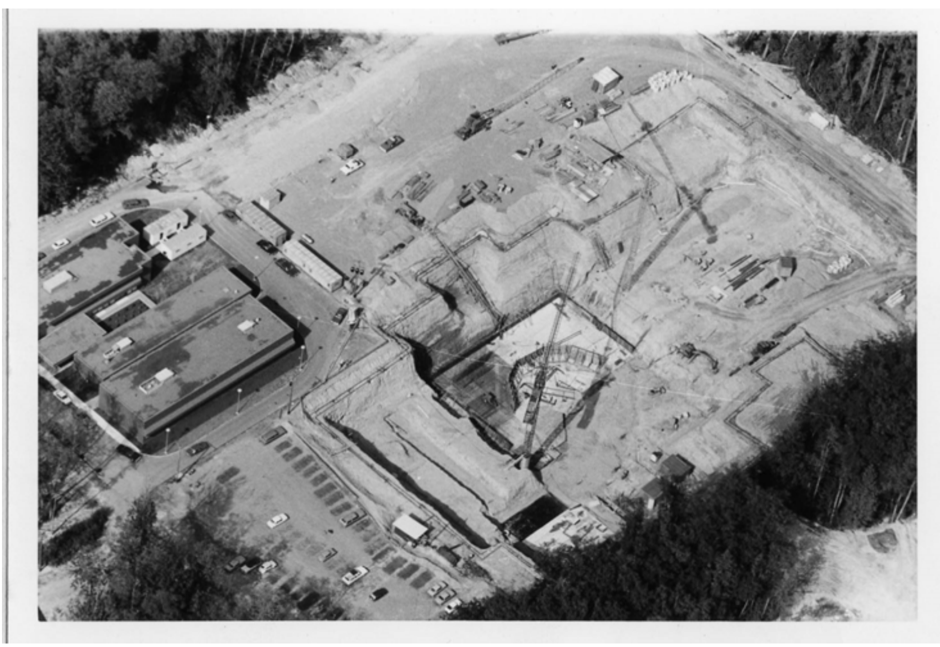
35 Years of the Main Cyclotron

(That 70's Show) from my perspective

Ewart Blackmore



1970

2004

Ewart Blackmore

1963-1967 Graduate Student, UBC Supervisor – John Warren
"Low energy reactions 3He (3He, 2p)4He and T(3He, pn)4He"
using the 3 MeV UBC Van der Graaf and Chalk River Tandem
Coffee table discussions on next accelerator for UBC

1967-1969 Post doc at Rutherford Lab, UK
Particle physics – Kaon leptonic decays
Measurement of H^- EM dissociation for the TRIUMF cyclotron design

1969-1972 TRIUMF Centre Region Cyclotron
1973-1975 Cyclotron inflector and probes/diagnostics
1975-1980 Assistant Director for Initial Operations
1981 Sabbatical at LAMPF in pion physics
1981-2008 Division Head – Experimental Facilities / Accelerator Technology /Engineering
1995-2006 Coordinated Canada's contribution to the LHC at CERN

Electric Dissociation of H^- in 1968

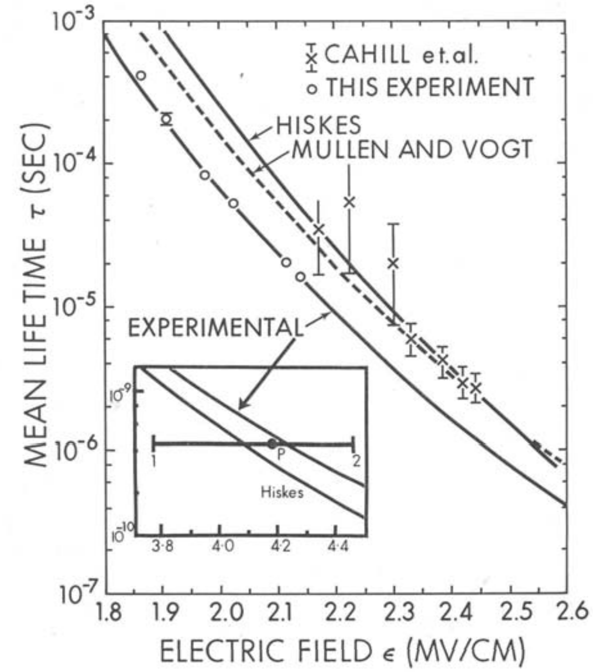
NUCLEAR INSTRUMENTS AND METHODS 74 (1969) 333–341; © NORTH-HOLLAND PUBLIS…

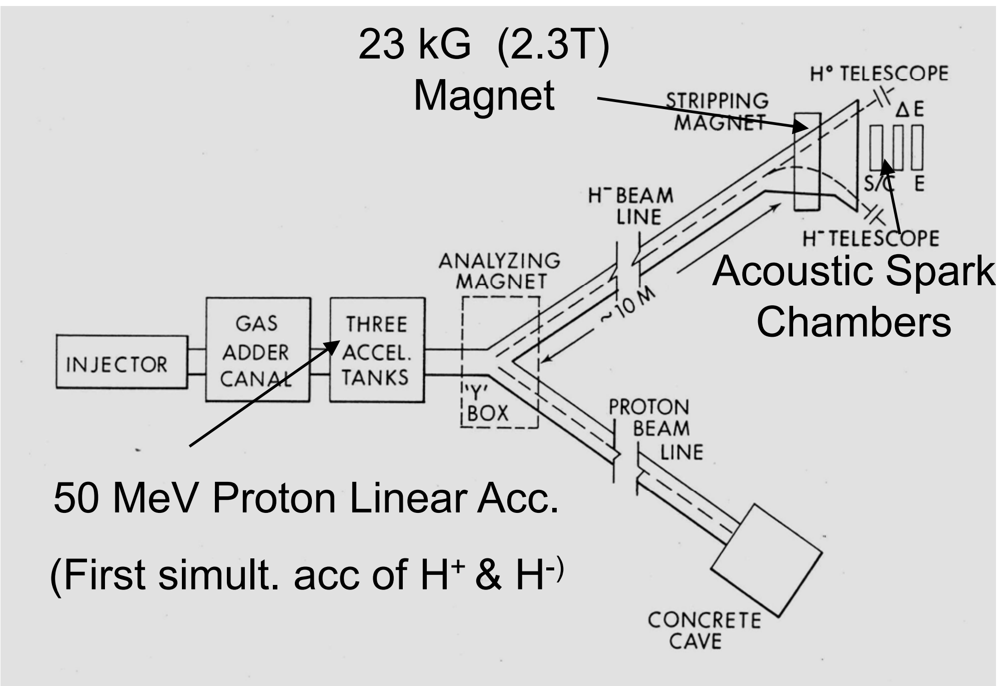
ELECTRIC DISSOCIATION OF H^- IONS BY MAGNETIC FIELDS

