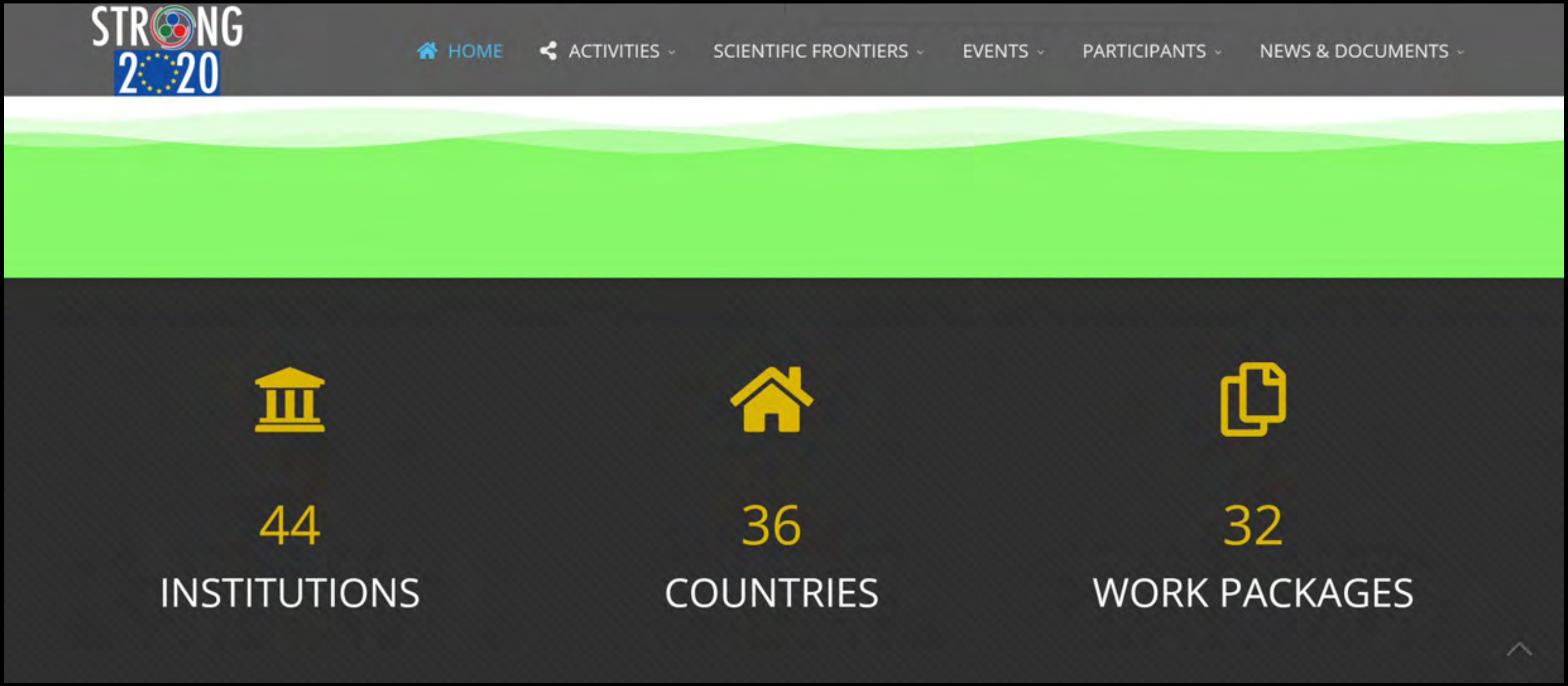
STRONG 2020

- http://www.strong-2020.eu/

- The STRONG-2020 project brings together many of the leading research groups and infrastructures involved today in the study of the strong interaction in Europe, and also exploits the innovation potential in applied research through the development of detector systems with applications beyond fundamental physics,



Funding: 10M€ for 4 years

Networking Activity

THEIA

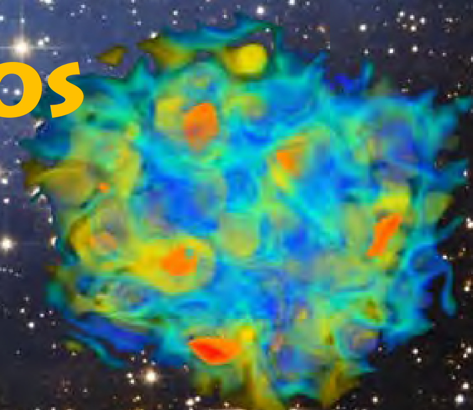
Strange Hadrons and the Equation-of-State of Compact Stars

