Particle Accelerators and Applied Superconductivity in Asia

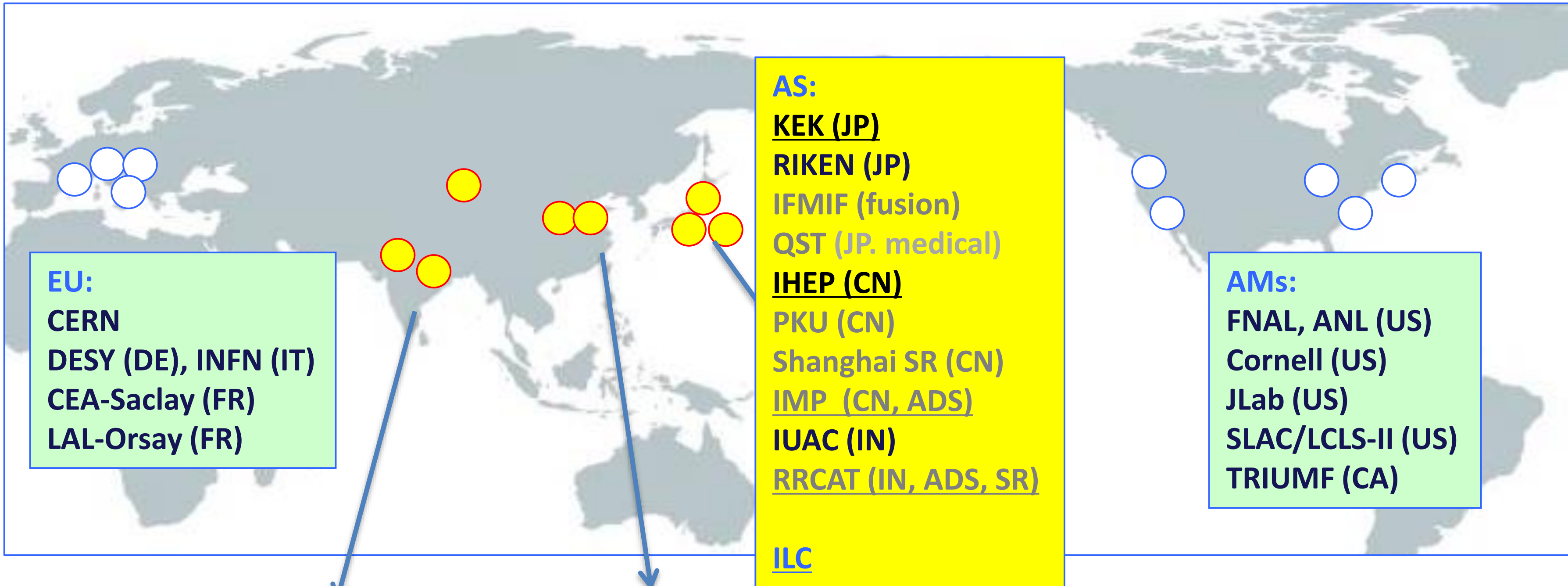
Akira Yamamoto
(KEK and CERN)

