Summary of the NuSTEC Workshop on Neutrino-Nucleus Pion Production in the Resonance Region

Jonathan Paley

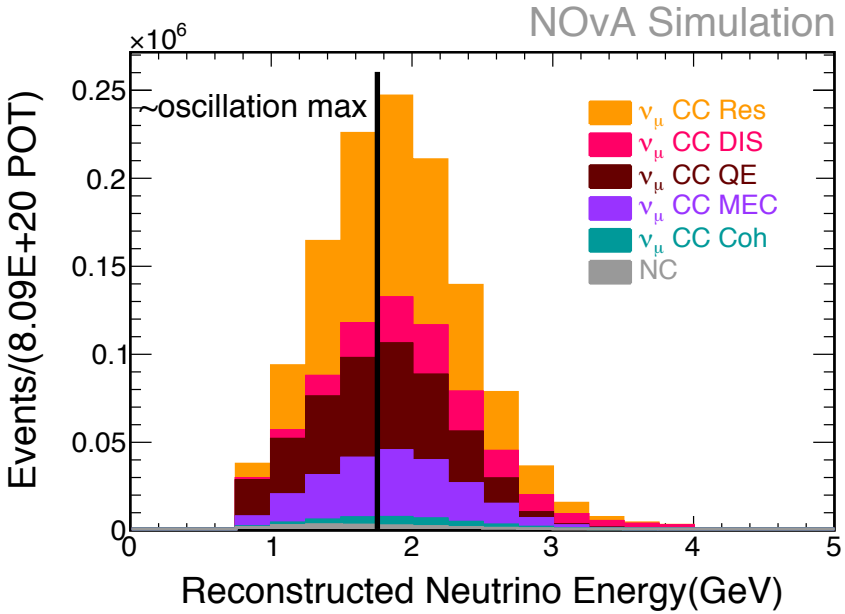
NuSTEC Board Meeting

December 10, 2019

Fermilab

How this workshop got started…

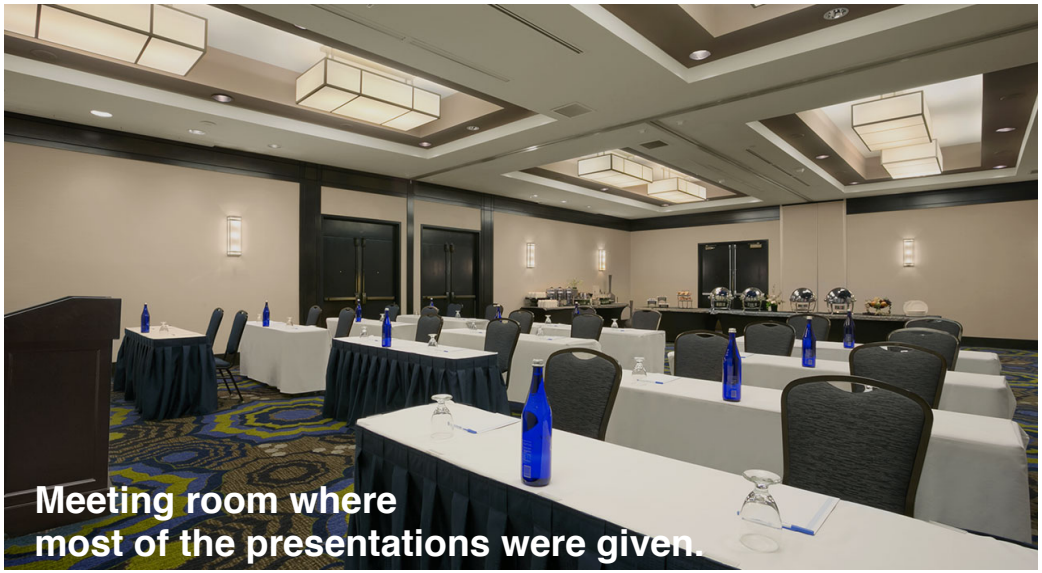
- During the NuSTEC Workshop on Shallow- and Deep-Inelastic Scattering at GSSI, I mentioned to Jorge that the workshop was excellent and very interesting, but what I worry most about is how well we are modeling the resonance region.



