Recent Soft-core Baryon-baryon Interactions

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Recent Soft-core NN, YN, and YY Interactions

I. Introduction: Channels, Chiral-QM and QCD, LE-physics, OBE- and ESC-models, Motivation

II. Modeling-strategy and Theoretical framework Momentum- and Coordinate Space

III. ESC02/03: Extended Soft-Core model
   a. OBE-contents, χ^2, phases, etc.
   b. Two-Meson-Exchange: ps-ps exchange
   c. Meson-Pair-Exchange: duality, heavy-meson-dominance, chiral EFT's
   d. Results Nucleon-Nucleon
   e. Interpretation CC's in QPC-model
   f. Propagators, form factors $\Leftrightarrow$ χPT

IV. a. Extension: $YN, \Xi N, YY$-channels
   b. Results YN: phases, well-depth's etc.
   c. Results YY: $\Lambda\Lambda$-system etc.

V. Conclusions and Prospects

Motivation for Improved Soft-core Models:

- NN Partial Wave Analysis:
  Nijmegen Multi-Energy PWA 1993 etc.
  (Stoks et al, Phys.Rev. C48, 1993)
- Nucleon-Nucleon: χ^2-gap
- Study Physics for $r < 1.4$ fm
- (Hyper) Nuclear Structure:
  1. Few-Body computations, e.g. ^3H, $^3_\Lambda H$, $^4_\Lambda H$, $^3_\Lambda He$, $^4_\Lambda He$, $^5_\Lambda He$, and $^4_\Sigma He$, $^6_{\Lambda\Lambda}He$
  2. Finite (Hyper) Nuclei computations: Faddeev,ATMS, UMOA, etc.
  3. Many-Body systems: G-matrix approach, 'Realistic' shell-model computations
- New YN and YY data: KEK, BNL, TJNAL, and

in construction JHF:

JAERI-KEK project J-∅PARC(2008 !?)

- Flavor Nuclear Physics

Goal: High Quality BB-potentials

- 1. Implementation Concepts Hadron Physics:
  - a. $SU_f(3)$-symmetry, Breaking CC's?
  - b. Chiral-Symmetry, Nambu-Goldstone mode
  - c. QCD and Constituent Quarks ('NRQM')
  - d. CC's: Quark-Pair-Creation (QPC-$^3P_0$)
    CC's: QCD Sum Rules

- 2. Description NN, YN, YY scattering

- 3. Succes in Hypernuclei spectrocopy

- 4. Three-body forces $\leftrightarrow$ Two-body forces

- 5. BB-interactions $\leftrightarrow$ QQ-interactions

Contemporary Views on Low Energy Physics:

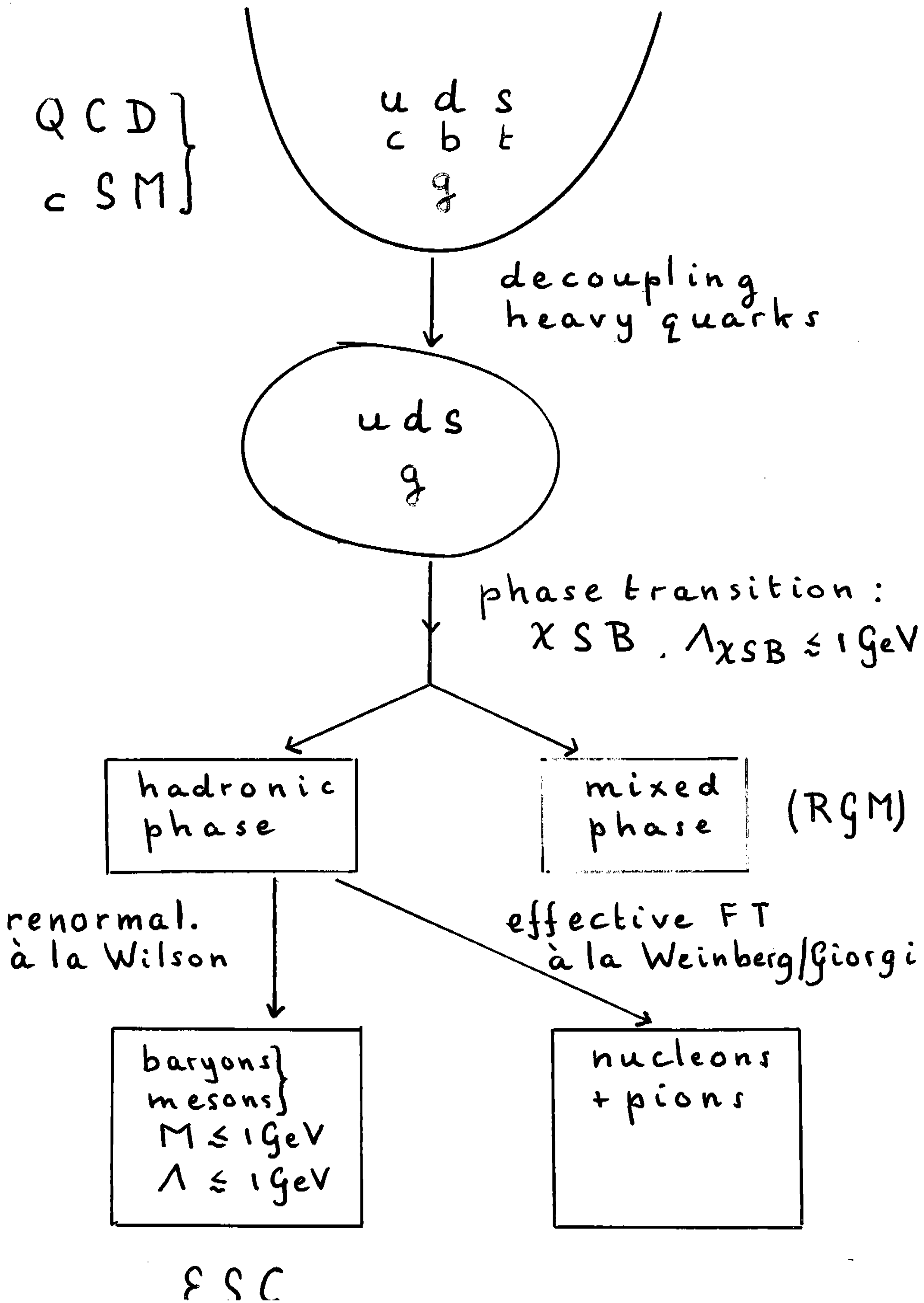
1. Wilson-scaling + Applequist-Carazzone decoupling
   Polchinsky, Nucl.Phys. 231 (1984)

2. Weinberg-Georgi Effective Field Theory
   Weinberg, Nucl.Phys. B363(1991)

3. Georgi-Manohar: Chiral-Quark model scenario
   Manohar and Georgi, Nucl.Phys. B234(1984)

4. Chiral Symmetry + asymptotics:
   -¿ constraints on πN etc.
   Weinberg, Phys.Rev. 177 (1969) 2604
   Harari & Gilman, Phys.Rev. 165 (1968) 1803

5. Effective Field Theory(EFT) $\Leftrightarrow$ ESC-model


QCD
cSM
u d s
c b t
g
decoupling
heavy quarks
u d s
g
phase transition :
χSB , $\Lambda_{\chi SB} \lesssim 1$ GeV
hadronic phase
mixed phase
(RGM)
renormal.
à la Wilson
effective FT
à la Weinberg/Giorgi
baryons
mesons
$M \lesssim 1$ GeV
$\Lambda \lesssim 1$ GeV
nucleons
+ pions
ESC

Soft-Core Interactions and Chiral-Quark-Model

- CQM: Manohar & Georgi, Nucl.Phys.B234 (1984).

$$\mathcal{L}_{QCD} = i\bar{\psi}_L\gamma \cdot D\psi_L + i\bar{\psi}_R\gamma \cdot D\psi_R - \bar{\psi}_L M\psi_R - \bar{\psi}_R M\psi_L$$

$$\psi_{L,R} = \begin{pmatrix} u \\ d \\ s \end{pmatrix}_{L,R} \quad , \quad M = \begin{pmatrix} m_u & & \\ & m_d & \\ & & m_s \end{pmatrix}$$

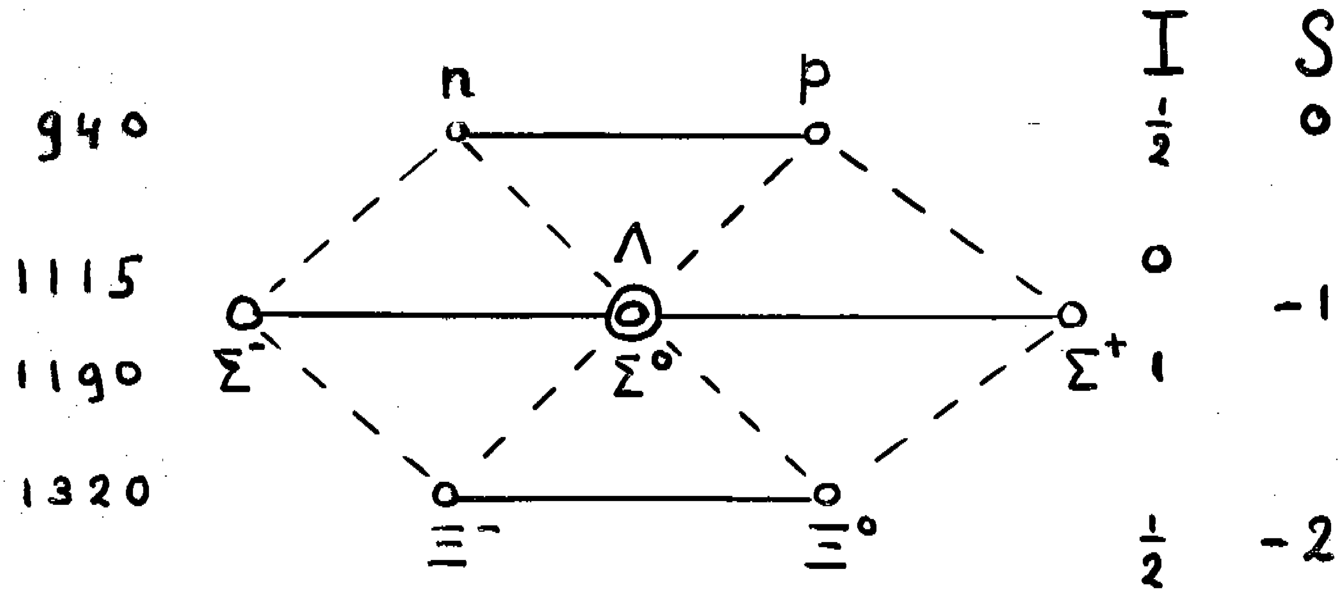
- QCD: 2 non-perturbative effects;
  (i) confinement ($\Lambda_{QCD} \approx 800$ MeV)
  (ii) Spontaneous CSB: NG-mode:
  $Q^2 \leq \Lambda_{\chi SB}$, large $\alpha_C \Rightarrow$ phase-transition: $\Lambda_{\chi SB} \approx 1$ GeV
  a) massless $Q\bar{Q}$-bound-states: NG-bosons
  b) $\langle\bar{\psi}\psi\rangle \neq 0 \;\Rightarrow$ constituent-quarks $m_Q \approx 300$ MeV
  c) $Q\bar{Q}$ (mesons), QQQ (baryons) bound-states,
  shielding strong α_c: color dipole-interactions.

- ?! Two-Phase $\Rightarrow$ Hybrid-model:
  Gluon $\oplus$ Meson-exchange between quarks !?

- $SU_f(3)$-symmetry: Quark Permutation
  symmetry S_3, ($m_u = m_d \approx m_s$).

• baryon-baryon systems

• $SU_F(3)$: baryon octet {8}



• 2-baryon channels

NN : pp , np , nn

YN : $\Sigma^+ p$, $\Sigma^- p \to \Sigma^- p$, $\Lambda p \to \Lambda p$

$\to \Sigma^0 n$ $\quad\quad$ $\to \Sigma^+ n$

$\to \Lambda n$ $\quad\quad$ $\to \Sigma^0 p$

ΞN : $\Xi^- p \to \Xi^- p$

YY $\quad \to \Lambda\Lambda, \Sigma\Sigma$

ΞΞ

Combined PW-analysis NN-, YN-, and YY-channels:

- realistic baryon-baryon potentials
- imposing (broken) $SU_F(3)$-symmetry
  constraints (broken) Chiral-symmetry
- determination $F/(F+D)$-ratio's α_{PV}, etc.
- determination BBM-coupling constants:

  $f_{\pi NN}, g_{\rho NN}, f_{\rho NN}, g_{\omega NN}$, etc.

  $f_{K\Lambda N}, g_{K\Sigma N}, g_{K^\star\Lambda N}, g_{K^\star\Sigma N}$, etc

---

Strategy:

- NN-fit ↑ pp+np : 4300 data

  ↕ $SU_f(3)$ + (short range assumptions)

- YN-fit $\Sigma^\pm p, \Lambda p$: 35 data

  ↓ $SU_f(3) + \ldots$

- YY-predictions $\Lambda\Lambda, \Xi N, \Sigma\Sigma$: $\Delta B_{\Lambda\Lambda}$

- Goal: BB-interactions ⇔ QQ-interactions !?

ESC02/03: Soft-core $NN + YN + YY$ ESC-model

- modified PRD17 (1978) , PRC40 (1989)
- NN: 20 free parameters: couplings, cut-off's, meson mixing and F/(F+D)-ratio's
- meson nonets:

$J^P = 0^-$ π, η, η', K

$= 1^-$ $\rho, \omega, \phi, K^\star$

$= 0^+$ $a_0(962), f_0(760), f_0(993), \kappa_1(900)$

$= 1^+$ $a_1(1270), f_1(1285), f_1(1460), K_1(1430)$

- gaussian form factors, $exp(-\mathbf{k}^2/2\Lambda^2_{B'BM})$
- pomeron exchange $\Leftrightarrow$ multi-gluon / pion exch.

- soft TPS: two-pseudo-scalar exchanges,
- soft MPE: meson-pair exchanges,

$\pi \otimes \pi$, $\pi \otimes \rho$, $\pi \otimes \epsilon$, $\pi \otimes \omega$, etc.

- Data fit:

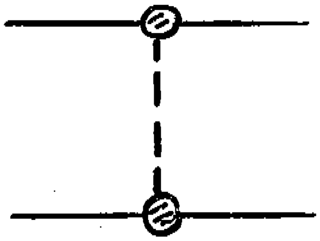
1. Nucleon-nucleon:

   Nijmegen PSA (1993), pp + np

   4301 data, $\chi^2_{dpt} = 1.11(!)$

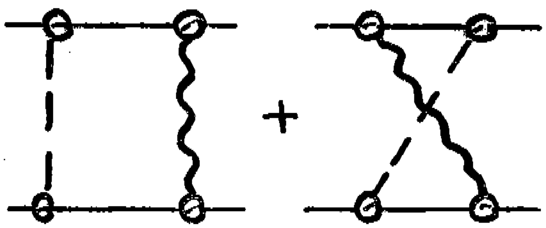
BB-interactions in the ESC-model:

One-Boson-Exchanges:



pseudo-scalar	π	K	η	η'
vector	ρ	K^*	ϕ	ω
scalar	δ	κ	S^*	ϵ
diffractive	~~A_2~~	~~K^{**}~~	~~f~~	P

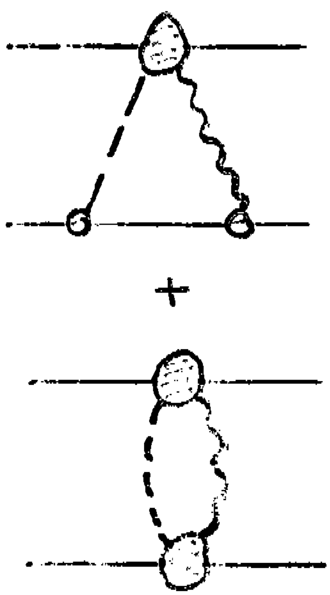
Two-Meson-Exchanges:



$$\begin{pmatrix} \pi \\ K \\ \eta \\ \eta' \end{pmatrix} \otimes$$

~~π~~	~~K~~	~~η~~	~~η'~~
ρ	K^*	ϕ	~~ω~~
δ	~~κ~~	~~S^*~~	ϵ
~~A_2~~	K^{**}	f	P

Meson-Pair-Exchanges:



$PP\widehat{S}_{\{1\}}$: $\pi\pi,\ K\bar{K},\ \eta\eta$

$PP\widehat{S}_{\{8\}_s}$: $\pi\eta,\ K\bar{K},\ \pi\pi,\ \eta\eta$

$PP\widehat{V}_{\{8\}_a}$: $\pi\pi,\ K\bar{K},\ \pi K,\ \eta K$

$PV\widehat{A}_{\{8\}_a}$: $\pi\rho,\ KK^*,\ K\rho,\ \ldots$

$PS\widehat{A}_{\{8\}}$: π~~ϕ~~ (ε), K~~ϕ~~ (ε), η~~ϕ~~ (ε)

