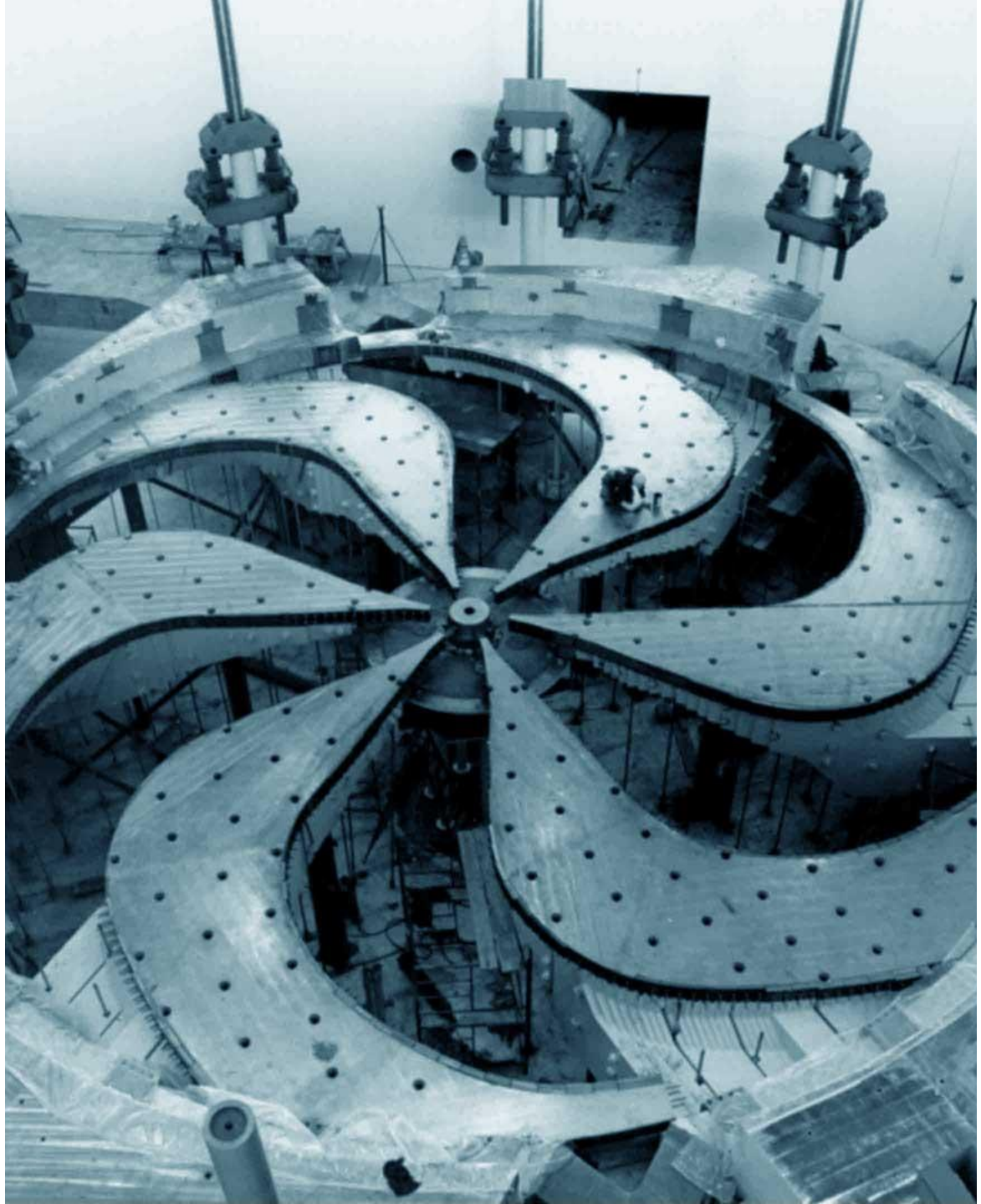
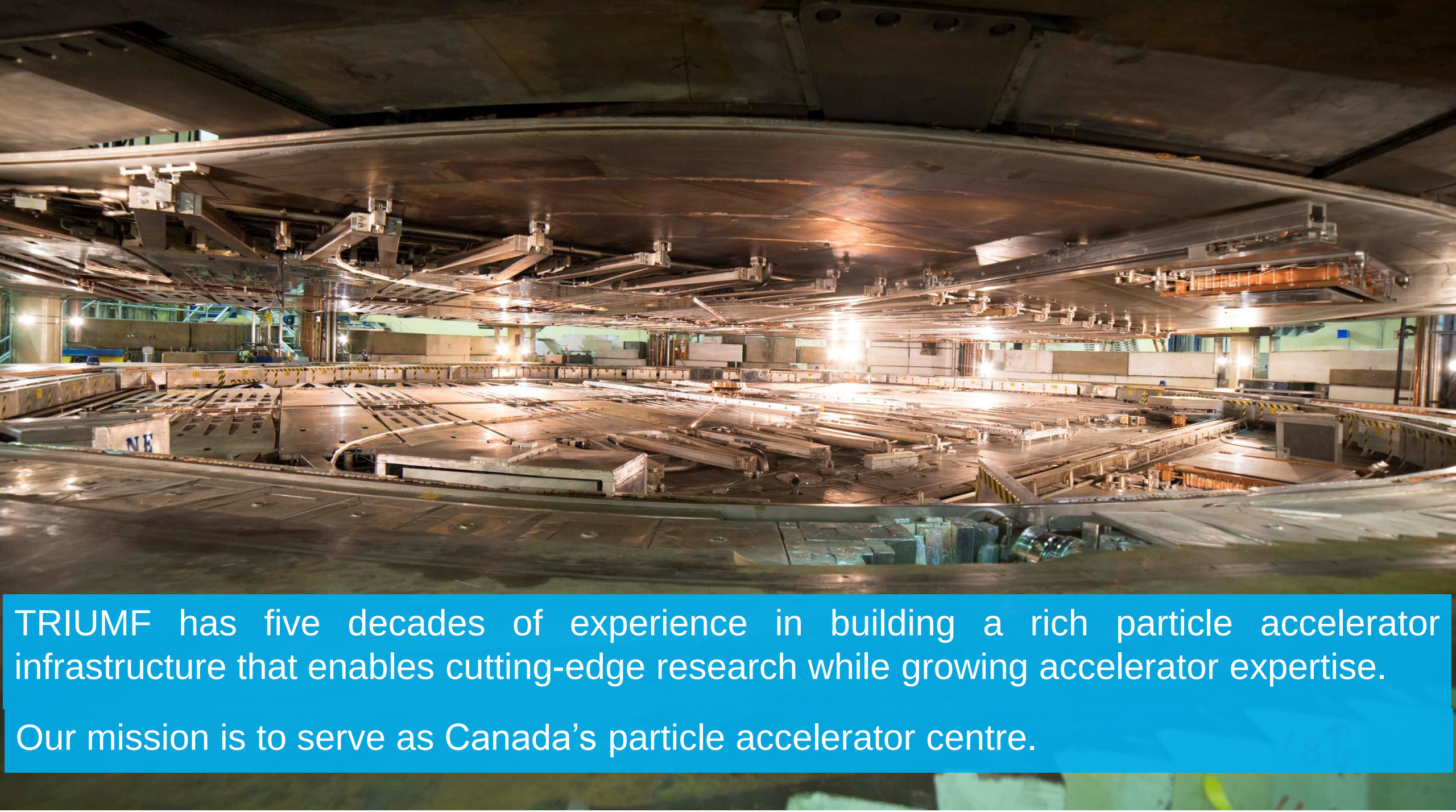
TRIUMF signature mark: Advances in SRF technology

Bob. Laxdal, TRIUMF



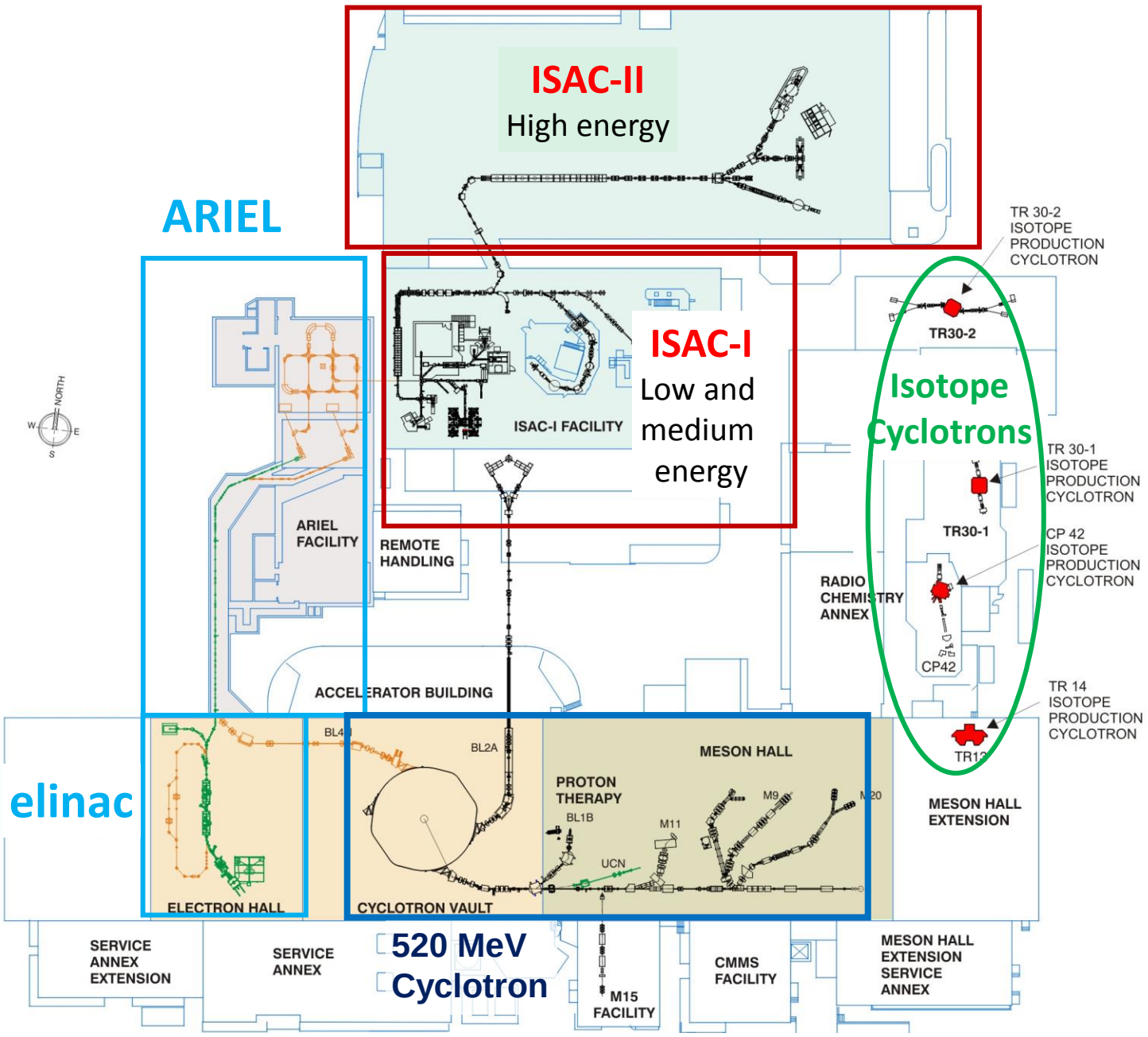
22/02/2021

Discovery, accelerated



TRIUMF has five decades of experience in building a rich particle accelerator infrastructure that enables cutting-edge research while growing accelerator expertise.

