An Ultracold Neutron Source for TRIUMF

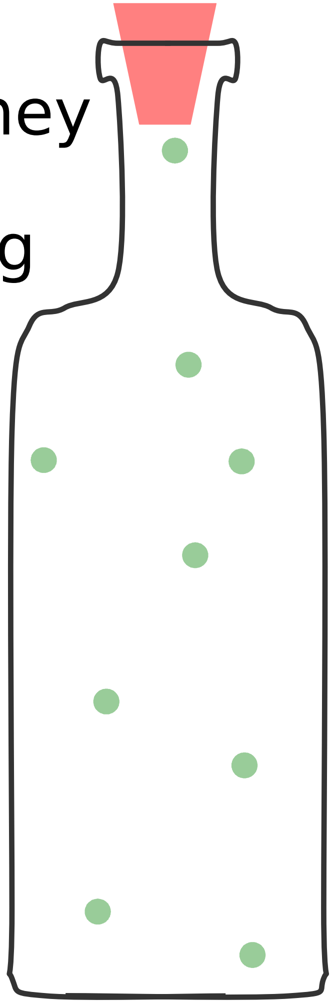
Jeff Martin (U. Winnipeg)

for Lothar Buchmann, Chuck Davis, Michael Gericke, Akira Konaka, Larry Lee, Yasuhiro Masuda, Ania Micherdzinska, Shelley Page, Des Ramsay, Wim van Oers

(KEK, TRIUMF, U. Manitoba, U. Winnipeg)

1. Introduction to Ultracold Neutrons (UCN)
2. UCN physics experiments
3. Source work at RCNP for TRIUMF
4. TRIUMF facility
5. CFI, relationship, collaboration, KEK

Ultracold Neutrons



- UCN are neutrons that are moving so slowly that they are totally reflected from surfaces of materials.
- So, they can be confined in material bottles for long periods of time.
- Typical parameters:
  - velocity < 8 m/s
  - temperature < 4 mK
  - kinetic energy < 300 neV
- Interactions:
  - gravity: V=mgh (h < 3 m)
  - weak interaction (allows UCN to decay)
  - magnetic fields: V=-μ•B (100% polarization)
  - strong interaction
- Experiments at UCN sources are chronically limited by UCN density. TRIUMF has the potential to be a world leader in this regard.

UCN Source at TRIUMF would be a world-class facility

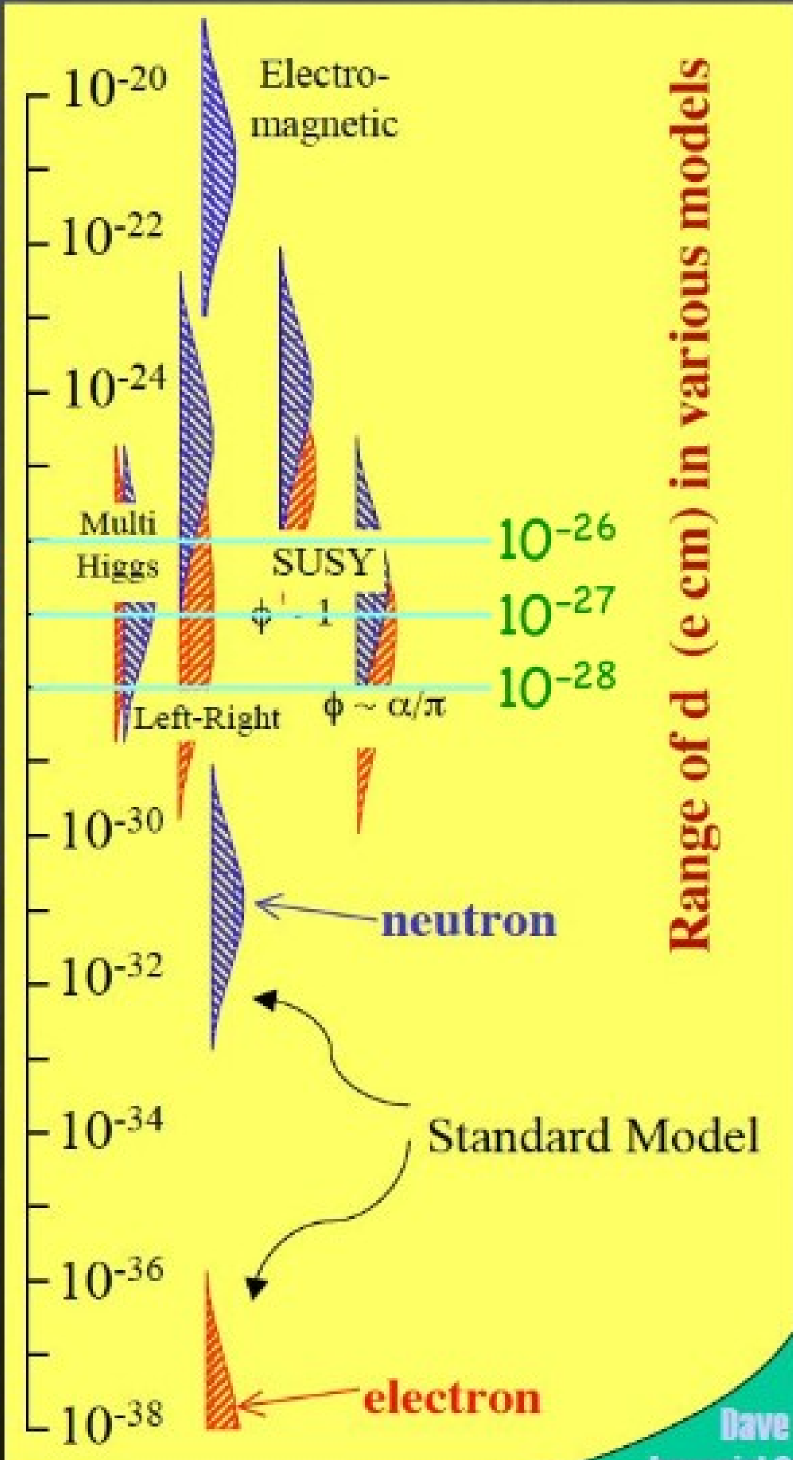
	Source type	E_c and τ_s	UCN density ρ_{UCN}(UCN/cm^3)
TRIUMF 5 kW$_{av}$ proton	0.8K He-II	E_c = 210 neV τ_s = 150 s	1.8 x 10^4 at experimental port
Grenoble 60MW reactor	0.5K He-II	E_c = 250 neV τ_s = 150 s	1000 in He-II
SNS cold neutron beam	0.3K He-II	E_c = 134 neV τ_s = 500 s	430 in He-II
Munich 20MW reactor	SD_2	E_c = 250 neV	10^4 in source
North Carolina 1 MW reactor	SD_2	E_c = 335 neV	1300 in source
PSI 12 kW$_{av}$ proton	SD_2	E_c = 250 neV τ_s = 888 s	2000 in source
Los Alamos 2.4 kW$_{av}$ proton	SD_2	E_c = 250 neV τ_s = 2.6 s	120 in source

