Simulation

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- Overview of the LCG simulation project
- Simulation physics validation
  - Test beam results
  - Simple benchmark studies

Introduction

- Simulation very important for high- energy physics experiments:
  - Detector design and optimization
  - Beamline simulations
  - Background and radiation estimates
  - Physics performance studies
  - Development of physics analyses
  - Determination of systematic errors
  - ...
- How good should simulation tools be (for LHC experiments)?
  - From the point of view of physics analysis:
    - **Dominant (systematic) error for LHC physics results should not be due to imperfect simulation**

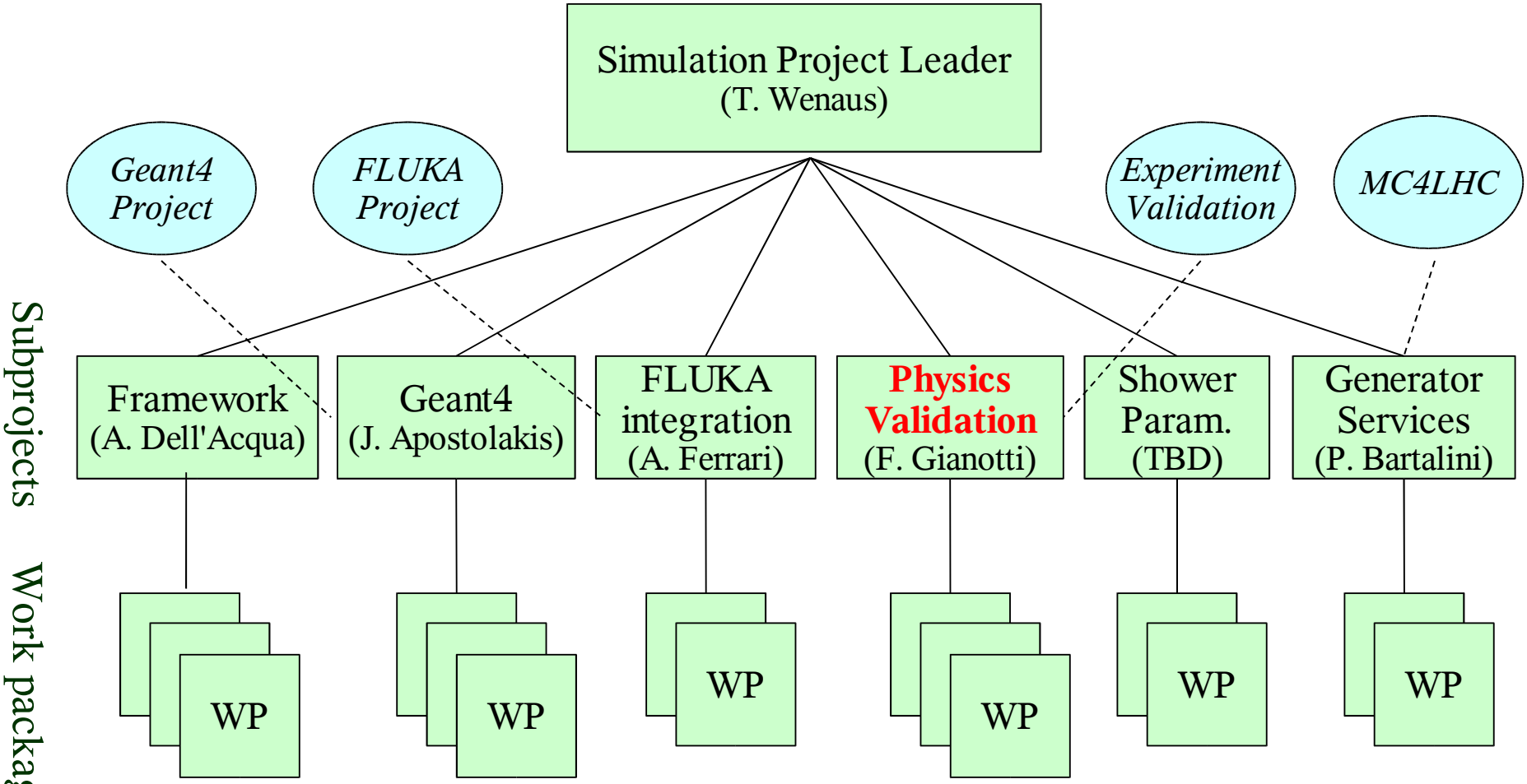
Simulation Ingredients

- Representation of experiment ("geometry")
- Event generators
- Transport of generated particles (e.g. within magnetic field)
- Particle decays
- Interaction of particles with active ("detector") and passive materials in the experiment and generation of secondary particles
- Simulation of detector/electronics response

