An Ultracold Neutron Source for TRIUMF

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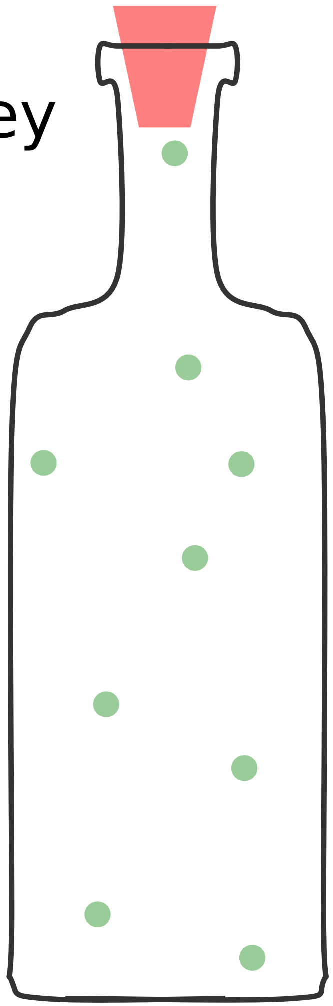
and the rest of the UCN working group

1. UCN interactions
2. UCN physics experiments
3. Source work at RCNP and TRIUMF
4. 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: $V=-\mu\bullet B$ (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

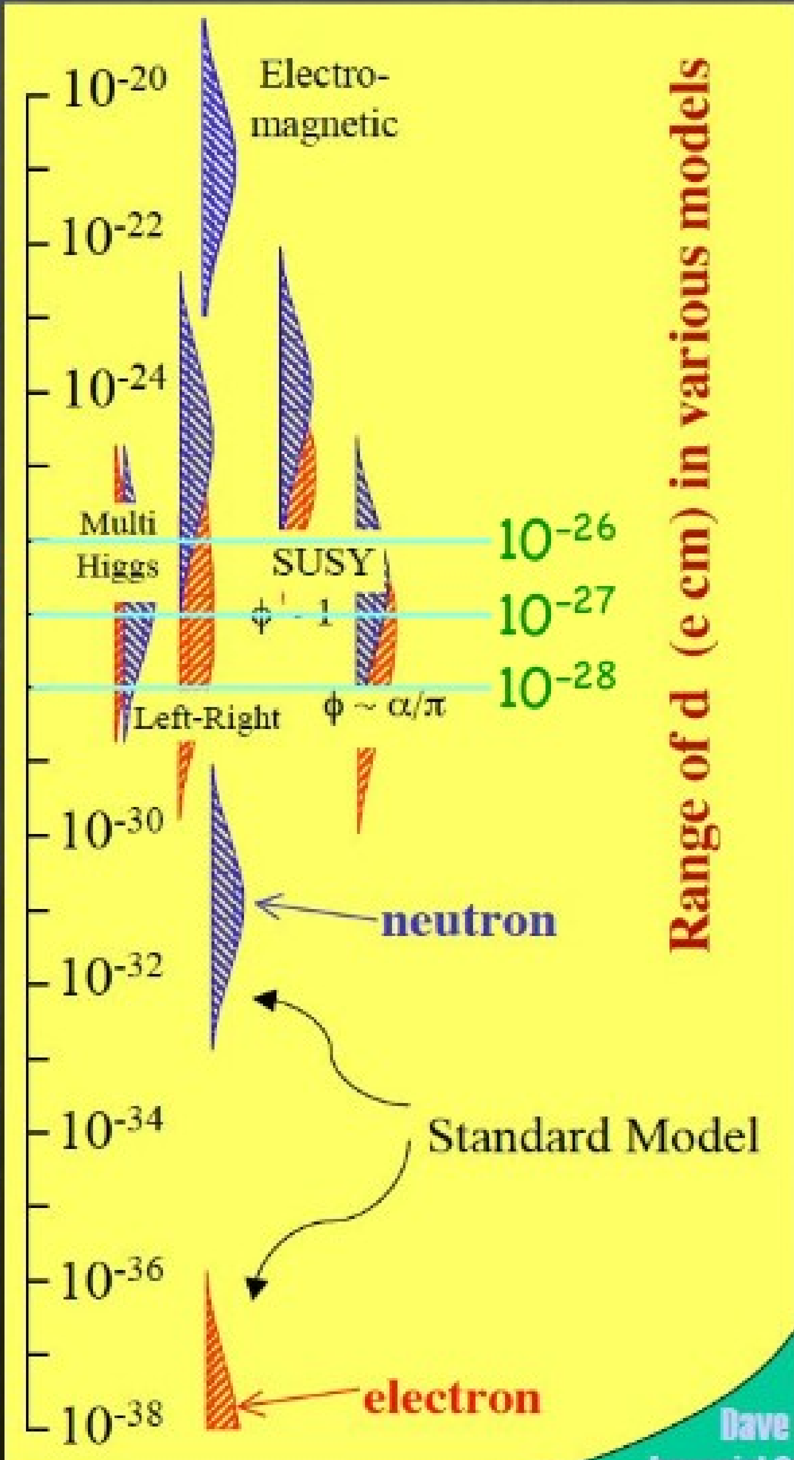
	Source type	E_c and τ_s	UCN density ρ_{UCN} (UCN/cm^3)
TRIUMF 5 kW$_{av}$ proton	0.8K He-II	E_c = 210 neV τ_s = 150 s	1.8 x 10^4 at experimental port
Grenoble 60MW reactor	0.5K He-II	E_c = 250 neV τ_s = 150 s	1000 in He-II
SNS cold neutron beam	0.3K He-II	E_c = 134 neV τ_s = 500 s	430 in He-II
Munich 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

