Heavy nucleus fragmentation theory and experiment
and
its importance to understanding the space environment

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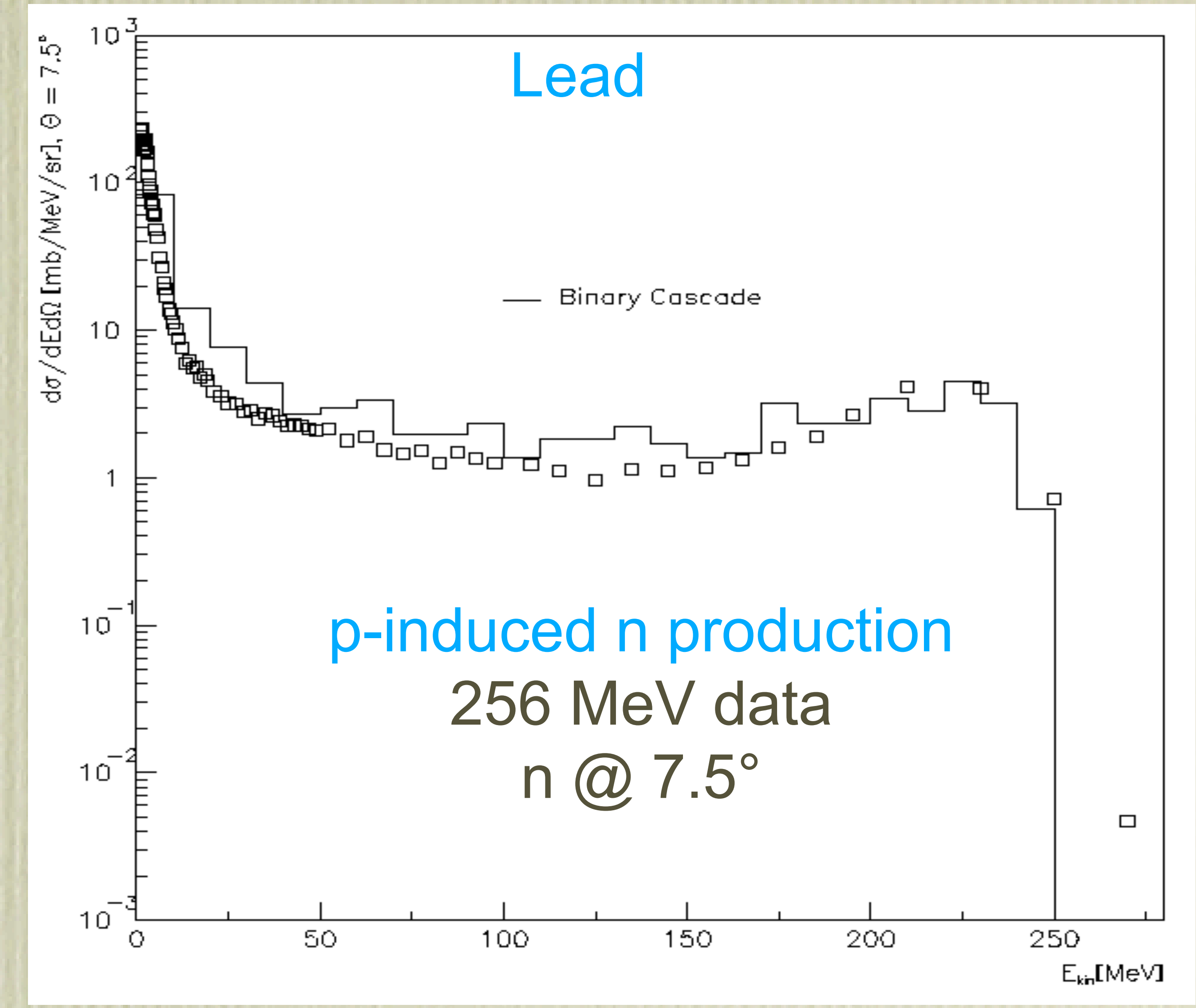
Context

- The tradition in the Radiation Effects on Semiconductors community is to identify ions by their Linear Energy Transfer (LET) and treat that parameter as a nearly complete descriptor of an ion
- For very high energy ions (above the Coulomb barrier), nuclear reactions occur. The highest energy ions have very low LET, but can deposit huge amounts of energy
- The details of the energy deposition from a reaction depend critically on the fragmentation pattern of the target nucleus
- These fragmentation patterns are poorly known.

