Accelerator Technology -
From Big Projects to Broad Application

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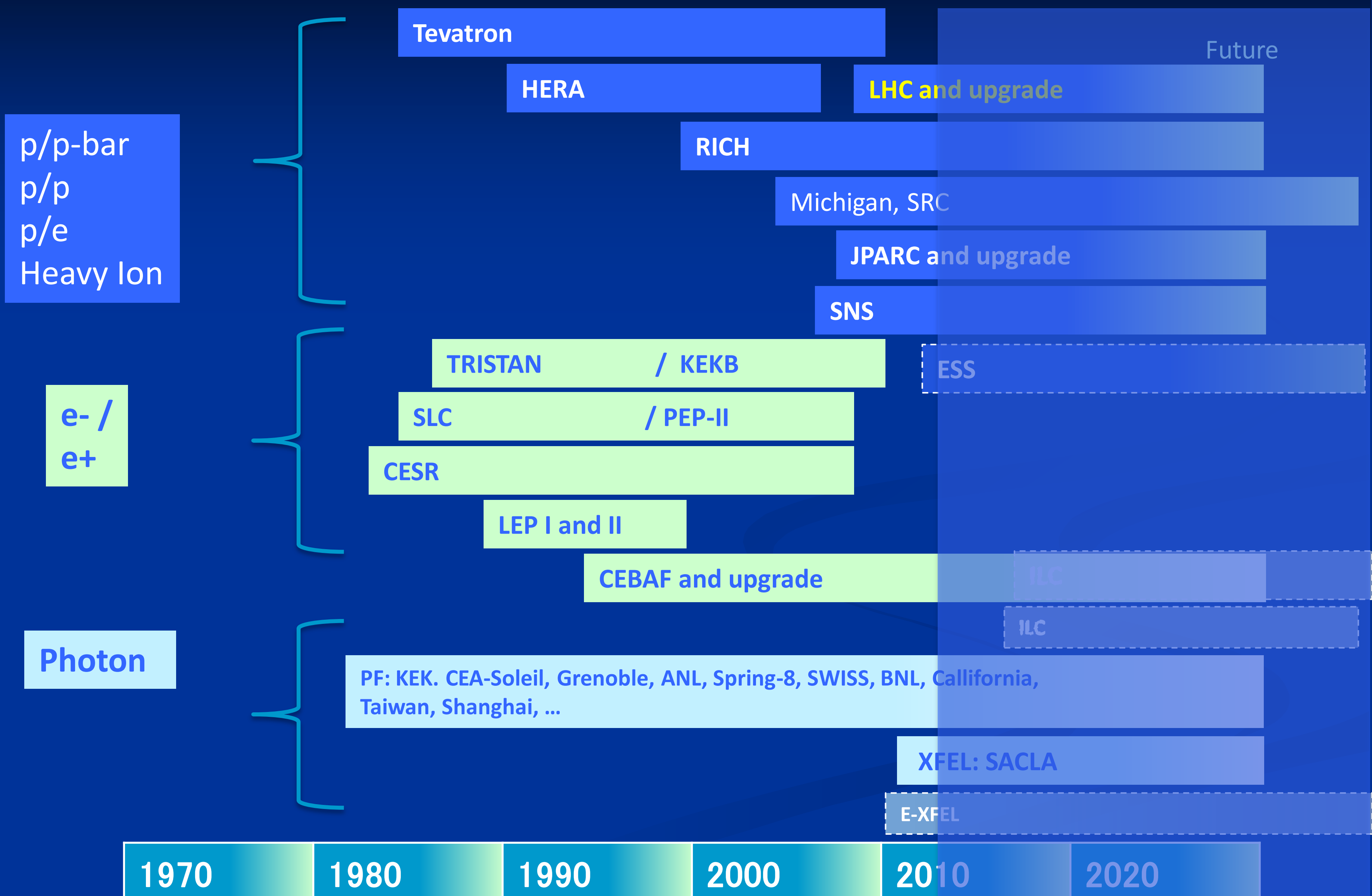
(KEK)

