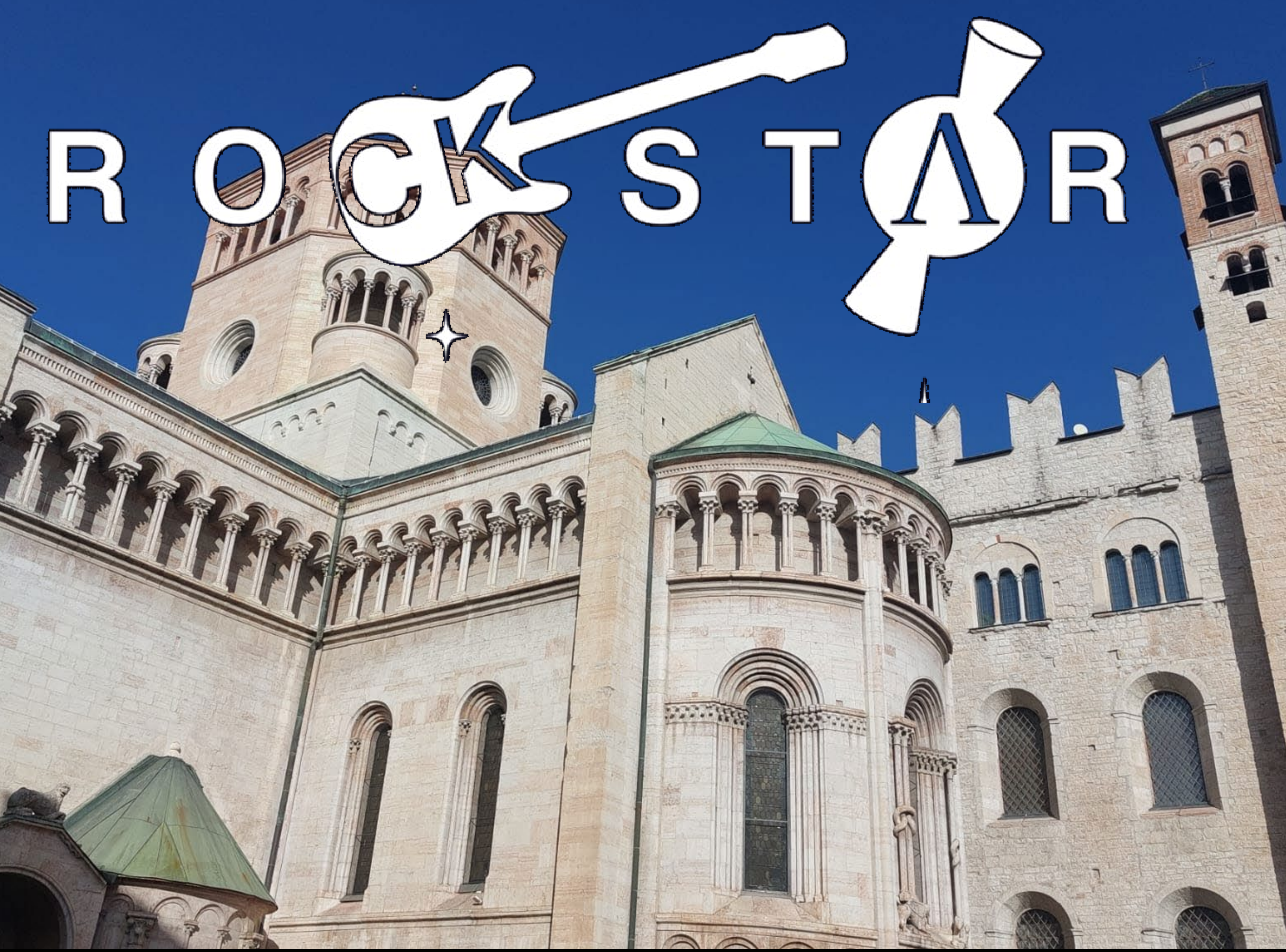
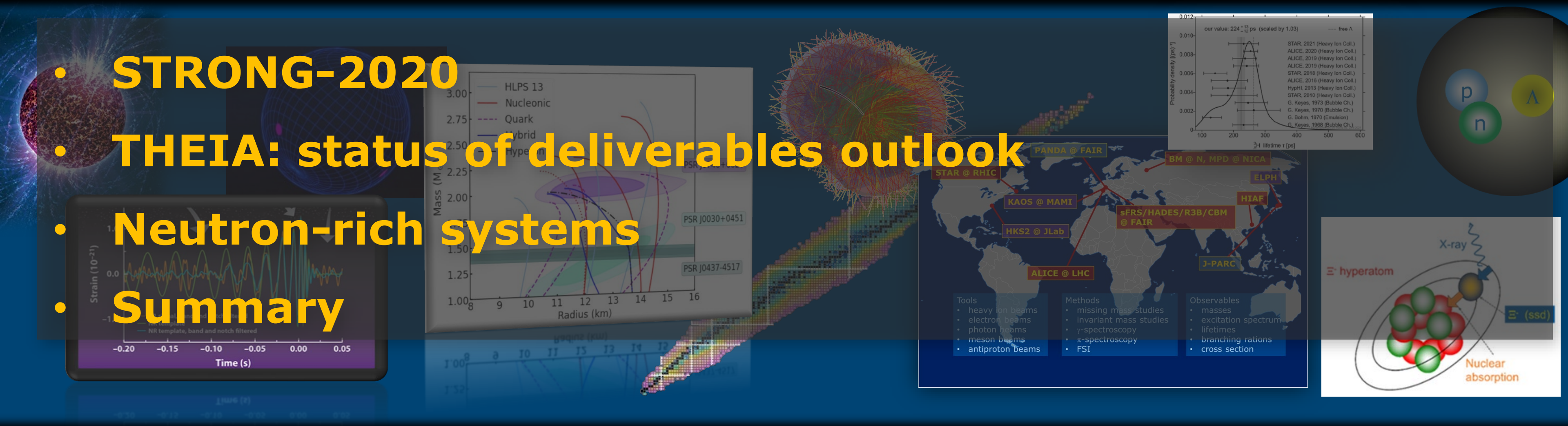
ROCKSTAR



Trento
9-13 October 2023

The European Networking Activity THEIA: achievements and prospects



- STRONG-2020
- THEIA: status of deliverables outlook
- Neutron-rich systems
- Summary

Josef Pochodzalla

JGU Mainz & Helmholtz-Institut – Mainz – European Union

JG|U
HIM Helmholtz-Institut Mainz
DFG Deutsche Forschungsgemeinschaft German Research Foundation
STRONG 2020

STRONG 2020 @ Horizon2020

- “The strong interaction at the frontier of knowledge: fundamental research and applications“
  - the partonic structure of hadrons
  - exotic hadronic states
  - properties of dense quark matter
  - properties of hot and dense quark-gluon plasm
  - precision tests of the Standard Model

- 32 work packages
  - 7 transnational Access Activities (TA)
  - 2 Virtual Access Activities (VA)
  - 7 Networking Activities (NA) ⇒ THEIA
  - 14 Joint Research Activities (JRA)
  - 1 Management and Coordination
  - 1 Cummunication and Outreach

- 2019 to July 2024 (4 years + extension)
- Budget 10M€ ⇒ THEIA 200k€

NA5 - THEIA @ STRONG 2020

- Objectives of THEIA (NA5)
  - *"Address the "neutron stars hyperon puzzle" (contradiction between the observation of 2-solarmasses neutron stars and microscopical predictions of a softening of the nuclear equation-of-state due to the presence of strange-quark hadrons) through combined theoretical and experimental studies of (anti)hypernuclei and bound strange-meson systems produced in hadronic collisions at various c.m. energies."*

- Each Activity within STRONG2020 had to define so called Workpackages, Deliverables and Milestones and the time of delivery

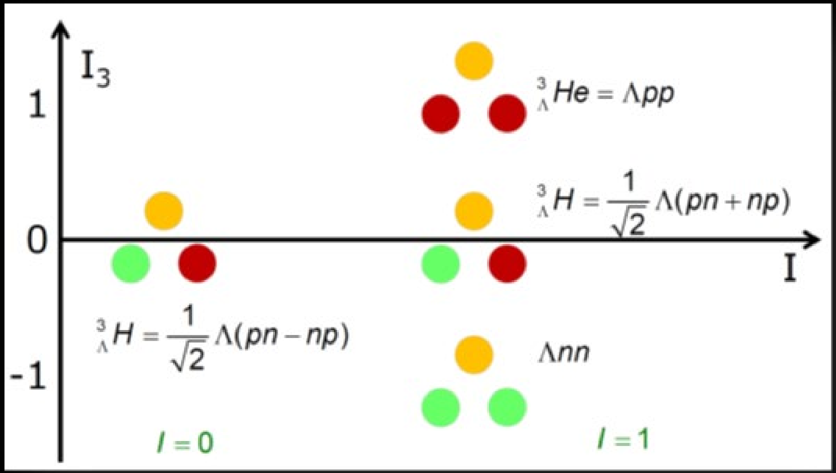
- Achievements are evaluated by the EU Project Officer

Deliverables and Milestones of NA5-THEIA

- D16.1: Study of A=3 hypernuclei ${}^{3}_{\Lambda}$H and ${}^{3}_{\Lambda}$n
  - month 36 - report
  - MS20: First data taking by WASA@GSI/FAIR searching for nnΛ
- D16.2: Study of antihyperons in nuclei; PANDA software tools
  - month 42 - demonstrator
  - MS21: Design report for antihyperons in nuclei
- D16.3: Theoretical and experimental studies of bound mesonic systems
  - month 30 - report
  - MS22: SIDDHARTA-2 progress report
- D16.4: Hypernuclear database is online and will continually updated
  - public/webpage
- Most important for the network: annual workshops

D16.1: A=3 Hypernuclei

- Three-baryon forces are essential to describe complex nuclei
- A=3 hypernnuclei are important cornerstones



- I=0, $J^p=1/2^+$ is only nucleus known for sure to be bound
- Observed branching ratio

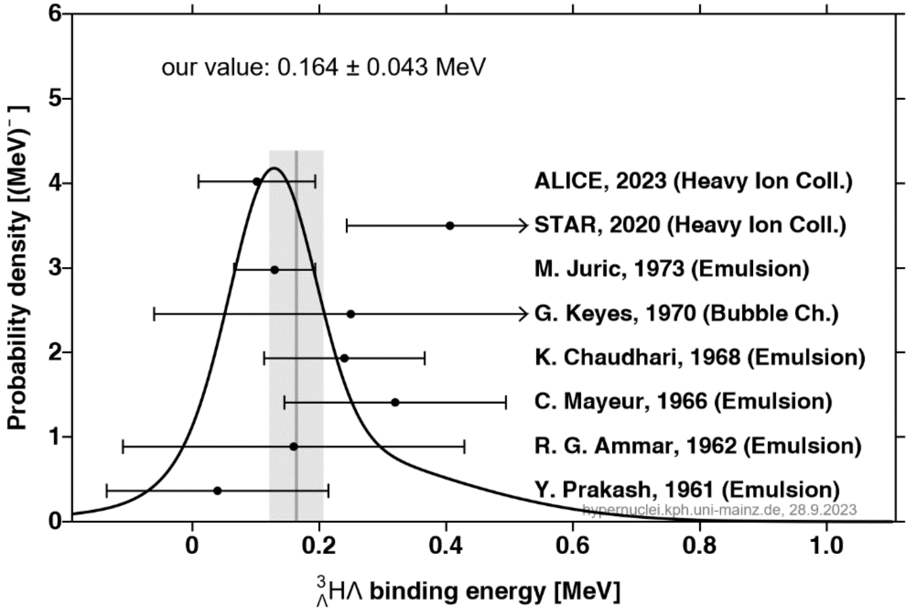
$$R_3 = \frac{\Gamma(^3_\Lambda H \rightarrow {}^3He + \pi^-)}{\Gamma(^3_\Lambda H \rightarrow X + \pi^-)} = 0.35 \pm 0.04$$

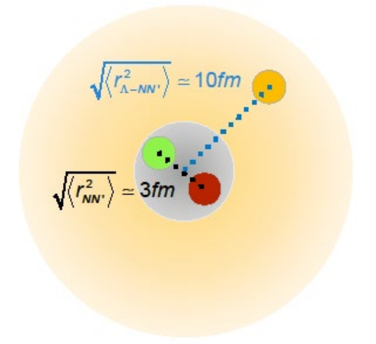
and small binding energy suggest groundstate spin $J^P=1/2^+$

- No experimental evidence for bound excited state
- No conclusive evidence for existence of neutral nnΛ

