Ultracold Neutrons at TRIUMF

Jeff Martin
The University of Winnipeg

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TRIUMF

International Spallation Ultracold Neutron Source

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

Collaborators: J. Birchall, J.D. Bowman, L. Buchmann, L. Clarke, C. Davis, B.W. Filippone, M. Gericke, R. Golub, K. Hatanaka, M. Hayden, T.M. Ito, S. Jeong, I. Kato, S. Komamiya, E. Korobkina, E. Korkmaz, L. Lee, K. Matsuta, A. Micherdzinska, W.D. Ramsay, S.A. Page, B. Plaster, I. Tanihata, W.T.H. van Oers, Y. Watanabe, S. Yamashita, T. Yoshioka

(KEK, 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.

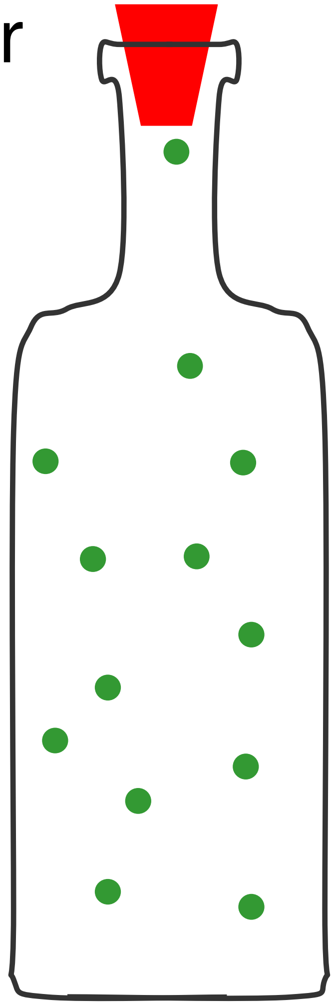
News: $10.9M proposal now funded in Canada and Japan.

Outline

- UCN production and source
  - Technical progress at TRIUMF
- Physics experiments at the UCN source
  - Prototyping experiments we're conducting in Japan toward a measurement of the neutron electric dipole moment.

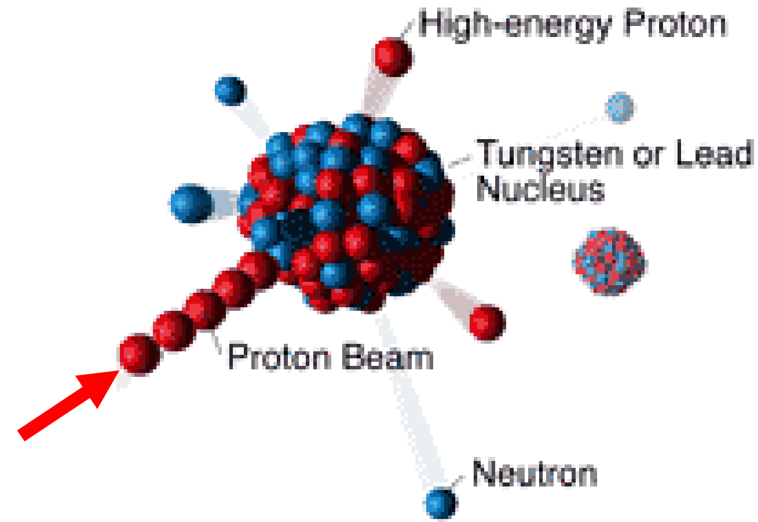
Ultracold Neutrons (UCN)

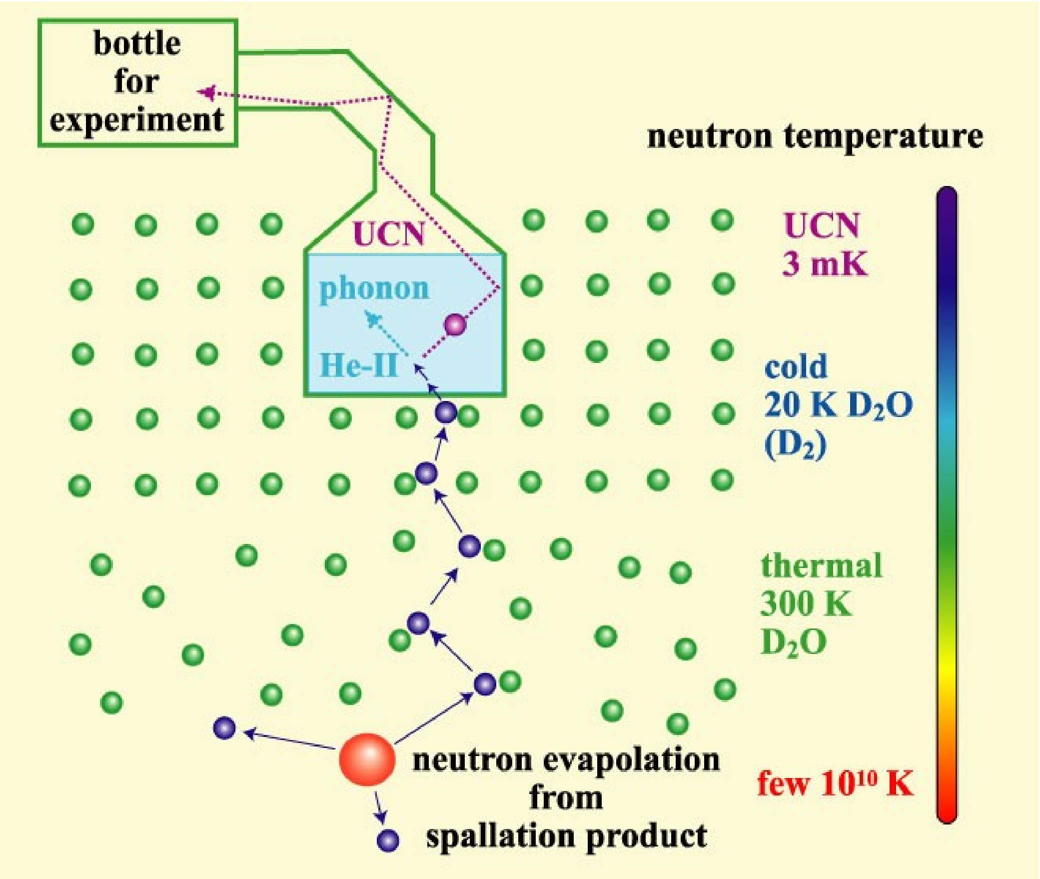
- UCN are neutrons that are moving so slowly that they are totally reflected from a variety of materials.
- So, they can be confined in material bottles for long periods of time.
- Typical parameters:
  - velocity < 8 m/s = 30 km/h = 20 mph
  - temperature < 4 mK
  - kinetic energy < 300 neV
- Interactions:
  - 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



