Hadronic Physics in Geant4

http://cern.ch/geant4

The full set of lecture notes of this Geant4 Course is available at

http://www.ge.infn.it/geant4/events/nss2003/geant4course.html

Outline

- Processes and hadronic physics
- Hadronic cross sections and models
- Comparison of hadronic models with data
- Physics lists

Hadronic Physics is a Problem!

- Even though there is an underlying theory (QCD), applying it is much more difficult than applying QED for EM physics
- We must deal with at least 3 energy regimes
  - QCD strings (> 20 GeV)
  - Resonance and cascade region (100 MeV – 20 GeV)
  - Chiral perturbation theory (< 100 MeV)
- Within each regime there are several models
  - Many of these are phenomenological
- Which ones to use? Which ones are correct?

The Geant4 Philosophy of Hadronics

- Provide several models and cross section sets in each region
- Let the user decide which physics is best
- Provide a general model framework that allows implementation of more processes and models at many levels
- Validate new models as models and data become available

What Does a Process Do?

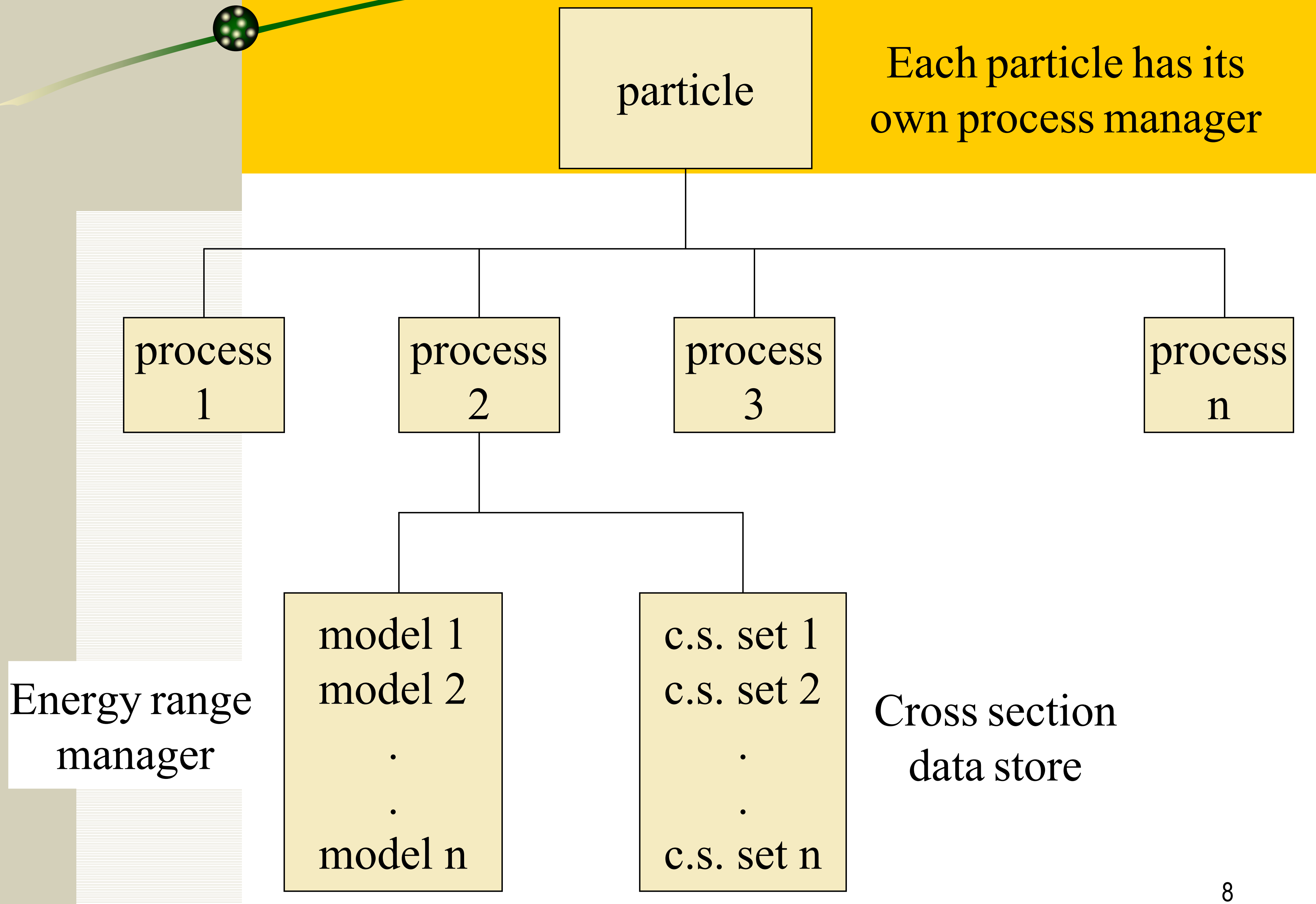
- Hadronic models and cross sections implement processes
- A process uses cross sections to decide when and where an interaction will occur
  - GetPhysicalInteractionLength()
- A process uses an interaction model to generate the final state
  - DoIt()
- Three types of process
  - PostStep, AlongStep, AtRest

Hadronic Processes

- At rest
  - stopped μ, π, K, anti-proton
  - radioactive decay
- Elastic
  - same process for all long-lived hadrons
- Inelastic
  - different process for each hadron
  - photo-nuclear
  - electro-nuclear
- Capture
  - π^-, K^- in flight
- Fission

