An alternative Muon Capture Implementation

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Introductory information

- E.g. recall Kevin's talk at 20th Geant4 Collaboration Meeting at Fermilab
  - https://indico.fnal.gov/contributionDisplay.py?contribId=45&confId=9717
- The implementation relies on the ideas/code from Kevin's prototype from 2012 and Vladimir's old and current implementations:
  - G4MuonMinusCapture (or G4HadronStoppingProcess)
  - G4MuonMinusBoundDecay (with modifications by KLG)
  - G4MuMinusCapturePrecompound

The Idea

- Introduce G4MuonicAtom *(in particles/hadrons/ions)*
  - And G4GenericMuonicAtom
  - Together with G4MuonicAtomHelper which:
    - Creates G4MuonicAtom
    - Provides auxiliary functions (some copied from G4MuonMinusBoundDecay)
- G4GenericMuonicAtom and G4MuonicAtom are modeled after G4GenericIon and G4Ions
  - The generic ones are "models" with the initial process managers. The process managers are then copied to the "good for tracking" atoms/ions created (for a given Z&A) using G4MuonicAtom or G4Ions when needed

The Idea (cont'd)

- Modeling after G4HadronStoppingProcess acting on G4MuonMinus create:
  - G4MuonMinusAtomicCapture acting on G4MuonMinus
  - G4MuonicAtomDecay acting on G4MuonicAtom

G4MuonMinusAtomicCapture

- G4VRestProcess
  - (G4HadronStoppingProcess is a G4HadronicProcess)
- Stops/Captures muons using default element selector
  - As in the first stage of G4HadronStoppingProcess
  - An EM cascade follows (creating gammas)
  - Creates G4MuonicAtom using auxiliary class G4MuonicAtomHelper

G4MuonicAtomDecay

- G4VRestDiscreteProcess
- A hybrid process using Decay methodology for Decay In Orbit (DIO) and G4MuMinusCapturePrecompound for Nuclear Capture (NC)
- Starting from G4MuonicAtom
  - Either: Lets the muon decay in orbit (DIO)
    - Based on the code from G4Decay (using phase space 4 body channel for now)
    - The results are the muon decay products plus the base atom of the G4MuonicAtom
  - Or: Lets the muon be captured by the nucleus (NC)
    - Using G4MuMinusCapturePrecompound with the results similar to as in G4HadronStoppingProcess (plus again the base atom)

Plans/Acknowledgements

- Commit the current code without activating G4MuonMinusAtomicCapture in the production physics lists
  - Allow time for testing
- At some point enable the code by modifying G4StoppingPhysics to replace G4MuonMinusCapture with G4MuonMinusAtomicCapture
- Extend the code, to handle the light nuclei in future

- Thank you to: Makoto, Vladimir I, Dennis W and others for feedback and support.

Some more Details

Other Details/Files involved

- Modify G4IonTable and G4ParticleDefinition (and G4ParticleTable) to accommodate G4MuonicAtom and G4GenericMuonicAtom
- Modify G4PhysicsListHelper.cc to add two new processes (using enums shown below)
  - G4HadronicProcessType::fMuAtomicCapture = 132
  - G4DecayProcessType::DECAY_MuAtom = 221
- Following the code/ideas related to G4GenericIon also modify G4StackManager.cc G4SteppingManager2.cc in addition to G4IonTable, G4ParticleDefinition and G4ParticleTable

More Details re: Process Manager

- G4MuonicAtom needs a different process manager with a different process (vs. G4Ions)
- E.g. see operations like:

```
G4ProcessManager* pm = tempSecondaryTrack->GetDefinition()->GetProcessManager();
if(!pm && tempSecondaryTrack->GetDefinition()->IsGeneralIon())
        { pm = G4ParticleTable::GetParticleTable()->GetGenericIon()->GetProcessManager(); }
if(!pm && tempSecondaryTrack->GetDefinition()->IsMuonicAtom())
        { pm = G4ParticleTable::GetParticleTable()->GetGenericMuonicAtom()->GetProcessManager();}
```

- G4MuonicAtom(s) return false from IsGeneralIon() as they have/need a different set of processes compared to G4Ions