MESON 2016 – Outlook

Avraham Gal, Hebrew University, Jerusalem

- **Exotics:** Remarks on Pentaquarks
- **In-medium Mesons**

  Nanova (ω, η'; ELSA) Mareš (η) Friedman (K^+)

  Tatsuno (K^-; DAΦNE) Scordo (K^-; DAΦNE)

  Itahashi (π^-; RIKEN) Tanaka (η'; GSI)

  Cieply, Hrtankova ($\bar{K}$) Iwasaki ($\bar{K}$; J-PARC)
- **Non-Strange Dibaryons**

  NN (deuteron) NΔ (JLab) & ΔΔ (COSY)
- **Strange & Charmed Dibaryons**

  Y*N (J-PARC), H, Ω^-N, Λ_cN

EXOTICS

Pentaquarks – old and new

Pentaquark Perspectives

- The first pentaquark, the $\mathcal{S} = -1$ Λ(1405) was predicted in 1959 by Dalitz and Tuan as a $\bar{K}$N quasibound state, five years before the term 'quark' was transformed by Gell-Mann from Literature to Physics. It was identified around 1960 in a Berkeley hydrogen bubble chamber experiment. A recent LQCD calculation confirms its $\bar{K}$N hadronic cluster structure, as opposed to a genuing pentaquark.
- A $\mathcal{S} = +1$ Θ^+(1530) pentaquark was claimed more than 10 years ago, but recent dedicated experimental searches have failed to confirm it. Its coupling to KN is very small.

Friedman and I suggested that it is formed copiously in absorption on two nucleons, $K^+(nN)\rightarrow\Theta^+N'$, thereby resolving the problem of too large K^+ nuclear cross sections at low energies (Friedman).

- The recent LHCb discovery of hidden-charm structures has led to several serious attempts to interpret these in terms of pentaquark(s) (Ryan, Karliner, Shen, Oset...).

The next 3 slides are from Karliner's talk

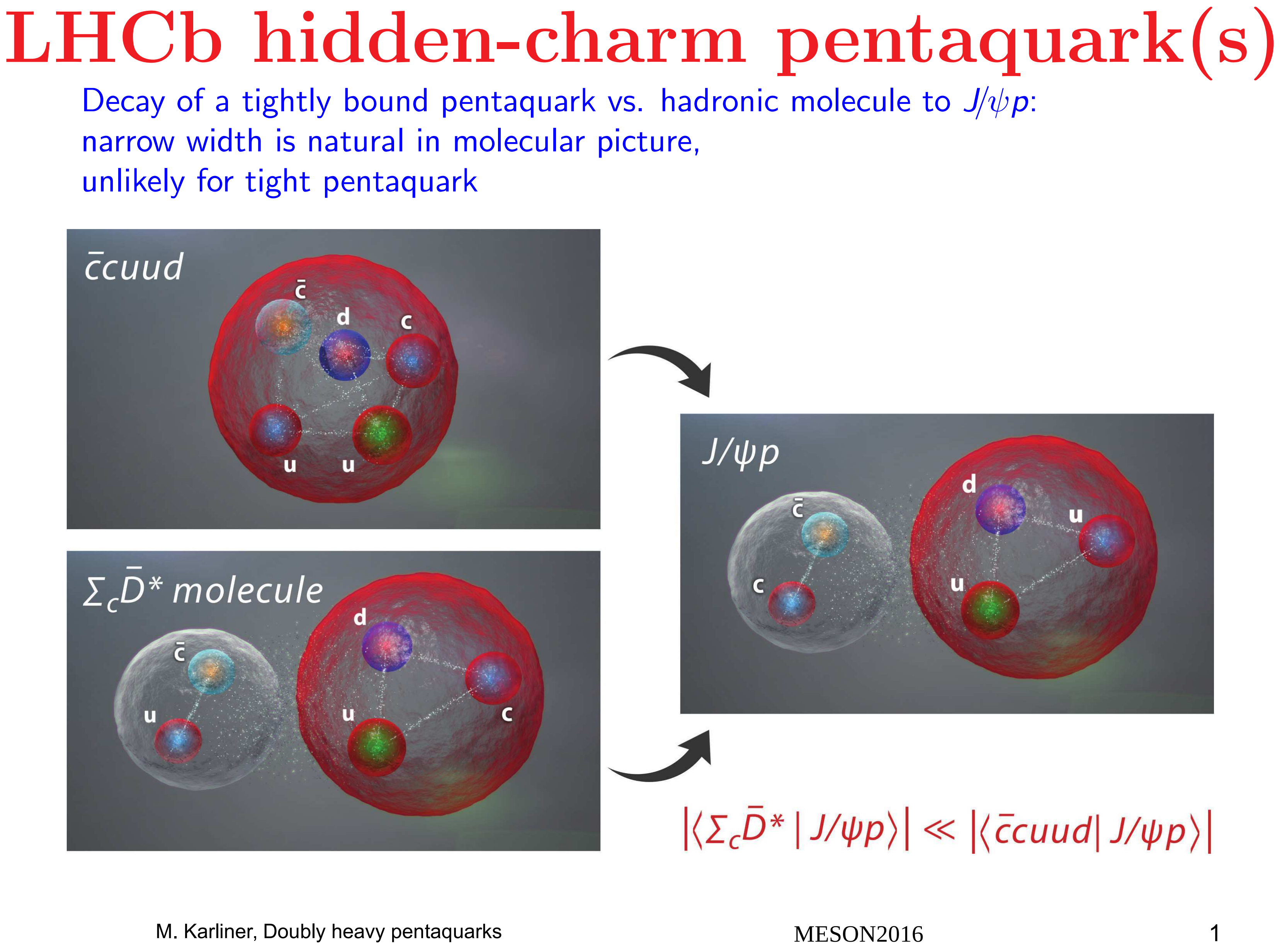
Vision of heavy-quark wonderland

new rich heavy flavor QCD spectroscopy

(a) bottomonium analogues of charmonium X, Y, Z states

(b) new exotics – doubly-heavy hadronic molecules
meson-meson, baryon-meson, baryon-baryon
the lightest one:
LHCb "pentaquark" $= \Sigma_c \bar{D}^* \; (\bar{c}cuud)$

(c) doubly heavy QQq baryons



LHCb hidden-charm pentaquark(s)

Decay of a tightly bound pentaquark vs. hadronic molecule to $J/\psi p$:
narrow width is natural in molecular picture,
unlikely for tight pentaquark

$$|\langle \Sigma_c\bar{D}^* \,|\, J/\psi p\rangle| \ll |\langle \bar{c}cuud |\, J/\psi p\rangle|$$

M. Karliner, Doubly heavy pentaquarks MESON2016 1

Preference of hadronic cluster structure

SUMMARY

- the new narrow exotic resonances are loosely bound states of $\bar{D}D^*$, $\bar{D}^*D^*$, $\bar{B}^*B^*$, $\Sigma_c\bar{D}^*$

  predictions:

– $\bar{D}^*D^*$ in $I=0$ and $I=1$ channels; $I=1$ seen!

– new isosinglet $\bar{B}B^*$ and $\bar{B}^*B^*$ states below threshold;
$\chi_{1b}(3P) = X_b$?

