GiBUU Status

Ulrich Mosel

with

Kai Gallmeister, Olga Lalakulich

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Theoretische Physik

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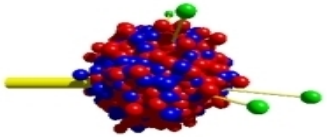

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GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

- **GiBUU** : **Theory and Event Generator**
  based on a BM solution of Kadanoff-Baym equations

- Physics content and details of implemntation in:
  Buss et al, Phys. Rept. 512 (2012) 1- 124
  Mine of information on theoretical treatment of potentials, collision terms, spectral functions and cross sections, useful for any generator development

- Code available from **gibuu.hepforge.org**

Transport Equation

Collision term

$$\mathcal{D}F(x,p) + \mathrm{tr}\left\{\mathrm{Re}\tilde{S}^{\mathrm{ret}}(x,p), -\mathrm{i}\tilde{\Sigma}^{<}(x,p)\right\}_{\mathrm{pb}} = C(x,p).$$

Drift term

$$\left[\left(1-\frac{\partial H}{\partial p_0}\right)\frac{\partial}{\partial t} + \frac{\partial H}{\partial \mathbf{p}}\frac{\partial}{\partial \mathbf{x}} - \frac{\partial H}{\partial \mathbf{x}}\frac{\partial}{\partial \mathbf{p}} + \frac{\partial H}{\partial t}\frac{\partial}{\partial p^0} + \mathrm{KB\ term}\right] F(x,p)$$

$$= \text{- loss term} + \text{gain term}$$

F(x,p) = 8-d phase-space density, contains spectral function

Kadanoff-Baym equation

- LHS: drift term + backflow (KB) terms
- RHS: collision term = - loss + gain terms (detailed balance)

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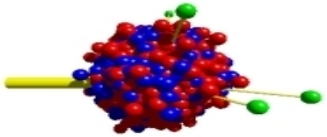

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GiBUU

The Giessen Boltzmann-Uehling-Uhlenbeck Project

- **GiBUU** describes (within the same unified theory and code)
  - heavy ion reactions, particle production and flow
  - pion and proton induced reactions
  - low and high energy photon and electron induced reactions
  - neutrino induced reactions

using the same physics input! And the same code!

NO TUNING!

GiBUU, v 1.6, released Oct 1, 2013

GiBUU 1.6.0 (10/01/2013)

- String threshold for baryon-baryon collisions increased to 3.4 +- 0.1 GeV
- Extended resonance model from EPJ A48 (2012) 111 enabled by default
- Kaon potentials added (in RMF mode)
- Possibility to tune the Kaon production cross sections in baryon-baryon collisions
- improved $\pi\pi$ cross sections, $f_2(1270)$ resonance added
- Pythia updated to version 6.4.27
- 2p-2h contributions for neutrino-induced events added
- Flux distributions of all major long baseline neutrino experiments implemented
- Energy reconstruction and migration matrices for neutrino experiments implemented
- Oscillation analysis for neutrino experiments implemented

