Status of our understanding of the YN/YY-interactions

Meson-exchange viewpoint

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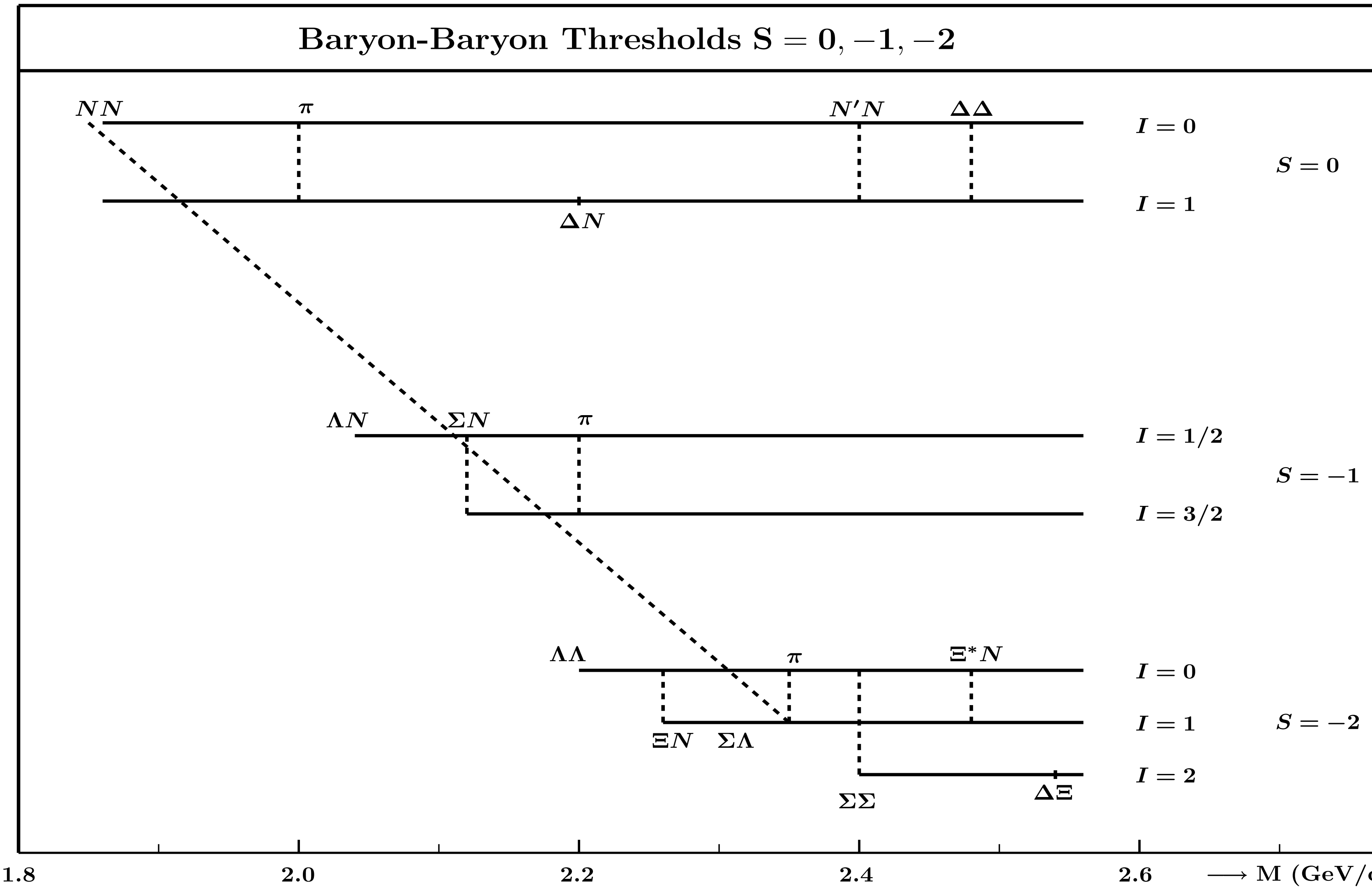
Particle and Flavor Nuclear Physics

- Objectives in Low/Intermediate Energy Physics:
  1. Study links Hadron-interactions and Quark-physics (QCD, QPC)
  2. Construction realistic physical picture of nuclear forces
     between the octet-baryons: N, Λ, Σ, Ξ
  3. Study (broken) $SU_F(3)$-symmetry
  4. Determination Meson Coupling Parameters $\Leftarrow$ NN+YN Scattering
  5. Analysis and interpretation experimental scattering data,
     and (hyper) nuclei-data
  6. Basis nuclear-model and nuclear-matter studies
  7. CERN, BNL, KEK, TJNAL, FINUDA, JPARC(2008), FAIR
  8. Extension to nuclear systems with c-, b-, t-quarks.

1a Baryon-baryon Channels $S = 0, -1, -2$

BB: The baryon-baryon channels $S = 0, -1, -2$



1b SU(3)-Symmetry Hadronen, BB-channels

Baryon-Baryon Interactions: SU(3)-Flavor Symmetry

- Quark Level: SU(3)$_{flavor}$ ⇔ Quark Substitutional Symmetry (!!)]
  'quarks are color blind'
- $p \sim UUD\ ,\ n \sim UDD\ ,\ \Lambda \sim UDS\ ,\ \Sigma^+ \sim UUS\ ,\ \Xi^0 \sim USS$
- Mass differences ⇔ Broken SU(3)$_{flavor}$ symmetry
- Baryon-Baryon Channels:

$$
\begin{array}{lllllll}
NN & : & pp & , & np & , & nn & S = 0 \\
YN & : & \Sigma^+ p & , & \Sigma^- p \rightarrow \Sigma^- p, \Sigma^0 n, \Lambda n & , & \Lambda p \rightarrow \Lambda p, \Sigma^+ n, \Sigma^0 p & S = -1 \\
\Xi N & : & \Xi^0 p & , & \Xi N \rightarrow \Xi^- p, \Lambda\Lambda, \Sigma\Sigma & & & S = -2 \\
\Xi Y & : & & , & \Xi\Lambda \rightarrow \Xi\Lambda, \Xi\Sigma & & & S = -3 \\
\Xi\Xi & : & \Xi^0\Xi^0 & , & \Xi^0\Xi^- & & & S = -4
\end{array}
$$

- SU(3) classification BB-channels:

$$\{8\} \otimes \{8\} = \{27\} \oplus \{10\} \oplus \{10^\star\} \oplus \{8_s\} \oplus \{8_a\} \oplus \{1\}$$

SU(3)-Symmetry Hadronen, BB-decuplet II

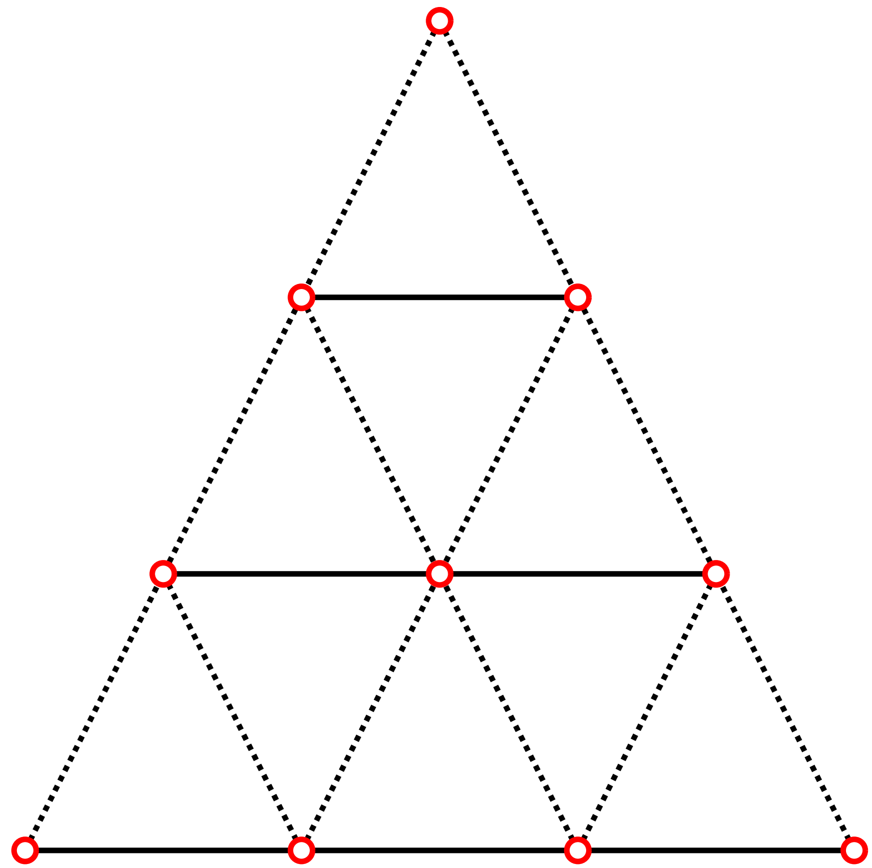
Baryon-Baryon Decuplet-states $\{10^\star\}$, ${}^{2s+1}L_J = {}^3S_1, {}^1P_1, {}^3D, \ldots$

$Y = 2, S = 0$ — $np(I = 0)$, deuteron

$Y = 1, S = -1$ — $\Lambda N, \Sigma N(I = 1/2)$

$Y = 0, S = -2$ — $\Xi N, \Lambda\Sigma, \Sigma\Sigma(I = 1)$

$Y = -1, S = -3$ — $\Xi\Sigma(I = 3/2)$



2 Introduction: Competing BB-models

Theory Interest in Flavor Nuclear Physics

- Recent Model building:

1. Nijmegen models: OBE and ESC Soft-core (SC)
   Rijken, Phys.Rev. C73, 044007 (2006)
   Rijken & Yamamoto, Phys.Rev. C73, 044008 (2006)
2. Chiral-Unitary Approach model
   Sasaki, Oset, and Vacas, Phys.Rev. C74, 064002 (2006)
3. Jülich Meson-exchange models
   Haidenbauer, Meissner, Phys.Rev. C72, 044005 (2005)
4. Bochum/Jülich Effective Field Theory models
   Epelbaum, Polinder, Haidenbauer, Meissner
5. Quark-Cluster-models: QGE + RGM
   Fujiwara et al, Progress in Part. & Nucl.Phys. 58, 439 (2007)
   Valcarce et al, Rep.Progr.Phys. 68, 965 (2005)
6. Lattice Computations: Nemura, ...

3 Role BB-interaction Models

Particle and Flavor Nuclear Physics (H.Bando)

- Concepts:

QCD: Colored quarks + gluons

Confinement SU$_c$(3)

Strong coupling $g_{QCD} \approx 1$

Lattice QCD: flux-tubes/strings

Flavor SU$_f$-symmetry

Spontaneous CSB

Principle: "Experientia ac ratione"

(Christiaan Huijgens 1629-169

Experiments:

NN-scattering

YN- & YY-scattering

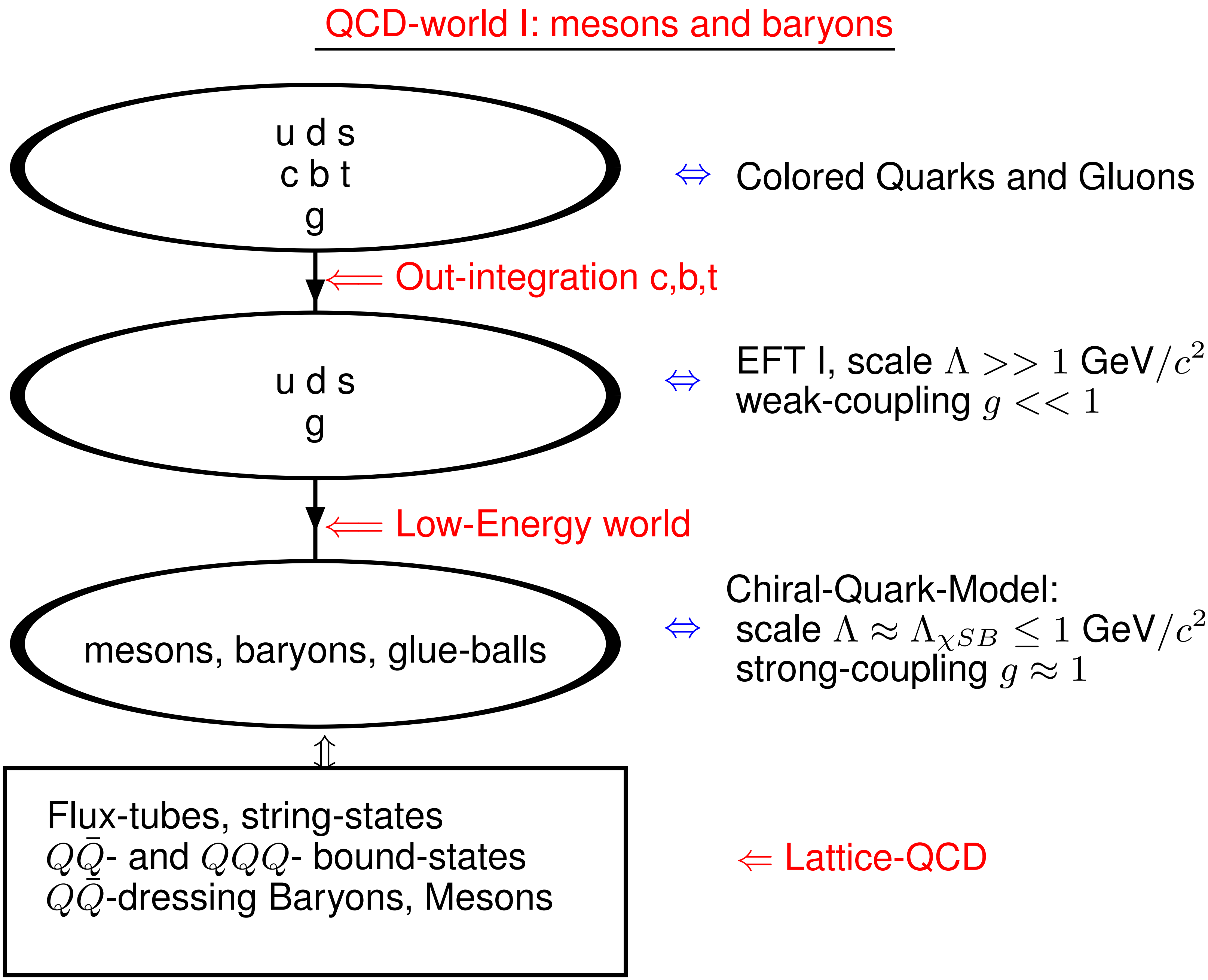
Nuclei & Hypernuclei

Nuclear- & Hyperonic matter

Neutron-star matter

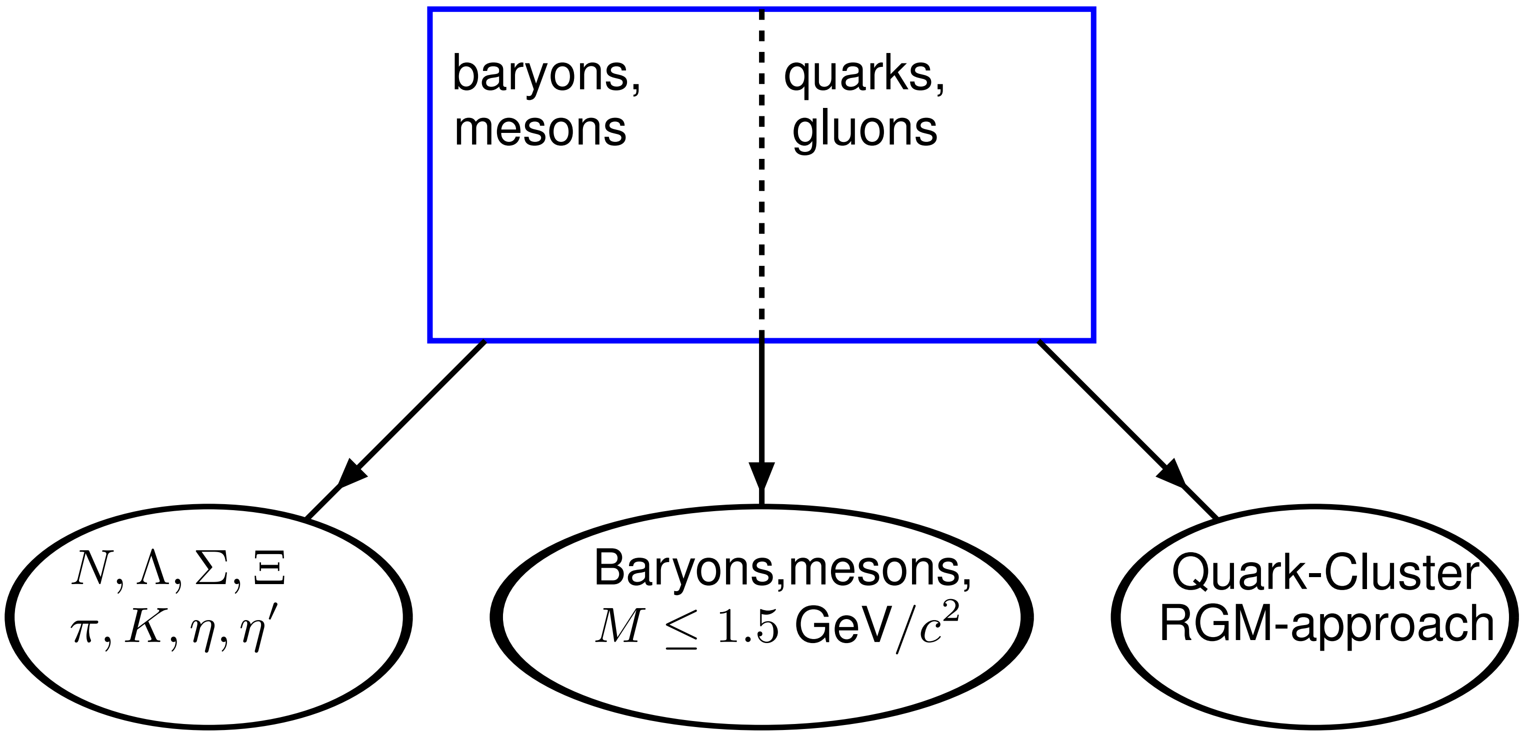
BB-interaction models

4a QCD-world I



4b QCD-world II

QCD-world II: Baryon/Meson-baryon Interactions



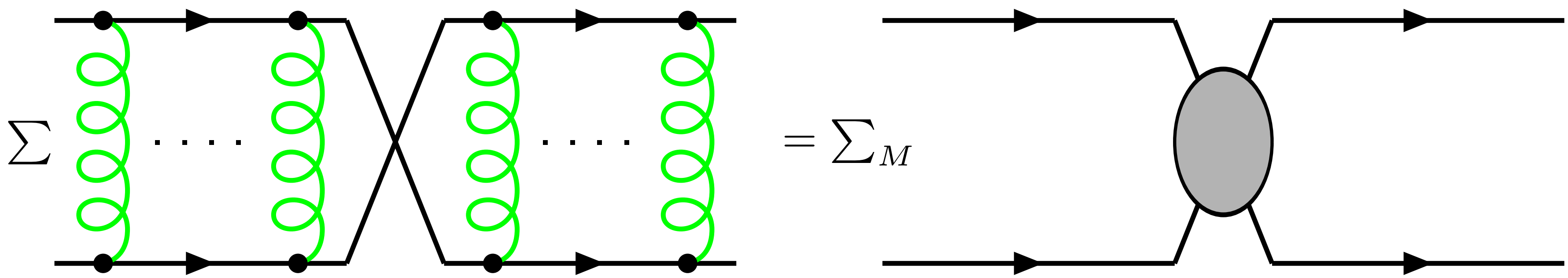
Goldstone-boson exch.
+ contact-terms
Chiral Pert. Models:
Van Kolck, Epelbaum,
Bonn-Jülich, Barcelona, etc.

