A tutorial on geant4 hadronic physics (GHAD)

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Program

- How to use GHAD?
- Implications for detector construction.
- A look inside (hadronic) processes, or how to tailor.
- What models and options are available?
- How good is it really?
- Where to find more information.

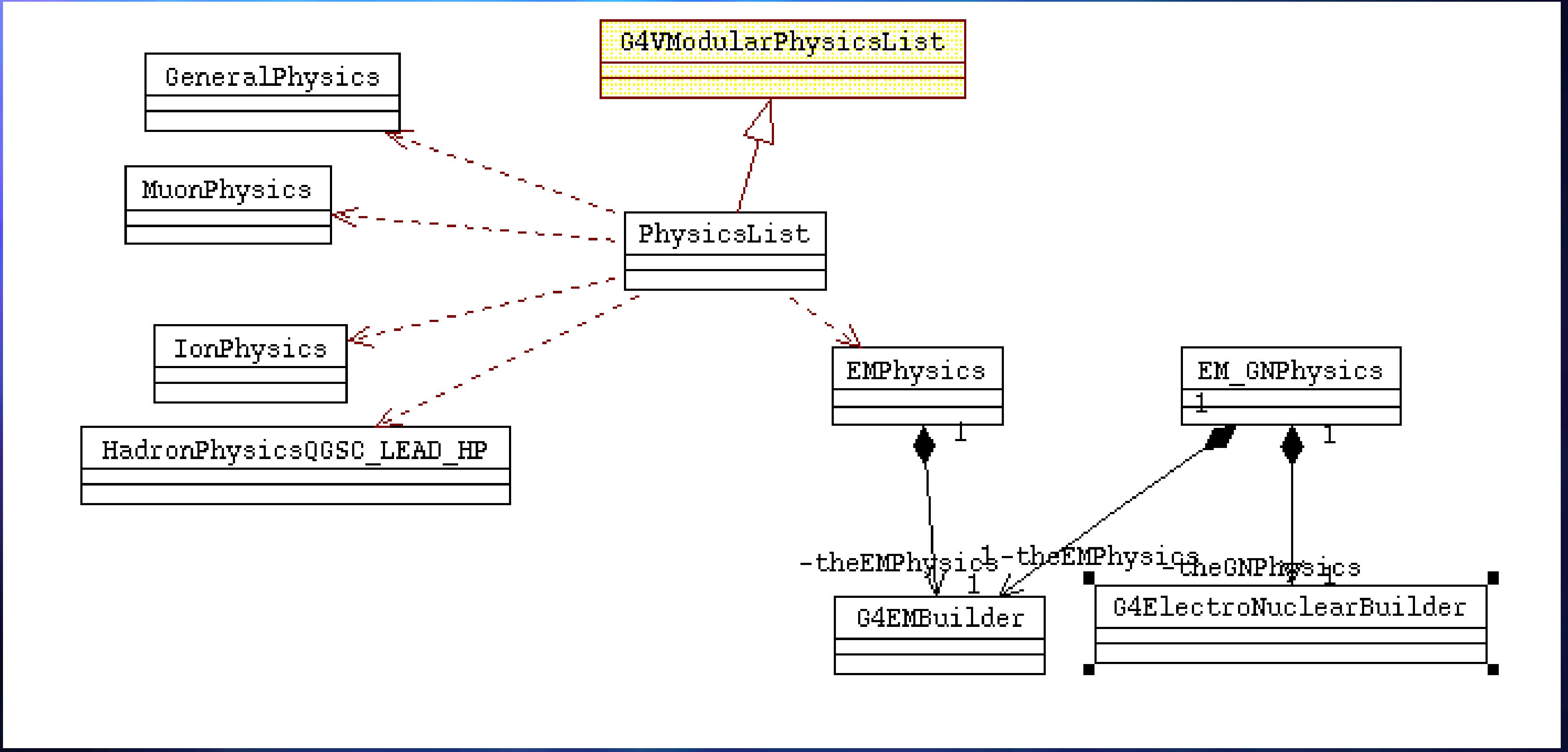
Part 1

How to use GHAD?

Physics lists – defining the physics

- GHAD physics, as all other physics, is used through geant4's physics lists.
- A physics lists is (user) code specifying the complete physics modeling used in your application.
  - Particle types
  - Decays
  - Electromagnetic physics
  - ...
  - Hadronic physics
- It associates processes with particles.

The approach to physics lists



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Geant4 physics lists versus geant3 packages

- In geant4, the physics lists serve the same purpose as the “packages” (GHEISHA, FLUKA, GCALOR) in geant3.
- Conceptually, the two are identical.
  - They provide the physics and its modeling to an application.
  - Each “package” is built of a complete and consistent set of models
- Early in geant4, the idea was that each user would (have to) build ‘his’ package.

In the case if hadronic physics, the problem was complexity.

- It takes 5 levels of implementation framework in geant4 to implement hadronics.
- These, and the models implementing them, are used to assemble the hadronic physics for the simulation engine.
- The number of options is quite large.
- Each comes with trade-offs in descriptive power and performance.
- There are 25 particle species to be tracked, that need complete and consistent physics.

Assume we want to study activation.

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Hence the educated guess physics lists/simulation engines

- It simply became clear that writing a good physics list is no trivial, in particular when hadronic physics is involved.
- It is nice to be able to exploit the full power in the flexibility and variety of hadronic physics modeling in geant4, but being forced to do so is not what we want.
- It is also nice to have the physics transparently in front of you and be able to exploit it in the best possible way, but being forced to understand it all is (very understandably) not what people want, either.

