Hadronic Physics

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Outline

- Hadronic Models
- Physics Lists
- Exercise

Hadronic Models

Hadronic Interactions

- Hadrons ($\pi^{\pm}$, $K^{\pm}$, K°_{L} , p , n , α , *etc.*), produced in jets and decays, travel through the detector (H , C , Ar , Si , Al , Fe , Cu , W , Pb ...)
- Therefore we need to model hadronic interactions

  hadron – nucleus -> *anything*
- In principle, QCD is the theory that describes all hadronic interactions in practice, perturbative calculations are applicable only in a tiny (but important !) phase-space region

  the hard scattering at high transverse momentum

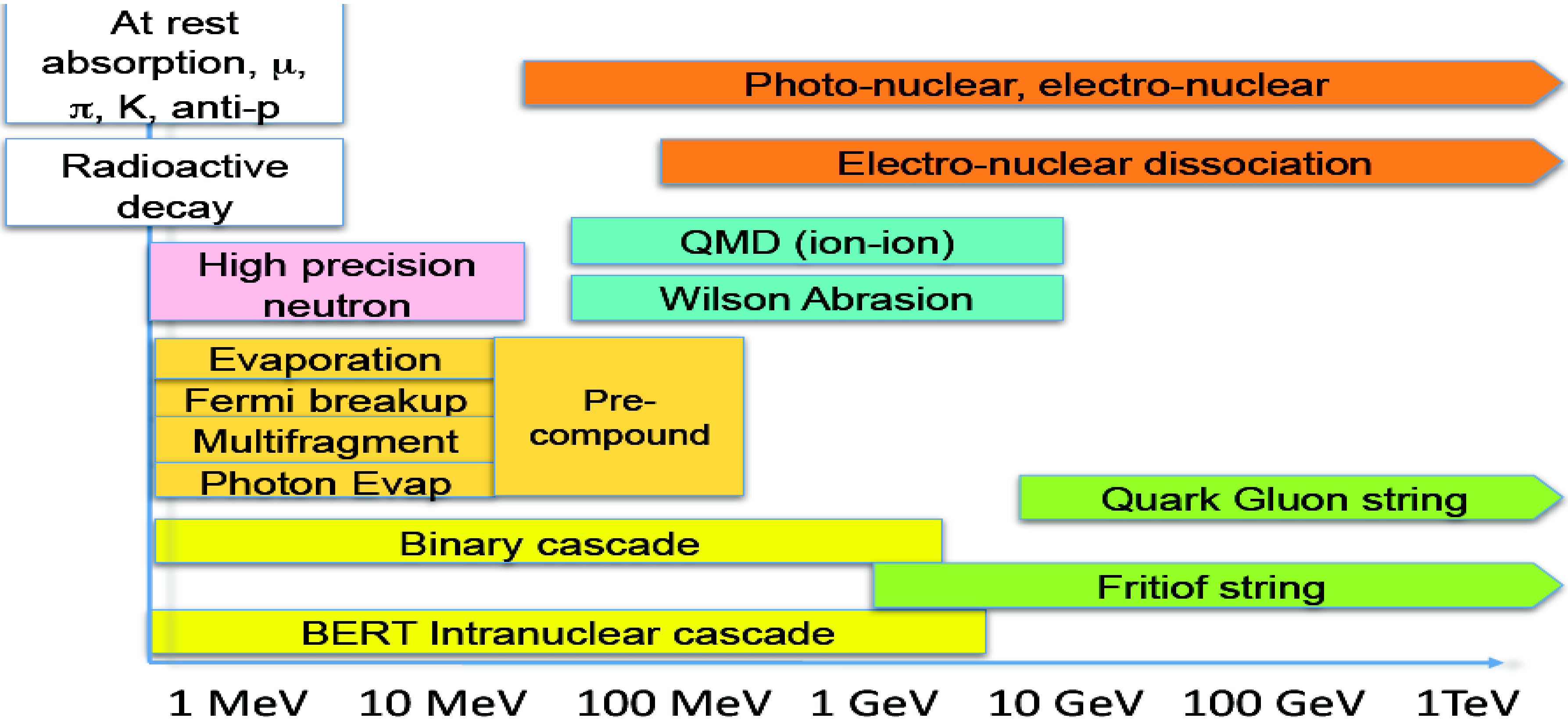
  whereas for the rest, *i.e.* most of the phase space

