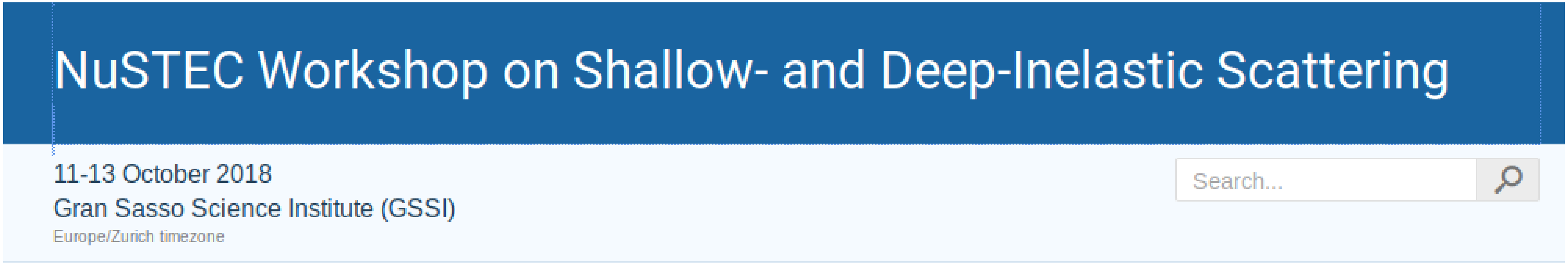
https://indico.cern.ch/event/727283/



NuSTEC Workshop on Shallow- and Deep-Inelastic Scattering

11-13 October 2018
Gran Sasso Science Institute (GSSI)
Europe/Zurich timezone

NUSTEC-News is at **GSSI - Gran Sasso Science Institute.**
Published by Teppei Katori · 13 hrs · L'Aquila ·

NuSTEC neutrino shallow Inelastic Scattering and Deep Inelastic Scattering workshop, day2. We had many talks related to duality, how to connect resonance region physics with DIS. #nuxsec
- talks
https://indico.cern.ch/event/727283/timetable/#20181012

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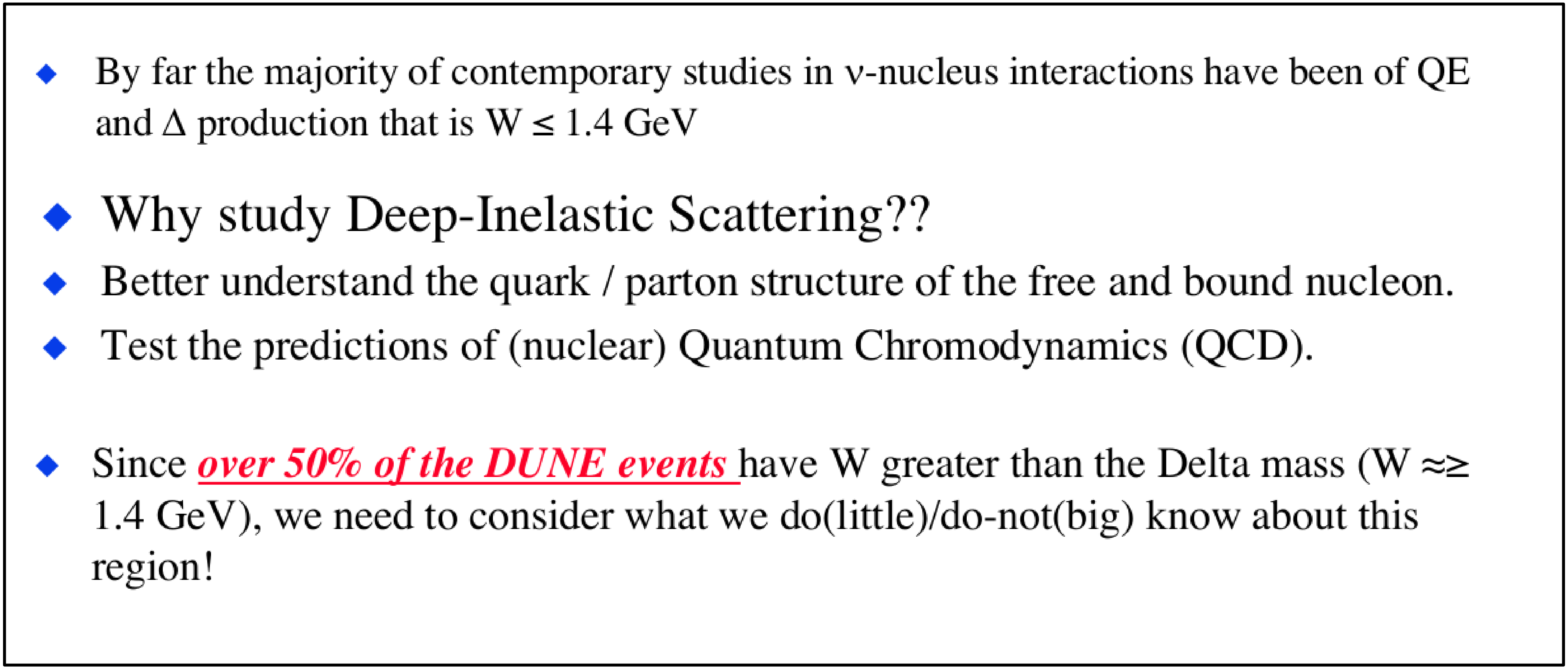
Teppei Katori @teppeikatori · 33m
AGKY model talk by Dr Costas Andreopoulos (#GENIE author), the standard for low W #hadronization in #neutrino experiments including @DUNEScience, new tune available in GENIEv3. #NuSTEC #nuxsec workshop at L'Aquila @GSSI_LAQUILA
@C_Andreopoulos @livuniphysics

Why a workshop on the SIS/DIS region?



- By far the majority of contemporary studies in ν-nucleus interactions have been of QE and Δ production that is W ≤ 1.4 GeV
- Why study Deep-Inelastic Scattering??
- Better understand the quark / parton structure of the free and bound nucleon.
- Test the predictions of (nuclear) Quantum Chromodynamics (QCD).
- Since ***over 50% of the DUNE events*** have W greater than the Delta mass (W ≈≥ 1.4 GeV), we need to consider what we do(little)/do-not(big) know about this region!

J. Morfin @ NuFACT2018

Why a workshop on the SIS/DIS region?

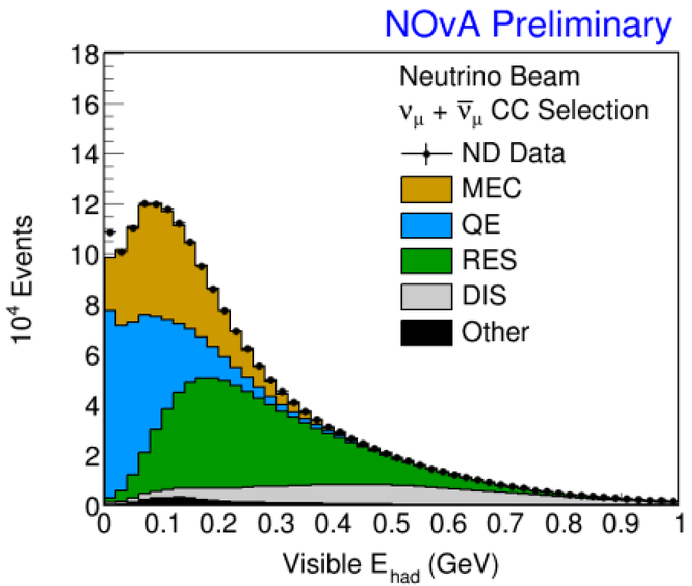
GENIE Tuning

From **NOvA ND data**:

- 10% increase in non-resonant inelastic scattering (DIS) at high W.

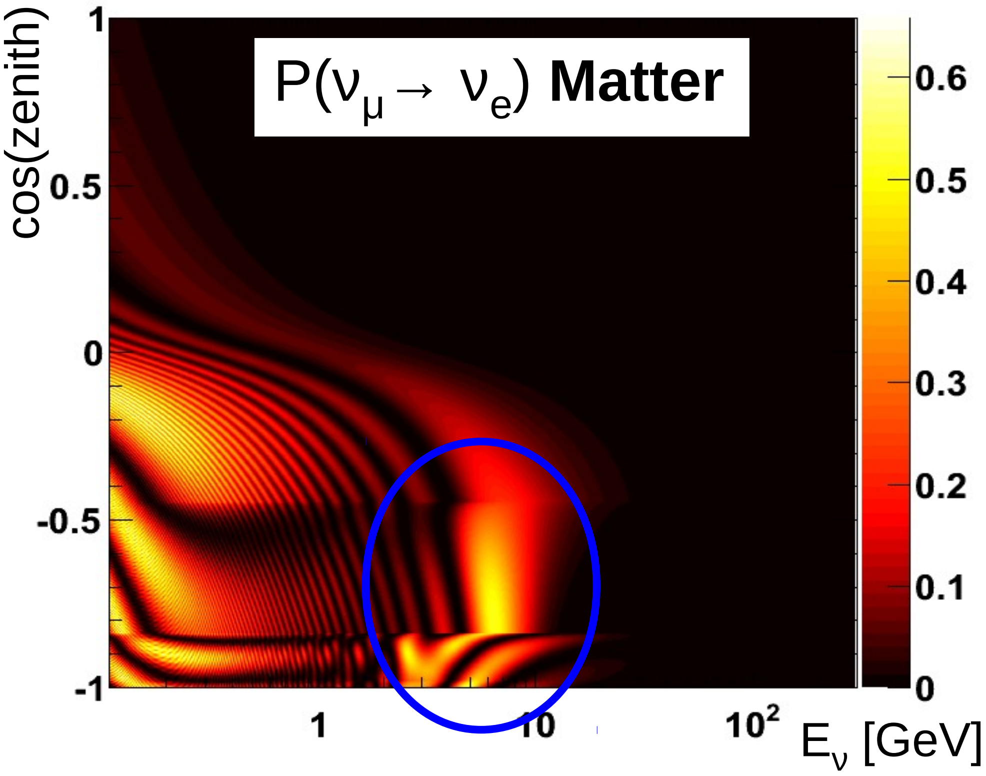
M. Muether “Deep Inelastic Scattering Impact on NOvA”

FHC Tune

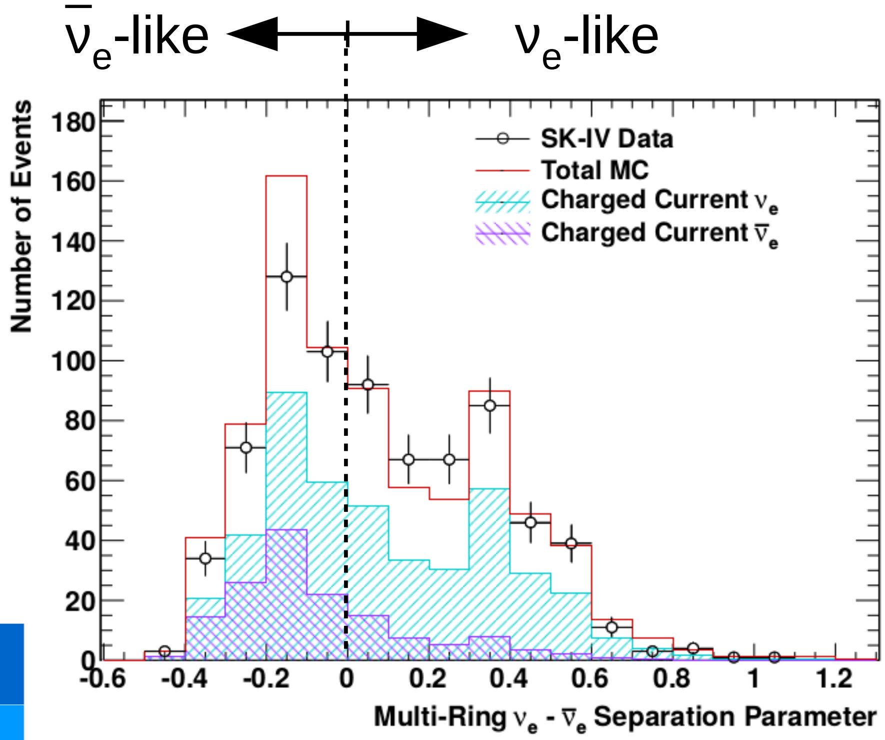


- Good agreement between MC and data in general.
- DIS has significant impact at high visible E_{had}.
- W distributions do not include the high-W DIS correction.
- Most DIS is in the “transition” regions.

Why a workshop on the SIS/DIS region?



Likelihood separation based on differences between DIS interactions of neutrinos and anti-neutrinos

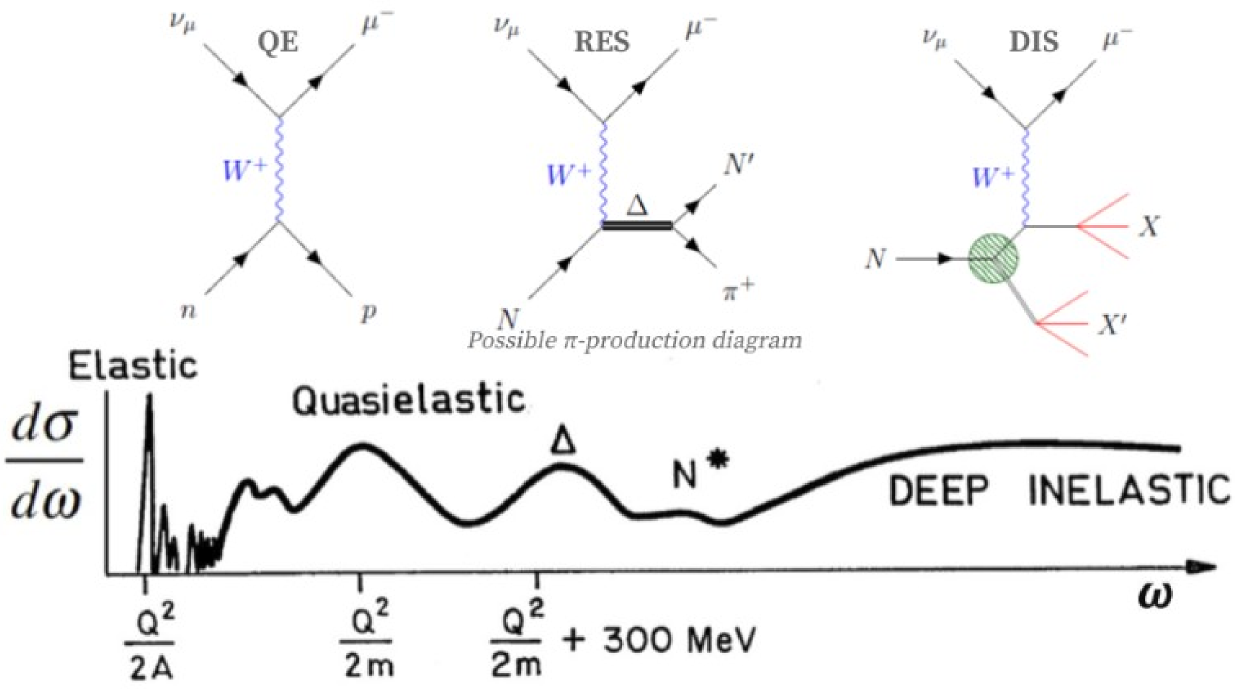


	Neutrino	Anti-neutrino
Nb of rings	More	Less
Nb of Michel e-	More	Less
Transverse momentum	Larger	smaller

CB, “SIS/DIS interactions and uncertainties in atmospheric oscillation analysis”