Current Fragmentation Validation

- Geant4 hadronic physics has been repeatedly validated for what the high-energy community needs: light particle emission.
- Its models are well established in this domain



Cribbed from: Geant4 and its validation,

L. Pandola, 9th Topical Seminar on Innovative Particle and Radiation Detectors, Siena (Italy), 2004.

Heavy Ion Breakup

- Very little data published on complete fragmentation
- This paper is one of very few with detailed fragmentation information

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Energy Deposition in Intermediate-Energy Nucleon-Nucleus Collisions

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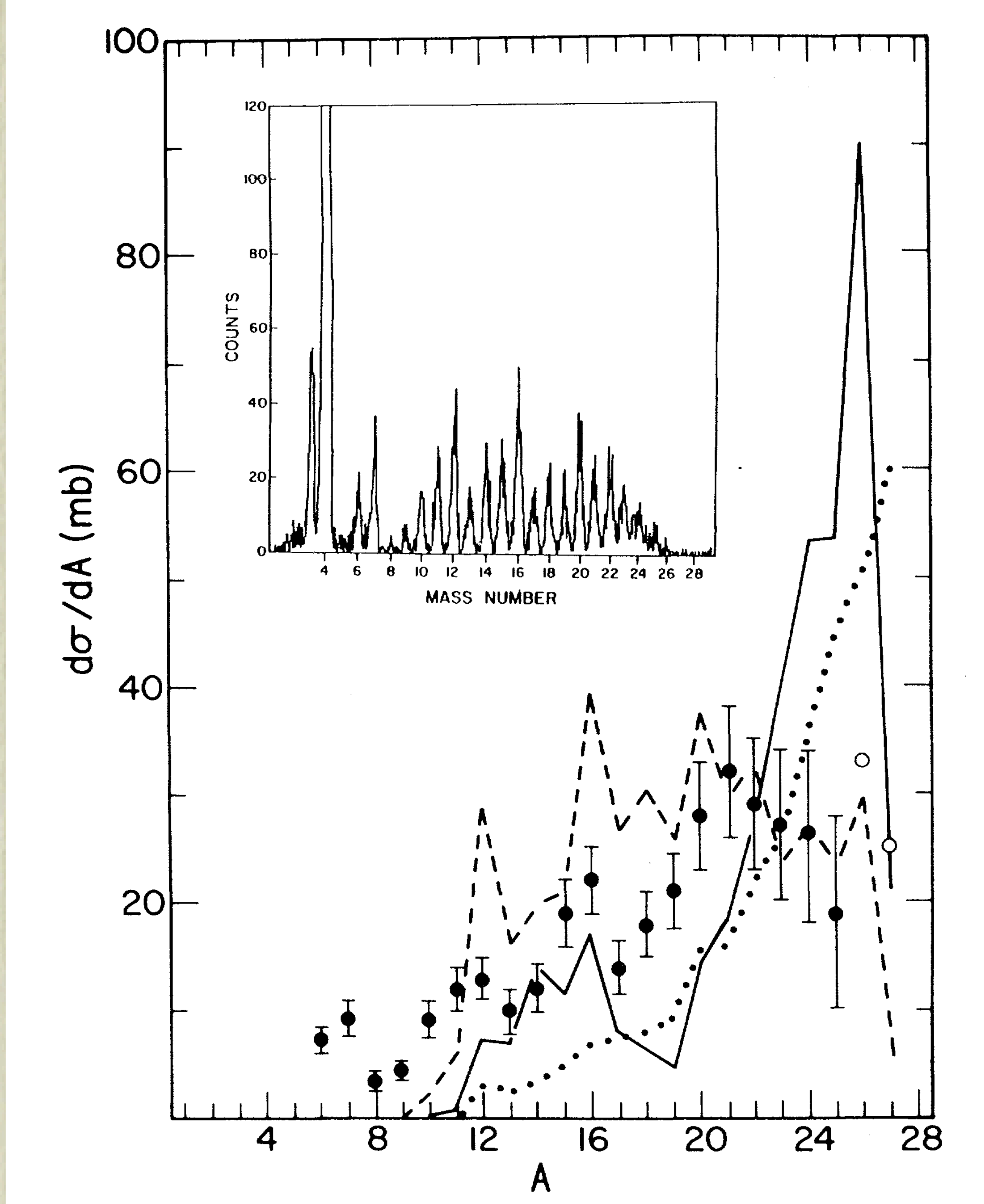
A global study of the mass, energy, and angular distributions of all products formed in collisions of 180-MeV protons with ^{27}Al is reported. These data are compared with calculations based on intranuclear-cascade-plus-evaporation, preequilibrium hybrid, and semiempirical models. It is found that there is evidence for enhanced energy deposition in nucleon–nucleus collisions relative to predictions of intranuclear cascade calculations. In contrast, preequilibrium calculations produce stronger energy damping, more consistent with observed data.

