SRF Development for High Energy Physics

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SRF 2011

U.S. DEPARTMENT OF ENERGY

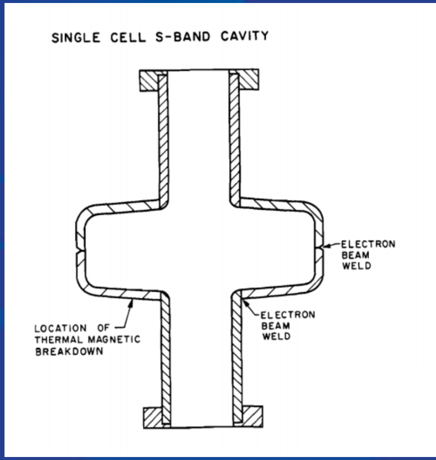
Fermilab

Introduction

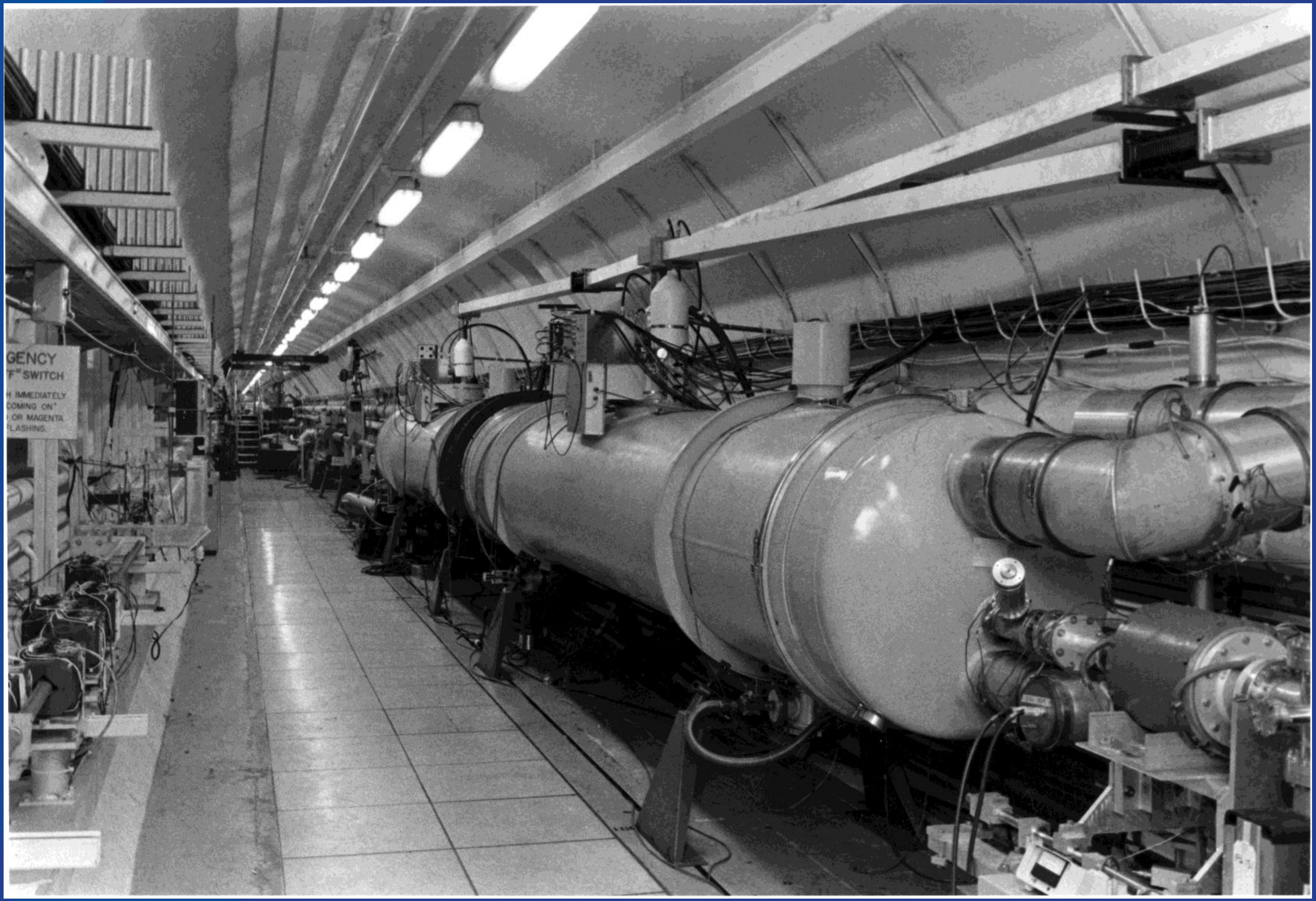
- The HEP community has shown increasing interest in SRF technology in recent years
  - ILC R&D program
  - Project X at Fermilab
  - Neutrino factories and muon colliders
- However, the application of SRF technology to HEP research has a long history
- Now let’s go back in time and take a look at that history

Stanford High Energy Physics Laboratory (HEPL) a.k.a. Hanson Experimental Physics Laboratory

- 1962: First measurements of superconducting cavity performance
  - Lead-plated S-band 2856 MHz muffin tin cavities
  - Qo ~ 1e8-1e9, Bp ~ 100 G (10 mT), 4 K
- 1965: First acceleration of electrons with a superconducting cavity
- 1972: First superconducting accelerator
  - Based on L-band 1300 MHz niobium cavities
  - Cavity performance limited by multipacting
    - the elliptical cavity shape was not yet developed

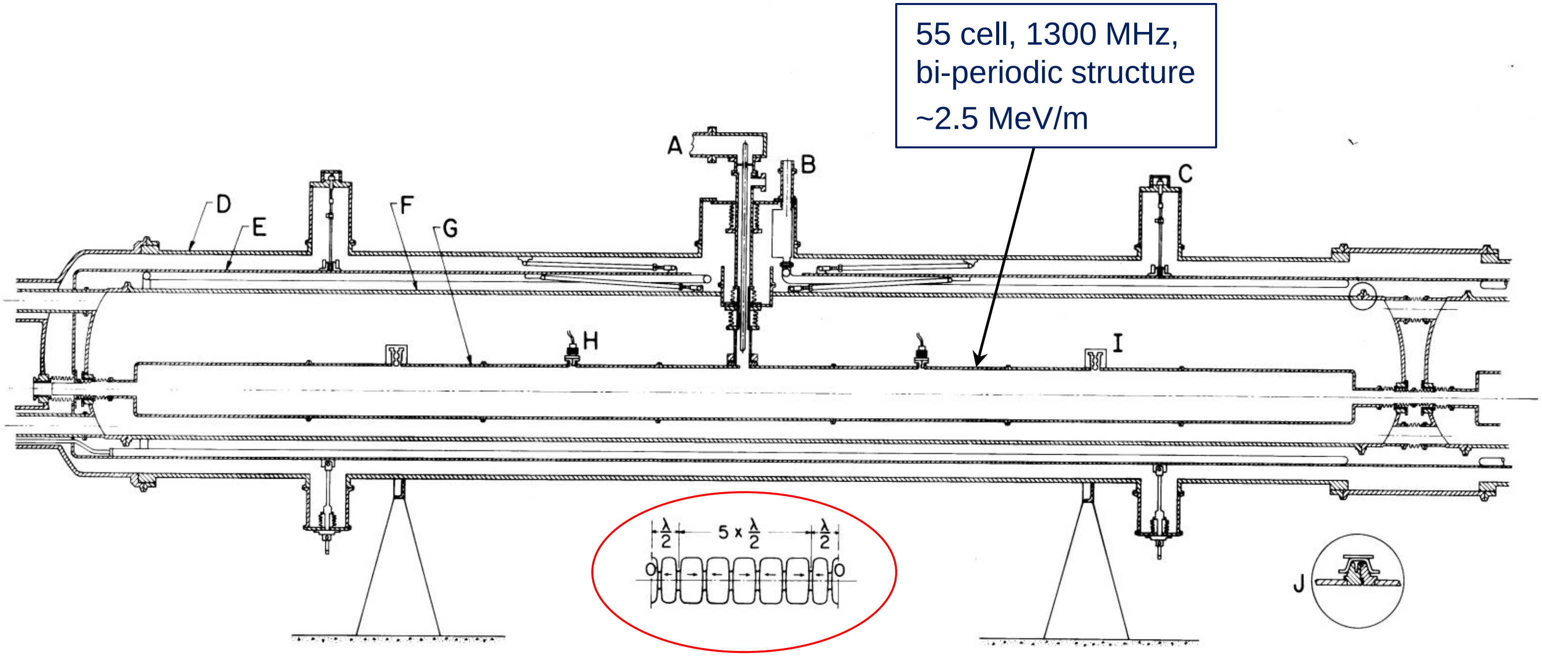


HEPL 1300 MHz Cryomodule Pair



Courtesy of T. Smith, HEPL

Layout of HEPL Cryomodule



Assembled 20-foot accelerator dewar module. This section has end caps at one end and is connected to another module at the other end.

