Progress on ultracold neutrons at TRIUMF

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for the TUCAN collaboration

CAP Congress
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Outline

- UCN production
- UCN at TRIUMF (Fall 2017 and 2018)
- New UCN source
- TUCAN nEDM experiment
- Outlook

The TUCAN collaboration 2019

(TRIUMF UltraCold Advanced Neutron)

- 10 institutions
  - Japan: 4
  - Canada: 6
- 45 members
  - 36 PIs and post-docs
  - 9 graduate students
- 16 stationed at TRIUMF

TRIUMF KEK RCNP The University of Winnipeg

The University of British Columbia University of Manitoba SFU Simon Fraser University Engaging the World Nagoya University

UNBC University of Northern British Columbia

Welcome to the UCN Session

TUCAN Talks this session

- ”Improving the sensitivity of the neutron electric dipole moment experiment at TRIUMF,” S. Sidhu
- ”Producing ultracold neutrons with a spallation source and superfluid helium,” W. Schreyer
- ”Measurements of the first polarized ultracold neutrons at TRIUMF,” S. Hansen-Romu

UCN Related talk by TUCAN collaborator

- “A new measurement of the permanent electric dipole moment of 129-Xe using 3-He SQUID detection,” F. Kuchler

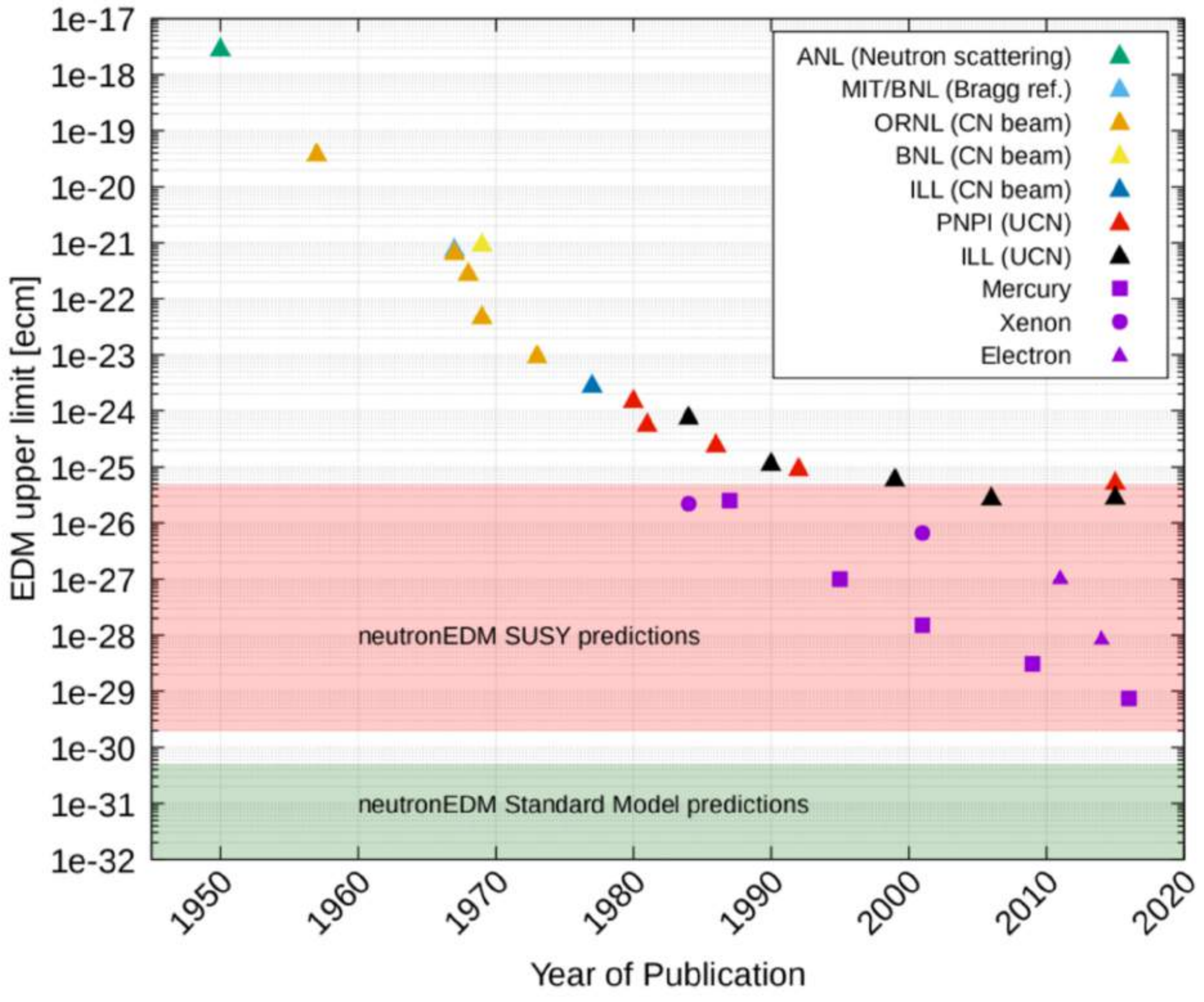
TUCAN project goals

The main scientific goal of the project is to measure the neutron electric dipole moment to a precision $\mathbf{10^{-27}}\boldsymbol{e}$cm.

Secondary goals are to create:

- the strongest UCN source in the world and
- an international user facility for fundamental research using ultracold neutrons $\Rightarrow$ two UCN ports

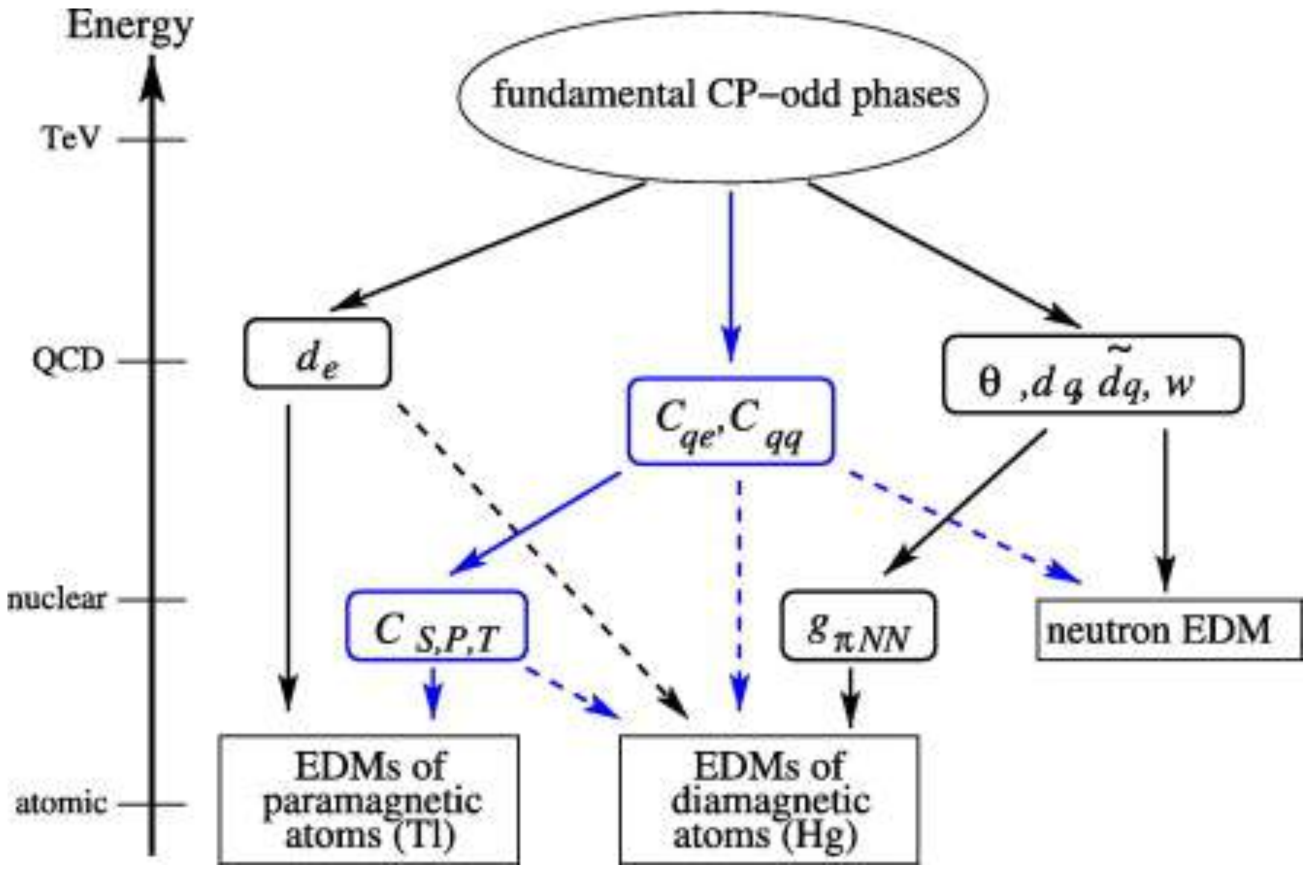
Neutron electric dipole moment measurement motivation



Non-zero EDM violates T and CP symmetries

- CP violation in SM (CKM matrix) not large enough to explain observed baryon asymmetry of universe
- EDMs are a sensitive direct probe of new physics
- Constrain parameter space for new physics models
- More directly coupled to underlying models than atomic EDMs

Link between atomic, neutron and fundamental EDMs



Neutron EDM directly linked to QCD scale parameters

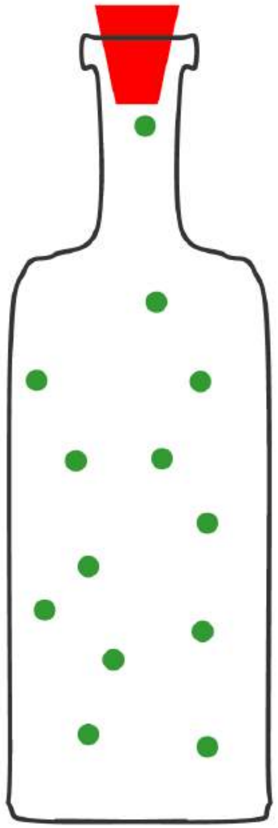
- Solid lines are more direct coupling between scales
- Dashed lines weaker coupling
- Current best limit on neutron EDM is from ^{199}Hg
  - More model dependent
  - depends pion-nucleon coupling
  - Remnant Schiff moment

Figure from Pospelov & Ritz, Annals of Physics 318 (2005) 119.

