

Scattering di elettroni e neutrini su nuclei ed effetti di stranezza

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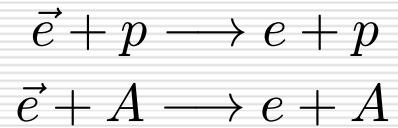
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Introduzione

- contributo dei quark del mare alle proprietà del nucleone
 - dati di EMC (1988)  prima evidenza che $g_A^S \neq 0$
 - nuovi esperimenti e molto lavoro teorico  neutrino-nucleo e parity-violating electron scattering
 - combinazione di diverse misure è necessaria per un'informazione completa
 - sensibilità del PVES dello scattering ν -nucleo al contributo di stranezza
 - effetti nucleari sotto controllo
-

PV electron scattering



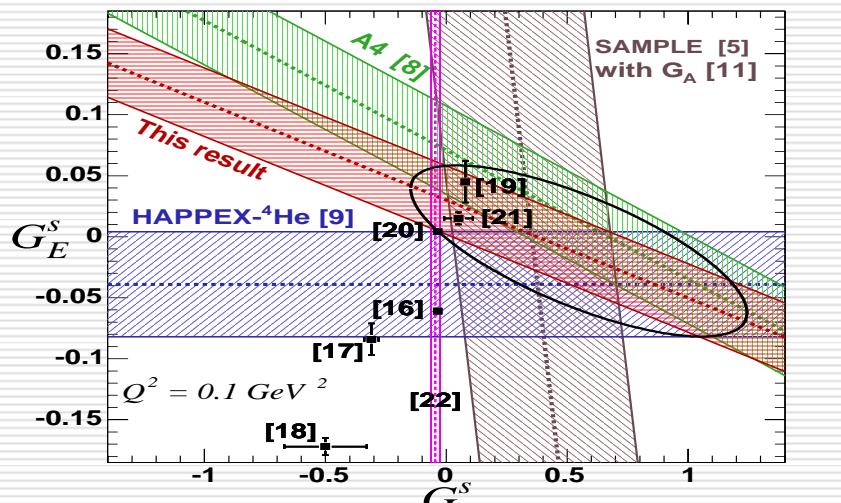
- molti esperimenti → SAMPLE @ MIT-Bates, HAPPEX
Collaboration @ JLab, GO Collaboration @ JLab, E158 @ SLAC,
A4 collaboration @ Mainz, PREX @ JLab
- determinare il contributo di stranezza ai fattori di forma
elettrico, magnetico ed assiale del nucleone
- si suppone che il modello standard sia valido
- misure fatte solo per scattering elastico $\vec{e}p$
- e per i nuclei? → ^2H , ^4He (HAPPEX), ^{208}Pb (PREX – livello
proposal)
- → effetti nucleari sotto controllo

PV risultati

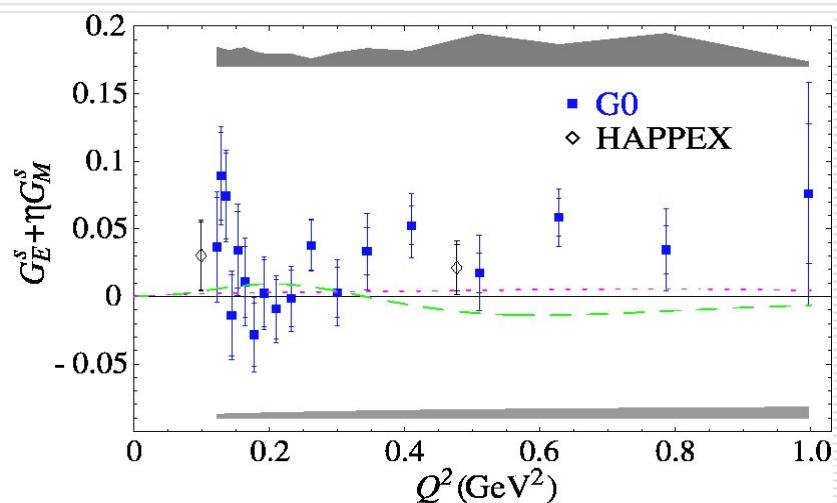
$$A = \frac{d\sigma_+ - d\sigma_-}{d\sigma_+ + d\sigma_-}$$