=> A large fraction of the above is experiment-independent and can be addressed by generic tools

  - Many general tools developed (Pythia, Geant3/4, Fluka, ...)
  - Common aspects of simulation at LHC now addressed by simulation project in LCG Application Area
    - Approved by LCG SC2 (Software Computing Committee) in March 2003

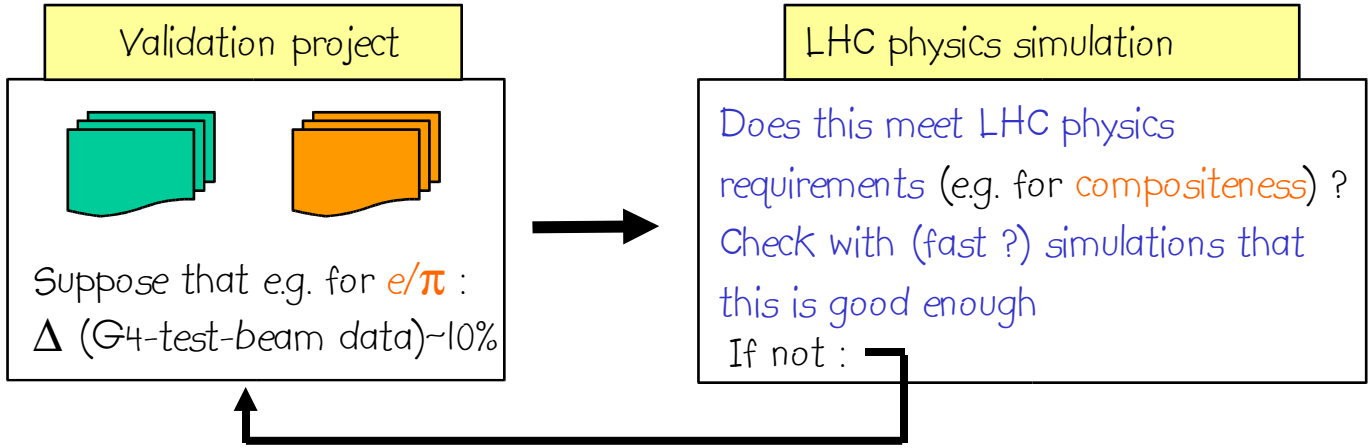
Overview of the LCG Simulation Project



For details: http://lcgapp.cern.ch/project/simu/

Simulation Physics Validation

- What do we need to validate?
  - Electromagnetic physics (by now ~ ok)
  - Hadronic physics (calorimetry, tracking, radiation background)
  - Simulation environment (MC truth, shower parametrization, CPU and memory requirements, ...)
- Continuation of extensive work done previously
  - Check coherence of results among experiments and subdetector-technologies
- Interplay between physics groups and validation:



