Ultracold Neutrons at TRIUMF

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NSERC CRSNG

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TRIUMF

International Spallation Ultracold Neutron Source

Spokespeople: Y. Masuda (KEK), J.W. Martin (Winnipeg)

Collaborators: T. Adachi, K. Asahi, J. Birchall, J.D. Bowman, L. Buchmann, C. Davis, T. Dawson, B.W. Filippone, M. Gericke, R. Golub, K. Hatanaka, M. Hayden, T.M. Ito, S. Jeong, A. Konaka, E. Korobkina, E. Korkmaz, L. Lee, R. Mastumiya, K. Matsuta, M. Mihara, A. Miller, W.D. Ramsay, S.A. Page, B. Plaster, I. Tanihata, W.T.H. van Oers, Y. Watanabe

(KEK, Titech, Winnipeg, Manitoba, ORNL, TRIUMF, NCSU, Caltech, RCNP, SFU, LANL, Tokyo, UNBC, Osaka, Kentucky)

We propose to construct the world's highest density source of ultracold neutrons and use it to conduct fundamental and applied physics research using neutrons.

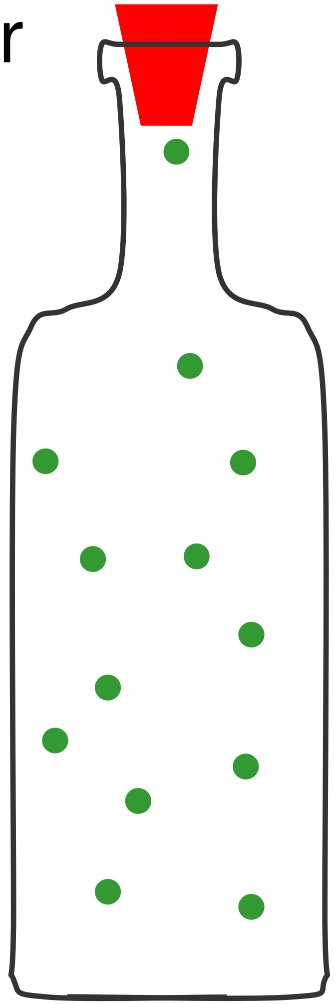
News: $10.9M proposal now funded in Canada and Japan.

Outline

- UCN production and source
  - Progress at RCNP
    (see talks by K. Hatanaka, R. Matsumiya)
  - Technical progress at TRIUMF
- Physics experiments at the UCN source
  - Prototyping experiments we're conducting at RCNP toward a measurement of the neutron electric dipole moment.
    (see talk by Masuda)

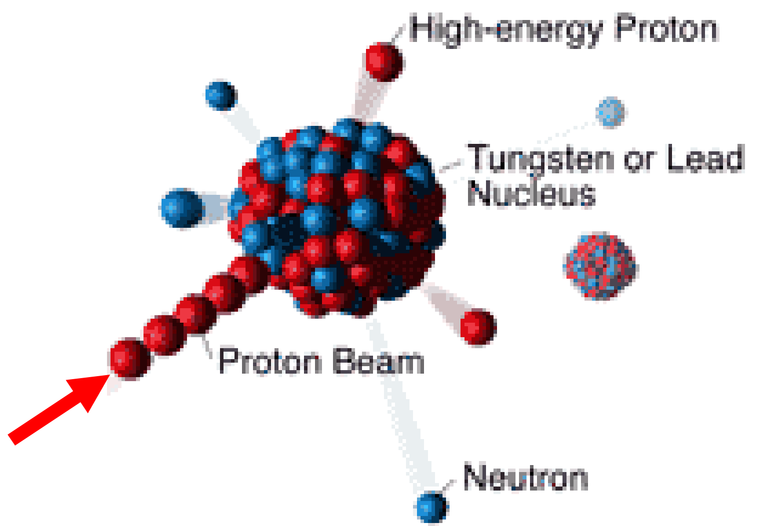
Ultracold Neutrons (UCN)

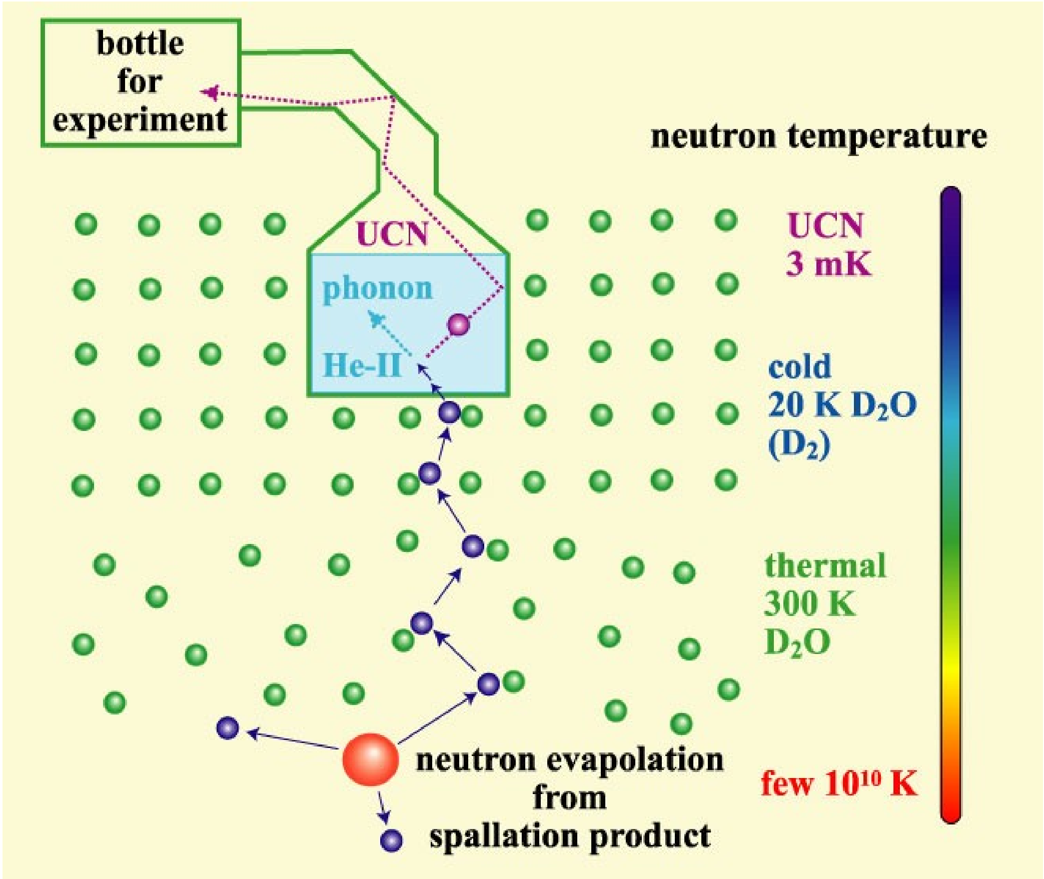
- UCN are neutrons that are moving so slowly that they are totally reflected from a variety of materials.
- So, they can be confined in material bottles for long periods of time.
- Typical parameters:
  - velocity < 8 m/s = 30 km/h = 20 mph
  - temperature < 4 mK
  - kinetic energy < 300 neV
- Interactions:
  - Gravity: $V = mgh$ $mg = 100$ neV/m
  - Magnetic: $V = -\mu \bullet B$ $\mu = 60$ neV/T
  - Strong: $V = V_{eff}$ $V_{eff} < 335$ neV
  - Weak: $\tau = 885.7$ s = 15 mins



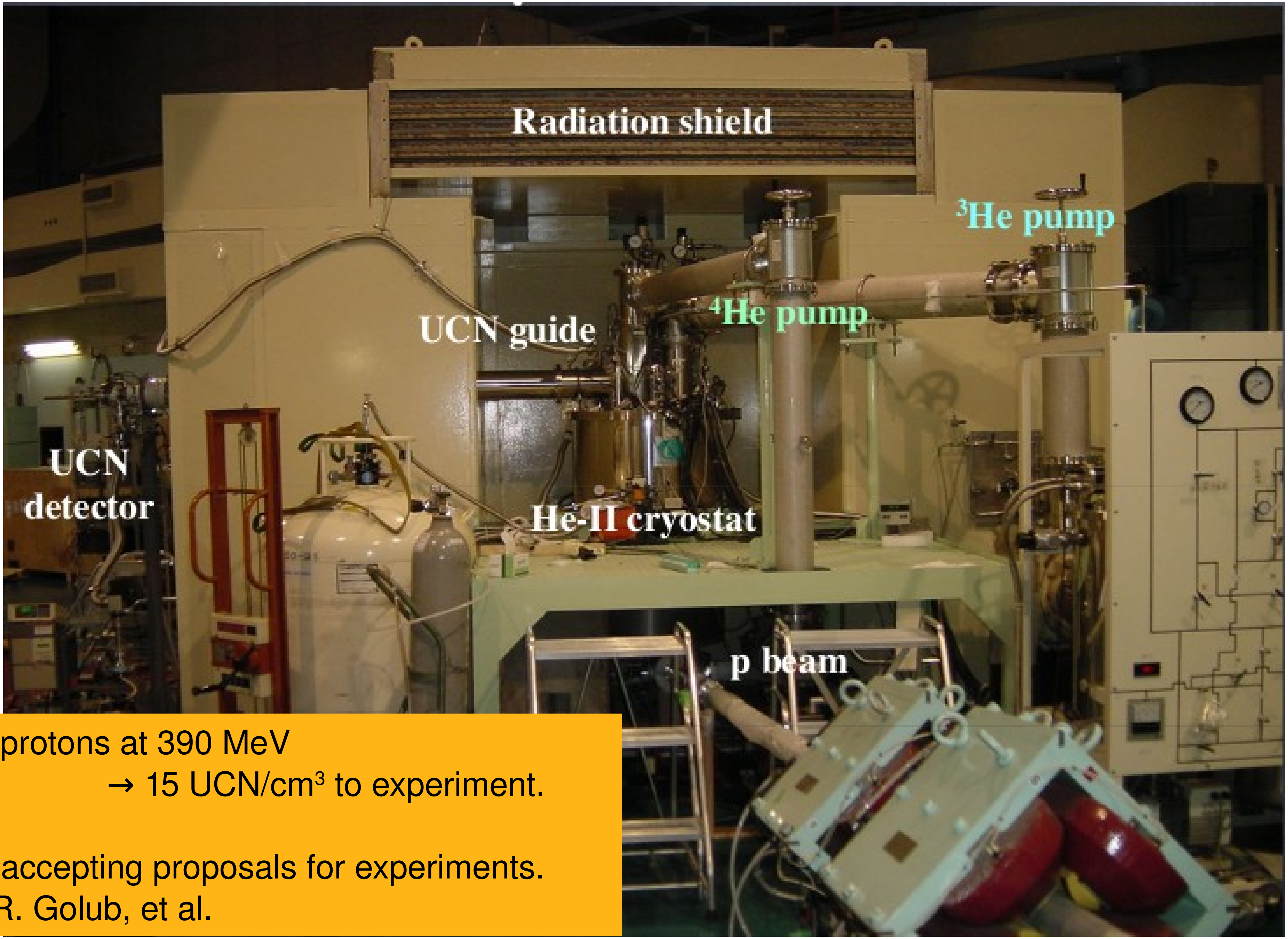
How to make UCN

- Liberate neutrons by proton-induced spallation.
- Moderate (thermalize) in cold (20 K) D_2O.
- Cold neutrons then “downscatter” to near zero energy (4 mK) in superfluid helium through phonon production.





