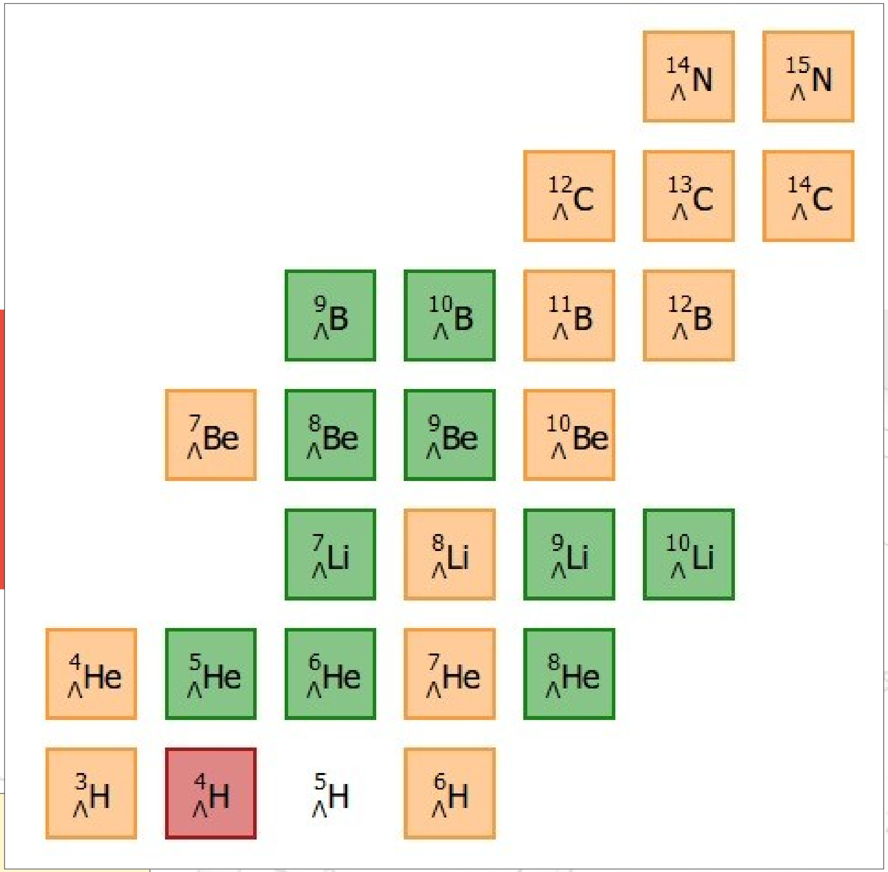
Hypernuclear Database



Philipp Eckert

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13.01.2021

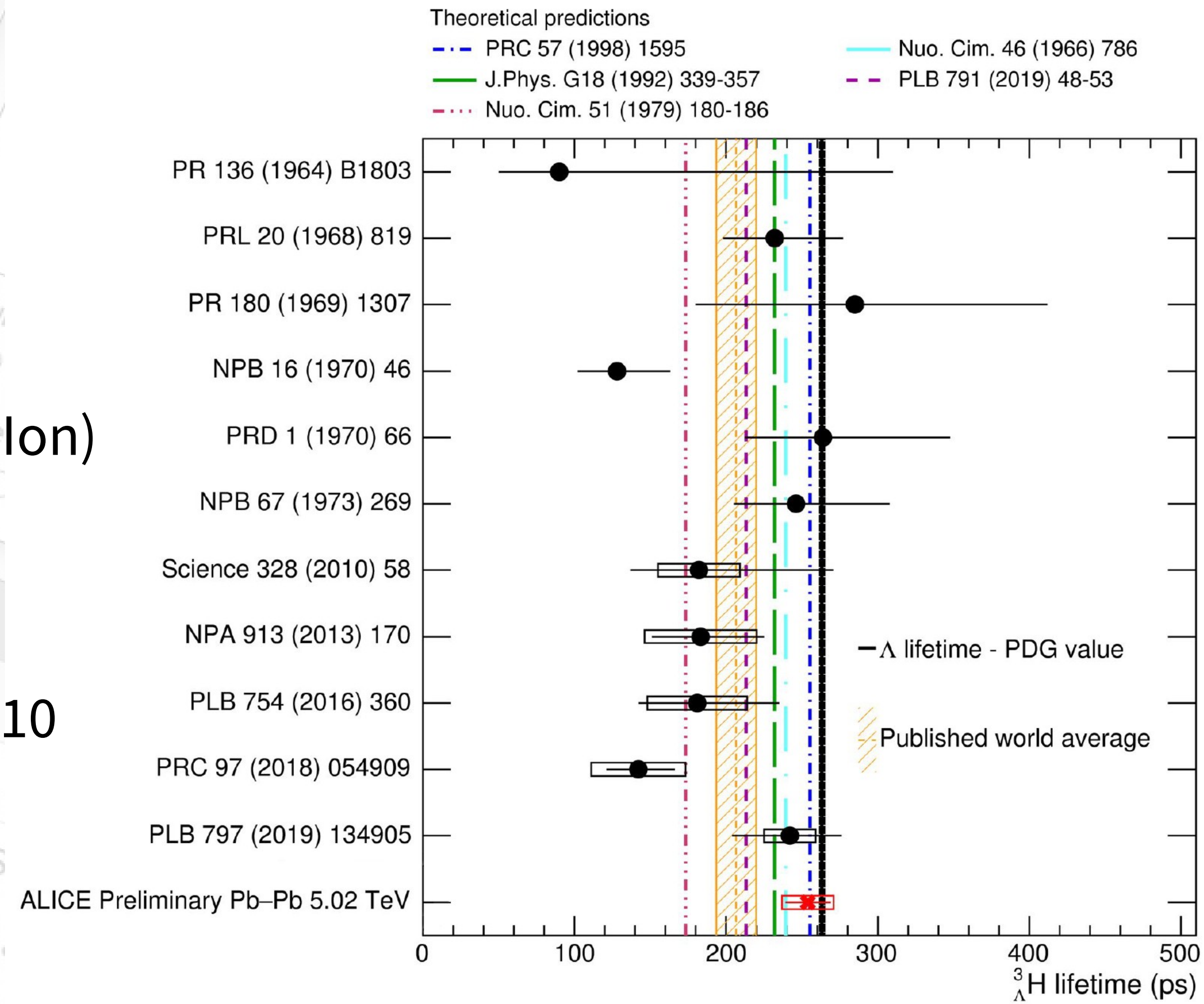
Content

1. Our Goal for a Database
2. Procedures of Averaging
3. First Physics Application
4. Live Presentation of current Status

1. Why a Database – Hypertriton Lifetime

Data situation:

- history of almost 60 years
- different exp. approaches (Emulsion, Bubble Ch., Heavy Ion)
- asymmetric errors
- missing systematics before 2010
- large progress in last years
- conflicts within the data?



F. Mazzaschi, "Status of the hypertriton lifetime from ALICE"

1. Our Goal for a Database

Collect data:

- complete collection of hypernuclear data
- include methods, references, …

Combine data:

- evaluate averages
- estimate and treat errors (scalings, corrections?)

Public availability:

- accessible to everyone via web
- interactive user interface to assess individual data sets
- generate downloadable content (plots, ideograms, datasets, refs.)

Expert Group

- overseeing the project

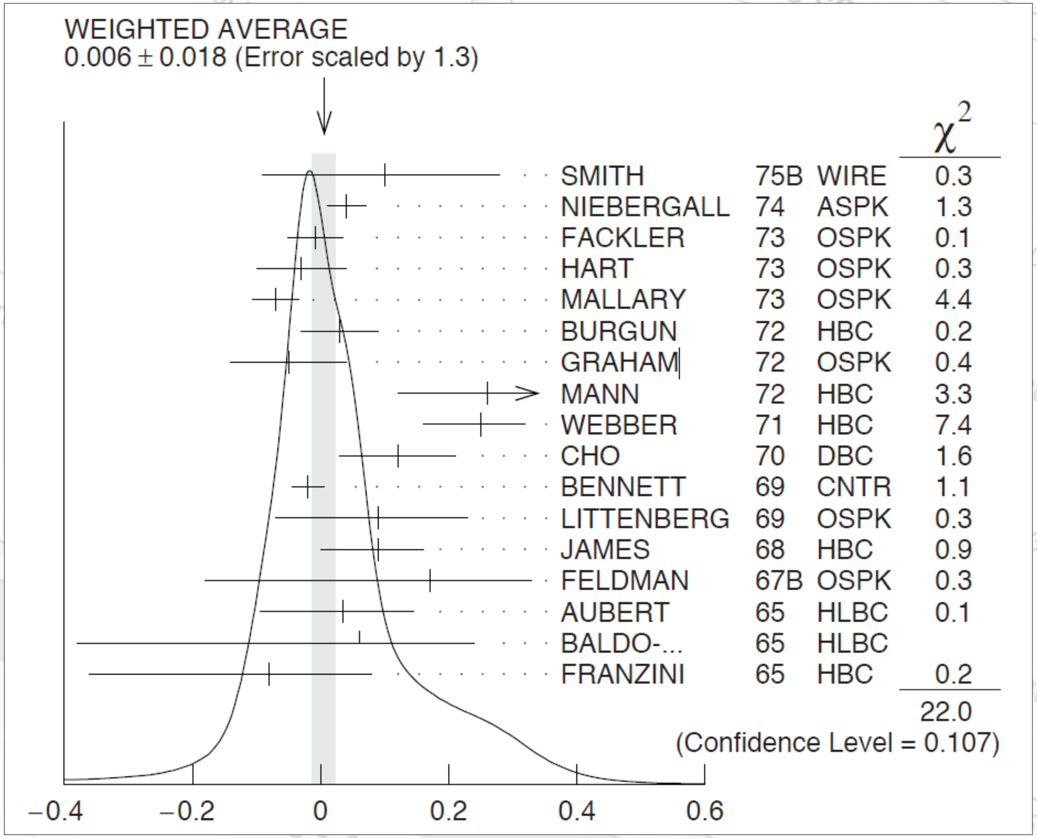
1. Key Feature: Ideograms

What an ideogram consists of:

- visualisation of experimental data (and the errors!)
- resulting average
- probability curve

→ **within seconds:**

- overview on data situation
- spot discrepancies



PDG: *„A typical ideogram“*, Review of Particle Physics

1. Content of the Database

Properties of a hypernucleus inside the data base:

1. binding energy

2. excitation energies

3. lifetime

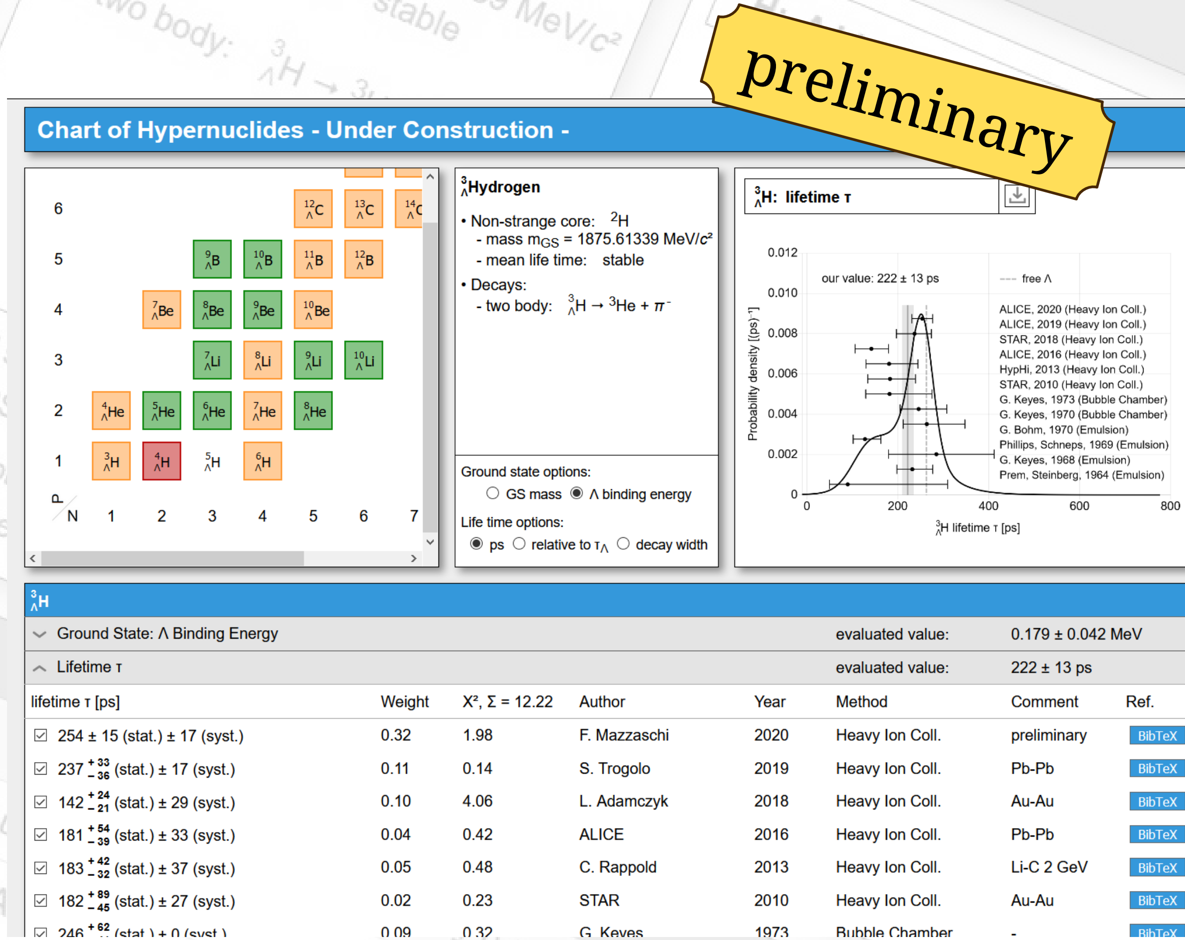
4. branching ratios (planned)

} consist of published measurements

5. non-strange core ← literature values, mass and lifetime

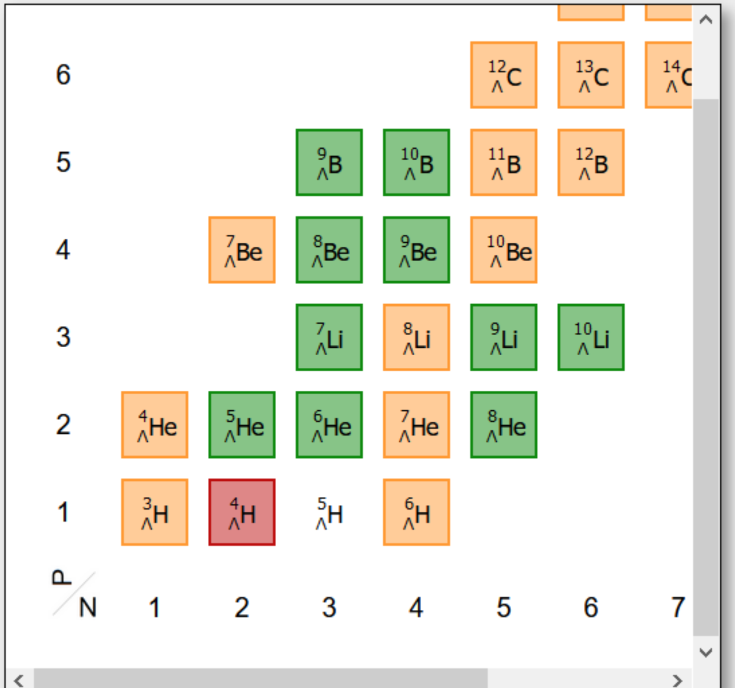
1. Where we are so far

- basic user interface exists
- averaging procedures are implemented
- ideograms can be generated and downloaded
- url on university server[1] (newest version offline)
- collected data for hypertriton's lifetime and binding energy



[1]: *https://www.blogs.uni-mainz.de/fb08-nuclear-physics/research/hypernuclei-database/*

Chart of Hypernuclides - Under Construction -

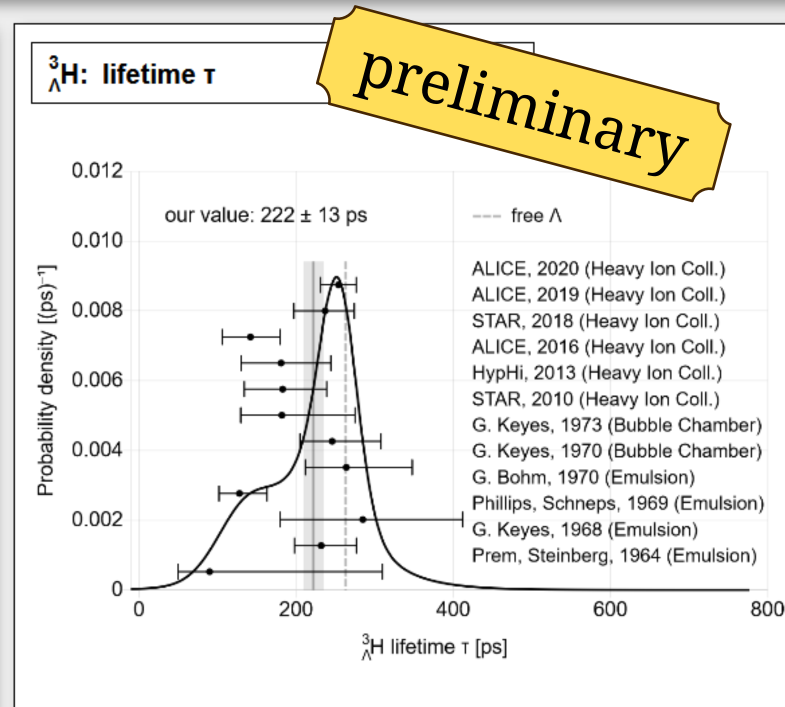


$^{3}_{\Lambda}$Hydrogen

- Non-strange core: ^{2}H
  - mass m_{GS} = 1875.61339 MeV/c^2
  - mean life time: stable
- Decays:
  - two body: $^{3}_{\Lambda}\text{H} \rightarrow {}^{3}\text{He} + \pi^-$

Ground state options:
○ GS mass ◉ Λ binding energy

Life time options:
◉ ps ○ relative to τ_Λ ○ decay width



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

﹀ Ground State: Λ Binding Energy	evaluated value:	0.179 ± 0.042 MeV
︿ Lifetime τ	evaluated value:	222 ± 13 ps

lifetime τ [ps]	Weight	Χ², Σ = 12.22	Author	Year	Method	Comment	Ref.
☑ 254 ± 15 (stat.) ± 17 (syst.)	0.32	1.98	F. Mazzaschi	2020	Heavy Ion Coll.	preliminary	BibTeX
☑ 237^{+33}_{-36} (stat.) ± 17 (syst.)	0.11	0.14	S. Trogolo	2019	Heavy Ion Coll.	Pb-Pb	BibTeX
☑ 142^{+24}_{-21} (stat.) ± 29 (syst.)	0.10	4.06	L. Adamczyk	2018	Heavy Ion Coll.	Au-Au	BibTeX
☑ 181^{+54}_{-39} (stat.) ± 33 (syst.)	0.04	0.42	ALICE	2016	Heavy Ion Coll.	Pb-Pb	BibTeX
☑ 183^{+42}_{-32} (stat.) ± 37 (syst.)	0.05	0.48	C. Rappold	2013	Heavy Ion Coll.	Li-C 2 GeV	BibTeX
☑ 182^{+89}_{-45} (stat.) ± 27 (syst.)	0.02	0.23	STAR	2010	Heavy Ion Coll.	Au-Au	BibTeX
☑ 246^{+62}_{-41} (stat.) ± 0 (syst.)	0.09	0.32	G. Keyes	1973	Bubble Chamber	-	BibTeX
☑ 264^{+84}_{-52} (stat.) ± 0 (syst.)	0.07	0.70	G. Keyes	1970	Bubble Chamber	-	BibTeX
☑ 128^{+35}_{-26} (stat.) ± 0 (syst.)	0.06	3.16	G. Bohm	1970	Emulsion	-	BibTeX