Josef Pochodzalla

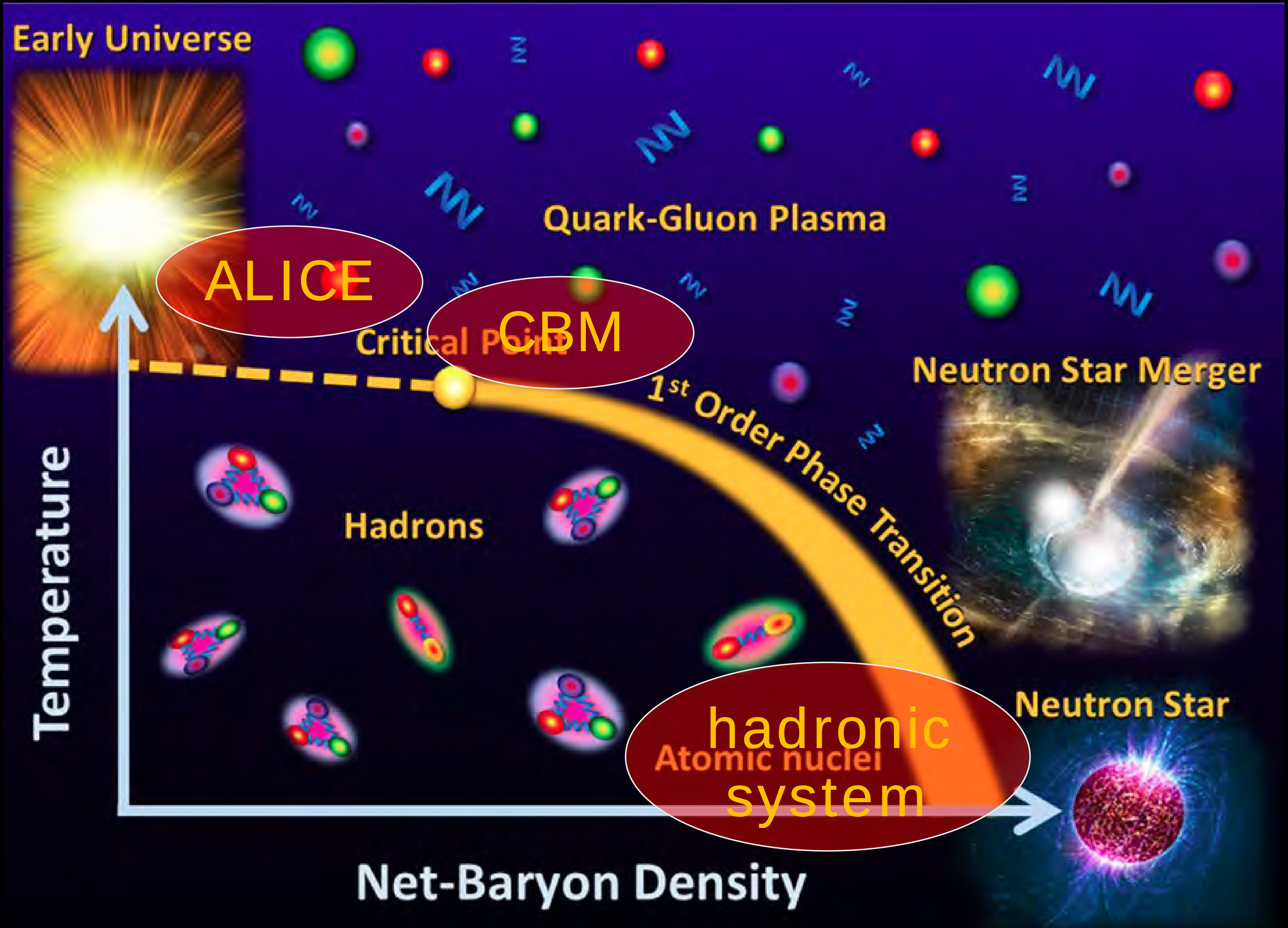
JGU Mainz & Helmholtz-Institut Mainz

HYPERION ∞

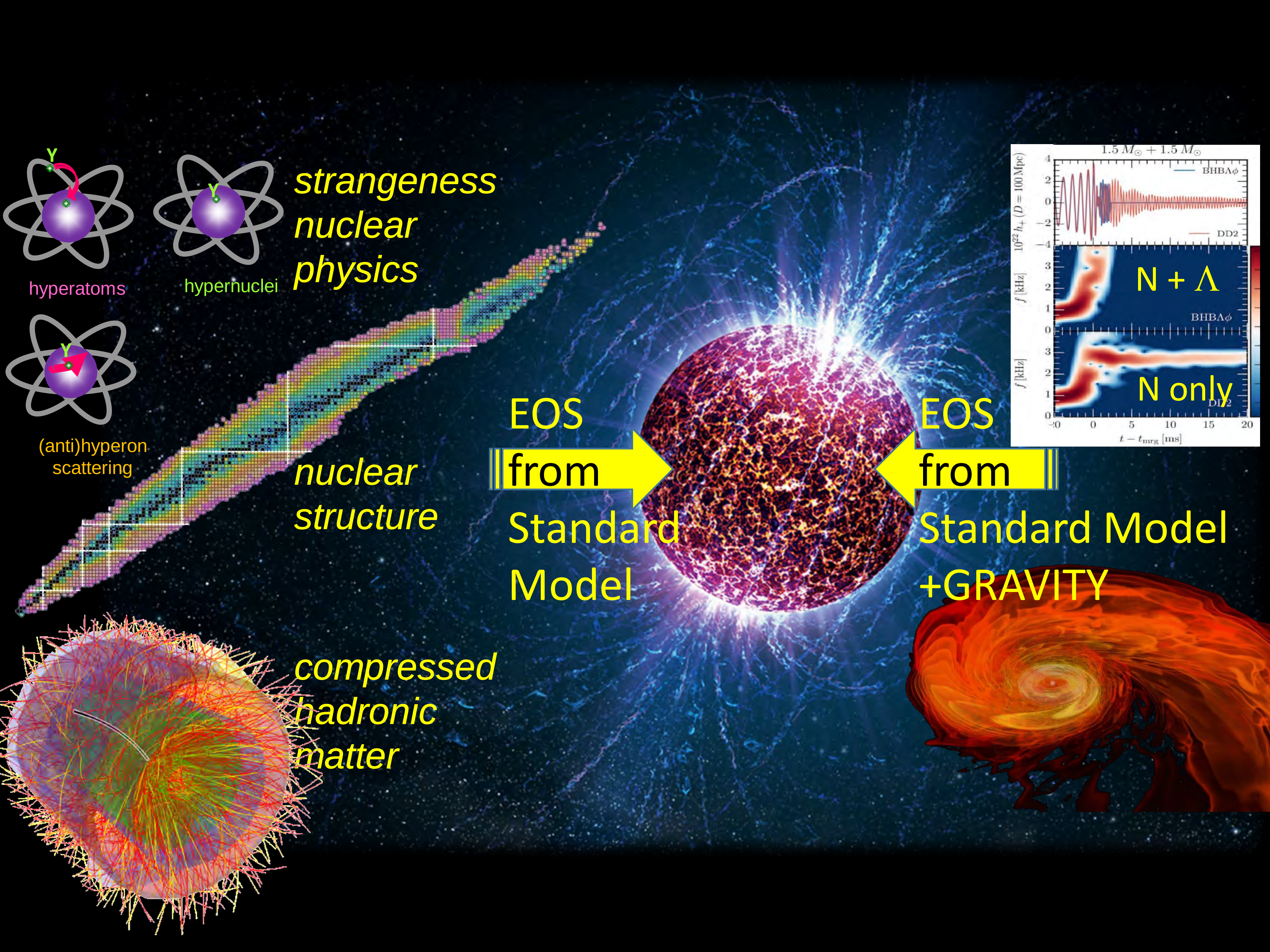
= EOS

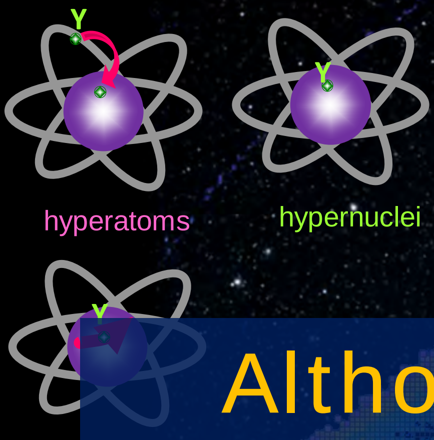


The Holy Grail of QCD Matter

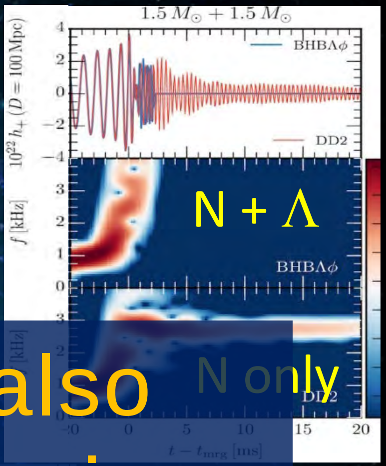


courtesy of Peter Senger and Norbert Herrmann


hyperatoms
hypernuclei
strangeness nuclear physics
(anti)hyperon scattering
nuclear structure
compressed hadronic matter
EOS from Standard Model
EOS from Standard Model +GRAVITY
$1.5\,M_\odot + 1.5\,M_\odot$
BHBΛφ
DD2
N + Λ
N only
$t - t_{mrg}$ [ms]
f [kHz]



strangeness nuclear physics



Although the hadronic EOS is also related to many other branches in nuclear or hadronic physics, the focus on the strangeness aspect guarantees specific, very effective and fruitful interactions among all participating groups in THEIA.

Members of THEIA

Universitat de Barcelona

Institute of Space Sciences Barcelona

Ruhr-Universität Bochum

- ≥ 24 institutions
- ≥ 8 countries
- ≥ 100 permanent scientists, postdocs
- ≥ 50 active PhD students or master students

Univ. of Southampton

Aristotle Univ. Thessaloniki

Univ. Tohoku

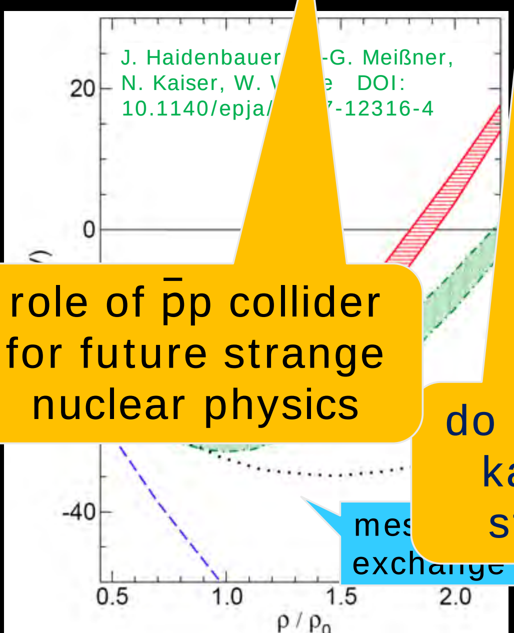
Univ. Tokyo

Österreichische Akademie der Wissenschaften Wien

Questions

YN and YY Interaction

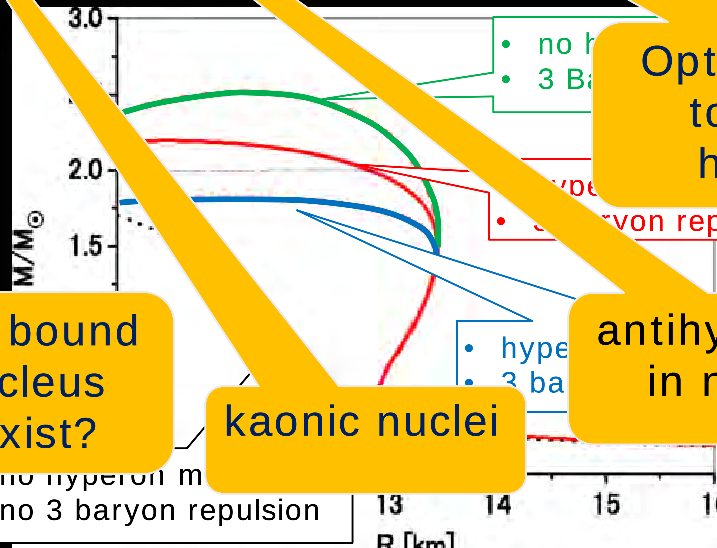
- YY vector meson repulsion: ϕ *meson coupled only to hyperons; yielding strong repulson at high* ρ
- Chiral forces: *YN from* χ*EFT predicts* Λ *s.p. potential more repulsive than from meson exchange*



Hyperonic Three-body force

- Natural solution based on the known importance of NNN forces in conventional nuclear physics

Y. Yamamoto, T. Furumoto, N. Yasutake, Th.A Rijken, Phys. Rev. C 90, 045805 (2014)



Quark Matter

- Phase transition to deconfined QM at densities lower than hyperon appearance
- That requires QM which
- (i) is significantly
- ... h to avoid reconfinement

