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Title: A Summary of the Hadron Reaction Models for Use in LANL Monte Carlo Transport Codes

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A Summary of the Hadron Reaction Models for Use in LANL Monte Carlo Transport Codes

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ABSTRACT

Current LANL codes use several nuclear interaction packages for radiation transport from proton beam sources. The Bertini model (up to 3.5 GeV) and the ISABEL model (up to 1 GeV) have the longest usage historically, in LAHET and MCNPX. For high-energy proton interactions, the event generator from FLUKA96 is used in LAHET3 and the older event generator from FLUKA89 is used in MCNPX. In addition, the CEM model (S. Mashnik) for medium-energy interactions is implemented in MCNPX.

New interaction physics packages are being developed for use in MCNP and other LANL codes:

- In collaboration with Nikolai Mokhov at FNAL, the inclusive event generator from the MARS code is being tested as an implementation in LAHET3 for eventual use in MCNP. This package may be considered as a high-speed option for nuclear reactions at high energies (into the TeV range).
- The LAQGSM code (K. Gudima, S. Mashnik and A. Sierk) will provide a full exclusive event generator at energies to 200 GeV using the quark-gluon string model. Computationally slower than the above inclusive model, LAQGSM provides a complete event simulation for secondary particle production at high energies.
- For medium energy interactions, the CEM2k model (S. Mashnik) is an advance on the CEM code in current use. Preequilibrium, evaporation and fission modeling development for CEM2k are also integrated in LAQGSM.

The development of the newer capabilities involves LANL staff and collaborators directly, which is advantageous for current code development efforts.

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Introduction (1)

- Current LANL Monte Carlo codes for proton transport (LAHET, MCNPX) use several interaction packages for the production of secondary particles from nuclear interactions for medium- and high energy incident particles.

- Several newer models are being prepared for implementation in the foreseeable future.

Introduction (2)

- These models may be classified as "medium-energy" (incident energies to several GeV) or "high-energy" (to 100 GeV or higher).

- This presentation is a *brief summary* of those models, which have been used historically in LANL codes, and which are currently under active development for potential application.

Role of the Interaction Package

- The role of the interaction package (model) is to simulate a nuclear event, providing specification of the secondary particles produced and the state of the residual nuclei.
- The INC model or high-energy event generator is followed in execution by a preequilibrium model, an evaporation-fission model and/or a Fermi breakup model for the emission of lower energy particles (nuclei and ions) from an excited residual nucleus.
- The description of particle transport, including the determination of an interaction point, are independent of the interaction model.

Historical LANL Usage

- Bertini intranuclear cascade model (LAHET and MCNPX).
- ISABEL intranuclear cascade model (LAHET and MCNPX).
- High- and medium-energy event generators from FLUKA89 (MCNPX).
- High- and medium-energy event generators from FLUKA96 (LAHET3.1).
- CEM97 intranuclear cascade model (MCNPX).

Bertini INC Model

- The original HETC model, adapted from Bertini's MECC7 code, used in all versions of LAHET. The model has been "frozen" for well over 20 years.
- Describes nucleon interactions to 3.5 GeV, pion interactions up to 2.5 GeV. [A "scaling law" is used for incident energies above these limits - *very* approximate.]
- In both LAHET and MCNPX, the INC model is coupled to a preequilibrium model (Prael), an evaporation/fission model (Atchison) and/or a Fermi breakup model (Prael) for the emission of lower energy particles (nuclei and ions) from an excited residual nucleus.

ISABEL INC Model

- Developed by Y. Yariv and Z. Fraenkel from the VEGAS code.
- Current implementation in LAHET and MCNPX allows nucleon, antinucleon, pion and kaon interactions and nucleus-nucleus interactions.
- Incident energy limited to about 1 GeV/amu, but could be continued to several GeV/amu.
- The INC model is coupled to the same de-excitation models as is the Bertini INC.

