Physics in Geant4 - part II

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Overview

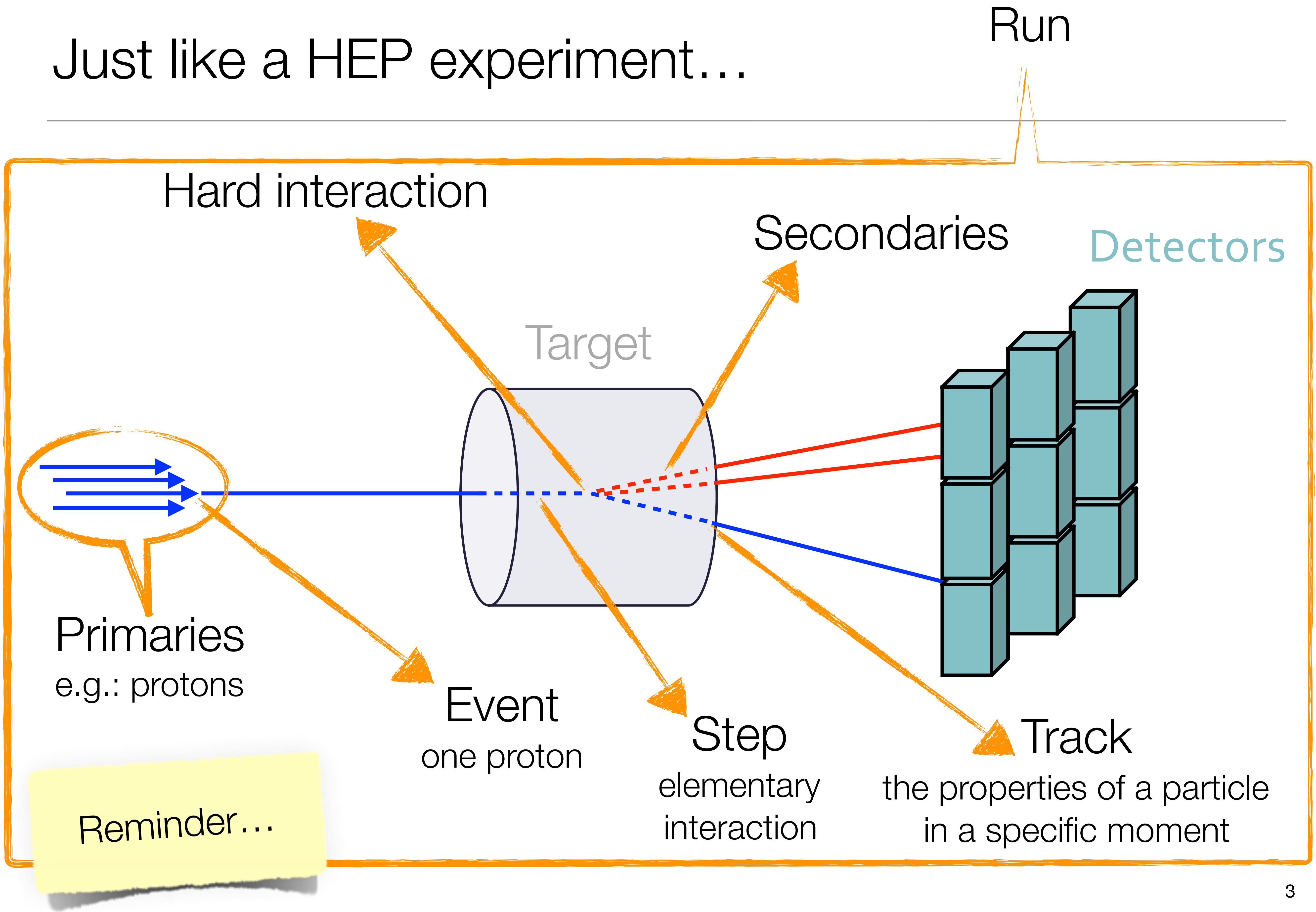
- Recap on tracking
- Cuts
- Overview on physics models

For these slides I took inspiration from:

- M. Asai (SLAC, Stanford)
- A. Dotti (SLAC, Stanford)
- S. Incerti (CNRS, Bordeaux)
- L. Pandola (INFN-LNS, Catania)

- You can download code and slides from: http://www.roma1.infn.it/~mancinit/Teaching/Trento/

Just like a HEP experiment…



Particle tracking

- It is the most common application of MC in Particle Physic
- Assume that all the possible interactions are known
- The distance *s* between two subsequent interactions is distributed as $$p(s) = \mu \exp(-\mu s)$$
- Being μ a property of the medium

Reminder…

Particle tracking

- μ is proportional to the probability of an interaction per unit length, therefore:

Reminder…

  - is proportional to the **total cross section**

$$\mu = N\sigma = N\sum_i \sigma_i$$

  - σ_i are the partial cross section of **all the competing processes**

  - depends on the **density** of the material
    (N is the number of scattering centres in the medium)

