NEAR Detector Physics & Beam Systematics Working Group Session

March. 24-28, 2004, MINOS collaboration meeting, Fermilab

CCLRC
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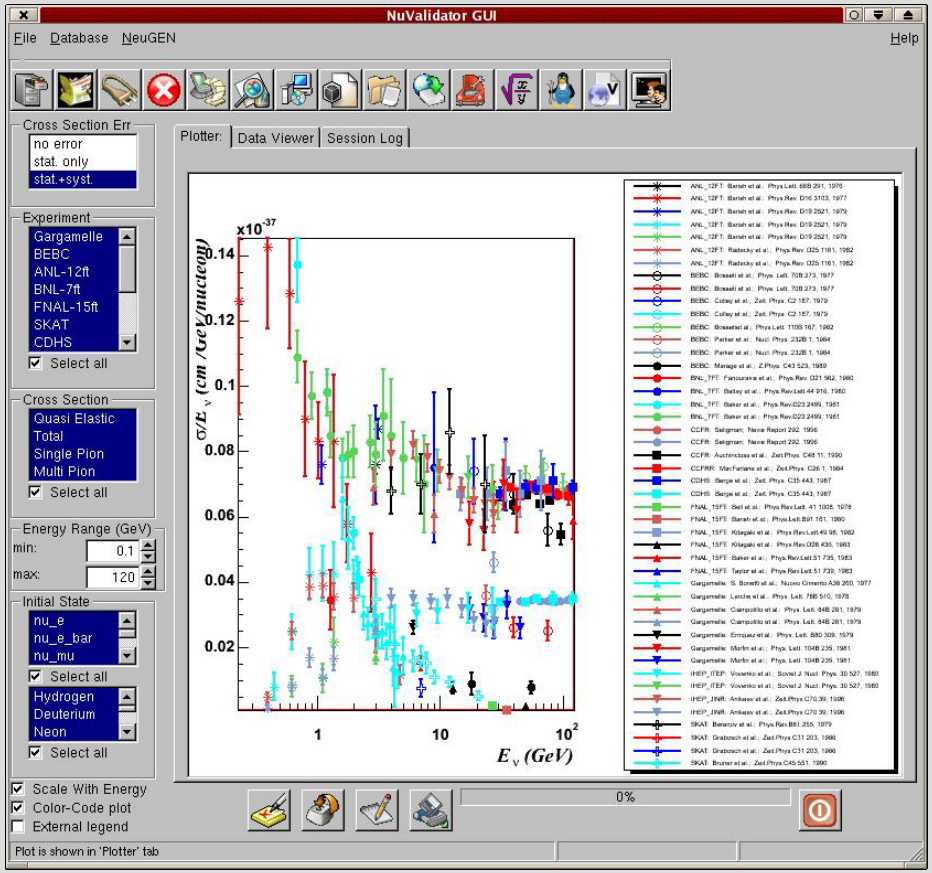

Neutrino Interaction Models & Model Tuning / Validation

Costas Andreopoulos

also for Hugh Gallagher (Tufts)

Outline

Brief Summary of our reports at the NuINT04 Workshop *(March 17-21, Gran Sasso, Assergi, Italy)*

- Mike Whalley's talk on the *DURHAM Neutrino Interaction data base*
- Costas Andreopoulos' talk on *Neutrino Interaction Model Validation*
  - *description of NuValidator project*
  - *tutorial using popular use cases*

Very brief description.
For technical details have a look at:
http://hepunx.rl.ac.uk/nu_validator/

Neutrino Interaction Models

- *The general picture*
- *A "glance" at Data / Model comparisons*

Future plans / Summary

The DURHAM Neutrino Cross Section web site

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Mozilla

File Edit View Go Bookmarks Tools Window Help

http://h2.phyip3.dur.ac.uk/hepdata/online/neutrino/

Home Bookmarks news ref etc hep UK comp MINOS home ROOT

A Compilation of Low Energy (<30 Gev) Neutrino Cross Sections

SPIRES-HEP
REACTION-DB

Experiments

All
Gargamelle
BEBC
ANL-12FT
BNL-7FT
FNAL-15FT
SKAT
CDHS
CCFR
CCFRR
IHEP-ITEP
IHEP-JINR
SERP-A1
CHARM
Other CERN
LSND

Measurements

CC-TOTAL (plot all)
CC-TOTAL-NUMU
CC-TOTAL-NUMUB
Quasi-Elastic
Quasi-Elastic-NUMU

Eichten 1973	Phys.Lett. 46B 274	Propane-Freon	2-10 (data)			
Bonnetti 1977 flux	Nuovo Cim. 38A 260	Propane-Freon		1.7-5(data)		
Lerche 1978 flux	Phys.Lett. 78B 510	Propane-Freon			3(CS)	
Lerche 1978	Nucl.Phys. B142 65	Propane-Freon	1-10		1-10	1-10
Krenz 1978	Nucl.Phys. B135 45	Propane-Freon			1-6	
Pohl 1979	Nuovo Cim. 26 332	Propane-Freon		1-10(data)		
Bolognese 1979	Phys.Lett. 81B 393	Propane-Freon			1-14(FG+DI)	1-14 (FG+DI)
Ciampolillo 1979 flux	Phys.Lett. 84B 281	Propane-Freon	2.9, 9 (data)			
Erriquez 1979 flux	Phys.Lett. B80 309	Propane-Freon	1-10 (data)			
Armenise 1979 flux	Nucl.Phys. B152 365	Propane-Freon		1-10		
Morfin 1981	Phys.Lett. 104B 235	Propane-Freon	15-150 (data)			
BEBC		**Target**	**Total CS**	**QE CS**	**Single Pion**	**Other**
Bosetti 1977	Phys.Lett. 70B 273	Neon-H2	20-200 (data)			
Colley 1979 flux	Zeit.Phys. C2 187	Neon-H2	10-50 (data)			
Allen 1980	Nucl.Phys. B176 269	Hydrogen			5-200 (FG)	
Bosetti 1982	Phys.Lett. 110B 167	Neon-H2	20-200 (data)			
Allasia 1983	Zeit.Phys. C20 95	Deuterium			5-200 (FG)	

Data Window

Exp	Author/Reference	Target	Reaction	Energy (GeV)	sig/E +- error (syst) 10^-38 cm^2/GeV	source
BEBC	Bosetti 1977 PL 70B,273	Neon-H2	numu nucleon --> mu- x	20 - 60	0.67 +- 0.06	paper
			numu nucleon --> mu- x	60 - 100	0.56 +- 0.05	paper
			numu nucleon --> mu- x	100 - 150	0.61 +- 0.05	paper
			numu nucleon --> mu- x	150 - 200	0.51 +- 0.05	paper
			numubar nucleon --> mu+ x	20 - 60	0.26 +- 0.03	paper
			numubar nucleon --> mu+ x	60 - 100	0.25 +- 0.03	paper
			numubar nucleon --> mu+ x	100 - 200	0.32 +- 0.04	paper

Done

The DURHAM group (UK) *[M. Whalley et al.]* (http://durpdg.dur.ac.uk/hepdata/),

in collaboration with

K2K *[M. Sakuda et al.]*
mini-BooNE *[S. Zeller et al.]* &
MINOS *[H. Gallagher et al.]*,