Japan UCN Source (Masuda, et al)



1 μa protons at 390 MeV
→ 15 UCN/cm^3 to experiment.

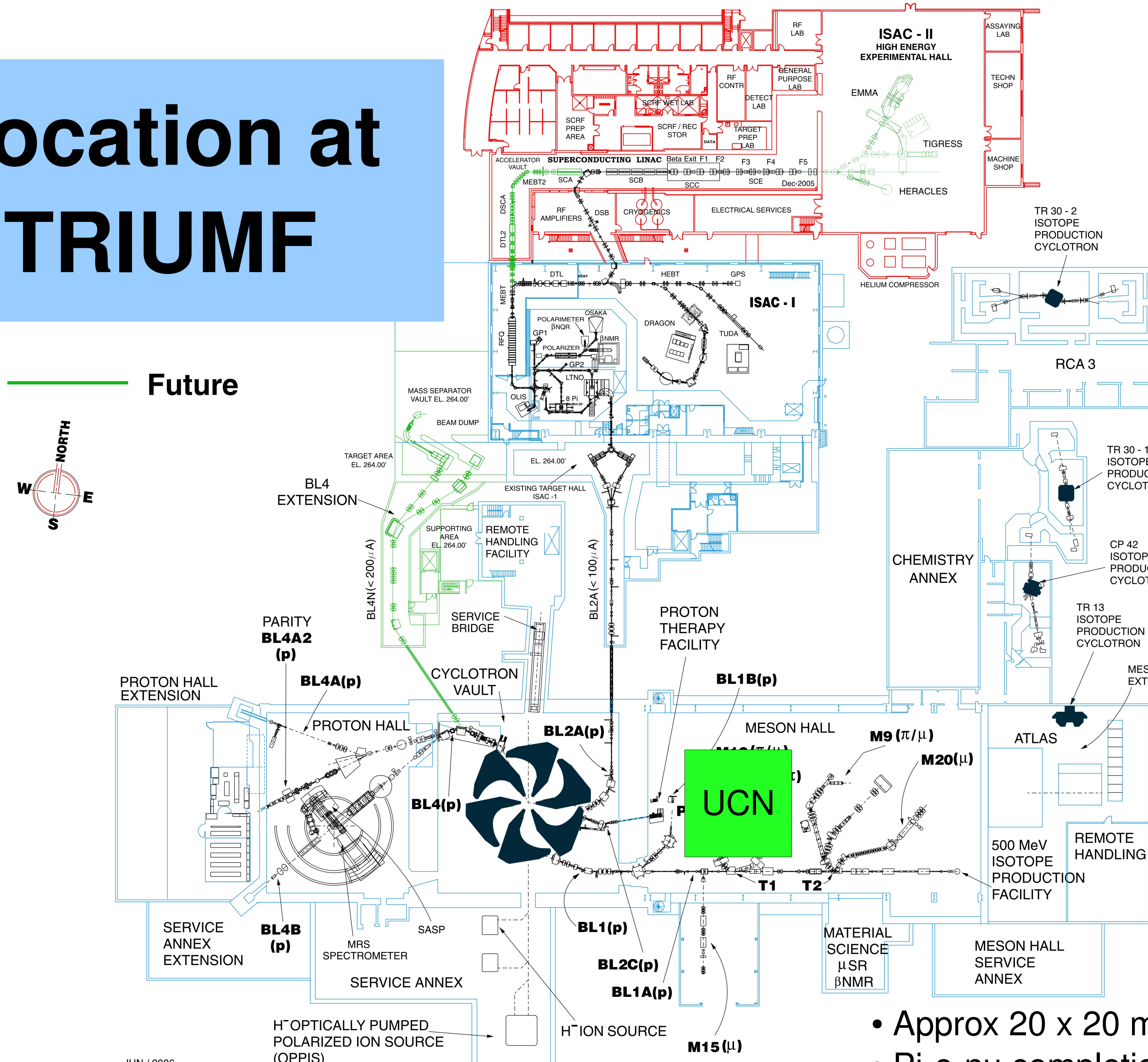
Now accepting proposals for experiments.
e.g. R. Golub, et al.

- Beam parameters for UCN source at TRIUMF:
  - 500 MeV protons at 40 μA
- At RCNP, Osaka:
  - 390 MeV protons at 1 μA
- A fifty-fold increase in beam power.
- Cyclotron operates ~ 8 months/yr.

World's UCN projects

	source type	E_c neV	P_{UCN} /cm^3/s	T_s s	ε_{ext}	ρ_{UCN} /cm^3 source/exp.
TRIUMF	spallation He-II	210	0.4×10^4 (10L)	150	~1	3×10^5 (20L) $1\text{-}5 \times 10^4$
ILL	n beam He-II	250	10	150	~1	**/1000
SNS	n beam He-II	134	0.3 (7L)	500	1	**/150
LANL *	spallation SD2	250	4.4×10^4 (240cm^3)	1.6	1.3×10^3/ 4.4×10^4	**/120
PSI	spallation SD2	250	2.9×10^5 (27L*)	6	0.1	2000 (2m^3) /1000
NCSU	reactor SD2	335	2.7×10^4 (1L)	**	**	1300/**
Munich	reactor SD2	250	**	**	**	1×10^4/**