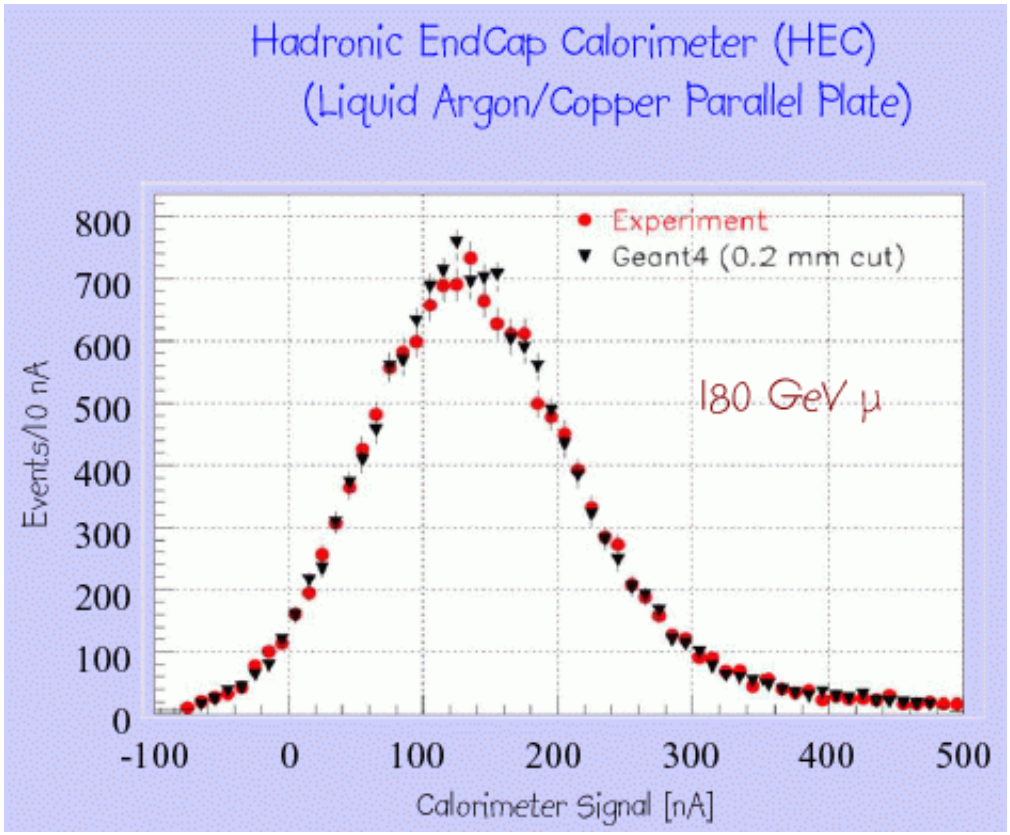
Simulation Physics Validation Work Packages

- Impact on LHC physics
- Input from LHC test beams
- Geometry
- Electromagnetic physics
- Hadronic physics:
  - Calorimetry
  - Tracking detectors
  - Background radiation
- Physics validation from outside LHC
- Special needs for simulation
- Simulation environment

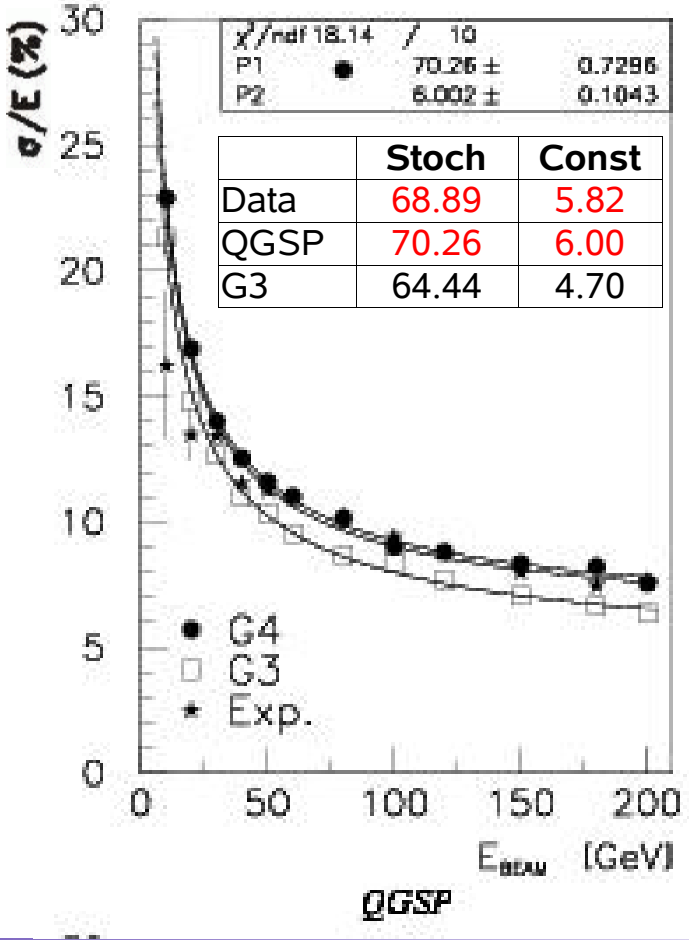
- The Simulation Physics Validation Project is the **primary forum for the simulation experts of all the LHC experiments** to meet and exchange information regarding physics validation
- Validation work is carried out both within the experiments (e.g. analysis of test beam data) and within LCG (e.g. simple benchmark studies)

