Hyperon-Nucleon and Hyperon-Hyperon Interactions

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Introduction

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I. Flavor Nuclear Physics,
QCD and BB-models

II. Different BB-models,
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III. Recent Extended-Soft-Core BB-Models:
OBE, TME, MPE, Pomeron, Form factors

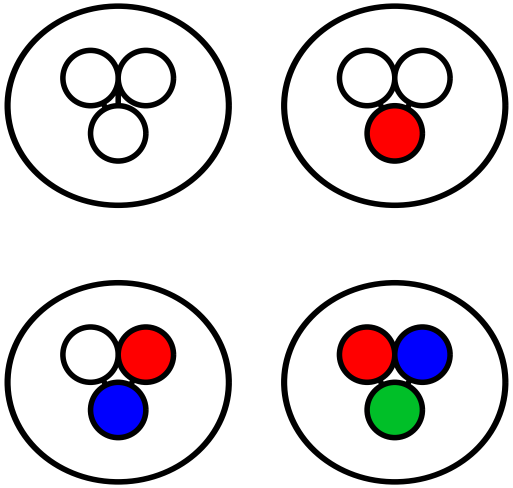
a. ESC04 NN interaction, S=0
b. BB and $^3P_0$ Quark-pair creation
c. ESC04/06 YN interaction, S=-1,
ΛN- spin-orbit interaction
d. ESC and YY/YN interaction, S=-2,
e.g. Nagara-event, $\Delta B_{\Lambda\Lambda}$

IV. Summary and Prospects

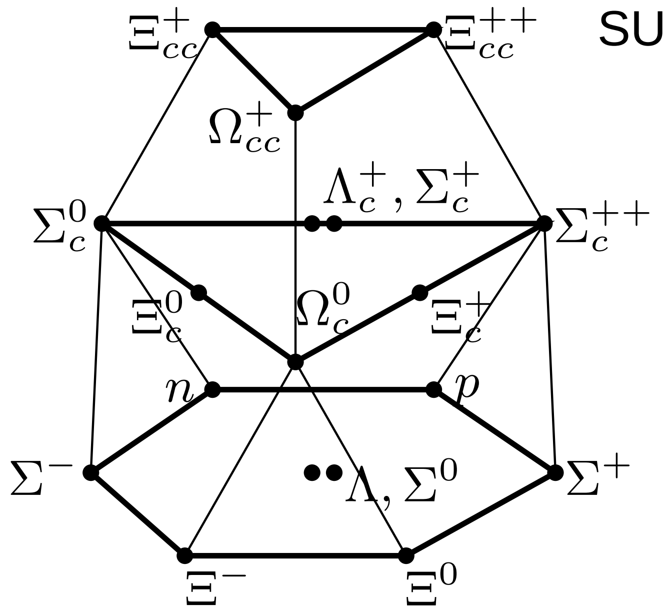
Particle and Flavor Nuclear Physics

Particle and Flavor Nuclear Physics

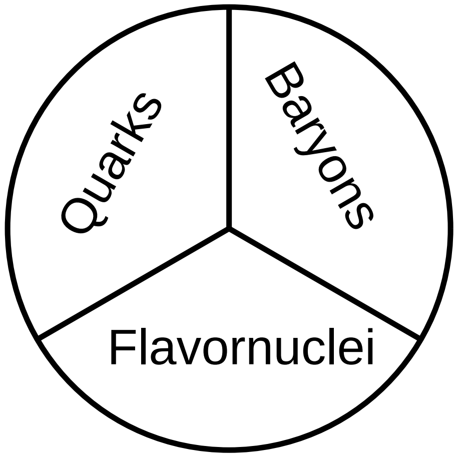
Baryons:



Quark flavors: u,d,s,c,b,t



Aspects of flavored matter:



H.Bandō(1985) (paraphrase):
"Extension NP to hyper/flavor NP
is important/desirable to understand
the different aspects of Matter

Introduction

Particle and Flavor Nuclear Physics

- Objectives in Low/Intermediate Energy Physics:

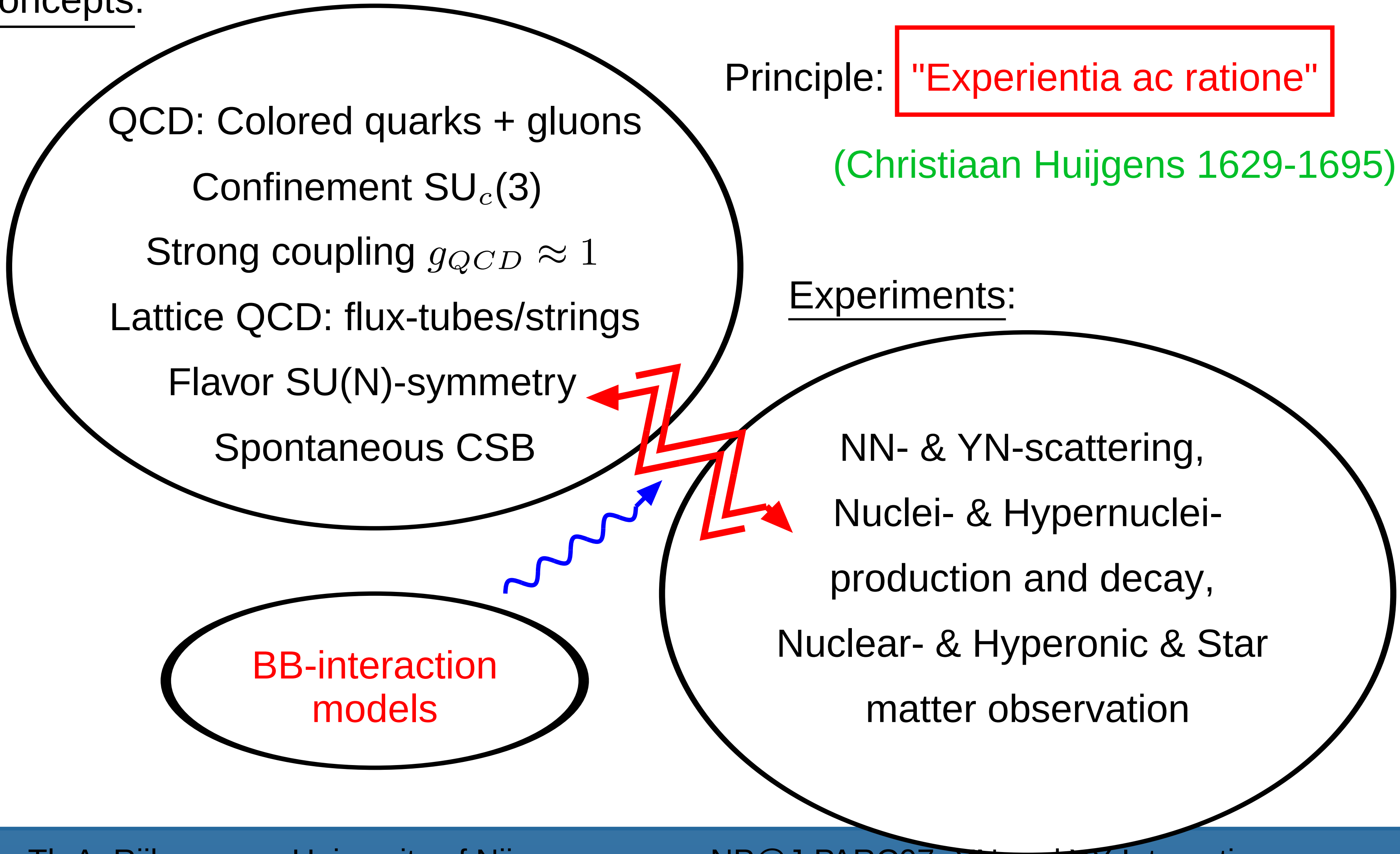
1. Study links Hadron-interactions and Quark-physics (QCD, SU$_F$(3),QPC)
2. Determination Meson Coupling Parameters $\Leftarrow$ NN+YN Scattering
3. Construction realistic physical picture of nuclear forces
   between the octet-baryons: N, Λ, Σ, Ξ
4. Study (Hyper) Nuclear structures:
   1. Few-Body systems, e.g. ${}^2H$, ${}^3H$, ${}^3_\Lambda H$, ${}^4_\Lambda H$,
      ${}^3_\Lambda He$, ${}^4_\Lambda He$, ${}^5_\Lambda He$, ${}^4_\Sigma He$, and ${}^6_{\Lambda\Lambda}He$
   2. Many-Body systems: Shell-models, Cluster-models, Star matter
5. CERN, BNL, KEK, TJNAL, FINUDA, J-PARC(2008), FAIR(2012):
   Analysis and interpretation experimental scattering data
   and (hyper) nuclei-data
6. Extension to flavor nuclear systems with c-, b-, t-quarks.

Introduction: Modern Physics and QCD

Contemporary View on Low Energy Physics

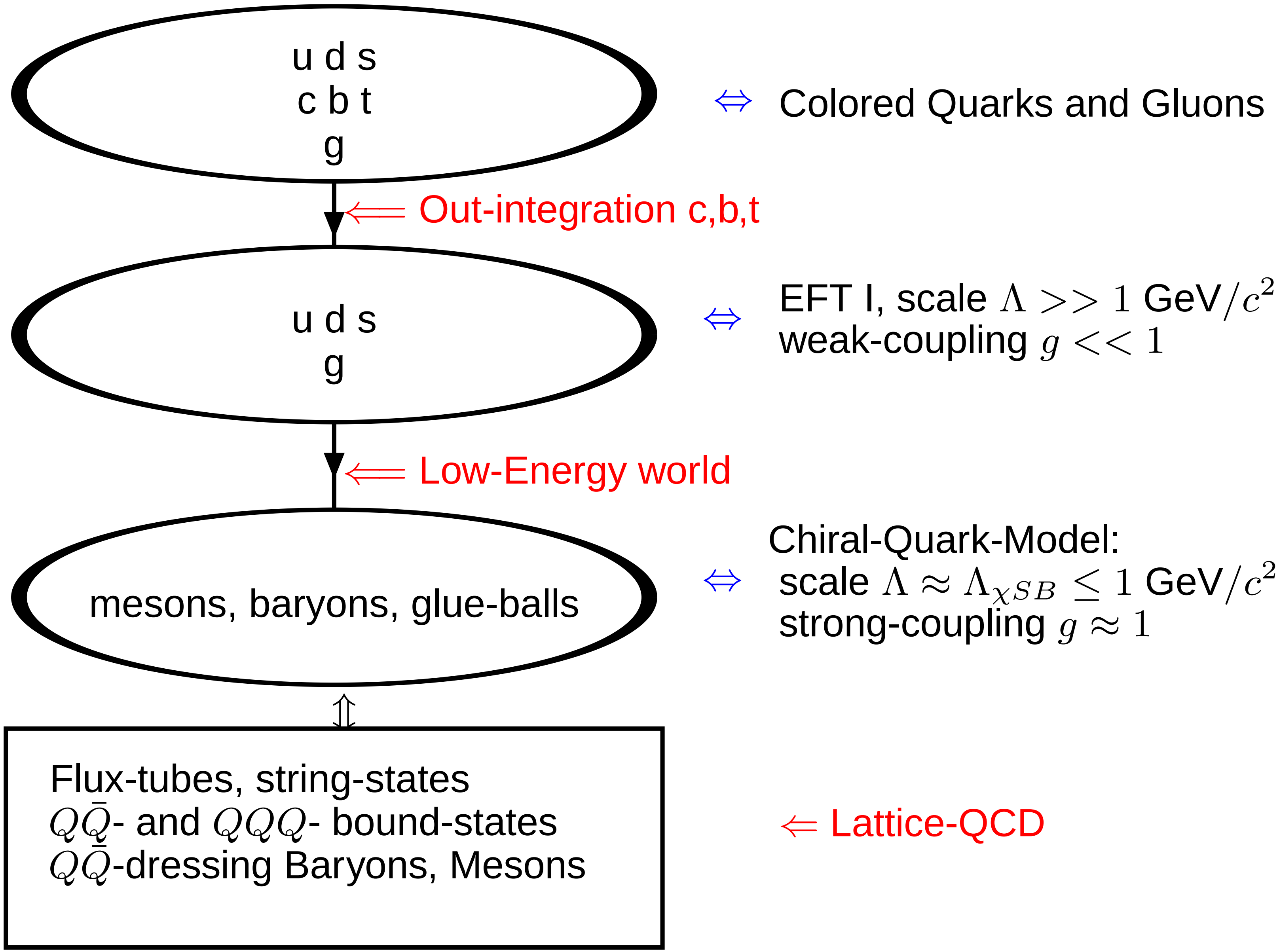
Baryon-baryon Strong Interactions

- Concepts:



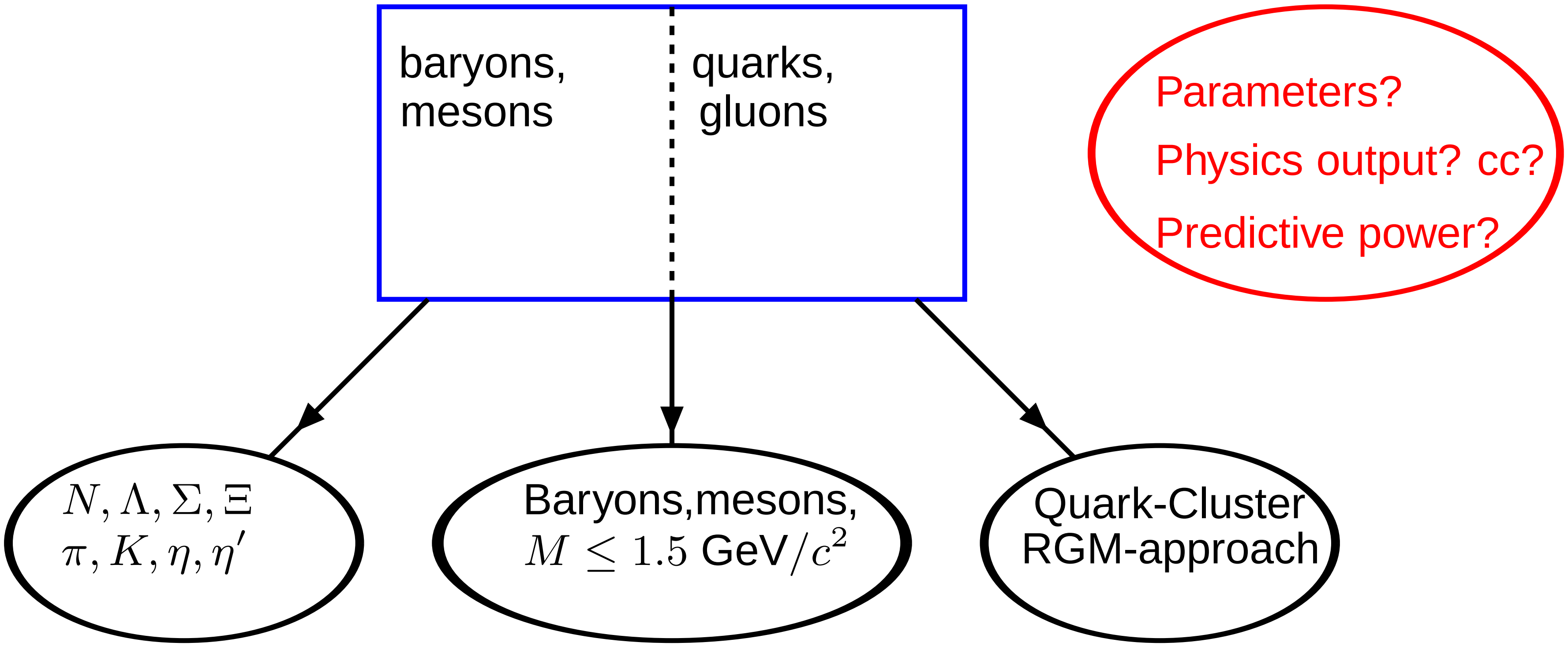
QCD-world I

QCD-world I: mesons and baryons



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,
Ehime, Jülich, etc.