A. RF power input.
B. Liquid nitrogen vent.
C. Dewar support and alignment adjustment.
D. Vacuum jacket (36 in. diameter tank).
E. Liquid nitrogen shield.
F. Helium dewar (24 in. diameter tank).
G. Accelerator structure. This is assembled from seven units, one of which is detailed at bottom center.
H. Field sampling probe. (Output to feedback electronics.)
I. Structure tuner.
J. Detail of 24 in. diameter V-band indium seal.

TRISTAN and KEKB

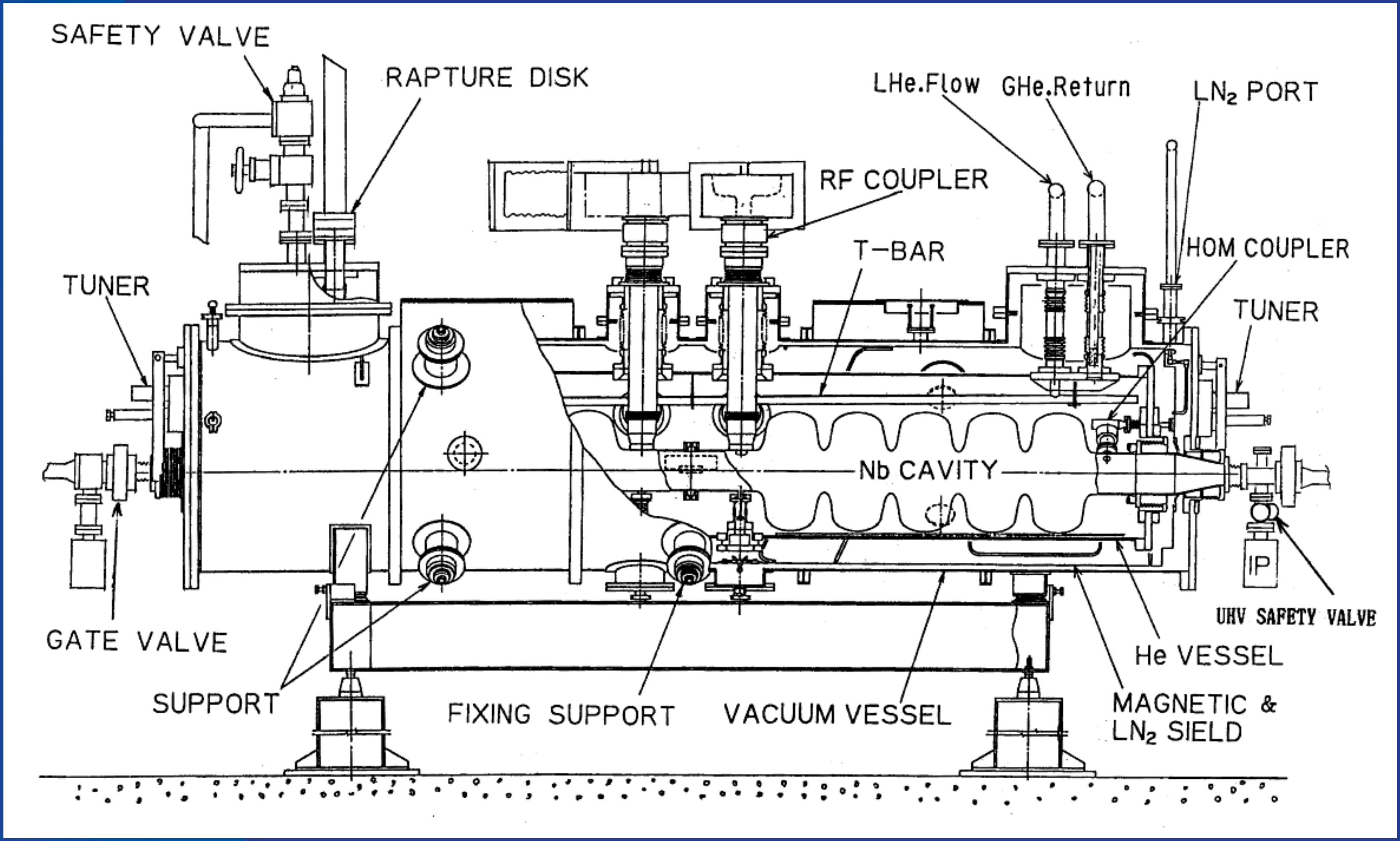
TRISTAN was an electron-positron collider constructed at KEK in the 80's

- 32 five-cell 508 MHz elliptical SC cavities housed in 16 cryomodules
- Installed in 1988 – 1989 (augmented existing NC cavities)
- E_{acc} = 5 MV/m, Q_o = 2e9 at 4.2 K, continuous wave
- TRISTAN was shut down in 1995

KEKB was an asymmetric-energy electron-positron collider constructed at KEK in the 90's

- Reused much of the TRISTAN infrastructure and components
- 8 single-cell 508 MHz SC cavities housed in 8 cryomodules
- E_{cavity} = 1.2 – 2 MV, Q_o ~ 1e9 at 4.2 K, continuous wave
- Heavy beam loading and HOM loading (IB = 1.4 A)
- KEKB has been shut down and is being upgraded to SuperKEKB

