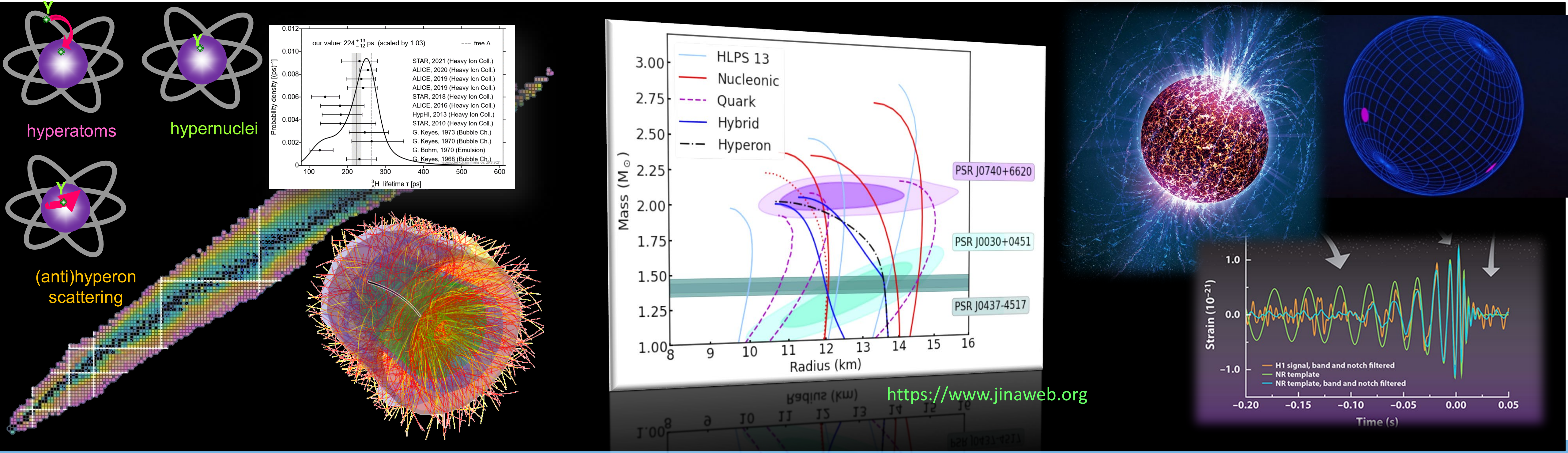


NA5 - THEIA: Strange Hadrons and the Equation-of-State of Compact Stars

Josef Pochodzalla

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

Deliverables:

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 scheduled in spring 2022	month 36
D16.2: Study of antihyperons in nuclei; PANDA software tools	month 42 - demonstrator
MS21: Design report for antihyperons in nuclei ready	month 42
D16.3: Theoretical and experimental studies of bound mesonic systems	month 30 - report
MS22: SIDDHARTA-2 progress report	month 30
D16.4: Hypernuclear database is online and will continually updated	month 54 - public/webpage

Annual workshops

D16.1: A=3 Hypernuclei

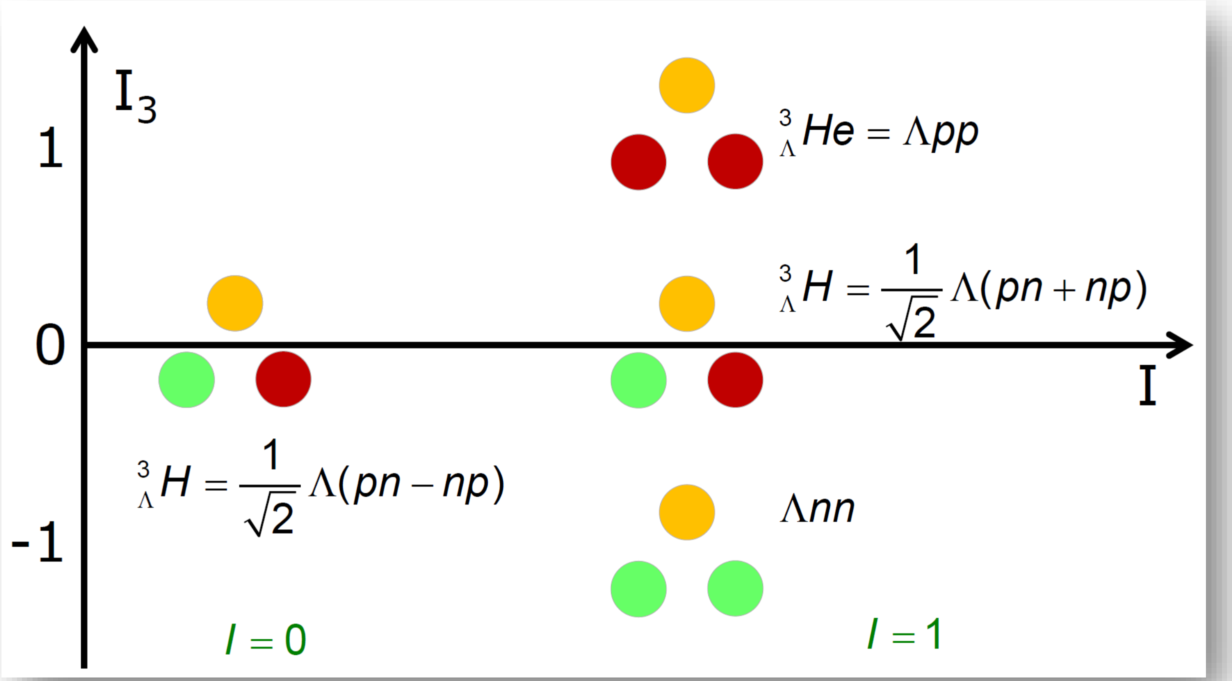
- Three-baryon forces are essential to describe complex nuclei
- A=3 hypernnuclei are important cornerstones

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

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

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

Report delivered

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.

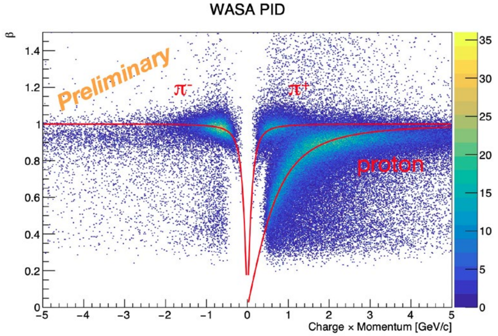
Summery: Nuclei containing strange baryons, so-called Hypernuclei, are unique femto-laboratories for multi-baryon interactions with hyperons. Light hypernuclei are particularly interesting since not only phenomenological models but also ab initio studies based on chiral effective field theory and even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

STRONG 2020

MS20: First data taking by WASA@GSI/FAIR

Milestone achieved
Analysis started

Photos by Jan Hosan and GSI/FAIR



Data taking (January – March 2022)

Run	Period	Data size
Commissioning run	28th Jan. - 7th Feb.	7 TB
Physics run for η' nuclei	22nd Feb. - 28th Feb.	40 TB
Physics run for HypHI	10th Mar. - 19th Mar.	48 TB

92 % of the prop.

Acquired data for S447 (hypernuclei)

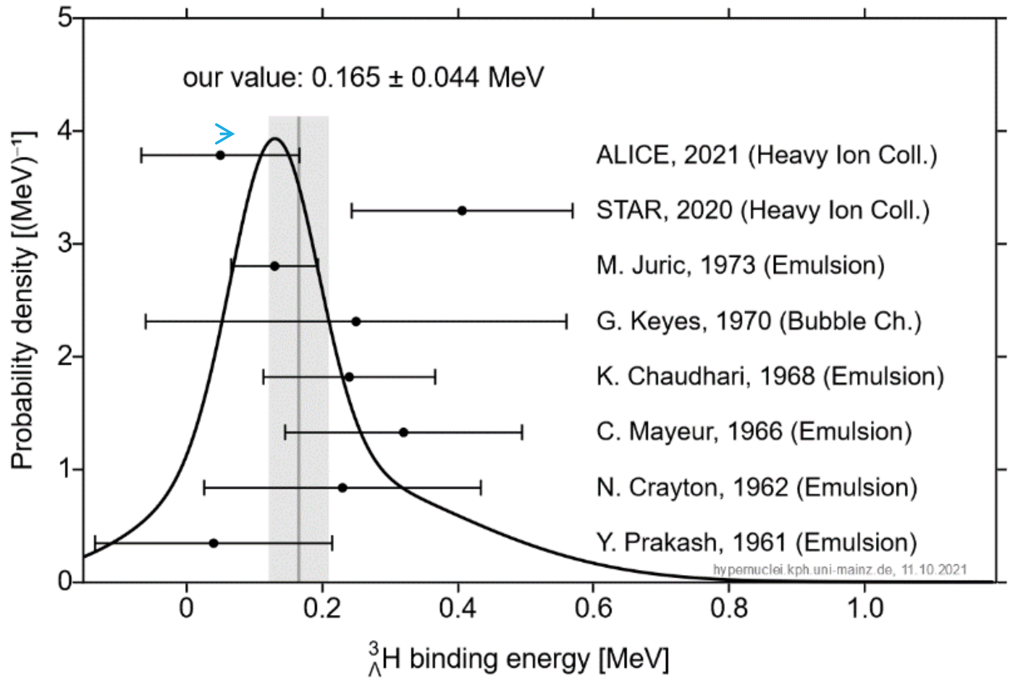
Beam	Fragment at S4	Amount	Time	Accepted trigger rate	
^{6}Li beam	^{3}He	3.3×10^{8}	40.9 hours	2600 Hz	$^{3}_{\Lambda}$H
	^{4}He	0.9×10^{8}	43.9 hours	1800 Hz	$^{4}_{\Lambda}$H
	deuteron	1.8×10^{8}			nnΛ
	proton (mid-rapidity)	5.3×10^{6}	3.2 hours	680 Hz	Λ
^{12}C beam	^{3}He	1.0×10^{8}	13.5 hours	2400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