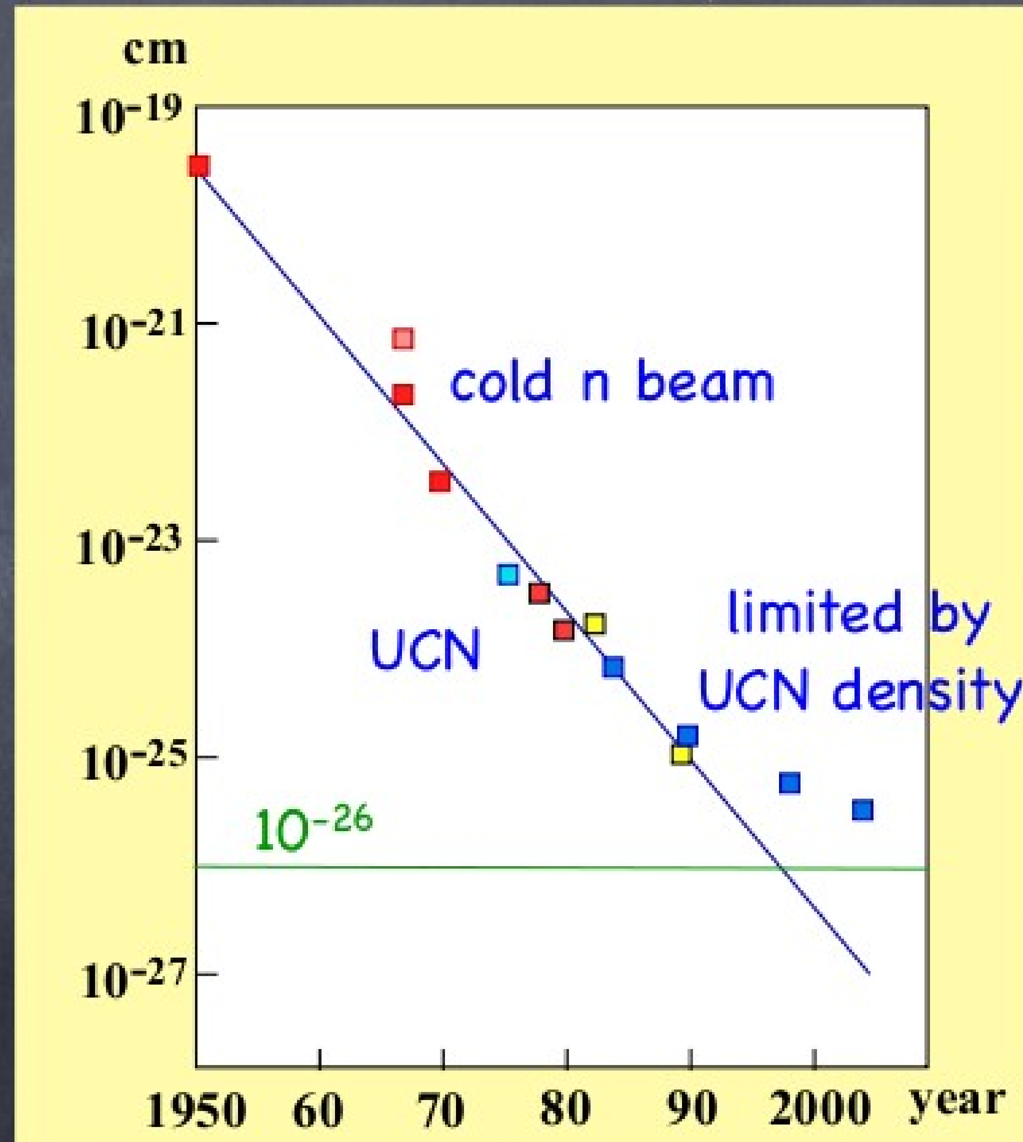
- fundamental interactions of UCN
  - EDM
  - gravity
  - beta-decay
  - nnbar oscillations
- astrophysics
  - BBN
  - r-process
- surface physics
- development towards JPARC 2nd target station UCN source