FRXBA01, IPAC'13, Shanghai, May 17, 2013

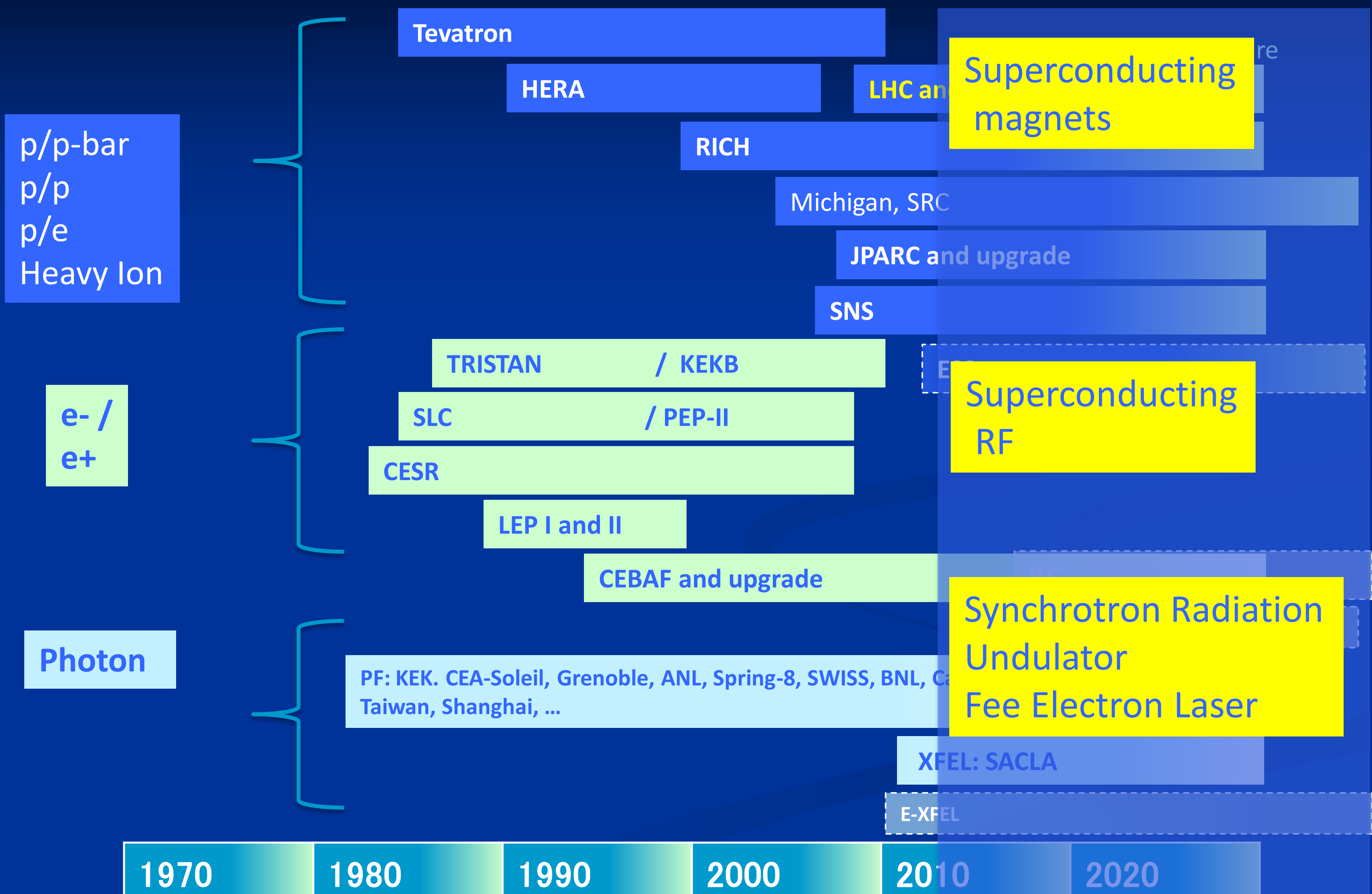
Outline

- Introduction
  - Progress in particle accelerators
- Accelerator technologies from "Big Projects" and "Applications"
  - LHC: Superconducting magnet technology
  - JPARC and Project-X: A research complex
  - EXFEL and ILC: superconducting RF technology
- General applications
  - Photon science, Medical application, and others
- Summary