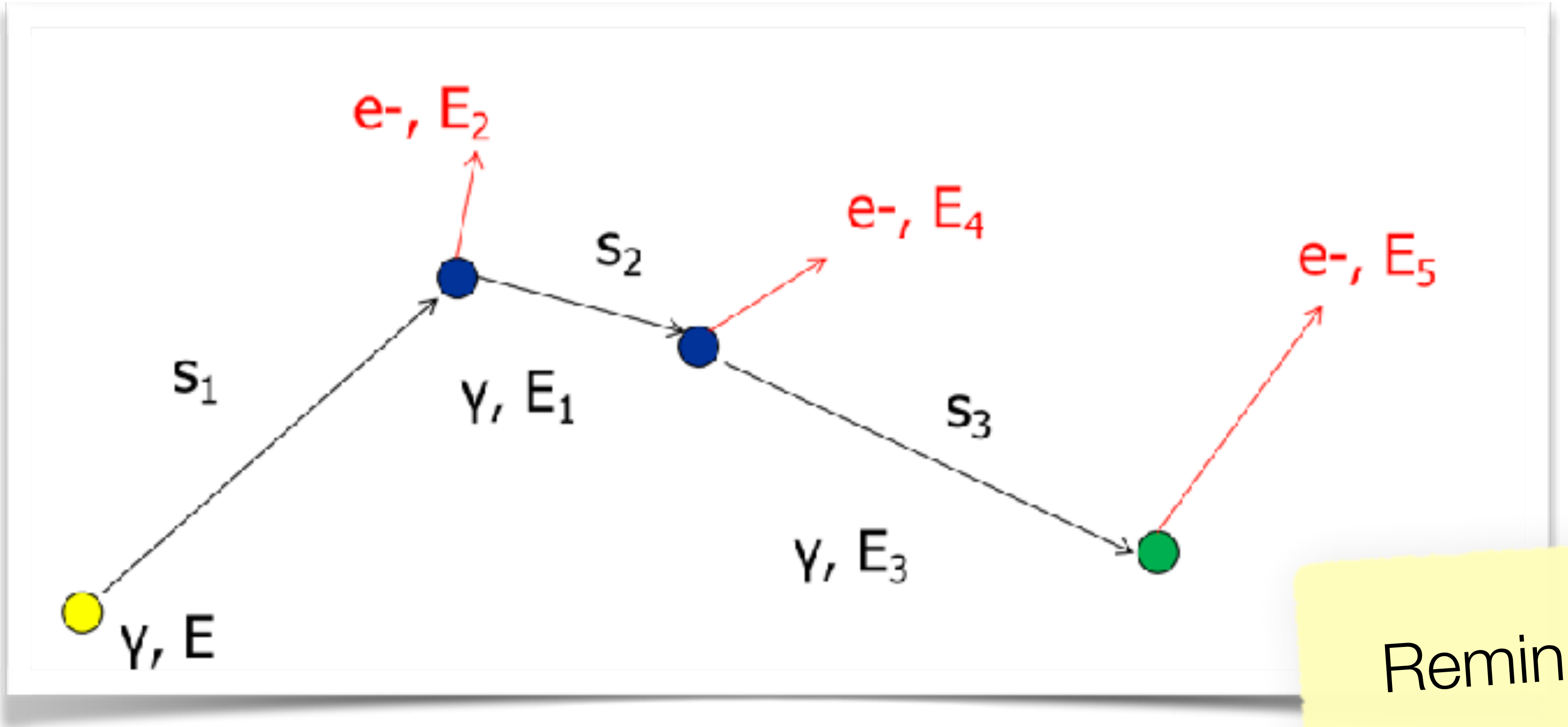
Particle tracking

Reminder…

- Divide the particle trajectory in **“steps”**
  - Straight free-flight tracks along the step
  - Could be limited by geometry boundaries
- Sampling the step length accordingly to $p(s)$
- Sampling the interaction at the end of the step
- Sampling the interaction accordingly to μ_i/μ
- Sampling the final state using the physics model of the interaction i
  - Update the properties of the primary particle
  - Add the possible secondaries produced (to be tracked later)

Particle tracking

- Follow all secondaries, until absorbed (or leave the geometry)
- μ depends on the energy (cross sections do!)



Reminder…

Tracking, not so easy…

- This basic recipe doesn't work well for charged particles
- The **cross sections** of some processes (ionisation and bremsstrahlung) **is very high**, so the **steps** would be very **small**
- In each interaction **only a small fraction of energy is lost** and the effect on the particle are small
- A lot of CPU time used to simulate many interactions having small effects