Deliverable 16.1: Hypertriton binding energy

- Present situation
  - Emulsion data suggest very small binding energy ~130keV
  - New data from STAR show stronger binding ~410keV
  - Recent Pb+Pb ALICE result $\sim 72 \pm 63_{stat} \pm 36_{syst}$ keV

Faktor 6

- Ongoing and planned activities
  - MAMI: high resolution pion spectroscopy 2022, $\delta B_{sys} \approx 20$keV
  - Jlab (C12-19-002)
  - Analysis of JPARC-E07 emulsion data
- R3B@FAIR: Cross section for $^{3}_{\Lambda}H$: giant Λ-halo?

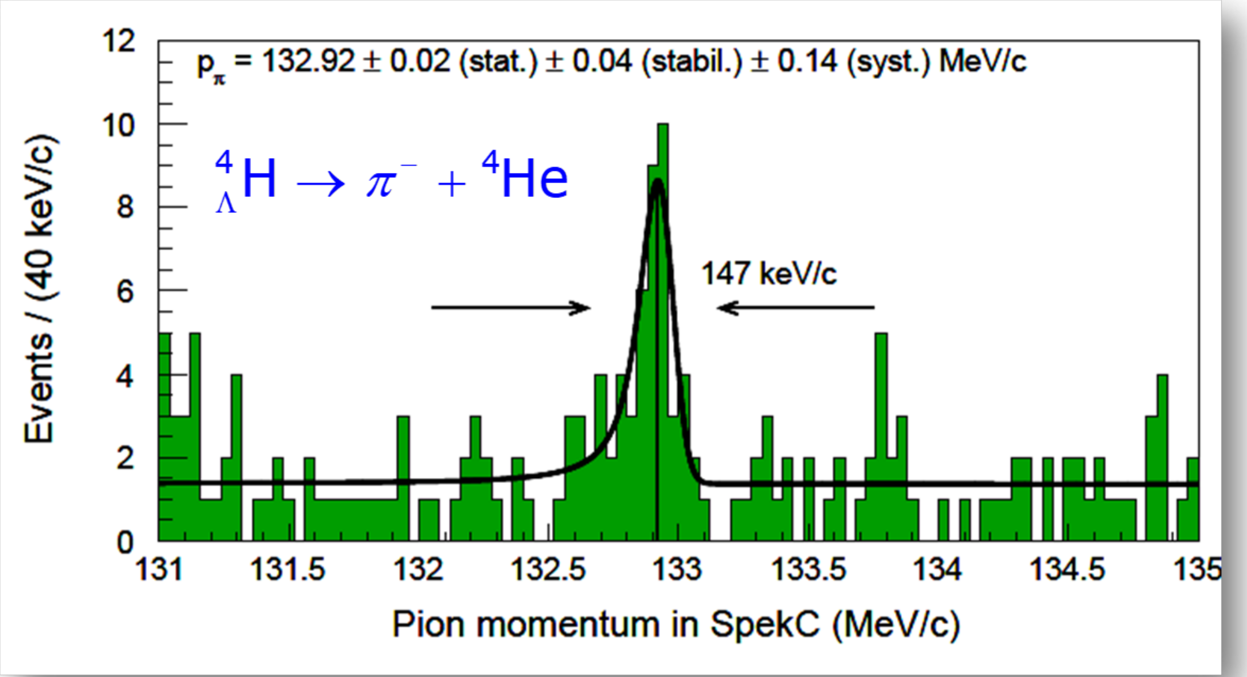


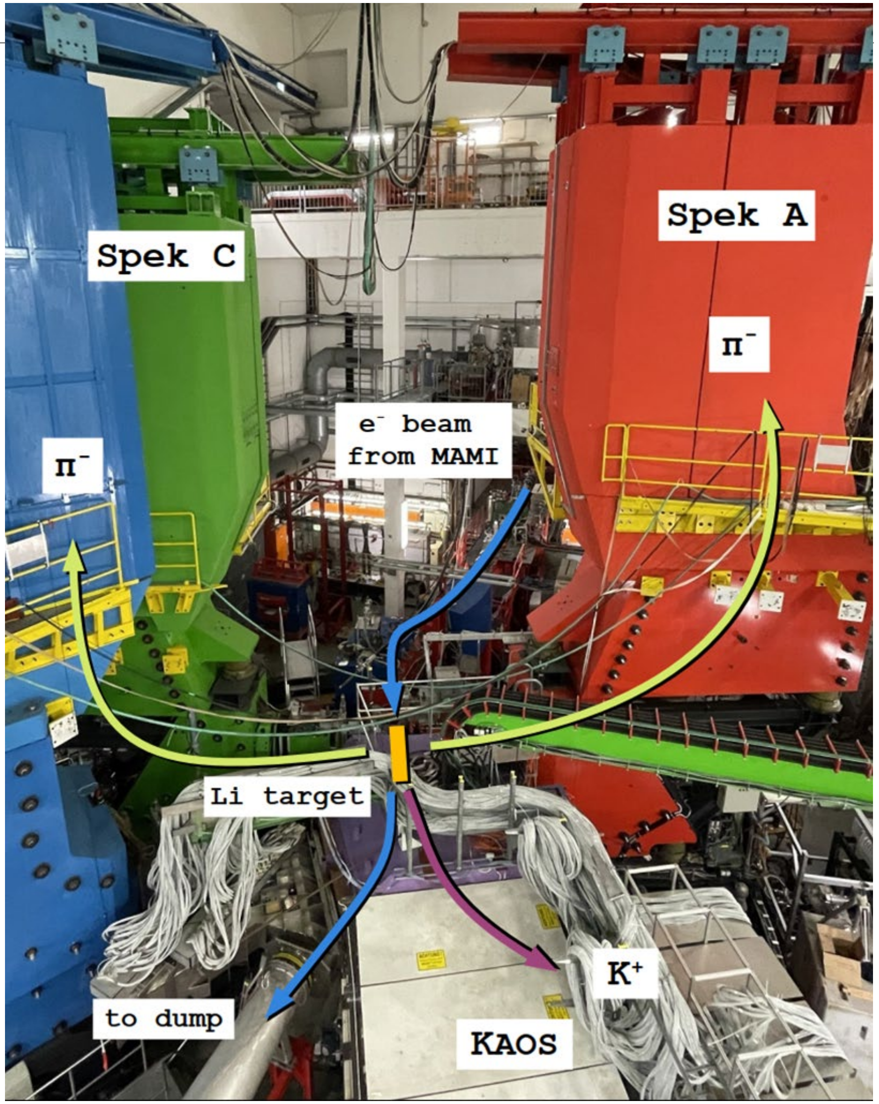
Decay Pion Spectroscopy @ MAMI

Two-body decays

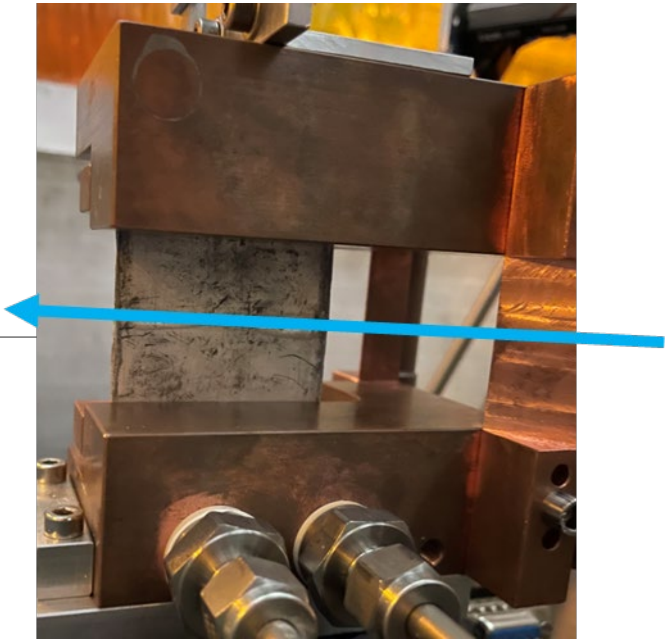
$^{3}_{\Lambda}\mathrm{H} \rightarrow {}^{3}\mathrm{He} + \pi^{-}$ @114MeV/c

