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UNIVERSITAS
WRATISLAVIENSIS

Neutrino Physics Division

→

Wrocław Neutrino Group"
by
Krzysztof M. Graczyk

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Staff

- prof. Jan Sobczyk
- dr hab. Dariusz Prorok
- dr Krzysztof Graczyk
- dr Cezary Juszczak

PhD Students

- Tomasz Golan

Research topics

- Nuclear effects in neutrino interactions (spectral function as a description of nucleus, random phase approximation, multinucleon ejection)
- Monte Carlo simulations, Final State Interactions
- Pion production in neutrino scattering off nucleon, nuclei
- Nucleon form factors
- Neural computation in particle physics
- Statistical data analysis (neutrino scattering data, electron scattering data, and heavy-ion collisions scattering data)

Our group takes part in T2K experiment

We are supported by the following grants:

- UMO-2-11/M/ST2/02578
- 4525/PB/IFT/11

•Keywords:

- ν -nucleon
- ν -nucleus scattering (RPA, Spectral Function, MEC, FSI, nuclear cascade models)
- structure of the nucleon and $\Delta(1232)$ resonance (nucleon and transition form factors)
- single π production induced by ν -N,A interactions
- Monte Carlo simulations
- statistical data analysis, neural networks
- T2K experiment, neutrino oscillations
- electron-proton scattering (two photon exchange effect)

•Methodology

- quantum field theory
- many body theory
- physics of hadrons
- relativistic hydrodynamics, mean field theory
- chiral field theory

<http://wng.ift.uni.wroc.pl>

or

<http://neutrino.ift.uni.wroc.pl>

MASTER OF SCIENCE

Pasternak
2005, Ph.D.
K. Graczyk

2006, Ph.D.
J. Nowak
(Minnesota St. U.)

Winter
School
2009

Wroclaw Neutrino Group

around
2001

Nowak
Ankowski
2005, Ph.D.
J. Pasternak
(Imperial College)

Żmuda
Golan
Dutkiewicz
2008, Ph.D.
A. Ankowski
(Rome U.)

Kobyliński
Juchnowski
2013, Ph.D.
T. Golan

Gonera
2013, Ph.D.
J. Żmuda

ICARUS

STAFF

- prof. J. Sobczyk
- dr. hab D. Prorok
- dr K. Graczyk
- dr C. Juszczak
- mgr J. Żmuda
- mgr T. Golan

Active participation
in:
NuInt (every 1.5 y.)
and
NuFact (every y.)
conferences



A cooperation with
neutrino groups from
Warszawa,
Kraków,
Katowice

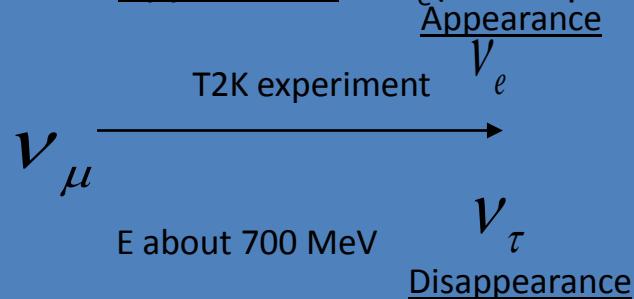


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Neutrino Oscillations

- Disappearance of ν_μ (Far and Near Detectors)
- Appearance of ν_e (T2K experiment)



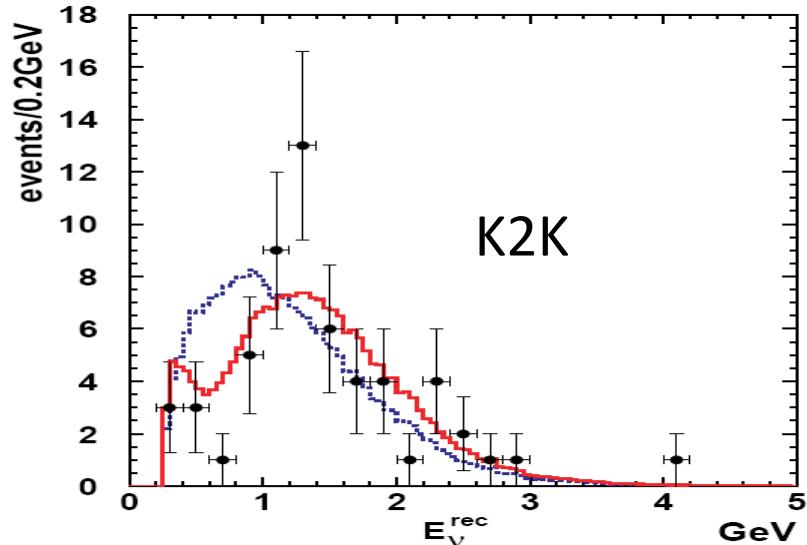
Rather Practical Motivation

Neutrino oscillation experiments

→ a need to constrain better systematic errors.

- neutrino-nucleon cross sections uncertainties are still around 20-30%.
- in all the cross section measurement experiments the neutrino flux was known with a poor precision
- interactions occur on nuclei with many complications coming from nuclear effects.

