Towards calibration of hyperon-nucleon interaction models using light hypernuclei

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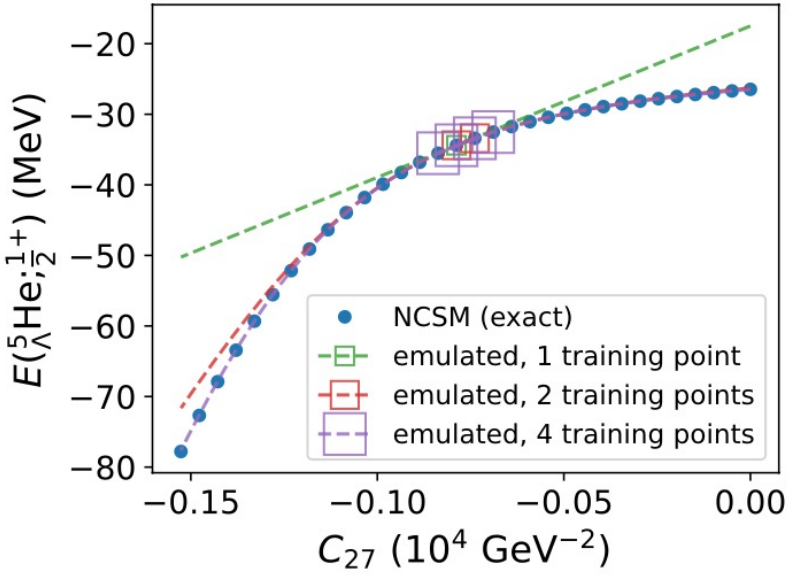
Energy levels light nuclei sensitive YN –> but model dependencies NN/NNN interactions (up to 0.36 MeV 5He HN)

Can we optimize YN forces from ab-initio calcs. of large # model evaluations ? Computational cost too high

Eigenvector continuation method – when Hamiltonian is a smooth fn. of a control variable the Eigen vectors are too!
-> Confined to a low dimensional sub-space , can be linearised

$H = H_0 + C_{27}V_{27} + C_{10^*}V_{10^*} + C_{10}V_{10} + C_{8a}V_{8a} + C_{8s}V_{8s}$,
where C_is are the 5 independent $SU_f(3)$ LECs and H_0 contains the kinetic energy, *NN+NNN* interactions, and hypernuclear meson-exchange and Coulomb interactions



Select 1,2, 4 exact NCSM eigen vectors to construct emulators

Accurate and fast emulation of ab-initio NCSM
(but extrapolation to larger space of N,hbarω necessary – sample 5-D space of LECs)

C_{27} -> most of variation of BE in hypertriton – excited states HN bring in other constants

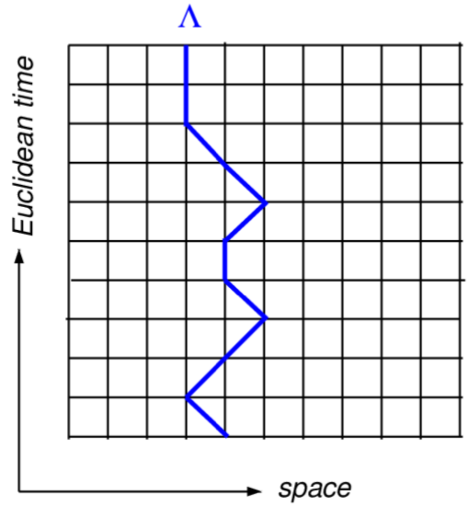
Emulator method - agreement excited states (and HT) through varying LOYN LECS

Lattice Monte Carlo Simulation

with two Impurity worldlines

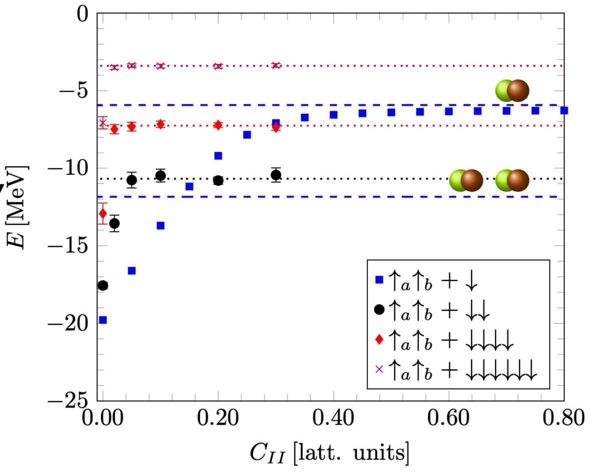
Fabian Hildenbrand, IAS-4 & IKP-3, Forschungszentrum Jülich, Germany

- Extend Lattice calcs from nuclear regime (up to A=40) in 3rd dimension (cascade LL hypernuclei)
- Impurity Monte Carlo (hyperon is the impurity) – calculate BE, radii, ..
- Apply transfer matrix on trial state in time steps – obtain lowest ES of Hamiltonian
- Auxillary fields – handle many particles replace NN with N-AF (parallel computing)
- Impurities – AFMC does not converge easily (extrapolation..?) -> treat impurity as a worldline on AF
- Two hyperons – WL-WL interaction WL-Background – contact terms a la ChEFT, WL filtering

