#### Review of RES/DIS overlap

Steve Dytman, Univ. of Pittsburgh Jorge Morfin, FNAL NuSTEC meeting 11 December, 2019

- NuSTEC DIS wkshp at Laquila (Fall, 2018)
- NuSTEC RES wkshp at Pittsburgh (Fall, 2019)
- All agree transition region is important
- Generators use simplified versions of theory
- Interesting NuSTEC project?

#### Overview

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#### More data for electron scattering than for neutrinos

- Especially true for nucleon targets!
- Studies of RES largely confined to  $P_{33}(1232)$  so far
- NOvA, MINERvA have new data for higher  $E_{v}$
- DUNE will need improved understanding
- This will involve both theory and experiment, NusTec can make important contributions



# Definitions (plot from MJA & JM review)

- DIS typically means interaction with quarks
- RES means interaction with quarks or nucleons->excited states
- Non-RES means (to me) pion production from nucleons
- DIS models have been extended to πN threshold (Bodek-Yang)
- SIS is the transition region between RES and DIS – low Q<sup>2</sup> and low W
- Soft DIS is low Q<sup>2</sup> and high W



# What we have – GENIE use 5 GeV $\nu_{\mu}$ C (G18\_02a) as an example

- Get RES from Berger-Sehgal
- Get DIS from Bodek-Yang/Pythia, hadronization from AGKY/Pythia
- Non-RES is BY extension to threshold (overall factor)
- Semi-arbitrary hard cutoff at W=1.95 GeV (fit to vN)



# What we have - GENIE, NuWro, NEUT

 Figure from Christophe Bronner shows significant disagreement. Note, there is no data because this is nuclear target.



## RES as we know it

- All based on *electron scattering (modern)* and *Rein-Sehgal 1981*
- PDG summary table on left, GENIE for v on right (lots of info!)
- Can v validate anything here? (need high statistics D expt.)



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# Deep Inelastic (DIS) properties

- Average over resonances, lose the structure (smearing in Fe)
- Need neutrino PDFs and hadronization, moderately wellknown
- Subject of NusTec workshop last fall
- Very active discussions with the emphasis on understanding existing data and anticipating needs
- Applicability of duality in describing W<2 GeV emphasized</li>





### Where RES works best - the Delta

- Strong state discovered long ago (Fermi?)
- Often hard to describe in DIS models
- >99% decay to  $1\pi$  easy for nucleon based modeling
  - Non-RES diagrams calculated long ago

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- Shape is Breit-Wigner with threshold effect
- Many (e,e' $\pi$ ) studies documented in MAID (non-RES is dashed)



Where DIS works best -W>2 GeV, Q<sup>2</sup>>1 GeV<sup>2</sup>

This dividing line is traditional, comes from scaling work long ago?

Plot from Athar-Morfin (to be published)





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# SIS Transition region (1.4 < W < 2.0 GeV)

#### Resonance structure grows more complex

- $2\pi$  becomes important, much harder to calculate Born diagrams
- more thresholds open ( $\eta N, \pi \Delta ...$ )
- More resonances

#### DIS calculates RES + non-RES

- Hard to calculate decays properly (ηN threshold very sharp rise)
- Can hadronization do multiplicity distributions properly?



# More detail from GENIE 5 GeV $v_{\mu}C$

- RES on left, DIS on right (N.B. really DIS + non-RES)
- Subdivided according to final state all, 1, 2, 3 pions, strange
- Very different interpretations!
- Goal for experiments? Even smeared out, would be great



# problems

- Can anyone calculate  $2\pi$  Born diagrams? (worthwhile?)
- Is there a proper way to transition between RES and DIS? Can duality give a prescription?
- Where is optimal place to merge? Smooth?
- ▶ What about edge cases, W<2/Q<sup>2</sup><1 and W>2/Q<sup>2</sup>>1?

# Solutions we know about

- Bodek-Yang handles entire region for inclusive
  - Ignores resonant structure which we think is important
  - Must add hadronization (KNO->Pythia)
- Ghent has resonance and DIS (Regge diagrams)
  - ▶ Transition by hand at W=1.7 GeV with width~1 GeV
  - Good way to start, but lacks theoretical guidance
- Minoo Khabirnezhad is working with Igor Kakorin to add  $\nu$ N  $1\pi$  Born diagrams to GENIE (spring, 2020)

## Summary

- This is important for DUNE
- At the same time, the physics content is interesting
  - Aspects of both theory and experiment
- Can help guide upcoming MINERvA analysis led by Jorge?
- Seems like a natural NuSTEC project!

