Possible hadron physics
To be done
With use of unstable nuclei

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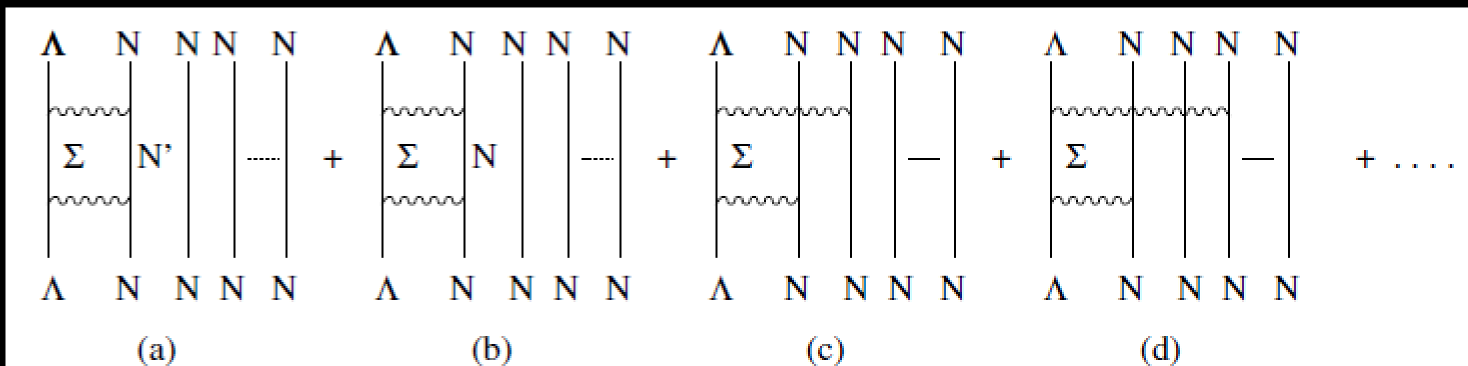
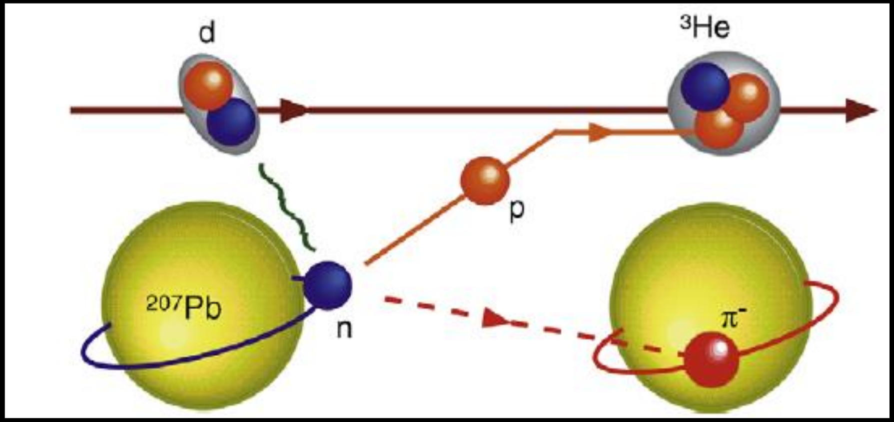
J. Phys. G (2002)

Coherent Λ–Σ^0 mixing in high-density neutron matter

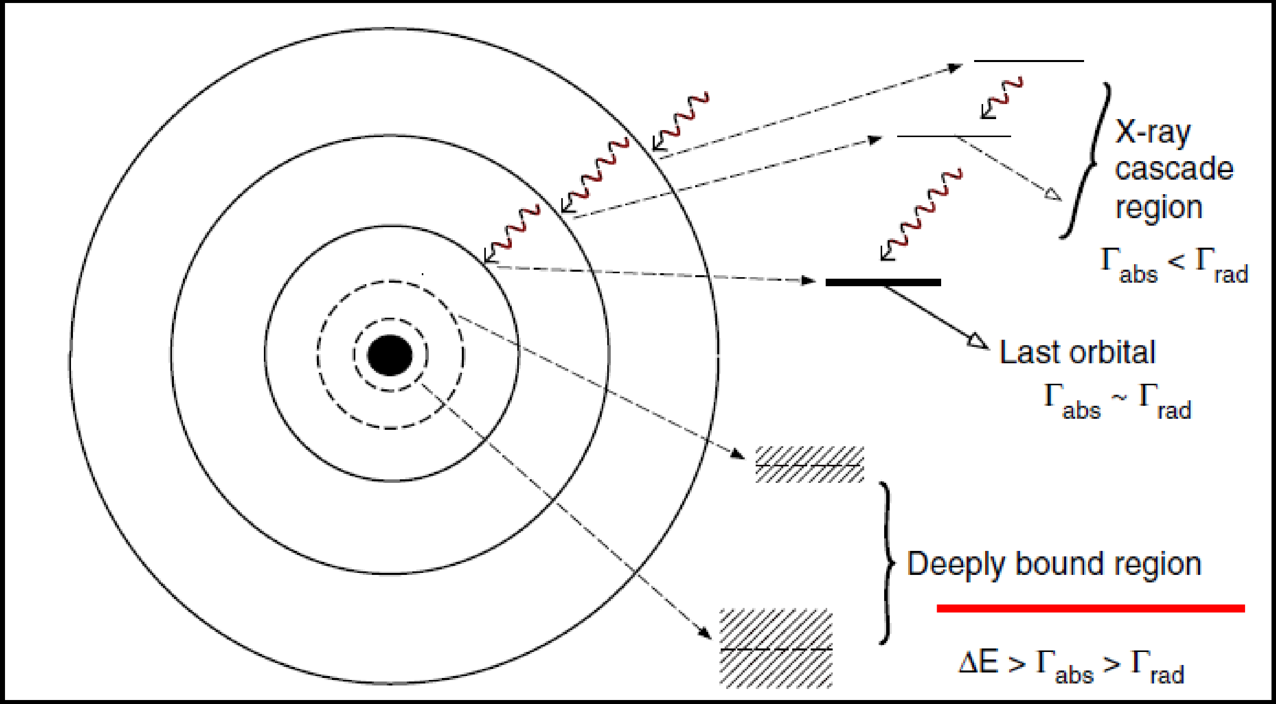
S Shinmura[1], Khin Swe Myint[2], T Harada[3] and Y Akaishi[4]



