



Reabsorção de Mésons π no CRISP





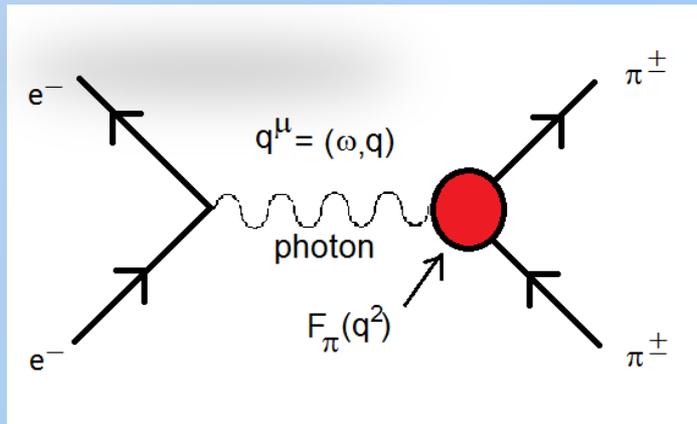
Generalidades sobre Mésons π

$E < 1\text{GeV}$ $P < 1\text{GeV}/c$

	Estados de Carga	Spin paridade J^π	Massa(MeV)	Largura Γ (MeV)
Nucleon	proton neutron	$1/2^+$	$m_p = 938.3$ $m_n = 939.6$	n(Livre)
Pion	π^+ π^0 π^-	0^+	$m_{\pi^\pm} = 139.6$ $m_{\pi^0} = 135.0$	$\pi^0 (\sim 8 \times 10^{-6})$
Δ -isobaro	$\Delta^{++}, \Delta^+, \Delta^0, \Delta^-$	$3/2^+$	$m_\Delta = 1232$	115
ρ - meson	ρ^+ ρ^0 ρ^-	1^+	$m_\rho = 769$	154
ω - meson	ω^0	1^+	$m_\omega = 783$	10



Tamanho e Estrutura do Méson π



$$F_\pi(q^2) = 1 + \frac{1}{6} q^2 \langle r^2_\pi \rangle + \dots$$

$$\langle r^2_\pi \rangle^{1/2} \cong 0.66 \text{ fm}$$

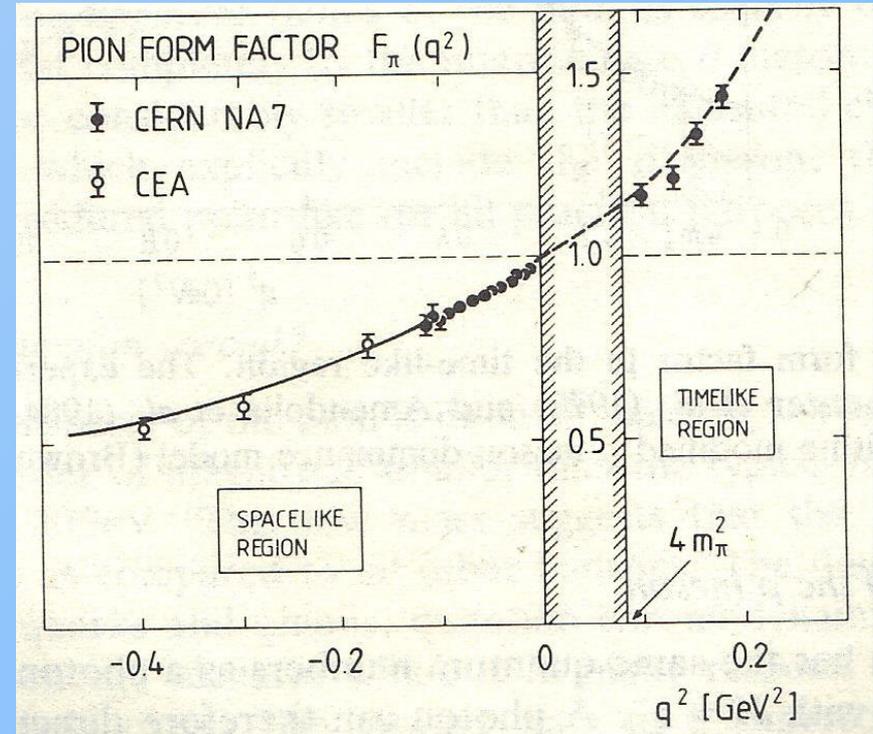
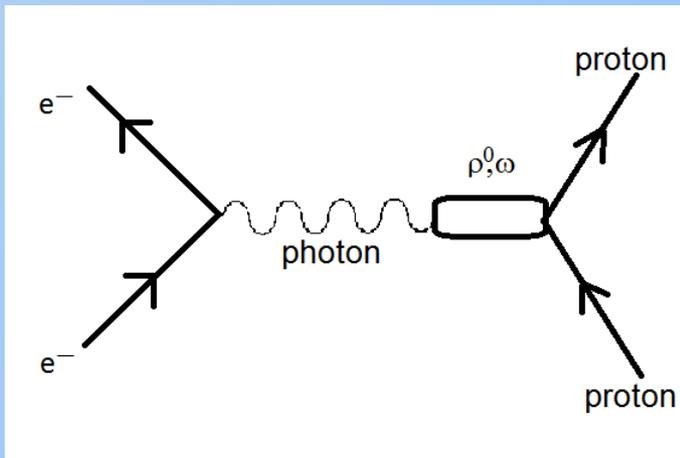
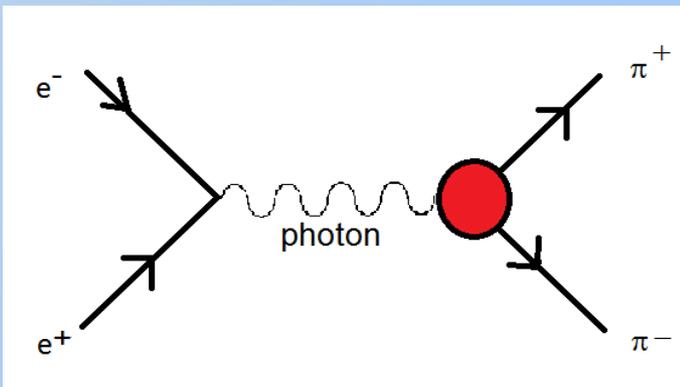


FIG. 1.3. Pion form factor in the space-like region with $q^2 < 0$ from Amendolia *et al.* (1984a,b). Its extrapolation to the time-like region is shown to the right. The curve is obtained with an improved ρ meson dominance fit (Brown *et al.* 1986).



Tamanho e Estrutura do Méson π



$$\text{Próton } \langle r_E^2 \rangle^{1/2} \cong \langle r_M^2 \rangle^{1/2} \cong 0.86$$

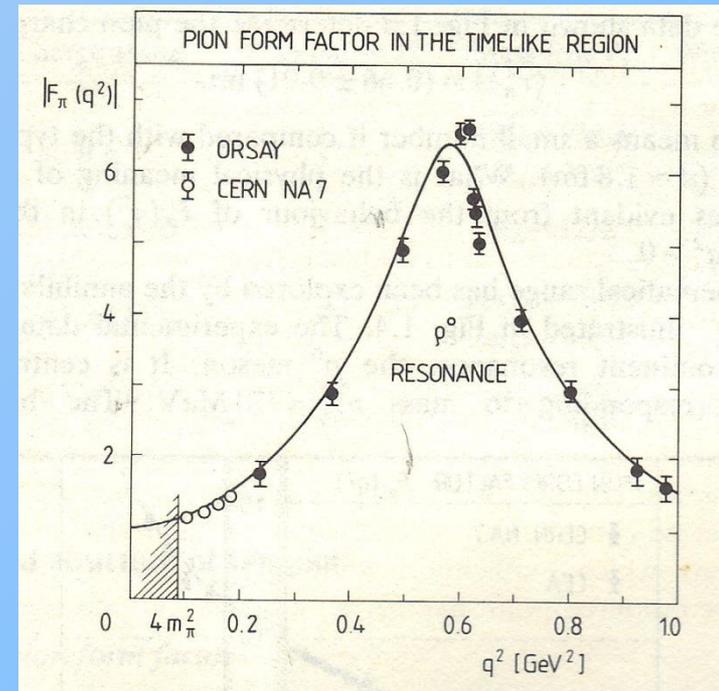


FIG. 1.5. Pion form factor in the time-like region. The experimental data are taken from Quenzer *et al.* (1978) and Amendolia *et al.* (1984a). The curve is obtained with a modified ρ meson dominance model (Brown *et al.* 1986).



Fotoprodução de Mésons π no Limiar

$$\text{Dipolo Elétrico} \begin{cases} E_{0+} & l = 0 & j^\pi = 1/2^- & q \rightarrow \text{dominante} \\ E_{2-} & l = 2 & j^\pi = 3/2^- & q^5 \rightarrow \text{pequeno} \end{cases}$$

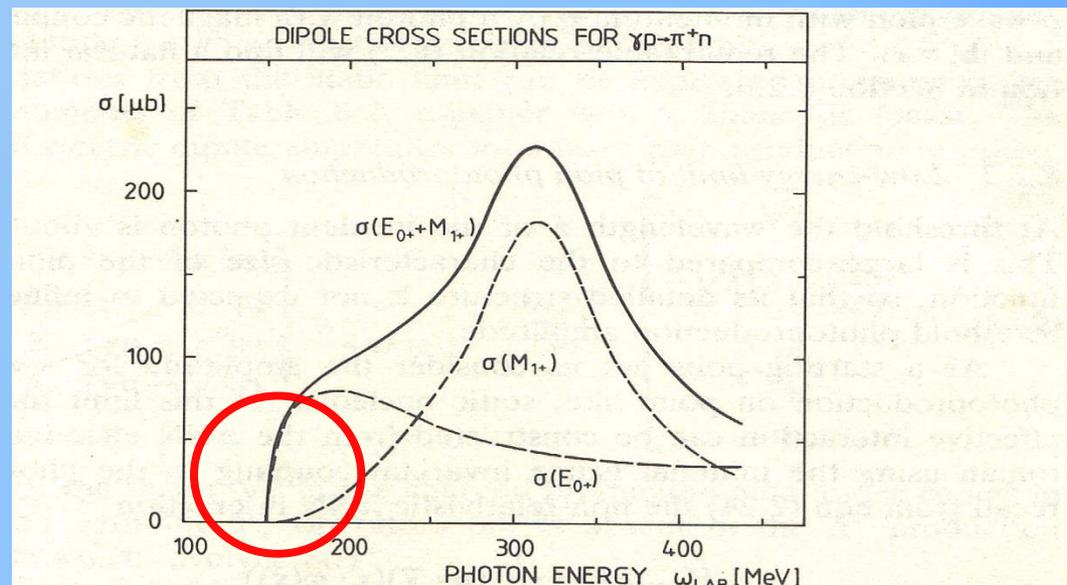
$$\text{Dipolo Magnético} \begin{cases} M_{1-} & l = 1 & j^\pi = 1/2^+ & q^3 \\ M_{1+} & l = 1 & j^\pi = 3/2^+ & q^3 \rightarrow \text{dominante} \end{cases}$$

$$\text{Limite estático } \frac{m_\pi}{M} \rightarrow 0$$

$$\text{Quadrupolo Elétrico} \{ E_{1+} \quad l = 1 \quad j^\pi = 3/2^+ \quad q^3 \rightarrow \text{pequeno}$$

$q \equiv |\mathbf{q}| \rightarrow \text{momento do pión}$

$$\frac{\sigma_E(\gamma n \rightarrow \pi^- p)}{\sigma_E(\gamma p \rightarrow \pi^+ n)} = \left(1 + \frac{m_\pi}{M}\right)^2 \cong 1.3$$



The dominant electric and magnetic dipole contributions to the $\gamma p \rightarrow \pi^+ n$ total cross-section.