$^{4}_{\Lambda}\mathrm{H} \rightarrow {}^{4}\mathrm{He} + \pi^{-}$ @133MeV/c



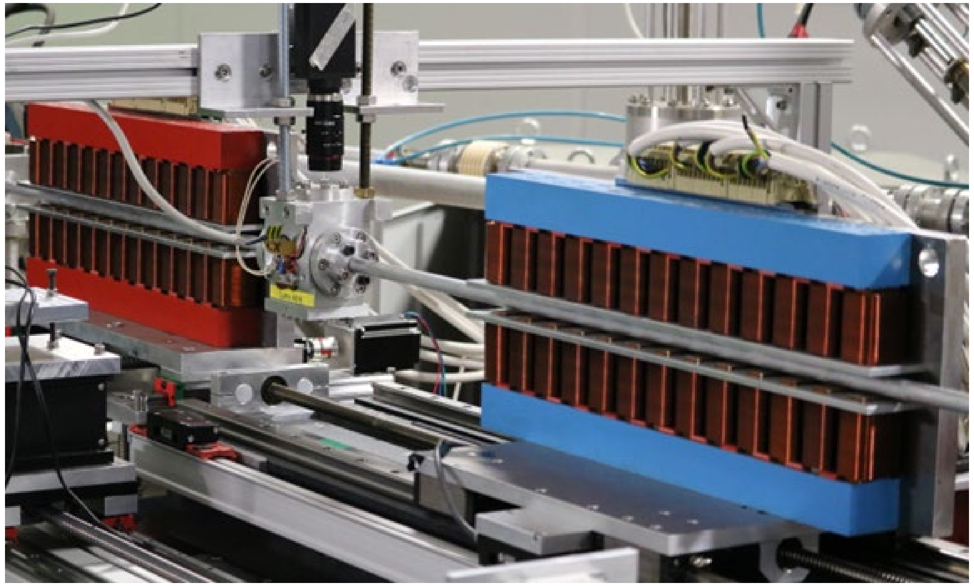


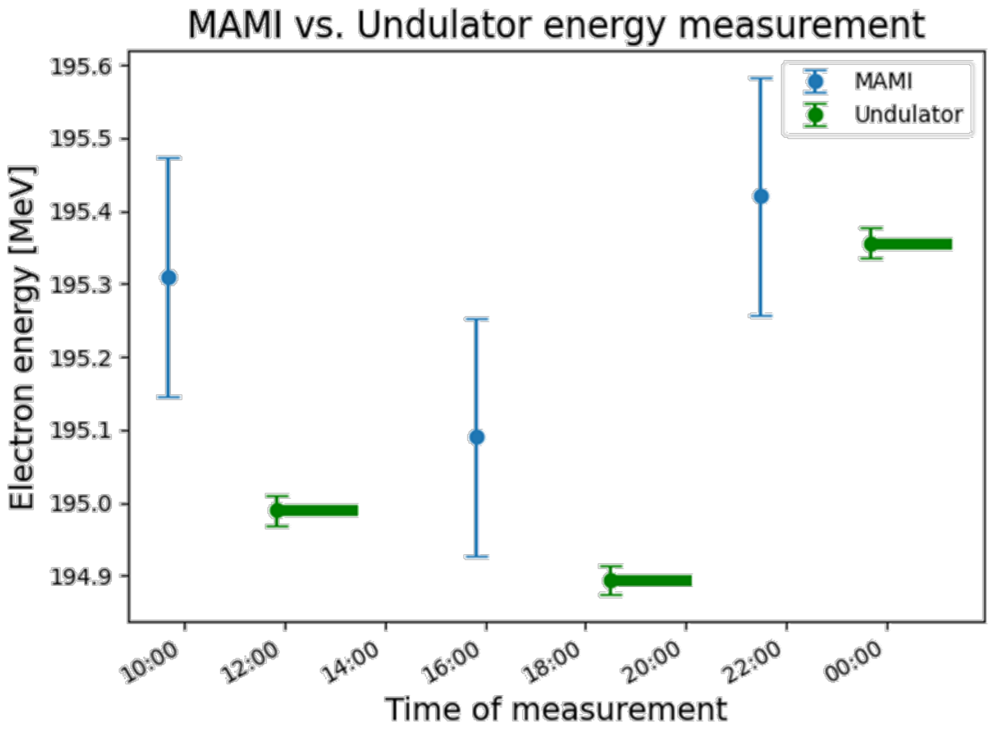
Required Improvements



Higher Luminosity → 5cm Lithium target

Absolute Energy → calibration via Undulator Light Interference





MAMI Experiment in 2022 performed

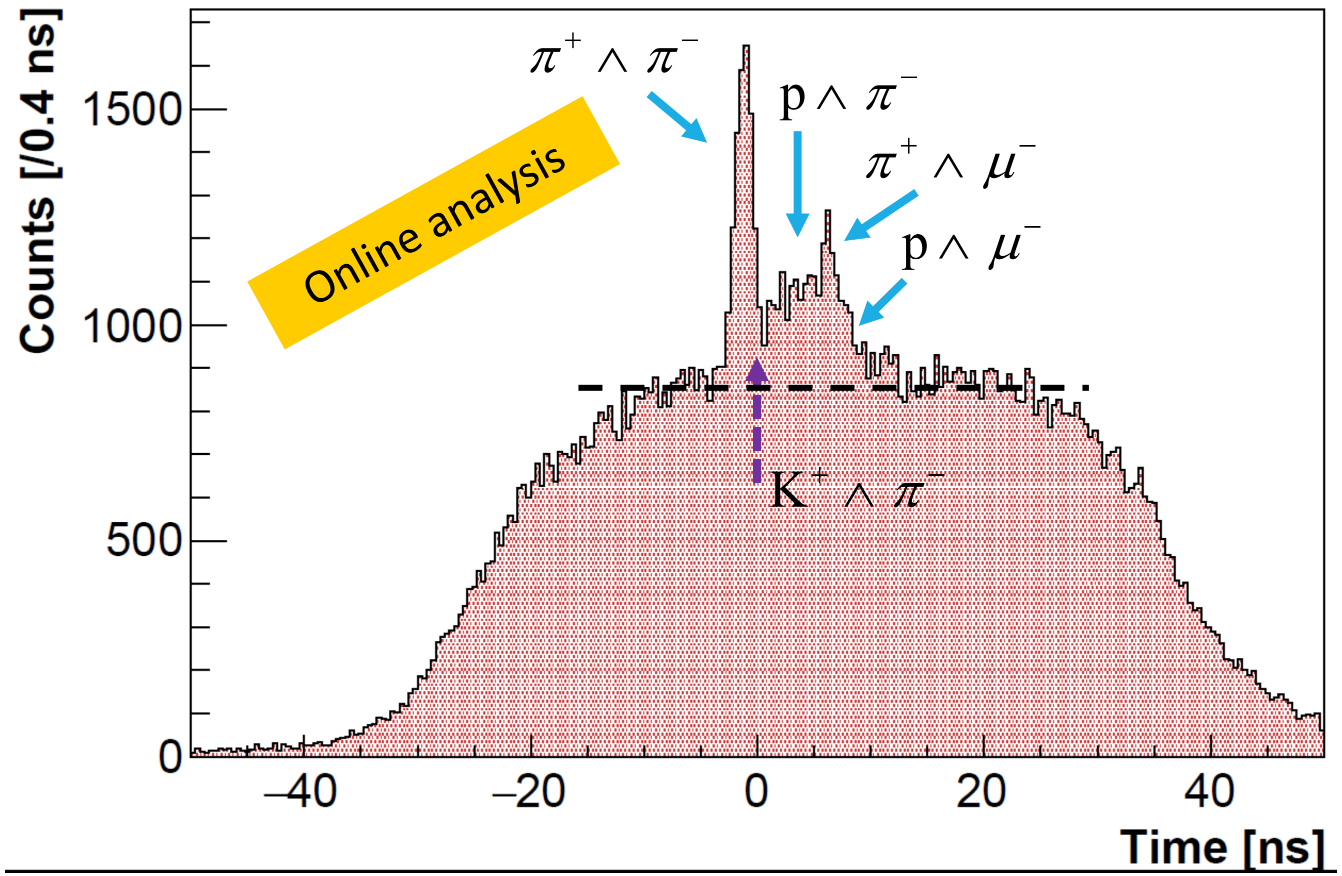
Commissioning: July 12 – August 1

Data taking: September 22 – October 17

Example: raw online timing diagram
KAOS-SPEK-A (~6h)