Our mission is to serve as Canada’s particle accelerator centre.



This mission is reflected in the wide variety of accelerator technologies that populate the campus.

Our strategy is to use internal projects and external collaborations as springboards to expand core competencies or gain new ones.

Rather than import technology, we typically develop it, accumulating a broad expertise within a relatively small lab.

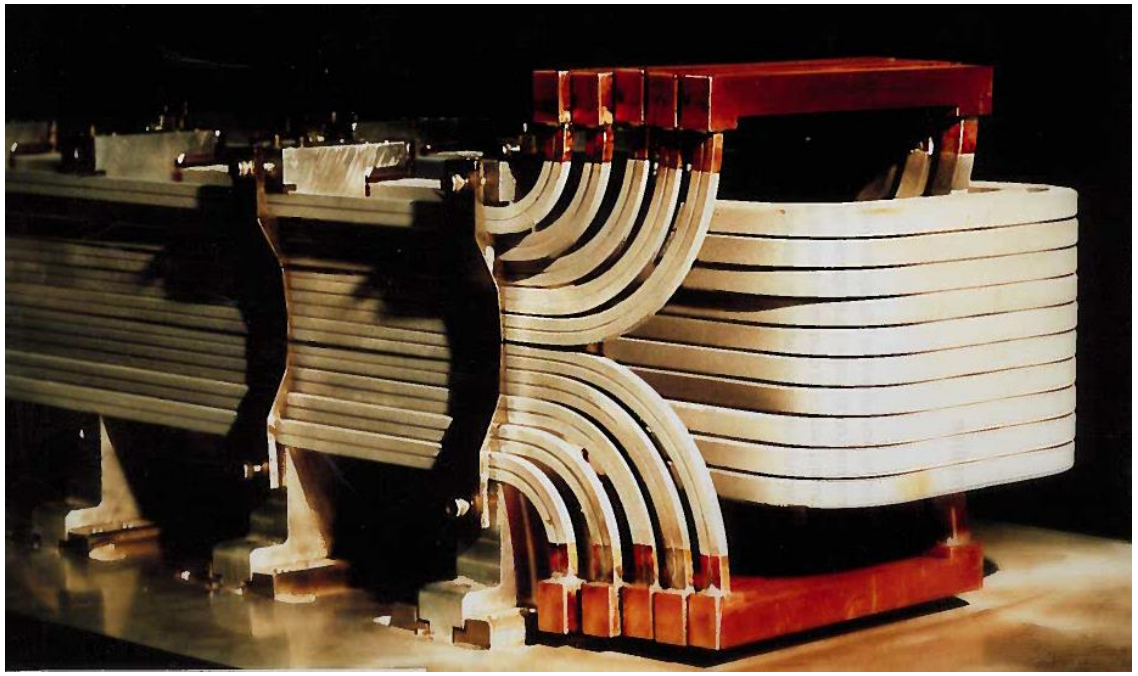
- This strategy is not universal but was developed as a TRIUMF culture through our early years
  - KAON, TR30, ISAC
- Gerardo played a pivotal role in developing this culture
- He believed strongly in collaboration and open science
- He assembled strong teams and was always looking for new talent or new partnerships to enhance our expertise

Discovery, accelerated

1980`s – 500MeV Accelerator was `the only game in town’

KAON Factory Development – (1985-94) H- Extraction

- Cyclotron studies focused on H- extraction
- Challenging R&D
- Other teams focussed on high energy rings beam dynamics and technology



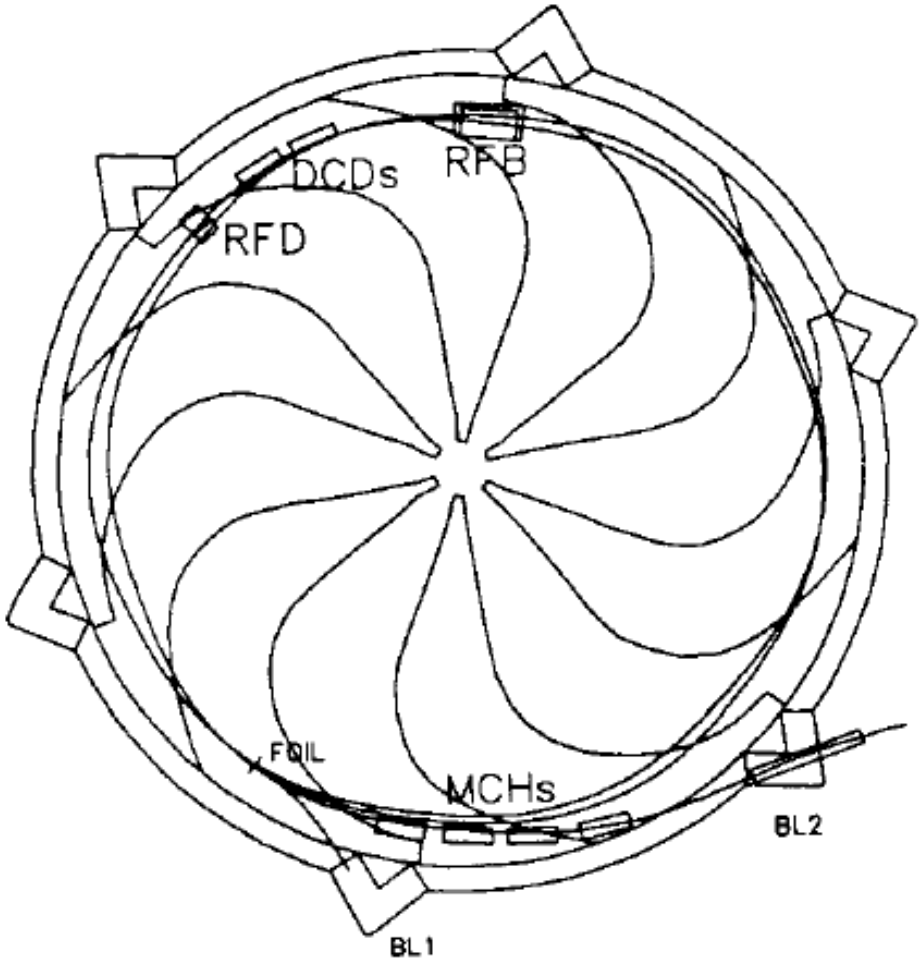
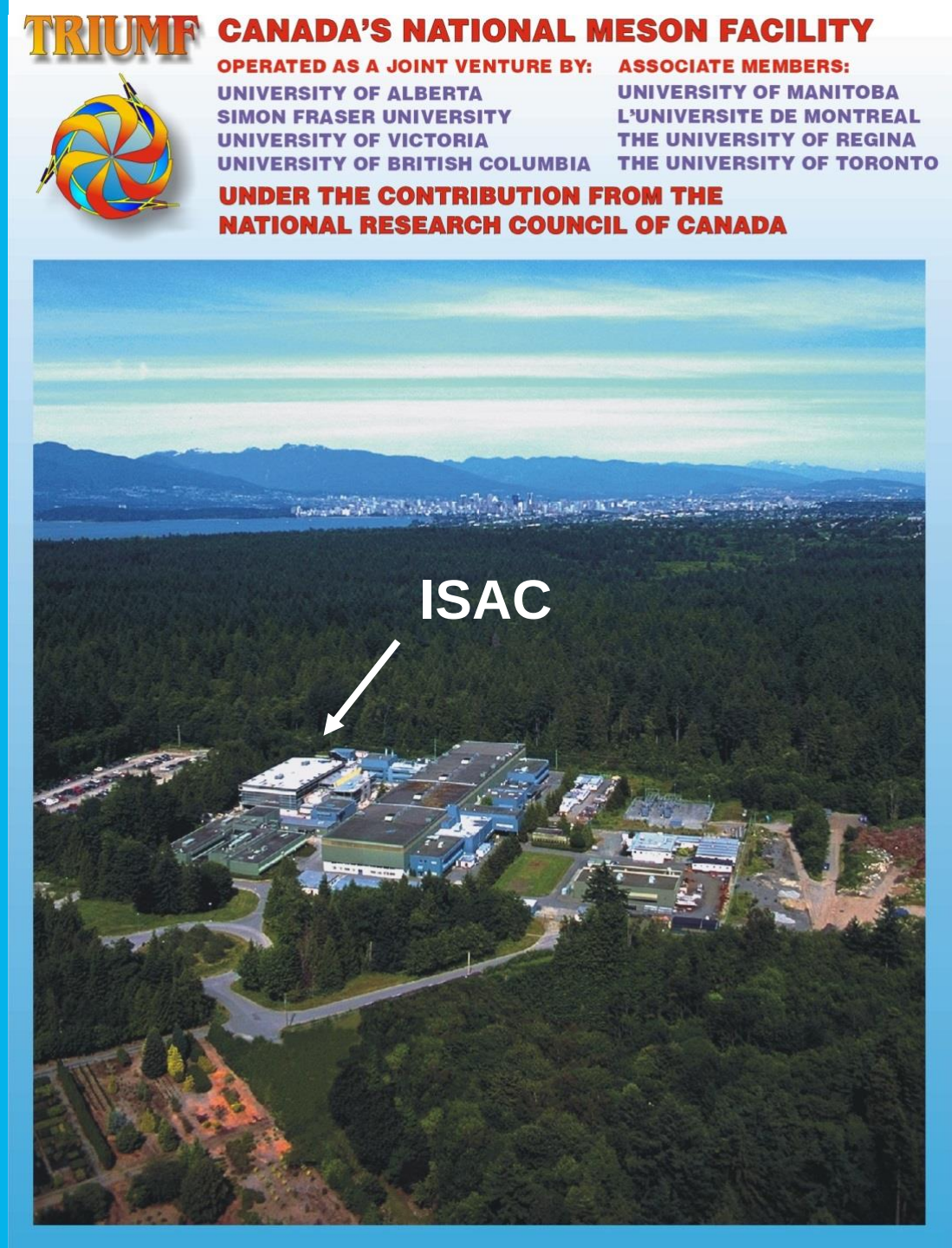


Fig. 2. Reference position of extraction elements in the cyclotron.