Hypertriton puzzle

nnΛ puzzle

Charge Symmetry breaking Λn - Λp

Optimal strategy to study ΛΛ hypernuclei

antihyperons in nuclei

kaonic nuclei

do deeply bound kaon-nucleus states exist?

role of p̄p collider for future strange nuclear physics

Deliverables and Milestones

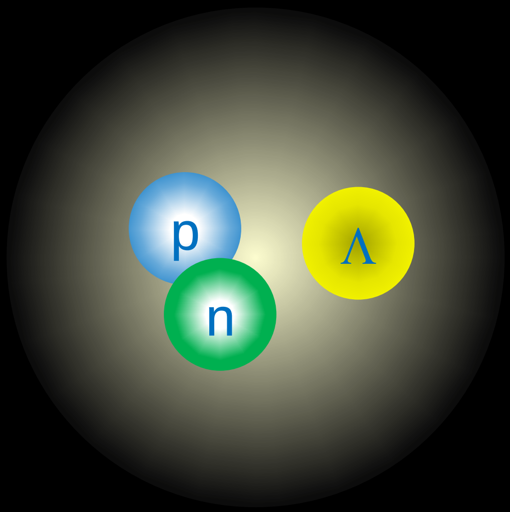
- Study of A=3 hypernuclei $^{3}_{\Lambda}H$ and $^{3}_{\Lambda}n$
- MS: First data taking by WASA@GSI/FAIR searching for nnΛ, tentatively scheduled in February (commissioning) and March (physics run) in 2022

- Study of antihyperons in nuclei; PANDA software tools demonstrator
- MS: Design report for antihyperons in nuclei ready

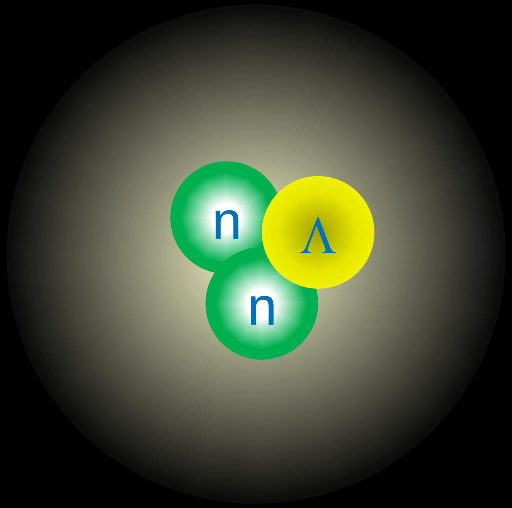
- Theoretical and experimental studies of bound mesonic systems
- MS: SIDDHARTA-2 progress report