Discovery of deeply boud pionic atom(1996); T.Yamazaki et al, ZPA (1996),
As predicted by Hirenzaki, Toki and Yamazaki, PRC (1991).

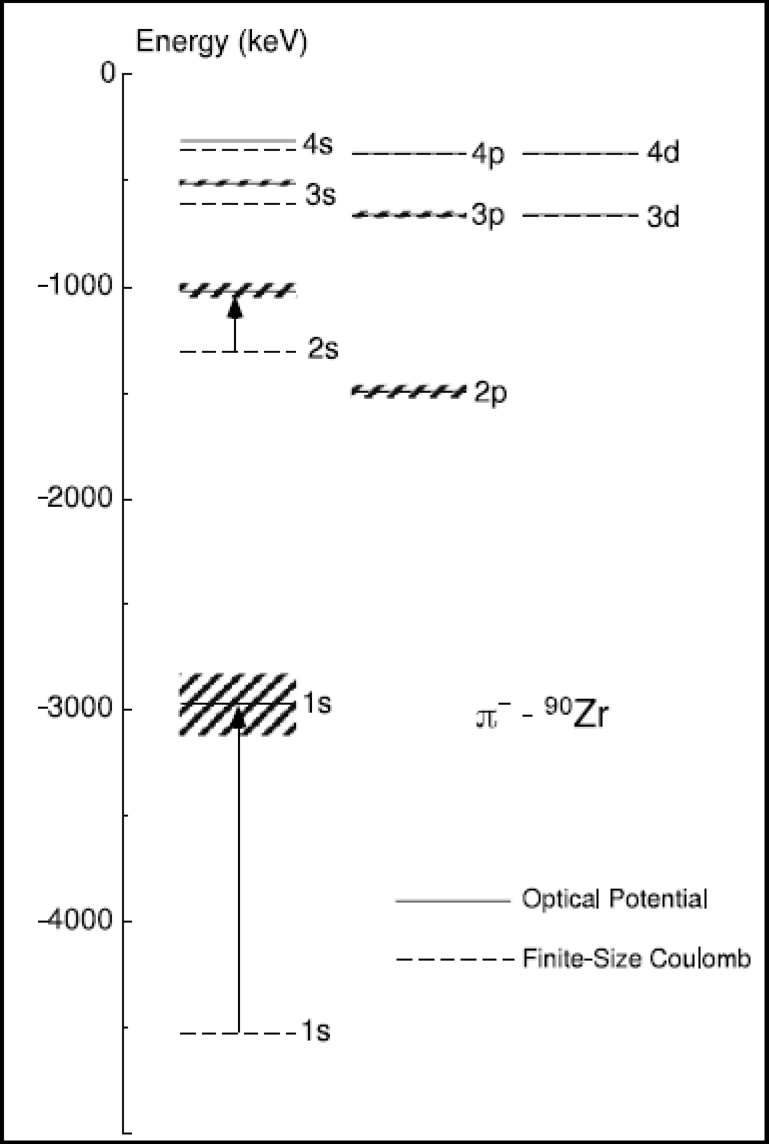


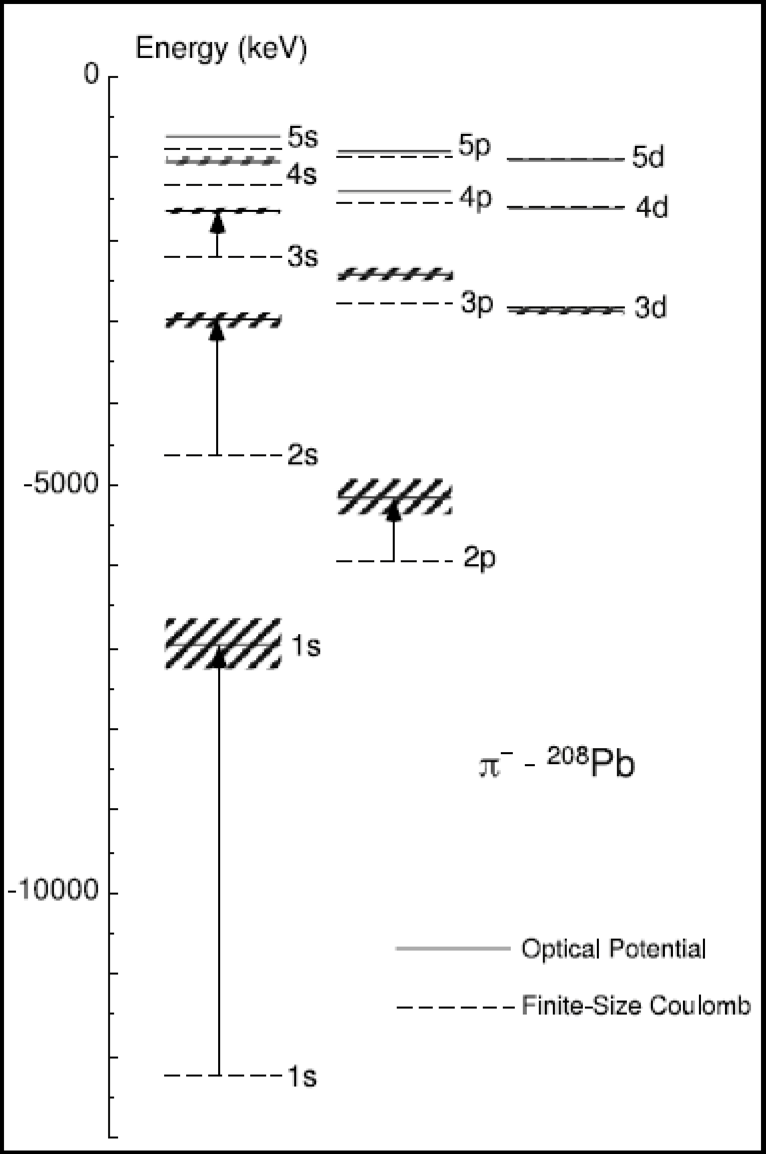
$(d,{}^{3}He)$ @GSI

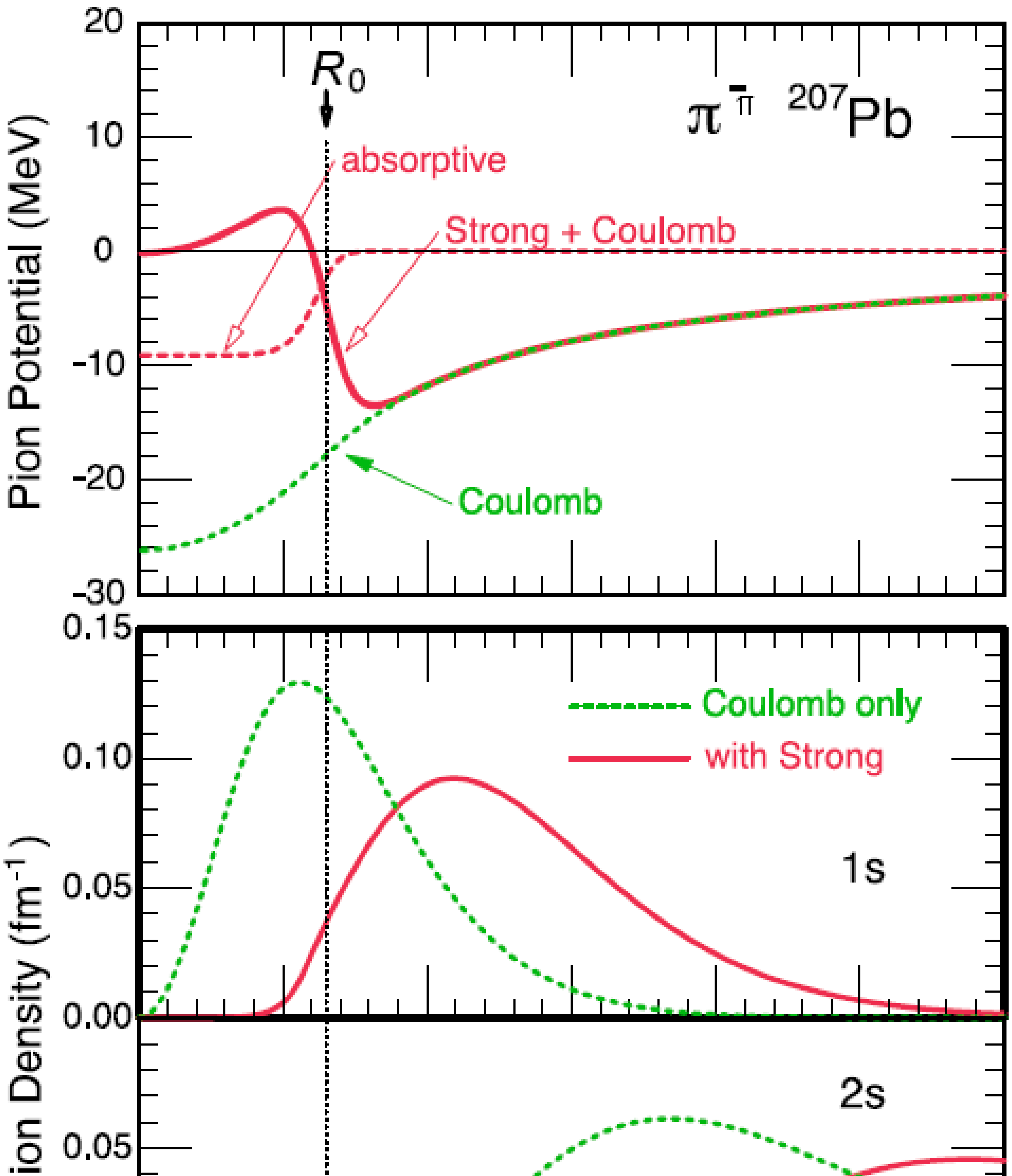


T.Yamazaki,S.Hirenzaki,R.S.Hayano and H.Toki, Phys.Rep.514(2012),1

Enhanced repulsion of pi-N interaction in s-wave







Atractive Coulom
+
Repulsive pi-N int.

``Coulomb-assisted pionic Nuclei"

Localized around the surface of the nucleus,i.e.,