– *heavy deuterons*: $\Sigma_c D^*$: LHCb $P_c(4450)$ $\Longrightarrow$ photoproduction
$\Sigma_c B^*$, $\Sigma_b\bar{D}^*$, $\Sigma_b B^*$, $\Sigma_Q\bar{\Lambda}_{Q'}$, $\Sigma_Q^+\Sigma_Q^-, \ldots$
η-mediated: $D_s\bar{D}_s^*$, $\Lambda_c\bar{D}_s^*, \ldots$

– doubly & triply heavy baryons QQq, QQQ @pp & e^+e^-

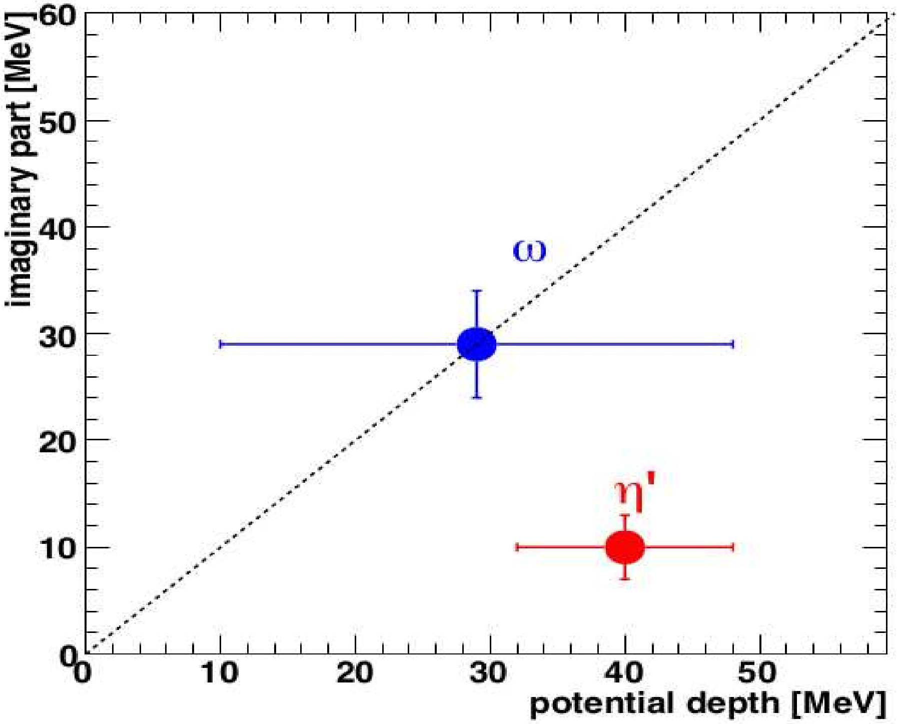
- exciting new spectroscopy in future e^+e^- high-$\mathcal{L}$ high-E colliders

In-medium mesons

A. Gal, E. Friedman, N. Barnea
A. Cieplý, J. Mareš, D. Gazda

Acta Physica Polonica B 45 (2014) 673

Meson-nucleus optical potential (Nanova)

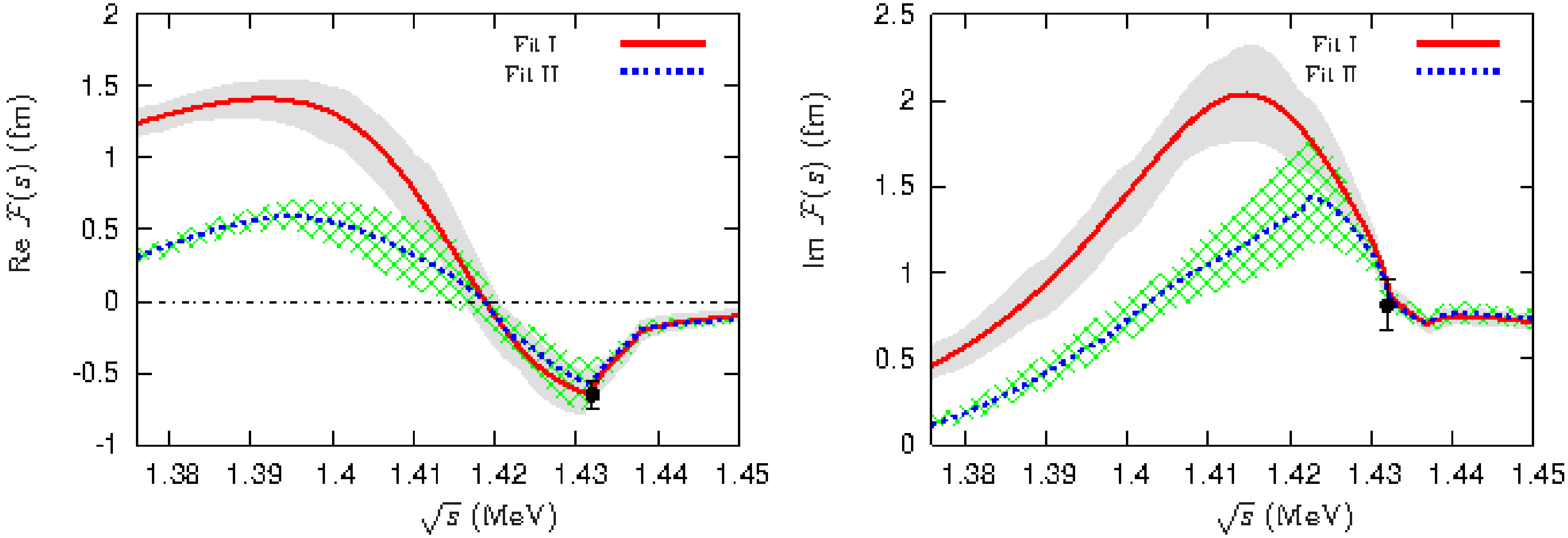


$$V_{\rm opt}(r) = -(\Delta m(\rho_0) + {\rm i}\Gamma_0/2)\,\frac{\rho(r)}{\rho_0} \sim f_{\rm mN}(0^{\rm deg}; \sqrt{s_{\rm mN}})\rho(r)$$

These are attractive potentials; energy dependence?

Subthreshold extrapolation needed for bound states.

$K^- p$ subthreshold ambiguity



Two NLO chiral-model fits by Guo-Oller, PRC 87 (2013) 035202

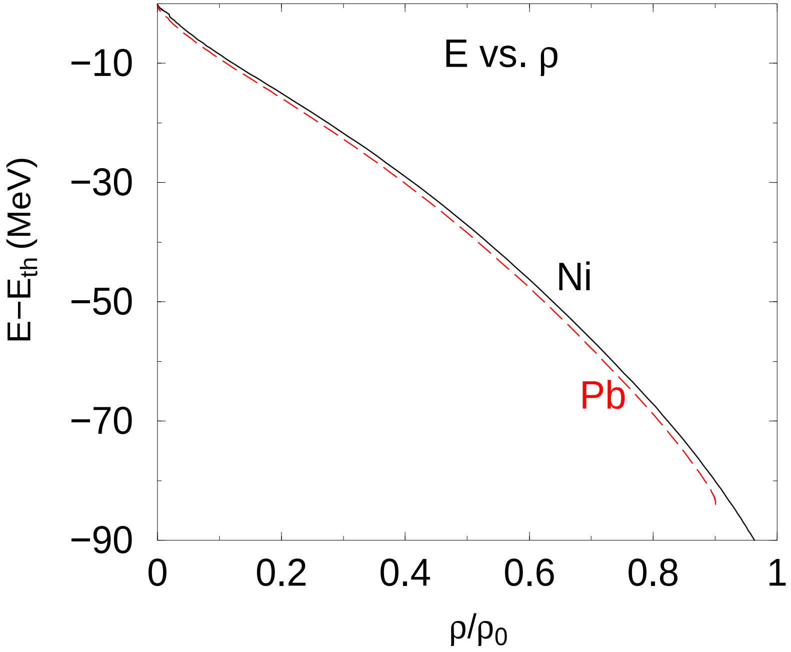
- **Fit I: meson-independent $f = 125.7 \pm 1.1$ MeV.**
- **Fit II: physical values for $f_\pi,\ f_K,\ f_\eta$.**
  Will create problems when confronted with K^--atom data.
- **Amplitudes constrained at threshold by SIDDHARTA.**
  $\bar{K}N$ pole robust, $\pi\Sigma$ pole correlated with fit.

Self-consistency imposed in K^- atom calculations

[Cieplý-Friedman-Gal-Gazda-Mareš, PLB 702 (2011) 402]:

$$\sqrt{s_{K^-N}} \to E_{\rm th} - B_N - B_K - \xi_N \frac{p_N^2}{2m_N} - \xi_K \frac{p_K^2}{2m_K}$$

$$\xi_{N(K)} = \frac{m_{N(K)}}{(m_N + m_K)} \qquad \frac{p_K^2}{2m_K} \sim -V_{K^-} \approx 100\ \text{MeV}$$



K^- is not at rest!