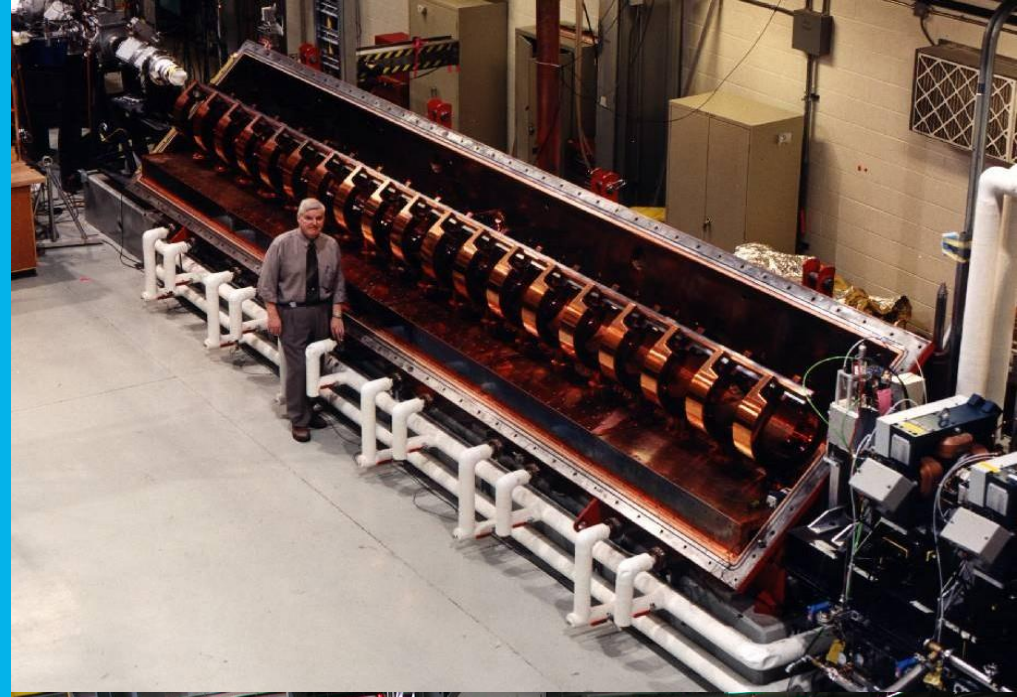
Early ISAC Years (1995-2000)

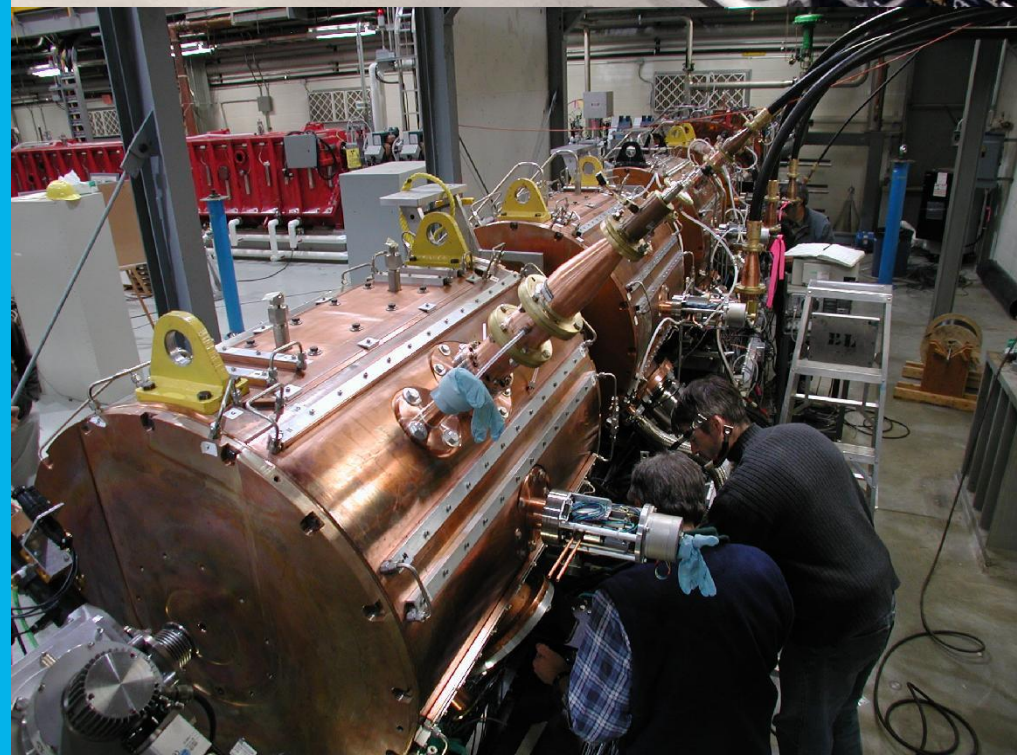
- By 1994 TRIUMF had moved on to the ISAC program and the dream for a TRIUMF based KAON factory was over
- But the ten years of KAON development was not completely in vain - TRIUMF evolved from a Cyclotron lab to an Accelerator Lab
- In 1995 several of the cyclotron and KAON accelerator physicists moved over to ISAC with Gerardo spearheading the post accelerator development



Early ISAC Years (1995-2000)

- We designed and built in house challenging and innovative linear accelerators
- Dec 2000 we accelerated the first beam from the ISAC RFQ-DTL linac
- Key collaborators through this period
  - John Staples – LBNL
  - Ken Crandall – LANL
  - Werner Pirkl, Alessandra Lombardi - CERN
  - Uli Ratzinger – GSI
  - Petr Ostroumov – INR Troitsk
  - Yuri Bylinsky – INR Troitsk





ISAC-II Concept 1998

- The idea ~1998 – brown book
- Discussed in a retreat in the woods of Vancouver Island
- Goal - increase ISAC ion energy to support Nuclear Physics studies at and above the Coulomb barrier
  - E≥6.5MeV/u for A/q=6 with full energy variability
- Bold decision
  - add a superconducting heavy ion linac of 40MV
  - Add ECR charge state booster (CSB)

Proceedings of the 15th International Conference on Cyclotrons and their Applications, Caen, France

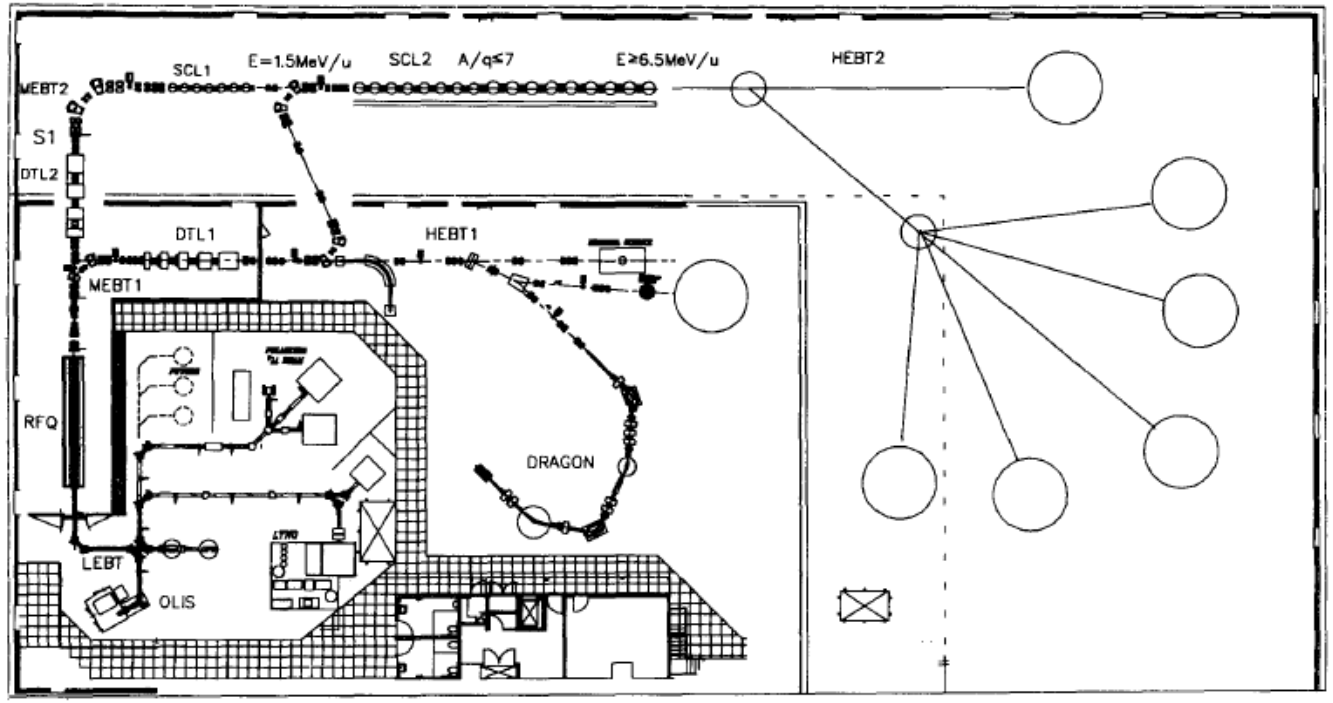


Figure 4: Layout of the proposed ISAC2 facility.

Conceptual design above is from brown book

Why superconducting for RIB post accelerator?