Key Technologies & Broad Application



Key Technologies & Broad Application



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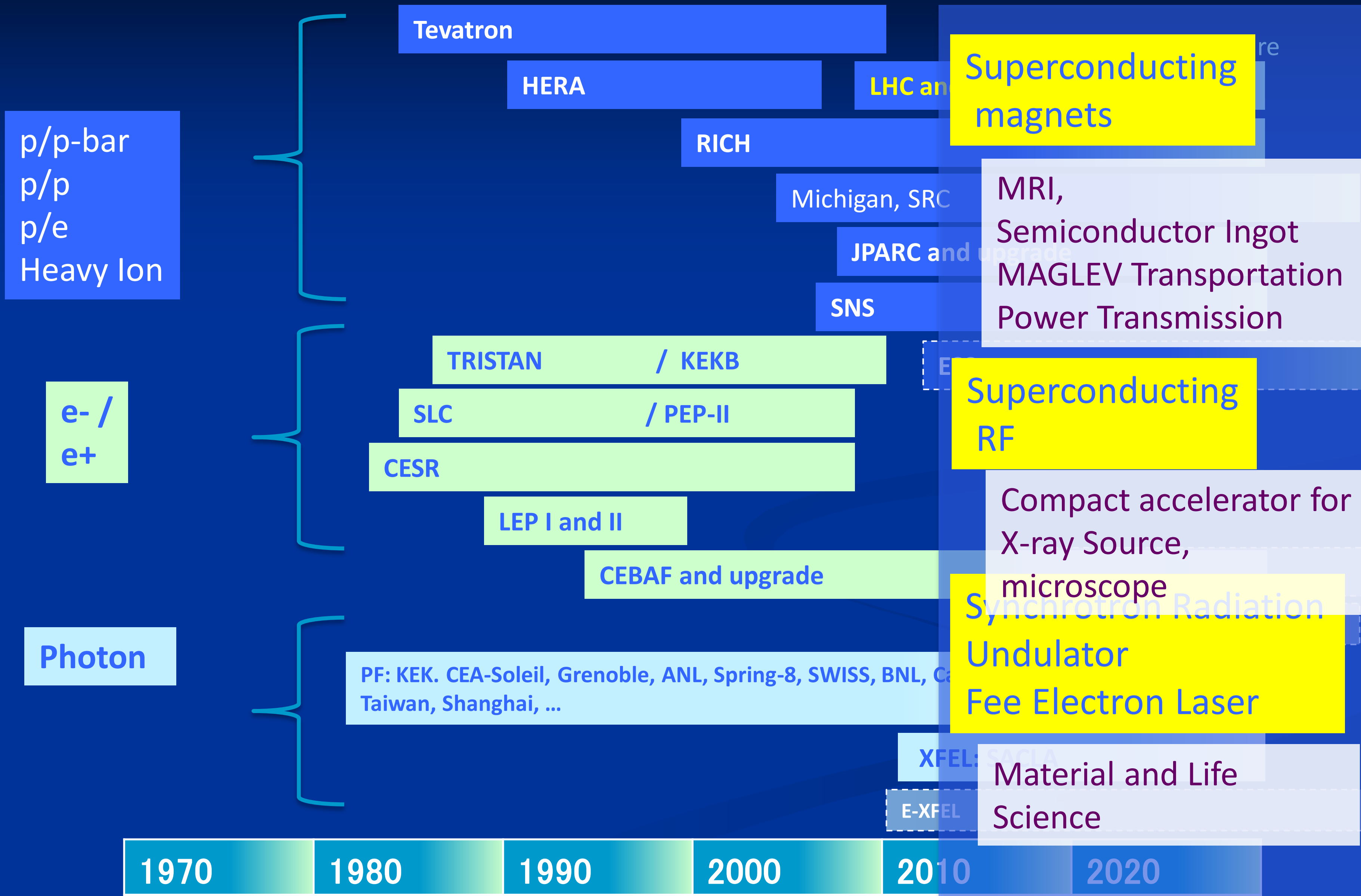