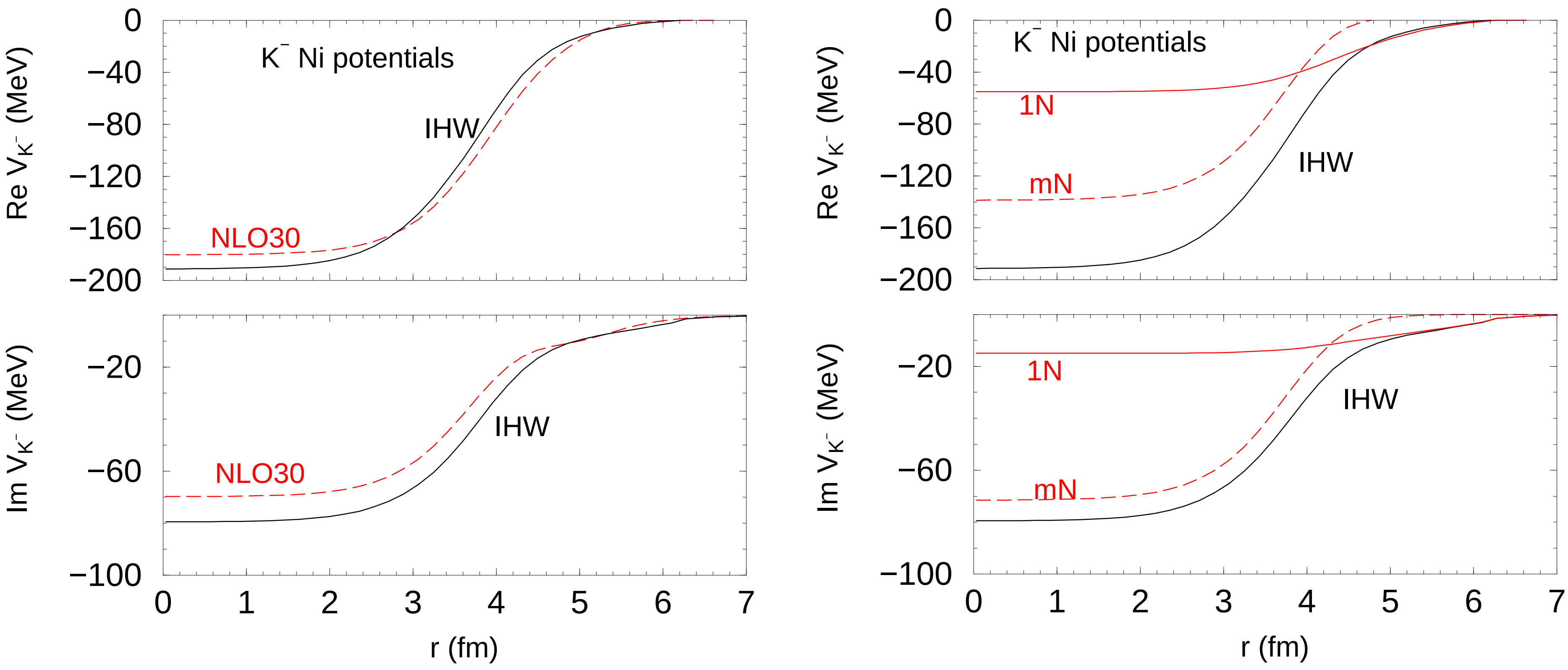
From E. Friedman, A. Gal

NPA 899 (2013) 60

K^-N subthreshold energy *vs*

nuclear density in K^- atoms.

A dominant in-medium effect

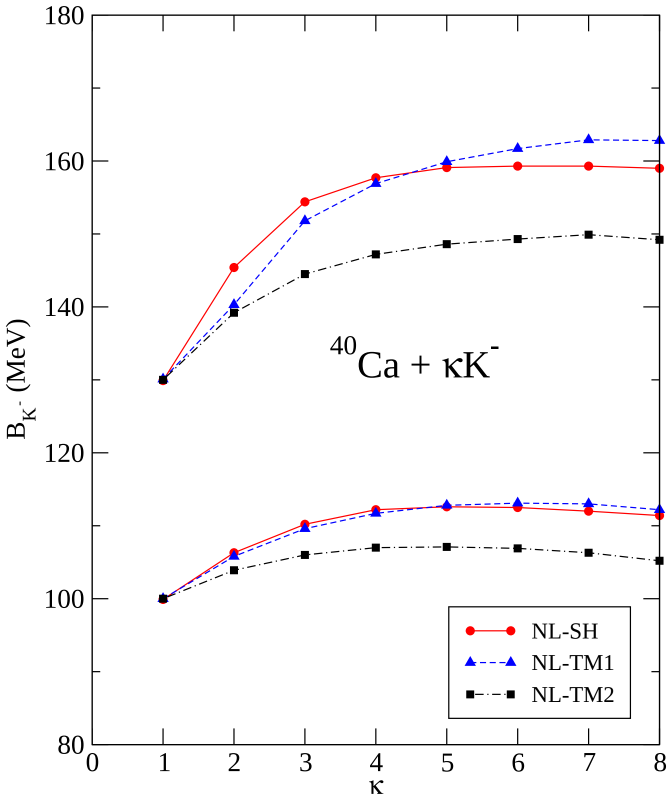


K^- atoms best-fit V_{K^-} for Ni & breakdown into in-medium 1N and phenomenological m(any)N contributions.

Work by Friedman-Gal, NPA 899 (2013) 60.

NLO30: A. Cieply, J. Smejkal, NPA 881 (2012) 115 (in-medium).

IHW: Y. Ikeda, T. Hyodo, W. Weise, NPA 881 (2012) 98.



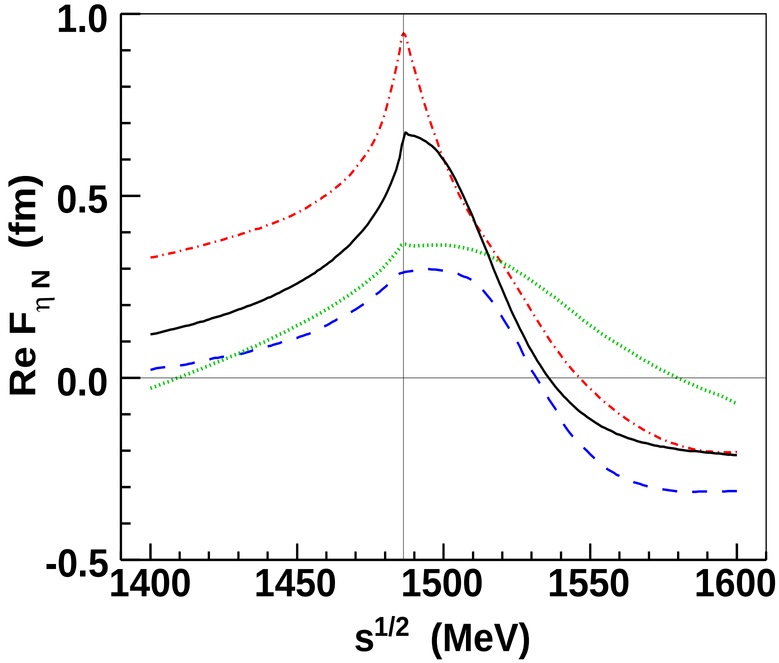
Gazda-Friedman-Gal-Mareš, PRC 77 (2008) 045206; 80 (2009) 035205

Saturation of $B_{\bar{K}}(\kappa)$ in RMF for multi-K^- ^{40}Ca nuclei.

