The Future of Superconducting Technology for Particle Accelerators

Akira Yamamoto

(KEK and CERN)

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Acknowledgments

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  - *HiLumi-LHC, and US-LARP collaboration*
  - *Euro-CirCol (FCC study body),*
  - *EUCARD-2 (to be succeeded by ARIES),*
  - *US Magnet Development Program (MDP), and*
  - *US-General Accelerator SRF R&D program (GARD-SRF),*
  - *Tesla Technology Collaboration (TTC), European XFEL, and LCLS-II,*
  - *Linear Collider Collaboration (LCC), and*
  - *Further SC magnet and SRF accelerator laboratories/projects.*

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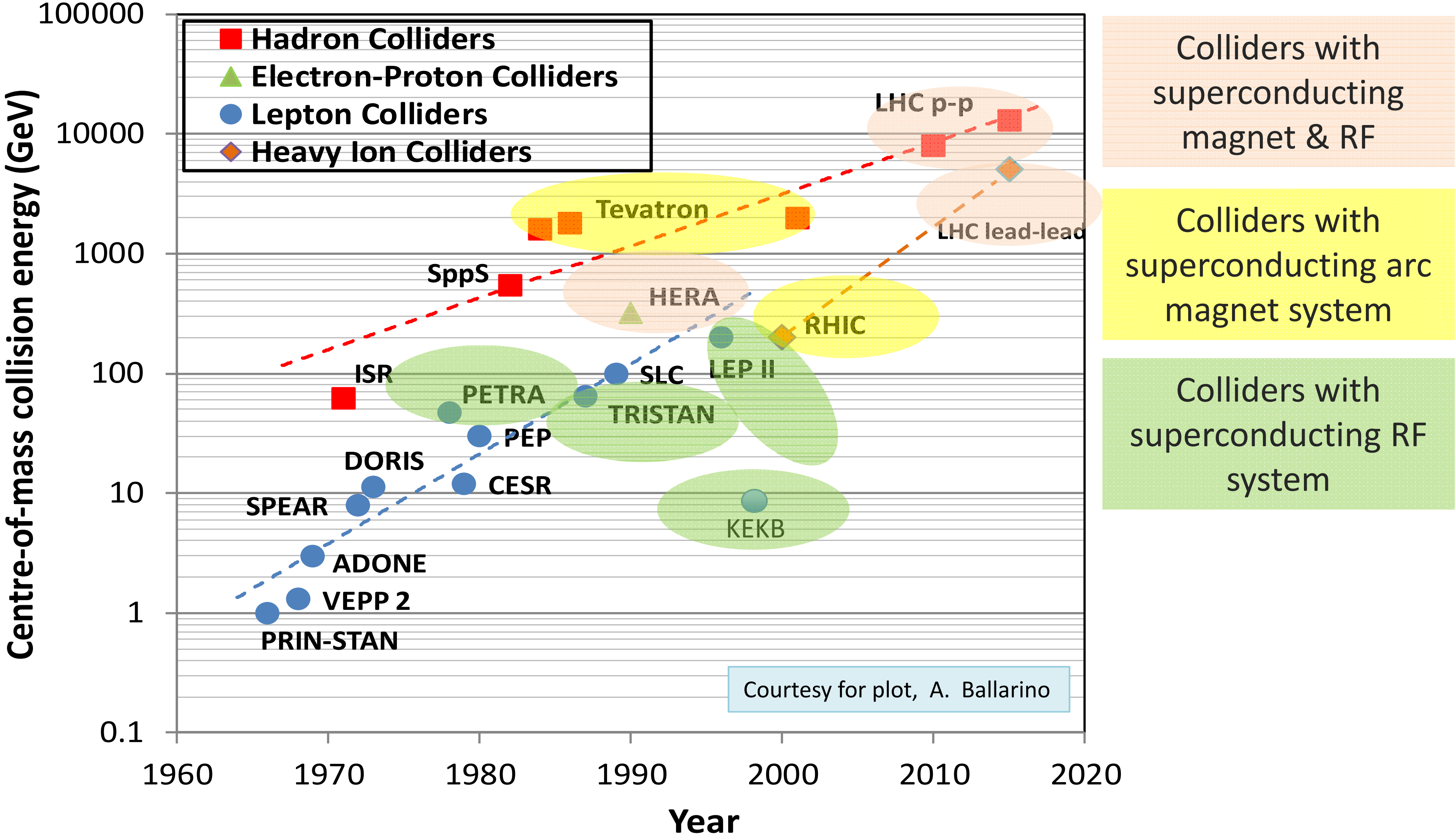
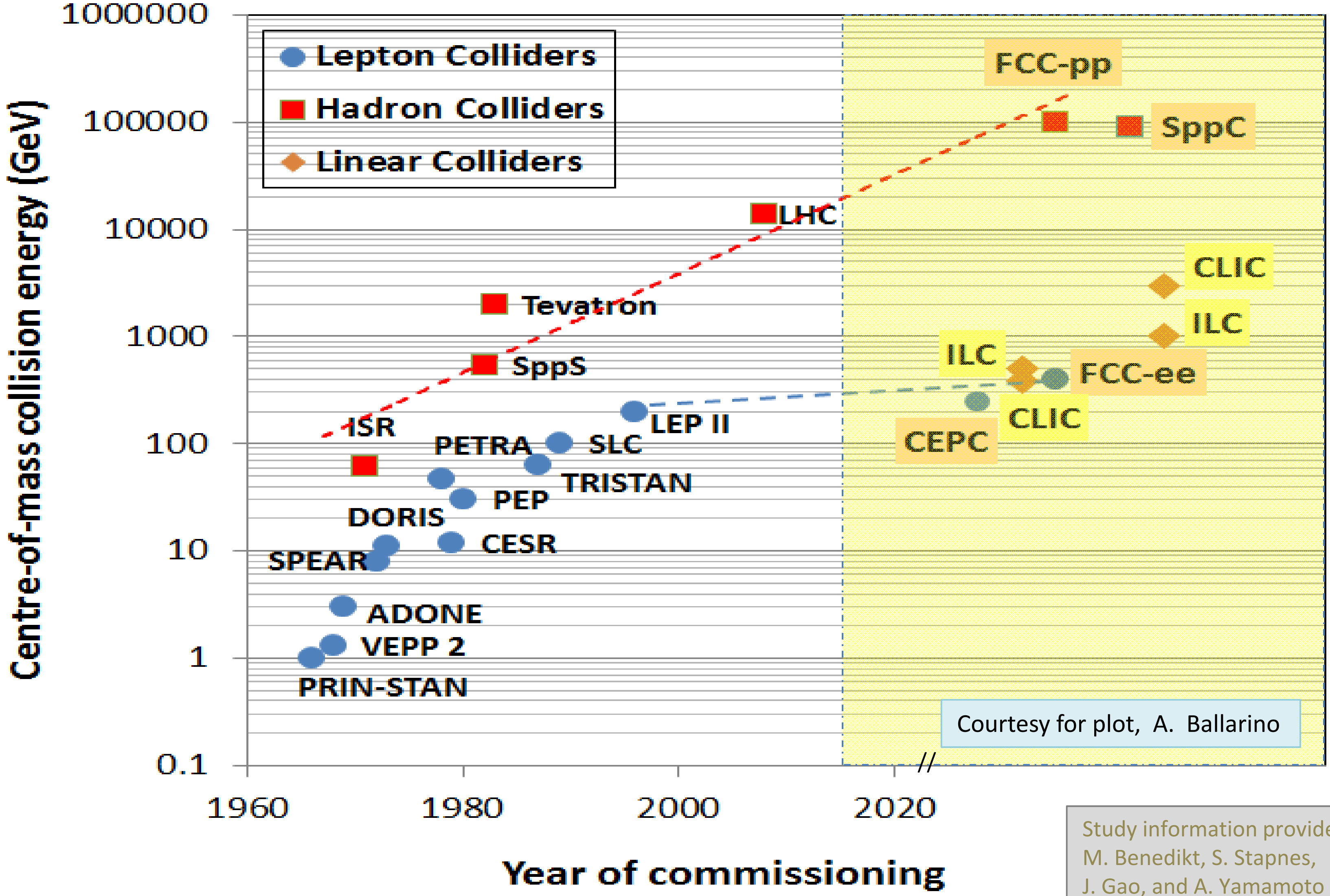
Outline

- **Introduction**
- Superconducting Magnets and the Future
- Superconducting RF and the Future
- Summary

Colliders constructed and operated



Future High Energy Colliders under Study

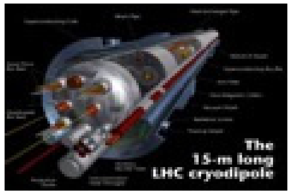


Study information provided by M. Benedikt, S. Stapnes, J. Gao, and A. Yamamoto

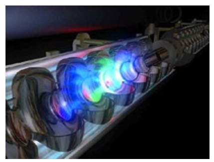
Courtesy, CZ. Antoine, H. Padamsee

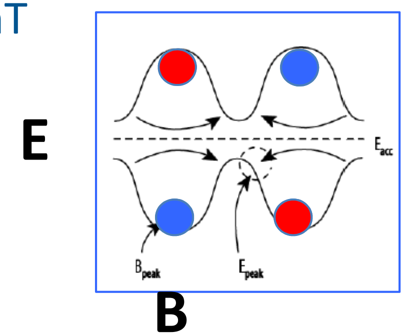
Superconducting Phases and Applications

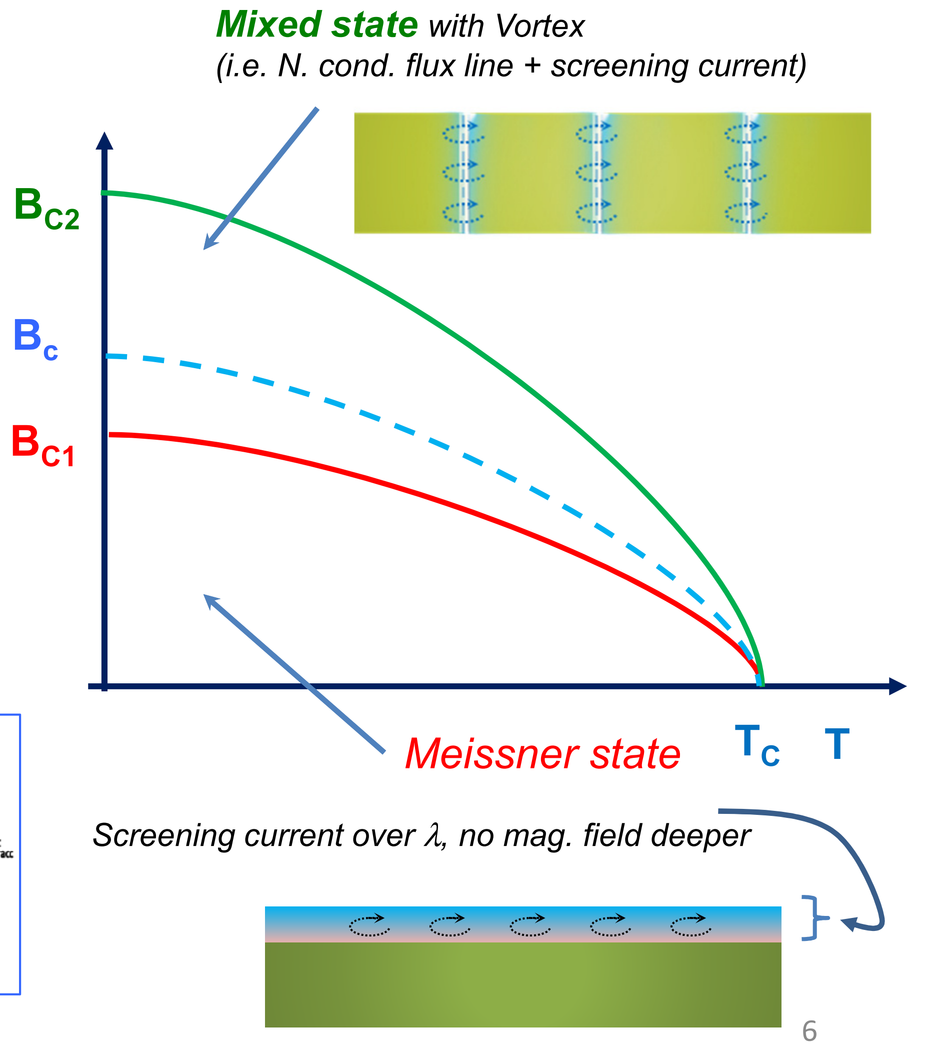
- **SC magnet → mixed state** w/ vortex
  - Bc2 : reaching high field
    - NbTi (Bc2, Tc) : 11.5 T, 9.5 K
    - Nb3Sn (Bc2, Tc) : 21.5 T , 18 K



- **SC RF → Meissner state** mandatory !
  - (B_{sh}: to be discussed later)
  - B_{C1} : Limit Meissner/mixed state
    - Nb (B_{c1}) : highest 180 mT



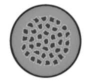


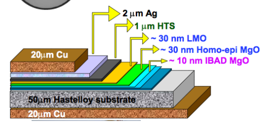


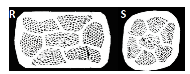
Courtesy, H. Padamsee, R. Flukiger, A. Ballarino

Possible Choices among SC Materials

Material	T_c [K]	ρ_n [μΩ.cm]	$B_c(0)$ [T]	$B_{c1}(0)$ [T]	$B_{c2}(0)$ [T]	Pen. depth λ(0) [nm]	Type
Pb	7.2	--	0.08	N/A	N/A	48	I
Nb	9.2	2	0.25	0.18	0.28	40	II
NbTi	9.2 ~9.5		--	0.067	11.5 ~ 14	60	II
NbN	17.3	35	--	(0.02)		150-200	II
Nb_3Sn	18.3	20	0.54	(0.05)	28 ~30	80	II
MgB_2	39	0.1-10	0.43	(0.03)	39	140	II
$YBa_2Cu_3O_7$ (REBCO family)	92	--	1.4	0.01	100	150	II
$Bi_2Sr_2Ca_1Cu_2O_8$ (BSCCO-2212)	94	--	--	0.025	>100/30	1800	II
$Bi_2Sr_2Ca_2Cu_3O_{10}$ (BSCCO-2223)	110	--	--	0.0135	>100/30	2000	II
Note Important for:				RF	Magnet		







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Advances in SC Magnets for Accelerators

1980

Progress:
- ISR-IR
- Tevatron (Fermilab)
- TRISTAN-IR (KEK)
- HERA (DESY)
- Nuclotron (JINR)
- LEP-IR (CERN)
- KEKB-IR (KEK)

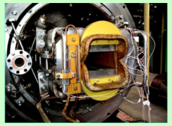
2000

In Operation:
- **RHIC (BNL)**
- **LHC (CERN)**
- **SRC (RIKEN) .....**
- **.....**

SC-Ring Cyclotron

Under Construction
- **FAIR (GSI) ....**
- **HL-LHC (CERN)**
- **NICA (JINR)**

Fast-cycle acc.



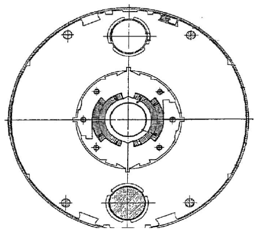
2020

To be realized
- JLEIC / eRHIC (e-Ion)
- FCC-hh / HE-LHC
- SppC

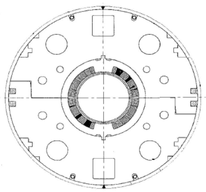
Main Dipole

Tevatron-D.

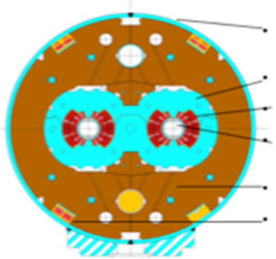
HERA-D.



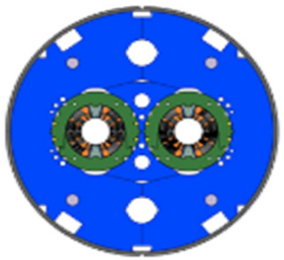
RHIC-D.



LHC.D (NbTi)

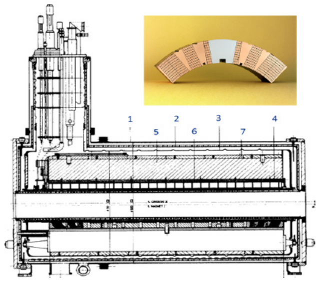


HL-LHC 11T-D (Nb_3Sn)



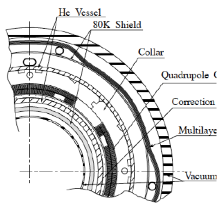
IR Quadrupole

ISR-IRQ.

