Recent Development of SRF Technologies Worldwide: Highlights from TTC2023 meeting at Fermilab

Eiji Kako (KEK, Japan)

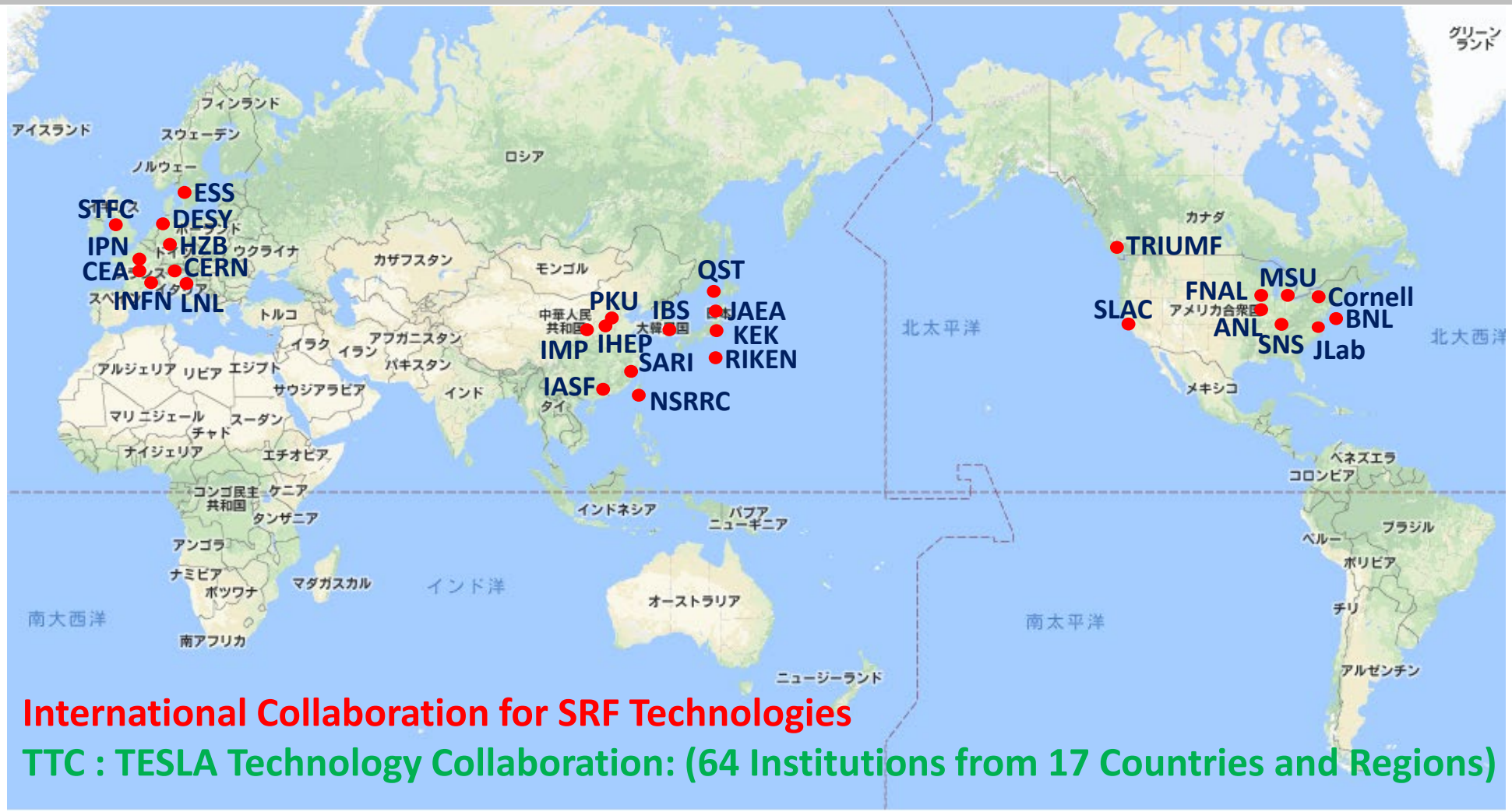
CEPC Workshop at Hangzhou

2024, October 24th

Outline

1. Introduction of TTC meeting
2. Highlights
   - Project status
   - SRF Technology
   - Hot topic discussion
3. Summary
4. Next TTC meeting

Worldwide Accelerator Laboratories for SRF R&D



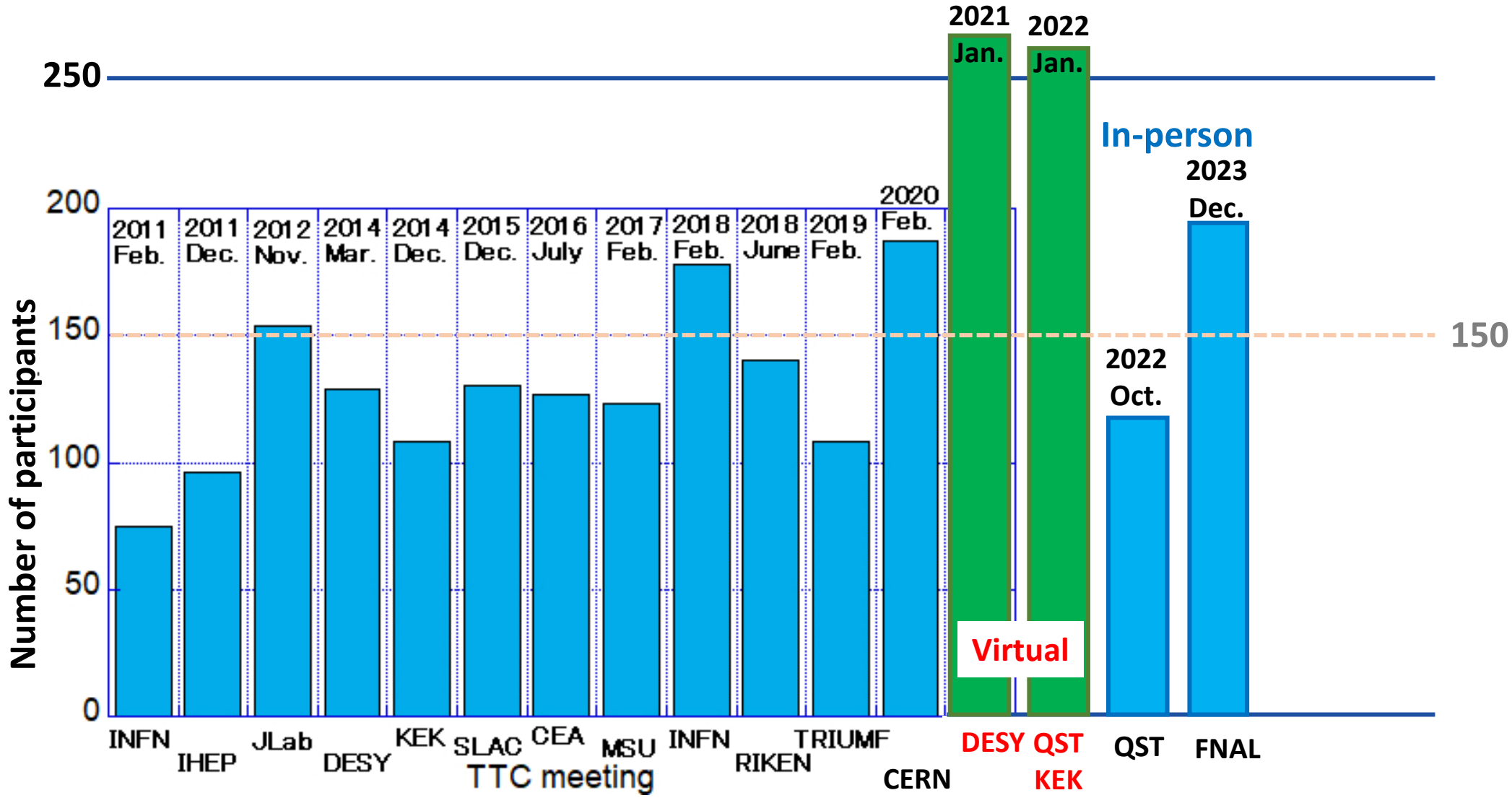
- Cryogenics (Liq. He)
- Surface preparation
- Vacuum Furnace
- HPR
- Clean room
- VT