- Annual workshops to guarantee effective and fruitful interactions

Task1: The A=3 Hypernuclei

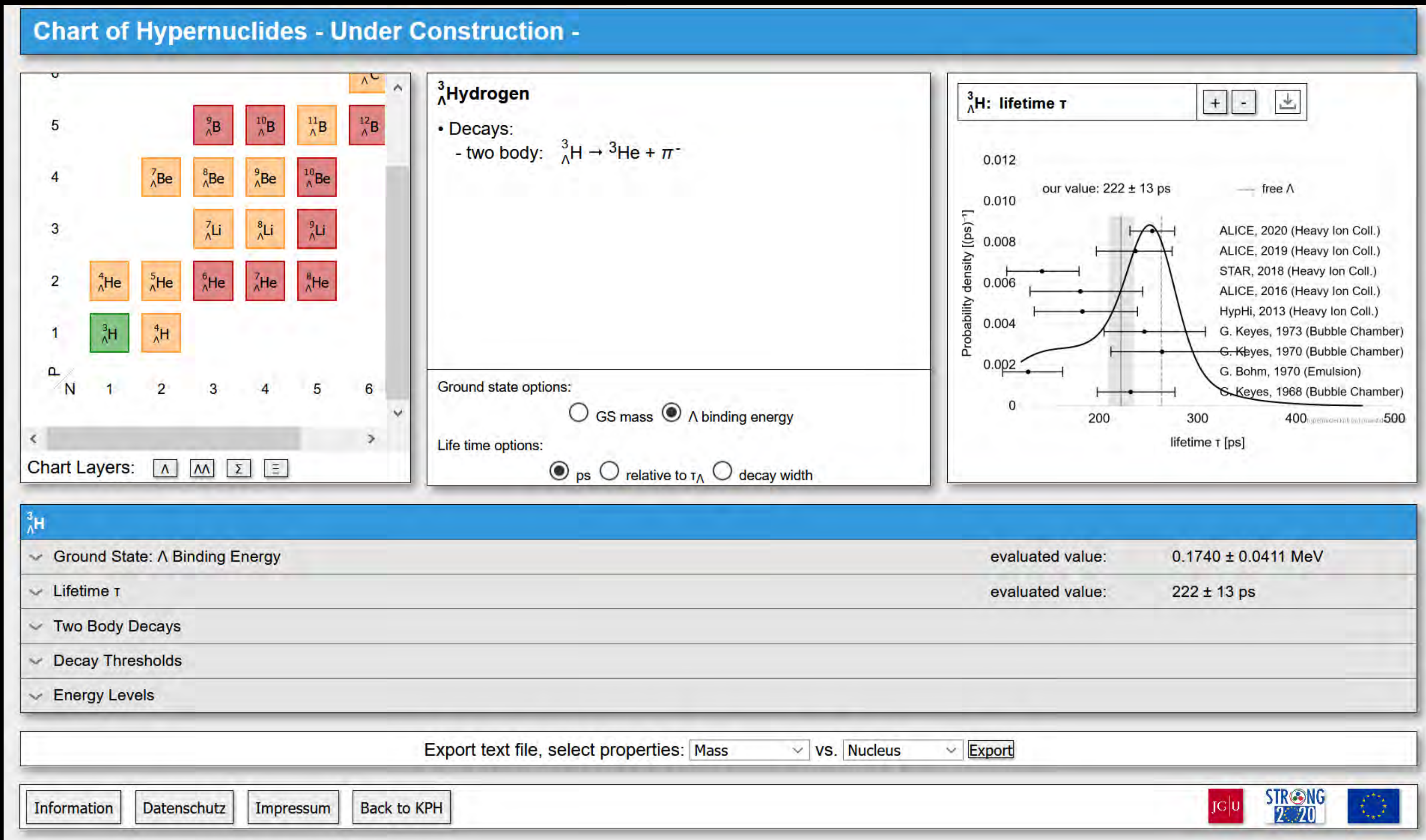


$^{3}_{\Lambda}H$



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

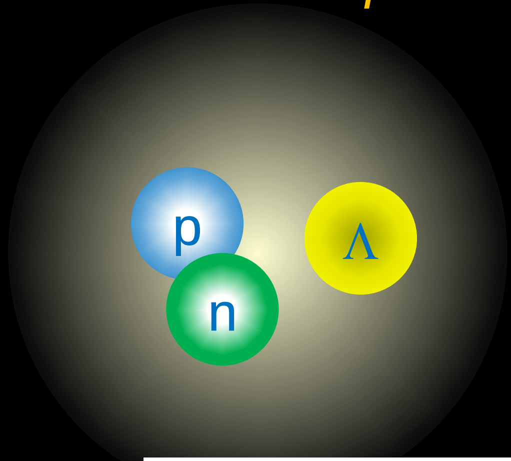
Deliverable 1: A=3 Hypernuclei

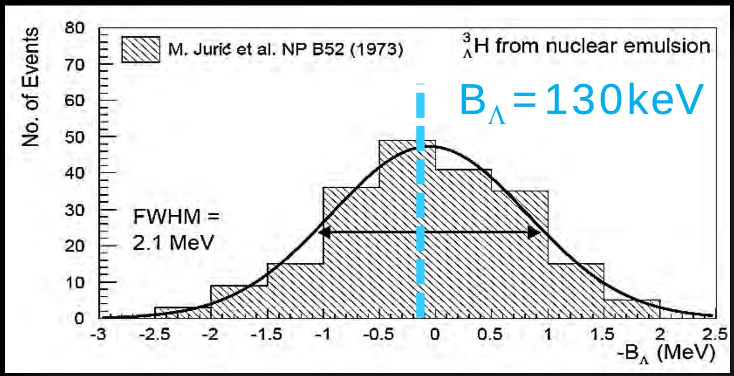


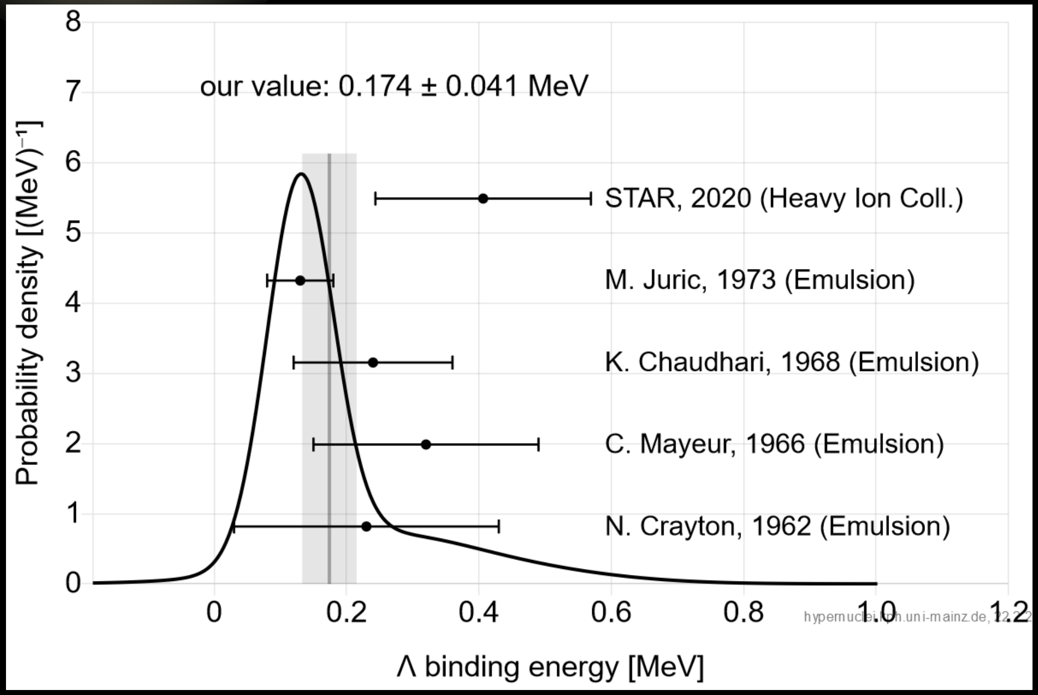
Task 1: The Hypertriton Puzzle

Do we understand the simplest Hypernucleus?

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



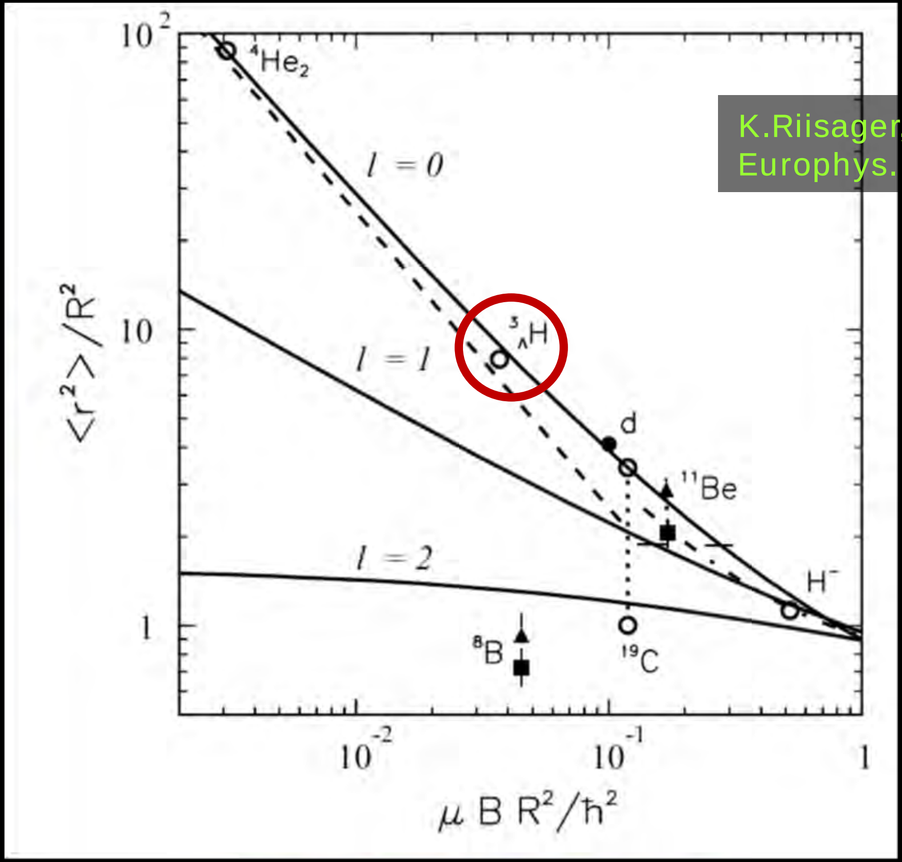




The $^3_\Lambda$H Puzzle: Part 1 - Λ Binding Energy

- $^3_\Lambda$H is most fascinating halo nucleus
  - Binding energy ≈174keV ⇒ Characteristic length of two-body s-wave halo system small

$$\langle \Delta r^2 \rangle = \hbar^2 / (4\mu B) \xrightarrow{^3_\Lambda \mathrm{H}} 9\,\mathrm{fm}$$

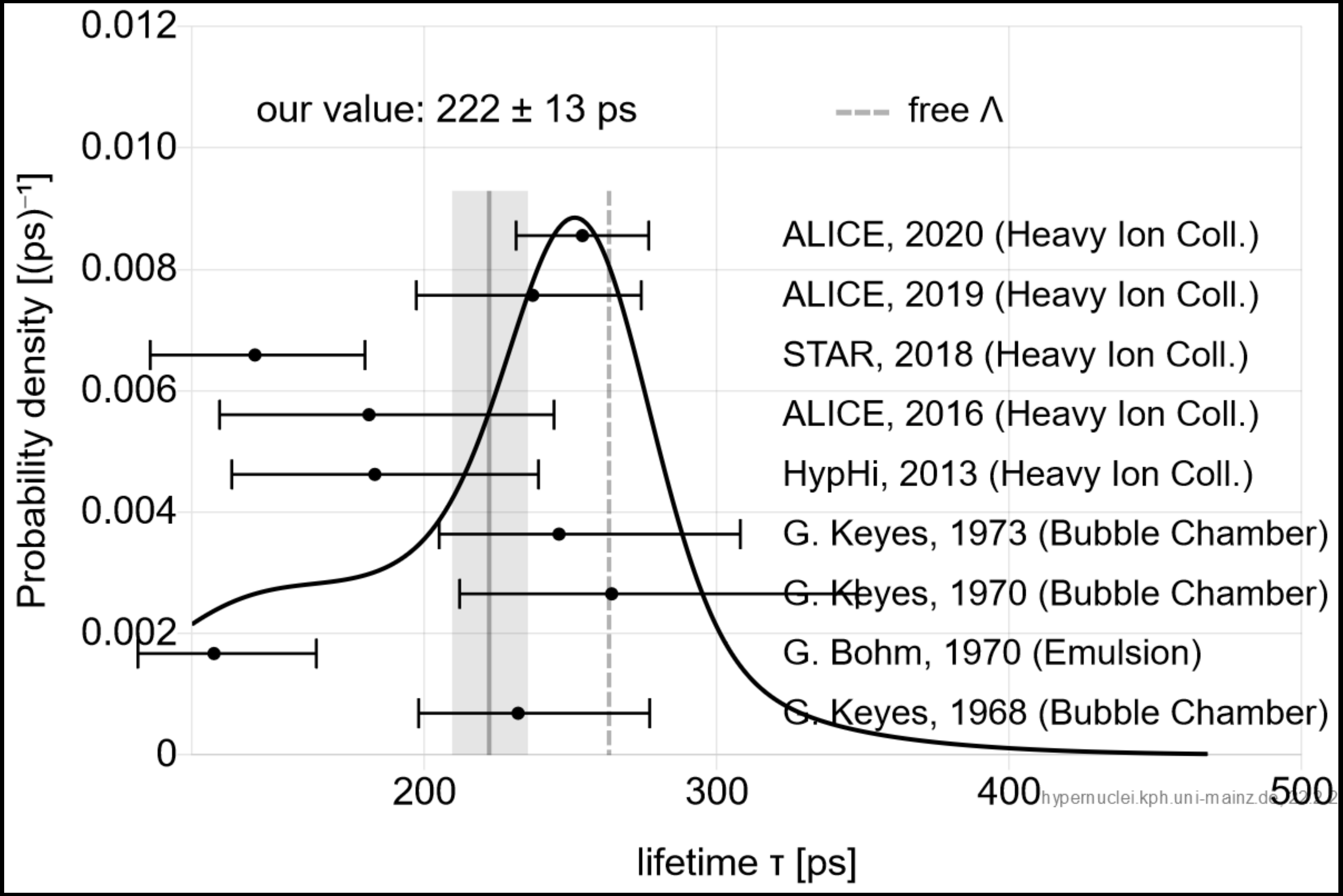


ratio of halo and core-potential square radii

scaled separation energy

K.Riisager,D.V.FedorovandA.S.Jensen, Europhys. Lett 49, 547 (2000)

