Title: The new ultracold neutron facility at TRIUMF

Date: May 23, 2017 01:00 PM

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Abstract: <p>A permanent non-zero electric dipole moment of the free neutron (nEDM) violates CP-symmetry. The search for an nEDM contributes to understanding the Baryon asymmetry,
as well as it has a high discovery potential for Beyond Standard Model physics. The tool of choice to investigate the nEDM are ultracold neutrons (UCN), since they have such low energies that they can be stored in traps and allow observation times of hundreds of seconds.
The distinct feature of TRIUMFs UCN facility is the combination of a neutron spallation source with a superfluid helium UCN converter - unique among all existing and planned UCN sources worldwide. The goal of the UCN project at TRIUMF is to provide a density of several hundreds of UCN per cubic cm to experiments at up to two ports, whereas one will be dedicated to determine the nEDM to the 10-27 eÂ·cm level of precision.
This presentation shall update the audience on the current status of the new UCN facility at TRIUMF. Additionally, a brief status update on the work of the CREMA collaboration (Charge Radius Experiments with Muonic Atoms) shall be given. Recent experiments performing laser spectroscopy on light muonic atoms shed new light on the Proton Radius Puzzle.</p>

TRIUMF

The new ultracold neutron facility at TRIUMF

Beatrice Franke
Perimeter Institute, Particle Physics Seminar

plus:
brief update on CREMA's work
towards the Proton Radius Puzzle

TRIUMF CREMA 'Charge Radius Experiment with Muonic Atoms'

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Physics Department, National Tsing Hua University, Taiwan
T.-L. Chen, Y.-W. Liu

TRIUMF

Root of the Puzzle: the Proton Radius was shrunk 2009

$$r_p^{\mathrm{CODATA}} = 0.88\mathrm{xx}\,\mathrm{fm} \pm 0.8\%$$

$$\Downarrow$$

$$r_p^{\mathrm{CREMA}} = 0.84\mathrm{xxx}\,\mathrm{fm} \pm 0.04\%$$

- 4 % smaller
- $>$ 10 fold precision

[P. J. Mohr *et al.*, Rev. Mod. Phys. 80, 633-730 (2008)]
[R. Pohl *et al.* (CREMA-coll.), Nature 466, 213 (2010)]
[A. Antognini *et al.* (CREMA-coll.), Science 339, 417 (2013)]

8 July 2010 www.nature.com/nature £10

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There's more to come

PLAGIARISM
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CHIMPANZEES
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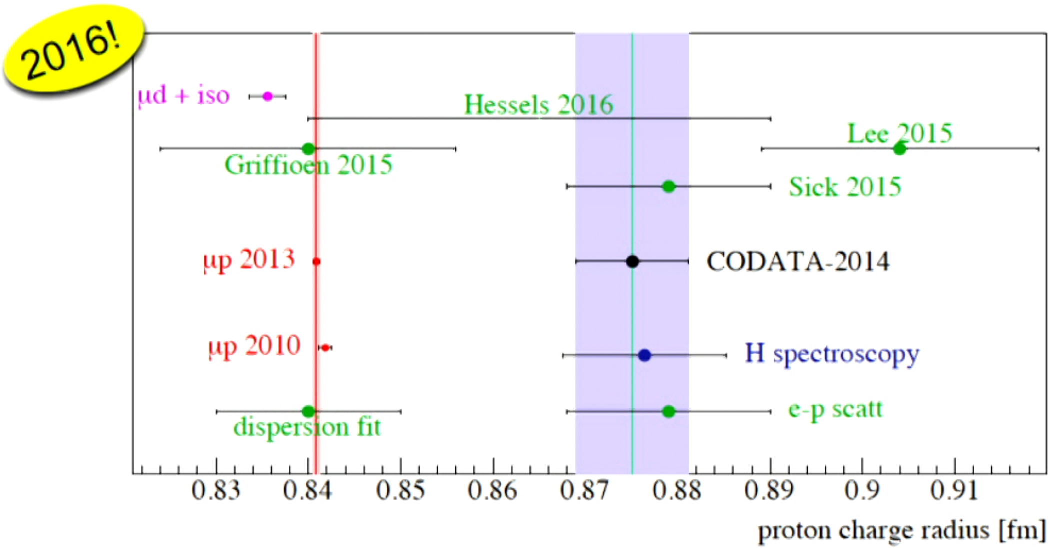
Root of the Puzzle: the Proton Radius was shrunk 2009

r_p^{CODATA}

r_p^{CREMA}

The Proton Radius Puzzle



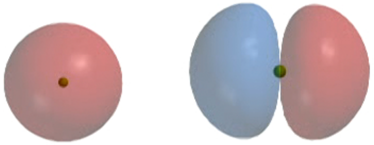
- 4 % smaller
- > 10 fold precisio

Summarizing all *electronic* measurements of r_p (spectroscopy and scattering) from hydrogen and deuterium data, yields a $5.6\,\sigma$ discrepancy to the CREMA measurement.

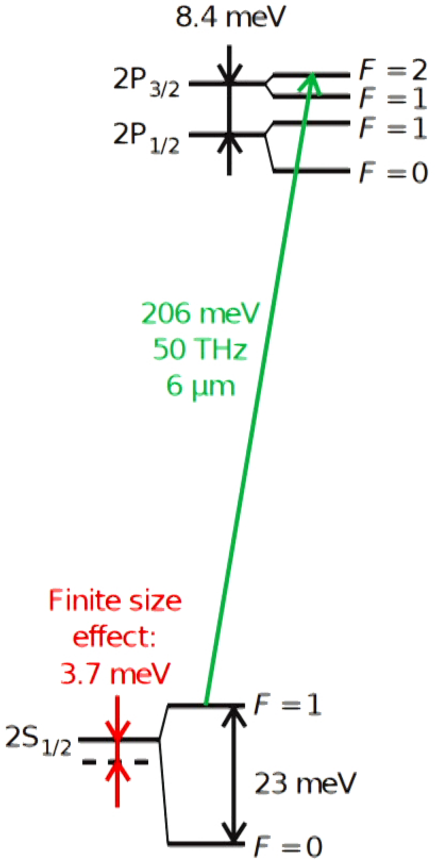
[P. J. Mohr *et al.*, Rev.
[R. Pohl *et al.* (CREMA
[A. Antognini *et al.* (CR

The Lamb shift (2S-2P) in muonic hydrogen (μp)

- Bound system of one μ^- and a proton (or other light nuclei such as the deuteron, helion, and α)
- Muon lifetime $\tau_\mu = 2.2\,\mu\mathrm{s}$
- $m_\mu \approx 200 \cdot m_\mathrm{e} \quad \Rightarrow \quad a_\mu \approx a_\mathrm{e}/200$
- Probability to be *inside* the nucleus $200^3 = 10^7\times$higher

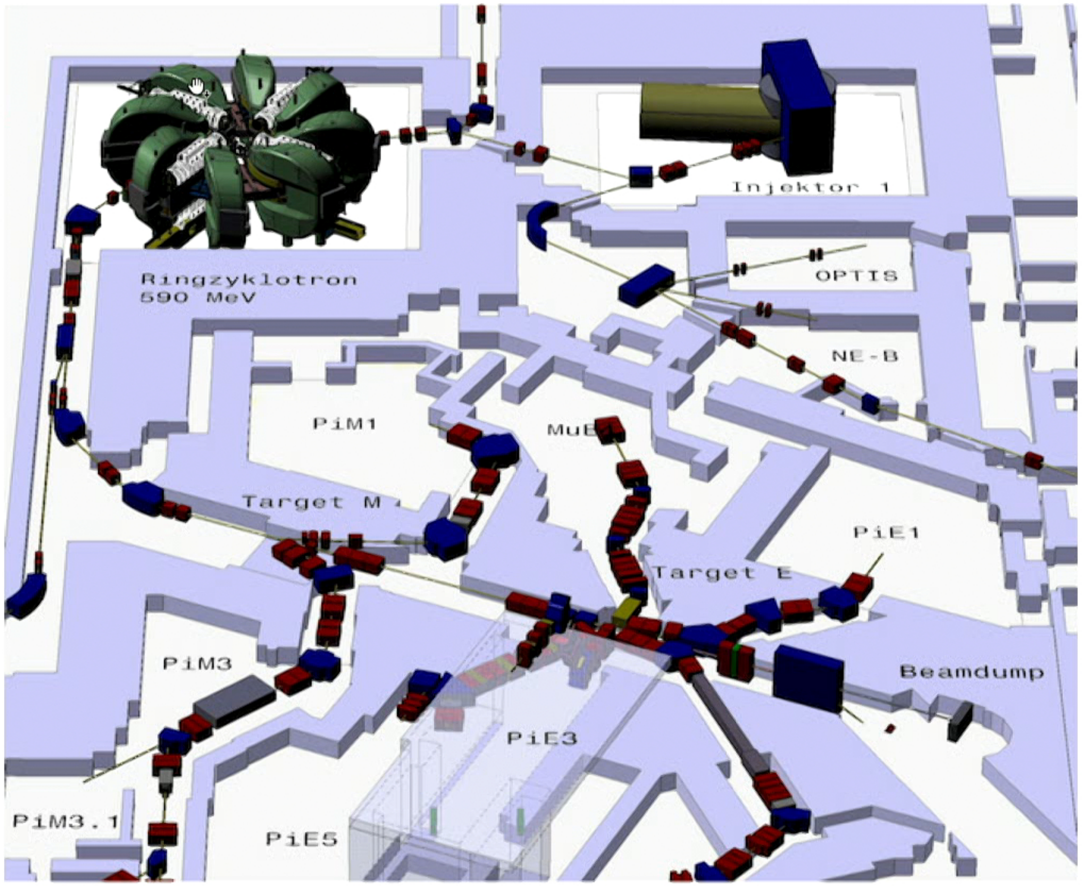


- S-states great probe for nuclear structure:
  - Lamb shift ($\Delta E_{2\mathrm{S}\rightarrow 2\mathrm{P}}$) ⇒ charge radius
  - $2\mathrm{S}$ & $2\mathrm{P}$ hyperfine structure ⇒ Zemach radius
  - Polarizablity of the nucleus
- Measure Lamb shift transitions between energy levels via laser spectroscopy