Sample Results from Test Beam Studies (I)

- Extensive test-beam studies being performed by all LHC experiments
- Example: **ATLAS** (A. Dell'Acqua, CHEP'03):

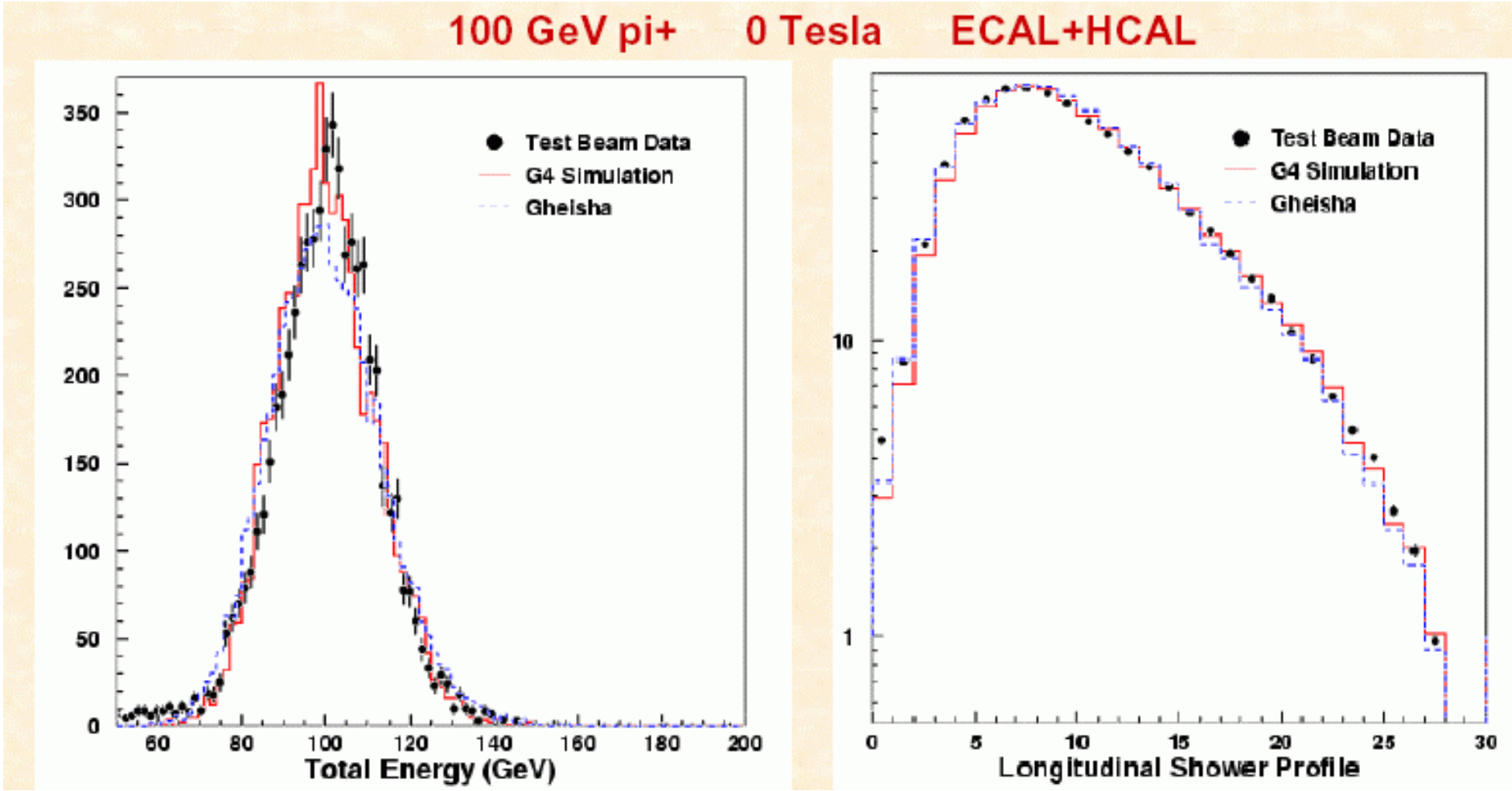


HEC Pion Energy Resolution



Sample Results from Test Beam Studies (II)

