NuWro status

Jan T. Sobczyk

Wrocław University

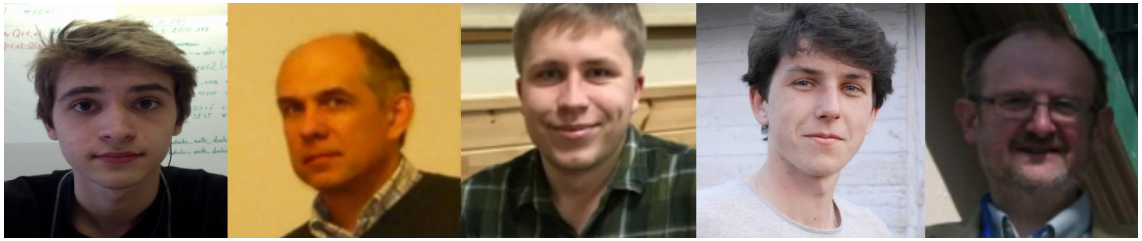
Nustec Board Meeting, December 10-11, 2018

Outline:

- General information
- Recent (or relatively recent) developments/activities
  - Nucleon cascade model (ongoing project)
  - Event reweighting
  - New MEC model (SUSAv2)
- Plans for the future
  - Phenomenological MEC model/models
  - Nuisance based validation tools
  - New theoretical models
  - Cooperation with GENIE
- NuWro workshop(s)

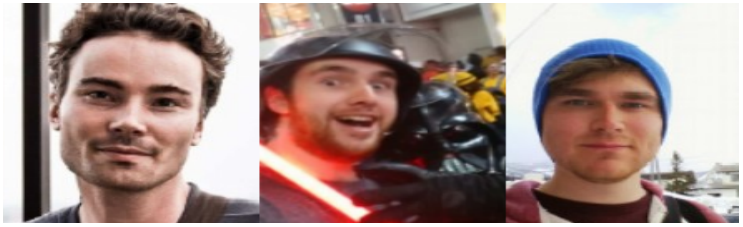
NuWro team

Active developers (in alphabetic order): Tomasz Bonus, Cezary Juszczak, Kajetan Niewczas, Michał Siemaszko, JTS



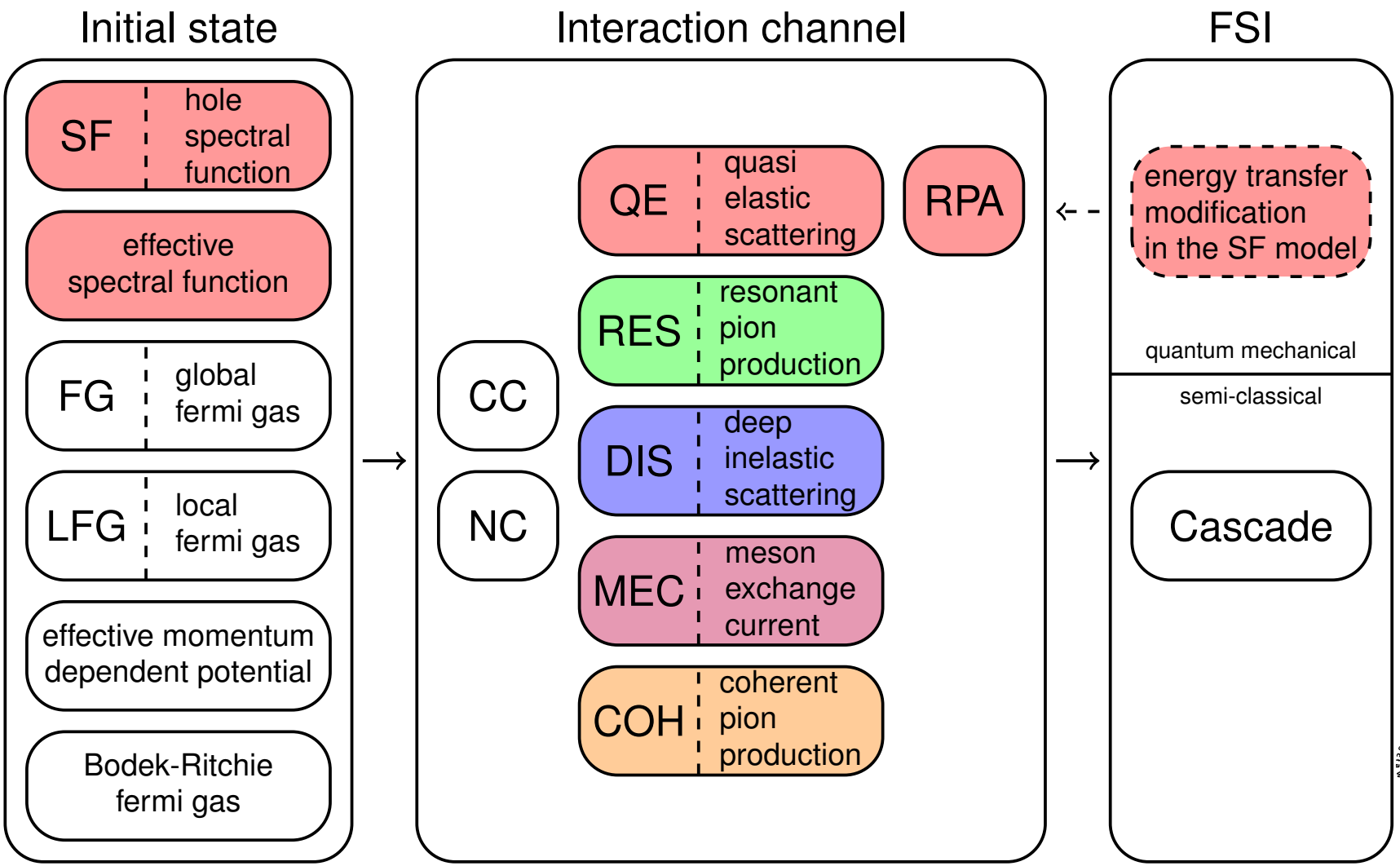
Former developers (in alphabetic order): Artur Ankowski, Tomasz Golan, Krzysztof Graczyk, Jarosław Nowak Jakub Żmuda

