BB-interactions, $\{8\} \otimes \{8\}$-channels

Generalized Yukawa Potentials

2nd EMMI workshop on anti-matter,hyper-matter and exotica production at LHC

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Outline/Content Talk

⋆ General Introduction

I. ESC-model: meson-exchanges: OBE, MPE

a. data fitting, couplings.

b. S= 0: NN-results; S=-1: YN-results.

II. Quark-pair-creation model (QPC)

III. S=-2: YN-, YY-results; S=-3,-4: YY-results

IV. Matter: universal repulsion

a. Multi-gluon, Pomeron

b. Nuclear saturation, NS-matter

⋆ Conclusions and Perspectives

V. CQM and Quark-interactions

Thanks to: Y. Yamamoto, M. Nagels,
T. Motoba, H-J. Schulze

ii Role BB-interaction Models

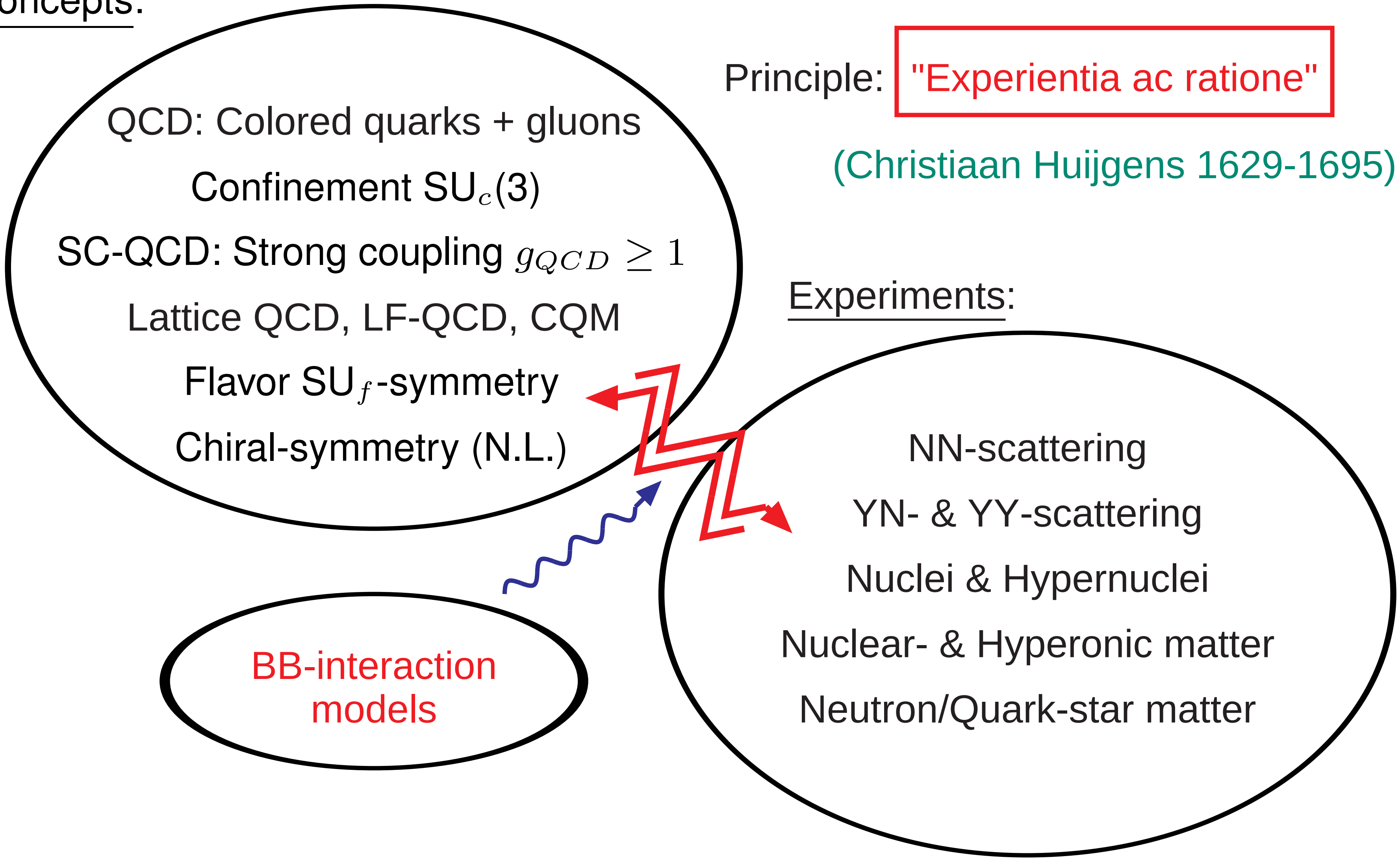
Particle and Flavor Nuclear Physics

- Concepts:

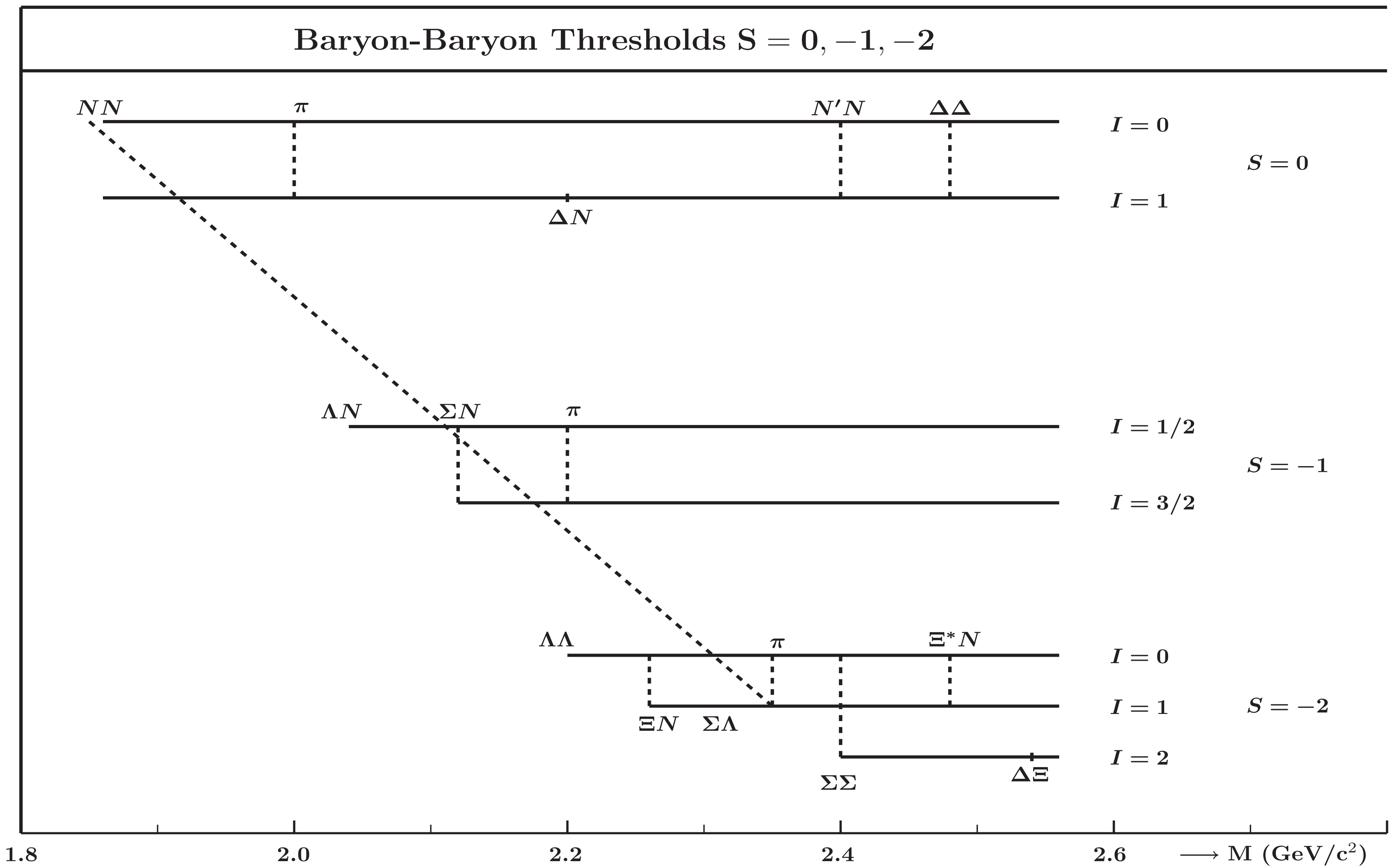
Principle: "Experientia ac ratione"

(Christiaan Huijgens 1629-1695)

Experiments:



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



Baryon-Baryon Interactions: SU(2), SU(3)-Flavor Symmetry

- Quark Level: SU(3)$_{flavor}$ ⇔ Quark Substitutional Symmetry (!!)]
  'gluons are flavor blind'

- $p \sim UUD\ ,\ n \sim UDD\ ,\ \Lambda \sim UDS\ ,\ \Sigma^+ \sim UUS\ ,\ \Xi^0 \sim USS \Leftrightarrow \{8\}$

- Mass differences ⇔ Broken SU(3)$_{flavor}$ symmetry

- Baryon-Baryon Channels:

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

- $p \sim UUD\ ,\ n \sim UDD\ ,\ \Lambda_c \sim UDC\ ,\ \Sigma_c^+ \sim UUC\ ,\ \Xi_c^0 \sim UCC \Leftrightarrow \{8\}$

ESC08c: Soft-core $NN + YN + YY$ ESC-model

- ESC08-model, PTP Suppl.185(2010), arXiv2015, PRC2017.
- NN: 20 free parameters: couplings, cut-off's,
  meson mixing and F/(F+D)-ratio's
- meson nonets:

$$J^{PC} = 0^{-+}: \quad \pi, \eta, \eta', K \quad ;= 1^{--}: \quad \rho, \omega, \phi, K^\star$$
$$= 0^{++}: \quad a_0(962), f_0(760), f_0(993), \kappa_1(900)$$
$$= 1^{++}: \quad a_1(1270), f_1(1285), f_0(1460), K_a(1430)$$
$$= 1^{+-}: \quad b_1(1235), h_1(1170), h_0(1380), K_b(1430)$$

- 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, $exp(-\mathbf{k}^2/2\Lambda^2_{B'BM})$
- Nagels, Rijken, Yamamoto, arXiv2015, PRC2017?

I.2 Method ESC08-model Analysis

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

Input data/pseudo-data:

• NN-data : 4300 scattering data + low-energy par's

• YN-data : 52 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

• Meson-fields: Yukawa-forces + Short range forces

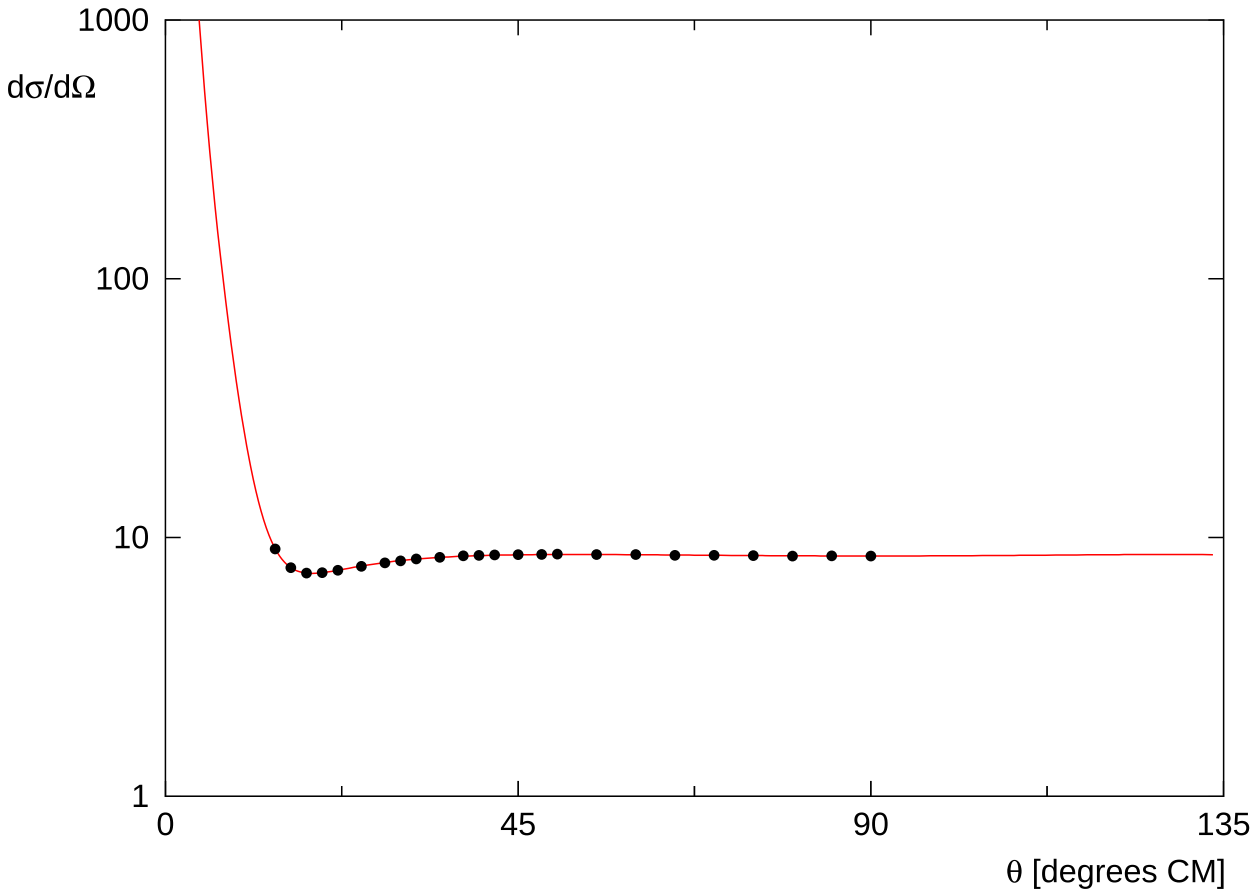
(gluon-exchange/Pomeron/Odderon, Pauli-repulsion)

Output: ESC08-models (2011, 2012, 2014, 2016)

• Fit NN-data $\chi^2_{p.d.p.}$=1.08-1.10 (!), deuteron, YN-data $\chi^2_{p.d.p.} = 1.09$

• Description all well-depth's, NO S=-1,-2,-3,-4 bound-states(!), small Λp spin-orbit (Tamura), $\Delta B_{\Lambda\Lambda}$ a la Nagara (!)

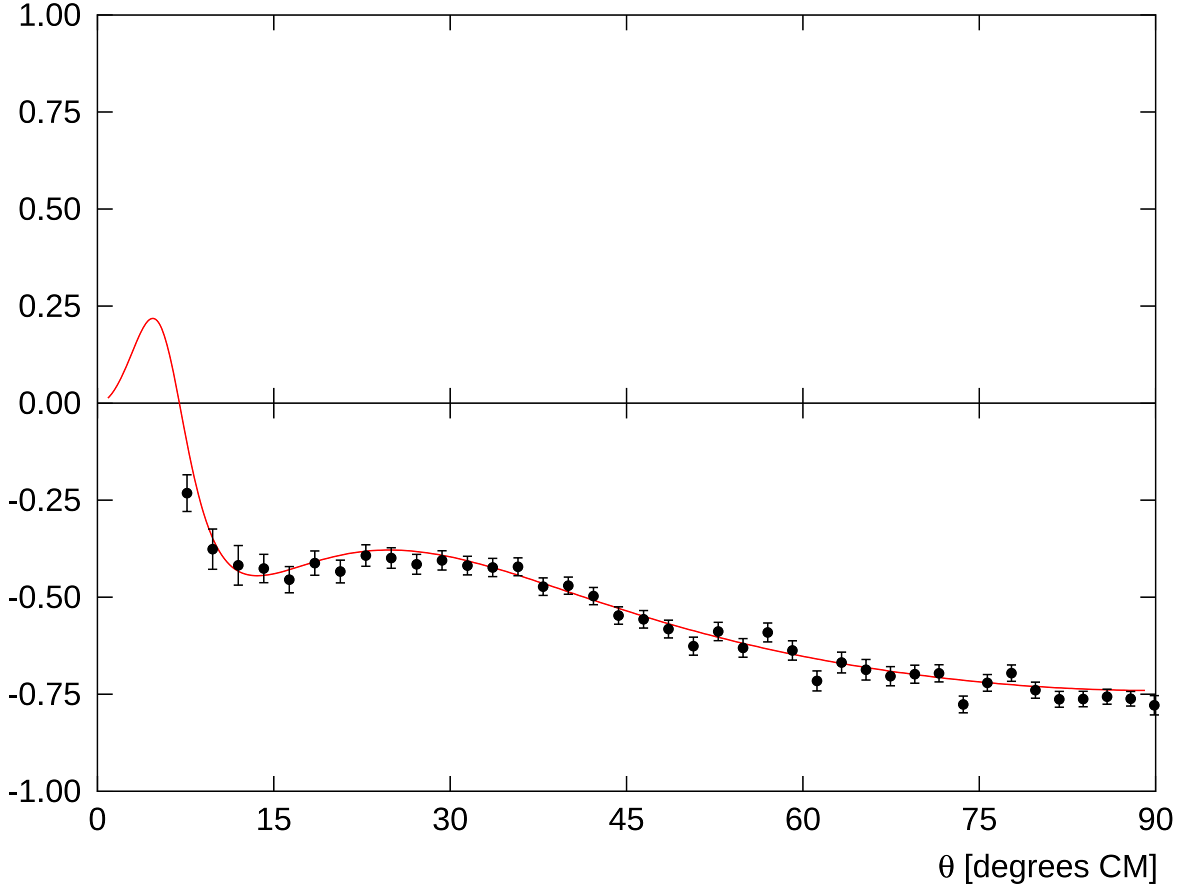
NNa PWA-93, 1



pp observable $d\sigma/d\Omega$ at T_{lab} = 50.06 MeV

PWA93 • Berdoz et al., SIN(1986)