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

Competing BB-models

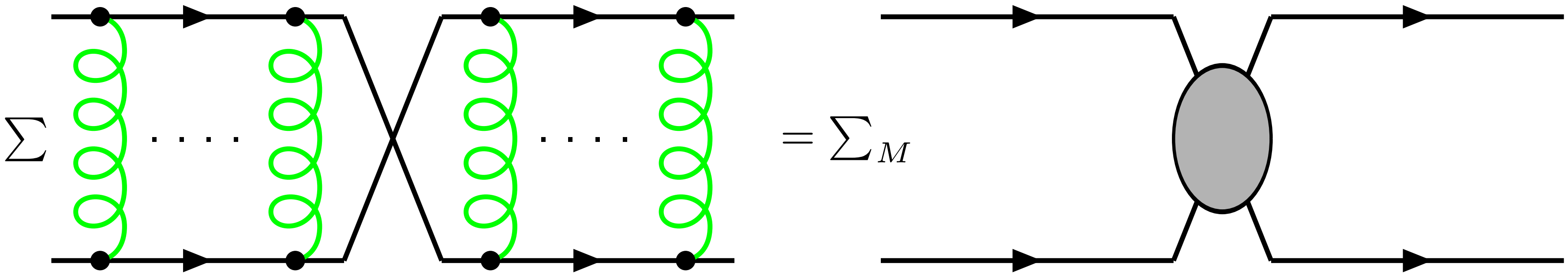
Theory Interest in Flavor Nuclear Physics

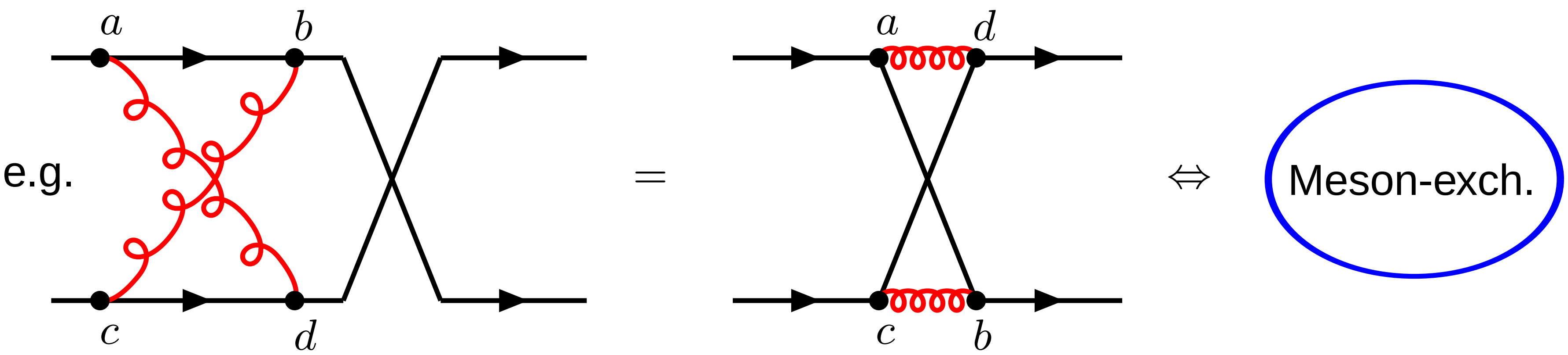
- Recent Model building:

1. Nijmegen models: OBE and ESC Soft-core (SC)
   Rijken, Phys.Rev. C73, 044007 (2006)
   Rijken & Yamamoto, Phys.Rev. C73, 044008 (2006)
   Rijken & Yamamoto, arXiv:nucl-th/060874 (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. Jülich Effective Field Theory models
   Polinder, Haidenbauer, Meissner, Nucl.Phys. A 779, 244 (2006)
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)

Gluon-Quark-Exchange ⇔ Meson-Exchange

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

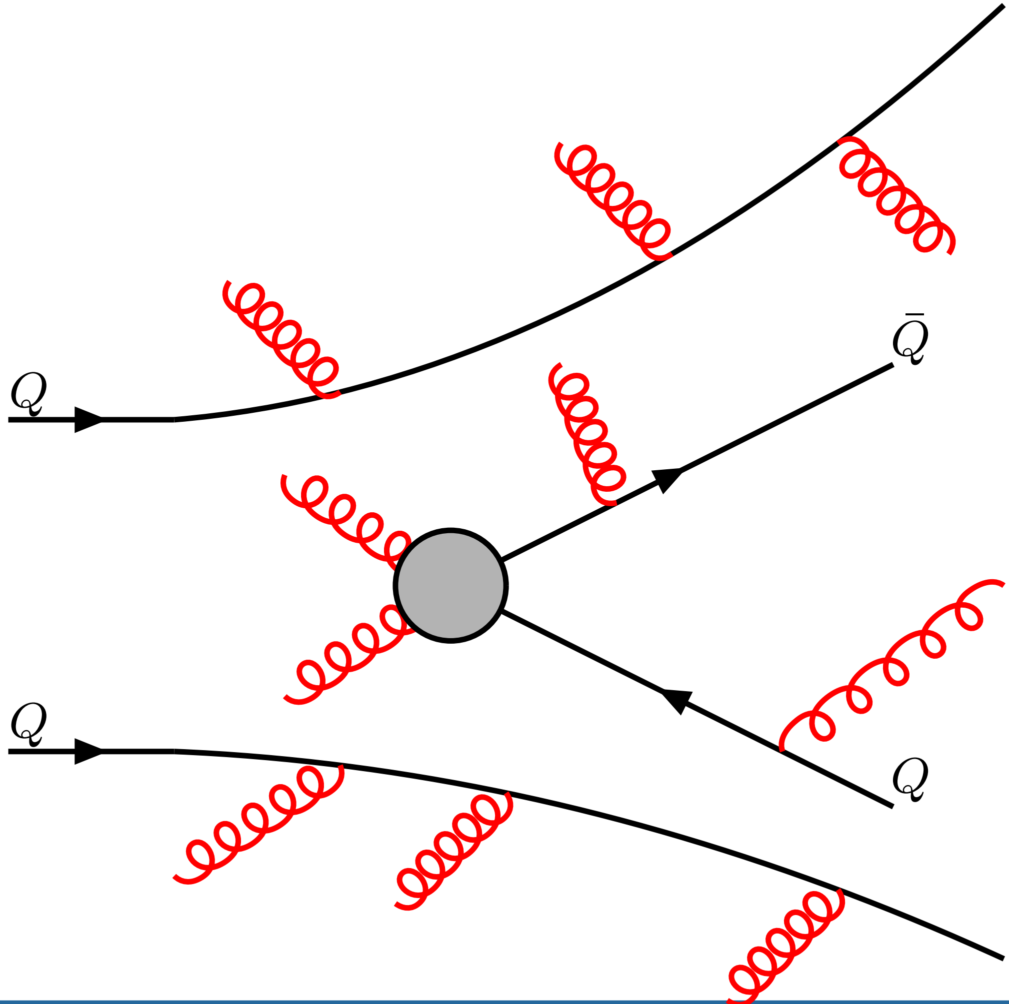




Quark-Pair-Creation in QCD

Quark-Pair-Creation in QCD $\Leftrightarrow$ Flux-tube breaking

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



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

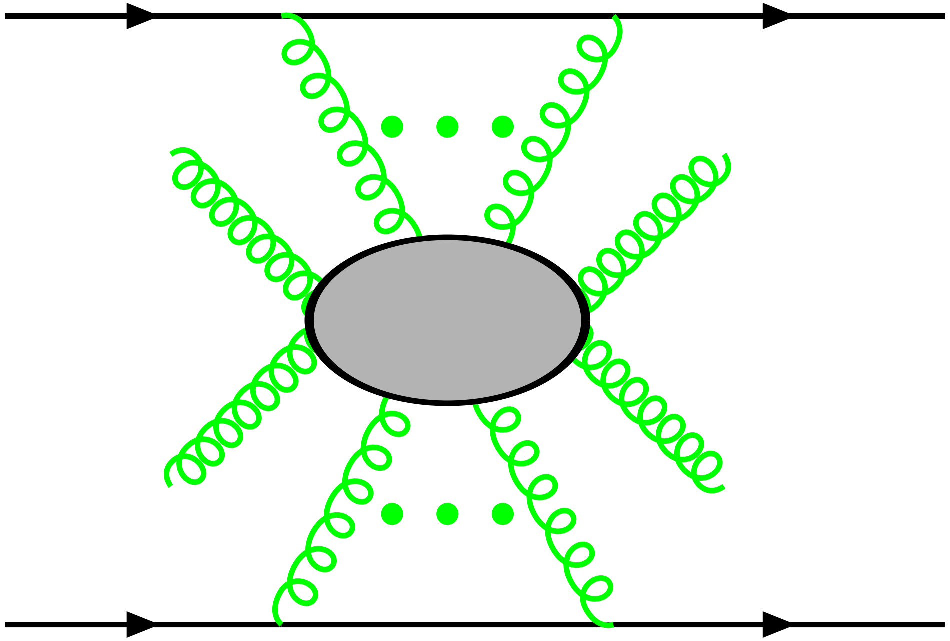
QCD: Flux-tube/String-breaking
$\Rightarrow^3 P_0(Q\bar{Q})$,
Isgur & Paton, PRD31(1985);
Kokoski & Isgur, PRD35(1987)

$\Rightarrow$ Meson coupling constants !

Gluon-exchange $\Leftrightarrow$ Pomeron

Gluon-exchange QCD $\Leftrightarrow$ Pomeron-exchange

- Gluon-exchange $\Leftrightarrow$ Pomeron-exchange



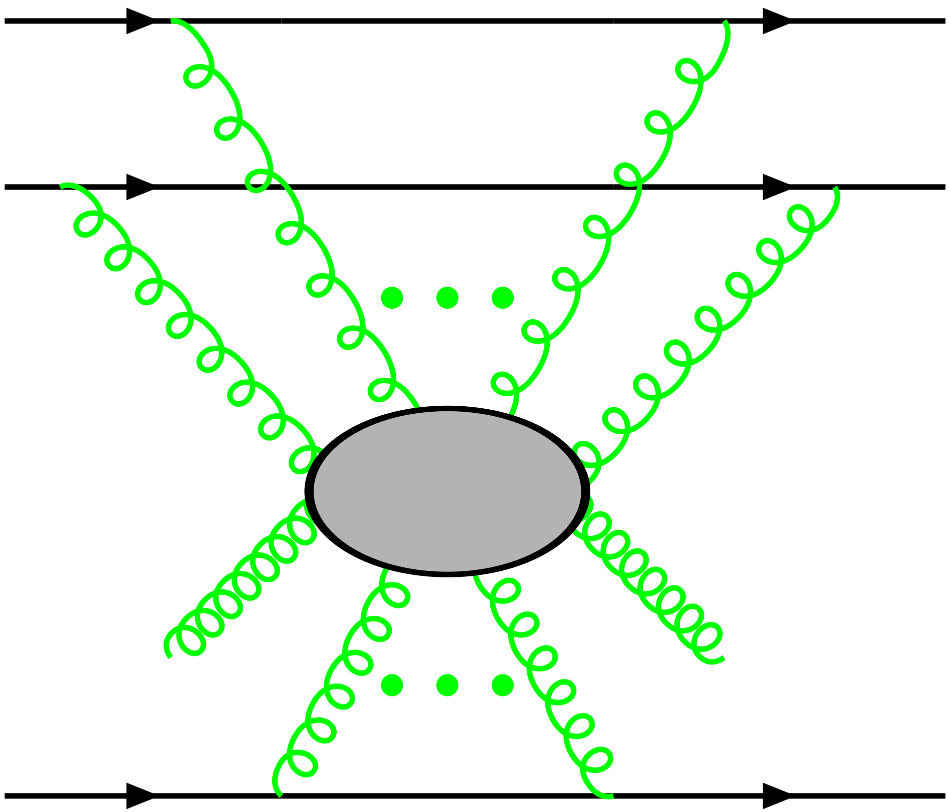
Multiple-gluon model: Low PR D12(1975), Nussinov PRL34(1975)
Scalar Gluon-condensate: ITEP-school:
$\langle 0|g^2 G^a_{\mu\nu}(0) G^{a\mu\nu}(0)|0\rangle = \Lambda_c^4$,
$\Lambda_c \approx 800$ MeV
Landshoff, Nachtmann, Donnachie, Z.Phys.C35(1987); NP B311(1988):
$\langle 0|g^2 T[G^a_{\mu\nu}(x) G^{a\mu\nu}(0)]|0\rangle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

$\Rightarrow$ LE Pomeron-potential!

Universal Three-body repulsion $\Leftrightarrow$ Pomeron

Universal Three-body repulsion $\Leftrightarrow$ Pomeron-exchange

- Multiple Gluon-exchange $\Leftrightarrow$ Pomeron-exchange



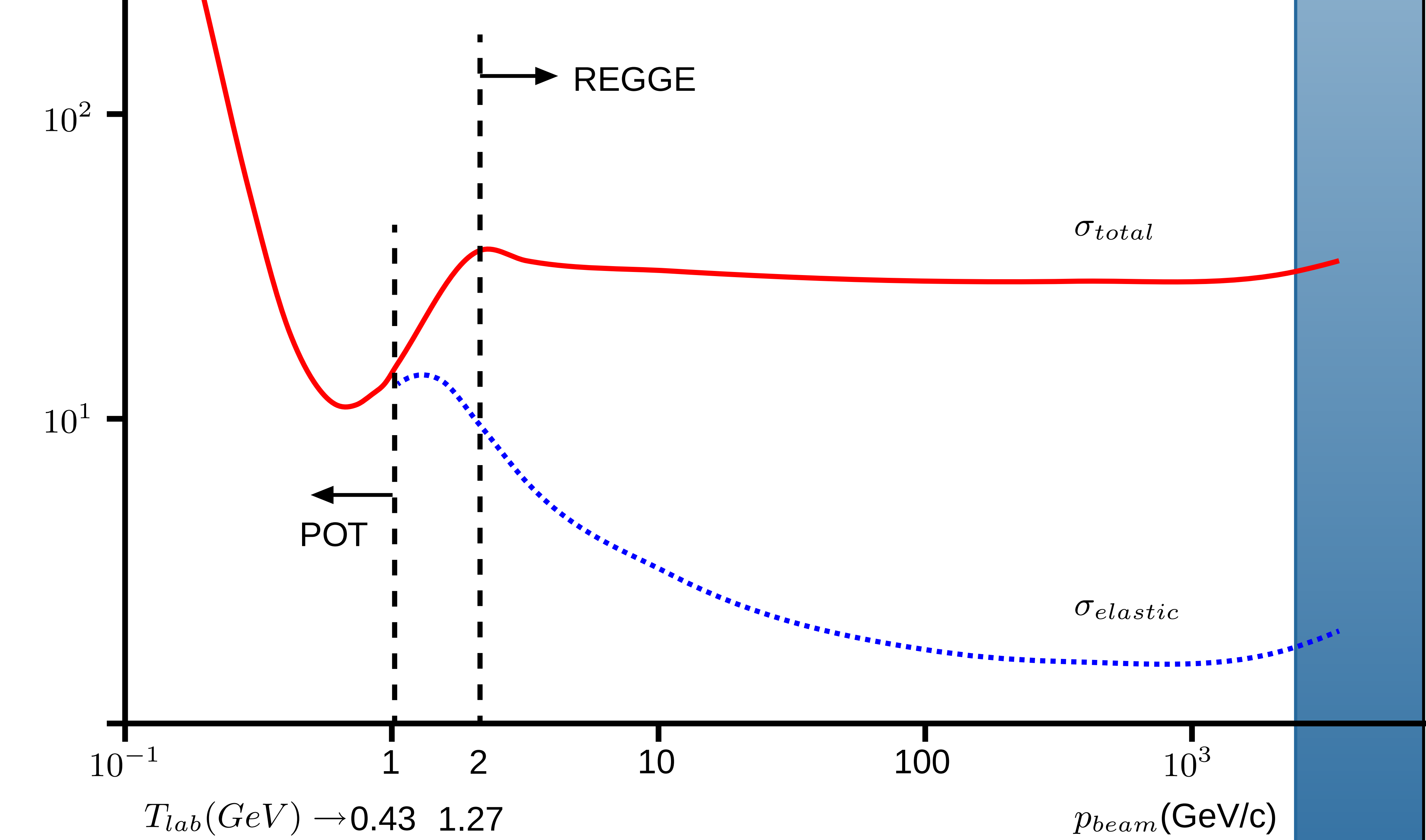
Soft-core models NSC97, ESC04:
(i) nuclear saturation, (ii) EOS too soft
Nishizaki,Takatsuka,Yamamoto,
PTP 105(2001); ibid 108(2002): NTY-conjecture = universal repulsion in BB

Lagaris-Pandharipande NP A359(1981):
medium effect $\longrightarrow$ TNIA,TNIR
Rijken-Yamamoto PRC73: TNR $\Leftrightarrow m_V(\rho)$

NTYR: Multiple-gluon-exchange $\leftrightarrow$
Pomeron + Triple-pomeron!?