Fotoprodução de Mésons π^0 no limiar

$$M_{1+} \quad l = 1 \quad j^\pi = 3/2^+ \quad q^3 \rightarrow \textit{dominante}$$

Threshold pion photoproduction on nucleons

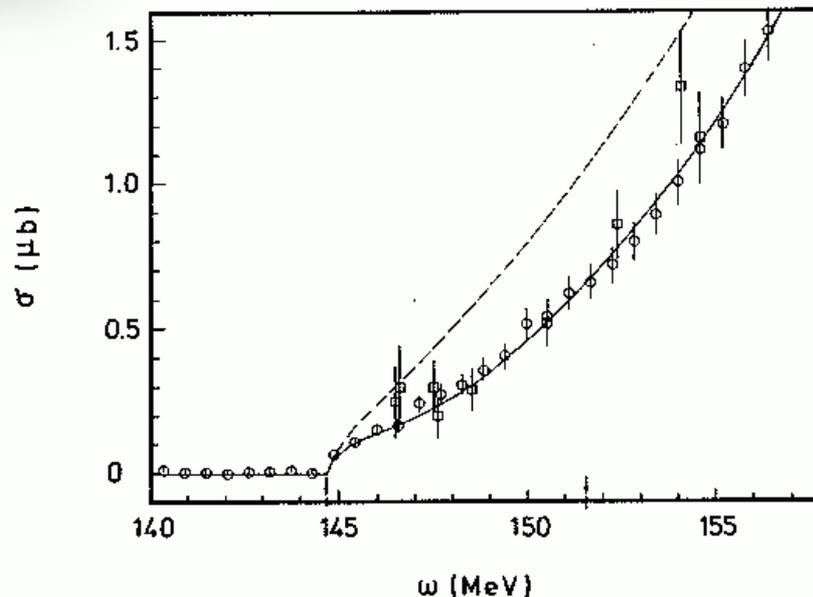
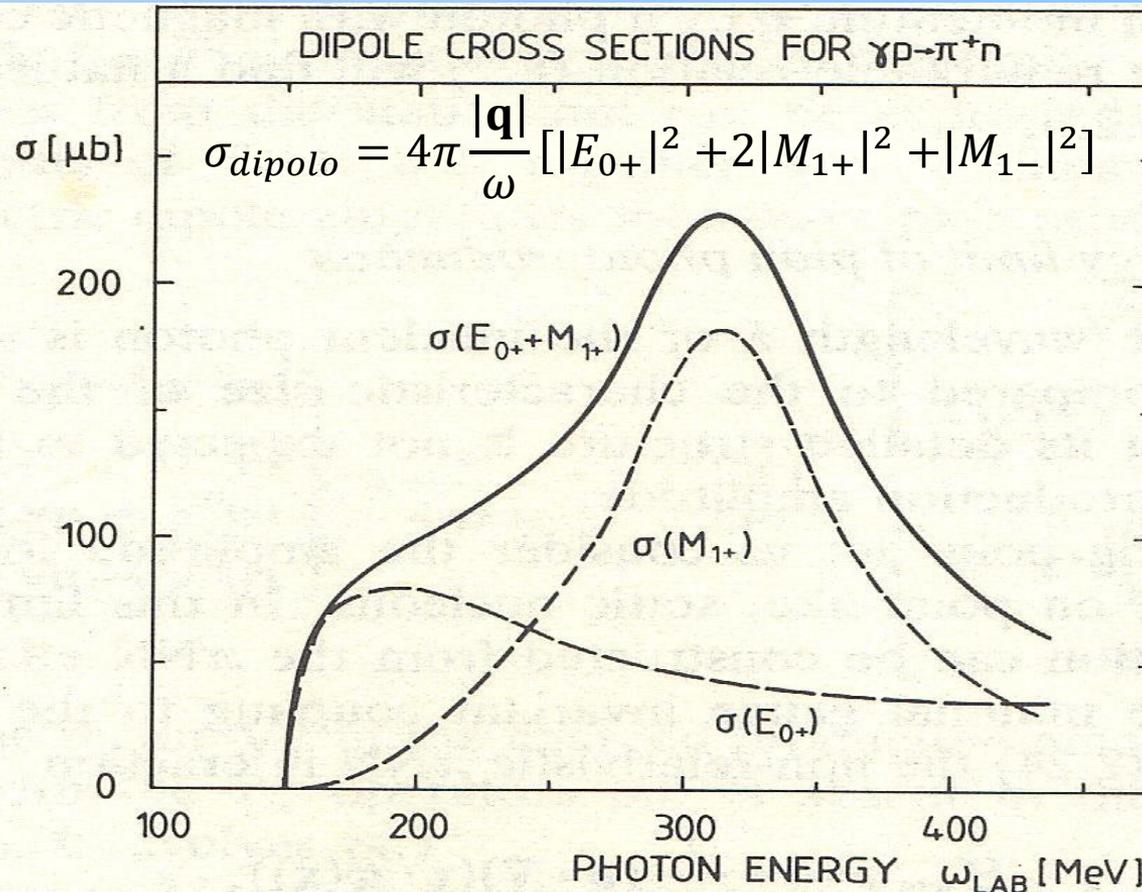


Figure 9. Total cross section for the reaction $\gamma + p \rightarrow \pi^0 + p$ as function of photon energy. Mainz data (\square) according to Beck *et al* (1990), Saclay data (\circ) of Mazzucato *et al* (1986). The full curve is a fit of the experimental data while the broken curve is obtained with a constant E_{0+} of $-2.5 \times 10^{-3}/m_\pi$ and the same p-wave multipoles as for the full curve.



Fotoprodução total de Mésons π

$\gamma N \rightarrow \pi N$ (fóton não polarizado)



The dominant electric and magnetic dipole contributions to the $\gamma p \rightarrow \pi^+ n$ total cross-section.



Fotoprodução de Mésons π na $\Delta(1232)$

D Drechsel and L Tiator

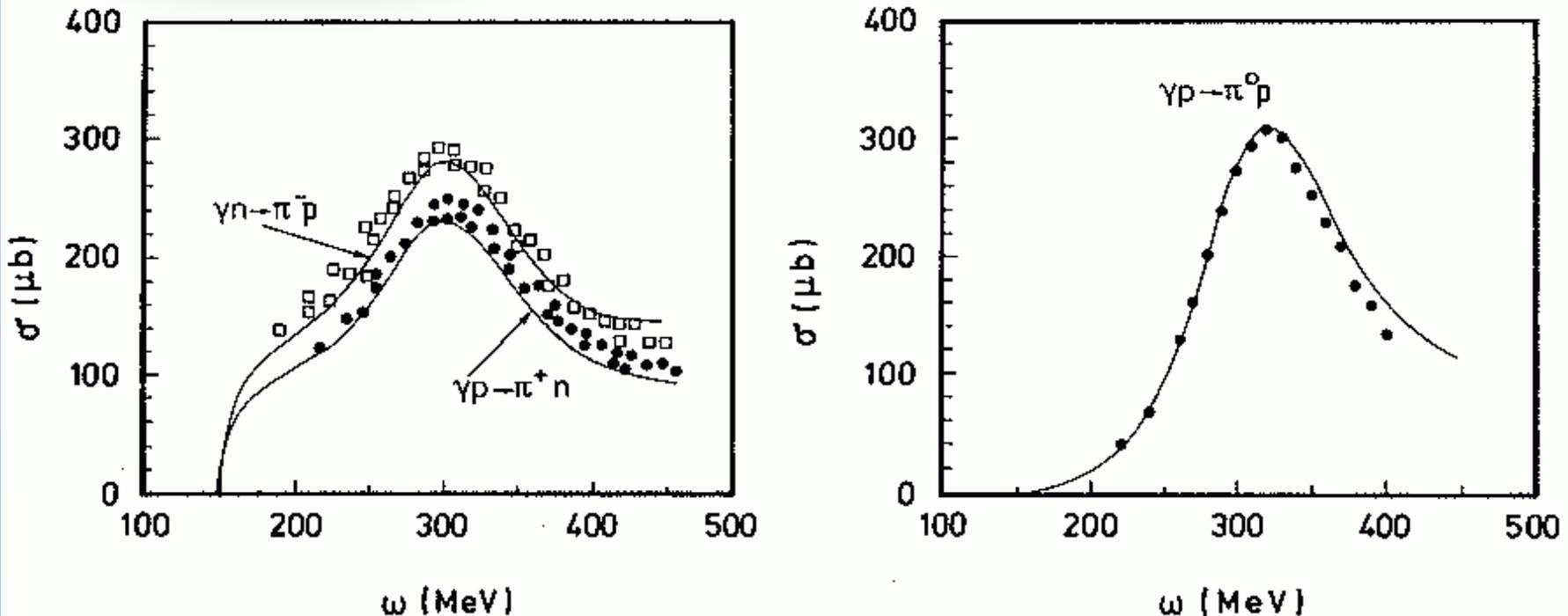
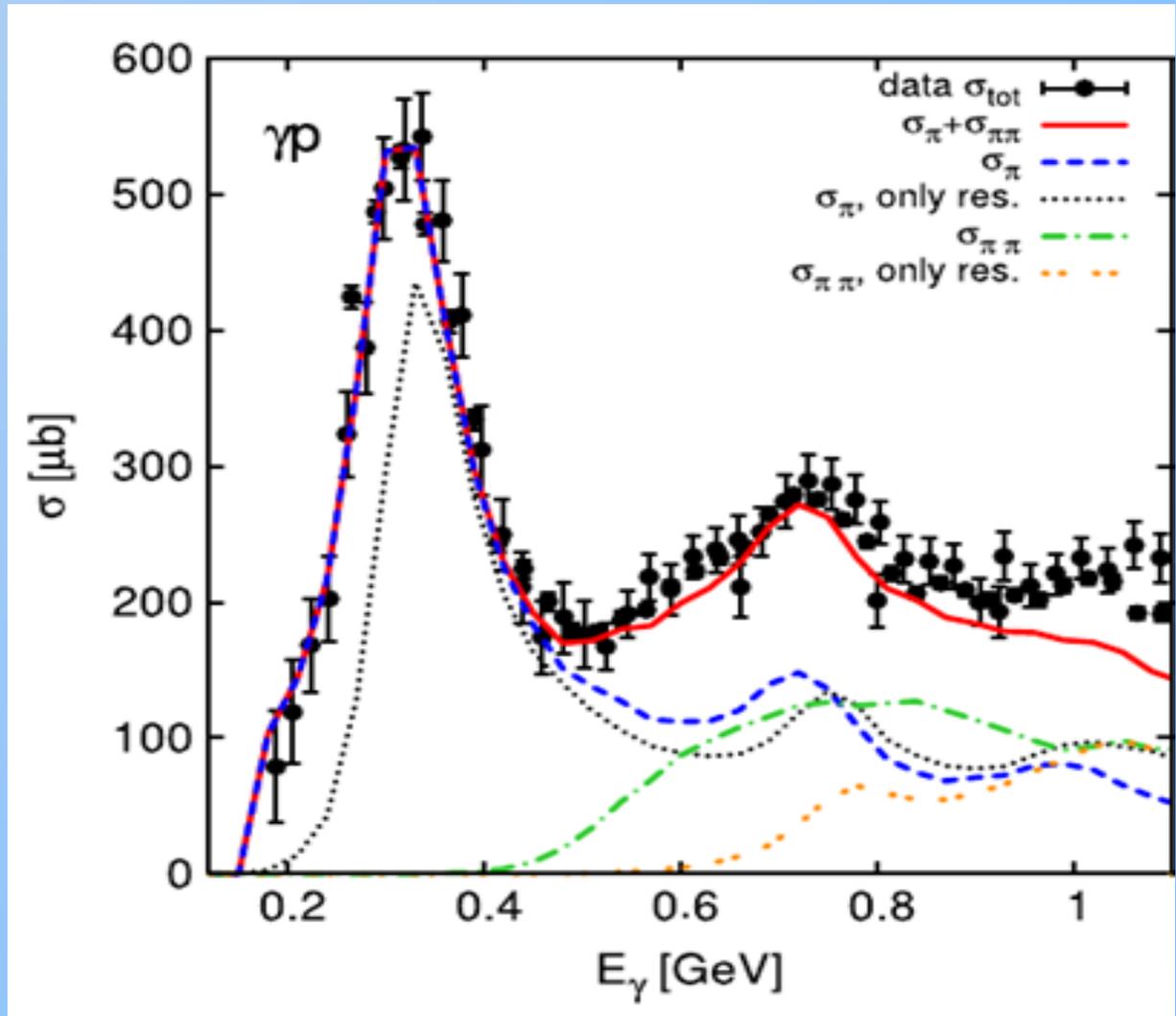


Figure 8. The total cross section for pion photoproduction as function of photon energy ω . (Data from Menze *et al* (1977) and Bagheri *et al* (1988), compared to calculations of Nozawa *et al* (1990).)