Phenomenological Meson Pair Interactions

1. $\underline{J^{PC} = 0^{++}}$: $\mathcal{H}_S = \frac{g_S}{m_\pi}\left(\bar{\psi}'\psi'\right)\left(\underline{\pi}\cdot\underline{\pi}\right)$

2. $\underline{J^{PC} = 1^{--}}$: $\mathcal{H}_V = \frac{g_V}{m_\pi^2}\left[\bar{\psi}'\gamma_\mu\underline{\tau}\psi' - \frac{(f/g)_V}{2M}\bar{\psi}'\sigma_{\mu\nu}\underline{\tau}\psi'\partial^\nu\right]\cdot$
$\cdot\left(\underline{\pi}\times\partial^\mu\underline{\pi}\right)$

3. $\underline{J^{PC} = 1^{++}}$: $\mathcal{H}_A = \frac{g_A}{m_\pi}\left(\bar{\psi}'\gamma_\mu\gamma_5\underline{\tau}\psi'\right)\left(\underline{\pi}\times\underline{\rho}^\mu\right)$

4. $\underline{J^{PC} = 1^{++}}$: $\mathcal{H}_{A'} = \frac{g_{A'}}{m_\pi^2}\left(\bar{\psi}'\gamma_\mu\gamma_5\underline{\tau}\psi'\right)\left(\sigma\partial^\mu\underline{\pi} - \underline{\pi}\partial^\mu\sigma\right)$

5. $\underline{J^{PC} = 1^{+-}}$: $\mathcal{H}_B = \frac{h_B}{m_\pi^2}\left(\bar{\psi}'\sigma_{\mu\nu}\gamma_5\psi'\right)\partial^\nu\left(\underline{\pi}\cdot\underline{\omega}^\mu\right)$

6. $\underline{J^{PC} = 2^{++}}$: $\mathcal{H}_T = \frac{g_T}{m_\pi^3}\left(\bar{\psi}'T_{\mu\nu}\psi'\right)\left(\partial^\mu\underline{\pi}\cdot\partial^\nu\underline{\pi}\right)$

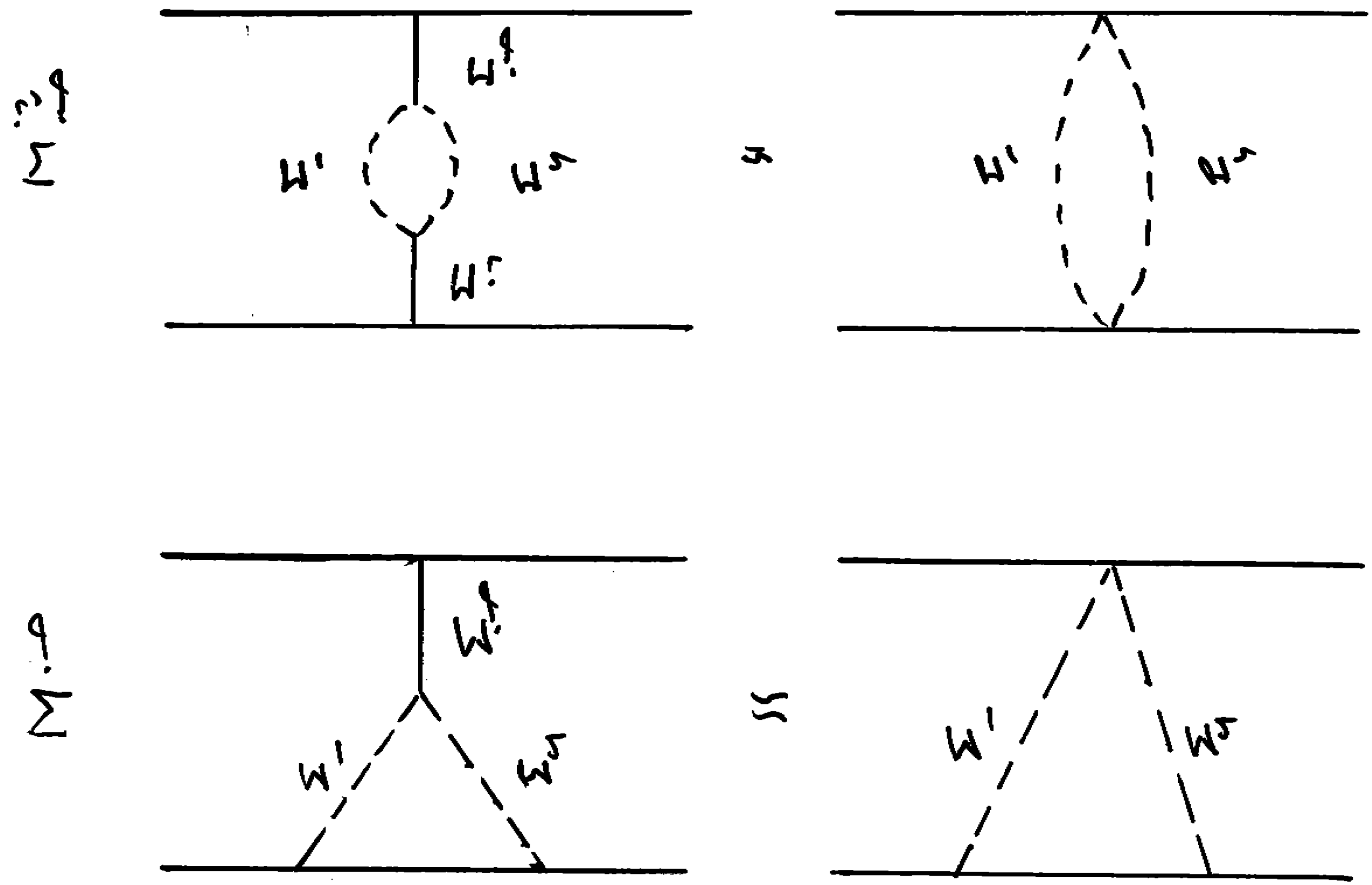
$$g_S = g_{(\pi\pi)_0},\quad g_P = g_{(\pi\sigma)_1}$$

$$g_V = f_{(\pi\pi)_1},\quad f_V = g_{(\pi\pi)_1}$$

etc.

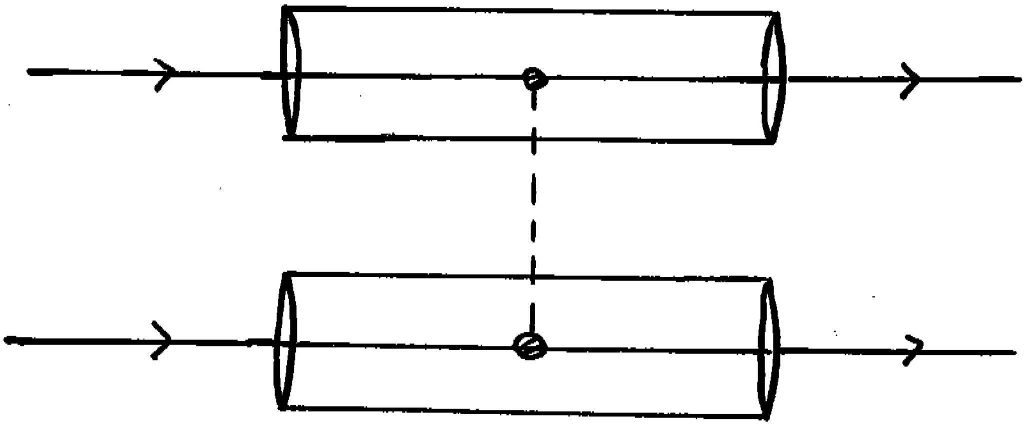
pair interactions

"freezing" heavy mesons ⇒



Nucleon Form Factors

- NRQM: pointlike, gaussian distributed quarks



- 3-quark wave function:

$$\tilde{\psi}_B(k_1, k_2, k_3) = \left(\frac{3R_B^2}{\pi}\right)^{3/2} \exp\left[-\frac{R_B^2}{6}\sum_{i<j}\left(\underline{k}_i - \underline{k}_j\right)^2\right]$$

- form factor $F(\Delta^2)$:

$$\tilde{V}(\Delta) \sim \frac{F(\Delta^2)}{\Delta^2 + m^2}, \quad \Delta = \underline{p}_1 - \underline{p}_2$$

$$F(\Delta^2) \Rightarrow \exp\left[-\frac{5}{42}R_B^2\Delta^2\right] \equiv \exp\left[-\frac{\Delta^2}{\Lambda^2}\right]$$

$$\Lambda = \left(\frac{5}{42}R_B^2\right)^{-1/2} \approx 2.9 R_B^{-1}$$

Quasi-potential Equation I

- Two-body Bethe-Salpeter equation:

$$\Psi(p^\mu) = \Phi(p^\mu) + G(P;p) \int d^4p' \; I(p,p') \; \Psi(p'^\mu)$$

- Klein-Macke-Salpeter scheme:
  1. Positive energy projection and p_0-inegration:

$$\phi_{++}(\mathbf{p}) = \Lambda_+^a(\mathbf{p})\Lambda_+^b(-\mathbf{p}) \int \frac{dp_0}{2\pi i}\Psi(p^\mu)$$

  2. Quasi-Potential integral equation wave function:

$$\begin{aligned}\phi_{++}(\mathbf{p}') &= \phi_{++}^{(0)}(\mathbf{p}') + E_2^{(+)}(\mathbf{p}';W) \cdot \\ &\times \int d^3p \; K^{irr}(\mathbf{p}',\mathbf{p}|W)\phi_{++}(\mathbf{p})\end{aligned}$$

  3. Green function:

$$E_2^{(+)}(\mathbf{p}';W) = \frac{1}{(2\pi)^3} \frac{\Lambda_+^a(\mathbf{p}')\Lambda_+^b(-\mathbf{p}')}{(W - 2E(\mathbf{p}') + i\delta)}$$

$\Rightarrow$ Klein-Macke-Thompson equation

$\Rightarrow$ Pair-suppression

Computational Methods

- coupled channel systems:

NN: $pp \to pp$, and $np \to np$

YN: a. $\Lambda p \to \Lambda p, \Sigma^0 p, \Sigma^+ n$
b. $\Sigma^- p \to \Sigma^- p, \Sigma^0 n, \Lambda n$
c. $\Sigma^+ p \to \Sigma^+ p$

YY: $\Lambda\Lambda \to \Lambda\Lambda, \Xi N, \Sigma\Sigma$

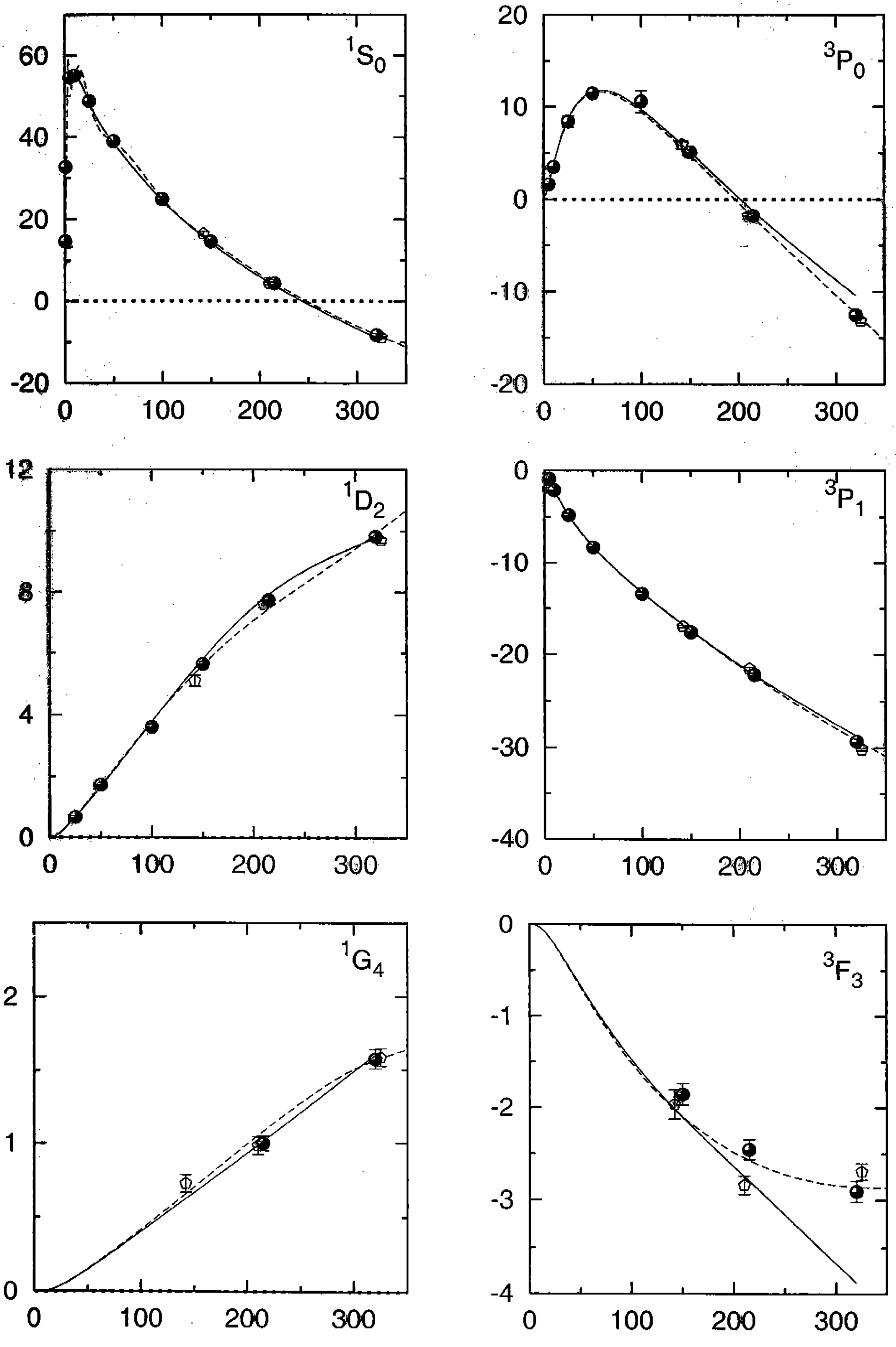
potential forms:

$$V(r) = \Big\{V_C + V_\sigma\ \underline{\sigma}_1 \cdot \underline{\sigma}_2 + V_T\ S_{12} + V_{SO}\ \underline{L} \cdot \underline{S} + V_{ASO}\ \frac{1}{2}(\underline{\sigma}_1 - \underline{\sigma}_2) \cdot \underline{L} + V_Q\ Q_{12}\Big\} P$$

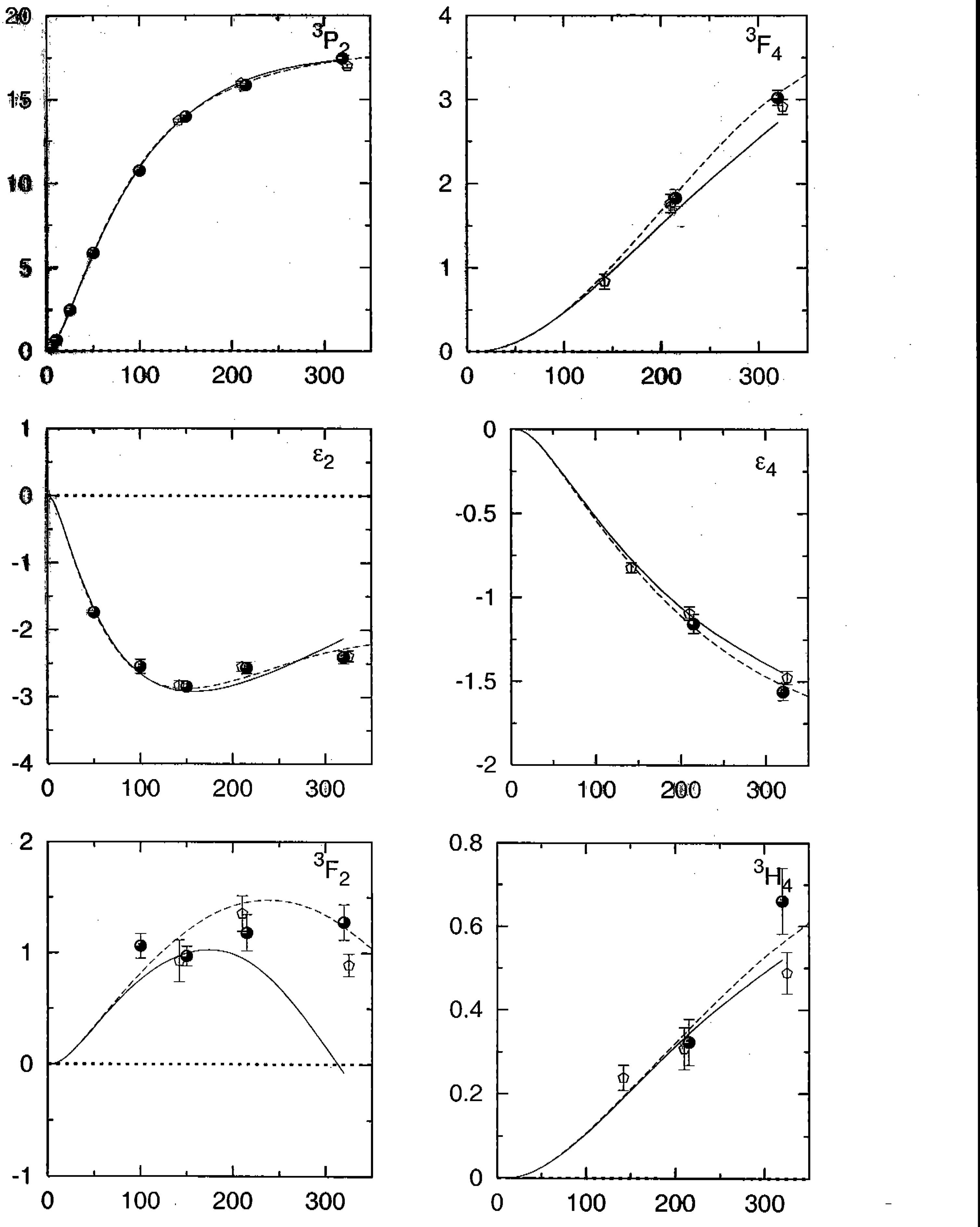
- many-channel Schrödinger equation: $H\Psi = E\Psi$

$$H = -\frac{1}{2m_{red}}\underline{\nabla}^2 + V(r) - \left(\underline{\nabla}^2 \frac{\phi}{2m_{red}} + \frac{\phi}{2m_{red}}\underline{\nabla}^2\right) + M$$