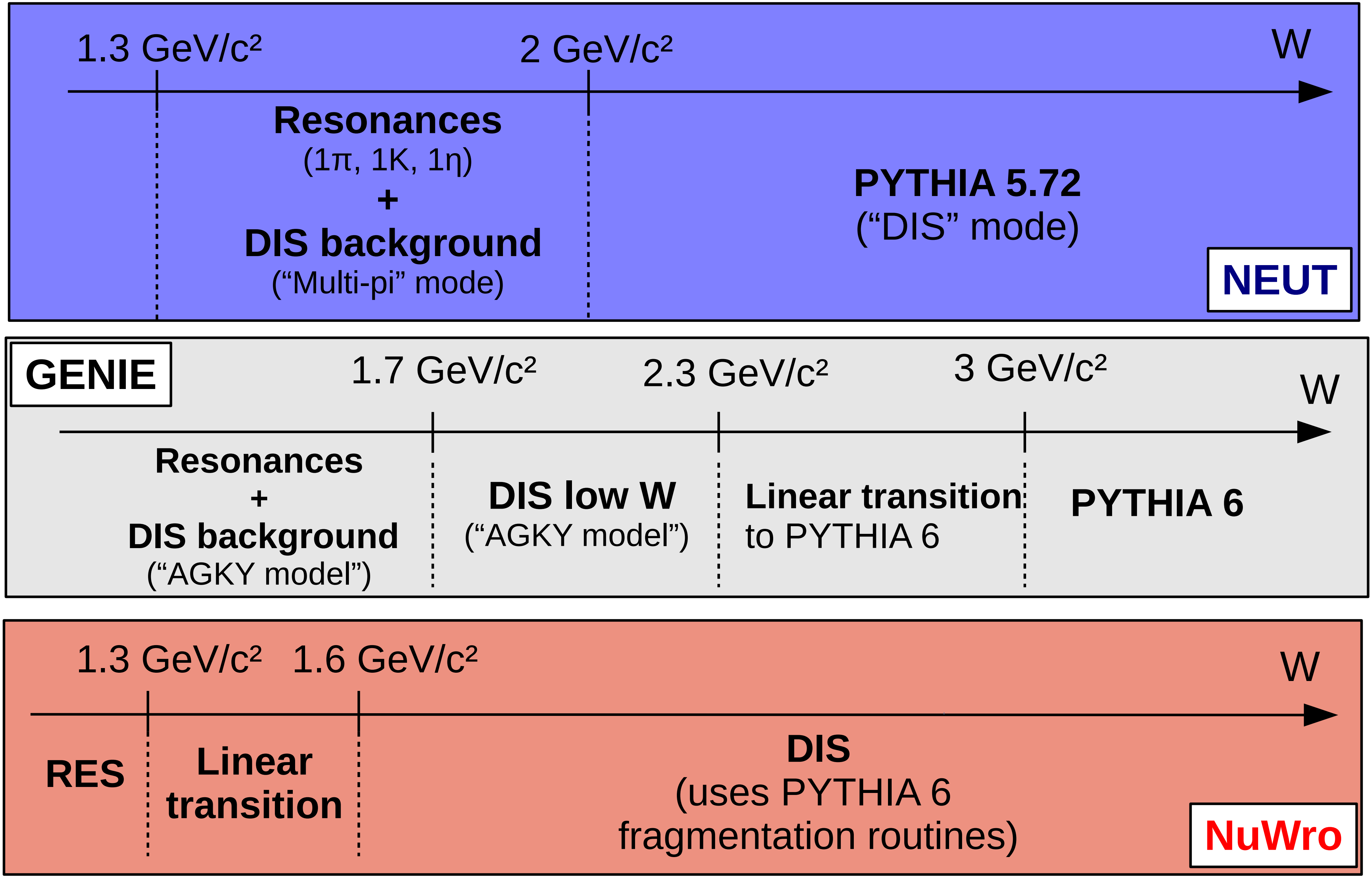
Scattering mechanisms at the few energy range

Broad energy range: several scattering mechanisms are important



J. Tena Vidal, “Tuning the pion production in GENIEv3”

SIS/DIS region in the generators



NEUT

1.3 GeV/c²

2 GeV/c²

W

Resonances
(1π, 1K, 1η)
+
DIS background
("Multi-pi" mode)

PYTHIA 5.72
("DIS" mode)

GENIE

1.7 GeV/c²

2.3 GeV/c²

3 GeV/c²

W

Resonances
+
DIS background
("AGKY model")

DIS low W
("AGKY model")

Linear transition
to PYTHIA 6

PYTHIA 6

NuWro

1.3 GeV/c²

1.6 GeV/c²

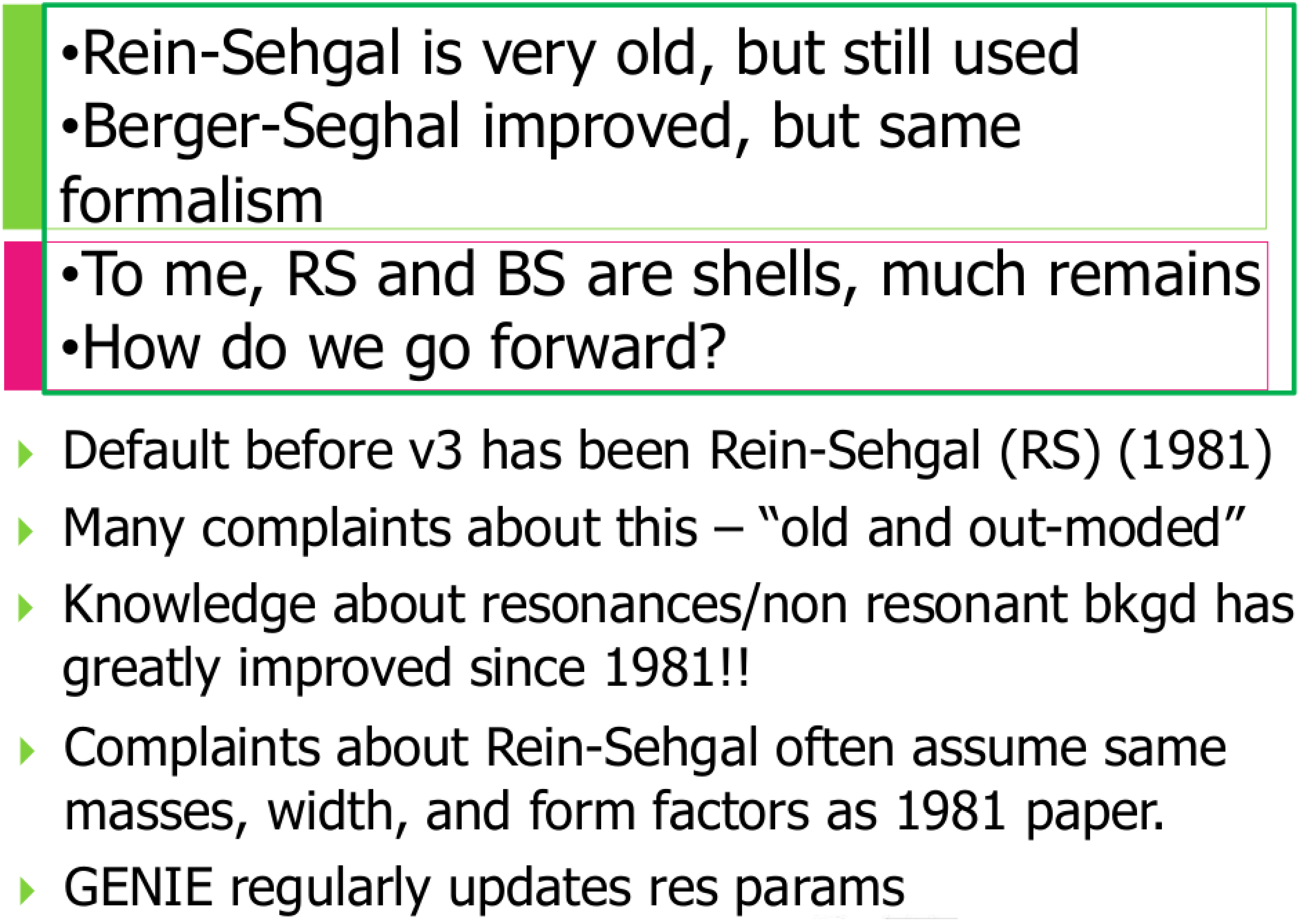
W

RES

Linear transition

DIS
(uses PYTHIA 6
fragmentation routines)

CB, "Generator comparisons SIS/DIS region"



•Rein-Sehgal is very old, but still used
•Berger-Seghal improved, but same formalism

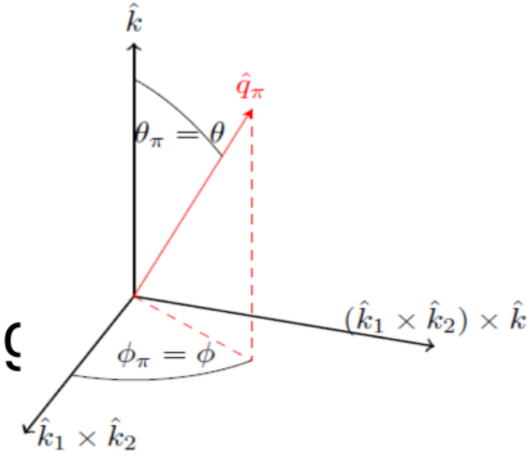
•To me, RS and BS are shells, much remains
•How do we go forward?

- Default before v3 has been Rein-Sehgal (RS) (1981)
- Many complaints about this – "old and out-moded"
- Knowledge about resonances/non resonant bkgd has greatly improved since 1981!!
- Complaints about Rein-Sehgal often assume same masses, width, and form factors as 1981 paper.
- GENIE regularly updates res params

S. Dytman, "Status of Resonances in GENIE"

MK-model

M. Kabirnezhad,
Phys. Rev. D **97**, 013002



- MK model is a model for single pion production i.e. resonant and non-resonant interactions includin **the interference effects**.
- Uses Rein-Sehgal model to describe resonant interaction (17 resonances) up to W=2 GeV.
- Lepton mass is included.
- non-resonant background is defined by a set of diagrams determined by HNV model.

E. Hernandez, J. Nieves and M. Valverde,
Phys. Rev. D **76** (2007) 033005

Output of the MK-model

$$d\,\sigma/dW\,dQ^2 d\Omega_\pi$$

M. Kabirnezhad, “Single pion production in neutrino interaction”

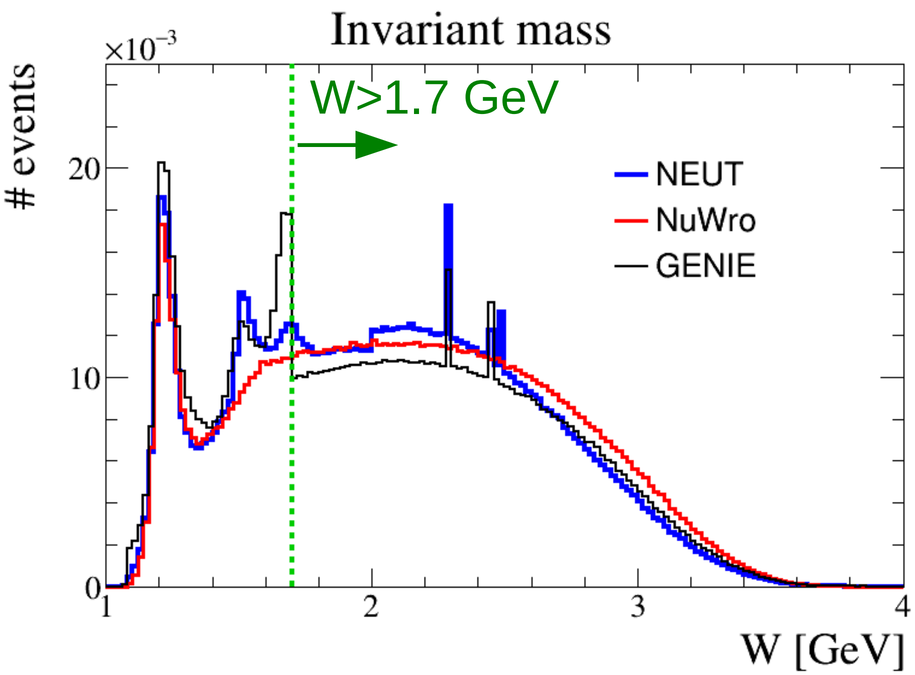
Neutrino interactions in resonance region beyond $\Delta(1232)$ is much more difficult to understand than in $\Delta(1232)$ region

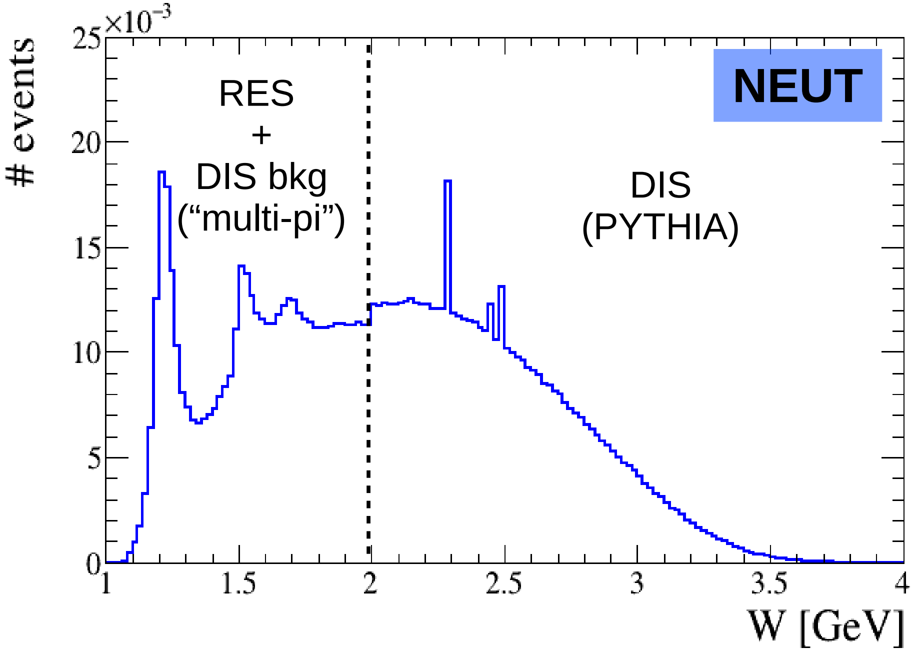
	$\Delta(1232)$ region	Beyond $\Delta(1232)$ region ($W \lesssim 2$ GeV)
Resonance	$\Delta(1232)$ dominates No other resonances	No single resonance dominate Several comparable resonances overlap
Non-resonant	Much smaller than $\Delta(1232)$ ChPT works → well-controlled	Comparable to resonant contributions ChPT not work
Relative phases among mechanisms	(fairly) well-controlled	Crucially important but not easy to control
Coupled-channels	Only πN	πN and $\pi\pi N$ are comparable and strongly coupled ηN, $K\Lambda$, $K\Sigma$ channels are also coupled

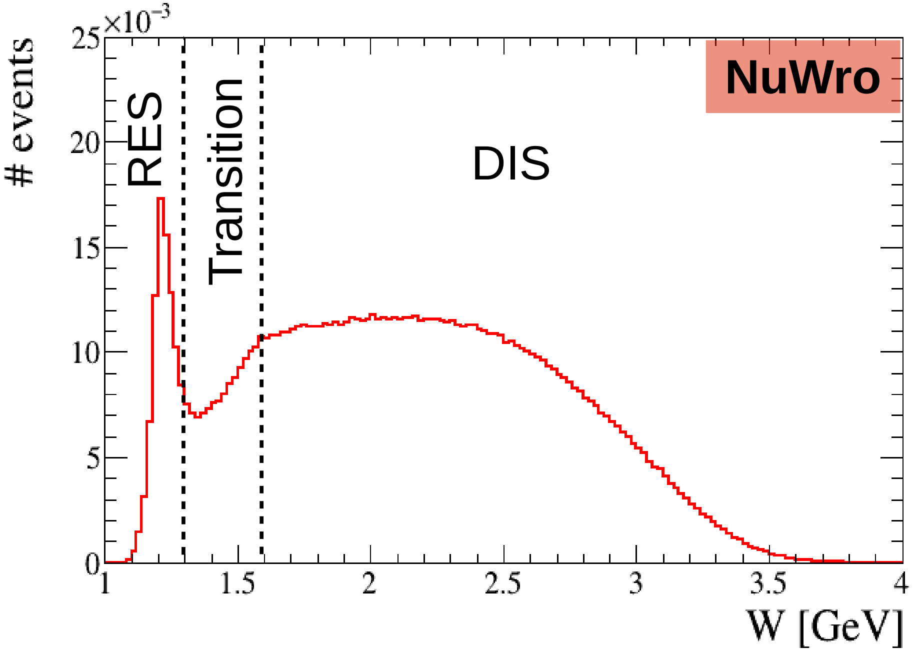
S. Nakamura, “Dynamical coupled-channels approach to Resonance Region beyond Δ(1232)”