- And so he told me I should organize a workshop on the topic…
- Many thanks to **Jorge M., Steve D.**, Dan C., Natalie J., Jan S., Teppei K., and Sato-san

Workshop details

- Workshop was held at Wyndham Pittsburgh University Hotel, just down the street from the UPitt Physics Department.
- Thanks to PittPACC sponsorship, we were able to keep the cost to attend very minimal. Breakfast, coffee breaks and a very nice workshop dinner were included. Critical travel support enabled important speakers and some early-career physicists to attend.



Workshop details

Wed 02/10 | Thu 03/10 | Fri 04/10 | Sat 05/10 | All days

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Wed 02/10

08:00	**Registration**	University of Pittsburgh	08:00 - 09:00
09:00	**Introduction to Res and Non-res Theory and Models** — *Steven DYTMAN*	University of Pittsburgh	09:00 - 09:50
10:00	**What We've Learned from e-A and pi-A Measurements (Jerry Miller)**	University of Pittsburgh	09:50 - 10:40
	Discussion: Discussion	University of Pittsburgh	10:40 - 11:00
11:00	**Coffee Break**	University of Pittsburgh	11:00 - 11:30
	Impact of Res+ modeling to the sub-GeV global neutrino oscillation program — *Jaroslaw NOWAK*	University of Pittsburgh	11:30 - 12:30
12:00			
13:00	**Lunch** — **Day 1**	University of Pittsburgh	12:30 - 14:00
14:00	**Impact of Res+ modeling to the GeV global neutrino oscillation program** — *Gregory PAWLOSKI*	University of Pittsburgh	14:00 - 15:00
15:00	**Impact of Res+ modeling to the global neutrino-nucleus scattering measurement program** — *Clarence WRET*	University of Pittsburgh	15:00 - 16:00
16:00	**Coffee Break: Coffee Break**	University of Pittsburgh	16:00 - 16:30
	Discussion	University of Pittsburgh	16:30 - 17:30
17:00			

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Thu 03/10

09:00	**B-S and R-S models**	University of Pittsburgh	09:00 - 09:40
10:00	**The MK Model** — *Dr. Minoo KABIRNEZHAD*	University of Pittsburgh	09:40 - 10:20
	Ghent model — *Dr. Natalie JACHOWICZ*	University of Pittsburgh	10:20 - 11:00
11:00	**Coffee Break: Coffee Break**	University of Pittsburgh	11:00 - 11:30
	Valencia model — *Dr. Juan NIEVES*	University of Pittsburgh	11:30 - 12:10
12:00	**DCC (coupled-channels) models** — *Dr. Toru SATO*	University of Pittsburgh	12:10 - 12:50
13:00	**Lunch: Lunch** — **Day 2**	University of Pittsburgh	12:50 - 14:20
14:00	**Discussion: Discussion**	University of Pittsburgh	14:20 - 15:20
15:00	**Coffee Break: Coffee Break**	University of Pittsburgh	15:20 - 15:50
	Duality in neutrino scattering — *Jorge MORFIN*	University of Pittsburgh	15:50 - 16:20
16:00	**General Issues with Implementation of Theory Models** — *Mr. Alexis NIKOLAKOPOULOS*	University of Pittsburgh	16:20 - 17:00
17:00	**Discussion: Challenges with existing models, outlook**	University of Pittsburgh	17:00 - 18:00
18:00			
19:00	**Workshop Dinner**		

