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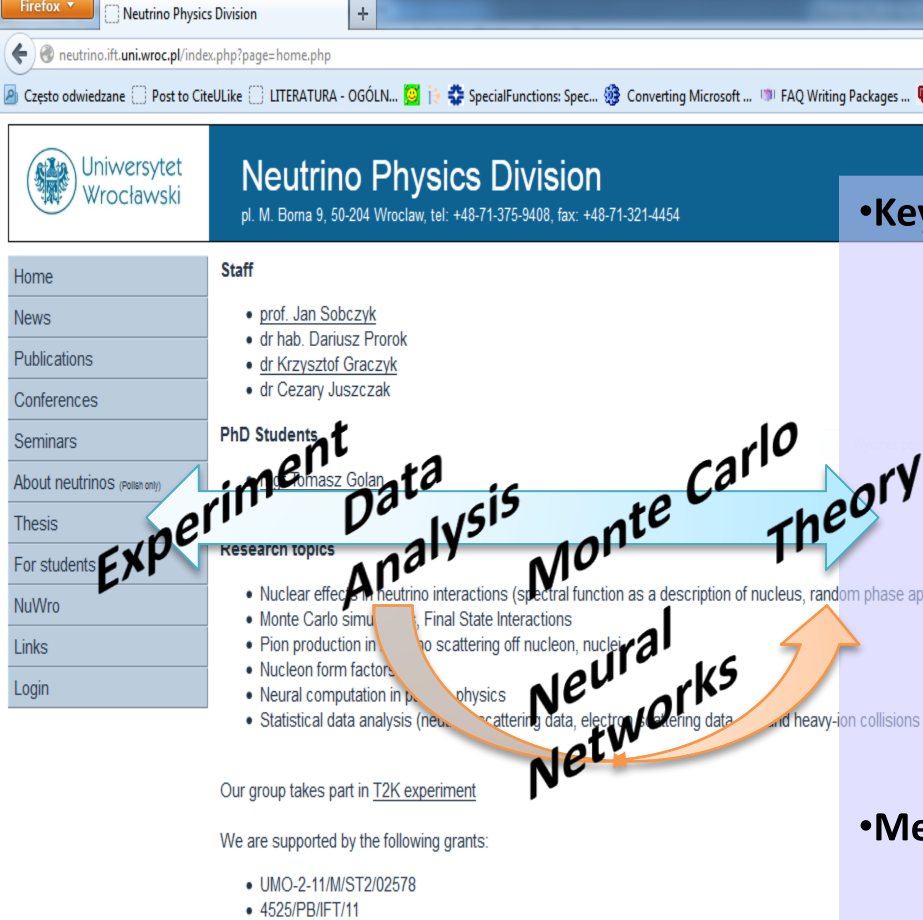
Neutrino Physics Division

→

Wrocław Neutrino Group”

by

Krzysztof M. Graczyk



- **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 hadrodynamics, mean field theory
  - chiral field theory

http://wng.ift.uni.wroc.pl
or
http://neutrino.ift.uni.wroc.p

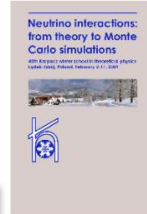
Wroclaw Neutrino Group

MASTER OF SCIENCE

Pasternak

2005, Ph.D.
K. Graczyk

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



Winter School 2009

Kobyliński

Juchnowski

2013, Ph.D.
T. Golan

ICARUS

T2K

around 2001

Nowak

Ankowski

2005, Ph.D.
J. Pasternak
(Imperial Colege)

Żmuda

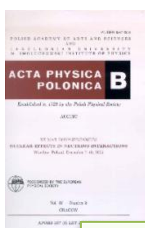
Golan

Dutkiewicz

2008, Ph.D.
A. Ankowski
(Rome U.)

Gonera

2013, Ph.D.
J. Żmuda



Max Born Symposium 2005

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)

Appearance ν_e

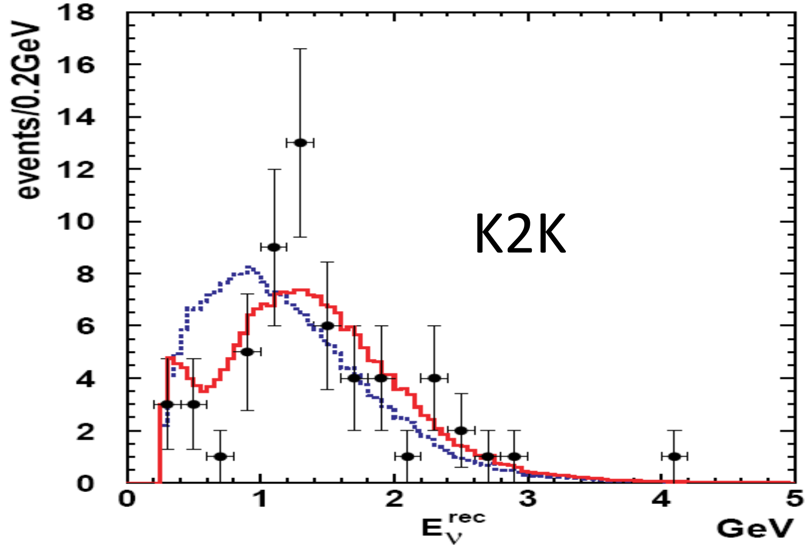
T2K experiment

$\nu_\mu \longrightarrow$

E about 700 MeV

ν_τ Disappearance

1 GeV ν's → motivation



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

Rather Practical Motivation

Neutrino oscillation experiments

→ a need to constrain better systematic errors.