EDM history

Theory

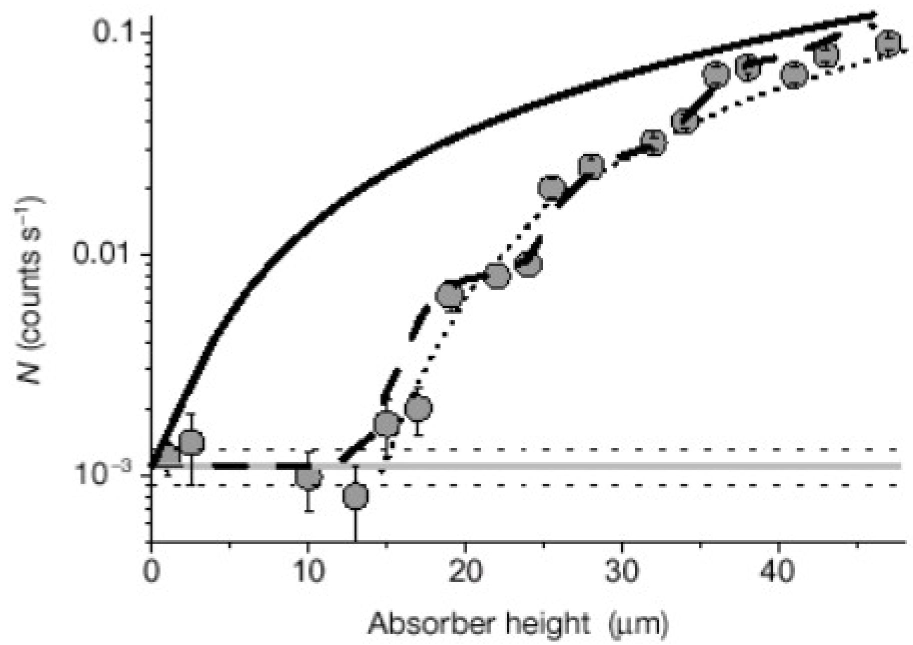


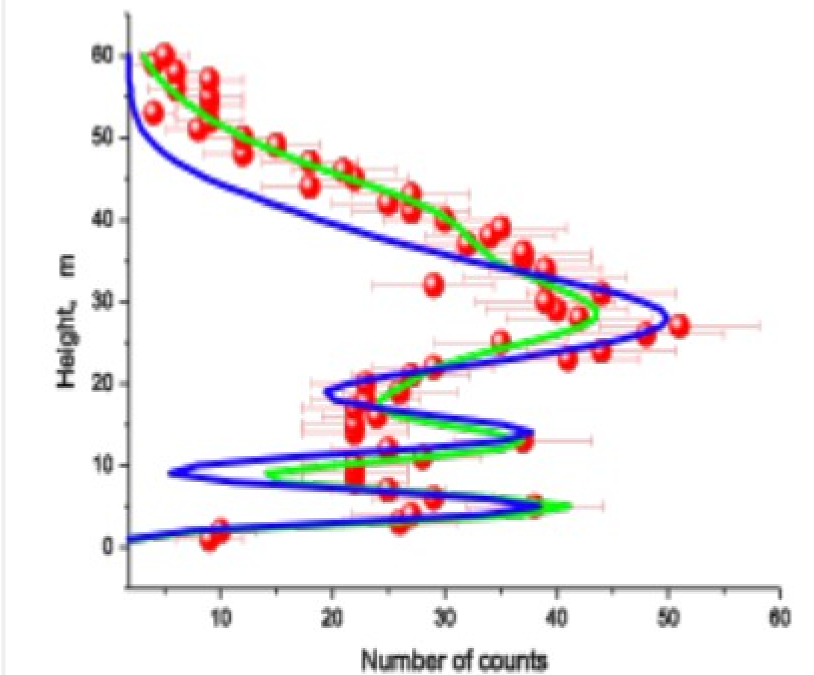
Experiment

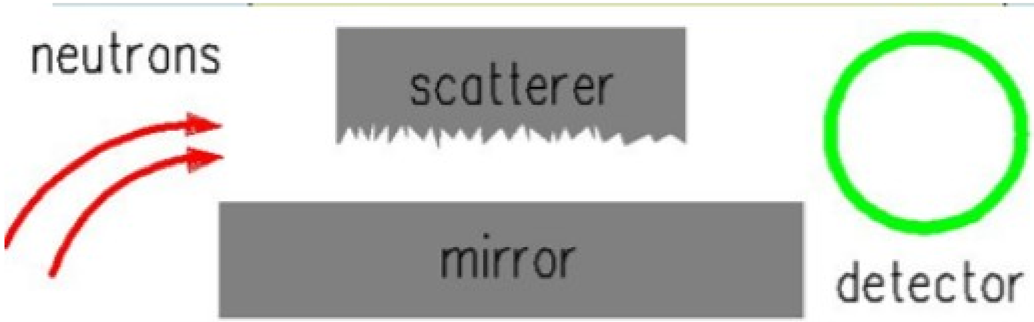


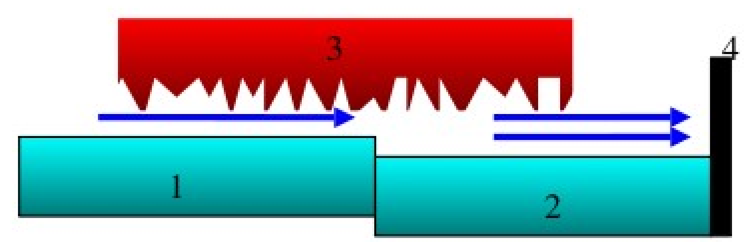
UCN quantum states in gravity

- test of gravity at 10 um scale







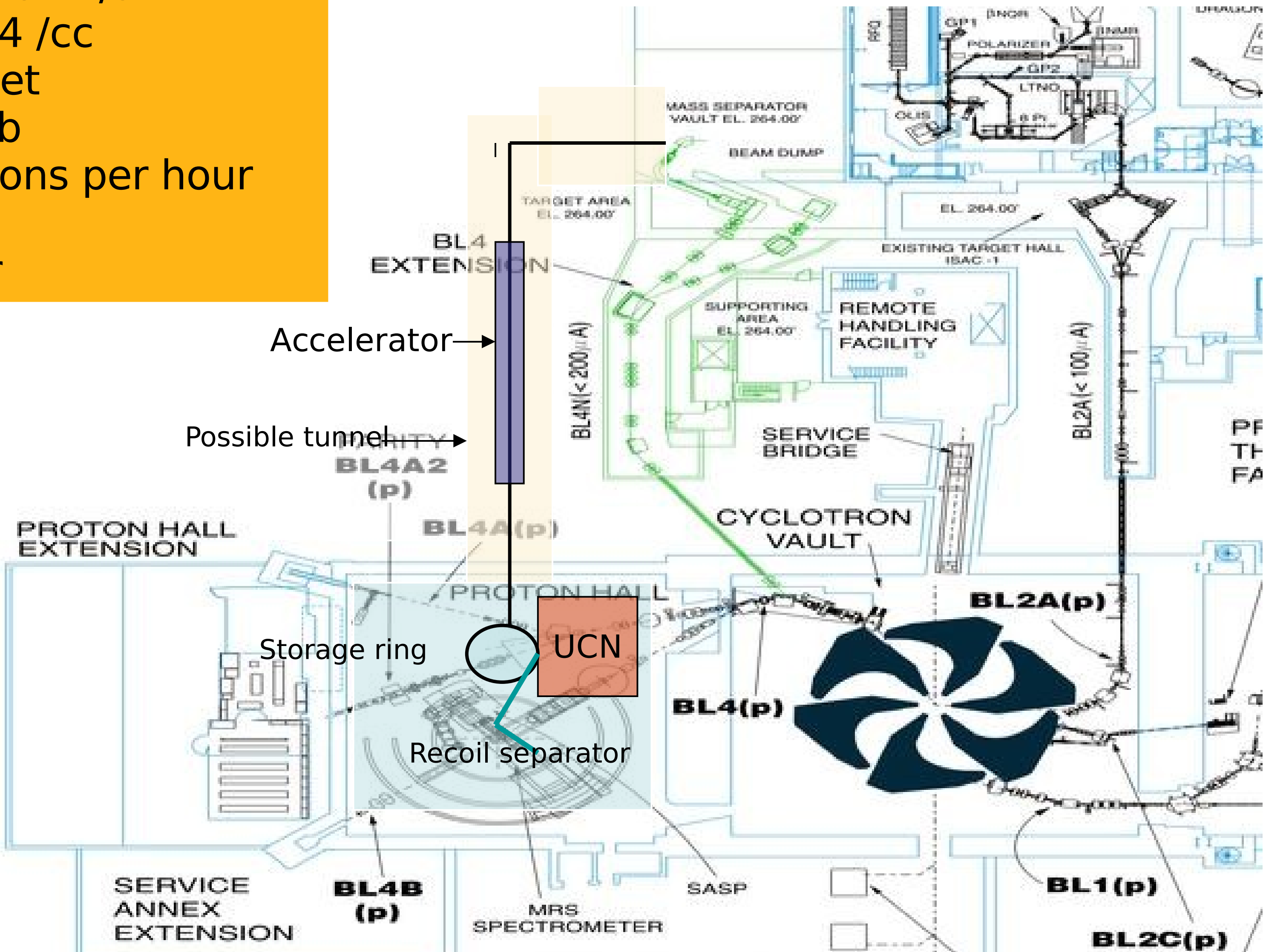


