Developments for the next generation neutron EDM search at TRIUMF

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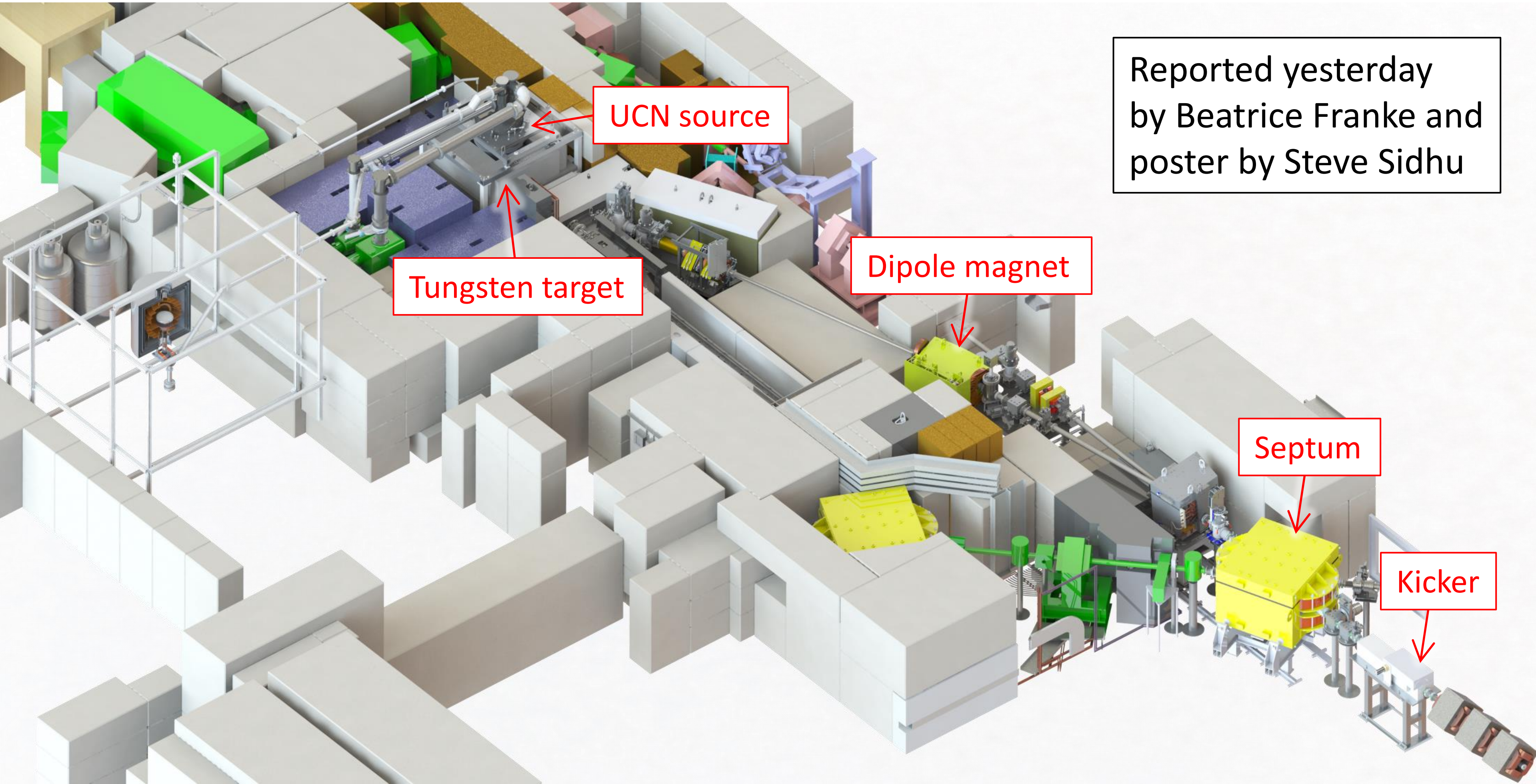
TRIUMF Japanese-Canadian UCN collaboration

nEDM2017

October 17, 2017

UCN experiment at TRIUMF

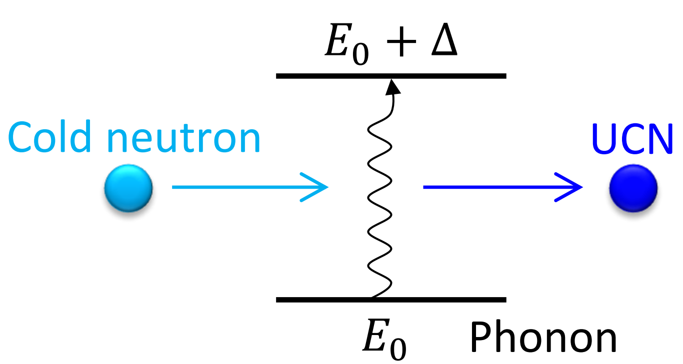
- New UCN beamline was constructed at TRIUMF.
- UCN source was shipped from Japan.
- Aiming the first UCN production in November 2017.

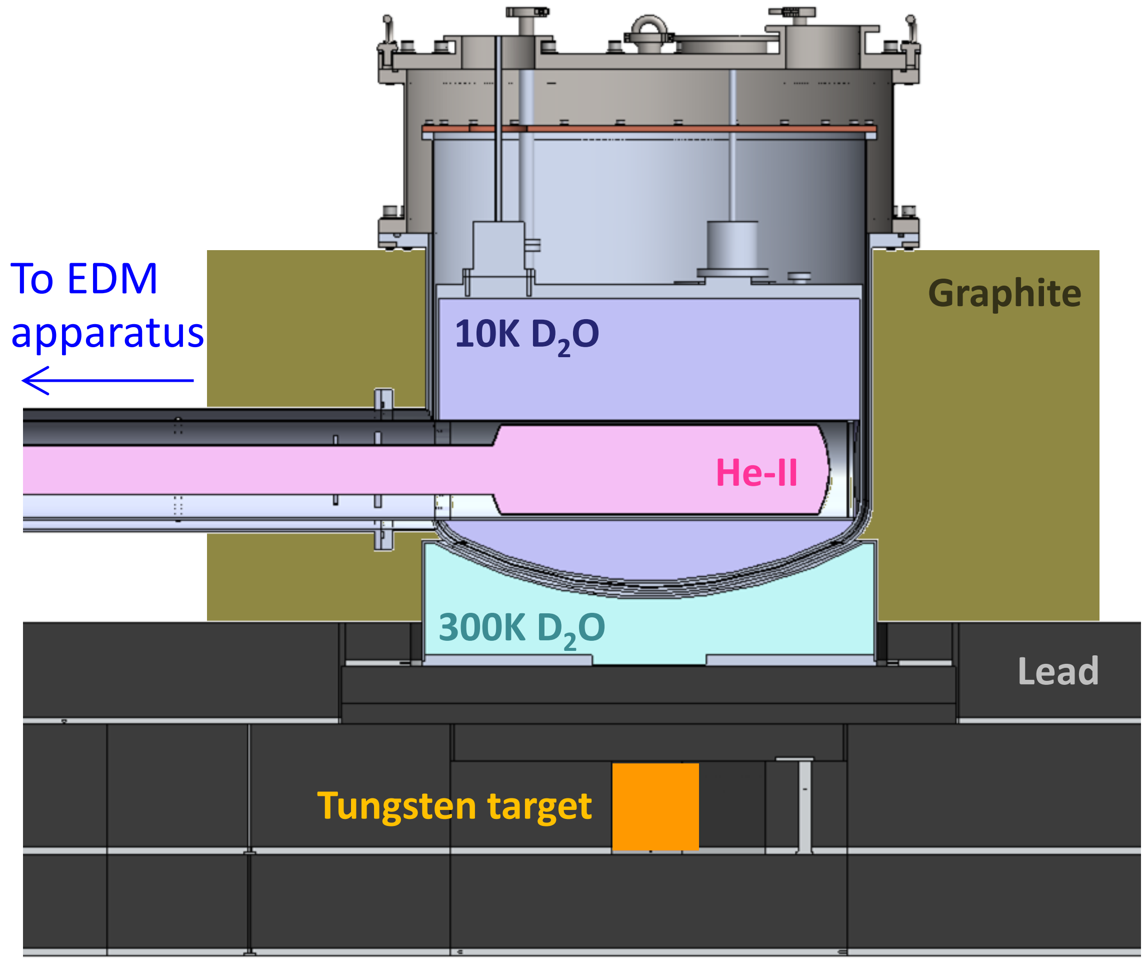


Reported yesterday by Beatrice Franke and poster by Steve Sidhu

UCN production by He-II at TRIUMF

- Neutron production by spallation of 480 MeV proton and tungsten target.
- Neutron moderation by 300K and 10K D_2O.
- UCN production from cold neutron by phonon excitation in superfluid helium (He-II).