D16.1:Hypertriton binding energy

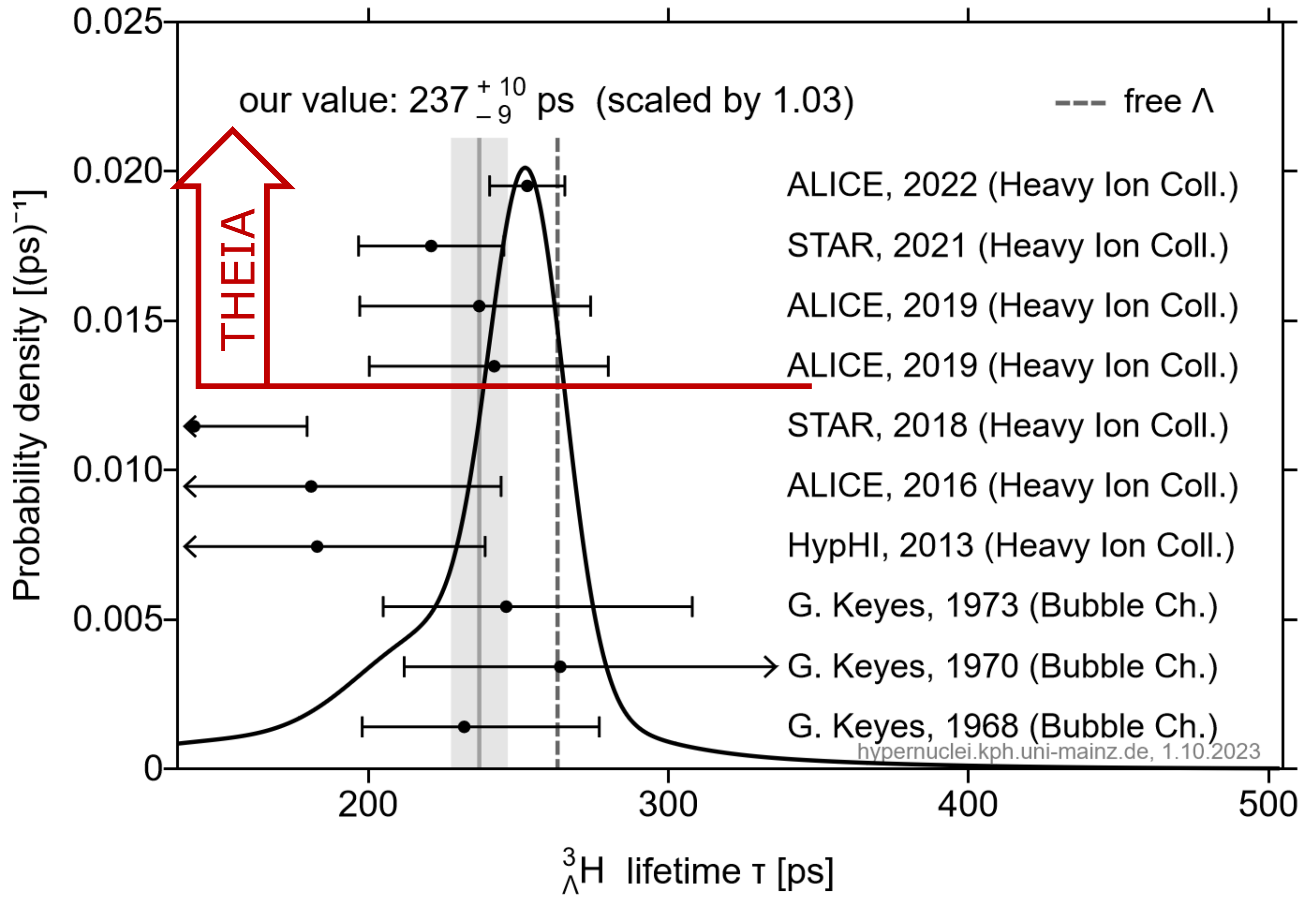
- Present situation
  - Emulsion data suggest very small binding energy ~130keV
  - New data from STAR show stronger binding ~$406 \pm 120_{stat} \pm 110_{syst}$ keV
  - Recent Pb+Pb ALICE result $102 \pm 63_{stat} \pm 67_{syst}$ keV





- Two-body s-wave halo: $\left\langle \Delta r^2 \right\rangle = \hbar^2 / (4 \mu B) \rightarrow 9\ fm$
- giant Λ-halo ⇒ large reaction cross section for $^{3}{}_{\Lambda}$H
  - R3B@FAIR by NuStar
  - WASA-FRS-HypHI

D16.1: Lifetime of $^{3}_{\Lambda}H$



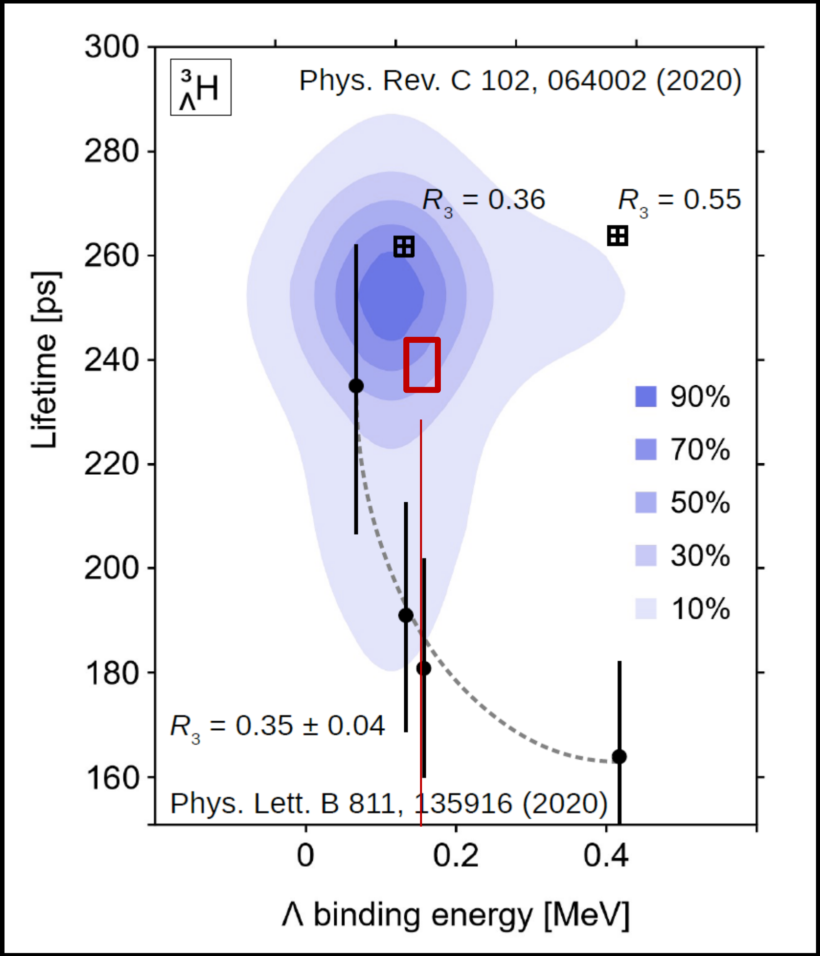
- Remark:
  - Ideograms are a good tool to visualize probability distributions ad deviations among data
  - in future supplement ideograms by *conflation of probability distributions* [1]https://arxiv.org/pdf/1005.4978.pdf

D16.1: Is there still a hypertriton puzzle?

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

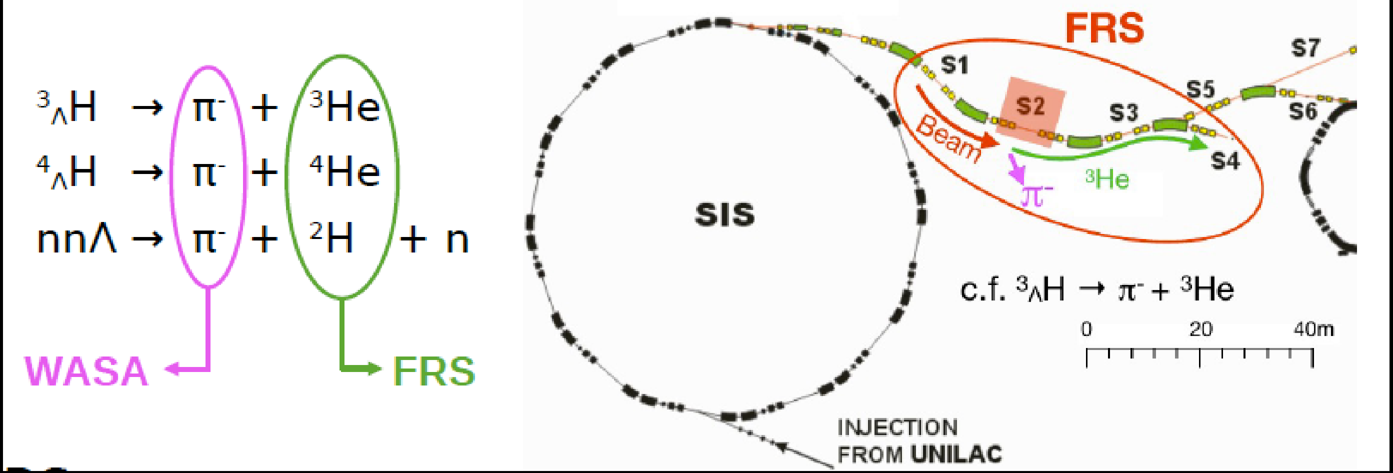
- Obiol, Gal et al., EFT
  - PLB 811, 135916 (2020)
  - π distorted waves and
  - ΣNN admixture important
  - $\Rightarrow$ strong relation between BE and τ

- Precise measurements of BE *and* τ will provide a stringent test of models



MS20: First data taking by WASA@GSI/FAIR

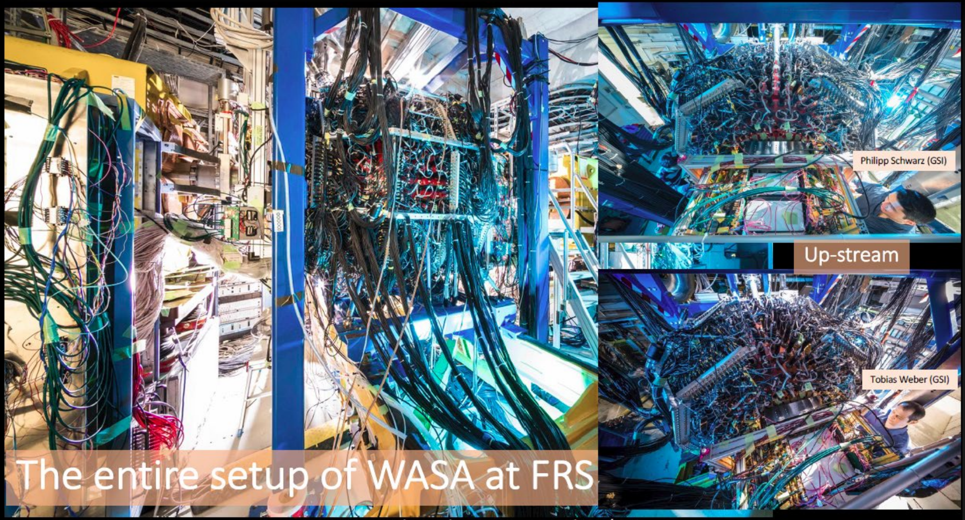
- Hypernnuclei are identified by two-body decays: π^- ∧ fragment
- Data taking Jan. – March 2022



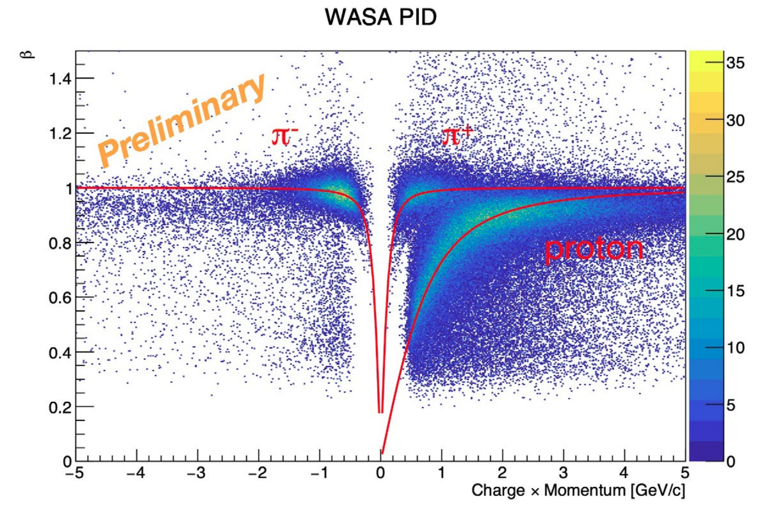
$^{3}_{\Lambda}\mathrm{H} \rightarrow \pi^- + {}^{3}\mathrm{He}$

$^{4}_{\Lambda}\mathrm{H} \rightarrow \pi^- + {}^{4}\mathrm{He}$

$nn\Lambda \rightarrow \pi^- + {}^{2}\mathrm{H} + n$



Photos by Jan Hosan and GSI/FAIR



- Analysis ongoing – waiting for first results

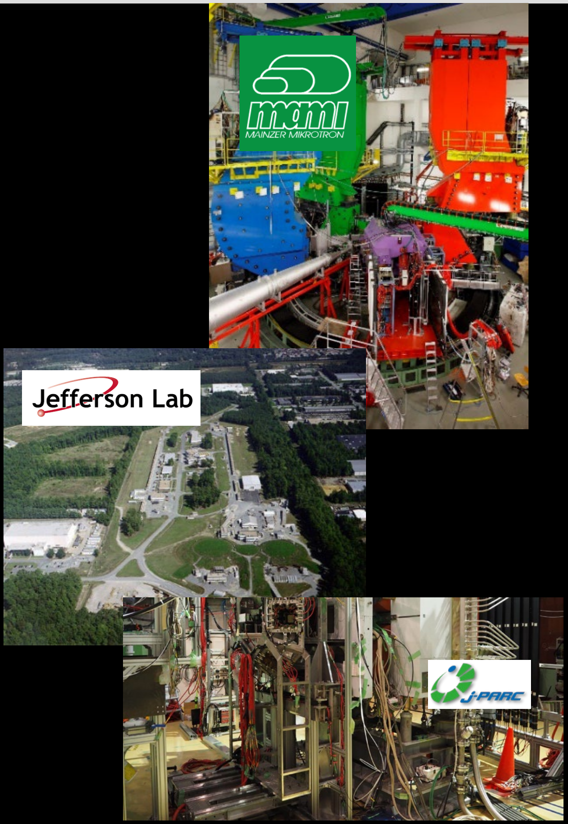
D16.1: Future mass measurements

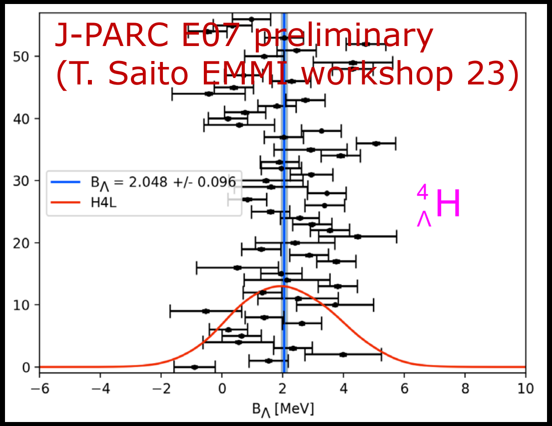
- A the Mainz Mikrotron (MAMI), a new high precision pion spectroscopy experiment aims at a measurement with a systematic uncertainty which is comparable to the statistical error of ≤ 20 keV.