1 GeV ν 's → motivation



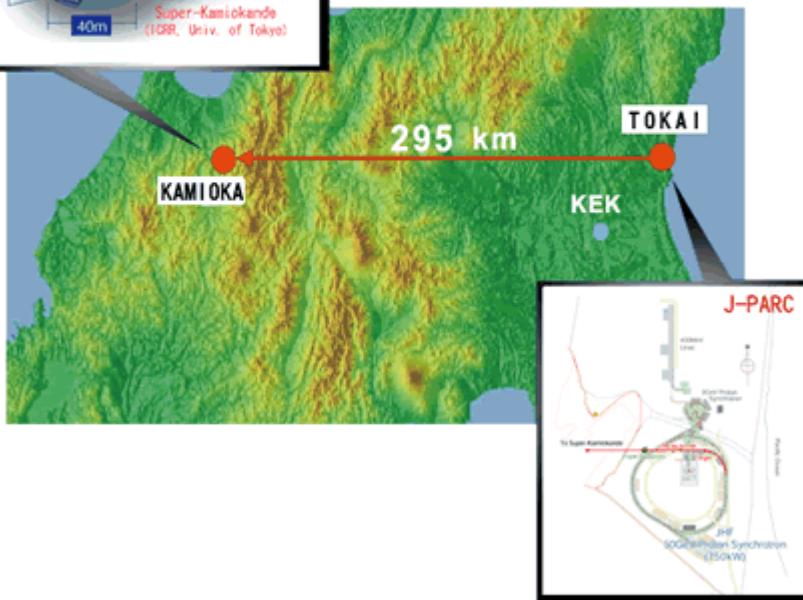
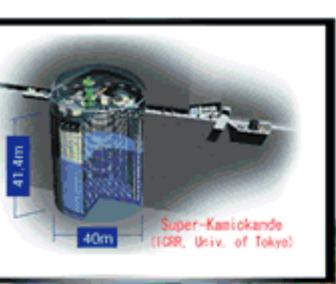
M. H. Ahn, Phys.Rev. D74 (2006) 072003

Fundamental Motivation

Neutrino, electron – nucleon, nuclei scattering

- weak, electromagnetic probe of the nucleon, nuclei
- Electroweak structure of hadrons

T2K Experiment



- Measurement of $\nu_\mu \rightarrow \nu_e$ (i.e., the confirmation that $\theta_{13} > 0$)
 - precision measurements of oscillation parameters in ν_μ disappearance;
 - a search for sterile components in ν_μ disappearance by observation of neutral-current

The T2K collaboration has about 500 members from 56 institutes in 11 countries.

We are the only theoretical group in T2K
(J. Sobczyk, T. Golan, J. Żmuda): software development



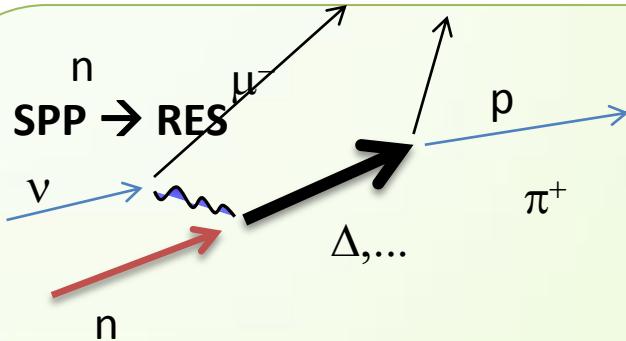
Phys.Rev.Lett. 107 (2011) 041801
Phys.Rev. D85 (2012) 031103

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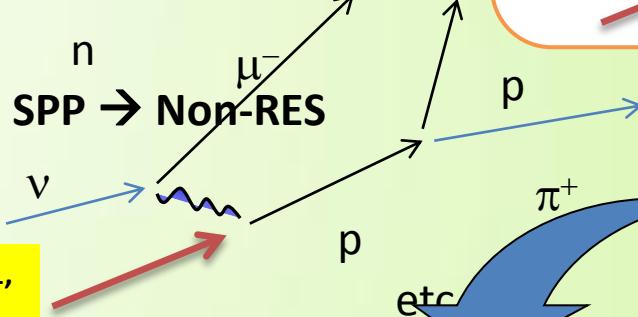
The 1 GeV neutrino scattering off nucleons, nuclei

ν -nucleon



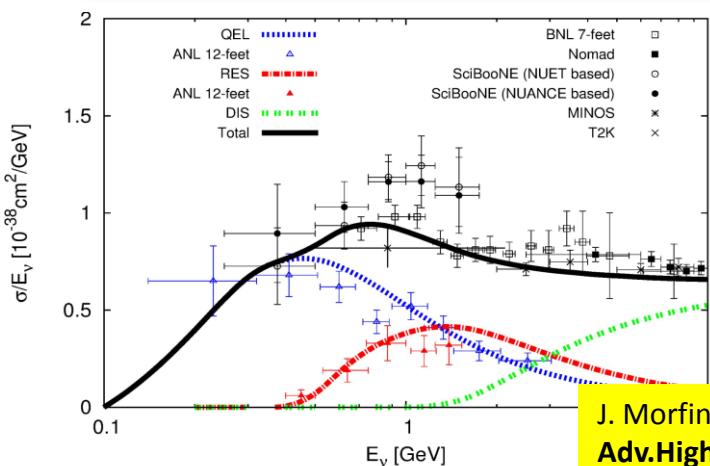
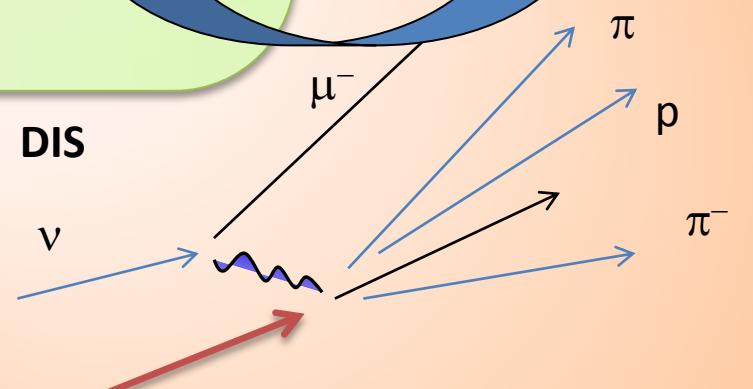
K.M.G, J. T. Sobczyk, Phys.Rev. D77 (2008) 053001,
 Phys.Rev. D77 (2008) 053003.
 K.M.G et al. Phys.Rev. D80 (2009) 093001.
 K.M.G, AIP Conf.Proc. 1405 (2011) 134-139