PACS numbers: 25.40.-h

Kwiatkowski results – 1

- Match of models to data was poor in 1983 even for total production cross sections

FIG. 1. Isobaric cross sections for fragments from the 180-MeV proton + ^{27}Al reaction. Inset: On-line mass spectrum for fragments with $E > 10$ MeV emitted at 20 deg. Symbols are as follows: closed circles, these data; open circles, data from Ref. 8; solid line, intranuclear-cascade-and-evaporation code of Refs. 2 and 3; dashed line preequilibrium exciton model of Ref. 4; and dotted line, semiempirical calculation of Ref. 9.



Kwiatkowski results – 2

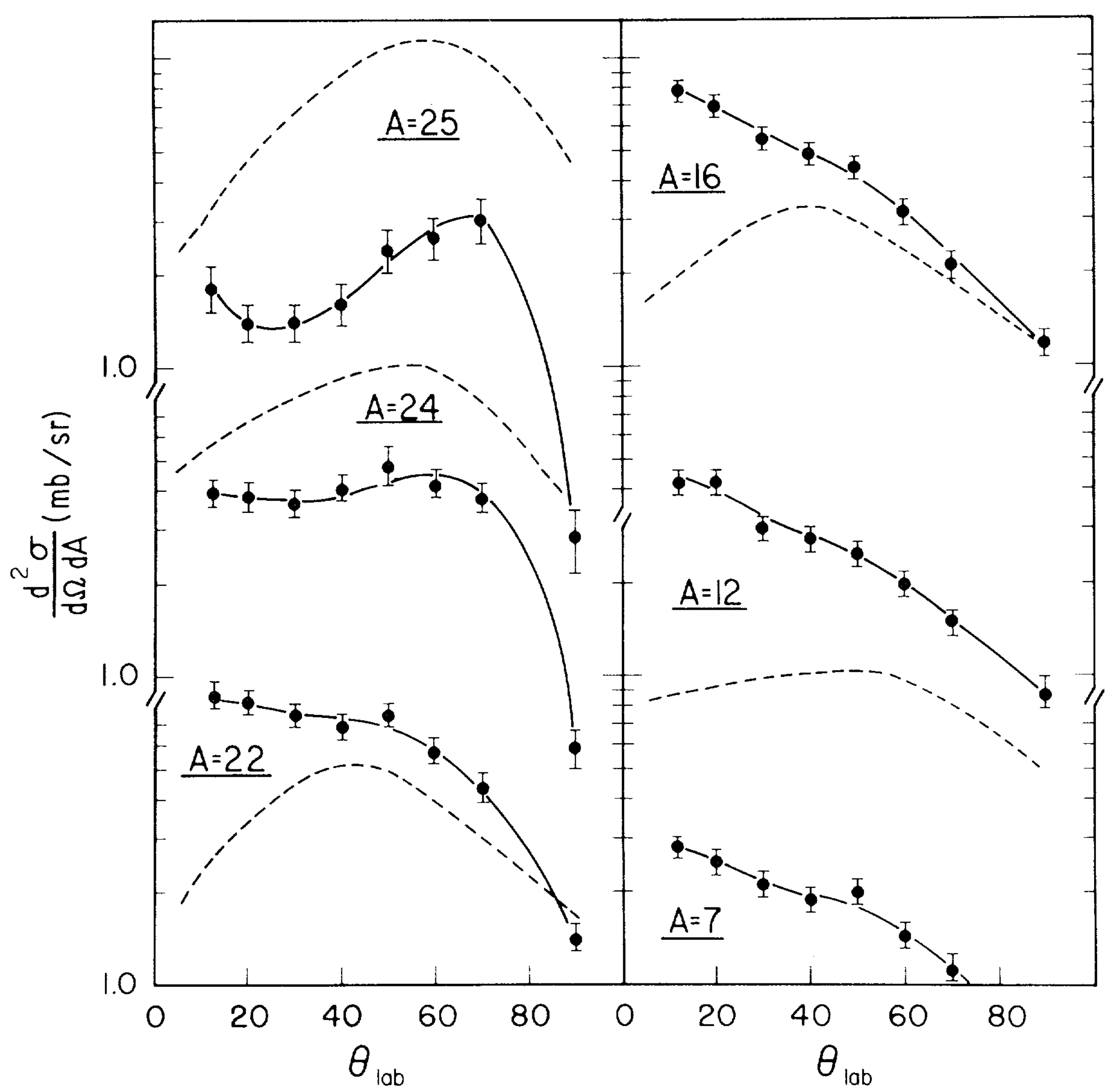


FIG. 2. Fragment angular distributions for the masses indicated, $d^2\sigma/d\Omega\, dA$, from the 180-MeV p + ^{27}Al reaction. Dashed lines are predictions of the intranuclear-cascade-plus-evaporation code (Refs. 2 and 3); solid lines represent a smooth average of the data (closed circles). The calculations predict no significant yield for A = 7.