- Example: **CMS** (from P. Arce, CHEP'03):



Simple Benchmark Studies

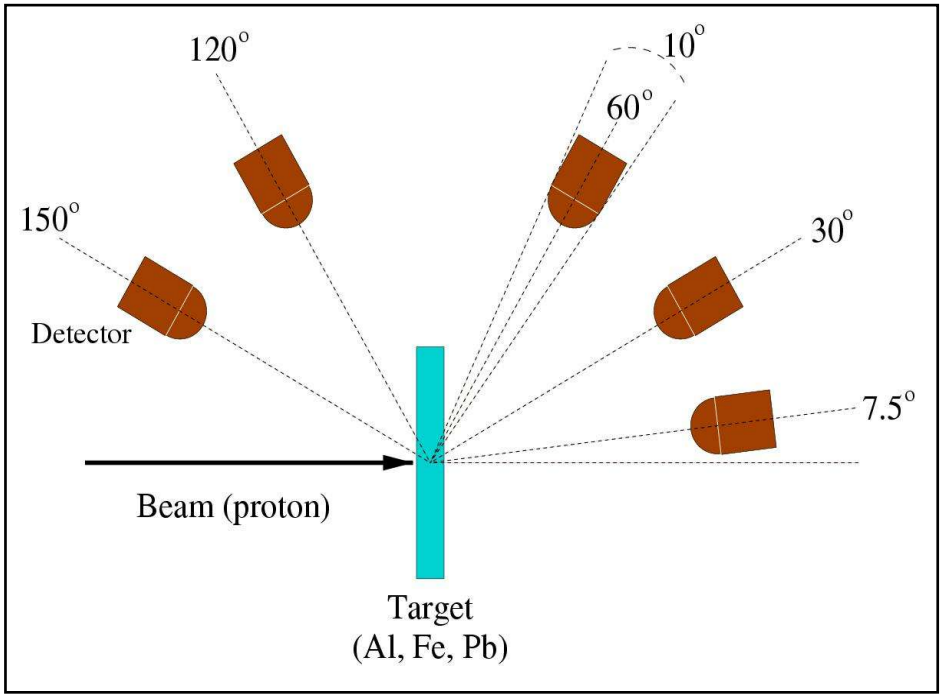
- Predictive power of detector simulation rests on correct simulation of individual interactions between particles and detector material
- Check that the simulation of such interactions is sufficiently accurate:
  - **Compare Geant4, Fluka and experimental data for simple benchmark geometries and materials for single incident particles of various energies**
- A very large number of such comparisons can be thought of, but:
  - Experimental data should be available
  - Should be relevant for LHC detectors/physics
  - Build on similar studies done previously
- Should repeat all studies with each new release of simulation package
  - Would like a (semi-)automatic test suite to repeat these studies when desired

Proton Thin-Target Hadronic Benchmark

- Chosen as starting point for simple benchmark studies
  - Continuation of work done by I. Gonzalez in context of Alice
  - Repeat studies with updated physics models and current version of Geant4
  - Check that problems found earlier are fixed
- Look at (p,xn) for different materials: Al, Fe, Pb
  - Consistency checks (energy-momentum conservation, ...)
  - Azimuthal distributions
  - Double-differential cross sections
- Used as a prototype to understand how to set up and maintain code for simple benchmark studies
- Work in progress – all results very preliminary