- At JLab, a missing-mass measurement of the hypertriton mass with a accuracy of less than 100 keV has been proposed.

- The J-PARC E07 collaboration plans to analyse hypertriton decays in their emulsion plates. Using Monte Carlo simulations, the statistical and systematic errors for the hypertriton binding energy in this emulsion measurement has been estimated to be approximately 30 keV each.
  - Systematic error?

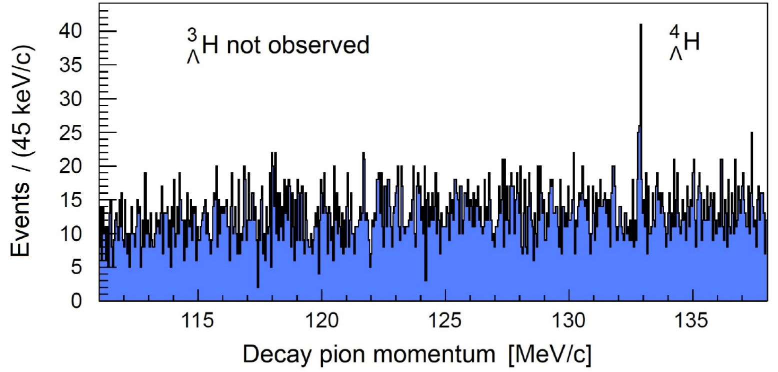
- Improved measurements by heavy ion experiments ALICE and STAR expected

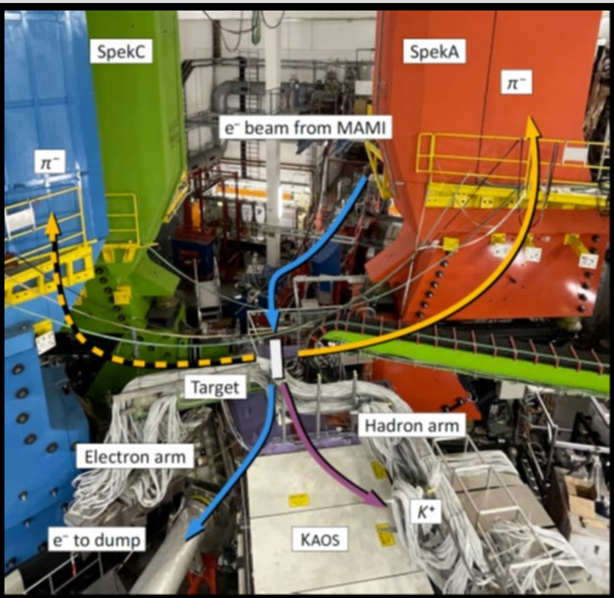




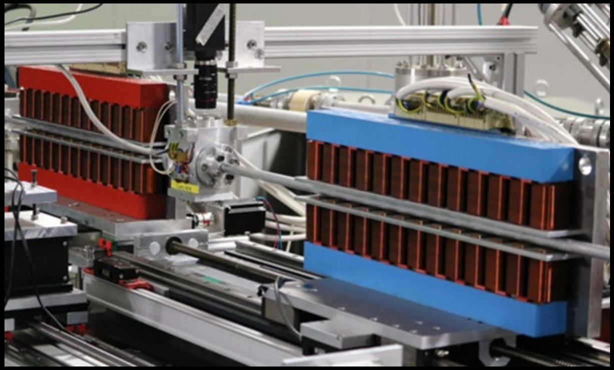
D16.1: Hypernuclei at MAMI

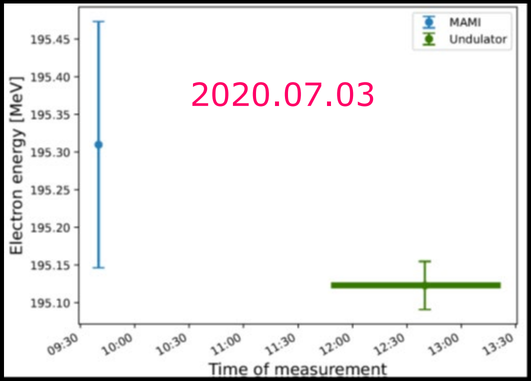
- Pion spectroscopy at MAMI (2012-2014)
  - Two-body pionic decay of hypernuclei
  - High-resolution spectrometers

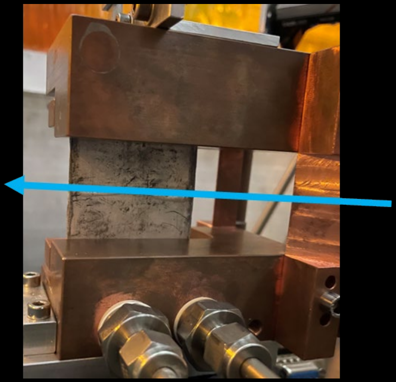




- Necessary Improvements
  - Higher Luminosity → 5cm Lithium target (PhD Philipp Eckert)
  - Absolute momentum → calibration via Undulator Light Interference (PhD Pascal Klag

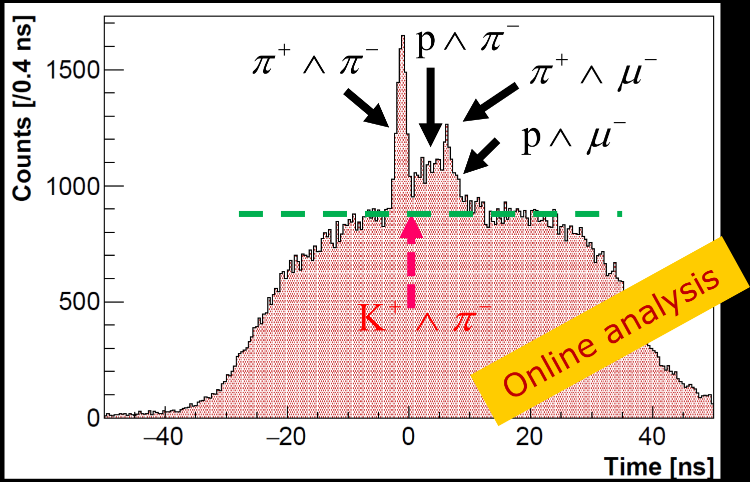




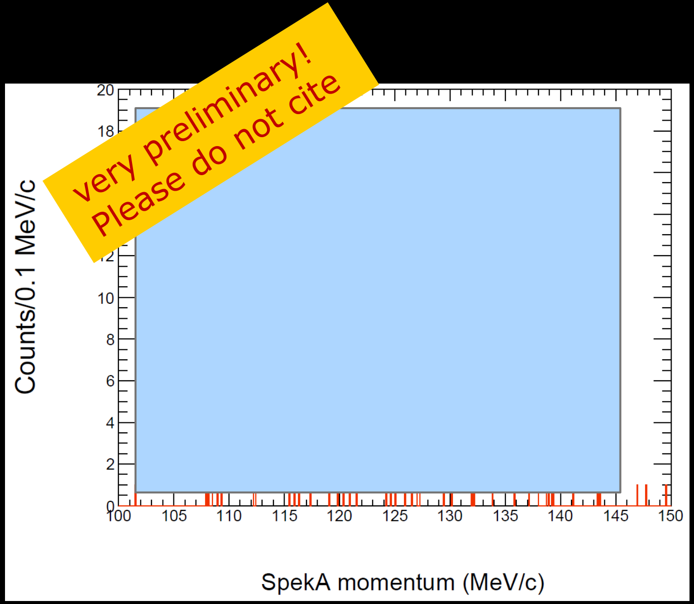


D16.1: Status of the Hypertriton measurement

- Commissioning: July 12 – August 1, 2022
- Data taking: September 22 – October 17, 2022
  - Example 1: raw online timing diagram KAOS-SPEK-A (~6h)

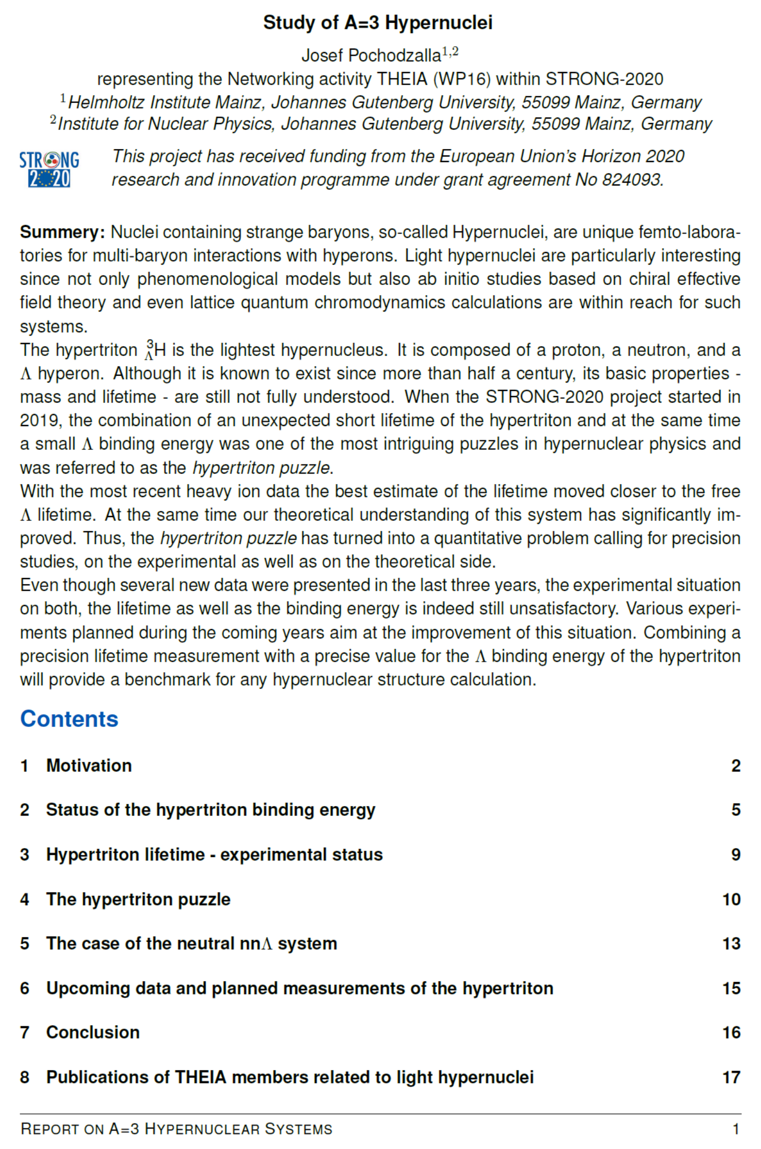


- „Raw“ pion spectrum of SPEK A
  - Momentum scale not calibrated !!
    (reason: new NMR system)
  - Optimization of signal:background
  - please do not cite any numbers!



D16.1: Study of $^{3}_{\Lambda}$H and $^{3}_{\Lambda}$n

- Report delivered September 2022



Study of A=3 Hypernuclei

Josef Pochodzalla[1,2]
representing the Networking activity THEIA (WP16) within STRONG-2020
[1] *Helmholtz Institute Mainz, Johannes Gutenberg University, 55099 Mainz, Germany*
[2] *Institute for Nuclear Physics, Johannes Gutenberg University, 55099 Mainz, Germany*

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093.

Summery: Nuclei containing strange baryons, so-called Hypernuclei, are unique femto-laboratories for multi-baryon interactions with hyperons. Light hypernuclei are particularly interesting since not only phenomenological models but also ab initio studies based on chiral effective field theory and even lattice quantum chromodynamics calculations are within reach for such systems.

The hypertriton $^{3}_{\Lambda}$H is the lightest hypernucleus. It is composed of a proton, a neutron, and a Λ hyperon. Although it is known to exist since more than half a century, its basic properties - mass and lifetime - are still not fully understood. When the STRONG-2020 project started in 2019, the combination of an unexpected short lifetime of the hypertriton and at the same time a small Λ binding energy was one of the most intriguing puzzles in hypernuclear physics and was referred to as the *hypertriton puzzle*.