The $^3_\Lambda H$ Puzzle: Part 2 - Lifetime

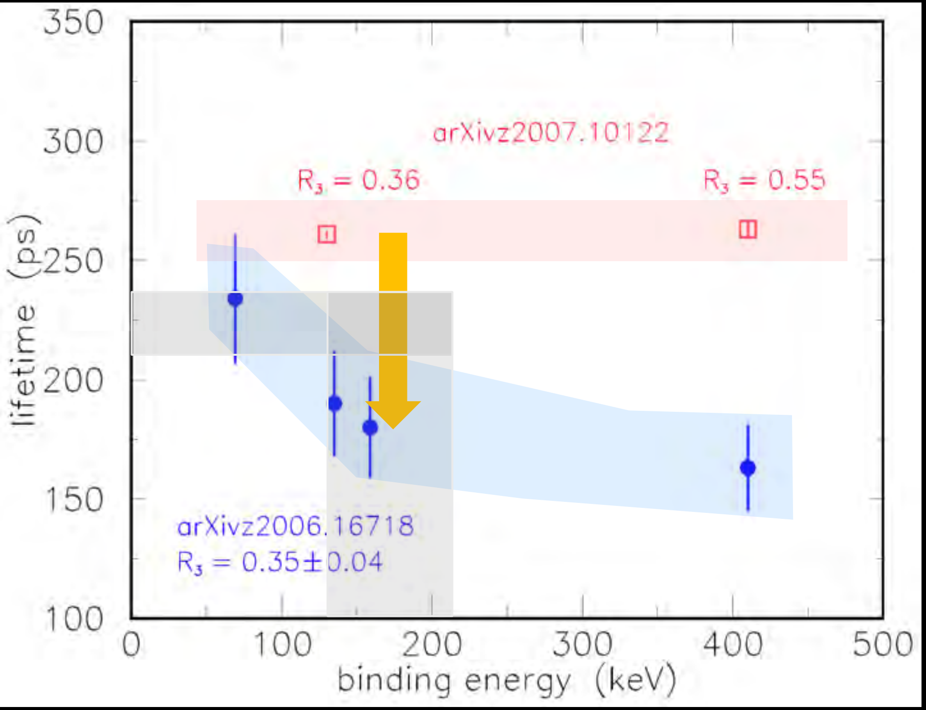


small binding energy ? small lifetime

Is there still a puzzle?

- Hildebrand & Hammer, EFT
  PRC 102, 064002 (2020)
- exp. $R_3 \approx 0.35$ favors small BE

- Obiol et al., EFT
  PLB 811, 135916 (2020)
  - π distorted waves and
  - ΣNN admixture important
  - $\Rightarrow$ strong relation between BE and τ
- Precise mearsurements of BE *and* τ will provide a stringent test of models



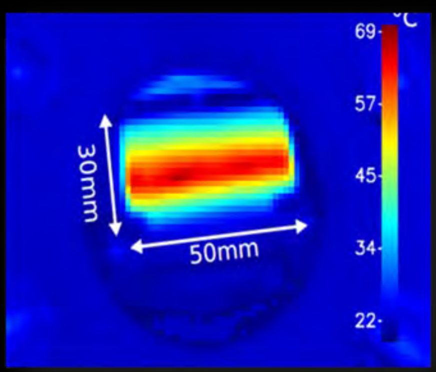
Approaching the $^{3}_{\Lambda}H$ Puzzle

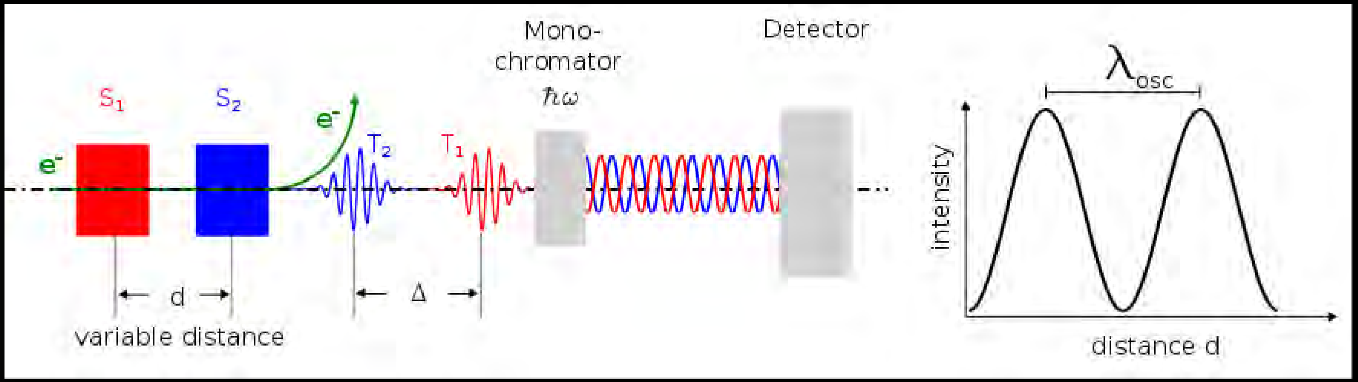
binding energy

- New precise and accurate mass measurement at MAMI in 2021/2022
- *Mainz & Sendai*
  - Make use of excellent beam quality at MAMI
  - Precision *absolute* energy calibration interference of undulator radiation

lifetime

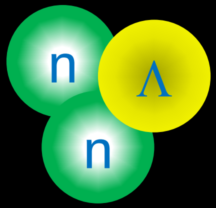
- new lifetime measurements
  - 2021: ELPH (γ, K^{+})
  - 2022: HYPHI (FAIR Phase 0)
  - 2023: ALICE – end run 3: 200x stat.
  - 202x: J-PARC (π^{-}, K^{0})





The nnΛ Puzzle

Does this "Femto Neutron Star" really exist?

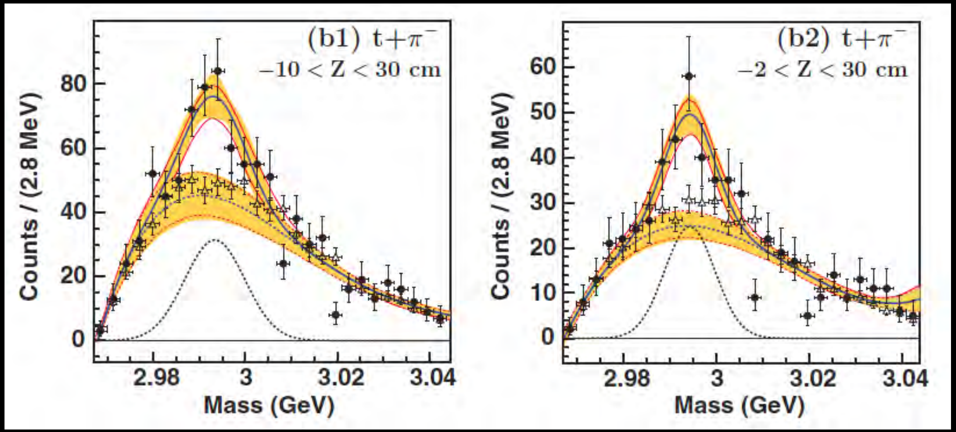


$^{3}_{\Lambda}n$

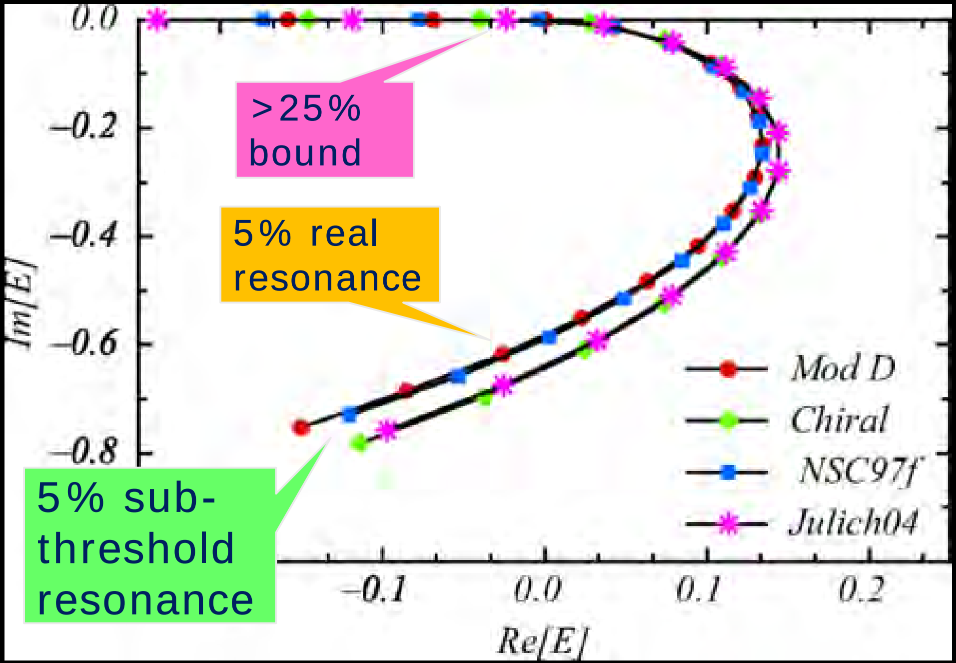
The nnΛ Puzzle

- Such a state has been suggested by the HypHI collaboration
- weak decay nnΛ→π^--^{3}H
  ⇒ bound state
- Statistical Decay Model $^6_\Lambda$He* at E_x=40MeV
  - Λ 30.7% nnΛ 17.3%
  - $^3_\Lambda$H 13.9% $^4_\Lambda$H 29.2%
  - $^4_\Lambda$He 3.9% $^5_\Lambda$He 4.8%
- but: all modern state of the art ab initio theories do not allow a bound nnΛ state