``halo-type bound states"

T.Yamazaki,S.Hirenzaki ,R.S.Hayano and H.Toki, Phys.Rep.514(2012),1

Deeply bound pionic atom/nuclei and in-medium chiral condensate

- An enhanced repulsion due to Tomozawa-Weinberg term b_1^* as characterized by the reduced in-medium pion decay constant f^*_π :

$$T^{(+)} = \frac{1}{2}(T_{\pi^- p} + T_{\pi^- n}) \equiv 4\pi\varepsilon_1 b_0 = 0$$

$$T^{(-)} = \frac{1}{2}(T_{\pi^- p} - T_{\pi^- n}) \equiv -4\pi\varepsilon_1 b_1 = \frac{\omega}{2f_\pi^2}$$

s-wave optical potential for π^- reads

Kolomeitsev-Kaiser-Weise, PRL90 (2003)

$$2m_\pi U_s = -4\pi\left[1 + \frac{m_\pi}{m_N}\right](b_0^*(\rho)\rho - b_1^*(\rho)\delta\rho)$$

$$= -\mathcal{T}^{(+)*}(\omega = m_\pi; m_\pi)\rho - \mathcal{T}^{(-)*}(\omega = m_\pi; m_\pi)\delta\rho$$

$$\mathcal{T}^{(-)*}(\omega; 0) \simeq \frac{\omega}{2(F_\pi^t)^2}$$

$$\frac{b_1}{b_1^*} = \left(\frac{F_\pi^t}{F_\pi}\right)^2$$

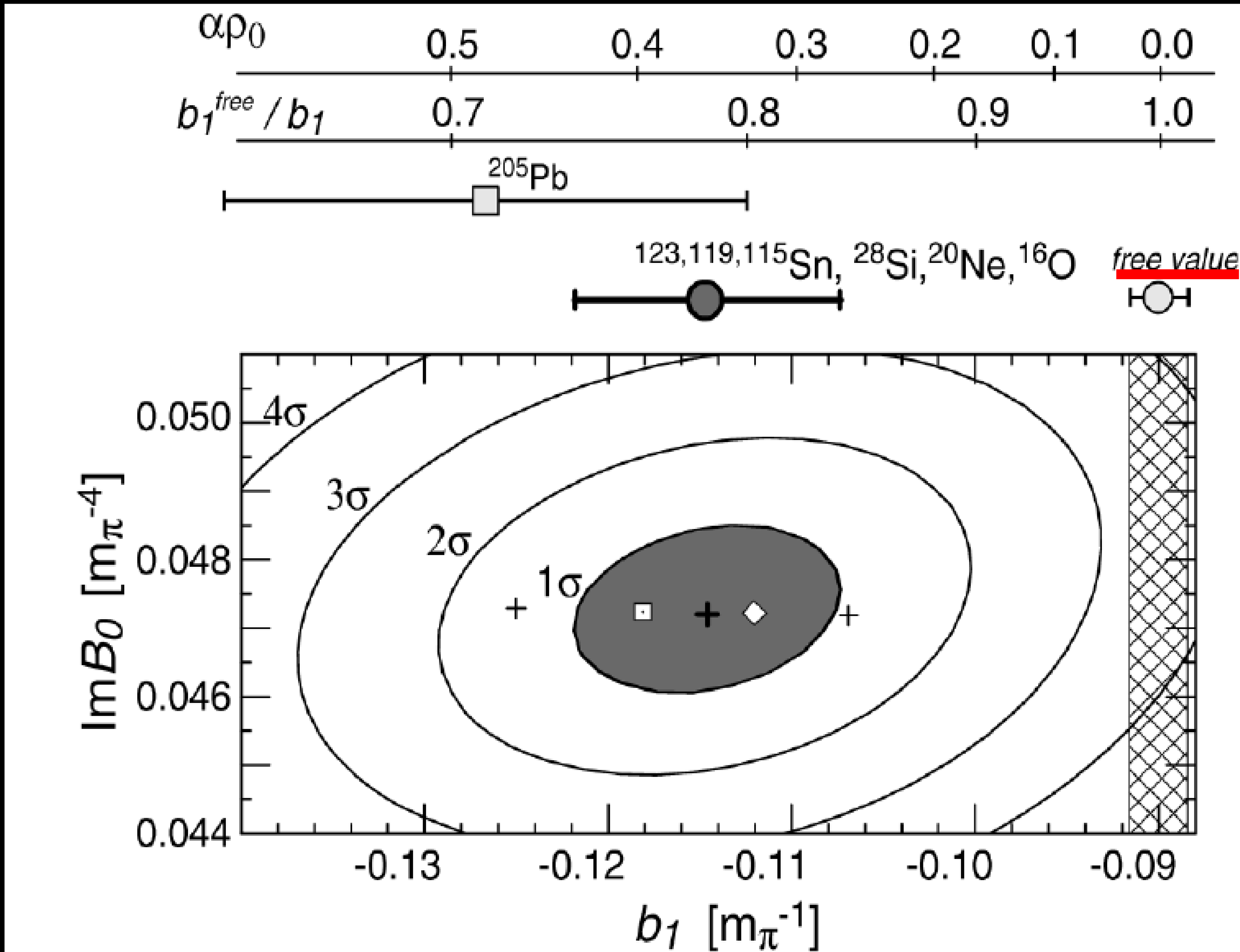
which can be related to that of the chiral condensate directly as