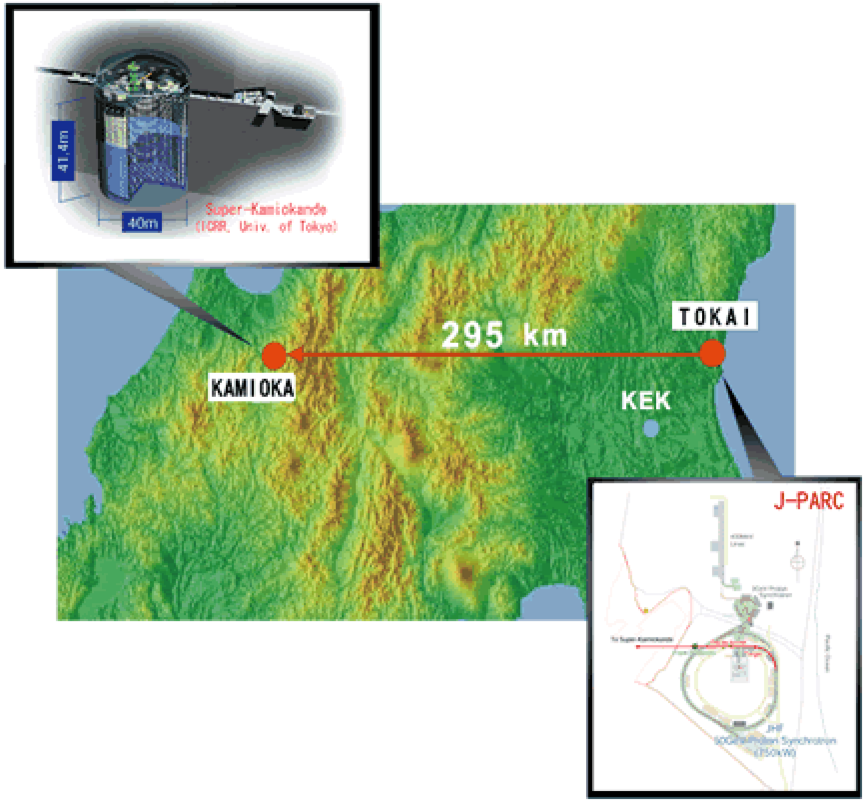
- neutrino-nucleon cross sections uncertainties are still around 20-30\%.
- in all the cross section measurement experiments the neutrino flux was known with a poor precision
- interactions occur on nuclei with many complications coming from nuclear effects.

Fundemental Motivation

Neutrino, electron – nucleon, nuclei scattering

→weak, electromagnetic probe of the nucleon, nuclei

→Electrweak structure of hadrons



T2K Experiment

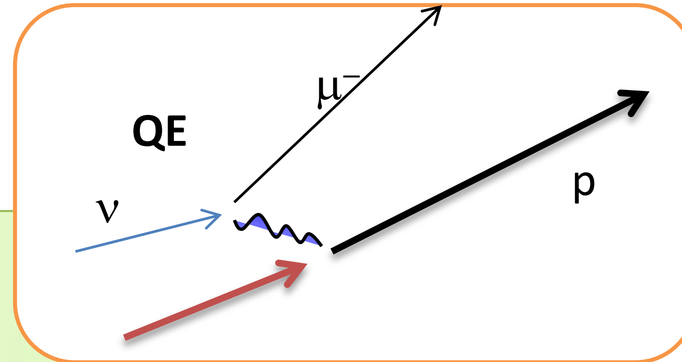
- Measurement of $\nu_\mu \rightarrow \nu_e$ (i.e., the confirmation that $\theta_{13} > 0$)
- precision measurements of oscillation parameters in ν_μ disappearance;
- a search for sterile components in ν_μ disappearance by observation of neutral-current

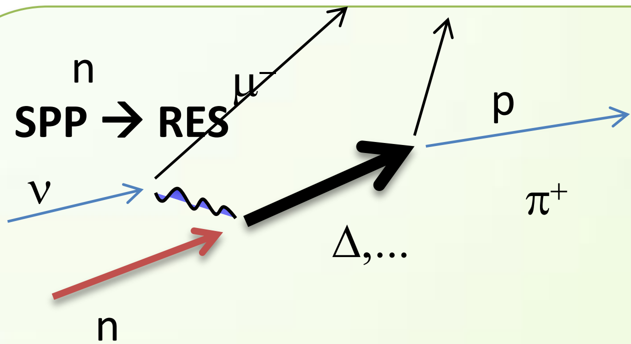
The T2K collaboration has about 500 members from 56 institutes in 11 countries.
We are the only theoretical group in T2K
(J. Sobczyk, T. Golan, J. Żmuda): software development

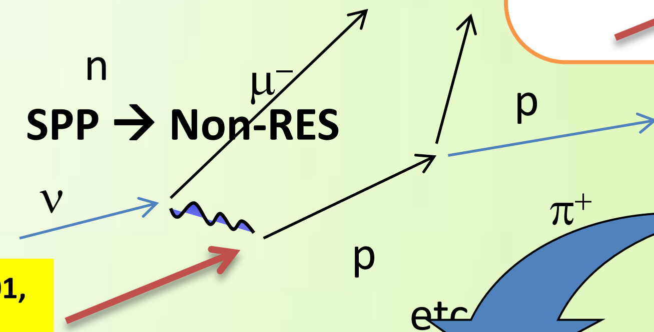
Phys.Rev.Lett. 107 (2011) 041801
Phys.Rev. D85 (2012) 031103

