Non-mesonic weak decay of the hypertriton in effective field theory

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Akademie věd
České republiky

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Outline

1. Hypertriton:

Particle content: Λ+n+p

Separation energy: B=130±50 KeV

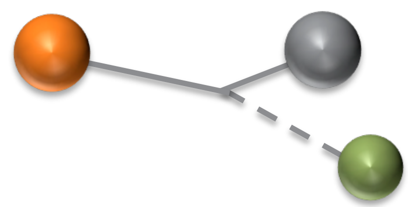
Smaller life time than Λ (?)

Spin=1/2

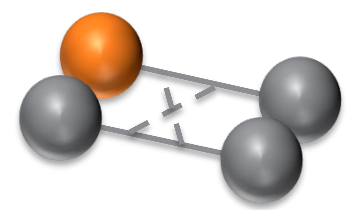
At least ~10%
(talks of Saito, and of
4c: Rappold, Piano, Xu)

2. Main weak decay modes:

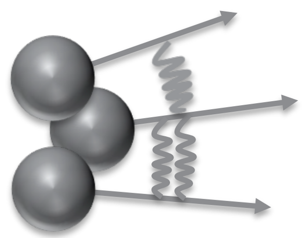
mesonic Λ→Nπ



Non-mesonic ΛN→NN

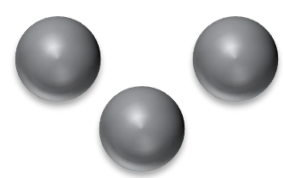


3. Strong final state interactions (current work)

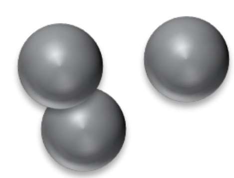


4. Decay products:

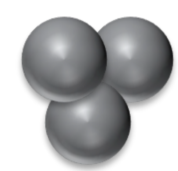
3N



d+n



^{3}H, ^{3}He

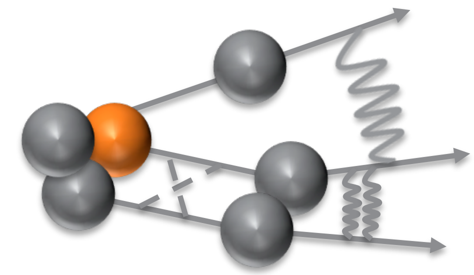


Previous work with OME potentials:
Golak et al., PRC56 (1997), 2892

ΛN→NN EFT in hypernuclei

$$\Gamma^{3N} = \frac{128}{9}\pi^3 M_N \sum_{m_{J_3}} \sum_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \int dp_{12}\, p_{12}^2 p_3^{(3N)} \int d\theta \sin(\theta)$$

$$\times \left| \left\langle \Psi_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \right| \left(1 + V_s \frac{1}{E + i\epsilon - H}\right) (1+P) V_{12}^w \left| \psi_{{}^3_\Lambda H} \right\rangle \right|^2$$



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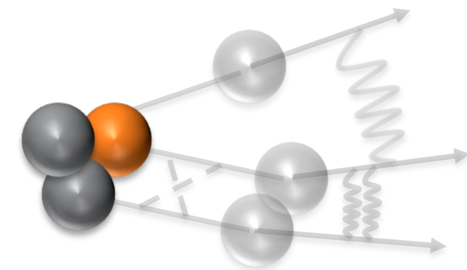
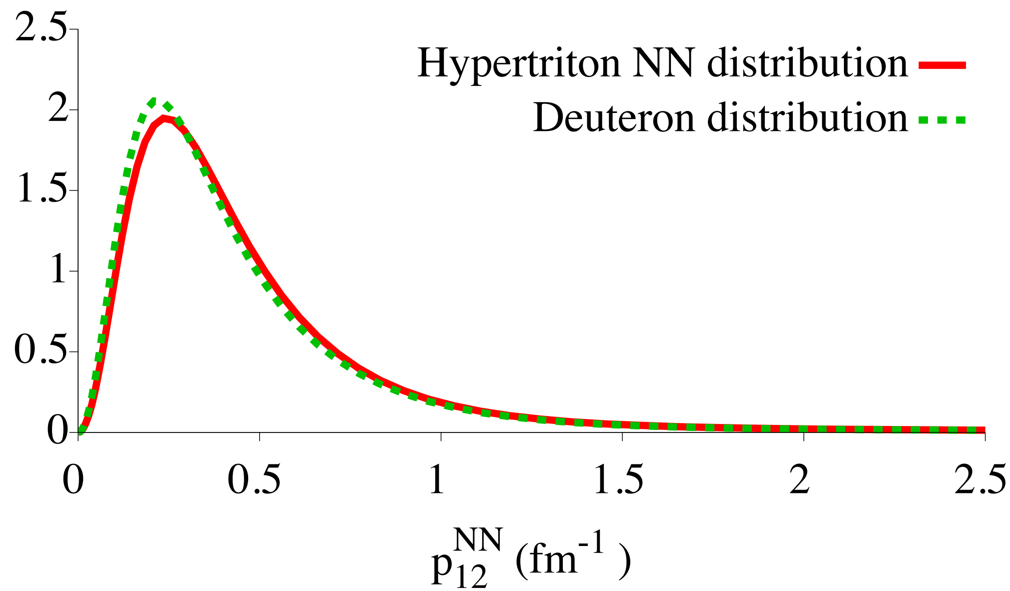


NLO YN and NN strong EFT potentials

H. Polinder, J. Haidenbauer, U.G. Meissner, NPA, 779, 244-266, 2006



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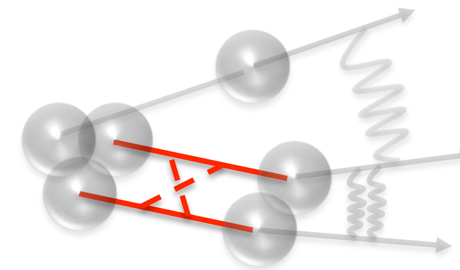

$V_{\Lambda N \to NN}$ and $V_{\Sigma N \to NN}$ calculated with EFT:

- Separation of scales: soft (m_π, q≈400 MeV) and hard (m_N)
- Relevant degrees of freedom: π, K, N, Λ , Σ (q=400 MeV)
- Symmetries: chiral, discrete (PV)

Recent baryon-baryon EFTs

Weak BB: J.-H. Jun (2001); A. Parreño, C. Bennhold, B.R. Holstein (2004); Zhu, S.-lin, C.M. Maekawa, B.R. Holstein, U.V. Kolck (2005).
Strong YN: J. Haidenbauer, Ulf-G. Meiβner, H. Polinder (2006).
Strong NN: R. Machleidt, D.R. Entem (2011); E. Epelbaum, H. Hammer, Ulf-G. Meiβner (2009).