2. Averaging Procedures – Error weighted Mean

Set of n measurements: $\mu_i \pm \sigma_i\ ,\qquad \sigma_i^2 = \sigma_{stat,i}^2 + \sigma_{syst,i}^2$

- weight for i^th^ measurement: $$w_i = \frac{1}{\sigma_i^2}$$
- weights normalized to 1: $$w'_i = \frac{w_i}{\sum_j w_j}$$
- total mean: $$\bar{x} = \sum_{i=1}^{n} \mu_i w'_i$$
- total variance: $$\sigma_{\bar{x}}^2 = \sum_{i=1}^{n} w'^2_i \sigma_i^2$$

2. Averaging Procedures – Asymmetric Errors

How to handle asymmetric errors?

$$\mu \pm \sigma \;\Rightarrow\; \mu + \sigma_{+} - \sigma_{-}$$

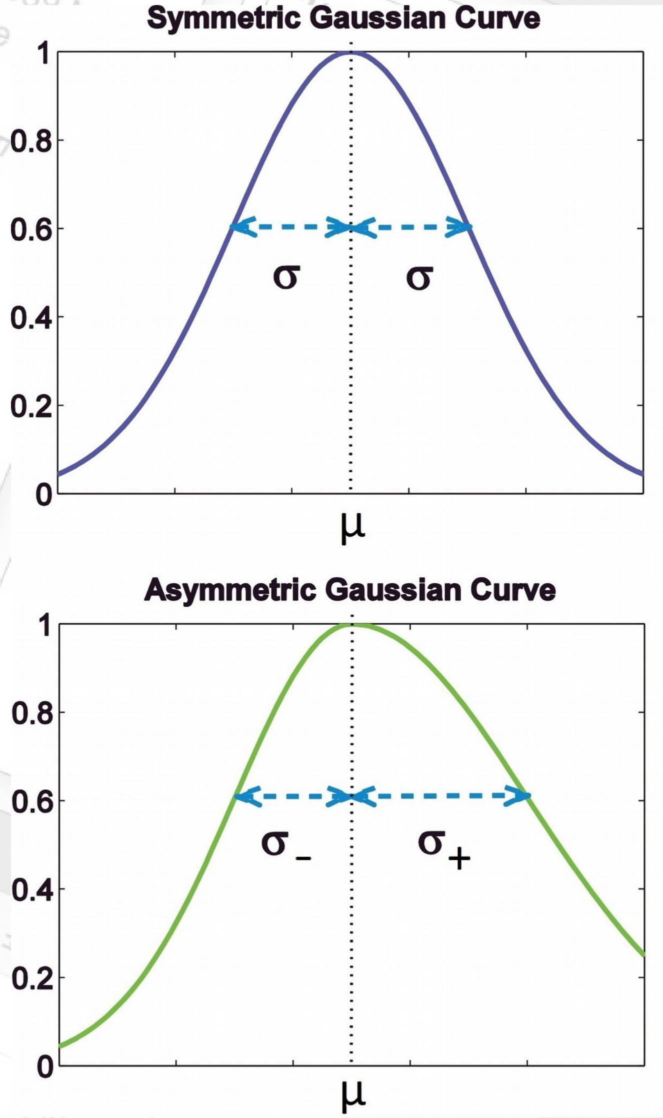
Idea:
parametrise pdf via asymmetric Gaussian curve

$$L(x) = e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma(x)}\right)^2}$$

turning σ into a function $\sigma(x)$ linear in x

$$\sigma(x) = \sigma_1 + \sigma_2 \cdot (x - \mu)$$

R. Barlow: “Asymmetric Statistical Errors“ (2004)
https://arxiv.org/abs/physics/0406120v1



2. Averaging Procedures – Asymmetric Errors

How to choose σ_1 and σ_2 within $\sigma(x) = \sigma_1 + \sigma_2 \cdot (x-\mu)$?

Restriction from Gaussian shaped function: $g(x) = e^{-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2}$

$$g(\mu-\sigma) = g(\mu+\sigma) = e^{-\frac{1}{2}} \Rightarrow L(\mu-\sigma_-) \overset{!}{=} L(\mu+\sigma_+) \overset{!}{=} e^{-\frac{1}{2}}$$

Solution given by

$$\sigma_1 = \frac{2\sigma_+\sigma_-}{\sigma_+ + \sigma_-} \qquad \sigma_2 = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

Then the $[\mu-\sigma_-,\ \mu+\sigma_+]$ interval is equivalent to a common 1σ interval,

→ both cover a probability of 68.27 %

2. Asymmetric Errors – Mean Value

Set of n measurements: $\mu_i + \sigma_{+,i} - \sigma_{-,i}$, $\quad \sigma_{\pm}^2 = \sigma_{stat,\pm}^2 + \sigma_{syst,\pm}^2$

- Mean value $\bar{x}$ can be found with:

$$\bar{x} \sum_i w_i = \sum_i \mu_i w_i \qquad w_i = \frac{\sigma_{1i}}{\left(\sigma_{1i} + \sigma_{2i}(\bar{x} - \mu_i)\right)^3}$$

depends on mean

→ numerical solution via iterations:

- Initial value $\bar{x}_0 = \frac{1}{n} \sum_{i=0}^{n} \mu_i$

- Accuracy of 10^{-5} can be achieved in about 5 iterations

2. Asymmetric Errors – Error Interval

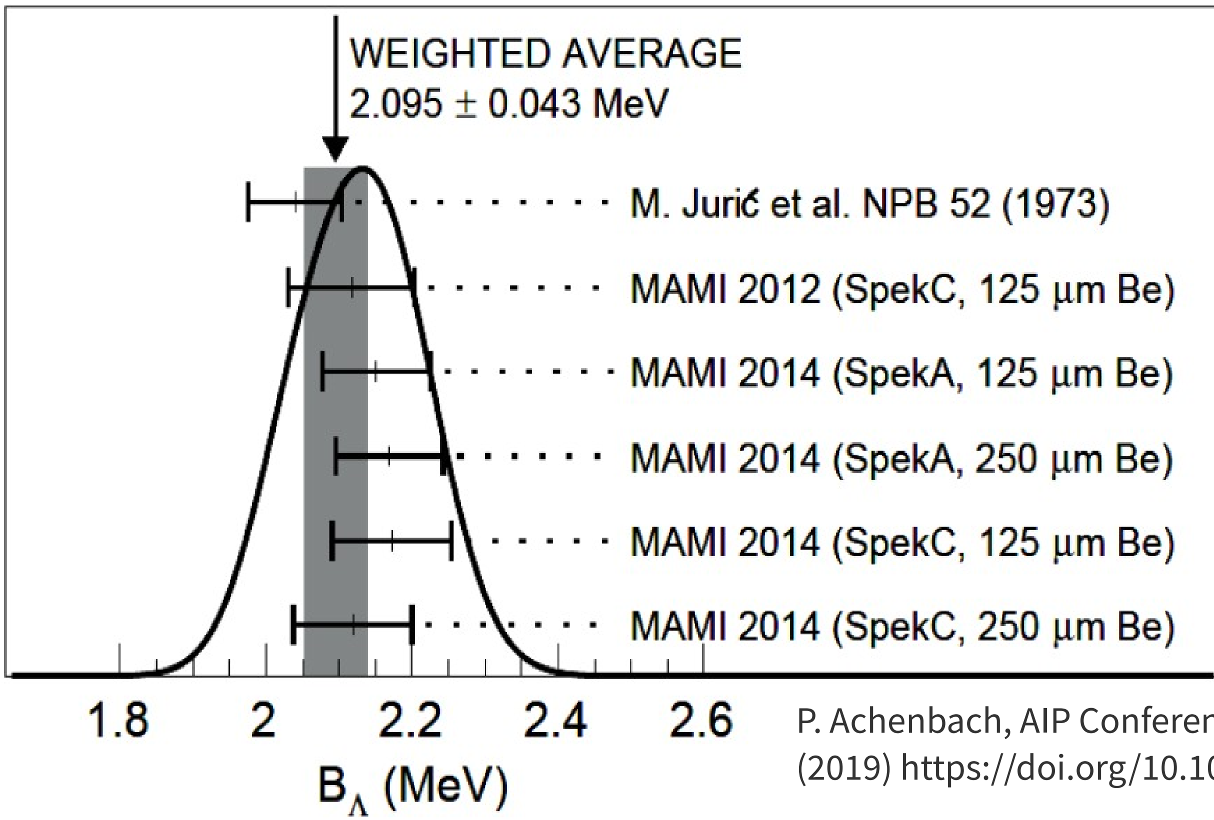
log-likelihood function: $$lnL(x) = -\frac{1}{2}\sum_{i=1}^{n}\left(\frac{x-\mu_i}{\sigma_i(x)}\right)^2$$

- lnL has maximum at $\bar{x}$
- from there, find both $e^{-\frac{1}{2}}$ points, equivalent to $lnL(\bar{x}) - lnL(\sigma_{\pm}) = -\frac{1}{2}$
- initial values $\sigma_{\pm,0} = \left(\sum_{i=1} \frac{1}{\sigma^2_{\pm,i}}\right)^{-\frac{1}{2}}$
- errors with accuracy 10^{-3} already found after 3 iterations!

