NuWro FSI model

Kajetan Niewczas and Jan T. Sobczyk

Wrocław University

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Cascade model – basic assumptions

- energies transfered to the target are large relative to nucleons binding energy
- particle wave packets allow for sufficient *identification* of particle position, momentum, energy
- particle de Broglie wavelength $\hat{\lambda}$ is much smaller than average internucleon distance d
- $\hat{\lambda}$ is also much smaller than mean free path Λ
- nucleus radius R is much larger than Λ: many scattering are expected and interference terms between scattered waves will cancell each other
- d is smaller than Λ and the time between scatterings Δt is larger than the interaction time T

Cascade model – basic assumptions

- altogether

$$\hat{\lambda} << d < \Lambda < R.$$

- assuming that interaction time is $T \sim 10^{-23}$s (from Δ width)

$$\frac{\Lambda}{\beta c} > T \quad \rightarrow \quad \frac{\Lambda}{3\beta} > 1\mathrm{fm}.$$

- on the right: Pauli blocking effect (difference between Λ and $\frac{1}{\rho\sigma}$) is important
- consider $p\ ^{208}$Pb scattering
- assume that nucleon entering lead nucleus gains kinetic energy ~ 40 MeV.

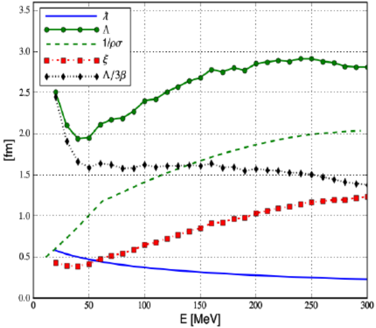


Fig. 1. Central collision proton on ^{208}Pb: $\hat{\lambda}$, Λ, $\xi = \Lambda/\hat{\lambda}/10$, $1/\rho\sigma$ and $\Lambda/3\beta$ as a function of incident proton energy.

from Y.Yariv

With $d \approx 2$ fm, a condition $d, \Lambda > 5\hat{\lambda}$ implies $E > 60$ MeV (i.e. $p > 340$ MeV/c). The cascade model makes sense.

Cascade model – sampling reinteraction points

For a particle at point $\vec{r}$:

- a probability to travel distance x is $P(x) = \exp\left(-\frac{x}{\lambda}\right)$
- mean free path is calculated

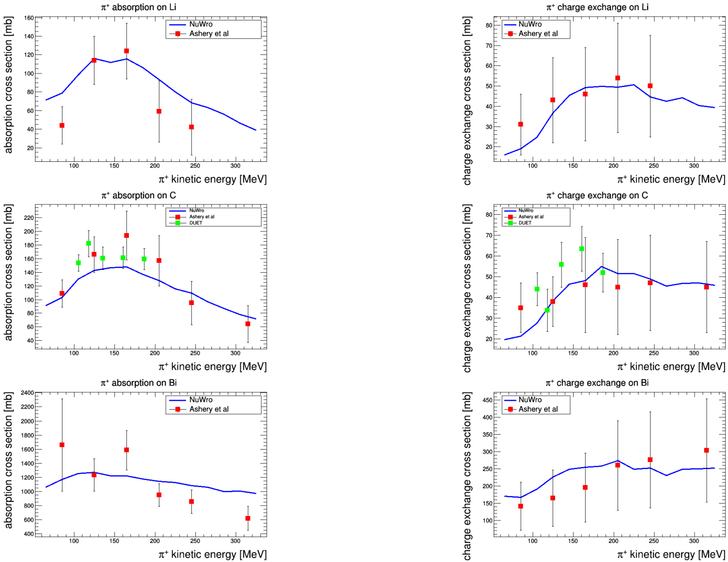
$$\lambda(\vec{r}) = \frac{1}{\sigma_n(\vec{r})\rho_n(\vec{r}) + \sigma_p(\vec{r})\rho_p(\vec{r})}$$

  where ρ_p and ρ_n are densities of protons and neutrons; σ_p and σ_n are total cross sections for scattering off proton and neutrons

The simplest cascade model realization

- select a step e.g. 0.2 fm
  - not too large (λ is defined only locally)
  - not too small (limited computer time)
- with the MC algorithm decide if an interaction occured
  - if YES, select its type
    - check for Pauli blocking and generate it
  - if NO, move particle by 0.2 fm

Performance of NuWro cascade for pions



NuWro cascade for nucleons

In-medium modifications

- **V.R. Pandharipande, S. Piper** corrections to the **elastic** part
  - → Reduced relative nucleon velocity and interaction phase space
  - → Potential obtained from Urbana v_{14} + TNI Hamiltonian

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

- **Inelasitc** 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 correlation effects included

How to test the model?

- Proton transperency
- Important to distinguish MC and experimental transparency.

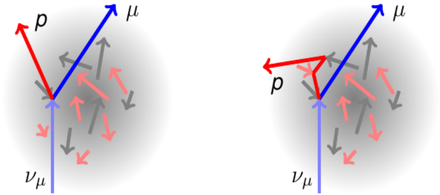
Nuclear transparency

Definition

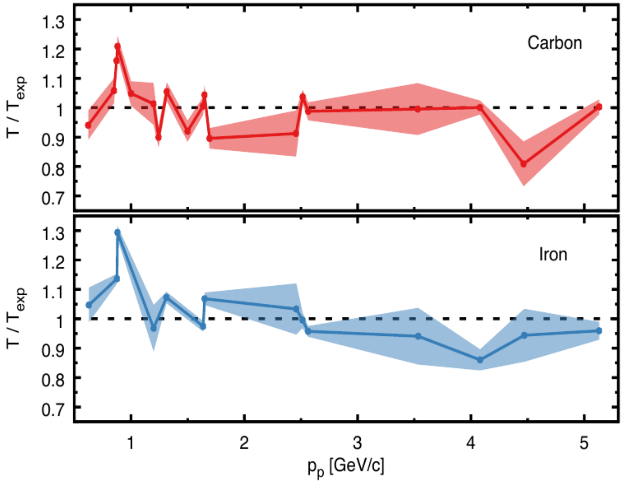
Nuclear transparency is the average **probability** for a knocked-out **proton** to **escape** the nucleus **without significant reinteraction**.

e.g. measured for Carbon: $\mathrm{T} \simeq 0.60$ [D. Abbott *et al.*, PRL 80 (1998), 5072]

$\sim$ 60% without FSI $\quad\quad$ $\sim$ 40% with FSI



Nuclear transparency



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