- Hadronic and mesonic degrees of freedom
- Chiral field theory motivated description
- Quark model motivated approach
- Isobar model



KMG, C. Juszczak, J.T.Sobczyk,
Nucl.Phys. A781 (2007) 22
 KMG, AIP Conf.Proc. 1222 (2010) 238

Quark-Hadron Duality

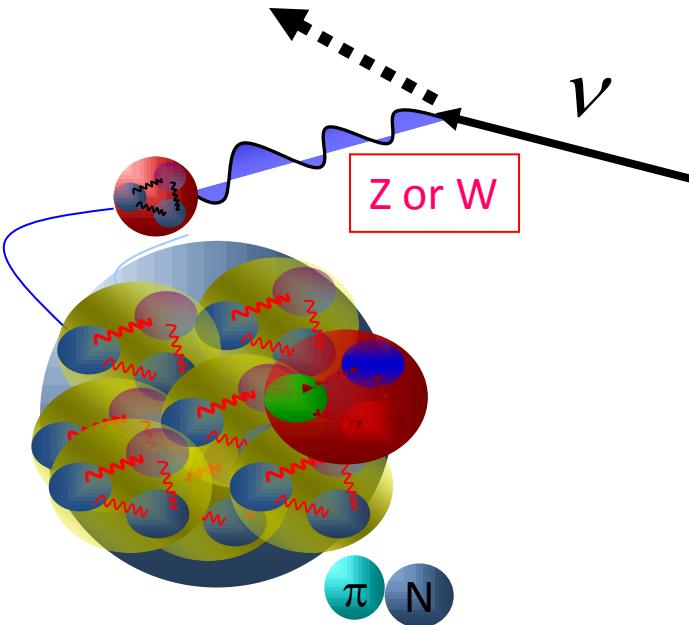


J. Morfin, J. Nieves, **J. T. Sobczyk**,
Adv.High Energy Phys. 2012 (2012) 934597

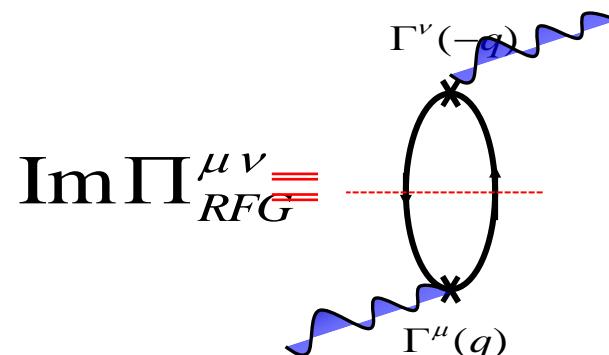
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ν -nucleus

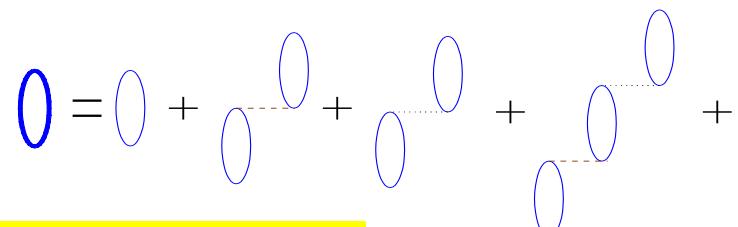


- QE and SPP can look the same in the detector
- Problem of reconstruction of neutrino energy



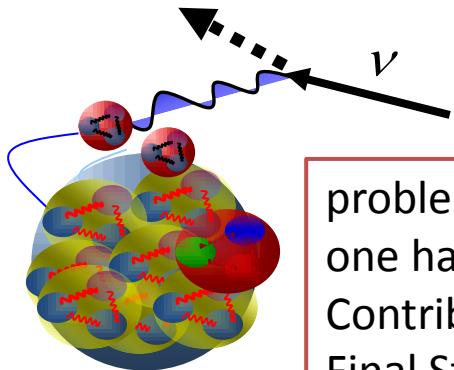
- One body currents from neutrino-nucleon scattering: an input of nuclear models
- Impuls approximation
- Fermi Gas model, a ground state of the nucleon
- Spectral function approach
- A bare nuclear model dressed by: e.g. RPA 1n-1h excitations, calculations within relativistic HadroDynamics .

$$i\Pi^{\mu\nu}(q) = \int \frac{d^4 p}{(2\pi)^4} \text{Tr} \left(G(p+q) \Gamma^\mu G(p) \Gamma^\nu \right)$$

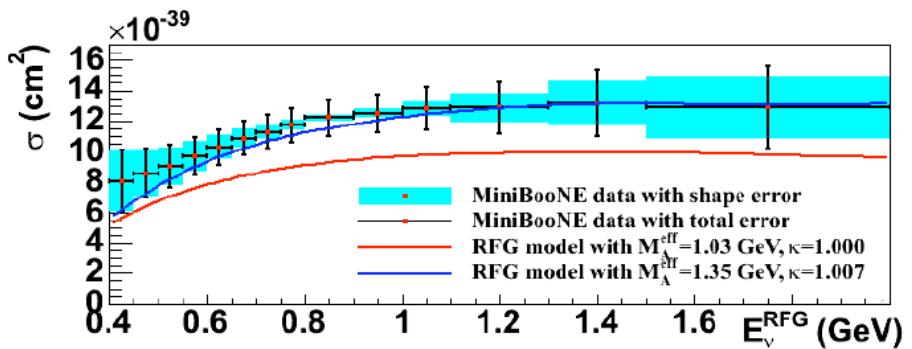


SF: A.Ankowski, J.T.Sobczyk, Phys.Rev. C74 (2006) 054316
 Phys.Rev. C77 (2008) 044311

KMG, J.T.Sobczyk, Eur.Phys.J. C31 (2003) 177,
 KMG, Nucl.Phys. A748 (2005) 313



problem of the axial mass
one has to take into account MEC
Contribution (beyond one body current)
Final State Interaction
Pion production and absorbtion etc.



