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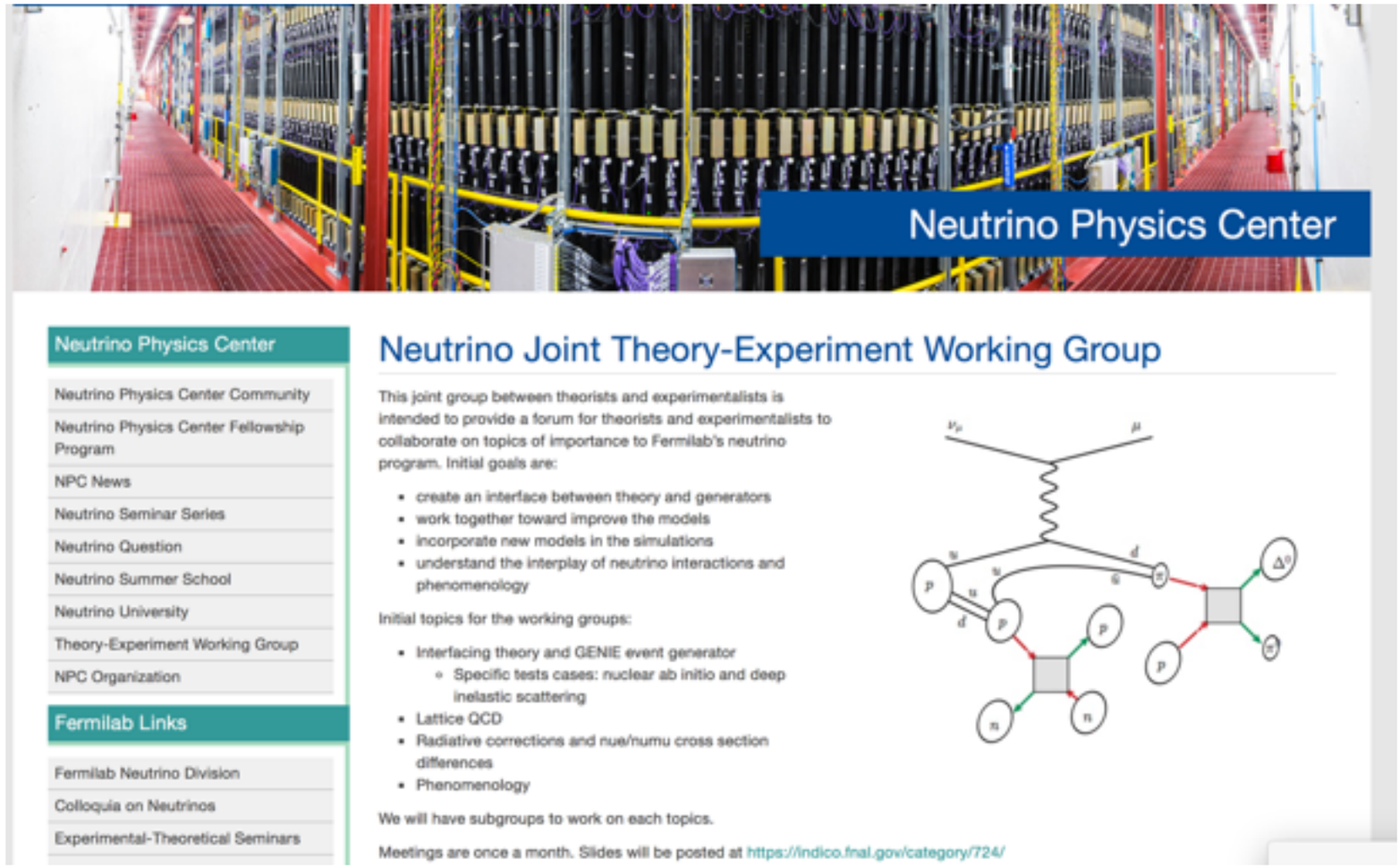
Joint Group Between Theorists and Experimentalists at Fermilab

Minerba, Adi and Walter, Fermilab

11 December 2018

Group Under the Neutrino Physics Center

- The joint group between theorists and experimentalists is part of the Neutrino Physics Center
- We encourage collaborators to apply the NPC Fellows and Intensity Frontier Fellow to get support for visits