Proton-proton total and elastic X-sections

Proton-proton total and elastic X-sections



Introduction, Acknowledgement

Recent Baryon-baryon ESC Interactions

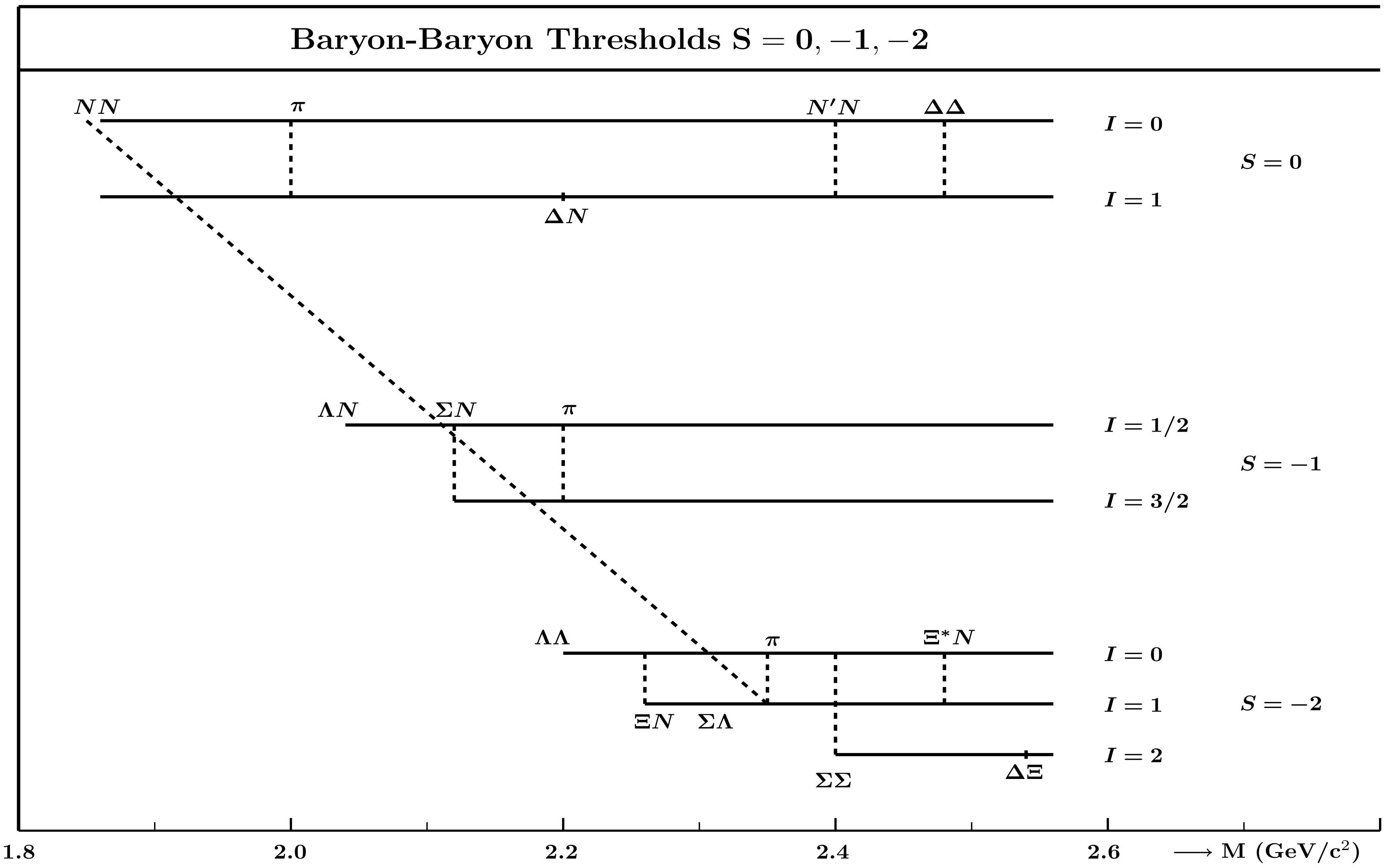
- Extended-soft-core Baryon-baryon Model ESC04:
  1. Meson Dynamics: OBE, TME, MPE
  2. Fit NN-, YN- scattering data
  3. Analysis Coupling-Constants: QPC, QCD-SR's
- Recent publications ESC-model:
  I, Nucleon-nucleon Interactions,
  Rijken, Phys.Rev. C73, 044007 (2006)
  II, Hyperon-nucleon Interactions,
  Rijken & Yamamoto, Phys.Rev. C73, 044008 (2006)
  III, $S = -2$ Hyperon-hyperon/nucleon Interactions,
  Rijken & Yamamoto, arXiv:nucl-th/060874 (2006)

- Acknowledgement: It is a great pleasure to thank prof. Yamamoto for his important and stimulating collaboration!

- ESC04, Major problems (left): 1. $\Sigma^+ p(^3S_1, I = 3/2)$, $\Rightarrow$ ESC06
  2. ΛN hypernuclei LS-splttings $\Rightarrow$ ESC06

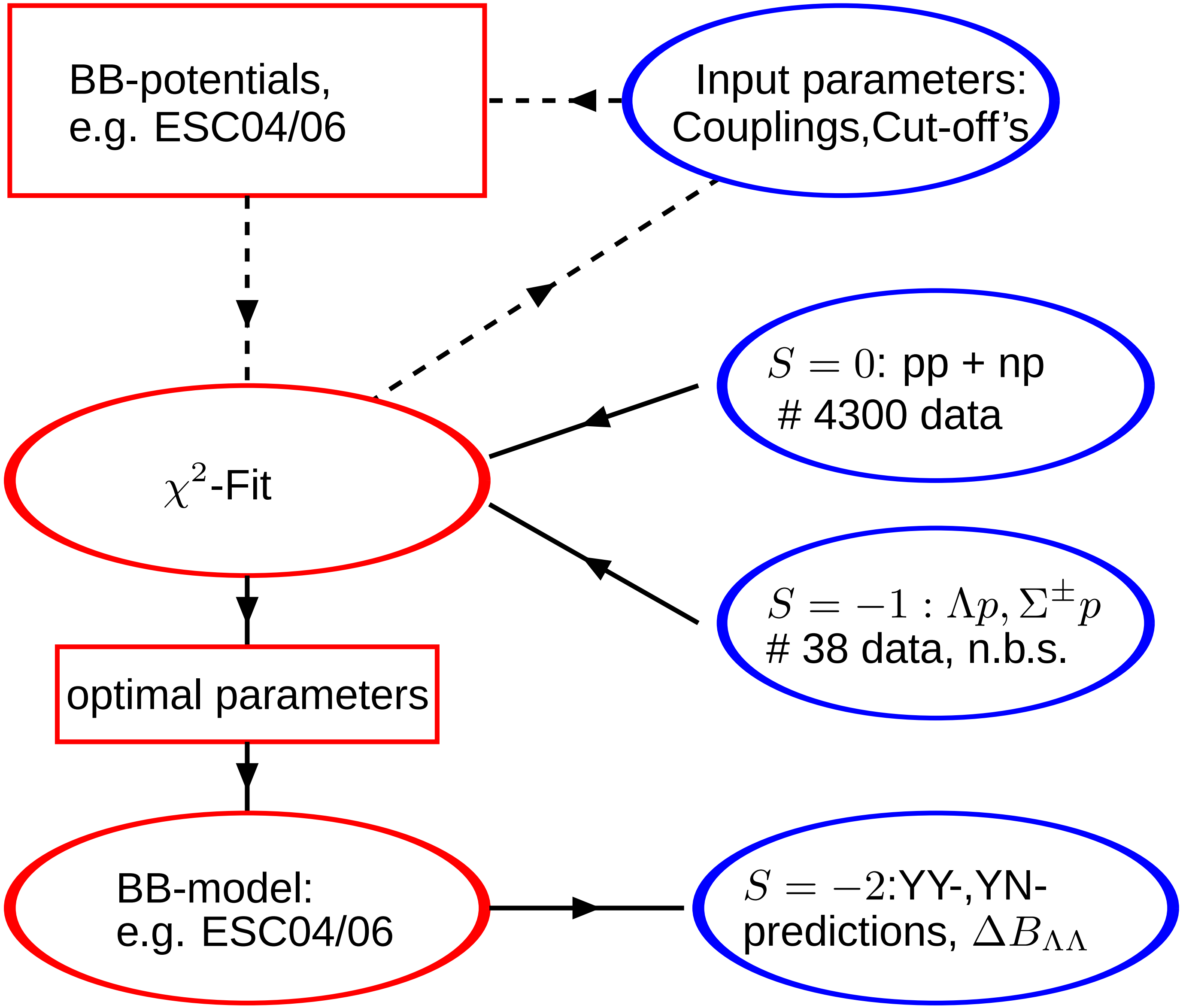
Baryon-baryon Channels $S = 0, -1, -2$

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



Combined Fit NN-,YN-data and BB-model Construction

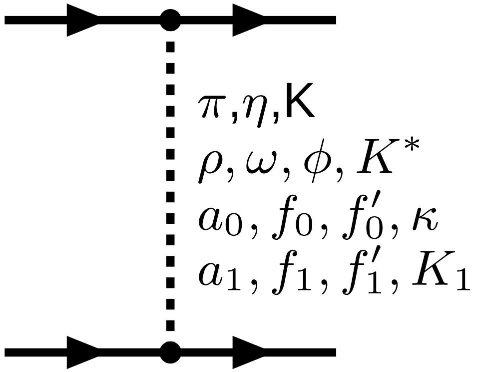
Combined Fit NN-, and YN-data and BB-model Building



ESC-model: BB

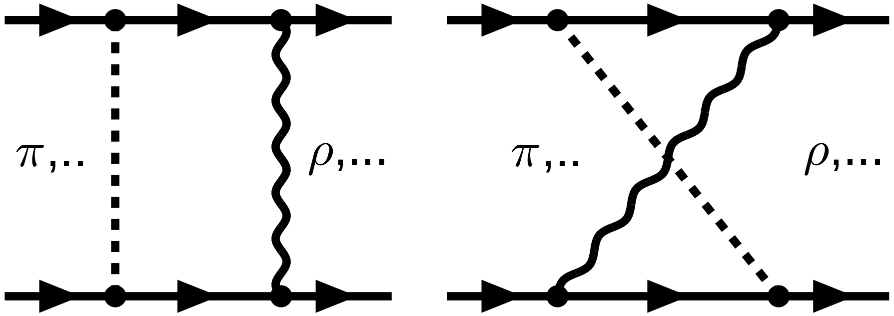
BB-interactions in the ESC-model:

One-Boson-Exchanges:



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

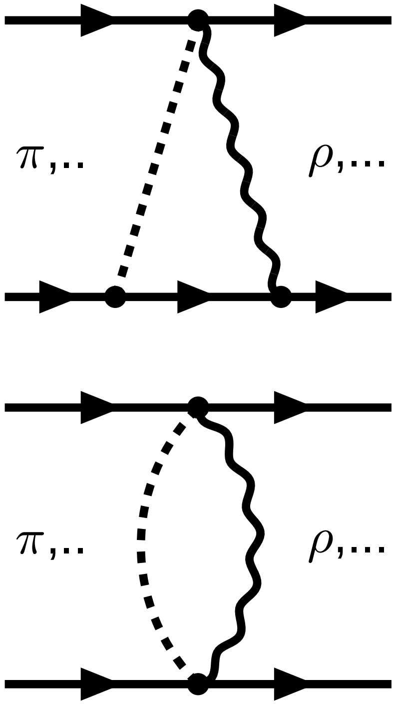
Two-Meson-Exchanges:



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

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

Meson-Pair-Exchanges:



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

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

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

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

$$PS\hat{A}_{\{8\}} \quad : \quad \pi\sigma,\ K\sigma,\ \eta\sigma$$

ESC-model

ESC04-NN: 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:

$$\begin{aligned} J^{PC} &= 0^{-+} \qquad \pi, \eta, \eta', K \\ &= 1^{--} \qquad \rho, \omega, \phi, K^\star \\ &= 0^{++} \qquad a_0(962), f_0(760), f_0(993), \kappa_1(900) \\ &= 1^{++} \qquad a_1(1270), f_1(1285), f_0(1460), K_1(1430) \end{aligned}$$

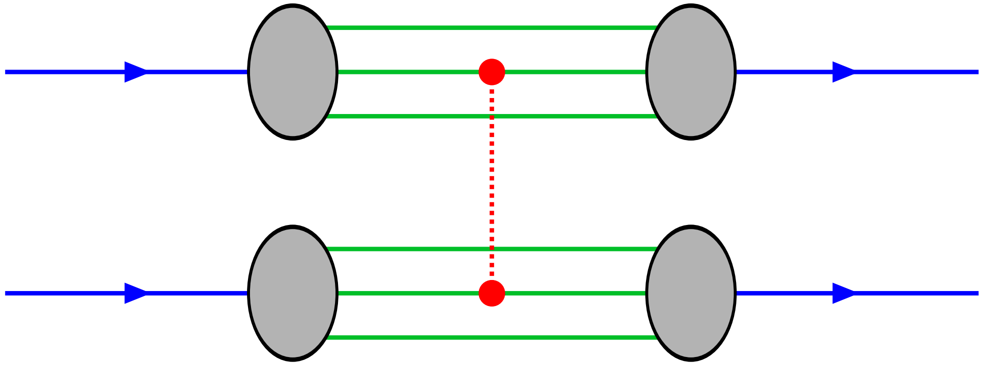
- soft form factors, $exp(-\mathbf{k}^2/2\Lambda^2_{B'BM}) \rightarrow$ "gaussian-yukawa's"
- pomeron exchange $\Leftrightarrow$ multi-gluon / pion exch.
- soft TPS: two-pseudo-scalar exchanges,
- soft MPE: meson-pair exchanges,
  $\pi \otimes \pi$, $\pi \otimes \rho$, $\pi \otimes \epsilon$, $\pi \otimes \omega$, etc.
- Data fit, 4301 NN-data, 38 YN-data:

1. Nucleon-nucleon: pp + np, $\chi^2_{dpt} = 1.15(!)$
2. Nucleon-nucleon $\oplus$ Hyperon-nucleon: $\chi^2_{dpt} = 1.25 - 1.35$

ESC-model: BB

Form Factors Composite Baryons

- NRQM: pointlike, gaussian distributed quarks



$$\mathrm{Baryon-quark\ wft}: \tilde{\psi}_{\mathrm{B}}(\mathrm{k}_1,\mathrm{k}_2,\mathrm{k}_3) = \left(\frac{3\mathrm{R}_{\mathrm{B}}^2}{\pi}\right)^{3/2} \exp\left[-\frac{\mathrm{R}_{\mathrm{B}}^2}{6}\sum_{\mathrm{i}<\mathrm{j}}\left(\underline{\mathrm{k}}_{\mathrm{i}}-\underline{\mathrm{k}}_{\mathrm{j}}\right)^2\right]$$

$$\mathrm{Form\ factor\ F}(\Delta^2): \tilde{\mathrm{V}}(\Delta) \sim \frac{\mathrm{F}(\Delta^2)}{\Delta^2+\mathrm{m}^2}, \qquad \Delta = \underline{\mathrm{p}}_1 - \underline{\mathrm{p}}_2$$