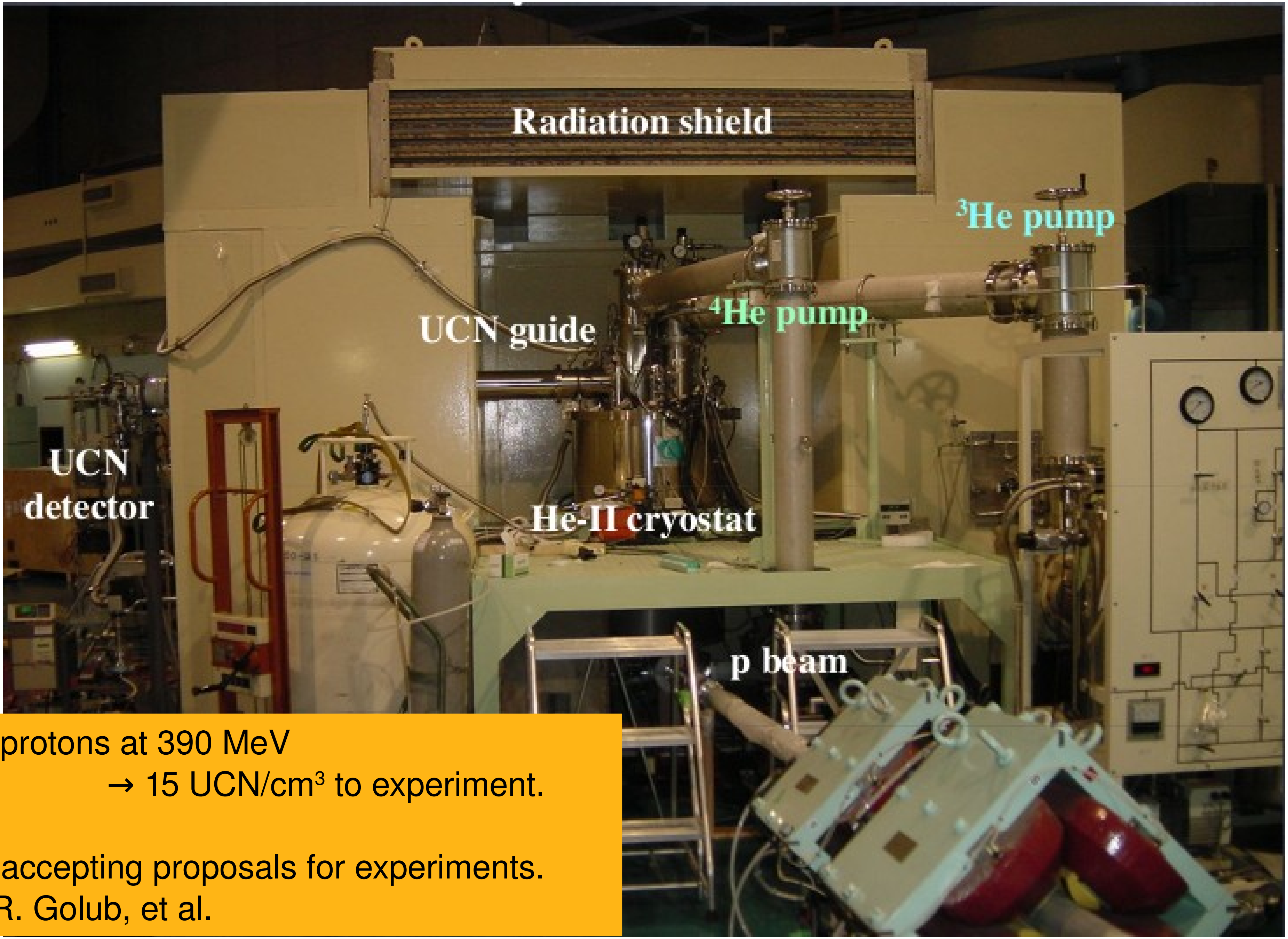
How to make UCN

- 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.

TRIUMF

CANADA'S NATIONAL LABORATORY FOR PARTICLE AND NUCLEAR PHYSICS

Owned and operated as a joint venture by a consortium of Canadian universities via a contribution through the National Research Council Canada

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

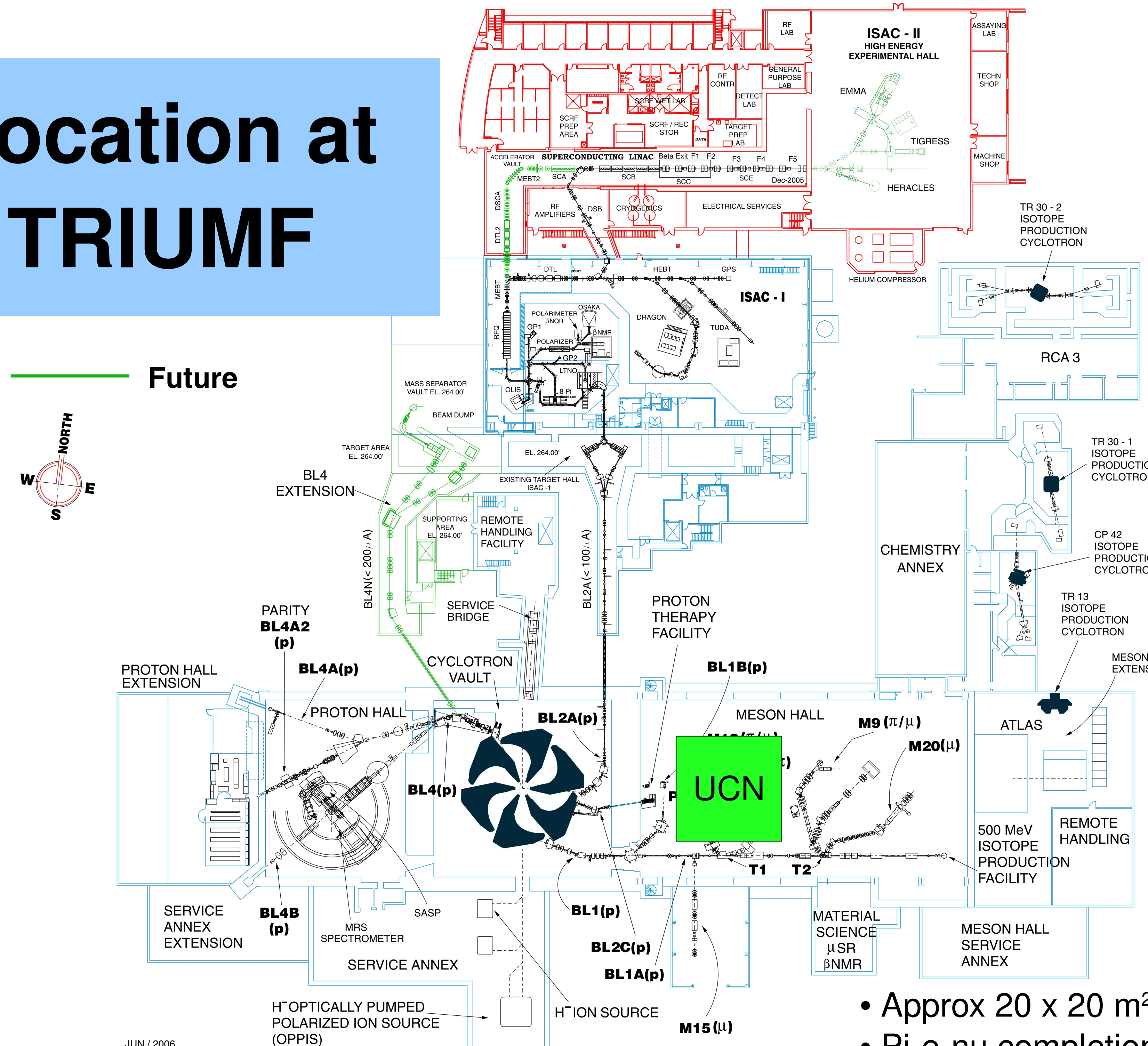
LABORATOIRE NATIONAL CANADIEN POUR LA RECHERCHE EN PHYSIQUE NUCLÉAIRE ET EN PHYSIQUE DES PARTICULES

Propriété d'un consortium d'universités canadiennes, géré en co-entreprise à partir d'une contribution administrée par le Conseil national de recherches Canada

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) 1-5 x 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