G. M. STINSON, W. C. OLSEN, W. J. McDONALD and P. FORD
Department of Physics, The University of Alberta, Edmonton, Canada
D. AXEN
Department of Physics, The University of British Columbia, Vancouver, Canada
E. W. BLACKMORE
Rutherford High Energy Laboratory, Chilton, Didcot, Berkshire, England

Received 21 May 1969

E = 0.3βγB MV/cm
H^- ion bound 0.755 eV

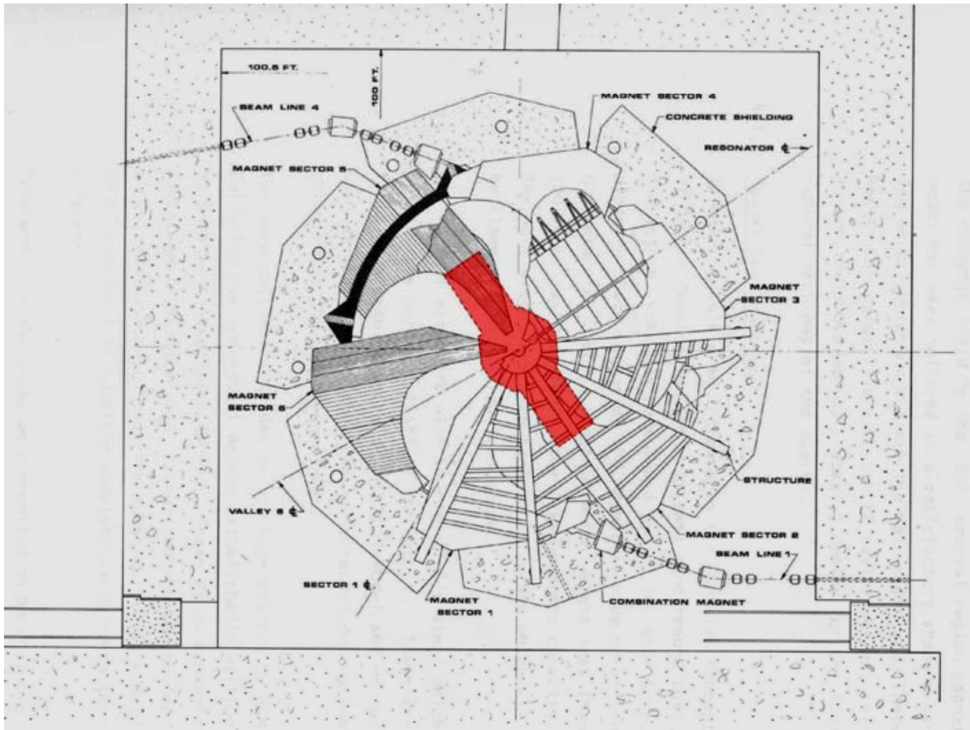




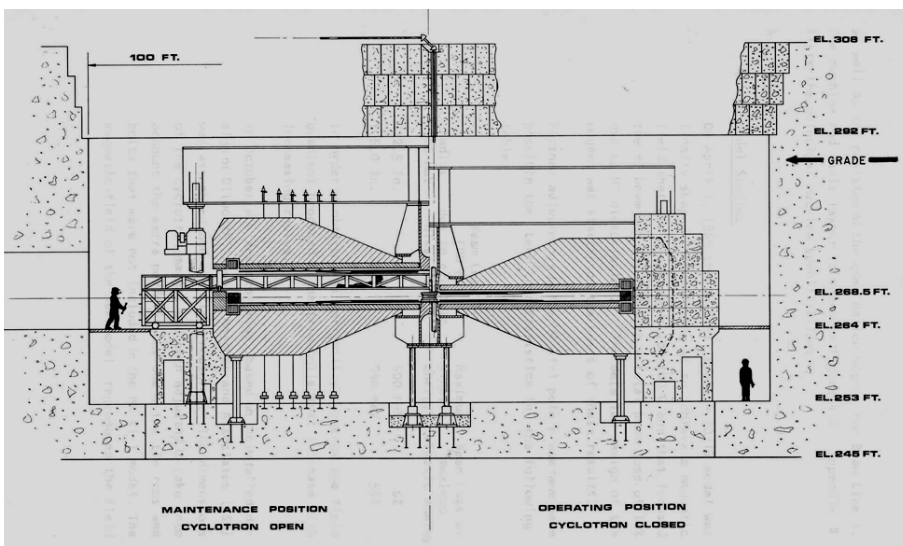
Consequences

- increase in cyclotron by 4%
- 20 scale model → 20.8 model
- peak field 5.76 kG
- confirmed in 1976 with TRIUMF beam