Location at TRIUMF

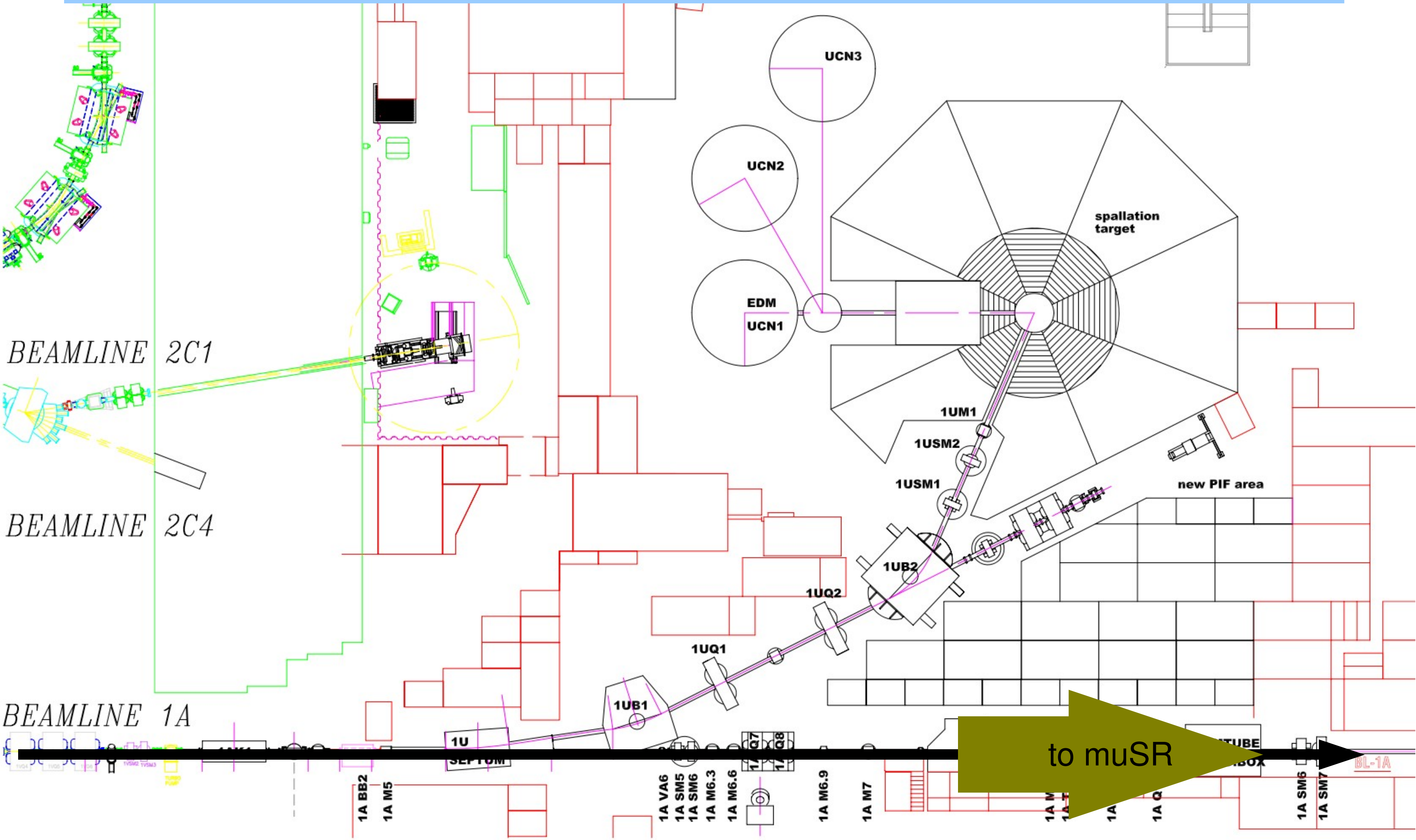


- Approx 20 x 20 m^2 box
- Pi-e-nu completion 2011

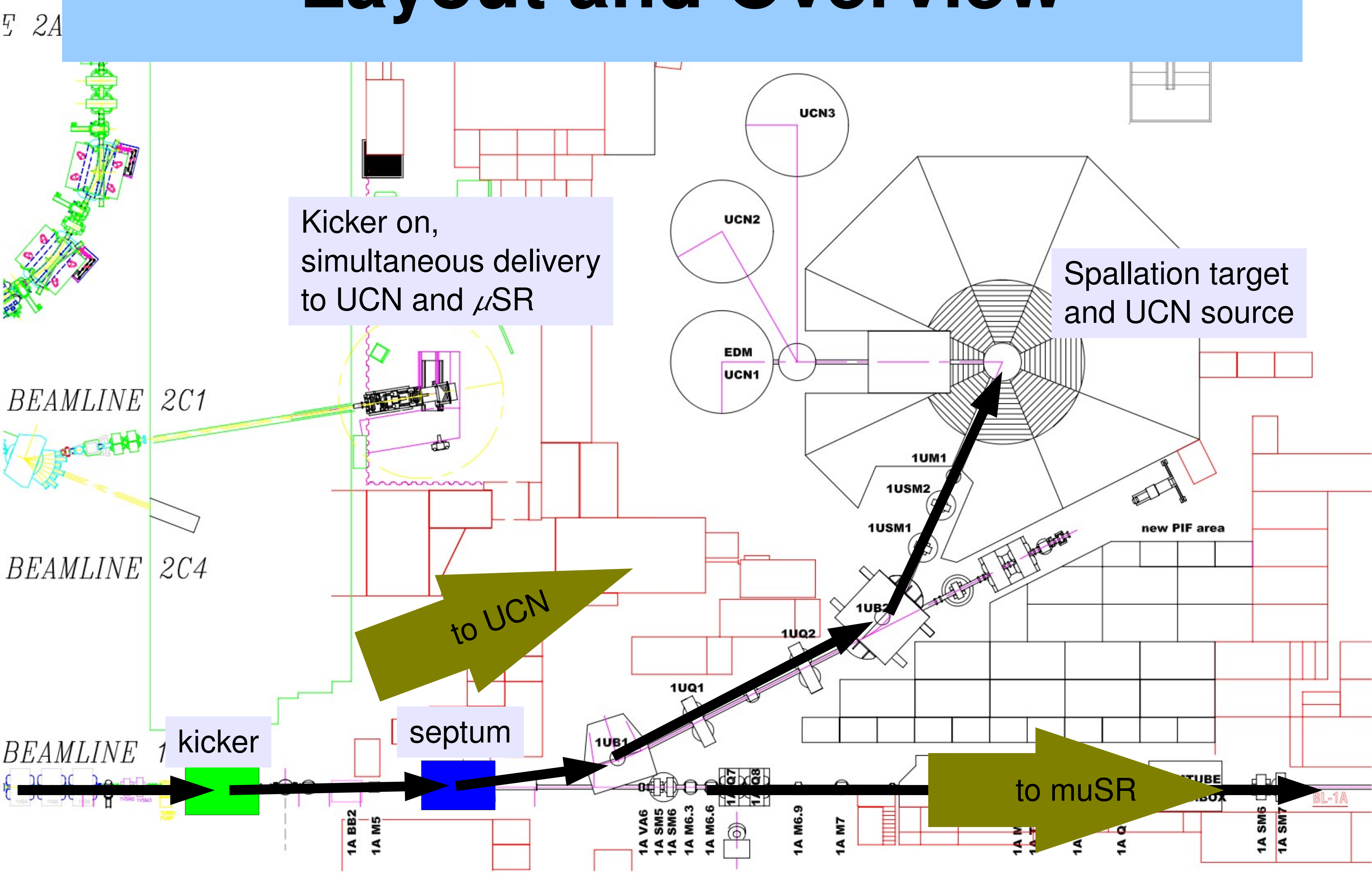
Technical Progress @ TRIUMF

- Layout
- Kicker
- Beamline
- Target / remote extraction / shielding
- (Cryostat), cryogenics
- Installation
- Cost / schedule / personnel requirements
- MOU's

Layout and Overview

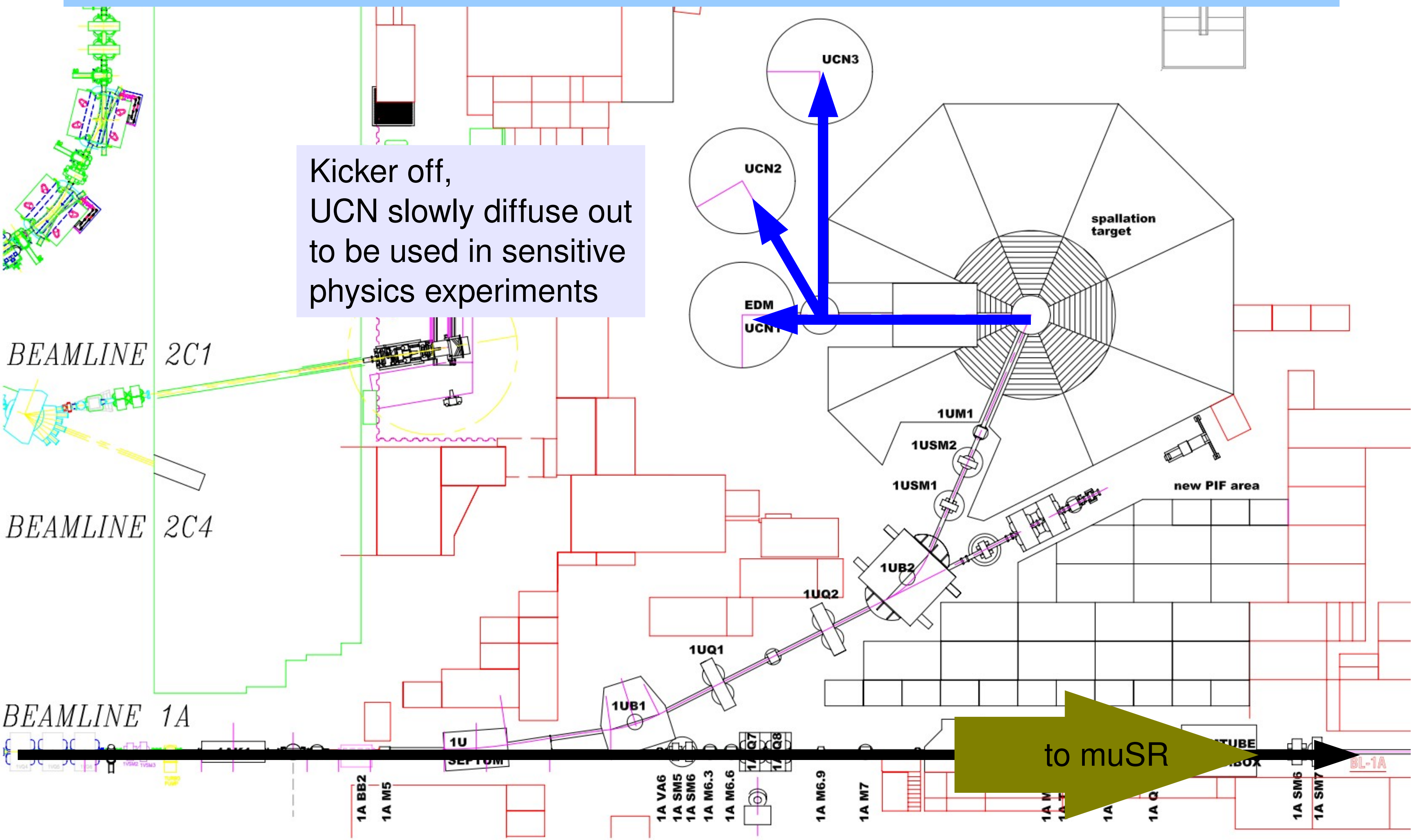


Layout and Overview



Layout and Overview

Kicker off,
UCN slowly diffuse out
to be used in sensitive
physics experiments



Kicker

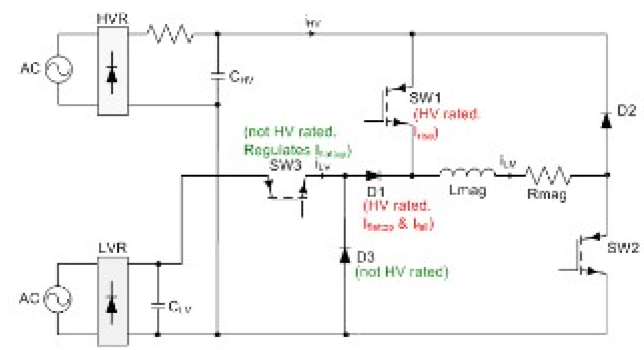
- Redirect 1A beam into UCN line on kHz timescale using existing TRIUMF beam structure.
- Integrated 7% to UCN, 93% to CMMS users.
- TRIUMF/CERN design
  - HV SS switches
  - Fast dipole magnet
- Engineering design.

Kicker Specs:

- 500 MeV protons (p = 1090 MeV/c)
- 15 mr maximum deflection (B*dl* = 0.0545 Tm); normal deflection 12 mr
- effective length 1.5 m (physical available 2 m)
- aperture 100 mm x 100 mm
- field uniform to ±5% over central 80 mm diameter region
- flat top 1 ms, flat to ±5% over the 1 ms
- fires every 3 ms (330 Hz rep. rate, able to run continuously)

Examples:

rise/fall time (μs)	turns	inductance (μH)	flattop current	peak voltage
5	4	30	725 A	4500 V
15	8	120	360 A	2900 V
26	12	270	240 A	2500 V