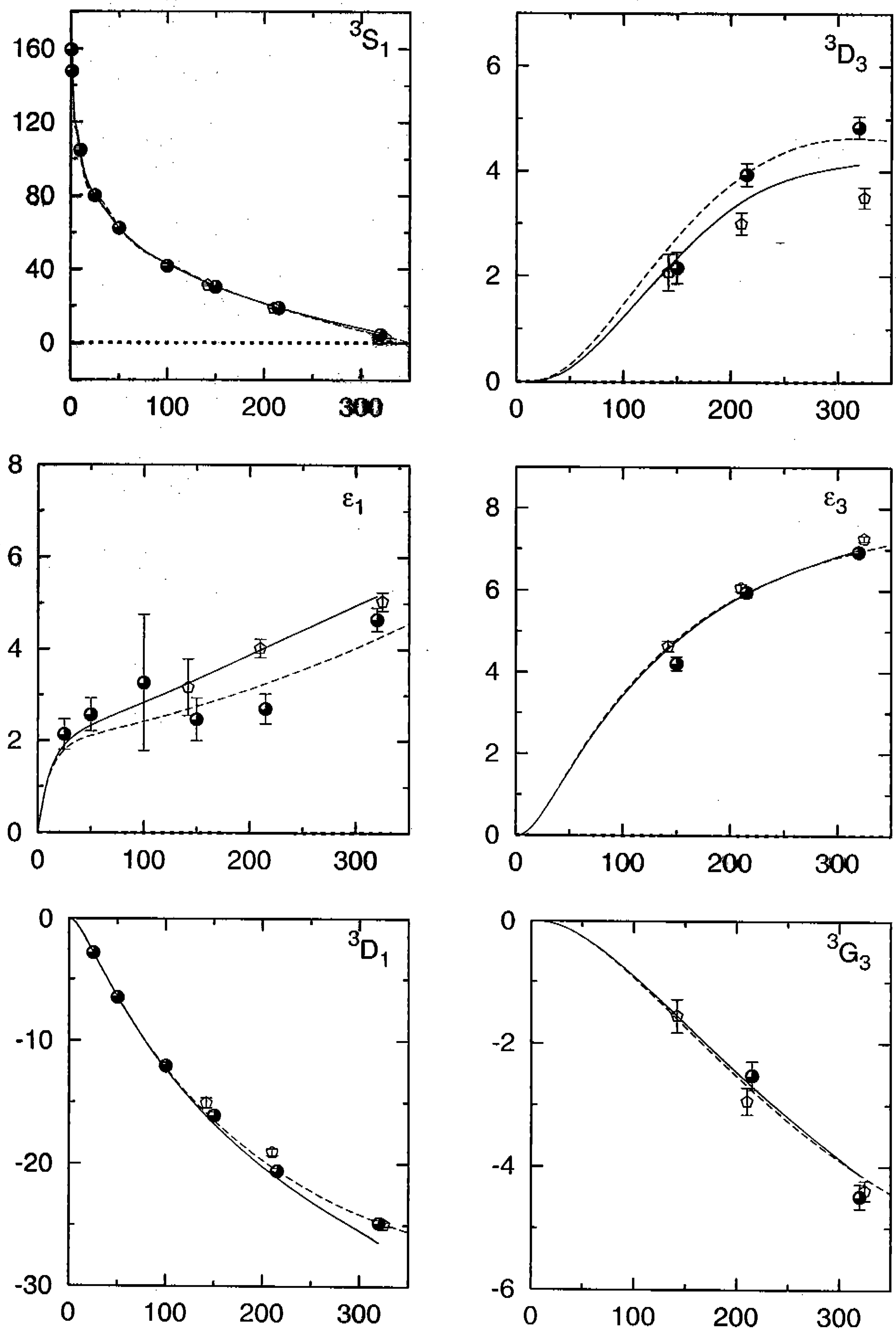
- $\phi(r)$: from (non-local) $\underline{q}^2$- terms



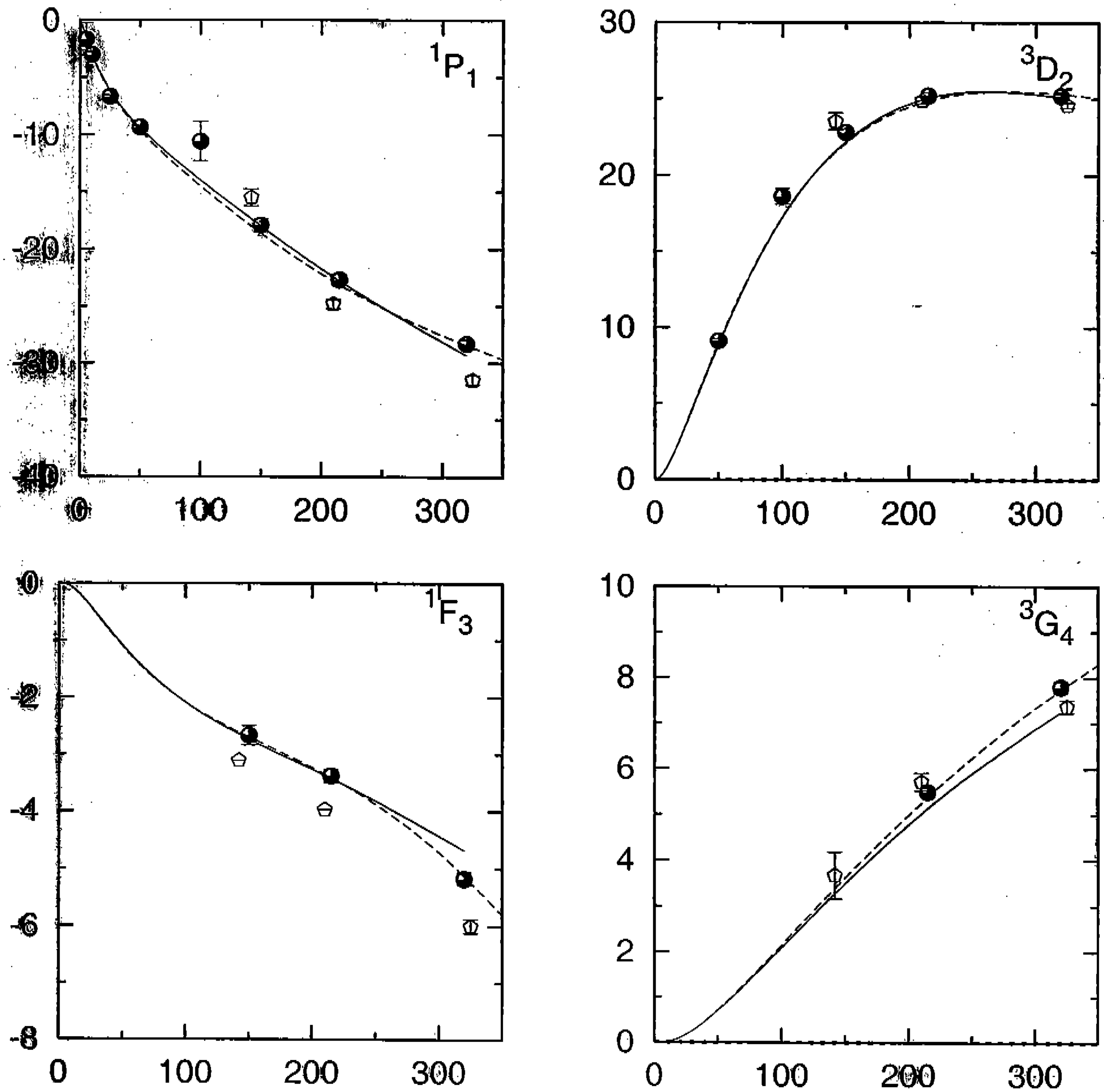
1S0
3P0
1D2
3P1
1G4
3F3
60
40
20
0
-20
10
-10
12
8
4
-30
-40
2
1
-1
-2
-3
-4
100
200
300



$^3P_2$
$^3F_4$
ε_2
ε_4
$^3F_2$
$^3H_4$
0
100
200
300



$^3S_1$
$^3D_3$
ε_1
ε_3
$^3D_1$
$^3G_3$



$^1P_1$
0
-10
-20
-30
-40
0
100
200
300
$^3D_2$
30
20
10
0
0
100
200
300
$^1F_3$
0
-2
-4
-6
-8
0
100
200
300
$^3G_4$
10
8
6
4
2
0
0
100
200
300

χ^2-distribution PSA93 and ESC02/03-model:

T_{lab}	#data	χ_0^2	$\Delta\chi^2$	$\hat{\chi}_0^2$	$\Delta\hat{\chi}^2$
0.383	144	137.55	14.0	0.960	0.098
1	68	38.02	41.9	0.560	0.617
5	103	82.23	14.3	0.800	0.139
10	209	257.99	33.9	1.234	0.117
25	352	272.20	36.7	0.773	0.104
50	572	547.67	113.3	0.957	0.198
100	399	382.45	32.2	0.959	0.081
150	676	673.05	74.3	0.996	0.110
215	756	754.52	115.8	0.998	0.153
320	954	945.38	233.3	0.991	0.244
Total	4233	4091.12	709.5	0.948	0.163

- χ_0^2: χ^2 PSA93, $\hat{\chi}_0^2$: χ^2_{pdpt} PSA93,

  The χ^2-access ESC02-model is denoted by $\Delta\chi^2$ and $\hat{\chi}^2$, respectively.

NN ESC02-model †:

Coupling constants, $F/(F+D)$-ratio's, mixing angles.

mesons		{1}	{8}	$F/(F+D)$
pseudoscalar	f	0.222	0.265	$\alpha_{PV} = \underline{0.355}$
vector	g	$\underline{2.778}$	$\underline{0.865}$	$\alpha_V^e = \underline{1.0}$
	f	-0.59	3.432	$\alpha_V^m = \underline{0.275}$
scalar	g	$\underline{2.567}$	$\underline{0.834}$	$\alpha_S = -0.906$
axial	g	-0.897	$\underline{2.843}$	$\alpha_A = 0.168$
diffractive	g	$\underline{2.628}$	0.000	$\alpha_D = 0.25$

$\Lambda_P = 852.0$MeV, $\Lambda_V = 902.0$, $\Lambda_S = 971.8$MeV
$\Lambda_P = 1370.4$MeV, $\Lambda_V = 1007.7$, $\Lambda_S = 1211.4$MeV

$\theta_P = -23.00^o$ ⋆), $\theta_V = 37.50^0$ ⋆)
$\theta_S = -10.485^o$, $\psi_D = 0.0^0$ ⋆)
$\underline{a_{PV} = 1.06}$ (!) Scalar mesons: zero in FF (!)

ESC-model 2002:

Pair Coupling Constants.

$g_{(\pi\pi)_0} = -0.002$	$g_{(\pi\pi)_1} = +0.028$	$f_{(\pi\pi)_1} = 0.025$
$g_{(\pi\eta)_1} = -0.424$	$g_{(\pi\rho)_1} = \underline{+0.635}$	$g_{(\pi\omega)_1} = -0.108$
$g_{(\pi\sigma)_1} = 0.148$	$g_{(\sigma\sigma)_0} = 0.0$	$g_{(\pi P)_1} = 0.000$

- $F/(F+D)$-ratio pair-couplings:

$$\alpha_V^e[(\pi\pi)_1] = \underline{0.85}, \quad \alpha_V^m[(\pi\pi)_1] = -0.921,$$
$$\alpha[(\pi\rho)_1] = 0.048, \quad \alpha[(\pi\eta)_1] = \underline{1.10},$$
$$\alpha[(\pi\omega)_1] = 0.168.$$

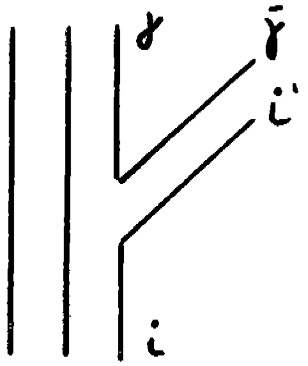
Meson-Baryon Couplings from $^3P_0$- Mechanism

$^3P_0$ Interaction Lagrangian:

$$\mathcal{L}_I = \gamma \underbrace{\left(\sum_i \bar{q}_i \; q_i \right)}_{} \cdot \underbrace{\left(\sum_j \bar{q}_j \; q_j \right)}_{}$$

Fierz Transformation

$$\begin{aligned}\mathcal{L}_I \;=\; -\frac{\gamma}{4} \sum_{i,j} \Big[&+ \; \bar{q}_i \; q_j \cdot \bar{q}_i \; q_j \\ &+ \; \bar{q}_i \gamma_\mu q_j \cdot \bar{q}_j \gamma^\mu q_i \\ &- \frac{1}{2} \; \bar{q}_i \sigma_{\mu\nu} q_j \cdot \bar{q}_j \sigma^{\mu\nu} q_i \\ &- \; \bar{q}_i \gamma_\mu \gamma_5 q_j \cdot \bar{q}_j \gamma^\mu \gamma^5 q_i \\ &+ \; \bar{q}_i \gamma_5 q_j \cdot \bar{q}_j \gamma^5 q_i \Big]\end{aligned}$$

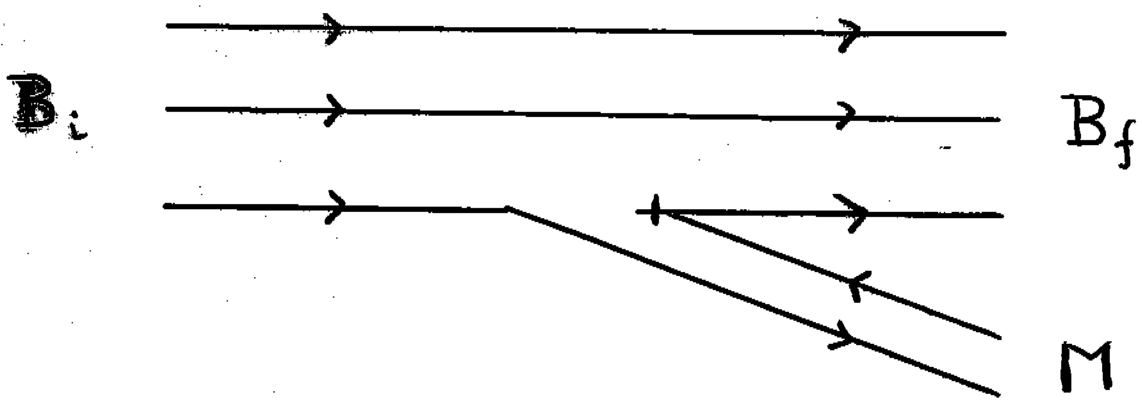


1. $\underline{g_\epsilon = g_\omega}$, and $\underline{g_{a_0} = g_\rho}$!?