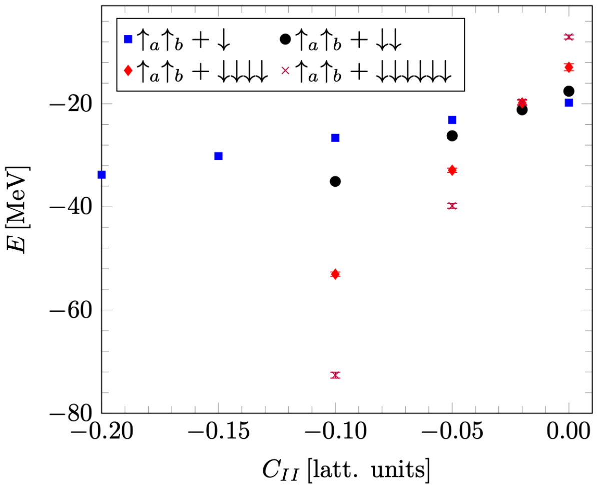


(D. Frame, T. A. Lähde, D. Lee, U.-G. Meißner)

Repulsive YY interaction



Attractive YY interaction

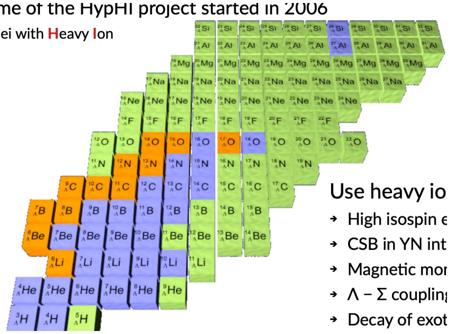


Christophe Rappold (Madrid)

HypHI and WASA-FRS experiments @ GSI

deal outcome of the HypHI project started in 2006

Hypernuclei with Heavy Ion

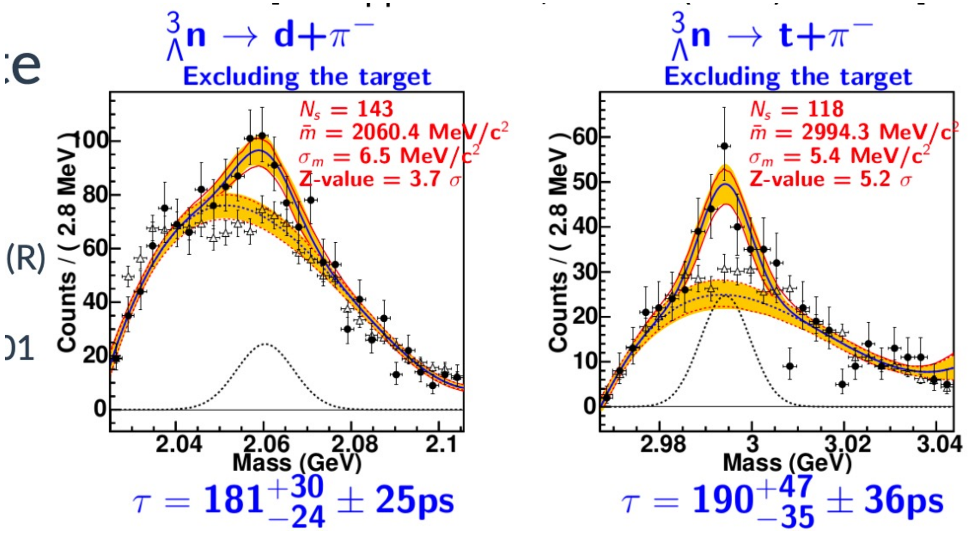


Use heavy io

- High isospin e
- CSB in YN int
- Magnetic mor
- $\Lambda - \Sigma$ couplin
- Decay of exot

nnΛ bound state ?

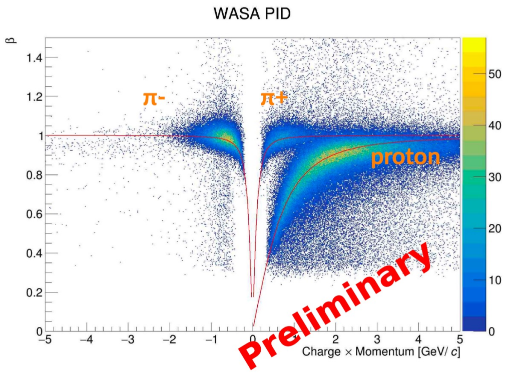
- Extend observation hypernuclei to drip lines
- Coalescence of Λ,.. from hot region in n spectator fragment
  Hypernuclei in flight – boosted γ~3 -> outside target region.
- HYPHI phase 0 - CS and multiplicities, inverse temp studies
- WASA-FRS data in 2022 – mom resolution fragments, RI beam

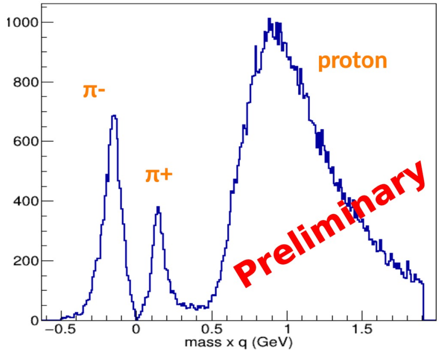


Short lifetime of $^{3}_{\Lambda}H$:

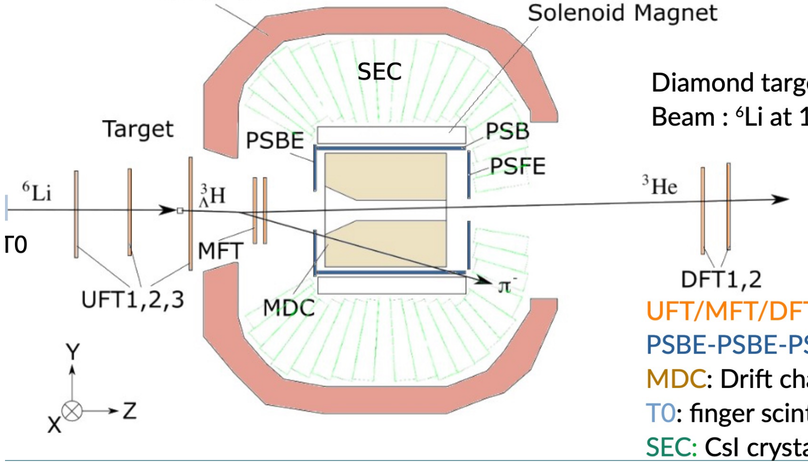
$\tau = 181^{+30}_{-24} \pm 25$ps $\tau = 190^{+47}_{-35}$

- Our published value : 183^{+43}_{-32} ps [C. Rappold et al., Nucl. Phys. A 913 (2013) 170]
- Plus other recent measurements : Combined lifetime analysis excludes all current models of $^{3}_{\Lambda}H$ [C. Rappold et al., Phys. Lett. B 728, 543 (2014)]





Fixed target, Reaction : $^{6}Li + ^{12}C$ @ 1.96 AGeV or $\sqrt{s_{NN}}$ = 2.7 GeV



Diamond target: 9.87 g/cm²

Beam : ^{6}Li at 1.96 AGeV ~ 2 x 10^7/s

UFT/MFT/DFT: Fiber Trackers

PSBE-PSBE-PSFE: Plastic scintillators

MDC: Drift chambers base on straw tubes

T0: finger scintillators

SEC: CsI crystal calorimeter

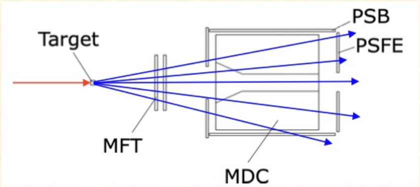
Studies of Hypernuclei with HI-beams, Nuclear Emulsions and Machine Learning

R. Saito (Riken) WASA FRS,
Emulsion-ML

Acquired data for S447 (hypernuclei)

Beam	Fragment at S4	Amount	Time	Accepted trigger rate	
^{6}Li beam	^{3}He	3.3×10^8	40.9 hours	2600 Hz	$^3_\Lambda$H
	^{4}He	0.9×10^8	43.9 hours	1800 Hz	$^4_\Lambda$H
	deuteron	1.8×10^8			nnΛ
	proton (mid-rapidity)	5.3×10^6	3.2 hours	680 Hz	Λ
^{12}C beam	^{3}He	1.0×10^8	13.5 hours	2400 Hz	$^3_\Lambda$H
	^{9}C	2.4×10^5			$^9_\Lambda$B

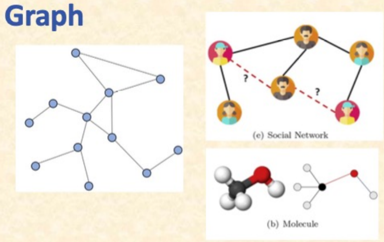
Track Finding



Multi particles in HI reaction
Combinatorial background

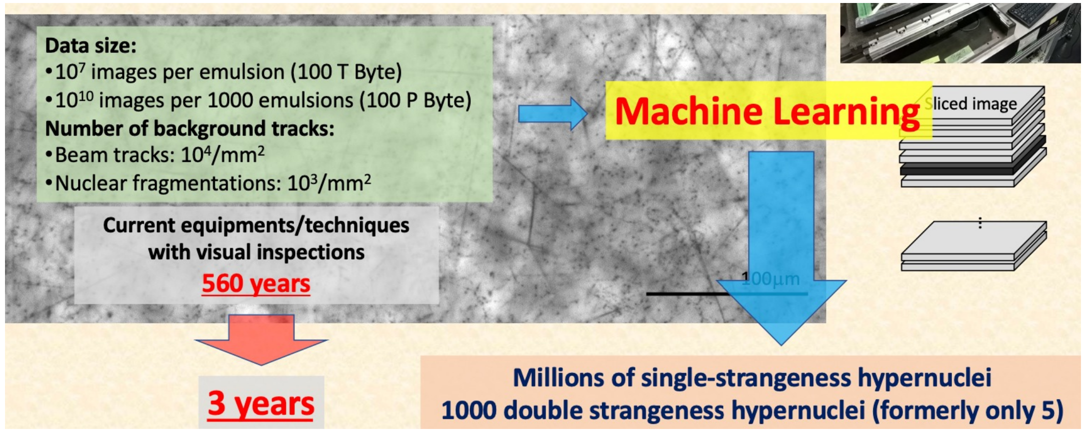
Track Finding with Graph Neural Network (GNN)