NNb PWA-93, 2

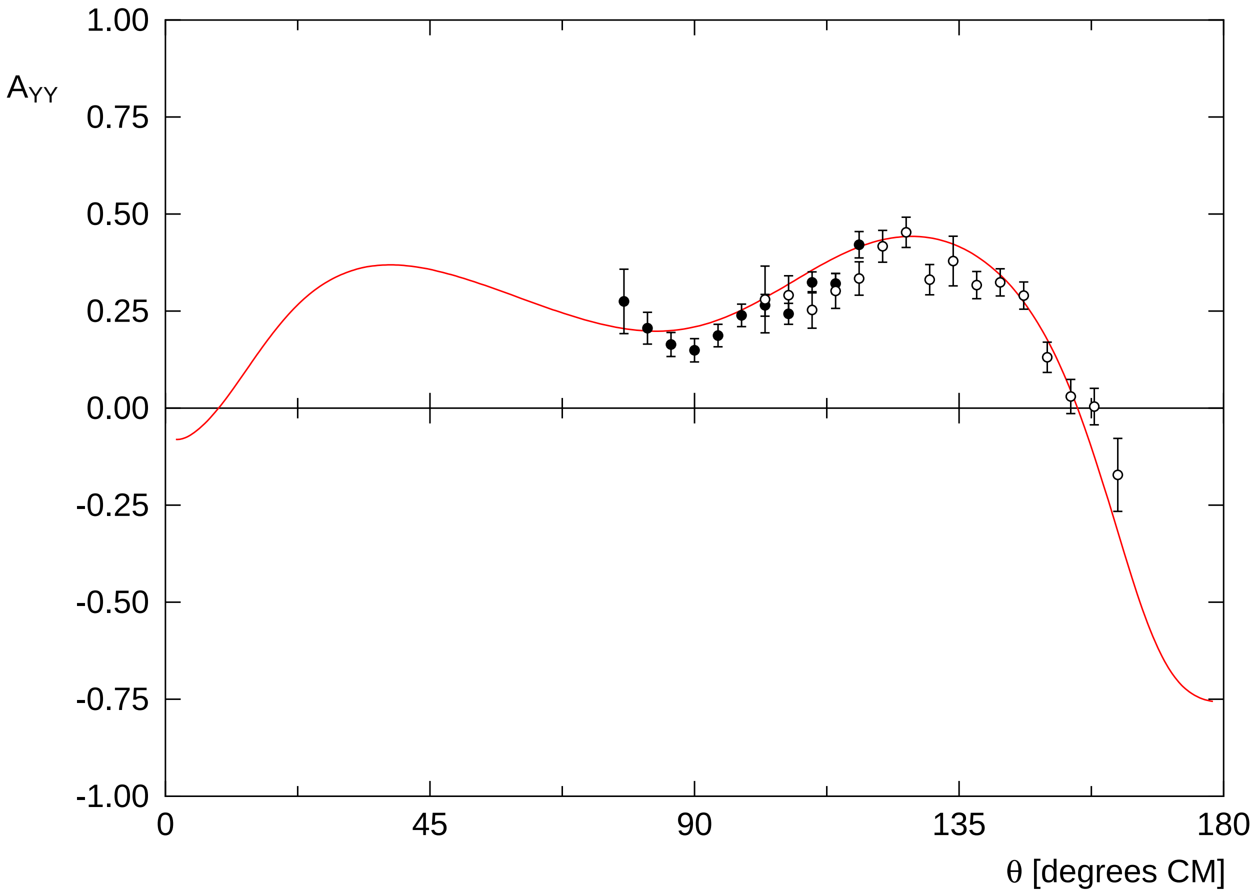


pp observable A_{XX} at T_{lab} = 350.0 MeV

PWA93

• von Przewoski et al., IUCF(1998)

NNc PWA-93, 3



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

PWA93

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

YN-results ESC08c, 2014:

- Notice: simultaneous NN + YN fit, $\chi^2_{p.d.p.}(YN) = 1.09$ (!)

Comparison of the calculated ESC08 and experimental values for the 52 YN-data that were included in the fit. The superscipts RH and M denote, respectively, the Rehovoth-Heidelberg Ref. Ale68 and Maryland data Ref. Sec68. Also included are (i) 3 Σ^+p X-sections at $p_{lab} = 400, 500, 650$ MeV from Ref. Kanda05, (ii) Λp X-sections from Ref. Kadyk71: 7 elastic between $350 \leq p_{lab} \leq 950$, and 4 inelastic with $p_{lab} = 667, 750, 850, 950$ MeV, and (iii) 3 elastic Σ^-p X-sections at $p_{lab} = 450, 550, 650$ MeV from Ref. Kondo00. The laboratory momenta are in MeV/c, and the total cross sections in mb.

YNb YN-results: ESC08c YN-fit

$\Lambda p \to \Lambda p$		$\chi^2 = 3.6$	$\Lambda p \to \Lambda p$		$\chi^2 = 3.8$
p_Λ	σ^{RH}_{exp}	σ_{th}	p_Λ	σ^{M}_{exp}	σ_{th}
145	180±22	197.0	135	187.7±58	215.6
185	130±17	136.3	165	130.9±38	164.1
210	118±16	107.8	195	104.1±27	124.1
230	101±12	89.3	225	86.6±18	93.6
250	83± 9	73.9	255	72.0±13	70.5
290	57± 9	50.6	300	49.9±11	46.0

$\Lambda p \to \Lambda p$		$\chi^2 = 12.1$			
350	17.2±8.6	28.7	750	13.6±4.5	10.2
450	26.9±7.8	11.9	850	11.3±3.6	11.4
550	7.0±4.0	8.6	950	11.3±3.8	12.9
650	9.0±4.0	18.5			

YNc YN-results: ESC08c YN-fit

$\Lambda p \to \Sigma^0 p$		$\chi^2 = 6.9$			
667	2.8 ±2.0	3.3	850	10.6±3.0	4.1
750	7.5±2.5	4.0	950	5.6±5.0	3.9

$\Sigma^+ p \to \Sigma^+ p$		$\chi^2 = 12.4$	$\Sigma^- p \to \Sigma^- p$		$\chi^2 = 5.2$
$p_{\Sigma+}$	σ_{exp}	σ_{th}	$p_{\Sigma-}$	σ_{exp}	σ_{th}
145	123.0±62	136.1	142.5	152±38	152.8
155	104.0±30	125.1	147.5	146±30	146.9
165	92.0±18	115.2	152.5	142±25	141.4
175	81.0±12	106.4	157.5	164±32	136.1
			162.5	138±19	131.1
			167.5	113±16	126.3
400	93.5±28.1	35.1	450.0	31.7±8.3	28.5
500	32.5±30.4	30.9	550.0	48.3±16.7	19.8
650	64.6±33.0	28.2	650.0	25.0±13.3	15.1

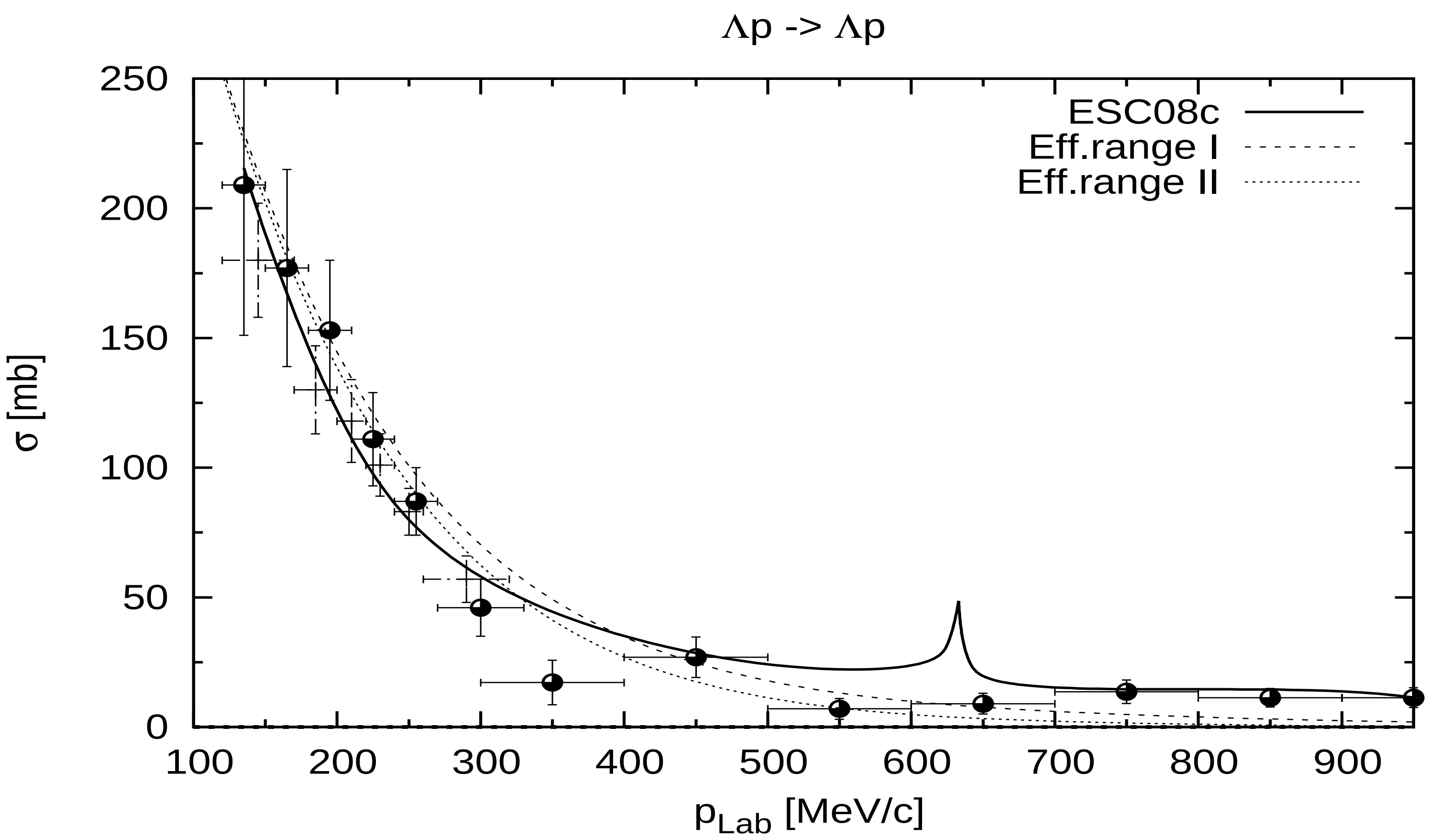
YNd YN-results: ESC08c YN-fit

$\Sigma^- p \to \Sigma^0 n$		$\chi^2 = 5.7$	$\Sigma^- p \to \Lambda n$		$\chi^2 = 4.8$
p_{Σ^-}	σ_{exp}	σ_{th}	p_{Σ^-}	σ_{exp}	σ_{th}
110	396±91	200.6	110	174±47	241.3
120	159±43	175.8	120	178±39	207.2
130	157±34	155.9	130	140±28	180.1
140	125±25	139.7	140	164±25	158.1
150	111±19	126.2	150	147±19	140.0
160	115±16	114.9	160	124±14	125.0

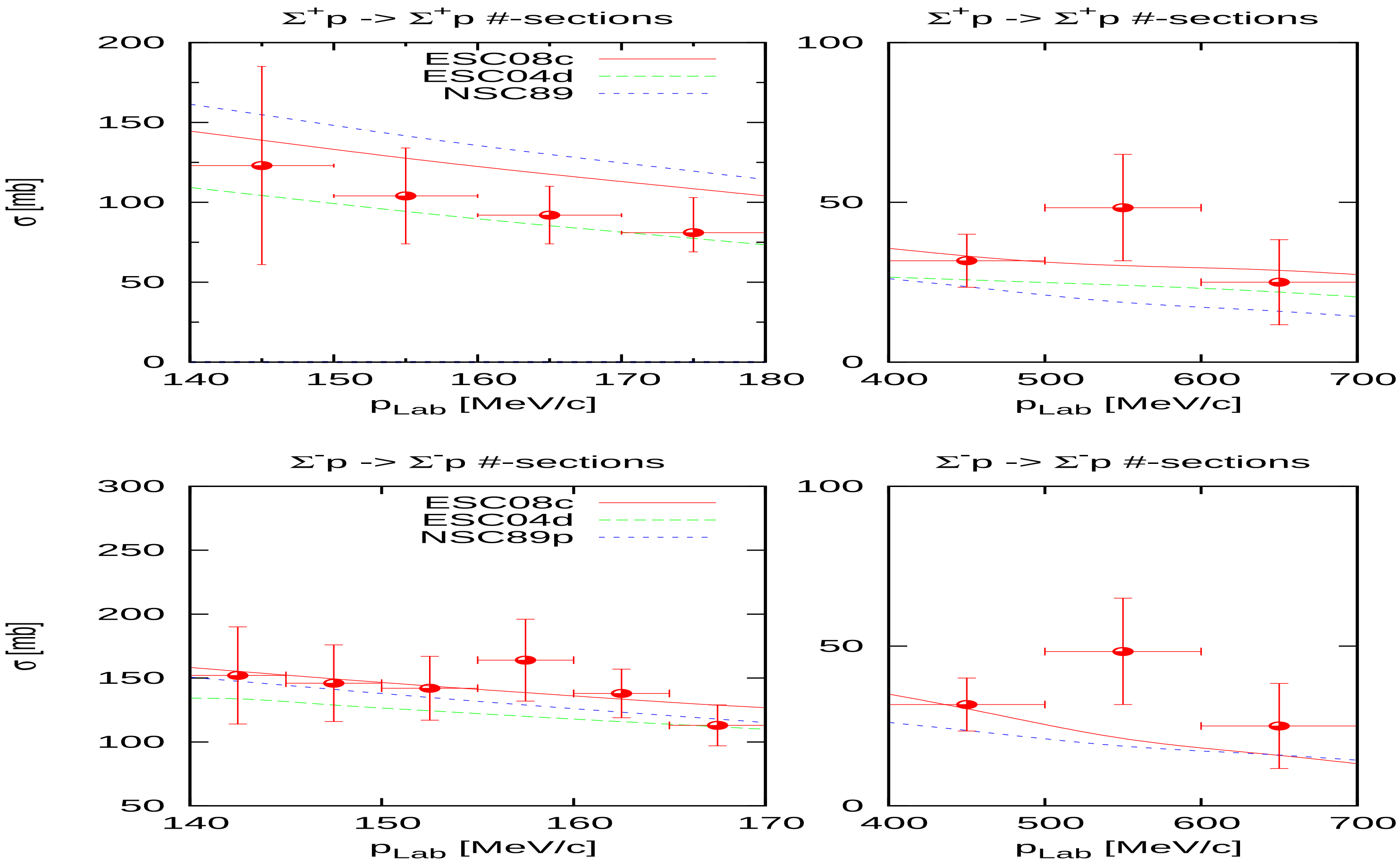
$r_R^{exp} = 0.468 \pm 0.010$ $\quad r_R^{th} = 0.455$ $\quad \chi^2 = 1.7$

YN.e: X-sections

Model fits total X-sections Λp. Rehovoth-Heidelberg-, Maryland-, and Berkeley-data

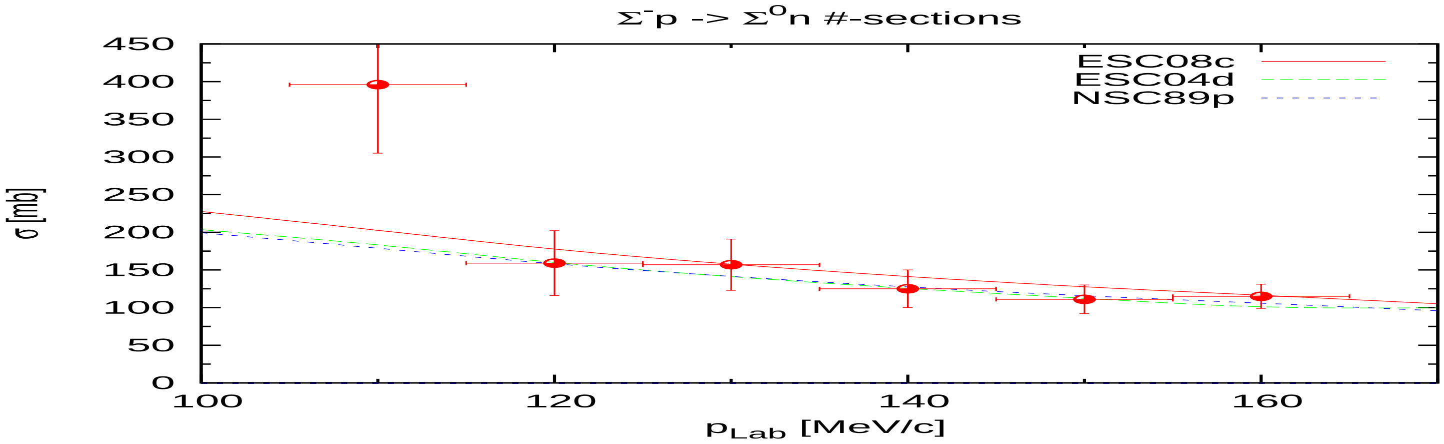


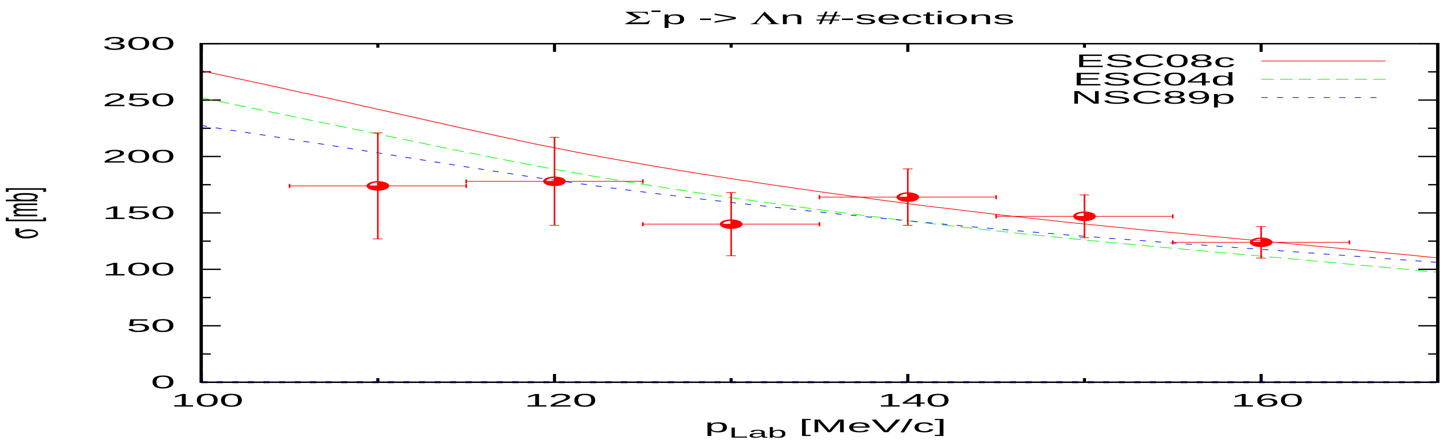
Model fits total elastic X-sections $\Sigma^{\pm}p$.
Rehovoth-Heidelberg-, KEK-data