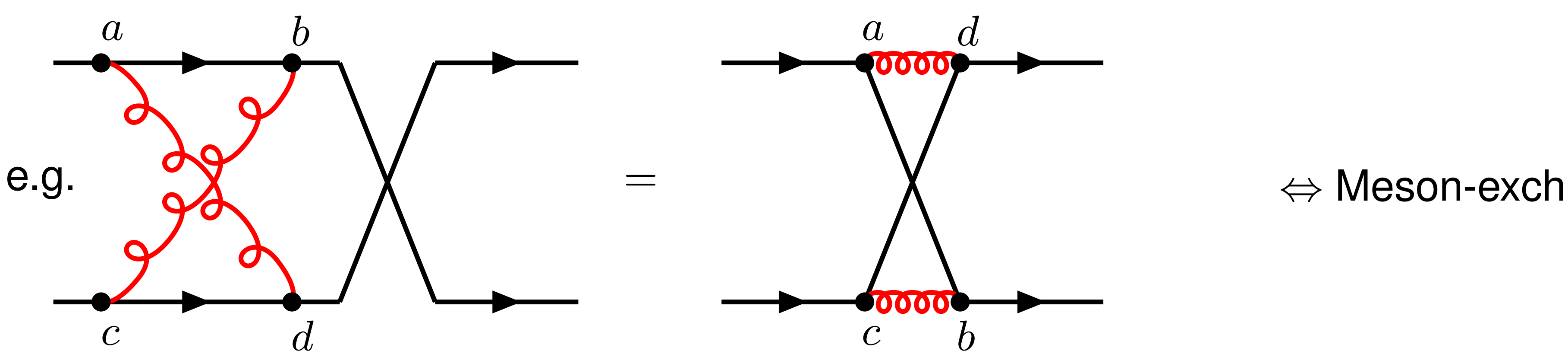
Meson-exchange models
Nijmegen NSC97, ESC04/08,
Ehime, Jülich, etc.

Quark-Gluon-
+ OBE-exchange
Tokyo, Kyoto-Niagatta,
Tübingen, Salamanca,
Nanjing, etc.

Gluon-Quark-Exchange ⇔ Meson-Exchange

- Strong-coupling regime QQ-interaction: Multi-gluon exchange

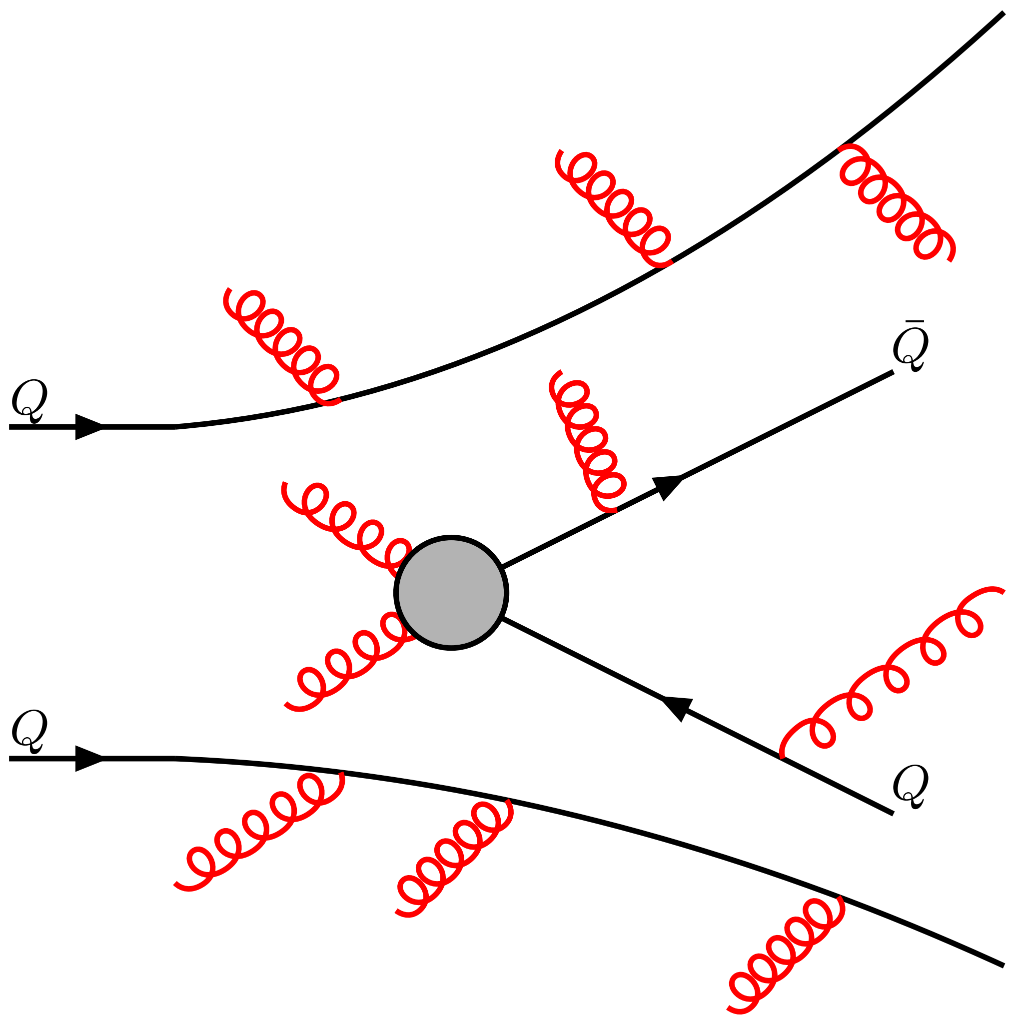




4d Quark-Pair-Creation in QCD

Quark-Pair-Creation in QCD ⇔ Flux-tube breaking

- Strong-coupling regime QQ-interaction: Multi-gluon exchange



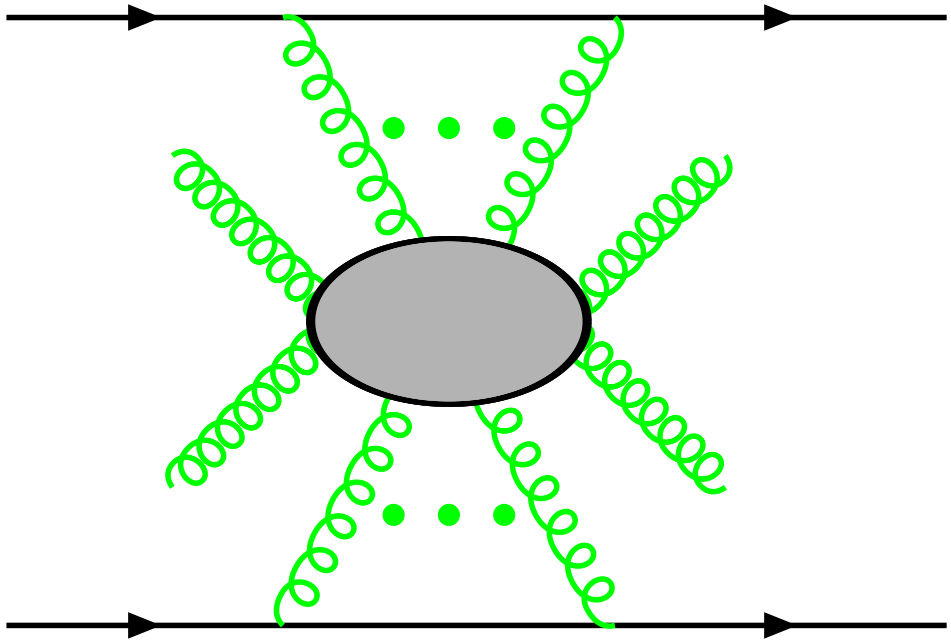
QPC: ${}^3P_0$-model:
Micu, NP B10(1969);
Carlitz & Kislinger, PR D2(1970
LeYaounanc et al, PR D8(1973

QCD: Flux-tube/String-breakinç
$\Rightarrow {}^3P_0(Q\bar{Q})$,
Isgur & Paton, PRD31(1985);
Kokoski & Isgur, PRD35(1987)

4e Gluon-exchange ⇔ Pomeron

Multiple Gluon-exchange QCD ⇔ Pomeron/Odderon

- Gluon-exchange ⇔ Pomeron-exchange



Multiple-gluon model: Low PR D12(19
Nussinov PRL34(1975)
Scalar Gluon-condensate: ITEP-schoo
$\langle 0|g^2 G^a_{\mu\nu}(0) G^{a\mu\nu}(0)|0\rangle = \Lambda_c^4$,
$\Lambda_c \approx 800$ MeV
Landshoff, Nachtmann, Donnachie,
Z.Phys.C35(1987); NP B311(1988):
$\langle 0|g^2 T[G^a_{\mu\nu}(x) G^{a\mu\nu}(0)]|0\rangle =$
$\Lambda_c^4 f(x^2/a^2), a \approx 0.2 - 0.3 fm$
QCD-vacuuum: Copenhagen picture,
Ambjorn & Olesen, NP B170(1980)

- Two/Even-gluon exchange ⇔ Pomeron
- Three/Odd-gluon exchange ⇔ Odderon

5a Six-Quark-core Effects

Six-Quark-Core Effect: Forbidden States

- Irreps [51], [33] of $SU(6)_{fs}$ and the Pauli-principle
- $SU(3)_f$-irreps $\{27\}, \{10^*\}$, etc. in terms of the $SU(6)_{fs}$-irreps:

$$
\begin{aligned}
V_{\{27\}} &= \frac{4}{9} V_{[51]} + \frac{5}{9} V_{[33]} \ , \\
V_{\{10^*\}} &= \frac{4}{9} V_{[51]} + \frac{5}{9} V_{[33]} \ , \\
V_{\{10\}} &= \frac{8}{9} V_{[51]} + \frac{1}{9} V_{[33]} \ , \\
V_{\{8_a\}} &= \frac{5}{9} V_{[51]} + \frac{4}{9} V_{[33]} \ , \\
V_{\{8_s\}} &= V_{[51]} \ , \quad V_{\{1\}} = V_{[33]} \ .
\end{aligned}
$$

Forbidden irrep $[51]$ has large weight in $\{10\}$ and $\{8_s\}$ ->
Adaption Pomeron strength for these irreps.

- Pomeron ⇔ Multi-gluon Exch. + Quark-core effect !

- Literature: P.T.P. Suppl. 137 (2000), Oka et al

5b Short-range Phenomenology-6

Corollary:

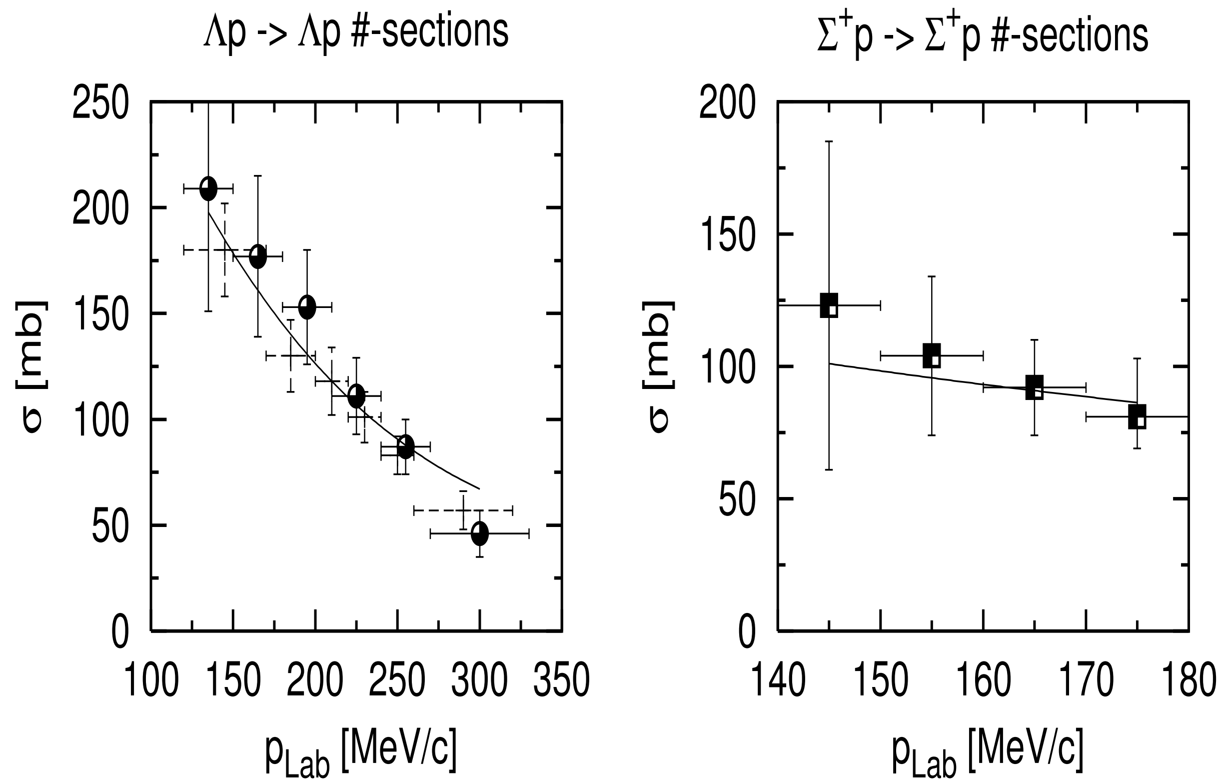
We have seen that the $[51]$-irrep has a large weight in the $\{10\}$- and $\{8_s\}$-irrep, which gives an argument for the presence of a strong Pauli-repulsion in these $SU(3)_f$-irreps $\Longrightarrow$

ESC08: implementation by adapting the Pomeron strength in irreps $\{10\}$ and $\{8_s\}$.

From the plots of the potentials for the NSC97f model (RSY99) one sees that the shapes of the potentials in the irreps $\{10\}$ and $\{8$ are similar, and moreover are attractive at short range.
Such similarity is expected from QCM and apparently is related to $SU(6)_{fs}$-symmetry.
This is also the case for the short range shape of the irreps $\{27\}$ and $\{10^*\}$, as seen in the figures.