Outside Wrocław developers/volunteers: Paweł Przewłocki, Patrick Stowell, Luke Pickering



Inspiration and motivation: Danka Kiełczewska

NuWro blueprint



Nuclear cascade model

Nuclear cascade model Kajetan Niewczas

- Propagates particles through the nuclear medium
- Probability of passing a distance λ:

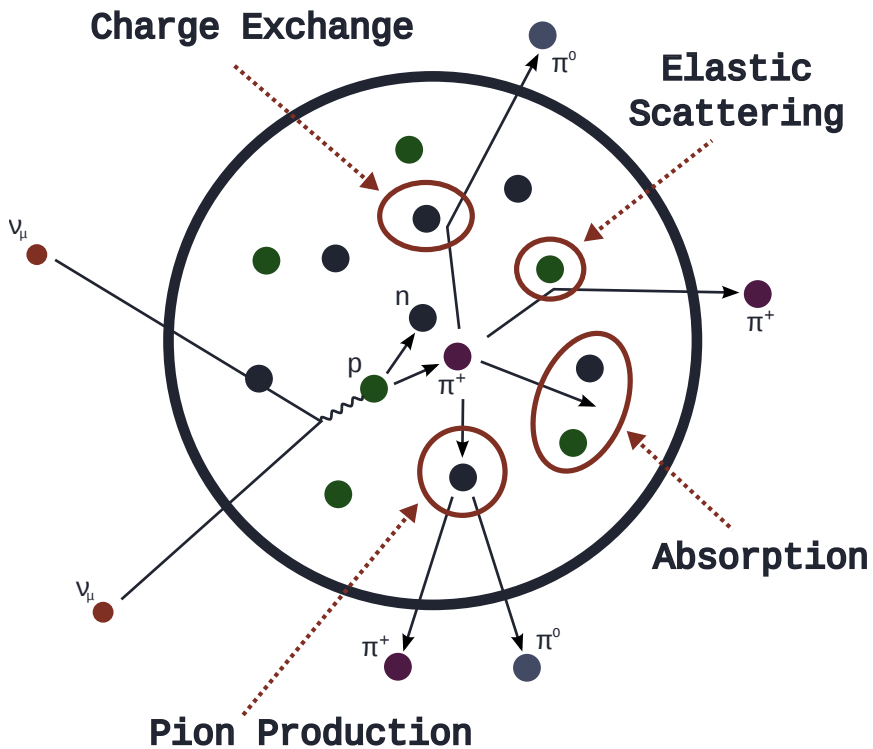
$$P(\lambda) = e^{-\lambda/\tilde{\lambda}}$$

where mean free path
$\tilde{\lambda} \equiv (\rho\sigma)^{-1}$
ρ - local density
σ - cross section

- Implemented for nucleons and pions

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

- Semi-classical – includes Pauli blocking, nucleon-nucleon correlation effects



from T. Golan

Nucleon cascade model – technicalities

- Based on Metropolis at al. algorithm
  N. Metropolis et al., Phys. Rev. 110 (1958) 185-203 and 204-219
- Propagation and interactions of on-shell nucleons
- Nuclear potential from LFG: $V(r) = E_F(r) + E_B$ (nucleons leaving nucleus loose energy)
- Total and elastic free NN cross sections fitted to PDG2016
  M. Tanabashi et al. (Particle Data Group), Phys. Rev. D98 (2018) 030001
- Fraction of 1π production in overall cross section from Bystricky et al.
  J. Bystricky at al, J. Physique 48 (1987) 1901
- Nuclear effects on the top of all that.

Nucleon cascade model – in-medium modifications

- V.R. Pandharipande, S. Pieper corrections to the elastic cross section
  - → Reduced relative nucleon velocity and available phase space
  - → Potential obtained from Urbana v_{14} + TNI Hamiltonian

  V.R. Pandharipande, S. Pieper, Phys. Rev. C45 (1992) 791-798

- Inelastic cross section modification: $\sigma^{*}_{\mathrm{NN}} = (1 - 0.2\rho/\rho_0)\sigma^{\mathrm{free}}_{\mathrm{NN}}$

  Y. Zhang, Z. Li, and P. Danielewicz, Phys. Rev. C75 (2007) 034615

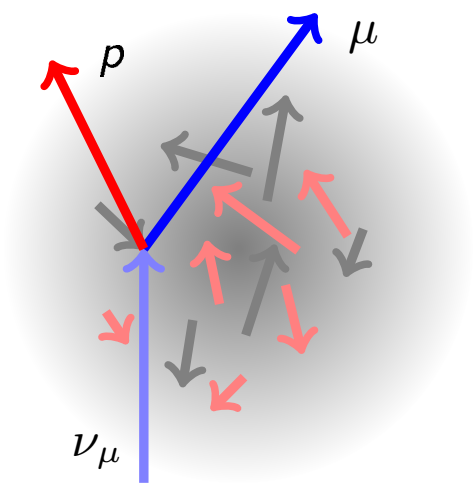
- Nucleon-nucleon correlations effects:
  - → "Effective" nuclear density due to nucleon-nucleon correlations
  - → Correlation function taken from ab initio nuclear matter calculations