TTC: TESLA Technology Collaboration

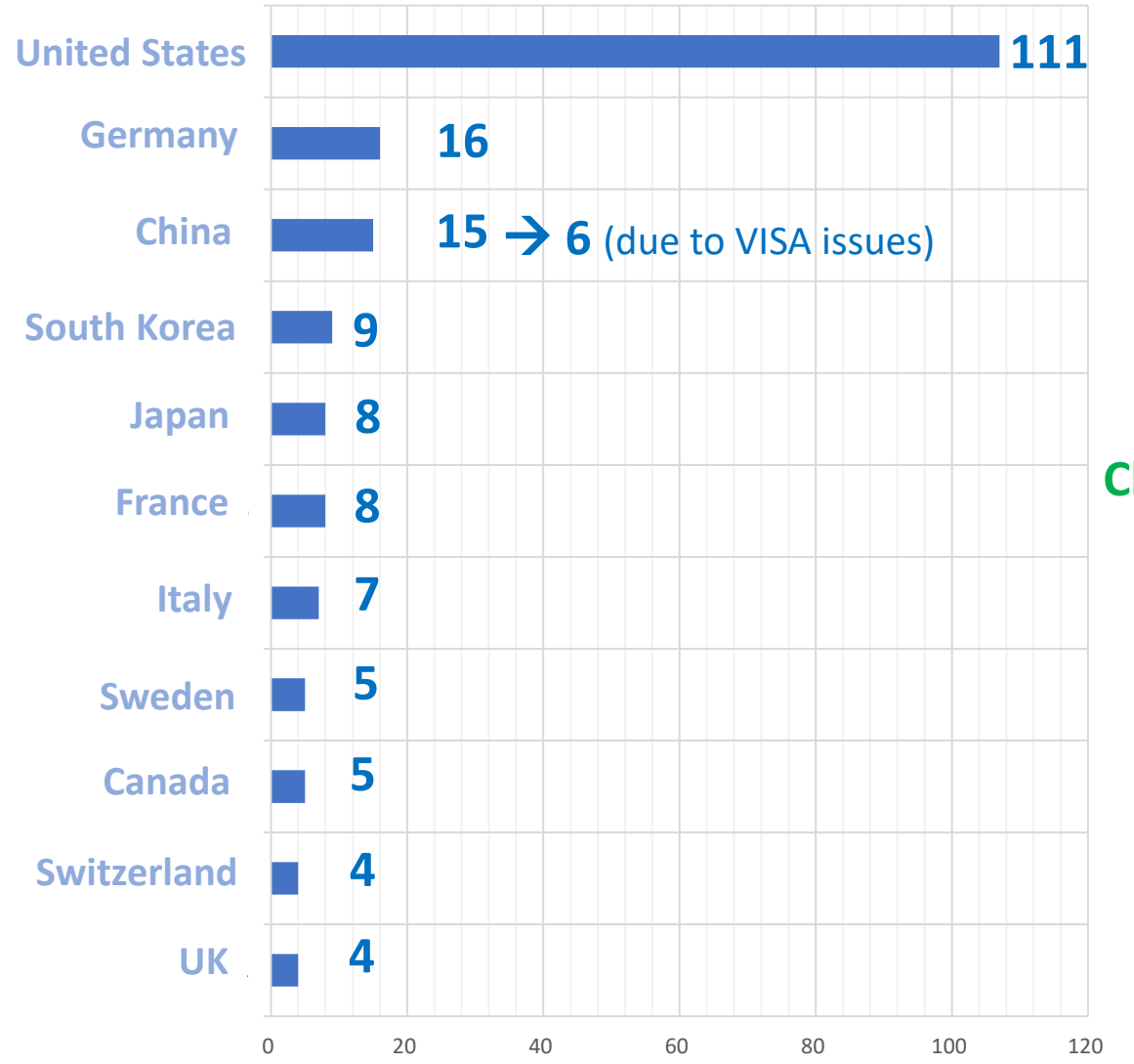
TTC2023 meeting at FNAL
December 5-8, 2023’

https://indico.fnal.gov/event/60446/

Number of participants in TTC

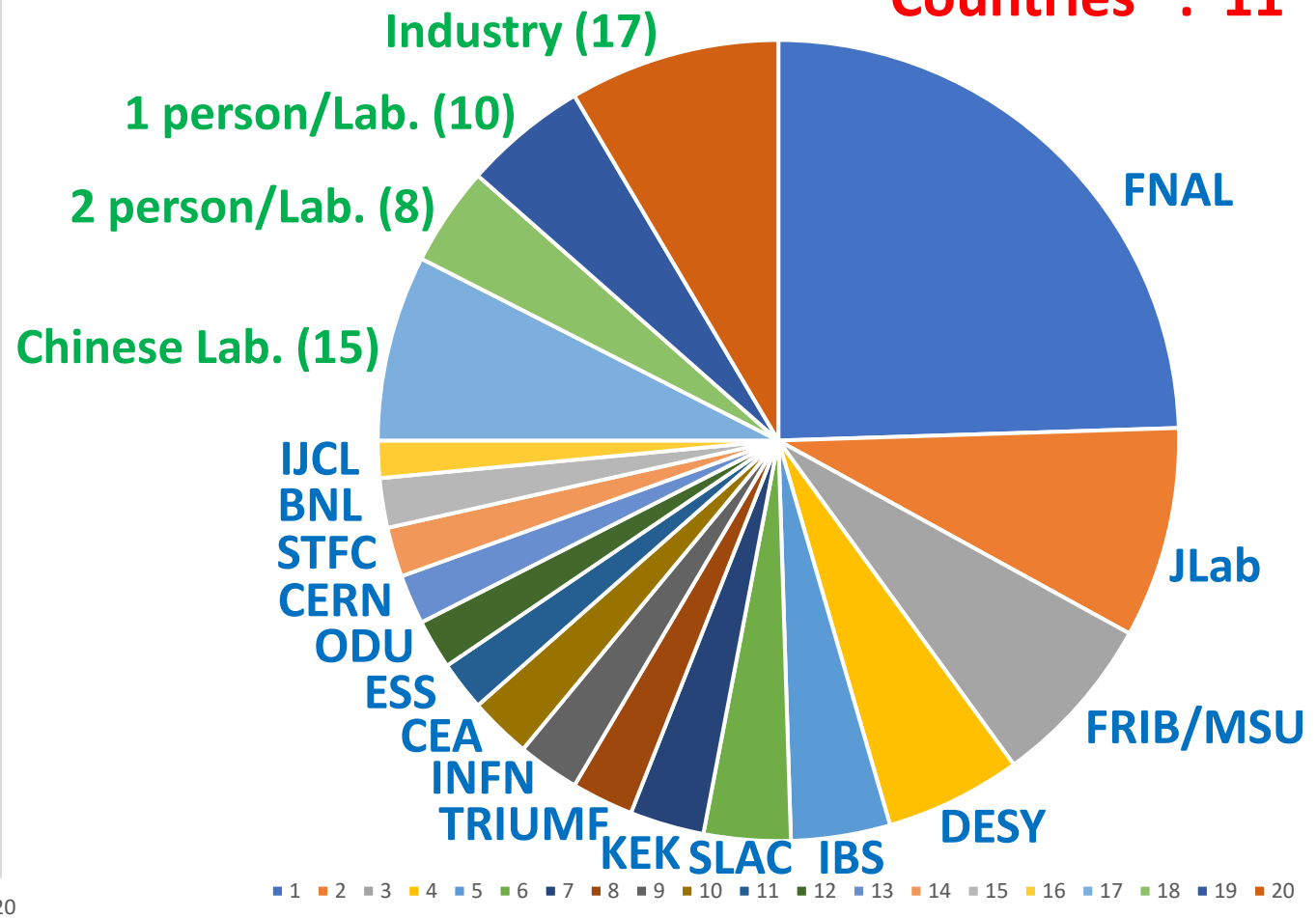


Participants in TTC-2023 Fermilab



Participants : 192

Countries : 11



Mission of the TESLA Technology Collaboration (1)

The mission of the TESLA Technology Collaboration is

- to advance SCRF technology R&D and related accelerator studies across the broad diversity of scientific applications.
- to keep open and provide a bridge for communication and sharing of ideas, developments, and testing across associated projects.