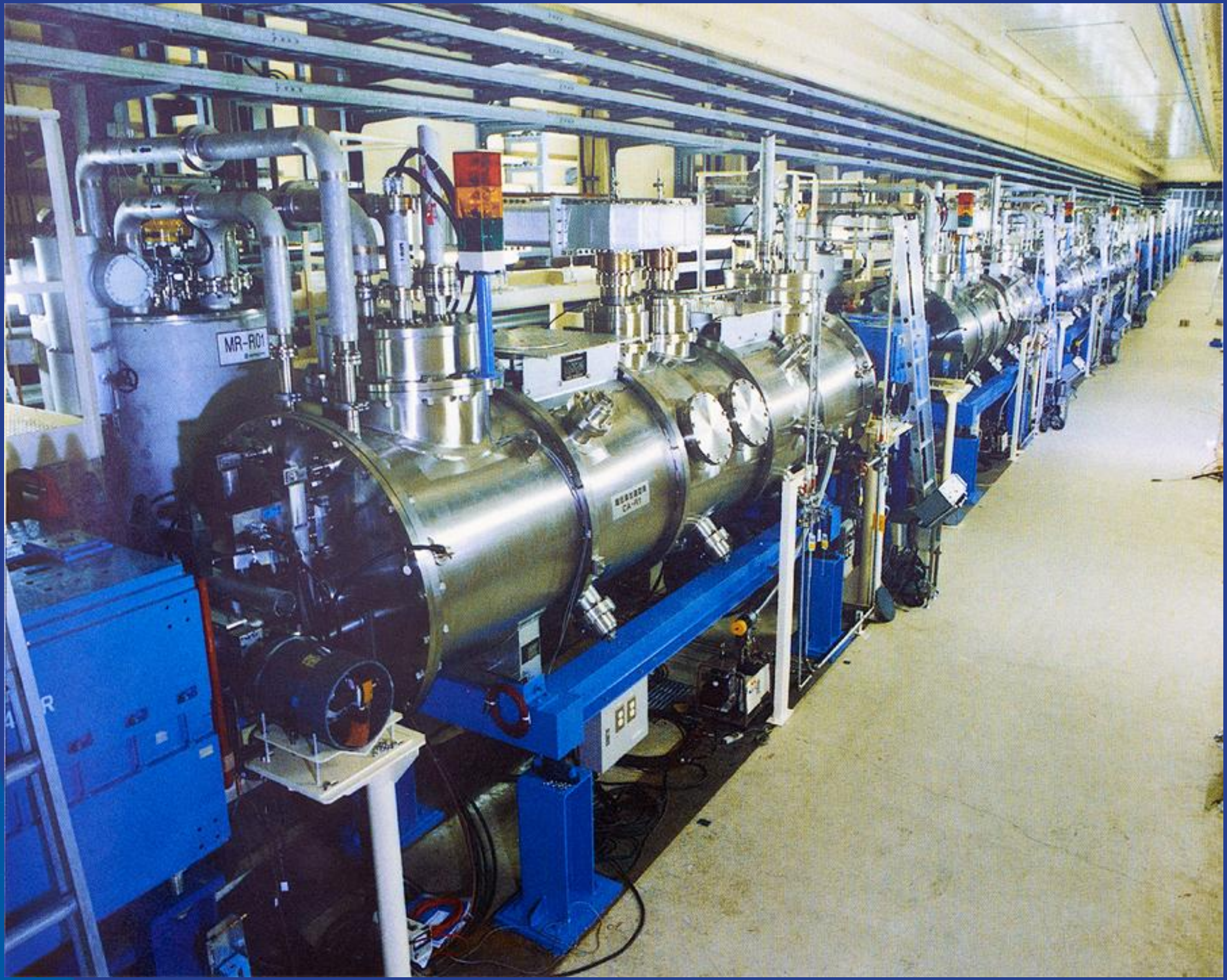
Cryostat for TRISTAN SRF Cavities



http://accelconf.web.cern.ch/accelconf/SRF89/papers/srf89g29.pdf

Courtesy of N. Toge, KEK

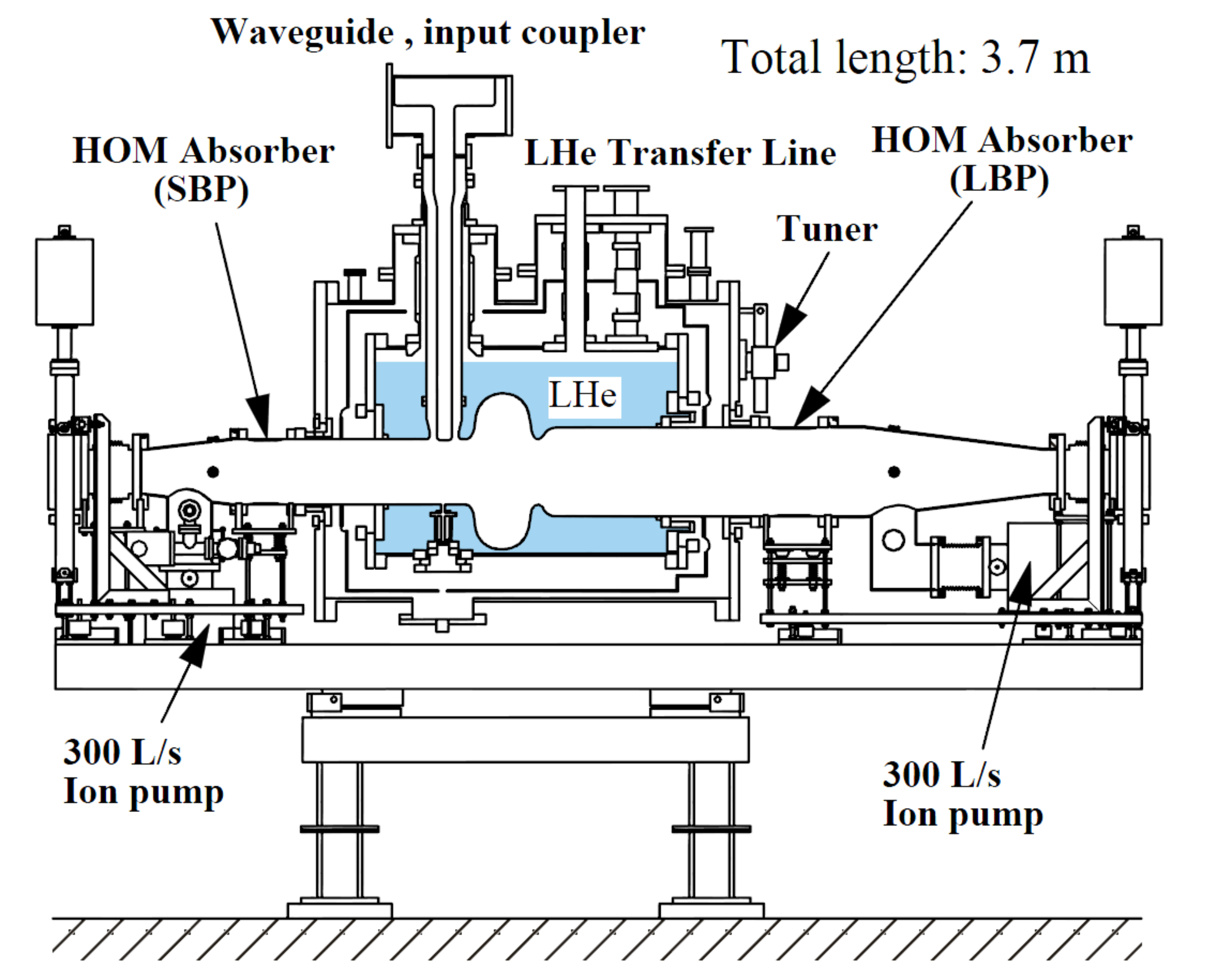
Cryomodules in the TRISTAN MR Tunnel



From KEK Annual Report 1988 - http://www-lib.kek.jp/ar/ar.html

Courtesy of N. Toge, KEK

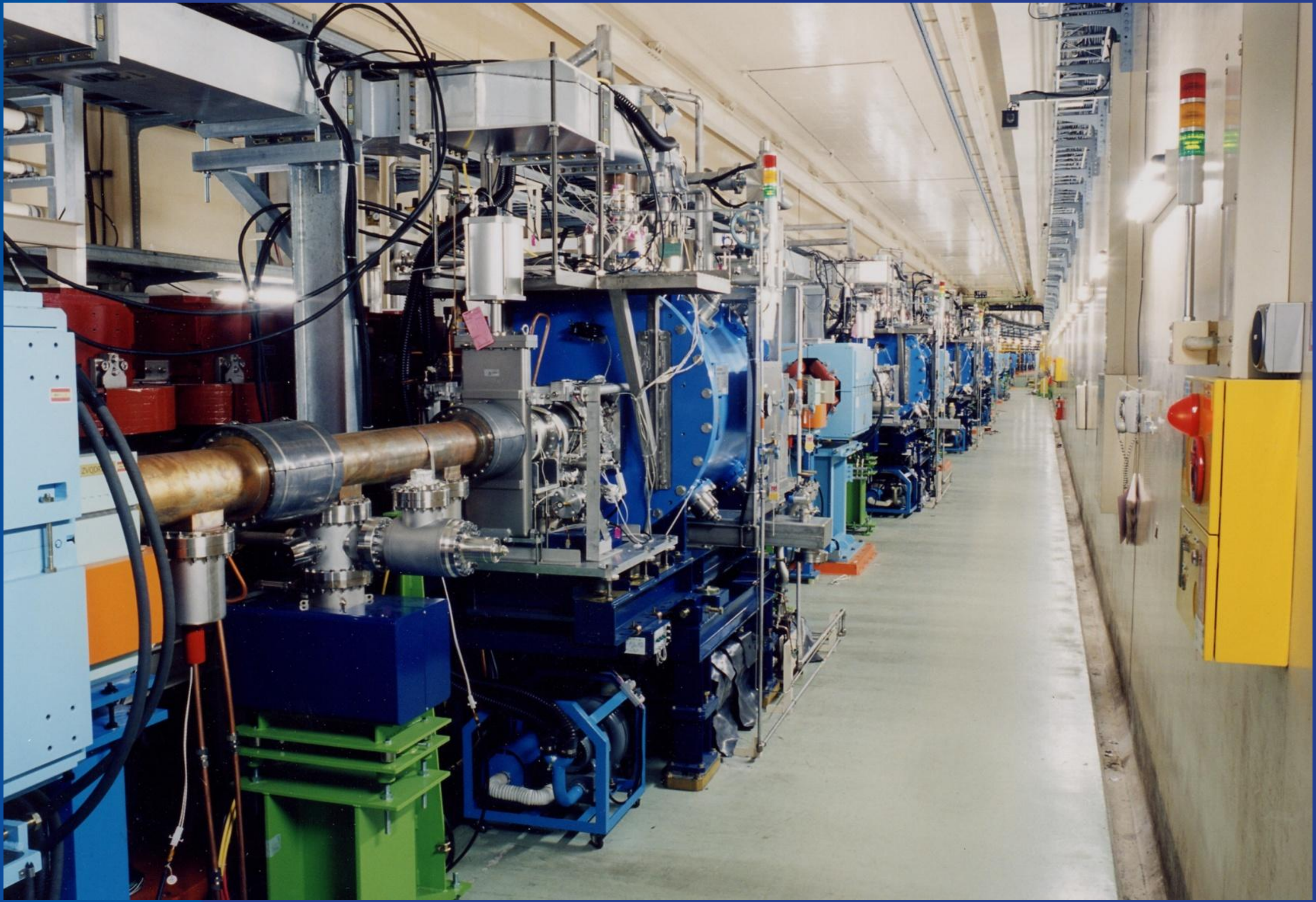
Cryostat for KEKB SRF Cavities



http://epaper.kek.jp/p99/PAPERS/THBL2.PDF

Courtesy of N. Toge, KEK

Cryomodules in the KEKB Tunnel



- KEK Annual Report 1998 - http://www-lib.kek.jp/ar/ar.html
- http://www-acc.kek.jp/kekb/pictures/KEKB_photo/ring1.jpg

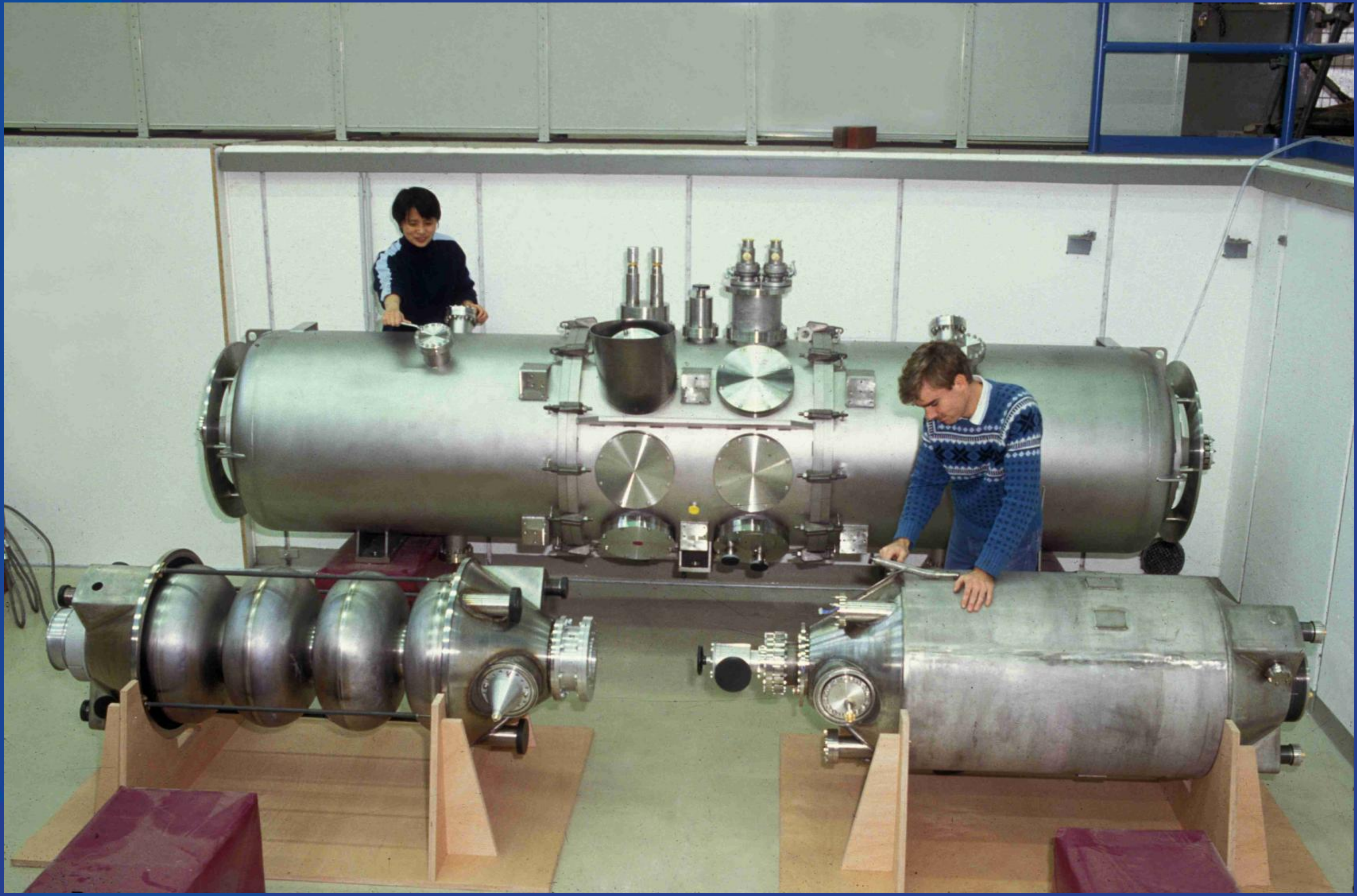
Courtesy of N. Toge, KEK

DESY HERA 500 MHz Cryomodules

- Electron-proton collider
- 16 SC cavities commissioned in electron storage ring in 1991-1992
  - Augmented 84 NC 500 MHz cavities to increase beam energy
- Bulk niobium, RRR 300, 4-cell, 500 MHz elliptical cavities
- E_{acc} = 5 MV/m, Q_0 = 2e9 at 4.2 K, continuous wave
- Two klystrons, combined, drive all 16 cavities (vector sum RF control)
- HERA experiment concluded in 2007
- The initiation of the TESLA Test Facility coincided approximately with the successful commissioning of the HERA SC cavities

Courtesy of W-D Moeller, DESY

HERA Cavities and Cryomodule



Courtesy of W-D Moeller, DESY

LEP Superconducting Cavities

- The LEP electron-positron collider at CERN was upgraded with SC cavities in the period 1992-1999
- Beam energy increased from ~46 GeV to ~100 GeV
- Final configuration: 288 four-cell cavities
  - 272 niobium sputtered onto copper cavities
  - 16 bulk niobium cavities
  - 48 copper cavities (originally 128)
- 352 MHz, 4.5 K, continuous wave
- 8 cavities per 1.3 MW klystron
- LEP cryomodules were removed in 2000-2001 to make way for the LHC