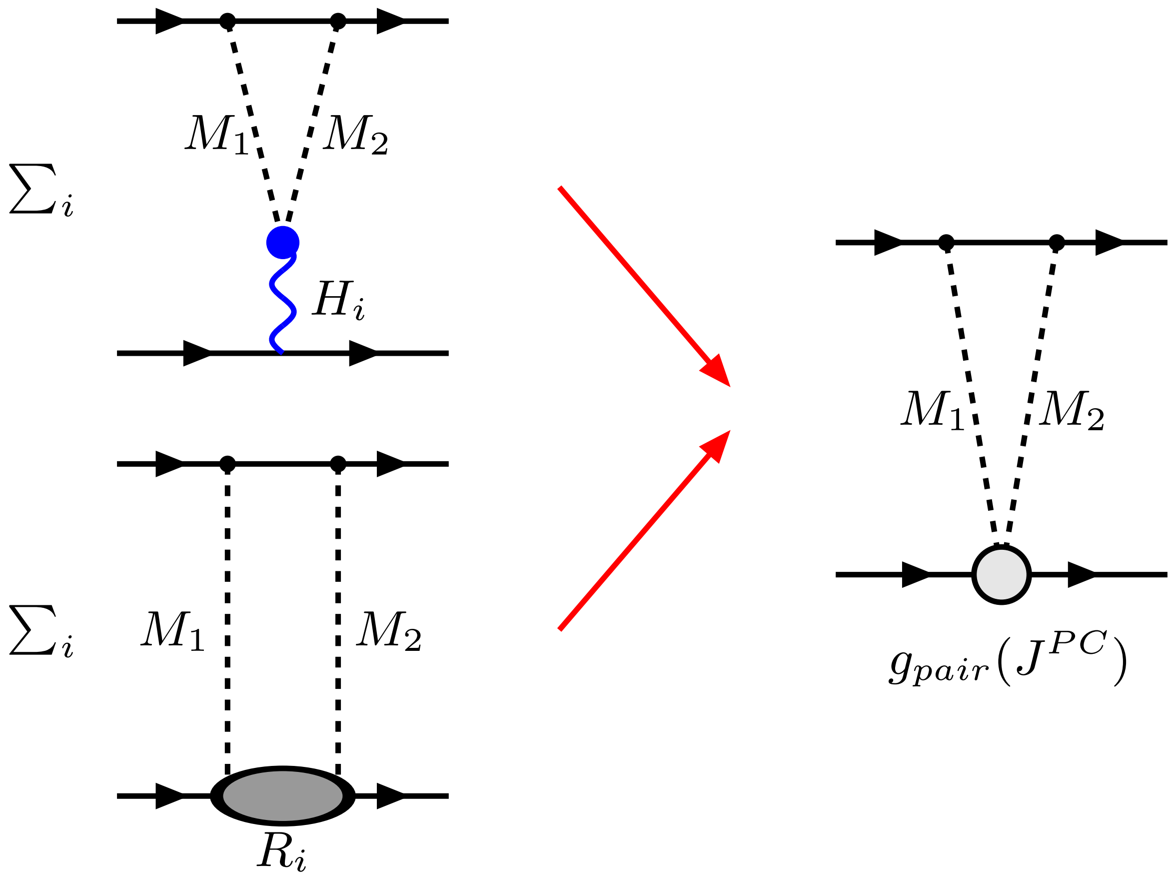
$$F(\Delta^2) \Rightarrow \exp\left[-\frac{5}{42}R_B^2\Delta^2\right] \equiv \exp\left[-\frac{\Delta^2}{\Lambda^2}\right]$$

$$\Lambda = \left(\frac{5}{42}R_B^2\right)^{-1/2} \approx 2.9R_B^{-1} \approx 700-1100MeV$$

Pair-vertex Mechanism

Pair-vertex mechanism

(Heavy) Meson- and Resonance saturation:



- Pair-graphs ⇔ Two-Meson cuts

ESC-model: BB

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:

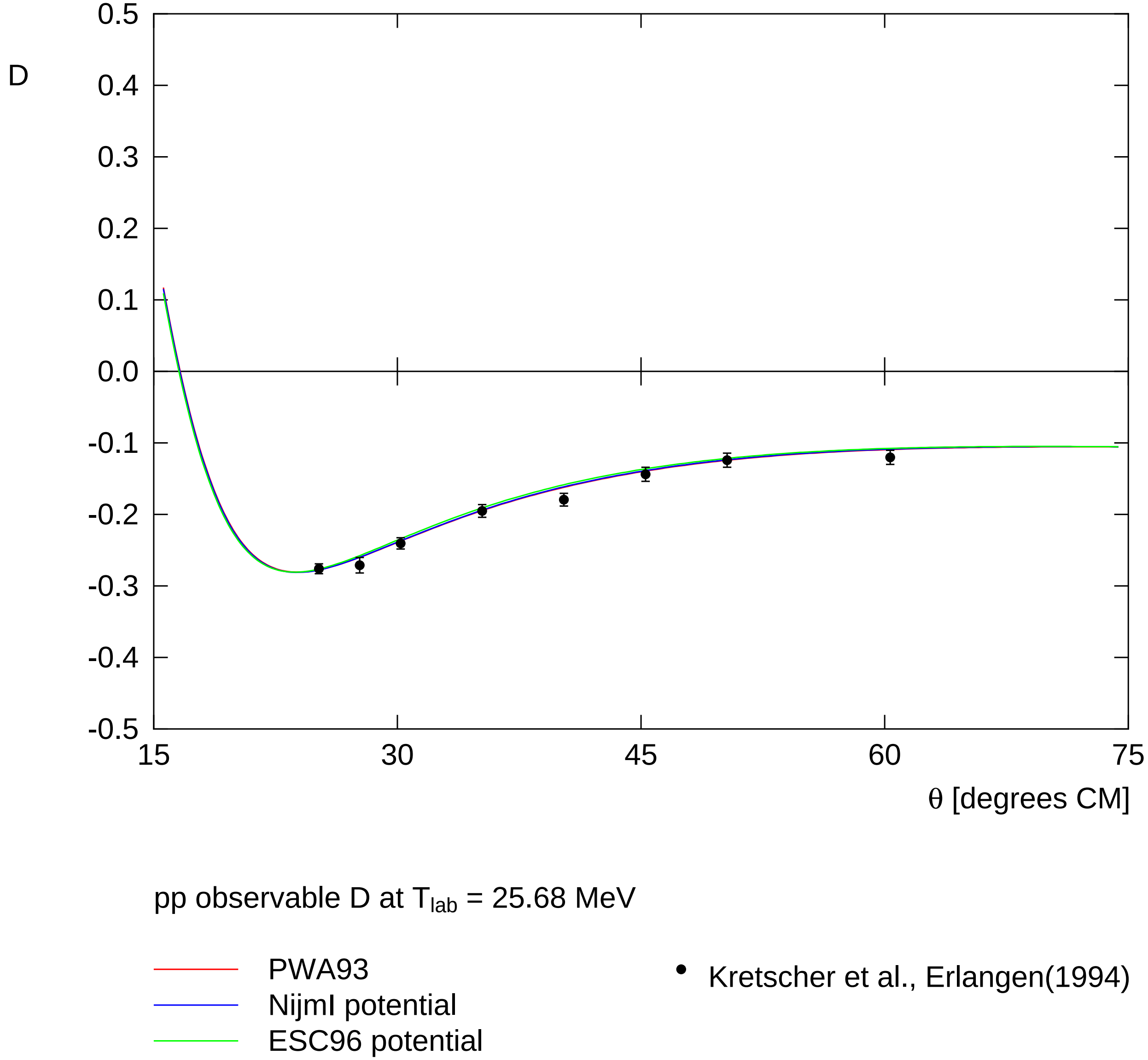
$$V(r) = \{V_C + V_\sigma\, \underline{\sigma}_1 \cdot \underline{\sigma}_2 + V_T\, S_{12} + V_{SO}\, \underline{L} \cdot \underline{S} + V_{ASO}\, \frac{1}{2}(\underline{\sigma}_1 - \underline{\sigma}_2) \cdot \underline{L} + V_Q\, Q_{12}\Big\}\, P$$

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

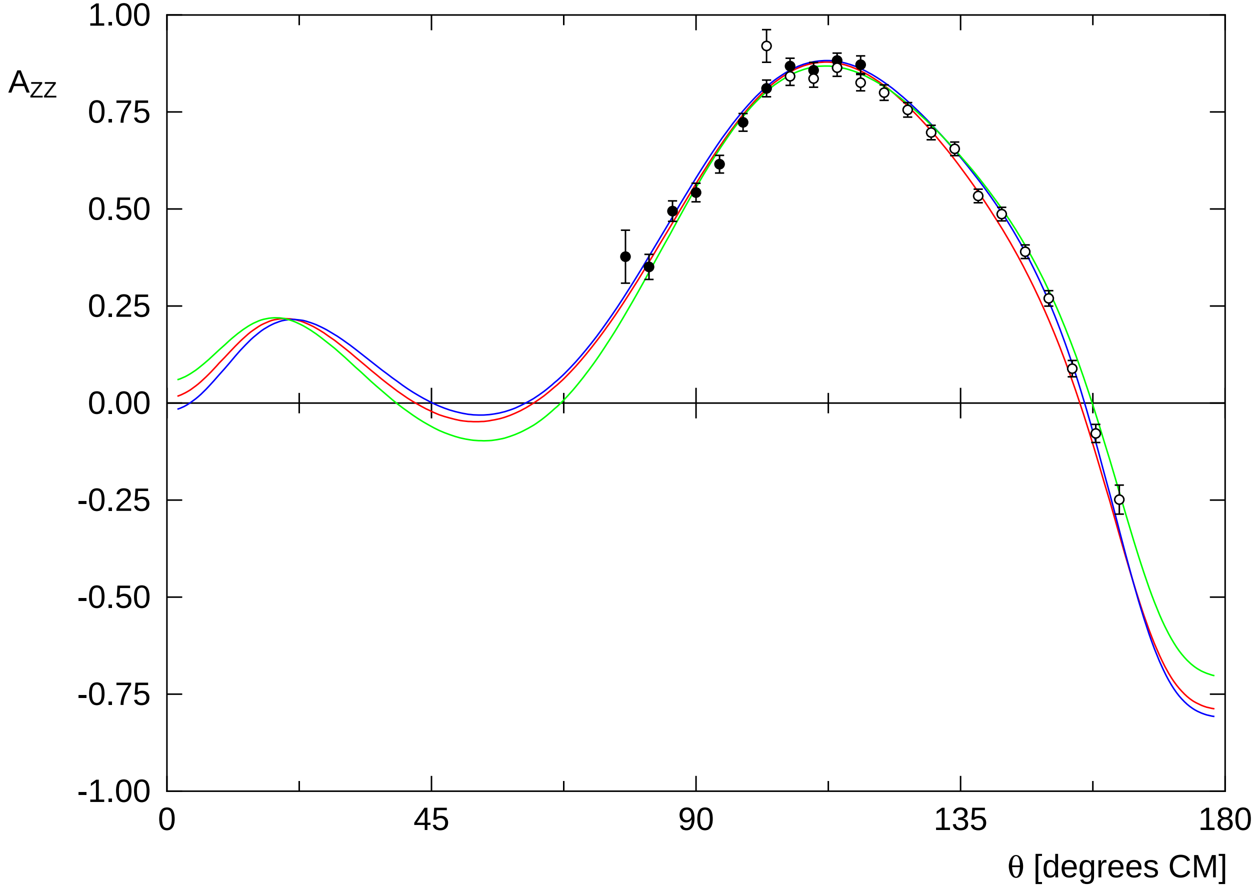
$$H = -\frac{1}{2m_{red}}\underline{\nabla}^2 + V(r) - \left(\underline{\nabla}^2 \frac{\phi}{2m_{red}} + \frac{\phi}{2m_{red}}\underline{\nabla}^2\right) + M$$

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

PWA-93


D
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
15
30
45
60
75
θ [degrees CM]
pp observable D at T_lab = 25.68 MeV
PWA93
NijmI potential
ESC96 potential
Kretscher et al., Erlangen(1994)

PWA-93

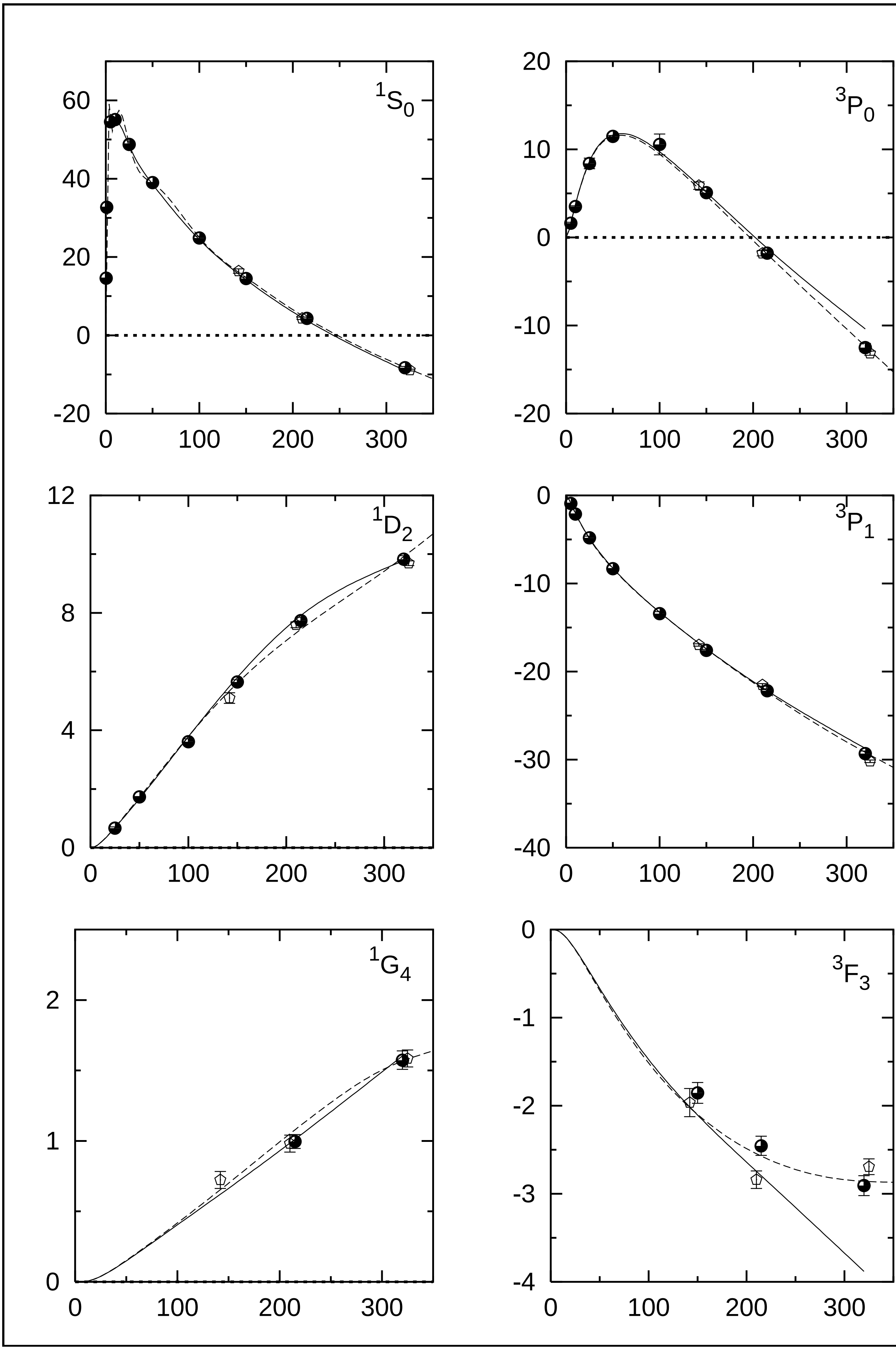


np observable A_{ZZ} at T_{lab} = 315.0 MeV

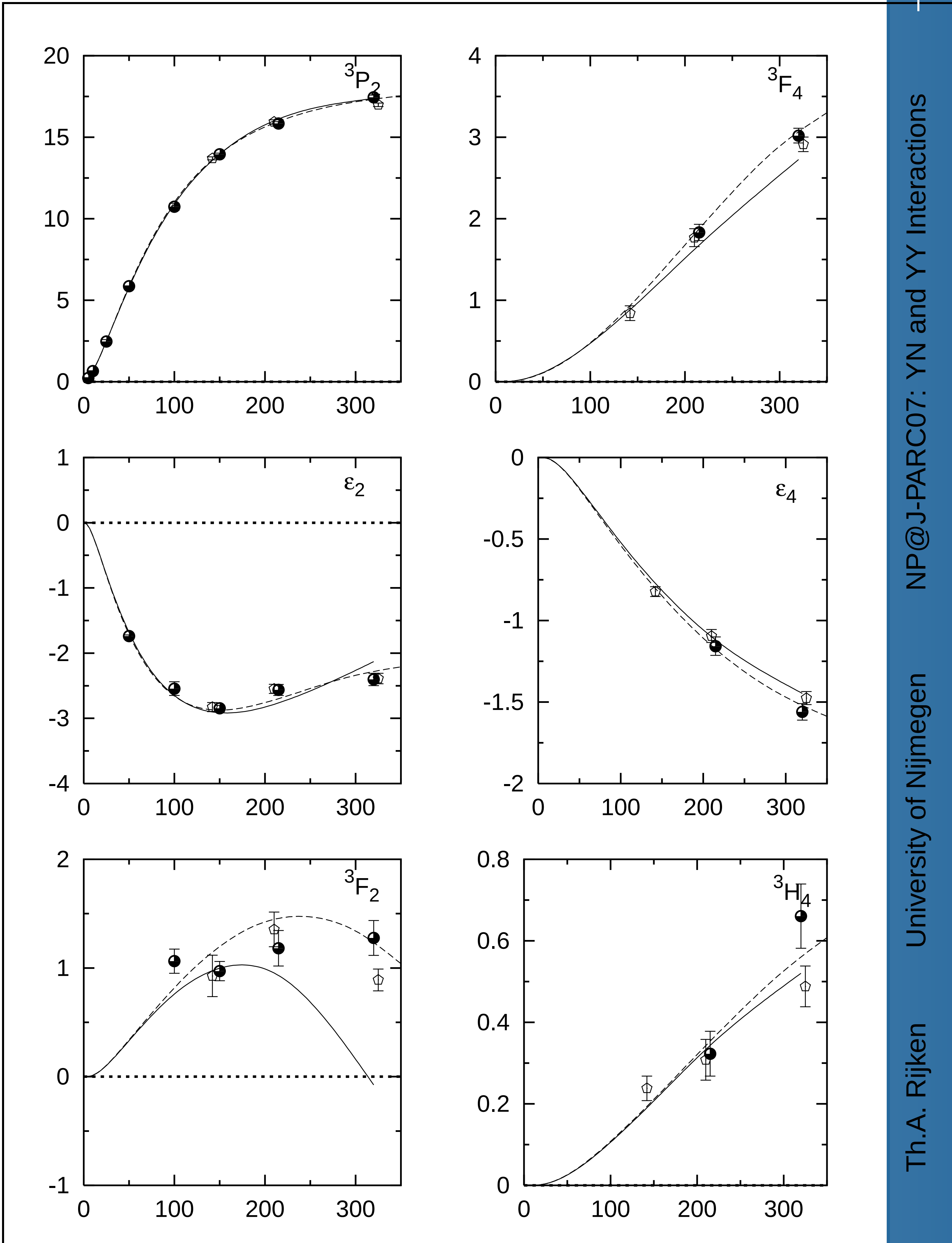
PWA93
Reid93 potential
ESC96 potential

• Arnold et al., PSI(2000)
○ Arnold et al., PSI(2000)