- Allows high gradient for continuous wave operation
- Allows large apertures and longitudinal phase space for high transmission
- Flexible machine – allows customized acceleration
- **But – requires unique know how**

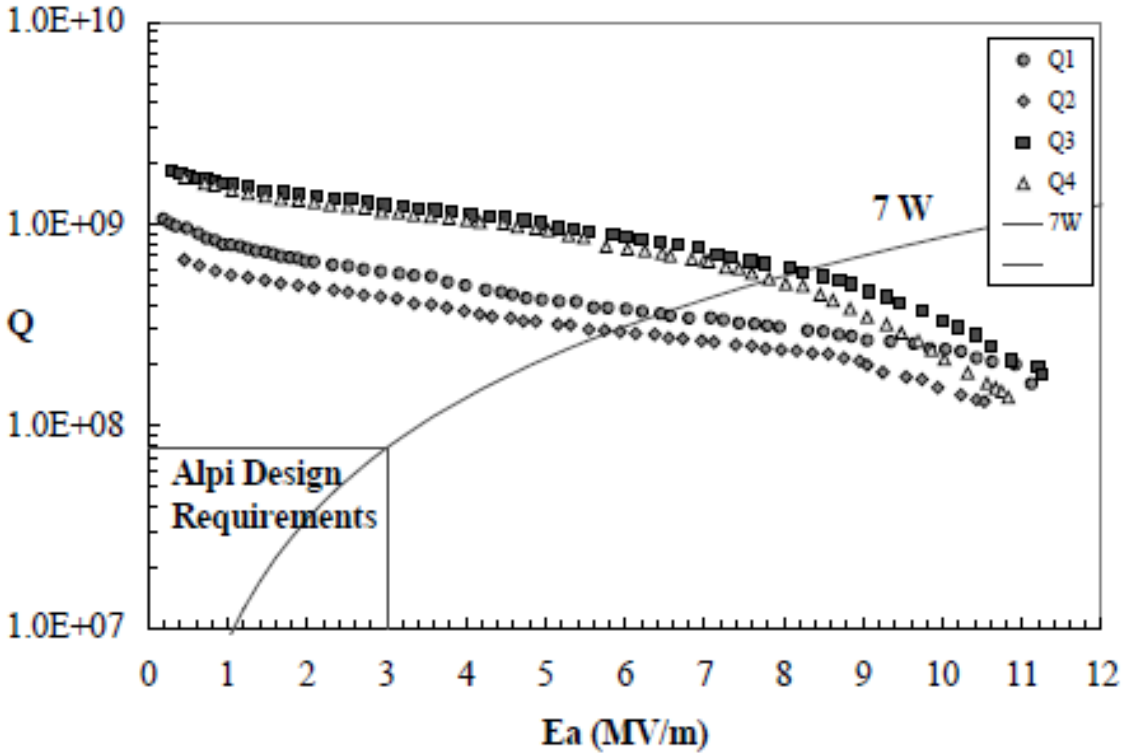
CW heavy ion SC-linacs performance landscape – circa 2000

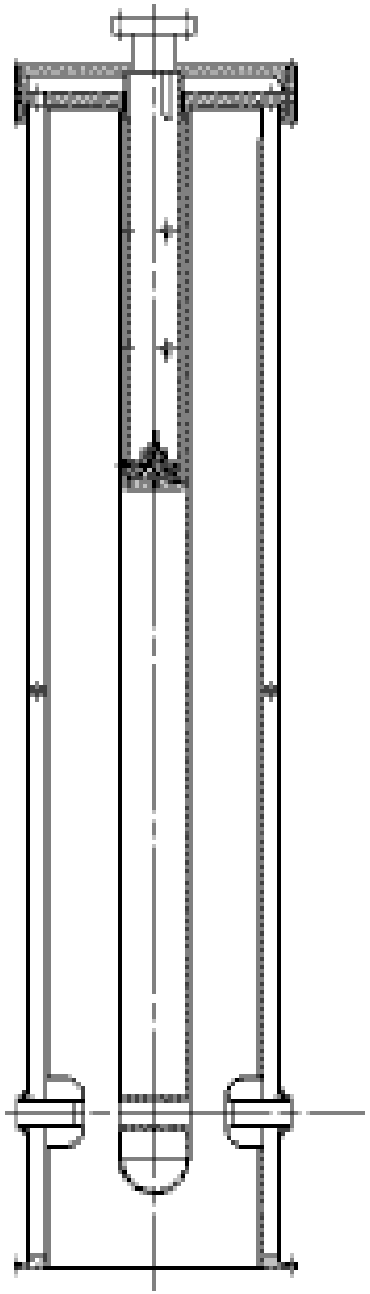
- ATLAS
  - Bulk niobium – Ep~15-20MV/m
- INFN-Legnaro
  - Sputtered Nb on Cu - Ep~20MV/m
  - Bulk niobium cavities – higher gradients demonstrated but little on-line experience
- JAERI
  - Explosively bonded Nb on Cu – Ep~23MV/m
- ISAC-II aimed for a considerable advancement
  - Bulk niobium cavities – Ep>30MV/m
  - Plan was to use new processing and clean room techniques and advanced cryomodule engineering to achieve high performance

EPAC 1998 Stockholm – Alberto Facco

ON-LINE PERFORMANCE OF THE LNL MECHANICALLY DAMPED SUPERCONDUCTING LOW BETA RESONATORS

A. Facco, V. Zviagintsev[1], S. Canella, A. M. Porcellato, F. Scarpa
INFN-Laboratori Nazionali di Legnaro, Padova, Italy; [1]on leave from ITEP, Moscow, Russia

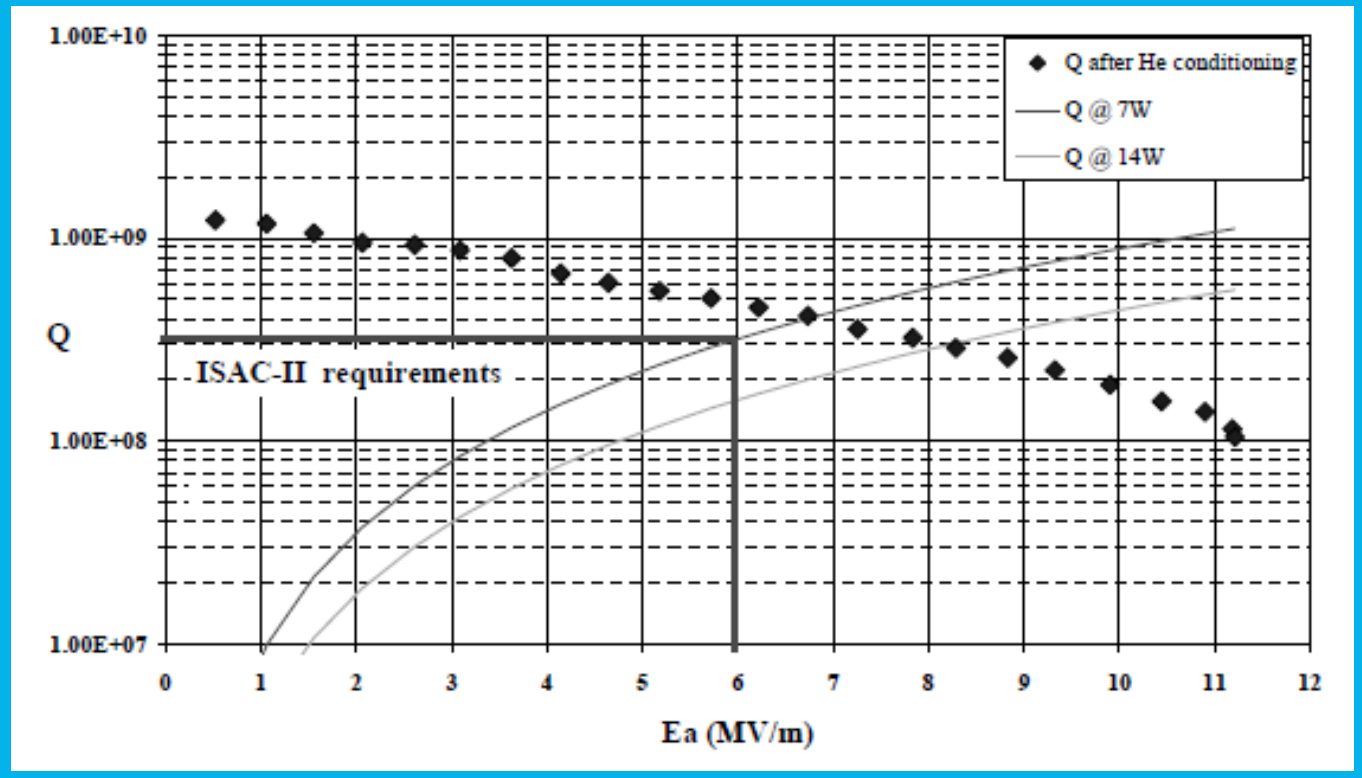




Alberto's QWR

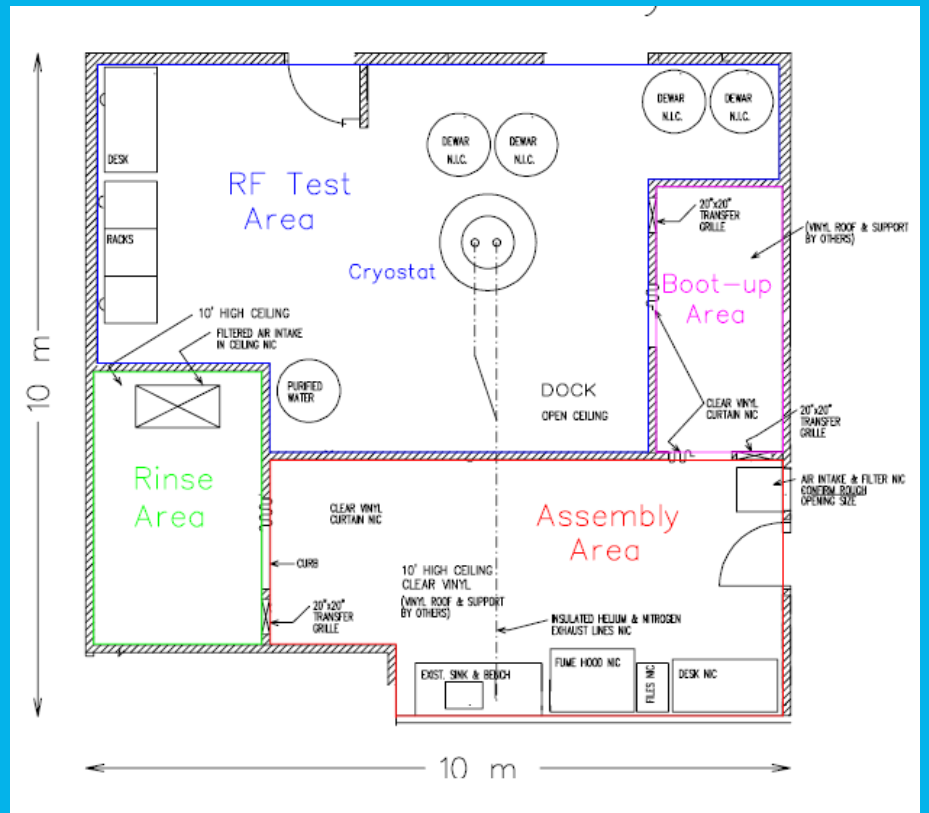
Off to Italy

- Gerardo was very positive about a collaboration with a lab from Italy
- We received funding for ISAC-II in April 2000 and began plans for a prototype resonator to be designed in collaboration with Alberto and fabricated in Italy
- Ken Fong and I visited Legnaro in Feb. 2001 for the first cold test with Alberto and Vladimir