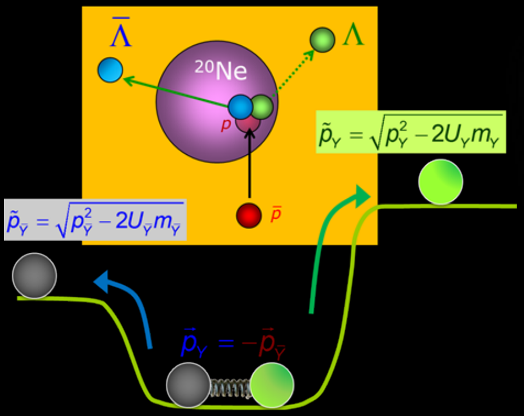
With the most recent heavy ion data the best estimate of the lifetime moved closer to the free Λ lifetime. At the same time our theoretical understanding of this system has significantly improved. Thus, the *hypertriton puzzle* has turned into a quantitative problem calling for precision studies, on the experimental as well as on the theoretical side.

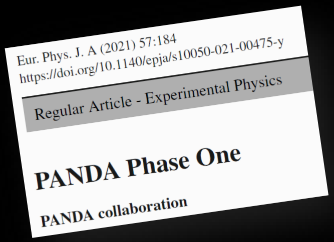
Even though several new data were presented in the last three years, the experimental situation on both, the lifetime as well as the binding energy is indeed still unsatisfactory. Various experiments planned during the coming years aim at the improvement of this situation. Combining a precision lifetime measurement with a precise value for the Λ binding energy of the hypertriton will provide a benchmark for any hypernuclear structure calculation.

Contents

Deliverable 16.2: Antihyperons in Nuclei

- two-body baryon-antibaryon interactions can be studied by two-particle correlation functions in HI
- PANDA will measure the effective potential of Λ hyperons by the exclusive $^{20}\mathrm{Ne}(\bar{p},\bar{\Lambda}\Lambda)$ reaction during PHASE-1 of PANDA
- ongoing work: development of reconstruction software (low momentum Λ and Λ decays !)



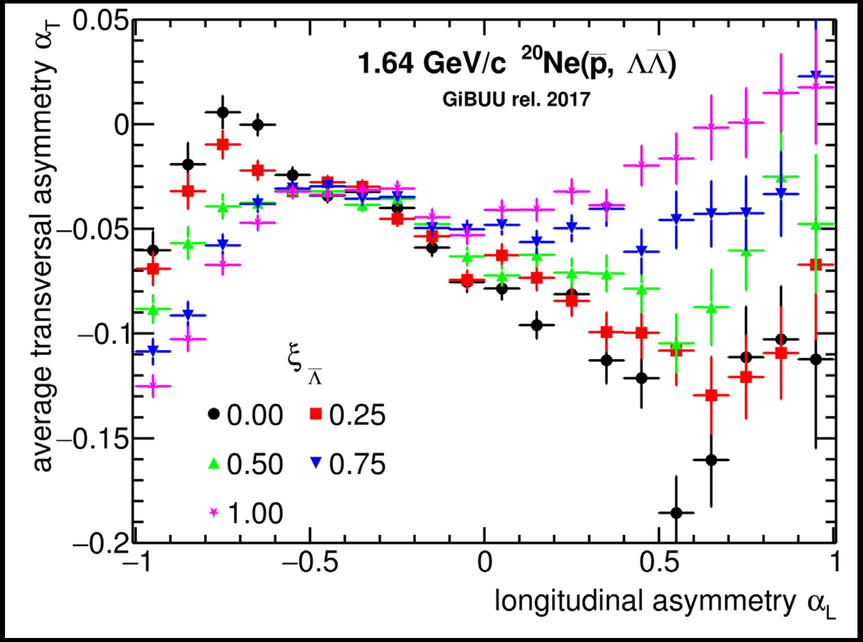


Eur. Phys. J. A (2021) 57:184
https://doi.org/10.1140/epja/s10050-021-00475-y

Regular Article - Experimental Physics

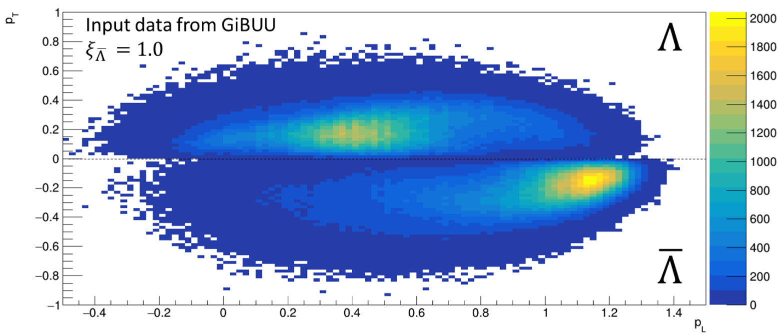
PANDA Phase One

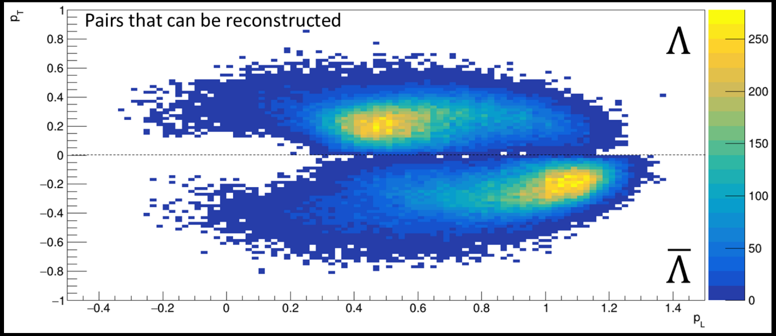
PANDA collaboration

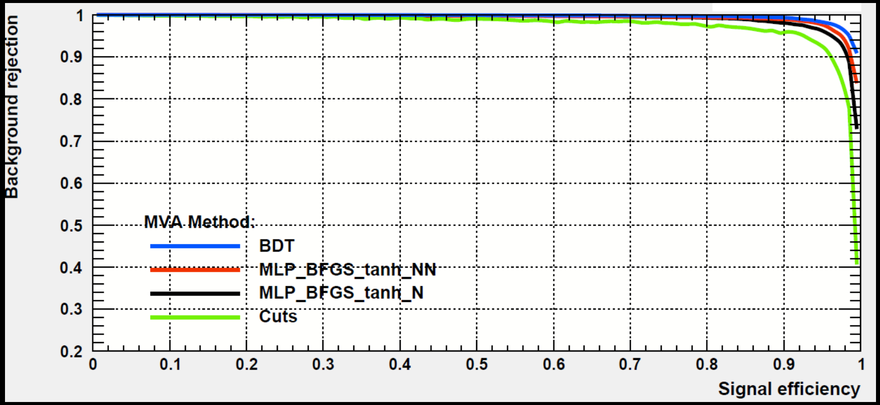


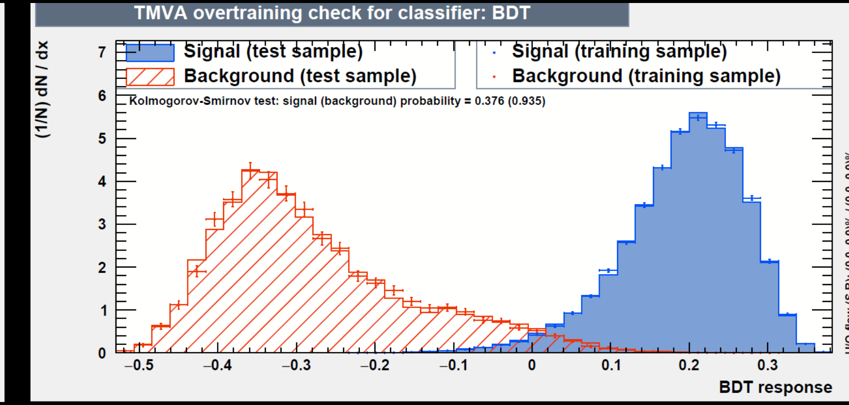
Pair reconstruction by PANDA

- Low momenta Λ and $\bar{\Lambda}$ difficult to reconstruct
  - Pairs are missing where the Λ or $\bar{\Lambda}$ has low momentum
  - Effects $|\alpha_L|>0.5$
- Methods to eliminate background
  - boosted decision tree (BDT)
  - multi-layer perceptron (MLP)
  - Conventional cuts