2. What about f_π , g_{a_1}, etc. ?

$$\langle N \pi \,|\, \mathcal{L}_I \,|\, N \rangle \sim \langle N \,|\, \Gamma_\pi \,|\, N \rangle \langle \pi \,|\, \Gamma_\pi \,|\, 0 \rangle$$

QPC: $^3P_0$-Model NN-Couplings Predictions



$$g_{BBM}(\mp) = \gamma_M \left(\frac{4\pi}{9}\right)^{1/4} X_M\left(I_M, L_M, S_M, J_M\right)\ F_M^{(\mp)}$$

$$F^{(-)} = (m_M R_M)^{3/2} \left(\frac{3R_B^2}{3R_B^2 + R_M^2}\right)\left(\frac{4R_B^2 + R_M^2}{3R_B^2 + R_M^2}\right)$$

- $\rho \to e^+e^-$: C.F.Identity & V.Royen-Weisskopf:

$$f_\rho = \frac{m_\rho^{3/2}}{\sqrt{2}|\psi_\rho(0)|} \Leftrightarrow \gamma \left(\frac{2}{3\pi}\right)^{1/2} \frac{m_\rho^{3/2}}{|\psi_\rho(0)|} \rightarrow$$

$$\gamma = \frac{1}{2}\sqrt{3\pi} = 1.535.$$

- QPC (Quark-Pair-Creation) Model:
- Micu(1969), Carlitz & Kissinger(1970)
- Le Yaouanc et al(1973,1975)

ESC02/03 Couplings and $^3P_0$-Model Relations

Meson	$r_M[fm]$	X_M	γ_M	$^3P_0$	ESC
$\pi(140)$	0.56	5/6	4.19*	$f = 0.27$	0.27
				$g = 3.67$	3.67
$\rho(770)$	0.56	1/2	1.53	$g = 0.78$	0.87
$\omega(783)$	0.56	3/2	1.53	$g = 2.40$	3.12
$a_0(962)$	0.56	$\sqrt{3}/2$	1.53	$g = 0.79$	0.83
$\epsilon(760)$	0.56	$3\sqrt{3}/2$	1.53	$g = 2.11$	2.57
$a_1(1270)$	0.56	$3\sqrt{3}/2$	1.53	$g = 2.73$	2.84

- QPC: $^3P_0$-model relations: "bare" couplings (!)

$$g_\omega = 3g_\rho, \quad g_\epsilon = 3g_{a_0}, \quad g_{a_0} \approx g_\rho, \quad g_\epsilon \approx g_\omega$$

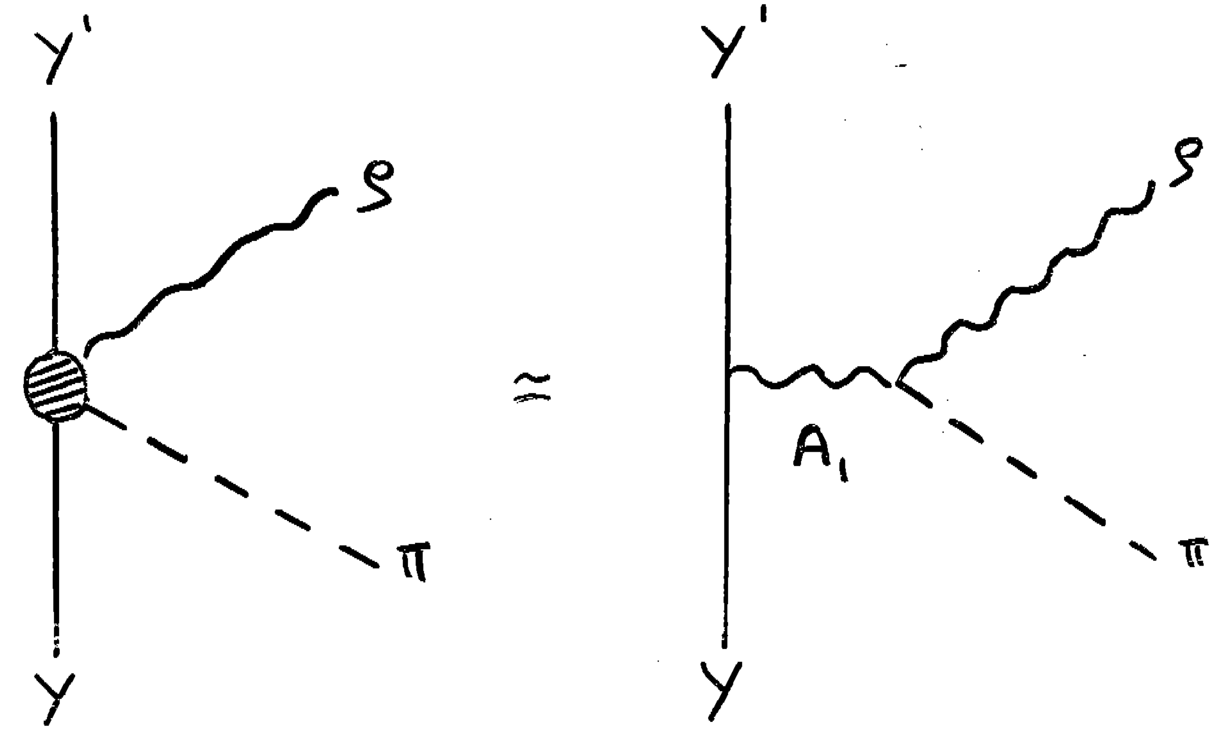
$$\varepsilon_0(\lambda) \sim \bar{q}q(^3P_0) \quad \varepsilon_a(\lambda) \sim \bar{q}q(^3S_1)$$

$$f_{NNa_1} \approx \frac{m_{a_1}}{m_\pi} f_{NN\pi} \text{ (CS, Schwinger67)}$$

* $\gamma = 3.85$ ($\rho \to \pi\pi$, $\epsilon \to \pi\pi$)

VI. Extension ESC to Hyperon-Nucleon

- MPE: Boson-Dominance and VMD,
  Chiral Lagrangians:



$$g_{Y'Y(\rho\pi)_1} = \widehat{g}_{Y'YA_1} g_{A_1\rho\pi} \frac{m_\pi^2}{m_{A_1}^2} \text{, e.g.}$$

$$\begin{aligned} g_{\Sigma\Lambda(\rho\pi)_1} &= \widehat{g}_{\Sigma\Lambda A_1} g_{A_1\rho\pi} \frac{m_\pi^2}{m_{A_1}^2} \\ &= \left(\widehat{g}_{\Sigma\Lambda A_1}/\widehat{g}_{NNA_1}\right) \; g_{NN(\rho\pi)_1} \\ &= \frac{2}{\sqrt{3}}(1-\alpha_A)\, g_{NN(\rho\pi)_1} \end{aligned}$$

- <u>OBE, TME ⇒ $SU(3)$</u>

Pair Couplings and $SU_f(3)$-symmetry:

1. $SU(3)$-singlet couplings $S^\alpha_\beta = \delta^\alpha_\beta \sigma/\sqrt{3}$:

$$\mathcal{H}_{S_1PP} = \frac{g_{S_1PP}}{\sqrt{3}} \left\{ \boldsymbol{\pi}\cdot\boldsymbol{\pi} + K^\dagger K + K_c^\dagger K_c + \eta_8\eta_8 \right\} \cdot \sigma$$

2. $SU(3)$-octet symmetric couplings I, $S^\alpha_\beta = (S_8)^\alpha_\beta$:

$$\begin{aligned}\mathcal{H}_{S_8PP} &= \frac{g_{S_8PP}}{2\sqrt{6}} \Big\{ 2(\mathbf{a}_0\cdot\boldsymbol{\pi})\eta_8 + \sqrt{3}\mathbf{a}_0\cdot(K^\dagger\boldsymbol{\tau}K) \\ &+\sqrt{3}\left\{(K_0^\dagger\boldsymbol{\tau}K)\cdot\boldsymbol{\pi} + h.c.\right\} - \Big\{(K_0^\dagger K)\eta_8 \\ &+h.c.\Big\} + f_0\left(\boldsymbol{\pi}\cdot\boldsymbol{\pi} - K^\dagger K - \eta_8\eta_8\right) \Big\}\end{aligned}$$

3. $SU(3)$-octet symmetric couplings II, $S^\alpha_\beta = (B_8)^\alpha_\beta$:

$$\begin{aligned}\mathcal{H}_{B_8VP} &= \frac{g_{B_8VP}}{2\sqrt{6}} \Big\{ \left[\left(\mathbf{B}_1^\mu\cdot\boldsymbol{\rho}_\mu\right)\eta_8 + \left(\mathbf{B}_1^\mu\cdot\boldsymbol{\pi}_\mu\right)\phi_8\right] \\ &+\frac{\sqrt{3}}{2}\left[\mathbf{B}_1\cdot(K^{*\dagger}\boldsymbol{\tau}K) + h.c.\right] \\ &+\frac{\sqrt{3}}{2}\left[(K_1^\dagger\boldsymbol{\tau}K^*)\cdot\boldsymbol{\pi} + (K_1^\dagger\boldsymbol{\tau}K)\cdot\boldsymbol{\rho} + h.c.\right] \\ &-\frac{1}{2}\left[(K_1^\dagger\cdot K^*)\eta_8 + (K_1^\dagger\cdot K)\phi_8 + h.c.\right] \\ &+H^0\left[\boldsymbol{\rho}\cdot\boldsymbol{\pi} - \frac{1}{2}\left(K^{*\dagger}\cdot K + K^\dagger\cdot K^*\right) - \phi_8\eta_8\right]\end{aligned}$$

- $\sigma \equiv \bar{\Psi}'\Psi'$, $\underline{a}_0 \equiv \bar{\Psi}'\underline{\tau}\Psi'$, $\underline{B}_1^\mu \equiv \bar{\Psi}'\gamma_5\sigma^{\mu\nu}\partial_\nu\underline{\tau}\Psi'$, ..

Pair Couplings and $SU_f(3)$-symmetry (cont.):

4. $SU(3)$-octet a-symmetric couplings I, $A^\alpha_\beta = (V_8)^\alpha_\beta$:

$$\mathcal{H}_{V_8PP} = \frac{g_{A_8PP}}{2}\Big\{ \rho'_\mu \cdot \boldsymbol{\pi}\times \overleftrightarrow{\partial^\mu}\boldsymbol{\pi} + i\rho'_\mu \cdot (K^\dagger \boldsymbol{\tau}\overleftrightarrow{\partial^\mu} K) + \Big(iK^{*\dagger}_\mu \boldsymbol{\tau}(K\overleftrightarrow{\partial^\mu}\boldsymbol{\pi}) + h.c.\Big) + \sqrt{3}\Big(iK^{*\dagger}_\mu \cdot (K\cdot \overleftrightarrow{\partial^\mu}\eta_8) + h.c.\Big) + i\sqrt{3}\phi_\mu (K^\dagger \overleftrightarrow{\partial^\mu} K)\Big\}$$

5. $SU(3)$-octet a-symmetric couplings II, $A^\alpha_\beta = (A_8)^\alpha_\beta$:

$$\mathcal{H}_{A_8VP} = \frac{g_{A_8VP}}{2}\Big\{ 2\mathbf{A}_1\cdot\boldsymbol{\pi}\times\boldsymbol{\rho} + i\mathbf{A}_1\cdot\Big[(K^\dagger\boldsymbol{\tau}K^*) - h.c.\Big] + \Big(i\Big[(K^\dagger_A\boldsymbol{\rho}\cdot\boldsymbol{\tau}K) - (K^\dagger_A\boldsymbol{\pi}\cdot\boldsymbol{\tau}K^*)\Big] + h.c.\Big) + \sqrt{3}\Big(i\Big[(K^\dagger_A\cdot K)\phi_8 - (K^\dagger_A\cdot K^*)\eta_8\Big] + h.c.\Big) + i\sqrt{3}f_1\Big[K^\dagger\cdot K^* - K^{*\dagger}\cdot K\Big]\Big\}$$

- $\rho'_\mu = \bar{\Psi}'\gamma_\mu \tau \Psi'$, $A_{1\mu} = \bar{\Psi}'\gamma_5\gamma_\mu\tau\Psi'$, ..

Comparison NN ⊎ YN ⊎ YY NSC & ESC-models

Item	NSC97	ESC02	ESC03
axial mesons	no	yes	yes
zero scalar FF	no	yes	yes
CC's: QPC relations	no	yes	yes
CC's: $SU(3)$-breaking	yes	no	yes
CC's: QPC $SU(3)$-breaking	no	no	yes
α's: QPC $F/(F+D)$	no	no	yes

Comparison NN ⊎ YN ⊎ YY ESC-models 2002/2003

- OBE-couplings:

J^{PC}		ESC02	ESC03	QPC($^3P_0$)
0^{-+}	α_{PV}	0.355	0.40	0.40
1^{--}	α_V^e	1.0	1.0	1.0
1^{--}	α_V^m	0.275	0.44	—
0^{++}	α_S	-1.08	0.85	1.0
1^{++}	α_A	0.16	0.36	0.40

- PAIR-couplings:

J^{PC}		ESC02	ESC03	QPC($^3P_0$)
0^{-+}	α_{PV}	0.355	0.40	0.40
1^{--}	α_V^e	0.79	1.0	1.0
1^{--}	α_V^m	-1.02	0.275	—
0^{++}	α_S	1.10	1.0	1.0
1^{++}	α_A	0.07	0.40	0.40

YN + YY ESC-model 2003 †:

Coupling constants, $F/(F+D)$-ratio's, mixing angles

mesons		{1}	{8}	$F/(F+D)$
pseudoscalar	f	0.222	0.267	$\alpha_{PV} = \underline{0.40}$
vector	g	$\underline{2.903}$	$\underline{0.664}$	$\alpha_V^e = 1.0$
	f	-0.631	3.562	$\alpha_V^m = 0.42$
scalar	g	$\underline{2.219}$	$\underline{0.840}$	$\alpha_S = \underline{0.85}$
axial	g	-1.048	$\underline{2.992}$	$\alpha_A = \underline{0.36}$
diffractive	g	2.550	0.000	$\alpha_D = 1.0$

$\Lambda_P = 855.5\text{MeV}$, $\Lambda_V = 908.9$, $\Lambda_S = 967.7\text{MeV}$
$\Lambda_P = 1369.9\text{MeV}$, $\Lambda_V = 1008.4$, $\Lambda_S = 1214.2\text{MeV}$

$\theta_P = -23.00^o\ ^{\star)}$, $\theta_V = 37.50^0\ ^{\star)}$, $\theta_A = 47.3^0\ ^{\star)}$
$\theta_S = -16.921^o$, $\theta_D = 37.50^0\ ^{\star)}$, $\psi_D = 0.0^0\ ^{\star)}$
$a_{PV} = \underline{1.12}$ (!) Scalar mesons: <u>zero in FF</u> (!)

YN + YY ESC-model 2003 †:

Pair Coupling Constants.

