Superconducting RF and Normal Conducting RF

Speaker: Hasan Padamsee

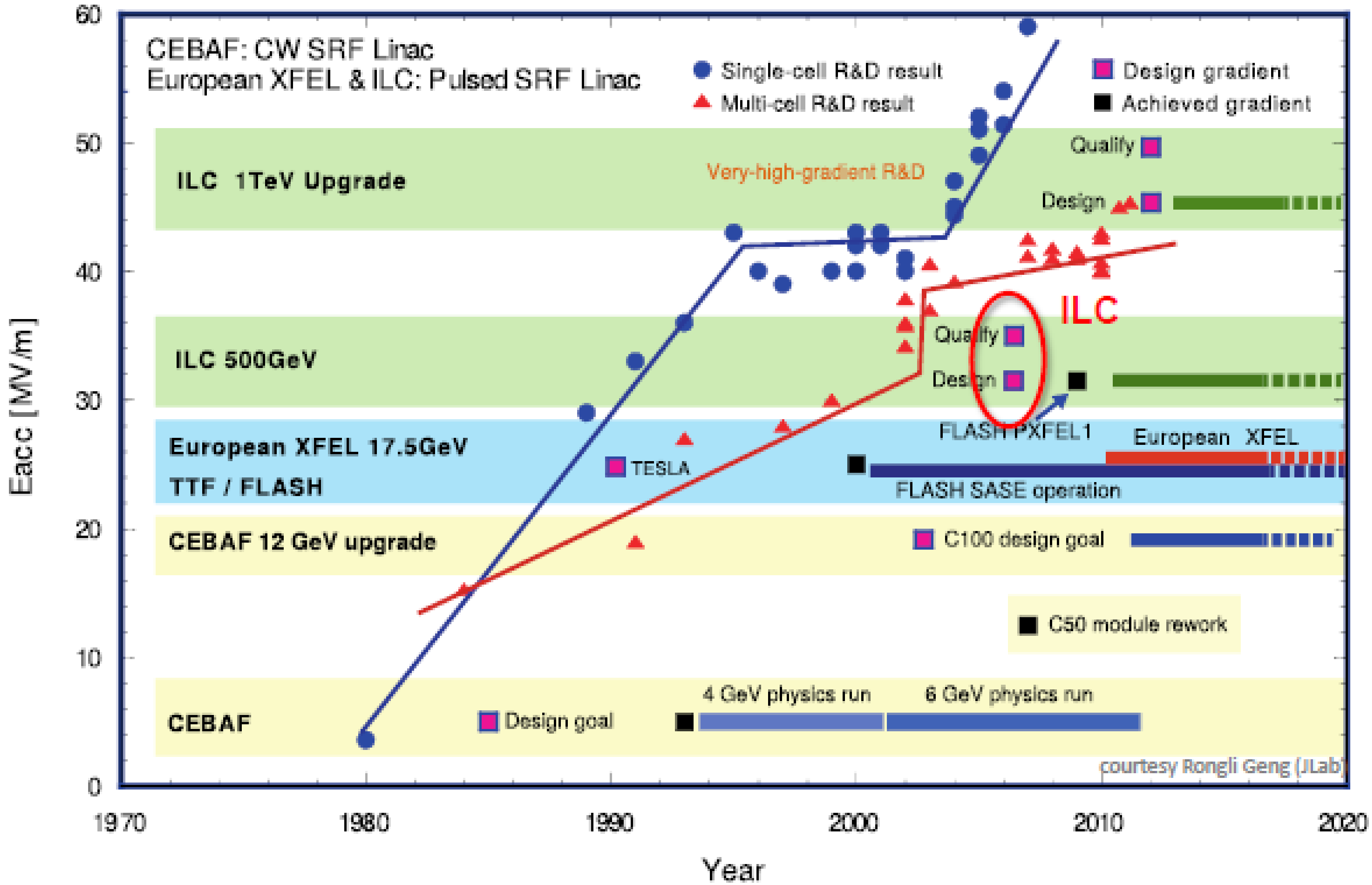
P5 Questions

- What are the great opportunities over the coming decade?
- What are the specific target applications?
- What technology demonstrator facilities are needed?
- How do the current investments feed into the longer term vision?
- What specific investments (both personnel and resources) should be made over the next decade?
- Are we on the right track or are there major gaps in maintaining a healthy program that is world leading and addresses the critical science and technology questions underpinning future accelerators for scientific investigation?
- What are the most significant ways in which this technology is being used by other fields?

What are the great opportunities over the coming decade?

- **Tremendous progress in SRF and NRF over the last 30 years**
  - **Opening paths to higher gradients and lower costs for the next decade**
- **SRF – CW from 5 MV/m to 35 MV/m**
- **NRF – pulsed from 20 MV/m pulsed to 70 MV/m**
  - **100 MV/m nearby**
- Proven benefits to HEP at Energy and Luminosity Frontiers over 30 years
  - TRISTAN, HERA, LEP-2, LHC, CESR-B, KEK-B, SLAC, SLC, PEP-B …
  - See back-up slides
- Technologies established
  - cavity, cryomodule, high power RF, engineering, accelerator operations
- Established: Getting ready for ILC has brought
  - Improved materials, quality control, engineering
  - World wide industrial base, world-wide SRF infrastructure
  - International collaborations

SRF (CW) The Quest for High Gradient



TESLA Shape

Re-entrant Shape

Low Loss Shape

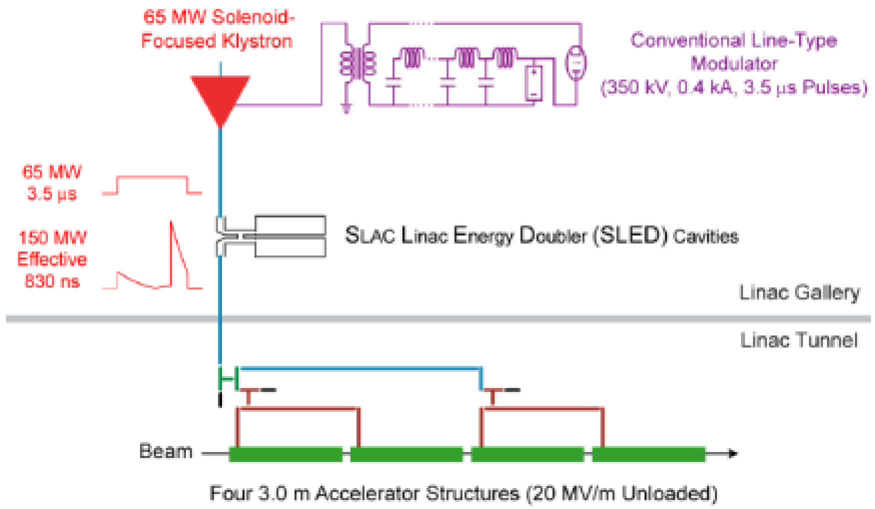
Single-Cell Cavities R&D shows the way to high gradients

TESLA/ILC Cavity – 9-cells

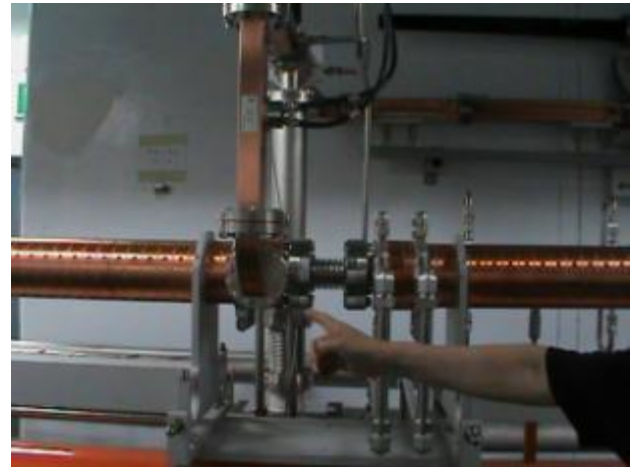
CEBAF Upgrade Cavity- 7-cells

SLAC Linac RF Unit

(One of 240, 50 GeV Beam)



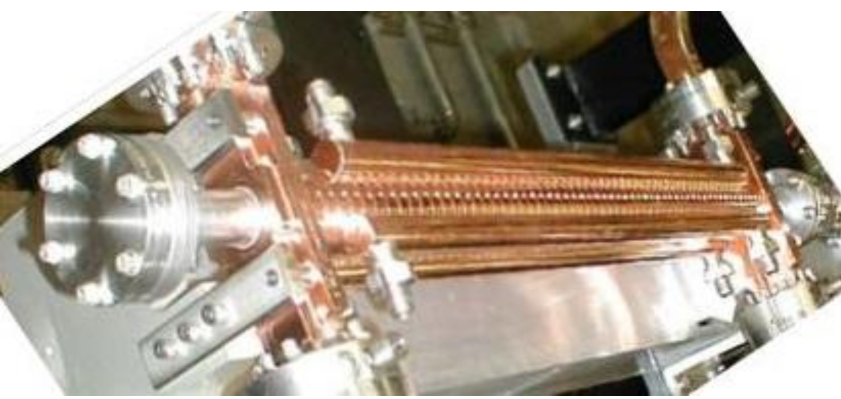
NRF (pulsed)

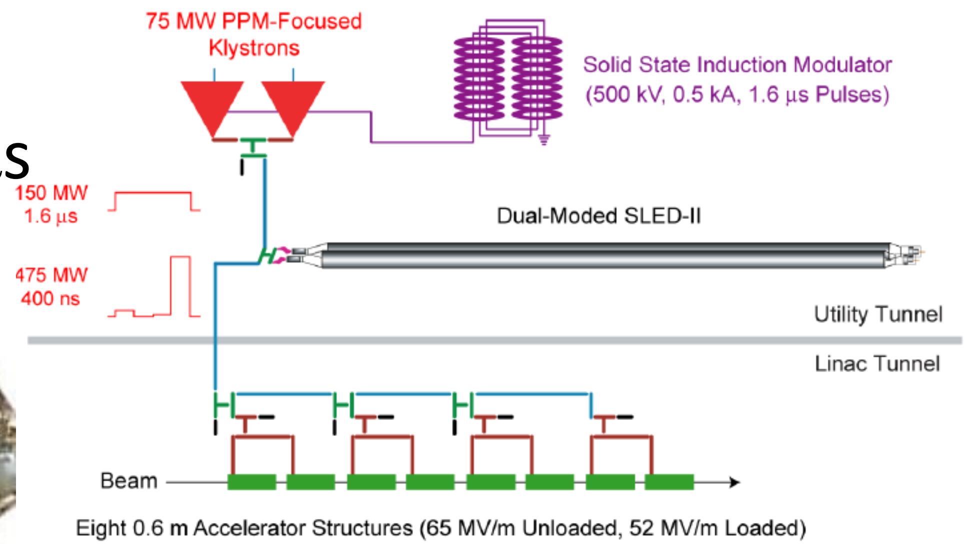


2.86 GHz
20 MV/m
1 μs

65 MW,

11.4 GHz, 65 MV/m 0.4 μs



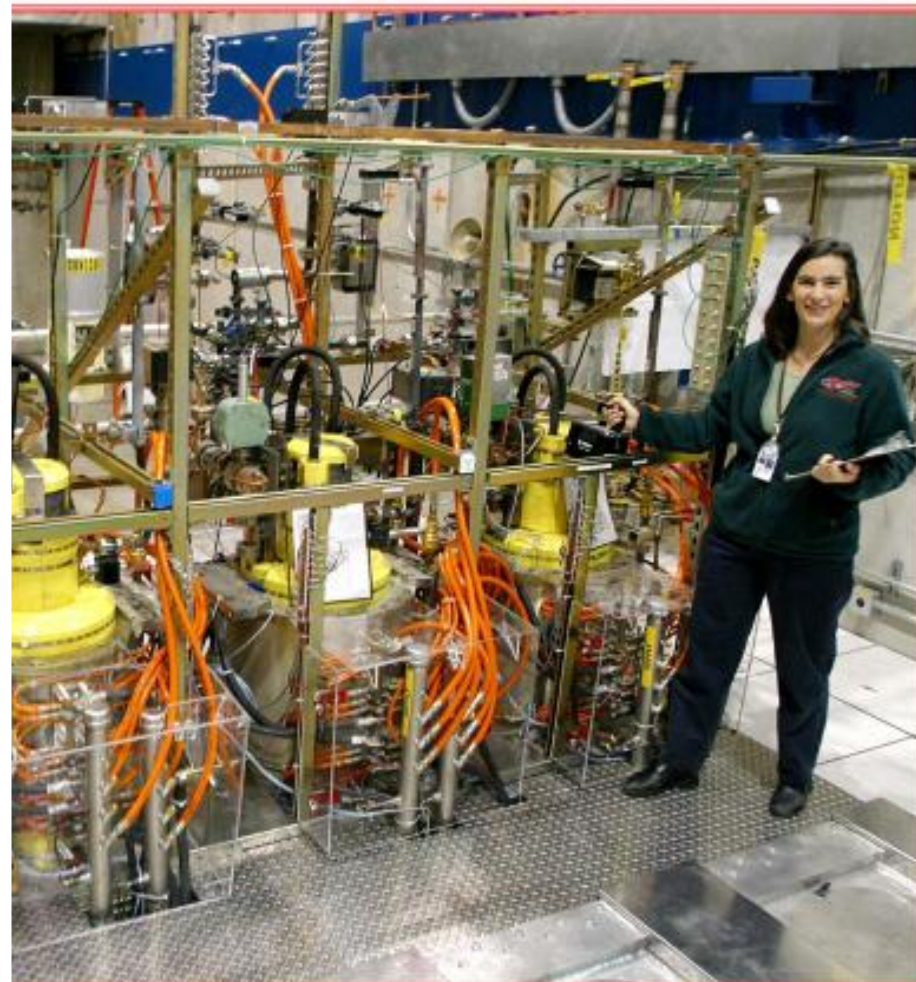


475 MW

NRF - Pulsed

SLAC

Two tubes tested at 75 MW with 1.6 μs pulses at 120 Hz.
Efficiency = 53-54%.



Pulse Compressor and Modulator Infrastructure at SLAC for 11.4 GHz NRF

What are the great opportunities over the coming decade(2)?

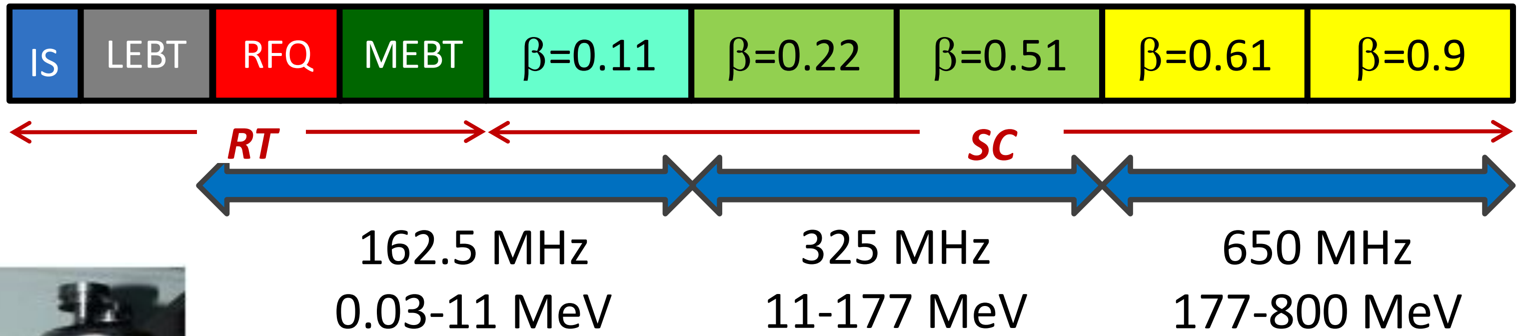
- Tremendous progress realized in SRF and NRF over the last 30 years
  - Opening paths to higher gradients and lower costs for the next decade
- SRF – CW from 5 MV/m -> 35 MV/m
- NRF – Pulsed from 20 MV/m (1μs) to 65 MV/m (0.5 μs)
  - 100 MV/m nearby at CLIC
- **SRF and NRF have proven benefits to HEP at Energy and Luminosity Frontiers over 30 years**
  - **SLAC, TRISTAN, HERA, SLC, LEP-2, LHC, CESR-B, KEK-B, PEP-B …**
  - **See back-up slides**
- **Established: Large Technology base**
  - **Cavity, cryomodule, high power RF, engineering, accelerator operations**
- **Established: Getting ready for ILC has brought**
  - **Improved materials, quality control, engineering**
  - **World wide industrial base, world-wide SRF infrastructure**
  - **International collaborations**

What are the specific target applications?

- SRF can benefit
  - Intensity Frontier
    - PIP-II Megawatt Proton Beams for
      - Neutrinos
    - LHC Luminosity upgrade (with Crab Cavities)
    - Neutrino Factory (+ Staging for Muon Collider)
  - Energy Frontier
    - Technology is Mature for Higgs Factory, ILC
    - With further development: TeV-ILC, Muon Collider, LHeC, TLEP…
- NRF (Energy Frontier)
  - NRF advances have fed into developments for the 1.5 TeV CLIC,
  - A large number of low frequency (200 – 350 MHz) NRF cavities are needed for buncher, phase rotator and cooling sections for NF and MC.
  - 200 MHz Muon Cooling cavities in high magnetic fields

Luminosity - Fermilab Proton Improvement Plan-II

Steve Holmes Linac Technology Map



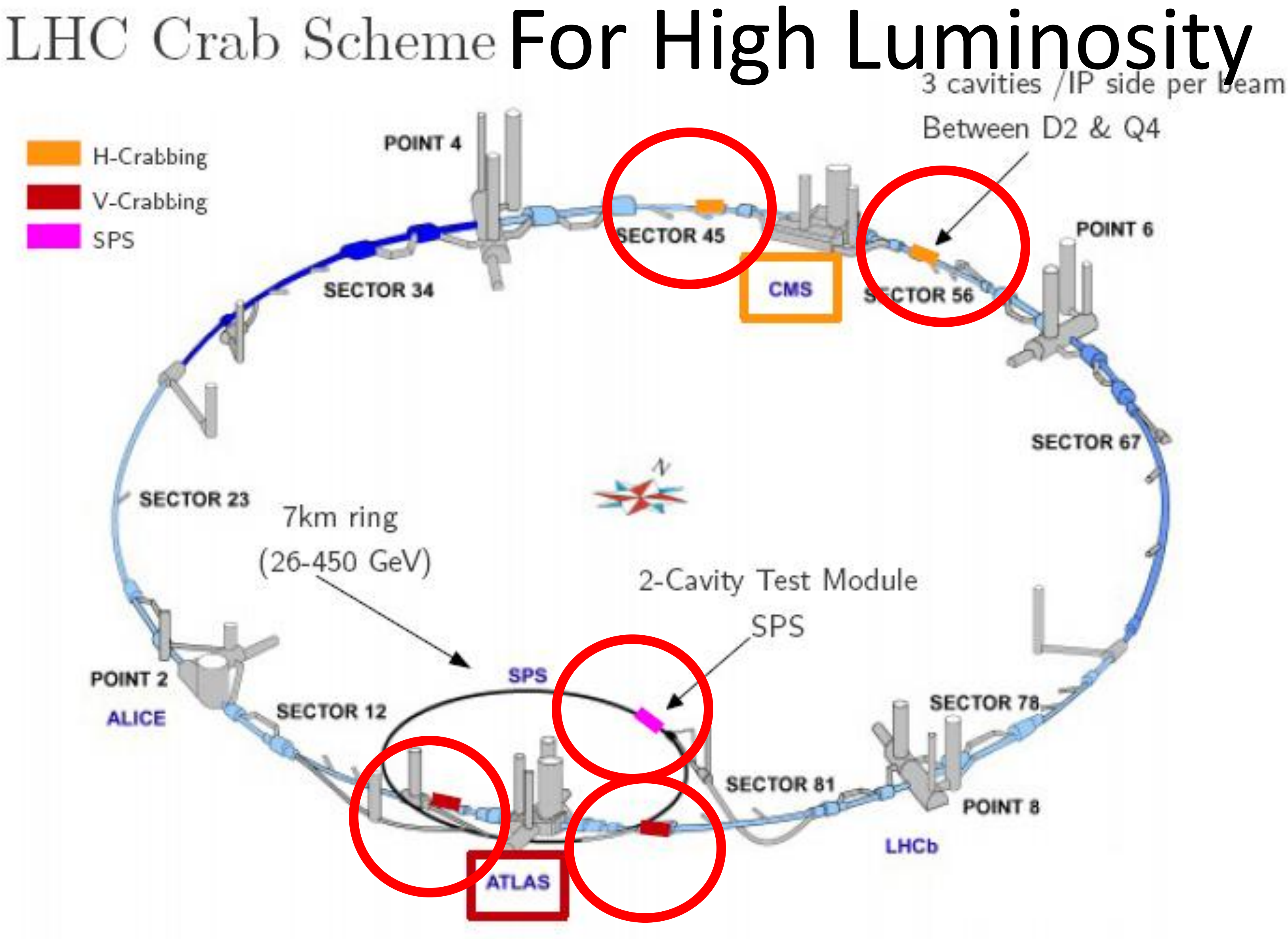

Half Wave


Spokes

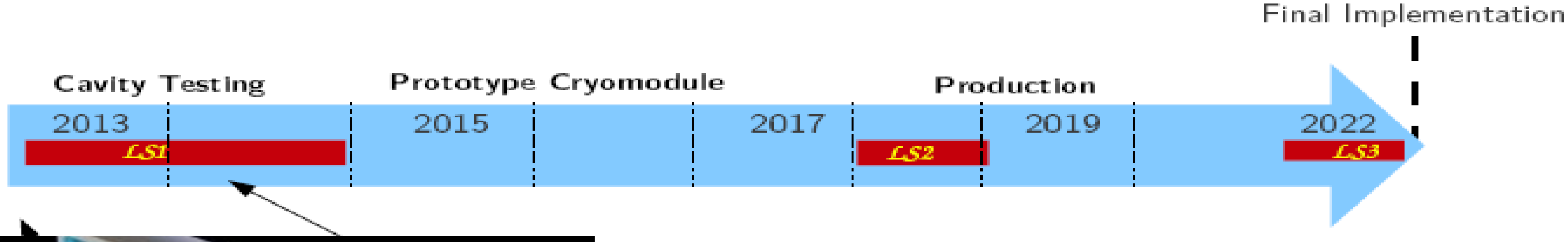

Medium-Beta Elliptical Cavities

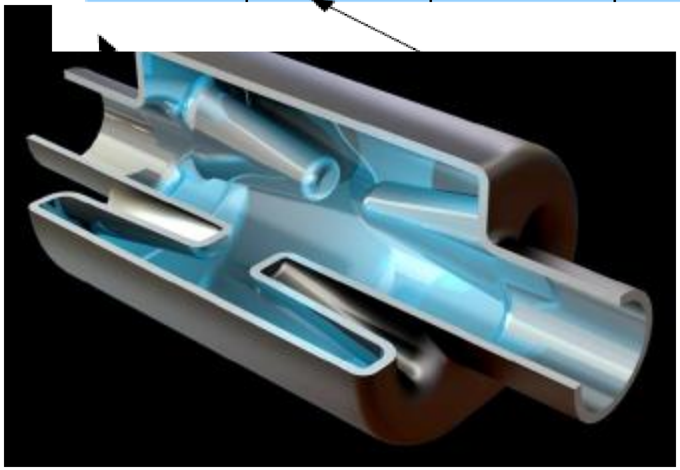
Strong overlap with low-beta nuclear physics and astrophysics SRF community

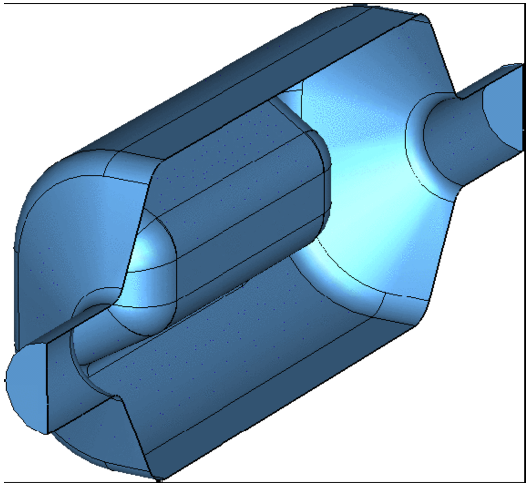
For High Luminosity



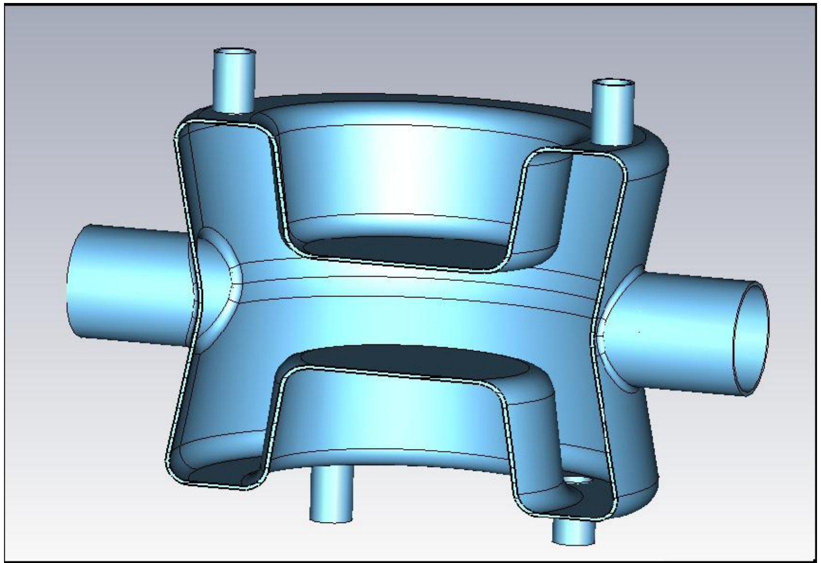
3 SRF Crab Cavity Candidates Under Development - Downselect Coming Soon