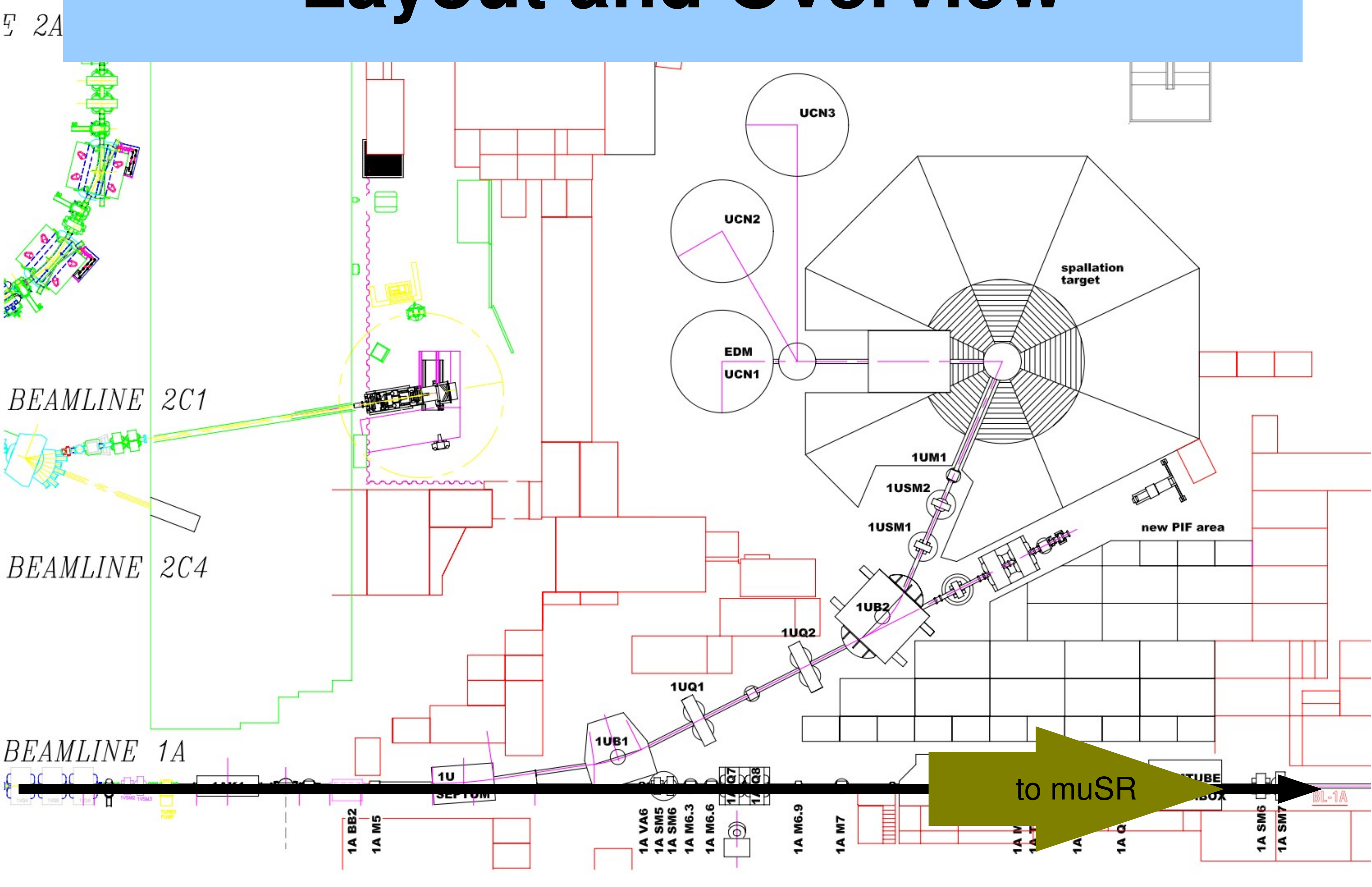
- Approx 20 x 20 m^2 box
- Pi-e-nu completion 2011

Technical Progress @ TRIUMF

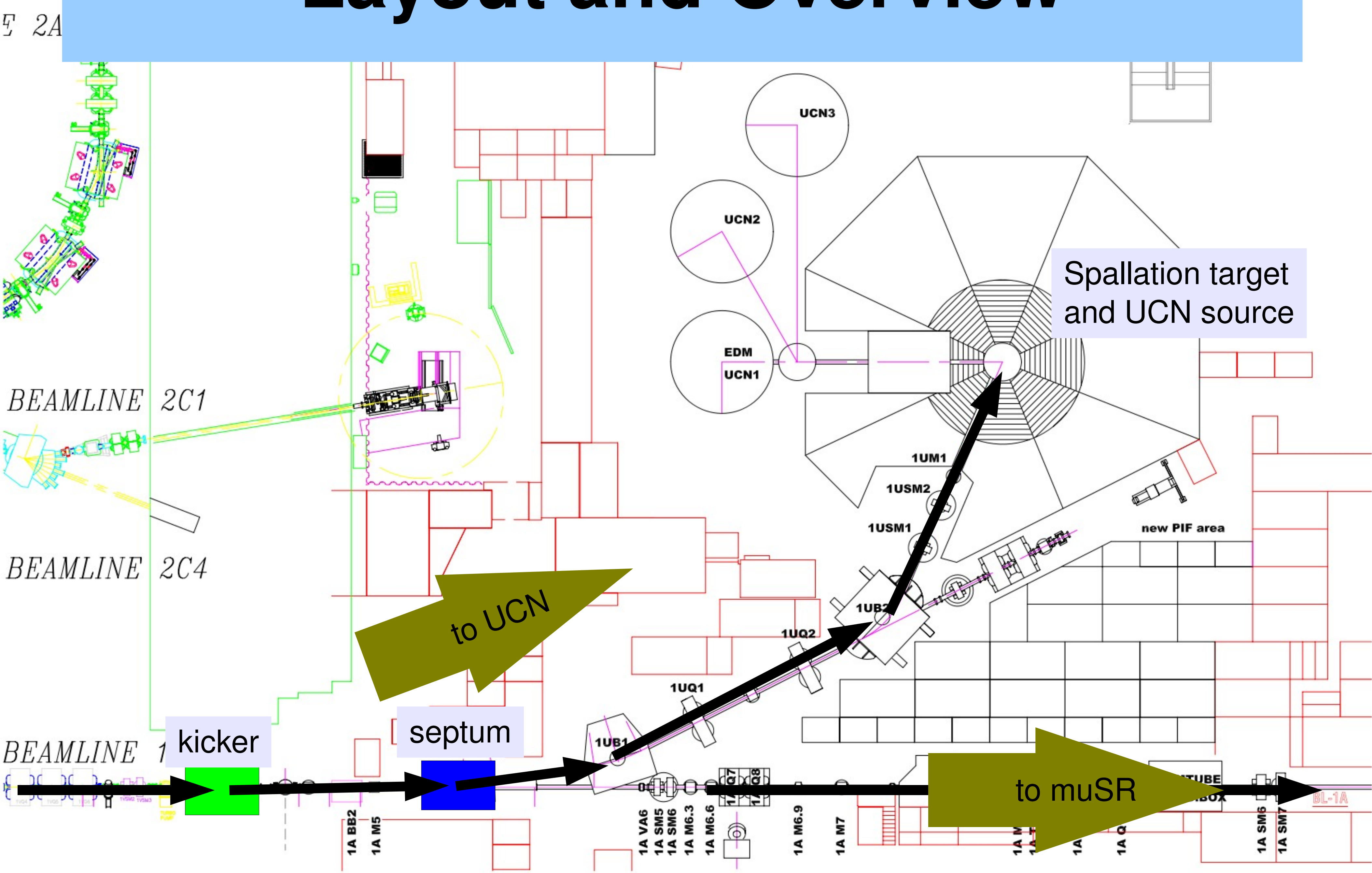
- Layout
- Kicker
- Beamline
- Target / remote extraction / shielding
- (Cryostat), cryogenics
- Installation
- Cost / schedule / personnel requirements
- MOU's

See: https://documents.triumf.ca/
-> Non-QMS collections
-> Experimental Facilities
-> UCN
for minutes, docs, etc.

