A RELATIVISTIC CALCULATION OF THE DEUTERON THRESHOLD ELECTRODISINTEGRATION AT BACKWARD ANGLES

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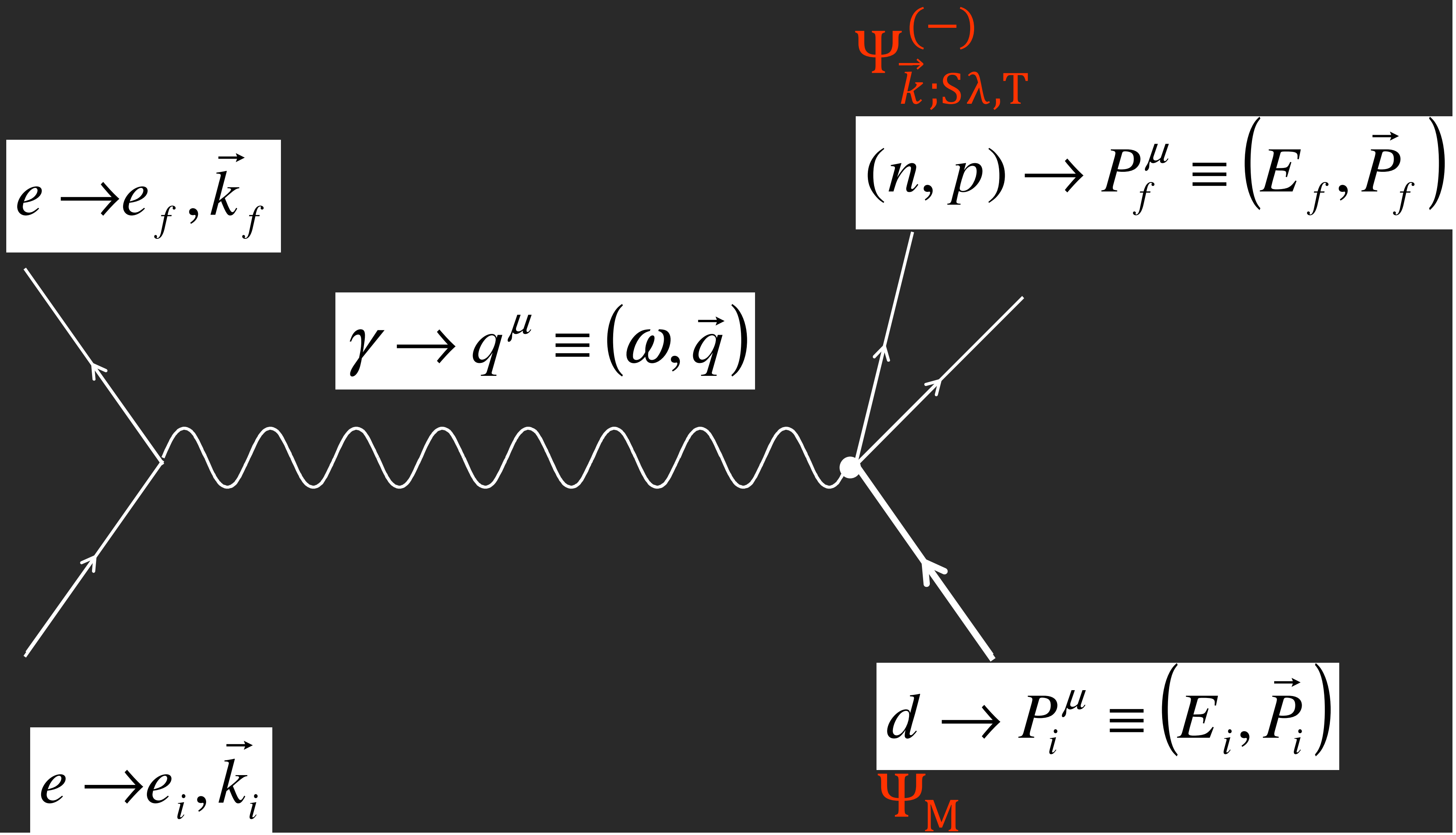
Reaction