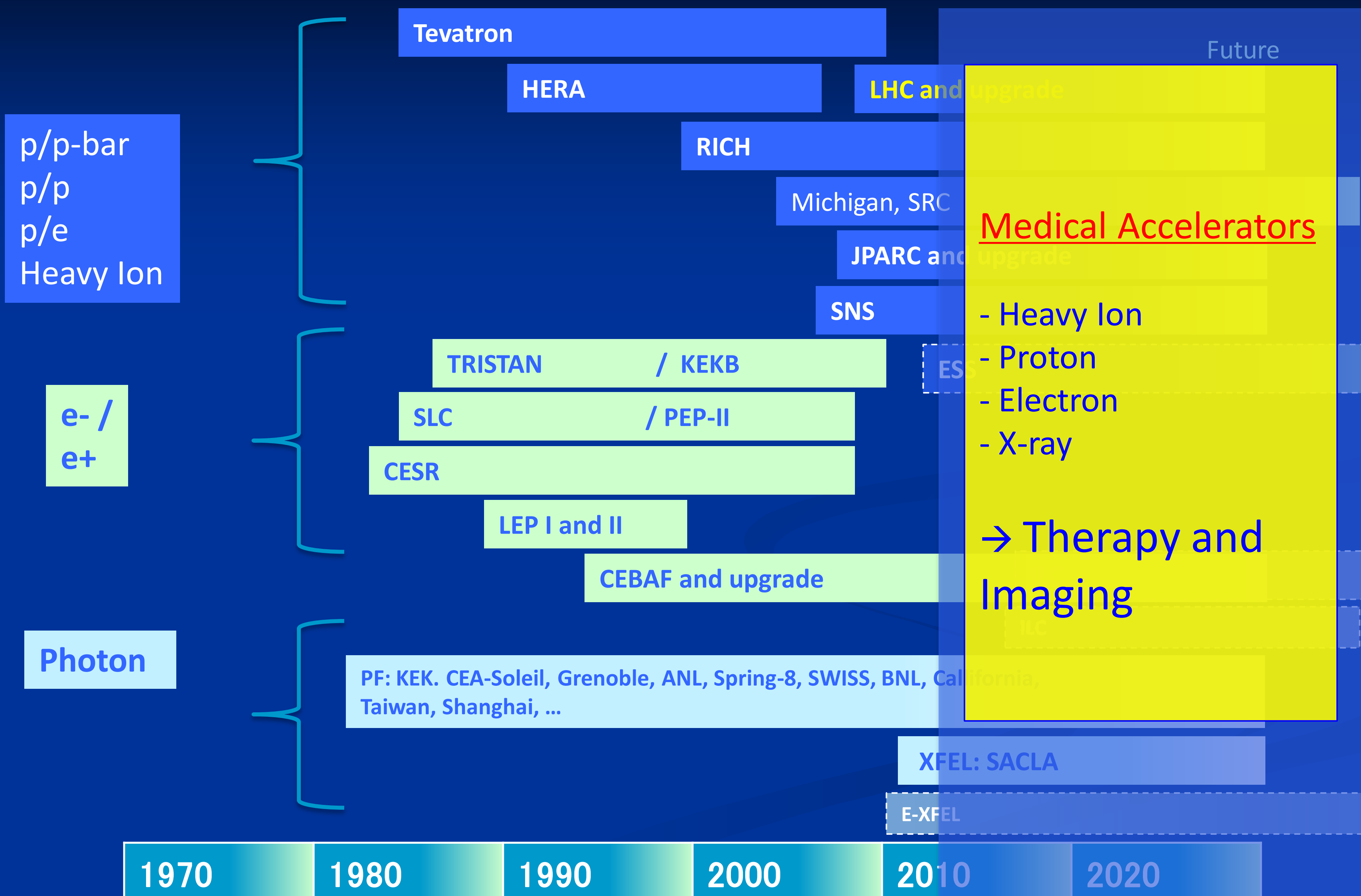
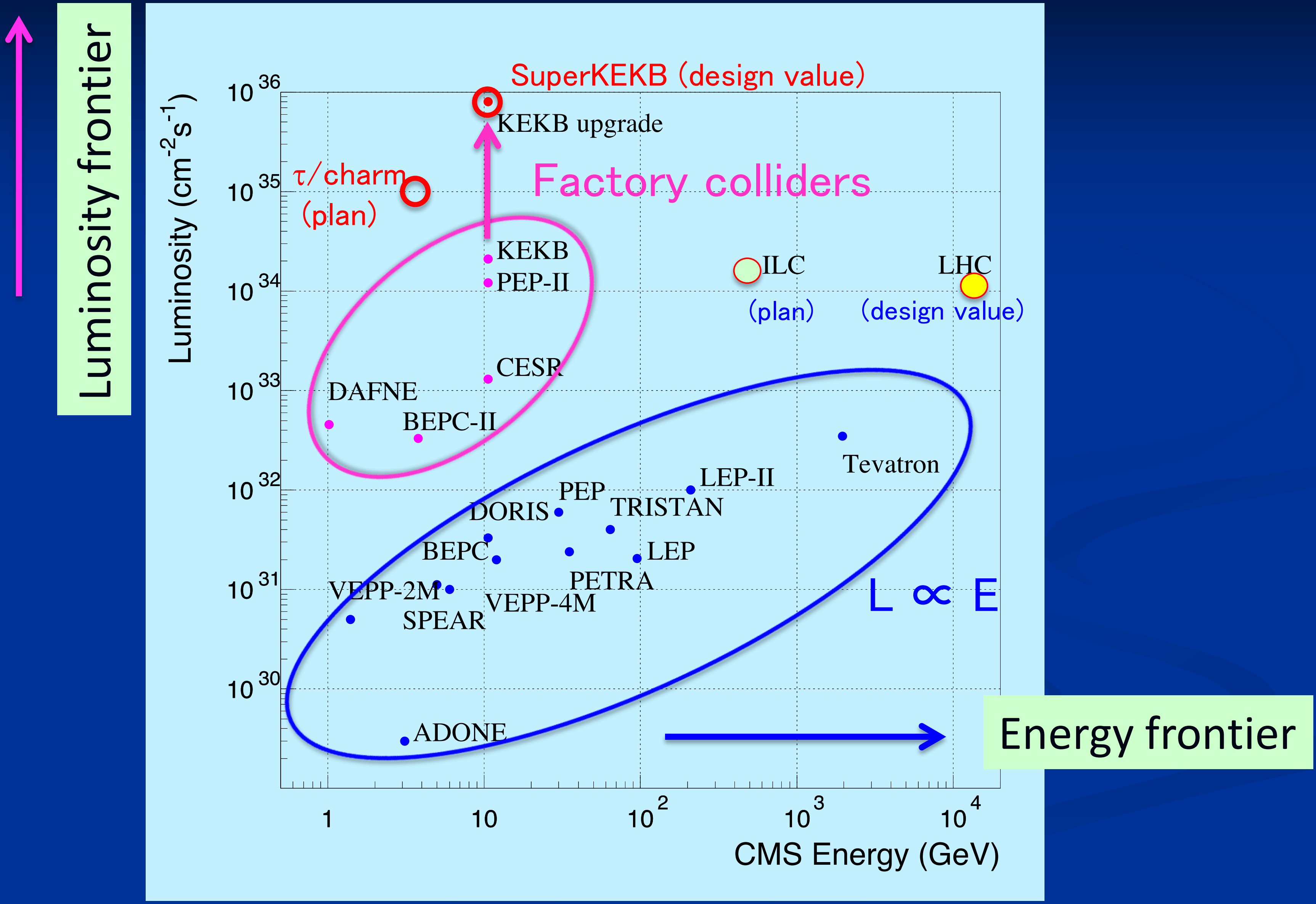