TRIUMF Cyclotron

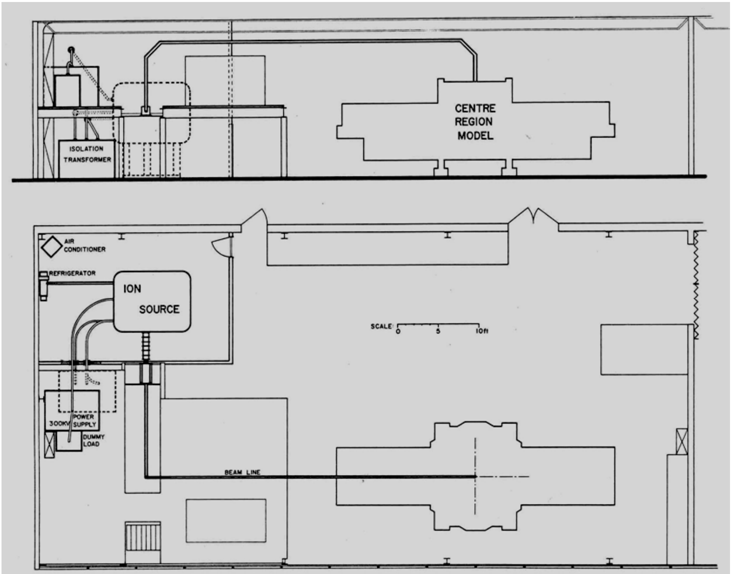


- 500 MeV, 100 μA, H^- ions
- simultaneous extraction 2 beams
- cost $8.4M in 1968

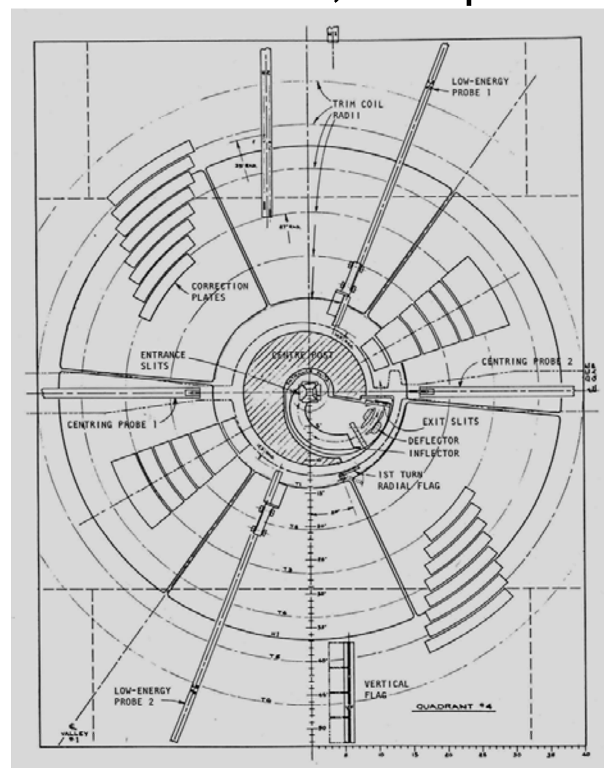


(1972)	TRIUMF(110)	UBC
Chief Eng'r	Joop Burgerjon	
Magnet:	Al Otter	Ed Auld
Beam	George Mackenzie	Mike Craddock
Dynamics:	Gerardo Dutto	
	Corrie Kost	
RF:	Roger Poirier	Karl Erdman
	Milos Zach	
Vacuum:	Dennis Healey	Dave Axen
ISIS:	Peter Bosman	Bruce White
Probes:	Bruno Duelli (EWB)	
Controls:	Don Heywood	Dick Johnson
	Dave Gurd	Ken Dawson (UofA)
Safety;	Ian Thorson	Brian Pate (SFU)
	Gary Wait	
CRC:	Ewart Blackmore	

Centre Region Cyclotron



- 80 ton magnet
- 8 resonators with flux guides
- 300 keV ion source 0.5 mA
- 3 MeV in 6.5 turns, 100 μA



Centre Region Layout

Centre Region Cyclotron

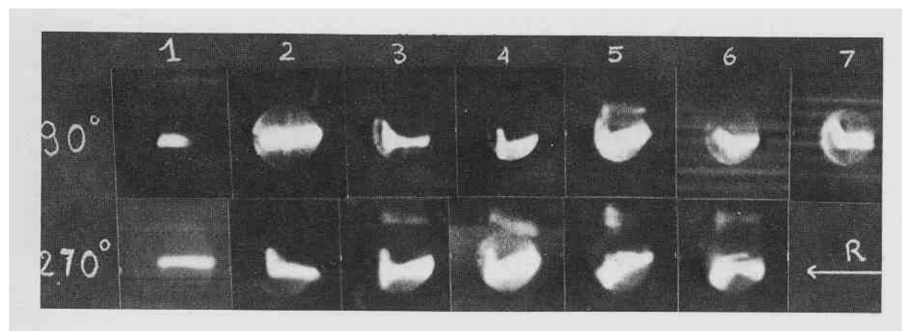
Prototype Testing

- ion source, injection system
- inflector and centre region
- resonators and rf amplifier
- probes and diagnostics
- controls

