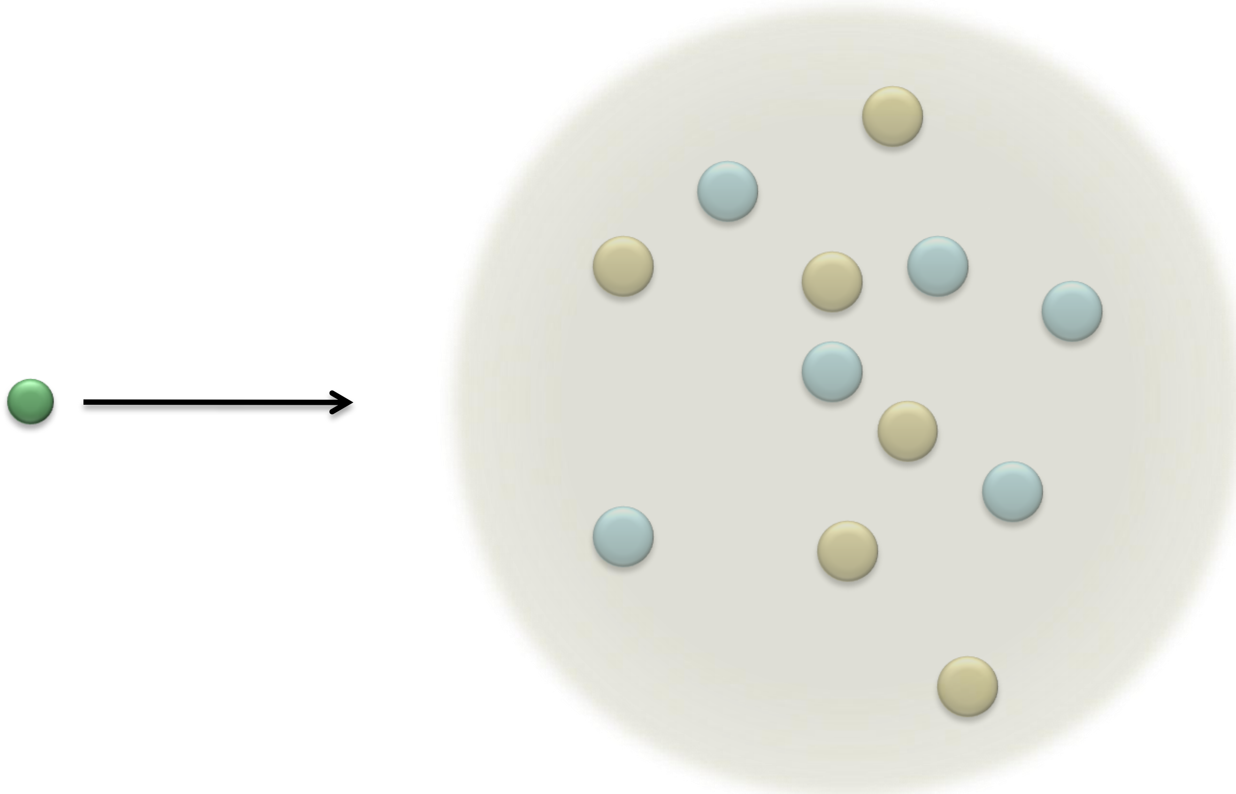
Oddziaływanie stanów końcowych w reakcjach neutrin z jądrami atomowymi

Tomasz Golan
IFT, UWr

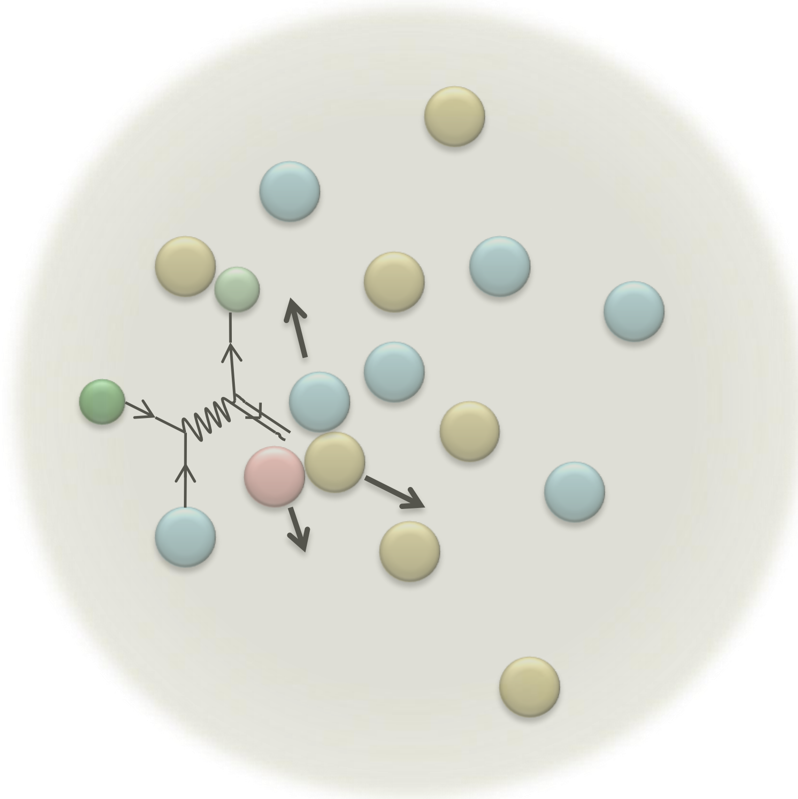
1. Oddziaływanie stanów końcowych
2. Eksperymenty vs. NuWro
3. Strefa formacji („formation zone”)?
4. Wpływ FZ na wyniki

Oddziaływanie stanów końcowych

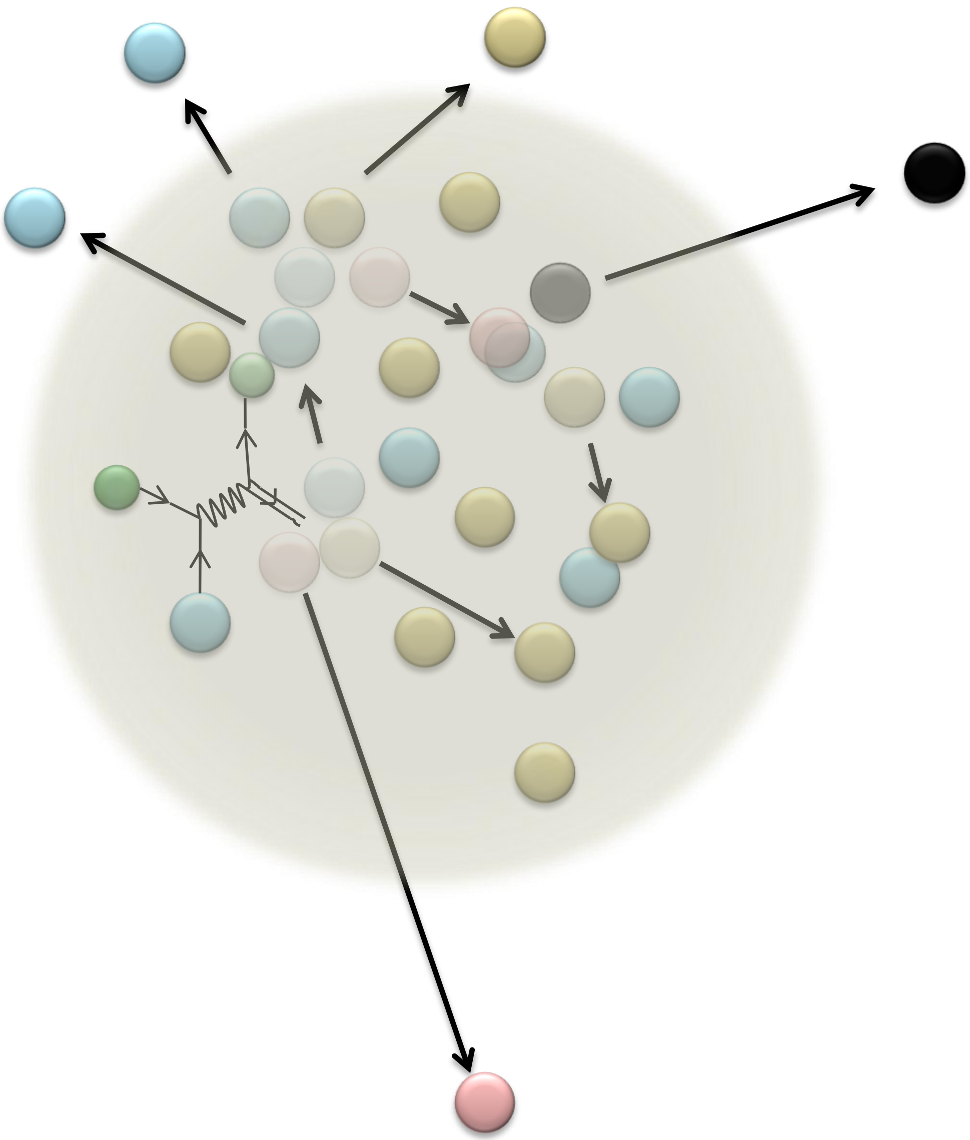
Oddziaływanie Stanów Końcowych



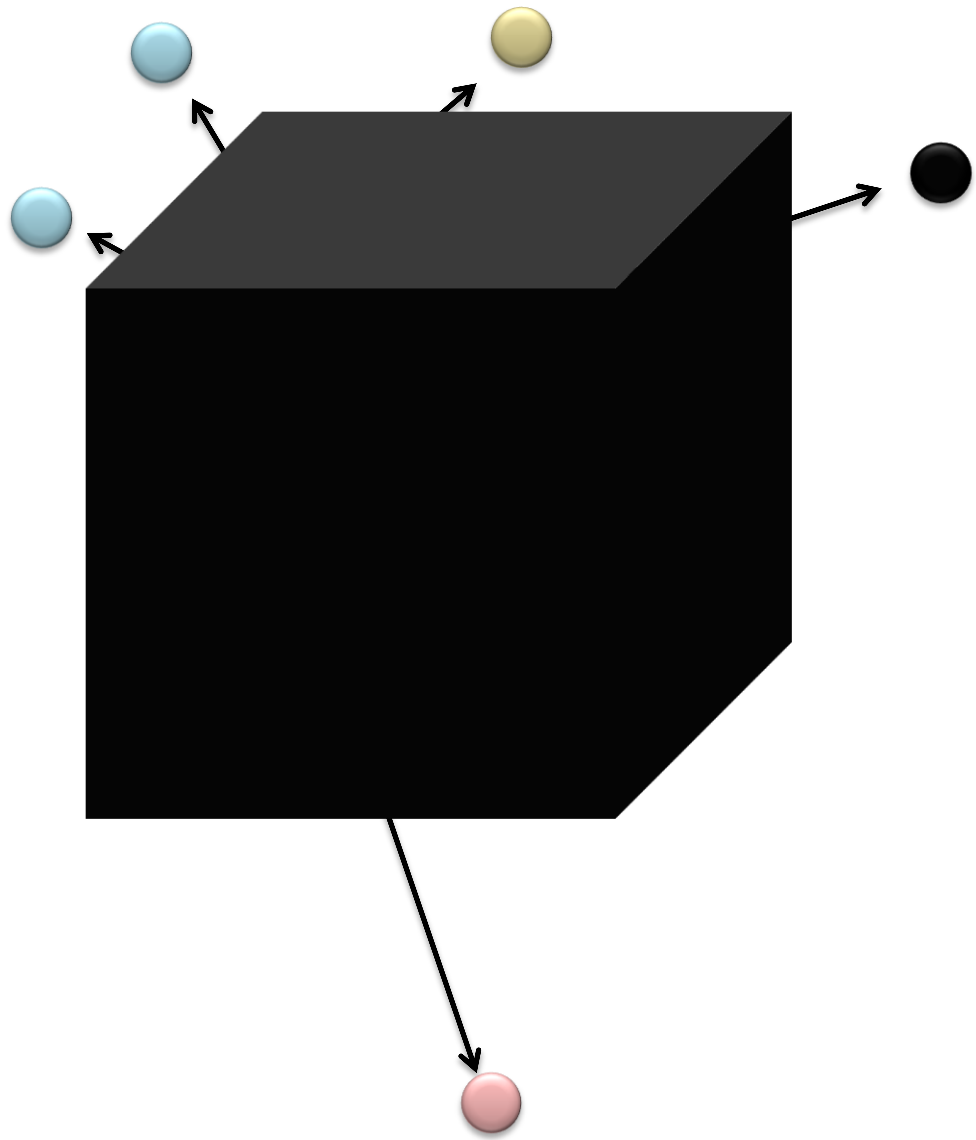
Oddziaływanie Stanów Końcowych



Oddziaływanie Stanów Końcowych



Oddziaływanie Stanów Końcowych

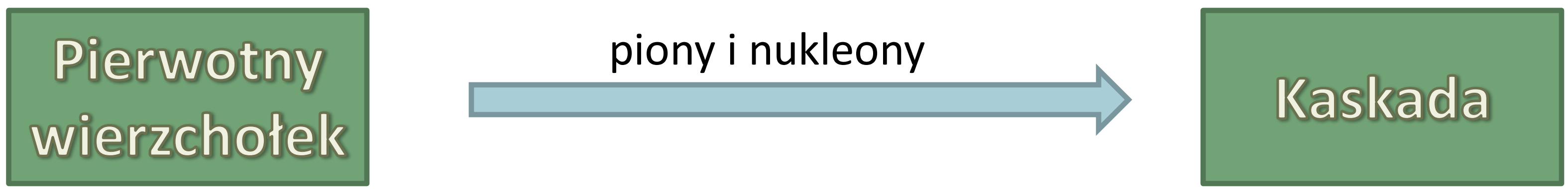


NuWro

Pierwotny wierzchołek

- Kwazi-elastyczne dla CC
  oraz elastyczne dla NC
- Rezonansowe
  (Δ oraz pojedyncza produkcja pionu)
- Głęboko nieelastyczne
- Koherentna produkcja pionów

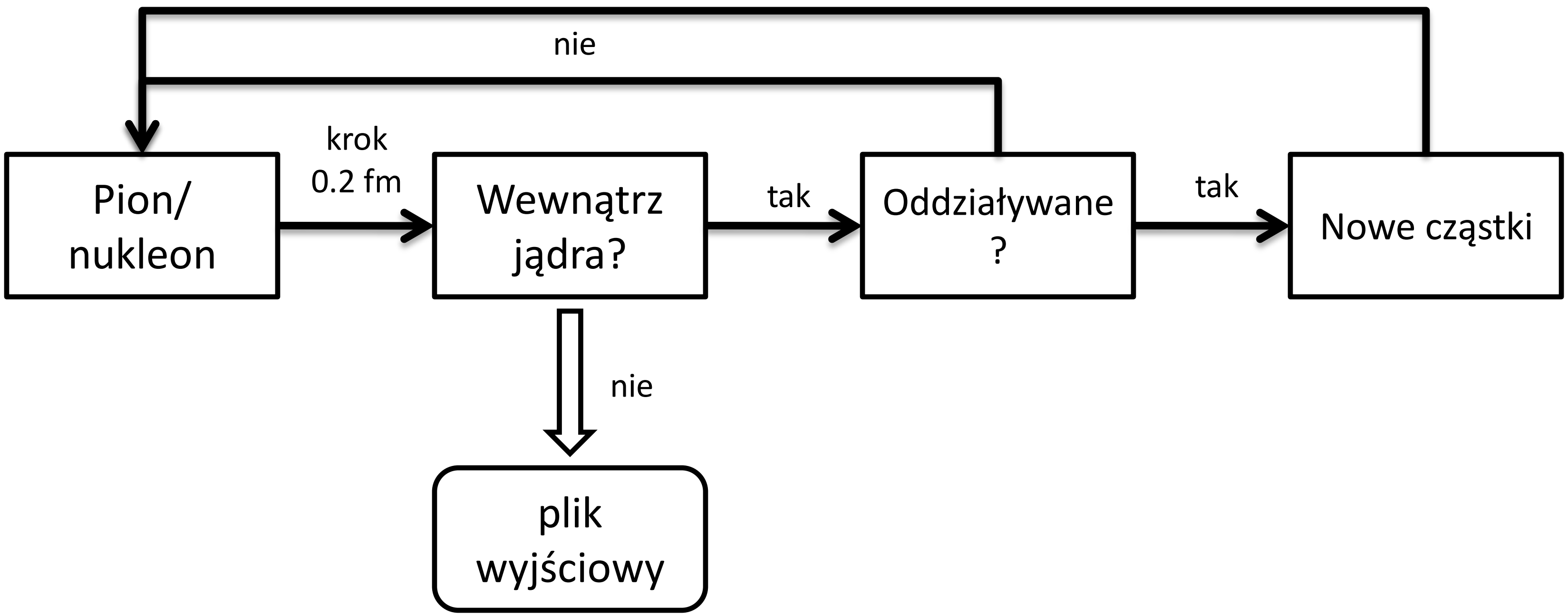
NuWro



- Kwazi-elastyczne dla CC oraz elastyczne dla NC
- Rezonansowe (Δ oraz pojedyncza produkcja pionu)
- Głęboko nieelastyczne
- Koherentna produkcja pionów