ΛN→NN EFT in hypernuclei

$$\Gamma^{3N} = \frac{128}{9}\pi^3 M_N \sum_{m_{J_3}} \sum_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \int dp_{12}\, p_{12}^2 p_3^{(3N)} \int d\theta \sin(\theta)$$

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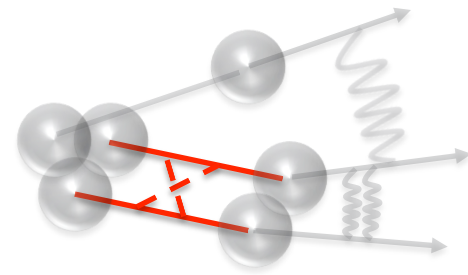
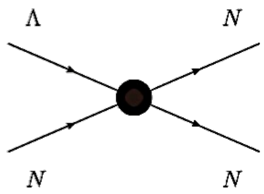


LO:



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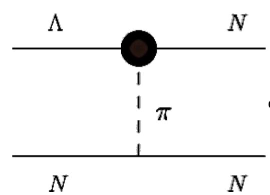

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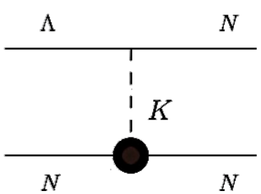


- Contact potential at LO
- LECs must be fixed by the experiment

$$V_{4P}(\vec{q}) = C_{00} + C_{01}(\vec{\sigma}_1 \cdot \vec{\sigma}_2)$$

Constraints on LO LECs: PRC84, 024606 (2011)

- Weak vertices: phenomenological Lagrangians

$$L_W^{\Delta S=1} = -iG_F m_\pi^2 \overline{\psi}_N (A_\Lambda + B_\Lambda \gamma_5) \vec{\tau} \cdot \vec{\phi}_\pi \psi_\Lambda \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

- Strong vertices: strong chiral Lagrangians
- OME potentials:

$$V_\mu(\vec{q}) = -G_F m_\pi^2 \frac{g_{BB\mu}}{2\bar{M}_S} \left(\hat{A}_\mu - \frac{\hat{B}_\mu}{2\bar{M}_W} \vec{\sigma}_1 \cdot \vec{q} \right) \frac{\vec{\sigma}_2 \cdot \vec{q}}{-q_0^2 + \vec{q}^2 + m_\mu^2}$$

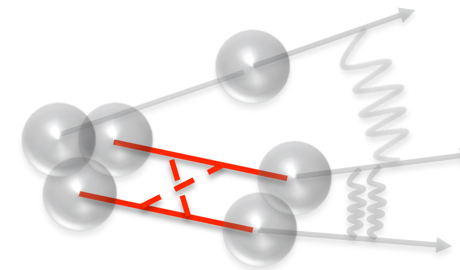
with $\mu = \pi, K$; $\hat{A}_\pi = A_\pi \vec{\tau}_1 \cdot \vec{\tau}_2$, $\hat{B}_\pi = B_\pi \vec{\tau}_1 \cdot \vec{\tau}_2$,

$$\hat{A}_K = \frac{C_K^{PV}}{2} + D_K^{PV} + \frac{C_K^{PV}}{2} \vec{\tau}_1 \cdot \vec{\tau}_2, \quad \hat{B}_K = \frac{C_K^{PC}}{2} + D_K^{PC} + \frac{C_K^{PC}}{2} \vec{\tau}_1 \cdot \vec{\tau}_2$$

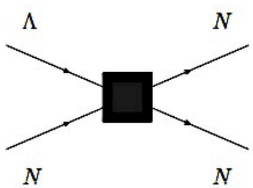
ΛN→NN EFT in hypernuclei

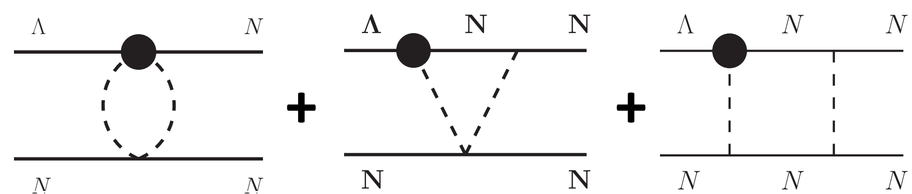
$$\Gamma^{3N} = \frac{128}{9}\pi^3 M_N \sum_{m_{J_3}} \sum_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \int dp_{12}\, p_{12}^2 p_3^{(3N)} \int d\theta \sin(\theta)$$

$$\times \left| \left\langle \Psi_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \right| \left(1 + V_s \frac{1}{E + i\epsilon - H}\right) (1+P) V_{12}^{w} \left| \psi_{{}^3_\Lambda H} \right\rangle \right|^2$$



NLO:



+  + (…)

- Neglecting initial momenta reduces the number of LECs

$$V_{4P}(\vec{q}) = C_{00} + C_{01}(\vec{\sigma}_1 \cdot \vec{\sigma}_2)$$
$$+ C_{10}\frac{\vec{\sigma}_1 \vec{q}}{2M_N} + C_{11}\frac{\vec{\sigma}_2 \vec{q}}{2M_N} + \mathrm{i}\, C_{12}\frac{(\vec{\sigma}_1 \times \vec{\sigma}_2)\,\vec{q}}{2M_N}$$
$$+ C_{20}\frac{\vec{\sigma}_1 \vec{q}\, \vec{\sigma}_2 \vec{q}}{4M_N^2} + C_{21}\frac{\vec{\sigma}_1 \vec{\sigma}_2\, \vec{q}^{\,2}}{4M_N^2} + C_{22}\frac{\vec{q}^{\,2}}{4M_N^2}$$

- Dimensional regularization
- Many more structures
- Mass differences M_Λ-M_N, M_Σ-M_N considered