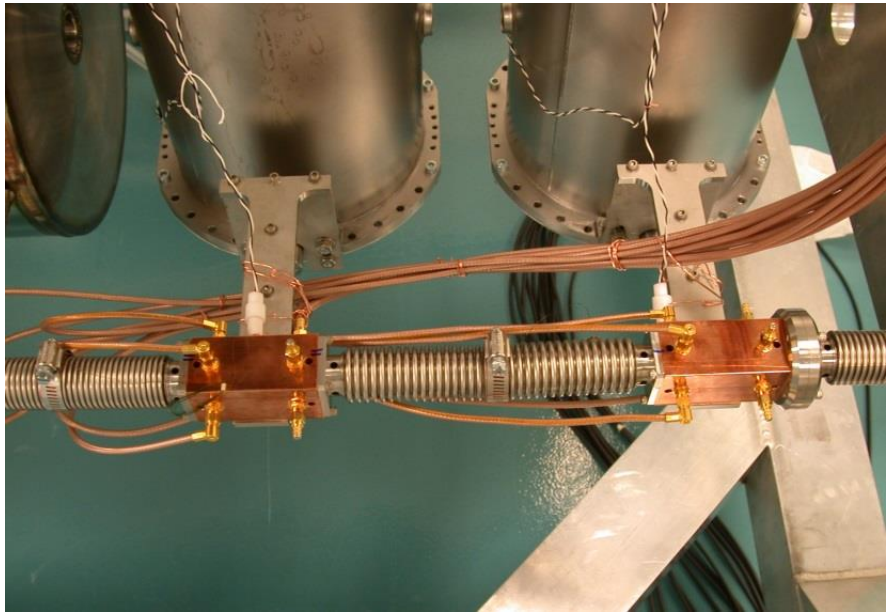
SRF Development 2001 - BC Research

- Newly formed SRF R&D group secured lab space at BC Research in 2001
- Tests began 2002 – moved to ISAC-II in 2003
- Tests support parallel developments of cavity performance, rf controls, cryogenic studies, cavity preparation, mechanical tuners



More Italian Connections

- Dario Giove – Milano - WPM
- Marco Poggi – LNL - diagnostics
- Matteo Pasini – LNL - Beam dynamics
- Marco Marchetto – LNL – Accelerator physics and operation

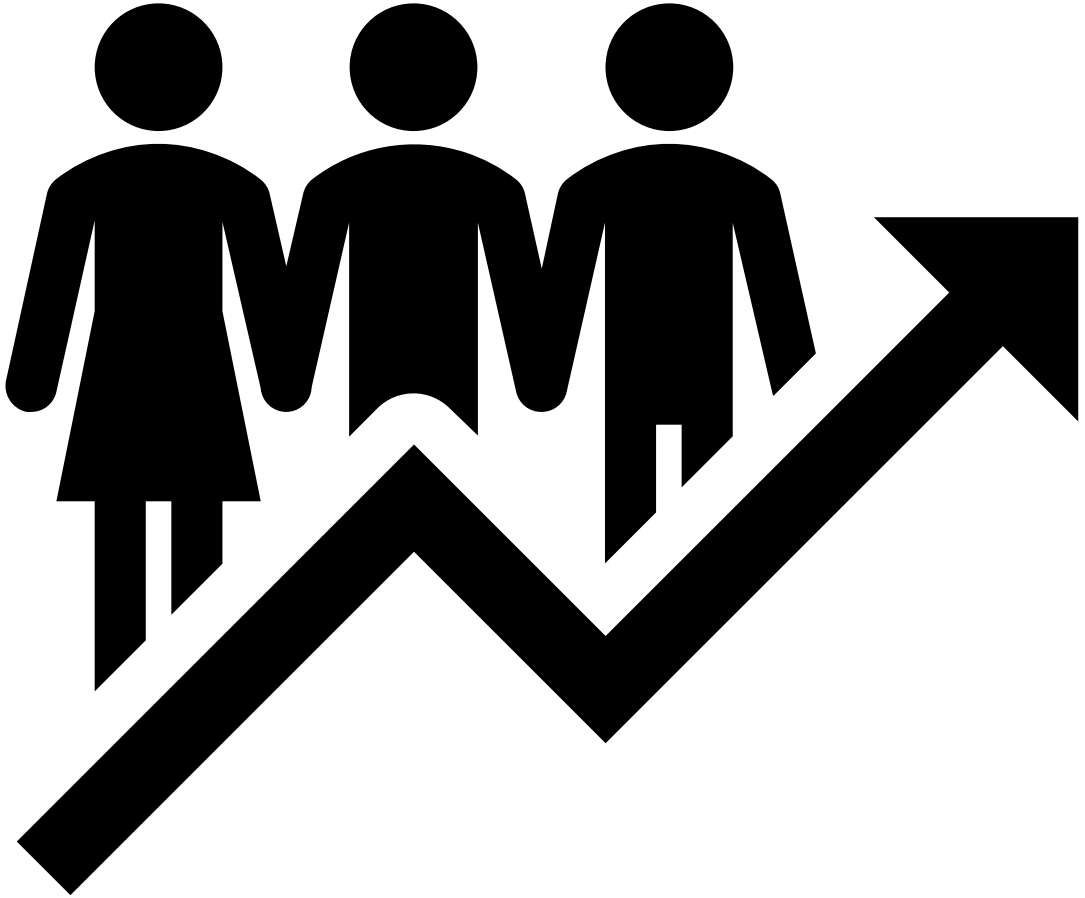


Other Key support

- Ken Shepard – Argonne – assorted wisdom

Towards High Gradient

- Choose high performing cavity – Facco`s Ferrari
  - Ordered 20 from Zanon in Italy
- Develop precision tuner to keep it on resonance
- Develop LN2 cooled coupler to provide rf bandwidth at high gradient
- Adopt clean room techniques to reduce field emission
- Develop strong SC solenoids with bucking coils inside cryomodule for strong transverse focussing



TRIUMF core team

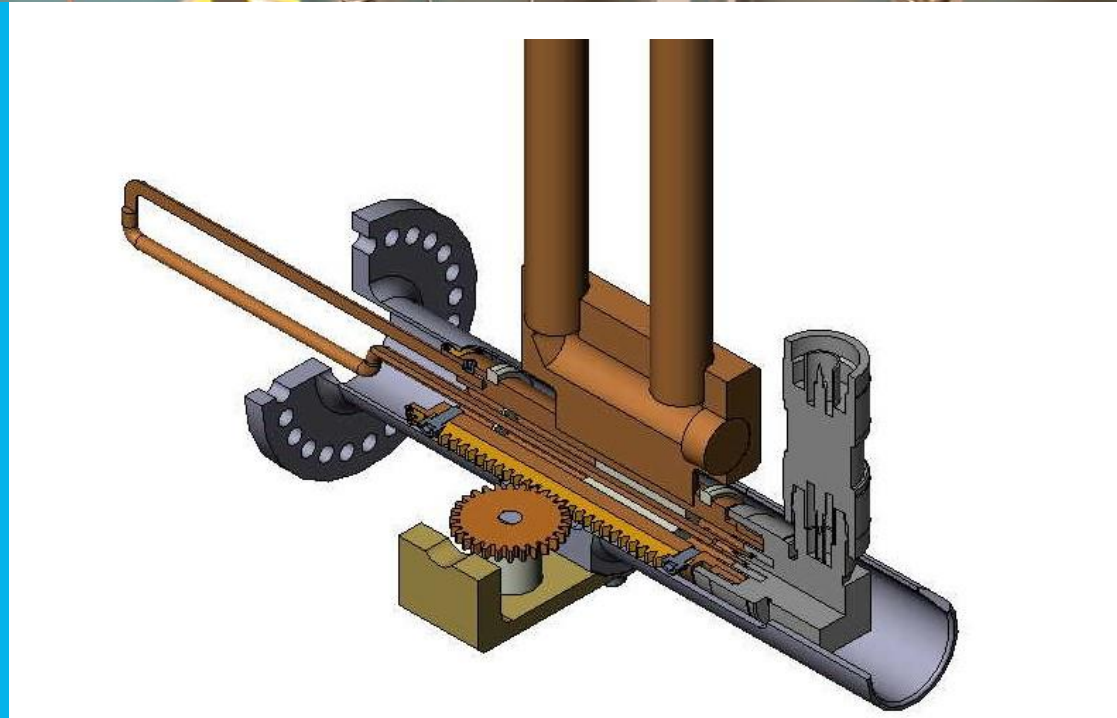
- Lead engineer – **Guy Stanford**
- Vacuum and Cryogenics – **Igor Sekachev**
- RF Controls – **Ken Fong**
- Cavity contract management – **Roger Poirier**
- RF single cavity tests – **Vladimir Zvyagintsev**
- RF infrastructure – **Amiya Mitra**
- Technical preparation and assembly
  - cavity processing and clean assembly - **Bhalwinder Waraich**
  - dirty assembly and test preparation - **Peter Harmer**