Graph



- Node : Data point
- Edge : Connection

Jie Zhou *et al.*, AI Open 1 (2020) 57–81

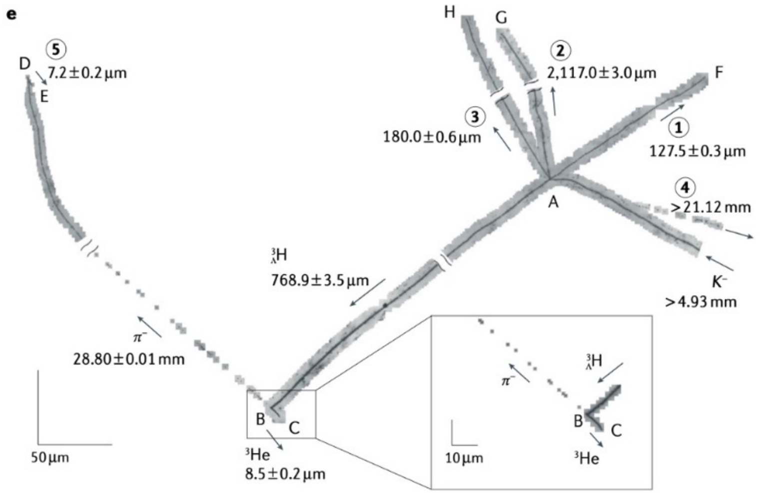


- Pytorch geometric MC ML, Improv momentum resolution from 9% (Kalman F) to 6%;
98% efficiency for pi-, reduced training times-

Nuclear emulsion – best spatial resolution of any detector

HT training data? Binarised tracks MC, background from real data -> GAN networks – indistinguishable

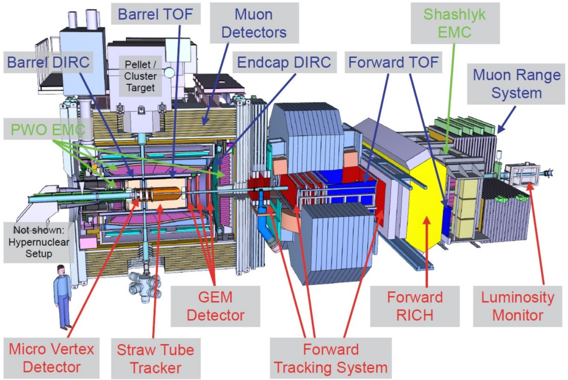
Detection – Mask R-CNN. Trained automatically (know the good events)
– first HT in emulsion discovered! (Nature paper) – 250x stats to come, Double HN, ..

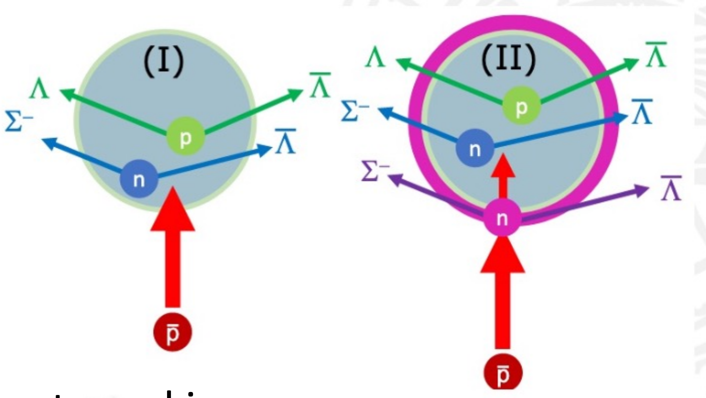


Antihyperons in Nuclei (with PANDA)

Michael Papenbrock

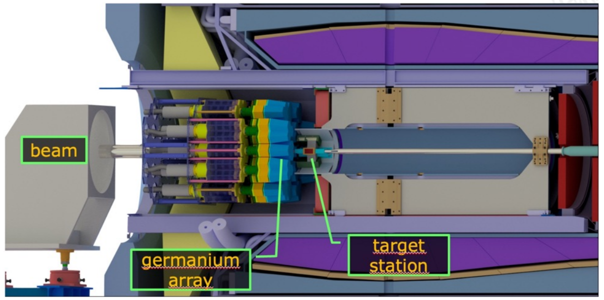
p_{beam} (GeV/c)	Reaction	$\sigma(\mu b)$	$\varepsilon(\%)$	Rate (s^{-1}) @ $10^{31}\ cm^{-2}s^{-1}$	S/B	Events / day
1.64	$\bar{p}p \rightarrow \bar{\Lambda}\Lambda$	64.0	16.0	44	114	$3.8 \cdot 10^6$
1.77	$\bar{p}p \rightarrow \bar{\Sigma}^0\Lambda$	10.9	5.3	2.4	>11**	207000
6.0	$\bar{p}p \rightarrow \bar{\Sigma}^0\Lambda$	20	6.1	5.0	21	432000
4.6	$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$	~ 1	8.2	0.3	274	260000
7.0	$\bar{p}p \rightarrow \bar{\Xi}^+\Xi^-$	~ 0.3	7.9	0.1	65	86000

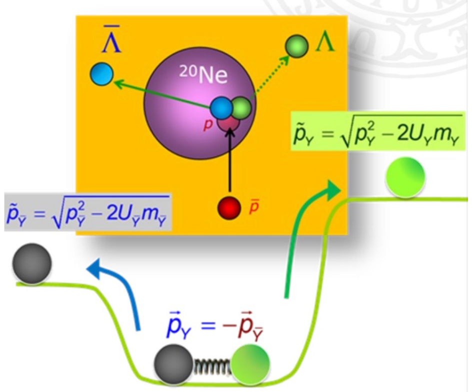




Neutron skin across isotopic chains (double ratio)

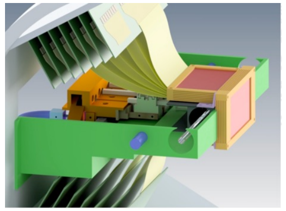
Hyperatoms and hypernuclei





Momentum asymmetries (transverse, long)
-> Effective antihyperon optical pot.