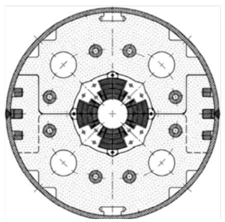


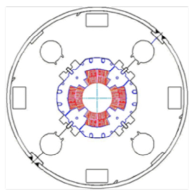
LEP-IR

Tristan / KEKB

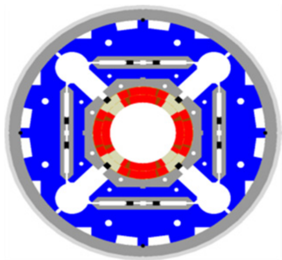


LHCC-IRQ (NbTI)



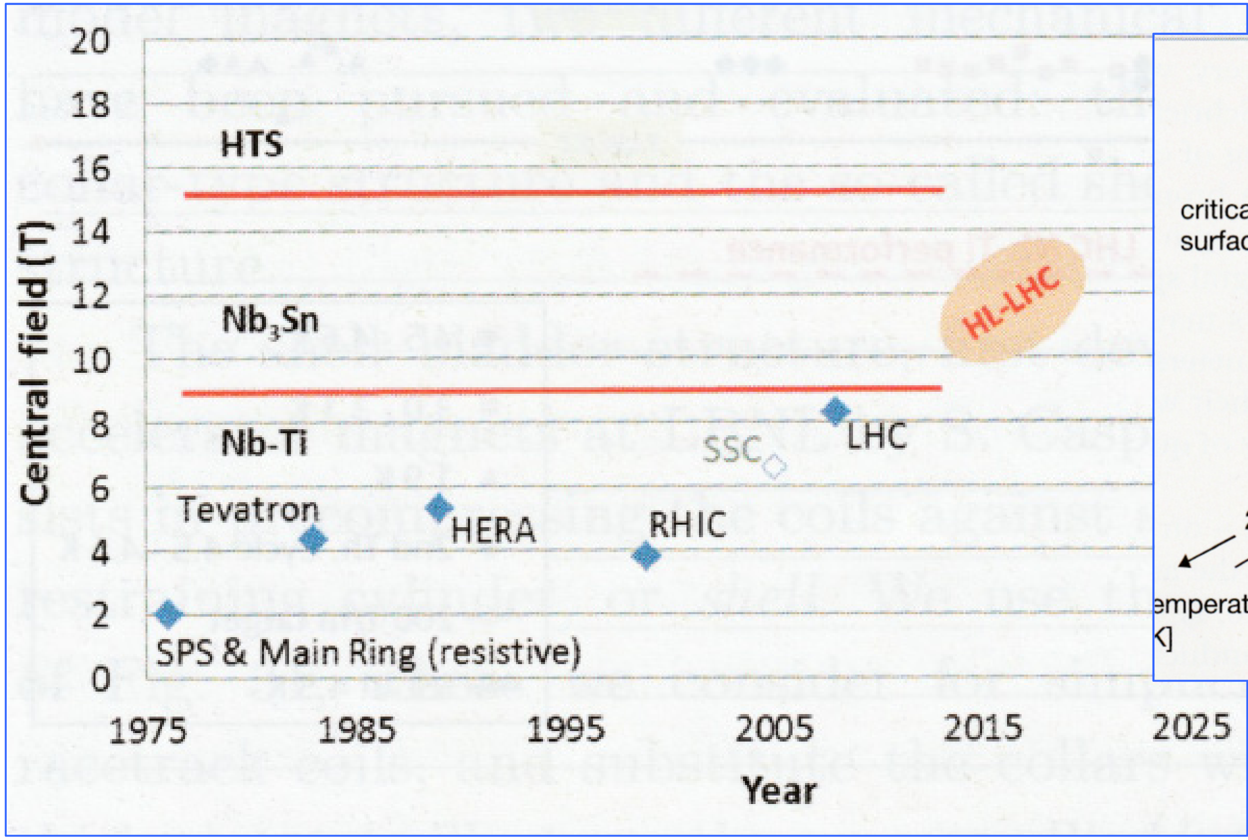


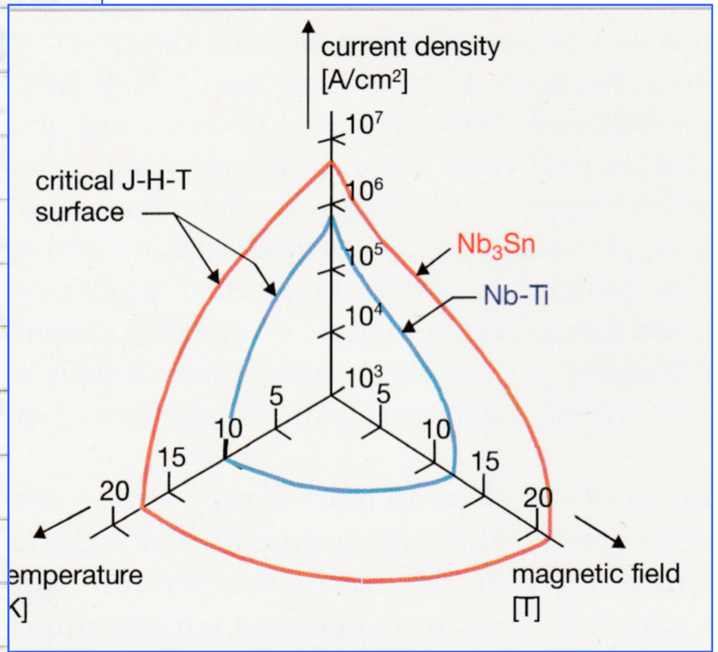
HL-LHC-IRQ (Nb_3Sn



Courtesy, L. Rossi,

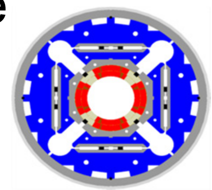
Nb_3Sn for realizing Higher Field





HL-LHC as a critical milestone for the Future of Acc. Magnet Technology

- **US-LARP Collaboration** has been taking the essential role to demonstrate:
  - **Nb3Sn** superconductor and acc. magnet-technology, overcoming the very brittle feature (like ceramic) after "winding, reacting", and impregnating w/ epoxy-resin, and
  - **Mechanical structuring w/ Bladder technology** for rigid & reliable supporting ***magnetic pressure*** proportional to **B^2** ,

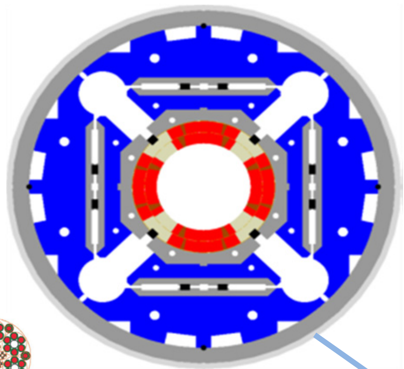


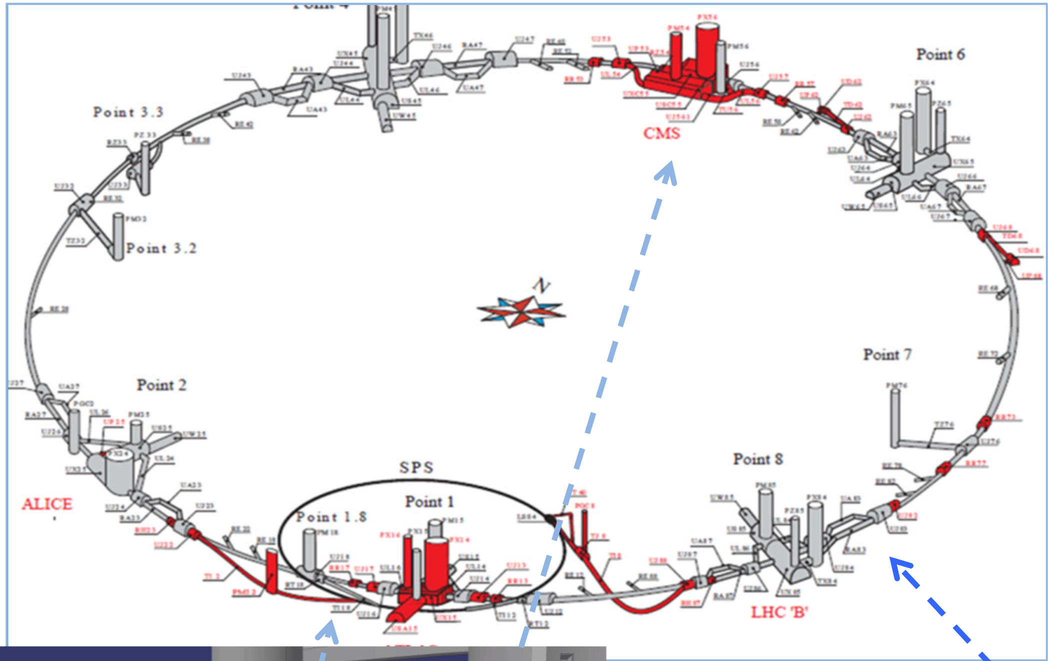
- **CERN** has been leading HL-LHC global collaboration and the Nb_3Sn accelerator-quality magnet technology being matured for the project realization. It shall be a fundamental step for future collider accelerators.

Courtesy, L. Rossi

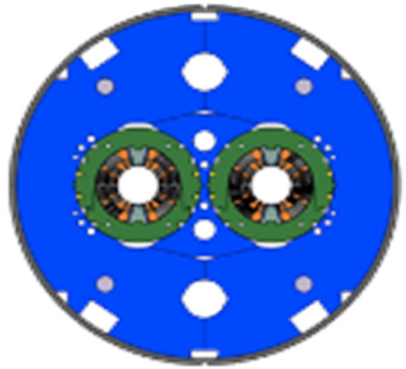
Nb_3Sn Superconducting Magnets (> 11 T) and MgB_2 SC Links for HL-LHC

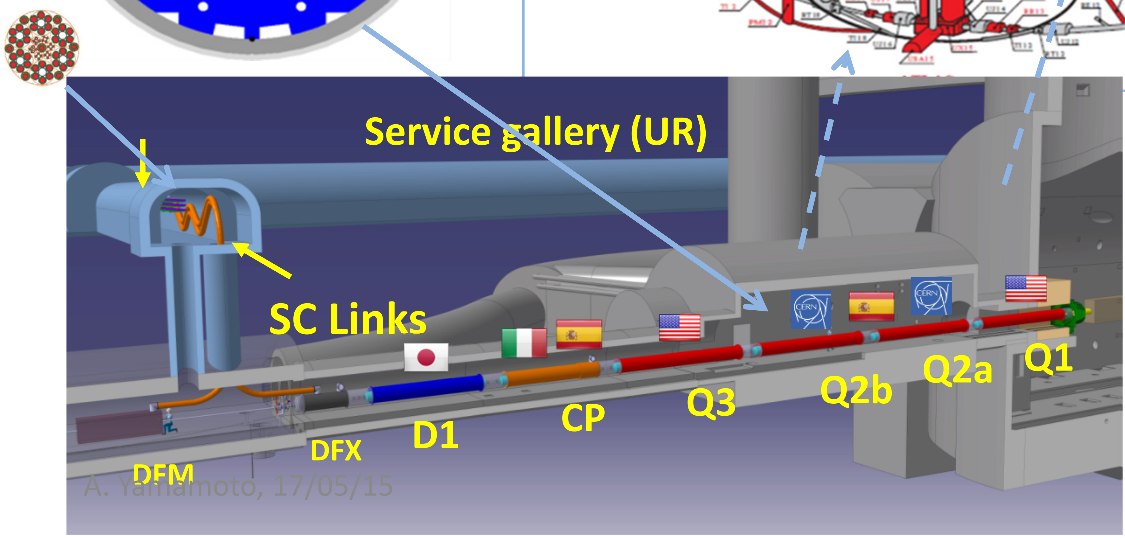
IR-FF Quadrupole (MQXF)

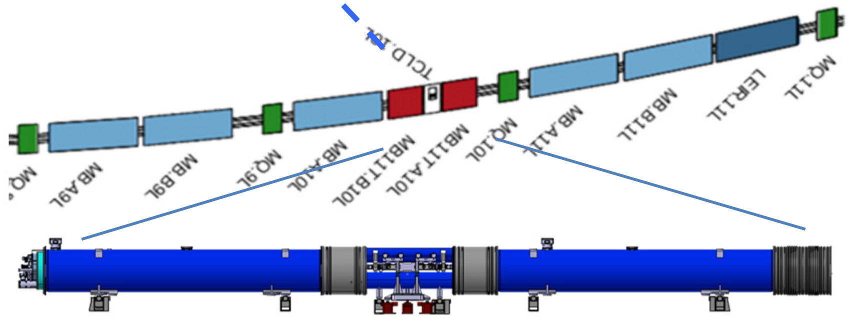




11 T Dipole w/ Collimator

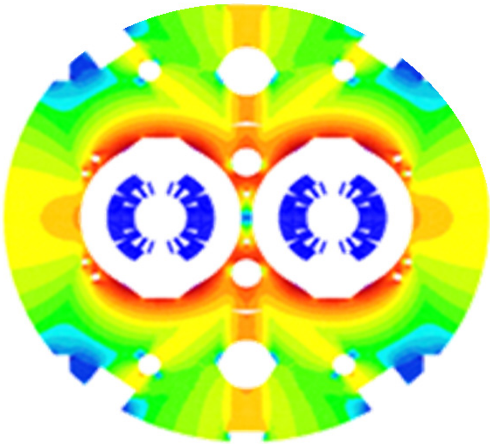


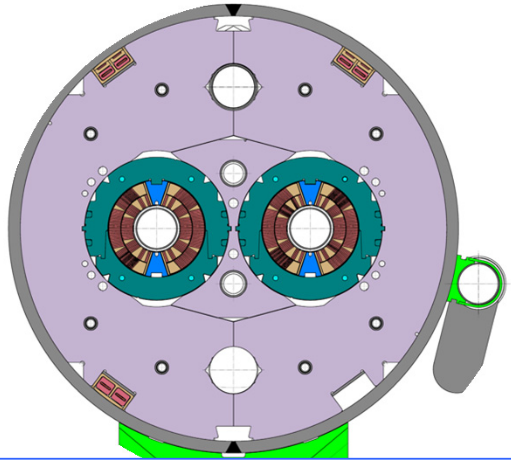


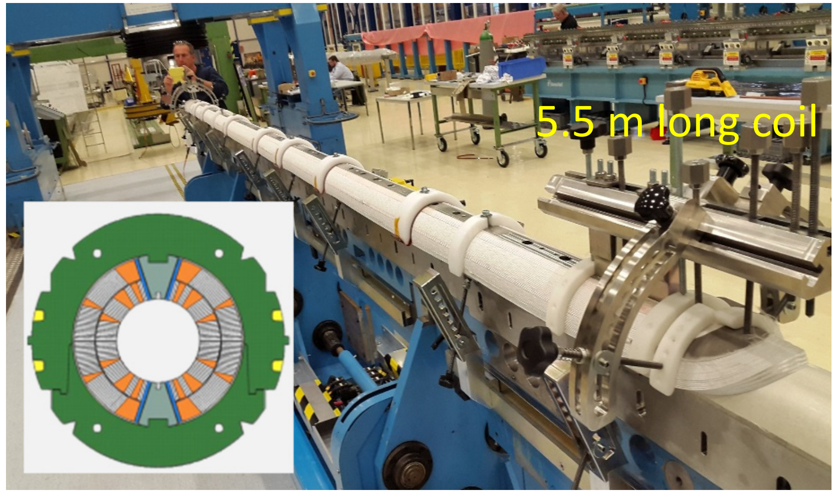


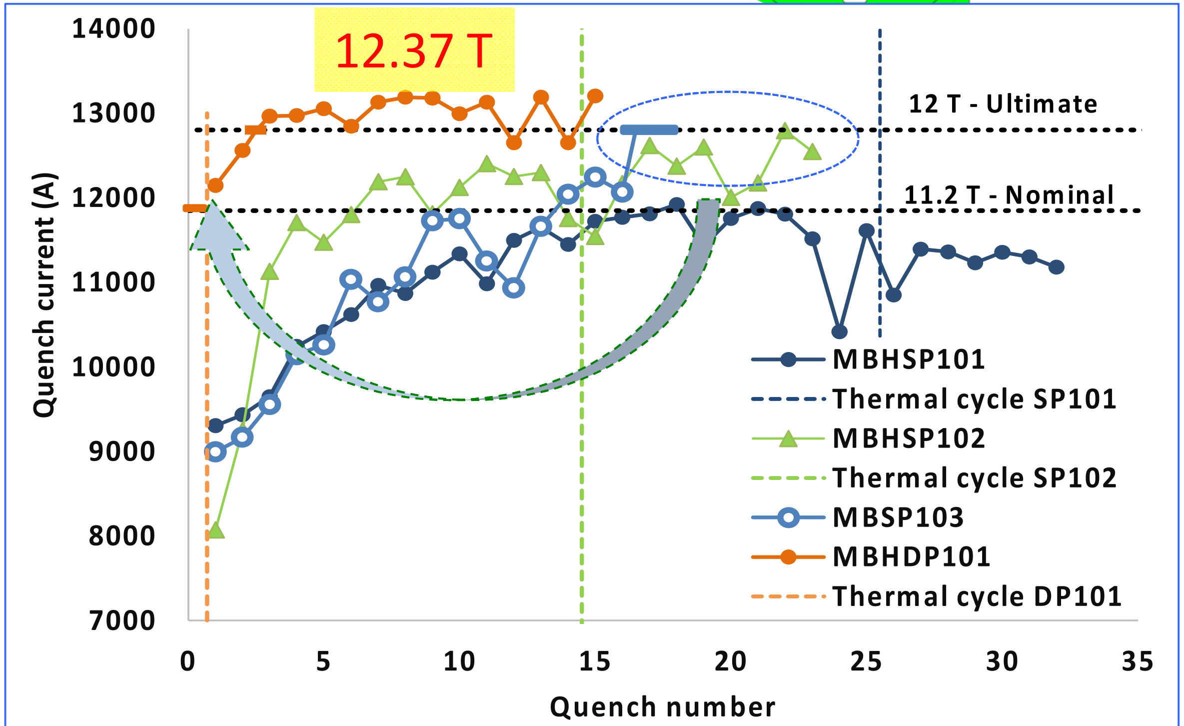
Courtesy, L. Bottura, F. Savary

HL-LHC, 11T Dipole Magnet



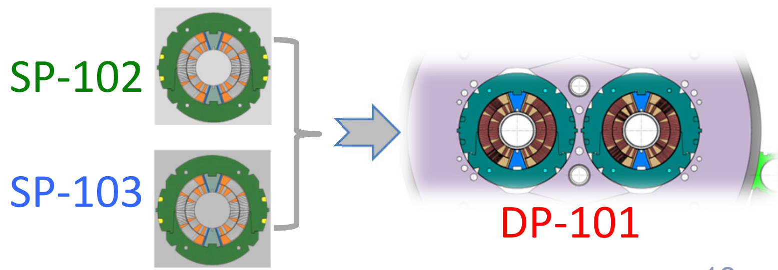




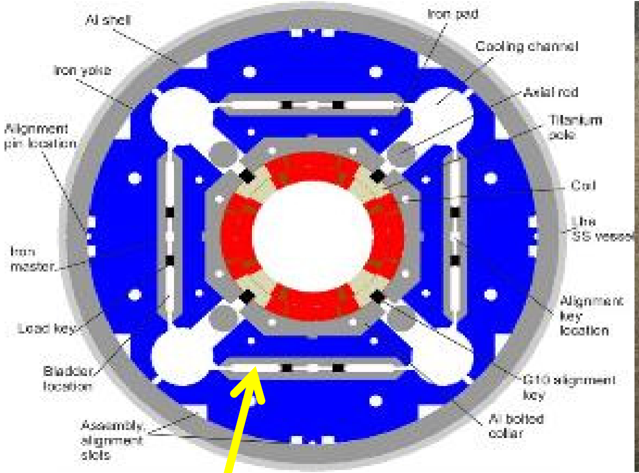


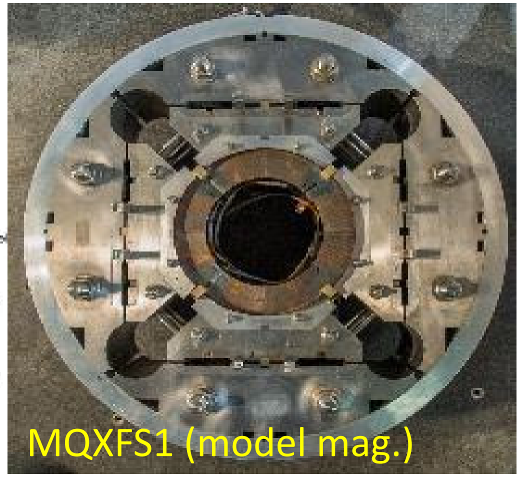
> 12 T achieved w/ the Twin Dipole, (MBHDP101), assembled:

- using two sets of coils already **"trained"** single aperture dipoles (MBHSP-102 & -103).