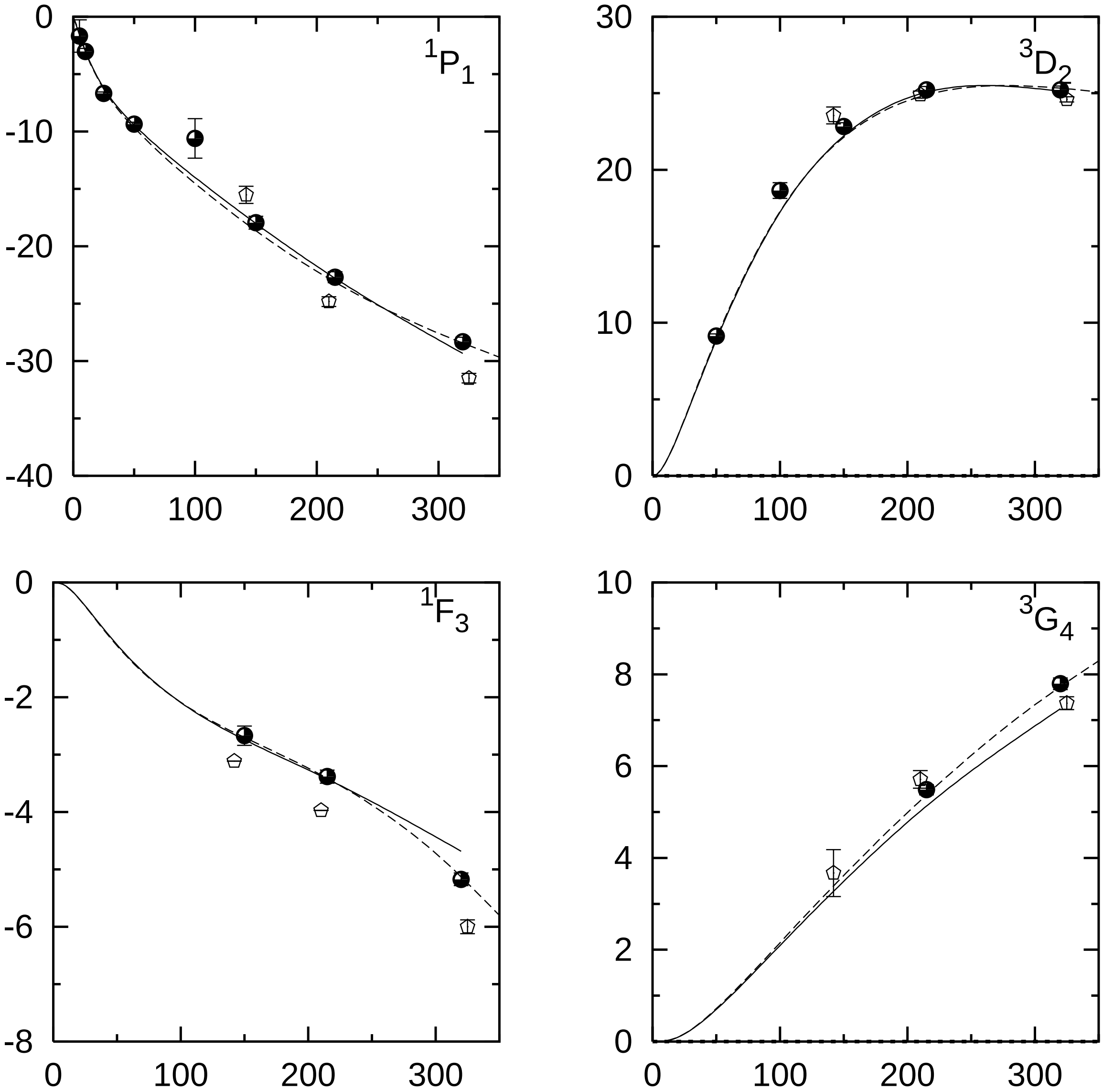
Phases-NN



Phases-NN

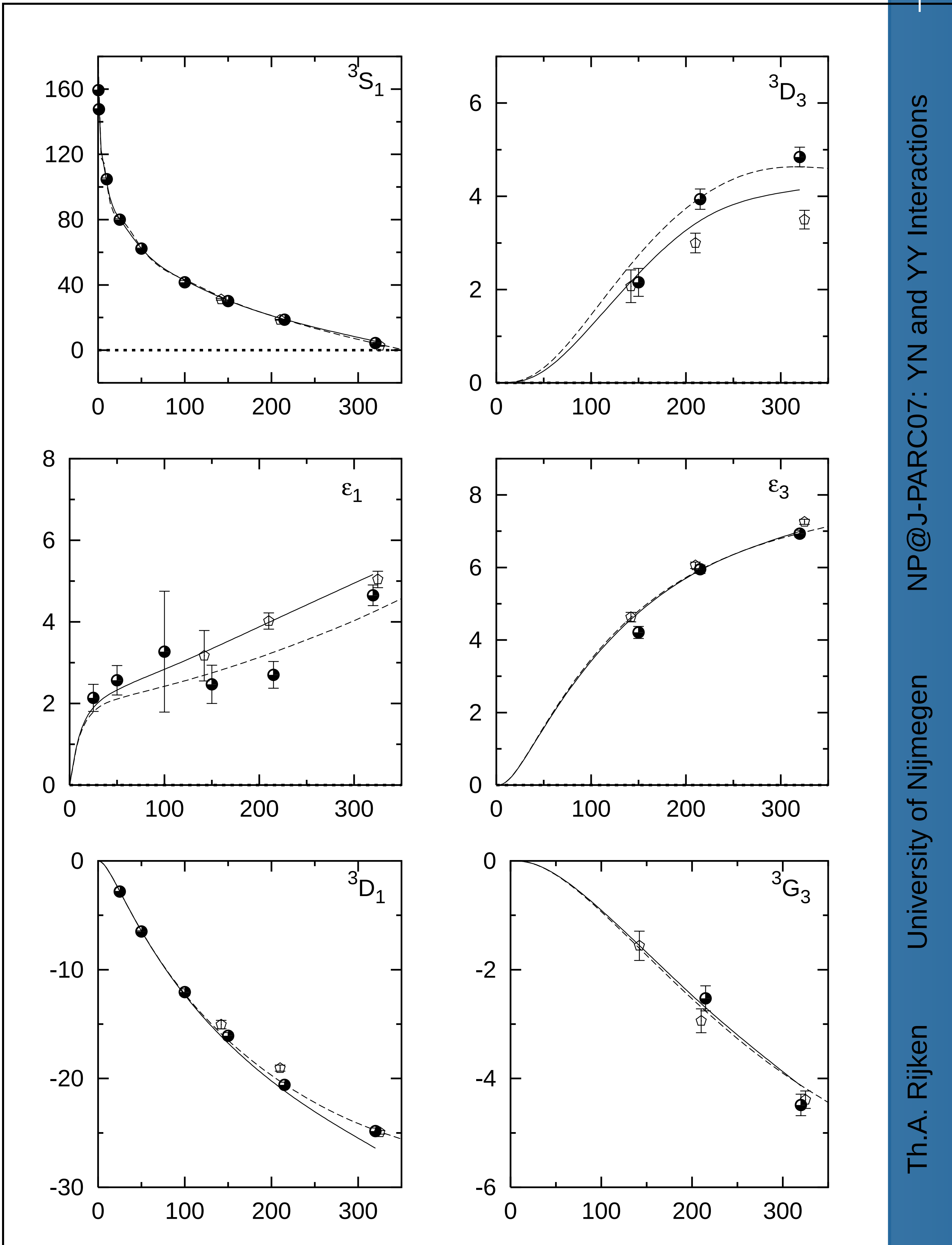


Phases-NN



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

Phases-NN



$^3S_1$
$^3D_3$
ε_1
ε_3
$^3D_1$
$^3G_3$
160
120
80
40
0
100
200
300

NN ESC04-model

- Notice: here only NN is fitted (!)

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

mesons		$I=0$	$I=1$	$F/(F+D)$
pseudoscalar	f	0.180	0.262	$\alpha_{PV}=0.388$
vector	g	3.124	0.779	$\alpha_V^e=1.0$
	f	0.071	3.317	$\alpha_V^m=0.387$
scalar	g	2.873	0.811	$\alpha_S=0.852$
axial	g	1.4717	2.423	$\alpha_A=0.652$
diffractive	g	2.203	0.000	$\alpha_D=---$

$\Lambda_P=829.9$MeV, $\Lambda_V=782.4$, $\Lambda_S=1161.3$MeV

$\Lambda_P=900.0$MeV, $\Lambda_V=890.2$, $\Lambda_S=1101.6$MeV

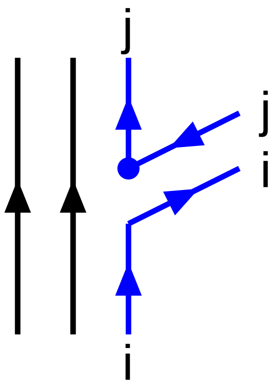
$\theta_P=-23.00^{o\ \star)}$, $\theta_V=37.50^{0\ \star)}$

$\theta_S=37.5^o$, $\psi_D=0.0^{0\ \star)}$

$a_{PV}=1.0$ (!) Scalar mesons: zero in FF (!)

QPC: $^3P_0$-model

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



$^3P_0$ Interaction Lagrangian:

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

Fierz Transformation

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

$$\chi^S_{ij} \sim \bar{q}_j\ q_i\ ,\ \chi^V_{\mu,ij} \sim \bar{q}_j\gamma_\mu q_i\ ,\ \chi^A_{\mu,ij} \sim \bar{q}_j\gamma_5\gamma_\mu q_i$$

1. $g_\epsilon = g_\omega$, and $g_{a_0} = g_\rho$!?
2. What about f_π , g_{a_1}, etc. ?
3. $g^V_{q,ij} = g^S_{q,ij} = -g^A_{q,ij} = g^P_{q,ij}$

QPC: $^3P_0$-model

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

$$f_\rho = \frac{m_\rho^{3/2}}{\sqrt{2}|\psi_\rho(0)|} \Leftrightarrow \gamma_0 \left(\frac{2}{3\pi}\right)^{1/2} \frac{m_\rho^{3/2}}{|\psi_\rho(0)|} \to$$

$$\gamma_0 = \tfrac{1}{2}\sqrt{3\pi} = 1.535.$$

- OGE one-gluon correction: $\gamma = \gamma_0 \left(1 - \frac{16}{3}\frac{\alpha(m_M)}{\pi}\right)^{-1/2}$

  $m_M \approx 1$GeV, $n_f = 3$, $\Lambda_{QCD} = 100$MeV: $\gamma \to 2.19$
  - QPC (Quark-Pair-Creation) Model:
  - Micu(1969), Carlitz & Kissinger(1970)
  - Le Yaouanc et al(1973,1975)

QPC: $^3P_0$-model

ESC04 Couplings and $^3P_0$-Model Relations

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

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

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

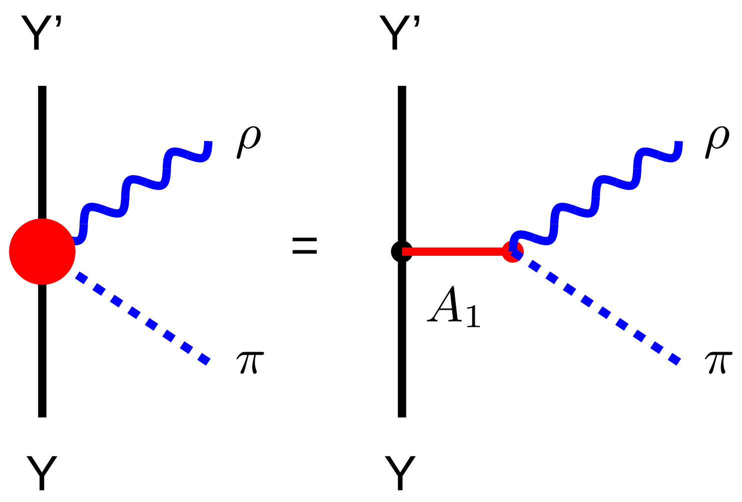
$$g_{a_0} \approx g_\rho, \quad g_\epsilon \approx g_\omega \quad \varepsilon_a(\lambda) \sim \bar{q}q(^3S_1)$$

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

ESC-model: extension to YN

Extension ESC to Hyperon-Nucleon

- MPE: Boson-dominance model:



See also: Itonaga's talk parallel session, June 2 on NM-weak decay

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

- OBE, TME ⇒ SU(3)

ESC-models

YN + YY ESC-model 2004: ESC04d

- Notice: simultaneous NN + YN fit, $\chi^2_{p.d.p.}(NN) = 1.32$ (!)

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

mesons		$\{1\}$	$\{8\}$	$F/(F+D)$
pseudoscalar	f	0.192	0.260	$\alpha_{PV} = 0.499$
vector	g	2.892	0.704	$\alpha_V^e = 1.0$
	f	-1.046	3.291	$\alpha_V^m = 0.430$
scalar	g	3.331	1.030	$\alpha_S = 0.841$
axial	g	1.834	2.431	$\alpha_A = 0.234$
diffractive	g	2.353	0.000	$\alpha_D = ---$

$\Lambda_P = 834.1$MeV, $\Lambda_V = 830.3$, $\Lambda_S = 1245.0$MeV
$\Lambda_P = 900.0$MeV, $\Lambda_V = 878.0$, $\Lambda_S = 1101.6$MeV
$\theta_P = -23.00^{o\ \star)}$, $\theta_V = 37.50^{0\ \star)}$, $\theta_A = -23.00^{0\ \star)}$
$\theta_P = -23.00^{o\ \star)}$, $\theta_V = 37.50^{0\ \star)}$
$\theta_S = 40.32^o$, $\psi_D = 0.0^{0\ \star)}$
$a_{PV} = 1.0$ (!) Scalar mesons: zero in FF (!)