AMICI meeting, 18 April, 2017

Outline

- **Introduction/Overview**
- Particle Physics
- Other Fields
- Future Prospects

Superconducting Acc. Labs in Asia



RRCAT: ISNS

IHEP: BES,

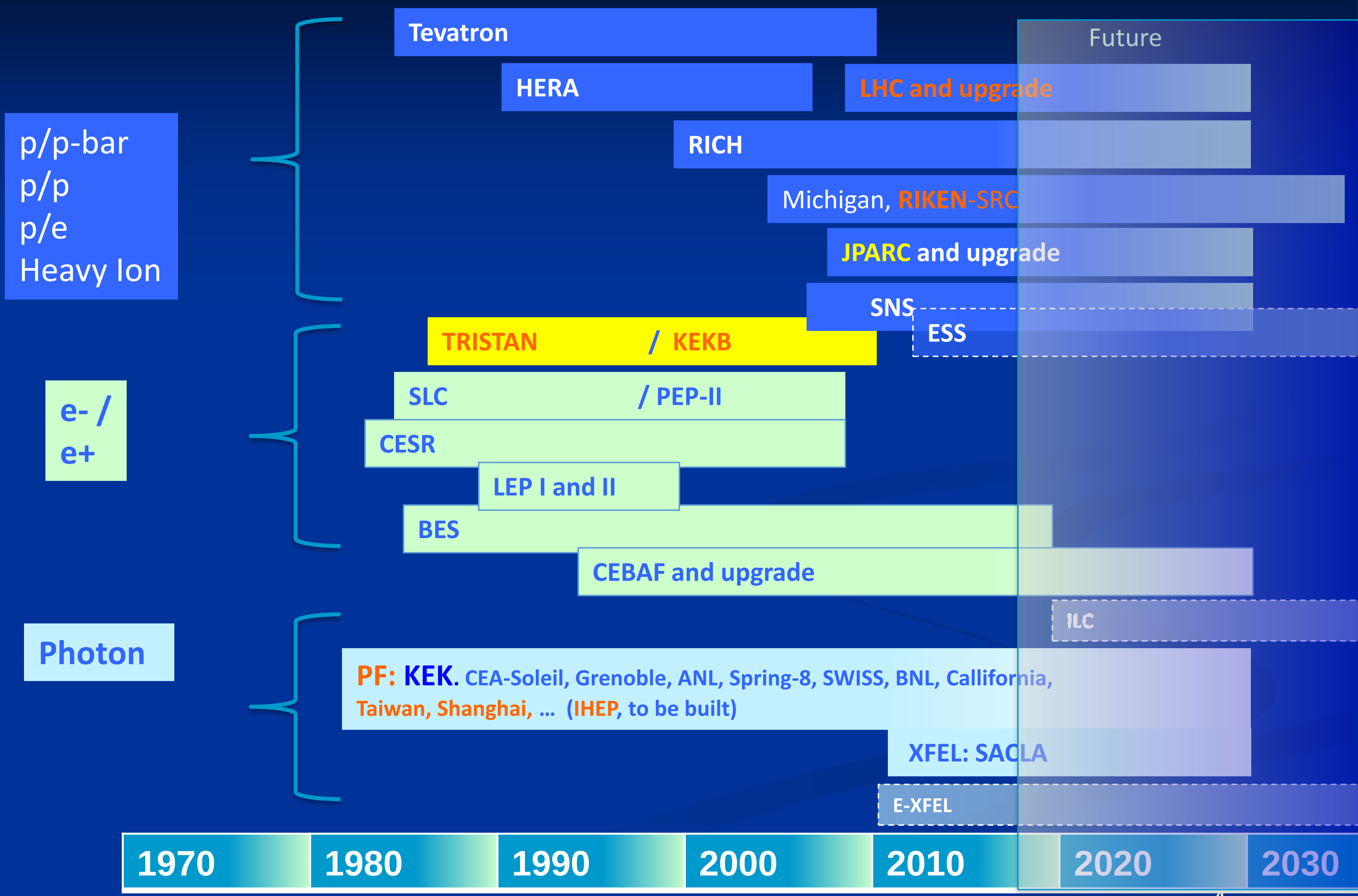
IMP-IHEP: ADS,

KEK: KEKB, JPARC, CERN-LHC

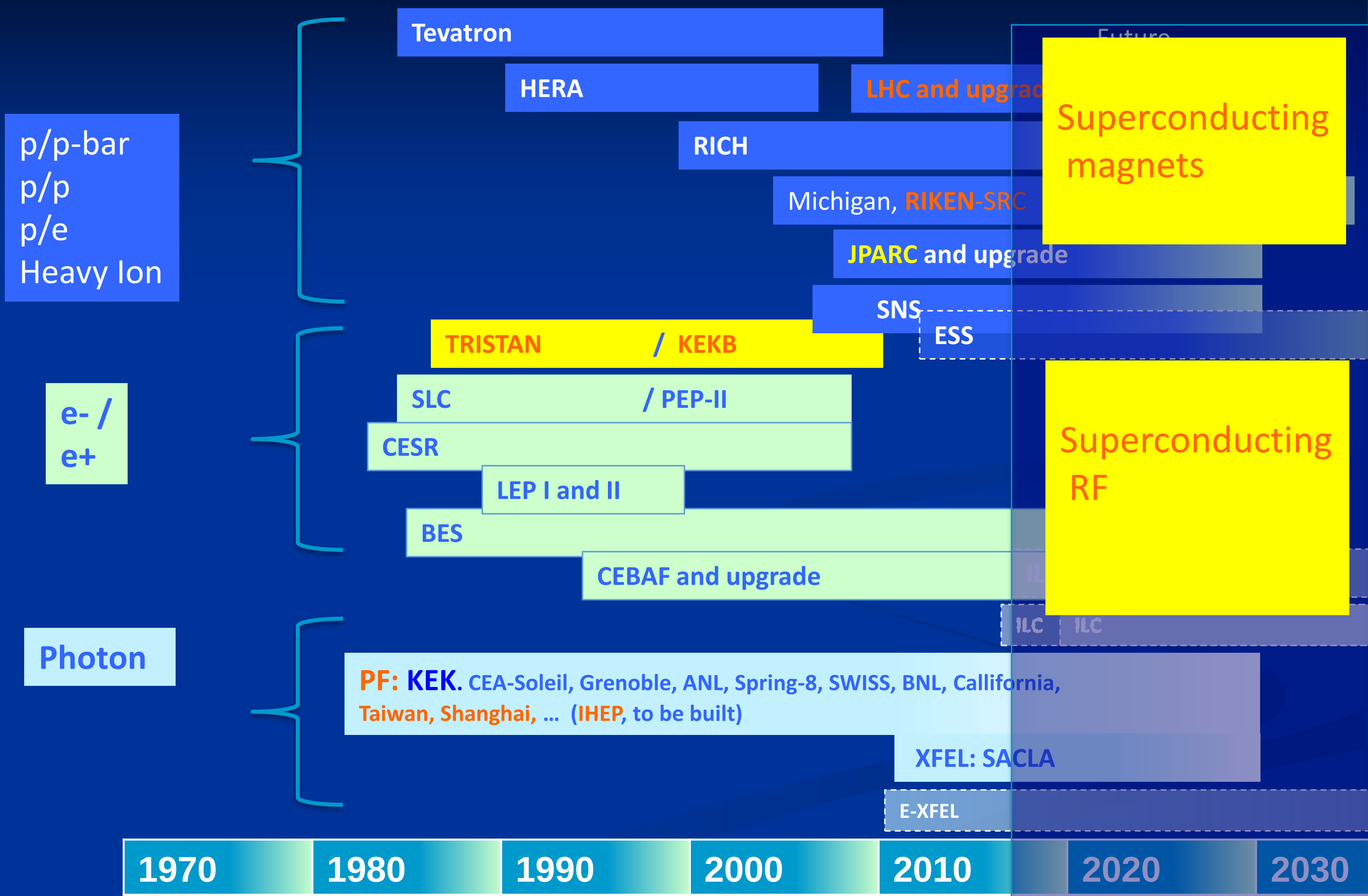
RIKEN: SC Cycrotron

NIRM: Medical

Acc. Programs and Key Technologies



Acc. Programs and Key Technologies



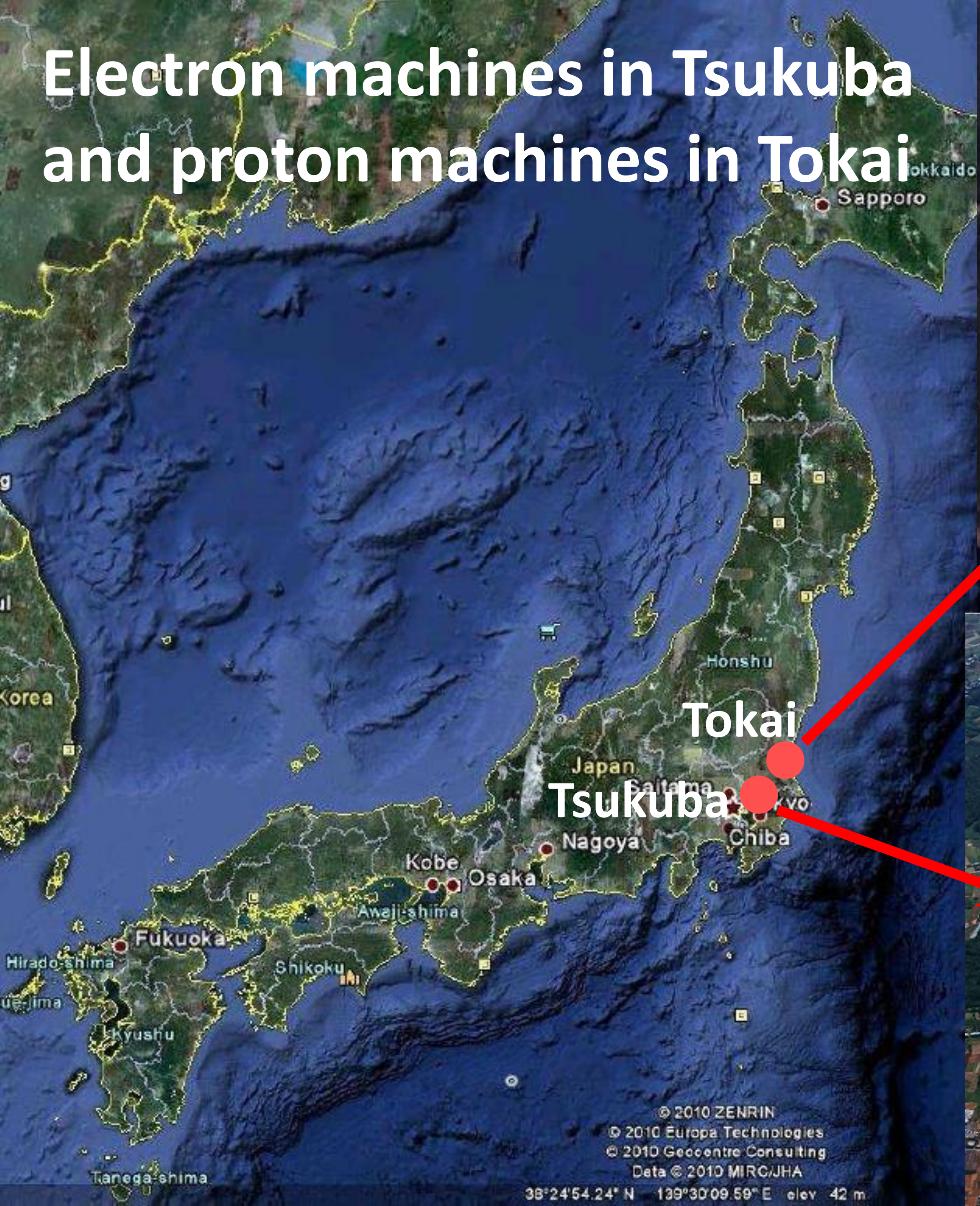
Progress in SC Accelerators

Location	Accelerator	E [TeV]	B [T]	Operation	Technology
Fermilab	Tevatron	2 x 0.9	4.0	1983-2011	SC Magnet
DESY	HERA	0.82	4.68	1990-2007	SC Magnet
BNL	RHIC	2 x 0.1	3.46	2000 -	SC Magnet
CERN	LHC	2 x 7	8.36	2009 -	SCM & SRF
CERN	FCC/HE-LHC	2x50 / 2x14	16	Study	SCM & SRF
IHEP	SPPS	2x50	16	Study	SCM & SRF
Location	Accelerator	E [GeV]	G / (Freq.) [MV/m] / [GHz]	Operation	Key Technology
KEK	TRISTAN	2 x 30	5 (0.5)	1986-1995	SRF
CERN	LEP	2 x 105	5 (0.5)	1989-2000	SRF
JLab	CEBAF	6	5 ~12 (1.3)	1995~	SRF
DESY	EXFEL	14	24 (1.3)	2017 ~	SRF
Global	ILC	2 x 250	31.5 (1.3)	Plan	SRF
CERN	FCC-ee	2 x 175	TBD	Study	SRF
IHEP	CEPC	2 x 120	TBD	Study	SRF

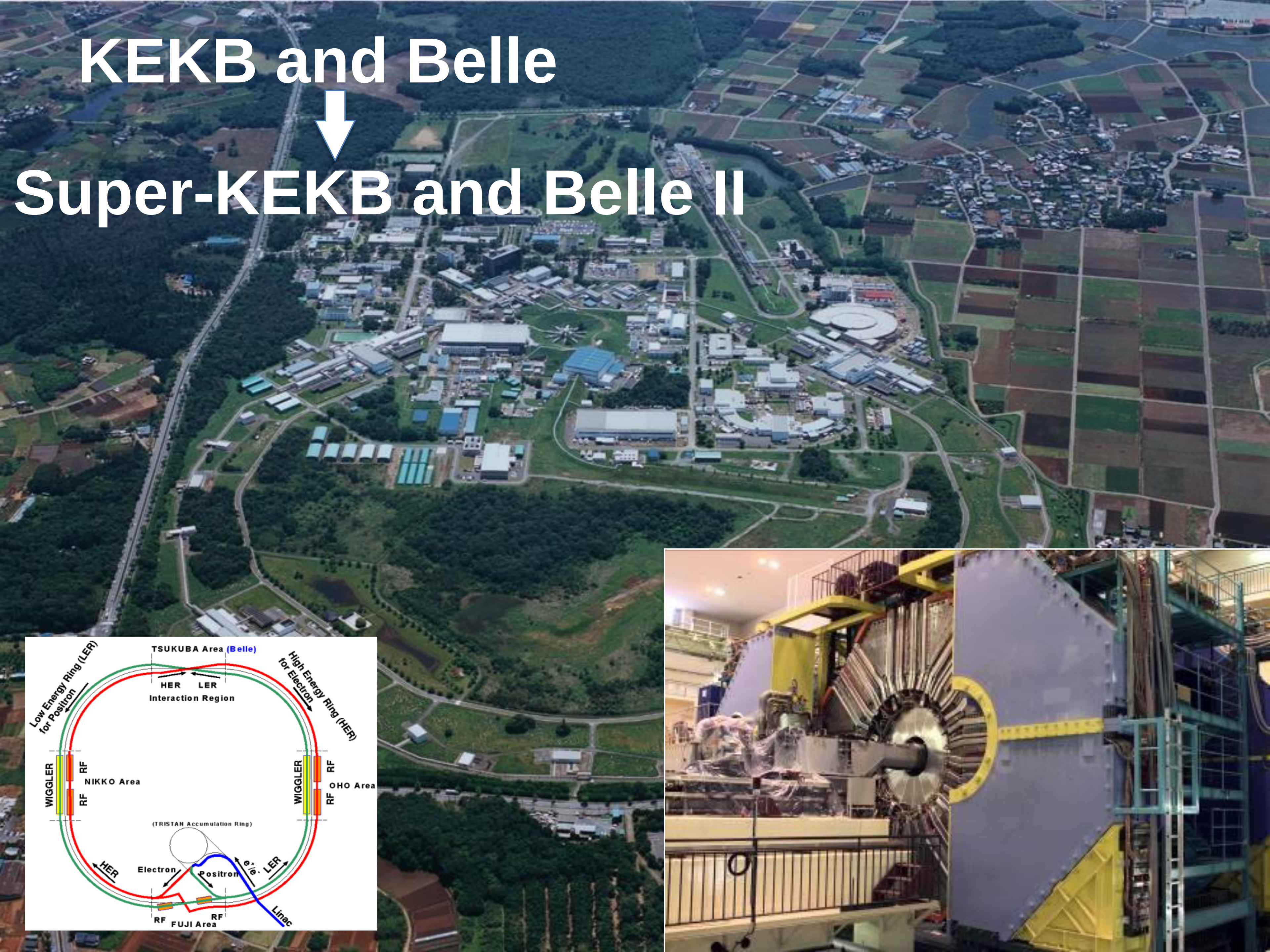
Outline

- Introduction/Overview
- **Particle Physics**
- Accelerator Applications
  – Photon Science, Medical, Energy, and …
- Future Prospects
- Summary

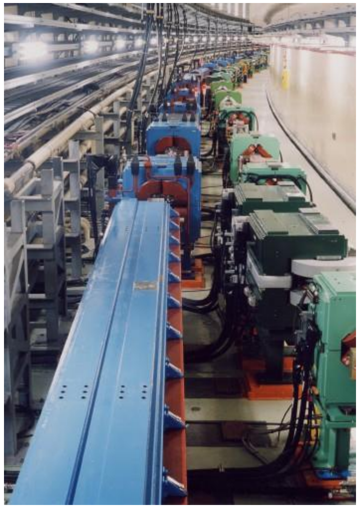
Electron machines in Tsukuba and proton machines in Tokai

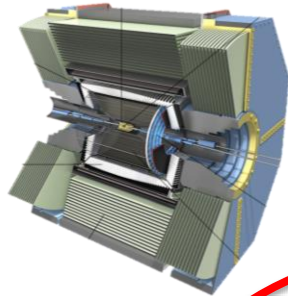


KEKB and Belle
↓
Super-KEKB and Belle II

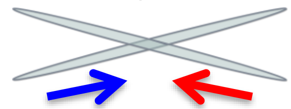


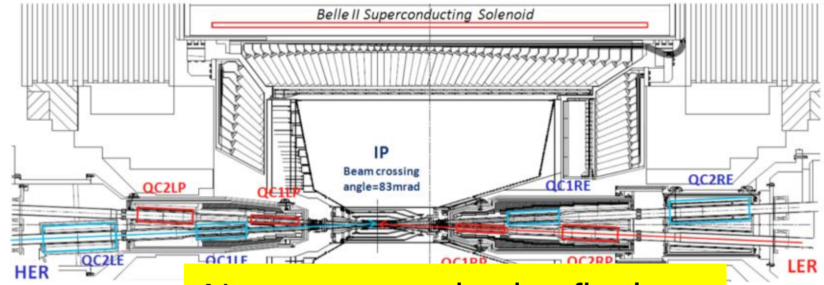
Upgrade to Belle II detector



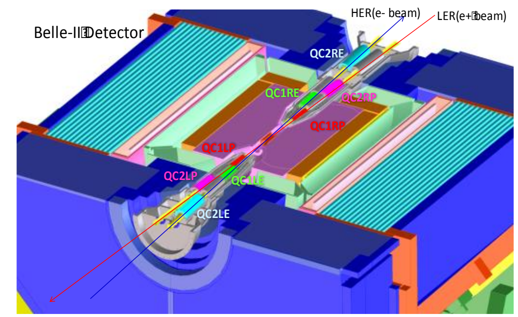


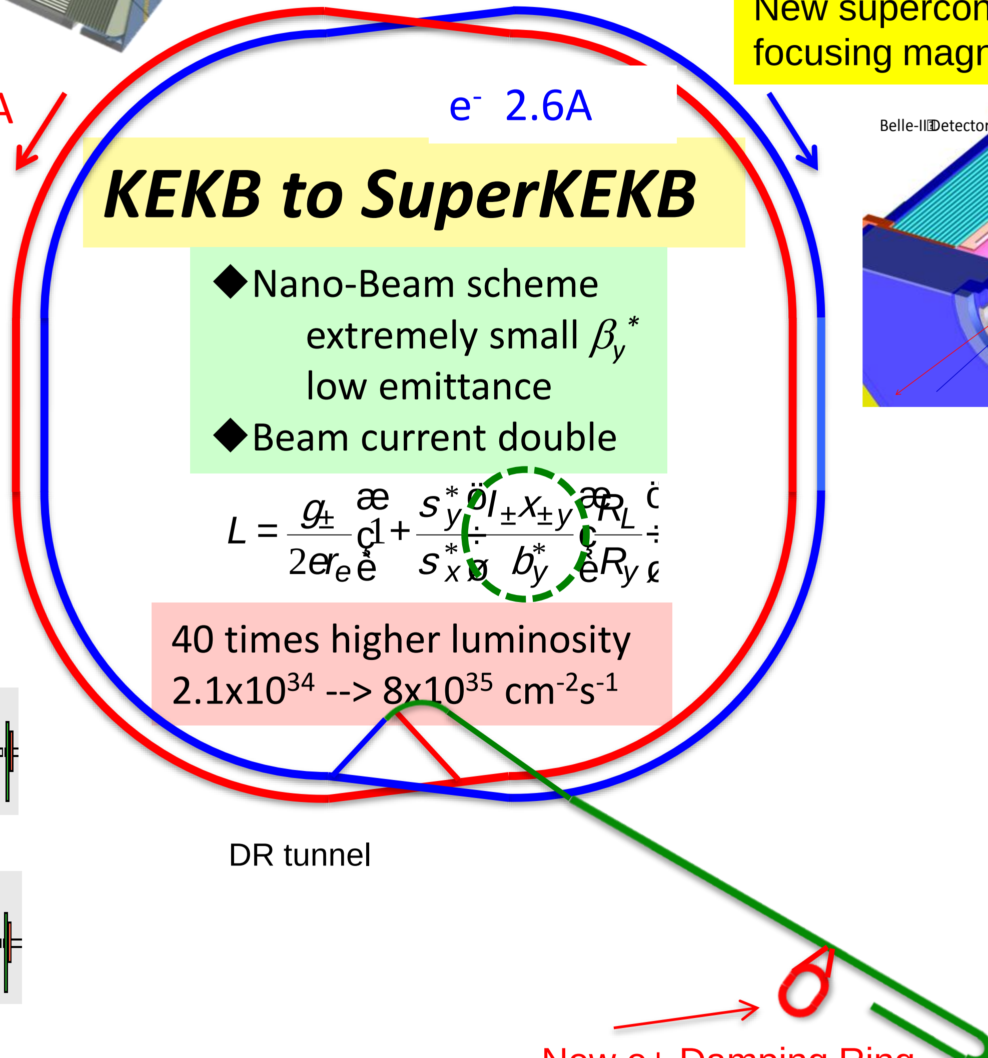
Colliding bunches





New superconducting final focusing magnets near the IP





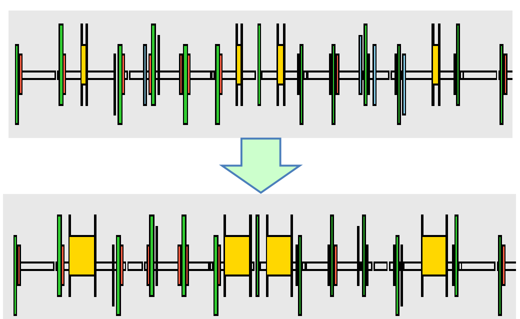
KEKB to SuperKEKB

- Nano-Beam scheme
  - extremely small β_y^*
  - low emittance
- Beam current double

$$L = \frac{\gamma_\pm}{2 e r_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_\pm \xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

