# Comparison of MC codes

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<td>NUWRO</td>
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ArgoNeuT

NuMu

3 GeV

CC

Argon

No meson in final state

Multiplicity of protons
ArgoNeuT

Numu, 3 GeV, CC, Argon
No meson in final state
ArgoNeuT

Numu, 3 GeV, CC, Argon
No meson in final state

Nucleon absorption

And/or formation zone?

After pion absorption
Nucleons are placed
Outside nucleus

% of events

No. of protons
No meson in final state

Multiplicity of protons with $T_k > 50$ MeV
ArgoNeuT

No meson in final state

Numu, 3 GeV, CC, Argon

% of events

No. of protons with Tk > 50 MeV

22.10.2012
No meson in final state

It is rather formation zone
Which (in NuWro model)
Depends on neutrino energy

ARGONUET

Numu, 3 GeV, CC, Argon

Depends on neutrino energy

% of events

No. of protons with Tk > 50 MeV

GENIE
Neut
NUANCE
NuWro
MicroBooNE

NuMu

1 GeV

CC

Argon

No meson in final state

Multiplicity of protons
MicroBooNE

Numu, 1 GeV, CC, Argon
No meson in final state

% of events

No. of protons

GENIE
Neut
NUANCE
NuWro
MicroBooNE

Numu, 1 GeV, CC, Argon
No meson in final state

Smaller neutrino energy
→ smaller difference between NuWro and others (FZ?)

Why does NUANCE have so many protons?
MicroBooNE

NuMu

1 GeV

CC

Argon

No meson in final state

Multiplicity of protons with $T_k > 50$ MeV
MicroBooNE

Numu, 1 GeV, CC, Argon
No meson in final state

% of events

No. of protons with Tk > 50 MeV
MicroBooNE

Numu, 1 GeV, CC, Argon
No meson in final state

NUANCE has more protons
Than other MCs
1. For higher neutrino energy NuWro has less protons than other Monte Carlo. Probably reason is formation zone which in NuWro model depends on a formation zone.

2. Why there is so many protons in NUANCE?

3. In such simple observable Monte Carlo should have better agreement...
ArgoNeuT

NuMu

3 GeV

CC

Argon

No selection

Total visible energy
(protons $E_k$ + leptons and mesons $E$)
**MicroBooNE**

- **NuMu**
- **1 GeV**
- **CC**
- **Argon**

**No selection**

**Total visible energy**

(protons $E_k +$ leptons and mesons $E$)
MicroBooNE

Numu, 1 GeV, CC, Argon

No. of events vs Total visible energy [MeV]

- GENIE (red)
- Neut (green)
- NUANCE (blue)
- NuWro (black)

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NUINT12 - T. Golan
No meson in final state

Momentum of most energetic proton
(counting only proton with Tk > 50 MeV)
MicroBooNE

Numu, 1 GeV, CC, Argon
No meson in final state

1 proton

No. of events

Momentum of most energetic proton [MeV]

2 protons

No. of events

Momentum of most energetic proton [MeV]

3 protons

No. of events

Momentum of most energetic proton [MeV]

100 events

More than 3 protons

No. of events

Momentum of most energetic proton [MeV]
MINERva

NuMu  5 GeV  CC  Carbon

Single pi+ in final state

Pi+ energy vs cosine
MINERvA

Numu, 5 GeV, CC, Carbon
Single pi+ in final state

Note:
Each generator is normalized
To different number of events
There is less backward pions
Than in other MCs
MINERva

NuMu  5 GeV  CC  Carbon

Single pi- in final state

Pi- energy vs cosine
MINERvA

Numu, 5 GeV, CC, Carbon
Single pi- in final state

In opposite to pi+
There is not so much
Backward pi-
Single \textbf{pi0} in final state

\textbf{Pi0} energy vs cosine
MINERvA

Numu, 5 GeV, CC, Carbon
Single pi0 in final state

Result is more smeared
Around maximum
Than other MCs
No pion in final state / 1 pion in final state

(Total kinetic energy in all protons) / (Energy transfer)
Numu, 5 GeV, CC, Carbon
No pion in final state / 1 pi in FS
MINERva