Measuring (n,ɣ) cross sections of the r-process (Buchmann)

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
- 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?

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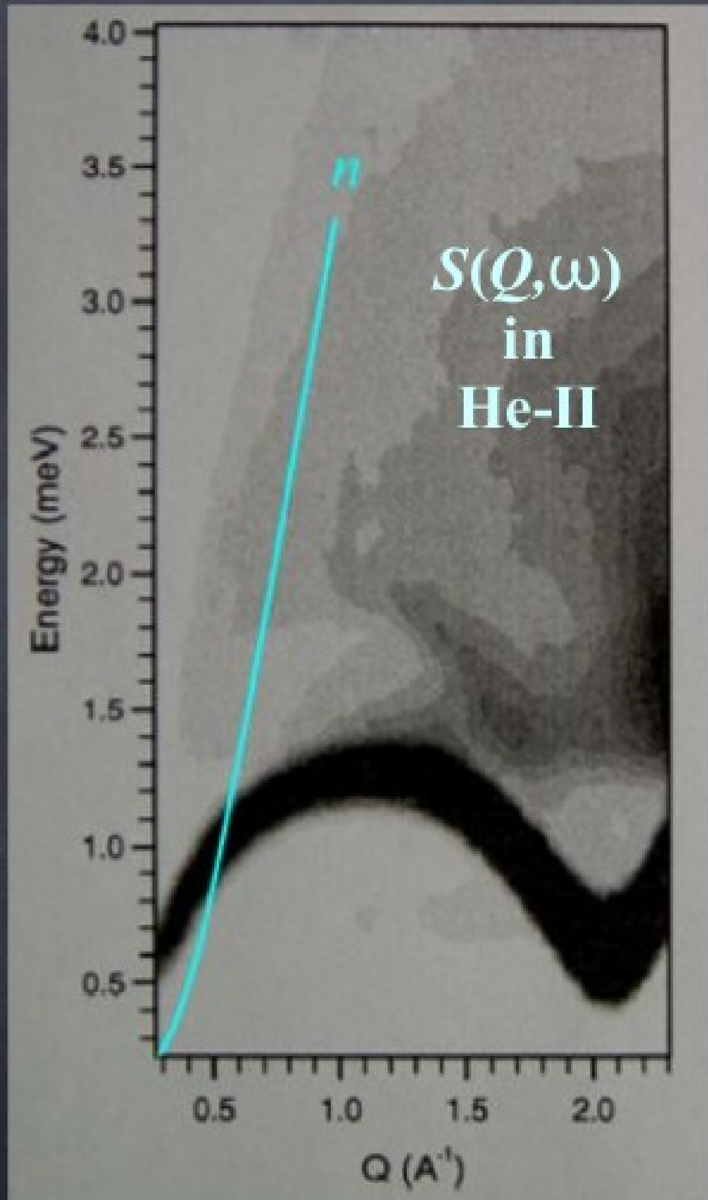
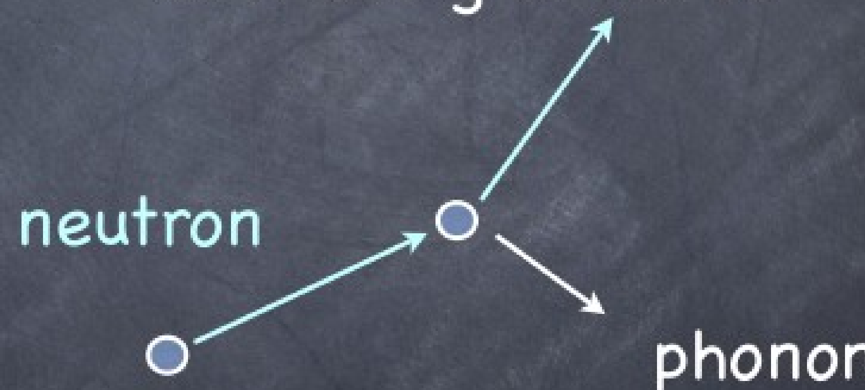


M.R. Gibbs et al. (1999)