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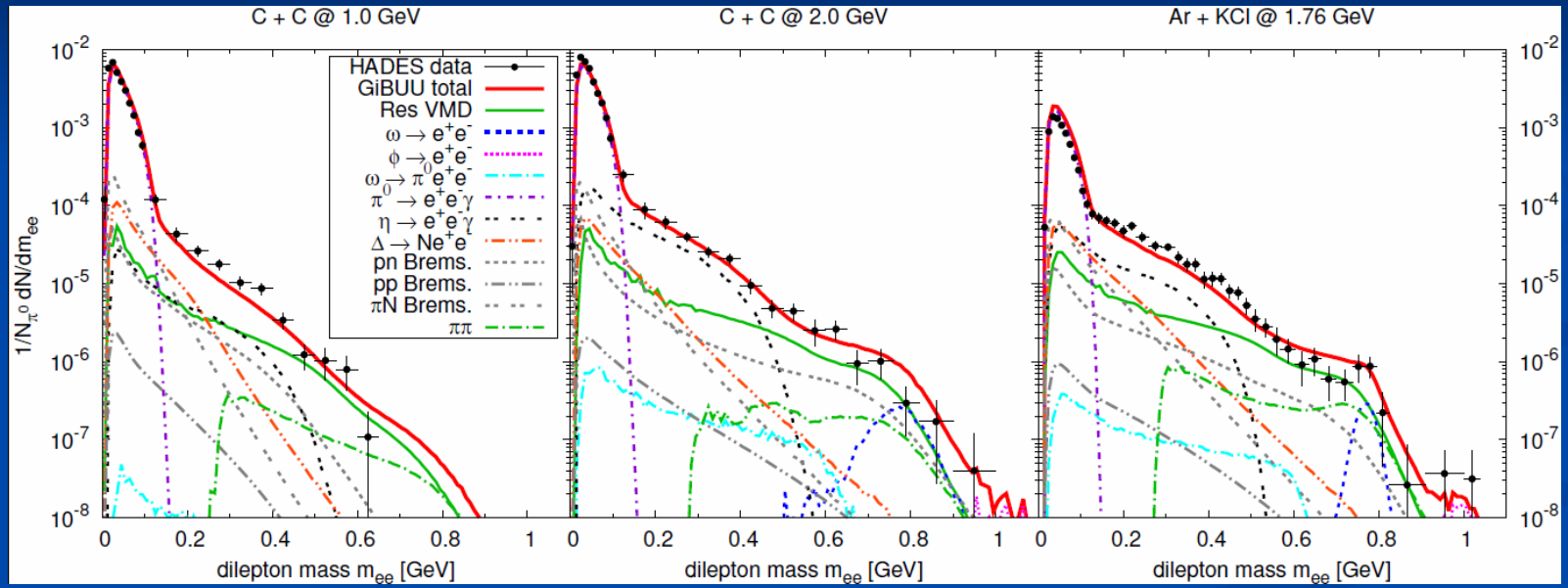
Dileptons

- Excellent test for many different reaction channels



Curves:
GiBUU
J. Weil et al.
Data:
HADES

$$A + A \rightarrow \gamma^* + X \rightarrow e^+ e^- + X$$

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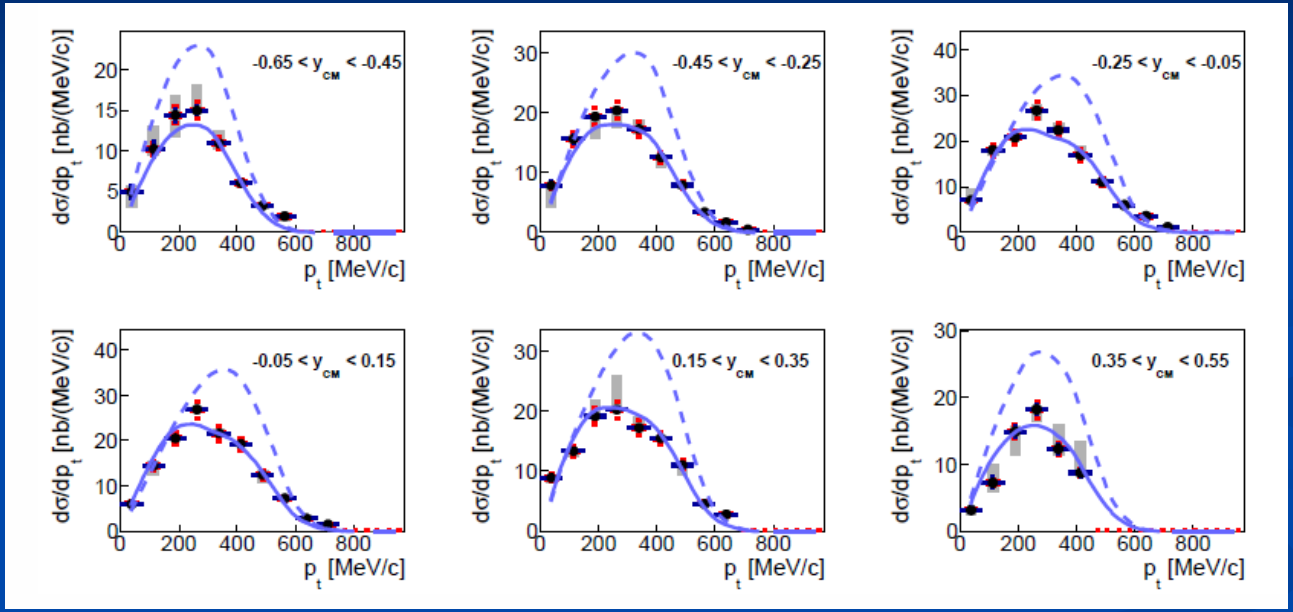
K^0_s at 3.5 GeV p + Nb