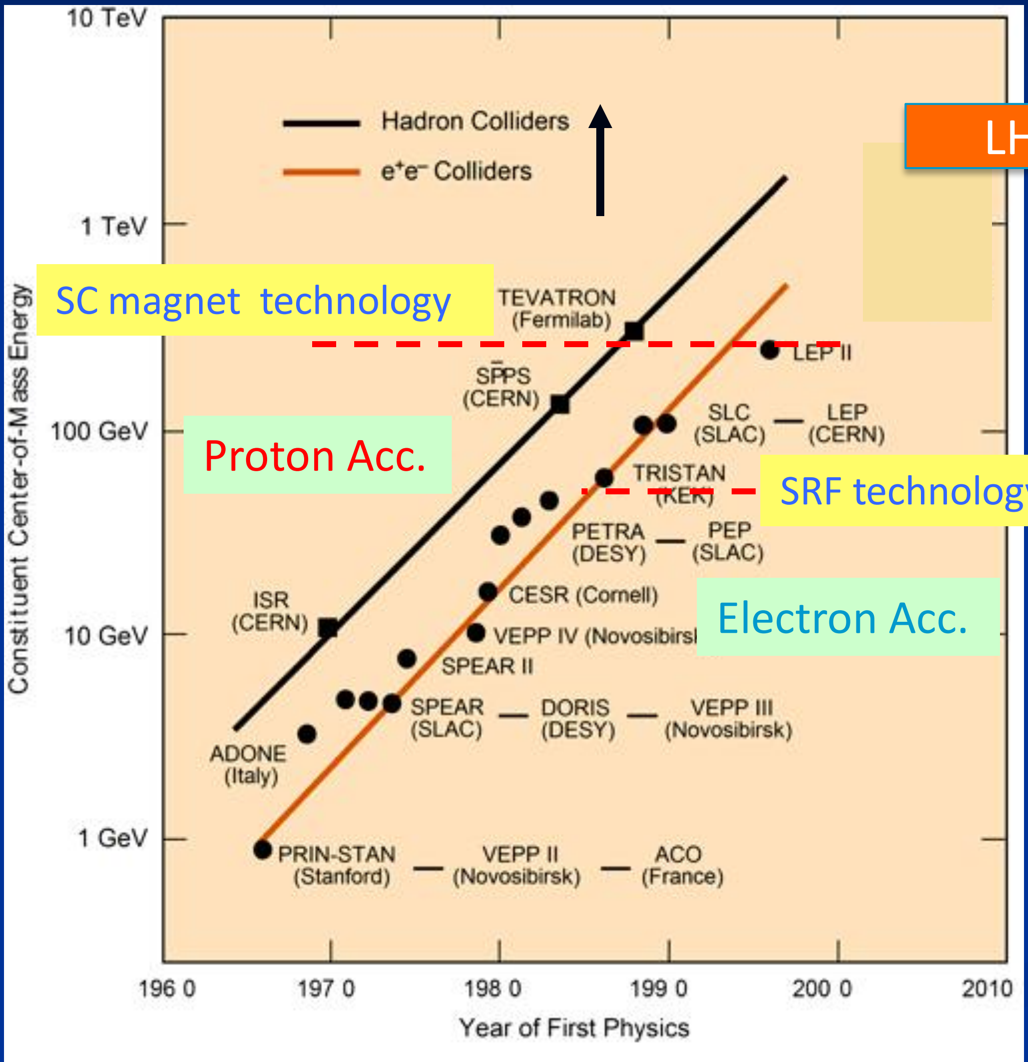
Key Technologies & Broad Application



Frontier of colliders

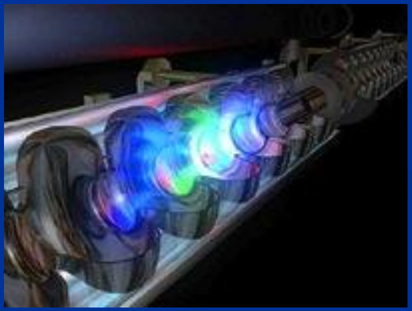


Progress in Particle Accelerator in energy frontiers



LHC

ILC



- Superconducting technology getting inevitable

Progress in SC "Big" Acc. Projects

Location	Accelerator (proton)	Energy [GeV]	B Field [T]	Operation	Key Technology
Fermilab	Tevatron	2 x 900	4.0	1983-2011	SC Magnet
DESY	HERA	820	4.68	1990-2007	SC Magnet
BNL	RHIC	2 x 100	3.46	2000 -	SC Magnet
CERN	LHC	2 x 7,000	8.36	2009 -	SCM / SCRF
Location	**Accelerator (electron)**	**Energy**	**E / (Freq.) MV/m / (GHz)**	**Operation**	**Key Technology**
KEK	TRISTAN	2 x 30	5 (0.5)	1986-1995	SCRF
CERN	LEP	2 x 105	5 (0.5)	1989-2000	SCRF
JLab	CEBAF	6	7 (1.3)	1995~	SCRF
KEK	KEKB	8	5 (0.5)	1999~2007	SCRF
DESY	EXFEL*	14	24 (1.3)	construction	SCRF
Fermilab	Project-X*	8	~20 (1.3)	Plan	SCRF
---	ILC*	2 x 250	31.5 (1.3)	Plan	SCRF

