Status of INCL cascade and ABLA evaporation models in Geant4

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Credits

- Pekka Kaitaniemi, HIP (CEA, 2007 November -) (coding)
- Alain Boudard (SphN-DAPNIA, CEA-Saclay, France. Our main contact to INCL.)
- Joseph Cugnon (University of Liége, Belgium. INCL model development.)
- Y. Yariv (SphN-DAPNIA, CEA-Saclay and Soreq, Israël. INCL development)
- ABLA group for kindly providing the code
- Christelle Schmidt, IPNL (for providing a C++ translation of ABLA fission code)

Background

As usual, 2005, Geant4 was actively seeking suitable new models to fully cover various user requirements.

- ▶ *2006*: INCL 4.2 cascade and ABLA v3 evaporation/fission models were agreed to be include into Geant4.
    - ▶ These state-of-the art codes are actively developed and published.
- ▶ *June 2006, CERN*: 1st Geant4 INCL ABLA mini-workshop.
- ▶ *December 2006, CEA*: 2nd meeting setting project time-line and starting translation.
- ▶ *January 2007* : Interfaces released (wrapping FORTRAN code). First test runs by Alex and Alberto.
- ▶ *July*: INCL raw translation ready.
- ▶ *August*: INCL tested. ABLA translated and testing continues.
- ▶ *September*: INCL cvs tag *incl-cand-00* provided for December Geant4 release.

Physical content in short

(A,Z)

p (1 GeV)

Intra-Nuclear Cascade

Excited nucleus
Evaporation

Spallation residue
α, β, γ decay
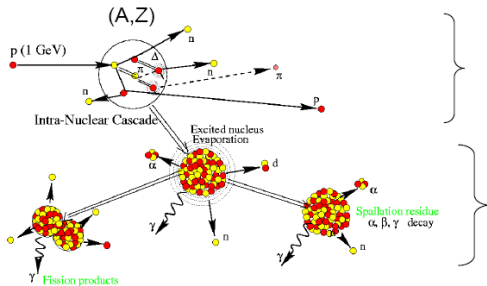
Fission products

Physical module

INCL4

Energetic pions
and nucleons
+ Remnant nucleus
(A,Z,E*,J,P,θ,φ)

Deexcitation
module (ABLA)

Evaporated particles,
Fission products,
Residual nuclei.
(No γ and radioactive decay)

INCL4:

Series of indep. NN interactions ($\lambda_b = h/p$) < ($\Lambda = 1/\rho.\sigma_{NN}.f$) in a potential

NN->NN; NN->NΔ; Δ<=>Nπ; Δ scattering   (No 2π channels)

All particles explicitly followed in time; straight trajectories (no refraction)

r-space density: realistic Wood-Saxon; p-space density: Fermi level.

Pauli blocking (local-statistic) and long range correlation

Stopping time fixed once for ever from emission rates

NO ad hoc PARAMETERS in the MODEL!
(Gives also σ_{Reac} and normalisations)

Physical content in short

INCL4.2	
Bullet particles	proton, neutron
	pions (π^+, π^0, π^-)
	deuteron, triton
	He3, alpha
Energy range	200 MeV - 3 GeV
Target nuclei	
Lightest	Carbon (C)
Heaviest	Uranium (U)
Models	built-in random number generators
	Woods-Saxon potential surface
	Coulomb potential
	non-uniform timestep
	pion and delta production cross sections
	delta decay
	Pauli blocking

ABLA V3	
Supported input	Excited nuclei
Output particles	proton, neutron
	alpha
	nucleus fragment
Models	proton emission
	neutron emission
	alpha emission
	fission

References:

J. Cugnon et al *Nuc. Phys. A352* (1981) 505

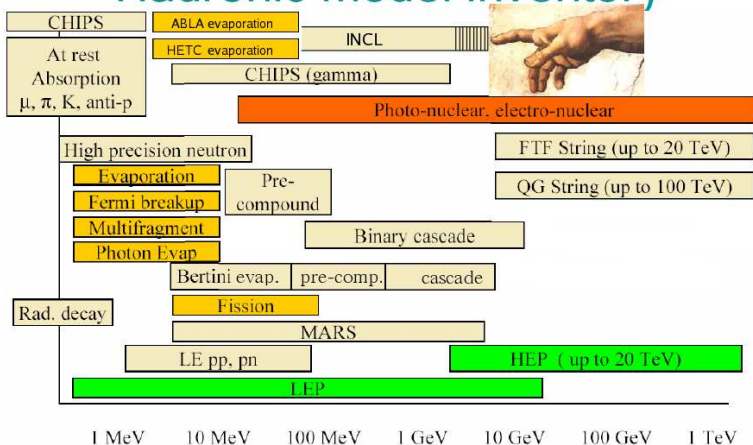J. Cugnon et al *Nuc. Phys. A462* (1987) 751

J. Cugnon et al *Nuc. Phys. A500* (1989) 701

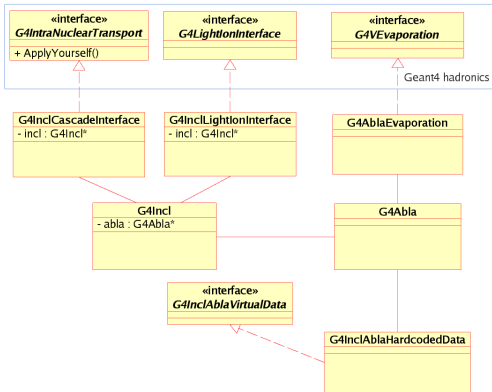A. Boudard et al *Phys. Rev. C66* (2002) 044615

A.R. Junghans et al *Nuc. Phys. A629* (1998) 635

J. Benlliure et al *Nuc. Phys. A628* (1998) 458

Geant4 9.1 Hadronic model inventory

Implementation

- ▶ First implementation of Liège cascade INCL4.2 and ABLA v3 evaporation follows closely original FORTRAN code.

