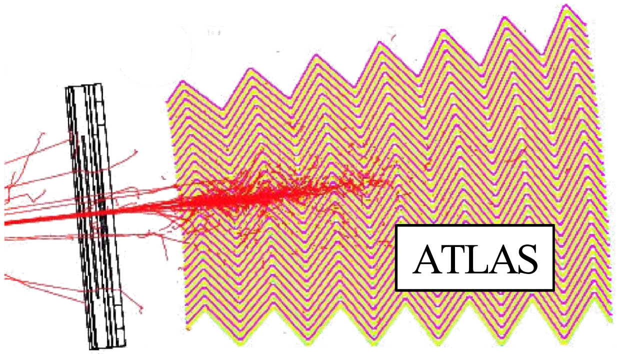
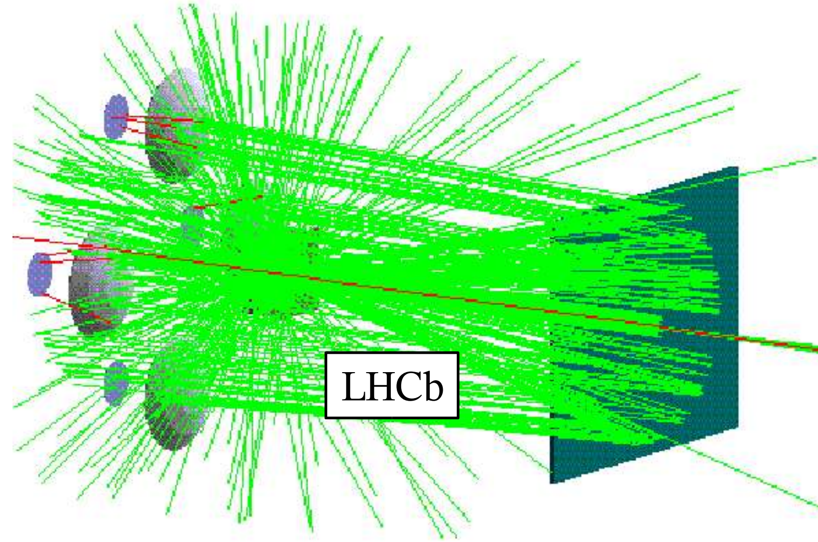
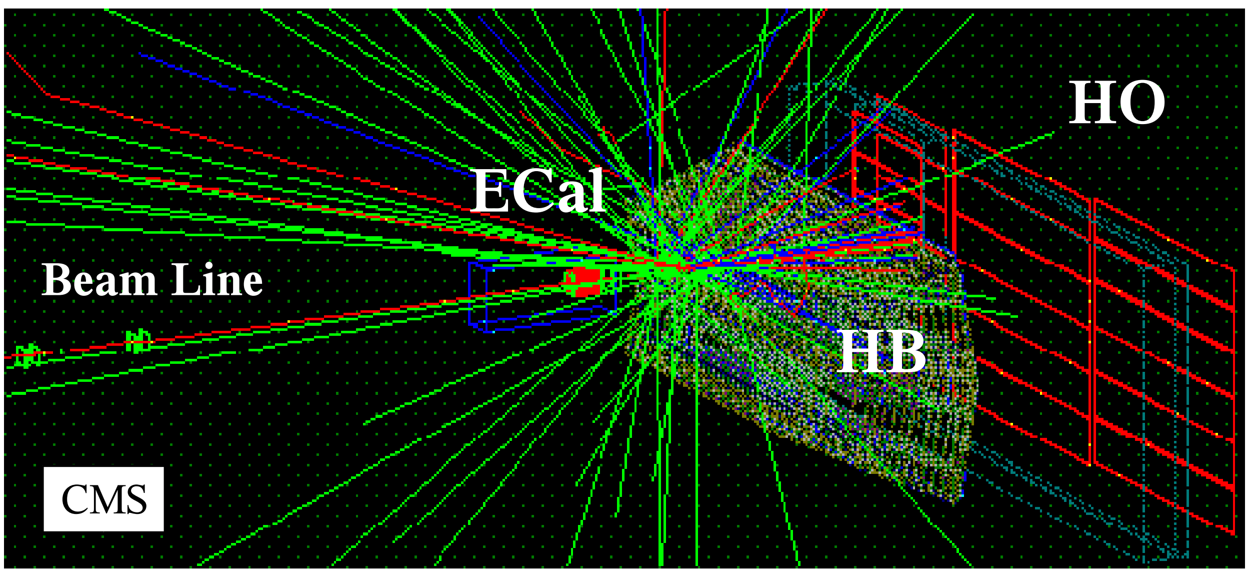
Physics Validation of Detector Simulation Tools for LHC

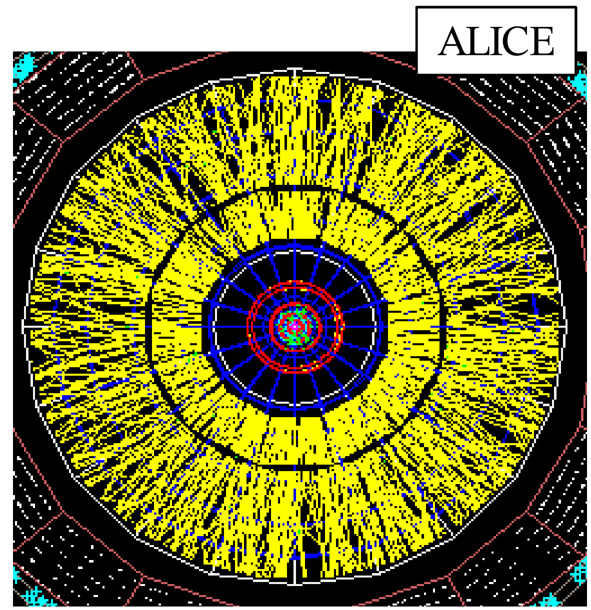


Juerg Beringer
CERN
on behalf of the
LCG Simulation
Physics Validation Project



- Simulation physics validation for LHC
- Recent results from test-beam studies
- Recent results from “Simple Benchmarks”
- Conclusions