Hadronic Processes and Cross Sections

- In Geant4 EM physics: 1 process → 1 model, 1 cross section
- In Geant4 Hadronic physics: 1 process → many possible models, cross sections
  - Mix and match !
- Default cross sections are provided for each model
- User must decide which model is appropriate


particle
Each particle has its own process manager
process 1
process 2
process 3
process n
model 1
model 2
.
.
model n
c.s. set 1
c.s. set 2
.
.
c.s. set n
Energy range manager
Cross section data store

Cross Sections

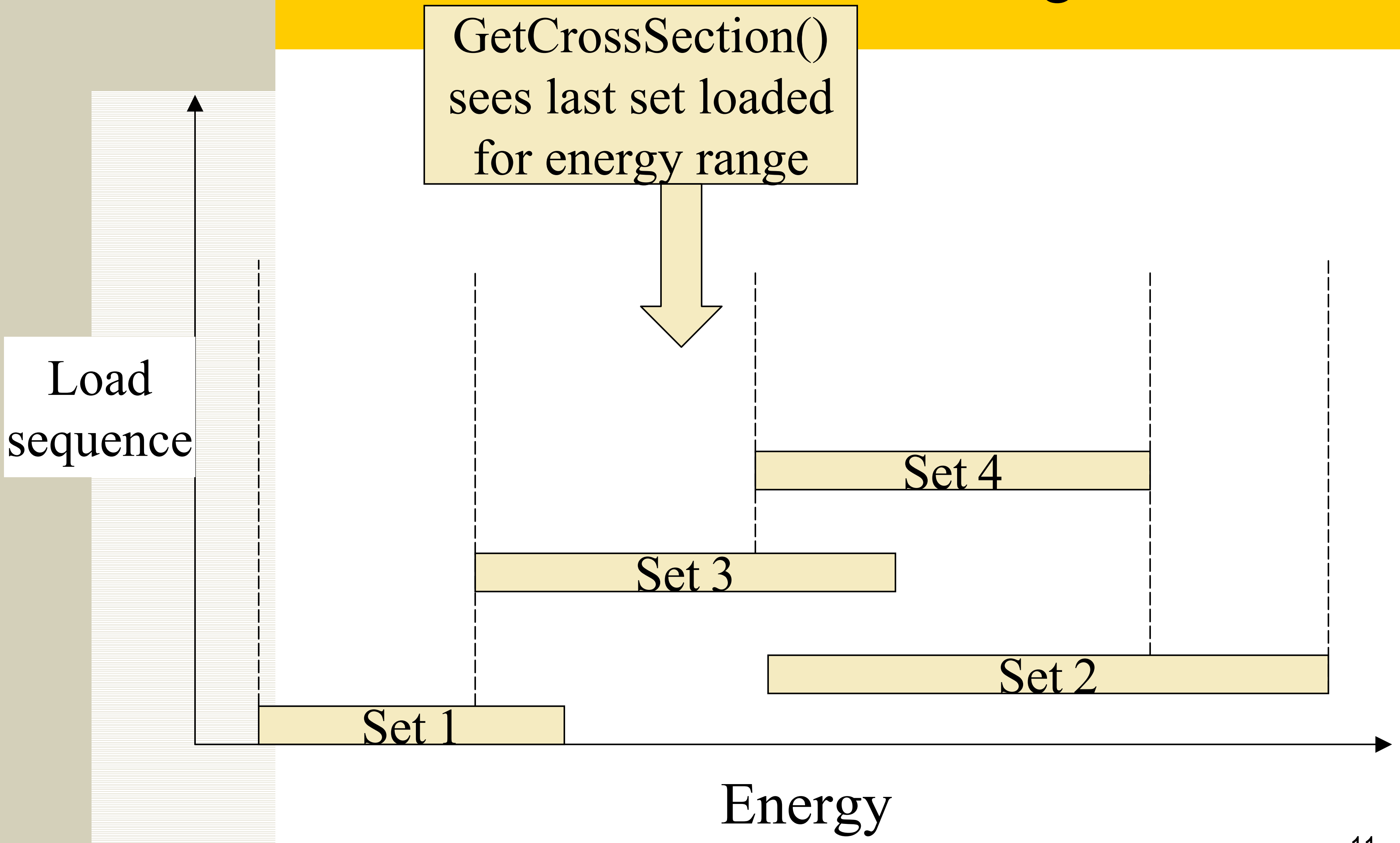
- Default cross section sets are provided for each type of hadronic process
  - Fission, capture, elastic, inelastic
  - Can be overridden or completely replaced

- Different types of cross section sets
  - Some contain only a few numbers to parameterize c.s.
  - Some represent large databases (data driven models)

Alternative Cross Sections

- Low energy neutrons
  - G4NDL available as Geant4 distribution data files
  - Available with or without thermal cross sections
- "High energy" neutron and proton reaction σ
  - 20 MeV < E < 20 GeV
- Ion-nucleus reaction cross sections
  - Good for E/A < 1 GeV
- Isotope production data
  - E < 100 MeV

Cross Section Management



Hadronic Models – Data Driven

- Characterized by lots of data
  - Cross section
  - Angular distribution
  - Multiplicity
- To get interaction length and final state, models simply interpolate data
  - Usually linear interp of cross section, coef of Legendre polynomials
- Examples
  - Neutrons (E < 20 MeV)
  - Coherent elastic scattering (pp, np, nn)
  - Radioactive decay