HADES data
solid curve:
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Neutrino GiBUU Publications since NUINT2012

1. **"Reaction Mechanisms at MINERνA"**
   U. Mosel, O. Lalakulich and K. Gallmeister.
   arXiv:1402.0297 [nucl-th]
   10.1103/PhysRevD.89.093003
   Phys. Rev. **D 89**, 093003 (2014)

2. **"Energy reconstruction in the Long-Baseline Neutrino Experiment"**
   U. Mosel, O. Lalakulich and K. Gallmeister.
   arXiv:1311.7288 [nucl-th]
   10.1103/PhysRevLett.112.151802
   Phys. Rev. Lett. **112**, 151802 (2014)

3. **"Pion production in the T2K experiment"**
   O. Lalakulich and U. Mosel.
   arXiv:1305.3861 [nucl-th]
   10.1103/PhysRevC.88.017601
   Phys. Rev. C **88**, no. 1, 017601 (2013)

4. **"Pion production in the MiniBooNE experiment"**
   O. Lalakulich and U. Mosel.
   arXiv:1210.4717 [nucl-th]
   10.1103/PhysRevC.87.014602
   Phys. Rev. C **87**, 014602 (2013)

5. **"Energy reconstruction in quasielastic scattering in the MiniBooNE and T2K experiments"**
   O. Lalakulich, U. Mosel and K. Gallmeister.
   arXiv:1208.3678 [nucl-th]
   10.1103/PhysRevC.86.054606
   Phys. Rev. C **86**, 054606 (2012)

6. **"Neutrino- and antineutrino-induced reactions with nuclei between 1 and 50 GeV"**
   O. Lalakulich, K. Gallmeister and U. Mosel.
   arXiv:1205.1061 [nucl-th]
   10.1103/PhysRevC.86.014607
   Phys. Rev. C **86**, 014607 (2012)

7. **"Many-Body Interactions of Neutrinos with Nuclei - Observables"**
   O. Lalakulich, K. Gallmeister and U. Mosel.
   arXiv:1203.2935 [nucl-th]
   10.1103/PhysRevC.86.014614
   Phys. Rev. C **86**, 014614 (2012)

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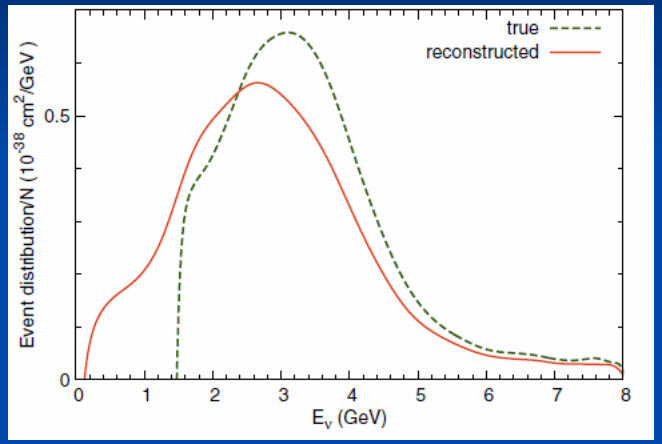
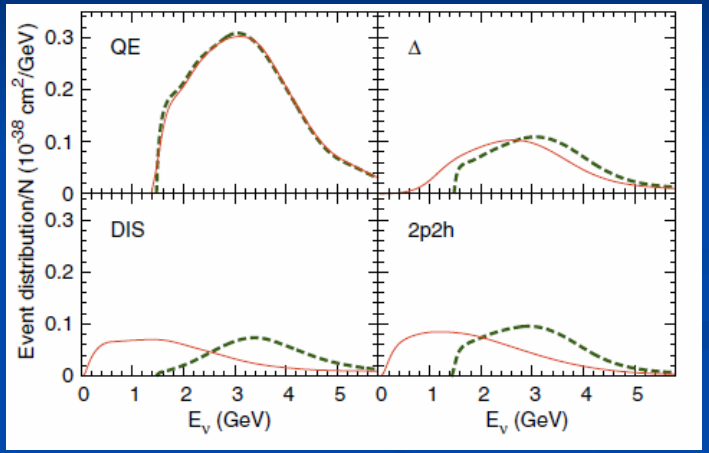
MINERvA Analysis