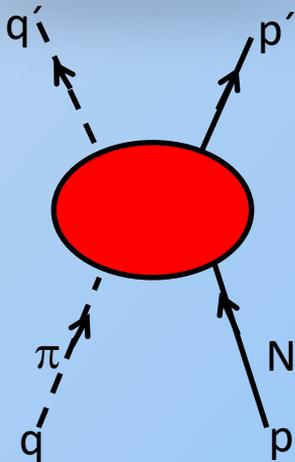
Fotoprodução de Mésons π na $\Delta(1232)$





Espalhamento do Píon – Nucleon

$$\pi(\mathbf{q}) + N(\mathbf{p}) \rightarrow \pi(\mathbf{q}') + N(\mathbf{p}')$$



$\mathcal{F}(\mathbf{q}', \mathbf{q})$

Sistema CM $\mathbf{p} = -\mathbf{q}$

4-Momento $q^\mu(\omega_q, \mathbf{q}) \quad p^\mu(E_p, \mathbf{p})$

Energia

$$W = E + \omega \quad E = (\mathbf{q}^2 + M^2)^{1/2} \quad \omega = (\mathbf{q}^2 + m_\pi^2)^{1/2}$$

Quadrado do 4-Momento Transferido

$$\mathbf{Q}^2 = (\mathbf{q}' - \mathbf{q})^2 = 2\mathbf{q}^2(1 - \cos(\theta))$$

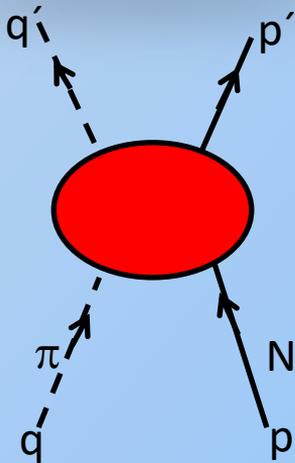
Variáveis de Mandelstam

$$s = W^2 \quad t = -\mathbf{Q}^2$$



Espalhamento do Píon – Nucleon

As informações sobre espalhamento podem ser representados por Deslocamento de Fase δ_α com a Matriz-S em cada canal α definido na forma:



$$S_\alpha(\omega) = e^{2i\delta_\alpha(\omega)} \quad \alpha = (I, l, j = l \pm 1/2)$$

$$\delta_\alpha \rightarrow \begin{cases} \pi N \rightarrow \pi N \text{ (Real) para } T_\alpha \cong 174 \text{ MeV (Sistema Laboratório)} \\ \pi N \rightarrow \pi\pi N \text{ (imaginária)} \end{cases}$$

Vamos tratar apenas da parte Real.



Espalhamento do Píon – Nucleon

A Matriz-S é relacionada com a amplitude de espalhamento pela relação:

$$S_{\alpha}(\omega) = e^{2i\delta_{\alpha}(\omega)} \quad f_{\alpha}(\omega) = \frac{1}{2i|\mathbf{q}|} [S_{\alpha}(\omega) - 1]$$

Alternativamente f_{α} pode ser escrita na forma: $f_{\alpha}(\omega) = \frac{1}{|\mathbf{q}|} e^{i\delta_{\alpha}} \text{sen}(\delta_{\alpha})$

Uma quantidade útil é a Matriz-K relacionada a Matriz-S na forma: $S_{\alpha} = \frac{1 + i|\mathbf{q}|K_{\alpha}}{1 - i|\mathbf{q}|K_{\alpha}}$

Na ausência de inelasticidades K_{α} é real e na forma: $K_{\alpha} = \frac{1}{|\mathbf{q}|} \tan\delta_{\alpha}$

No limiar a Matriz-K define a constante de proporcionalidade: $a_{\alpha} = \lim_{|\mathbf{q}| \rightarrow 0} |\mathbf{q}|^{-2l} K_{\alpha}$

$$\alpha = (I, l, j = l \pm 1/2)$$



Espalhamento do Píon – Nucleon

$$T_{\pi} < 300 \text{ MeV}$$

π^+p , π^-p dominado por $\Delta(1232)$

Mas, P-wave πN importante próximo do limiar.

Comprimento de espalhamento:

$$a(\text{NN}) \sim 10/m_{\pi}$$

$$a(\pi\text{N}) \sim 0.1/m_{\pi}$$

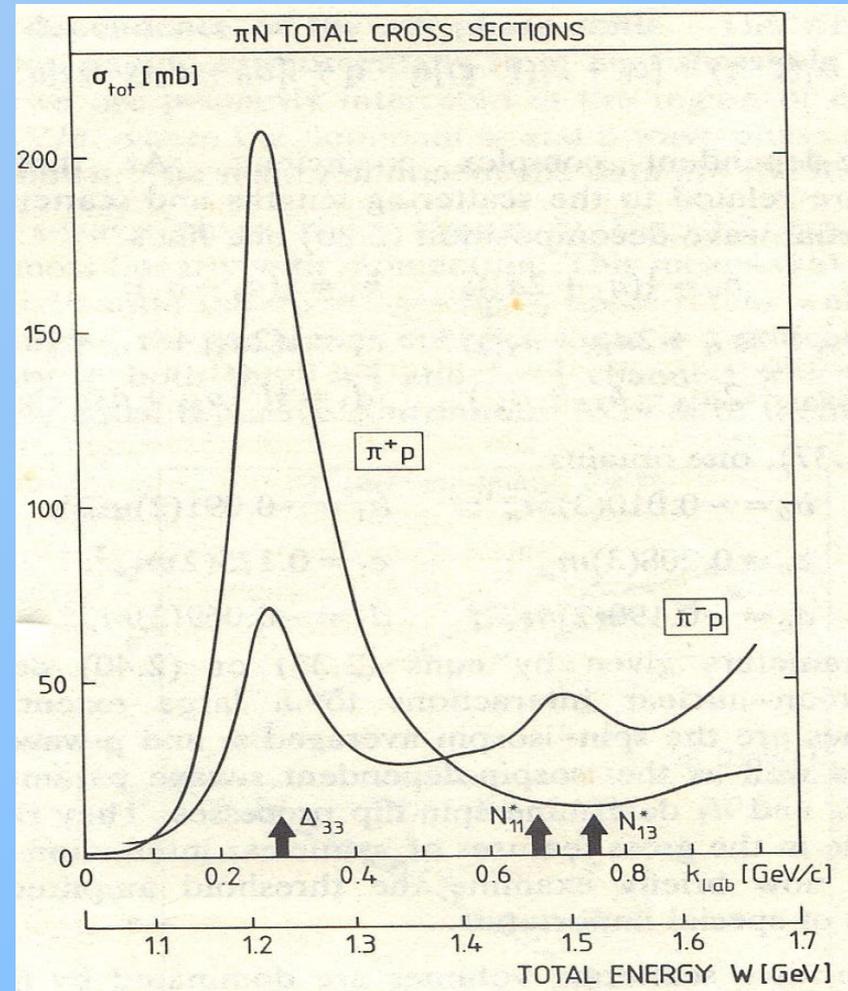


FIG. 2.2. Total cross-sections for π^+p and π^-p scattering as a function of the total c.m. energy W and the pion lab momentum k_{lab} .



Absorção de Fotopíons

Não conserva momentum.

$$\pi N \leftrightarrow N \quad p = (2Mm_\pi)^{1/2} \cong 510 \text{ MeV}/c$$

$$\pi NN \leftrightarrow NN \quad \omega \cong T_1 + T_2 \quad \mathbf{q} = \mathbf{p}_1 + \mathbf{p}_2 \quad \text{conserva momentum}$$

$$\omega = m_\pi \quad \mathbf{q} = 0 \quad T_1 = T_2 = \frac{1}{2} m_\pi \quad \mathbf{p}_{rel.} = \mathbf{p}_1 = \mathbf{p}_2 = (Mm_\pi)^{1/2} \cong 360 \text{ MeV}/c$$

Aplica-se o princípio do Balanço Detalhado

$$\sigma(d\pi^+ \rightarrow pp) = \frac{2}{3} \frac{p^2}{q^2} \begin{cases} \sigma(pp \rightarrow d\pi^+) \\ 2\sigma(pn \rightarrow d\pi^0) \end{cases}$$



Absorção de Fotopíons na região $\Delta(1232)$

$$\sigma(d\pi^+ \rightarrow pp) = \left\{ \begin{array}{l} \left(\frac{3.5}{T_{\pi}^{1/2}} \text{MeV}^{1/2} + \frac{3.3\Gamma_0^2}{(E - E_R) + \frac{\Gamma_0^2}{4}} \right) \text{mb} \\ E_R = 2136 \text{MeV} \quad \Gamma_0 = 150 \text{MeV} \\ E = [(m_{\pi} + M_d)^2 + 2T_{\pi}M_d]^{1/2} \end{array} \right.$$

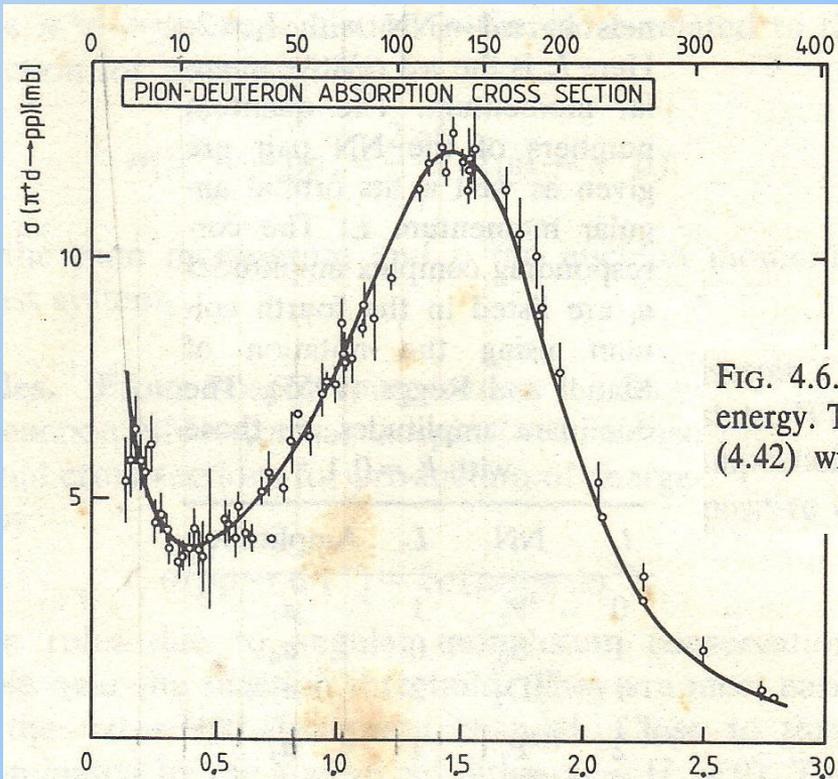


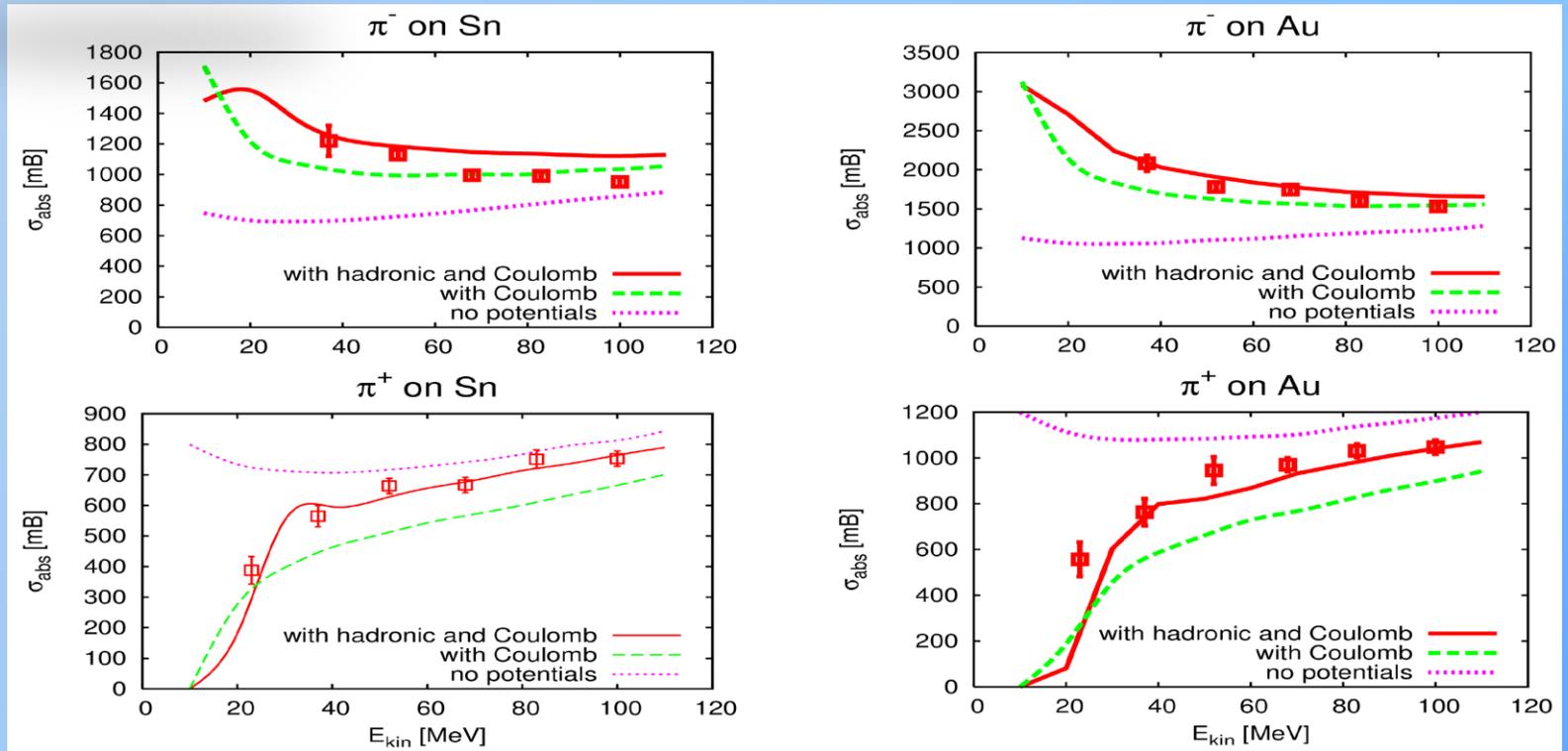
FIG. 4.6. The πd absorption cross-section versus pion momentum and kinetic energy. The solid curve corresponds to the phenomenological three-parameter fit (4.42) with correct threshold behaviour and resonance shape. (From Ritchie 1983.)

