# PREPARATION OF THE HYPERTRITON BINDING ENERGY MEASUREMENT @ MAMI

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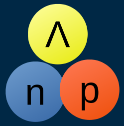
**PANIC 2021**

For the A1 Collaboration & Tohoku Collaborators

# HYPERTRITON AND ITS BINDING ENERGY

- Simplest known hypernucleus → consisting of 1p, 1n and 1Λ




- Binding energy from Juric in 1973[1]:

$$B_\Lambda = 130 \pm 50\,\text{keV}$$

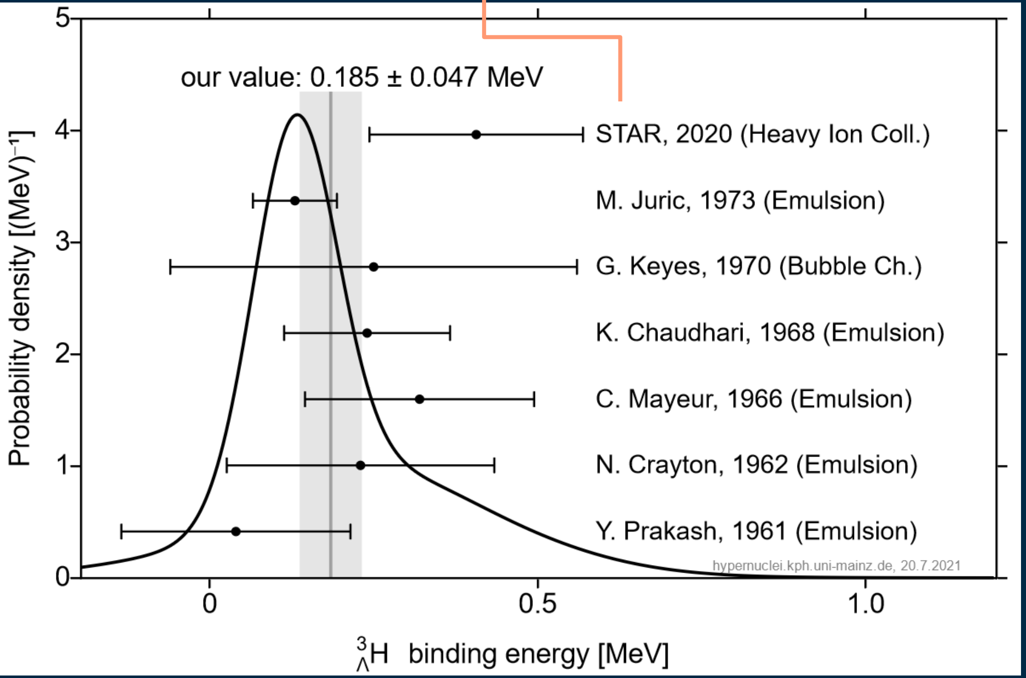
However:

- Systematic error missing
- New measurement by STAR: 406 ± 120 (stat.) ± 110 (syst.) keV

How well do we actually know Hypertriton?