Superthermal UCN production in He-II

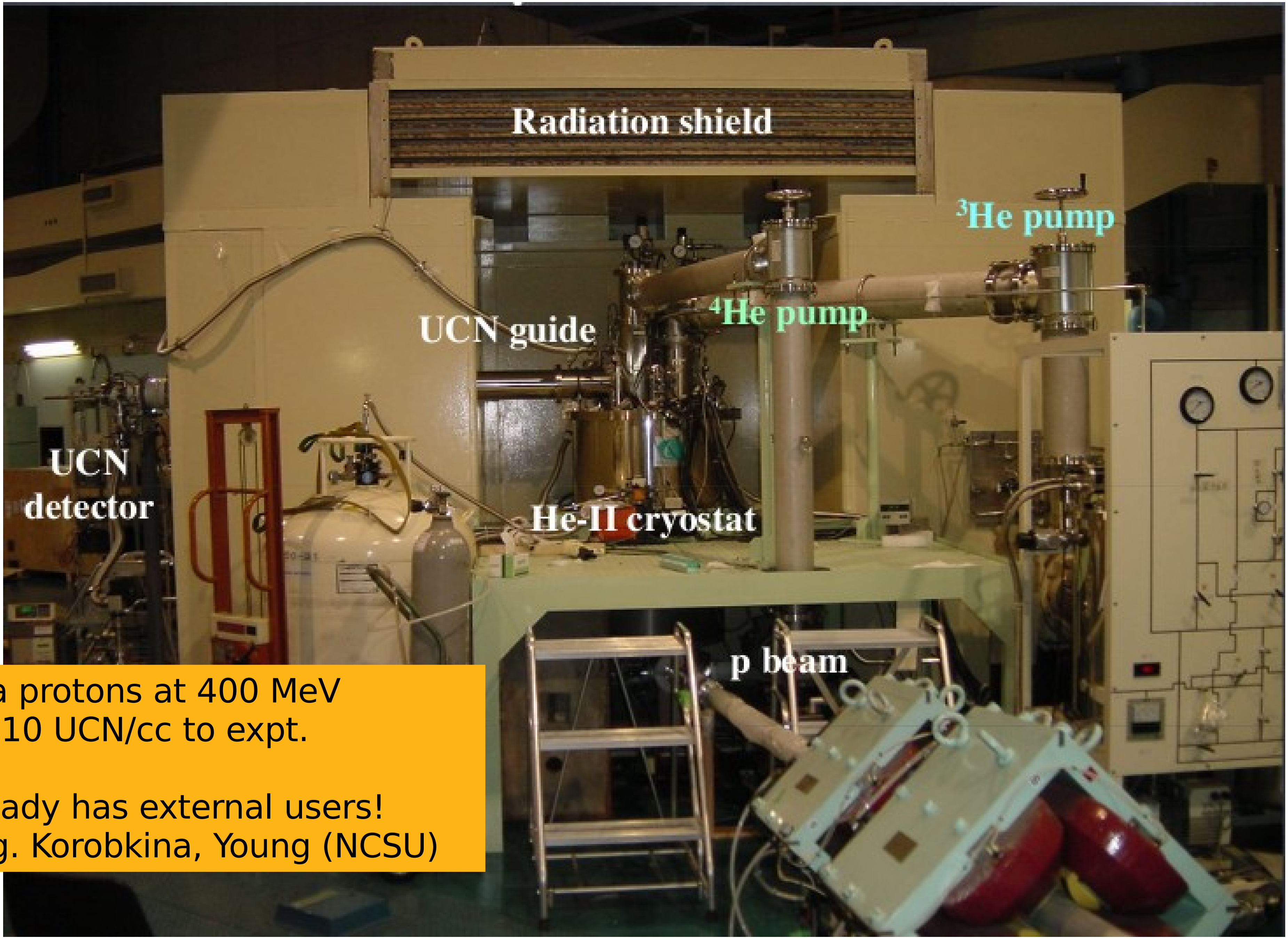
Coherent inelastic neutron scattering in He-II



