STRONG-2020

WP16 - NA5 THEIA – Josef Pochodzalla

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

“Experimental and theoretical advances on two and three-body interactions with hyperons and nucleons would lead to further constraints for future analyses (of neutron stars)”

Laura Tolos@SPICE

Main Topics of WP16

- Theoretical and experimental studies of bound mesonic systems (report ✓)
- Study of A=3 hypernuclei $^{3}_{\Lambda}$H and $^{3}_{\Lambda}$n (report ✓)
- Study of antihyperons in nuclei; PANDA software tools (report ✓)
- Hypernuclear database (webpage ✓)

All project deliverables achieved

MS22: SIDDHARTA-2 progress report

High precision light kaonic atoms X-ray spectroscopy is a unique tool for performing experiments equivalent to scattering at vanishing relative energies, to determine the antikaon–nucleus interaction at threshold without the need of extrapolation to zero energy. The SIDDHARTA-2 collaboration is going to perform the first measurement of kaonic deuterium transitions to the fundamental level, which is mandatory to extract the isospin dependent antikaon–nucleon scattering lengths.

In the reporting period (up to M22) the SIDDHARTA-2 setup in its Phase 1 version, i.e. SIDDHARTINO, was installed and in operation on the DAFNE collider. SIDDHARTINO (FIG. 1) represents the reduced SIDDHARTA-2 setup, containing 1/6 of the Silicon Drift Detectors and it is being used to optimize the experimental setup during the commissioning of the collider.

Study of A=3 Hypernuclei

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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.

D16.2: Development of dedicated simulation and software tools for the measurement of antihyperons in nuclei.

Falk Schupp[1,§], Josef Pochodzalla[1,2]
representing the Networking activity THEIA (WP16) within STRONG-2020
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Summery: The exclusive production of hyperon-antihyperon pairs close to their production threshold in $\bar{p}$-nucleus collisions offers a unique and yet unexplored opportunity to elucidate the

Annual workshops

- November 25-29, 2019 in Speyer
- Joint THEIA-STRONG2020 and JAEA/Mainz REIMEI Web Seminar 2020/2021 [49 talks]
- HYP2022 in Prague, June 27 – July 1, 2022 (hybrid)
- ECT* Workshop “**SPICE**: **S**trange hadrons as a **P**recision tool for strongly **I**nteraCting systEms“ May 13-17, 2024

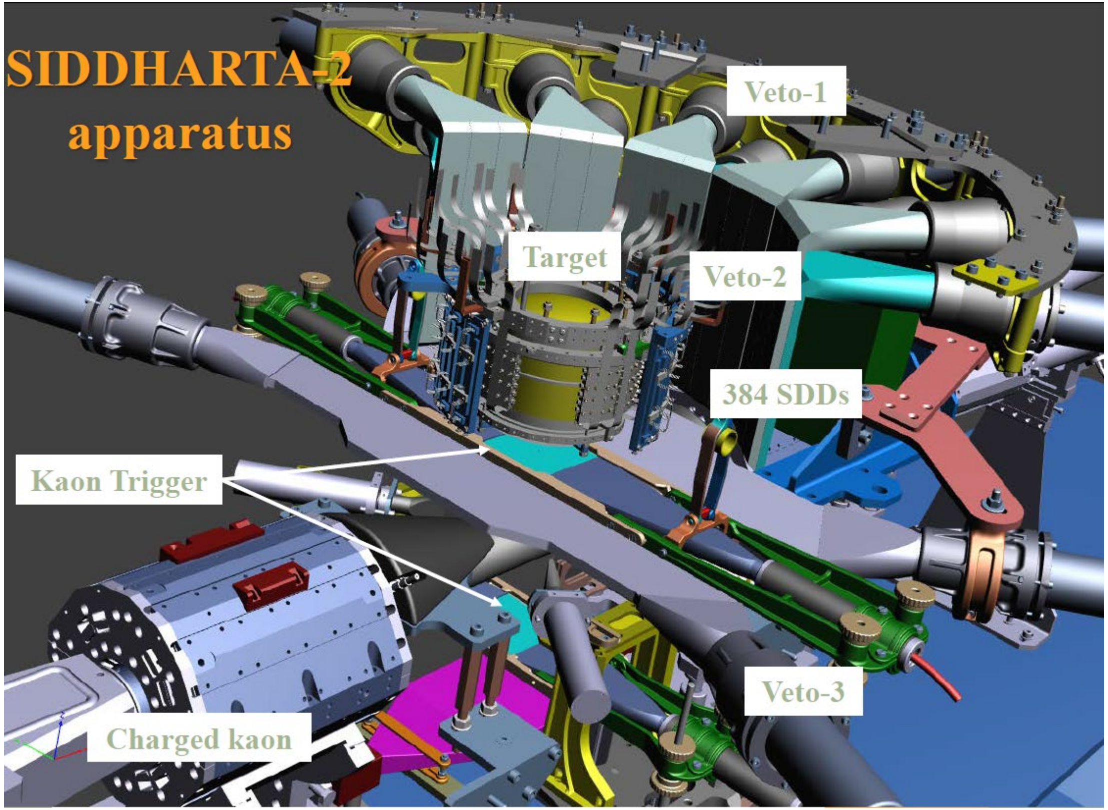
Annual meetings were the backbone of the networking activity THEIA