➡ Deuteron electrodisintegration

one-photon-exchange approximation



Framework

➡ Relativistic Hamiltonian Dynamics :Instant Form implementation

- Relativistic invariance achieved through Poincaré group algebra
- Generators independent of time and energy
- Hamiltonian and boost generators contain interaction terms

Cross Section

➡ Deuteron electrodisintegration cross section

invariant response functions

$$\frac{d^2\sigma}{d\varepsilon' d\Omega'} = \sigma_M \left[W_2(Q^2, q_\mu P_i^\mu) + W_1(Q^2, q_\mu P_i^\mu) \tan^2 \theta/2 \right]$$

Mott cross section

relevant response function for θ ≥ 155º

keeping only W_1 : involves $\left| A(q\hat{z}, \vec{k}; S\lambda, T, M) \right|^2$

$$A(q\hat{z}, \vec{k}; S\lambda, T, M) = \left\langle \Psi^{(-)}_{\vec{k};S\lambda,T}(\vec{V}_f) \middle| \vec{j}_{\perp}(q\hat{z}) \middle| \Psi_M(\vec{V}_i) \right\rangle$$

Breit frame

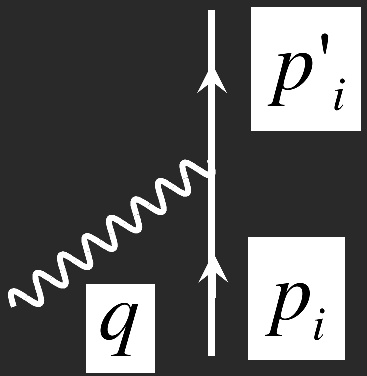
transverse component of the current

Electromagnetic Currents

➡1- and 2-body currents

$$\vec{j} = \sum_{i=1,2} \vec{j}_i(\vec{p}'_i, \vec{p}_i) + \vec{j}_{12}(\vec{p}'_1, \vec{p}'_2, \vec{p}_1, \vec{p}_2)$$

➡1-body current



$$j_i^\alpha = \bar{u}\left[F_{1,i}\gamma^\alpha + \frac{\mathrm{i}}{2m} F_{2,i}\sigma^{\alpha\beta} q_\beta \right] u$$

nucleon Dirac form factor ($F_{1,i}$)

nucleon Pauli form factor ($F_{2,i}$)

Dirac spinor (u)

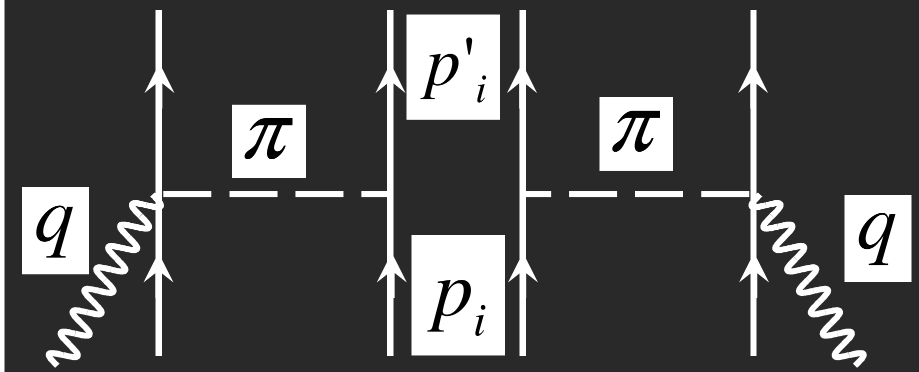
Höhler parametrization of f.f.