$g_{(\pi\pi)_0}$	$=$	-0.002	$g_{(\pi\pi)_1}$	$=$	+0.080	$f_{(\pi\pi)_1}$	$=$	0.073
$g_{(\pi\eta)_1}$	$=$	-0.284	$g_{(\pi\rho)_1}$	$=$	+0.565	$g_{(\pi\omega)_1}$	$=$	-0.13
$g_{(\pi\sigma)_1}$	$=$	0.152	$g_{(\sigma\sigma)_0}$	$=$	0.0	$g_{(\pi P)_1}$	$=$	0.000

- $F/(F+D)$-ratio pair-couplings:

$$\left[\begin{array}{lclclcl} \alpha_V^e[(\pi\pi)_1] & = & 1.0 & \alpha_V^m[(\pi\pi)_1] & = & 0.275\ , \\ \alpha[(\pi\rho)_1] & = & 0.40 & \alpha[(\pi\eta)_1] & = & 1.0\ , \\ \alpha[(\pi\omega)_1] & = & 0.40 & & & \end{array}\right.$$

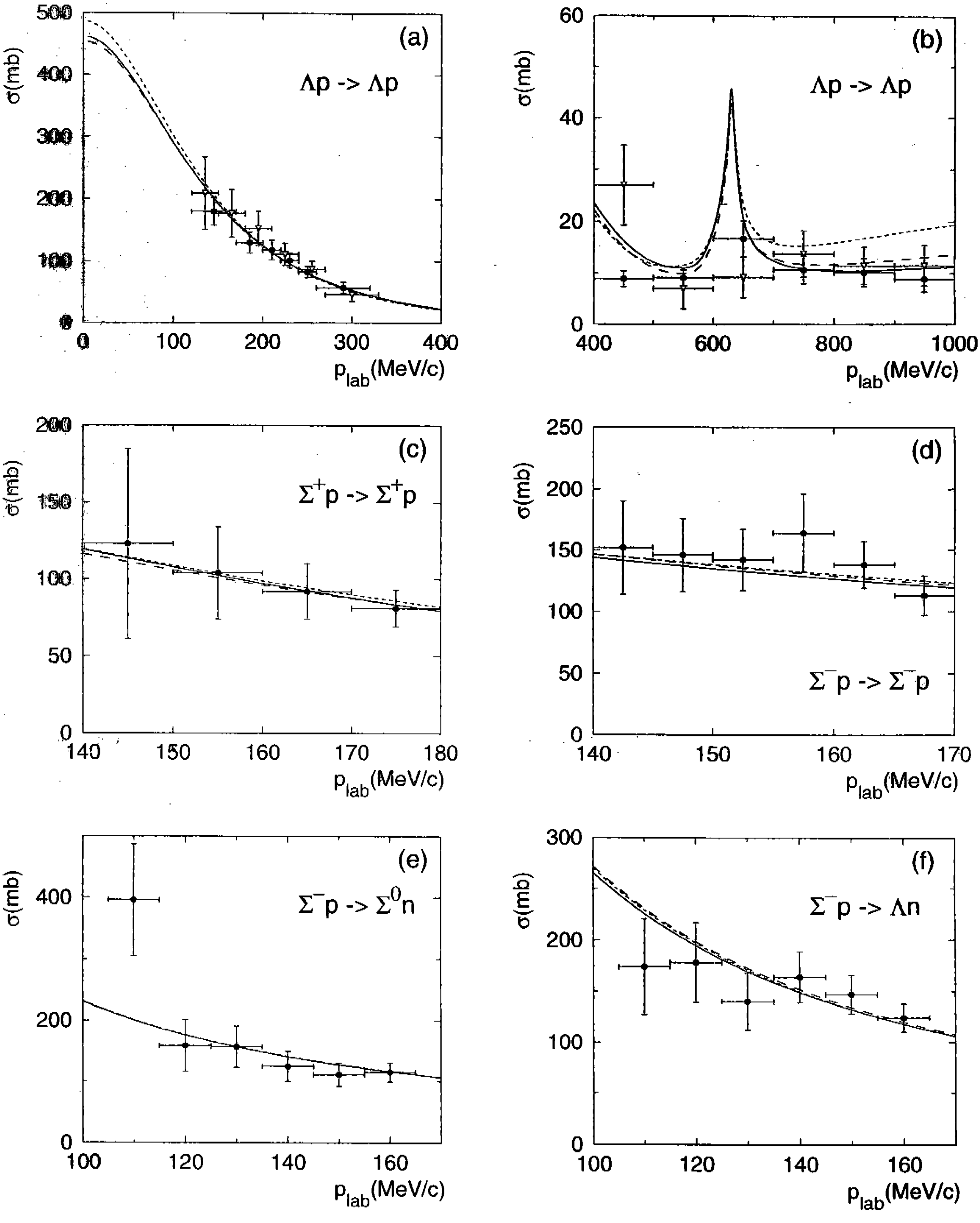
- $\Lambda_K = 900\text{MeV}$, $\Lambda_{K^*} = 908.9\text{MeV}$

- Constraints on YN-models:
  - (i) Consistent with NN + Broken $SU(3)$
  - (ii) No bound-states in any YN-channel
  - (iii) Fit to the existing YN-data:
    ($\Sigma^+ p, \Lambda p, \Sigma^- p$ cross sections).

- Free parameters:

  - (iv) OBE-models (NSC97a-e) :
    $\alpha_s,\ \theta_S(\alpha_S),\ \psi_D(\alpha_D)$
    $(\Lambda_\pi = \Lambda_\eta \neq \Lambda_K,\ \Lambda_\rho = \Lambda_\phi = \Lambda_{K^*},$
    $\Lambda_\delta = \Lambda_{f_0(975)} = \Lambda_\kappa!!)$
    $SU(3)$-breaking couplings $\Delta g(Y_8)_{P,V,S}$

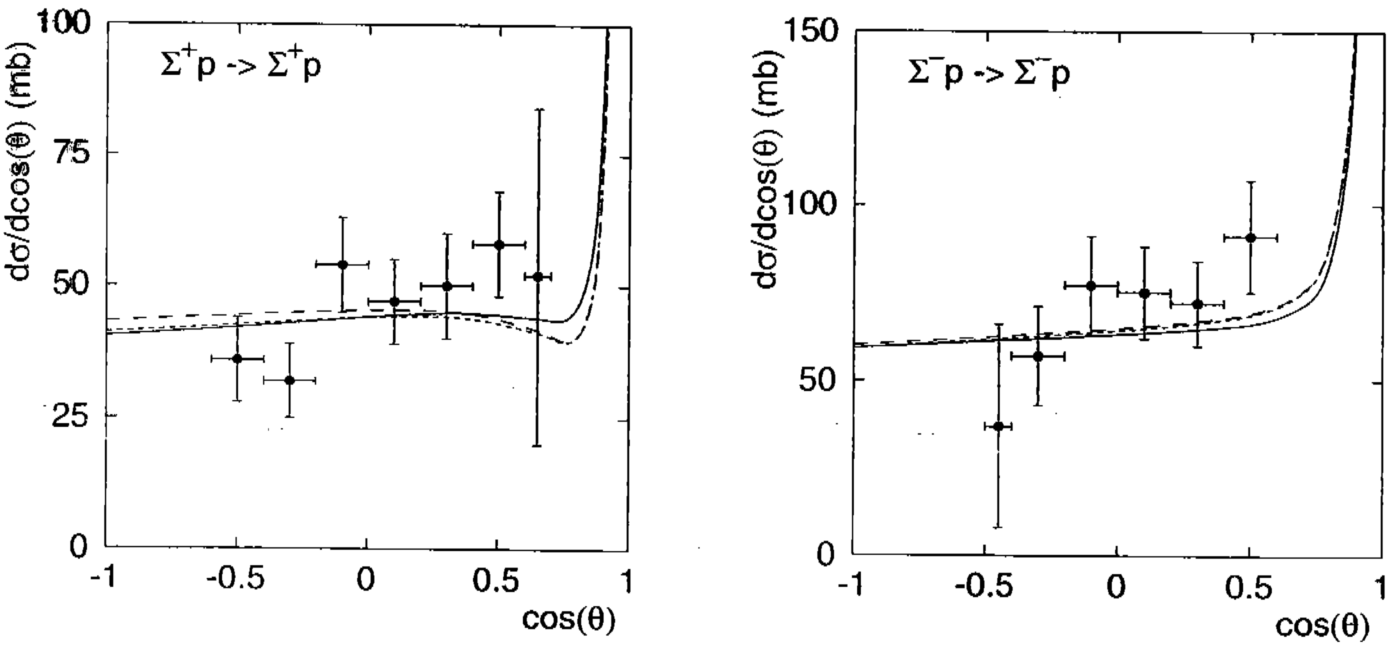
  - (v) ESC02/03-models :
    simultaneous NN + YN fit
    $(\Lambda_\pi \neq \Lambda_{\eta'} \neq \Lambda_K,\ \Lambda_\rho = \Lambda_{K^*} \neq \Lambda_\omega,$
    $\Lambda_\delta = \Lambda_\kappa \neq \Lambda_\epsilon)$
    ESC02: $SU(3)$-breaking couplings: no
    ESC03: $SU(3)$-breaking couplings: yes,
    a la QPC($^3P_0$), 1-parameter !



Rijken, Stoks, Yamamoto: Fig.2

$$\Sigma^- p \to \Sigma^0 n,\ \Lambda n : \qquad r_R = \frac{\Sigma^0}{\Sigma^0 + \Lambda}$$

$$r_R(\mathrm{exp}) = 0.468 \pm 0.010$$

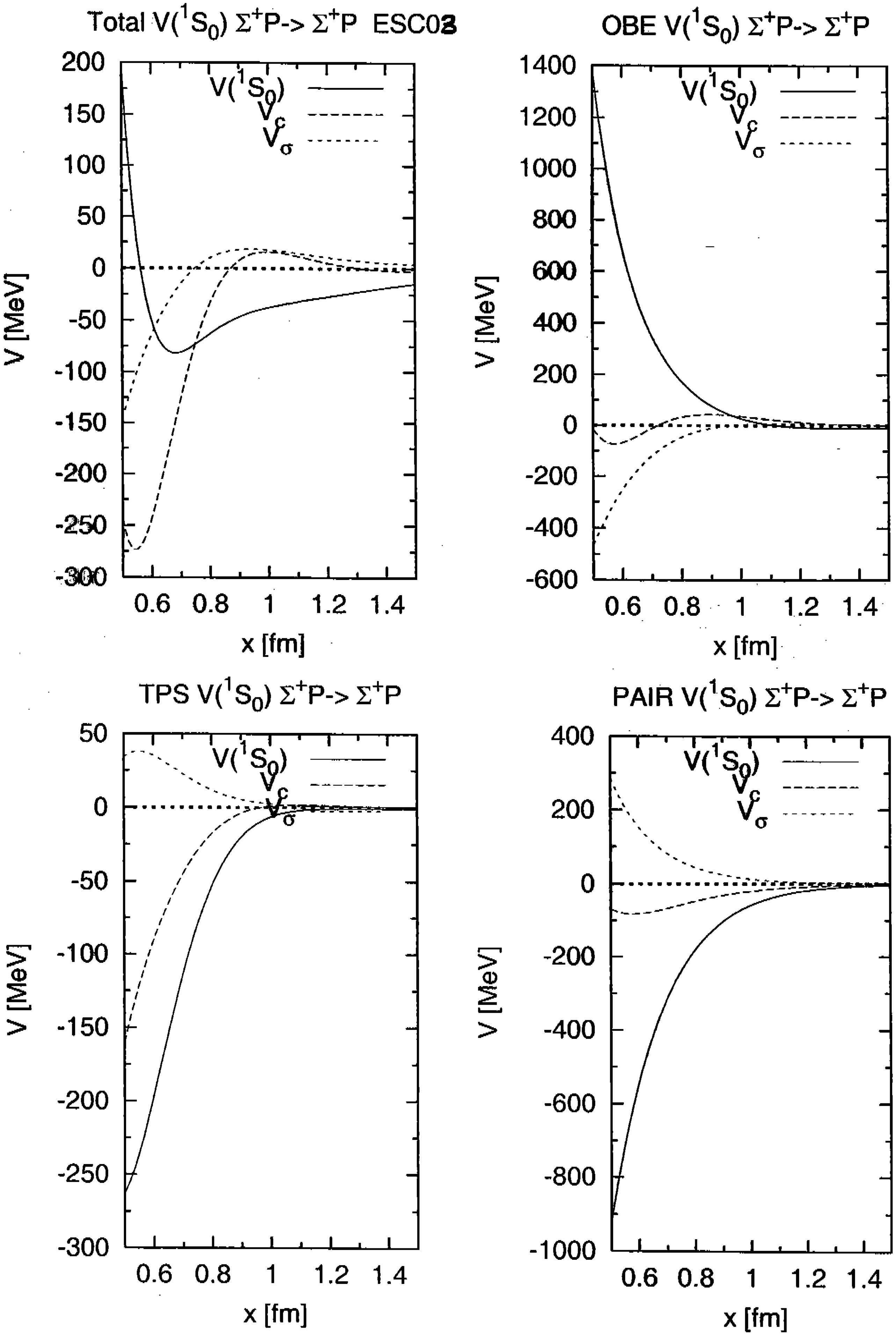


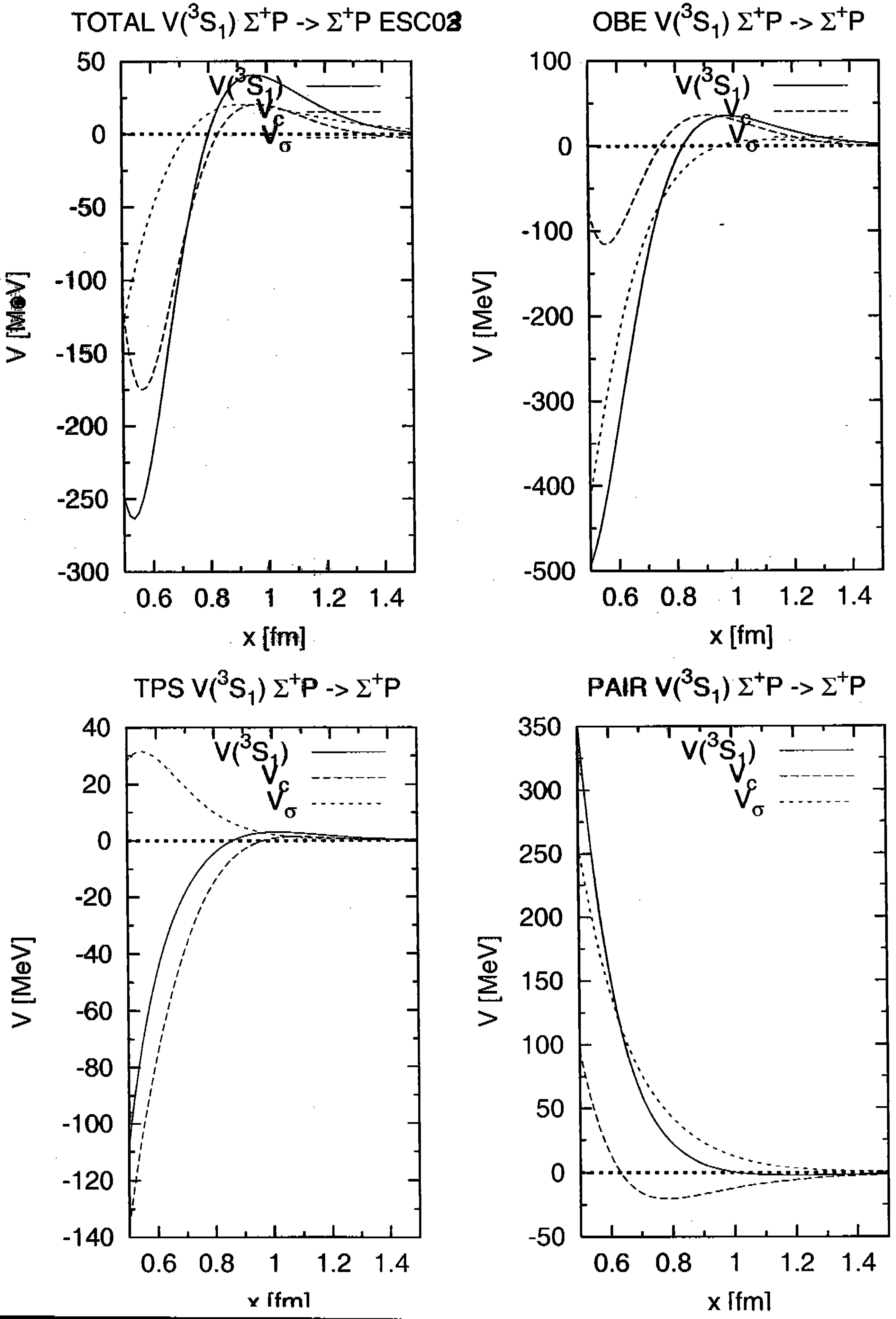
Rijken, Stoks, Yamamoto: Fig.3

ESC03 nuclear-bar Σ^+p phases in degrees:

p_{Σ^+}	200	400	600	800	1000
T_{lab}	16.7	65.5	142.8	244.0	364.5
$^1S_0$	32.90	20.91	4.80	-10.33	-23.90
$^3S_1$	17.81	21.48	17.94	12.85	6.74
ϵ_1	-2.17	-3.14	-1.15	1.55	3.65
$^3P_0$	5.45	10.99	5.40	-5.22	-16.91
$^1P_1$	3.60	14.72	22.45	22.59	18.44
$^3P_1$	-2.91	-8.73	-14.72	-20.75	-26.26
$^3P_2$	1.34	8.17	17.34	24.96	29.66
ϵ_2	-0.38	-1.89	-2.71	-1.99	-0.28
$^3D_1$	0.28	1.45	2.00	0.03	-4.64
$^1D_2$	0.32	2.14	5.36	8.58	10.18
$^3D_2$	-0.45	-2.32	-4.44	-6.91	-9.87
$^3D_3$	0.06	0.94	3.06	5.75	8.40

- $a_s = -3.18$fm , $r_s = 3.95$fm
- $a_t = -3.18$fm , $r_t = 1.30$fm


Total V($^1S_0$) $\Sigma^+P \to \Sigma^+P$ ESC08
OBE V($^1S_0$) $\Sigma^+P \to \Sigma^+P$
TPS V($^1S_0$) $\Sigma^+P \to \Sigma^+P$
PAIR V($^1S_0$) $\Sigma^+P \to \Sigma^+P$
V($^1S_0$)
V_c
V_σ
V [MeV]
x [fm]