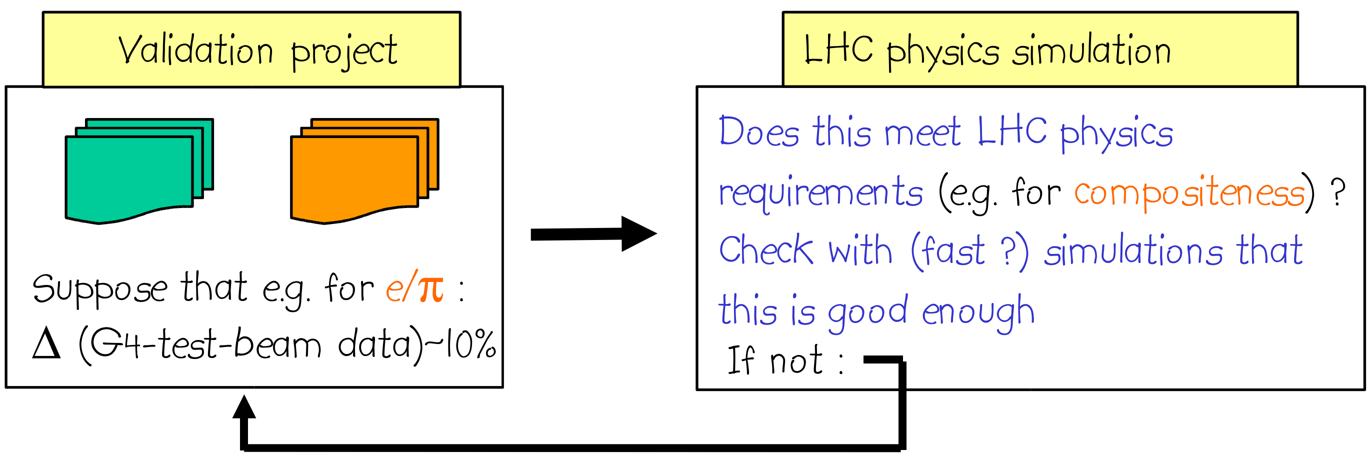




Introduction

- Main detector simulation tools for LHC experiments:
  - **Geant3** (being phased out)
  - **Geant4**
  - **Fluka**

- How good should these simulation tools be (for LHC experiments)?
  - **Dominant (systematic) error for LHC physics results should not be due to imperfect simulation**



Simulation Physics Validation Project

- **LHC-wide simulation physics validation project** started within the Application Area of the LHC Computing Grid Project (LCG)
- **Goals:**
  - Assess adequacy of the simulation physics and environment for LHC physics
  - Primary forum for people to work together on issues of common interest
  - Study coherence of results across experiment and sub-detector technologies
- **Expected output of the project (by about end of 2004?):**
  - Understanding of weaknesses and strengths of Geant4 / FLUKA
  - Understanding of uncertainties and inadequacies of Geant4 / FLUKA
    - Contribution to systematic errors of measurements when data will be available
  - Optimized physics lists, balancing technical against physics performance
  - Benchmark suite with relevant plots and tests for automatic (or semi-automatic) validation of future releases of simulation tools
  - Documentation of results

What Do We Need to Validate?

- **Physics of shower packages (Geant4, Fluka) – this is the main goal**
  - Hadronic physics (calorimetry, tracking, radiation background)
  - Electromagnetic physics (by now ~ OK)
- Adequacy and usability of simulation environment
  - E.g. CPU, memory, interactivity as well as generators, MC truth, ...
- **Validation will be based mainly on:**
  - Comparison with LHC detector test-beam data
  - "Simple benchmarks": thin targets, simple geometries
  - Simulation of complete LHC detectors (to check usability of simulation tools)
- **Note:**
  - A lot of work already done by LHC experiments and by Geant4, FLUKA teams
  - As well as by other (non-LHC) experiments
  - Work carried out both within experiments and LCG

Hadronic Physics Simulation

- In contrast to simulation of electromagnetic processes, hadronic physics simulation must rely on different **models** because there is no unified theory that can describe hadronic showers from first principles
  - Many different models optimized for different applications
- **Fluka:**
  - A single combination of models that work for a wide range of applications
- **Geant4:**
  - Physics model is determined through "physics list" assembled by the user
  - Need to choose optimized "standard" physics list(s) for LHC experiments
  - Examples of physics lists of interest:
    - LHEP
    - QGSP with Bertini or Binary Cascade
    - ...