Novel Features

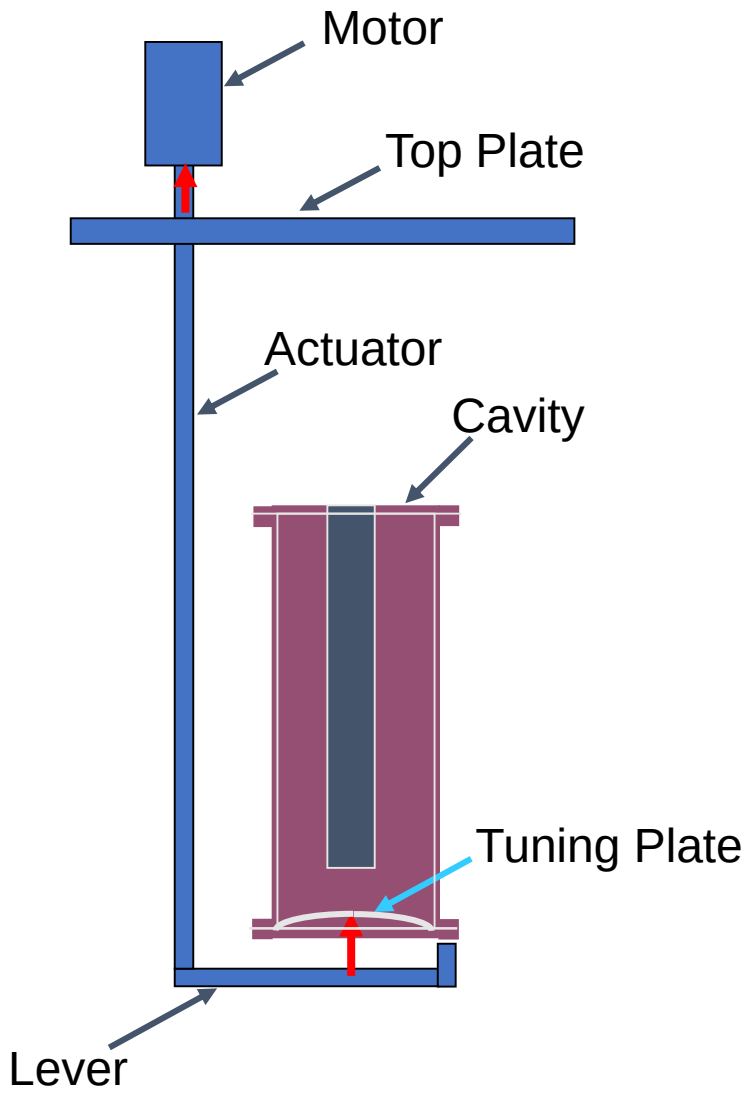
- High pressure rinsing of cavities, careful selection of materials and clean room assembly to reduce cavity contamination and field emission
- 9T superconducting solenoid with bucking coils to reduce fringe fields
- Wire position monitor alignment

Coupling Loop with Direct Cooling (Roger Poirier)

- Developed from INFN Legnaro adjustable coupling loop
- Modifications
  - Stainless steel body for thermal isolation
  - Direct LN2 cooling
  - Aluminum Nitride to cool inner conductor



ISAC-II Cavity Mechanical Tuner (Tom Ries)



Precise and responsive tuner developed

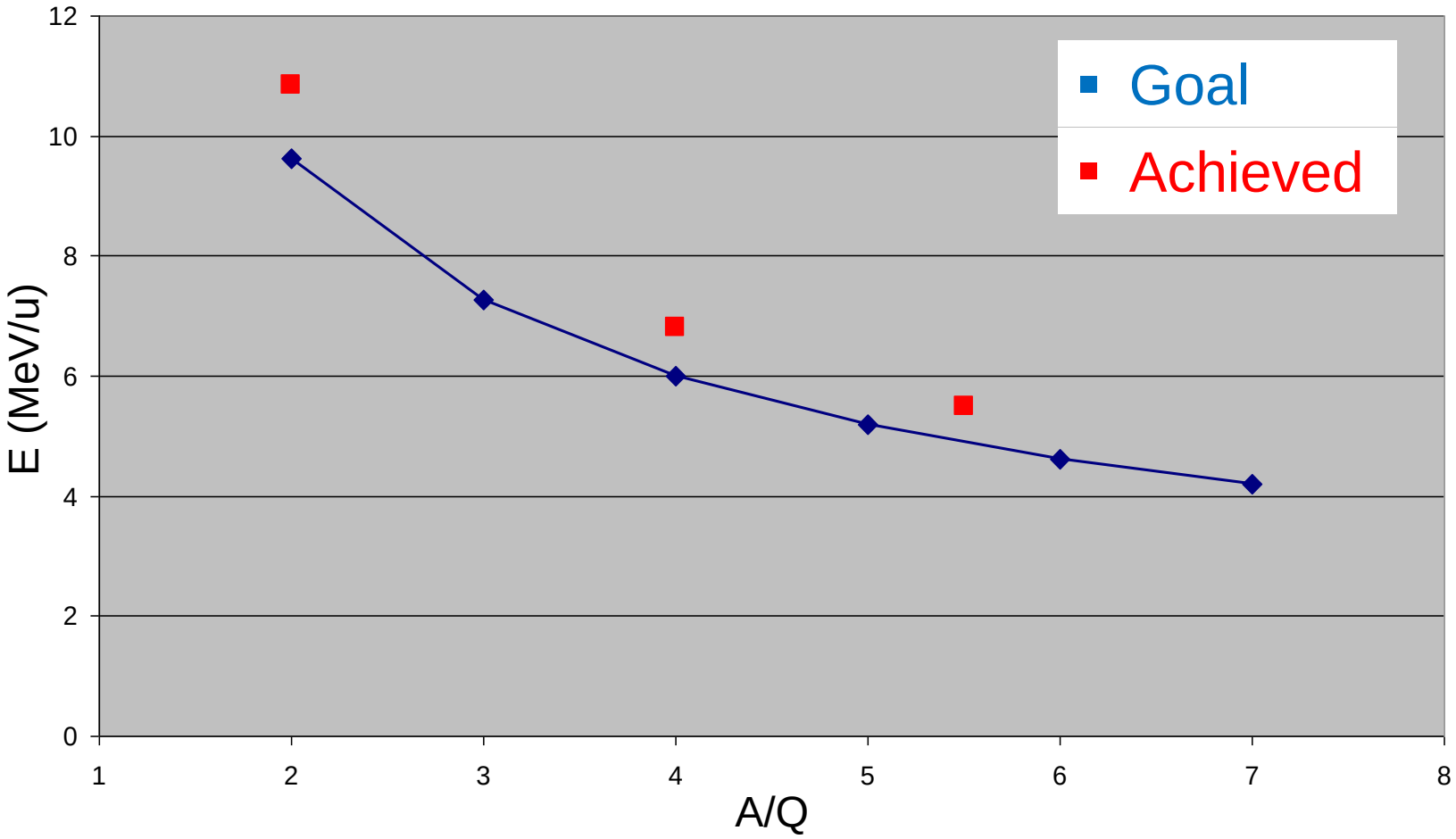
Cryomodule Milestones

- Alpha particle acceleration in clean room – Nov. 2004
- Single cryomodule test with beam in accelerator vault – July 2005
- All cryomodules installed in vault – March 12, 2006
- First accelerated beam – April 8, 2006
- True to Gerardo's example we celebrated each one!

Performance exceeds design goals

The average gradient for the on-line cavities corresponded to a peak surface field of 36MV/m