3 MV Kick Voltage Demonstrated

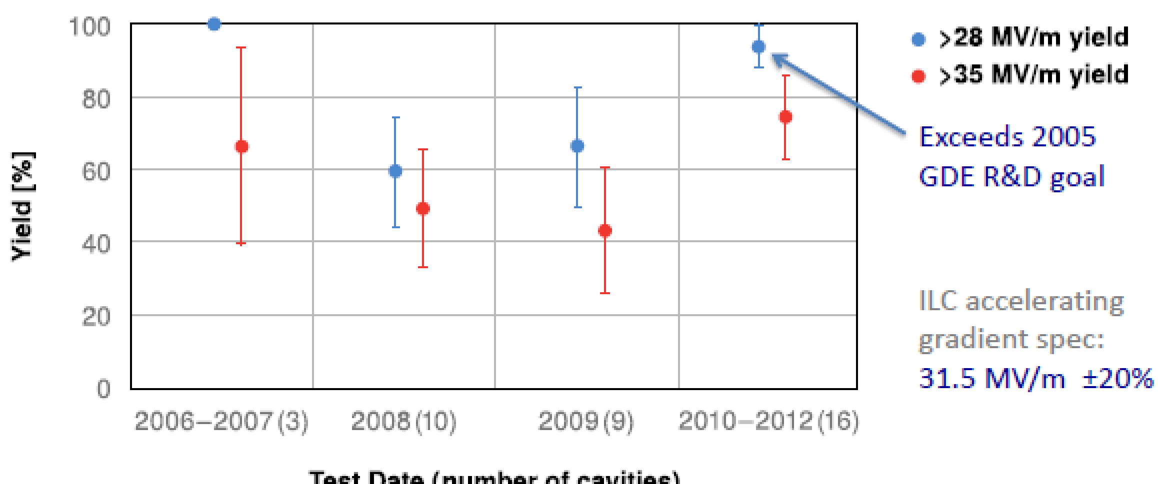


Energy Frontier
SRF Linac Technology - Mature for ILC Launch

1.3 GHz Nb 9-cellCavities	16,024
Gradient	28 - 42 MV/m
Q	Near 10^{10}
Cryomodules	1,855
SC quadrupole pkg	673
10 MW MB Klystrons & modulators	436 *

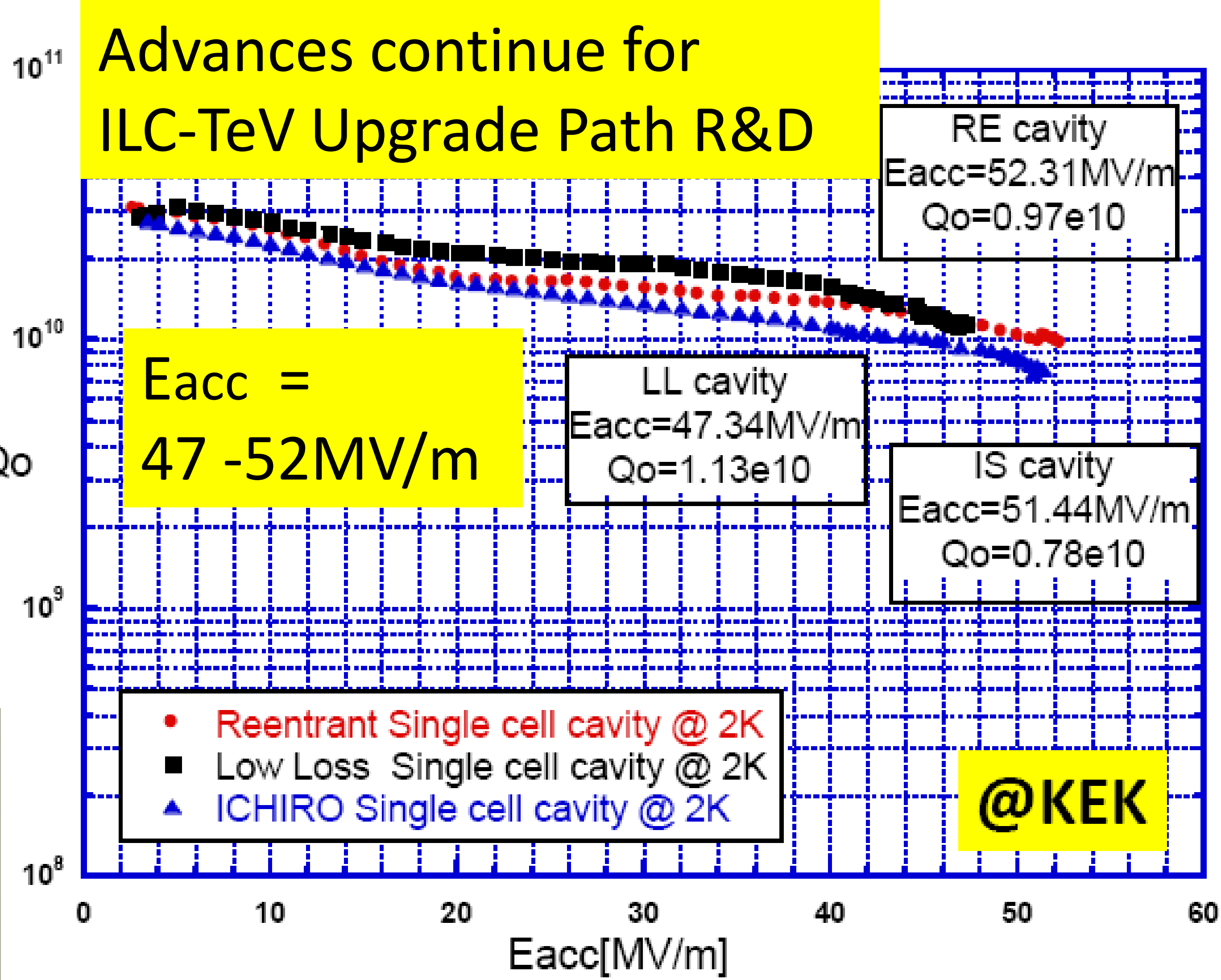
* site dependent

Worldwide gradient R&D



Target Gradient Yield in Hand

Proof of high gradient w/ single cells (1)



Advanced-Shape Multi-Cell Cavities Developed But Limited by Field Emission to ~40 MV/m

Cornell Re-Entrant 9-cell # 1

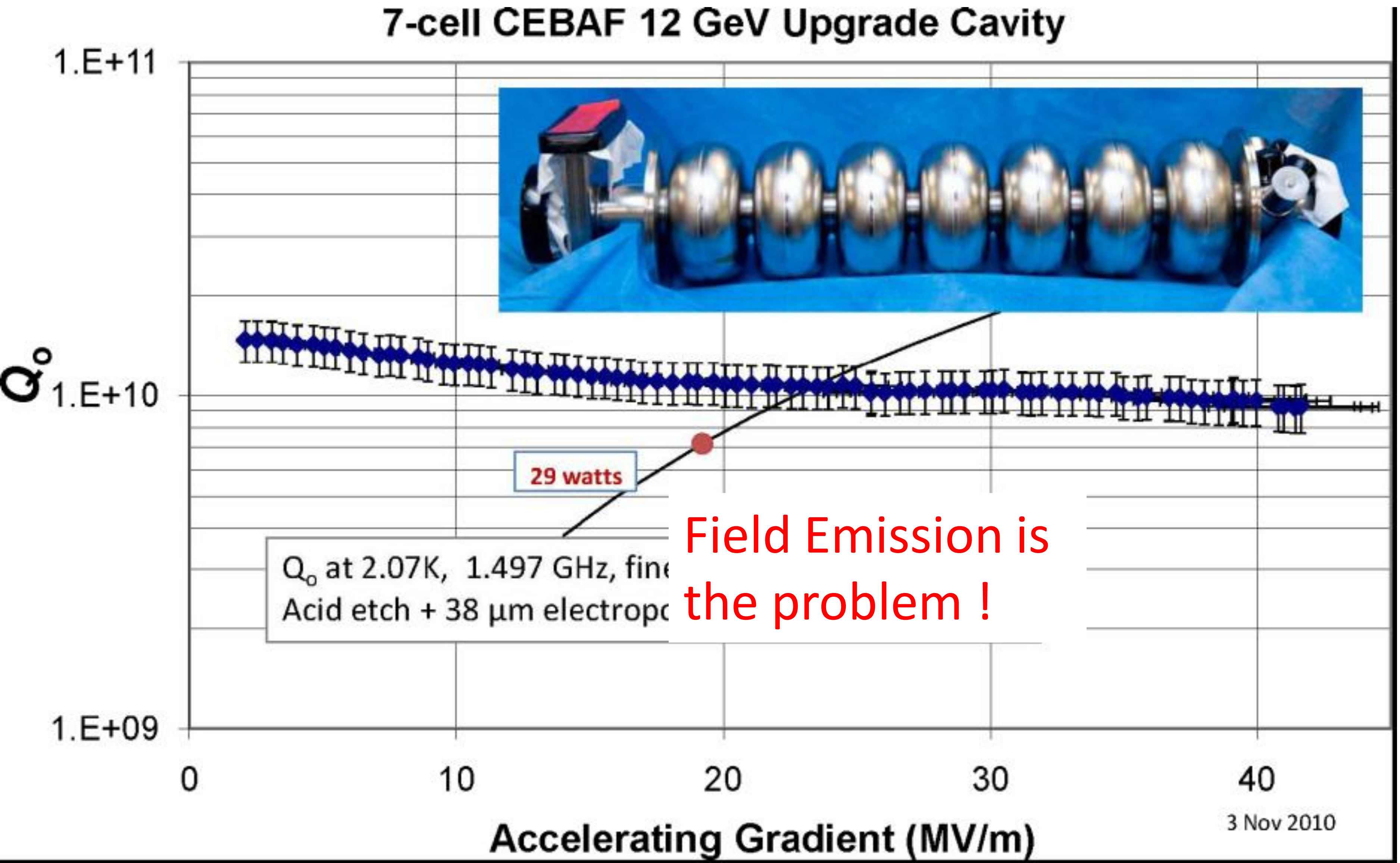
KEK/Jlab S0-study on ICHIRO#7 in 2010

Step-II : full cavity

Ichiro#7

w/ end groups

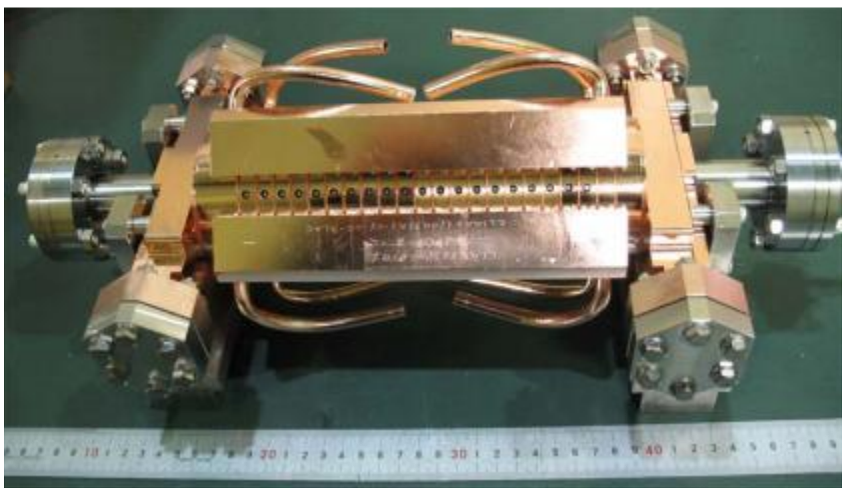
42 MV/m Demonstrated With



Field Emission is the problem !

NRF - CLIC accelerating structures

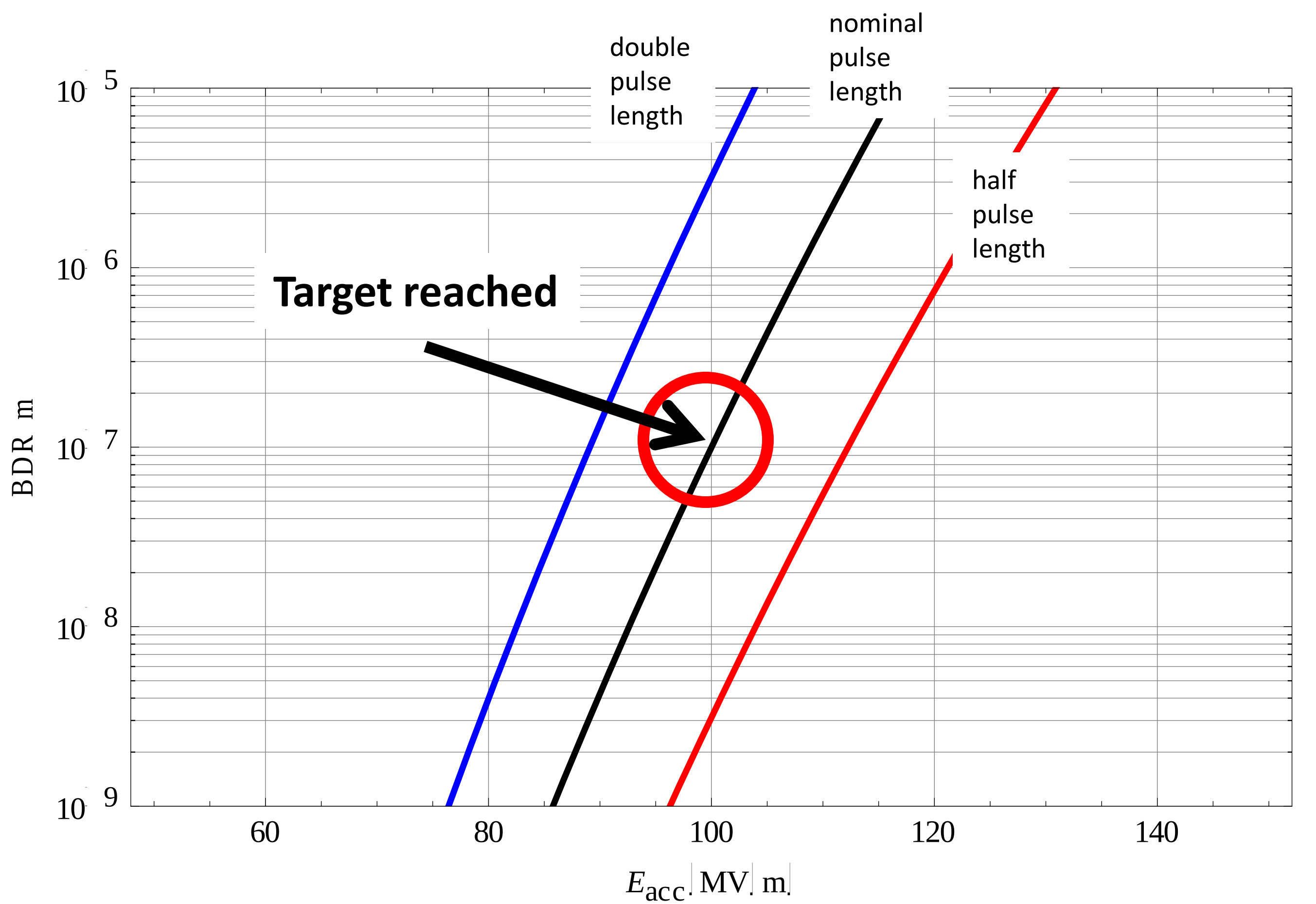
- Target 100 MV/m accelerating gradient at the correct Breakdown Rate and pulse length!
- Target reached in first few 12 GHz structures



W. Wuensch: 7th LC School, 2012

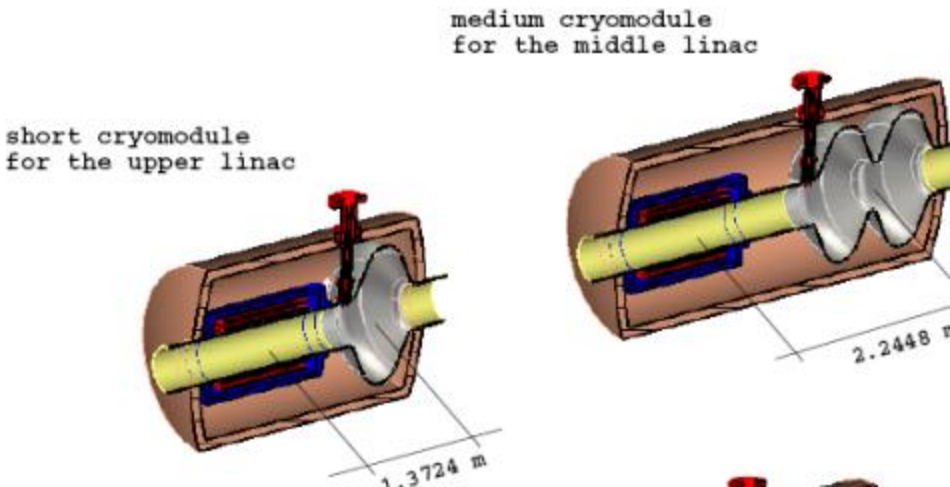
R&D On-Going to Understand and Reduce Breakdown Rate (BDR)

Observed: $BDR \propto E^{30}\,\tau^{5}$



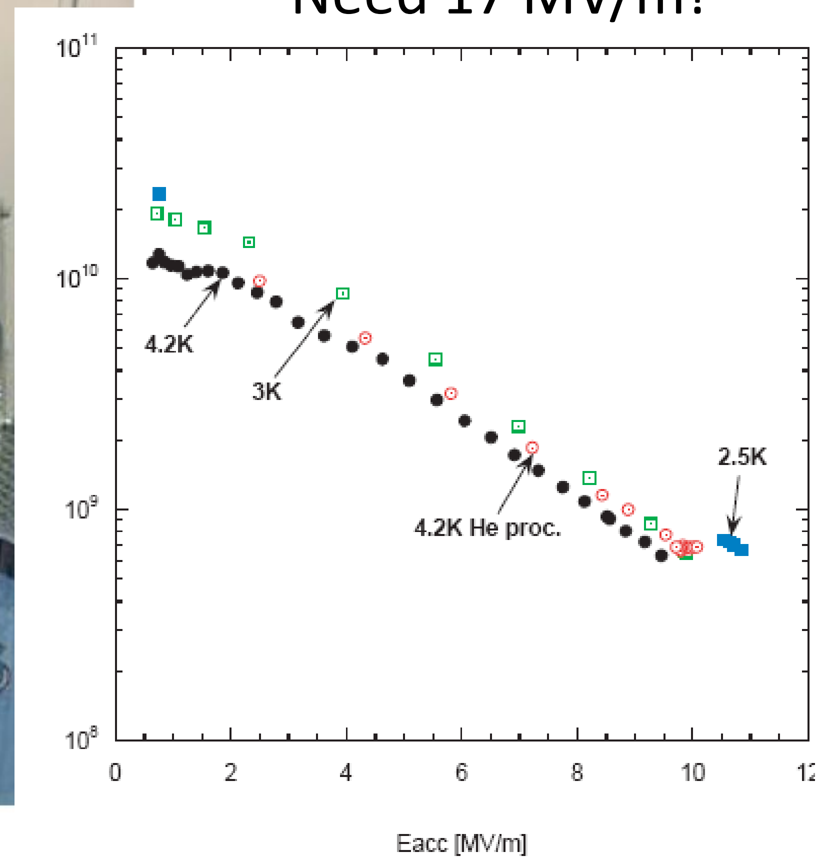
SRF for the 25 GeV Neutrino Factory & Muon Collider - International Design Study (IDS)

- NF with FFAG, LINAC and RLAs requires
- 385 single cell cavities@201 MHz, 17 MV/m
  - Fermilab MAP is working on 325 MHz instead of 200 MHz
- Sheet Nb will be too expensive!
  - Need Nb-Cu
    - Either Nb thin film on Cu
    - Composite Nb-Cu



Cornell-CERN Collaboration
201 MHz Sputtered Nb on Cu **Best 10 MV/m, 10^9**

Need 17 MV/m!



1.5 TeV Muon Collider (IDS)

- 430 cells - 201 MHz @ 17 MV/m
- 4685 cells – 804 MHz @ 25 MV/m
- For 3 TeV
- + 5724 cells – 804 MHz @ 25 MV/m
- 804 MHz SNS cavity reaches 15 – 18 MV/m

How do the current investments feed into the longer term vision?

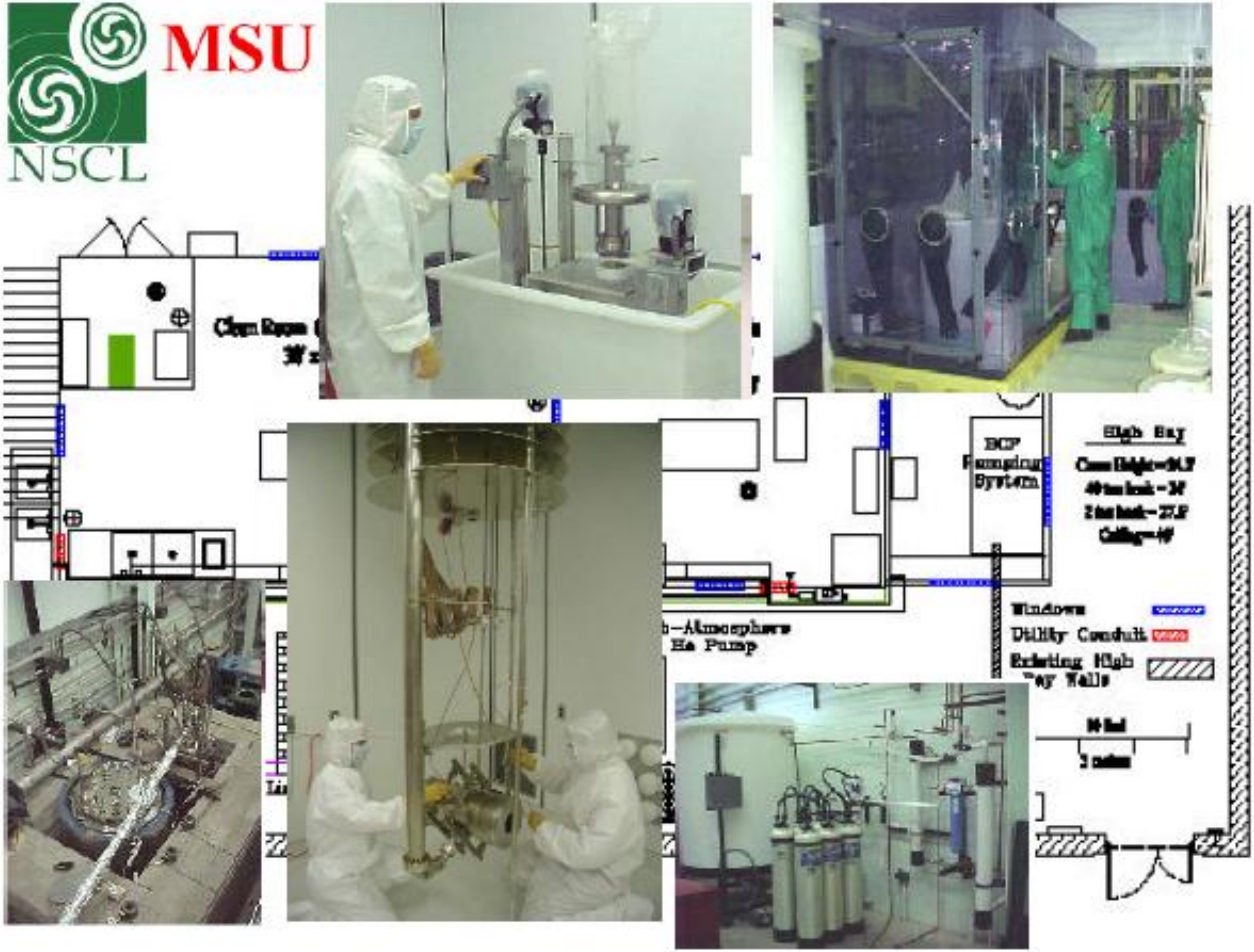
- **Infrastructures installed in US (and World) Labs**
  - **> 300 M$ Investment**
  - **Mostly Ready for HEP Energy and Luminosity Paths**
    - **ILC, LHC-Crab, PIP-2**
- Science helped advance SRF performance to current levels
  - Improving understanding opens routes to better performance, reliability, and new applications
  - Overcome multipacting, thermal breakdown, field emission, high field Q-slope

Cornell SRF Cavity Test Pits

Jlab Cavity Test Stations

Jlab - Cryomodule Assembly and Test Areas

Cryomodule Test Facility (CMTF)


MSU
NSCL
High Bay
BCP Pumping System
Windows
Utility Conduit
Existing High Bay Walls
He Pump

Fermilab/Argonne:
Cavity Processing Infrastructure

1.3 GHz EP/BCP Tool
(Joint ANL/FNAL)

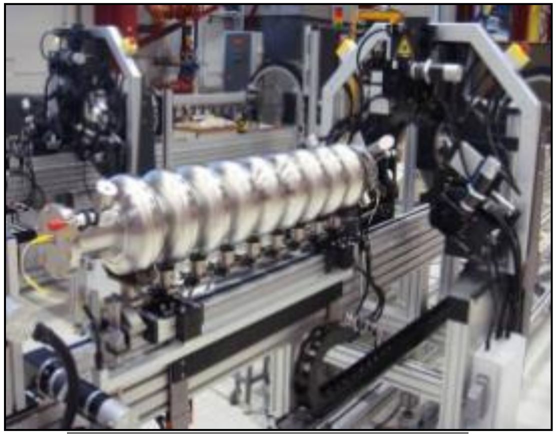
High pressure rinse tool: 1.3 GHz Cavity (Joint ANL/FNAL)

IB4 Cavity Proc. Lab EP Tool

IB4 Cavity Proc. Lab Class 10 Cleanroom

1.3 GHz Tumbler

Fermilab Infrastructure: Cavity Testing, Tuning



ILC/XFEL Cavity Tuning Machine

Vertical Test Stand

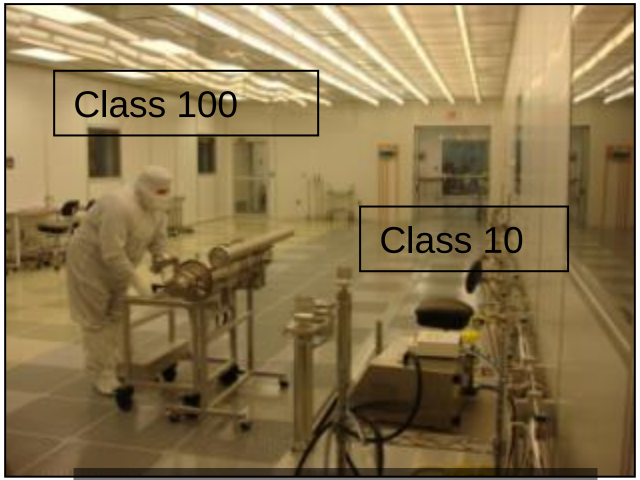
Vertical Test Stands 1, 2 and 3

9-cell TESLA-style cavity

1.3 GHz installation into Horizontal Test Stand

Vertical Cavity Test Facility Control Room

Fermilab Infrastructure: Cavity String, Cold Mass, Cryomodule Assembly, Beam Test Assy



Cavity String Assembly Clean Room

Cavity String Assembly

Cold Mass Assembly

Cryomodule Test Infrastructure

Final Assembly

ILC-Driven World Wide Industrial Base

E. ZANON S.p.A.

research instruments

2 Europe
3 Americas
4 Asia

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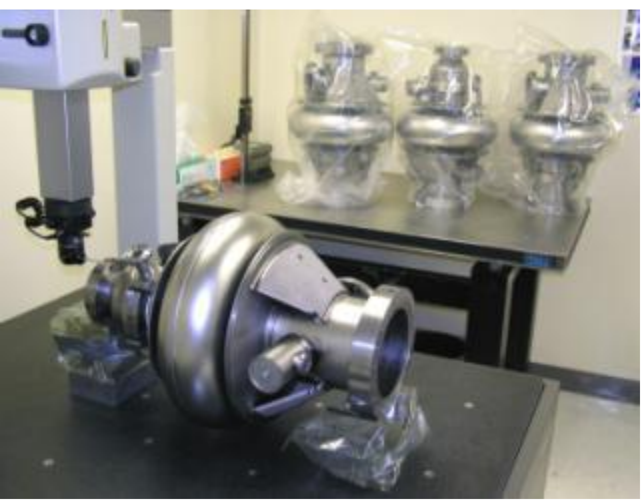
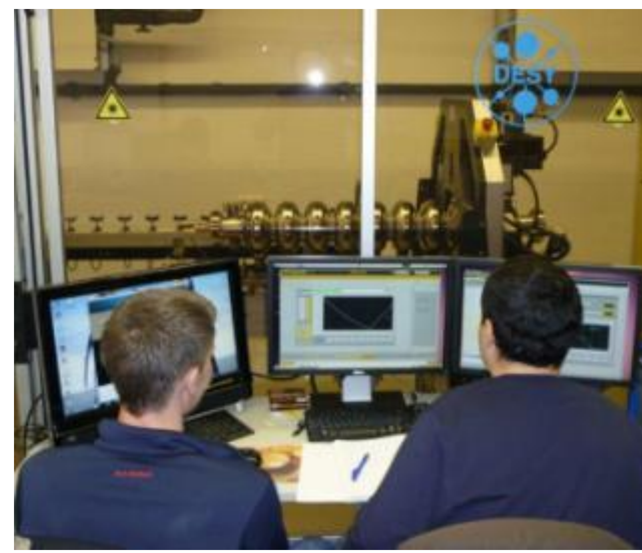
Global Industrial Cavity Fabrication Partners – *qualified**

* (or soon to be)

AES, Long Island, NY
Welder, Chemical Treatment, Clean Rooms, Clean Water



Cavity Production at RI, Germany



Cavity Production at EZ, Italy

How do the current investments feed into the longer term vision?