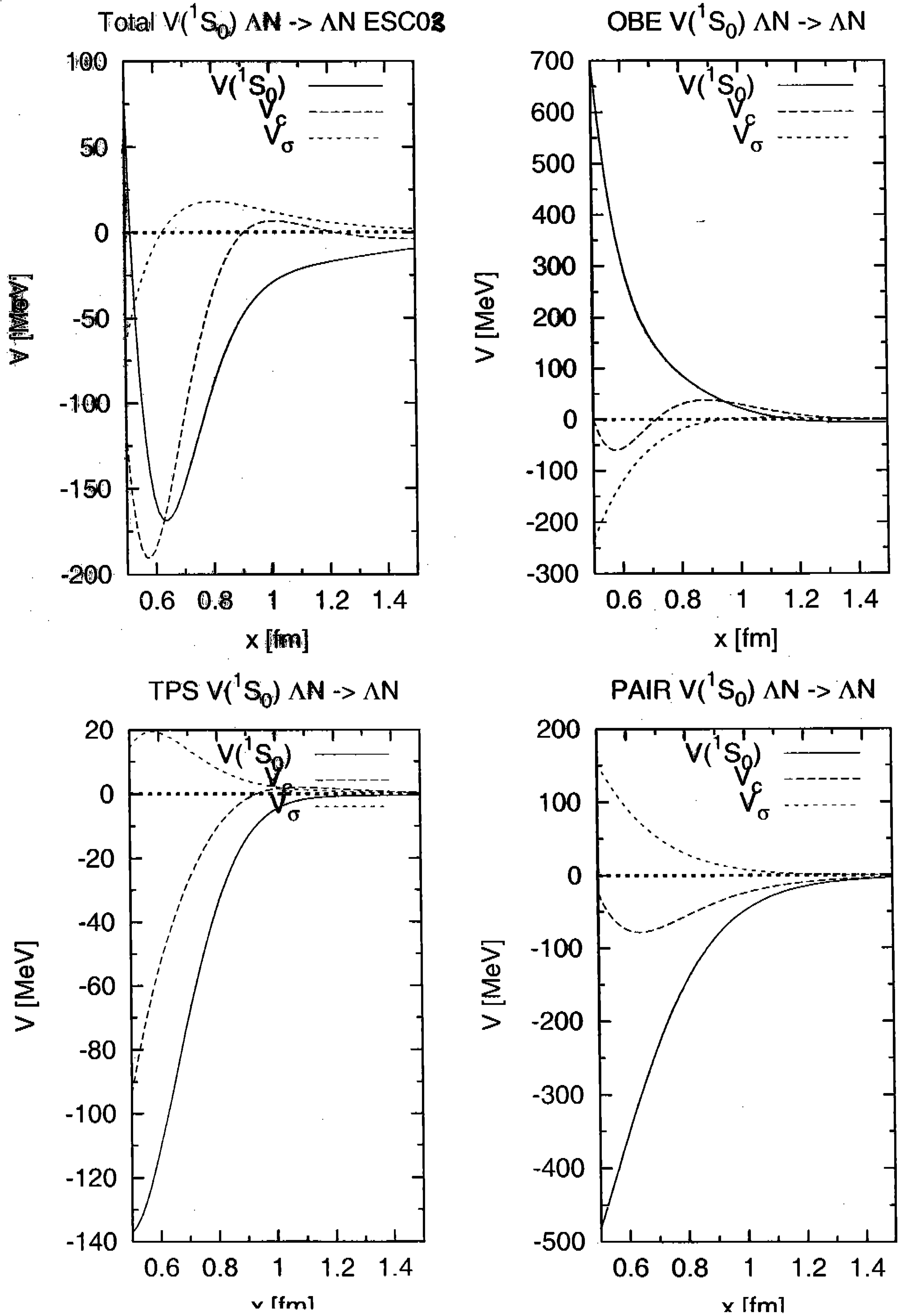


TOTAL V($^3S_1$) Σ^+P -> Σ^+P ESC03
OBE V($^3S_1$) Σ^+P -> Σ^+P
TPS V($^3S_1$) Σ^+P -> Σ^+P
PAIR V($^3S_1$) Σ^+P -> Σ^+P
V($^3S_1$)
V_c
V_σ
V [MeV]
x [fm]

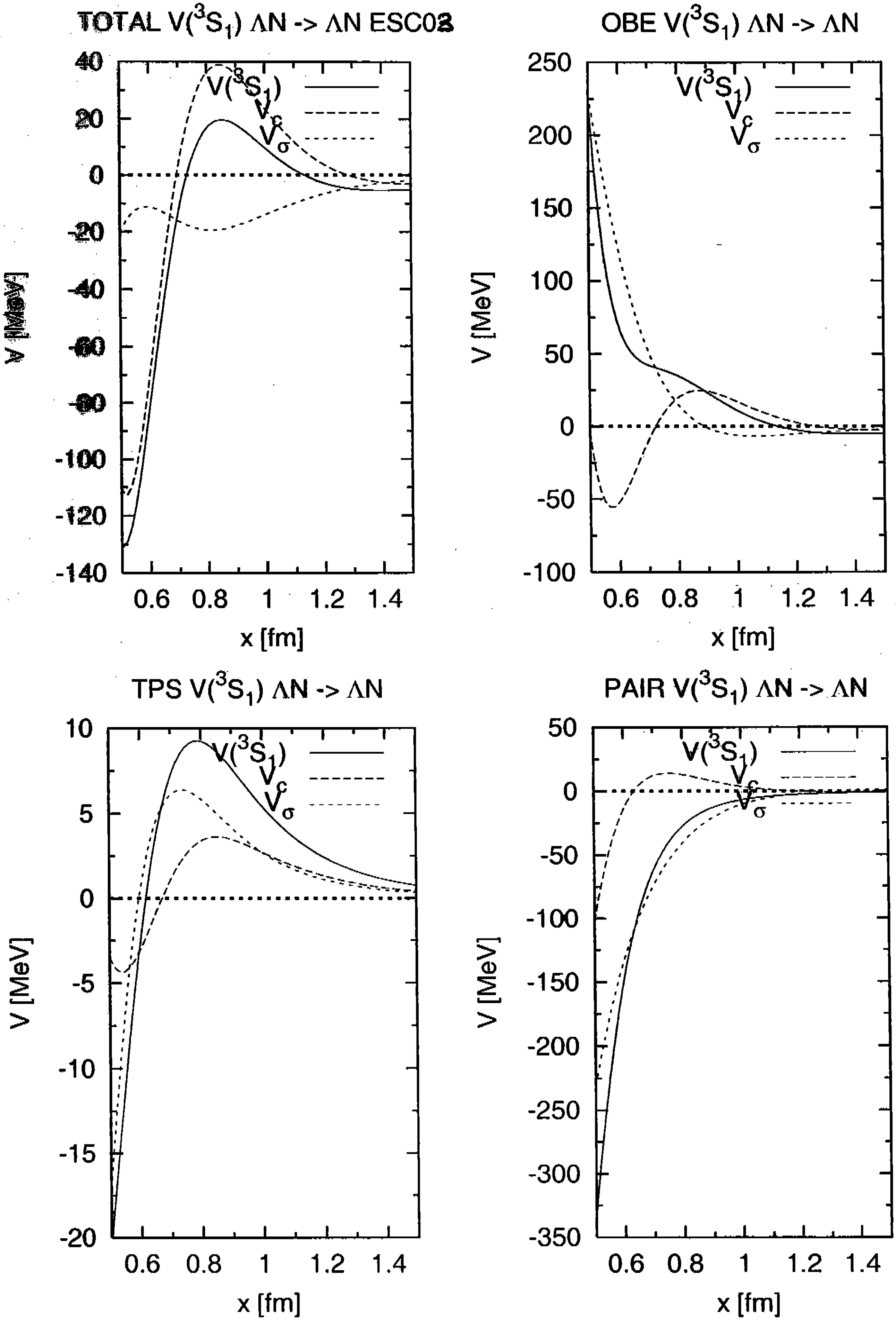
ESC03 nuclear-bar Λp phases in degrees:

p_Λ	100	200	300	400	500	600	6
T_{lab}	4.5	17.8	39.6	69.5	106.9	151.1	1
$^1S_0$	22.49	28.77	26.30	20.63	13.93	7.06	
$^3S_1$	20.32	28.31	28.90	27.23	26.49	34.69	6
ϵ_1	0.01	-0.04	-0.39	-1.42	-3.91	-12.97	-3
$^3P_0$	0.07	0.48	0.98	0.89	-0.25	-2.30	-
$^1P_1$	-0.01	-0.13	-0.62	-1.76	-3.63	-6.10	-
$^3P_1$	0.06	0.32	0.61	0.63	0.21	-0.49	-
$^3P_2$	0.15	1.01	2.67	4.64	6.29	7.29	
ϵ_2	-0.00	-0.00	-0.04	-0.15	-0.33	-0.57	-
$^3D_1$	0.00	0.04	0.28	1.01	2.87	9.48	1
$^1D_2$	0.00	0.05	0.28	0.86	1.81	2.99	
$^3D_2$	0.00	0.07	0.33	0.93	1.81	2.82	

- $a_s = -2.12$fm , $r_s = 3.18$fm
- $a_t = -1.82$fm , $r_t = 2.85$fm



Total V(1S0) ΛN -> ΛN ESC08
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
100
50
0
-50
-100
-150
-200
0.6
0.8
1
1.2
1.4
OBE V(1S0) ΛN -> ΛN
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
700
600
500
400
300
200
100
0
-100
-200
-300
0.6
0.8
1
1.2
1.4
TPS V(1S0) ΛN -> ΛN
V(1S0)
Vc
Vσ
V [MeV]
20
0
-20
-40
-60
-80
-100
-120
-140
0.6
0.8
1
1.2
1.4
PAIR V(1S0) ΛN -> ΛN
V(1S0)
Vc
Vσ
V [MeV]
200
100
0
-100
-200
-300
-400
-500
0.6
0.8
1
1.2
1.4


TOTAL V(3S1) ΛN -> ΛN ESC08
V(3S1)
Vc
Vσ
V [MeV]
x [fm]
OBE V(3S1) ΛN -> ΛN
V(3S1)
Vc
Vσ
V [MeV]
x [fm]
TPS V(3S1) ΛN -> ΛN
V(3S1)
Vc
Vσ
V [MeV]
x [fm]
PAIR V(3S1) ΛN -> ΛN
V(3S1)
Vc
Vσ
V [MeV]
x [fm]

Partial wave contributions to $U_\Lambda(\rho_0)$

	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	sum
ESC03	−11.1	−15.1	1.1	0.0	0.4	−4.3	−0.9	−29.8
ESC02	−9.6	−27.3	1.0	0.0	1.2	−5.4	−1.1	−41.2
NSC97e	−12.7	−25.5	2.1	0.5	3.2	−1.2	−1.1	−34.7
NSC97f	−14.3	−22.4	2.4	0.5	4.0	−0.7	−1.2	−31.7

Contributions to $U_\Lambda(\rho_0)$ from the central, spin-spin, LS and tensor parts of the G-matrix interactions.

	$U_0(S)$	$U_{\sigma\sigma}(S)$	$U_0(P)$	$U_{\sigma\sigma}(P)$	$U_{LS}(P)$	$U_{Ten}(P)$
ESC03	−6.54	1.52	−0.04	−0.39	−0.39	0.08
ESC02	−9.22	0.11	−0.09	−0.37	−0.55	0.15
NSC97e	−9.55	1.05	0.72	−0.44	−0.46	0.17
NSC97f	−9.19	1.70	0.92	−0.50	−0.47	0.22

- private communication Y. Yamamoto

Partial wave contributions to $U_\Sigma(\rho_0)$

model		$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Σ	Γ_Σ
ESC03	$T=1/2$	6.1	−17.2	1.4	1.2	−4.8	−1.4	−0.6		
	$T=3/2$	−8.9	8.7	−4.3	−1.8	5.0	−4.7	−0.3	−21.5	7.5
ESC02	$T=1/2$	3.1	−18.9	0.7	2.1	−3.2	1.2	−0.5		
	$T=3/2$	−10.7	86.3	0.7	−1.8	4.4	−6.5	0.3	57.1	25.3
NSC97e	$T=1/2$	14.8	−9.3	2.0	2.3	−4.0	0.3	−0.4		
	$T=3/2$	−12.1	−4.8	−3.9	−1.8	5.4	−2.8	−0.2	−14.6	16.3
NSC97f	$T=1/2$	14.9	−9.6	1.9	2.3	−4.0	0.4	−0.4		
	$T=3/2$	−12.2	−4.2	−3.8	−1.8	5.5	−2.7	−0.2	−13.9	16.0

Potentials of Σ^-, Σ^0 and Σ^+
in neutron matter at $kF = 1.35$ fm^{-1}

model	Σ^-	Σ^0	Σ^+
ESC03	−4.6	−10.8	−16.9
ESC02	+54.5	+28.6	+2.7
NSC97e	−15.2	−7.3	+0.6
NSC97f	−14.7	−7.0	+0.7

- private communication Y. Yamamoto

Strengths of Λ spin-orbit splittings

$$
\begin{aligned}
U_B^{ls}(r) &= K_B \left(\frac{1}{r}\frac{d\rho}{dr}\right) \mathbf{l}\cdot\mathbf{s} \\
K_N &= -\frac{\pi}{2} S_{LS} \quad \text{and} \quad K_\Lambda = -\frac{\pi}{3}\left(S_{LS} + S_{ALS}\right) \ , \\
S_{LS,ALS} &= \frac{3}{q}\int_0^\infty r^3 j_1(qr) G_{LS,ALS}(r) dr \ .
\end{aligned}
$$

	S_{LS}	S_{ALS}	K_S	$\Delta E_{LS}\left({}^9_\Lambda Be\right)$
NHCD	−22.0	7.3	15	0.15*
NHCF	−22.8	5.0	19	0.20*
NSC89	−28.0	7.9	21	
NSC97f	−23.9	7.0	18	0.16*
ESC02	−30.7	10.4	21	
ESC03	−21.5	12.2	9.7	≈ 0.08
Experiment				0.031 ± 0.002**

*) E. Hiyama et al, Phys. Rev. Lett. 85 (2000) 270.

**) H.Tamura, Nucl.Phys. A691 (2001) 86c-92c.

Comparison NN ⊎ YN ⊎ YY ESC-models 2002/2003

	NSC97f	ESC02	ESC03	'EXP.'
U_{Λ}	-31.1	-41.3	-30	-28
U_{Σ}	-11.6	+57.8	-25	-(15-20)
Γ_{Σ}	15.5	27.7	7.5	8
U_{Ξ}	?	16	?	17
$B_{\Lambda\Lambda}$	?	1.6	5.0	1.0

YY: The $\Lambda\Lambda$-systems III

- Danyz et al (1963) , Dalitz et al (1989):

  $\Xi^- + {}^{12}C \rightarrow {}^{10}_{\Lambda\Lambda}Be + p + 2n$

  $\Xi^- + {}^{14}N \rightarrow {}^{10}_{\Lambda\Lambda}Be + t + p + n$

  ${}^{10}_{\Lambda\Lambda}Be \rightarrow {}^{9}_{\Lambda}Be + p + \pi^-$, $\underline{\Delta B_{\Lambda\Lambda} = 4.7 \pm 0.4\text{MeV}}$!??

- Dover, Maui 1993: $|V_{\Lambda\Lambda}(^1S_0)| \approx |V_{NN}(^1S_0)|$
  $\rightarrow$ strong attraction in $\Lambda\Lambda$-systems, H (?)