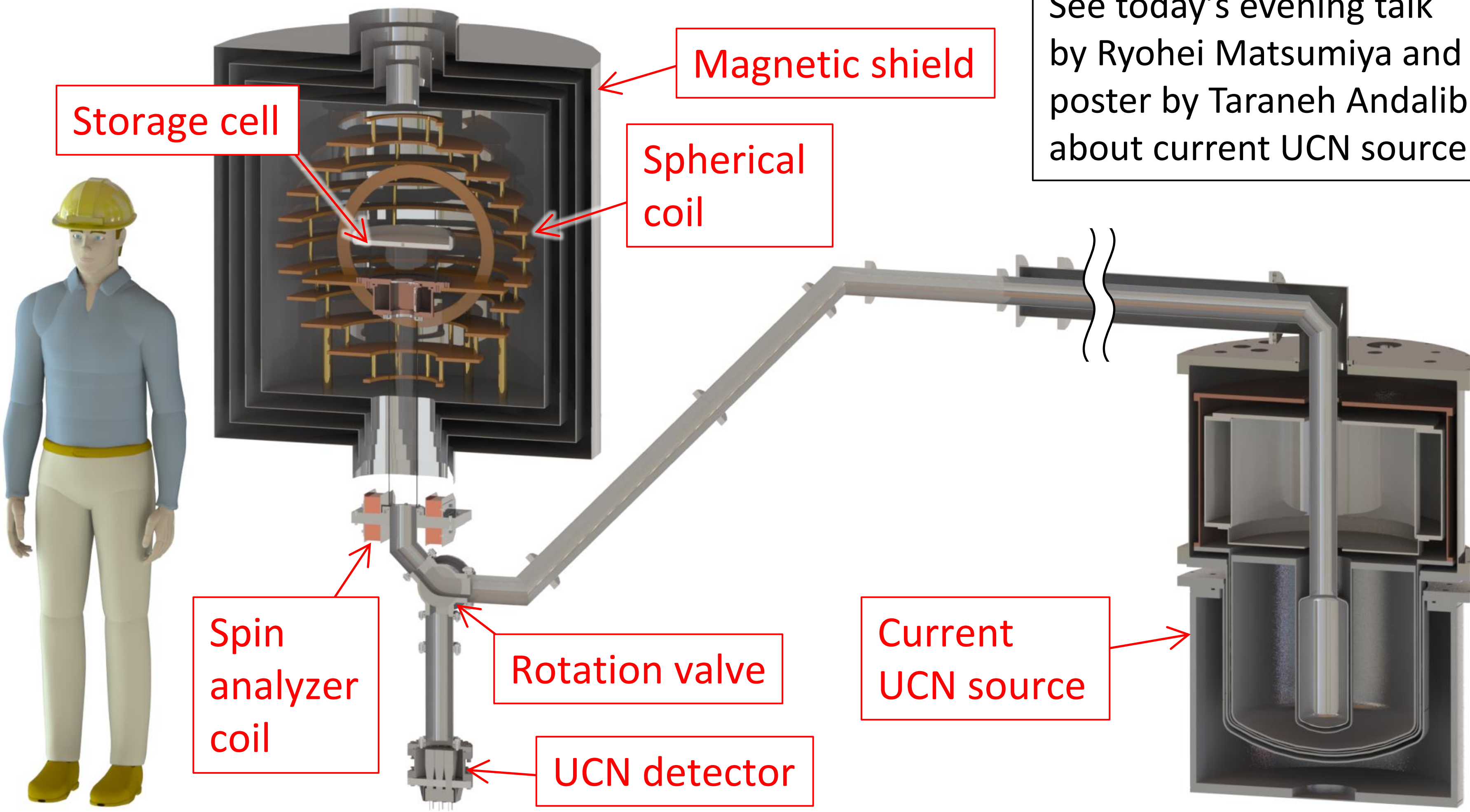




Phase 1 experiment

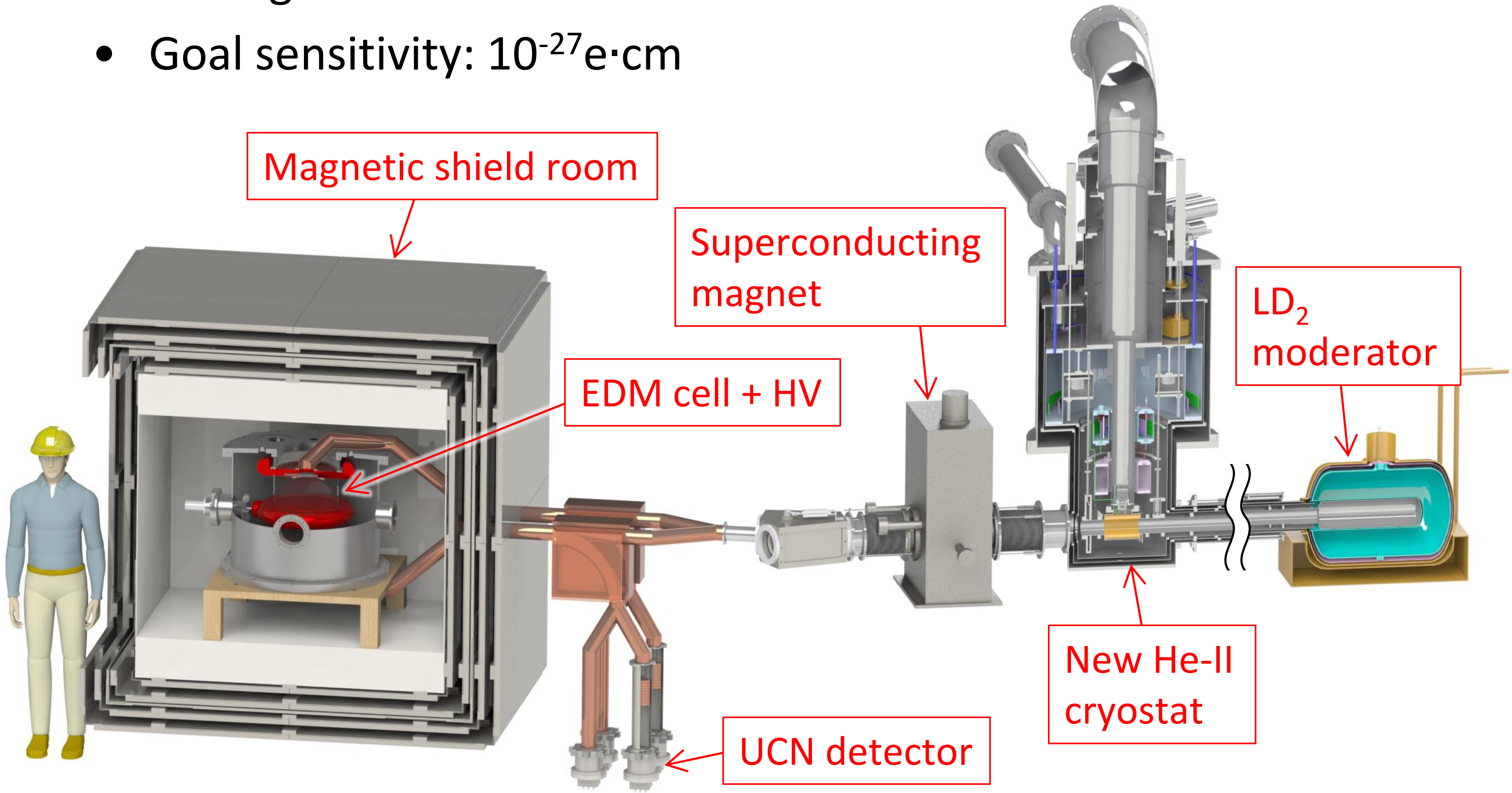
- Use the UCN source and EDM apparatus shipped from Japan.
- Proton beam operation at 1μA. (Limited by He-II heating.)
- Aiming to start in 2018.