- Infrastructures installed in US Labs (and Worldwide Labs)
  - > 300 M$ Investment
  - Mostly Ready for HEP accelerators
- **Advances in science and technology help to advance RF to meet HEP energy/luminosity goals**
  - **Improving understanding to open routes to better performance, reliability, and new applications**
    - **Overcome multipacting, thermal breakdown, field emission, high field Q-slope**
  - **Develop structures, power couplers and dampers to support high beam current**

What investments to make over the next decade?

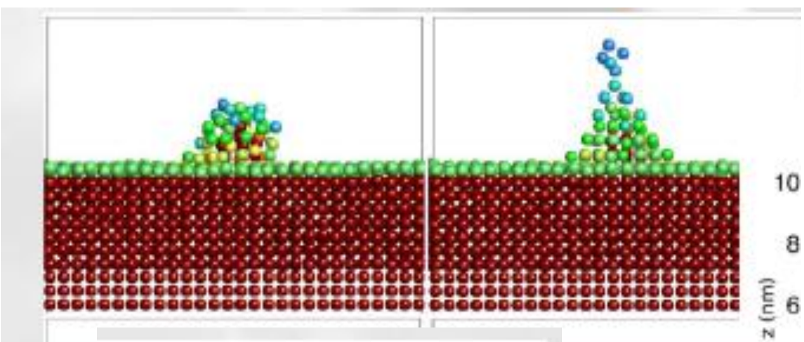
- I rely on the wisdom of panels to recommend adequate project-related funding to develop the RF for the chosen path, be it
  - ILC, NF, MC, LHC, PIP-II…
- Independent of that knowledge, I can make a few general suggestions for an important “basal level of R&D support”
- To reap many benefits from high level infrastructure installed and available talent at many labs.
  - Cornell, Fermilab, Jlab, BNL, MSU, SLAC …

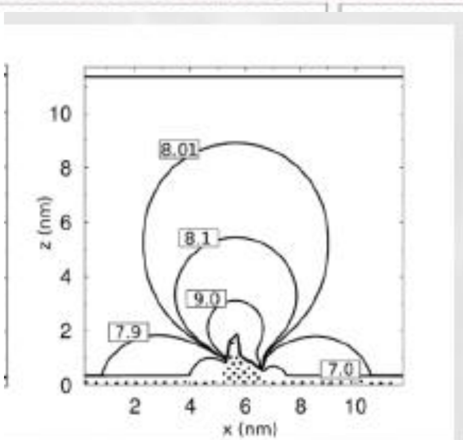
What investments to make over the next decade?

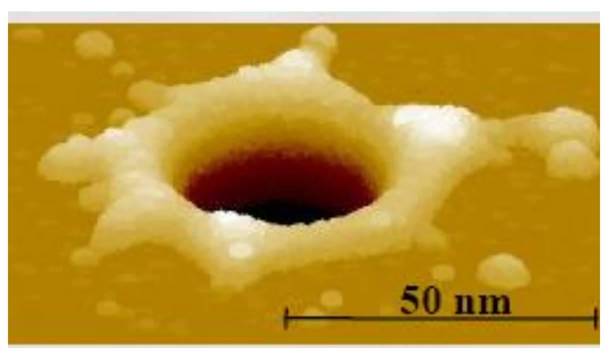
- 1) **Support the science**: Invest in basic understanding of performance limits to benefit ANY future path. Need more R&D for
  - Field emission reduction, breakdown rate reduction for NRF
  - Higher Q
  - Higher gradients
  - High quality Nb on copper coatings
  - Explore Nb3Sn - the best choice for new material with proof-of-principle
- 2) **Invest in Cost Reduction efforts**
  - There are many paths with demonstrated potential to yield major benefits.
  - Seamless cavities by hydroforming and spinning
  - Composite Nb-Cu
  - Large-grain Nb
- 3) Fund **"evolutionary" paths with proof-of-principle in hand – there are many**
- 4**)** Fund **"revolutionary"** paths to demonstrate proof-of-principle before major commitments
- 5) A basal funding rate of 10 - 15 M$/year across several labs

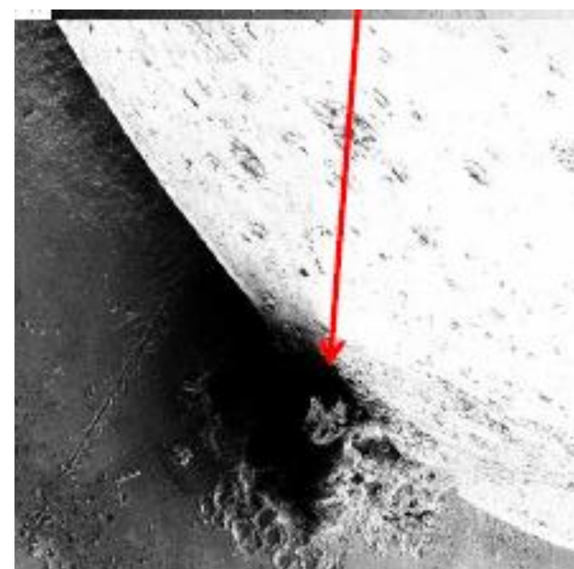
Better Understand Breakdown in Copper RF

- Atomistic simulations show electric field induces tensile stress
- Local “irregularities” on the surface concentrate the stress..
- Understand /eliminate source of such “irregularities”
- Protrusions result - initiating formation of field emitters
- -> field enhancement-> plasma discharge -> surface damage!

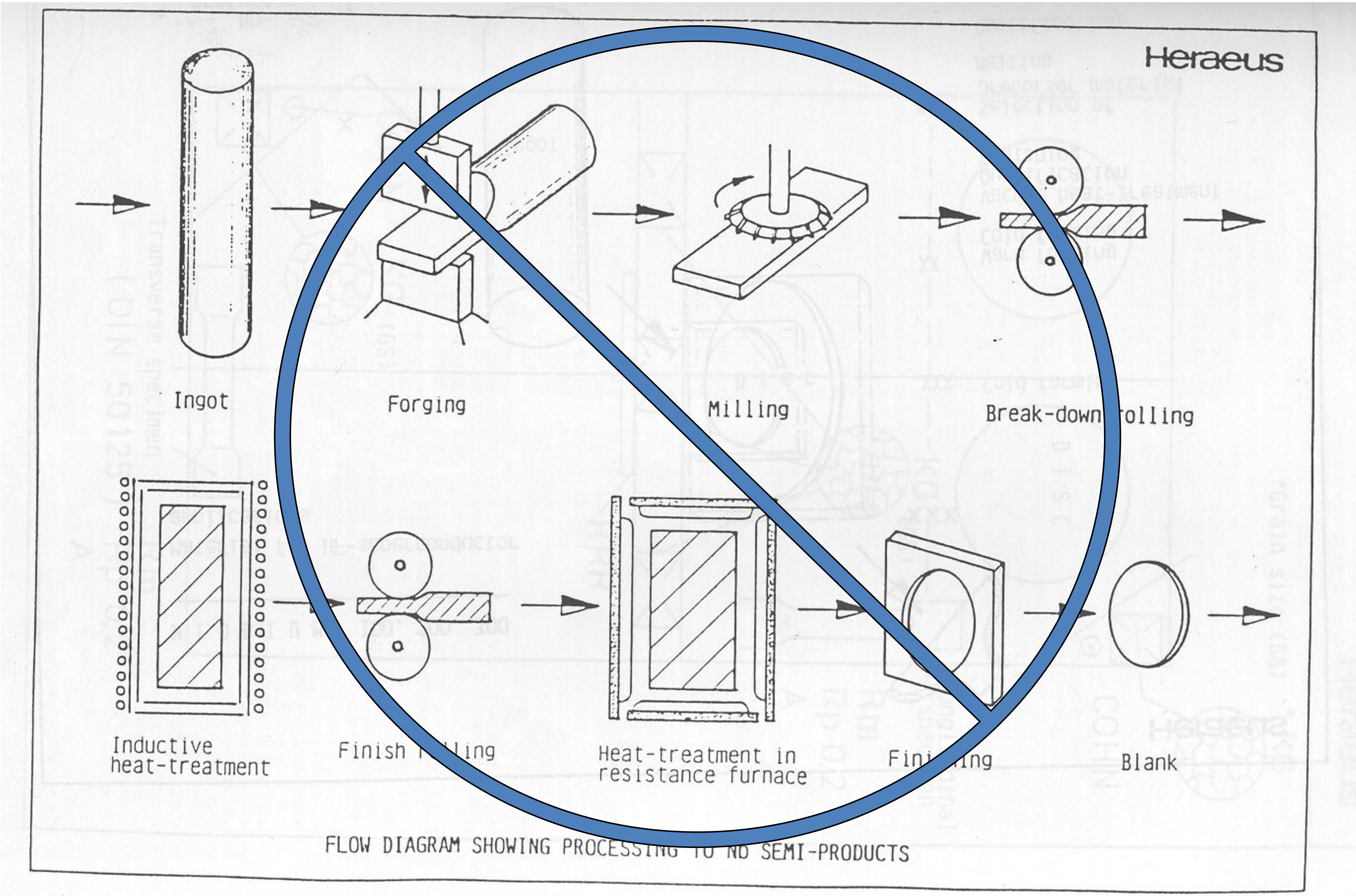




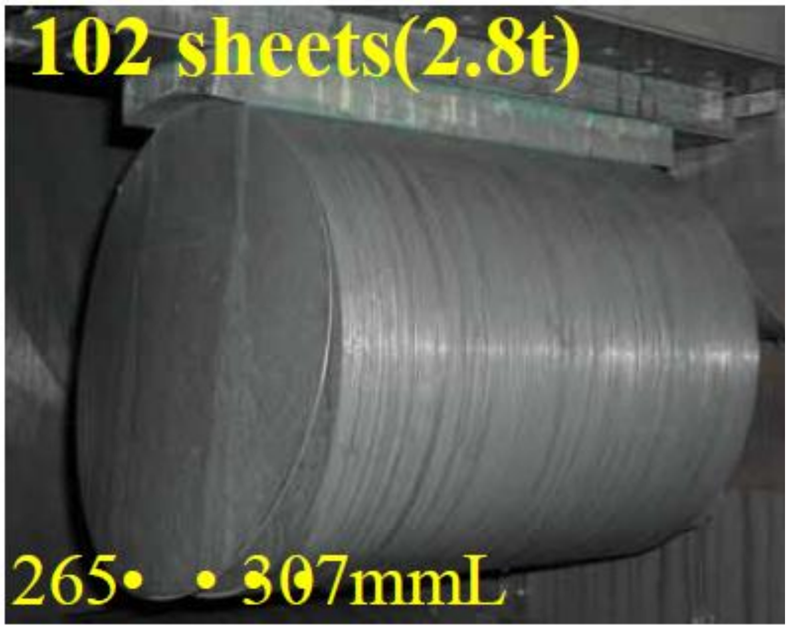




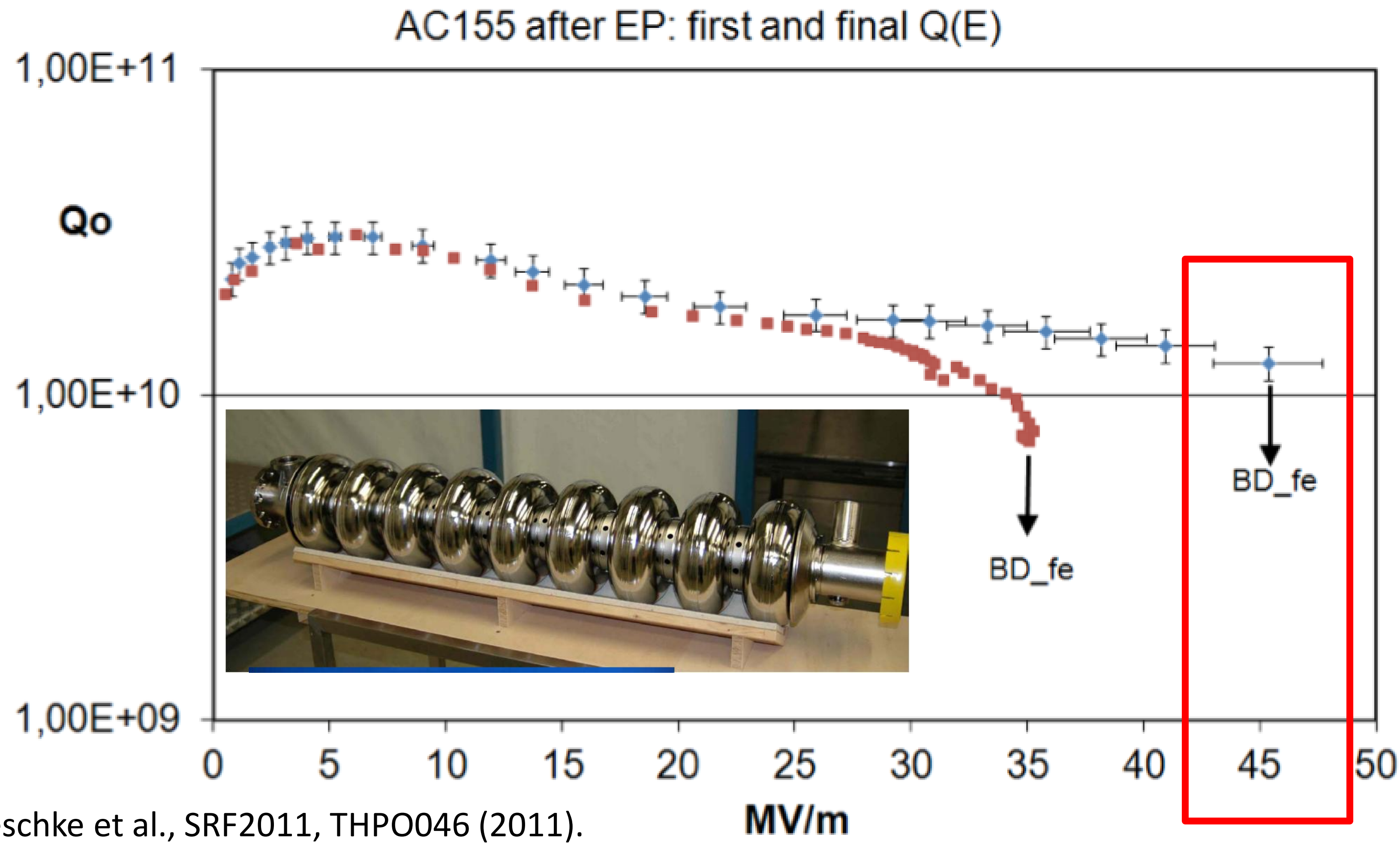
Nb Cost Reduction: Go Directly from Ingot to Sheet?



Multi-Wire EDM Slicing of Ingot
-> Large Grain Nb, fewer defects



High Q_0 via Large Grain Nb, 45 MV/m

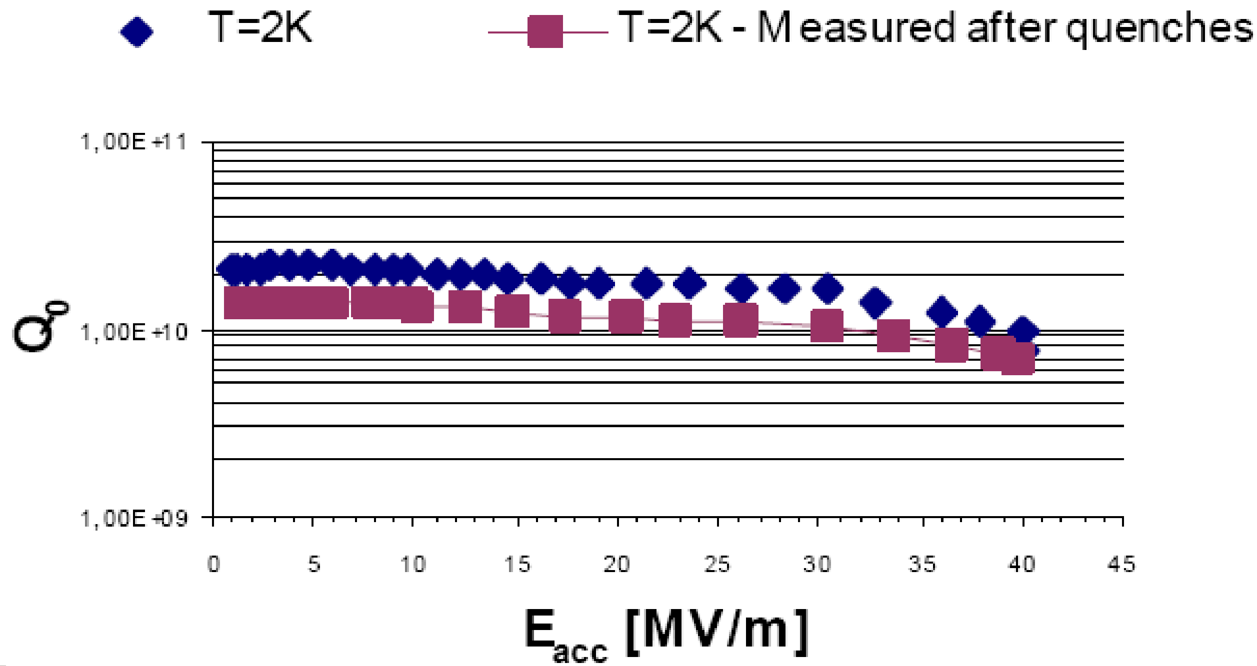


D. Reschke et al., SRF2011, THPO046 (2011).

Eacc

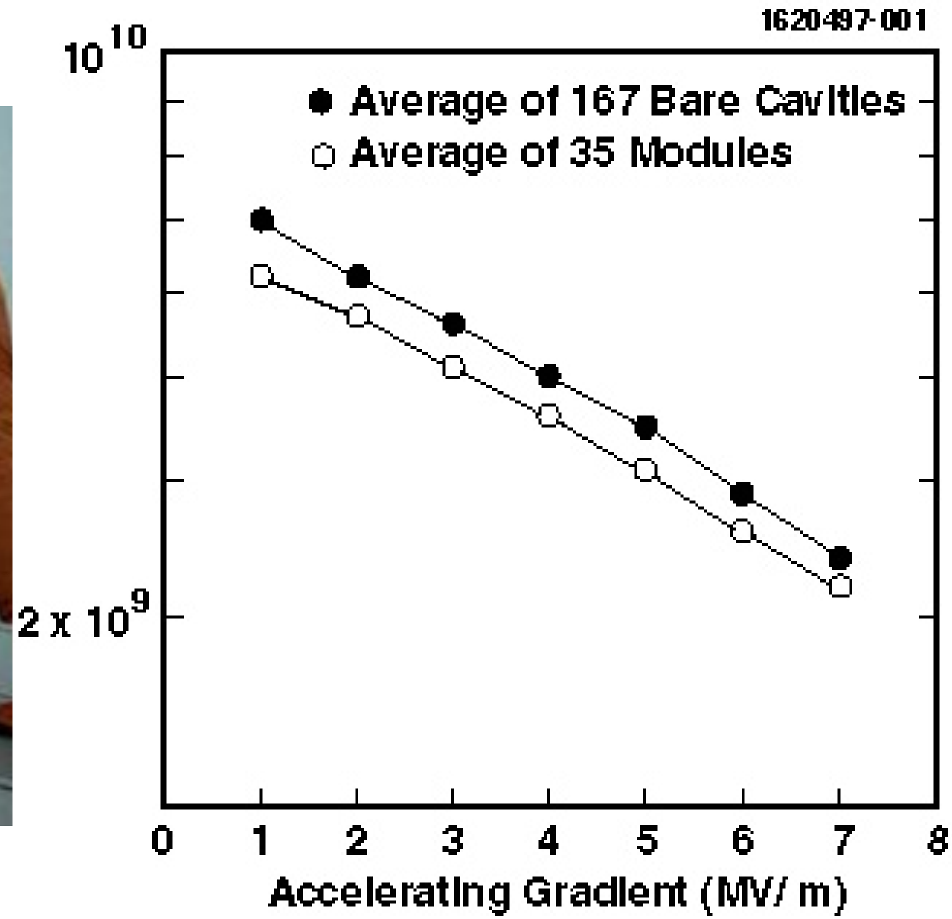
500 MHz Cavity via spinning Nb-Cu Composite Cornell/INFN -Legnaro

1300 MHz Nb and Nb-Cu Cavities
Hydroforming and Spinning
DESY- KEK - Reach 40 MV/m

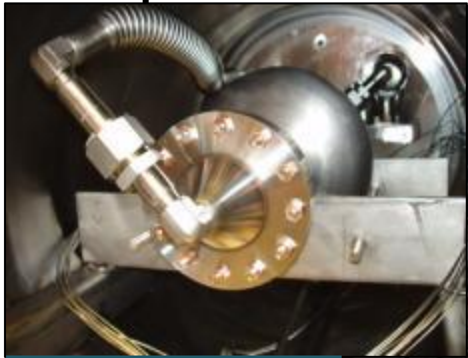


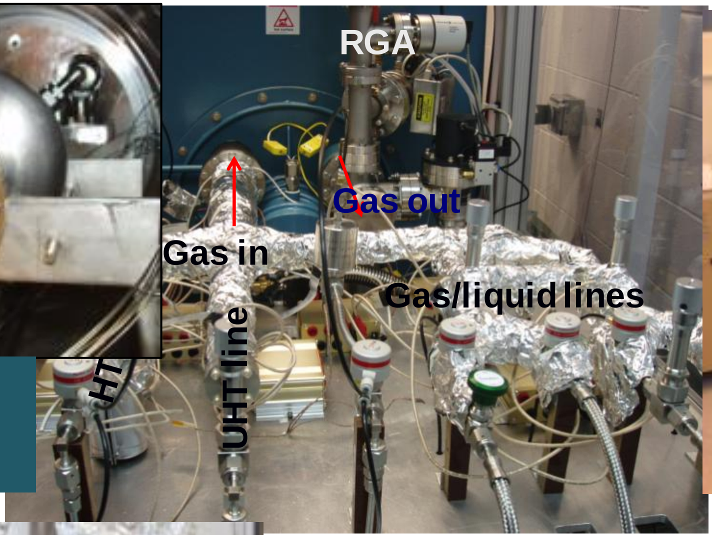
LEP-2, 350 MHz, Magnetron Sputtered Nb-Cu