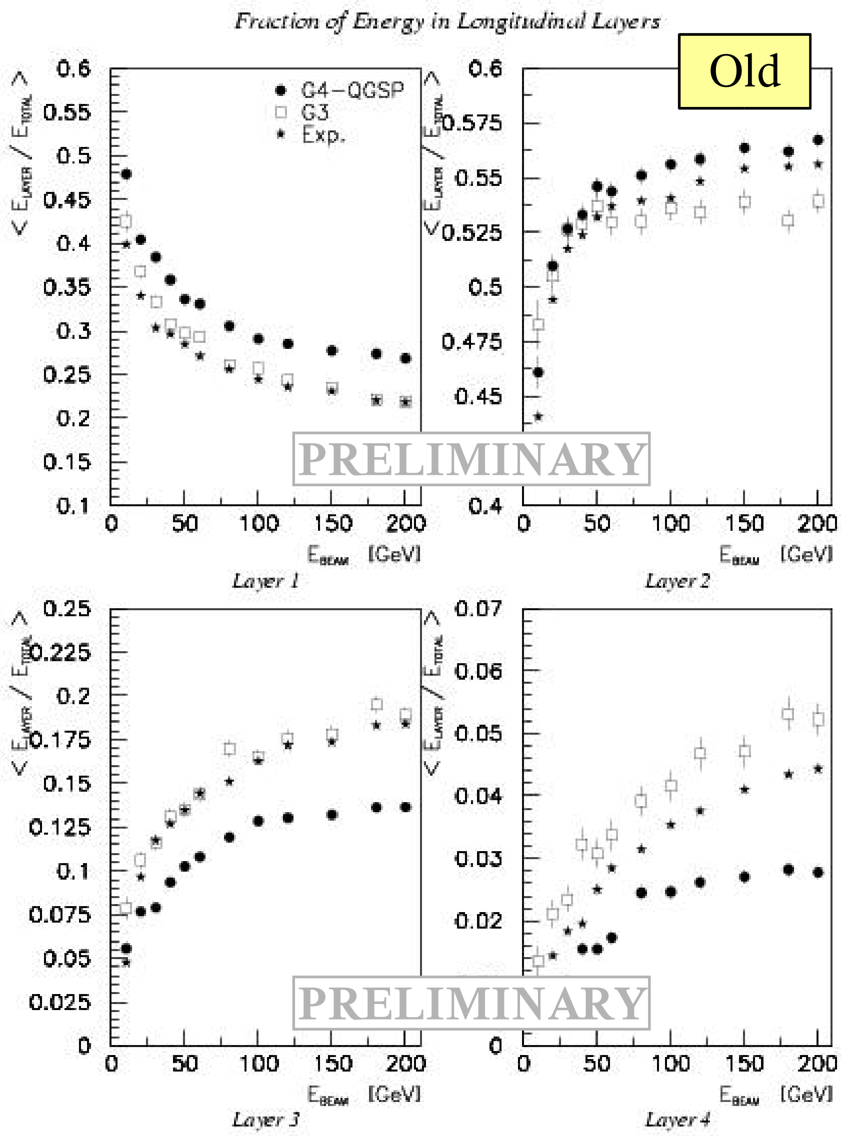
Recent Results from Test-Beam Studies

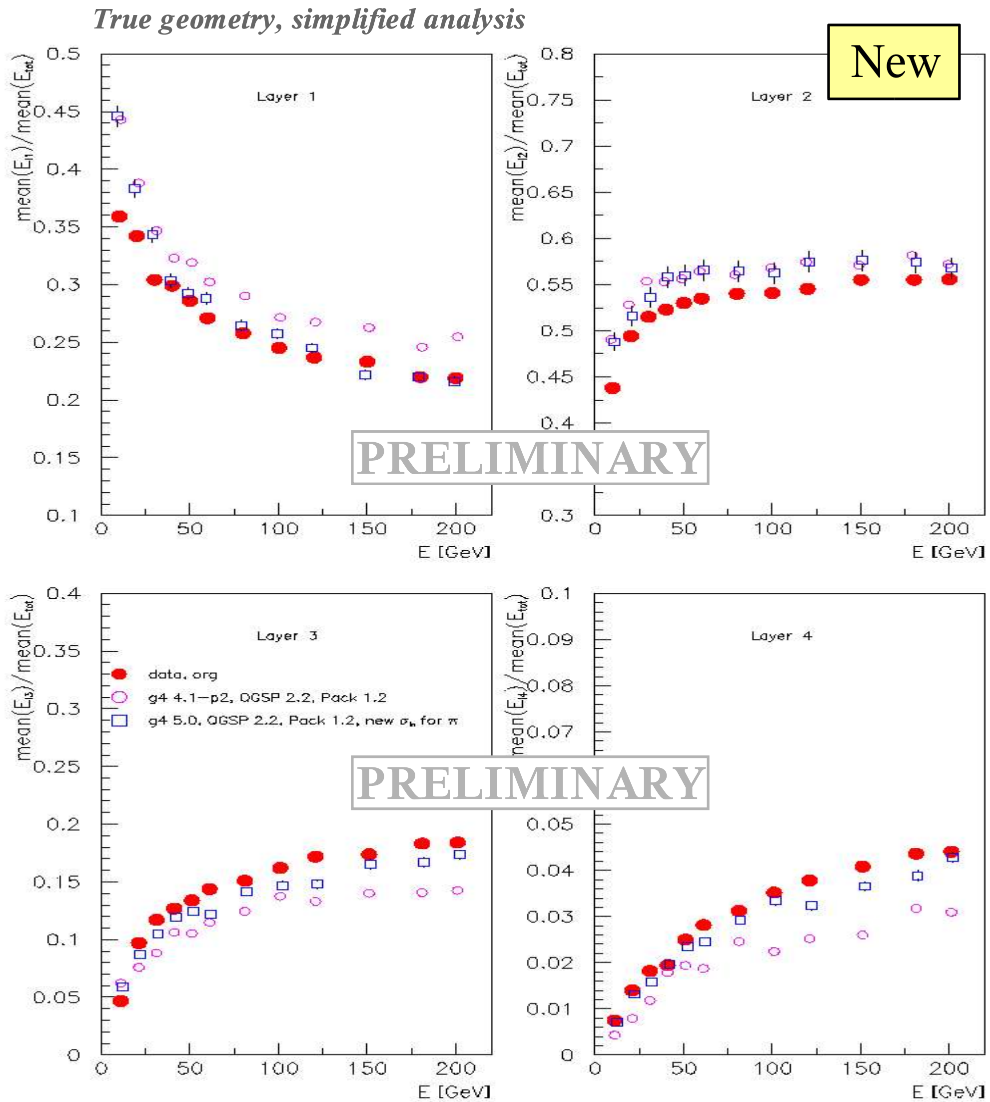
- Many detailed comparisons between test-beam results and simulation have been made for different sub-detectors, different particles/energies, and using different physics models for the simulation
- Can present here only **a few recent examples**:
  - Pion shower profile in the ATLAS hadronic end-cap calorimeter
  - Pion energy resolution in the CMS ECAL+HCAL prototype
  - Cluster size and hadronic interactions in the ATLAS pixel detector
- **Examples are shown to illustrate work in progress – not final results!**
- Many more results can be found on the web page of the physics validation project at:

  http://lcgapp.cern.ch/project/simu/validation/

Pion Shower Profile in the ATLAS HEC

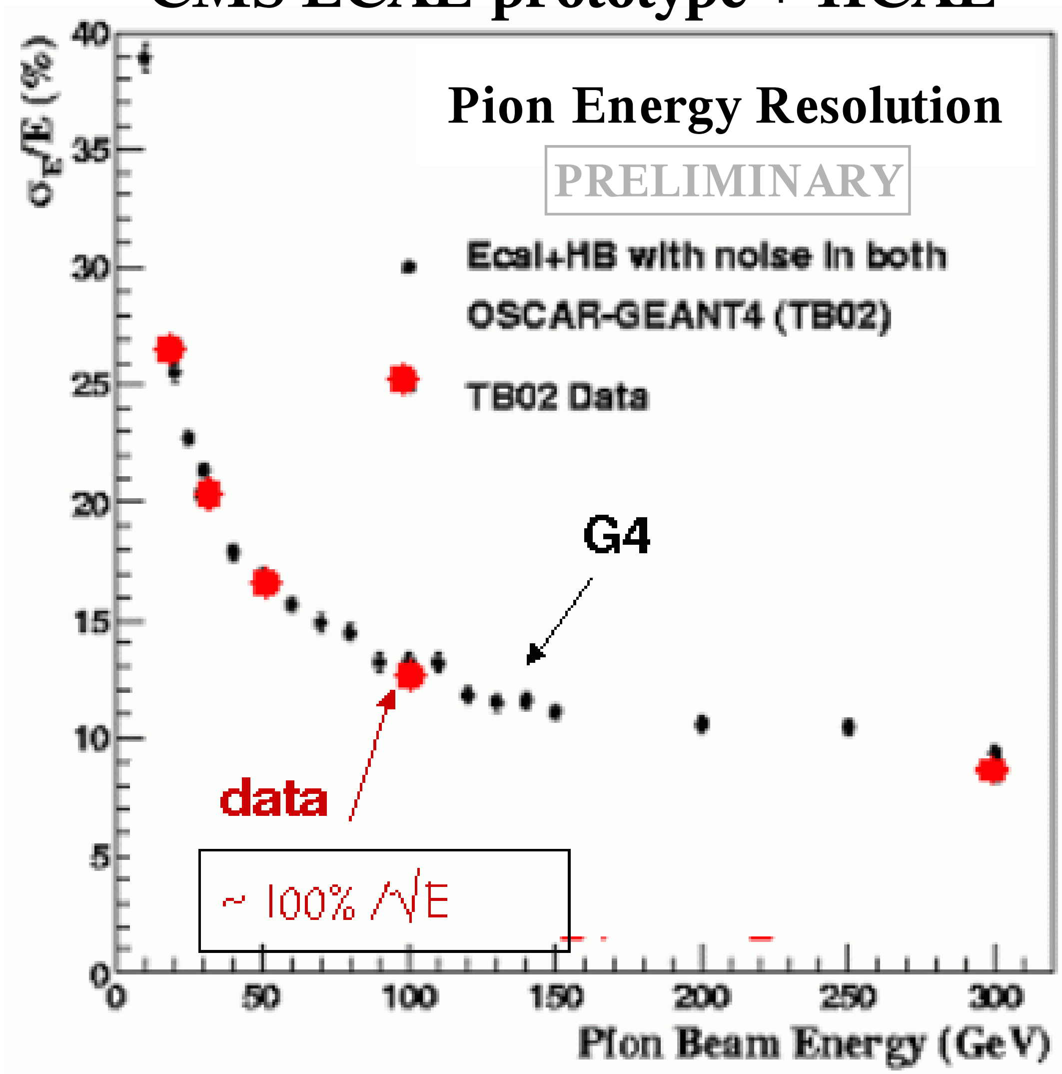
- Improvement in pion shower profile after fixing 10% mismatch in σ_π