Group started last year, Nov 2017

- We meet once a month to discuss progress and separate meetings to follow up with work

Topics

- We identified specific topics for the working groups and started to work
- Theorists inputs to GENIE:
  - Nuclear ab initio
  - DIS
  - Radiative corrections and nue/numu cross section differences
  - Lattice QCD
- Theory for experiment and Experiment for theory

Radiative Corrections Plans

- Radiative corrections and nue/numu cross section differences
  - Doreen, Adi, Daniel, Steve, Richard and Kevin are leading the effort for QE
    - More details at https://indico.fnal.gov/event/16766/session/0/material/0/0.pdf
  - Walter and Stefan are leading the effort for radiative corrections in DIS
    - More details at https://indico.fnal.gov/event/17207/session/0/material/0/0.pdf

T2K as an example

Error source	1-ring μ-like		1-ring e-like			
	ν-mode	$\bar{\nu}$-mode	ν-mode	$\bar{\nu}$-mode	ν-mode CC1π	$\nu_e/\bar{\nu}_e$
SK Detector	2.40	2.01	2.83	3.79	13.16	1.47
SK FSI+SI+PN	2.20	1.98	3.02	2.31	11.44	1.58
Flux + Xsec constrained	2.88	2.68	3.02	2.86	3.82	2.31
E_b	2.43	1.73	7.26	3.66	3.01	3.74
$\sigma(\nu_e)/\sigma(\nu_\mu)$	0	0	2.63	1.46	2.62	3.03
NC1γ	0	0	1.07	2.58	0.33	1.49
NC Other	0.25	0.25	0.14	0.33	0.99	0.18
Osc	0.03	0.03	3.86	3.60	3.77	0.79
All Systematics	4.91	4.28	8.81	7.03	18.32	5.87

Kendall, INT workshop

- Important systematic for DUNE measurements

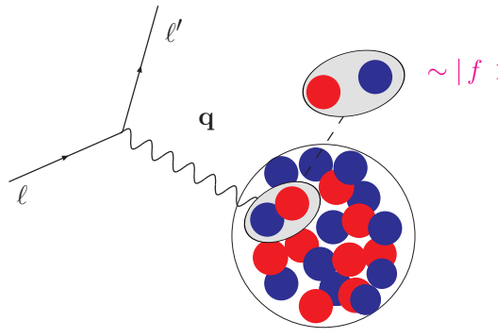
CCQE and Two-body Physics

Saori Pastori

- Saori Pastori, Joe Carlson are developing the short time approximation that allows for evaluation of xsec in A 40 comprehensive of two-body physics i. e. two body correlations and associated currents

In STA:

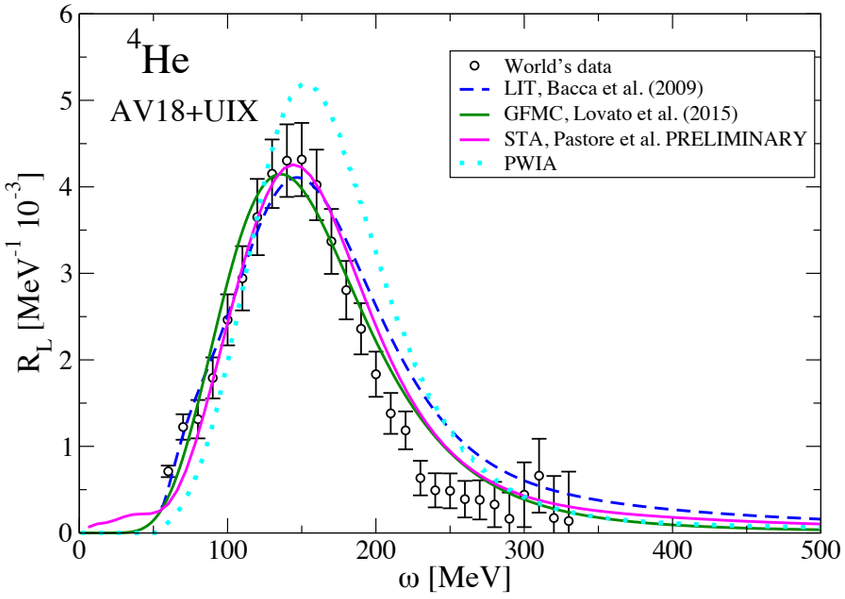
Response functions are given by the scattering off pairs of fully interacting nucleons that propagate into a correlated pair of nucleons