SPICE: Strange hadrons as a Precision tool for strongly InteraCting systEms

- May 13-17, 2024, ECT*
- 51 registered participants
- 43 talks
  - Kaonic systems 11
  - Hypernuclei 15
  - Baryons structure 4
  - Baryon-baryon interactions 6
  - Dense systems 3
  - Other topics 4

SIDDHARTA-2 at DAΦNE

- Primary goal: kaonic deuterium
- Optimized setup
  - Shielding
  - Readout
  - Veto
  - Trigger
  - …
- New components
  - Ge detectors
  - Solid targets
  - …



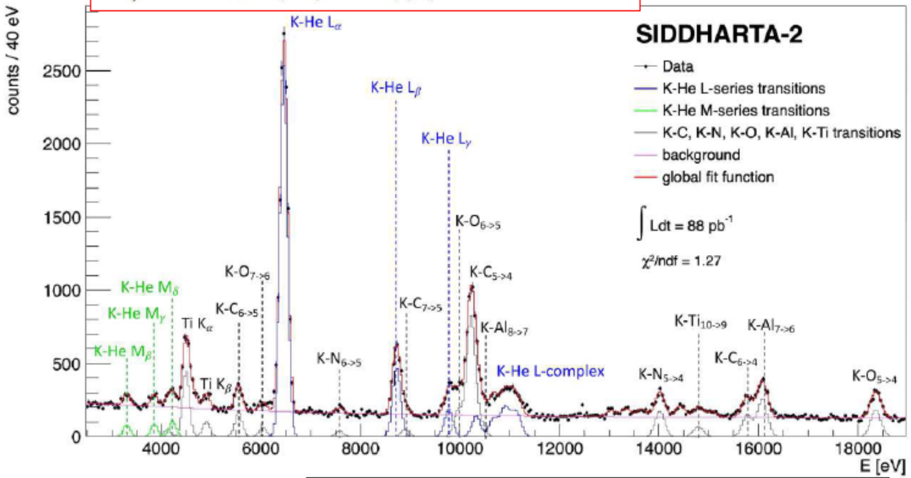
SIDDHARTA-2 at DAΦNE (Francesco Sgaramella)

- First data on Kaonic He (2022)
  - 2p level energy shift and width in gaseous target at 2.25 g/l
  - paves the way to heavy kaonic atoms