New apparatus upstream
Cascade HN
$\Lambda\Lambda$ hypernuclei from cascade$^-$ capture
Active Boron target

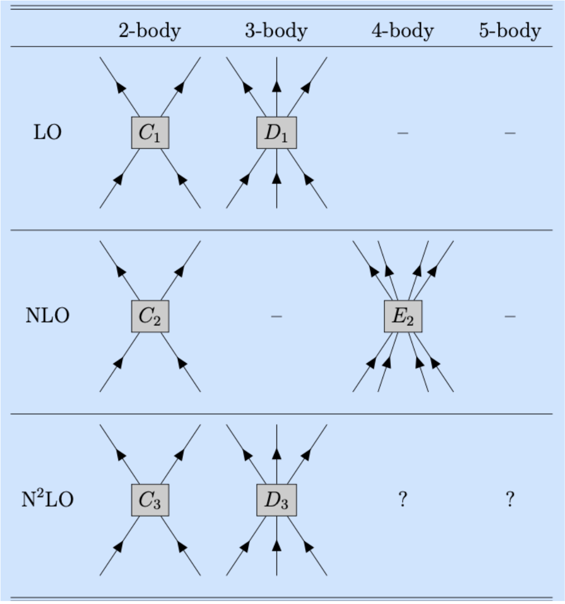


Four body force in Pionless Effective Field Theory

Mirko Bagnarol

Hebrew University of Jerusalem
Racah Institute of Physics

Pionless ChEFT – pions integrated out



LO term is contact term

Solve SE with cutoff Parameter (variational principle)

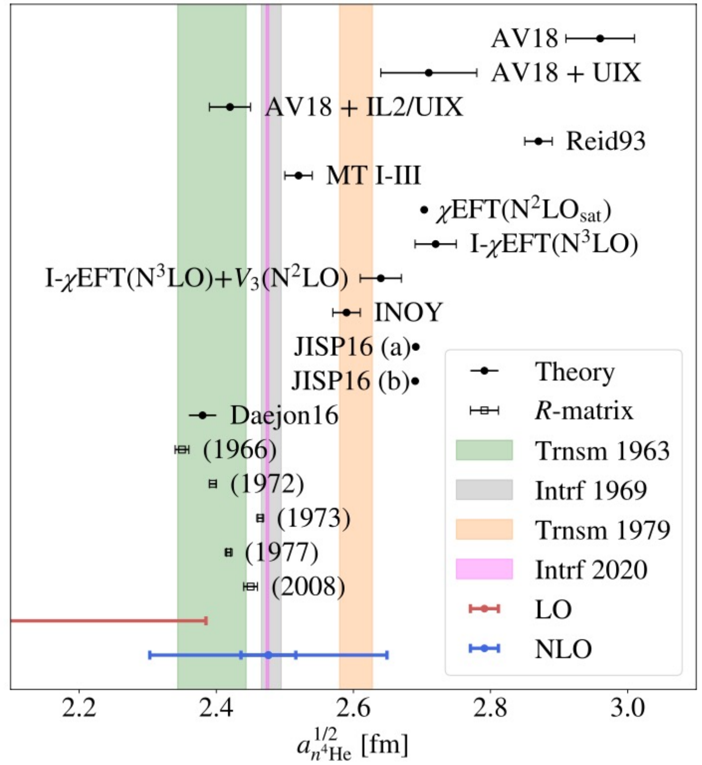
NLO – mom dependent 2-body terms, three counterterms
and a 4-body force (latter necessary and sufficient for renormalization)

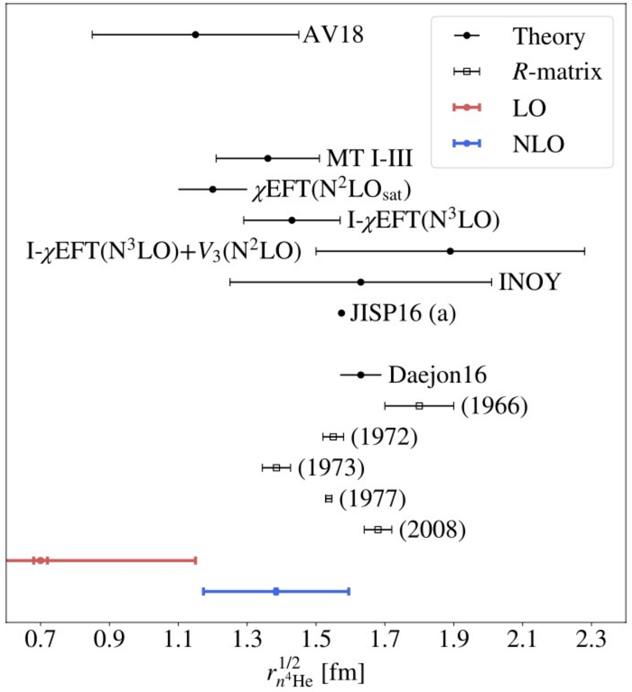
Model has 6 parameters fixed to few body observables