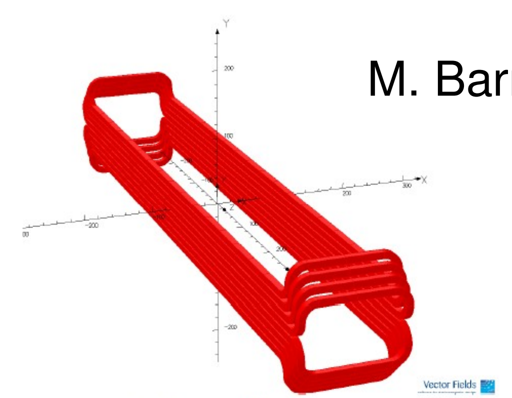
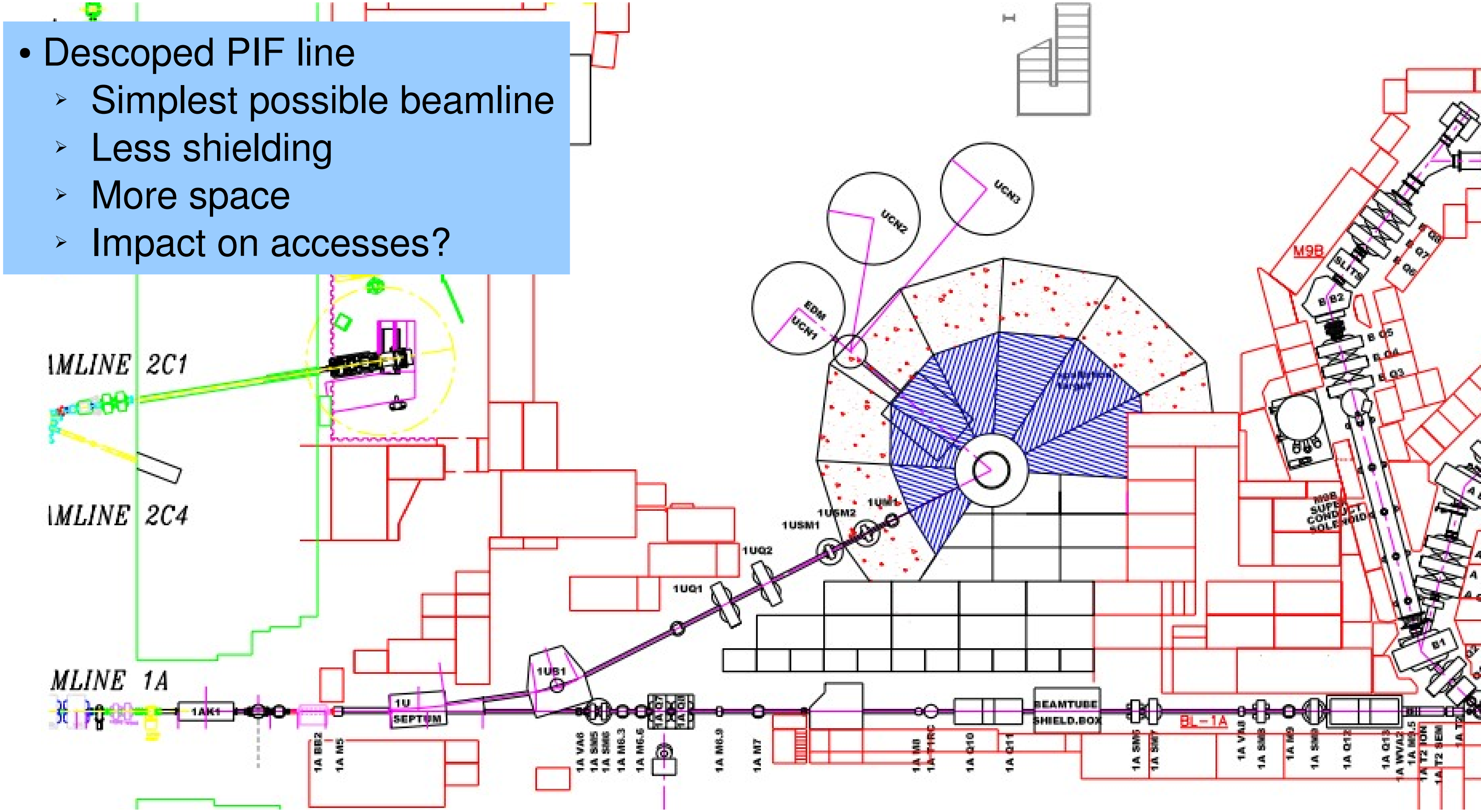


Fig. 1: Proposed coils for UCN kicker

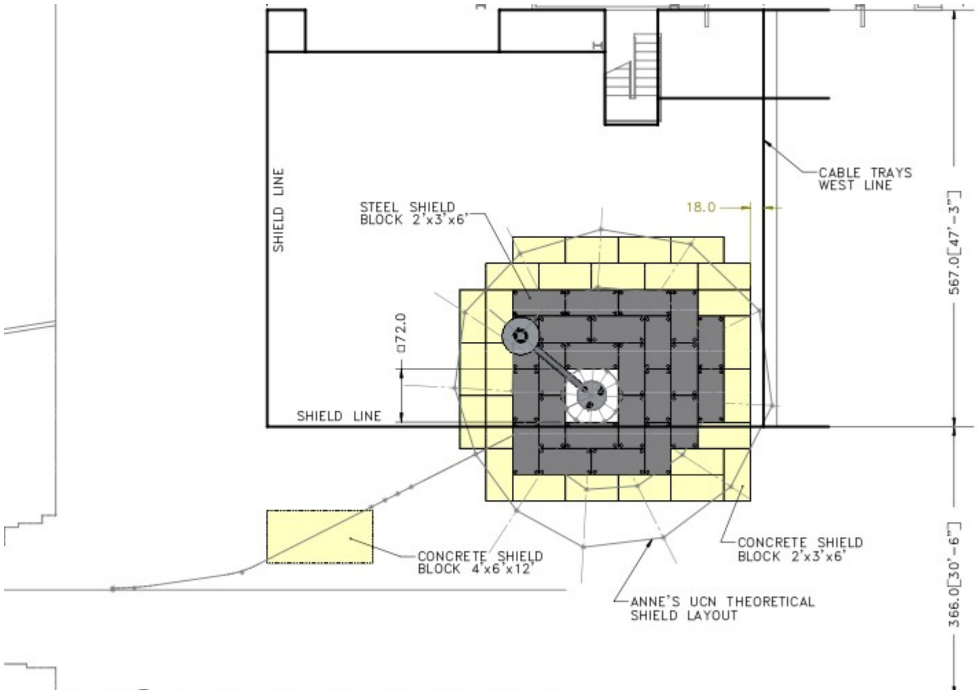
M. Barnes

Revised Layout, March 2010

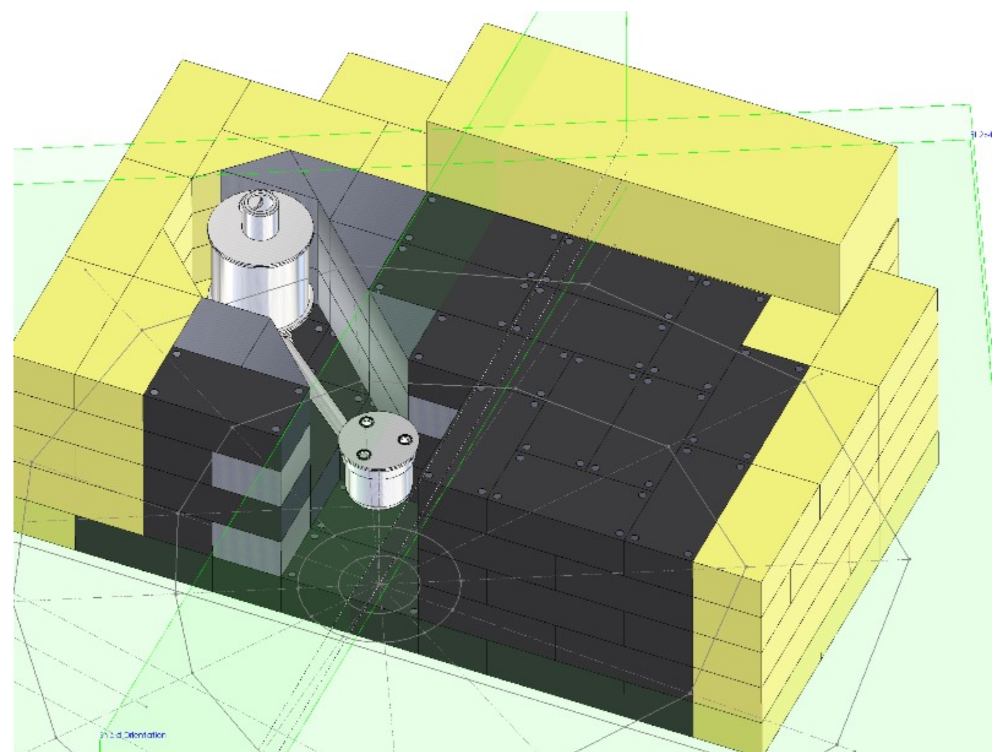
- Descoped PIF line
  - Simplest possible beamline
  - Less shielding
  - More space
  - Impact on accesses?



Revised Layout, March 2010



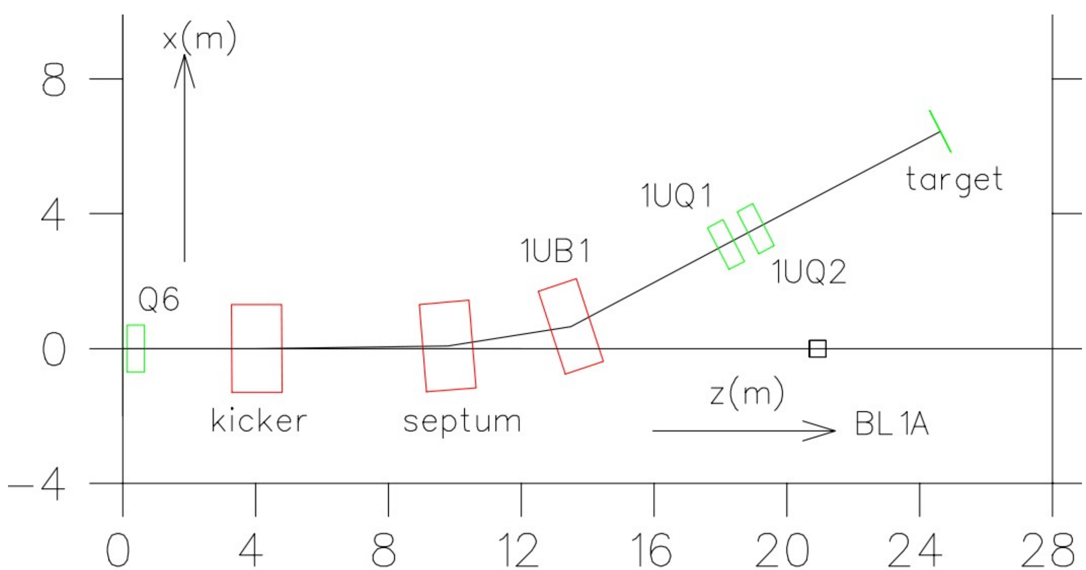
- Building out shield package.
- Recycling shielding where possible.