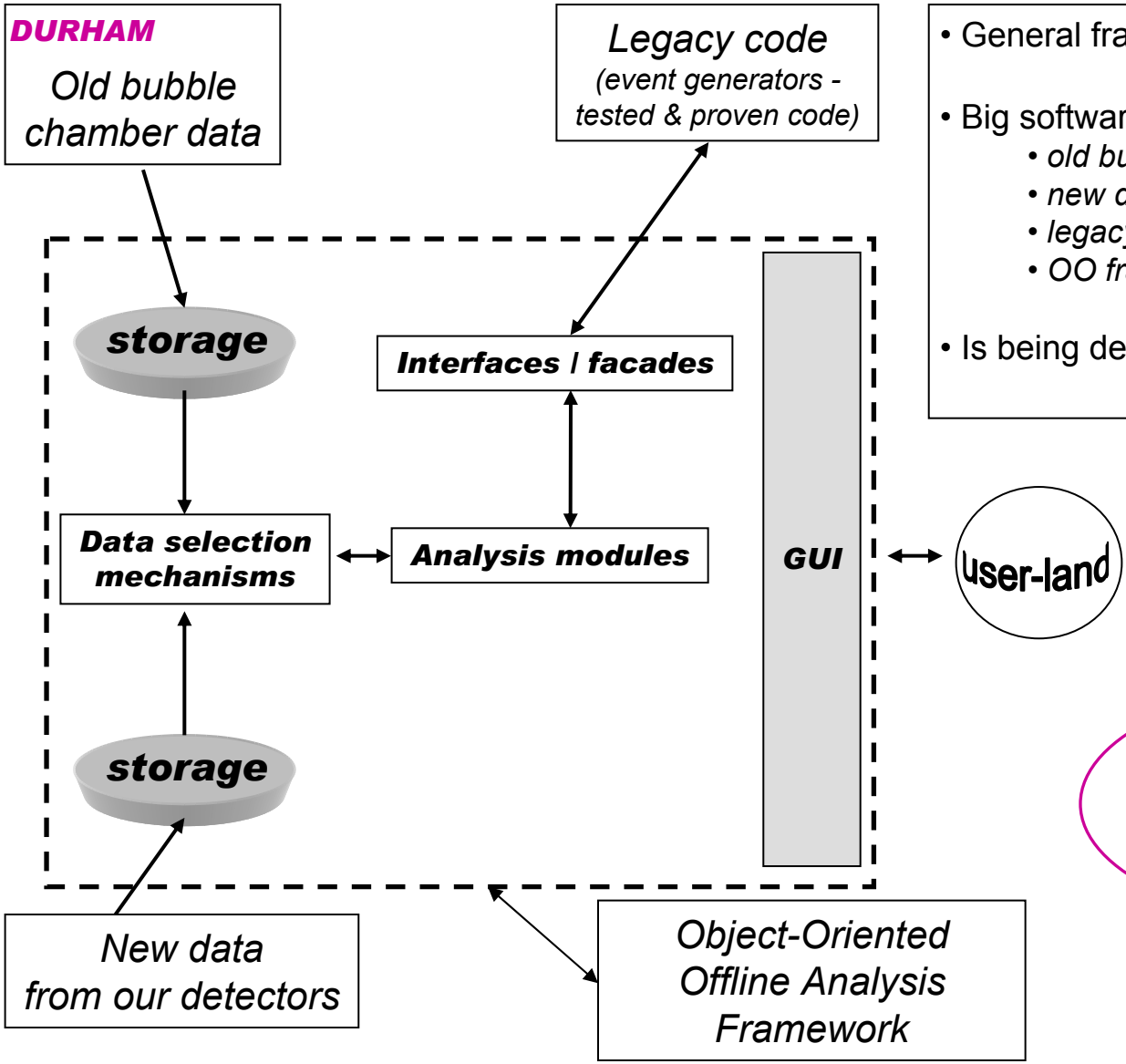
has compiled & validated a large portion of existing neutrino cross section data

Group had very good progress since the last collaboration meeting.

The neutrino data review is now officially available from DURHAM.

More work needed!

What is the NuValidator project?



- General framework for "cross section analyses"
- Big software project. A bridge between
  - *old bubble chamber data*
  - *new data from 'your' experiment*
  - *legacy code (neutrino generators)*
  - *OO framework of modern experiments*
- Is being developed for **MINOS**, **but is <u>not MINOS-specific</u>.**

A software tool with many application in neutrino experiments

Applications in MINOS / Current Status

Many possible applications (both quantitative and qualitative)

Examples:

- *validating event generators*
- *evaluating different models for some process*
- *as a development tool for generators (regression testing)*
- *tuning model parameters*
- *quantifying systematic uncertainties*

Since the last collaboration meeting:

- *the software project is now in very mature state*
- *all major coding efforts are done*

- *start using this tool & the cross section database in* ***global quantitative studies***

Availability

NuValidator will be 'freely' (GNU GPL) available at a relatively short time-scale:

- *An anonymous CVS server is being setup at* ***Rutherford Lab.***
- *Tarballs / RPMs from the NuValidator site:* **http://hepunx.rl.ac.uk/nu_validator/**

Its web site already contains useful instructions, examples, HOWTO's, …

Browsing bubble chamber data (1/3):

Connection to the Cross Sections database

connect

disconnect

print dbase info

Data-base connection dialog

- in this case, dbase is kept locally
- If the DURHAM group feels it is within its scope to provide this service too, one could connect directly to their server:
  - *no need for local/slave server*
  - *need to be online to run*
  - *RO access*

Browsing bubble chamber data (2/3):

Selecting a data subset and plot it

type of xsec errors

experiments

processes

energy range

neutrino type

target

NuValidator GUI

File Database NeuGEN Help

Cross Section Err
- no error
- stat. only
- stat.+syst.

Experiment
- Gargamelle
- BEBC
- ANL-12ft
- BNL-7ft
- FNAL-15ft
- SKAT
- CDHS

Select all

Cross Section
- Quasi Elastic
- Total
- Single Pion
- Multi Pion

Select all

Energy Range (GeV)
min: 0.1
max: 120

Initial State
- nu_e
- nu_e_bar
- nu_mu

Select all

- Hydrogen
- Deuterium
- Neon

Select all

Scale With Energy
Color-Code plot
External legend

Plot is shown in 'Plotter' tab

Plotter | Data Viewer | Session Log

σ/E_ν (10^{-38} cm^2/GeV/nucleon)

1.6, 1.4, 1.2, 1, 0.8, 0.6, 0.4, 0.2

1, 10, 10^2

E_ν (GeV)

Save As...

Save in NEUGEN3

calc
gen
inc
lib
phys
spi

File name:

Files of type: GIF (*.gif)

GIF (*.gif)
ROOT macro (*.C)
Encapsulated postscript (*.eps)

Save
Cancel

0%

Save the plot as gif, eps, or C macro

Get the inputs, query the dbase, plot the result

Browsing bubble chamber data (3/3):

Check out the actual numeric values for the selected set

Textual view of the data

Get the inputs, query the dbase, write out the result in tabular form

Right-click on the editor, print the data or save them in text format

NuValidator GUI

File Database NeuGEN Help

Cross Section Err: no error, stat. only, stat.+syst.

Experiment: Gargamelle, BEBC, ANL-12ft, BNL-7ft, FNAL-15ft, SKAT, CDHS, Select all

Cross Section: Quasi Elastic, Total, Single Pion, Multi Pion, Select all

Energy Range (GeV) min: 0.1 max: 120

Initial State: nu_e, nu_e_bar, nu_mu, Select all

Hydrogen, Deuterium, Neon, Select all

Scale With Energy, Color-Code plot, External legend

Plotter | Data Viewer | Session Log

Data-Base Viewer:

E	Emin	Emax	xsec/E	+dstat	-dstat	+dsyst	-dsyst
3	0	6	2.3	+ 0.09	- 0.09	+ 0	-
0.23	0	0	0.29	+ 0.08	- 0.08	+ 0	-
0.4	0	0	0.57	+ 0.1	- 0.1	+ 0	-
0.6	0	0	0.77	+ 0.1	- 0.1	+ 0	-
0.8	0	0	0.72	+ 0.14	- 0.14	+ 0	-
1	0	0	0.85	+ 0.12	- 0.12	+ 0	-
1.4	0	0	1.1	+ 0.28	- 0.28	+ 0	-
1.8	0	0	1	+ 0.21	- 0.21	+ 0	-
2.8	0	0	1.2	+ 0.33	- 0.33	+ 0	-
1.1	0	0	0.84	+ 0.066	- 0.066	+ 0	-
3.1	0.2	6	2.7	+ 0.093	- 0.093	+	
0.45	0.4	0.5	0.036	+ 0.019	- 0.019	+	
0.62	0.5	0.8	0.15	+ 0.033	- 0.033	+	
0.87	0.8	1	0.37	+ 0.069	- 0.069	+	
1.1	1	1	0.48	+ 0.094	- 0.094	+	
1.4	1	2	0.58	+ 0.13	0.13	+	
2	2	2	0.78	+ 0.16	- 0.16	+	
4.2	2	6	0.74	+ 0.66	- 0.66	+	
0.62	0.5	0.6	0.05	+ 0.02	- 0.02	+	
0.88	0.8	1	0.15	+ 0	- 0	+	
1.1	1	1	0.12	+ 0.05	- 0.05	+	
1.4	1	2	0.3	+ 0.1	- 0.1	+	
0.4	0.3	0.5	0.019	+ 0.006	- 0.006	+	
4.8	4	6	0.55	+ 0.15	- 0.15	+ 0	-
0.4	0.3	0.5	0.006	+ 0.004	- 0.004	+ 0	-
0.62	0.5	0.8	0.052	+ 0.012	- 0.012	+ 0	-
0.87	0.8	1	0.15	+ 0.025	- 0.025	+ 0	-

New, Open..., Close, Save, Save As..., Print..., Cut, Copy, Paste, Select All, Find..., Find Again, Goto...

0%

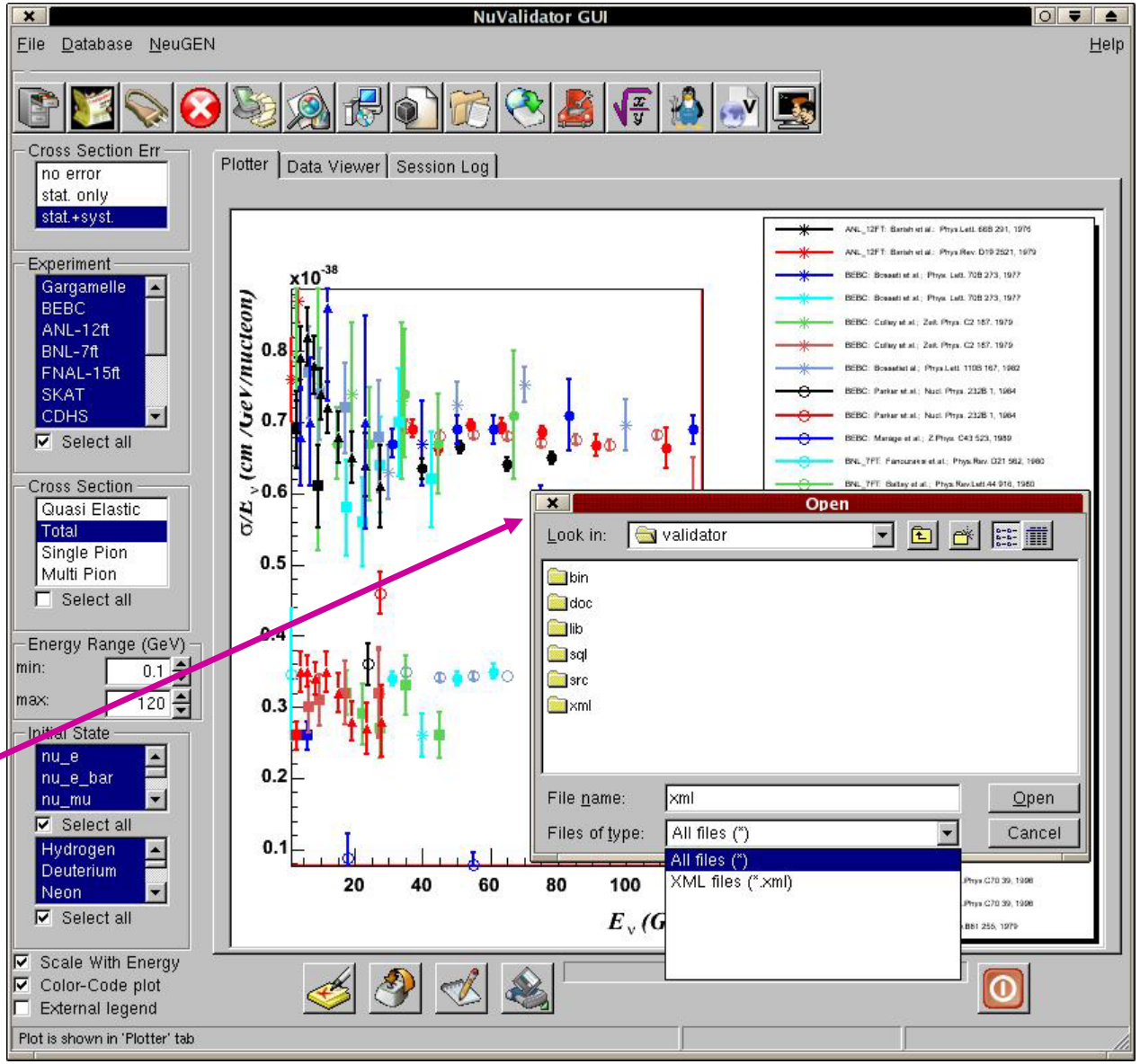
Connecting to dbase

Extending the DURHAM dbase (1/2):

Editing & Loading the XML cross sections file(s)

- *Edit the supplied XML file*
- *Add the data using some very simple and intuitive rules.*
- *In future, we could probably provide a way to enter new data via the GUI*

Open a File Dialog, find and select the updated XML file



Extending the DURHAM dbase (2/2):

Uploading XML data to the data base

If you never setup a local dbase before, click on *bootstrap dbase* first

Upload the XML data to the RDBMS

NuValidator GUI

File | Database | NeuGEN | Help

- Connect
- Disconnect
- Check connection
- Print dbase-info
- Bootstrap dbase
- UpLoad XML file to dbase
- Enter custom SQL query
- Enter custom SQL query <from file>
- Plot xsec data <from GUI options>
- Print xsec data <from GUI options>

Session Log

ANL-12ft
BNL-7ft
FNAL-15ft
SKAT
CDHS
Select all

Cross Section: Quasi Elastic, Total, Single Pion, Multi Pion, Select all

Energy Range (GeV) min: 0.1 max: 120

Initial State: nu_e, nu_e_bar, nu_mu, Select all

Hydrogen, Deuterium, Neon, Select all

Scale With Energy
Color-Code plot
External legend

σ (10^{-38} cm^2/nucle

E_ν (GeV)

0%

Plot is shown in 'Plotter' tab

Running NeuGEN (1/3):
Configuring Physics Input

NuValidator GUI

File Database NeuGEN Help

Cross Section Err: no error, stat. only, stat.+syst.

Experiment: Gargamelle, BEBC, ANL-12ft, BNL-7ft, FNAL-15ft, SKAT, CDHS — Select all

Cross Section: Quasi Elastic, Total, Single Pion, Multi Pion — Select all

Energy Range (GeV): min: 0.1, max: 120

Initial State: nu_e, nu_e_bar, nu_mu — Select all; Hydrogen, Deuterium, Neon — Select all

Scale With Energy; Color-Code plot; External legend

Plotter | Data Viewer | Session Log

σ/E_ν (10^{-38} cm^2/GeV/nucleon); E_ν (GeV)