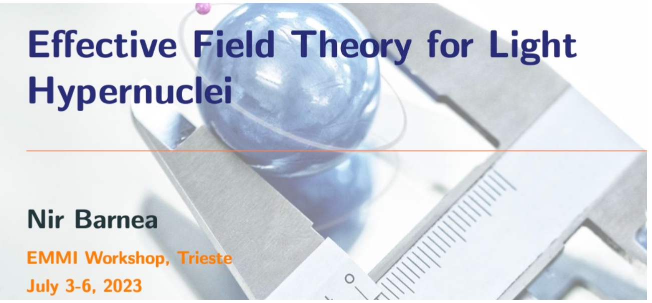
Busch formula – extract free space scattering parameters a_0 and r_{eff} from bound state energies

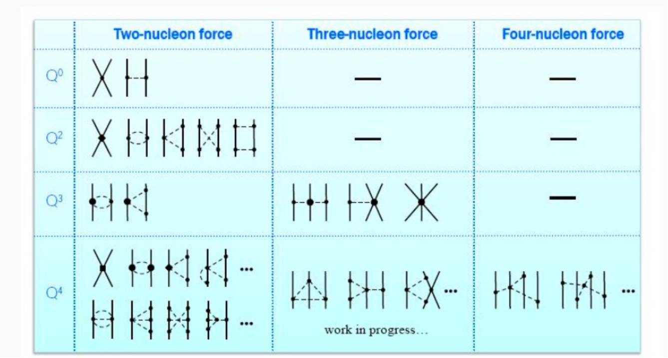
$$k \cot \delta_0 = -2\sqrt{\mu\omega}\frac{\Gamma\left(\frac{3}{4} - \frac{E}{2\hbar c\omega}\right)}{\Gamma\left(\frac{1}{4} - \frac{E}{2\hbar c\omega}\right)}$$

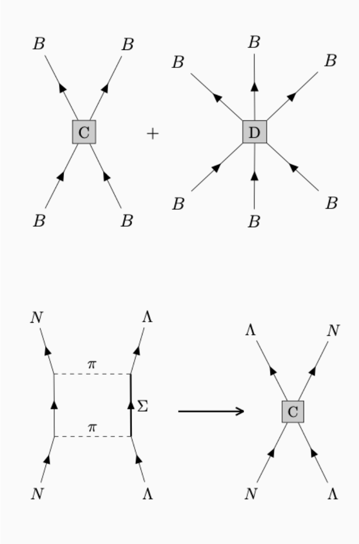
Basis states:
Single - correlated gaussian with orb, spin, Isospin part
+ Ad-hoc designed states that capture 4He core









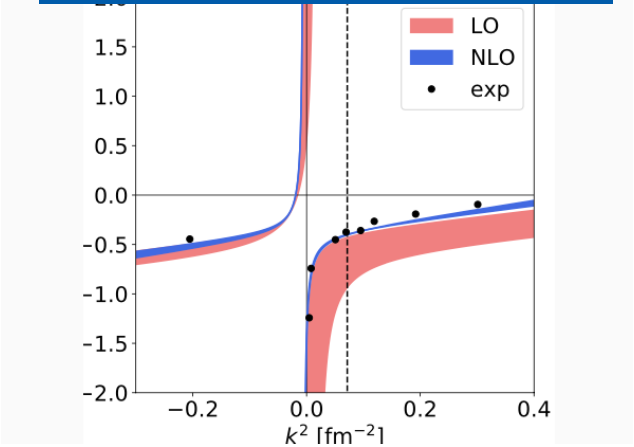


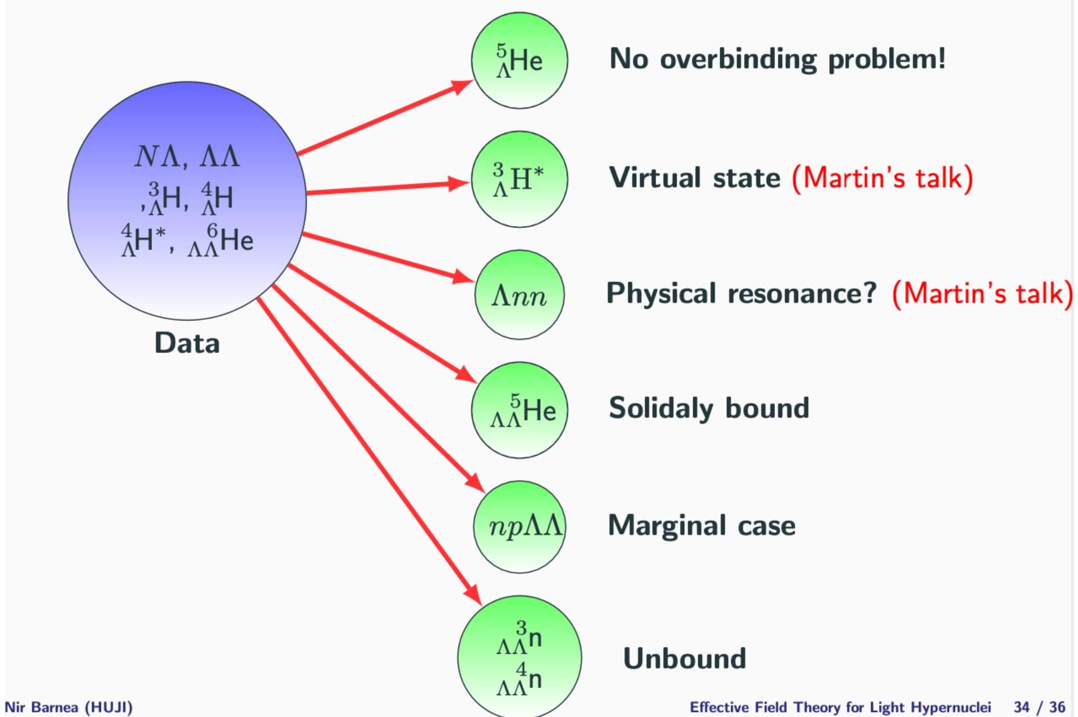
5BF – maybe for hyperons !