→ Key to understand hyperon-nucleon forces in 3 body system

new STAR value more than 3 times larger than Juric's

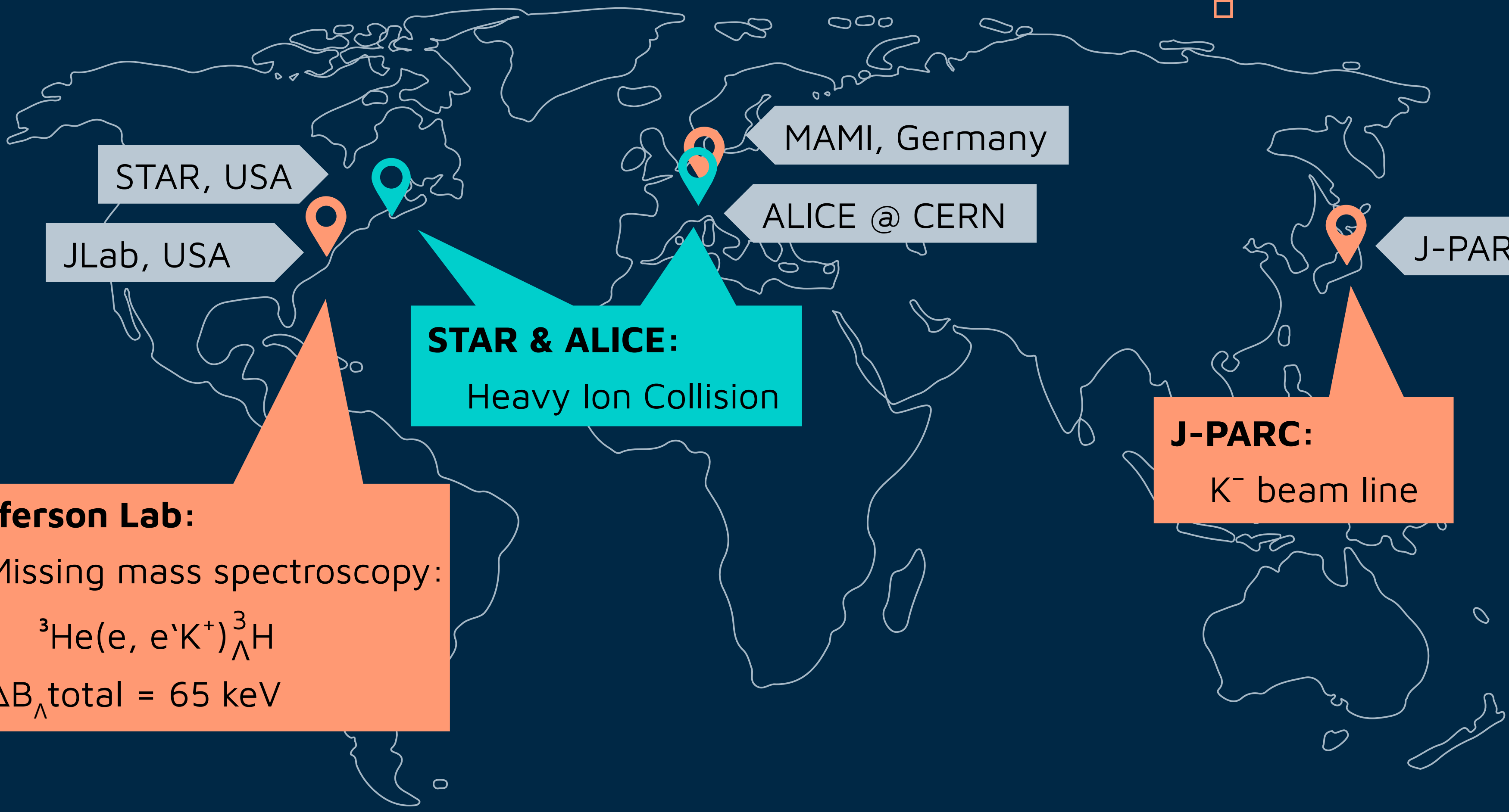



hypernuclei.kph.uni-mainz.de

[1]Nucl. Phys. B 52, 1 (1973) 1-30


# WORLDWIDE ACTIVITIES –

## Experiments adressing Binding Energies of Light Hypernuclei




**STAR & ALICE:**

Heavy Ion Collision

**Jefferson Lab:**

- Missing mass spectroscopy:

  $^{3}\mathrm{He}(e, e'K^{+})^{3}_{\Lambda}\mathrm{H}$

- $\Delta B_{\Lambda}$total = 65 keV

**J-PARC:**

$K^{-}$ beam line

# DECAY PION SPECTROSCOPY @ Mainz Microtron [MAMI]

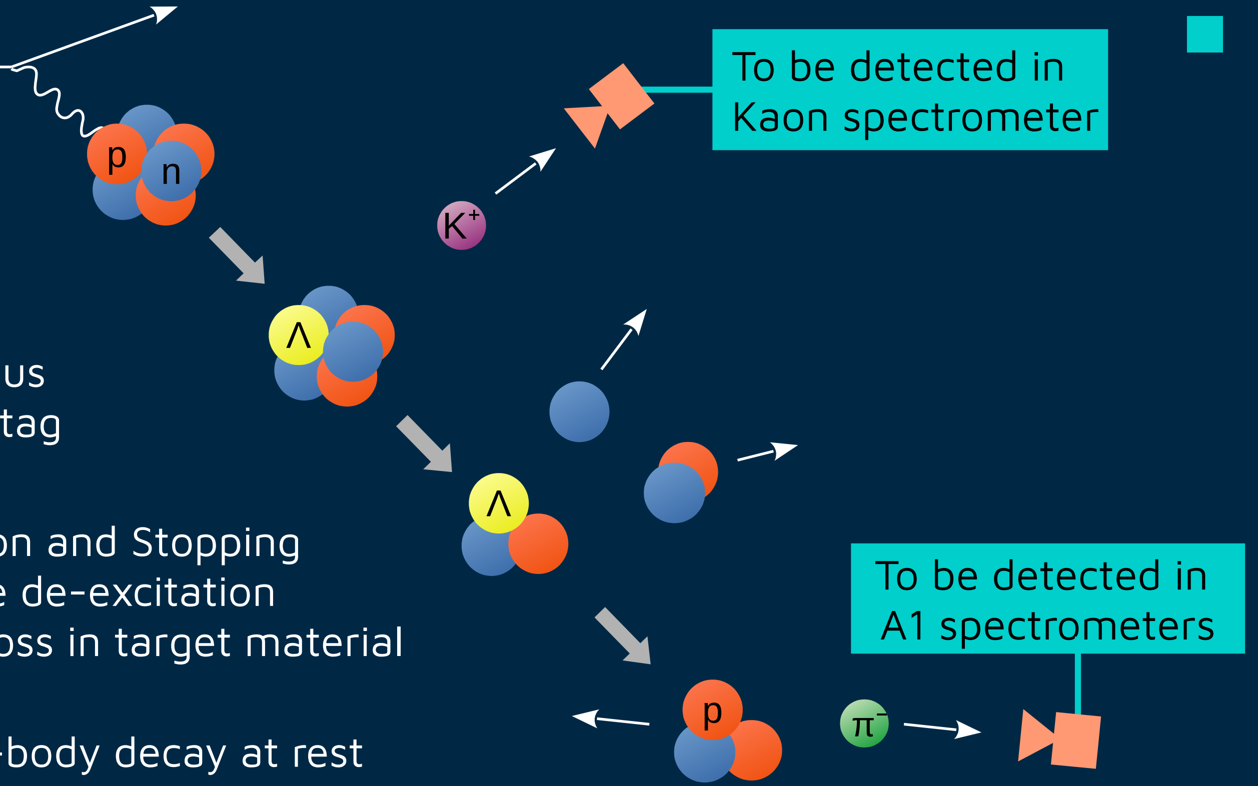
1. Electron scattering off proton
   - E = 1.5 GeV, 10 μA

2. $\Lambda$ – $K^+$ creation
   - highly excited hypernucleus
   - detect $K^+$ as strangeness tag

$\tau_\Lambda$ = 263 ps

3. Fragmentation and Stopping
   - $\Lambda$ can survive de-excitation and energy loss in target material

4. 2-body decay at rest
   - $\Lambda \rightarrow p + \pi^-$
   - binding energy via pion momentum