NeuGEN Config Dialog

Axial Vector Mass: Quasi-Elastic (GeV): 1.01; Resonances (GeV): 0.95

Parton Density Functions: PDFLIB PDF Group: 1; PDFLIB PDF Set: 11

DIS / Renonance tuning

multiplicity	v-p	v-n	vbar-p	vbar-n
2	0.78	0.21	0.21	0.11
3	0.54	0.31	0.33	0.27

Use Input Values | Use Defaults | Restore Defaults | Cancel

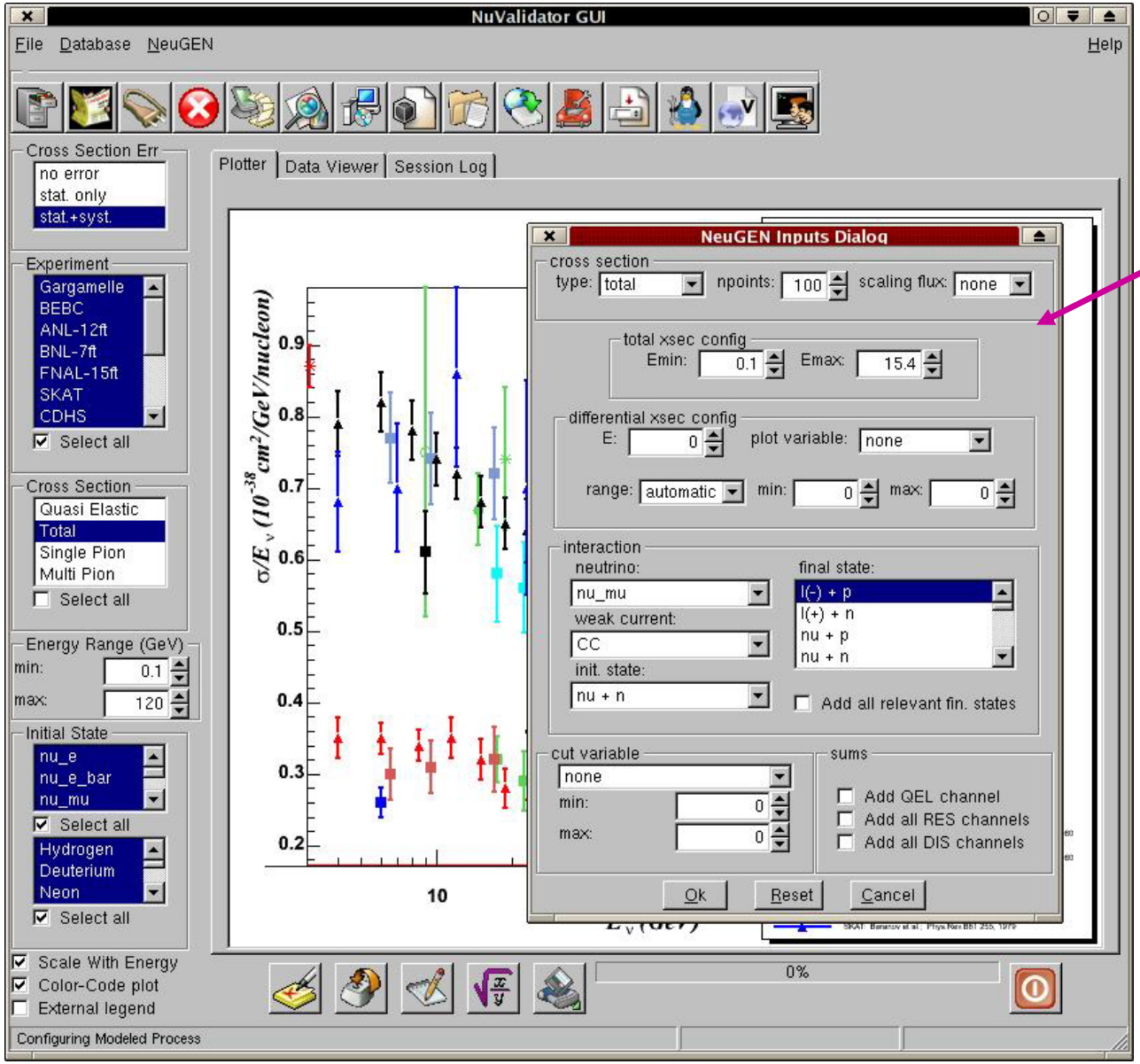
0%

Configuring NeuGEN Physics Input

NeuGEN Physics Input Configuration Dialog

Specifying:
Ma(QEL), Ma(RES), PDFs, DIS/RES tuning parameters

Running NeuGEN (2/3):
Configuring modelled process



Dialog for specifying what to get out of NeuGEN

Xsec type (total/differential), scaling flux, plot var. (q^2, W,…), energy range, neutrino type, weak current, initial state, final state, etc,…

Running NeuGEN (3/3):

Get model prediction to compare with data

Gargamelle, ANL-12FT & SKAT

QEL

nu_mu

NeuGEN prediction

NuValidator GUI

File Database NeuGEN Help

Cross Section Err: no error, stat. only, stat.+syst.

Experiment: Gargamelle, BEBC, ANL-12ft, BNL-7ft, FNAL-15ft, SKAT, CDHS, Select all

Cross Section: Quasi Elastic, Total, Single Pion, Multi Pion, Select all

Energy Range (GeV) min: 0.1 max: 120

Initial State: nu_e, nu_e_bar, nu_mu, Select all

Hydrogen, Deuterium, Neon, Select all

Scale With Energy, Color-Code plot, External legend

Plotter | Data Viewer | Session Log

σ/E_ν (10^{-38} cm^2/GeV/nucleon)

1.6, 1.4, 1.2, 1, 0.8, 0.6, 0.4, 0.2

1, 10

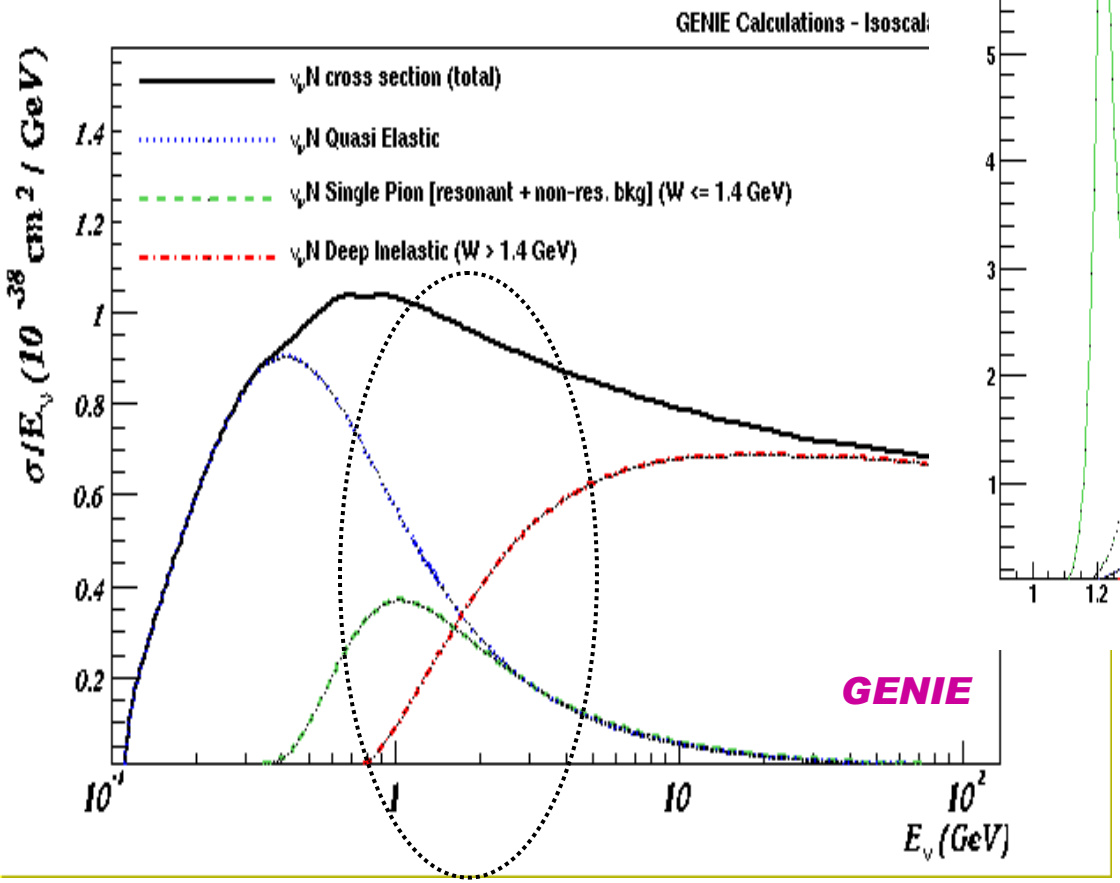
E_ν (GeV)