To this end,

- The TTC will support and encourage free and open exchange of scientific and technical knowledge, expertise, engineering designs, and equipment.

Mission of the TESLA Technology Collaboration (2)

- The TTC organizes regular collaboration meetings where new developments are reported, recent findings are discussed, and technical issues concluded.

- Live presentation by in-person and face-to-face discussions in a small room are our essential features in the TTC meeting. We should strictly maintain these special characteristics in the TTC meeting without any exception as a principal to be respected.

Time Schedule in TTC meeting

4 Days: 4 WGs discussion in 2 parallel sessions

Time	Date	December, 4	December, 5 (Tue)	December, 6 (Wed)	December, 7 (Thu)	December, 8 (Fri)
8:30 - 9:00			Registration	Registration	Registration	Registration
9:00 - 9:30 9:30 - 10:00 10:00 - 10:30			Welcome/Introduction Plenary talk 1 Plenary talk 2	Plenary talk 3 Plenary talk 4 Plenary talk 5	Plenary talk 6 Plenary talk 7 Plenary talk 8	Special Seminar 1 Special Seminar 2
10:30 - 11:00	Coffee Break					
11:00 - 11:30 11:30 -12:00 12:00 - 12:30			WG1 / WG3 (parallel)	WG1 / WG3 (parallel)	WG2 / WG4 (parallel)	Summary WG1/WG3 Summary WG2/WG4 TB/CB report
12:30 - 14:00	Lunch					
14:00 - 14:30 14:30 - 15:00 15:00 - 15:30			WG1 / WG3 (parallel)	WG2 / WG4 (parallel)	WG2 / WG4 (parallel)	Tour
15:30 - 16:00	Coffee Break					
16:00 - 16:30 16:30 - 17:00 17:00 - 17:30			WG1 / WG3 (parallel)	WG2 / WG4 (parallel)	Hot Topics	
17:30 - 18:00						
18:00 - 18:30 18:30 - 19:00 19:00 - 19:30 19:30 - 20:00			CB meeting	TB meeting	Dinner	

- 8 Plenary talks (for 30 min.)
- 2 Special seminars (for 45 min.)
- Hot topic discussion (for 90 min.)
- Site Tour

Invited talks in plenary sessions

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FEATURE TESLA TECHNOLOGY COLLABORATION

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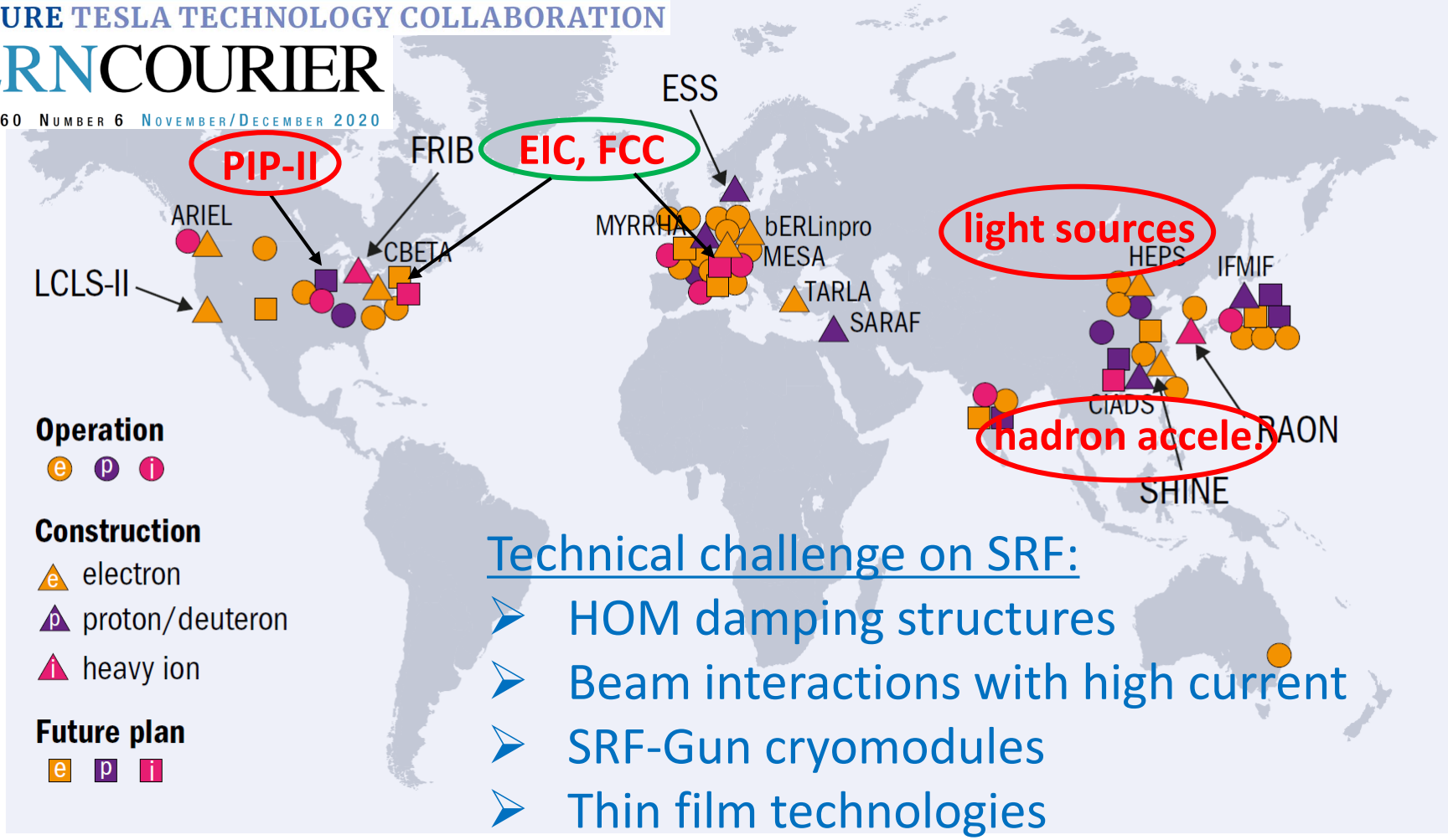
VOLUME 60 NUMBER 6 NOVEMBER/DECEMBER 2020

SRF accelerators over the world



Construction

Future Project

Special Seminars:

- Science of FRIB
- Quantum computing

Technical challenge on SRF:

- HOM damping structures
- Beam interactions with high current
- SRF-Gun cryomodules
- Thin film technologies

Hot topic discussion:

- Conduction cooled SRF cavity technologies

Discussion on Working Groups

- **WG-1:** Progress on High Q and High Gradient activities.
- **WG-2:** Developments and experiences with emerging TEM- and TE-mode cavities: Spoke resonators and Crab cavities.
- **WG-3:** Novel clean assembly techniques, in-situ mitigation, and recovery processes.
- **WG-4:** Design, experience, and operation with high-beta/beta=1 cryomodules and sub-components.
- **Hot topic discussion:**
  Challenges for conduction-cooled SRF cavity technology

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   - Project status
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Highlights in TTC meeting