# DECAY PION SPECTROSCOPY – A1 Setup

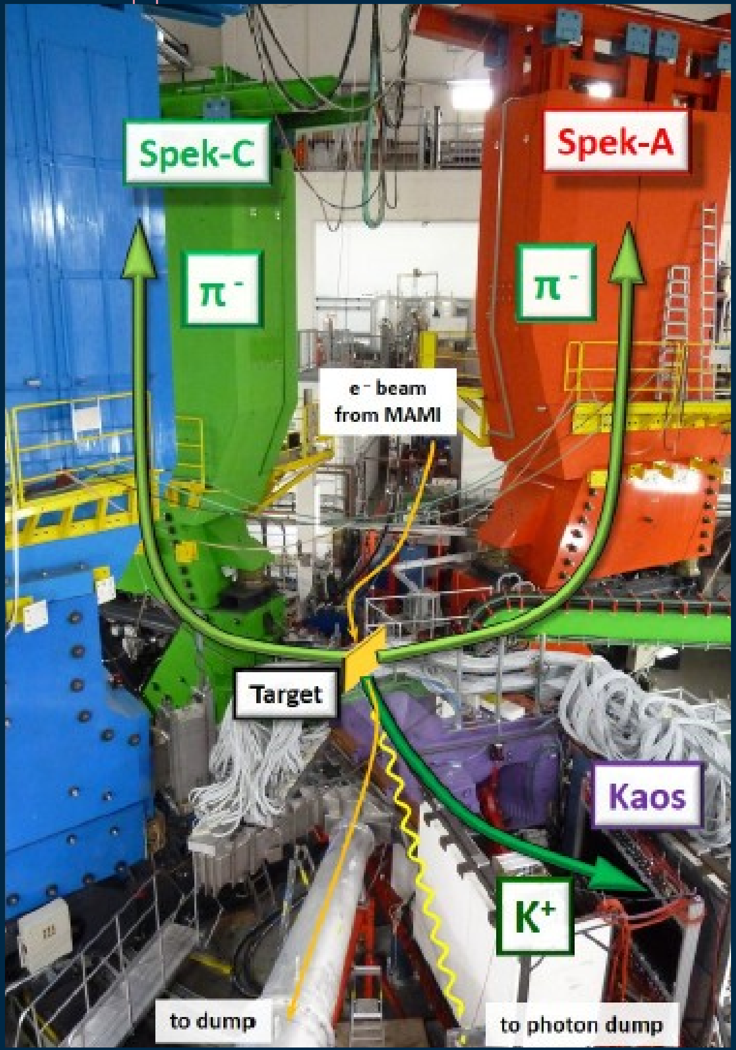
Magnetic spectrometers of A1

- Offer high momentum precision of ~$10^{-5}$
- Suits well for detection of decay pions:

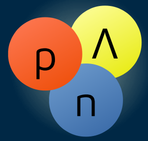
$$m_{hyp.} = \sqrt{m_{ncl}^2 + p_\pi^2} + \sqrt{m_\pi^2 + p_\pi^2}$$

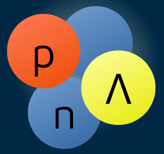
Dedicated Kaon spectrometer [KAOS]

- Closer to interaction point
  → compensate short Kaon lifetime
- In beamline to cover forward angles



# RESULT FROM 2014 – OBSERVATION OF $^{4}_{\Lambda}H$




- Determination of $^{4}_{\Lambda}H$'s Λ binding energy:

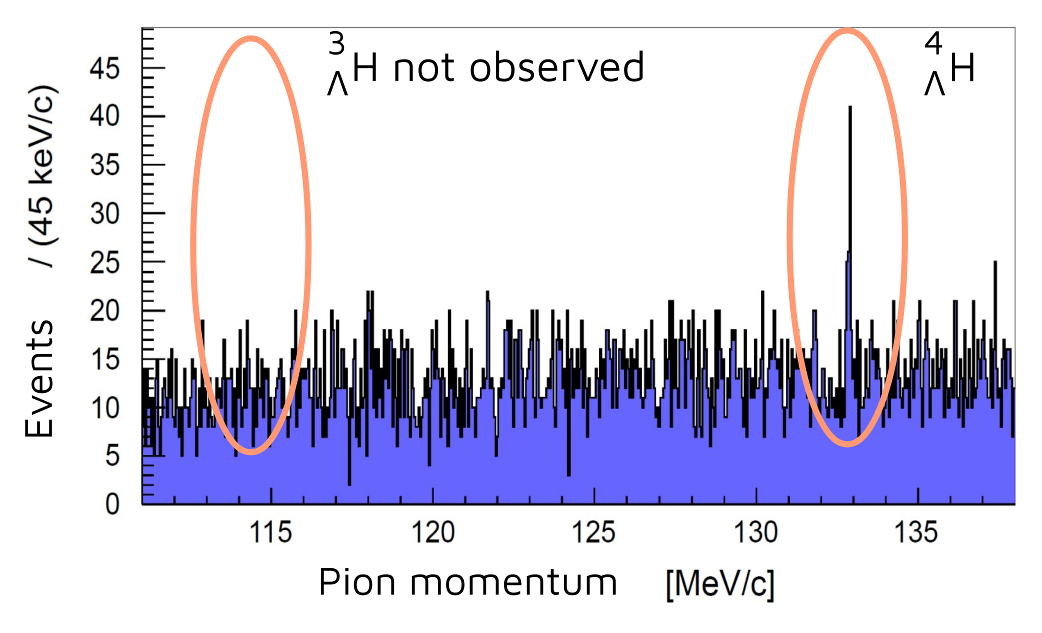
$B_{\Lambda}$ = 2157 ± 5 (stat.) ± 77 (syst.) keV[1]

However:

- Systematic error dominating
- Hypertriton not observed

New experiment in 2022:

- Improved target design
- New spectrometer calibration






[1] F. Schulz, NPA 954, 149 (2016)

# NEW TARGET DESIGN
## – From Beryllium to Lithium

Yield estimate for $^{9}$Be and $^{7}$Li:

- Respective yield of $^{3}_{\Lambda}$H and $^{4}_{\Lambda}$H similar

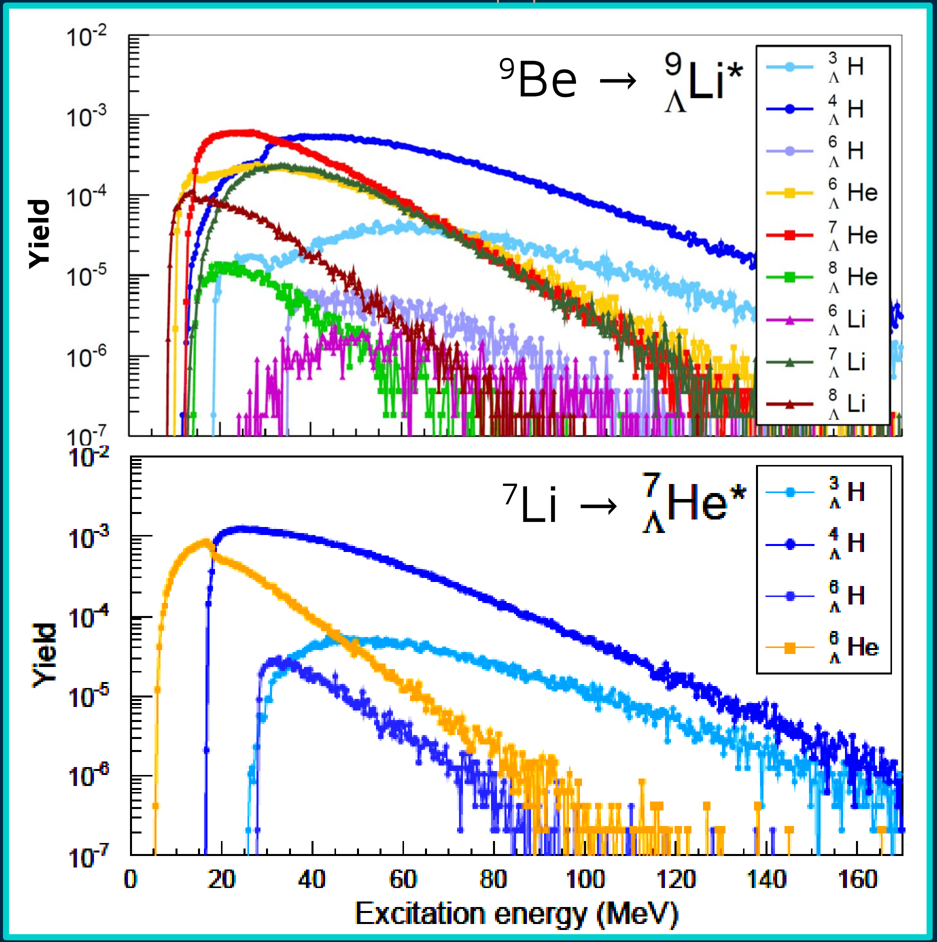
  → $^{3}_{\Lambda}$H yield is factor of ~10 lower

  → Higher luminosity is needed

- More background for $^{9}$Be?

  → Especially heavy helium critical due to similar decay pion momenta:

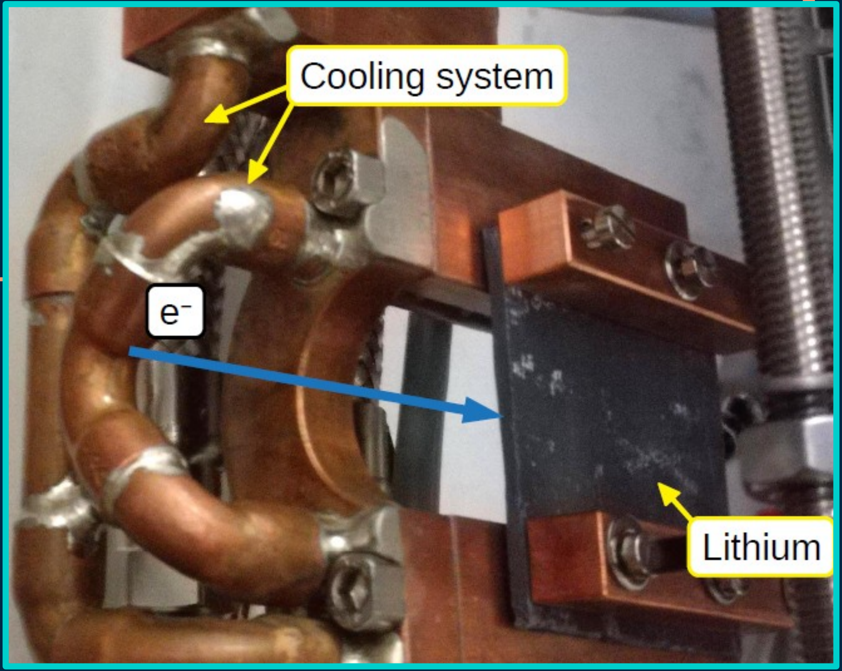
$^{3}_{\Lambda}$H: 114.3 $^{7}_{\Lambda}$He: 115.7 $^{8}_{\Lambda}$He: 116.5 [MeV/c]