$$\frac{\langle\bar{q}q\rangle^*}{\langle\bar{q}q\rangle} \approx \left(\frac{b_1}{b_1^*}\right)^{1/2}\left(1 - \gamma\frac{\rho}{\rho_0}\right)$$

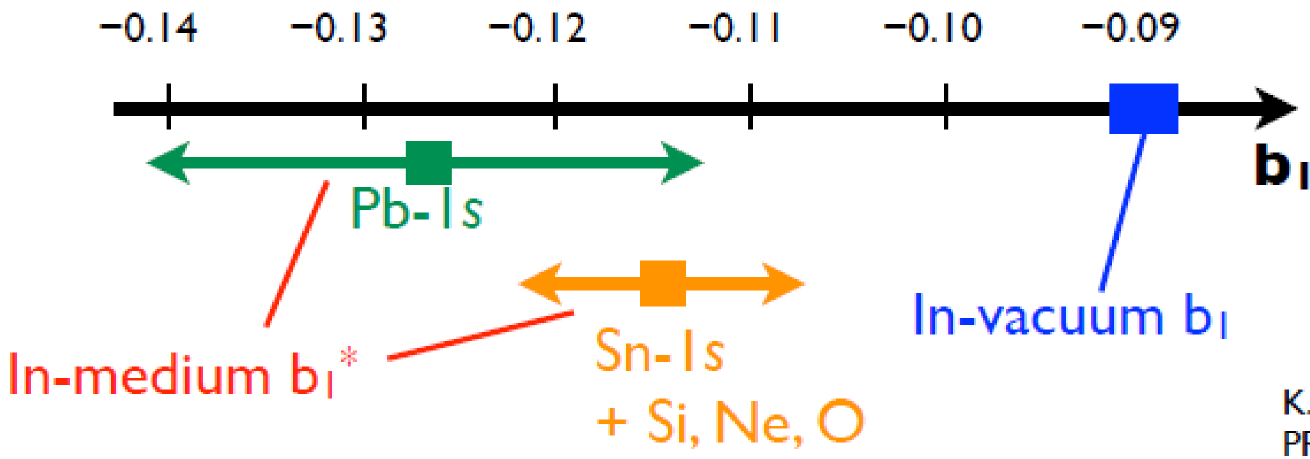
Jido,Hatsuda and TK, PLB670(2008))

QCD vacuum may be effectively changed and chiral symmetry is partially restored even at density lower than the normal nuclear density in finite nuclei!