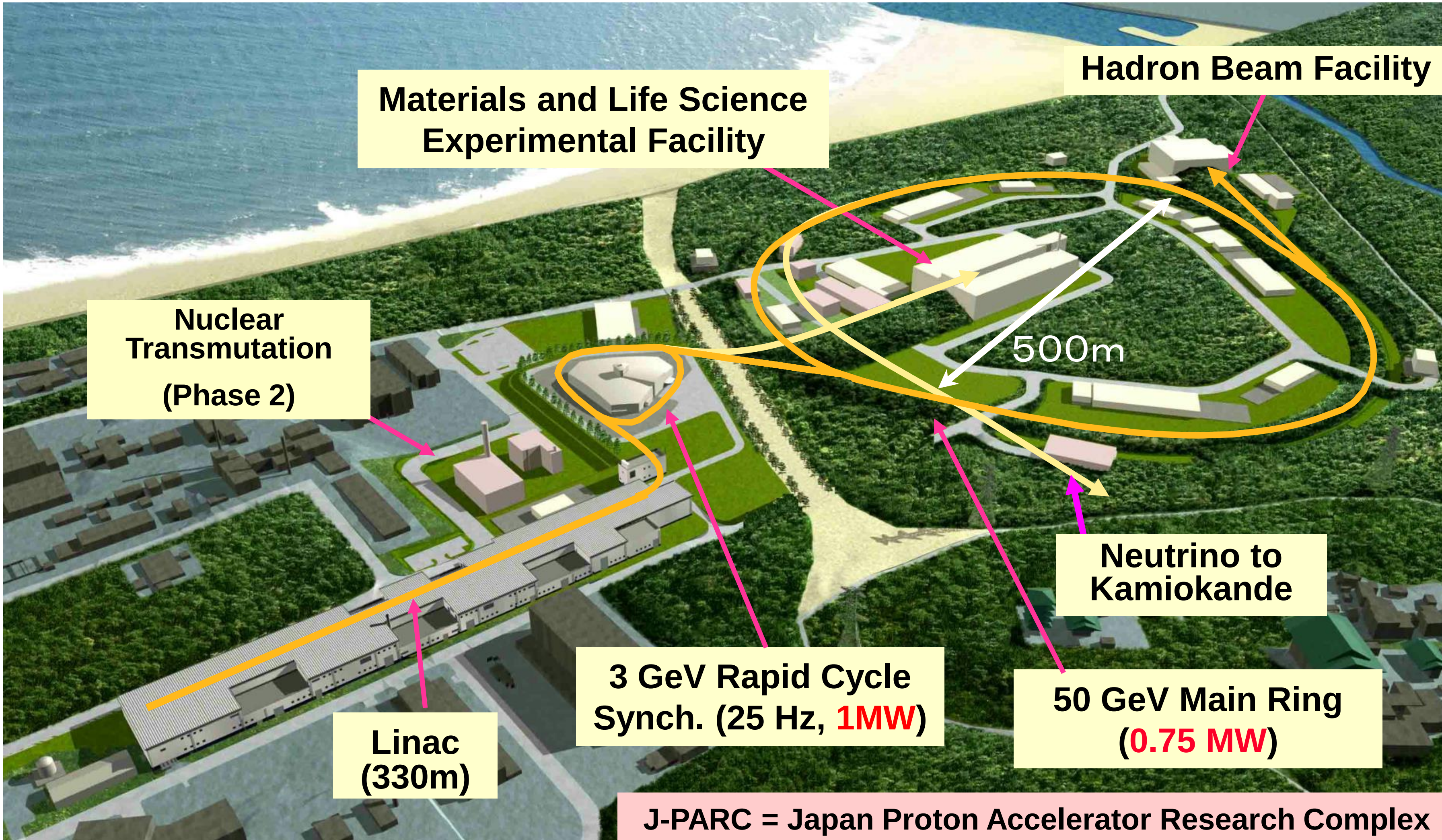
40 times higher luminosity
2.1×10^{34} --> 8×10^{35} cm^{-2}s^{-1}

Redesign the lattice to squeeze the emittance (replace short dipoles with longer ones, increase wiggler cycles)



Reinforce RF systems for higher beam currents

J-PARC Facility



Joint Project between KEK and JAEA

KEK High Energy Accelerator Research Organization

T2K (Tokai to Kamioka) experiment

2010~ (Running)

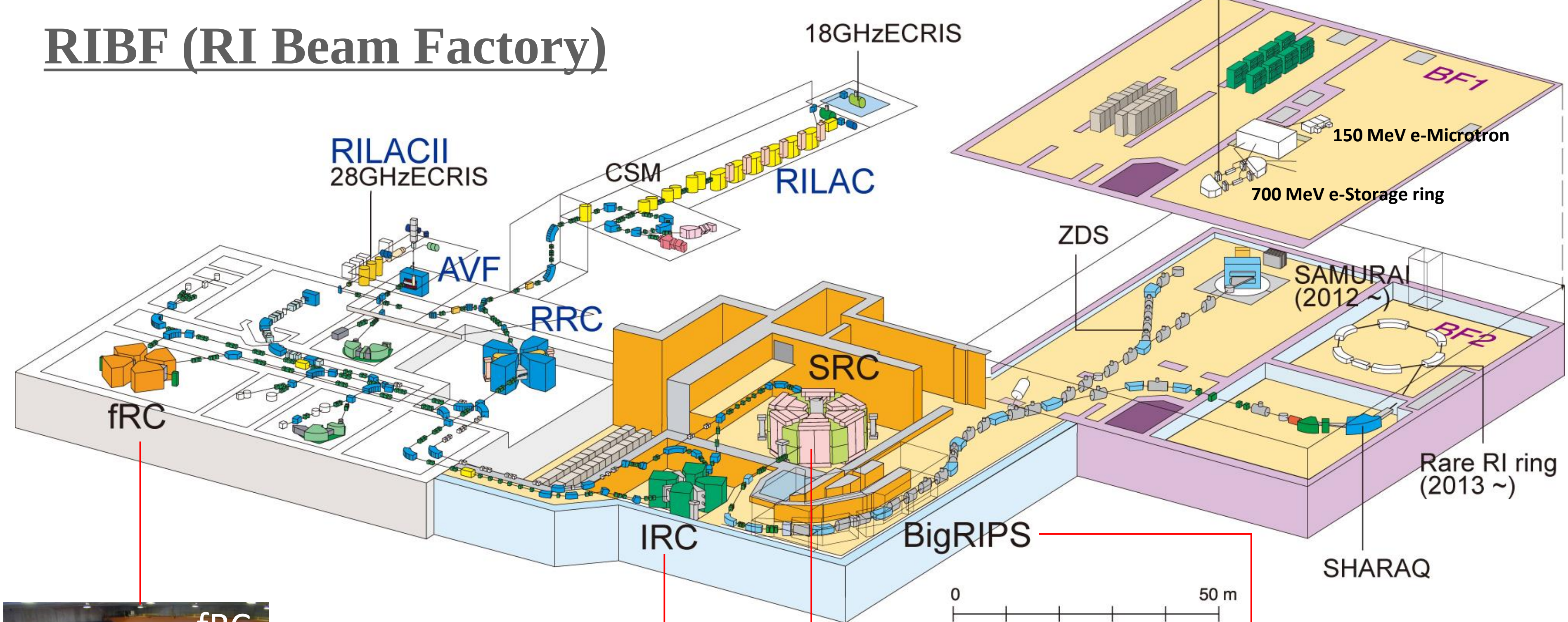
- High intensity ν_μ beam from J-PARC MR to Super-Kamiokande
- Observation of $\nu_\mu \rightarrow \nu_e$ (2013)
- Goals updated
  - Precise measurement of ν_e appearance
  - Precise meas. of ν_μ disappearance

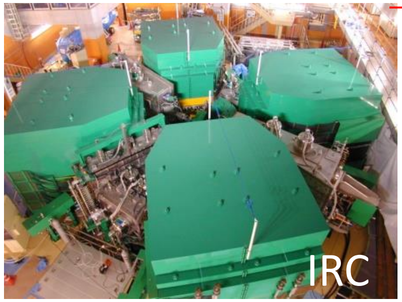
→ Measure CPV phase, contribution to mass hier. determ.

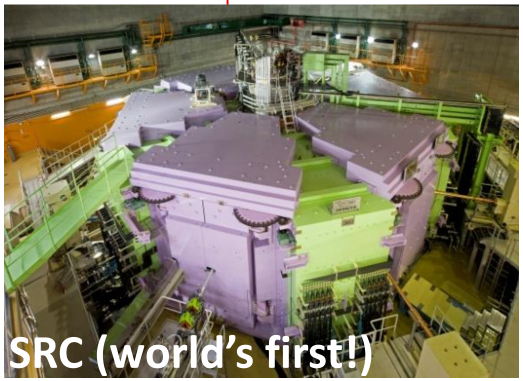
SRC: All ions @345 MeV/u
BigRIPS: RI beams via In-flight U Fission or Projectile Fragmentation

O. Kamigaito, FRXCB2

RIBF (RI Beam Factory)

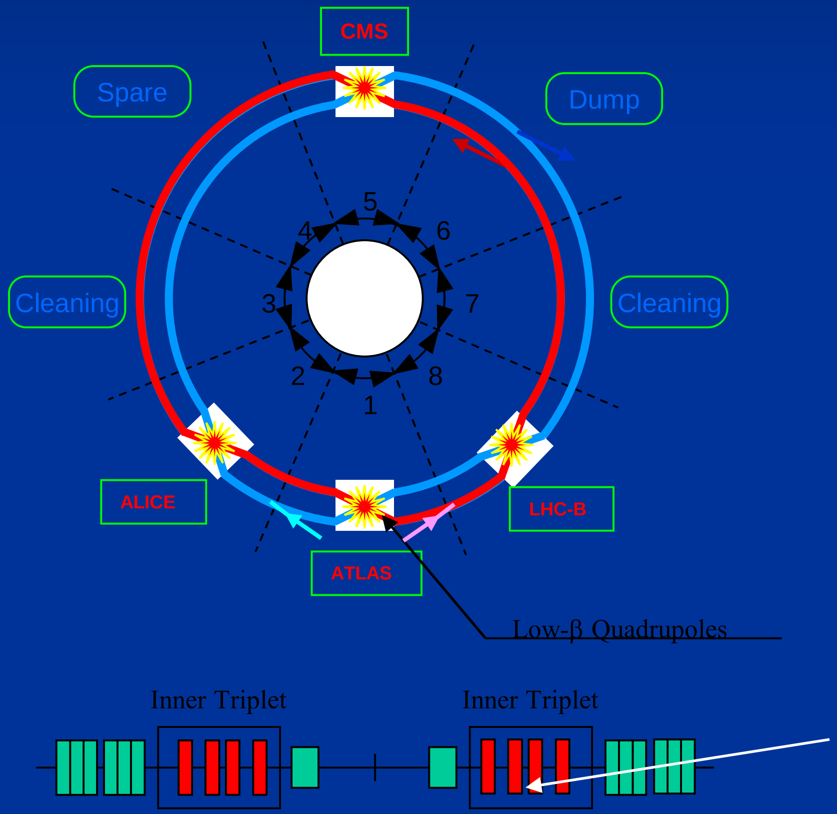


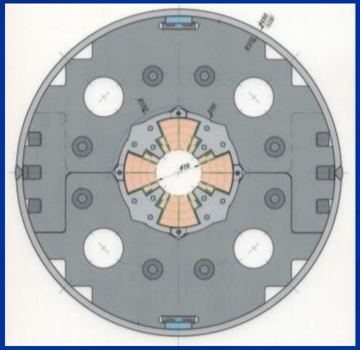




IPAC'11 Y. Yano (Budker prize)