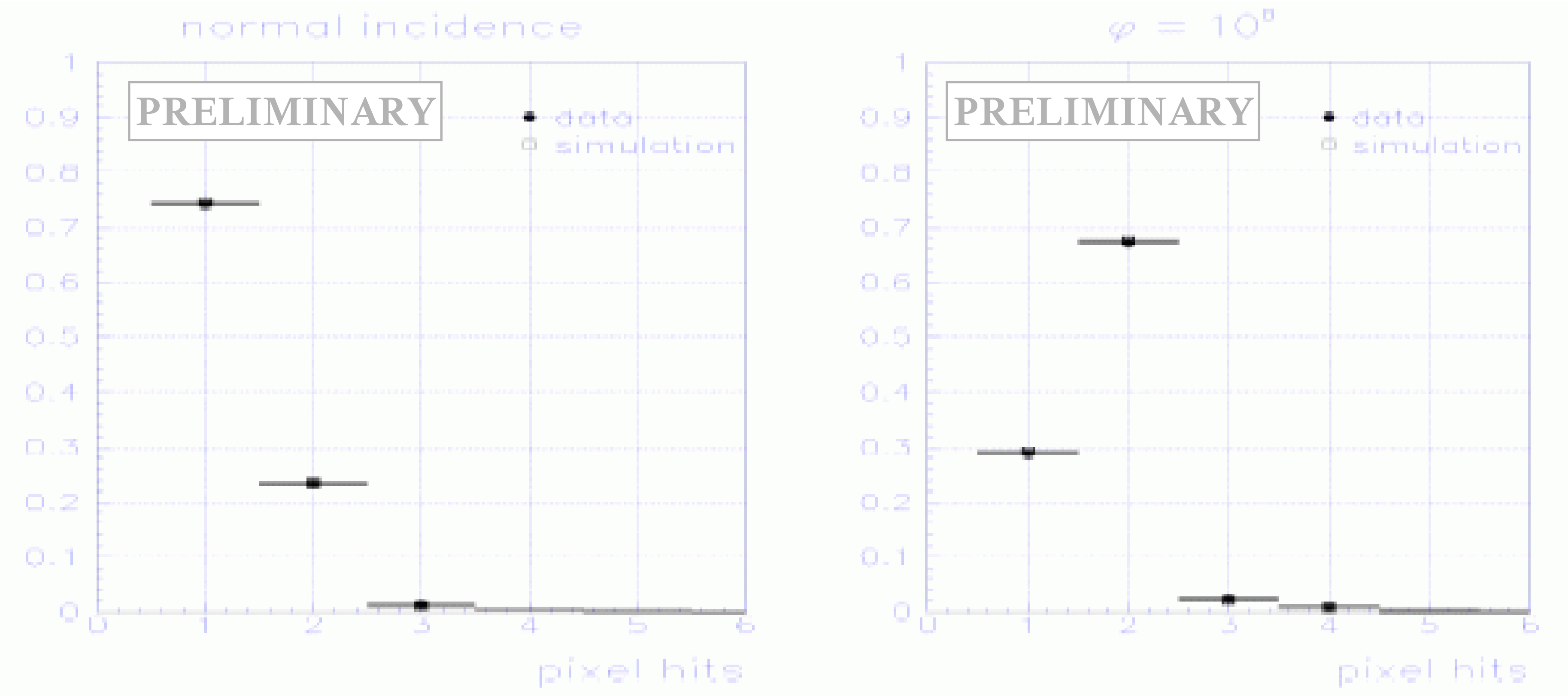


Pion Energy Resolution in CMS

CMS ECAL prototype + HCAL

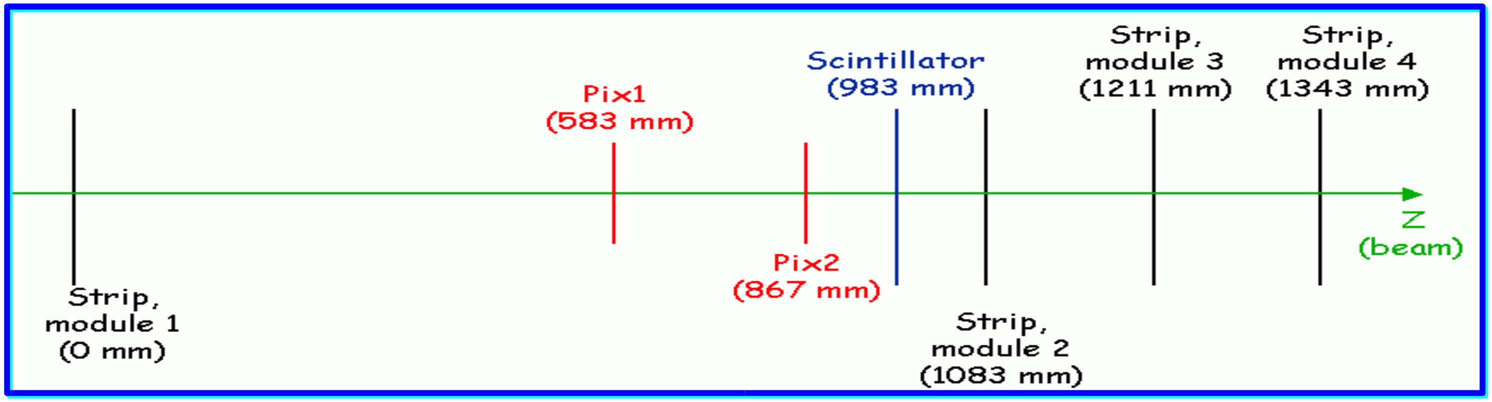


Cluster Size in the ATLAS Pixel Test Beam

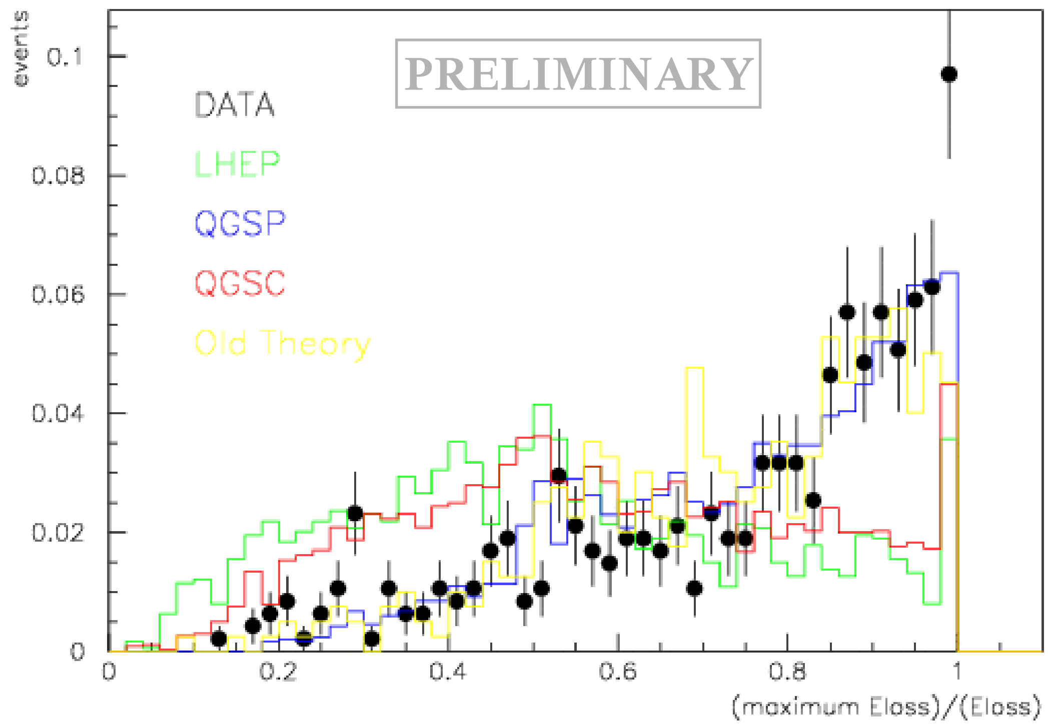


- Summer 2003 data
- Very good agreement between test beam data and simulation

Hadronic Interactions in ATLAS Pixel Test Beam



- Plot shows maximum energy in single pixel divided by total cluster energy
  - Sensitive to production of heavy nuclear fragments and their energies
- Study done using most recent Geant4 physics lists
  - QGSP found to be best physics list for ATLAS calorimeter simulation
  - Also best one in this study

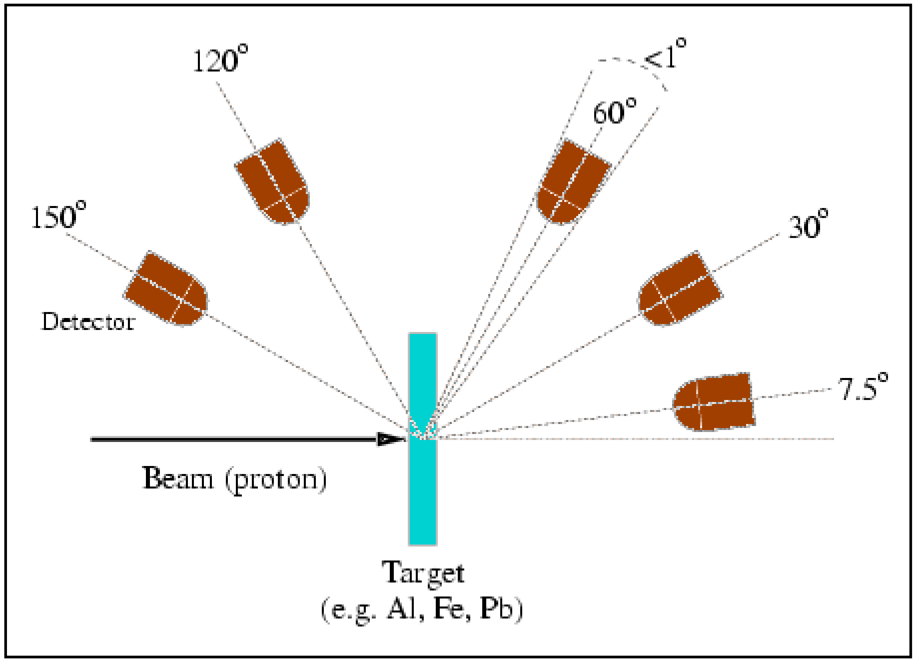


Simple Benchmark Studies

- Predictive power of detector simulation rests on correct simulation of individual microscopic interactions between incident particles and detector material
- Cannot be studied in simple/easy way with LHC detector simulations where multiple interactions/showers/cascades occur
  - Complex phenomenology may average out problems at the microscopic level
- **Study simple benchmark layouts and compare Geant4, FLUKA and experimental data for single incident particles of various energies**
  - Choose benchmarks where experimental data is available
  - Benchmark should be relevant for LHC
  - Examples:
    - **Double-differential (p,xn) production cross sections**
    - Pion absorption below 1 GeV
    - ...
- Benchmark test suite to repeat studies for new simulation software releases