Best 7 MV/m, Q = 2 x 10^9

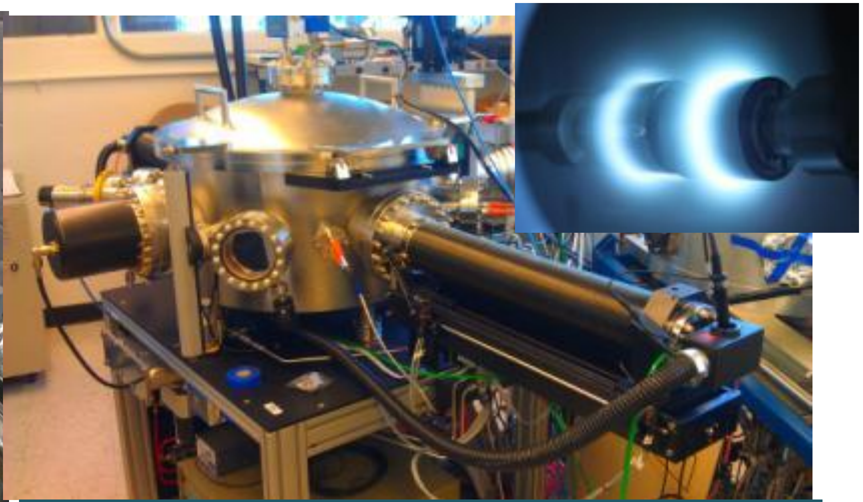


Can we develop new coating methods to get rid of that nasty Q-slope???? Jlab and others

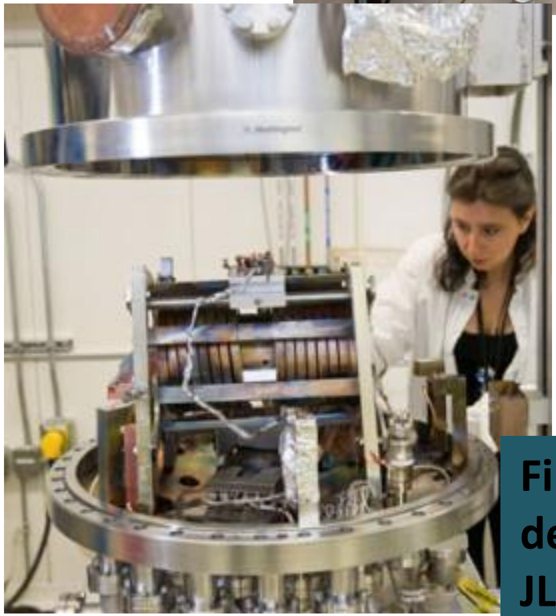




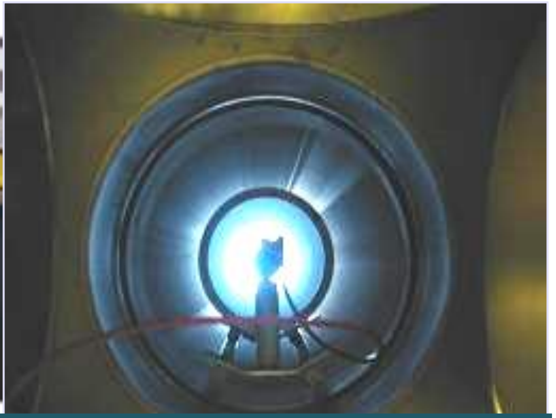
Cavity ALD at ANL



High-impulse deposition at LBNL



Film deposition at JLab

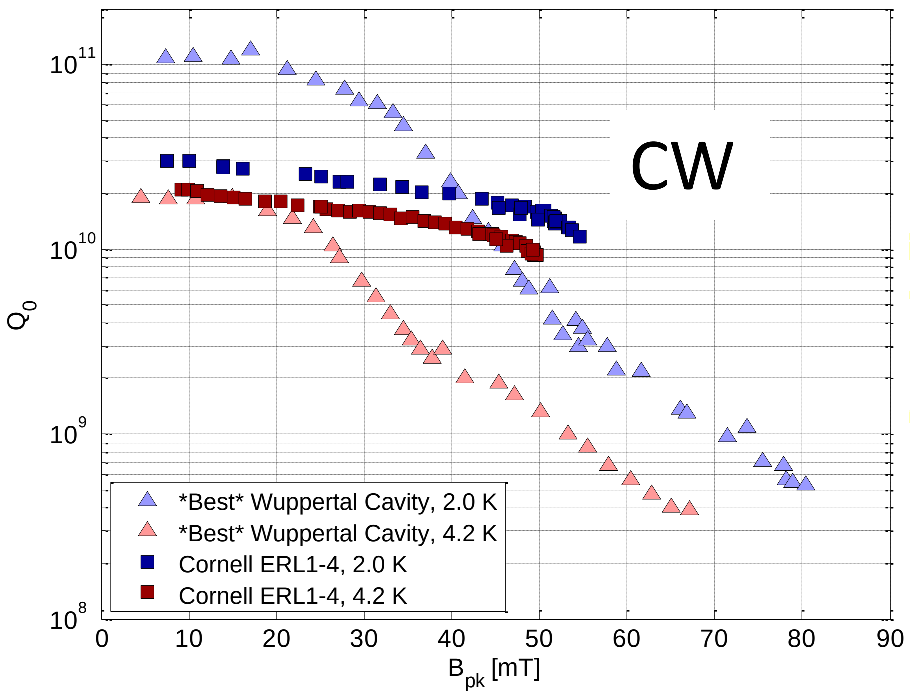


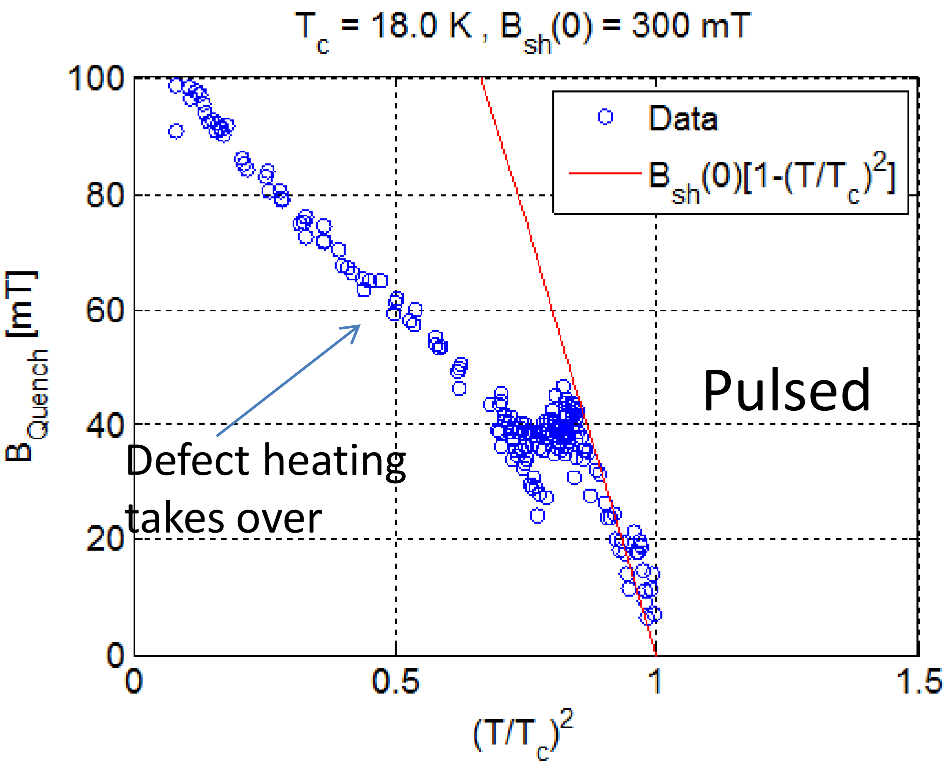
CED at AASC, 1st coated Nb-Cu cavity in hand, 2012

Revolutionary Paths - Exotic materials and techniques (see back up slides)

- Nb coating on Cu
  - Magnetron sputtering pursued > 20 years
    - best 15 MV/m @ 1500 MHz, 10 MV/m at 400 MHz
  - New methods: Energetic deposition
    - Sample Nb properties and RRR improvement demonstrated
    - No encouraging cavity results yet
- Multilayers, ALD, CVD….
    - 5 years.. no cavity results
    - Back up slide: New fundamental studies contest benefits of multi-layer shielding
- HTS (candidates in order of increasing attraction)
  - YBaCuO - Reject- Has nodes in energy gap => Q will be low
  - MgB2 – Questionable advantages
    - Two energy gaps, lower gap is less than Nb3Sn gap, so surface resistance will be higher
    - Hc ranges from 0.26 – 0.6 (Nb, Hc = 0.2, Nb3Sn Hc = 0.4)
  - Pnictides – very new
    - Tc best 50 K, some evidence for S-wave gap around 8 (Nb3Sn, Δ= 3) Could lead to high Q
  - Sorry to be so pessimistic, but facts are facts
  - Only Nb3Sn shows encouraging results

Nb3Sn - $B_{ultimate}$(T) Measurement at high T



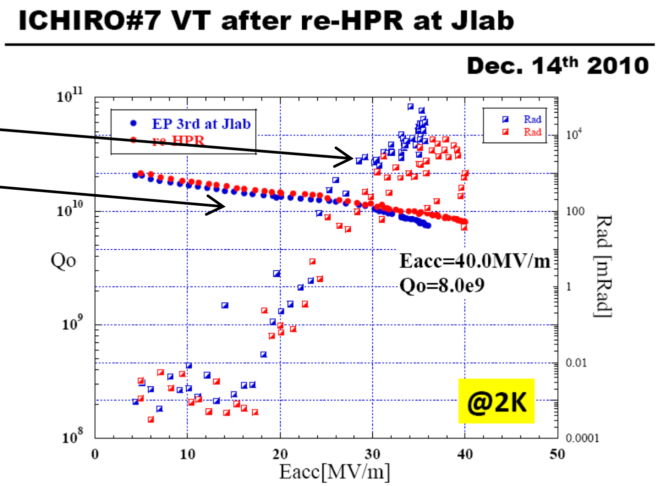


- Single cell 1.3 – 1.5 GHz cavities with Q = 10^{10} to 10^{11} demonstrated.
- CW gradients to 18 MV/m at Q =10^9
- Pulsed rf data at high temp data extrapolates to B_{sh} ~ 300 mT

=> Eacc > 80 MV/m >> Nb – Hsh = Hcritical

Are we on the “right” track or are there major gaps in maintaining a healthy program that is world leading and addresses the critical science and technology questions underpinning future accelerators for scientific investigation?

- There is “little to zero” investment in the following highly promising topics
  - Muti-cell Nb cavities for 45 – 55 MV/m and high Q for TeV-ILC
    - Field emission reduction
    - Medium field Q-slope reduction
  - R&D on understanding and reducing BDR for Cu - CLIC
  - Low frequency Nb-Cu cavities for NF and MC
  - Cost reduction
    - Large Grain Nb
    - Seamless cavities from Nb and Nb-Cu composite sheets
    - Cavities from Nb-Cu thin films
      - Esp beneficial to low frequency cavities for NF and MC



- Fundamental science of new materials
  - Nb3Sn is the one to pursue – could lead to 100 MV/m
- It will take at least 10 years to understand the science & develop such technologies fully

What are the most significant ways in which this technology is being used by other fields?

Proven and Upcoming Applications of SRF and NRF

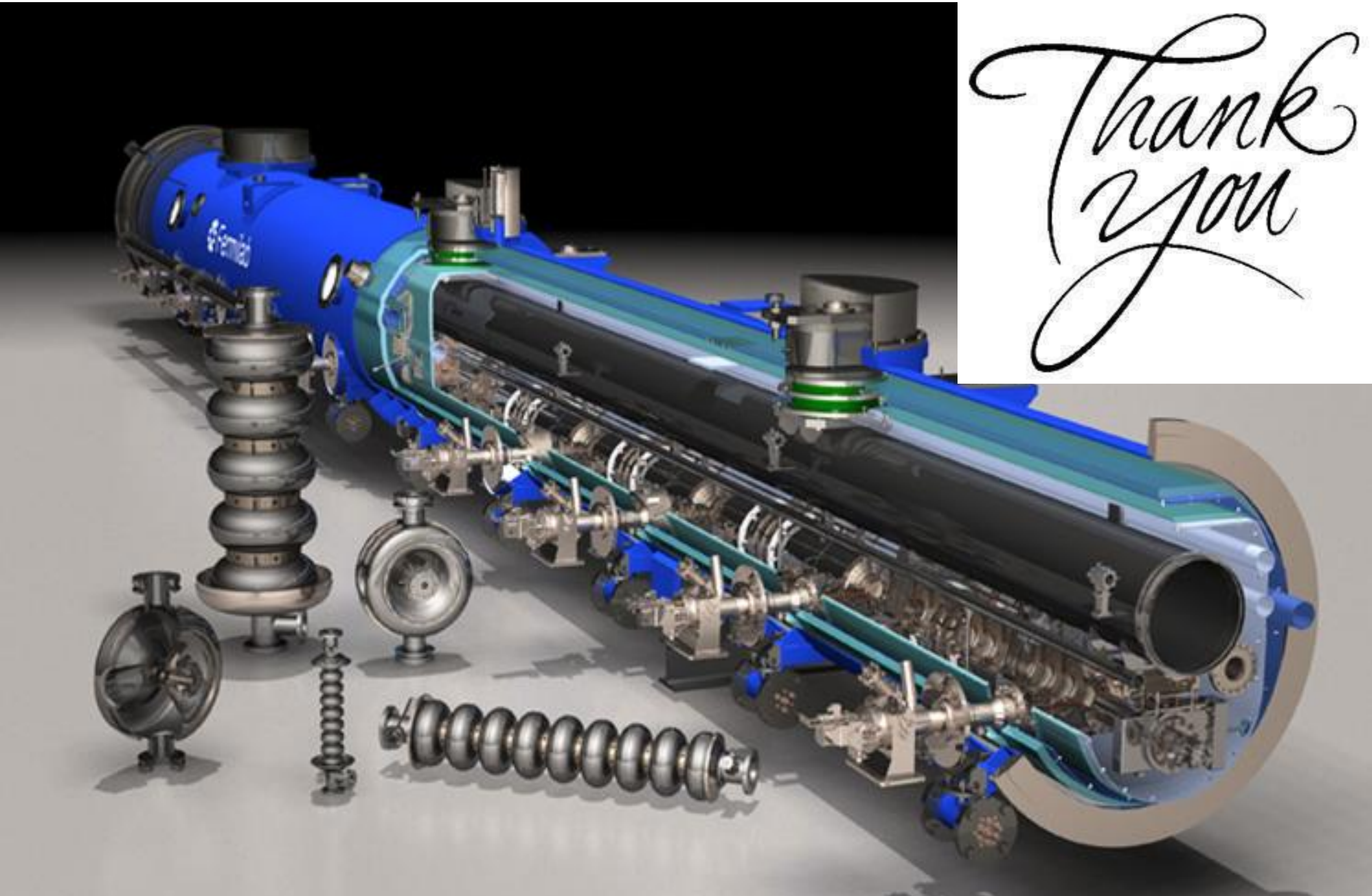
- Nuclear Physics
  - Ions (total > 1 GeV)
    - Low Energy: ATLAS, TRIUMF…
    - Nuclear Astrophysics FRIB (MSU), Spiral-2 (France)…
    - Coherent Electron Cooling – RHIC
    - Energy Boost - RHIC
  - Electrons (total 12 GeV)
    - CEBAF and CEBAF upgrade
- Light Sources
  - Storage Rings
    - **Most storage rings use NRF**
    - Storage Rings with SRF
      - CESR, CLS, Taiwan, Diamond, Soleil, ESRF, SwissLS,, ELLETRA, BNL-NSLS-2, Shangai, Pohang, Beijing
  - Quantum Beam,
    - Inverse Compton scattering X-rays source at KEK
  - FELs,
    - SRF- JlabFEL, JAERI, FLASH, EXFEL, XFELO
    - NRF- LCLS, SPRING-8, Compact XFELs – Korea, China, Turkey
- ERLs - SRF
  - Cornell, KEK, ALICE, BERLIN-PRO, LHeC, eRHIC, eLIC
- Neutron Sources
  - SNS, ESS

High Intensity Proton Linacs
Beam Power 1–5 MW

- Anticipated for Neutrons, Irradiation of Materials, Accelerator Transmutation of Nuclear Waste, Energy Production
- ESS
  - European Spallation Source, Sweden
- CSNS – China
- Proton Drivers
  - SPL (CERN)
- ADS
  - MYRRAH
    IFMIF
  - India
  - Japan
  - China

SUMMARY

- **Tremendous progress over last 30 years**
  - Gradients from 5 to 35 MV/m, NRF from 20 -> 100 MV/m
  - Many Applications to HEP
  - And other accelerators for NP, Nuclear Astrophysics, Light Sources, Neutron Sources, High Intensity Protons for ADS, Materials Irradiation (ITER), Energy Production
  - Substantial infrastructure development
- **Many paths are still open for**
  - Gradient and Q improvement
  - Lowering cost
  - Understanding performance to better performance
  - Exploring new materials, and new techniques
- **Strong synergy between HEP and non-HEP application**s
  - TESLA technology for ILC drove new applications for non-HEP
    - XFEL, LCLS-II, ERLs, SNS…
  - NP low beta development drives application for high intensity protons for nuetrinos and muons
- **Technology development takes a LONG time..10 – 20 years to come to fruition**
- **Large investments have established strong base in infrastructure and talent**
- **Make sure funding is healthy so paths do not dry up.**

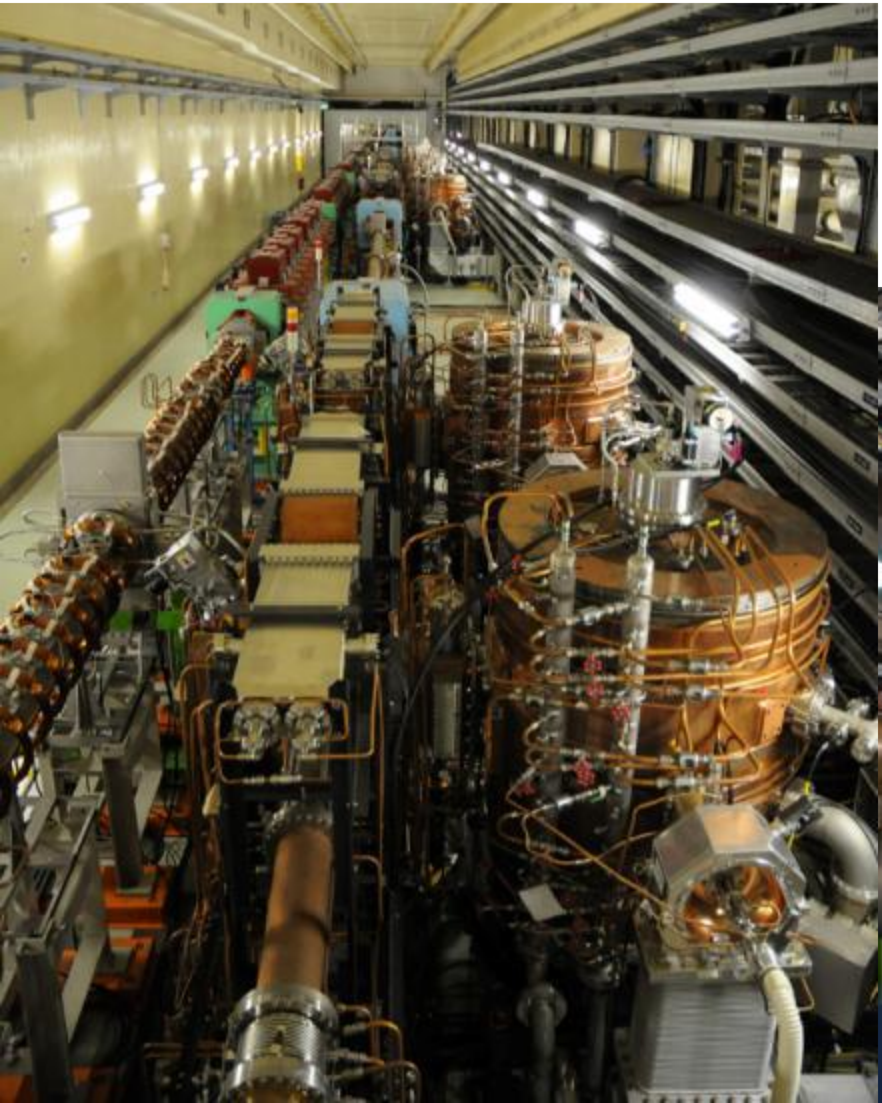


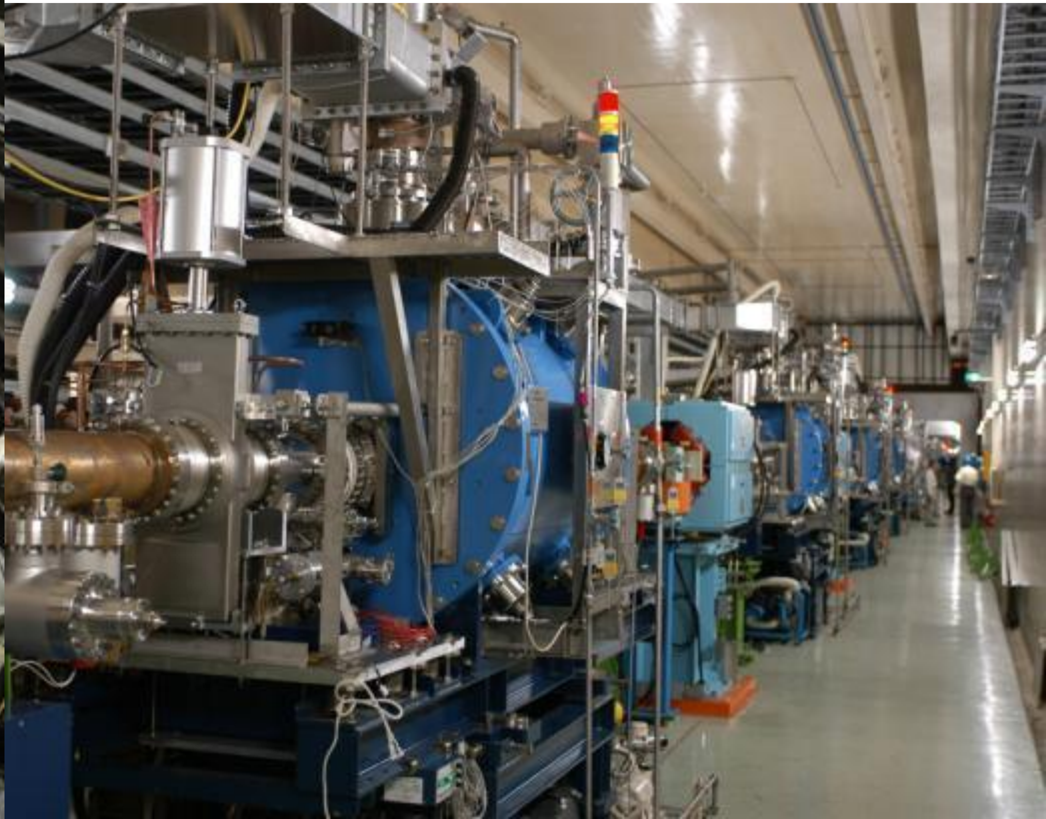
From Henderson, LCLS-II Meeting @SLAC, Oct.9-11, 2013

Back-Up Slides

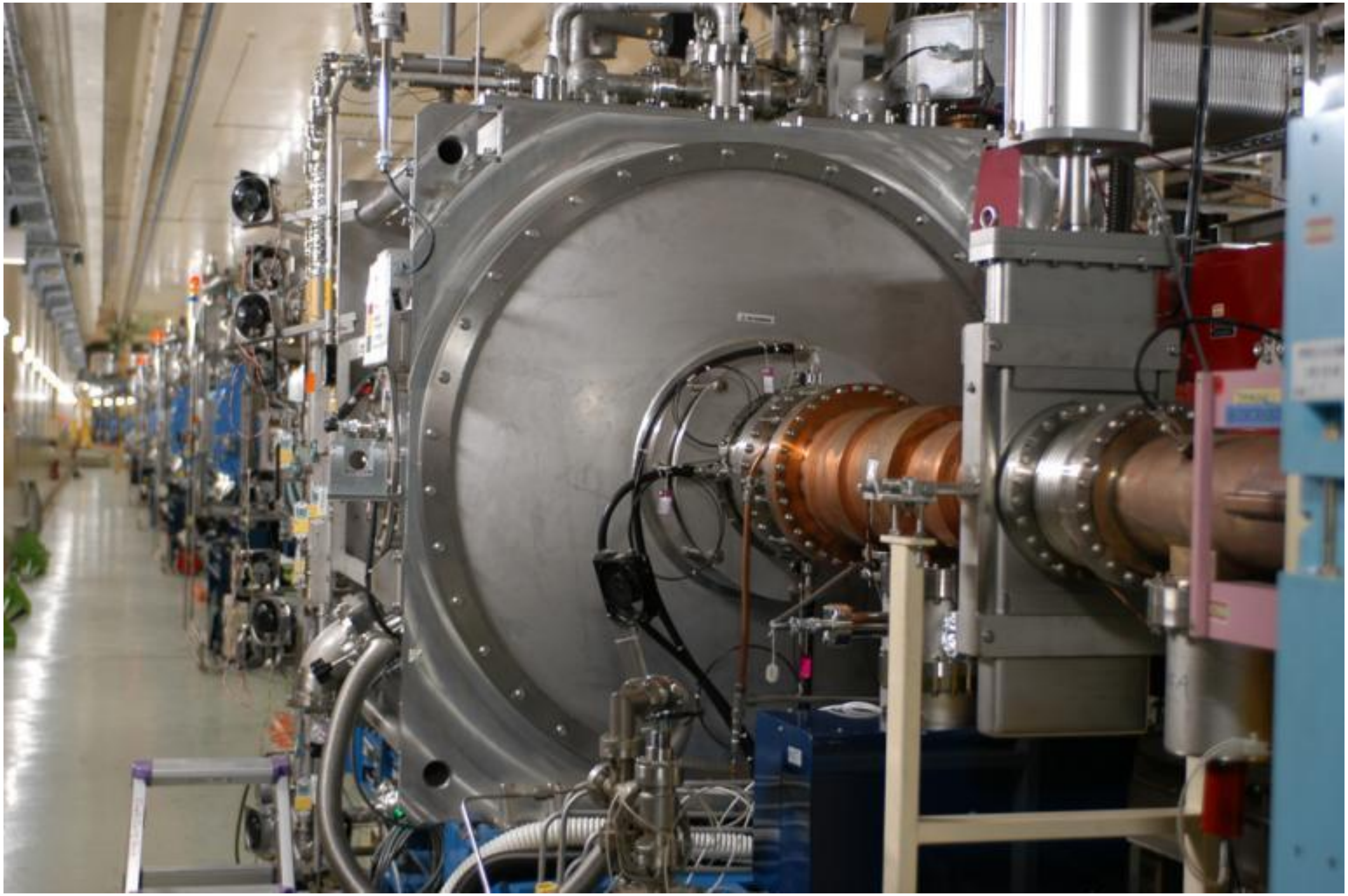
- Applications, Past, Under-Construction and Future
- New Materials Information