0%

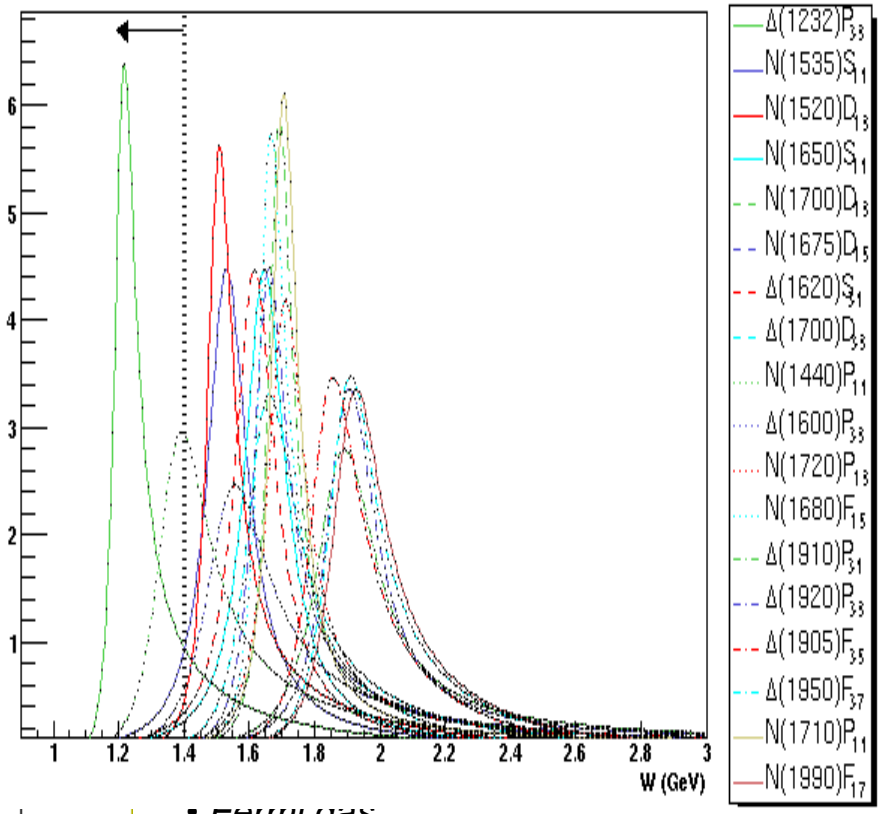
Running NeuGEN

Neutrino Interaction Models

Neutrino generators have more or less common phenomenological inputs



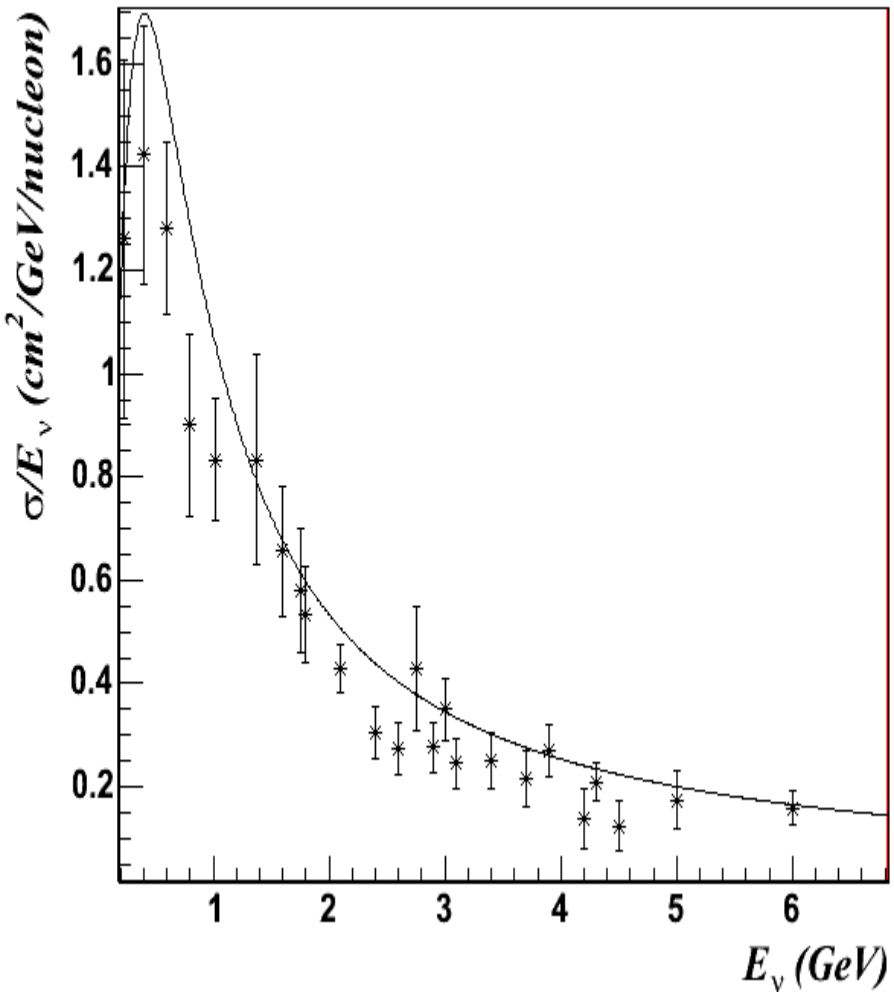
- ***QEL:*** *Llewellyn-Smith model*



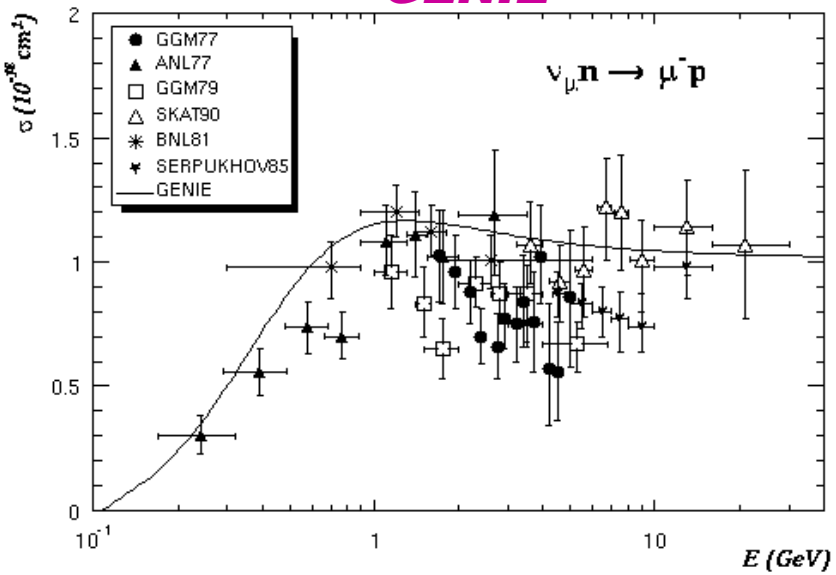
- *Fermi gas*
- *Pauli blocking*
- *Shadowing / Anti-shadowing / EMC*
- *Spectral functions*
- *Charge exchange*
- *Final State Interactions*