CERN-LHC Insertion Quadrupole



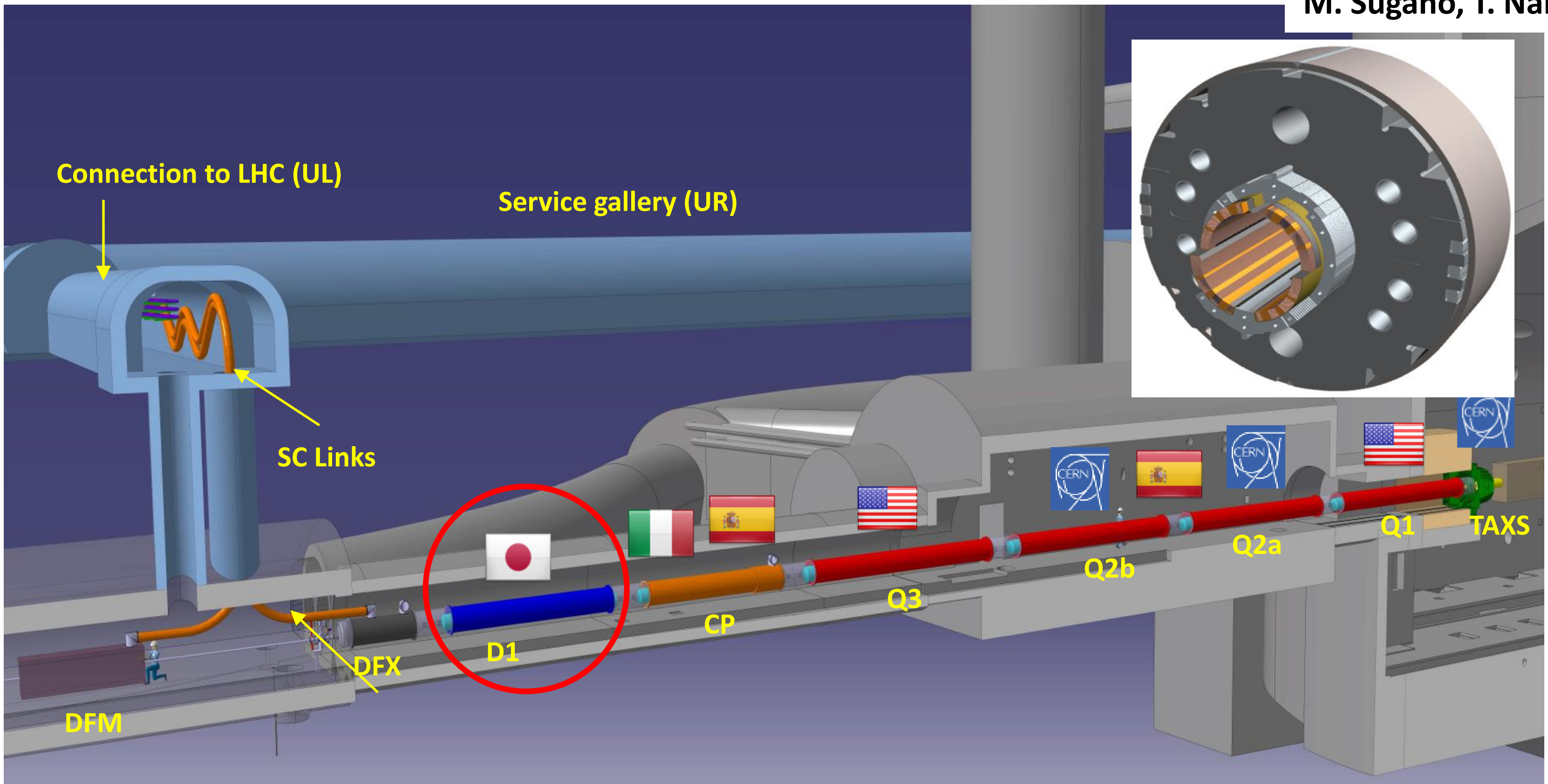


Fermilab and KEK collaboration for Inner Triplets

IR Upgrade for HL-LHC

HL-LHC (2024-2035):
3000 fb^{-1}, 5×10^{34} cm^{-2} sec^{-1}

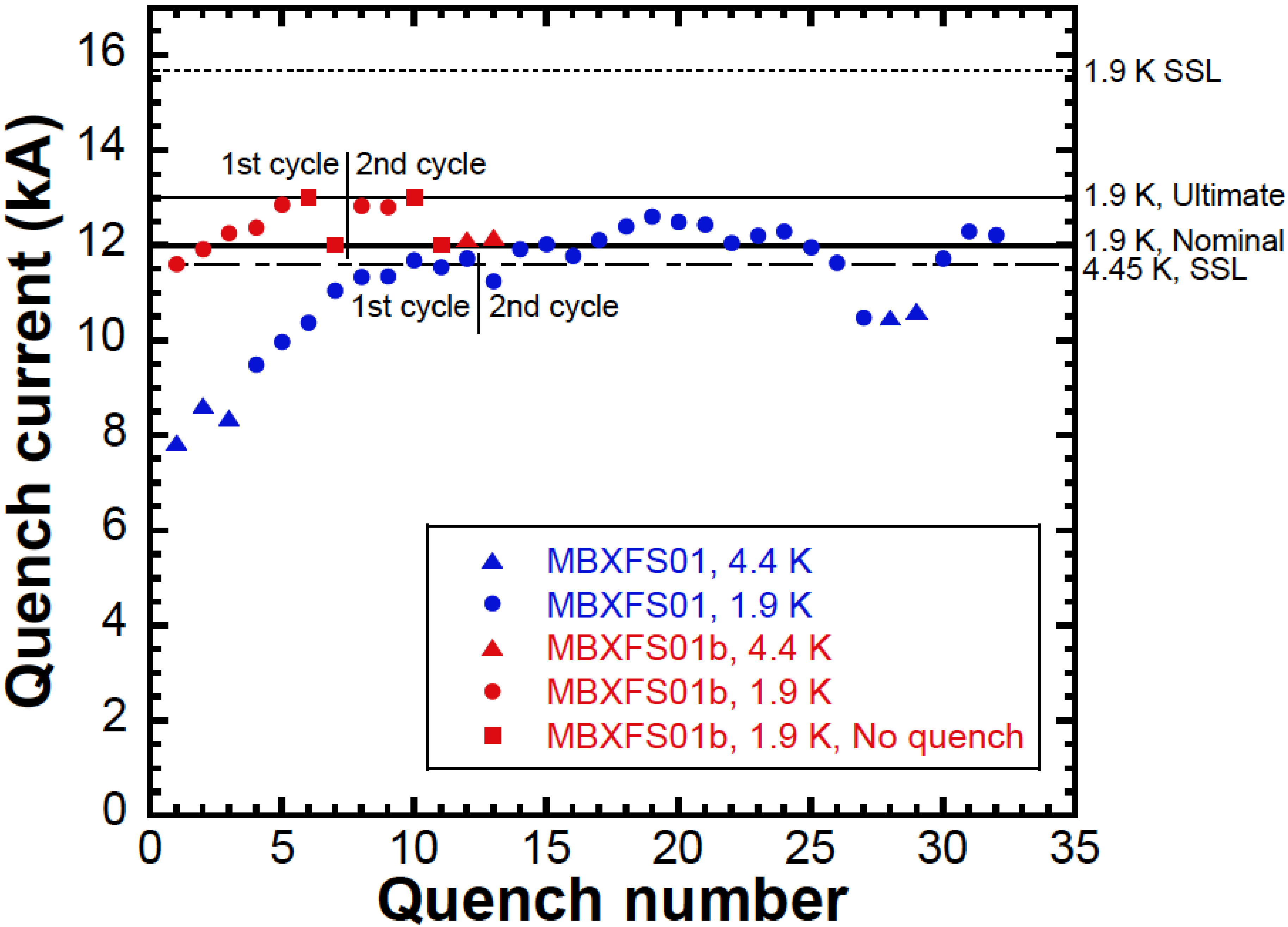
M. Sugano, T. Nakamoto



Development of new beam separation dipole (D1) at KEK

- **Large aperture** to obtain smaller β^* : ϕ70 mm → ϕ150 mm
- **Stronger kick** for shorter distance between D1 and D2:
  Field integral 26 Tm → 35 Tm by SC magnet

Proposal to funding agency: 1 full-scale prototype, 6 series magnets.



Quench current (kA)
Quench number
1.9 K SSL
1.9 K, Ultimate
1.9 K, Nominal
4.45 K, SSL
1st cycle
2nd cycle
1st cycle
2nd cycle
MBXFS01, 4.4 K
MBXFS01, 1.9 K
MBXFS01b, 4.4 K
MBXFS01b, 1.9 K
MBXFS01b, 1.9 K, No quench

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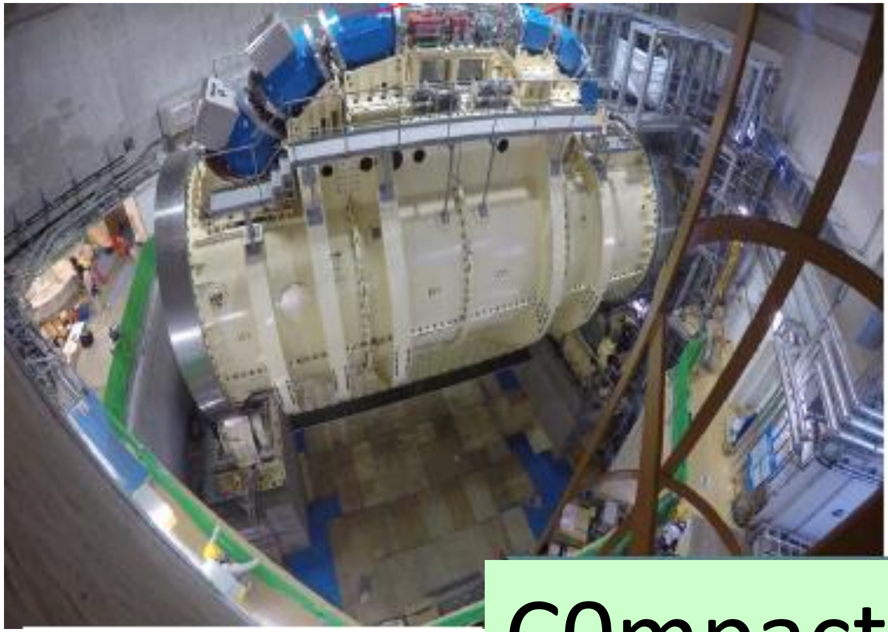
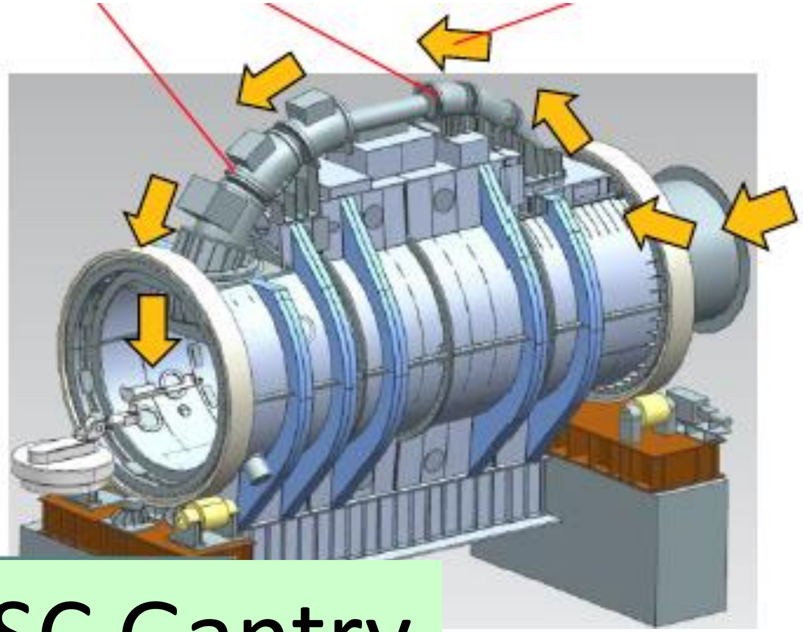
  - **RIKEN (Nuclear Physics) , NIRS (Medical)**
- Future Prospects

Outline of Carbon Facilities in Operation in the World

Institute /Hospital	Location (Country)	Start year	Rooms	Irradiation method	Max. Energy MeV/u	Operation schedule
NIRS	Chiba (Japan)	1994 ~	3+2	Wobbler Layer stacking Hybrid Scanning	400(C)	24 hours /6 days /10 month
GSI	Darmstadt (Germany)	1997~ 2008	1	Raster Scanning	400(C)	3 blocks /year
HIBMC	Hyogo (Japan)	2001~	5	Wobbler	320(C) 230(p)	16 hours / 5 days /12 month
IMP	Lanzhou (China)	2006~	2	Wobbler Layer stacking	100 for V 400 for H	24 hours /7 day /variable
HIT	Heidelberg (Germany)	2009~	3	Raster Scanning	430(C) 250(P)	16 hours / 5 days /12 month
GHMC	Gunma (Japan)	2010~	3	Wobbler Layer stacking	400(C)	8 hours / 5 days /12 month
CNAO	Pavia (Italy)	P: 2011~ (C: 2012)	3	Raster Scanning	400(C) 250(P)	220 days/yr





C0mpact SC Gantry

Outline

- Introduction
- Particle and Physics
- Other field
- **Future Prospects**
  - **Superconducting Magnets – Nb3Sn and HTS**
  - **SRF --- ILC (Global),**
    ADS (China), ISNS (India)