Experimental (p,xn) Data from Los Alamos

- Double-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
  - TOF measurement with neutron detectors at 5 angles
  - Systematic errors of 22% to 30%
  - 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



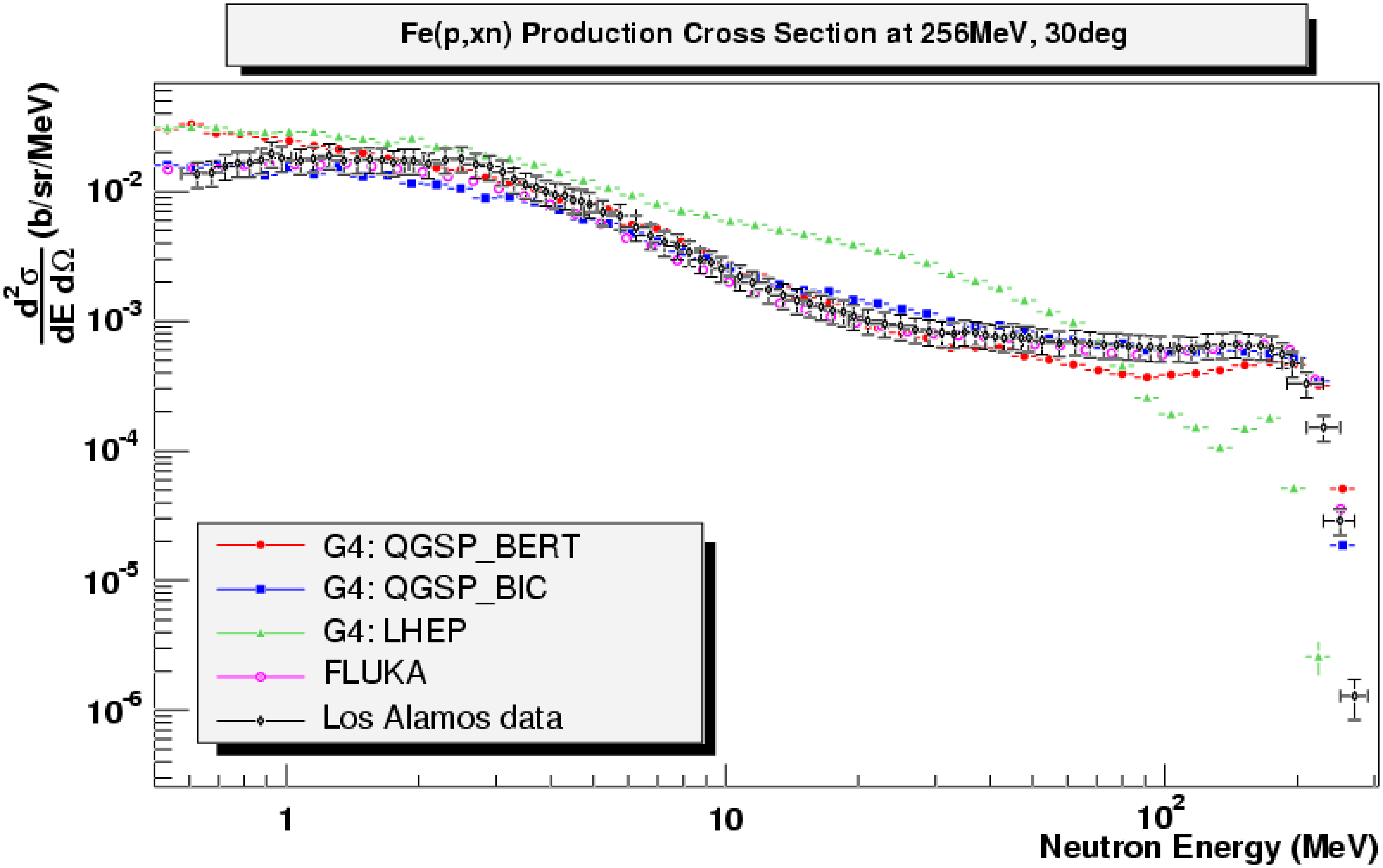
- Some level of disagreement with data from Phys Rev C47, 1647 (1993)
- Agreement with data measured at Saturne accelerator for 800 MeV protons (Phys Rev Lett 82, 4412 (1999))

Hadronic Physics Models

- **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
- **Software versions:**
  - Geant4 5.2.p01 with PACK 2.1, LHEP 3.6, QGSP_BERT 0.5, QGSP_BIC 0.5
  - Fluka 2002.4