The performance set a new high-water mark for heavy ion SC linacs

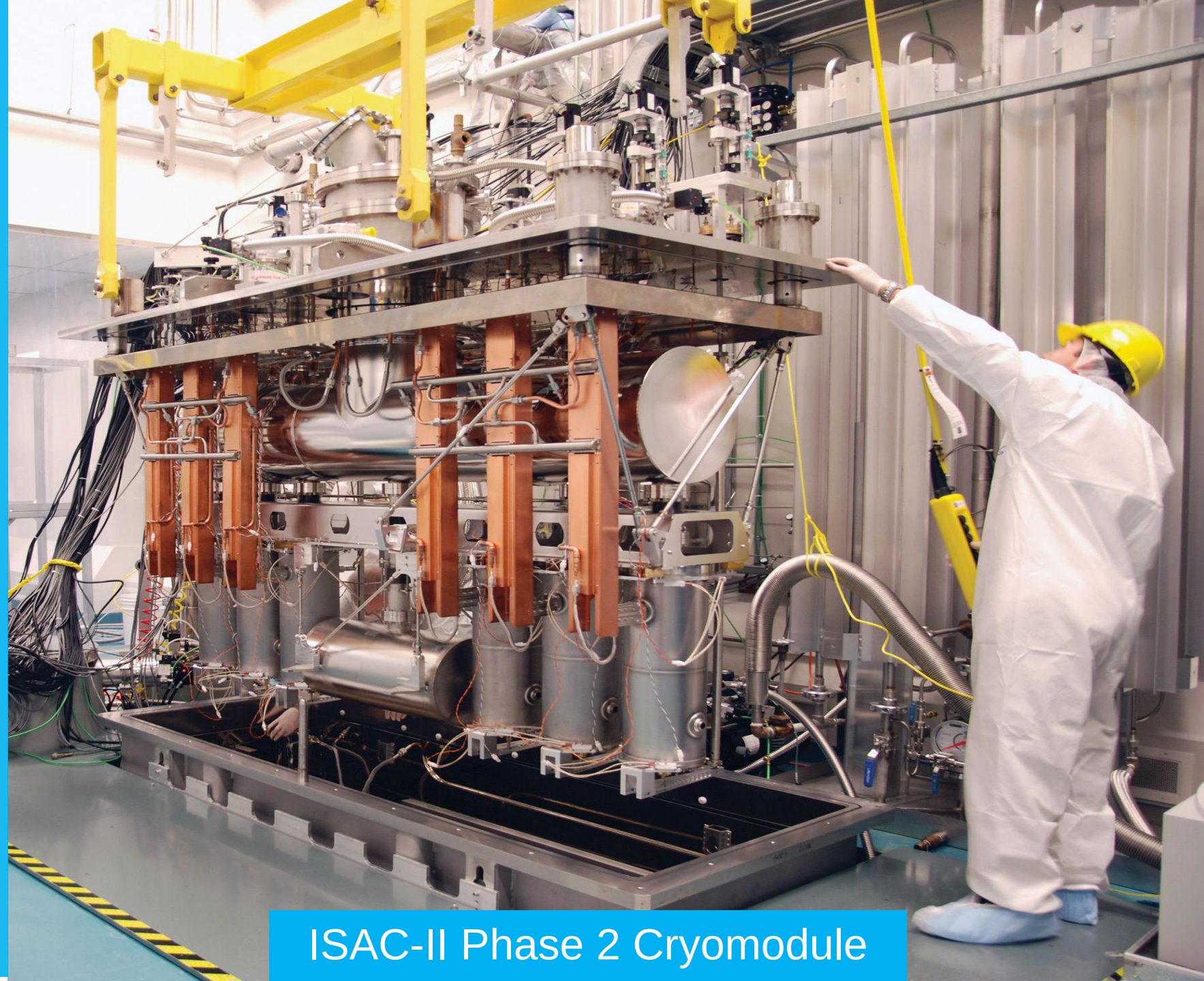


The family portrait

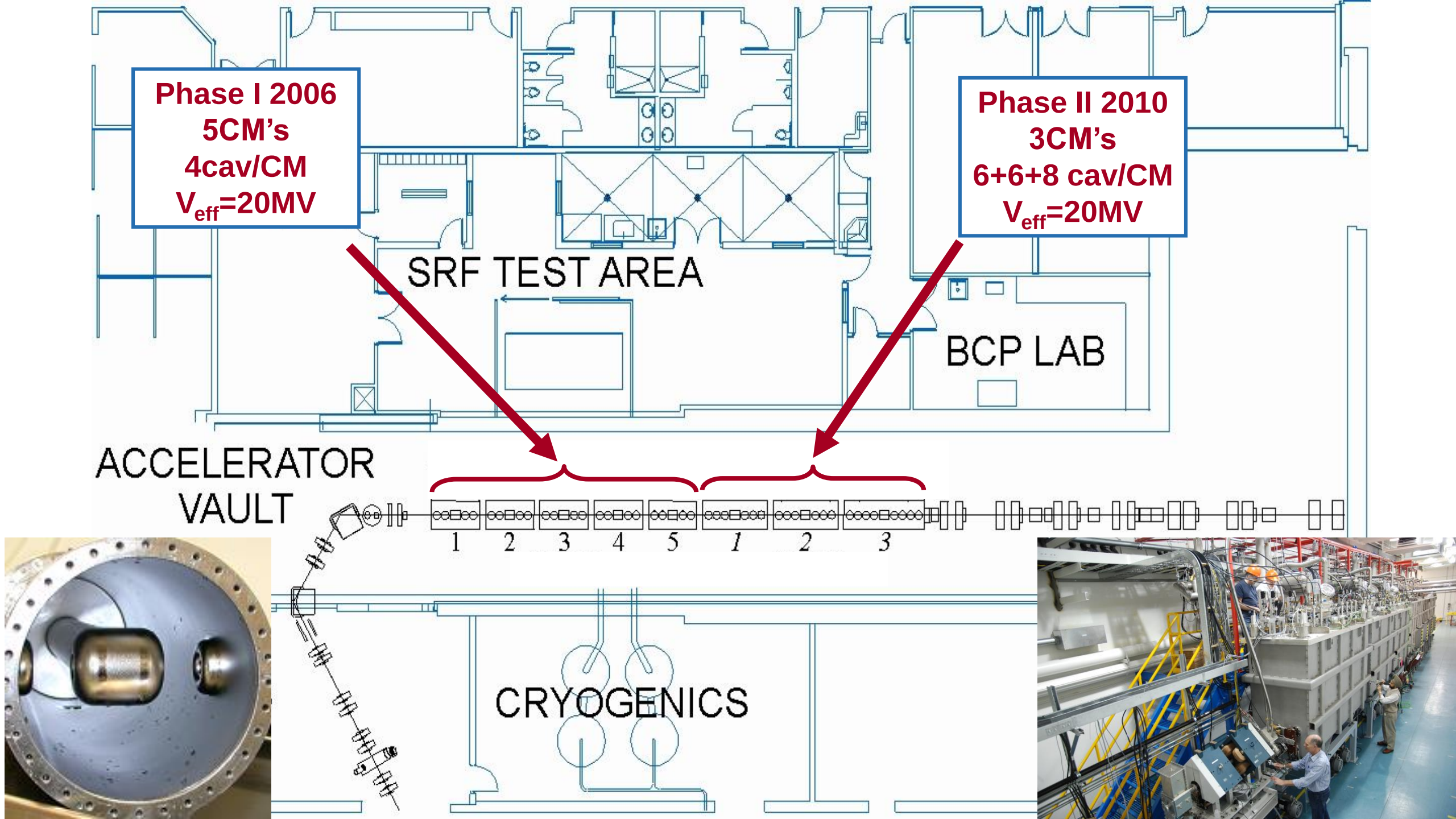
ISAC-II accelerator (phase 2 2005-2010)

A second phase of the project comprised the packaging of 20 more cavities into three cryomodules

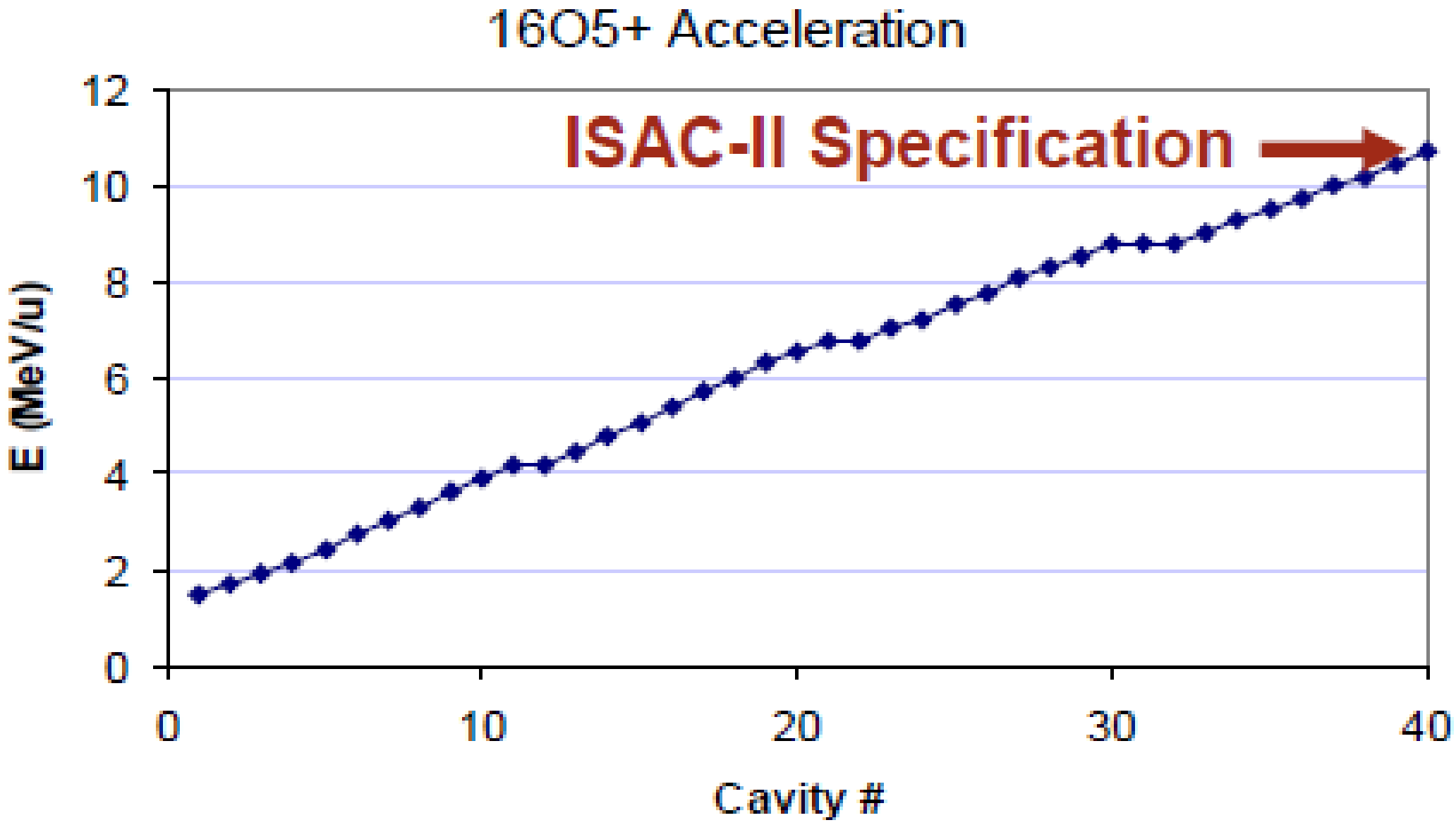
Highlight: Developed PAVAC as a SRF cavity fabricator.



ISAC-II Phase 2 Cryomodule


Phase I 2006
5CM's
4cav/CM
V_{eff}=20MV
Phase II 2010
3CM's
6+6+8 cav/CM
V_{eff}=20MV
SRF TEST AREA
BCP LAB
ACCELERATOR
VAULT
1 2 3 4 5 1 2 3
CRYOGENICS

Success – April 2010



SRF – Building on strengths

Discovery, accelerated

ARIEL e-Linac (2008-2014)

The SRF group next developed 1.3GHz technology for electron acceleration in the ARIEL e-Linac

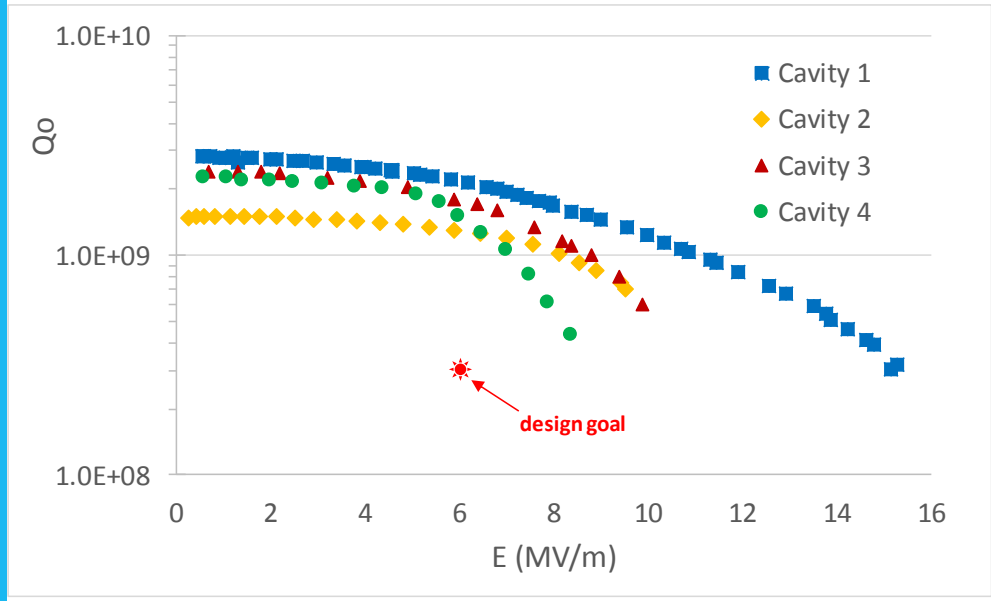
First beam accelerated September 2014. All Canadian cryomodules - Cavities by PAVAC