A dipende da $G_{E(M)}^\gamma$, $G_{E(M)}^Z$ e G_A

- misure per il contributo strano a G_E e G_M . Complicazioni per G_A
- HAPPEX-1 (*ep, $Q^2=0.48\text{GeV}^2$*) $G_E^s + 0.392G_M^s = 0.014 \pm 0.020 \pm 0.010$
- HAPPEX-2 (*ep, $Q^2=0.1\text{GeV}^2$*) $G_E^s + 0.080G_M^s = 0.030 \pm 0.025 \pm 0.006 \pm 0.012$
- A4 (*ep, $Q^2=0.108\text{GeV}^2$*) $G_E^s + 0.106G_M^s = 0.071 \pm 0.036$



HAPPEX-2 G0



PV su nuclei

- $d\sigma \propto | \mathcal{M}^\gamma + \mathcal{M}^Z |^2 \simeq | \mathcal{M}^\gamma |^2 + (\mathcal{M}^\gamma)^\star \mathcal{M}^Z + (\mathcal{M}^Z)^\star \mathcal{M}^\gamma$
- $A = \frac{d\sigma_+ - d\sigma_-}{d\sigma_+ + d\sigma_-} = A_0 \frac{v_L R_L^{AV} + v_T R_T^{AV} + v'_T R_T^{VA}}{v_L R_L + v_T R_T}$

correnti elettromagnetica e neutra

$$\begin{aligned} j_{\text{em}}^\mu &= F_1(Q^2) \gamma^\mu + i \frac{\kappa}{2M} F_2(Q^2) \sigma^{\mu\nu} q_\nu \\ j_{\text{nc}}^\mu &= F_1^V(Q^2) \gamma^\mu + i \frac{\kappa}{2M} F_2^V(Q^2) \sigma^{\mu\nu} q_\nu - G_A(Q^2) \gamma^\mu \gamma^5 \end{aligned}$$

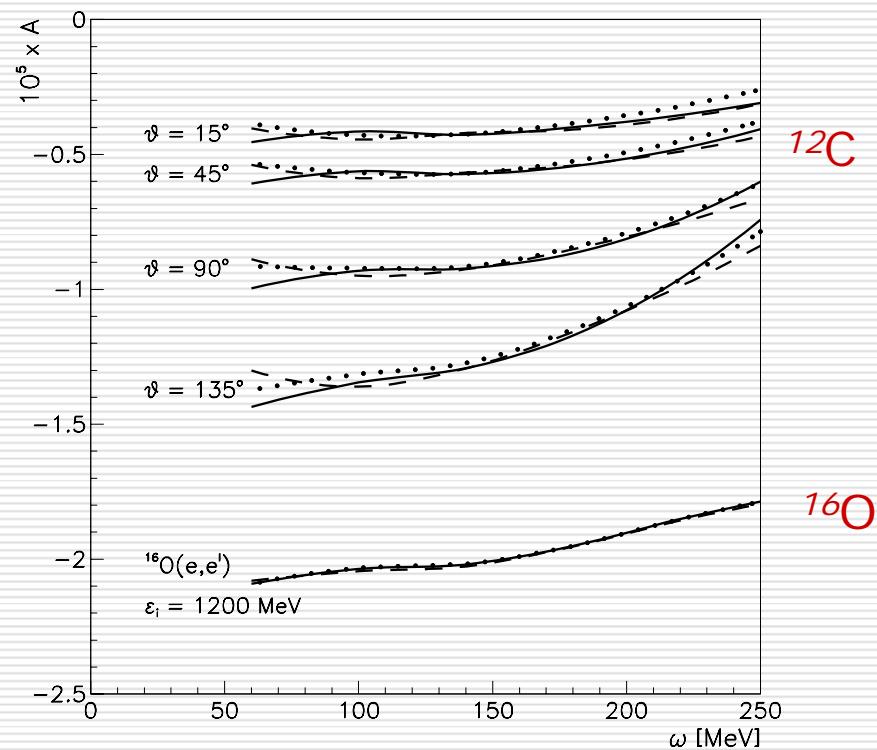
fattori di forma

$$F_i^{\text{V,p(n)}} = (1/2 - 2 \sin^2 \theta_W) F_i^{\text{p(n)}} - 1/2 F_i^{\text{n(p)}} - 1/2 F_i^{\text{s}}$$
$$[\sin^2 \theta_W \simeq 0.23]$$

PV asymmetry

- ^{12}C $\rightarrow q=400 \text{ MeV}/c$
- ^{16}O $\rightarrow \varepsilon=1200 \text{ MeV e}$
 $\vartheta = 32^\circ$
- stati legati e potenziali diversi

