Hadronic Physics Models

Geant4 Users' Tutorial at CERN
25-27 May 2005
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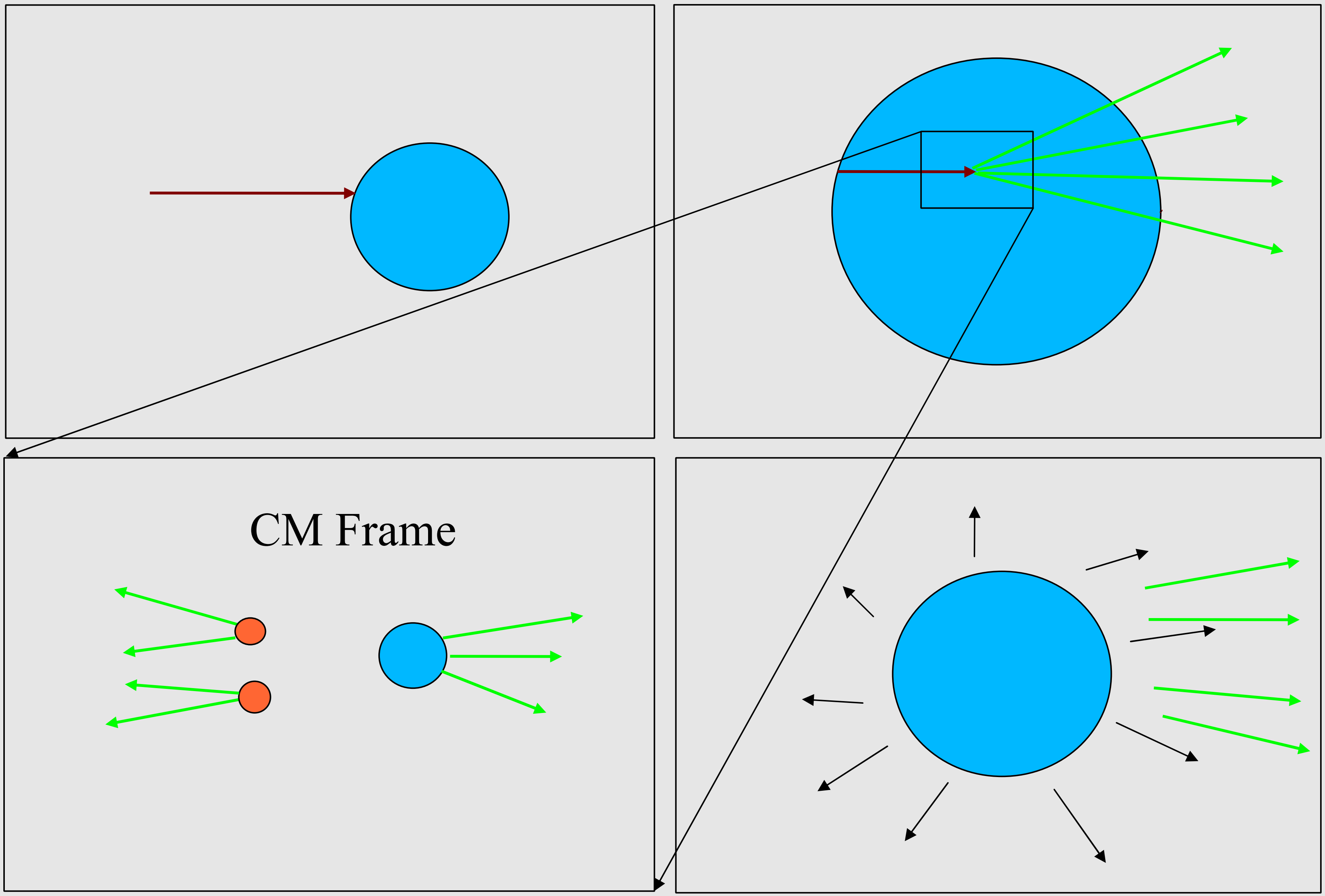
Outline

- ***Parameterized models***
  - ***high energy***
  - ***low energy***
- ***Bertini cascade model***
- ***High precision neutron models***
- ***Photo- and electro-nuclear models***
- ***Isotope production***

Parameterized Models

- Two models available:
  - Low Energy Parameterized (LEP) for < 20 GeV
  - High Energy Parameterized (HEP) for > 20 GeV
  - LEP and HEP each refer to a collection of models, one for each particle type
- Both derived from GHEISHA model used in Geant3
- Core code:
  - hadron fragmentation
  - cluster formation and fragmentation
  - nuclear de-excitation