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Fri 04/10

09:00	**GiBUU implementation and uncertainties, outlook** — *Prof. Ulrich MOSEL*	University of Pittsburgh	09:00 - 09:40
10:00	**GENIE implementation and uncertainties, outlook** — *Adi ASHKENAZI*	University of Pittsburgh	09:40 - 10:20
	Coffee Break: Coffee Break	University of Pittsburgh	10:20 - 10:50
11:00	**NEUT implementation and uncertainties, outlook** — *Christophe BRONNER*	University of Pittsburgh	10:50 - 11:30
	NuWro implementation and uncertainties, outlook — *Mr. Kajetan NIEWCZAS*	University of Pittsburgh	11:30 - 12:10
12:00	**Lunch: Lunch** — **Day 3**	University of Pittsburgh	12:10 - 14:00
13:00			
14:00	**e-A Scattering Measurements and e4nu** — *Lawrence WEINSTEIN*	University of Pittsburgh	14:00 - 14:40
15:00	**Other relevant pion scattering measurements (LArIAT, DUET, etc.)** — *Jake CALCUTT*	University of Pittsburgh	14:40 - 15:20
	Coffee Break: Coffee Break	University of Pittsburgh	15:20 - 16:00
16:00	**Discussion: Generator experts: challenges with existing models, outlook**	University of Pittsburgh	
17:00			

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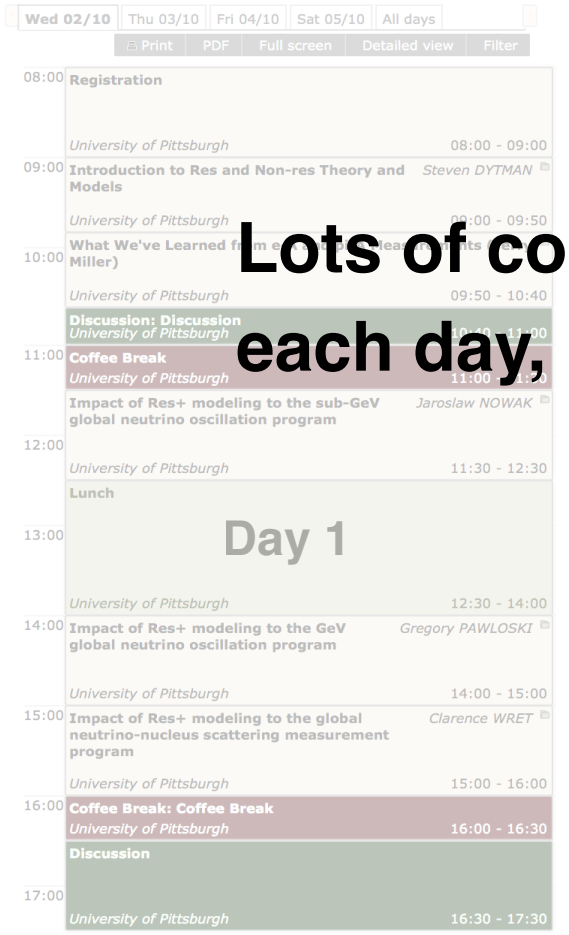
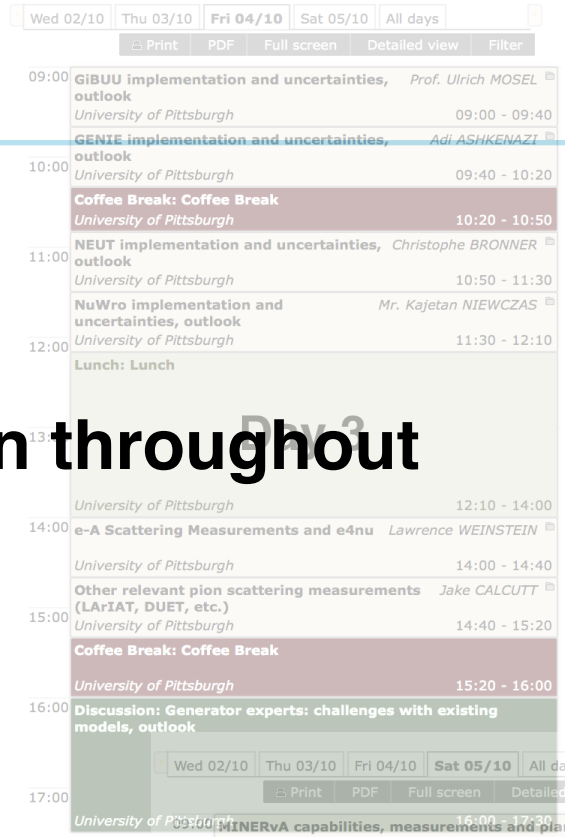
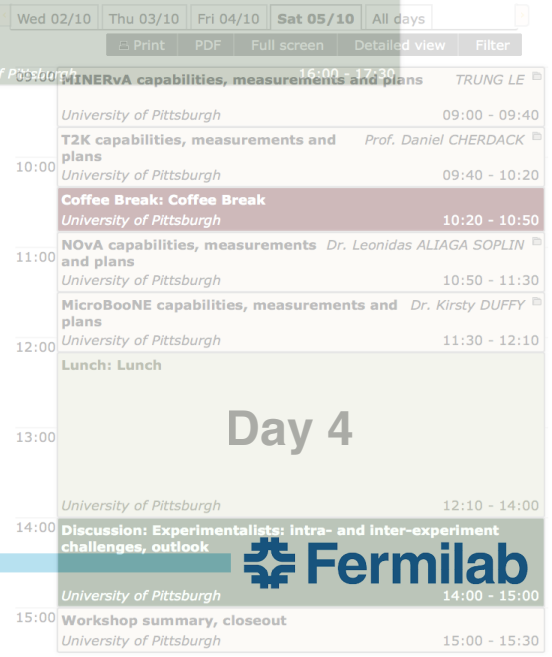
Sat 05/10