UCN Physics

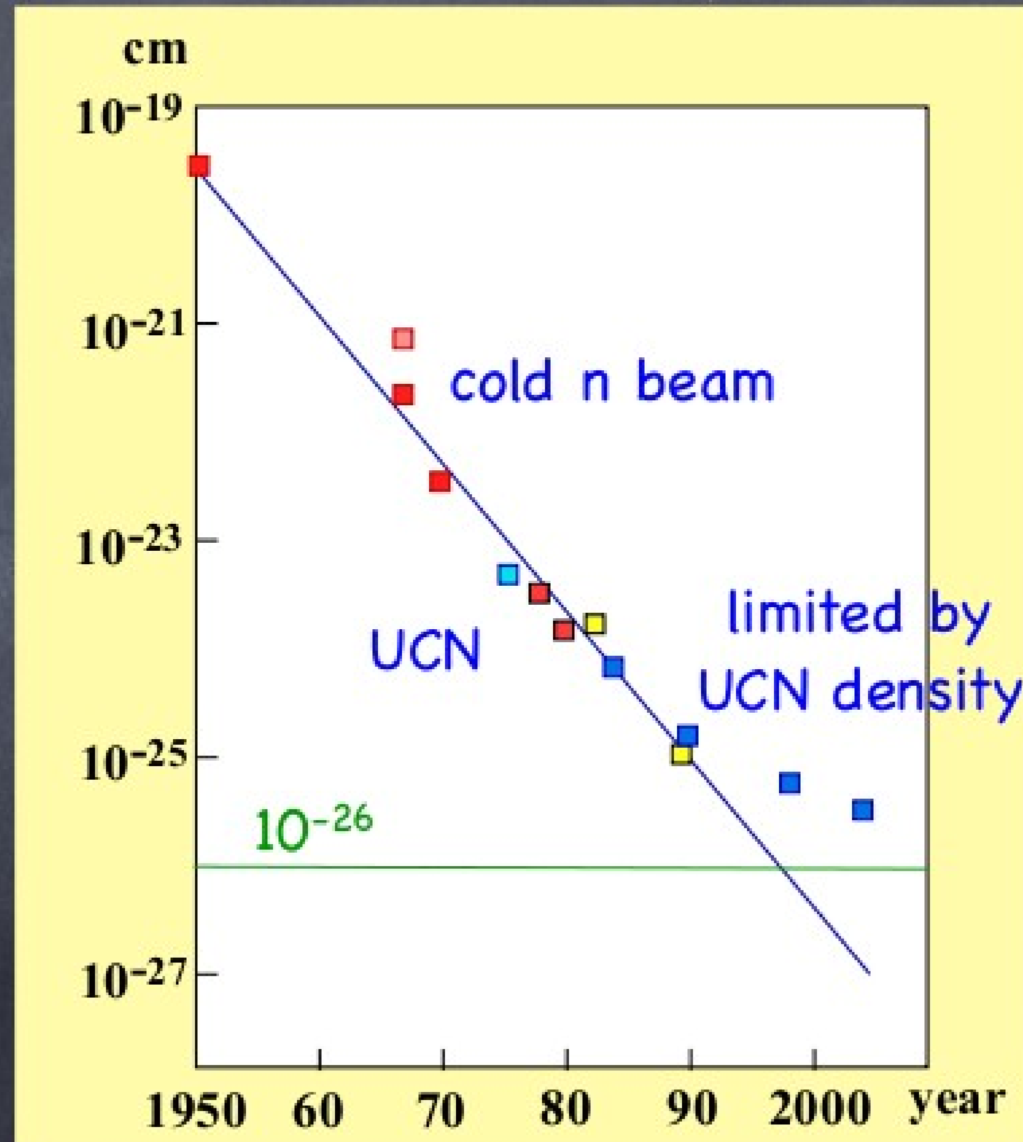
- fundamental interactions of UCN
  - EDM
  - gravity
  - beta-decay
  - nnbar oscillations
- astrophysics
  - BBN
  - r-process
- surface physics
- development towards JPARC 2nd target station UCN source