Inflector/Deflector

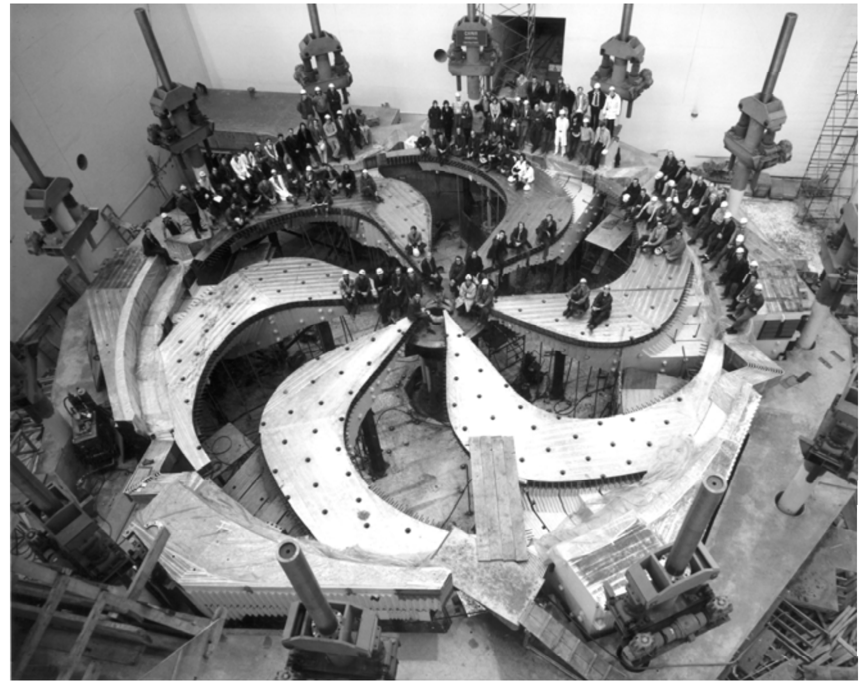
Achieved/Learned

- first beam to full energy October 1972
- intensity to 100 μA June 1973
- resonators too sensitive to temperature
- correction plates required
- beam dynamics understood
- ISIS, inflector and probes design
- fabricator identified (EBCO Industries)



First six turns of beam

Cyclotron Systems and Challenges



Magnet

- fabrication and assembly went well (1972)
- 4000 tons of steel in 50 ton shipments
- first field maps-centre field too high by 100 g
- difference in steel permeability 0.5” vs 5”
- required gouging out 16 tons of steel
- field tolerance of 1 g required (1 in 4000)
- took ~ 9 months of shimming/measurements
- delays gave other groups time to be ready

Field mapping using flip coils

TRIUMF

Cyclotron Systems and Challenges

Radiofrequency System

- 80 resonators, 1.8 MW 23 MHz
- installation and alignment
- water connections, rf contacts

<u>(1974 - 1980) RF early operations</u>

- outgassing and hydrogen pumping
- water leaks and vibrations
- rf contact damage, strongback temp.
- centre region electrodes melting
- frequency tuning – temp. and press.
- damage to diagnostic probes
- resonator strongback sagging

<u>(1990-1992) Resonator replacement</u>

- 24 new resonators installed -stiffer

(2000-present) RF Amplifier refurbish

![TRIUMF]

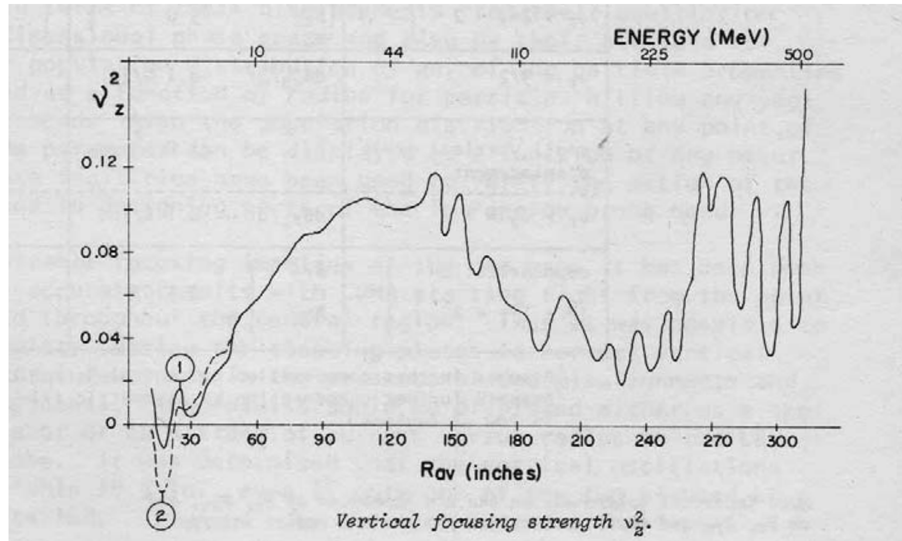
Cyclotron Systems and Challenges

Beam Dynamics

• large magnet, low field, large gap → weak focusing

• low ΔE/turn → many turns, tight tolerance on mag field, isochronism and vertical centring

• high intensity → space charge, large phase acceptance



Ion Source & Injection

• high intensity → reliability and filament lifetime

• polarized source polarization and intensity

• 40 m long injection line, cyclotron fringe field, reproducibility

• inflector HV reliability at high current

Cyclotron Systems and Challenges

Safety and Remote Handling

- understanding beam losses in cyclotron and minimizing
- system reliability inside cyclotron
- improved remote handling capability for routine and more complicated tasks
- beam lines, target areas, TNF etc

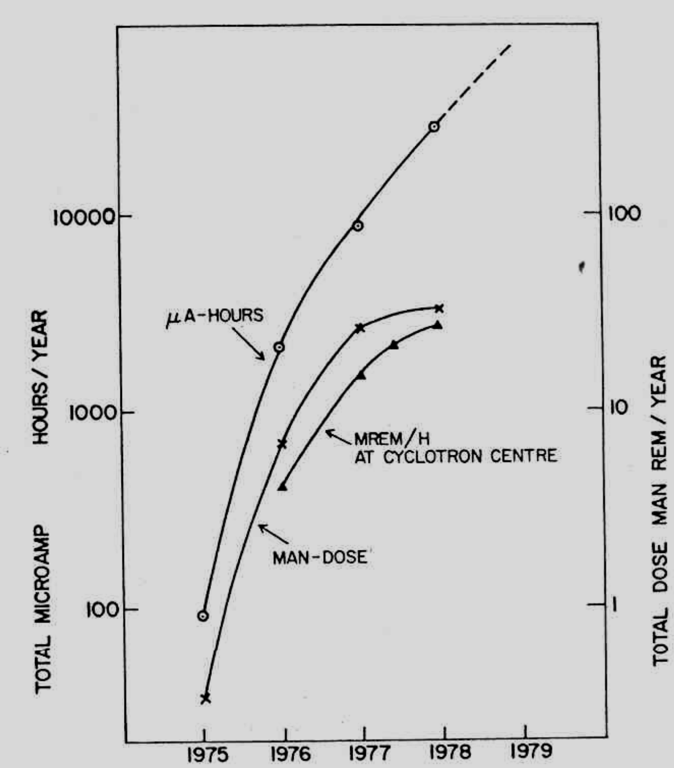


Fig. 2. Microampere-hours per year and residual activity in the cyclotron since first beam.