- ▶ *Left:* Models are interfaced to Geant4 using standard hadronic interfaces.

- ▶ For coming releases we will re-design models and include extensions of INCL5 and future ABLA releases.

Implementation

Everything is located at
`hadronic/models/incl/`.

Interfacing to Geant4 hadronic physics
framework:

- **G4InclCascadeInterface**
  `G4HadFinalState* ApplyYourself(`
  `const G4HadProjectile& aTrack,`
  `G4Nucleus& theNucleus);`

- **G4InclLightIonInterface**

- **G4AblaEvaporation**
 (Not yet tested; code to be relocated to
  `hadronic/models/abla`)

In this project, we have tested
non-standard tools:

- *Doxygen* for
  documentation system
  (documentation, including
  LaTeX, directly taged in
  code).

- *ROOT* scripting for
  FORTRAN - C++
  verification. (Running
  INCL in hybrid language
  mode, and plotting.)

- *Wiki* technology
  (http://g4inclabla.-
  wikispaces.com) as a
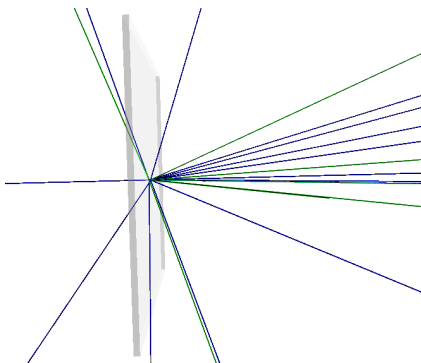 collaborating tool.

n(425 MeV) + 63Cu

p(1GeV) + Pb (3 mm) Geant4 simulation
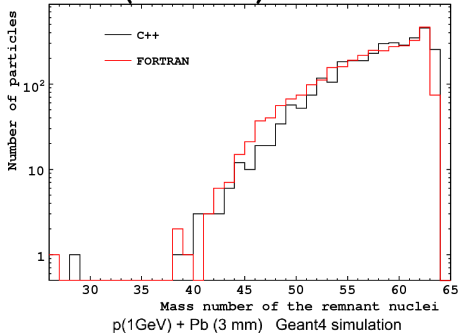
- ▶ *Up:* Validating Geant4 implementation of INCL cascade and ABLA evaporation models.
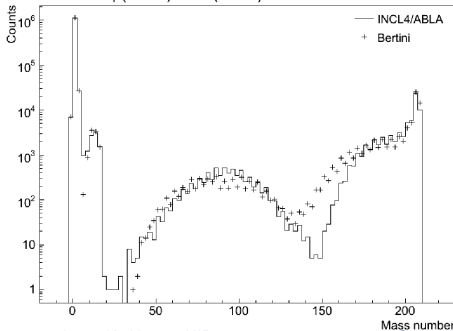
- ▶ *Down:* Comparison of isotope production between Geant4 models Bertini cascade (with evaporation) and INCL4.2 with ABLA v3.

```
INCL4 4.2 C++ thin-target calculation:

Run setup:
Bullet:
          Type: 1
          Energy: 500 MeV
Target:
          A: 208
          Z: 82
Events: 100

Calculation output in ROOT file: ../data/Pb208Proton500MeV100Events.root

Output information:
Total number of events:
          Asked by the user: 99
          Transparent: 47
          Proper cascades: 52
Maximum impact parameter: 10.9878
Geometrical cross-section: 3792.89 mb
Total reaction cross section: 1992.23 mb
```

Release will come with example application utilizing INCL4.2 and ABLA v3 models.

Left: 500 MeV proton projectiles hitting 2 mm Pb target – Geant4 visualization of INCL4.2 model with log from example application.

Future plans

- *September 2007*:
  - Test INCL cvs tag *incl-cand-00* for the December release.
  - Fixing ABLA bugs.
  - CHEP'07 proceedings: A Heikkinen, P Kaitaniemi, A Boudard, *Implementation of INCL4 cascade and ABLA evaporation codes in Geant4*,
- *October*: Prepare a cvs tag for ABLA. Continue removing FORTRAN and C-like features from code.
- *November*:
  - Test final candidate for INCL and ABLA.
  - Workshop to re-design the code (CERN, CEA?). We need to remember that INCL5 C++ will be released also as totally independent code.
- *June 2008*: Fully re-designed INCL and ABLA expect to be released.
- *December 2009*: At least some of the INCL5 extensions (light ion projectiles, low energy) to be released. Updated ABLA?

In conclusion

- ▶ INCL candidate tag is now ready. It contains set of tests, an example application, and a short documentation for Physics Reference Manual.
- ▶ In ABLA testing we have have found problems in fission, yet candidate tag for December release should come in time.
- ▶ We will proceed with re-modeling of INCL code.
  - ▶ A significant requirement/complication is that we want to synchronize design Geant4 and stand-alone C++ version of INCL.
  - ▶ Could we use incl -namespace instead of naming convention G4*?
- ▶ We seem to have now enough manpower to attack these issues:
  - ▶ Pekka Kaitaniemi is starting in November his INCL relates PhD work at CEA.
  - ▶ Also, a significant contribution might come from INFN-Catania. They are interested developing Geant4 capability for Carbon medical beams.
    - ▶ We are planning a mini-workshop latest in November to launch this collaboration.