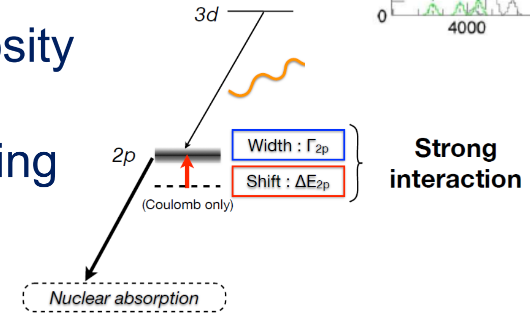
- Kaonic deuterium run will be completed in 2024
  - Total integrated luminosity 800pb^{-1}
  - Analysis of run 1 ongoing

$$\varepsilon_{2p} = E^{exp}_{3d\to 2p} - E^{e.m}_{3d\to 2p} = -1.9 \pm 0.8\,(stat) \pm 2.0\,(sys)\ eV$$

$$\Gamma_{2p} = 0.01 \pm 1.60\,(stat) \pm 0.36\,(sys)\ eV$$

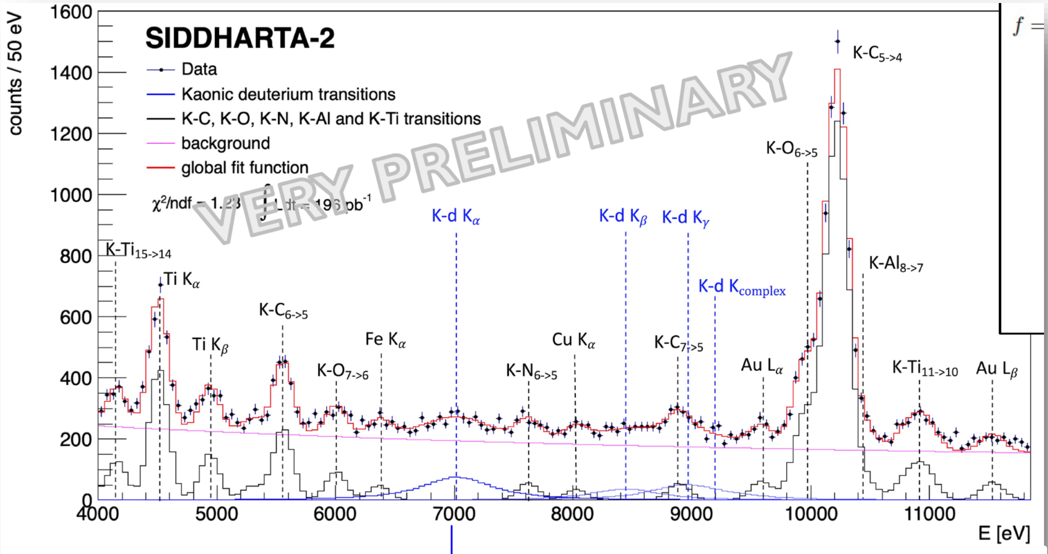


Sgaramella F., Tüchler M., et al., 2023, Eur. Phys. J. A, 59 (3) 56



K-d at SIDDHARTA-2 (Francesco Sgaramella)

- Kaonic deuterium run completed in 2024
  - Total integrated luminosity 800pb^{-1}
  - Preliminary analysis



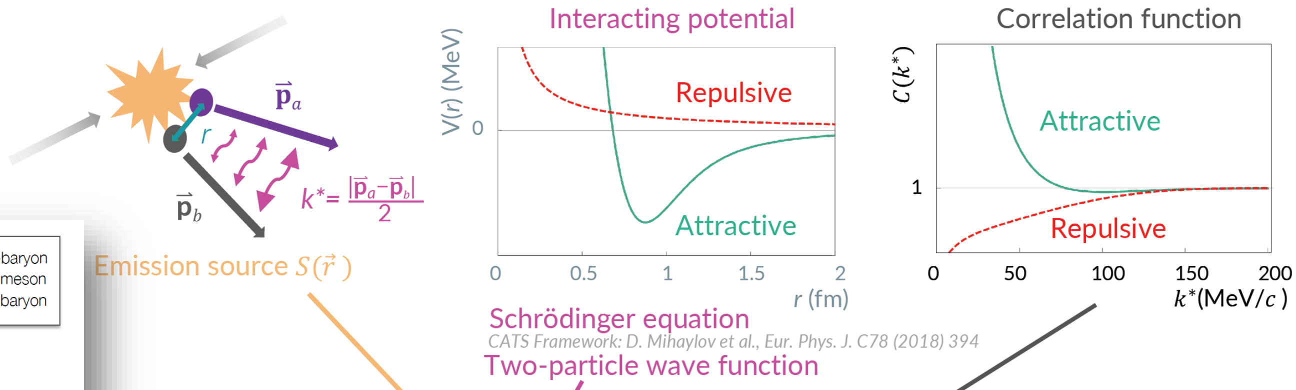
$$\varepsilon_{1s} = E^{meas}_{2p\rightarrow 1s} - E^{e.m.}_{2p\rightarrow 1s} = -816 \pm 53\ (\text{stat}) \pm 2\ (\text{syst})\ \text{eV}$$