About ultracold neutrons

Definition and typical parameters

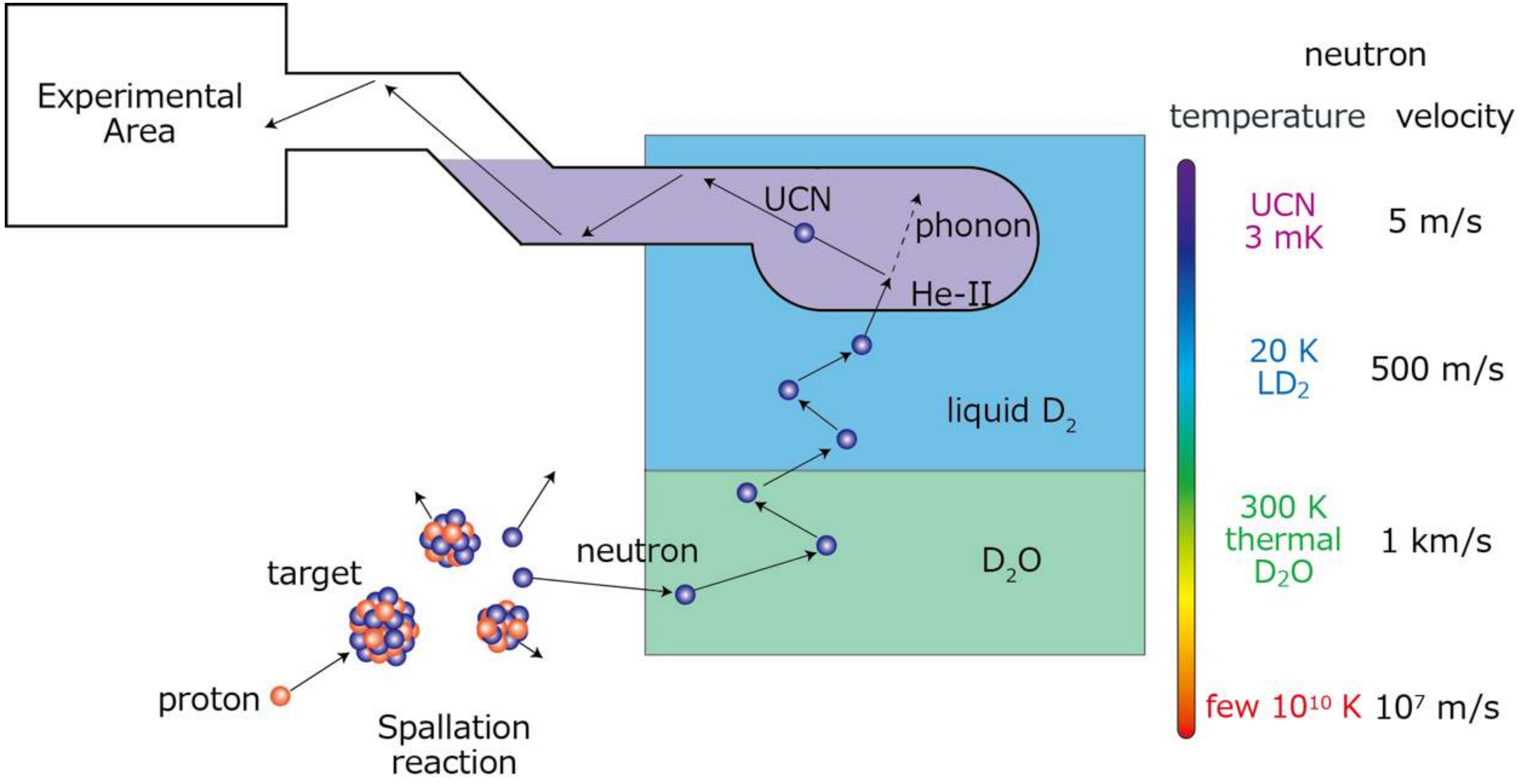
- Neutrons moving so slowly they reflect from material walls
- Velocities < 7 m/s
- Temperature < 4 mK
- Kinetic energy < 300 neV

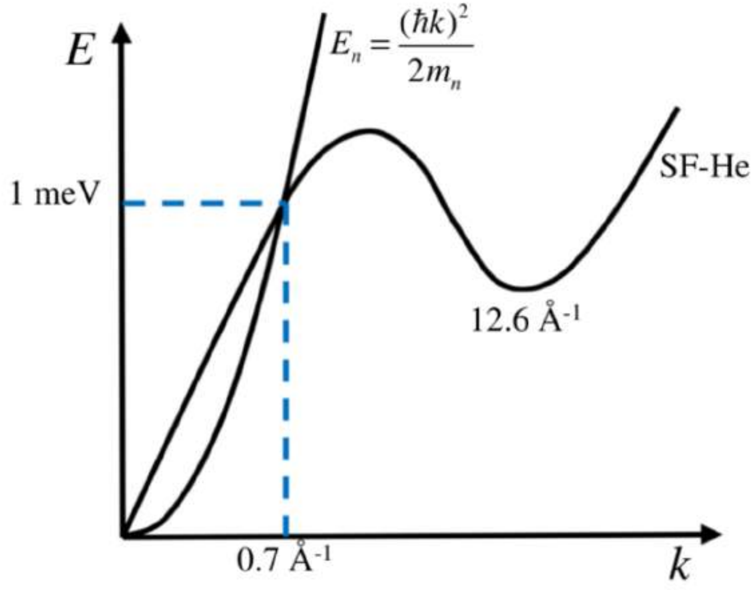


Interactions are all of similar scale

- Gravity: 100 neV / m
- Magnetic: 60 neV / T
- Nuclear: V_{eff} < 335 neV (Z dependent)
- Weak: τ = 885.7 s (15 min)

UCN recipe using spallation neutrons and superfluid He-II





Start with TRIUMF 480 MeV protons on tungsten create spallation neutrons

- Layers of moderators to thermalize neutrons
- Down-scatter by interaction phonons / rotons in He-II