NRF and SRF for KEK-B





KEK-B SRF CRAB Cavity for High Luminosity



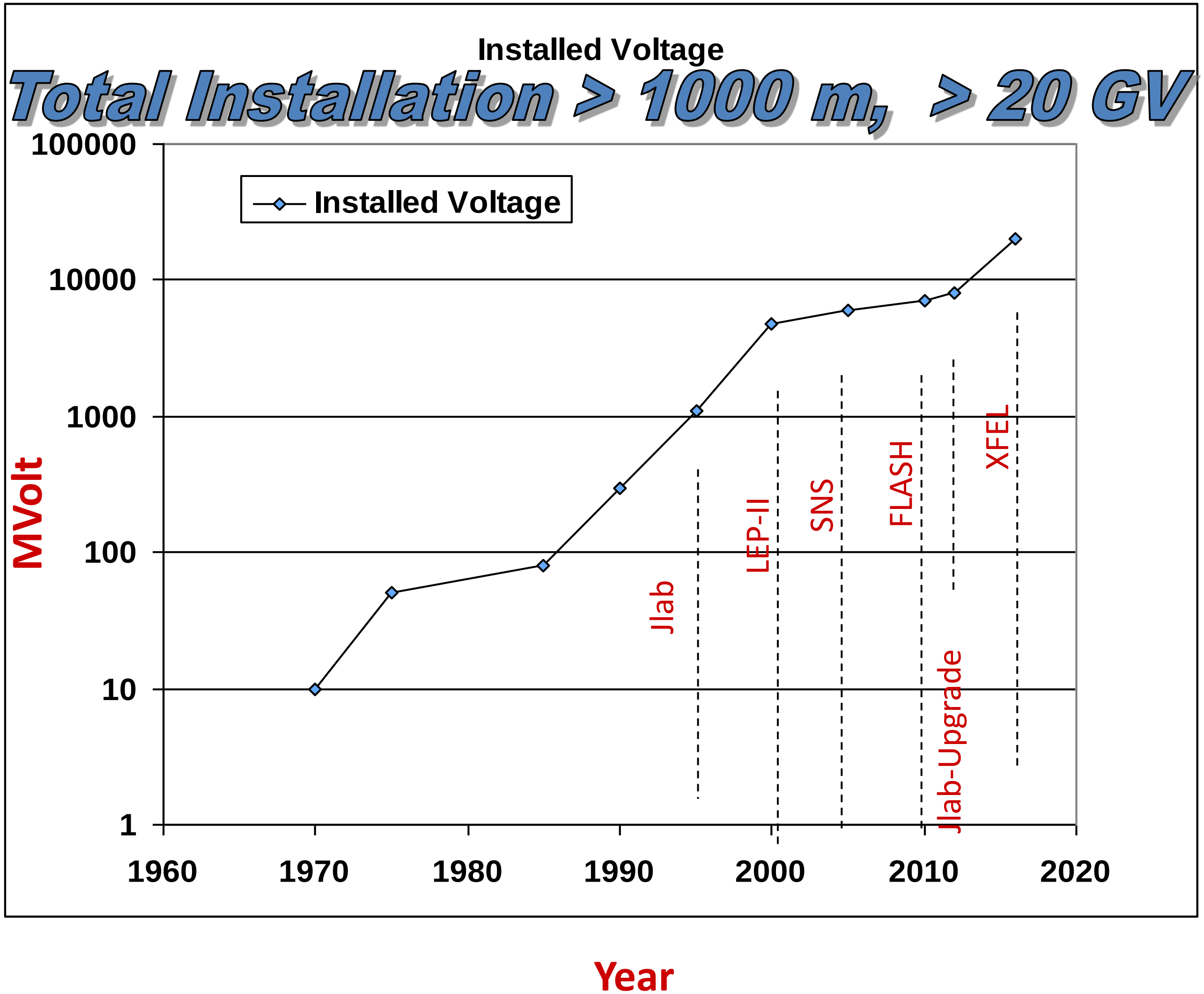
NRF for PEP-B

BR_043 8-19-97

50 Yr-Growth of Installed SRF Voltage

for v/c=1 Accelerators

A "Livingston Plot" for RF Superconductivity

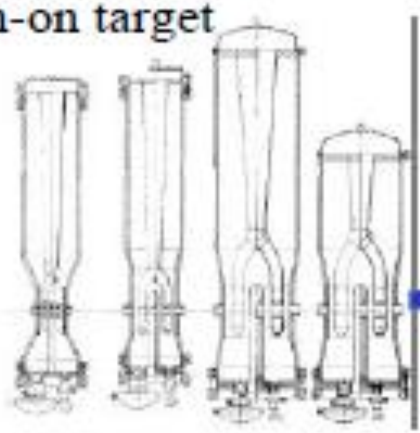


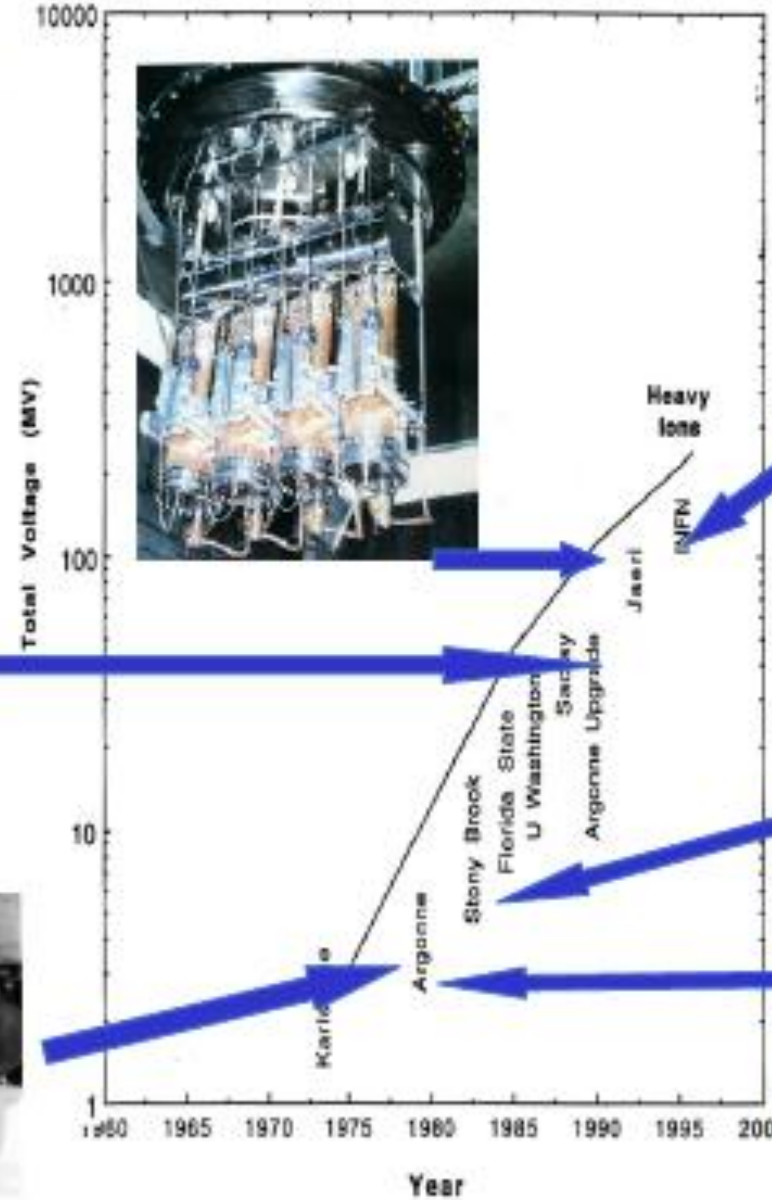
NUCLEAR SCIENCE WITH SUPERCONDUCTING HEAVY-ION ACCELERATORS

10 Facilities World Wide

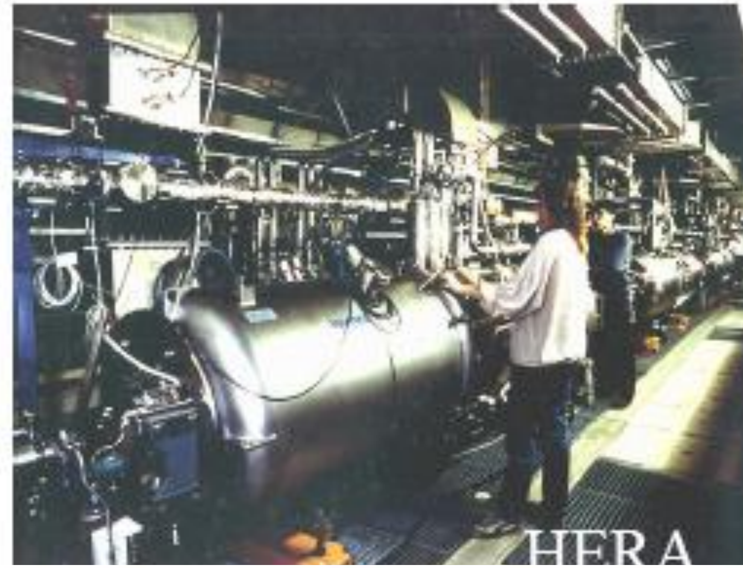
> 270 resonators

> 120,000 hours of beam-on target

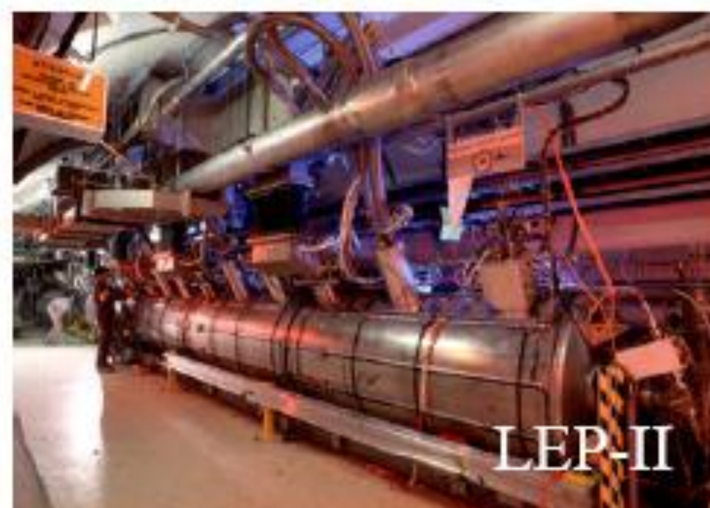




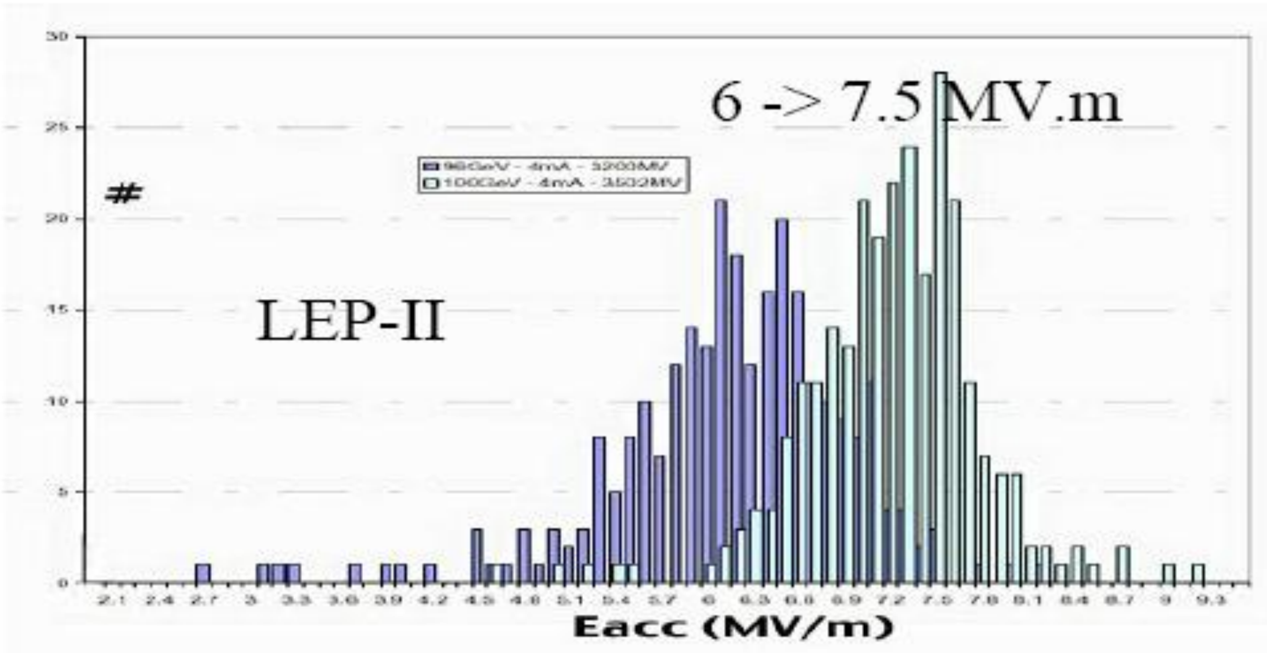
SRF Installations at HEP e- Accelerators From 30 GeV to 108 GeV



288 Cavities



LEP-II SRF System and Performance

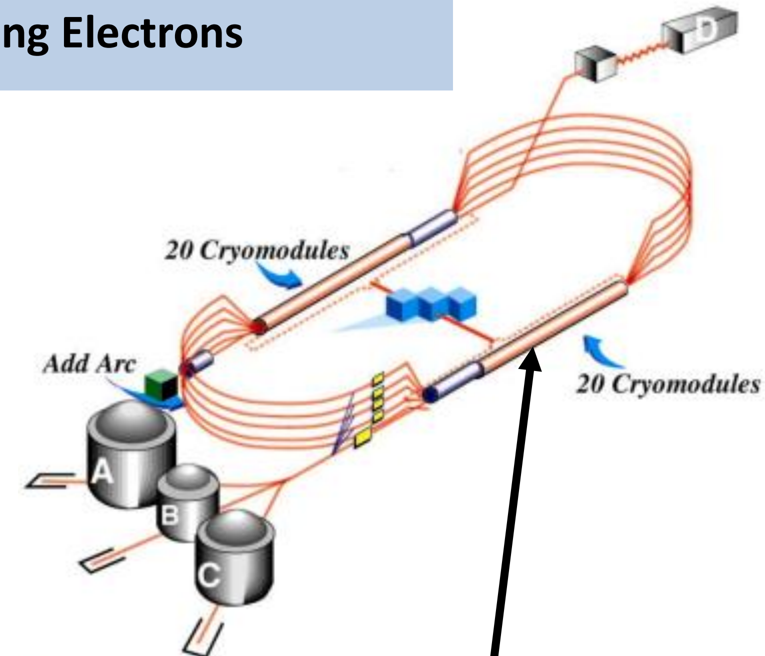


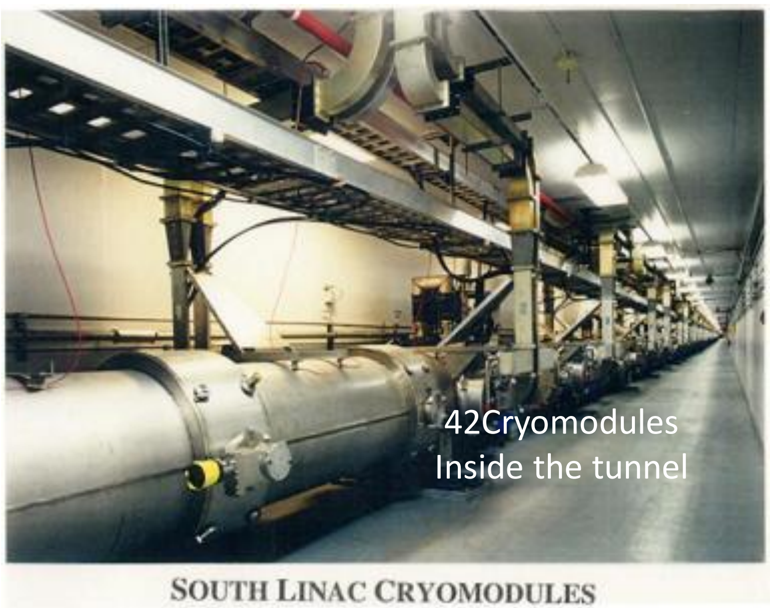
Operating Gradients

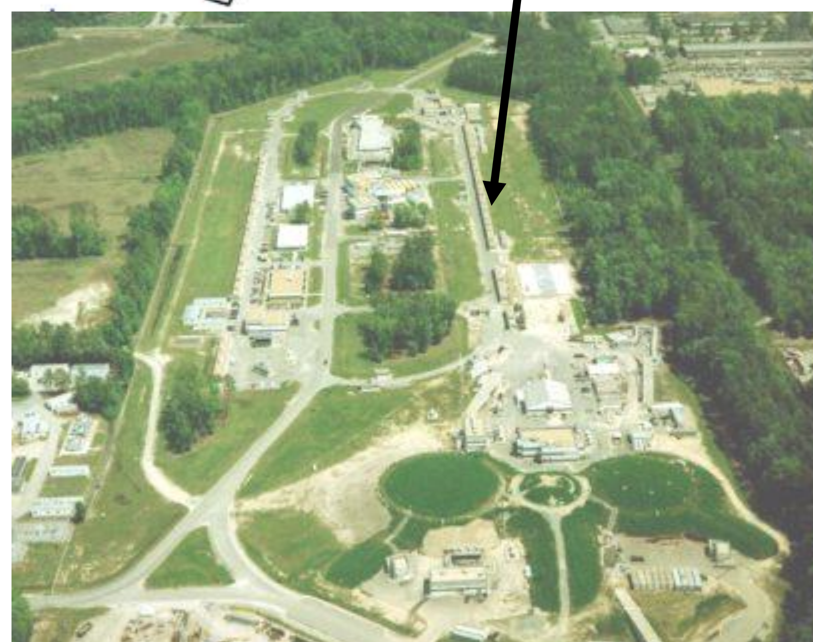
LEP-II , 288 Nb-Cu cavities,

6 -12 GeV Re-circulating Linear Accelerator for Nuclear Physics Using Electrons

7 MV/m

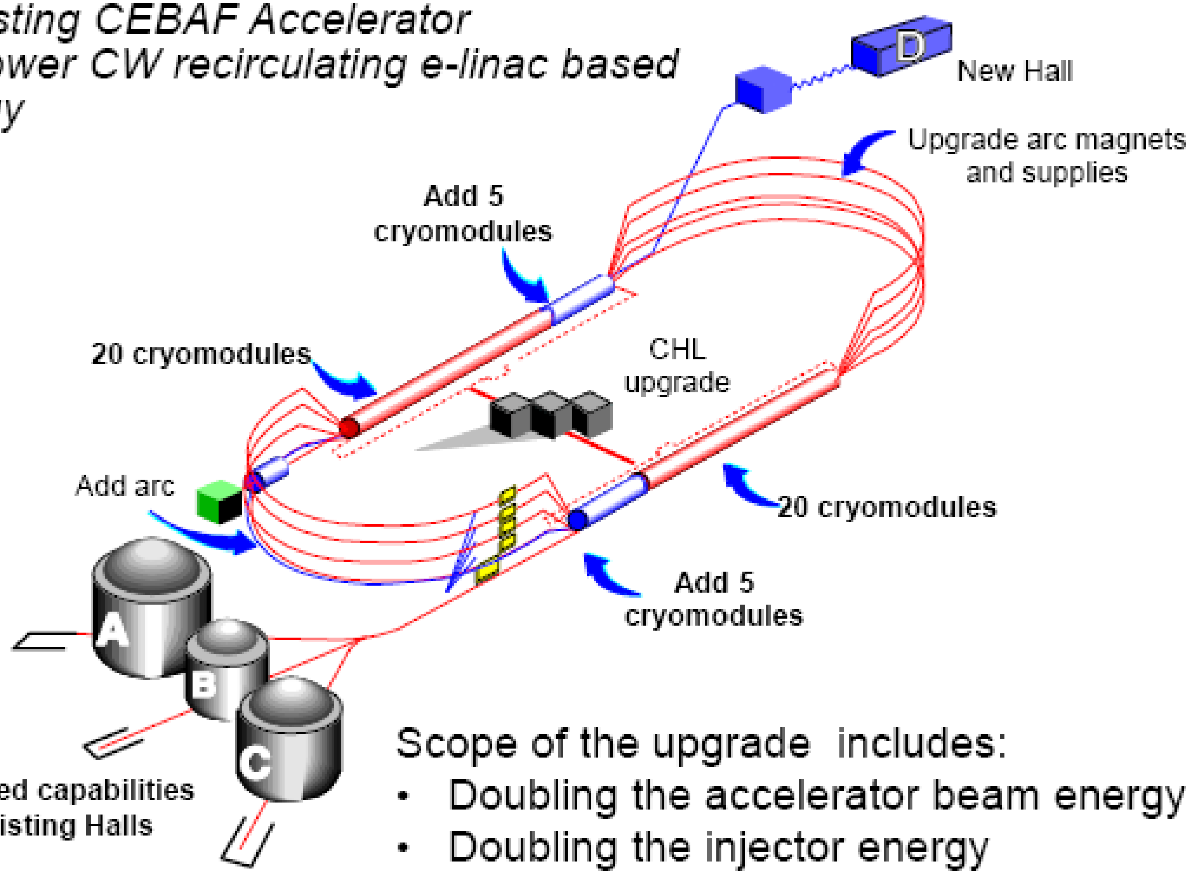






12 GeV Upgrade

Built upon the existing CEBAF Accelerator
First large high-power CW recirculating e-linac based on SRF technology



Scope of the upgrade includes:

- Doubling the accelerator beam energy
- Doubling the injector energy
- New Hall and beam-lines
- Upgrades to existing Experimental Halls

SRF for LHC (Protons)

- 16 Cavities capable of 10 MV/m

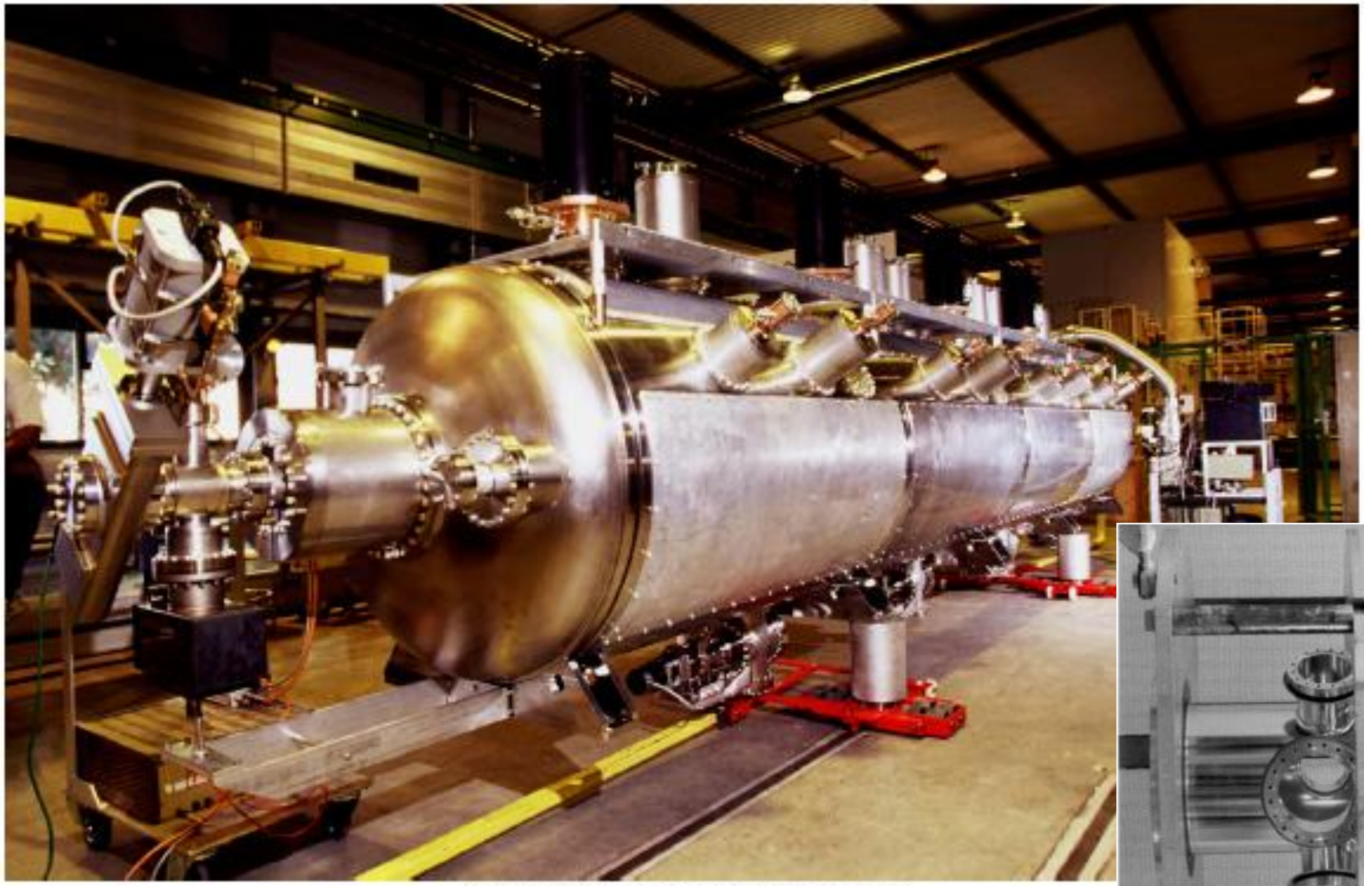
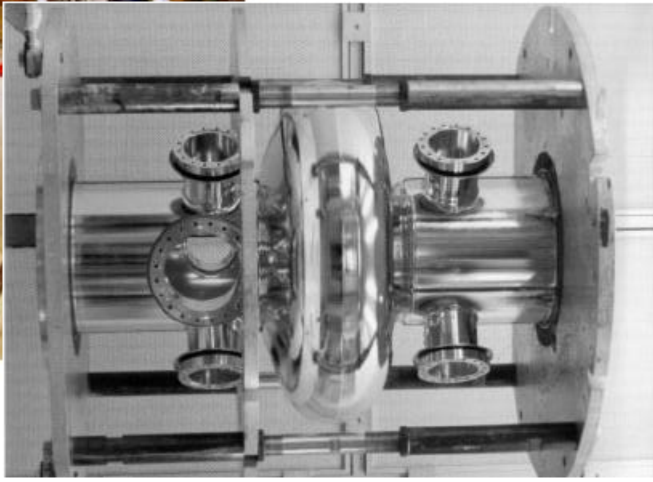