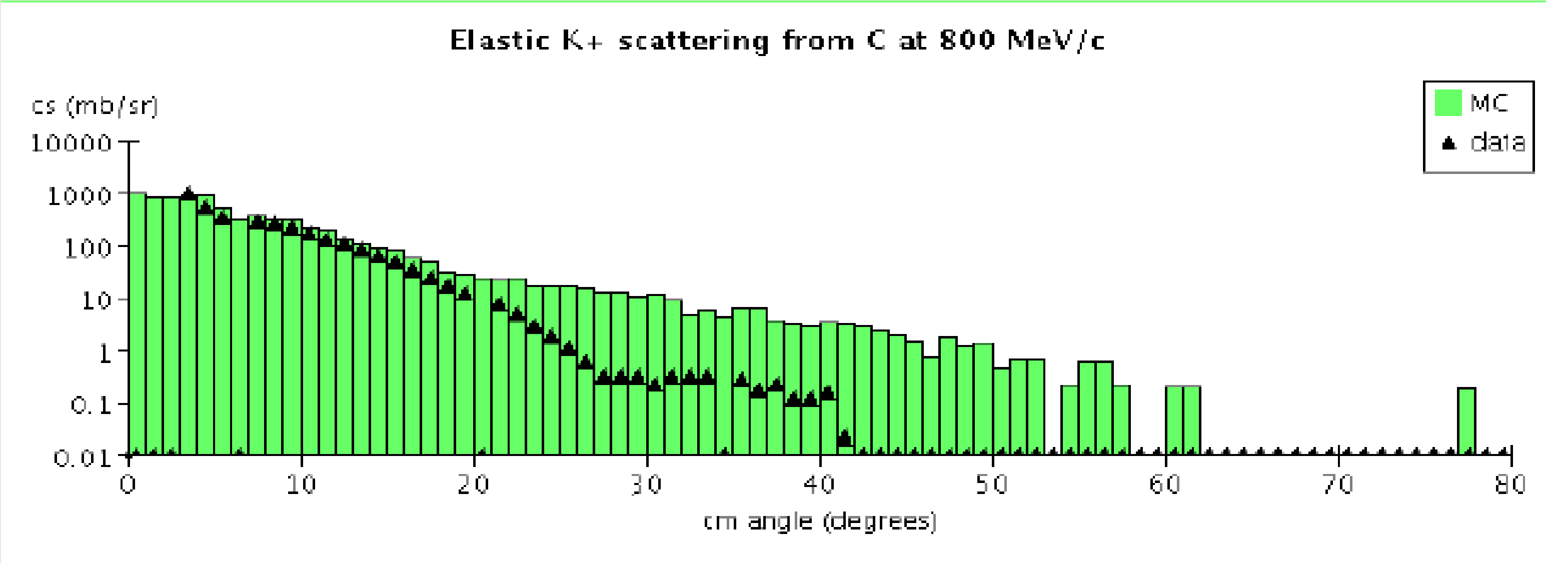
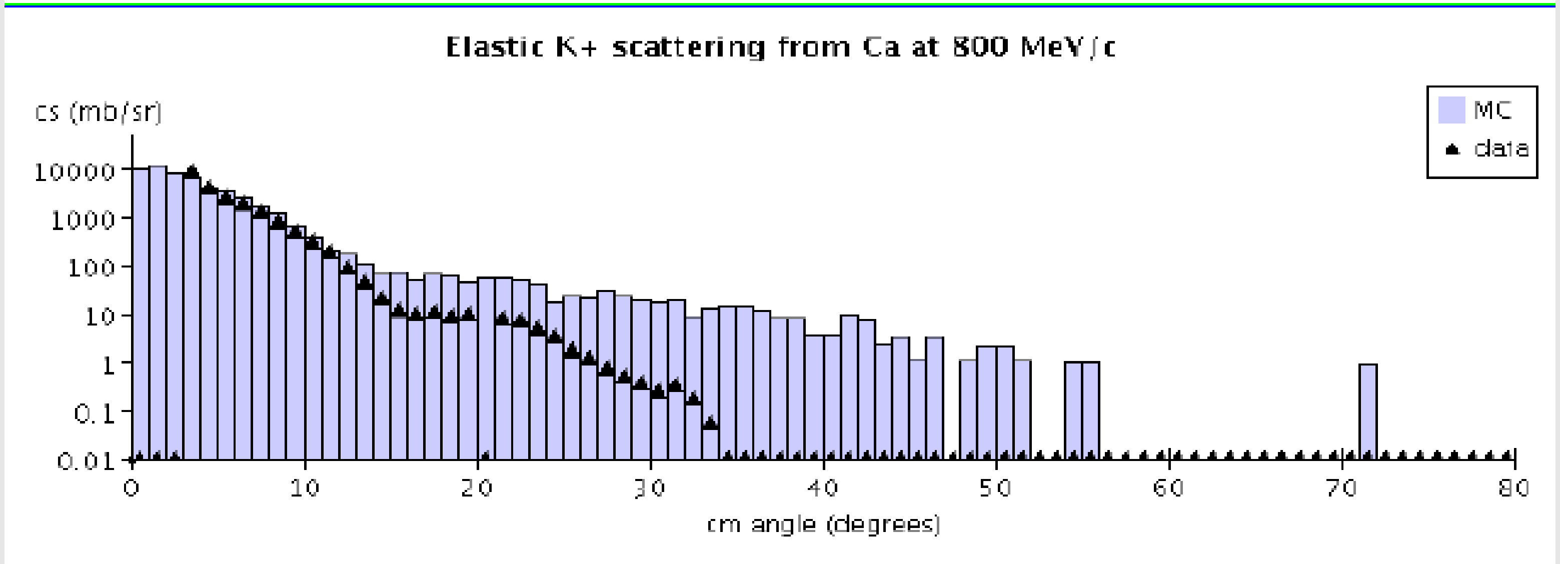
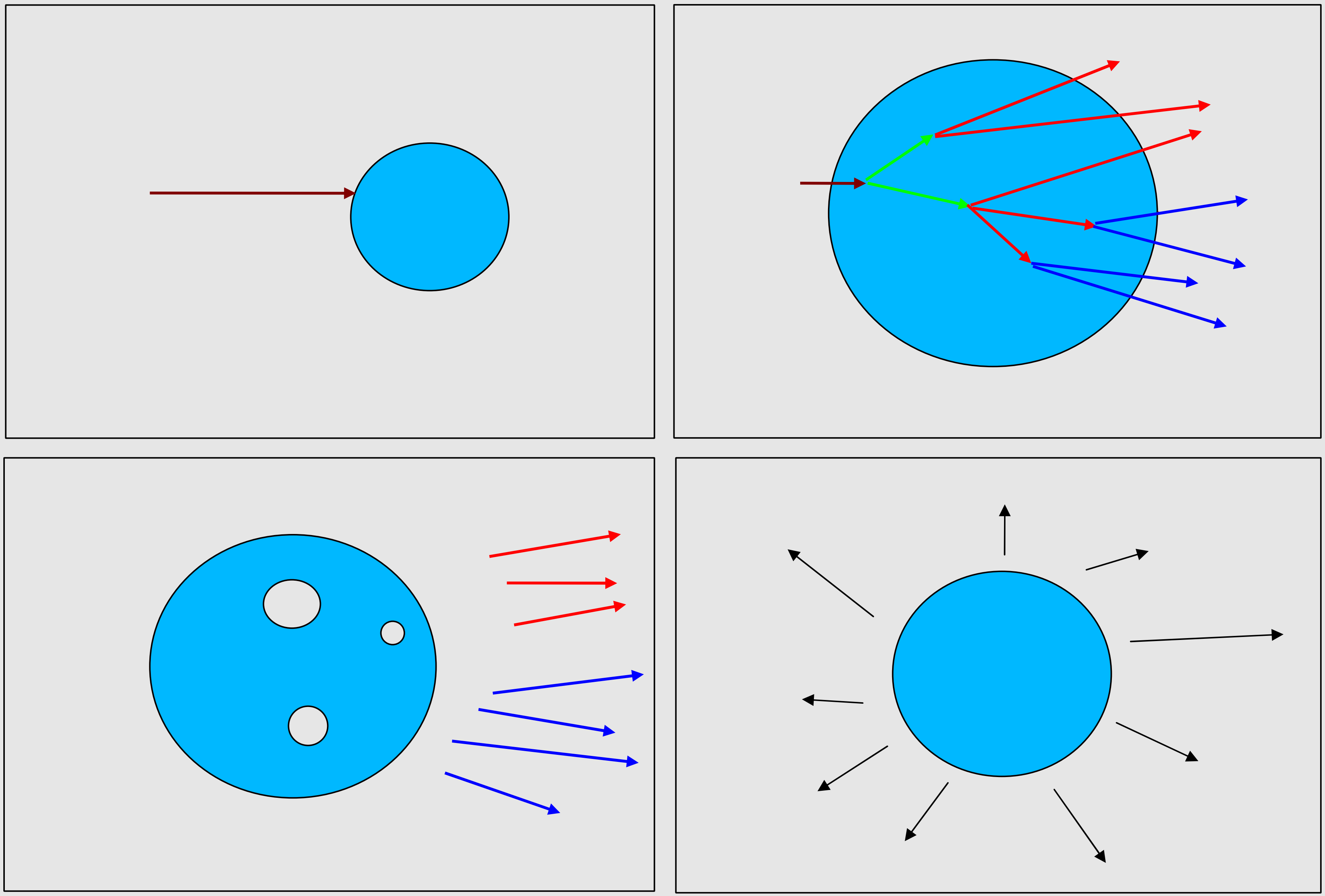
LEP, HEP (Comic Book Version)