K.Suzuki et al, PRL92 (2004), 072302



Present b_I precision



K. Suzuki et al., PRL92(04)072302.

b_I^* still has a large error

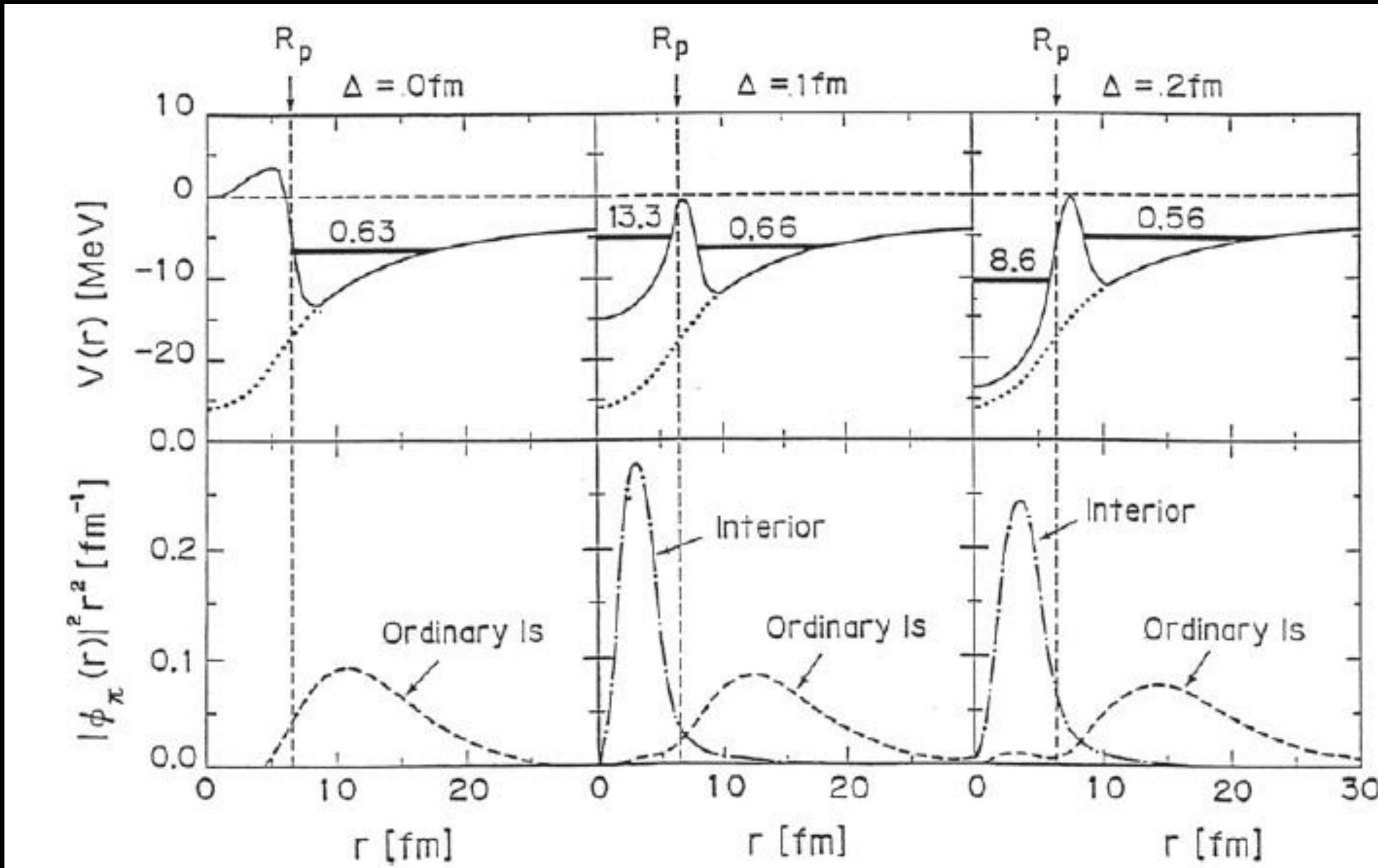
$$V_{s\text{-wave}} = b_0\,\rho + b_I\,(\rho_n - \rho_p) + B_0\,\rho^2$$

← spectroscopy of pionic atoms

In-medium b_I is calculated based on deeply bound pionic states data combined with light spherical pionic atom data.

Neutron skin dependence of pion w-f.

T. Yamazaki et al, Phys. Rep.514 (2012)



In-medium $\eta \rightarrow 3\pi$ decay

S.Sakai and T.K., PTEP(2015), (2016)

Possible effects of isospin asymmetry on hadron decay in nuclear medium

○ $\eta \rightarrow 3\pi$ ($\pi^+\pi^-\pi^0$, $3\pi^0$) decay (in free space)

✓ Isospin-symmetry breaking in QCD (*u*-*d* quark mass difference)

- G parity violating process (η:even,π:odd)

※ Small QED corrections (Sutherland(1966), Baur et al.(1996), Ditsche et al.(2009))

⇨ Small decay width (~70 eV from current algebra)

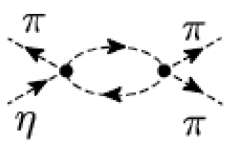
Osborn and Wallace (1970)

✓ Final-State Interaction among π ← Significance of σ (s-wave 2π) channel

- Perturbative approach

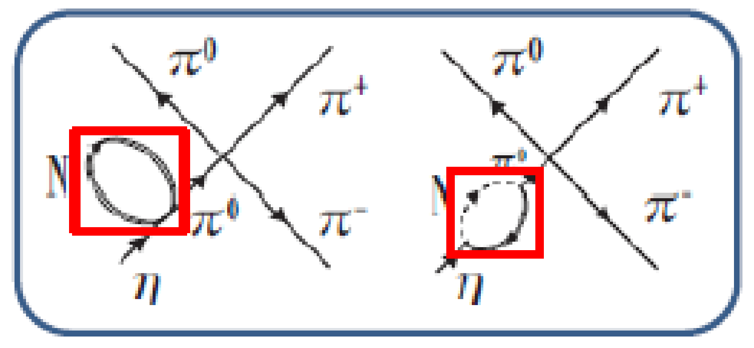
  Chiral perturbation theory: Gasser and Leutwyler(1985),Bijnens and Ghorbani(2007)

  Ex.)