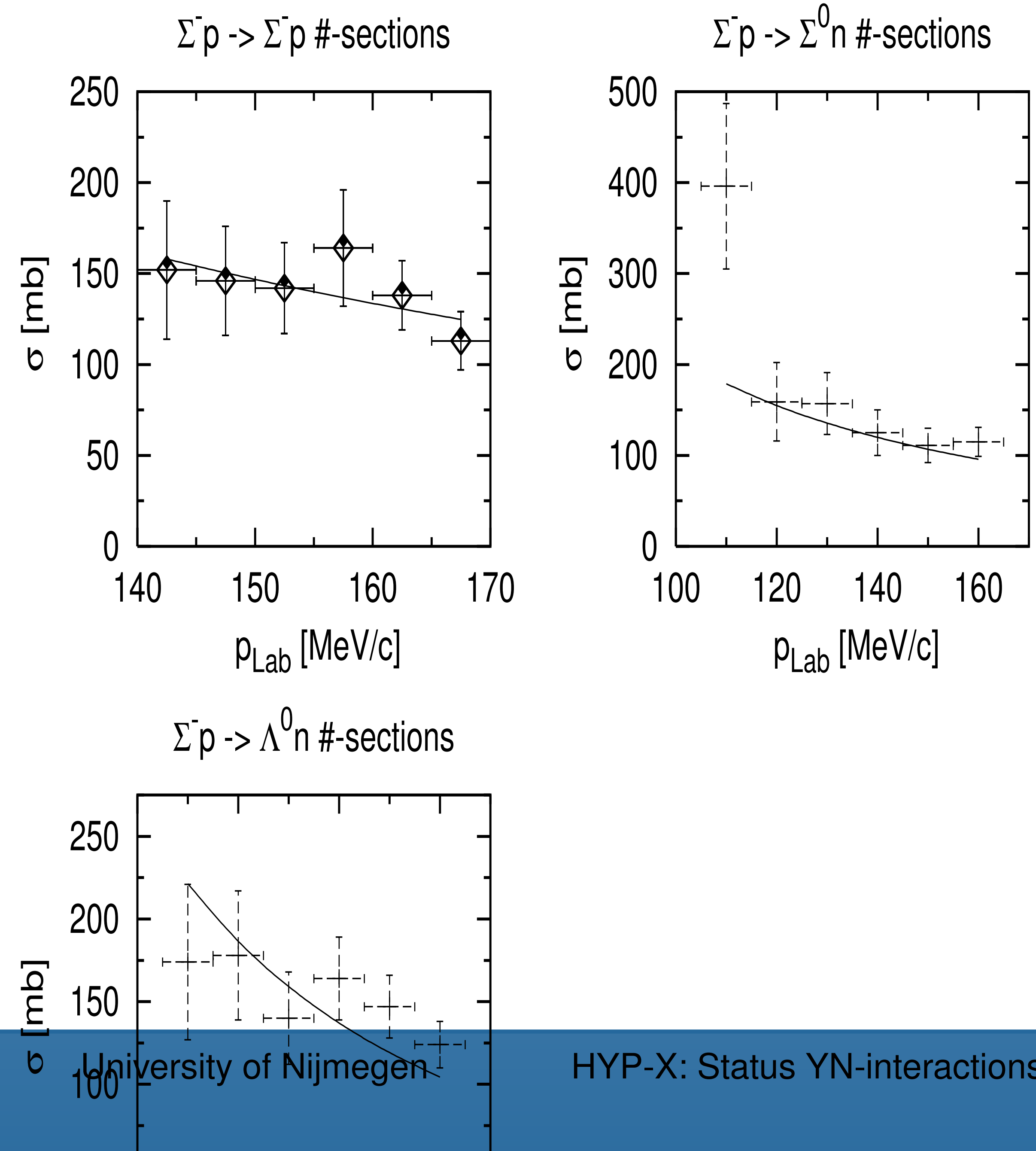
7a YN X-sections

YN cross-sections



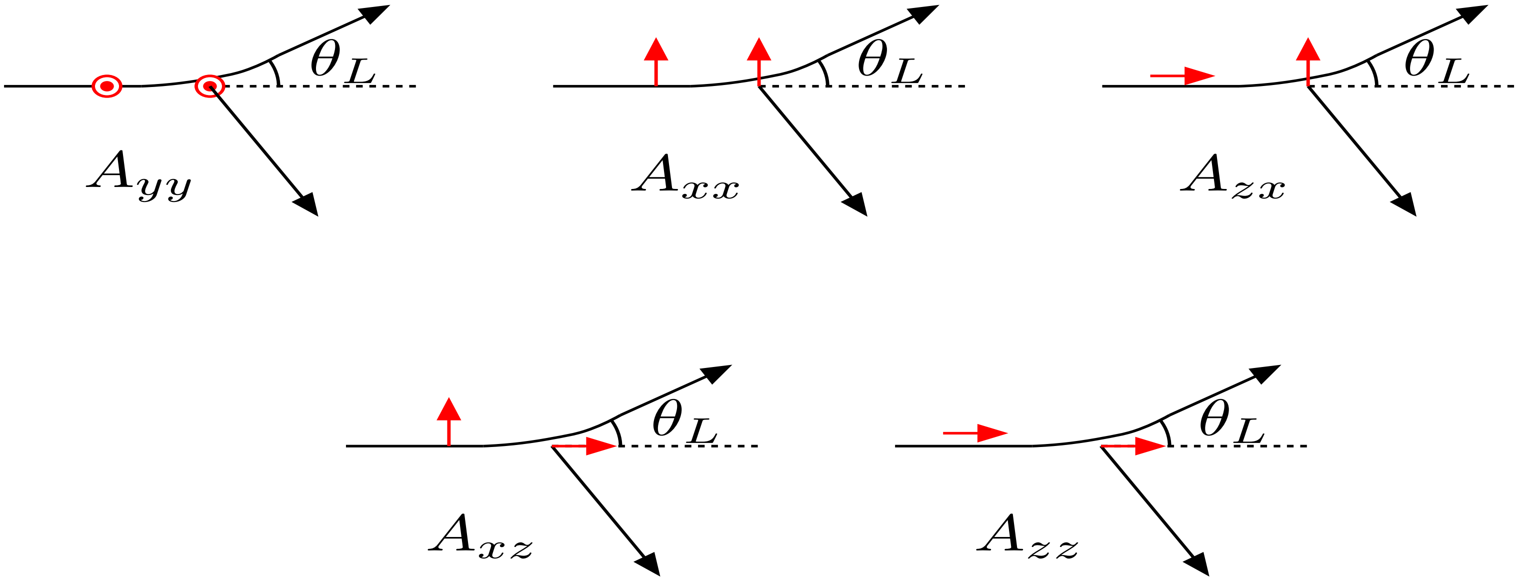
7b YN X-sections

YN cross-sections



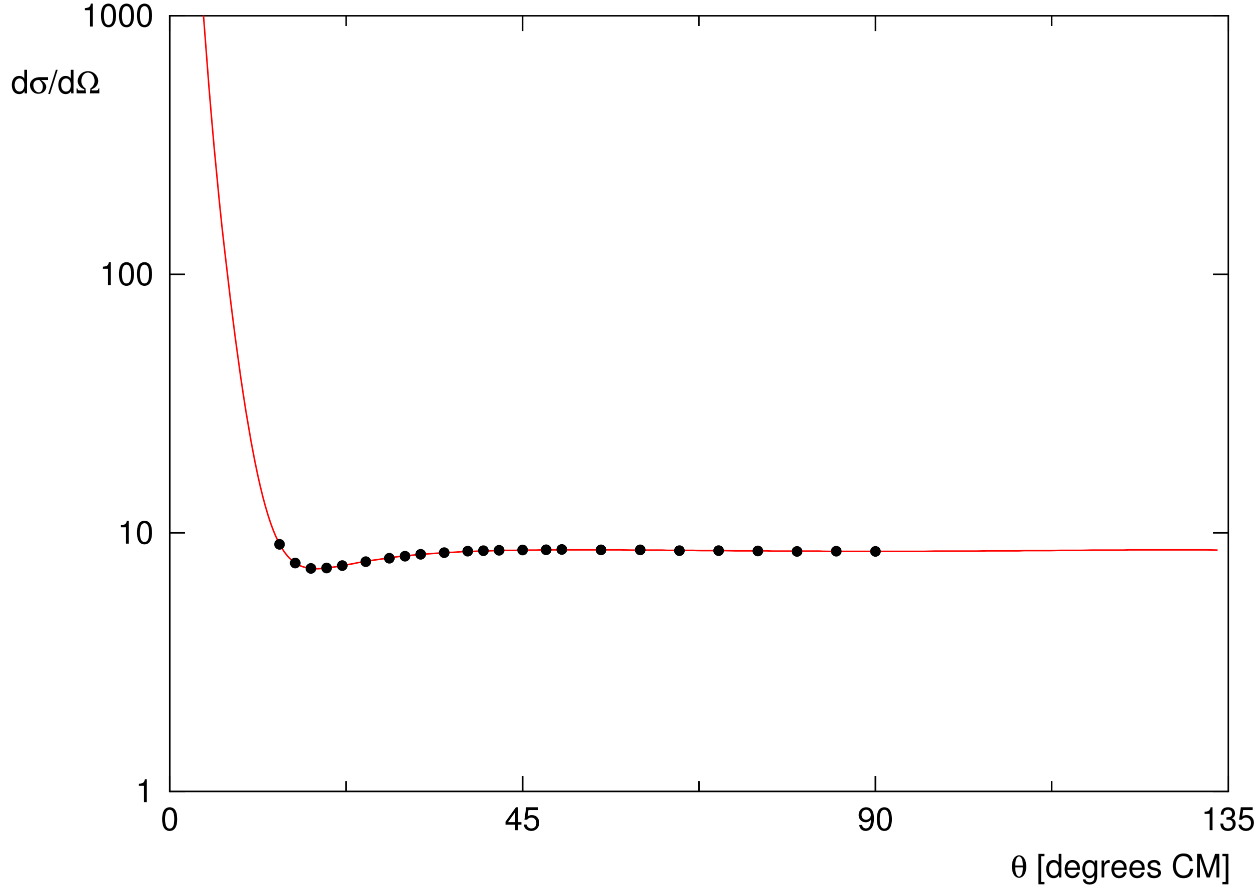
8c Spin-correlation parameters II

Spin-correlation parameters A_{yy}, A_{xx}, A_{zx}, A_{xz}, and A_{zz}.



Spin-correlation parameters A_{yy}, A_{xx}, A_{zx}, A_{xz}, and A_{zz}.

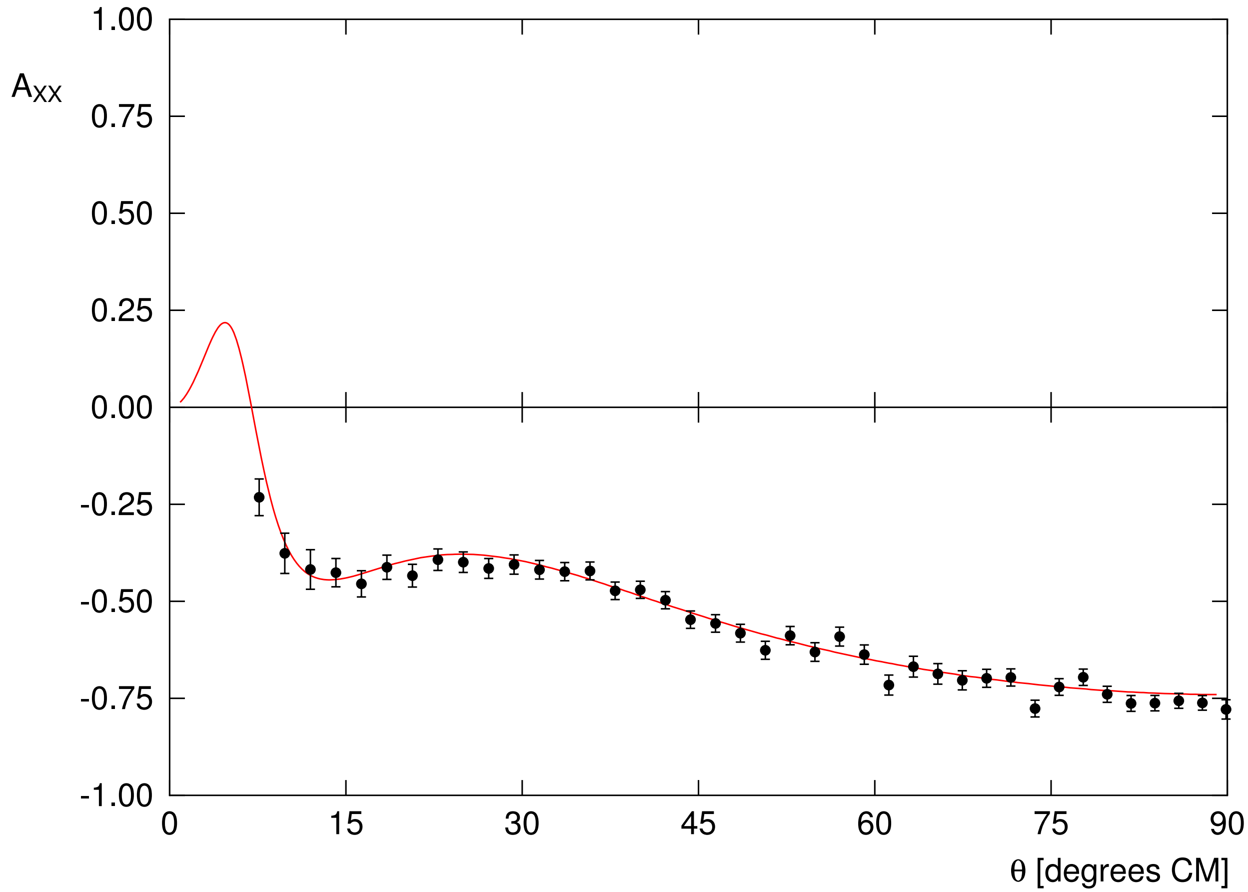
8d PWA-93, 1



pp observable dσ/dΩ at T_{lab} = 50.06 MeV

PWA93 • Berdoz et al., SIN(1986)

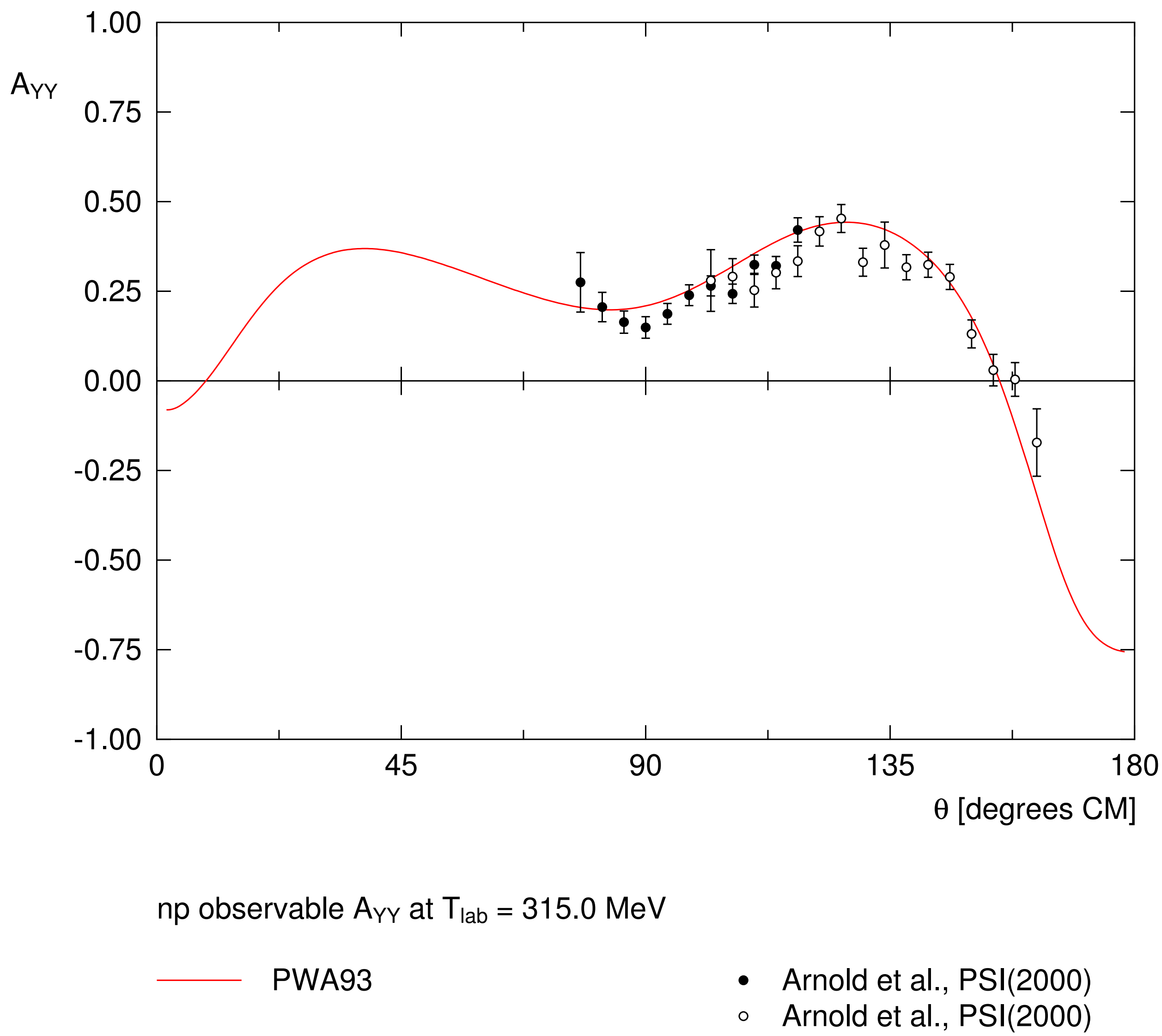
8e PWA-93, 2



pp observable A_{XX} at T_{lab} = 350.0 MeV

PWA93 • von Przewoski et al., IUCF(1998)

8f PWA-93, 3



1.00
A_{YY}
0.75
0.50
0.25
0.00
-0.25
-0.50
-0.75
-1.00
0
45
90
135
180
θ [degrees CM]
np observable A_{YY} at T_{lab} = 315.0 MeV
PWA93
Arnold et al., PSI(2000)
Arnold et al., PSI(2000)

9 Methodology ESC08-model Analysis

Strategy: Combined Analysis NN-, YN-, and YY-data

Input data/constraints:

- NN-data : 4300 scattering data + low-energy par's
- YN-data : 38 scattering data
- Nuclei/hyper-nuclei data: BE's Deuteron, well-depth's $U_\Lambda, U_\Sigma, U_\Xi$
- Hadron physics: experiments + theory

  a) Flavor SU(3), (b) Quark-model, (c) QCD $\leftrightarrow$ gluon dynamics

Output: ESC-models (ESC04,ESC06,ESC08), ESC08b:

- Fit NN-data $\chi^2_{p.d.p.}$=1.135 (!), deuteron, YN-data $\chi^2_{p.d.p.} = 0.60$
- Description all well-depth's, NO S=-1 bound-states (!), small Λp spin-orbit (Tamu

  $\Delta B_{\Lambda\Lambda}$ a la Nagara (!)

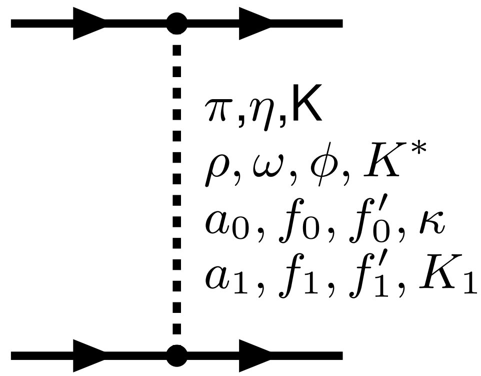
Predictions: (a) Deuteron $D(Y=0)$-state in $\Xi N(I=1,^3S_1)$ (!??), (b) (Y=-2)-bound-state $\Xi\Xi(I=1,^1S_0)$ (!??)

- Predictions model-dependent: Need more precise e.g. $\Sigma^+p-, \Lambda p-, \Xi N-$ info!!!

10b ESC-model: OBE+TME

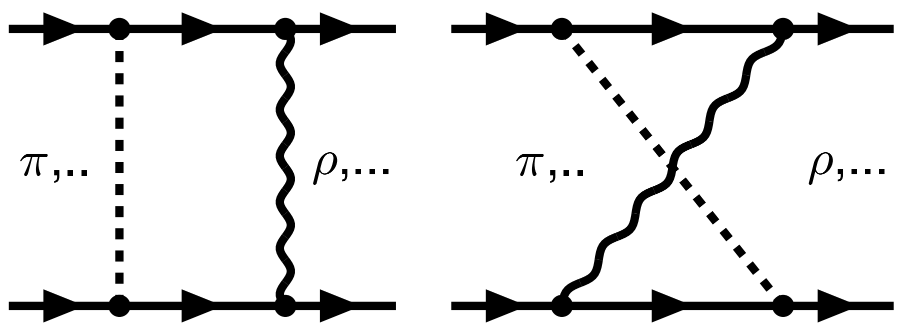
BB-interactions in the ESC-model:

One-Boson-Exchanges:



pseudo-scalar	π	K	η
vector	ρ	K^*	ϕ
axial-vector	a_1	K_1	f_1'
scalar	δ	κ	S^*
diffractive	A_2	K^{**}	f

Two-Meson-Exchanges:

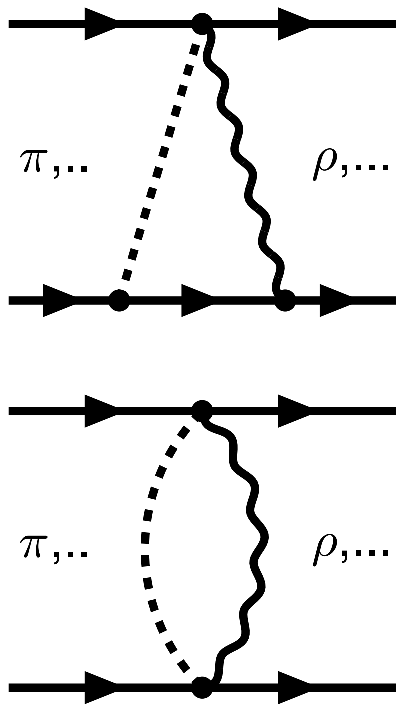


$$\begin{pmatrix} \pi \\ K \\ \eta \\ \eta' \end{pmatrix} \otimes \left\{ \begin{array}{cccc} \pi & K & \eta & \eta' \\ \rho & K^* & \phi & \omega \\ a_1 & K_1 & f_1 & f_1' \\ \delta & \kappa & S^* & \epsilon \\ A_2 & K^{**} & f & P \end{array} \right.$$

10c ESC-model: Meson-Pair exchanges

BB-interactions in the ESC-model (cont.):

Meson-Pair-Exchanges:



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

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

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

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

$$PV\hat{B}_{\{8\}} \quad : \quad \pi\omega,\ K\omega,\ \eta\omega$$

10a ESC-model,dynamical contents

ESC08b: Soft-core $NN + YN + YY$ ESC-model

- extended ESC04-model, PRC73 (2006)
- NN: 20 free parameters: couplings, cut-off's,
  meson mixing and F/(F+D)-ratio's
- meson nonets:

$$J^{PC} = 0^{-+}: \quad \pi, \eta, \eta', K \quad ; = 1^{--}: \quad \rho, \omega, \phi, K^\star$$
$$= 0^{++}: \quad a_0(962), f_0(760), f_0(993), \kappa_1(900)$$
$$= 1^{++}: \quad a_1(1270), f_1(1285), f_0(1460), K_a(1430)$$
$$= 1^{+-}: \quad b_1(1235), h_1(1170), h_1(1380), K_b(1430)$$

- soft TPS: two-pseudo-scalar exchanges,
- soft MPE: meson-pair exchanges: $\pi \otimes \pi$, $\pi \otimes \rho$, $\pi \otimes \epsilon$, $\pi \otimes \omega$, etc.
- pomeron/odderon exchange ⇔ multi-gluon / pion exchange
- quark-core effects,
- gaussian form factors, $exp(-\mathbf{k}^2/2\Lambda^2_{B'BM})$
- Simultaneous NN+YN Data (constrained) fit, 4301 NN-data, 38 YN-data:

1. Nucleon-nucleon: pp + np, $\chi^2_{dpt} = 1.135(!)$
2. Hyperon-nucleon: $\Lambda p + \Sigma^\pm p$, $\chi^2_{dpt} = 0.63$

Computational Methods

- coupled channel systems:

NN: $pp \rightarrow pp$, and $np \rightarrow np$
YN: a. $\Lambda p \rightarrow \Lambda p, \Sigma^0 p, \Sigma^+ n$
b. $\Sigma^- p \rightarrow \Sigma^- p, \Sigma^0 n, \Lambda n$
c. $\Sigma^+ p \rightarrow \Sigma^+ p$
YY: $\Lambda\Lambda \rightarrow \Lambda\Lambda, \Xi N, \Sigma\Sigma$

- potential forms:

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

- multi-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

10 e ESC08-model: coupling constants etc.

YN + YY ESC-model 2008/09: ESC08b

- Notice: simultaneous NN + YN fit, $\chi^2_{p.d.p.}(NN) = 1.135$ (!)

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

mesons		$\{1\}$	$\{8\}$	$F/(F+D)$
pseudoscalar	f	0.166	0.265	$\alpha_{PV} = 0.43$
vector	g	3.242	0.778	$\alpha_V^e = 1.0$
	f	-2.745	3.933	$\alpha_V^m = 0.54$
scalar	g	4.174	1.101	$\alpha_S = 0.75$
axial	g	0.707	1.188	$\alpha_A = 0.02$
	f	0.256	-0.189	
pomeron	g	3.335	0.000	$\alpha_D = ---$

$\Lambda_P = 872.1$ MeV, $\Lambda_V = 707.6$, $\Lambda_S = 1193.3$
$\Lambda_P = 893.7$, $\Lambda_V = 1116.5$ $\Lambda_S = 1146.0$, $\Lambda_A = 1254.8$
$\theta_P = -23.00^{o\ \star)}$, $\theta_V = 37.50^{0\ \star)}$, $\theta_A = -40.46^{0\ \star)}$, $\theta_S = 37.50^{o-\star}$
$a_{PV} = 1.0$ (!) Scalar mesons: zero in FF (!)