Reminder…

The solution: approximate

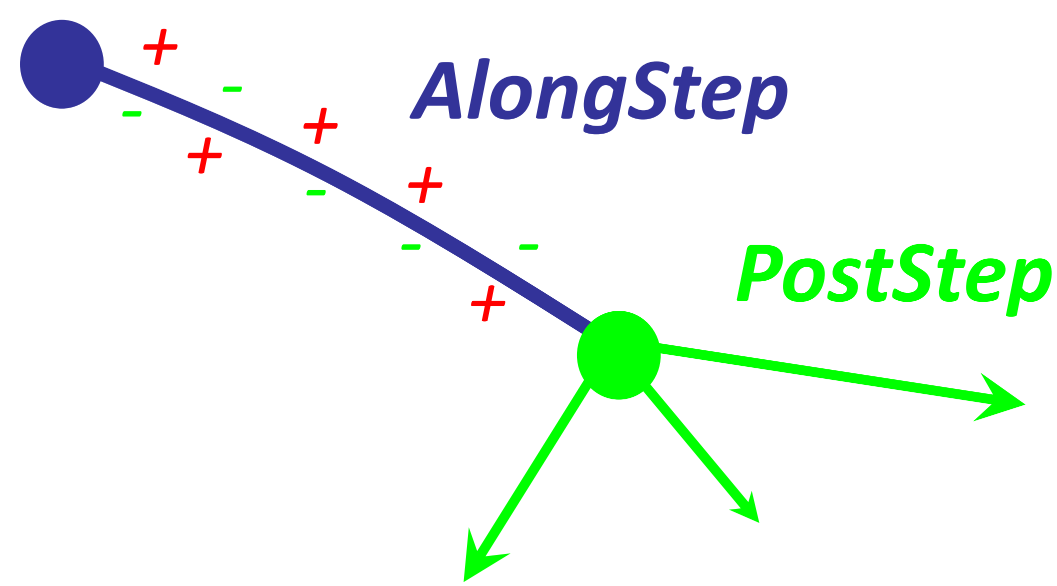
- Simulate explicitly interactions only if the energy loss is above a threshold E_0 (**hard** interactions)
    - Detailed simulation
- The effects of all sub-threshold interactions is described cumulatively (**soft** interactions)
- Hard interactions occur much less frequently than soft interactions

Reminder…

The `G4VProcess`

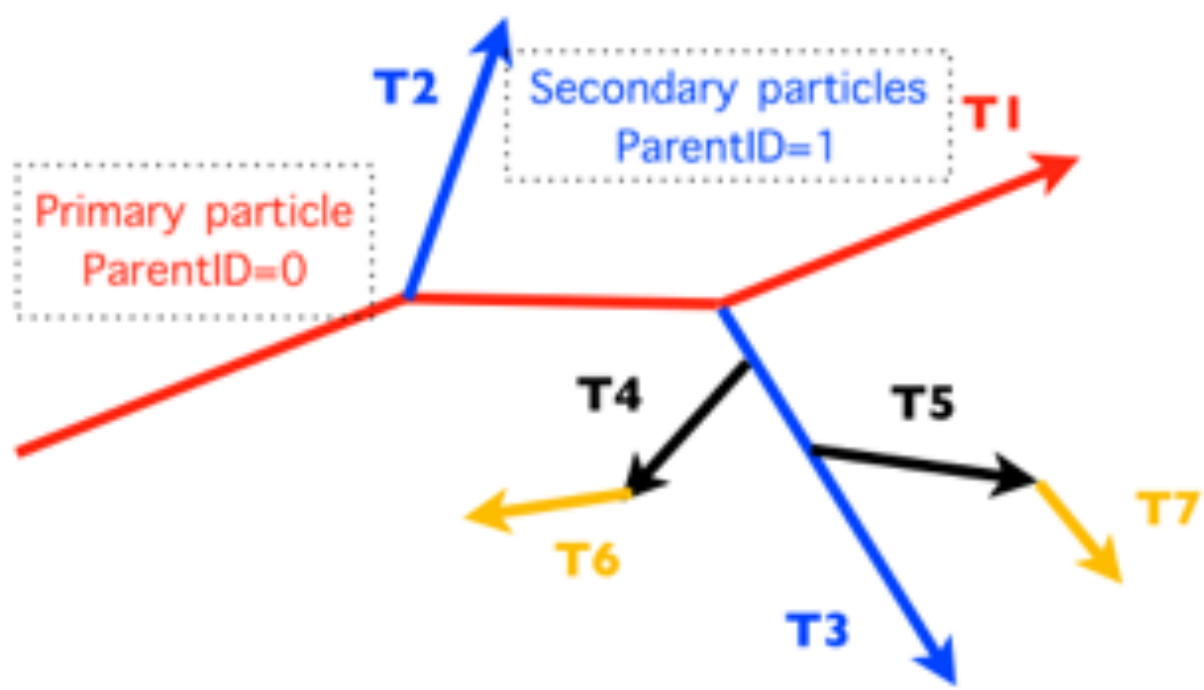
- All physics processes derive from `G4VProcess`
- `G4VProcess` is an abstract class
- It defines the common interface of all processes in Geant4
- Three kind of “actions”:
  - **AlongStep**
    all the soft interactions
  - **PostStep**
    all the hard interactions
  - **AtRest**
    decays, e+ annihilation