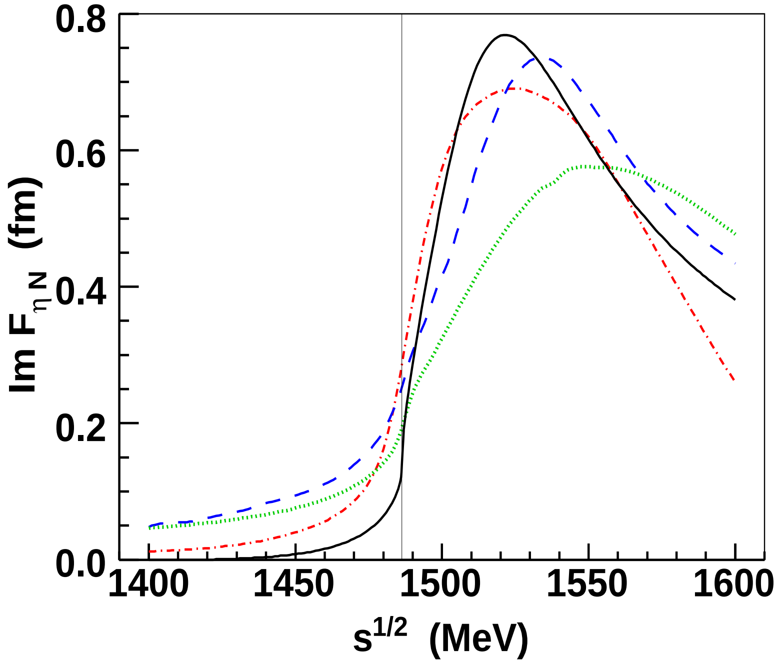
Vector-meson repulsion among $\bar{K}$ mesons.

$B_{\bar{K}}(\kappa \to \infty) << (m_K + M_N - M_\Lambda) \approx 320$ **MeV, hence $\bar{K}$ mesons do not replace hyperons in self-bound strange matter.**

$F_{\eta N}(\sqrt{s})$ in N(1535) models



Real $F_{\eta N}(\sqrt{s})$

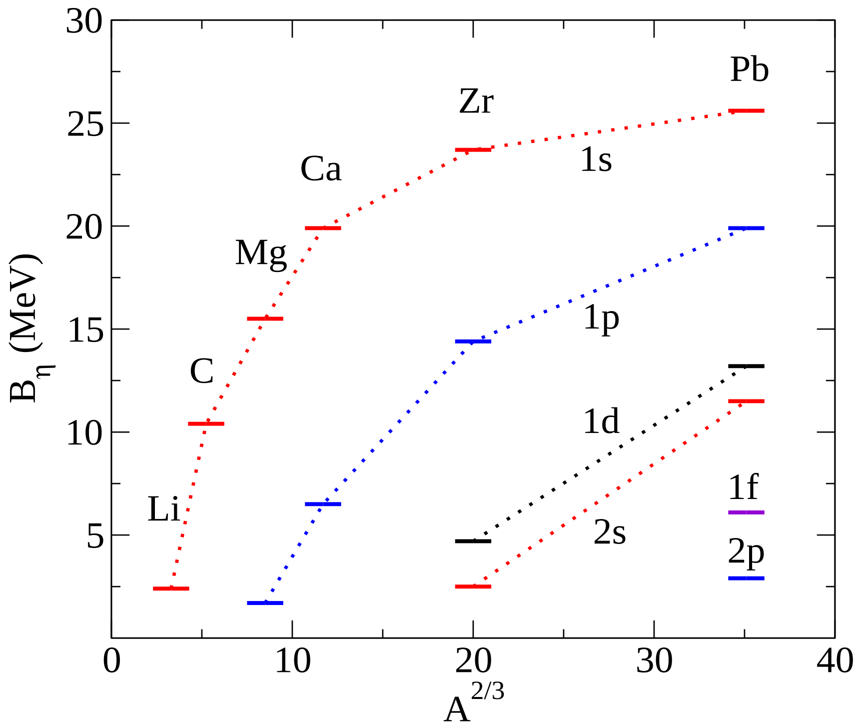


Imaginary $F_{\eta N}(\sqrt{s})$

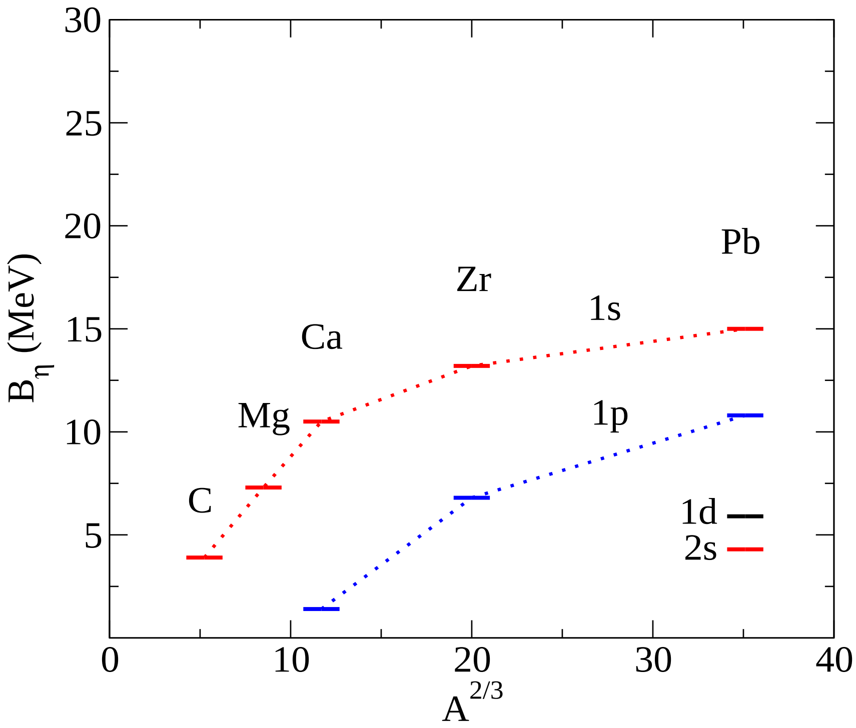
Cieply-Friedman-Gal-Mareš, NPA 925 (2014) 126

- Model dependence of Re $a_{\eta N}$ $\sim$0.3–1.0 fm. Weaker attraction & absorption upon going subthreshold.
- Construct in-medium $F_{\eta N}(\sqrt{s};\rho)$ and hence $V_{\eta}(\sqrt{s};\rho)$, to apply self consistently.

η-nuclear spectra model predictions



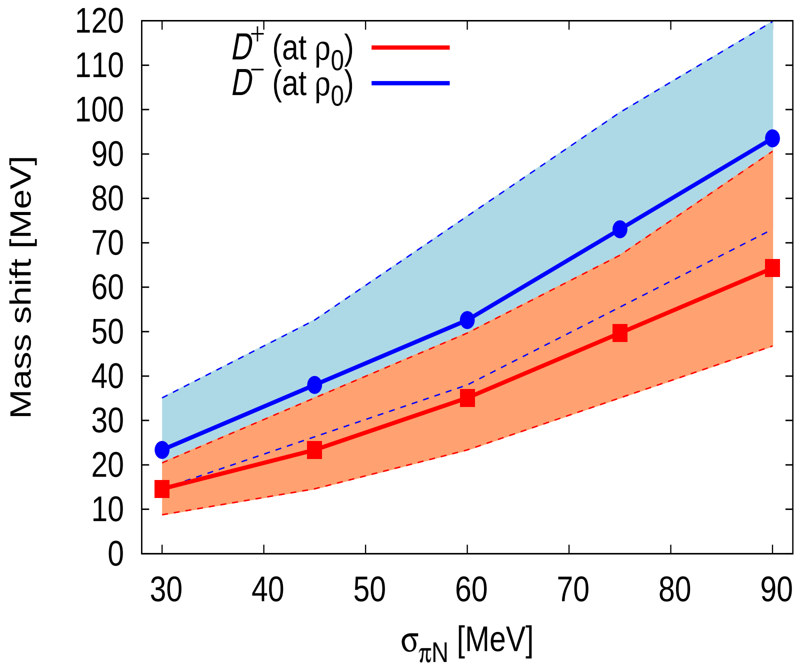
Green-Wycech ηN model
PRC 71 (2005) 014001