Quasi Elastic Neutrino Scattering Cross Sections

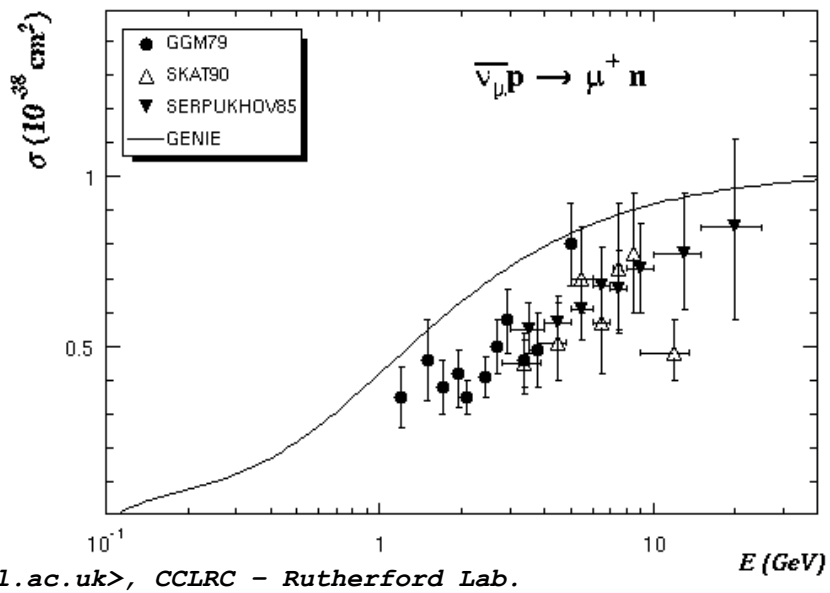
NeuGEN



GENIE

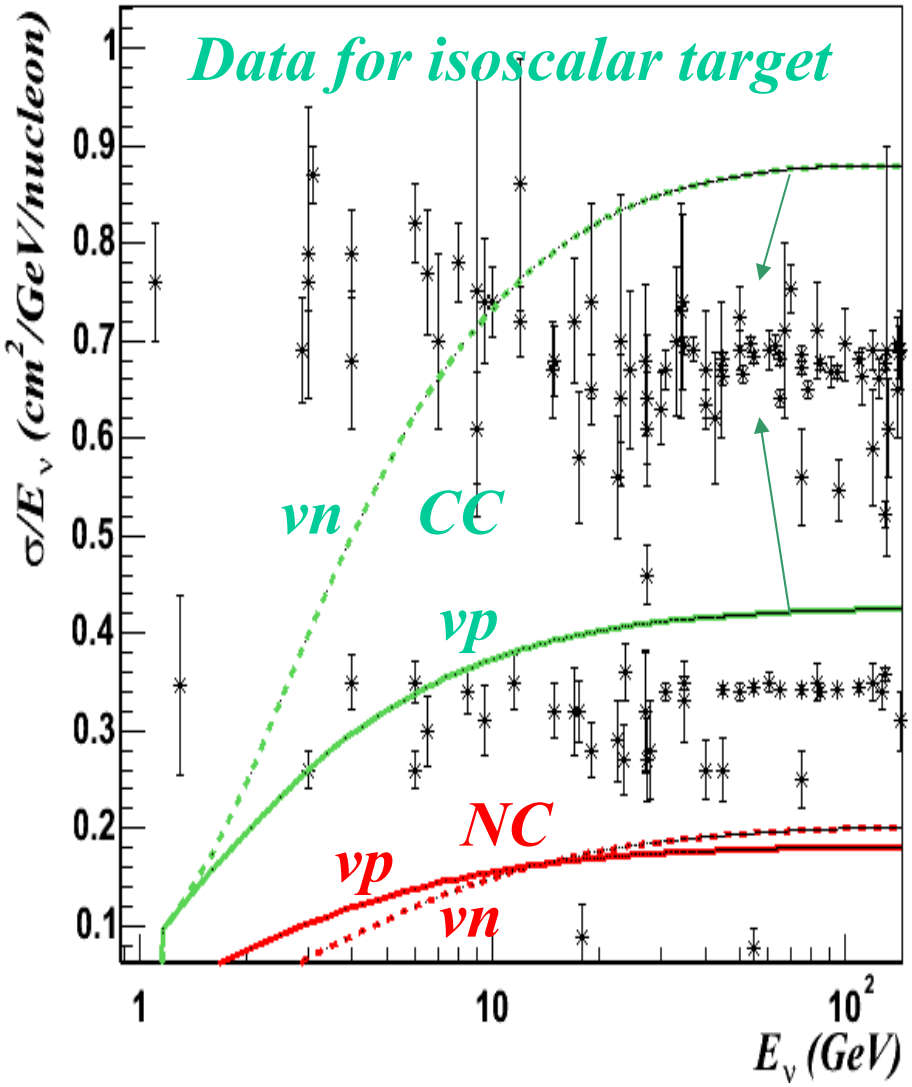


No nuclear effects included

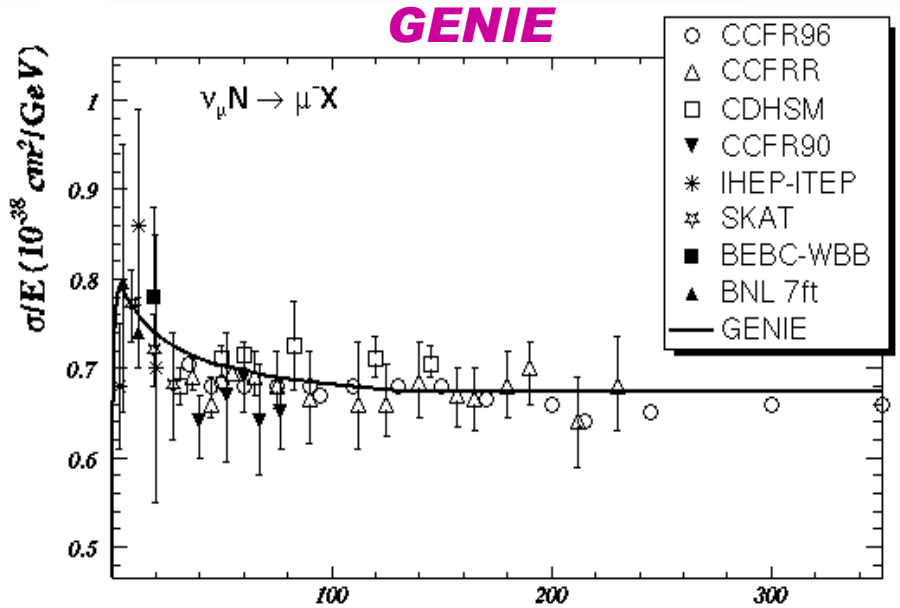


Deep Inelastic Neutrino Scattering Cross Sections

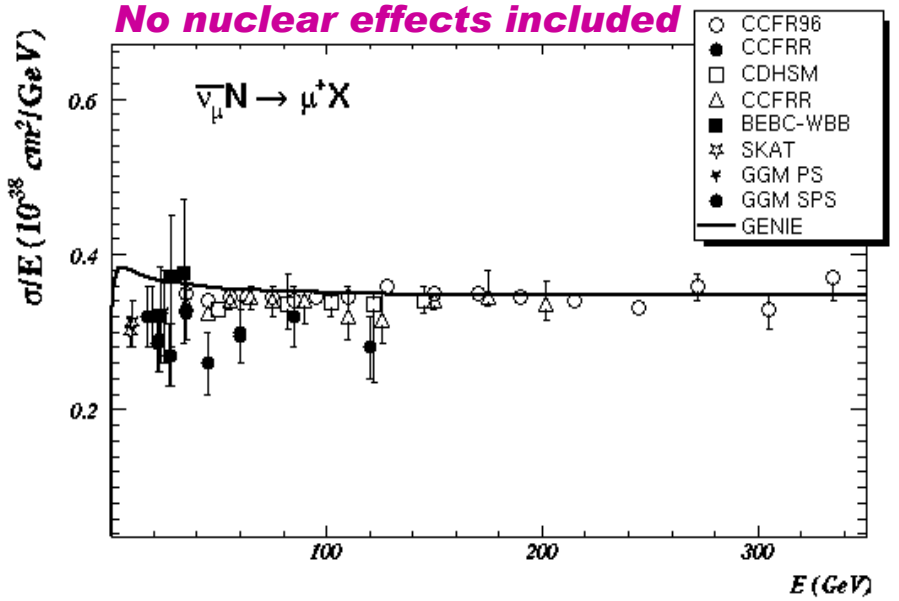
NeuGEN



GENIE



No nuclear effects included

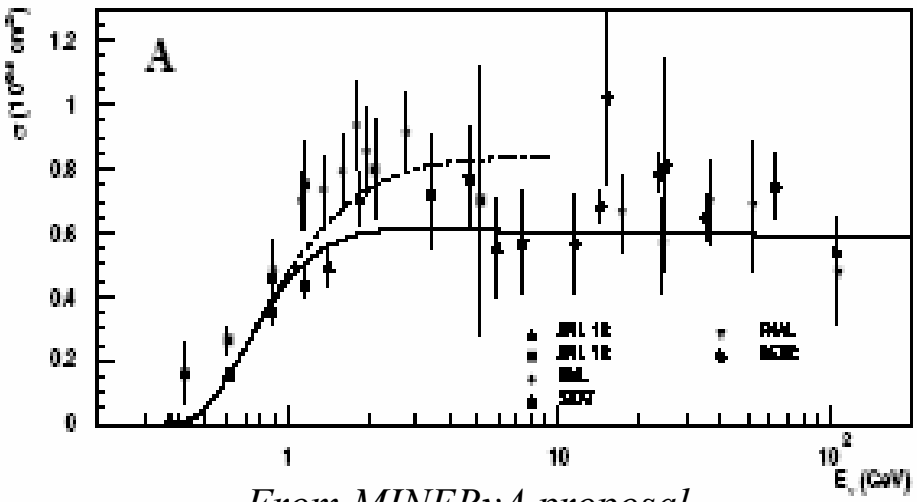


Neutrino Single Pion Production Cross Sections

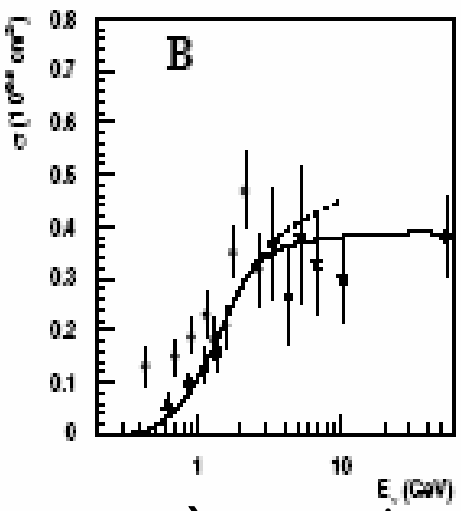