Layout and Overview

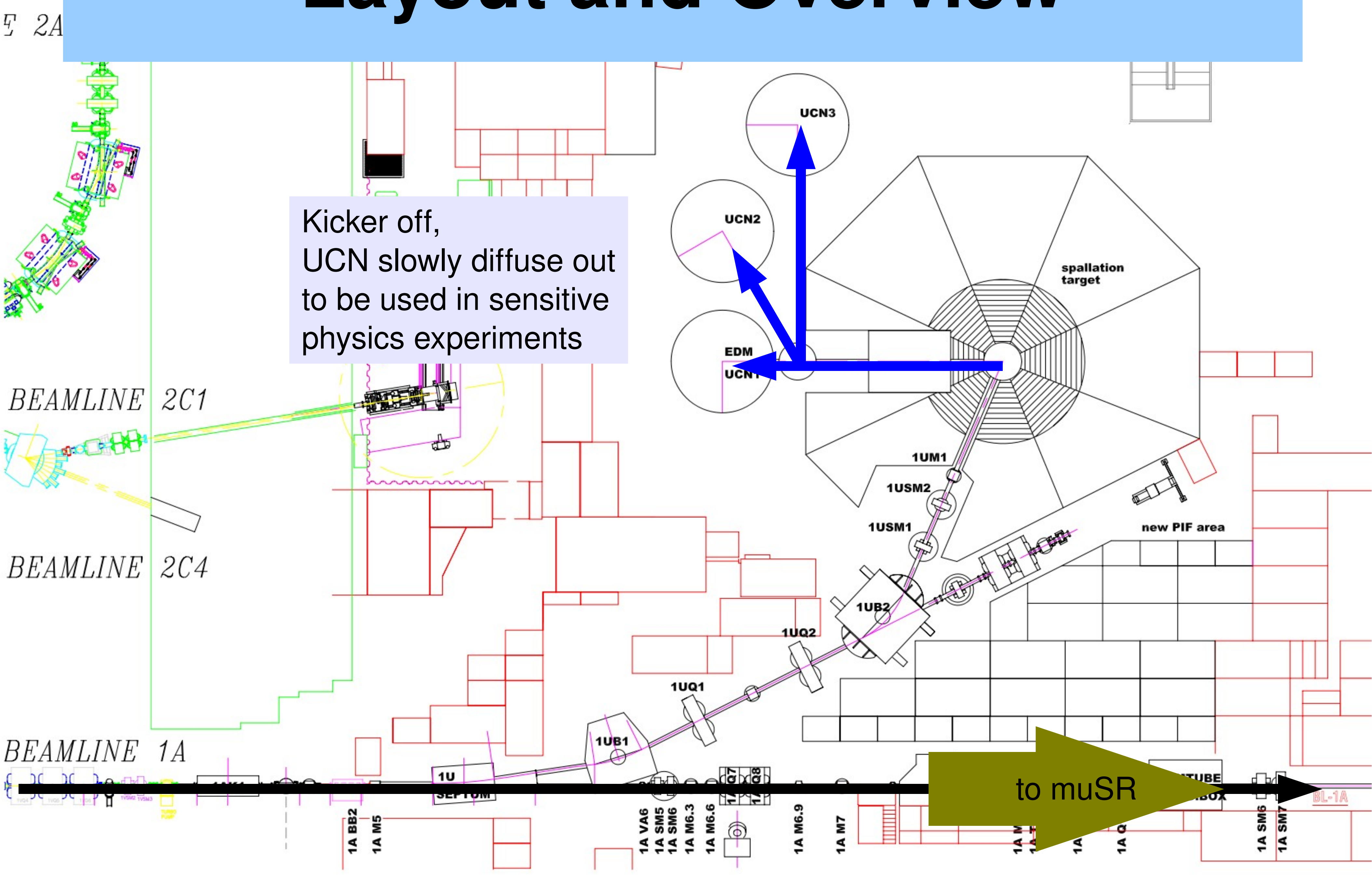


Layout and Overview



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.
- Power supply based on TRIUMF/CERN experience. Relies on HV solid state switches.
- Engineering design.

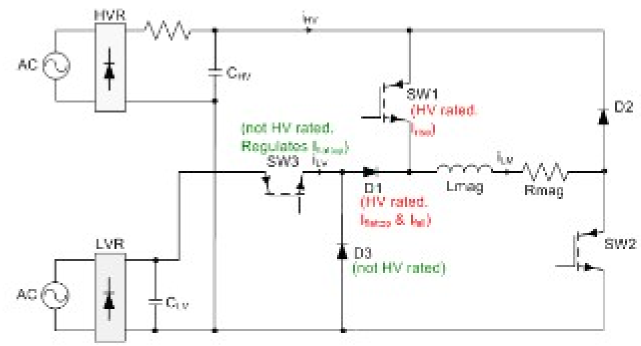
Kicker Specs:

- 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:

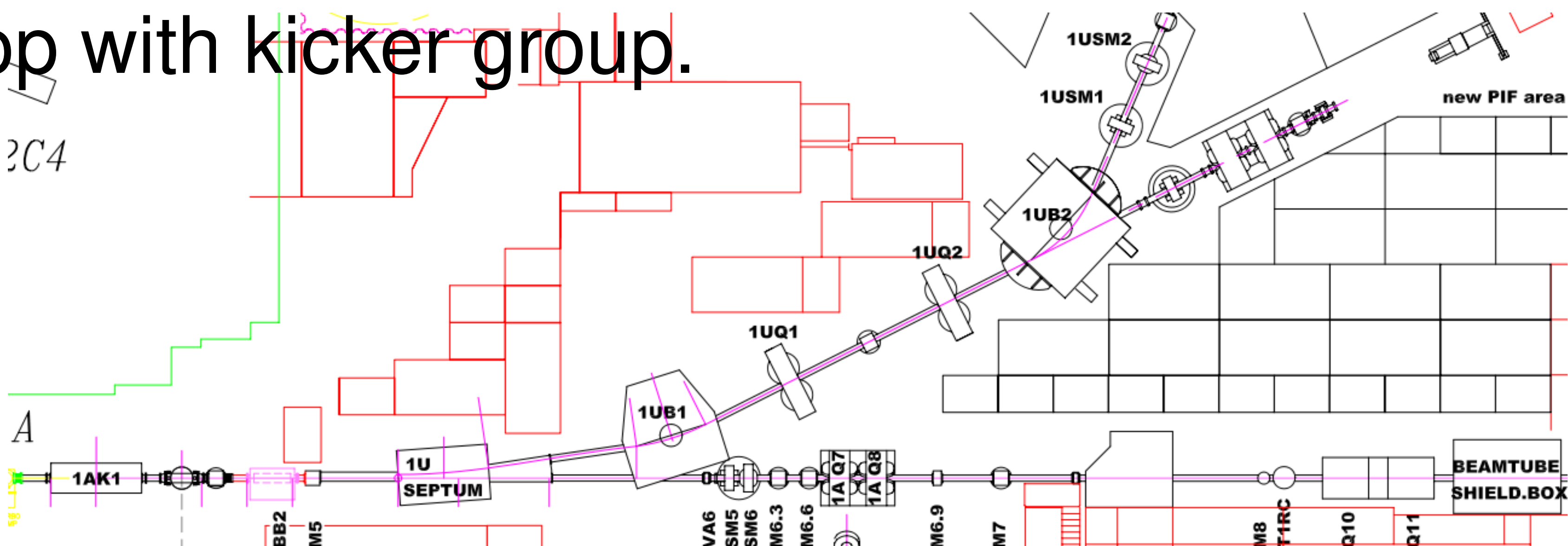
rise/fall time (μs)	turns	inductance (μH)	flattop current	peak voltage
5	4	30	725 A	4500 V
15	8	120	360 A	2900 V
26	12	270	240 A	2500 V

Kicker Power Supply



Beamline

- Optics studies for new layout, TRIUMF design note.
  - Small spot size achievable at spallation target.
- Beamline can use refurbished parts.
- Septum and first bender are new. Specs to develop with kicker group.



Target / Remote Handling / Shielding

- 3 cm dia x 10 cm long W.
- Cooling: water or He?
- Shielding calcs indicate 3 m steel, 2 m concrete
- Growth of target activity indicates levels manageable.
- Remote extraction via custom plug.
- Hermetic shielding