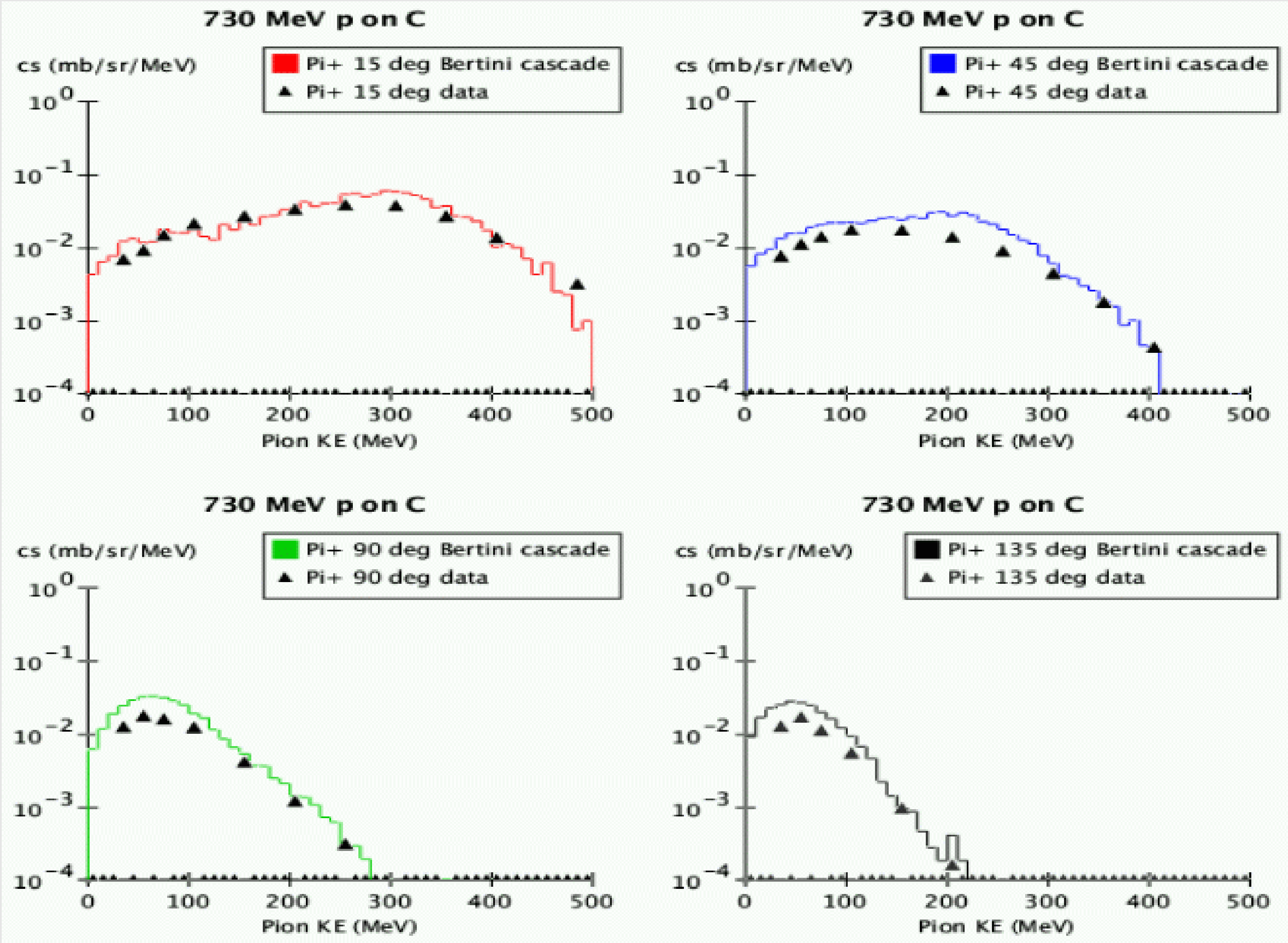
LEP, HEP models (text version)