$$R_\alpha(q,\omega) \quad = \quad \sum_f \delta\left(\omega + E_0 - E_f\right) \langle\, 0|O_\alpha^\dagger(\mathbf{q})|f\rangle\langle f|O_\alpha(\mathbf{q})|0\rangle$$

$$O_\alpha(\mathbf{q}) \quad = \quad O_\alpha^{(1)}(\mathbf{q}) + O_\alpha^{(2)}(\mathbf{q}) = \text{1b} + \text{2b}$$

$$|f\rangle \quad \sim \quad |\psi_{p,P,J,M,L,S,T,M_T}(r,R)\rangle = \text{correlated two} - \text{nucleon w.f.}$$



Longitudinal Response function at $q = 500$ MeV

* We retain two-body physics consistently in the nuclear interactions and electroweak currents

* $R_\alpha(q,\omega)$ requires only direct calculation of g.s. $|0\rangle$ w.f.'s *

* STA can be implemented to accommodate for more two-body physics, *e.g.*, pion-production induced by e and ν

- Saori Pastori, Josh Barrow, et al. working on the GENIE implementation

https://indico.fnal.gov/event/18545/session/1/material/0/2.pdf

Spectral Function

Noemi Rocco

- Noemi Rocco, Steven Gardiner et al. working with the spectral function implementation

https://indico.fnal.gov/event/18545/session/1/material/0/0.pdf

Theoretical framework: IA + realistic SF

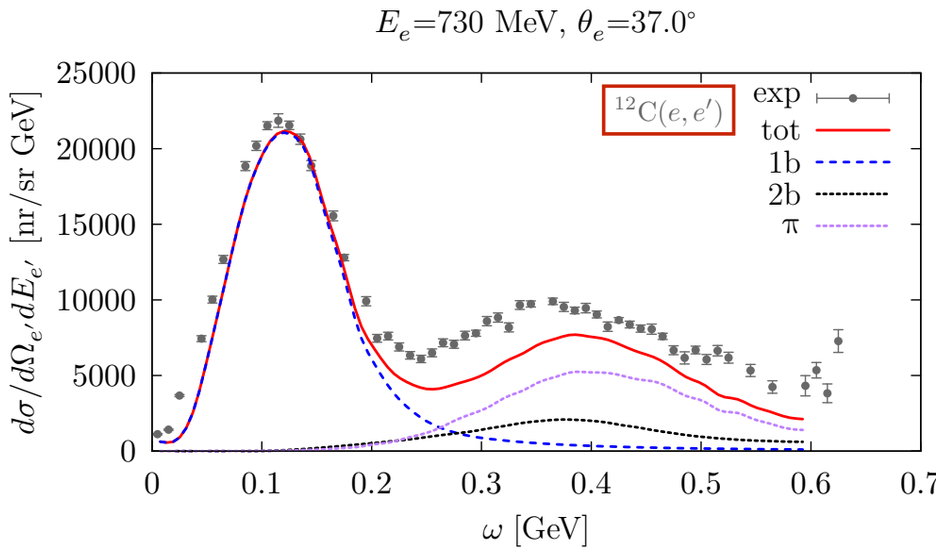
- For sufficiently large values of |**q**|, the IA can be applied under the assumptions

$$|f\rangle \longrightarrow |p\rangle \otimes |f\rangle_{A-1}$$

$$J_\alpha = \sum_i j^i_\alpha$$

$$d\sigma_A = \int dE\, d^3k d\sigma_N P(\mathbf{k}, E) \rightarrow \frac{1}{\pi}\mathrm{Im}\, G(\mathbf{k}, E)$$

- The intrinsic properties of the nucleus are described by the hole spectral function