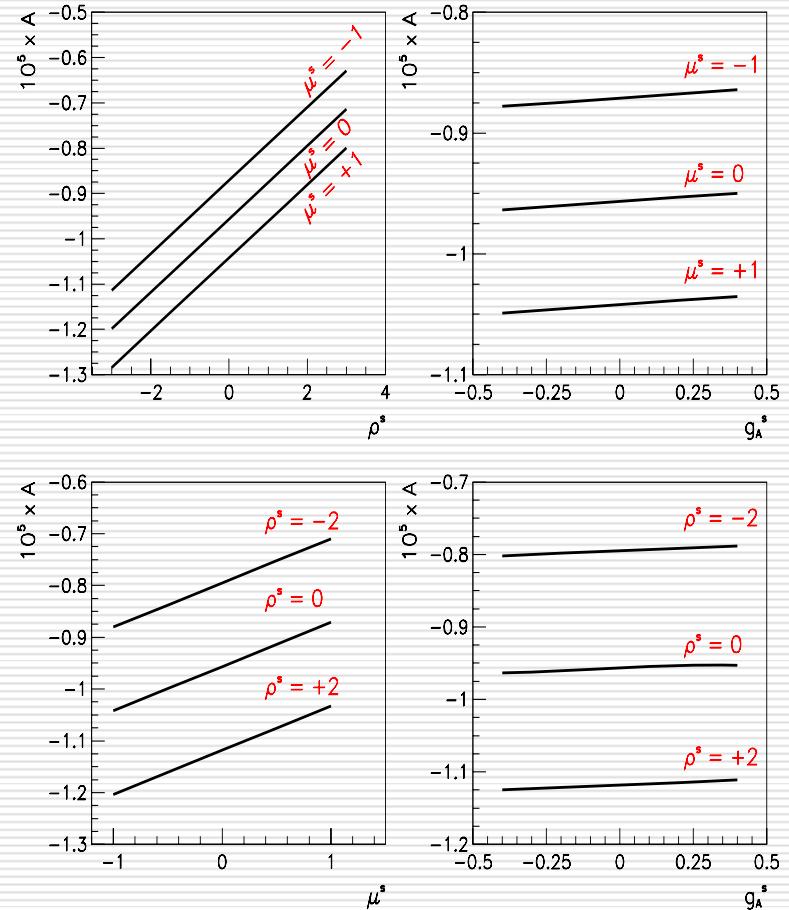
A. Meucci, C. Giusti, F.D. Pacati,
Nucl. Phys. A 756 (2005) 359-381



PV asymmetry

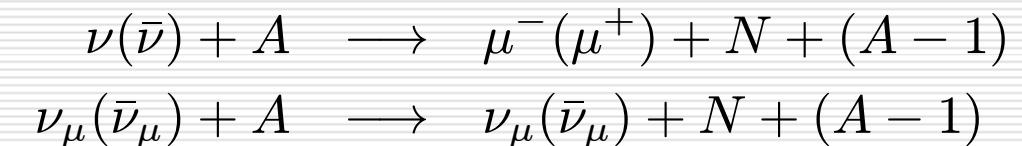
- ^{12}C ($q = 500 \text{ MeV}/c$ e $\vartheta = 30^\circ$)
- poca sensibilità a g_A^s

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Scattering neutrino-nucleo

scattering semi-inclusivo



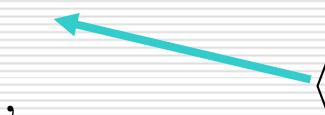
■ $d\sigma = \frac{G_F^2}{2} 2\pi L^{\mu\nu} W_{\mu\nu} \frac{d^3 k}{(2\pi)^3} \frac{d^3 p_N}{(2\pi)^3}$

■ $G_F \simeq 1.16639 \times 10^{-11} \text{ MeV}^{-2}$ costante di Fermi
 $(\times \cos^2 \vartheta_C \simeq 0.9749 \text{ per reazioni CC})$

tensore adronico

$$W^{\mu\nu}(\omega, q) = \sum_n \langle n; \chi_{\mathbf{p}_N}^{(-)} | J^\mu(\mathbf{q}) | \Psi_0 \rangle \langle \Psi_0 | J^{\nu\dagger}(\mathbf{q}) | n; \chi_{\mathbf{p}_N}^{(-)} \rangle$$

$\times \delta(E_0 + \omega - E_f)$,



$$\langle \chi_{\mathbf{p}_N}^{(-)} | j^\mu(\mathbf{q}) | \varphi_n \rangle$$

si calcola come nel caso (e,e'p)