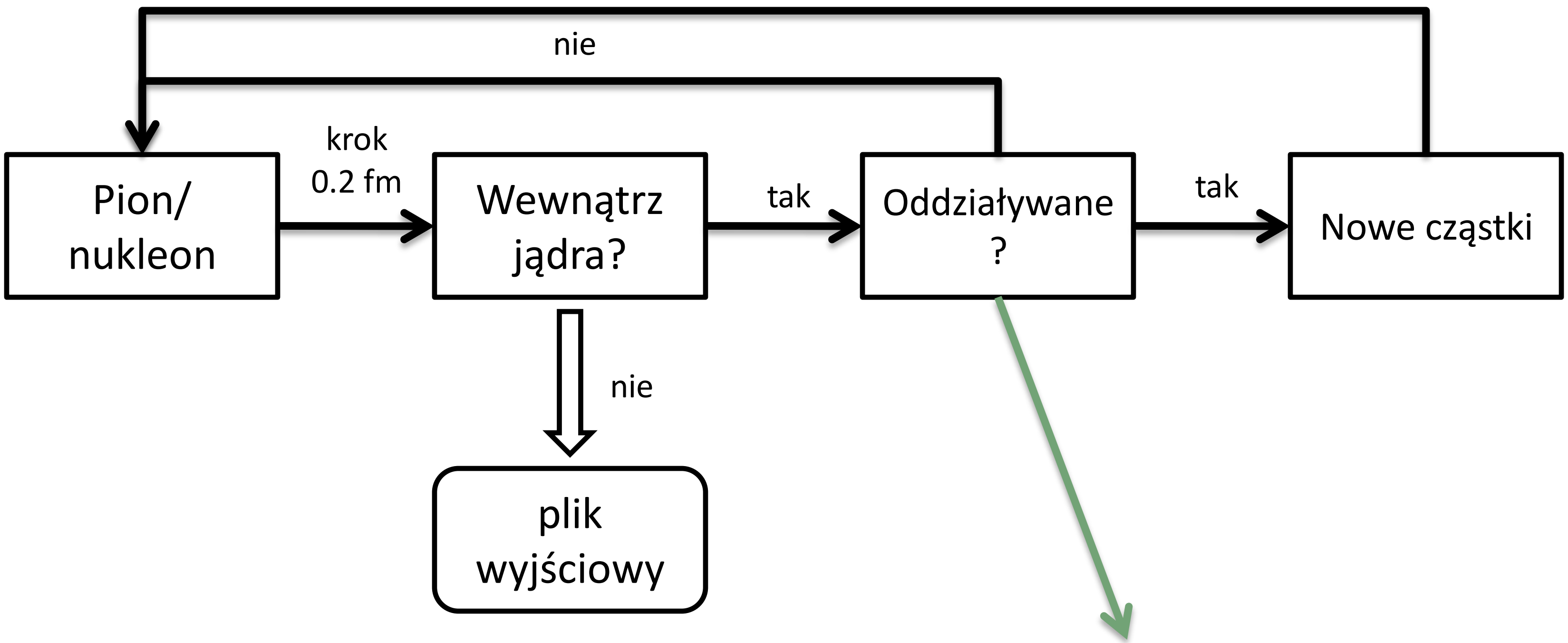
- Nukleony:
  - Elastyczne
  - Pojedyncza produkcja pionu
  - Podwójna produkcja pionu
- Piony:
  - Elastyczne
  - CEX
  - Pojedyncza produkcja pionu
  - Podwójna produkcja pionu
  - Absorpcja

Kaskada



nie
krok
0.2 fm
Pion/
nukleon
Wewnątrz
jądra?
tak
Oddziaływane
?
tak
Nowe cząstki
nie
plik
wyjściowy

Kaskada



PHYSICAL REVIEW VOLUME 110, NUMBER 1 APRIL 1, 1958

**Monte Carlo Calculations on Intranuclear Cascades.
I. Low-Energy Studies*†**

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ANTHONY TURKEVICH, *Enrico Fermi Institute for Nuclear Studies, University of Chicago, Chicago, Illinois*
J. M. MILLER, *Columbia University, New York, New York*
AND
G. FRIEDLANDER, *Brookhaven National Laboratory, Upton, New York*

(Received November 26, 1957)

Metropolis.h

$\sigma_{ii} \mapsto \pi^{+}$-p lub π^{-}-n
$\sigma_{ij} \mapsto \pi^{+}$-n lub π^{-}-p

$$\sigma_{\pi^0} = (\sigma_{\pi^+} + \sigma_{\pi^-})/2$$

TABLE I. Total cross sections used in cascade calculation. The quantities σ_{ii}, σ_{ij}, and $\sigma_{ij(\mathrm{abs})}$ are defined in the text.

Nucleons			Pions			
Kinetic energy (Mev)	σ_{ii}[a] (mb)	σ_{ij}[b] (mb)	Kinetic energy (Mev)	σ_{ii}[c] (mb)	σ_{ij}[c] (mb)	$\sigma_{ij(\mathrm{abs})}$[d] (mb)
335	24.5	33.0	49	16	15	20
410	26.4	34.0	85	50	21	32
510	30.4	35.1	128	114	43	45
660	41.2	36.5	184	200	66	36
840	47.2	37.9	250	110	44	18
1160	48.0	40.2	350	51	23	0
1780	44.2	42.7	540	20	22	0
3900	41.0	42.0	1300	30	30	0

$\sigma_{ii} \mapsto$ p-p lub n-n
$\sigma_{ij} \mapsto$ p-n

Metropolis.h

produkcja pojedynczego pionu $\mapsto$ 11% π^0 dla ii
$\mapsto$ 43% π^0 dla ij

produkcja pionów

$(1 - f_\pi)$
produkcja dwóch pionów:
• 80% $\pi^0\pi^0$ lub $\pi^+\pi^-$

TABLE II. Parameters used in inelastic nucleon-nucleon collisions.

Energy range (Mev)	Type	f_{inel}[a]	A[b]	B[b]	f_{π^0}
335–410	*ii*	0.07	0.1	0	1.0
	ij	0.04	2.2	−1.0	1.0
410–510	*ii*	0.20	0.9	0	1.0
	ij	0.07	1.8	−1.1	1.0
510–660	*ii*	0.31	2.7	0	1.0
	ij	0.15	2.3	−0.7	1.0
660–840	*ii*	0.43	9.0	0	1.0
	ij	0.27	8.8	−0.2	1.0
840–1160	*ii*	0.58	14.3	0	0.97
	ij	0.37	15.0	0	0.97
1160–1780	*ii*	0.65	19.2	0	0.80
	ij	0.36	29.4	0	0.80
>1780	*ii*	0.69	∞	0	0.44
	ij	0.35	∞	0	0.44

Metropolis.h

CEX lub produkcja pionu

↦ 53% π^0 dla ii

↦ 44% π^0 dla ij i 0

25% $\pi^0\pi^0$ lub $\pi^-\pi^+$ dla podwójnej produkcji pionów

TABLE III. Parameters used in pion-nucleon collisions.

Energy range (Mev)	Type	f_{inel}[a]	f_{CE}[b]	A[c]	B[c]	f_π[a]
49–85	*ii*	0	0	3.2	−1.8	
	ij	0.45	1.0	1.1	0.8	1.00
	0	0.42	1.0	3.4	−1.8	
85–128	*ii*	0	0	2.2	−2.1	
	ij	0.57	1.0	1.9	0.7	1.00
	0	0.36	1.0	2.1	−2.0	
128–184	*ii*	0	0	1.9	−1.5	
	ij	0.62	1.0	2.2	0.8	1.00
	0	0.36	1.0	1.9	−1.4	
184–250	*ii*	0.03	0	2.2	−0.3	
	ij	0.64	0.95	2.2	1.0	1.00
	0	0.37	0.90	2.1	0	
250–350	*ii*	0.06	0	2.6	2.0	
	ij	0.62	0.89	2.0	1.4	1.00
	0	0.40	0.84	2.5	1.7	
350–540	*ii*	0.16	0	3.0	4.0	
	ij	0.56	0.72	2.7	2.6	0.98
	0	0.50	0.67	3.0	4.0	
540–1300	*ii*	0.30	0	3.0	4.0	
	ij	0.58	0.51	3.0	3.6	0.91
	0	0.59	0.50	3.0	4.0	
>1300	*ii*	0.88	0	3.0	4.0	
	ij	0.94	0.06	3.0	4.0	0.24
	0	0.94	0.05	3.0	4.0	

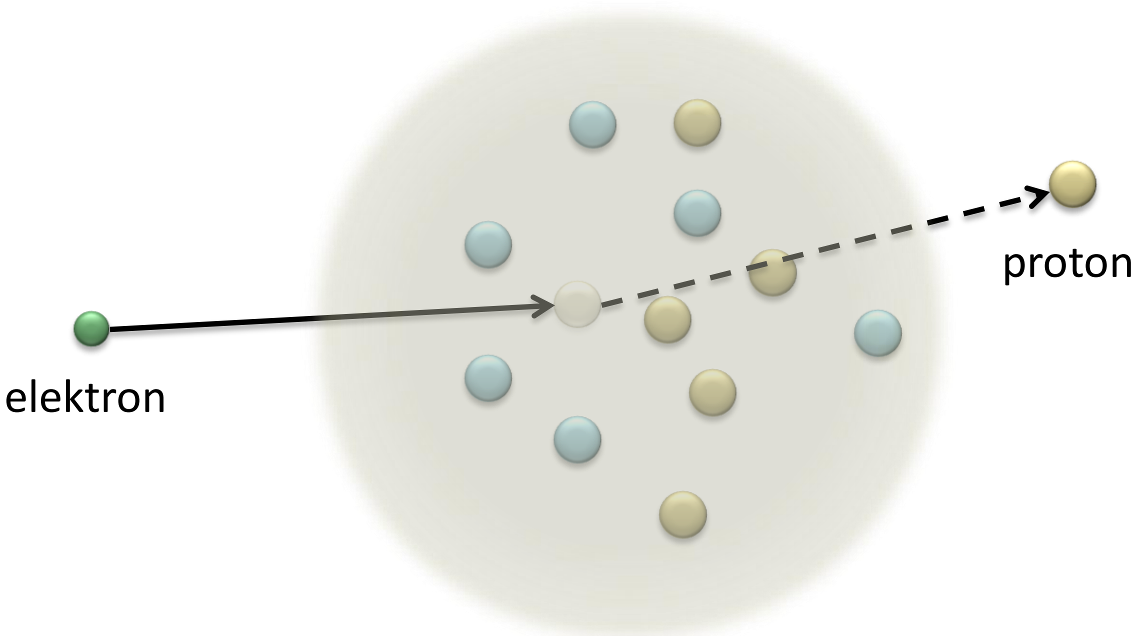
Eksperymenty vs. NuWro

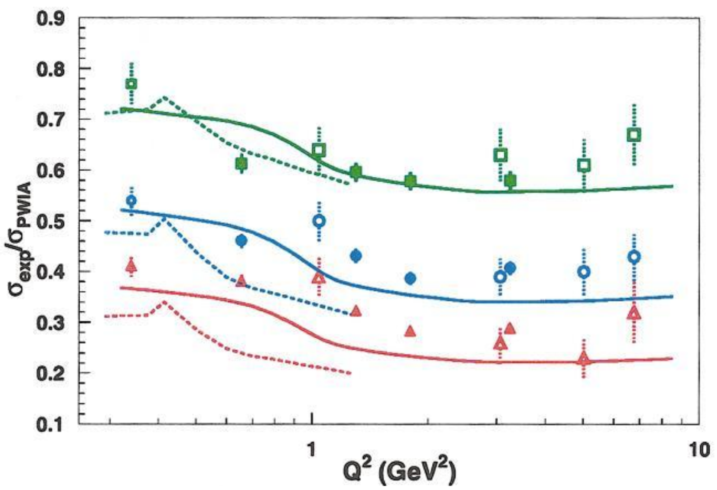
Abbott

VOLUME 80, NUMBER 23 PHYSICAL REVIEW LETTERS 8 JUNE 1998

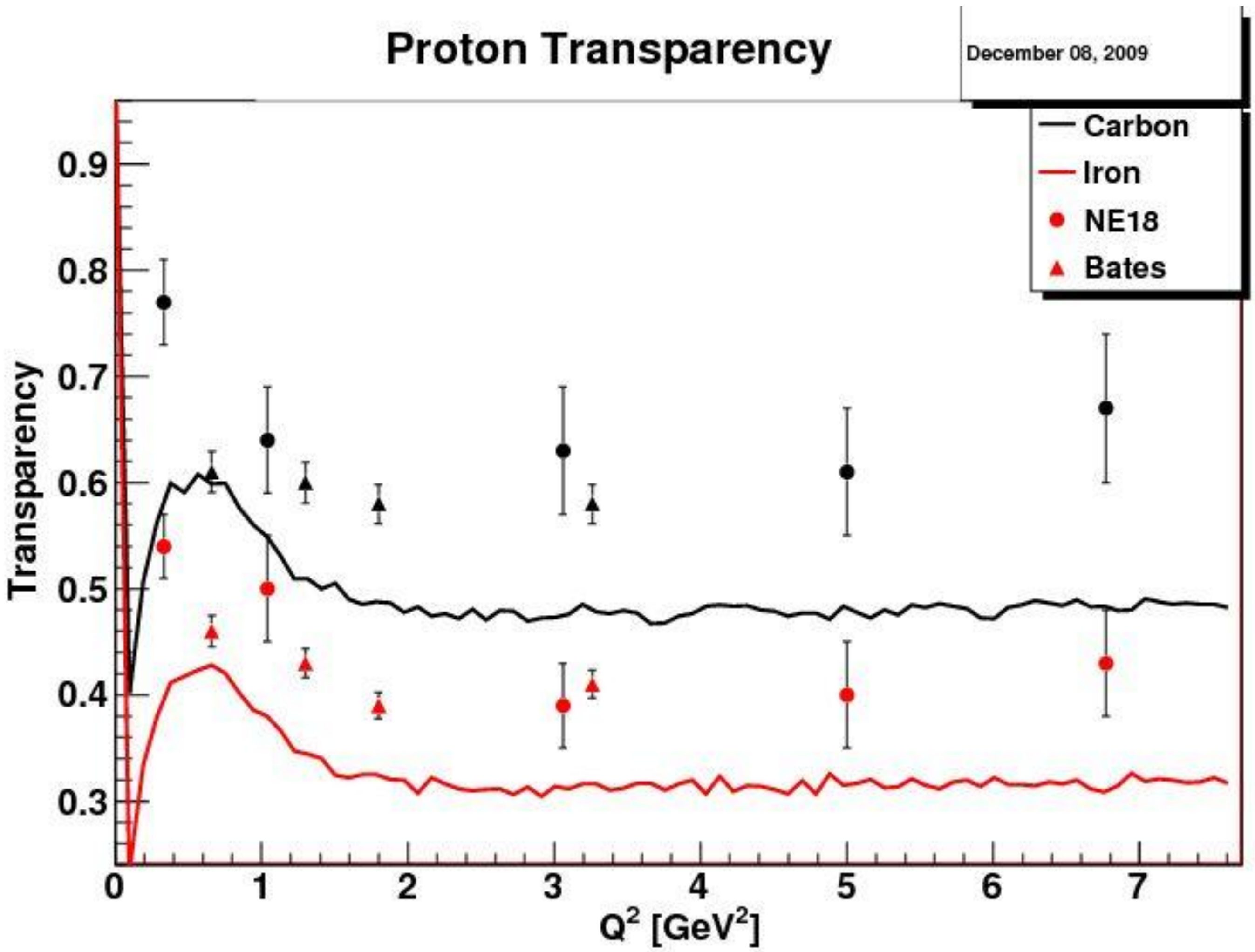
Quasifree $(e, e'p)$ Reactions and Proton Propagation in Nuclei