- model-D: ϵ unitary singlet ?!
  $\rightarrow$ 'universal scalar attraction'

- KEK-373: NAGARA-event (2001), Nakazawa et al

  $\Xi^- + {}^{12}C \rightarrow {}^{6}_{\Lambda\Lambda}He + {}^{4}He + t$,

  ${}^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He + p + \pi^-$, $\underline{\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.28 \text{ MeV}}$

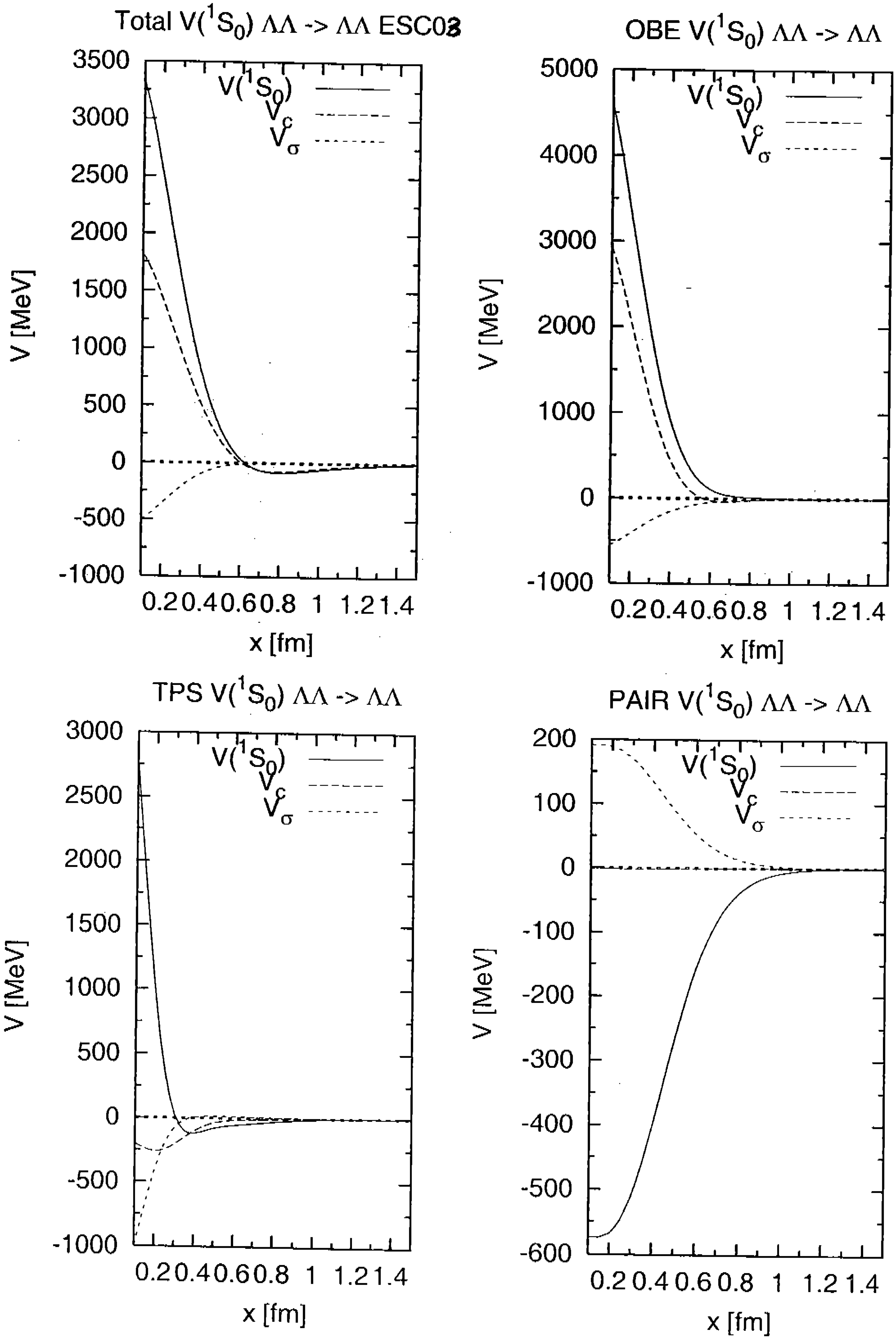
  ${}^{10}_{\Lambda\Lambda}Be \rightarrow {}^{9}_{\Lambda}Be^* + p + \pi^-$, $\underline{\Delta B_{\Lambda\Lambda} \approx 1.0 \text{ MeV}}$!!

- Soft-core models: NSC89, NSC97:
  $|V_{\Lambda\Lambda}(\epsilon)| < |V_{\Lambda N}(\epsilon)| < |V_{NN}(\epsilon)|$
  $\rightarrow$ weak attraction/repulsion in $\Lambda N, \Xi N$-sytems.

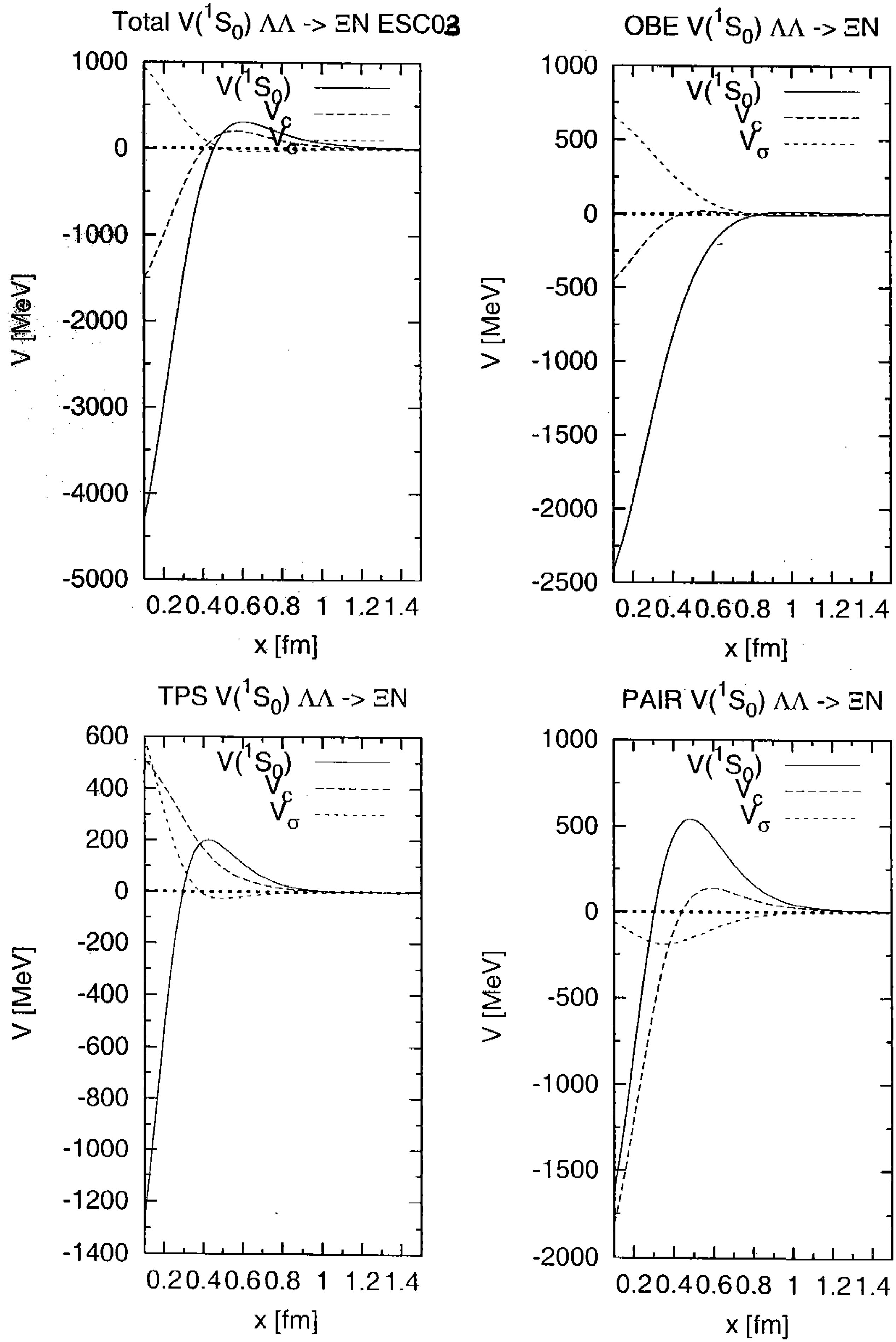
- ESC02-model: $\Delta B_{\Lambda\Lambda} \approx$ <u>1.6 MeV</u> !!

ESC03-model: $\Delta B_{\Lambda\Lambda} \approx 5.0$ MeV !?

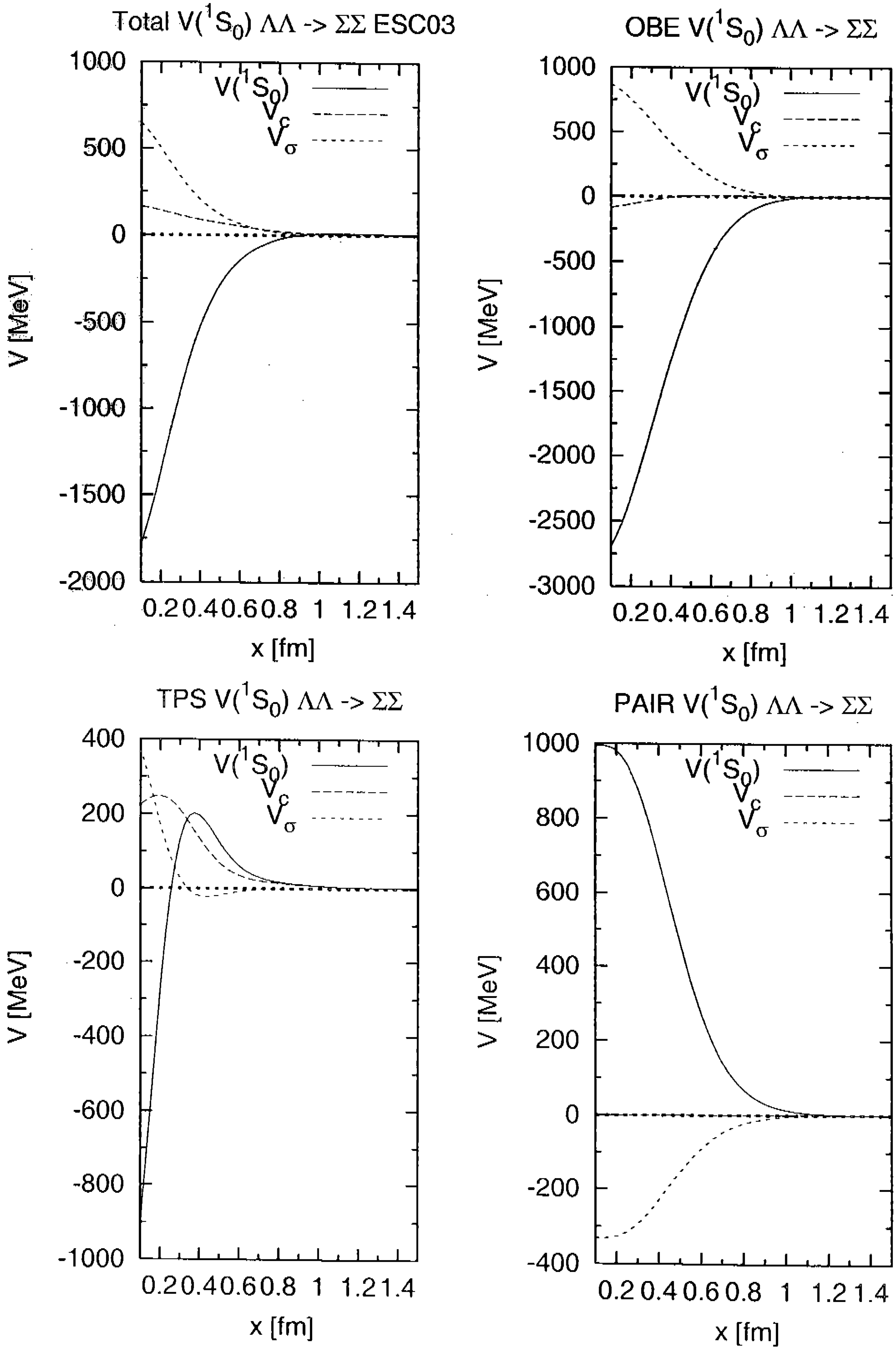
Ξ-well-depth = <u>16 MeV $\approx$ experiment</u>

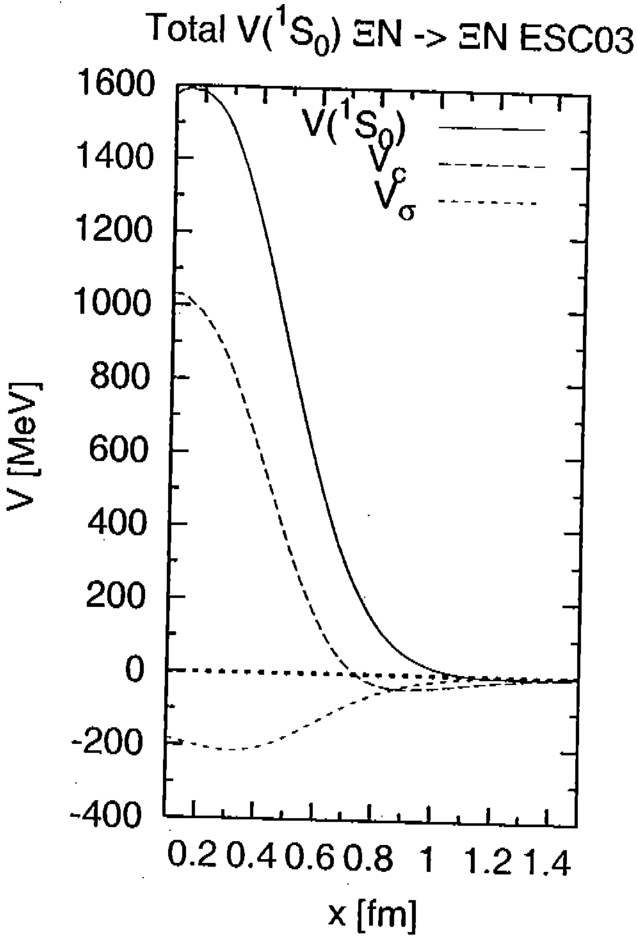


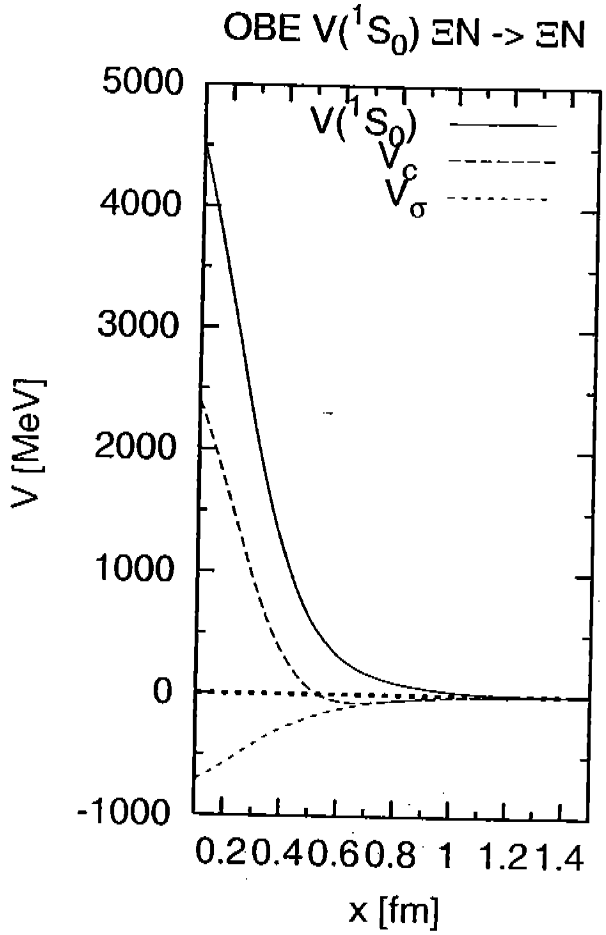
Total V(¹S₀) ΛΛ -> ΛΛ ESC03
OBE V(¹S₀) ΛΛ -> ΛΛ
TPS V(¹S₀) ΛΛ -> ΛΛ
PAIR V(¹S₀) ΛΛ -> ΛΛ
V(¹S₀)
V_c
V_σ
V [MeV]
x [fm]

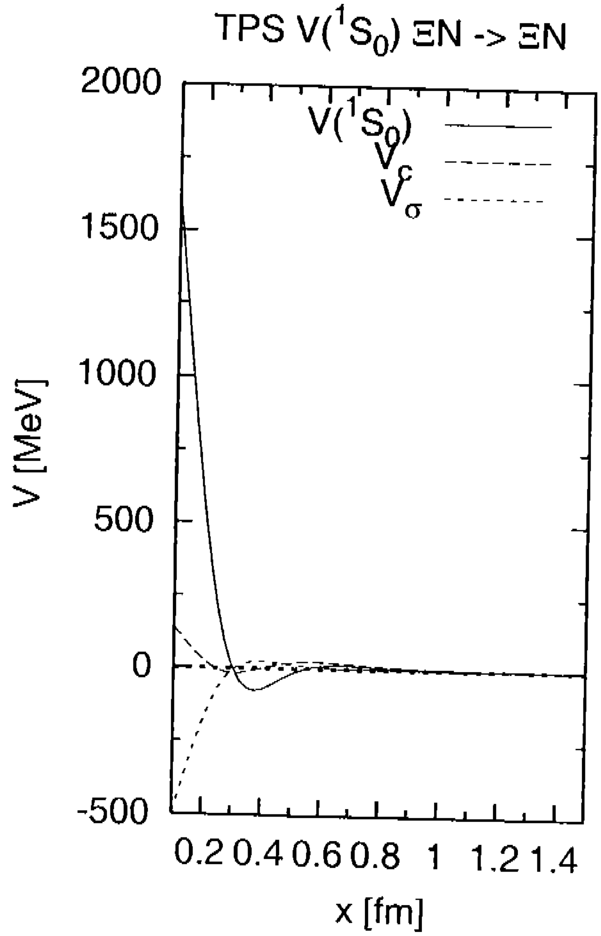


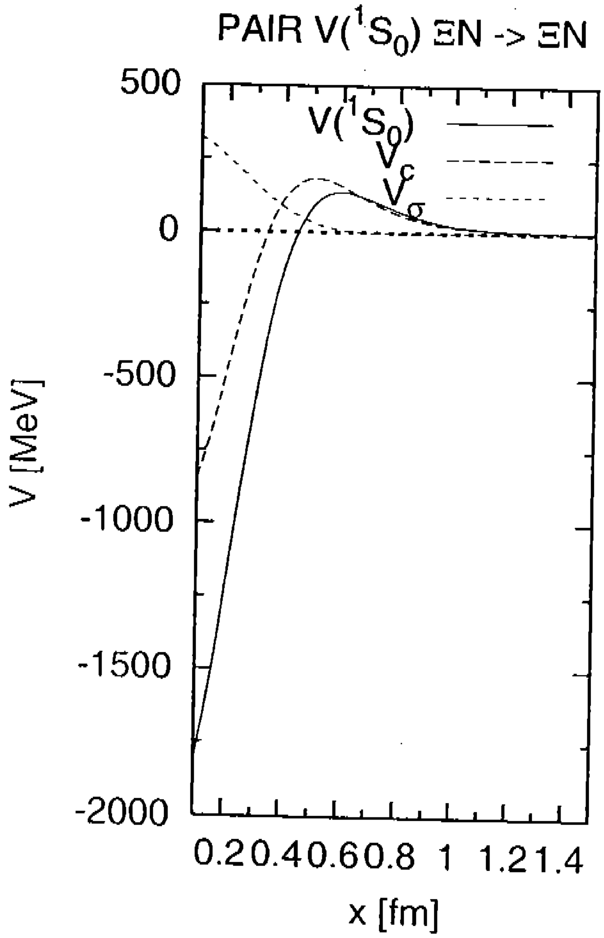
Total V(¹S₀) ΛΛ -> ΞN ESC03
V(¹S₀)
V_c
V_σ
V [MeV]
x [fm]
OBE V(¹S₀) ΛΛ -> ΞN
TPS V(¹S₀) ΛΛ -> ΞN
PAIR V(¹S₀) ΛΛ -> ΞN