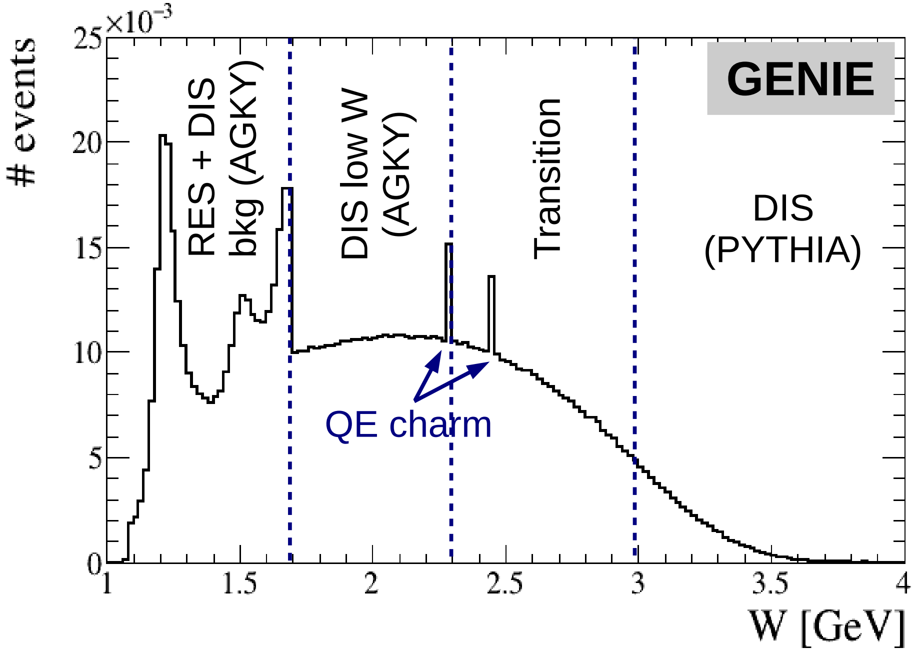
Invariant mass distribution

ν_μ on Fe, E_ν=6.0 GeV









NEUT Low W model

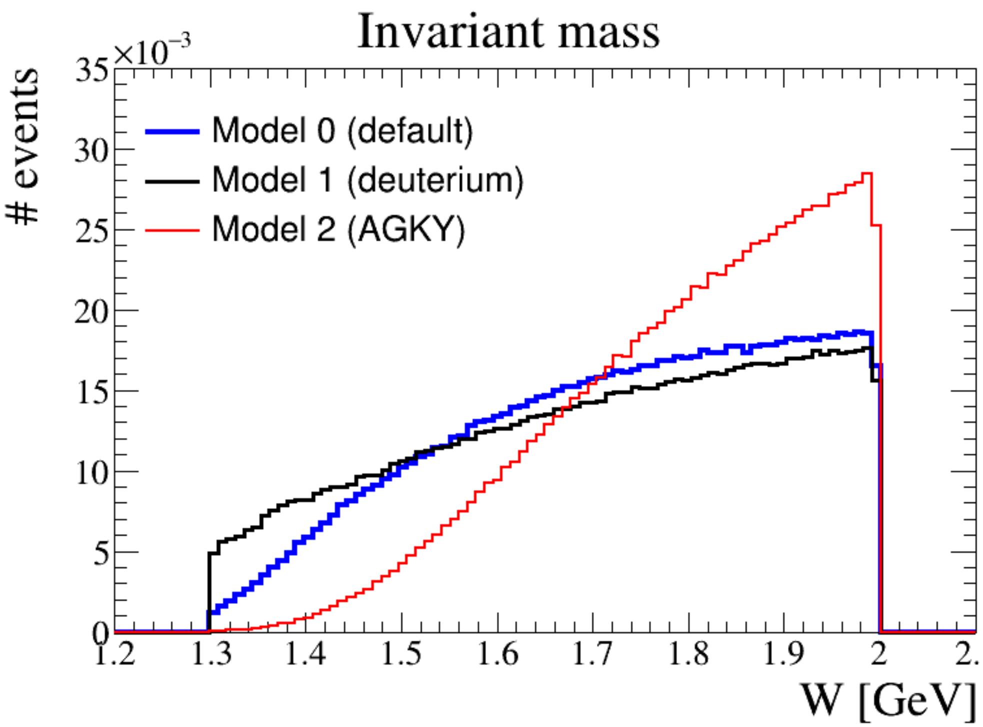
W<2 GeV region:

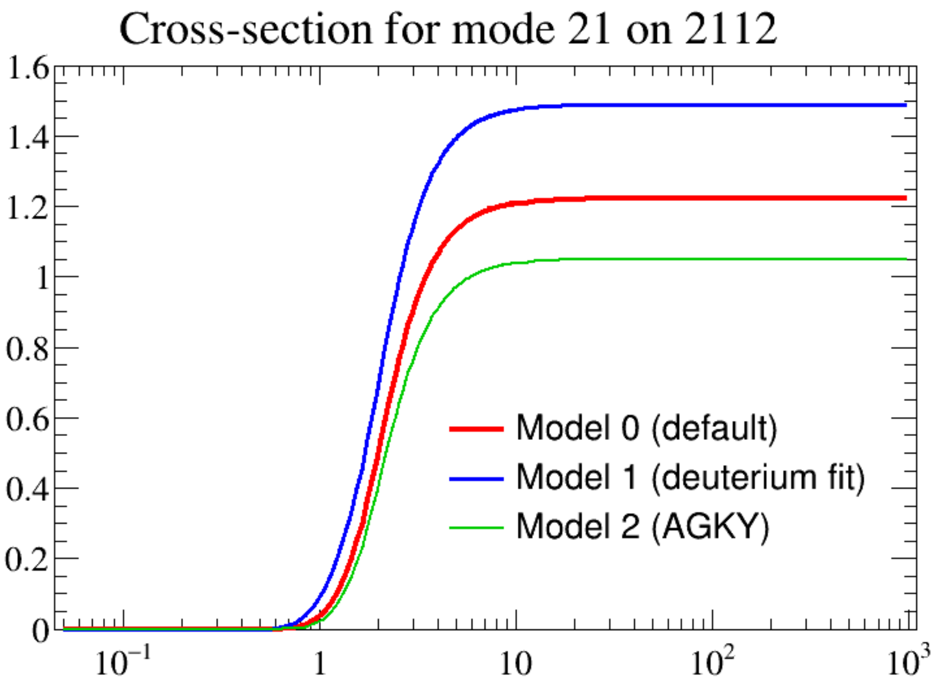
- Single particle production (lepton + baryon +X): resonances
- More than one particle (lepton + baryon +nX ,n≥2): custom DIS model “multi-pion” mode

- To determine the number of hadrons produced, use a multiplicity model
- Gives the probability to produce a given number of hadrons as a function of W, $\nu/\bar{\nu}$ and target nucleon

Neutrino on neutron

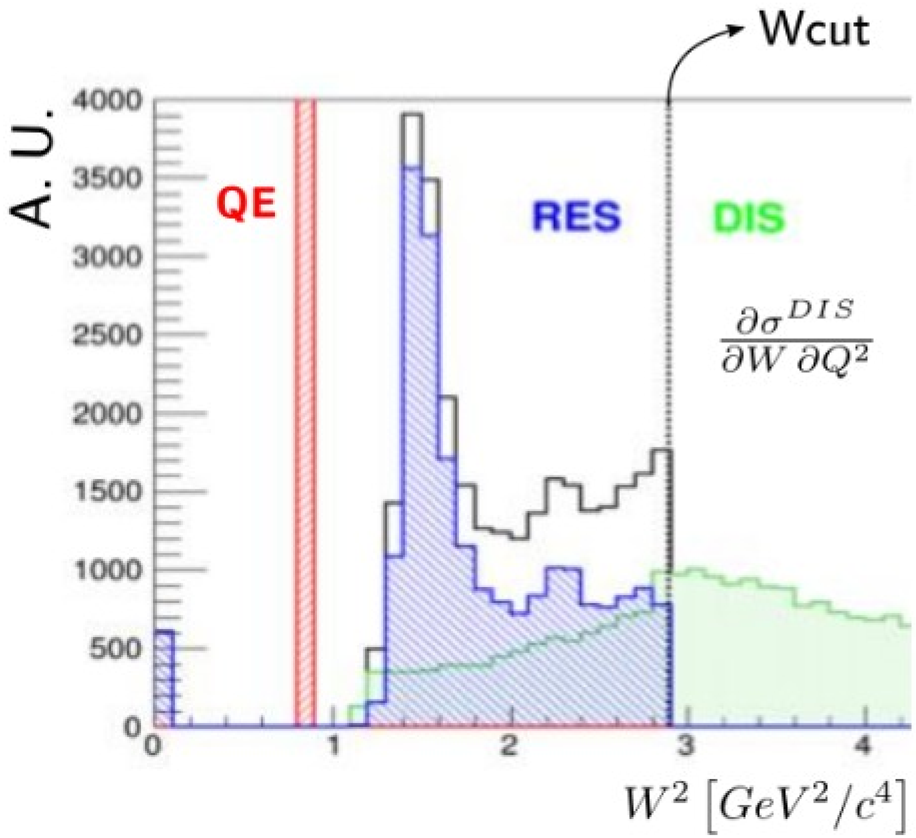
Neutrino on neutron xsec





1. The RES contribution to the cross section
2. Shallow Inelastic Scattering transition region (SIS) between the Δ peak and the DIS regime
   - A non-resonant background needs to be added
3. DIS also contributes to RES production after hadronization.

Different models must be merged together while avoiding double counting

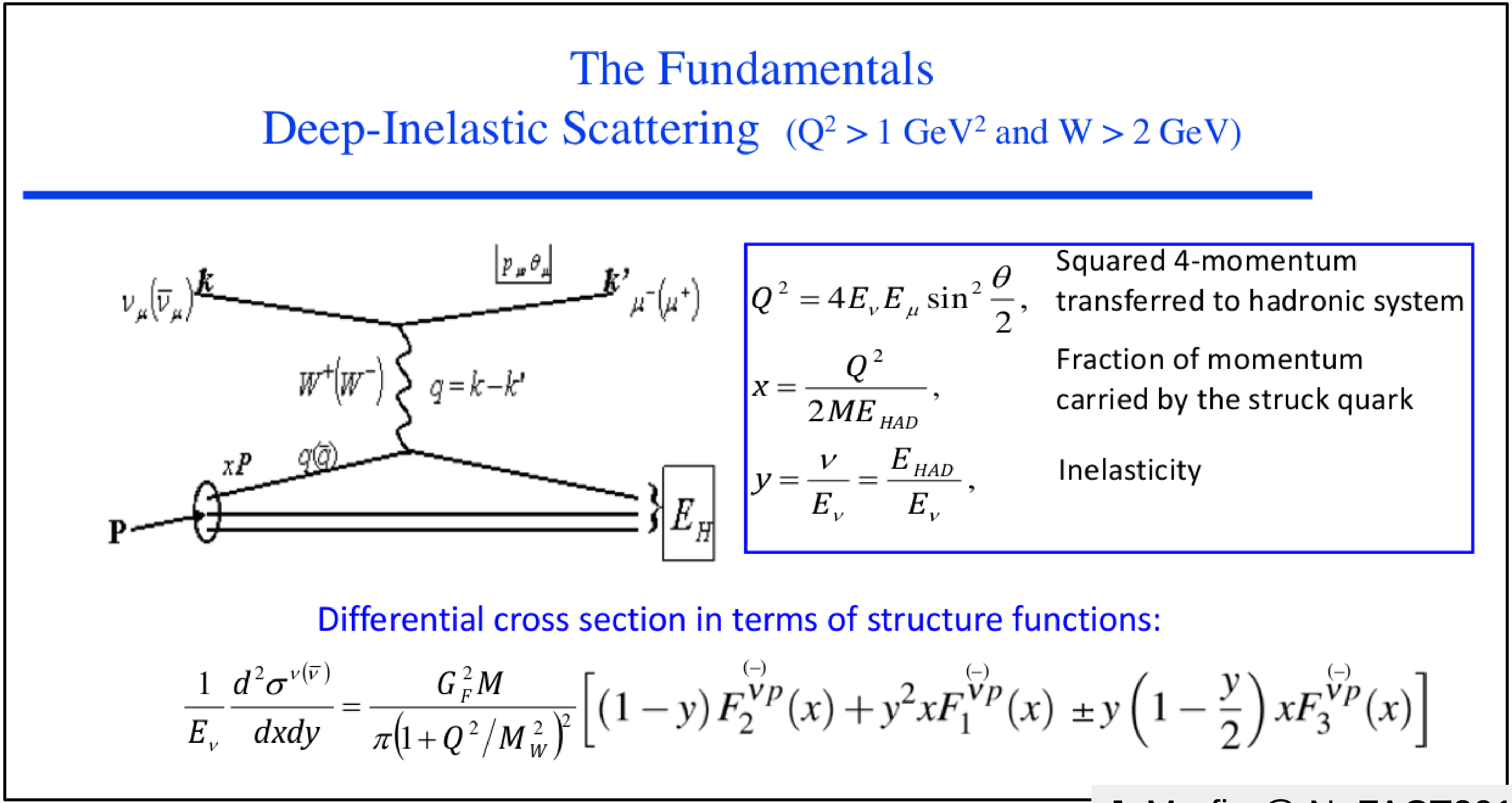


global fit to free nucleon integrated cross sections

Parameters to be tuned within the SIS region ⇒ 8 parameters

1. RES parameters
   - M_A^{RES}: dipole parametrization factor
   - RES-XSecScale
2. SIS non-resonant background parameters
   - W_{cut} to determine the end of the SIS region
   - R_m parameters for proton and neutron, multiplicity 2 and 3
3. DIS parameters
   - DIS-XSecScale

J. Tena Vidal, “Tuning the pion production in GENIEv3”



The Fundamentals

Deep-Inelastic Scattering (Q² > 1 GeV² and W > 2 GeV)

$Q^2 = 4E_\nu E_\mu \sin^2\frac{\theta}{2}$,	Squared 4-momentum transferred to hadronic system
$x = \frac{Q^2}{2ME_{HAD}}$,	Fraction of momentum carried by the struck quark
$y = \frac{\nu}{E_\nu} = \frac{E_{HAD}}{E_\nu}$,	Inelasticity

Differential cross section in terms of structure functions:

$$\frac{1}{E_\nu}\frac{d^2\sigma^{\nu(\bar\nu)}}{dxdy} = \frac{G_F^2 M}{\pi\left(1+Q^2/M_W^2\right)^2}\left[(1-y)\,F_2^{\overset{(-)}{\nu}p}(x) + y^2 x F_1^{\overset{(-)}{\nu}p}(x) \pm y\left(1-\frac{y}{2}\right) x F_3^{\overset{(-)}{\nu}p}(x)\right]$$

J. Morfin @ NuFACT2018

- Use quark-parton model to compute F_2 and xF_3 from Parton Distribution Functions
- PDFs can be computed in QCD with free parameters determined by a fit to data
- Only works for $Q^2>Q_0^2$(typically ~1 GeV)