D. Abbott et al.





Abbott

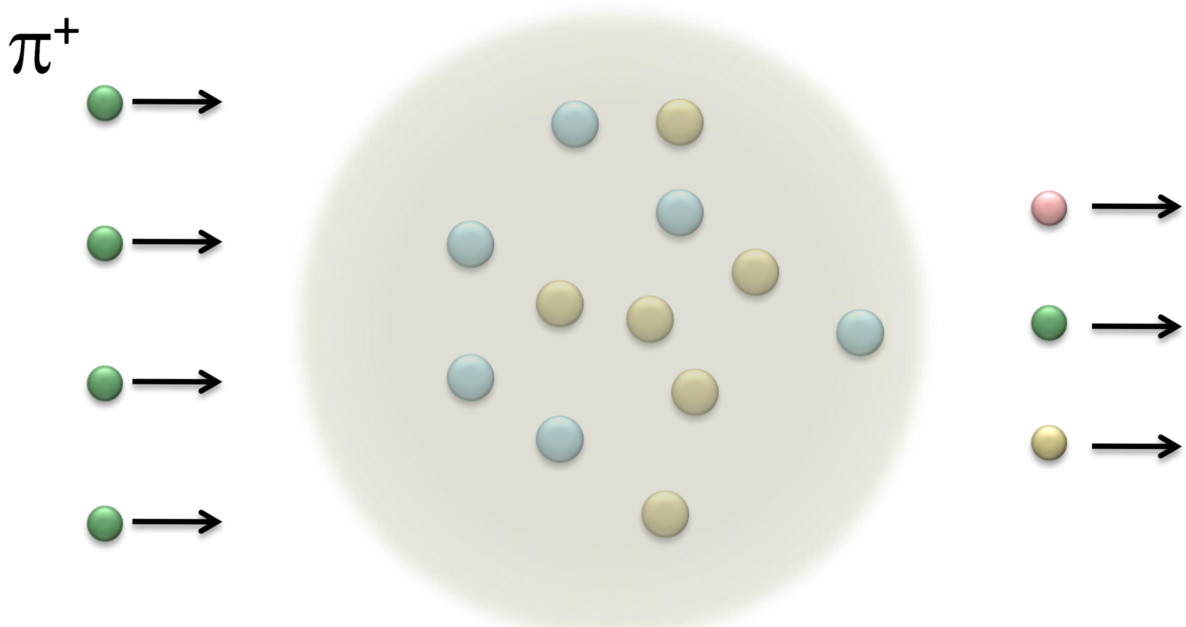


Proton Transparency
December 08, 2009
Carbon
Iron
NE18
Bates
Transparency
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0
1
2
3
4
5
6
7
Q² [GeV²]

Ashery

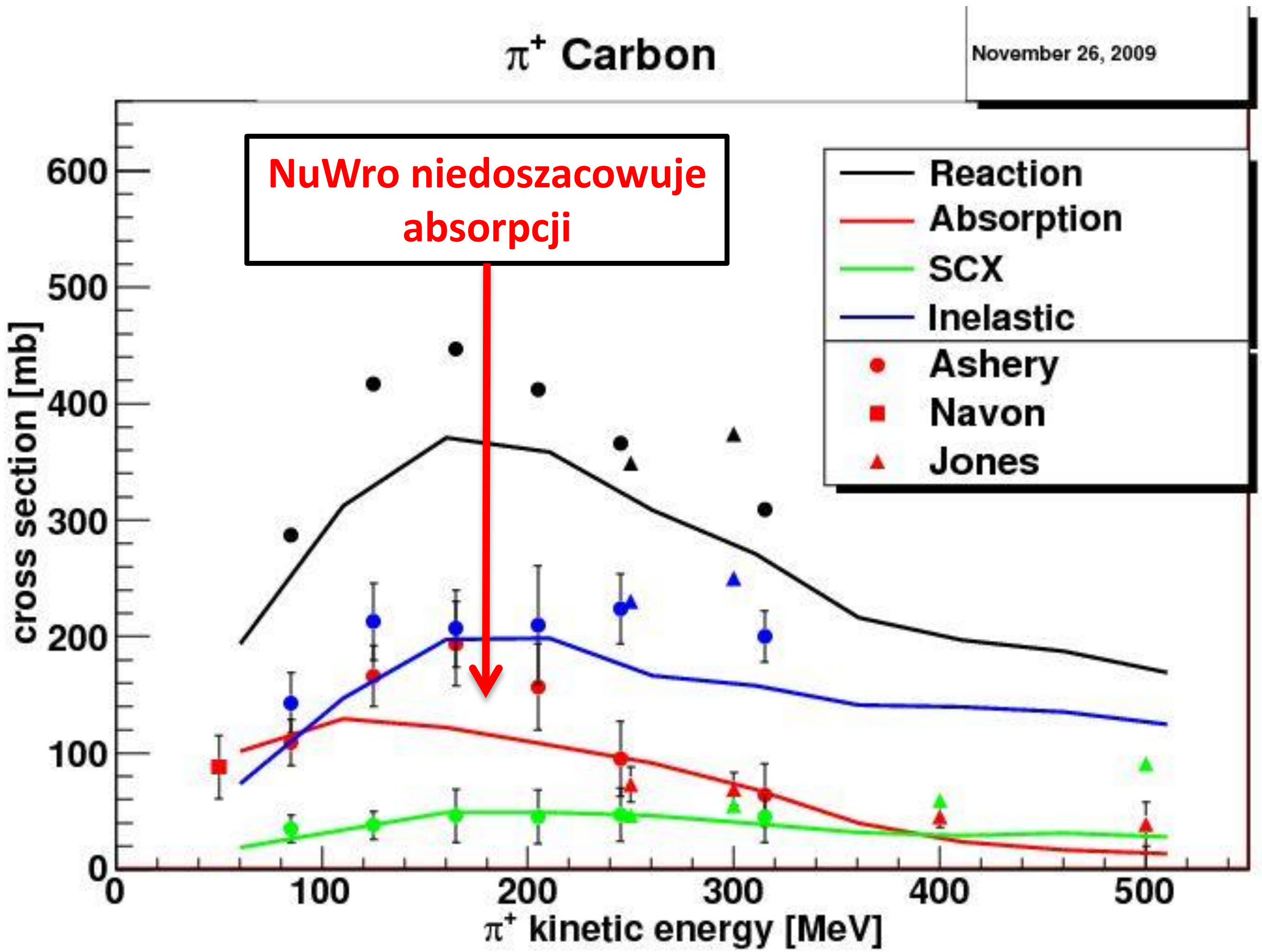
TABLE I. Values of N_{eff}, total pion nucleus cross sections (Ref. 1) and cross sections for true absorption, inelastic scattering, elastic scattering (calculated—see Appendix) and charge exchange (estimated—see Sec. IV B) reactions.

E_π (MeV)	Nucl.	N_{eff}	$\sigma_{abs}+\sigma_{cx}$ (mb)	σ_{cx} [a] (mb)	σ_{abs} (mb)	σ_{tot} [b] (mb)	σ_{el} [c] (mb)	σ_{inel} (mb)
85	Li	2.53	75 ± 13	31 ± 15	44 ± 20	260 ± 4	111 ± 11	74 ± 18
π^+	C	3.67	144 ± 15	35 ± 12	109 ± 20	465 ± 12	178 ± 18	143 ± 26
	Al	4.88	307 ± 29	55 ± 27	252 ± 40	1010 ± 30	372 ± 37	331 ± 56
	Fe	6.79	500 ± 55	79 ± 40	421 ± 70	1900 ± 80	616 ± 61	784 ± 115
	Nb	8.29	905 ± 100	100 ± 50	805 ± 143	2570 ± 300	817 ± 160	848 ± 350
	Bi	10.81	1800 ± 650	141 ± 70	1659 ± 655	4200 ± 600	1220 ± 240	1180 ± 920



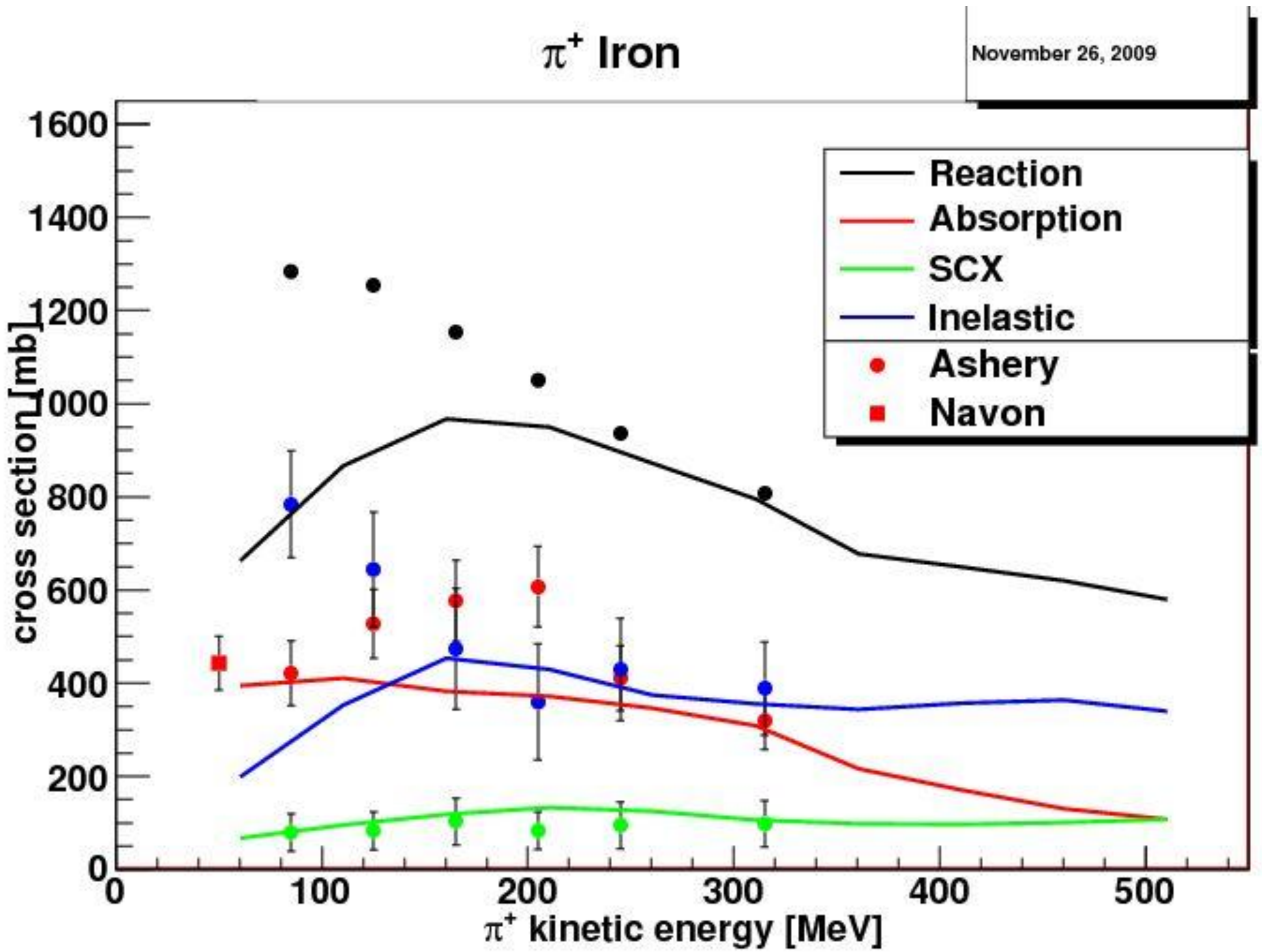
- $0\ \pi \mapsto$ absorpcja
- $\pi^0 \mapsto$ CEX
- $\pi^- \mapsto$ DCX
- nieelastyczne

Ashery



π+ Carbon
November 26, 2009
NuWro niedoszacowuje absorpcji
Reaction
Absorption
SCX
Inelastic
Ashery
Navon
Jones
cross section [mb]
π+ kinetic energy [MeV]
0
100
200
300
400
500
600

Ashery



π^+ Iron
November 26, 2009
Reaction
Absorption
SCX
Inelastic
Ashery
Navon
cross section [mb]
1600
1400
1200
1000
800
600
400
200
0
0
100
200
300
400
500
π^+ kinetic energy [MeV]

Merenyi

PHYSICAL REVIEW D VOLUME 45, NUMBER 3 1 FEBRUARY 1992

Determination of pion intranuclear rescattering rates in ν_μ-Ne versus ν_μ-D interactions for the atmospheric ν flux

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(Received 4 April 1991; revised manuscript received 23 October 1991)

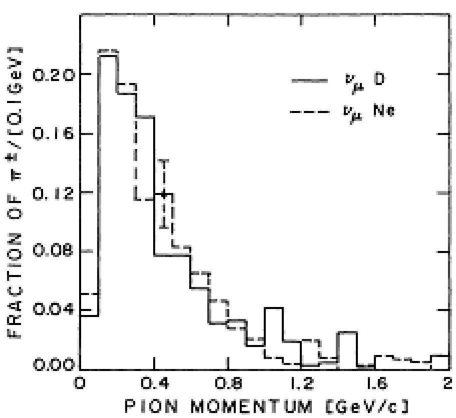


TABLE I. The ν_μD and ν_μNe samples, weighted to an atmospheric E_ν spectrum. The neutrino energies span the range $0.4 \le E_\nu \le 6.0$ GeV. Values without the correction for unobserved neutral pions are given in parentheses.

Reaction	Fractional population: Deuterium	Fractional population: Neon
$\nu n \to \mu^- p$	0.49±0.03	0.57±0.04 (0.61±0.04)
$\nu p \to \mu^- \pi^+ p$	0.19±0.02	0.14±0.02
$\nu n \to \mu^- \pi^0 p$	0.09±0.01	0.05±0.02 (0.03±0.01)
$\nu n \to \mu^- \pi^+ n$	0.14±0.02	0.08±0.02
$\nu n \to \mu^- \pi^- \pi^+ p$	0.02±0.01	0.03±0.01
$\nu n \to \mu^- \pi^0 \pi^0 p$	0.01±0.01	0.04±0.02 (0.02±0.01)
$\nu p \to \mu^- \pi^+ (l\pi^0) p, l \ge 1$	0.01±0.01	0.02±0.01
$\nu n \to \mu^- \pi^+ (l\pi^0) n, l \ge 1$		0.01±0.01
$\nu p \to \mu^- \pi^+ \pi^+ (m\pi^0) n, m \ge 0$	0.01±0.01	0.02±0.01
$\nu N \to \mu^- + (\ge 3\pi's) N$	0.03±0.03	
$\nu N \to \mu^- +$ strange particles	0.01±0.01	0.0±0.01
$\nu p \to \mu^- \pi^- p$	0	0.01±0.01
$\nu N \to \mu^- + (Q_h = 0, +3, +4)$	0	0.03±0.01

Merenyi

	Deuterium	Neon	NuWro (before FSI)	NuWro
0π	0.49 +/- 0.03	0.57 +/- 0.04	0.58025	0.67195
$1\pi^+$	0.33 +/- 0.02	0.22 +/- 0.02	0.29279	0.18949
$1\pi^0$	0.09 +/- 0.01	0.05 +/- 0.02	0.0704	0.0656
$1\pi^- + 1\pi+$	0.02 +/- 0.01	0.03 +/- 0.01	0.01236	0.01076
$2\pi^0$	0.01 +/- 0.01	0.04 +/- 0.02	0.00211	0.00441
$1\pi^+ + n*\pi^0$, n>0	0.01 +/- 0.01	0.02 +/- 0.01	0.03389	0.02284
$2\pi^+ + n*\pi^0$, n>=0	0.01 +/- 0.01	0.02 +/- 0.01	0.00558	0.0137
$1\pi^-$	0 +/- 0	0.01 +/- 0.01	0.00093	0.0142

Merenyi

~8% absorpcji

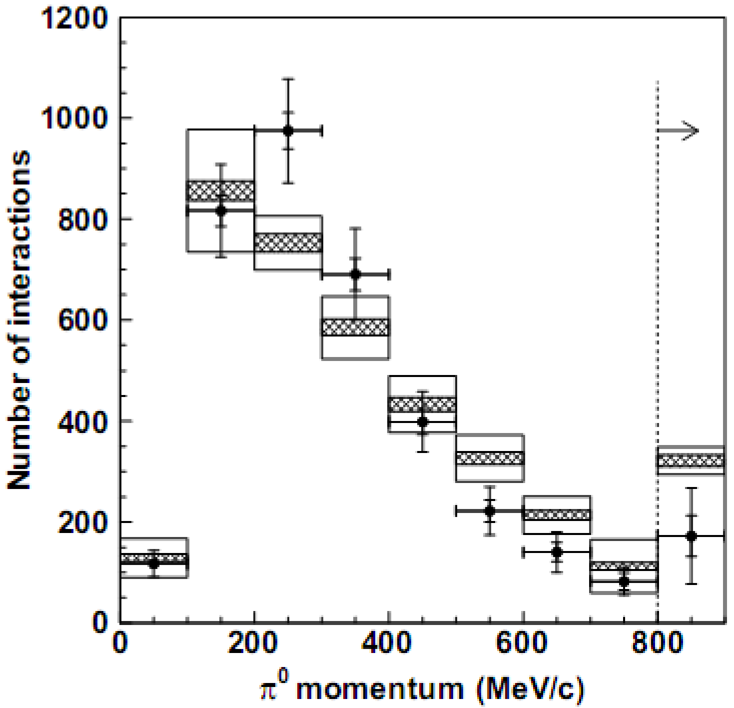
~9% absorpcji

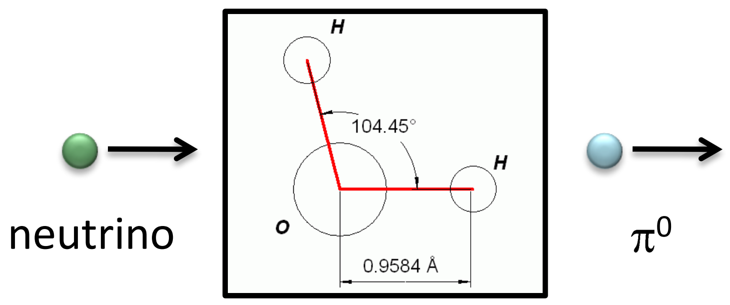
	Deuterium	Neon	NuWro (before FSI)	NuWro
0π	0.49 +/- 0.03	0.57 +/- 0.04	0.58025	0.67195
$1\pi^+$	0.33 +/- 0.02	0.22 +/- 0.02	0.29279	0.18949
$1\pi^0$	0.09 +/- 0.01	0.05 +/- 0.02	0.0704	0.0656
$1\pi^- + 1\pi+$	0.02 +/- 0.01	0.03 +/- 0.01	0.01236	0.01076
$2\pi^0$	0.01 +/- 0.01	0.04 +/- 0.02	0.00211	0.00441
$1\pi^+ + n*\pi^0$, n>0	0.01 +/- 0.01	0.02 +/- 0.01	0.03389	0.02284
$2\pi^+ + n*\pi^0$, n>=0	0.01 +/- 0.01	0.02 +/- 0.01	0.00558	0.0137
$1\pi^-$	0 +/- 0	0.01 +/- 0.01	0.00093	0.0142