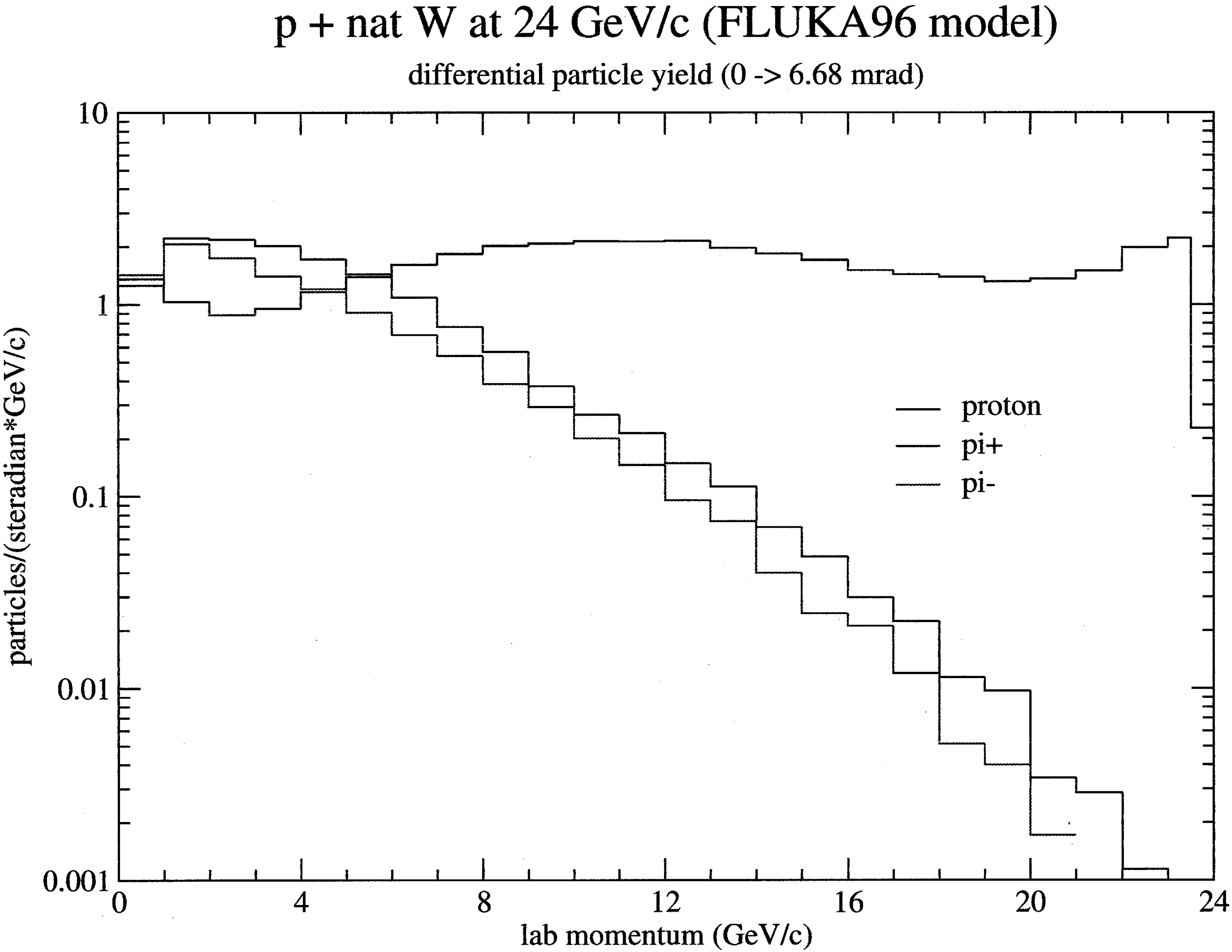
FLUKA96 Models (1)

- Primary model is an implementation of J. Ranft's dual-parton model high-energy event generator for hadronic interactions from ~10 GeV to ~100 TeV.
- Added to LAHET3 in 1997; an earlier version from FLUKA89 is in MCNPX.
- The FLUKA code package also includes a somewhat obsolescent medium energy event generator.
- In either of the above codes, it is coupled to the same low-energy emission models as are used with the Bertini and ISABEL models.