	mA-hrs	Dose mSv
1984	322 (88%)	474
1994	490 (90%)	267
2004	687 (92%)	307 (ISAC)

Cyclotron Commissioning

Reg at the controls

The "Commissioning Team"

Milestones

Injected beam	November 17, 1974
500 MeV	December 15, 1974
100 μA	July 1977 (beam dump)

Don Heywood	Reg Richardson
Dave Gurd	George Mackenzie
Corrie Kost	Ewart Blackmore
Gerardo Dutto	Milos Zach

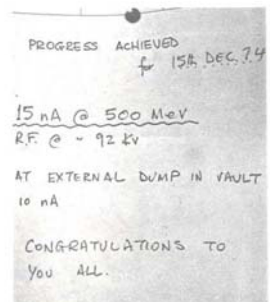
missing Mike Craddock

TRIUMF

First Beam December 15, 1974

	Maximum Radius of Beam	Energy (if centred)
Nov. 17	42 in.	6 MeV
Nov. 18	55 in.	10 MeV
	(Radiation in vault!)	
	85 in.	24 MeV
	Replaced low-energy probe	
Nov. 22	150 in.	71 MeV
Nov. 23	183 in.	113 MeV
	Replaced B-20 cryogenerator	
Nov. 25	179 in.	109 MeV
	Vacuum problems	
Nov. 26	195 in.	135 MeV
	Deflector sparking	
Nov. 27	223 in.	195 MeV
Nov. 28	231 in.	210 MeV
	Check v_z^2 = 0.02 at R=223in.	
Dec. 1	259 in.	295 MeV
Dec. 3	265 in.	315 MeV
	Beam appears to be centred 300 kV supply in ISIS kaput	
Dec. 11	Trying to re-establish beam RF problems	
Dec. 12	273 in.	345 MeV
	Sparking in ISIS	
Dec. 14	278 in.	363 MeV
Dec. 15 12:10	278 in.	363 MeV
13:07	**309 in.**	**500 MeV**




Cyclotron Operations and Beam Delivery

IEEE Transactions on Nuclear Science, Vol.NS-22, No.3, June 1975

PRODUCTION OF SIMULTANEOUS, VARIABLE ENERGY BEAMS
FROM THE TRIUMF CYCLOTRON

J. Reginald Richardson*, E.W. Blackmore, G. Dutto,
C.J. Kost, G.H. Mackenzie, TRIUMF and M.K. Craddock
Physics Department, University of British Columbia,
Vancouver, B.C.

Specification (1972)

2 beams – 100, 10 μA

180-520 MeV

Achieved (today)