- Modeling sequence:
  - initial interaction of hadron with nucleon in nucleus
  - highly excited hadron is fragmented into more hadrons
  - particles from initial interaction divided into forward and backward clusters in CM
  - another cluster of backward going nucleons added to account for intra-nuclear cascade
  - clusters are decayed into pions and nucleons
  - remnant nucleus is de-excited by emission of p, n, d, t, alpha

Using the LEP and HEP models

- The LEP and HEP models are valid for p, n, π, K, Λ, Σ, Ξ, Ω, α, t, d
  - LEP valid for incident energies of 0 – ~30 GeV
  - HEP valid for incident energies of ~10 GeV – 15 TeV
- Invocation sequence
  - ```
    G4ProtonInelasticProcess* pproc = new G4ProtonInelasticProcess();
    G4LEProtonInelastic* LEproton = new G4LEProtonInelastic();
    pproc -> RegisterMe(LEproton);
    G4HEProtonInelastic* HEproton = new G4HEProtonInelastic();
    HEproton -> SetMinEnergy(20*GeV);
    pproc -> RegisterMe(HEproton);
    proton_manager -> AddDiscreteProcess(pproc);
    ```
    ```

Validation of LEP, HEP Models





Bertini Cascade Model

- The Bertini model is a classical cascade:
  - it is a solution to the Boltzman equation on average
  - no scattering matrix calculated
  - can be traced back to some of the earliest codes (1960s)
- Core code:
  - elementary particle collider: uses free-space cross sections to generate secondaries
  - cascade in nuclear medium
  - pre-equilibrium and equilibrium decay of residual nucleus
  - detailed 3-D model of nucleus

Bertini Cascade (Comic Book Version)



Bertini Cascade (text version)

- Modeling sequence:
  - incident particle penetrates nucleus, is propagated in a density-dependent nuclear potential
  - all hadron-nucleon interactions based on free-space cross sections, angular distributions, but no interaction if Pauli exclusion not obeyed
  - each secondary from initial interaction is propagated in nuclear potential until it interacts or leaves nucleus
  - during the cascade, particle-hole exciton states are collected
  - pre-equilibrium decay occurs using exciton states
  - next, nuclear breakup, evaporation, or fission models

Using the Bertini Cascade

- In Geant4 the Bertini model is currently used for p, n and π
  - valid for incident energies of 0 – 10 GeV
  - may be extended to 15 GeV when new validation data are available
  - currently being extended to kaons and hyperons
- Invocation sequence
  - ```
    G4CascadeInterface* bertini = new G4CascadeInterface();
    G4ProtonInelasticProcess* pproc = new G4ProtonInelasticProcess();
    pproc -> RegisterMe(bertini);
    proton_manager -> AddDiscreteProcess(pproc);
    ```
    ```