FLUKA96 Models (2)

- The current code was provided by A. Ferrari and P. Sala (CERN), but no formal collaboration exists presently.

- The adjacent figure illustrates results from the FLUKA high-energy event generator for the yield of secondary protons and pions from 24 GeV/c protons incident on natural W.



p + nat W at 24 GeV/c (FLUKA96 model)
differential particle yield (0 -> 6.68 mrad)
particles/(steradian*GeV/c)
10
1
0.1
0.01
0.001
0
4
8
12
16
20
24
lab momentum (GeV/c)
proton
pi+
pi-

CEM2K

- For medium energy interactions, the CEM2K model (Stepan Mashnik, LANL T-16) is an advance on the CEM97 model in current use in MCNPX and MARS.
- Interactions by nucleons, pions and photons up to ~5 GeV with targets A >= 9.
- Preequilibrium, evaporation/fission and Fermi breakup modeling for CEM2K also under active development by S. Mashnik and A. Sierk (LANL T-16).
- The latter models are also integrated in LAQGSM (see below).

LAQGSM (1)

- The LAQGSM code will provide a full exclusive event generator at energies to 200 GeV using the Quark-Gluon String Model.
- Under active development by Konstantin Gudima (Academy of Sciences of Moldava and LANL visiting scientist) with S. Mashnik and A. Sierk, LANL T-16.
- Computationally slower than the MARS inclusive model.
- LAQGSM provides a complete event simulation for secondary particle production at high energies.

LAQGSM (2)

- The high-energy generator provides an interaction capability for all the shower particles with significant lifetime arising from interactions below 200 GeV/c.
- Includes a nucleus-nucleus capability.
- Includes a coalescence model for emission of energetic d, t, ^{3}He and α particles.
- The preequilibrium, evaporation/fission and Fermi breakup modeling used in CEM2K is also integrated in LAQGSM.

MARS Inclusive Model

- In collaboration with Nikolai Mokhov at FNAL, the inclusive event generator from the MARS code is being tested as an implementation in LAHET3 for eventual use in MCNP. [MARS is extensively used at LANL.]
- Describes interaction of nucleons, antinucleons, pions, kaons, and photons into the TeV range, with an inclusive representation of secondary particle production.
- Particle production described by systematics.
- High-speed alternative appropriate to particle flux and energy deposition calculations.

Liege INC Model

- Under continuous development by Joseph Cugnon (University of Liege, Belgium).
- Coupled to an evaporation/fission model by Karl-Heinz Schmidt (GSI)
- Implementation as an option in LAHET3 was performed at Saclay under the direction of Sylvie Leray.
- Eventual inclusion in MCNPX is projected.

Benchmarking and Comparisons

- An active collaboration exists for code intercomparison and benchmarking with available experimental data.
- Primary participants are Nikolai Mokhov (FNAL), Stepan Mashnik, A. J. Sierk, R. E. Prael (LANL) and K. Gudima (Moldava/LANL), with contributions by A. Ferrari (CERN).
- Results recently presented will be published as:

S. G. Mashnik, K. K. Gudima, N. V. Mokhov, R. E. Prael and A. J. Sierk, "Benchmarking Codes for Proton Radiography Applications", ***SATIF-6: Shielding Aspects of Accelerators, Targets and Irradiation Facilities***, Palo Alto (April, 2002).

Conclusion

- With the advent of the newer models for nuclear interactions at medium- and high-energies, we have the opportunity to work in collaboration with the authors of these models in the implementation into our Monte Carlo radiation transport codes.
- We have an increased opportunity for intercomparison of results among the various models and the simultaneous benchmarking against available experimental data.
- We will be able to provide multiple run-time options for the physics modeling for nuclear interactions.