Constraints:
ΛN - femtoscopy
ΛΛ – lattice QCD

Universality –
also applies to atomic systems

$n + d\ (S=\frac{1}{2}, T=\frac{1}{2})$ scattering





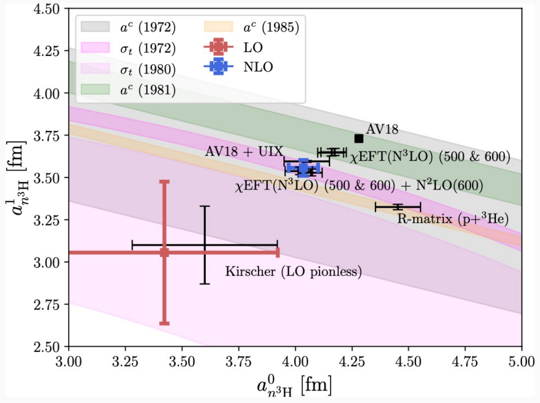
Charge symmetry breaking

^{3}H <-> ^{3}He diff large (25%)

Λ, Σ mixing?

ChEFT – biggest effect from contact interactions. Spin singlet> Spin triplet

BEFT reproduces observations !



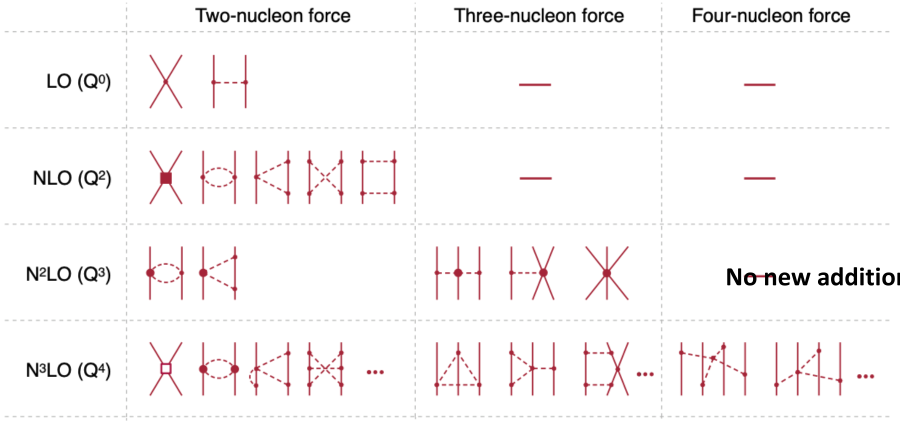
Schäfer and

$n + {}^3\mathrm{H}$ scattering lengths

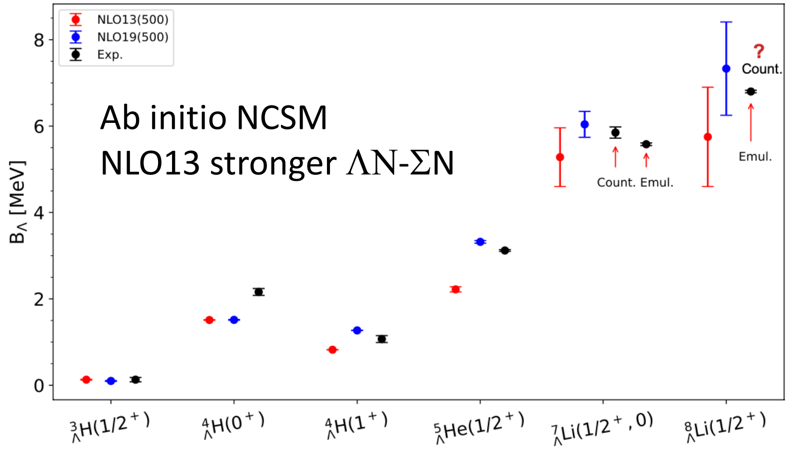
Hyperon-nucleon interaction and light hypernuclei

Johann Haidenbauer

IAS, Forschungszentrum Jülich, Germany



No new additional LECS in two-body



Ab initio NCSM
NLO13 stronger ΛN-ΣN

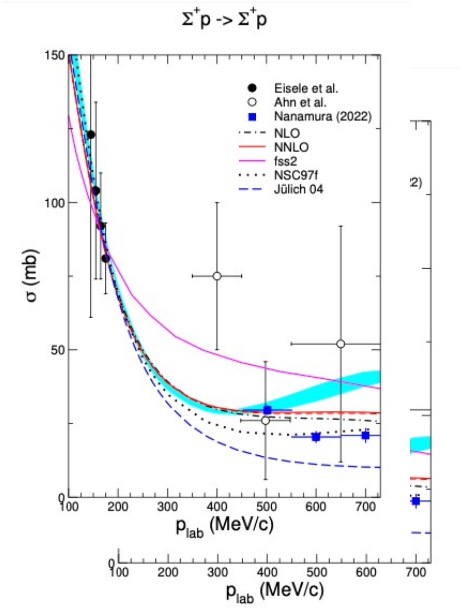
→ ${}^4_\Lambda$H(1^+), ${}^5_\Lambda$He, ${}^7_\Lambda$Li, ${}^8_\Lambda$Li are fairly well described by **NLO19**;