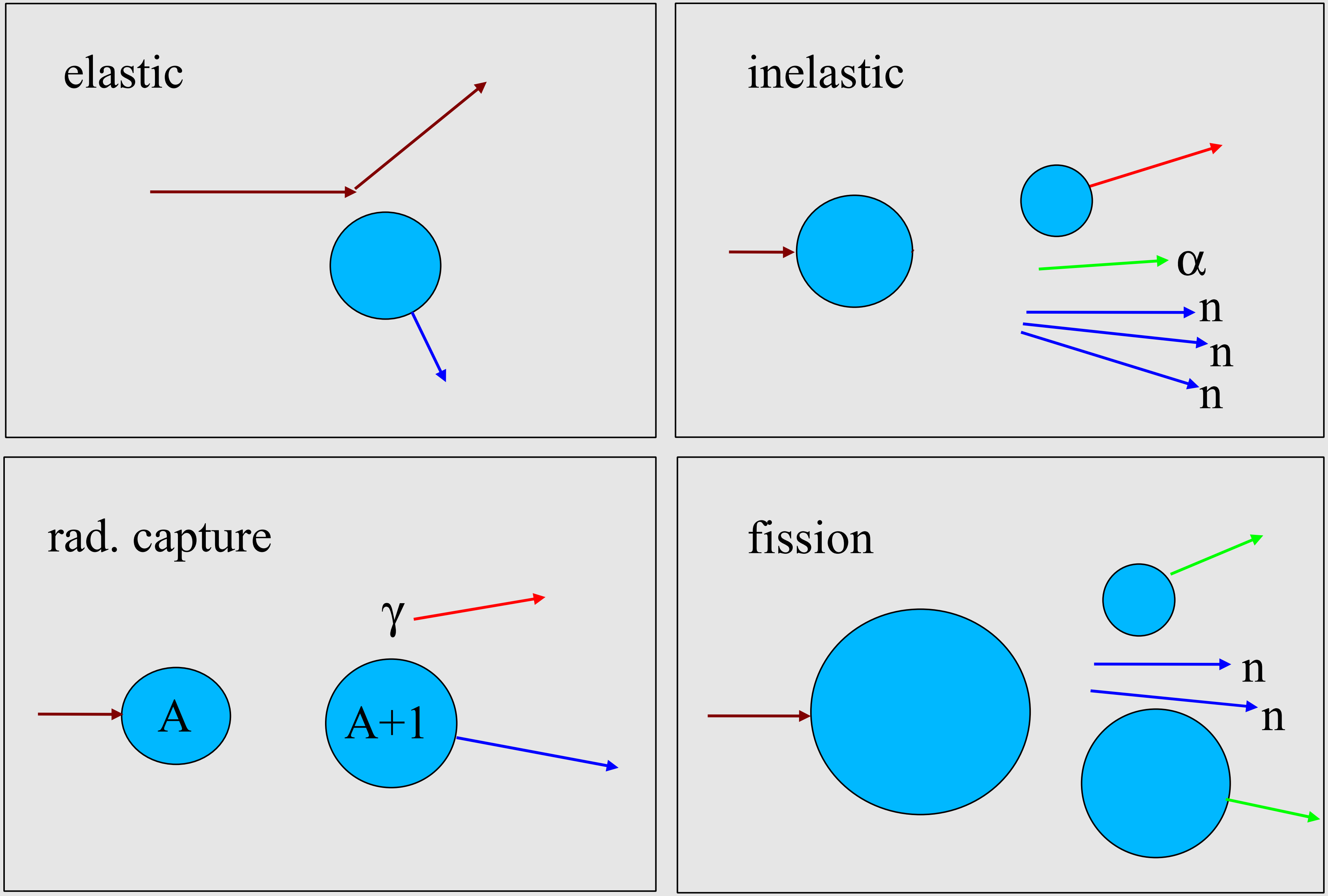
Validation of the Bertini Cascade



High Precision Neutron Model

- ***Data-driven model***
  - ***little theoretical input***
  - ***cross sections, angular distributions, fission yields, photon emission probabilities, etc. taken from evaluated neutron data libraries***
- ***Intended for low energy neutrons (< 20 MeV)***
  - ***OK for thermal neutrons as well***
  - ***elastic, inelastic scattering, neutron-induced fission and radiative capture models available***
- ***Core code:***
  - ***G4NDL neutron data library***
  - ***interpolaters***

HP Neutrons (Comic Book Version)