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

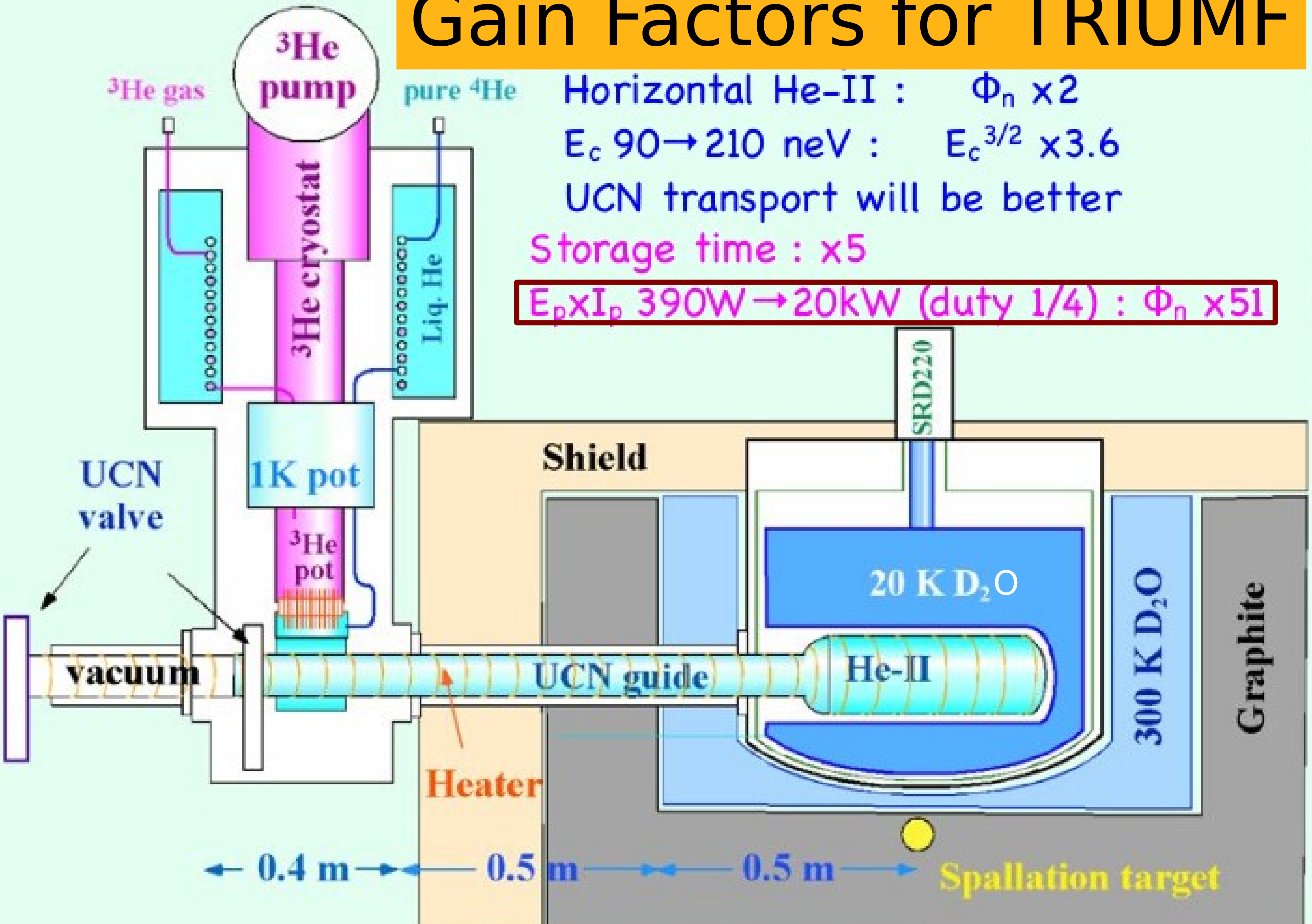
Horizontal He-II : Φ_n x2

E_c 90→210 neV : $E_c^{3/2}$ x3.6

UCN transport will be better

Storage time : x5

$E_p x I_p$ 390W→20kW (duty 1/4) : Φ_n x51

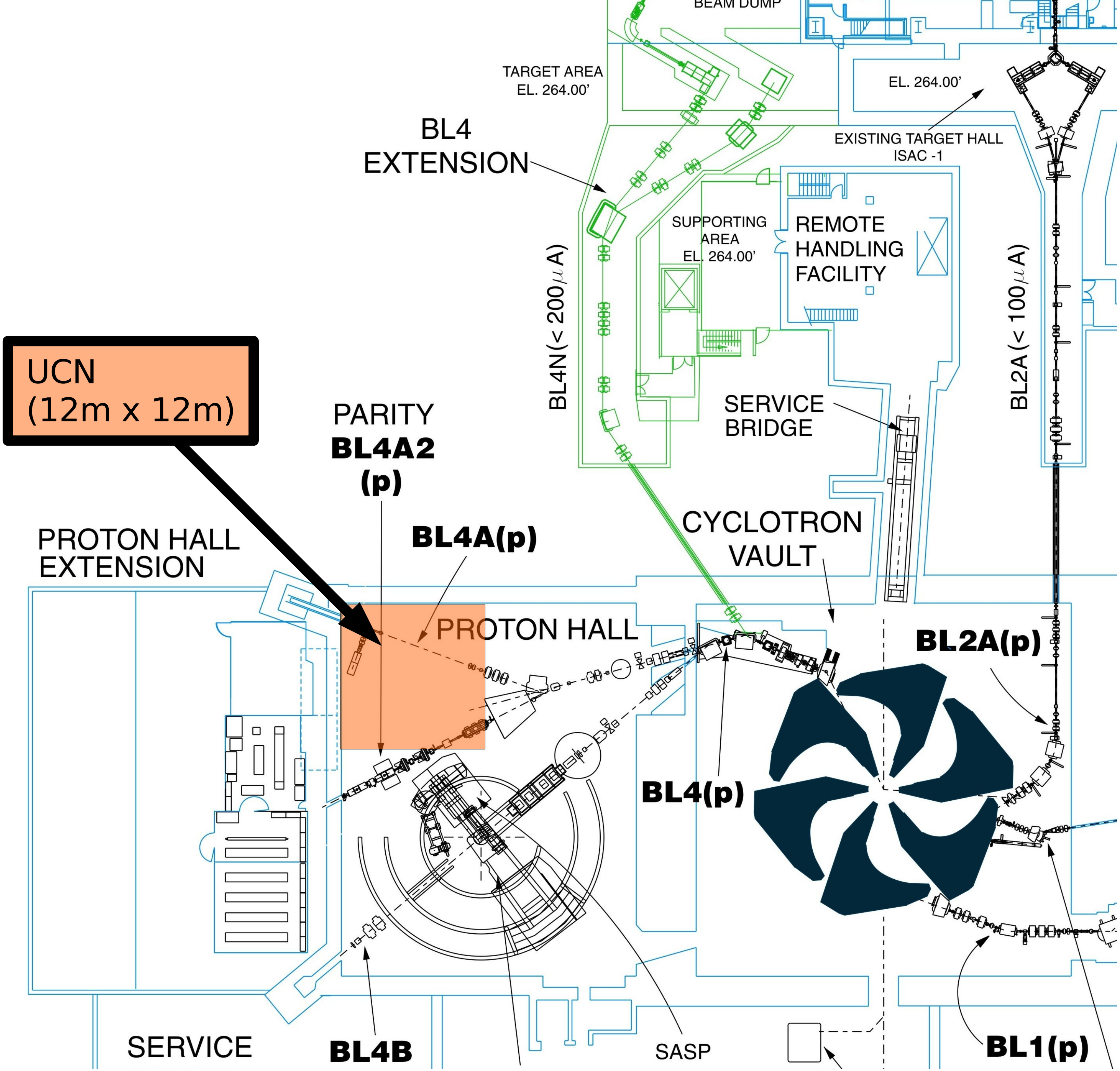


Schedule

- 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.