Nucleon cascade model – transparency

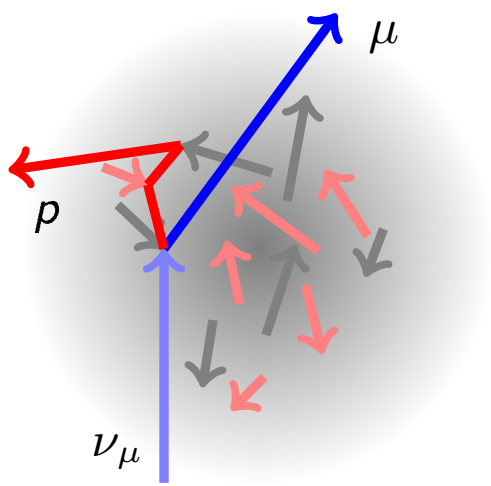
Nuclear transparency T is the probability for a knocked-out proton to escape the nucleus without significant reinteraction (soft reinteraction cannot be identified experimentally).

For Carbon experimental measurements: $\mathrm{T} \simeq 0.60$ [D. Abbott *et al.*, PRL 80 (1998), 5072]

$\sim 60\%$ events without FSI



$\sim 40\%$ events with FSI



Transparency data from $(e, e'p)$ experiments

In NuWro computations experimental setup is reproduced.

Exclusive QE proton knockout
at fixed kinematics:

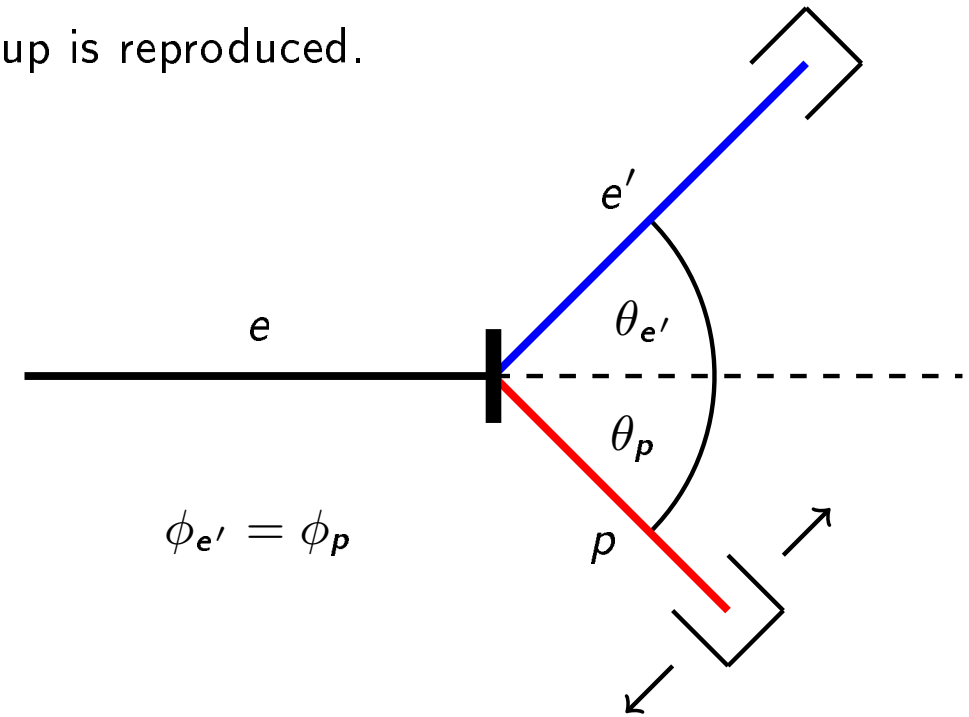
- beam: E_e
- electron: $E_{e'}$, $\theta_{e'}$, $\phi_{e'}$
- proton: E_p, θ_p, ϕ_p

With provided: $\frac{\Delta p}{p}$, $\Delta\theta$, $\Delta\phi$

Cuts on "missing" variables:

- energy: $E_m = \omega - T_{p'} - T_{A-1}$
- momentum: $\vec{p}_m = \vec{p}_{p'} - \vec{q}$