$$\sigma_a(\omega) = \sigma_{\gamma, MQD}(\omega) + \sigma_{\gamma, \pi}(\omega)$$



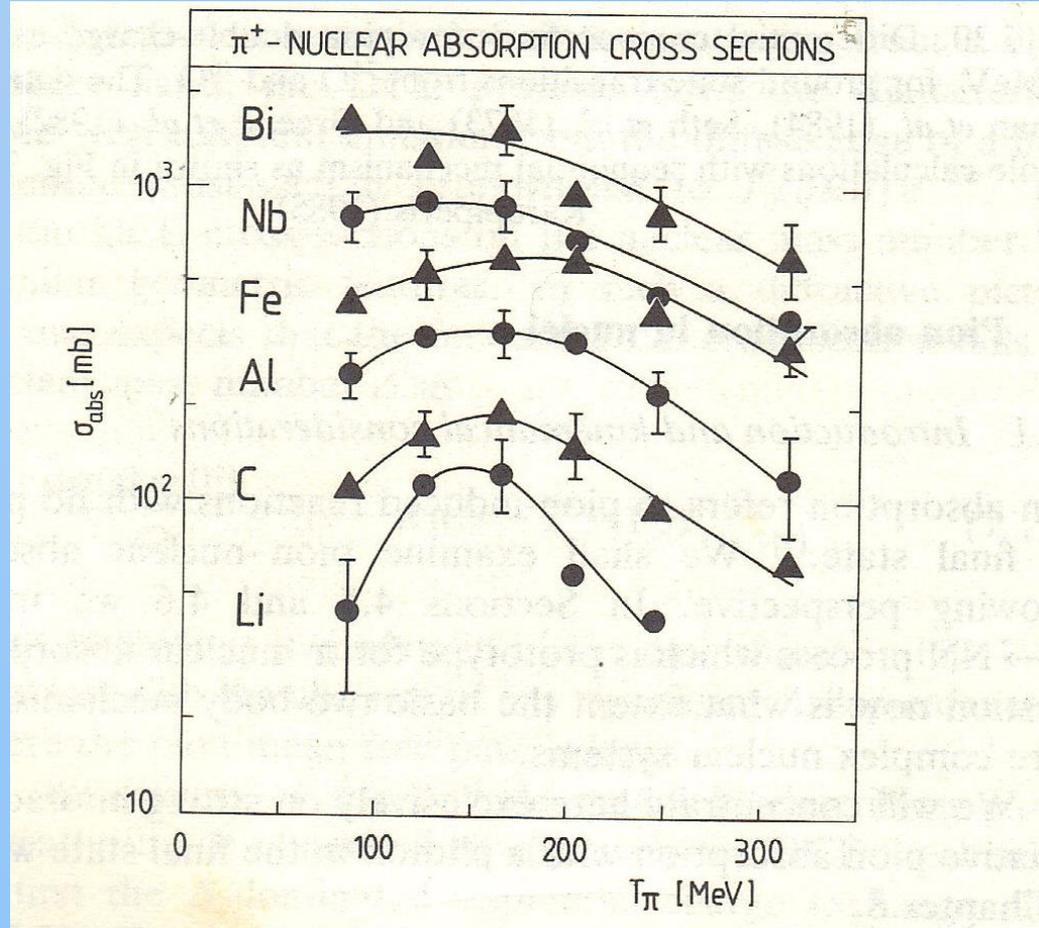
Absorção de mésons π no Núcleo

É tratado de forma análoga a ótica.





Absorção de mésons π no Núcleo

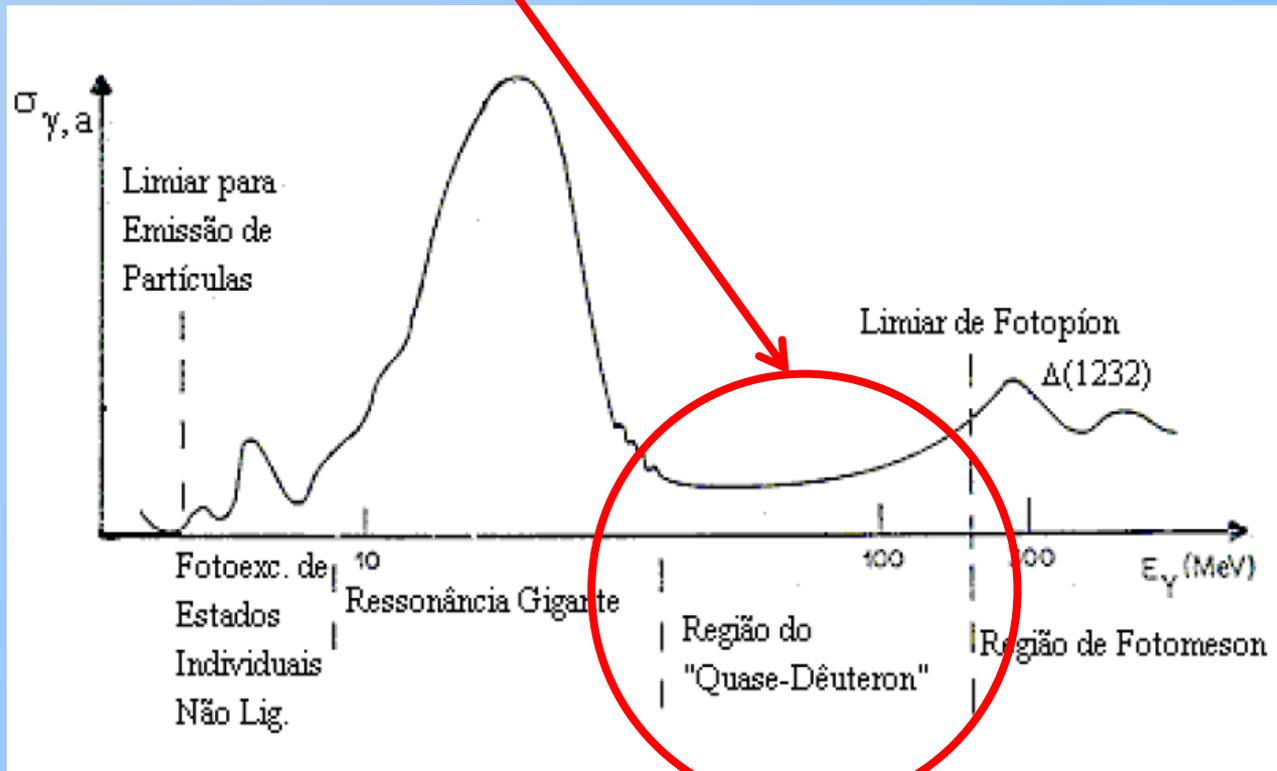


Pion absorption cross-section for various nuclei as a function of incident kinetic energy T_π . (From Ashery *et al.* 1981b.)



Foto Absorção via Quase-Deuteron (Modelo de Levinger)

$$\sigma_{\gamma, MQD}(\omega) = 6.5 \frac{Z(A-Z)}{A} e^{-(24.2/\omega)} \left(61.2 \frac{(\omega - 2.224)^{3/2}}{\omega^3} \right) \text{ (mb)}$$





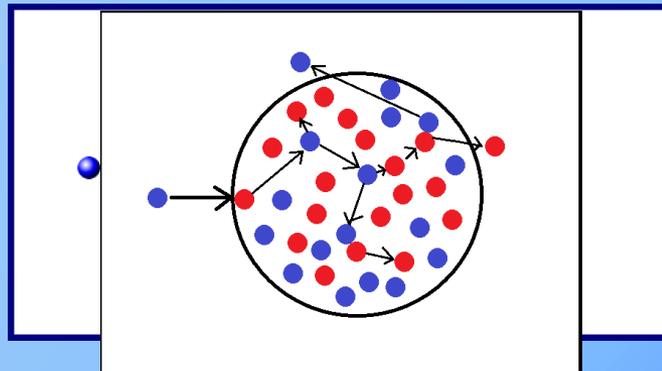
Efeitos no núcleo devido a fotoabsorção.

Em energias intermediárias temos a formação de núcleo composto e seu posterior decaimento.

$$\sigma_{fotoabs.,canal} = \sigma_{NC} P_{canal}$$

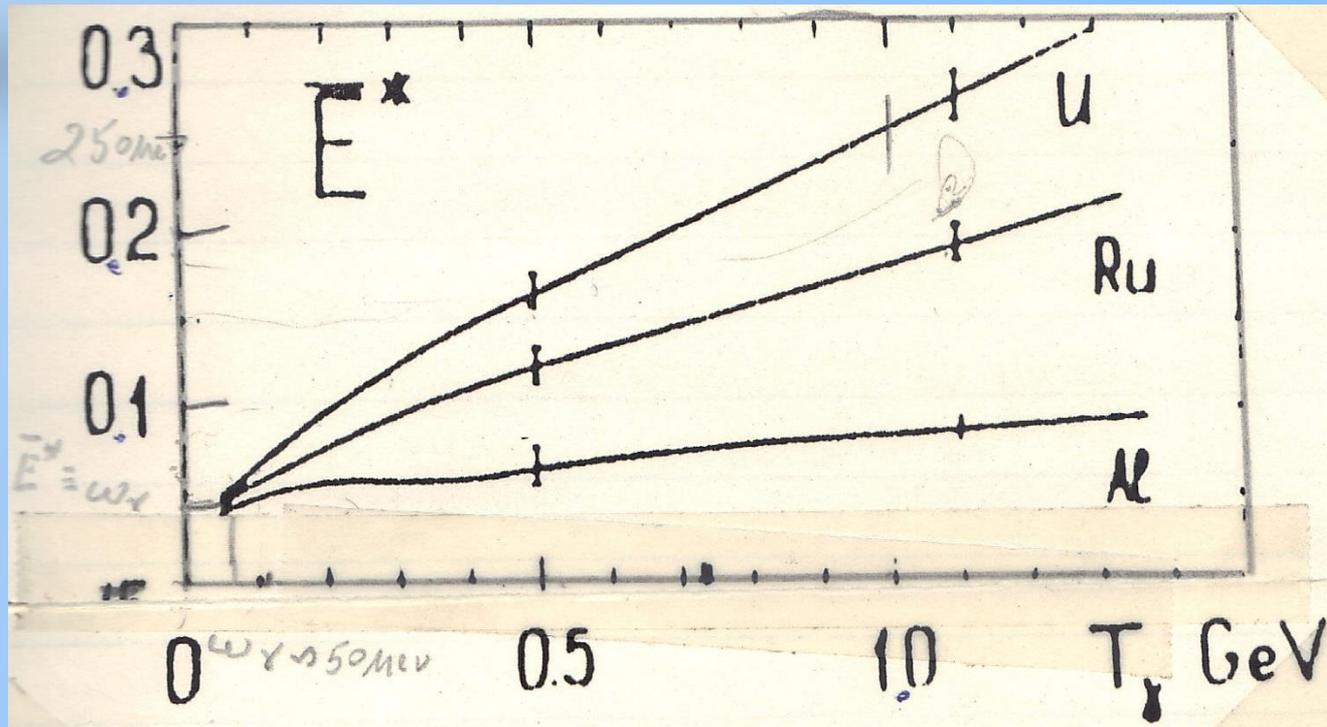
Estudamos o canal de fissão onde $P_{canal} \equiv \frac{\Gamma_f}{\sum \Gamma_{canais}}$

O núcleo composto é formado por um complexo e rápido processo denominado cascata intranuclear que deriva do núcleo original para uma coletividade de núcleos residuais com energia de excitação bem definida.