keeping full Lorentz structure

Electromagnetic Currents

➡2-body currents - π exchange current: PV coupling

seagul diagrams



$$k_i = p'_i - p_i$$

$$\vec{j}_{12} = -\mathrm{i} G_E^V \left(\vec{\tau}_1 \times \vec{\tau}_2\right)_z \frac{f_{\pi NN}^2}{m_\pi^2} \frac{f_\pi^2}{k_2^\mu k_{2_\mu} - m_\pi^2} \left[\bar{u}_1 \vec{\gamma} \gamma_5 u_1\right] \left[k_2^\nu \bar{u}_2 \gamma_\nu \gamma_5 u_2\right] + 1 \rightleftarrows 2$$

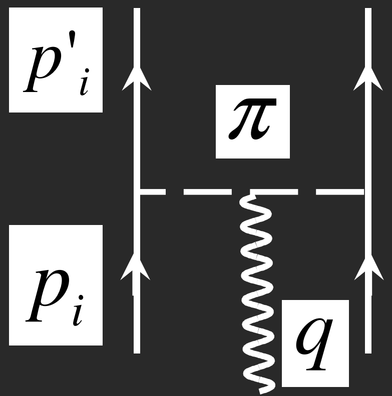
nucleon isovector
Sachs form factor

keeping full Lorentz structure

Electromagnetic Currents

➡ 2-body currents - π exchange current: PV coupling

π in flight diagram



$$k_i = p'_i - p_i$$

$$\vec{j}_{12} = \mathrm{i} G_E^V \left(\vec{\tau}_1 \times \vec{\tau}_2\right)_z \frac{f_{\pi NN}^2}{m_\pi^2} \left(\vec{k}_2 - \vec{k}_1\right)$$

$$\frac{f_\pi^2}{k_1^\mu k_{1_\mu} - m_\pi^2} \frac{f_\pi^2}{k_2^\mu k_{2_\mu} - m_\pi^2} \left[k_1^\nu \bar{u}_1 \gamma_\nu \gamma_5 u_1\right] \left[k_2^\nu \bar{u}_2 \gamma_\nu \gamma_5 u_2\right]$$

nucleon isovector Sachs form factors

keeping full Lorentz structure

Relativistic Hamiltonian

➡Relativistic Hamiltonian to generate wave funct.

$$H^{\mu} = 2\sqrt{p^2 + m^2} + v^{\mu}$$

- ▶ v^{μ} NN interaction and consists of
  - ➢ v_{R} – short range part paramatrized as Argonne v_{18}
  - ➢ v_{π}^{μ} – relativistic OPEP
  - ➢ $\begin{cases} \mu = 1 \text{ – pseudovector coupling} \\ \mu = -1 \text{ – pseudoscalar coupling} \\ \mu = 0 \text{ – minimal non-locality choice} \end{cases}$ related by unitary transform.

Relativistic OPEP

➡ Relativistic OPEP with off-shell term - nonlocal

off-shell term

$$v_\pi^\mu(\vec{p}\,',\vec{p}) = \frac{m}{E'} v_\pi^{NR} \frac{m}{E} - \underbrace{\mu(E'-E)\frac{m}{E'} O \frac{m}{E}}_{\text{off-shell term}}$$

$$v_\pi^{NR} = -\frac{f_{\pi NN}^2}{m_\pi^2}\frac{f_\pi^2}{k^2+m_\pi^2}$$

$$O = \frac{\vec{\sigma}_1\cdot\vec{p}\,'\vec{\sigma}_2\cdot\vec{p}\,'}{E'+m} - \frac{\vec{\sigma}_1\cdot\vec{p}\,\vec{\sigma}_2\cdot\vec{p}}{E+m}$$

- choosing $\mu = 1$ for consistency with π exchange current
- initial and final states generated with this interaction