➡ **application in online calculator possible!**

2. How to treat Shared Systematic Errors

Example for $^{4}_{\Lambda}$H binding energy:



B_Λ (MeV)	δB (MeV)
2.04	0.064
2.117	0.087
2.151	0.074
2.169	0.074
2.172	0.081
2.119	0.081

P. Achenbach, AIP Conference Proceedings **2130**, 030007 (2019) https://doi.org/10.1063/1.5118397

2. Treatment of Shared Systematic Errors

Set of measurements with same systematic error σ_{syst}

$$\mu_i \pm \sigma_{stat,i} \pm \sigma_{syst}$$

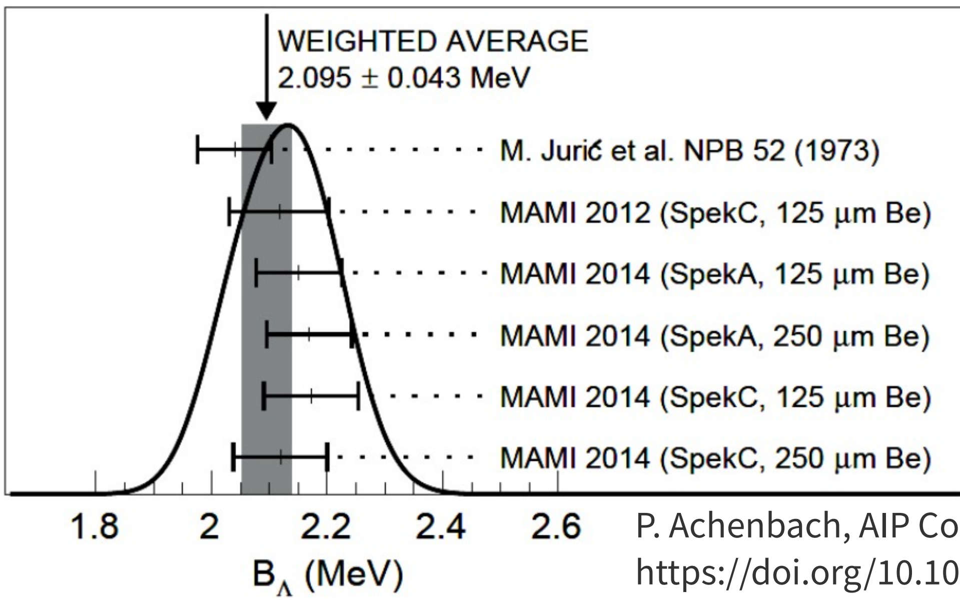
→ modified systematic error: $\sigma_{syst,i} = \sigma_{syst} \cdot \sigma_{stat,i} \left(\sum_j \frac{1}{\sigma_{stat,j}^2} \right)^{\frac{1}{2}}$

"This procedure has the advantage that, with the modified systematic errors [...], each measurement may be treated as independent and averaged in the usual way with other data." – PDG

inside the database, measurements are grouped in settings

2. Shared Systematic Errors – Example

Example calculation for ${}^{4}_{\Lambda}\mathrm{H}$ binding energy:



B_Λ (MeV)	δB (MeV)	w	χ^2
2.04	0.064	0.45	0.74
2.117	0.087	0.24	0.06
2.151	0.074	0.09	0.15
2.169	0.074	0.11	0.34
2.172	0.081	0.06	0.20
2.119	0.081	0.05	0.02
		1.00	1.50

P. Achenbach, AIP Conference Proceedings **2130**, 030007 (2019)
https://doi.org/10.1063/1.5118397

- error treatment avoids overestimation of MAMI's influence:
  → weights distributed **almost 1:1** instead of 1:5
- no underestimation of resulting error

2. How to treat published Averages?

Example: Jurič's hypertriton binding energy $B_{\Lambda} = 130 \pm 50\,\mathrm{keV}$

Published value consists of **four different** single values:

Hypernucleus	Decay mode	No of events	$B_{\Lambda} \pm \Delta B_{\Lambda}$ (MeV)
$^{3}_{\Lambda}H$	$\pi^{-} + {}^{1}H + {}^{2}H$	24	0.23 ± 0.11
	$\pi^{-} + {}^{3}He$	58	0.06 ± 0.11
	total	82	0.15 ± 0.08

	$B_{\Lambda} \pm \Delta B_{\Lambda}$ (MeV)
	Bohm et al.[a)]
$^{3}_{\Lambda}H$	0.01 ± 0.07

Combination to mean not trivial:

3.2.1. The $^{3}_{\Lambda}H$ hypernucleus

From the observation of 82 examples of $^{3}_{\Lambda}H$, the binding energy of this hypernucleus is found to be 0.15 ± 0.08 MeV. An accurate determination of the binding energy of the $^{3}_{\Lambda}H$ hypernucleus is of great importance to estimate the strength of the ΛN interaction in the singlet state. Combining the result obtained in this experiment with the data compiled by Bohm et al. [2], reanalysed using the methods and selection criteria defined in the present work, the best estimate for the binding energy of $^{3}_{\Lambda}H$ is found to be $B_{\Lambda} = 0.13 \pm 0.05$ MeV.

M. Jurič, Nuclear Physics B, Vol. 52, 1, p 1 – 30 (1973)

2. How to treat published Averages – Options

Options for adopting the values to the database:

1. only take underlying measurements

includes 2 and 3 body channels of Jurič and Bohm

Problem: final mean value can‘t be reproduced

2. only take mean value:

Problem: loss of information on underlying measurements

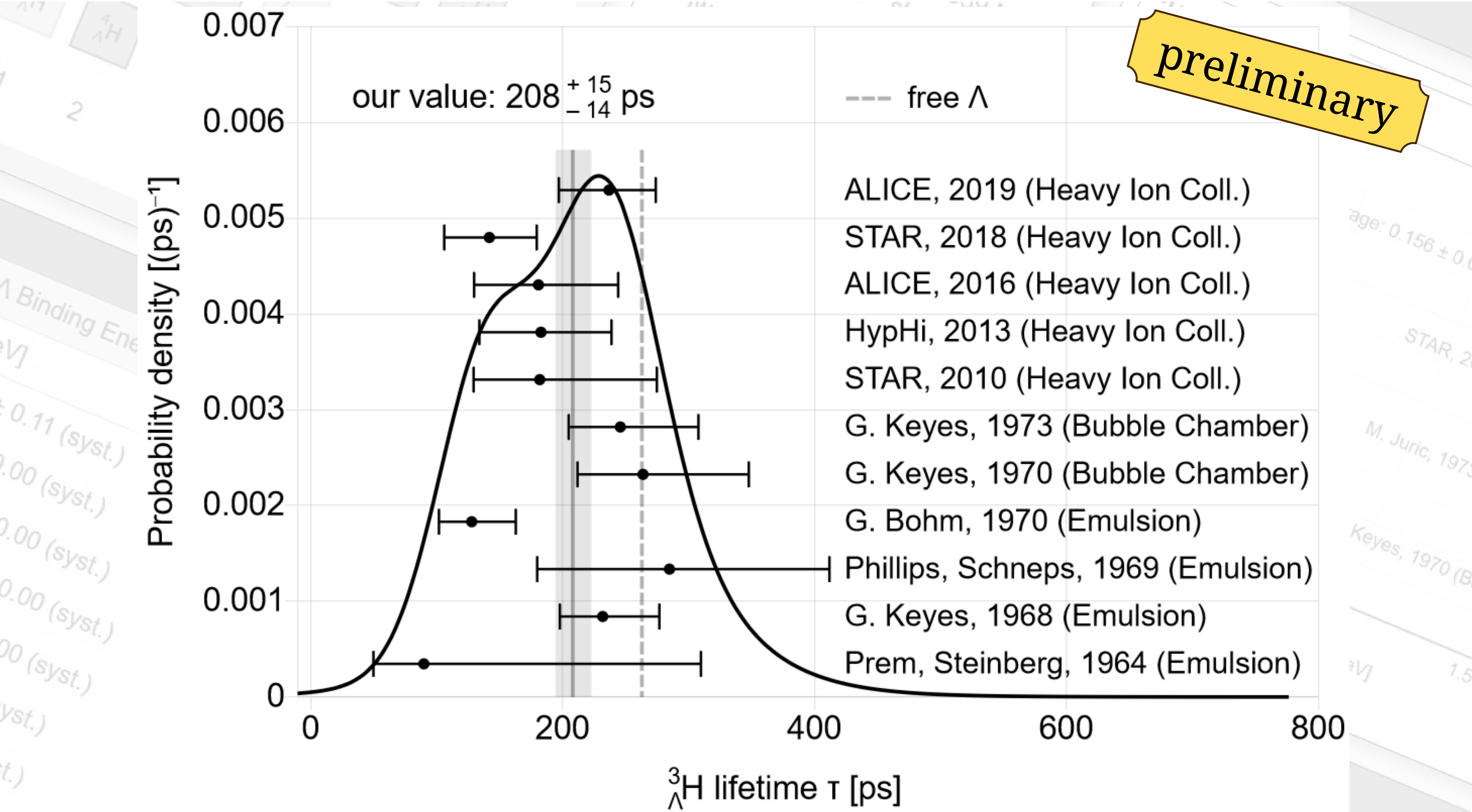
3. take all values:

Problem: assure that no measurement appears twice in average!