- Odderon: $g_O = 0.946, f_O = -1.161, m_O = 454.6$ MeV, FI51=1+1.15

11a ESC08b(NN+YN), details NN-fit

χ^2-distribution PSA93 and ESC08b-model

T_{lab}	#data	χ_0^2	$\Delta\chi^2$	$\hat{\chi}_0^2$	$\Delta\hat{\chi}^2$
0.383	144	137.55	31.2	0.960	0.216
1	68	38.02	36.6	0.560	0.539
5	103	82.23	11.2	0.800	0.108
10	209	257.99	25.9	1.234	0.089
25	352	272.20	39.3	0.773	0.112
50	572	547.67	122.8	0.957	0.215
100	399	382.45	25.6	0.959	0.064
150	676	673.05	128.8	0.996	0.191
215	756	754.52	114.4	0.998	0.151
320	954	945.38	271.0	0.991	0.284
Total	4233	4091.12	806.9	0.948	0.187

- χ_0^2: χ^2 PSA93, $\hat{\chi}_0^2$: χ^2_{pdpt} PSA93,
- The χ^2-access ESC08b(NN+YN)-model is denoted

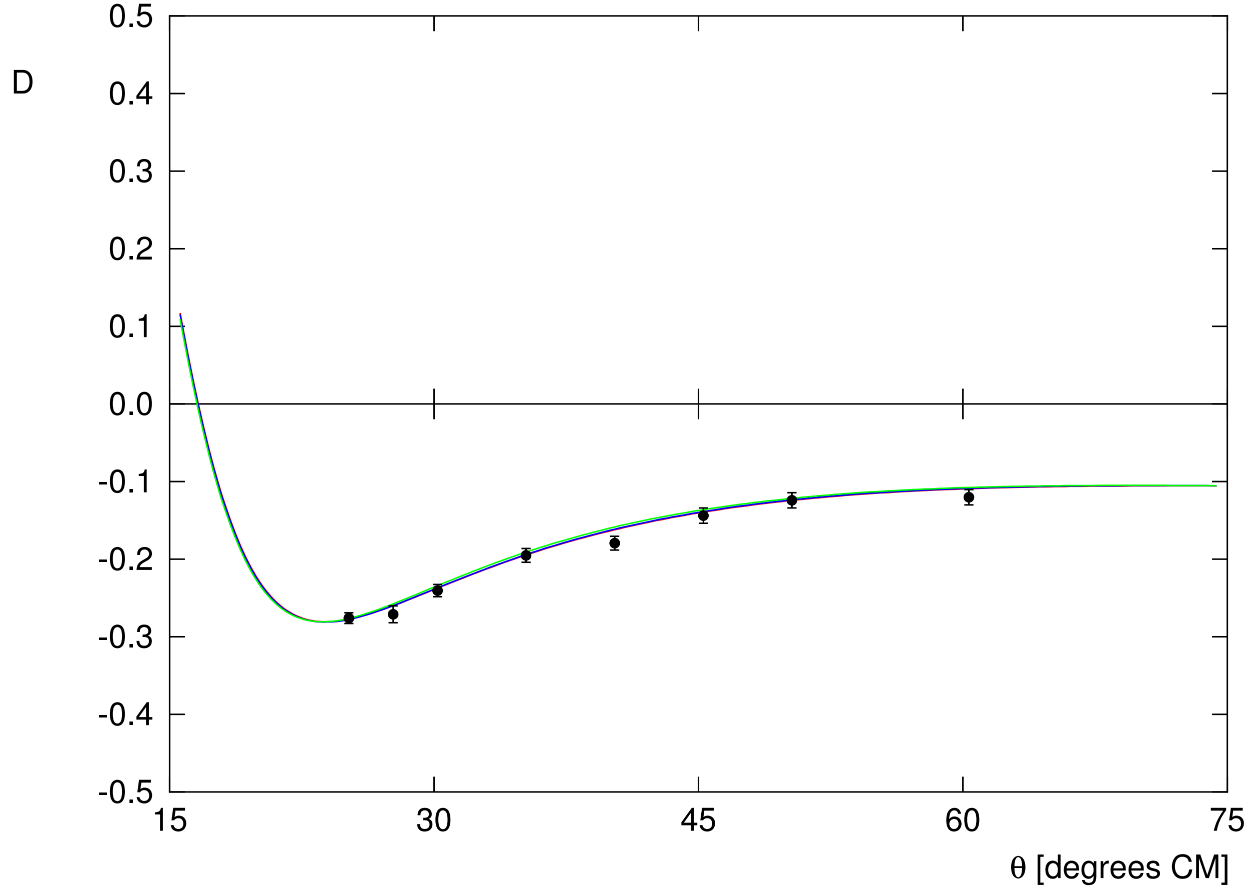
11b ESC08, NN Low-energy parameters

Low energy parameters ESC08b(NN+YN)-model

	Experimental data	ESC08b
$a_{pp}(^1S_0)$	-7.823 $\pm$ 0.010	-7.772
$r_{pp}(^1S_0)$	2.794 $\pm$ 0.015	2.751
$a_{np}(^1S_0)$	-23.715 $\pm$ 0.015	-23.739
$r_{np}(^1S_0)$	2.760 $\pm$ 0.015	2.694
$a_{nn}(^1S_0)$	-18.70 $\pm$ 0.60	-14.91
$r_{nn}(^1S_0)$	2.75 $\pm$ 0.11	2.89
$a_{np}(^3S_1)$	5.423 $\pm$ 0.005	5.423
$r_{np}(^3S_1)$	1.761 $\pm$ 0.005	1.754
E_B	-2.224644 $\pm$ 0.000046	-2.224678
Q_E	0.286 $\pm$ 0.002	0.269

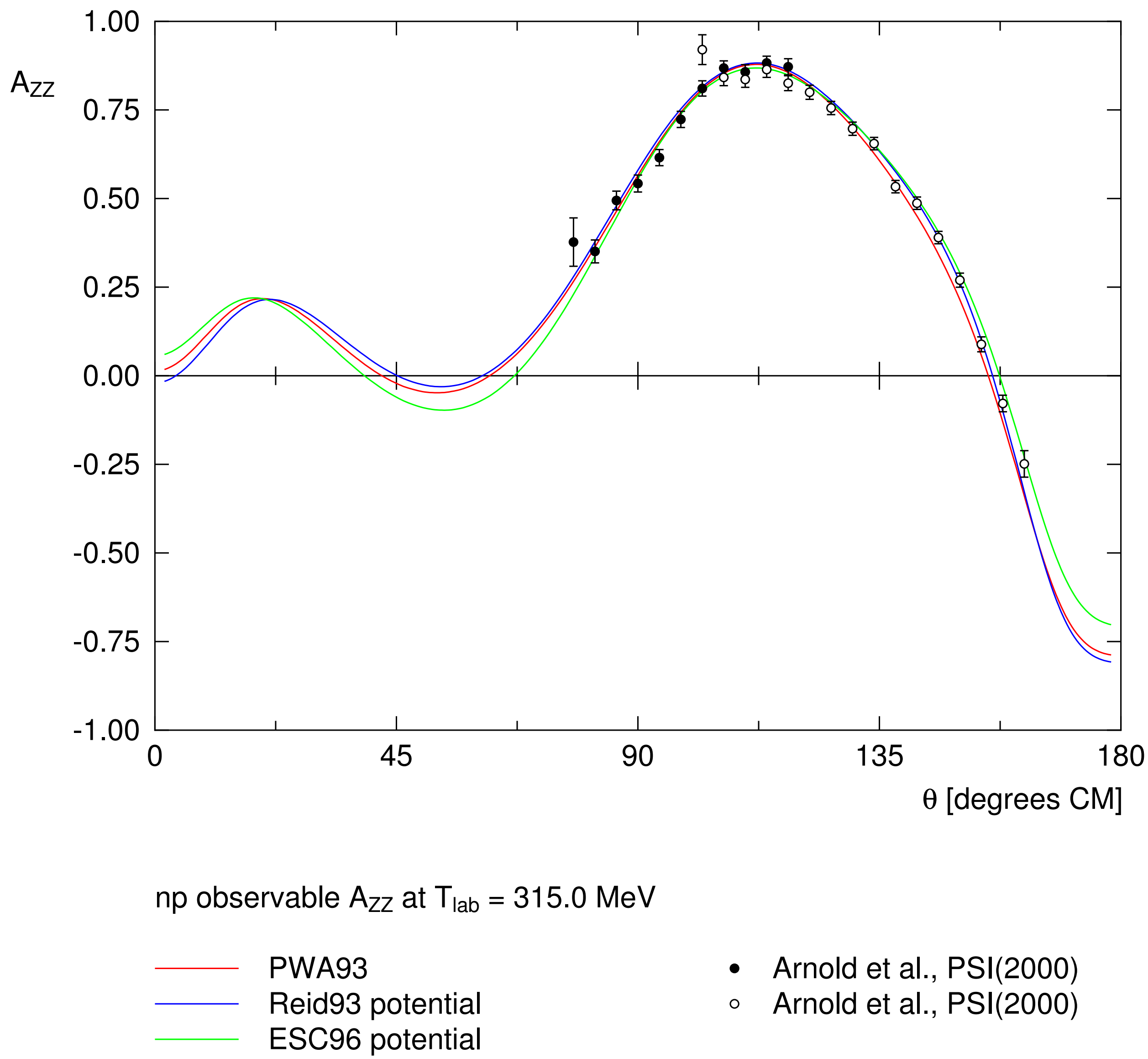
- Units: [a]=[r]=[fm], [E_B]=[MeV], [Q_E]=[fm]^2.

11c PWA-93 and ESC, 1



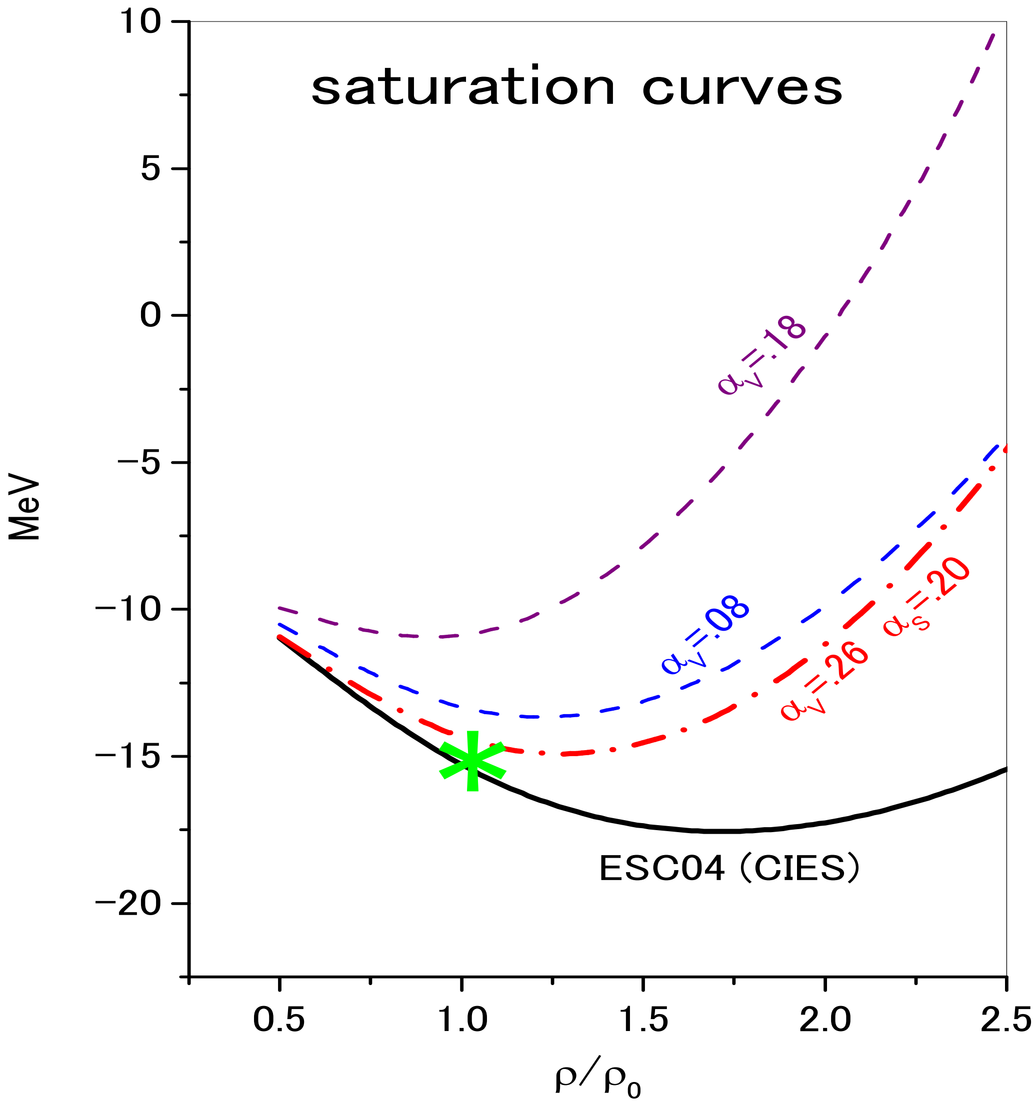
pp observable D at T_{lab} = 25.68 MeV

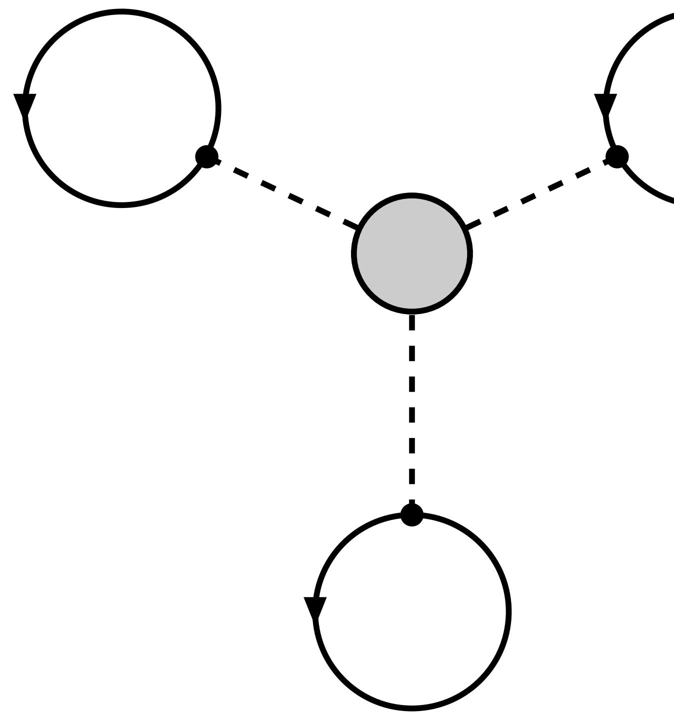
11d PWA-93 and ESC, 2



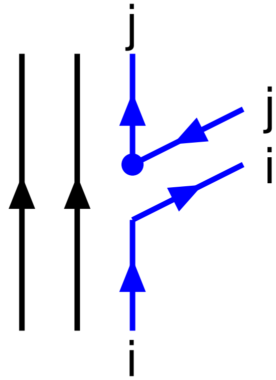
11e Nuclear Matter, Saturation

ESC04(NN): Binding Energy per Nucleon B/A





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



$^3P_0$ Interaction Lagrangian:

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

Fierz Transformation

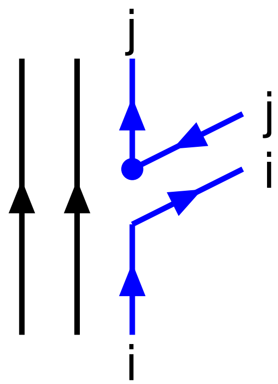
$$\mathcal{L}_I^{(S)} = -\frac{\gamma}{4} \sum_{i,j} \Big[+\ \bar{q}_i\ q_j \cdot \bar{q}_j\ q_i + \ \bar{q}_i \gamma_\mu q_j \cdot \bar{q}_j \gamma^\mu q_i - \ \bar{q}_i \gamma_\mu \gamma_5 q_j \cdot \bar{q}_j \gamma^\mu \gamma^5 q_i + \bar{q}_i \gamma_5 q_j \cdot \bar{q}_j \gamma^5 q_i - \frac{1}{2}\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

$$\chi_{ij}^S \sim \bar{q}_j\ q_i\ ,\ \chi_{\mu,ij}^V \sim \bar{q}_j \gamma_\mu q_i\ ,\ \chi_{\mu,ij}^A \sim \bar{q}_j \gamma_5 \gamma_\mu q_i$$

1. $g_\epsilon = g_\omega$, and $g_{a_0} = g_\rho$!?
2. What about f_π , g_{a_1}, etc. ?
3. $g_{q,ij}^V = g_{q,ij}^S = -g_{q,ij}^A = g_{q,ij}^P$

12b QPC: $^3S_1$-model

Meson-Baryon Couplings from $^3S_1$-Mechanism



$^3S_1$ Interaction Lagrangian:

$$\mathcal{L}_I^{(V)} = \gamma \left(\sum_j \bar{q}_j \gamma_\mu q_j\right) \cdot \left(\sum_i \bar{q}_i \gamma^\mu q_i\right)$$

Fierz Transformation

$$\mathcal{L}_I^{(V)} = -\frac{\gamma}{4} \sum_{i,j} \Big[+ 4\bar{q}_i\, q_j \cdot \bar{q}_j\, q_i - 2\bar{q}_i \gamma_\mu q_j \cdot \bar{q}_j \gamma^\mu q_i - 2\bar{q}_i \gamma_\mu \gamma_5 q_j \cdot \bar{q}_j \gamma^\mu \gamma^5 q_i - 4\bar{q}_i \gamma_5 q_j \cdot \bar{q}_j \gamma^5 q_i \Big]$$

$$\mathcal{L}_I = a\mathcal{L}_I^{(S)} + b\mathcal{L}_I^{(V)} \qquad ESC08b : b/a \approx 1/6$$

1. $g_{\epsilon,a_0} \sim (a-4b),\ g_{\omega,\rho} \sim (a-2b)$!?
2. $g_{A_1,E_1} \sim -(a+2b),\ g_{\pi,\eta} \sim (a-4b)$!?
3. But: $\pi - A_1$-mixing -> Complicated sector!