Sezione d'urto neutrino-nucleo

$$\begin{aligned}\frac{d\sigma}{d\varepsilon d\Omega d\Gamma_N} &= \frac{G^2}{4\pi^2} k\varepsilon \left[v_0 R_{00} + v_{zz} R_{zz} - v_{0z} R_{0z} \right. \\ &\quad \left. + v_T R_T \pm v_{xy} R_{xy} \right] \frac{|\mathbf{p}_N| E_N}{(2\pi)^3} \begin{pmatrix} 1 & (\text{NC}) \\ \cos^2 \vartheta_C & (\text{CC}) \end{pmatrix}\end{aligned}$$

componenti del tensore leptonico $\longrightarrow v_{\lambda\lambda}$

funzioni di risposta

$$R_{00} = \int d\Omega_N W^{00}, \quad R_{zz} = \int d\Omega_N W^{zz},$$

$$R_{0z} = \int d\Omega_N 2 \operatorname{Re}(W^{0z}),$$

$$R_T = \int d\Omega_N (W^{xx} + W^{yy}), \quad R_{xy} = \int d\Omega_N 2 \operatorname{Im}(W^{xy})$$

Corrente debole

□ corrente carica

$$j^\mu = \left[F_1^V(Q^2) \gamma^\mu + i \frac{\kappa}{2M} F_2^V(Q^2) \sigma^{\mu\nu} q_\nu - G_A(Q^2) \gamma^\mu \gamma^5 + F_P(Q^2) q^\mu \gamma^5 \right] \tau^\pm$$

$$F_i^V = F_i^P - F_i^N \quad \text{fattore di forma assiale}$$

$$G_A = g_A G = \frac{1.26}{(1+Q^2/M_A^2)^2}$$
$$M_A = (1.026 \pm 0.021) \text{ GeV}$$

□ corrente neutra

$$\blacksquare \quad j^\mu = F_1^V(Q^2) \gamma^\mu + i \frac{\kappa}{2M} F_2^V(Q^2) \sigma^{\mu\nu} q_\nu - G_A(Q^2) \gamma^\mu \gamma^5$$

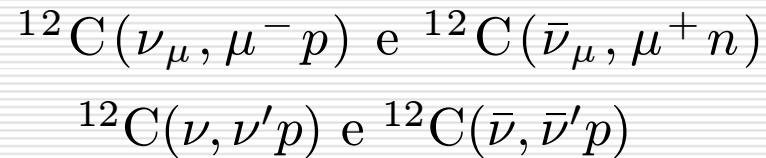
$$\blacksquare \quad F_i^{V,p(n)} = (1/2 - 2 \sin^2 \theta_W) F_i^{p(n)} - 1/2 F_i^{n(p)} - 1/2 F_i^S \quad [\sin^2 \theta_W \simeq 0.23]$$

$$\blacksquare \quad F_1^S(Q^2) = \frac{(\rho^S + \mu^S)\tau}{(1+\tau)(1+Q^2/M_V^2)^2}, \quad F_2^S(Q^2) = \frac{(\mu^S - \tau\rho^S)}{(1+\tau)(1+Q^2/M_V^2)^2} \quad \begin{matrix} \tau=Q^2/(4M^2) \\ M_V=0.843 \text{ GeV} \end{matrix}$$

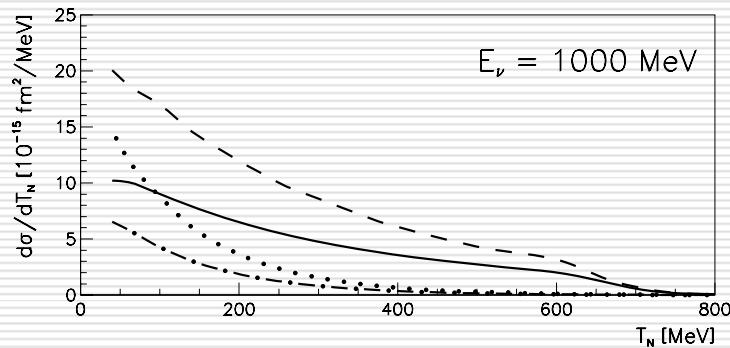
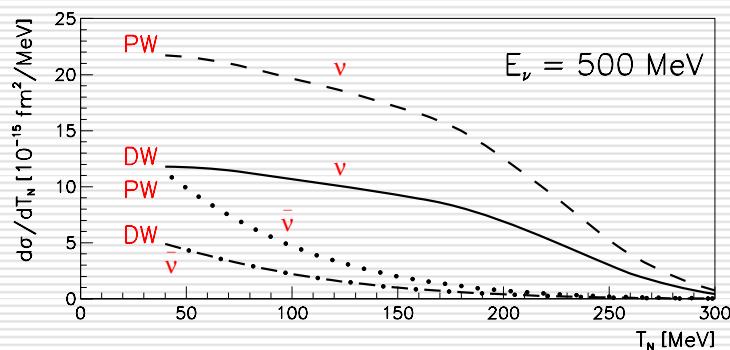
$$\blacksquare \quad G_A = 1/2 (\tau_3 g_A - g_A^S) G \quad [\tau_3 = +1 (-1) \text{ protone (neutrone)}]$$