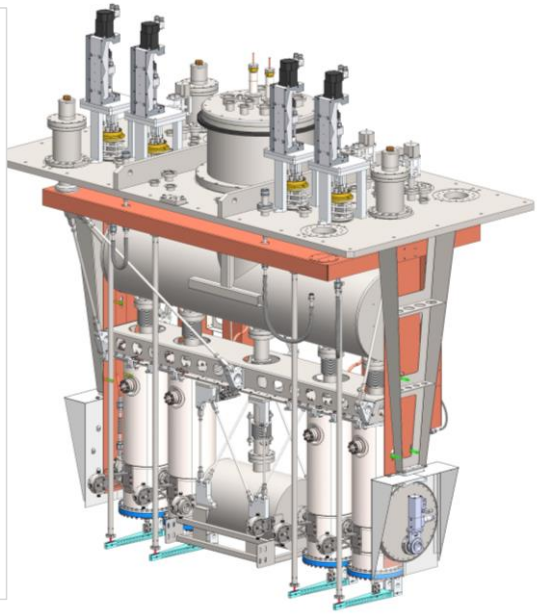
SRF Technology Development for S. Korea (2015-2018)

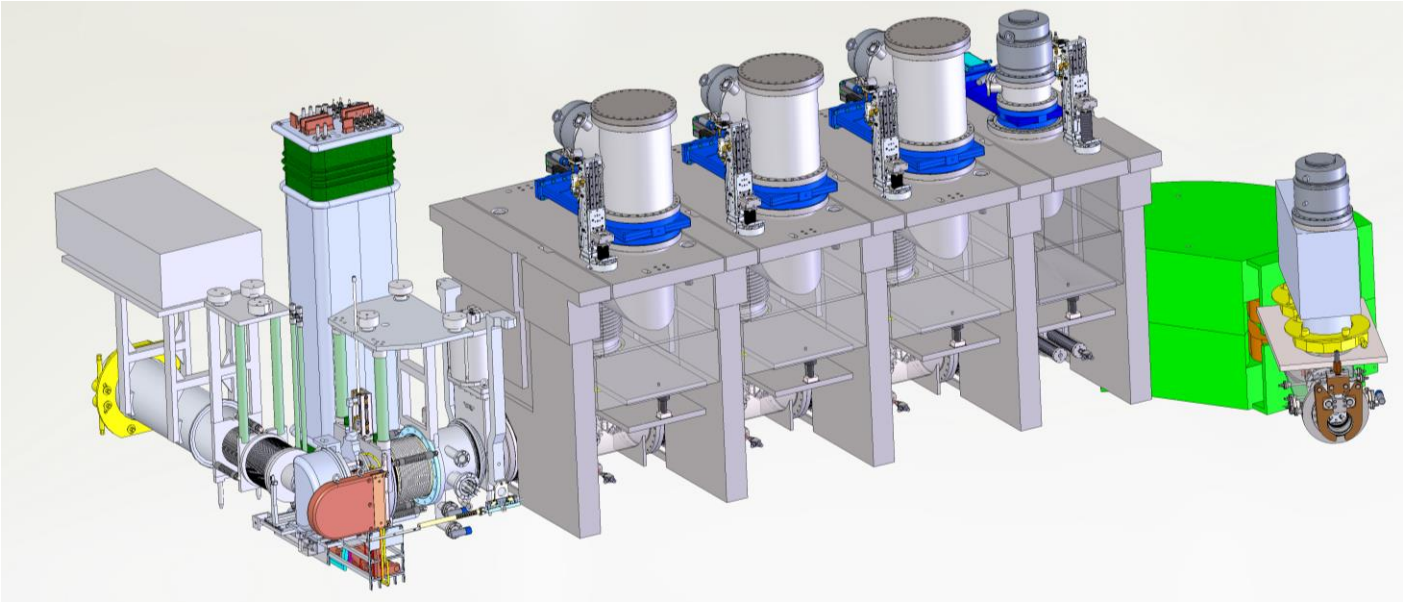
- TRIUMF developed and successfully tested a new variant (balloon geometry) of a single spoke resonator for Hadron acceleration
- Design eliminates the high level multipacting that plagues standard geometries
- The cavity design and prototyping was sponsored by RISP (S. Korea) and is being used in their heavy ion driver linac

TRIUMF and VECC (Kolkata) (2008-present)

- TRIUMF and VECC have been collaborating on mutually aligned projects since 2008 – ANURIB in Kolkata and ARIEL in Vancouver
- An electron cryomodule has been delivered to VECC in 2019
- A heavy ion cryomodule will be completed this year (all cavities are now qualified)
- An ARIEL RIB target module and beamline will be delivered in 2022.

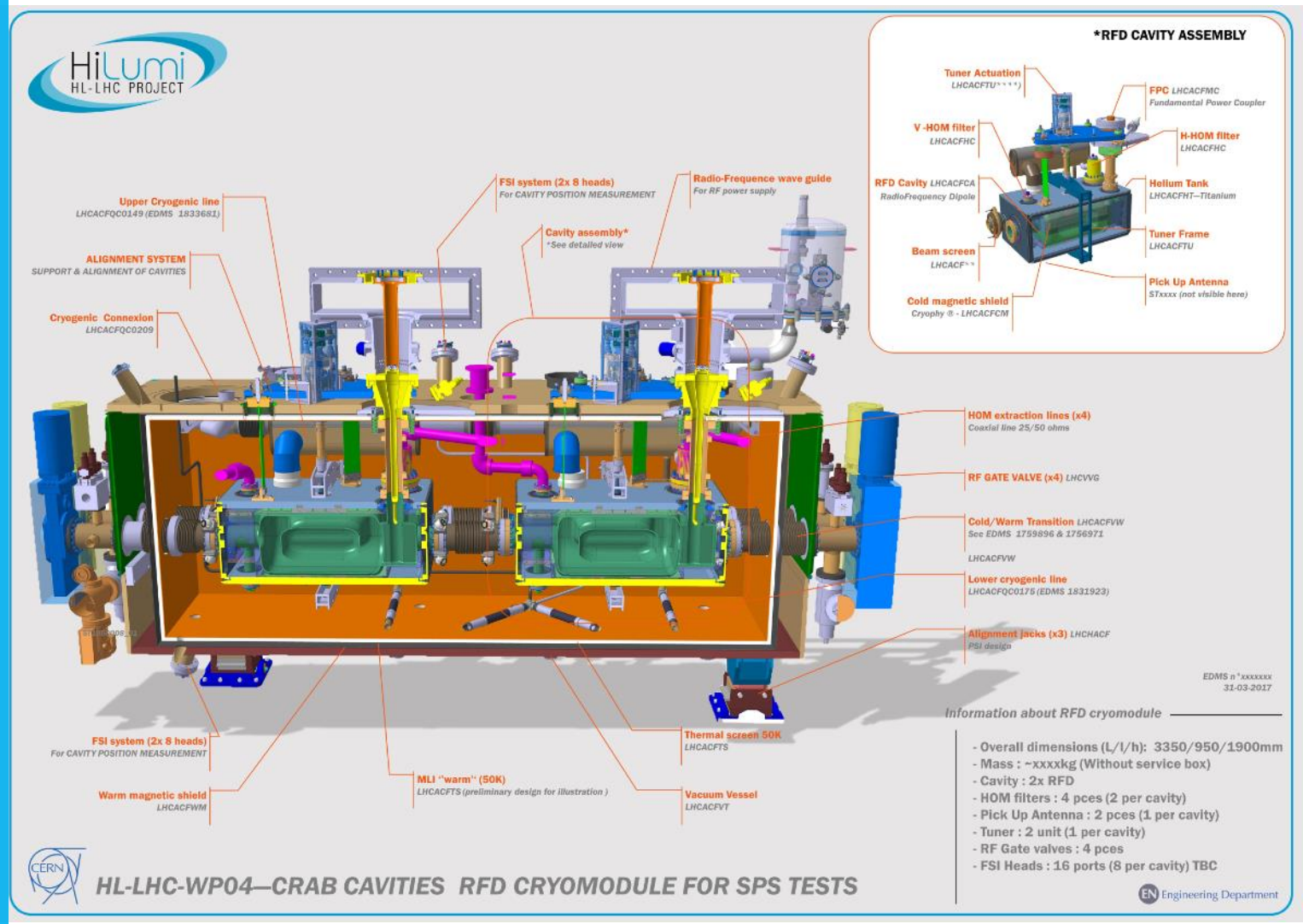






HL-LHC Crab Cavity Cryomodules (2021-2024)

- CERN requires crab cavities in the LHC as part of a Luminosity upgrade
- TRIUMF will receive 10 RFD resonators produced and qualified by US lab consortium
- TRIUMF to assemble each pair of RFDs into five cryomodules
- The project supplies critical infrastructure to CERN, supporting both the HL-LHC and the Canadian particle physics community



TRIUMF - SRF HQP Training

- Several PhDs, MScs and post-docs have been trained in SRF R&D over the last decade
- Topics range from
  - Cavity design and fabrication techniques
  - Optimization of cavity processing
  - Material studies with muSR and beta NMR facilities
  - Beam loading in SRF structures

Superconducting RF Legacy

- SRF at TRIUMF was born in the Dutto era and Gerardo was a key facilitator during the early days
- SRF is now a core competence of TRIUMF
- The success of ISAC-I and ISAC-II showed us that we can take on challenging new technologies and succeed magnificently
- The developments paved the way for ARIEL and enables TRIUMF to continue to support internal and external projects and student education as Canada’s centre for accelerator science and technology

Gerardo was a dedicated leader and an exceptional international ambassador.

He also possessed an endless capacity for persuasion. He had a major hand in shaping the expertise within accelerator science and technology at TRIUMF.

On a personal note Gerardo was a significant mentor during my formative years at TRIUMF.

Thank you Gerardo

Discovery, accelerated