Extraction of Mean Energy Excitation from Experiments



Cálculo de Barachenkov com bins de 100MeV



Extraction of Mean Energy Excitation from Experiments

Cálculo de Barachenkov com ΔE de 20MeV - Frascati

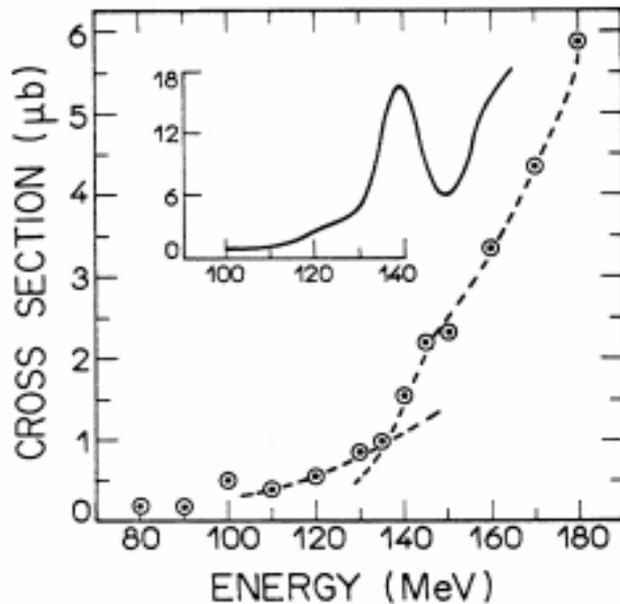
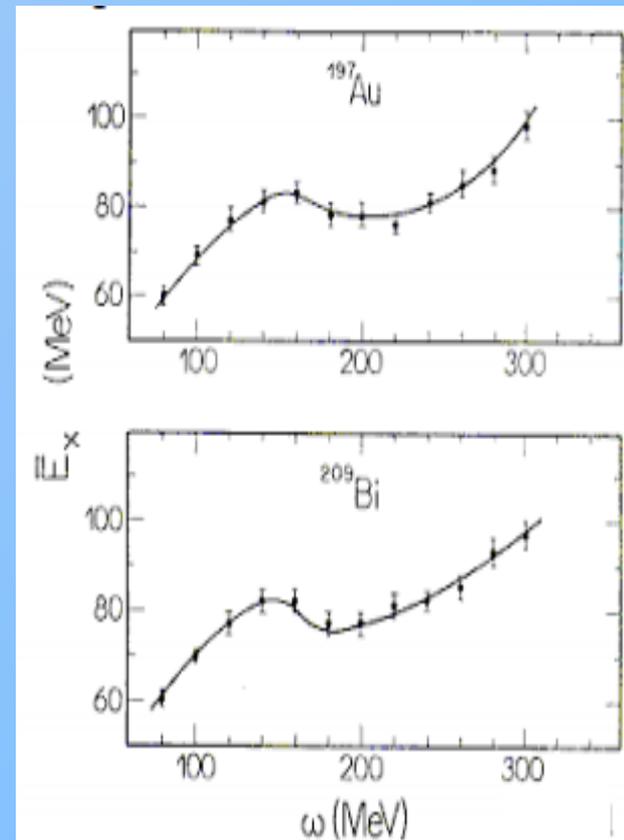


FIG. 1. Electrofission cross section of ^{182}W (data points); the dashed lines are to guide the eye. The inset shows the corresponding unfolded photofission cross section (also shown in Fig. 2).





$$\sigma_{e,f} = \sum_{\lambda,l} \int_0^{E_e} \sigma_f^{\lambda,l}(\omega) N^{\lambda,l}(E_e, \omega) \frac{d\omega}{\omega}$$

$\lambda \rightarrow$ Elétrica ou Magnética $l \rightarrow$ multipolaridade

A Seção de Choque de Fissão do núcleo composto é dada pela expressão:

$$\sigma^f = \sum_{A_{NC}, Z_{NC}, l} \int dE^* \sigma_{NC}(A_{NC}, Z_{NC}, E^*, l) \omega_f(A_{NC}, Z_{NC}, E^*, l)$$

A probabilidade de fissão do NC é:

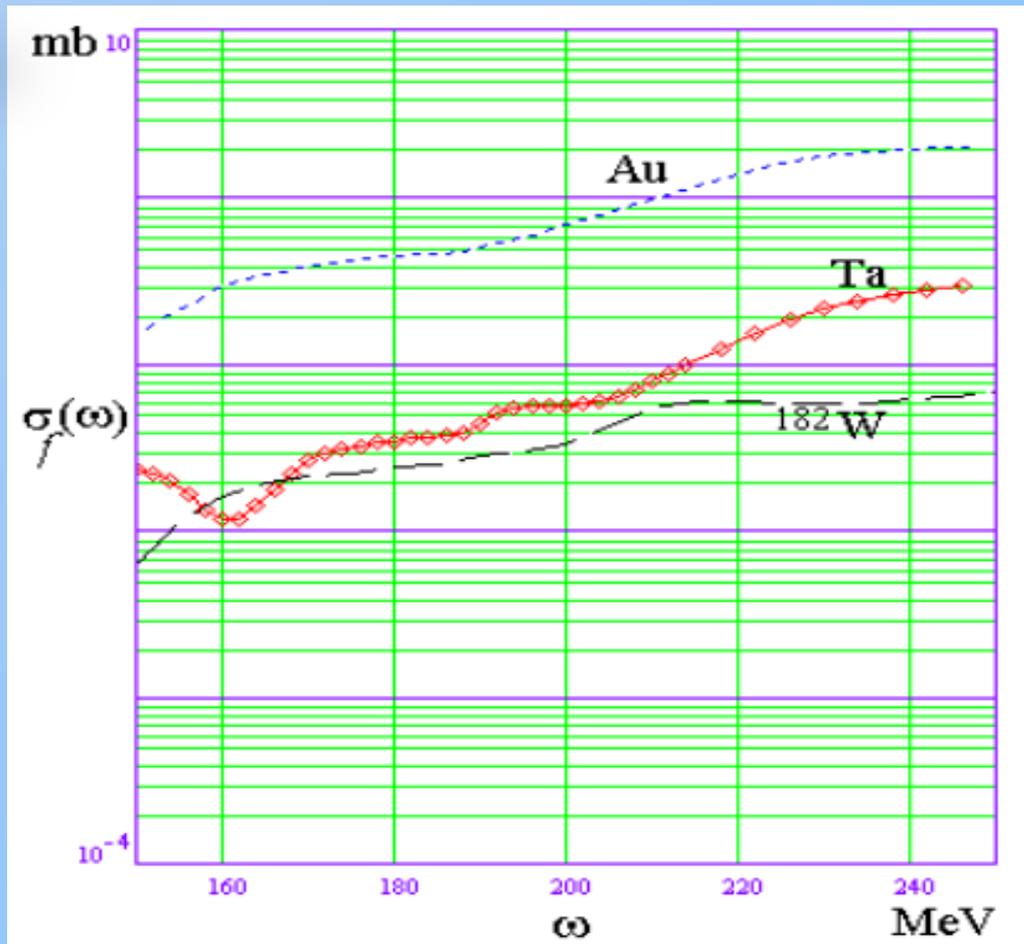
$$\omega_f(A_{NC}, Z_{NC}, E^*, l) = \sum_x P_x(E^*, l) \omega_x^f(A_{NC}, Z_{NC}, E^*, l)$$

$P_x(E^*, l)$ é a probabilidade do núcleo emitir x partículas antes do estado fundamental



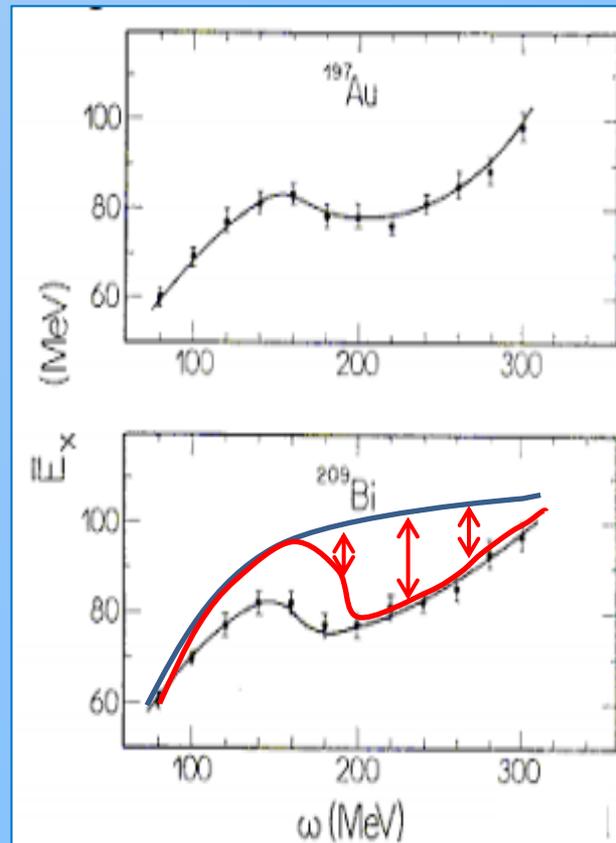
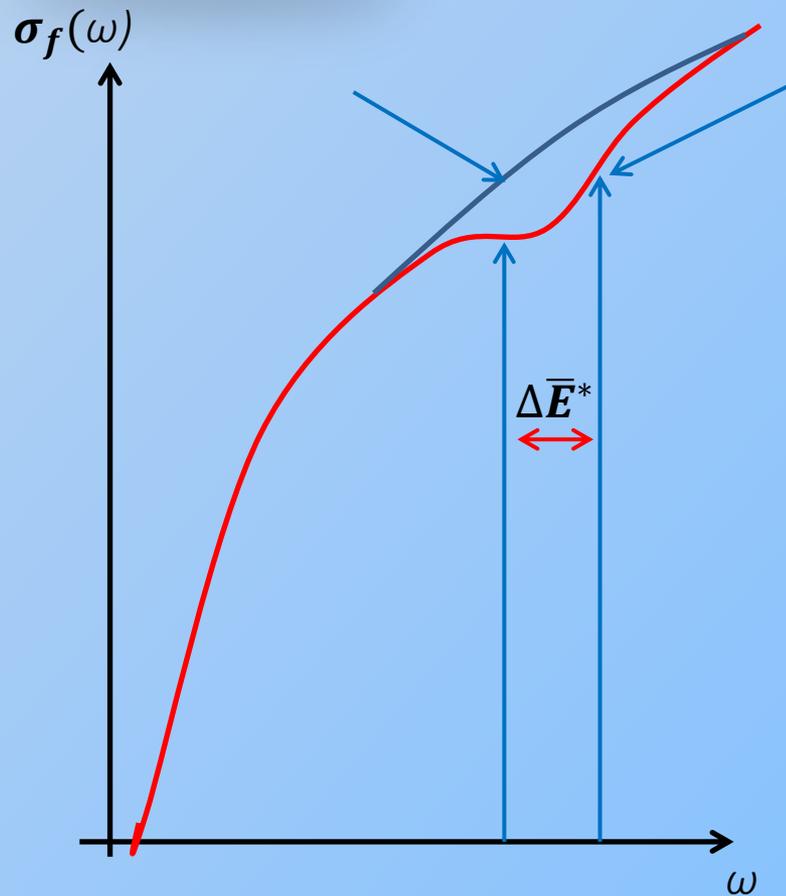
$$\sigma_{e,f} = \sum_{\lambda,l} \int_0^{E_e} \sigma_f^{\lambda,l}(\omega) N^{\lambda,l}(E_e, \omega) \frac{d\omega}{\omega}$$

$\lambda \rightarrow$ Elétrica ou Magnética $l \rightarrow$ multipolaridade



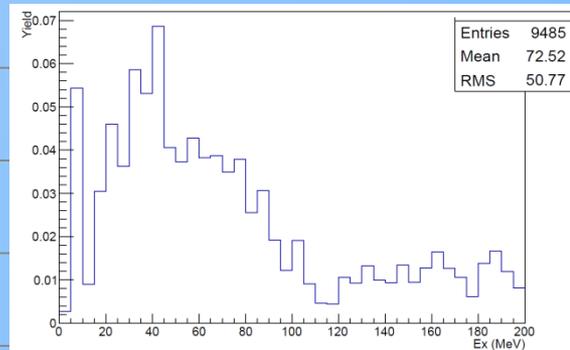
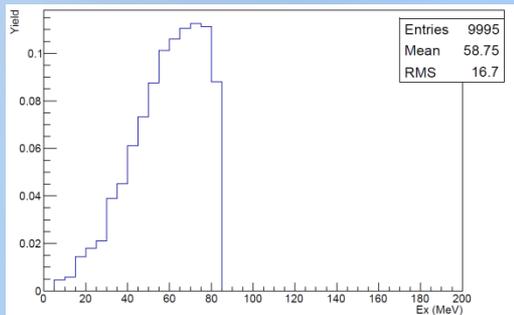