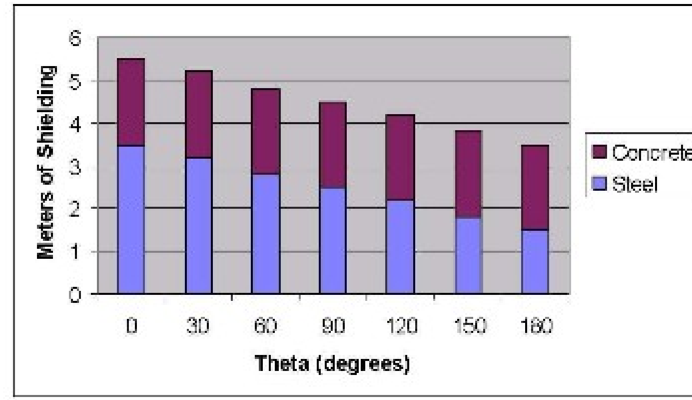
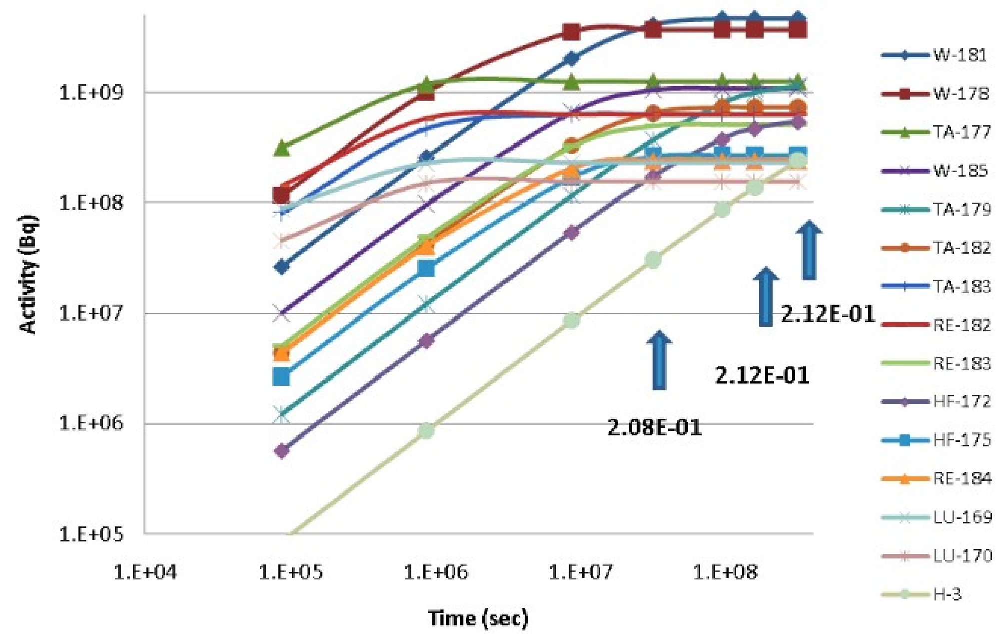
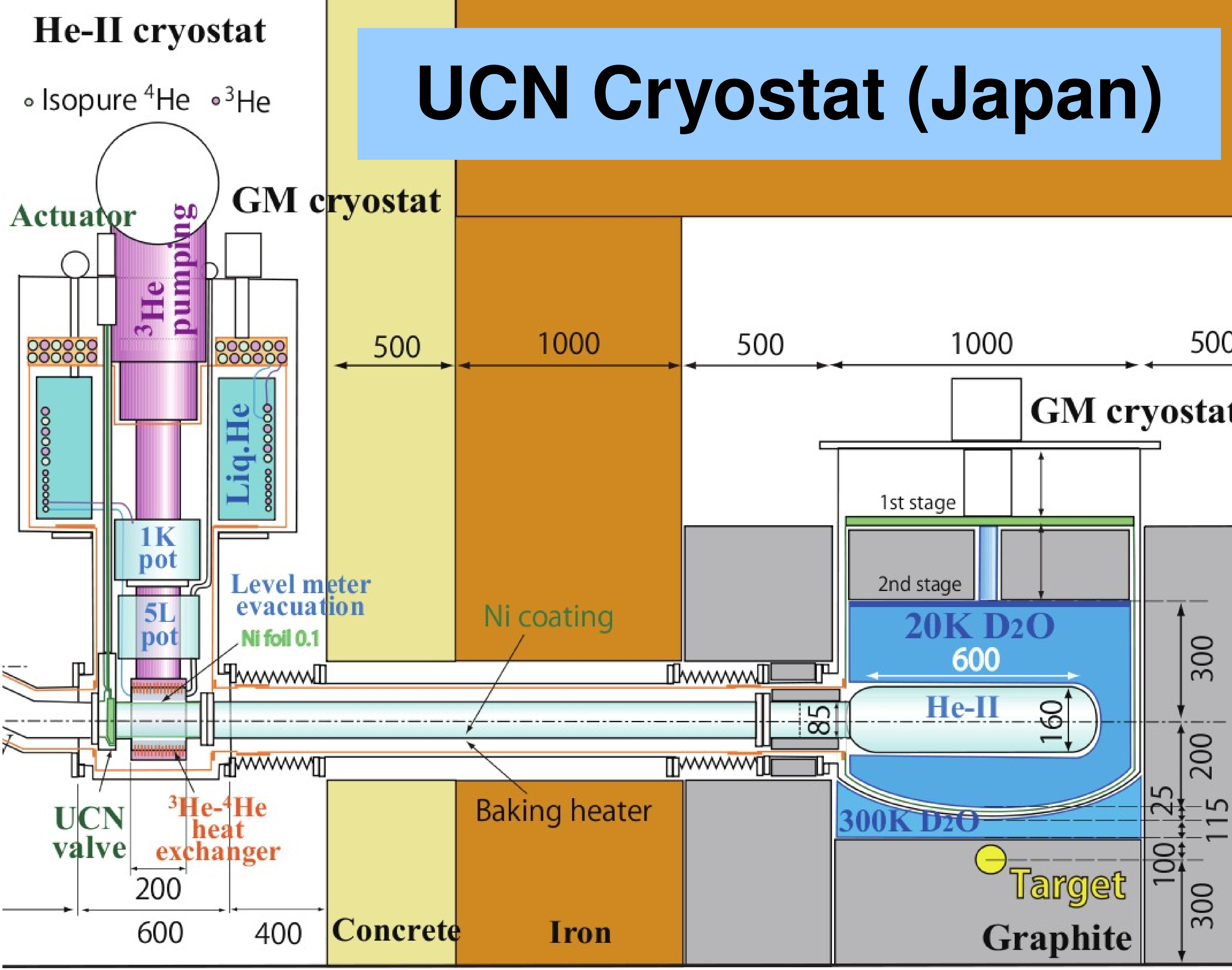
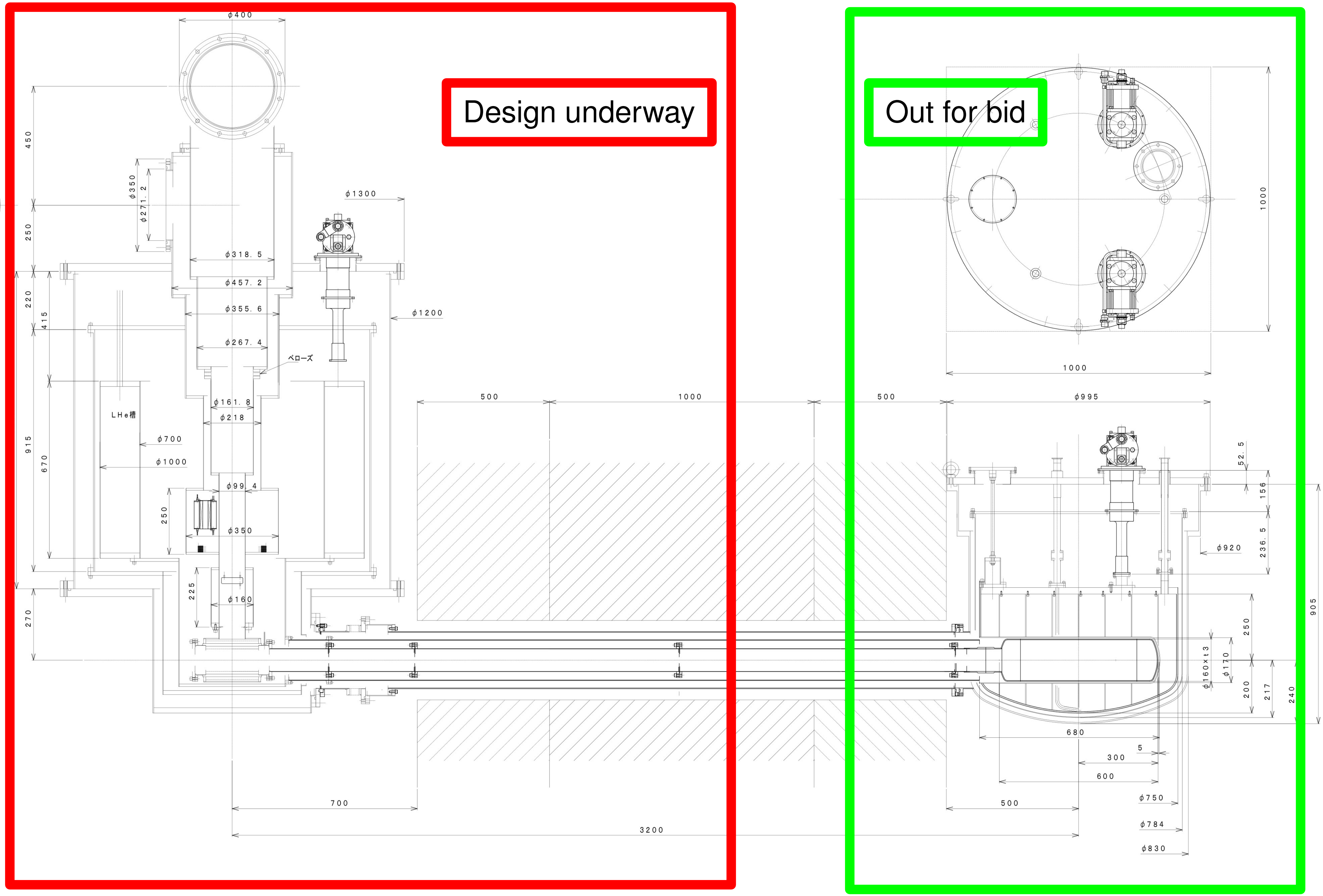


Figure 3: Shielding required for a 40 μA, 500 MeV proton beam incident on a thick tungsten target. The design dose rate is 3 μSv/hr immediately outside the shielding.