Extrapolation from Q^2 = 1.0 GeV^2 to Q^2 = 0

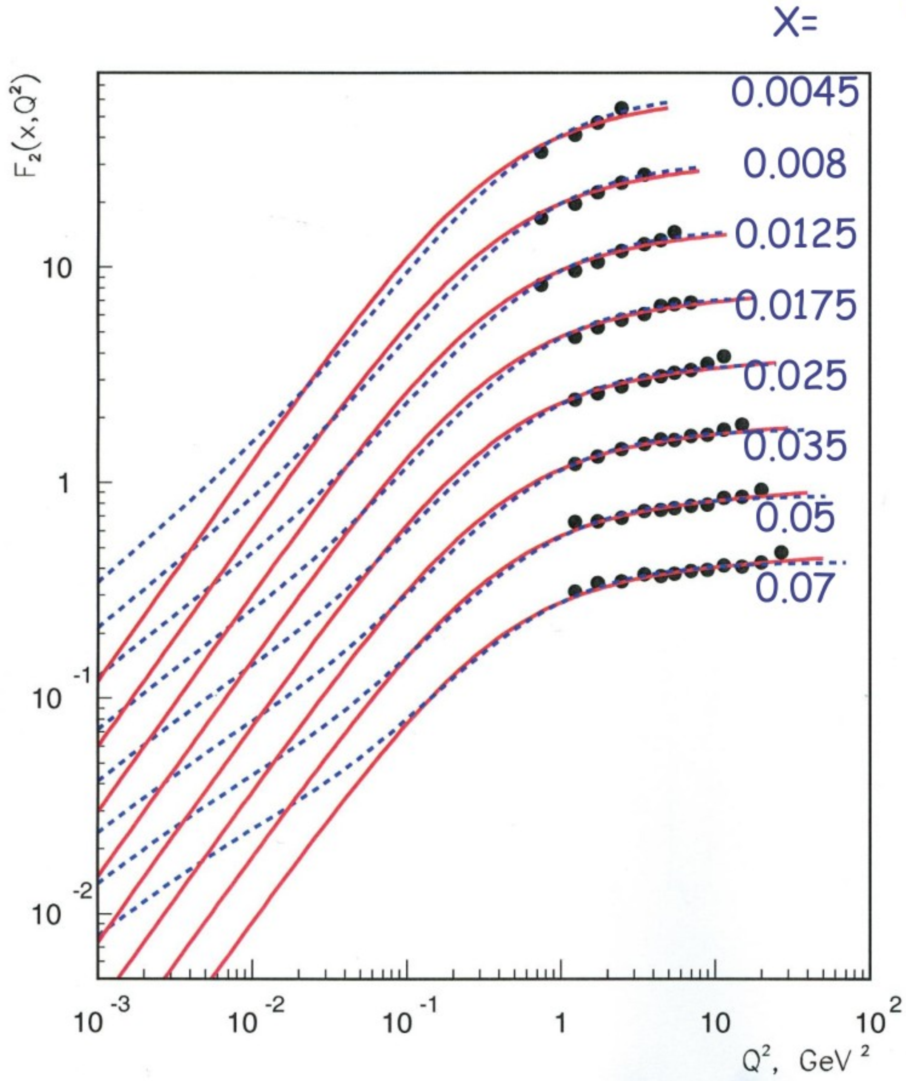
Solid lines: M. Bertini et al. 1996 (Default in NUNDIS)

$$F_2(x,Q^2) = A\Big[1+\epsilon\ln\Big(Q^2(1/x-1)+M^2\Big)\Big]\ln(1+Q^2/(Q^2+a^2))\ .$$

Dashed lines: Donnachie-Landshoff 1994

$$F_2(x,Q^2)\sim Ax^{-0.0808}\left(\frac{Q^2}{Q^2+a}\right)^{1.0808}+Bx^{0.4525}\left(\frac{Q^2}{Q^2+b}\right)^{0.5475}$$

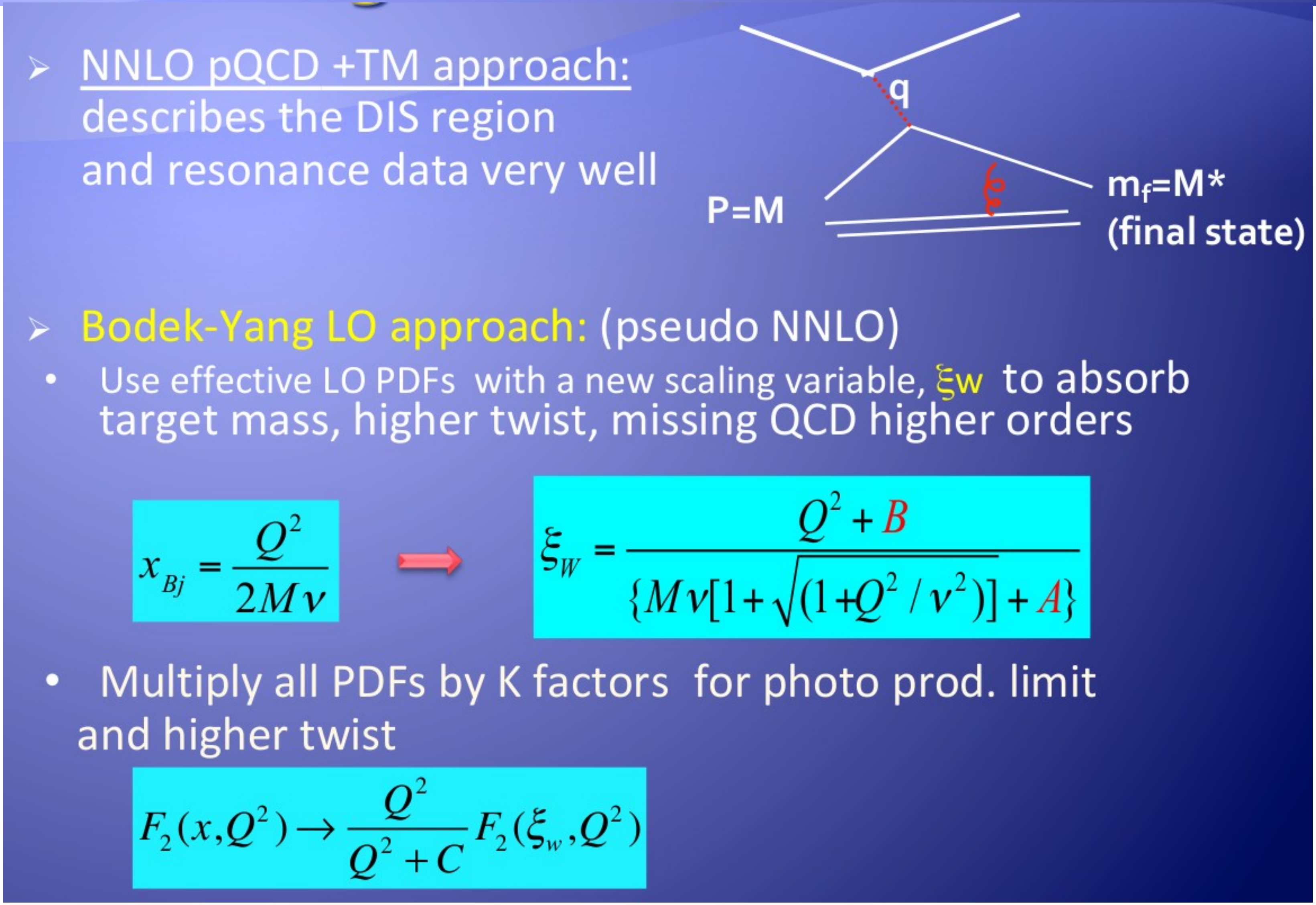
data points from NMC Collab., M. Arneodo et al., Nucl. Phys. B 483 (1997) 3-43
Data/cuves scaled for clarity, factors from 1 to 128



P. Sala, “Neutrino interactions in FLUKA: NUNDIS”

Bodek-Yang Model

- Bodek-Yang model aims for describing DIS cross section in all Q^2 regions



- NNLO pQCD +TM approach:
  describes the DIS region
  and resonance data very well

- **Bodek-Yang LO approach:** (pseudo NNLO)
  - Use effective LO PDFs with a new scaling variable, ξ_w to absorb target mass, higher twist, missing QCD higher orders

$$x_{Bj} = \frac{Q^2}{2M\nu} \Rightarrow \xi_W = \frac{Q^2 + B}{\{M\nu[1+\sqrt{(1+Q^2/\nu^2)}] + A\}}$$

  - Multiply all PDFs by K factors for photo prod. limit and higher twist

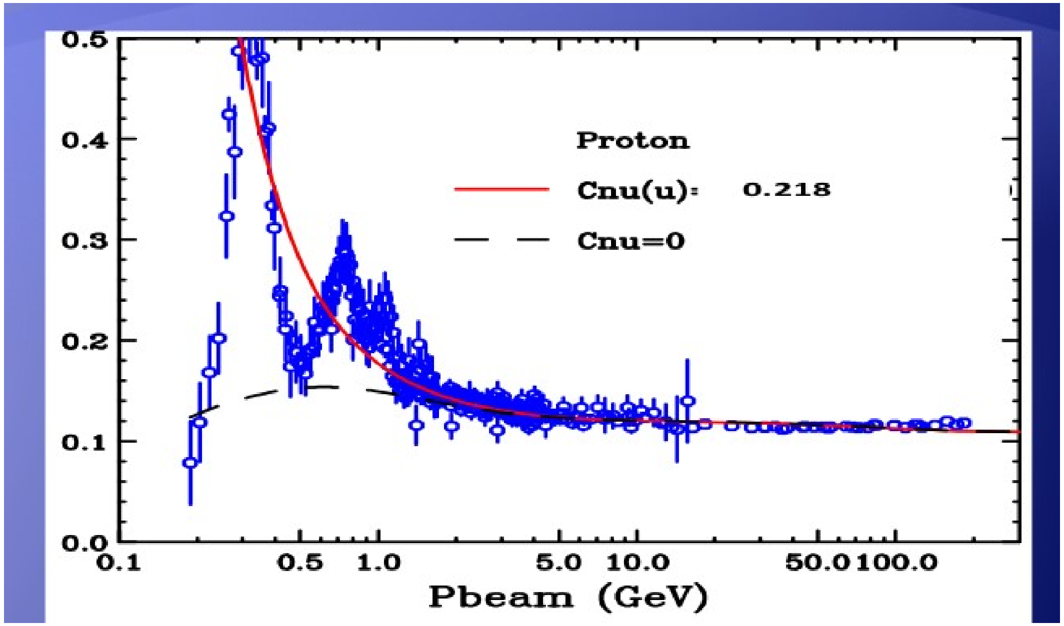
$$F_2(x,Q^2) \rightarrow \frac{Q^2}{Q^2+C} F_2(\xi_w,Q^2)$$

U-K Yang, “The status of Bodek-Yang model”

Quark-Hadron Duality

complementarity between quark and hadron descriptions of observables

Uses the idea of duality for the low Q^2 region

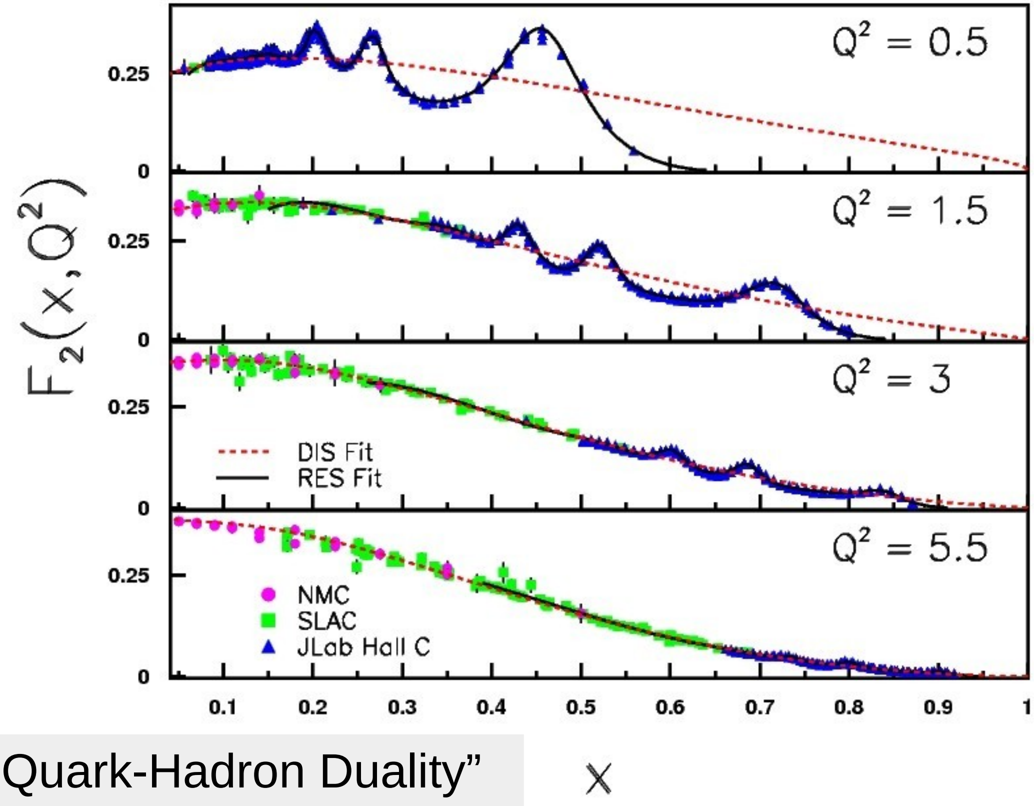


At high enough energy:

Hadronic Cross Sections averaged over appropriate energy range = Perturbative (Quark-Gluon)

Σ_{hadrons} Σ_{quarks}

Can use either set of complete basis states to describe physical phenomena **provided you sum over enough states**

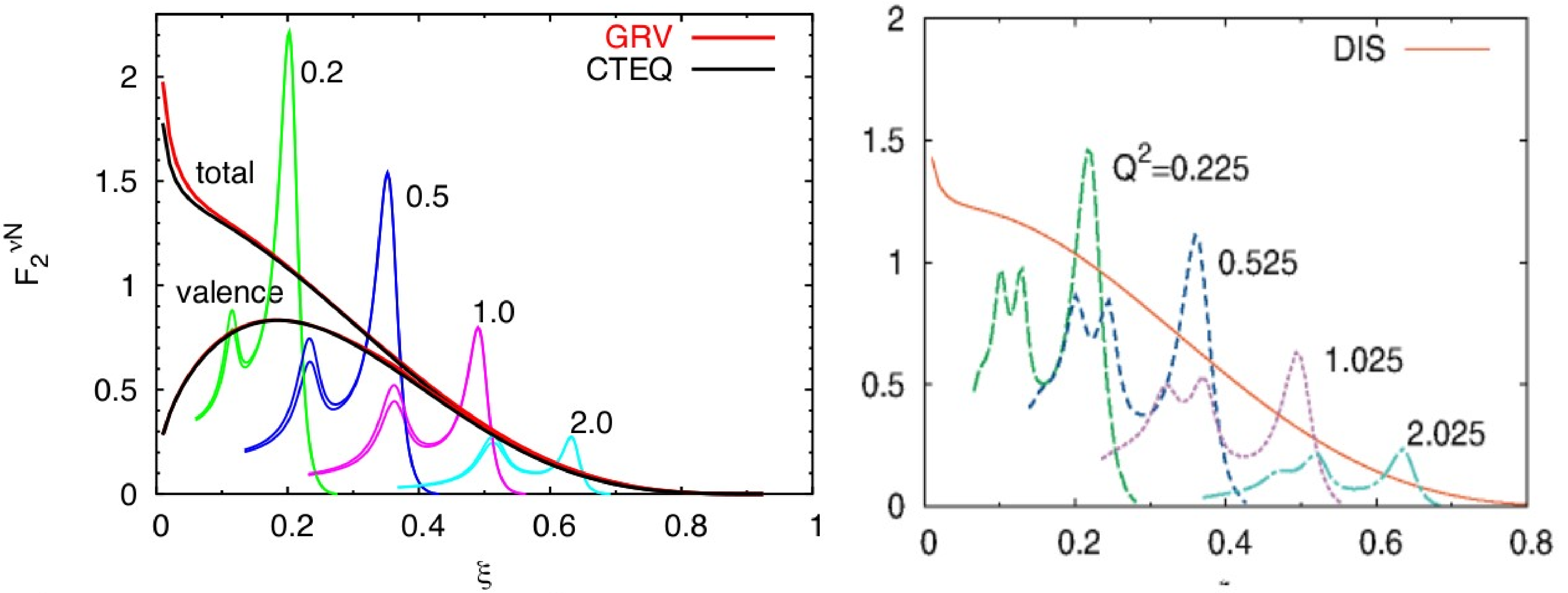


Eric Christy, “Quark-Hadron Duality”

What about neutrino scattering ? - From Olga Lalakulich
Duality supposedly holds for the **averaged** neutrino $F_2^N = (F_2^n+F_2^p) / 2$

Neutrino on isoscalar target $F_2(\xi)$ vs ξ.