K2K

Measurement of single π^0 production in neutral current neutrino interactions with water by a 1.3 GeV wide band muon neutrino beam

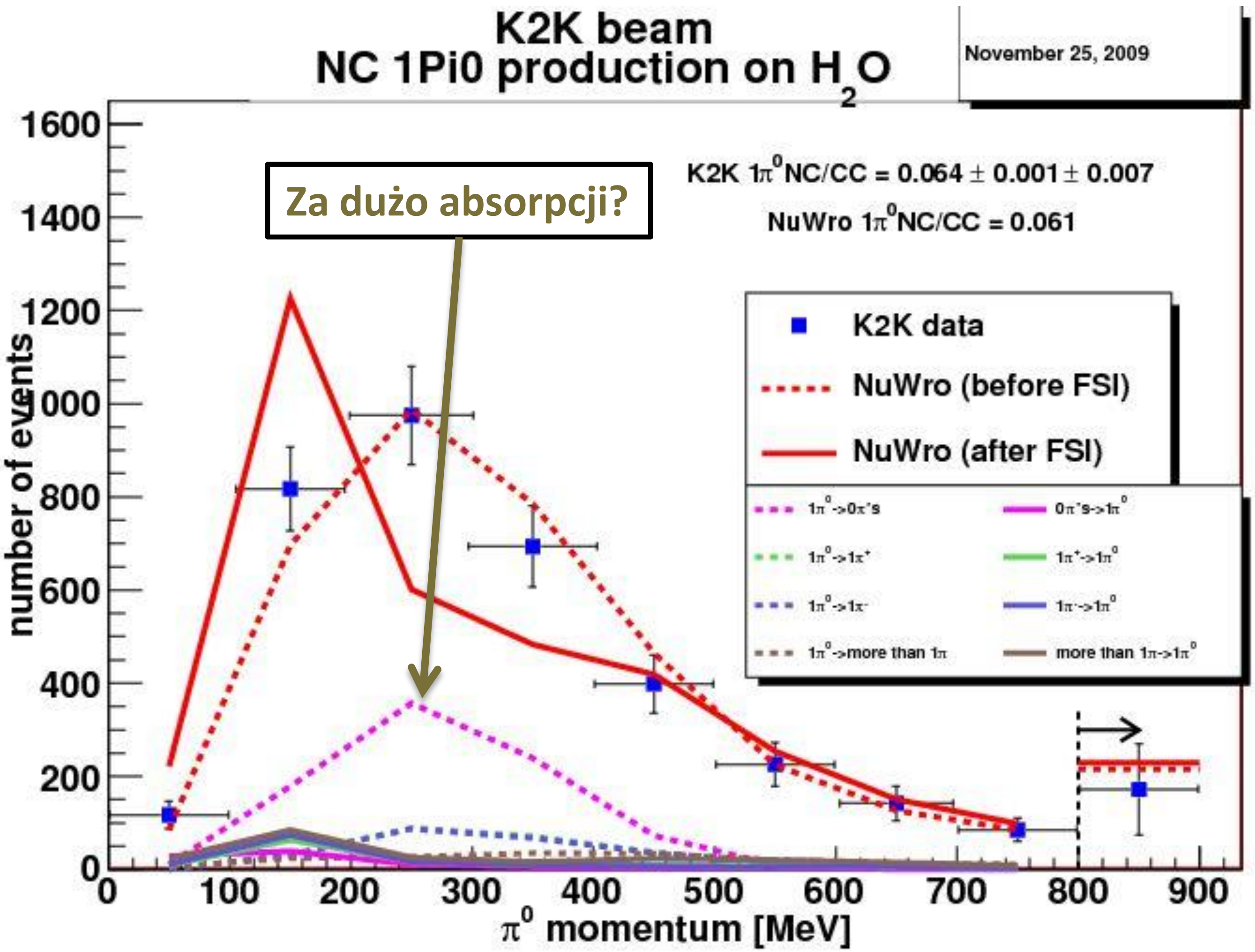
(The K2K Collaboration) arXiv:hep-ex/0408134v1 26 Aug 2004





By taking the ratio, the relative cross section for $NC1\pi^0$ interactions to the total $\nu_\mu CC$ cross section is measured to be $0.064 \pm 0.001\,(stat.) \pm 0.007\,(sys.)$.

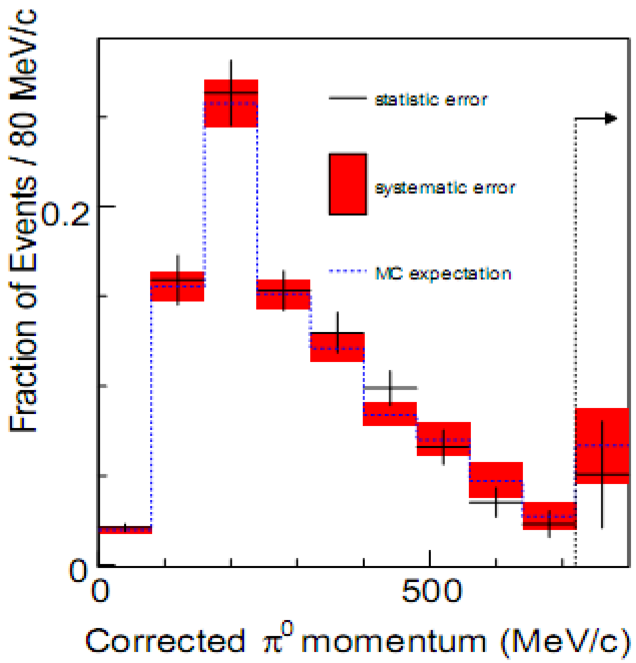
K2K


K2K beam
NC 1Pi0 production on H_2O
November 25, 2009
K2K $1\pi^0$NC/CC = 0.064 ± 0.001 ± 0.007
NuWro $1\pi^0$NC/CC = 0.061
Za dużo absorpcji?
K2K data
NuWro (before FSI)
NuWro (after FSI)
$1\pi^0$->0π's
0π's->$1\pi^0$
$1\pi^0$->$1\pi^+$
$1\pi^+$->$1\pi^0$
$1\pi^0$->$1\pi^-$
$1\pi^-$->$1\pi^0$
$1\pi^0$->more than 1π
more than 1π->$1\pi^0$
number of events
π^0 momentum [MeV]
0
100
200
300
400
500
600
700
800
900
1600
1400
1200
1000
800
600
400
200
0

SciBooNE

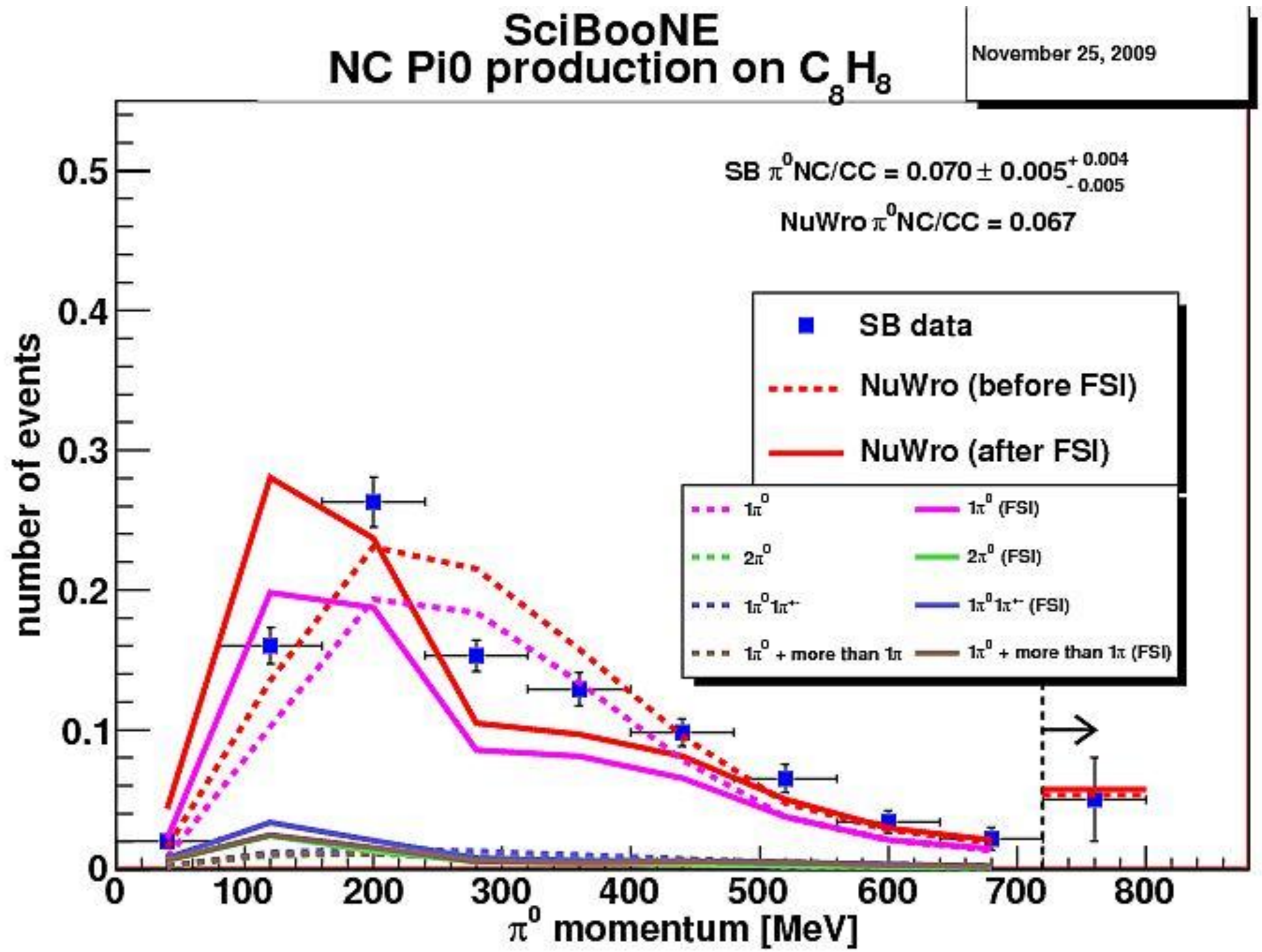
Measurement of Inclusive Neutral Current π^0 Production on Carbon in a Few-GeV Neutrino Beam

(The SciBooNE Collaboration)



The ratio of the NCπ^0 production to total CC cross sections is measured to be $(7.7 \pm 0.5(\text{stat.}) \pm 0.5(\text{sys.})) \times 10^{-2}$ at mean neutrino energy 1.1 GeV.

SciBooNE



SciBooNE
NC Pi0 production on C_8H_8
November 25, 2009
SB π^0NC/CC = $0.070 \pm 0.005^{+0.004}_{-0.005}$
NuWro π^0NC/CC = 0.067
SB data
NuWro (before FSI)
NuWro (after FSI)
$1\pi^0$
$1\pi^0$ (FSI)
$2\pi^0$
$2\pi^0$ (FSI)
$1\pi^0 1\pi^{+-}$
$1\pi^0 1\pi^{+-}$ (FSI)
$1\pi^0$ + more than 1π
$1\pi^0$ + more than 1π (FSI)
number of events
π^0 momentum [MeV]
0
0.1
0.2
0.3
0.4
0.5
100
200
300
400
500
600
700
800

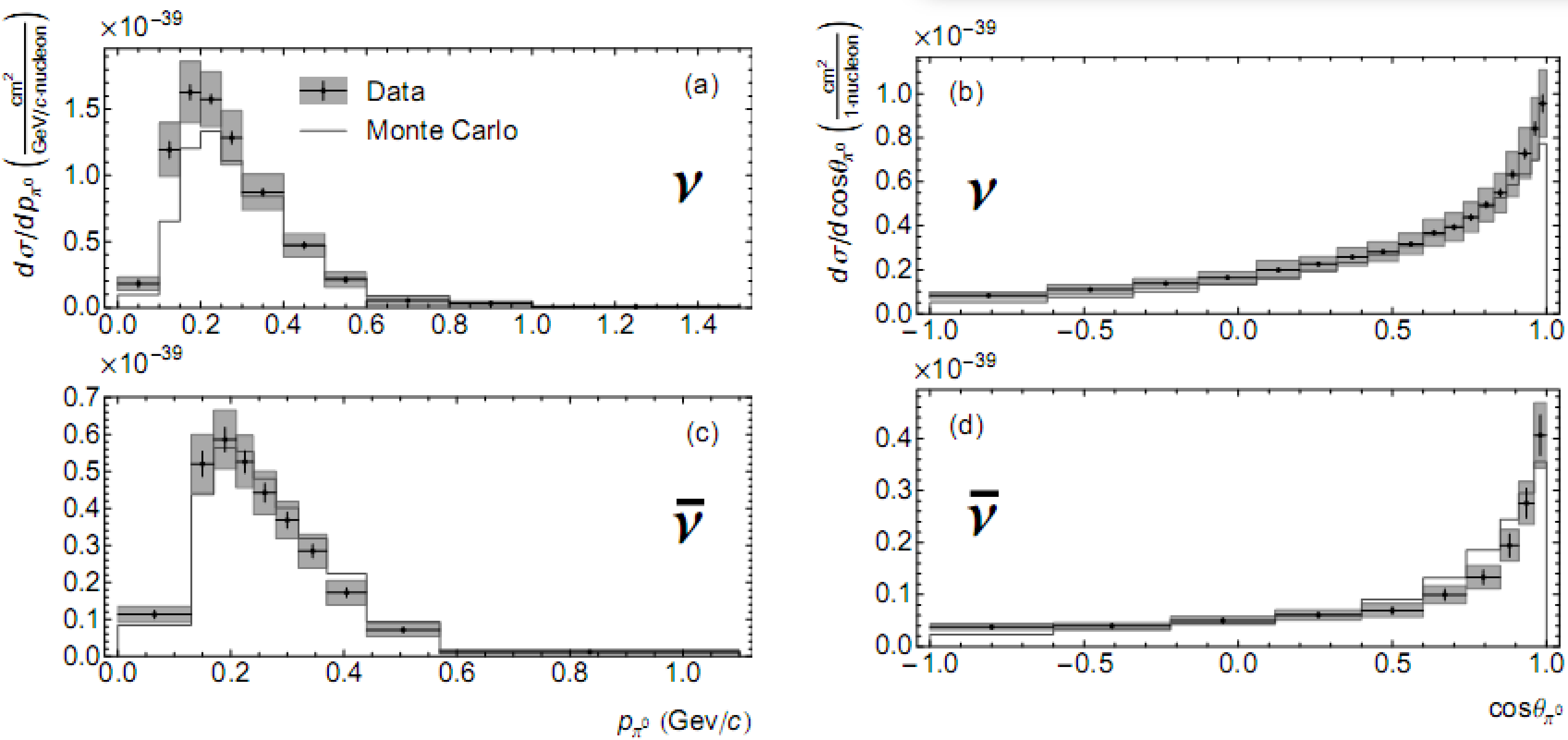
MiniBooNE

Measurement of ν_μ and $\bar{\nu}_\mu$ induced neutral current single π^0 production cross sections on mineral oil at $E_\nu \sim \mathcal{O}(1\text{ GeV})$