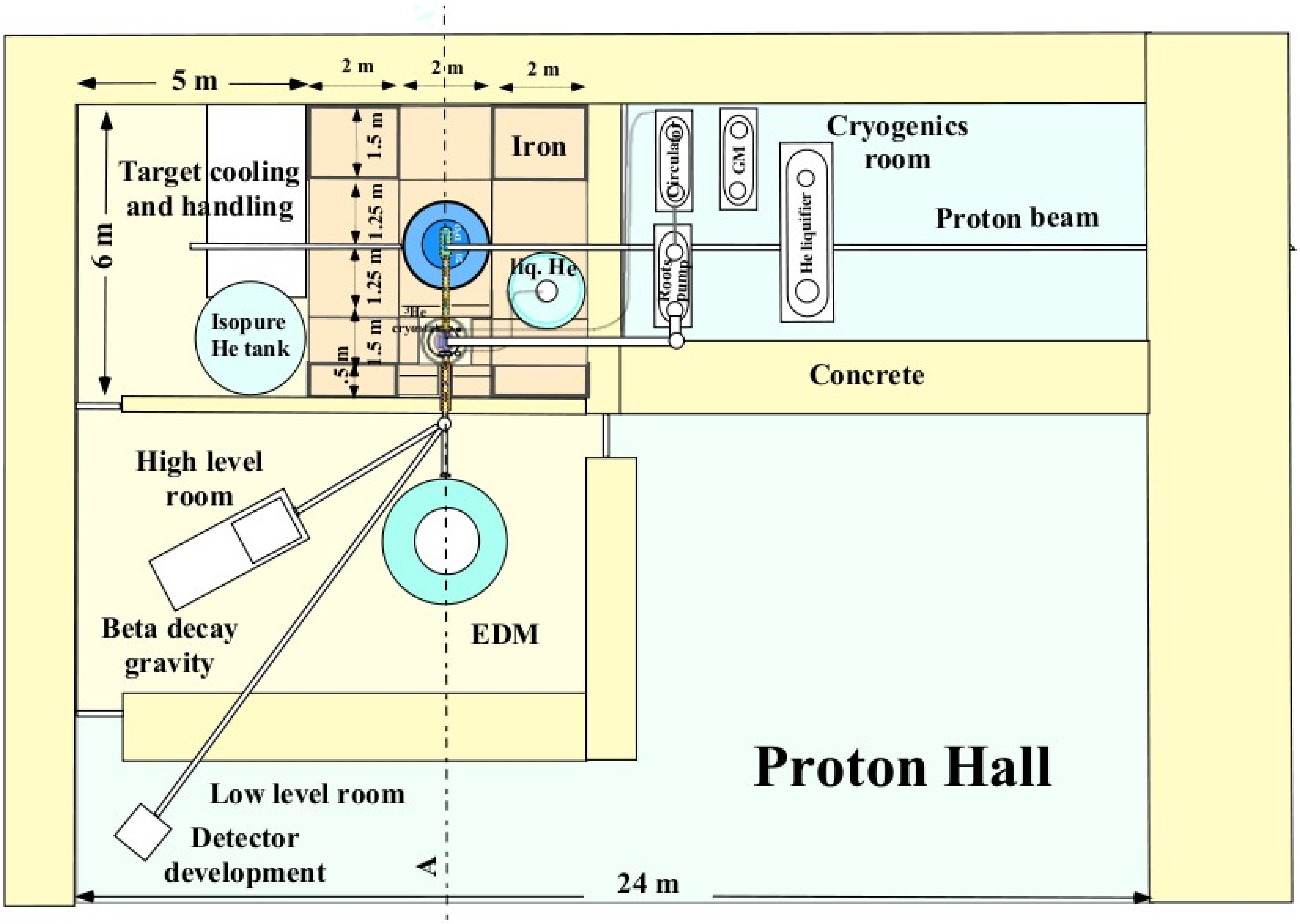


BEAM DUMP
TARGET AREA
EL. 264.00'
EL. 264.00'
BL4
EXTENSION
EXISTING TARGET HALL
ISAC -1
SUPPORTING
AREA
EL. 264.00'
REMOTE
HANDLING
FACILITY
BL4N(< 200μA)
BL2A(< 100μA)
UCN
(12m x 12m)
PARITY
BL4A2
(p)
SERVICE
BRIDGE
CYCLOTRON
VAULT
PROTON HALL
EXTENSION
BL4A(p)
PROTON HALL
BL2A(p)
BL4(p)
SERVICE
BL4B
SASP
BL1(p)

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)

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



layout still needs some work... cryogenics location, shielding, remote handling

Cost

- Cryostat, LHe cooling costs very well-understood (1.4 M$ CAD)
- Shielding, remote handling 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

Shameless advertising

International Workshop: UCN Sources and Experiments

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

PLEASE STOP BY THE AUDITORIUM
(after you're done here)