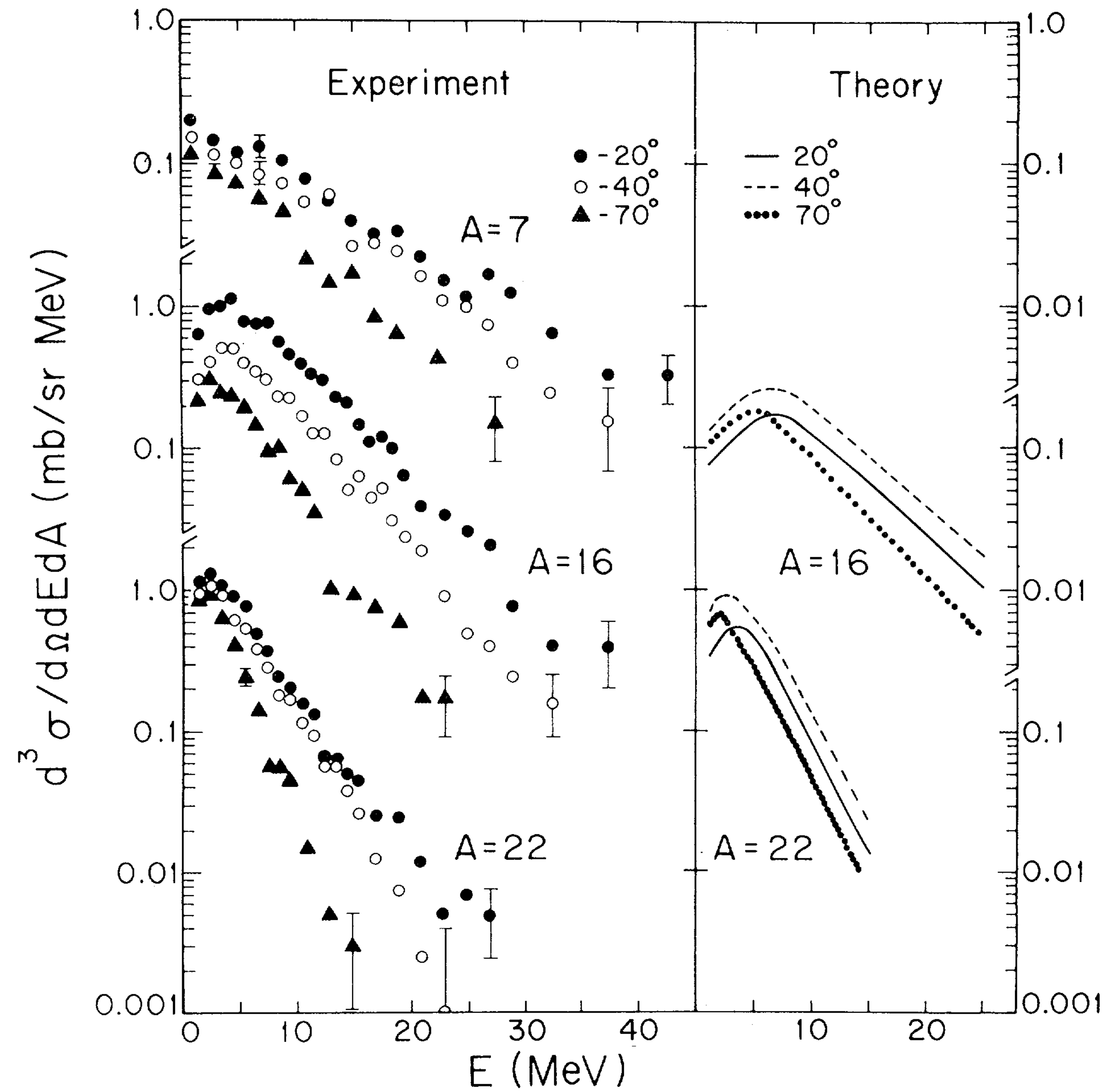
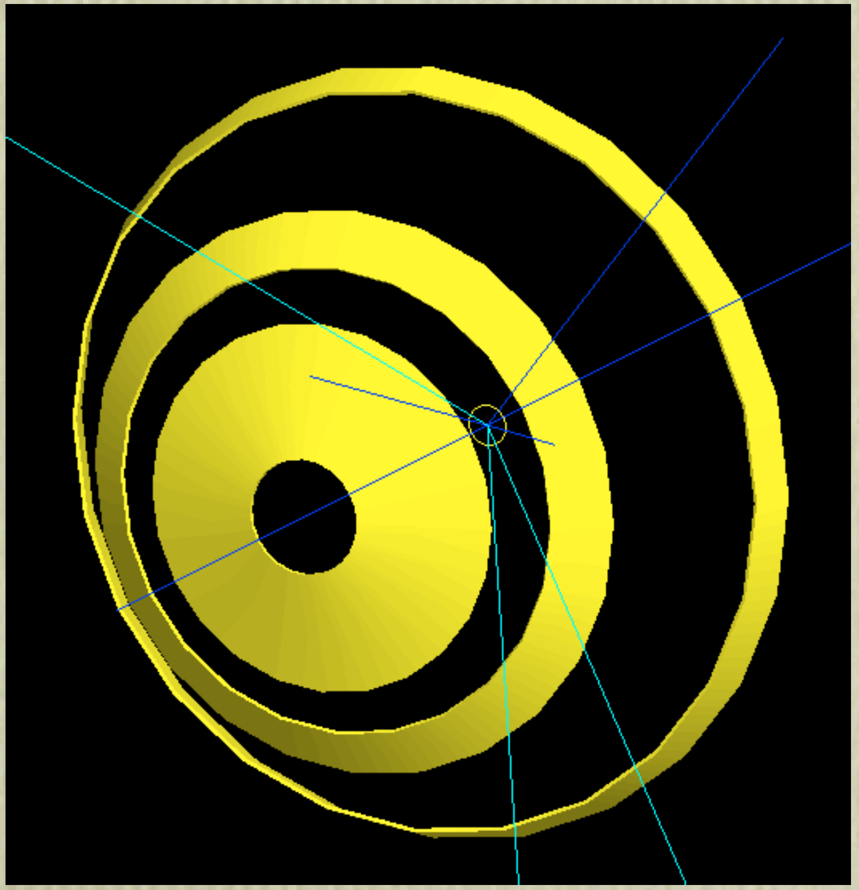