EDM history

Theory

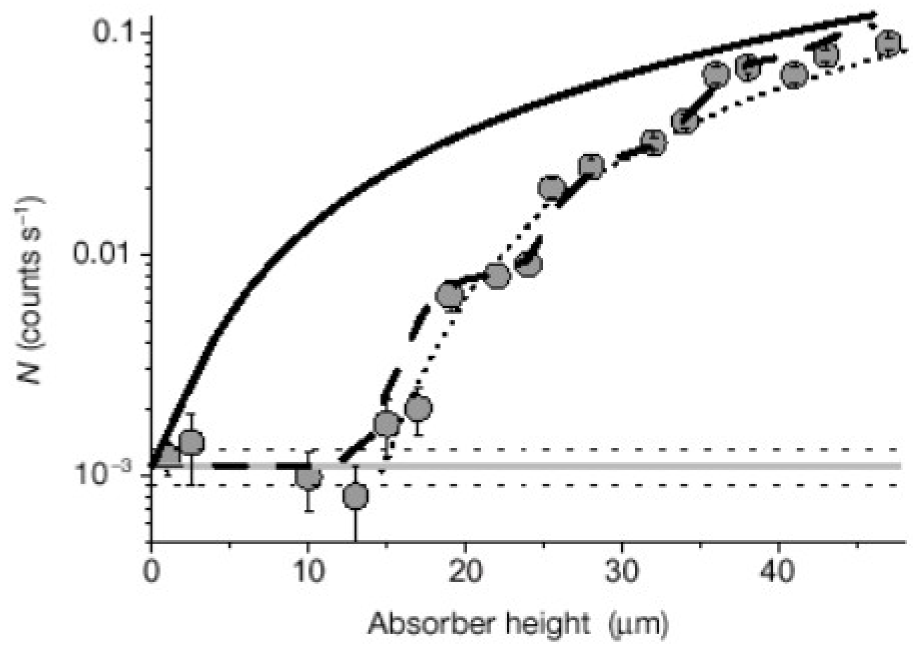


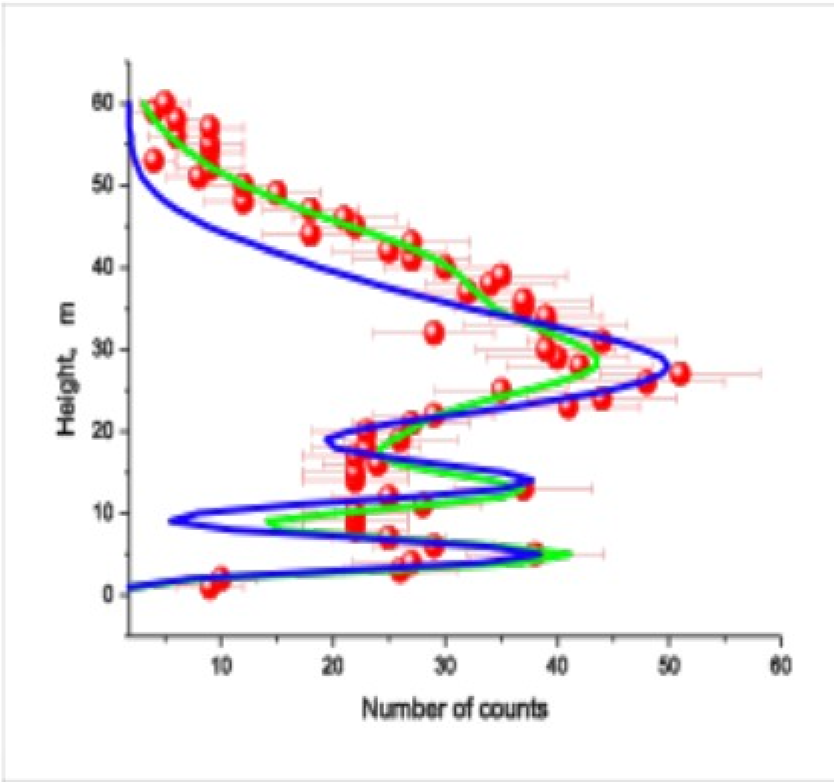
Experiment

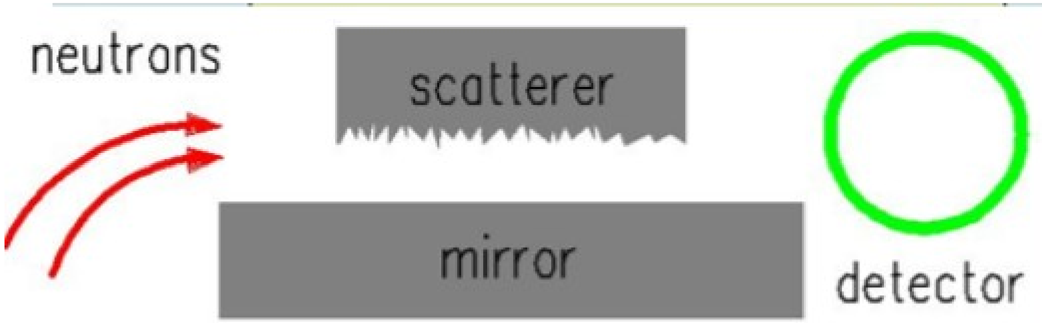


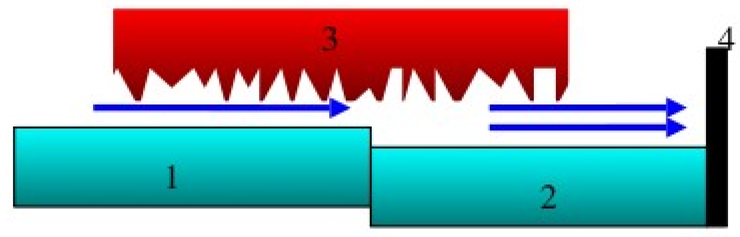
UCN quantum states in gravity

- test of gravity at 10 um scale







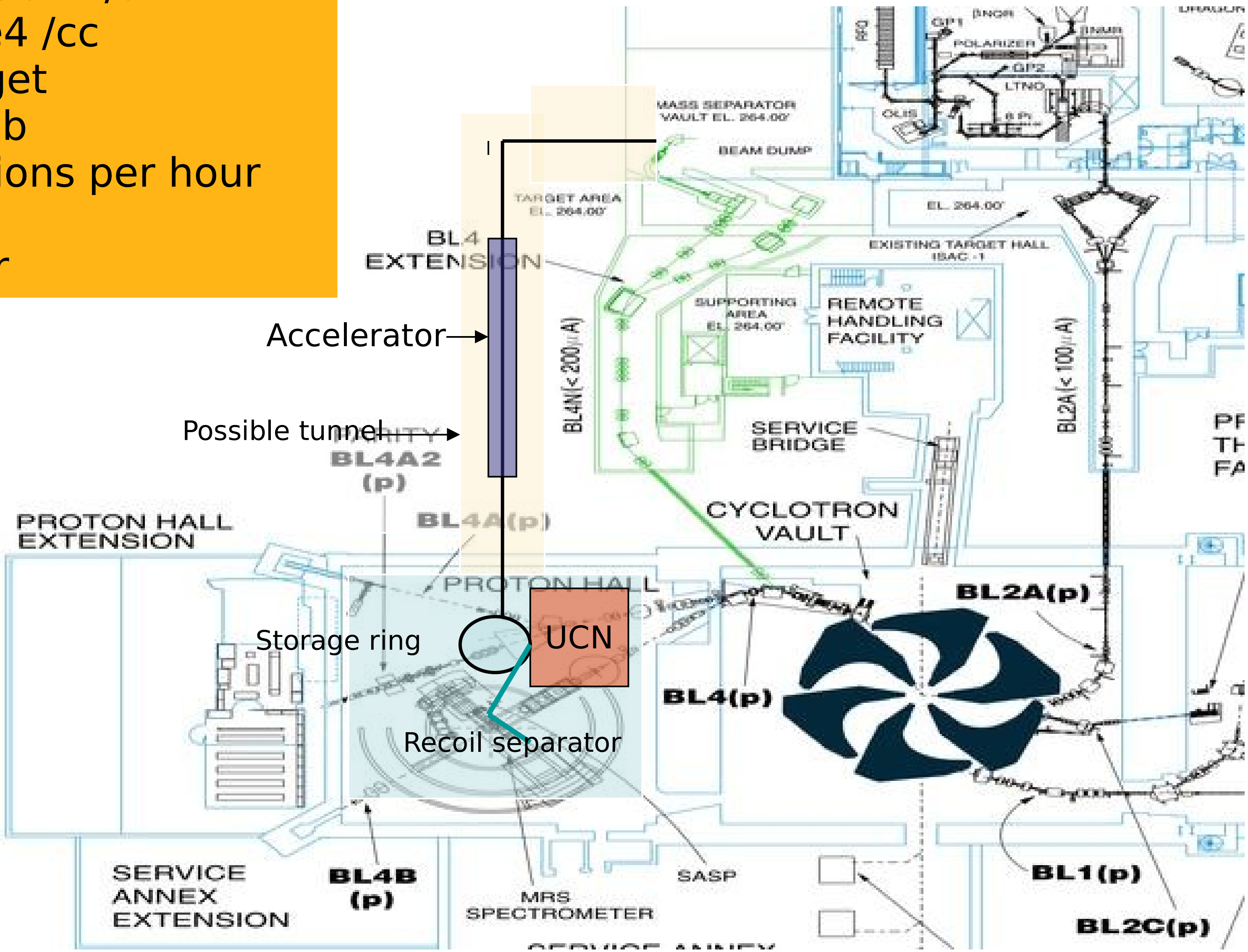


Measuring (n,ɣ) cross sections of the r-process (Buchmann)

132Sn stored in ring interacts with free neutron (UCN) target.

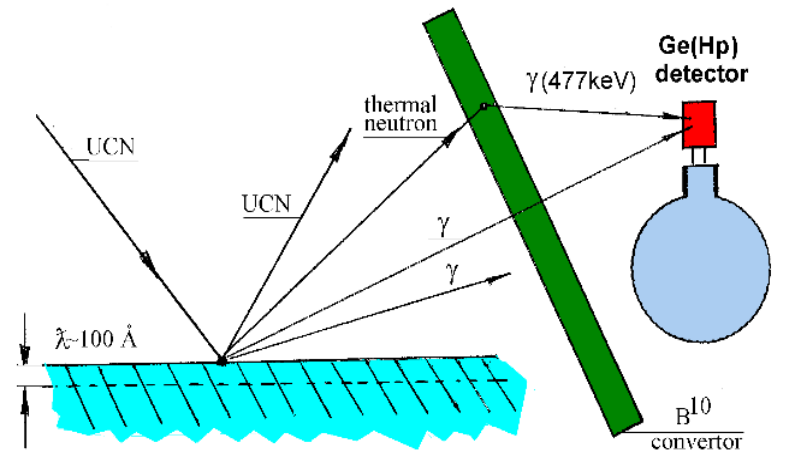
132Sn current 5e17 /s
UCN density 2e4 /cc
meter-long target
sigma ~ 100 mb
=> 50 interactions per hour

recoil separator



Surface Physics

- Many ideas to use UCN to study 10 nm thin surface films
  - (n,gamma)
  - UCN loss measurements
  - n scattering
  - reflectometry
    - polarization for magnetic films



Korobkina, NCSU

- shown to be sensitive to low-frequency excitations (interesting for surface physics)
- In all cases, lack of UCN worldwide is the problem

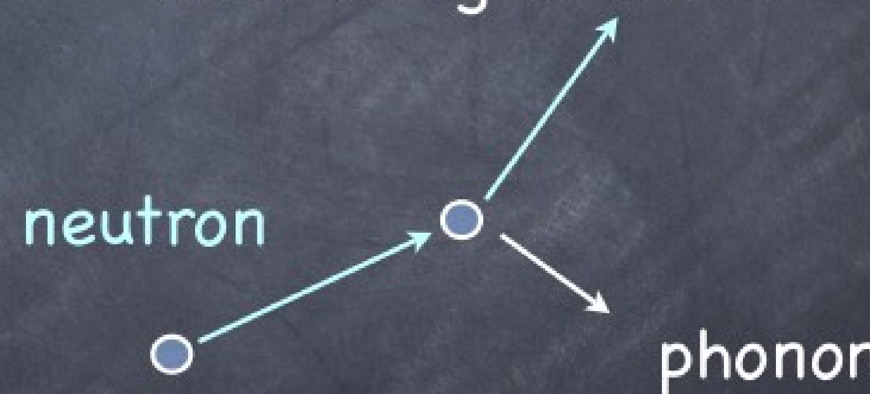
How do we achieve this UCN density?

	Source type	E_c and τ_s	UCN density $\rho_{UCN}(UCN/cm^3)$
TRIUMF 5 kW_{av} proton	0.8K He-II	E_c = 210 neV τ_s = 150 s	1.8 x 10^4 at experimental port
Grenoble 60MW reactor	0.5K He-II	E_c = 250 neV τ_s = 150 s	1000 in He-II
SNS cold neutron beam	0.3K He-II	E_c = 134 neV τ_s = 500 s	430 in He-II
Munich 20MW reactor	SD_2	E_c = 250 neV	10^4 in source
North Carolina 1 MW reactor	SD_2	E_c = 335 neV	1300 in source
PSI 12 kW_{av} proton	SD_2	E_c = 250 neV τ_s = 888 s	2000 in source
Los Alamos 2.4 kW_{av} proton	SD_2	E_c = 250 neV τ_s = 2.6 s	120 in source

Superthermal UCN production in He-II

M.R. Gibbs et al. (1999)