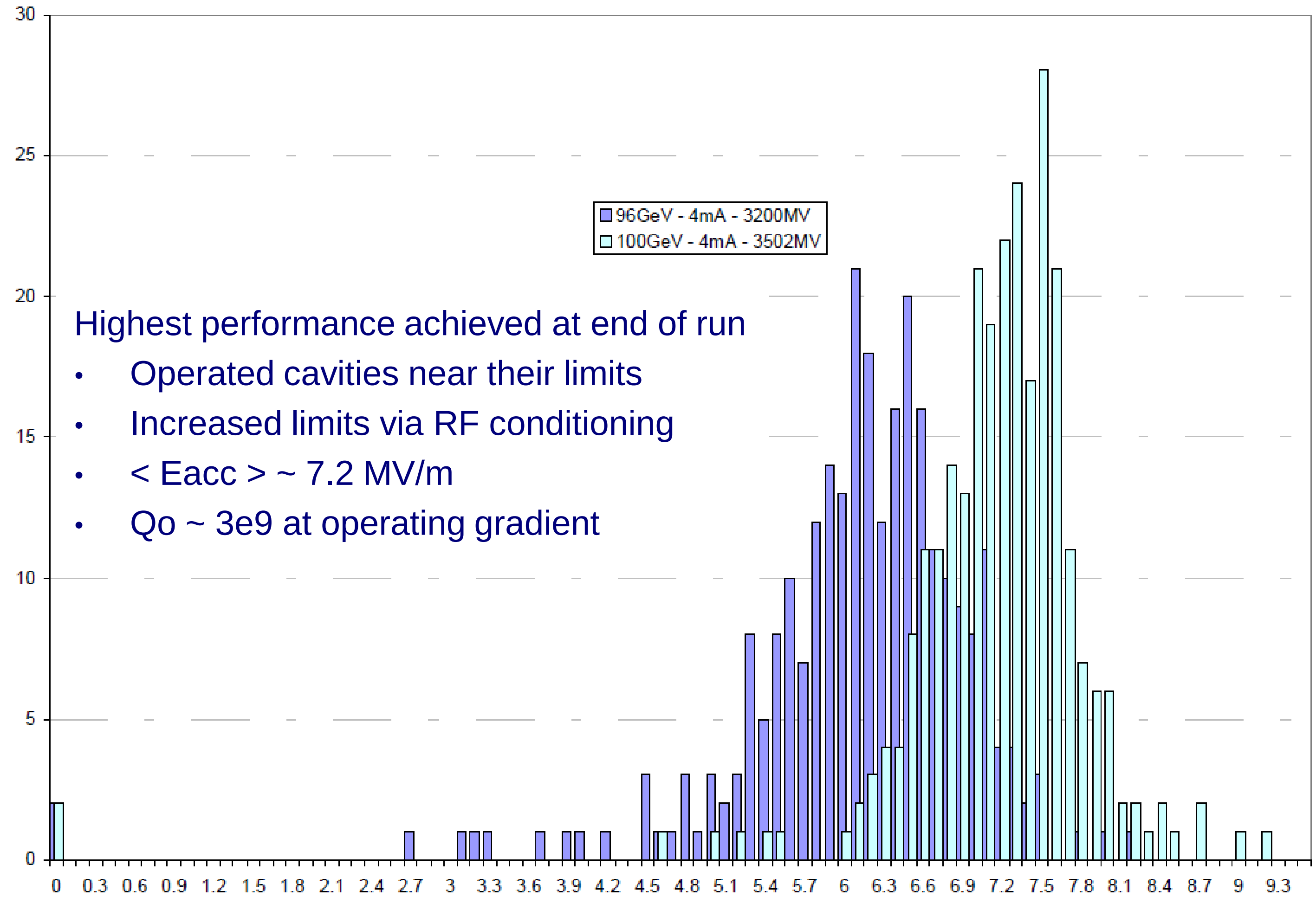
LEP 352 MHz Cavity and Cryomodule

4 cavities / cryomodule

72 modules going into storage

Courtesy of CERN

Achieved Gradients in LEP Cu/Nb Cavities in 1999



Highest performance achieved at end of run

- Operated cavities near their limits
- Increased limits via RF conditioning
- < Eacc > ~ 7.2 MV/m
- Qo ~ 3e9 at operating gradient

P. Brown et al., "Performance of the LEP200 Superconducting RF System," SRF1999.

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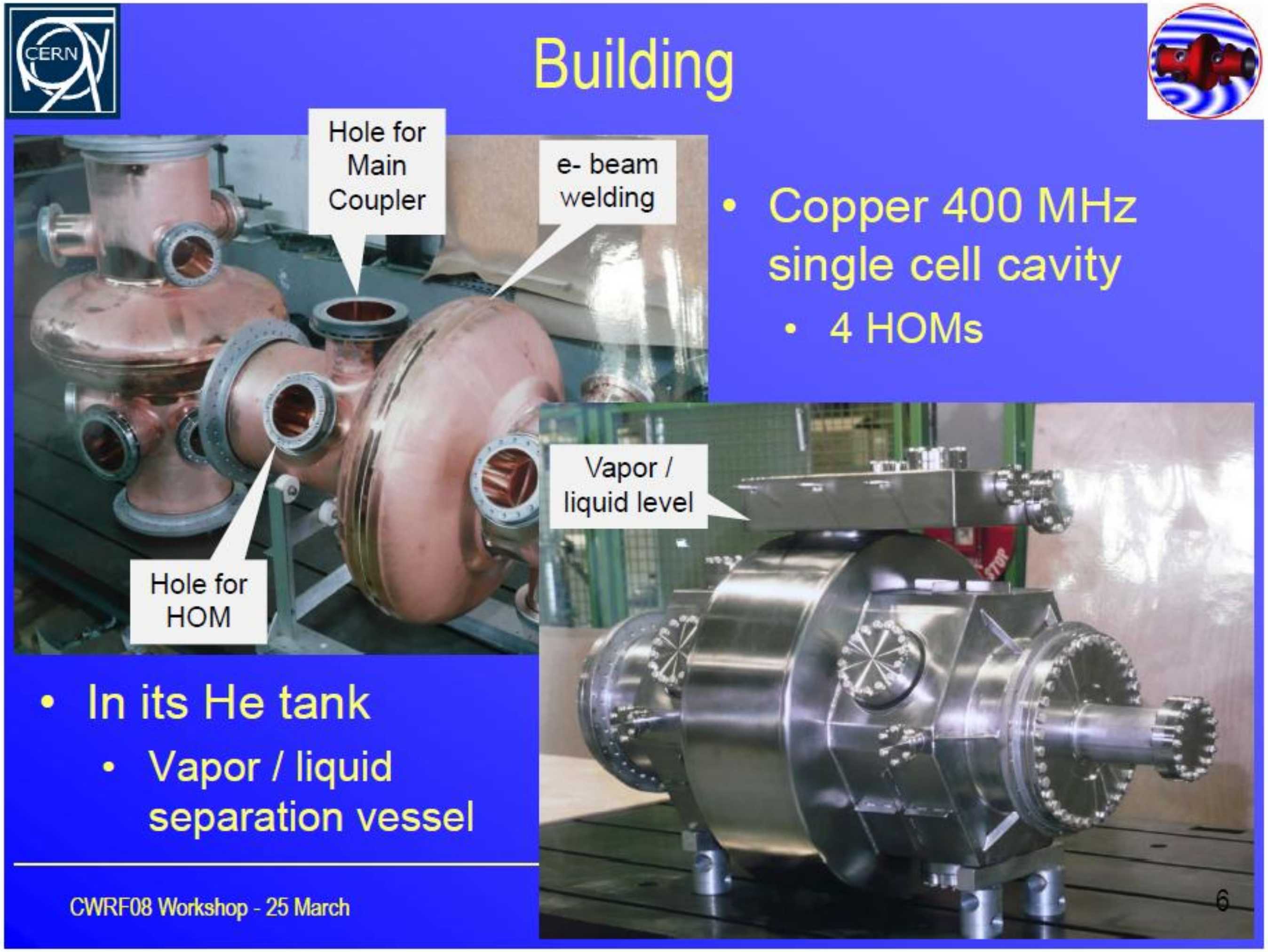
LHC Superconducting Cavities