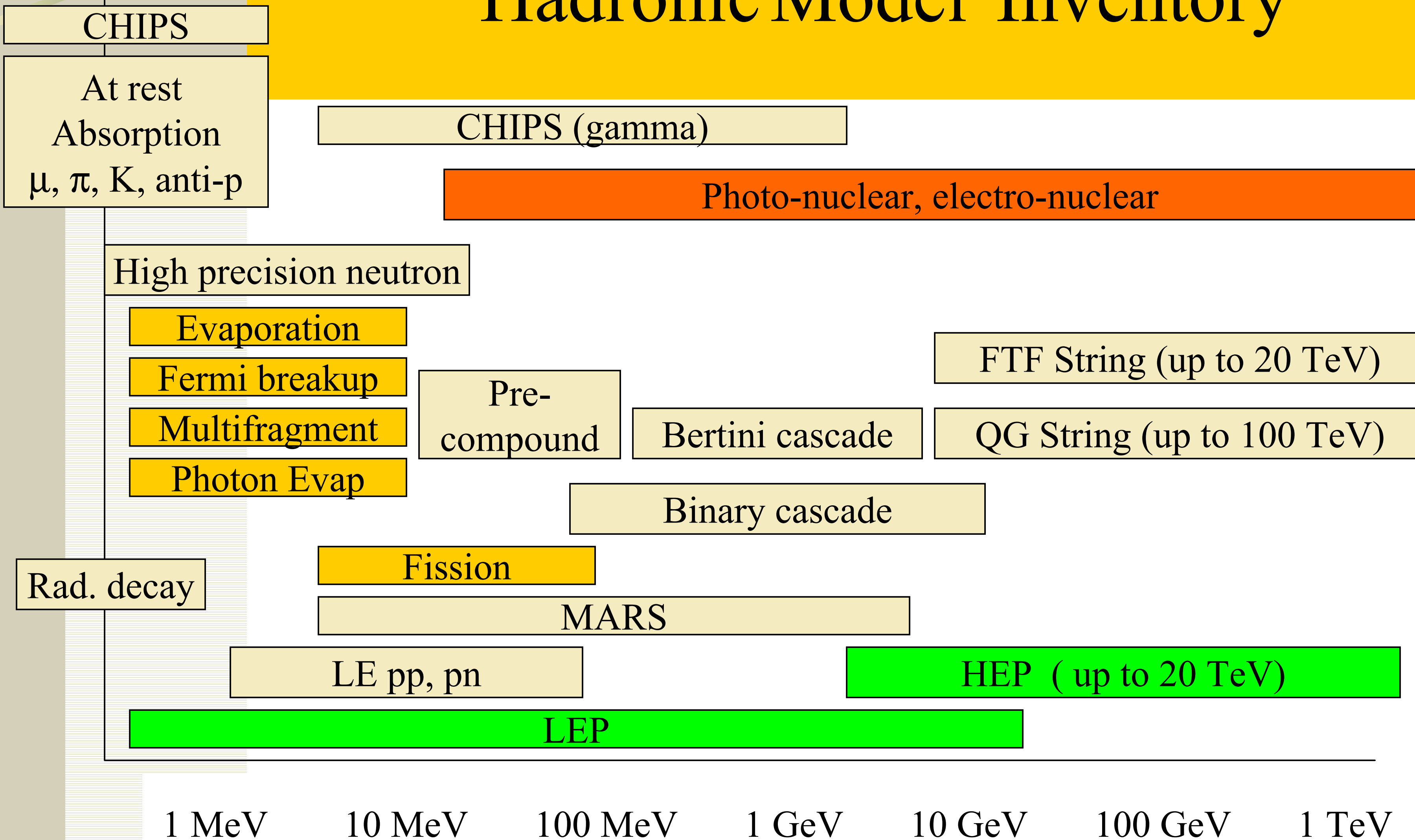
Hadronic Models – Theory Driven

- Dominated by theory (QCD, Strings, ChPT, …)
  - Not as much data (used for normalization, validation)
- Final states determined by sampling theoretical distributions
- Examples:
  - Parton String (projectiles with E > 5 GeV)
  - Intra-nuclear cascade (intermediate energies)
  - Nuclear de-excitation and breakup
  - Chiral invariant phase space (all energies)