Vertical UCN source cryostat

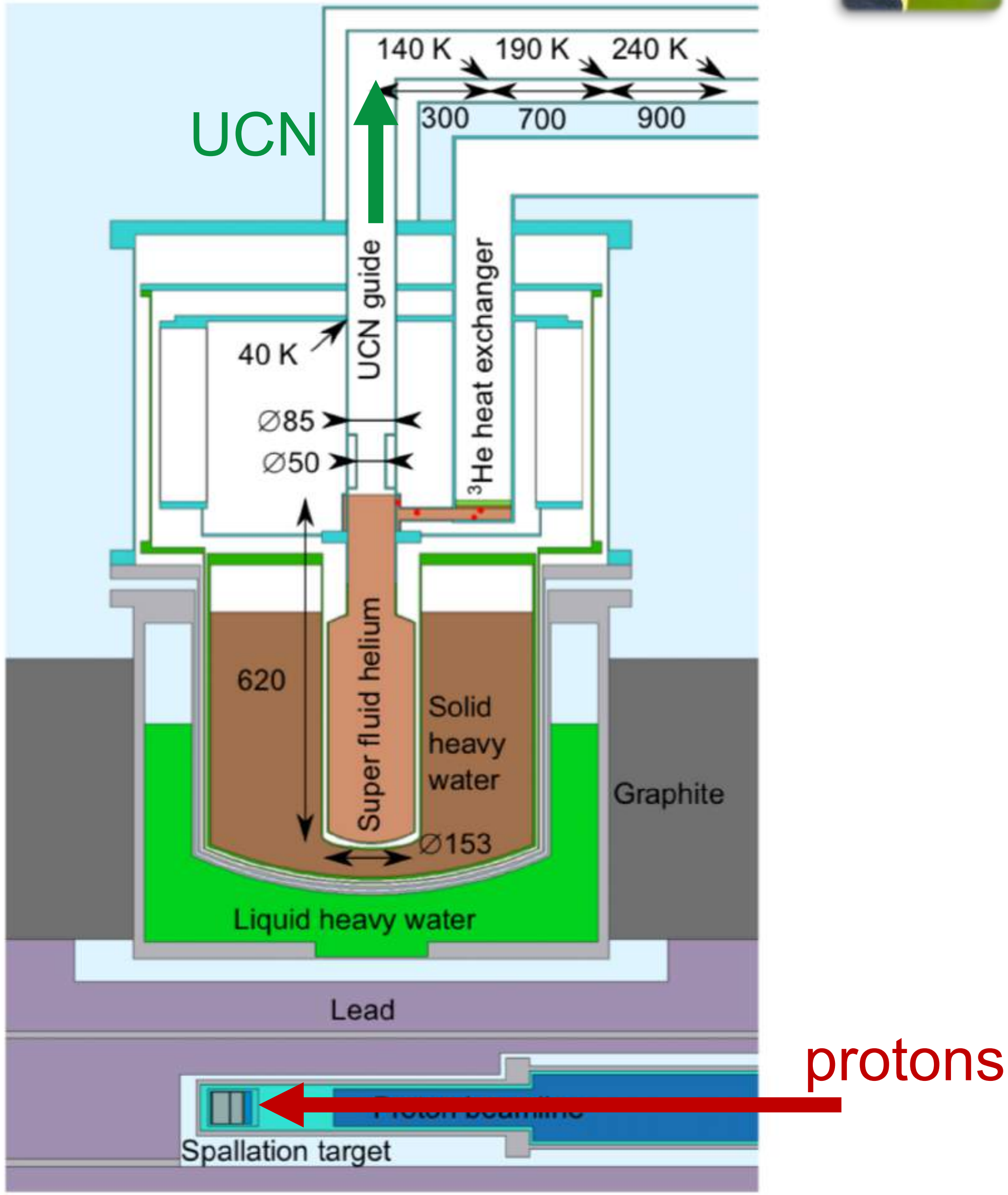
from KEK/RCNP, Japan

UCN from down-scatter in He-II

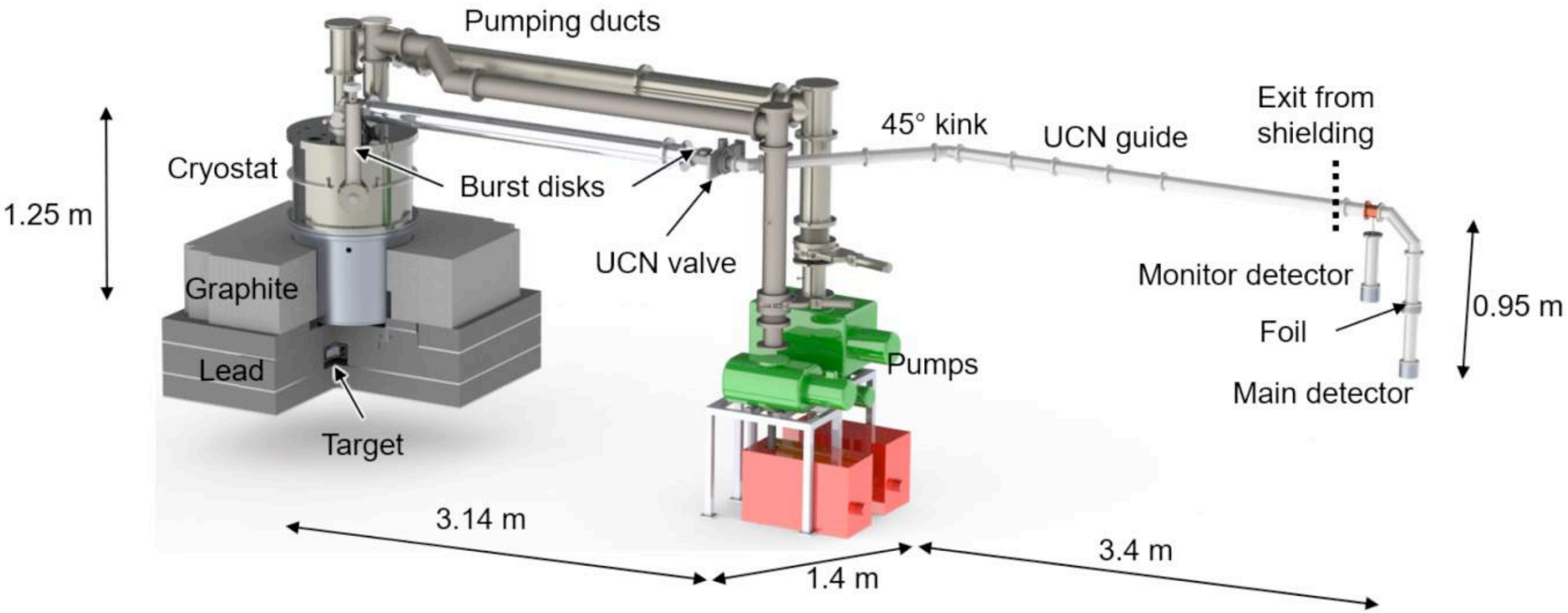
- Spallation from tungsten target
- 300 K moderators: lead, graphite and liquid D_2O
- 10 K moderator: solid D_20
- <1 K moderator: He-II produced by custom ^{3}He dilution refrigerator

⇨ Running at 1 μA beam (as at RCNP).

Phys. Rev. C 99 (2019) 025503



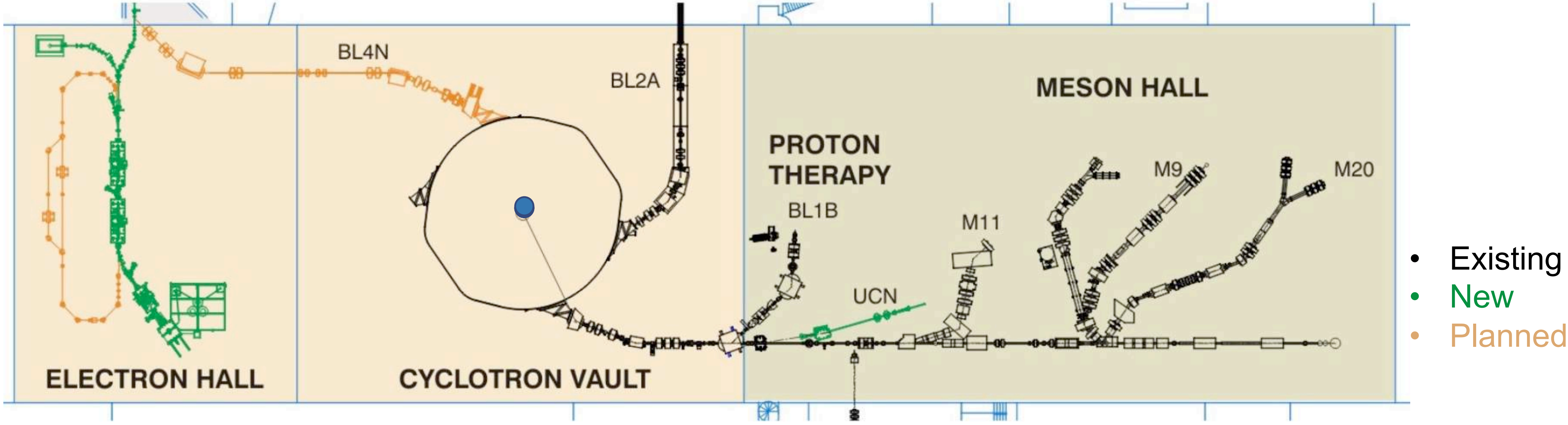
The vertical source and UCN guides



https://arxiv.org/pdf/1809.04071.pdf

Phys. Rev. C 99 (2019) 025503

The TRIUMF beam delivery system

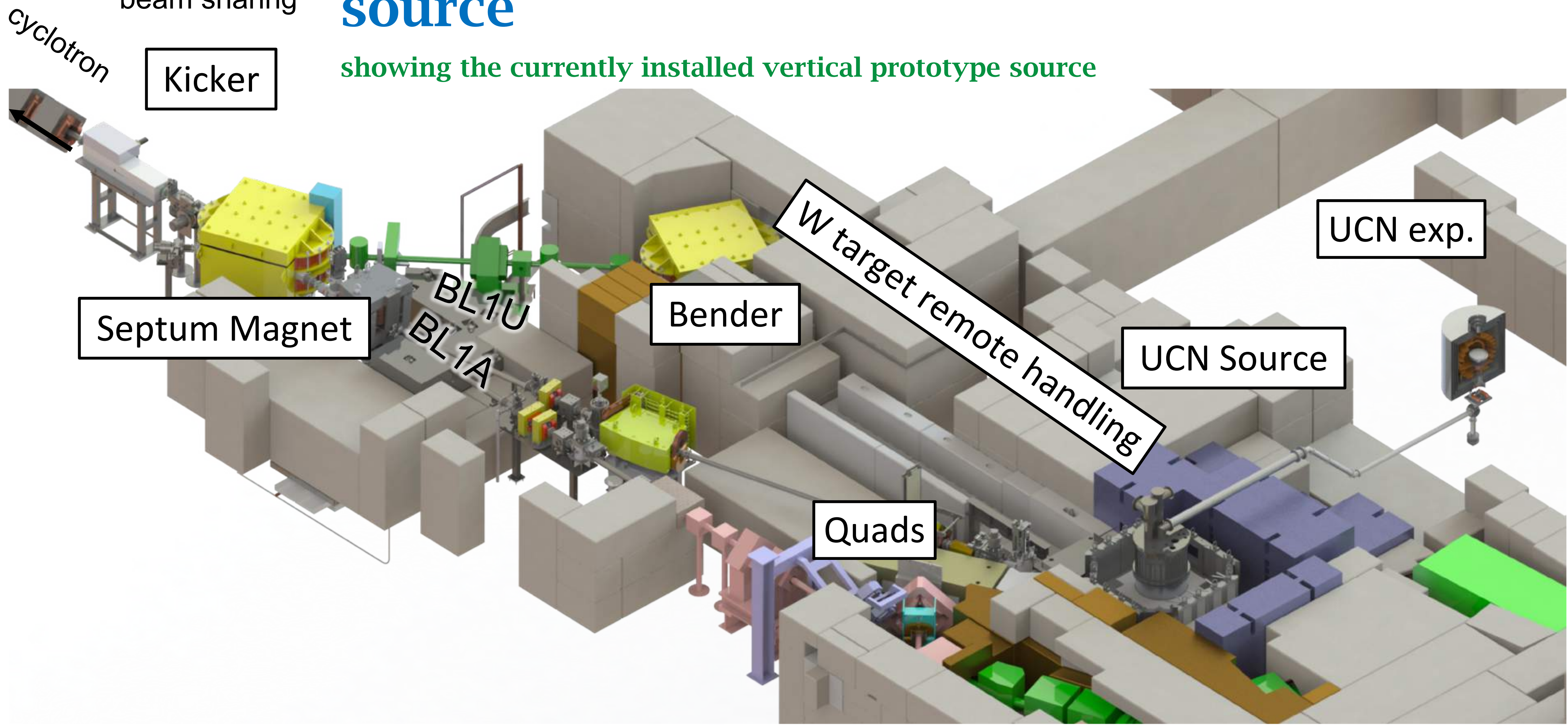


- H^- ions are accelerated.
- Foils strip electrons and p^+ can be extracted at selectable radii (and energies).
- Energies up to 500 MeV