3(4) beams

BL1A -120 μA 500 MeV

BL2A -100 μA 500 MeV

BL2C -70 μA 100 MeV

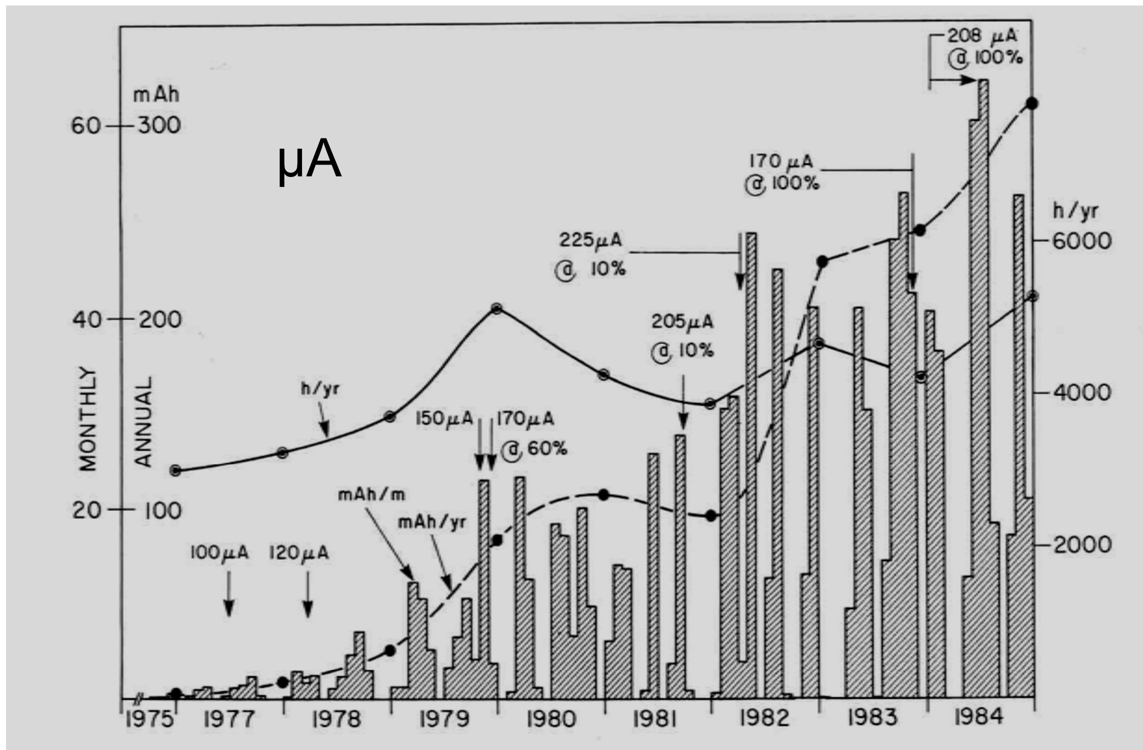
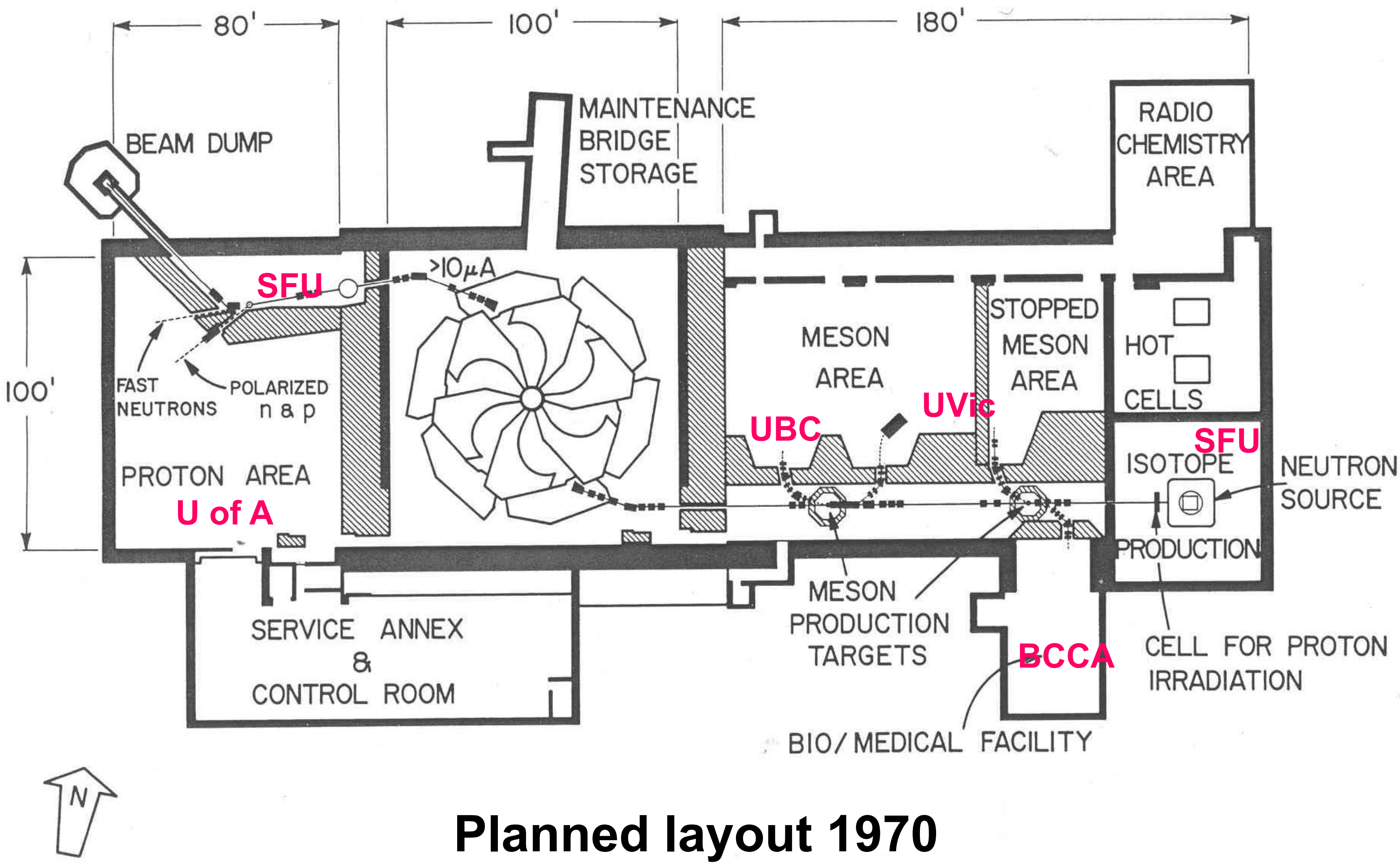


Fig. 71. Beam charge delivered (broken line) and hours of operation (solid line) over the past several years. Milestones in extracted peak current are also indicated. The histogram shows the charge delivered per month.