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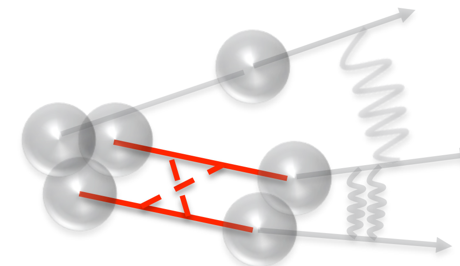
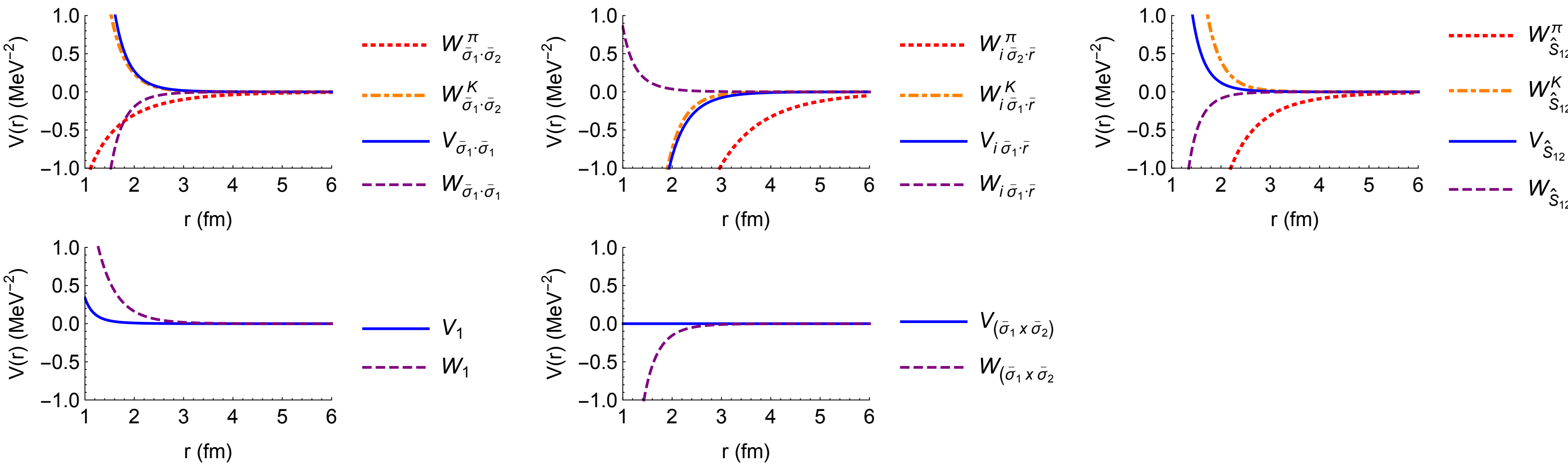


Legend: π, K, 2π (1) , 2π (τ·τ)



- $(\vec r \cdot \vec p)$, $\vec\sigma_1 \cdot (\vec r \times \vec p)$ and other structures give much smaller contributions
- Fourier transform + Dispersion relations **T. Ericson, W. Weise, Pions and Nuclei (Oxford, 1988)**

ΛN→NN EFT in hypernuclei

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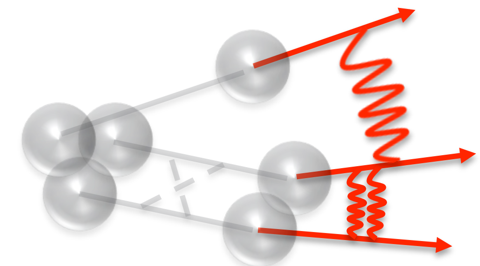

Rescattering state |U>

1. Solve 2-body force: $(1 + t_{12}G_0)(1 - V_{12}G_0) = 1$

2. Find iterative equation, $G = G_0 + G_0 V G$

$$\begin{aligned} |U\rangle = & t_{12}G_0(1+P)V^w|\phi_{^3_\Lambda H}\rangle + (1+t_{12}G_0)V_{123}^{(3)}G_0(1+P)V^w|\phi_{^3_\Lambda H}\rangle \\ & + t_{12}G_0 P|U\rangle + (1+t_{12}G_0)V_{123}^{(3)}G_0(1+P)|U\rangle \end{aligned}$$

ΛN→NN EFT in hypernuclei

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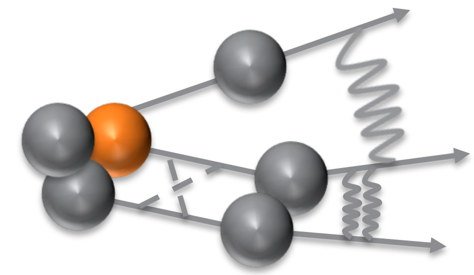

- $\Gamma_{3N} \sim 10\Gamma_{d+n}$
- K destructive interference

	$\Gamma_{d+n}\ (s^{-1})$	$\Gamma_{3N}\ (s^{-1})$
π	$0.54 \cdot 10^7$	$0.57 \cdot 10^8$
π+K	$0.15 \cdot 10^7$	$0.18 \cdot 10^8$

ΛN→NN EFT in hypernuclei

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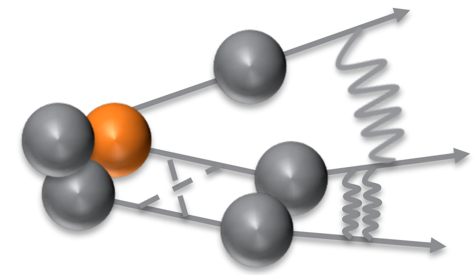
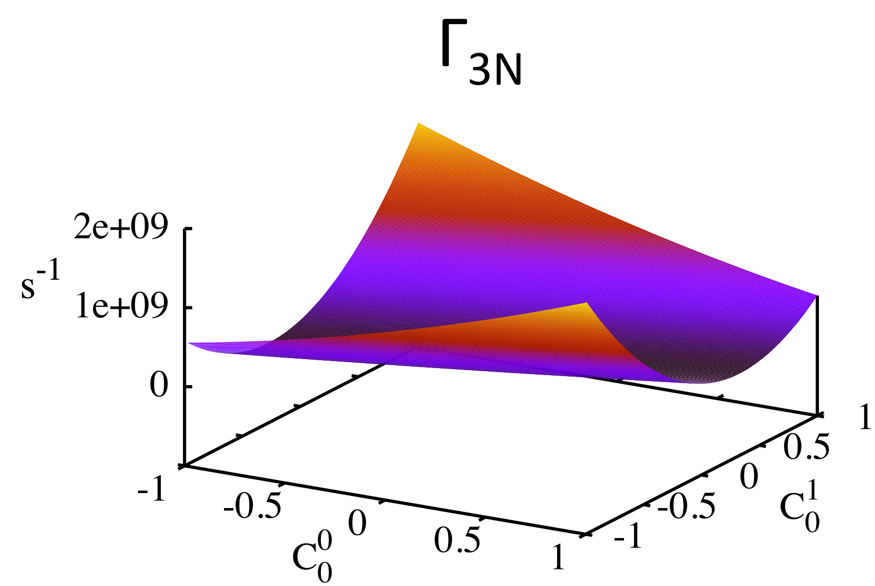


- **Exploring the parameter space**
- **LECs with opposite signs interfere constructively**



Summary
& Conclusions

Thanks

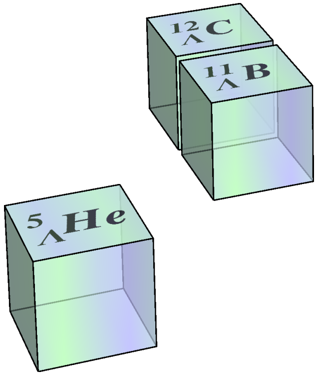
The hypertriton can be studied with precise few-body techniques. Its weak non-mesonic decay has been studied complementing exact wave functions obtained solving Faddeev equations with the leading order piece of the weak $\Lambda N \rightarrow NN$ transition

We have developed an EFT for the two-body $\Lambda N \rightarrow NN$ transition driving the decay of hypernuclei.