YNg: X-sections

Model fits total inelastic X-sections
$$\Sigma^- p \to \Sigma^0 n, \Lambda n.$$

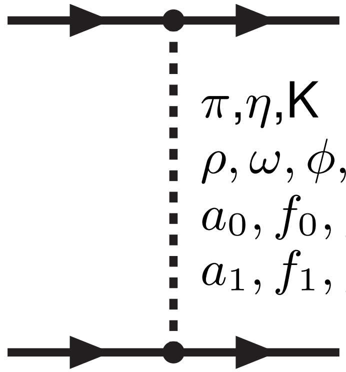




I.3 ESC-model: OBE+TME

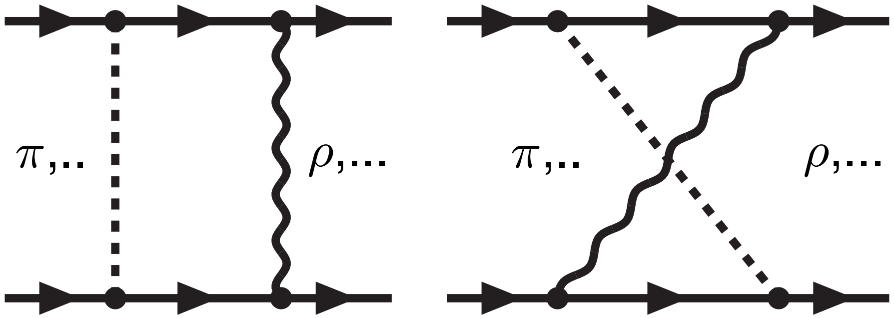
BB-interactions in the ESC-model:

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

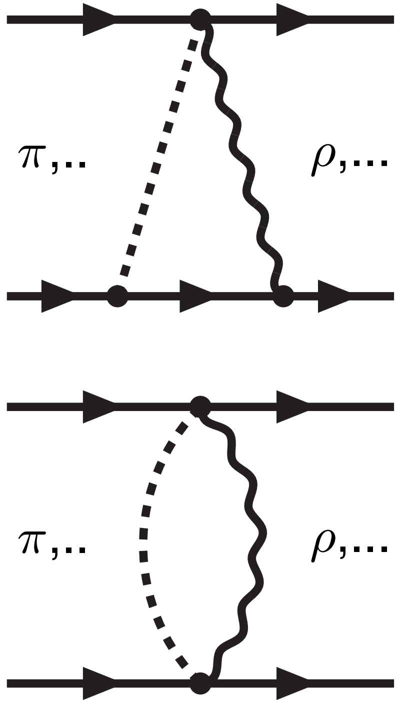
Two-Meson-Exchanges:



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

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

Meson-Pair-Exchanges:



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

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

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

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

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

SU(3)-symmetry and Coupling Constants

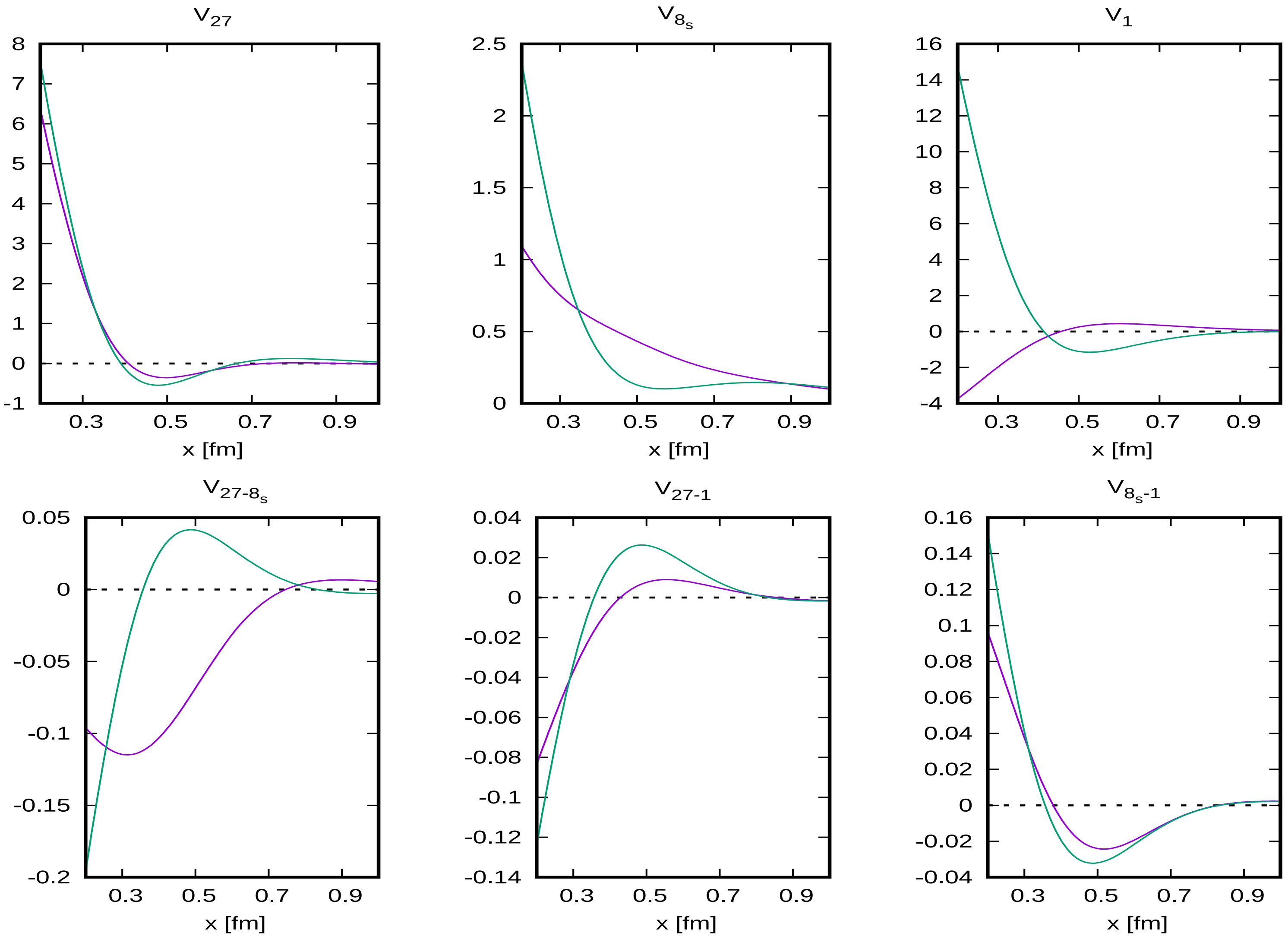
The baryon octet can be represented by a 3×3-matrices (Gel64,Swa66):

$$B = \begin{pmatrix} \frac{1}{\sqrt{2}}\,\Sigma^0 + \frac{1}{\sqrt{6}}\,\Lambda & \Sigma^+ & -p \\ \Sigma^- & -\frac{1}{\sqrt{2}}\,\Sigma^0 + \frac{1}{\sqrt{6}}\,\Lambda & -n \\ \Xi^- & -\Xi^0 & -\sqrt{\frac{2}{3}}\,\Lambda \end{pmatrix} .$$

Similarly the meson-nonets

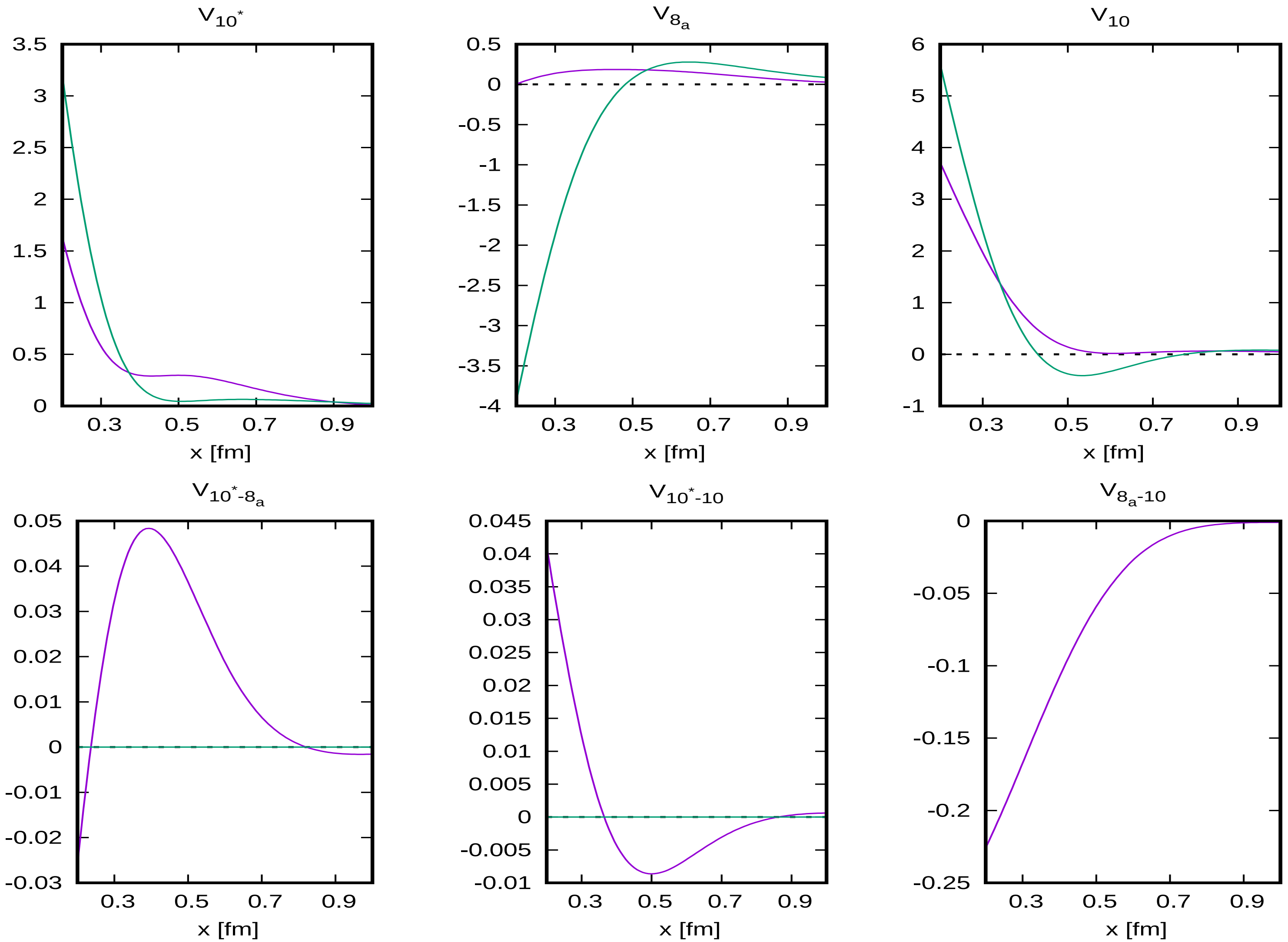
$$P = \begin{pmatrix} \frac{\pi^0}{\sqrt{2}} + \frac{\eta_0}{\sqrt{6}} + \frac{X_0}{\sqrt{3}} & \pi^+ & -K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \frac{\eta_0}{\sqrt{6}} + \frac{X_0}{\sqrt{3}} & -K^0 \\ -K^- & -\bar{K}^0 & -\sqrt{\frac{2}{3}}\eta_0 + \frac{X_0}{\sqrt{3}} \end{pmatrix}$$

SU3-sym-irreps, SU3-breaking:



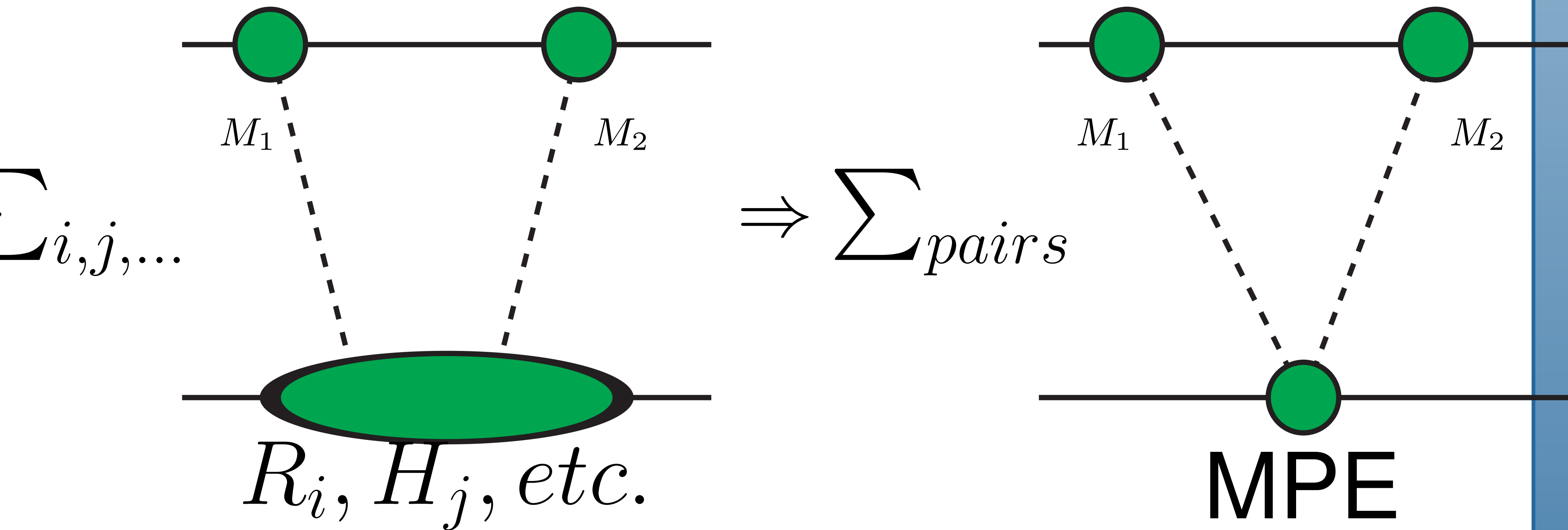
Figuur 4: Potentials in the symmetric SU(3)-irrep

SU3-asym-irreps, SU3-breaking:



Figuur 5: Potentials in the anti-symmetric SU(3)-

Interpretation Meson-Pair Vertices :



- Pair-vertex: Resonances, Heavy-bosons, Z-graphs

ESC-model and Chiral-symmetry

Non-linear realization Chiral-symmetry:

1. Non-linear Goldstone-boson sector,
   (i) Pseudo-vector couplings pseudoscalars, SU(2), SU(3)
   (ii) two-pion(ps) etc vertices, no triple, quartic .. vertices.
2. SU(2), SU(3)-symmetry scalar, vector and axial-vector mesons.

References:

a. J. Schwinger, Phys. Rev. Lett. **18**, 923 (1967); Phys. Rev. **167**, 1432 (1968); *Particles and Sources*, Gordon and breach, Science publishers, Inc., New York, 1969

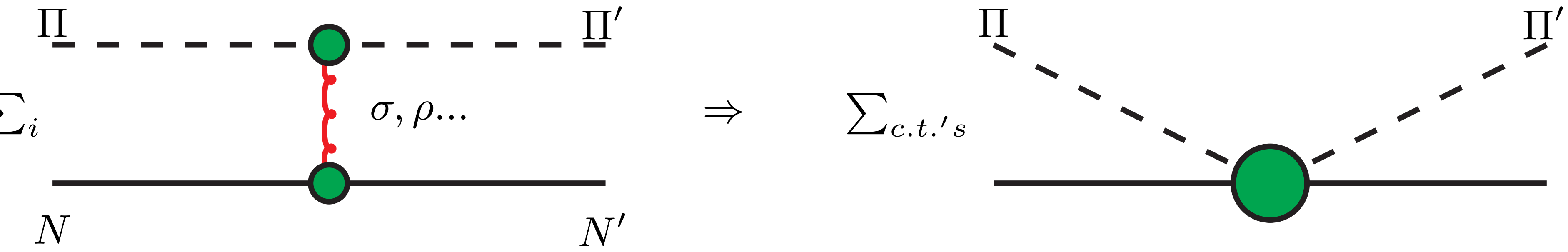
b. S. Weinberg, Phys. Phys. 166 (1968) 1568; Phys. Phys. 177 (1969) 2604.

c. V. De Alfaro, S. Fubini, G. Furlan, and C. Rosetti, *Currents in Hadron Physics* Ch. 5, North-Holland Pulishing Company, Amsterdam 1973.

Meson-exchange and EFT

- Coefficients in the $(NN2\pi$ EFT-interaction Lagrangian (Ordonez & van Kolck 1992)

$$\mathcal{L}^{(1)} = -\bar{\psi}\left[8c_1 D^{-1} m_\pi^2 \frac{\boldsymbol{\pi}^2}{F_\pi^2} + 2c_2\gamma_\mu \boldsymbol{\tau}\cdot\boldsymbol{\pi}\times\mathbf{D}^\mu - 4c_3\mathbf{D}_\mu\cdot\mathbf{D}^\mu + 2c_4\sigma_{\mu\nu}\boldsymbol{\tau}\cdot\mathbf{D}^\mu\times\mathbf{D}^\nu\right]\psi\ ,$$



Γ_α: EFT c.t.'s

Interpretation NLO contact terms ΠN-interaction from:

Propagators & Form Factors & MPE-vertices

Low t(Q)-expansion Propagators & Form Factors ⇒
EFT-type interaction terms

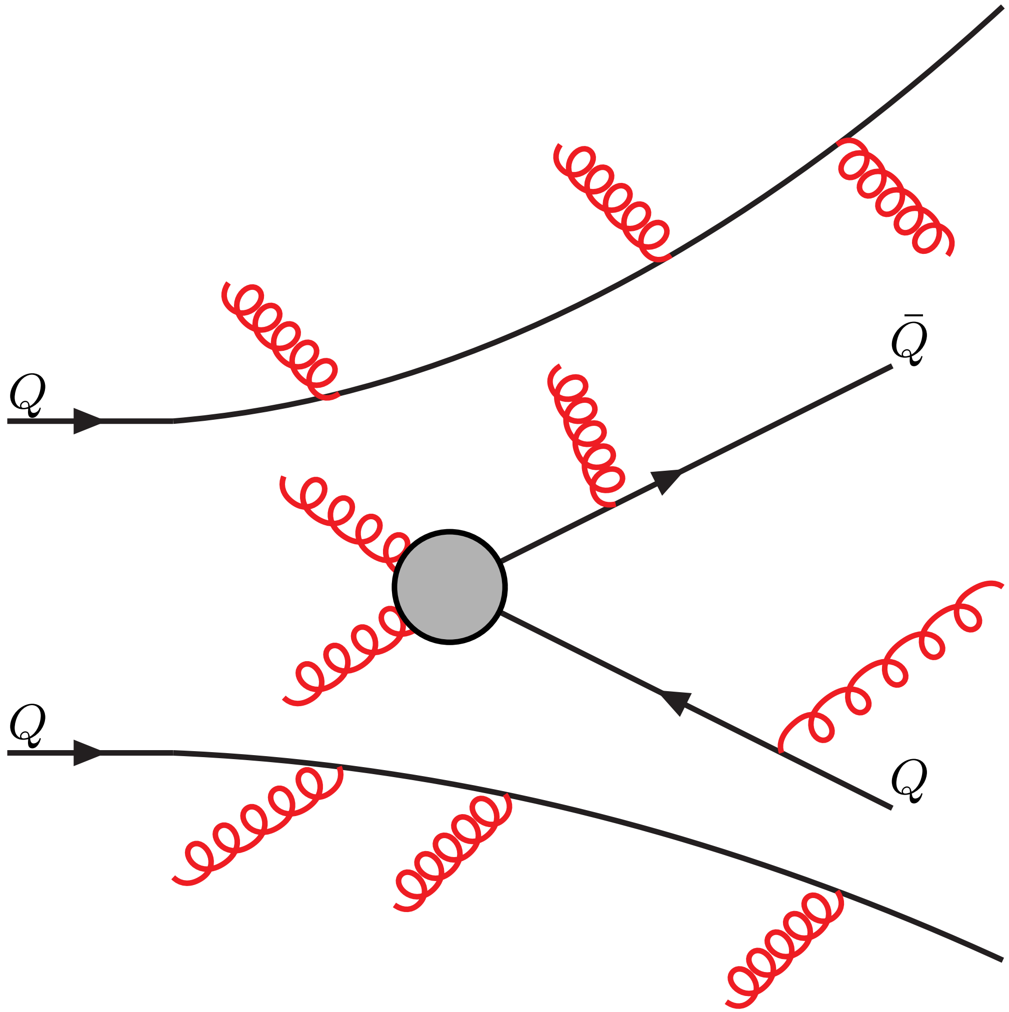
Hadronic Degrees of freedom:

- EFT/χPT: Nucleons etc. and Pions ⇒ Low energy region

II.4 Quark-Pair-Creation in QCD

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

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

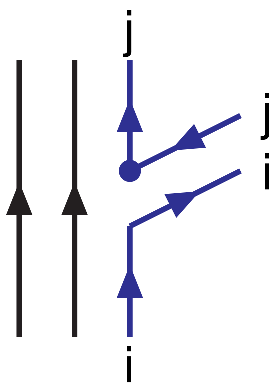


QPC: ${}^3P_0$-dominance:
Micu, NP B10(1969);
Carlitz & Kislinger, PR D2(1970),
LeYaounanc et al, PR D8(1973).