See today's evening talk by Ryohei Matsumiya and poster by Taraneh Andalib about current UCN source



Phase 2 experiment

- Upgrade the UCN source and EDM apparatus.
- Proton beam operation at 40μA.
- Aiming to start in 2020.
- Goal sensitivity: 10^{-27}e·cm



Keys for precise EDM measurement

- Statistical error is larger in the recent EDM result.

$$\sigma_d = \frac{\hbar}{2\alpha E T\sqrt{N}}$$

α: Visibility (spin polarization)
E: Electric field
T: Spin presession time
N: Number of UCN

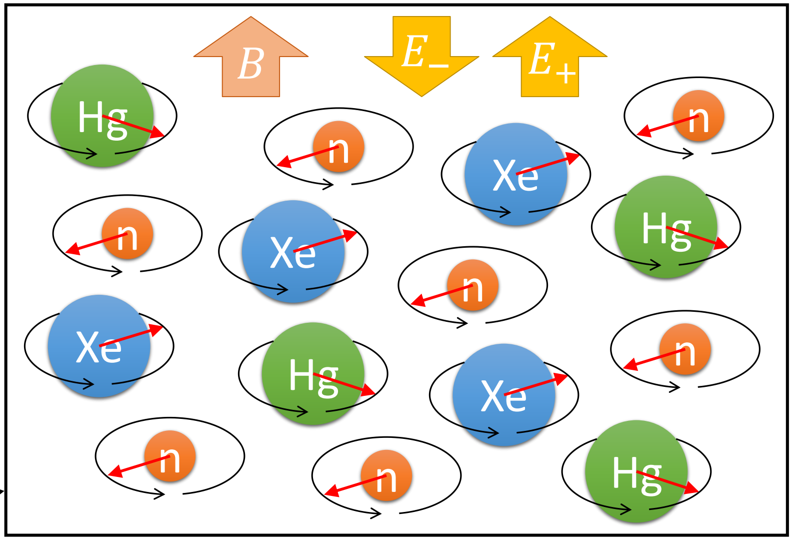
Sensitivity reach (based on simulation)

$N_0 = 2 \times 10^7$ UCN
$\alpha_0 = 0.95$
$E = 12$ kV/cm
$\tau_{cell} = 100$ sec.
$T_1 = 2000$ sec.
$T_2 = 1000$ sec.
$T = 100$ sec.

$\sigma_{stat} = 5 \times 10^{-26}$ e·cm per cycle
$\sigma_{stat} = 10^{-27}$ e·cm in 100 days

- High polarization, high electric field, long UCN storage lifetime and high UCN density are required.
- Magnetic field inhomogeneity is main source of systematic error.
→ Comagnetometry by polarized atoms confined in EDM cell with UCN is essential.

Comagnetometry by atoms



EDM cell

Requirements for phase 2 EDM experiment

- Every component has challenging requirements.

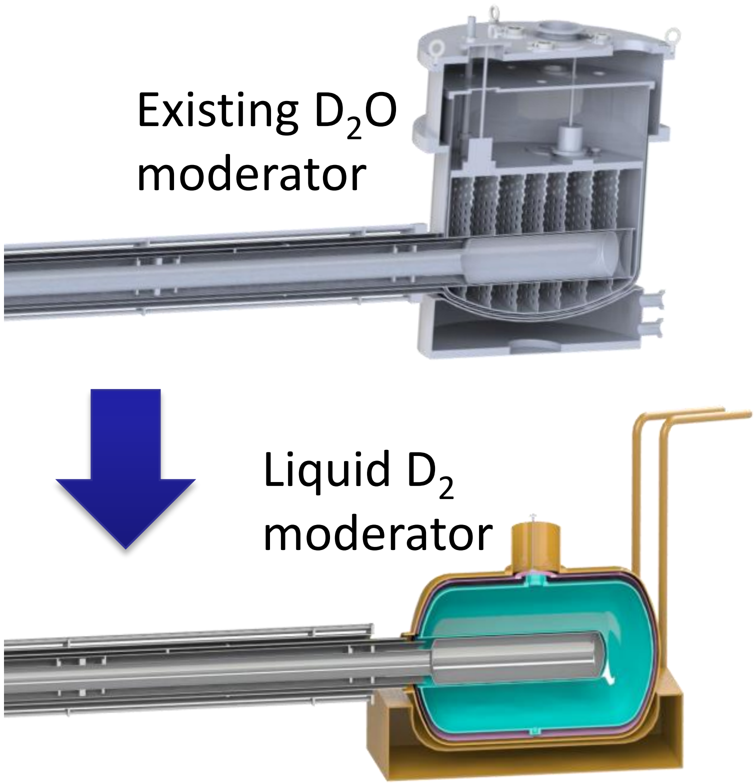
Requirements to achieve 10^{-27}e·cm sensitivity

System	Requirement	Value
Neutron moderator, UCN source	High UCN production rate	$>2.3\times10^{7}$UCN/sec.
UCN guide	High transportation eff.	>4%
Polarizer	High polarization	>95%
EDM cell and high voltage	High electric field	>12kV/cm
	Low leakage current	<10pA
	Long UCN storage life time	>100sec.
	Large radius	>0.1m
Magnetic field system	Field stability	1-8 pT stability over EDM cycle
	Field homogeneity	<0.1nT/m
Comagnetometer	Precise B_0 measurement	10fT per EDM cycle
UCN detector	High counting rate	>1.3MHz
	Efficiency stability	<0.05% over hour

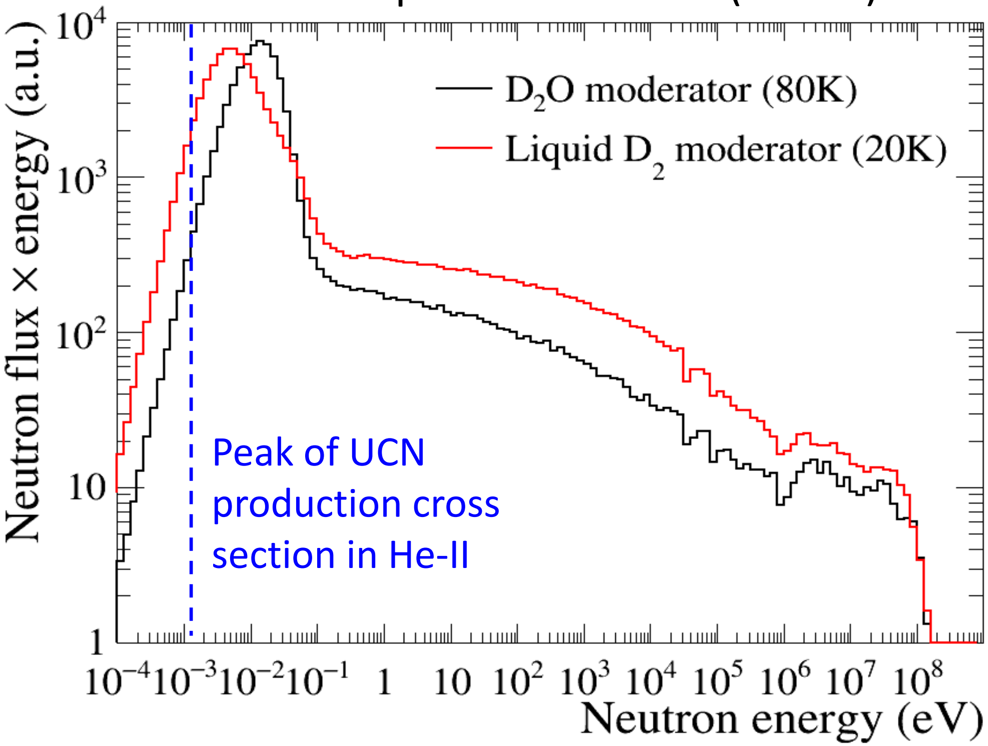
Neutron moderator

- We are currently using D_2O moderator.
- Liquid D_2 moderator will increase the cold neutron flux to He-II (*i.e.* UCN production rate).
- Safety issue: liquid D_2 is explosive.
- Optimizing the geometry by MC simulation.