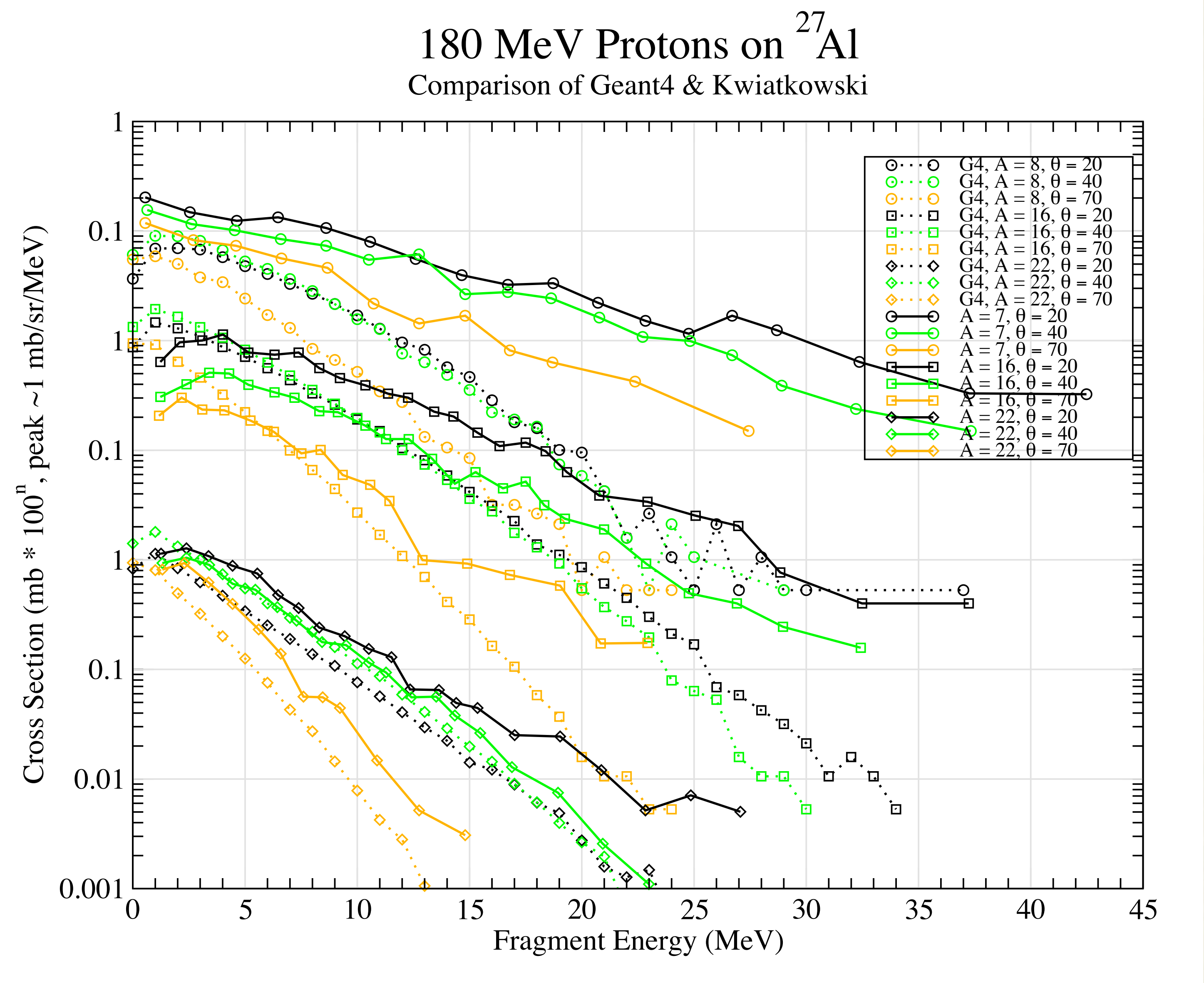