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

II.5 QPC: ${}^3P_0 \oplus {}^3S_1$-model

Meson-Baryon Couplings from QPC-mechanism



${}^3P_0$ and ${}^3S_1$ Interaction Lagrangians:

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

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

Fierz Transformation

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

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

$$\mathcal{L}_I = \mathcal{L}_I^{(S)} + \mathcal{L}_I^{(V)},\ \chi^S_{ij} \sim \bar{q}_j\ q_i\ ,\ \chi^V_{\mu,ij} \sim \bar{q}_j \gamma_\mu q_i\ ,\ \chi^A_{\mu,ij} \sim \bar{q}_j \gamma_5 \gamma_\mu q_i$$

- Empirically: $g_\epsilon \approx g_\omega$, and $g_{a_0} \approx g_\rho \Rightarrow {}^3P_0$-dominance!

II.6 QPC-model

Pair-creation in QCD: running pair-creation constant γ:

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

$$f_\rho = \frac{m_\rho^{3/2}}{\sqrt{2}|\psi_\rho(0)|} \Leftrightarrow \gamma_0 \left(\frac{2}{3\pi}\right)^{1/2} \frac{m_\rho^{3/2}}{|\psi_\rho(0)|} \to \gamma_0 = \frac{1}{2}\sqrt{3\pi} = 1.535.$$

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

- 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)

- ESC-model: "quantitative science"(!!):
  1. QPC: $\gamma = 2.19 \to$ prediction c.c.'s
  2. Quantitavely excellent results, Rijken, *nn-online*, THEF 12.01.

ESC08c Couplings and $^3S_1 +^3 P_0$-Model Description

Meson	$r_M[fm]$	γ_M	$^3S_1$	$^3P_0$	QPC	ESC08c
$\pi(140)$	0.30	5.51	$g = -1.37$	$g = +5.12$	3.76 (3.99)	3.65
$\eta'(957)$	0.60	2.22	$g = -1.61$	$g = +6.02$	4.41 (5.38)	4.32
$\rho(770)$	0.80	2.37	$g = -0.09$	$g = +0.65$	0.57 (0.68)	0.58
$\omega(783)$	0.70	2.35	$g = -0.48$	$g = +3.60$	3.12 (3.09)	3.11
$a_0(962)$	0.80	2.22	$g = +0.12$	$g = +0.46$	0.59 (0.61)	0.54
$\epsilon(620)$	0.70	2.37	$g = +0.63$	$g = +2.35$	2.98 (2.98)	2.98
$a_1(1270)$	0.60	2.09	$g = -0.09$	$g = -0.67$	-0.76 (-0.77)	-0.82
$f_1(1285)$	0.60	2.09	$g = -0.08$	$g = -0.60$	-0.68 (-0.69)	-0.76

- Weights $^3S_1/^3P_0$ are $A/B = /0.211/0.789 \approx 1:4$.
- SU(6)-breaking: (56) and (70) irrep mixing, $\varphi = -22^o$.
- QCD pair-creation constant: $\gamma(\alpha_s = 0.30) = 2.19$.
- QCD cut-off: $\Lambda_{QCD} = 259.6$ MeV, QQG form factor: $\Lambda_{QQG} = 986.2$ MeV.
- ESC08c: Pseudoscalar and axial mixing angles: -11^o and $+50^o$.

III.1 G-matrix ESC-models ⋆

Comments Λ- and Ξ-hypernuclei, well-depths

• S=-1 systems: Inclusion of the three-body repulsive (TBR) and attractive (TBA) interactions: In the case of the Λ-hypernuclei the G-matrix analysis shows that the experimental B_Λ values and excited spectra can be reproduced in a natural way by ESC08c. The multipomeron (MPP) repulsive contributions, which are decisively important in the high density region, should almost be canceled by the three-body attractions (TBA) in the normal density region.

• S=-2 systems: For Ξ-hypernuclei the ΞN ESC08c interactions are not adequate for the Ξ-nucleus binding energies given by the emulsion data of the twin Λ-hypernuclei. As in the case of the Λ-hypernuclei, we expect a big role of the MPP+TBA contribution. For a clear analysis, however, the experimental data of B_Ξ are too scarce. On the other hand, MPP contributions are essential in the problem of Ξ-mixing in neutron star matter.

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	Γ_Σ
ESC08c	$1/2$	11.1	–22.0	2.4	2.1	–6.1	–1.0	–0.7		
	$3/2$	–12.8	30.7	–4.8	–1.8	6.0	–1.4	–0.2	+1.4	
ESC08c$^+$	$1/2$	11.1	–20.4	2.6	2.1	–5.8	–0.6	–0.8		
	$3/2$	–11.9	31.8	–4.2	–1.6	6.4	–0.4	–0.6	+7.9	

- MPP: $\Delta U_\Sigma(\rho_0) \approx +(4-6)$ MeV
- TNA: TNA(ΣNN = TNA(NNN); TNA($\Sigma NN \approx 0$): $U_\Sigma \to +17$ MeV !
- Nagels, Rijken, Yamamoto, arXiv:1501.06636 (2015)
- Limitation short-range repulsion: Experimental $\Sigma^+ P$ X-sections!
- Conflict with K^--atomic data (Gal, Friedman, Mares):

  $(\mathbf{a})$ Experimental $\Sigma^+ P$ X-sections wrong (??)

  $(\mathbf{b})$ 3BF ΣNN repulsive (!?)

III.3 ESC-models: YY $\star$

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

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

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

$^{10}_{\Lambda\Lambda}Be \rightarrow^{9}_{\Lambda} Be + p + \pi^-$, $\Delta B_{\Lambda\Lambda} = 4.7 \pm 0.4$ MeV !?? • KEK-373: NAGARA-event (2001), Nakazawa et al

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

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

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

- Soft-core models: NSC89, NSC97, ESC04, ESC08:
  $|V_{\Lambda\Lambda}(\epsilon)| < |V_{\Lambda N}(\epsilon)| < |V_{NN}(\epsilon)|$
  $\rightarrow$ weak attraction/repulsion in $\Lambda N, \Xi N$-sytems.
- ESC08c-model: $\Delta B_{\Lambda\Lambda} \approx 1.0$ MeV !!

- Ξ-well-depth experiment WS -(14-16) MeV
- Ξ-cross sections small $\Rightarrow$ well-depth problem!?

Deuteron $D(Y=0)$-state in $\Xi N(I=1,{}^3S_1)$ in nuclear medium (?!)

III.4 $\Lambda\Lambda$ and ΞN: Low-energy pars ⋆

$S = -2, \Lambda\Lambda, \Xi N$: Low-energy parameters

- Effective -range parameters [fm]:

$ESC08c$: $a_{\Lambda\Lambda}(^1S_0) = -0.44$, $r_{\Lambda\Lambda}(^1S_0) = 9.53$, $(V_{[51]} + V_{[33]})/2$,

....

$$a_{\Xi N}(^1S_0, T=0) = \text{coupled with } \Lambda\Lambda, \Sigma\Sigma$$

$$a_{\Xi N}(^1S_0, T=1) = +0.56\ ,\ r_{\Xi N}(^3S_1) = -3.04 \qquad (7V_{[51]} + 2V_{[33]})/9$$

$$a_{\Xi N}(^3S_1, T=1) = +0.14\ ,\ r_{\Xi N}(^3S_1) = +41.0 \qquad (17V_{[51]} + 10V_{[33]})/27$$

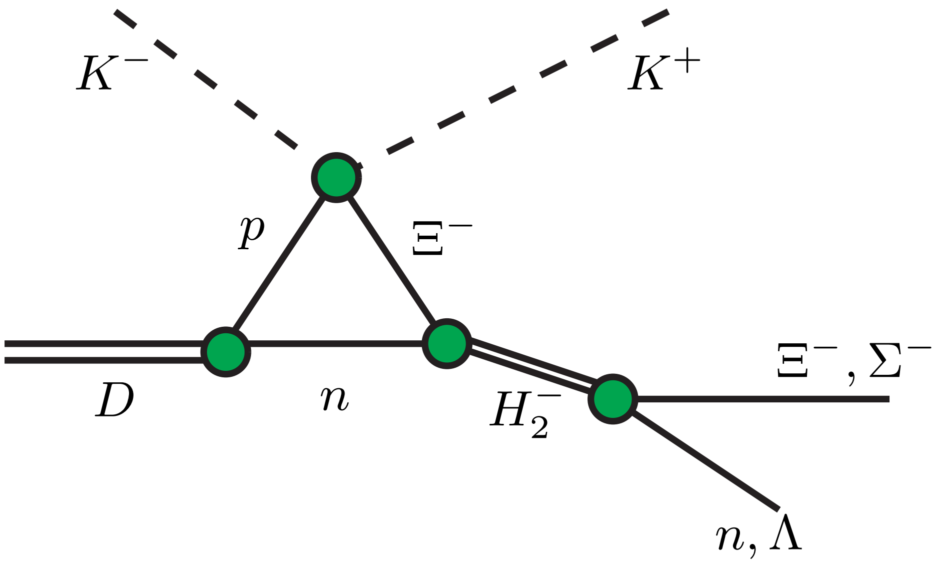
$$a_{\Xi N}(^3S_1, T=0) = -0.27\ ,\ r_{\Xi N}(^3S_1) = -10.25 \qquad (5V_{[51]} + 4V_{[33]})/9$$

$$a_{\Xi N}(^1S_0, T=2) = +9.47\ ,\ r_{\Xi N}(^3S_1) = -48.92 \qquad (5V_{[51]} + 4V_{[33]})/9$$

- ESC08c: $\Xi N(^3S_1, T=1)$ NO Strange Deuteron!

III.5 Dibaryon states Experimental: H_2^- ⋆

Experiment and Strange Deuteron H_2^-

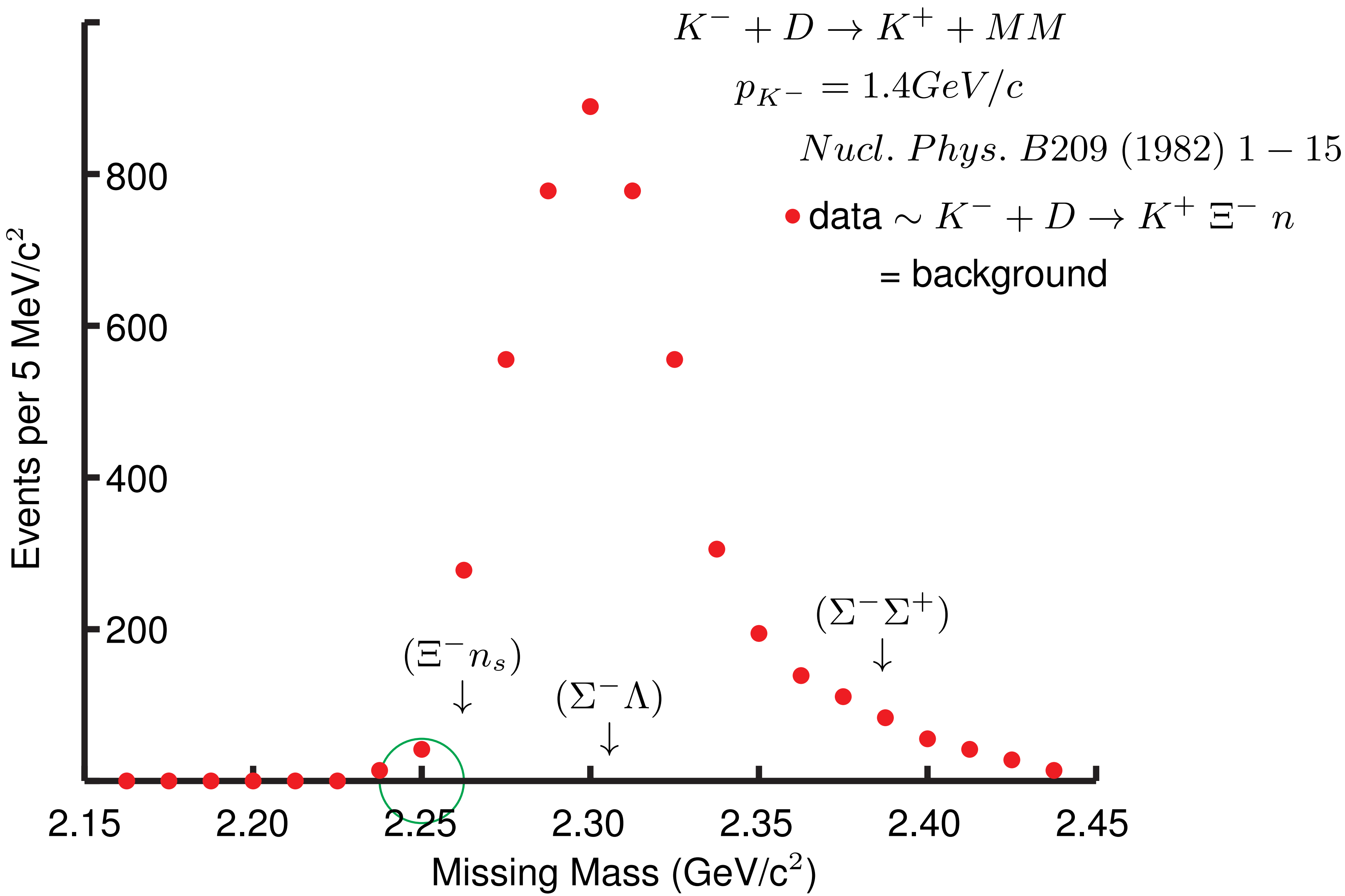


- $K^- + D \rightarrow K^+ + MM$,
  $p_{K^-} = 1.4\ GeV/c$
- $H_2^- = (\Xi^- n)_{b.s.} \rightarrow \Lambda\Lambda\ (+e^- + \bar{\nu}_e)$
- H_2^-: production X-section?
- $K^- + D \rightarrow H_2^0 + K^0$

- Rome-Saclay-Vanderbilt Collaboration:
  D'Agostini et al, Nucl. Phys. B209 (1982)
- Conclusion: No evidence for the existence of $Q = -1, S = -2$ dibaryonic states, in the mass range 2.1-2.5 GeV/c^2.
- Q: Conflict with $U_\Xi = -(3 - 14)$ MeV ?!
- J-PARC: E03, E07 experiments?!