09:00	**MINERvA capabilities, measurements and plans** — *TRUNG LE*	University of Pittsburgh	09:00 - 09:40
10:00	**T2K capabilities, measurements and plans** — *Prof. Daniel CHERDACK*	University of Pittsburgh	09:40 - 10:20
	Coffee Break: Coffee Break	University of Pittsburgh	10:20 - 10:50
11:00	**NOvA capabilities, measurements and plans** — *Dr. Leonidas ALIAGA SOPLIN*	University of Pittsburgh	10:50 - 11:30
	MicroBooNE capabilities, measurements and plans — *Dr. Kirsty DUFFY*	University of Pittsburgh	11:30 - 12:10
12:00	**Lunch: Lunch** — **Day 4**	University of Pittsburgh	12:10 - 14:00
13:00			
14:00	**Discussion: Experimentalists: intra- and inter-experiment challenges, outlook**	University of Pittsburgh	14:00 - 15:00
15:00	**Workshop summary, closeout**	University of Pittsburgh	15:00 - 15:30

Workshop details







Lots of continued discussion throughout each day, including meals!

Day 1 - Intro & Impact of Res+ modeling to the Global Neutrino Program

- Introduction to Res and Non-res Theory and Models - Steve Dytman
- What We've Learned from e-A and pi-A Measurements - Jerry Miller
- Impact of Res+ modeling to the sub-GeV global neutrino oscillation program - Jarek Nowak
- Impact of Res+ modeling to the GeV global neutrino oscillation program - Greg Pawloski
- ~~Impact of Res+ modeling to the sub-GeV global neutrino-nucleus scattering measurement program~~ → Impact of Neutrino-Nucleus Scattering Measurements on Resonance Modeling (focused on recent results) - Clarence Wret

- Some key points:
  - Resonance modeling is particularly important for NOvA & DUNE, where large fraction of oscillated signal falls in the energy range where resonance “turns on”.
  - Interference between resonance and non-resonance pion production could be important
  - Very nice pion scattering data make it clear that FSI is quite important, and that effects don’t necessarily scale as $A^{2/3}$
  - Current 3-flavor measurements are not limited by conservative uncertainties on Res models; impact on DUNE note clear (to me at least).