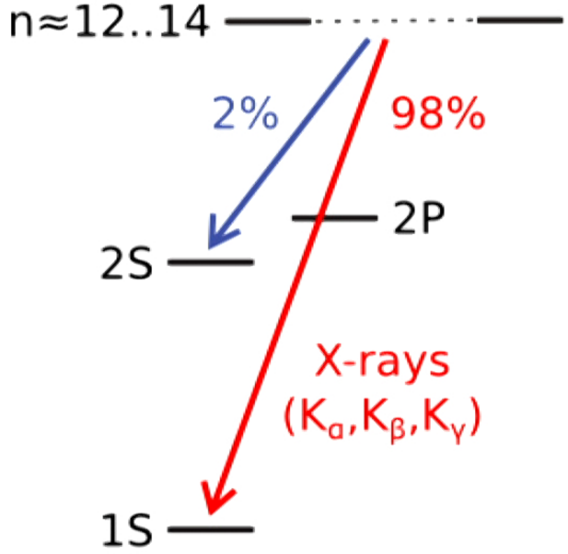
The Paul Scherrer Institute (PSI), Switzerland

HIPA facility at the Paul Scherrer Institute

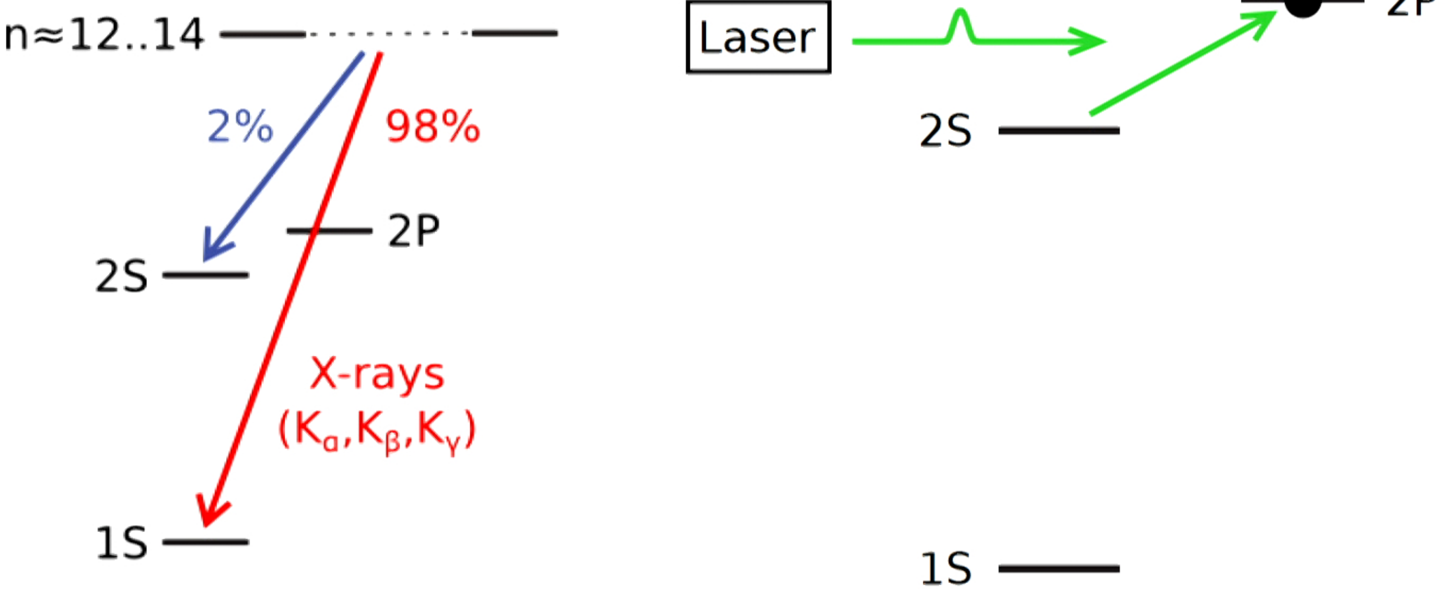


- High Intensity Proton Accelerator
- $\sim 2\,\mathrm{mA}$ of $590\,\mathrm{MeV}$ p^+ are shot on a carbon target to create pions (PiE5 area)
- pions decay to muons
- muons are cooled/slowed down in a special beamline
- non-destructive muon detector provides trigger for laser
- μ^- enter gas target (hydrogen, deuterium, ^{3}He, or ^{4}He)
- bound state is formed between light nucleus and one muon

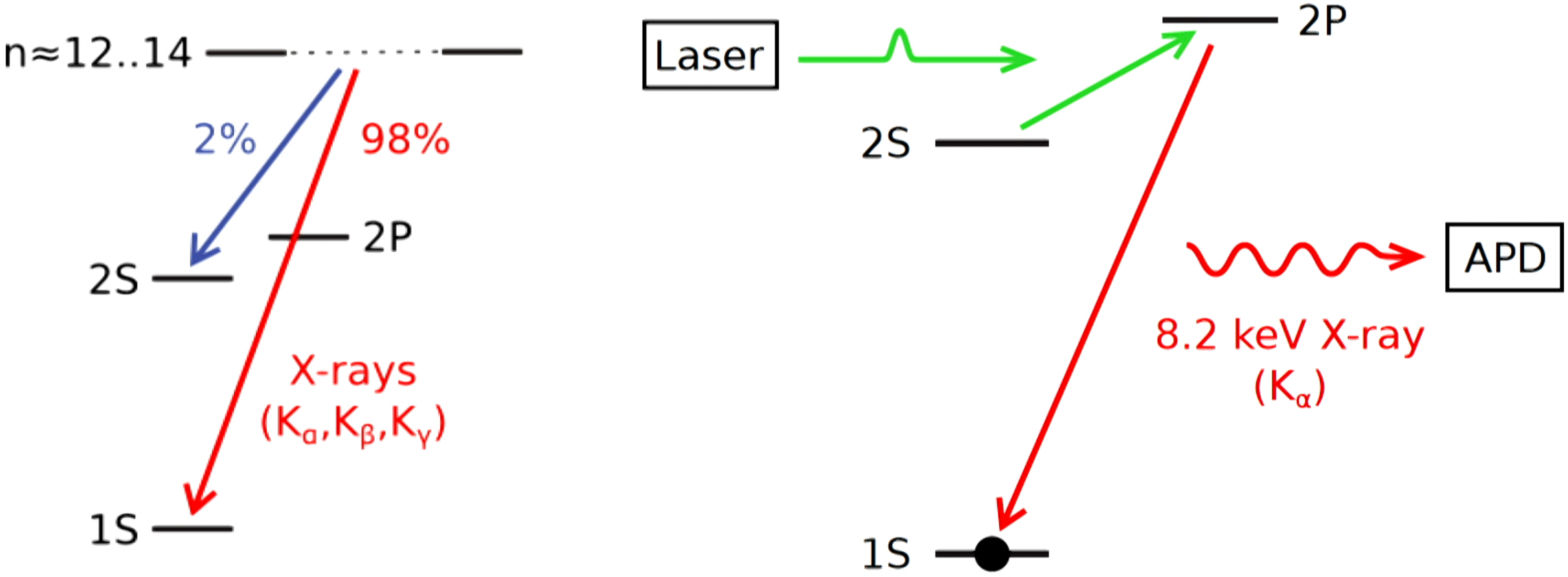
Measurement of muonic Lamb shift transitions



Measurement of muonic Lamb shift transitions



Measurement of muonic Lamb shift transitions



Steps to extract nuclear properties from transition energy

- Make sure systematics are under control
- Most systematics are below our measurement sensitivity
- We needed to check on *Quantum Interference*

- Use theory to extract charge radius from transition frequency
- What are the current state of the art theory term calculations?
- Summarize contributions from several different experts
- Data from hydrogen and deuterium published, helium-3 and helium-4 are underway

What is Quantum Interference (QI)? "Coherent excitation of multiple allowed excited states", a polarization & geometry dependent effect (vanishes in 4π)

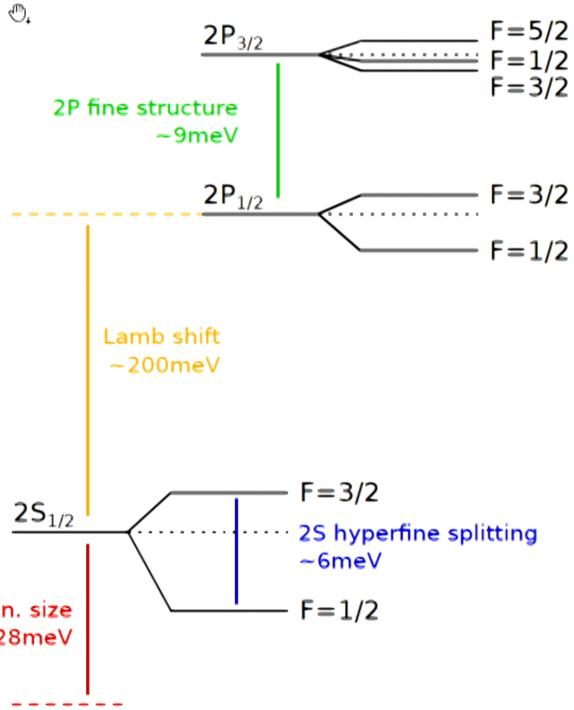
[eg. E. Hessels, M. Horbatsch, PRA 82, 052519 (2010); R. Brown *et al.*, PRA 87, 032504 (2013); and Refs therein]