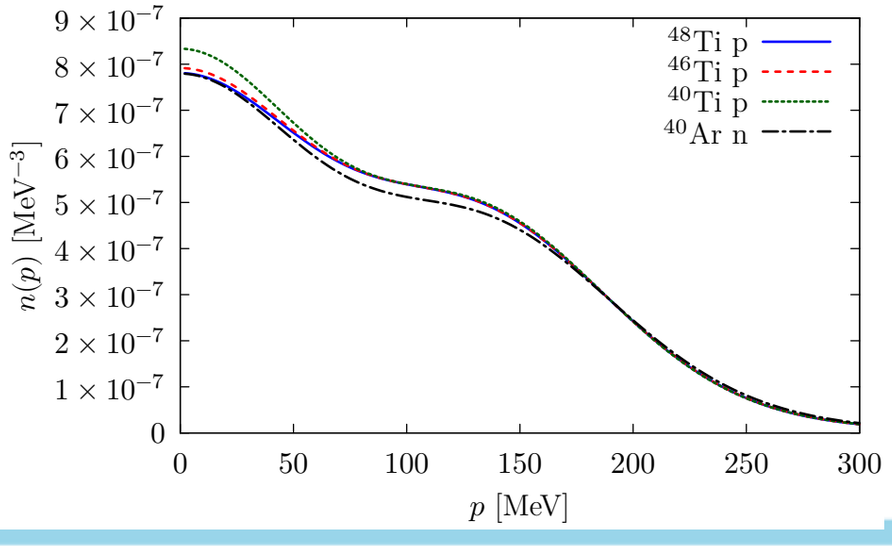


- The SCGF is an ab-initio method allowing to accurately determine the one-body Green's function by solving the Dyson equation

$$G_{\alpha\beta}(E) = G^0_{\alpha\beta}(E) + \sum_{\gamma\delta} G^0_{\alpha\gamma}\Sigma^*_{\gamma\delta}(E) G_{\delta\beta}(E)$$

initial reference state — Self energy

- Single n(p)-momentum distribution of ^{40}Ar (Ti)



- Account for resonance excitations and subsequent π production using the Sato-Lee model

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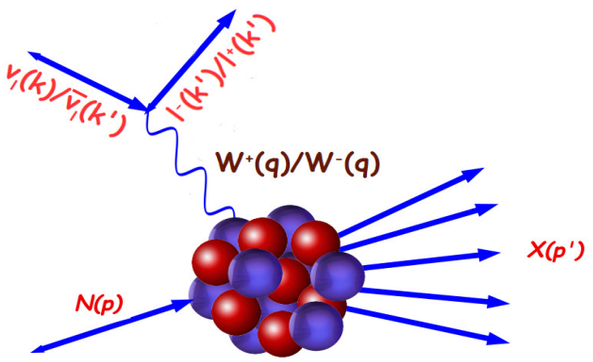
Deep Inelastic Scattering plans

Huma Haider

- Deep inelastic scattering:
  - In GENIE, DIS is calculated in an effective leading order model using the modification prescribed by Bodek and Yang
  - No A(mass number) scaling at all in GENIE
  - Use GRV98 LO parton distributions
- Nuclear medium effects are not the same for the electromagnetic and weak interactions
- Huma's group has a model in which the nuclear structure functions are calculated using dynamical origin of Nuclear Medium Effect are A dependent
- Huma is leading the effort
  - The model is written in Fortran, Huma is converting it to C++

- More details at:

https://indico.fnal.gov/event/17049/session/0/material/0/0.pdf



Hadronization in GENIE: Upgradeding to Pythia 8

- Teppei and Shivesh are leading the effort

Shivesh Mandalia

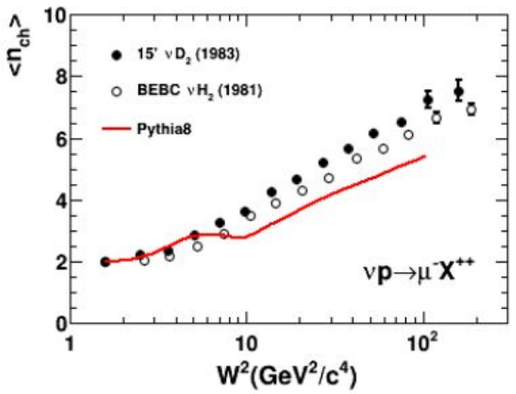
Katori, Lasorak, Mandalia, Terri, JPS Conf.Proc. 12 (2016) 010033