- NuMu
- 5 GeV
- CC
- Carbon

2 pions in final state / more than 2 pi in FS

(Total kinetic energy in all protons) / (Energy transfer)
MINERvA

Numu, 5 GeV, CC, Carbon
2 pions in final state / more than 2 pions in FS

2 pions

more than 2 pions
Summary

1. On the comparison an agreement between generators is good, but not excellent.

2. Probably the weakest point of each MC is nucleon cascade.

3. More comparison between generators and looking for reasons of disagreement may be helpful.

We should go deeper...
OBRIGADO!
**MINERva**

- Anti NuMu
- 5 GeV
- CC
- Carbon

**Single pi+ in final state**

**Pi+ energy vs cosine**
Anti Numu, 5 GeV, CC, Carbon
Single pi+ in final state

MINERvA

Genie

Neut

NuWro
MINER\(\nu\)a

- Anti NuMu
- 5 GeV
- CC
- Carbon

Single $p^{-}$ in final state

$\pi^{-}$ energy vs cosine
MINERvA

Anti Nuμ, 5 GeV, CC, Carbon
Single π⁻ in final state
Anti NuMu 5 GeV CC Carbon

Single $\pi^0$ in final state

$\pi^0$ energy vs cosine
MINERvA

Anti Numu, 5 GeV, CC, Carbon
Single pi0 in final state
Anti NuMu 5 GeV CC Carbon

No pion in final state

(Total kinetic energy in all protons) / (Energy transfer)
Anti Numu, 5 GeV, CC, Carbon
No pion in final state
MINERva

Anti NuMu

5 GeV

CC

Carbon

1 pion in final state

(Total kinetic energy in all protons) / (Energy transfer)
MINERvA

Anti Numu, 5 GeV, CC, Carbon
1 pion in final state
Anti NuMu \[ \ \] 5 GeV \[ \ \] CC \[ \ \] Carbon

2 pions in final state

(Total kinetic energy in all protons) / (Energy transfer)
Anti Numu, 5 GeV, CC, Carbon
2 pions in final state
MINERva

Anti NuMu 5 GeV CC Carbon

More than 2 pions in final state

(Total kinetic energy in all protons) / (Energy transfer)
MINERvA

Anti Numu, 5 GeV, CC, Carbon
More than 2 pions in final state
No pion in final state

(Total kinetic energy in all neutrons) / (Energy transfer)
MINERvA

Numu, 5 GeV, CC, Carbon
No pion in final state
MINERva

NuMu

5 GeV

CC

Carbon

1 pion in final state

(Total kinetic energy in all neutrons) / (Energy transfer)
MINERvA

Numu, 5 GeV, CC, Carbon
1 pion in final state
MINER\(\text{va}\)

- NuMu
- 5 GeV
- CC
- Carbon

2 pions in final state

\[\frac{(\text{Total kinetic energy in all neutrons})}{(\text{Energy transfer})}\]
MINERvA

Numu, 5 GeV, CC, Carbon
2 pions in final state
NuMu

5 GeV

CC

Carbon

More than 2 pions in final state

(Total kinetic energy in all neutrons) / (Energy transfer)
MINERvA

Numu, 5 GeV, CC, Carbon
More than 2 pions in final state
MINERvva

AntiNuMu  5 GeV  CC  Carbon

No pion in final state

(Total kinetic energy in all neutrons) / (Energy transfer)
MINERvA

Anti Numu, 5 GeV, CC, Carbon
No pion in final state
MINERvA

Anti NuMu

5 GeV

CC

Carbon

1 pion in final state

(Total kinetic energy in all neutrons) / (Energy transfer)
Anti Numu, 5 GeV, CC, Carbon
1 pion in final state
MINERvA

Anti NuMu 5 GeV CC Carbon

2 pions in final state

(Total kinetic energy in all neutrons) /
(Energy transfer)
MINERvA

Anti Numu, 5 GeV, CC, Carbon
2 pions in final state
MINERνa

Anti NuMu

5 GeV

CC

Carbon

More than 2 pions in final state

(Total kinetic energy in all neutrons) / (Energy transfer)
Anti Numu, 5 GeV, CC, Carbon
More than 2 pions in final state