- Do we really understand the Λ–neutron interaction?
  - N-N scattering: 4000 data
  - Y-p scattering: 100 data
  - Y-n scattering: 0 data



C. Rappold et al., Phys. Rev. C 88 , 041001(R) (2013)

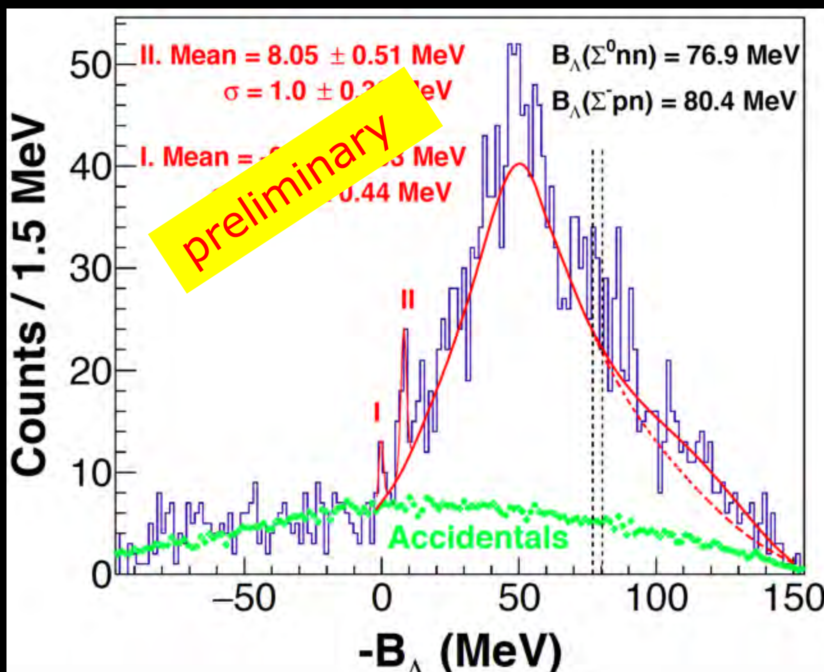


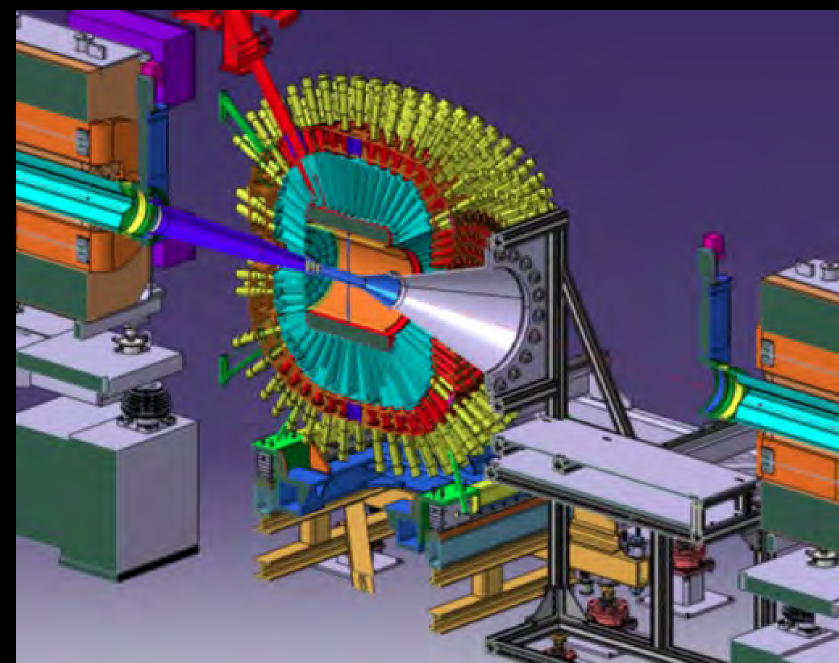
Iraj R. Afnan and Benjamin F. Gibson
Phys. Rev. C 92, 054608

Approaching the nnΛ

- 2018: J-Lab E12-17-003
  - $^{3}H(e,e'K^{+})(nn\Lambda)$
  - missing mass experiment
  - Preliminary results: *neither solidly confirm nor rule out tnnΛ*

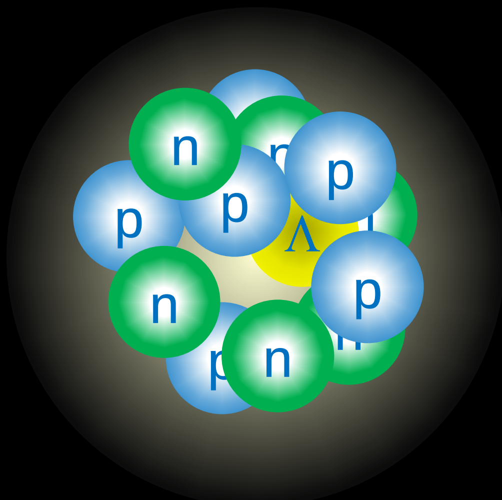
- 2022: FRS+WASA for S447
  - $^{6}Li+^{12}C$
  - for d+π 2 times better mass resolution
  - 8 times better S/BG ratio

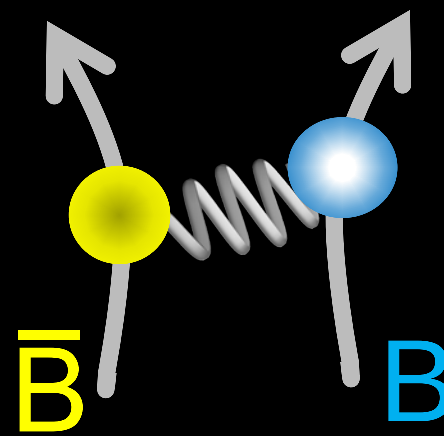




The existence of this „femto-neutron star" would require to re-think our understanding of three-body interactions

Task2: $\bar{Y}$ – A interaction



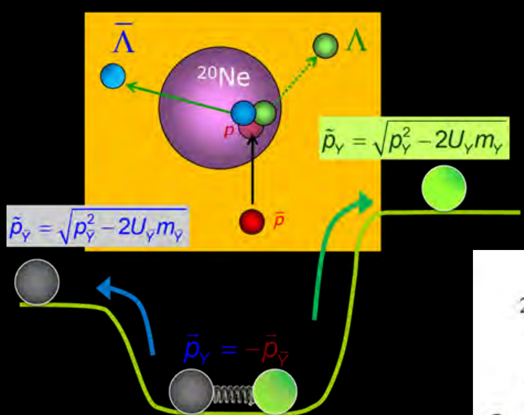


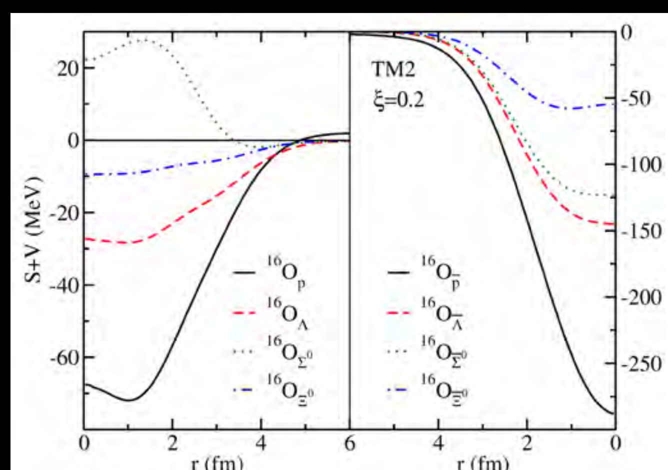
$^{A}_{\bar{\Lambda}}Z$

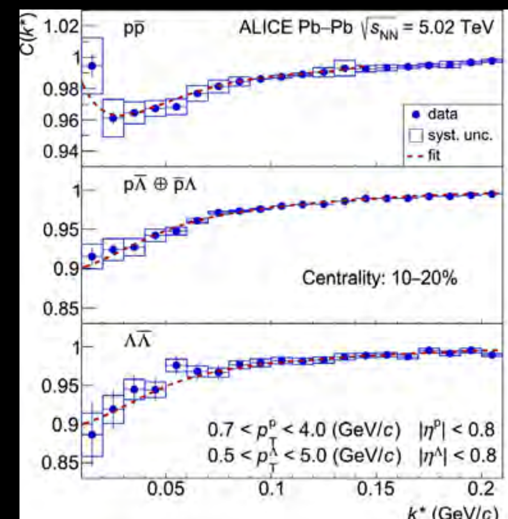
$\bar{Y}$-N and $\bar{Y}$-Y

Antihyperons in Nuclei

- Baryon-antibaryon interactions can be studied by two-particle correlation functions in HI
- PANDA will measure the effective potential of $\bar{\Lambda}$ hyperons by the exclusive ^{20}Ne($\bar{p}$,$\bar{\Lambda}\Lambda$) reaction during PHASE-1