only 0-pion events

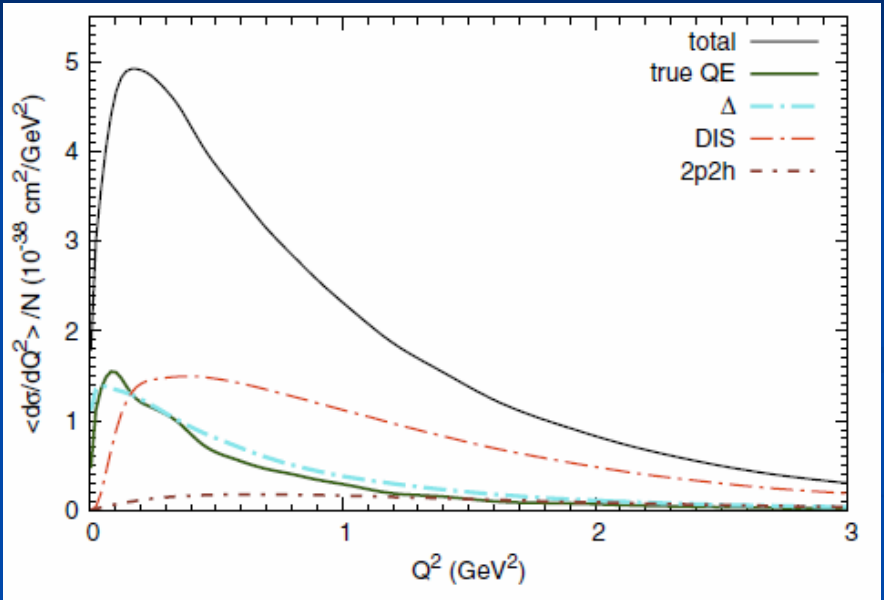


Mosel et al.,
PR D89 (2014) 093003

Flux cuts are dangerous:
distort true distribution!
Minerva cuts out (too?) large part

Energy reconstruction
strongly affected by
all channels, not just 2p2h!