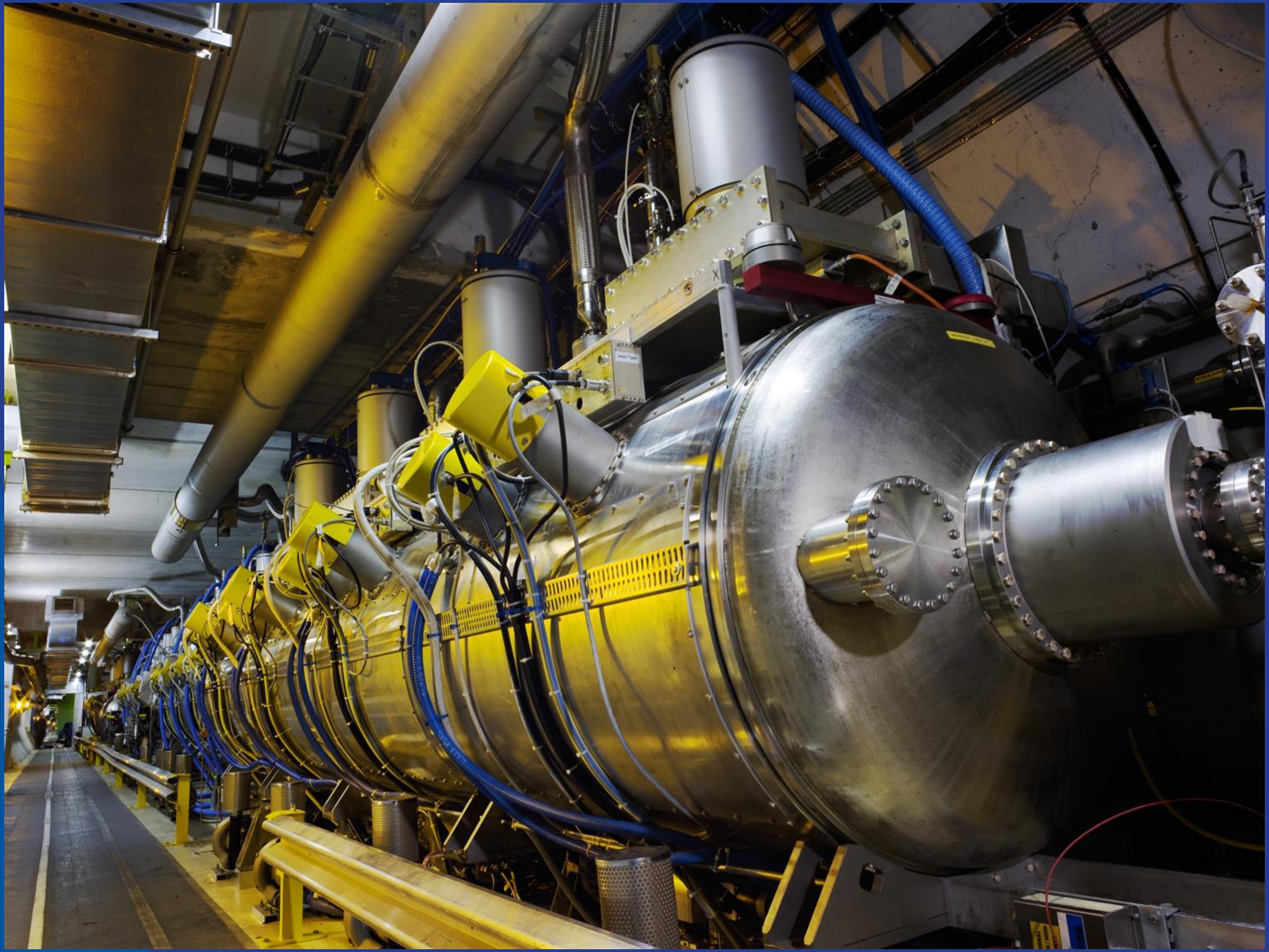
- 400 MHz, single-cell, niobium sputtered onto copper cavities, 4.5 K, continuous wave
- Four cavities per cryomodule
- Sixteen cavities total
- 2 MV / cavity (5.3 MV/m), $Q_0 > 1e9$
- One klystron per cavity

LHC SC Cavity



P. Maesen, "LHC Superconducting Cavities," CWRF2008

LHC Cryomodule



Courtesy of CERN

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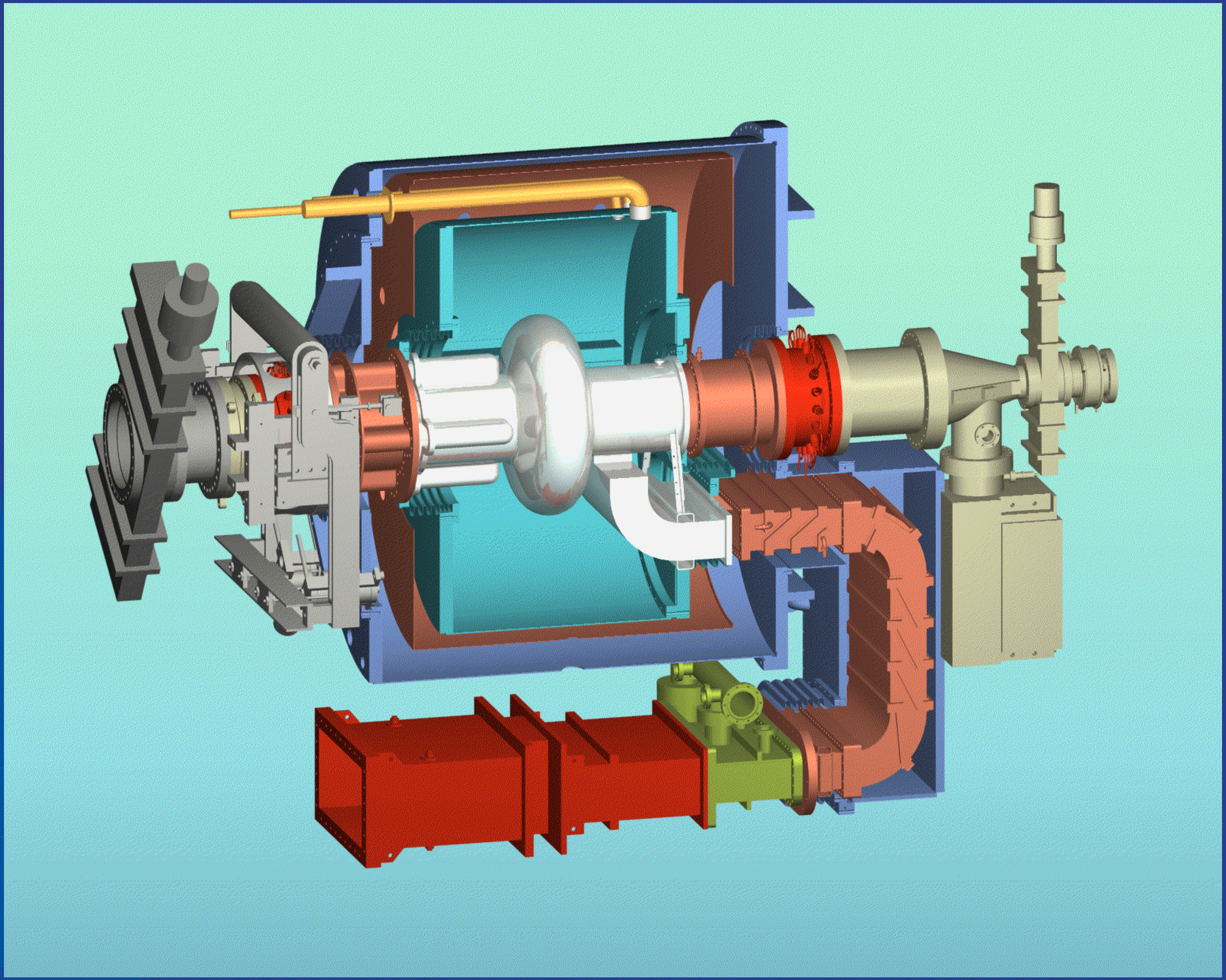
CESR – Cornell Electron Storage Ring