12d QPC: $^3P_0$-model and ESC04/ESC08

ESC04/08 Couplings and $^3P_0$-Model Relations

Meson	$r_M[fm]$	X_M	γ_M	$^3P_0$	ESC04	ESC08
$\pi(140)$	0.66	$5/6$	4.84	$f = 0.26$	0.26	0.27
$\rho(770)$	0.66	1	2.19	$g = 0.93$	0.78	0.78
$\omega(783)$	0.66	3	2.19	$g = 2.86$	3.08	3.39
$a_0(962)$	0.66	1	2.19	$g = 0.93$	0.82	1.10
$\epsilon(760)$	0.86	3	2.19	$g = 2.85$	3.22	4.09
$a_1(1270)$	0.66	$5\sqrt{2}/6$	2.19	$g = 2.51$	2.43	1.19

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

$$g_\omega = 3 g_\rho, \qquad g_\epsilon = 3 g_{a_0}, \qquad \varepsilon_0(\lambda) \sim \bar{q}q(^3P_0)$$

$$g_{a_0} \approx g_\rho, \qquad g_\epsilon \approx g_\omega \qquad \varepsilon_a(\lambda) \sim \bar{q}q(^3S_1)$$

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

12f HBS and ESC04/ESC08 Pair-couplings

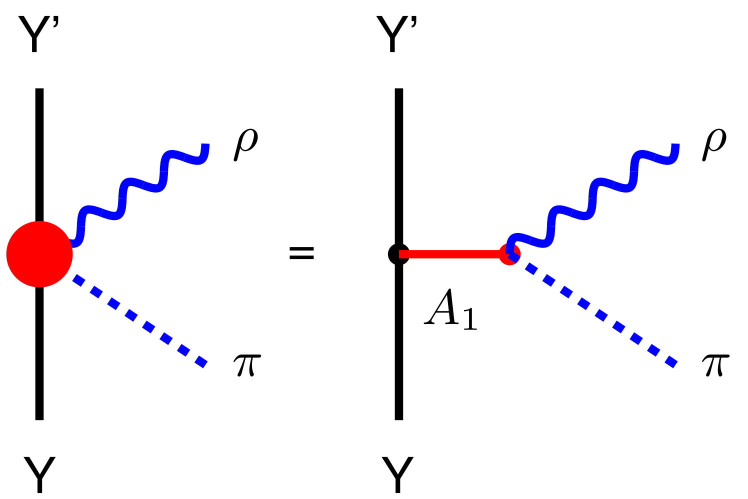
ESC04/08 Pair-couplings with HBS and QPC

J^{PC}	Coupling	HBS	HBS	ESC04d	ESC08b	$F/(F+D$
0^{++}	$g_{(\pi\pi)_0}$	-0.03	$f_0(760, 993), P$	0.00	0.00	—
	$g_{(\pi\eta)_1}$	-0.28	$a_0(980, 1450)$	–0.10	-0.02	1.00
1^{--}	$g_{(\pi\pi)_1}$	0.04	$\rho(760)$	0.03	0.00	1.00
	$f_{(\pi\pi)_1}$	0.16	$\rho(760)$	0.14	-0.24	0.40
1^{++}	$g_{(\pi\rho)_1}$	0.42	$A_1(1270)$	0.83	0.62	-0.28
	$g_{(\pi\sigma)_1}$	0.31	$A_1(1270)$	–0.04	-0.03	-0.28
1^{+-}	$g_{(\pi\omega)_1}$	-0.16	$B_1(1235)$	-0.17	-0.07	0.43

- Heavy-boson-saturation (HBS) comparison Pair-couplings and $F/(F+D)$-ratio's:

SU(3)-Extension ESC to Hyperon-Nucleon

- MPE: Boson-dominance model:



$$
\begin{aligned}
g_{Y'Y(\rho\pi)_1} &= \hat{g}_{Y'YA_1} g_{A_1\rho\pi} \cdot \left(m_\pi^2/m_{A_1}^2\right) \;, \quad \text{e.g.} \\
g_{\Sigma\Lambda(\rho\pi)_1} &= \hat{g}_{\Sigma\Lambda A_1} g_{A_1\rho\pi} \left(m_\pi^2/m_{A_1}^2\right) \\
&= \left(\hat{g}_{\Sigma\Lambda A_1}/\hat{g}_{NNA_1}\right) \; g_{NN(\rho\pi)_1} \\
&= \frac{2}{\sqrt{3}}(1-\alpha_A) g_{NN(\rho\pi)_1}
\end{aligned}
$$

13b Short-range Phenomenology-3

$SU(6)_{fs}$-contents of the various potentials on the isospin,spin basis.

	(S,I)	$V = aV_{[51]} + bV_{[33]}$
$NN \to NN$	$(0,1)$	$V_{NN}(I=1) = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$NN \to NN$	$(1,0)$	$V_{NN} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$\Lambda N \to \Lambda N$	$(0,1/2)$	$V_{\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Lambda N \to \Lambda N$	$(1,1/2)$	$V_{\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Sigma N \to \Sigma N$	$(0,1/2)$	$V_{\Sigma\Sigma} = \frac{17}{18}V_{[51]} + \frac{1}{18}V_{[33]}$
$\Sigma N \to \Sigma N$	$(1,1/2)$	$V_{\Sigma\Sigma} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Sigma N \to \Sigma N$	$(0,3/2)$	$V_{\Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$\Sigma N \to \Sigma N$	$(1,3/2)$	$V_{\Sigma\Sigma} = \frac{8}{9}V_{[51]} + \frac{1}{9}V_{[33]}$

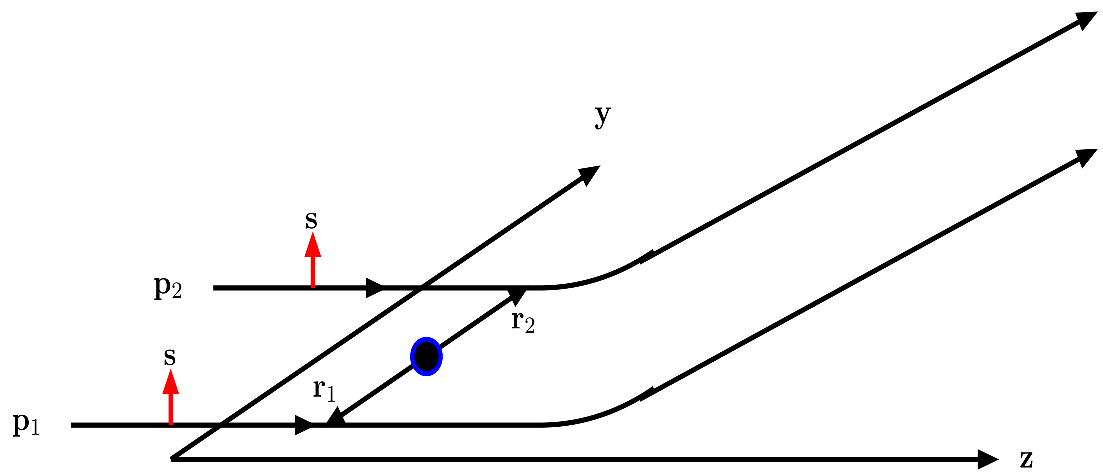
14a ESC08-model: $\Sigma^+ P$-phases

ESC08b nuclear-bar $\Sigma^+ p$ phases in degrees:

p_{Σ^+}	200	400	600	800	1000
$T_{\rm lab}$	16.7	65.5	142.8	244.0	364.5
$^1S_0$	29.65	18.03	2.20	-12.59	-25.82
$^3S_1$	-15.34	-31.84	-47.42	-59.89	-68.06
ϵ_1	-2.05	-5.69	-8.09	-9.64	-10.93
$^3P_0$	6.54	15.76	15.32	12.49	11.55
$^1P_1$	2.25	5.41	4.13	-0.03	-4.04
ρ_1	0.00	0.00	0.00	0.00	0.00
$^3P_1$	-3.20	-9.80	-16.93	-24.24	-30.64
$^3P_2$	1.63	10.54	23.85	35.40	41.07
ϵ_2	-0.41	-2.09	-2.99	-2.41	-1.33
$^3D_1$	0.34	1.70	1.52	-1.94	-8.03
$^1D_2$	0.34	2.23	5.40	8.14	8.77
$^3D_2$	-0.49	-2.68	-5.69	-10.03	-15.73
$^3D_3$	0.05	0.59	0.82	-0.94	-4.69

ESC08b: Left-Right asymmetry $\Sigma^+ P$

Left-Right Asymmetry Polarized-beam Scattering (e.g. $\Lambda, \Sigma^+ p$)



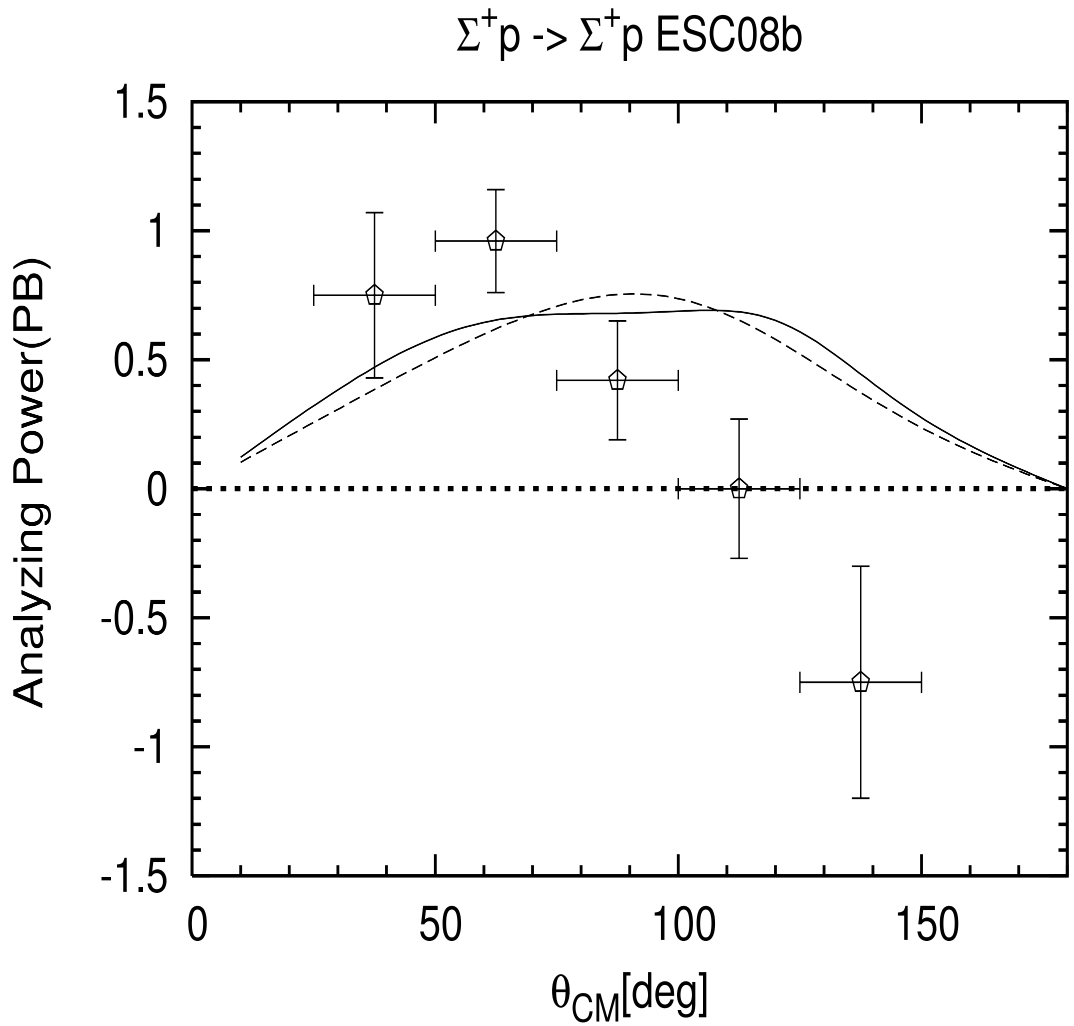
$$V = V_{SO}\mathbf{L}\cdot\mathbf{S}\ ,\ V_{SO} < 0, \quad Asymmetry = \frac{L-R}{L+R} > 0$$

$\mathbf{P}_b = \mathbf{s} \parallel x-axis: \quad (p_1, r_1) \to \mathbf{L}\cdot\mathbf{S} > 0, \quad V < 0 \ ; \quad (p_2, r_2) \to \mathbf{L}\cdot\mathbf{S} < 0 \quad V > 0.$

$$\bar{\epsilon} = \left\{ \int_0^\pi d\phi \int_{-1}^{+1} d\cos\theta \frac{d\sigma}{d\Omega} - \int_\pi^{2\pi} d\phi \int_{-1}^{+1} d\cos\theta \frac{d\sigma}{d\Omega} \right\} / \sigma_{tot} \Rightarrow 2\pi A_4/\sigma_{tot}$$

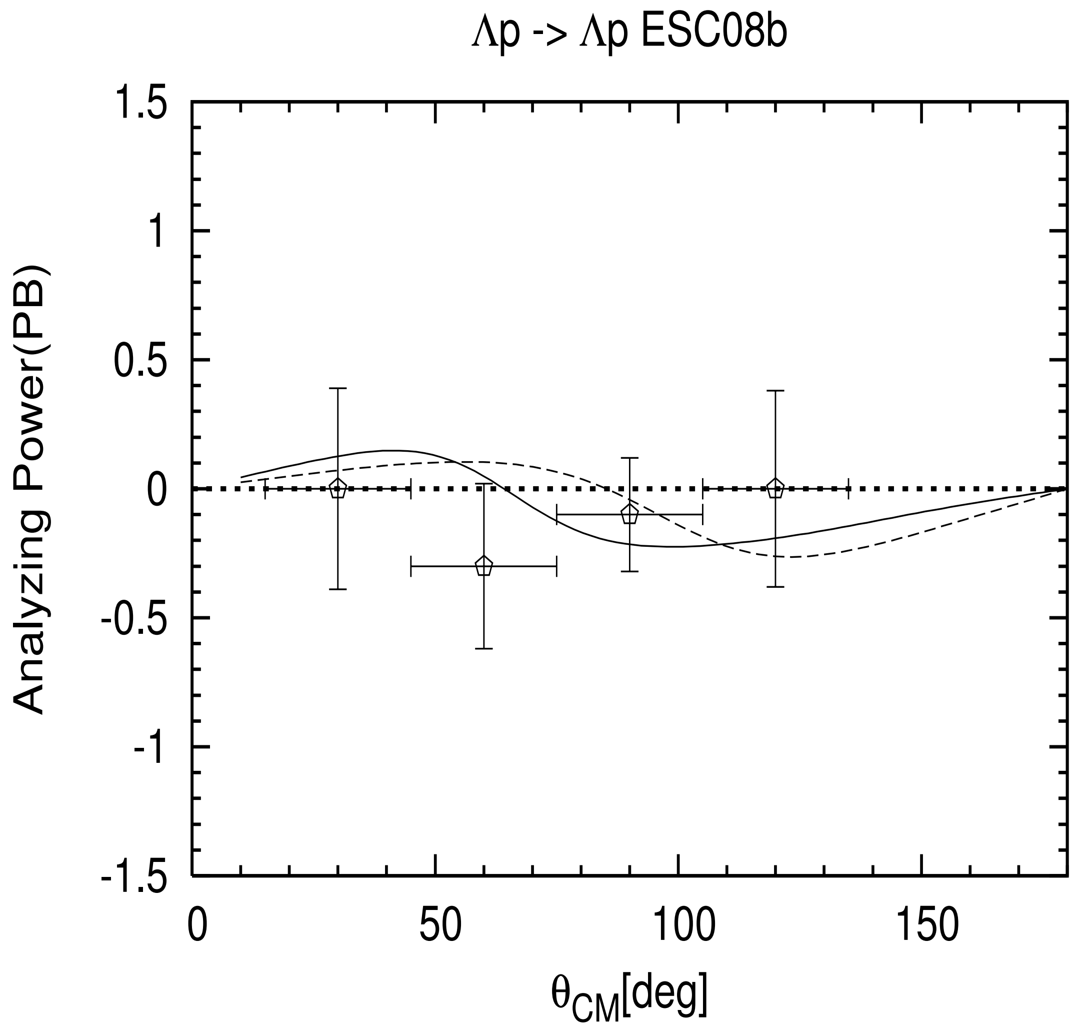
$$A_4 = \frac{1}{8}\Im\left[2S_1\left(2P_0^* + 3P_1^* - 5P_2^*\right) + \sqrt{2}D\left(4P_0^* - 3P_1^* - P_2^*\right)\right]$$

ESC08b: Left-Right asymmetry $\Sigma^+ P$



- Data: Nakai et al

ESC08b: Left-Right asymmetry $\Lambda^+ P$



- Data: Nakai et al

14b ESC08-model: ΛP-phases

ESC08b nuclear-bar Λp phases in degrees:

p_Λ	100	200	300	400	500	600	633.4
$T_{\rm lab}$	4.5	17.8	39.6	69.5	106.9	151.1	167.3
$^1S_0$	25.91	31.41	27.76	21.23	14.04	7.14	5.20
$^3S_1$	19.72	26.34	25.32	21.97	19.52	25.20	47.59
ϵ_1	0.18	0.97	2.36	4.40	8.12	17.35	30.36
$^3P_0$	0.07	0.43	0.88	0.88	0.21	-0.84	
$^1P_1$	-0.09	-0.66	-2.06	-4.34	-7.30	-10.46	
$^3P_1$	-0.01	-0.17	-0.75	-1.91	-3.52	-5.11	
$^3P_2$	0.15	1.05	2.93	5.51	8.39	11.36	
ϵ_2	0.00	-0.01	-0.07	-0.22	-0.46	-0.76	
$^3D_1$	0.00	0.07	0.46	1.68	4.57	11.87	16.74
$^1D_2$	0.00	0.06	0.37	1.16	2.44	4.05	
$^3D_2$	0.00	0.09	0.48	1.41	2.92	4.84	
$^3D_3$	0.00	0.04	0.24	0.70	1.37	2.05	

- $a_s = -2.56 \text{fm}$, $r_s = 3.14 \text{fm}$

ESC08-model: YN-results I

ESC08b YN+YY Fitting results (I):

$\Lambda p \to \Lambda p$: $\chi^2 = 4.94$

1	$p_\Lambda = 135$	180.0	$\pm$	22.0	THEORY=	211.5	$\chi^2 = 2.05$
2	$p_\Lambda = 145$	130.0	$\pm$	17.0	THEORY=	146.8	$\chi^2 = 0.97$
3	$p_\Lambda = 165$	118.0	$\pm$	16.0	THEORY=	114.7	$\chi^2 = 0.01$
4	$p_\Lambda = 185$	101.0	$\pm$	12.0	THEORY=	97.3	$\chi^2 = 0.10$
5	$p_\Lambda = 195$	83.0	$\pm$	9.0	THEORY=	81.2	$\chi^2 = 0.04$
6	$p_\Lambda = 210$	57.0	$\pm$	9.0	THEORY=	57.2	$\chi^2 = 0.00$
7	$p_\Lambda = 225$	209.0	$\pm$	58.0	THEORY=	231.4	$\chi^2 = 0.15$
8	$p_\Lambda = 230$	177.0	$\pm$	38.0	THEORY=	176.3	$\chi^2 = 0.00$
9	$p_\Lambda = 250$	153.0	$\pm$	27.0	THEORY=	133.9	$\chi^2 = 0.50$
10	$p_\Lambda = 255$	111.0	$\pm$	18.0	THEORY=	101.8	$\chi^2 = 0.26$
11	$p_\Lambda = 290$	87.0	$\pm$	13.0	THEORY=	77.7	$\chi^2 = 0.51$
12	$p_\Lambda = 300$	46.0	$\pm$	11.0	THEORY=	52.5	$\chi^2 = 0.35$

ESC08-model: YN-results II

ESC08b YN+YY Fitting results (II):

$\Sigma^- p \to \Sigma^- p$:								$\chi^2 = 4.73$
13	$p_{\Sigma^-} = 142.5$	152.0	$\pm$	38.0	THEORY=	134.6		$\chi^2 = 0.21$
14	$p_{\Sigma^-} = 147.5$	146.0	$\pm$	30.0	THEORY=	128.9		$\chi^2 = 0.33$
15	$p_{\Sigma^-} = 152.5$	142.0	$\pm$	25.0	THEORY=	123.6		$\chi^2 = 0.54$
16	$p_{\Sigma^-} = 157.5$	164.0	$\pm$	32.0	THEORY=	118.7		$\chi^2 = 2.01$
17	$p_{\Sigma^-} = 162.5$	138.0	$\pm$	19.0	THEORY=	114.0		$\chi^2 = 1.60$
18	$p_{\Sigma^-} = 167.5$	113.0	$\pm$	16.0	THEORY=	109.6		$\chi^2 = 0.04$
$\Sigma^- p \to \Sigma^0 n$:								$\chi^2 = 5.78$
19	$p_{\Sigma^-} = 110$	396.0	$\pm$	91.0	THEORY=	193.4		$\chi^2 = 4.96$
20	$p_{\Sigma^-} = 120$	159.0	$\pm$	43.0	THEORY=	171.9		$\chi^2 = 0.09$
21	$p_{\Sigma^-} = 130$	157.0	$\pm$	34.0	THEORY=	152.3		$\chi^2 = 0.02$
22	$p_{\Sigma^-} = 140$	125.0	$\pm$	25.0	THEORY=	136.8		$\chi^2 = 0.22$
23	$p_{\Sigma^-} = 150$	111.0	$\pm$	19.0	THEORY=	124.1		$\chi^2 = 0.48$
24	$p_{\Sigma^-} = 160$	115.0	$\pm$	16.0	THEORY=	113.5		$\chi^2 = 0.01$

