TECHNISCHE UNIVERSITÄT DARMSTADT

On the Hypertriton Lifetime

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Outline

- Theoretical Framework
- Motivation for our Calculation

- Weak interaction and Final State Interactions
- Phase Space

- Our Results
- Analysis and Summary

$^{3}_{\Lambda}\mathbf{H}$ Theoretical Framework
$\Rightarrow$ Pionless EFT

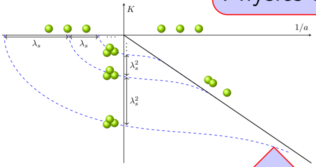
Shallow S-Wave State

$J^P = \frac{1}{2}^+$

Distinguishable

Theoretical Framework
⇒ Pionless EFT

Physics Determined by a and Λ_*



Large Scattering Length

Shallow S-Wave State

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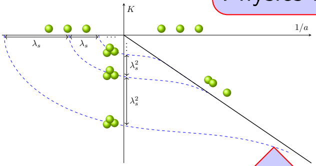

Large Scattering Length

Universal Relations Between Observables

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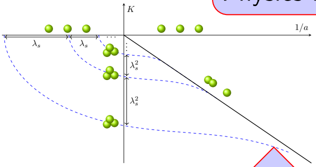

Large Scattering Length

Shallow S-Wave State

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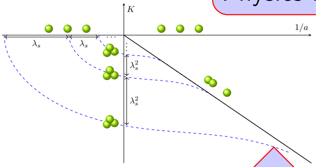
Distinguishable

→ Universal Relations Between Observables

- B_Λ and $< r^2 >$
- B_Λ and τ
- B_Λ and $a_{\Lambda d}$

Theoretical Framework
⇒ Pionless EFT

Physics Determined by a and Λ_*



Universal Relations Between Observables

- B_Λ and $< r^2 >$
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Large Scattering Length

Pionless EFT
Controllable Uncertainties
Systematic Improvement

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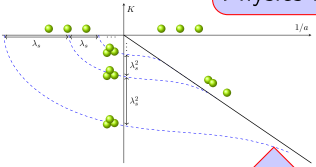
Physics Determined by a and Λ_*



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Large Scattering Length

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Shallow S-Wave State

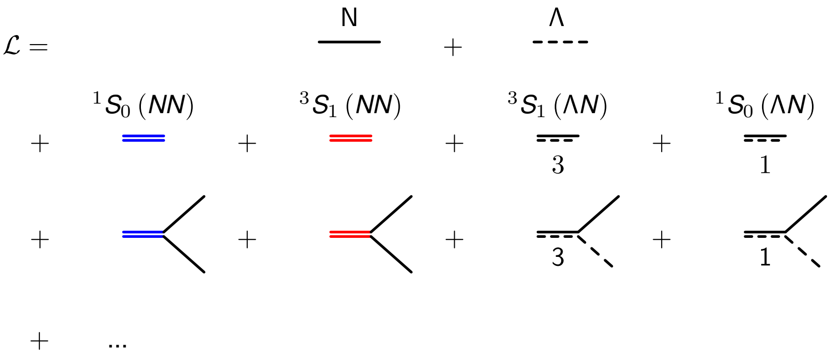
$J^P = \frac{1}{2}^+$

Distinguishable

Focus Today B_Λ and τ

$^{3}_{\Lambda}$H $^{3}_{\Lambda}$n

Lagrangian Hypertriton and Λnn



$^{3}_{\Lambda}\mathrm{H}$ Integral Equations Hypertriton

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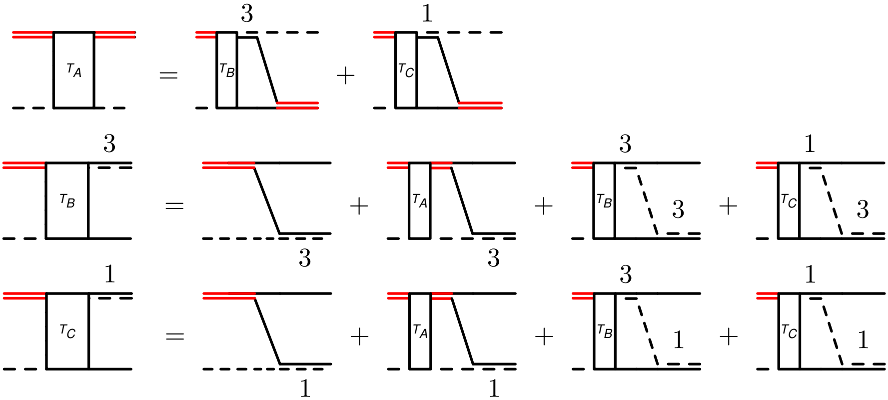
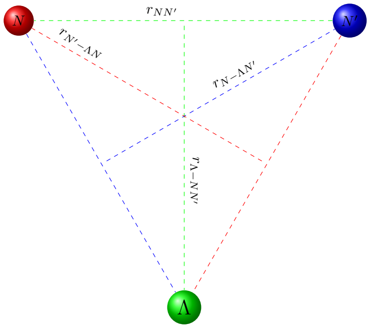