$$\Gamma_{1s} = 756 \pm 271\ (\text{stat})\ \text{eV}$$

A new Pillar for Strange Systems: Femtoscopy

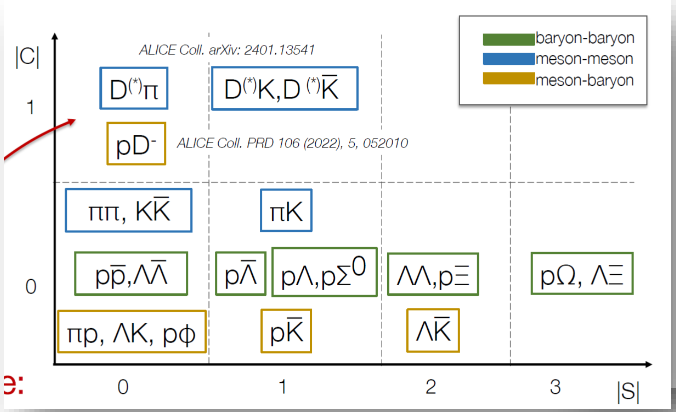
(Raffaele Del Grande, Valentina Mantovani Sarti)

The femtoscopy technique at the LHC



$$C(k^*) = \int S(\vec{r}) \left|\psi(\vec{k}^*, \vec{r})\right|^2 d^3\vec{r} = \mathcal{N}(k^*) \frac{N_{\mathrm{same}}(k^*)}{N_{\mathrm{mixed}}(k^*)}$$

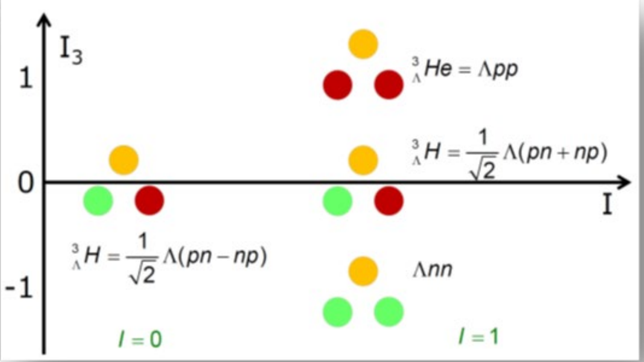
Measuring $C(k^*)$, fixing the source $S(\vec{r})$, study the interaction

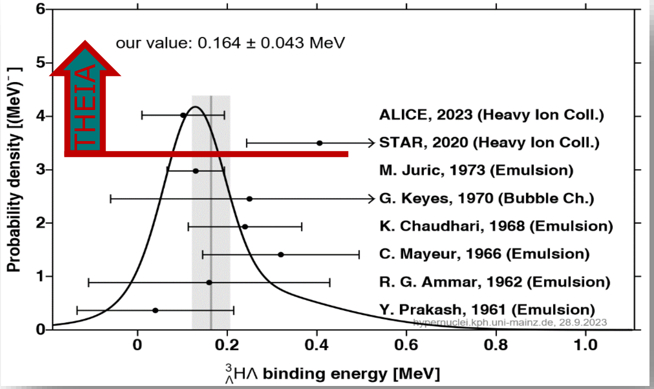


A=3 Hypernuclei

- 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 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

- Precise measurements of BE *and* τ will provide a stringent test for multi-baryon forces