III.6 Dibaryon states Experimental: H_2^- ⋆

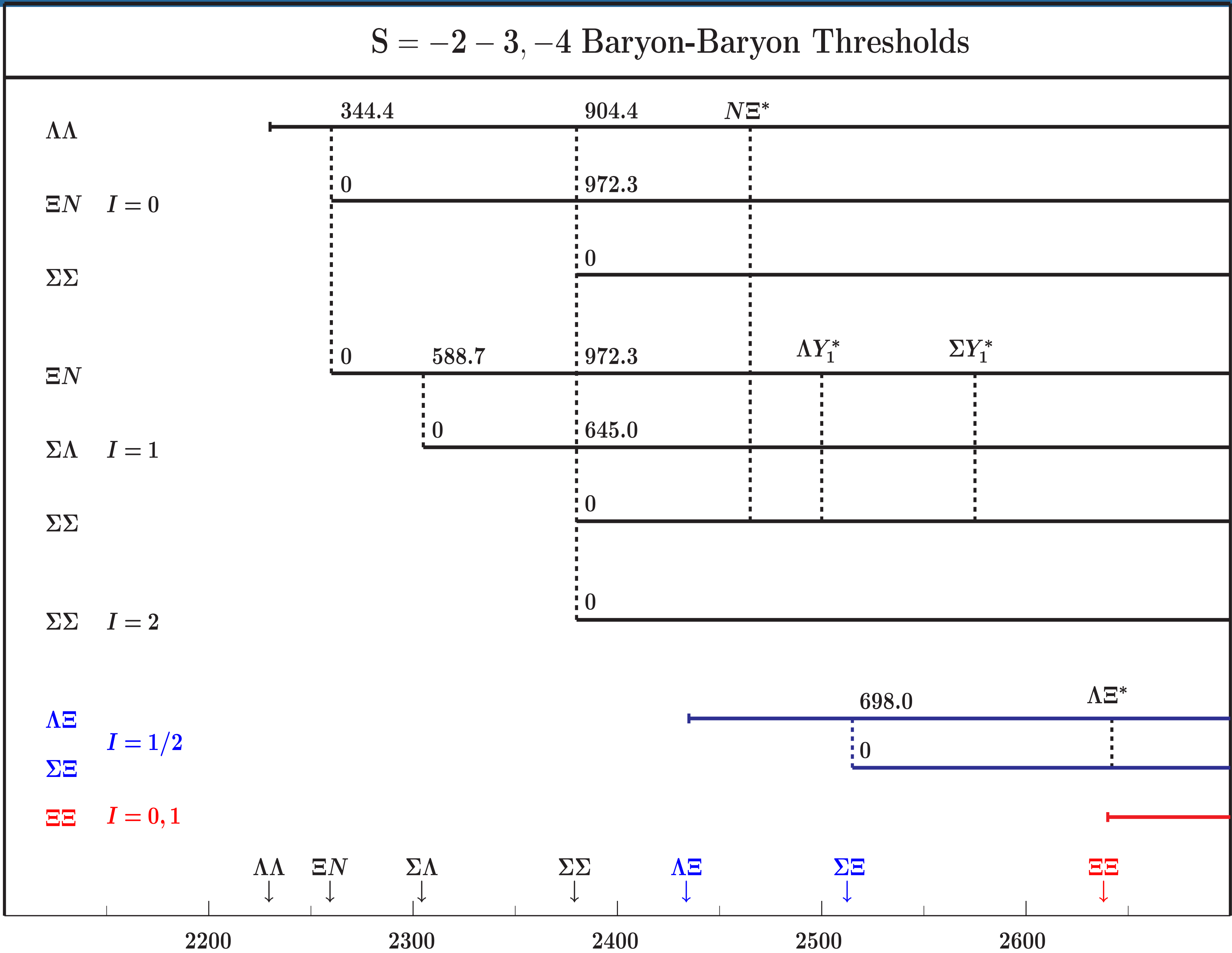
Experiment and Strange Deuteron H_2^-



Many-body: Three-body etc. Forces

- Two-body forces inadequate to explain:
  1. Nuclear saturation is notorious problem!
  2. U_Σ: $\Sigma^+ p$: SU(3)+X-sections $\rightarrow$ limit on two-body repulsion $\Rightarrow$ problem to obtain large $U_\Sigma \approx +15$ MeV.
  3. U_Ξ: Small ΞN scattering X-sections: how to obtain $U_\Xi \approx -14$ MeV? How to accomodate the Nakazawa et al Ξ-hypernuclei, produced by (K^-, K^+)-reactions with $^{12}C, ^{16}O, ^{14}N$?
  4. N-star: How to avoid softening of EoS for neutron star matter with hyperons, the so-called "hyperon-puzzle"?
- Sources three-body forces:
  - a ESC-model: meson-pair interactions $\Rightarrow$ "Effective two-body" contributions for $U_\Lambda, U_\Sigma, U_\Xi$.
  - b Multi-pomeron interactions $\Rightarrow$ extra repulsion for U_Σ, and a universal repulsion for any matter, i.e. no softening EoS.

III.8 ESC-models: $S = -2, -3, -4$ YY,YN



$\Lambda/\Sigma\Xi$, $\Xi\Xi$: PW's and SU3-irreps

$SU(3)_f$-contents of the various potentials
on the isospin basis.

Space-spin antisymmetric states $^1S_0,\ ^3P,\ ^1D_2, \ldots$		
$\Xi\Xi \to \Xi\Xi$	$I = 1$	$V_{\Xi\Xi}(I=1) = V_{27}$
$\Lambda\Xi \to \Lambda\Xi$		$V_{\Lambda\Lambda}\left(I=\frac{1}{2}\right) = \left(9V_{27} + V_{8_s}\right)/10$
$\Lambda\Xi \to \Sigma\Xi$	$I = \frac{1}{2}$	$V_{\Lambda\Sigma}\left(I=\frac{1}{2}\right) = \left(-3V_{27} + 3V_{8_s}\right)/10$
$\Sigma\Xi \to \Sigma\Xi$		$V_{\Sigma\Sigma}\left(I=\frac{1}{2}\right) = \left(V_{27} + 9V_{8_s}\right)/10$
$\Sigma\Xi \to \Sigma\Xi$	$I = \frac{3}{2}$	$V_{\Sigma\Sigma}\left(I=\frac{3}{2}\right) = V_{27}$

$\Lambda/\Sigma\Xi, \Xi\Xi$: PW's and SU3-irreps

$SU(3)_f$-contents of the various potentials
on the isospin basis.

Space-spin symmetric states $^3S_1,\ ^1P_1,\ ^3D, \ldots$		
$\Xi\Xi \to \Xi\Xi$	$I=0$	$V_{\Xi\Xi}(I=0) = V_{10}$ (!)
$\Lambda\Xi \to \Lambda\Xi$		$V_{\Lambda\Lambda}\ \left(I=\frac{1}{2}\right) = \left(V_{10}+V_{8_a}\right)/2$
$\Lambda\Xi \to \Sigma\Xi$	$I=\frac{1}{2}$	$V_{\Lambda\Sigma}\left(I=\frac{1}{2}\right) = \left(V_{10}-V_{8_a}\right)/2$
$\Sigma\Xi \to \Sigma\Xi$		$V_{\Sigma\Sigma}\left(I=\frac{1}{2}\right) = \left(V_{10}+V_{8_a}\right)/2$
$\Sigma\Xi \to \Sigma\Xi$	$I=\frac{3}{2}$	$V_{\Sigma\Sigma}\left(I=\frac{3}{2}\right) = V_{10^\star}$ (!)

$S = -3, \Lambda\Xi, \Sigma\Xi$: Low-energy parameters

- Effective -range parameters [fm]:

$$
\begin{aligned}
ESC08c: \quad & a_{\Lambda\Xi}(^1S_0) = -0.56\ , \ r_{\Lambda\Xi}(^1S_0) = 8.32, \quad (9V_{27} + V_{8_s})/10,\ I = 1/2 \\
& a_{\Lambda\Xi}(^3S_1) = +0.40\ , \ r_{\Lambda\Xi}(^3S_1) = 0.87, \quad (V_{10} + V_{8_a})/2,\ I = 1/2 \\
& a_{\Sigma\Xi}(^1S_0) = -1.71\ , \ r_{\Sigma\Xi}(^1S_0) = 3.71, \quad V_{27},\ I = 3/2 \\
& a_{\Sigma\Xi}(^3S_1) = -0.85\ , \ r_{\Sigma\Xi}(^3S_1) = 8.02, \quad V_{10^*},\ I = 3/2.
\end{aligned}
$$

$S = -4, \Xi\Xi$: Low-energy parameters

$$
\begin{aligned}
ESC08c: \quad & a_{\Xi\Xi}(^1S_0) = -1.90\ , \ r_{\Xi\Xi}(^1S_0) = 4.28, \quad V_{27}\ , I = 1 \\
& a_{\Xi\Xi}(^3S_1) = +0.52\ , \ r_{\Xi\Xi}(^3S_1) = 2.74, \quad V_{10}\ , I = 0
\end{aligned}
$$

- ESC08c: $^1S_0$-bound state? NO!

Nuclear and Hyperonic Matter

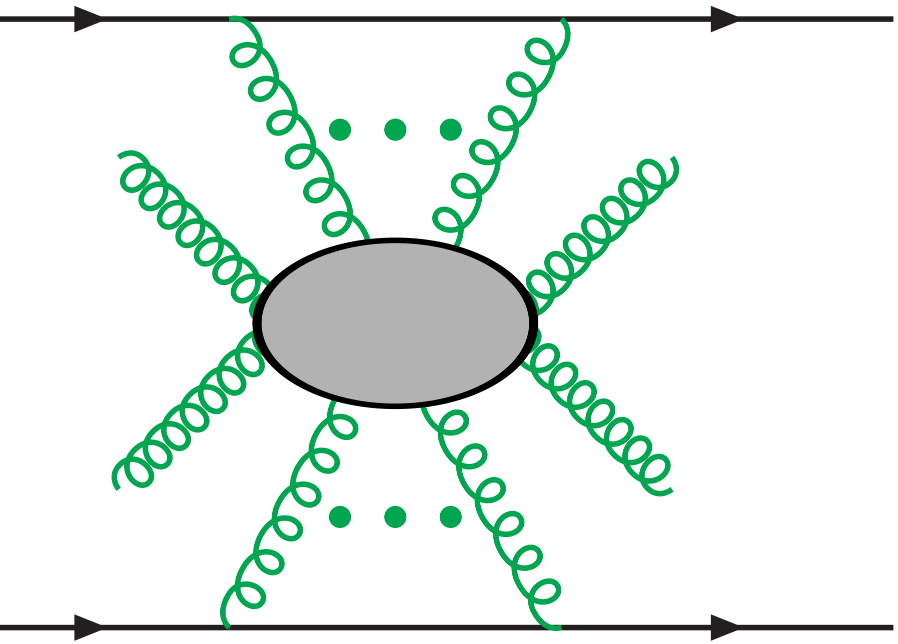
- Soft-core BB-interactions ⇒ Too soft EoS
- Appearance Hyperons ⇒ Neutron-star masses too small

- Conjecture: Universal repulsion in Baryonic matter

IV.1 Gluon-exchange ⇔ Pomeron

Multiple Gluon-exchange QCD ⇔ Pomeron/Odderon

• Gluon-exchange ⇔ Pomeron-exchange

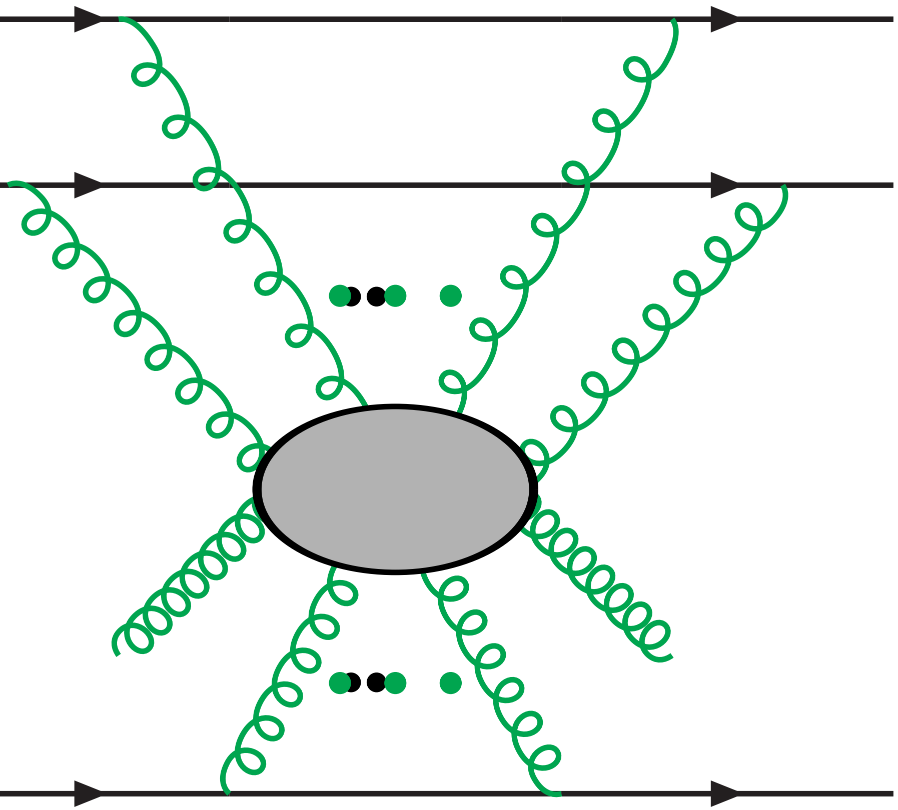


Multiple-gluon model: Low PR D12(1975), Nussinov PRL34(1975)
Scalar Gluon-condensate: ITEP-school:
$\langle 0|g^2 G^a_{\mu\nu}(0) G^{a\mu\nu}(0)|0\rangle = \Lambda_c^4,$
$\Lambda_c \approx 800$ MeV
Landshoff, Nachtmann, Donnachie, Z.Phys.C35(1987); NP B311(1988):
$\langle 0|g^2 T[G^a_{\mu\nu}(x) G^{a\mu\nu}(0)]|0\rangle =$
$\Lambda_c^4 f(x^2/a^2), a \approx 0.2 - 0.3 fm$
Triple-Pomeron: $g_{3P}/g_P \sim 0.15 - 0.20,$
Kaidalov & T-Materosyan, NP B75 (1974)
Quartic-Pomeron: $g_{4P}/g_P \sim 4.5,$
Bronzan & Sugar, PRD 16 (1977)

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

Universal Three-body repulsion ⇔ Pomeron-exchange

- Multiple Gluon-exchange ⇔ Pomeron-exchange



Soft-core models NSC97, ESC04/08:
(i) nuclear saturation, (ii) EOS too soft
Nishizaki,Takatsuka,Yamamoto,
PTP 105(2001); ibid 108(2002): NTY-
conjecture = universal repulsion in BB

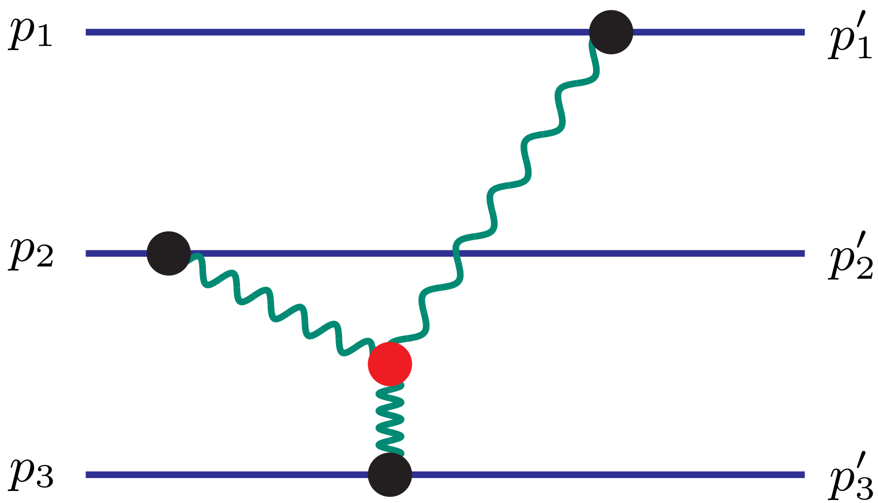
Lagaris-Pandharipande NP A359(1981):
medium effect → TNIA,TNIR
Rijken-Yamamoto PRC73: TNR ⇔ $m_V(\rho)$

TNIA ⇔ Fujita-Miyazawa (Yamamoto)

TNIR ⇔ Multiple-gluon-exchange ↔
Triple-Pomeron-model (TAR 2007)
String-Junction-model (Tamagaki 2007)

IV.3 Three-Body Forces: triple-pomeron repulsion

Triple-pomeron Universal Repulsive TBF:



Triple-pomeron Exchange-graph

- $V_{eff}(x_1, x_2) = 3\rho_{NM} \int d^3x_3 V(x_1, x_2, x_3)$

$$V_{eff} \Rightarrow 3 g_{3P} g_P^3 (\rho_{NM}/M^5)(m_P/\sqrt{2\pi})^3 \ \exp(-m_P^2 r^2/2) > 0(!)$$

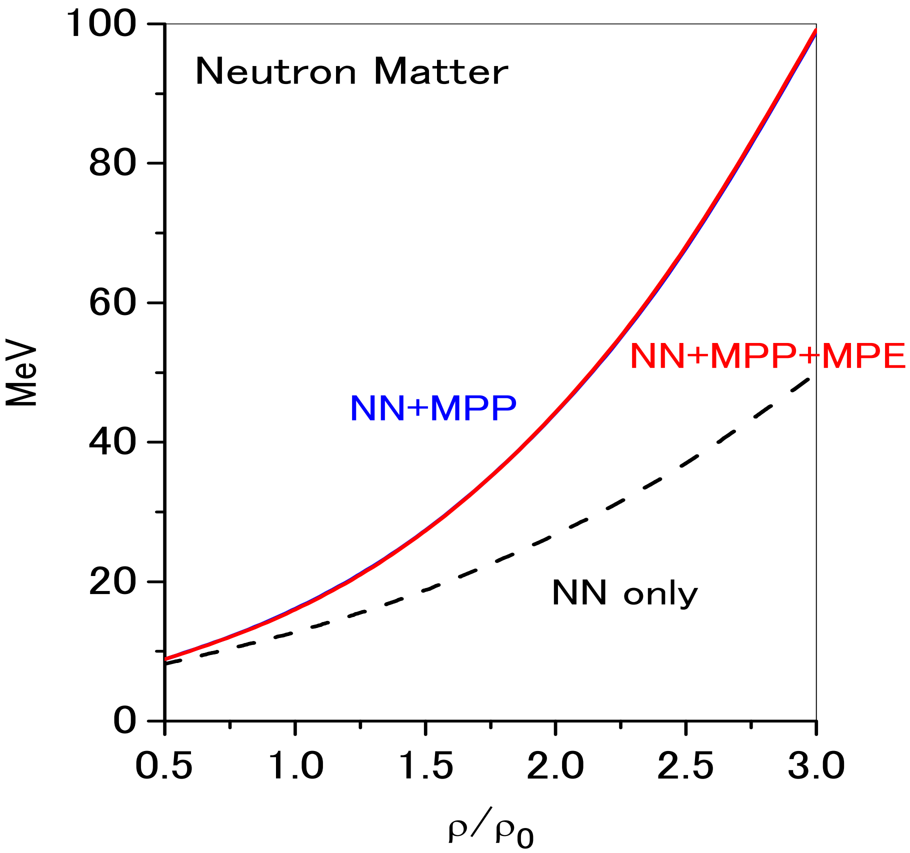
- $g_{3P}/g_P = (6-8)(r_0(0)/\gamma_0(0)) \approx (6-8) * 0.025$ $\Leftarrow$ Sufficient ?