  soft scattering, re-scattering, hadronization, nucleus de-excitation

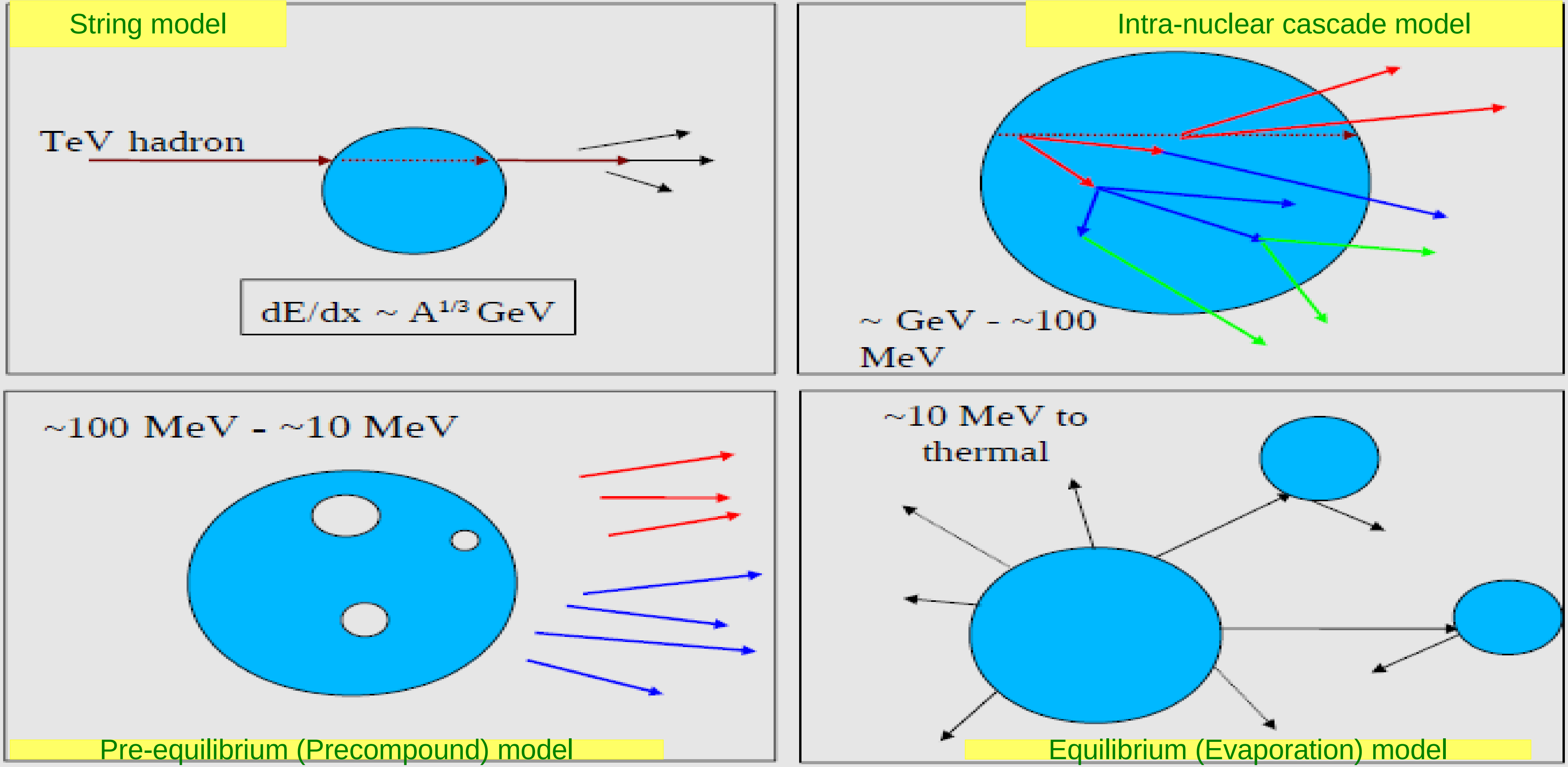
  only approximate models are available
- Hadronic models are valid for limited combinations of

  particle type – energy – target material

Partial Hadronic Model Inventory



Hadronic Interactions from TeV to meV



An Interesting Complication: Neutrons

- Neutrons are abundantly produced
  - Mostly “soft” neutrons, produced by the de-excitation of nuclei, after hadron-nucleus interactions
  - It is typically the 3rd most produced particle (after electrons and gammas)
- Before a neutron “disappears” via an inelastic interactions (or decays or exits the world volume), it can have many **elastic scatterings** with nuclei, and eventually can “thermalize” in the environment
- CPU time can vary by an order of magnitude depending on the physical accuracy of the **neutron transportation** simulation
  - For typical high-energy applications, a simple treatment is enough (luckily!)
  - For other applications, a more precise, **data-driven and isotope-specific** treatment is needed, especially for neutrons with kinetic energies below **~ MeV**