$$E_m < 80 \text{ MeV}, \quad |\vec{p}_m| < 300 \text{ MeV/c}$$



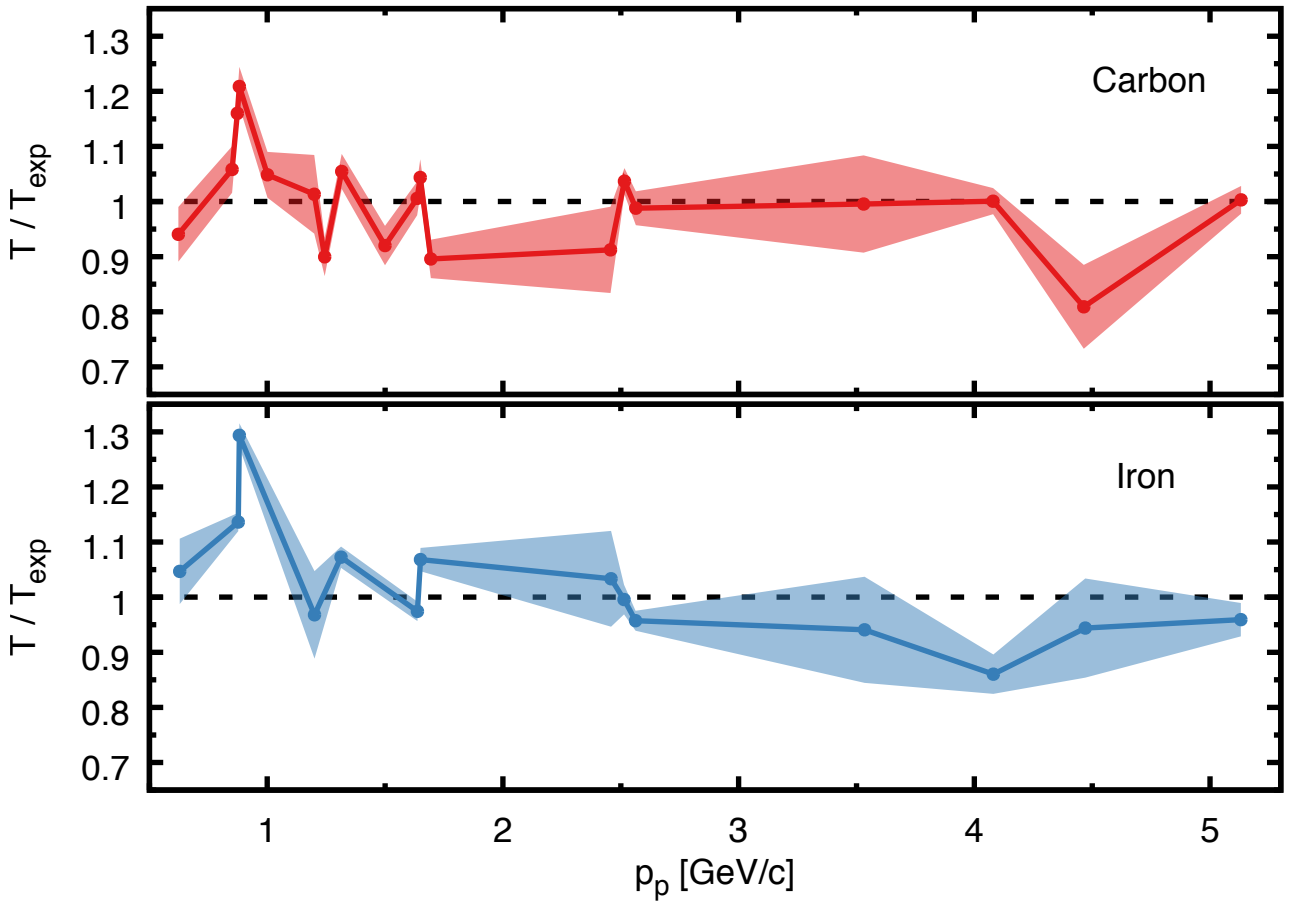
Transparency:

$$\langle T \rangle_{\theta_p} = \frac{\sigma_{\text{exp}}}{\sigma_{\text{PWIA}}} \frac{1}{c_A}$$

σ_{PWIA} - expected value without FSI
(model dependent)