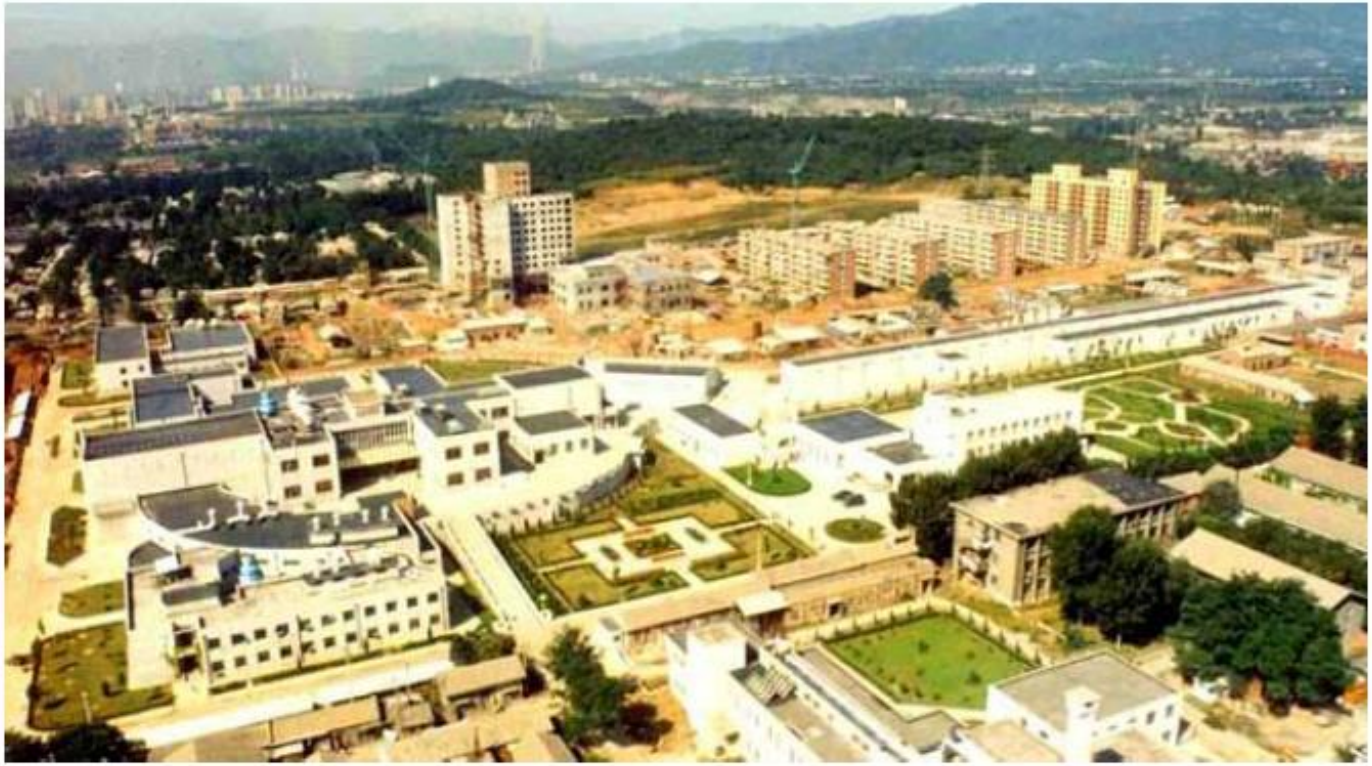
From BEPC to BEPCII

BEPC was completed in 1988 with luminosity $1\times10^{31}cm^{-2}s^{-1}$ @1.89GeV

BEPC II was completed in 2009

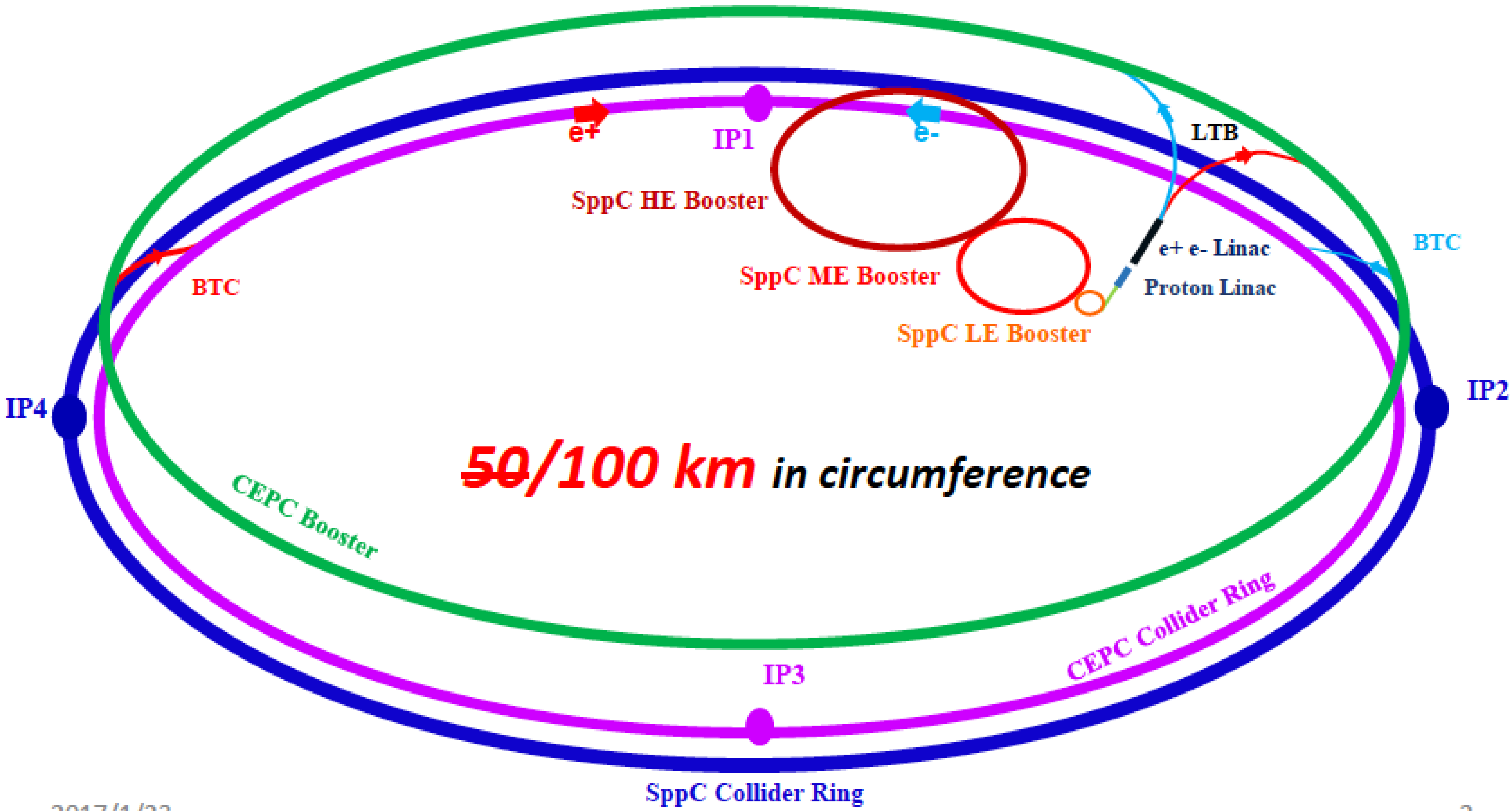
Luminosity reached on April 5, 2016: $10\times10^{32}cm^{-2}s^{-1}$ @1.89GeV

After BEPCII what is the next high energy collider?



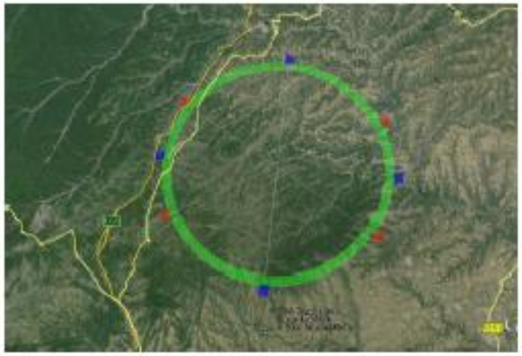
CEPC-SPPC

CEPC is an 240-250 GeV Circular Electron Positron Collider, proposed to carry out high precision study on Higgs bosons, which can be upgraded to a 70 TeV or higher pp collider **SPPC**, to study the new physics beyond the Standard Model.



Site selections (some main places)

1)



2)

3)

1) Qinhuangdao

2) Shanxi Province

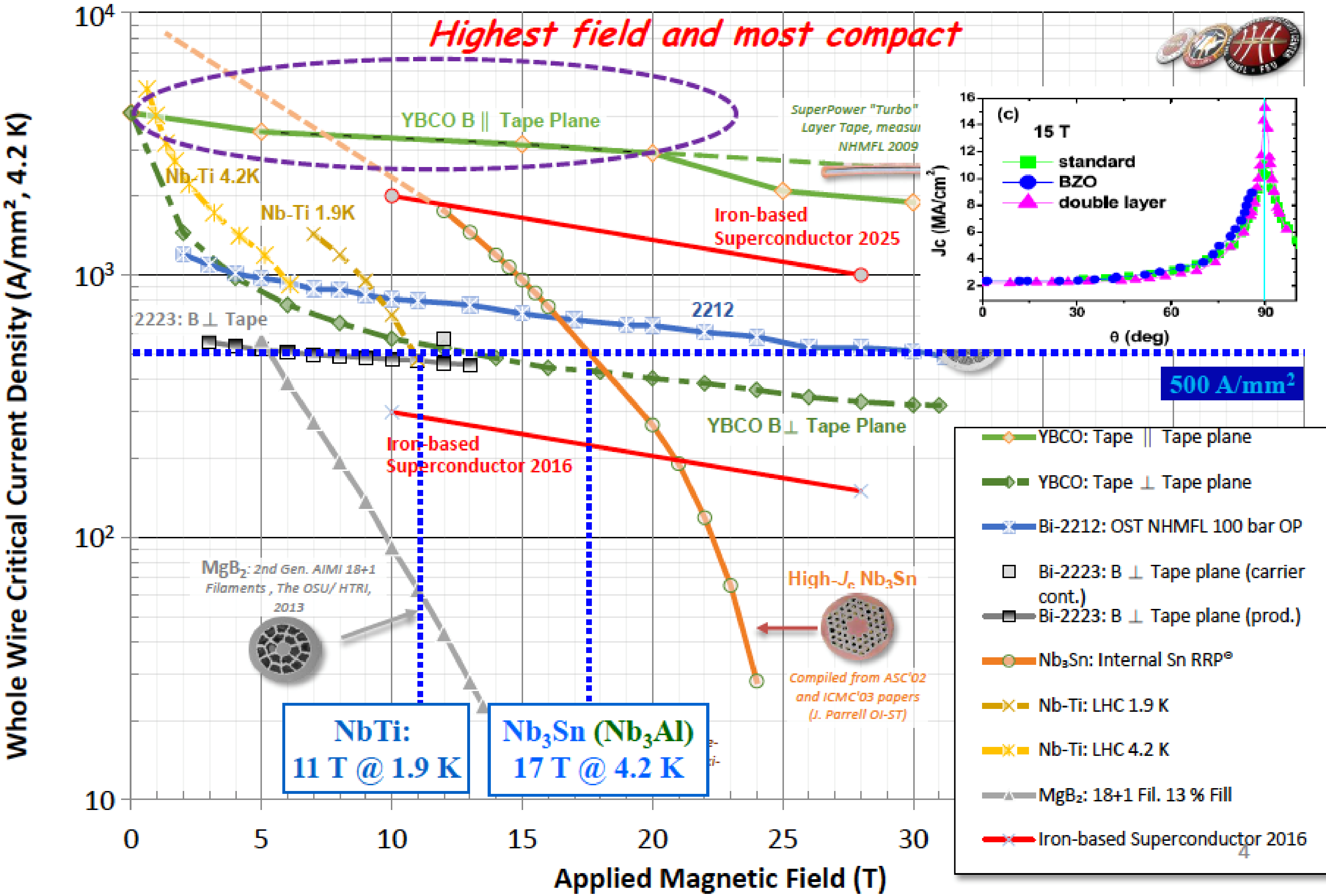
3) Near Shenzhen and Hongkong

SPPC Design Scope (201701 version)

Y. Wang, J. Tang, Q. Xu et al.

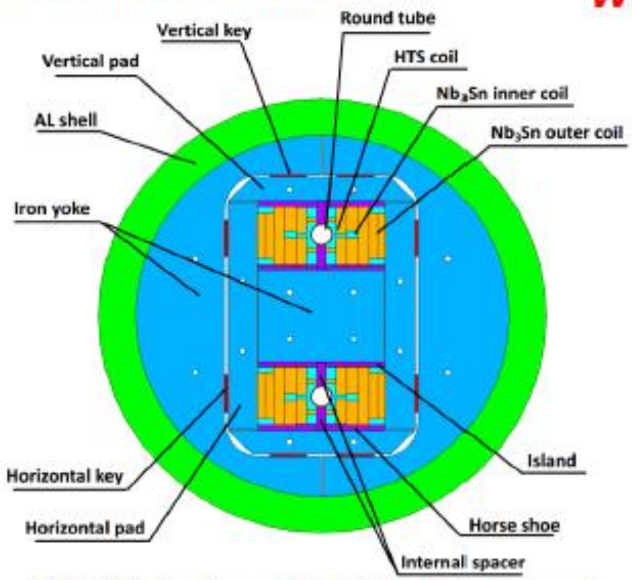
- **Baseline design**
  - Tunnel circumference: 100 km
  - Dipole magnet field: 12 T, using iron-based HTS technology
  - Center of Mass energy: >70 TeV
  - Injector chain: 2.1 TeV
- **Upgrading phase**
  - Dipole magnet field: 20 -24T, iron-based HTS technology
  - Center of Mass energy: >125 TeV
  - Injector chain: 4.2 TeV (adding a high-energy booster ring in the main tunnel in the place of the electron ring and booster)
- **Development of high-field superconducting magnet technology**
  - Starting to develop required HTS magnet technology before applicable iron-based HTS wire is available (in 5~10 years)
  - models by ReBCO (or Bi-2212) and LTS wires can be used for specific studies: stress management, quench protection, field quality control and fabrication methods

How to design a “good” accelerator magnet?