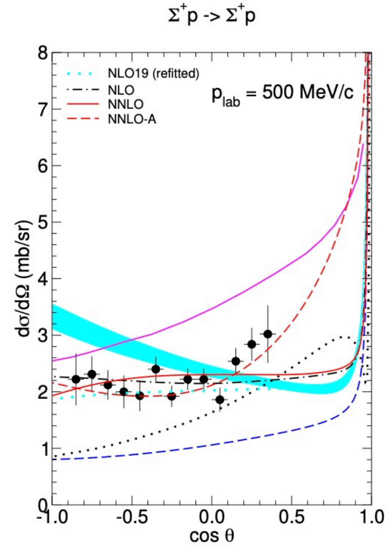
NLO13 underestimates separation energies

ChEFT up to NNLO

Recent imrovements in quality of data
hyperon nucleon scattering (CLAS, J-PARC)
Mom correlation functions (STAR, HADES ALICE..)
LatticeQCD, ab inito effective field theories, ..

N2LO – Improvements in description P wave, higher waves in NN scattering





Full determination of all P-wave LECs – more channels, pol observables..

york-ac-

Approaching a SU(3) Energy Density Functional

Horst Lenske
Institut für Theoretische Physik, JLU Giessen

SU(3) relations for covariant octet EDF

Lagrangian for hypernuclear matter

3 sets of 3 fundamental coupling constants

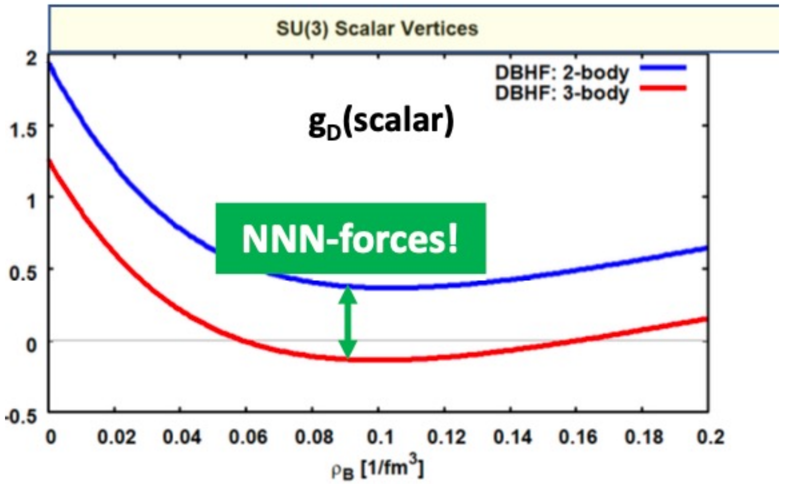
$$\boxed{\mathcal{L}_{int}^{\mathcal{P}} = -\sqrt{2}\left\{g_D\left[\overline{\mathcal{B}}\mathcal{B}\mathcal{P}_8\right]_D + g_F\left[\overline{\mathcal{B}}\mathcal{B}\mathcal{P}_8\right]_F\right\} - g_S\frac{1}{\sqrt{3}}\left[\overline{\mathcal{B}}\mathcal{B}\mathcal{P}_1\right]_S}$$

***P*=Pseudoscalar, Vector, and Scalar Meson Exchange**

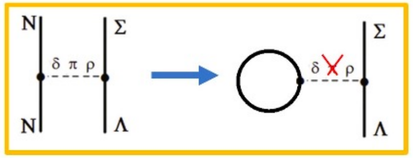
Inherit SU(3) symmetry,
Sym breaking from use of physical masses, Coupling Consts

In-medium couplings needed :
Some known and imposing some as zero
Mixing angle

Ccovariant SU(3) Density functional can be constructed
- evaluated in a mean field approximation

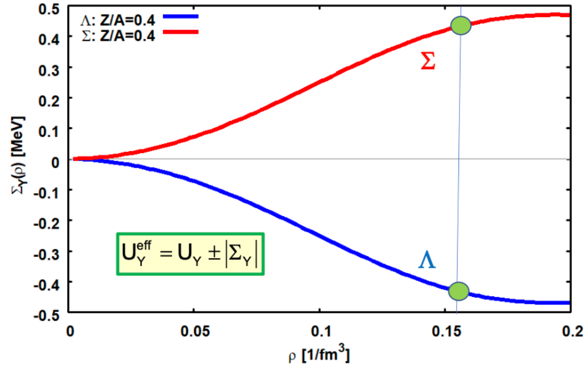


Λ-Σ Mixing inAsymmetric Nuclear Matter Induced by the Static Isovector Mean-Field



Λ and Σ Self-Energies Induced by the Isovector Mean-Field

$$\Sigma_\Lambda(1,2) = \left[\tau_{A3}(2)\ T_{Y3}(2)\right]U_{\Lambda\Sigma}(2)G_\Sigma(2,1)U_{\Sigma\Lambda}(1)\left[\tau_{A3}(1)\ T_{Y3}(1)\right]$$



- Depth of effective Λ potential increases
- Depth of effective Σ potential decreases

Simulating YYN/YYY Repulsion
Exploratory SU(3)-EDF Study of a Neutron Star