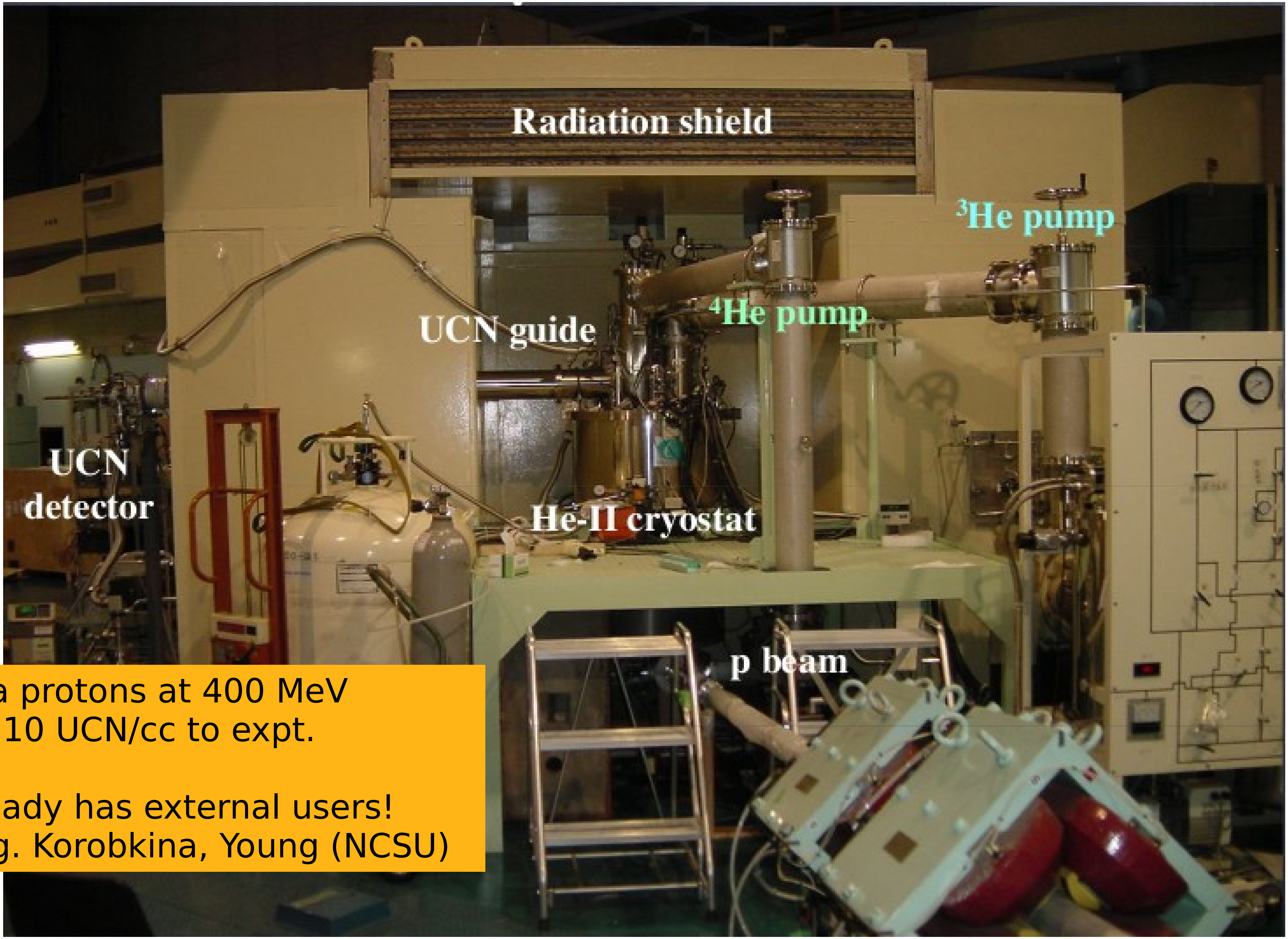
Coherent inelastic neutron scattering in He-II



Born approximation

$$d^2\sigma/dQd\omega$$
$$= k_f/k_i\, a^2\, S(Q,\omega)$$
$$= \sigma_{coh}/4\pi \cdot k_f/k_i \cdot S(Q,\omega)$$

RCNP UCN Source (Masuda, et al)



1 ua protons at 400 MeV
=> 10 UCN/cc to expt.

Already has external users!
- e.g. Korobkina, Young (NCSU)

Gain Factors for TRIUMF

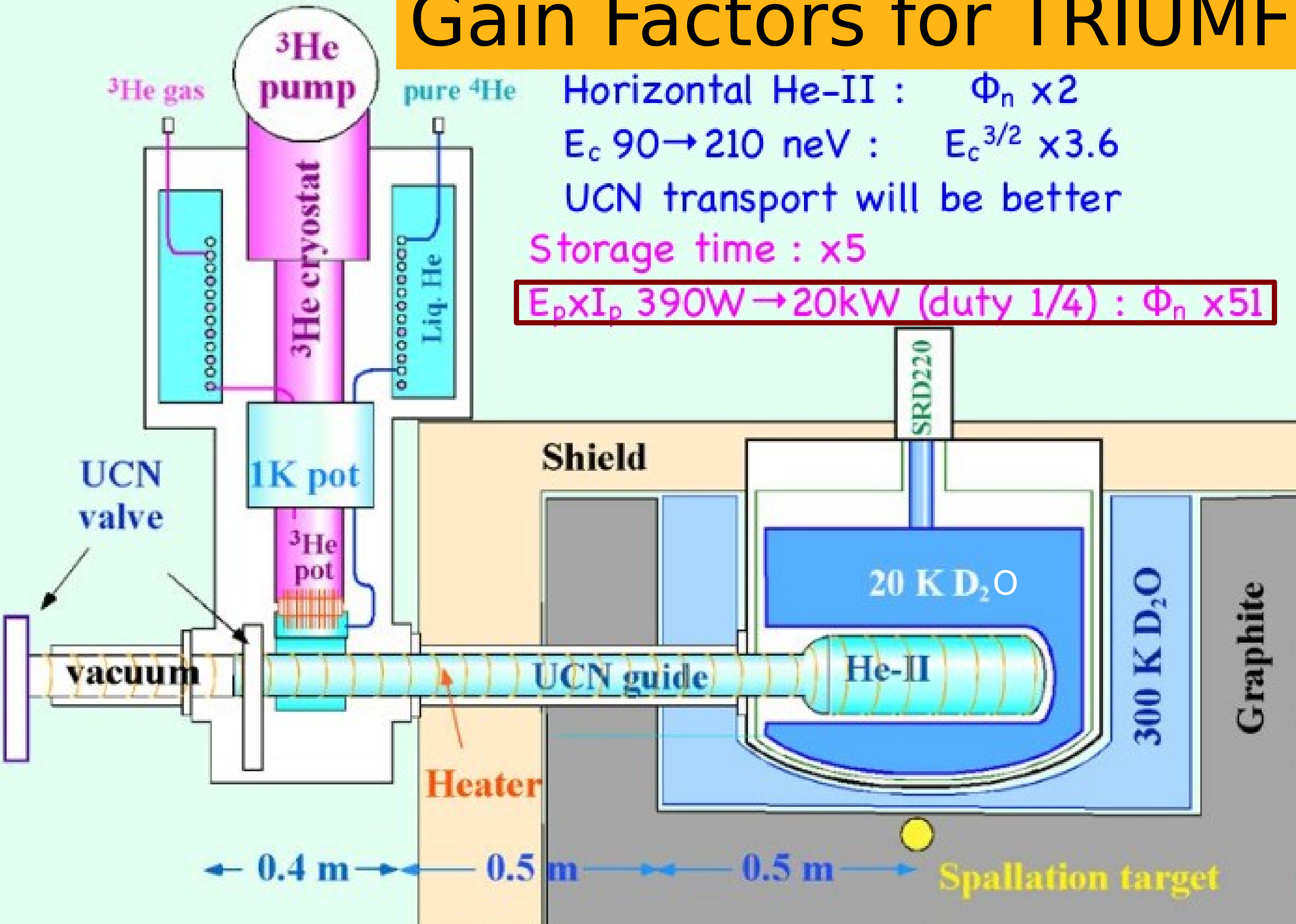
Horizontal He-II : Φ_n x2

E_c 90→210 neV : $E_c^{3/2}$ x3.6

UCN transport will be better

Storage time : x5

E_pxI_p 390W→20kW (duty 1/4) : Φ_n x51



Recent Progress on UCN at TRIUMF

- Aug. 2007 TUG working group (Canadians + Masuda), draft of white paper.
- Sept. 2007 International UCN Workshop (+ world experts).
- Sept. 2007 Presentation to Agency Committee on TRIUMF (ACT)
- Oct. 2007 phone meetings
- Nov. 2007 ACOT

My old advertisement slide...

International Workshop: UCN Sources and Experiments

September 13-14, 2007

TRIUMF, Vancouver, Canada

http://www.triumf.info/hosted/UCN

~25 speakers from all over the world

ILL, FRM-II, NCSU, LANL, PSI, KEK, Mainz, ...

Supported by TRIUMF and TUNL

Speakers at TRIUMF UCN Workshop Sept. 13-14, 2007

H. Abele, Heidelberg

S. Baessler, Mainz/UVa

L. Buchmann, TRIUMF

M. Daum, PSI

S. Gardner, U. Kentucky

P. Geltenbort, ILL

E. Gutsmiedl, Munich FRM-II

R. Golub, NCSU

B. Filippone, Caltech

P. Huffman, NCSU

T. Ito, LANL

E. Korobkina, NCSU

C.-Y. Liu, Indiana U.

M. Makela, LANL

J.W. Martin, U. Winnipeg

Y. Masuda, KEK

P. Mumm, NIST

J. Nico, NIST

J. Ng, TRIUMF

M. Pospelov, U. Victoria/Perimeter Inst.

J.-M. Poutissou, TRIUMF

W.M. Snow, Indiana U.