- Electron-positron collider completed in 1979
- Upgraded with four SC cavities in the period 1997 – 1999 (replaced NC cavities)
  - 500 MHz, single-cell, one cavity per cryomodule
  - Eacc = 6 MV/m, Qo > 1e9 at 4.2 K, continuous wave
  - Heavy beam loading and HOM loading (I_B ~ 0.8 A max)
  - Cavity and Cryomodule design was industrialized with Accel (now RI) and sold to several light sources world wide
  - AES is presently fabricating two of these systems

Courtesy of Cornell University

CESR-B 500 MHz Cryomodule

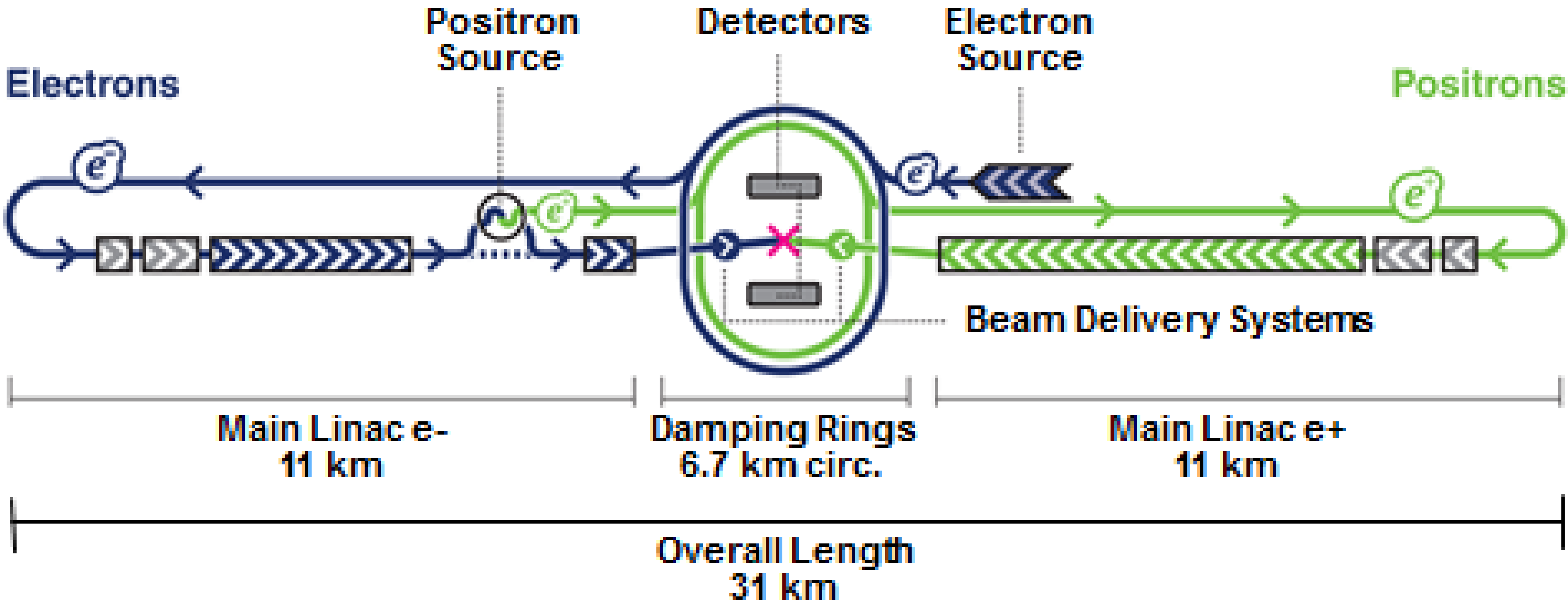


Courtesy of Cornell University

Future HEP Applications of SRF Technology

- International Linear Collider
  - Approximately 17,000 cavities over 31 km
- Project X
  - 3 GeV continuous-wave H- linac followed by 8 GeV pulsed H- linac
- Large Hadron Collider upgrades
  - Crab cavities for interaction region
- Muon Collider / Neutrino Factory
  - Project X driver plus downstream acceleration of muon beam

International Linear Collider Layout

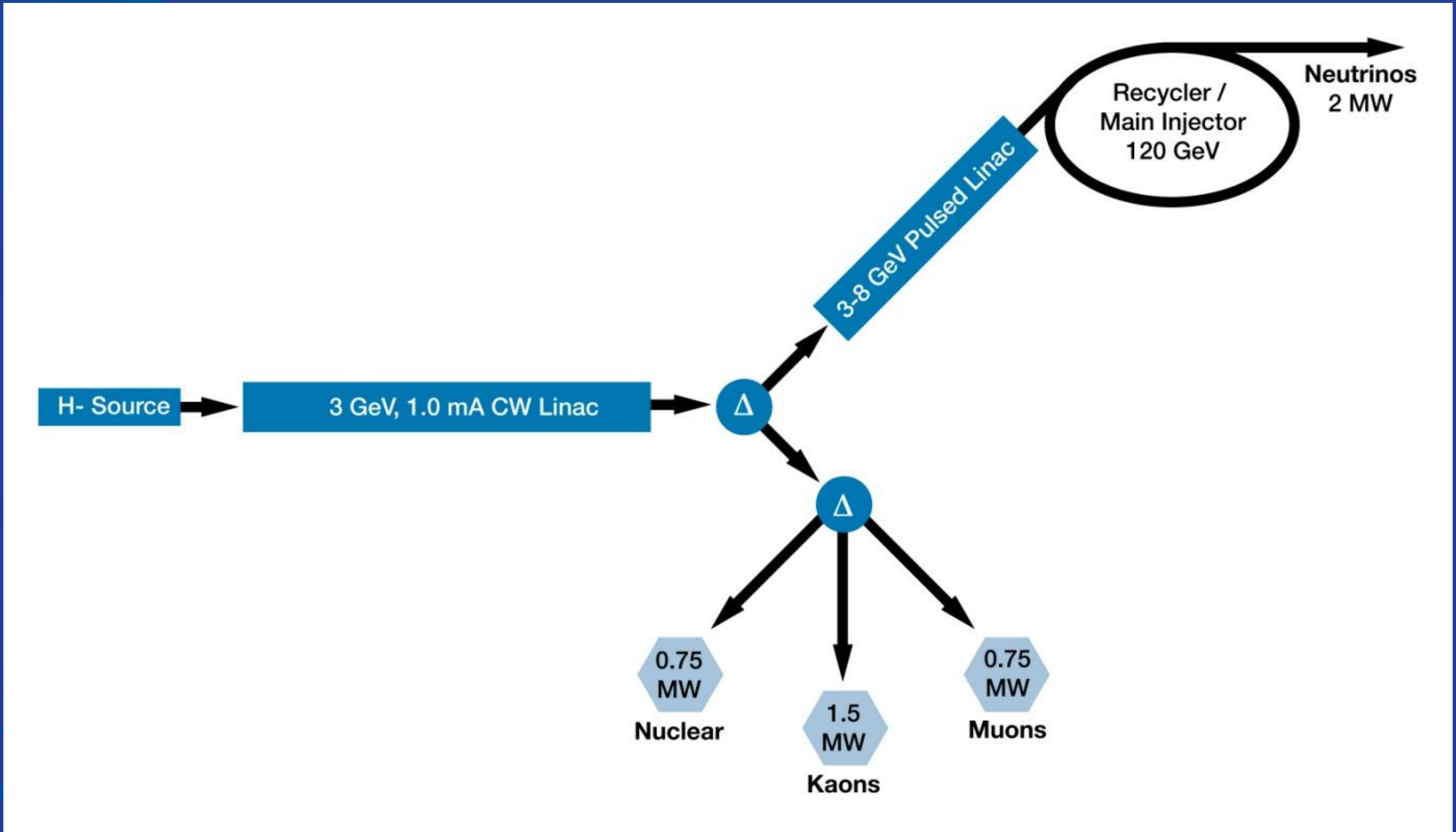


ILC Cavities and Cryomodules

Each cryomodule contains (8 cavities + 1 magnet) or (9 cavities)

Total ~2000 cryomodules, ~17000 cavities.