Minerva Q^2 Reconstruction



True Q^2 distribution, *all* events

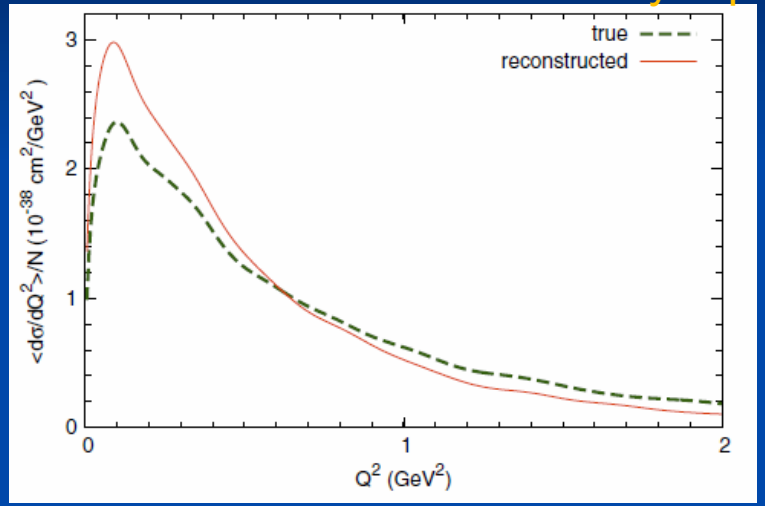
Dominant:
QE, DIS, Δ

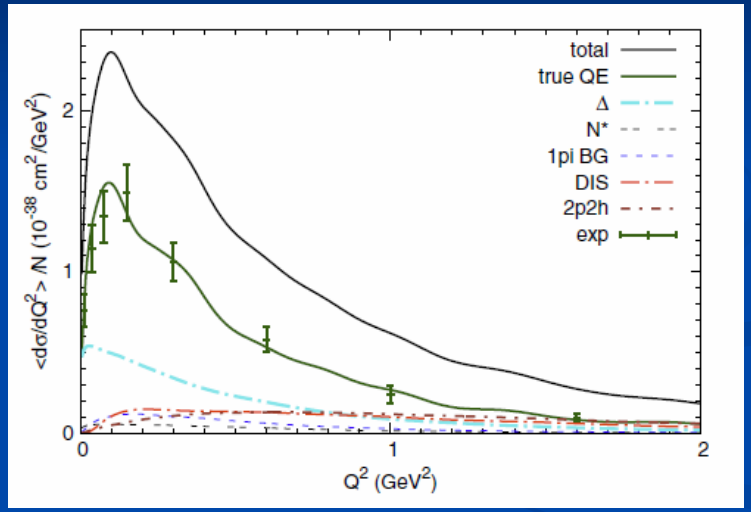
Δ and true QE very similar,
difficult to separate

Mosel et al.,
PR D89 (2014) 093003

MINERvA Q^2 Reconstruction

Only 0-pion events





Dramatic sensitivity to reconstruction in peak area: accuracy of ‚data'??

Mosel et al.,
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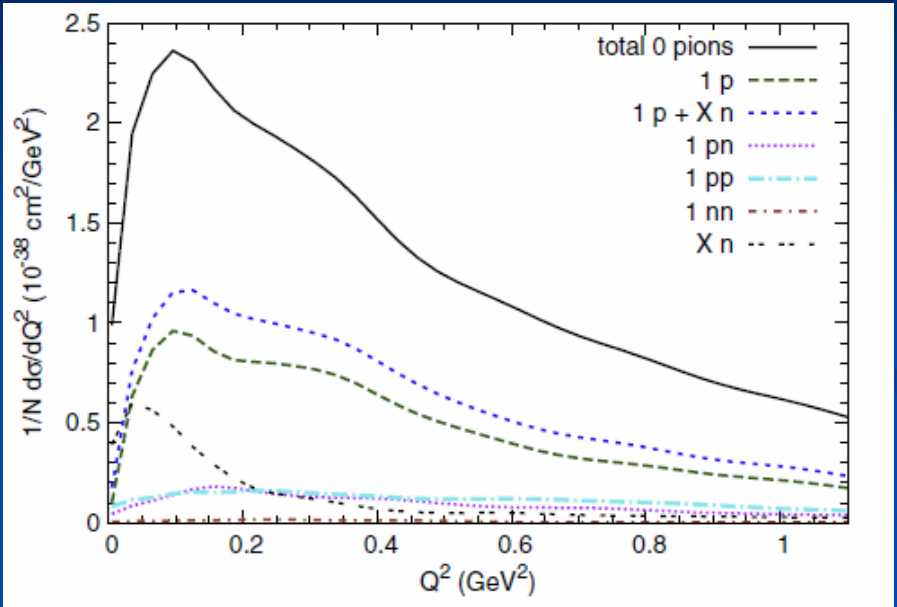
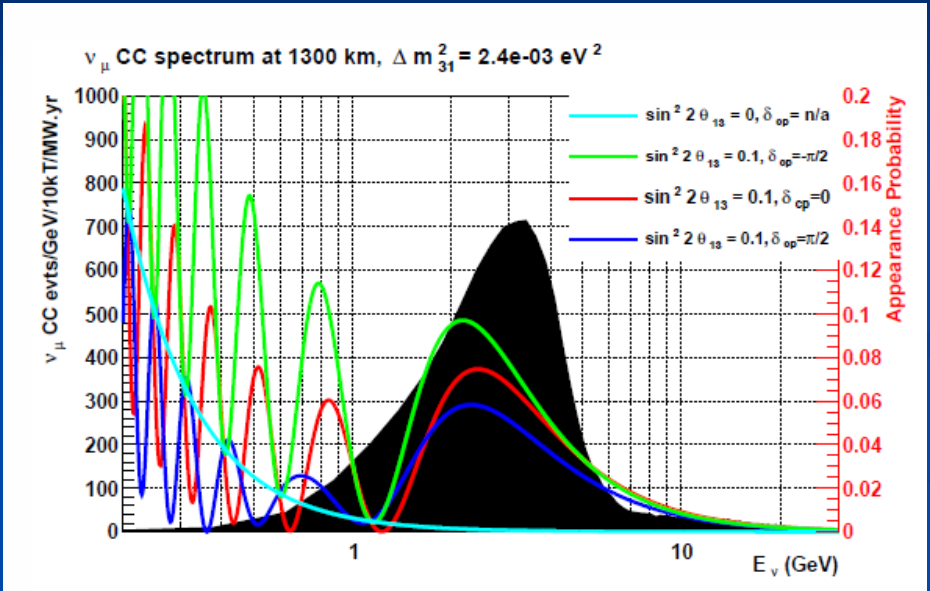
MINERvA Q^2 Reconstruction