ESC-models

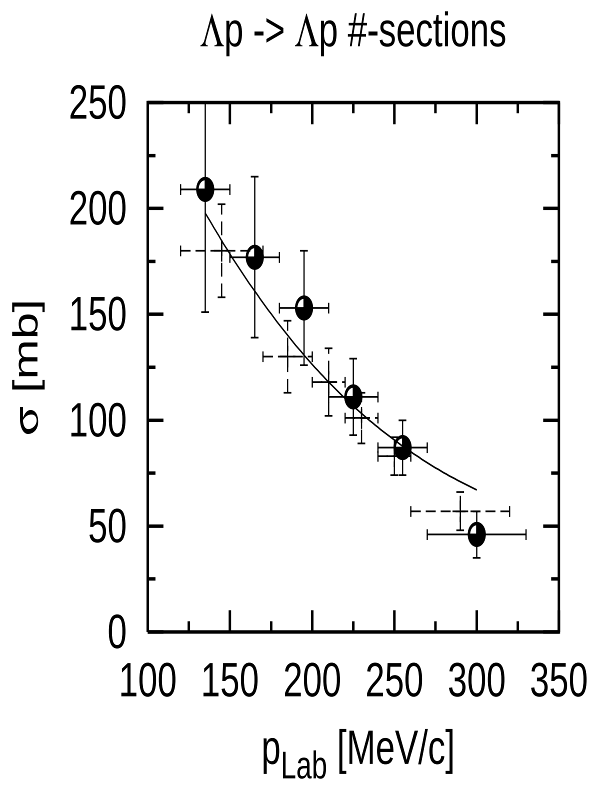
ESC04/06 Pair-couplings with HBS and QPC

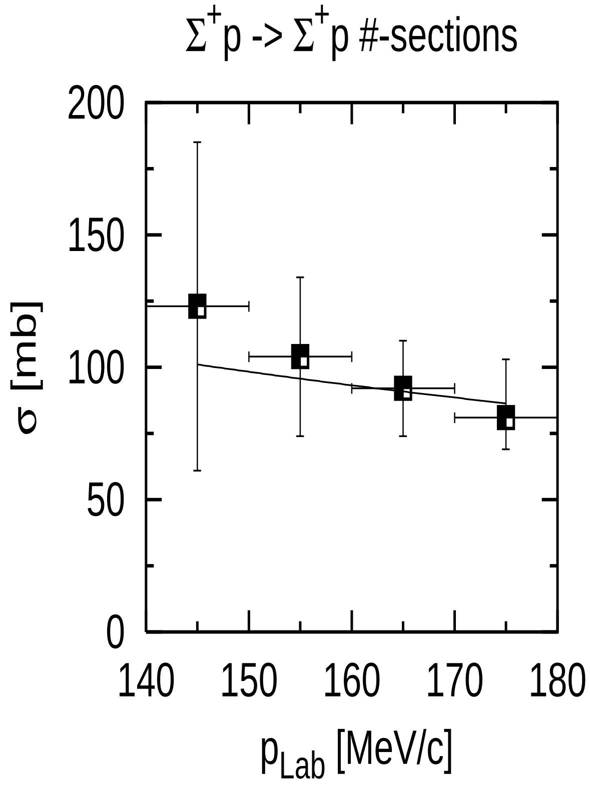
J^{PC}	Coupling	HBS	HBS	ESC04d	ESC06d	$F/(F+D)$
0^{++}	$g_{(\pi\pi)_0}$	-0.03	$f_0(760, 993), P$	0.00	0.00	—
	$g_{(\pi\eta)_1}$	-0.28	$a_0(980, 1450)$	–0.10	-0.47	1.00
1^{--}	$g_{(\pi\pi)_1}$	0.04	$\rho(760)$	0.03	0.05	1.00
	$f_{(\pi\pi)_1}$	0.16	$\rho(760)$	0.14	0.06	0.40
1^{++}	$g_{(\pi\rho)_1}$	0.42	$A_1(1270)$	0.83	0.50	0.47
	$g_{(\pi\sigma)_1}$	0.31	$A_1(1270)$	–0.04	0.23	0.47
1^{+-}	$g_{(\pi\omega)_1}$	-0.16	$B_1(1235)$	-0.17	-0.12	0.43

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

YN X-sections

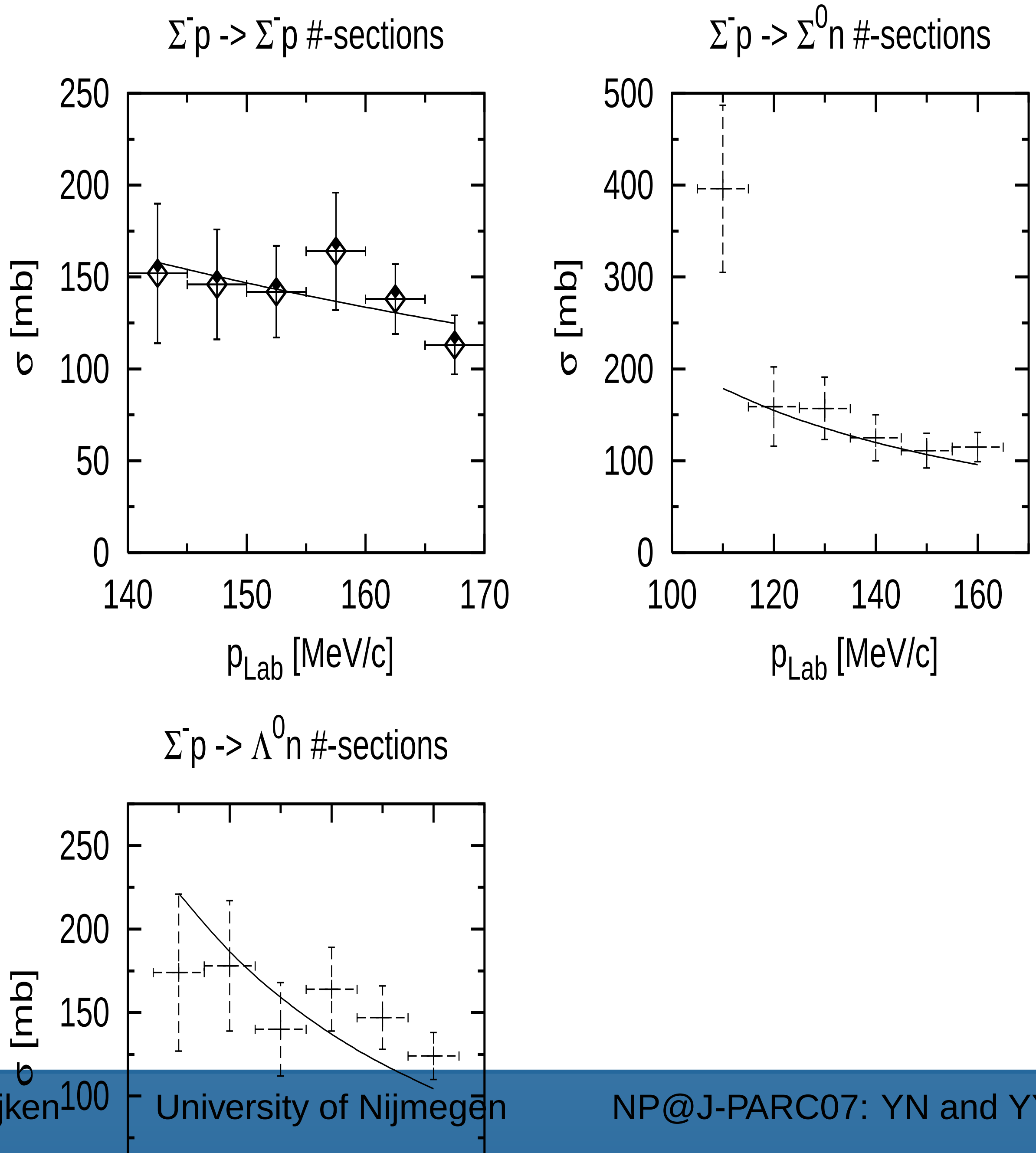
YN cross-sections





YN X-sections

YN cross-sections



ESC04-model

ESC04d 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
5					
$^1S_0$	36.93	23.58	7.38	-7.24	-20.02
$^3S_1$	-8.17	-18.53	-29.91	-39.31	-45.79
ϵ_1	-2.39	-5.73	-6.28	-4.71	-2.03
$^3P_0$	6.57	12.76	6.27	-5.25	-17.62
$^1P_1$	12.21	73.72	76.54	73.30	69.37
ρ_1	-0.18	-1.05	-1.30	-1.48	-1.61
$^3P_1$	-3.31	-9.03	-4.38	-10.89	-18.32
$^3P_2$	1.54	8.85	16.30	19.72	19.91
ϵ_2	-0.46	-2.24	-3.06	-2.28	-0.59
$^3D_1$	0.37	1.80	2.00	-0.60	-5.67
$^1D_2$	0.38	2.39	5.936	8.61	9.56
$^3D_2$	-0.55	-2.88	-5.56	-8.73	-12.61
$^3D_3$	0.07	1.02	3.02	4.58	4.72

ESC06-Mesons

Meson Table ESC06

N $^{2S+1}L_J$	J^{PC}	$I=1$	$I=0$	$I=1/2$
1 $^1S_0$	0^{-+}	$\pi(140)$	$\eta(495), \eta'(958)$	K(495)
1 $^3S_1$	1^{--}	$\rho(760)$	$\omega(783), \phi(1019)$	$K^*(892)$
1 $^3P_0$	0^{++}	$a_0(980)$	$\epsilon(760), S^*(993)$	$\kappa(900)$
1 $^3P_1$	1^{++}	$a_1(1270)$	$D(1285)$, $E(1420)$	$K_1(1400)$
2 $^1S_0$	0^{-+}	$\pi(1300)$	$\eta(1295)$	K(1460)
2 $^3S_1$	1^{--}	$\rho(1450)$	$\omega(1420), \phi(1680)$	$K^*(1410)$
2 $^3P_0$	0^{++}	$a_0(1450)$	$\epsilon(1370), S^*(1580)$	$\kappa(1430)$
1 $^1P_1$	1^{+-}	$b_1(1235)$	$h_1(1170), h_1'(1380)$	$K_{1B}(1400)$
2 $^3P_2$	2^{++}	$a_2(1320)$	$f_2(1274), f_2, (1525)$	$K_2^*(1430)$

NN+YN ESC06-model

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

mesons	$I=0$	$I=1$	$F/(F+D)$
pseudoscalar	$f_{\eta'_1} = 0.188$	$f_{\pi_1} = 0.268$	$\alpha_{PV} = 0.434$
	$f_{\eta'_2} = -0.035$	$f_{\pi_2} = 0.280$	
vector	$g_{\omega_1} = 1.932$	$g_{\rho_1} = 0.822$	$\alpha_V^e = 1.0$
	$f_{\omega_1} = 1.209$	$f_{\rho_1} = 3.909$	$\alpha_V^m = 0.285$
	$g_{\omega_2} = 3.124$	$g_{\rho_2} = -0.114$	
	$f_{\omega_2} = -1.290$	$f_{\rho_2} = 0.183$	
scalar	$g_{\epsilon_1} = 2.268$	$g_{\delta_1} = 0.316$	$\alpha_S = 1.0$
	$g_{\epsilon_2} = 2.531$	$g_{\delta_2} = 0.597$	
axial	$g_{f'_1} = 1.744$	$g_{a_1} = 2.156$	$\alpha_A = 0.129$
diffractive	$g_P = 2.801$	0.000	$\alpha_D = ---$

$\Lambda_P = 789.3$ MeV, $\Lambda_V = 1121.7$ MeV, $\Lambda_S = 1061.5$ MeV

$\Lambda_P = 900.0$ MeV, $\Lambda_V = 918.8$ MeV, $\Lambda_S = 1085.1$ MeV

$\theta_P = -23.00^{o\ \star)}$, $\theta_V = 37.50^{0\ \star)}$

$\theta_{S,1}$‘ $= 24.3^o$, $\theta_{S,2} = 37.5^o$

$a_{PV} = 1.0$ (!) Scalar mesons: zero in FF (!)

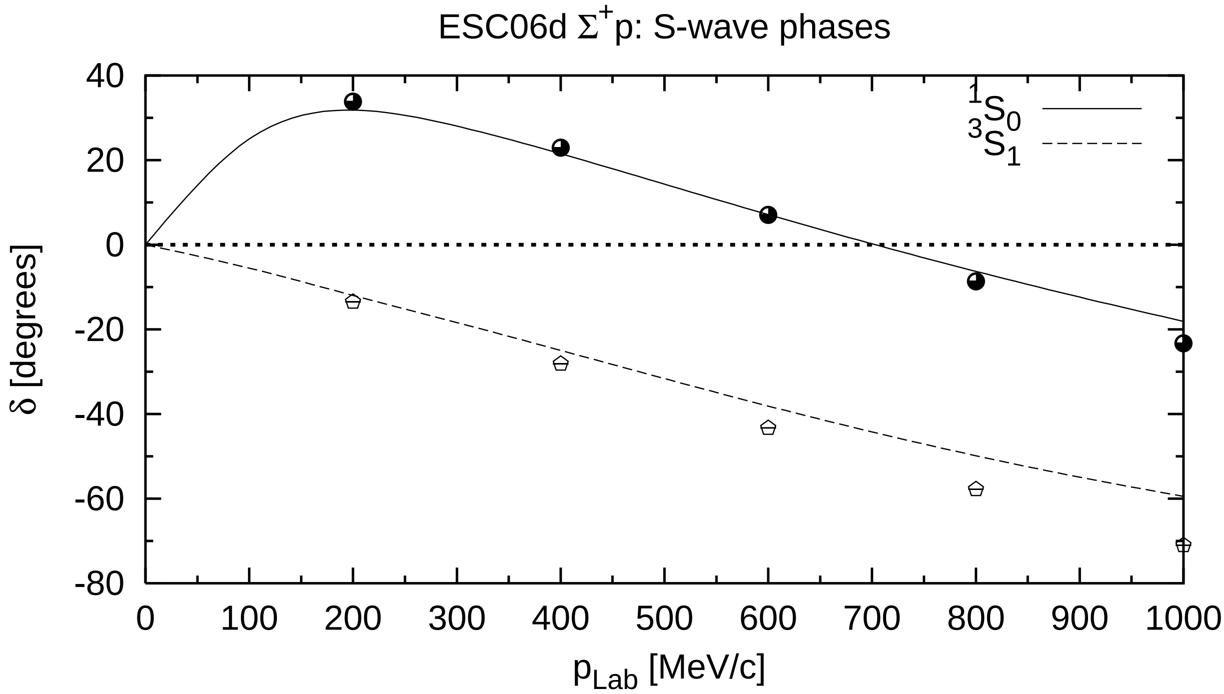
ESC06-model

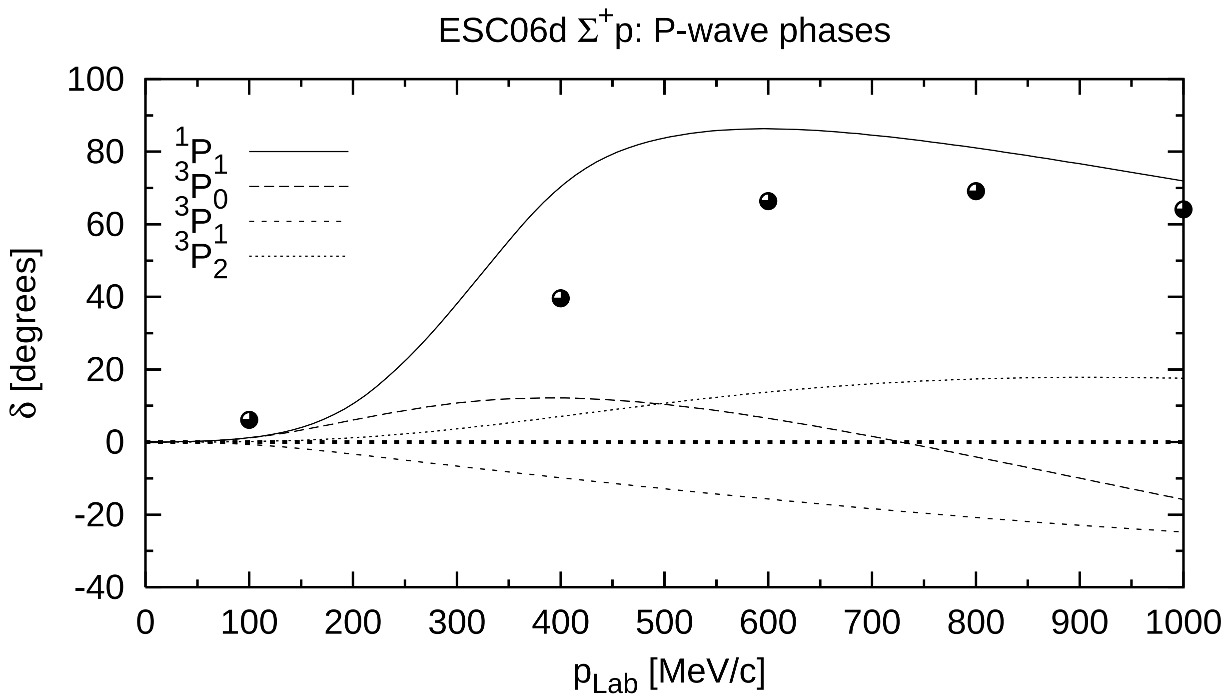
ESC06d nuclear-bar $\Sigma^+ p$ phases in degrees:

p_{Σ^+}	200	400	600	800	1000
$T_{\rm lab}$	16.7	65.5	142.8	244.0	364.5
5					
$^1S_0$	31.81	21.52	7.12	–6.28	–18.10
$^3S_1$	–11.98	–24.97	–38.12	–49.85	–59.45
ϵ_1	–2.20	–5.82	–7.38	–7.15	–5.88
$^3P_0$	6.06	12.14	6.55	–4.09	–15.83
$^1P_1$	10.56	70.34	86.31	81.02	71.94
$^3P_1$	–3.33	–9.83	–15.71	–20.78	–24.79
$^3P_2$	1.19	7.06	13.78	17.37	17.58
ϵ_2	–0.43	–2.15	–3.24	–2.90	–1.60
$^3D_1$	0.35	1.63	1.51	–1.38	–6.62
$^1D_2$	0.35	2.16	5.24	8.54	10.53
$^3D_2$	–0.52	–2.84	–5.80	–9.38	–13.59
$^3D_3$	0.06	0.82	2.51	4.28	5.46