Reminder…



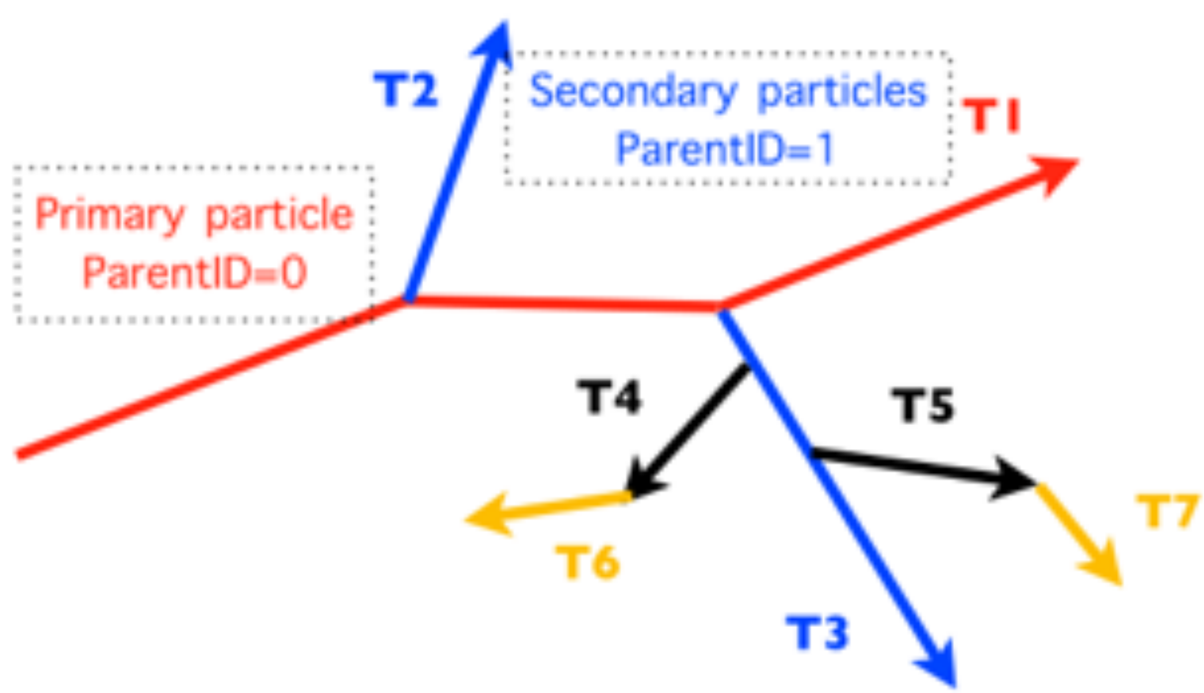
Geant4 way of tracking

- Force step ending at **geometry boundaries**
- All **AlongStep** processes **co-occur**
- The **PostStep** compete, i.e.: **only one** is selected



Geant4 way of tracking

- **If particle is at rest** chose one of the **AtRest** processes
- The secondaries are saved in the stack
- To be further tracked with a **last in first out** approach



let’s run an example!

Let’s cut it out… (cuts in MC)

- The traditional Monte Carlo solution is to set a tracking cut-off in energy:

  - a particle is stopped when its energy goes below it
  - its residual energy is deposited at that point
- Imprecise stopping and energy deposition location
- Particle and material dependence

Let’s cut it out… (cuts in Geant4)

- Geant4 does not have tracking cuts
  i.e.: all tracks are tracked down to 0 energy

- A Cut in Geant4 is a production threshold

- It is applied only for physics processes that have infrared divergence
  - Bremsstrahlung
  - Ionisation e^- (δ rays)
  - Protons from hadronic elastic scattering