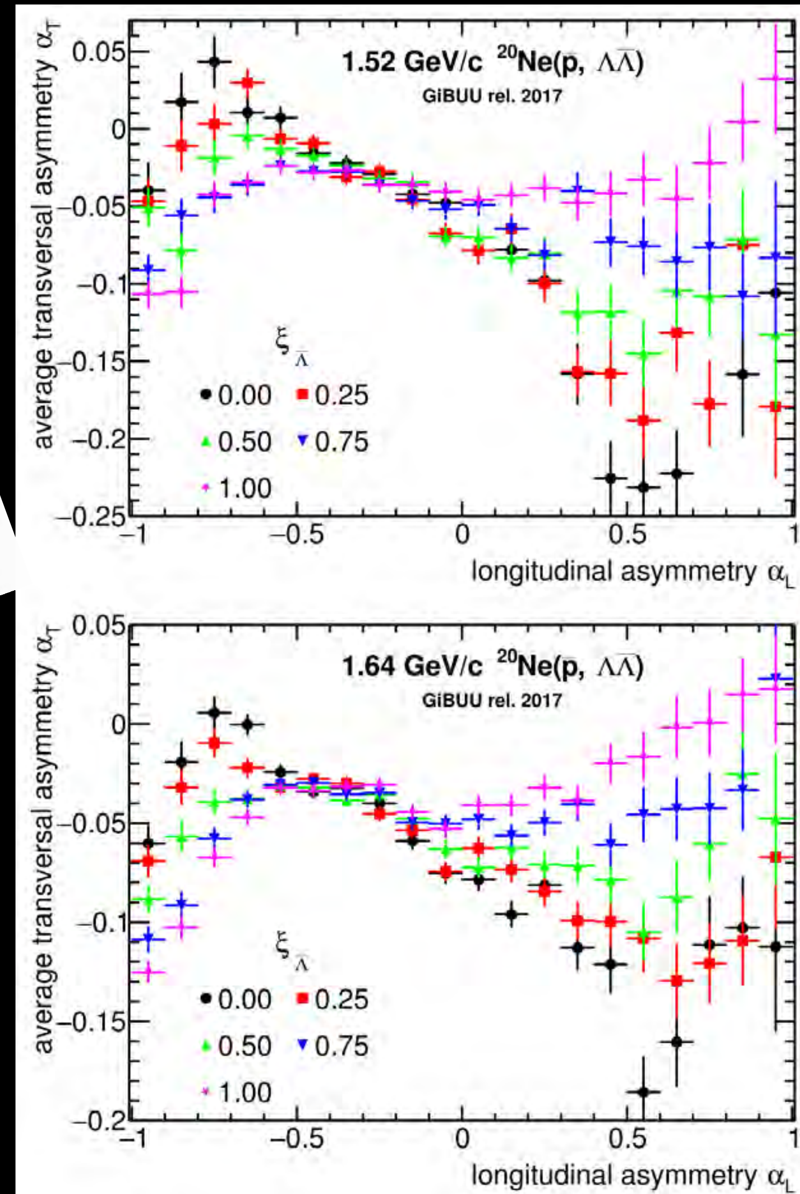






Jaroslava Hrtánková and Jirí Mareš
J. Phys.: Conf. Ser. 599 012007

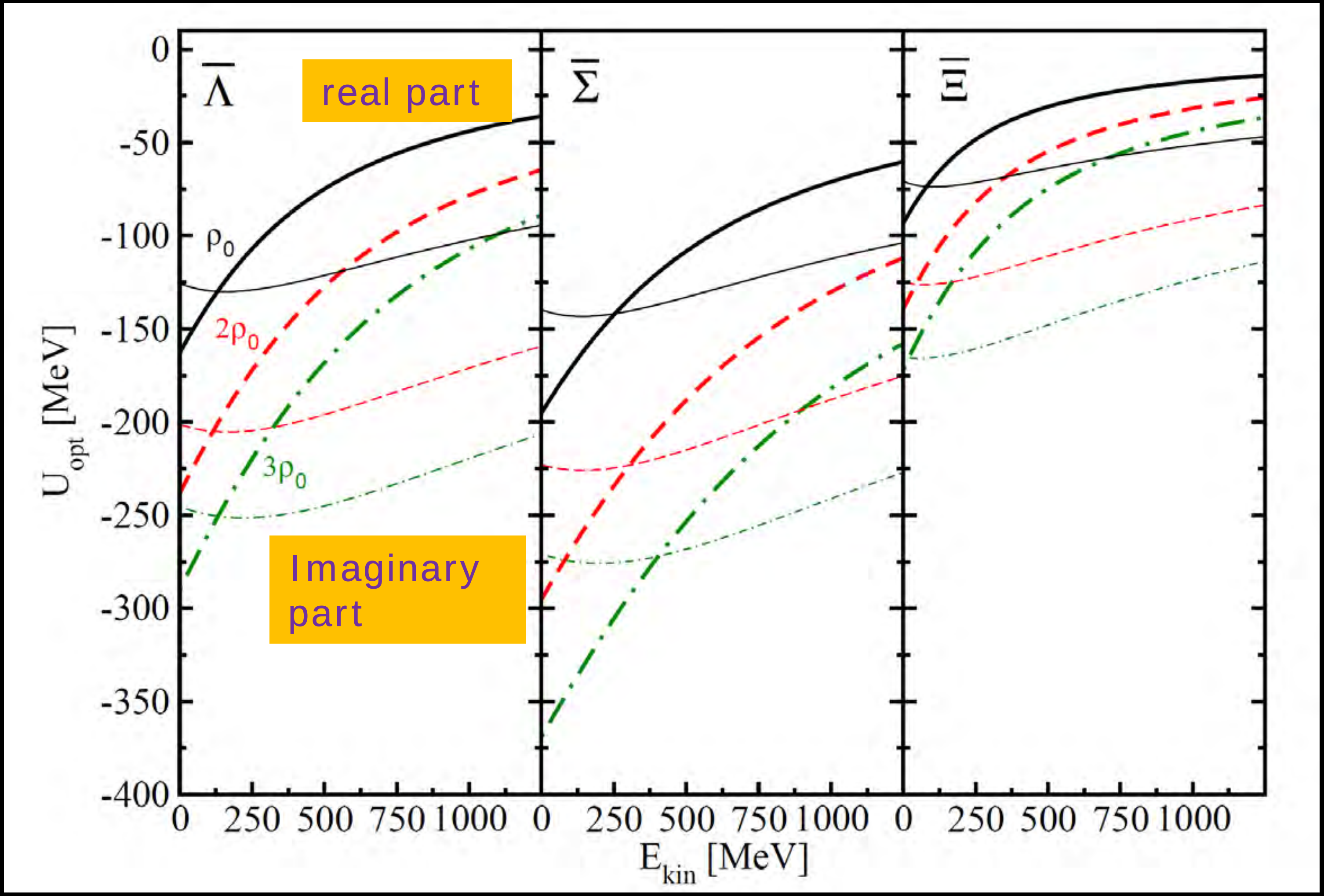
PANDA Phase One



- Many things to study
  - Influence of Coplanarity
  - Other targets (Ar)
  - ...
  - Analysis tools

The Non-Linear Derivative model

Combines RMF & MDI



T. Gaitanos, A. Chorozidou, NP (in print) arXiv:2101.08470

- Kaonic system
- This workshop

Hypernuclei with stopped K^-

- ..old story...