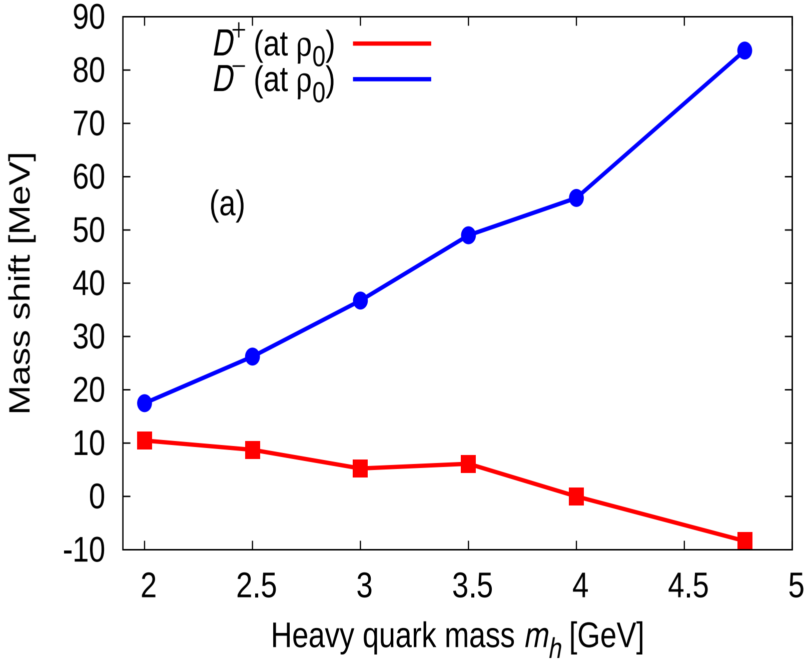
Cieply-Smejkal ηN model
NPA 919 (2013) 46

- In these models the subthreshold Im $f_{\eta N}$ is sufficiently small to generate widths ∼2–3 MeV for CS input.
- No ηd, η^3He bound states in few-body calculations
  by Barnea-Friedman-Gal, PLB 747 (2015) 345.

‘Surprise’ for D mesons in dense matter



$\mathrm{D}^{\mp}$ mass shift vs. $\sigma_{\pi N}$



$\mathrm{D}^{\mp}$ mass shift vs. m_Q

D mass increase from χ-symmetry restoration

K. Suzuki, P. Gubler, M. Oka, PRC 93 (2016) 045209

- Naively, from mean-field considerations, one expects attraction for $\mathrm{D}^+ = \mathrm{c}\bar{d}$, similar to $\mathrm{K}^- = \mathrm{s}\bar{u}$. Both $\mathrm{D}^- = \bar{c}\mathrm{d}$ and $\mathrm{K}^+ = \bar{s}\mathrm{u}$ undergo repulsion (see Friedman’s talk).

Non-strange dibaryons

Long-range dynamics of dibaryons

A. Gal, H. Garcilazo, PRL 111 (2013) 172301
Nucl. Phys. A 928 (2014) 73-88

A. Gal, Meson Assisted Dibaryons
Acta Physica Polonica B 47 (2016) 471–484

Nonstrange s-wave dibaryon SU(6) predictions
F.J. Dyson, N.-H. Xuong, PRL 13 (1964) 815

dibaryon	I	S	SU(3)	legend	mass
$\mathcal{D}_{01}$	0	1	$\overline{\mathbf{10}}$	deuteron	A
$\mathcal{D}_{10}$	1	0	**27**	nn	A
$\mathcal{D}_{12}$	1	2	**27**	$N\Delta$	$A+6B$
$\mathcal{D}_{21}$	2	1	**35**	$N\Delta$	$A+6B$
$\mathcal{D}_{03}$	0	3	$\overline{\mathbf{10}}$	$\Delta\Delta$	$A+10B$
$\mathcal{D}_{30}$	3	0	**28**	$\Delta\Delta$	$A+10B$

Assuming 'lowest' SU(6) multiplet, 490, within 56 × 56.

M=A+B[$I(I+1)$+$S(S+1)$**-2**], **A=1878 MeV from** $M(d)$≈$M(v)$.

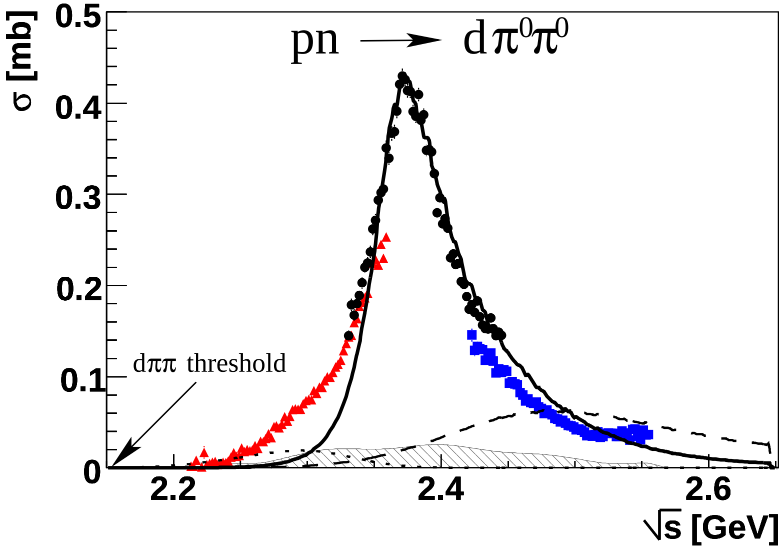
$B = 47$ **MeV from** $M(\mathcal{D}_{12})$≈**2160 MeV observed in** $\pi^+ d \to pp$.

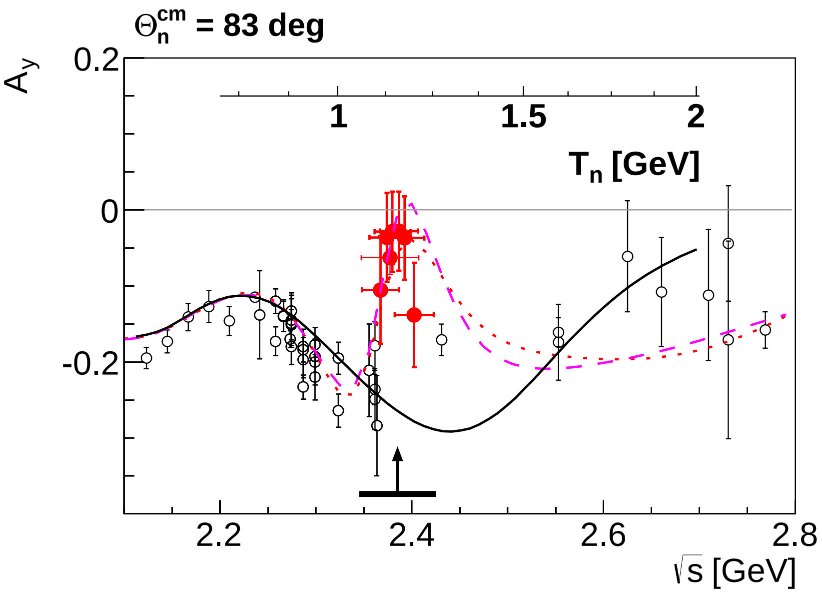
Hence, $M(\mathcal{D}_{03}) = M(\mathcal{D}_{30}) \approx 2350$ **MeV** [**2**$M(\Delta)$ ≈**2465 MeV**].