FIG. 3. Laboratory energy distributions, $d^3\sigma/d\Omega\, dE\, dA$, for fragments with A = 7, 16, and 22 in the 180-MeV p + ^{27}Al reaction. Points represent data obtained at laboratory angles of 20 (closed circles), 40 (open circles), and 70 (triangles) deg in the laboratory system. Lines are predictions of the intranuclear-cascade-plus-evaporation code (Refs. 2 and 3).

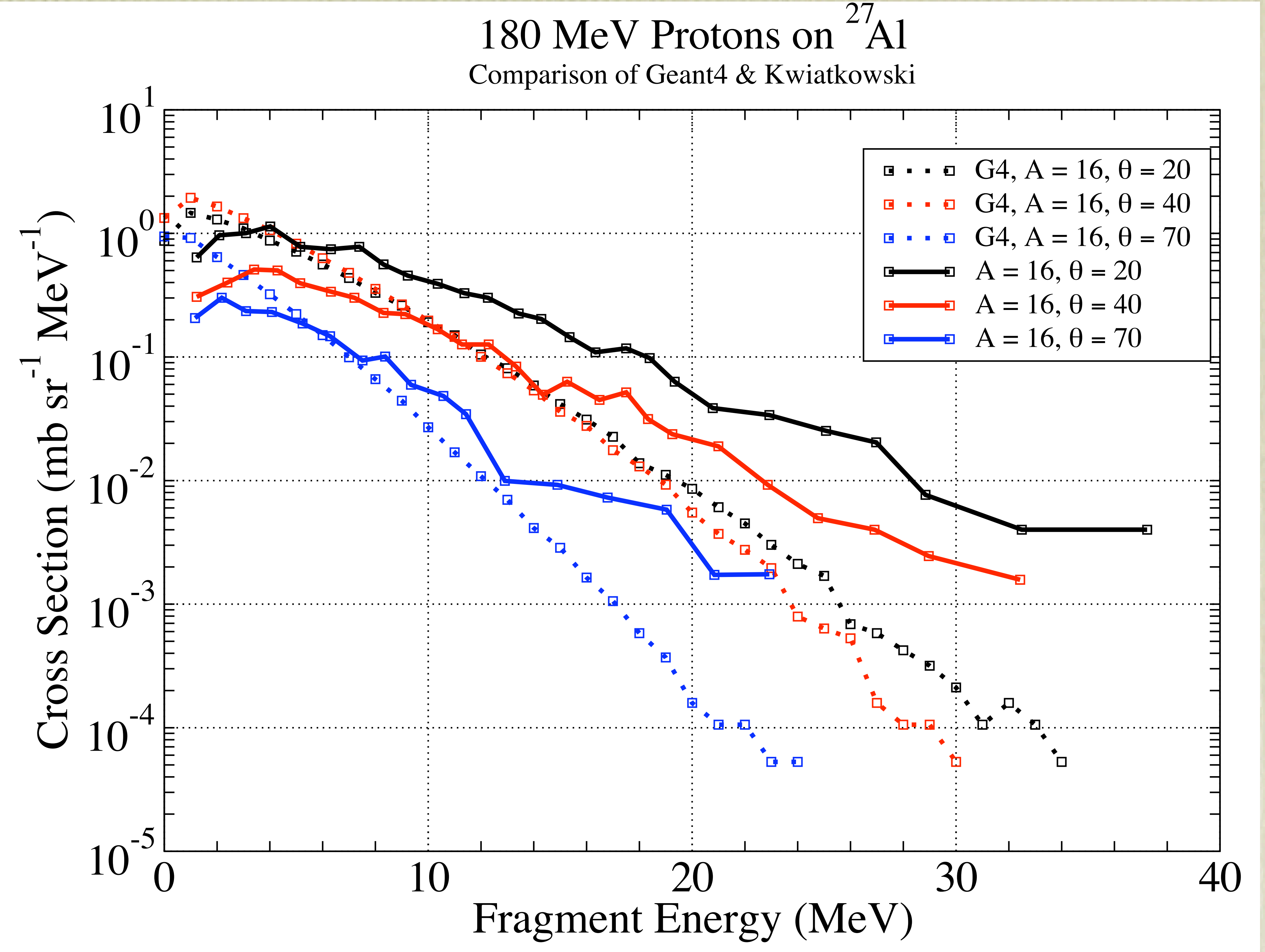
Compare Geant4 to Kwiatkowski

- Run 180 MeV protons using LHEP-BIC physics
- Create enhanced solid-angle detector for good count rate