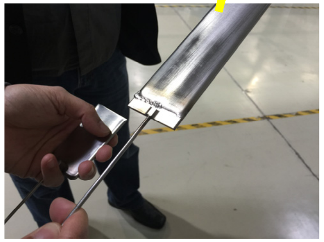


Nb_3Sn Quadrupole (MQXF) at IR

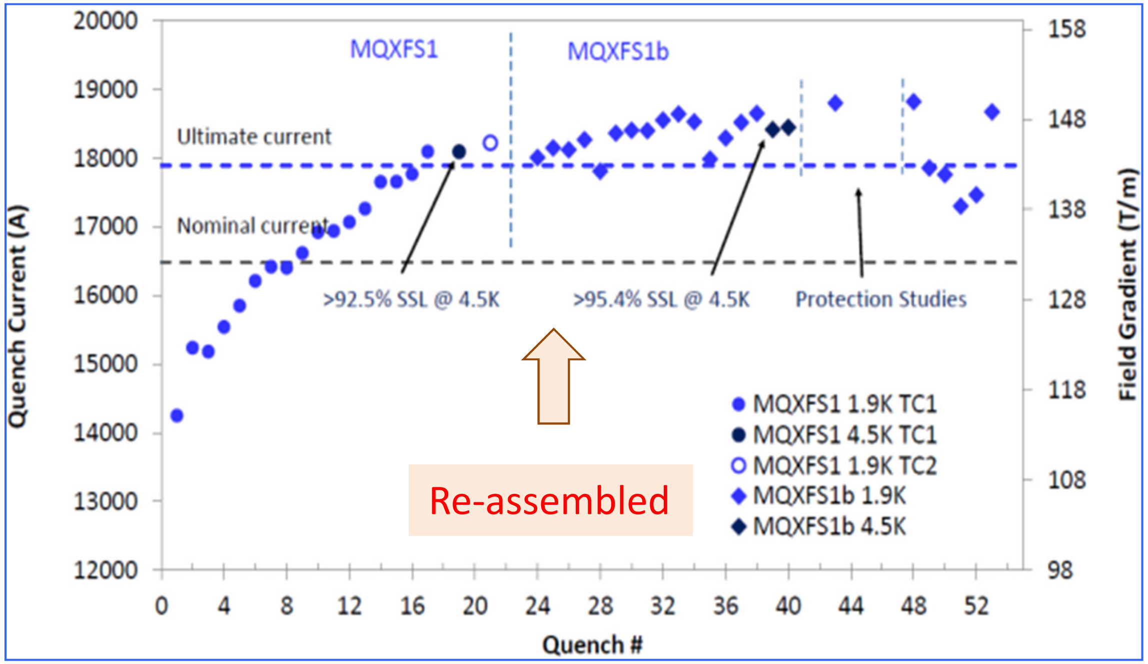


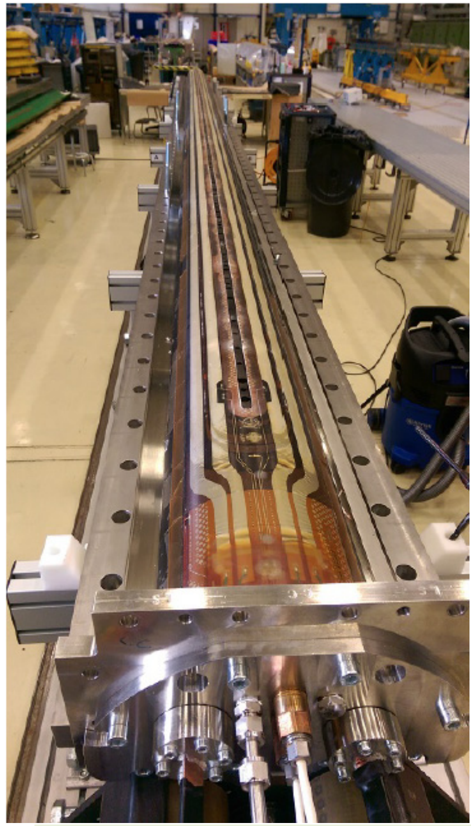


Courtesy,
- LARP:
  G. Ambrosio, G. Chlachidze
- HiLumi:
  E. Toddesco, P. Ferracin



Bladder, as a key concept/technology developed at LBNL





7 m long prototpe coil, at CERN, Jan. 2017

A. Yamamoto, 17/05/15

Courtesy, M. Benedikt

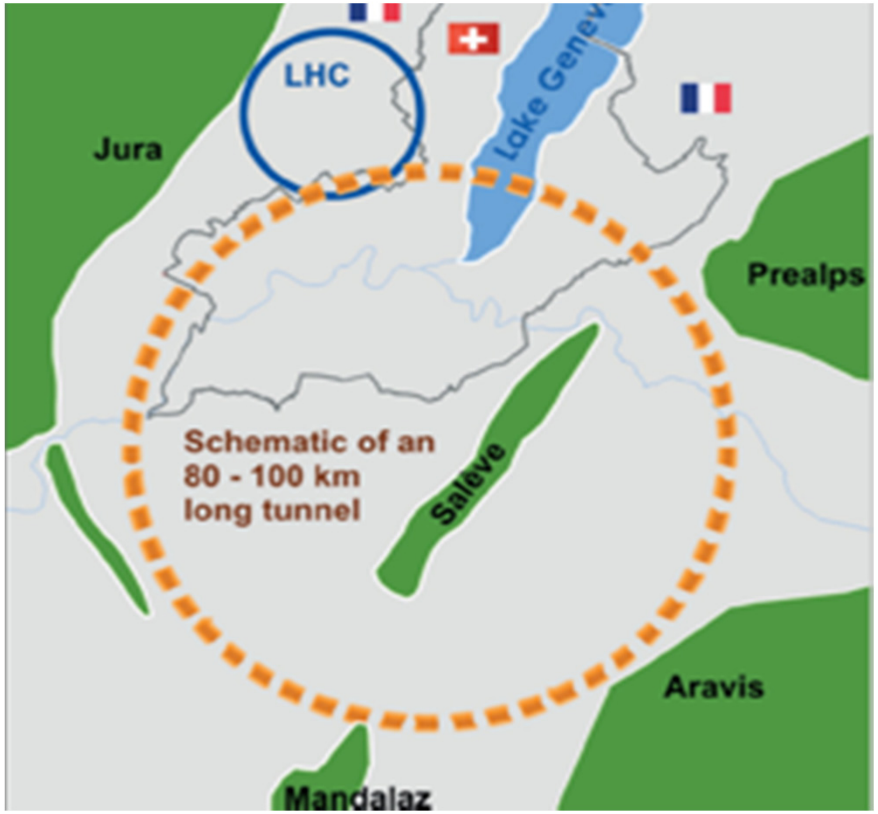
Future Circular Collider Study

FCC

- **pp** collider (FCC-hh)
  - Defines infrastructure requirements

    16 Tesla superconducting magnets →
  - **100 TeV** centre of mass in
  - **100 km** long tunnel
- **e^+e^-** collider (FCC-ee)
  - Potential intermediate step

    SRF cavities →
  - **Extreme luminosities** at 90–350 GeV



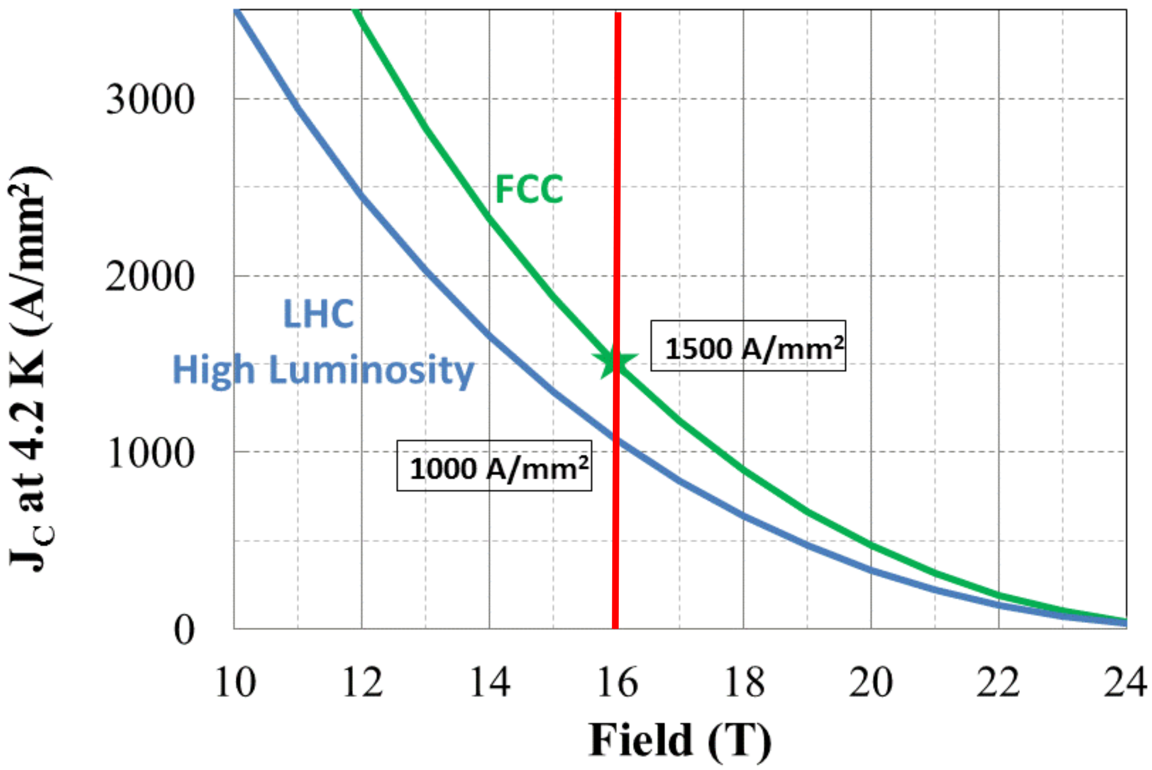
HE LHC

- based on 16T FCC magnets
- Energy doubling
  - **Leverage** existing CERN accelerator complex

Courtesy, A. Ballarino

Nb_3Sn conductor program

- **Nb_3Sn** is one of the **major cost & performance** factors for FCC-hh
- **Highest attention** is given



Main development goals by 2020:

- **J_c (16T, 4.2K) > 1500 A/mm²**

  i.e. 50% increase wrt HL-LHC wire
- Potentials for large scale production and cost reduction

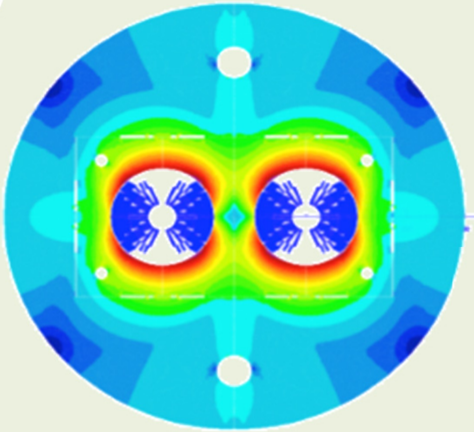
Global cooperation on going :

- CERN/KEK/Tohoku – JASTEC, Furukawa
- CERN/Bochvar High-tec. Res. Inst
- CERN/KAT
- CERN/Bruker
- T.U. Vienna, Geneve U., U. Twente,
- Florida S.U. - Appl. Superc. Center
- New US-DOE "Mag. Dev. Program (**MDP**)

Courtesy, M. Benedikt, L. Bottura, D. Tommasini, S. Gourlay

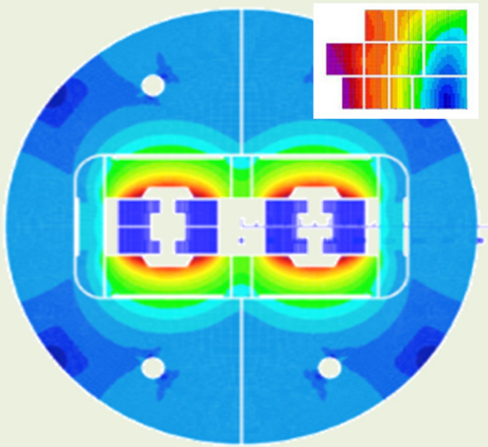
16 T Dipole Options and R&D sharing

Cos-θ

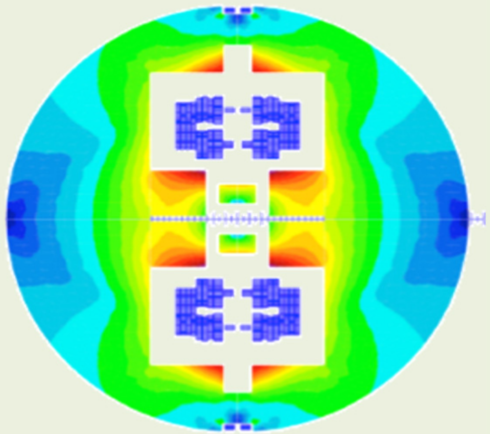


EuroCirCol
A key to New Physics

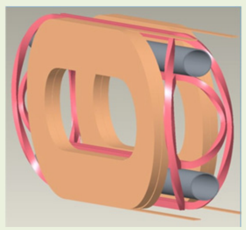
Blocks



Common coils

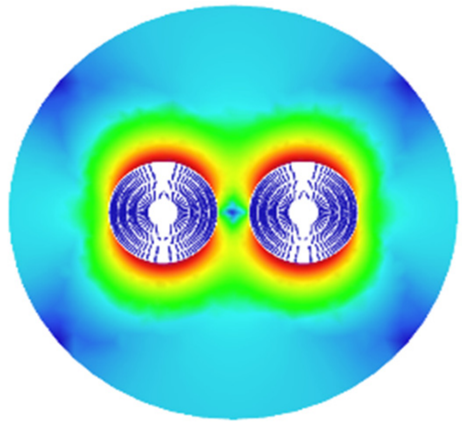


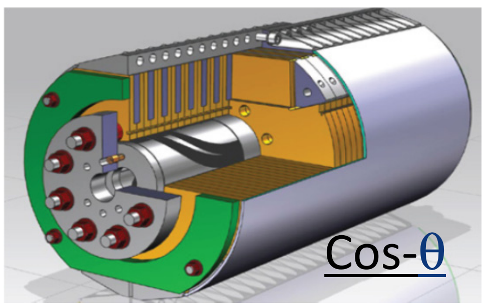
Pioneering work at BNL



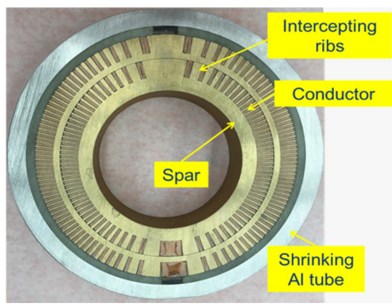
Swiss contribution
via PSI

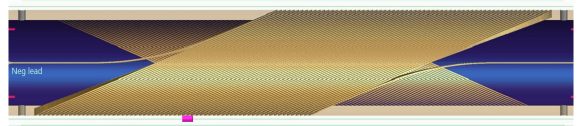
Canted Cos-θ (CCT)





U.S. MAGNET DEVELOPMENT PROGRAM



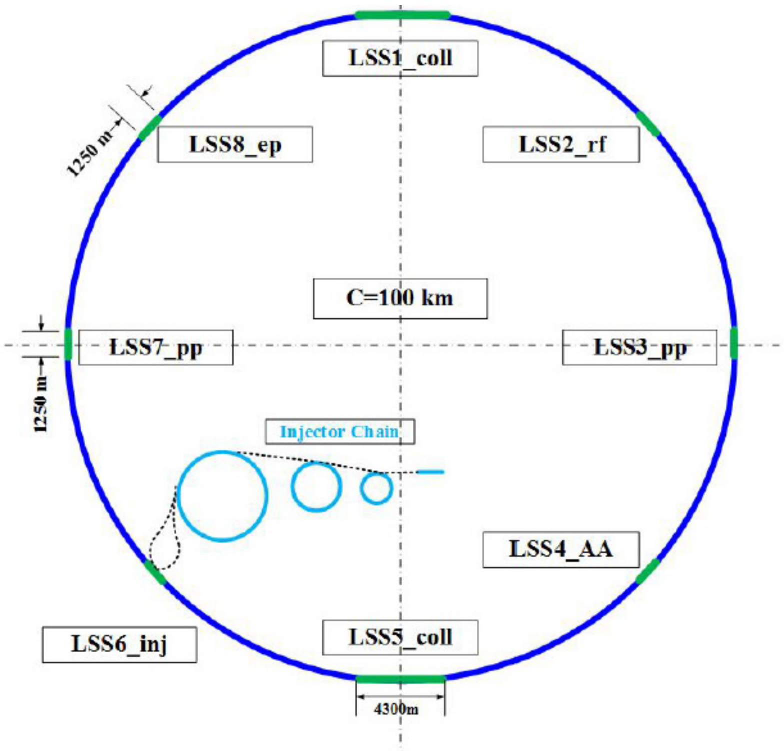


CCT,
Pioneering work at LBNL

Courtesy, J. Gao, Q. Xu

Design Study and Develoment for SppC in China

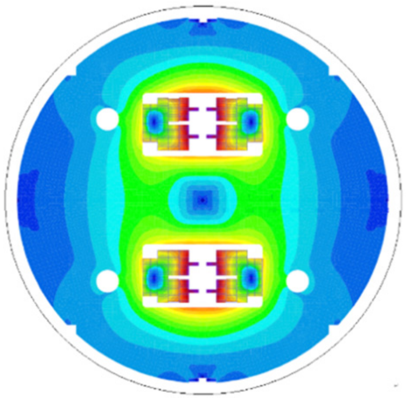
SppC w/ 100 km Circumference in design study, updated in 2016

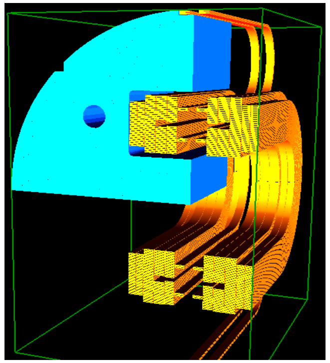


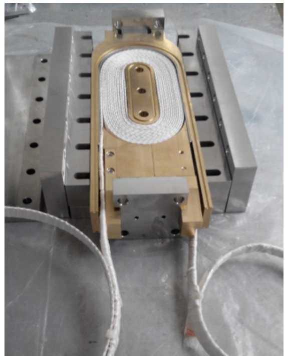
Design Study of the SppC Dipole Magnet

- A cooperative work started with institution of **Beijing, Hefei, Xi'an and Shanghai**, since 2014

- "Cosine-Theta vs **"Common Coil"** being studied,
- An approach with a 20T "common coil' started w/ small sub-scale coil development.