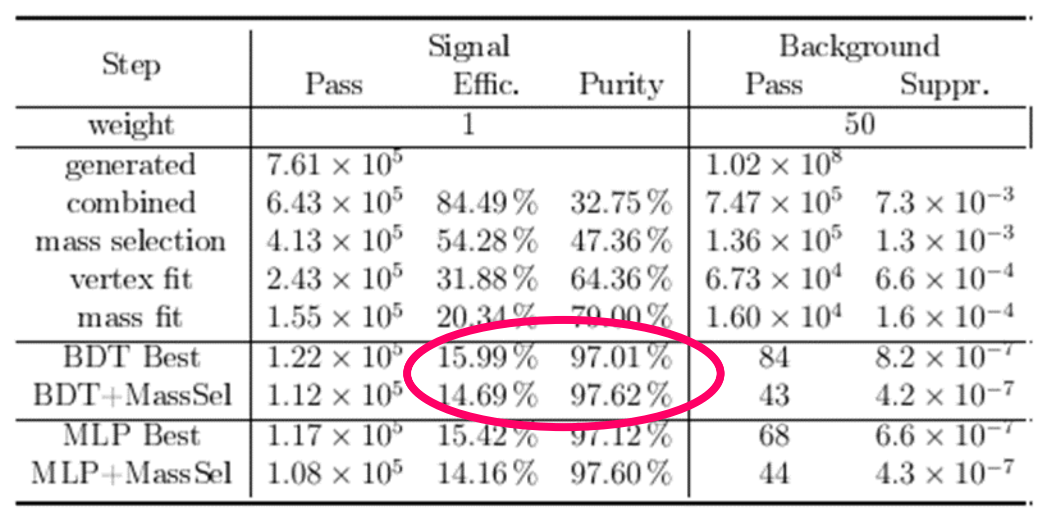




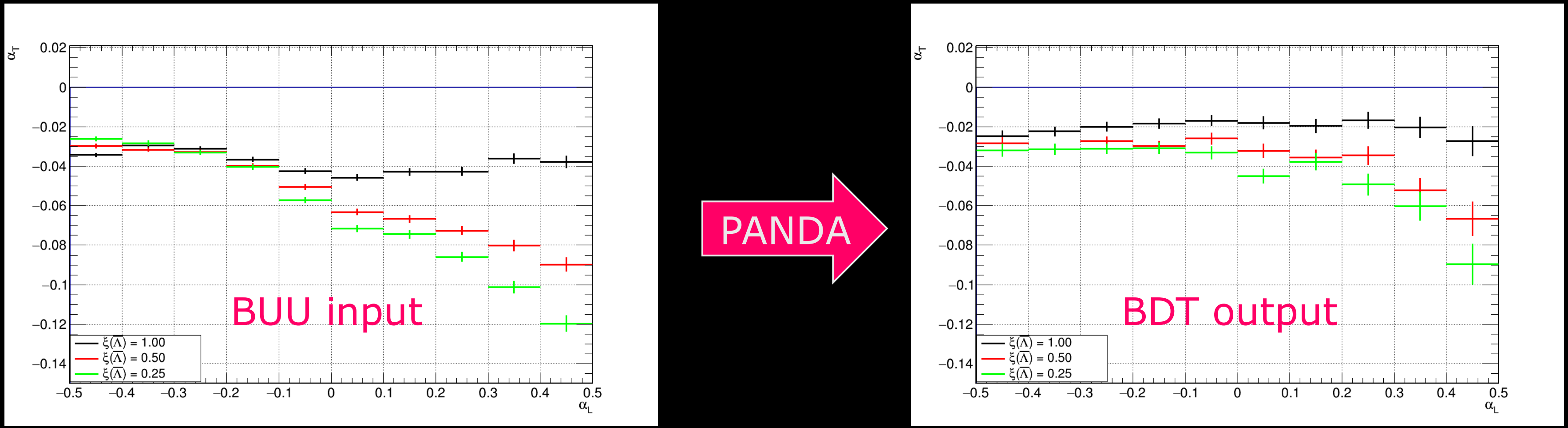


Reconstruction of ΛΛ pairs

- BDT and MLP similar



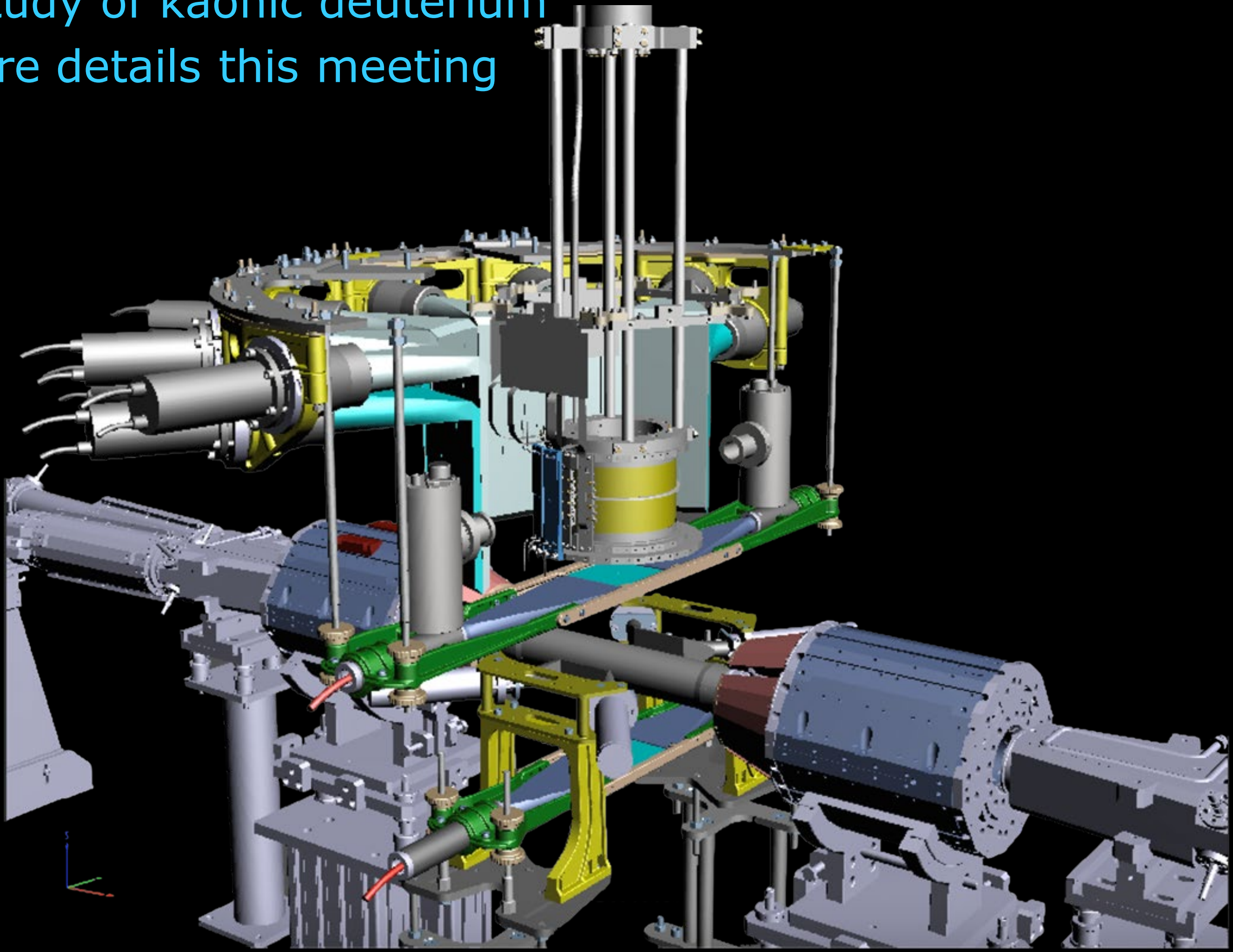
Step	Signal Pass	Signal Effic.	Signal Purity	Background Pass	Background Suppr.
weight	1			50	
generated	7.61×10^5			1.02×10^8	
combined	6.43×10^5	84.49 %	32.75 %	7.47×10^5	7.3×10^{-3}
mass selection	4.13×10^5	54.28 %	47.36 %	1.36×10^5	1.3×10^{-3}
vertex fit	2.43×10^5	31.88 %	64.36 %	6.73×10^4	6.6×10^{-4}
mass fit	1.55×10^5	20.34 %	79.00 %	1.60×10^4	1.6×10^{-4}
BDT Best	1.22×10^5	15.99 %	97.01 %	84	8.2×10^{-7}
BDT+MassSel	1.12×10^5	14.69 %	97.62 %	43	4.2×10^{-7}
MLP Best	1.17×10^5	15.42 %	97.12 %	68	6.6×10^{-7}
MLP+MassSel	1.08×10^5	14.16 %	97.60 %	44	4.3×10^{-7}



- Other sensitive observable: p_T distributions
- Report on D16.2/MS21 in preparation

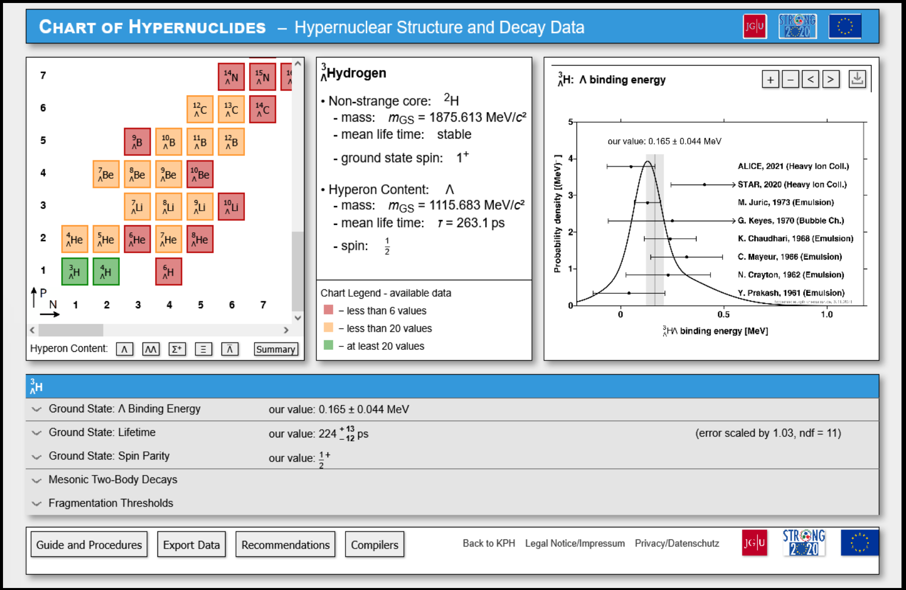
D16.3: SIDDHARTA-2

- Goal: study of kaonic deuterium
- See more details this meeting



New D16.4: Hypernucleus Database

- an interactive hypernucleus database is being built at Mainz
  - https://hypernuclei.kph.uni-mainz.de/
  - https://lambda.phys.tohoku.ac.jp/HypernuclearDatabase/
  - goal: provides complete overview of existing data
    - Masses, lifetimes, branching ratios
  - summary plots, errors etc.generated automatically
  - export data and plots to files possible
- First report is published in HADRON2021 proceedings
- DB will continuously updated with new data
- Planned improvements:
  - Supplement ideograms by conflation of probability distributions
  - Double hypernuclei…



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

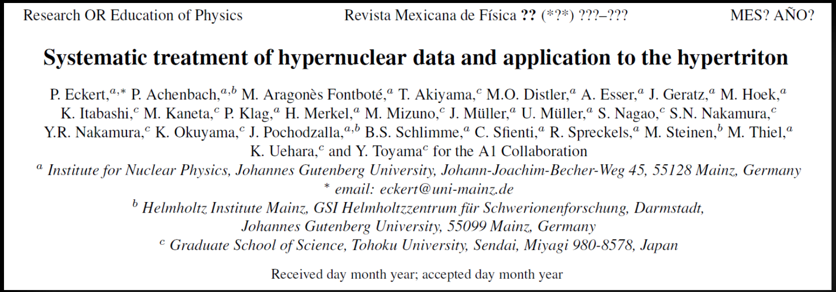
- Non-strange core: ^{2}H
  - mass: m_{GS} = 1875.613 MeV/c^2
  - mean life time: stable
  - ground state spin: 1^+
- Hyperon Content: Λ
  - mass: m_{GS} = 1115.683 MeV/c^2
  - mean life time: τ = 263.1 ps
  - spin: $\frac{1}{2}$

Chart Legend - available data

- 🟥 – less than 6 values
- 🟧 – less than 20 values
- 🟩 – at least 20 values

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

Ground State: Λ Binding Energy	our value: 0.165 ± 0.044 MeV	
Ground State: Lifetime	our value: 224^{+13}_{-12} ps	(error scaled by 1.03, ndf = 11)
Ground State: Spin Parity	our value: $\frac{1}{2}^+$	
Mesonic Two-Body Decays		
Fragmentation Thresholds		



Research OR Education of Physics   Revista Mexicana de Física **??** (*?*) ???–???   MES? AÑO?

Systematic treatment of hypernuclear data and application to the hypertriton

P. Eckert,[a,*] P. Achenbach,[a,b] M. Aragonès Fontboté,[a] T. Akiyama,[c] M.O. Distler,[a] A. Esser,[a] J. Geratz,[a] M. Hoek,[a] K. Itabashi,[c] M. Kaneta,[c] P. Klag,[a] H. Merkel,[a] M. Mizuno,[c] J. Müller,[a] U. Müller,[a] S. Nagao,[c] S.N. Nakamura,[c] Y.R. Nakamura,[c] K. Okuyama,[c] J. Pochodzalla,[a,b] B.S. Schlimme,[a] C. Sfienti,[a] R. Spreckels,[a] M. Steinen,[b] M. Thiel,[a] K. Uehara,[c] and Y. Toyama[c] for the A1 Collaboration

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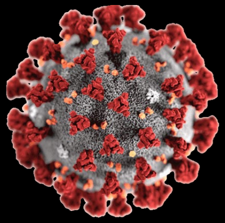
Received day month year; accepted day month year

Deliverable: Workshops

- First workshop November 25-29, 2019 in Speyer
- …then came Corona
- Joint THEIA-STRONG2020 and JAEA/Mainz REIMEI Web-Seminar 2021/2022
- HYP2022 in Prague, June 27 – July 1, 2022 (hybrid)
- Workshop "Meson and Hyperon Interactions with Nuclei" in Kitzbühel, September 14-16, 2022
- ECT* Workshop "**SPICE**: **S**trange hadrons as a **P**recision tool for strongly **I**nteraCting systEms" May 13-17, 2024



THEIA-STRONG2020 - Workshop 2019

HYP 2022 PRAGUE

14th International Conference on Hypernuclear and Strange Particle Physics

June 27 – July 1, 2022
Prague, Czech Republic

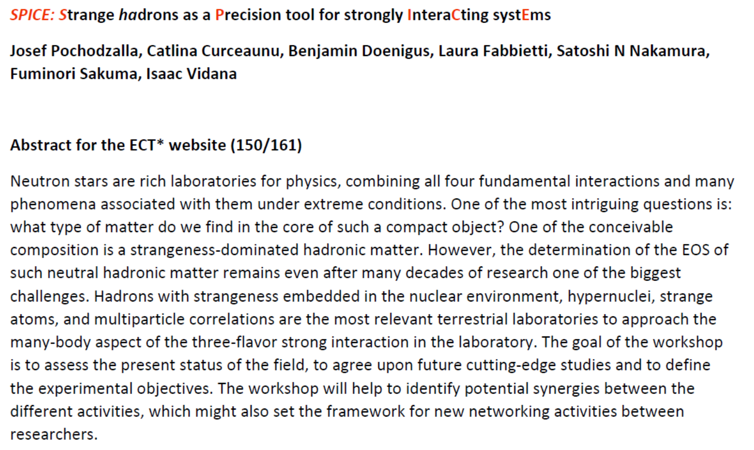
ExtreMe Matter Institute EMMI
EMMI Workshop
Meson and Hyperon Interactions with Nuclei
Kitzbuehel, Austria, September 14 - 16, 2022

Scientific program:
QCD structure of the η′ and anomalous glue
η′ and η interactions with nucleons and nuclei, and the search for possible bound states
Hypertriton binding energy and lifetime
Hyperon interactions with neutron rich matter; hypernucleus spectroscopy
Connections to neutron star structure
Nucleon resonances and resonances in medium

credits (image): Steven Bass

Scheidenberger, Y. Tanaka

More about EMMI:
www.gsi.de/emmi



*SPICE: **S**trange **h**adrons as a **P**recision tool for strongly **I**nteraCting systEms*

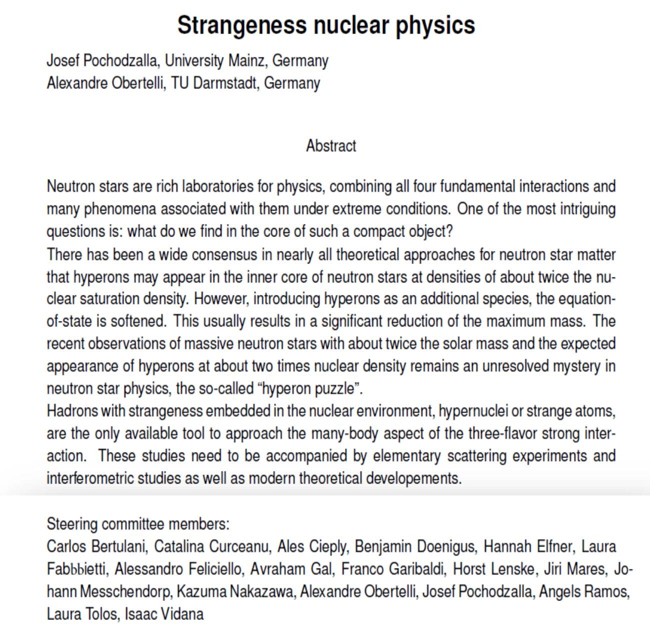
Josef Pochodzalla, Catlina Curceaunu, Benjamin Doenigus, Laura Fabbietti, Satoshi N Nakamura, Fuminori Sakuma, Isaac Vidana

Abstract for the ECT* website (150/161)

Neutron stars are rich laboratories for physics, combining all four fundamental interactions and many phenomena associated with them under extreme conditions. One of the most intriguing questions is: what type of matter do we find in the core of such a compact object? One of the conceivable composition is a strangeness-dominated hadronic matter. However, the determination of the EOS of such neutral hadronic matter remains even after many decades of research one of the biggest challenges. Hadrons with strangeness embedded in the nuclear environment, hypernuclei, strange atoms, and multiparticle correlations are the most relevant terrestrial laboratories to approach the many-body aspect of the three-flavor strong interaction in the laboratory. The goal of the workshop is to assess the present status of the field, to agree upon future cutting-edge studies and to define the experimental objectives. The workshop will help to identify potential synergies between the different activities, which might also set the framework for new networking activities between researchers.