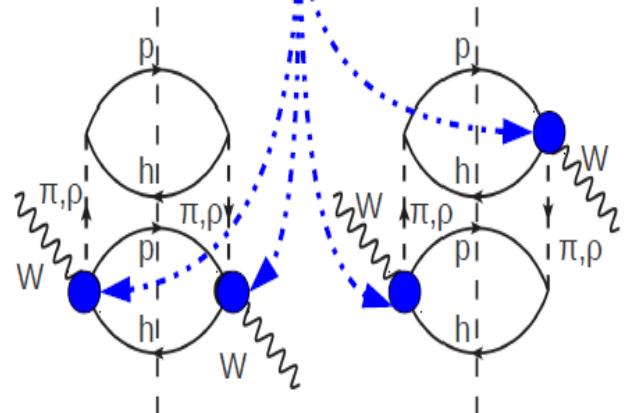
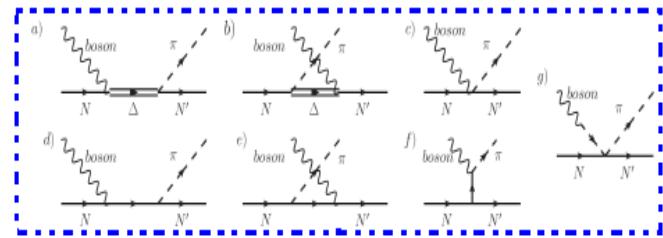
Seminar of T. Katori

J.T.Sobczyk, J.Żmuda, arXiv:1210.6149

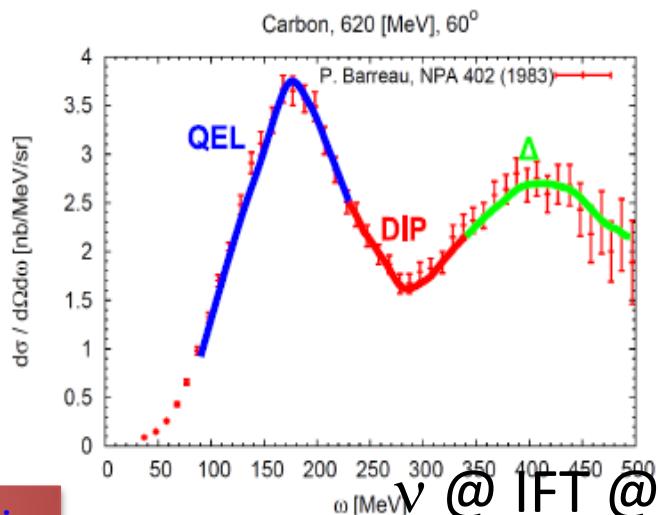
J.T.Sobczyk, Phys. Rev. C86, 015504 (2012)

C. Juszczak, J.T.Sobczyk, J.Żmuda, Phys.Rev. C82 (2010) 045502

K.M. Graczyk, C. Juszczak, J.T.Sobczyk, T. Golan, will be available next week



From J. Żmuda



FSI: propagation of nucleons throw nuclei, →

Metropolis algorithm → NuWr

Tomek Golan Movie



Experiment at Home

Monte Carlo simulations

with

NuWro

- Authors:

- mgr Tomasz Golan
- dr Krzysztof Graczyk
- dr Cezary Juszczak
- dr Jarosław Nowak
- prof. Jan Sobczyk
- Maciej Tabiszewski
- mgr Jakub Żmuda

NuWro - Wrocław Neutrino Events Generator

Wrocław Neutrino Group

[Documentation](#) [FAQ](#) [Downloads](#) [Publications](#) [Repository*](#)

NuWro - Wroclaw Neutrino Event Generator

Monte Carlo event generator for simulation neutrino nucleus scattering developed by the Wrocław Neutrino Group.

• mgr Tomasz Golan,
• dr Krzysztof Graczyk,
• dr Cezary Juszczak,
• dr Jarosław Nowak,
• prof. Jan Sobczyk,
• Maciej Tabiszewski
• mgr Jakub Żmuda

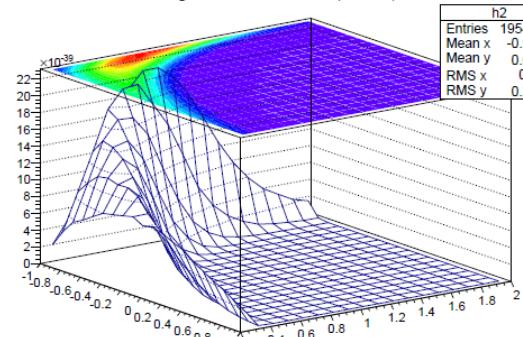
- mgr Tomasz Golan,
• dr Krzysztof Graczyk,
• dr Cezary Juszczak,
• dr Jarosław Nowak,
• prof. Jan Sobczyk,
• Maciej Tabiszewski
• mgr Jakub Żmuda

- ❑ All major neutrino-nucleus interaction channels (QEL, DIS, RES and COH)
- ❑ Covers ν energies from MeV to TeV
- ❑ density profiles and binding energies for most of nuclei
- ❑ Local Fermi Gas and Spectral Function models of nucleus.
- ❑ Intra-Nuclear cascade with pion-nucleon and nucleon-nucleon scattering.
- ❑ scattering of **complex neutrino beams** on real **detector** geometries
- ❑ the detector geometry is read from a data file (NuWro can be used by many different experiments)
- ❑ The object oriented data analysis –compatible with root CERN frametool.