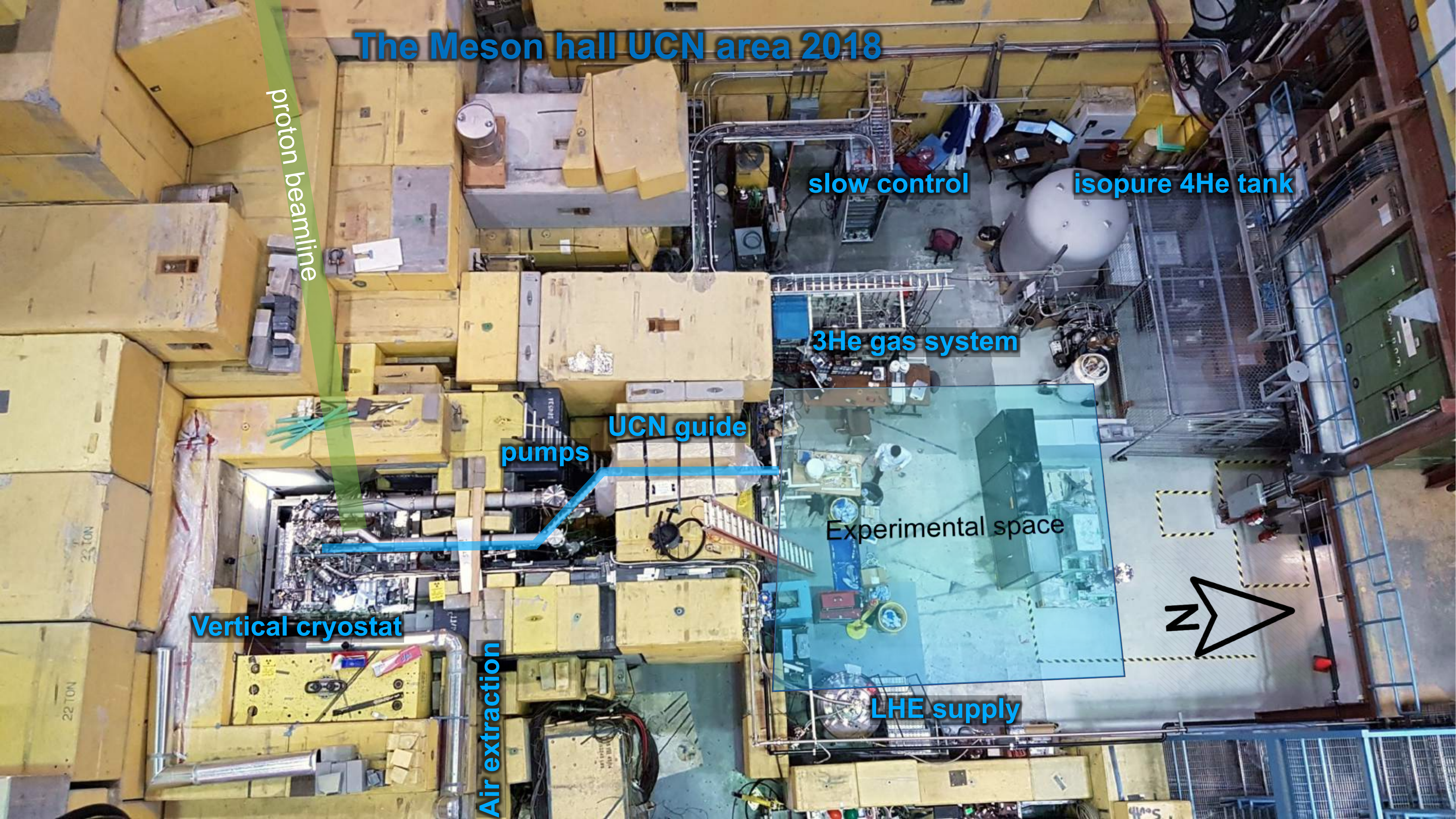
- Three beamlines up to 120 μA
- Simultaneous operation of different facilities
  - Nuclear Physics, Particle Physics, Life Sciences, Material and Molecular Science, Eye Cancer Proton Therapy
- UCN shares the beam with CMMS
  (Center for Material and Molecular Science)

New beamline at TRIUMF for the UCN source

showing the currently installed vertical prototype source



Nucl. Inst. And Methods A 927 (2019) 101


The Meson hall UCN area 2018
proton beamline
slow control
isopure 4He tank
3He gas system
UCN guide
pumps
Experimental space
Vertical cryostat
Air extraction
LHE supply
N

First UCN at TRIUMF (Fall 2017)

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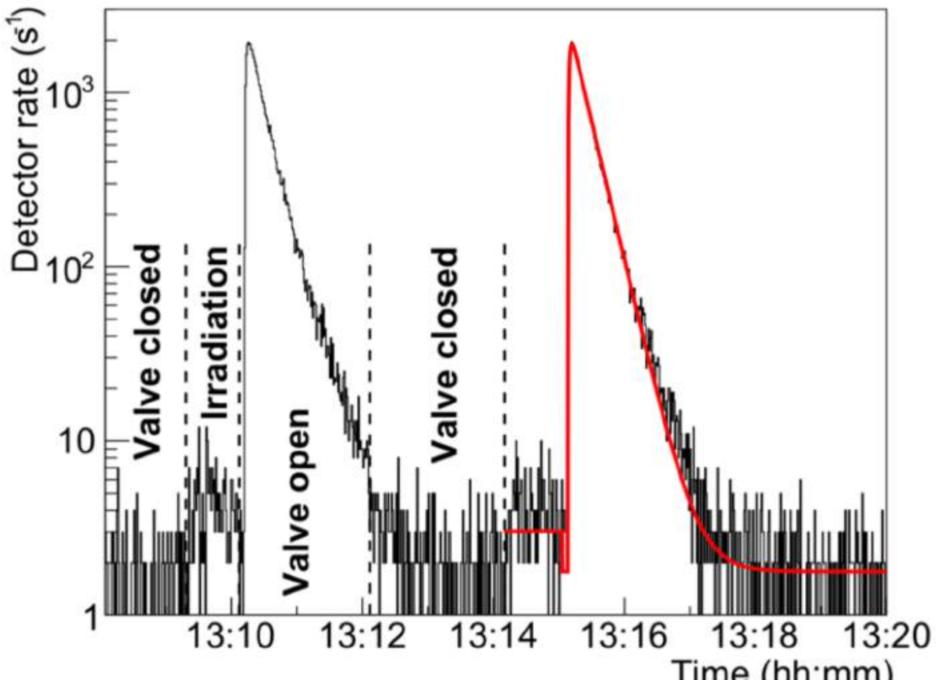
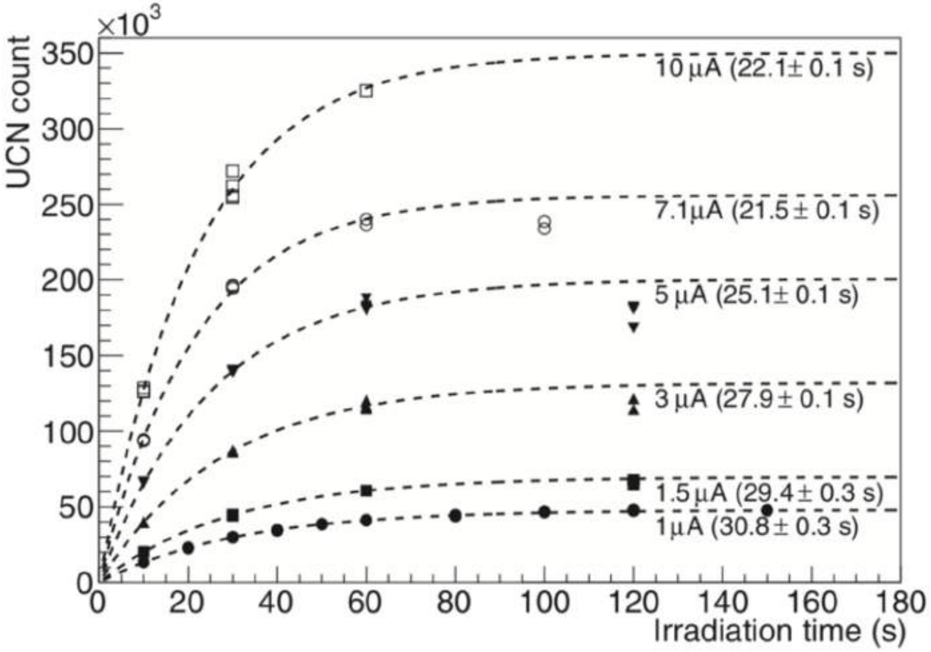
- Extracted 325,000 UCN after one-minute irradiation (at 10 μA)
- UCN density in source estimated to be 5.3 cm^{-3}
- Storage lifetime degraded during run from 37 s to 24 s
- Also demonstrated continuous mode UCN detection rate of 1500 Hz