Day 2 - Models, Models and more Models

- B-S and R-S models - Konstantin Kuzmin
- The MK Model - Minoo Kabirnezhad
- The Ghent Model - Natalie Jachowicz
- The Valencia Model - Juan Nieves
- DCC (coupled-channels) models - Toru Sato
- Duality in Neutrino Scattering - Jorge Morfin
- General Issues with Implementation of Theory Models - Alexis Nikolakopoulos

- Some key points:
  - Interference between resonances is a work-in-progress
  - A lot of good models presented, each with pros and cons.
  - Need to get these into generators!

Day 3 - Generators, e4nu and more π scattering measurements

- GiBUU implementation and uncertainties, outlook - Ulrich Mosel
- GENIE implementation and uncertainties, outlook - Adi Ashkenazi
- NEUT implementation and uncertainties, outlook - Christophe Bronner
- NuWro implementation and uncertainties, outlook - Kajetan Niewczas
- e-A Scattering Measurements and e4nu - Larry Weinstein
- Pion Scattering Measurements - Jake Calcutt

- Some key points:
  - Lots of work going on to try to include interference of resonances, eg MK and DCC models into NEUT
  - tuning generators to electron scattering data is a crucial first step, still have a way to go
  - pion scattering data is important for FSI and properly accounting for secondary interactions in our detectors; new data will hopefully come out soon (eg, Ar)

Day 4 - Current Experiment Capabilities, Measurements and Plans

- MINERvA - Trung Le
- T2K - Dan Cherdack
- NOvA - Leo Aliaga
- MicroBooNE - Kirsty Duffy

- Some key points:
  - MINERvA has measured four pion production channels on CH for both nu and nu-bar.
    - muon kinematics probe shape and and rate predictions, error bars seem too large to me to really use this to distinguish between models
    - pion kinematics probe details of FSI models, error bars seem good enough to begin distinguishing between some simple models
  - T2K has large number of relevant results. ~Same story regarding uncertainties.
  - NOvA and MicroBooNE are poised to make impactful measurements (high stats, reasonable shape uncertainties)
  - All experiments have many more measurements “in the works”

My Take

- “Pions are hard” - theory perspective
  - the models that we’ve been using for our predictions for neutrino oscillation experiments are clearly out-dated
  - many other models out on the market, but it is very non-trivial to get them into our mainstream generators.
  - most models do well in some kinematic ranges, but fail [miserably] elsewhere.
  - can/should we consider “Franken-models”?
- “Pions are hard” - experimentalist’s perspective
  - identifying charged pions in data is highly non-trivial
    - can sometimes look like muons
    - can undergo significant scattering, making reconstruction and identification challenging
  - what is actually reported? Need clear definitions of “signal”, need to avoid model bias
  - systematic uncertainties can be quite large; detector response, calibration and flux need better control

Summary/Conclusion

- In general I think the meeting format was well received by attendees.
  - Intentionally left lots of time for discussion.
  - Still managed to keep the workshop to under 4 days.
- Some things could be improved:
  - Official note-takers
  - Forgot to take group photo! (at least not on my camera…)
- Summary paper is in the works
  - Annotations to slides/presentation. Hoping to have this wrapped up by the end of next month
  - Summarizing all of the discussion is challenging; I will need the help of many of you who attended.

Summary of the NuSTEC Workshop on Neutrino-Nucleus Pion Production in the Resonance Region

L. Aliaga,[1] A. Ashkenazi,[2] C. Bronner,[3] J. Calcutt,[2] D. Cherdack,[2] K. Duffy,[1] S. Dytman,[4] N. Jachowicz,[5] M. Kabirnezhad,[6] K. Kuzmin,[7] G. A. Miller,[8] T. Le,[9] J. Morfin,[1] U. Mosel,[10] J. Nieves,[11] K. Niewczas,[2] A. Nikolakopoulos,[5] J. Nowak,[12] J. Paley,[1] G. Pawloski,[2] T. Sato,[13] L. Weinstein,[2] and C. Wret[14]

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