The 1 GeV neutrino scattering off nucleons, nuclei

ν-nucleon





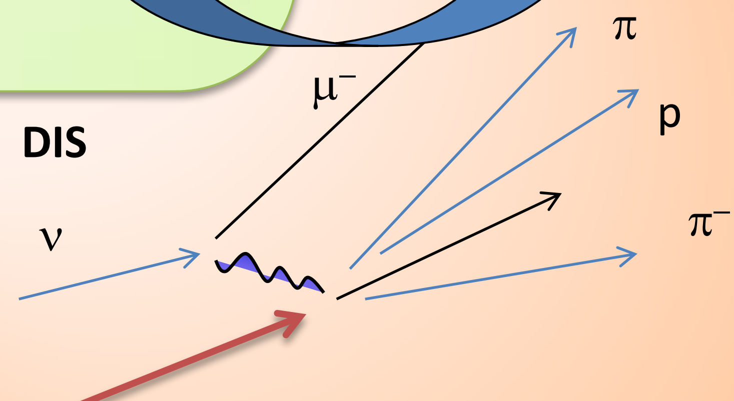


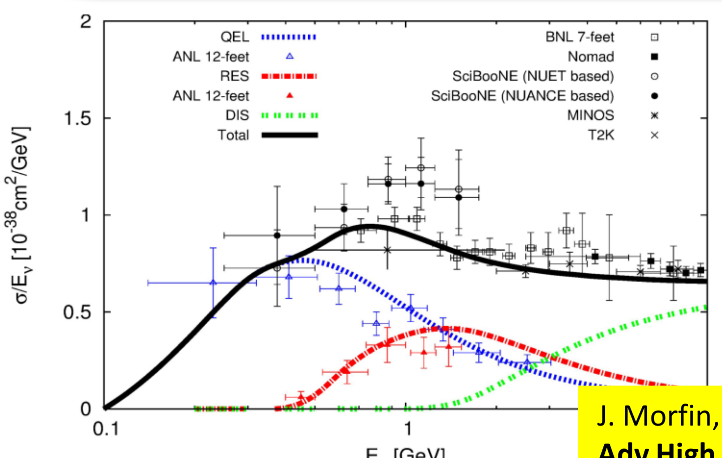
KMG, C. Juszczak, J.T.Sobczyk, **Nucl.Phys. A781 (2007) 22**
KMG, **AIP Conf.Proc. 1222 (2010) 238**

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 filed theory motivited description
- Quark model motiveted approach
- Isobar model

Quark-Hadron Duality





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

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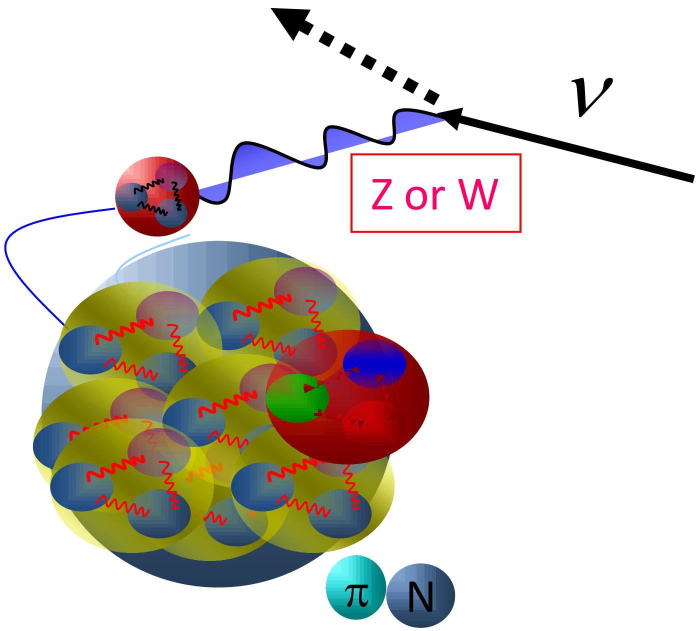
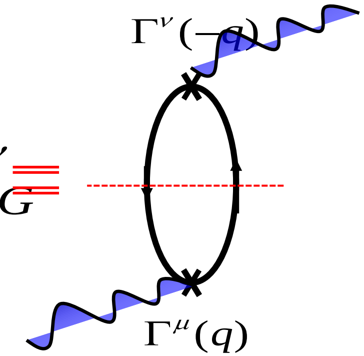
ν-nucleus



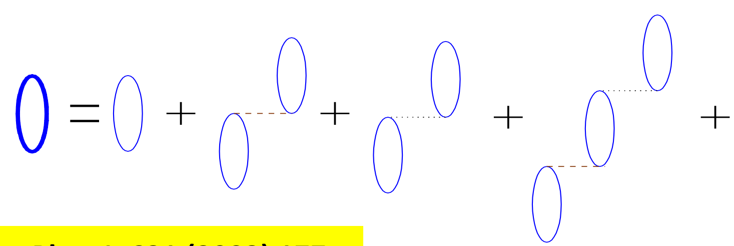
- QE and SPP can look the same in the detector
- Problem of reconstruction of neutrino energy

$$\mathrm{Im}\,\Pi^{\mu\nu}_{RFG} =$$



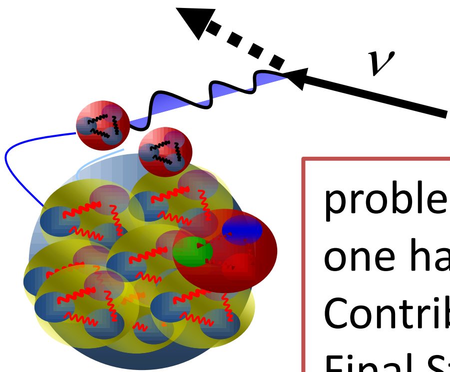
- One body currents from neutrino-nucleon scattering: an input of nuclear models
- Impuls approximation
- Fermi Gas model, a ground state of the nucleon
- Spectarl function approach
- A bare nuclear model dressed by: e.g. RPA 1n-1h excitations, calculatins within relativistic HadroDynamics .

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

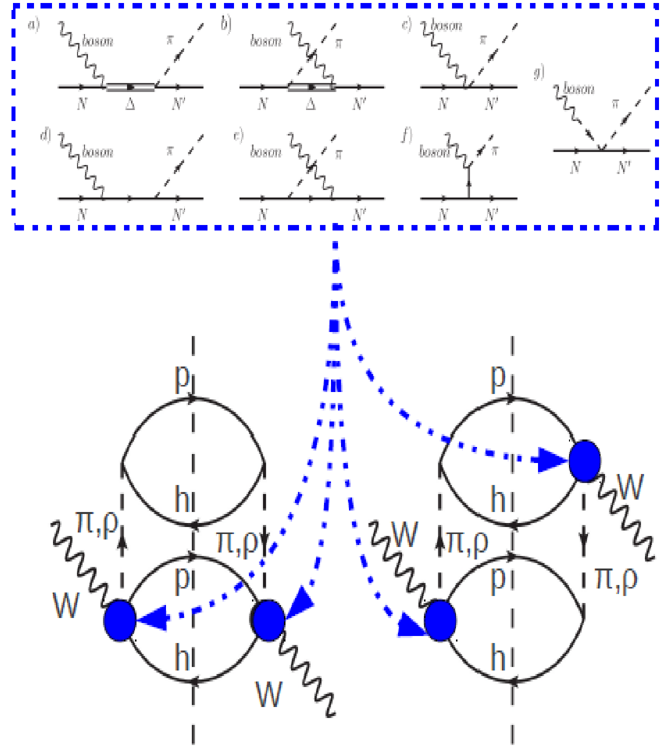


SF: A.Ankowski, J.T.Sobczyk, **Phys.Rev. C74 (2006) 054316**
Phys.Rev. C77 (2008) 044311