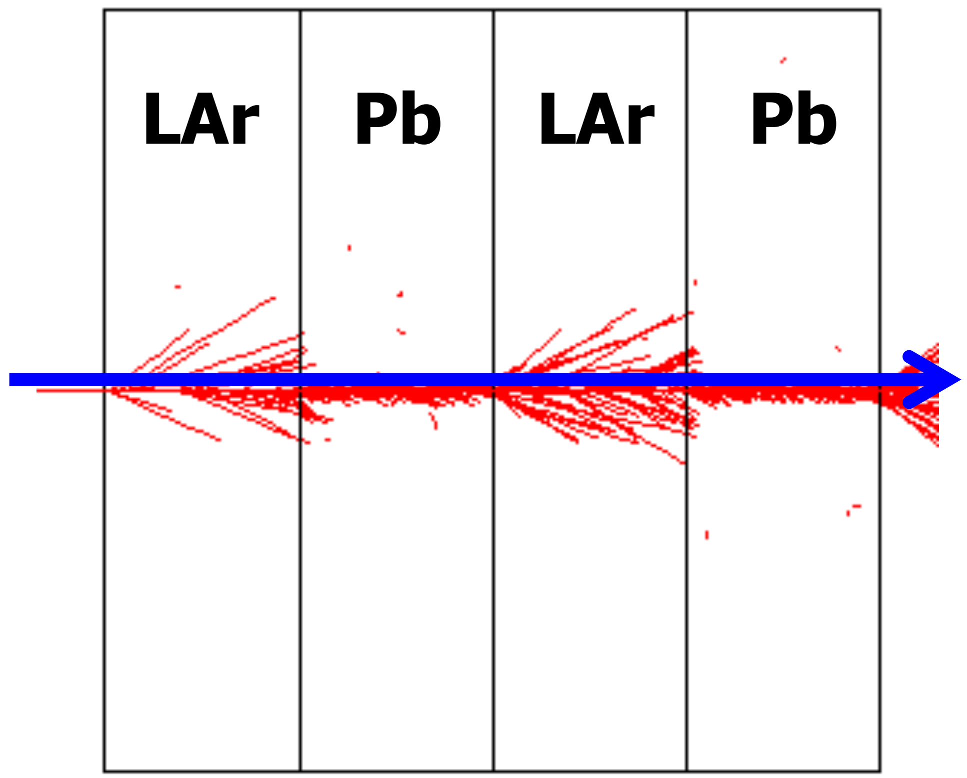
A range cut

- The threshold is a **distance**!
- Default = 1 mm
- Particles unable to travel at least the range cut value are not produced

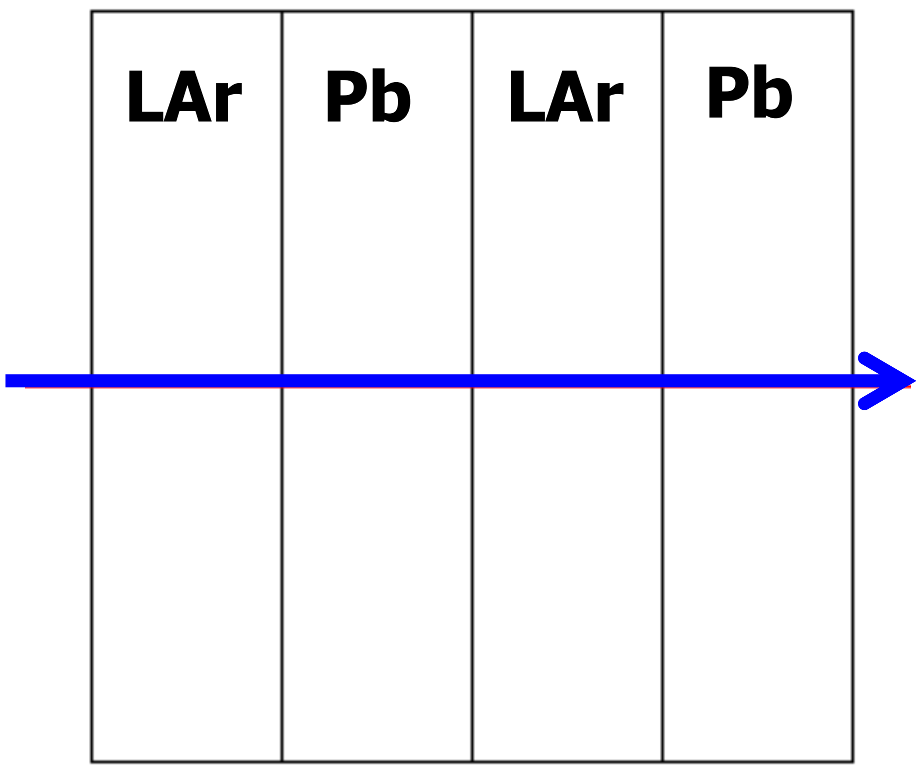
- Sets the "spatial accuracy" of the simulation
- Production threshold is internally converted to an energy threshold for each material