Wave Functions

➡ Deuteron wave function – bound state

$$\psi_M(\vec{p};0) = \psi_{M;S}(\vec{p};0) + \psi_{M;D}(\vec{p};0)$$

$$\text{in the pair cm frame}: \vec{V}_i = 0$$

Deuteron properties

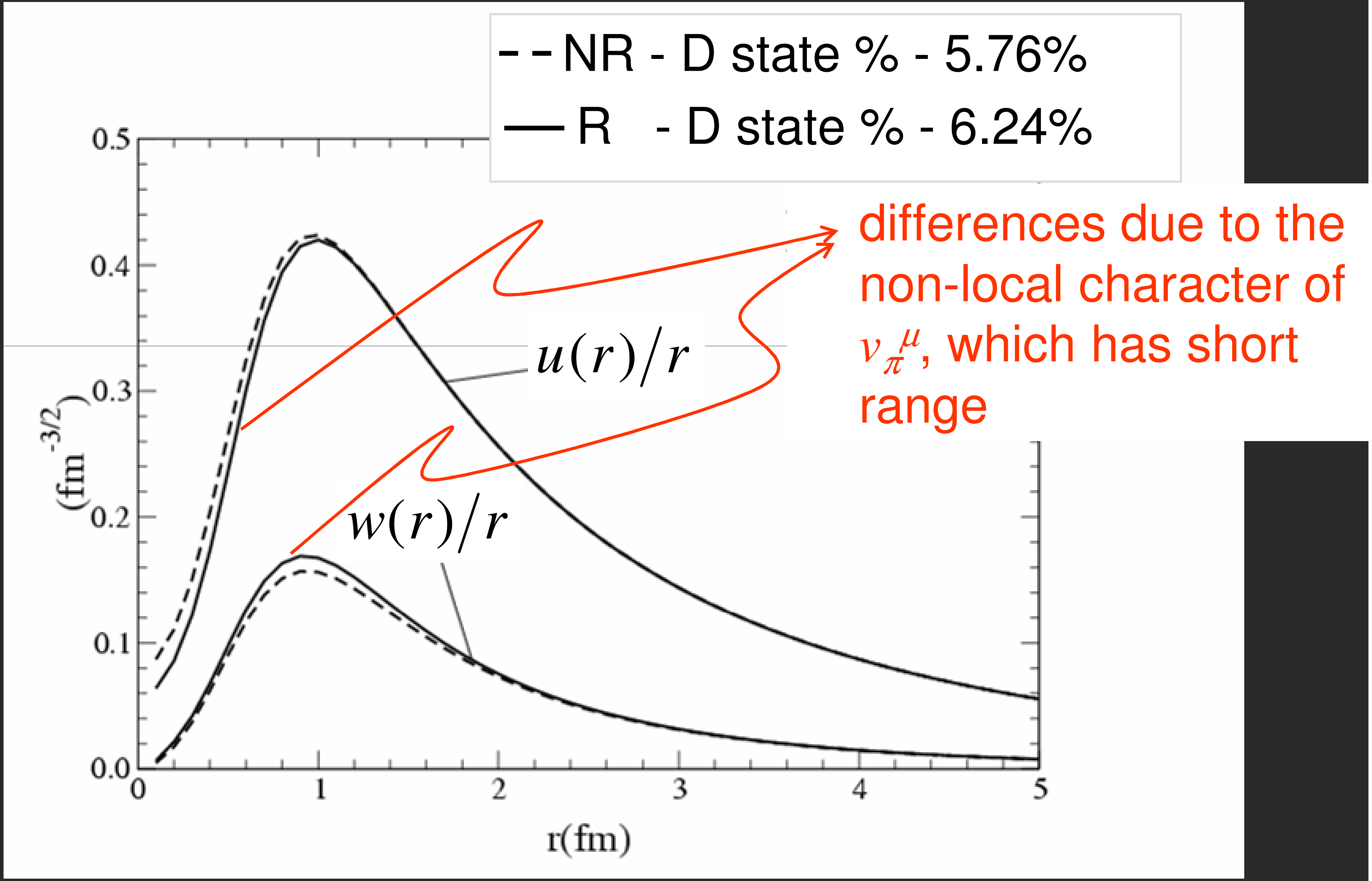
	Exp	R v^1	NR v_{18}
E (MeV)	-2.2246	-2.225	-2.225
%D-state		6.24	5.76
Q_d(fm^2)	0.2859(3)	0.272	0.270
D/S ratio	0.0256(4)	0.026	0.025