14c ESC08-model, YN-results III

ESC08b YN+YY Fitting results (III):

$\Sigma^- p \to \Lambda n$:				$\chi^2 = 4.55$
25	$p_{\Sigma^-} = 142.5$	174.0 ± 47.0	THEORY= 238.4	$\chi^2 = 1.88$
26	$p_{\Sigma^-} = 142.5$	178.0 ± 39.0	THEORY= 203.8	$\chi^2 = 0.44$
27	$p_{\Sigma^-} = 142.5$	140.0 ± 28.0	THEORY= 176.1	$\chi^2 = 1.66$
28	$p_{\Sigma^-} = 142.5$	164.0 ± 25.0	THEORY= 153.8	$\chi^2 = 0.16$
29	$p_{\Sigma^-} = 142.5$	147.0 ± 19.0	THEORY= 135.7	$\chi^2 = 0.35$
30	$p_{\Sigma^-} = 142.5$	124.0 ± 14.0	THEORY= 120.7	$\chi^2 = 0.06$
Capture ratio at rest: r_C :				
31		0.468 ± 0.010	THEORY= 0.466	$\chi^2 = 0.06$

14d ESC08-model, YN-results IV

ESC08b YN+YY Fitting results (IV):

$\Sigma^+ p$:							$\chi^2 = 4.04$
32	$p_{\Sigma+} = 145$	123.0	$\pm$	62.0	THEORY=	112.2	$\chi^2 = 0.03$
33	$p_{\Sigma+} = 155$	104.0	$\pm$	30.0	THEORY=	105.7	$\chi^2 = 0.00$
34	$p_{\Sigma+} = 165$	92.0	$\pm$	18.0	THEORY=	100.0	$\chi^2 = 0.20$
35	$p_{\Sigma+} = 175$	81.0	$\pm$	12.0	THEORY=	94.8	$\chi^2 = 1.32$
36†	$p_{\Sigma+} = 400$	74.8	$\pm$	25.0	THEORY=	55.1	$\chi^2 = 0.62$
37†	$p_{\Sigma+} = 500$	26.0	$\pm$	20.0	THEORY=	53.4	$\chi^2 = 1.87$
38†	$p_{\Sigma+} = 650$	51.7	$\pm$	40.0	THEORY=	51.9	$\chi^2 = 0.00$
Total 38 Scattering data:							$\chi^2 = 24.10$

- $\dagger$: Kanda et al, Nucl.Phys. 2005

14e ESC08b-model: YN-results V

ESC08b YN+YY: Pseudo-data (constraints):

Low-Energy Parameters Λp:									
a_s	-1.95	$\pm$	0.10	THEORY=	-2.56	Φ^2	$=$	37.3
a_t	-1.86	$\pm$	0.01	THEORY=	-1.80	Φ^2	$=$	31.7
r_s	2.90	$\pm$	0.10	THEORY=	3.14	Φ^2	$=$	—
r_t	2.70	$\pm$	0.10	THEORY=	3.35	Φ^2	$=$	—
Low-Energy Parameters $\Sigma^+ p$:									
a_t	+0.62	$\pm$	0.05	THEORY=	0.78	Φ^2	$=$	10.8
r_s	—	$\pm$	—	THEORY=	-1.33	Φ^2	$=$	—
Low-Energy Parameters $\Lambda\Lambda$:									
a_s	-1.00	$\pm$	0.10	THEORY=	-0.47	Φ^2	$=$	111.0
r_s	—	$\pm$	—	THEORY=	8.19	Φ^2	$=$	—
Low-Energy Parameters ΞN:									
$a_t(I=0)$	-6.00	$\pm$	0.10	THEORY=	-0.03	Φ^2	$=$	—
$a_t(I=1)$	-6.00	$\pm$	0.05	THEORY=	+1.99	Φ^2	$=$	—
Spin-orbit constraint Λp:									
$K_\Lambda(V)$	0.00	$\pm$	0.10	THEORY=	1.65	Φ^2	$=$	67.7

15a G-matrix ESC-models

Partial wave contributions to $U_\Lambda(\rho_0)^{(a)}$

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
	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	sum
ESC04a	–13.7	–20.5	0.6	0.2	0.5	–4.5	–1.0	–38.5
ESC04d	–13.6	–26.6	3.2	–0.2	0.9	–6.4	–1.4	–44.1
ESC08b	–12.3	–19.7	2.7	–0.2	1.5	–4.2	–1.7	–34.0
ESC08b*	–13.3	–25.1	2.5	–0.2	1.4	–4.5	–1.7	–41.0

- (a): QTQ-approximation, ESC08*: CIES-method

- private communication Y. Yamamoto

15b G-matrix ESC-models

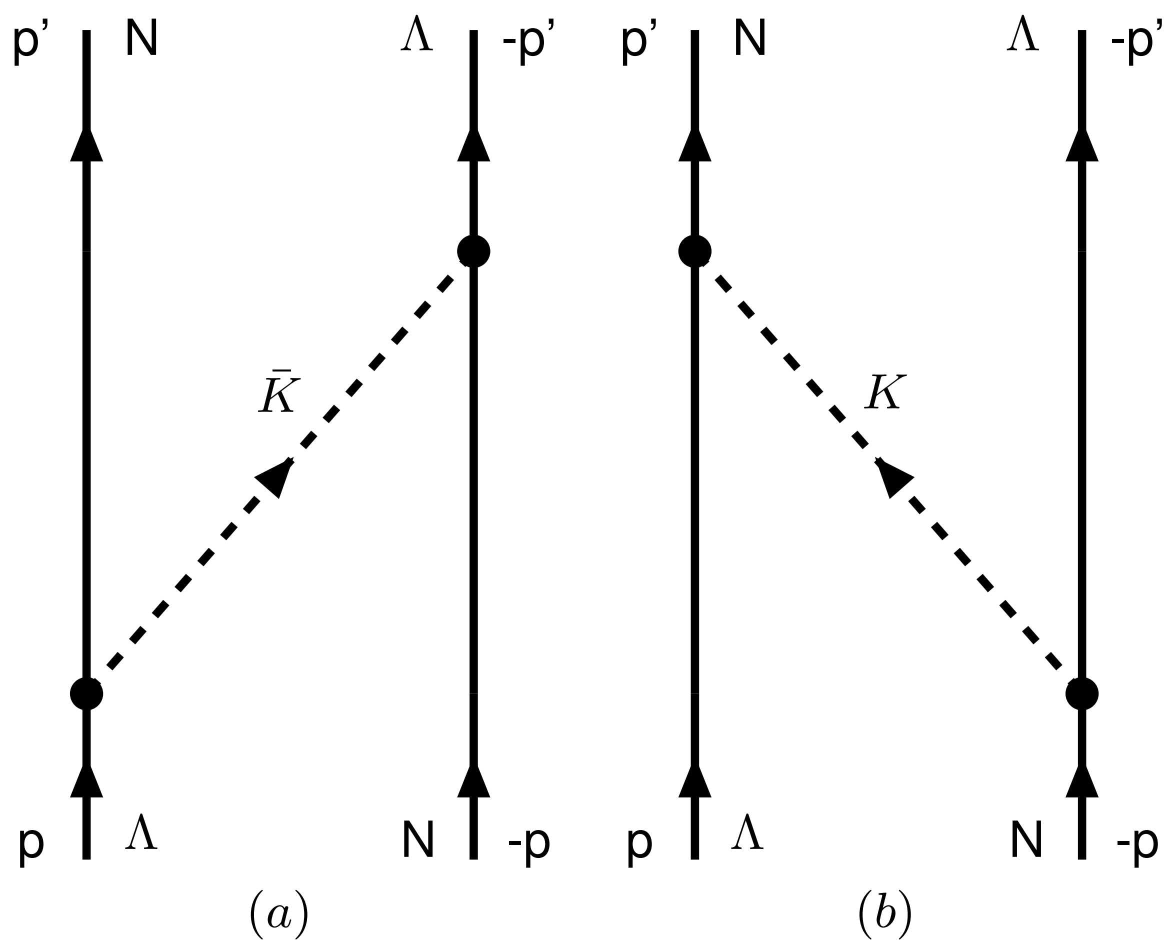
Partial wave contributions to $U_\Sigma(\rho_0)$

model	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Σ
NSC97f	$1/2$	14.9	–9.6	1.9	2.3	–4.0	0.4	–0.4	
	$3/2$	–12.2	–4.2	–3.8	–1.8	5.5	–2.7	–0.2	–13.9
ESC04d	$1/2$	6.5	–21.0	2.6	2.4	–6.7	–1.7	–0.9	
	$3/2$	–10.1	14.0	–8.5	–2.6	5.9	–5.7	–0.2	–26.0
ESC06d	$1/2$	7.2	–21.5	1.9	2.3	–6.1	–1.0	–0.8	
	$3/2$	–10.8	39.1	–10.6	–2.5	6.0	–4.5	–0.1	–1.2
ESC06d*	$1/2$	8.1	–20.5	2.1	2.3	–6.0	–1.0	–0.8	
	$3/2$	–10.1	43.8	–10.6	–2.2	6.3	–3.6	–0.0	+8.2
ESC08b	$1/2$	10.3	–26.2	2.5	2.2	–7.9	–1.7	–0.8	
	$3/2$	–10.6	52.7	–6.2	–2.0	7.4	0.8	–0.1	+20.3

- private communication Y. Yamamoto

VLS and VLSA Spin-orbit OBE-graphs, I

Strangeness Exchange (a,b)-graphs



Figuur 9: K,K*-exchange time-ordered graphs.

16a VLS and VLSA Spin-orbit OBE-graphs, II

BDI70 ALS-potentials for strange-meson-exchanges

$$(a) \oplus (b) \quad : \quad \widetilde{V}_K(\mathbf{q},\mathbf{k}) = -\frac{f_P^2}{m_\pi^2}\left[\frac{1}{2\omega}\left\{\frac{1}{\omega-a}+\frac{1}{\omega+a}\right\}\boldsymbol{\sigma}_1\cdot\mathbf{k}\boldsymbol{\sigma}_2\cdot\mathbf{k}\right.$$

$$\left.+\frac{1}{M_\Lambda+M_N}\left\{\frac{1}{\omega-a}-\frac{1}{\omega+a}\right\}(\boldsymbol{\sigma}_1\cdot\mathbf{k}\boldsymbol{\sigma}_2\cdot\mathbf{q}-\boldsymbol{\sigma}_1\cdot\mathbf{q}\boldsymbol{\sigma}_2\cdot\mathbf{k})\right]$$

$$\Rightarrow \quad -\frac{f_P^2}{m_\pi^2}\left[-2\frac{M_\Lambda-M_N}{M_\Lambda+M_N}\Big(\boldsymbol{\sigma}_1\cdot\mathbf{k}\boldsymbol{\sigma}_2\cdot\mathbf{q}-\boldsymbol{\sigma}_1\cdot\mathbf{q}\boldsymbol{\sigma}_2\cdot\mathbf{k}\Big)\right]\mathcal{P}_f\cdot\frac{1}{\omega^2-}$$

Notice: this result corresponds with the answer in the PS-PS theory!

$$P_8 = 2\Big(\boldsymbol{\sigma}_1\cdot\mathbf{q}\boldsymbol{\sigma}_2\cdot\mathbf{k}-\boldsymbol{\sigma}_1\cdot\mathbf{k}\boldsymbol{\sigma}_2\cdot\mathbf{q}\Big)\;,\quad P_6=(i/2)\,(\boldsymbol{\sigma}_1-\boldsymbol{\sigma}_2)\cdot\mathbf{n}$$

$$= -(1+\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\;P_6$$

This leads to the following expression $(a = M_\Lambda - M_N)$

$$\widetilde{V}_K(\mathbf{q},\mathbf{k}) \quad\Rightarrow\quad -\frac{f_P^2}{m_\pi^2}\left[2\frac{M_\Lambda-M_N}{M_\Lambda+M_N}\cdot(i/2)\,(\boldsymbol{\sigma}_1-\boldsymbol{\sigma}_2)\cdot\mathbf{n}\right]\mathcal{P}_x\cdot\frac{1}{\omega^2-a^2}$$

16b VLS and VLSA Spin-orbit ESC-models, II

Strengths of Λ spin-orbit potential-integrals

$$\begin{aligned} K_\Lambda &= K_{S,\Lambda} + K_{A,\Lambda} \ \text{ where} \\ K_{S,\Lambda} &= -\frac{\pi}{3} S_{SLS} \ \text{ and } \ K_{A,\Lambda} = -\frac{\pi}{3} S_{ALS} \ \text{ with} \\ S_{SLS,ALS} &= \frac{3}{q}\int_0^\infty r^3 j_1(qr) V_{SLS,ALS}(r) dr \ . \end{aligned}$$

	K_S	K_A	$K_\Lambda^{(0)}$	$K_\Lambda(BDI)$	$K_\Lambda(Pair)$	ΔE_{LS}
ESC04b	16.0	–8.7	7.3	(–2.4)	(–3.3)	
ESC04d	22.3	–6.9	15.4	(–5.0)	(–6.9)	
NILS06d	21.5	–6.1	15.4	(–5.1)	(–6.6)	
ESC07	20.9	–9.6	11.3	(–4.7)	(–5.2)	
NHC-D	30.7	–5.9	24.8	(-3.4)	—	0.15*
NHC-F	29.7	–6.7	23.0	(-3.8)	—	0.20*
Experiment						0.031

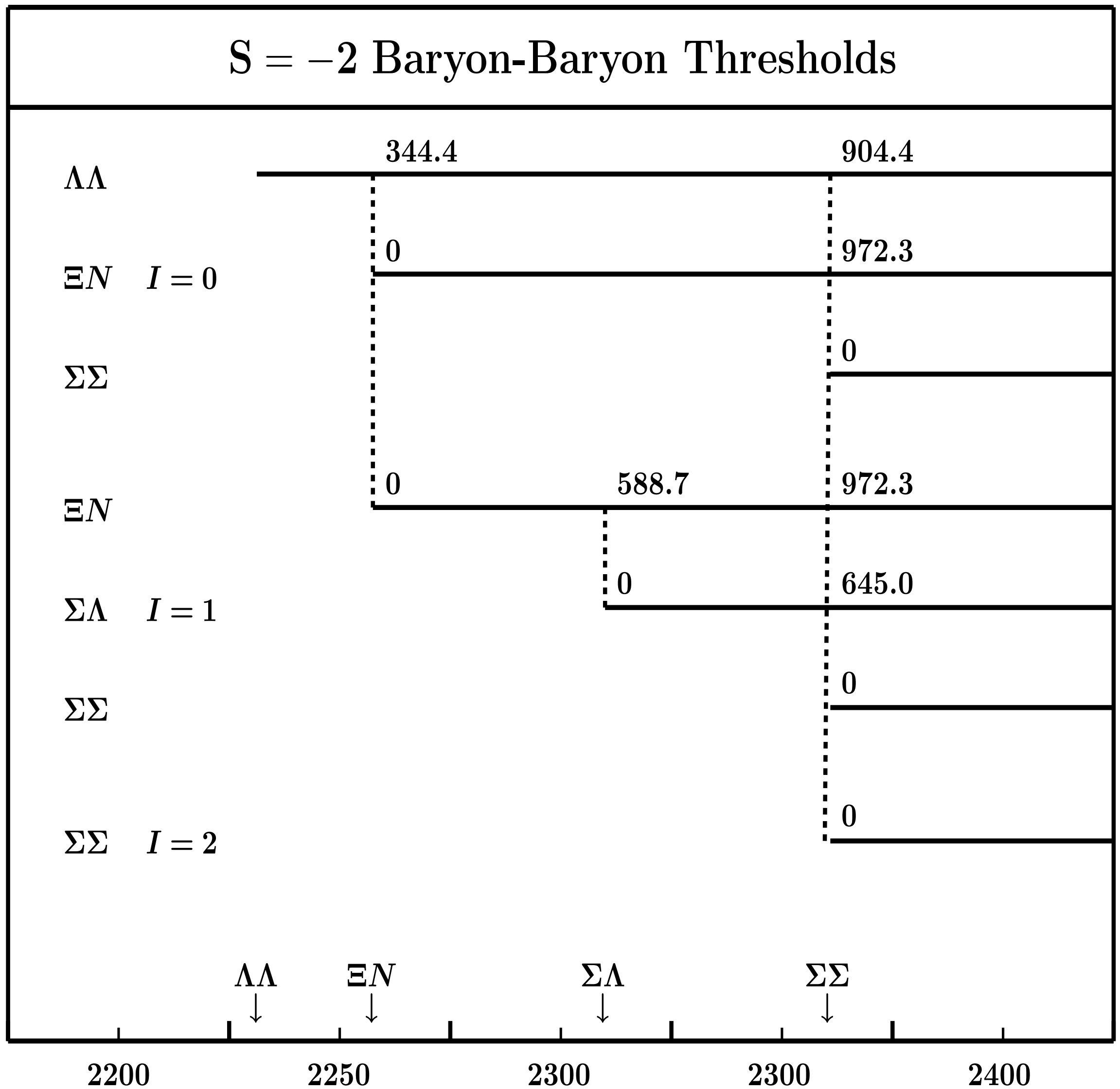
• private communication Y. Yamamoto

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

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

17a ESC-models: $S = -2$ YY,YN

YY: The $\Lambda\Lambda$-systems etc. ESC2004/06



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17b ESC-models: YY

YY: The $\Lambda\Lambda$-systems ESC2004/07

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

$$\Xi^- +^{12} C \rightarrow^{10}_{\Lambda\Lambda} Be + p + 2n \ , \ \Xi^- +^{14} N \rightarrow^{10}_{\Lambda\Lambda} Be + t + p + n$$

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

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

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

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

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

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

- 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.
- ESC04d-model: $\Delta B_{\Lambda\Lambda} \approx 1.0$ MeV !!
  Ξ-well-depth =-18.7 MeV $\approx$ experiment -(14-16) MeV (!?)