Observed:
π^- decay

200 stopped K^-/s

Table 1
Comparison of ${}^{4}_{\Lambda}H$ production rates by stopping K^- mesons

KEK (Tokyo)		European K^- Collaboration	
Target	Rate ($\times 10^{-3}$)	Target	Rate ($\times 10^{-3}$)
^{7}Li	30		
^{9}Be	15.7		
^{12}C	10.0	C, N, O	7.3
^{16}O	4.7		
^{40}Ca	< 2.7	Ag, Br	2.4

C,N,O/Ag,Br≈
8/58≈0.13

Table 2
Production rates of ${}^{3}_{\Lambda}H$ and ${}^{5}_{\Lambda}He$ measured by the European K^- Collaboration

Target	${}^{3}_{\Lambda}H$ rate ($\times 10^{-3}$)	${}^{5}_{\Lambda}He$ rate ($\times 10^{-3}$)
C, N, O	1.62	21.6
Ag, Br	0.54	1.4

D.H. Davies Nucl. Phys. A 754 (2005) 3c

H. TAMURA *et al.*

TABLE $^{3}_{\Lambda}$H I. Elementary processes to form the Λ compound nucleus from K^- absorption at rest. The branching ratio of each process, $R^{(i)}$, is obtained from the experimental branching ratio of the $\Lambda\pi$ and $\Sigma\pi$ productions, $BR^{(i)}$, and the conversion probability of Σ (0.5). In the conversion of Σ^0, a factor of 0.5 is assumed as the branching ratio between $\Sigma^0 p$ and $\Sigma^0 n$ reactions. In the present model, we considered only one compound hypernucleus for each process as shown in the last column.

		$R^{(i)}$		Compound nucleus	
i	Elementary process	$BR^{(i)}$	Conversion probability	^{12}C target	^{16}O target
1	$K^- p \to \Lambda\pi^0$	0.044		$^{12}_{\Lambda}$B*	$^{16}_{\Lambda}$N*
2	$K^- n \to \Lambda\pi^-$	0.087		$^{12}_{\Lambda}$C*	$^{16}_{\Lambda}$O*
3	$K^- p \to \Sigma^-\pi^+,\ \Sigma^- p \to \Lambda n$	0.168	×0.5	$^{11}_{\Lambda}$Be*	$^{15}_{\Lambda}$C*
4	$K^- p \to \Sigma^0\pi^0,\ \Sigma^0 p \to \Lambda p$	0.129	×0.5×0.5	$^{11}_{\Lambda}$Be*	$^{15}_{\Lambda}$C*
5	$K^- p \to \Sigma^0\pi^0,\ \Sigma^0 n \to \Lambda n$	0.129	×0.5×0.5	$^{11}_{\Lambda}$B*	$^{15}_{\Lambda}$N*
6	$K^- p \to \Sigma^+\pi^-,\ \Sigma^+ n \to \Lambda p$	0.377	×0.5	$^{11}_{\Lambda}$B*	$^{15}_{\Lambda}$N*
7	$K^- n \to \Sigma^-\pi^0,\ \Sigma^- p \to \Lambda n$	0.033	×0.5	$^{11}_{\Lambda}$B*	$^{15}_{\Lambda}$N*
8	$K^- n \to \Sigma^0\pi^-,\ \Sigma^0 p \to \Lambda p$	0.017	×0.5×0.5	$^{11}_{\Lambda}$B*	$^{15}_{\Lambda}$N*
9	$K^- n \to \Sigma^0\pi^-,\ \Sigma^0 n \to \Lambda n$	0.017	×0.5×0.5	$^{11}_{\Lambda}$C*	$^{15}_{\Lambda}$O*

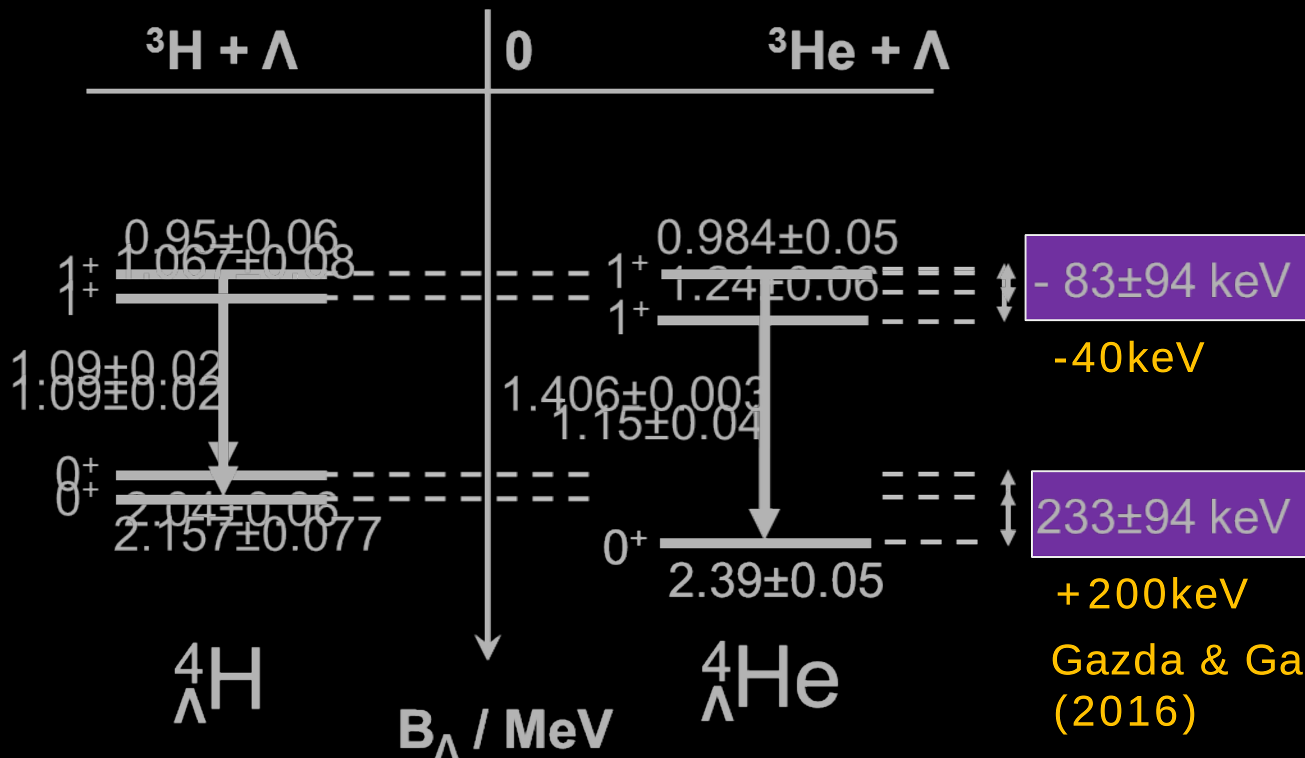
	$^{3}_{\Lambda}$H	$^{4}_{\Lambda}$H	$^{4}_{\Lambda}$He	$^{5}_{\Lambda}$He	$^{6}_{\Lambda}$He	$^{7}_{\Lambda}$He	$^{7}_{\Lambda}$Li	$^{8}_{\Lambda}$Li	$^{9}_{\Lambda}$Li	$^{7}_{\Lambda}$Be	$^{8}_{\Lambda}$Be	$^{9}_{\Lambda}$Be	$^{10}_{\Lambda}$Be
g.s.	2.6 9.1	2.1 4.0	2.1 1.1	17.3 18.0	5.6 10.4	0.2 1.1	2.1 1,2	2.6	0.3	0.1	0.8	2.5	0.5
1ex		5.4 10.2	5.3 2.5			0.1 2.2	3.6 2.4		0.4			6.5	0.8
2ex						0.2 3.3	4.2 3.5		0.2			4.3	0.7
3ex							5.1 4.6		0.1				1.0

$^{11}_{\Lambda}$B* at $E_x = 40$MeV

$^{8}_{\Lambda}$Li* at $E_x = 40$MeV

CSB in A=4 Hypernuclei

- before 2015: not compatible with *all* state-of-the-art calculations



- strong, spin-dependent charge symmetry breaking (CSB) in A = 4 mirror hypernuclei !
- Compatible with *ab initio* calculations

Backbone of THEIA Workshops

- First workshop in Speyer Nov. 2019
- https://indico.gsi.de/event/8950/
- Second workshop planned in Oct 2020
- $\Rightarrow$ replaced by web-seminar

- https://indico.gsi.de/category/513/
- weekly meeting each Wednesday
- Usually 2 talks

- Future meetings
  - 2021: ???
  - 2022: HYP in Prague
  - 2023: ? ECT* ?

REIMAI project
„Doubly strange systems"
JAEA & Mainz
Kiyoshi Tanida & JP

Important task for you

- Please acknowledge STRONG2020 and THEIA
- “This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement STRONG – 2020 - No 824093”.
- Likewise, for publications, infrastructures, other related results, please put the following acknowledgement:
- “This [infrastructure][publication/article][insert type of result] is part of a project that has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement STRONG – 2020 - No 824093”.


Thank you
for your attention

Grant Agreement

- Grant Agreement N°824093
  - 1 June2020 to 31 May 2023
  - Budget 10 M €
- 32WorkPackages(WPs)
  - ManagementandCoordination
  - DisseminationandCommunication
  - 7 TransnationalInfrastructures(TA)
    - COSY,MAMI,ELSA,GSI,LNF,CERN,ECT*
  - 2 VirtualInfrastructures(VA)
  - 7 NetworkingActivities(NA)
  - 14 JointResearchActivities(JRA)