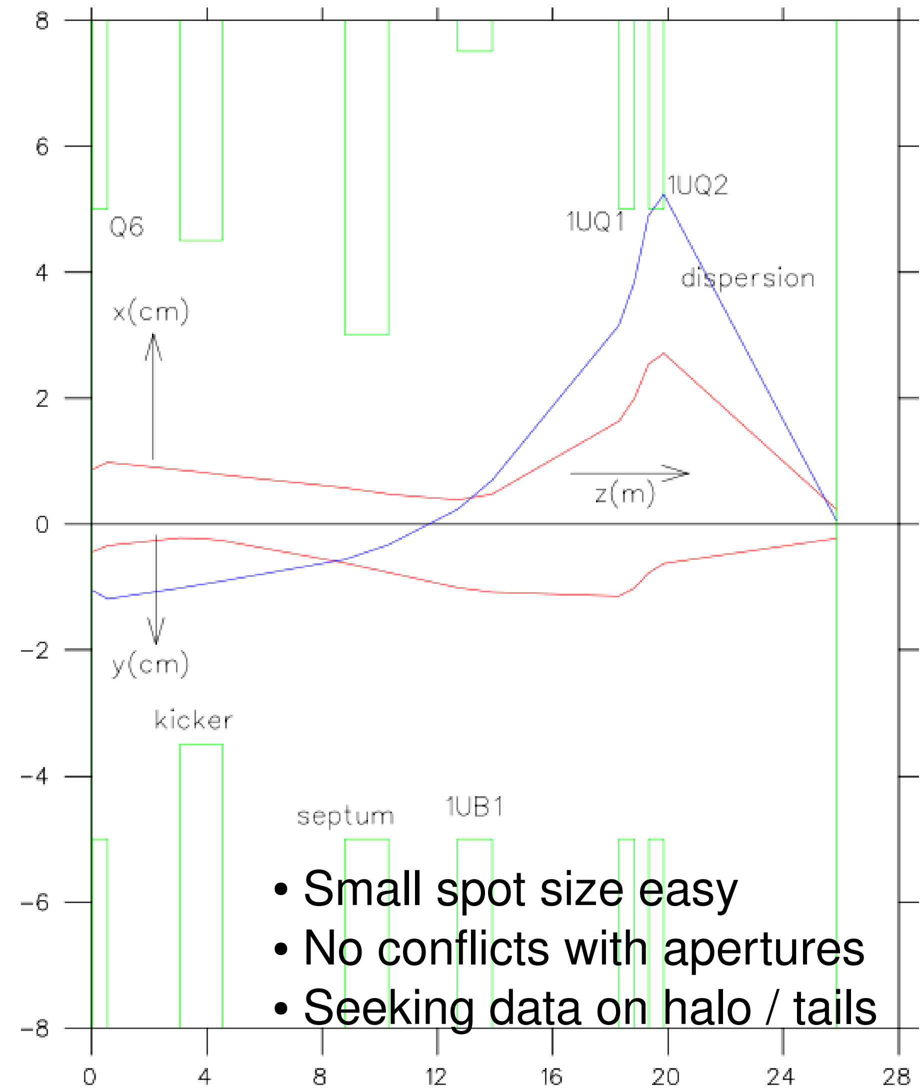


- Gives confidence in cost.
- Needs consistency with remote handling, installation.

Beamline

- Optics studies for new layout! (J. Doornbos)
- Septum and first bender are new. KEK support.
- Many other parts to be reused.





Target / Remote Handling / Shielding

- 3 cm dia x 12 cm long W.
- Shielding calcs
  - 3 m steel, 2 m concrete
- Growth of target activity manageable.
- Remote extraction via custom plug.
- Design to be consistent with remote handling, existing MH infrastructure.

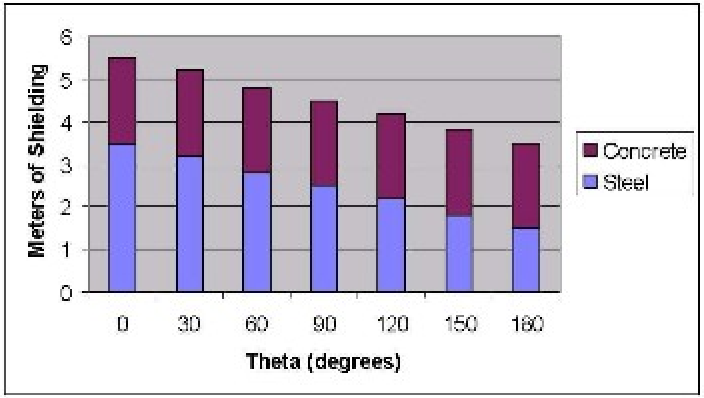
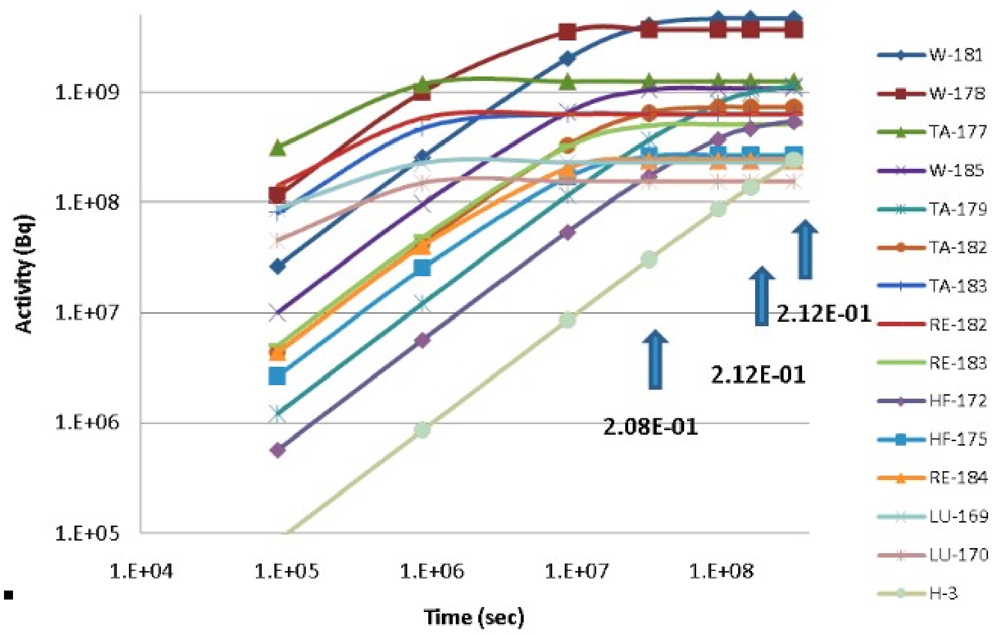
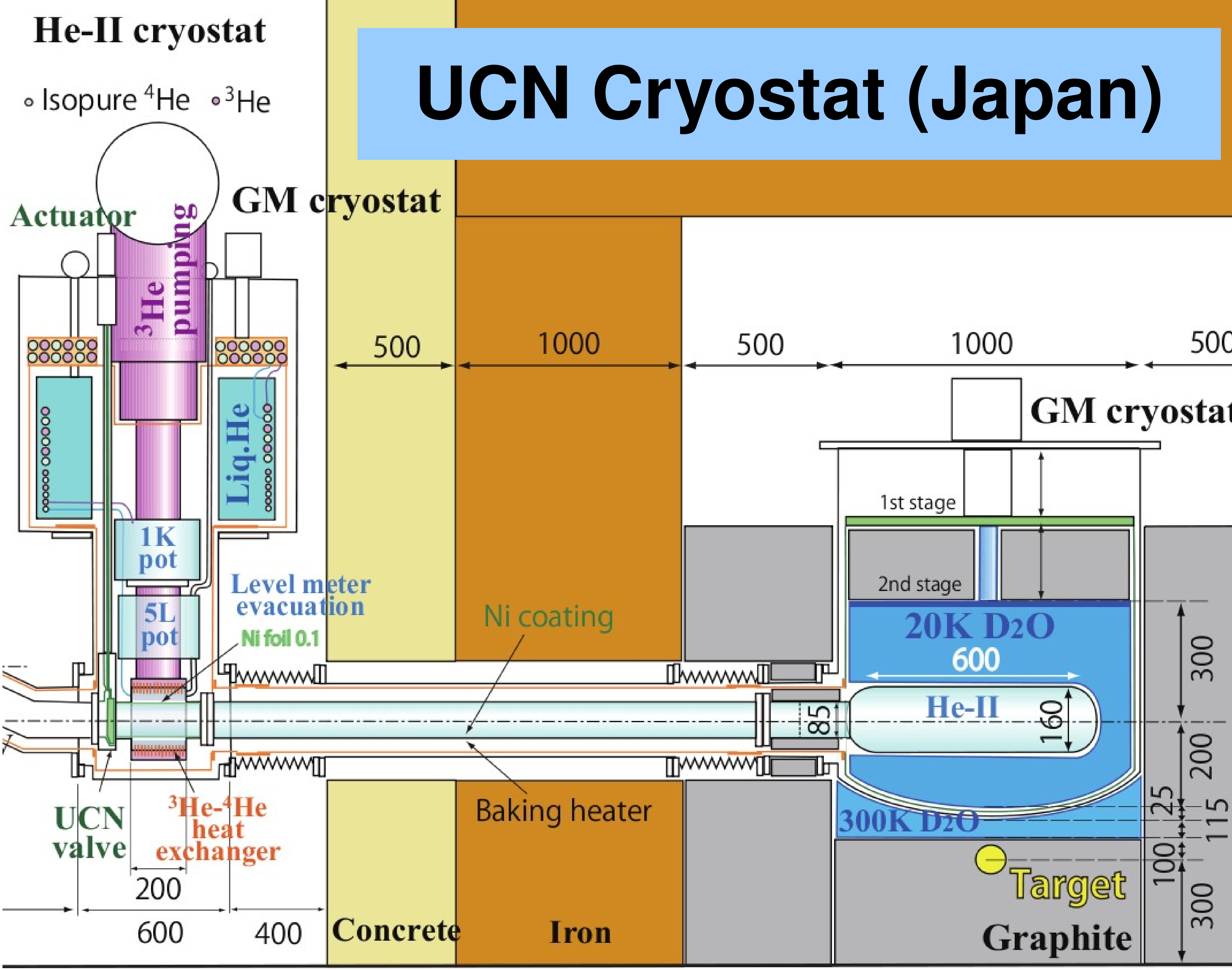
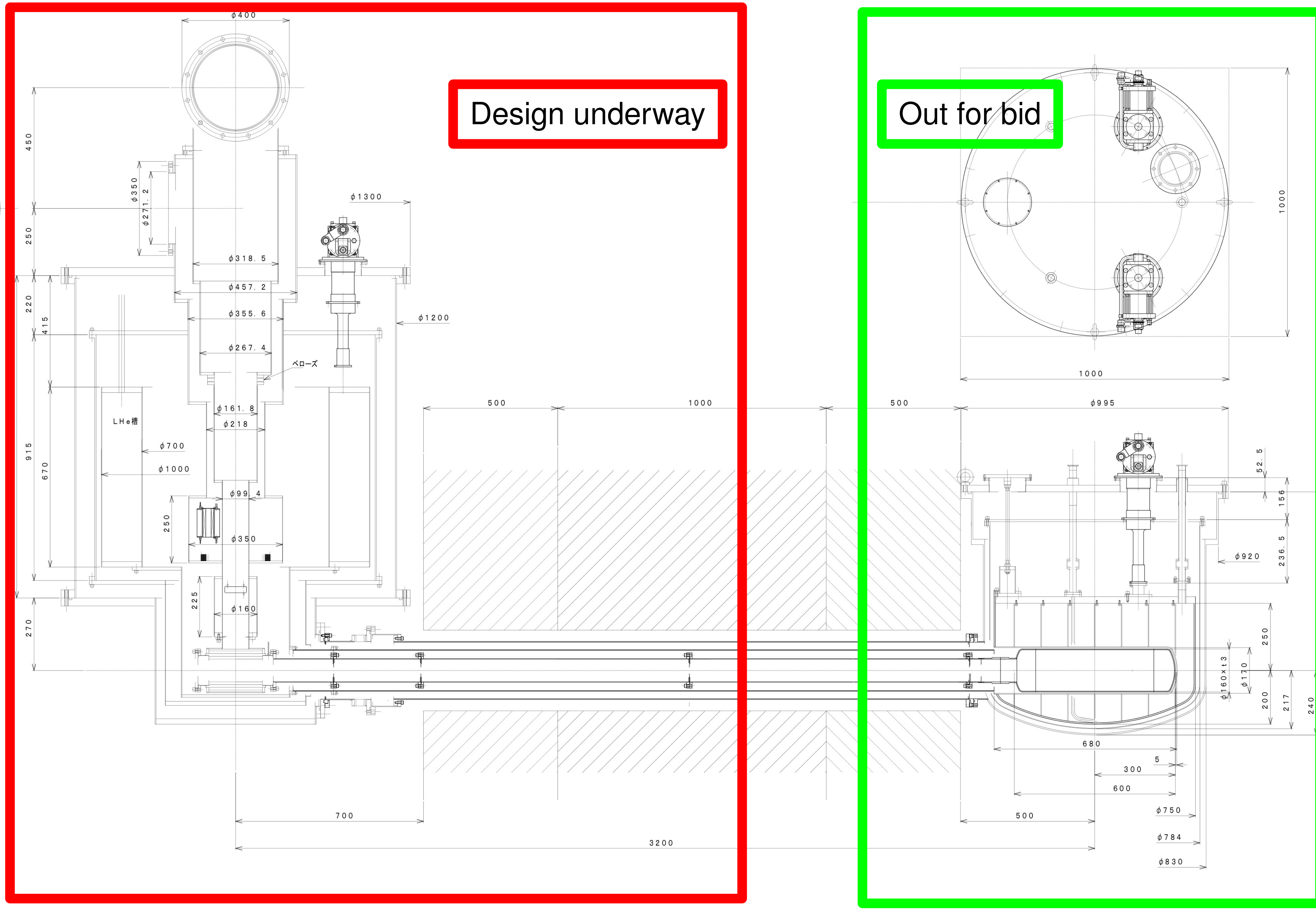