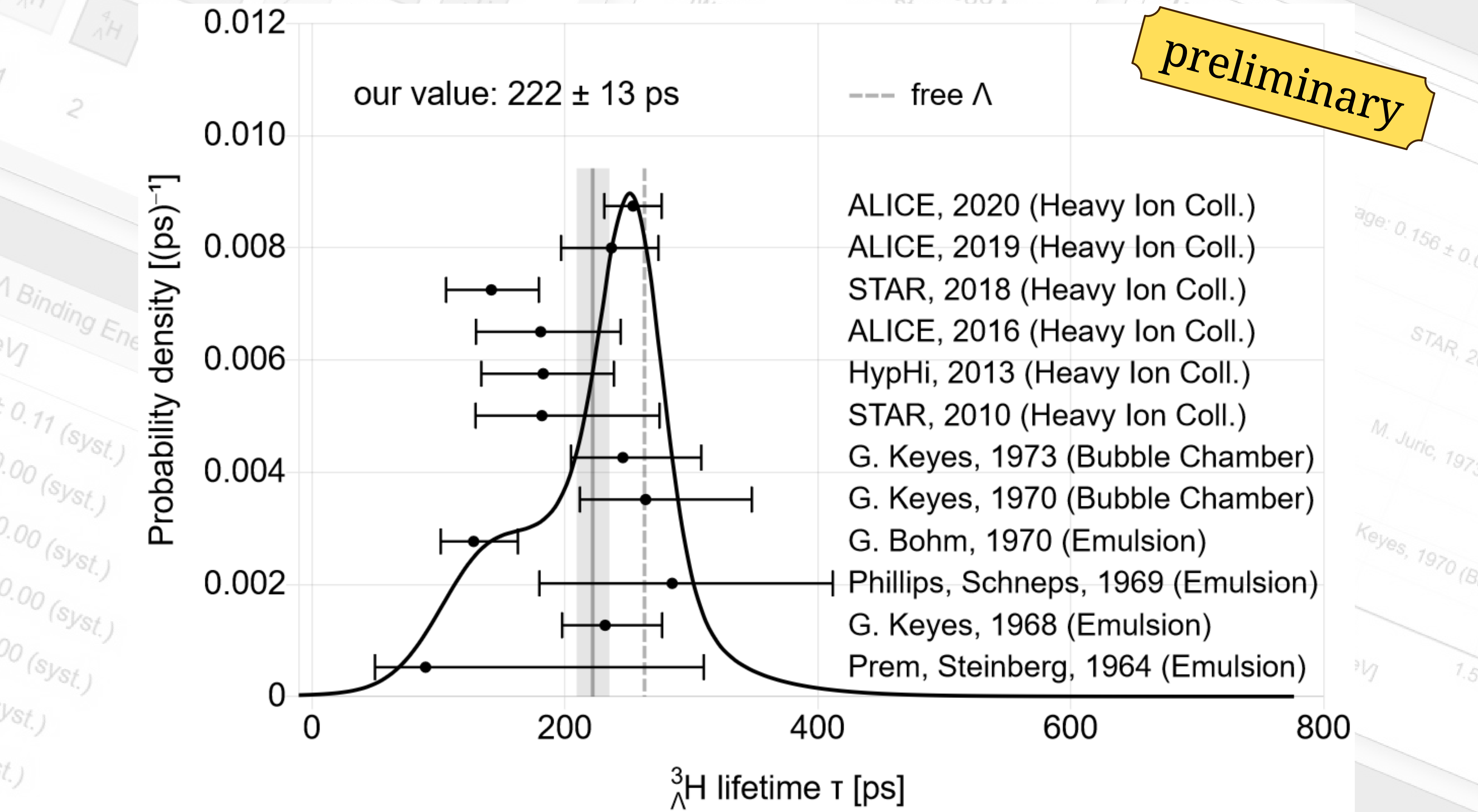
➡ **go for 3rd option → measurements grouped in collections**

3. First Results: Hypertriton Lifetime

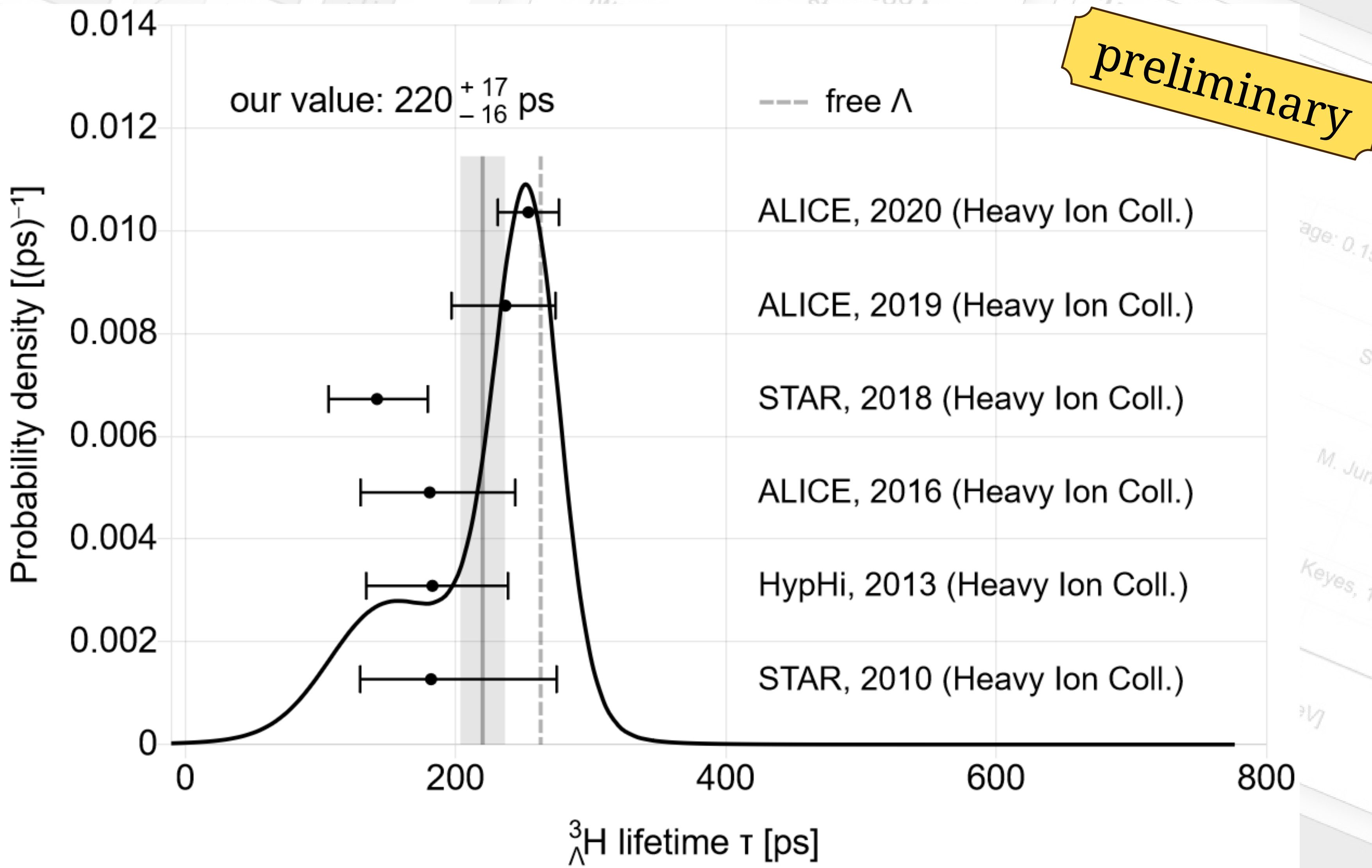
Status 2019



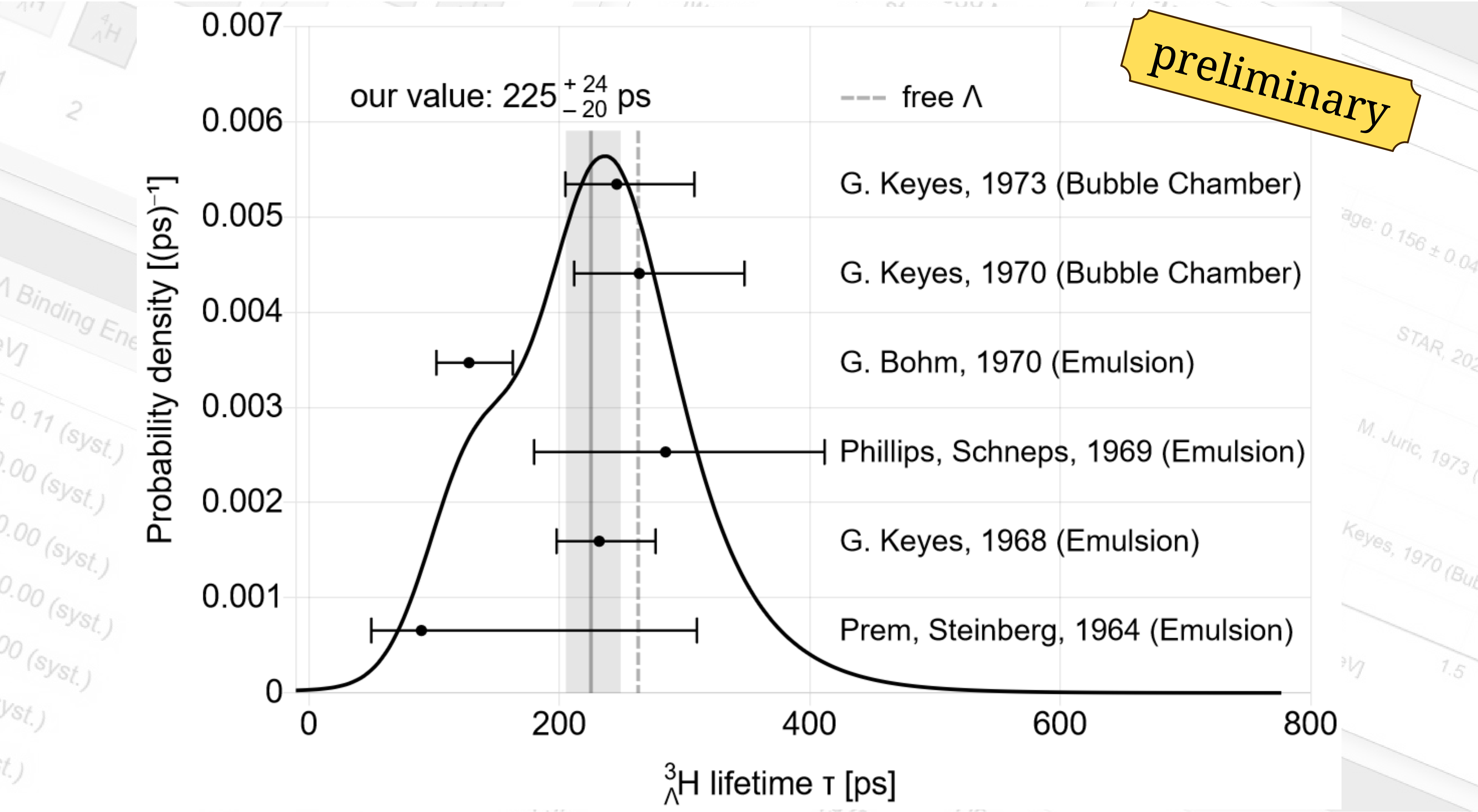
3. The Hypertriton Lifetime | New ALICE Value