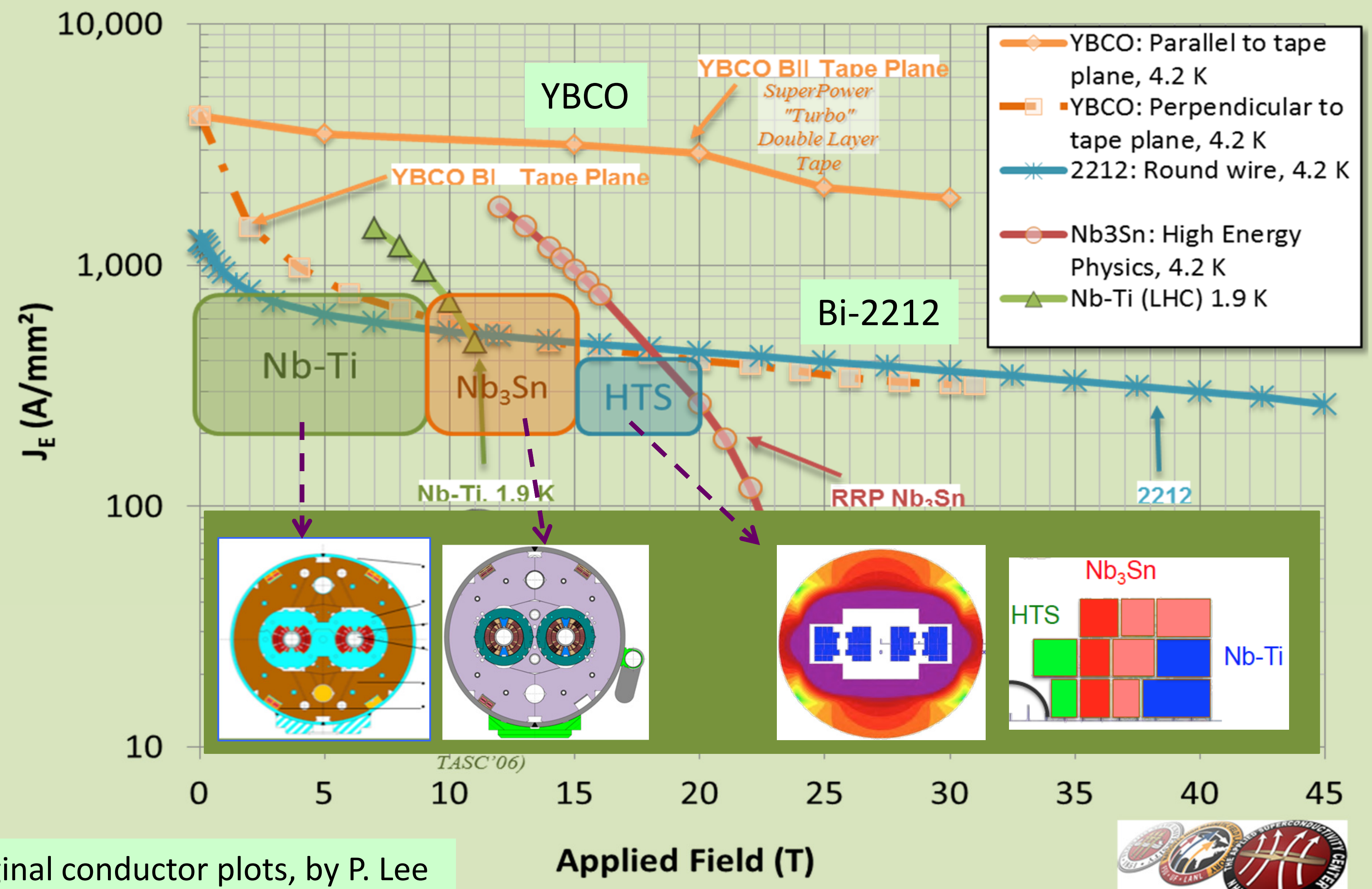






Courtesy, P. Lee, L. Rossi

High-Field Superconductor and Magnets



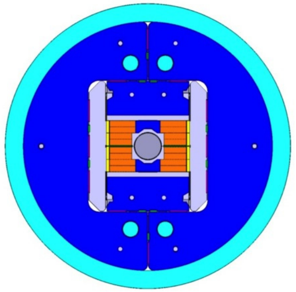
Original conductor plots, by P. Lee

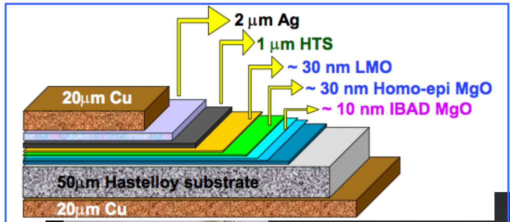
Courtesy, L. Rossi, L. Bottura, G. Kirby

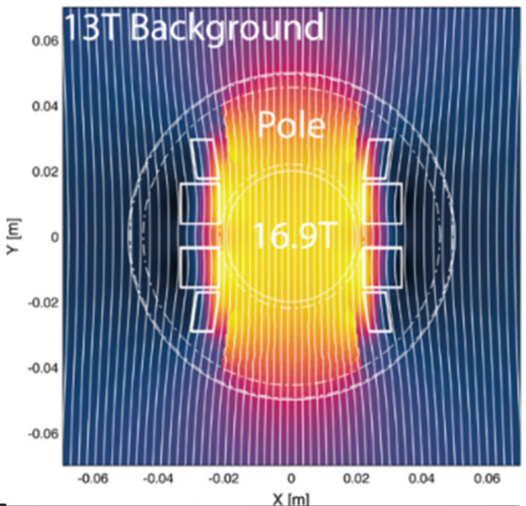
HTS Block Coil R&D for 20 T

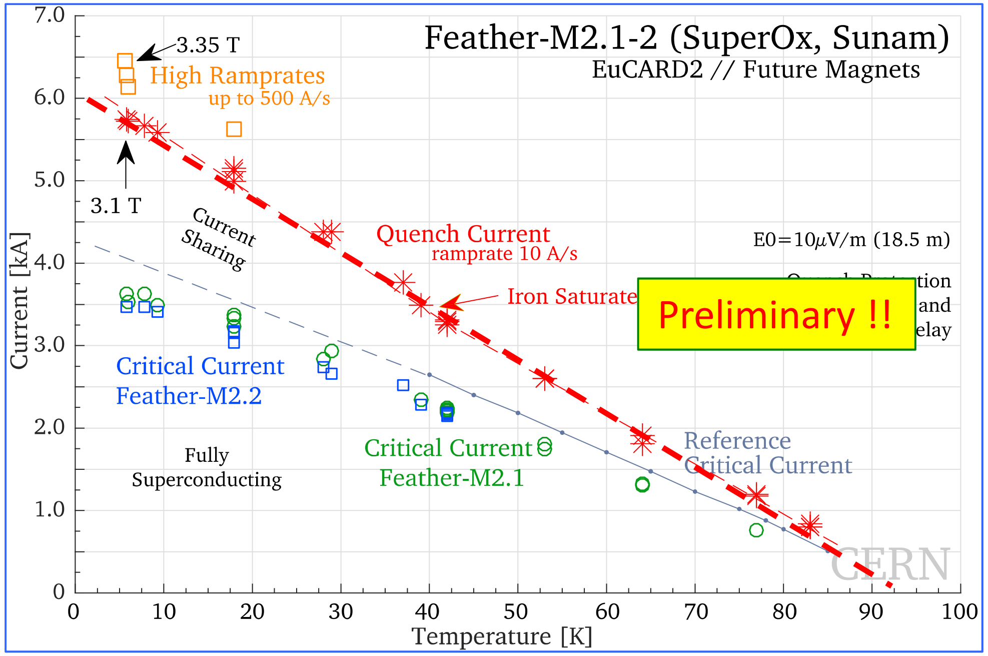
- 5 T HTS (REBCO) stand-alone dipole (5 T) to be tested in a background field of 13 T

Smooth temp. dependence indicating full- conductor performance demonstrated





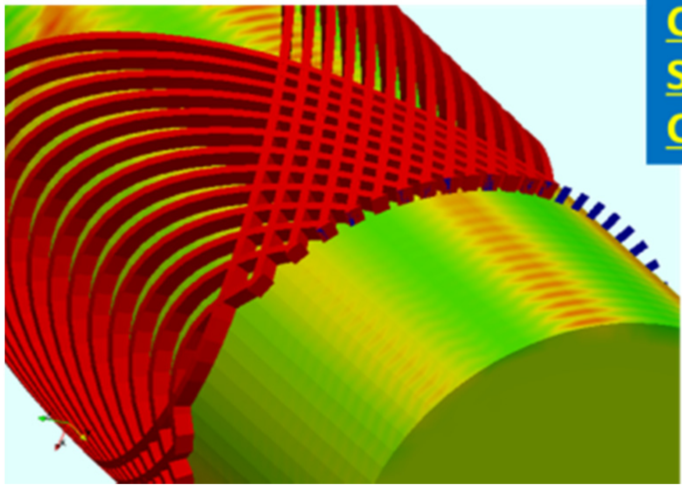




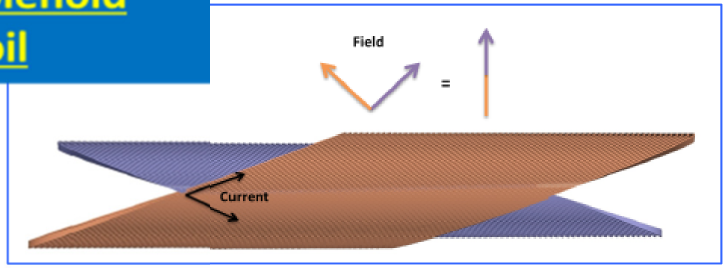
J. Van Nugteren, G. Kirby, G. de Rijk, et al.,

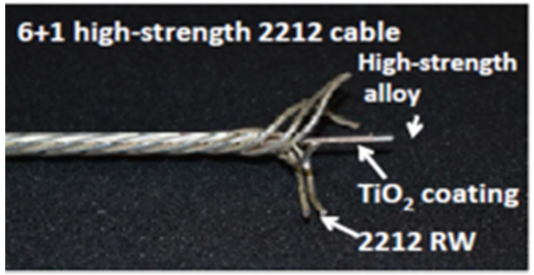
Courtesy, S. Caspi, G. Kirby

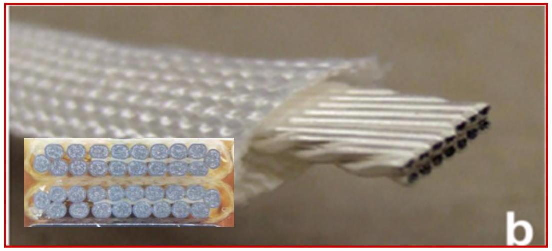
Canted Cosine Theta (CCT) Coil suitable with Brittle HTS Conductor

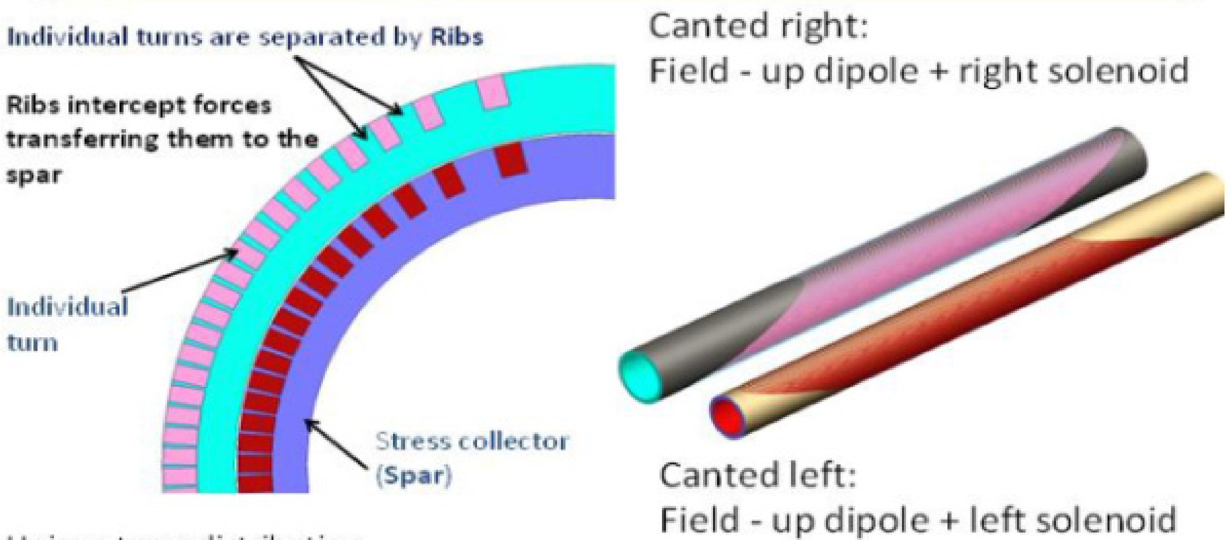


Canted Solenoid Coil









Unique turns distribution

$J_z \sim \cos\vartheta$

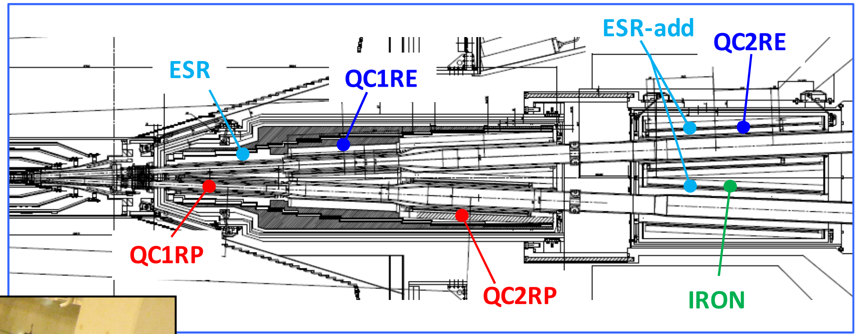
*D.I. Meyer and R. Flasck "A new configuration for a dipole magnet for use in high energy physics application", Nucl. Instr.and Methods 80, pp. 339-341, 1970.)

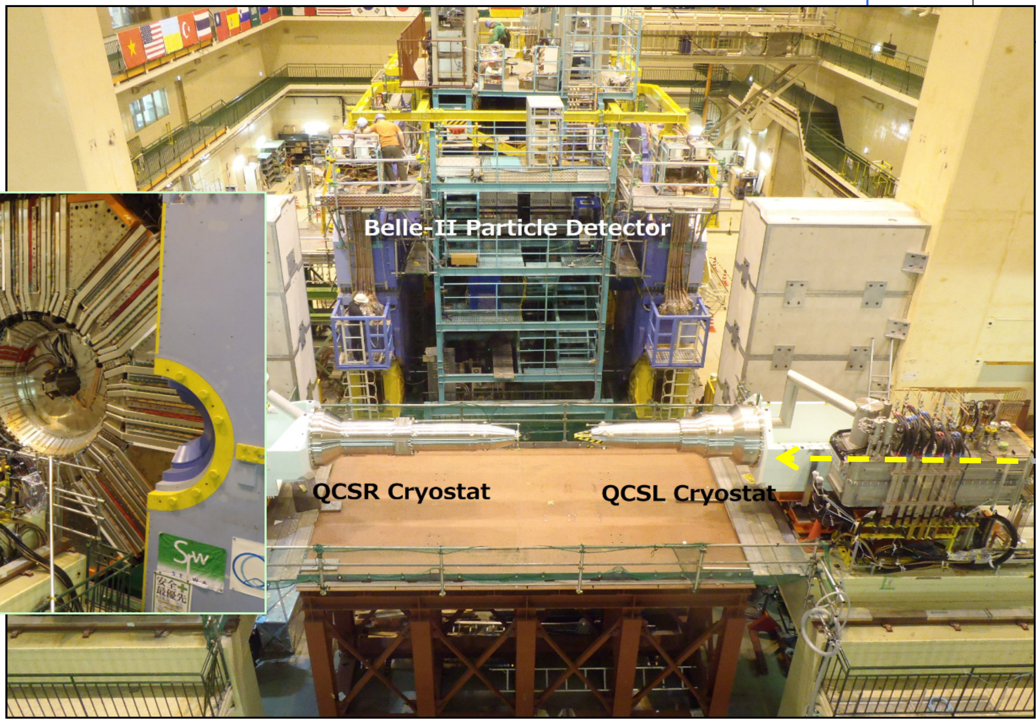
Courtesy, N. Ohuchi

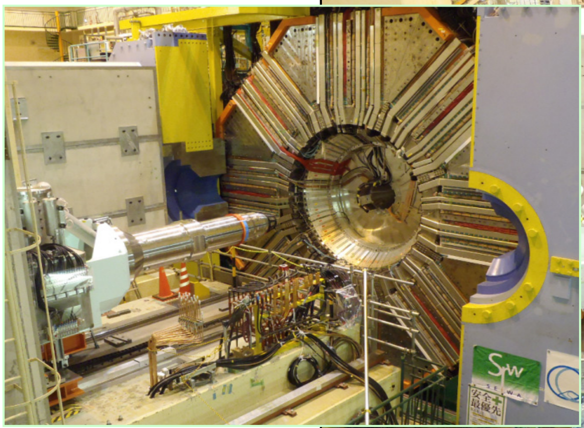
A topic at KEK: S-KEKB IRQs just integrated w/ BELLE-II !

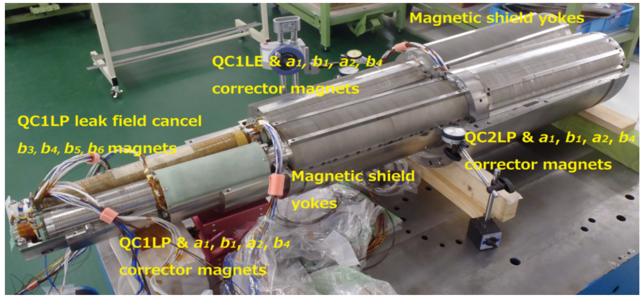
55 SC magnets integrated into 2 cryostats

- 8 main quadrupoles
- 43 correctors
- 4 compensation solenoids

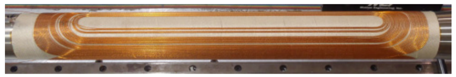




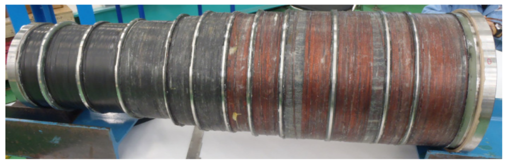




3 Main-Q & 16 Correctors assembled



Corrector coils by **direct-winding** at BNL



Compensation solenoid

- The Super-KEKB IR magnet system integrated in March 2017, and
- Belle-II detector moved to the IR.