Extraction of Mean Energy Excitation from Experiments

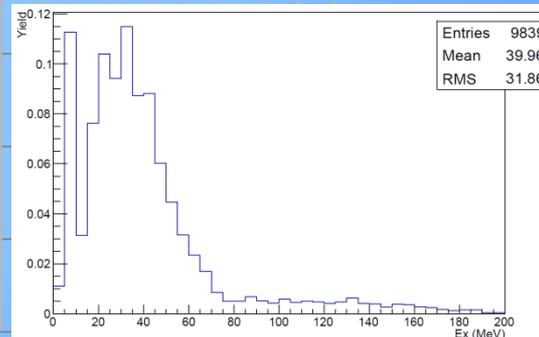
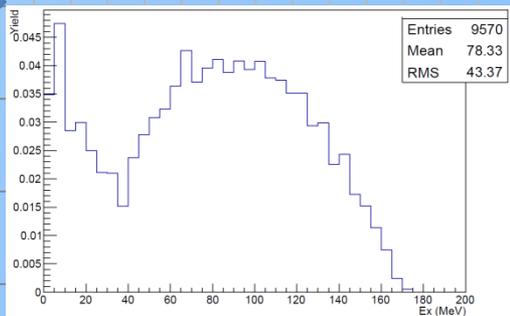
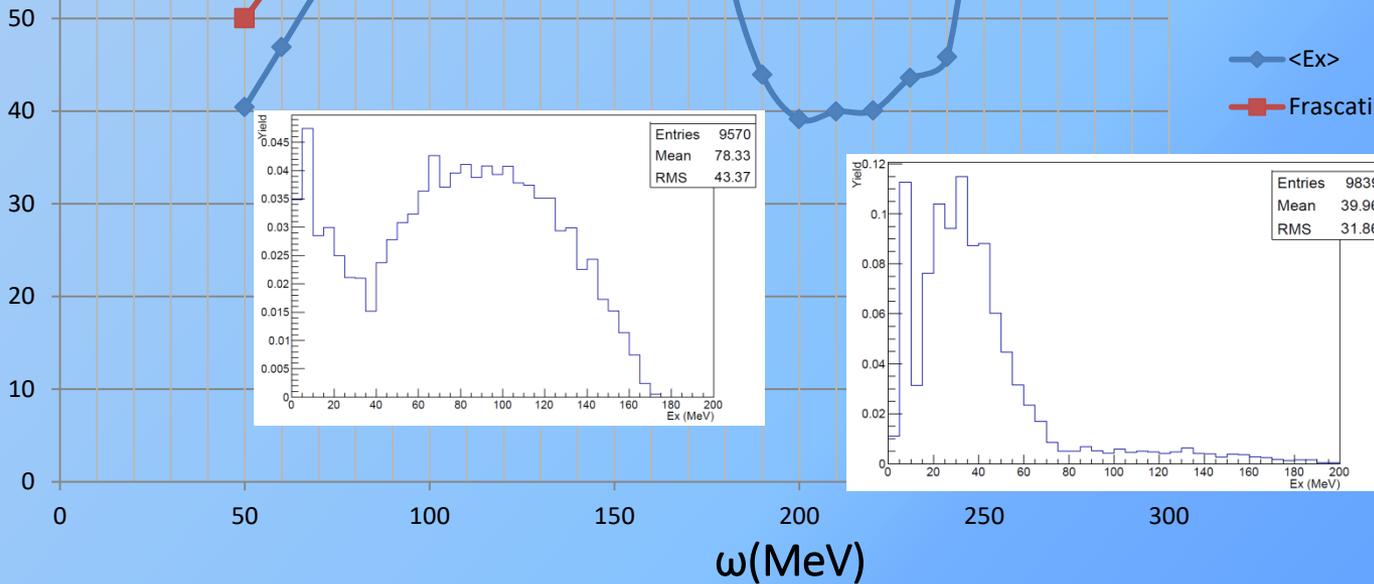


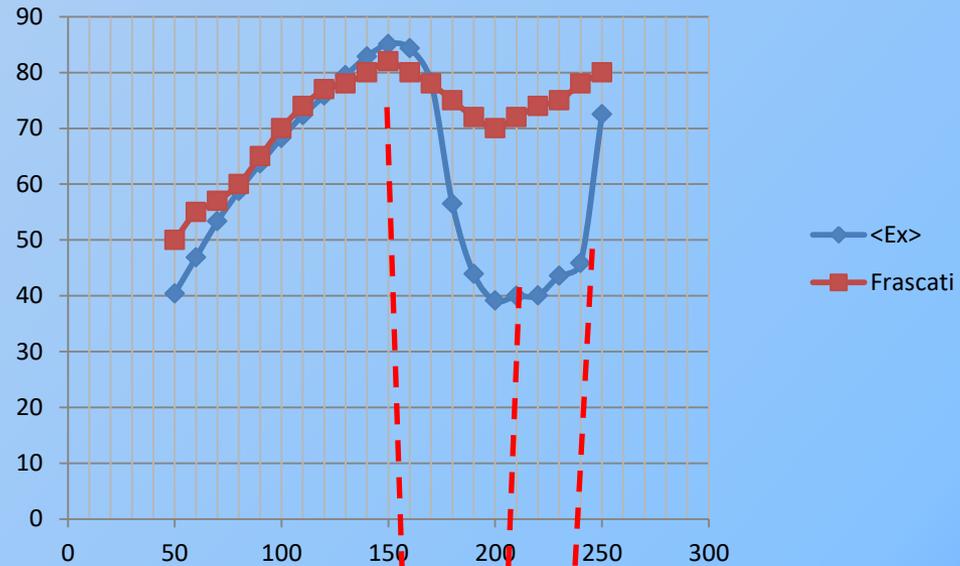


CRISP - ^{184}W

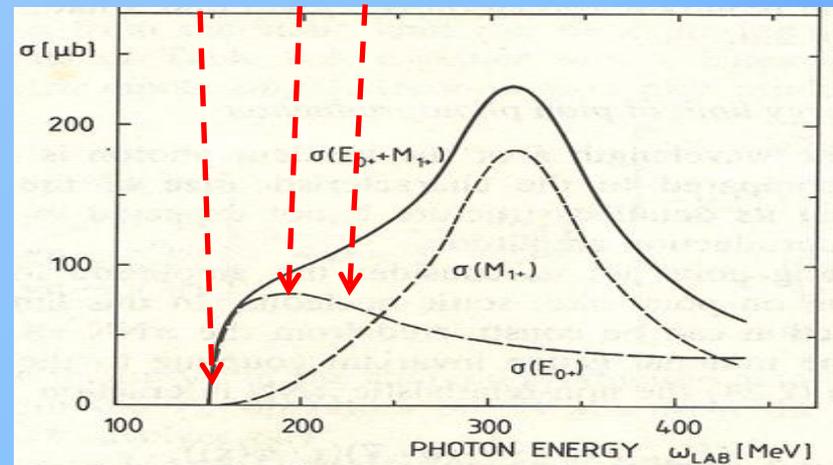


$\bar{E}^* (\text{MeV})$



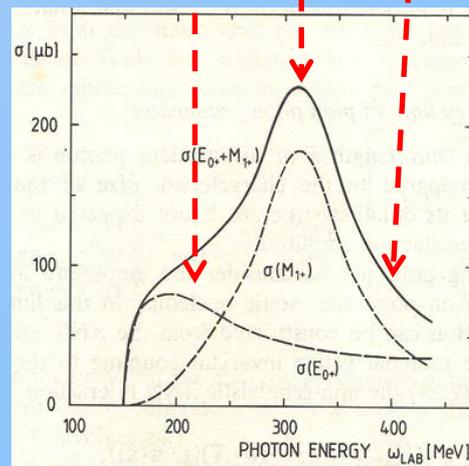
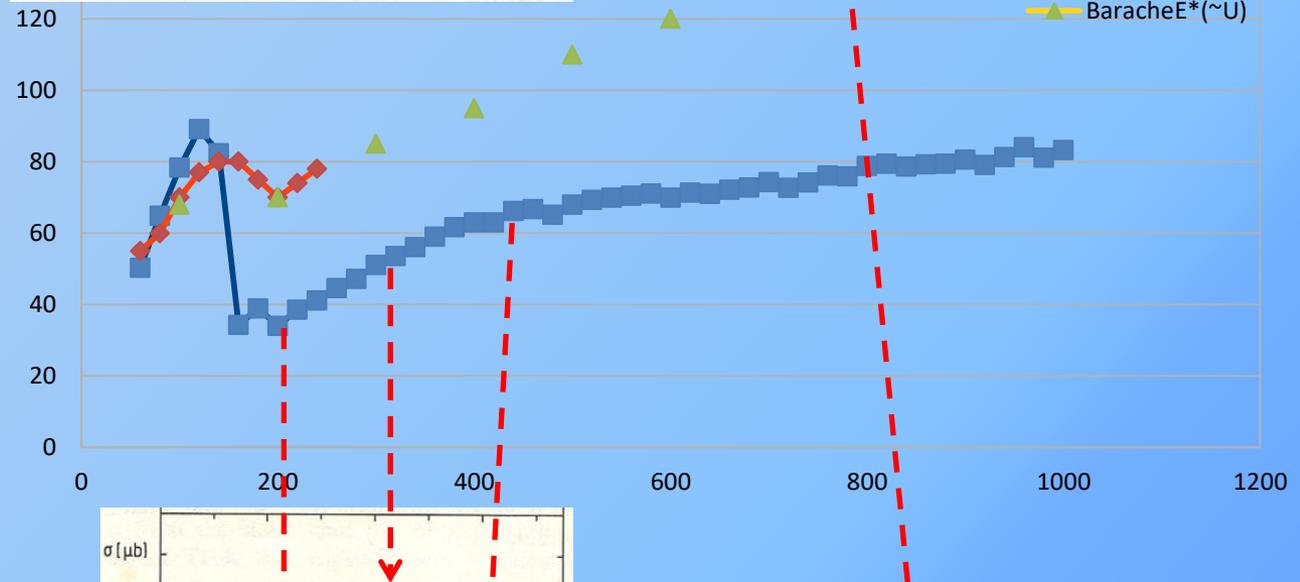
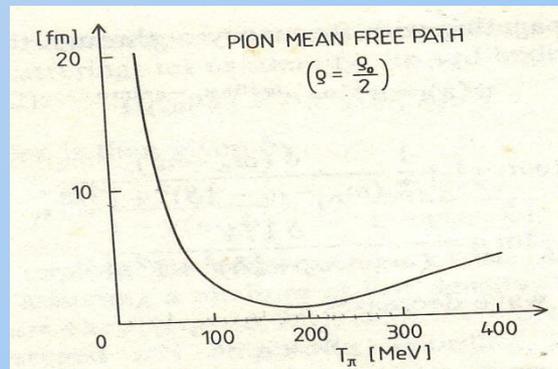


CRISP acompanha a multipolaridade E_{0+} e M_{1+} da fotoprodução de píons.