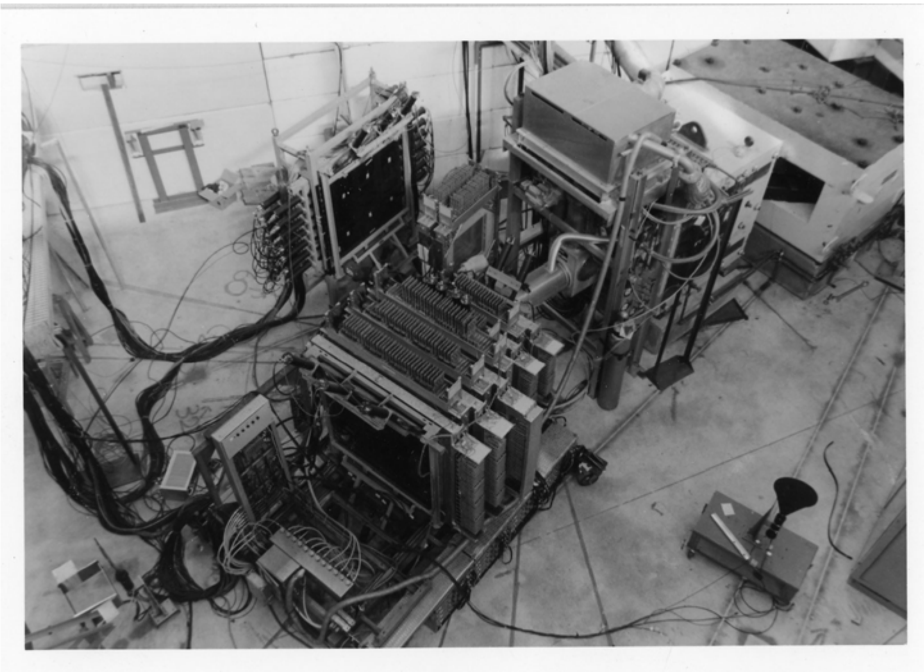
Experimental Areas & Beamlines



Planned layout 1970

Experimental Areas & Beamlines

Proton Hall



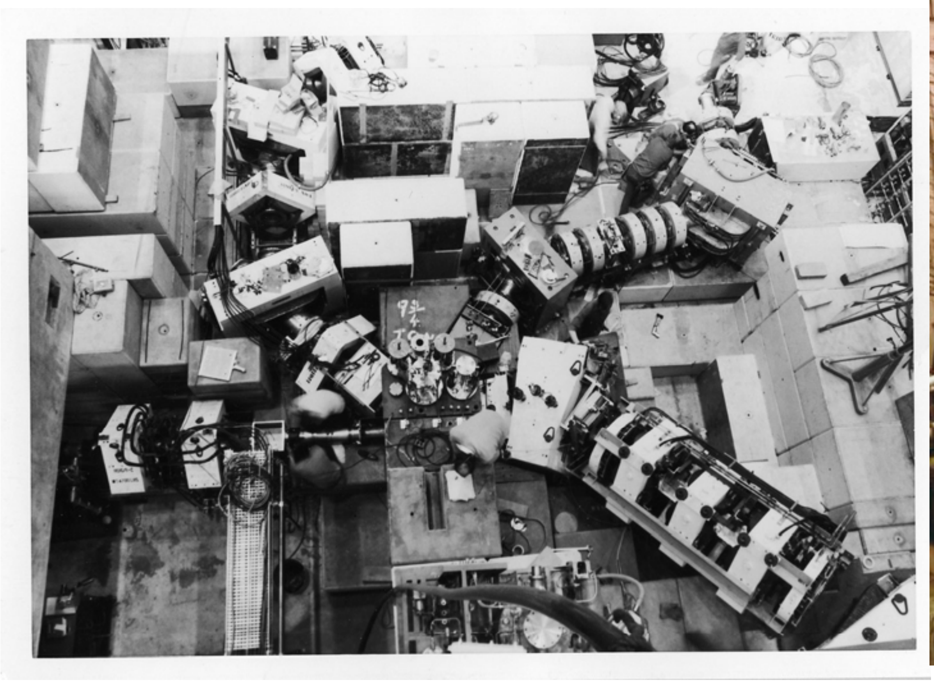
Basque Experiment - 1975

MRS Spectrometer
1976

TRIUMF

Experimental Areas & Beamlines

Meson Hall



T2 target M9, M20, M8
(1975)

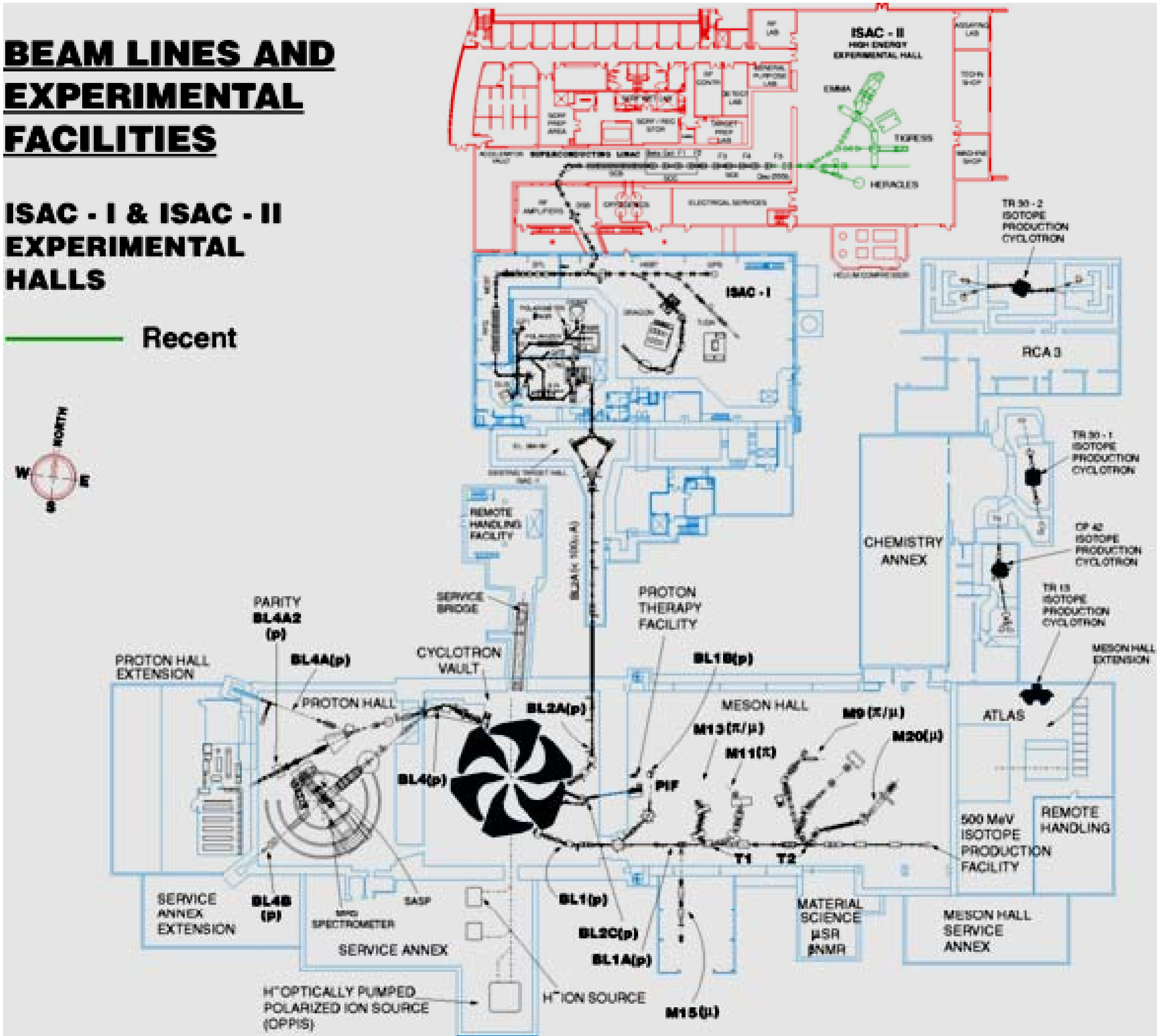
TNF Beam Dump
(1977)