Because of this

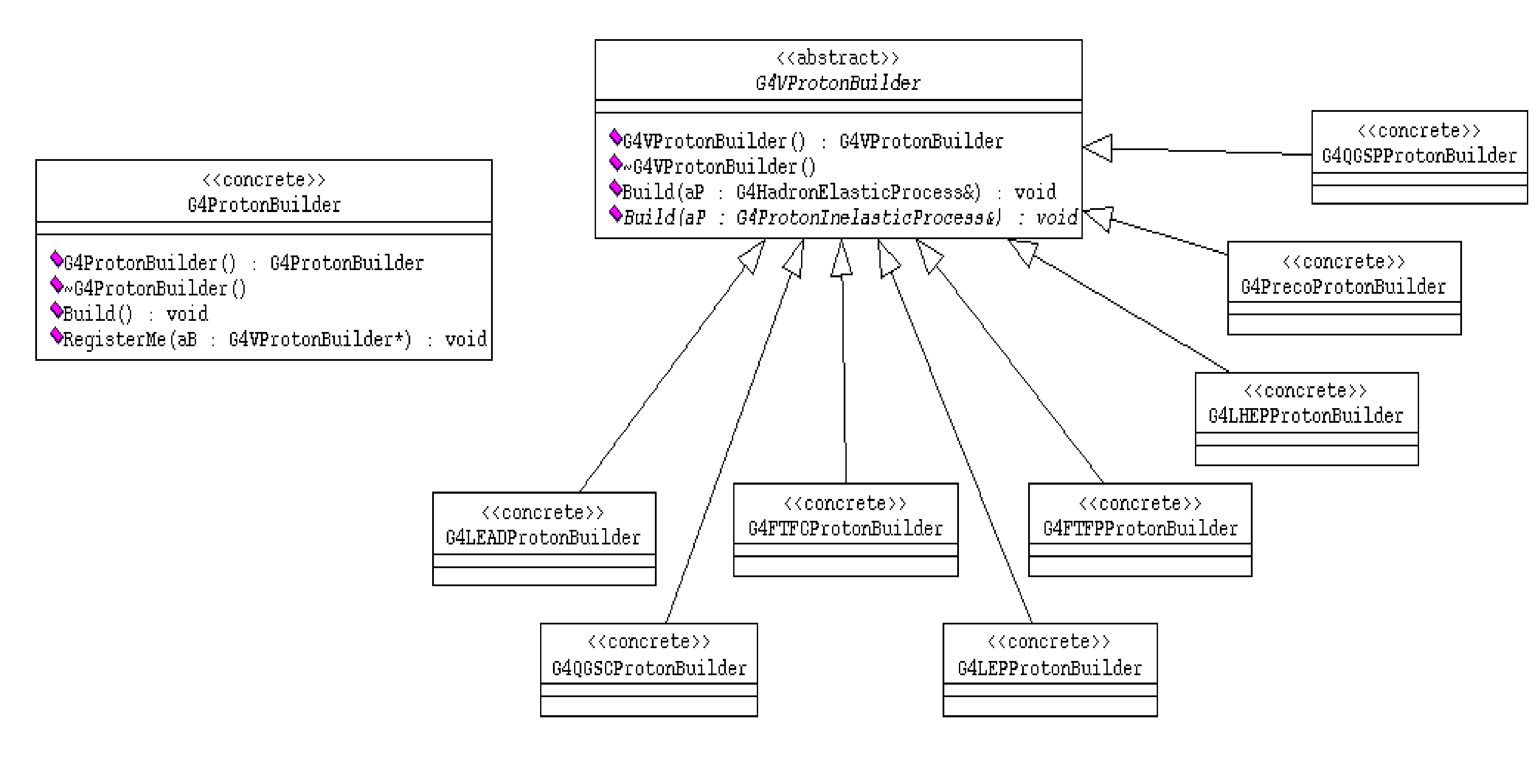
- We have systematically accumulated experience with various combinations of cross-section and models over the last years.
- Today we provide a set of physics lists institutionalizing this knowledge.
- Publishing them to the general audience was one of the main milestones of the hadronic working group for 2002.

Use case packages of Physics Lists

- LCG simulation project.
- HEP calorimetry.
- HEP trackers.
- 'Average' collider detector
- Low energy dosimetric applications
  with neutrons
- low energy nucleon penetration shielding
- linear collider neutron fluxes
- high energy penetration shielding
- medical and other life-saving neutron applications
- low energy dosimetric applications
- high energy production targets
  - e.g. 400GeV protons on C or Be
- medium energy production targets
  - e.g. 15-50 GeV p on light targets
- LHC neutron fluxes
- Air shower applications (still working on this)
- low background experiments

- http://cmsdoc.cern.ch/~hpw/GHAD/HomePage

To make tailoring easier, and the code more readable, we introduced Builders.