Selected papers:

- C. Juszczak, T. Golan, J.T. Sobczyk, Phys. Rev. C86 (2012) 015505
- C. Juszczak , J. T. Sobczyk, J. Żmuda, Phys. Rev. C82 (2010) 045502
- C. Juszczak, Acta Phys.Polon. B40 (2009) 2507
- J. Nowak, J. T. Sobczyk, Acta Phys.Polon. B37 (2006) 1955
- C. Juszczak, J. A. Nowak, Nucl. Phys. Proc. Suppl. 159 (2006) 211
- J. T. Sobczyk, J. A. Nowak, K.M. Graczyk, Nucl.Phys.Proc.Supp. 139 (2005) 266

$d\sigma/d\cos \theta dT$ (nuwro)



• NuWro is the first MC generator to

- include such dynamical effects like spectral function and Meson Exchange Current.
- has an online interface <http://nuwro.ift.uni.wroc.pl>
- It is probably the fastest event generation, compared to other codes.

Calendar

[Have a safe day!](#)

Thursday, June 7
2:30 p.m.

[Theoretical Physics Seminar](#) - Curia II
Speaker: Daping Du,

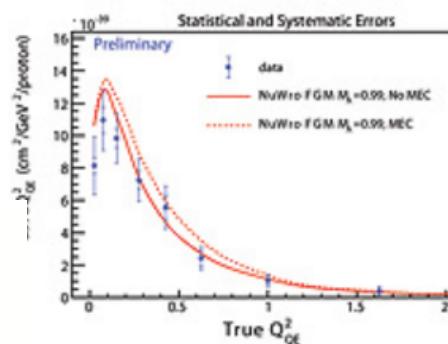
Special Announcement

**Tevatron Impact Monday,
Users' Meeting Tuesday -
Wednesday**

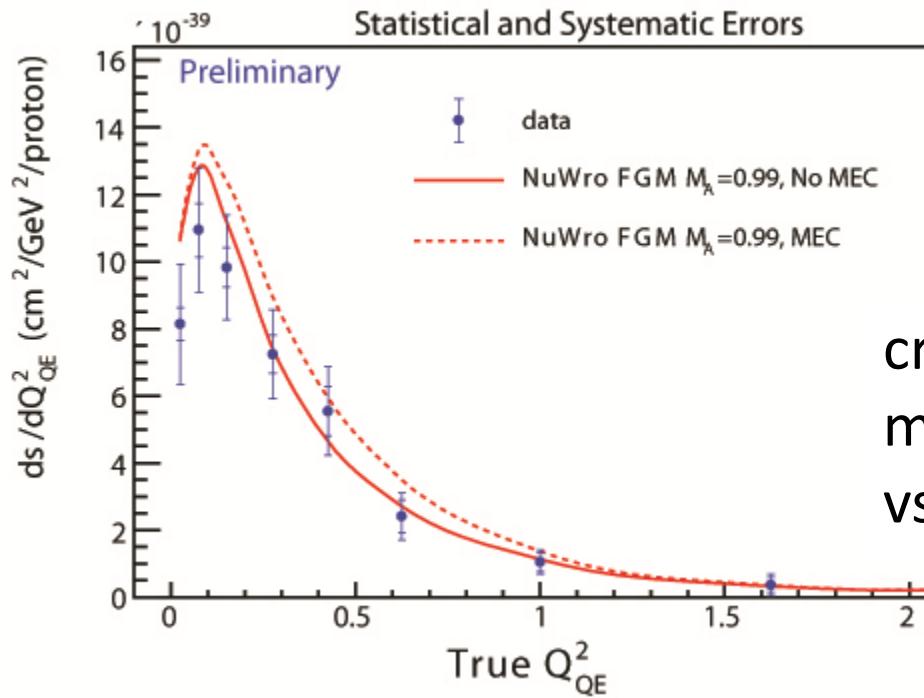
The [Tevatron Impact](#) symposium is [online](#). It will take place from 1 to 6 p.m. on Monday, followed by a reception in

Special Result of the Week

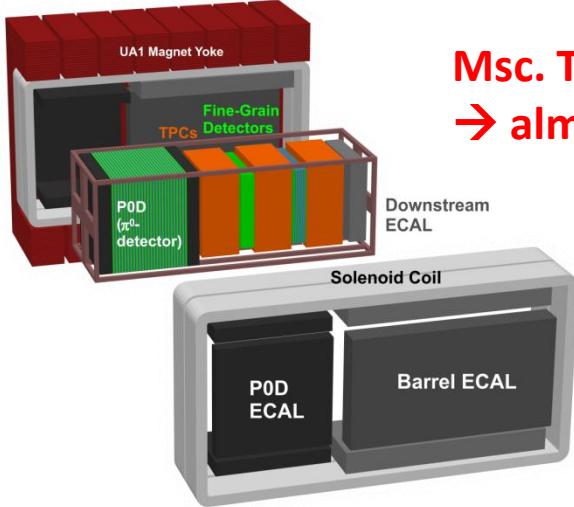
Fingerprinting the neutrino



This plot shows the likelihood of an anti-neutrino interacting with a proton to produce a muon and a neutrino as a function of the square of the