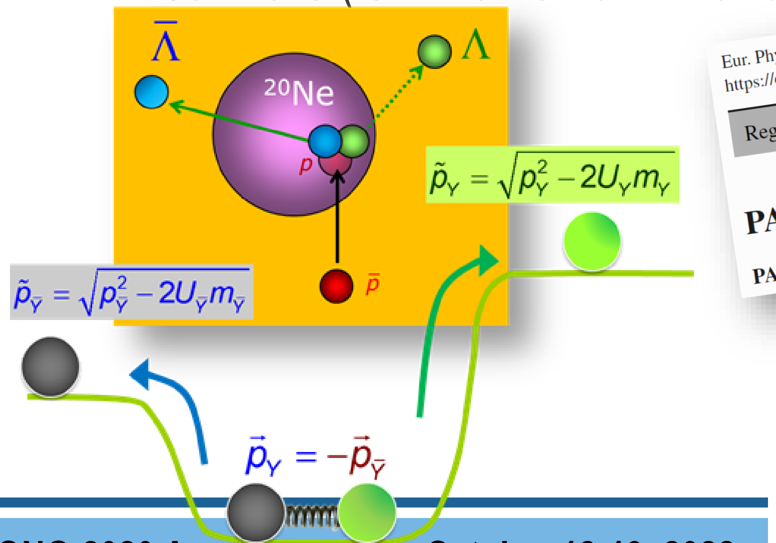
Detector calibration ongoing

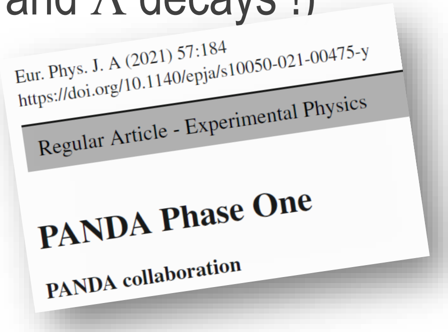
Analysis has just started



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}Ne($\bar{p}$,$\bar{\Lambda}\Lambda$) reaction during PHASE-1 of PANDA
- ongoing work: development of reconstruction software (low momentum Λ and Λ decays !)