$^3_\Lambda$H Matter Radii



Calculation of Form Factors out of the Wave Functions:

$$F_i\left(\mathbf{k}^2\right) = \int \mathrm{d}^3 p \int \mathrm{d}^3 q \, \Psi_i\left(p, q\right) \Psi_i\left(p, \left|\mathbf{q} - \mathbf{k}\right|\right)$$

Directly Related to Different Matter Radii as Expansion in k^2

$$F_i\left(\mathbf{k}^2\right) = 1 - \frac{1}{6}\mathbf{k}^2 \langle r^2_{i-jk} \rangle + \ldots$$

2-Body⇒ One Radius
3-Body⇒ Many Radii

→

Most Interesting
$r_{\Lambda-NN'} \Leftrightarrow r_{\Lambda d}$

$^{3}_{\Lambda}$H Matter Radii Hypertriton

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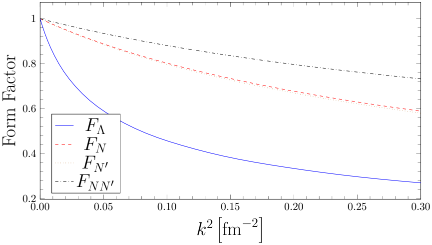


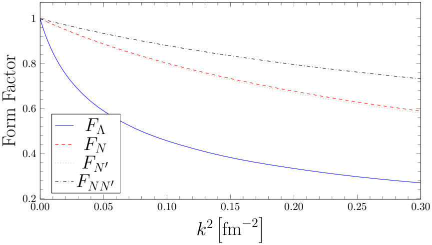
Expectation from Two-Body Calculation:

$$B_2 = \frac{1}{2\mu a^2} \quad \text{and} \quad \langle r^2 \rangle = \frac{a^2}{2}$$

$$\Rightarrow \sqrt{\langle r^2_{NN'} \rangle} \approx 3.04 \text{ fm}$$

$$\sqrt{\langle r^2_{\Lambda-NN'} \rangle} \approx 10.34 \text{ fm}$$

Matter Radii Hypertriton



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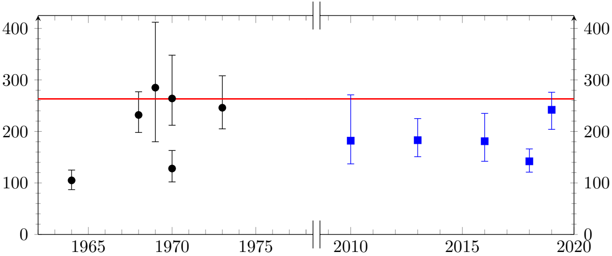
$$\sqrt{\langle r^2_{\Lambda-NN'} \rangle} \approx 10.34\ \text{fm}$$

$\sqrt{\langle r^2_{\Lambda-NN'} \rangle}$[fm]	$\sqrt{\langle r^2_{N'-\Lambda N} \rangle}$[fm]	$\sqrt{\langle r^2_{N-N'\Lambda} \rangle}$[fm]	$\sqrt{\langle r^2_{NN'} \rangle}$[fm]
10.79	3.96	4.02	2.96
$+3.04/-1.53$	$+0.40/-0.25$	$+0.41/-0.25$	$+0.06/-0.05$

Insensitive to Details of Λ-N Interaction

$^3_\Lambda$H Lifetime Hypertriton
Channels and Isospin Rule

- Two-Body Picture Works
- Calculate Lifetime in a Theory with Fundamental Deuteron
- Focus on B_Λ Dependence



Lifetime Hypertriton
Channels and Isospin Rule

$^{3}_{\Lambda}\mathrm{H} \mapsto \pi^{-} + {}^{3}\mathrm{He}$, $^{3}_{\Lambda}\mathrm{H} \mapsto \pi^{0} + {}^{3}\mathrm{H}$,