F. Wietfeldt, Tulane U.

A. Young, NCSU

G. Hampel, Mainz

K. Hickerson, Caltech

Results of Workshop

- Very strong statement from the international UCN community (particularly R. Golub) that a He-II source should be pursued. Masuda clearly regarded as a leader in this field.
- TRIUMF would be an ideal venue for such a source.
- Many interesting physics experiments would be possible with the higher UCN densities achievable at this source.

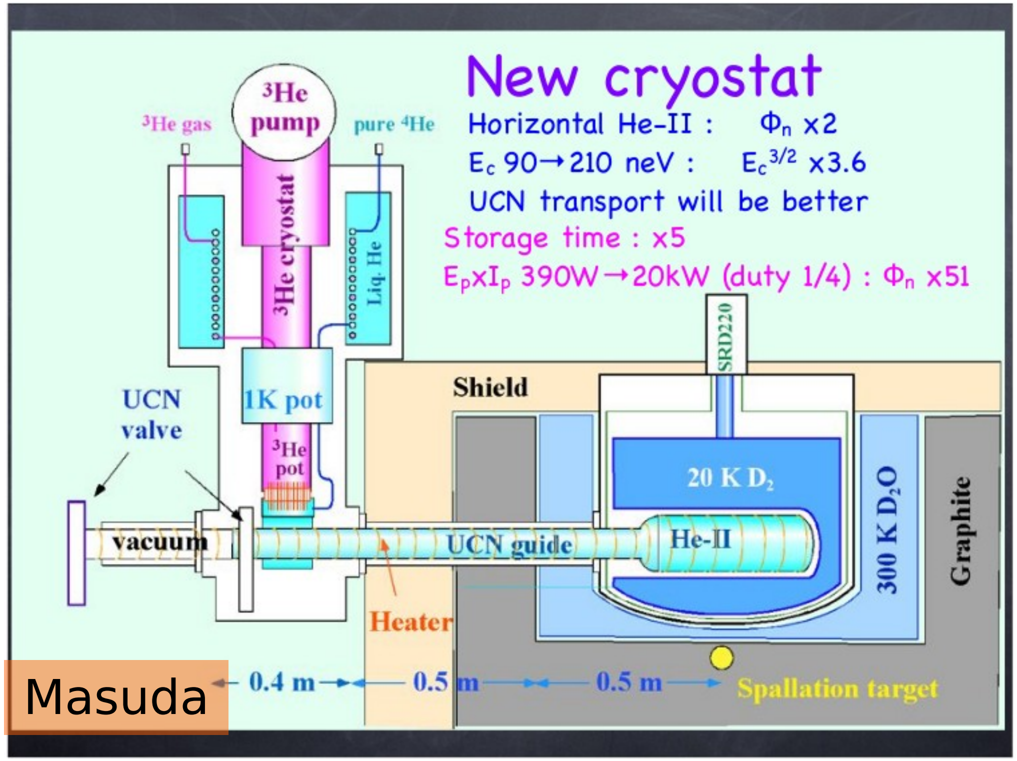
Schedule

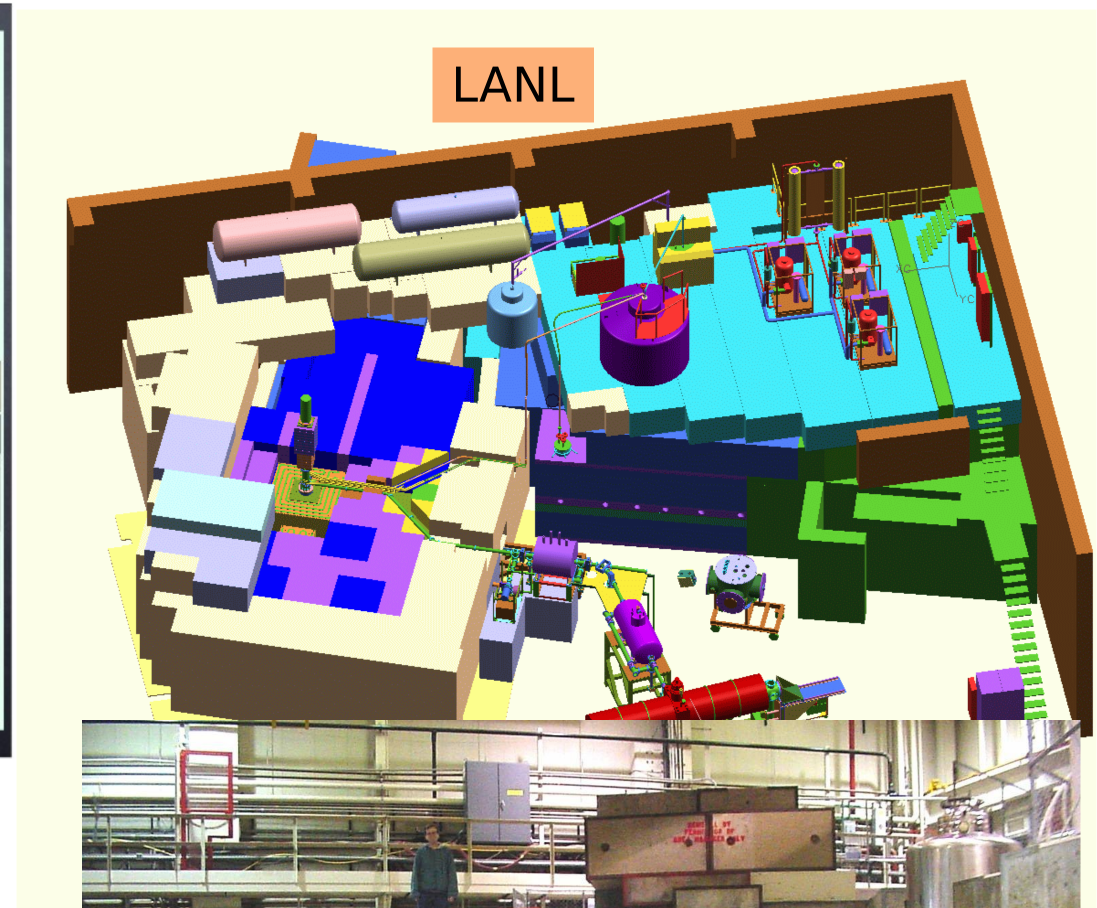
- Prior to 2010, pursue development of new UCN cryostat for TRIUMF at RCNP, Osaka.
  - This would allow us to demonstrate all the gain factors from horizontal extraction, better UCN guides. (aside from beam power)
- After 2010, begin construction of UCN source at TRIUMF (2010 = coincident with major reconstruction for ISAC 3).

Technical Issues for UCN

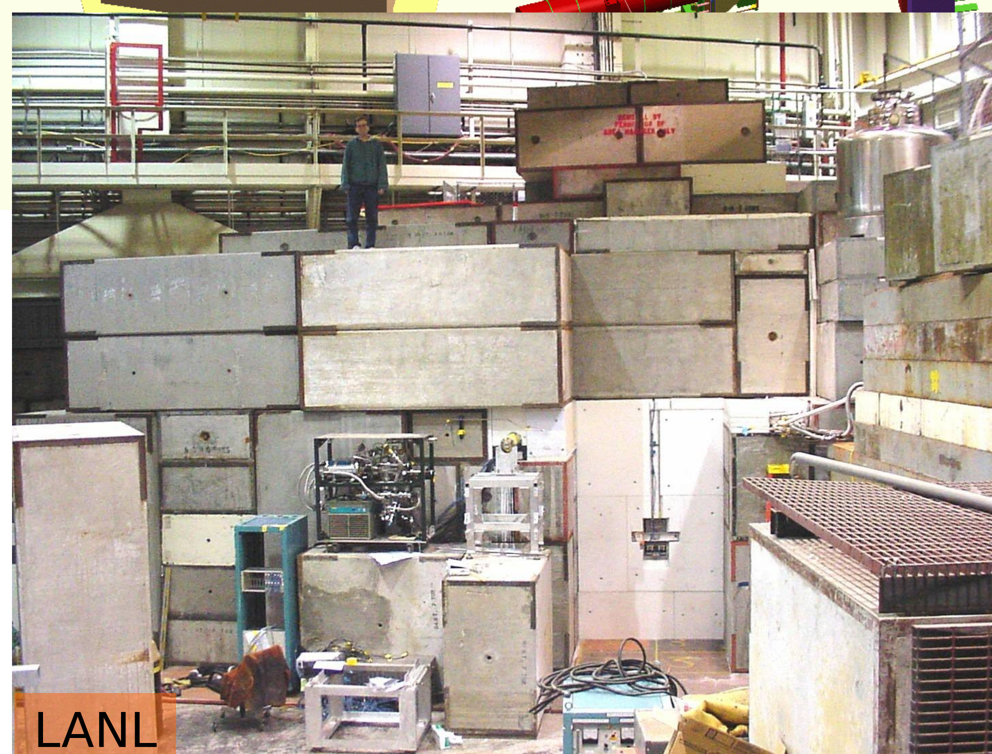
- Location.
- Beam sharing (dependent on location).
- Space (dependent on location).
- To carry out precision experiments, it is highly advantageous to pulse the UCN source. E.g. RCNP uses 1 min beam on, 3 mins beam off. During beam off, UCN can be counted (or their decays, etc.)
  - pulsing at ion source incompatible with ISAC.
  - achieve pulsing by diverting beam to well-shielded dump using kicker.