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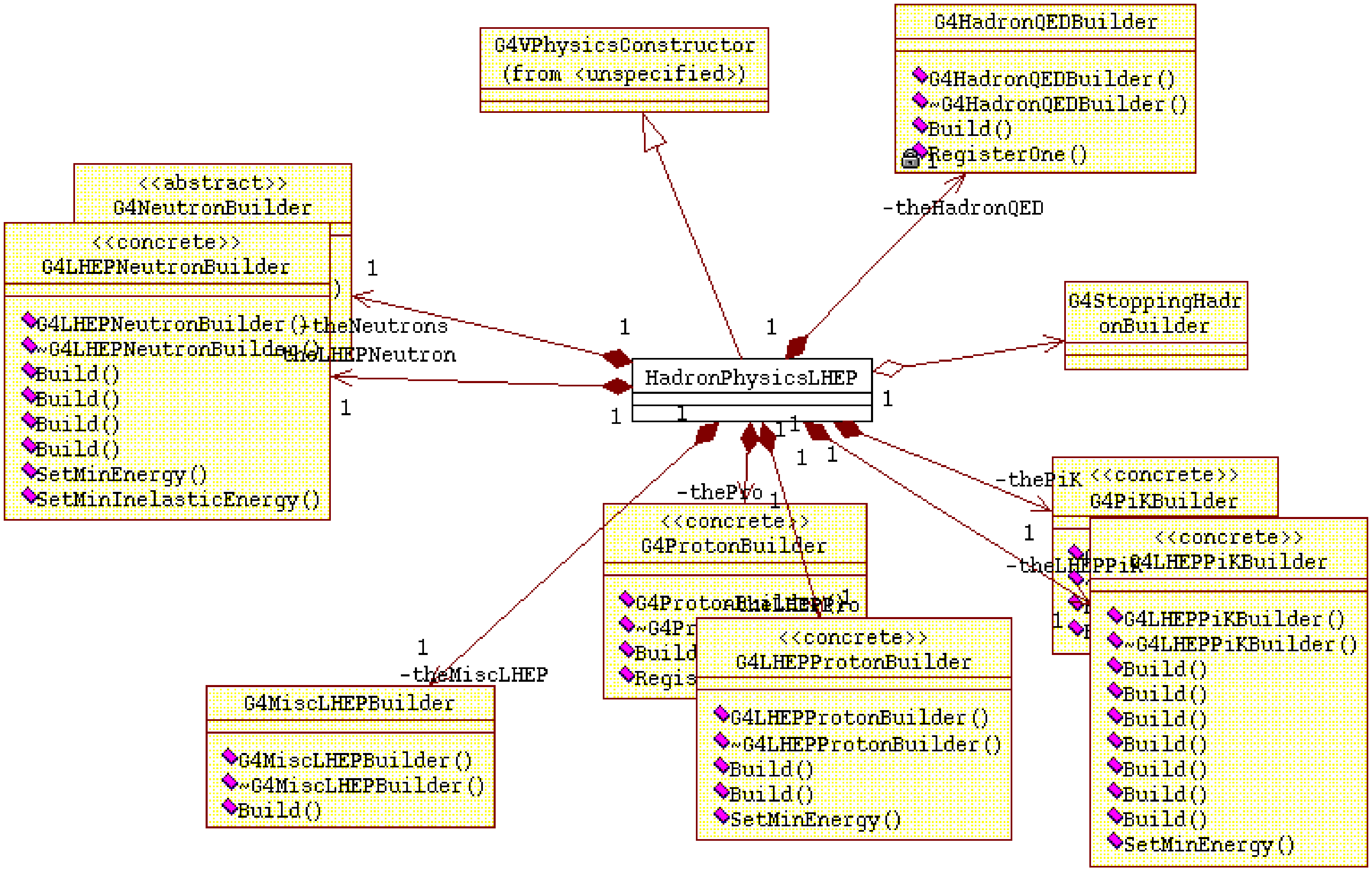

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Now, what does this mean ?

- You can now
  - Just pick a physics list from the '*menu'.*
  - Aggregate your own cocktail from limited complexity of the builders
  - Use all 5 framework levels with their full power.

➔ A structured reduction in the level of complexity exposed to you.

The WWW pages – a small demo.