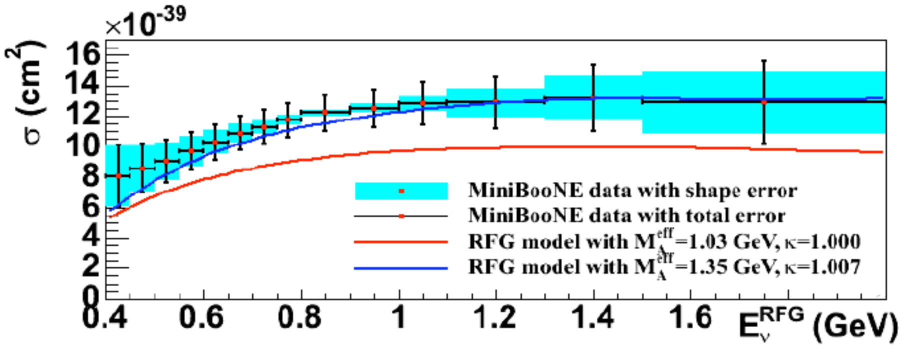
KMG, J.T.Sobczyk, **Eur.Phys.J. C31 (2003) 177,**
KMG, Nucl.Phys. A748 (2005) 313



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.

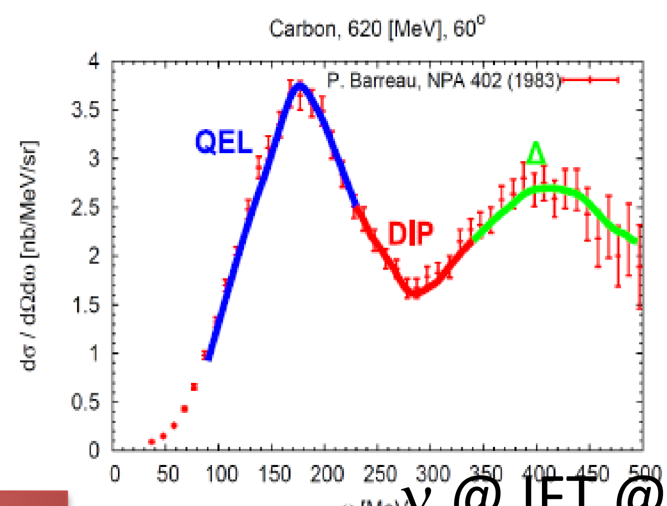


From J. Żmuda



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



FSI: propagation of nucleons throw nuclei, → Metropolis algorithm → NuWr

[Tomek Golan Movie]

Experiment at Home

Monte Carlo simulations

with

NuWro

NuWro (Neutrino-Wrocław) Monte Carlo Generator

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

Selected papers:

•**C. Juszczak, T. Golan, J.T. Sobczyk, Phys. Rev. C86 (2012) 015505**

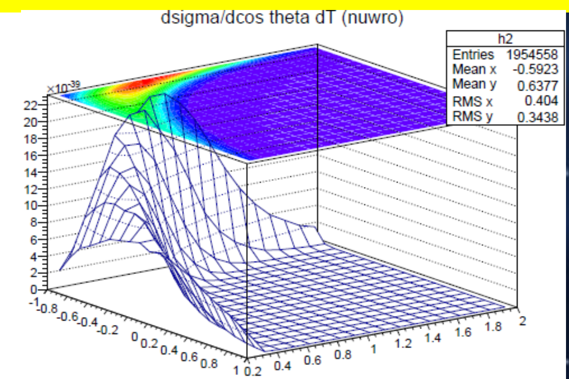
•**C. Juszczak , J. T. Sobczyk, J. Żmuda, Phys. Rev. C82 (2010) 045502**

•**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.Suppl. 139 (2005) 266**



- ❑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.

•NuWro is the firts 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 a probably the fastest event generation, compared to other codes.