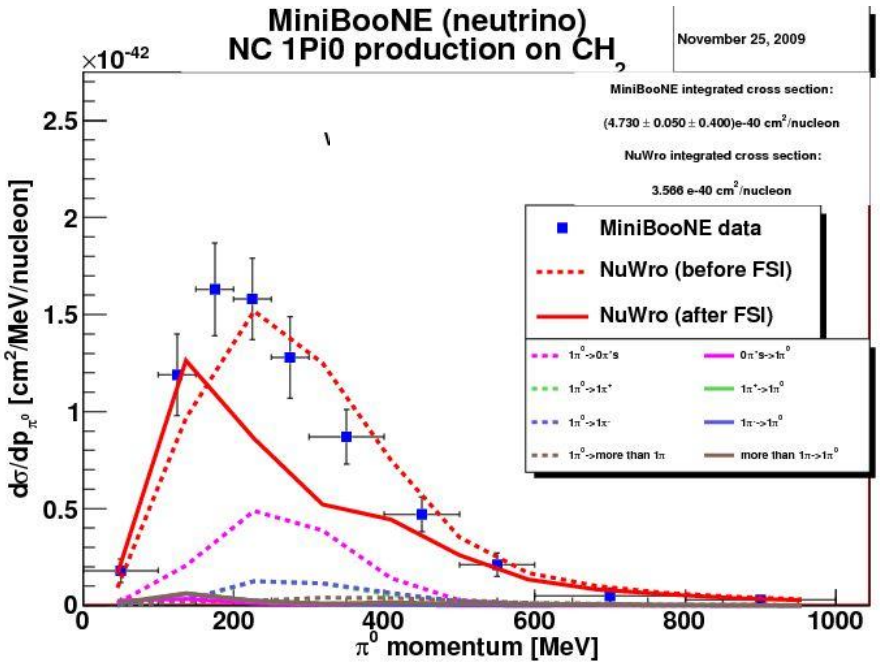
(The MiniBooNE Collaboration)

arXiv:0911.2063v1 [hep-ex] 11 Nov 2009

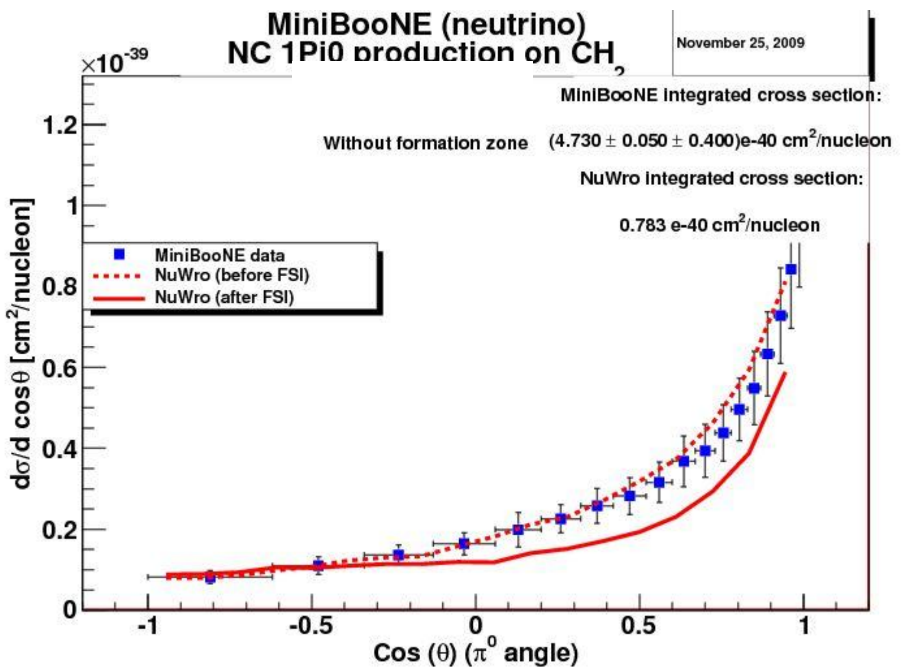
to a prior measurement. These cross sections were found to be $(5.71 \pm 0.08_{stat} \pm 0.76_{sys}) \times 10^{-40}$ cm^2/nucleon for ν_μ-induced production and $(1.28 \pm 0.07_{stat} \pm 0.21_{sys}) \times 10^{-40}$ cm^2/nucleon $\bar{\nu}_\mu$-induced production.



MiniBooNE

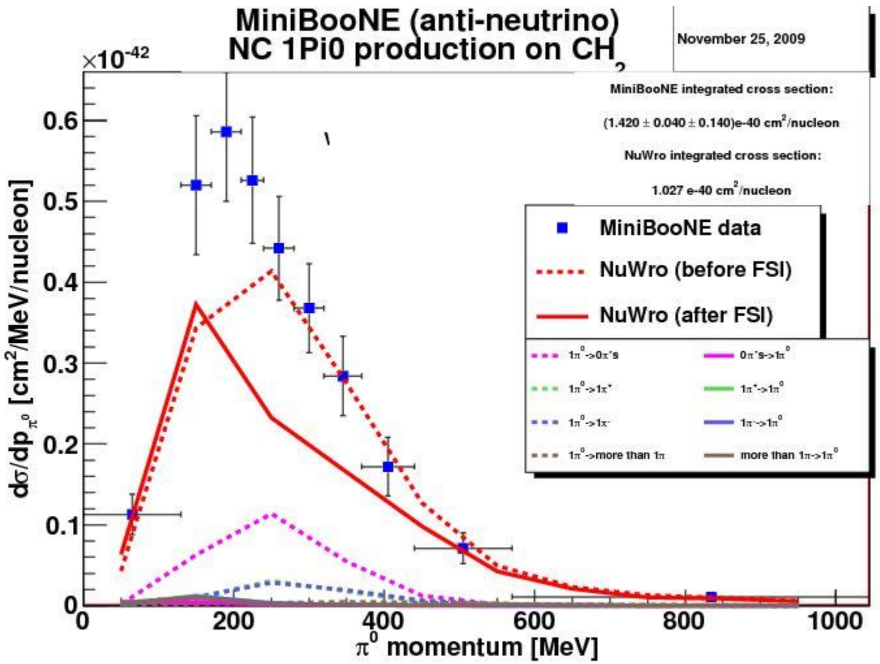


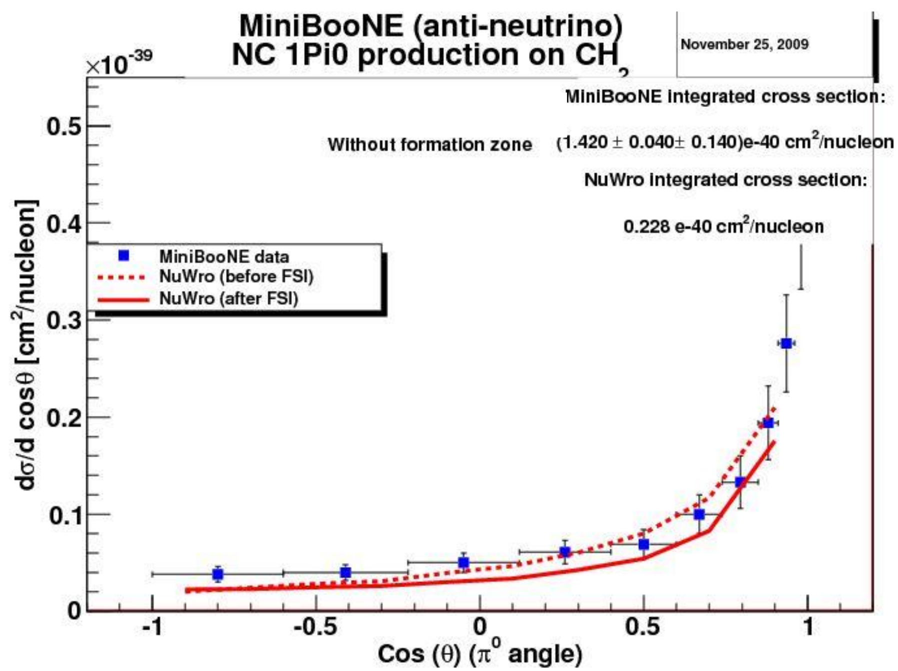
MiniBooNE (neutrino)
NC 1Pi0 production on CH2
November 25, 2009
×10^-42
MiniBooNE integrated cross section:
(4.730 ± 0.050 ± 0.400)e-40 cm²/nucleon
NuWro integrated cross section:
3.566 e-40 cm²/nucleon
MiniBooNE data
NuWro (before FSI)
NuWro (after FSI)
dσ/dp [cm²/MeV/nucleon]
π0 momentum [MeV]



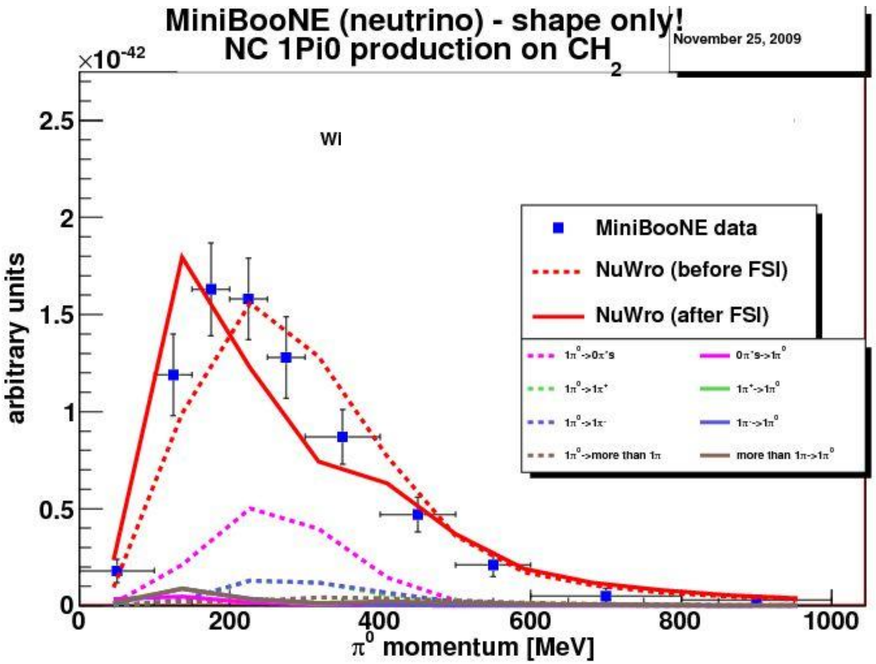
MiniBooNE (neutrino)
NC 1Pi0 production on CH2
November 25, 2009
×10^-39
MiniBooNE integrated cross section:
Without formation zone
(4.730 ± 0.050 ± 0.400)e-40 cm²/nucleon
NuWro integrated cross section:
0.783 e-40 cm²/nucleon
MiniBooNE data
NuWro (before FSI)
NuWro (after FSI)
dσ/d cosθ [cm²/nucleon]
Cos (θ) (π0 angle)

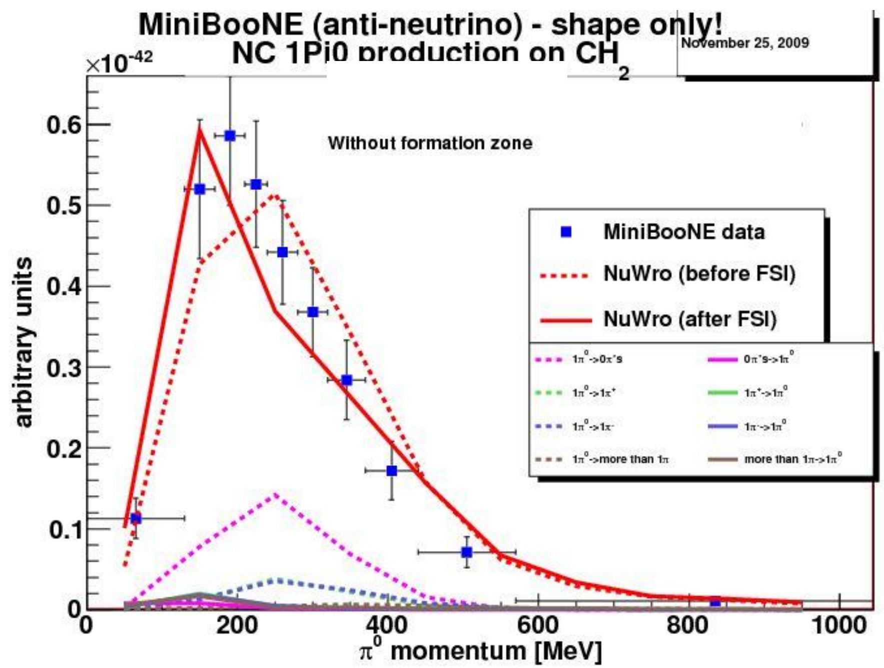
MiniBooNE


MiniBooNE (anti-neutrino)
NC 1Pi0 production on CH2
November 25, 2009
MiniBooNE integrated cross section:
(1.420 ± 0.040 ± 0.140)e-40 cm²/nucleon
NuWro integrated cross section:
1.027 e-40 cm²/nucleon
MiniBooNE data
NuWro (before FSI)
NuWro (after FSI)
×10-42
dσ/dpπ0 [cm²/MeV/nucleon]
π0 momentum [MeV]


MiniBooNE (anti-neutrino)
NC 1Pi0 production on CH2
November 25, 2009
MiniBooNE integrated cross section:
Without formation zone
(1.420 ± 0.040± 0.140)e-40 cm²/nucleon
NuWro integrated cross section:
0.228 e-40 cm²/nucleon
MiniBooNE data
NuWro (before FSI)
NuWro (after FSI)
×10-39
dσ/d cosθ [cm²/nucleon]
Cos (θ) (π0 angle)

MiniBooNE


MiniBooNE (neutrino) - shape only!
NC 1Pi0 production on CH_2
November 25, 2009
WI
MiniBooNE data
NuWro (before FSI)
NuWro (after FSI)
arbitrary units
π^0 momentum [MeV]

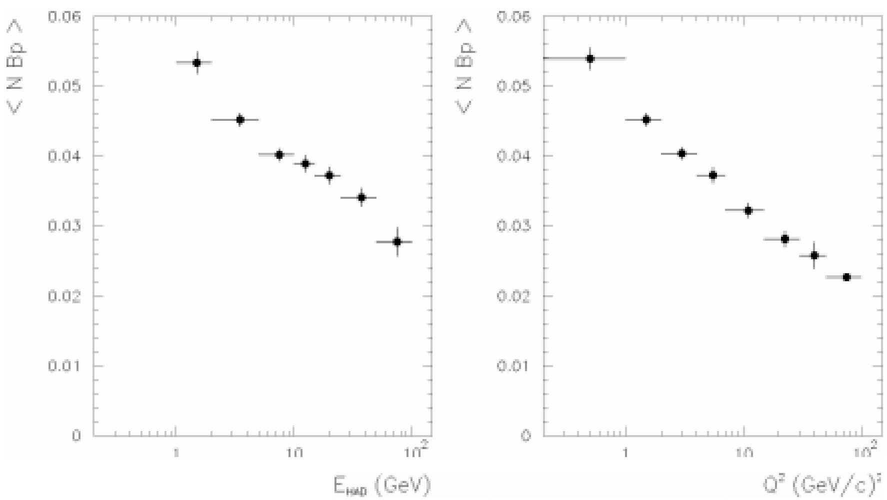

MiniBooNE (anti-neutrino) - shape only!
NC 1Pi0 production on CH_2
November 25, 2009
Without formation zone
MiniBooNE data
NuWro (before FSI)
NuWro (after FSI)
arbitrary units
π^0 momentum [MeV]