Input to NuPECC Long Range Plan 2024

- ① missing mass studies
- ③ γ-spectroscopy
- ⑤ final state interaction
- ② invariant mass studie
- ④ π-spectroscopy
- ⑥ scattering



Strangeness nuclear physics

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Alexandre Obertelli, TU Darmstadt, Germany

Abstract

Neutron stars are rich laboratories for physics, combining all four fundamental interactions and many phenomena associated with them under extreme conditions. One of the most intriguing questions is: what do we find in the core of such a compact object?
There has been a wide consensus in nearly all theoretical approaches for neutron star matter that hyperons may appear in the inner core of neutron stars at densities of about twice the nuclear saturation density. However, introducing hyperons as an additional species, the equation-of-state is softened. This usually results in a significant reduction of the maximum mass. The recent observations of massive neutron stars with about twice the solar mass and the expected appearance of hyperons at about two times nuclear density remains an unresolved mystery in neutron star physics, the so-called "hyperon puzzle".
Hadrons with strangeness embedded in the nuclear environment, hypernuclei or strange atoms, are the only available tool to approach the many-body aspect of the three-flavor strong interaction. These studies need to be accompanied by elementary scattering experiments and interferometric studies as well as modern theoretical developements.

Steering committee members:
Carlos Bertulani, Catalina Curceanu, Ales Cieply, Benjamin Doenigus, Hannah Elfner, Laura Fabbbietti, Alessandro Feliciello, Avraham Gal, Franco Garibaldi, Horst Lenske, Jiri Mares, Johann Messchendorp, Kazuma Nakazawa, Alexandre Obertelli, Josef Pochodzalla, Angels Ramos, Laura Tolos, Isaac Vidana

Upcoming events

- STRONG-2020 Annual Meeting
  - 20.-22. November 2023
  - CERN
  - https://indico.cern.ch/event/1264833/overview

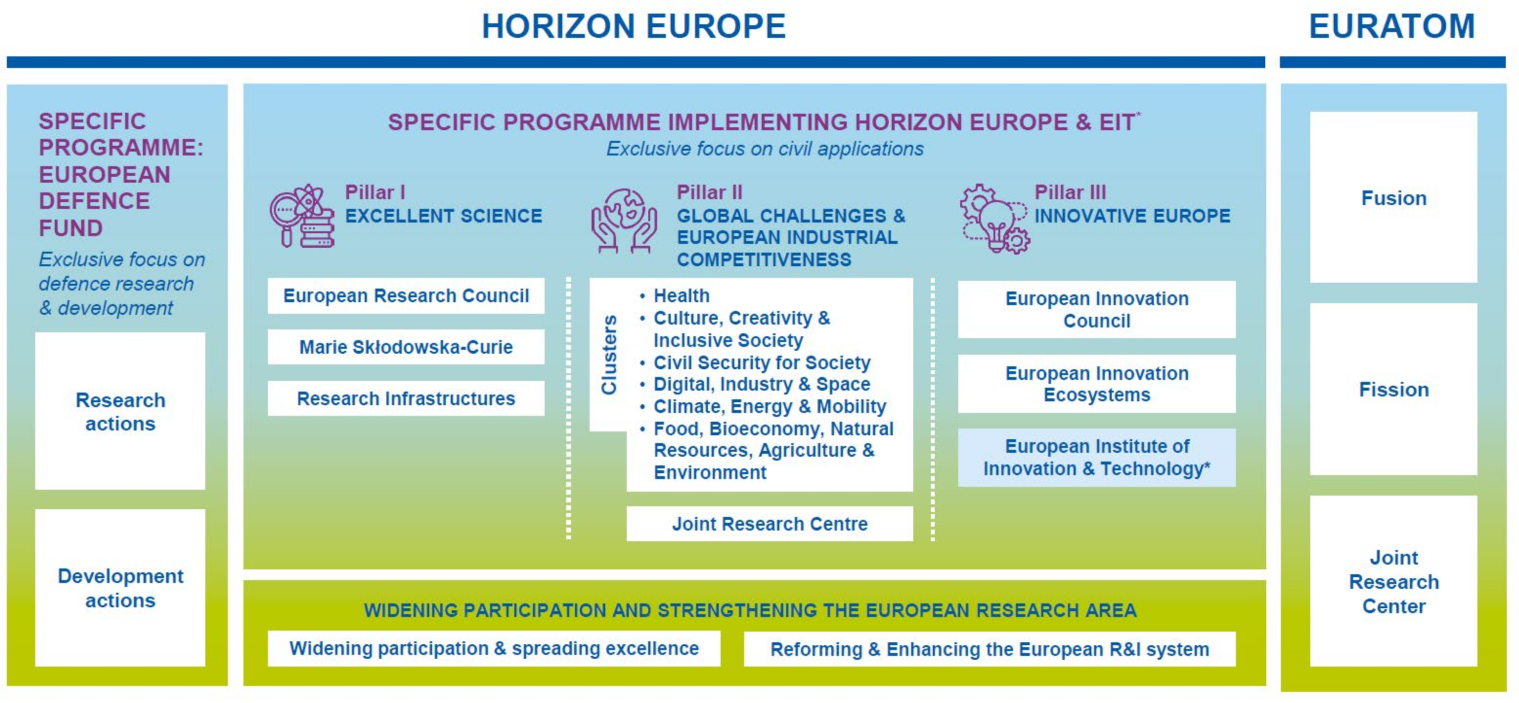
- THEIA -ECT* Workshop SPICE 13.-17. May, 2024

- STRONG2020 Workshop on "Present and future perspectives in Hadron Physics"
  - Frascatiy, 17.-19 June 2024

- STRONG-2020 Annual Meeting
  - 20.-21. June 2024
  - Frascati
  - https://indico.cern.ch/event/1264833/overview

What comes next from EU?

- Programme HORIZON EUROPE successor of Horizon-2020
  - https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en



HORIZON EUROPE

EURATOM

SPECIFIC PROGRAMME: EUROPEAN DEFENCE FUND

Exclusive focus on defence research & development

- Research actions
- Development actions

SPECIFIC PROGRAMME IMPLEMENTING HORIZON EUROPE & EIT*

Exclusive focus on civil applications

Pillar I
EXCELLENT SCIENCE

- European Research Council
- Marie Skłodowska-Curie
- Research Infrastructures

Pillar II
GLOBAL CHALLENGES & EUROPEAN INDUSTRIAL COMPETITIVENESS

Clusters
- Health
- Culture, Creativity & Inclusive Society
- Civil Security for Society
- Digital, Industry & Space
- Climate, Energy & Mobility
- Food, Bioeconomy, Natural Resources, Agriculture & Environment

Joint Research Centre

Pillar III
INNOVATIVE EUROPE

- European Innovation Council
- European Innovation Ecosystems
- European Institute of Innovation & Technology*

WIDENING PARTICIPATION AND STRENGTHENING THE EUROPEAN RESEARCH AREA

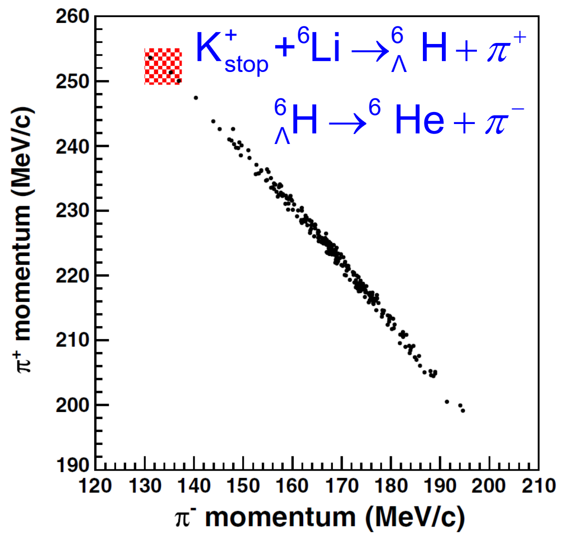
- Widening participation & spreading excellence
- Reforming & Enhancing the European R&I system

EURATOM:
- Fusion
- Fission
- Joint Research Center

- Absence of the structure adapted to the scale and size of the STRONG-2020
- Infrastructures (Pillar I): focused on infrastructure development and does not consider activities such as JRA and NA
- No calls for Hadron Physics until the end of 2024

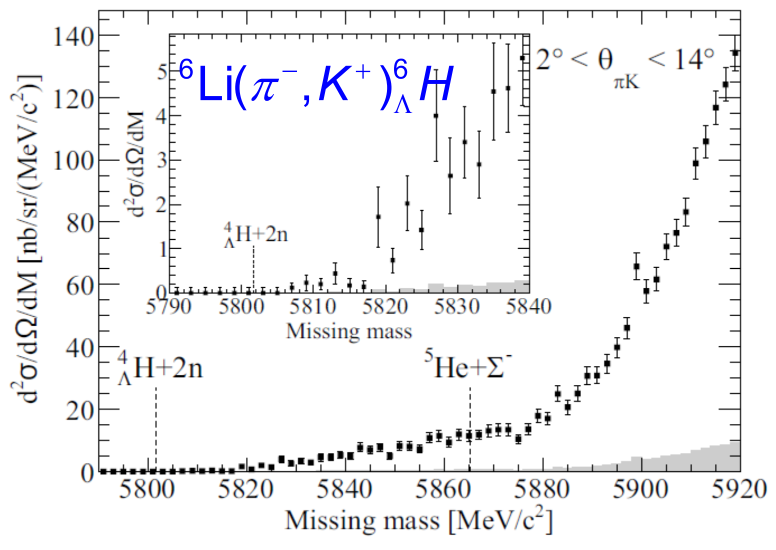
Quest for neutron rich systems

- nnΛ: not yet clear whether it exists or not
- nn$\Lambda\Lambda$ might explain the E906 observation, but is theoretically questionable (PLB 790, 502, 2019)
- ${}^6_\Lambda$H observation by FINUDA not confirmed at J-PARC



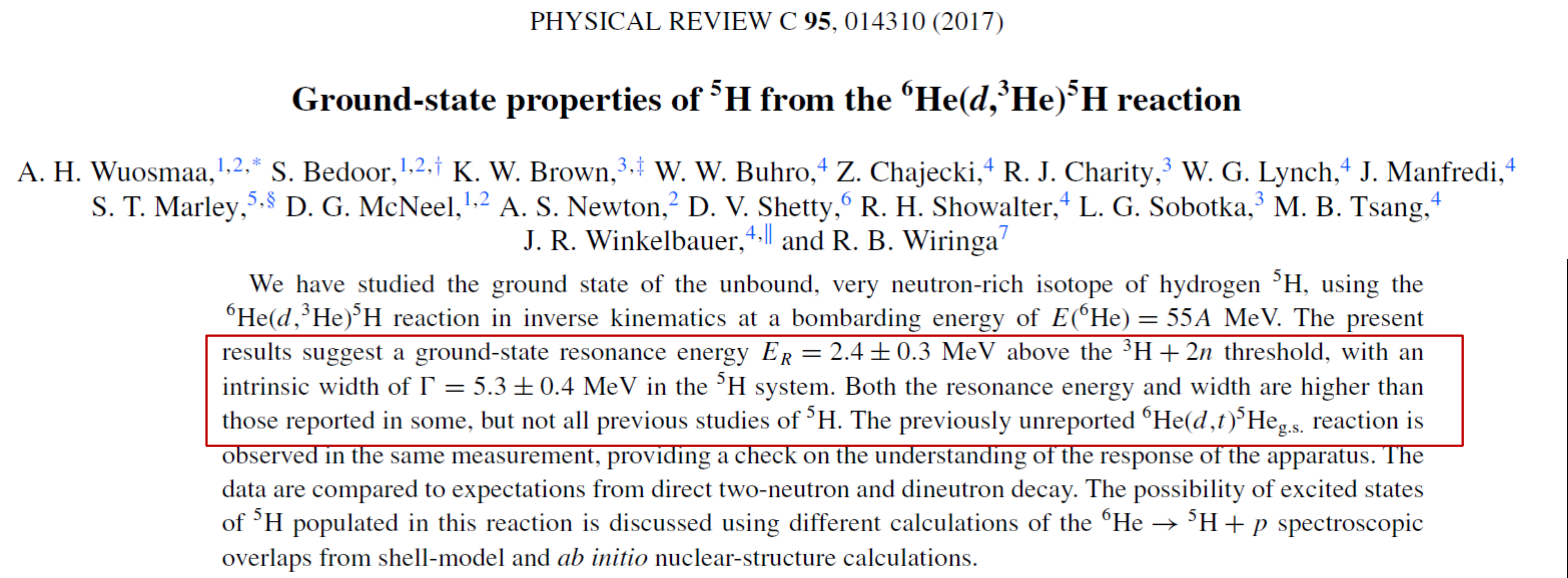
FINUDA
PRL. **108,** 042501

J-PARC E10
PRC **96**, 014005 (2017)



- May be it is good idea to look at conventional neutron rich systems
  - ^{5}H core of ${}^6_\Lambda$H
  - tetraneutron system clearly observed; however properties unclear
  - neutron rich hydrogen isotopes („femto neutron stars“)
    - ^{4}H, ^{5}H: obvious signals have been seen.
    - ^{6}H, ^{7}H: weak signals are seen, properties unclear