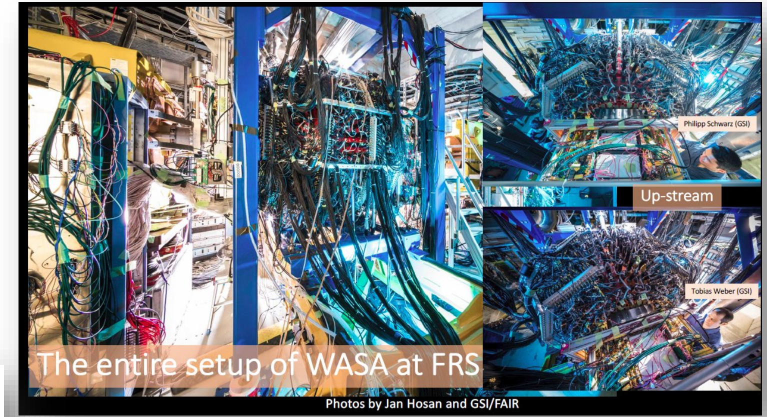




Search for nnΛ by WASA@GSI/FAIR

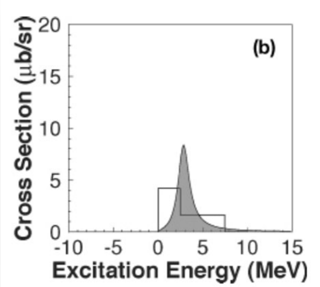
(Takehito Saito)

- Hypernnuclei are identified by two-body decays: π^- Λ fragment
- Sucessful data taking Jan. – March 2022
- Analysis still ongoing - waiting for first results

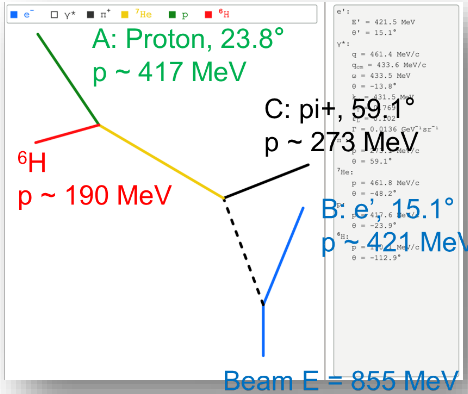


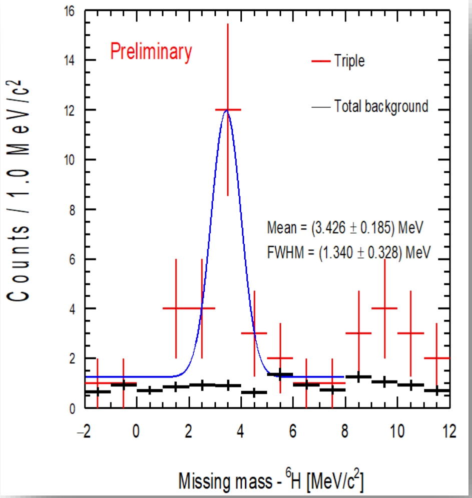
Conventional neutral system (Tianhao Shao)

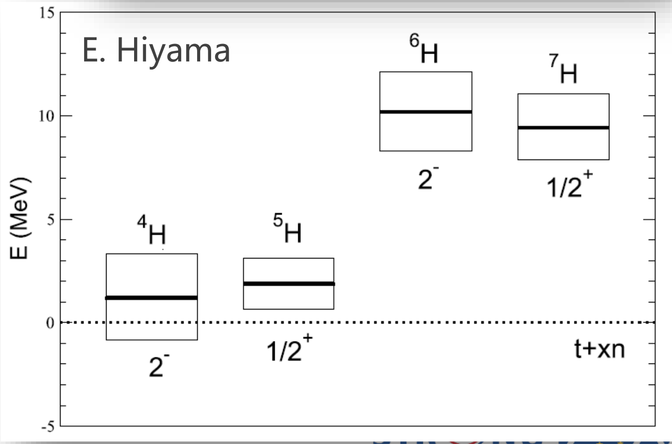
- nnΛ and the $^6_\Lambda H$ are under discussion
- A tetra-neutron nnnn "state" is established
- Heavy hydrogen isotopes (^6H, ^7H) unclear
- ^6H @ MAMI: missing mass $^7Li(e, e'p\pi^+)^6H$
- MAMI: ^6H ground state ~ 3.4 MeV, width ~ 1.3 MeV ?