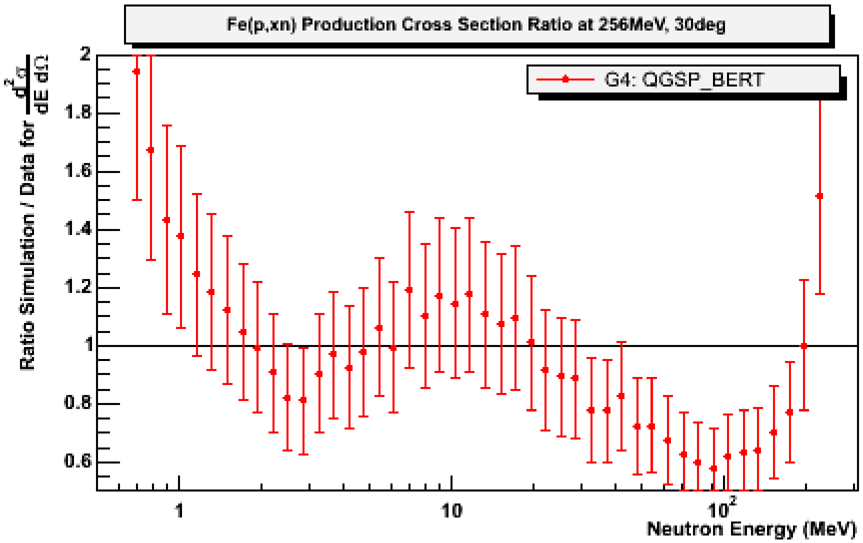
Simulated and Experimental Cross Sections

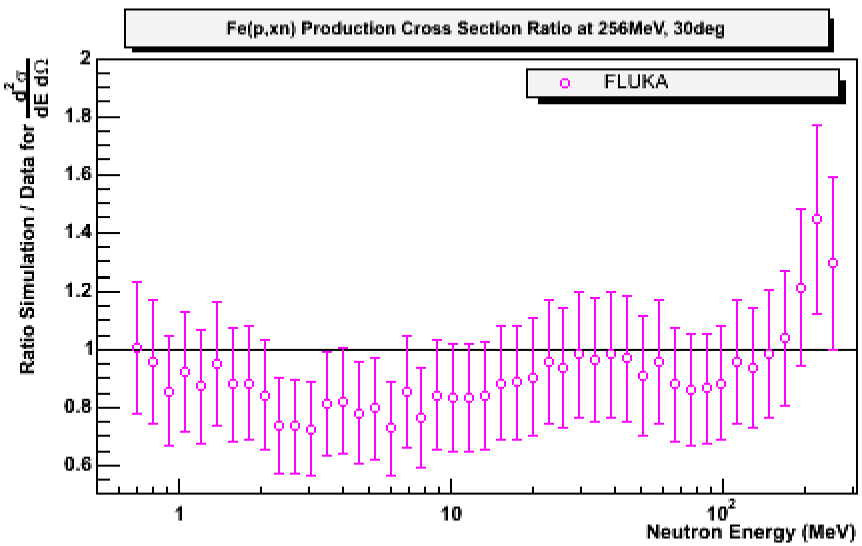
- Typical example: Fe(p,xn) production cross sections at 30° (256MeV p)

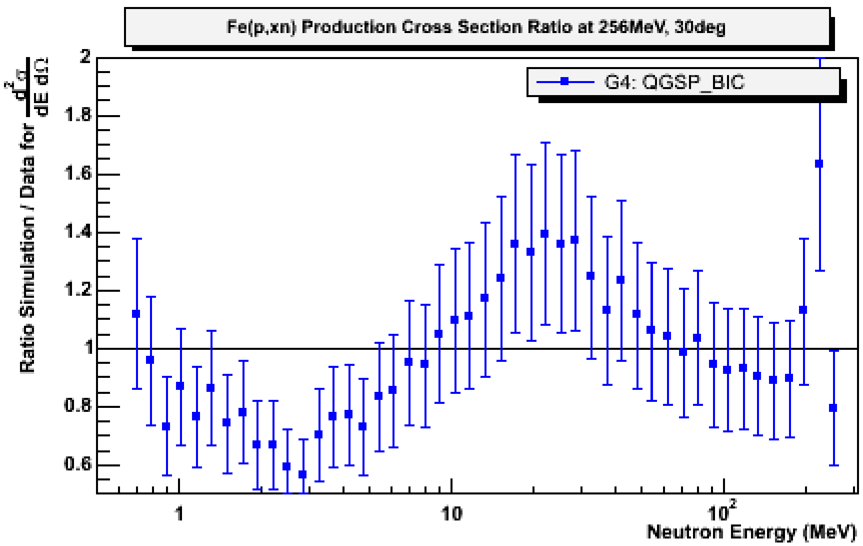


Ratio Simulated / Experimental Cross Sections

- Ratio simulated / experimental data for data shown on previous slide
- Error bars include errors from experimental data (stat+syst) and from simulation (stat)
  - Dominated by experimental syst. errors
- **Typical agreement at level of 1σ to 2σ**







Conclusions

- Common LHC-wide simulation physics validation effort in progress
  - **Make sure dominant (systematic) error of LHC physics results will not be due to inadequacies of simulation physics and software**
- First cycle of electromagnetic and hadronic physics validation ~completed
- **In most cases, Geant4 successfully reproduces test-beam data (equal or better than Geant3)**
  - All LHC experiments have taken test-beam data with many subdetectors this summer – new extensive round of comparisons in progress
- Agreement with Los Alamos data in general at the level of 1σ to 2σ for simulated (p,xn) production cross sections for Fluka and for Geant4 physics lists based on Bertini or Binary Cascade
  - Accuracy of comparison limited by systematic error of experimental data
  - Further such benchmark studies in progress