Left Dortmund model ;rightGiessen (Lalakulich et al.) except for strange quark contribution electron and neutrino on isoscalar related by 5/18



E. A. Paschos, “Quark-Hadron Duality in Neutrino Nucleon Scattering and Analogies in Nuclei

What about individually ν-n and ν-p scattering?

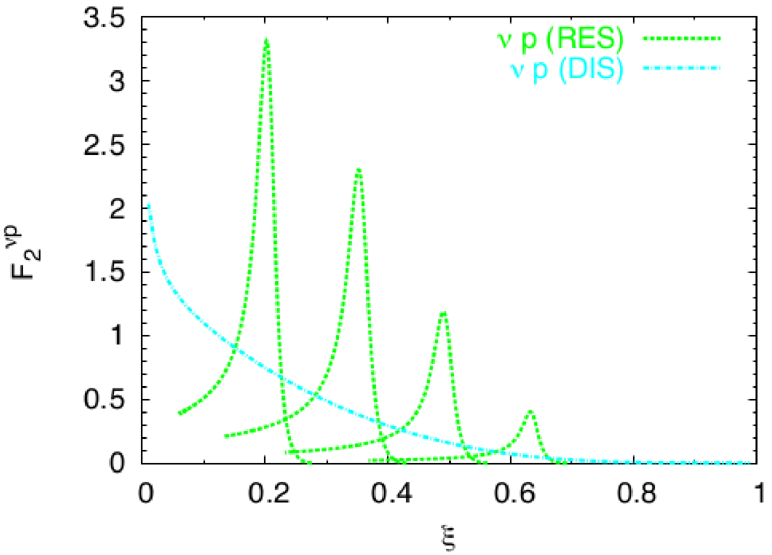
Resonance estimates from Lalakulich, Melnitchouk and Paschos

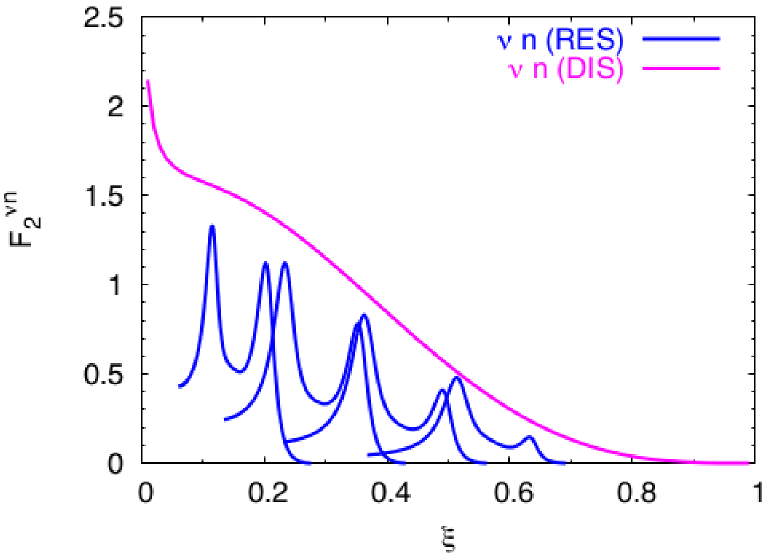
Oops!

Low-lying resonances: $F_2^{\nu n(res)} < F_2^{\nu p(res)}$, DIS: $F_2^{\nu n(DIS)} > F_2^{\nu p(DIS)}$

$$F_2^{\nu p(res-3/2)} = 3F_2^{\nu n(res-3/2)}$$
$$F_2^{\nu p(res-1/2)} \equiv 0$$

$F_2^{\nu n(res)}$: finite contributions from isispin-3/2 and -1/2 resonances





However, it is a different story when talking of NUCLEI not NUCLEON – now Fe

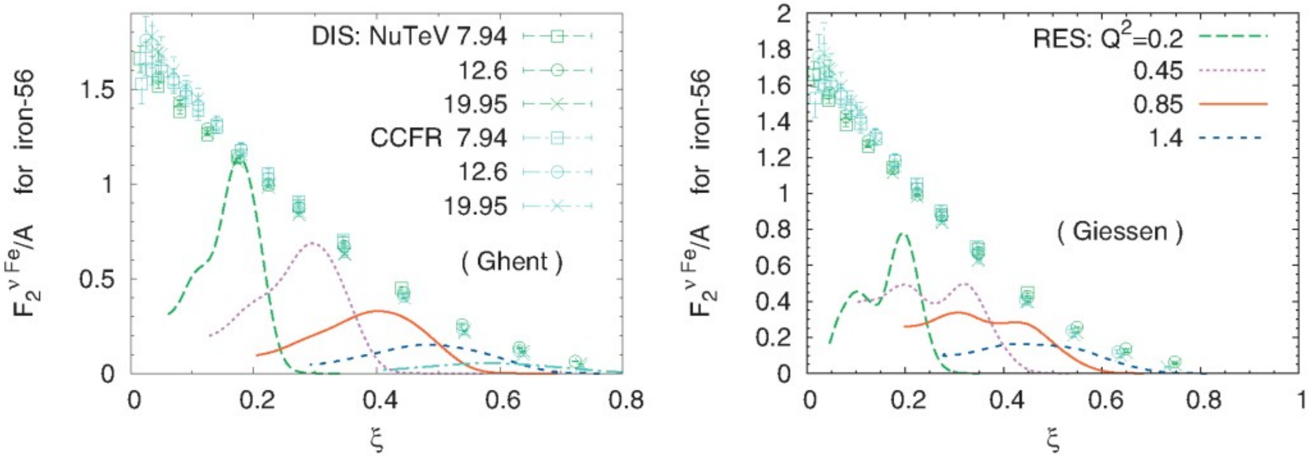
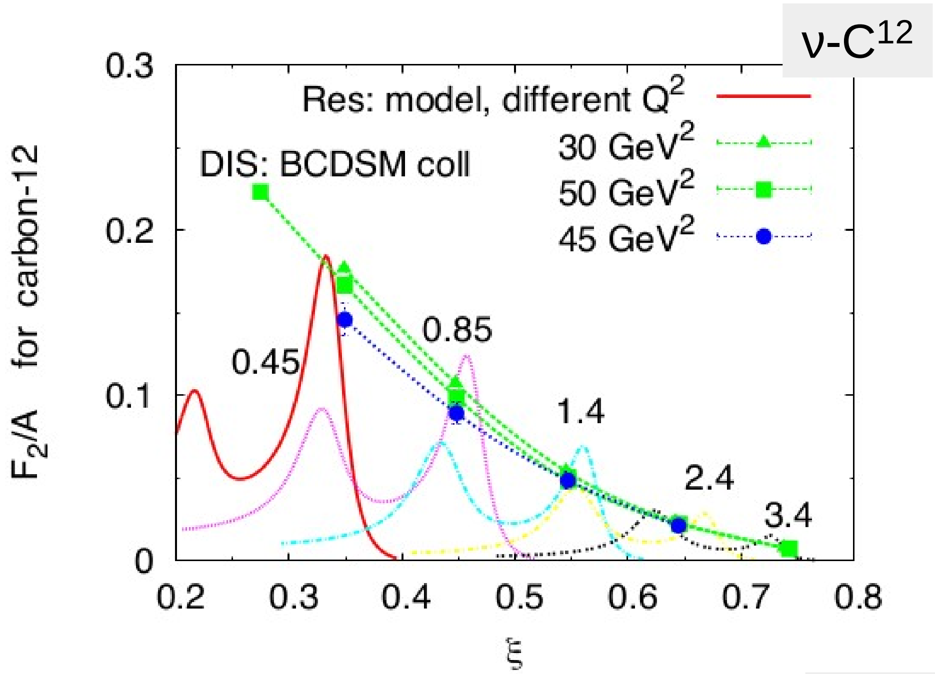
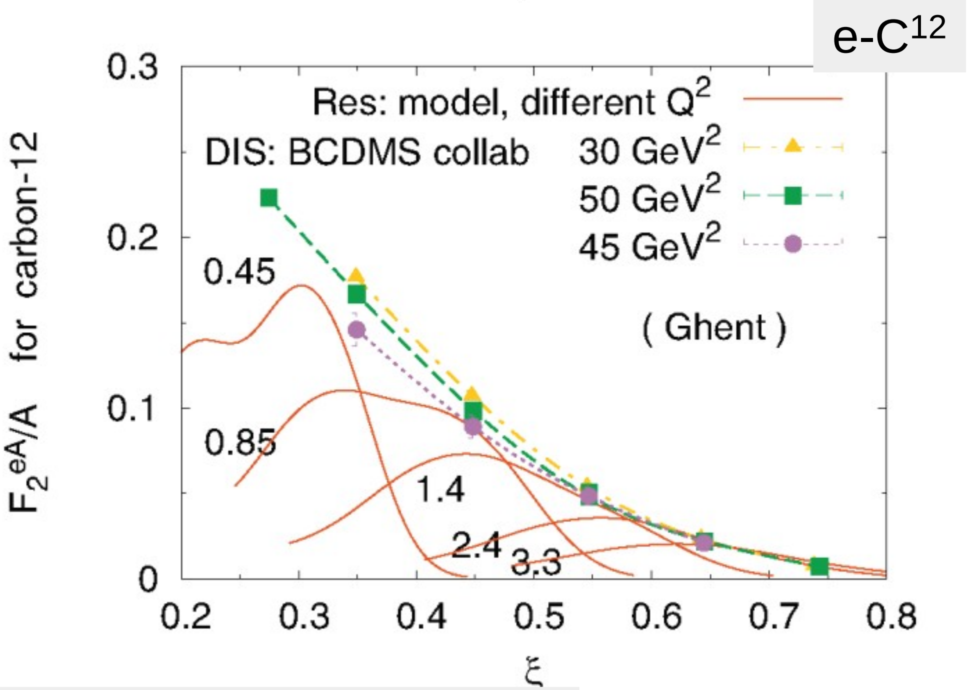


FIGURE 5. (color online) The computed resonance curves $F_2^{\nu^{56}Fe}/56$ as a function of ξ, calculated within Ghent(left) and Giessen (right) models for $Q^2 = 0.2, 0.45, 0.85$, 1.4, and 2.4 GeV^2. The calculations are compared with the DIS data from Refs. [26, 27]. The DIS data refer to measurements at $Q^2_{DIS} = 7.94$, 12.6 and 19.95 GeV^2.

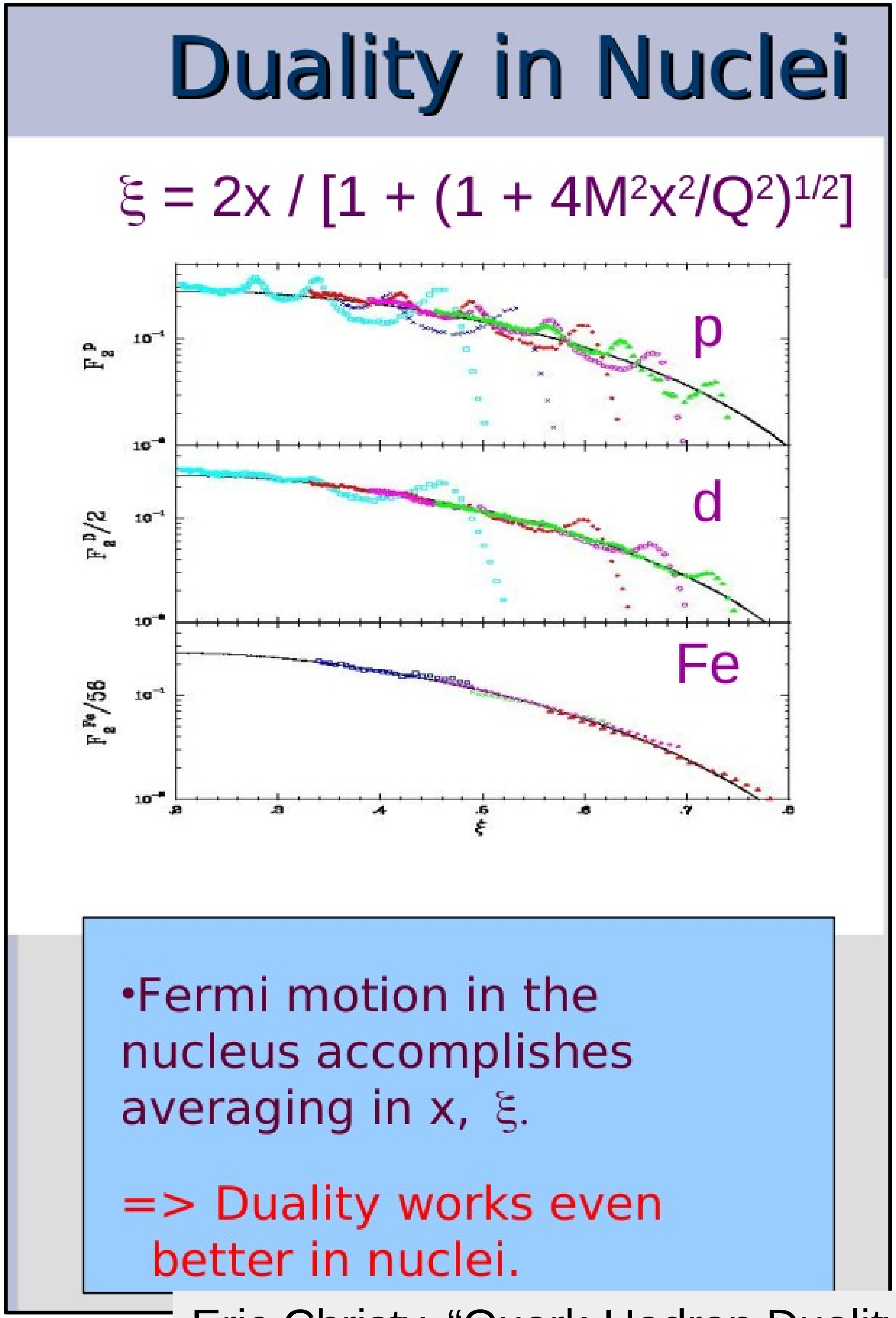
- $F_2^{\nu p\ \nu n}$: In neutrino–nucleon scattering duality does NOT hold for proton and neutron individually
- $F_2^{\nu p\ \nu n}$: Duality HOLDS for the averaged structure functions. Need equal number of neutrons and protons…
- Is non-resonant pion production included? If not, could it explain the difference?