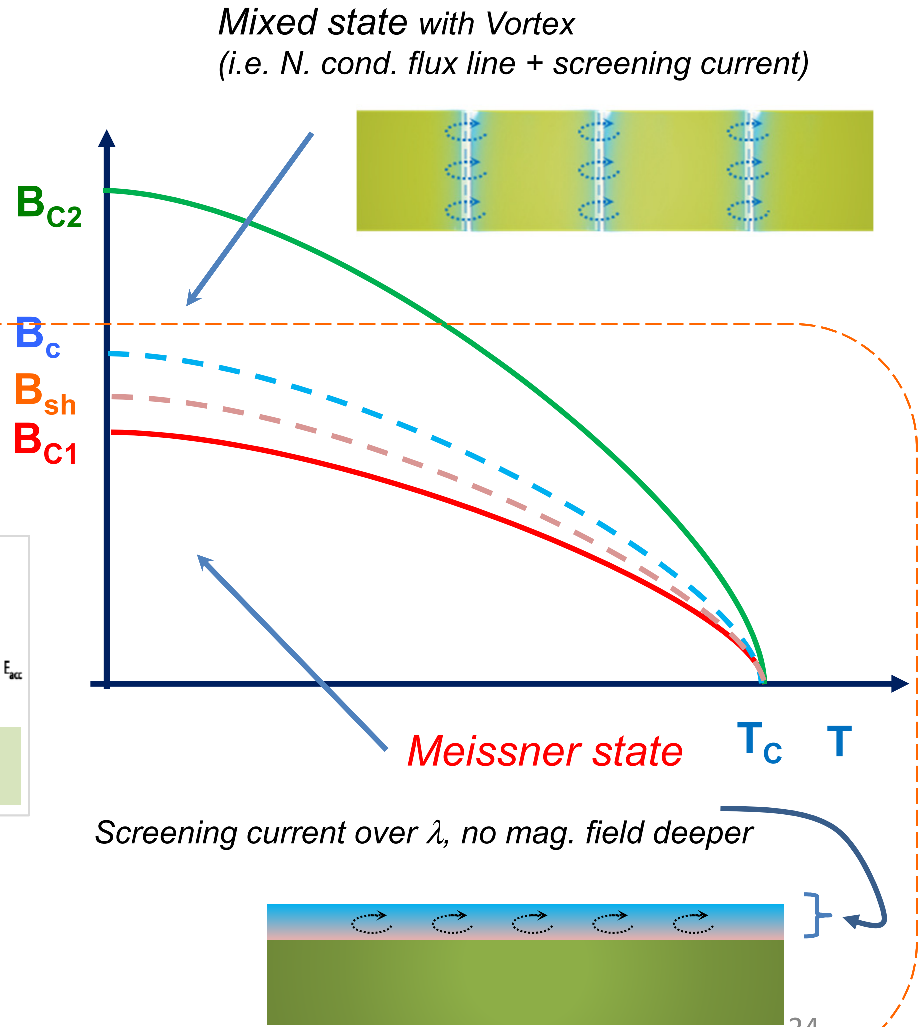
Outline

- Introduction
- Superconducting Magnet and the Future
- **Superconducting RF and the Future**
- Summary

Courtesy, CZ. Antoine, H. Padamsee

Superconducting Phases and Applications

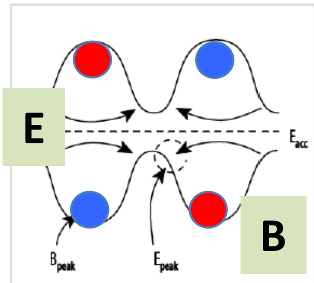
- SC magnet → mixed state w. vortex
  - Bc2 = reaching high field
    - NbTi (Hc2, Tc) : 11.5 T, 9.5 K
    - Nb3Sn (Hc2, Tc) : 21.5 T , 18 K
  - Vortices dissipate in !



- **SC RF** → Meissner state mandatory !

  More precisely:

  - B_{sh} **= practical limit for SRF**
    - $Bs_{sh\text{-}Nb}$: 210 mT
    - $Bs_{sh\text{-}NbSN}$: 430mT
    - $Bs_{sh\text{-}MgB2}$: 310mT
  - B_{C1} = limit Meissner/mixed state
    - **Bc1 = ~ 0.8 x B-sh, →**$Bc1_{Nb}$: 180 mT



Courtesy, H. Padamsee, R. Flukiger,

Possible Choices for SRF among SC Materials

Material	T_c [K]	ρ_n [μΩ.cm]	$B_c(0)$ [T]	$B_{c1}(0)$ [T]	$B_{sh}(0)$ [T]	$B_{c2}(0)$ [T]	Pen. depth $\lambda(0)$ [nm]	Type
Pb	7.2		0.08	--	--	--	28	I
Nb	9.2	2	(0.25)	0.18	0.21	0.28	40~50	II
NbTi	9.2 ~9.5		--	0.067	--	11.5 ~ 14	60	II
NbN	16.2	70	(0.23)	(0.02)	0.16		150-200	II
Nb_3Sn	18.3	8-20	(0.54)	(0.05)	0.43	28 ~30	80-110	II
MgB_2	39	0.1-10	(0.43)	(0.03)	0.31	39	140-185	II
$YBa_2Cu_3O_7$ (REBCO family)	92		(1.4)	0.01		100	150	II
$Bi_2Sr_2Ca_1Cu_2O_8$ (BSCCO-2212)	94		--	0.025		>100/30	1800	II
$Bi_2Sr_2Ca_2Cu_3O_{10}$ (BSCCO-2223)	110		--	0.0135		>100/30	2000	II
Note Important for:				RF		Magnet		

Advances in SRF Technology and Accelerators

1980

Progress (1988~)

- TRISTAN
- LEP-II
- HERA
- CEBAF
- CESR
- KEKB
- BES
- cERL

2000

In Operation: → Numbers

- SNS: 1 GeV
- FLASH: 1 GeV → ~60
- CEBAF 12 GeV Upgrade → 80
- ISAC-II, ARIEL
- Super-KEKB
- Hi-ISOLDE
- **European XFEL** → 800
- Further Light Sources …

Under Construction:

- **LCLS=II** → 300
- **FRIB** → 340
- PIP-II → 115
- **ESS** → 150
- CBETA
- RAON

2020

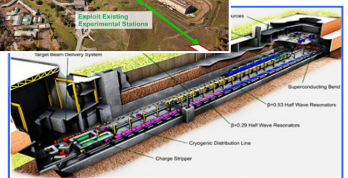
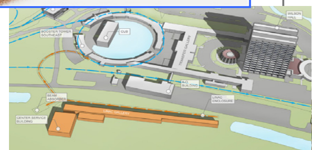
To be realized:

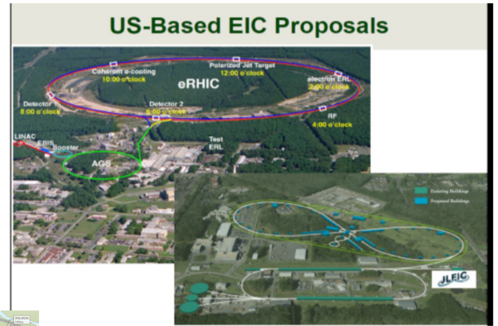
- HL-LHC-Crab → 20
- JLEIC / eRHIC
- **ILC → 16,000**
- FCC
- CEPC/SPPS
- **ADS**







A. Yamamoto, 17/05/15

Advances in SRF Technology and Accelerators

Progress (1988~)

- TRISTAN
- KEKB
- BES
- cERL

In Operation: → Numbers

- SNS: 1 GeV
- FLASH: 1 GeV → ~60
- European XFEL → 800
- Further Light Sources …

Under Construction:

- LCLS=II → 300
- FRIB → 340
- PIP-II → 115
- ESS→ 150
- CBETA
- RAON

To be realized:

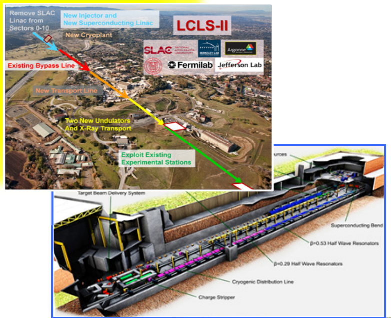
- HL-LHC-Crab → 20
- CEPC/SPPS
- ADS

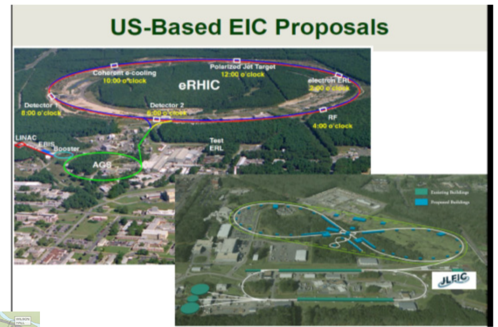
- > **2,000** SRF cavities realized, in last 10 years !
- **Many more** cavities to be realized in near future.

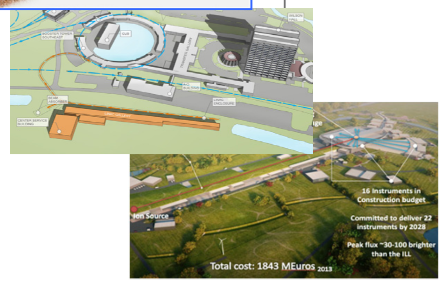
1980 — 2000 — 2020





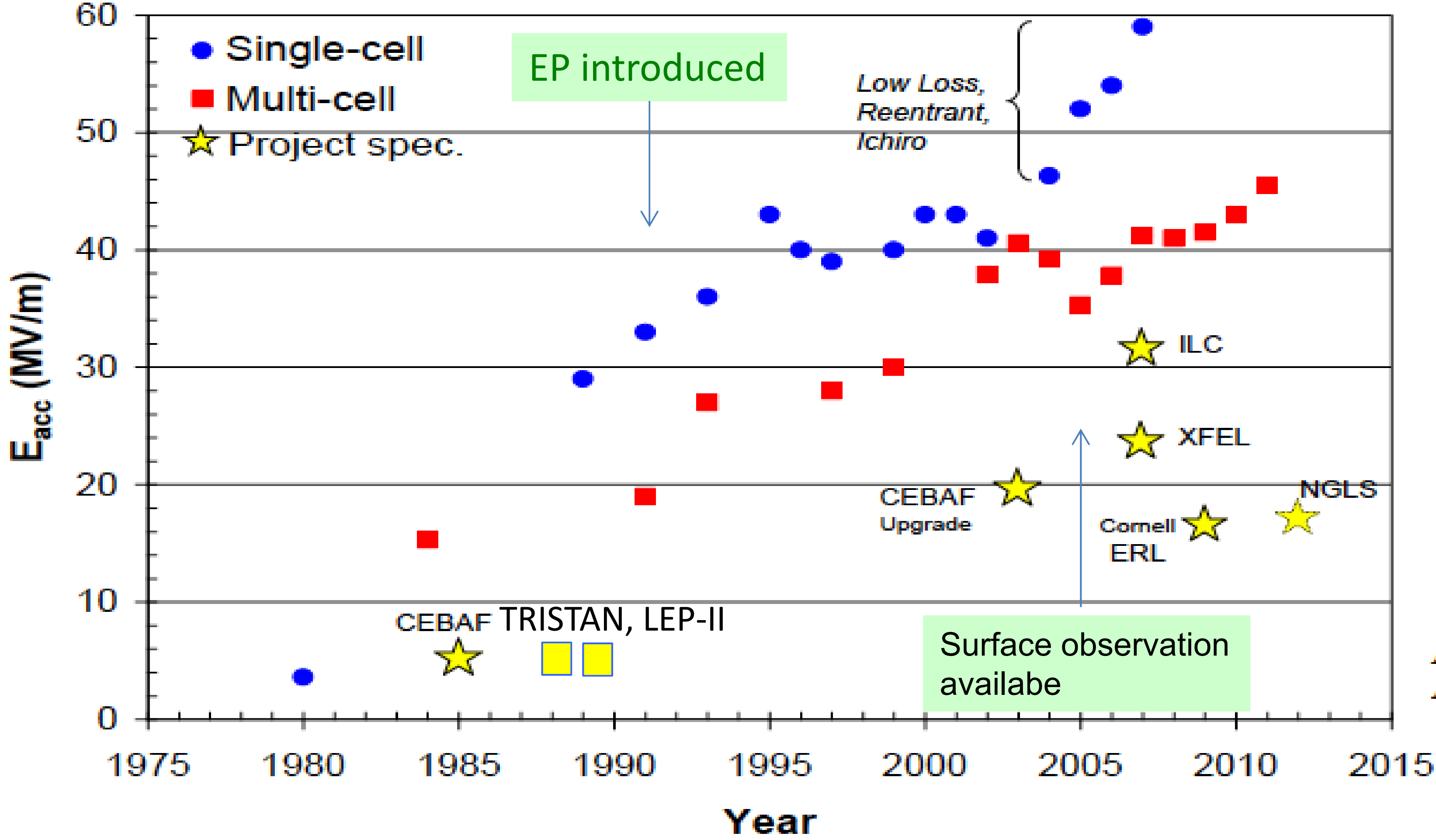







Courtesy: G. Ciovati, R. Geng

Advances in SRF Field Gradient



Gradient, > X 5 improved

Data is courtesy of R. Geng, JLab

G. Ciovati, IPAC'13

Courtesy, H. Weise

European XFEL, SRF Linac Completed

Progress:

2013: Construction started

…

2016: E- XFEL Linac completion

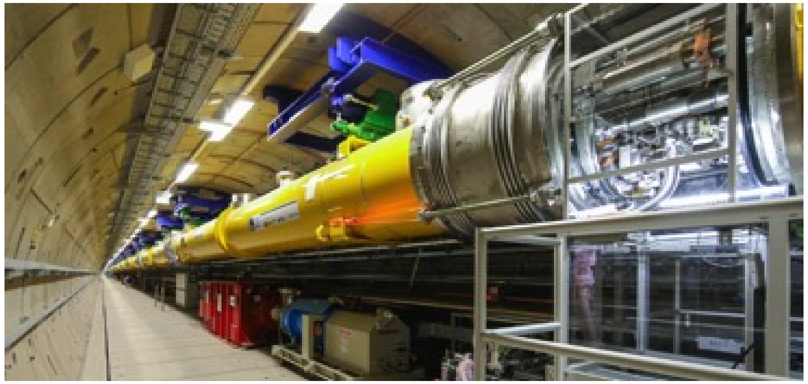
2017: E-XFEL beam start

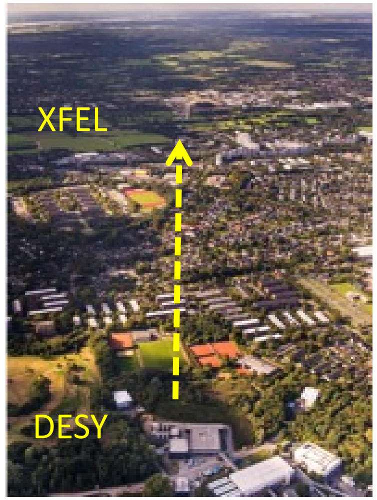
Note : ~ 1/10 scale to ILC-ML

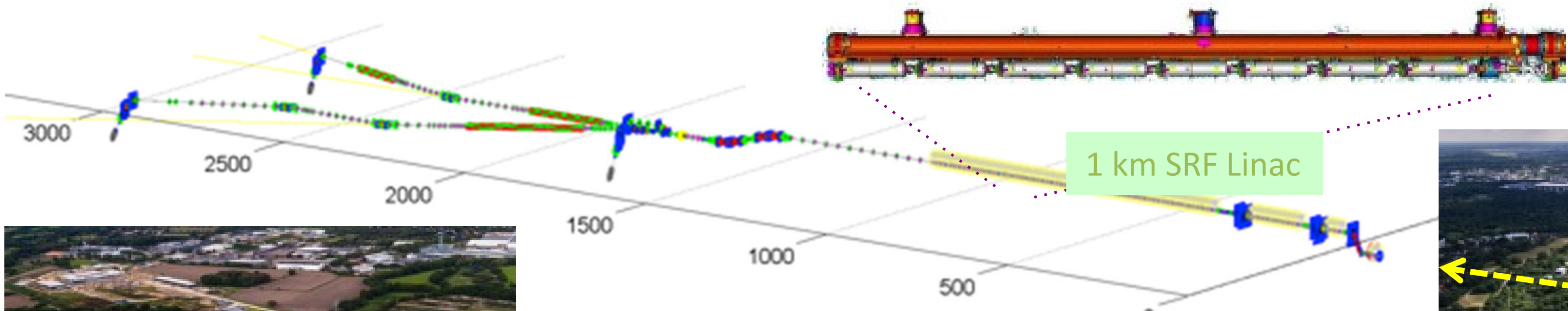
1.3 GHz / 23.6 MV/m

800+4 SRF acc. Cavities

100+3 Cryo-Modules (CM)

