Hadronic Models and Validation

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• Overview
• Hadronic models
• Model validation
• Plans and Conclusions
Overview of Hadronic Validation (1)

• Hadronic model validation required by BaBar
  – Energy range of interest: ~50 MeV to ~3 GeV
  – Particles: p, n, π, K + anti-particles

• This energy range also useful for calorimetry in LC detectors
  – Difficult energy range:
    • Many resonances
    • Theoretically messy
    • Not typically covered by low energy models
    • Not covered by high energy models
Overview of Hadronic Validation (2)

• Until December 2002, only one model, LEP (aka GHEISHA), covered this range

• Now three more models (for some particles)
  – Binary cascade
  – Bertini cascade
  – JQMD

• All require extension, validation. Bug fixes required for some
LEP Model (1)

- Energy, angle, multiplicity distributions based on parameterizations of experimental data

- Aims to get average quantities right – conservation rules generally don’t apply event-by-event

- Not designed for low energies (but used anyway)
  - No modeling of nucleus

- Fast
  - Applicable to all long-lived hadrons (\( T < 25 \text{ GeV} \))
LEP Model (2)

- **Problems:**
  - Bugs, many shortcomings
  - Reported to Geant4 by R. Cassell, G. Bower, D. Wright, some (but not all) fixes included in V5.0, 5.1

- **Solutions:**
  - Replace with new models where appropriate
  - If no new model for given particle, implement fixes
Binary Cascade Model

- Projectile is propagated through 3-D model of nucleus
- Only two-particle collisions are allowed
- Conservation laws observed
- Secondaries produced by decay of resonances and propagated to next collision
- 4 X slower than LEP
- Valid only for p, n (40 MeV < T < 10 GeV)
Bertini Cascade Model

- Nucleus treated as average nuclear medium
- Final state of each collision taken from cross section data
- Conservation laws observed
- Secondaries propagated to next collision
- 2-3 X slower than LEP
- Valid for p, n, π (100 MeV < T < 5 GeV)
Other Models

- JQMD (JAERI Quantum Molecular Dynamics)
- Geant4 interface to Fortran code by T. Koi
- Projectile propagated in field of nucleus, interacts with every nucleon in target

- **Speed increases rapidly with A**
  - 20 X LEP for C
  - 3300 X LEP for Pb
Validation Test Suite (1)

- Thin target (2-4 mm), pencil beam
- Allow only one interaction per event
- Look at final state particles at production vertex
- Only hadronic and transportation processes used
- Implement as simple Geant4 (5.0) example using JAIDA
Validation Test Suite (2)

• Look at energy, angle spectra of final state p, \( \pi \) from 730, 800 MeV incident p (typical BaBar hadron energies)

• Compare to (p,p’) data of McGill (1984) and (p,p \( \pi \)) of Cochran (1972)

• Targets: C, Ca, Pb
How To Invoke New Models

G4ProcessManager* pMan = G4Proton::Proton()->GetProcessManager();
G4ProtonInelasticProcess* theProtonInelProc = new G4ProtonInelasticProcess();

G4BinaryCascade* theBinCascade = new G4BinaryCascade();
theBinCascade->SetMinEnergy(100.0*MeV);
theProtonInelProc->RegisterMe(theBinCascade);

G4LEProtonInelastic* protonLEP = new G4LEProtonInelastic();
protonLEP->SetMaxEnergy(100.0*MeV);
theProtonInelProc->RegisterMe(protonLEP);

pMan->AddDiscreteProcess(theProtonInelProc);
LEP Validation (1)
LEP Validation (3)
Bertini Cascade Validation (1)
Bertini Cascade Validation (2)
Binary Cascade Validation (1)
Binary Cascade Validation (2)
Binary Cascade Validation (3)
Pion Production Validation (1)

**730 MeV p on C**

- **Pi+ 15 deg Bertini cascade**
- **Pi+ 15 deg data**

- **Pi+ 45 deg Bertini cascade**
- **Pi+ 45 deg data**

- **Pi+ 90 deg Bertini cascade**
- **Pi+ 90 deg data**

- **Pi+ 135 deg Bertini cascade**
- **Pi+ 135 deg data**
Pion Production Validation (2)
Pion Production Validation (3)
Plans

• Much more thin target validation to be done in this energy range
  – Lower and higher energies
  – n, π, K projectiles

• Use BaBar data for validation
  – So far, not easy to see model differences
  – Still looking for clean tests
  – Test beam data at these energies would be great
Conclusions

New hadronic models now available in Geant4
– Bertini cascade, binary cascade, JQMD
– For energy range 50 MeV – 5 GeV
– Not yet available for all hadrons

• Validation tests are in progress (turning the crank)

• Early result: LEP model should be replaced wherever possible, but repairs should continue

• Plan to include new hadronic processes in next version of BaBar simulation production