Case of an isoscalar nucleus: carbon 12





J. Morfin @ NuFACT2018



Duality in Nuclei

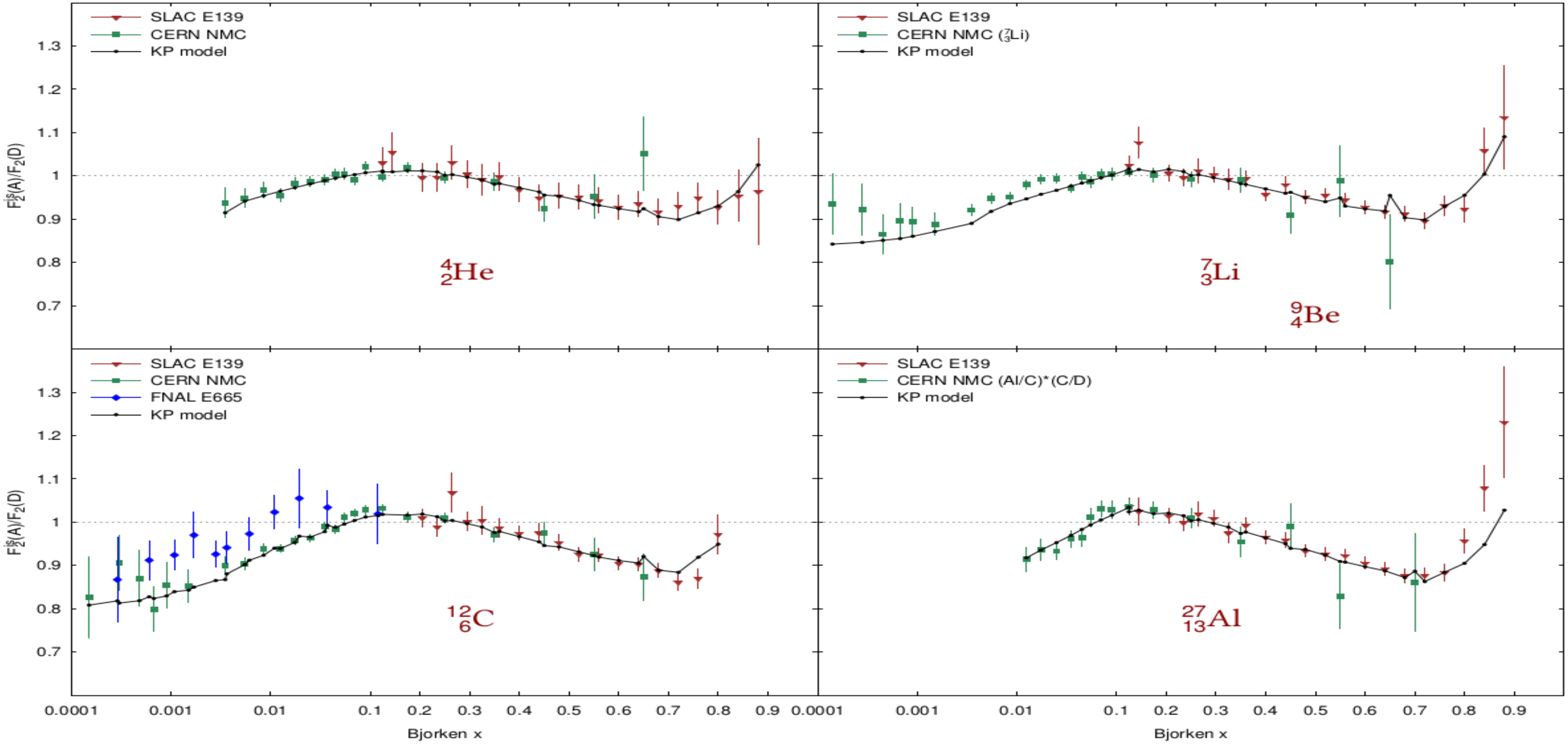
$\xi = 2x / [1 + (1 + 4M^2x^2/Q^2)^{1/2}]$

- Fermi motion in the nucleus accomplishes averaging in x, ξ.

=> Duality works even better in nuclei.

Eric Christy, “Quark-Hadron Duality”

Summary of results on the nuclear ratios F_2^A/F_2^D

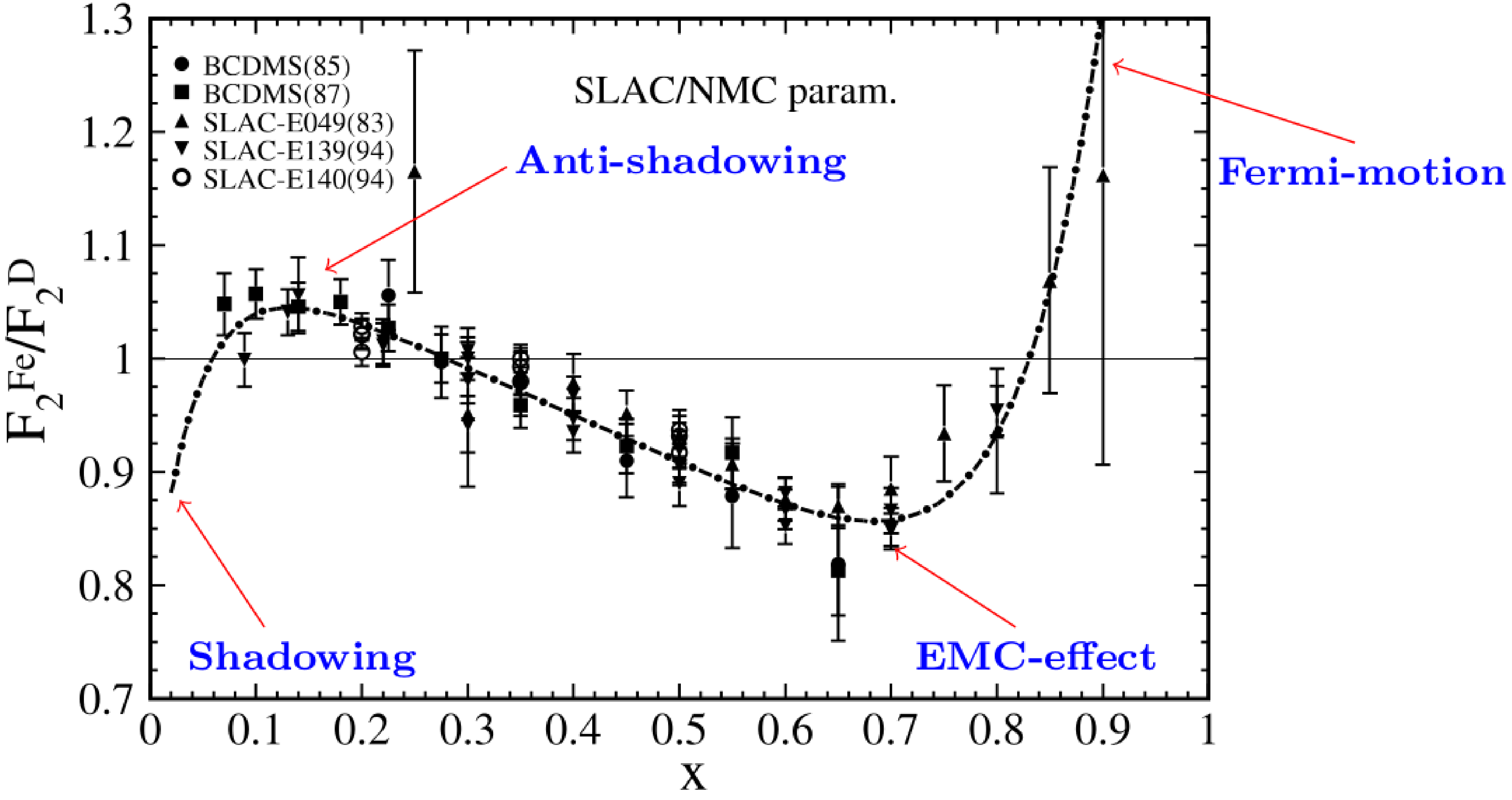


- The data on the ratio of nuclear structure functions F_2^A/F_2^B (nuclear EMC effect) show nontrivial oscillating shape spanning different kinematical regions of Bjorken x.
- The data in the DIS region can be understood if we address a number of corrections including nuclear momentum distribution and binding effects, off-shell correction, meson-exchange currents as well as the matter propagation effects of hadronic component of virtual photon. Those nuclear effects result in the corrections relevant in different regions of x.

S. Kulagin, “Nuclear Medium Effects on the Structure Functions”

- Cross-sections in nuclear collisions are modified

$$F_2^A(x) \neq ZF_2^p(x) + NF_2^n(x)$$

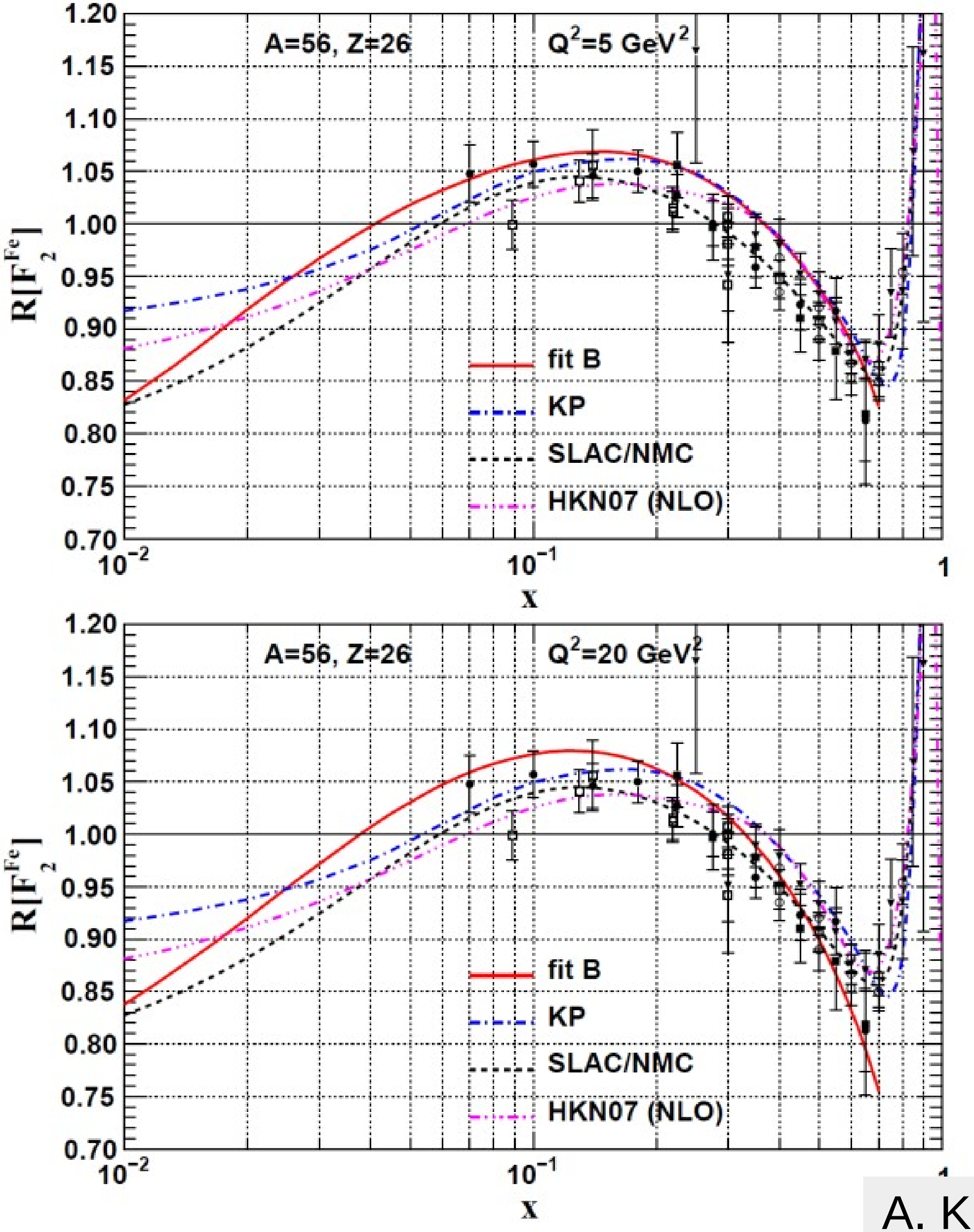


- Can we translate this modifications into **universal nuclear PDFs**?

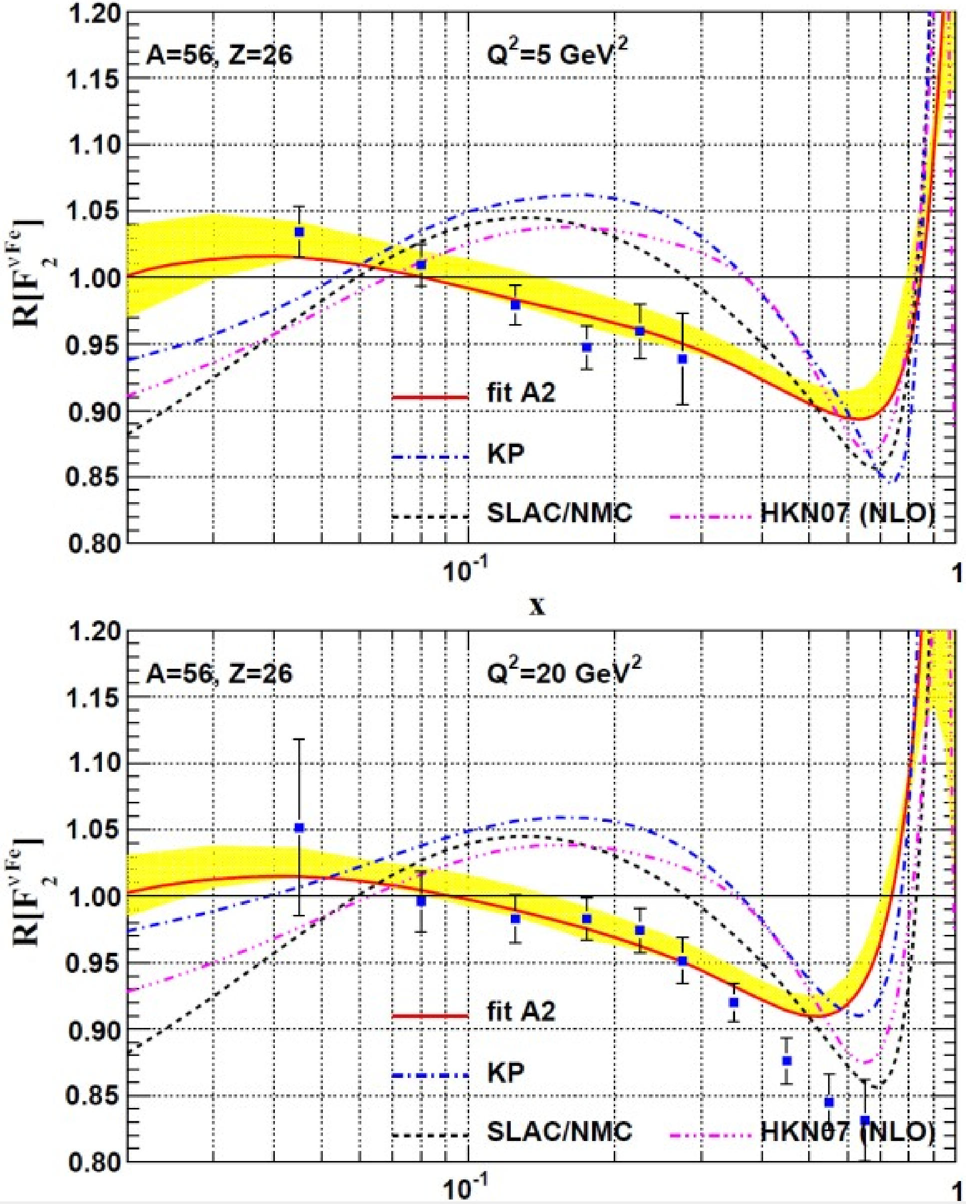
A. Kusina, “nPDFs from e/mu-A and nu-A scattering

nPDFs from charged-lepton DIS data [PRD 80 (2009) 094004]

$F_2^{\ell^\pm \mathrm{Fe}} / F_2^{\ell^\pm \mathrm{D}}$



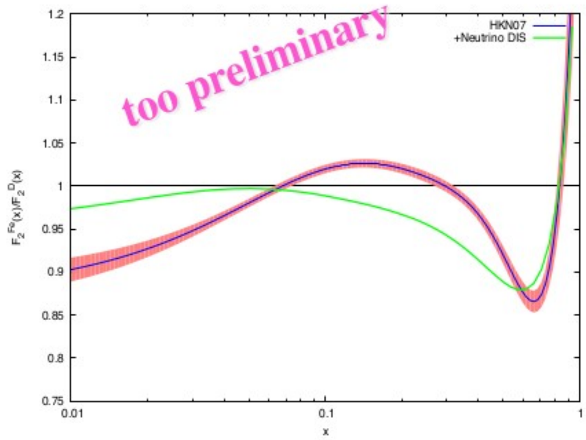
$F_2^{\nu \mathrm{Fe}} / F_2^{\nu \mathrm{D}}$ [PRD 77 (2008) 054013]