Neutron High Precision (**HP**)

- **H**igh **P**recision treatment of low-energy neutrons
  - **Ekin < 20 MeV** , down to thermal energies
  - Includes 4 types of interactions:
    elastic scattering, **radiative capture**, **fission**, **inelastic scattering**
  - Based on evaluated neutron scattering data libraries
    (pointed by the environmental variable **G4NEUTRONHPDATA**)
  - It is precise, but very slow !
- Not needed for most high-energy applications; useful for:
  - Cavern background, shielding, radiation damage, radio-protection
- Not used in most physics lists
  - If you need it, use one of the _**HP** physics lists:
    FTFP_BERT_**HP** , QGSP_BERT_**HP** , QGSP_BIC_(All)**HP** , Shielding(LEND)

Physics Lists

What is a Physics List ?

- A class that specifies all the particles, physics processes, and production thresholds needed by your Geant4 application
- One and only one physics list should be present in each application
- There is no default physics list : it should always be explicitly specified
- It is a very flexible way to build a physics environment :
  - Users can pick only the particles they need
  - Users can assign to each selected particle only the processes they are interest in
- But users must have a good understanding of the physics required in their application :
  - Omission of particles or physics processes will cause errors or poor simulation

Why do we Need a Physics List ?

Nature has just one “physics”: so why Geant4 does not provide a complete and unique set of particles and physics processes that everyone can use?

- There are many different physics models, corresponding to a variety of approximations of the real phenomena
  - Both for electromagnetic physics and even more for hadronic physics

  According to the application, one can be better than another. Comparing them can give an idea of systematic errors.

- Simulation speed is important
  - Users may prefer a less detailed but faster approximation
- Often all the physics and particles are not needed:
  - *E.g.* most high-energy applications do not need a detailed transportation of low-energy neutrons

Reference Physics Lists

- Writing a complete and realistic physics list for EM physics and even more for HAD physics is involved, and it depends on the application. To make things easier, pre-packaged **reference physics lists** are provided by Geant4, according to some reference use cases
- Few choices are available for EM physics (different production cuts and/or multiple scattering configurations); several possibilities are available for hadronics physics
  - **FTFP_BERT**, **FTFP_BERT_HP**, **Shielding**, **FTFP_INCLXX**, **QGSP_BERT**, **QGSP_BIC_EMY**, *etc.*
- These lists are "best guesses" of the physics needed in a given case; they are intended as starting point (and their builders can be re-used); **users are responsible of validating the physics lists for their application**

How to Use a Reference Physics List

Let's consider the example of FTFP_BERT :
In your main program:

```
#include "FTFP_BERT.hh"
...
int main( int argc, char** argv ) {
   ...
   G4VModularPhysicsList* physicsList = new FTFP_BERT;
   runManager->SetUserInitialization( physicsList );
   ...
}
```

Exercise

Today’s Exercise

- Try to shoot a hadron (*e.g.* a proton) in your set-up
  - Try eventually to make your detector bigger, to contain most of the so-called hadronic shower
- Visualize the shower for a few events
  - Do they look similar ?
- Observe how the properties of shower changes
  - Between e- / e+ / gamma (*i.e.* electromagnetic showers)
and pi- / pi+ / proton / neutron (*i.e.* hadronic showers)
  - Between different beam energies , *e.g.* 1 GeV , 10 GeV , 100 GeV
  - Between different physics lists, *e.g.* FTFP_BERT *vs* QGSP_BIC_HP

“Offline” Exercise

- Build a simplified sampling hadronic calorimeter
  - *E.g.* Iron – Scintillator , or Copper – Liquid-Argon
  - Typical size in HEP experiment to have good containment : 1 − 2 meters
  - Typical shape : cylinder
- Using the user actions, print some of the properties of showers
  - Such as the visible energy (mean value and its fluctuations, *i.e.* its *rms*), shower shapes (longitudinal and lateral / radial)
- Observe how the properties of shower changes
  - By changing the sampling calorimeter, *e.g.* absorber material and/or active material, and their respective sizes...