≠ due to:

- local character of NR interaction
- nonlocal character of R interaction

Wave Functions

➡ Deuteron wave function – bound state



Wave Functions

➡ *np* wave function – scattering state
standard Lippmann-Shwinger equation

plane wave piece

interaction piece

$$\Psi^{(-)}_{\vec{k},S\lambda T}(\vec{p};0) = \phi_{\vec{k},S\lambda T}(\vec{p};0) + \psi^{(-)}_{\vec{k},S\lambda T}(\vec{p};0)$$

in the pair cm frame : $\vec{V}_f = 0$

incoming boundary conditions

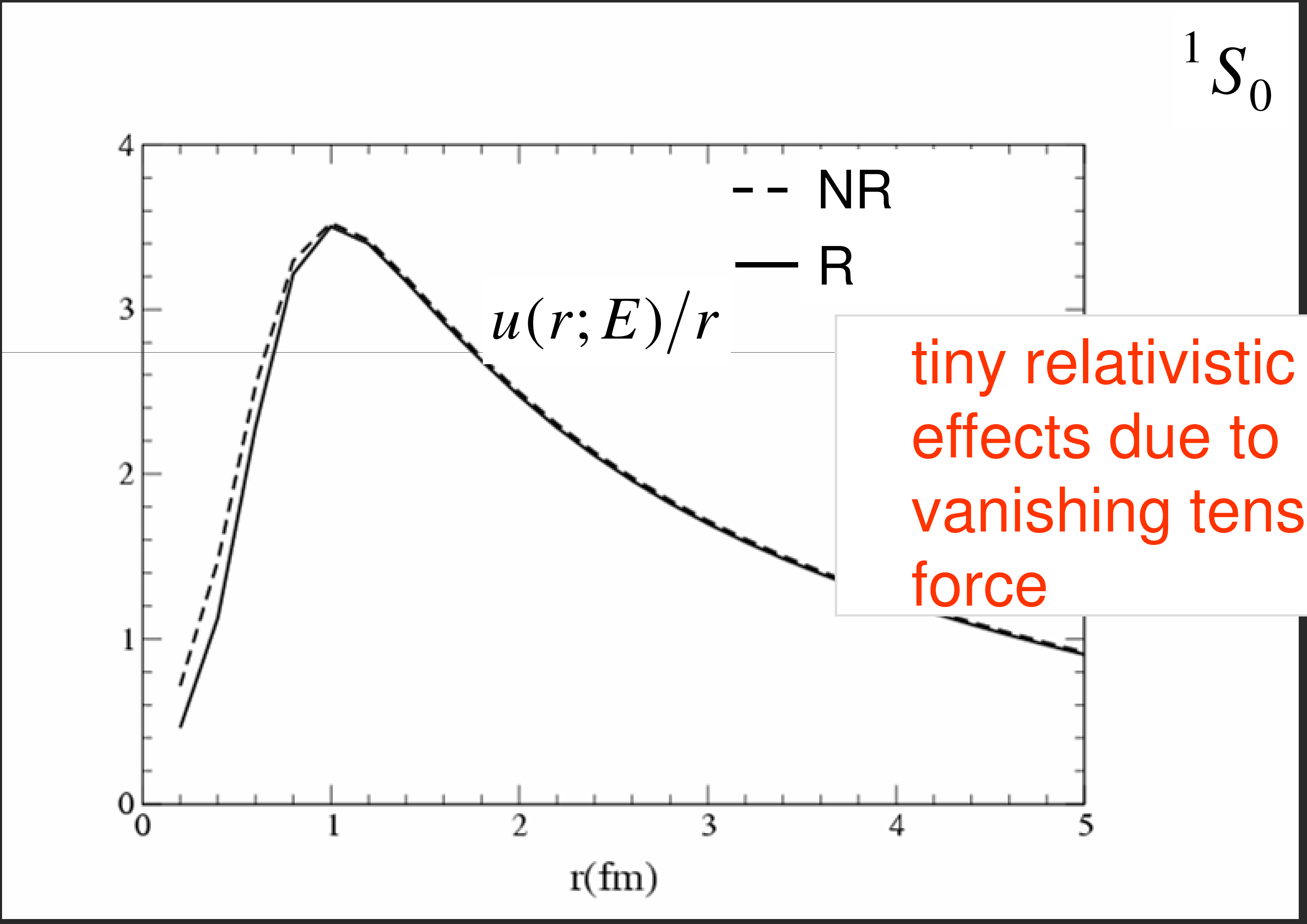
all channels up to J=3

$$\frac{1}{2}\sum_{M_S'}\int \frac{d\vec{k}'}{(2\pi)^3}\frac{T^{ST}_{\lambda\lambda'}{}^{*}(\vec{k},\vec{k}')}{E_k - E_{k'} - i\varepsilon}\phi_{\vec{k}',S\lambda' T}(\vec{p};0)$$

NN T-matrix

Wave Functions

➡np wave function – scattering state



tiny relativistic effects due to vanishing tensor force

Boosts

➡ Boosting wave functions from cm to Breit frame

$$\Psi(\vec{p};\vec{V}) \equiv B(\vec{p};\vec{V})\Psi(\vec{p}_{\parallel}/\gamma, \vec{p}_{\perp};0)$$