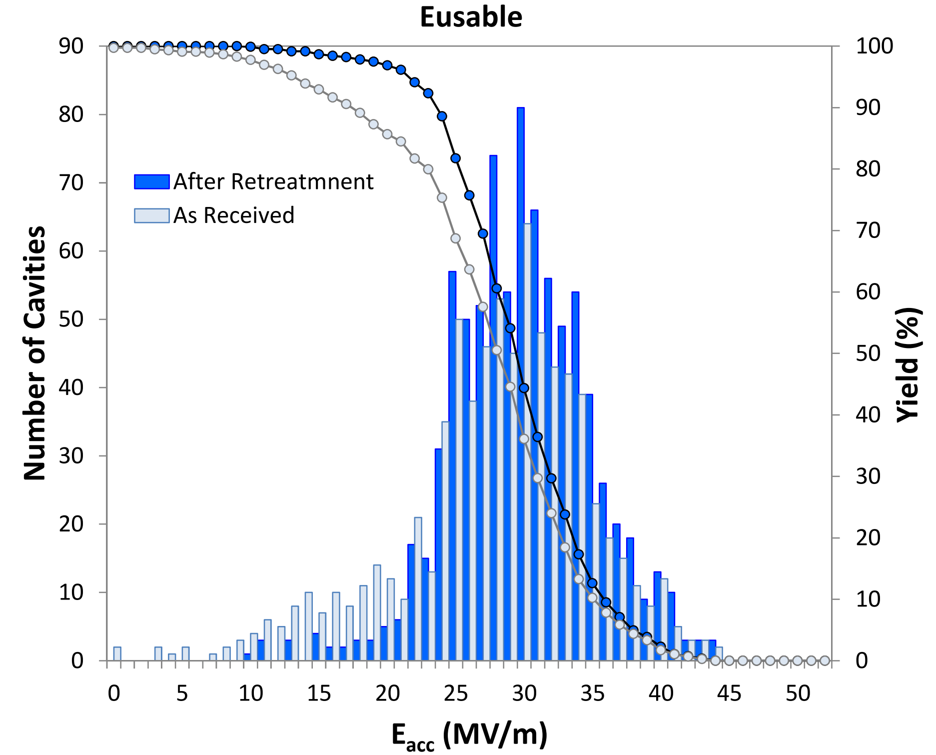


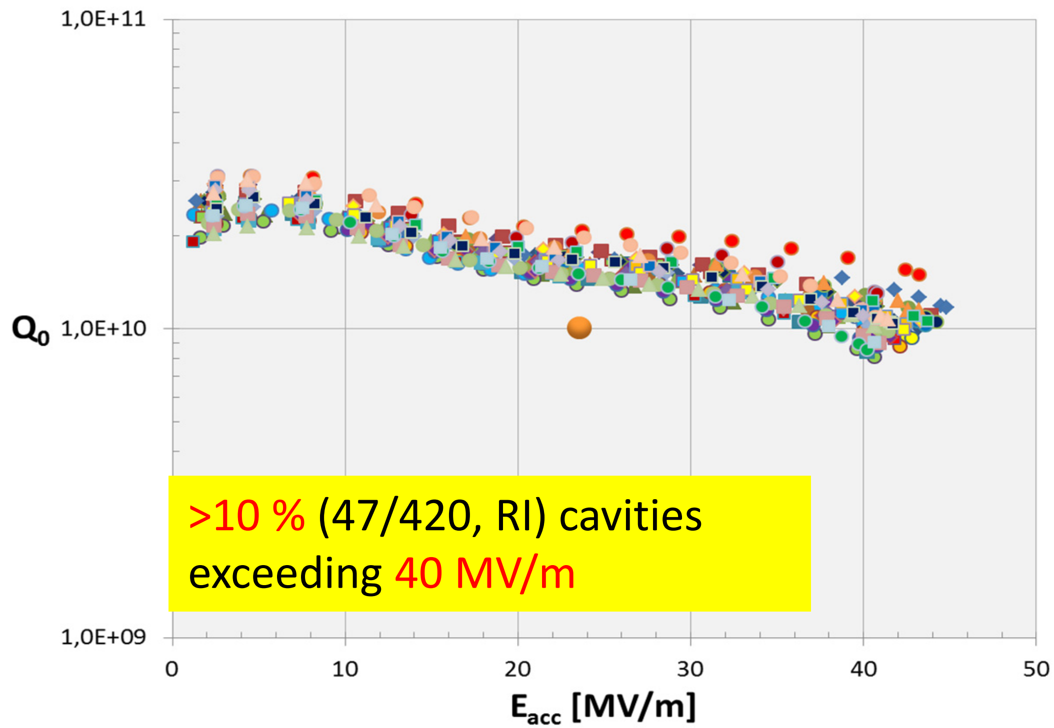




Courtesy, D. Reschke , N. Walker, C. Pagani

European XFEL: SRF Cavity Performance



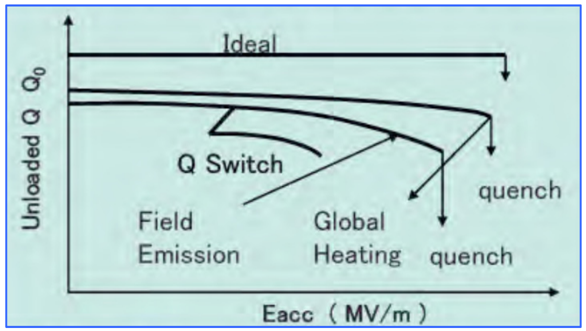


After Retreatment:

E-usable: 29.8 ± 5.1 [MV/m]

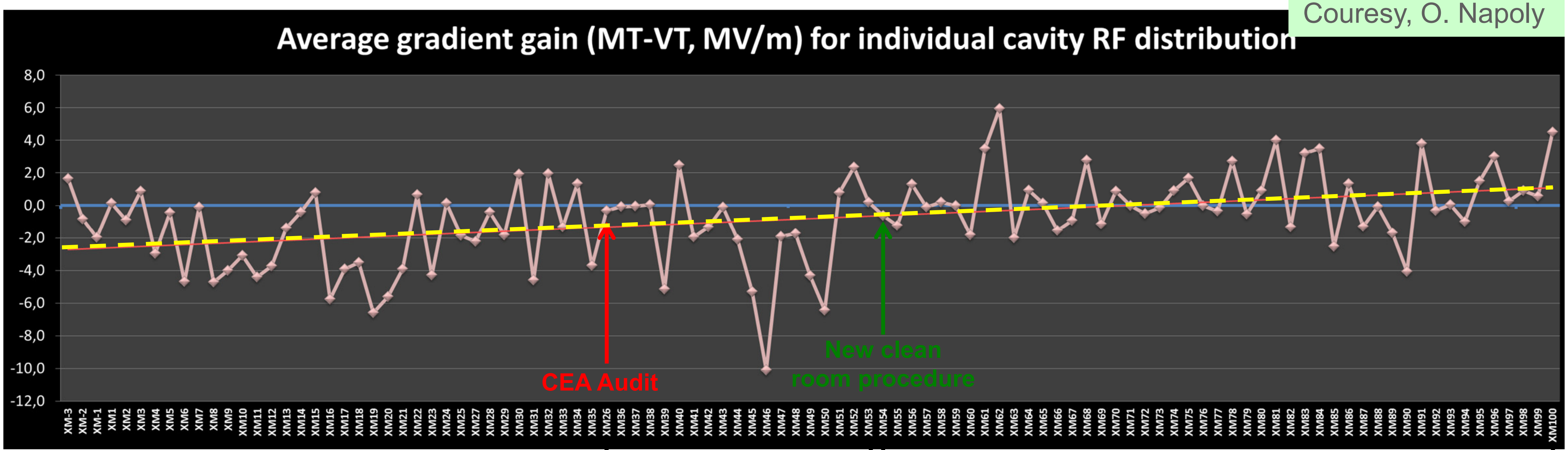
(RI): E usable 31.2 ± 5.2 [MV/m]), w/ 2nd EP

(EZ): E usable 28.6 ± 4.8 [MV/m]) , w/ BCP (instead of 2nd EP)



Gradient Performance: Cryomodule v.s. Cavity

Couresy, O. Napoly



1st sample of 34 series CM
ΔE_{op} = -2.1 MV/m

2nd sample of 19 series CM
ΔE_{op} = -1.7 (-0.9) MV/m

last 47 series CM
ΔE_{op} =+0.5 MV/m

Degradation mitigated through critical efforts during the 100 European XFEL cryomodule assembly. No-degradation achieved.

Congratulations !

European XFEL generates its First laser light

NEWS, 04 MAY 2017

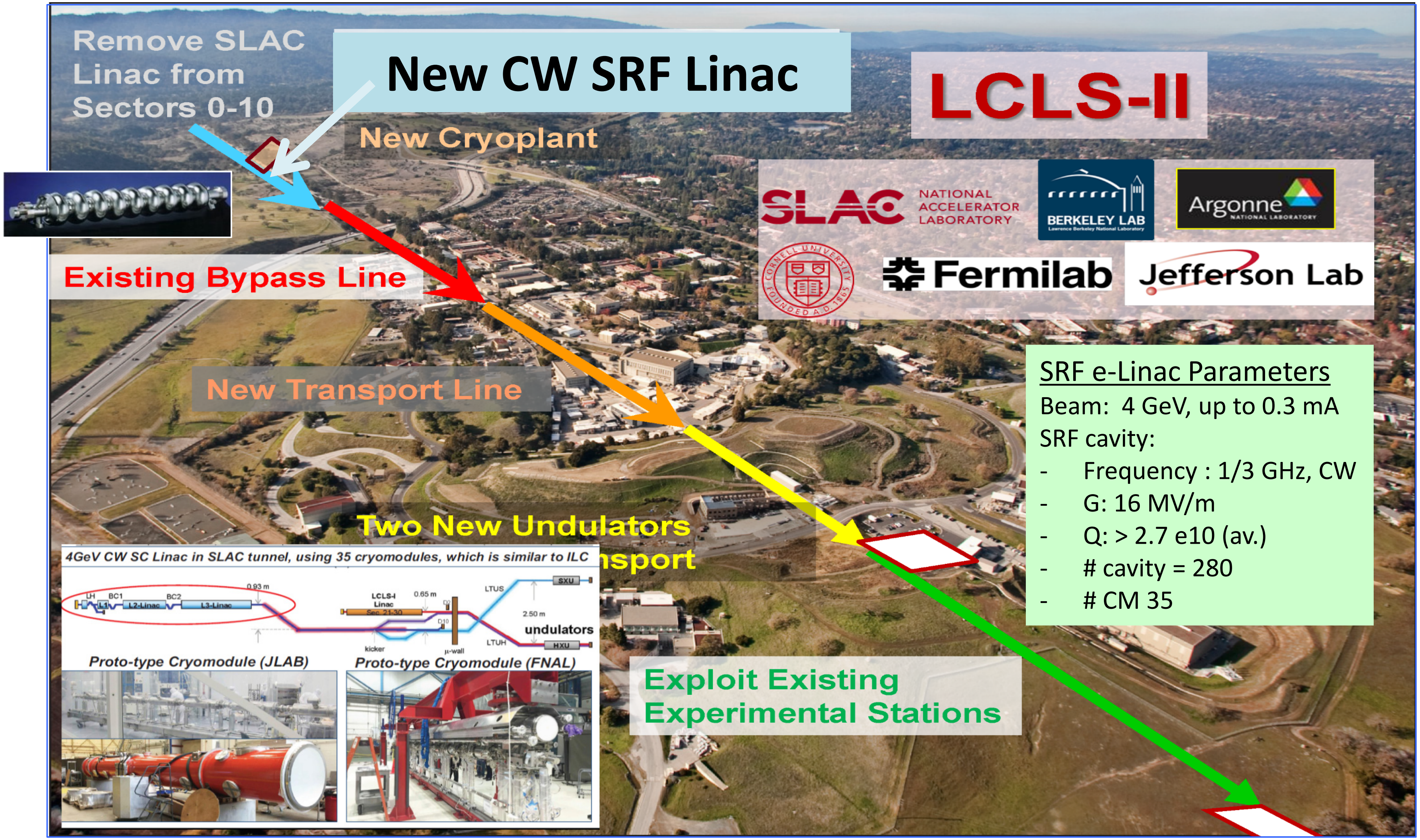
Biggest X-ray laser in the world generates its first laser light

http://www.xfel.eu/news/2017/european_xfel_generates_its_first_laser_light/

Courtesy, M. Ross

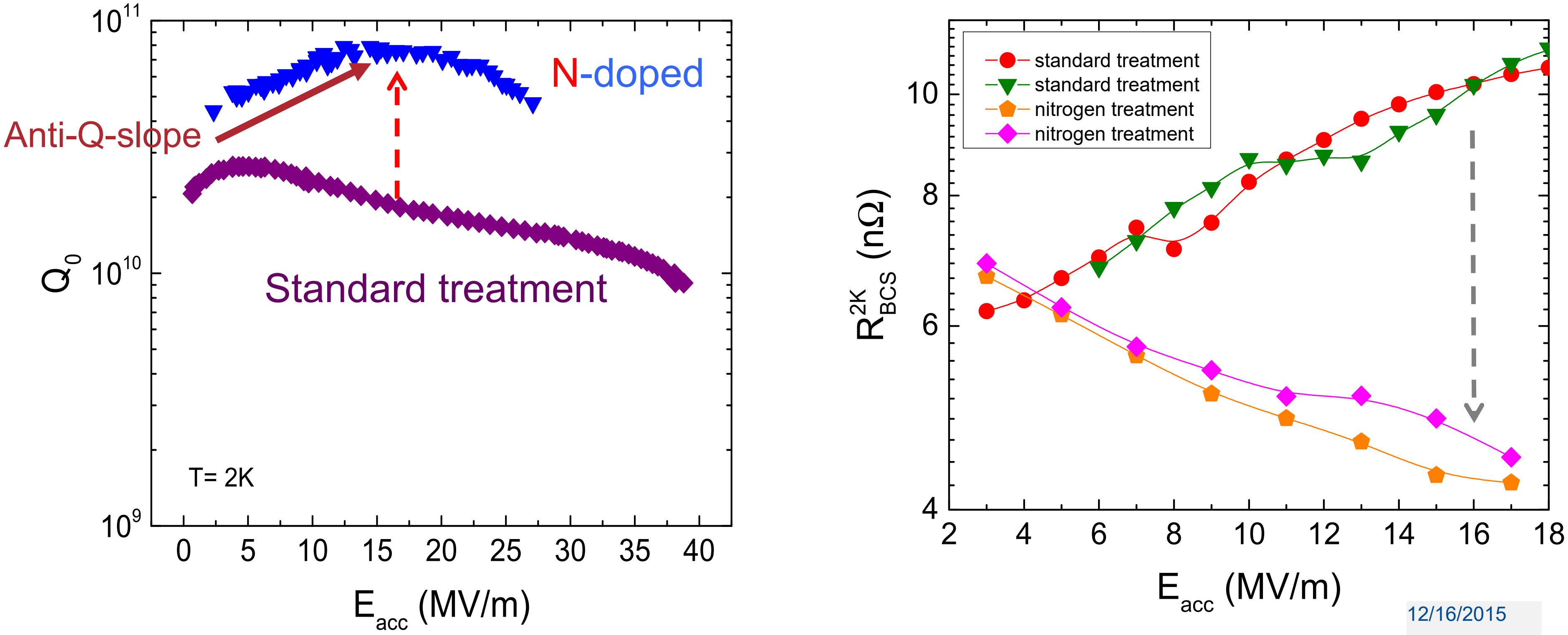
LCLS-II Concept

Use 1st km of SLAC Linac for CW SCRF Linac



Courtesy, A .Grasselino

N-Doping Effect on Q and BCS Surface Resistance



12/16/2015

- >2 x R_{BCS} improvement at 2 K, 16 MV/m
- 2-4 times higher quality factors achieved

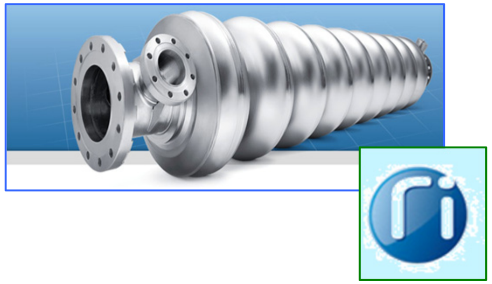
Anti-Q-slope emerges from the BCS surface resistance decreasing with field
→ **Unexpected, unprecedented**

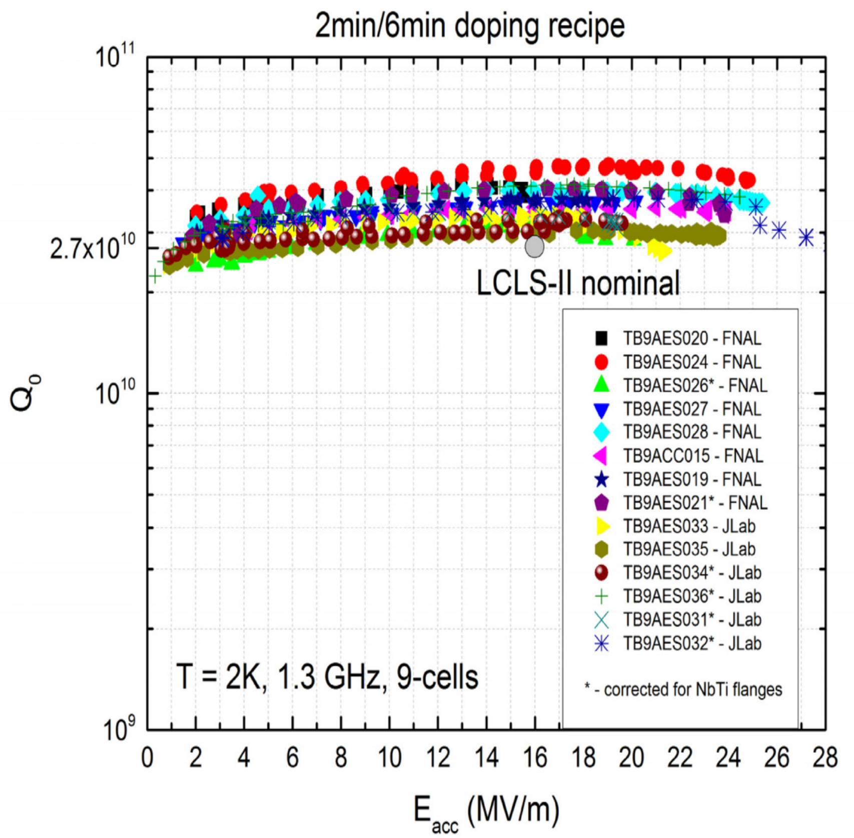
A. Grassellino et al, 2013 Supercond. Sci. Technol. 26 102001 (Rapid Communication)
A. Romanenko and A. Grassellino, Appl. Phys. Lett. 102, 252603 (2013)

Courtesy, A .Grasselino

"N Doping" Technology transferred to Industry

- Successfully transferred to European SRF cavity vendors, and implemented to LCLS-II





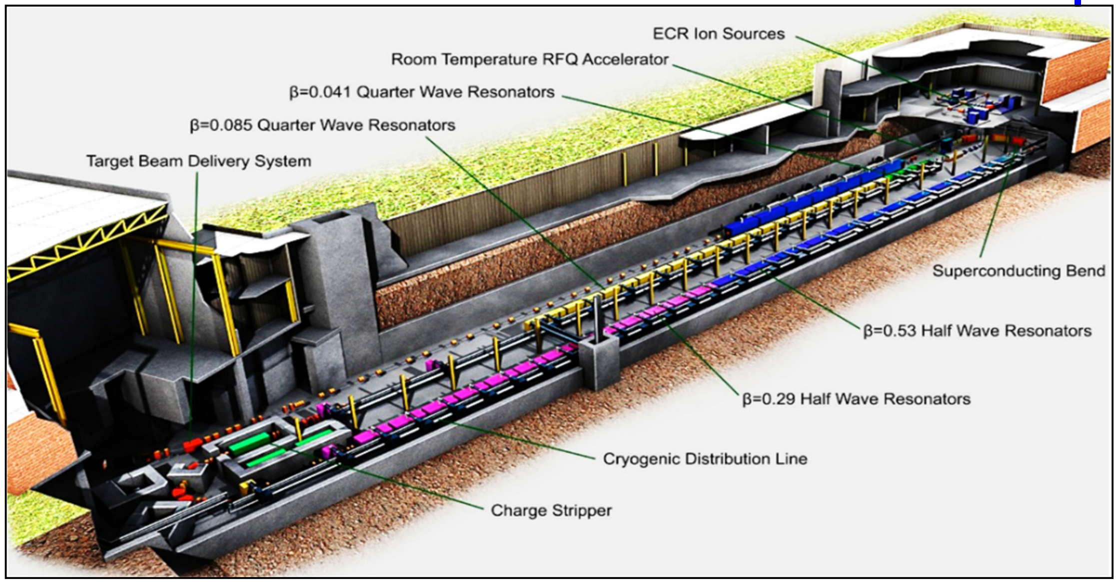
<Q>=3.6e10
$\langle E_{max} \rangle$=22.2 MV/m
E_{max}median=22.8MV/m

