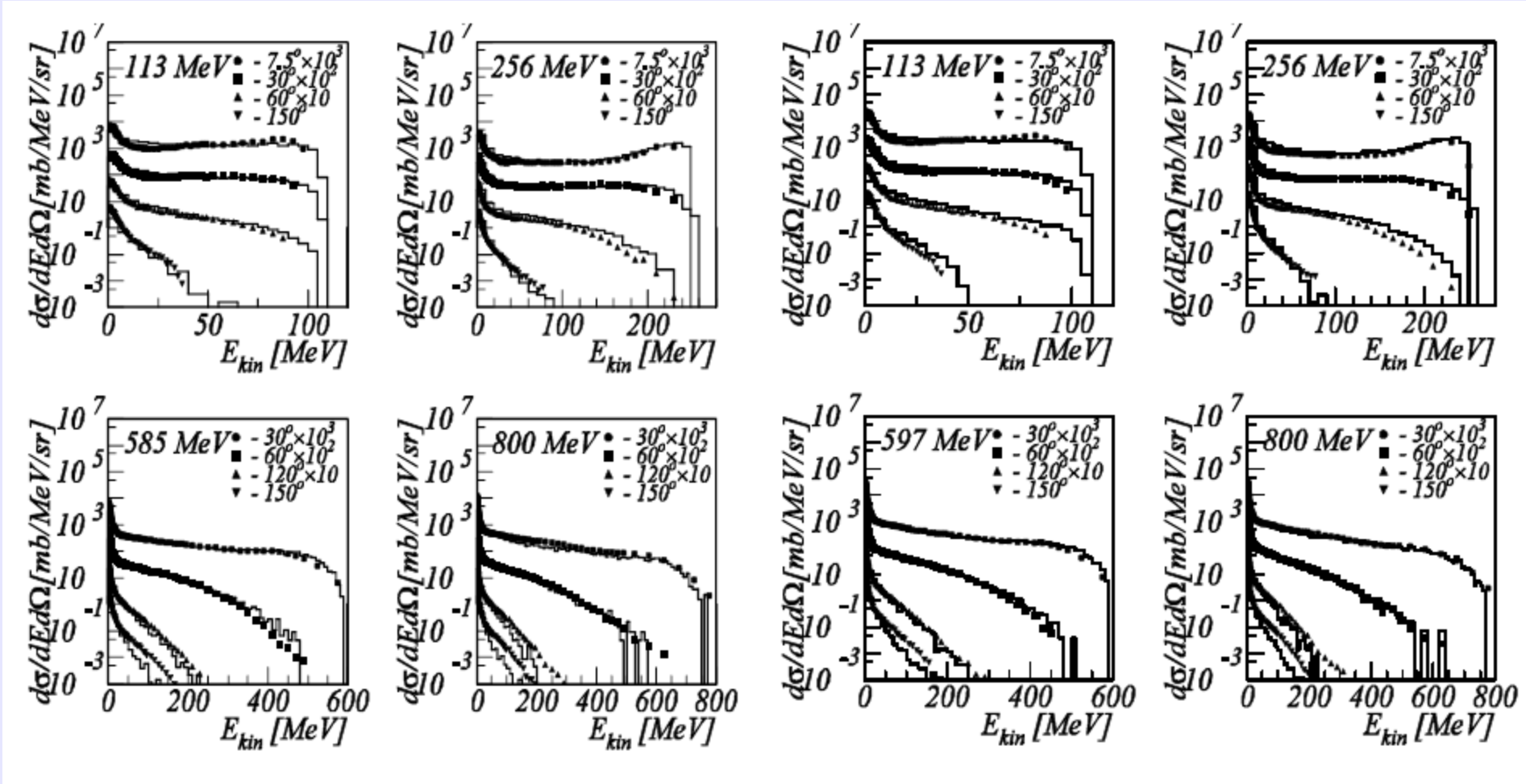
Hadronic Validation

- Extensive validation suite for cascade models
  - for incident energies below 1 GeV
- HARP data to be published soon
  - will test Geant4 hadronic models in the multi-GeV region for the first time
- Validation suite and regression tests planned for
  - Low energy parameterized models
  - High energy parameterized models