Status of ^{5}H

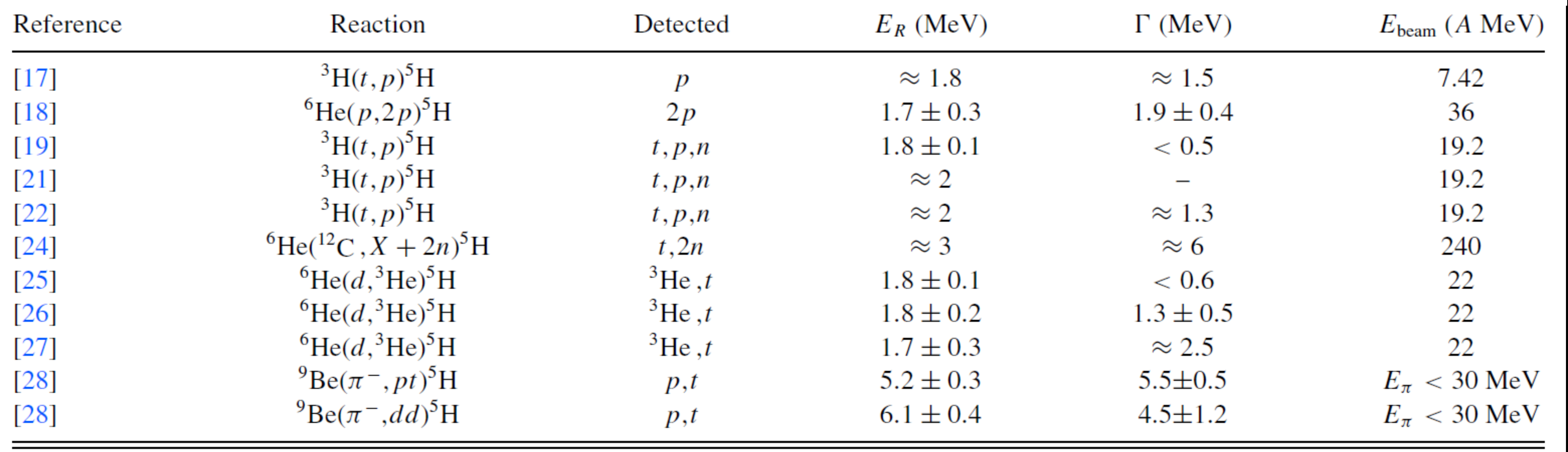


PHYSICAL REVIEW C **95**, 014310 (2017)

Ground-state properties of ^{5}H from the ^{6}He(d,^{3}He)^{5}H reaction

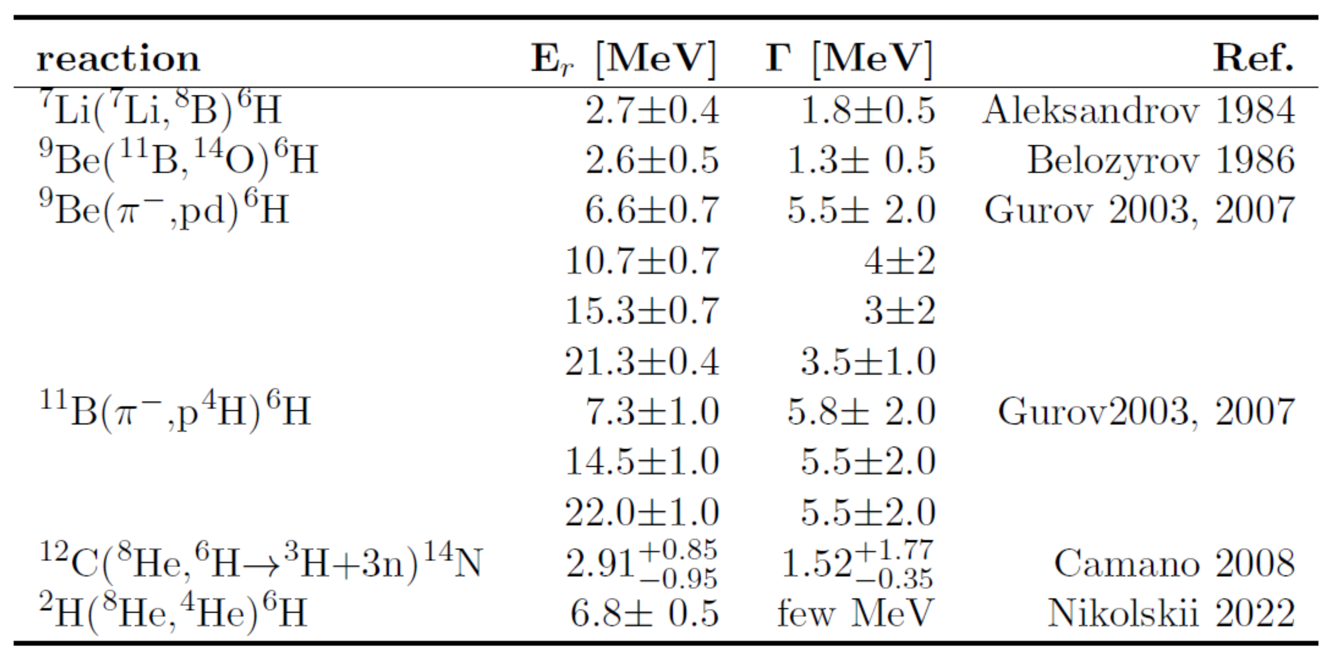
A. H. Wuosmaa,[1,2,*] S. Bedoor,[1,2,†] K. W. Brown,[3,‡] W. W. Buhro,[4] Z. Chajecki,[4] R. J. Charity,[3] W. G. Lynch,[4] J. Manfredi,[4] S. T. Marley,[5,§] D. G. McNeel,[1,2] A. S. Newton,[2] D. V. Shetty,[6] R. H. Showalter,[4] L. G. Sobotka,[3] M. B. Tsang,[4] J. R. Winkelbauer,[4,‖] and R. B. Wiringa[7]

We have studied the ground state of the unbound, very neutron-rich isotope of hydrogen ^{5}H, using the ^{6}He$(d,{}^3$He$)^5$H reaction in inverse kinematics at a bombarding energy of $E(^6\text{He}) = 55A$ MeV. The present results suggest a ground-state resonance energy $E_R = 2.4 \pm 0.3$ MeV above the $^3\text{H} + 2n$ threshold, with an intrinsic width of $\Gamma = 5.3 \pm 0.4$ MeV in the ^{5}H system. Both the resonance energy and width are higher than those reported in some, but not all previous studies of ^{5}H. The previously unreported ^{6}He$(d,t)^5$He$_{\text{g.s.}}$ reaction is observed in the same measurement, providing a check on the understanding of the response of the apparatus. The data are compared to expectations from direct two-neutron and dineutron decay. The possibility of excited states of ^{5}H populated in this reaction is discussed using different calculations of the $^6\text{He} \rightarrow {}^5\text{H} + p$ spectroscopic overlaps from shell-model and *ab initio* nuclear-structure calculations.

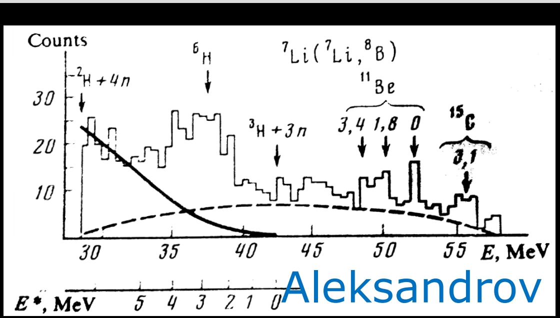


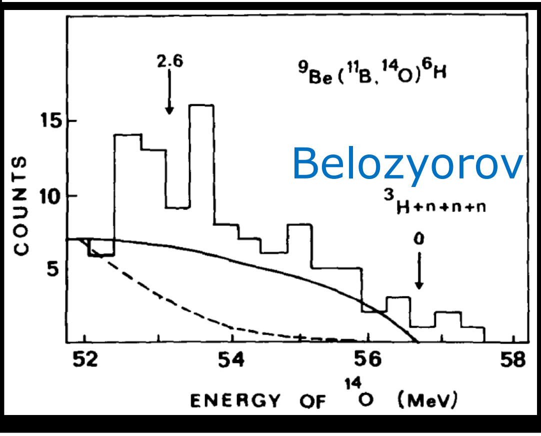
Reference	Reaction	Detected	E_R (MeV)	Γ (MeV)	E_{beam} (A MeV)
[17]	^{3}H$(t,p)^5$H	p	≈ 1.8	≈ 1.5	7.42
[18]	^{6}He$(p,2p)^5$H	$2p$	1.7 ± 0.3	1.9 ± 0.4	36
[19]	^{3}H$(t,p)^5$H	t,p,n	1.8 ± 0.1	< 0.5	19.2
[21]	^{3}H$(t,p)^5$H	t,p,n	≈ 2	–	19.2
[22]	^{3}H$(t,p)^5$H	t,p,n	≈ 2	≈ 1.3	19.2
[24]	^{6}He$(^{12}\text{C},X+2n)^5$H	$t,2n$	≈ 3	≈ 6	240
[25]	^{6}He$(d,{}^3\text{He})^5$H	^{3}He$,t$	1.8 ± 0.1	< 0.6	22
[26]	^{6}He$(d,{}^3\text{He})^5$H	^{3}He$,t$	1.8 ± 0.2	1.3 ± 0.5	22
[27]	^{6}He$(d,{}^3\text{He})^5$H	^{3}He$,t$	1.7 ± 0.3	≈ 2.5	22
[28]	^{9}Be$(\pi^-,pt)^5$H	p,t	5.2 ± 0.3	5.5 ± 0.5	$E_\pi < 30$ MeV
[28]	^{9}Be$(\pi^-,dd)^5$H	p,t	6.1 ± 0.4	4.5 ± 1.2	$E_\pi < 30$ MeV

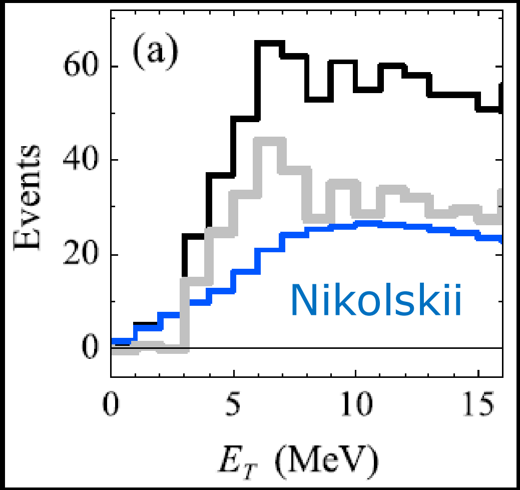
Status of ^{6}H (1)

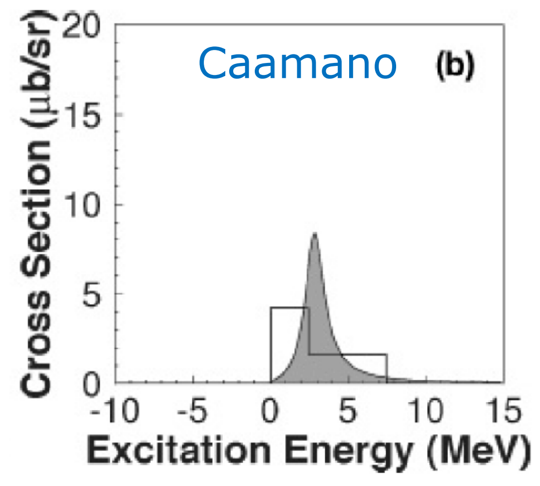


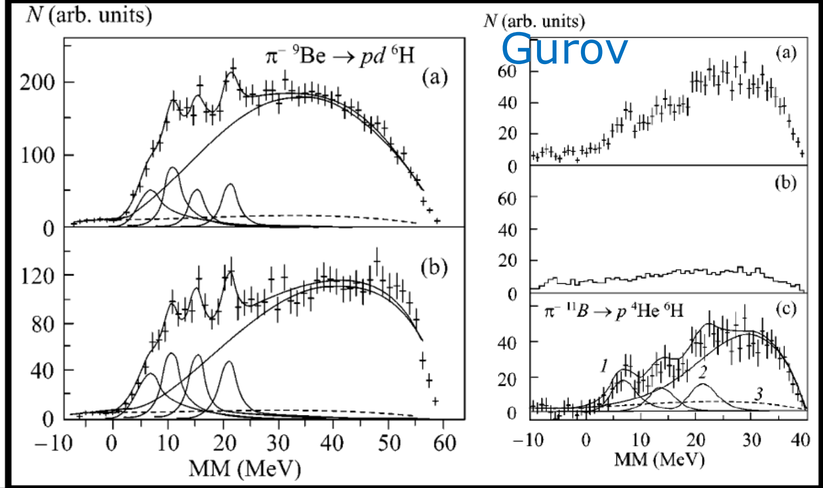
reaction	E_r [MeV]	Γ [MeV]	Ref.
^{7}Li(^{7}Li,^{8}B)^{6}H	2.7±0.4	1.8±0.5	Aleksandrov 1984
^{9}Be(^{11}B,^{14}O)^{6}H	2.6±0.5	1.3± 0.5	Belozyrov 1986
^{9}Be(π^-,pd)^{6}H	6.6±0.7	5.5± 2.0	Gurov 2003, 2007
	10.7±0.7	4±2	
	15.3±0.7	3±2	
	21.3±0.4	3.5±1.0	
^{11}B(π^-,p^{4}H)^{6}H	7.3±1.0	5.8± 2.0	Gurov2003, 2007
	14.5±1.0	5.5±2.0	
	22.0±1.0	5.5±2.0	
^{12}C(^{8}He,^{6}H→^{3}H+3n)^{14}N	$2.91^{+0.85}_{-0.95}$	$1.52^{+1.77}_{-0.35}$	Camano 2008
^{2}H(^{8}He,^{4}He)^{6}H	6.8± 0.5	few MeV	Nikolskii 2022