Cut in energy

- 460 keV
- good for LAr
- not for Pb

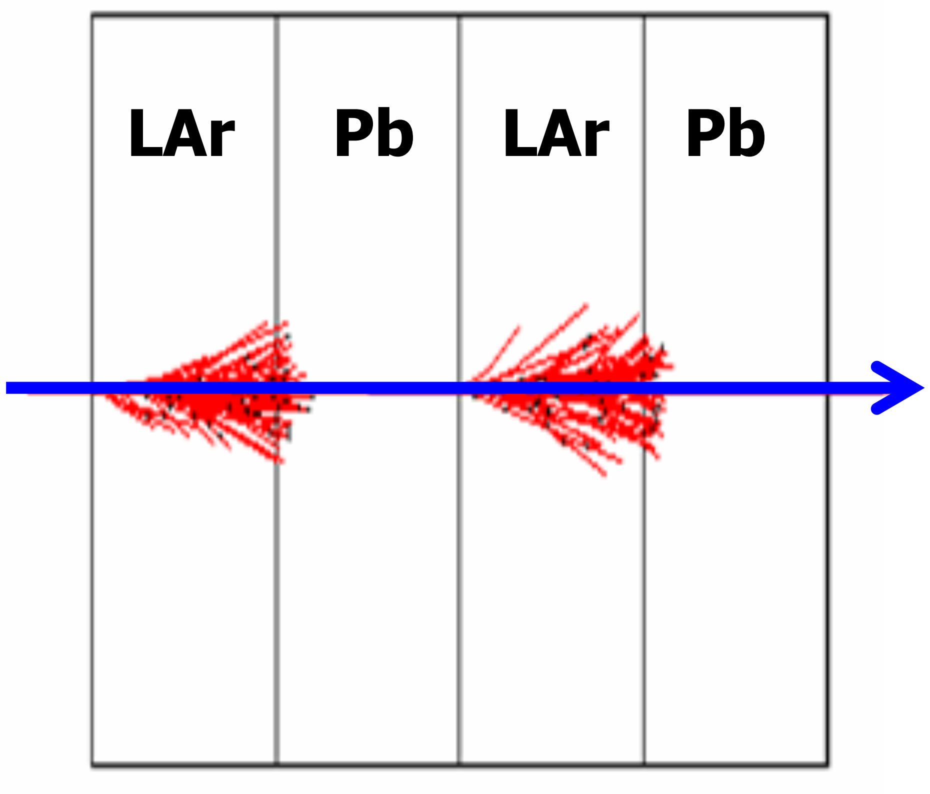


- 2 MeV
- good for Pb
- not for Lar



Cut in range

- 1.5 mm
- ~460 KeV in LAr
- ~2 MeV in Pb



run with the hares and
hunt with the hounds...
(good for both!)

Setting the cuts

- Optional method in G4VPhysicsList

```
void MyPhysicsList::SetCuts()
{
    //G4VUserPhysicsList::SetCuts();
    defaultCutValue = 0.5 * mm;
    SetCutsWithDefault();

    SetCutValue(0.1 * mm, "gamma");
    SetCutValue(0.01 * mm, "e+");
  G4ProductionCutsTable::GetProductionCutsTable()
        ->SetEnergyRange(100*eV, 100.*GeV);
}
```

- not all models are able to work with very low production thresholds
- an energy threshold limit is used,
- its default value is set to 990 eV.
- You can change this value

Cuts UI command

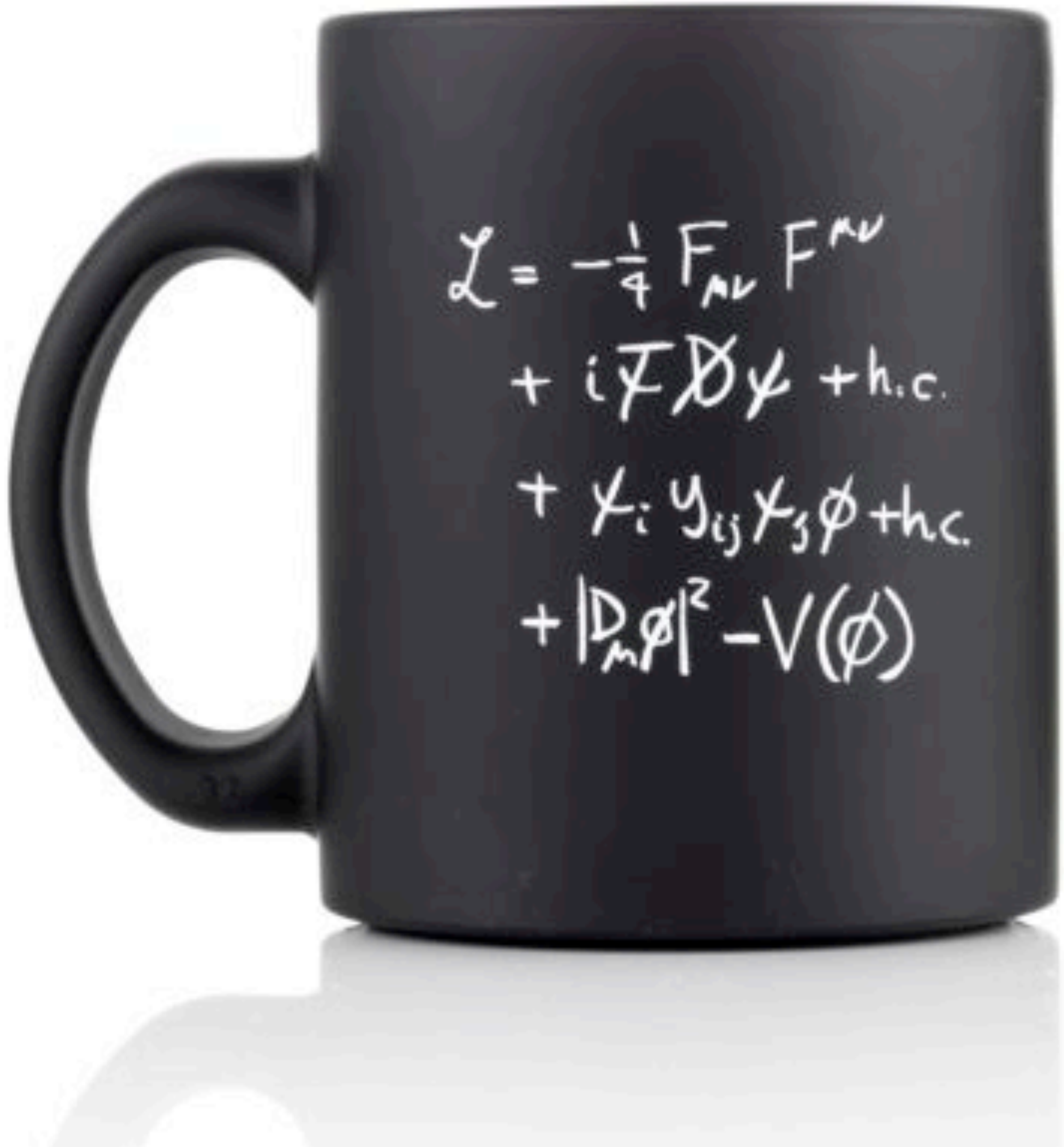
```
# Universal cut (whole world, all particles)
/run/setCut 10 mm

# Override low-energy limit
/cuts/setLowEdge 100 eV

# Set cut for a specific particle (whole world)
/run/setCutForAGivenParticle gamma 0.1 mm

# Set cut for a region (all particles)
/run/setCutForARegion myRegion 0.01 mm

# Print a summary of particles/regions/cuts
/run/dumpCouples
```