- Investigations on QI in CREMA are published
- Compare point-like detector vs. acceptance angle of CREMA

[Amaro, Franke, et.al., PRA **92**, 022514 (2015)]

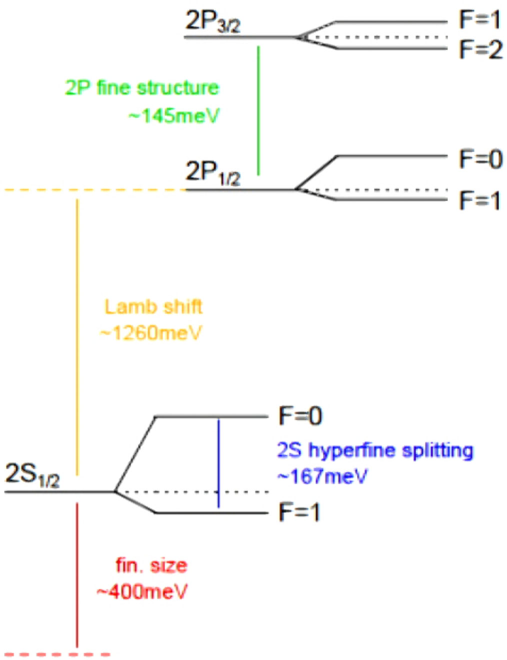
$n = 2$ levels in muonic deuterium and helium-3

μD



[Krauth et.al., Ann. Phys. **366** p. 168 (2016)]

μ^3He$^+$



[Franke, Krauth, et.al., arXiv:1705.00352, submitted to EPJD]

$n = 2$ levels in muonic deuterium and helium-3

Theory of n=2 levels

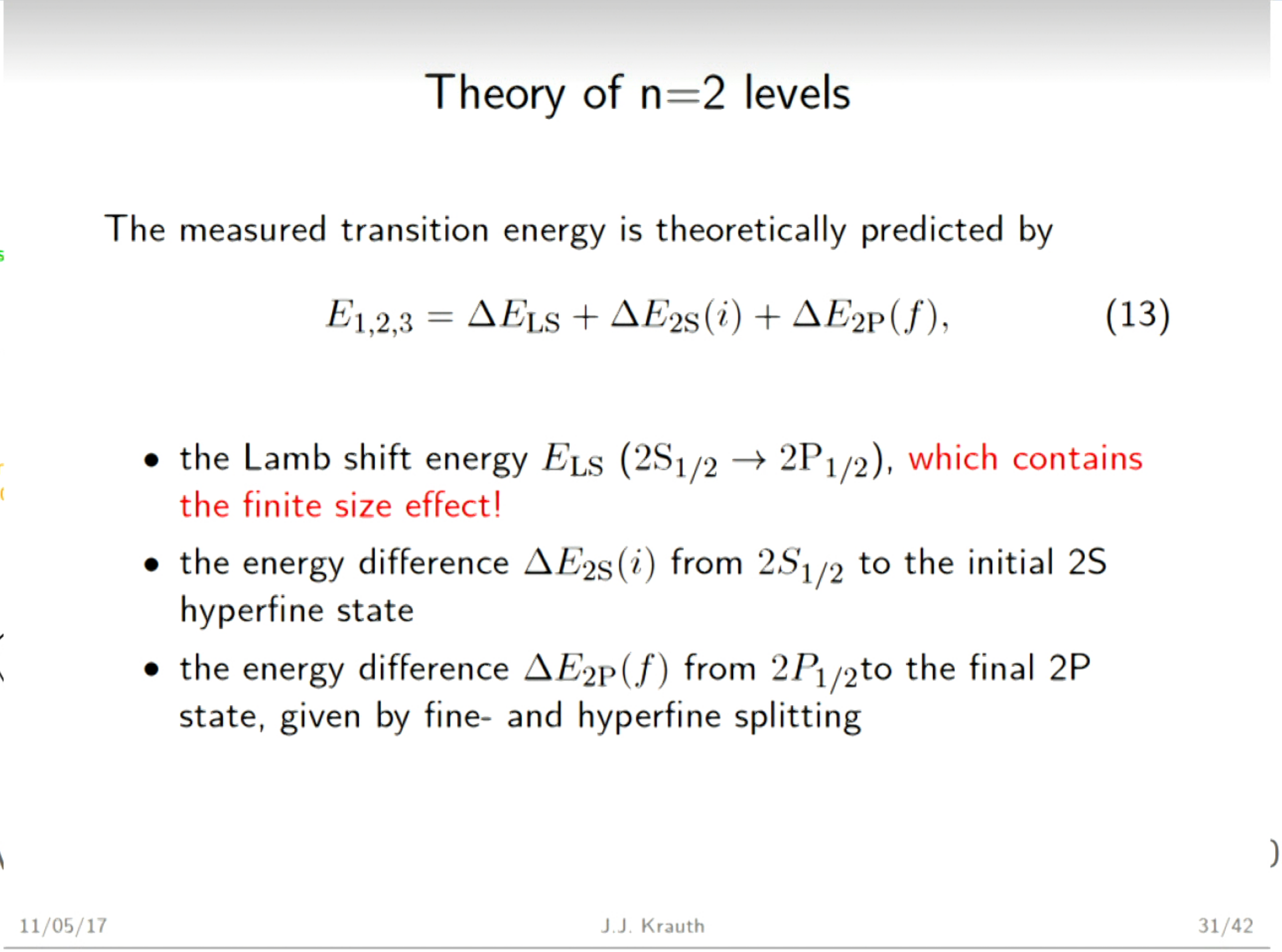
The measured transition energy is theoretically predicted by

$$E_{1,2,3} = \Delta E_{\mathrm{LS}} + \Delta E_{\mathrm{2S}}(i) + \Delta E_{\mathrm{2P}}(f), \qquad (13)$$

- the Lamb shift energy E_{LS} ($2\mathrm{S}_{1/2} \rightarrow 2\mathrm{P}_{1/2}$), which contains the finite size effect!
- the energy difference $\Delta E_{\mathrm{2S}}(i)$ from $2S_{1/2}$ to the initial 2S hyperfine state
- the energy difference $\Delta E_{\mathrm{2P}}(f)$ from $2P_{1/2}$to the final 2P state, given by fine- and hyperfine splitting