The 2π exchange mechanism has been incorporated sistematically in the EFT. It has a sizeable effect at medium and short ranges and should play an important role once more experimental data are available.

Due to the lack of experimental data we have explored the decay rate as a function of the two low-energy constants appearing at leading order.

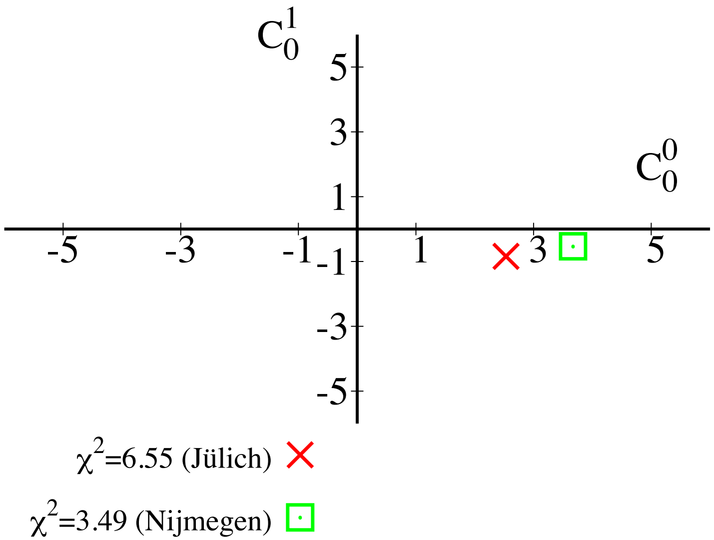
Current and future work:
-explore the effect of final state interactions and the Σ contribution.
-extend the work to mesonic decays and to A=4 hypernuclei.