UCN Cryostat (Japan)




Design underway
Out for bid
ϕ400
ϕ350
ϕ271. 2
ϕ1300
ϕ318. 5
ϕ457. 2
ϕ355. 6
ϕ1200
ϕ267. 4
ベローズ
ϕ161. 8
ϕ218
LHe槽
ϕ700
ϕ1000
ϕ99. 4
ϕ350
ϕ160
ϕ995
ϕ920
ϕ170
ϕ750
ϕ784
ϕ830
700
3200
500
1000
680
300
600
905

Cryogenics

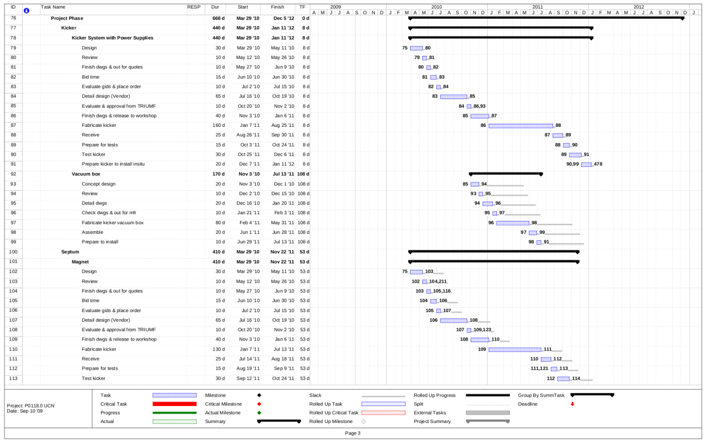
- Estimated LHe consumption < 1000 LL/day.
- Needs are consistent with liquifier requested in TRIUMF 5YP.
- Locate new liquifier near/in Meson Hall.
  - transfer / warm return lines direct to UCN
  - proposal to alter Japan section cryocoolers and use LHe instead
- Liquifier overhead to support other 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 CMMS users (Meson Hall).
- e.g. kicker install requires vault access.
- Installation schedule in development (meeting at 1 pm today) with TRIUMF experts.

Cost / sched / personnel / MOU's / reviews

- Complete resource-loaded schedule in development.
- Materials cost re-estimate also in progress.
- MOU's between KEK-TRIUMF-Winnipeg in prep
- Important dates:
  - Preproject phase (now)
  - TRIUMF Gate 2 review February 2010
  - CFI award finalization March 2010
  - Start of project, release of CFI funds April 2010
  - NSERC support Apr 2010, Osaka UCN workshop Apr 2010



Physics Experiments for the TRIUMF UCN Source

- neutron lifetime
- gravity levels
- n-EDM

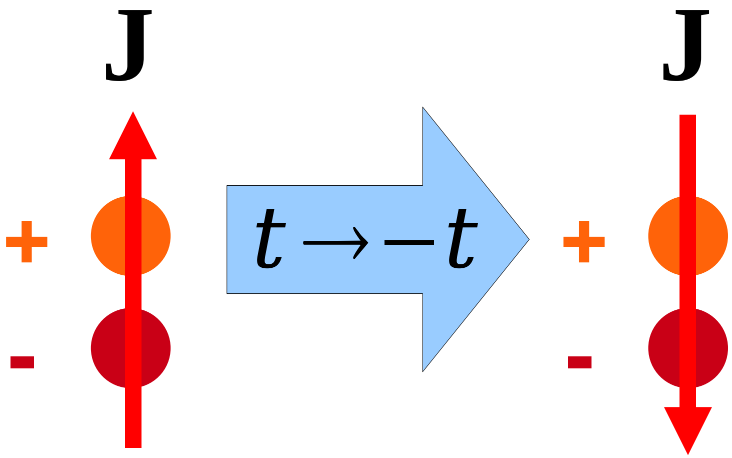
near term

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

dreams

All ideas / letters / proposals welcome

Neutron Electric Dipole Moment (n-EDM, d_n)



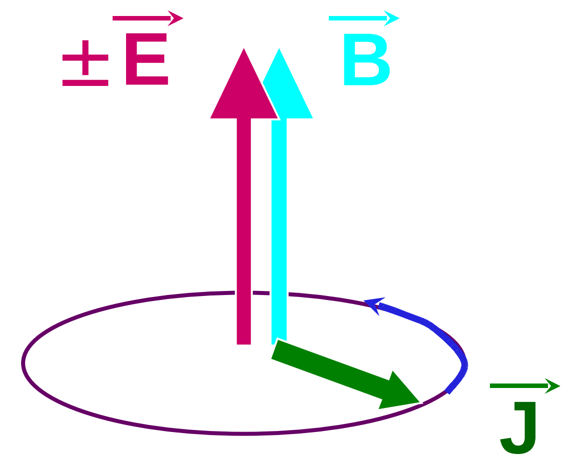
$$d_n \Rightarrow \not{T} \Rightarrow \not{CP}$$

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

• Complementary to Rn-EDM TRIUMF ISAC.

Experimental technique:

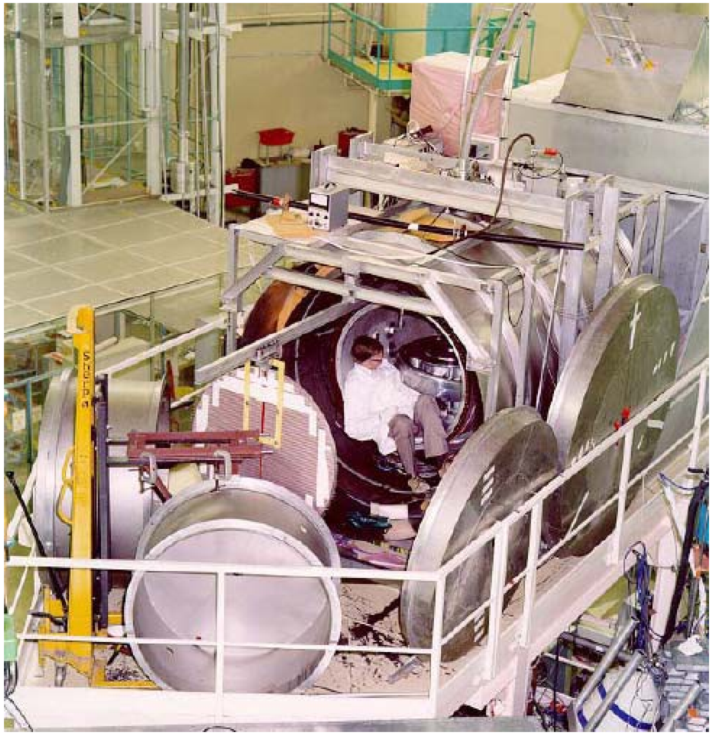
- put UCN in a bottle with *E*-, *B*-fields
- search for a change in spin precession frequency upon *E* reversal.