Figure 1 One complete RF module

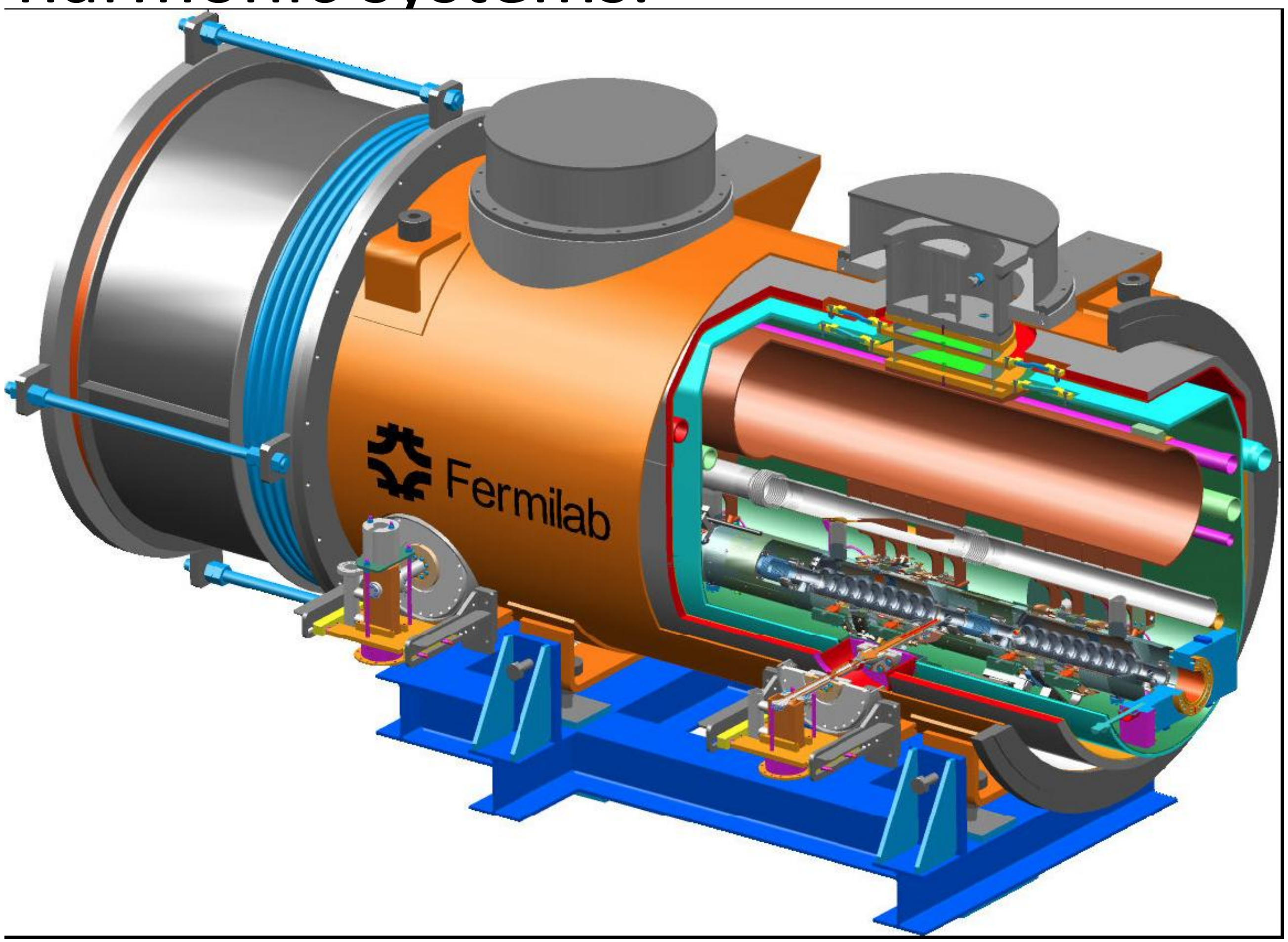


FLASH/EUR XFEL Cavity Performance

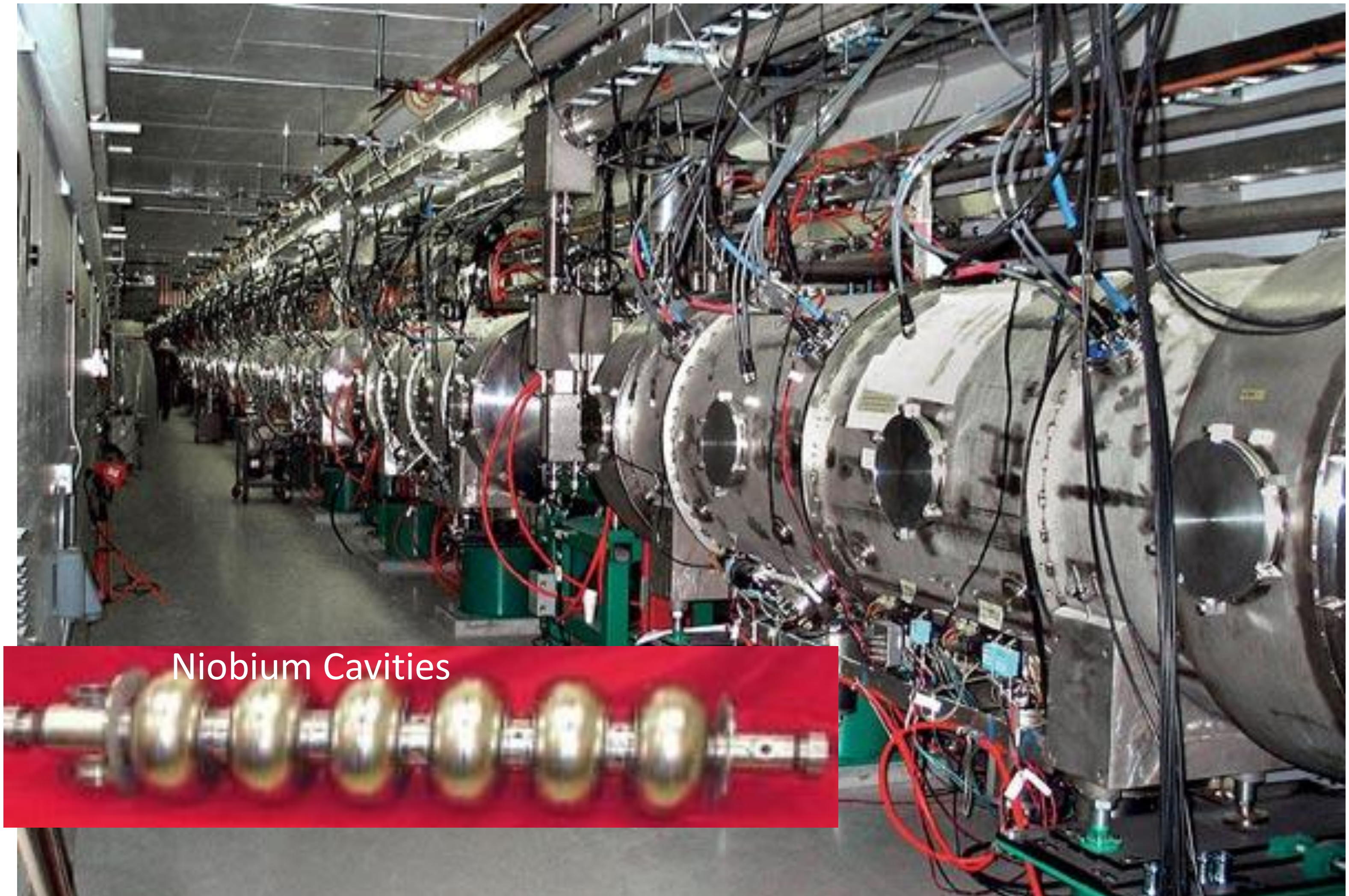
Figure 1: Layout of the FLASH linac including the experimental hall (not to scale).

3rd Harmonic System for FLASH Provided by FNAL

- SRF harmonic systems.

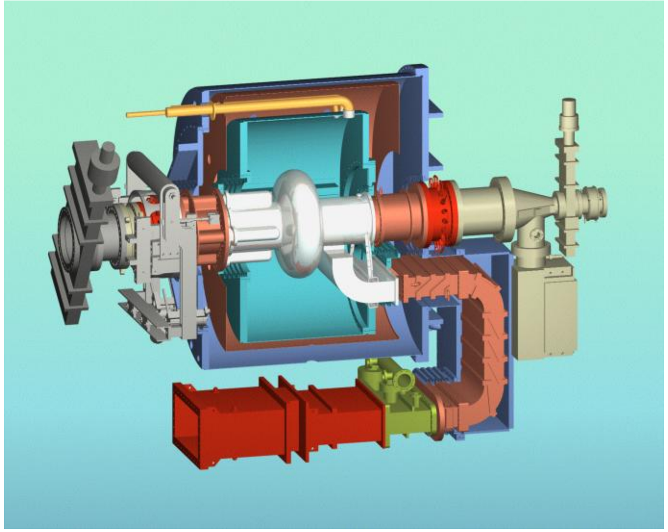


SNS (1 GeV protons, > 1 MW)
Low Energy Neutrons by Spallation In A Target



SRF in Electron Storage Rings for X-Rays

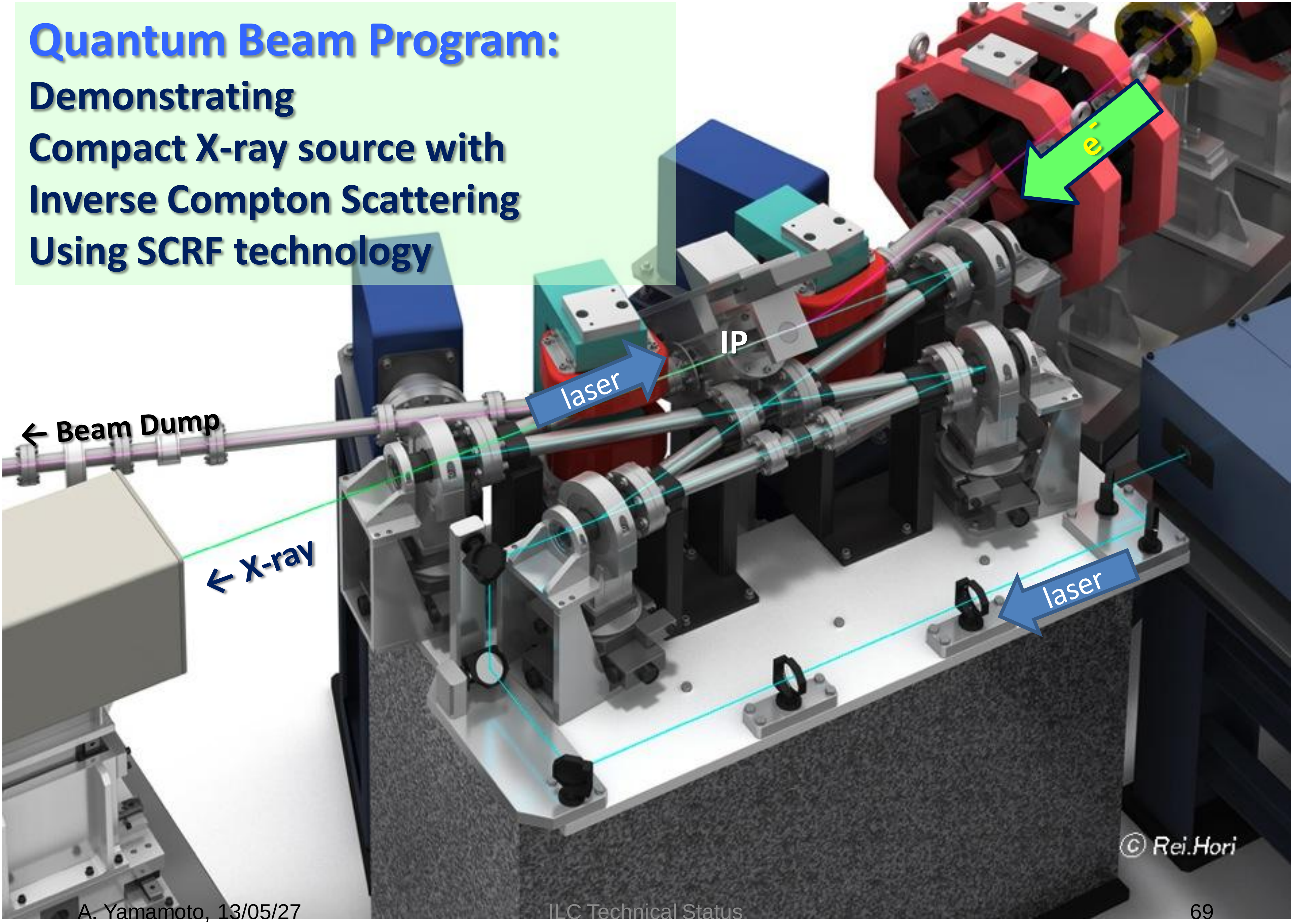
- CESR/CHESS (USA)
- Canadian Light Source
- Taiwan Light Source
- DIAMOND Light Source (UK)
- Shanghai Light Source



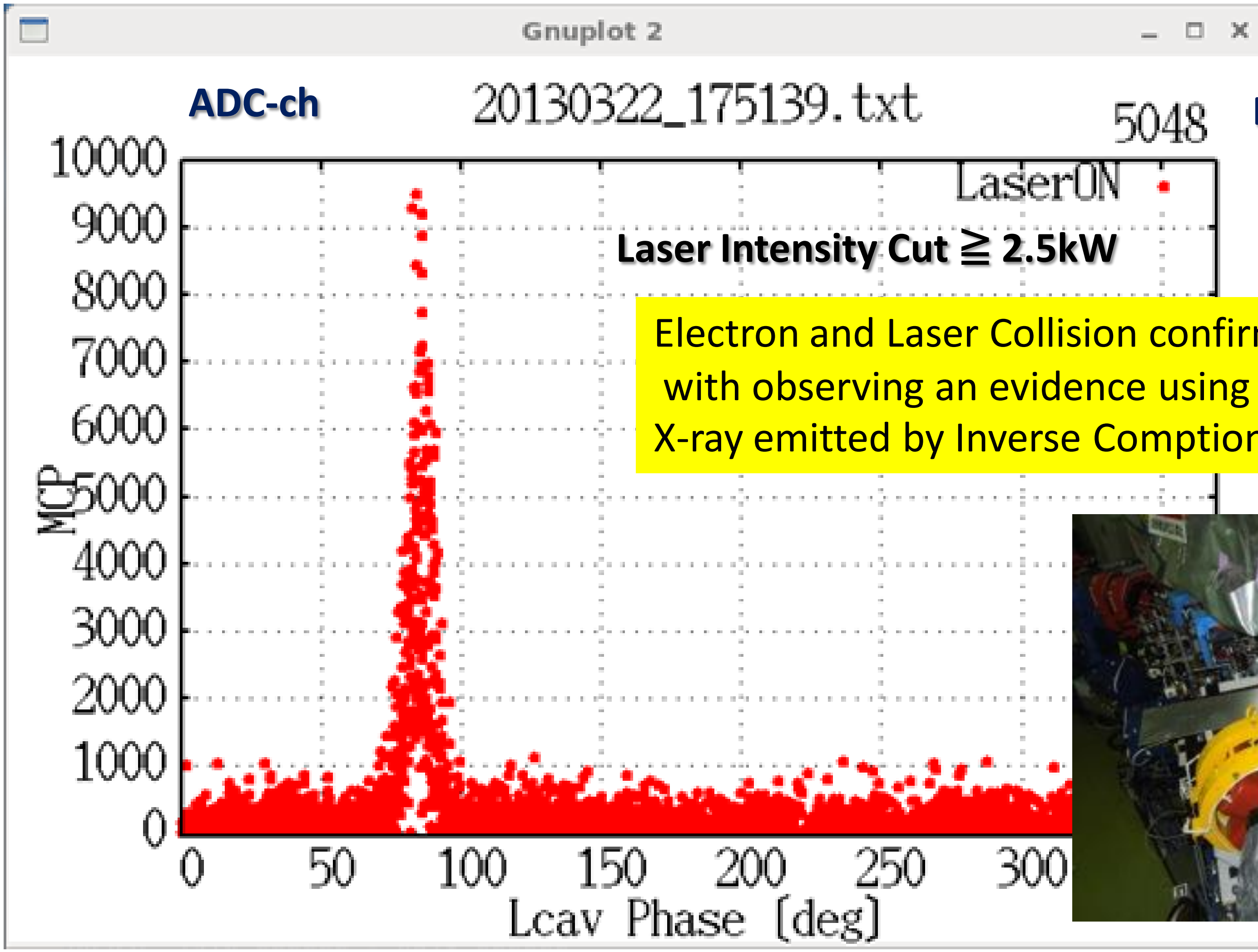
- SOLEIL (France)
- Beijing Tau-Charm Factory
- Swiss Light Source
  - For life time increase
- ELETTRA (Italy)
  - For life time increase
- NSLS2 BNL (USA) *(under construction)*

Quantum Beam Program:

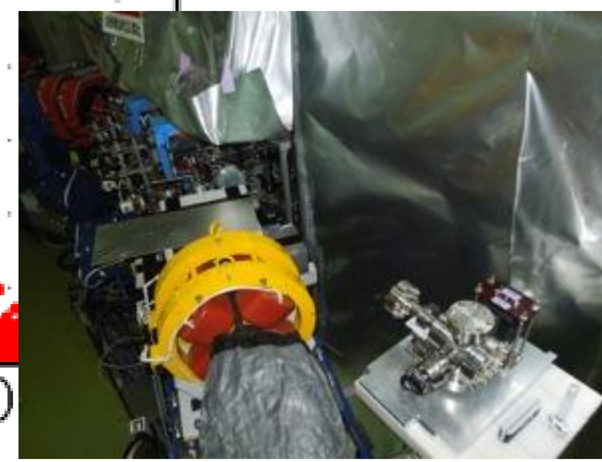
Demonstrating
Compact X-ray source with
Inverse Compton Scattering
Using SCRF technology



X-ray observed (w/ MCP, 22nd Mar.2013)



Electron and Laser Collision confirmed
with observing an evidence using MCP :
X-ray emitted by Inverse Comption scattering

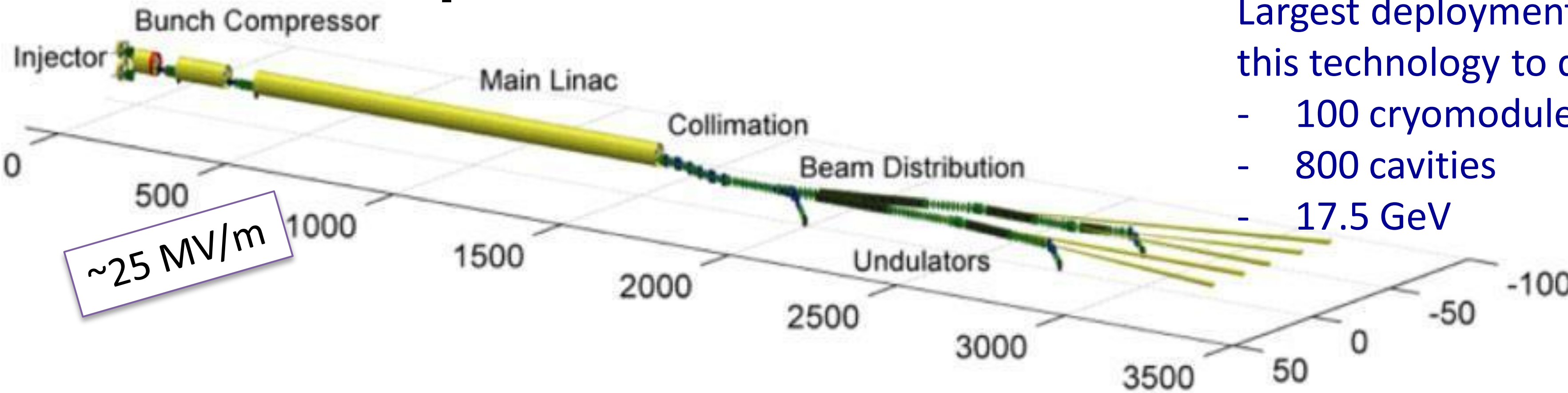


XFEL (18 GeV) Under Construction

The biggest SRF application to date

800 cavities , 24 MV/m, 18 GeV

European XFEL @ DESY



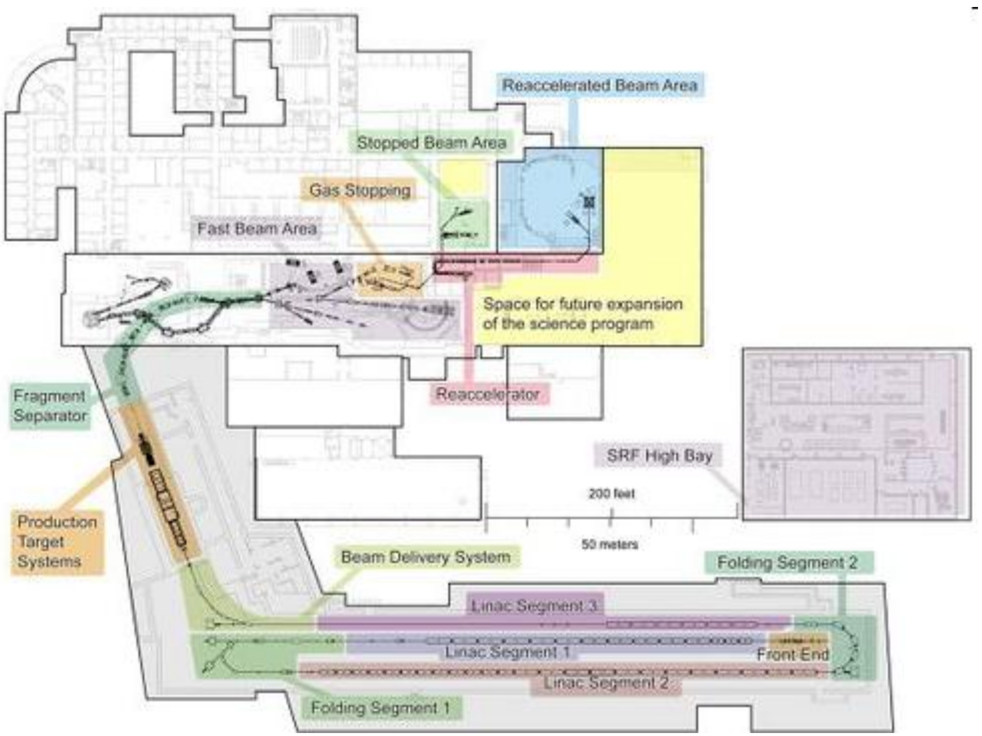
Largest deployment of this technology to date
- 100 cryomodules
- 800 cavities
- 17.5 GeV

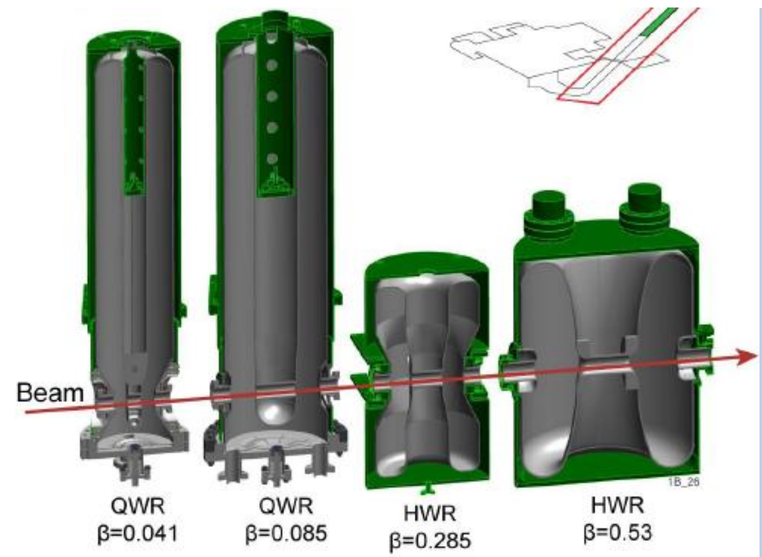
Institute	Component Task
CEA Saclay / IRFU, France	Cavity string and module assembly; cold beam position monitors
CNRS / LAL Orsay, France	RF main input coupler incl. RF conditioning
DESY, Germany	Cavities & cryostats; contributions to string & module assembly; coupler interlock; frequency tuner; cold-vacuum system; integration of superconducting magnets; cold beam-position monitors
INFN Milano, Italy	Cavities & cryostats
Soltan Inst., Poland	Higher-order-mode coupler & absorber
CIEMAT, Spain	Superconducting magnets
IFJ PAN Cracow, Poland	RF cavity and cryomodule testing
BINP, Russia	Cold vacuum components

