The beam MC:
A short overview

Part I: Hadronic interactions

- Proton interactions in aluminum with primary momentum above 10GeV/c are modeled by a local implementation of a parameterization from Sanford and Wang using existing measurements of production cross sections.
- $\pi^{\pm}$ production is taken from the "CERN compilation" of production data from experiments around 1970. The main source is the paper by Cho, *et al.* from the ZGS experiment of Derrick's group. The normalization, for historical reasons, is $\lesssim 20\%$ higher than that measured by Cho, *et al.*.
- Charged kaon production is taken from the KEK report of Yamamoto. This agrees with the original formula in the paper by Wang.
- π^0, K^0, $\overline{\mathrm{K}}_0$ production are derived from corresponding charged particle production.
- The above measurements were on beryllium targets. The Be-Al correction is made with the formula given by Busza *et al.* at higher energies.
- Hadronic interactions in other materials or below 10GeV/c primary momentum are dealt with by GEANT defaults. This difference in interaction models affects only $\sim 1\%$ of those mesons producing neutrinos at our detectors.

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Part II: Other aspects

- GEANT volumes in the target area model the physical set-up at the 1cm level in general, at the 1mm level within the horns. The full decay tunnel and beam dump are also simulated (although the latter has negligible effect).
- The input proton profile is taken from measurements by upstream monitors.
- Output information is kept in the form of flux tables as a function of neutrino energy and radius from the axis at various distances from the target corresponding to different detector locations.
- The magnetic field in the horn and target are modeled assuming a stable distribution of current. This assumption is currently under study.

Some references for meson production

“Empirical Formula for Inclusive Proton Spectra Between 10 and 300GeV” C.L.Wang, PRD vol16, num 7, p2196 (1997)
This paper has a set of parameters which we do **.NOT.** use. Its normalization is strikingly low. However, it is the same functional form used in our parameterization of these measurements.

“Pion Production in Proton Beryllium Collisions at 12.4GeV/c” Cho, *et al* PRD vol4, num7, p1967 (1971).
These are the ANL-ZGS data. They present a fit which we do not use, but which gives nearly the same results as the one we do.

”Experimental Study of Particle Production at Small Angles in Nucleon-Nucleon Collisions at 19 and 23 GeV/c” Dekkers, *et al*, PR, vol137,num4B,p962 (1965).
These data taken at CERN are quite extensive. They are the ones that give leverage to disentangle the dependence on beam momentum.

“Differential Production Cross Sections of Low–Momentum Particles from 12.3BeV/c Protons on Beryllium and Copper.” Marmer, et al. PR vol179,num5,p1294 (1969).
Also at the ANL-ZGS. They measured copper as well as beryllium, but we only used the beryllium data.

“Pion Production at 12^o and 15^o in Proton-Beryllium Collisions at 12.5GeV/c” Ashbury, et al, PR, vol178, num5, p2086 (1969).

“Pion Production from Beryllium at 3^o by 12.3GeV/c Protons,” G.J.Marmer and D.E.Lundquist, PRD, vol,num3,p1089 (1971).
This is just a few points with very large errors.