Kamae-Fujita, PRL 38 (1977) 468, 471: proton polarization in $\gamma d \to pn$ **supports a dibaryon at** M ≈**2380 MeV.**

Evidence for $\mathcal{D}_{03}(2380)$, $B \sim 80$ & $\Gamma \sim 70$ MeV

Adlarson et al. PRL 106 (2011) 242302 & 112 (2014) 202301





from $pd \to d\pi^0\pi^0 + p_s$ $\quad$ $^3D_3 - {}^3G_3$ pn **resonance**

also in $pd \to d\pi^+\pi^- + p_s$ $\quad$ np **analyzing power**

SAID NN fit requires a resonance pole

WASA@COSY & SAID, PRC 90 (2014) 035204

Given $\Gamma(\Delta) \approx$120 MeV, what makes $\mathcal{D}_{03}$ that narrow?

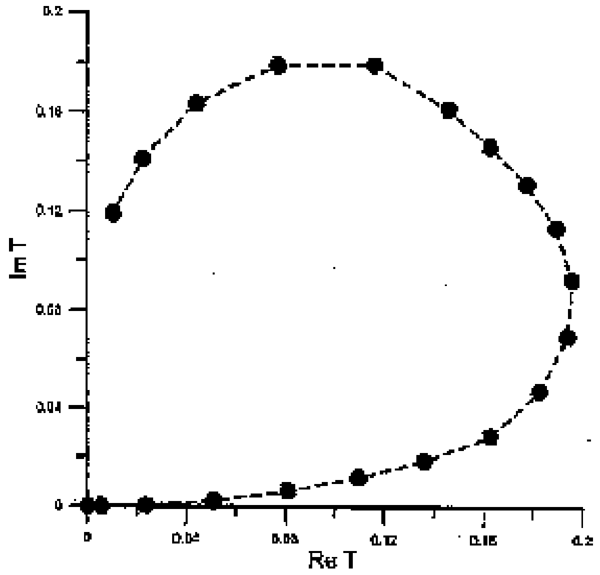
$\mathcal{D}_{12}$ $N\Delta$ dibaryon candidate

ΔN $I(J^P) = 1(2^+)$ Dibaryon

NN $^1D_2$ amplitude
$1880 < W < 2260$
MeV.

Hoshizaki resonance
at

$W = 2144 - i55$ MeV



$NN \leftrightarrow \pi d$ reactions resonate near $N\Delta$ threshold

Hoshizaki, PTP 89 (1993) 563: W=2144-i55 MeV

Arndt et al. PRD 35 (1987) 128: W=2148-i63 MeV

$\mathcal{D}_{12}(2150)$ $N\Delta$ dibaryon near threshold (2.17 GeV)

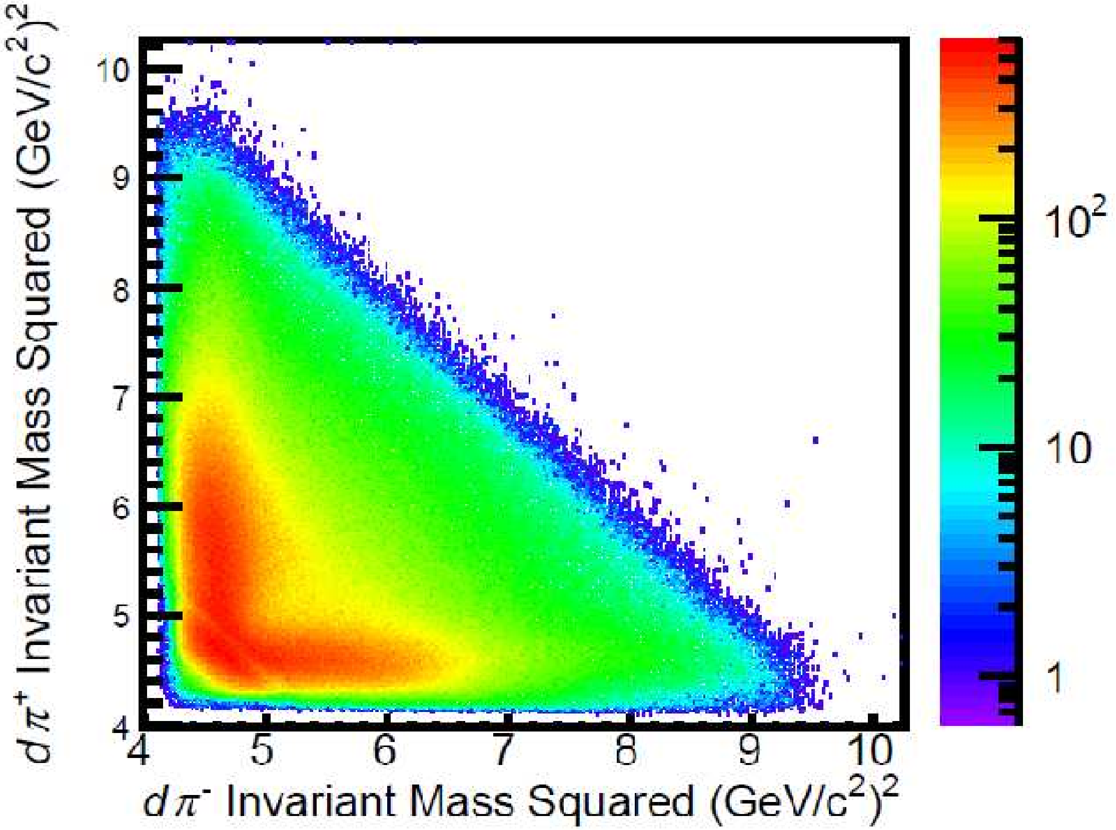
- **Long ago established in coupled-channel $pp(^1D_2) \leftrightarrow \pi^+d(^3P_2)$ scattering & reactions. Hoshizaki's & Arndt et al's analyses: $M \approx 2.15$ GeV, $\Gamma \approx 110 - 130$.**

- **Nonrelativistic πNN Faddeev calculation, Ueda (1982): $M = 2.12$ GeV, $\Gamma = 120$ MeV.**

- **Relativistic-kinematics πNN Faddeev gives $W(\mathcal{D}_{12}) \approx 2153 - \mathrm{i}65$, $W(\mathcal{D}_{21}) \approx 2167 - \mathrm{i}67$ (MeV), poles robust to variations of NN & πN input.**

- **CLAS $\gamma d \to d\pi^+\pi^-$ data [APS 04/2015] suggest $M_{BW} \approx 2.12$ GeV, $\Gamma_{BW} \approx 125$ MeV.**

$\mathcal{D}_{12}$ $N\Delta$ dibaryon search at JLab



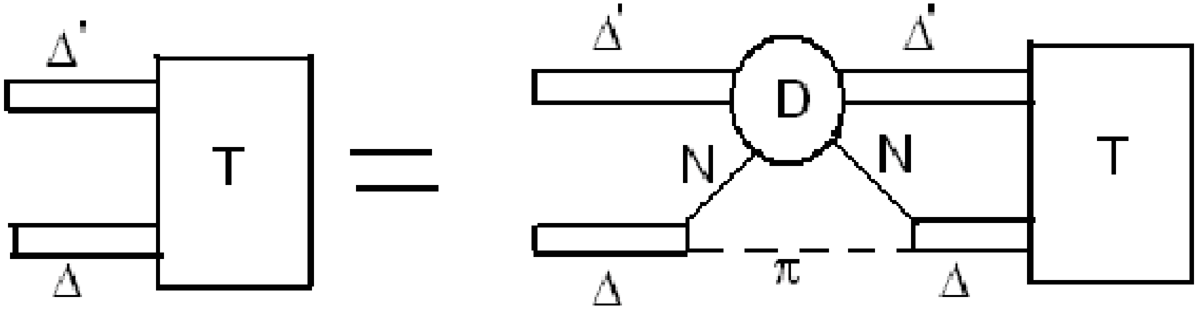
$M_{d\pi^+}$ **vs.** $M_{d\pi^-}$ **in** $\gamma d \to d\pi^+\pi^-$ **(APS 04/2015).**

Acceptance-corrected CLAS (g13) data.