Experimental Data from Los Alamos

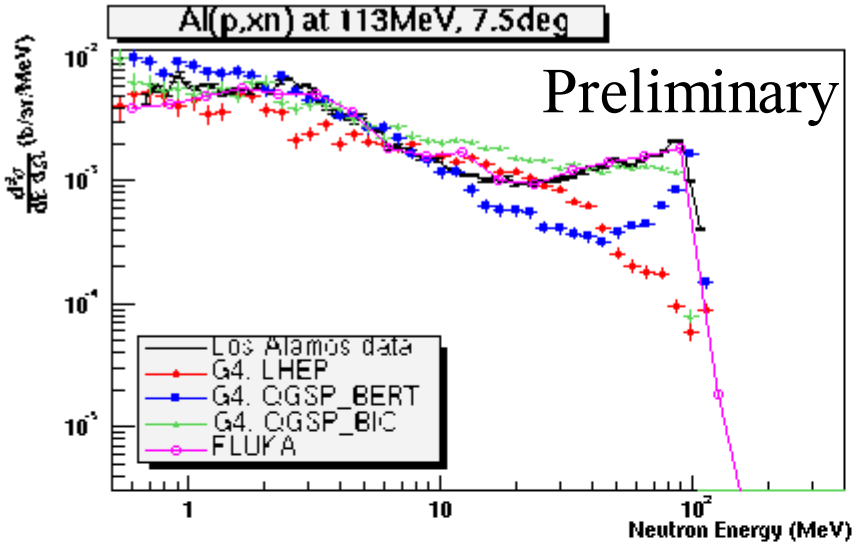
- Differential (p,xn) cross sections measured at LAMPF
  - Incident proton energies: 113, 256, 597, 800 MeV
  - Thin targets (Al, Fe, Pb, ...)
    - ≤ 1 interaction per incident proton
    - Measure Al(p,xn) etc
  - Neutron detectors at 5 angles
  - References:
    - Nucl Sci Eng 102 (1989) 310
    - Nucl Sci Eng 110 (1992) 289
    - Nucl Sci Eng 112 (1992) 78
    - Nucl Sci Eng 115 (1993) 1