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

Supported by TRIUMF and TUNL

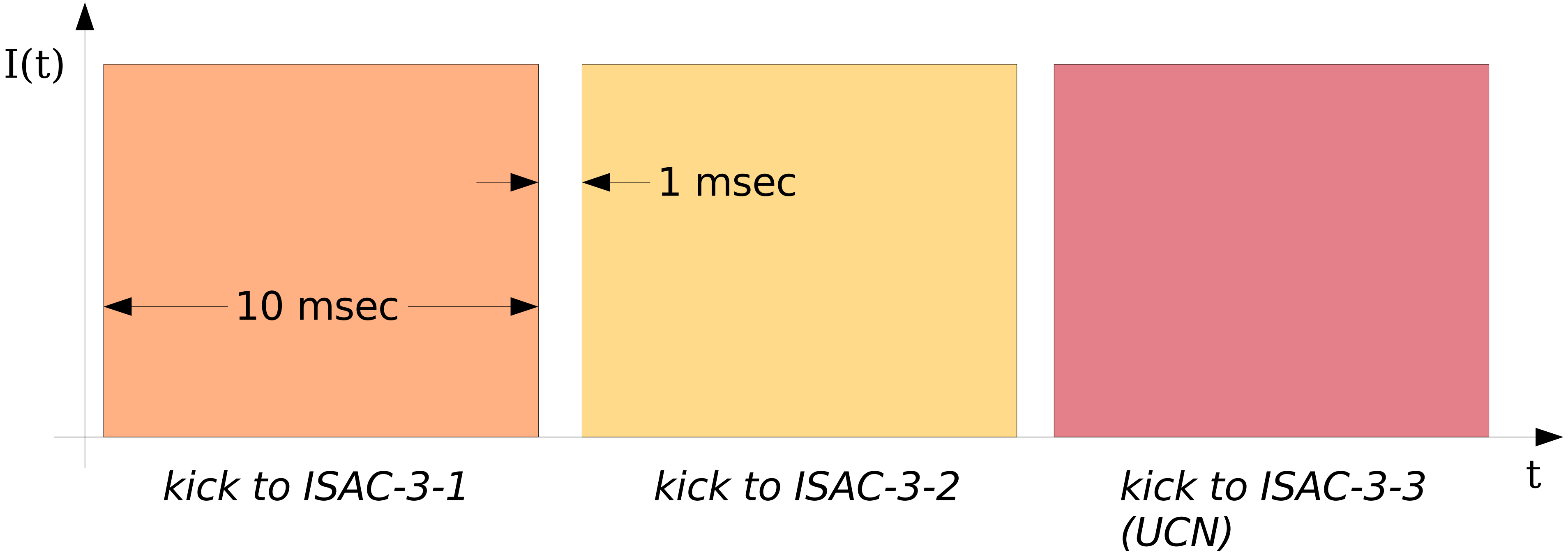
Summary

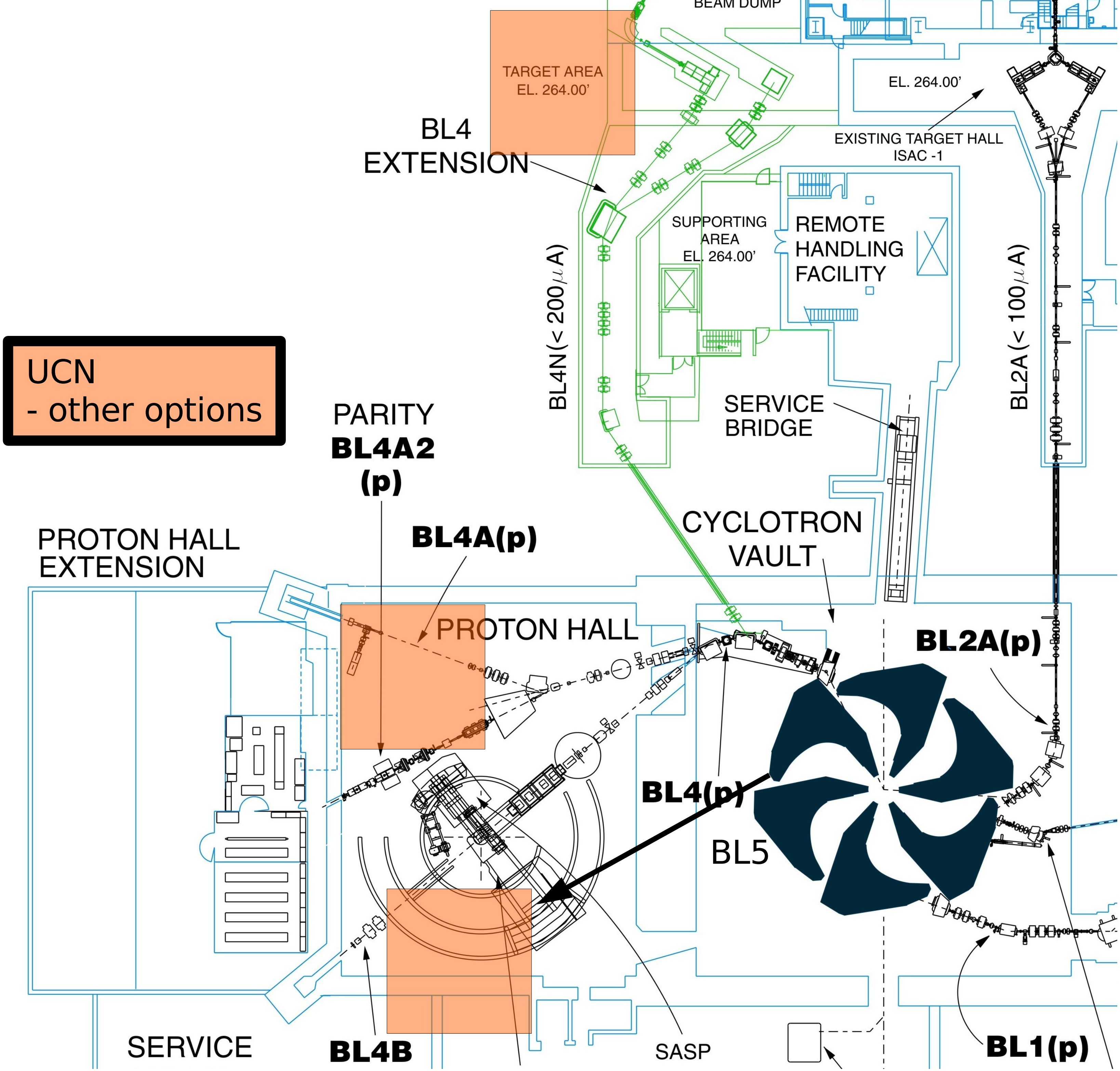
- An opportunity exists to create the world's highest density UCN source at TRIUMF
- A flagship physics experiment done this facility would be world's best
- We would like to pursue this unique and timely opportunity

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




UCN
- other options
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PROTON HALL
BL2A(p)
BL4(p)
BL5
SERVICE
BL4B
SASP
BL1(p)

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.

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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

C. Morris, LANL

P. Mumm, NIST

J. Nico*, NIST

J. Ng, TRIUMF

S. Paul*, T.U. Muenchen

M. Pospelov*, U. Victoria/Perimeter Inst.

J.-M. Poutissou, TRIUMF

W.M. Snow*, Indiana U.

F. Wietfeldt, Tulane U.

A. Young, NCSU

O. Zimmer*, ILL

Agenda

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.

Options considered

- for duty cycle
  - fast kicker + local beam dump in hall
- for BL4 sharing with ISAC
  - two stripper foils on same extraction probe + septum
    - difficult, more appropriate for BL1
  - other lines: BL1, BL5
  - (gamma,n) or photofission source of neutrons (Behr)
    - requires further study
- for space
  - locate UCN source in ISAC 2^{nd} target
- for LHe
  - modest consumption 200 L/day

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