Suggests $d\pi^\pm$ **correlation below** $N\Delta$ **threshold.**

Calculation of $\mathcal{D}_{03}(2380)$ $\Delta\Delta$ dibaryon in terms of π's, N's & Δ's

- **Approximate $\pi\pi NN$ problem by $\pi N\Delta'$ problem.**
- **Separable pair interactions: πN Δ-isobar form factor by fitting $\delta(P_{33})$; $N\Delta'$ $\mathcal{D}_{12}(2150)$-isobar form factor by fitting $NN(^1D_2)$ scattering.**
- **3-body S-matrix pole equation reduces to effective $\Delta\Delta'$ diagram:**



Results & Discussion

- **Using 0.9 & 1.3 fm sized P_{33} form factors: $\mathrm{M}(\mathcal{D}_{03})$=2363±20, $\Gamma(\mathcal{D}_{03})$=65±17 in good agreement with WASA@COSY.**
- **Although bound w.r.t. $\Delta\Delta$, $\mathcal{D}_{03}(2380)$ is resonating w.r.t. the $\pi-\mathcal{D}_{12}(2150)$ threshold. The subsequent decay $\mathcal{D}_{12}(2150)\to\pi d$ is seen in the πd Dalitz plot projection.**
- **NN-decoupled dibaryon resonances $\mathcal{D}_{21}$ & $\mathcal{D}_{30}$ predicted 10–30 MeV higher, respectively; see also Bashkanov-Brodsky-Clement, Novel 6q Hidden-Color Dibaryons in QCD, PLB 727 (2013) 438. Width calculation?**

Recent Quark Model Calculations

- **Orbitally symmetric [6] I(JP)=0(3+) w.f. is $\sqrt{1/5}\Delta\Delta + \sqrt{4/5}$CC. How do CC hidden-color components affect the mass & width?**
- **H. Huang et al., PRC 89 (2014) 034001, use the Salamanca chiral quark model (CQM) to go from 1→4 ΔΔ channels, then to full 10: M = 2425 → 2413 → 2393 MeV Γ=177→175→150 MeV, so Γ is too big.**
- **Y. Dong et al., PRC 91 (2015) 064002, find in CQM: M=2380 MeV, Γ=70 MeV, with 67% CC that strongly suppresses the $\mathcal{D}_{03}(2380)$ width, since pion emission will hardly occur from CC components...**

Quark-based model calculations of $\mathcal{D}_{03}$ & $\mathcal{D}_{12}$

M(GeV)	[1]	[2]	[3]	[4]	[5]	[6]	[7]	[8]	exp/phen
$\mathcal{D}_{03}$ ($\Delta\Delta$)	2.35	2.36	2.44	2.38	$\leq$2.26	2.40	2.46	2.36**	2.38
$\mathcal{D}_{12}$ ($N\Delta$)	2.16*	2.36	–	2.36	–	–	2.17	–	$\approx$2.15

1. **Dyson-Xuong, PRL 13 (1964) 815; *input **postdiction.**
2. **Mulders-Aerts-de Swart, PRD 21 (1980) 2653.**
3. **1980: Oka-Yazaki, PLB 90, 41 (2.46) Cvetic et al. 93, 489 (2.42)**
4. **Mulders-Thomas, JPG 9 (1983) 1159.**
5. **Goldman-Maltman-Stephenson-Schmidt-Wang, PRC 39 (1989) 1889.**
6. **...Zhang-Shen..., PRC 60 (1999) 045203; PRC 91 (2015) 064002.**
7. **Mota-Valcarce-Fernandez-Entem-Garcilazo, PRC 65 (2002) 034006.**
8. **Ping-Huang-Pang-Wang, PRC 79 (2009) 024001, 89 (2014) 034001.**

BOTH $\mathcal{D}_{12}$ & $\mathcal{D}_{03}$ related correctly only by [1].

Negative Quark Model Results

- A recent work by W. & A. Park & S.H. Lee, PRD 92 (2015) 014037, casts doubts on ANY low-lying compact non-strange 6q dibaryon.
- Color $\otimes$ isospin $\otimes$ spin components compatible with a [6] orbital symmetry are constructed, so hidden-color components are fully included.
- A nonrelativistic potential model is used, with $m_u = m_d = 340$ MeV & $m_s = 610$ MeV, and with two versions of color confinement plus color-spin hyperfine interaction, fitted to the baryon octet and decuplet masses, assuming narrow-width baryons.

- A variational calculation finds “no compact bound states against strong decay”.
- The I=0, S=3 compact dibaryon candidate is at least 150 MeV above the $\Delta\Delta$ threshold. Worse for other candidates, e.g. Jaffe’s $\mathcal{H}$ as (uuddss) [6] I=S=0, PRD 93 (2016) 074007.
- Hadronic-basis structure of non-strange dibaryons in terms of nucleons, Δs & pions is implied for low-lying dibaryons.
- Physical thresholds & p-wave pion emission must be realistically incorporated in future dibaryon calculations.

Strange & charmed dibaryons

$\mathcal{S}$ = -2, -3, -4 deuteron-like $8_F \times 8_F$ dibaryons?

	$\Sigma\Sigma$ $(I=2, {}^1S_0)$	$\Lambda\Xi$ $(I=\frac{1}{2}, {}^1S_0)$	$\Sigma\Xi$ $(I=\frac{3}{2}, {}^1S_0)$	$\Sigma\Xi$ $(I=\frac{3}{2}, {}^3S_1)$	$\Xi\Xi$ $(I=1, {}^1S_0)$
NSC97	+	−	+	+	+
EFT (LO)	−	+	+	−	+
EFT (NLO)	−	−	−	−	−

NSC97: V.G.J. Stoks, T.A. Rijken, Phys. Rev. C **59** (1999) 3009

EFT (LO): J. Haidenbauer, U.-G. Meißner, Phys. Lett. B **684** (2010) 275

EFT (NLO): JH, UGM, S. Petschauer, Eur. Phys. J. A **51** (2015) 17

- Based on ≈40 Λp, Σp, $\Xi^- p$ low-energy data points.
- Systematics of EFT (LO): The $\mathcal{S} = -3, -4$ sectors require only the 5 LECs determined in the YN sector fit, independently of the 6th LEC required in the $\mathcal{S} = -2$ sector (this LEC is consistent with zero). Hence get PREDICTIONS.
- ${}^1S_0$ in SU(3)$_{\rm f}$ **27** (as nn), ${}^3S_1$ in SU(3)$_{\rm f}$ $\overline{\mathbf{10}}$ (as deuteron).
- Model dependence is assessed by varying a cutoff momentum in the range 550 – 700 MeV/c. **SU(3) breaking aborts binding at NLO.**

Color Magnetic (CM) gluon exchange interaction

For orbitally symmetric $L = 0$ color-singlet n-quark cluster:

$$V_{CM} \approx \sum_{i<j} -(\lambda_i \cdot \lambda_j)(s_i \cdot s_j)\mathcal{M}_0 \rightarrow [-\frac{n(10-n)}{4} + \Delta\mathcal{P}_{\rm f} + \frac{S(S+1)}{3}]\mathcal{M}_0$$

where $\mathcal{M}_0 \sim 75$ MeV, $\mathcal{P}_{\rm f} = \pm 1$ for any symmetric/antisymmetric flavor pair, $\Delta\mathcal{P}_{\rm f}$ means with respect to the SU(3)$_{\rm f}$ **1** antisymmetric representation of n quarks, $n = 3$ for a baryon (B) and $n = 6$ for BB.