fattori di forma strani

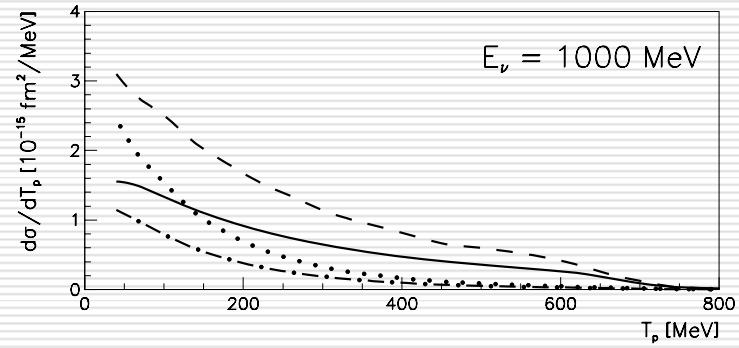
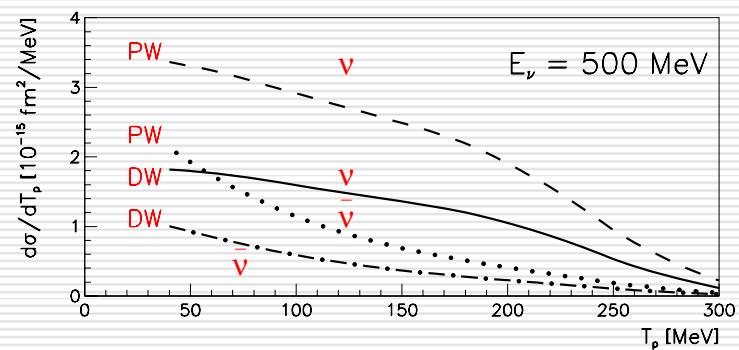
Sezione d'urto



corrente carica



corrente neutra

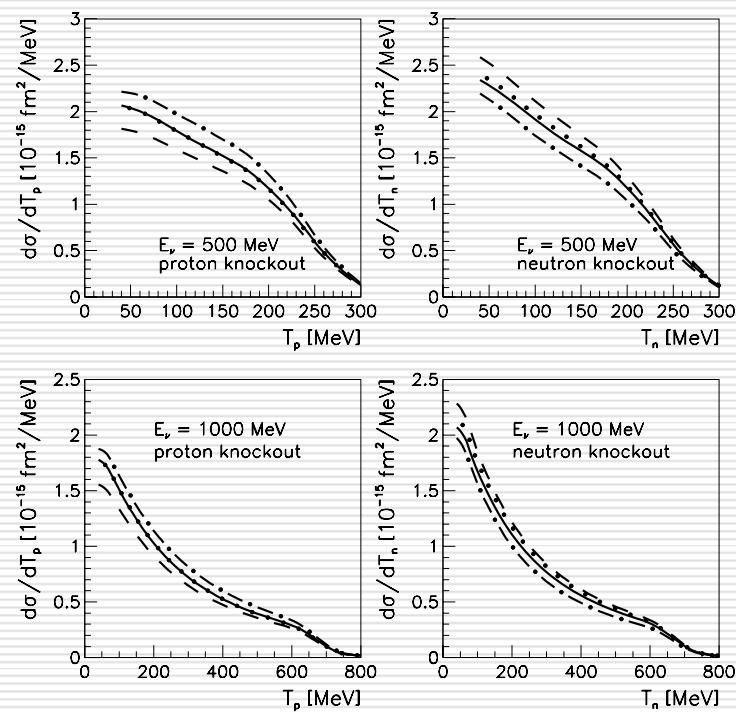


A. Meucci, C. Giusti, F.D. Pacati, Nucl. Phys. A 773 (2006) 250-262

Effetto della stranezza sulla sezione d'urto NC

- dashed no stranezza
- solid $g_A^s = -0.10$
- dot-dashed $g_A^s = -0.10$ e $\mu^s = -0.50$
- dotted $g_A^s = -0.10$ e $\rho^s = +2.0$