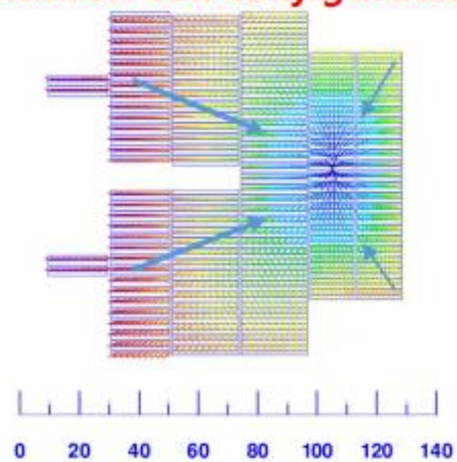
Concept of the SPPC 20-T Dipole Magnet

K. Zhang, Q. Xu et al.

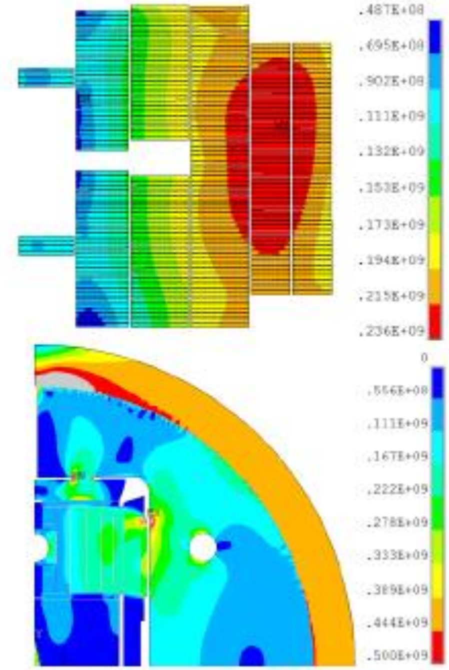


2D & 3D structure of the 20T dipole magnet

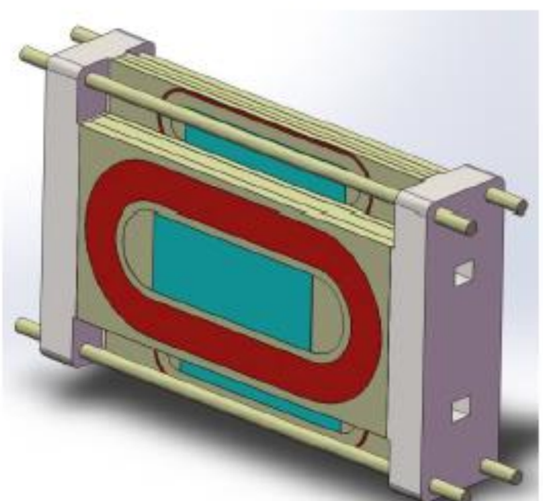
With common coil configuration

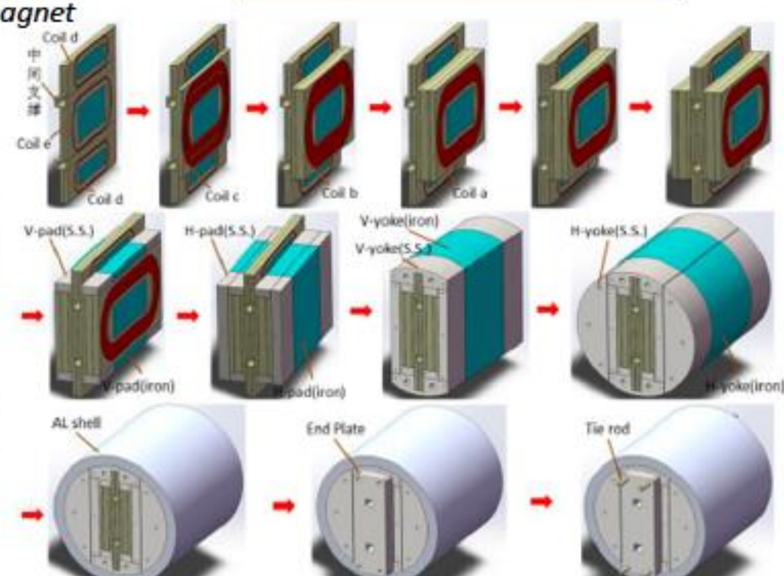


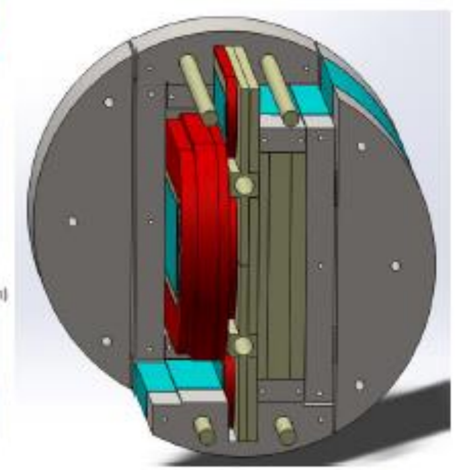
Lorentz force per aperture:
Fx=23.4 MN/m ; Fy=2.38 MN/m



Stress distribution after excitation







K. Zhang et. al., 2-D Mechanical Design Study of a 20-T Two-in-One Common-Coil Dipole Magnet for High-Energy Accelerators, IEEE Trans. Appl. Supercond., VOL. 26, NO. 4, 2016, 4003705

ILC GDE to LCC

1980' ~ Basic Study

2004 | 2006 | '07 | '08 | '09 | '10 | '11 | '12 | '13 | '14 | '15 | '16 | '17

ILC-GDE

LCC

Ref. Design (RDR)

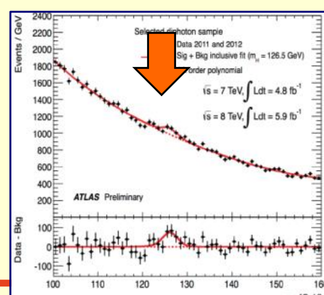
Technical Design Phase

TDR publication

LHC

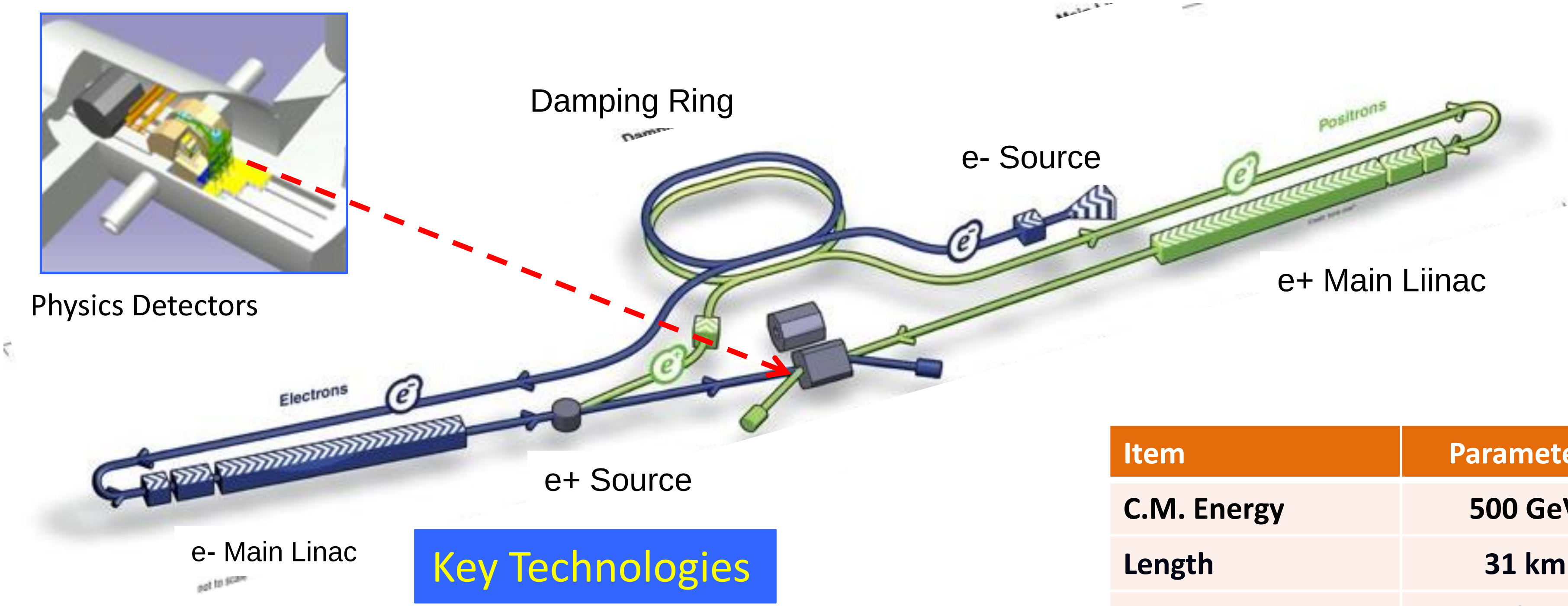
Selection of SC Technology

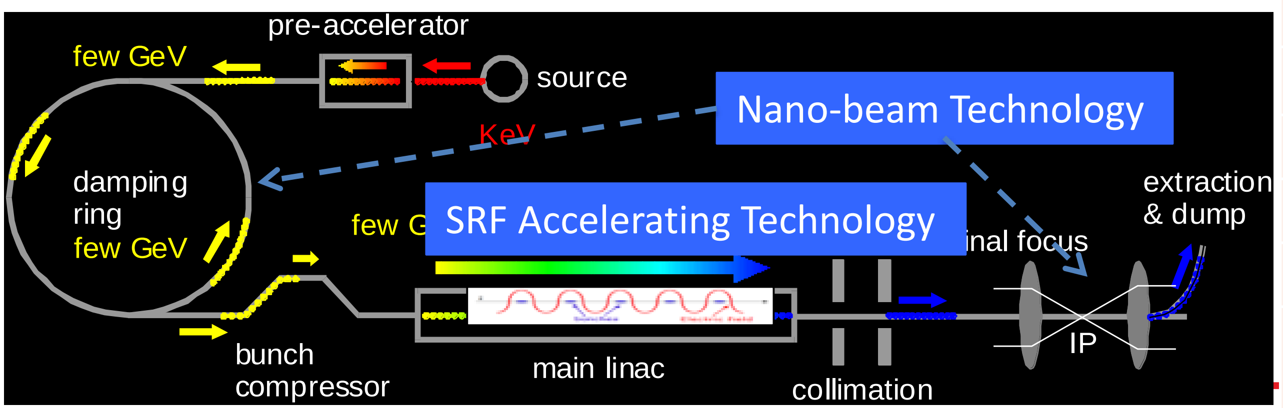
126 GeV



Higgs discovered

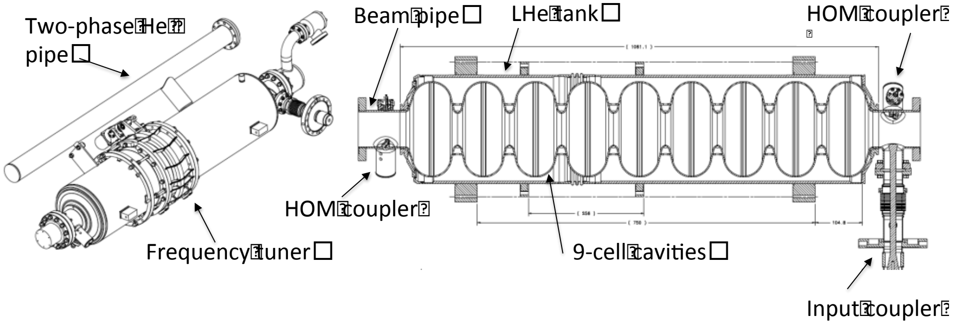
ILC Acc. Design Overview (TDR)