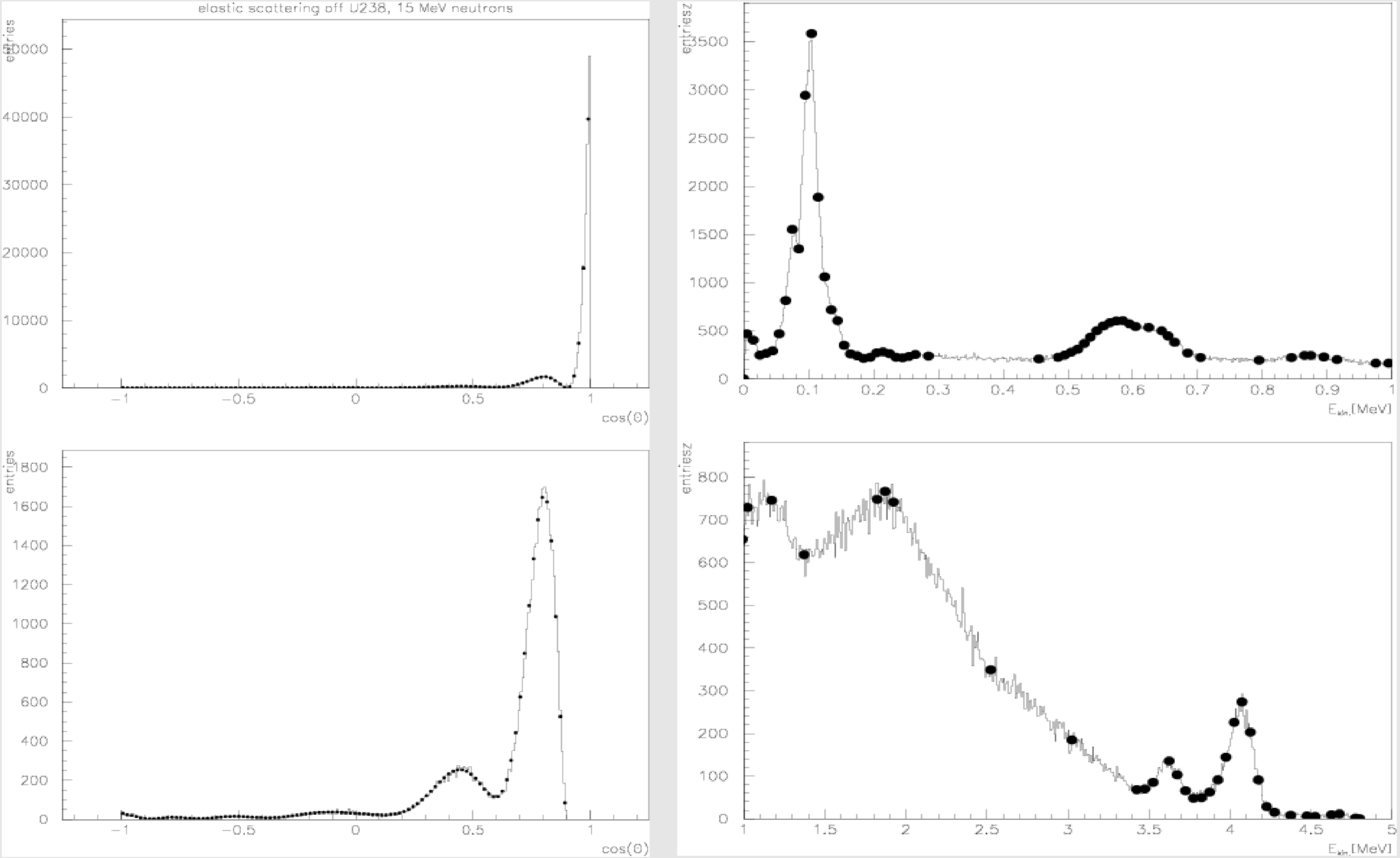
High Precision Neutron Model

- ***Modeling:***
  - ***elastic scattering: get final state by looking up differential cross section or Legendre coefficients to get angular distributions***
  - ***radiative capture: look up photon multiplicities or production cross sections, then sample from discrete and continuous energy spectra, and tabulated angular distributions***
  - ***inelastic scattering: use cross section data to choose from among 35 final states of up to four particles***
  - ***fission: use tabulated neutron yields and angular distribution parameters, several options for generating final state neutrons and fission fragments***

Using the HP Neutron Model

- First set environment variable to point to data library:
  - setenv NeutronHPCrossSections somedir/G4NDL3.7
  - G4NDL3.7 must first be downloaded from Geant4 distribution page into your directory
- Invocation sequence
  - G4HadronElasticProcess* nelproc = new G4HadronElasticProcess(); G4NeutronHPElasticData* neldata = new G4NeutronHPElasticData(); G4NeutronHPElastic* nelmodel = new G4NeutronHPElastic(); nelproc -> RegisterMe(nelmodel); nelproc -> AddDataSet(neldata); neutron_manager -> AddDiscreteProcess(nelproc);
  - repeat for inelastic neutron scattering, neutron-induced fission and radiative neutron capture

Validation of the HP Neutron Model



Isotope Production Models

- ***Default model***
  - ***isotope produced = residual nucleus of any reaction***
  - ***produced isotope is tracked***
- ***Neutron-induced production:***
  - ***G4NeutronIsotopeProduction***
  - ***valid for*** $E_n < 100$ ***MeV***
  - ***requires G4NDL and NeutronHPCrossSections env. var. to be set***
  - ***uses G4Track object to get surrounding material, then nucleus, then production cross sections***