12/16/2015

Courtesy, K. Saito

FRIB SRF Linac Scope

Features:
- Heavy ion beam intensity frontier machine,
  e.g. 200 MeV/u, $5x10^{13}$ $^{238}U/s$, 360μA, 400 kW
- All SRF from low beta to medium beta section
- Large nuclear physics user (~1300 users) facility
- CD3 in 2022

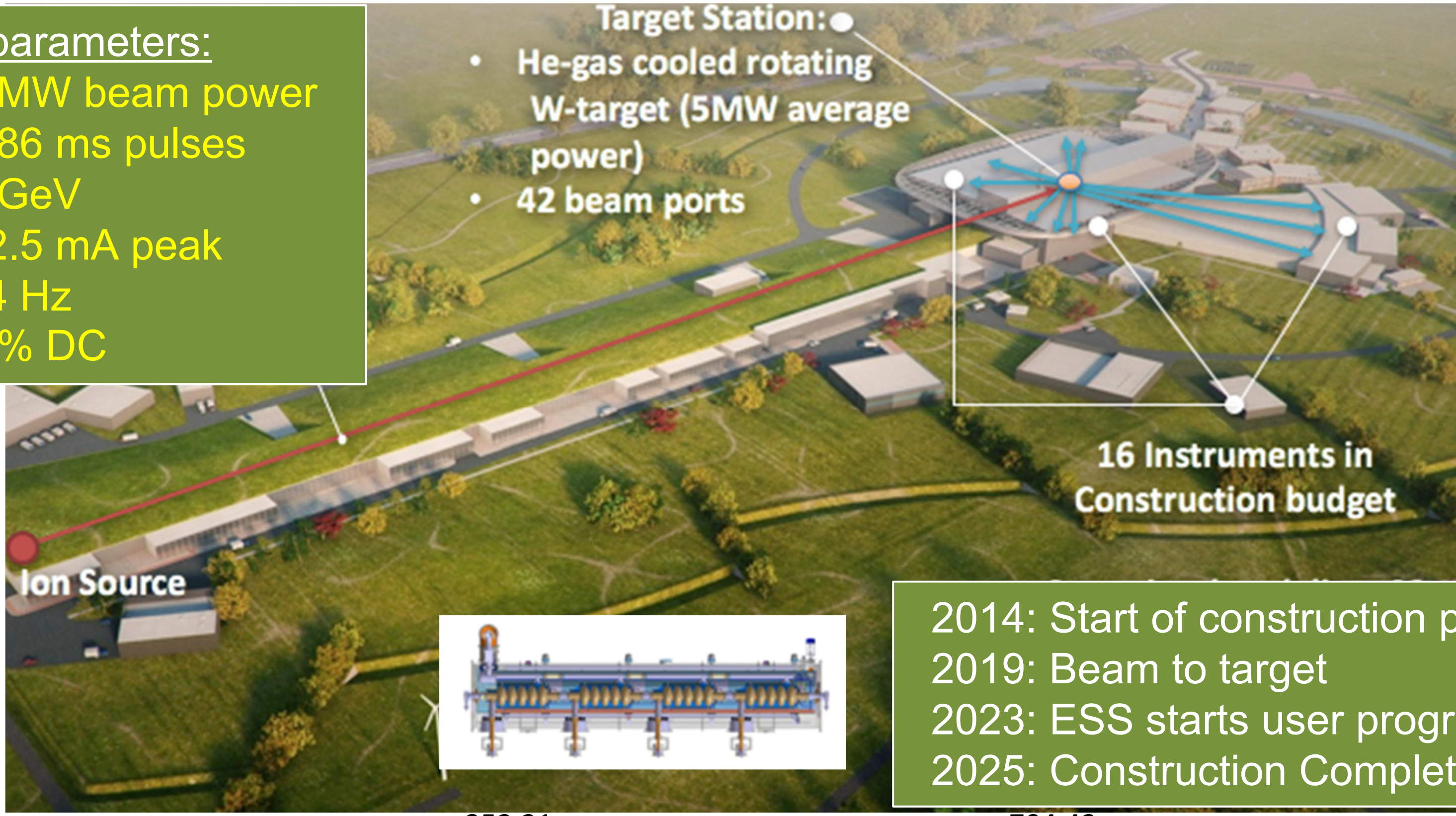


Three folded SRF linac (~500 m)
- Energy upgradability > 400 MeV/u by filling vacant slots

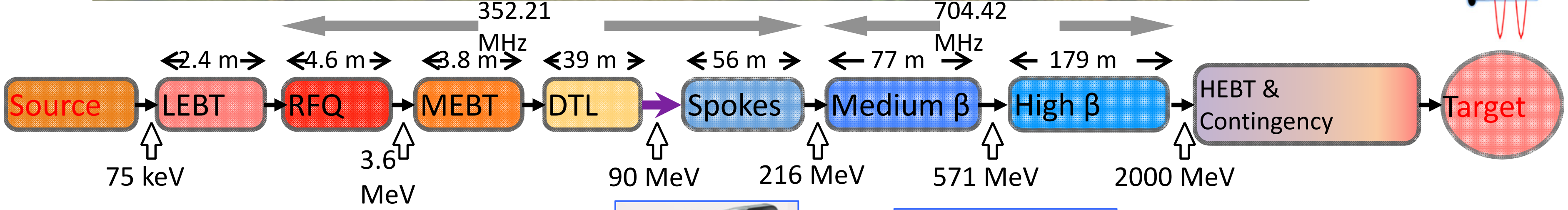
European Spallation Sources

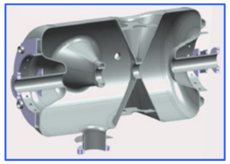
Courtesy, Christine Darve

Key parameters:
- 5 MW beam power
- 2.86 ms pulses
- 2 GeV
- 62.5 mA peak
- 14 Hz
- 4 % DC



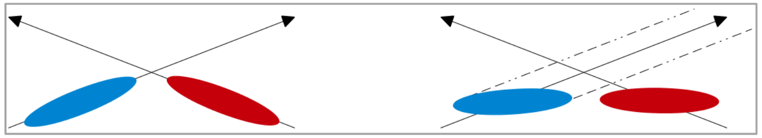
2014: Start of construction phase
2019: Beam to target
2023: ESS starts user program
2025: Construction Complete

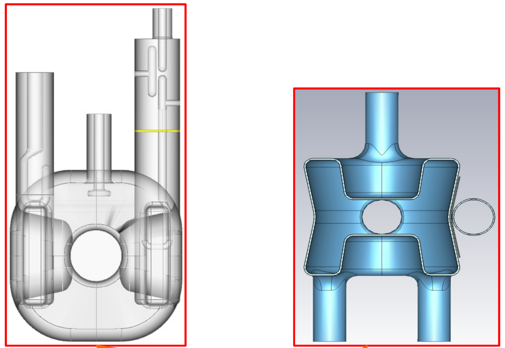


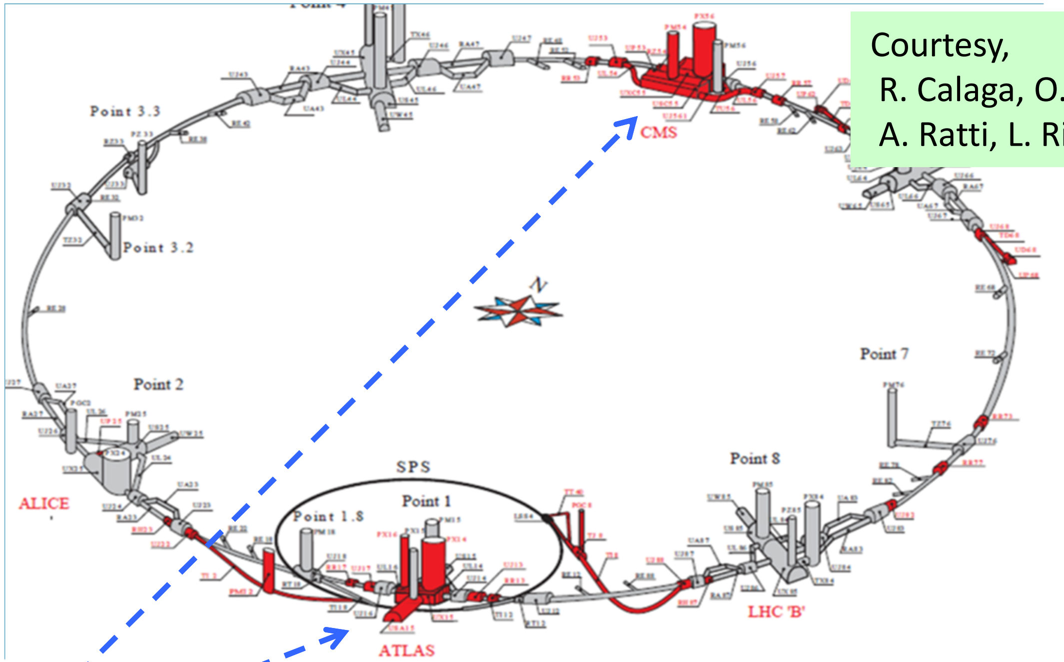


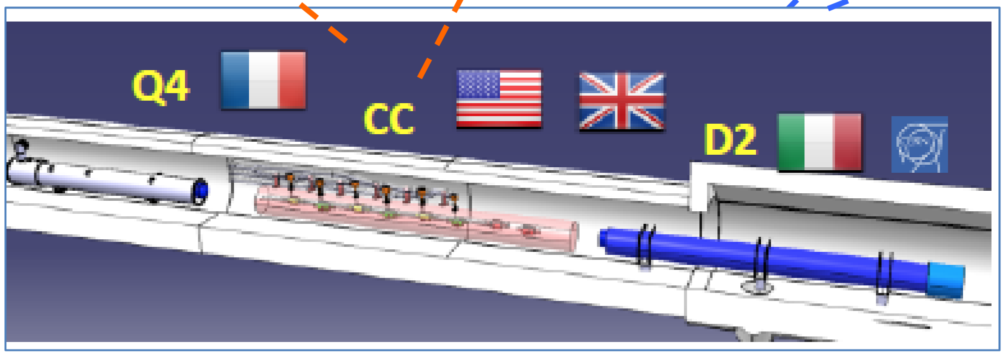
Nb SRF Crab Cavities for HL-LHC

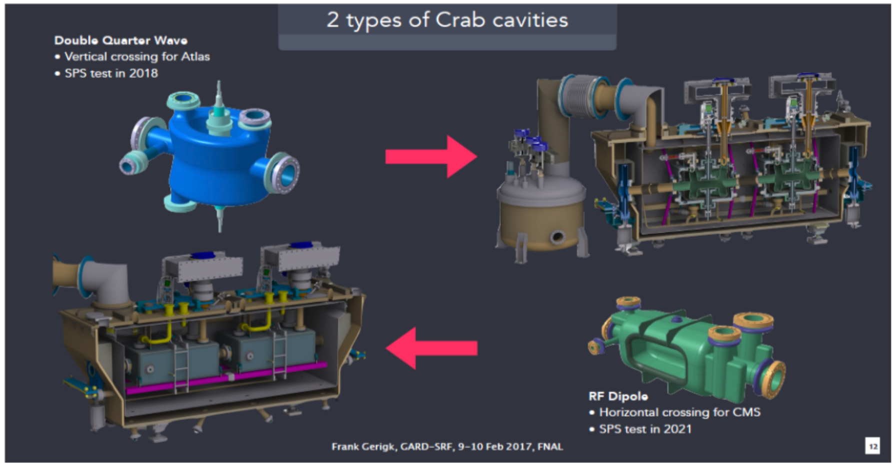
Courtesy,
R. Calaga, O.Capatina
A. Ratti, L. Ristori



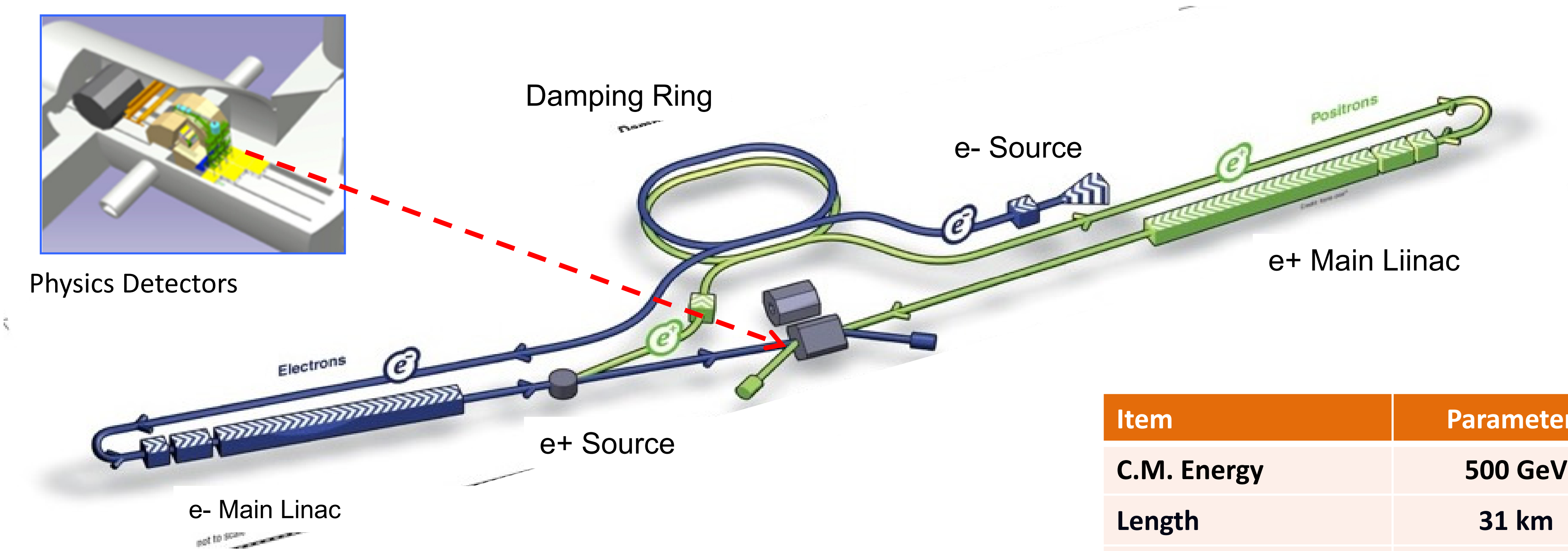


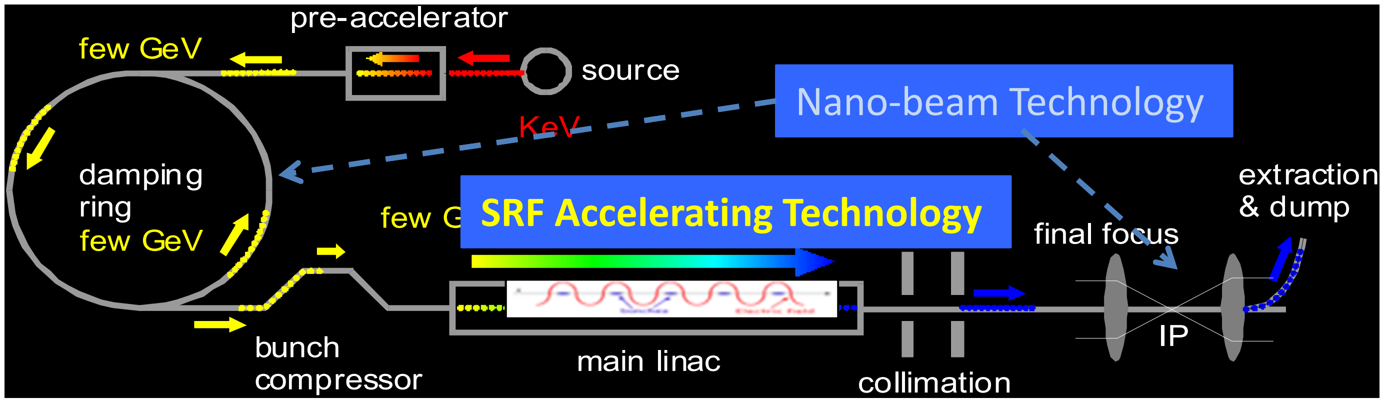






ILC proposed in TDR-2013





Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA
Beam size (y) at FF	5.9 nm
SRF Cavity G. Q_0	31.5 MV/m Q_0 = 1x10^{10}

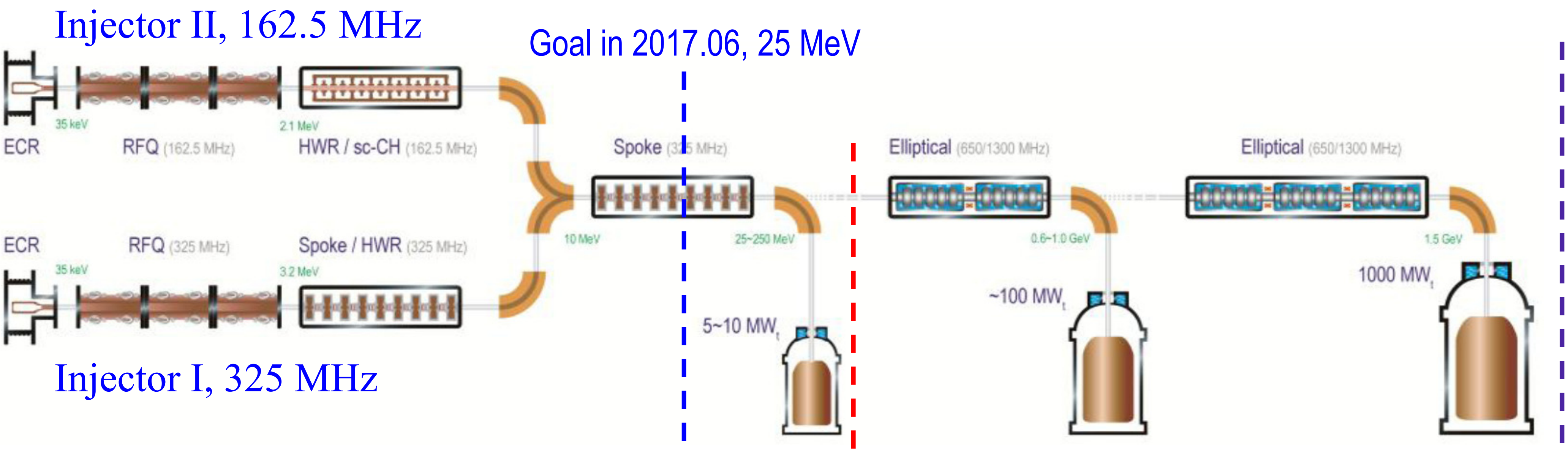
Roadmap of ADS project in China

Courtesy, YM. Li & YL. CHi

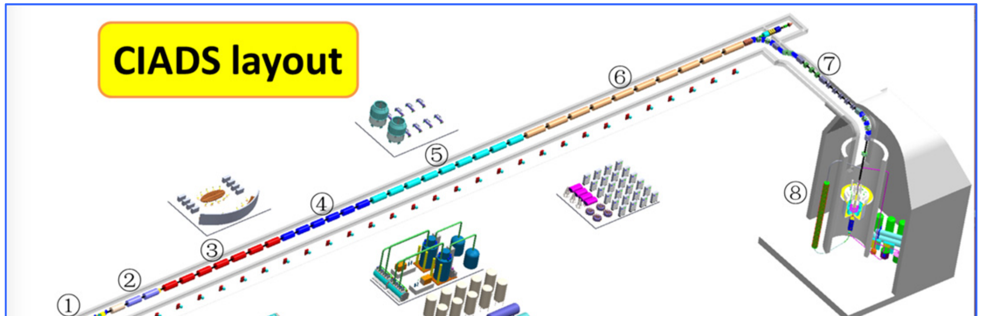
"Strategic Technology Pilot Project" of the Chinese Academy of Sciences
Key technology R&D, Y2011-17,