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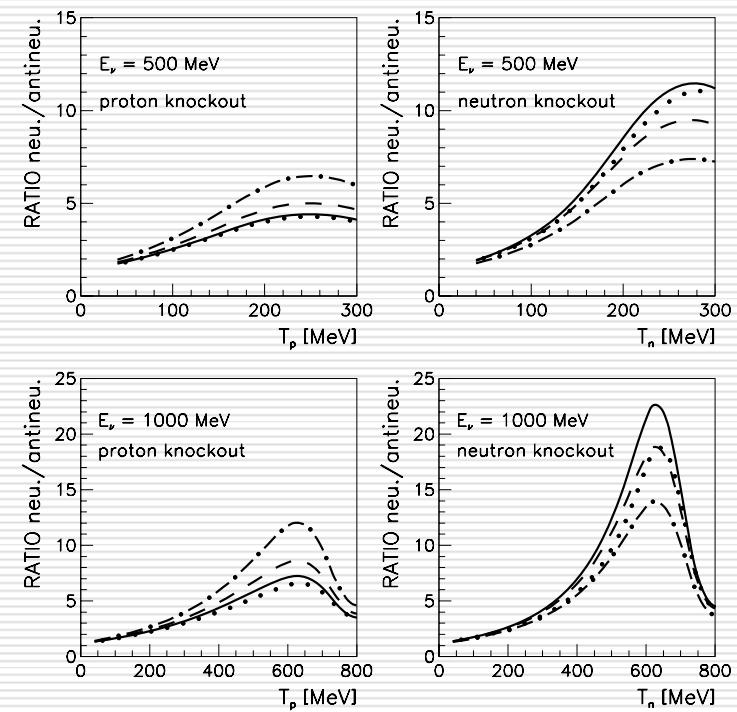
Quantità utili per studiare la stanezza

- misura di sezione d'urto difficile
- rapporto $\nu/\bar{\nu}$ $R_{\nu/\bar{\nu}} = \frac{(d\sigma/dT_N)_\nu}{(d\sigma/dT_N)_{\bar{\nu}}}$ misura di $\bar{\nu}$
- rapporto p/n $R_{p/n} = \frac{(d\sigma/dT_p)_{\nu(\bar{\nu})}}{(d\sigma/dT_n)_{\nu(\bar{\nu})}}$ misura di $(d\sigma/dT_n)_{\nu(\bar{\nu})}$
- rapporto NC/CC $R_{NC/CC} = \frac{(d\sigma/dT_N)_{\nu(\bar{\nu})}^{NC}}{(d\sigma/dT_N)_{\nu(\bar{\nu})}^{CC}}$ **esperimento FINeSSE**
- asimmetria $\mathcal{A} = \frac{[(d\sigma/T_N)_\nu - (d\sigma/dT_N)_{\bar{\nu}}]^{NC}}{[(d\sigma/dT_N)_\nu - (d\sigma/dT_N)_{\bar{\nu}}]^{CC}}$ misura di $\bar{\nu}$

Neutrino/antineutrino

- dashed no stranezza
- solid $g_A^S = -0.10$
- dot-dashed $g_A^S = -0.10$ e $\mu^S = -0.50$
- dotted $g_A^S = -0.10$ e $\rho^S = +2.0$