- Project status:
  1. PIP-II, 2. EIC, FCC and CEPC
  3. Synchrotron Light sources in China
  4. Hadron Accelerators in China
- SRF Technology:
  5. SRF-Gun Cryomodule
  6. Thin-Film Technology
- Hot topic discussion:
  7. Conduction cooled SRF Cavity

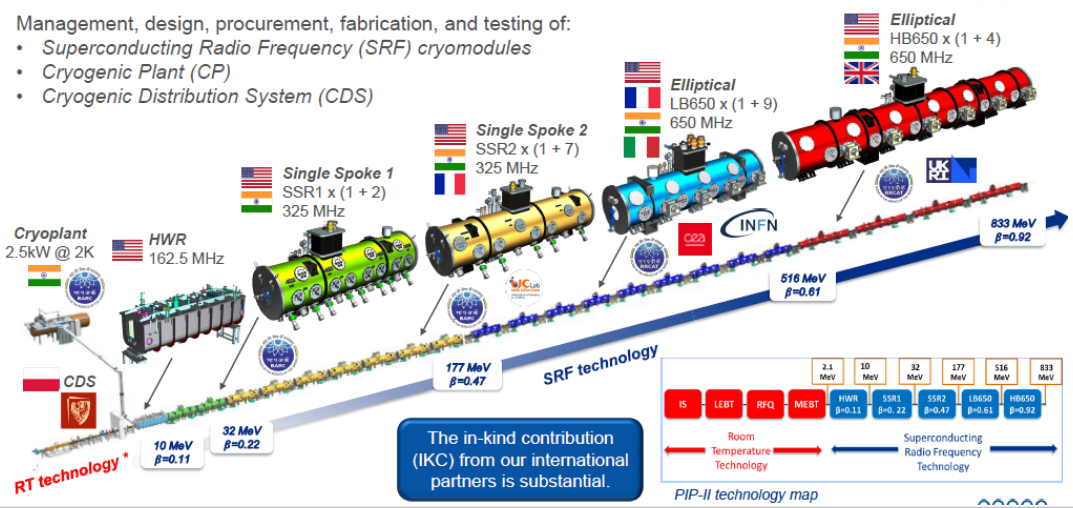
Highlight: PIP-II

Recent Progress on SRF developments for PIP-II project

Donato Passarelli

PIP-II 800 MeV SRF Linac

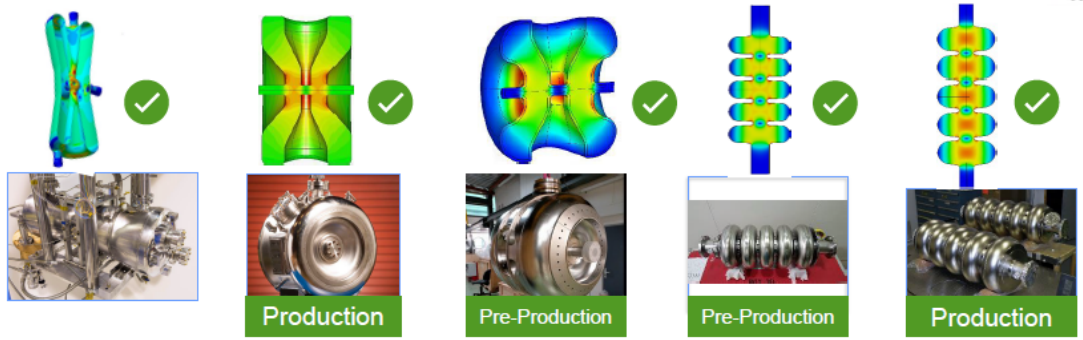
Management, design, procurement, fabrication, and testing of:
- *Superconducting Radio Frequency (SRF) cryomodules*
- *Cryogenic Plant (CP)*
- *Cryogenic Distribution System (CDS)*



The in-kind contribution (IKC) from our international partners is substantial.

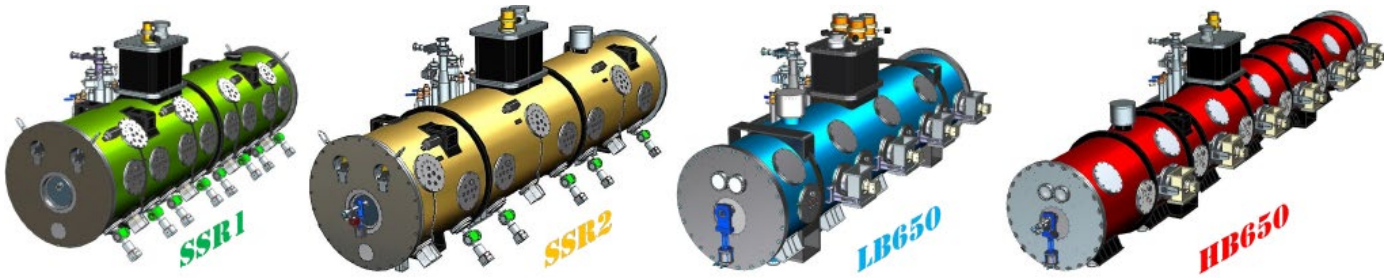
PIP-II technology map

PIP-II SRF Cavities



Name (Qty.)	HWR (8)	SSR1 (16)	SSR2 (35)	LB650 (36)	HB650 (24)
Type	Half-Wave	Single Spoke	Single Spoke	Elliptical	Elliptical
β	0.11	0.22	0.47	0.61	0.92
Frequency [MHz]	162.5	325	325	650	650
Q_0	$8.5 \cdot 10^9$	$8.2 \cdot 10^9$	$8.2 \cdot 10^9$	$2.4 \cdot 10^{10}$	$3.3 \cdot 10^{10}$
Gradient [MV/m]	9.7	10	11.47	16.9	18.8
Processing	EP	Rotational BCP	Rotational BCP	Mid-T bake	N-doping

✓ *Fabrication, processing, and cold testing performance successfully demonstrated*

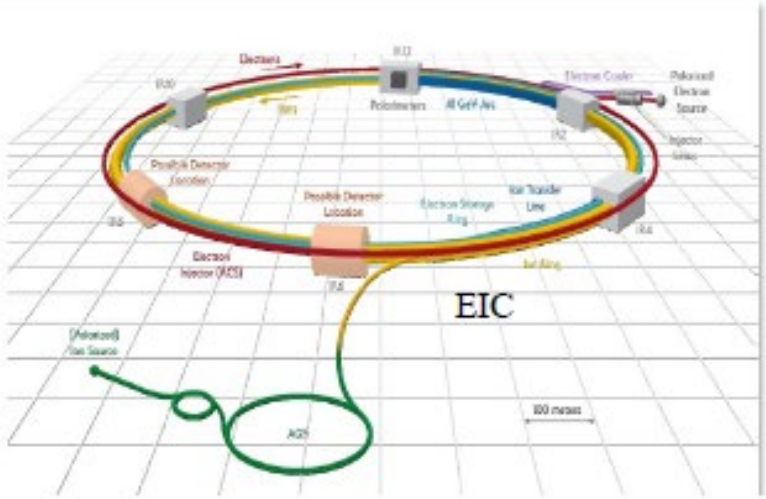


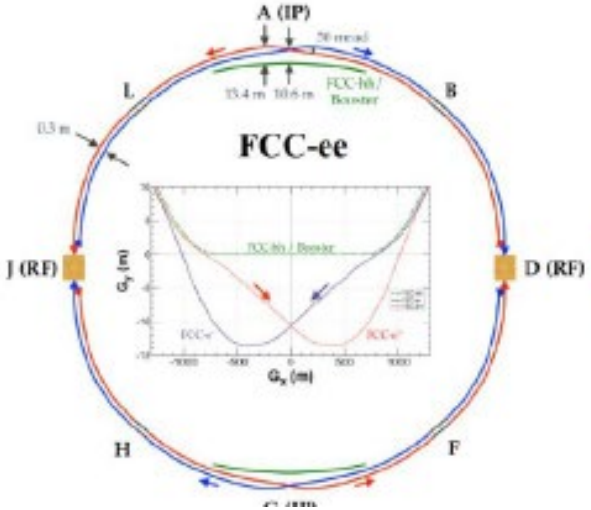
The CMs standardization allows lessons learned being applicable from one CM to another