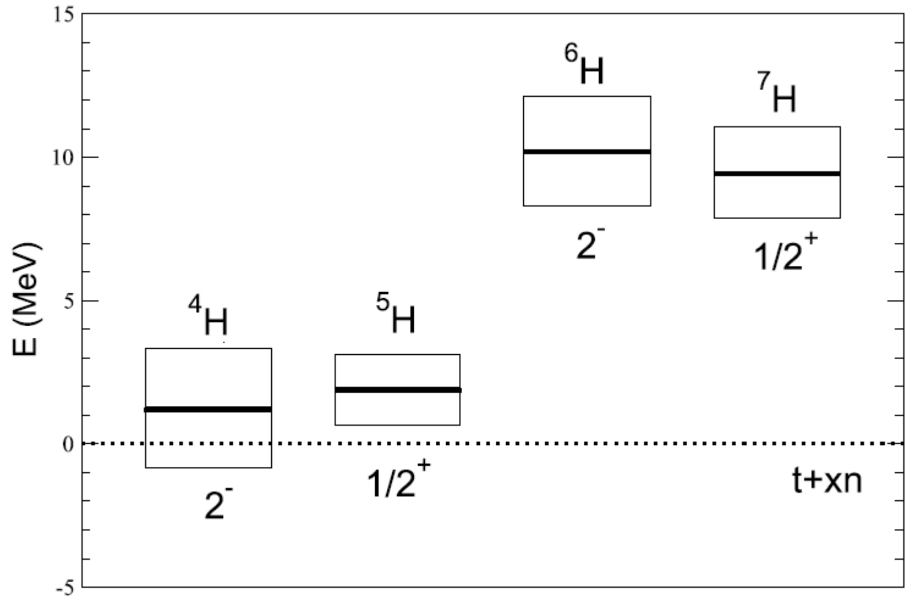






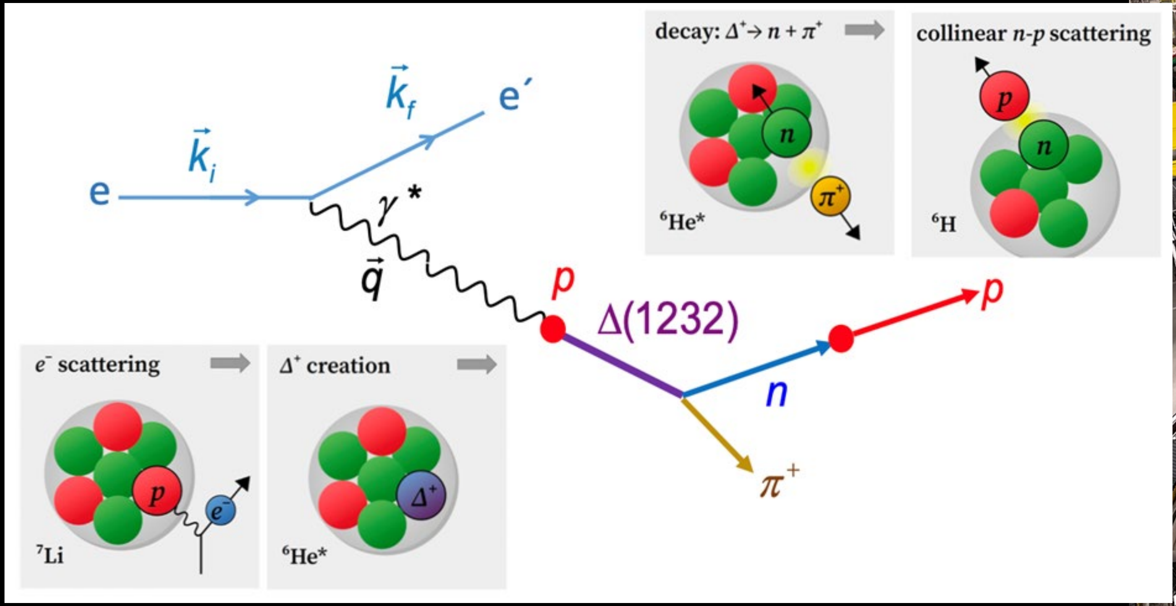
Status of ^{6}H (2)

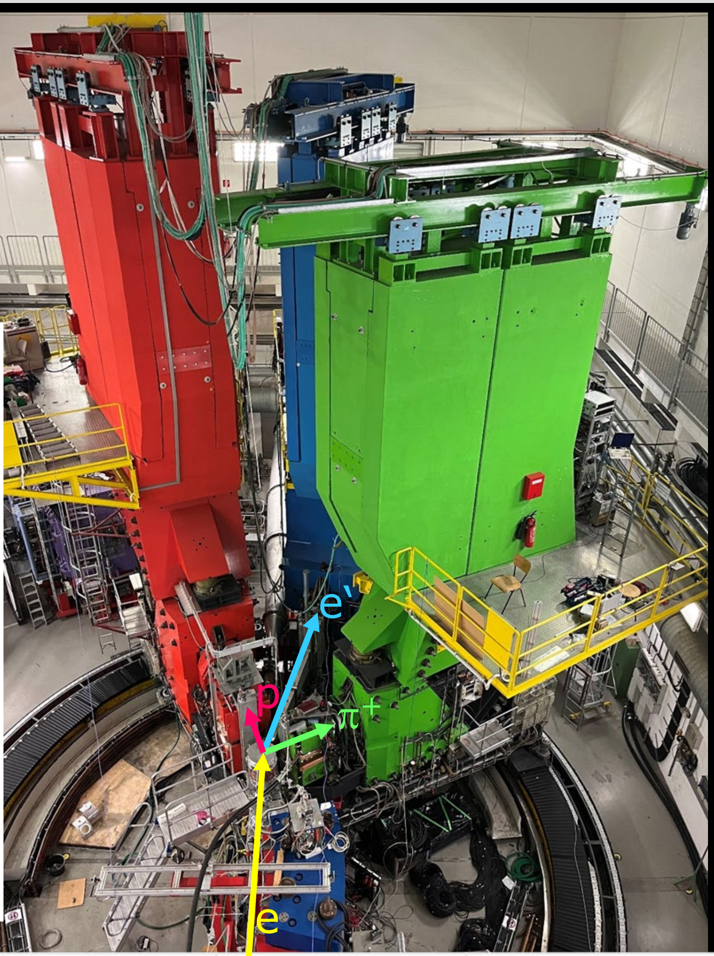
- Negative results
  - ^{9}Be($\pi^-_{stopped}$,pd)X,^{7}Li(π^{-s}_{topped},p)X showed no evidence of ^{6}H states
  - ^{6}Li(π^-,π^+)X: at E(π^-)=220 MeV no evidence for ^{6}H was found in missing mass range -10 MeV to +30 MeV in the ^{3}H+3n scale, thus casting doubt on the existence of ^{6}H
- Theoretical calculations
  - Poppelier et. al., PL 1985: $J^\pi = 0^-$, E = 2.8 MeV
  - Bevelacqua, PRC 1986: $J^\pi = 1^+$, E = 1.34 MeV
  - Gorbatov et. al., YF 1989: $J^\pi = 2^-$, E = 6.3 MeV
  - Aoyama et. al., NPA 2004: E = 6.6 MeV
  - Hiyama et. al., PLB 2022: E ~ 10 MeV, Γ~4MeV



Experiment at MAMI (July/Sep 2023)

- Reaction $^{\mathrm{nat}}\mathrm{Li}(e,e'\pi^{+}p)^{5,6}\mathrm{H}$
  - $^{6}\mathrm{Li}(1^{+})$ 7.4% ; $^{7}\mathrm{Li}(3/2^{-})$ 92.6%
- Missing mass rekonstruction
- Kinematics inspired by





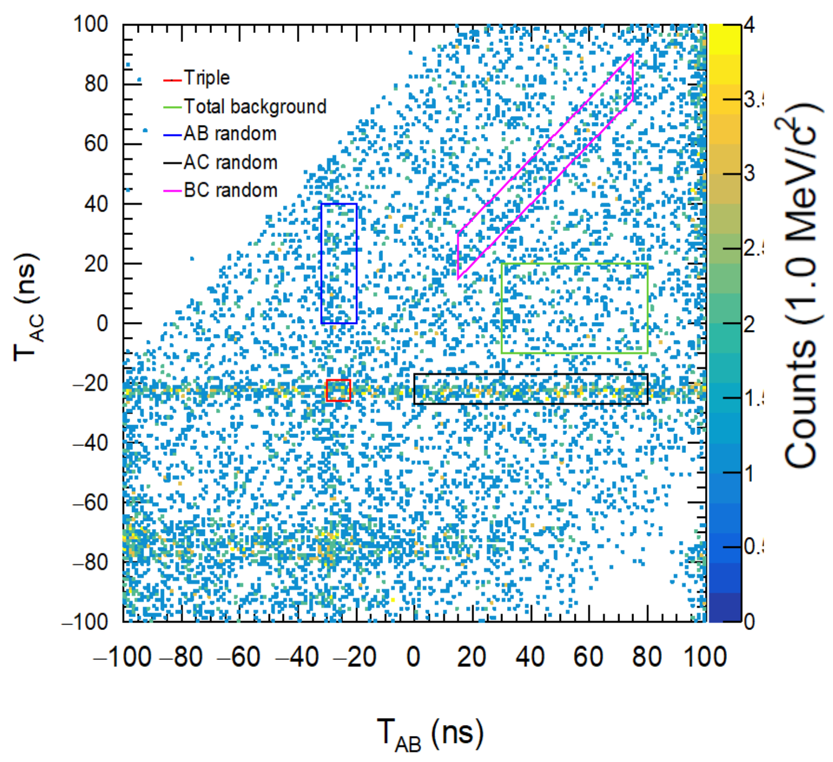
- Moderate momentum transfer to $^{6}\mathrm{H}$
- Triple coincidence → low background

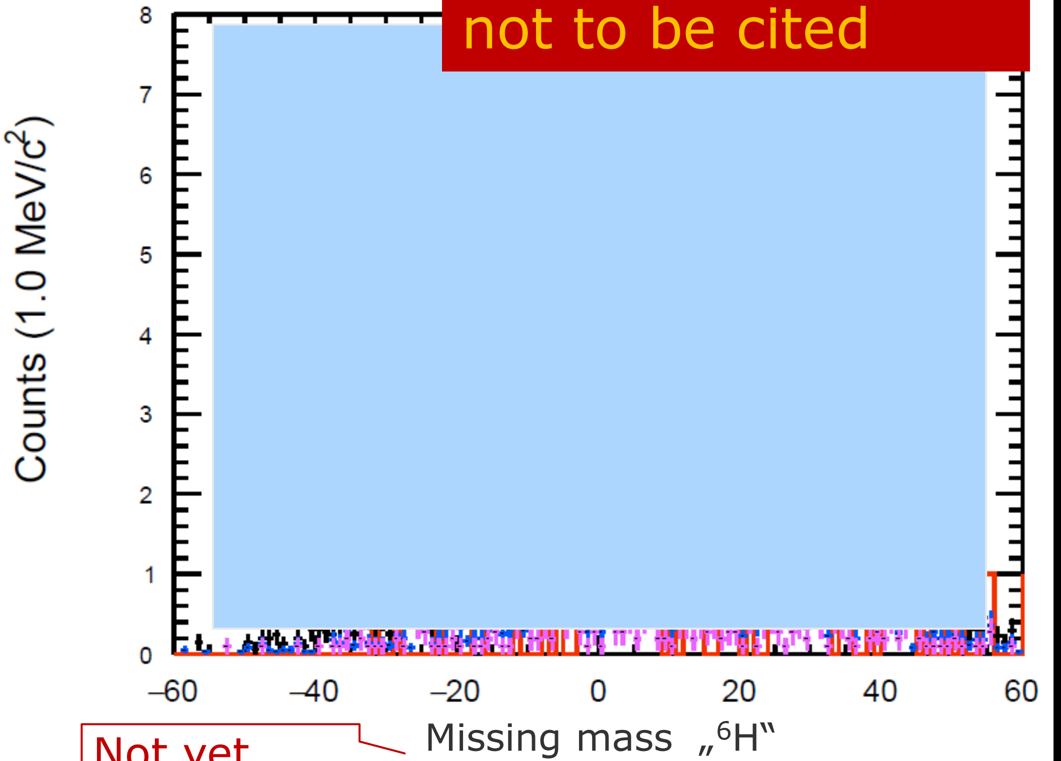
Spectrometer	Degree (°)	Momentum (MeV/c)
A (proton)	-23.8	417
B (e')	15.1	421
C (π^{+})	59.1	273

Online results !

Experiment performed in July and September 2023

- Calibration run last week (because of new NMR system)
- Here: online analysis; assuming ^{7}Li target
- No calibration applied
- Very likely MM scale will shift by 2-3 MeV into bound region





Very preliminary !
not to be cited

Not yet calibrated

Conclusion

- STRONG-2020 as well as THEIA were strongly affected by COVID-19 as well as the war against the Ukraine
- THEIA has already or will deliver all promised deliverables
- Sucessor of STRONG-2020 unclear
  - STRONG2020 Workshop on “Present and future perspectives in Hadron Physics”, Frascatiy, 17.-19 June 2024
- Still many open issues in strageness nuclear physics
  - Neutron-rich systems
  - Doubly-strange systems
  - …