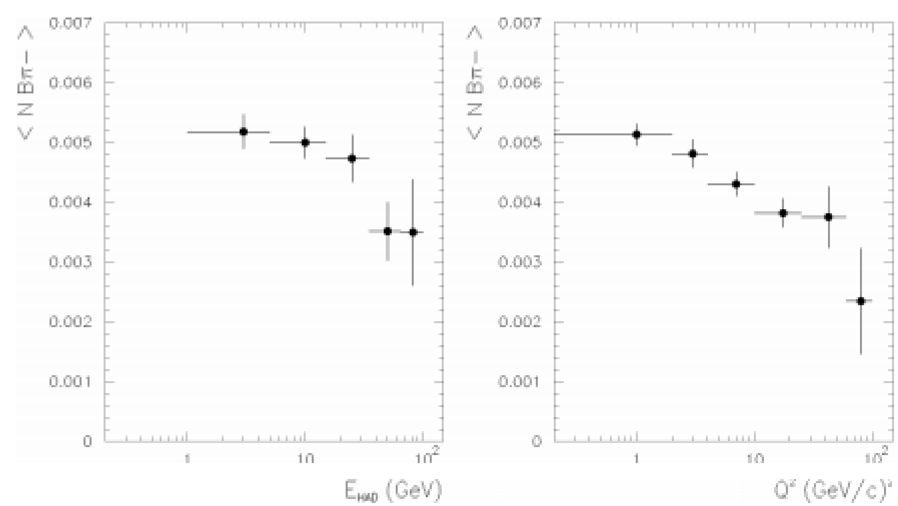
Formation Zone

Formation Zone

A study of nuclear effects in ν interactions with the NOMAD detector

M. Veltri[a*]





Formation Zone

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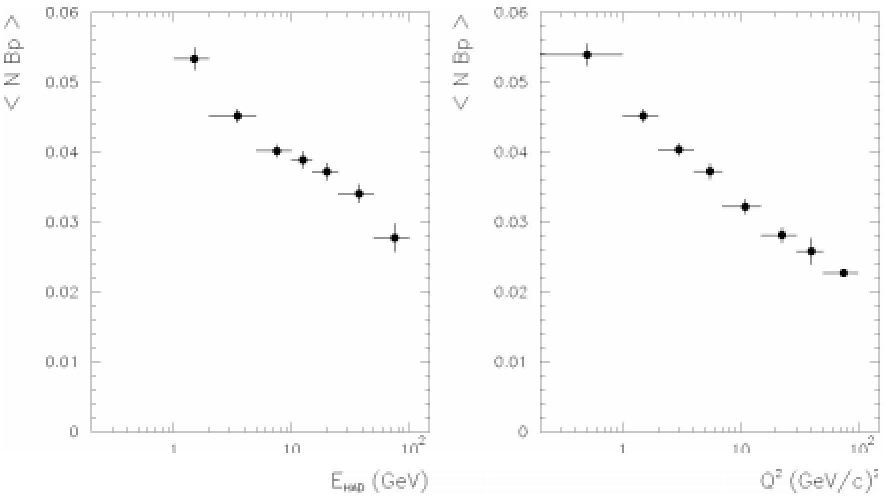
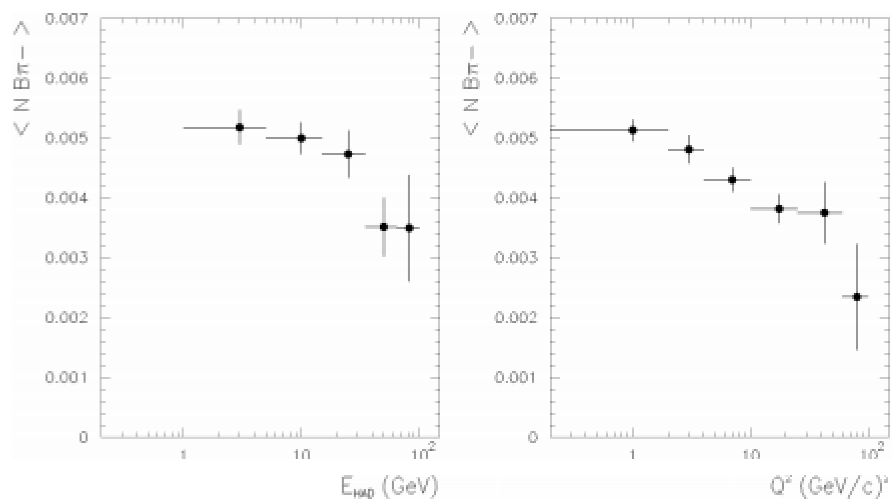


ilość wstecznych protonów maleje
ze wzrostem energii => formation zone?



Formation Zone

A study of nuclear effects in ν interactions with the NOMAD detector

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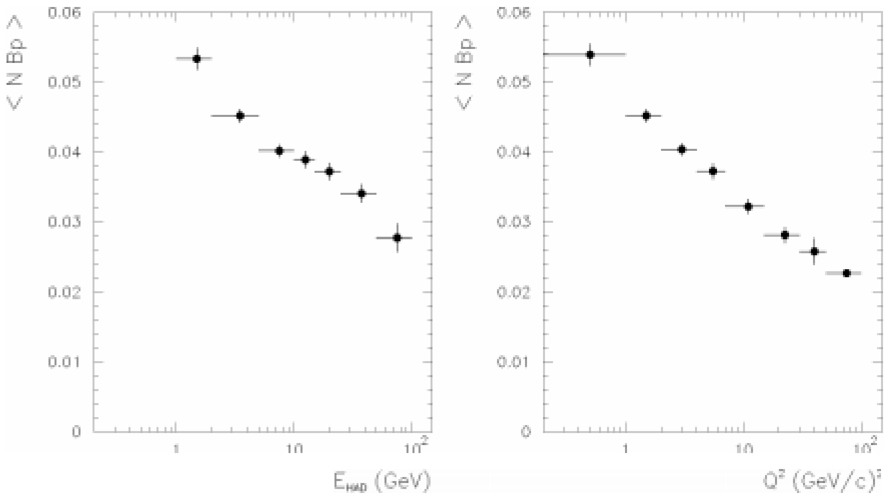
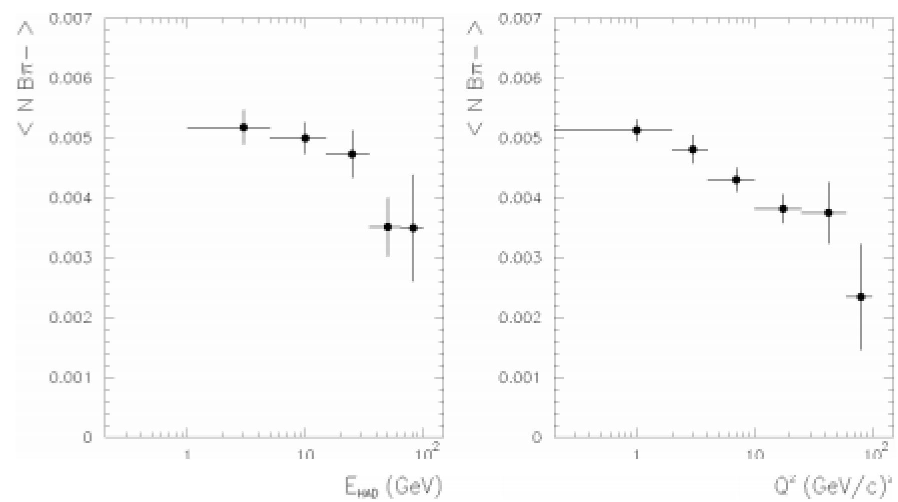


ilość wstecznych protonów maleje ze wzrostem energii => formation zone?

wsteczne piony mogą powstawać już w pierwiotnym wierzchołku => efekt jest mniejszy niż dla protonów



Formation Zone

Formation Zone Description in Multiproduction

L. Stodolsky

Talk at the VIIth International Colloquium on Multiparticle Reactions, Oxford, July 1975.

Efekt Landaua - Pomeranchuka

$$\tau = \frac{E}{k \cdot p}$$

Formation Zone

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$$\tau = \frac{E}{k \cdot p}$$

energia elektronu

czteropęd elektronu

czas między kolejnymi zderzeniami

czteropęd fotonu

Formation Zone

Formation Zone Description in Multiproduction

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Talk at the VIIth International Colloquium on Multiparticle Reactions, Oxford, July 1975.

Efekt Landaua - Pomeranchuka

$$\tau = \frac{E}{K \cdot P}$$

Formation Zone

$$\tau_{\rm Lab} = \frac{2E_s}{(m_p x)^2 + m_s^2 + p_{s\perp}^2}, \qquad x = \frac{E_s}{E_p}.$$

$$p_p = (E_p, 0, 0, \sqrt{E_p^2 - m_p^2}), \qquad p_s = (E_s, \vec{p}_{s\perp}, \sqrt{E_s^2 - m_s^2 - \vec{p}_{s\perp}^2})$$

Formation Zone

$$\tau_{\mathrm{Lab}} = \frac{2E_s}{m_s^2 + p_{s\perp}^2} \Longrightarrow \chi_{\mathrm{Lab}} = \frac{2.\,p_s}{m_s^2 + p_{s\perp}^2}$$

Formation Zone

$$\tau_{\rm Lab} = \frac{2E_s}{m_s^2 + p_{s\perp}^2} \Longrightarrow \chi_{\rm Lab} = \frac{2\, p_s}{m_s^2 + p_{s\perp}^2}$$

$\Downarrow$

$$\tau_{\rm Lab} \approx \gamma_s \tau_s$$

$$\gamma_s = \frac{E_s}{m_s}$$

$$\tau_s = \tau_0 \frac{m_s^2}{m_s^2 + p_{s\perp}^2}$$

Formation Zone

$$\tau_{\text{Lab}} = \frac{2E_s}{m_s^2 + p_{s\perp}^2} \quad \Longrightarrow \quad \chi_{\text{Lab}} = \frac{2\, p_s}{m_s^2 + p_{s\perp}^2}$$

$$\Downarrow$$

$$\tau_{\text{Lab}} \approx \gamma_s \tau_s$$

$$\gamma_s = \frac{E_s}{m_s}$$

$$\tau_s = \tau_0 \frac{m_s^2}{m_s^2 + p_{s\perp}^2}$$

SKAT	$l_f = \frac{P}{\mu^2}$
FLUKA	$t_{lab} \approx \frac{\hbar E_{lab}}{p_T^2 + M^2}$
GENIE	$L = \frac{momentum}{mass} * t_0$

Formation Zone

W układzie, w którym cel spoczywa:

$$\Delta E_2 = \nu_2 = \frac{q \cdot p_2}{m_2}$$

zasada nieoznaczoności

$$\Delta \tau = \frac{m_2}{q \cdot p_2}$$

boost do układu laboratoryjnego

$$\Delta x_{lab} = \frac{p_{2lab}}{m_2} \cdot \Delta \tau = \frac{p_{2lab}}{m_2 \nu_2}$$

Formation Zone

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$$\Delta E_2 = \nu_2 = \frac{q \cdot p_2}{m_2}$$

zasada nieoznaczoności →

$$\Delta \tau = \frac{m_2}{q \cdot p_2}$$

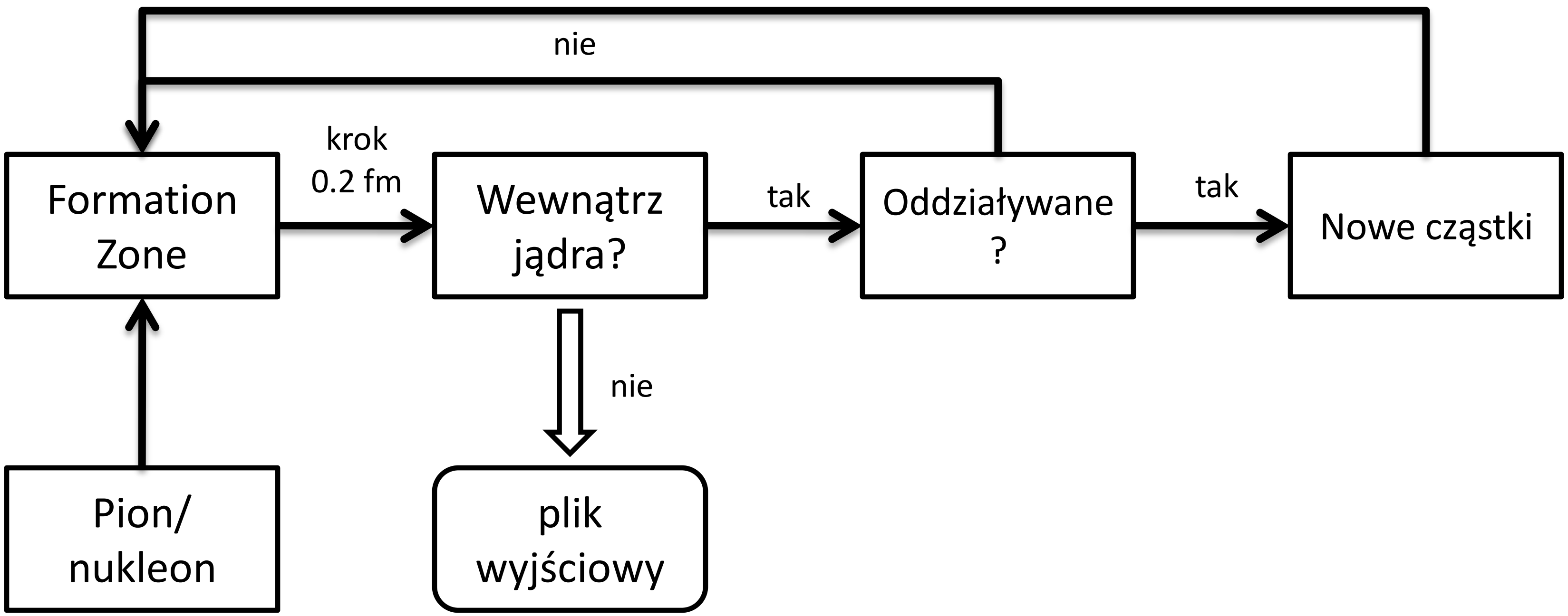
boost do układu laboratoryjnego ↓

$$\Delta x_{lab} = \frac{p_{2lab}}{m_2} \cdot \Delta \tau = \frac{p_{2lab}}{m_2 \nu_2}$$