Figure 3: Shielding required for a 40 μA, 500 MeV proton beam incident on a thick tungsten target. The design dose rate is 3 μSv/hr immediately outside the shielding.



UCN Cryostat (Japan)




Design underway
Out for bid
LHe槽
ベローズ

Cryogenics Infrastructure

- Estimated LHe consumption < 1000 LL/day.
- Liquefier available from KEK from previous SKS project.
  - Maekawa compressor support avail. in Vancouver!
- Locate KEK liquifier near/in Meson Hall.
  - Transfer / cold / warm return lines direct to UCN
  - Use LHe to replace Japan cryocoolers
- Liquifier overhead to support other (μSR) users with dewars / warm return.

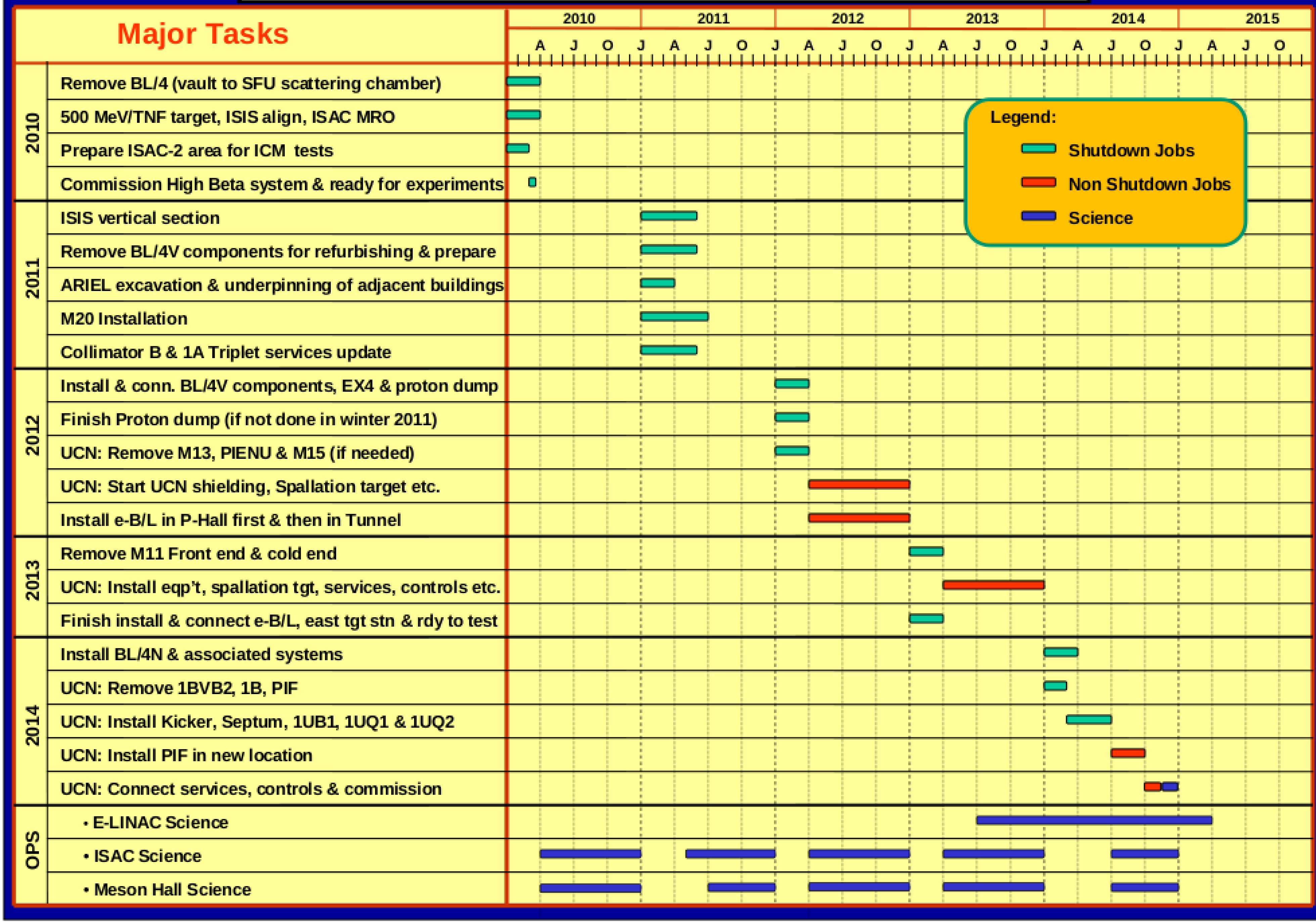
Installation

- Legacy infrastructure removal, followed by installation of key components (e.g. kicker and septum) to be conducted in series of shutdowns in order to minimize impact on cyclotron running (ISAC) and μSR users (Meson Hall).
- e.g. kicker install requires vault access.
- Draft schedule developed.
- Impact of beamline design on schedule.

Vijay Verma/Mark Keyzer

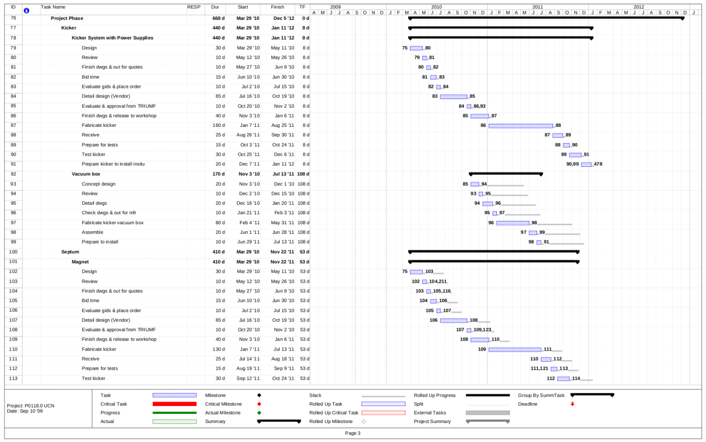
Shutdown Plan (2010-2015) - DRAFT

December 11, 2009



Cost / sched / personnel / MOU's / reviews

- Resource-loaded schedule basically complete.
- Materials cost re-estimate in progress (A. Miller).
- MOU in prep (KEK-RCNP-TRIUMF-Winnipeg).
- Important dates:
  - CFI award finalization March 31, 2010.
  - NSERC support April 1, 2010.
  - MOU signed ASAP!!!
  - Release of CFI funds.



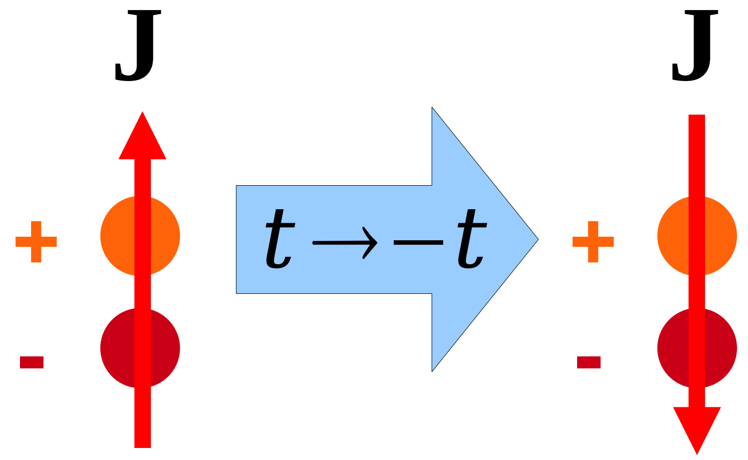
Physics Experiments for the TRIUMF UCN Source

Near term:
- neutron lifetime
- gravity levels
- n-EDM

Dreams:
- n$\bar{n}$-oscillations
- Free n target

All ideas / letters / proposals welcome

Neutron Electric Dipole Moment (n-EDM, d_n)

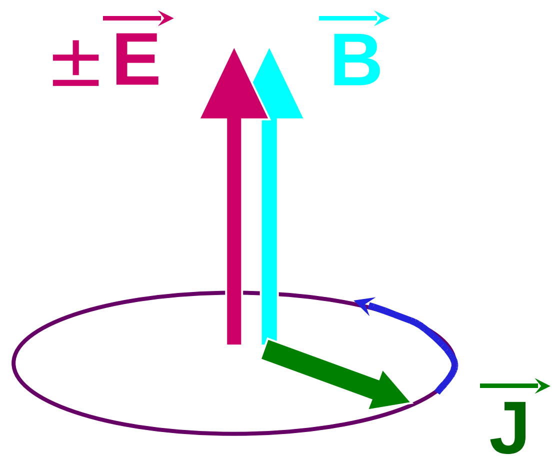


$$d_n \Rightarrow \not{T} \Rightarrow \not{CP}$$

New sources of CP violation are required to explain the baryon asymmetry of the universe.