Conceptual to technical design for the UCN source and experiment





arrow of time

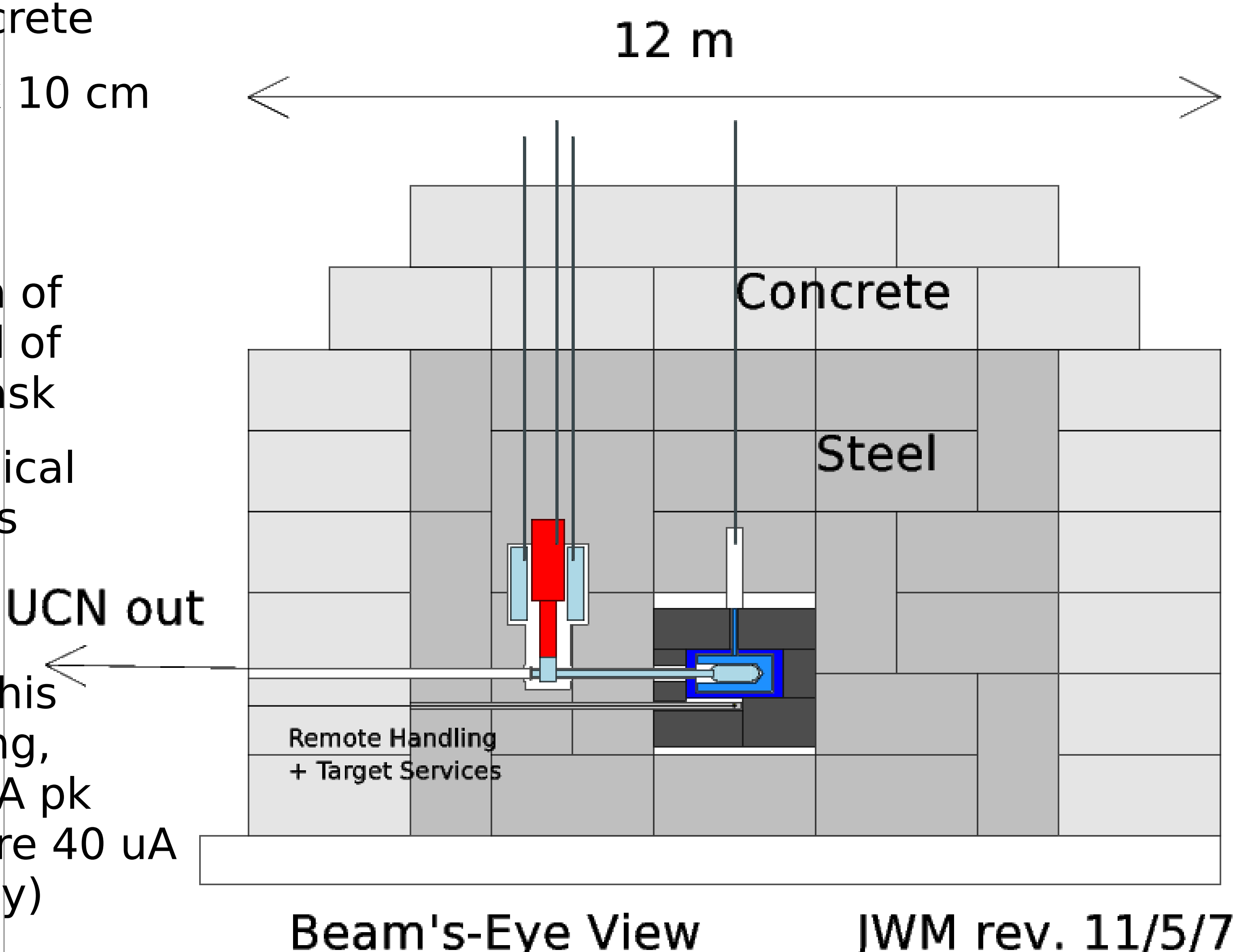


Issues:
- radiation
- cryogenics
- neutronics
- division of tasks
  - Masuda, Golub, others? very interested in cryogenics and neutronics
  - need TRIUMF support to bring to fruition

Shielding, Remote Handling, Spallation target

Based on LANL design

- 3m steel, 2m concrete
- W target 2 cm Ø x 10 cm long
- He-gas cooling
- Remote extraction of target via removal of shielding block, cask
- Need better technical design of cryostats suitable for easier access/extraction
- LANL design has this amount of shielding, certified for 100 uA pk currents. (we desire 40 uA pk, at lower energy)