$\vec{p}_{\parallel}$: paralel to $\vec{V}$

$\vec{p}_{\perp}$: perpend to $\vec{V}$

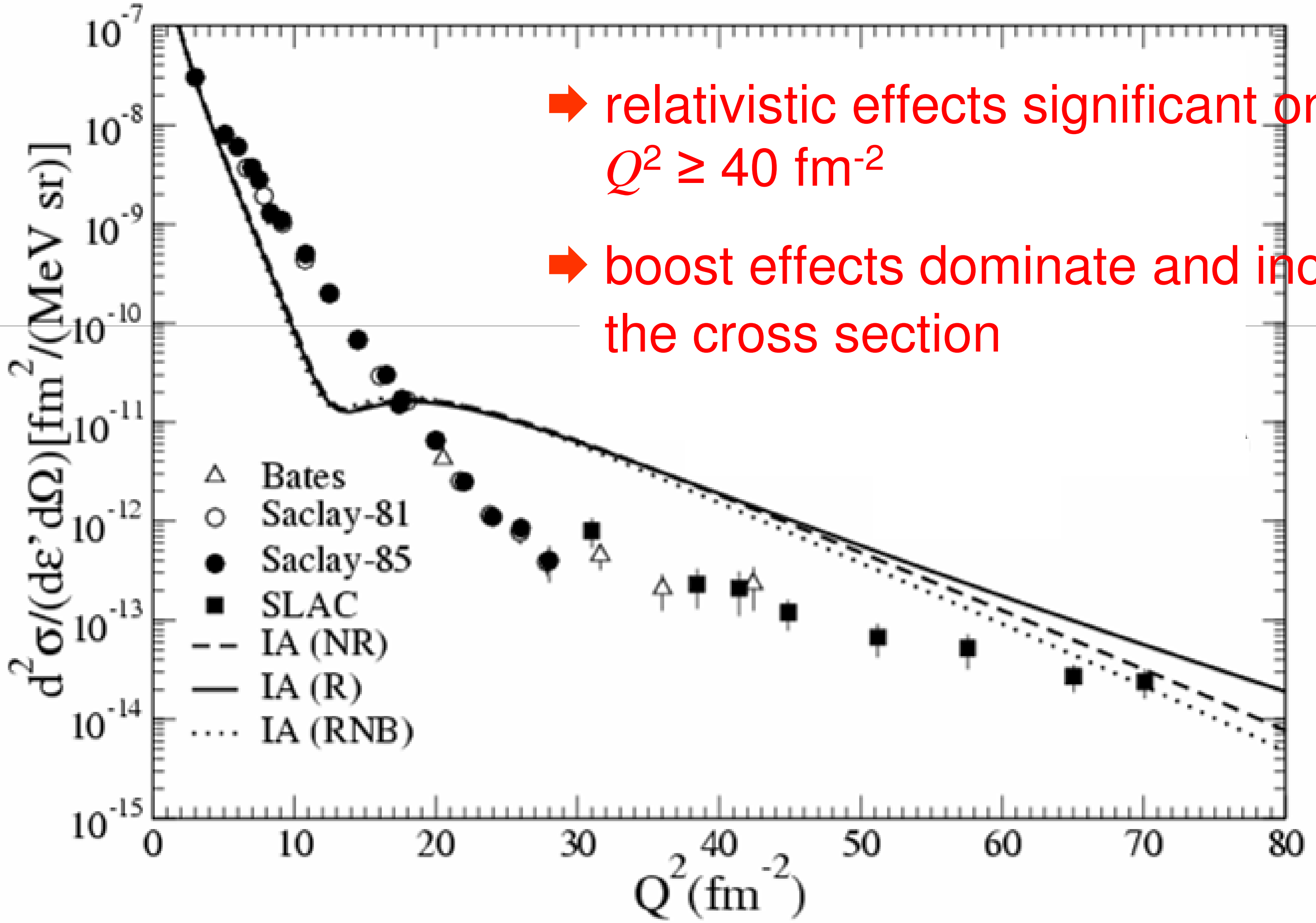
$\vec{p}_{\parallel}/\gamma$: Lorentz contraction in move direction

$$B(\vec{p};\vec{V}) = \frac{1}{\sqrt{\gamma}}\left[1 - \frac{i}{4m}\vec{V}\cdot(\vec{\sigma}_1 - \vec{\sigma}_2)\times\vec{p}\right]$$

- kinematical boost corrections retained
- spin-dependent (Thomas preces.) included to order V^2
- interaction-dependent terms neglected