NeuGEN

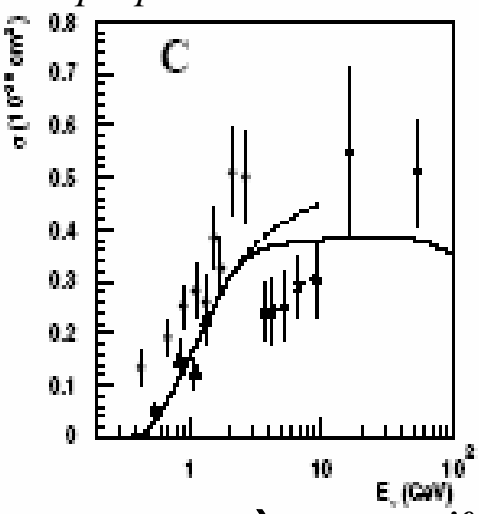
nu_mu+p → mu + p + pi+

Charged Current Single Pion Production



From MINERvA proposal

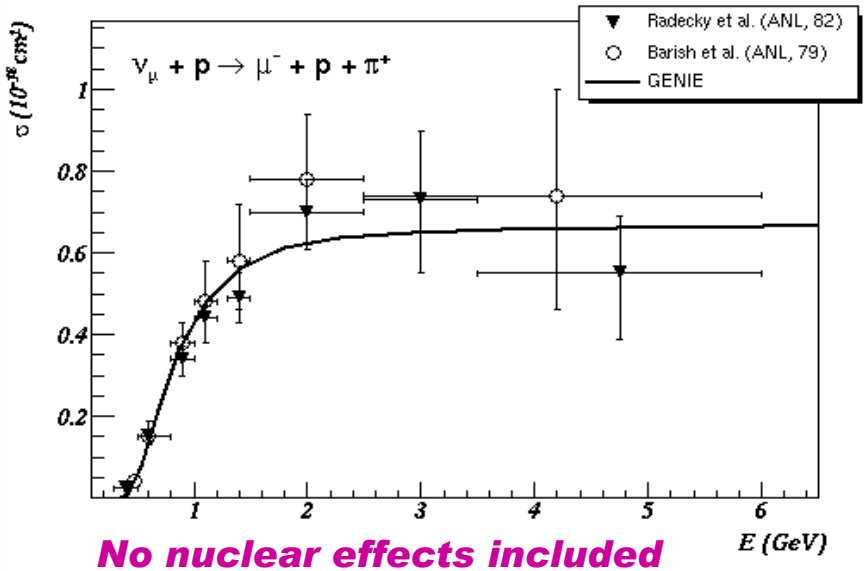




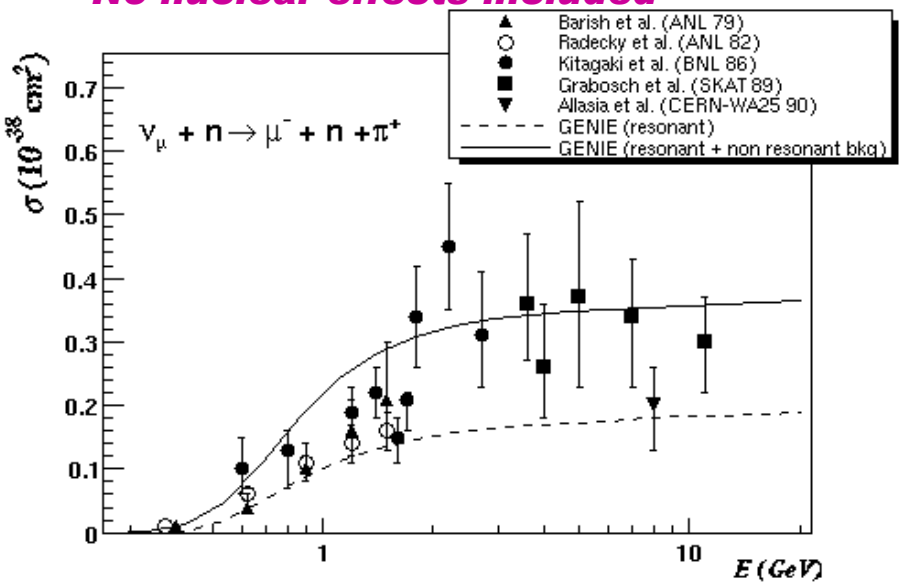
nu_mu+n → mu + n + pi+

nu_mu+n → mu + p + pi0

GENIE



No nuclear effects included



Additions to GENIE

- *New OO design*

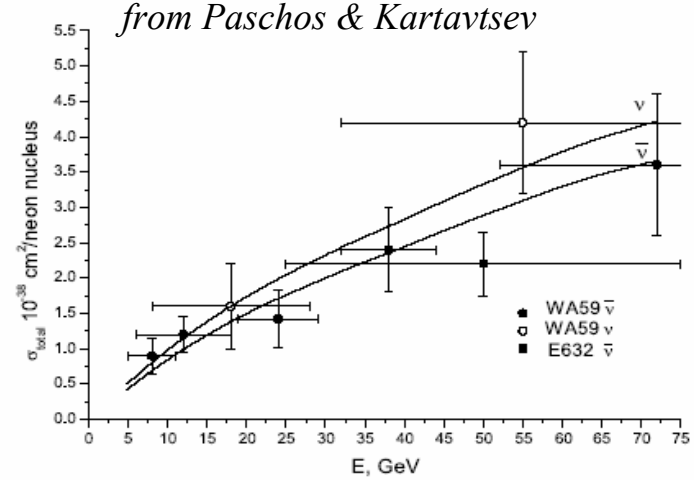
- *Old, debugged C++ GENIE code (QEL, SPP, DIS) is being translated to the new framework*