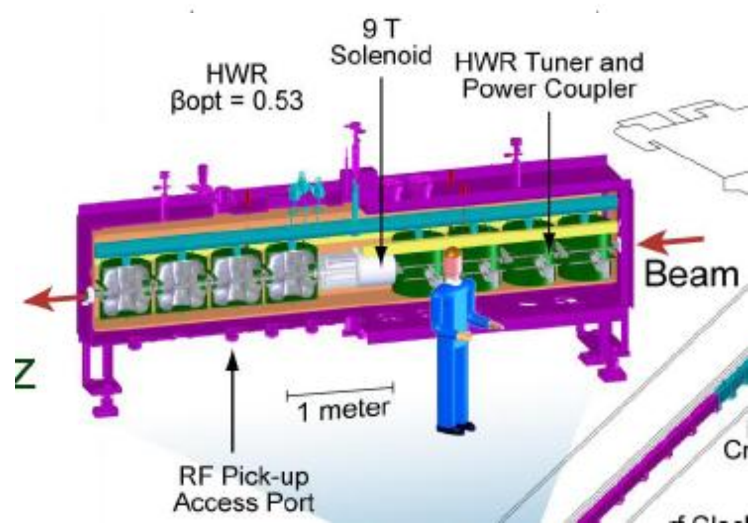
The ultimate 'integrated systems test' for ILC. Commissioning with beam 2nd half 2015

FRIB, Facility for Rare Isotope Beams Under Construction at MSU

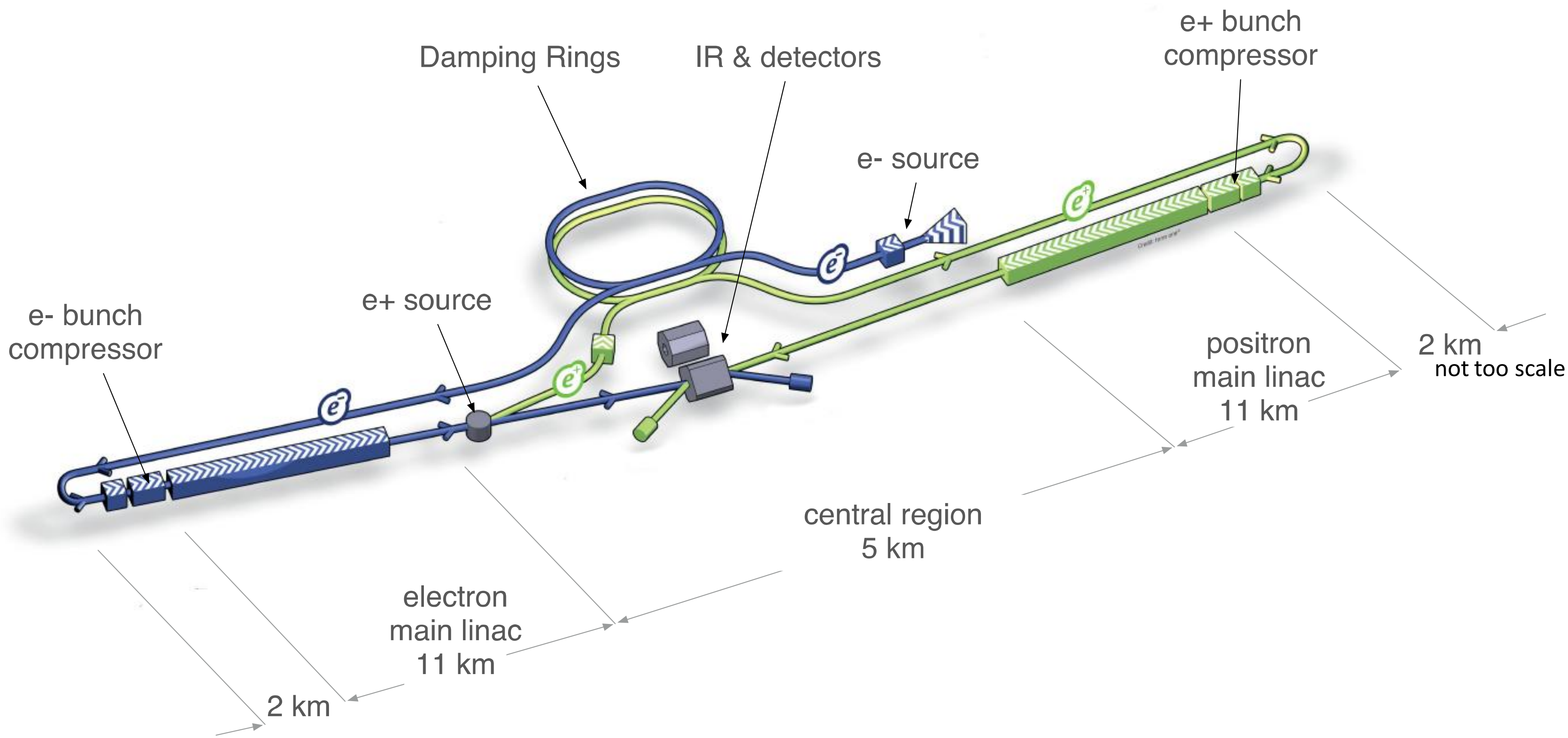
- 336 Resonators to be built
  - QWR and HWR
  - Schematic of FRIB



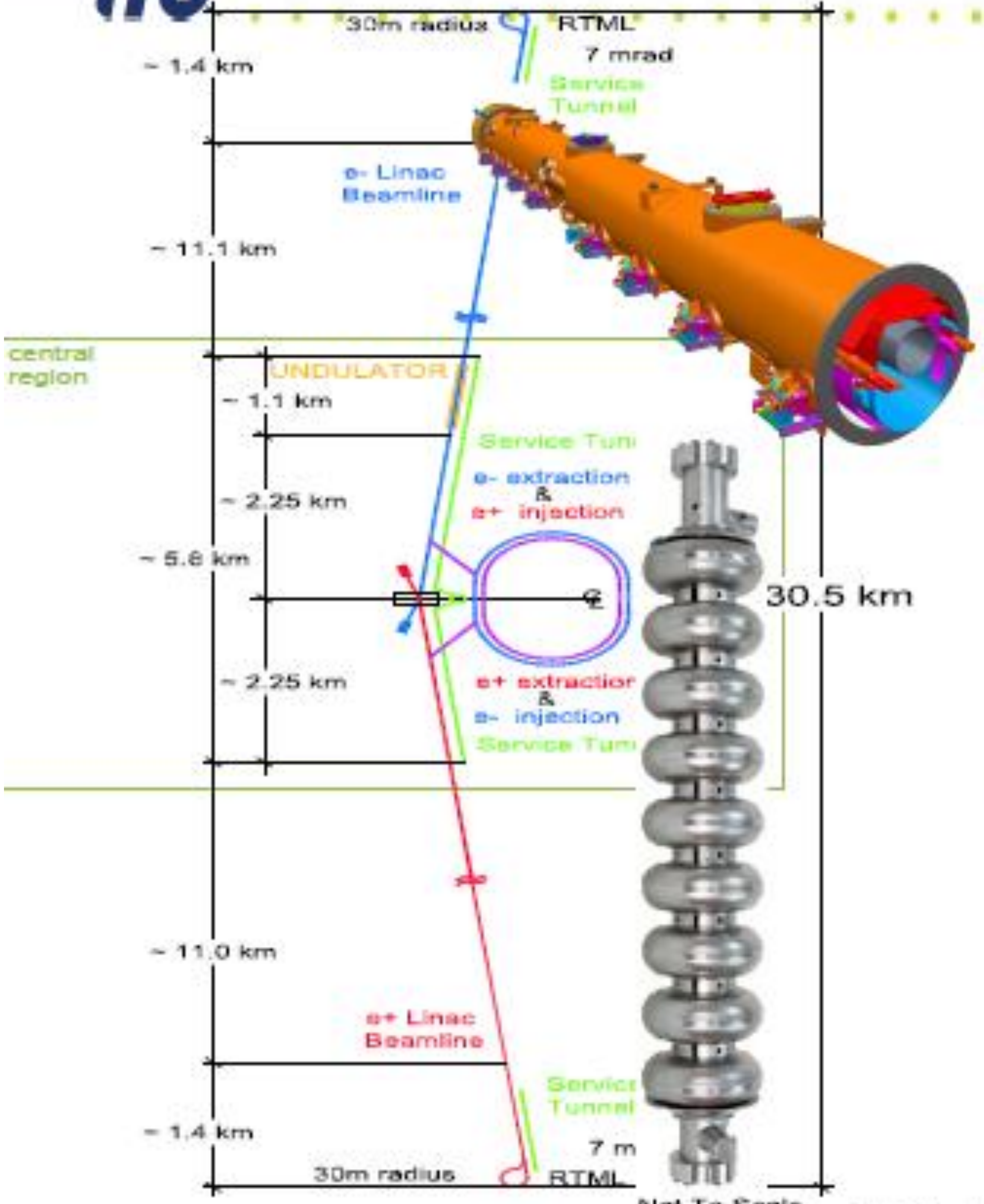




ILC


Damping Rings
IR & detectors
e+ bunch
compressor
e- source
e- bunch
compressor
e+ source
positron
main linac
11 km
2 km
not too scale
central region
5 km
electron
main linac
11 km
2 km

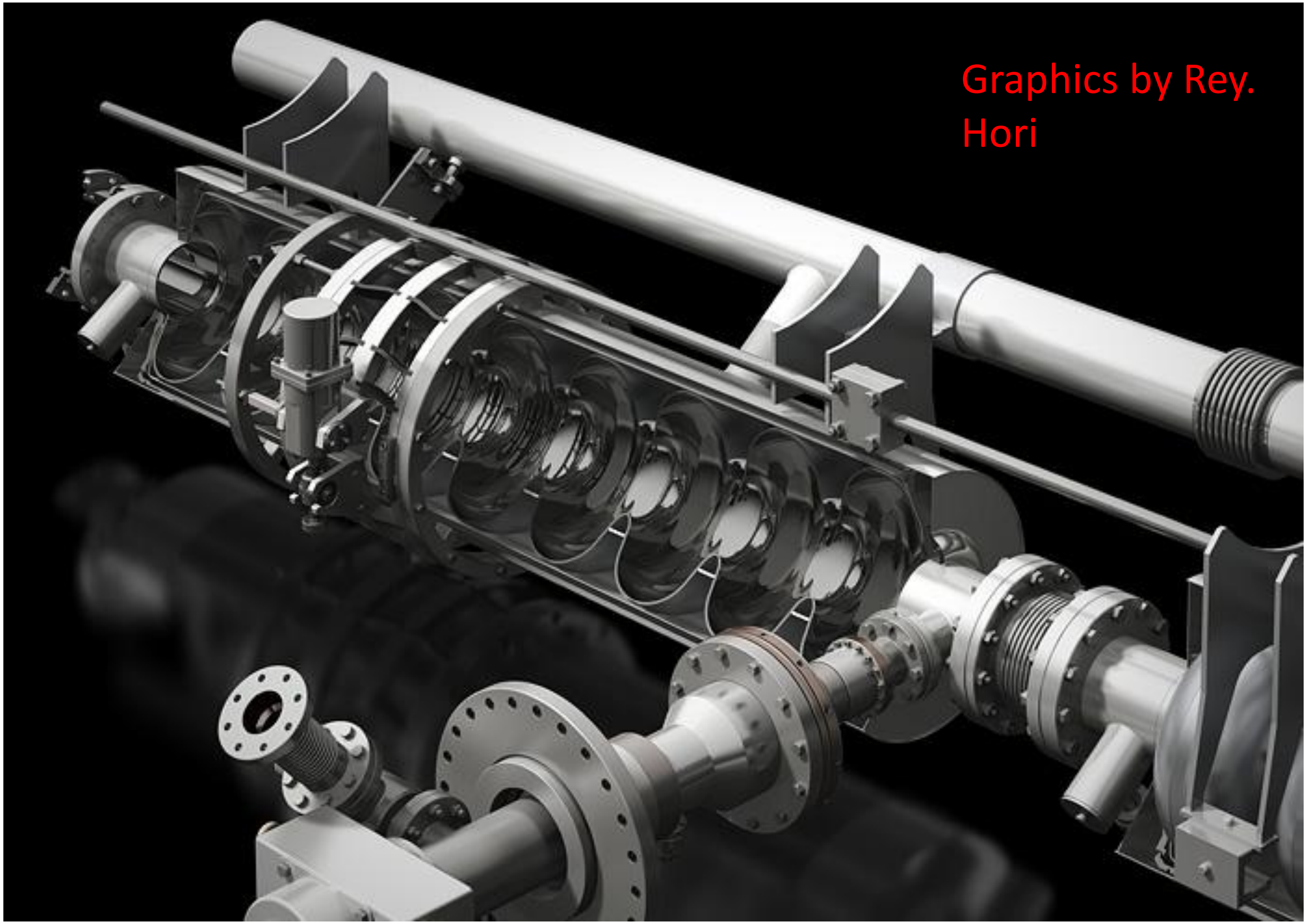
ILC in a Nutshell



- 200-500 GeV E_{cm} e^+e^- collider $L \sim 2\times10^{34}\ cm^{-2}s^{-1}$
  - upgrade: ~1 TeV
- SCRF Technology
  - 1.3GHz SCRF with 31.5 MV/m
  - 17,000 cavities
  - 1,700 cryomodules
  - 2×11 km linacs
- Developed as a truly global collaboration
  - **G**lobal **D**esign **E**ffort – **GDE**
  - ~130 institutes
  - http://www.linearcollider.org/ILC

ILC Cavity Assembly

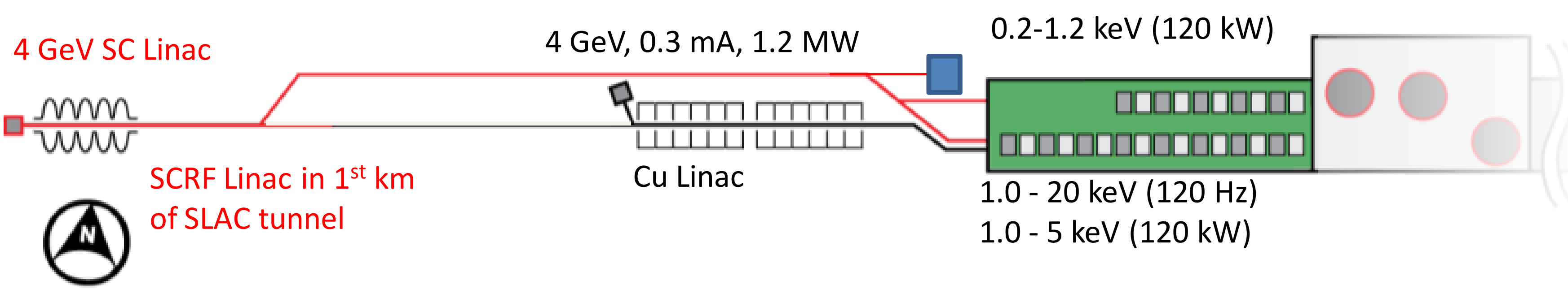
(Helium tank, mag. shield, tuner and coupler)



LCLS-II (SLAC) Based on ILC Technology – But 16 MV/m and High Q

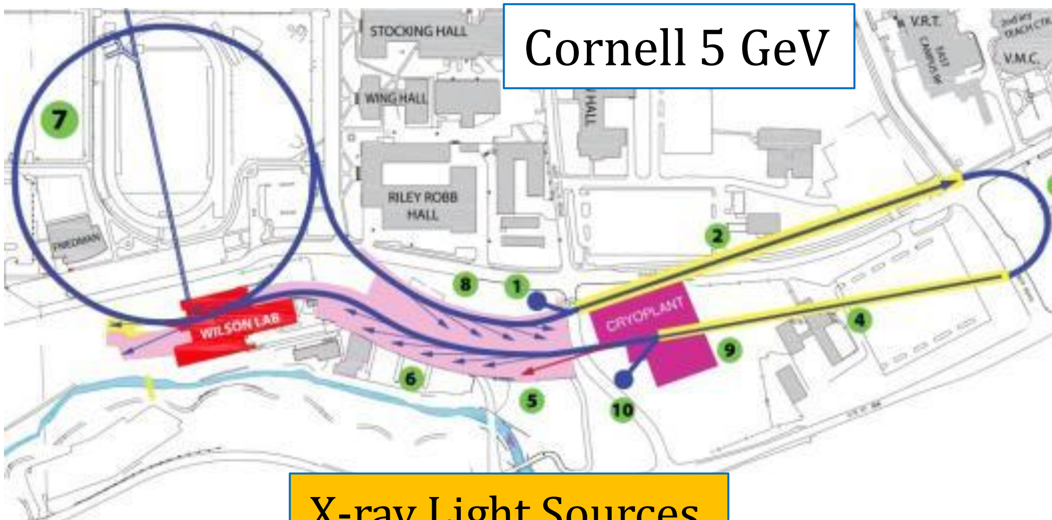
- Two sources: high rate SCRF linac
- and 120 Hz Cu LCLS-I linac

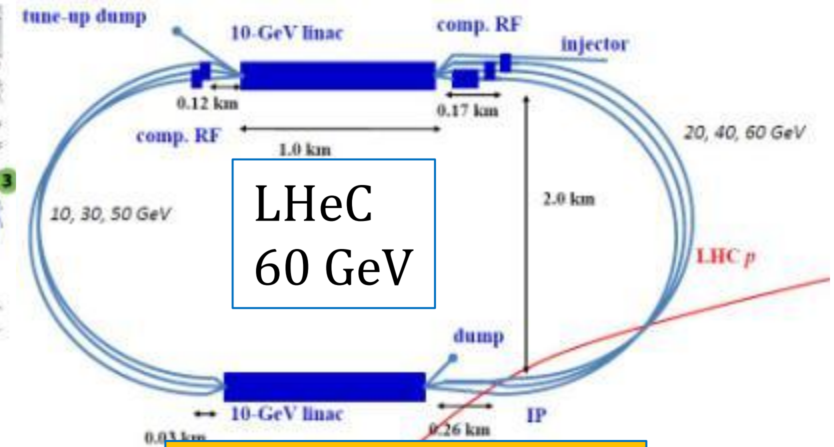
Undulator	SC Linac (up to 1 MHz)	Cu Linac (up to 120Hz)
North	0.25-1.2 keV	
South	1.0-5.0 keV	up to 20 keV higher peak power pulses

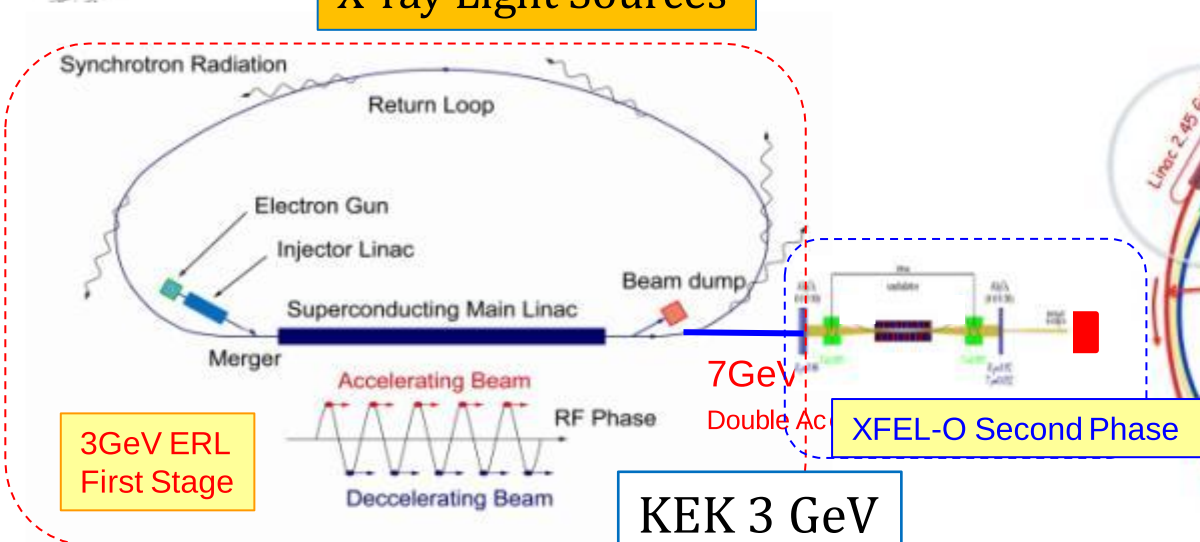


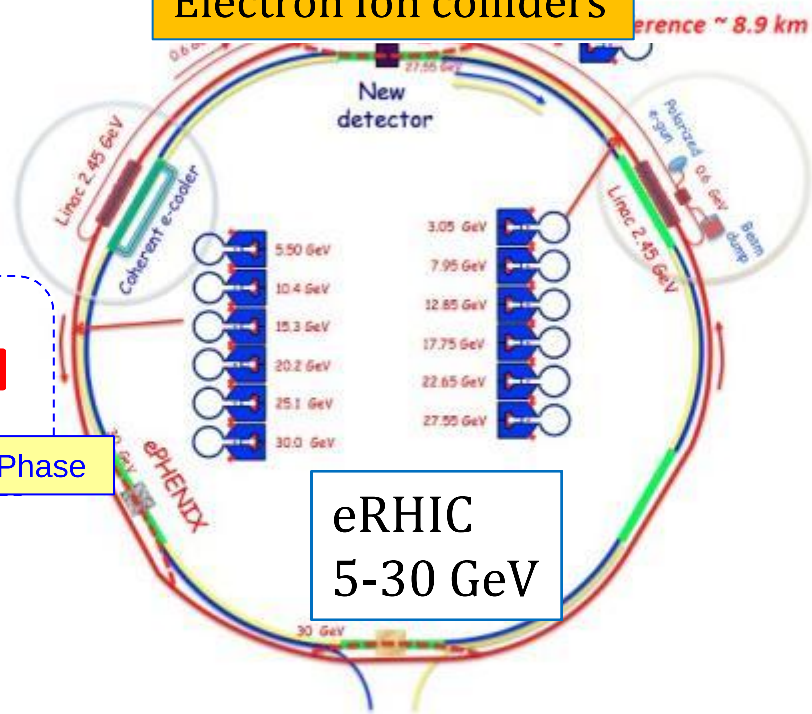
ERLs

“Big” Machines

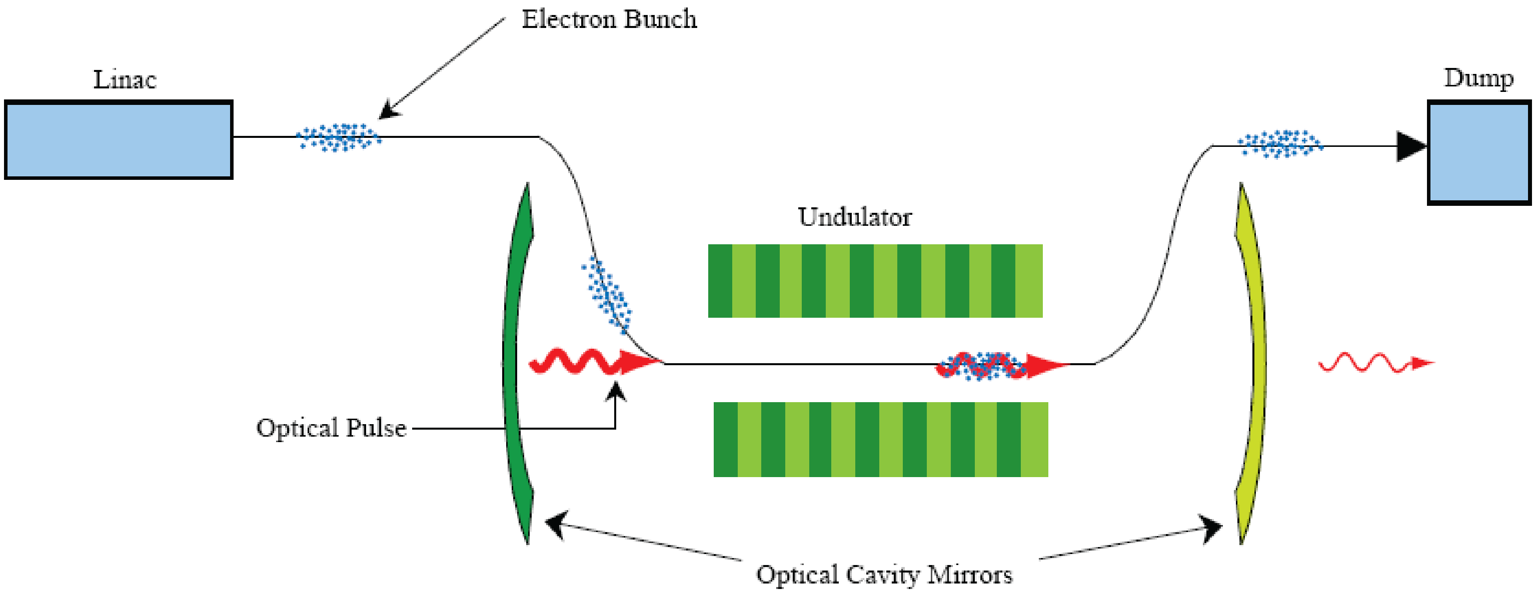








X-Ray FEL-Oscillator (Argonne)



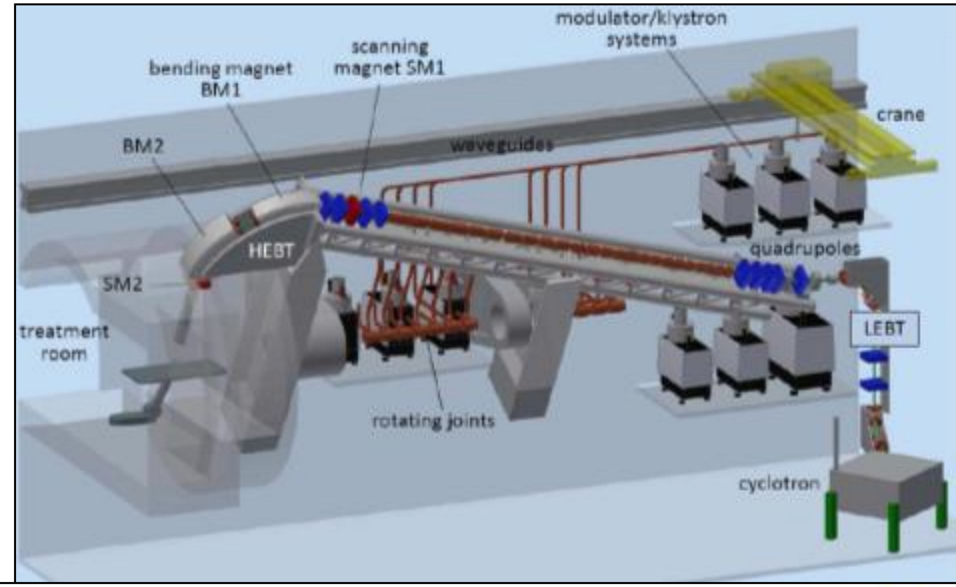
- A low-gain device with high Q optical cavity
- Optical pulse formed over many electron passes
- Difficult for x-rays
  - Electron beam qualities
  - High-reflectivity normal incidence mirror

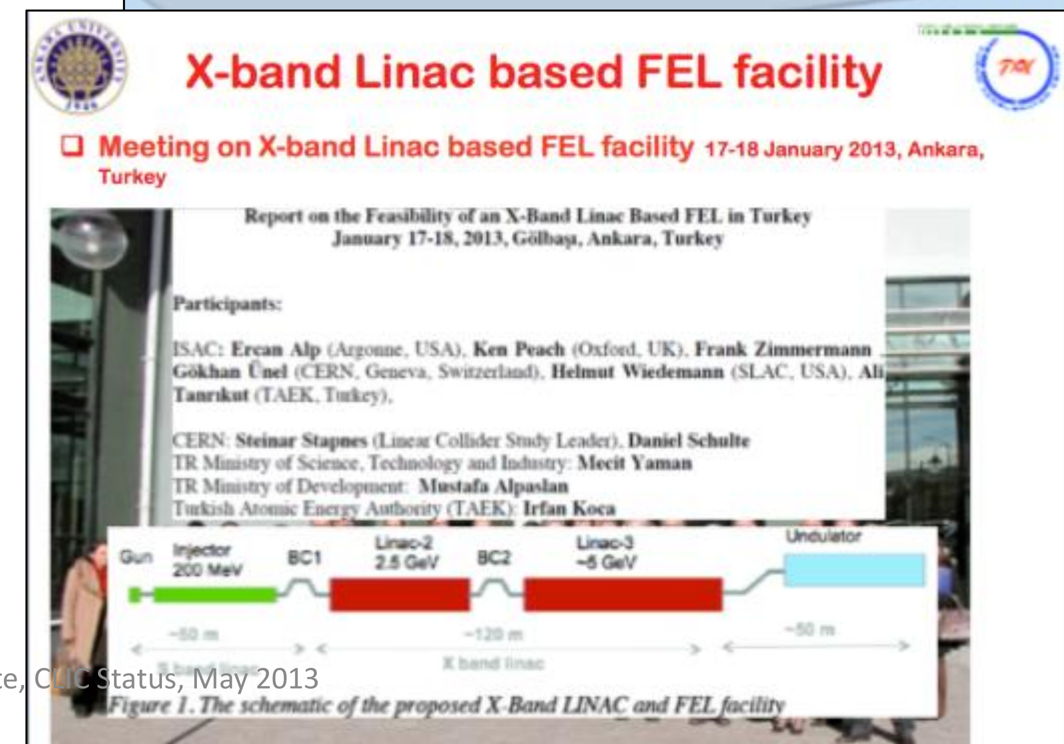
X-Band Revival

- The 15 year, ~ 100 M$ development of X-band technology for a linear collider produced a suite of robust, high power components.
- With the low bunch charge being considered for future XFELs, X-band technology affords a low cost, compact means of generating multi-GeV, low emittance bunches.
  - Gradients of 70-100 MV/m possible vs ~ 25 MV/m at S-Band and ~ 35 MV/m at C-Band
- The number of XFELs is likely to continue to grow (e.g., normal conducting linacs being considered in Korea and China).
- To expand X-band use, need to have components industrialized and a small demonstration accelerator built, such as the 150 MeV C-band linac at Spring-8 in Japan where they have done light source studies.