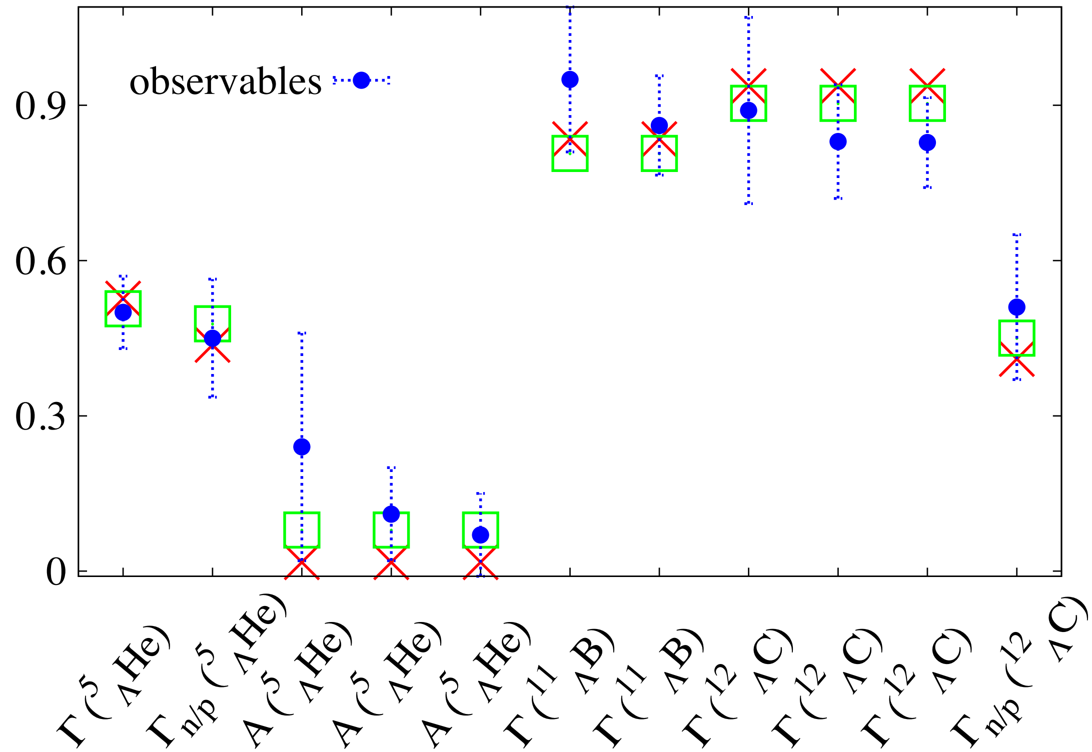


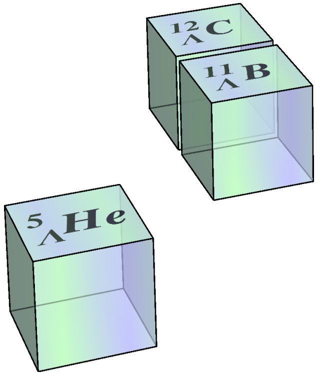
ΛN→NN EFT in hypernuclei

LO LECs fit to the data

contact+π



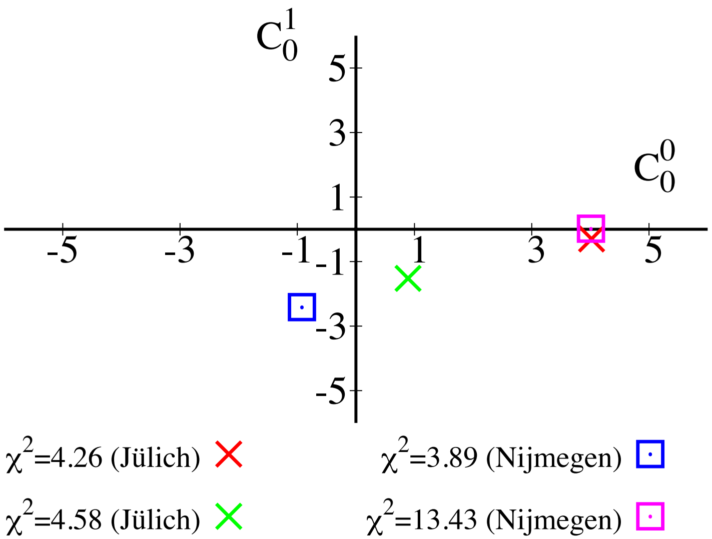


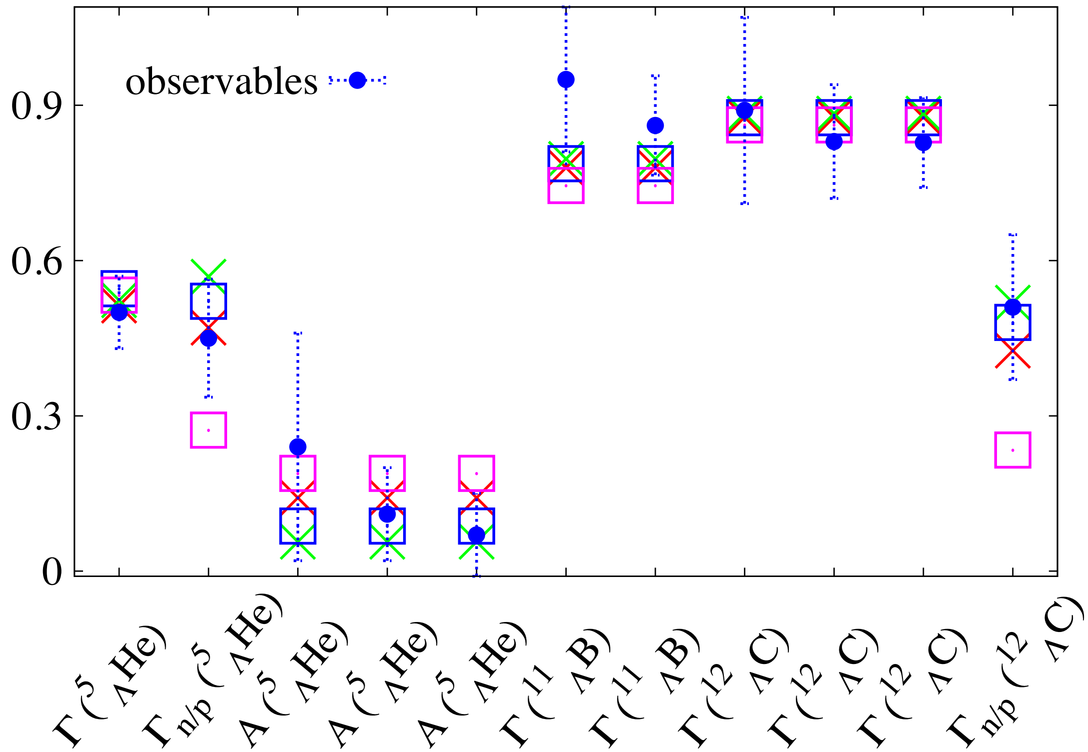


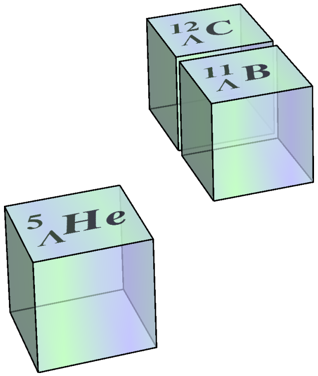
ΛN→NN EFT in hypernuclei

LO LECs fit to the data

contact+π+K



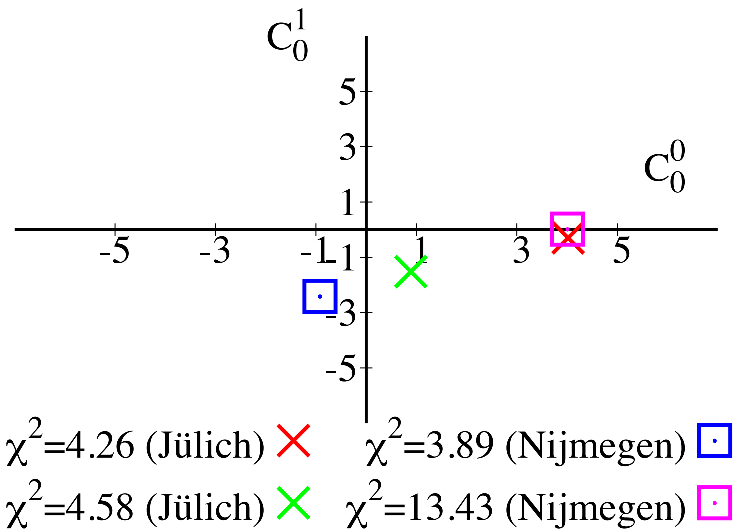


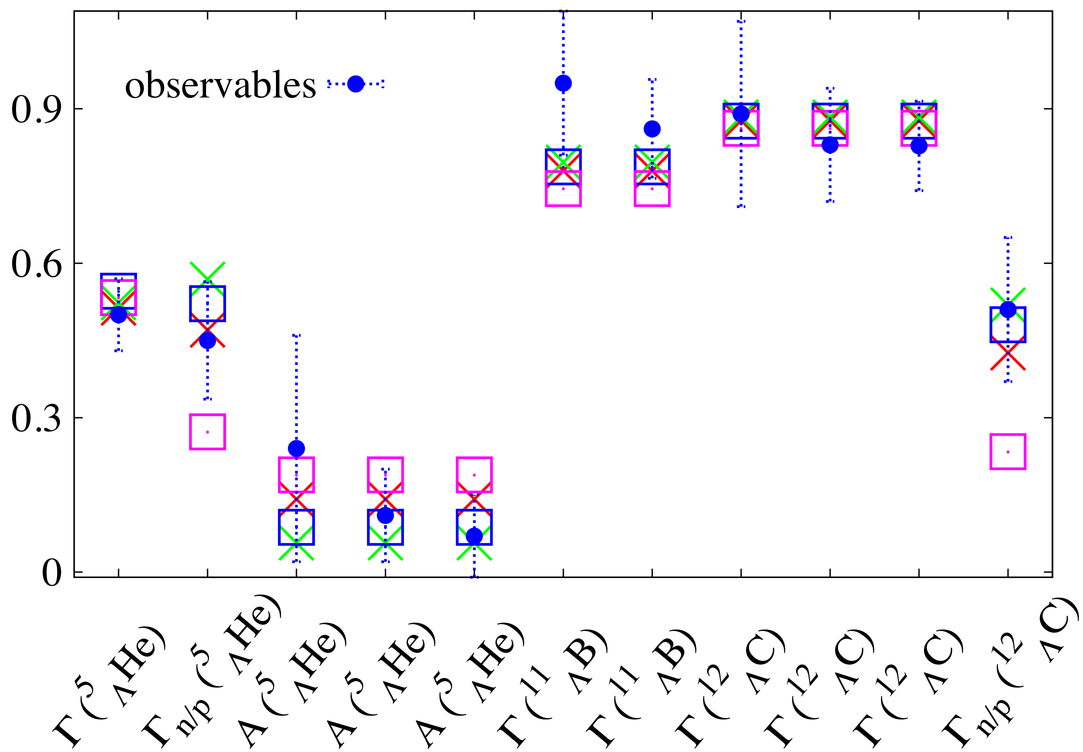


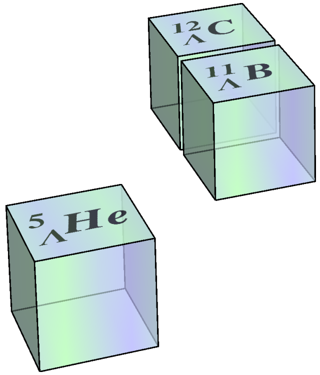
ΛN→NN EFT in hypernuclei

LO LECs fit to the data

α=0.36 fm (π+K+X)