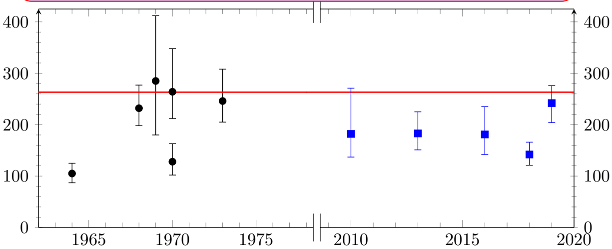
$^{3}_{\Lambda}\mathrm{H} \mapsto \pi^{-} + d + p$, $^{3}_{\Lambda}\mathrm{H} \mapsto \pi^{0} + d + n$,

~~$^{3}_{\Lambda}\mathrm{H} \mapsto \pi^{-} + p + n + p$~~, ~~$^{3}_{\Lambda}\mathrm{H} \mapsto \pi^{0} + p + n + n$~~

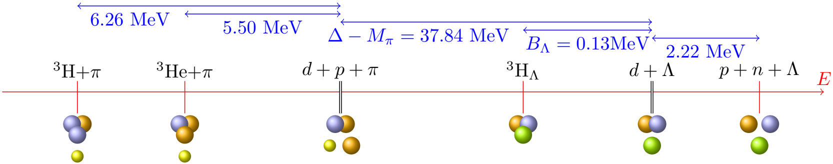
Charged and Uncharged Channel Are Related by the $\Delta I = \frac{1}{2}$ Rule
$\Rightarrow$ Calculate only one

- Two-Body Picture Works
- Calculate Lifetime in a Theory with Fundamental Deuteron
- Focus on B_{Λ} Dependence

Leptonic and Non-Mesonic Decays are Negligible



Lifetime Hypertriton
Thresholds and Feynman Diagrams



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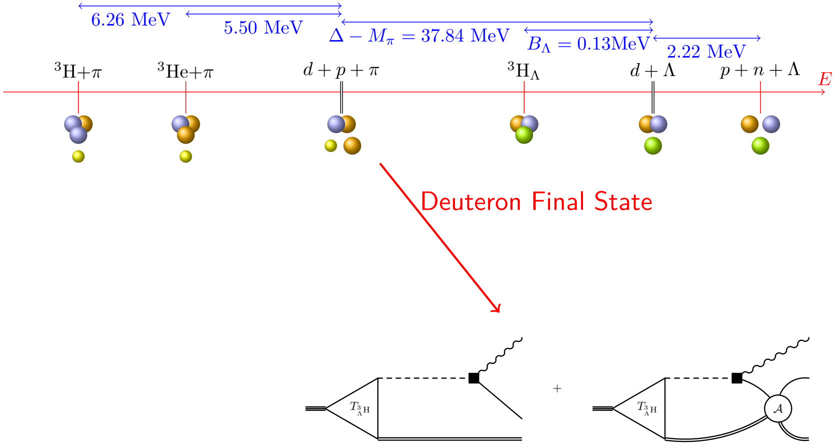

Lifetime Hypertriton
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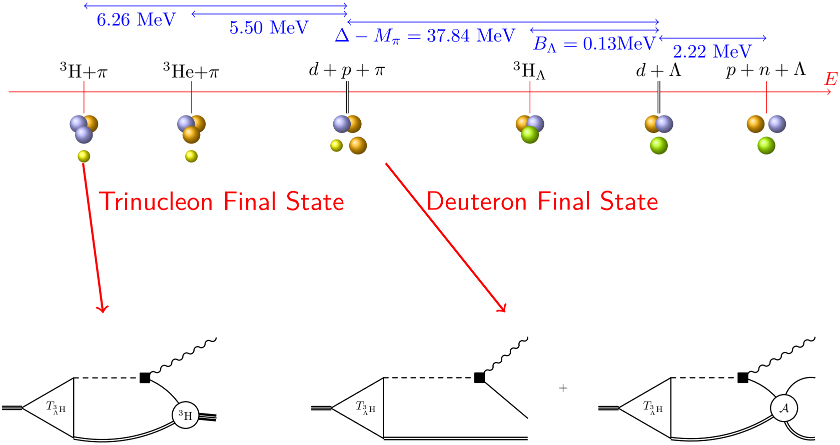