- *Short-term additions:*
  - *Coherent pi production (Paschos model)*
  - *Paschos model of resonance production*
  - *Resonance interference in Rein-Seghal model*
  - *Bodek-Yang model (PDFs at high x, low Q^2)*
  - *Fermi gas model*

- *Longer-term additions:*
  - *Shadowing / Anti-shadowing / EMC*
  - *Spectral functions*
  - *Charge exchange*
  - *Final State Interactions*

- *Developing plan to make any new calculation available to NeuGEN-3x*

Coherent vN scattering,
from Paschos & Kartavtsev



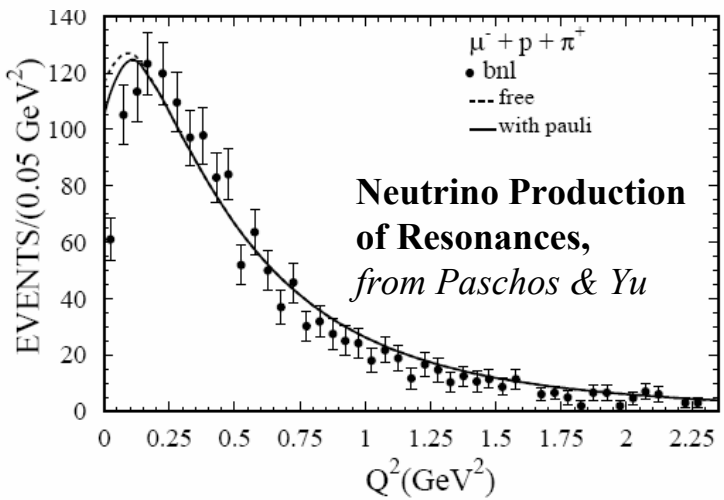


Figure 6: Q^2-spectrum of the process $\nu p \rightarrow \mu^- p \pi^+$.

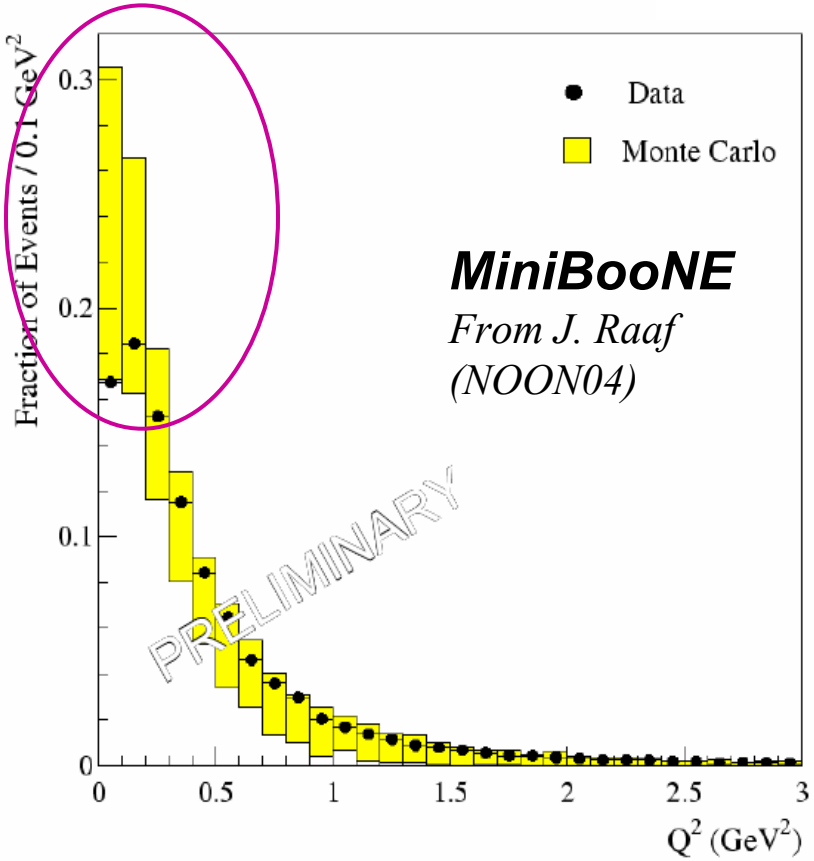
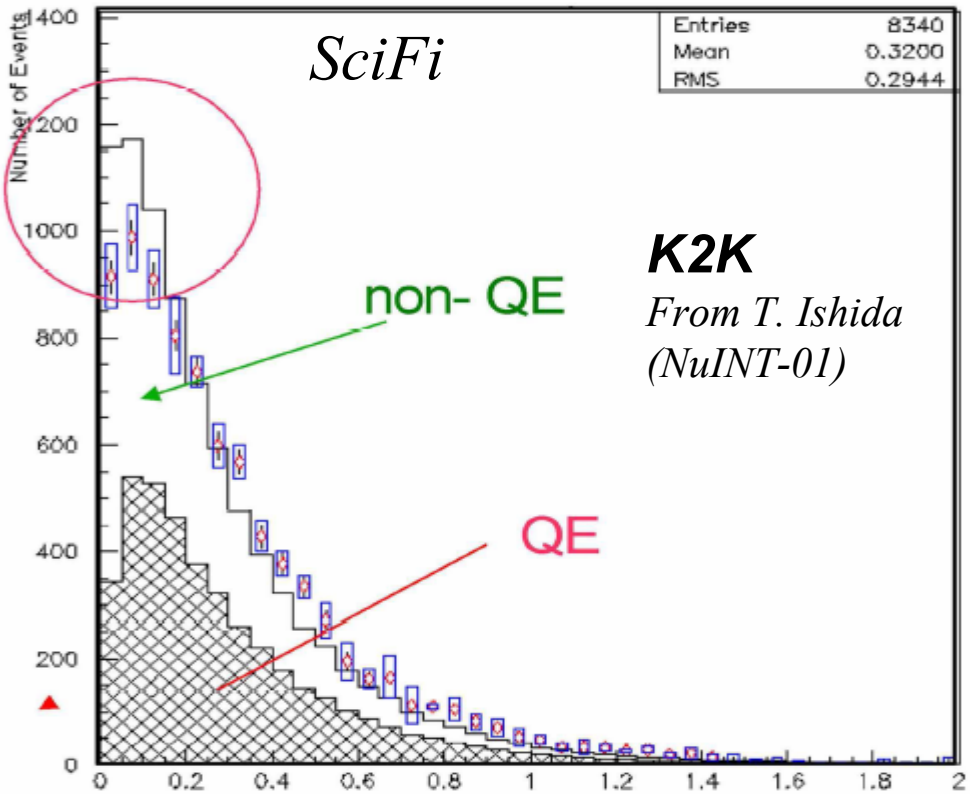
Future work

Work on NuValidator *(in collaboration with Hugh)*

- Adding support for running more neutrino generators *(NUANCE initially – talk with David Casper)*.
- Extending the existing v-N data-base *(discussion in progress with Mike Whalley / DURHAM)*
- Adding e-N scattering data to the data-base *(testing the 'vector' part of v interaction models)*
- Designing a general framework for implementing the 'analysis modules' & code them
- ***Start using/exploiting these tools & DURHAM dbase for various global quantitative studies***

Work on Neutrino Generator *(in collaboration with Hugh)*

- Resuming work on the Object-Oriented Neutrino Generator *(GENIE)*
- *Coding & Evaluating all different (clearly described) models for any given process*
- ***Immediate benefits*** *(model evaluation using NuValidator / calculations available to NeuGEN-3x)*
- ***Hopefully the full software product in place by NuINT-05*** *(in 18 months)*

Summary

- *Non-trivial / not well understood differences between data & neutrino monte carlos*
- *Need **measurements** + better theoretical understanding + extensive/detailed modelling & validation*
- *We (MINOS) will have all the tools in place to do our best in tuning our neutrino interaction model*