For $n = 6$, SU(3)$_{\rm f}$ **1** [2,2,2] is Jaffe's $\mathcal{H}(uuddss)$ [PRL 38 (1977) 195]:

$$\mathcal{H} \sim \mathcal{A}[\sqrt{1/8}\ \Lambda\Lambda + \sqrt{1/2}\ N\Xi - \sqrt{3/8}\ \Sigma\Sigma,]_{I=S=0}$$

$$< V_{CM} >_{\mathcal{H}} -2 < V_{CM} >_{\Lambda} = -2\mathcal{M}_0$$

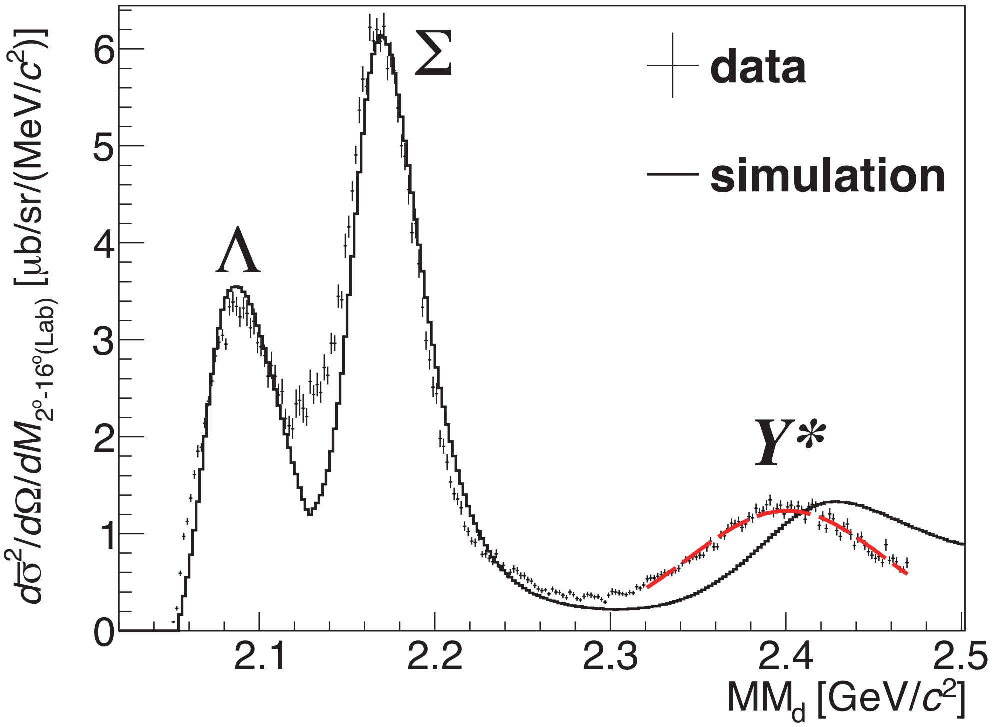
$$\text{where} \quad 4\mathcal{M}_0 = < V_{CM} >_{\Delta} - < V_{CM} >_{N} \sim M_{\Delta} - M_N \approx 300 \text{ MeV}$$

Leading dibaryon candidates: Oka, PRD 38 (1988) 298

$\mathcal{S}$	SU(3)$_\mathrm{f}$	I	J^π	BB structure	$\Delta < V_{CM} >$
0	[3,3,0] $\overline{\mathbf{10}}$	0	3^+	$\mathcal{D}_{03}\ (\Delta\Delta)$	0
-1	[3,2,1] **8**	1/2	2^+	$\sqrt{1/5}\ (N\Sigma^* + 2\ \Delta\Sigma)$	$-\mathcal{M}_0$
-2	[2,2,2] **1**	0	0^+	$\mathcal{H} = \sqrt{1/8}\ (\Lambda\Lambda + 2\ N\Xi - \sqrt{3}\ \Sigma\Sigma)$	$-2\mathcal{M}_0$
-3	[3,2,1] **8**	1/2	2^+	$\sqrt{1/5}\ [\sqrt{2}\ N\Omega - (\Lambda\Xi^* - \Sigma^*\Xi + \Sigma\Xi^*)]$	$-\mathcal{M}_0$

- **A bound $\mathcal{H}$ overbinds ${}^{6}_{\Lambda\Lambda}$He [Gal, PRL 110 (2013) 179201]. SU(3)$_\mathrm{f}$ breaking pushes it to $\approx N\Xi$ threshold, 26 MeV above $\Lambda\Lambda$ threshold [HAL QCD, NPA 881 (2012) 28; Haidenbauer & Meißner, ibid. 44].**
- **$N\Omega$ dibaryon: HAL QCD, Nucl. Phys. A 928 (2014) 89.**
- **Let's focus on $\mathcal{S}=-1$.**

J-PARC E27 $d(\pi^+, K^+)$ missing-mass spectrum



Y* quasi-free peak shifted by ≈−22 MeV, indicating Y*N attraction [Y* = Σ(1385) & Λ(1405)].

2 dibaryons below K$^-$pp? (i) deep Σ*N, E27 (ii) shallow Λ*N, E15 (Iwasaki).

$\Lambda(1405)N$ & $\Sigma(1385)N$ dibaryons?

- $\Lambda(1405)N$ **is a doorway to an I=1/2, J^P=0$^-$** $\bar{K}NN$**, found quasibound in all calculations. Its lower components are** $\pi\Lambda N$ **and** $\pi\Sigma N$**, but** $\pi\Lambda N$ **cannot support any strongly attractive meson-baryon s-wave interaction.**
- **The** $\pi\Lambda N$ **system can benefit from strong meson-baryon** p**-wave interactions fitted to** $\Delta(1232) \to \pi N$ **and** $\Sigma(1385) \to \pi\Lambda$ **form factors. Maximize isospin and angular momentum couplings by full alignment: I=3/2, J^P=2$^+$, Good example of a Pion Assisted Dibaryon, not Oka's I=1/2, J^P=2$^+$ CM-based candidate.**
  Gal-Garcilazo, NPA 897 (2013) 167 & Refs. therein.

- **A $\pi\Lambda N - \pi\Sigma N$ resonance about 10–20 MeV below the $\pi\Sigma N$ threshold is found by solving coupled-channel Faddeev equations. The resonance energy is sensitive to the pion-baryon p-wave form factors.**

- **Expect doorway states $\Sigma(1385)N$ and $\Delta(1232)Y$, the lower of which is $\Sigma(1385)N$ with I=3/2, J^P=2$^+$. These are different from I=1/2, J^P=0$^-$ assigned to $\Lambda(1405)N$, viewed as a doorway to $\bar{K}NN$.**

- **Adding a $\bar{K}NN$ channel does not help, because the leading $^3S_1$ NN configuration is Pauli forbidden.**

- **Search for this $\mathcal{Y}$ dibaryon at GSI & J-PARC in:**
  $p + p \rightarrow \mathcal{Y}^{++} + K^0$, $\mathcal{Y}^{++} \rightarrow \Sigma^+ + p$,
  or $\pi^+ + d \rightarrow \mathcal{Y}^{++} + K^0$, $\mathcal{Y}^{++} \rightarrow \Sigma^+ + p$.

- **A (π^+, K^+) reaction as in E27 would lead to YN decay states similar to those expected in searches of K^-pp. Another possibility at J-PARC or GSI is:**
  $\pi^- + d \rightarrow \mathcal{Y}^- + K^+$, $\mathcal{Y}^- \rightarrow \Sigma^- + n$.

Summary

- **The two experimentally established nonstrange dibaryons $\mathcal{D}_{12}(2150)$ & $\mathcal{D}_{03}(2380)$ are derived quantitatively with long-range hadronic physics guidelines using pions, nucleons & Δs input.**
- **Search for NN-decoupled $\mathcal{D}_{21}$ & $\mathcal{D}_{30}$ dibaryons.**
- **Develop EFT description for these dibaryons.**
- **Does $\Sigma(1385)$ play the role of $\Delta(1232)$ for strange dibaryon candidates?**
  $\Sigma(1385)N$ ($I=\frac{3}{2},2^+$) vs. $\Lambda(1405)N$ ($I=\frac{1}{2},0^-$).
- **Charmed dibaryons?**
  $\pi\Lambda_c N$ ($I=\frac{3}{2},2^+$) Gal..., PRD 90 (2014) vs.
  DNN ($I=\frac{1}{2},0^-$) ...Oset, PRC 86 (2012)].