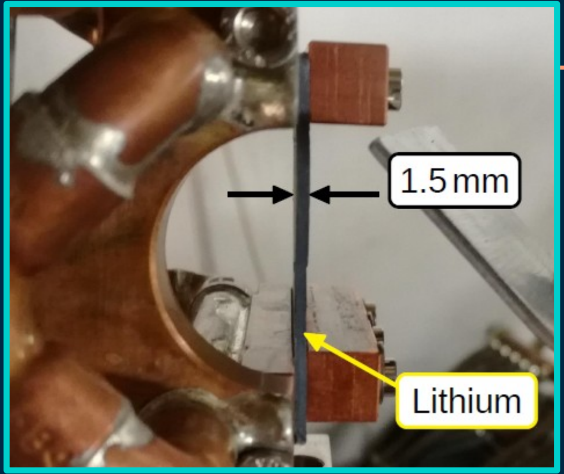


# NEW TARGET DESIGN – From Beryllium to Lithium

- Low density of lithium: $\rho_{Be}/\rho_{Li} = 3.5$

  → allows for new target design:
- 5 cm long → total thickness of 2.7 g/cm$^2$
- Thin sheet → minimize energy loss for pions




Downsides of lithium:

- Low melting point at 180°C
- Reactive with $O_2$, $N_2$, $H_2O$

→ Cooling system

→ Glove box with argon

# TARGET MONITORING VIA THERMAL CAMERA

Thermal camera with infrared optics:

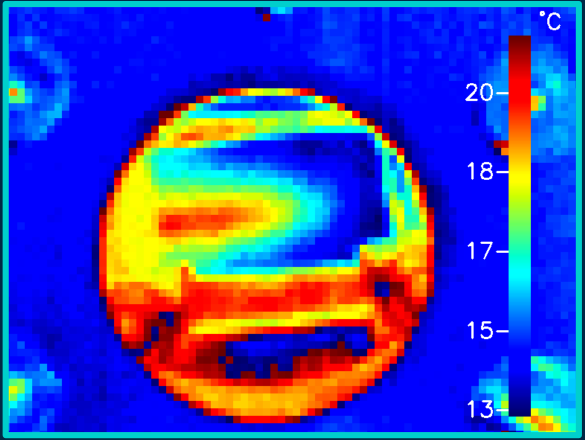
- Observe target temperature during experiment
- Align target to beam


First target test @ MAMI beam:

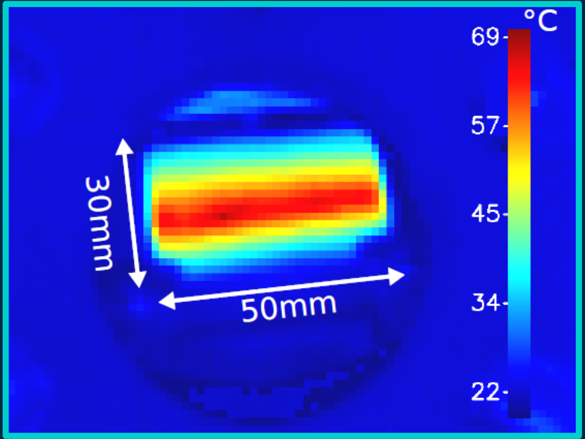
- Max. temperature of 70°C with 10 μA

  → No damage to the lithium
- Alignment of target to beam clearly visible
- Camera survived radiation exposure