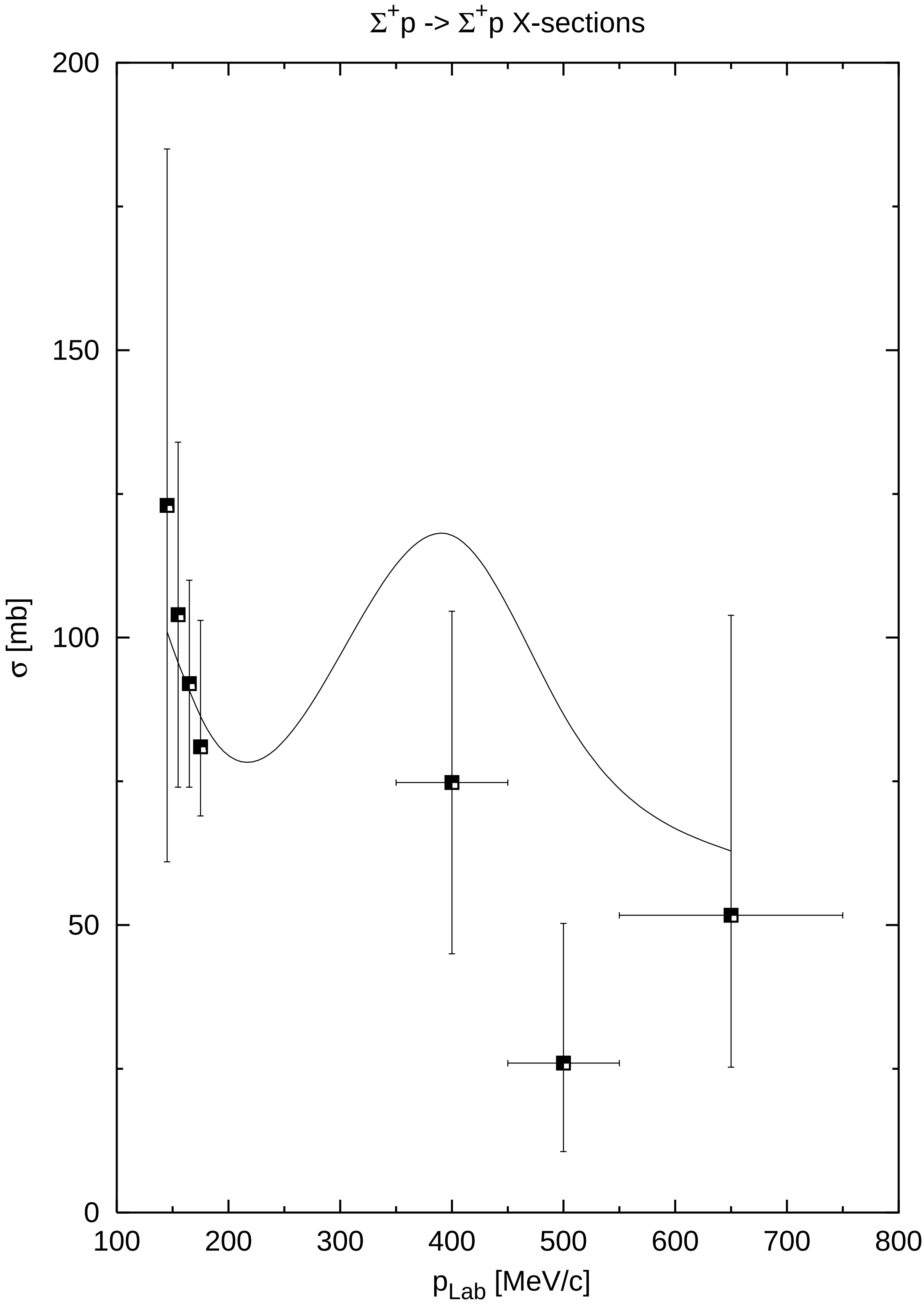
• $a_s = -2.01\text{fm}$, $r_s = 4.13\text{fm}$

Phases-SP,ESC06d





X-sections SP,ESC06d



G-matrix ESC-models

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

	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	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
ESC06d	–13.3	–30.7	3.5	–0.2	1.7	–4.3	–1.2	–44.5
ESC06d*	–11.8	–26.9	3.8	0.0	2.1	–3.4	–1.1	–37.2
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

- R & Y, PR C73, 044008 (2006), and private communication Y. Yamamoto

(See Yamamoto's talk INPC07,next week)

G-matrix ESC-models

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

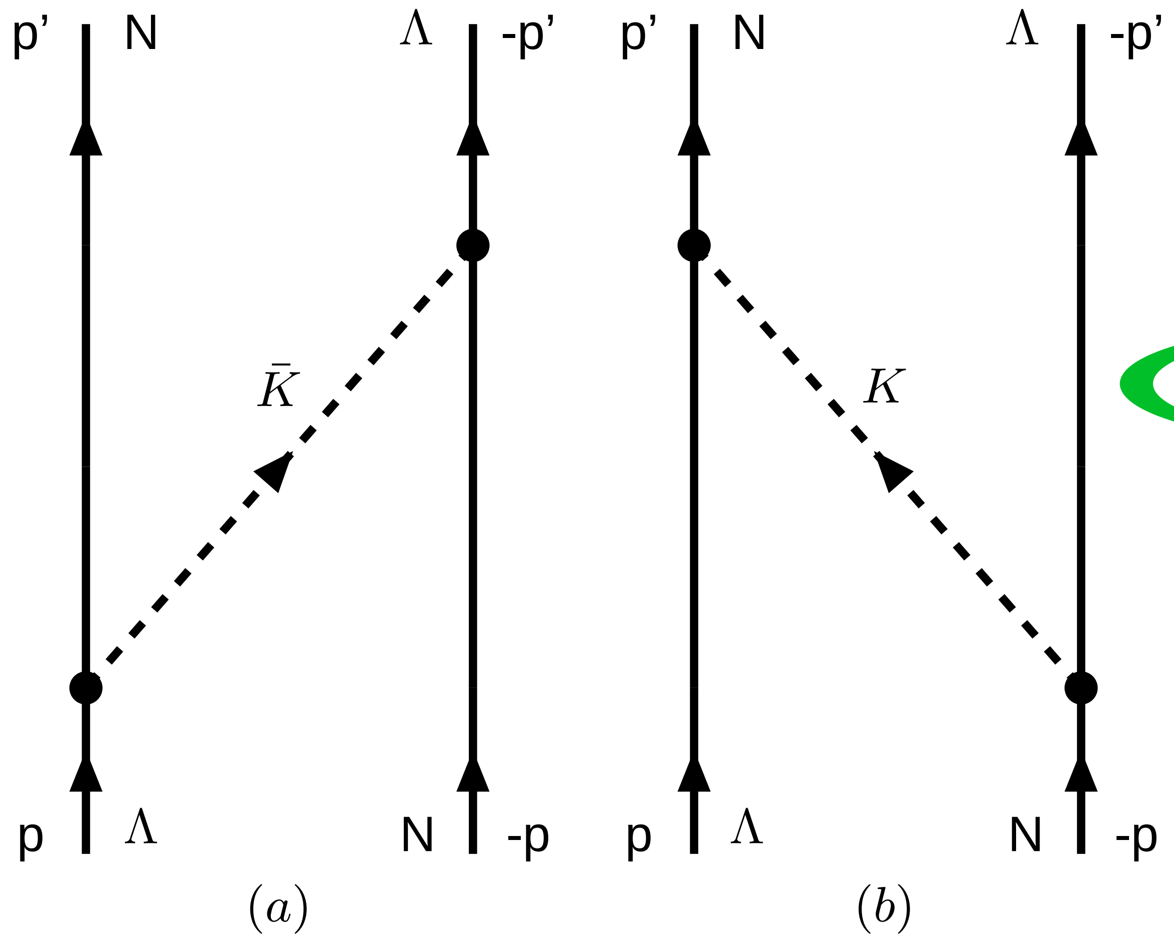
model		$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	D	U_Σ	Γ_Σ
ESC04a	$T=1/2$	11.6	–26.9	2.4	2.7	–6.4	–2.0	–0.8		
	$T=3/2$	–11.3	2.6	–6.8	–2.3	5.9	–5.1	–0.2	–36.5	
ESC04d	$T=1/2$	6.5	–21.0	2.6	2.4	–6.7	–1.7	–0.9		
	$T=3/2$	–10.1	14.0	–8.5	–2.6	5.9	–5.7	–0.2	–26.0	
ESC06d	$T=1/2$	7.2	–21.5	1.9	2.3	–6.1	–1.0	–0.8		
	$T=3/2$	–10.8	39.1	–10.6	–2.5	6.0	–4.5	–0.1	–1.2	
ESC06d*	$T=1/2$	8.1	–20.5	2.1	2.3	–6.0	–1.0	–0.8		
	$T=3/2$	–10.1	43.8	–10.6	–2.2	6.3	–3.6	–0.0	+8.2	
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

- R & Y, PR C73, 044008 (2006), and private communication Y. Yamamoto

(See Yamamoto's INPC07 talk, next week)

VLS and VLSA Spin-orbit OBE-graphs, I

Strangeness Exchange (a,b)-graphs



$\Rightarrow$ BDI70 V_{ALS}

(Dover & Gal, P.P.N.P 12, 1984)

Figuur 5: K,K*-exchange time-ordered graphs.

VLS and VLSA Spin-orbit OBE-graphs, II

BDI70 ALS-potentials for strange-meson-exchanges

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

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

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

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

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

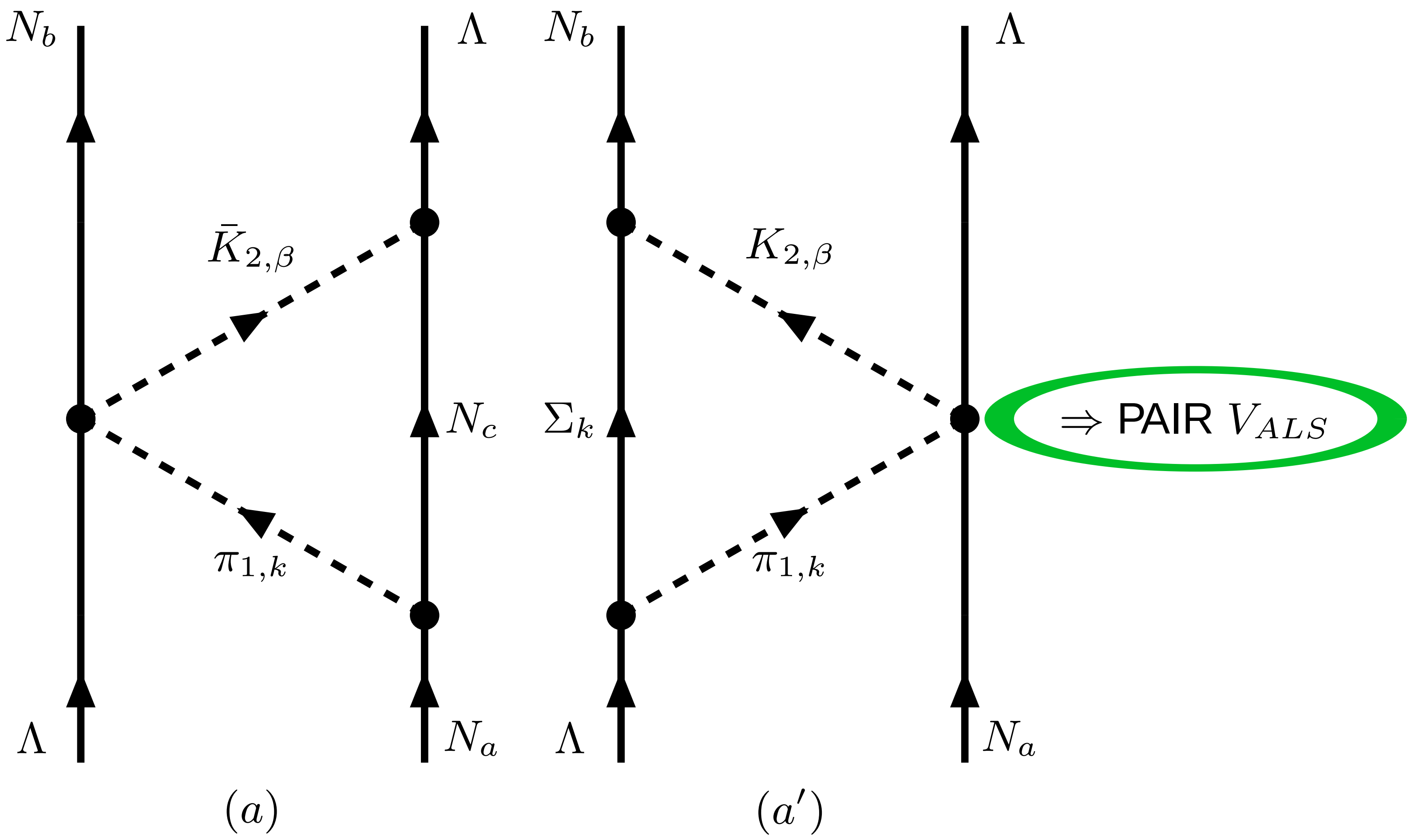
$$= -(1+\boldsymbol{\sigma}_1\cdot\boldsymbol{\sigma}_2)\;P_6$$

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

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

VLS and VLSA Spin-orbit Pair-graphs, I

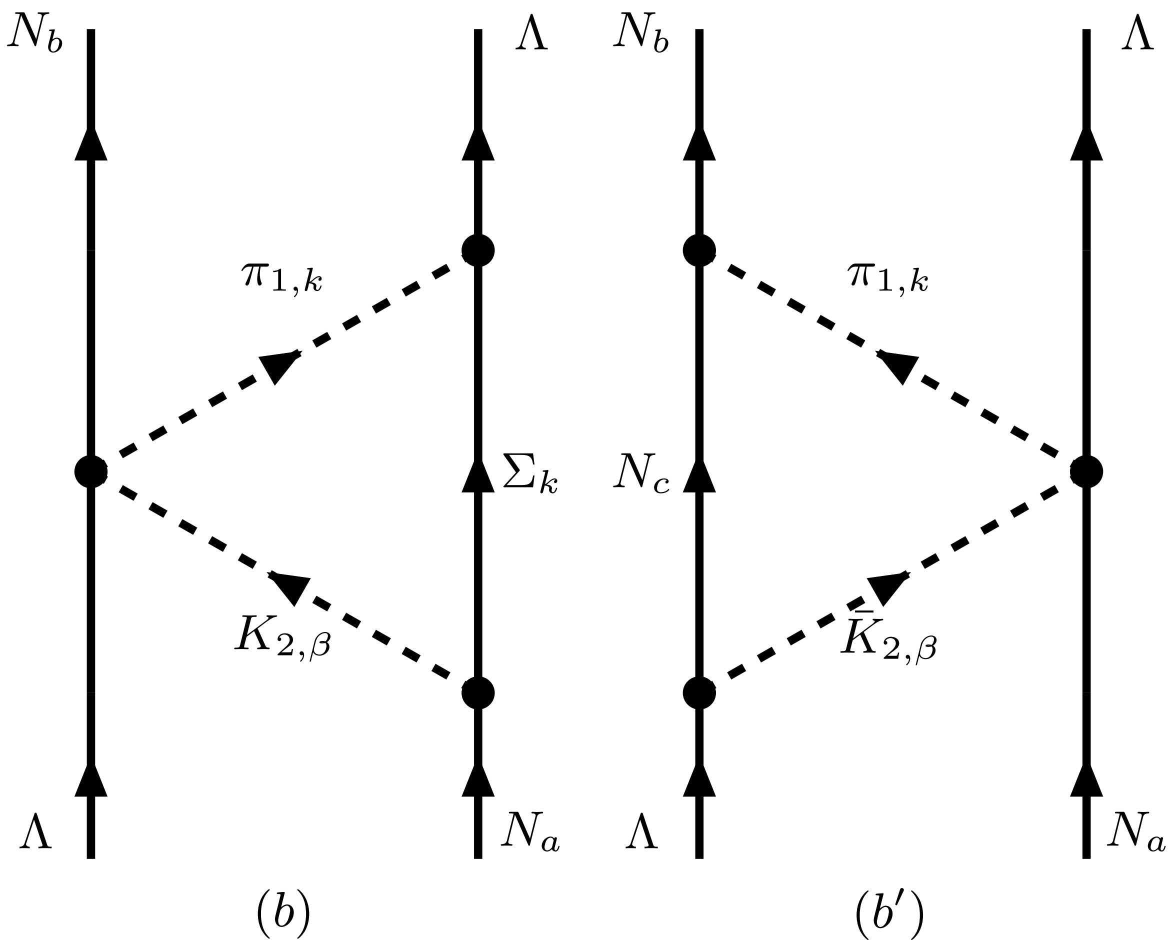
Strangeness Exchange (a,a')-graphs



Figuur 6: $\pi - K$-exchange one-pair exchange graphs.