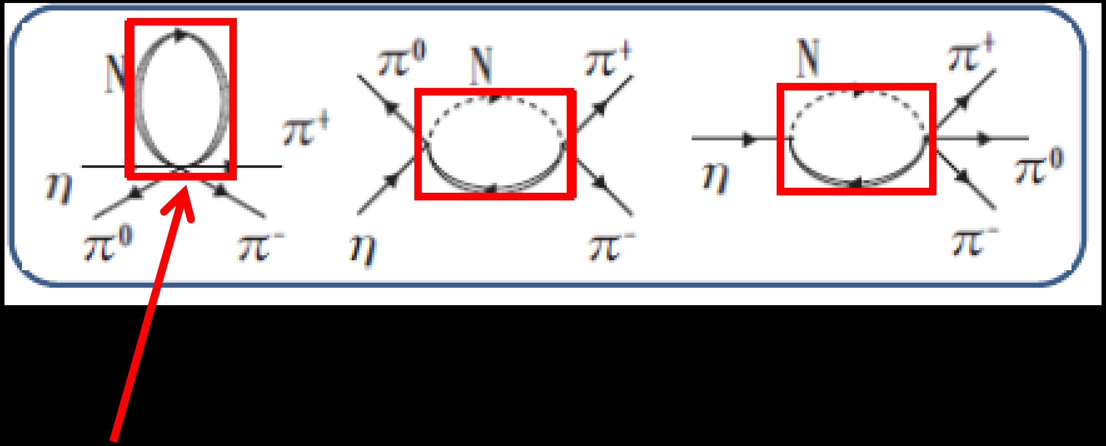


- Non-perturbative approach
  - Chiral Unitary approach (resummation scheme): Borasoy and Nissler(2005)
  - Dispersive approach (Roiesnel and Truong(1981), Kambor et al.(1996), Anisovich and Leutwyler(1996),...)

Modification of the mixing angle in the asymmetric nuclear medium



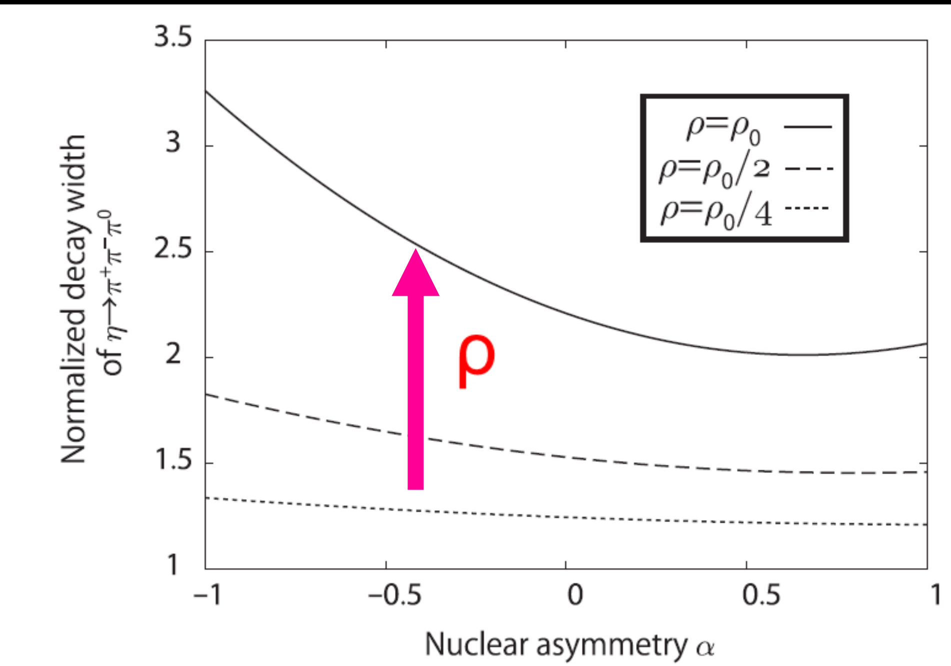
Vertex corrections in the (asymmetric) nuclear medium