See tomorrow's morning talk by Wolfgang Schreyer

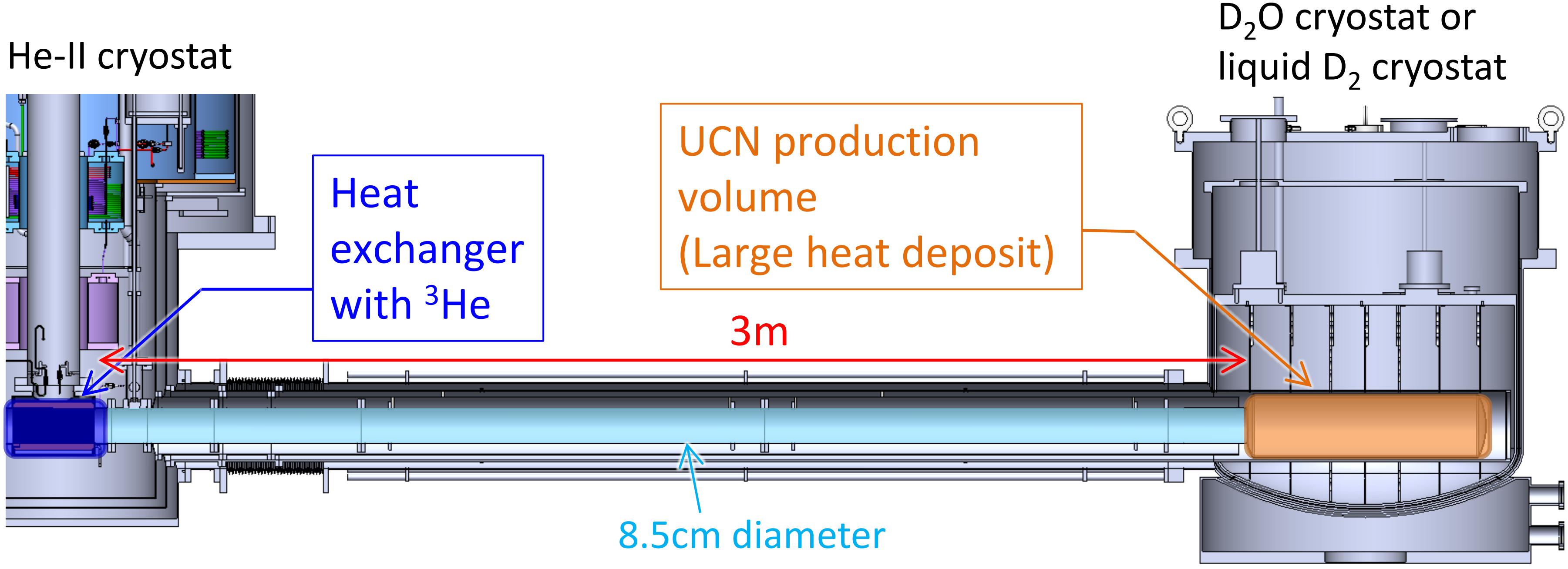


Neutron spectrum to He-II (MCNP)



UCN source (original plan)

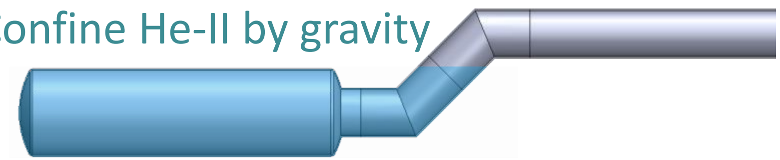
- He-II must be kept cold to suppress UCN upscattering.
- Cooling power of current cryostat is not enough for 40μA beam.
- Original plan of new UCN source.
  - Heat exchanger with ^{3}He is 3m distant from UCN production volume.
  - He-II is confined by aluminum foil.
  - UCN storage volume is filled with He-II.
  - Target temperature of He-II is $<$ 0.8K.



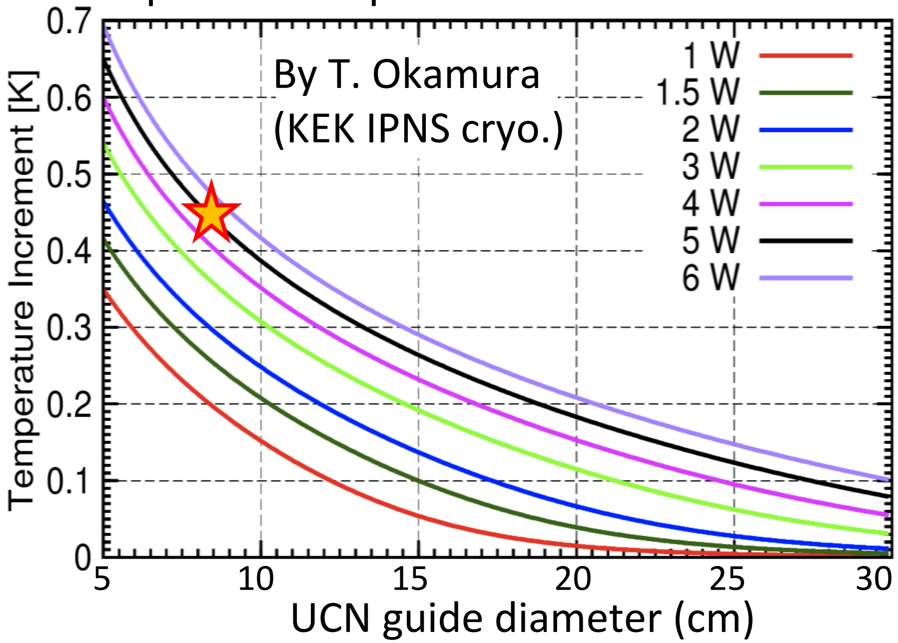
UCN source (new plan)

- Heat transfer of original plan is not enough.
- Moderated the target temperature of He-II to 1.0-1.2K.
  - Confine He-II by gravity.
  - Reduce He-II volume ratio to 25% level.
- Cooling method options.
  - Heat exchange with ^{3}He (primary).
  - Direct pumping of He-II (alternative).

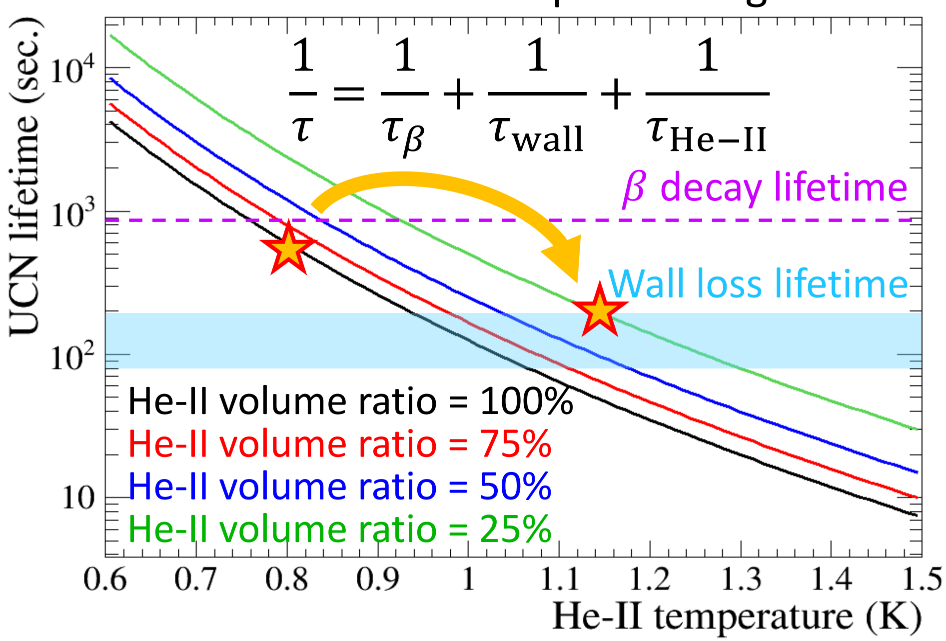
See tomorrow's morning talk by Shinsuke Kawasaki



