Computed Pion Yields from a Tantalum Rod Target: Comparing MARS15 and GEANT4 Across Proton Energies

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The choice of proton driver energy is an important variable in maximising the pion flux available in later stages of the neutrino factory. Simulations of pion production using a range of energies are presented and cross-checked for reliability between the codes `MARS15` and `GEANT4`. The distributions are combined with postulated apertures for the pion decay channel and muon front-end to estimate the usable muon flux after capture losses. Resolution of discrepancies between the codes awaits experimental data in the required energy range.

Table 1
Parameters for the pion production simulations.

Target	material	Solid tantalum
	shape	Cylindrical
	length	20 cm
	radius	1 cm
p^+ beam	distribution	Parabolic, circular
	radius	1 cm (=target)
	divergence	0 (parallel beam)

1. Benchmark Problem

All simulations used the same scenario of a proton beam hitting a tantalum rod directly at one end, with the parameters shown in table 1. A *circular parabolic* distribution with density $\rho(r) \propto 1 - r^2$ is used to model the projection of a typical proton beam with a uniformly-filled transverse phase space ellipsoid into two dimensions.

Proton energies of 2.2, 3, 4, 5, 6, 8, 10, 15, 20, 30, 40, 50, 75, 100 and 120 GeV were chosen to span the range from linac-based proposals such as the SPL at CERN, via rapid-cycling synchrotron or FFAG chains, up to slow-cycling, high-energy synchrotrons such as the FermiLab booster.

2. Code Behaviour, Models and Ranges

Particle production codes adopt different models of hadron production in different energy ranges: `MARS15` uses CEM2003 below 3 GeV and inclusive production above 5 GeV, with interpolation between. `GEANT4` can be run in several 'use cases', discussed at greater length in [1]. Below 3 GeV it can use GHEISHA (the default, inherited from `GEANT3`), Bertini cascade (BERT) or binary cascade (BIC) models; GHEISHA is always used from 3–25 GeV. In each case, the Quark-Gluon String Model can be turned on (QGSM) or off (LHEP) above 25 GeV. Finally, there is the seventh option (QGSC) of chirally-invariant QGSM with GHEISHA elsewhere.

3. Total Pion Production

Production of pions in both codes is shown in figure 1. This does not itself identify the optimal proton energy, as many pions are emitted backwards or highly transverse relative to the front-end channel. There is broad (though not accurate) agreement between the codes, suggesting a maximum somewhere from 10–30 GeV.

Our `GEANT4` results use QGSP by default. An examination of other models revealed the divergence at low energies shown in figure 2.

4. Captured Muon Estimates

Pions within $(30\,\mathrm{MeV/c})^2$ bins in initial (p_L, p_T) space were run through a decay and phase rotation channel using the tracking code `Muon1` [2], producing survival probabilities for each bin. This 'probability grid' was used against the pion distributions to quickly estimate the

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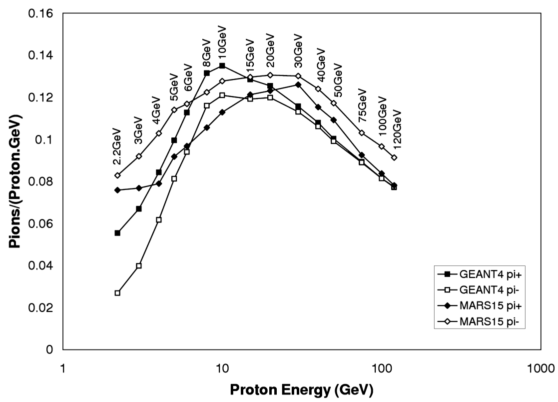

Figure 1. Predicted total yield of pions leaving the rod, per unit beam power at various energies.

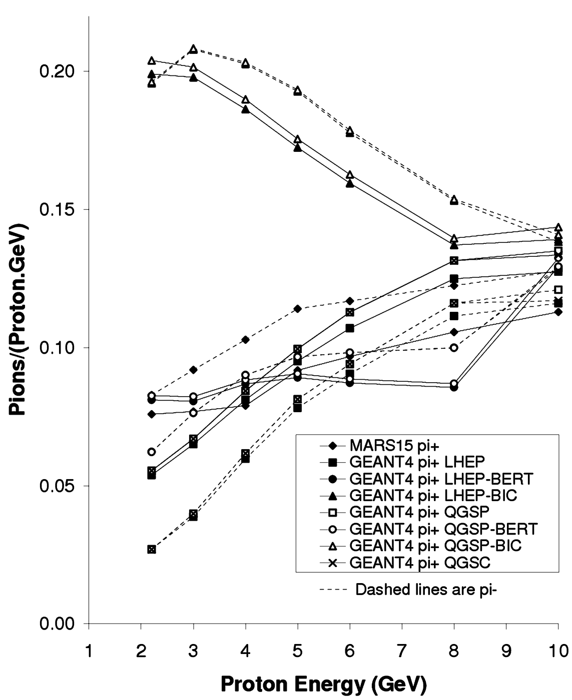

Figure 2. Divergence of binary cascade (BIC) in GEANT4 from the other hadronic models and MARS15 in terms of total pion yield.

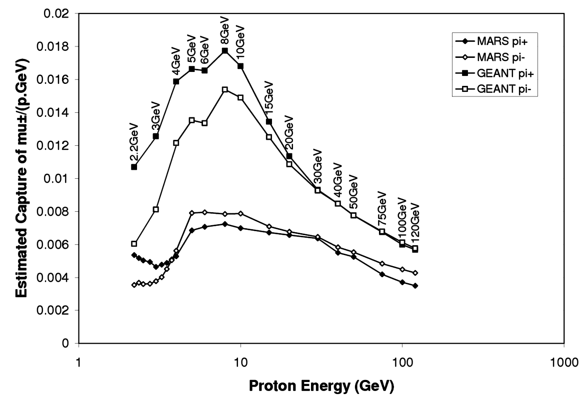

Figure 3. Predicted muon yields after transmission through an example front-end.

transmitted yield, shown in figure 3.

There are large disagreements in yield because GEANT4 produces more forward-focussed pions and the transmission is sensitive to the phase-space density in the forward region. There is, however, better agreement in the location of the optimal energy ranges.

5. Conclusion

The proton driver energy ranges that roughly maximise our predicted muon yields from the front-end are shown below. The HARP experiment should reduce uncertainty in the 2.2–14 GeV region, allowing more accurate future models.

Code	Optimal π^+	Optimal π^-
MARS15	5–30 GeV	5–10 GeV
GEANT4	4–10 GeV	8–10 GeV

REFERENCES

1. K.A. Walaron, UKNF Note 30: Simulations of Pion Production in a Tantalum Rod Target using GEANT4 with comparison to MARS (2005).
2. S.J. Brooks, Quantitative Optimisation Studies of the Muon Front-End for a Neutrino Factory, Proc. EPAC'04.