c_A - correlation factor

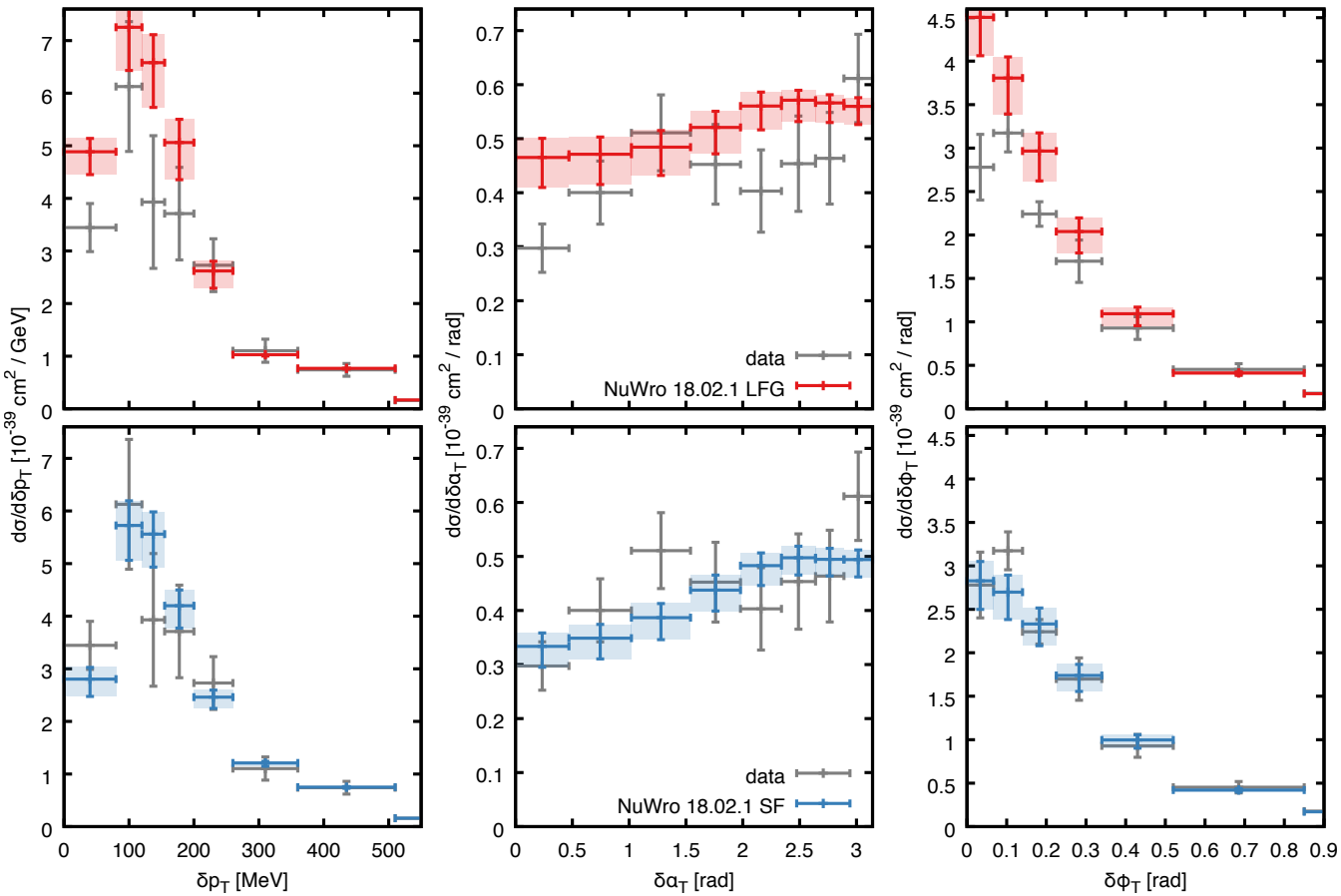
Nuclear transparency in NuWro



Simulations done for NC ν_e scattering on protons with Spectral Function.

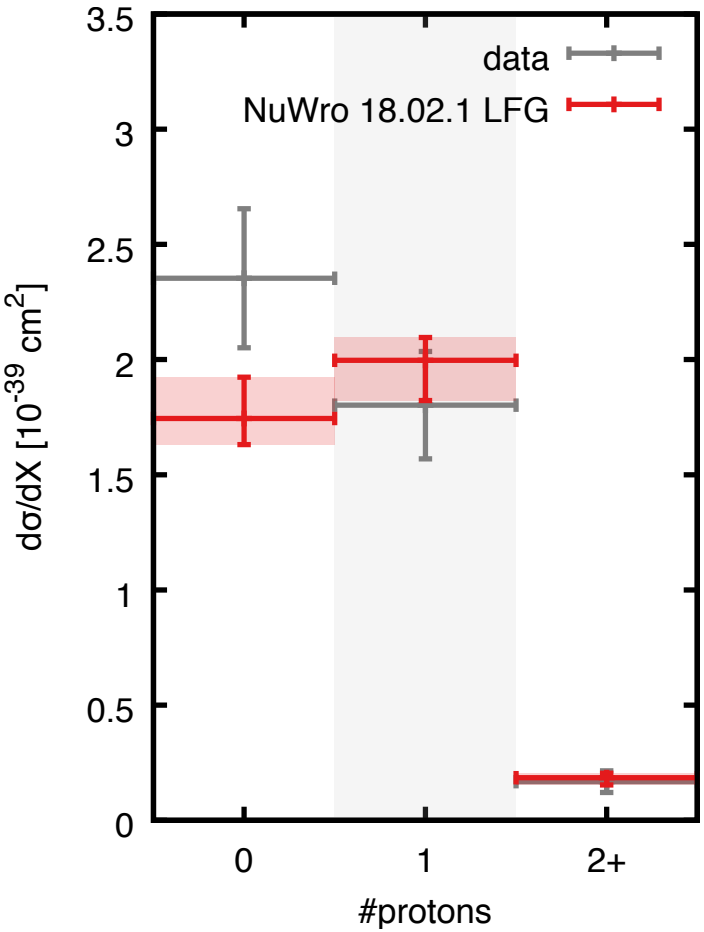
Data/MC agreement within $\sim 30\%$, typically much better

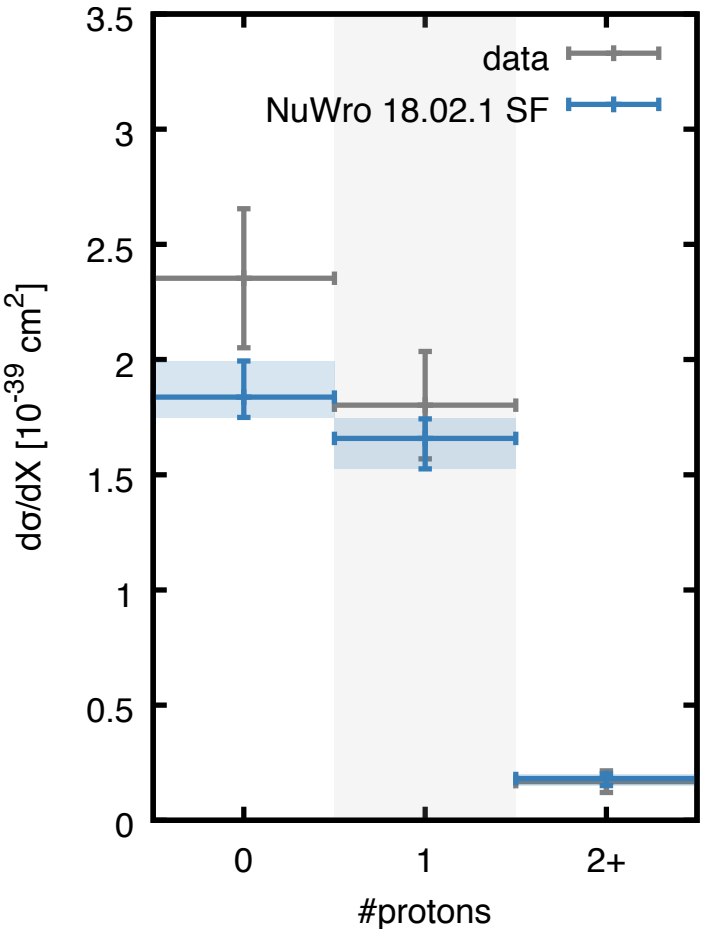
Impact of mean free path uncertainty: single transverse variables