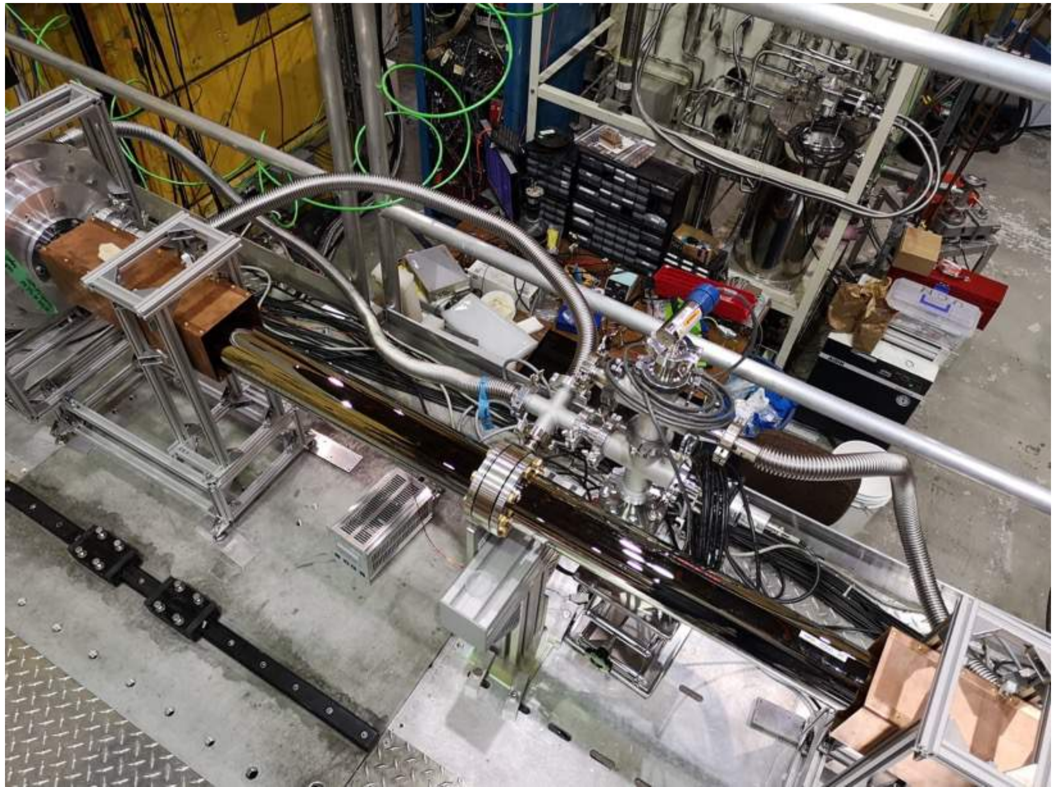
UCN at TRIUMF (Fall 2018 Run)

Goals of the tests

- Characterize guides that will go into new source extraction
- Studies of valve UCN losses
- Studies of guide bend UCN losses
- Tests of warm bore superconducting magnet
- First polarized UCN tests

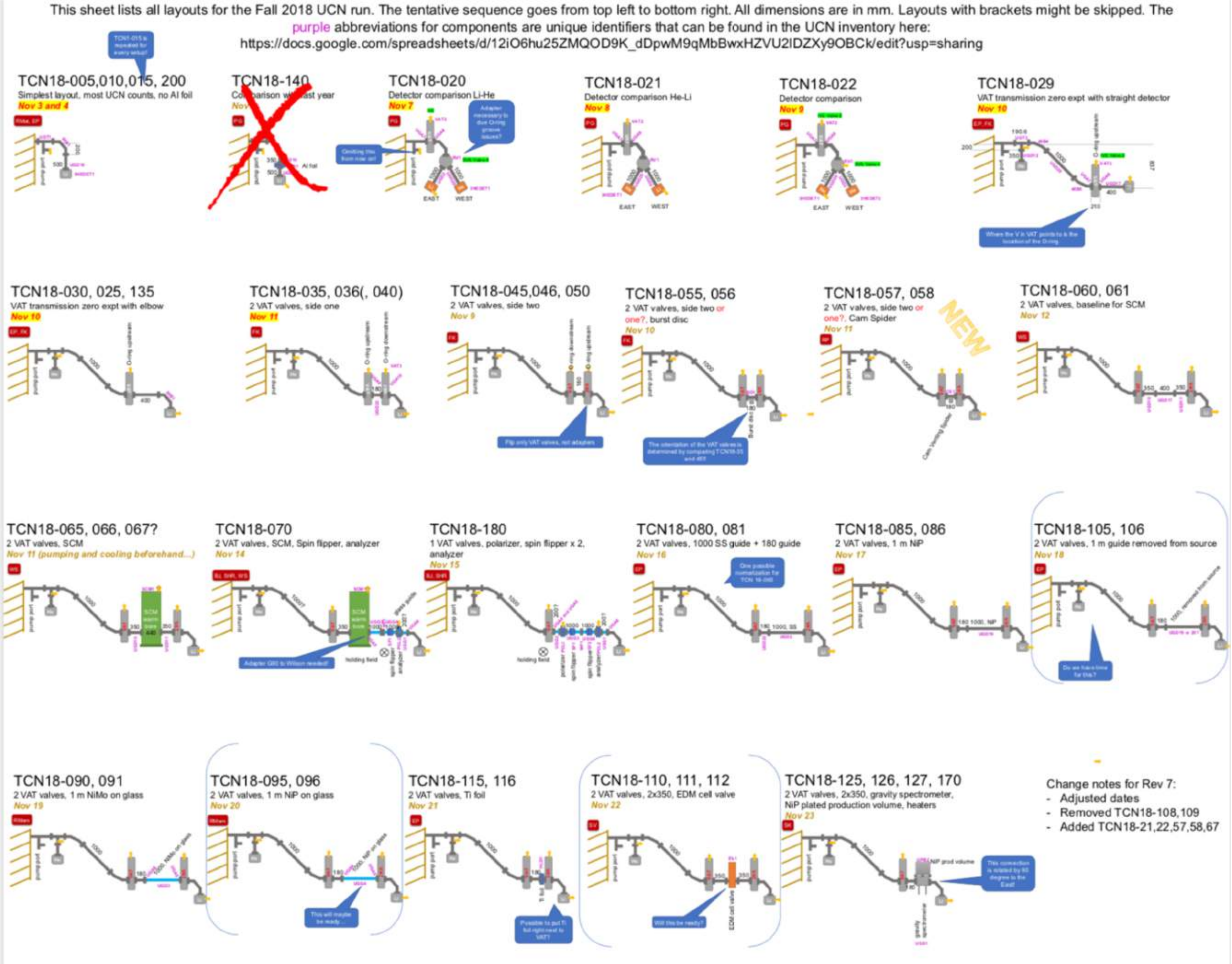
29 experimental setups completed in 31 days

- Video of fall runs



UCN at TRIUMF

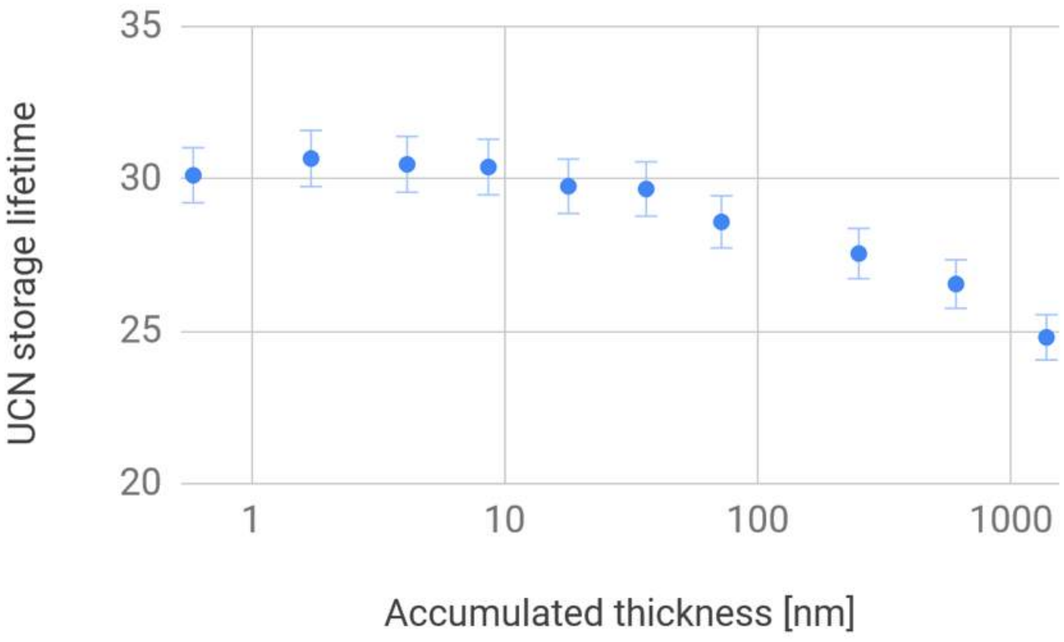
Fall 2018 runs



Highlights from 2018 UCN runs

2018

- UCN yield increased to 71,000 per shot
- At the end, we spoiled the source with nitrogen up to 335 mbar*l



VAT UCN valve (off the shelve)
- Transmission 89±3%
- Storage lifetime between two: too short, needs improvement

6Li detector sees 56±1% more neutrons: need to check 3He detector...