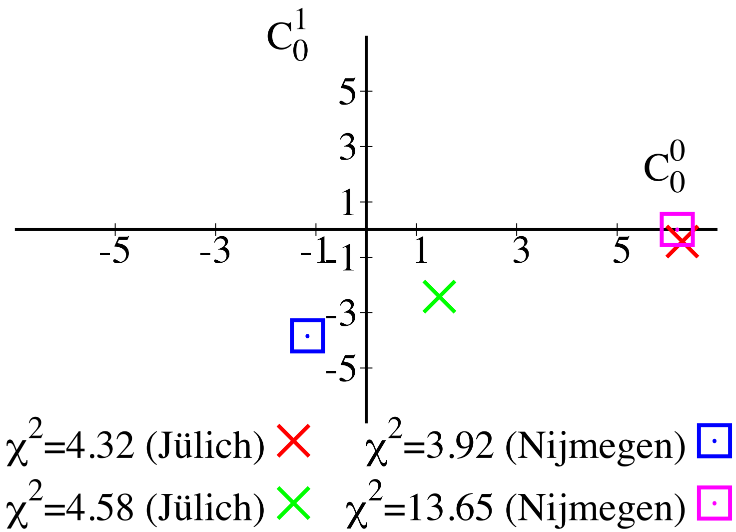


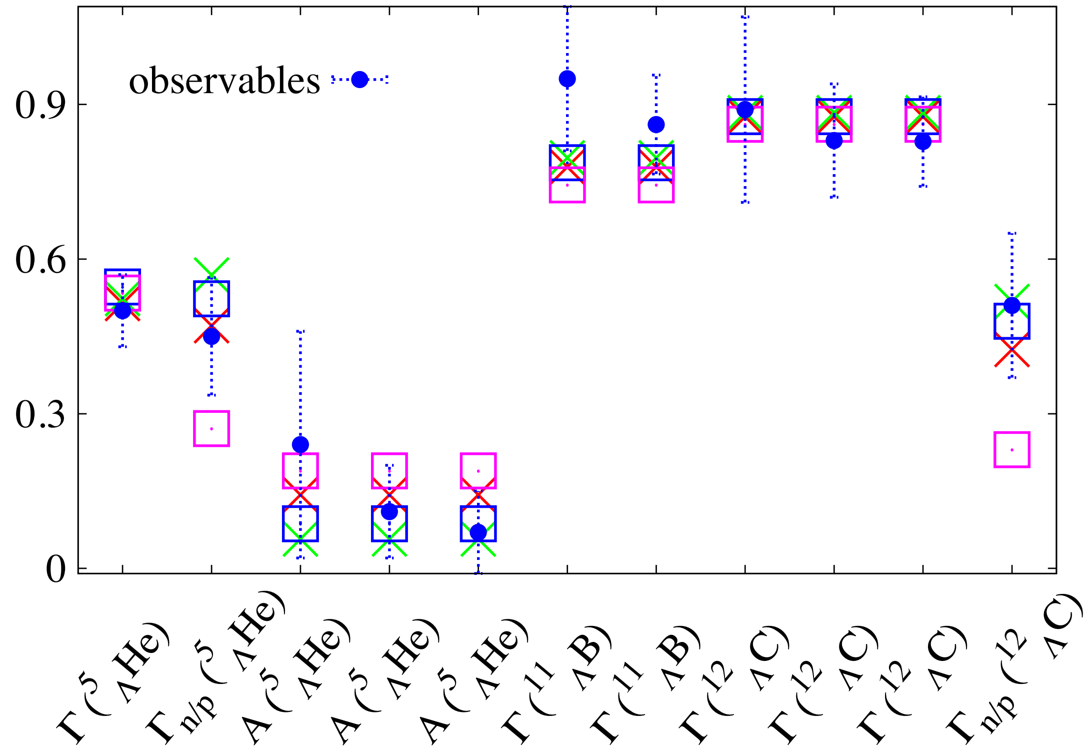


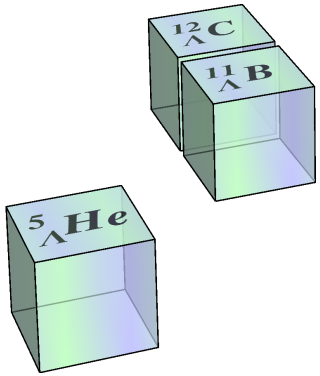
$\Lambda N \rightarrow NN$ EFT in hypernuclei

LO LECs fit to the data

α=0.30 fm (π+K+X)