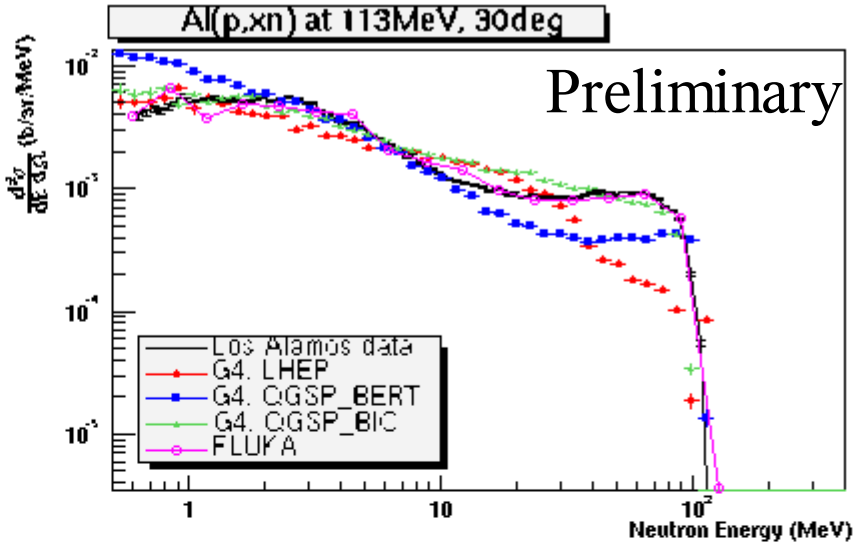


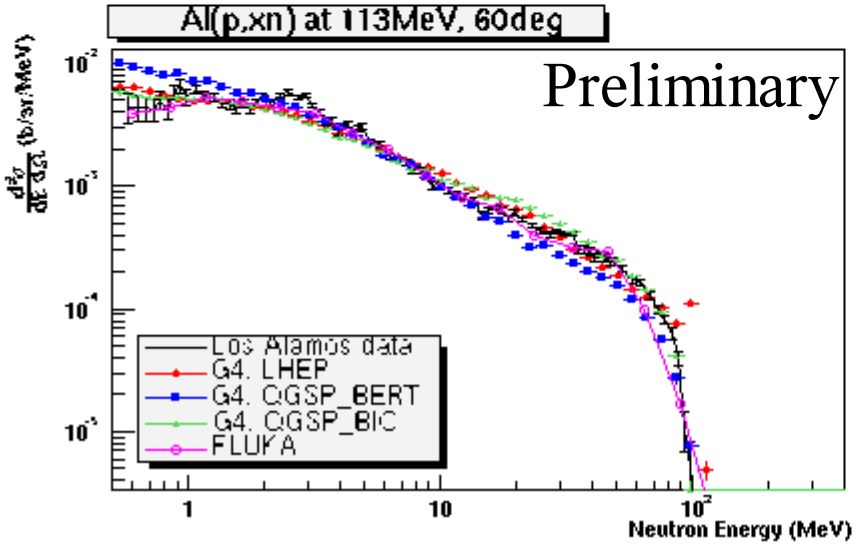
Some Physics Models for Hadronic Interactions

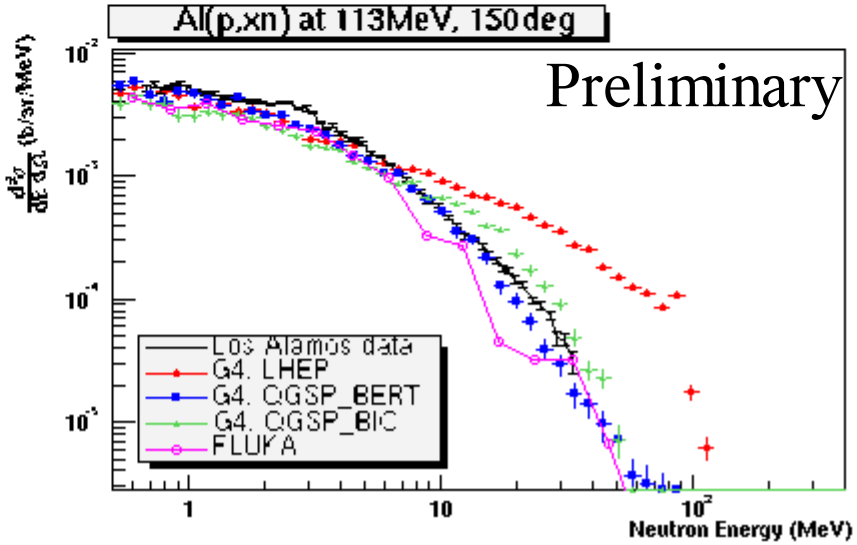
- LHEP (Geant4)
  - LEP and HEP parametrized models for inelastic scattering
  - Based on Gheisha package of Geant3
- QGSP_BERT (Geant4)
  - Quark gluon string model, pre-equilibrium decay model, evaporation phase
  - Bertini cascade below 3 GeV
- QGSP_BIC (Geant4)
  - Quark gluon string model, pre-equilibrium decay model, evaporation phase
  - Binary cascade below 3 GeV
  - Better description of forward scattered particles, significantly slower
- FLUKA
  - Physics model as implemented in Fluka package

Double-Differential n Production Cross Section









Plans and Milestones

- Other simple benchmark studies (some already in progress):
  - Pion absorption below 1 GeV (experimental data for Al, Co, Fe, Bi, Au)
  - Rapidity distributions on H/Ar/Xe at 200 GeV (old bubble chamber data)
  - Slow nucleons in pA interactions
  - ...
- Schedule for simulation physics validation project:
  - Sep 2003: First cycle of electromagnetic physics validation complete
  - Jan 2004: First cycle of hadronic physics validation complete
  - Mar 2004: Simulation test and benchmark suite available
  - Dec 2004: Final physics validation document complete

Summary and Conclusions

- Simulation very important for high- energy physics experiments
- Want to make sure that dominant (systematic) errors of LHC physics results will not be due to inadequacies of simulation physics and software
- Many aspects of simulation are experiment-independent
  - Now addressed under the umbrella of the LCG Simulation Project
  - Participation of both experiments and LCG
- Work on simple benchmark studies for simulation physics validation is in progress
- Time-scale for completing simulation physics validation is December 2004