T2K results, Phys.Rev. D98 (2018) 032003

Impact of mean free path uncertainty: proton multiplicity

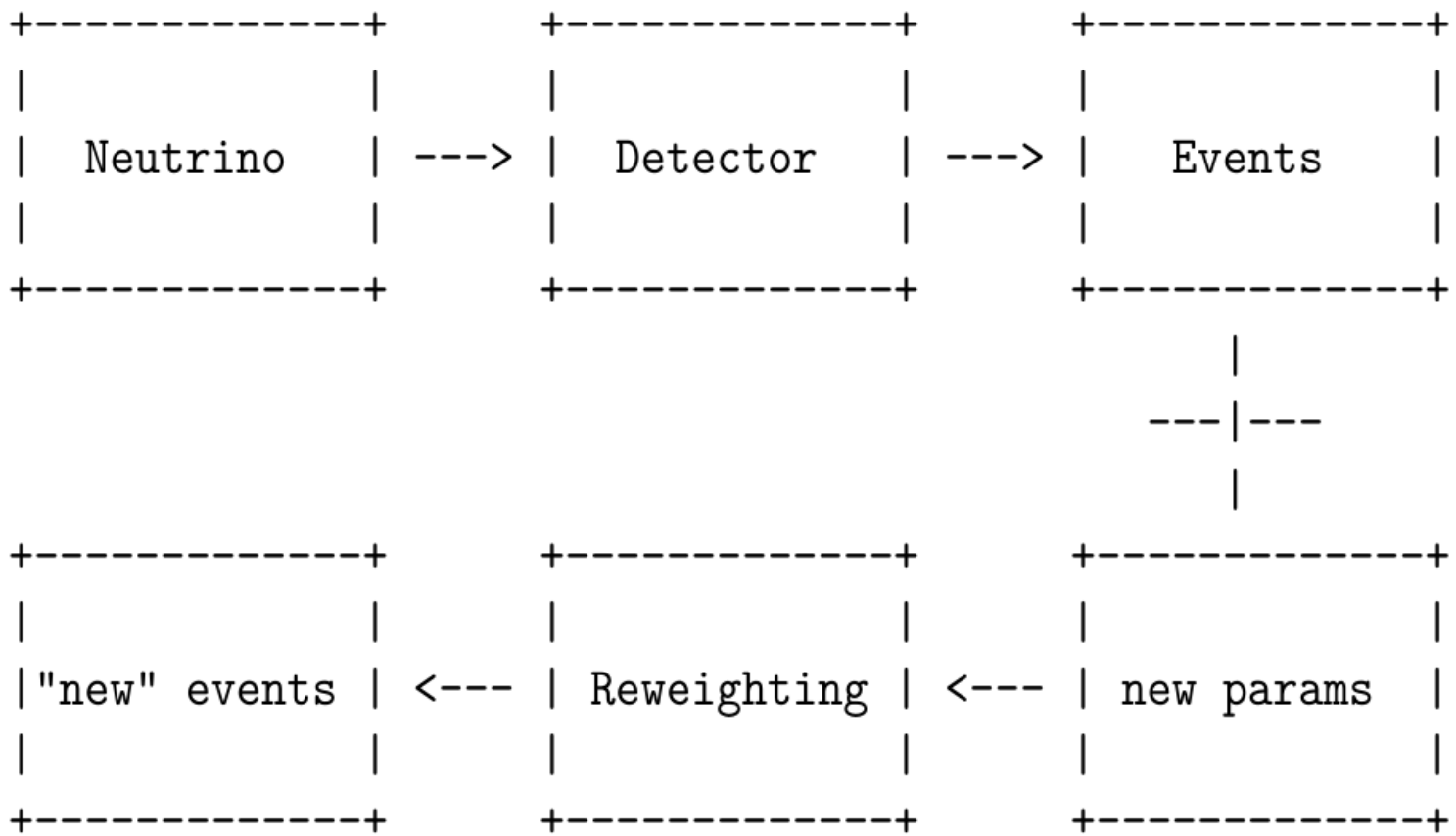




T2K results, Phys.Rev. D98 (2018) 032003

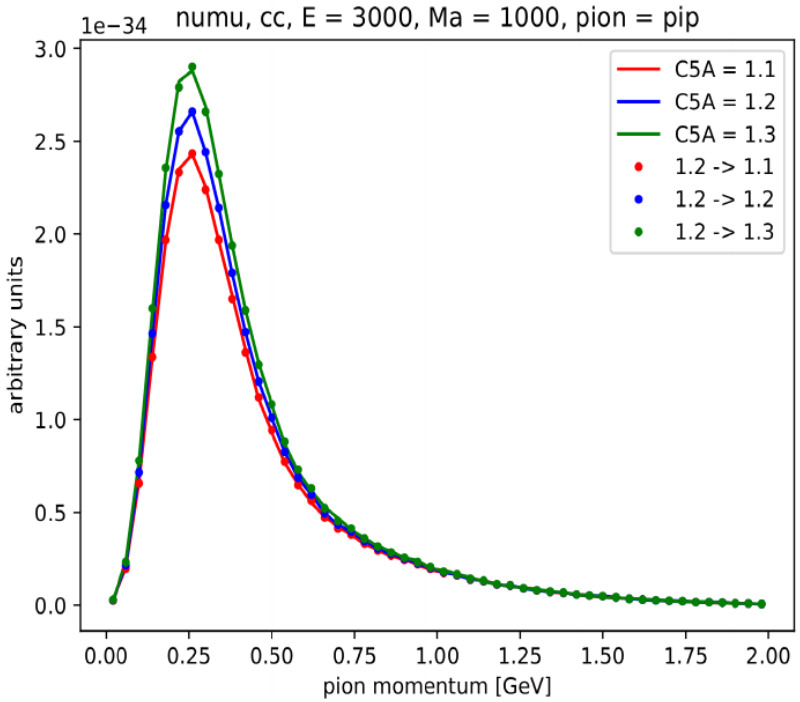
Event reweighting

Event reweighting Cezary Juszczak and Tomek Golan