Reaction	E [MeV]	Γ [MeV]
$^7Li(^7Li,^8B)^6H$	2.7±0.4	1.8±0.5
$^9Be(^{11}B,^{14}O)^6H$	2.6±0.5	1.3±0.5
$^9Be(\pi^-,pd)^6H$	6.6±0.7	5.5±2.0
$^{11}B(\pi^-,p^4H)^6H$	7.4±1.0	5.8±2.0
$^{12}C(^8He,^6H \to t+3n)^{14}N$	$2.91^{+0.85}_{-0.95}$	$1.52^{+1.77}_{-0.35}$
$^2H(^8He,^4He)^6H$	> 4.5	5



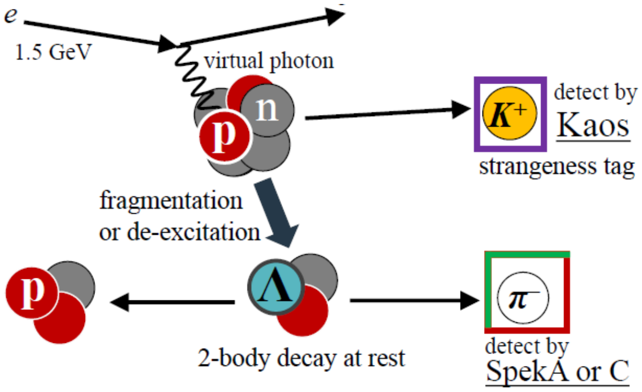


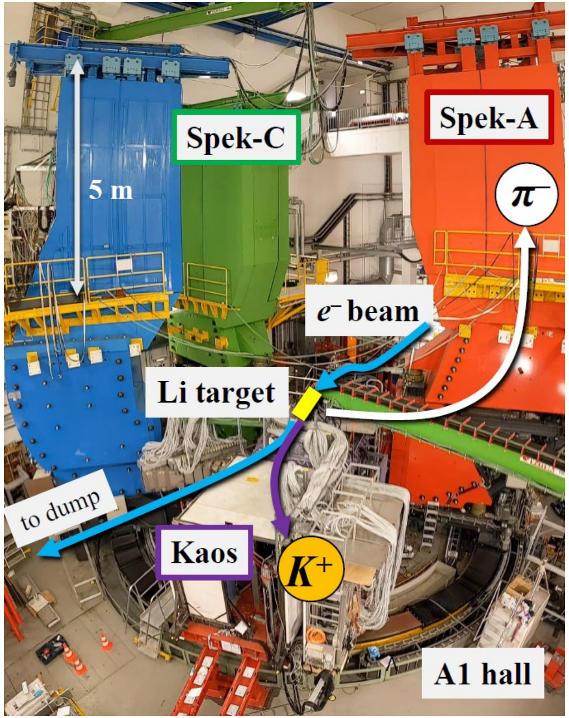


Precision Mass measurement light hypernuclei

(Philipp Eckert, Pascal Klag, Ryoko Kino)