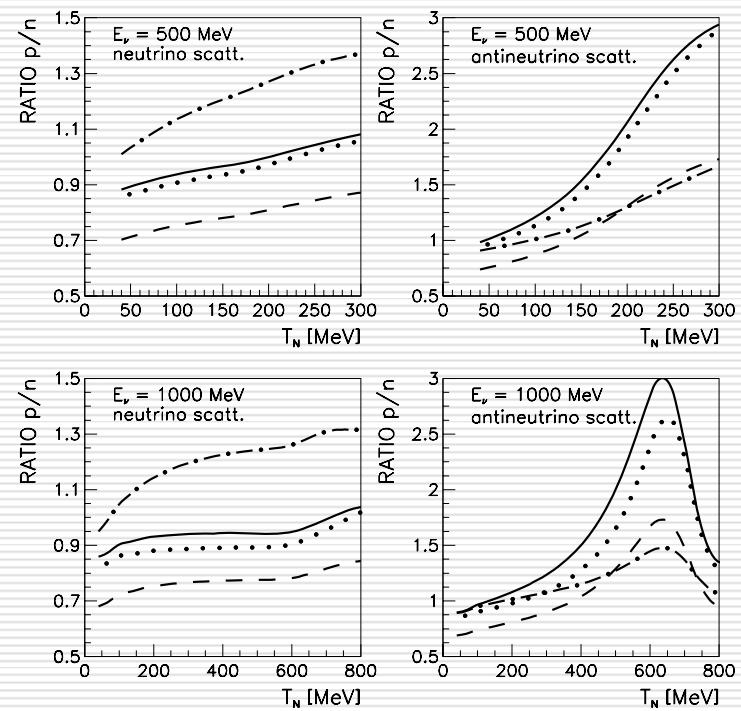
A. Meucci, C. Giusti, F.D. Pacati,
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Rapporto p/n

- dashed no stranezza
- solid $g_A^s = -0.10$
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- dotted $g_A^s = -0.10$ e $\rho^s = +2.0$

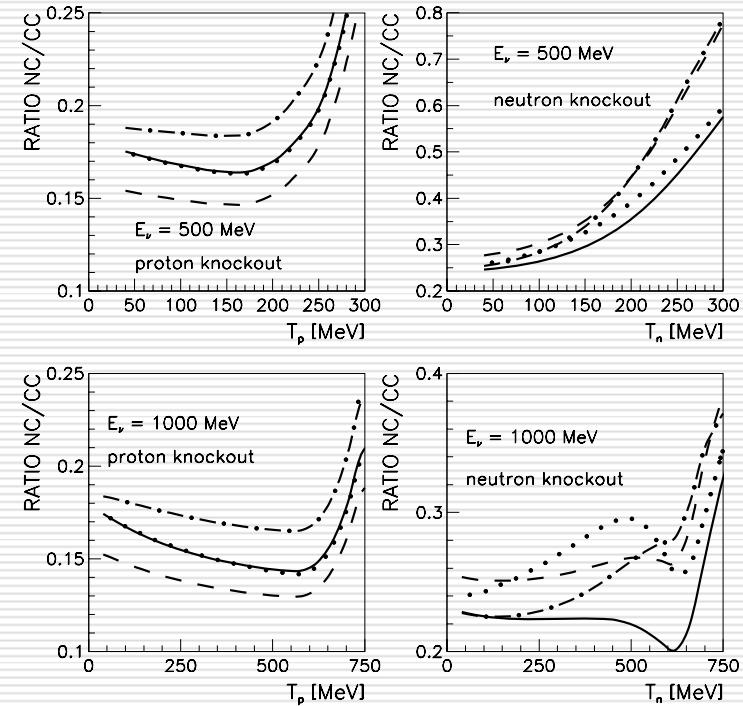
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Rapporto NC/CC

- dashed no stranezza
- solid $g_A^s = -0.10$
- dot-dashed $g_A^s = -0.10$ e $\mu^s = -0.50$
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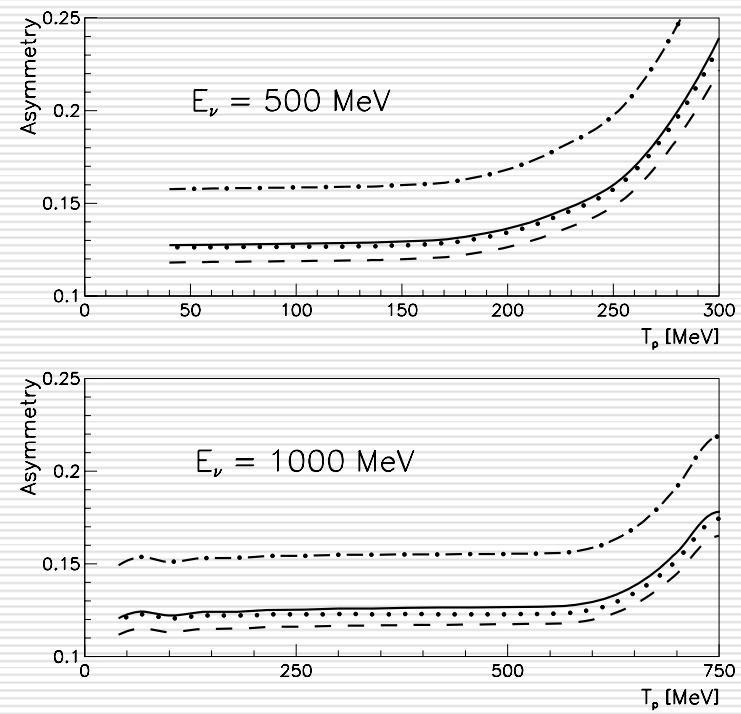
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Asimmetria