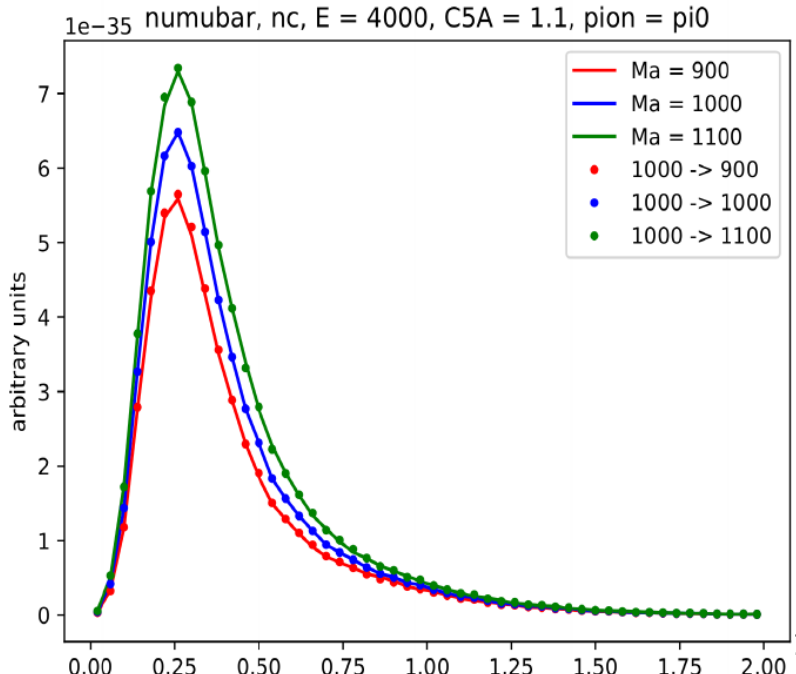


It is critical in time consuming detector simulations.

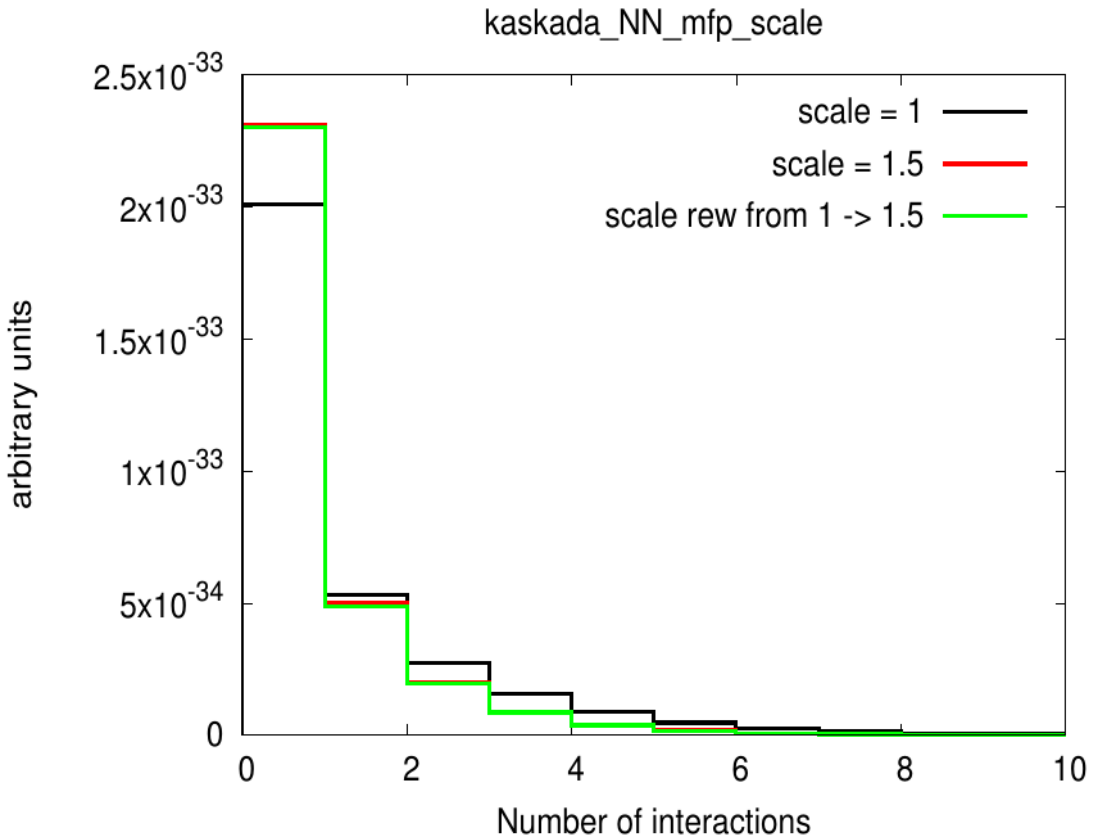
Event reweighting - RES examples



A completely new setup based on the work done by Luke Pickering and Patrick Stowell.