17c ESC-models: YY

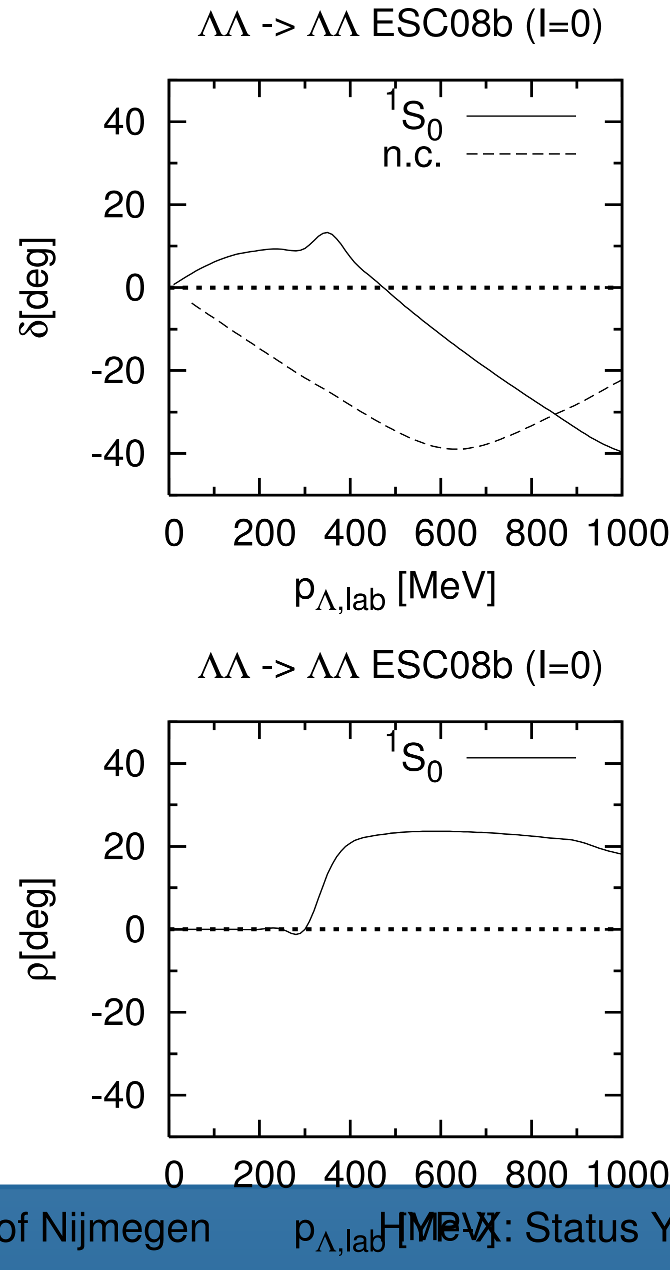
$\Delta B_{\Lambda\Lambda}$ Nijmegen ESC-models:

model	$\Delta B_{\Lambda\Lambda}$ MeV	$P_{\Xi N}()$
ESC04a	1.36	0.44
ESC04b	1.37	0.45
ESC04c	0.97	1.15
ESC04d	0.98	1.18
ESC07	0.80	
NSC97f	0.34	0.19
NHC-D[a]	1.05	0.14
exp[b]	1.01 ± 0.20	

- a: NHC-D $r_{HC} = 0.53$ fm.
- b: H. Takahashi et al, PRL 87, 212502 (2001)

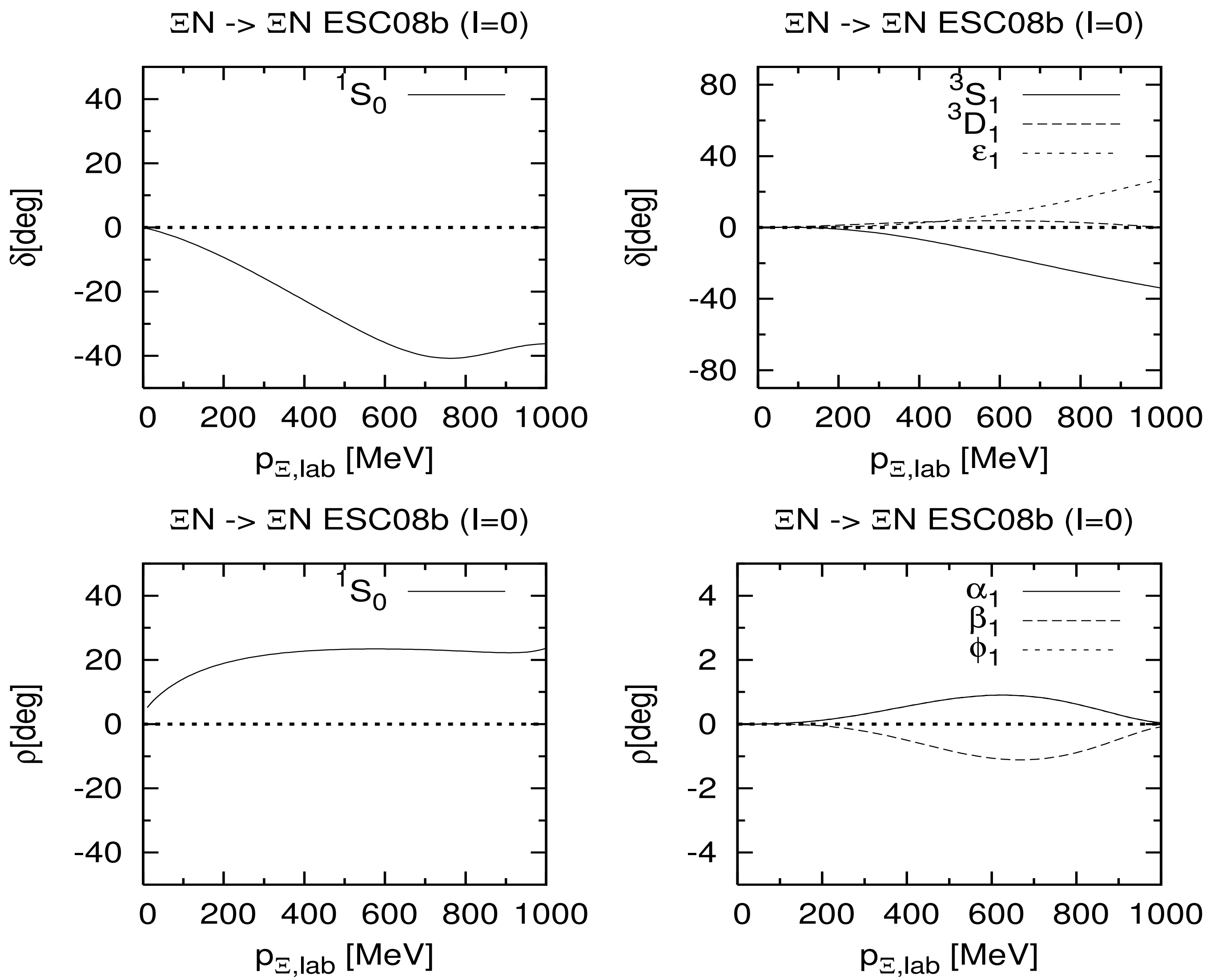
18a $\Lambda\Lambda$-phases

$\Lambda\Lambda$ phases



18b ΞN-phases

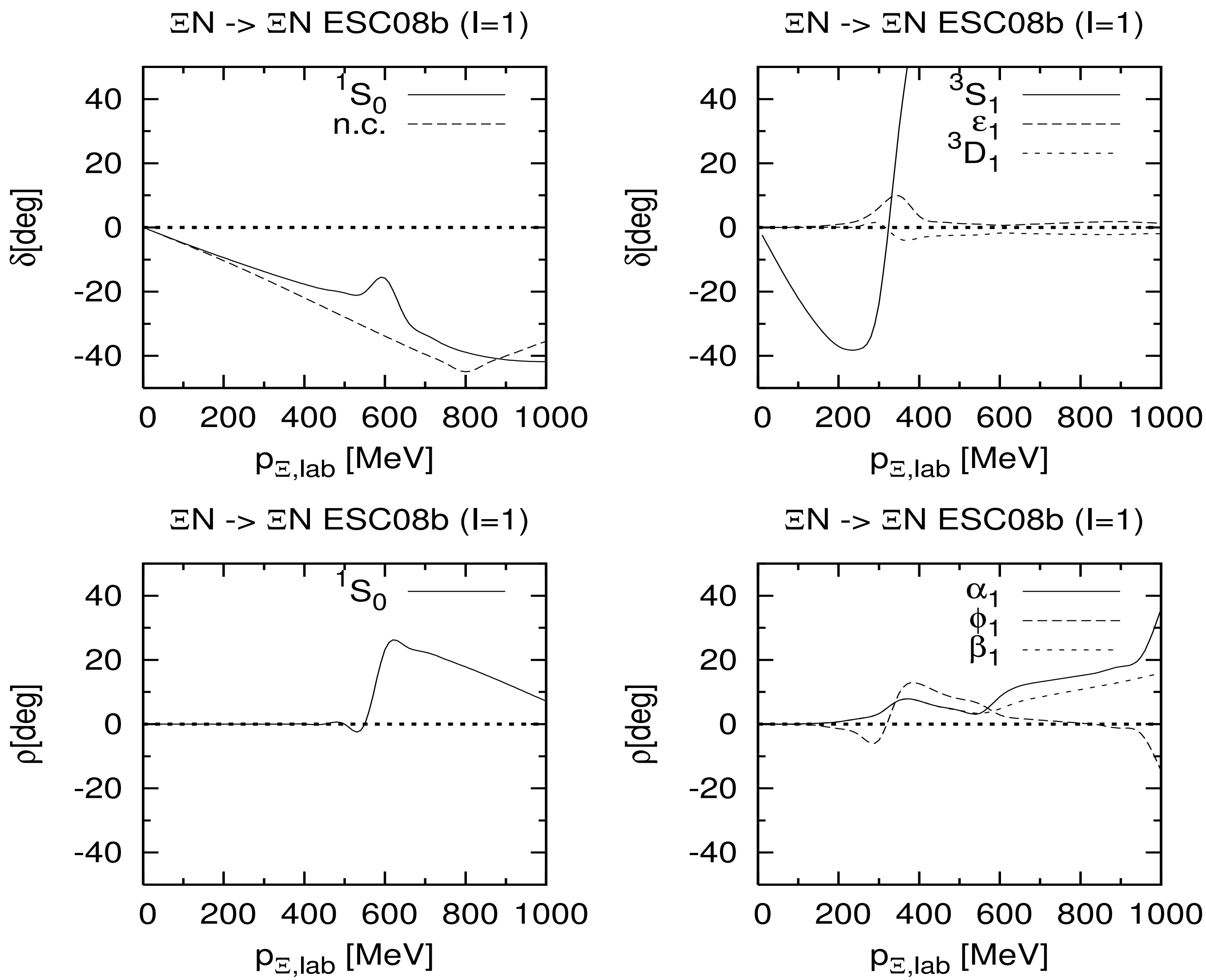
ΞN phases



Figuur 11: ESC08b $I = 0$ ΞN-phases.

18c ΞN-phases

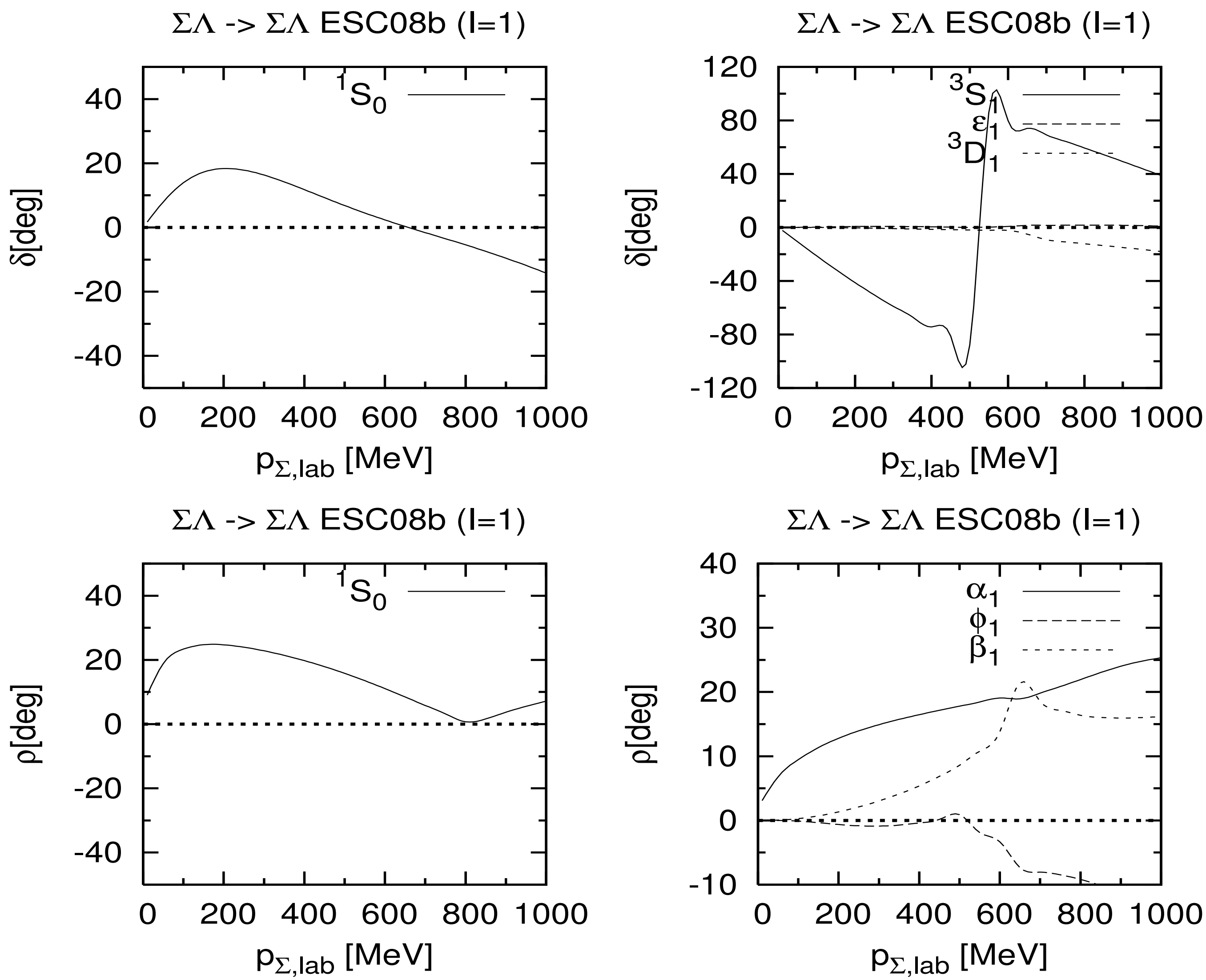
ΞN phases



Figuur 12: ESC08b $I = 1$ ΞN-phases.

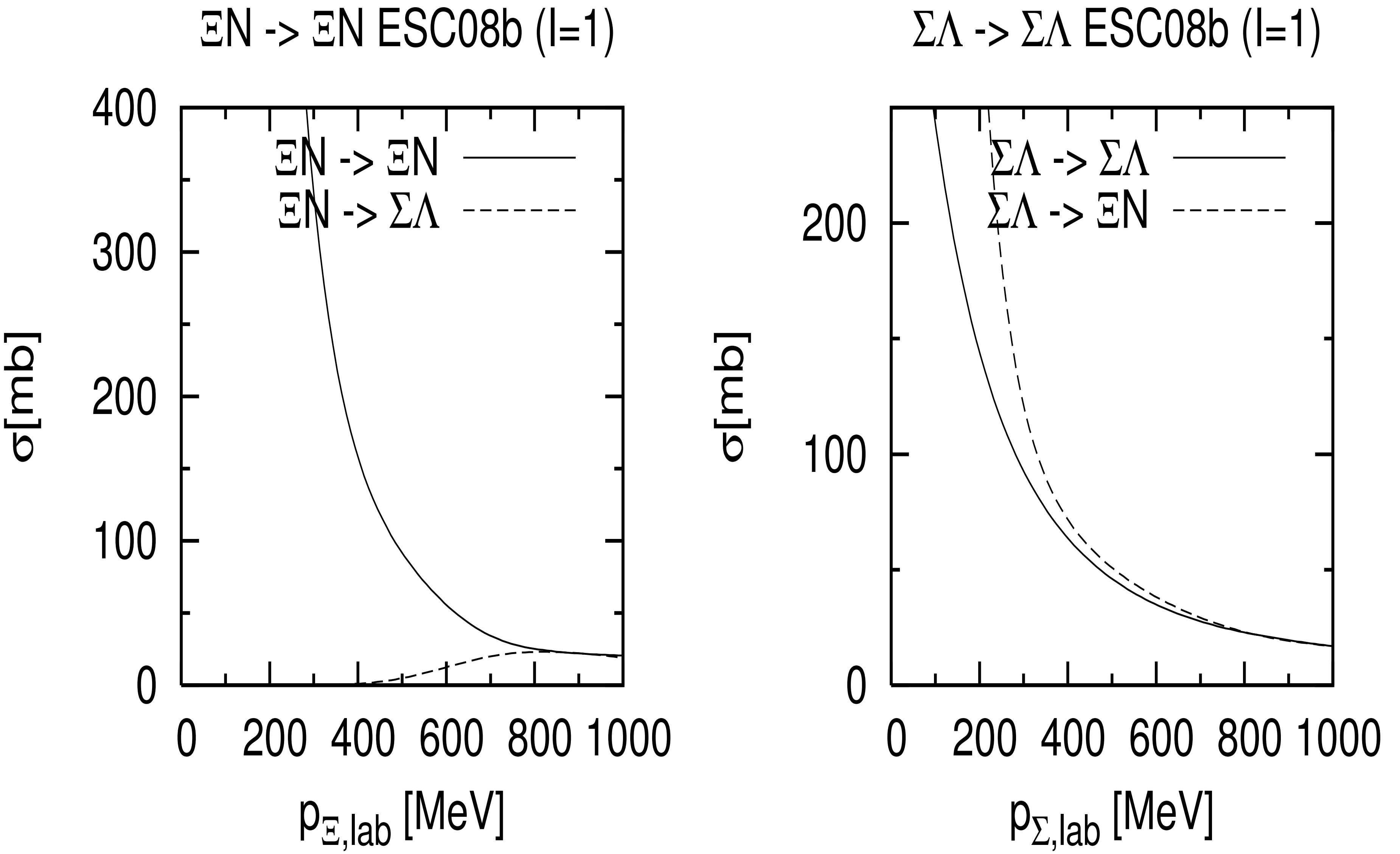
18d $\Sigma\Lambda$-phases

$\Sigma\Lambda$ phases



Figuur 13: ESC08b $I = 1 : \Sigma\Lambda$-phases.