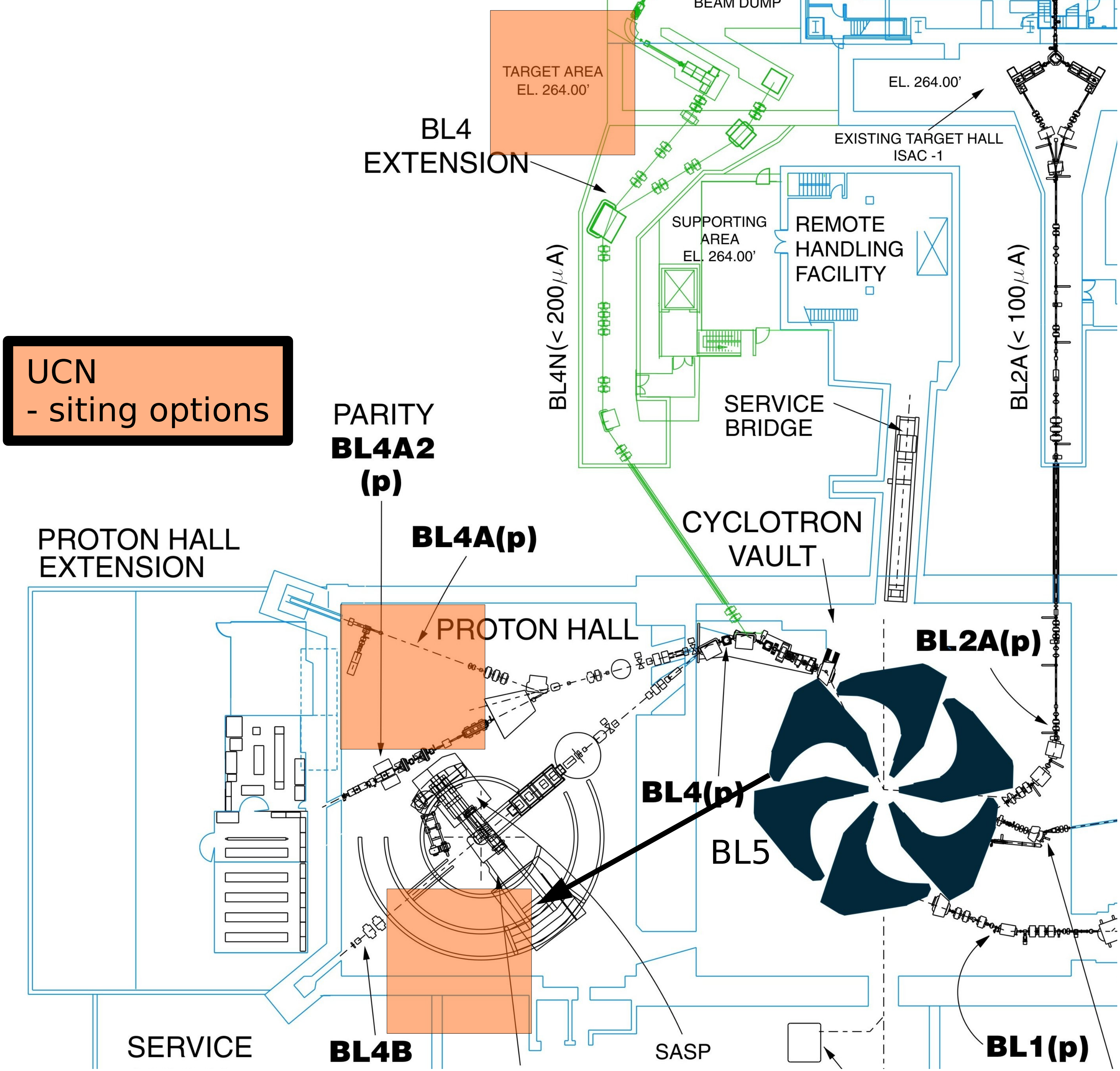


Cryogenics/Shielding Numbers from Masuda

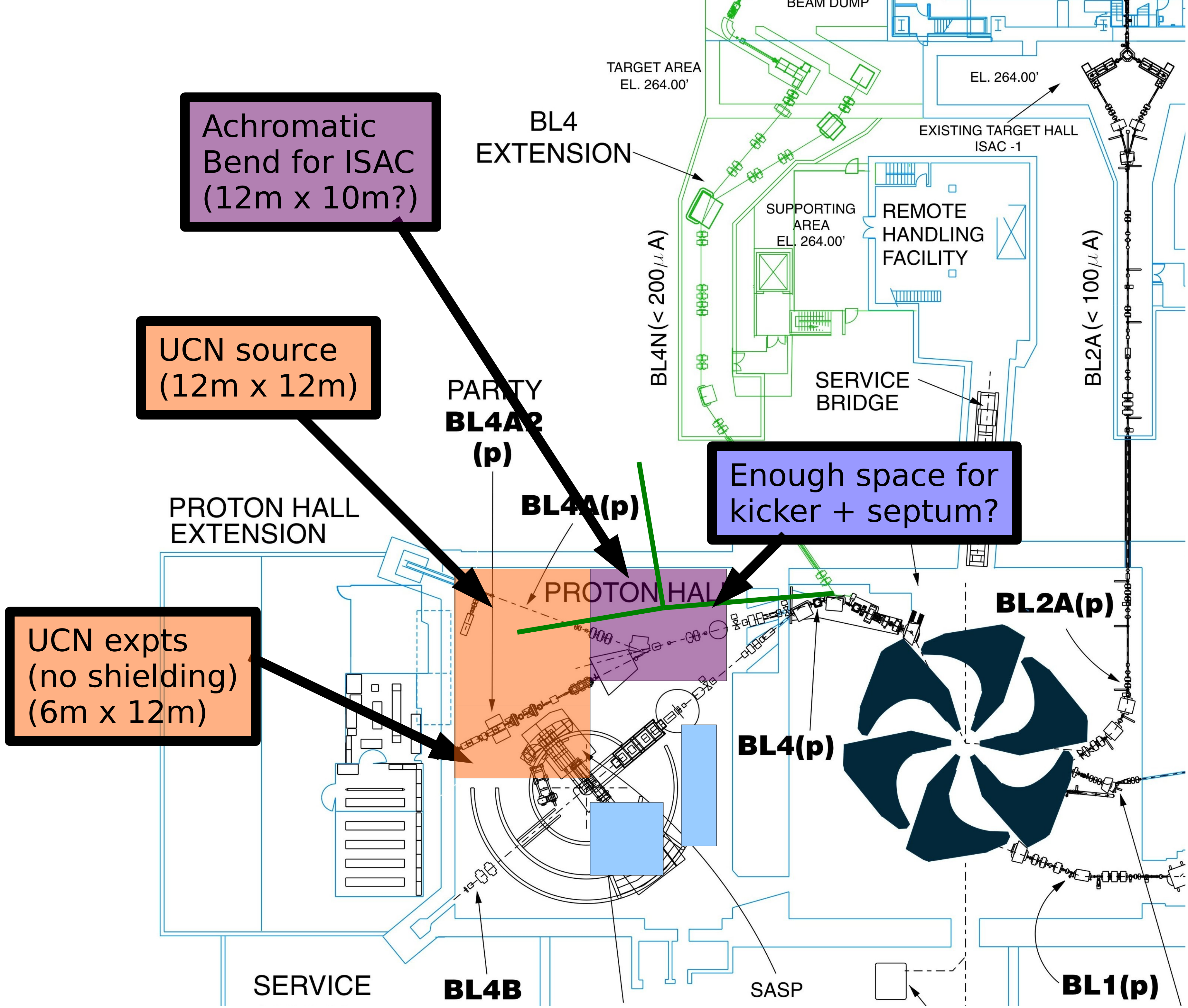
- According to MC + estimates, for time-avg p-beam power of 12 kW in W target:
  - 0.45e12 n/cm2/s in He-II
  - 2.3 W in He-II
  - 30-60 W in 20 K D2O
  - 1.7 kW in 300 K D2O
- Masuda's current 3He pump can take 8 W.
- Clever arrangement of 208Pb can reduce gamma-heating of He-II even lower.
- Radiation #'s consistent/lower cf. LANL.

Solutions Discussed for Technical Issues (thanks, accel group!)

- Location: BL4A area
  - UCN source viewed as an ISAC-3 target station, located in Proton Hall
  - Advantages:
    - UCN fully integrated into ISAC-3 program in terms of physics (fundamental symmetries) and facility (another ISAC-3 target station).
    - simultaneous operation with ISAC-3 by decoupling on kHz scale with kicker/ion source manipulation. Advantageous for ISAC-3: run all three targets simultaneously.
    - use another kicker to divert beam to dump in ISAC-3 area to achieve UCN pulsing (1 min on / 3 mins off).
    - recent designs of ISAC-3 BL4N take the beam further into Proton Hall (towards UCN). And more shielding already required in that area.
  - Disadvantages:
    - space in Proton Hall getting tight.
    - coupled to ISAC-3.
- Location: ISAC-3 target hall.
- Location: BL5 port (new port)