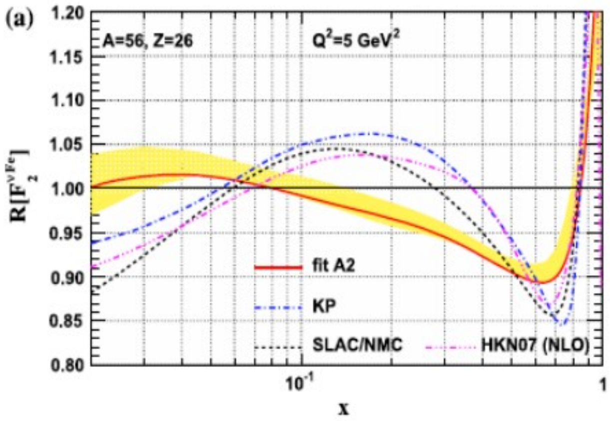


Kumano group getting the same shape ratio for ν-Fe as nCTEQ

[S. Kumano, Fermilab theory seminar, March 9, 2016]

Our research in progress (M. Hirai, SK, K. Saito)

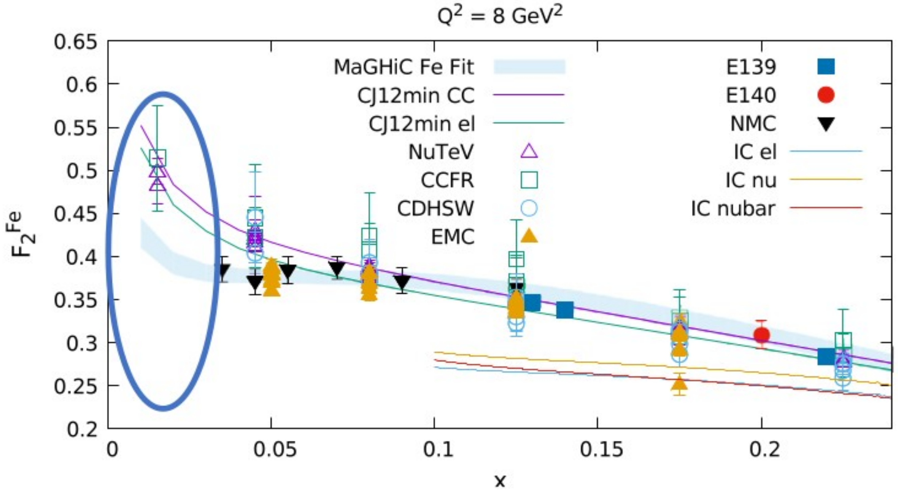




We are getting a similar modification to the nCTEQ one.

Is that all?

- PROBLEM: this conclusions are based only on the NuTeV experiment in particular including correlated errors! (if errors added in quadrature still slight tensions exist).
  - On top of this fitting just the NuTeV data the obtained $\chi^2/\mathrm{dof} \geq 1.3$
  - Even dividing the NuTeV data into neutrino and anti-neutrino and fitting them separately it still gives $\chi^2/\mathrm{dof} \geq 1.3$ (neutrinos).
- CHORUS is generally compatible.
- How about CCFR? If we analyses CCFR data instead of the NuTeV we are able to obtain a compromise fit



Recent Jlab analysis of F_2 from μ + Fe compared to F_2 from ν + Fe scaled by 5/18 to account for quark charges.

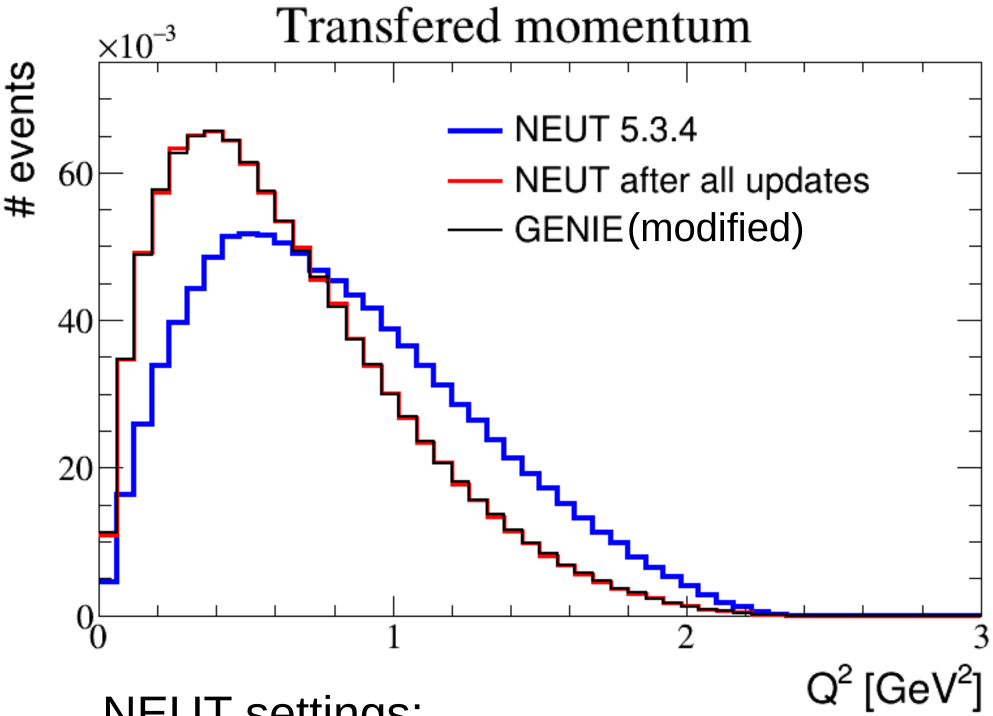
Narbe Kalantarians, Cynthia Keppel, M. Eric Christy

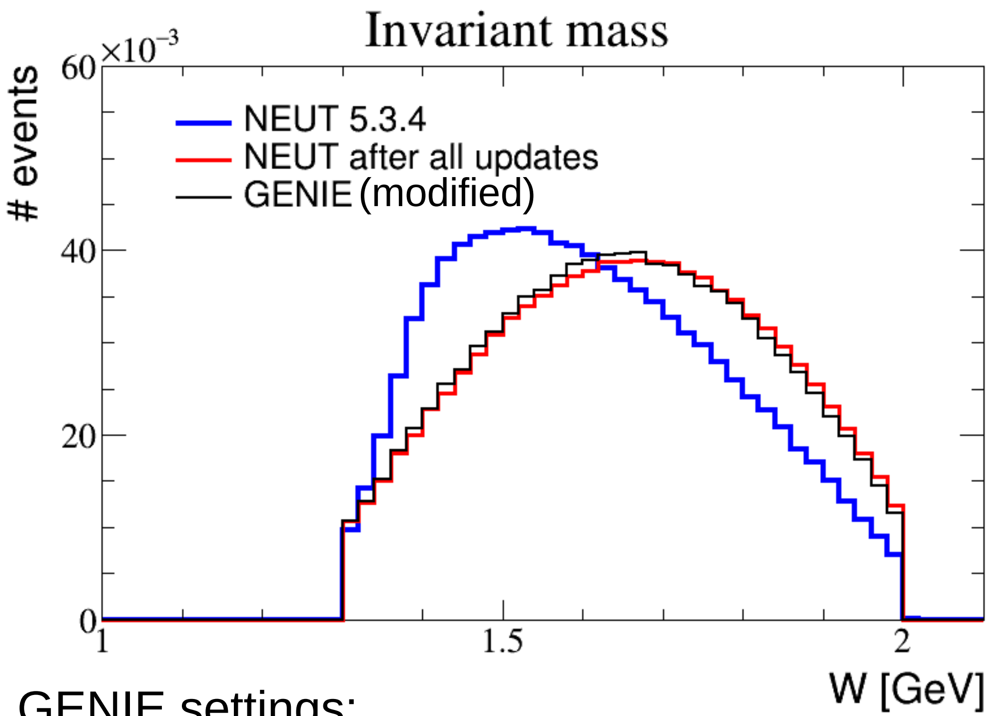
Phys.Rev. C96 (2017) no.3, 032201

See similar lack of shadowing for ν + Fe

Generator comparison
Low W DIS model

- NEUT and GENIE use similar method and inputs to generate (x,y)/(W,Q^2) in their low W models
- Found when doing generator comparison for NuINT 2015 that obtained distributions were different for the 2
- Now consistent if used in the same way (DIS only, 1.7 GeV < W < 2 GeV, at least 2 pions)





NEUT settings:

- default

GENIE settings:

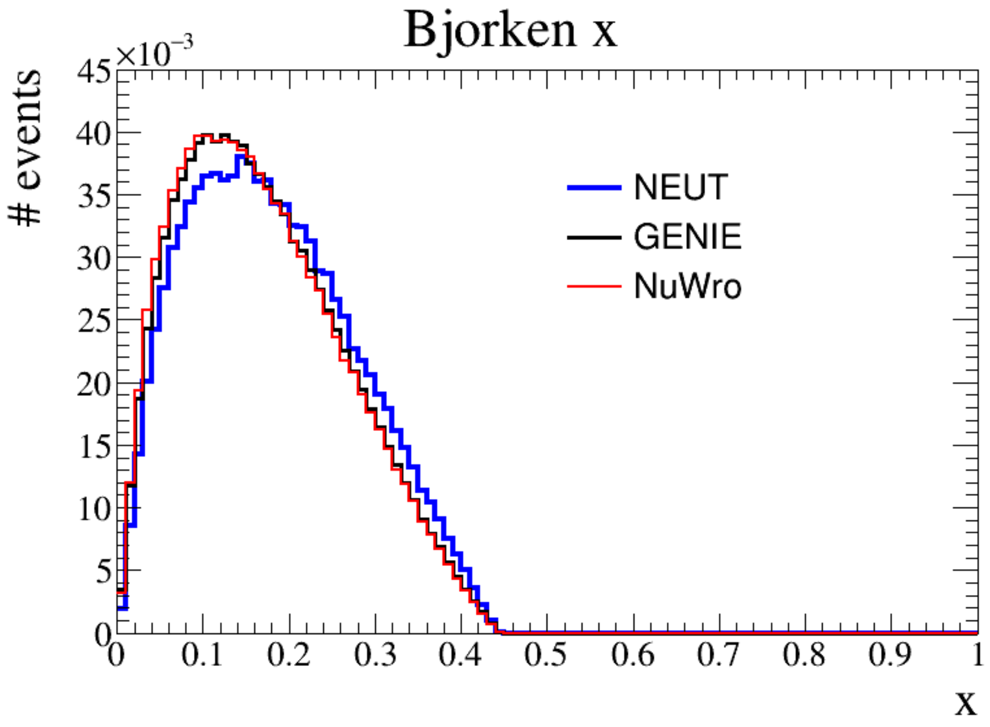
- DISSF-Use2016Corrections false → true
- DISSF-LowQ2CutoffF1F2 0.8 → 0.0

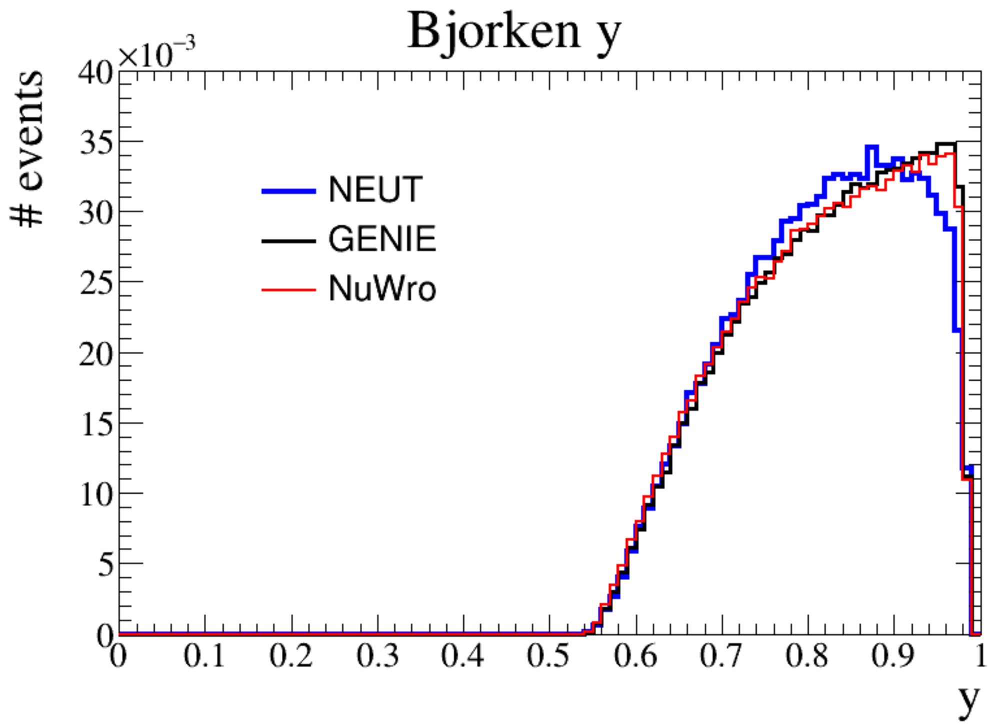
2 GeV ν_μ on free protons, $n_\pi \geq 2$

High W models

At high W, all generators use PYTHIA

- NEUT uses PYTHIA 5, GENIE and NuWro PYTHIA6
- In NEUT, event is fully generated by PYTHIA
- GENIE and NuWro generate (x,y), select target quark and use PYTHIA fragmentation routines
- NEUT and GENIE use GRV98, NuWro uses GRV94





8 GeV ν_μ on free protons, W>3 GeV

CB, “Generator comparisons SIS/DIS region”

“I would not trust PYTHIA for anything with less than 6 pions”

Physics assumptions/limitations:

Always want to confine previously deconfined color.

Target-m not really present in x-section or q/g kinematics.

Only tested for $W > 4$ GeV, small W in $e^+e^- \to h$ only, last global overview in 1987?

“Jet joining” not well-understood for low hadron multiplicity.

Strong isospin not traced in string.

Strings are traditionally non-interaction.

First and foremost: Event generators ♡ Data

So if you have data & analysis code, share them publicly!

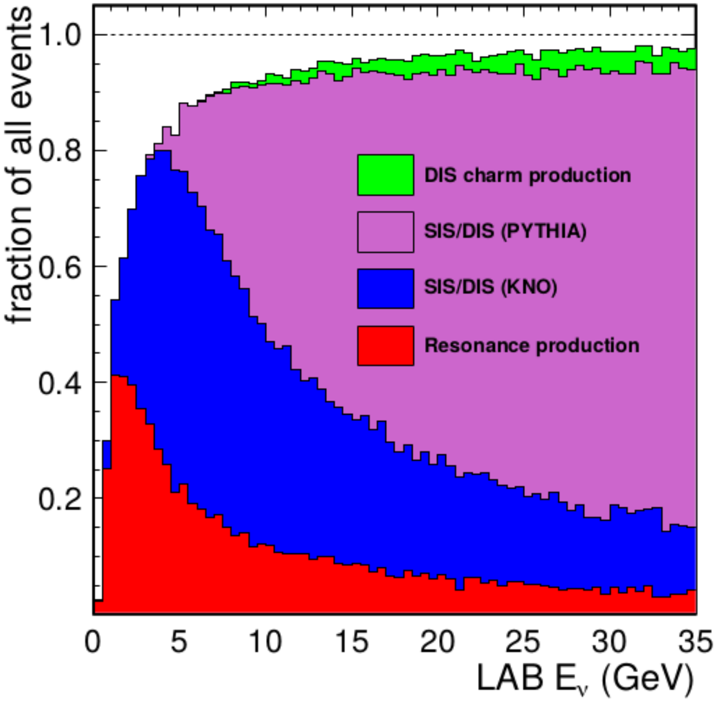
Low-energy and low-multiplicity improvements require experimental input, *i.e. need simple way to compare to data in the development process*.