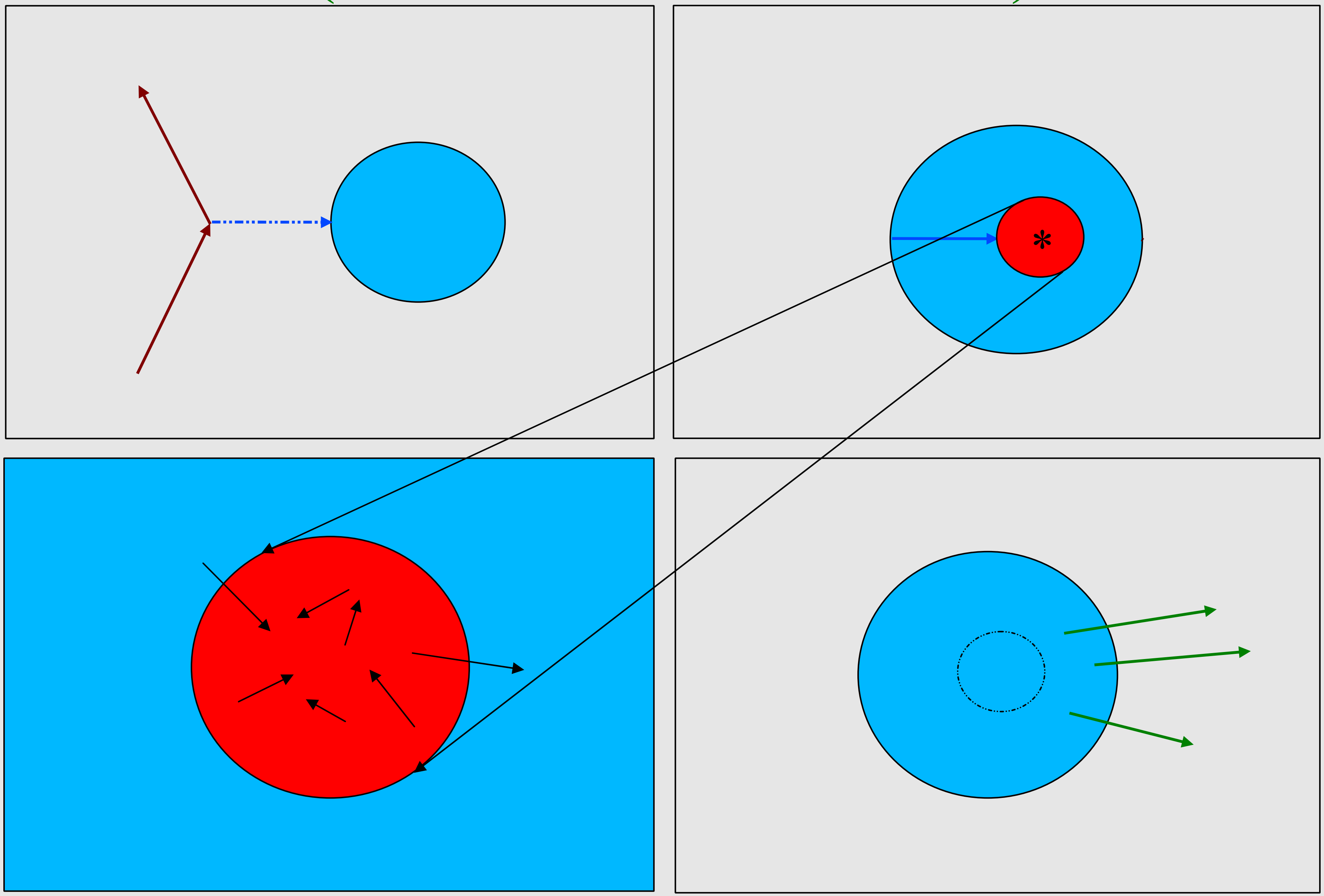
Using the Isotope Production Models

- Default production model:
  - Disable: process -> DisableIsotopeProductionGlobally();
  - Enable: process -> EnableIsotopeProductionGlobally();
- Neutron-induced production model:
  - setenv NeutronHPCrossSections somedir/G4NDL3.7
  - G4HadronInelasticProcess* inelproc = new G4HadronInelasticProcess(); G4NeutronIsotopeProduction* isomodel = new G4NeutronIsotopeProduction(); inelproc -> RegsisterIsotopeProductionModel(isomodel);

Electro- and Photo-nuclear Models

- ***Hybrid models: both electromagnetic and hadronic***
  - ***use parameterization of measured photon cross sections***
  - ***several theoretical models (one EM, two hadronic)***
- ***Core code:***
  - ***CHIPS (Chiral Invariant Phase Space) model***
  - ***quark-gluon string model***
  - ***method of equivalent photons (for incident e+/e-)***
- ***Valid for e^-, e^+, γ all energies up to 100 TeV***
  - ***CHIPS below 3.5 GeV***
  - ***quark-gluon string model above 3 GeV (VDM)***

Electro-nuclear model (below 3 GeV)
(Comic Book Version)



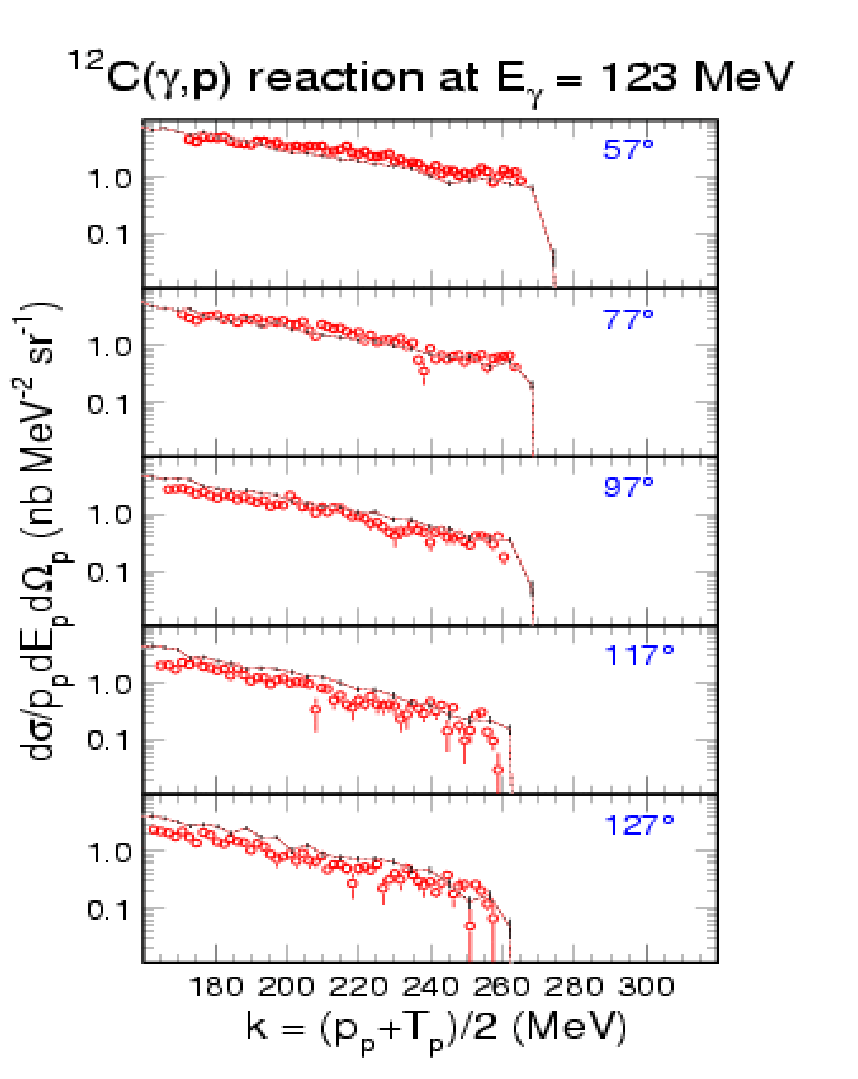
Electro-nuclear model (text version)