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

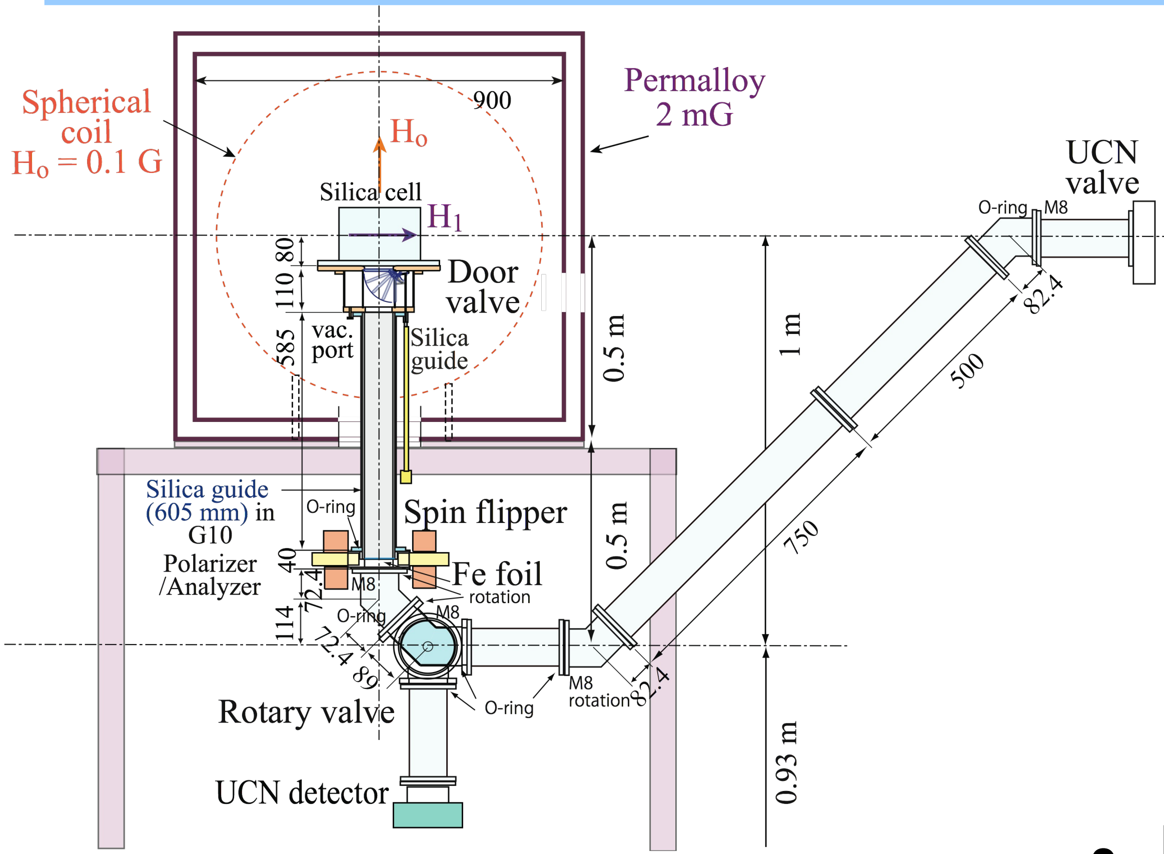
Past and Future n-EDM efforts

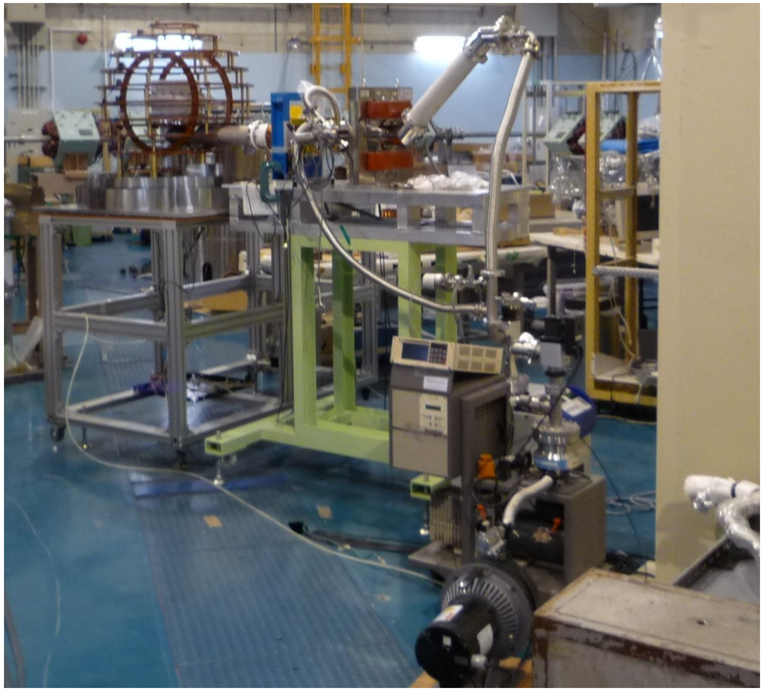
- Sussex-RAL-ILL expt. ($d_n < 3 \times 10^{-26}$ e-cm)
  - 0.7 UCN/cc, room temp, in vacuo
- CryoEDM (Sussex-RAL-ILL)
  - 1000 UCN/cc, in superfluid 4He
- SNS
  - 430 UCN/cc, in superfluid 4He
- PSI
  - 1000 UCN/cc, in vacuo
- TRIUMF: 10,000 UCN/cc



Sussex-RAL-ILL experiment

n-EDM development in Japan

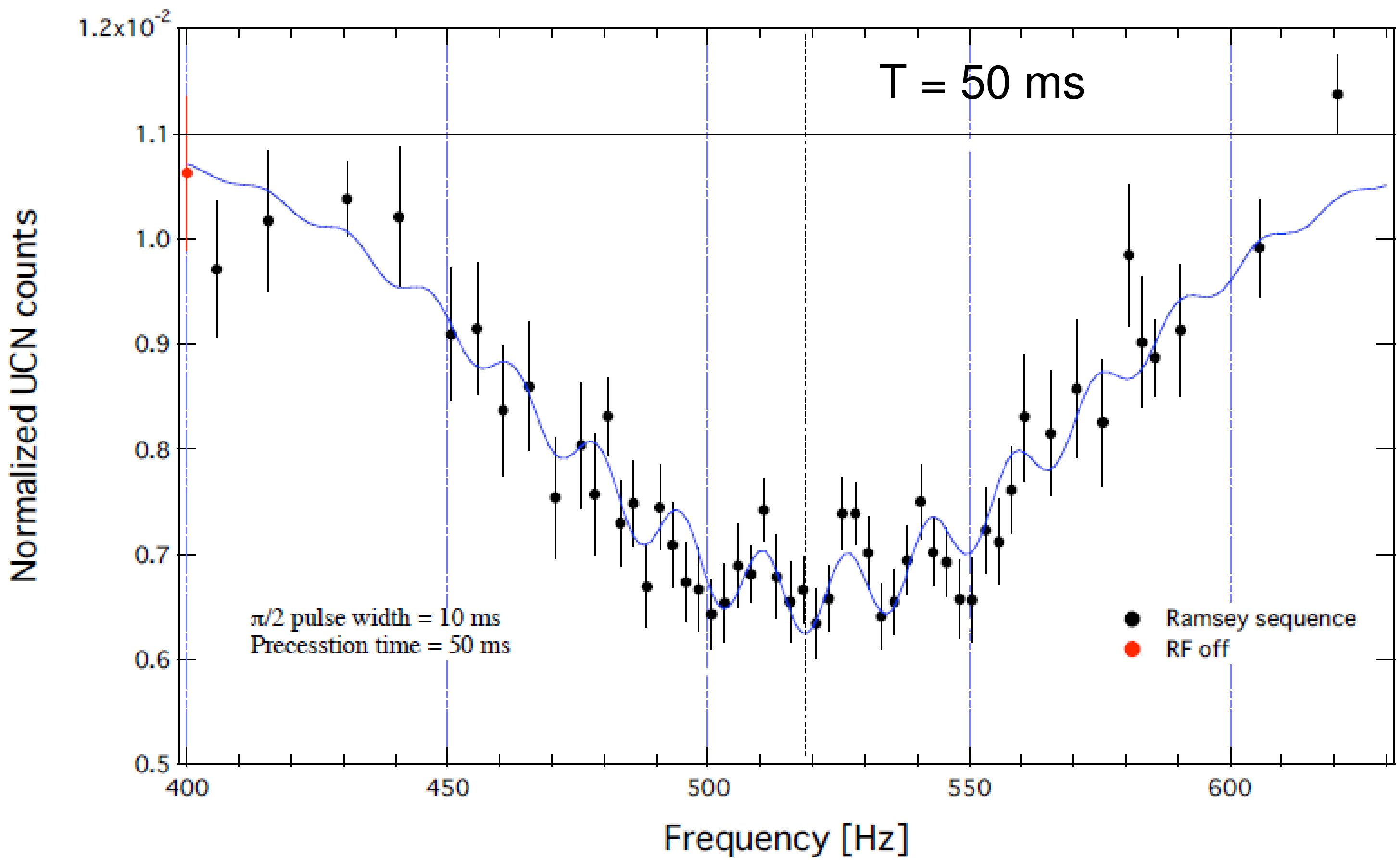




- Masuda, et al. First experiments July 7-16 at RCNP, Osaka.

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

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



Successful demonstration of the basic technique behind precision EDM measurements.
Improvements in field homogeneity, profile, magnitude should allow longer T.