0-pion events only

Mosel et al.,
PR D89 (2014) 093003

LBNE, δ_{CP} Sensitivity



Need to know neutrino energy to better than about 100 MeV

Need energy to distinguish between different δ_{CP}

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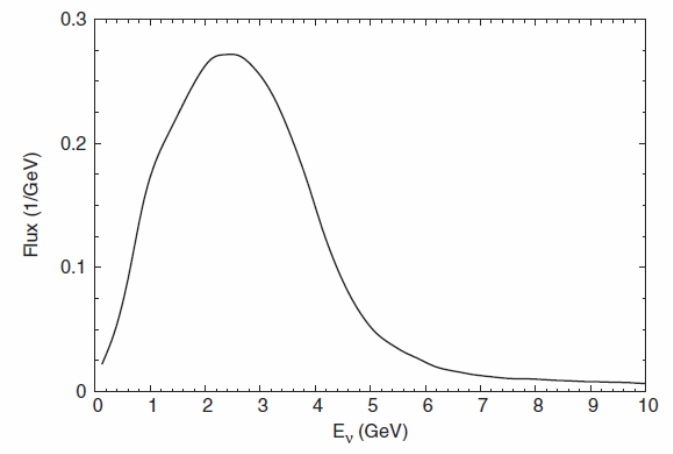
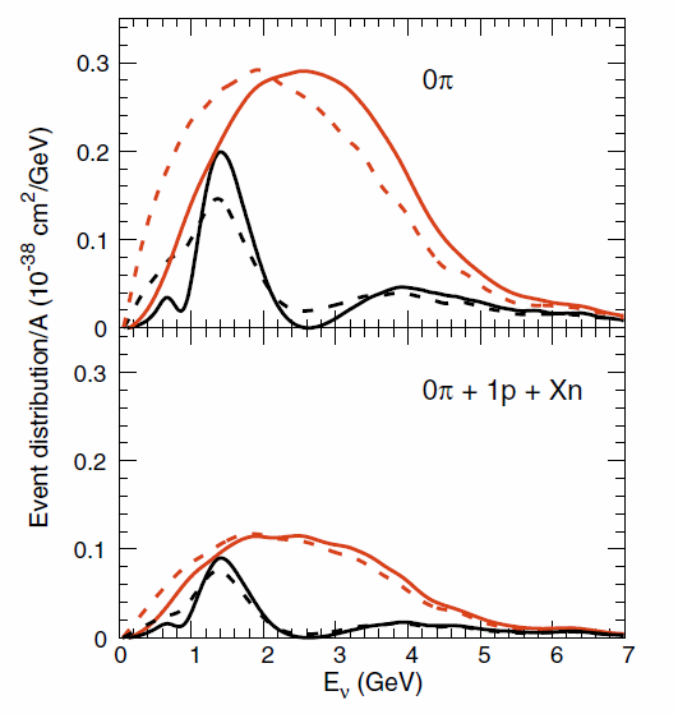
LBNE