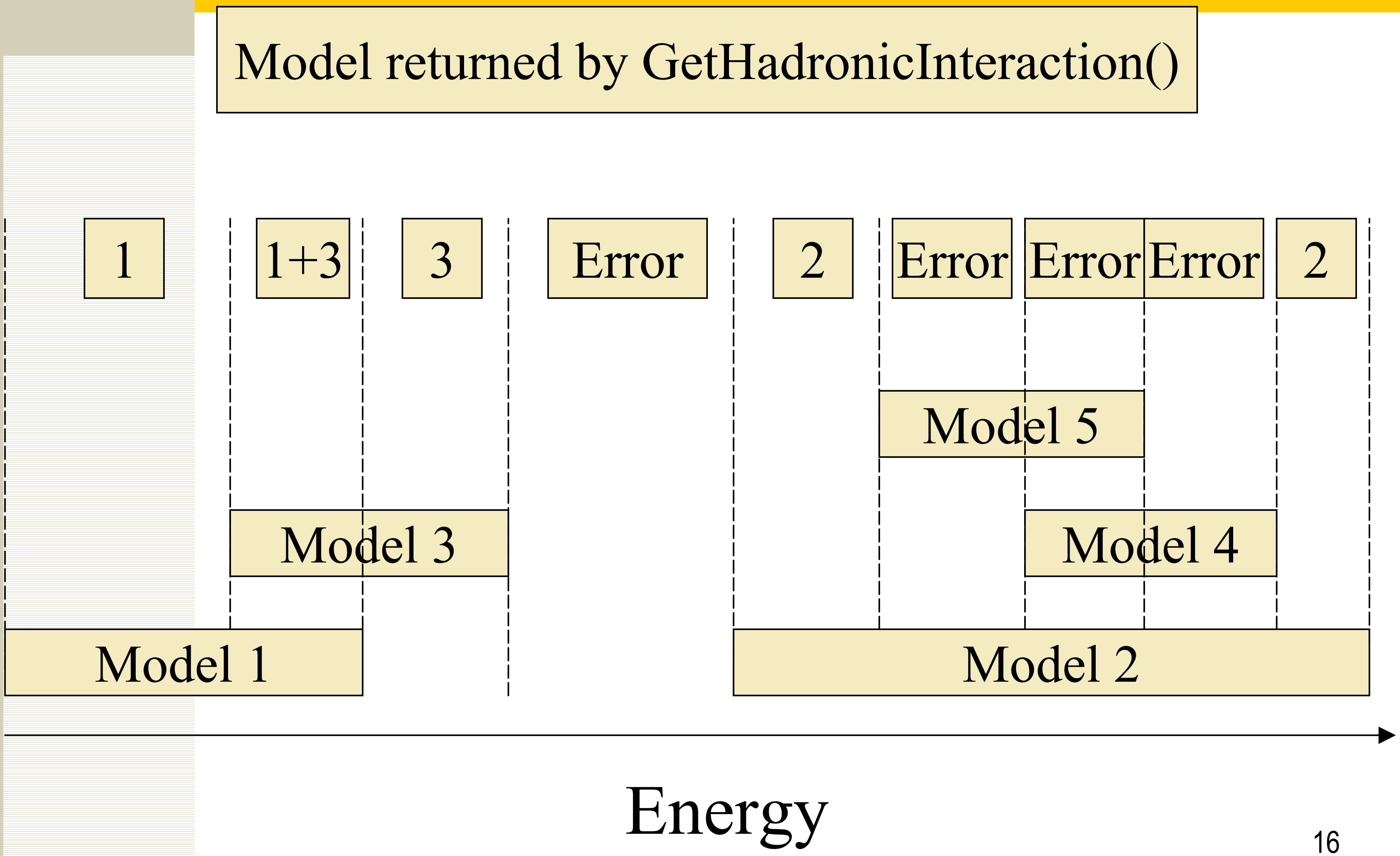
Hadronic Models - Parameterized

- Depends on both data and theory
  - Enough data to parameterize cross sections, multiplicities, angular distributions
- Final states determined by theory, sampling
  - Use conservation laws to get charge, energy, etc.
- Examples
  - LEP, HEP models (GHEISHA)
  - Fission
  - Capture

Hadronic Model Inventory



Model Management



Hadronic Process/Model Framework

- Process
  - At rest
  - In flight
    - Cross sections
    - Models
      - Data driven
      - Parameterized
      - Theory driven
        - Intranuclear cascade
        - String/ parton
          - QGSM frag. model
          - Feynman frag. model
          - Lund frag. model