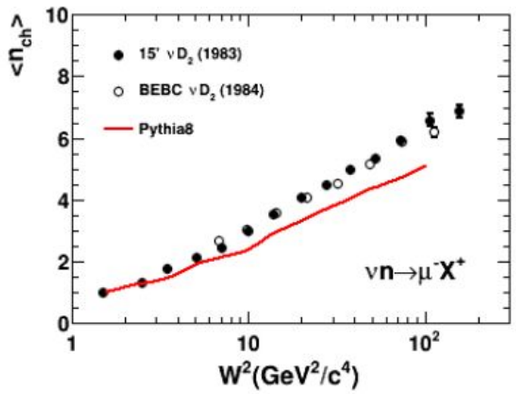
S. Mandalia
2018-11-14

First attempt at Pythia 8 implementation

PYTHIA8 Implementation Results!

PYTHIA v8186



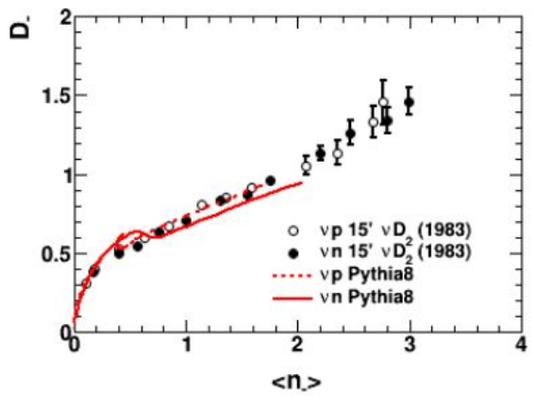


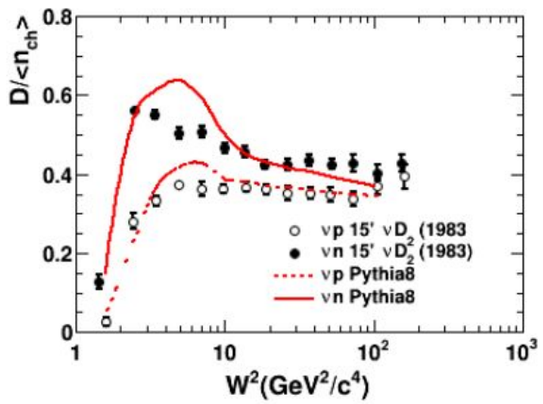
Splines generated using

- ν_μ and $\overline{\nu_\mu}$
- Target = proton and neutrons
- Max energy = 80 GeV
- Knots = 500
- HadronizationTest event generator list

Event generated using

- ν_μ and $\overline{\nu_\mu}$
- Target = proton and neutrons
- Events = 100,000
- Energy = 0.5 - 80 GeV
- HadronizationTest event generator list





More plots available at https://goo.gl/pbAmOy

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https://indico.fnal.gov/event/19092/session/1/material/0/0.pdf

Other Topics

- Lattice QCD is calculating the axial form factor
  - Andreas is leading the effort
  - More details at https://indico.fnal.gov/event/18130/session/0/material/0/0.pdf
- Interfacing theory and GENIE generator
  - Stefan, Walter, Gabe, MB, et al. started discussions about making an interface in GENIE to allow rapid model implementation
- Phenomenology, Pedro is leading the effort

Phenomenology Effort

Adi and Steve

Fermilab theorist can benefit from common experimental knowledge.

The first goal we have set was learning how to use GENIE event generator, to estimate the standard model background for new physics model, and simulate some of the models.

Adi and Steve

Phenomenology Effort

We've initiated a survey among Fermilab theorist and identified several types of models they would like to simulate:

- New Nuclear Models
- Models including new particles and their interactions:
  - Simplified models of new/Dark particles, demanding simulation
  - New particles effectively changing incoming neutrino flux
  - New particles effectively changing coupling constants

Adi and Steve

GENIE for Theorists effort

We've initiated an ongoing workshop including 3 tutorial sessions give by GENIE author, Steve Dytman.
GENIE was installed on the public theory machine and all theorists have been given access to it.

During the tutorial theorists have learnt to

- Run GNEIE and use ROOT to read its output
- Calculate total and differential cross sections of lepton-nuclei SM
- Generate events accordingly with various incoming fluxes.

We'll consider a follow-up session or other efforts depending on the success of this event.