- Complementary to Rn-EDM TRIUMF ISAC.

(See talk by A. Ritz)



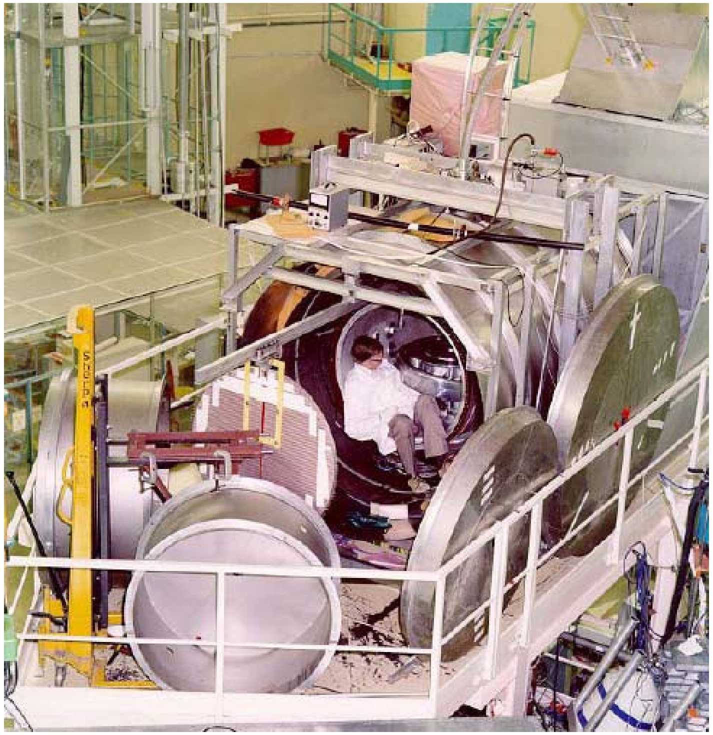
Experimental technique:

- put UCN in a bottle with *E*-, *B*-fields
- search for a change in spin precession frequency upon *E* reversal.

$$h\nu = 2\mu_n B \pm 2d_e E$$

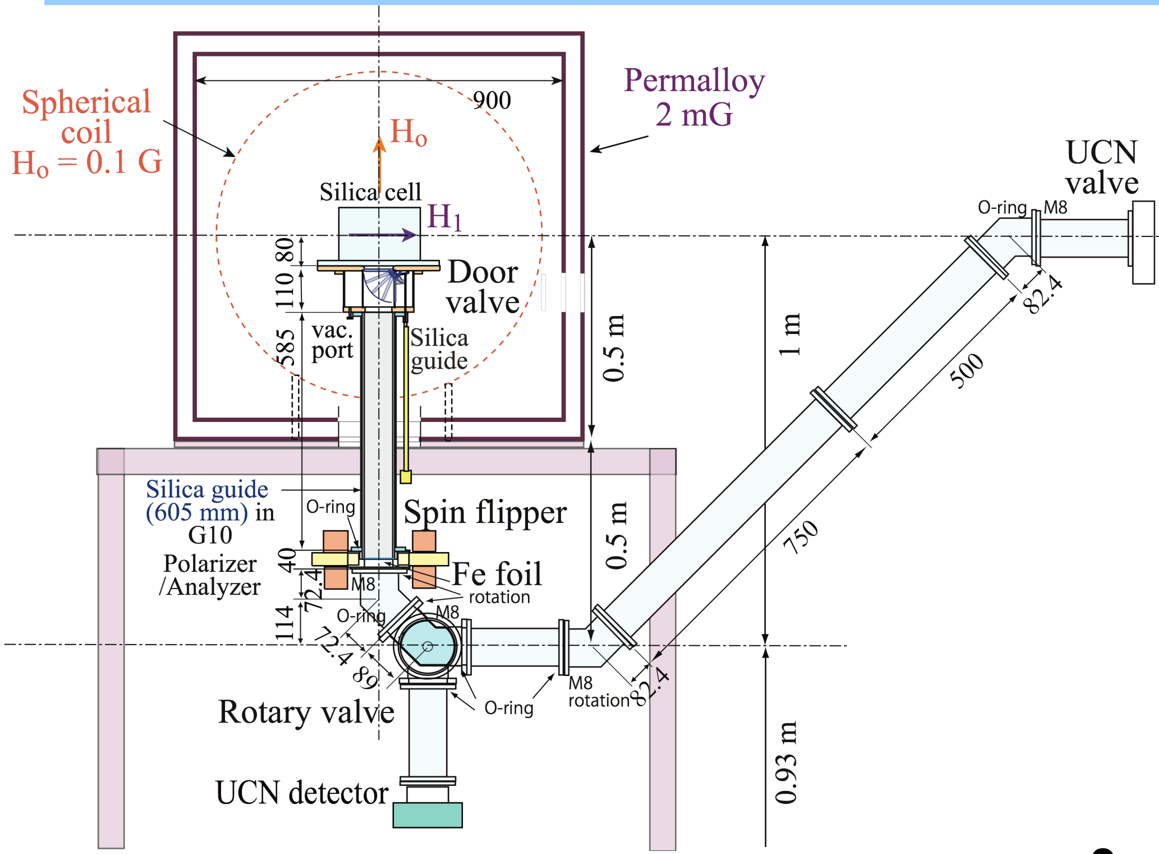
Past and Future n-EDM efforts

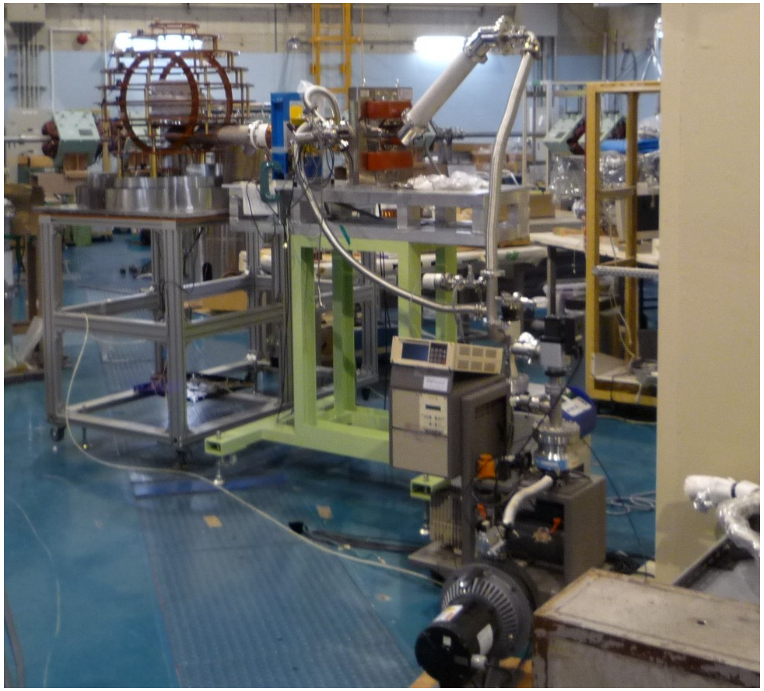
- Sussex-RAL-ILL expt. ($d_n < 3\times10^{-26}$ e-cm)
  - 0.7 UCN/cc, room temp, in vacuo
- CryoEDM (Sussex-RAL-ILL)
  - 1000 UCN/cc, in superfluid ^{4}He
- SNS
  - 430 UCN/cc, in superfluid ^{4}He
- PSI
  - 1000 UCN/cc, in vacuo
- TRIUMF: 10,000 UCN/cc



Sussex-RAL-ILL experiment

n-EDM development in Japan

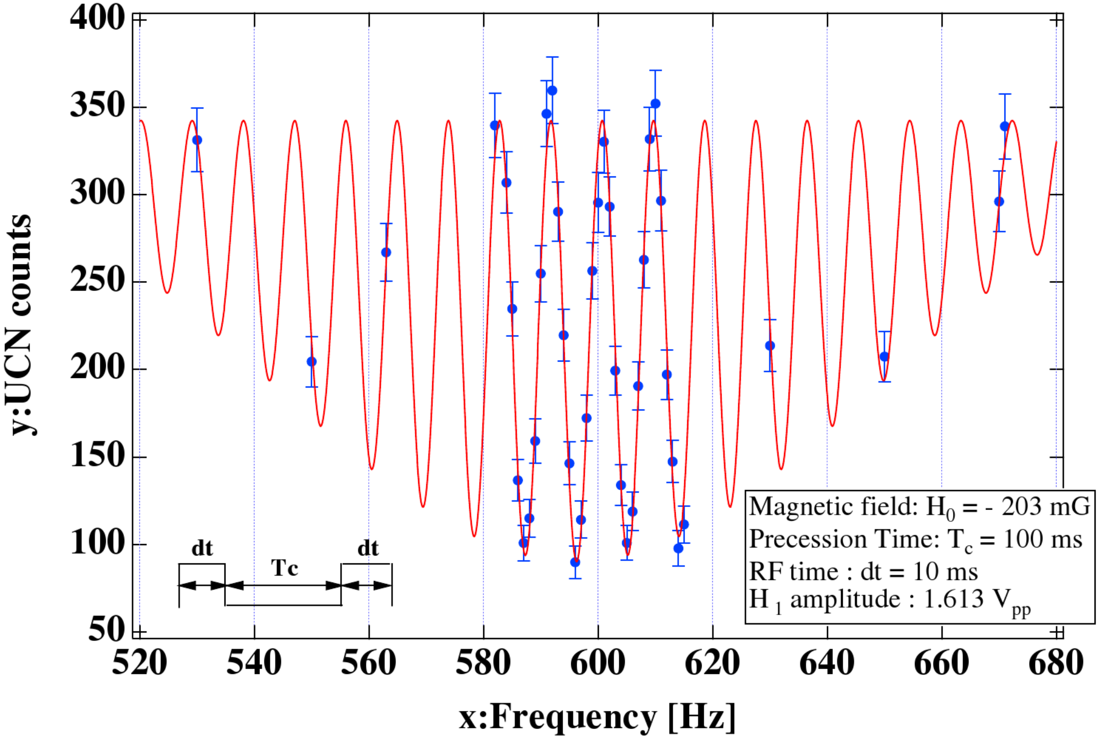




- Masuda, et al. Beam tests July 7-16, 2009 and December 8-13, 2009 at RCNP, Osaka.