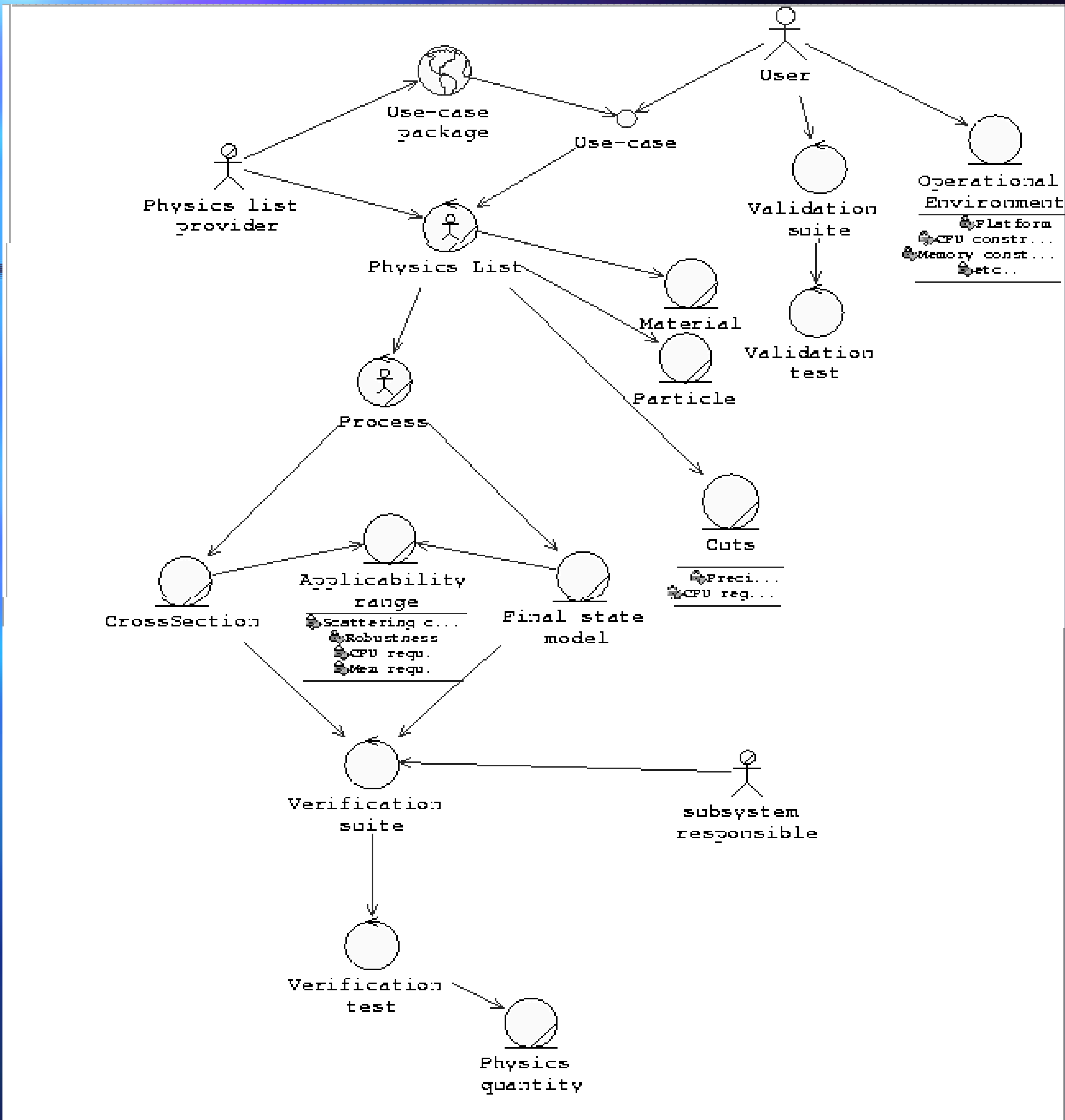
- There is a ‘physics lists’ topic on the geant4 HyperNews.
- We go to:
  - http://cmsdoc.cern.ch/~hpw/GHAD/HomePage

The recommended procedure:

- Start by trying the provided physics lists.
  - It makes it such that results by different groups can be compared.
  - You will profit from validation and verification done by others.
- Of course you are still encouraged to tailor the physics lists that we provide, and/or build your own where you need.
- Please also let us know about your findings.
- Plots you may whish to provide can enter WWW for everyone’s benefit.

→ Do not use examples/novice/N04 as example for a hadronic physics list.

The support process – static view



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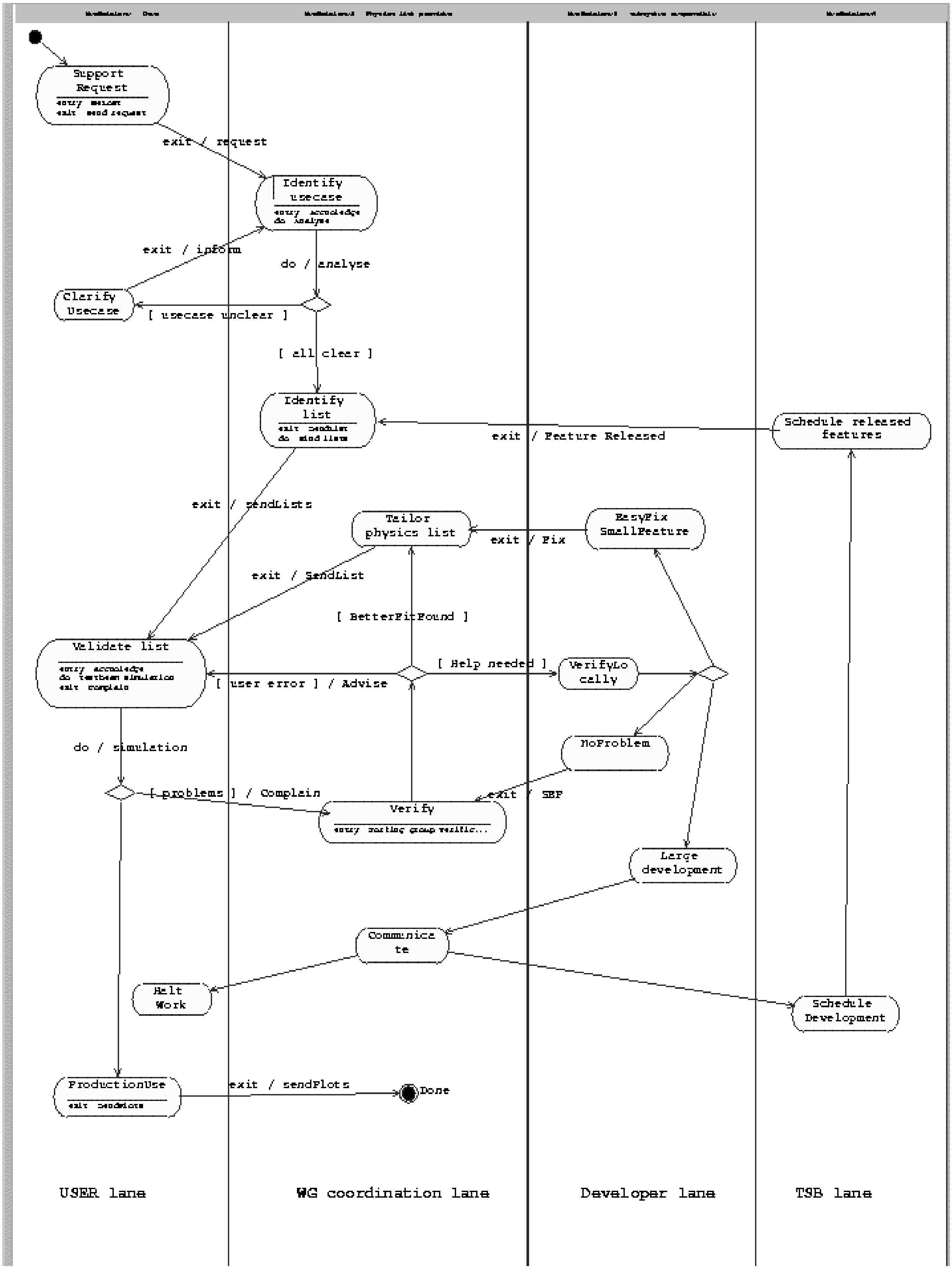