Event reweighting - nucleon FSI

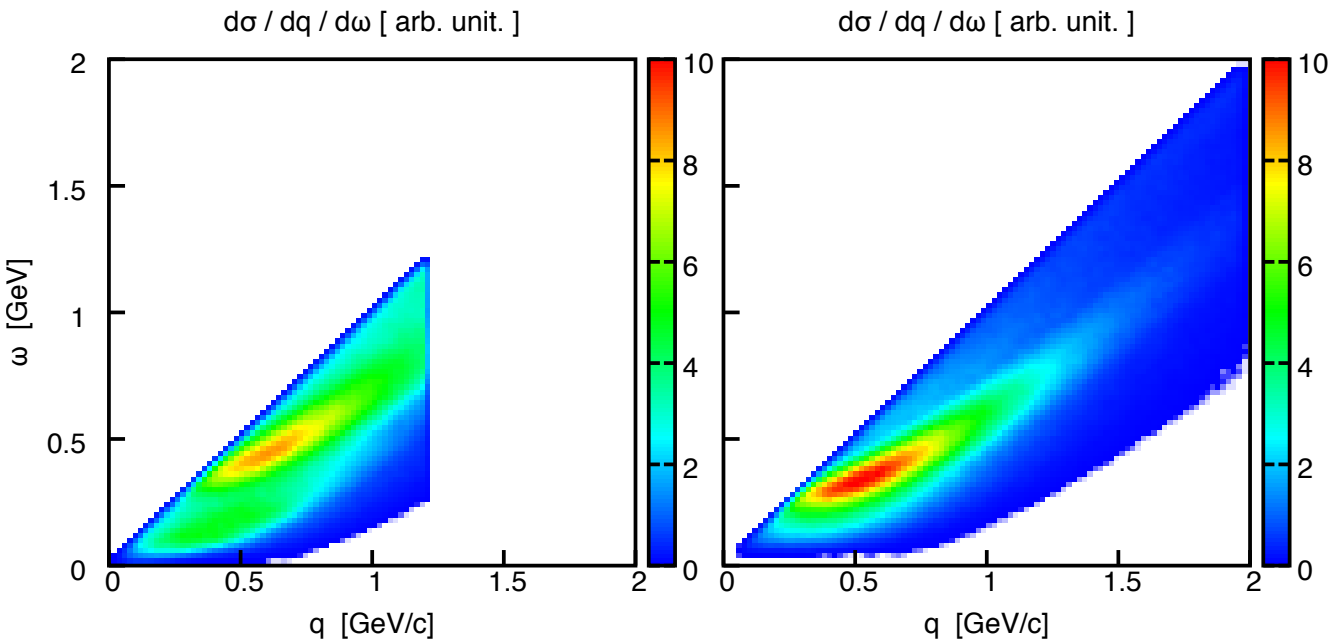


Mean free path is scaled by 1.5 on every step.

The results are promising but the study is no longer under active development :(.

New MEC model

New MEC model: SuSAv2 Kajetan Niewczas



$E_\nu = 3$ GeV, carbon target.

- Using tables from Guillermo Megias.
- Previously the implementation was done in GENIE
- Other NuWro MEC models: Nieves, Marteau, TE.

Plans for the future

Phenomenological MEC model

- An attempt to rescale Nieves model responses based on the available data T2K and MINERvA CC0π data for ν_μ and $\bar{\nu}_\mu$.
- Motivated by GENIE MINERvA tune.

Nuisance based validation program

- The program was launched over a year ago.
- Now the idea is to use Nuisance framework
- Last week two students Tomasz Bonus and Michał Siemaszko were trained by Nuisance experts Luke Pickering, Callum Wilkinson, Clarence Wret.

Incorporation of Ghent group theoretical models

- Making progress thanks to joint Ghent-Wrocław PhD program realized by Kajetan Niewczas.
- The main focus on 2p2h model.
- Discussions on 1p1h and π production models.

Cooperation with GENIE

- We think about putting NuWro (as a whole) in the GENIE environment together with other "GENIE tunes"

NuWro workshop

NuWro workshop 2017 (December 3-5)

	Sunday, 03.12		Monday, 04.12		Tuesday, 05.12
9:00	Welcome	9:00	*Correlations in neutrino-nucleus scattering* **Natalie Jachowicz**	9:00	*NUISANCE + NuWro reweighting* **Patrick Stowell** **Luke Pickering**
9:05	*NuWro (WRONG) first years* **Jarosław Nowak**	9:45	*Neutrino-induced pion production* **Raúl González Jiménez**		
9:30	*Discussion* **Sara Bolognesi**	10:30	*Discussion* **Federico Sánchez**	9:45	*Discussion* **Callum Wilkinson**
10:30	Coffee break	11:30	Coffee break	10:45	Coffee break
11:00	*Discussion* **Sara Bolognesi**	12:00	*Discussion* **Federico Sánchez**	11:15	*Discussion* **Callum Wilkinson**
12:00	*Neutrino SIS and DIS interactions* **Teppei Katori**			12:15	*NuWro cascade model* **Tomasz Golan**
12:45	Lunch break	13:00	Lunch break	13:00	Lunch break
14:45	*NuWro interaction models: primary vertex* **Kajetan Niewczas**	15:00	*NuWro — structure of the code* **Cezary Juszczak**	15:00	*NuWro validation (part 2.)* **Jan Sobczyk**
15:30	Coffee break	15:45	Coffee break	15:45	Coffee break
16:00	*MicroBooNE* **Raquel Castillo** (remotely)	16:15	*NuWro treatment of nuclear effects* **Tomasz Golan**	16:15	*Final discussion and NuWro next steps* **Together**
		17:00	*NuWro validation (part 1.)* **Jan Sobczyk**		

- The next workshop should be organized in 2019
- Perhaps in the future "NuWro collaboration".
- Volunteers are welcome!

Thank you!