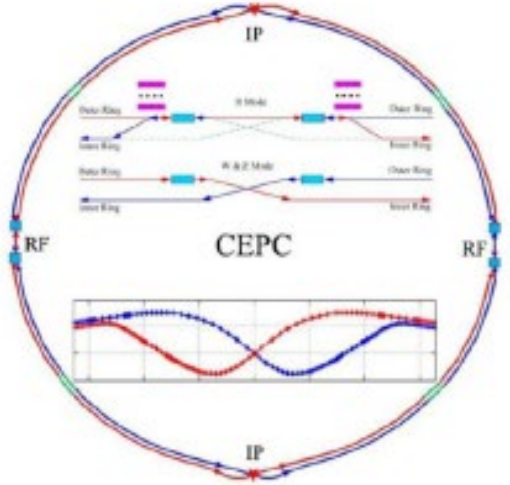
Highlight: EIC, FCC and CEPC (1)

Overview of SRF cavities for coming & future circular lepton and electron-ion colliders

Jiquan Guo, JLab

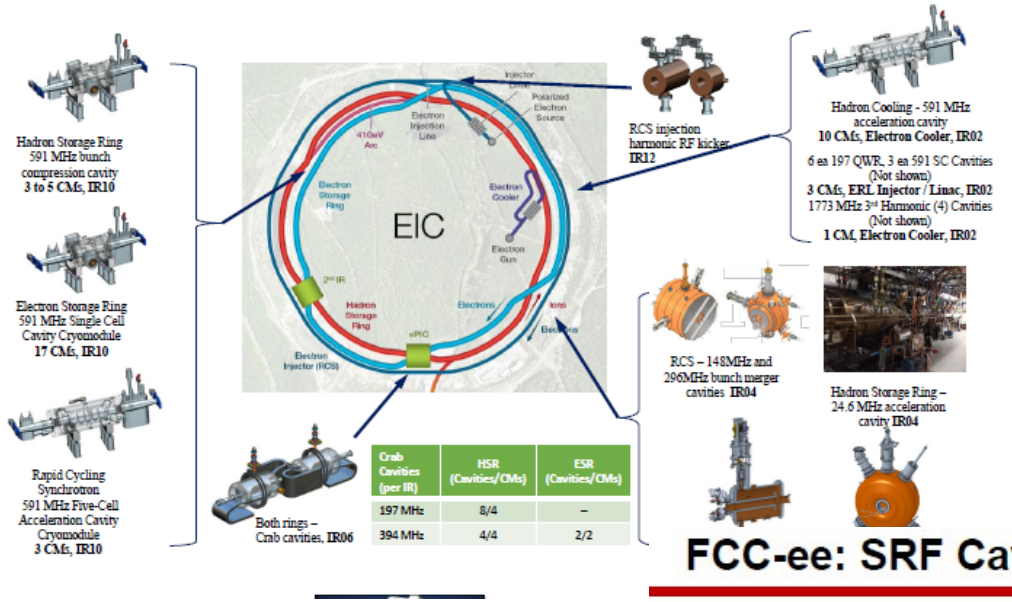






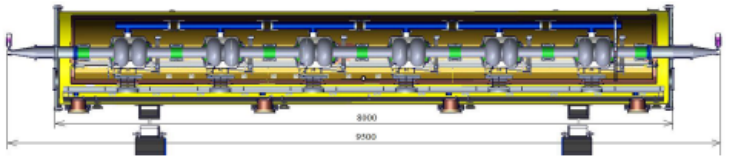
Highlight: EIC, FCC and CEPC (2)

EIC: RF systems

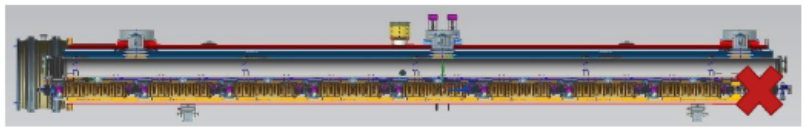


Crab Cavities (per IR)	HSR (Cavities/CMs)	ESR (Cavities/CMs)
197 MHz	8/4	–
394 MHz	4/4	2/2

CEPC: 650MHz 2-cell and 1.3GHz 9-cell Cryomodule



- 650MHz: 6×2-cell cavities per cryomodule
- Two coax HOM damper per cavity (~1kW/each) plus warm BLAs (~5kW each) outside vacuum vessel



ESLA cryomodules,
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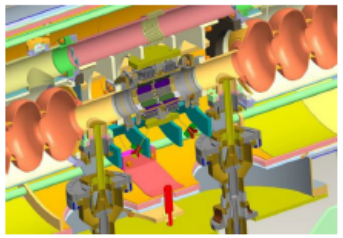
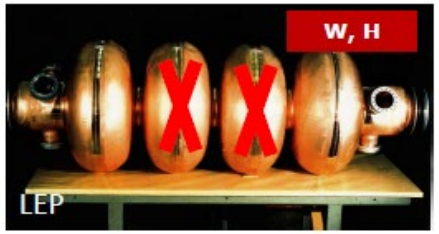
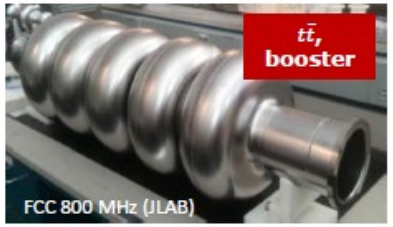


FCC-ee: SRF Cavity Baseline

400 MHz 1-cell cavities
Nb/Cu, 4.5 K



400 MHz 2-cell cavities
Nb/Cu, 4.5 K



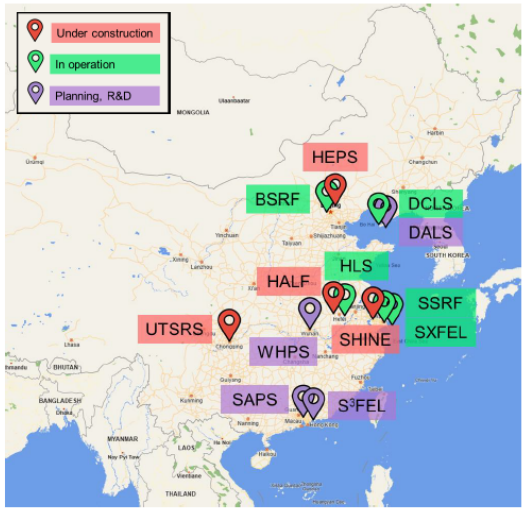
800 MHz 5-cell cavities
Bulk Nb, 2 K

Highlight: Synchrotron Light sources in China

Overview of SRF projects for Synchrotron Light Sources in China

Pei Zhang
(Institute of High Energy Physics, CAS)

Major light sources in mainland China



Beijing
Beijing Synchrotron Radiation Facility (BSRF)
High Energy Photon Source (HEPS)

Shanghai
Shanghai Synchrotron Radiation Facility (SSRF)
Shanghai soft X-ray Free-Electron Laser facility (SXFEL)
Shanghai High Repetition Rate X-ray FEL and Extreme Light Facility (SHINE)

Hefei
Hefei Synchrotron Radiation Facility (HLS)
Hefei Advanced Light Facility (HALF)

Others
Dalian Coherent Light Source (DCLS)
Dalian Advanced Light Source (DALS)
Ultrafast Transient Synchrotron Radiation Facility
Shenzhen Superconducting Soft X-Ray FEL (S3FEL)
Southern Advanced Photon Source (SAPS)
Wuhan Photon Source (WHPS)

Not an exhaustive list.