[Krauth et.al., A)352,

$n=2$ levels in muonic deuterium and helium-3



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[Krauth et.al., A)352,

$n=2$ levels in muonic deuterium and helium-3

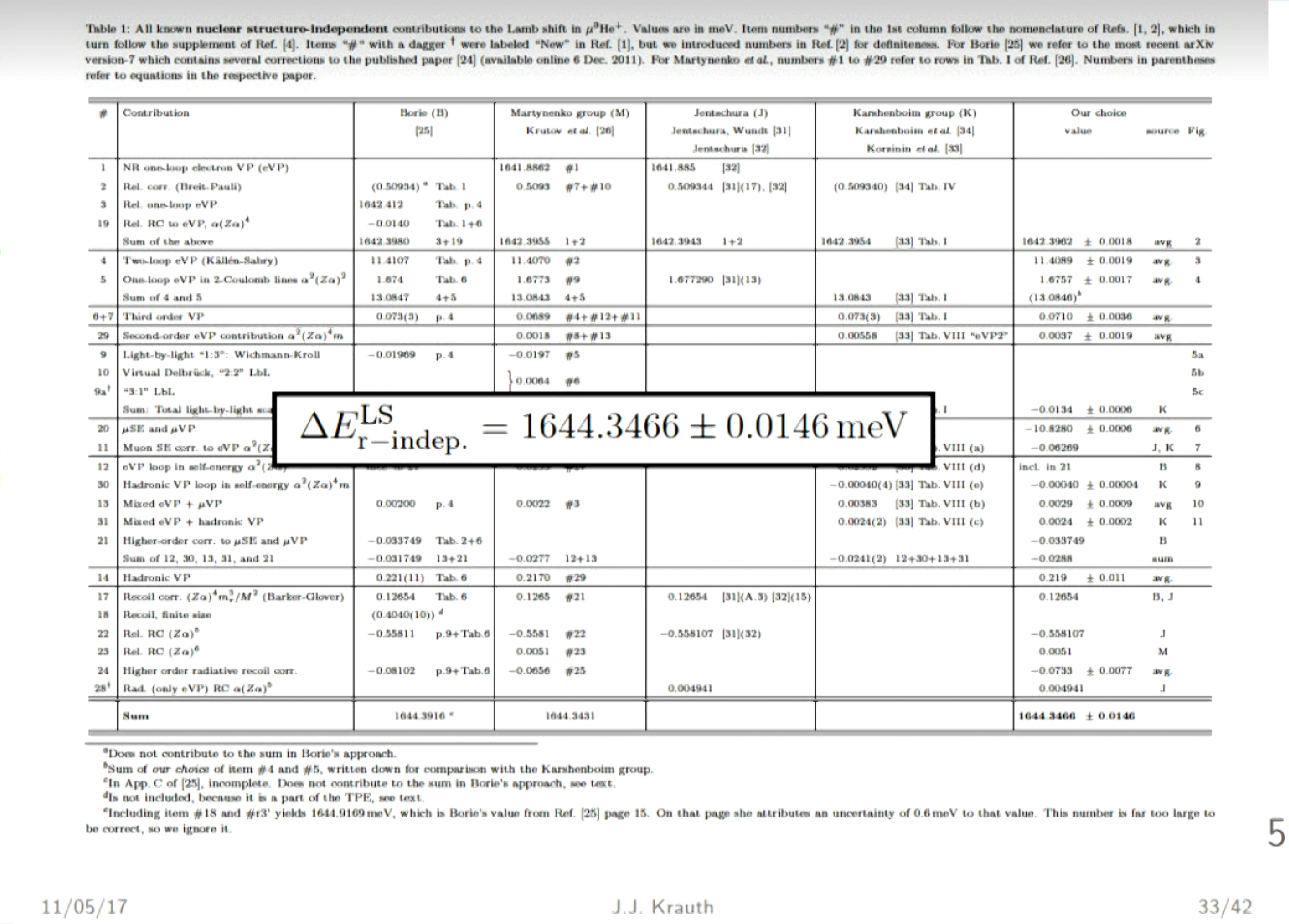


Table 1: All known **nuclear structure-independent** contributions to the Lamb shift in μ^3He$^+$. Values are in meV. Item numbers "#" in the 1st column follow the nomenclature of Refs. [1, 2], which in turn follow the supplement of Ref. [4]. Items "#" with a dagger † were labeled "New" in Ref. [1], but we introduced numbers in Ref. [2] for definiteness. For Borie [25] we refer to the most recent arXiv version-7 which contains several corrections to the published paper [24] (available online 6 Dec. 2011). For Martynenko *et al.*, numbers #1 to #29 refer to rows in Tab. I of Ref. [26]. Numbers in parentheses refer to equations in the respective paper.

#	Contribution	Borie (B) [25]	Martynenko group (M) Krutov *et al.* [26]	Jentschura (J) Jentschura, Wundt [31] Jentschura [32]	Karshenboim group (K) Karshenboim *et al.* [34] Korzinin *et al.* [33]	Our choice value	source	Fig.
1	NR one-loop electron VP (eVP)		1641.8862 #1	1641.885 [32]				
2	Rel. corr. (Breit-Pauli)	(0.50934) ^{a} Tab. 1	0.5093 #7+#10	0.509344 [31](17), [32]	(0.509340) [34] Tab. IV			
3	Rel. one-loop eVP	1642.412 Tab. p. 4						
19	Rel. RC to eVP, $\alpha(Z\alpha)^4$	−0.0140 Tab. 1+6						
	Sum of the above	1642.3980 3+19	1642.3955 1+2	1642.3943 1+2	1642.3954 [33] Tab. I	1642.3962 ± 0.0018	avg	2
4	Two-loop eVP (Källén-Sabry)	11.4107 Tab. p. 4	11.4070 #2			11.4089 ± 0.0019	avg.	3
5	One-loop eVP in 2-Coulomb lines $\alpha^2(Z\alpha)^2$	1.674 Tab. 6	1.6773 #9	1.677290 [31](13)		1.6757 ± 0.0017	avg.	4
	Sum of 4 and 5	13.0847 4+5	13.0843 4+5		13.0843 [33] Tab. I	(13.0846)^b		
6+7	Third order VP	0.073(3) p. 4	0.0689 #4+#12+#11		0.073(3) [33] Tab. I	0.0710 ± 0.0036	avg.	
29	Second-order eVP contribution $\alpha^2(Z\alpha)^4m$		0.0018 #8+#13		0.00558 [33] Tab. VIII "eVP2"	0.0037 ± 0.0019	avg	
9	Light-by-light "1:3": Wichmann-Kroll	−0.01969 p. 4	−0.0197 #5					5a
10	Virtual Delbrück, "2:2" LbL		} 0.0064 #6					5b
9a†	"3:1" LbL							5c
	Sum: Total light-by-light sc				. I	−0.0134 ± 0.0006	K	
20	μSE and μVP					−10.8280 ± 0.0006	avg.	6
11	Muon SE corr. to eVP $\alpha^2(Z$				. VIII (a)	−0.06269	J, K	7
12	eVP loop in self-energy $\alpha^2(Z$				. VIII (d)	incl. in 21	B	8
30	Hadronic VP loop in self-energy $\alpha^2(Z\alpha)^4m$				−0.00040(4) [33] Tab. VIII (e)	−0.00040 ± 0.00004	K	9
13	Mixed eVP + μVP	0.00200 p. 4	0.0022 #3		0.00383 [33] Tab. VIII (b)	0.0029 ± 0.0009	avg	10
31	Mixed eVP + hadronic VP				0.0024(2) [33] Tab. VIII (c)	0.0024 ± 0.0002	K	11
21	Higher-order corr. to μSE and μVP	−0.033749 Tab. 2+6				−0.033749	B	
	Sum of 12, 30, 13, 31, and 21	−0.031749 13+21	−0.0277 12+13		−0.0241(2) 12+30+13+31	−0.0288	sum	
14	Hadronic VP	0.221(11) Tab. 6	0.2170 #29			0.219 ± 0.011	avg.	
17	Recoil corr. $(Z\alpha)^4m_r^3/M^2$ (Barker-Glover)	0.12654 Tab. 6	0.1265 #21	0.12654 [31](A.3) [32](15)		0.12654	B, J	
18	Recoil, finite size	(0.4040(10)) ^{d}						
22	Rel. RC $(Z\alpha)^5$	−0.55811 p.9+Tab.6	−0.5581 #22	−0.558107 [31](32)		−0.558107	J	
23	Rel. RC $(Z\alpha)^6$		0.0051 #23			0.0051	M	
24	Higher order radiative recoil corr.	−0.08102 p.9+Tab.6	−0.0656 #25			−0.0733 ± 0.0077	avg.	
28†	Rad. (only eVP) RC $\alpha(Z\alpha)^5$			0.004941		0.004941	J	
	Sum	1644.3916 ^{c}	1644.3431			**1644.3466 ± 0.0146**		

$$\Delta E^{\mathrm{LS}}_{\mathrm{r-indep.}} = 1644.3466 \pm 0.0146\,\mathrm{meV}$$

---

[a] Does not contribute to the sum in Borie's approach.

[b] Sum of *our choice* of item #4 and #5, written down for comparison with the Karshenboim group.

[c] In App. C of [25], incomplete. Does not contribute to the sum in Borie's approach, see text.

[d] Is not included, because it is a part of the TPE, see text.

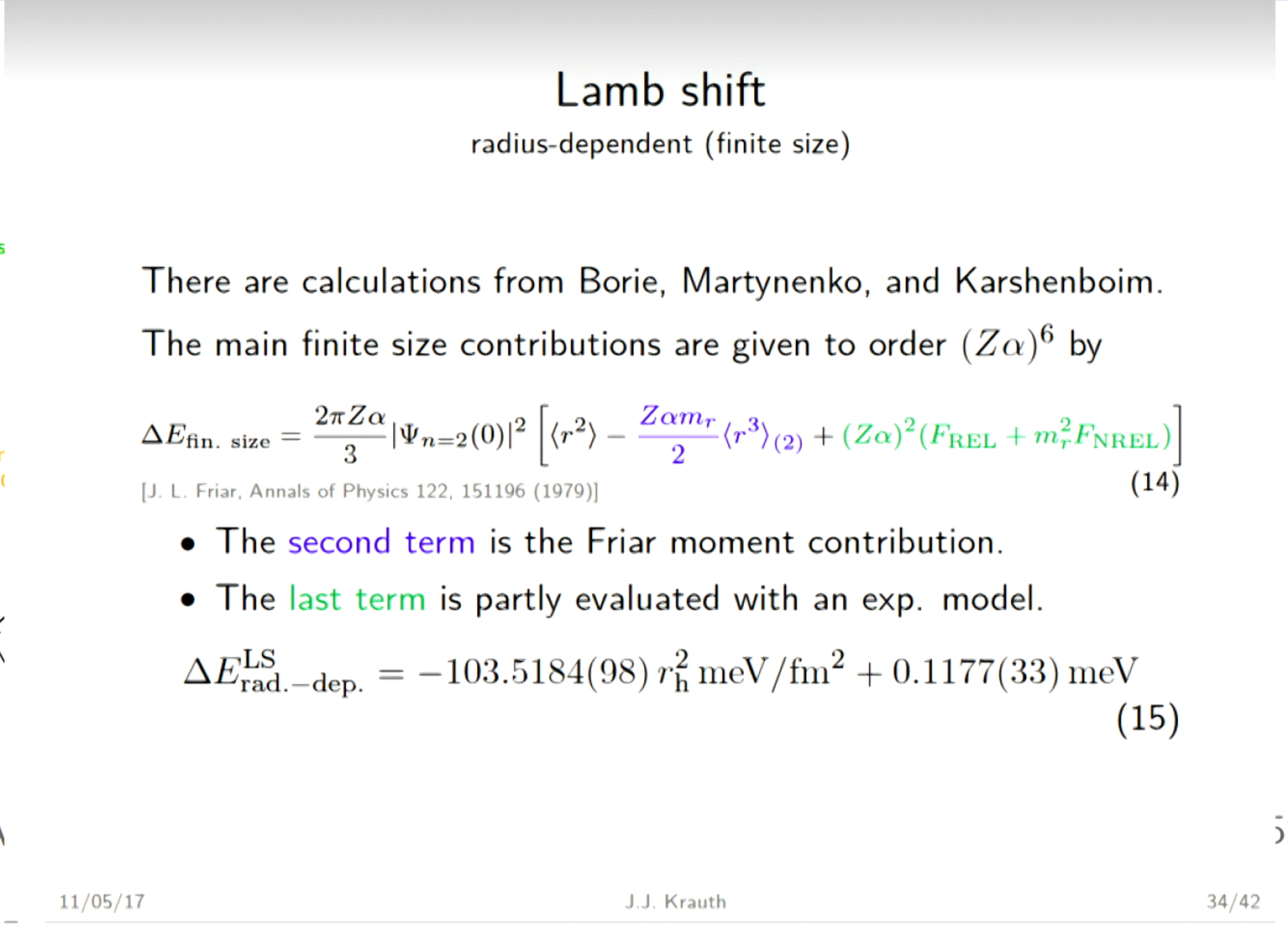
[e] Including item #18 and #r3' yields 1644.9169 meV, which is Borie's value from Ref. [25] page 15. On that page she attributes an uncertainty of 0.6 meV to that value. This number is far too large to be correct, so we ignore it.