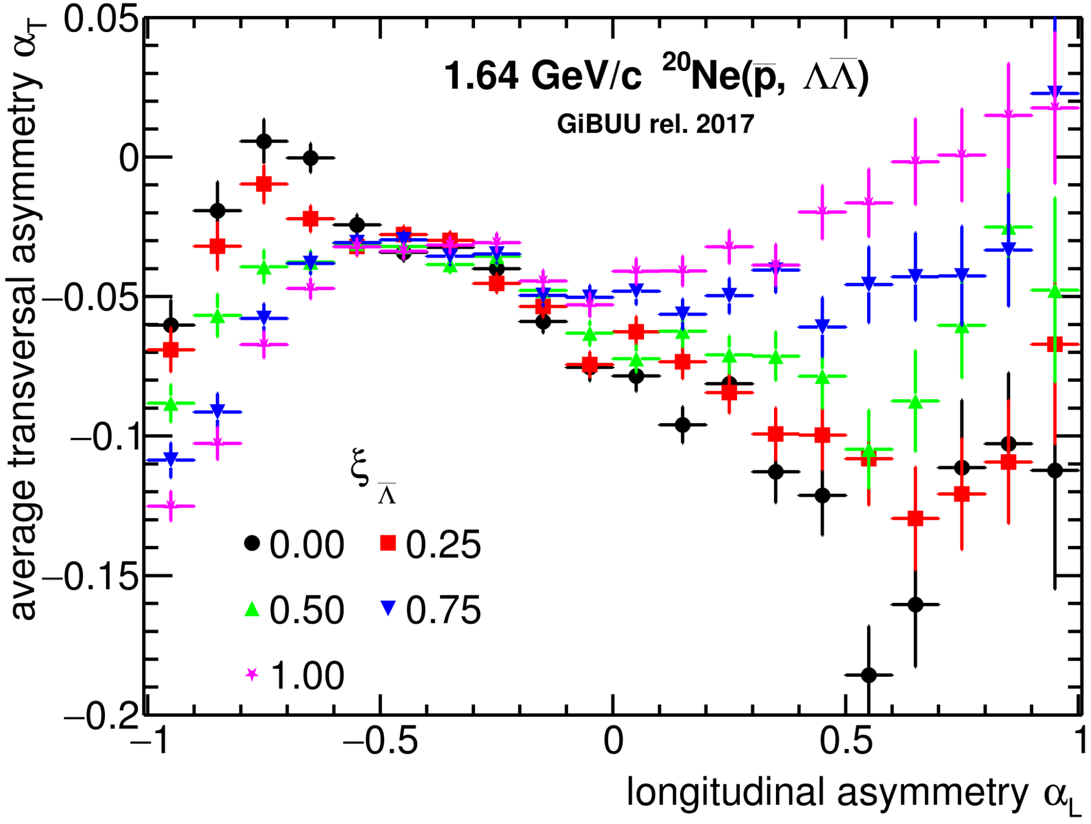



Eur. Phys. J. A (2021) 57:184
https://doi.org/10.1140/epja/s10050-021-00475-y

Regular Article - Experimental Physics

PANDA Phase One

PANDA collaboration

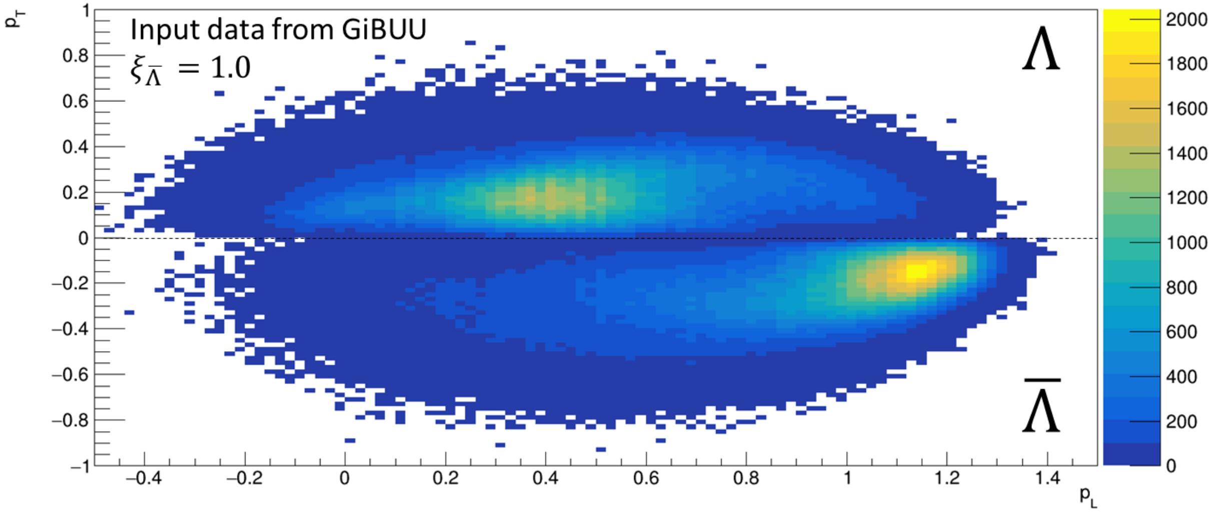


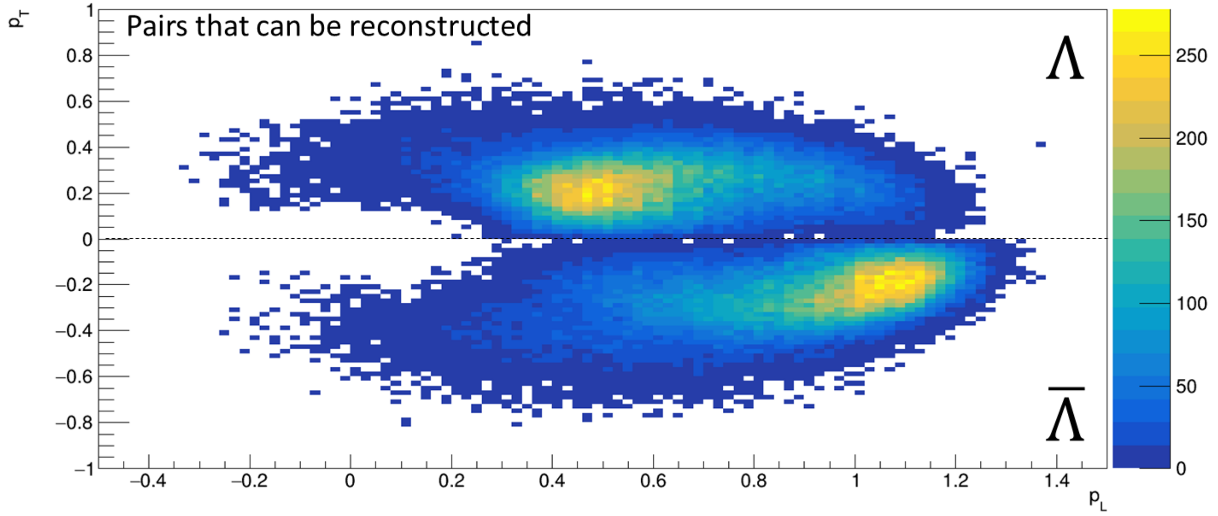
Pair reconstruction by PANDA

Low momenta Λ and $\overline{\Lambda}$ difficult to reconstruct

Pairs are missing where the Λ or $\overline{\Lambda}$ has low momentum

Losing approximately 20% of pairs due to low momentum hyperon



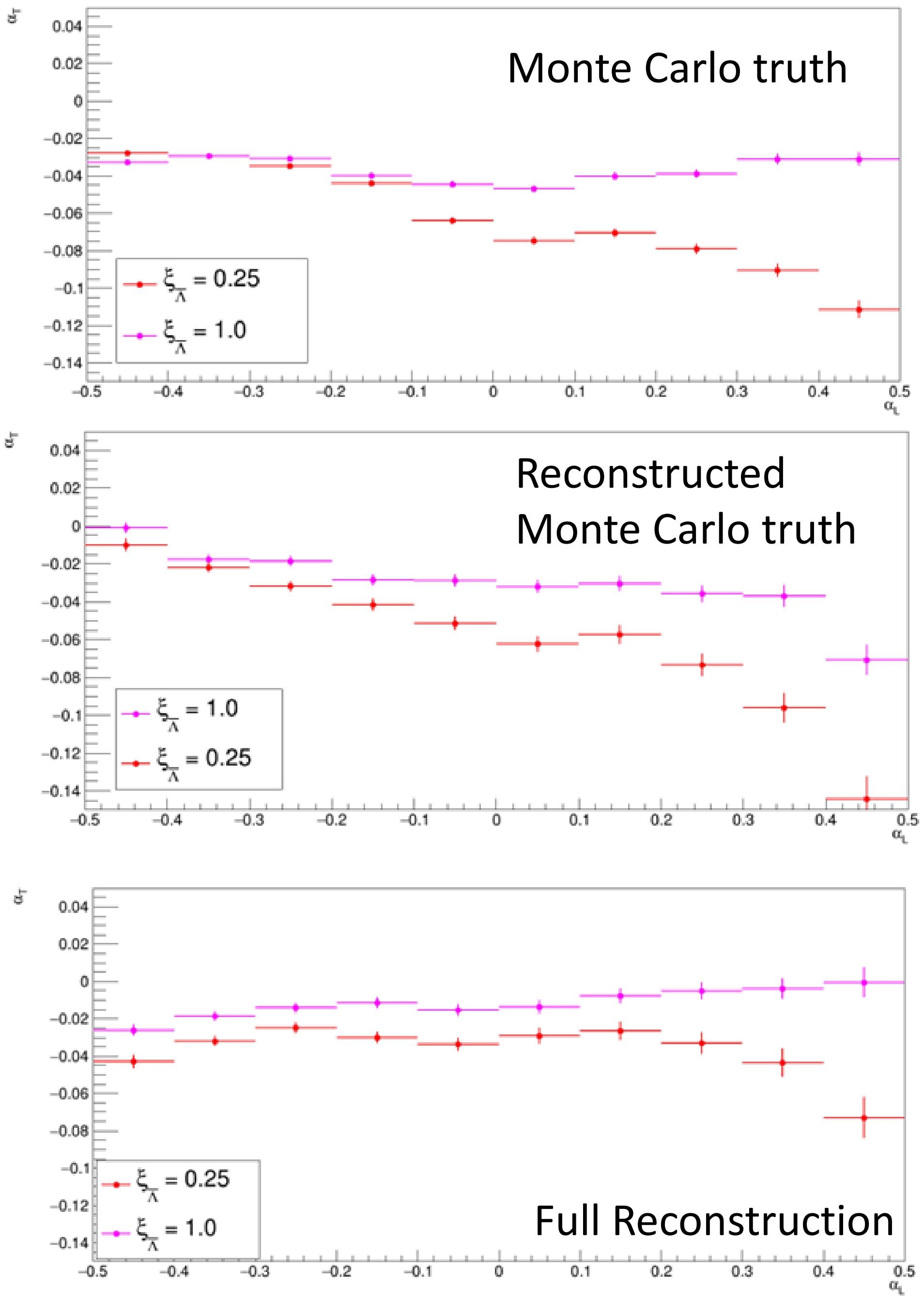


Best reconstruction efficiency in the region of α_L=[−0.2;0.4]