- Existing projects: BSRF, SSRF
- New projects: HEPS, HALF, SAPS

Beijing Synchrotron Radiation Facility

Shanghai Synchrotron Radiation Facility

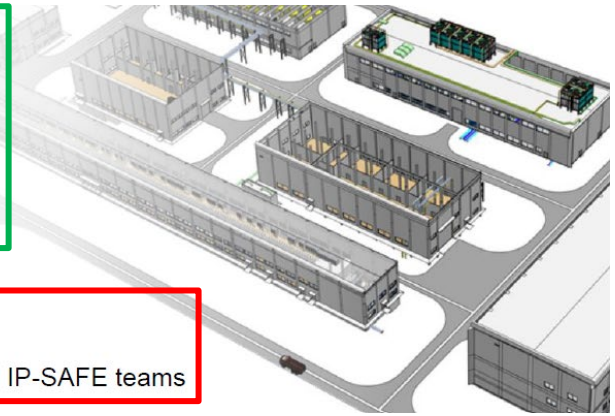
High Energy Photon Source

Hefei Advanced Light Facility

Southern Advanced Photon Source

Highlight: Hadron Accelerators in China

Recent Status of SRF Projects for Hadron Accelerators in China



Yuan He,
Chief Engineer of CiADS
on behalf of CiADS, HIAF, CSNS-II and IP-SAFE teams

Ongoing Projects

- CAFe2
- CiADS
- HIAF
- CSNS-II
- IP-SAFE

Potential Upgrade Projects

- CiADS Beam Intensity
- HIAF SCL2 with stripping foil

Highlight: SRF-Gun Cryomodule

compiled and edited by Elmar Vogel for the "TTC community"

Two types of SRF gun cavities

Parameter range, laboratories and projects

VHF-band quarter wave resonator (QWR) SRF guns

RF frequency:	113 MHz to 200 MHz
exit energy:	1 MeV to 1.8 MeV
cathode *E* field:	6 MV/m to 30 MV/m
peak on axis *E* field:	6 MV/m to 30 MV/m

laboratories & projects:

- SLCS-II HE Low-Emittance Injector by SLAC/FRIB/ANL/HZDR collaboration
- BNL – SRF gun for hardon cooling
- (Wisconsin/SLAC/ANL SRF gun – no longer used)

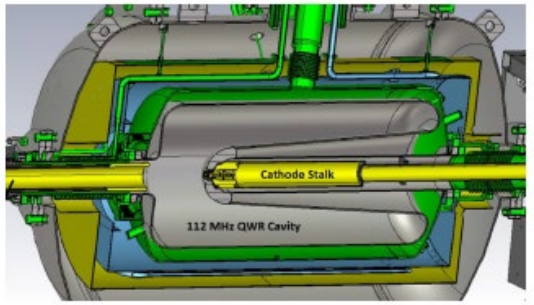
L-band (elliptical shaped) SRF guns

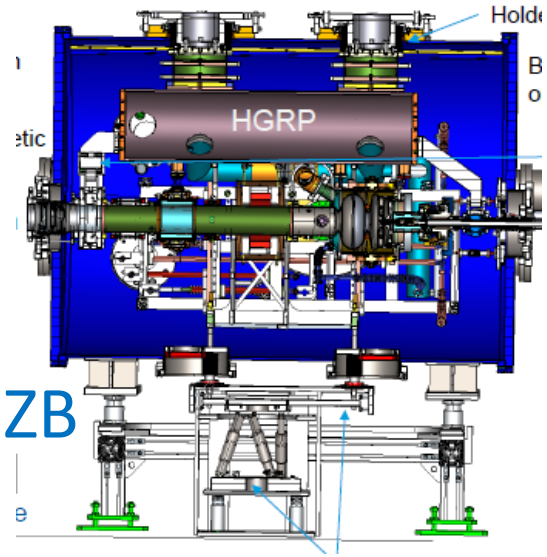
RF frequency:	1.3 GHz
exit energy:	1 MeV to 4 MeV
cathode *E* field:	7.5 MV/m to >40 MV/m (>60 MV/m?)
peak on axis *E* field:	7.5 MV/m to >40 MV/m (>60 MV/m?)

laboratories & projects:

- HZDR – photoinjector for ELBE (THz FEL)
- HZB – for bERLinPro (ERL)
- MSU/KEK – for photocathode R&D (former KEK-ERL)
- Osaka University – for electron microscopy
- PKU – DC-SRF gun
- DESY – for Eu XFEL HDG operation, cavity for PolFEL

BNL

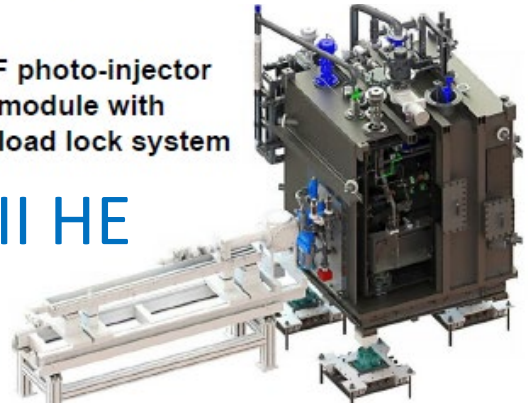




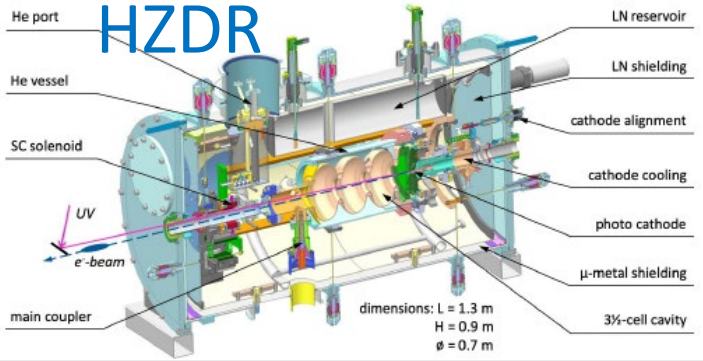
HZB

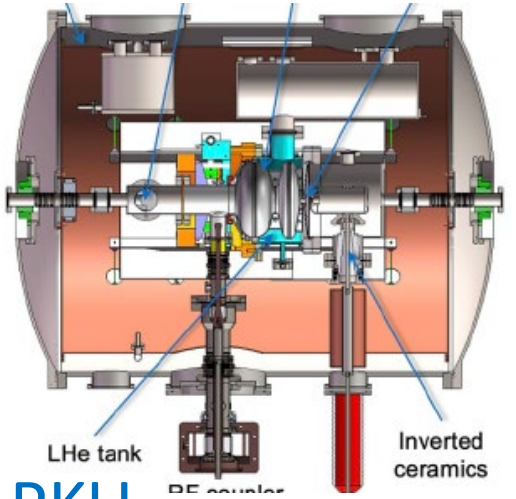
LEI SRF photo-injector cryomodule with cathode load lock system

LCLS-II HE



HZDR





PKU

Highlight: Thin-Film Technology

OUTLINE

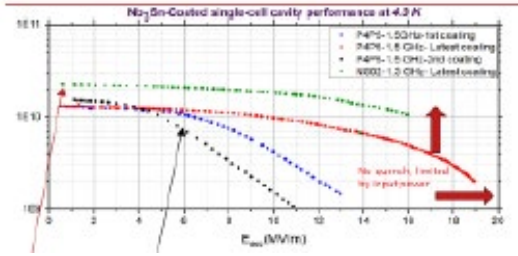
A.-M. Valente-Feliciano

Recent progress in SRF thin film developments since SRF 2023

- ❑ Nb Thin Film Technology
- ❑ Beyond Nb – Alternate Materials
  - Nb_3Sn
  - NbTiN
  - MgB_2
- ❑ Beyond Nb – Multilayers
- ❑ SRF Thin Film Characterization
- ❑ Substrates