[Krauth et.al., A

52,

11/05/17 J.J. Krauth 33/42

$n=2$ levels in muonic deuterium and helium-3



Lamb shift

radius-dependent (finite size)

There are calculations from Borie, Martynenko, and Karshenboim.

The main finite size contributions are given to order $(Z\alpha)^6$ by

$$\Delta E_{\text{fin. size}} = \frac{2\pi Z\alpha}{3}|\Psi_{n=2}(0)|^2\left[\langle r^2\rangle - \frac{Z\alpha m_r}{2}\langle r^3\rangle_{(2)} + (Z\alpha)^2(F_{\text{REL}} + m_r^2 F_{\text{NREL}})\right] \tag{14}$$

[J. L. Friar, Annals of Physics 122, 151196 (1979)]

- The second term is the Friar moment contribution.
- The last term is partly evaluated with an exp. model.

$$\Delta E^{\text{LS}}_{\text{rad.-dep.}} = -103.5184(98)\, r_{\text{h}}^2\, \text{meV/fm}^2 + 0.1177(33)\, \text{meV} \tag{15}$$

[Krauth et.al., A

52,

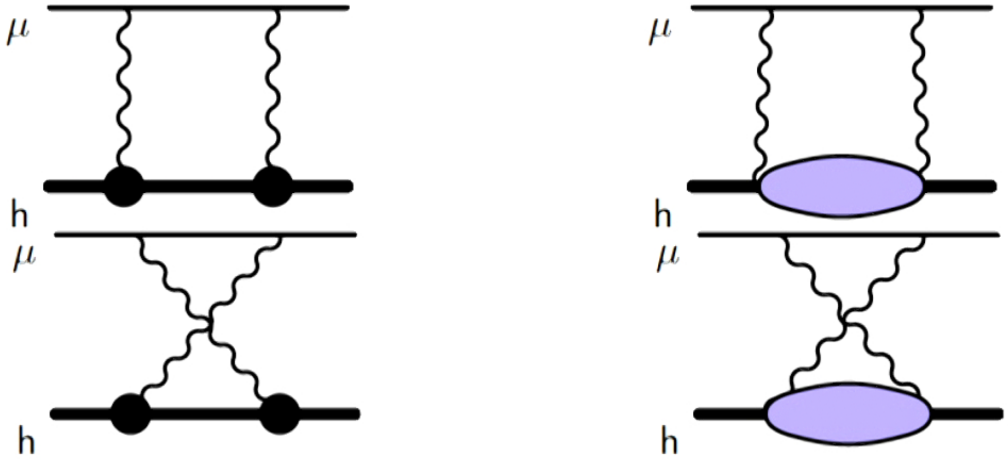
$n=2$ levels in muonic deuterium and helium-3

Lamb shift

two-photon exchange (TPE)

$$\Delta E^{\mathrm{LS}}_{\mathrm{TPE}} = \Delta E^{\mathrm{LS}}_{\mathrm{Friar}} + \Delta E^{\mathrm{LS}}_{\mathrm{inelastic}} = 15.30(52)\,\mathrm{meV} \qquad (16)$$

elastic (Friar moment) inelastic (polarizability)



→ TPE: main limitation for determination of r_{h}!

[Krauth et.al., A

2,

$n = 2$ levels in muonic deuterium and helium-3

Lamb shift

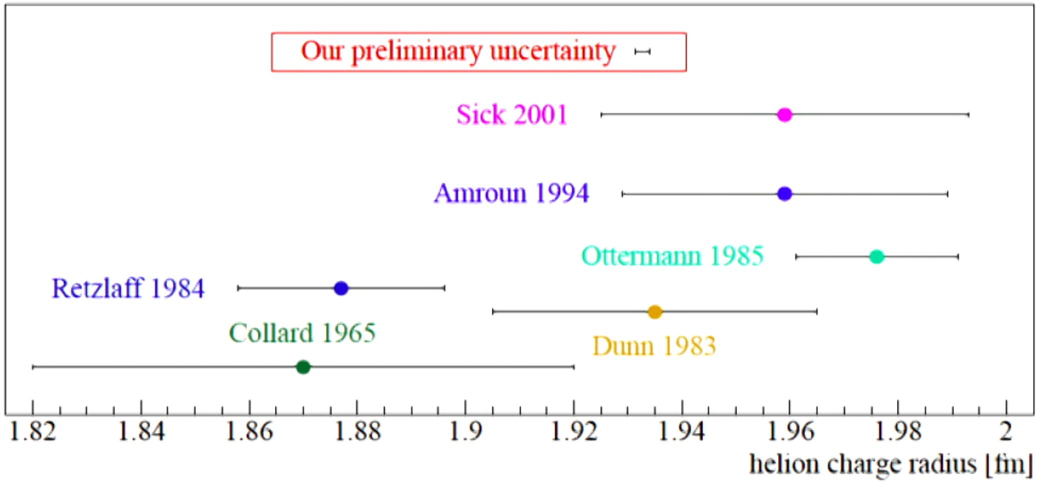
helion rms charge radius

extract charge radius from muonic data and theory:

- 3 measured transitions, 2 fit parameters (LS, 2S HFS)
- $\Delta E_{\mathrm{LS}} = \Delta E_{\mathrm{QED}} + \Delta E_{\mathrm{fin.size}}(C \times r_{\mathrm{h}}^2) + \Delta E_{\mathrm{TPE}}^{\mathrm{LS}}$

This yields:

$\rightarrow r_{\mathrm{h}}(\mu^3\mathrm{He}^+) = 1.97xxx(12)^{\mathrm{exp}}(128)^{\mathrm{theo}}\ \mathrm{fm}$ Preliminary!

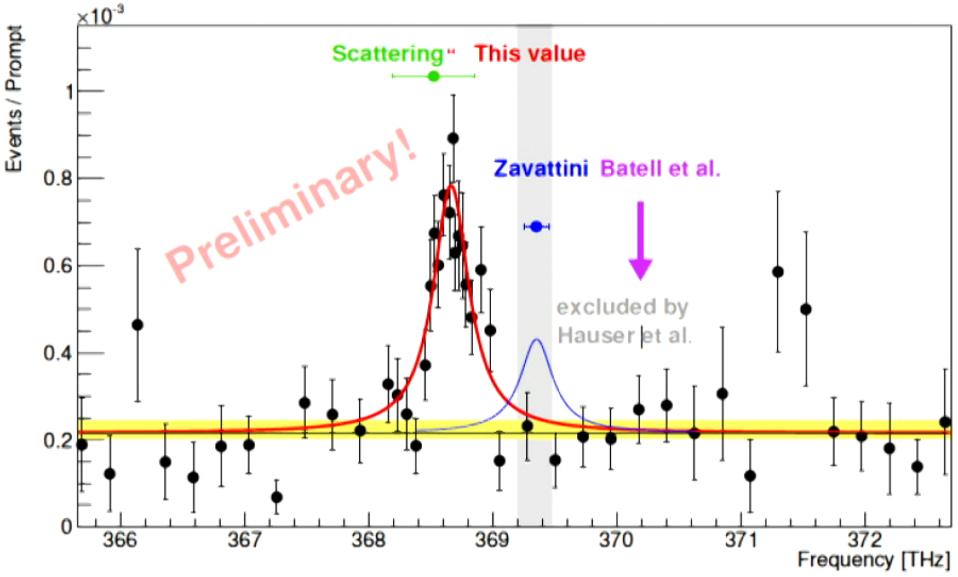


[Krauth et.al., A

$n = 2$ levels in muonic deuterium and helium-3

[Krauth et.al., A

Muonic helium-4 ($\mu^4\mathrm{He}^+$)



experimental accuracy of $17\,\mathrm{GHz}$

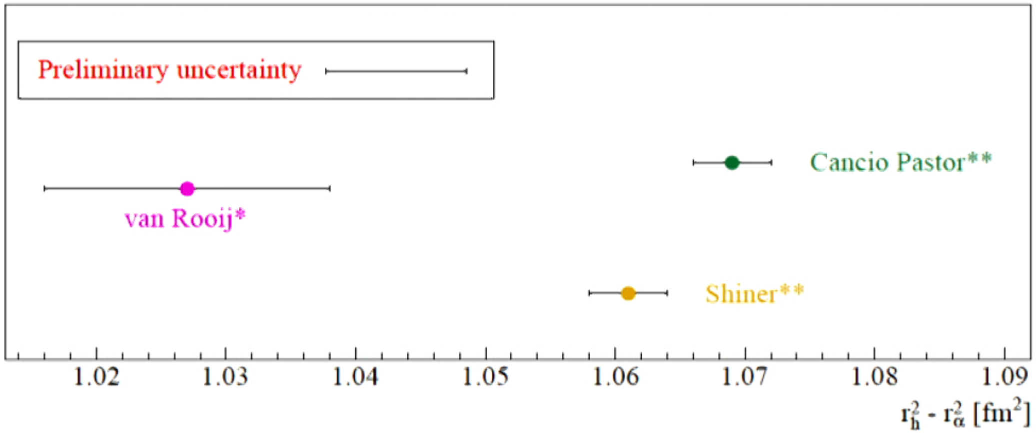
with theory we get: $r_\alpha(\mu^4\mathrm{He}^+) = 1.68xxx(19)_{\mathrm{exp}}(58)_{\mathrm{theo}}\,\mathrm{fm}$

compared to $1.68100(400)\,\mathrm{fm}$ from e-scatt..