Support Request
exit / request
Identify usecase
exit / inform
do / analyse
Clarify Usecase
[usecase unclear]
[all clear]
Identify list
exit / Feature Released
Schedule released features
exit / sendLists
Tailor physics list
exit / Fix
EasyFix SmallFeature
exit / SendList
[BetterFitFound]
Validate list
[Help needed]
VerifyLocally
[user error] / Advise
NoProblem
do / simulation
[problems] / Complain
exit / SBF
Verify
Large development
Communicate
Halt Work
Schedule Development
ProductionUse
exit / sendPlots
Done
USER lane
WG coordination lane
Developer lane
TSB lane

Part 2

Some implications for detector construction

On Material construction

- There are three ways to construct materials in geant4
  - From it's isotopic composition
  - From it's elements
  - As an effective material (Aeff, Zeff)

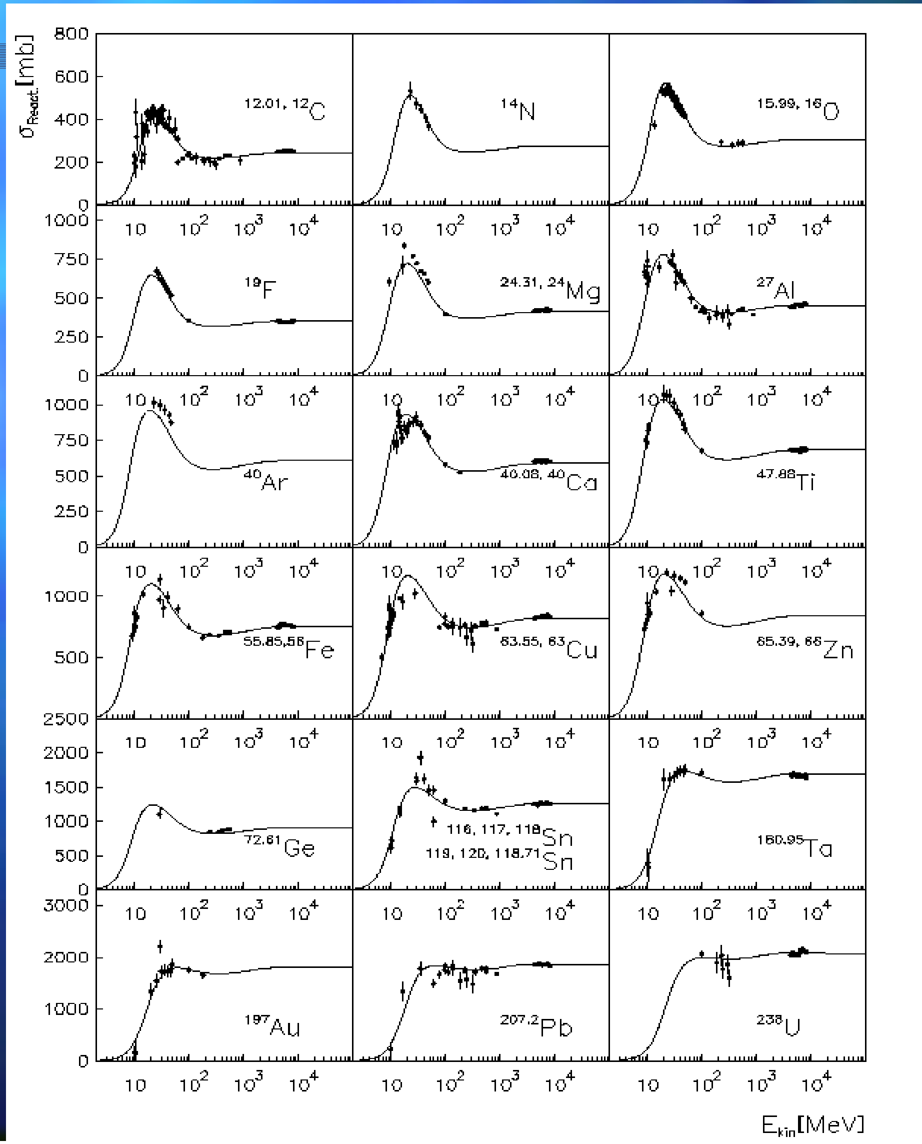
Effective materials

- Hadronics cross-section are not a function of material properties, but a function of nuclear properties.
- If you use effective numbers, the element composition cannot be automatically recovered.
- The cross-section will be ‘highly approximativ’ at best.
- The final states will have wrong properties.