Material studies and development of Nb_3Sn-coated cavities

JLab



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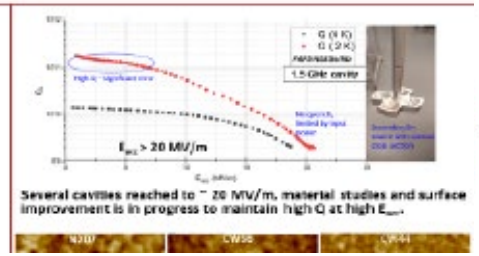

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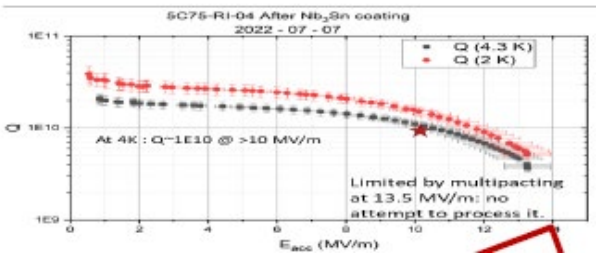
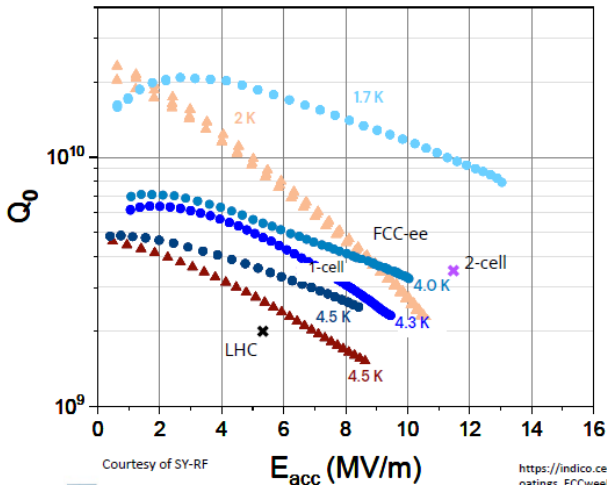


Nb Thin Film Technology

400 MHz Nb/Cu cavities

CERN

G. Rosaz et al.



2K 4K "LHC Type" - DCMS

2K 4K HiPIMS

2K 4K HiPIMS + HPR + RF conditioning

Best ever produced 400MHz Nb/Cu
FCC 1 cell specs reached ✓
Chemistry : SUBU
EP commissioned and ready for 2024

Next target: FCC 2-cells specs

https://indico.cern.ch/event/1202105/contributions/5391683/attachments/2662106/4612074/HIPIMS%20N

Summary

- ❑ **Nb Thin Film Technology**
  - ❑ Results on cavities at different frequencies
  - ❑ Demonstrations of Nb/Cu Q-slope mitigation
- ❑ **Beyond Nb: Alternate Materials**
  - ❑ Progress with Nb_3Sn by vapor diffusion towards cryomodules and conduction cooled cavities
  - ❑ Further development of alternate Nb_3Sn coating techniques HiPIMS, sputtering, CVD…
- ❑ **Beyond Nb: Multilayer Structures**
  - ❑ Further development on samples for characterization and RF measurement (QPR)
  - ❑ Development of concept from samples to cavities
- ❑ **Advance substrate fabrication & preparation**
- ❑ **SRF Film Characterization**
  - ❑ μ-SR, β-NMR, PCT, QPR, flux expulsion …
- ❑ **Superconducting TF applications beyond SRF keep expanding (devices, sensors quantum …)**
  - ❑ Nb/Al_2O_3 films for qubits
  - ❑ NbTiN Films for Superconducting Digital Logic
  - ❑ Film based cavities for Axion research (NbTi cavity, *INFN, C. Pira*)

Highlight: Conduction cooled SRF Cavity (1)

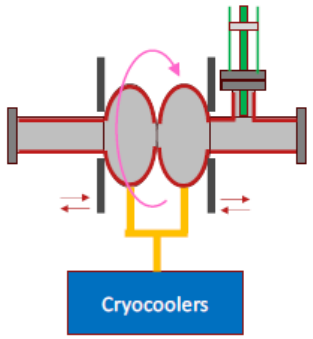
Introduction to Hot-Topic discussion

TESLA Technology Collaboration Meeting
Fermilab, Batavia, IL
4-8 December 2023

Gianluigi Ciovati

Challenges for Conduction-Cooled SRF Cavities

- Choice of cryocooler
  - GM, PT, GM-JT
- Thermal link design
  - Cu, Al, foils, straps, bulk
- Nb_3Sn thin-film performance
  - On Nb: thermal diffusion, magnetron sputtering, electroplating
  - On Cu: CVD, PVD, magnetron sputtering, bronze route
- Tunability of Nb_3Sn-coated cavities
  - Warm, cold
- Low-loss fundamental power coupler
- Thermoelectric magnetic flux



Choice of cryocoolers

GM-type

- 7.5 kW for 2 W at 4 K
- ~$45k
- Limited mechanical loading to cold stage
- Vibrations at 1.2 Hz

PT-type

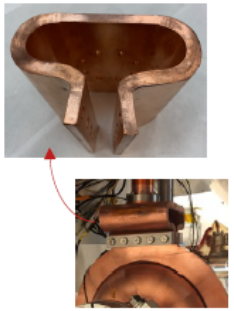
- 12.5 kW for 2 W at 4 K
- ~$60k
- No moving parts

GM-JT-type

- 14.1 kW for 9 W at 4 K
- Fixed temperature
- Limited mechanical loading to cold stage
- Requires separate shield cooler

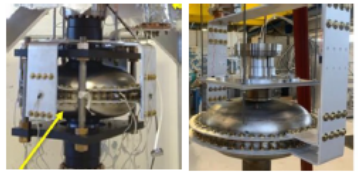
Thermal link design

Cu foils with press-welded terminals



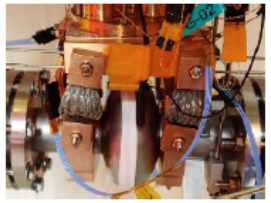
- 99.9% purity Cu foils
- Flexible connection
- Apiezon N grease used at interfaces

Aluminum bus-bars



- 99.9999% purity Al bars
- "rigid" connection
- Indium foil used at interfaces
- Time-consuming assembly

Cu thermal braids + Cu clamps



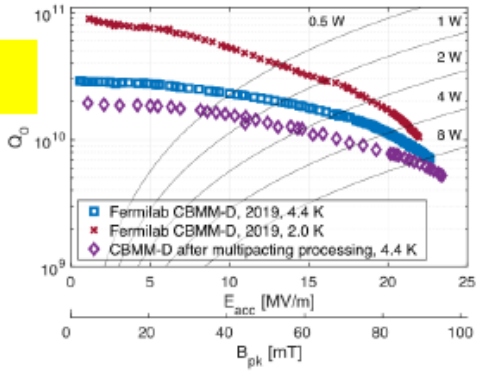
- Braided Cu straps
- Flexible connection
- Indium foil used at interfaces
- High clamping force (required for low thermal resistance) can damage the brittle Nb_3Sn film

Highlight: Conduction cooled SRF Cavity (2)

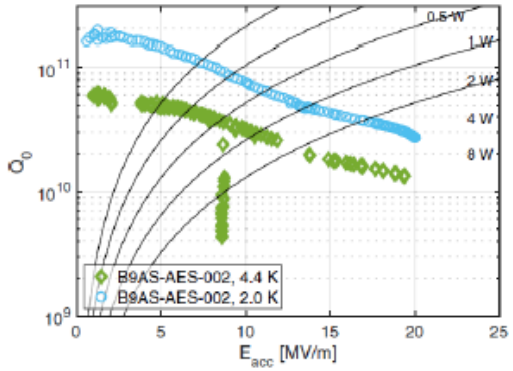
Nb_3Sn thin-film performance — Fermilab

State-of-the-art performance of Nb_3Sn thin-film on Nb by vapor diffusion in liquid He:

1.3 GHz single-cell

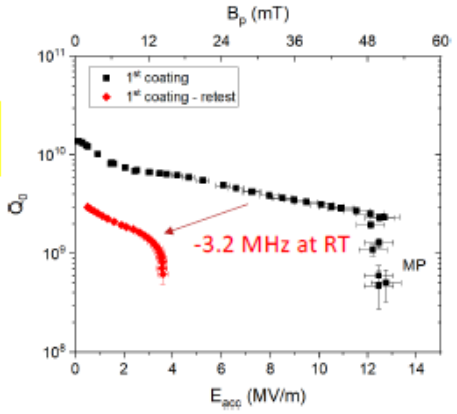


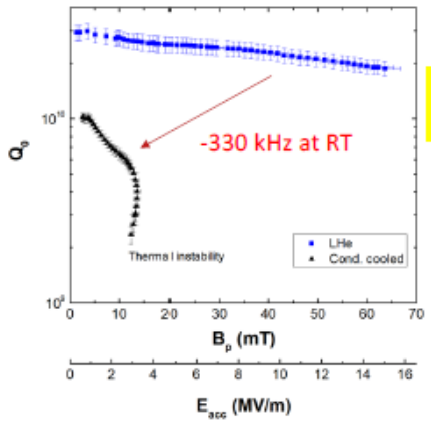
650 MHz single-cell



Tunability — Fermilab

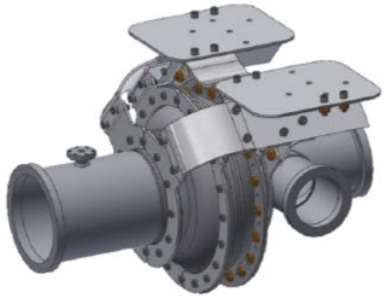
952 MHz single-cell





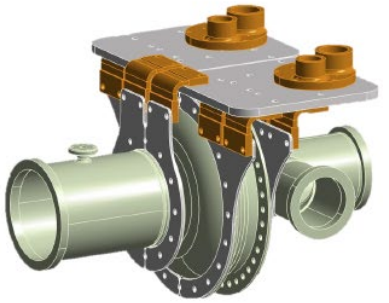
1.3 GHz single-cell

Cornell Univ.

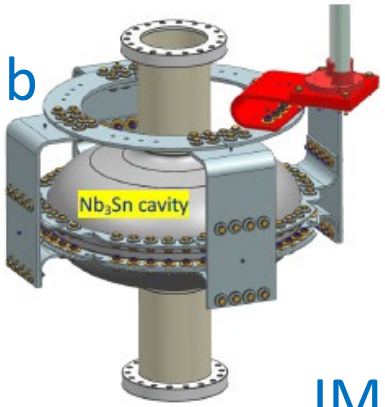


Design iterations

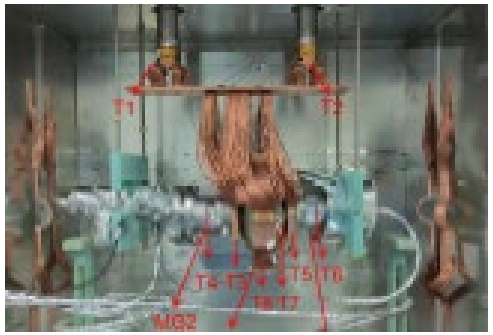
- Supply / vendor challenges
- Spatial requirements
- Simpler design (identical straps)
- Reduced cost



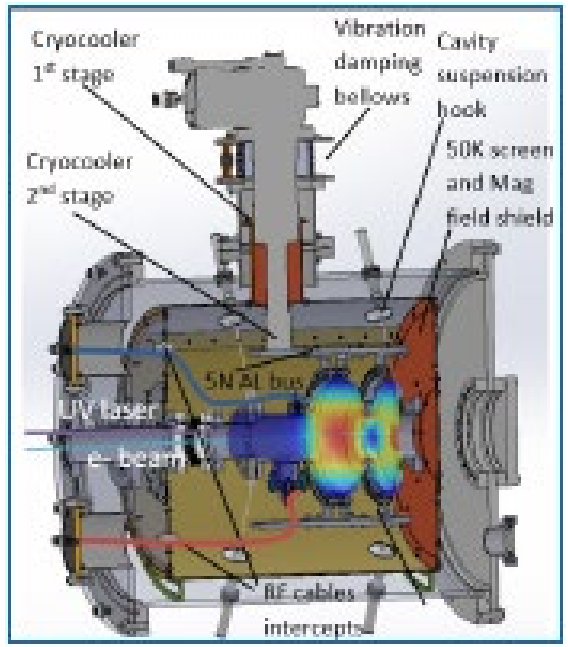
Fermilab



IMP



Euclid BeamLabs



Outline

1. Introduction of TTC meeting
2. Highlights
   - Project status
   - SRF Technology
   - Hot topic discussion
3. Summary
4. Next TTC meeting

Summary

- Many large-scale SRF accelerator projects are under construction and planning for future in worldwide.
- R&D of SRF technologies have been rapidly progressing for many applications.
- Compact accelerator system with conduction-cooled SRF cavities using Nb3Sn will be realized very soon.

Next TTC meeting

TESLA Technology Collaboration Meeting
November 11-15, Lund, Sweden

WG-1: Progress on High-G and High-Q Activities
WG-2: 4K operation with Nb on copper and higher temperature materials
WG-3: Operational Experiences of Cavity and Cryomodule Performances.
WG-4: Sustained Market Availability of Cryomodule Components and Materials

TTC Scientific Program Committee
Detlef Reschke (DESY), SPC Co-Chair
Hiroshi Sakai (KEK), SPC Co-Chair
Eiji Kako (KEK), TTC Chair
Bob Laxdal (TRIUMF), Deputy TTC Chair
Sergey Belomestnykh (FNAL)
Anne-Marie Valente-Feliciano (JLAB)
Catherine Madec (CEA)
Hans Weise (DESY)
Jie Gao (IHEP)
Akira Yamamoto (CERN/KEK)

TTC Local Organising Committee
Cecilia Maiano (ESS), LOC Chair
Paolo Pierini (ESS)
Nuno Elias (ESS)
Caroline Prabert (ESS)
Zeinab Afshari (ESS)

https://indico.ess.eu/event/3539/

TTC2024 meeting at ESS/LUND
November 11-15, 2024

Time	November, 11 (Mon)	November, 12 (Tue)	November, 13 (Wed)	November, 14 (Thu)	November, 15 (Fri)
8:30 - 9:00		Registration			
9:00 - 9:30		Welcome/Introduction	Plenary talk 3	Plenary talk 6	Special Seminar 1
9:30 - 10:00		Plenary talk 1	Plenary talk 4	Plenary talk 7	
10:00 - 10:30	Site Visit (1) 10:00 - 12:00	Plenary talk 2	Plenary talk 5	Plenary talk 8	Special Seminar 2
10:30 - 11:00		Coffee Break	Coffee Break	Coffee Break	Coffee Break
11:00 - 11:30		WG1 / WG3 (parallel)	WG1 / WG3 (parallel)	WG2 / WG4 (parallel)	Summary WG1/WG3
11:30 -12:00					Summary WG2/WG4
12:00 - 12:30					TB/CB report
12:30 - 14:00		Lunch	Lunch	Lunch	Closing Lunch
14:00 - 14:30		WG1 / WG3 (parallel)	WG2 / WG4 (parallel)	WG2 / WG4 (parallel)	Site Visit (3) 14:00 - 16:00
14:30 - 15:00					
15:00 - 15:30	Site Visit (2) 15:00 - 17:00				
15:30 - 16:00		Coffee Break	Coffee Break	Coffee Break	
16:00 - 16:30		WG1 / WG3 (parallel)	WG2 / WG4 (parallel)	Special Topics	
16:30 - 17:00					
17:00 - 17:30					
17:30 - 18:00					
18:00 - 18:30		CB meeting	TB meeting		
18:30 - 19:00				Dinner	
19:00 - 19:30					
19:30 - 20:00					

Thank you for your attention!