Expected temperature difference in He-II



UCN lifetime due to upscattering in He-II

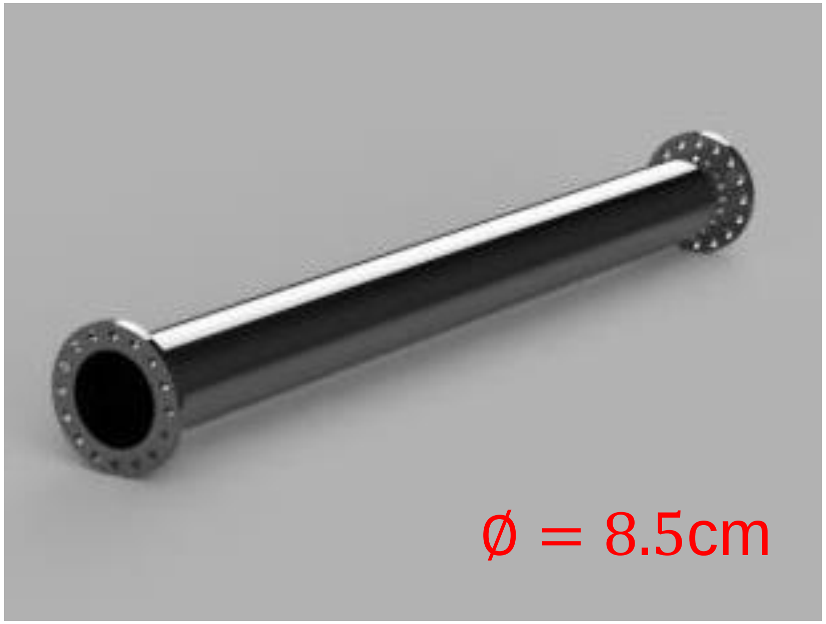


UCN guide

- Coating the surface of UCN guide with high Fermi potential material (*e.g.* Nickel).
- Alkali cleaning and high temperature baking to remove hydrogen *etc.*
- Measurement of Fermi potential of NiP *etc.* at J-PARC.

See today's evening talk by Edgard Pierre

UCN guide used at TRIUMF



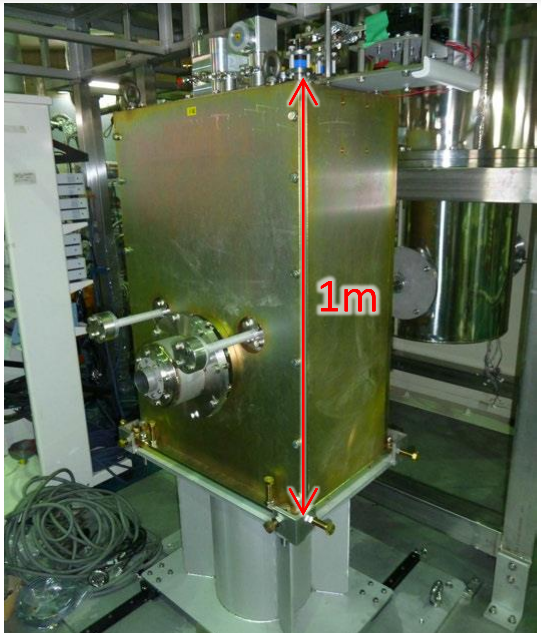
UCN lifetime at RCNP

Year	Improvement	UCN lifetime (sec.)
2002	First UCN production	14
Jun. 2006	Use ^{3}He cryostat	29
Nov. 2006	Improve cryostat	34
July 2007	Remove ^{3}He contamination	39
Apr. 2008	Fomblin coating	47
Dec. 2009	Alkali cleaning	61
Feb. 2011	High temperature (120°C) baking	81

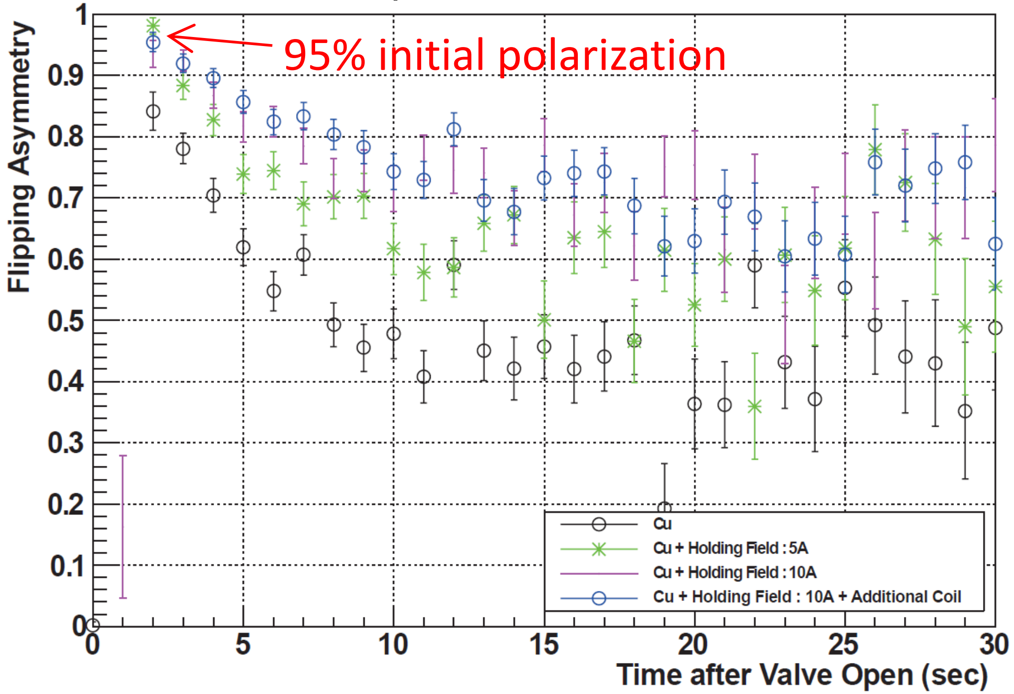
Polarizer

RCNP

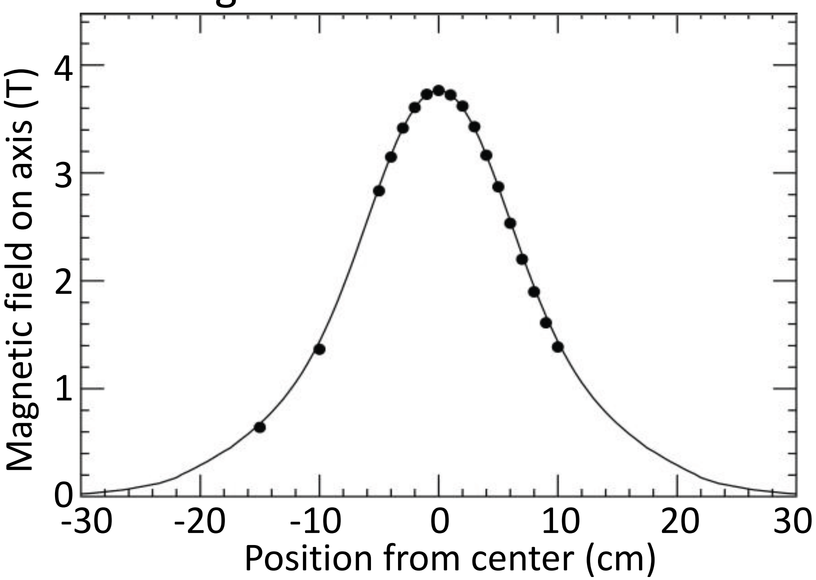
- Superconducting polarizer was developed at RCNP and shipped to TRIUMF.
- Produce 3.75T magnetic field at the center.
- 95% UCN polarization was achieved at RCNP.