Project X Reference Design



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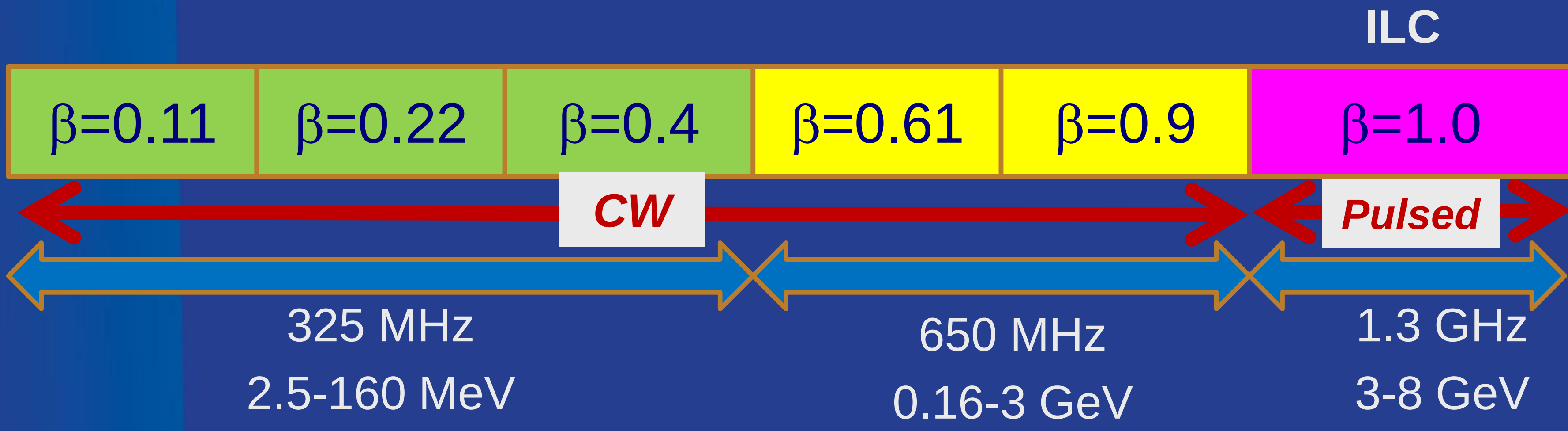
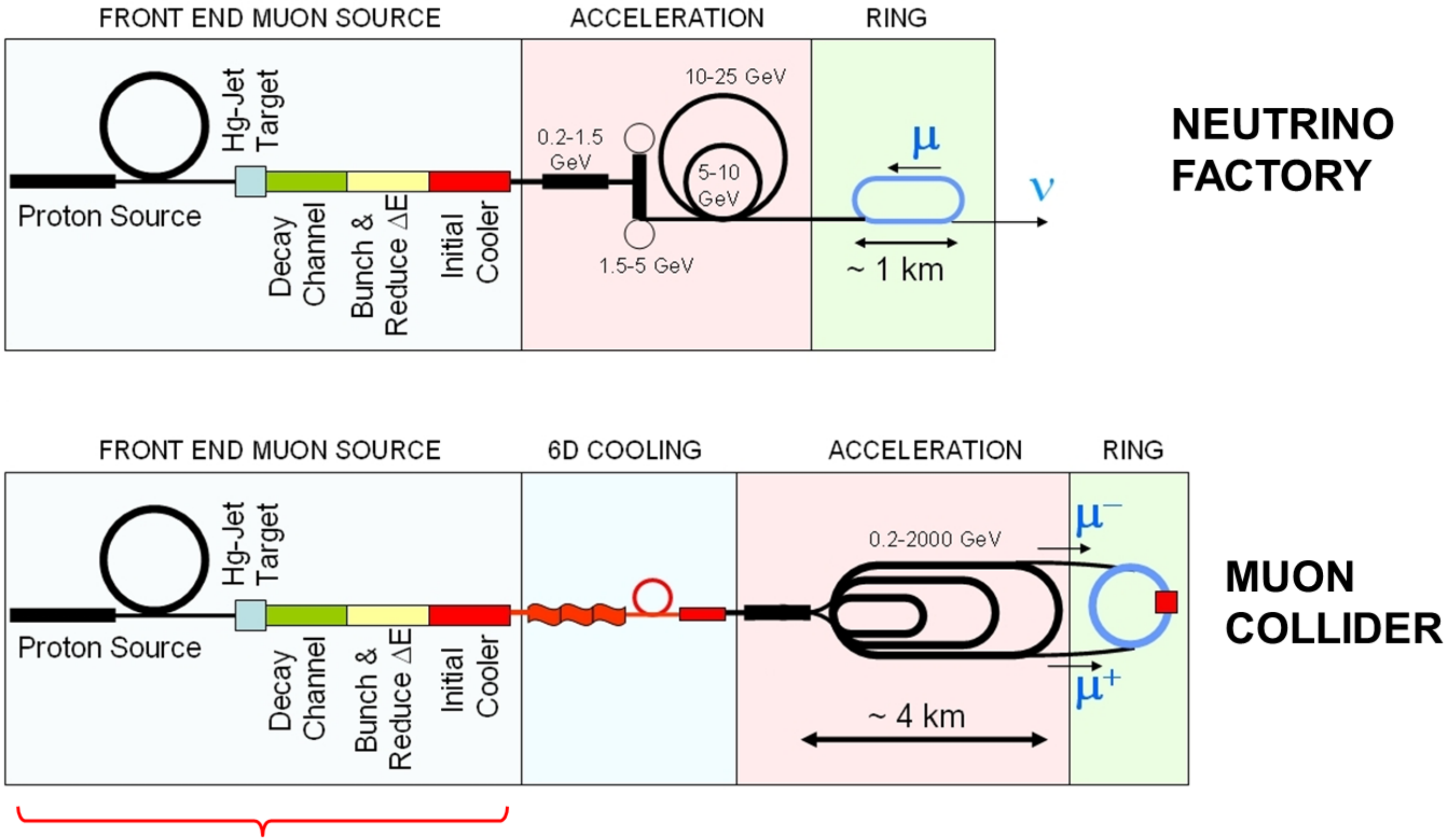
PX SRF Linac Technology Map



Section	Freq	Energy (MeV)	Cav/mag/CM	Type
SSR0 (β_G=0.11)	325	2.5-10	18 /18/1	SSR, solenoid
SSR1 (β_G=0.22)	325	10-42	20/20/ 2	SSR, solenoid
SSR2 (β_G=0.4)	325	42-160	40/20/4	SSR, solenoid
LB 650 (β_G=0.61)	650	160-460	36 /24/6	5-cell elliptical, doublet
HB 650 (β_G=0.9)	650	460-3000	160/40/20	5-cell elliptical, doublet
ILC 1.3 (β_G=1.0)	1300	3000-8000	224 /28 /28	9-cell elliptical, quad

Courtesy of Bob Kephart, Fermilab

Muon Collider cf. Neutrino Factory



In present MC baseline design, Front End is same as for NF

Courtesy of S. Geer, Fermilab

Summary

- HEP has been a driver for the development of SRF technology for many years
  - Starting at Stanford in the early 60's
  - Successful implementation at HERA, CESR, TRISTAN, KEKB, LEP, and LHC
- HEP has continued this role in recent years with the ILC R&D program and Project X
- HEP plans for future accelerators require SRF technology
  - ILC, Project X, LHC upgrades, and Muon collider / Neutrino factory
- Substantial overlap with non-HEP applications is driving collaborations world wide
  - Spallation neutron sources, nuclear physics, light sources, and Accelerator Driven Systems

Acknowledgements

- Thanks to all of the colleagues in the SRF community for 50 years of effort to develop and utilize SRF technology
- Thanks for the many publications, from which I have obtained the information for this presentation
- Special thanks to Wolf-Dietrich Moeller, Todd Smith, and Nobu Toge