Stage 1: Research facility (CIADS)
(600 MeV, 10 mA, 10 MWt)
Y2017-23,

Stage 2: Demo facility (CDADS)
(~1.0GeV, 10~25 mA, 500 MWt)



Accelerator segments	First CW beam	Maximum (MeV)
RFQ	Jun. 21, 2014	2.15
TCM1 (1 HWR)	Nov. 24, 2014	2.55
CM1 (6 HWRs)	Jun. 24, 2015	5.3
CM1+CM2 (6 + 6 HWRs)	Sept. 24, 2016	10.2



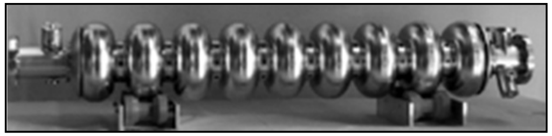
China Initiative Accelerator Driven System

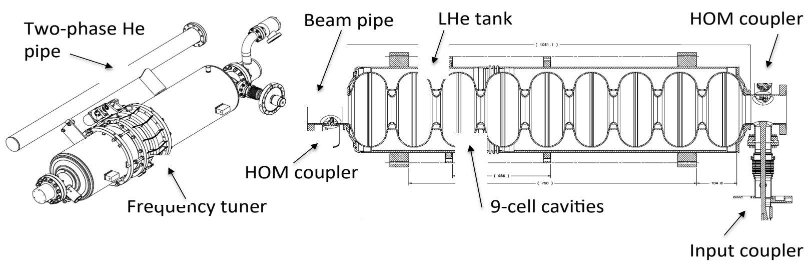
SRF Accelerator Technology to be advanced

- **Material**
  - Bulk-Nb: Disk directly sliced out of Nb-Ingot (having large grain)
  - Thin layer of Nb coating/sputtering on Cu, Nb3Sn on Nb, MgB2, …
- **Mechanical fabrication**
  - Cavity-shape optimization in optimum balance of E- and B-peak
  - Assembly technology w/ electron BW (or laser BW as an alternate)
  - Hydro-forming for minimizing welding joints
- **Surface treatment/Process**
  - "Nitrogen doping" at 800 C → High Q
  - **"Nitrogen infusion"** at 120 C, → High-Q and -G
  - Cost effective process, such as EP w/ vertical position, w/o HF, …

- **Energy Recovery Linac (ERL) technology**

SRF Cavity and Cryomodule Fabrication Process





16,024 x 1.1

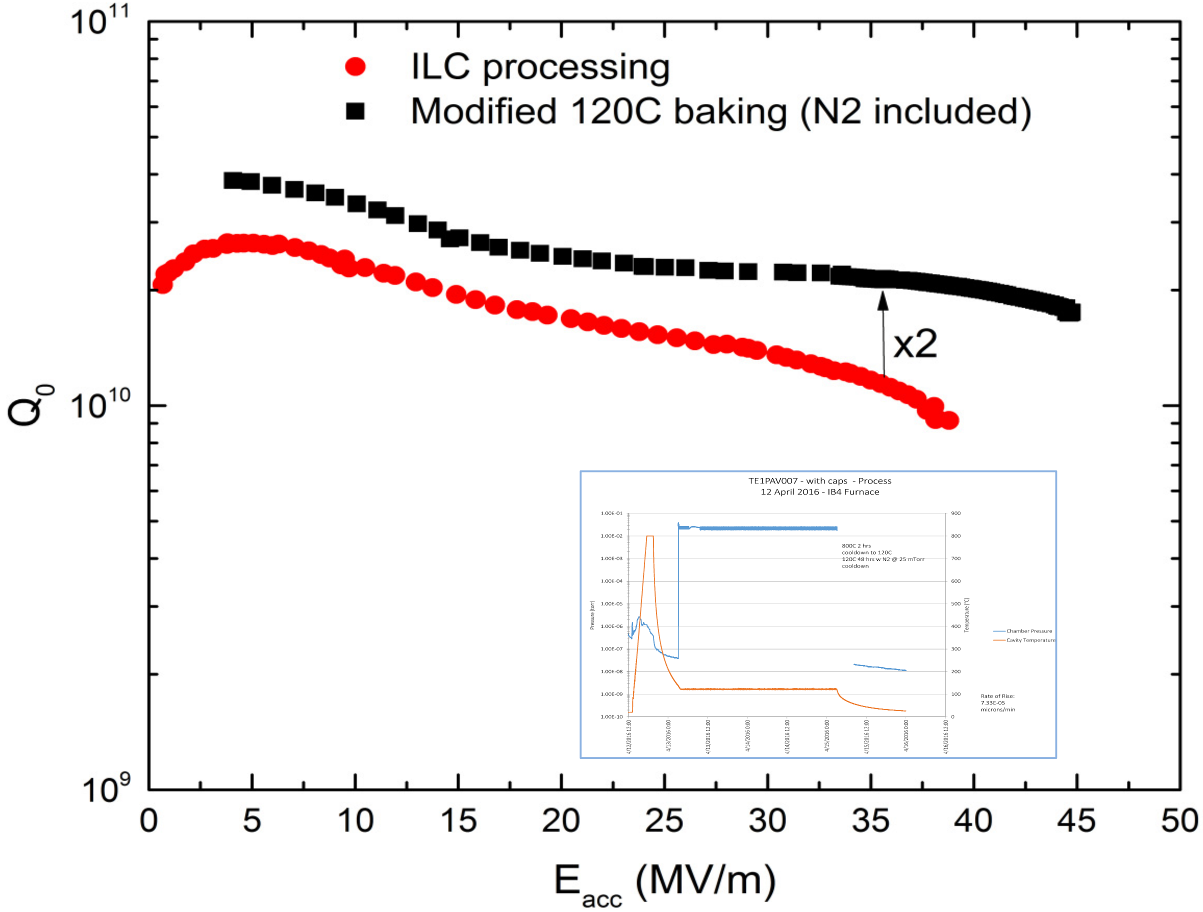
1,855

- Purchasing Material/Sub-component
- Manufacturing Cavity
- Surface Processing → N –doping, - infusion
- Assembling LHe-Tank
- Qualifying Cavity

- Cavity String Assembly
- Cryomodule Assembly
- Qualifying CMs

Courtesy, A. Grassellino

“N infusion” during 120C bake, improving both G and Q



Achievements at Fermilab:

G-max = 45.6 MV/m →194 mT

Q (at 35 MV/m) : ~ 2.3e10

Improvements:

G : ~ 15 %

Q : x 2 → Cryogenics saving

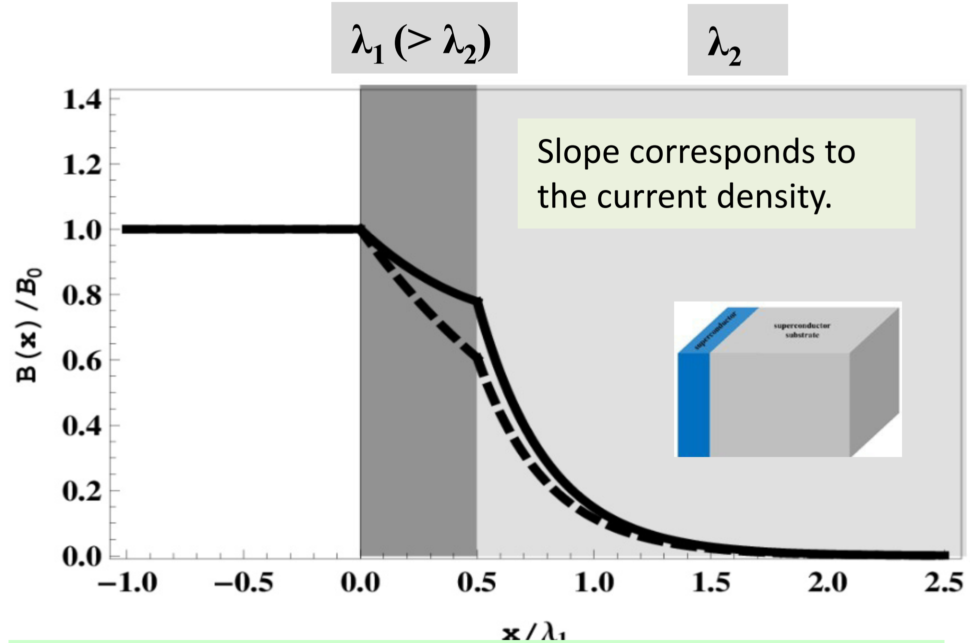
arXiv:1701.06077

- The recipe discovered and demonstrated at **Fermilab** (by A. Grassellino et al.).
- Global collaboration extends the R&D and demonstrate the statistics.
- US-DOE and JP-MEXT support the cost-reduction R&D based on the N-infusion technology.

Courtesy, R. Laxdal, T. Kubo

Possible Consideration and Models

- 120C bake is known to manipulate mean free path at very near surface (~nm) on clean bulk Nb.
- The Nitrogen (N) infusion is a variation of the 120 C bake where N dopes the near surface w/o working lossy nitrides.
- A dirty (doped) layer at the surface seems beneficial in order to increase the quench field above Bc1.



Surface current is suppressed:

- means an enhancement of the field limit, because of the theoretical field limit to be determined by the current density.

- C.Z. Antoine, et al. APL 102, 102603 (2013).
- T. Kubo et al, Appl. Phys. Lett. 104, 032603 (2014).
- A. Gurevich, AIP Advances 5, 017112 (2015).
- T. Kubo, Supercond. Sci. Technol. **30**, 023001 (2017) .. (Figure above)

Courtesy, S. Belomestnykh

GARD-SRF Decadal Roadmap in the USA

- **GARD** is a General Accelerator R&D program funded **by the US DOE**, and SRF technology is an important part of GARD.
- **GARD-SRF** will pursue fundamental science, underpinning cavity performance and evolutionary and transformational R&Ds in two directions.
- **High-Q Frontier**
  - Continue exploration of the effect of interstitial impurities on bulk Nb surface resistance;
  - Study the effect of doping on the quality factor of cavities (in a range of 0.65 ~ 3.9 GHz);
  - Work towards amelioration of trapped vortices via innovative ideas:
  - Develop Nb_3Sn coating, and Investigate feasibility of other materials for high Q.
- **High-G Frontier**
  - Research of the fundamental SRF science questions;
  - Layered structures and advanced vortex dynamics concepts;
  - New materials, films, and multilayers including Nb3Sn as a practical material;
  - Field emission mitigation;
  - Microphonic and Lorentz force detuning compensation R&D;
  - Novel SRF cavity shapes.

- **The community puts together** a plan to upgrade existing facilities and develop new ones in order to facilitate R&D activities under the two Frontiers.

Superconducting Technology to be inevitable for Future Colliders to be "Green Accelerators"

Linear Colliders (energy extendable):

ILC- e+e- (2 x 125 → 500 GeV) :

- SRF beam acceleration, High efficiency
- AC plug-power: 125 → 300 MW

Circular Colliders (max. energy fixed):

FCC-e+e- (2 x 175 GeV):

- SRF beam acceleration and compensation for synchrotron radiation
- AC Plug-Power: 360 MW

FCC-pp (2 x 50 TeV):

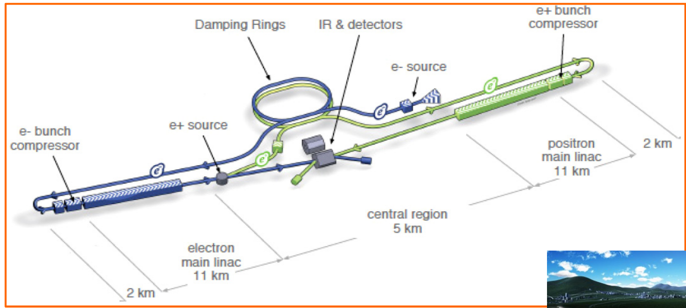
- SC magnets to handle circulating beam
- SRF beam acceleration
- AC Power: 360 MW

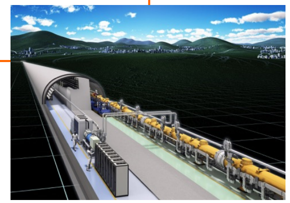
CEPC e+e- (2 x 120 GeV):

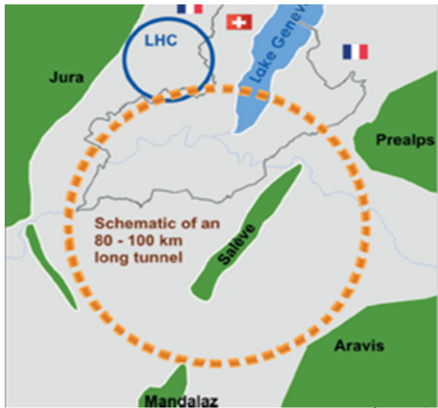
- SRF beam acceleration, in particular, for compensation for synchrotron radiation

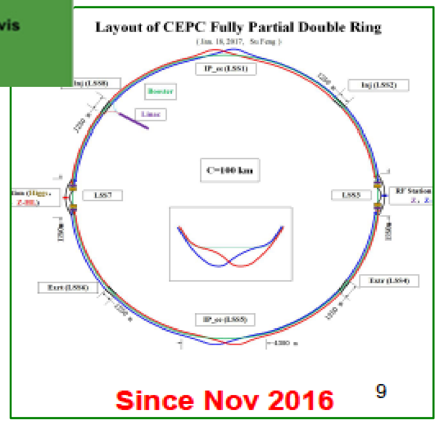
SPPC- pp (2 x 50 GeV):

- SC magnets to handle circulating beam
- SRF beam acceleration



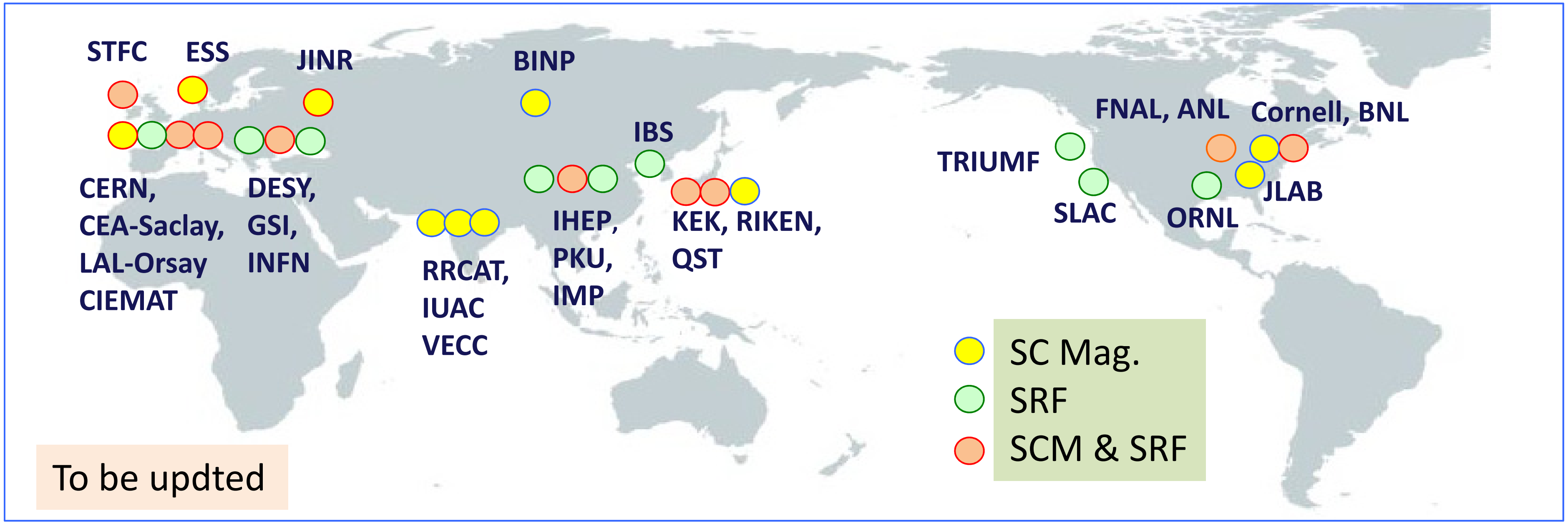






A. Yamamoto, 17/05/15

Global Future of the Superconducting Technology for Accelerators,



Future projects/Studies to be realized / anticipated

- Particle/Nuclear Phys.: ILC, FCC/HE-LHC, CEPC-SppC, JLEIC / eRHIC, and …
- Photon Science: CW-XFEL, and …
- Neutron Sources: CSNS, and …
- Medical Applications: Therapy, and further to be extended
- Industrial Applications: to be extended

Summary

- **Superconducting technology will be inevitable** to approach any energy/power frontier particle accelerators, increasing energy and saving power consumption, (**Green Accelerators**).

- **High-field (> 10 T) magnet technology** is being **matured** with Nb3Sn superconductor, to be applied in real projects, and further investment and cost-saving will be inevitably required for far future energy/power frontier. HTS needs to be matured in magnet technology and the cost saving in mass production will be a key for future accelerator application.

- **SRF technology** has been much **advanced** in past 20 years, **with bulk Nb** technology. **Thin-film** science and technology **will be a key** for extending the field gradient and for saving cooling power in future application expansion, as well as ERL SRF technology.

- The superconducting technology will be extended to wide range of science and technology including Pphoton science, Spallation neutron sources, Medical application, and further **industrial** applications.

Many thanks for your kind Attention

Please refer to related Invited talks and other presentations in this Conference

- *01: Circular and Linear Colliders*
  - **Crab Cavity Systems for Future Colliders:** *S. Verdu-Andres (BNL)*
- *02: Photon Sources and Electron Accelerators*
  - **Commissioning of the European XFEL:** *W. Decking (DESY)*
- *04: Hadron Accelerators*
  - **Progress on the ESS Project Construction :** *R.Garoby (ESS)*
  - **The Energy Efficiency of High Intensity Proton Driver Concepts:** *V.P. Yakovlev (Fermilab)*
- *07: Accelerator Technology*
  - **Development of and Testing of Spoke Cavities** *F. He (IHEP)*
- *10: Closing*
  - **The Future of High Energy Accelerators**: *J. Mnich (DESY)*