Links to Other N
NRF Applications

Introduction	*Steinar STAPNES*	
Council Chamber, CERN		08:30 - 08:40
CLIC activities/plans	*Walter WUENSCH*	
Council Chamber, CERN		08:40 - 08:55
PSI activities/plans	*Dr. Ricardo ZENNARO*	
Council Chamber, CERN		08:55 - 09:10
Trieste/Fermi plans	*Dr. Gerardo D'AURIA*	
Council Chamber, CERN		09:10 - 09:25
TERA activities/plans	*Ugo AMALDI*	
Council Chamber, CERN		09:25 - 09:40
Shanghai activities/plans	*Dr. Qiang GU et al.*	
Council Chamber, CERN		09:40 - 09:55
Tsinghua	*Jiaru SHI*	
Council Chamber, CERN		09:55 - 10:10
ALBA	*Mr. Francis PéREZ*	
Council Chamber, CERN		10:10 - 10:25
Coffee		
Council Chamber, CERN		10:25 - 10:45
SLAC activities/plans	*Prof. Sami TANTAWI*	
Council Chamber, CERN		10:45 - 11:00
Ankara/Turkish activities/plans	*Avni AKSOY*	
Council Chamber, CERN		11:00 - 11:15
MAX-lab	*Mrs. Francesca CURBIS*	
Council Chamber, CERN		11:15 - 11:30
Argonne activities/plans	*Dr. Wei GAI*	
Council Chamber, CERN		11:30 - 11:45
Short discussion		
Council Chamber, CERN		11:45 - 12:00

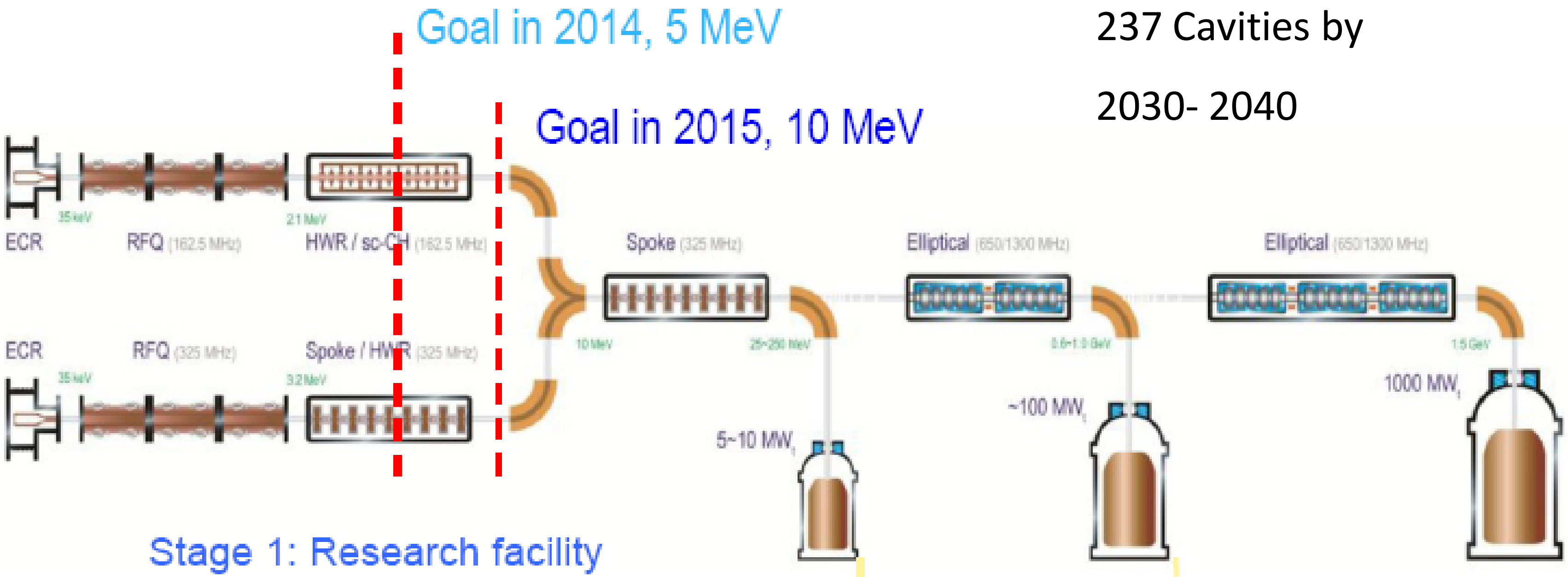




Roadmap of ADS Project in China

237 Cavities by

2030- 2040



Stage 1: Research facility

(~10 MWt, ~2023)

key technology R&D

Stage 2: Exp. facility

(~100 MW$_t$, ~2030)

Stage 3: Demo facility

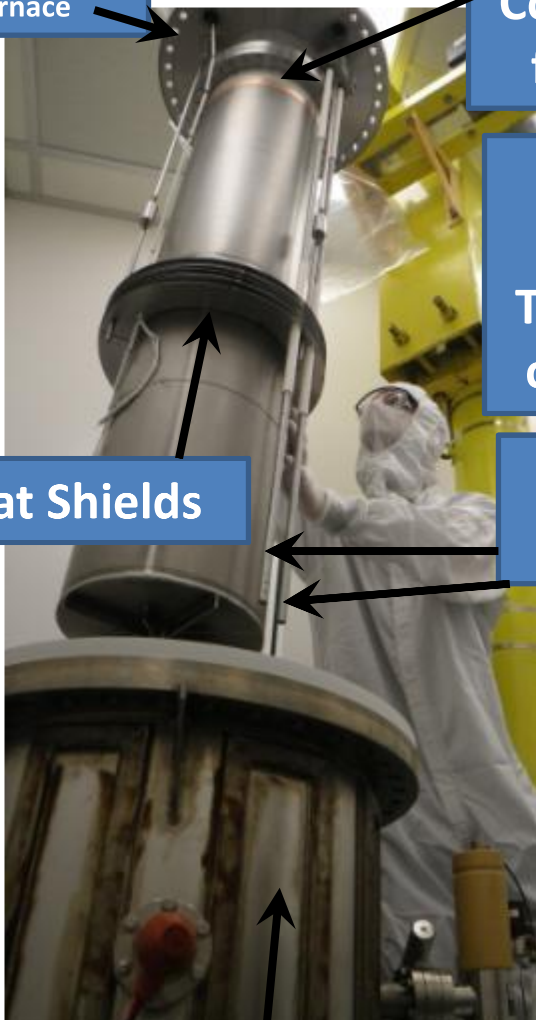
(~1000 MW$_t$, ~2040)

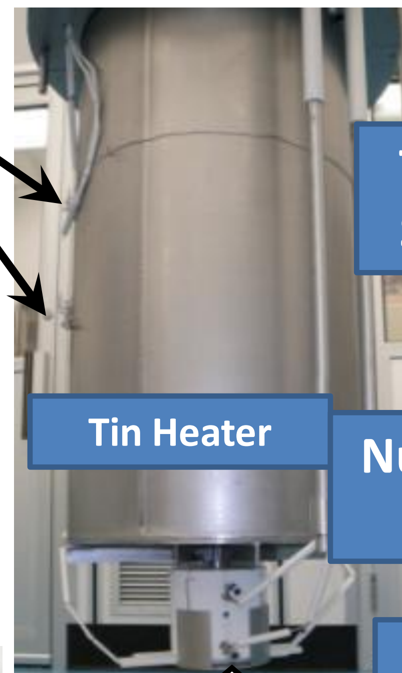
"strategic Priority Research Program" of the Chinese Academy of Sciences

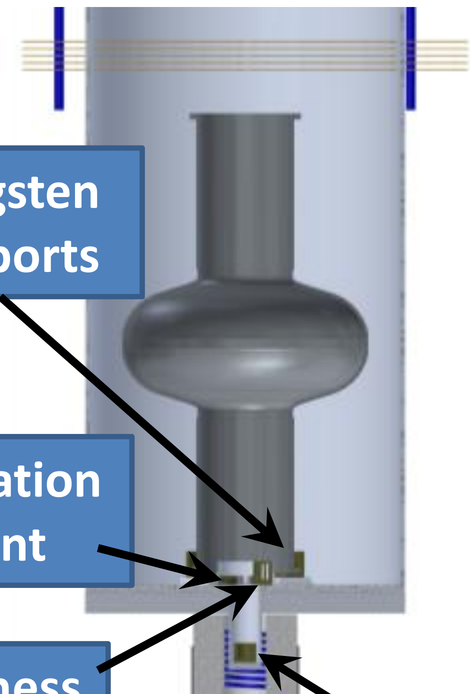
Information on New Materials

Nb_3Sn Coating Chamber
Cornell University

Coating chamber is inserted into UHV furnace. Separate vacuum system keeps furnace free from tin contamination

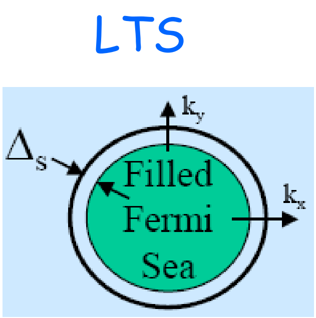


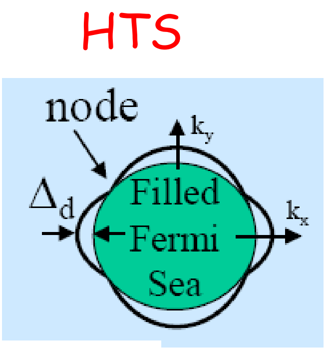


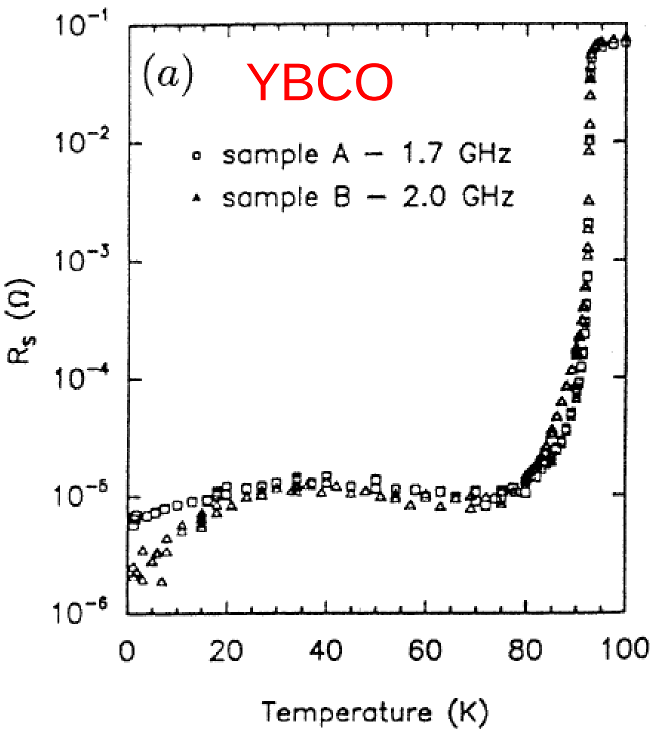


Courtesy Sam Posen, Cornell

About YBCO







Hein M A 1996 *Studies in High Temperature Superconductors* vol 18 ed A Narlikar (Nova Science Publishers) pp 141–216

- Has nodes in the energy gap. This leads to **power-law** behavior of $\lambda(T)$ and $R_s(T)$ and **high** residual losses

- $\xi \sim 1 - 2$ nm ($<< \lambda$) $\rightarrow$ superconducting pairing is easily disrupted by defects (cracks, grain boundaries)
- "Granular" superconductors:
- => high grain boundary resistance contributing to R_{res}

hV_F

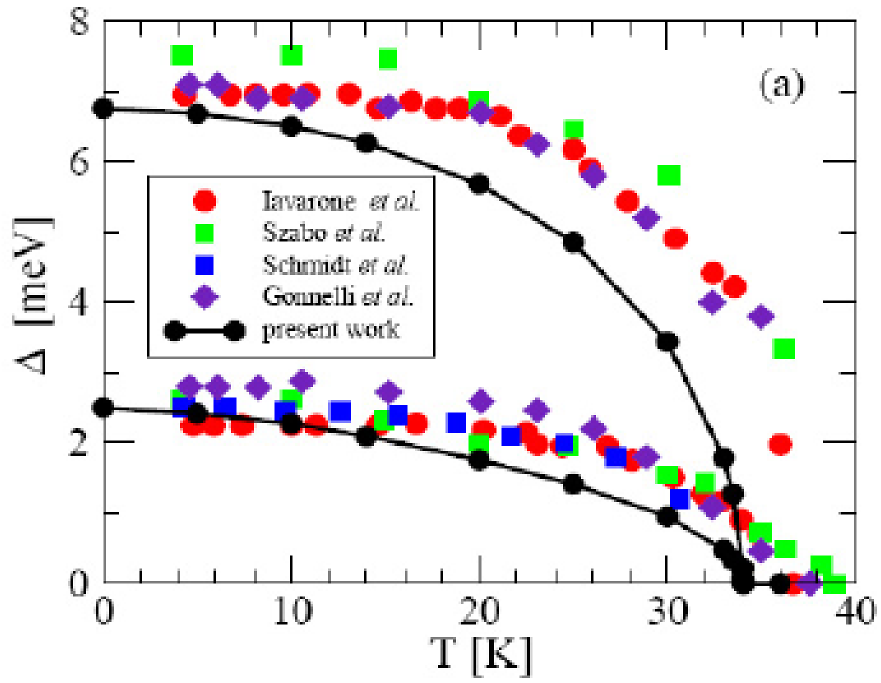
High Tc Properties

Material	T_c (K)	$H_c(0)$ [T]	$H_{c1}(0)$ [mT]	$H_{c2}(0)$ [T]	$\lambda(0)$ [nm]	Δ [meV]
Pb	7.2	0.08	Na	na	48	1.4
Nb	9.2	0.2	170	0.4	40	1.5
Nb_3Sn	18	0.54	50	30	85	3.1
NbN	16.2	0.23	20	15	200	2.6
MgB_2	40	0.43	30	3.5-60	140	2.3; 7.1
YBCO	93	1.4	10	>100	150	20

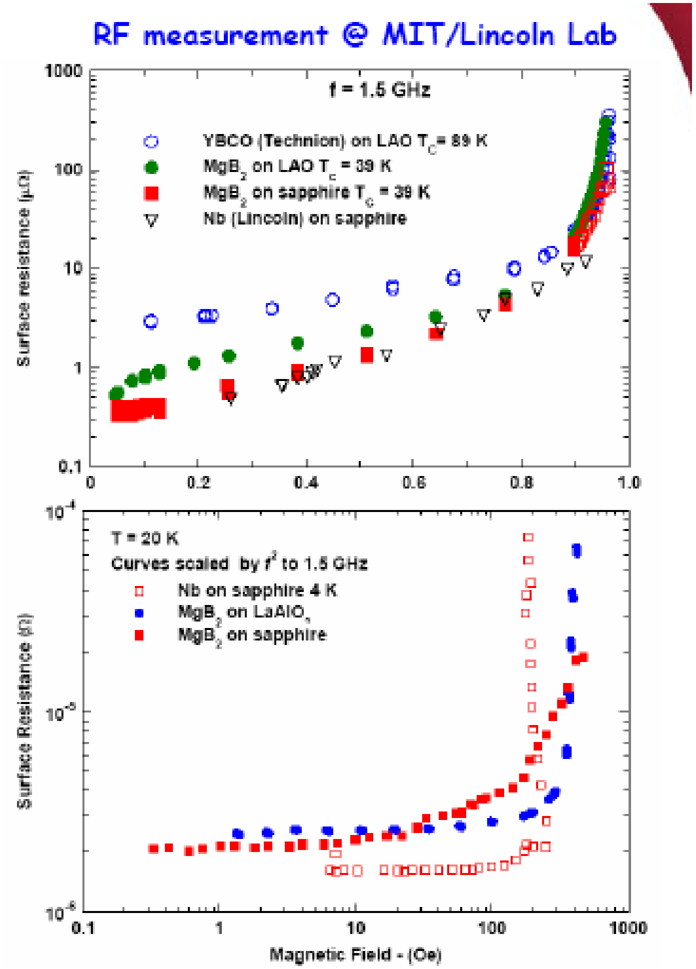
- Since coherence length $\xi_0 = \frac{\hbar V_F}{kT_c}$
- All high *Tc* materials have short coherence length (ξ_0) so they are less forgiving of inter-grain defects, esp important for granular materials,
- MgB2: Rs is dominated by the smaller gap, so the BCS resistance of MgB2 will not be lower than Rs for Nb3Sn because Δ is smaler
  - Δ of MgB2 = 2.3 meV < Δ of Nb3Sn = 3.1 meV.
- If new oxypnictides are S-wave superconductors, one can expect a much lower Rs at 2K because Δoxy = 5-10 meV > Δ Nb3Sn = 3 meV
- Surface resistance measurements at 26 GHz support a good fit to the S-wave behavior, with 2Δ/kBTc = 8

MgB2 – Two Energy Gaps, and Rs

A. Floris et al., cond-mat/0408688v1 31 Aug 2004

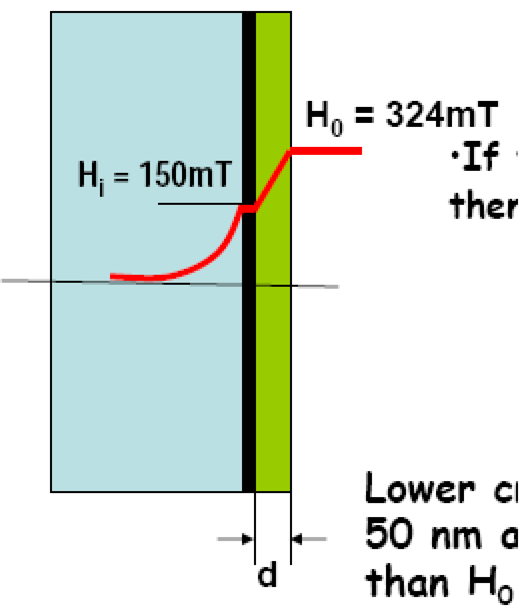


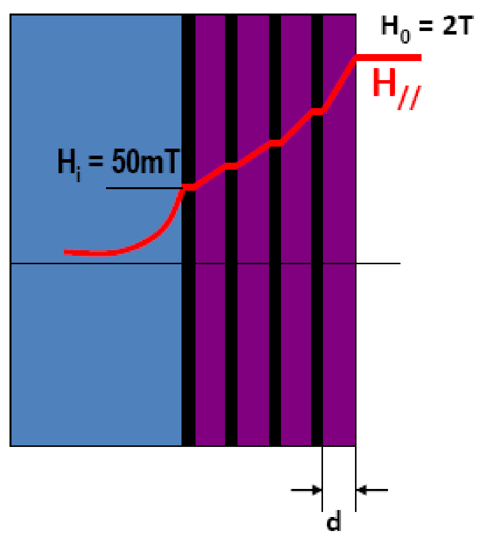
MgB2 Gap = 2 meV < Nb3Sn-gap = 3 meV



Multilayers

- The key idea is the fact that *Hc1* increases when the film thickness d gets close and less than to λ (magnetic penetration depth)
- New studies (Posen SRF2013) show that Hc1 of SIS films is theoretically zero
- Hsh of SIS films is less than bulk film



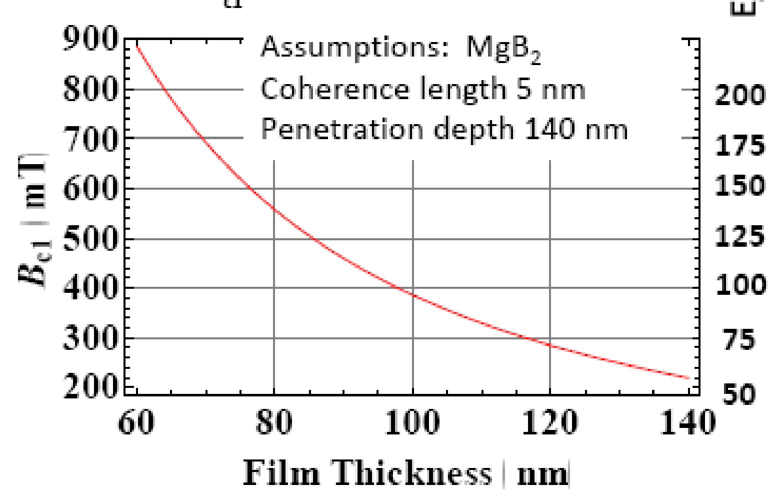


- Use thin films with thickness $d < \lambda_L$ to enhance the lower critical field

$$B_{c1} = \frac{2\phi_0}{\pi d^2} \ln \frac{d}{\tilde{\xi}}, \quad d < \lambda$$

[Gurevich, APL 88 (2006) 012511]

Predicted H_{c1} as a function of film thickness



Hc of MgB2

[1] http://faculty.kfupm.edu.sa/PHYS/kaziq/Research/MgB2%20Scaling.pdf
[2] http://prl.aps.org.proxy.library.cornell.edu/abstract/PRL/v86/i11/p2420_1
[3] http://prb.aps.org/abstract/PRB/v66/i5/e052505
[4] http://prl.aps.org/abstract/PRL/v87/i4/e047001
[5] http://prb.aps.org/abstract/PRB/v65/i2/e020502
[6] http://www.sciencedirect.com/science/article/pii/S0921453401006177
[7] http://prl.aps.org/abstract/PRL/v102/i11/e117001

Hc of Mg B2

Author (ref)	Bc [T]	Sample	Method	ξ, λ measured?
Ziq [1]	0.558	Mg strips and B powder annealed at 950 C	Area under magnetization curve – could this be affected by pinning?	No
Finnemore et al [2]	0.68	Sintered pellet, 950 C annealing	κ=Hc2/[0.707Hc]= with high temp κ (26) and low temp Hc2 (12.5 T)	Calculated from crit fields – ξ = 5.2 nm, λ = 140 nm. Hc = 2e-15/(2 sqrt(2) π λ ξ) = 0.309 T disagrees
Zehetmayer et al [3]	0.28	Single crystal	2 ways: integrating magnetization curve &	Yes, from magnetization measurements
Bouquet et al [4]	0.34	Mg metal and B powder annealed at 850 C	Integrating specific heat data	No
Haas and Maki [5]	0.27	None	Theory calculations	No
Wang et al [6]	0.26	Sintered powder at 850 C	Integration of specific heat	Yes, but not clear how determined. ξ = 4.9 nm, λ = 185 nm. Hc = 2e-15/(2 sqrt(2) π λ ξ) = 0.248 T agrees
Moshchalkov et al [7]	0.36	Single crystals	They didn't calculate it but they give values for ξab, λab	ξ = 13 nm, λ = 47.8 nm. Hc = 2e-15/(2 sqrt(2) π λ ξ) gives the value in this table