→ next test in early 2022 within A1 target chamber




misaligned




hits straight

# ACCURATE BEAM ENERGY DETERMINATION

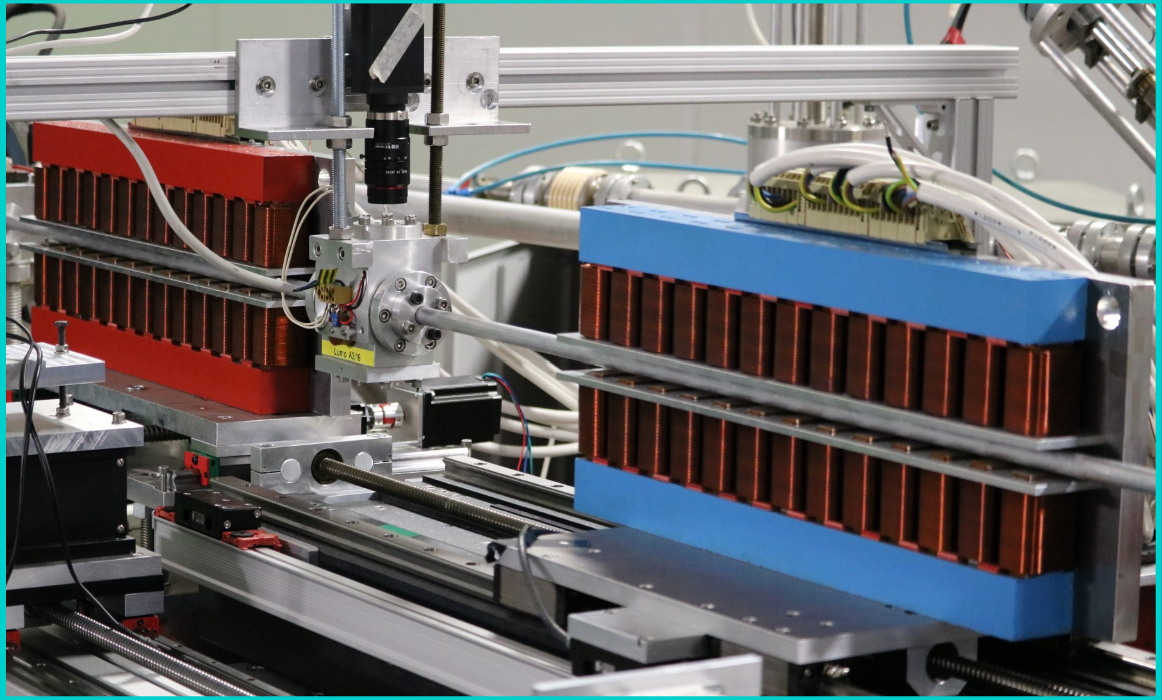
Spectrometer calibration via elastic $e^-$ scattering:

- Uncertainty in $e^-$ energy: 160 keV
- Limited spec. accuracy to $10^{-4}$

→ New approach: Undulator Light Interference

Two undulators (red and blue):

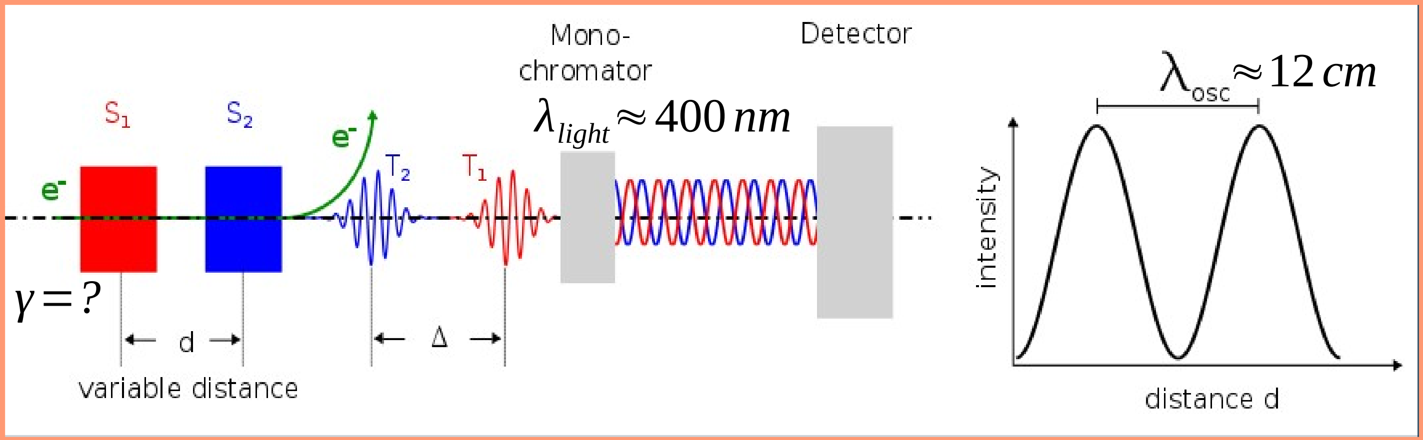
- Alternating magnetic field
- Passing electrons emit synchrotron radiation



by P. Klag

# ACCURATE BEAM ENERGY DETERMINATION

Undulators Selection of one wavelength Interference pattern




Light from two sources UV camera

Figure from PhD thesis of P. Klag (in preparation)