$n = 2$ levels in muonic deuterium and helium-3

[Krauth et.al., A

Charge radius difference in muonic helium



value from re-evaluated theory in

* Patkos et al., PRA 95, 012508 (2017)

** Patkos et al., PRA 94, 052508 (2016)

Status and outlook for CREMA

- $r_\mathrm{p}(\mu\mathrm{p})$ $6\,\sigma$ smaller than CODATA
  [Pohl *et al.* Nature 2010, Antognini *et al.* Science 2013]
- $r_\mathrm{d}(\mu\mathrm{d})$ $6\,\sigma$ smaller than CODATA, consistent with $r_\mathrm{p}(\mu\mathrm{d})$
  [Pohl *et al.* Science 2016]
- $r_\mathrm{h}(\mu^3\mathrm{He}^+)$ and $r_\alpha(\mu^4\mathrm{He}^+)$ so far agree with e^--scattering (preliminary!)
- more experiments to come:
  Hydrogen spectroscopy (2S-4P, 2S-6P, 2S-2P), He^+ spectroscopy, MUSE, μp(HFS), $\mu^3\mathrm{He}^+$(HFS) and others

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Japanese–Canadian UCN nEDM collaboration

KEK	T. Adachi, S. Jeong, S. Kawasaki, Y. Watanabe
RCNP Osaka	K. Hatanaka, I. Tanihata, R. Matsumiya, E.Pierre (also TRIUMF)
UBC	E. Altiere, D. Jones, K. Madison, E. Miller, T. Momose, J. Weinands, T. Hayamizu
U Winnipeg	C. Bidinosti, B. Jamieson, R. Mammei (also TRIUMF), J.Martin
U Manitoba	T. Andalib, J. Birchall, M. Gericke, M. Lang, J. Mammei, S.Page, L. Rebenitsch, S. Hansen-Romu, S. Ahmed
TRIUMF	C. Davis, B. Franke, K. Katsika, T. Kikawa, A. Konaka (also UVic and Osaka U.), F. Kuchler, L.Lee (also U. Manitoba), R. Picker (also SFU), W.Ramsay, W.vanOers (also U. Manitoba), T. Lindner (also UW)
UNBC	E. Korkmaz
SFU	J. Sonier

We are an open collaboration and are accepting new membership requests!

TRIUMF's UCN Project: the objective

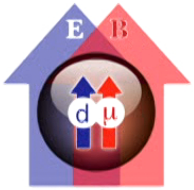
- Operate world's strongest intensity ultracold neutron (UCN) source:
  combination of spallation neutron source and superfluid He converter

- Search for the neutron electric dipole moment (nEDM) to a precision of $10^{-27}\,e$cm
- Establish UCN user facility with a second port & and attract international scientific community

The neutron electric dipole moment $d_{\rm n}$

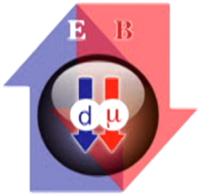
Does the spin of the neutron couple to an electric field?
Hamiltonian of a neutron in a magnetic field and an electric field

$$\mathcal{H} = -\mu_{\rm n}\frac{\vec{\sigma}}{|\vec{\sigma}|}\vec{B} - d_{\rm n}\frac{\vec{\sigma}}{|\vec{\sigma}|}\vec{E}$$



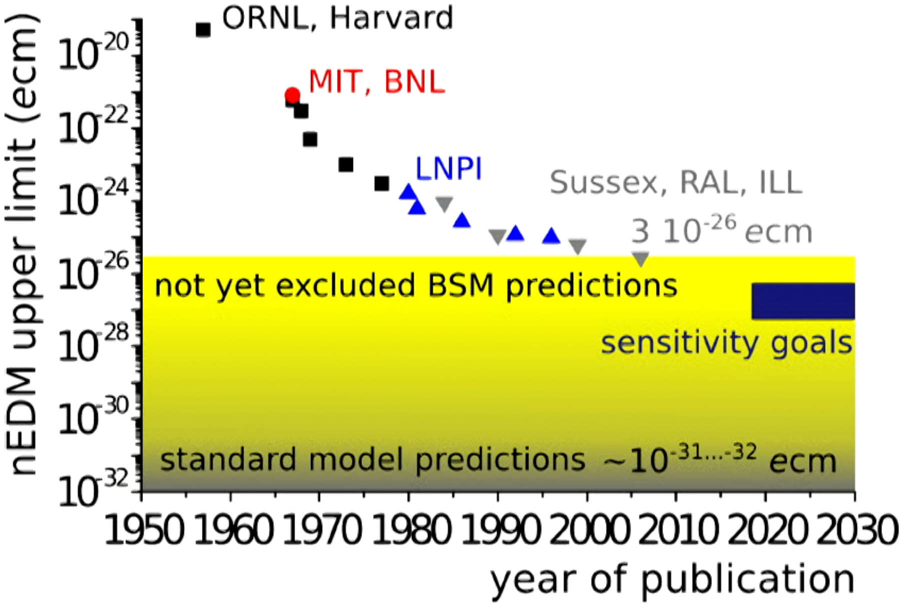
Time reversal symmetry T is not conserved:

$$\mathrm{T}\mathcal{H} = -\mu_{\rm n}\frac{-\vec{\sigma}}{|\vec{\sigma}|}(-\vec{B}) - d_{\rm n}\frac{-\vec{\sigma}}{|\vec{\sigma}|}\vec{E} \neq \mathcal{H}$$



CPT theorem: T-violation ⇔ CP-violation.

⇒ CP-violating processes are needed to understand the Baryon Asymmetry of our Universe (BAU)



Beyond Standard Model (BSM) physics shall fix BAU and predict
more CP-violation ⇔ larger nEDM

Introduction to ultracold neutrons

- $E_{\mathrm{UCN}} \leq 300\,\mathrm{neV} \mathrel{\widehat{=}} 3.5\,\mathrm{mK}$ ("ultracold")
- Strong interaction results in pseudopotential $\widehat{=}$ optical potential V_{Fermi}
- UCN undergo total reflection under *all angles of incidence*

  if $E_{\mathrm{UCN}} \leq V_{\mathrm{Fermi,\,material}}$

  $\Rightarrow$ UCN are storable, like a gas
- Gravitational effects: $E_{\mathrm{UCN}}(1\,\mathrm{m}) \approx 100\,\mathrm{neV}$
- Magnetic fields depict a spin-dependent potential: $E_{\mathrm{UCN}}(1\,\mathrm{T}) \approx 60\,\mathrm{neV}$
- Weak interaction: $\tau_{\mathrm{n}} \approx 900\,\mathrm{s}$

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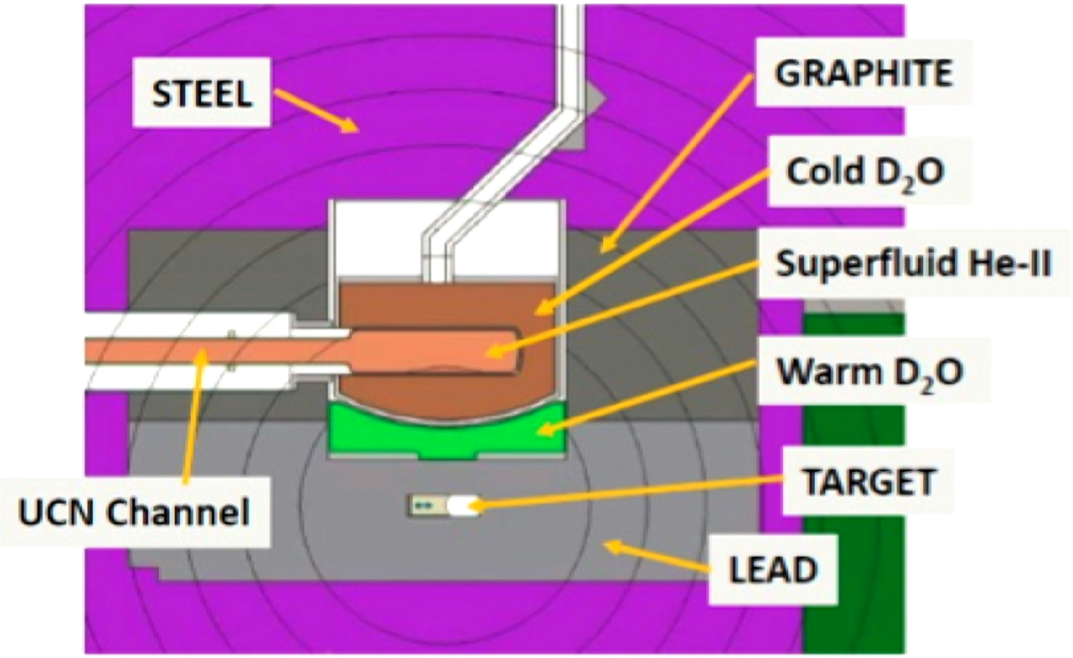
What to do with UCN?