- dashed no stranezza
- solid $g_A^s = -0.10$
- dot-dashed $g_A^s = -0.10$ e $\mu^s = -0.50$
- dotted $g_A^s = -0.10$ e $\rho^s = +2.0$

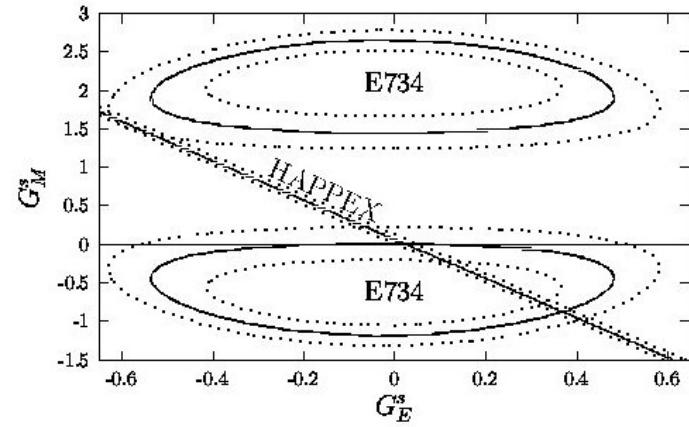
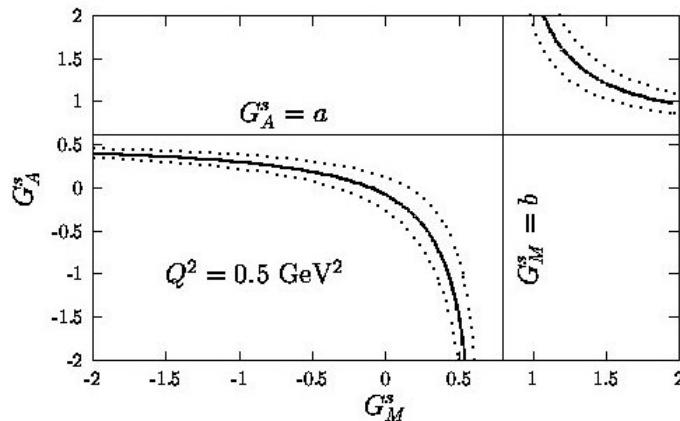
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Esperimenti con i neutrini

- BNL E734 @ Brookhaven → scattering νp e $\bar{\nu} p$ nel range $0.45 \leq Q^2 \leq 1.05 (\text{GeV}/c)^2$ → ha suscitato molto interesse ma precisione e sensibilità limitate impediscono di trarre conclusioni certe
- FINeSSE @ FermiLab → $E_\nu = 500 - 1000 \text{ MeV}$
- parte del programma BooNE (oscillazioni di neutrino)
- misura di $R_{\text{NC/CC}}$ ed estrazione di g_A^s nel range $0.25 \leq Q^2 \leq 0.75 (\text{GeV}/c)^2$
- fascio di ν e $\bar{\nu}$

Determinazione dei fattori di forma strani



- 2 soluzioni per i fattori di forma strani a $Q^2 = 0.5 \text{ GeV}^2$ ottenute dai dati di E734 (νp e $\bar{\nu} p$) e HAPPEX-1 ($\vec{e} p$)

Favorita la soluzione 1 anche se G_E^s e G_M^s sono compatibili con 0

S. Pate,
Phys. Rev. Lett. 92 (2004) 082002

	soluzione 1	soluzione 2
G_E^s	0.02 ± 0.09	0.37 ± 0.04
G_M^s	0.00 ± 0.21	-0.87 ± 0.11
G_A^s	-0.09 ± 0.05	0.28 ± 0.10

Determinazione dei fattori di forma strani

- se usiamo anche i dati di G0 ($\vec{e}p$)  indicazione circa l'andamento di G_E^s , G_M^s e G_A^s nel range $0.45 \leq Q^2 \leq 1.05 \text{ GeV}^2$
- incertezza tipica dell'ordine del 20-25% a causa dei dati di (νp e $\bar{\nu}p$)
- esperimento FINeSSE

S. Pate, *et al.*, hep-ex/0512032