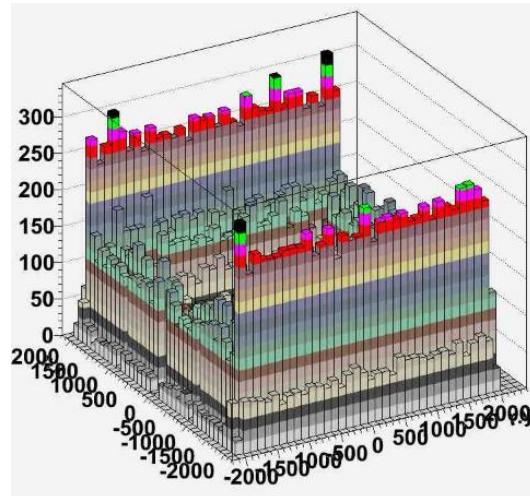


cross section
measurements by Minerva
vs. NuWro



Msc. Thesis of Miroslaw Nyznar

→ almost accomplished



Nuwo Charts Register Help						Log
Main Charts > Show charts						
Refine your search using common tricks: <value> =value >value <=value> >=value *value value* !value !value* <>value value1,value2,... number> number<						
Select All	Select Visible	Unselect All	0 items selected	Action:	Download	Submit
#	min	Params	Id Eventout	Nuwo version	Date created	
1		r.x,y LE902	68	11f_dvn118	2012-11-09 14:27:50	<input type="checkbox"/>
2		r.x,y LE903	68	11f_dvn118	2012-11-09 14:27:50	<input type="checkbox"/>
3		r.x,y LE902	124		2012-11-08 21:40:58	<input type="checkbox"/>
4		r.x,y LE903	124		2012-11-08 21:39:49	<input type="checkbox"/>
5		in[0].x,in[0].y,in[0].z	123		2012-11-08 14:16:58	<input type="checkbox"/>
6		out[0].out[1].t	123		2012-11-08 14:16:58	<input type="checkbox"/>
7		r.x,y	51		2012-06-08 23:08:37	<input type="checkbox"/>
8		in[0].x,in[0].y,in[0].z	51		2012-06-08 23:08:37	<input type="checkbox"/>
9						

Main>Nuovo>Run

Select version
nuovo11v0

random seed
0

Control the random seed persistence 0 - use time(NULL) as a seed for random number generator 1 - read state from file Random_seed or use seed+time(NULL) if it has not found other values - use given number as the seed for the generator

number of events
1000000

The number of equally weighted events to be saved

number of test events
1000000

The number of events used to calculate the cross sections

user events
0

beam type
1 2 3 select from file

target type
0 1 2 select from file

nucleus p
0

nucleus n
0

nucleus density
0

nucleus Eb
0

nucleus kf
0

nucleus target
0

nucleus model
0

dyn el ec Quasi elastic charged current

dyn el nc Quasi elastic neutral current

dyn res cc Resonant charged current

Resonant neutral current

Deep inelastic charged current

Deep inelastic neutral current

Coherent charged current

Coherent neutral current

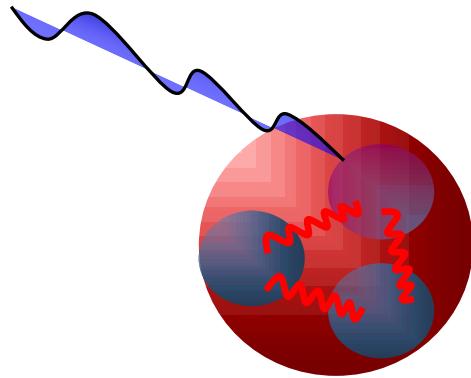
Other

running online

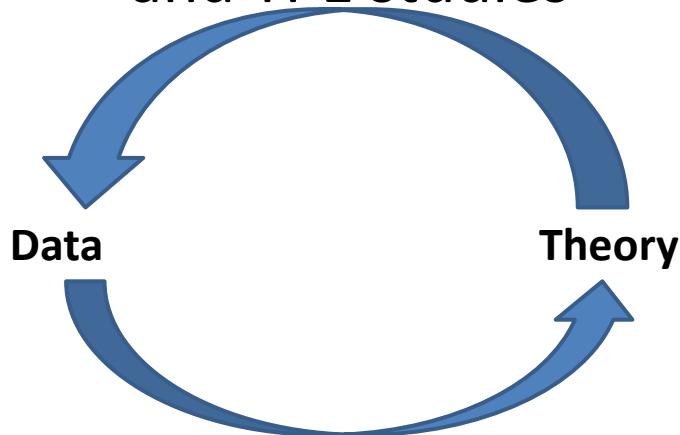
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Exploring Structure of the Proton :Electromagnetic Probe