EDM Statistics

- ILL: $$\sigma\left(d_n\right) = \frac{\hbar}{2\alpha E T \sqrt{N}}$$
  - 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.
  - Next run is Dec. 8-14, 2009.
- 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 believe this will ultimately lead to a competitive experimental concept.

Timeline

- 2007-8: UCN source supported by TRIUMF committees, included in plan for TRIUMF
- July 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
- 2012-13: Install, commission at TRIUMF
- 2012-15: First experiments

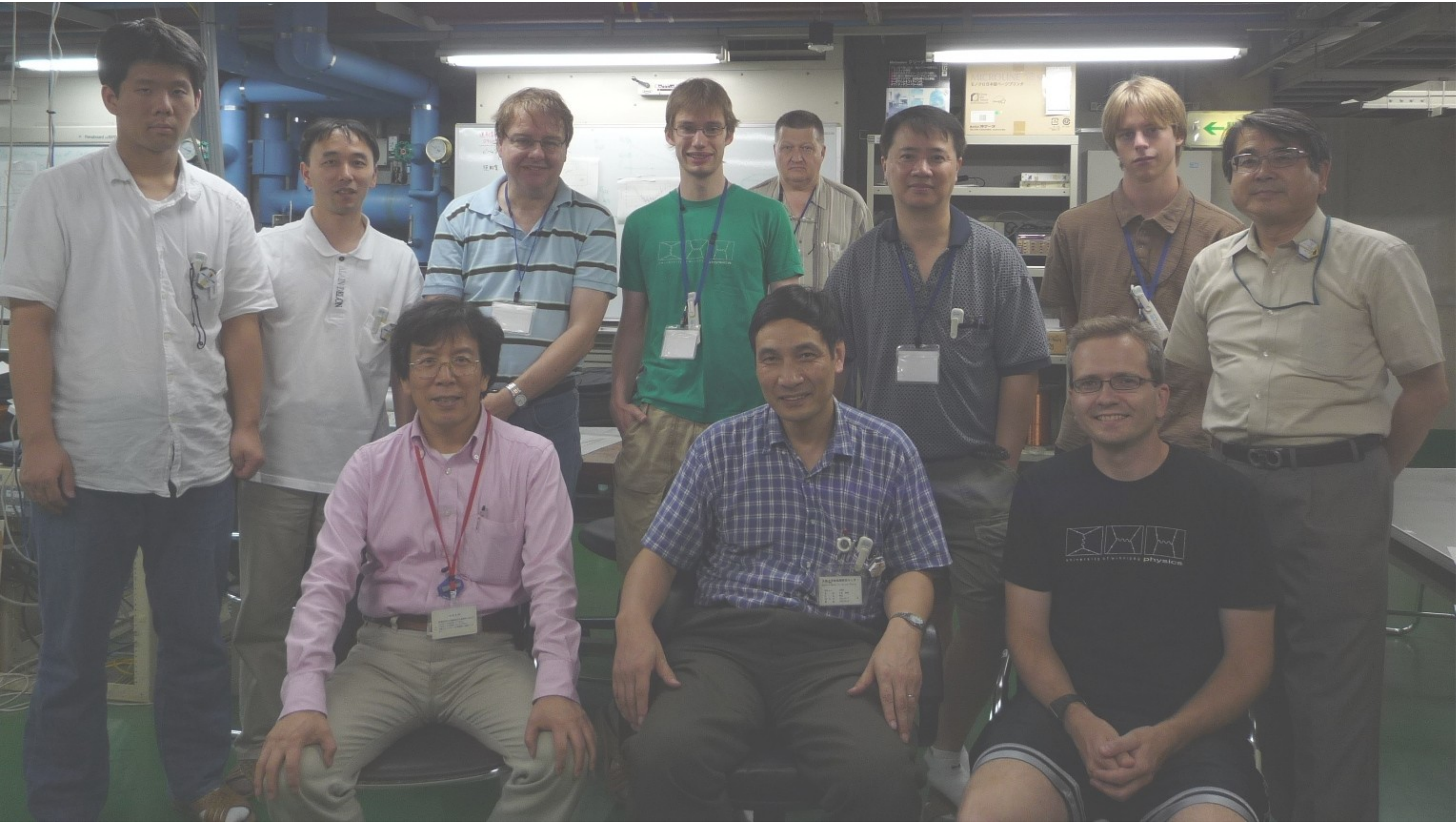
Summary of CFI request

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

- 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.

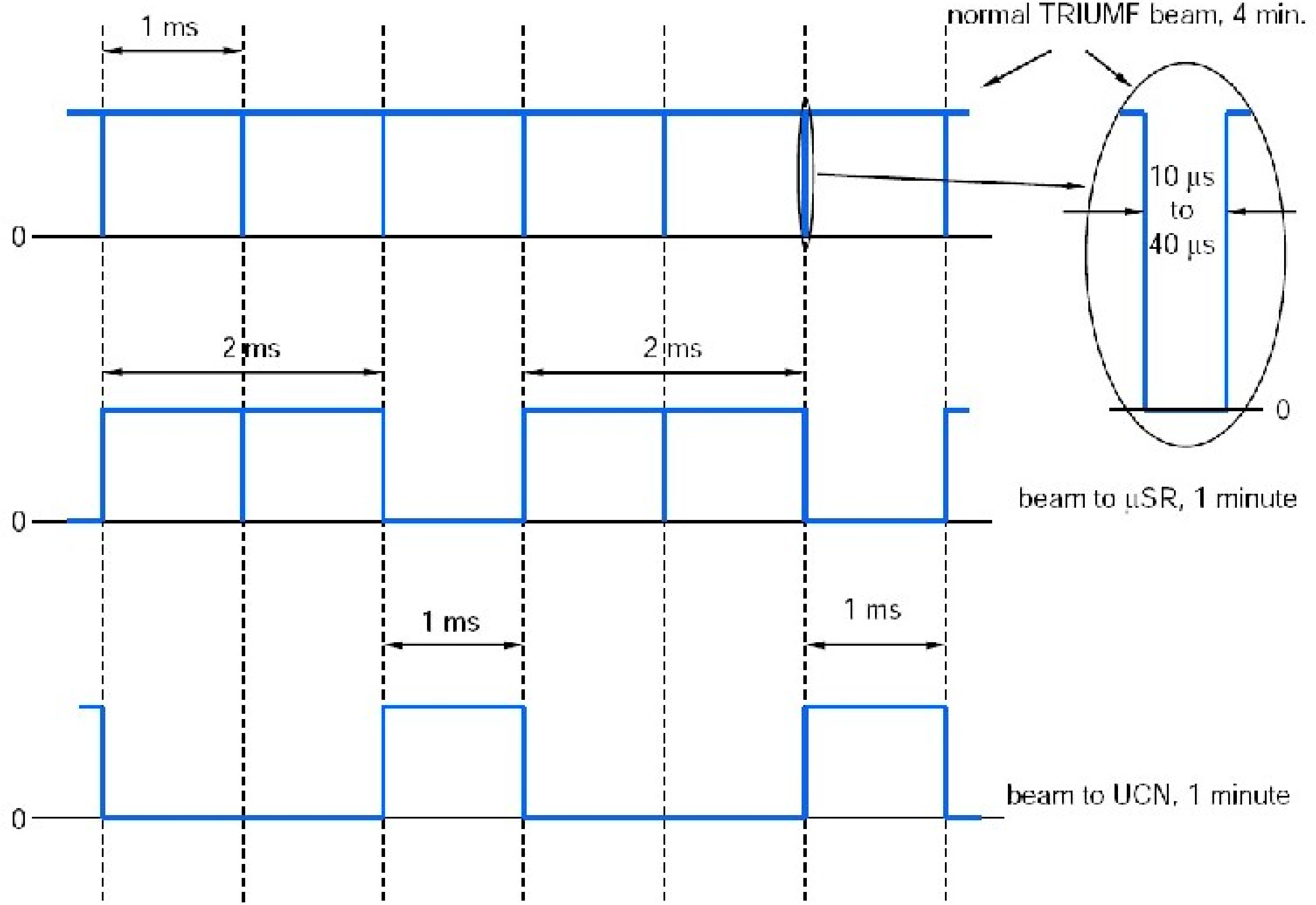
TRIUMF support for University Initiatives

Thank you!



Osaka, July 2009.

Kicker Concept



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