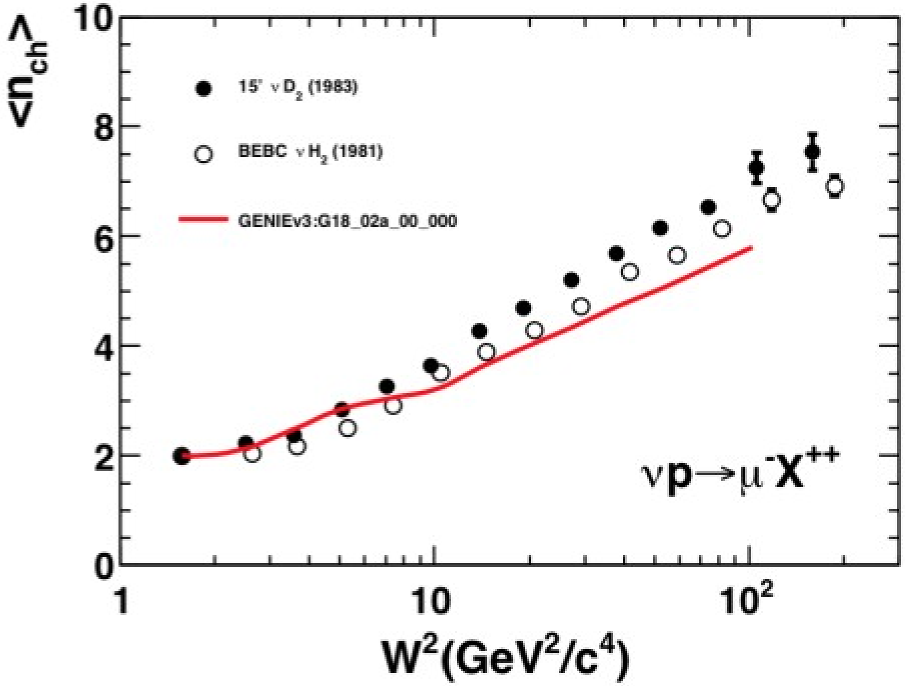
S. Prestel, “The LUND hadronization model”

Hadronization modelling in GENIE

Three main elements:

- PYTHIA6, valid at higher W
- Empirical model, valid for SIS/DIS at W < 3 GeV
- Empirical model, specialised for DIS charm production



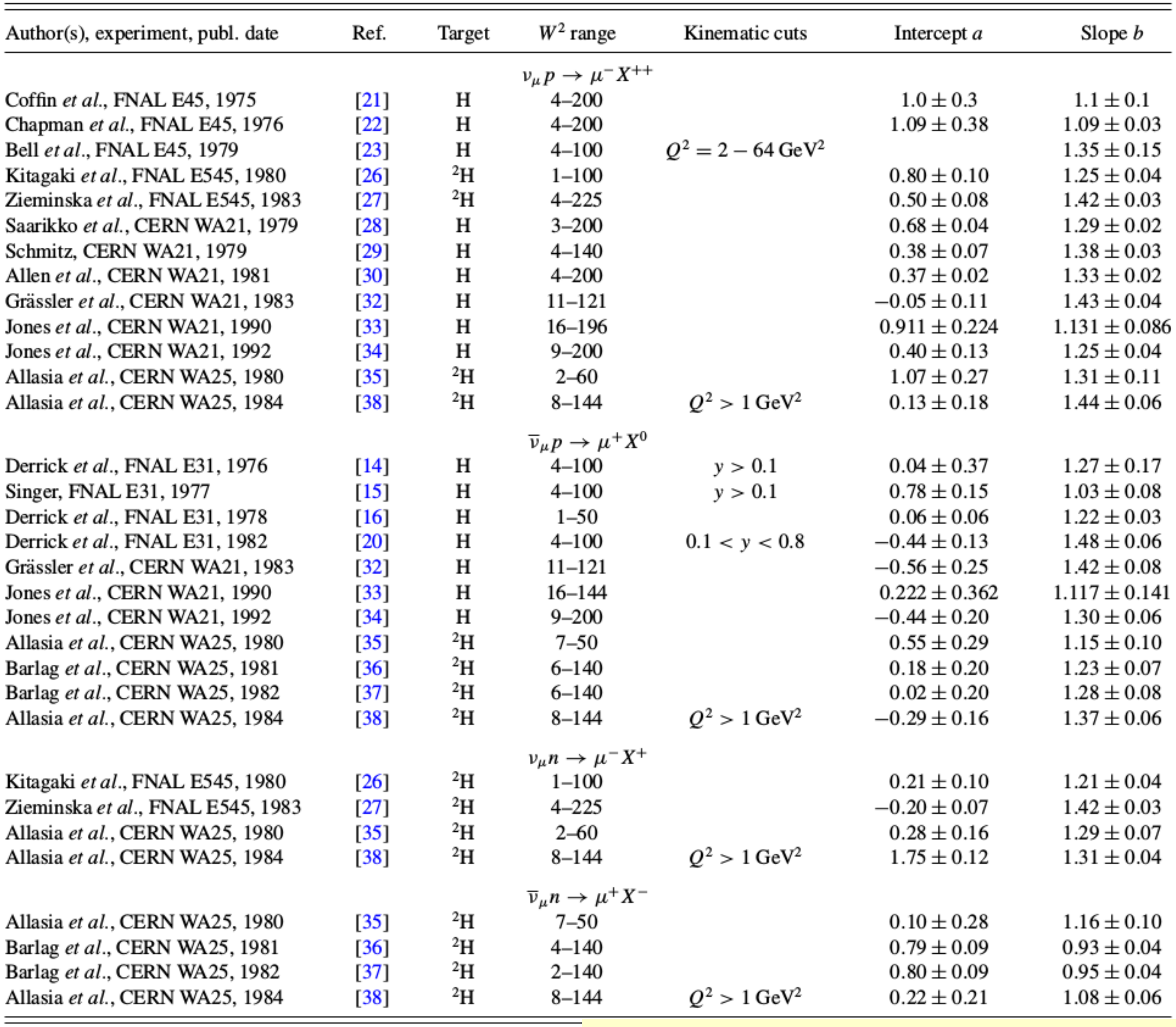


- Hadronization modelling and tuning become next GENIE priorities.

C. Andreopoulos, “Hadronization models in GENIE”

Low W multiplicity models

- Use data from bubble chamber experiments to measure free parameters
- To decorrelate from final state interaction modelisation, use data from hydrogen and deuterium experiments



Author(s), experiment, publ. date	Ref.	Target	W^2 range	Kinematic cuts	Intercept a	Slope b
			$\nu_\mu p \to \mu^- X^{++}$			
Coffin *et al.*, FNAL E45, 1975	[21]	H	4–200		1.0 ± 0.3	1.1 ± 0.1
Chapman *et al.*, FNAL E45, 1976	[22]	H	4–200		1.09 ± 0.38	1.09 ± 0.03
Bell *et al.*, FNAL E45, 1979	[23]	H	4–100	$Q^2 = 2 - 64\,\mathrm{GeV}^2$		1.35 ± 0.15
Kitagaki *et al.*, FNAL E545, 1980	[26]	^{2}H	1–100		0.80 ± 0.10	1.25 ± 0.04
Zieminska *et al.*, FNAL E545, 1983	[27]	^{2}H	4–225		0.50 ± 0.08	1.42 ± 0.03
Saarikko *et al.*, CERN WA21, 1979	[28]	H	3–200		0.68 ± 0.04	1.29 ± 0.02
Schmitz, CERN WA21, 1979	[29]	H	4–140		0.38 ± 0.07	1.38 ± 0.03
Allen *et al.*, CERN WA21, 1981	[30]	H	4–200		0.37 ± 0.02	1.33 ± 0.02
Grässler *et al.*, CERN WA21, 1983	[32]	H	11–121		-0.05 ± 0.11	1.43 ± 0.04
Jones *et al.*, CERN WA21, 1990	[33]	H	16–196		0.911 ± 0.224	1.131 ± 0.086
Jones *et al.*, CERN WA21, 1992	[34]	H	9–200		0.40 ± 0.13	1.25 ± 0.04
Allasia *et al.*, CERN WA25, 1980	[35]	^{2}H	2–60		1.07 ± 0.27	1.31 ± 0.11
Allasia *et al.*, CERN WA25, 1984	[38]	^{2}H	8–144	$Q^2 > 1\,\mathrm{GeV}^2$	0.13 ± 0.18	1.44 ± 0.06
			$\overline{\nu}_\mu p \to \mu^+ X^0$			
Derrick *et al.*, FNAL E31, 1976	[14]	H	4–100	$y > 0.1$	0.04 ± 0.37	1.27 ± 0.17
Singer, FNAL E31, 1977	[15]	H	4–100	$y > 0.1$	0.78 ± 0.15	1.03 ± 0.08
Derrick *et al.*, FNAL E31, 1978	[16]	H	1–50		0.06 ± 0.06	1.22 ± 0.03
Derrick *et al.*, FNAL E31, 1982	[20]	H	4–100	$0.1 < y < 0.8$	-0.44 ± 0.13	1.48 ± 0.06
Grässler *et al.*, CERN WA21, 1983	[32]	H	11–121		-0.56 ± 0.25	1.42 ± 0.08
Jones *et al.*, CERN WA21, 1990	[33]	H	16–144		0.222 ± 0.362	1.117 ± 0.141
Jones *et al.*, CERN WA21, 1992	[34]	H	9–200		-0.44 ± 0.20	1.30 ± 0.06
Allasia *et al.*, CERN WA25, 1980	[35]	^{2}H	7–50		0.55 ± 0.29	1.15 ± 0.10
Barlag *et al.*, CERN WA25, 1981	[36]	^{2}H	6–140		0.18 ± 0.20	1.23 ± 0.07
Barlag *et al.*, CERN WA25, 1982	[37]	^{2}H	6–140		0.02 ± 0.20	1.28 ± 0.08
Allasia *et al.*, CERN WA25, 1984	[38]	^{2}H	8–144	$Q^2 > 1\,\mathrm{GeV}^2$	-0.29 ± 0.16	1.37 ± 0.06
			$\nu_\mu n \to \mu^- X^+$			
Kitagaki *et al.*, FNAL E545, 1980	[26]	^{2}H	1–100		0.21 ± 0.10	1.21 ± 0.04
Zieminska *et al.*, FNAL E545, 1983	[27]	^{2}H	4–225		-0.20 ± 0.07	1.42 ± 0.03
Allasia *et al.*, CERN WA25, 1980	[35]	^{2}H	2–60		0.28 ± 0.16	1.29 ± 0.07
Allasia *et al.*, CERN WA25, 1984	[38]	^{2}H	8–144	$Q^2 > 1\,\mathrm{GeV}^2$	1.75 ± 0.12	1.31 ± 0.04
			$\overline{\nu}_\mu n \to \mu^+ X^-$			
Allasia *et al.*, CERN WA25, 1980	[35]	^{2}H	7–50		0.10 ± 0.28	1.16 ± 0.10
Barlag *et al.*, CERN WA25, 1981	[36]	^{2}H	4–140		0.79 ± 0.09	0.93 ± 0.04
Barlag *et al.*, CERN WA25, 1982	[37]	^{2}H	2–140		0.80 ± 0.09	0.95 ± 0.04
Allasia *et al.*, CERN WA25, 1984	[38]	^{2}H	8–144	$Q^2 > 1\,\mathrm{GeV}^2$	0.22 ± 0.21	1.08 ± 0.06

Phys. Rev. C 88, 065501 (2013)

Many problems:

- ✗ inconsistent results between datasets
- ✗ actual data hard to find
- ✗ no systematic uncertainties most of the time

- NEUT model 0 uses [16] ($\bar{\nu}$-p) for all types
- GENIE uses [27] for ν and [37] for $\bar{\nu}$, and symmetry νp ↔ νn for some parameters

CB, “SIS/DIS interactions and uncertainties in atmospheric oscillation analysis”

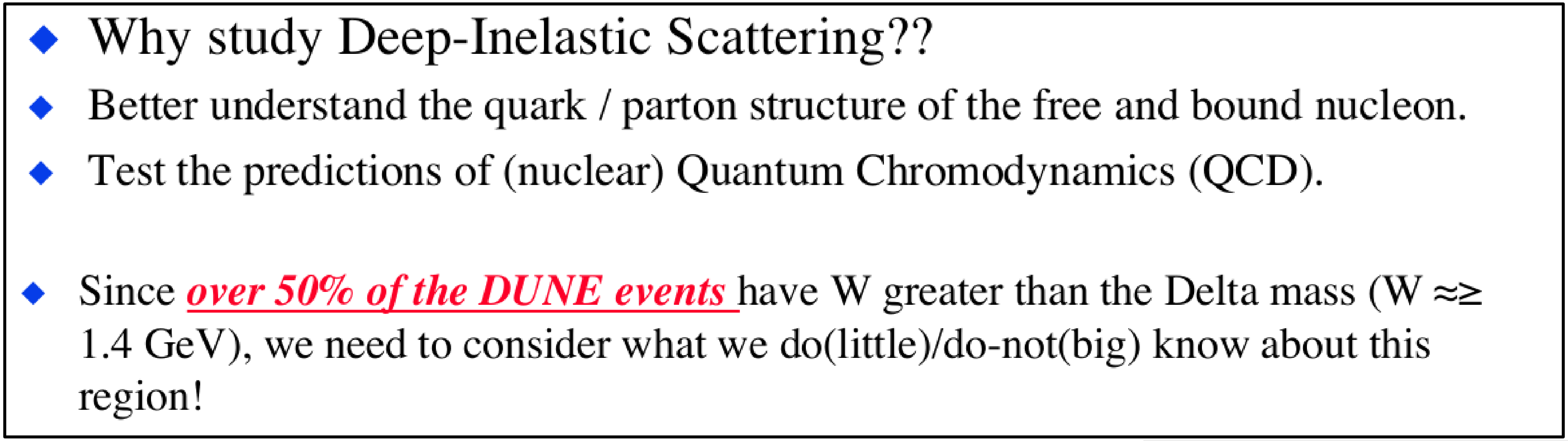
5. Conclusion: SIS systematics errors for ν-oscillation

Type	type of error	approach	ongoing issue	size of error
resonance	Single pion production	Form factors, external data on e and nu	MiniBooNE-MINERvA data tension	large, but studied well
SIS	Non-resonant background	External data on e and nu	Not many studies. Very phenomenological	???
SIS	Bodek-Yang correction	Change Bodek-Yang parameters by eyes	There is are correlations on model parameters	maybe large?
SIS	Higher resonance	???	MC must be wrong	???
DIS	differential xs	NuTeV-GENIE comparison (bottom-up)	Disagreement seen only at very low x (<0.03)	1-2% by GENIE
DIS	A-scaling, empirical	MINERvA-GENIE (bottom-up)	No understanding MINERvA data	maybe large?
DIS	A-scaling, nuclear PDF	From nuclear PDF, CT10? nCTEQ? (top-down)	GRV98 is only compatible with B-Y correction	expected to be small
Hadronization	low W averaged charged hadron multiplicity	Change AGKY model parameters	Not many data.	maybe large?
Hadronization	high W averaged charged hadron multiplicity	bubble chamber-PYTHIA comparison	Lund string function need to be tune for lowE	1-2% by GENIE

Some of systematic errors are identified to be dangerous…,
- What kind of systematic errors do we have on nuSIS&DIS?

T. Katori, “Neutrino SIS systematic errors for oscillation experiments”

Where do we go from here?



- Why study Deep-Inelastic Scattering??
- Better understand the quark / parton structure of the free and bound nucleon.
- Test the predictions of (nuclear) Quantum Chromodynamics (QCD).

- Since *over 50% of the DUNE events* have W greater than the Delta mass (W ≈≥ 1.4 GeV), we need to consider what we do(little)/do-not(big) know about this region!

J. Morfin @ NuFACT2018

- Saw there were many things we did not understand/open questions for both aspects
- Considering releasing commented slides (instead of proceedings) and recommendation / proposal to go forward
- Hoping to see progress on SIS/DIS understanding / simulation / uncertainties at next NuINT