Relativistic γ via undulator equation:

$$\lambda_{osc} = 2\gamma^2 \lambda_{light}$$

Accuracy of gamma depends on:

- Length measurement
- Monochromator-calibration
- Optical alignment

**Analysis has show:**

**Precision of 15 keV possible**

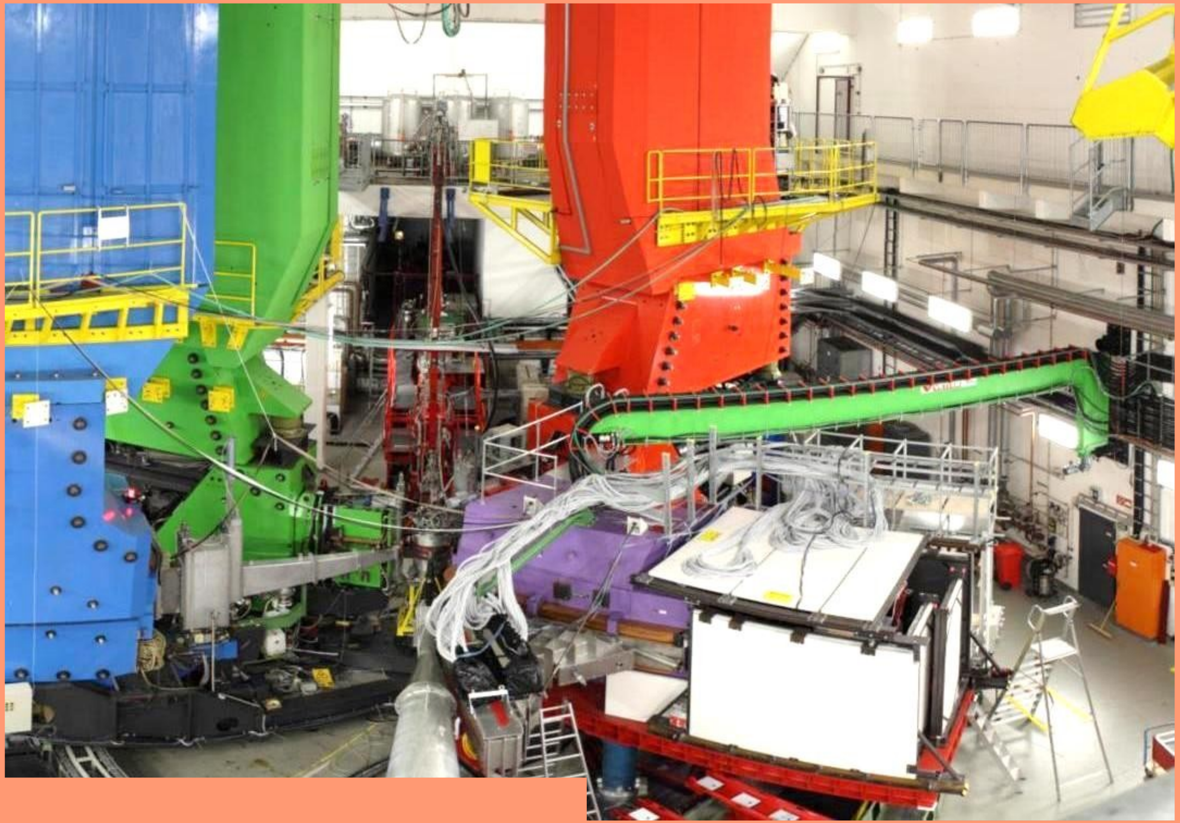
# FINAL GOAL

Hypertriton`s Λ binding energy:

- Systematic error of 20 keV
- Use new lithium target

  → also allows for ${}^{4}_{\Lambda}H$ production

  → remeasurement with enhanced statistics?
- Planned in mid of 2022



THANK YOU FOR YOUR ATTENTION

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# Hydrogen-4-Lambda Level Structure