- Never use effective A, Z with hadronic physics

  (There are situations, here you will not be able to avoid it, so we cannot protect against it.)

Proton induced reactions



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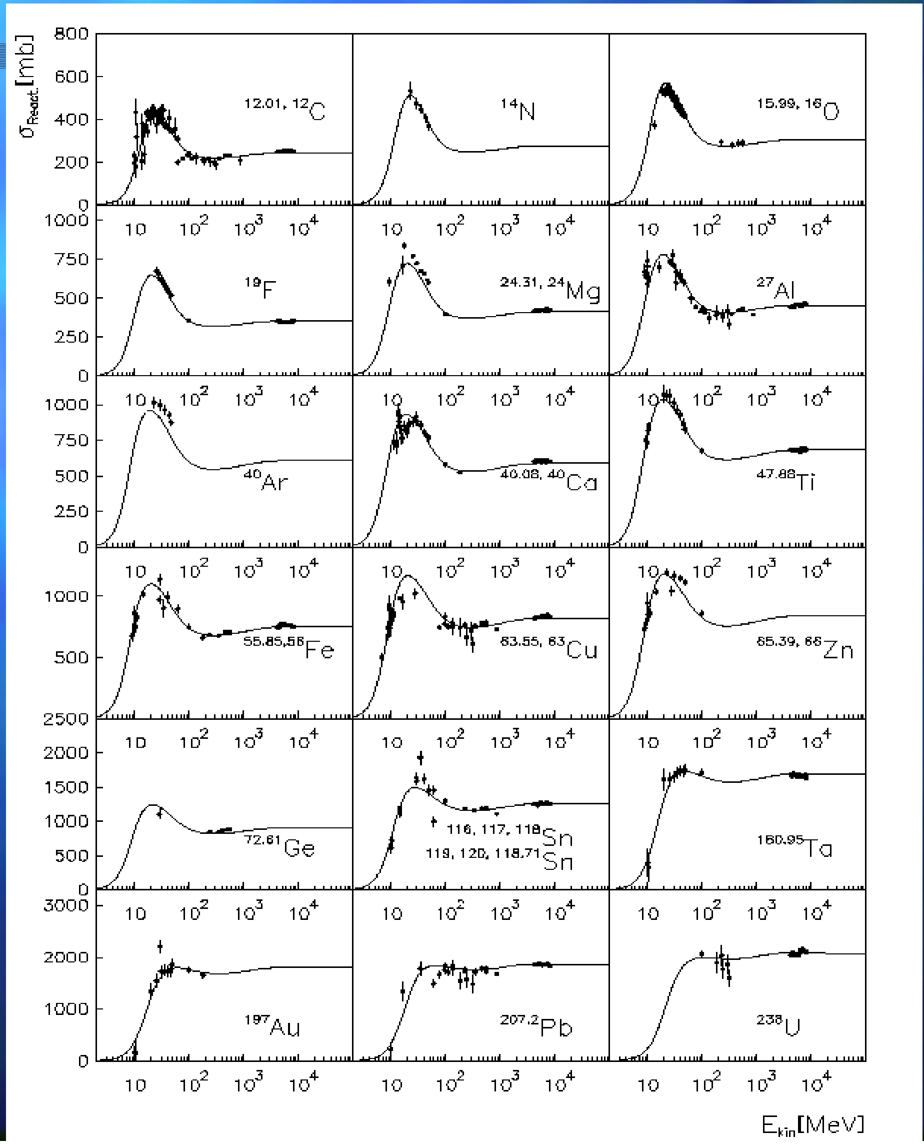
From elementary composition

- This is good enough for most high energy applications.

Proton induced reactions



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Isotope wise composition

- When detailled simulation of low energy neutrons is important, element info is not sufficient (E<20MeV) to get the cross-section and final states right.
  - For different isotopes, the neutron nuclear resonances will be at entirely different positions
  - For different isotopes, the final state channels open can differ drastically.
- → You may be tempted to construct your materials from Isotopes in this case

Isotope wise composition

- In case the neutron_hp models are used (detailed neutron transport below 20MeV), geant4 recovers the natural isotopic composition, in case materials and mixtures are specified in terms of their constituting elements.
- If you have enriched isotopes (like Uranium-238), please use the isotopes directly, to specify your material.