Spin flipper efficiency: >98%
Foil polarizer power: 60%
Superconducting polarizer power: 55%...
Need to understand: depolarization?

"Measurements of the first polarized ultracold neutrons at TRIUMF," S. Hansen-Romu

UCN production volume prototype
Storage lifetime 70 s before baking, 83 s after baking at 150C

Transmission of a smooth 90^{o} bend 9% better than a mitered one.

Next generation UCN source introduction

Similar basic layout with major improvements:

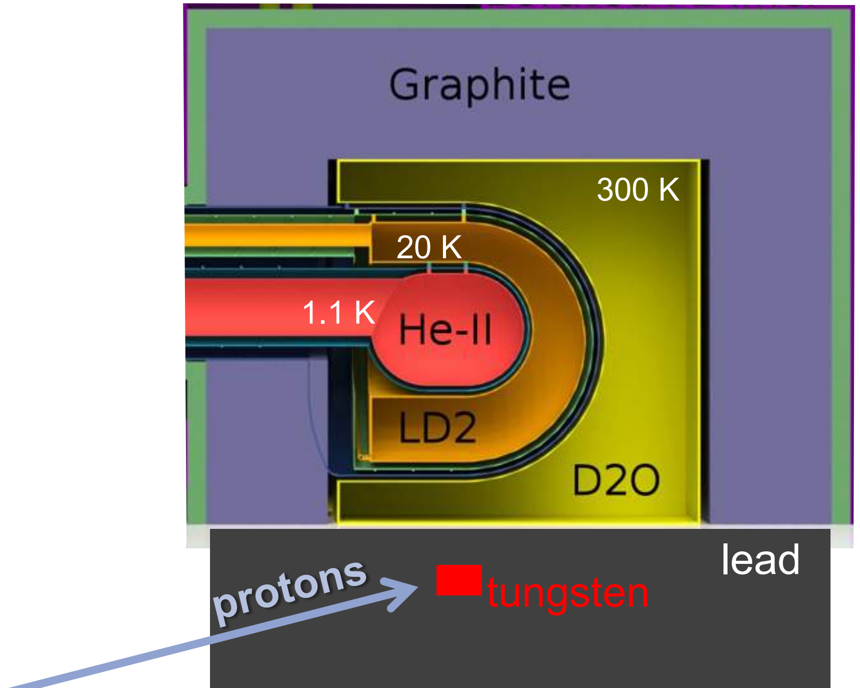
- Beam current: 1 μA ⇒ 40 μA
- Production volume: 8 L ⇒ 28 L
- Cold moderator: sD_2O ⇒ LD_2
- Production rate: $2x10^5$ /s ⇒ $1.8x10^7$/s

($>$ 600 $s^{-1}cm^{-3}$)

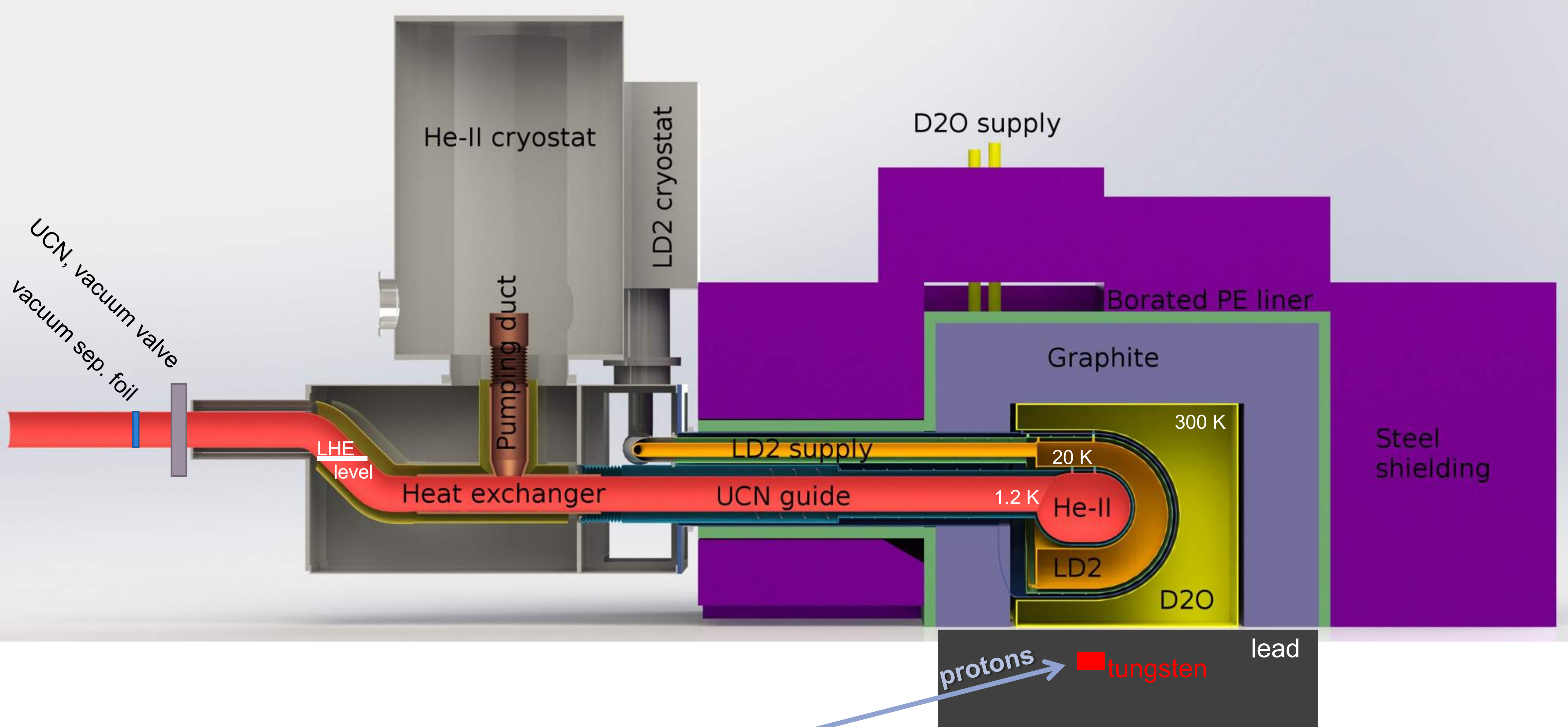
- Cooling power: 0.3 W ⇒ 10 W
- He-II temperature: 0.85 K ⇒ 1.10 K
- Near horizontal extraction while containing He with gravity
- Warm vacuum separation foil

Simulation studies in upcoming talk

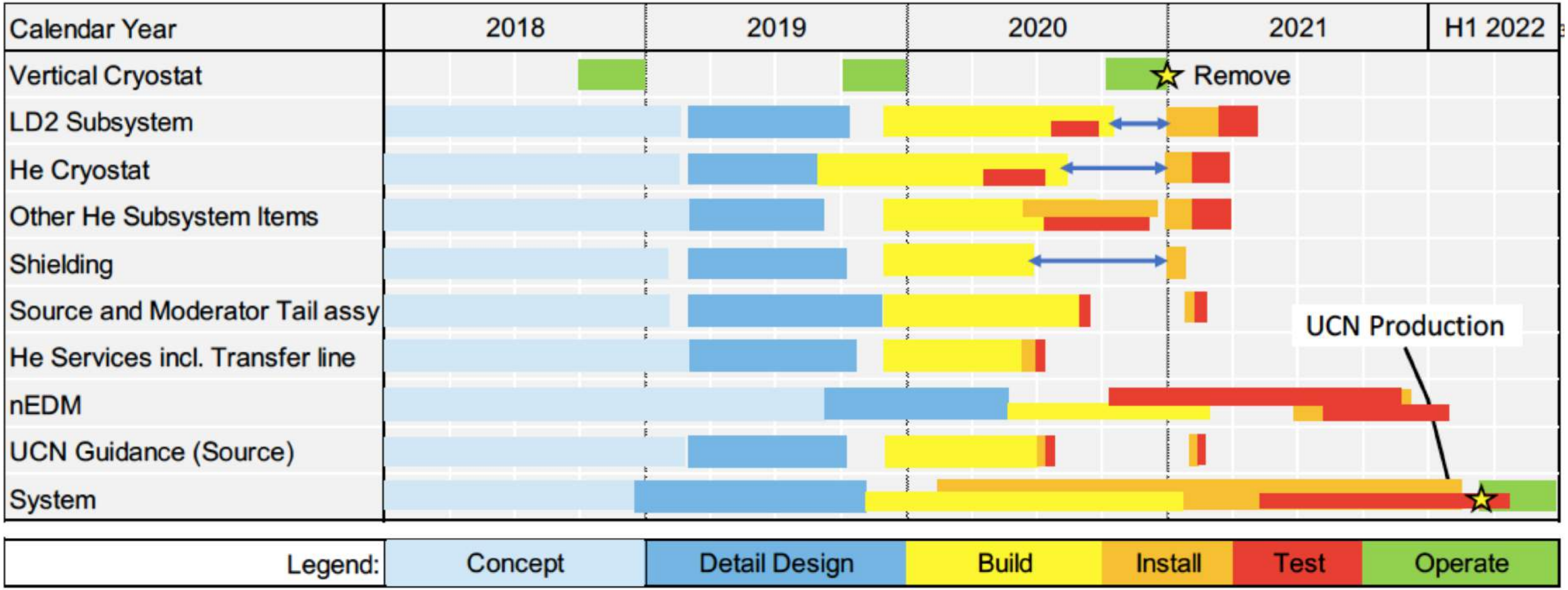
”Producing ultracold neutrons with a spallation source and superfluid helium,” W. Schreyer