- Decay-pion spectroscopy at MAMI





- Two-body pionic decay of hypernuclei

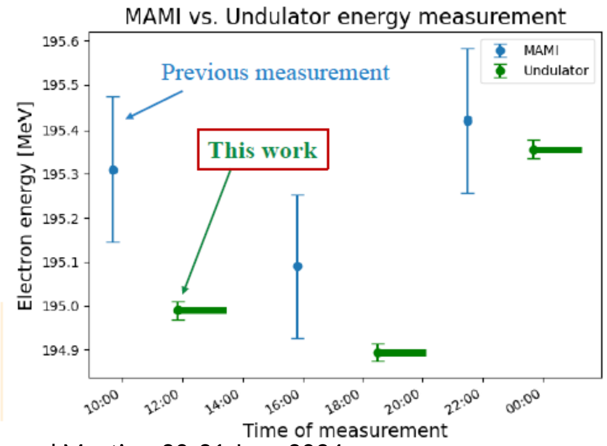
⇒ monochromatic pions

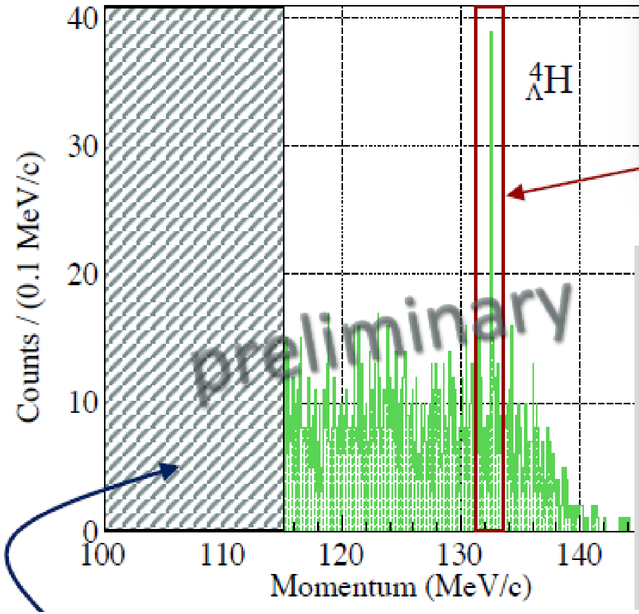
- Data taking: September/October 2022
- Accurate calibration of spectrometers with undulators; March/April 2024

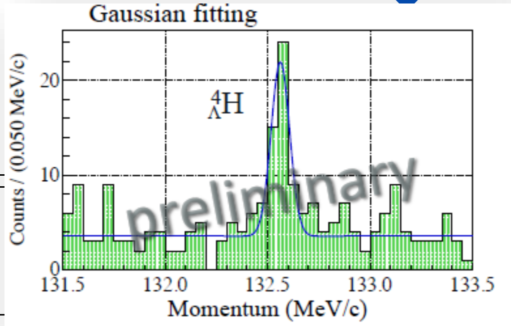
Status of the analysis

(Pascal Klag, Tianhao Shao, Ryoko Kino)

- Parameter adjustment done
- Particle tracking done
- Particle identification in KAOS in progress
- Momentum calibration started







expected pion peak from $^3_\Lambda$H

preliminary $^4_\Lambda$H (only SPEK-A):
$p_\pi = 132.54 \pm 0.008 \pm ?? \text{ MeV/c}$
Final systematic error expected ~ 10keV

2014 (SPEK-A and SPEK-C):
$p_\pi = 132.87 \pm 0.007 \pm 0.106 \text{ MeV/c}$

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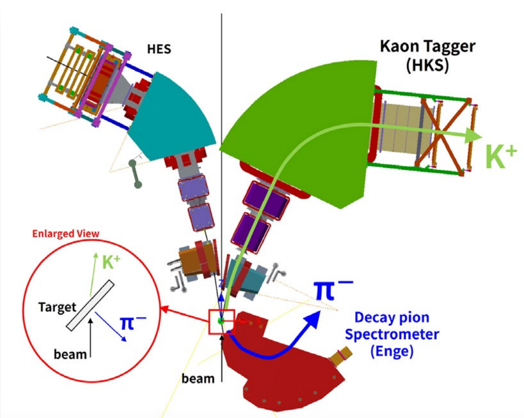
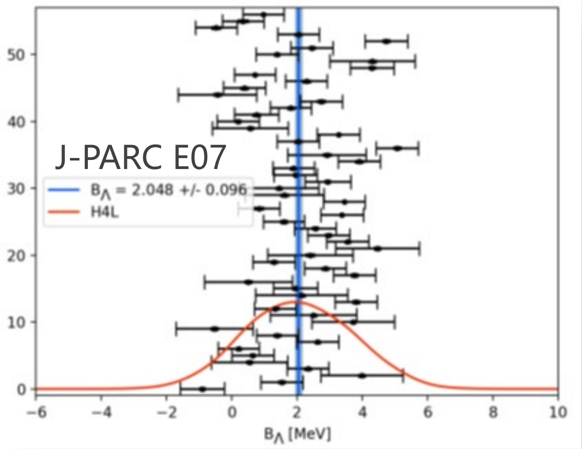
Ongoing Projects

- At JLab, a missing-mass measurement of the hypertriton mass with a accuracy of less than 100 keV has been approved (Toshi Gogami)
- Decay pion spectroscopy aiming at a accuracy ≈ 20keV is proposed (Sho Nagao)

- J-PARC E07 is analysing hypertriton decays in their emulsion plates, aiming at an accuracy of 30 keV each. (Take Saito) Systematic error?