Different potentials can be distinguished

High sensitivity remains high after full reconstruction

Work in progress: Background



Deliverable 16.3: SIDDHARTA-2

Goal: study of kaonic deuterium

Luminosity Monitor

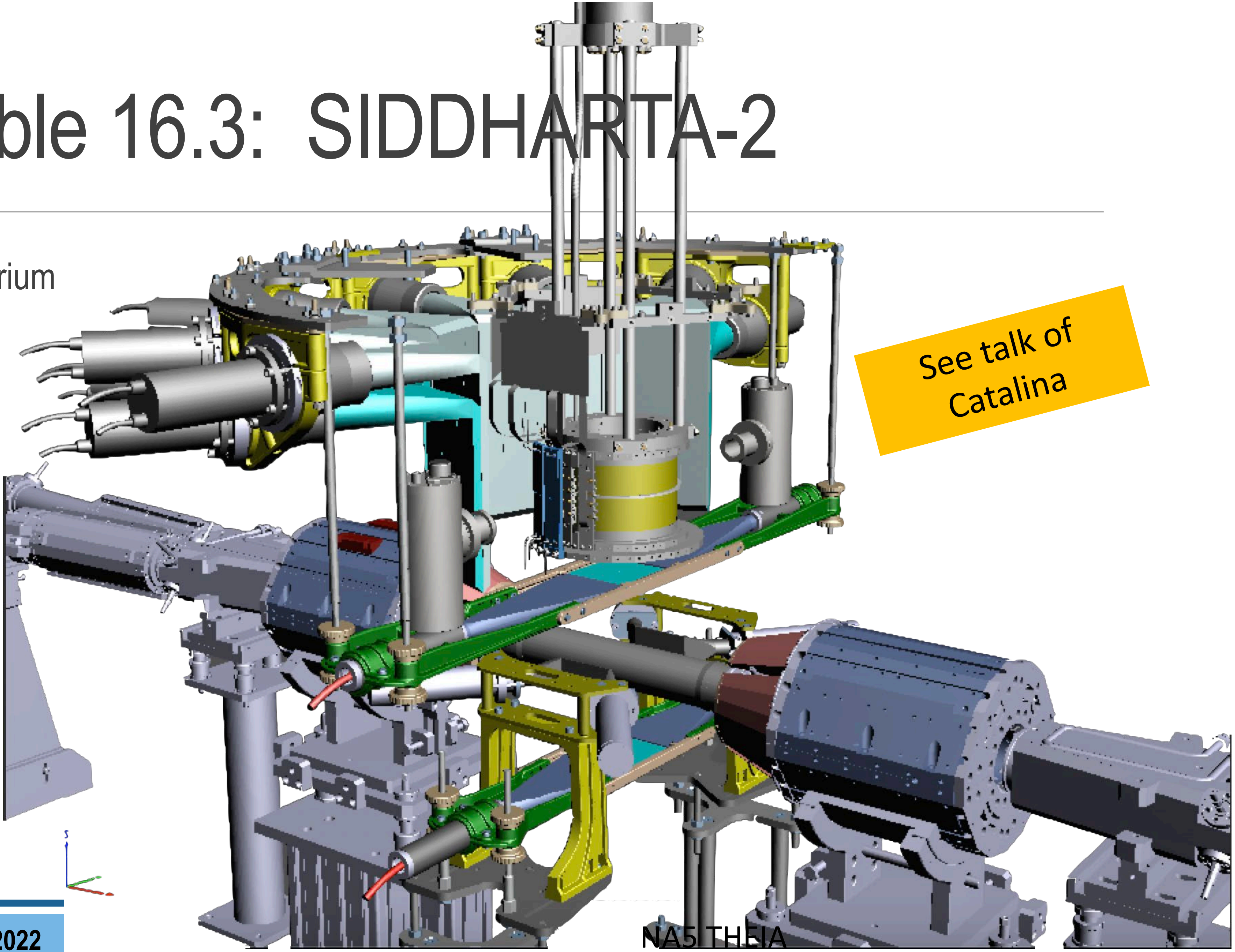
Kaon Trigger

Cryogenic gaseous target

SDD detectors

Veto-2 system

Veto-1 system

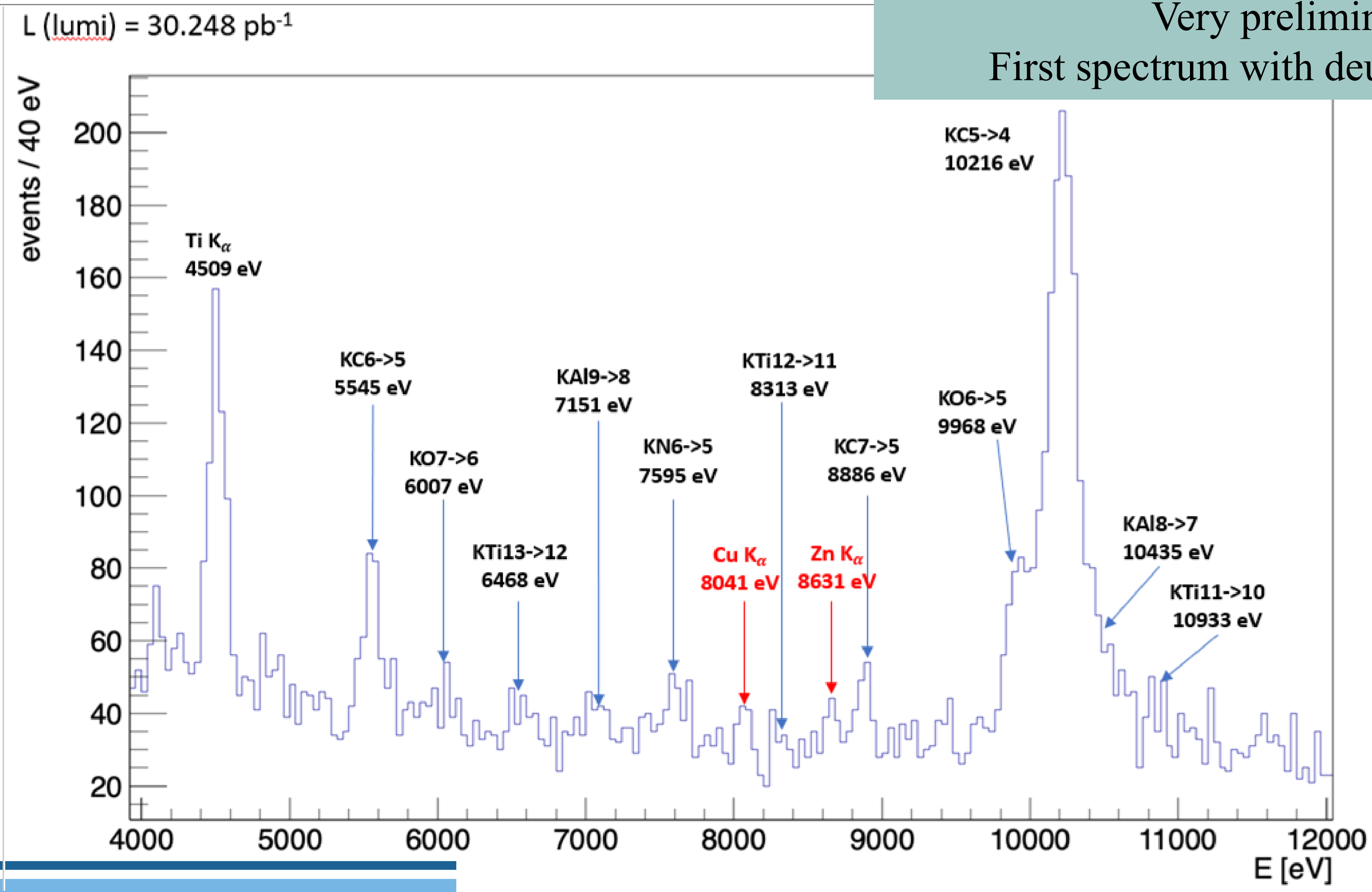


See talk of Catalina

Siddharta 2 Kaonic Deuterium

See talk of Catalina

Very preliminary
First spectrum with deuterium target



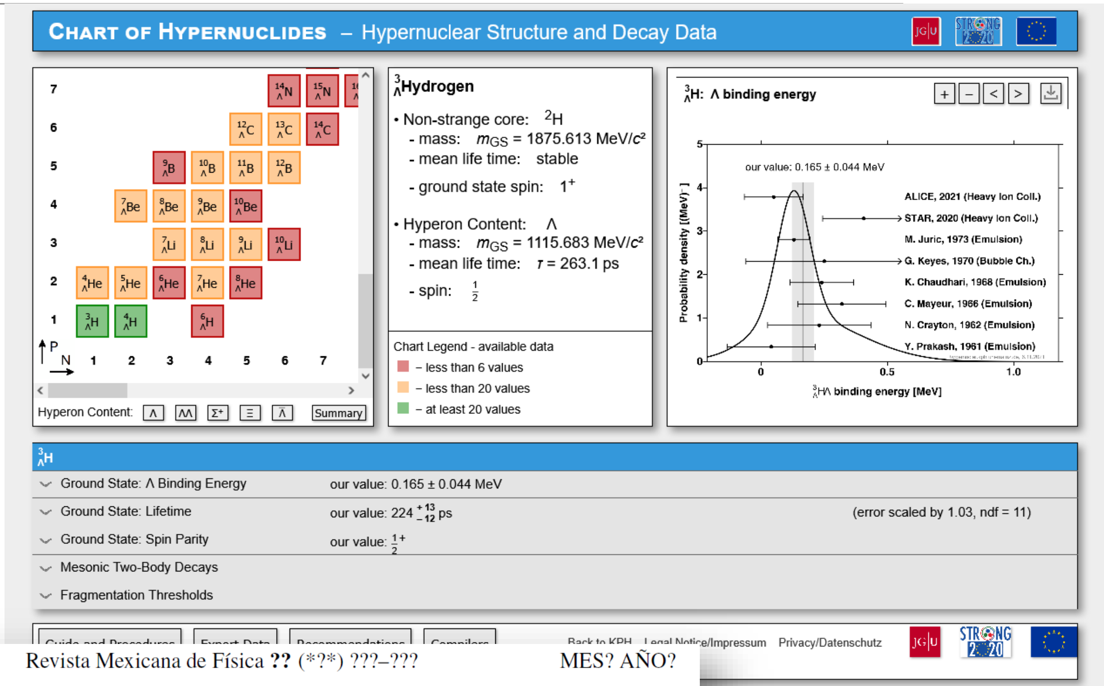
GDPR

New Deliverable 16.4: Hypernucleus Database

- an interactive hypernucleus database is being built at Mainz
  - https://hypernuclei.kph.uni-mainz.de/
  - goal: provides complete overview of existing data
  - summary plots, errors etc generated automatically
  - export data and plots to files possible

- DB will continuously updated with new data

- First report is published in HADRON2021 proceedings



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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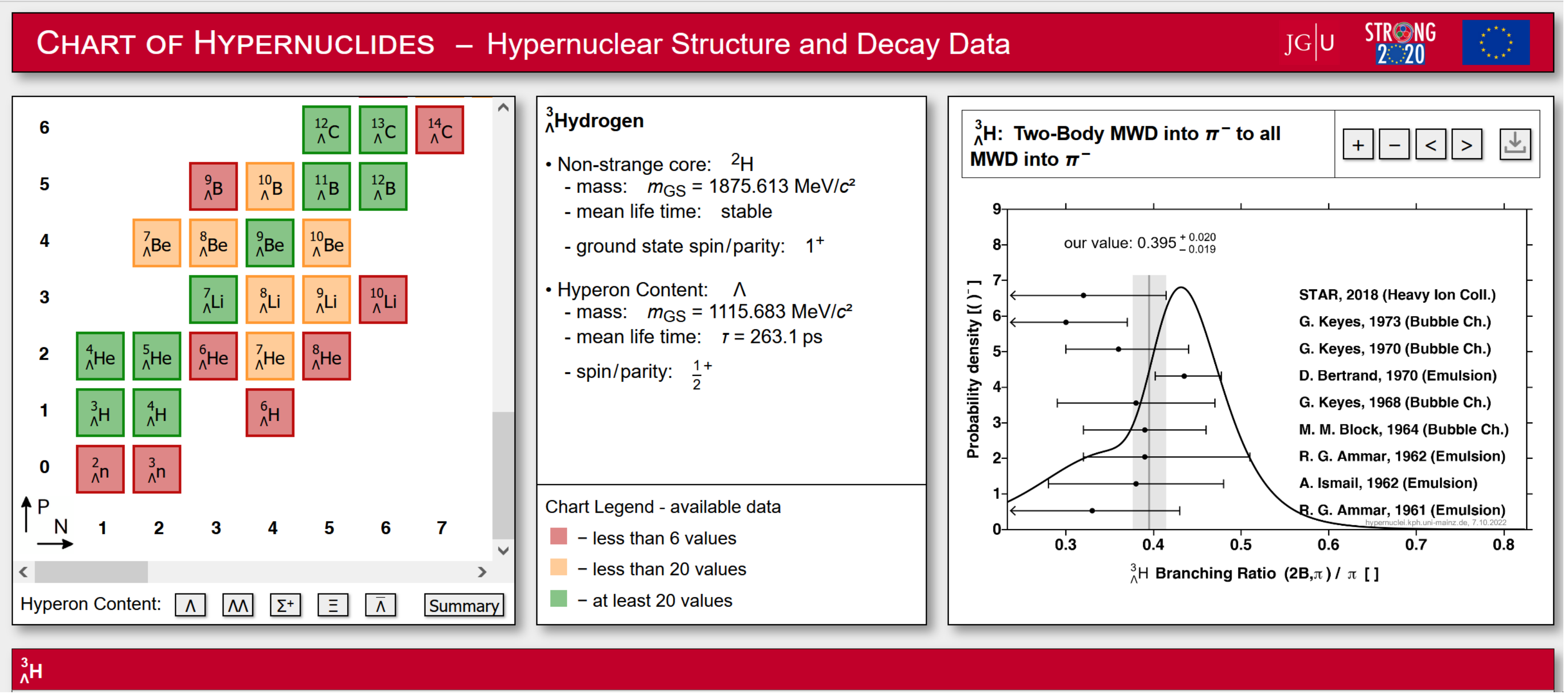
[*] *email: eckert@uni-mainz.de*
[b] *Helmholtz Institute Mainz, GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Johannes Gutenberg University, 55099 Mainz, Germany*
[c] *Graduate School of Science, Tohoku University, Sendai, Miyagi 980-8578, Japan*