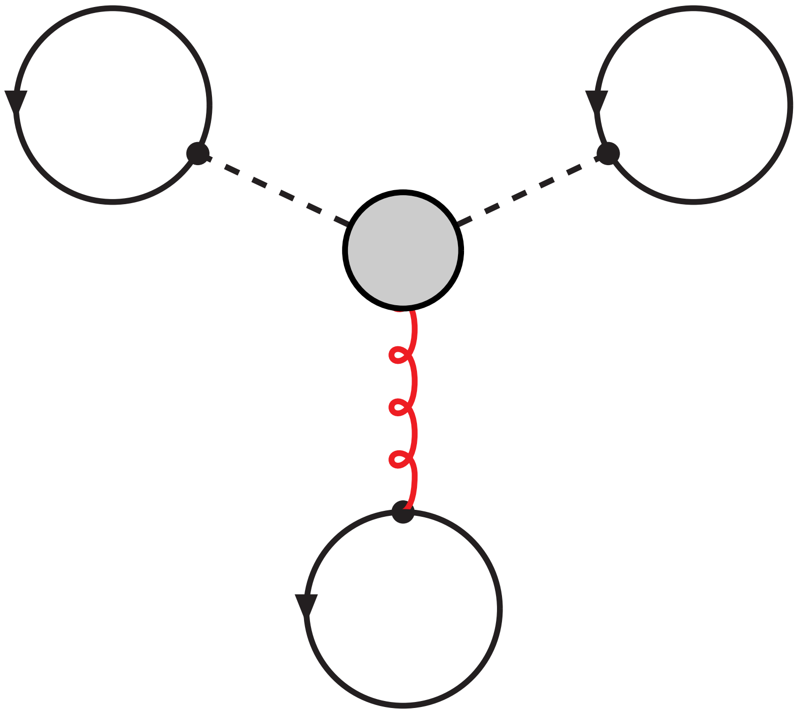
IV.4 ESC08: Nuclear Matter, Saturation II

ESC08(NN): Saturation and Neutron matter

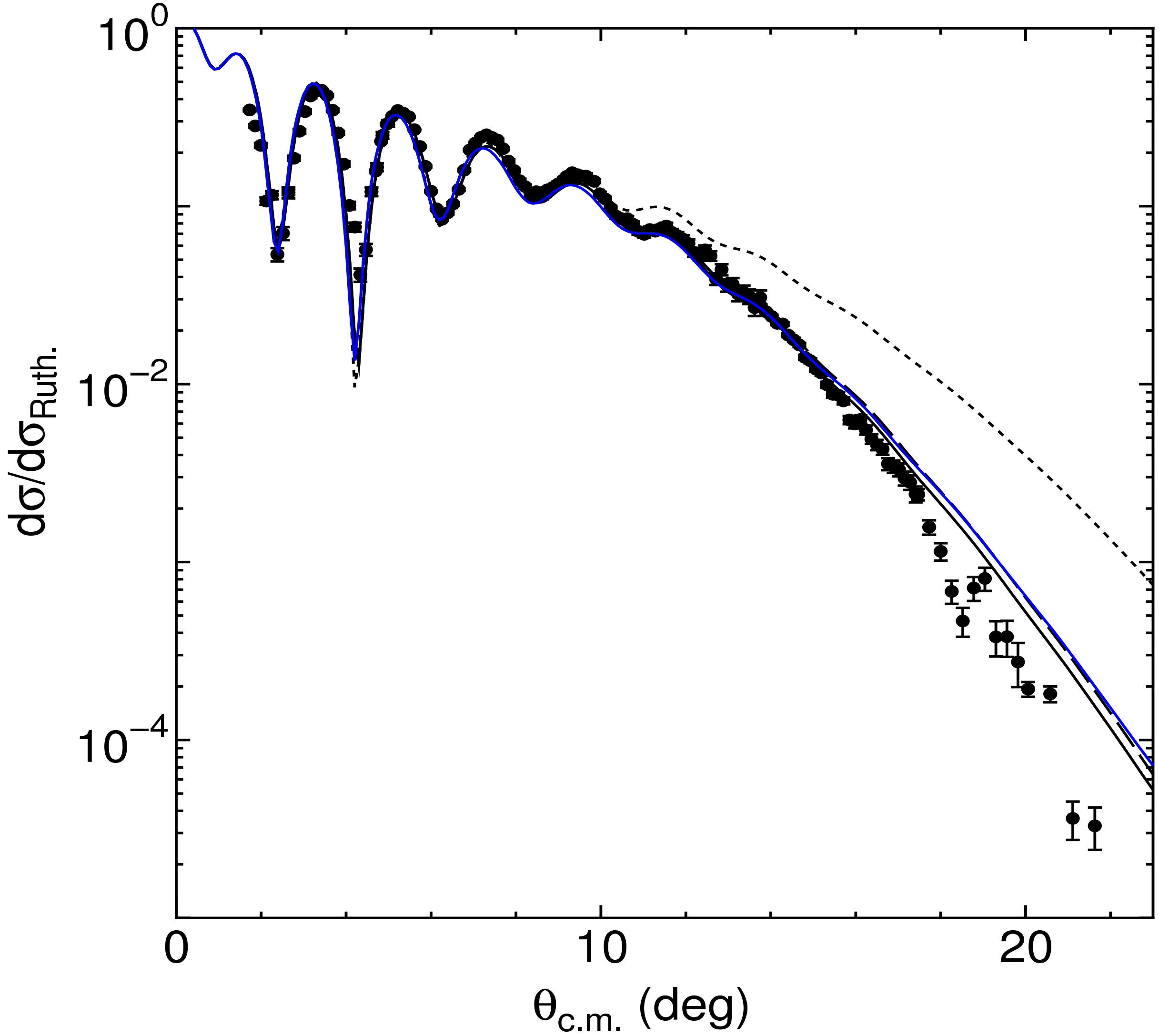
'Exp': $M/M_\odot = 1.44$, $\rho(cen)/\rho_0 = 3 - 4$, $B/A \sim 100$ MeV

Schulze-Rijken, PRC84: $M/M_\odot(V_{BB}) \approx 1.35$

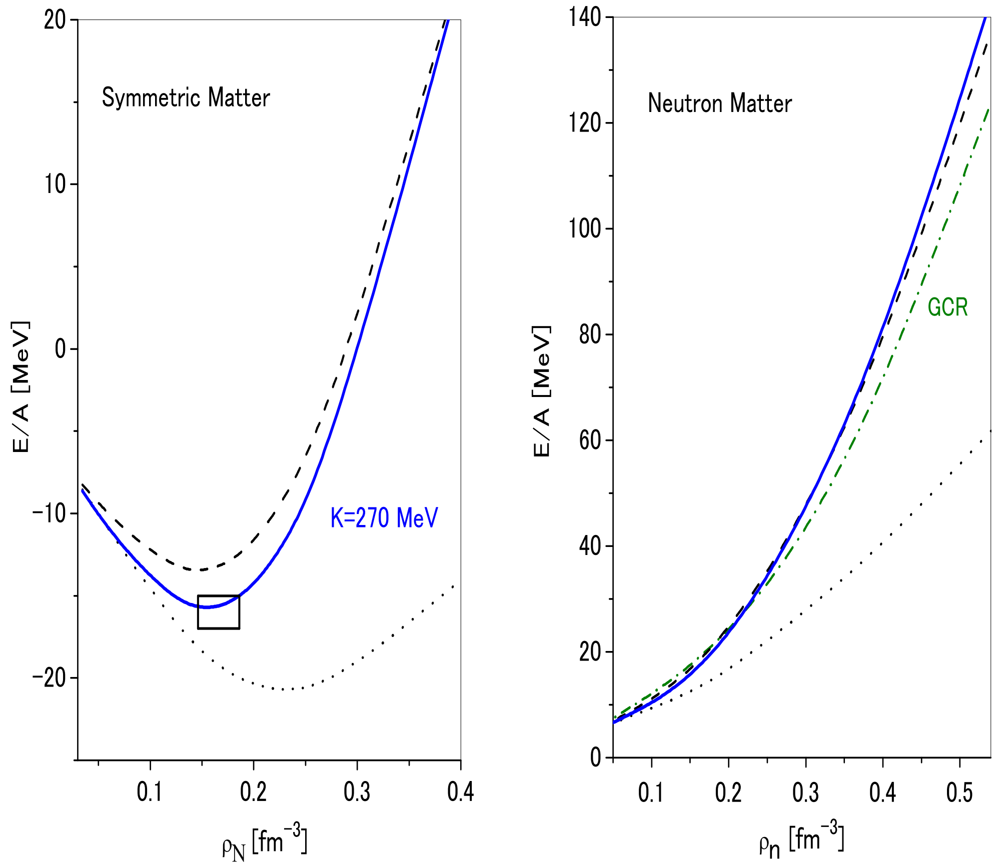




$O_{16} - O_{16}$ Scattering with MPP+TNIA



ESC08c(NN): Saturation and Neutron matter



Saturation curves for ESC08c(NN) (dashed), ESC08c(NN)+MPP (solid).

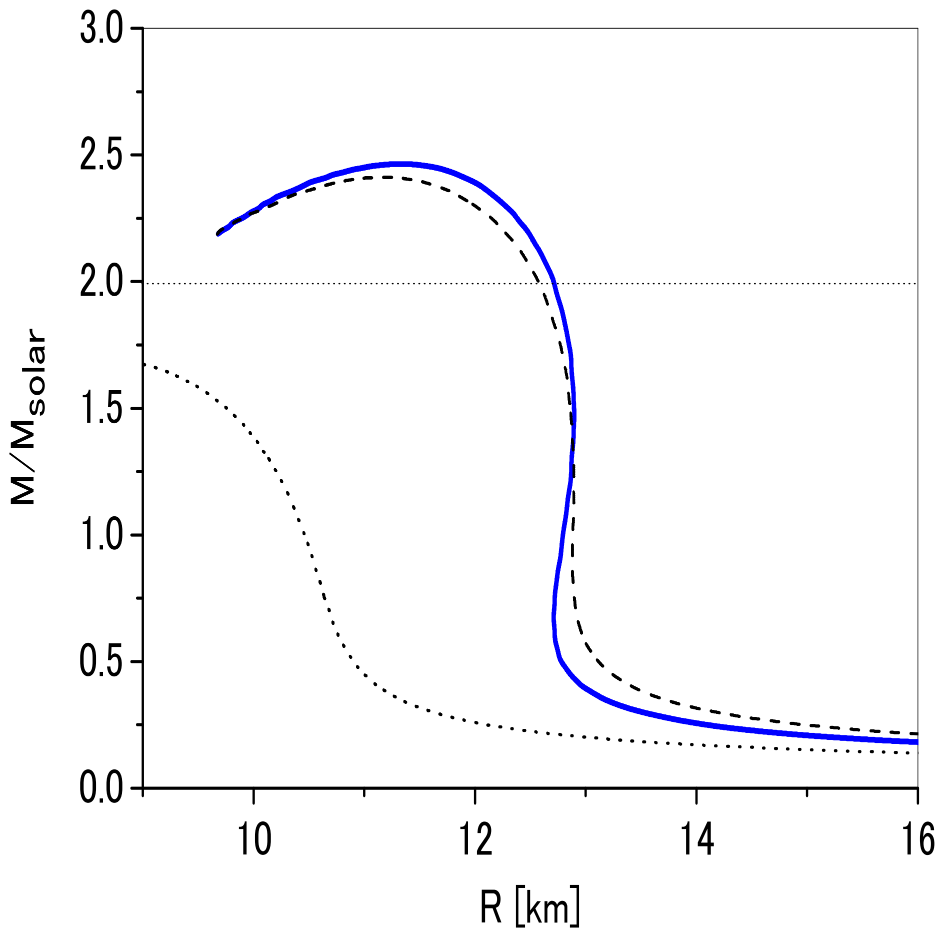
Right panel: neutron matter

Left panel: symm.matter, (NO TNIA(F-M,L-P)).

Dotted curve is UIX model of Gandolfi et al (2012).

IV.7 ESC08: Nuclear Matter, Saturation V ⋆

ESC08c(NN): Neutron-star mass nuclear matter



Solution TOV-equation:
Neutron-Star mass as
a function of the radius R.

Dotted: MP0, no MPP
Solid : MP1, triple+quartic MPP
Dashed: MP2, triple MPP.

Yamamoto, Furumoto,
Yasutake, Rijken

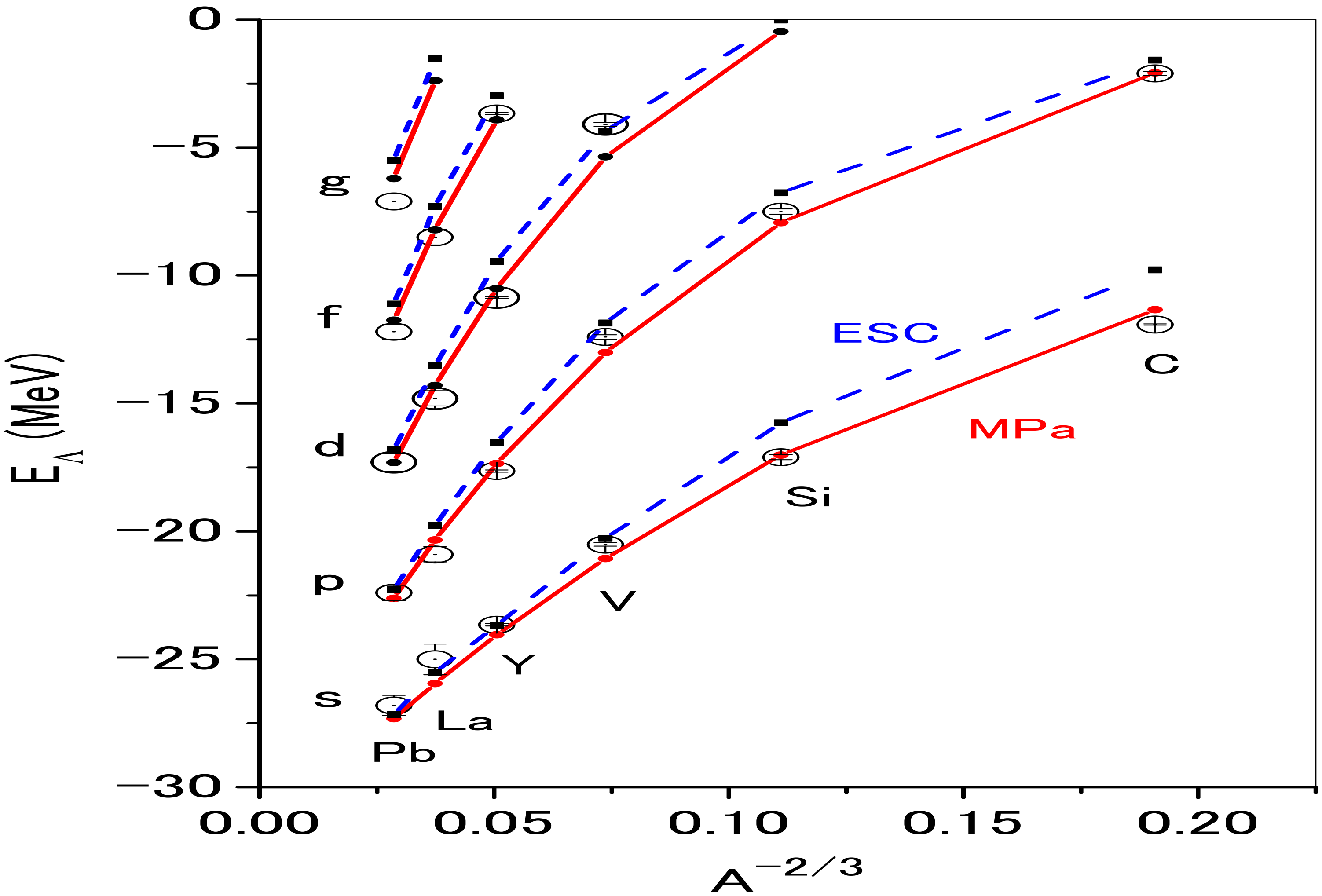
ESC08: MPP function:
(i) EoS, NStar mass
(ii) Nuclear saturation

(iii) HyperNuclear overbinding.

IV.8 ESC08: Λ-binding energies ⋆

ESC08(NN+YN): Λ Binding Energy

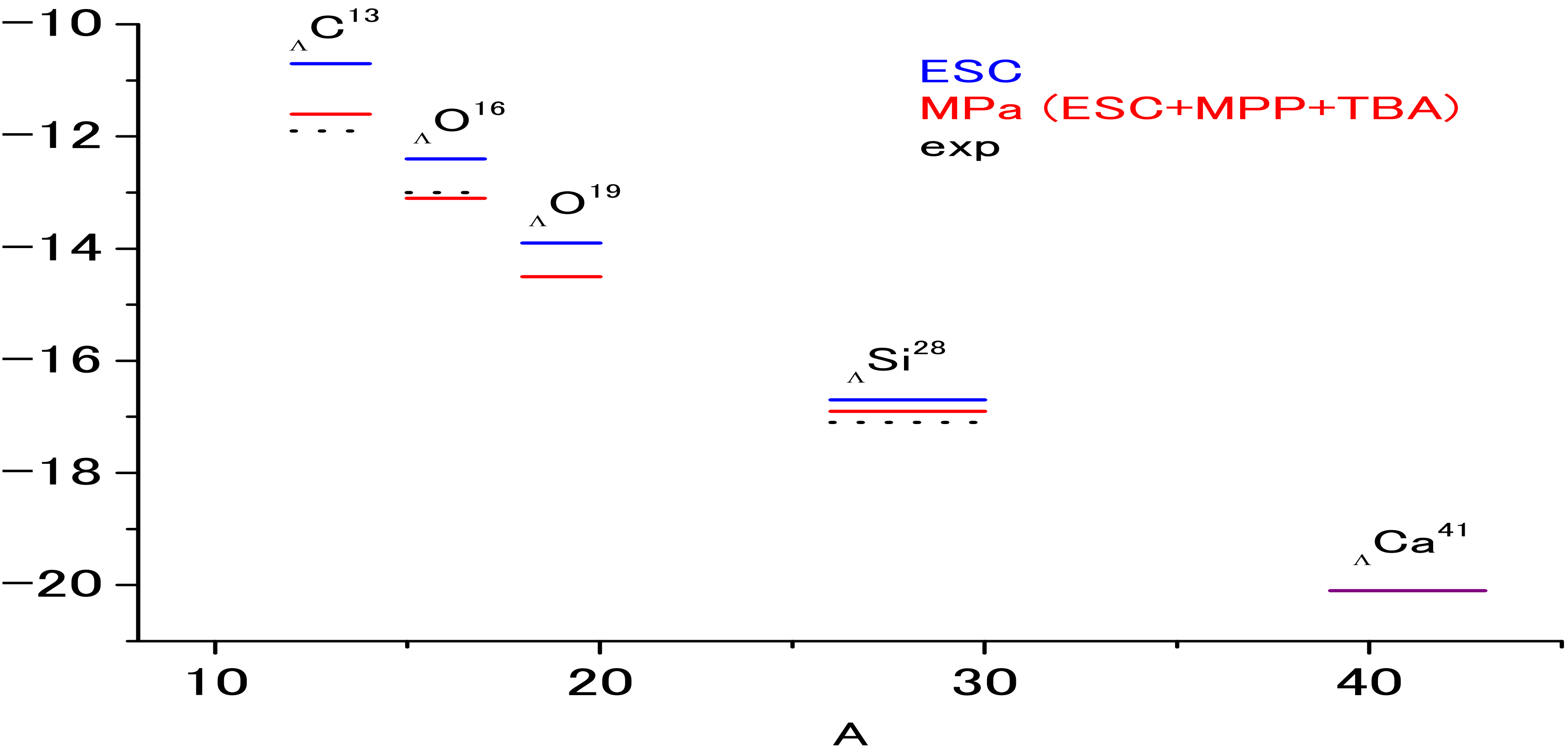
With TNIA(F-M,L-P) + Triple/Quartic-pomeron Repulsion