Neural Networks vs. Theory and TPE studies



gluon

probably quark u

proton

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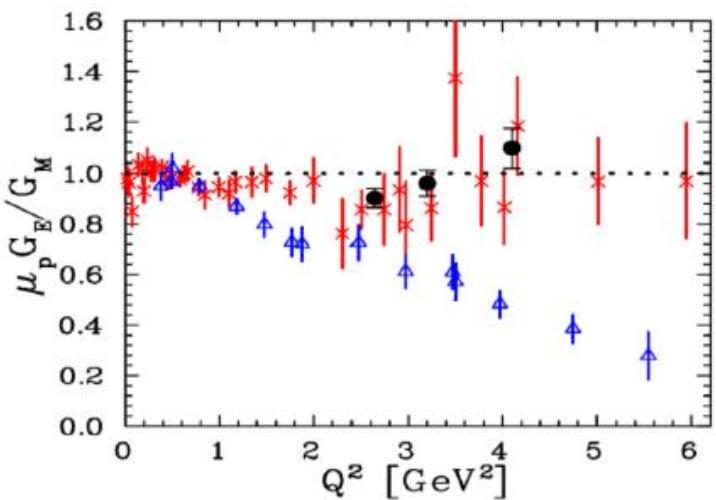
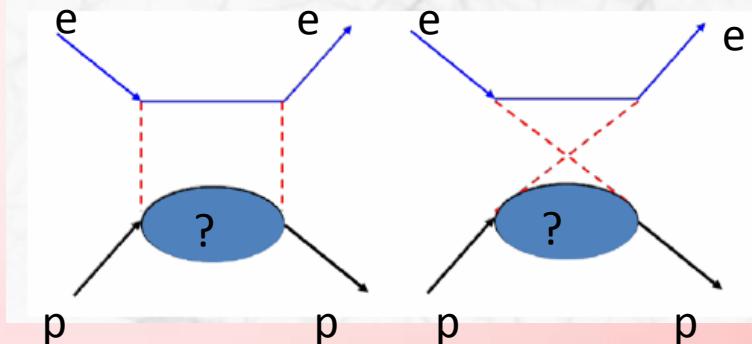


FIG. 3: (Color online) Extracted values of $\mu_p G_p / G_M$ from this work (circles), a global analysis of previous cross section data (Fig. 2 of Ref [9]) (crosses), and high- Q^2 polarization transfer measurements [5, 6] (triangles).

Figure : Taken from Qattan *et al.*, Phys. Rev. Lett. 94 (2005) 142301.



Two-Photon Hard Contribution,
which account for nontrivial hadronic
Structure

Investigation of the off shell nucleon
properties

TPE plays important role in the proton radius estimation!

- General idea taken from NNPDF group (<http://nnpdf.hepforge.org/>), parton distribution functions modeled by neural networks.
 - I start from JHEP 0205 (2002) 062;
-

KMG, P. Plonski, R. Sulej, JHEP 1009 (2010) 053

$$\langle \mathcal{O}(G_E, G_M) \rangle = \int \mathcal{D}G_E \mathcal{D}G_M \mathcal{O}(G_E, G_M) \mathcal{P}(G_E, G_M)$$

- Consider all possible neural network parametrizations, and classify them with a help of Bayesian statistics. A physical observable will be given by an average over all models.
- Estimate of the model uncertainties...

IDEA

Replace common sense by the Bayesian objective procedure...

Bayesian framework based on D. MacKay

It allows to

- classify quantitatively models;
- choose the best one to represent the data, based on the objective mathematical algorithm;
- establish weights and α parameter;
- compute uncertainties for network response and network parameters.
- * Totally different philosophy than NNPDF approach!

- Prior assumption: $\mathcal{P}(\mathcal{A}_1) = \dots = \mathcal{P}(\mathcal{A}_M) = \dots$,
- From Bayes' theorem: $\mathcal{P}(\mathcal{A}_n | \mathcal{D}) = \mathcal{P}(\mathcal{D} | \mathcal{A}_n) \mathcal{P}(\mathcal{A}_n) / \mathcal{P}(\mathcal{D})$, where $\mathcal{P}(\mathcal{D})$ is some real constant.
- One has to compute an evidence $\mathcal{P}(\mathcal{D} | \mathcal{A}_n)$ – GoF.
- For given network \mathcal{A}_n we must establish \vec{w}_{MP} . The maximize the posterior probability,

$$\underbrace{\mathcal{P}(\vec{w} | \{\mathcal{D}, \{\mathcal{I}\}, \mathcal{A}_n\})}_{\text{posterior}} = \frac{\underbrace{\mathcal{P}(\mathcal{D} | \{\vec{w}, \{\mathcal{I}\}, \mathcal{A}_n\})}_{\text{likelihood fun.}} \underbrace{\mathcal{P}(\vec{w} | \{\{\mathcal{I}\}, \mathcal{A}_n\})}_{\text{prior}}}{\mathcal{P}(\mathcal{D} | \{\mathcal{I}\}, \mathcal{A}_n)}, \quad (28)$$

- $\mathcal{P}(\mathcal{D} | \vec{w}, \{\mathcal{I}\}, \mathcal{A}_n) \sim \exp(-S_{ex}(\mathcal{D}, \vec{w}))$
- Two types of prior assumptions: physical and neural network: $\{\mathcal{I}\} = \{\mathcal{I}\}_{ANN} \cup \{\mathcal{I}\}_{phys}$.
- ANN constraints introduced to prevent overtrained solutions: $\{\mathcal{I}\}_{ANN} = \{\alpha, \text{rodzaj regularyzatora}\}$

$$\begin{aligned} \mathcal{P}(\vec{w} | \{\{\mathcal{I}\}_{ANN}, \mathcal{A}_n\}) &= \mathcal{P}(\vec{w} | \{\alpha, \mathcal{A}_n\}) \\ &\sim \exp(-\alpha E_w(\vec{w})) \end{aligned}$$

Occam's razor

Method in natural way prefers simpler model than complex description.

$$\mathcal{N}_{g,t} : \mathbb{R}^2 \mapsto \mathbb{R}^3, \quad \mathcal{N}_{g,t}(Q^2, \epsilon; \mathcal{A}_{g,t}, \vec{w}) = \begin{pmatrix} G_M \\ G_E \\ \Delta C_{2\gamma} \end{pmatrix}.$$