LBNE Flux



Mosel et al,
Phys.Rev.Lett.
112 (2014) 151802

μ disappearance



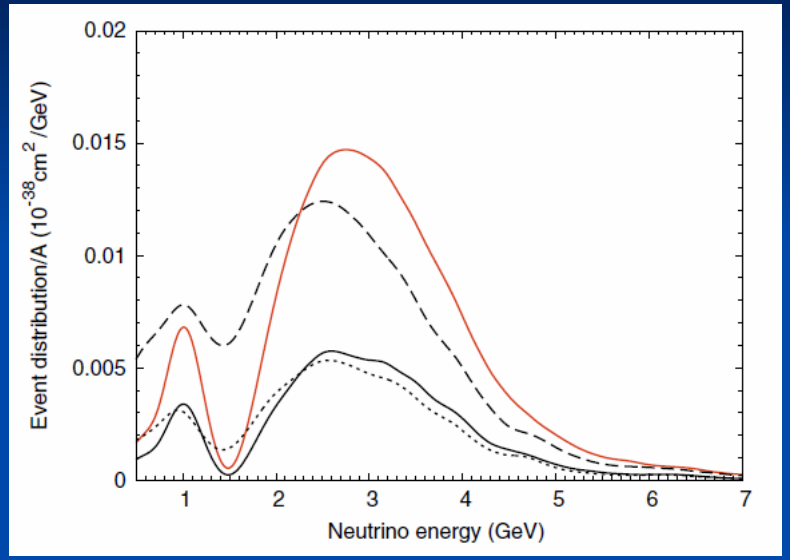
Solid: true
Dashed: reconstructed
Upper: Near detector
Lower: Far detector

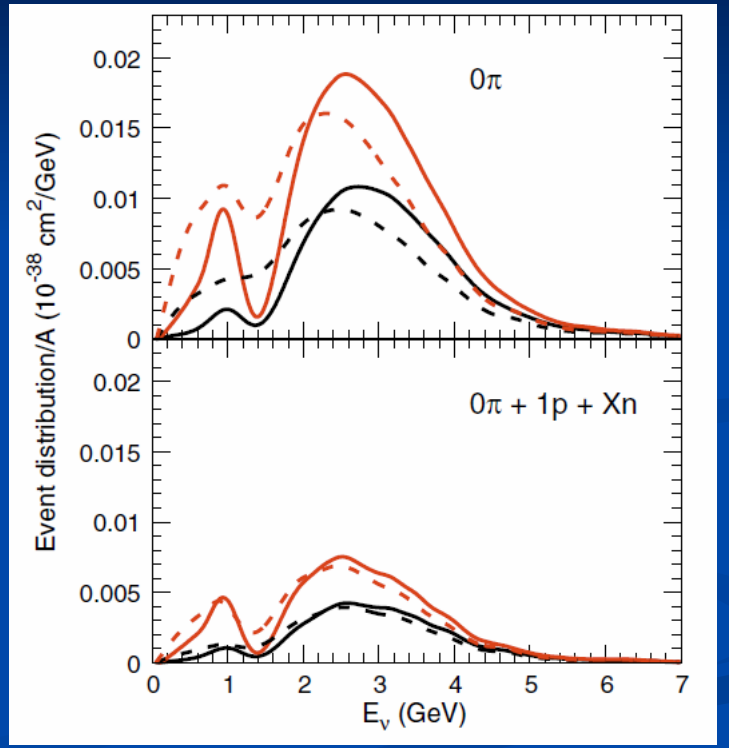
NUINT 2014

LBNE

e appearance

$\delta = 0$





Mosel et al,
Phys.Rev.Lett.
112 (2014) 151802

Solid: true
Dashed: reconstr
Upper: $\delta_{CP} = +\pi/2$
Lower: $\delta_{CP} = -\pi/2$

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GiBUU Status

- Code
  - Code is open for download
  - Code is open for improvements
- Recent Results:
  - Reaction Mechanisms at MINERvA: artifacts of flux cuts
  - LBNE: QE-based method for energy reconstruction can reach necessary energy resolution for proper event selection: 0 pi, 1p, Xn. Viable alternative to calorimetry
- 0 pi, 1p, Xn event sample would also improve MINERvA reconstruction

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