Level 1

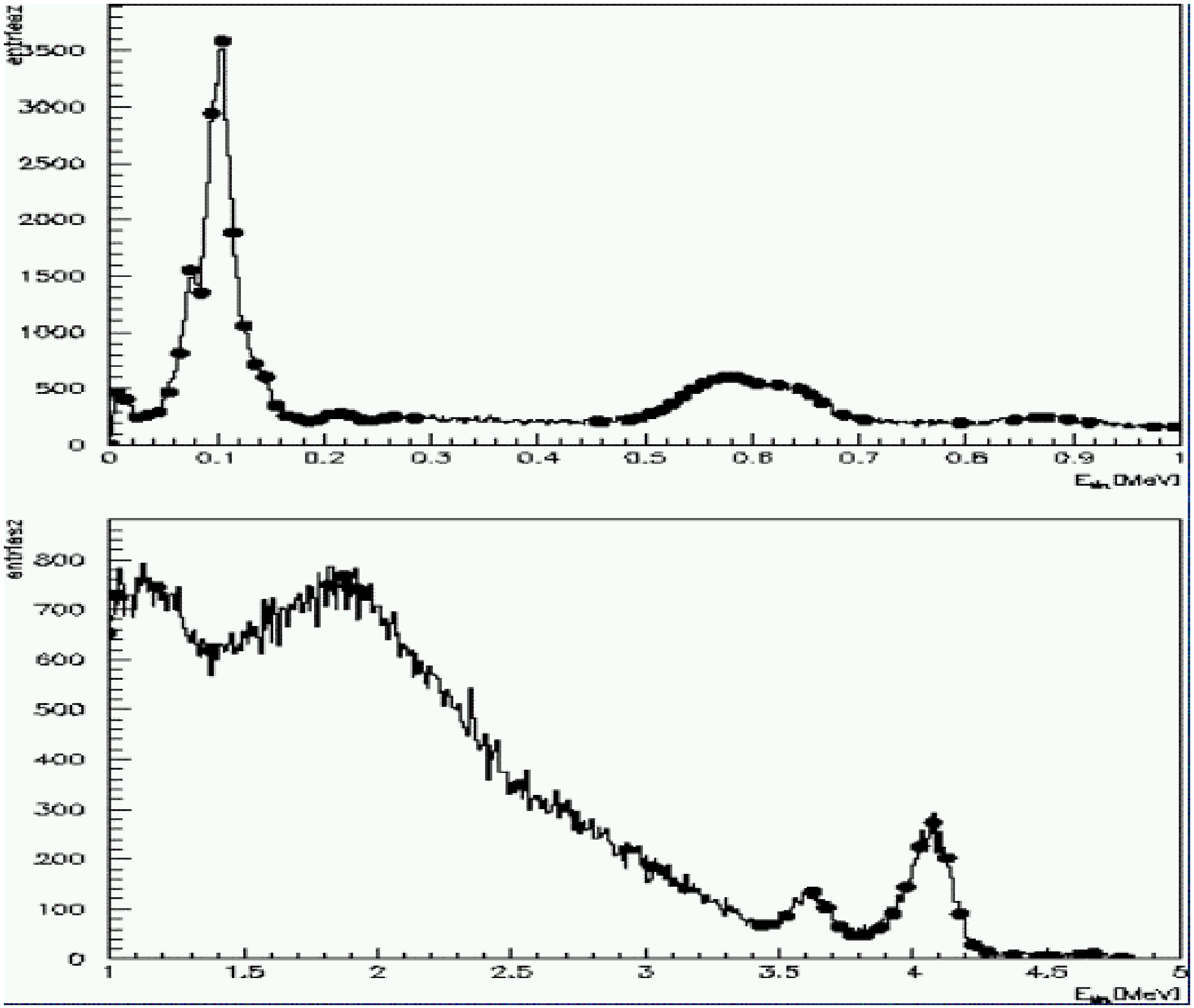
Level 2

Level 3

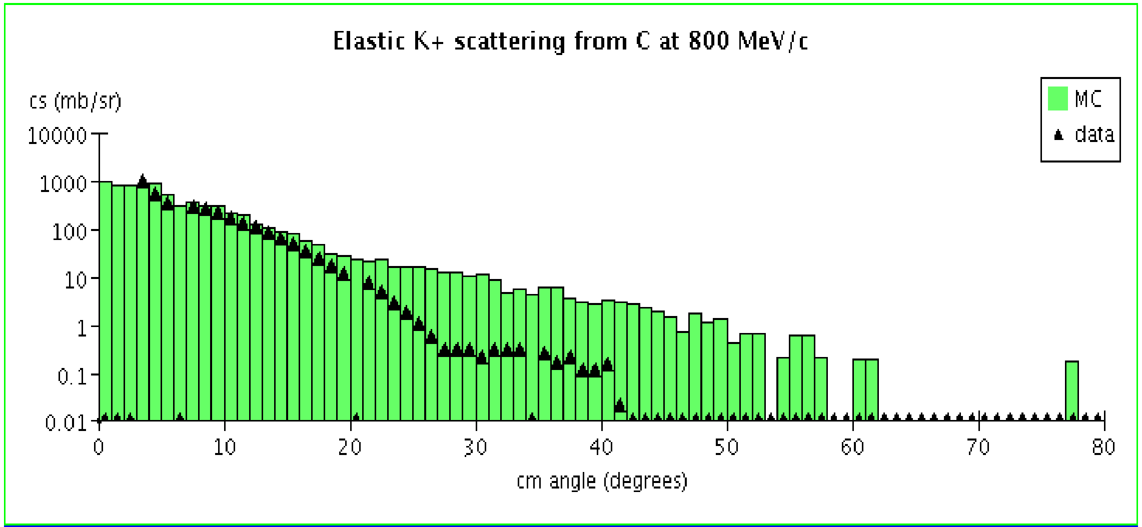
Level 4

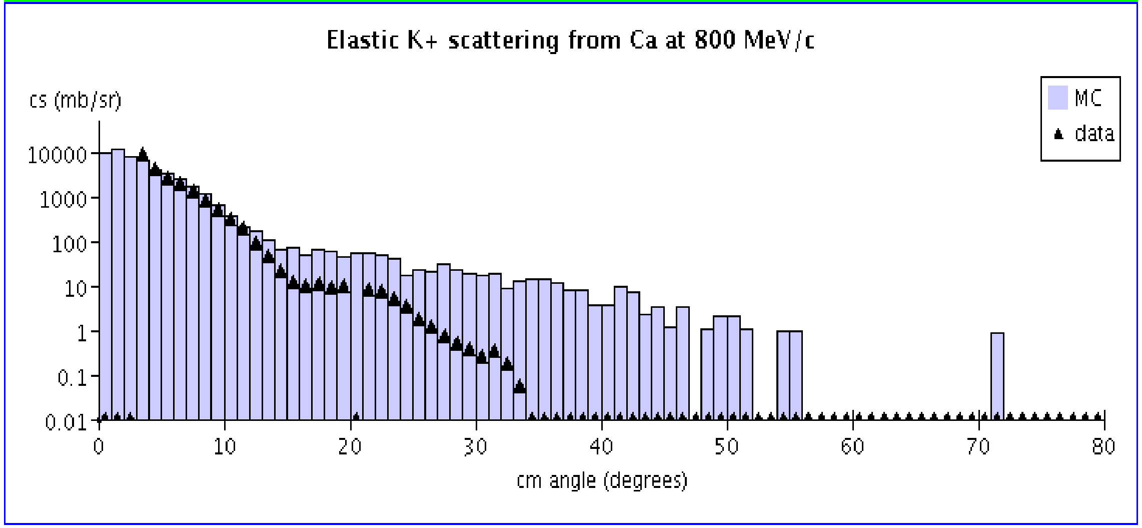
Level 5

γ from 14 MeV Neutron Capture on Uranium

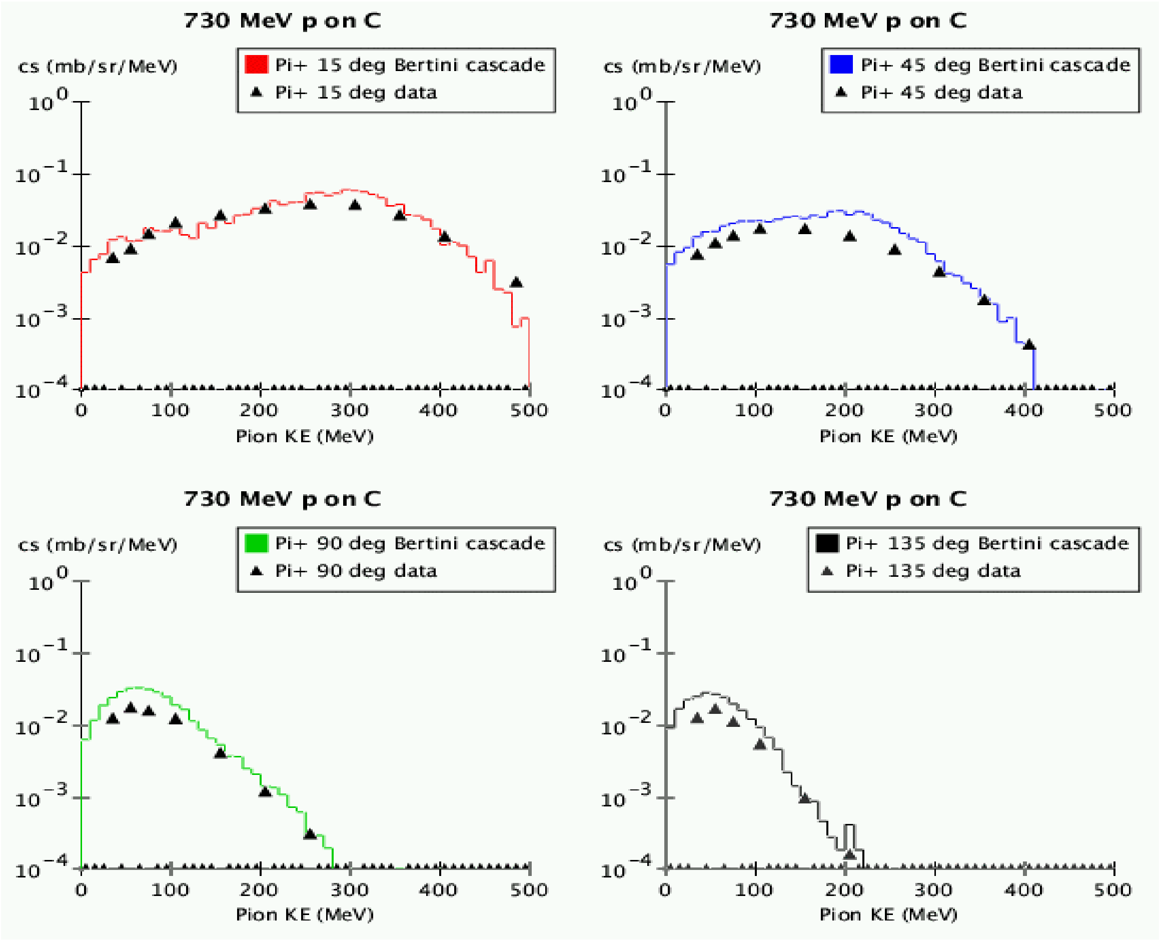


Geant4 Elastic Scattering 800 MeV/c K on C and Ca



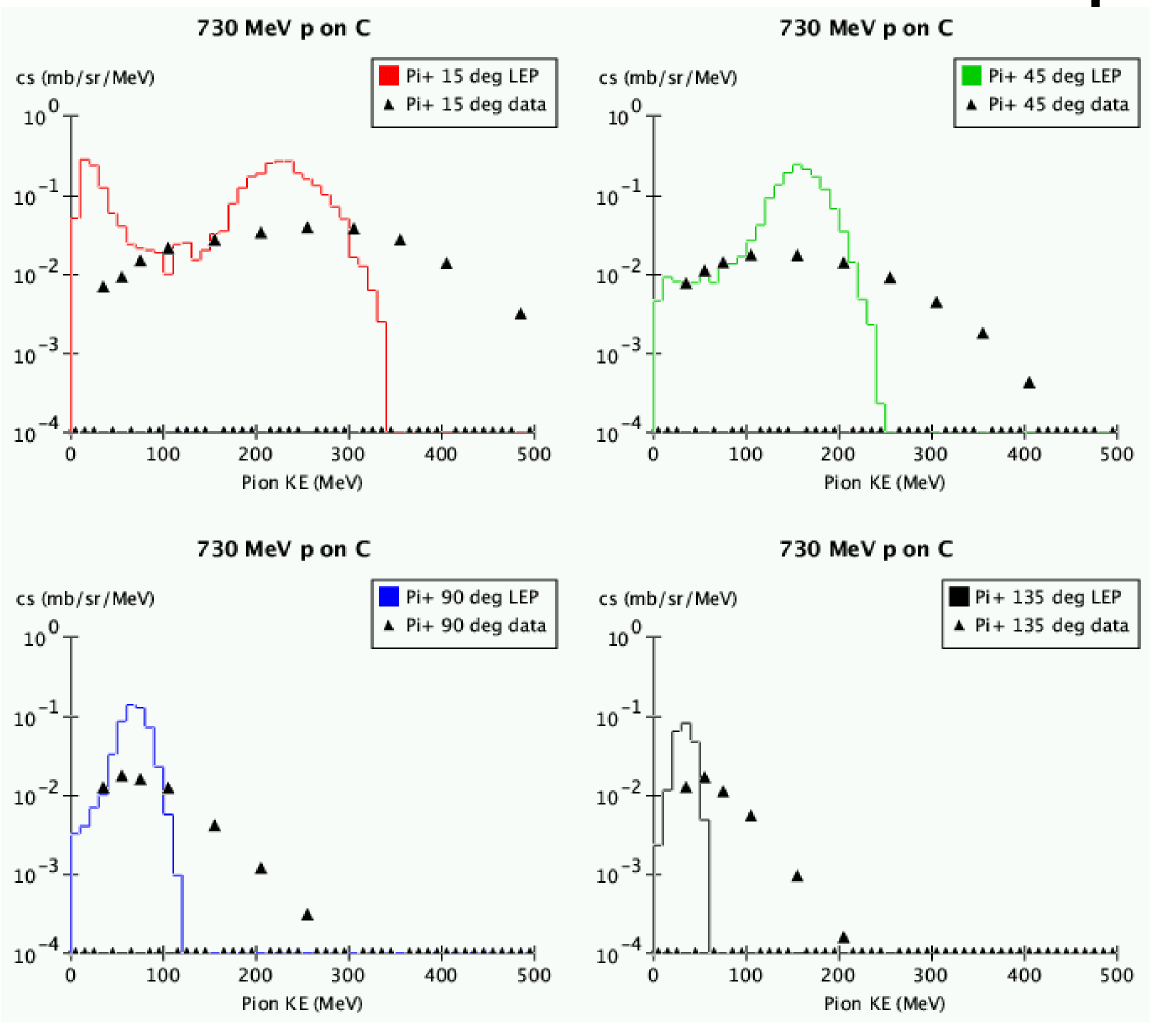


Bertini cascade model
π production from 730 MeV p on C

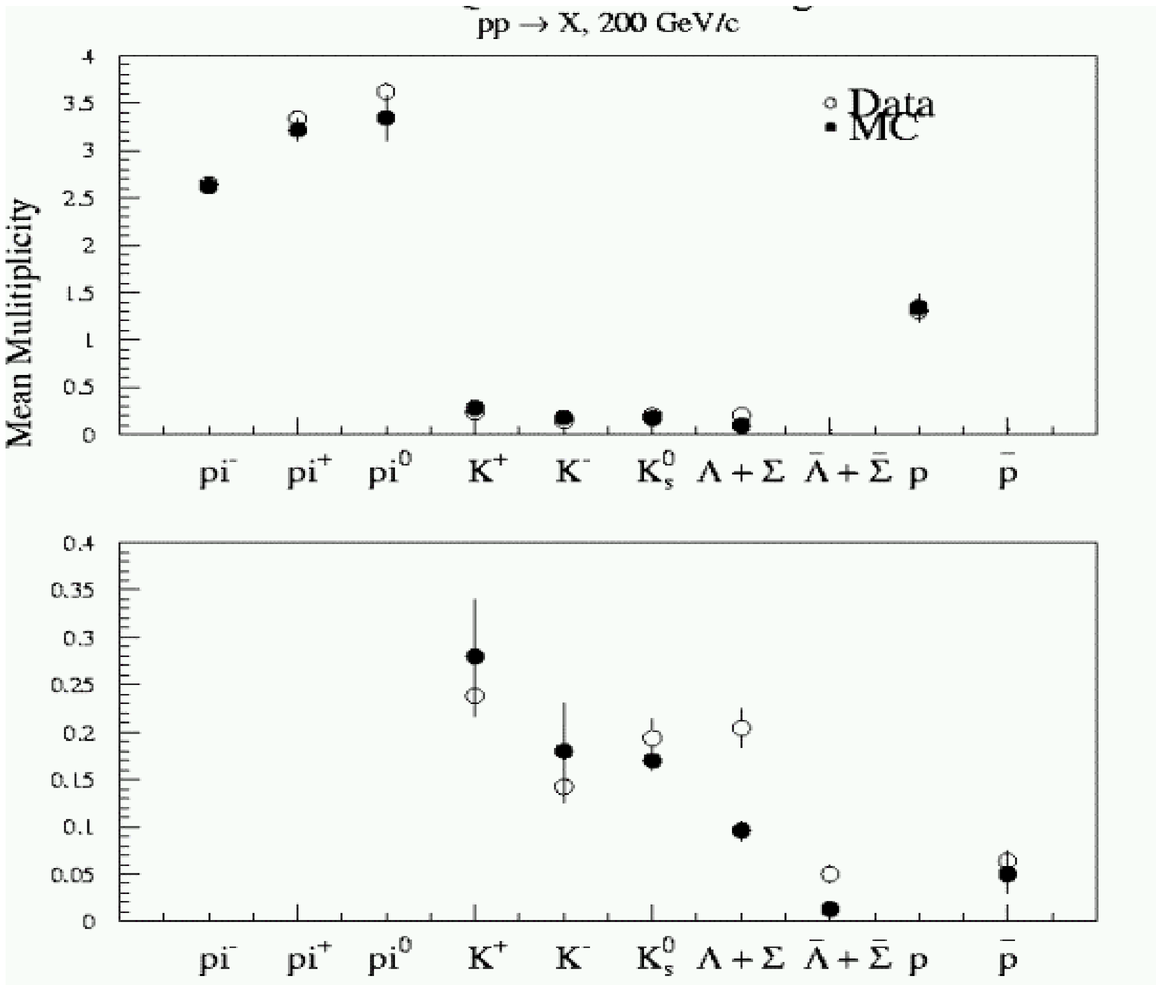


LEP Model

π production from 730 MeV p on C

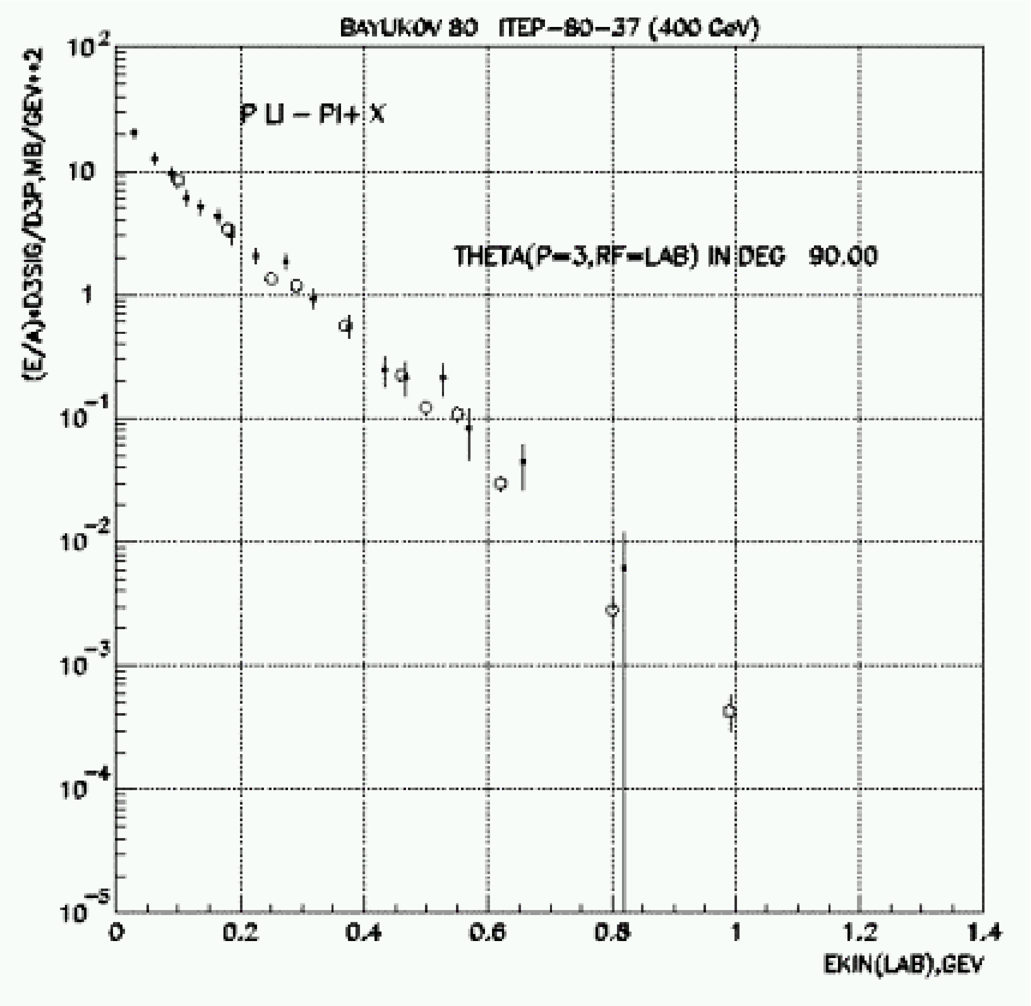


QGS Model
pp → X 200 GeV/c



QGS Model

p + Li → π + X   (400 GeV)



Physics Lists
putting physics into your simulation

- User must implement a physics list