- Development of:
  - Comagnetometers
  - Ramsey resonance
  - New B-field geometry

Ramsey Resonance Results
Y. Masuda, et al, in preparation



Dec. 12, 2009, achieved:

T_2 ~ 300 ms

Scaling to operating B_0 field:

T_2 ~ 300 ms * $(600/30)^2$ = 120 s

would be competitive with ILL!
(assuming motional narrowing)

Nearing state-of-the-art in low-field NMR!

- Successful demonstration of the basic technique behind precision EDM measurements.
- Improvements in field homogeneity, profile, magnitude, shielding for longer T_2.

EDM Statistics

- ILL: $$\sigma(d_n) = \frac{\hbar}{2\alpha ET\sqrt{N}}$$
  - α=0.64, τ=130 s, E=10 kV, N=14000 UCN/cycle
  - 1 UCN/cc: $\sigma(d_n)=1.7 \times 10^{-25}$ e-cm/day
  - Final stat. error: $\sigma(d_n)=1.5 \times 10^{-26}$ e-cm
- TRIUMF with increased UCN density:
  - 10^4 UCN/cc: $\sigma(d_n)=1.7 \times 10^{-27}$ e-cm/day
- e.g. SNS projected:
  - $\sigma(d_n) \sim 3 \times 10^{-27}$ e-cm/day (B. Filippone, FNAL seminar 06)

n-EDM at TRIUMF

- Complete experiments in Japan, 2009-2012.
- Develop LOI/proposal for TRIUMF ~ 2010-11.
- Unique aspects of the EDM work in Japan:
  - New UCN production mechanism aiming for highest density
  - Higher UCN density allows smaller cell size
  - New DC coil geometry
  - Xe comagnetometer

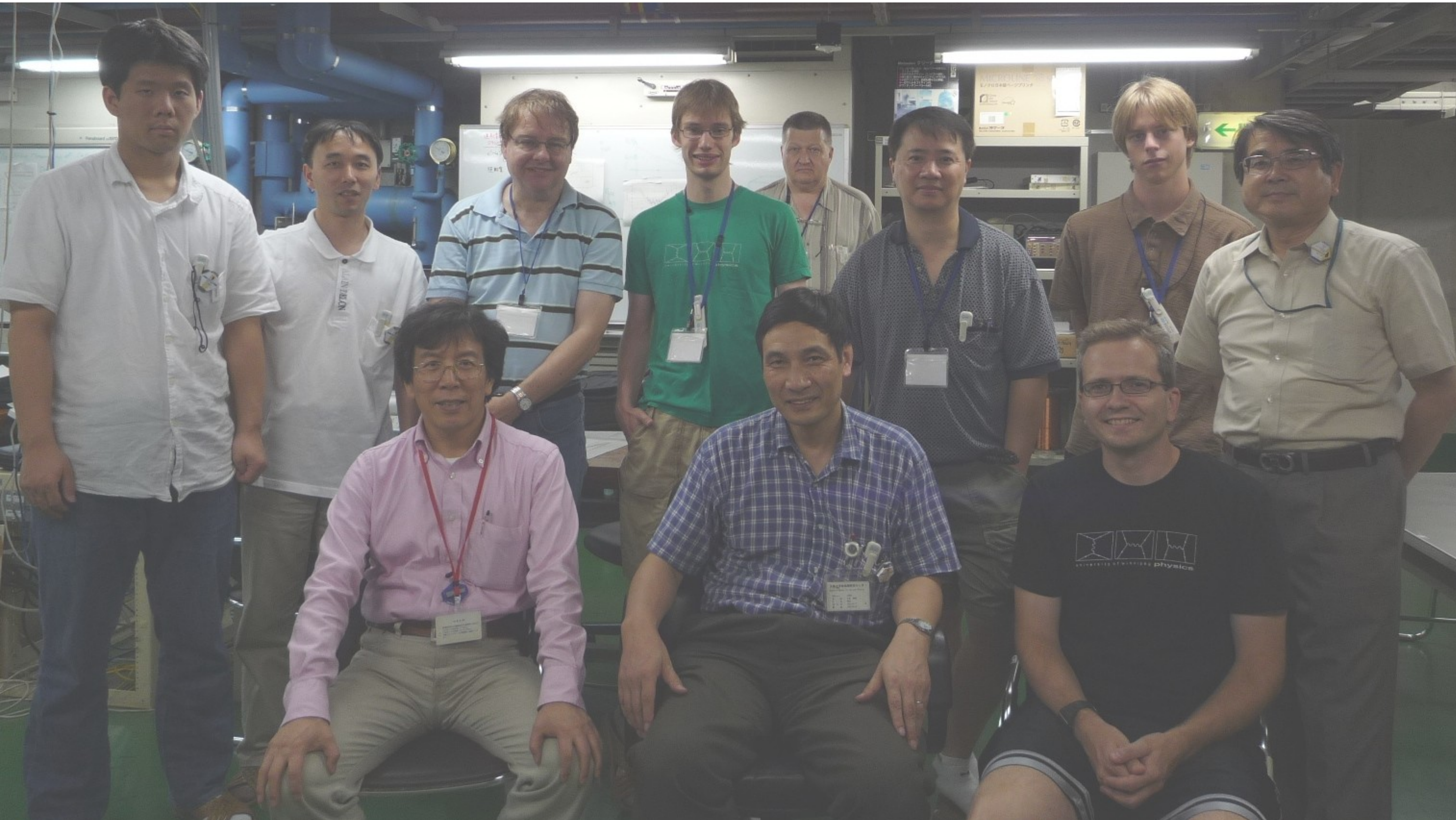
We gratefully welcome new collaborators to this exciting experiment!!!

Next data-taking run starts April 18.

Timeline

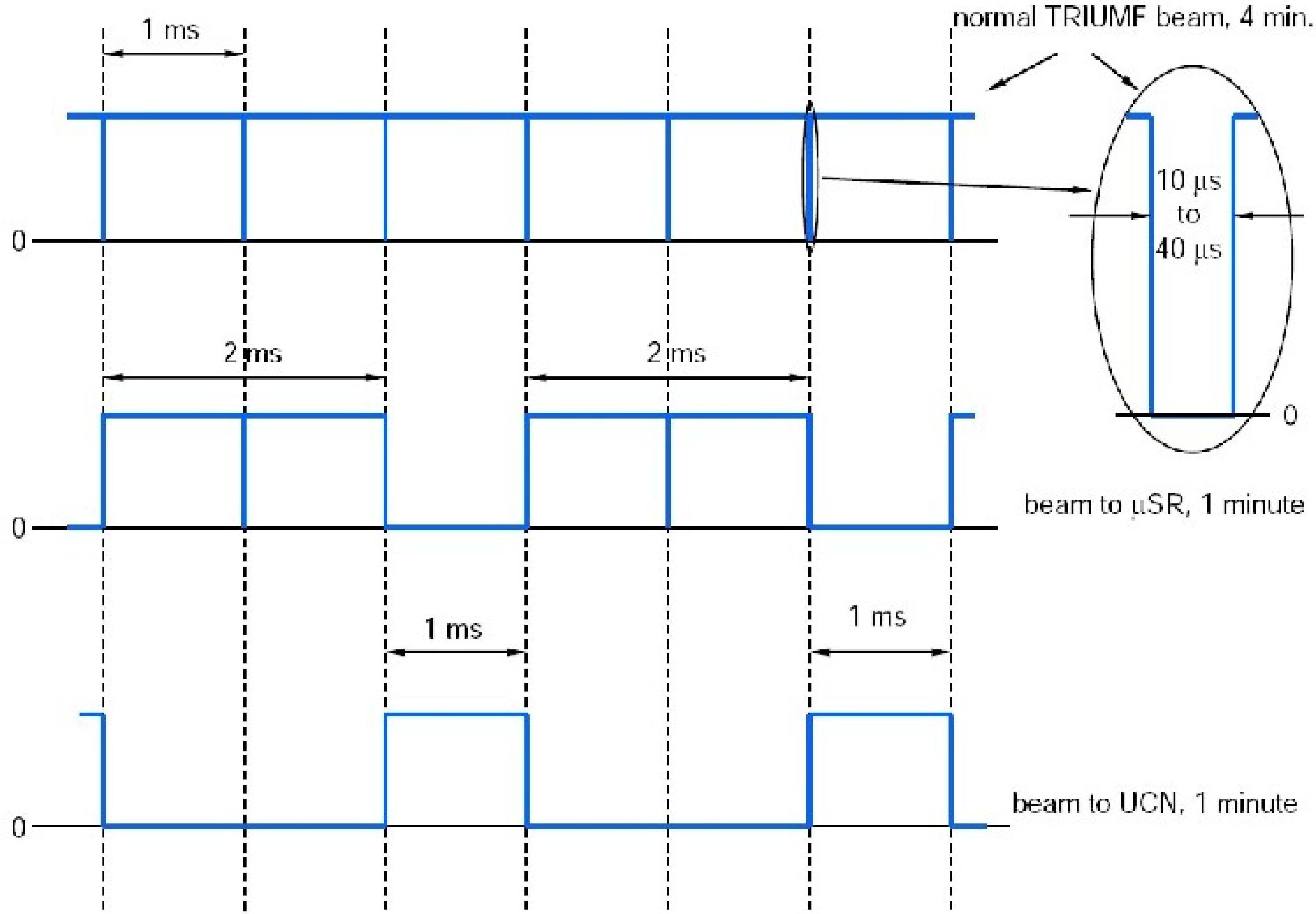
- June 2009: Source funded in Canada and Japan!!!
  - JSPS, CFI, TRIUMF, Acsion Ind., Govt of MB, UWpg.
- 2009-12:
  - develop UCN source in Japan, EDM experiment
  - preparations and design at TRIUMF
  - develop collaborations and proposals for experiments
- 2012-14: Install, commission at TRIUMF
- 2014-15: First experiments

Thank you!



Osaka, July 2009.

Kicker Concept



- Downstream users affected only at 7% level.
- UCN data when cyclotron is on (8 months/yr.)

Summary of CFI request

Item	Cost	Funding Source
UCN cryostat system	$4M	Japanese collaborators
Beamline	$2M	TRIUMF 5YP request
Kickers, shielding, spallation target	$4.225M	CFI NIF
Moderator design	$0.675M	Manitoba + Acsion Industries
Total	$10.9M	+$0.25 M UWpg

TRIUMF support for University Initiatives

- UCN cryostat system includes:
  - Existing UCN source ($2M)
  - Modifications to source for TRIUMF ($2M)
    - Horizontal extraction, improved guide technology, etc.
- Canadian money for physics experiments:
  - separate budget from NSERC.