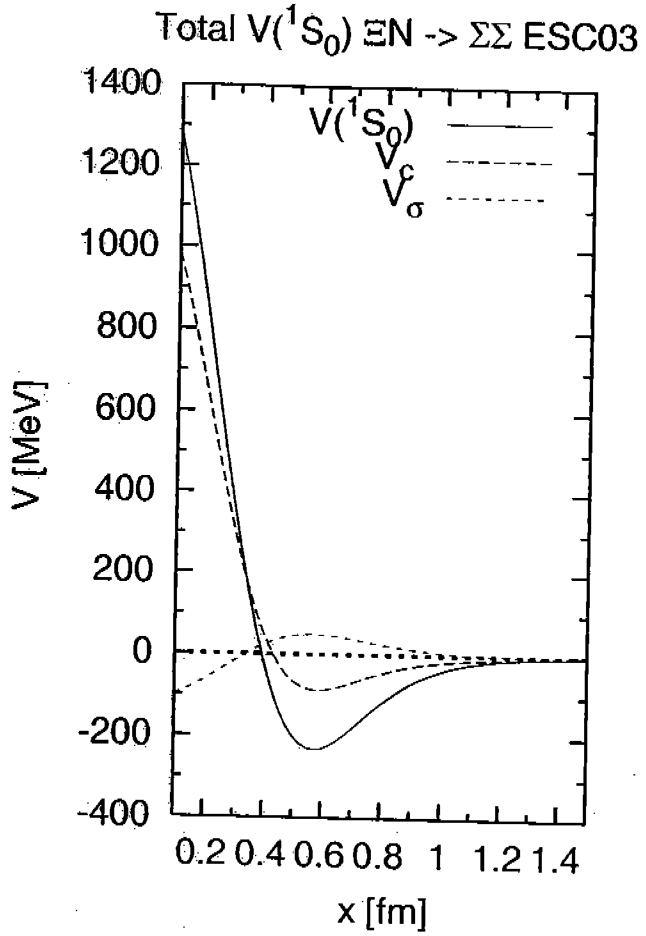

Total V(1S0) ΛΛ -> ΣΣ ESC03
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
OBE V(1S0) ΛΛ -> ΣΣ
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
TPS V(1S0) ΛΛ -> ΣΣ
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
PAIR V(1S0) ΛΛ -> ΣΣ
V(1S0)
Vc
Vσ
V [MeV]
x [fm]

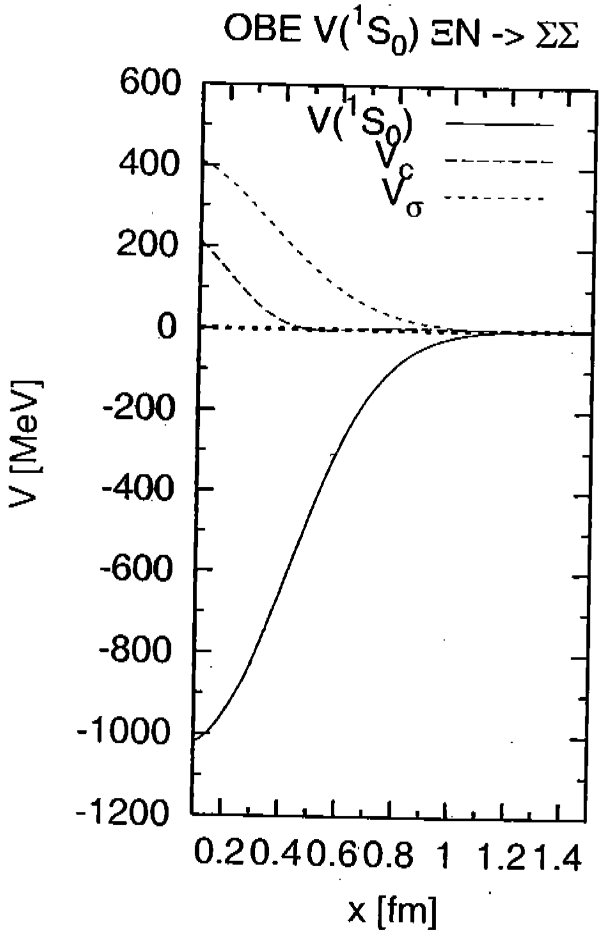

Total V(1S0) ΞN -> ΞN ESC03
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
1600
1400
1200
1000
800
600
400
200
0
-200
-400
0.2 0.4 0.6 0.8 1 1.2 1.4

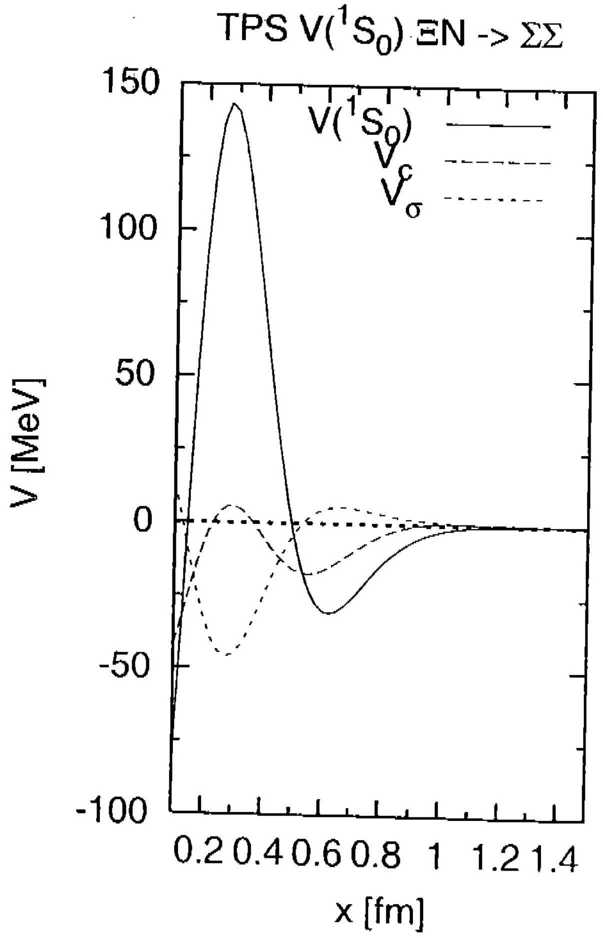

OBE V(1S0) ΞN -> ΞN
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
5000
4000
3000
2000
1000
0
-1000
0.2 0.4 0.6 0.8 1 1.2 1.4

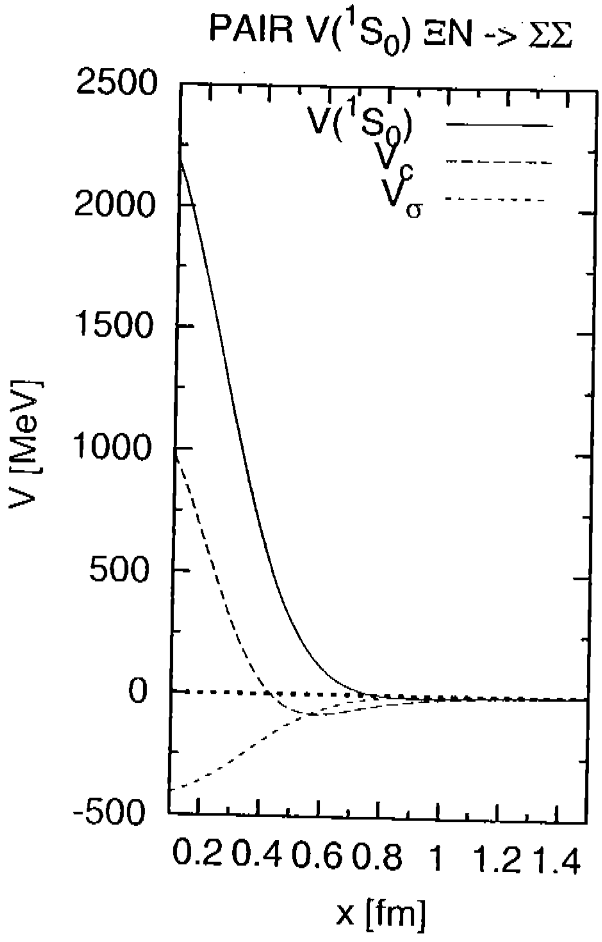

TPS V(1S0) ΞN -> ΞN
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
2000
1500
1000
500
0
-500
0.2 0.4 0.6 0.8 1 1.2 1.4

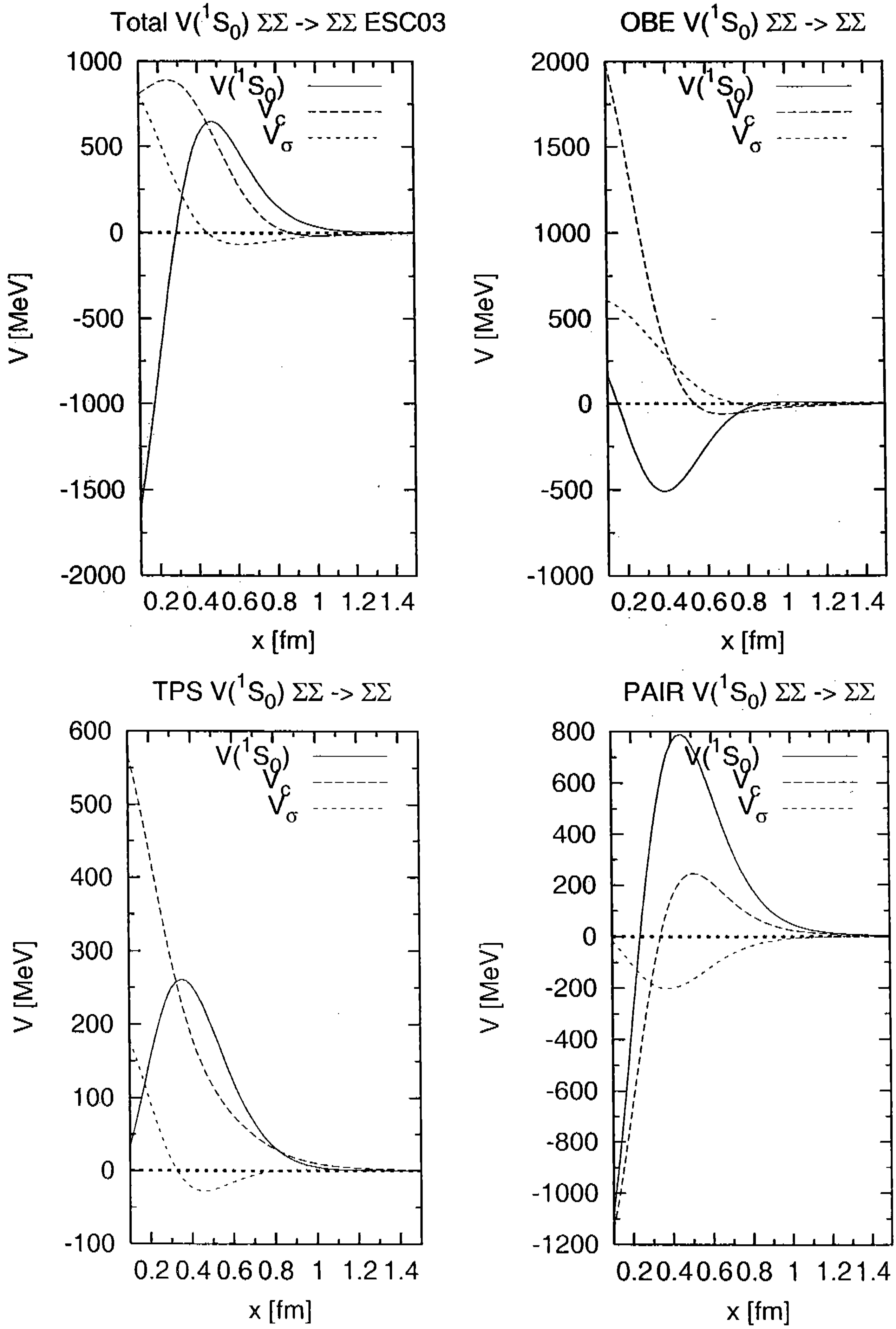

PAIR V(1S0) ΞN -> ΞN
V(1S0)
Vc
Vσ
V [MeV]
x [fm]
500
0
-500
-1000
-1500
-2000
0.2 0.4 0.6 0.8 1 1.2 1.4


Total V(1S0) ΞN -> ΣΣ ESC03
V(1S0)
Vc
Vσ
V [MeV]
1400
1200
1000
800
600
400
200
0
-200
-400
0.2 0.4 0.6 0.8 1 1.2 1.4
x [fm]


OBE V(1S0) ΞN -> ΣΣ
V(1S0)
Vc
Vσ
V [MeV]
600
400
200
0
-200
-400
-600
-800
-1000
-1200
0.2 0.4 0.6 0.8 1 1.2 1.4
x [fm]


TPS V(1S0) ΞN -> ΣΣ
V(1S0)
Vc
Vσ
V [MeV]
150
100
50
0
-50
-100
0.2 0.4 0.6 0.8 1 1.2 1.4
x [fm]


PAIR V(1S0) ΞN -> ΣΣ
V(1S0)
Vc
Vσ
V [MeV]
2500
2000
1500
1000
500
0
-500
0.2 0.4 0.6 0.8 1 1.2 1.4
x [fm]


Total V($^1S_0$) ΣΣ -> ΣΣ ESC03
V($^1S_0$)
V_c
V_σ
V [MeV]
x [fm]
OBE V($^1S_0$) ΣΣ -> ΣΣ
V($^1S_0$)
V_c
V_σ
V [MeV]
x [fm]
TPS V($^1S_0$) ΣΣ -> ΣΣ
V($^1S_0$)
V_c
V_σ
V [MeV]
x [fm]
PAIR V($^1S_0$) ΣΣ -> ΣΣ
V($^1S_0$)
V_c
V_σ
V [MeV]
x [fm]

Conclusions and Applications/Prospects

Conclusions:

1. NN: record low $\chi^2_{p.d.p.}$ (ca 18/13? par's), meson-exchange dynamics $\Leftrightarrow$ theory (QPC !)
2. Long-range forces ($\pi\pi$) complete $\oplus$ $SU_f(3)$-consistent ($K\bar{K}, \pi K$, etc.)
3. YN,YY: couplings $SU_f(3)$-symmetry, $^3S_1(\Sigma N, I = 1/2)$ is repulsive/attractive (?), ΛN: p-waves attractive on average
4. Scalar-meson nonet structure $\Leftrightarrow \Delta B_{\Lambda\Lambda}$

Applications/extensions ESC Models:

- 'Effective Interactions' in Hyper-nuclei
- Calculation Three-Body-Forces
- Calculation Meson-Exchange-Corrections
- Nuclear-, Neutron-star- , and 'Strange-matter'

Prospects:

- High-quality Description NN, YN, YY scattering
- Tests in nuclear and hypernuclear spectrocopy
- Tests in future scattering experiments (JHF !)