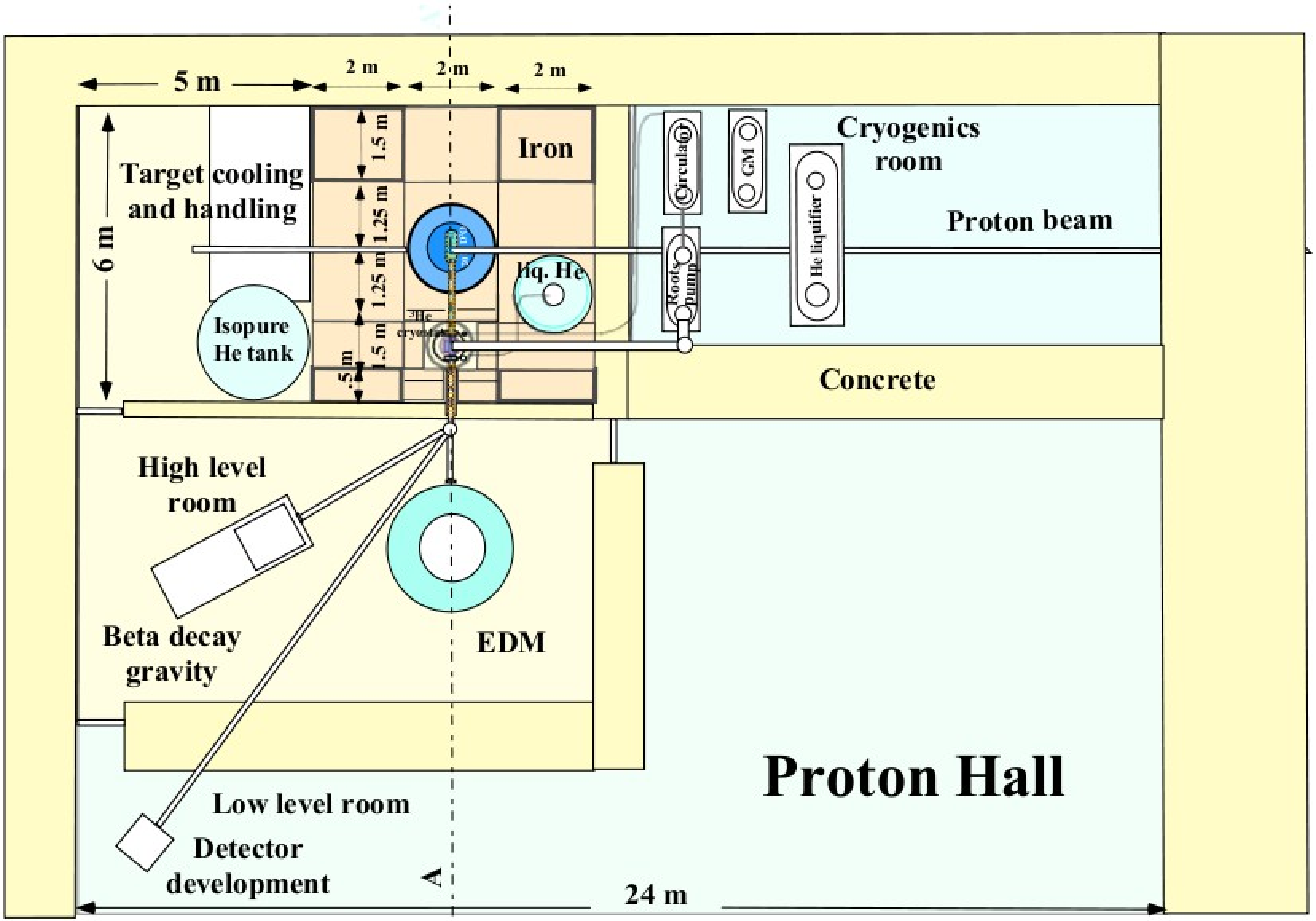


UCN
- siting options
TARGET AREA
EL. 264.00'
BEAM DUMP
EL. 264.00'
EXISTING TARGET HALL
ISAC -1
BL4
EXTENSION
SUPPORTING
AREA
EL. 264.00'
REMOTE
HANDLING
FACILITY
BL4N(< 200μA)
BL2A(< 100μA)
SERVICE
BRIDGE
PARITY
BL4A2
(p)
CYCLOTRON
VAULT
PROTON HALL
EXTENSION
BL4A(p)
PROTON HALL
BL2A(p)
BL4(p)
BL5
SERVICE
BL4B
SASP
BL1(p)



Achromatic Bend for ISAC (12m x 10m?)
UCN source (12m x 12m)
UCN expts (no shielding) (6m x 12m)
Enough space for kicker + septum?
BEAM DUMP
TARGET AREA EL. 264.00'
EL. 264.00'
EXISTING TARGET HALL ISAC -1
BL4 EXTENSION
SUPPORTING AREA EL. 264.00'
REMOTE HANDLING FACILITY
BL4N(< 200µA)
BL2A(< 100µA)
SERVICE BRIDGE
PARITY BL4A2 (p)
PROTON HALL EXTENSION
BL4A(p)
PROTON HALL
BL2A(p)
BL4(p)
SERVICE
BL4B
SASP
BL1(p)

Potential Layout in Proton Hall (rev. 9/6/07)



Jeff needs to fix for consistency

Cost

- Cryostat, LHe cooling costs very well-understood (1.4 M$ CAD)
- Masuda request to Japanese funding sources for 2.4 M$ CAD over the next four years (the above plus EDM development) explicitly mentions TRIUMF. (submitted Nov. 2007)
- Shielding, remote handling, etc., costs yet to be estimated. Base on experience from TRIUMF, LANL, and RCNP. (Prior to shielding simulations.)

Collaboration

- Strong interest from Canadian Subatomic Physics community (Winnipeg and Manitoba groups) and from world-wide UCN community
- strong KEK group who have already created a world-class facility (Masuda et al)
- well-attended working group at August TRIUMF townhall meeting
- big event: UCN workshop at TRIUMF Sept. 13-14, 2007
  - world experts in attendance
- Interest in submitting a CFI proposal for UCN source in 2008 from Canadian groups

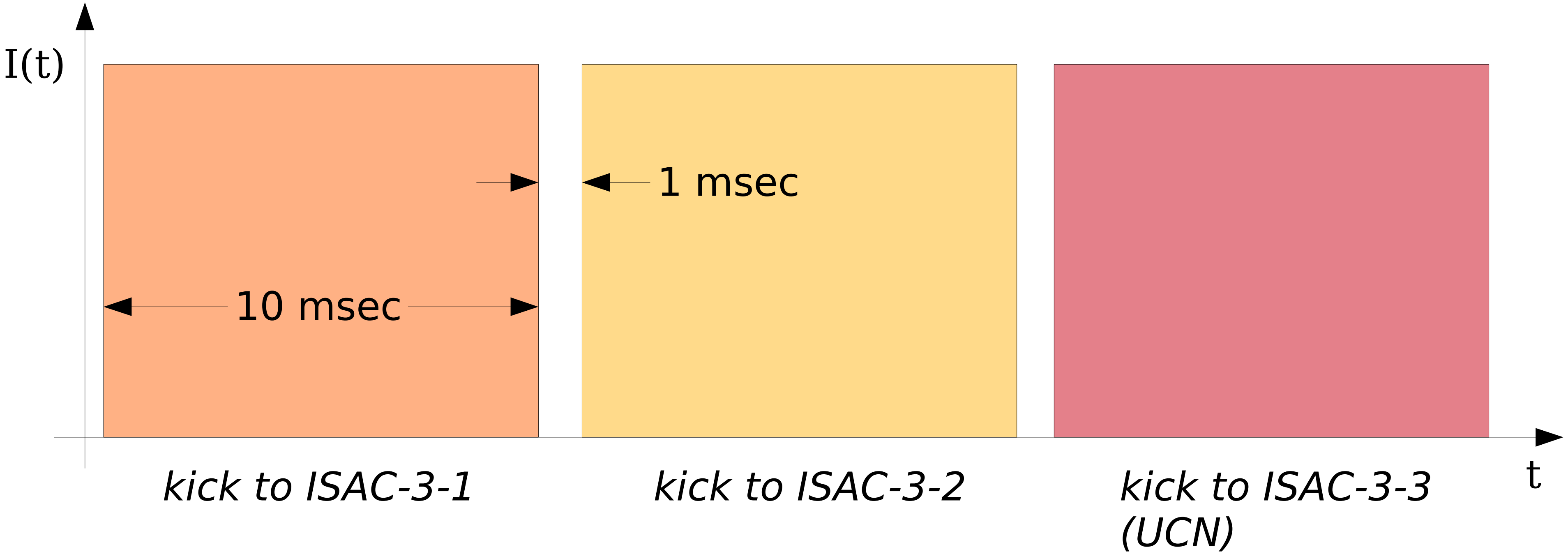
Summary

- An opportunity exists to create the world's highest density UCN source at TRIUMF
- A flagship physics experiment done this facility would be world's best
- The UCN facility would be tied to the ISAC-3 program in terms of both physics and facility
- We would like to pursue this unique and timely opportunity

Back-ups

simultaneous operation with ISAC-3 by decoupling on kHz scale with kicker/ion source manipulation. Advantageous for ISAC-3: run all three targets simultaneously.

ion source current vs. time



Solutions Discussed for Technical Issues

- Location:
  - BL5 area
    - Advantages:
      - decoupled from ISAC 3.
    - Disadvantages:
      - new beam port must be constructed
      - beam line must not conflict with cyclotron probe extraction point
      - high-power dump required to achieve pulsing with kicker.
      - space in Proton Hall tighter – likely requires excavation for dump.

Shameless advertising

International Workshop: UCN Sources and Experiments

September 13-14, 2007
TRIUMF, Vancouver, Canada
http://www.triumf.info/hosted/UCN

~25 speakers from all over the world
ILL, FRM-II, NCSU, LANL, PSI, KEK, Mainz, ...

Supported by TRIUMF and TUNL

Agenda
from townhall meeting (Aug. 07)

Aug. 1

morning - plenary session, charge, and introduction of working groups

12:00 lunch

13:00 Welcome + Charge (Martin) (10+5)
13:15 UCN Sources Worldwide and for TRIUMF (Masuda) (45+10)
14:10 Photofission, (gamma,n) Sources and UCN (Behr) (10+10)
14:30 coffee (30)
15:00 SCRF joint session: Electron Linac Design (Koscielniak) (20+10)
15:30 UCN Infrastructure and Proton Hall Floorplan (Davis) (10+10)
15:50 Proton Hall Radiation Limits (Trudel) (10)
16:00 Discussion (Chair: Davis) (30)
16:30 tour of proton hall? (if desired) (Davis) (30)

Aug. 2

09:00 Continued infrastructure Discussion (60)
10:00 UCN Physics Intro (Martin) (10+5)
10:15 UCN Beta Decay (Melconian) (20+10)
10:45 coffee (30)
11:15 n-EDM (Masuda and/or Hayden?) (20+10)
11:45 radioactive beams (Buchmann) (10+10)

12:05 lunch

13:15 gravity levels (Konaka) (5+10)
13:30 other physics (Martin) (15+10)
13:55 discussion of physics priorities and strategy (chair: Martin) (35)
14:30 begin writing
    more joint sessions
    draft Aug. 3 morning presentation

Aug. 3

morning - presentations of results from the working groups.

Outline of White Paper

- Physics
  - prioritized and realistic, as much as possible
- UCN Source
  - proposed intensity at TRIUMF
  - world context and relevance
- Required Infrastructure
  - floorspace, shielding
  - duty cycle
  - He liquefier
- Required funding
  - CFI and collaboration, and international