Weak Interaction

$$\mathcal{M}_{\Lambda\mapsto n\pi^0} = -iG_F M_\pi^2 \bar{u}\left(\mathbf{p}'\right)\left[\tilde{A}_\pi + \tilde{B}_\pi\gamma_5\right] u\left(\mathbf{p}\right)$$

non-relativistic reduction

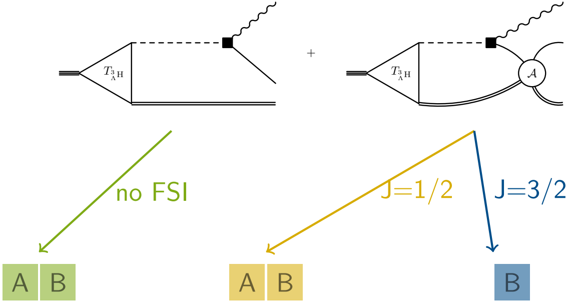
$$\mathcal{M}^{\text{reduced}}_{\Lambda\mapsto n\pi^0} = -iG_F M_\pi^2\left(A_\pi + \frac{B_\pi}{M_\Lambda + m}\boldsymbol{\sigma}\cdot\mathbf{k}\right)$$

two contributions A_π and B_π

A

B

$^{3}_{\Lambda}\mathrm{H}$ Contributions to the Deuteron Final State



square product leads towards interference terms

$^{3}_{\Lambda}\mathbf{H}$

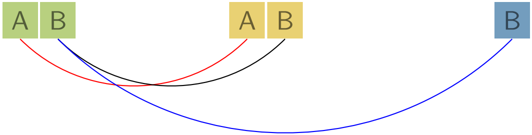
Contributions to the Deuteron Final State

A B

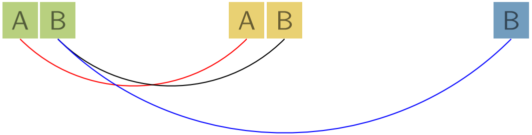
A B

B

Contributions to the Deuteron Final State



${}^{3}_{\Lambda}\mathrm{H}$ Contributions to the Deuteron Final State



$$\Gamma = A^2 + A^2 + A\,A + B^2 + B^2 + B^2 + B\,B + B\,B$$

not small !

$^{3}_{\Lambda}$H Phase Space and α dependence

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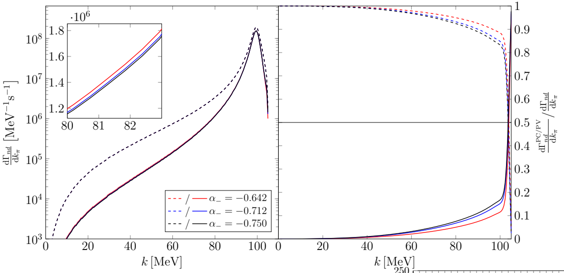
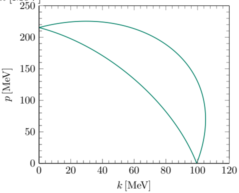
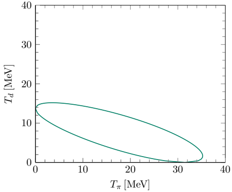


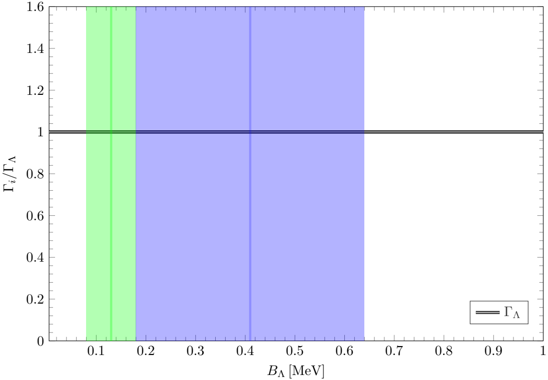
- dependence on α negligible
- small changes in PC and PV contributions
- final state interactions are important

- main contribution at high k_π
- full phase space calculation





$^{3}_{\Lambda}$H Hypertriton Width and Branching Ratios



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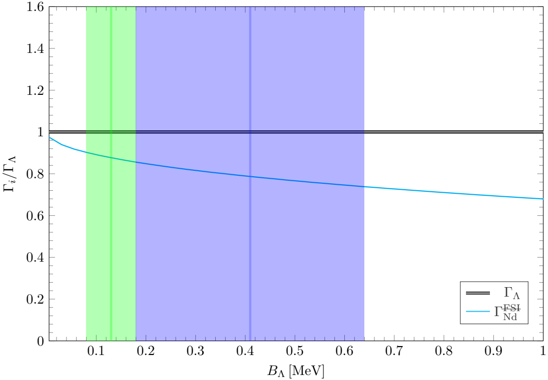