- Search for the neutron electric dipole moment
- Measure the neutron lifetime
- Investigate beta decay correlations
- Sensitivity to energies of down to peV allows to search for exotic interactions, fifth forces, axions, dark matter, quantized states in gravitational potential, etc.

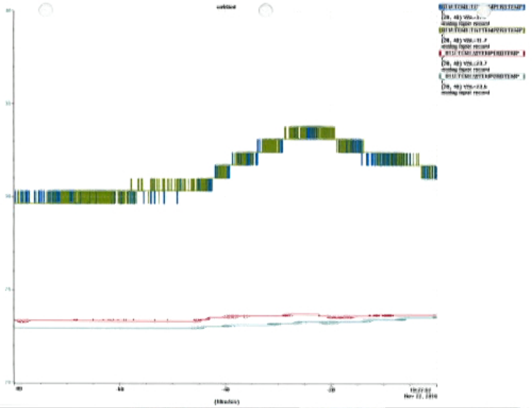
How to produce UCN: TRIUMF's source as example

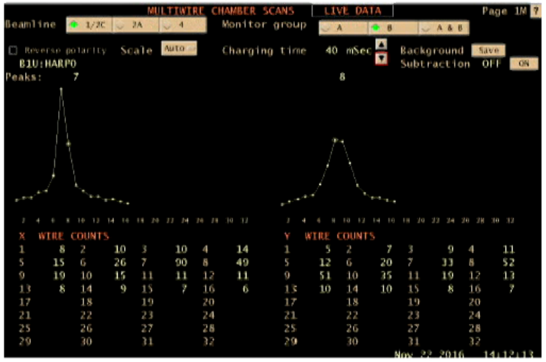
- Free n via spallation
- Moderation to thermal and cold neutron energies: $E_{\mathrm{kin}} \propto T_{\mathrm{mod}} \geq 10\,\mathrm{K}$
- 'Superthermal' conversion process in superfluid He: $E_{\mathrm{kin}}(\mathrm{cold\ n}) \rightarrow$ phonon/roton excitation $\underbrace{T_{\mathrm{He-II}}}_{=0.8\,\mathrm{K}} \neq \underbrace{T_{\mathrm{UCN}}}_{\leq 3.5\,\mathrm{mK}}$