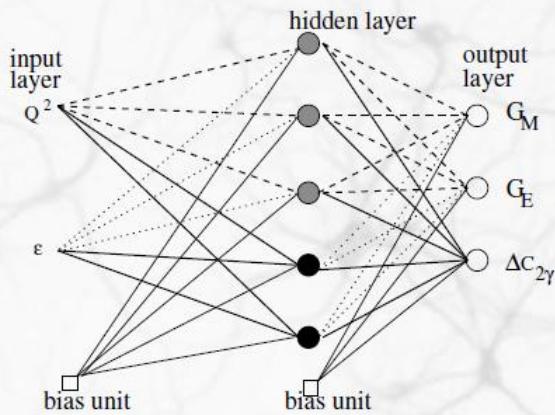


Figure : ANN: 2-(3-2)-3, $\mathcal{A}_{3,2}$

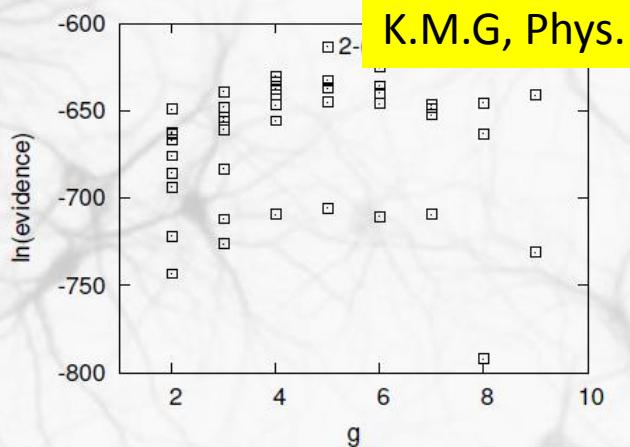
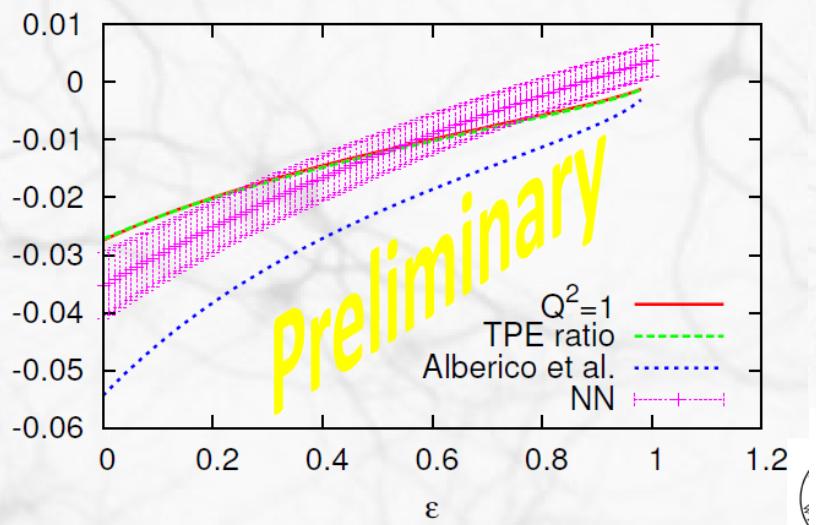


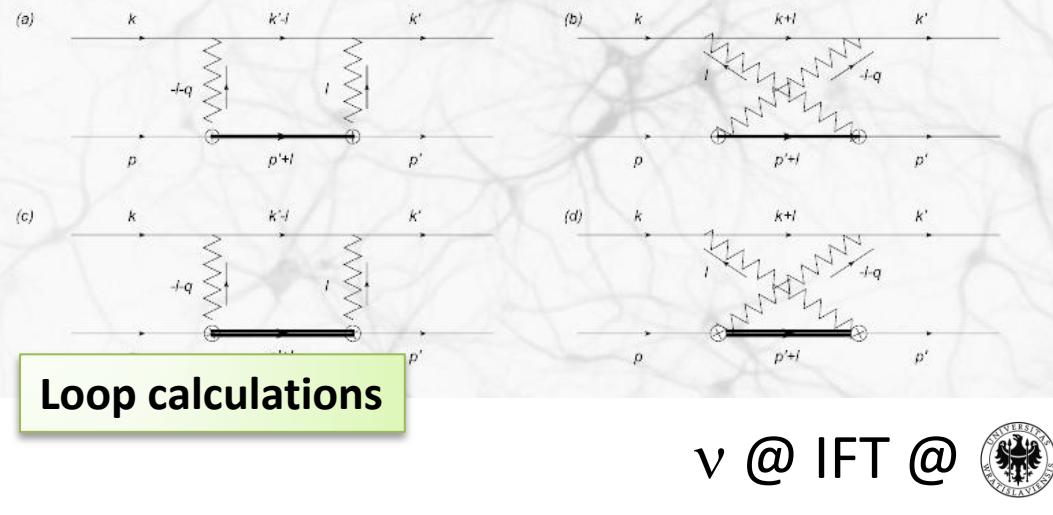
Figure : Network 2-(5-6)-3 is the most suitable to describe the data.

- 1000 trainings for each considered architecture;
- 45 different architectures;
- $4 \leq g + t = M \leq 12$;
- 3 months of working of more than 40 CPU

$$(\delta_{\text{TPE}} - \delta_{\text{MT}})/(1 + \delta_{\text{TPE}} - \delta_{\text{MT}})$$



KMG, in arxive March, 2013



Loop calculations

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Future

- Further NuWro developing
 - developing existing NuWro intranuclear cascade model
 - adding a new module with electron and photo nucleon/nucleus interactions.
- multinucleon emission contribution to the neutrino interaction cross section
- Detailed studies of $\Delta(1232)$ resonance region
- Two boson exchange effect in lepton scattering off nucleons
- Developing of NN methods