IA results

Tcm=1.5MeV, θ=155°

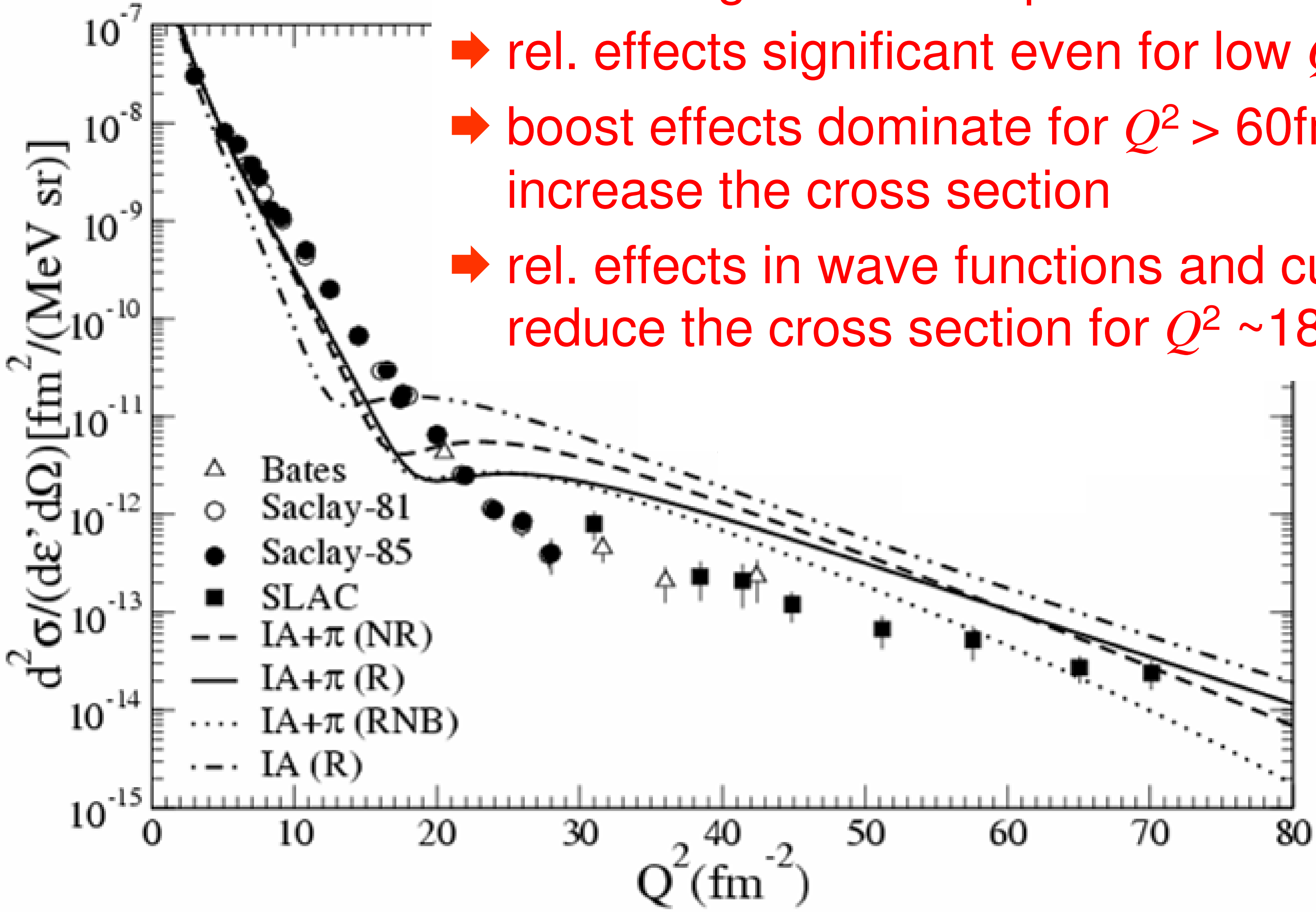


- relativistic effects significant only for $Q^2 \geq 40$ fm^{-2}
- boost effects dominate and increase the cross section

IA+π results

Tcm=1.5MeV, θ=155º

- π exchange current important contribution
- rel. effects significant even for low Q^2
- boost effects dominate for $Q^2 > 60\text{fm}^{-2}$ and increase the cross section
- rel. effects in wave functions and currents reduce the cross section for $Q^2 \sim 18 - 40\ \text{fm}^{-2}$



Summary

➡ IA

- relativistic effects significant only for $Q^2 \geq 40$ fm^{-2}
- boost effects dominate and increase the cross section
- dominant boost correction comes from Lorentz contraction

Summary

➡ IA+π

- π-exchange current means important contribution specially in the relativistic calculation
- relativistic effects are significant even for low Q^2
- relativistic effects in wave functions and currents reduce cross section in the region Q^2 ~18 – 40 fm^{-2}
- boosts effects dominate only for $Q^2 > 60$ fm^{-2} and increase the cross section
- dominant boost contribution comes from Lorentz contraction
- retardation in currents gives negligible effect

Summary

- ➡ NR and R calculations do not reproduce data at $Q^2 > 40$ fm^{-2}
- ➡ Need of new model for the currents?
  - ➢ Inclusion of additional short range two-body currents
- ➡ Need of more work to understand the discrepancy between theory and data