TRIUMF

BEAM LINES AND EXPERIMENTAL FACILITIES

ISAC - I & ISAC - II EXPERIMENTAL HALLS

Recent



TRIUMF Cyclotron (1974-2009)
"A Success Story"

Real Advantages

- simultaneous beams, variable energy & intensity
- reliability after initial teething problems
- versatility in meeting science demands

Real Surprises

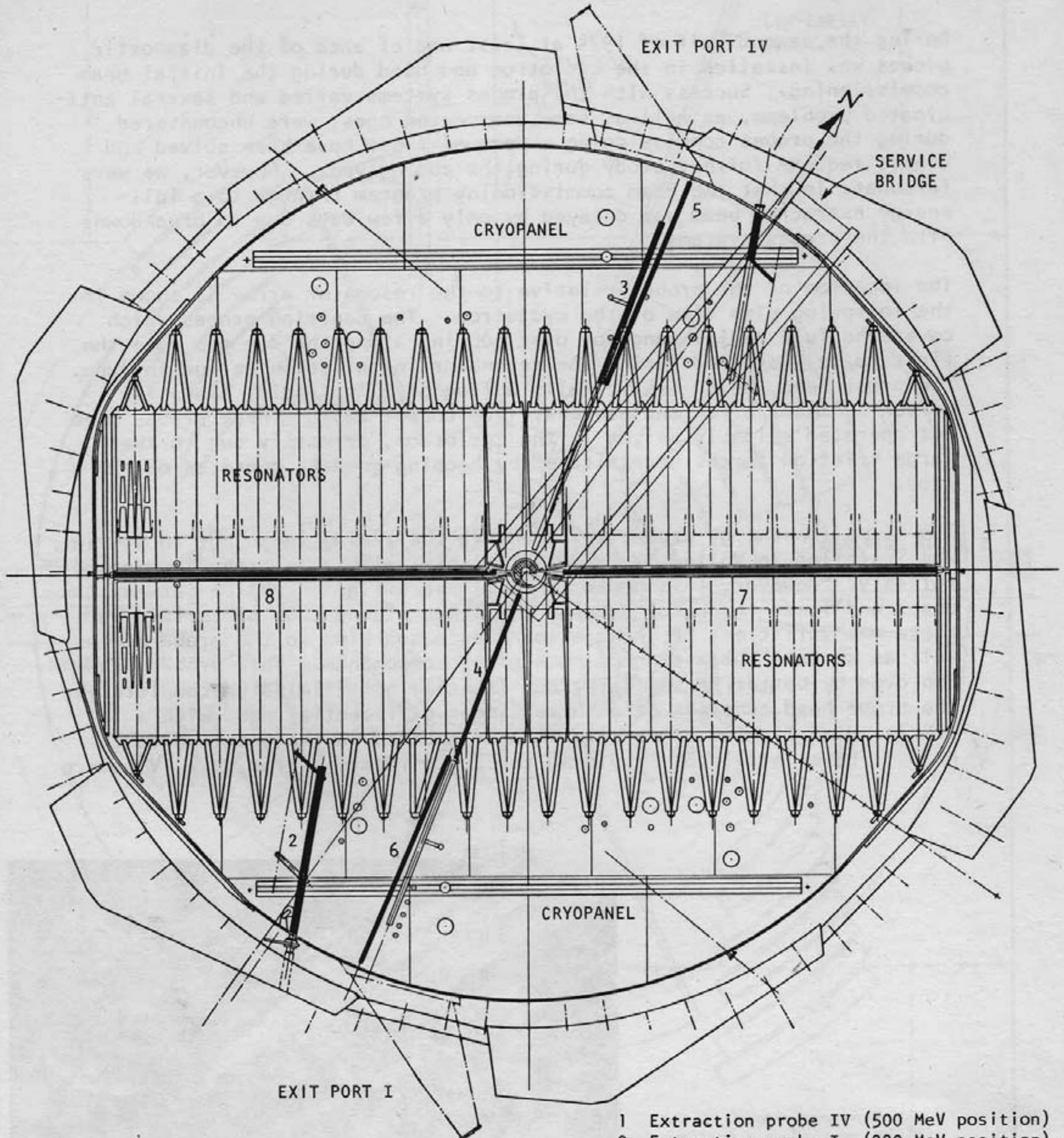
- delivers 3x more beam than originally specified
- has lasted 35 years and still going strong
- nuclear physics (original motivation)
  particle physics
  material sciences
  isotope production (TR series of cyclotrons)
  medical applications
  ISAC (nuclear physics)

TRIUMF

Thank You !

Merci !

Probes and Beam Diagnostics



Plan view of the cyclotron showing the various diagnostic and extraction probes.

1 Extraction probe IV (500 MeV position)
2 Extraction probe I (200 MeV position)
3 Low-energy probe 1 (outer position)
4 Low-energy probe 2 (inner position)
5 High-energy probe 1
6 High energy probe 2
7 Centring probe 1
8 Centring probe 2