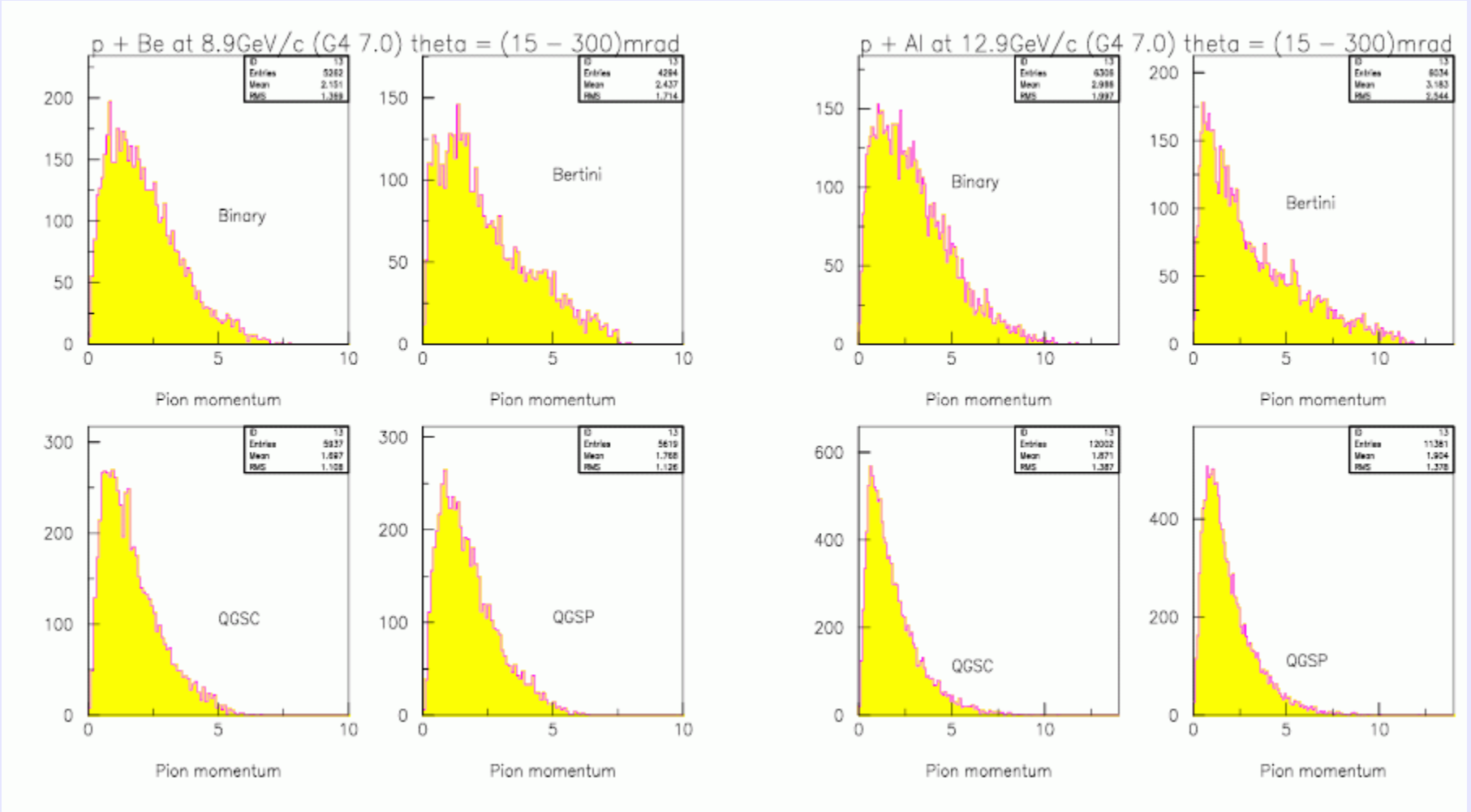
Neutrons Produced by Sub-GeV Protons

Aluminum target

Iron target



Harp Validation (no data yet)



Summary

- Electromagnetic processes now provide stable energy deposit for range cuts down to 100 nm
- Extensive testing and validation of multiple scattering is ongoing, and other validation tests are planned
- New processes and new elements are available in high precision neutron models
- Neutrino scattering will soon be available
- Ion physics will be extended to higher energies
- Hadronic validation tests are ongoing for cascade models, more tests planned for other models