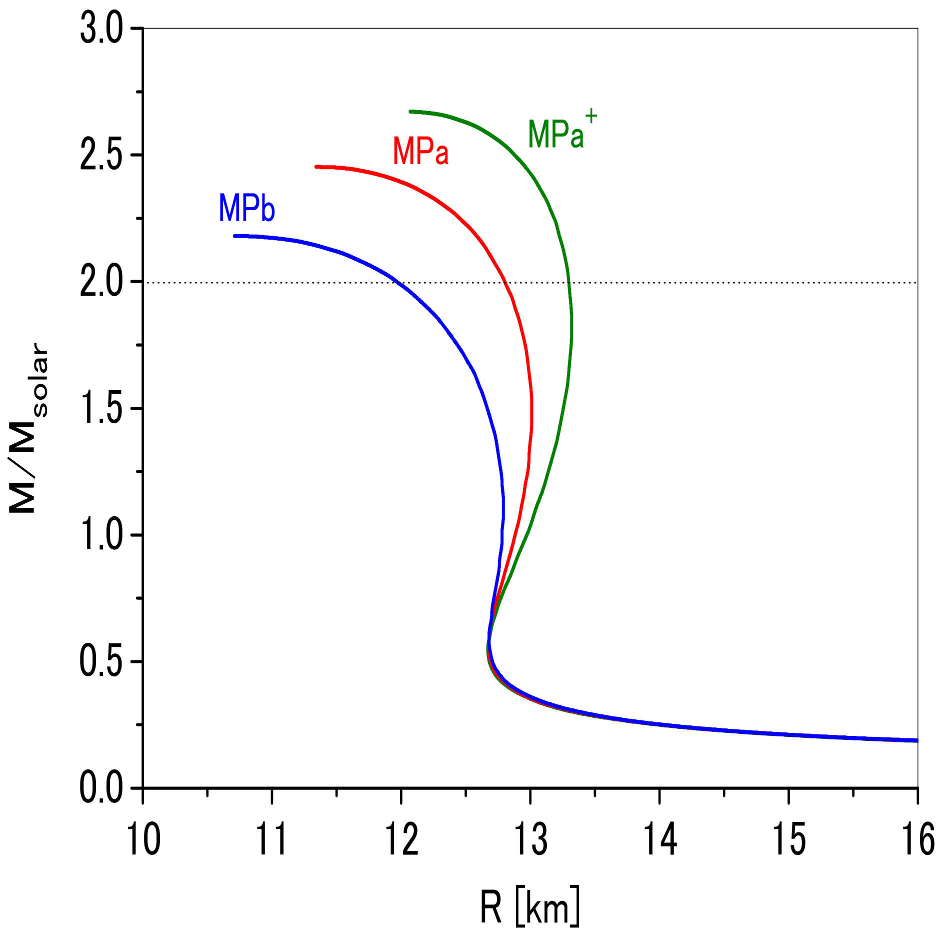
IV.9 ESC08: Λ-binding energies ⋆

ESC08(NN+YN): Λ Binding Energy AMD, M.Isaka et al

With TNIA(F-M,L-P) and Triple-pomeron Repulsion



ESC08c(NN+YN): Symmetric and Neutron-star matter



Solution TOV-equation:
Neutron-Star mass as
a function of the radius R.

Dotted: MP0, no MPP
Green : MPa$^+$, trip+quart MPP
Red : MPa, triple MPP.

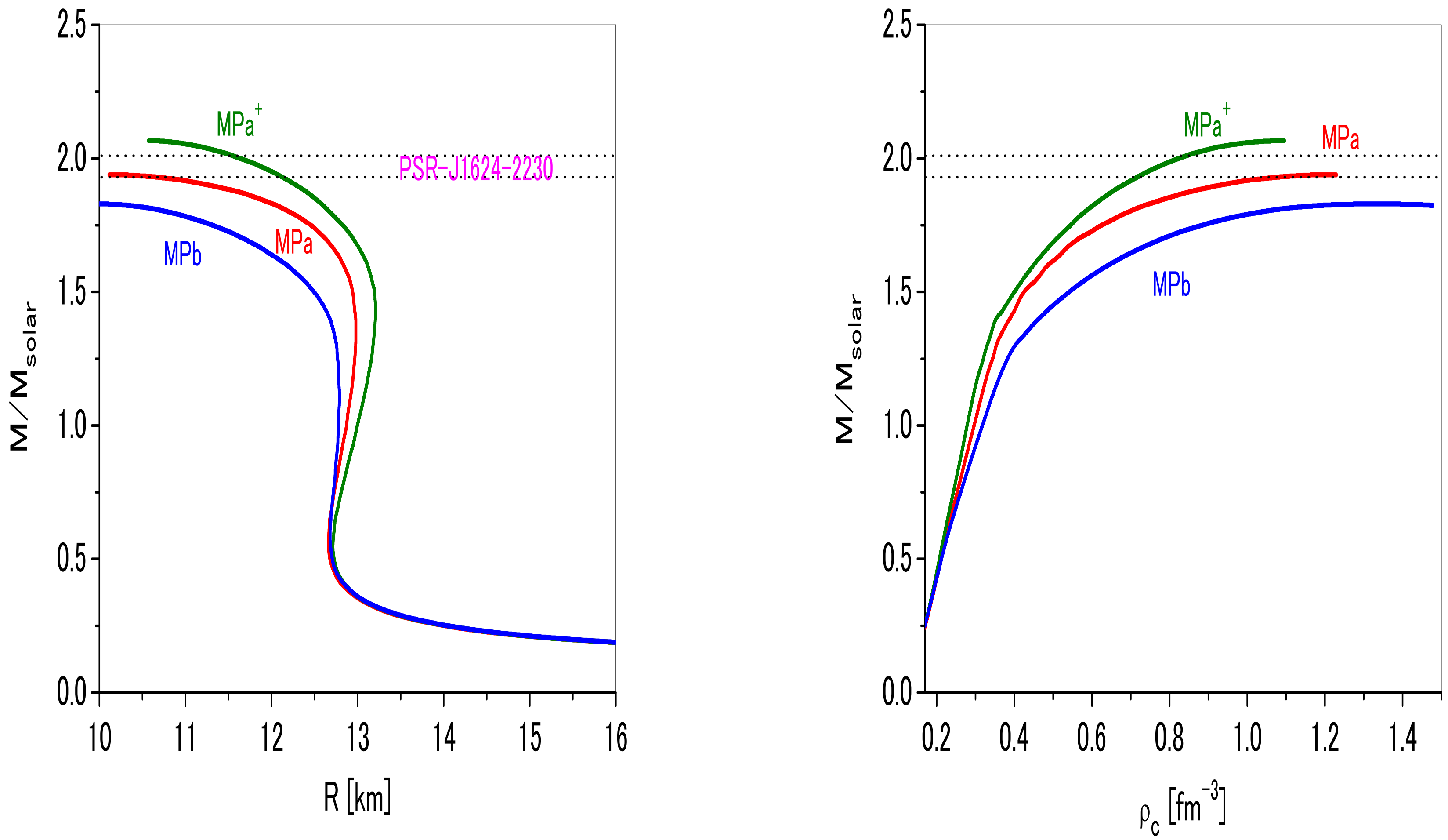
Blue : MPb, triple MPP.

Yamamoto, Furumoto,
Yasutake, Rijken

ESC08: MPP function:
(i) EoS, NStar mass
(ii) Nuclear saturation

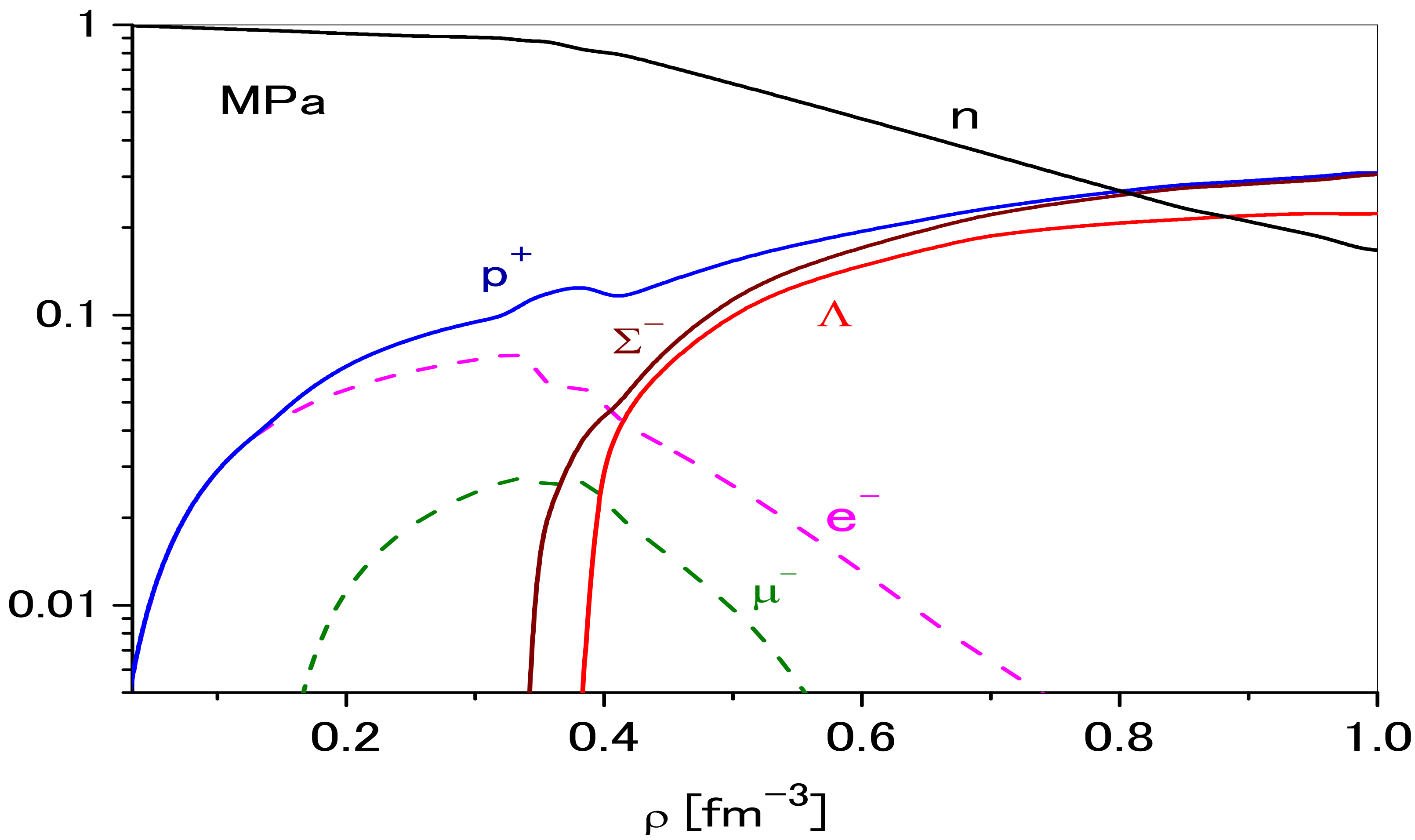
(iii) HyperNuclear overbinding.

ESC08c(NN+YN): Symmetric and Neutron-star matter



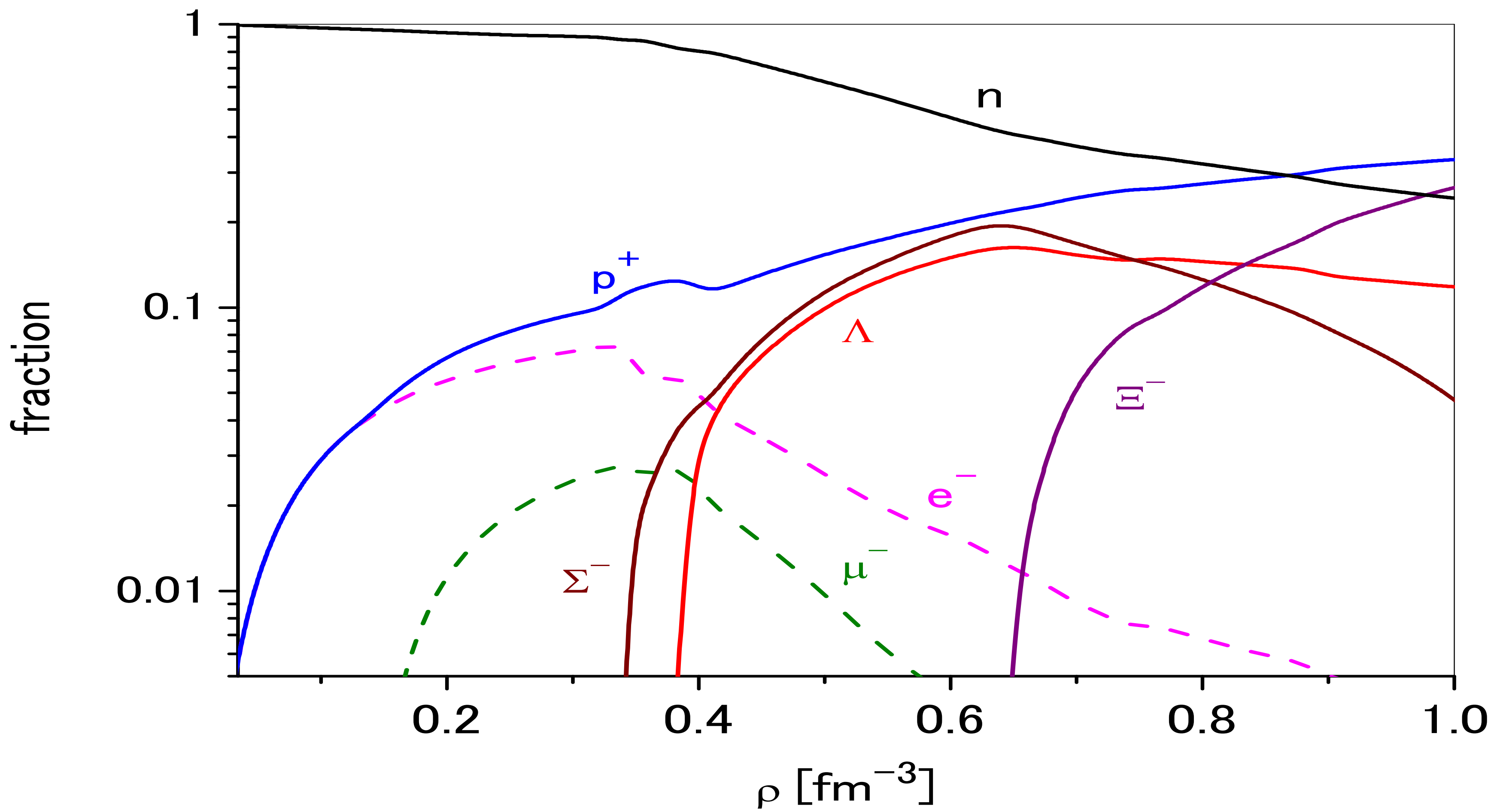
IV.12 ESC08: Nuclear and NS matter ⋆

ESC08c(NN+YN): Symmetric and Neutron-star matter



IV.13 ESC08: Nuclear and NS matter ⋆

ESC08c(NN+YN): Symmetric and Neutron-star matter



⋆ Conclusions and Status YN-interactions

Conclusions and Perspectives

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 more repulsive.
3. Scalar-meson nonet structure ⇔ Nagara $\Delta B_{\Lambda\Lambda}$ values.
4. NO S=-1 Bound-States, NO $\Lambda\Lambda$-Bound-State.
5. NO S=-2,-3,-4 Bound-States.

Meson-exchange description of the YN/YY-interactions:

a. Well-depths $U_\Lambda, U_\Sigma, U_\Xi$ significant contributions 3-body forces.
c. Hyperons: NStar mass $M/M_\odot = (1.44 - 2.2)$ ⇔ Multi-Pomeron.

Application: Three-body forces !

Application: QPC educated guesses !?

Application: soft Q-Q and Q-Baryon interactions !?