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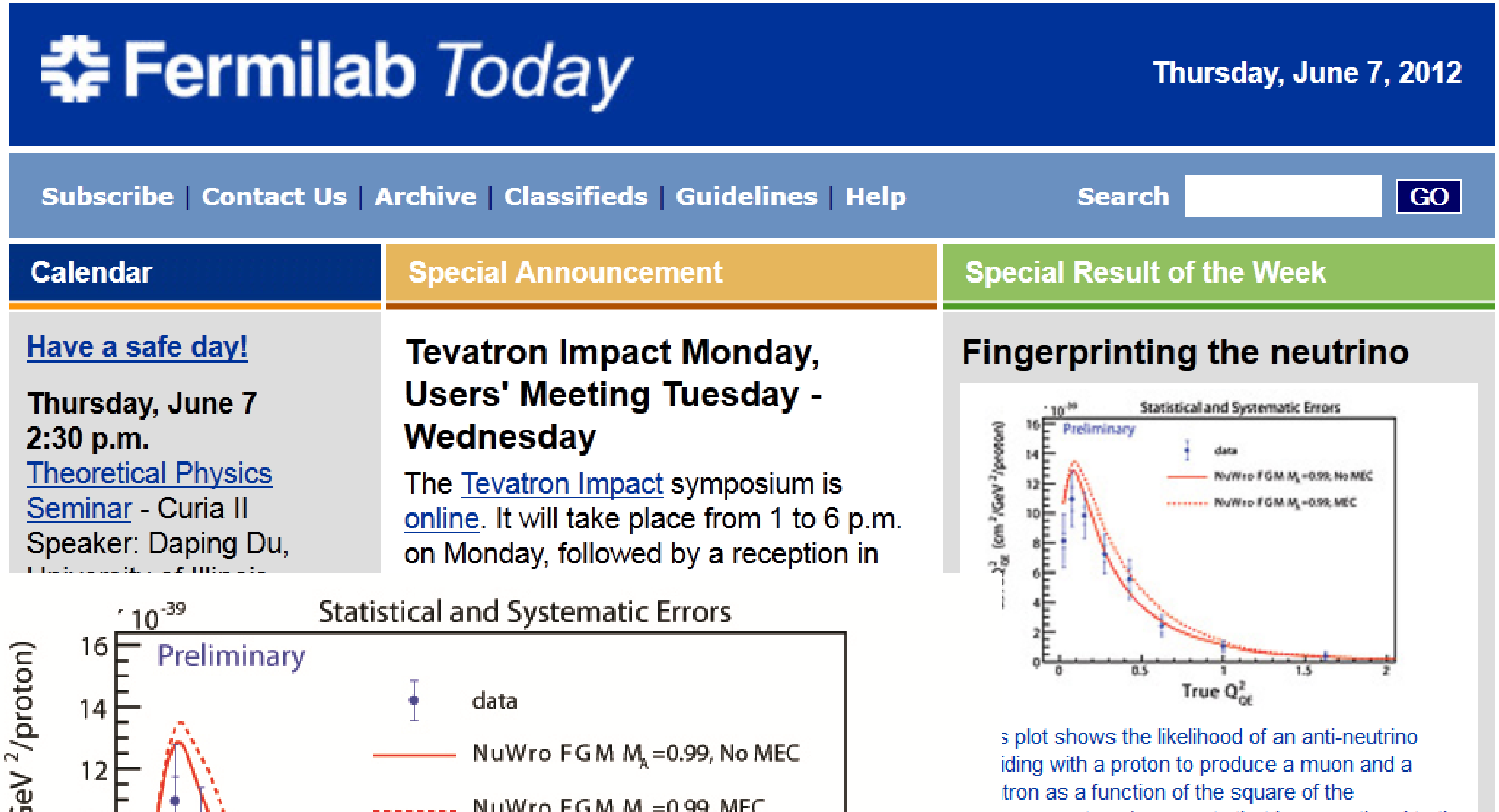
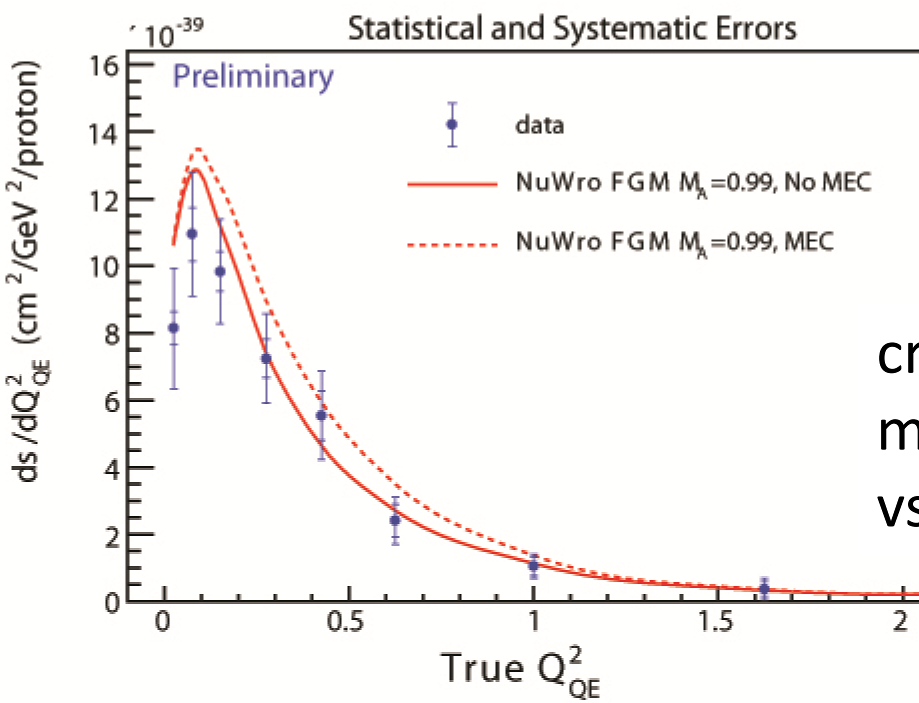
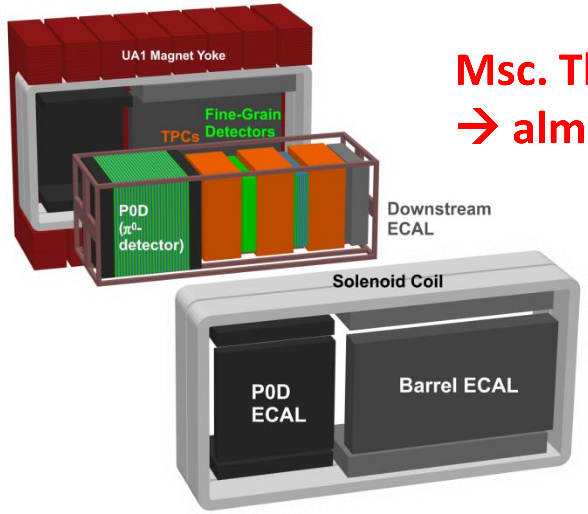
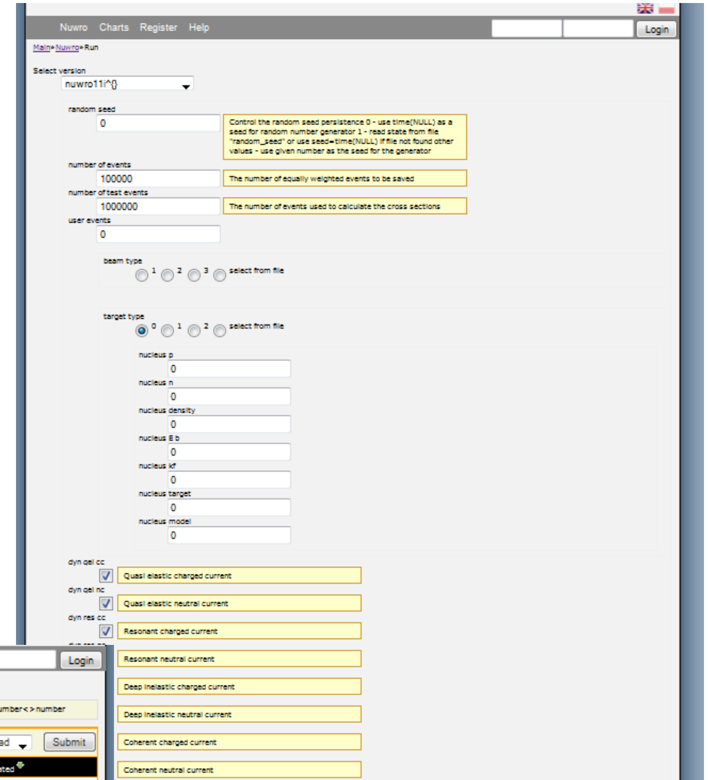