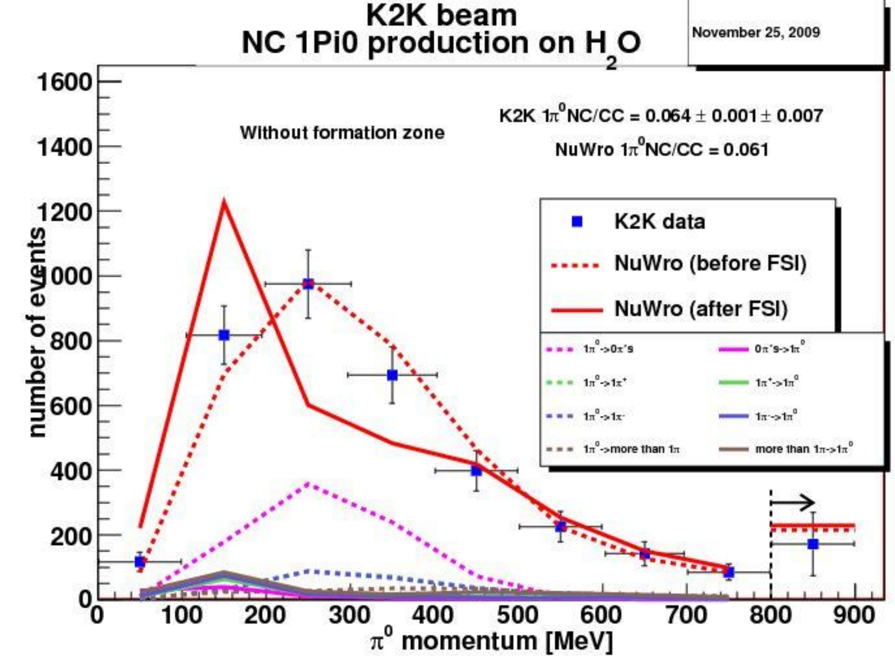
Efekt Landaua - Pomeranchuka

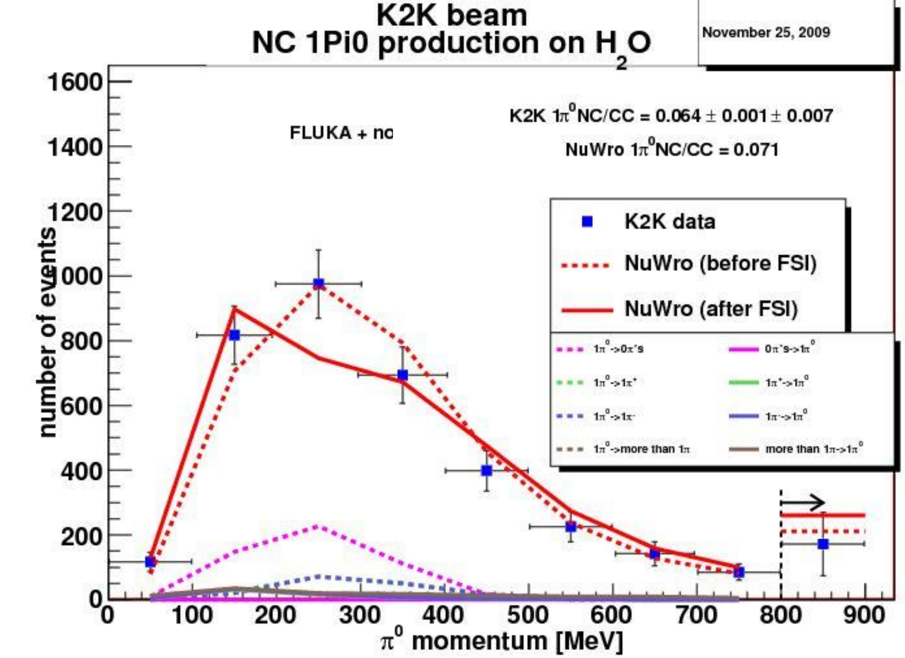
$$\tau = \frac{E}{K \cdot P}$$

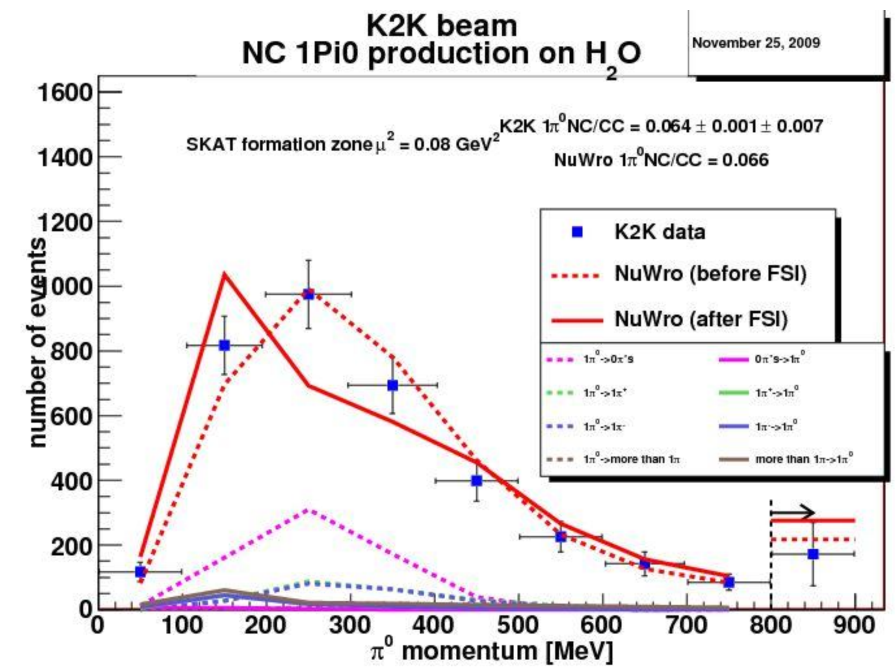
Formation Zone

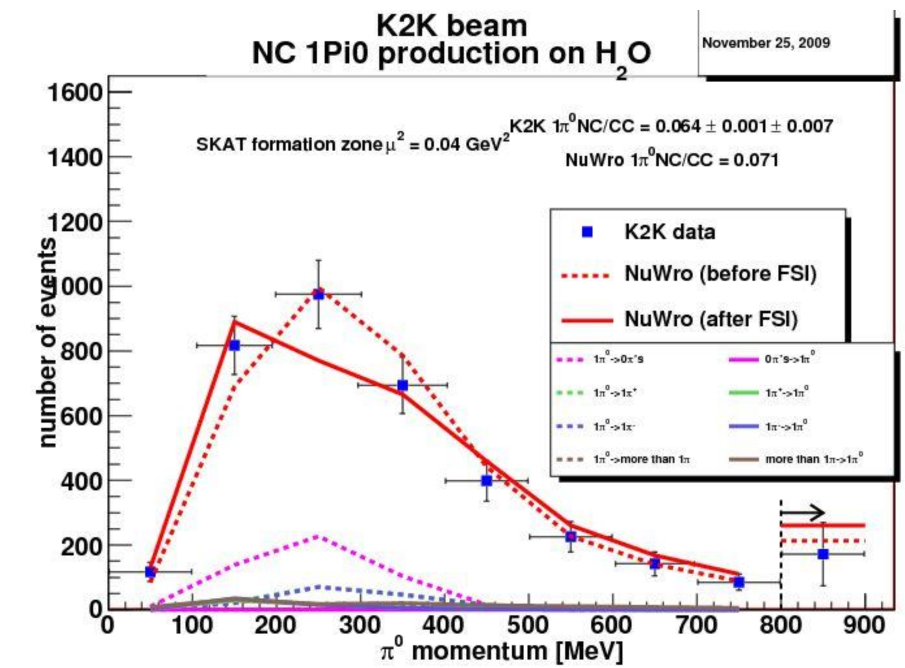


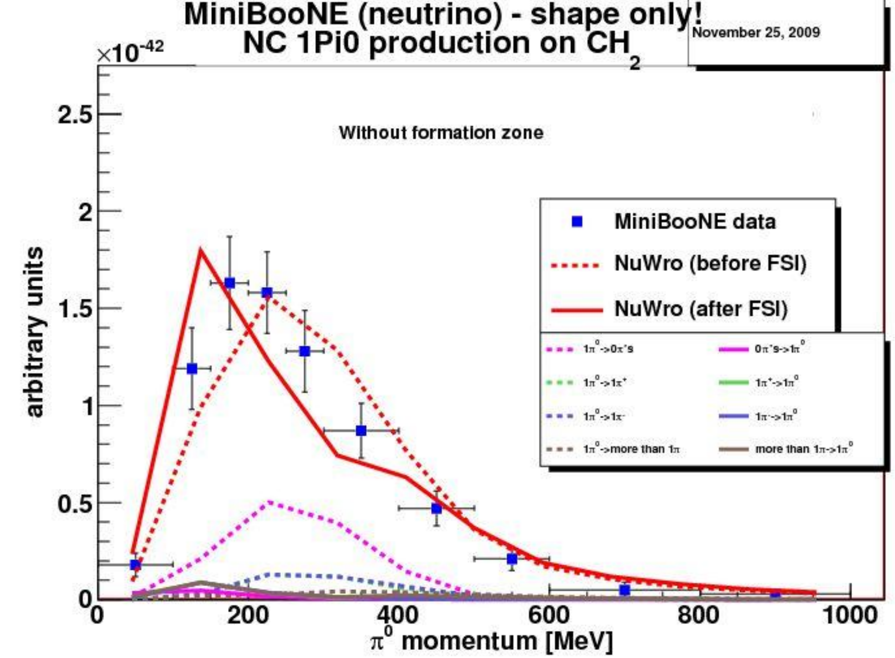
Wpływ FZ na wyniki

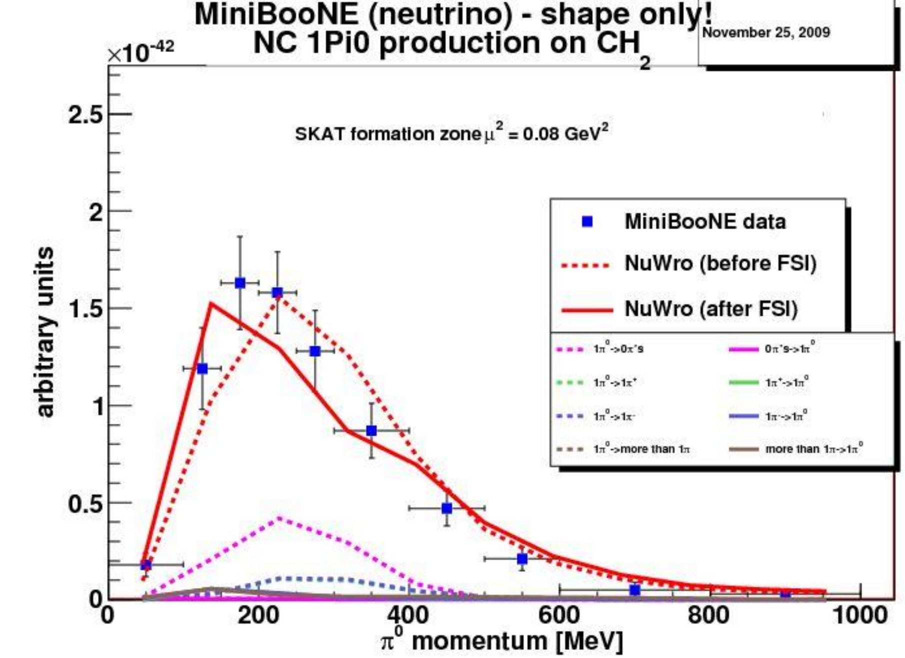

K2K beam
NC 1Pi0 production on H2O
November 25, 2009
Without formation zone
K2K 1π0NC/CC = 0.064 ± 0.001 ± 0.007
NuWro 1π0NC/CC = 0.061
K2K data
NuWro (before FSI)
NuWro (after FSI)
number of events
π0 momentum [MeV]


K2K beam
NC 1Pi0 production on H2O
November 25, 2009
FLUKA + nc
K2K 1π0NC/CC = 0.064 ± 0.001 ± 0.007
NuWro 1π0NC/CC = 0.071
K2K data
NuWro (before FSI)
NuWro (after FSI)
number of events
π0 momentum [MeV]


K2K beam
NC 1Pi0 production on H2O
November 25, 2009
SKAT formation zone μ2 = 0.08 GeV2
K2K 1π0NC/CC = 0.064 ± 0.001 ± 0.007
NuWro 1π0NC/CC = 0.066
K2K data
NuWro (before FSI)
NuWro (after FSI)
number of events
π0 momentum [MeV]


K2K beam
NC 1Pi0 production on H2O
November 25, 2009
SKAT formation zone μ2 = 0.04 GeV2
K2K 1π0NC/CC = 0.064 ± 0.001 ± 0.007
NuWro 1π0NC/CC = 0.071
K2K data
NuWro (before FSI)
NuWro (after FSI)
number of events
π0 momentum [MeV]


MiniBooNE (neutrino) - shape only!
NC 1Pi0 production on CH2
November 25, 2009
×10^-42
Without formation zone
MiniBooNE data
NuWro (before FSI)
NuWro (after FSI)
1π0->0π's
0π's->1π0
1π0->1π+
1π+->1π0
1π0->1π-
1π-->1π0
1π0->more than 1π
more than 1π->1π0
arbitrary units
π0 momentum [MeV]


MiniBooNE (neutrino) - shape only!
NC 1Pi0 production on CH2
November 25, 2009
×10^-42
SKAT formation zone μ2 = 0.08 GeV2
MiniBooNE data
NuWro (before FSI)
NuWro (after FSI)
1π0->0π's
0π's->1π0
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1π0->1π-
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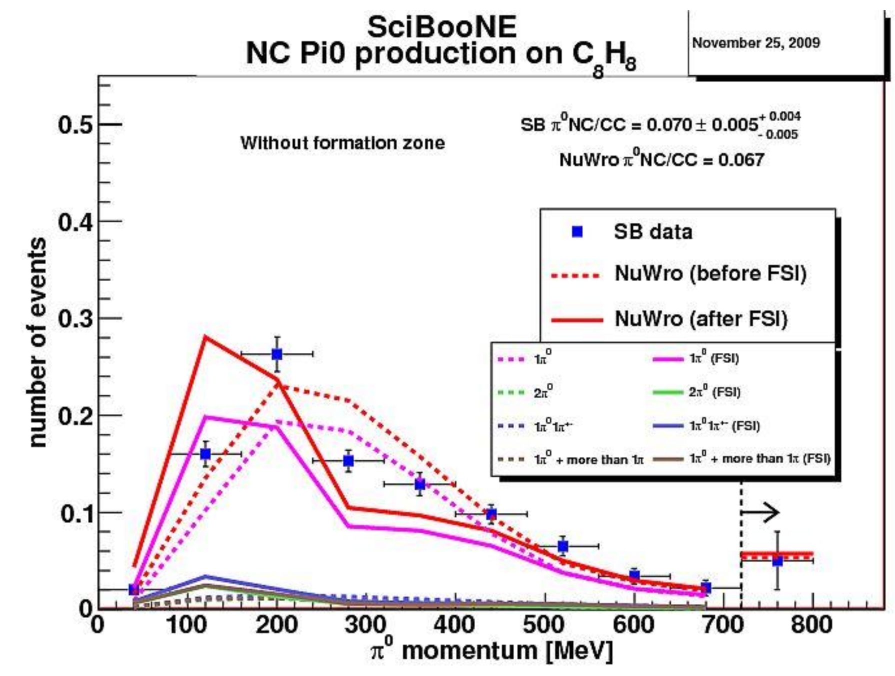
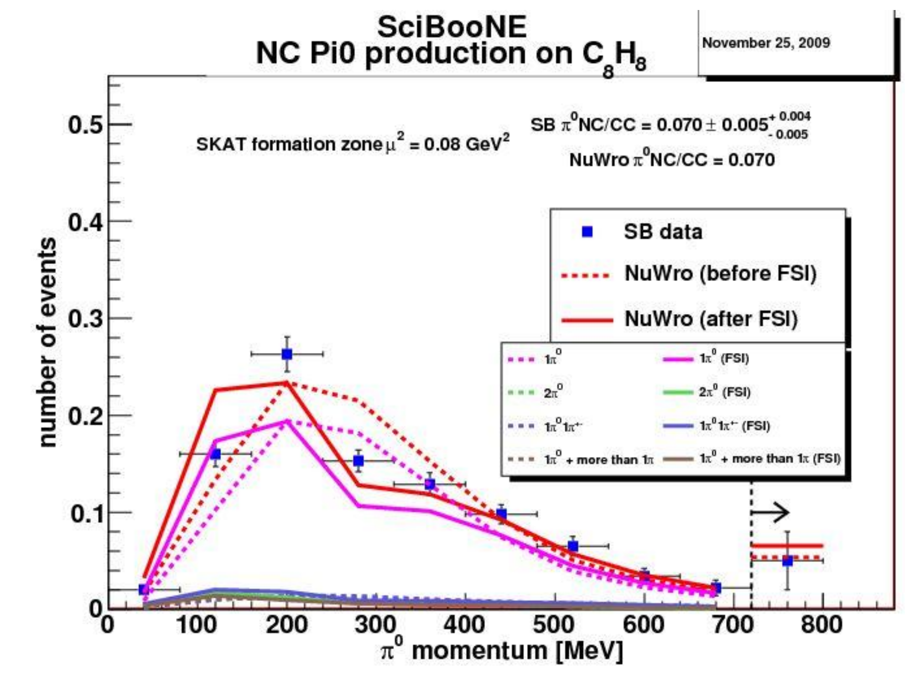
arbitrary units
π0 momentum [MeV]


SciBooNE
NC Pi0 production on C8H8
November 25, 2009
SB π0NC/CC = 0.070 ± 0.005 +0.004 -0.005
Without formation zone
NuWro π0NC/CC = 0.067
SB data
NuWro (before FSI)
NuWro (after FSI)
1π0
1π0 (FSI)
2π0
2π0 (FSI)
1π01π+-
1π01π+- (FSI)
1π0 + more than 1π
1π0 + more than 1π (FSI)
number of events
π0 momentum [MeV]


SciBooNE
NC Pi0 production on C8H8
November 25, 2009
SB π0NC/CC = 0.070 ± 0.005 +0.004 -0.005
SKAT formation zone μ2 = 0.08 GeV2
NuWro π0NC/CC = 0.070
SB data
NuWro (before FSI)
NuWro (after FSI)
1π0
1π0 (FSI)
2π0
2π0 (FSI)
1π01π+-
1π01π+- (FSI)
1π0 + more than 1π
1π0 + more than 1π (FSI)
number of events
π0 momentum [MeV]

	Deuterium	Neon	NuWro (before FSI)	NuWro (without FZ)	NuWro (FZ → μ^2 = 0.08 GeV^2)	NuWro (FZ → μ^2 = 0.04 GeV^2)
0π	0.49 +/- 0.03	0.57 +/- 0.04	0.58025	0.67195	0.661176	0.645767
$1\pi^+$	0.33 +/- 0.02	0.22 +/- 0.02	0.29279	0.18949	0.214192	0.229892
$1\pi^0$	0.09 +/- 0.01	0.05 +/- 0.02	0.0704	0.0656	0.0673907	0.0705707
$1\pi^- + 1\pi+$	0.02 +/- 0.01	0.03 +/- 0.01	0.01236	0.01076	0.0099101	0.0100001
$2\pi^0$	0.01 +/- 0.01	0.04 +/- 0.02	0.00211	0.00441	0.00326003	0.00304004
$1\pi^+ + n*\pi^0$, n>0	0.01 +/- 0.01	0.02 +/- 0.01	0.03389	0.02284	0.0222302	0.0239102
$2\pi^+ + n*\pi^0$, n>=0	0.01 +/- 0.01	0.02 +/- 0.01	0.00558	0.0137	0.00856007	0.00676014
$1\pi^-$	0 +/- 0	0.01 +/- 0.01	0.00093	0.0142	0.00918007	0.00699014