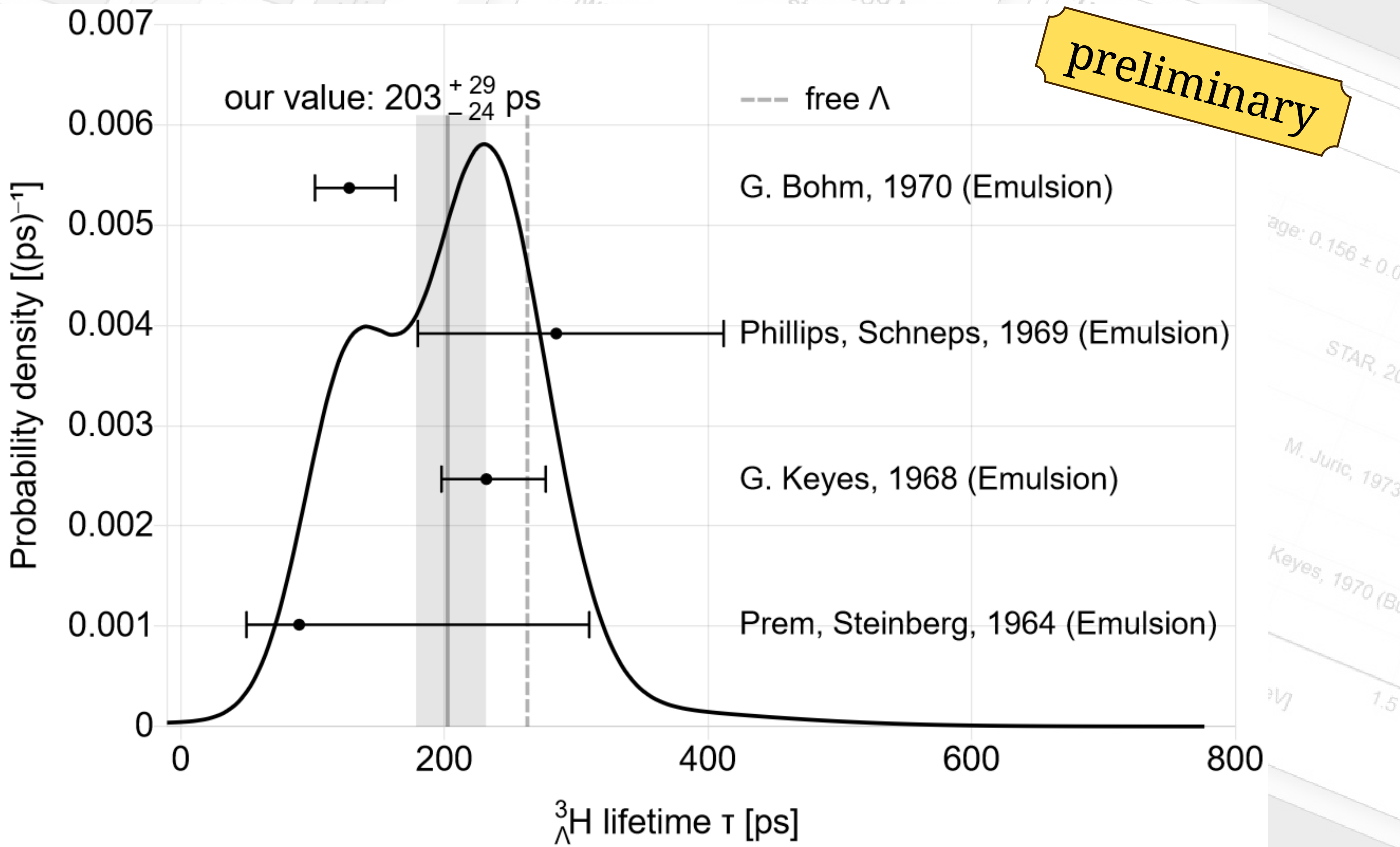
3. The Hypertriton Lifetime | Heavy Ion only



3. The Hypertriton Lifetime | Without Heavy Ion



3. The Hypertriton Lifetime | Emulsion only



3. The Hypertriton Lifetime – Summary

preliminary

- new ALICE value dominates average (weigth of 1/3)

- our total average value is:

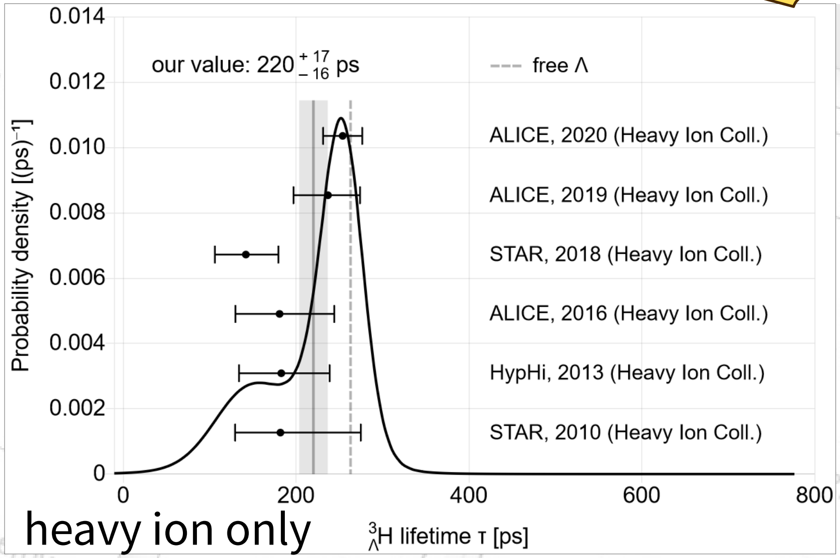
$$\tau_{{}^{3}_{\Lambda}\mathrm{H}} = 222 \pm 13 \text{ ps}$$

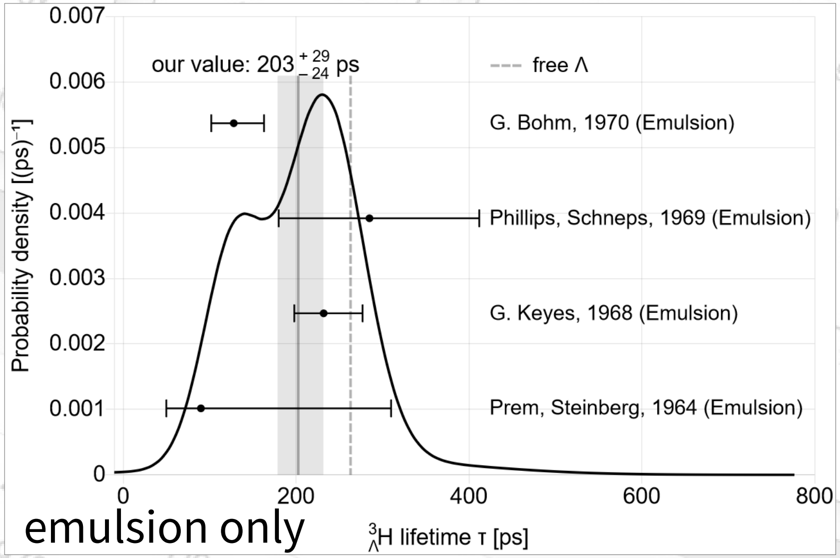
- heavy ion only result almost the same:

$$\tau_{{}^{3}_{\Lambda}\mathrm{H}} = 220^{+17}_{-16} \text{ ps}$$

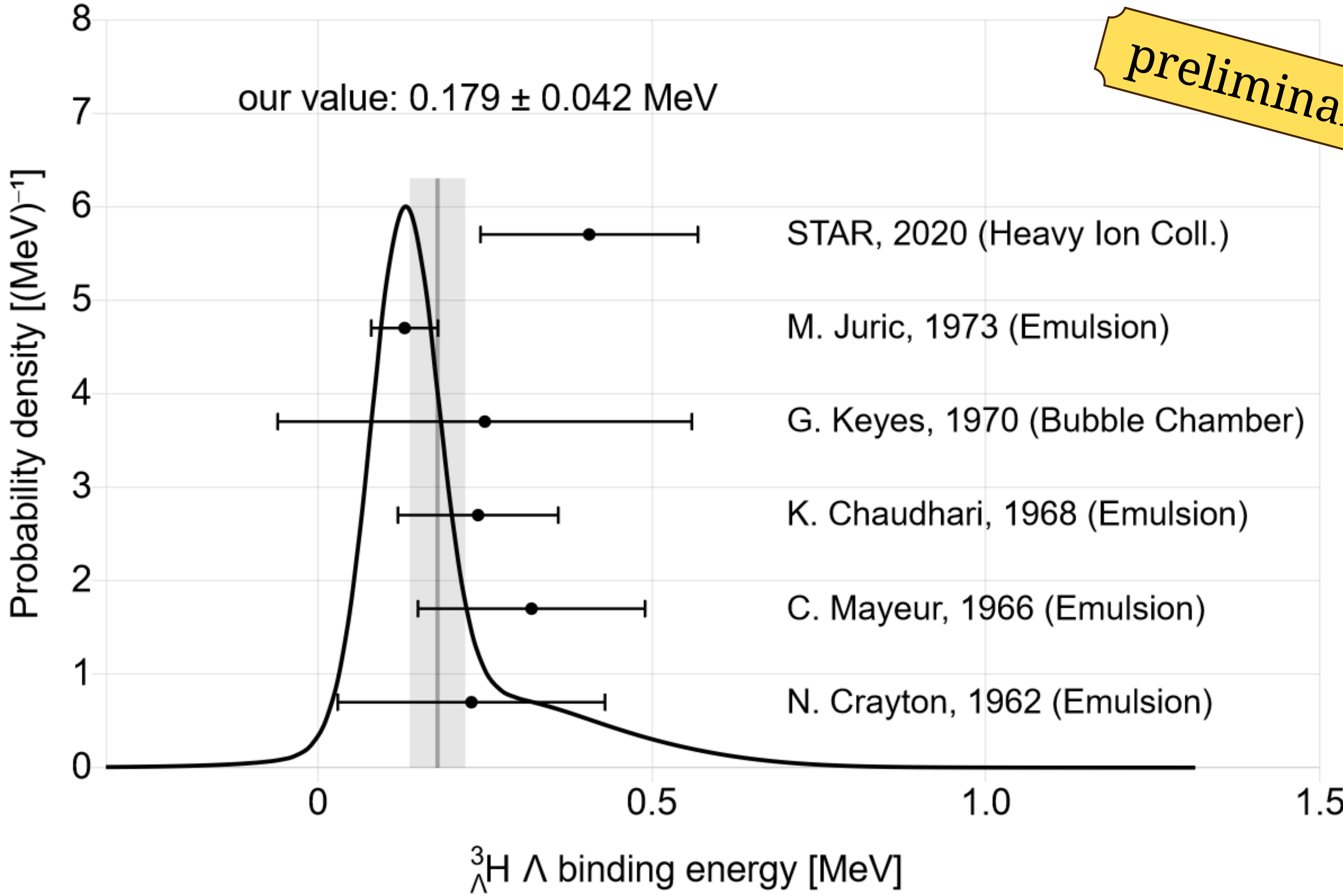
- both, heavy ion only and emulsion only show a double structure:

→ hidden sytsematics?





3. Other Result: Hypertriton Binding Energy

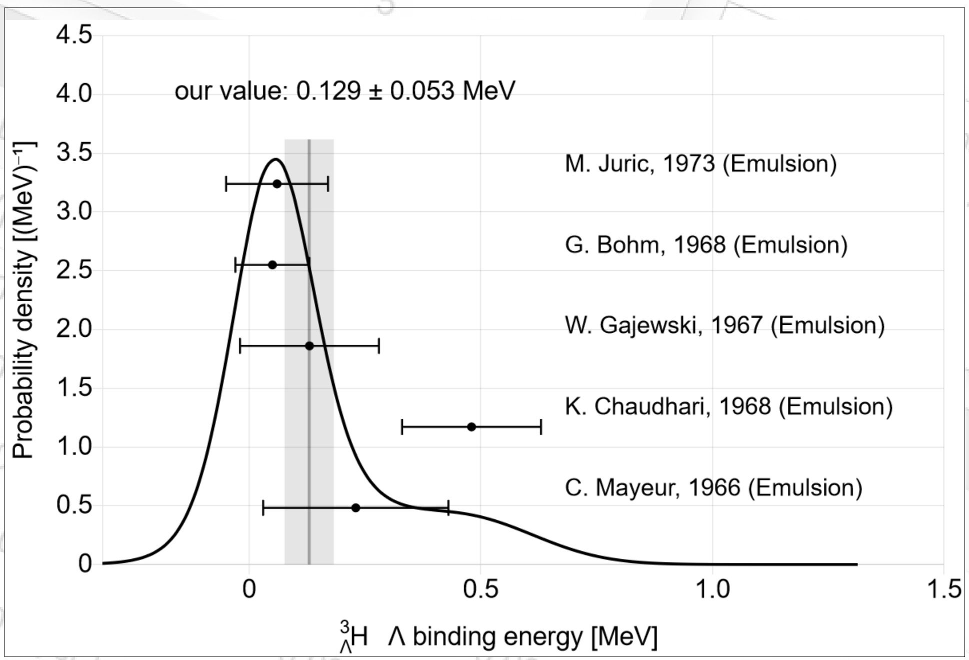


3. Hypertriton Binding Energy

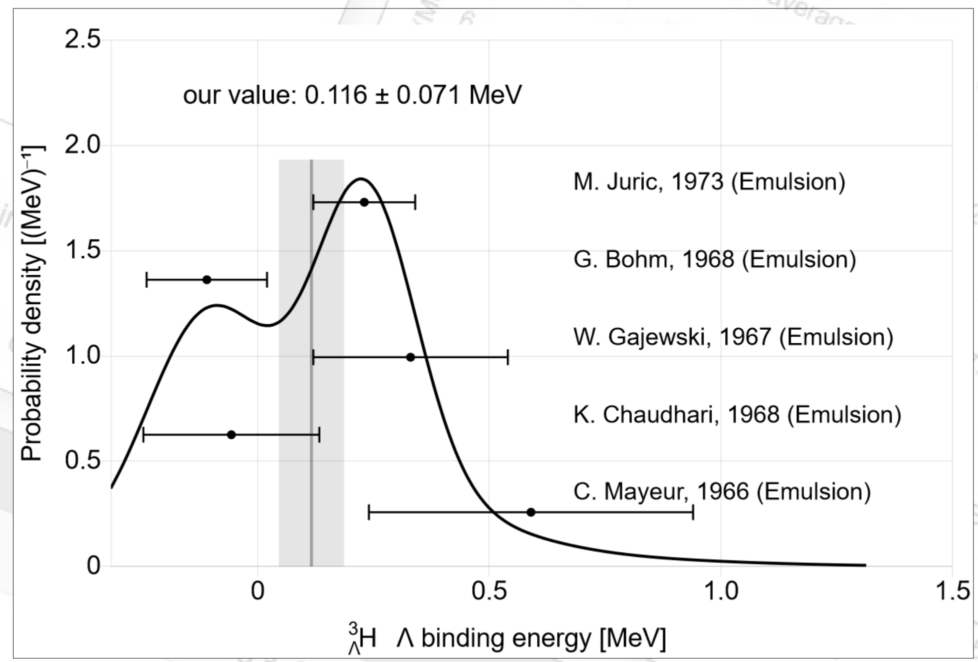
preliminary

Comparing 2-body and 3-body decays in emulsion data:

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



$^{3}_{\Lambda}\mathrm{H} \Rightarrow \pi^{-} + {}^{1}\mathrm{H} + {}^{2}\mathrm{H}$



2-body: $B_{\Lambda} = 129 \pm 53\ \mathrm{keV}$

3-body: $B_{\Lambda} = 116 \pm 71\ \mathrm{keV}$

3. Outlook – Recalibration of Historical Data?

Particle masses have changed over the decades … → **PDG values:**

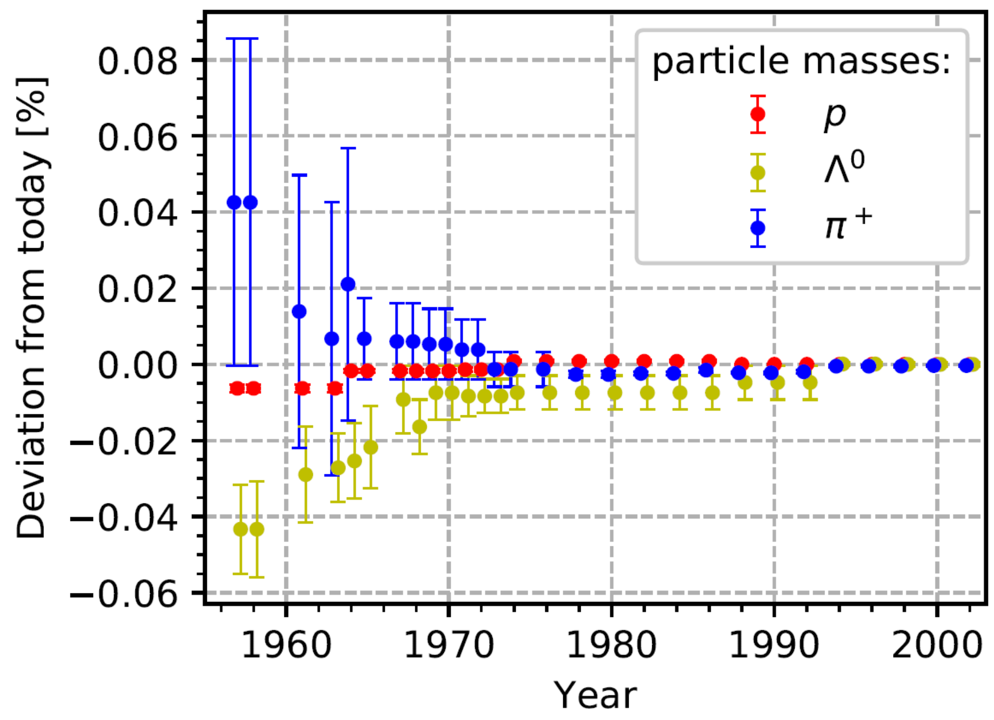
Deviation of **0.02 % in Λ mass equals to 220 keV** in total!