  - Derive a class from G4VUserPhysicsList
  - Define the particles required
  - Register models and cross sections with processes
  - Register processes with particles
  - Set secondary production cuts
  - In main(), register your physics list with the Run Manager

- Care is required
  - Multiple models, cross sections allowed per process
  - No single model covers all energies, or all particles
  - Choice of model is heavily dependent on physics studied

Physics Lists by Use Case

- Geant4 recommendation: use example physics lists
  - Go to Geant4 home page → Site Index → physics lists
- Many hadronic physics lists available including
  - HEP calorimetry
  - Shielding penetration (high and low energies)
  - Dosimetry
  - LHC, LC neutron fluxes
  - Medical
  - Low background (underground)

Code Example

```
void MyPhysicsList::ConstructProton() {
    G4ParticleDefinition* proton = G4Proton::ProtonDefinition();
    G4ProcessManager* protMan = proton→GetProcessManager();
    // Elastic scattering
    G4HadronElasticProcess* protelProc
                    = new G4HadronElasticProcess();
    G4LElastic* protelMod = new G4LElastic();
    protelProc→RegisterMe(protelMod);
    protMan→AddDiscreteProcess(protelProc);
```

Code Example (continued)

```
// Inelastic scattering
G4ProtonInelasticProcess* protinelProc =
                                    new G4ProtonInelasticProcess();
G4LEProtonInelastic* proLEMod = new G4LEProtonInelastic();
protLEMod→SetMaxEnergy(20.0*GeV);
protinelProc→RegisterMe(protLEMod);

G4HEProtonInelastic* protHEMod = new G4HEProtonInelastic();
protHEMod→SetMinEnergy(20.0*GeV);
protinelProc→RegisterMe(protHEMod);
}
```

Conclusion

- Geant4 provides a large number of electromagnetic, hadronic, decay and optical physics processes for use in simulation

- Cross sections, either calculated or from databases, are available to be assigned to processes

- Interactions are implemented by models which are then assigned to processes. For hadrons there are many models to choose from. For EM usually only one.