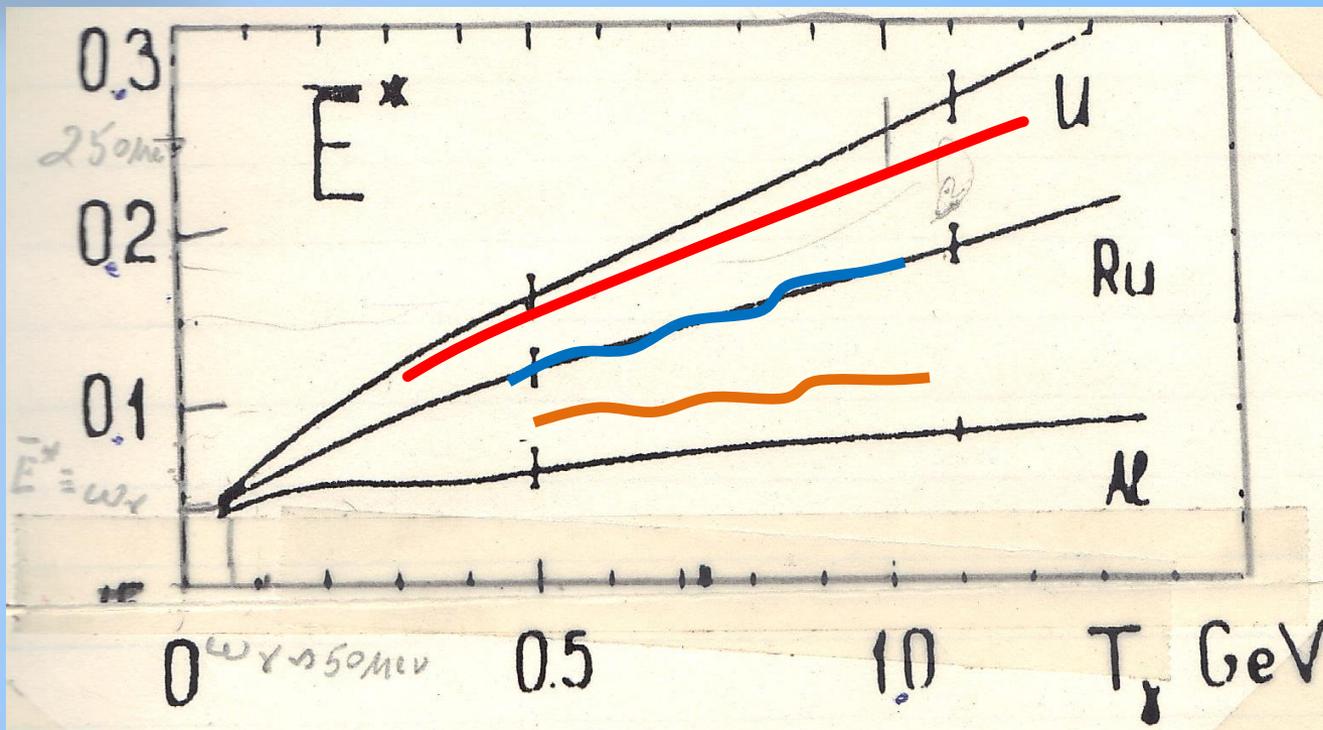
O meu CRISP não
reproduz corretamente
a energia de excitação
média.
Erra em $> 3x$.



Experimentalmente
o cálculo de Barachenkov
esta correto.



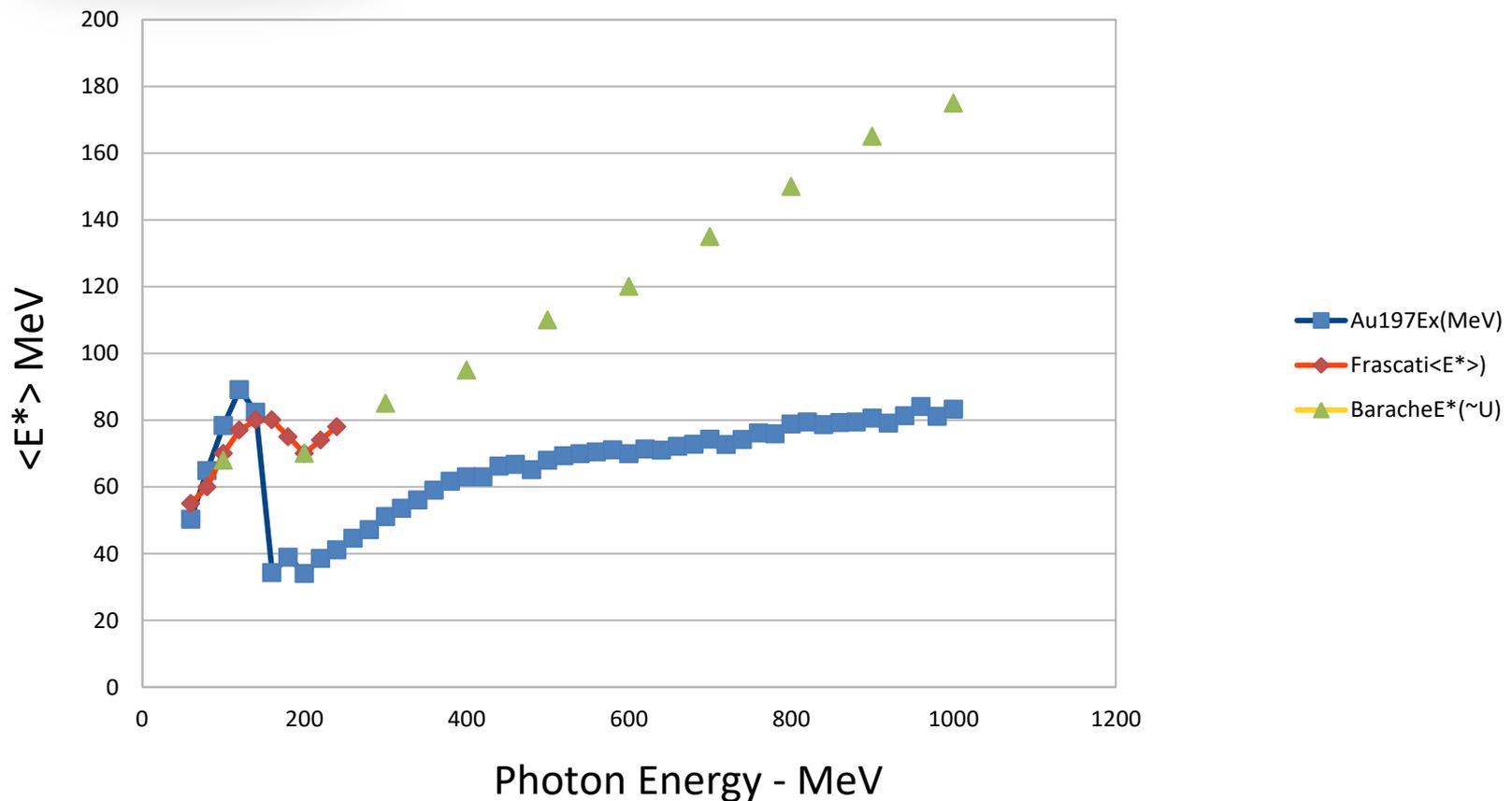
CRISP do Ramón reproduz o Au sobre o Ru no cálculo de Barachenkov. A minha simulação do Au é próxima do Al
Deveriam ser mais próximas do U!





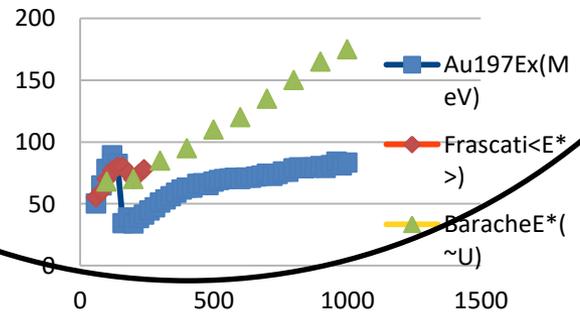
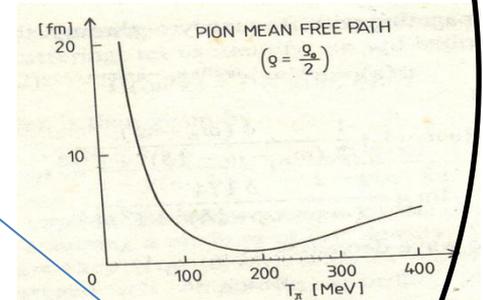
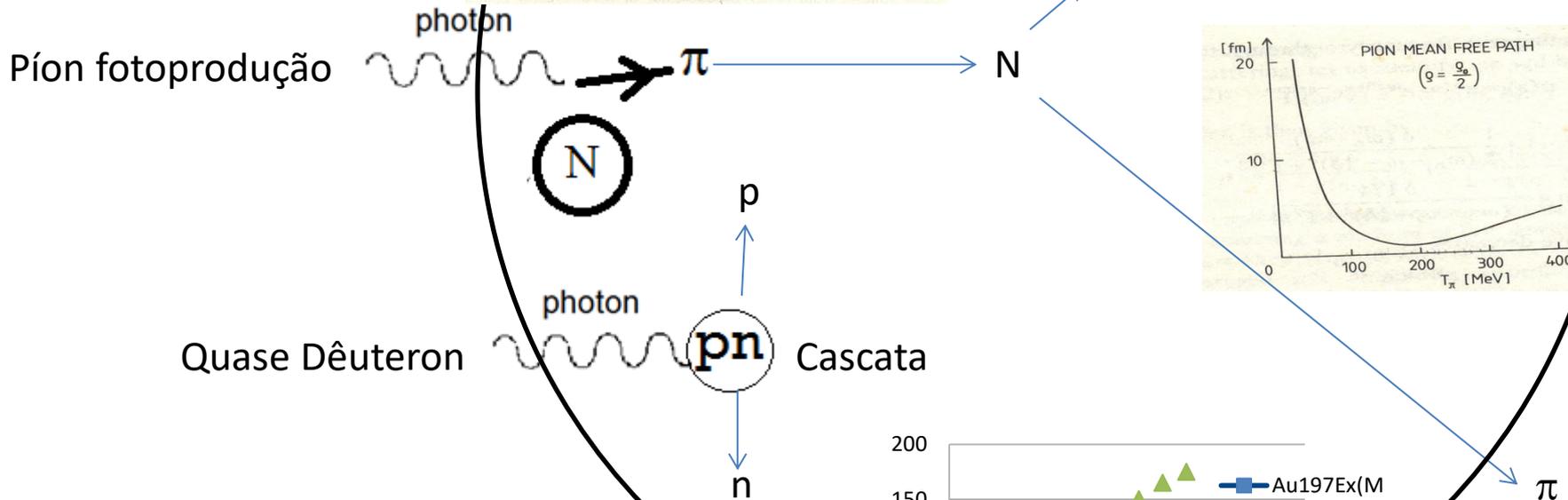
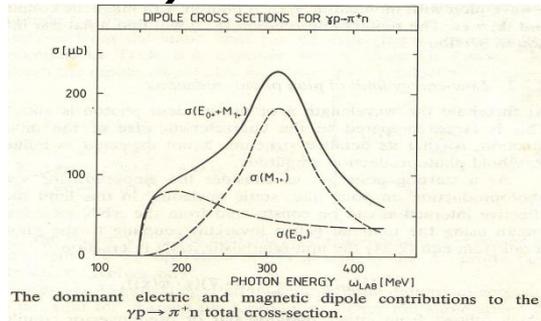
Correções necessárias no CRISP.

Por que os níveis de energia de excitação não condizem com o esperado?





Propostas de correções.

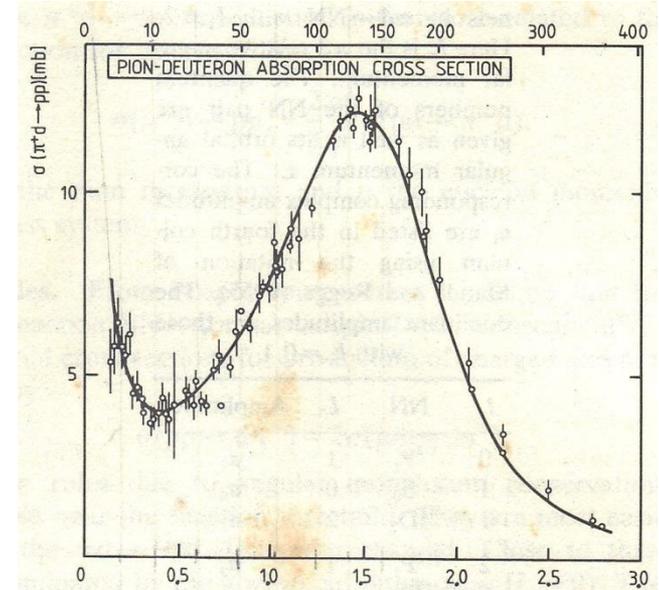




Propostas de correções via π - dêuteron.