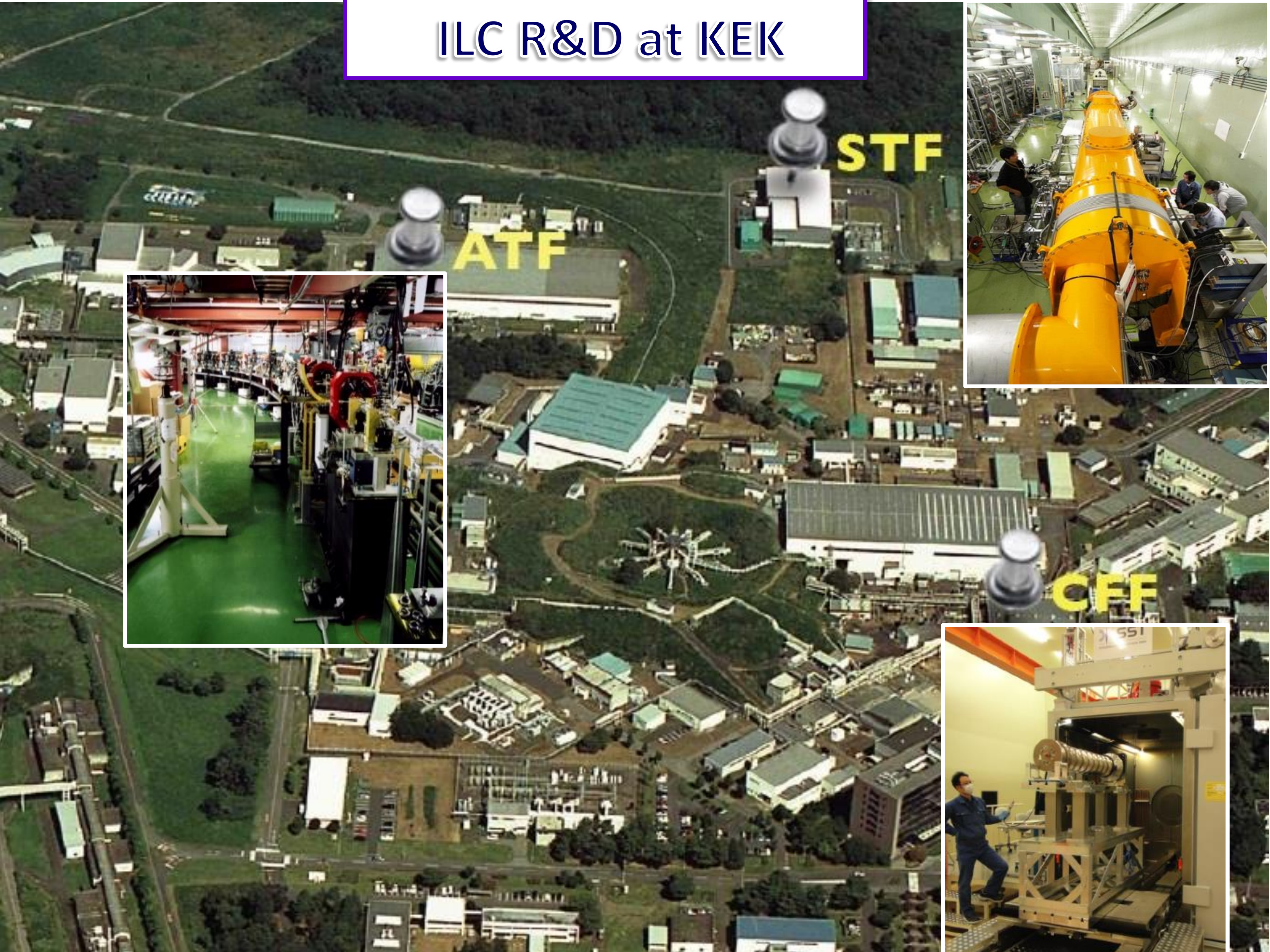
Item	Parameters
C.M. Energy	500 GeV
Length	31 km
Luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Repetition	5 Hz
Beam Pulse Period	0.73 ms
Beam Current	5.8 mA
Beam size (y) at FF	5.9 nm
SRF Cavity G. Q_0	31.5 MV/m Q_0 = 1x10^{10}

ILC SRF ML Parameters

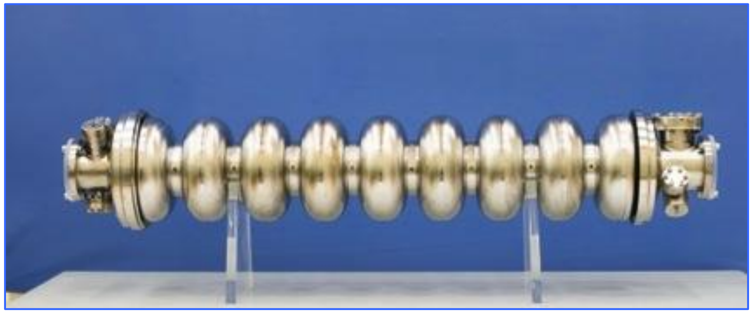


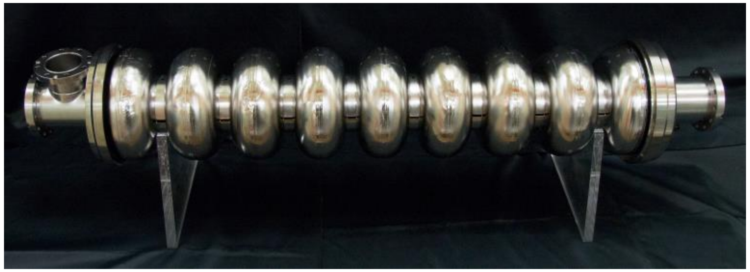
1.3 GHz Nb 9-cellCavities	16,024
Cryomodules	1,855
SC quadrupole pkg	673
10 MW MB Klystrons & modulators	~400

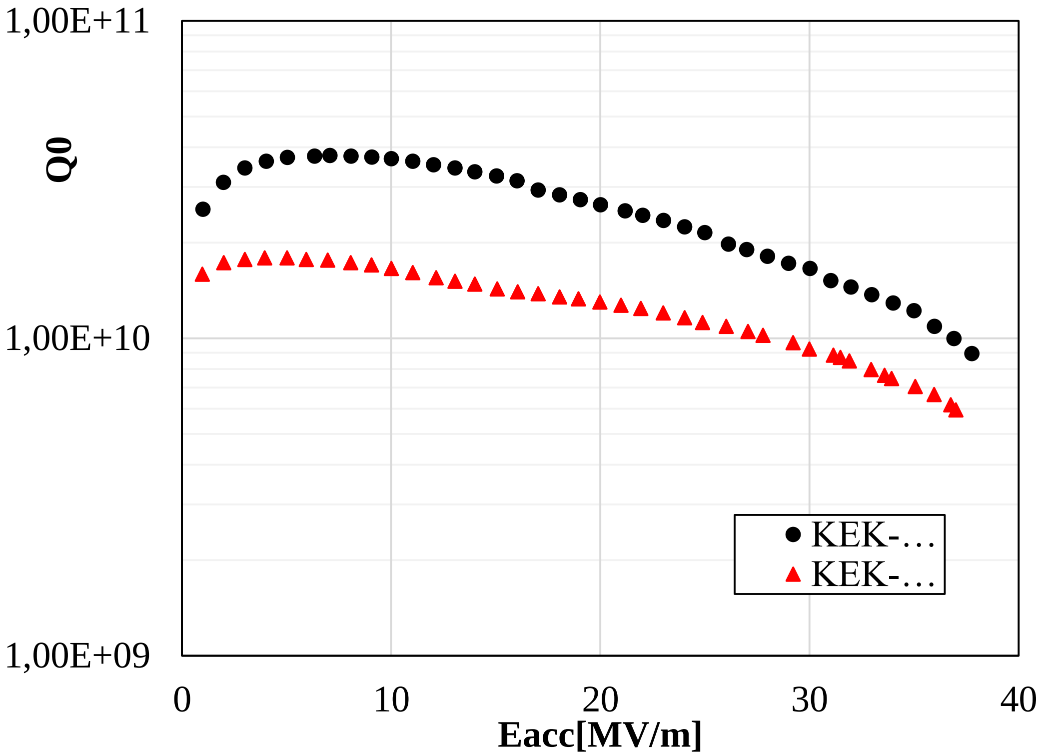
ILC R&D at KEK



KEK 9-Cell Cavity (KEK-01/02)reached 36/38 MV/m







KEK-01 (Rolled, FG, 2014): Reached 36 MV/m
KEK-02 (Ingot-sliced, LG, 2016): Reached 38 MV/m

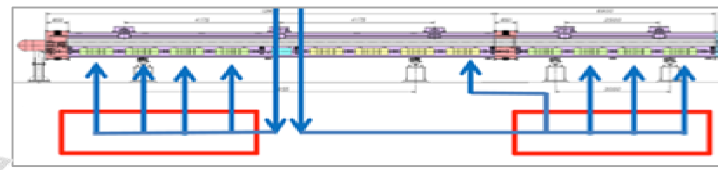
Y. Yamamoto, E. Kako, H. Hayano

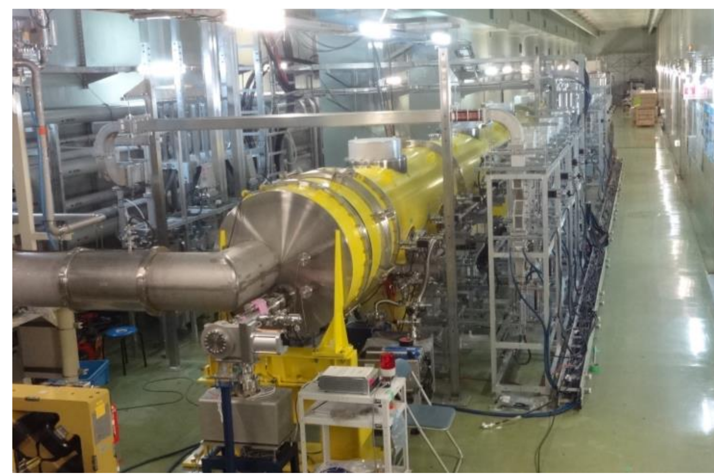
KEK-STF: Cavity/CM Performance, and RF and Beam Test Preparation

SRF cavity Gradient (MV/m) before/after CM Assembly												
Module	CM1a				CM1b				CM2a			
Cav. #	1	2	3	4	5	6	7	8	9	10	11	12
V. Test (CW)	37	36	38	36	37	35	39	36	12	36	32	32
in CM (pulse)	**39**	**37**	**35**	**36**	**26**	**16**	**26**	**32**	**18**	**34**	**33**	**32**
	Gradient stable				Degraded				Gradient stable			

FY14: CM1+CM2a (8+4) assembly
FY15: Cavity individually tested in CM
RF power system in preparation
FY16: **8-cavity** string to be RF tested
FY17: Beam Acceleration expected
（to reach ＞250 MeV)

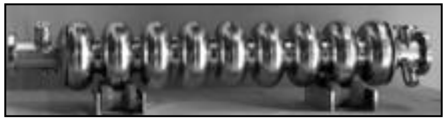
*<G> : 30 MV /m (12 Cav.) , 35 MV/m (best 8)





A SCRF Industrialization Model

Host-Lab



Technical Coordination
for Lab-Consortium

Regional Hub-Lab: A

Regional Hub-Lab: E, & …

World-wide
Industry responsible to
‘Build-to-Print’
manufacturing

Regional Hub-Lab: B

Regional Hub-Lab: D

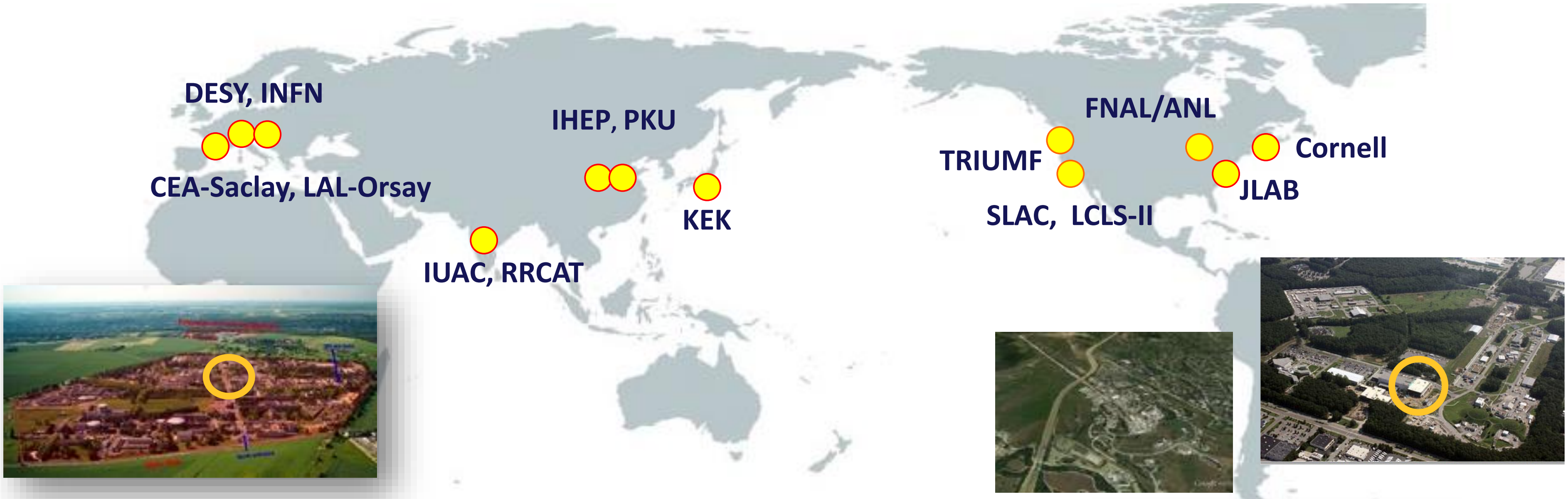
Regional Hub-Lab:
C: **responsible to Hosting System Test and Gradient Performance**

Regional hub-laboratories responsible to regional procurements to be open for any world-wide industry participation

: Technical coordination link
: Procurement link

China has been already modelling/functioning as an industrialization partner

Global SRF Collaboration



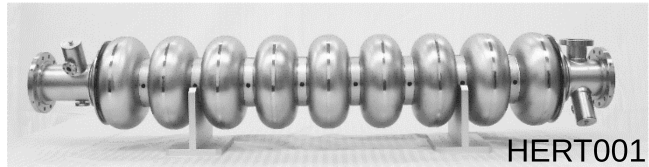
Europian Collab.

Asian Collab.