Received day month year; accepted day month year

Deliverable 16.4: Hypernucleus Database

New content: branching ratios

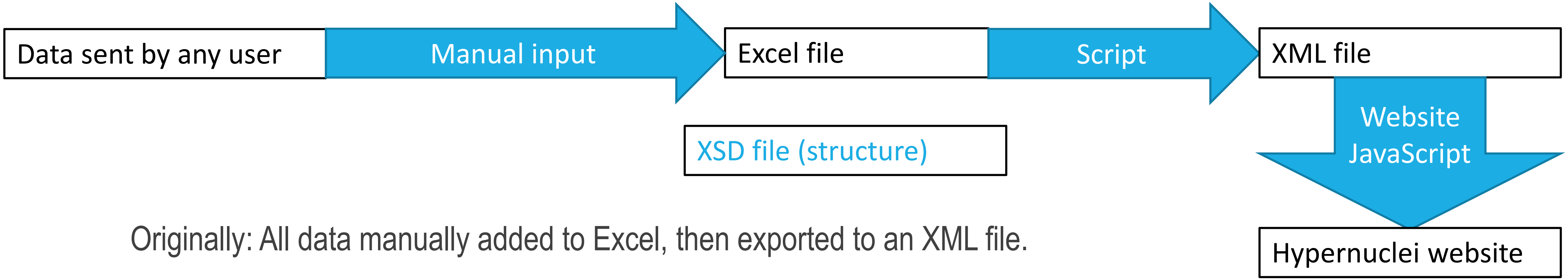


Supplements ideograms by *conflation of probability distributions*[1]

alternative to averaging the probabilities or averaging the data

[1]https://arxiv.org/pdf/1005.4978.pdf

Deliverable 16.4: Hypernucleus Database
Original structure (Based on XML file)



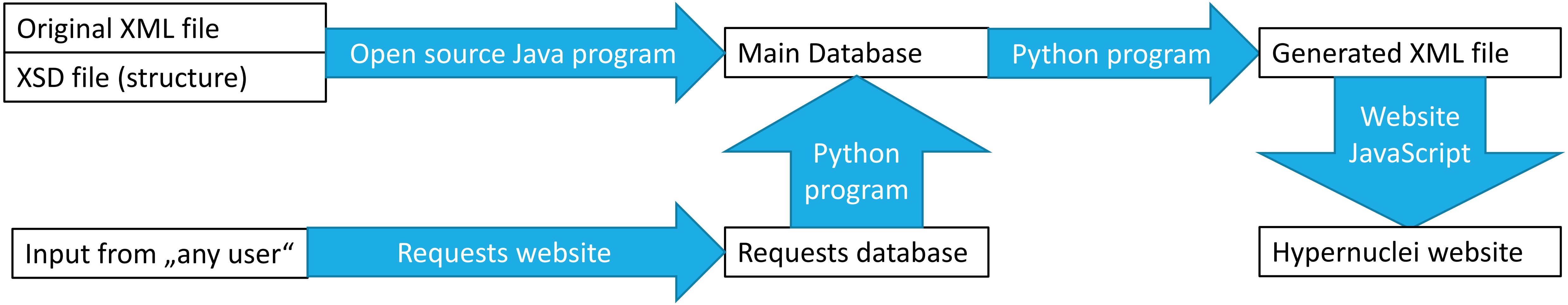
Originally: All data manually added to Excel, then exported to an XML file.

Transition to a database:

- More robust
- Easier to add new data
- Better suited for online hosting

Relational database structure: Tables related via IDs

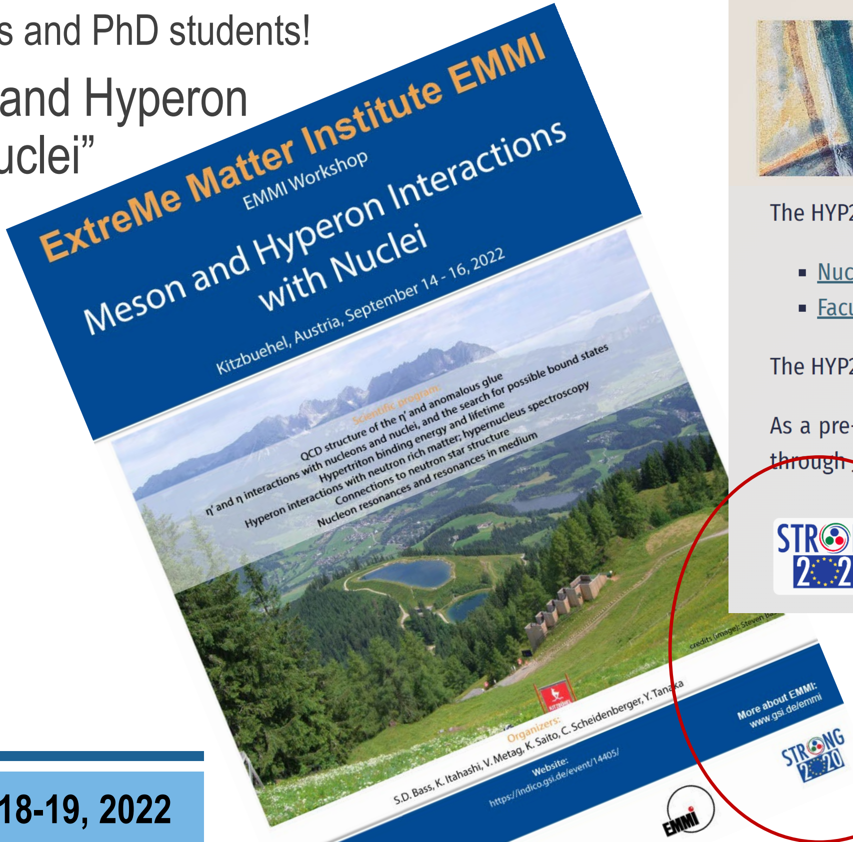
Deliverable 16.4: Hypernucleus Database
New Structure (With POSTGRESQL database)



Deliverable: Workshops

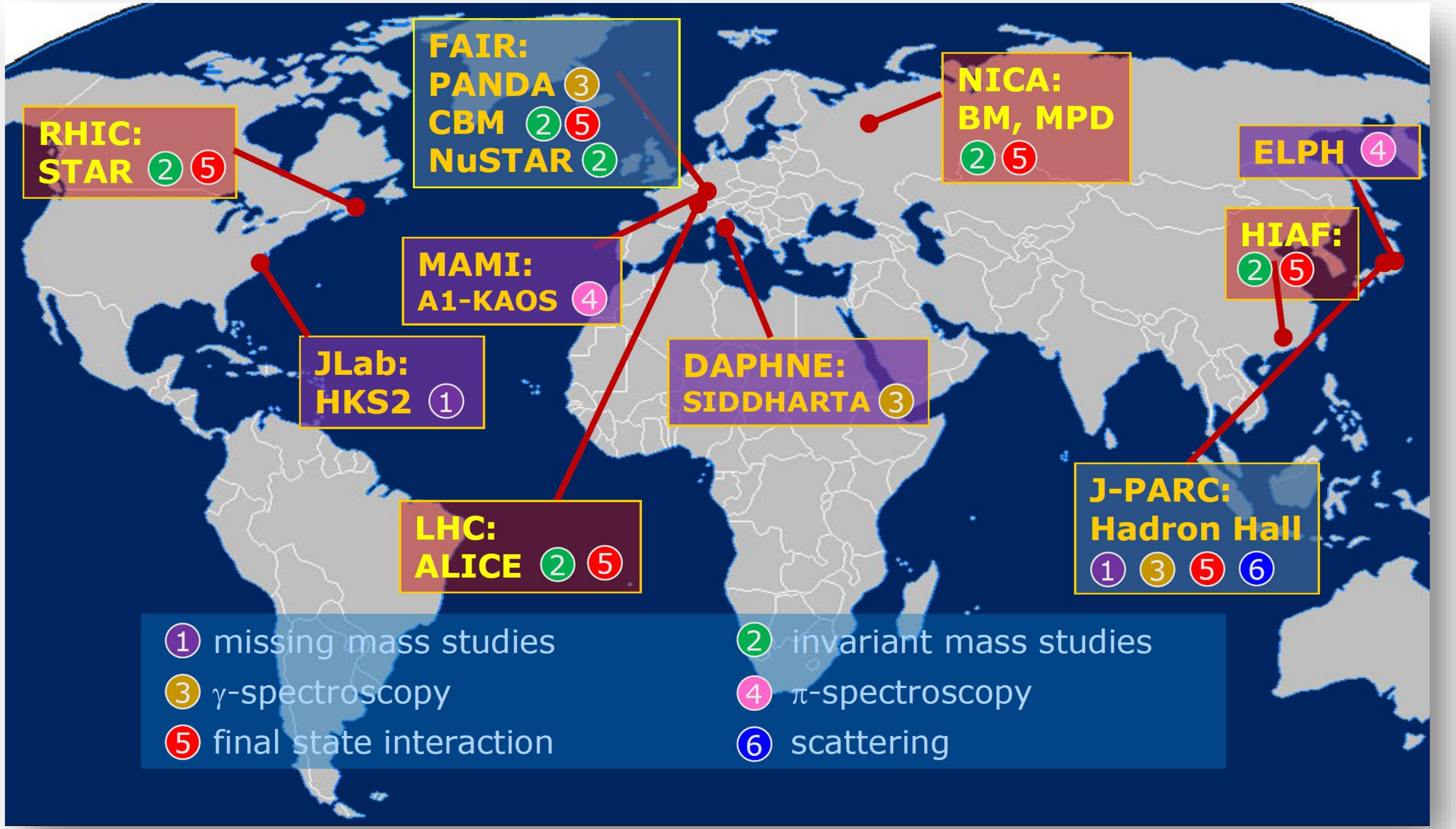
Major meetings in 2022

- HYP2022 in Prague, June 27 – July 1, 2022 (hybrid)
  - Supported 23 participants
  - Many young scientists and PhD students!
- Workshop “Meson and Hyperon Interactions with Nuclei”