UCN polarization at RCNP



Magnetic field distribution

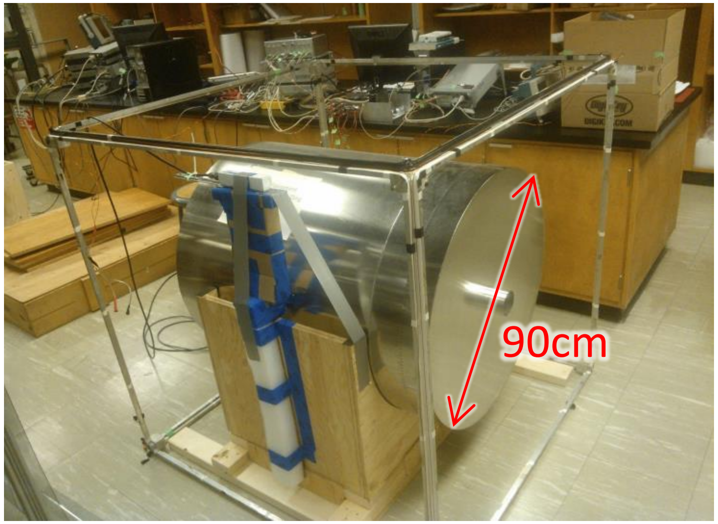


International UCN Source and nEDM Experiment at TRIUMF CDR (2015)

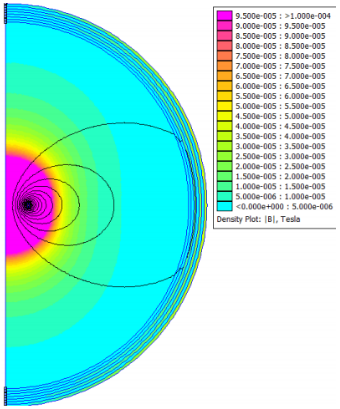
Magnetic field

- Magnetic field from cyclotron is $350\mu T$ with 100nT fluctuation. $\rightarrow$ Need to be reduced $< 10pT$.
- We will achieve it by magnetic shield and compensation coil.