	Deuterium	Neon	NuWro (before FSI)	NuWro (without FZ)	NuWro ($FZ \to \mu^2 = 0.08$ GeV^2)	NuWro ($FZ \to \mu^2 = 0.04$ GeV^2)
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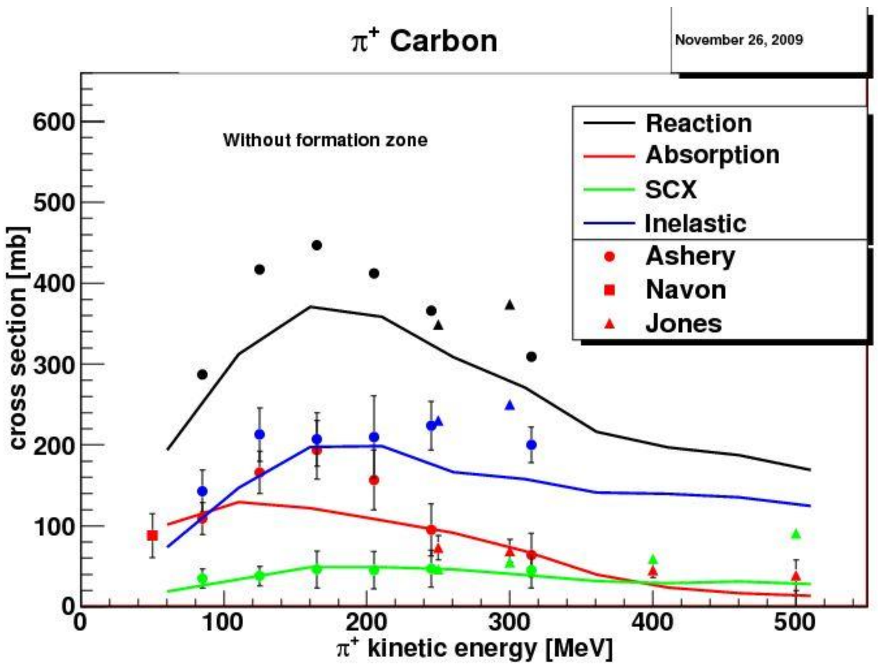
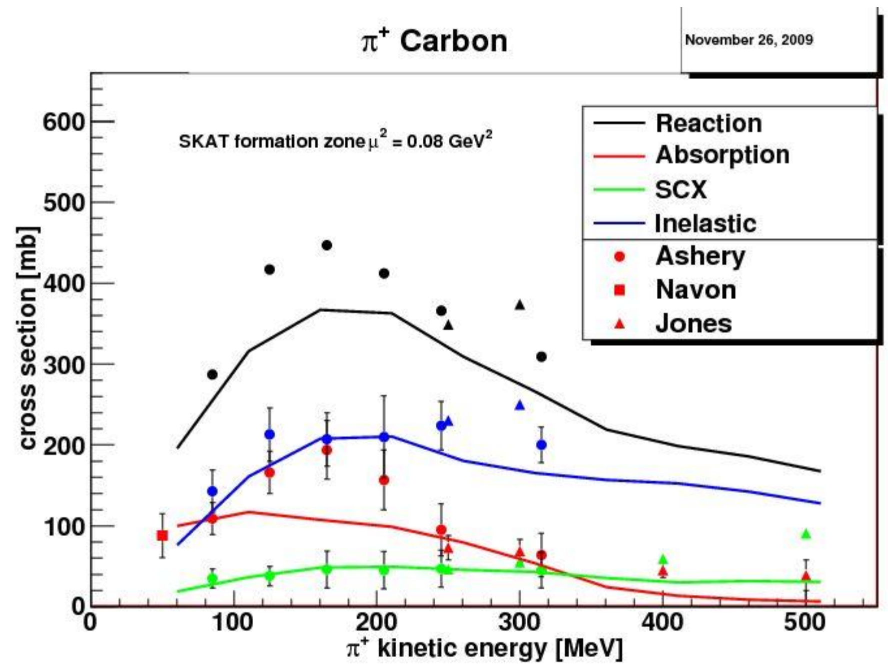
$1\pi^-$	0 +/- 0	0.01 +/- 0.01	0.00093	0.0142	0.00918007	0.00699014





Formation Zone

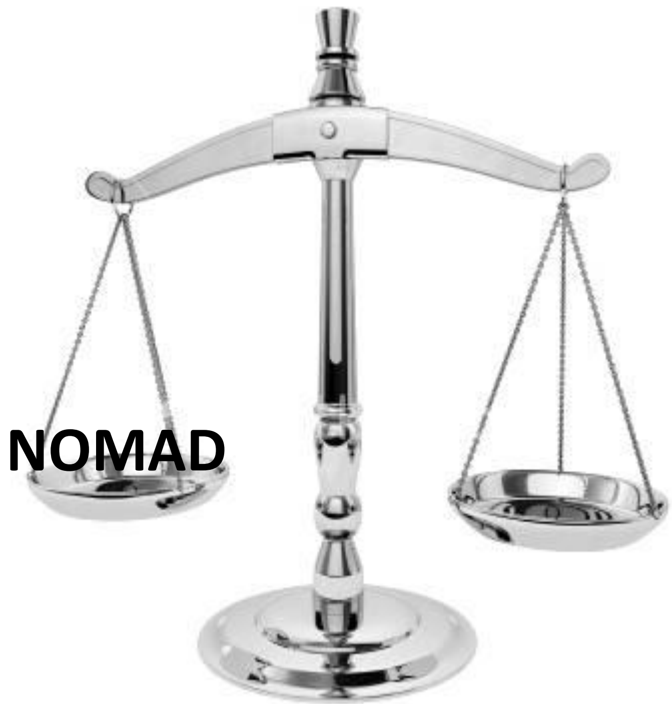
- Wyniki z FZ są zdecydowanie bliższe rzeczywistości
- Model jest zgodny z intuicją – im większa energia tym większy formation length

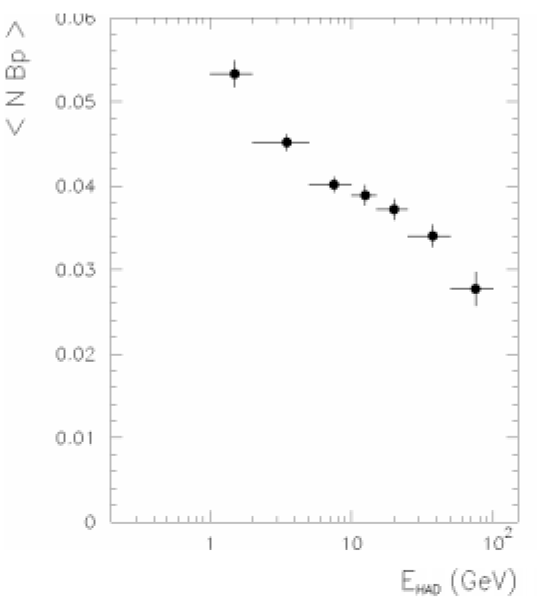
Formation Zone

- Wyniki z FZ są zdecydowanie bliższe rzeczywistości
- Model jest zgodny z intuicją – im większa energia
  tym większy formation length

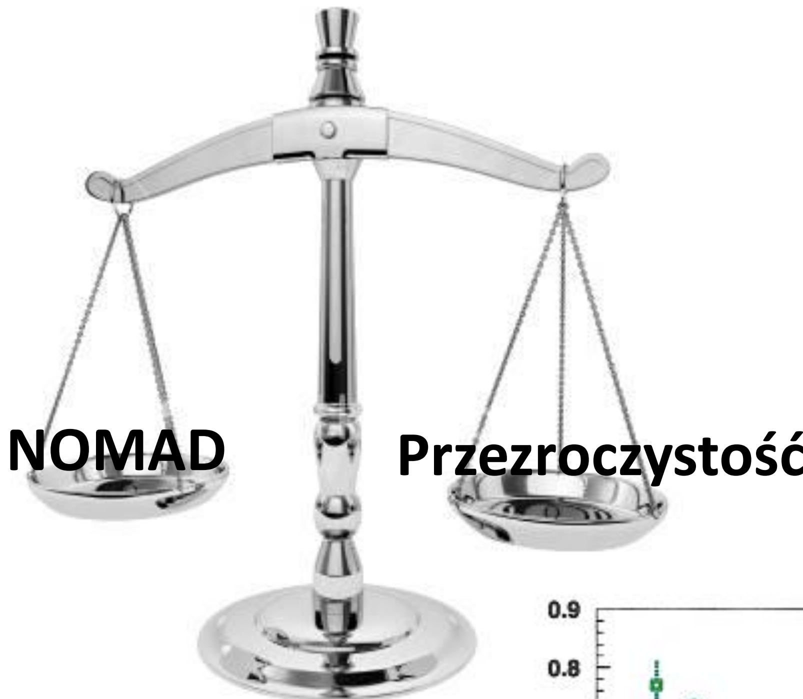
… a co dla bardzo dużych energii?

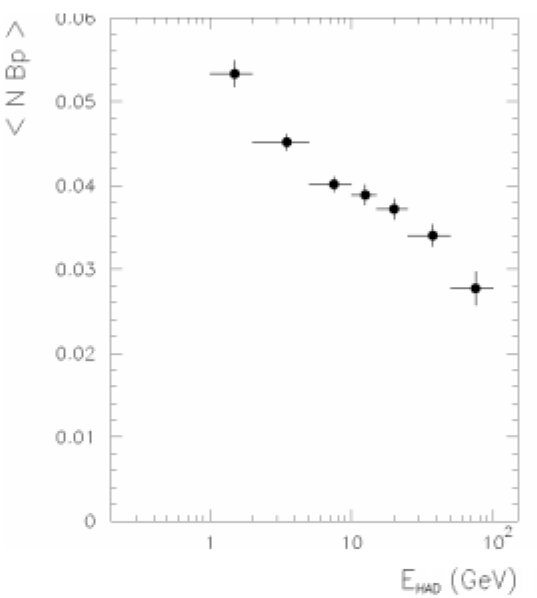
Formation Zone

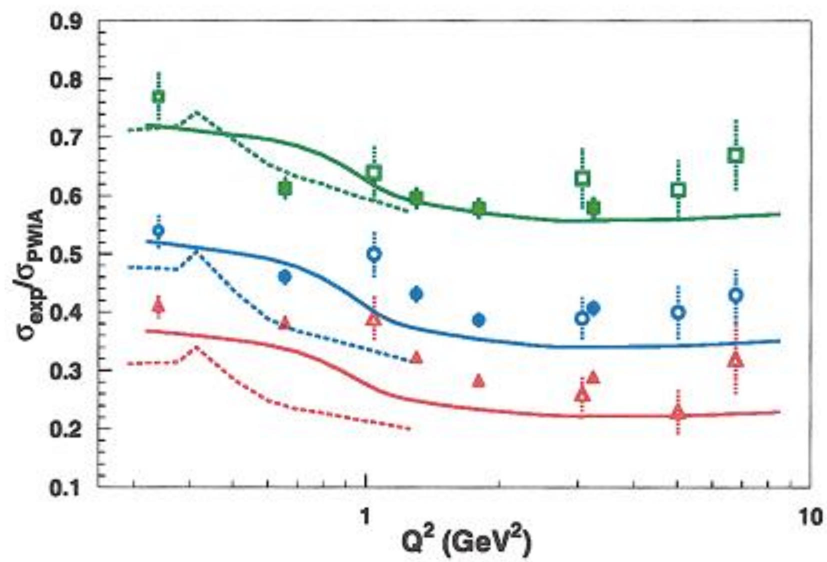


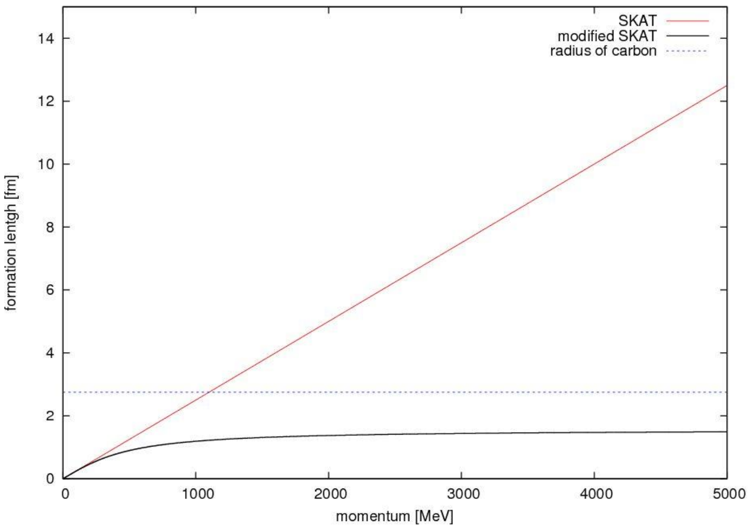


Formation Zone

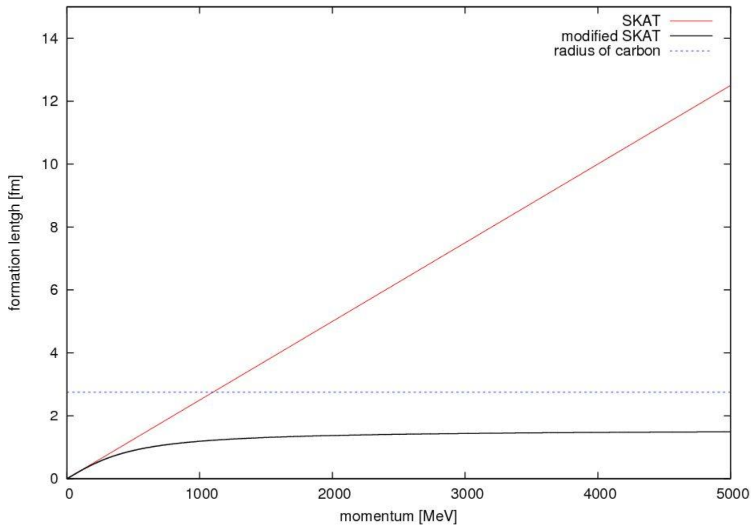




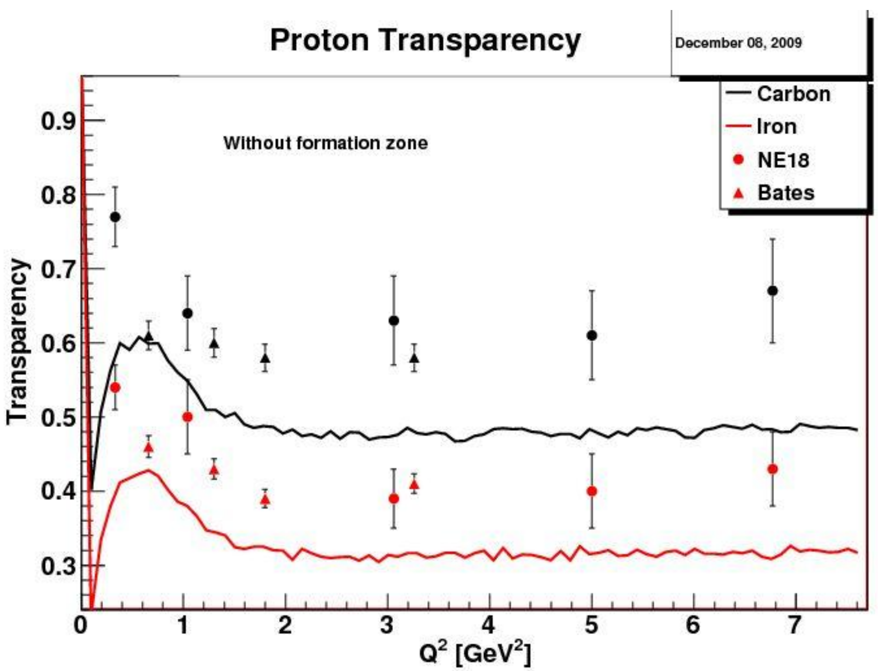


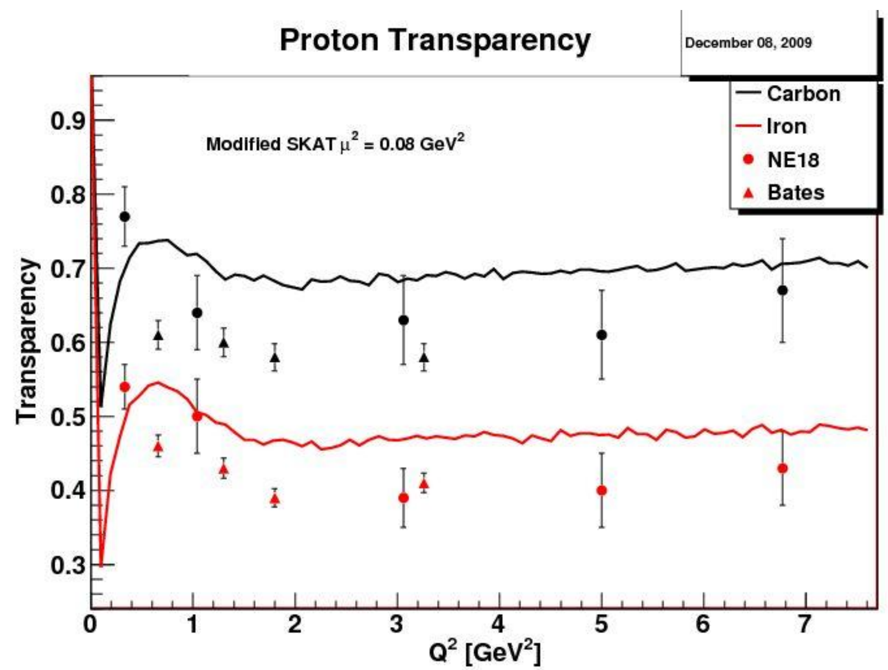


modified SKAT = atan(SKAT)



modified SKAT = atan(SKAT)





Podsumowanie

- NuWro przyzwoicie odtwarza dane doświadczalne
- Mając dobry pierwotny wierzchołek (produkcja pionów – Merenyi?), można łatwo dostosować parametry kaskady
- Formation zone?
    - efekt Landaua-Pomeranchuka
    - co dla oddziaływań nieelastycznych? rezonansowych?
    - co dla bardzo dużych energii?

Dziękuję za uwagę!