Commissioning of new beamline BL1U end of 2016

- First beam in beamline 1U on Nov 22nd 2016
- First beam on target and neutron production,
  confirmed by radiation protection group and warming of target cooling water
- Beam tuning and magnet tests, steered beam on collimator
- 10 sample activations by thermal and cold neutrons





```
Charging time    40  mSec
Background
Subtraction  OFF
 B1U:HARPO
Peaks:    7                                    8

 X   WIRE COUNTS                         Y   WIRE COUNTS
 1        8   2      10   3     10   4    14     1        5   2       7   3      9   4    11
 5       15   6      26   7     90   8    49     5       12   6      20   7     33   8    52
 9       19  10      15  11     11  12    11     9       51  10      35  11     19  12    13
13        8  14       9  15      7  16     6    13       10  14      10  15      8  16     7
17           18          19         20          17           18          19          20
21           22          23         24          21           22          23          24
25           26          27         28          25           26          27          28
29           30          31         32          29           30          31          32
                                                                      Nov 22 2016   14:12:13
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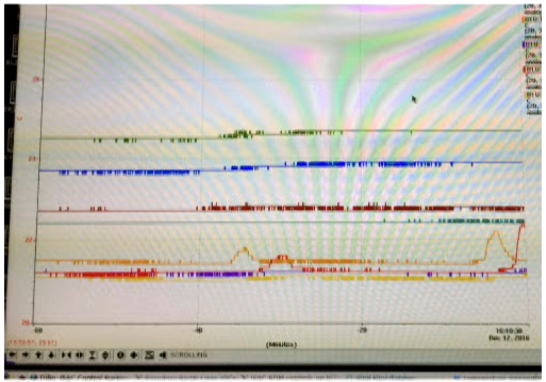
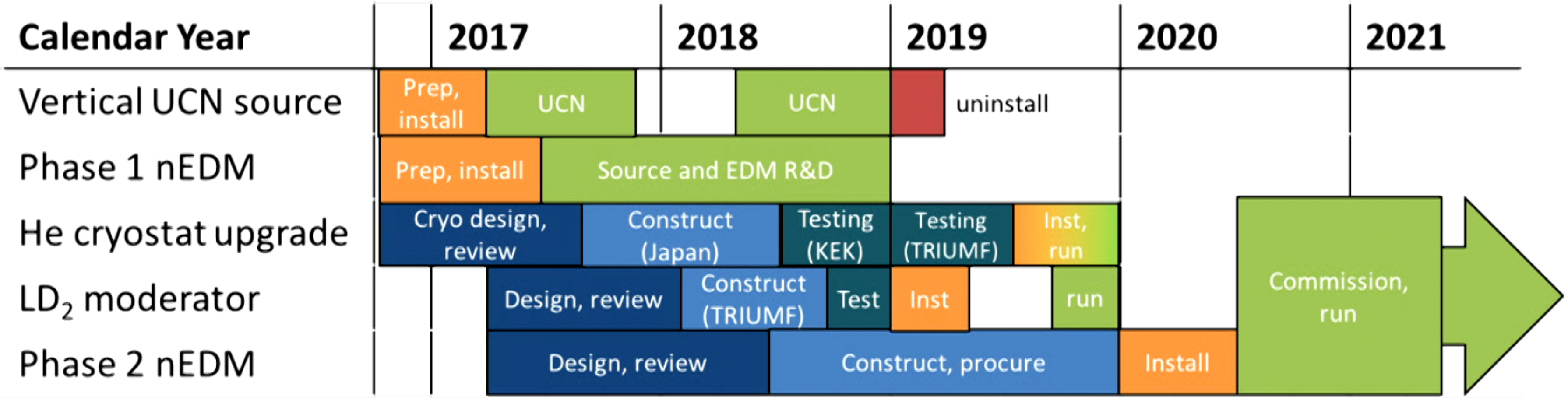


Installation work and cooling test of UCN source 2017

- Vertical cryostat (1st generation) UCN source arrived from Japan in October, and modified to fulfill Canadian safety standards as non-pressure vessel
- Cryostat installed above target, including all services (show video here!)
- Installation work was completed in four(!) months, HIGH pressure due to shutdown schedule
- Cooling test very successful! The UCN production volume reached 0.9 K, and heater tests showed the cryostat can handle up to few W of heat load.
- First UCN production on-site expected THIS SUMMER

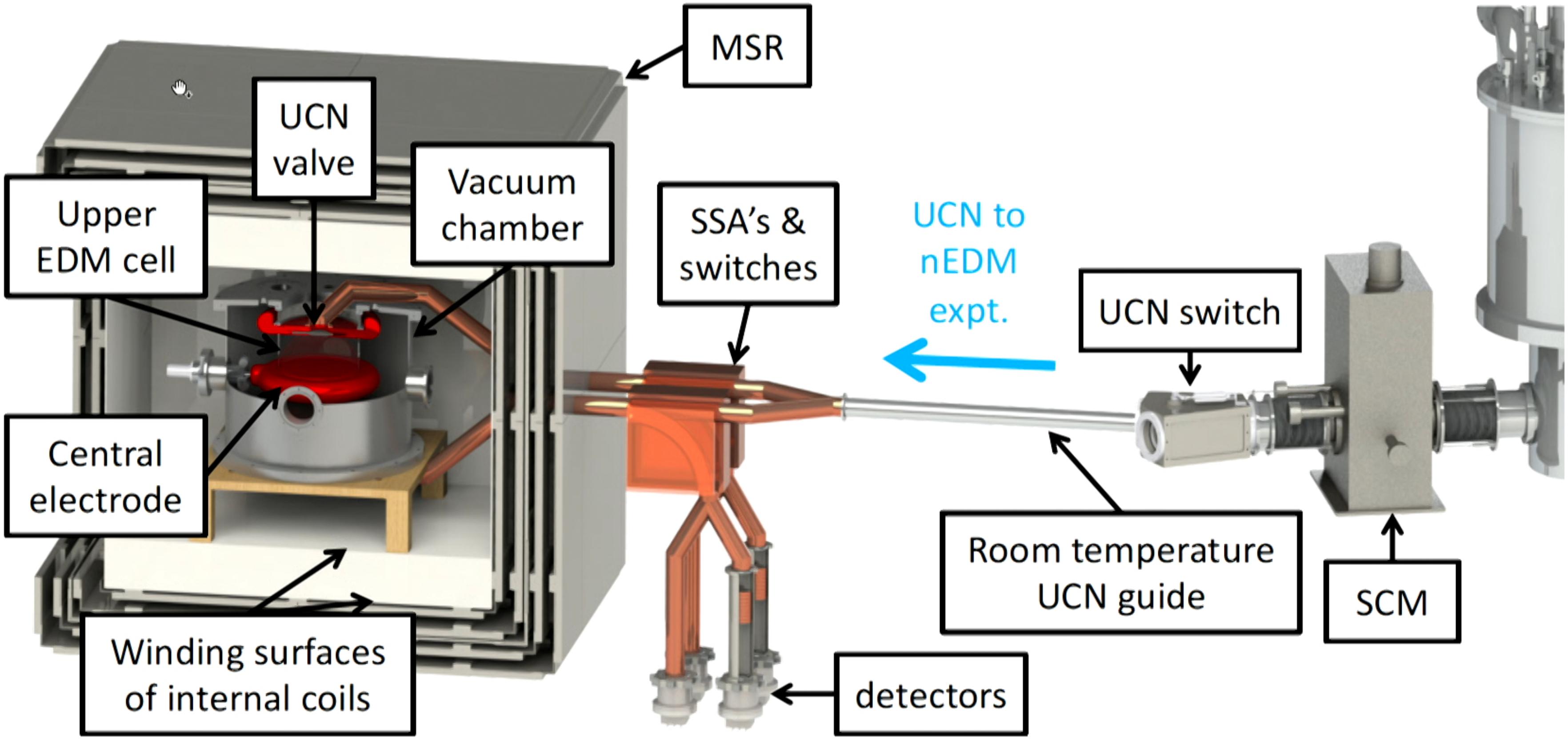
Conclusion of current status: Overarching schedule

- Work towards higher current ($1\,\mu\mathrm{A} \rightarrow 40\,\mu\mathrm{A}$) and higher UCN densities
- Design and build 3rd generation horizontal source (and liquid deuterium moderator system)
- Detailing and procurement of Phase 2 nEDM apparatus



Calendar Year		**2017**	**2018**	**2019**	**2020**	**2021**
Vertical UCN source	Prep, install	UCN	UCN	uninstall		
Phase 1 nEDM	Prep, install	Source and EDM R&D				
He cryostat upgrade	Cryo design, review	Construct (Japan)	Testing (KEK)	Testing (TRIUMF) Inst, run	Commission, run	
LD_2 moderator		Design, review Construct (TRIUMF)	Test	Inst run		
Phase 2 nEDM		Design, review	Construct, procure		Install	

Details on neutron EDM Phase 2 setup



Exotic interactions inside an nEDM spectrometer

A clock comparison of n & ^{199}Hg Larmor precession:
During nEDM measurements the ratio

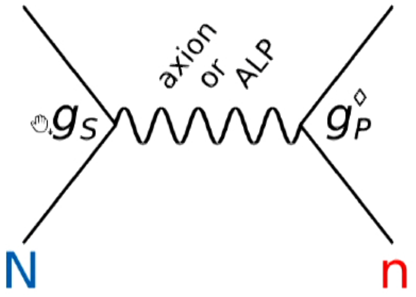
$$R = \frac{f_\mathrm{n}}{f_\mathrm{Hg}}$$

is used to correct for magnetic field changes.
R is measured at high precision and can also be used to search for an exotic interaction!
'Starting position':

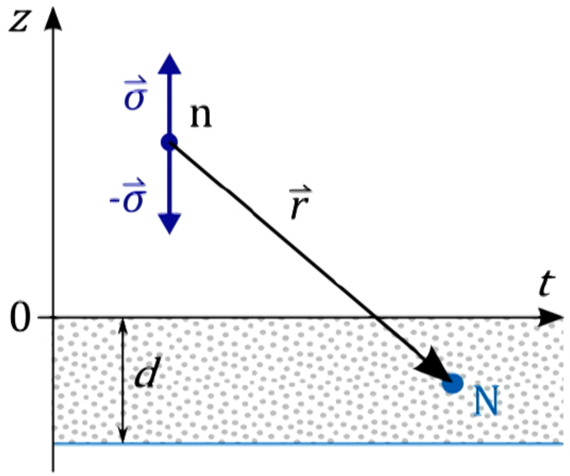
- Fundamental particle (n), spin polarized
- Precession frequency measured precisely
- Close to high density of unpolarized nucleons (wall material)

Very well suited to look for a dipole-monopole interaction:
spin-dependent & CP-violating

Pseudomagnetic field created by axion-like particles?



$$V(\vec{r}) = g_s g_p \frac{(\hbar c)^2}{8\pi m c^2}(\vec{\sigma}\cdot\hat{\vec{r}})\left(\frac{1}{r\lambda}+\frac{1}{r^2}\right)e^{\frac{-r}{\lambda}}$$



Spin-dependent interaction results in a pseudomagnetic field b normal to the surface.

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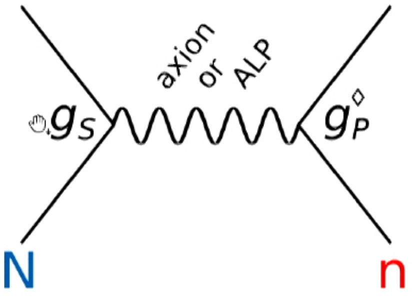

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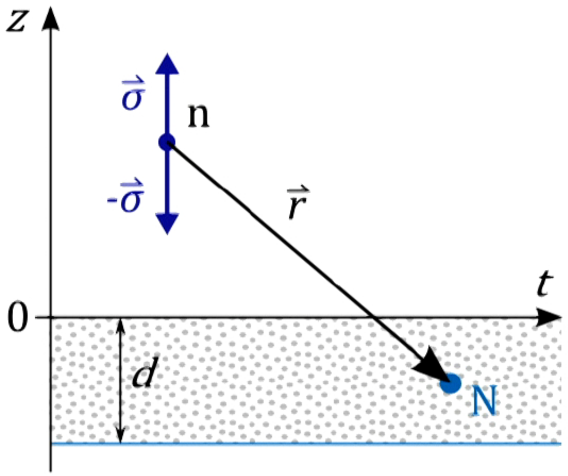

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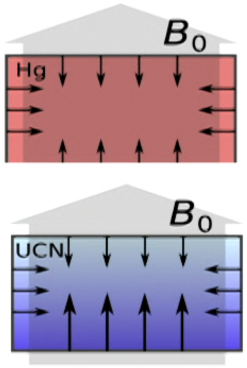
- Thermal Hg atoms sample the vessel homogeneously

⇒ Effect of b on Hg cancels

- UCN display an inhomegeneous density distribution, this will effectively enhance b at the bottom

⇒ Net effect on neutrons



Exotic interactions inside an nEDM spectrometer

Pseudomagnetic field alters f_n and thus also R.

$$R = \frac{f_\mathrm{n}}{f_\mathrm{Hg}} \xrightarrow{\text{corrections}} \frac{\gamma_\mathrm{n}}{\gamma_\mathrm{Hg}} \xrightarrow{\text{exotic interaction}} \frac{\gamma_\mathrm{n}}{\gamma_\mathrm{Hg}}\left(1 \pm \frac{b}{B_0}\right)$$

Integrate over all nucleons & UCN density distribution:

$$g_S g_P^\diamond = b\,\frac{H^2\gamma^\diamond m^\diamond}{6\hbar h N\lambda^2}\left(1-e^{-\frac{H}{\lambda}}\right)^{-1}\left(1-e^{-\frac{d}{\lambda}}\right)^{-1}$$

We measured: $b = (0.28 \pm 0.53)\,\mathrm{pT}$

$\Rightarrow g_S g_P \lambda^2 < 2.2\cdot 10^{-27}\,\mathrm{m}^2$ for $1\,\mu\mathrm{m} < \lambda < 5\,\mathrm{mm}$ at 95 % CL

TRIUMF

Exotic interactions inside an nEDM spectrometer

PAUL SCHERRER INSTITUT

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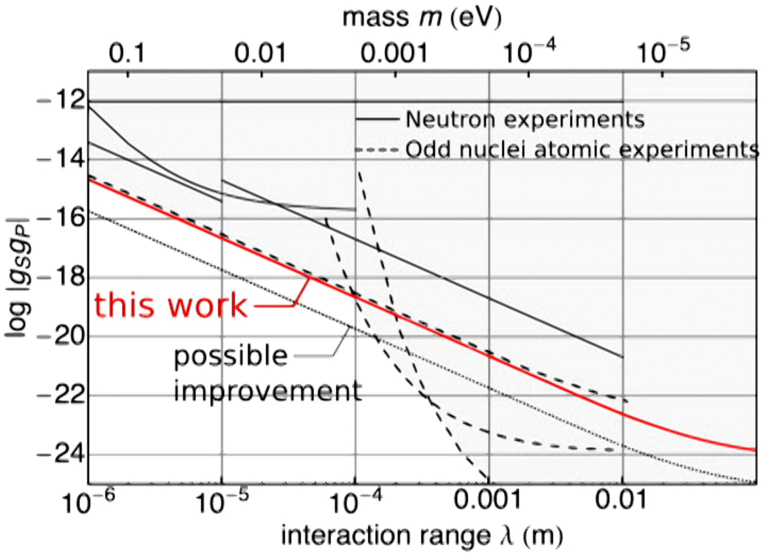

[Afach et.al., PLB **745**, 58 (2015)]

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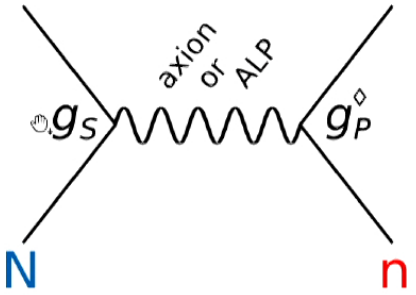

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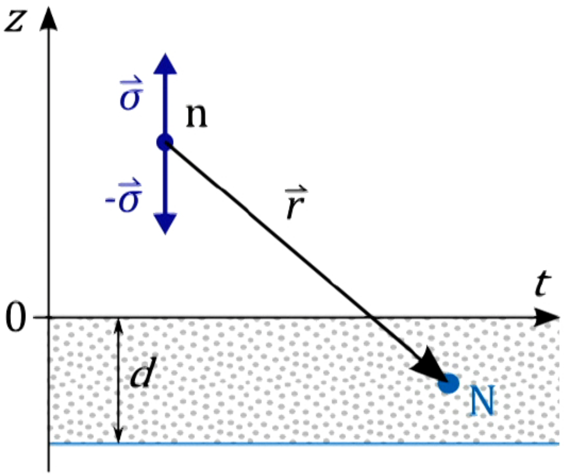

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