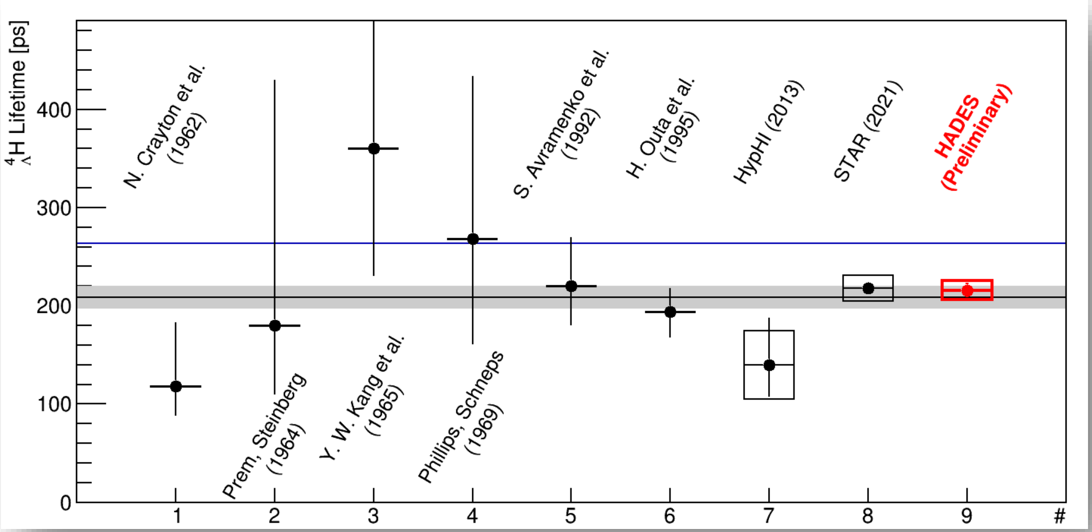
- New heavy ion data (STAR, ALICE, HADES)

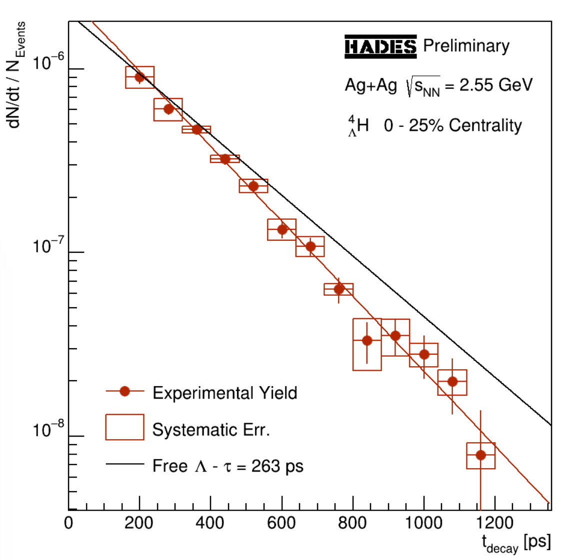




Hypernuclei at HADES
(Simon Spies)

- Ag+Ag collisions at $\sqrt{s_{NN}}$= 2.55 GeV with the HADES
- Very competitive result for the lifetime of $^4{}_\Lambda H$





Conclusions

- Strangeness nuclear physics fills an gap between hadron structure and nuclear physics
- THEIA has fulfilled all tasks
- The field of strangeness nuclear physics is extremely active, many new experiments and theoretical developments or on the horizon
- Community will try to keep annuals meetings alive