⇕

Influence on nuclei like hypertriton?

Correction by P. Liu et al.[1] on Juric's hypertriton measurement:

150 keV → 270 keV



→ **Find agreement for consistent correction!**

[1]: Chinese Physics C Vol. 37, No. 1 (2019) 010201

3. Outlook – Systematic Error for Historical Data?

Suggestion by Davis[1]: $\sigma_{syst} = 40\,\mathrm{keV}$

Example: hypertriton binding energy

- dominated by Juric's value

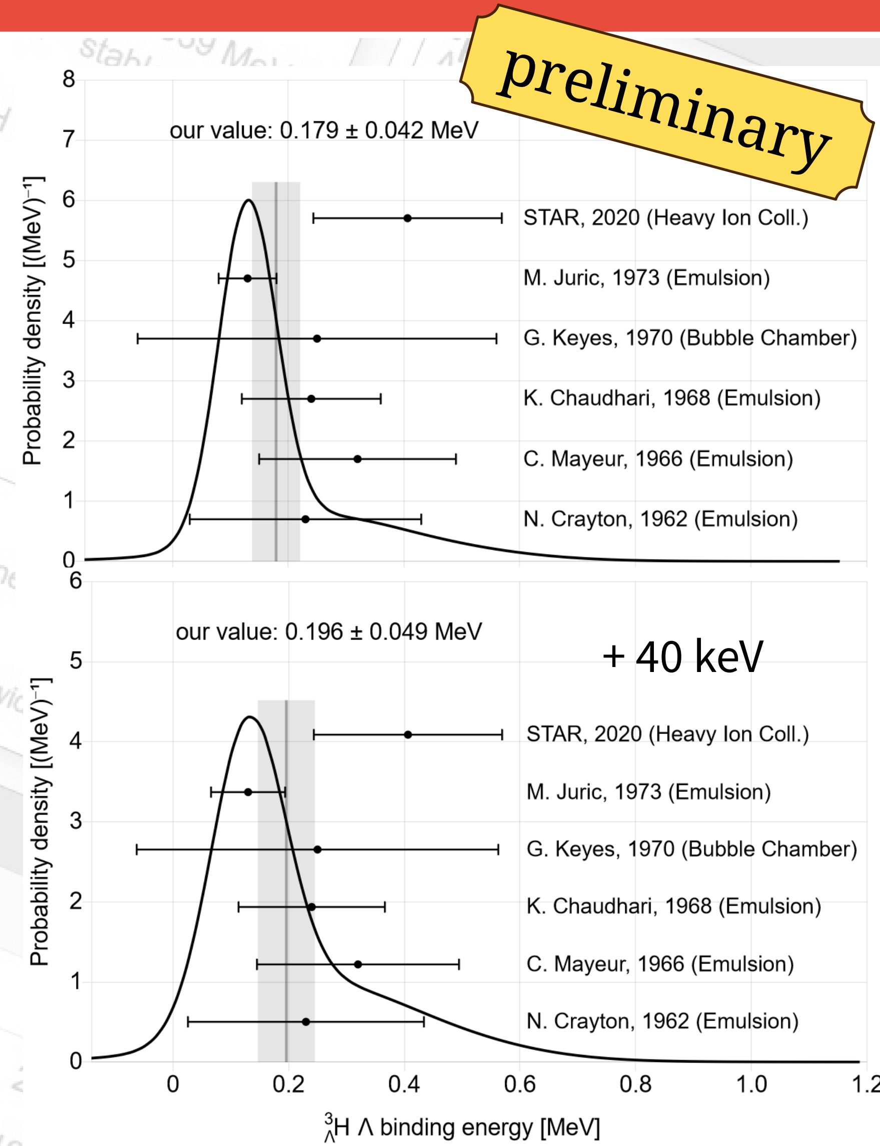
$$B_\Lambda = 130 \pm 50\,\mathrm{keV}$$

- with additional systematic error

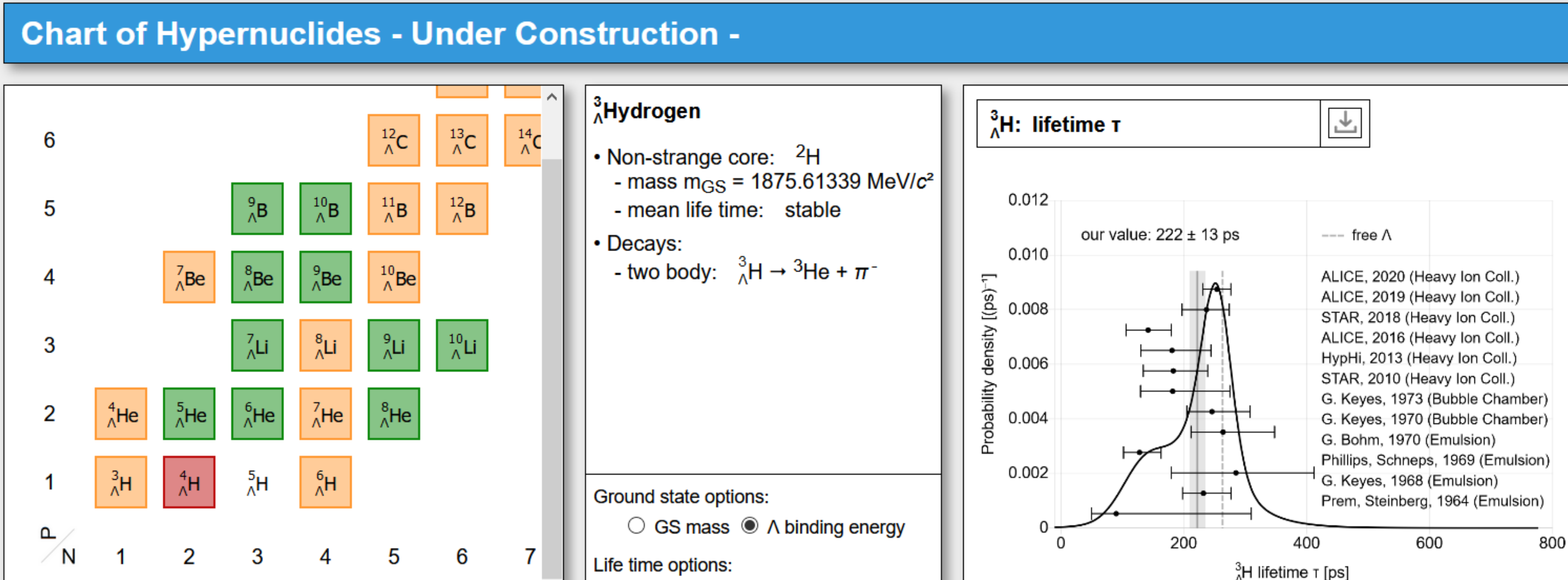
$$B_\Lambda = 130 \pm 64\,\mathrm{keV} \quad \text{(total error)}$$

→ comparably large change in average:

$$\bar{B}_\Lambda = 179 \pm 42\,\mathrm{keV} \Rightarrow 196 \pm 49\,\mathrm{keV}$$



[1]: D. H. Davis, Nuclear Physics A 754 (2005) 3c–13c



4. Live Presentation

lifetime τ [ps]	Weight	X², Σ = 12.22	Author	Year	Method	Comment	Ref.
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Invitation to join Expert Group

- Preparatory group was established after THEIA Workshop in Speyer:
  P. Achenbach, J. Millener, S.N. Nakamura, H. Tamura
- After database goes online this group will be extended by experimentalists from Europe, Japan & U.S. (up to maybe 10)

  → Form an **expert group covering experimental methods** such as:

- Emulsion technique
- Heavy-ion collision
- Electroproduction missing-mass spectroscopy
- Decay-pion spectroscopy
- γ-spectroscopy
- Strangeness exchange spectroscopy

This expert group should oversee the hypernuclear database entries

- Everybody from this community can volunteer
- Theory advise and review was suggested (A. Gal volunteered)
- Dissemination of data tables is planned

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- Emulsion tech... ...ctroscopy
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- Electroproduct... ...ssing-mass spectroscopy
- Strangeness exchange spectroscopy

Thank you for your attention!

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4. Tables – “measurement“

property	description
value	pubished mean value
errorstatp	errors in plus and minus direction
errorstatm	
errorsystp	
errorsystm	
nevents	number of observed events (optional)
reference	table with information about author etc.
include	boolean for contribution to world average
setting	label measurements with same systematics (optional)
method	description of experimental approach
comment	additional note (optional)
compiler	person who submitted the measurement (optional)
compiledate	date of submission (optional)

4. Tables – “collection“

property	description
value	pubished mean value
errorstatp	errors i...
nevents	number of observed events (optional)
reference	table with information about author etc.
include	boolean for contribution to world average
setting	label measurements with same systematics (optional)
method	description of experimental approach
comment	additional note (optional)
compiler	person who submitted the measurement (optional)
compiledate	date of submission (optional)

property	description
method	description of experimental approach (optional)
more measurements and/or collections	

4. Tables – “reference“ and “collaboration“

reference:

property	description
author	person who performed and/or published the measurement
collaboration	table for corresponding collaboration
year	when article was published
bibtex	explicit BibTeX code

collaboration:

property	description
name	collaboration name
url	link to collaboration‘s webpage