Cuts per region

- Complex detector may contain many different sub-detectors involving:
  - finely segmented volumes
  - position-sensitive materials (e.g. Si trackers)
  - large, undivided volumes (e.g. calorimeters)
- The same cut may not be appropriate for all of these
- User can define regions (independent of geometry hierarchy tree) and assign different cuts for each region
- A region can contain a subset of the logical volumes

To limit the step

- To have more precise energy deposition
- To increase precision in magnetic field
- Include `G4StepLimiter` in your physics list
  - as a Physics process
  - compete with the others



Physics processes | an overview…

γ model inventory

- Many models available for each process
- Differ for energy range, precision and CPU speed
- Final state generators

Model	E_{min}	E_{max}
G4LivermoreRayleighModel	100 eV	10 PeV
G4PenelopeRayleighModel	100 eV	10 GeV
G4KleinNishinaCompton	100 eV	10 TeV
G4KleinNishinaModel	100 eV	10 TeV
G4LivermoreComptonModel	100 eV	10 TeV
G4PenelopeComptonModel	10 keV	10 GeV
G4LowEPComptonModel	100 eV	20 MeV
G4BetheHeitlerModel	1.02 MeV	100 GeV
G4PairProductionRelModel	10 MeV	10 PeV
G4LivermoreGammaConversionModel	1.02 MeV	100 GeV
G4PenelopeGammaConversionModel	1.02 MeV	10 GeV
G4PEEFluoModel	1 keV	10 PeV
G4LivermorePhotoElectricModel	10 eV	10 PeV
G4PenelopePhotoElectricModel	10 eV	10 GeV

ElectroMagnetic models

- The same physics processes can be described by different models
- For instance: Compton scattering can be described by
  - `G4KleinNishinaCompton`
  - `G4LivermoreComptonModel` (low-energy, based on the Livermore database)
  - `G4PenelopeComptonModel` (low-energy, based on the Penelope analytical model)
  - `G4LivermorePolarizedComptonModel` (low-energy, Livermore database with polarization)
  - `G4PolarizedComptonModel` (Klein-Nishina with polarization)
  - `G4LowEPComptonModel` (full relativistic 3D simulation)
- Different models can be combined, so that the appropriate one is used in each given energy range (à performance optimization)

You MUST:

Reminder…

- Describe your experimental set-up
- Provide the primary particles input to your simulation
- Decide **which particles** and **physics models** you want to use out of those available in Geant4 and the precision of your simulation (cuts to produce and track secondary particles)

EM Physics constructors

G4EmStandardPhysics – default
G4EmStandardPhysics_option1 – HEP fast but not precise
G4EmStandardPhysics_option2 – Experimental
G4EmStandardPhysics_option3 – medical, space
G4EmStandardPhysics_option4 – optimal mixture for precision
G4EmLivermorePhysics
G4EmLivermorePolarizedPhysics
G4EmPenelopePhysics
G4EmLowEPPhysics
G4EmDNAPhysics_option…
…

Combined Physics
Standard > 1 GeV
LowEnergy < 1 GeV

- Advantage of using of these classes – they are tested on regular basis and are used for regular validation

Hadronic processes

- At rest
  - Stopped muon, pion, kaon, anti-proton
  - Radioactive decay
  - Particle decay (decay-in-flight is PostStep)
- Elastic
  - Same process to handle all long-lived hadrons (multiple models available)
- Inelastic
  - Different processes for each hadron (possibly with multiple models vs. energy)
  - Photo-nuclear, electro-nuclear, mu-nuclear
- Capture
  - Pion- and kaon- in flight, neutron
- Fission