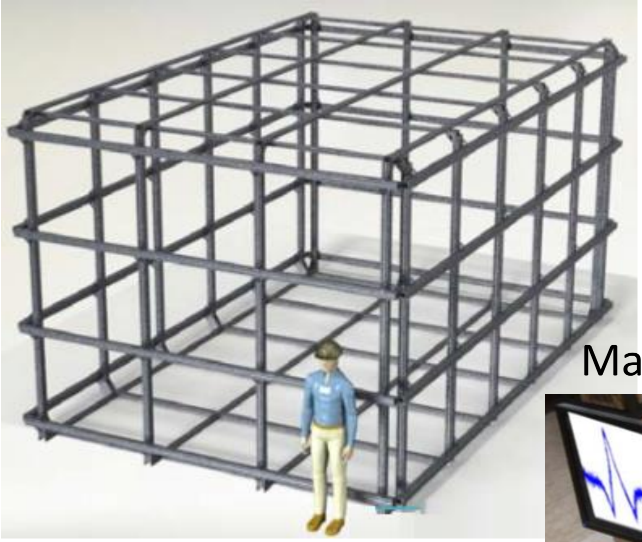
Magnetic shield prototype in Winnipeg



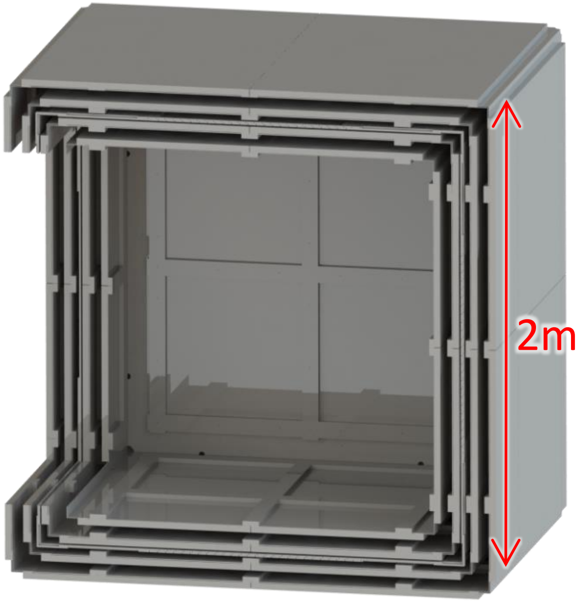
Simulation



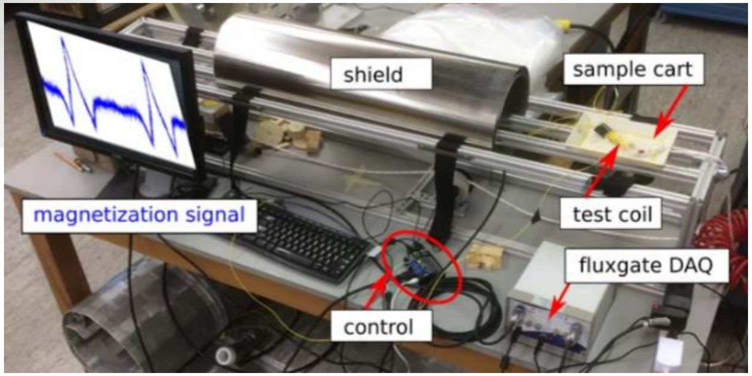
Design of compensation coil



Design of magnetic shield room



Magnetisation detector prototype



See Thursday's talk by Christopher Bidinosti and poster by Shomi Ahmed

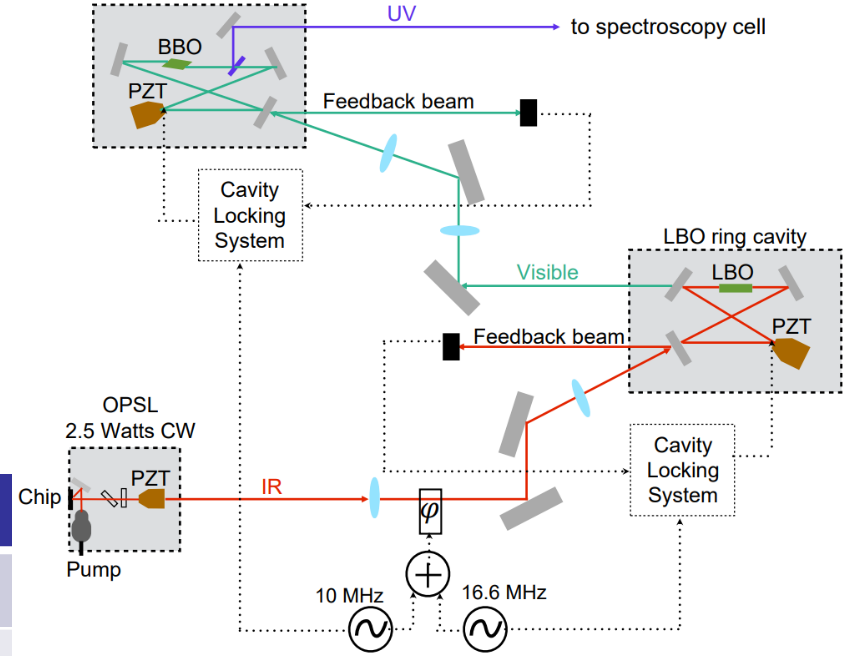
Comagnetometer

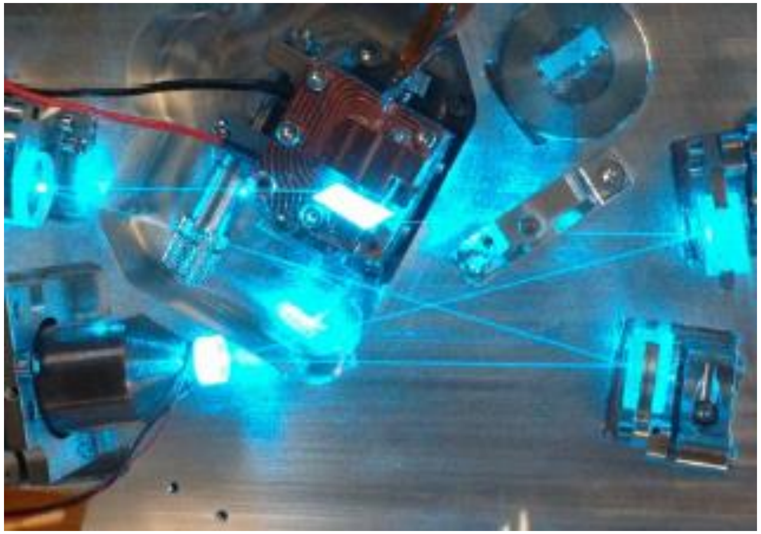
- Dual Xe/Hg comagnetometer is planned to correct false EDM.
- R&D for ^{129}Xe.
  - 2 photon direct laser probe.
  - HV breakdown vs. operating pressure.

	^{199}Hg	^{129}Xe	Neutron
Spin	1/2	1/2	1/2
γ(MHz/T)	7.65	-11.77	-29.16
UCN capture σ (barns)	2150	21	
Transition (nm)	253.7	252.4	
Transition process	One-photon	Two-photon	

See tomorrow's morning talk by Tomohiro Hayamizu and poster by Emily Altiere and Eric Miller

253 nm CW laser system @ UBC



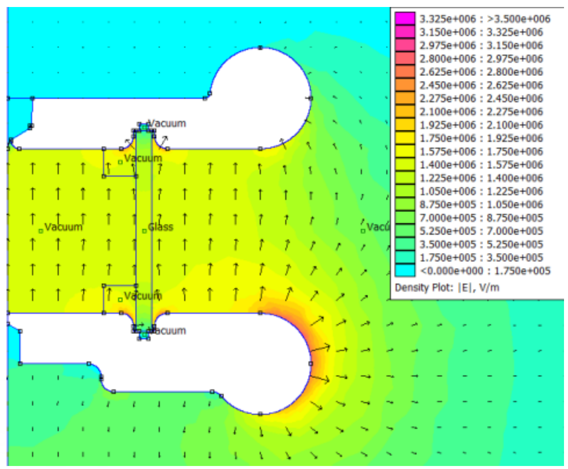


EDM cell and high voltage

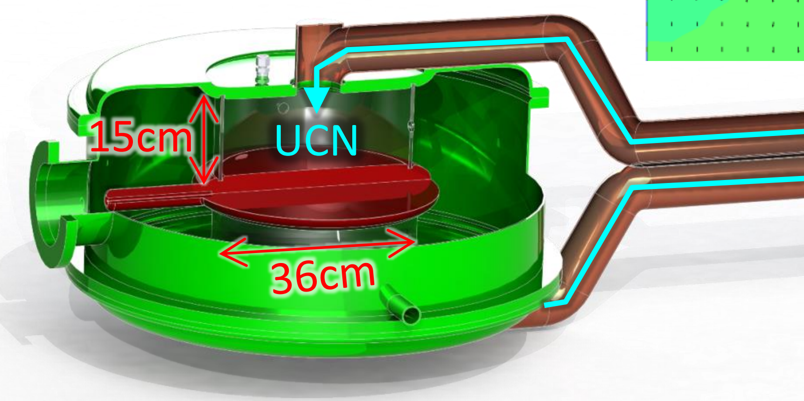
- High voltage test at TRIUMF.
- Double EDM cell is planned.
- Optimization of EDM cell geometry by MC simulation.
- Material studies for EDM cell (DLC, dPS, dPE).