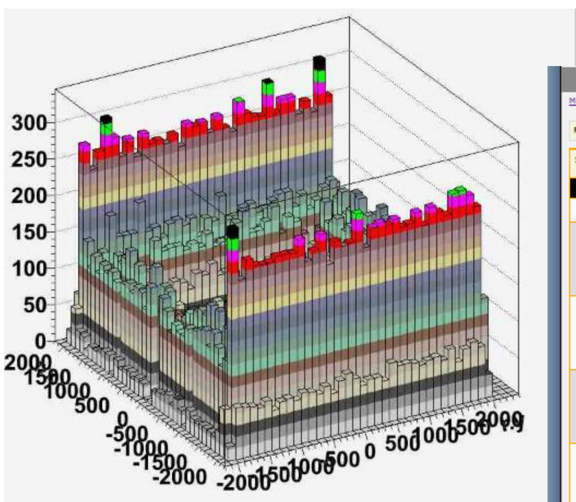


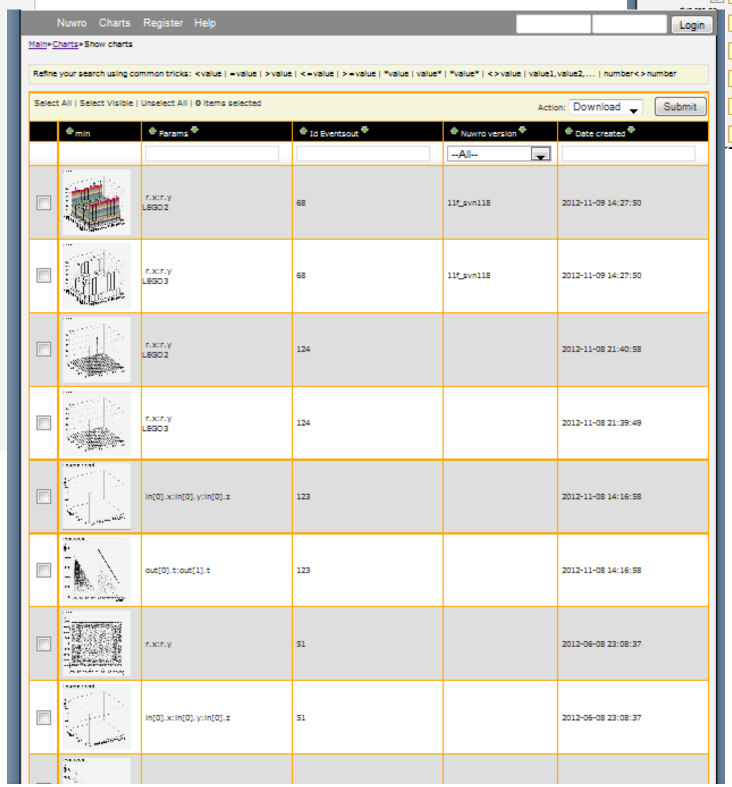
cross section
mesurements by Minerva
vs. NuWro