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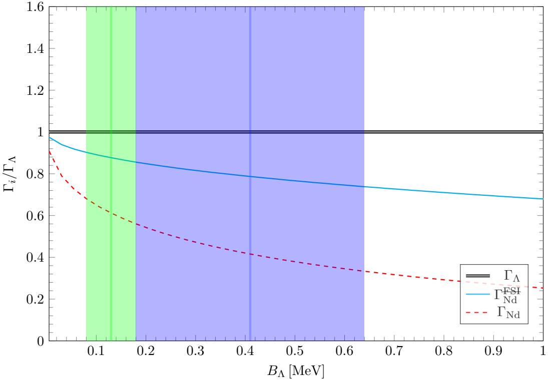

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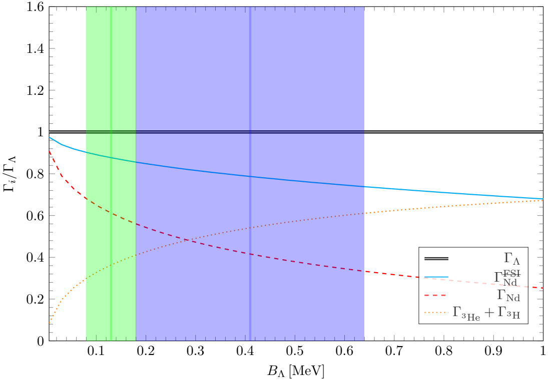

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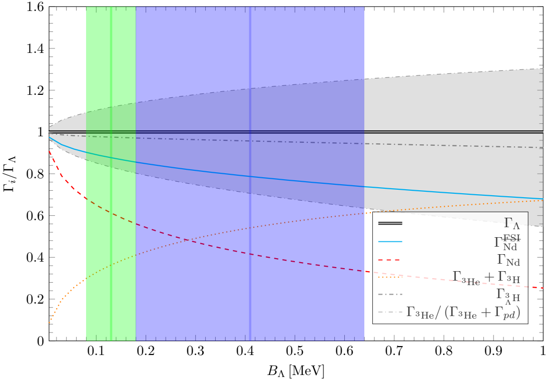

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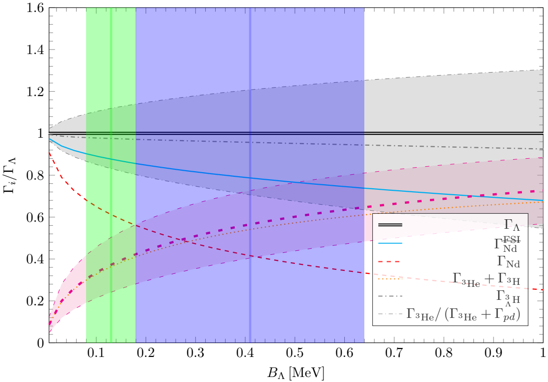

- $\Gamma_{^3_\Lambda H}$ Barely Depends on B_Λ
- Final State Interactions are Important
- $\Gamma_{^3He}/(\Gamma_{^3He} + \Gamma_{pd})$ Depends Strongly on B_Λ
- STAR Branching ratio $0.32(5)(8)$

Emulsion Data: $R = \Gamma_{^3He}/(\Gamma_{^3He} + \Gamma_{pd}) = 0.3 - 0.4$

$^{3}_{\Lambda}$H Hypertriton Width and Branching Ratios

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Our Results:

- $\Gamma_{^3_\Lambda H}(0.13) = 0.98 \pm 0.15\Gamma_\Lambda$
- $\Gamma_{^3_\Lambda H}(0.41) = 0.98 \pm 0.25\Gamma_\Lambda$
- $R(0.13) = 0.38 \pm 0.05$
- $R(0.41) = 0.57 \pm 0.11$

$^3_\Lambda$H Hypertriton Width and Branching Ratios

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Consistent:

- Calculation by Congleton for Γ and R
- Calculation by Kamada for Γ and R
- Emulsion Data $0.05\text{MeV} \lesssim B_\Lambda \lesssim 0.2\text{MeV}$

$^3_\Lambda$H Hypertriton Width and Branching Ratios

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Slight Tension:

- STAR results Branching ratio $R = 0.32 \pm 0.05 \pm 0.08$

${}^{3}_{\Lambda}\mathbf{H}$ Hypertriton Width and Branching Ratios

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Good part:

- EFT systematic improvment possible
- Go to NLO or three-body

Summary

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- Elegant theory with few input parameters
- Branching ratio as results and not as input
- Consistent results with a fundamental deuteron including the full three-body phase space
- Branching ratio favors small binding energies
- Systematic improvement possible in the future
- Important to combine different observables: binding energy, lifetime and branching ratios to resolve the hypertriton puzzle