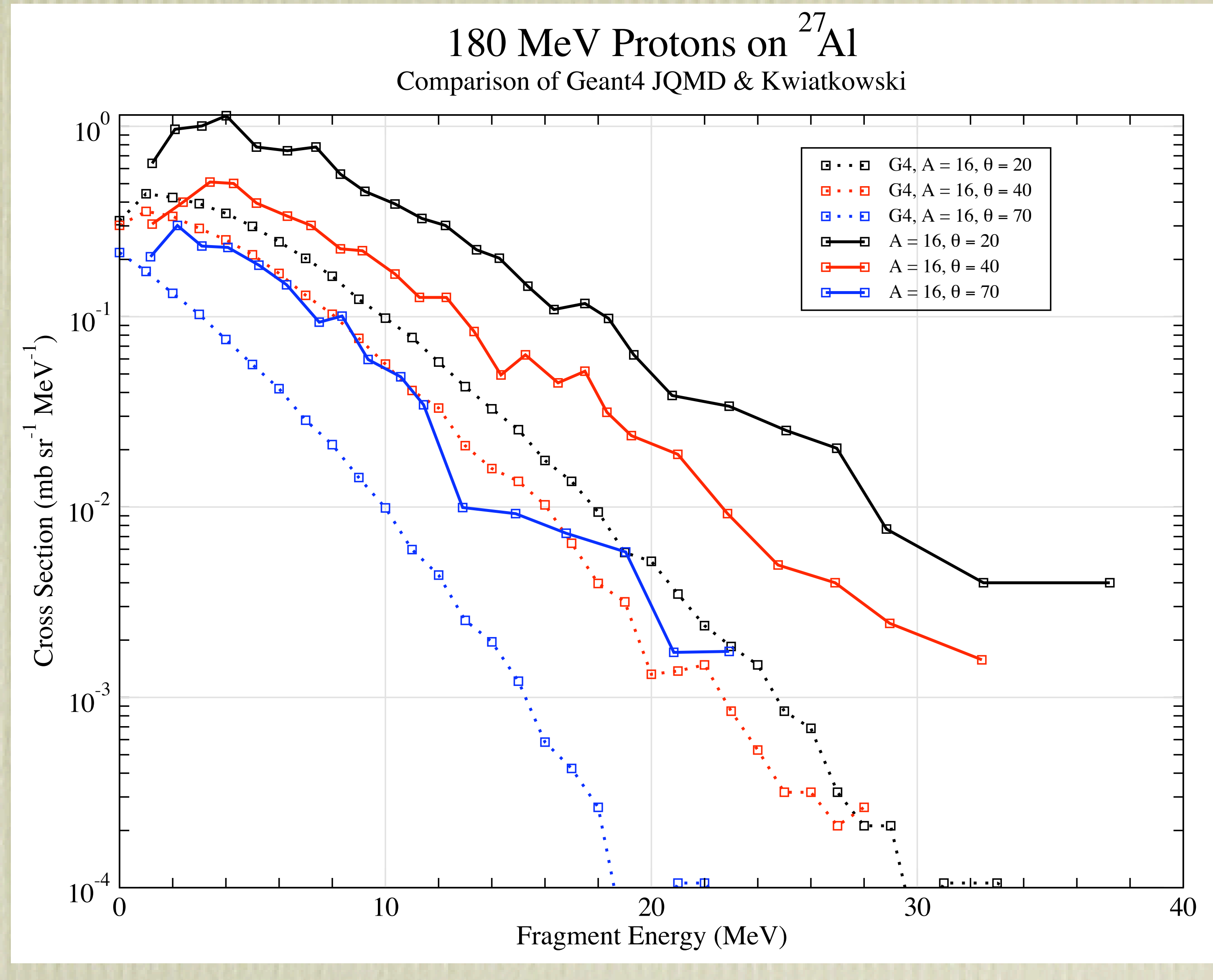


Detail of oxygen results



New data with G4-JQMD

- JQMD gives a ‘temperature’ which is OK
- Oxygen yield still about 3x low

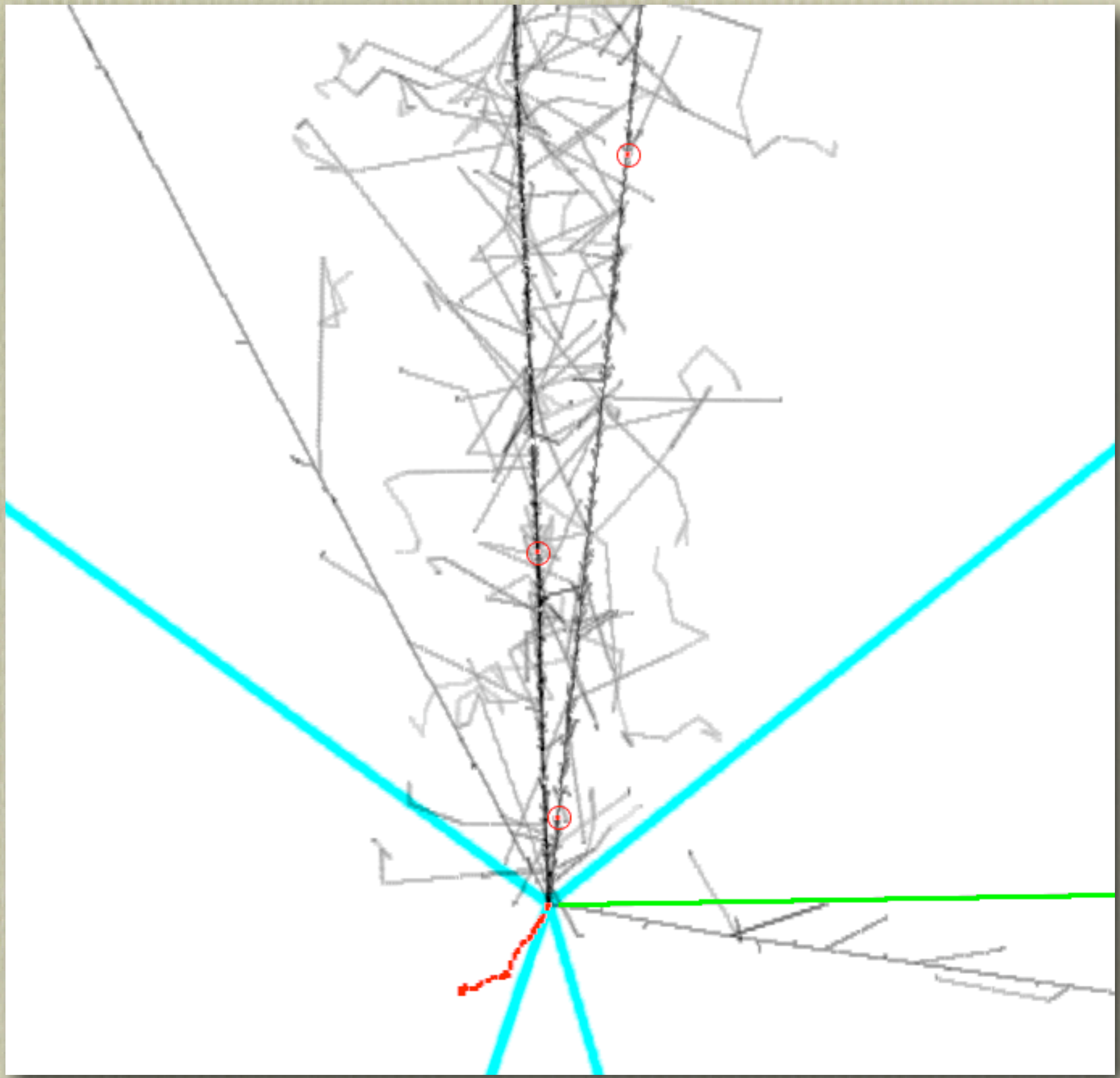


Discussion of problem

- Intermediate mass fragments are the key: light fragments are lightly ionizing, and the heaviest bits are very slow due to momentum conservation.
- Although these systems are not necessarily thermalized, if one pretends they have a nuclear temperature, it is about 30%-50% too low
- Since this is in the scale factor for an exponential, it results in orders of magnitude error in rate of events for a given energy deposition
- Current solution: scale all depositions due to the events up 50%. It's really ugly, but it works (sort of).

Why is the deficit critical?

- High-energy heavy fragments deposit a lot of energy locally
- High-energy heavy fragments create collisions cascades and may create inter-element short circuits
- High-energy light fragments spread energy around, less likely to create an upset



So why am I giving this talk?

- Right now, our community is the only 'consumer' of this information
- If we don't make an effort to attract some interest, no one else will
- There is a lot of interesting physics in the fragmentation process, and it is related to similar problem facing the high-energy physics community
- Accurate SEU modeling is doomed unless we solve this