18e $\Xi N, \Sigma\Lambda(I = 1)$ X-sections



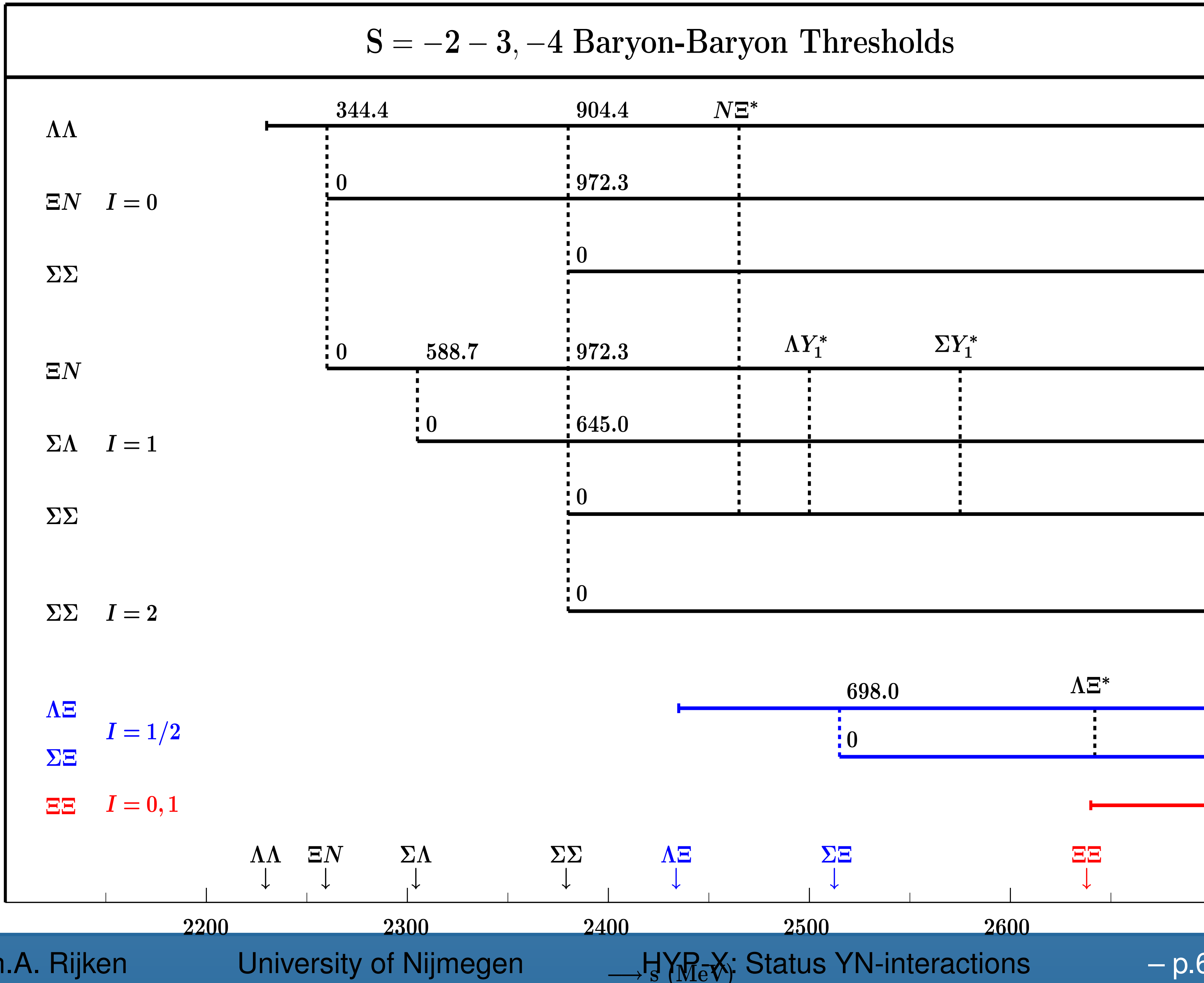
18f G-matrix ESC-models

Partial wave contributions to $U_\Xi(\rho_0)$ at normal density.

model		$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	U_Ξ
NHC-D	$T=0$	–4.5	2.6	–1.8	–0.2	–0.6	–1.7	
	$T=1$	0.2	5.3	–2.6	0.0	–2.9	–5.6	–11.9
ESC04c	$T=0$	5.9	–15.7	1.2	–0.1	–1.8	–1.2	
	$T=1$	6.8	1.9	–0.8	0.1	–0.3	–1.7	–5.5
ESC04d	$T=0$	6.4	–19.6	1.1	1.2	–1.3	–2.0	
	$T=1$	6.4	–5.0	–1.0	–0.6	–1.4	–2.8	–18.7
ESC04d*	$T=0$	6.3	–18.4	1.2	1.5	–1.3	–1.9	
	$T=1$	7.2	–1.7	–0.8	–0.5	–1.2	–2.5	–12.1
ESC08a	$T=0$	6.0	–1.0	-0.3	–2.6	1.3	–0.9	
	$T=1$	8.5	–28.0	0.6	0.4	–3.7	–0.6	–20.2
ESC08b	$T=0$	6.6	0.6	-0.4	–1.6	0.5	–0.7	
	$T=1$	9.0	–42.2	0.7	–0.1	–3.6	–1.1	–32.4

- ESC04d*: Medium Effect $\alpha_V = 0.18$. • private communication Y. Yamamoto

19a ESC-models: $S = -2, -3, -4$ YY,YN



ESC08: $\Lambda\Xi, \Sigma\Xi$- and $\Xi\Xi$-systems

- R-conjugation (Gell-Mann 1961): $\Rightarrow$

Connection $(NN, \Lambda N/\Sigma N)$ and $(\Xi\Xi, \Lambda/\Sigma\Xi$-channels:

$$p \leftrightarrow \Xi^- \quad , \quad n \leftrightarrow \Xi^0 \quad , \Lambda \leftrightarrow \Lambda \quad , \quad \Sigma^0 \leftrightarrow \Sigma^0$$
$$K^+ \leftrightarrow K^- \quad , \quad K^0 \leftrightarrow \bar{K}^0 \quad , \quad \eta \leftrightarrow \eta \quad , \quad \pi^0 \leftrightarrow \pi^0$$

- For the BB-states:

$$R\psi_{27}(Y,I,I_3) = \psi_{27}(-Y,I,-I_3), \qquad R\psi_{10}(Y,I,I_3) = \psi_{10^*}(-Y,I,-I_3),$$
$$R\psi_{8s}(Y,I,I_3) = \psi_{8s}(-Y,I,-I_3),$$
$$R\psi_{8a}(Y,I,I_3) = -\psi_{8a}(-Y,I,-I_3), \qquad R\psi_{1}(Y,I,I_3) = \psi_{1}(-Y,I,-I_3),$$

$\Rightarrow$ in SU(3)-structure $(\Xi\Xi, \Lambda/\Sigma\Xi)$-potentials compared to $(NN, \Lambda\Sigma N)$
the SU3-irreps $\{10\} \leftrightarrow \{10^\star\}$ are interchanged!

- R-conjugation $\ni$ SU(3)$_f$, interactions not invariant(!)

$\Lambda/\Sigma\Xi$, $\Xi\Xi$: SU(6)$_{fs}$-irreps

$SU(6)_{fs}$-contents of the various potentials on the isospin,spin basis.

	(S,I)	$V = aV_{[51]} + bV_{[33]}$
$\Xi\Xi \rightarrow \Xi\Xi$	$(0,1)$	$V_{\Xi\Xi} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$\Xi\Xi \rightarrow \Xi\Xi$	$(1,0)$	$V_{\Xi\Xi} = \frac{8}{9}V_{[51]} + \frac{1}{9}V_{[33]}$
$\Lambda\Xi \rightarrow \Lambda\Xi$	$(0,1/2)$	$V_{\Lambda\Lambda} = \frac{1}{2}V_{[51]} + \frac{1}{2}V_{[33]}$
$\Lambda\Xi \rightarrow \Lambda\Xi$	$(1,1/2)$	$V_{\Lambda\Lambda} = \frac{13}{18}V_{[51]} + \frac{5}{18}V_{[33]}$
$\Sigma\Xi \rightarrow \Sigma\Xi$	$(0,1/2)$	$V_{\Sigma\Sigma} = \frac{17}{18}V_{[51]} + \frac{1}{18}V_{[33]}$
$\Sigma\Xi \rightarrow \Sigma\Xi$	$(1,1/2)$	$V_{\Sigma\Sigma} = \frac{13}{18}V_{[51]} + \frac{5}{18}V_{[33]}$
$\Sigma\Xi \rightarrow \Sigma\Xi$	$(0,3/2)$	$V_{\Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$
$\Sigma\Xi \rightarrow \Sigma\Xi$	$(1,3/2)$	$V_{\Sigma\Sigma} = \frac{4}{9}V_{[51]} + \frac{5}{9}V_{[33]}$

19c $\Lambda/\Sigma\Xi, \Xi\Xi$: SU(6)$_{fs}$-irreps

$\Lambda/\Sigma\Xi, \Xi\Xi$: Low-energy parameters

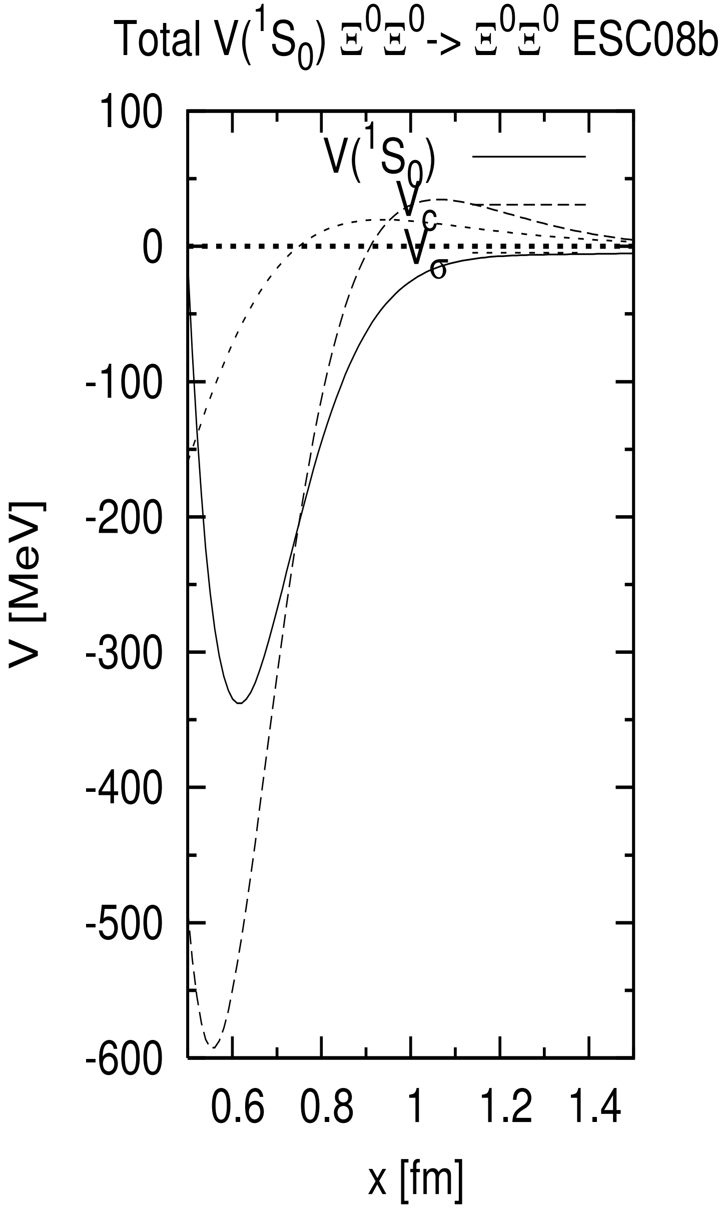
- Effective -range parameters:

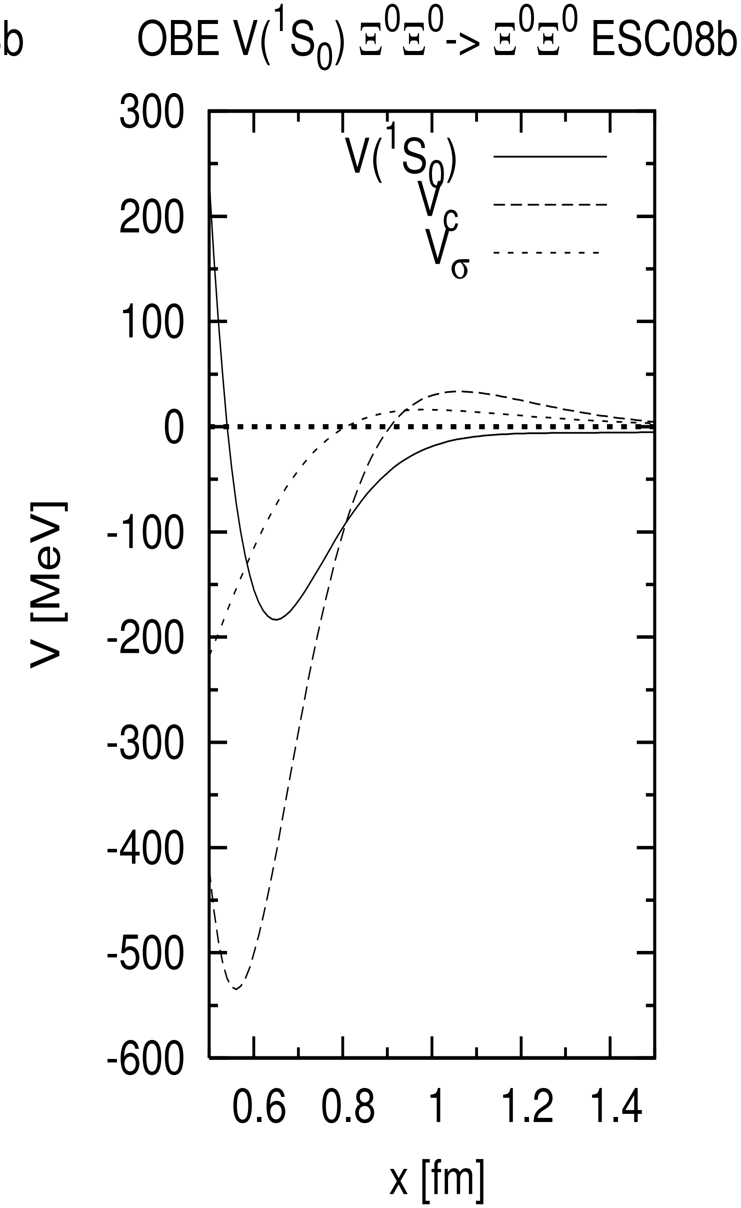
$$ESC08a : a_{\Xi\Xi}(^1S_0) = -18.8[fm] \quad , \quad r_{\Xi\Xi}(^1S_0) = 1.81[fm]$$
$$a_{\Xi\Xi}(^3S_1) = 0.73[fm] \quad , \quad r_{\Xi\Xi}(^3S_1) = 0.16[fm]$$

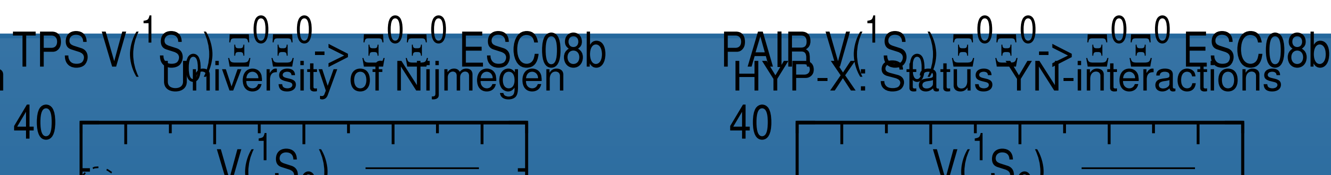
$$ESC08b : a_{\Xi\Xi}(^1S_0) = 122.5[fm] \quad , \quad r_{\Xi\Xi}(^1S_0) = 1.68[fm]$$
$$a_{\Xi\Xi}(^3S_1) = 0.82[fm] \quad , \quad r_{\Xi\Xi}(^3S_1) = 0.49[fm]$$

- ESC08b: $^1S_0$-bound state !!?

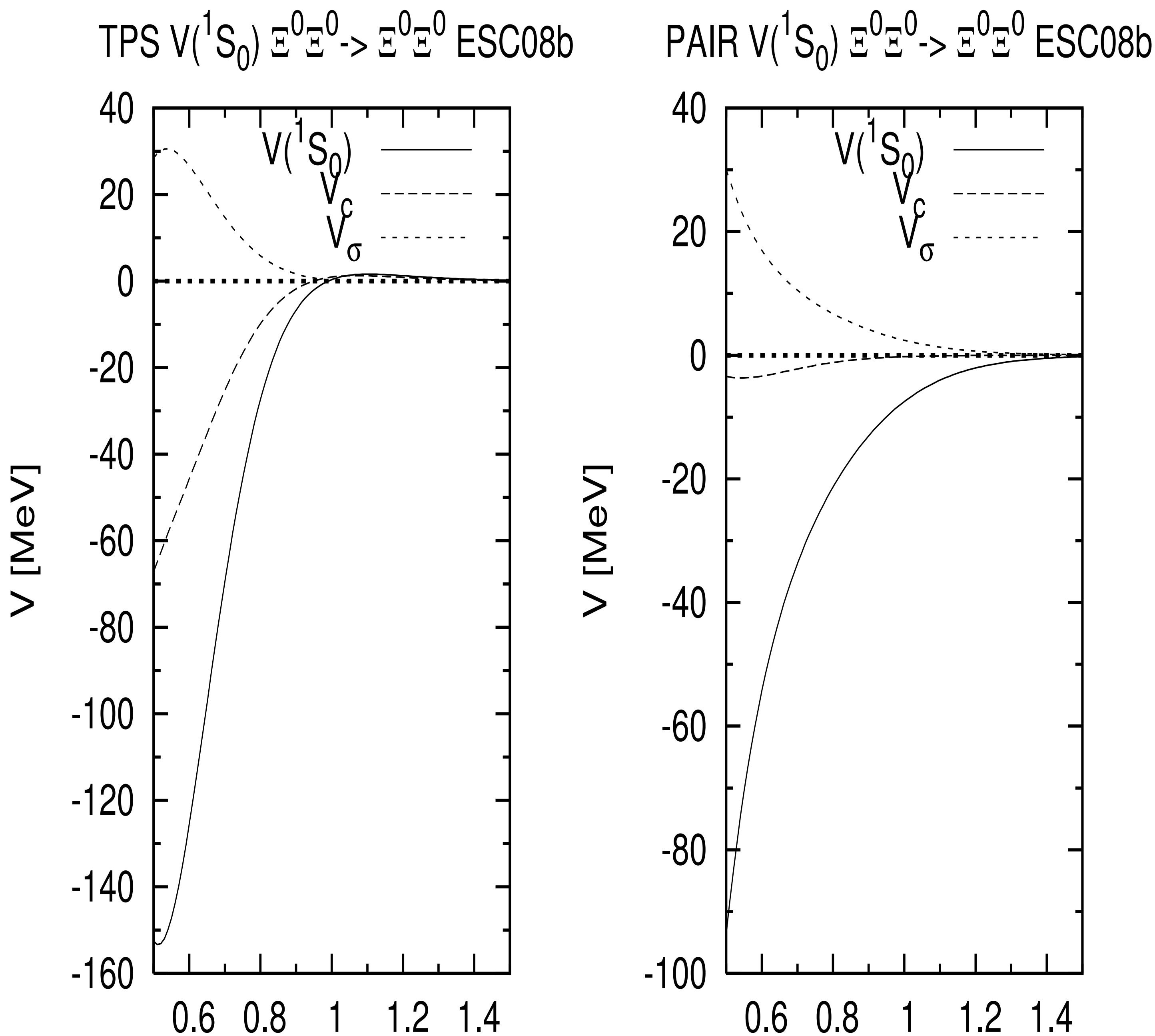
19d ESC08b: $\Xi\Xi(^1S_0)$-potential







ESC08b: $\Xi\Xi(^1S_0)$-potential



Summary and Comparison ESC04 and ESC08

Construction ESC-solutions: Important role G-matrix input
$U_\Lambda, U_\Sigma, U_\Xi, \Delta B_{\Lambda\Lambda}$, spin-spin and spin-orbit ΛN.

Improving ESC-model: ESC04 $\Rightarrow$ ESC08:

1. introduction quark-core effects,
2. axial-vector mesons B-field formalism (Nakanishi),
3. complete 1/M corrections pair terms ($\pi\omega$ etc.),
4. introduction Odderon.

Results:

a. superior NN-fit and YN-fit,
b. ${}^3P_0 \rightarrow {}^3P_0 + {}^3S_1$-scheme c.c.'s ,
c. superior $U_\Lambda, U_\Sigma, U_\Xi$, etc.,
d. important change tensor forces for S=-2,-3 systems
$\Rightarrow$ possibility 'deuteron-like' $\Xi N({}^3S_1, I=1)$-state !
$\Rightarrow$ favorable accessibility K^-K^+-experiments !

Conclusions and Status YN-interactions

Conclusions and Prospects

1. High-quality Simultaneous Fit/Description $NN \oplus YN$,
   OBE, TME, MPE meson-exchange dynamics.
   $SU_f(3)$-symmetry, (Non-linear) chiral-symmetry.
2. NN,YN,YY: Couplings $SU_f(3)$-symmetry, $^3P_0$-dominance QPC,
   Quark-core effect: $^3S_1(\Sigma N, I = 3/2)$ is strongly repulsive,
   ΛN: spin-orbit interaction is small,
3. Scalar-meson nonet structure $\Leftrightarrow$ Nagara $\Delta B_{\Lambda\Lambda}$ values.
4. Prediction $D_{\Xi N} = \Xi N(I = 1, ^3S_1)$ b.s. !? , $D_{\Xi\Xi} = \Xi\Xi(I = 1, ^1S_0)$ b.s. !?

Status of understanding the YN/YY-interactions:

a. ESC08: Excellent G-matrix predictions for the $U_\Lambda, U_\Sigma, U_\Xi$ well-depth's,
   ΛN spin-spin and spin-orbit, and Nagara-event okay.

b. Similar role tensor-force in $^3S_1$ NN-, $\Lambda/\Sigma N$-, ΞN-, and $\Lambda/\Sigma\Xi$-channels.

c. Different good solutions (e.g. ESC08a,b) $\Rightarrow$
   predictions are 'solution-sensitive/dependent'.

- JPARC, TJNAL, FINUDA: new data Hypernuclei, Ξ-hypernuclei (!)
- JPARC: $\Sigma^+P, \Lambda P$ scattering !!?