Next generation UCN source design

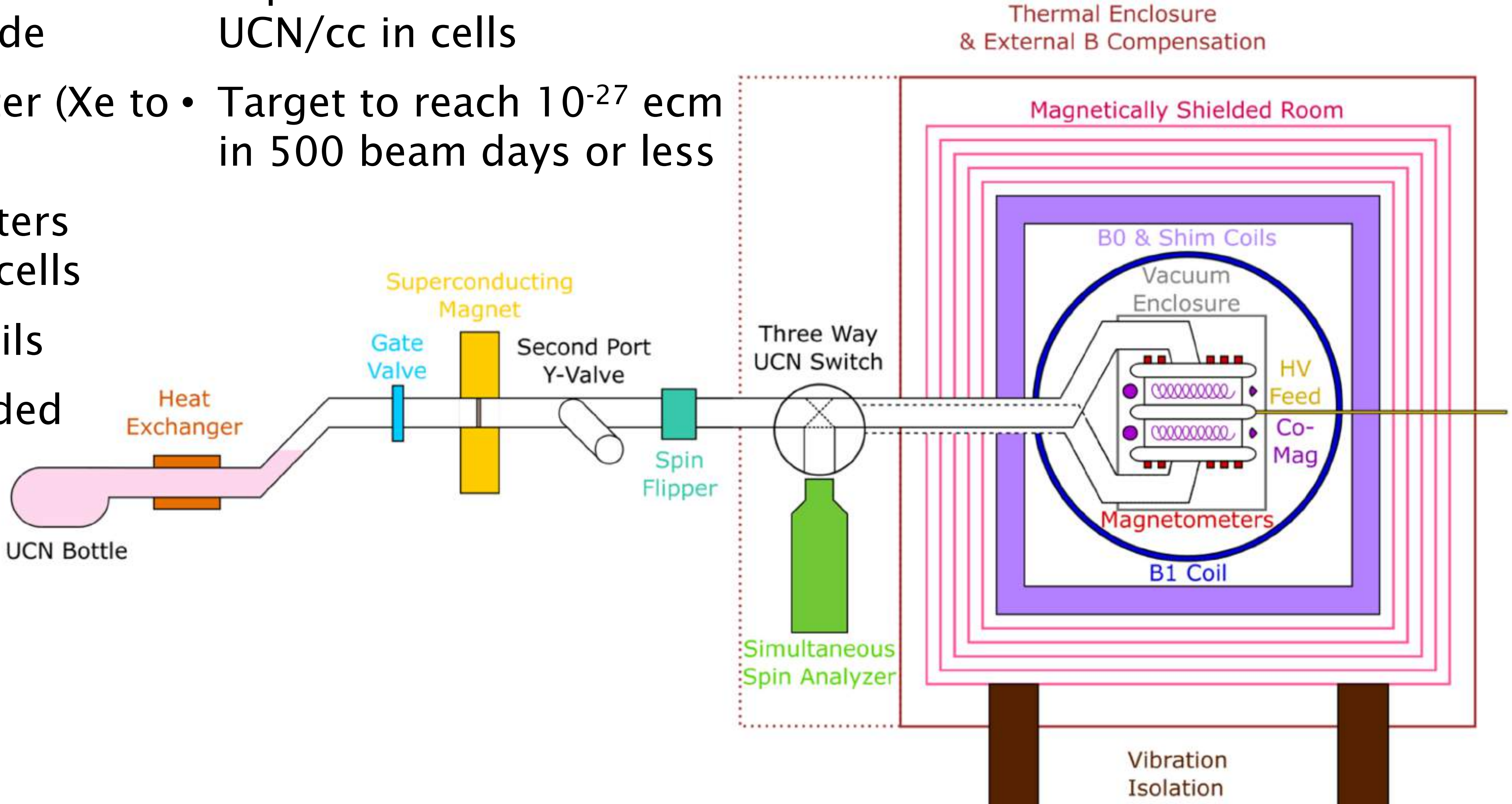


TUCAN Project Timeline

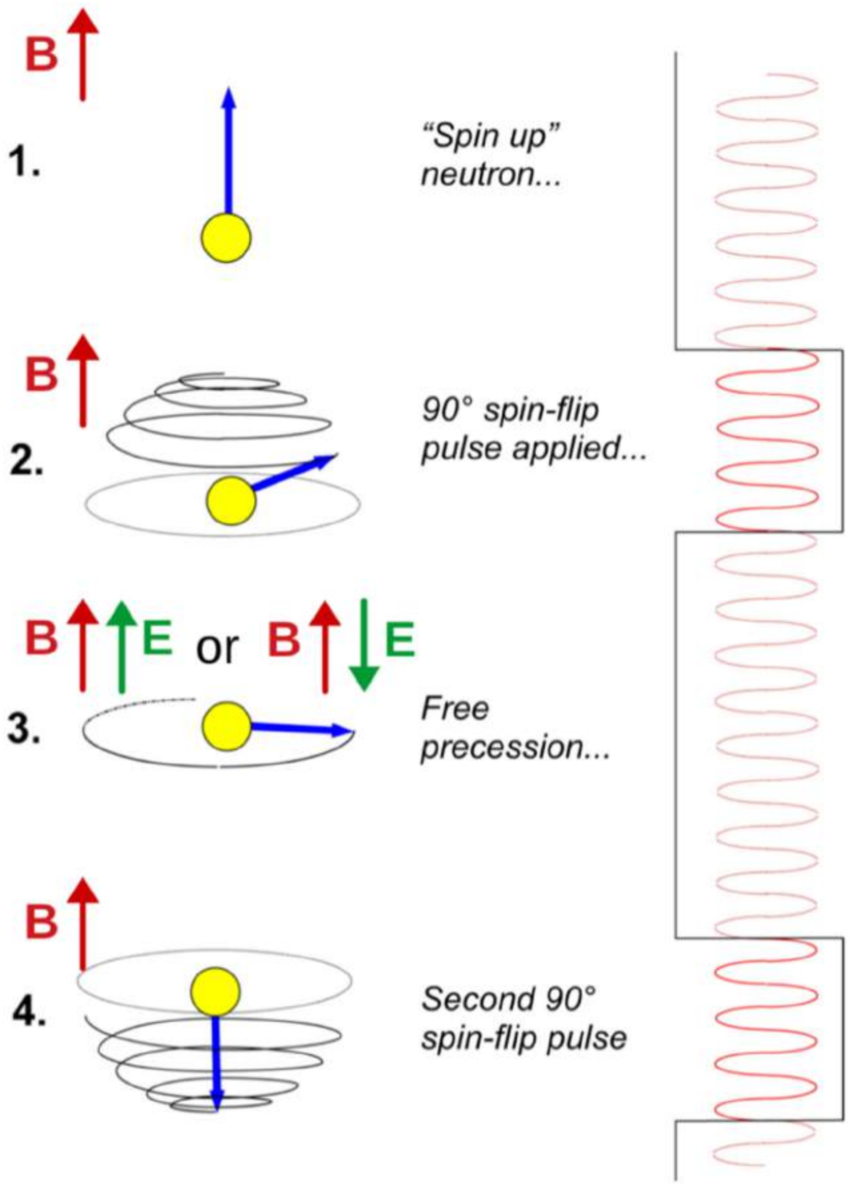


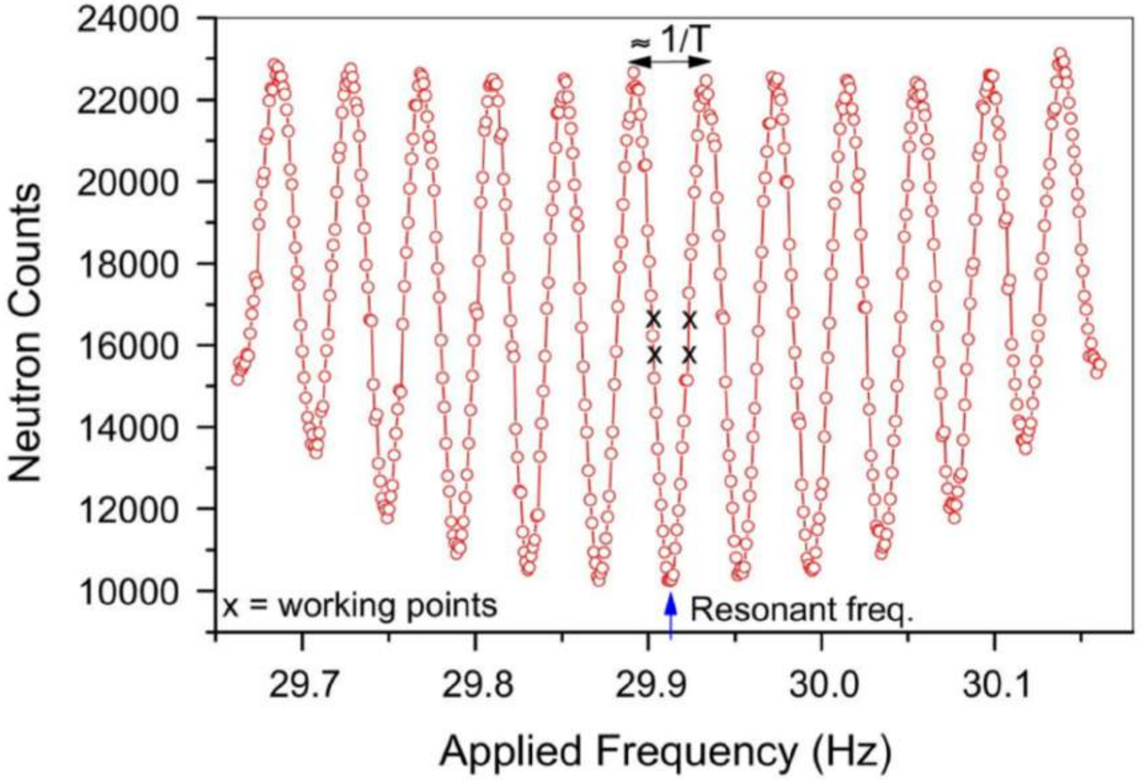
TUCAN EDM experiment layout

- Double cell EDM spectrometer at room temperature
- Central HV electrode
- Hg comagnetometer (Xe to follow later)
- Alkali magnetometers surrounding EDM cells
- Self shielded B_0 coils
- Magnetically shielded room
- Thermal enclosure and mag field compensation
- Expect several hundred UCN/cc in cells
- Target to reach 10^{-27} ecm in 500 beam days or less