V.1 SU(3,C)-Symmetry Hadronen, BB-channels

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

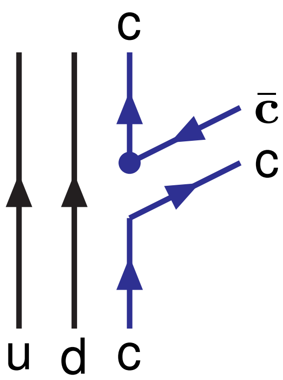
- SU$_F$(4): 2 octets with (P,N)-base: SU(3,s) $\oplus$ SU(3,c)
- Quark Level: SU(3,S)$_{flavor}$ $\Rightarrow$ SU(3,C)$_{flavor}$ S-quark $\Rightarrow$ C-quark
- $\Lambda \sim UDS \to \Lambda_c^+ \sim UDC \;\;,\;\; \Sigma^+ \sim UUS \to \Sigma_c^{++} \sim UUC$
- Mass differences $\Leftrightarrow$ Broken SU(3,C)$_{flavor}$ symmetry
- Baryon-Baryon Channels with "charm":

NN	:	pp	,	np	,	nn	$C=0$
Y_cN	:	$\Sigma_c^{++}p$	,	$\Sigma_c^0 p \to \Sigma_c^0 p, \Sigma_c^+ n, \Lambda_c^+ n$	,		$C=1$
	:		,	$\Lambda_c^+ p \to \Lambda_c^+ p, \Sigma_c^{++} n, \Sigma_c^+ p$	,		$C=1$
$\Xi_{cc}N$	:	$\Xi_{cc}^+ p$	,	$\Xi_{cc}N \to \Xi_{cc}^- p, \Lambda_c^+\Lambda_c^+, \Sigma_c\Sigma_c$			$C=2$
$\Xi_{cc}Y_c$	:		,	$\Xi_{cc}\Lambda_c^+ \to \Xi_{cc}\Lambda_c^+, \Xi_{cc}\Sigma_c$			$C=3$
$\Xi_{cc}\Xi_{cc}$	:	$\Xi_{cc}^{++}\Xi_{cc}^{++}$	,	$\Xi_{cc}^{++}\Xi_{cc}^+$	,	$\Xi_{cc}^+\Xi_{cc}^+$	$C=4$

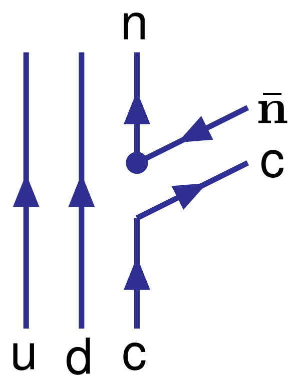
- SU(3,c): Gell-Mann-Nishina: $Q = I_3 + \frac{B+S+C}{2}$

V.2 QPC: educated guesses

QPC guesses Meson-Baryon Couplings



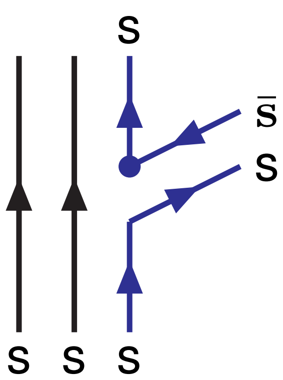
$\Lambda_c \to \Lambda_c \phi_c$



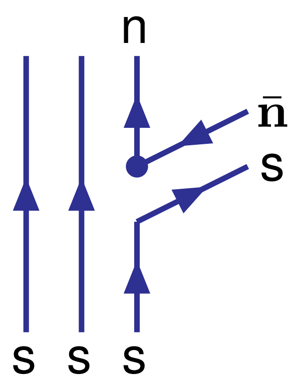
$\Lambda_c \to N D^*$

Charmed Baryon octet

$\Rightarrow$ $\Lambda_c N, \Sigma_c N, \Xi_c N$,
$\Lambda_c \Lambda_c$ etc. Potentials
$\Lambda_c \Lambda_c$ bound states?
$V_{\Lambda_c \Lambda_c} < V_{\Lambda\Lambda}$!?
QPC constants: γ_n, γ_c



$\Omega \to \Omega \phi$

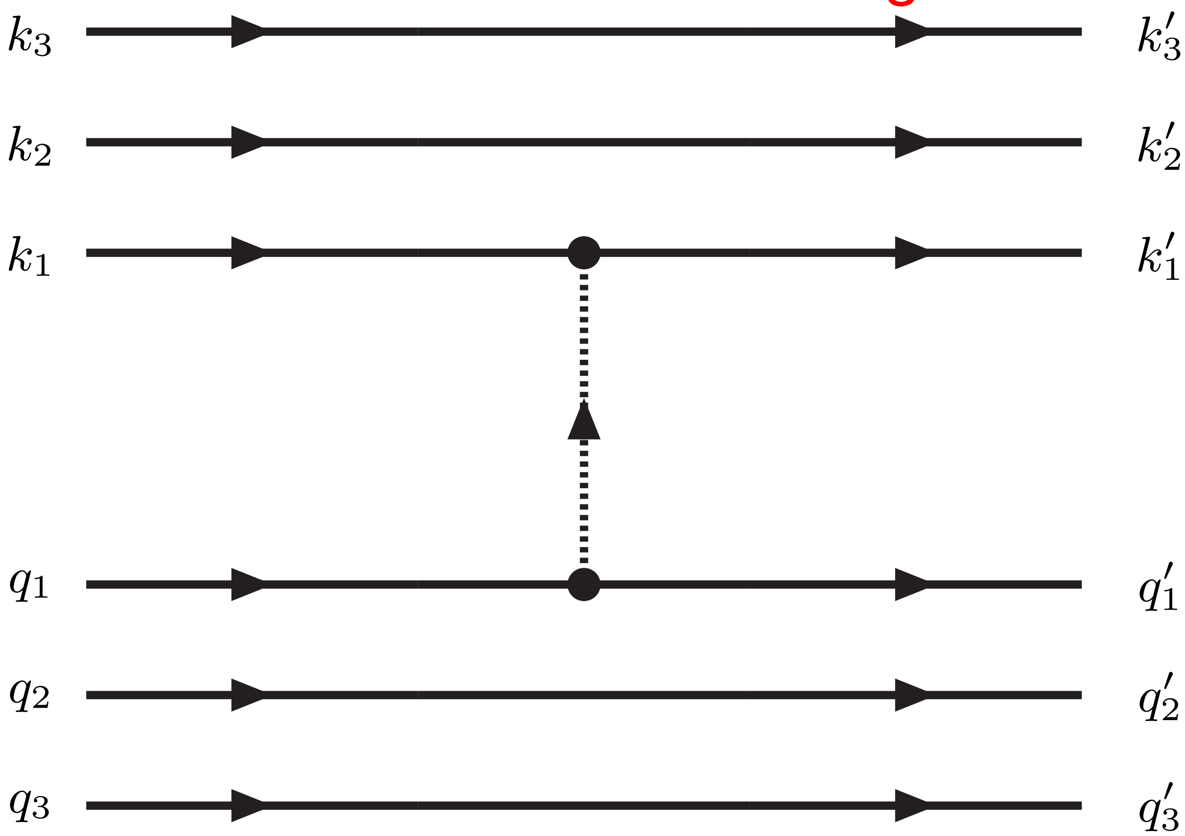


$\Omega \to \Xi K$

Strange Baryon decuplet

$\Rightarrow$ $\Omega\Omega, \Omega$N Potentials
$\Omega\Omega$ bound states?
$V_{\Omega\Omega} < V_{\Omega N} < V_{NN}$!?
QPC constants: γ_n, γ_s

CQM and Meson-exchange



Quark momenta meson-exchange

CQM and Meson-exchange

• NN-meson Vertices Phenomenology: At the nucleon level the general $1/MM$-structure vertices in Pauli-spinor space is dictated by Lorentz covariance:

$$\bar{u}(p',s')\Gamma\, u(p,s) = \chi_{s'}^{\prime\dagger} \left\{ \Gamma_{bb} + \Gamma_{bs} \frac{\boldsymbol{\sigma}\cdot\mathbf{p}}{E+M} - \frac{\boldsymbol{\sigma}\cdot\mathbf{p}'}{E'+M'}\Gamma_{sb} - \frac{\boldsymbol{\sigma}\cdot\mathbf{p}'}{E'+M'}\Gamma_{ss}\frac{\boldsymbol{\sigma}\cdot\mathbf{p}}{E+M} \right\} \chi_s$$

$$\approx \chi_{s'}^{\prime\dagger} \left\{ \Gamma_{bb} + \Gamma_{bs} \frac{(\boldsymbol{\sigma}\cdot\mathbf{p})}{2\sqrt{M'M}} - \frac{(\boldsymbol{\sigma}\cdot\mathbf{p}')}{2\sqrt{M'M}}\Gamma_{sb} - \frac{(\boldsymbol{\sigma}\cdot\mathbf{p}')\,\Gamma_{ss}\,(\boldsymbol{\sigma}\cdot\mathbf{p})}{4M'M} \right\} \chi_s$$

$$\equiv \sum_l c_{NN}^{(l)}\, O_l(\mathbf{p}',\mathbf{p})\, (\sqrt{M'M})^{\alpha_l} \quad (l = bb, bs, sb, ss)$$

$$c_{NN}^{(l)} : 1,\ \boldsymbol{\sigma},\ \boldsymbol{\sigma}\cdot\mathbf{p},\ \boldsymbol{\sigma}\cdot\mathbf{p}',\ \boldsymbol{\sigma}\cdot\mathbf{p}'\times\mathbf{p},\ .....$$

Question: How is this structure reproduced using the coupling of the mesons to the quarks directly? *In fact, we have demonstrated that for the CQM, i.e.* $m_Q = \sqrt{M'M}/3$*, the ratio's* $c_{QQ}^{(l)}/c_{NN}^{(l)}$ *can be made constant, i.e. independent of (l), for each type of meson.* Then, by scaling the couplings the expansion coeffients can be made equal. (Q.E.D.)

CQM and Axial-vector coupling

$\mathbf{\Gamma}_5$-vertex: Impose conservation of the quark axial current:

$$J^a_\mu = g_a \bar{\psi}\gamma_\mu\gamma_5\psi + \frac{if_a}{\mathcal{M}}\partial_\mu(\bar{\psi}\gamma_5\psi), \quad \partial \cdot J^A = 0 \Rightarrow$$

$f_a = \left(2m_Q\mathcal{M}/m^2_{A_1}\right) g_a$. With $m_{A_1} = \sqrt{2}m_\rho \approx 2\sqrt{2}m_Q$

$$J^a_\mu = g_a \left[\bar{\psi}\gamma_\mu\gamma_5\psi + \frac{i}{4m_Q}\partial_\mu(\bar{\psi}\gamma_5\psi)\right].$$

Inclusion f_a- and zero in form-factor gives for NNM- and QQM-coupling + folding:

$$\mathbf{\Gamma}_{5,NN} \Rightarrow \chi'^\dagger_N \left[\boldsymbol{\sigma} + \frac{1}{4M'M}\left\{2\mathbf{q}(\boldsymbol{\sigma}\cdot\mathbf{q}) - \left(\mathbf{q}^2 - \mathbf{k}^2/4\right)\ \boldsymbol{\sigma} + \underline{i(\mathbf{q}\times\mathbf{k})}\right\}\right]\ \chi_N,$$

$$\mathbf{\Gamma}_{5,QQ} \Rightarrow \chi'^\dagger_N \left[\boldsymbol{\sigma} + \frac{1}{4M'M}\left\{2\mathbf{q}(\boldsymbol{\sigma}\cdot\mathbf{q}) - (\mathbf{q}^2 - \mathbf{k}^2/4)\ \boldsymbol{\sigma} + \underline{9i(\mathbf{q}\times\mathbf{k})}\right\}\right]\ \chi_N$$

CQM and Axial-vector coupling

Orbital Angular Momentum : $\mathbf{\Gamma} = \sum_{i=1}^{3} \bar{u}_i \boldsymbol{\gamma}_i \gamma_5 u_i = \langle \bar{u}_N \mathbf{\Sigma}_N u_N \rangle$
measures the contribution of the quarks to the nucleon spin.
In the quark-parton model: large portion of the nucleon spin due to orbital angular and/or gluonic contributions (see e.g. Leader & Vitale 1996)
Therefore consider the additional interaction at the quark level

$$\begin{aligned} \Delta\mathcal{L}' &= \frac{i g_a''}{\mathcal{M}^2}\, \epsilon^{\mu\nu\alpha\beta}\, \left[\bar{\psi}(x)\mathcal{M}_{\nu\alpha\beta}\psi(x)\right]\, A_\mu, \\ \mathcal{M}_{\nu\alpha\beta} &= \gamma_\nu \left(x_\alpha \frac{\partial}{\partial x^\beta} - x_\beta \frac{\partial}{\partial x^\alpha}\right). \end{aligned}$$

The vertex for the NNA$_1$-coupling is given by

$$\langle p', s'|\Delta L'|p, s; k, \rho\rangle = \int d^4x \langle p', s'|\Delta\mathcal{L}'|p, s; k, \rho\rangle \sim \varepsilon_\mu(k,\rho)\, \epsilon^{\mu\nu\alpha\beta} \cdot$$

$$\times \int d^4x\, e^{-ik\cdot x}\, \langle p', s'|i\bar{\psi}(x)\gamma_\nu \left(x_\alpha \nabla_\beta - x_\beta \nabla_\alpha\right)\psi(x)|p, s\rangle$$

CQM and Axial-vector coupling

The dominant contribution comes from $\nu = 0$. Evaluation:

$$\langle p', s'|\Delta L'|p, s; k, \rho\rangle \Rightarrow +(2\pi)^4 i\delta^{(4)}(p' - p - k)\ (2\alpha/3)\ g_a''\varepsilon_m(k, \rho)\ \cdot$$

$$\times \sum_{i=1}^{3} \left[u^\dagger(k_i', s')\ u(k_i, s)\right]\ \boldsymbol{\varepsilon}(k, \rho) \cdot \mathbf{q} \times \mathbf{k}\ e^{-\alpha(\mathbf{q}^2 - 2\mathbf{q}\cdot\mathbf{Q})/2}$$

$$\Rightarrow \Delta\boldsymbol{\Gamma}'^{m}_{5,QQ} \propto \frac{g_a''}{M'M}(2R_N M/M_N)^2)\ \sqrt{\frac{E' + M'}{2M'}\ \frac{E + M}{2M}} \cdot \left[\chi_N'^{\dagger}\chi_N\right]\ (\mathbf{q} \times \mathbf{k})_m.$$

Adjusting g_a'' can give the spin-orbit of the NNA_1-vertex correctly:
coupling to orbital angular momentum operator of the quarks in a baryon ⇔ "spin-crisis"!?

1. Quark-parton picture: The spin-crisis in the quark-parton model revealed: the nucleon spin is mainly orbital and/or gluonic!
2. Constituent-quark picture: nucleon spin is sum quark spins.
Required is an extra spin-orbit coupling in **the non-forward matrix element** axial current to connect the QQ-axial-vector vertex with the nucleon level.

V.8 Low-k Quark-interactions

BB-interactions ⇒ Quark-interactions

- Corollary: ESC-model NN, YN, YY, Hypernuclear data ⇒ QQ-meson couplings.
- Application: Low-k Q-Q and Q-Baryon meson-exch. interactions
- Generalized NJL-model: short-range approximation

$$e^{-k^2/\Lambda^2}(k^2+m^2)^{-1} \approx \exp(-k^2/U^2), U^2 = \Lambda^2 m^2/(\Lambda^2+m^2)$$

⇒ *contact interaction* in a dense quark gas.

- NJL: "contact-term" form

$$V_{QQ} = \sum_i f_i[\bar{\psi}\Gamma'_i\psi][\bar{\psi}\Gamma_i\psi] = f_S\,[\bar{\psi}\psi]^2 + f_P\,[\bar{\psi}\gamma_5\psi]^2 + ...$$

- Treatment Quark-phase, Quark-Hatron-phase in e.g Nstars !?

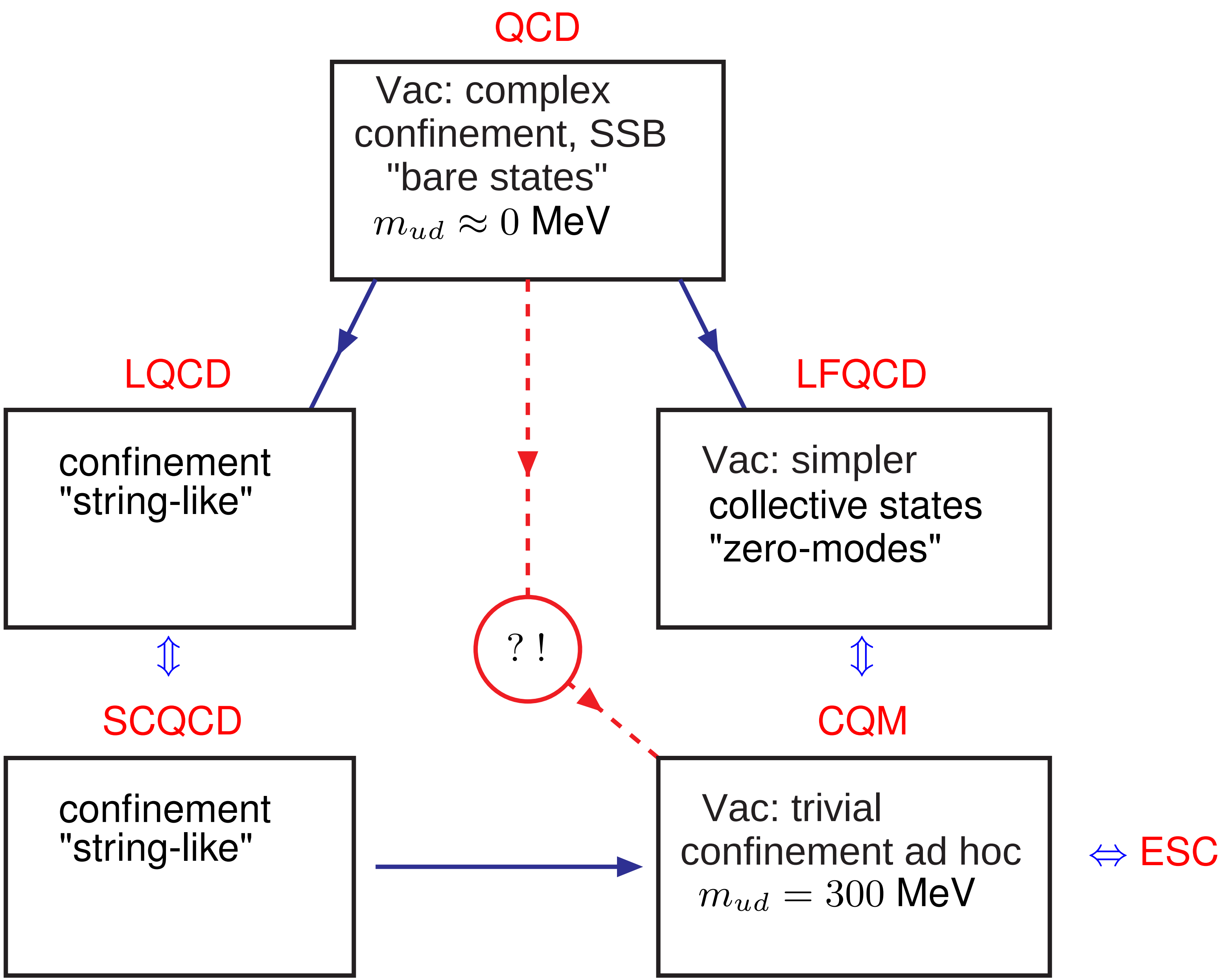
Reserve slights: Topics not addressed in this Talk

A. YN data fit ESC08c .

B. QCD, LQCD, SCQCD, and CQM-model .

C. QQM-couplings ⇔ BBM-couplings.

D. ESC-model ⇔ QQ,BQ-potentials.


QCD
Vac: complex
confinement, SSB
"bare states"
$m_{ud} \approx 0$ MeV
LQCD
confinement
"string-like"
LFQCD
Vac: simpler
collective states
"zero-modes"
? !
SCQCD
confinement
"string-like"
CQM
Vac: trivial
confinement ad hoc
$m_{ud} = 300$ MeV
$\Leftrightarrow$ ESC

c Strong-Coupling Lattice QCD (SCQCD) ⋆

Strong-Coupling Lattice QCD (SCQCD) $\rightarrow$

• Nuclear Phenomena: lattice spacing $a \geq 0.1$ fm, $g \geq 1.1$
$\Rightarrow$ strong coupling expansion (might be) useful!

• Miller PRC39(1987), Kogut & Susskind PRD11(1975),
Isgur & Paton, PR D31(1985)

• Implications SCQCD:
(a) quarks different baryons can be treated distinguishable
(b) baryons interact (dominantly) by mesonic exchanges
(c) the gluons in wave-functions are confined in narrow tubes
(d) quark-exchange is suppressed by overlap narrow flux-tubes

• Implications narrow tube picture SCQCD:
(e) pomeron/odderon exchange: via narrow flux tubes
(f) pomeron & odderon couple to individual quarks of the baryons (Landshoff & Nachtmann)

• Constituent Quark-model (CQM): succesful!
(1) e.g. magnetic moments (2) derivation(?!) (Wilson et al, LFQCD)

• LQCD (Sasaki, Nemura, Inoue) $\approx$ meson-exchange BB-irreps