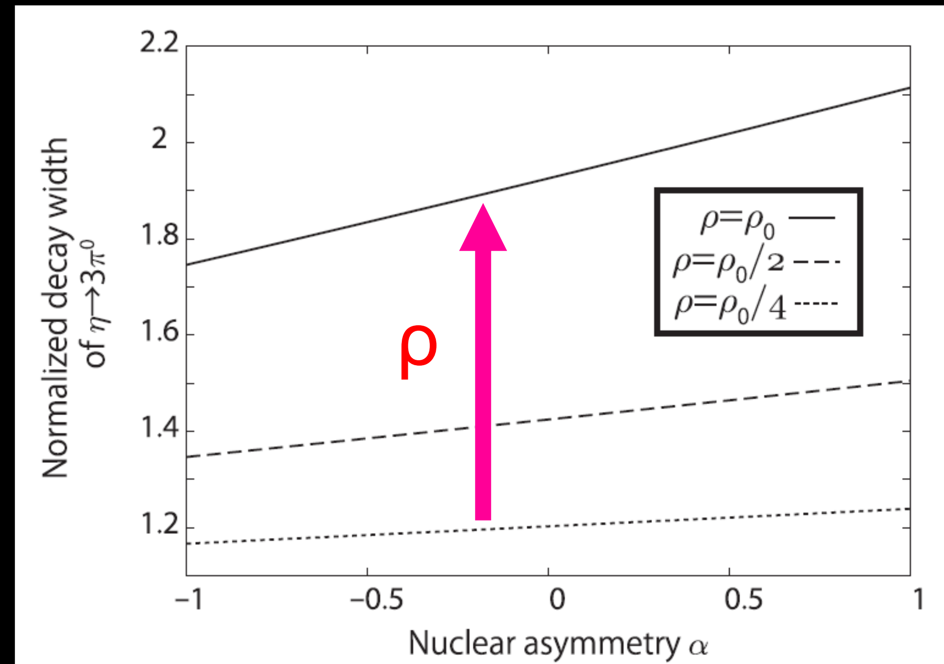


ρ **-dependent**

Charged decay

Neutral decay





$$\alpha \equiv \delta\rho/\rho \qquad \delta\rho = \rho_n - \rho_p$$

Isospin asymmetry of the nuclear medium does affect the η-→3π decay, but the total density dependence overwhelms it, which is caused by the Enhancement in the sigma channel and can reflect the partial restoration of the chiral symmetry.

S.Sakai, TK, PTPEP (2015), (2016)

$\eta \to \pi^0\pi^+\pi^-$ decay width in nuclear medium

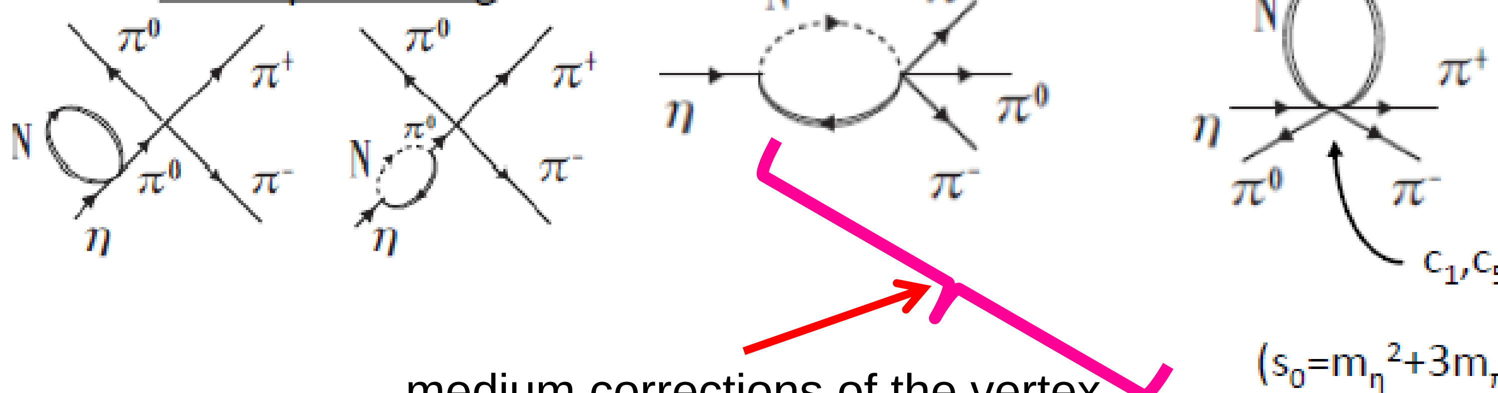
Result of calculation

$$\mathcal{M}_{\eta\to\pi^0\pi^+\pi^-} = -\frac{m_1^2}{3\sqrt{3}f^2}\left(1+\frac{3(s-s_0)}{m_\eta^2-m_{\pi^0}^2}\right)+\sin\theta^{(0)}\mathcal{M}^{(4)\mathrm{vac}}_{\eta\to\pi^0\pi^+\pi^-}$$

$$+\left\{-\frac{\delta\rho}{f^2}\frac{s-s_0}{m_\eta^2-m_{\pi^0}^2}\left(\frac{g_A^2 m_\eta^2}{4\sqrt{3}f^2}+\frac{2c_5 m_\pi^2}{\sqrt{3}f^2}\right)\right\}-\frac{4c_1{}_1^2}{3\sqrt{3}f^4}\frac{3(s-s_0)}{m_\eta^2-m_{\pi^0}^2}$$

$$+\left(\frac{g_A^2}{48\sqrt{3}f^4}(m_\eta-E_{\pi^0})-\frac{2c_5 m_\pi^2}{3\sqrt{3}f^4}\right)\delta\rho-\frac{4c_1\rho}{f^2}\frac{m_1^2}{3\sqrt{3}f^2}$$

From η-π^0 mixing



medium corrections of the vertex

$(s_0 = m_\eta^2 + 3m_\pi^2)$