Msc. Thesis of Mirosław Nyznar
→ almost acomplished







running online

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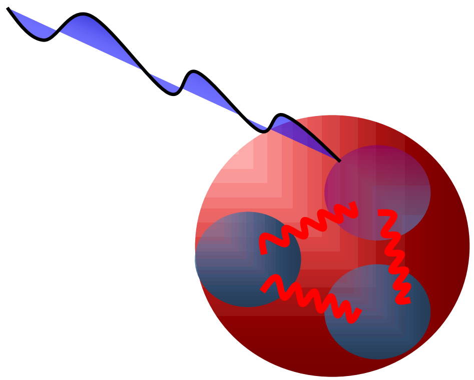
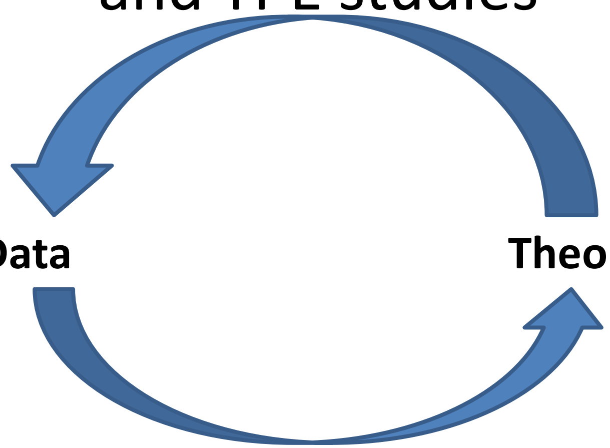
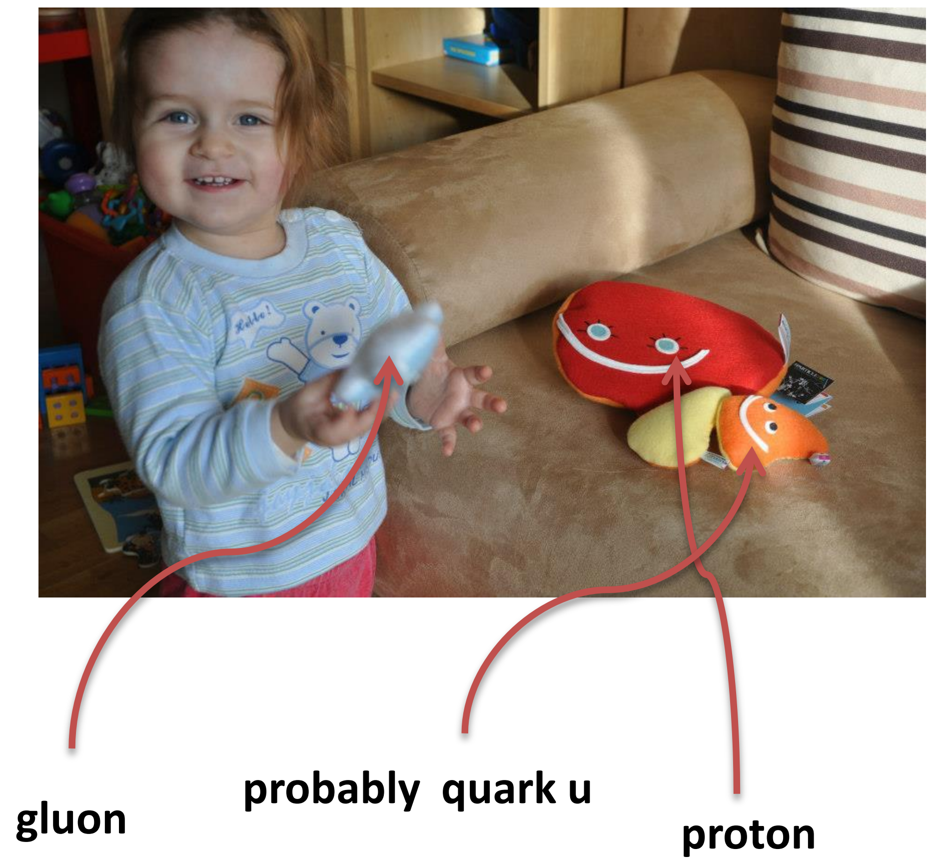
Exploring Structure of the Proton :Elctromagnetic Probe



Neural Networks vs. Theory and TPE studies





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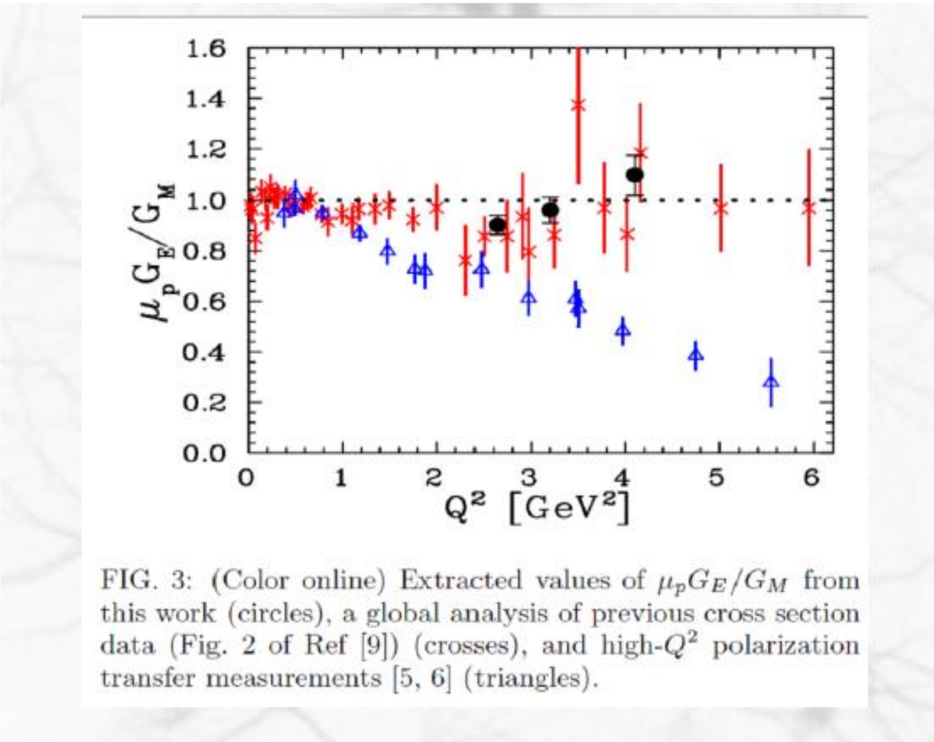
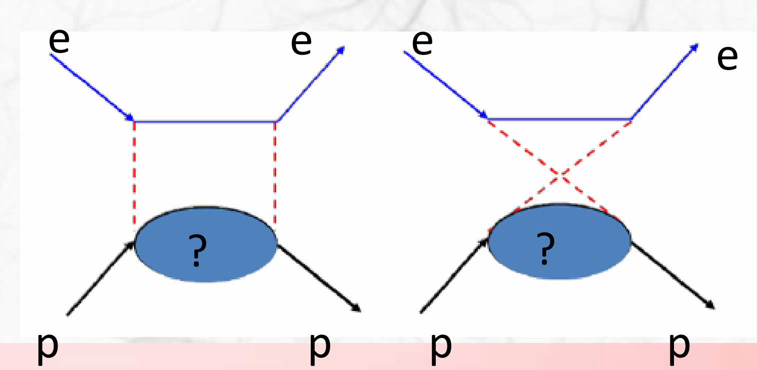


Figure : Taken from Qattan *et al.*, Phys. Rev. Lett. **94** (2005) 142301.



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!