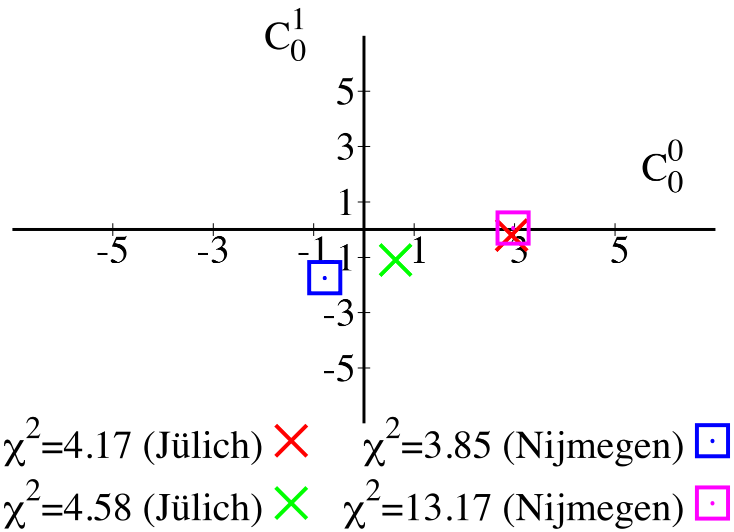


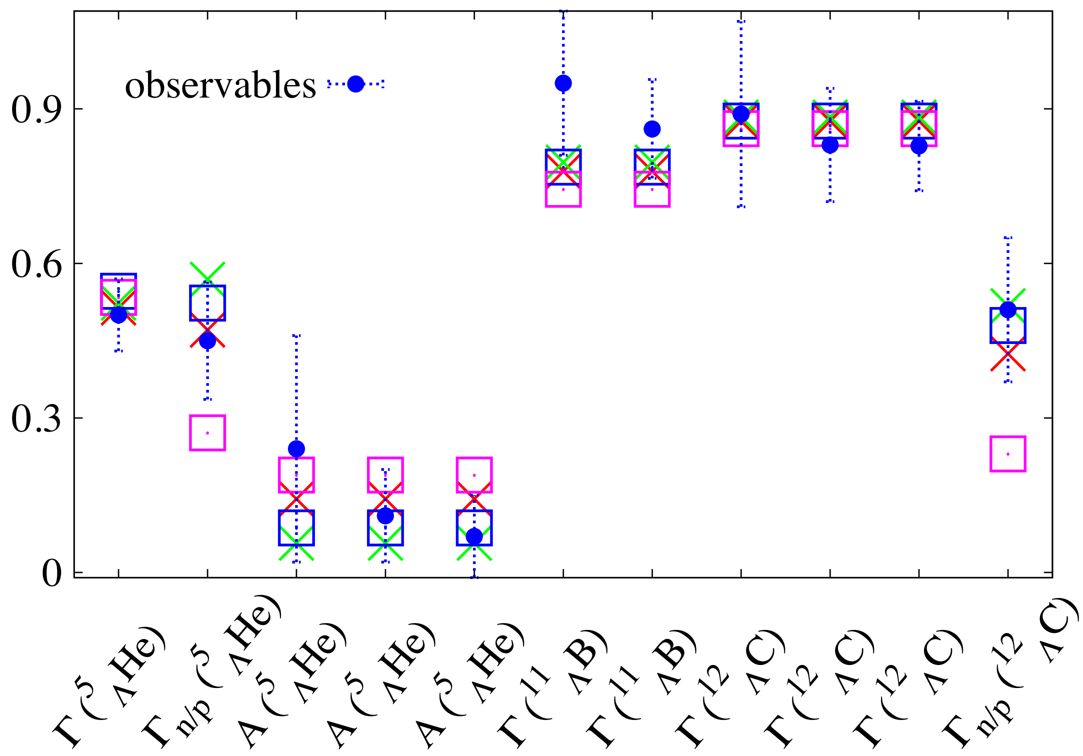


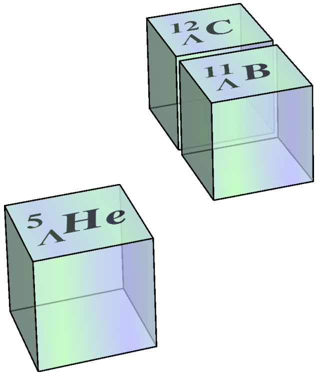
ΛN→NN EFT in hypernuclei

LO LECs fit to the data

α=0.42 fm (π+K+X)

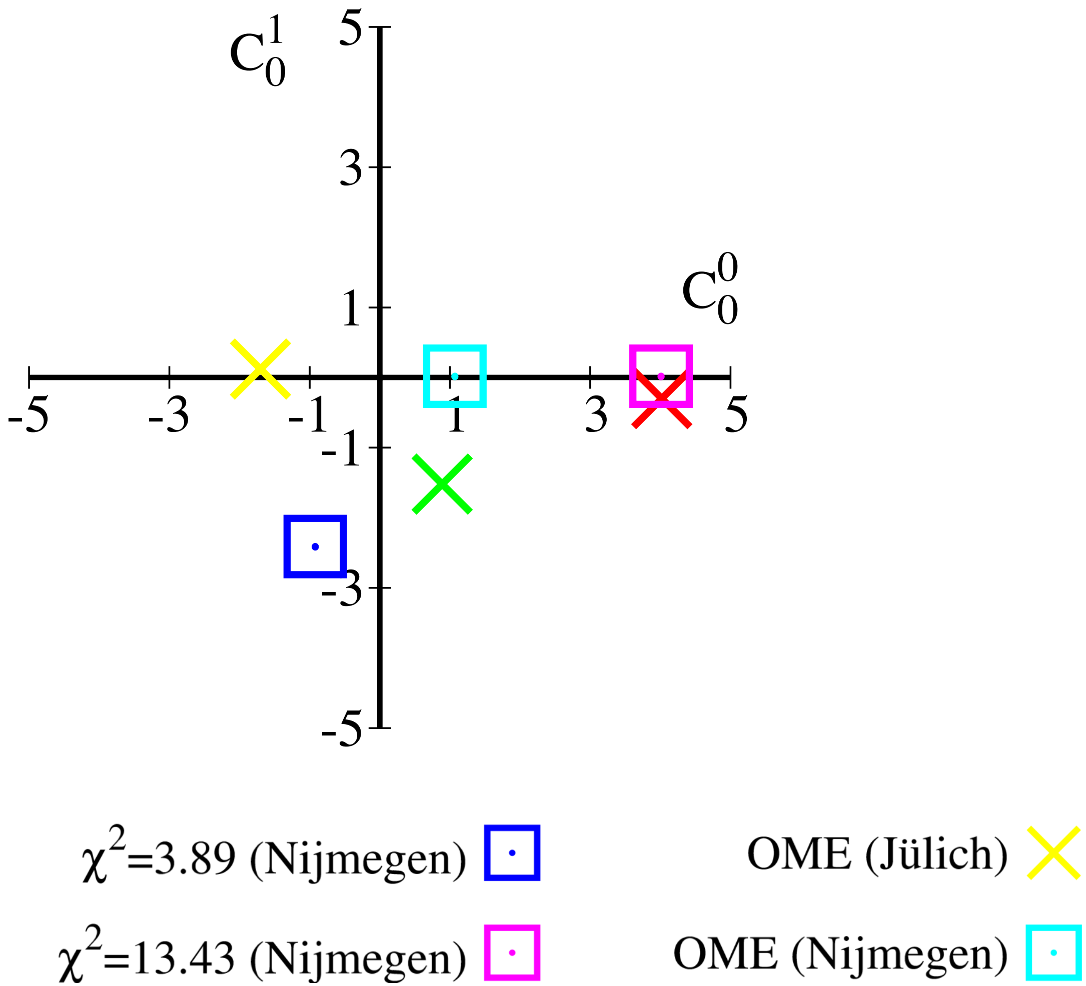






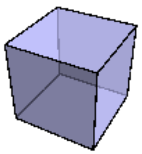
ΛN→NN EFT in hypernuclei

EFT fits and OME

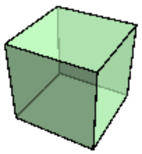


Non-mesonic weak decay of hypernuclei

Experimental measurements:

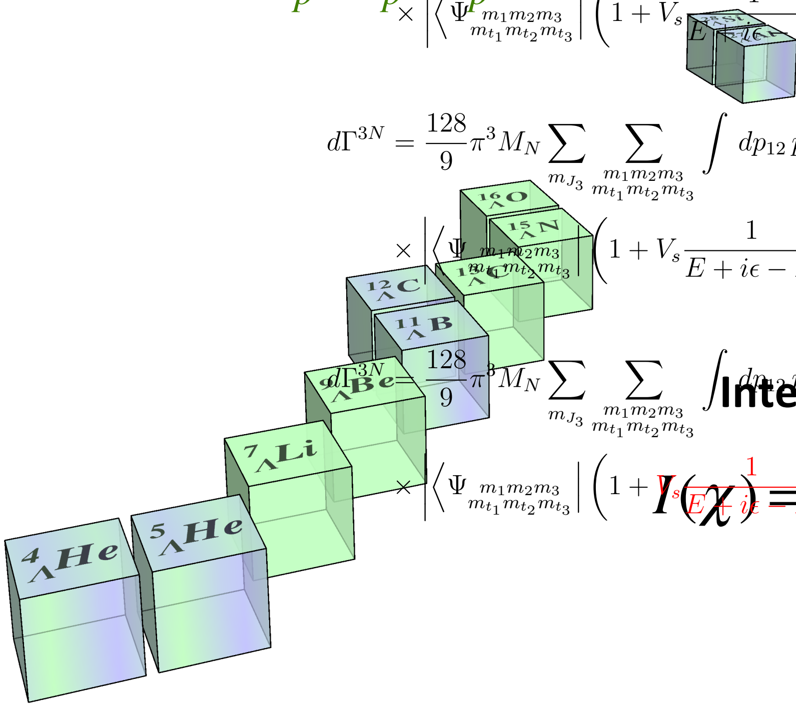


τ_{nm}



$N_n(T_n, \theta_n)$

$N_p(T_p, \theta_p)$



Theoretical descriptions:

$$d\Gamma^{3N} = \frac{128}{9}\pi^3 M_N \sum_{m_{J_3}} \sum_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \int dp_{12}\, p_{12}^2 p_3^{(3N)} \int d\theta \sin(\theta) \times \left| \left\langle \Psi_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \right| \left(1 + V_s \frac{1}{E + i\epsilon - H}\right)(1+P) V_{12}^w \left| \psi_{{}^3_\Lambda H} \right\rangle \right|^2$$

$$\Gamma_{nm} = \Gamma_n + \Gamma_p = \frac{1}{\tau_{nm}}$$

$$d\Gamma^{3N} = \frac{128}{9}\pi^3 M_N \sum_{m_{J_3}} \sum_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \int dp_{12}\, p_{12}^2 p_3^{(3N)} \int d\theta \sin(\theta) \times \left| \left\langle \Psi_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \right| \left(1 + V_s \frac{1}{E + i\epsilon - H}\right)(1+P) V_{12}^w \left| \psi_{{}^3_\Lambda H} \right\rangle \right|^2$$

$$\frac{\Gamma_n}{\Gamma_p} = \frac{1}{2}\left(\frac{N_n^w}{N_p^w} - 1\right) \sim \frac{1}{2}\left(\frac{N_n}{N_p} - 1\right)$$

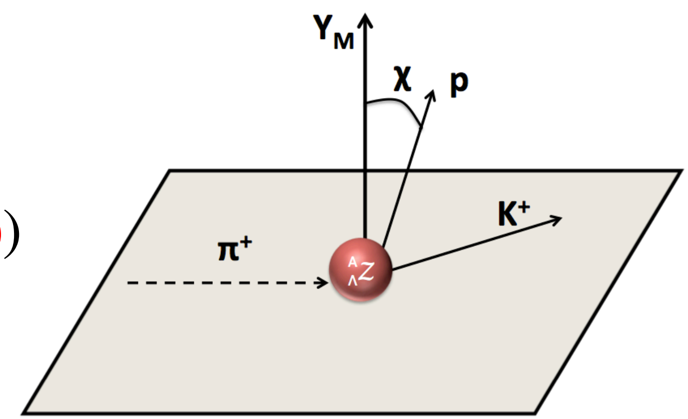
$$d\Gamma^{3N} = \frac{128}{9}\pi^3 M_N \sum_{m_{J_3}} \sum_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \int dp_{12}\, p_{12}^2 p_3^{(3N)} \int d\theta \sin(\theta) \times \left| \left\langle \Psi_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \right| \left(1 + V_s \frac{1}{E + i\epsilon - H}\right)(1+P) V_{12}^w \left| \psi_{{}^3_\Lambda H} \right\rangle \right|^2$$

$$A_p(\chi) = \frac{3}{J+1} \frac{\sum_{M_i} I(M_i) M_i}{\sum_{M_i} I(M_i)} \cos(\chi) \sim \frac{N_p^+ - N_p^-}{N_p^+ + N_p^-}$$

$$d\Gamma^{3N} = \frac{128}{9}\pi^3 M_N \sum_{m_{J_3}} \sum_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \int dp_{12}\, p_{12}^2 p_3^{(3N)} \int d\theta \sin(\theta) \times \left| \left\langle \Psi_{\substack{m_1 m_2 m_3 \\ m_{t_1} m_{t_2} m_{t_3}}} \right| \left(1 + V_s \frac{1}{E + i\epsilon - H}\right)(1+P) V_{12}^w \left| \psi_{{}^3_\Lambda H} \right\rangle \right|^2$$

Intensity of protons:

$$I(\chi) = I_0(1 + P_y A_p(\chi))$$



Outline

1. Hypertriton:

Particle content: Λ+n+p

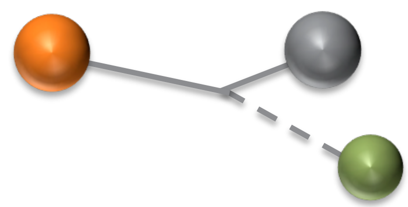
Separation energy: B=130±50 KeV

Life time $\tau=216^{+19}_{-16}$ ps ($\tau_\Lambda=263.1\pm2.0$ ps)

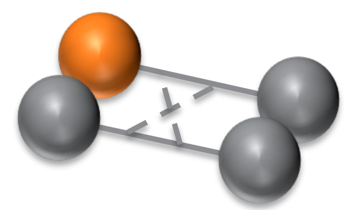
Spin=1/2 **(Rappold, Phys. Lett. B728)**

2. Main weak decay modes:

mesonic Λ→Nπ

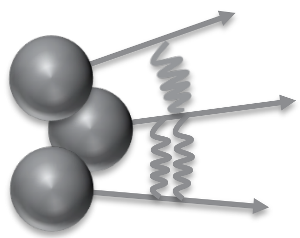


Non-mesonic ΛN→NN



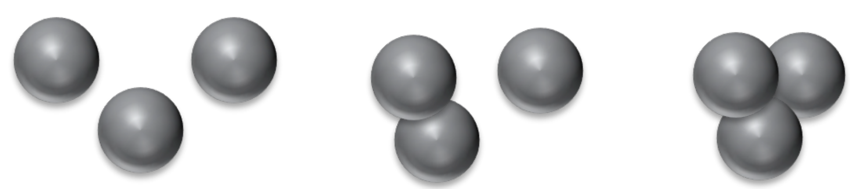
3. Strong final state interactions

(current work)



4. Decay products:

3N d+n ^{3}H, ^{3}He



Previous work with OME potentials:
Golak et al., PRC56 (1997), 2892