VLS and VLSA Spin-orbit Pair-graphs, II

Strangeness Exchange (b,b')-graphs



Figuur 7: $\pi - K$-exchange one-pair exchange graphs.

VLS and VLSA Spin-orbit ESC-models, II

Strengths of Λ spin-orbit potential

$$U_\Lambda^{ls}(r) = K_\Lambda \left(\frac{1}{r}\frac{d\rho}{dr}\right) \mathbf{l}\cdot\mathbf{s} \ , \quad K_\Lambda = K_{S,\Lambda} + K_{A,\Lambda} \ \text{where}$$

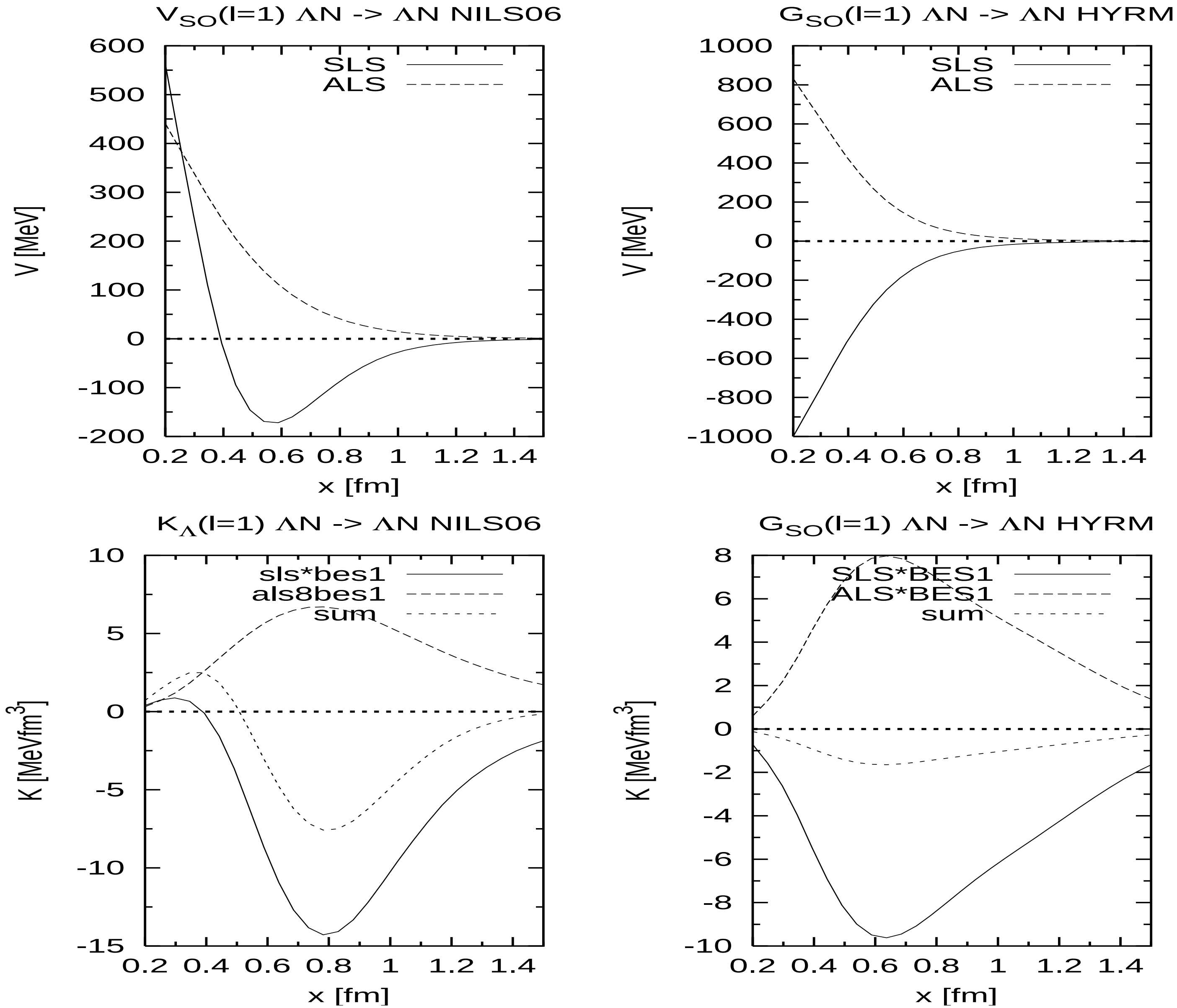
$$K_{S/A,\Lambda} = -\frac{\pi}{q}\int_0^\infty r^3 j_1(qr) V_{SLS,ALS}(r)dr \ .$$

	K_S	K_A	$K_\Lambda^{(0)}$	$K_\Lambda(BDI)$	$K_\Lambda(Pair)$	K_Λ	ΔE_{LS}
ESC04a	18.4	–7.8	10.5	(–2.6)	(–3.7)	(4.2)	
ESC04b	16.0	–8.7	7.3	(–2.4)	(–3.3)	(1.6)	
ESC04c	27.0	–6.9	20.0	(–5.1)	(–5.4)	(9.5)	
ESC04d	22.3	–6.9	15.4	(–5.0)	(–6.9)	(3.3)	
ESC06d	24.3	–5.5	18.9	(–5.2)	(–6.6)	(7.1)	
NILS06d	21.5	–6.1	15.4	(–5.1)	(–6.6)	(3.7)	
NHC-D	30.7	–5.9	24.8	(-3.4)	—	(21.4)	0.15*
NHC-F	29.7	–6.7	23.0	(-3.8)	—	(19.2)	0.20*
Experiment	H. Tamura, Nucl.Phys. A754 (2005)					0.043	

*) E. Hiyama et al, P.R.L. 85 (2000) 270 (See Hiyama's INPC07 talk)

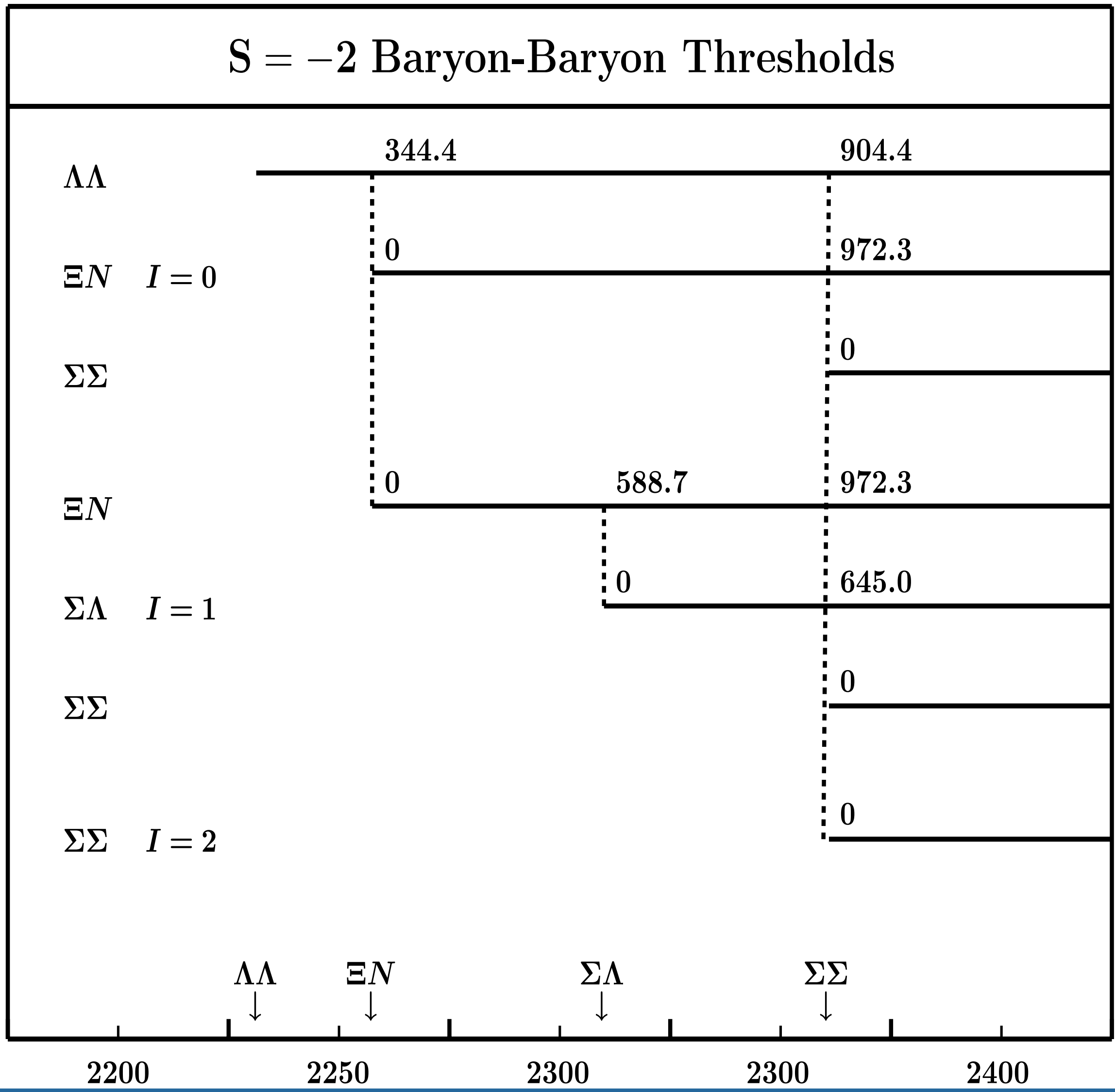
VLS and VLSA Spin-orbit ESC-models, III

SLS+ALS: NILS06d and HKMYY(NSC97a)



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

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



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ESC-models: YY

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

- 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

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

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

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

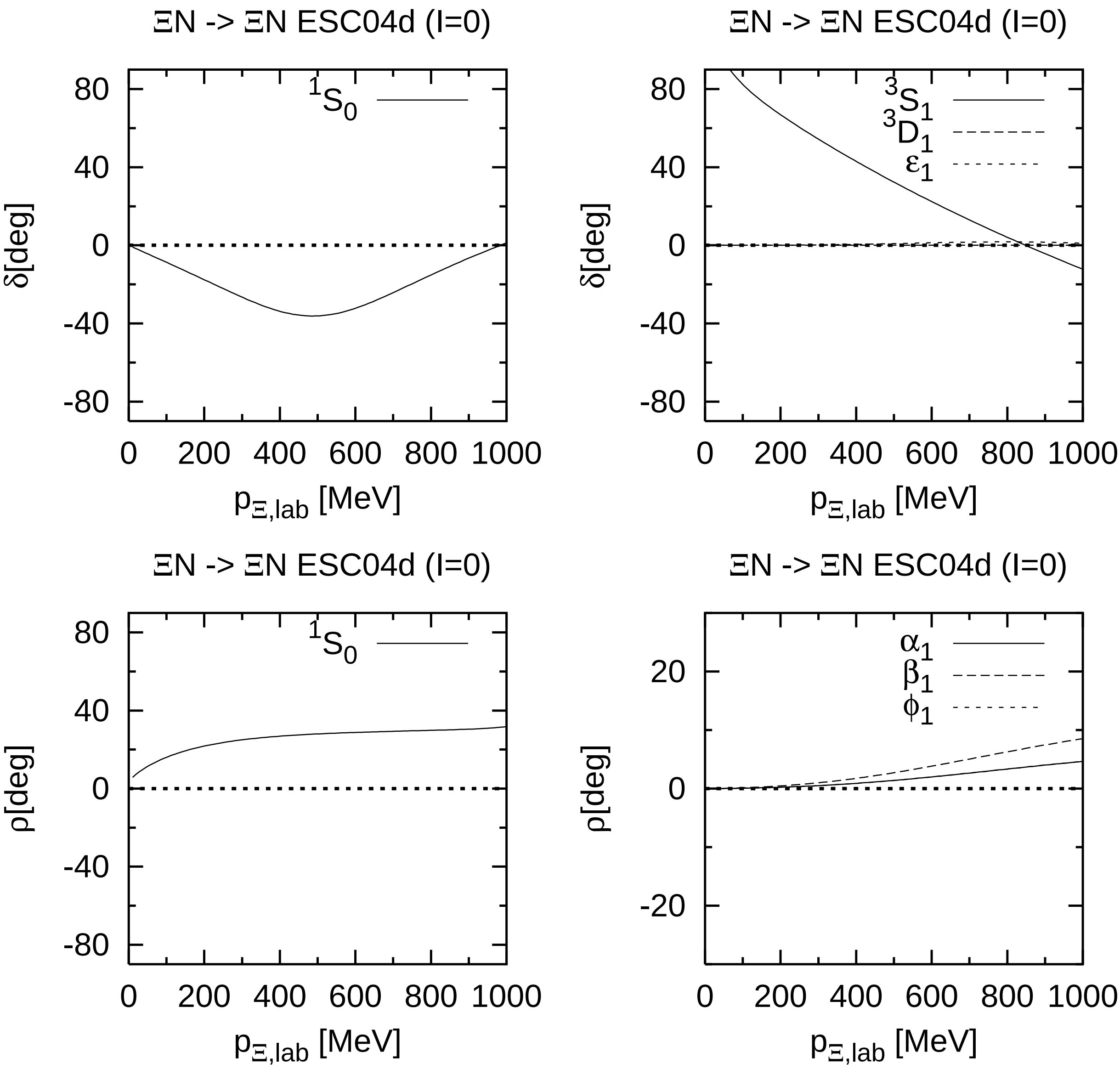
- Soft-core models: NSC89, NSC97:
  $|V_{\Lambda\Lambda}(\epsilon)| < |V_{\Lambda N}(\epsilon)| < |V_{NN}(\epsilon)|$
  $\rightarrow$ weak attraction/repulsion in $\Lambda N, \Xi N$-sytems.
- ESC04d-model: $\Delta B_{\Lambda\Lambda} \approx 1.0$ MeV !!
  Ξ-well-depth =-18.7 MeV $\approx$ experiment - 16 MeV (!?)

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
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)



Figuur 9: ESC04d I=0 ΞN-pha

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
ESC04a	$T=0$	8.1	–10.0	1.0	–0.3	–0.4	–0.7	
	$T=1$	–4.5	21.8	–0.7	0.7	–0.1	0.3	+15.1
ESC04b	$T=0$	5.9	–2.4	0.7	0.7	1.0	–0.4	
	$T=1$	0.5	27.9	0.6	0.9	–0.3	1.2	+36.3
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
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

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

Epilogue

Conclusions and Applications/Prospects ESC-model

1. High-quality Descriptions NN, YN, YY scattering
2. Simultaneous Fit/Description $NN \oplus YN$,
   meson-exchange dynamics $\Leftrightarrow$ theory (QPC !)
3. Long-range forces ($\pi\pi$) complete $\oplus$
   $SU_f(3)$-consistent ($K\bar{K}, \pi K$, etc.)
4. YN,YY: couplings $SU_f(3)$-symmetry,
   $^3S_1(\Sigma N, I = 3/2)$ is weakly (ESC04d)/ strongly (ESC06d) repulsive,
   ΛN: p-waves attractive on average
5. Scalar-meson nonet structure $\Leftrightarrow$ Nagara $\Delta B_{\Lambda\Lambda}$ values.

Applications/extensions ESC Models:

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

Prospects:

- Tests in nuclear and hypernuclear spectrocopy
- Future scattering experiments (JPARC, FAIR) + ESC-model $\Rightarrow$
  Determination Meson-couplings!!

Summary and Proloque

General Summary and Prospects