Physical quantities $\Leftarrow$ model independent $\Leftarrow$ Measurements

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

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

- 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...

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

IDEA

Replace common sense by the Bayesian objective procedure...

Bayesian framework based on D. MacKay

It allows to

- classify quantitatively models;
- chose 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!**

1. Prior assumption: $\mathcal{P}(\mathcal{A}_1) = \ldots = \mathcal{P}(\mathcal{A}_M) = \ldots,$
2. 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.
3. One has to compute an evidence $\mathcal{P}(\mathcal{D}|\mathcal{A}_n)$– GoF.
4. For given network $\mathcal{A}_n$ we must establish $\vec{w}_{MP}$. The maximize the posterior probability,

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

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

$$\mathcal{P}\left(\vec{w}|\,\{\{\mathcal{I}\}_{ANN},\mathcal{A}_n\right) = \mathcal{P}\left(\vec{w}|\,\{\alpha,\mathcal{A}_n\right) \sim \exp\left(-\alpha E_w(\vec{w})\right)$$

Occam's razor

Method in natural way prefers simpler model than complex description.

K.M.G, Phys. Rev. C 84, 034314 (2011)

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

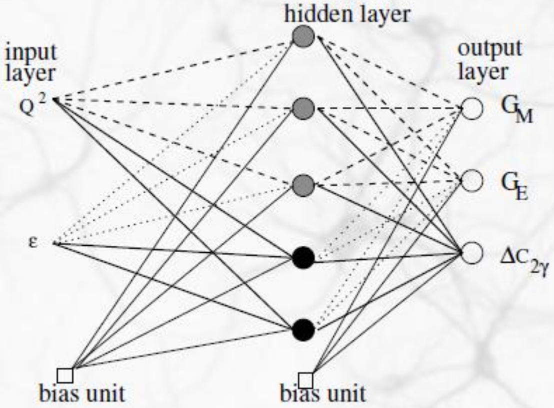


Figure : ANN: 2-(3-2)-3, $\mathcal{A}_{3,2}$

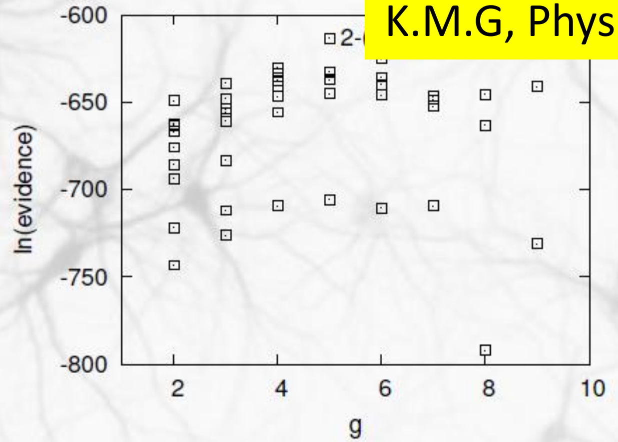
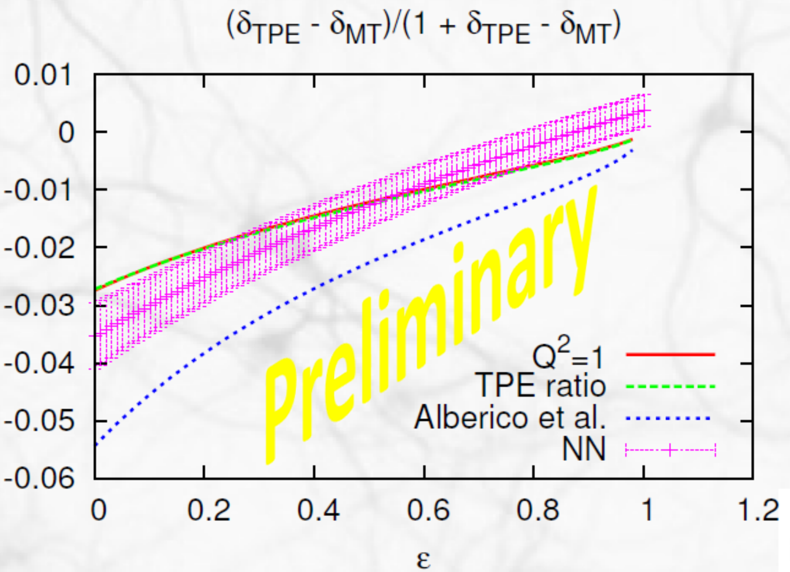
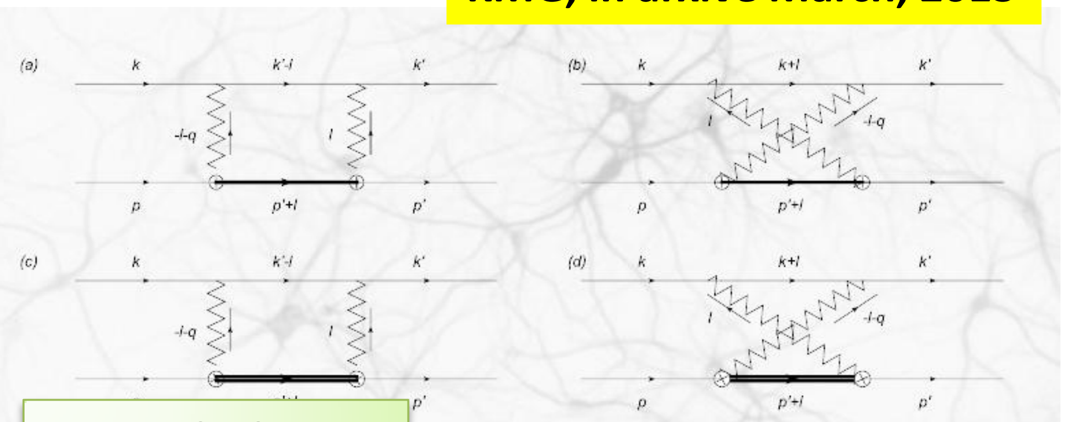


Figure : Network 2-(5-6)-3 is the most suitable to describe the data.

- 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

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