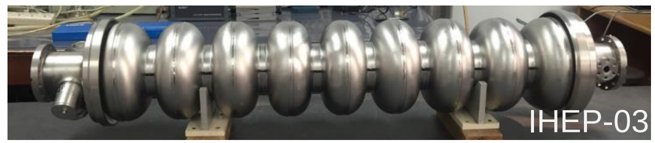
America(s) Collab.

ILC 1.3 GHz SCRF R&D at IHEP

2016 9-cell **TESLA**, **fine grain** cavity with HOM, by High-Energy Racing, process and test at KEK



2014 9-cell **TESLA-like**, fine grain cavity with HOM, 16.8 MV/m by EP, process and test at KEK



2012 9-cell **Low Loss**, **large grain** cavity with HOM, 20 MV/m by EP, process and test at FNAL

2010 9-cell low-loss, large grain cavity without HOM, 20 MV/m by CP, test at KEK and JLAB

2008 single cell low-loss large and fine cavity, max. 40 MV/m by CP, process and test at KEK

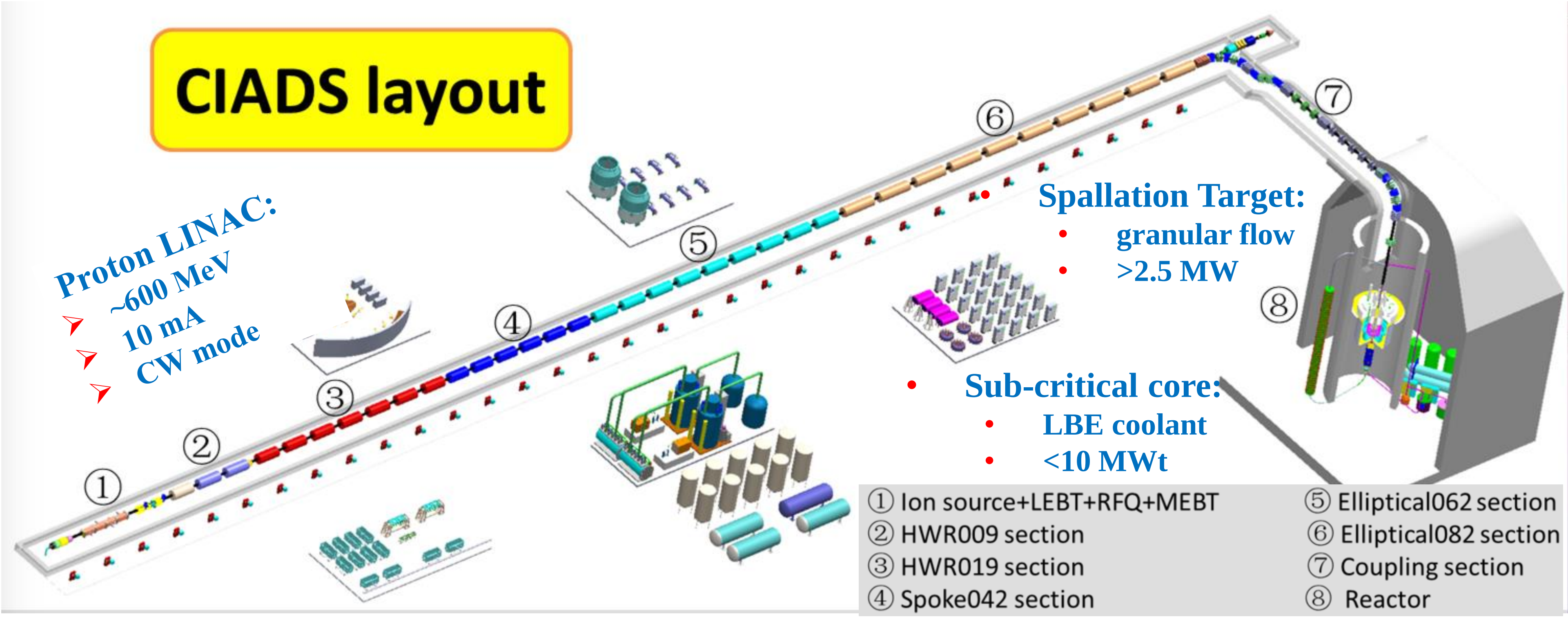
The CAS ADS Program (2011-2017)

- The program of "**Advanced Nuclear Fission Energy --- the Accelerator Driven Sub-critical System** " was initiated by CAS under the frame of "**Strategic Technology Pilot Project**" in 2011
- The ultimate goal is to build an industrial-scale demo facility for the development of advanced fission energy
- The budget is ¥1.78 billion for a five-year period
- **IMP is the leading institute** to carry out the research in cooperation with a number of participants.

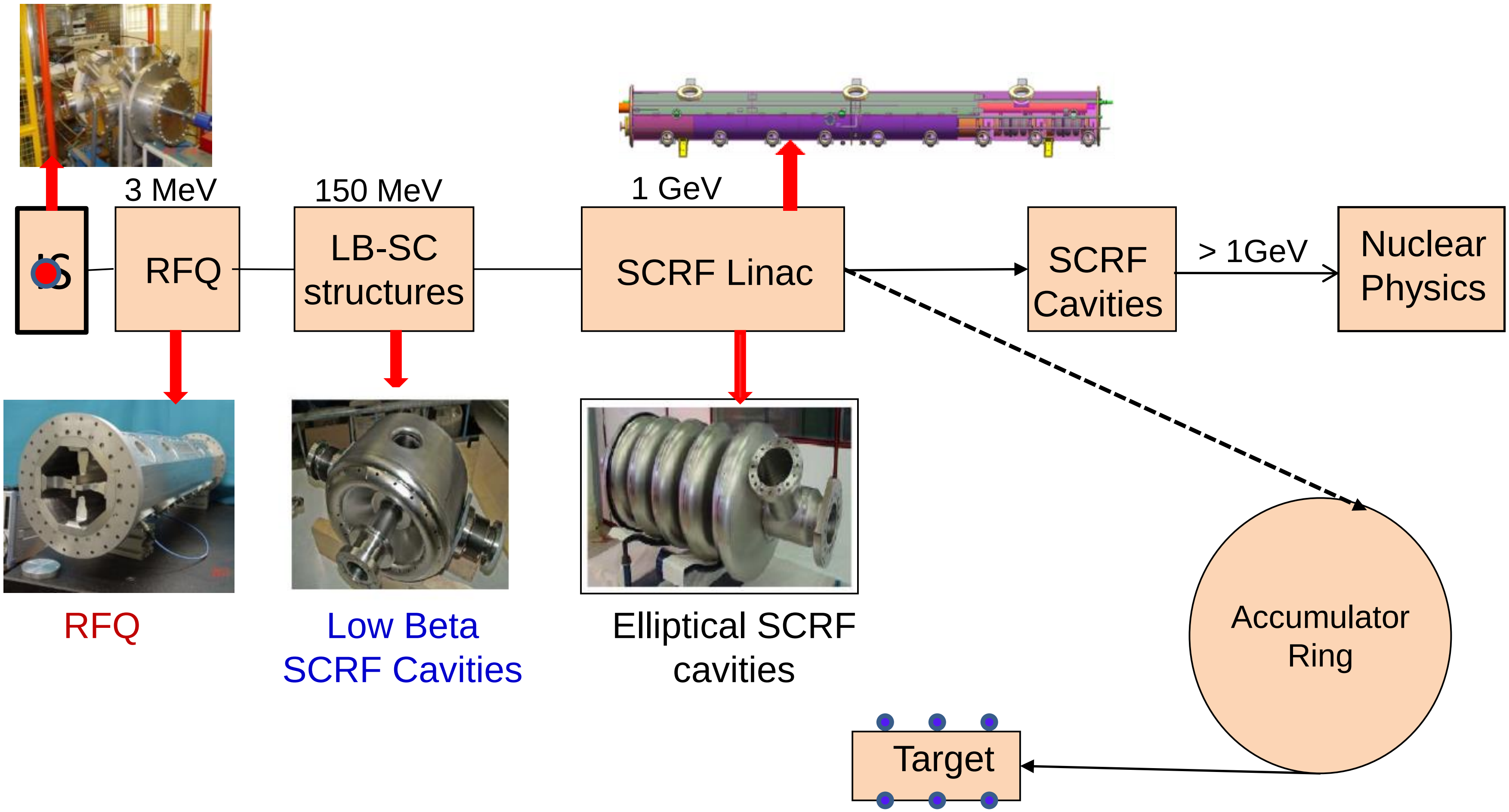
New Project CIADS (2017-2022)

China Initiative Accelerator Driven System

- Location: Huizhou, Guangdong Prov.



RRCAT (India): Proposed ISNS Facility



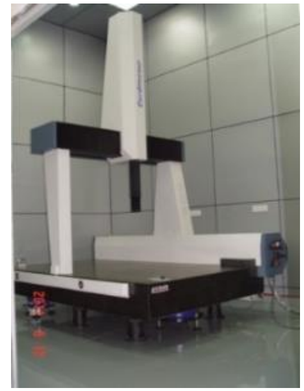
The SRF infrastructure to support : ISNS activity and
Participation in IIFC related activities

RRCAT: SRF Infrastructure facilities

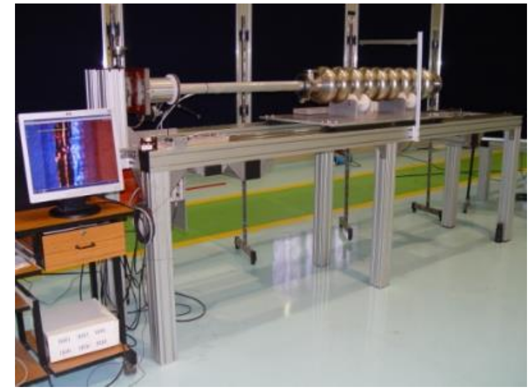
Cavity fabrication & inspection facility

Cavity Forming Facility

15 kW EBW Machine



3D CMM

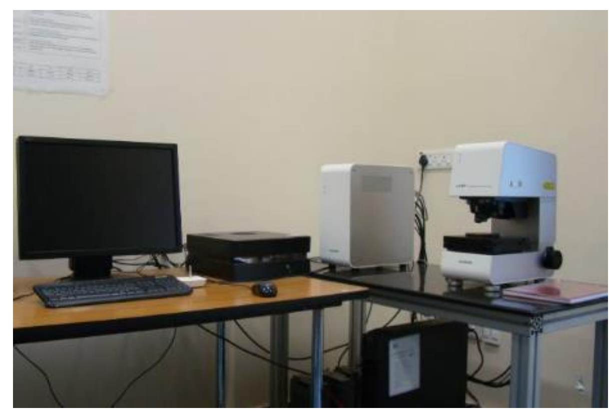


Optical Inspection Bench

Material Characterization facility

SIMS Facility

Universal Testing Machine



Laser scanning confocal microscope

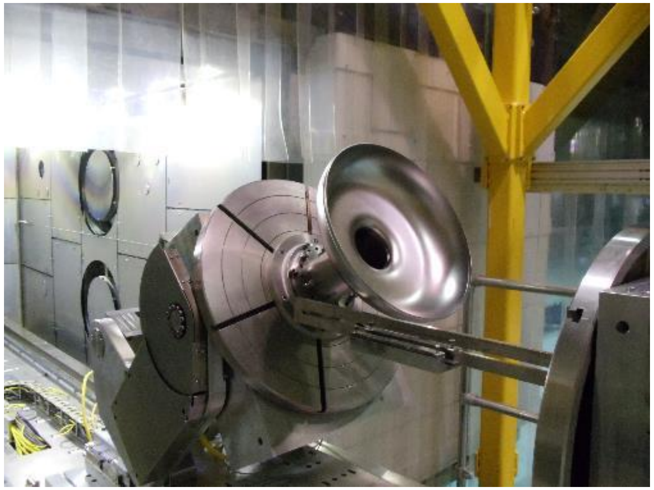
RRCAT* Cavity Fabrication Facility

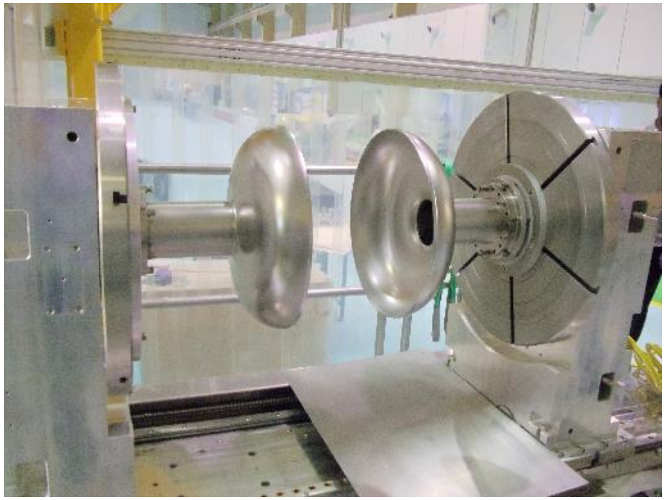
Nd-YAG laser beam welding facility – for 1.3 GHz single-cell cavity

A novel technique of fabrication of SRF cavities using Nd-YAG laser welding process, has been developed at RRCAT. The process has received patent from Japan.

A 1.3 GHz single-cell cavity fabricated using the facility was processed and tested at Fermilab. The cavity produced an accelerating gradient > 31 MV/m

Welding of single-cell 650 MHz cavity





Thank you for your attentions