Inserir um modelo fenomenológico tipo “Quase-Deuteron” competitivamente (Metrópolis) com o processo $\pi(q) + N(p) \rightarrow \pi(q') + N(p')$ na fase de cascata intranuclear.

$$\sigma(d\pi^+ \rightarrow pp) = \left\{ \begin{array}{l} \left(\frac{3.5}{T_{\pi}^{1/2}} \text{MeV}^{1/2} + \frac{3.3\Gamma_0^2}{(E - E_R) + \frac{\Gamma_0^2}{4}} \right) \text{mb} \\ E_R = 2136 \text{MeV} \quad \Gamma_0 = 150 \text{MeV} \\ E = [(m_{\pi} + M_d)^2 + 2T_{\pi}M_d]^{1/2} \end{array} \right.$$





Píon fotoprodução

photon



p

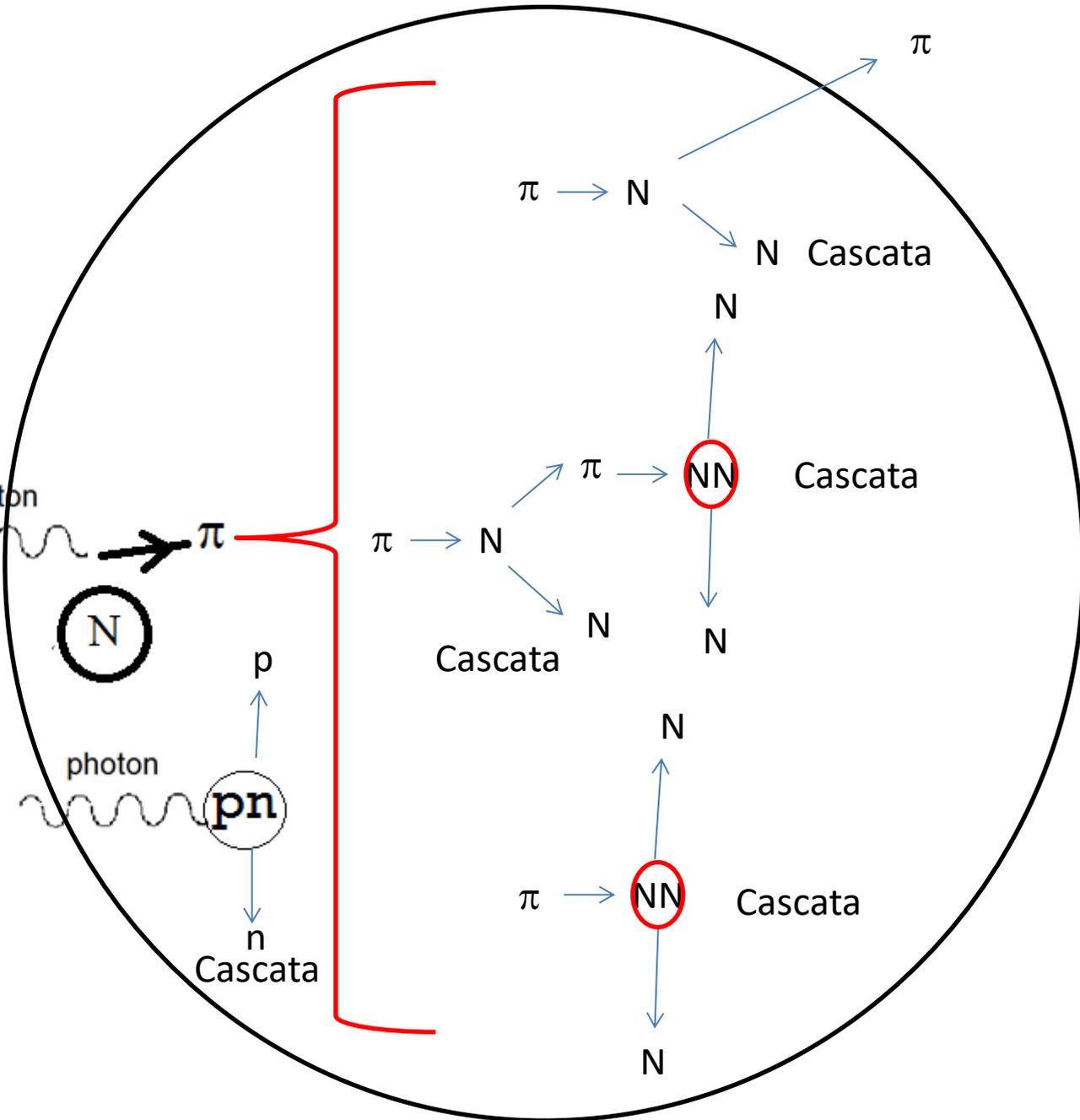
photon



n

Quase Dêuteron

Cascata



π

π → N

N Cascata

N

π → NN

Cascata

π → N

Cascata

N

N

N

π → NN

Cascata

N



Propostas de correções via Quase Dêuteron.

Com base na distribuição de probabilidades pelo processo de Metrópolis modificamos o CRISP para incorporar os já inclusos processos πp e πn simultaneamente como $\pi d \rightarrow NN$.

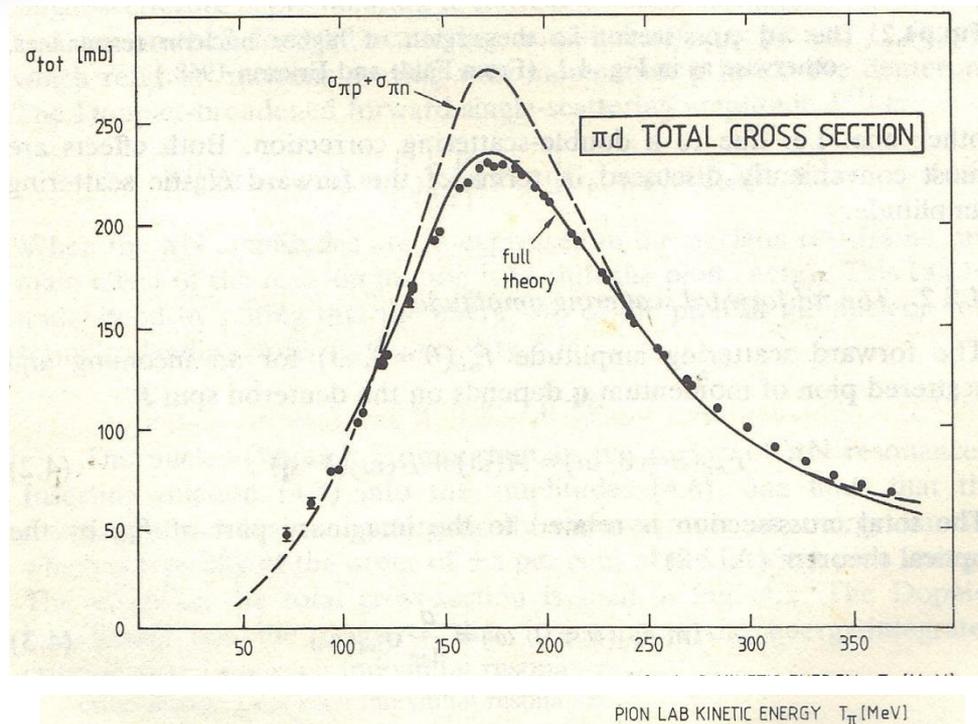
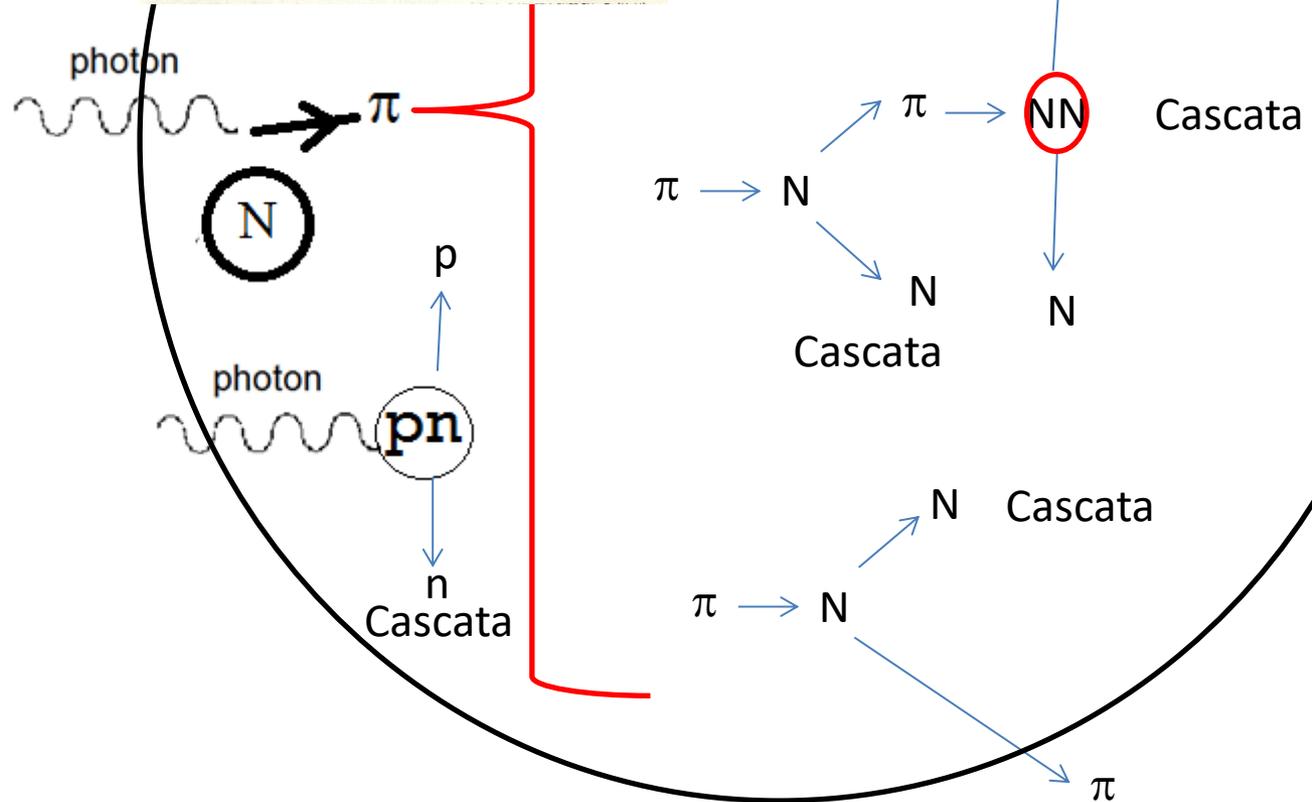
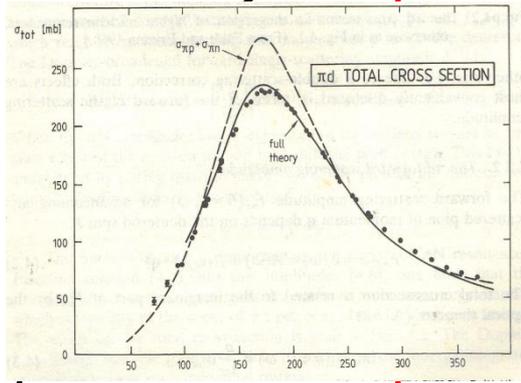


FIG. 4.1. The πd total cross-section in the $\Delta(1232)$ region compared to the sum of the πn and πp total cross-sections. The solid line labelled 'full theory' is given for comparison. It includes nucleon motion and double-scattering corrections as well as small additional terms. (From Pedroni *et al.* 1978.)





A questão do Nível de Fermi

$$n(\mathbf{p}) = \begin{cases} 1 & \dots |\mathbf{p}| \leq p_F \\ 0 & \dots |\mathbf{p}| \geq p_F \end{cases}$$

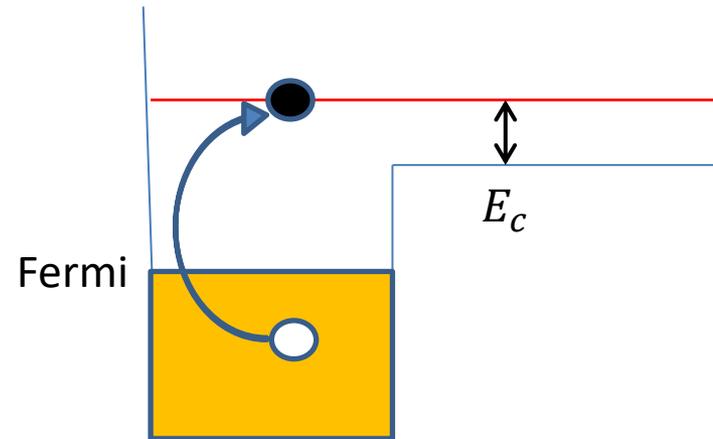
Degenerescência $\rightarrow 2$

$$\rho_i = 2 \int n_i(\mathbf{p}) \frac{d^3 p}{(2\pi)^3} = \frac{(p_F^i)^3}{3\pi^2} \quad i = (p, n)$$

$$\rho = \rho_p + \rho_n$$

Se o número $p = n$

$$\rho = \frac{(p_F^3)^3}{3\pi^2}$$



$$p_F = 1.36 \text{fm}^{-1} \cong 2m_\pi$$

$$\varepsilon_F \cong 40 \text{MeV} \cong 0.3m_\pi$$

$$\rho_0 = 0.17 \text{fm}^{-3} \cong 0.5m_\pi^3$$



Principal ref. bibliográfica:

Pions and Nuclei
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