➔ Normally you do not need to use the G4Isotope in your detector construction

Example: Neutrons in Lithium

- Neutron inelastic cross-section at 150eV:
  - Li-7: 0.00 millibarns
  - Li-6: 12.2 barns !
- Open inelastic channels:
  - Li-7: none
  - Li-6: nLi→tα

  (which makes Li-6 a well known shielding isotope)

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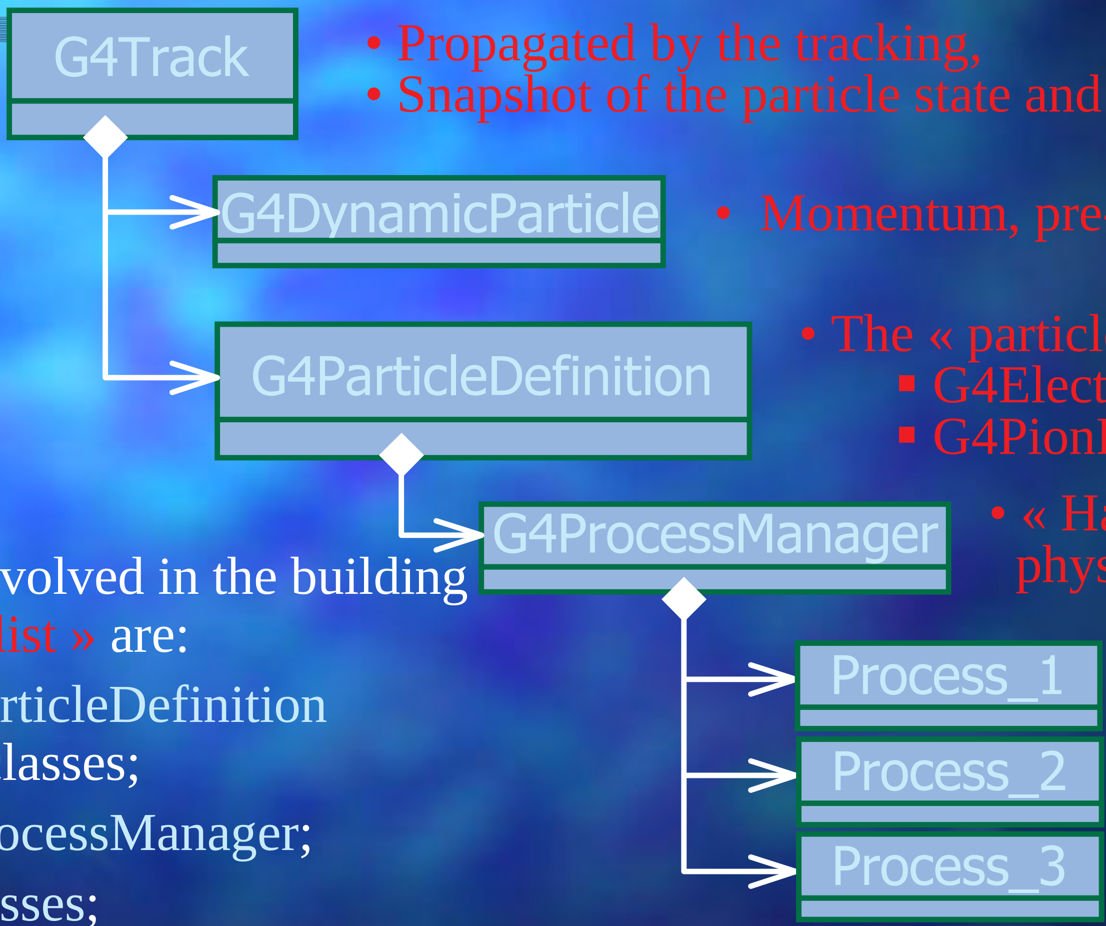
Part 3

A look inside (hadronic) processes, or how to tailor.

What is tracked in GEANT4 ?



- G4Track:
  - Propagated by the tracking,
  - Snapshot of the particle state and location.
- G4DynamicParticle:
  - Momentum, pre-assigned decay…
- G4ParticleDefinition:
  - The « particle type »:
    - G4Electron,
    - G4PionPlus…
- G4ProcessManager:
  - « Hangs » the physics sensitivity;
- Process_1, Process_2, Process_3:
  - The physics processes;

- The classes involved in the building the « physics list » are:
  - The G4ParticleDefinition concrete classes;
  - The G4ProcessManager;
  - The processes;

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The process tracking interface.

- There are three situations, where <tracking> may want to ask information from <process>:
  - AtRest:
    - Decay, e^+ annihilation …
  - AlongStep:
    - To describe 'continuous' interactions, occuring along the path of the particle, like ionisation;
  - PostStep actions:
    - Most hadronic interactions, …

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The process tracking interface.

- A process will implement any combination of the three AtRest, AlongStep and PostStep actions:
  - Eg: decay = AtRest + PostStep
- Each action defines two methods:
  - GetPhysicalInteractionLength():
    - Used to ***limit the step size***:
      - because the process « triggers » an interaction, a decay, geometry boundary, a user's limit …
  - DoIt():
    - Implements the ***actual action*** to be applied on the track;
    - Typically final state generation.

G4VProcess & G4ProcessManager

- In praxi the G4ProcessManager has three vectors of actions:
  - One for the AtRest methods of the particle;
  - One for the AlongStep ones;
  - And one for the PostStep actions.
- It is those vectors the user sets up in the physics list and which are used by the tracking.

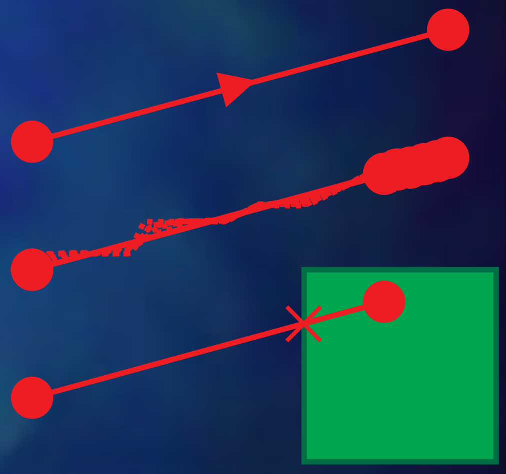
A word of caution on processes ordering

- Ordering of following processes is critical:
  - Assuming n processes, the ordering of the AlongGetPhysicalInteractionLength of the last processes should be:

    [n-2] …

    [n-1] multiple scattering

    [n] transportation
- Why ?
  - Processes return a « true path length »;
  - The multiple scattering « virtually folds up » this true path length into a ***shorter*** « geometrical » path length;
  - Based on this new length, the transportation can geometrically limits the step.