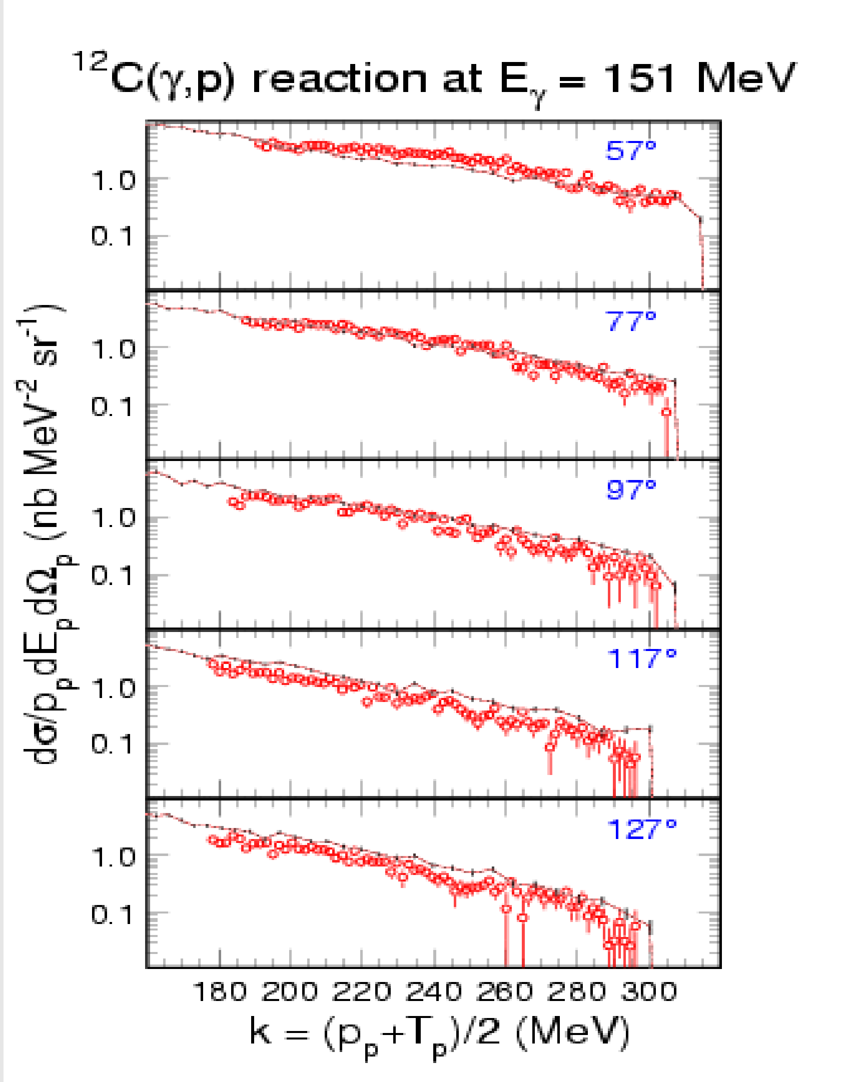
- Modeling sequence:
  - virtual photon from e+/e- converted to real photon by method of equivalent photons
  - real photon cross section determines interaction rate
  - below 3.5 GeV:
    - real photon interacts inside nuclear matter, creates quasmon (generalized hadron in CHIPS model)
    - quasmon decays by quark fusion
  - above 3 GeV, photon treated as a hadron:
    - quark-gluon string formed and decayed
    - residual nucleus is de-excited

Using the Electro- and Photo-Nuclear Models

- Electro-nuclear model (for e+, e- only):
  - G4ElectronNuclearProcess* enproc = new G4ElectronNuclearProcess(); G4ElectroNuclearReaction* enModel = new G4ElectroNuclearReaction(); enproc -> RegisterMe(enModel); electron_manager -> AddDiscreteProcess(enproc);
- Photo-nuclear model (γ):
  - G4PhotoNuclearProcess* gnproc = new G4PhotoNuclearProcess(); G4GammaNuclearReaction* gnmodel = new G4GammaNuclearReaction(); gnmodel -> SetMaxEnergy(3.5*GeV); gnproc -> RegisterMe(gnmodel); gamma_manager -> AddDiscreteProcess(gnproc);

Validation of the Photo-nuclear/CHIPS Model





Summary/Recommendations (1)

- LEP/HEP are the simplest and most versatile
  - all energies, all (long-lived) hadrons
  - use if no other model available
  - also the fastest
  - good for general purpose simulation where hadronic physics is not the main focus
- Bertini cascade is better for p,n,π
  - ~ 8X slower than LEP
  - only valid below 10 GeV
  - alternative is Binary cascade
  - useful for calorimetry and medium energy experiments

Summary/Recommendations (2)

- High precision neutron models are the most accurate
  - but only for neutrons below 20 MeV
  - good for studying accelerator background, shielding, dosimetry, medical etc.
- Electro- and gamma-nuclear models
  - hybrid hadronic/EM
  - only model for hadronic interaction of e+, e-, γ below 3.5 GeV
- Isotope production
  - useful for shielding, space radiation, space electronics, medical studies