NA5 THEIA

Input to NuPECC Long Range Plan 2024



Strangeness nuclear physics

Josef Pochodzalla, University Mainz, Germany
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

Deliverables:

Despite many rescrictions, all delivarables and milestone will be achieved within duration of STRONG2020

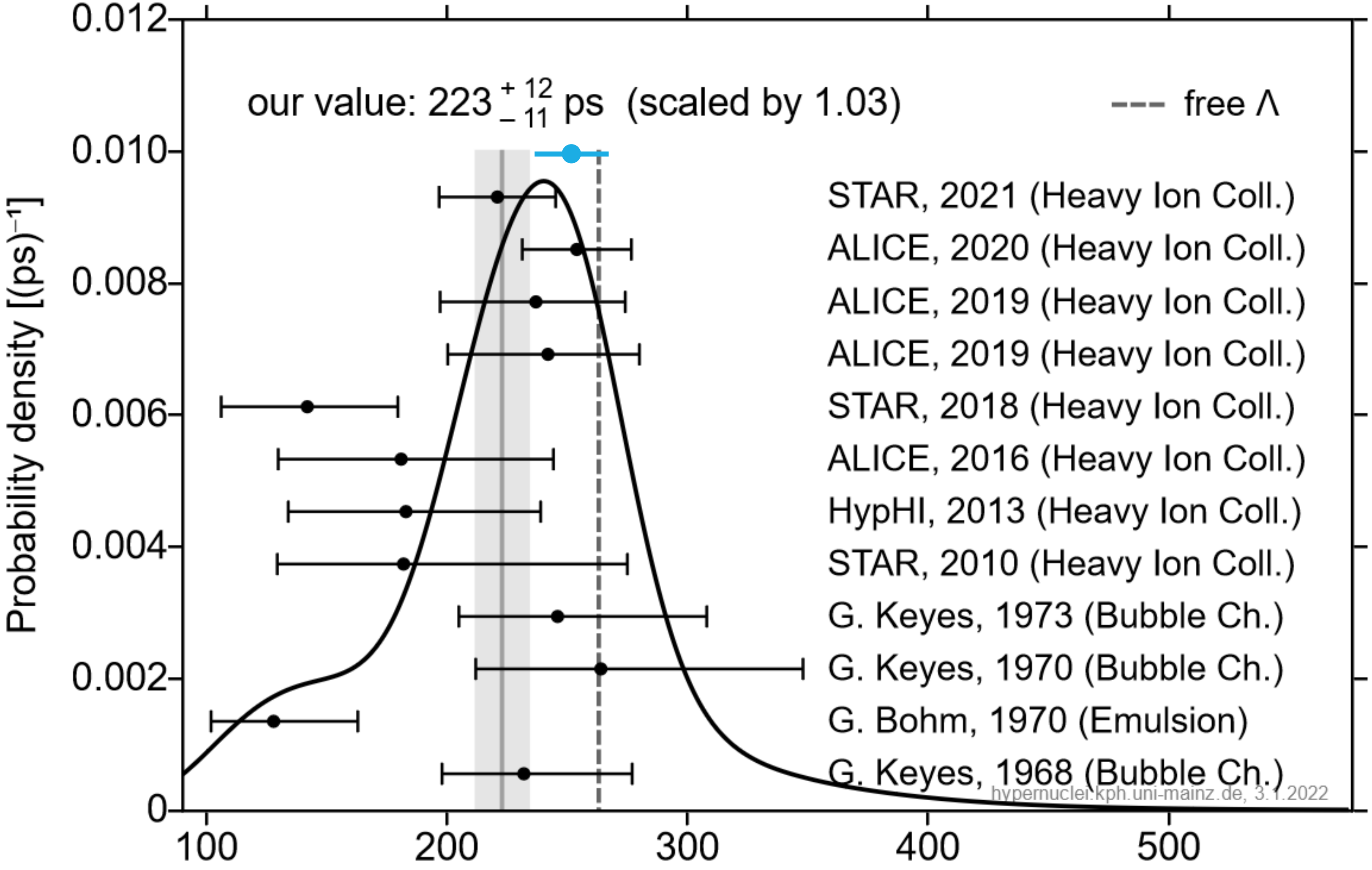
D16.1: Study of A=3 hypernuclei $^{3}_{\Lambda}$H and $^{3}_{\Lambda}$n	report	4
MS20: First data taking by WASA@GSI/FAIR searching for $nn\Lambda$ scheduled in spring 2022		4
D16.2: Study of antihyperons in nuclei; PANDA software tools	demonstrator	(4)
MS21: Design report for antihyperons in nuclei ready	report	
D16.3: Theoretical and experimental studies of bound mesonic systems	report	4
MS22: SIDDHARTA-2 progress report		
D16.4: Hypernuclear database is online and will continually updated	public/webpage	(4)

Annual workshops are resumed in 2022 – prolongation would be helpful to have the final workshop early 2024

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

Recent ALICE result (2022)

~253±11$_{stat}$±6$_{syst}$ ps



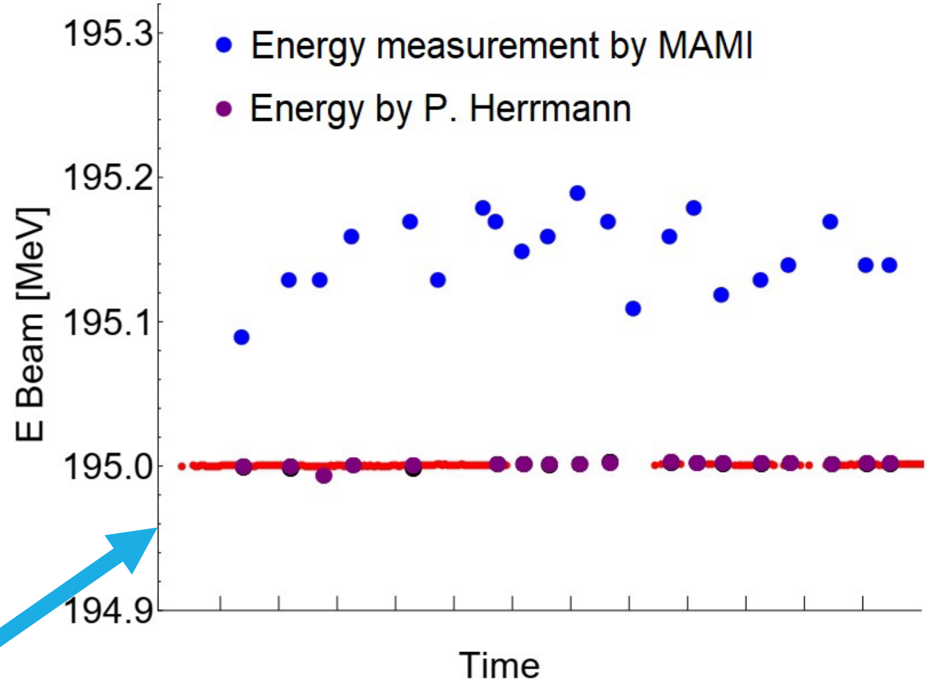
Systematic Error due to Spectrometer Calibration

Spectrometer calibration via elastic e$^-$ scattering

- Recent ${}^{4}_{\Lambda}$H binding energy error: ± 77 (syst.) keV
- Reason: Uncertainty in MAMI's e$^-$ energy: ±160 keV

However: MAMI much more stable than that

Still no absolute value



P. Herrmann, via an in beam line energy spectrometer

→ New approach: Undulator Light Interference

Acceptance of PANDA

Reconstruction efficiency strongly depends on asymmetry

Poor reconstruction efficiency for high or low longitudinal asymmetries

Asymmetries (+1,+1) and (−1,−1)

$\Rightarrow p(\Lambda)=0$ or $p(\overline{\Lambda})=0$