See tomorrow's afternoon talk by Florian Kuchler

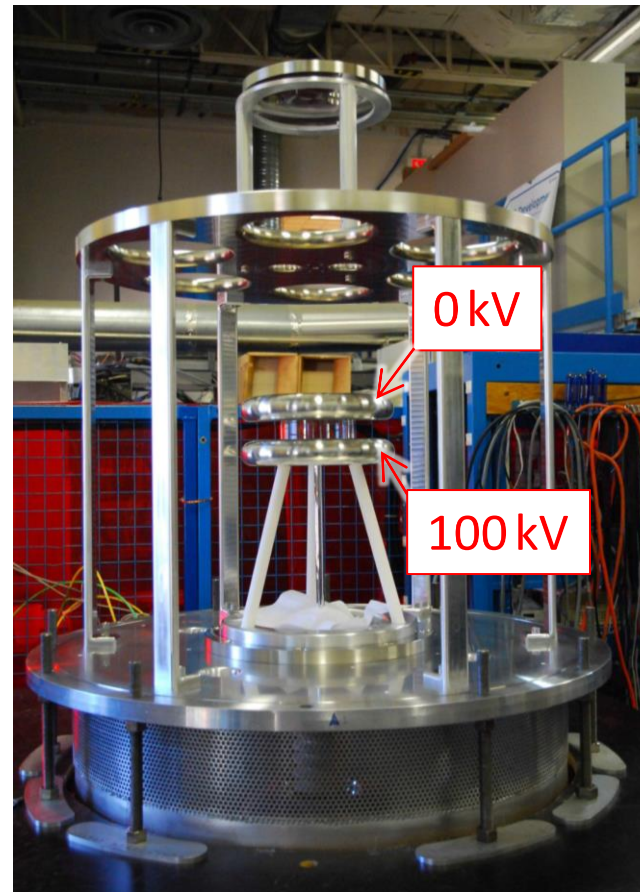
Electric field calculation



Layout of double EDM cell

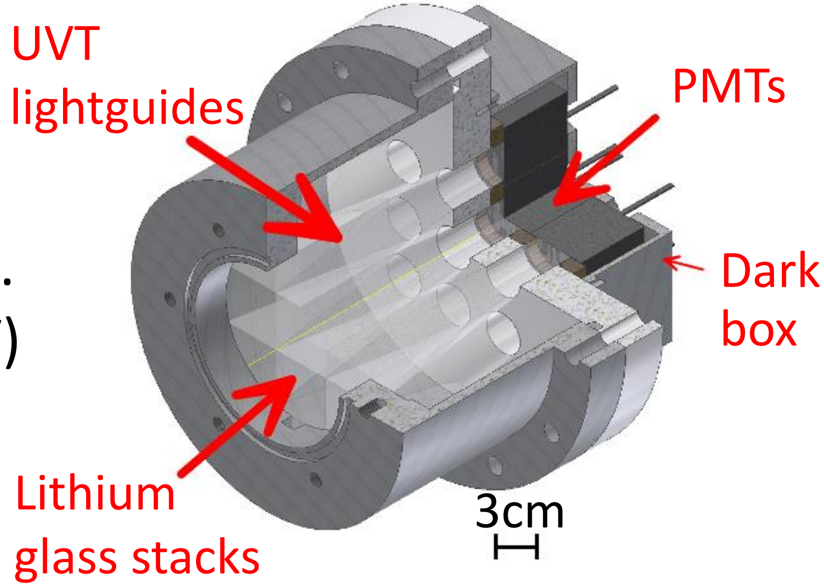


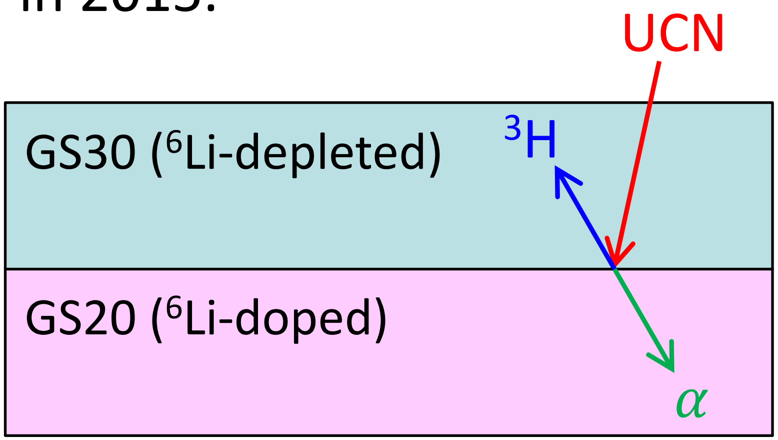
High voltage test setup at TRIUMF

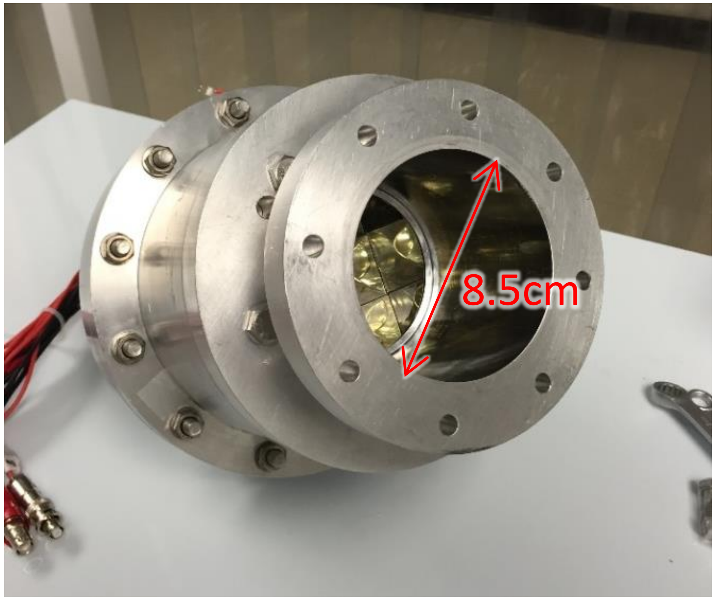


UCN detector

- High rate counting (>1.3MHz) and efficiency stability (0.05% / hour) are required.
- Detection via neutron capture in ^{6}Li. $^{6}Li + n \rightarrow {}^{3}H(2.73MeV) + \alpha(2.05MeV)$
- Detector was well characterized by beam test at PSI UCN beamline in 2015.





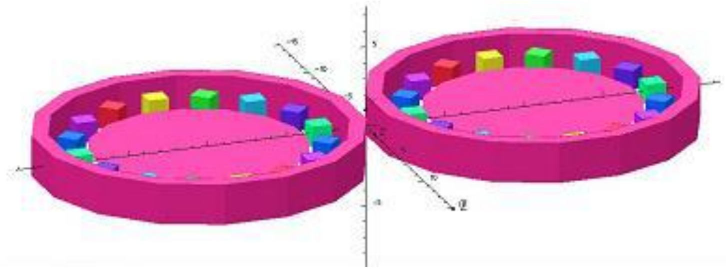


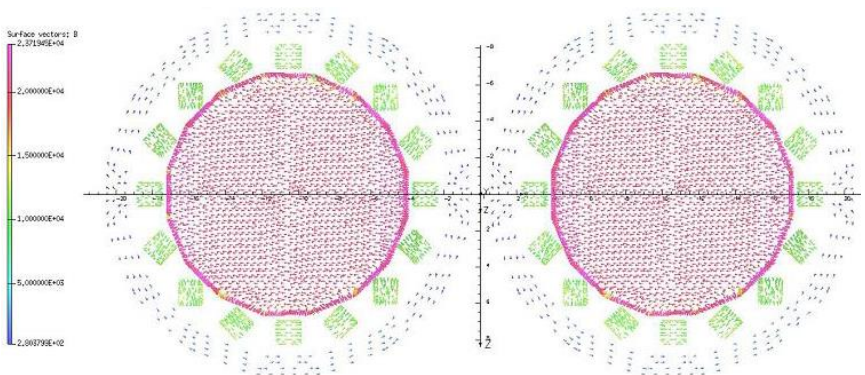
See Thursday's talk by Sean Hansen-Romu

Simultaneous spin analysis

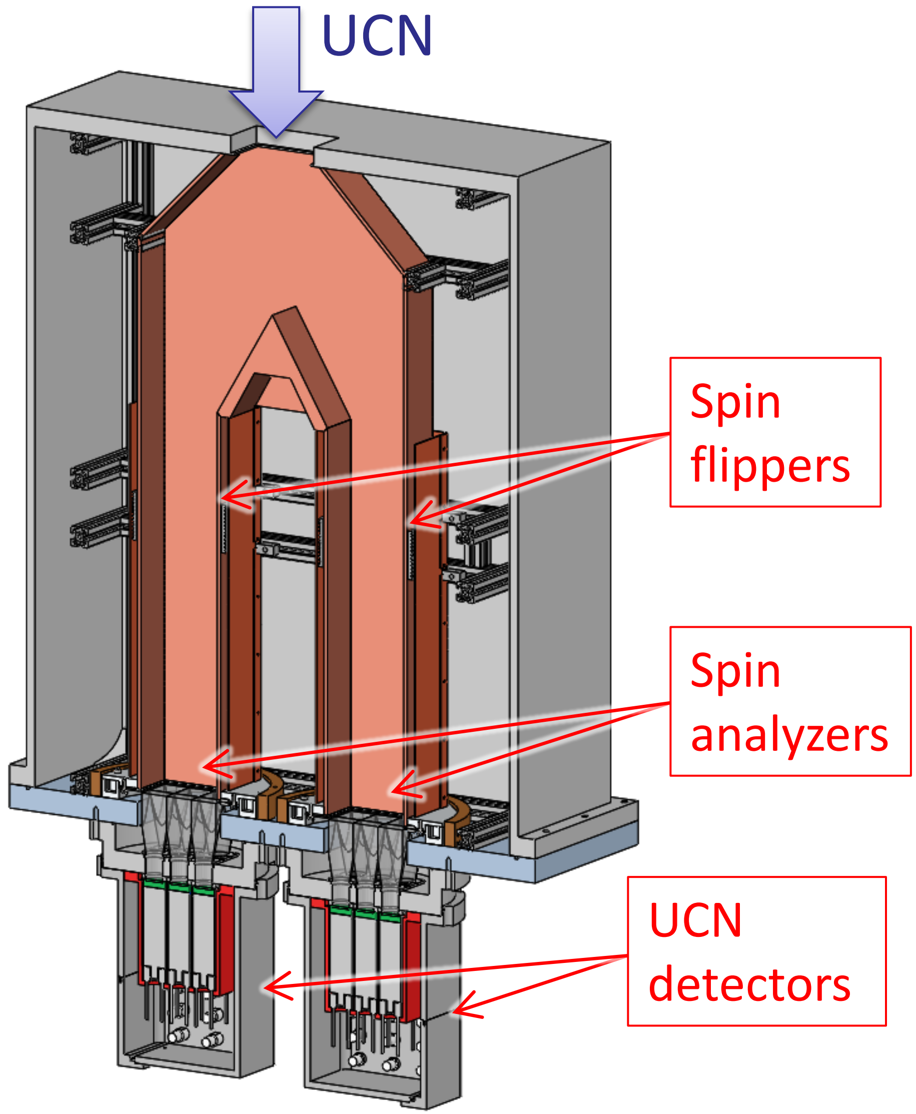
- Increase the UCN statistics by measuring both spin state simultaneously.
- Increase visibility due to less depolarization while storing above analyzer foil.

Spin analyzer foil magnetic field





Layout of simultaneous spin analysis



Summary

- We are aiming to start next generation EDM experiment in 2020 to search for neutron EDM down to 10^{-27}e·cm.
- Every experimental component has challenging requirements to achieve 10^{-27}e·cm sensitivity.
- We received $15.7 million from Canada Foundation for Innovation (CFI) for infrastructure investment.
- More details of recent studies will be reported by subsequent speakers and posters.