- For other processes ordering does not matter.

A few examples of processes

G4Transportation
G4Decay
G4eIonization
G4ionIonization
G4MuBremsStrahlung
G4SynchrotronRadiation
G4OpAbsorption
G4HadronElasticProcess
G4NeutronInelasticProcess
Etc..

→These are registered with the process managers by the physics lists and the builders.

Hadronic vs. electromagnetic processes

- In EM physics (mostly):
  - 1 process = 1 model and 1 cross-section.
- In hadronic physics (mostly):
  - 1 process = an assembly and selection of many cross-sections data-sets, models, production codes, model components, sub-assemblies, options.
  - Default cross-section are provided for each process.
  - You decide in the physics list, what exactly you use.
  - Mix, match, assemble.

A sample inelastic process.

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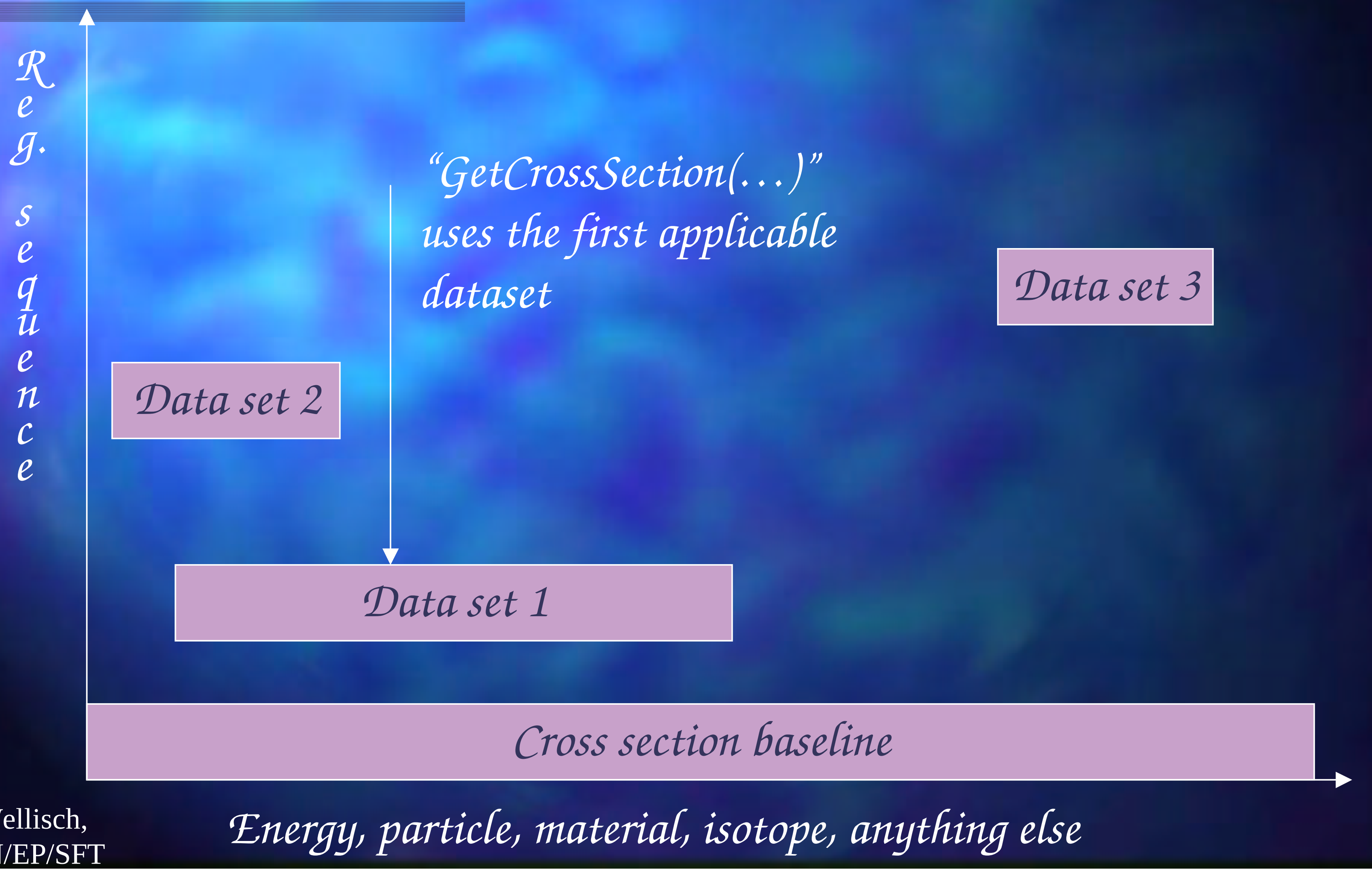
Cross section logic:
“AddDataSet(…)” fills a FILO stack



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A sketch of model management

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