Hadronic physics challenge

- Three energy regimes
  - < 100 MeV
  - resonance and cascade region (100 MeV - 10 GeV)
  - > 20 GeV (QCD strings)
- Within each regime there are several models
- Many of these are phenomenological

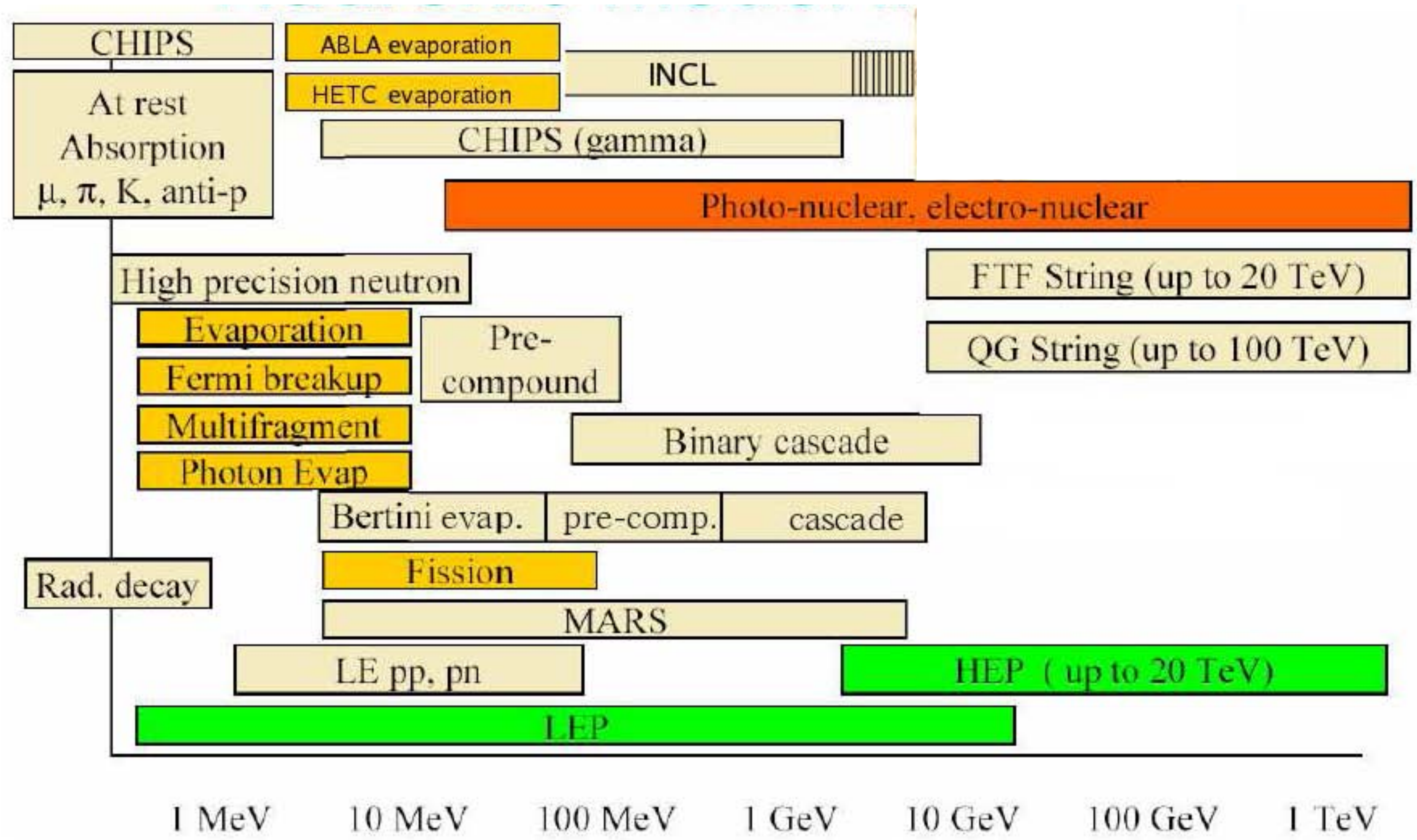
Hadronic models

- Two families of builders for the high-energy part
  - **QGS**, or list based on a model that use the Quark Gluon String model for high energy hadronic interactions of protons, neutrons, pions and kaons
  - **FTF**, based on the FTF (FRITIOF like string model) for protons, neutrons, pions and kaons
- Three families for the cascade energy range
  - **BIC**, binary cascade
  - **BERT**, Bertini cascade
  - **INCLXX**, Liege Intranuclear cascade model

ParticleHP

- Data-driven approach for inelastic reactions for n (in place since many years, named NeutronHP) p, d, t, 3He and α
- Data based on TENDL-2014 (charged particles) and ENDFVII.r1 (neutrons).
- For neutrons, includes information for elastic and inelastic scattering, capture, fission and isotope production
- Range of applicability: from thermal energies up to 20 MeV
- Very precise tracking, but also very slow
- Use it with care: thermal neutron tracking is very CPU-demanding

Haronic model inventory



http://geant4.cern.ch/support/proc_mod_catalog/models

thank you for your attention!