Ramsey method for EDM measurement





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

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

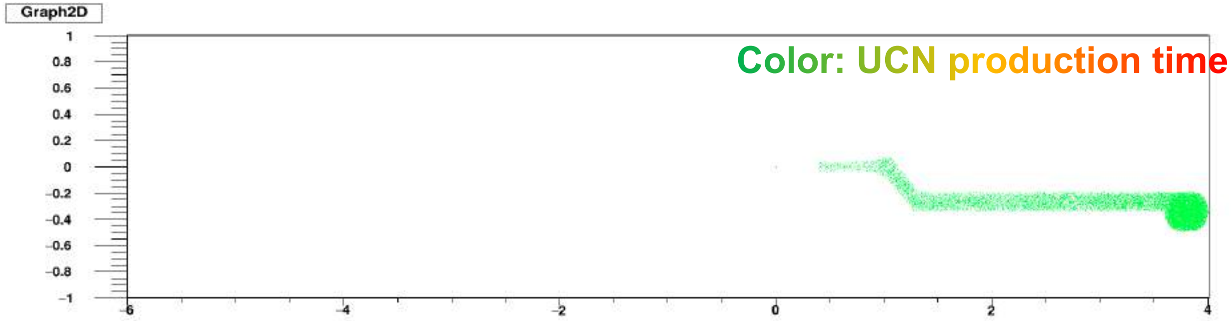
Status:	< 3.6 x 10^{-26} ecm	(4 yr, 95% CL)
TUCAN:	< 10^{-27} ecm	(400 d)

Baker et al, Phys. Rev. Lett. 97, 131801 (2006)
Baker et al, NIMA, 736, 184 (2014)
Pendlebury, Phys. Rev. D, 92, 092003 (2015)

Two highlights of EDM developments

nEDM statistical analysis

- UCN transport Monte Carlo used to evaluate statistical reach at TRIUMF



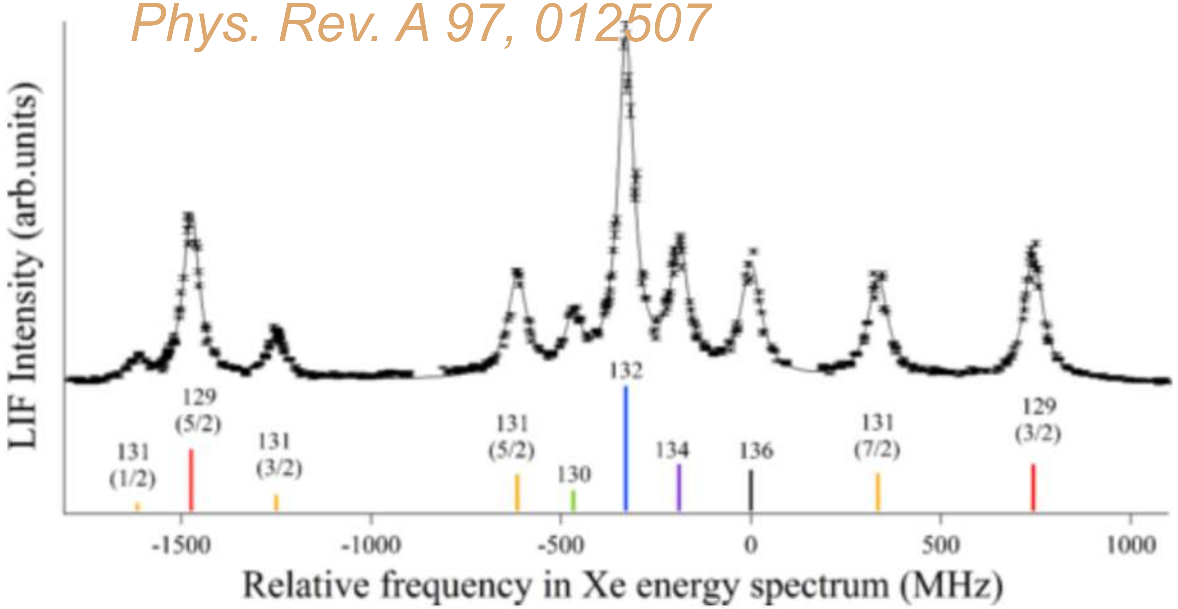
- Includes
  - Detailed source model
  - Superconducting polarizer
  - Switches, detector etc

"Improving the sensitivity of the neutron electric dipole moment experiment at TRIUMF," S.Sidhu

Xe comagnetometer

- High-res. 2-photon spectrum of a $5p^5 6p \leftarrow 5p^6$ transition of xenon

Phys. Rev. A 97, 012507



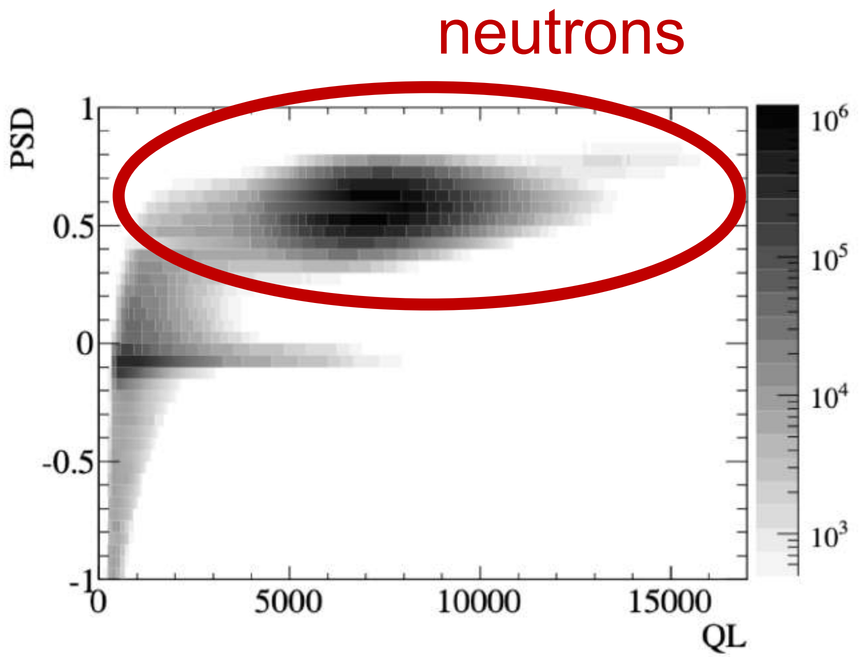
- This transition will be used for the comagnetometer

Detector developments

6Li scintillating glass read out by PMT and lightguide

Eur. Phys. J A 53 (2017) 3

- Learned in fall 2018 that lightguides outgas too much to allow no foil



Detector R&D planned

- Considering MPPC in vacuum
  - No lightguide … but need to develop circuit compatible with vacuum
- Redesign of lightguides in quartz
  - Needed to remove foil between detector and UCN
  - Improve vacuum seal
  - Improve mechanical connection of lightguides to vacuum flange

Summary and Outlook

Very exciting last years

- Beam installation 2014-16
- Beam commissioning 2016-17
- Vertical UCN source in 2017
- First UCN at TRIUMF 2017
- CDR for next generation source prepared 2018
- Funding for source and nEDM secured
- Successfully completed extensive UCN experiment program in Nov 2018

Busy next year(s)

- Detailed UCN source design and construction start in 2019
- Conceptual design report of nEDM by sept 2019
- Installation of UCN source upgrade shutdown 2021
- First UCN with new source planned in 2021
- nEDM data taking start planned for 2022

The end...

Thanks for your attention!

The TUCAN collaboration

S. Ahmed[3,4], T. Andalib[3,4], C. Bidinosti[3,8], Y. Bilinsky[5], J. Birchall[4], M. Das[3,4], C. Davis[5], E. Cudmore[5], A. Ezzat[2], B. Franke[5], M. Gericke[4], S. Hansen-Romu[3,4], K. Hatanaka[6], B. Jamieson[3], K. Katsika[5], S. Kawasaki[1], T. Kikawa[5,11], M. Kitaguchi[10], A. Konaka[5,6], F. Kuchler[5], E. Korkmaz[7], M. Lang[3,4], L. Lee[5], T. Lindner[5,3], Y. Makida[1], J. Mammei[4], R. Mammei[3], C. Marshall[5], J.W. Martin[3], R. Matsumiya[5], K. Mishima[9], T. Momose[2], T. Okamura[1], S. Page[4], R. Picker[5,8], E. Pierre[6,5], J. Pon[5], D. Preddy[5], W.D. Ramsay[5], Y-N. Rao[5], L. Rebenitsch[3,4], W. Schreyer[5], H. Shimizu[10], S. Sidhu[8], J. Sonier[8], I. Tanihata[6], W.T.H. van Oers[4,5], Y. Watanabe[1], D. Yosifov[5]

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Picture: ^{3}He gas panel