* Plan

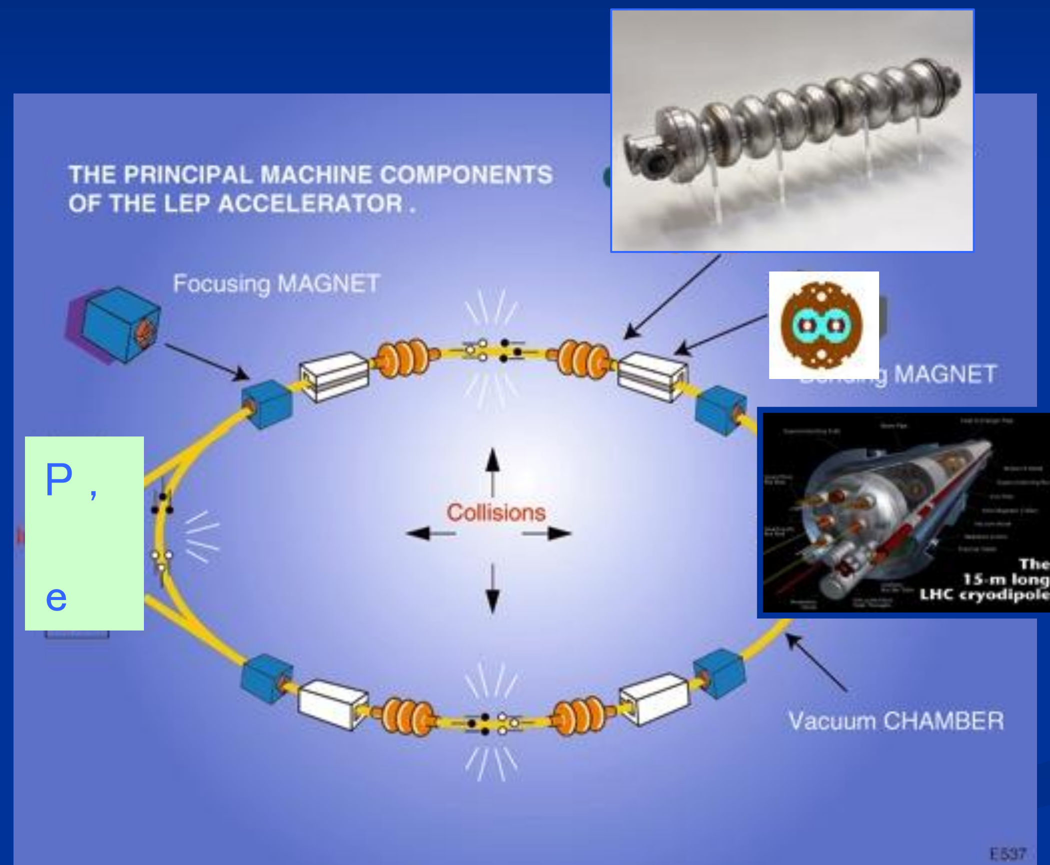
Fundamental Fields and Role of Superconductivity in Particle Accelerators

Acceleration

- **Electric Field: E**
  - Static,
  - RF

Beam Handling

- **Magnetic Field ： B**
  - Bending
    （Dipole Magnet）
  - Focusing
    （Quadrupole Magnet）



Superconductivity taking an essential role

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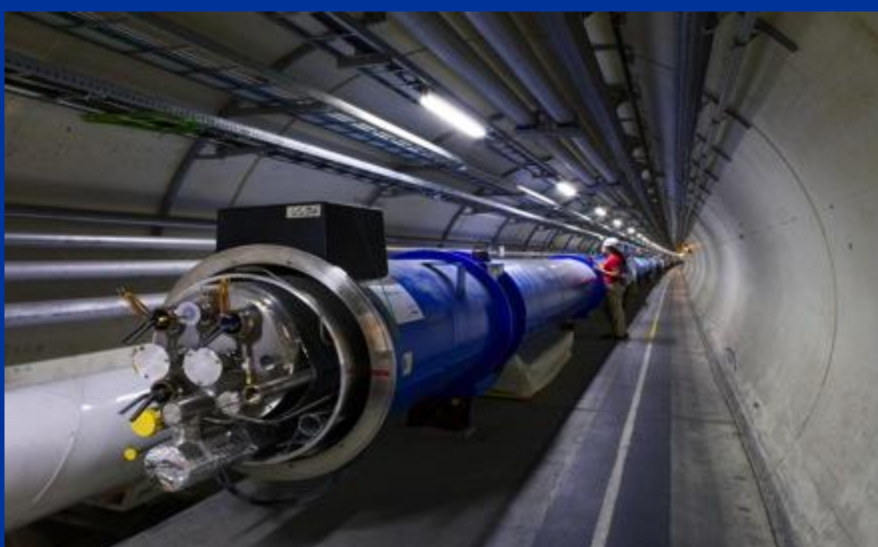
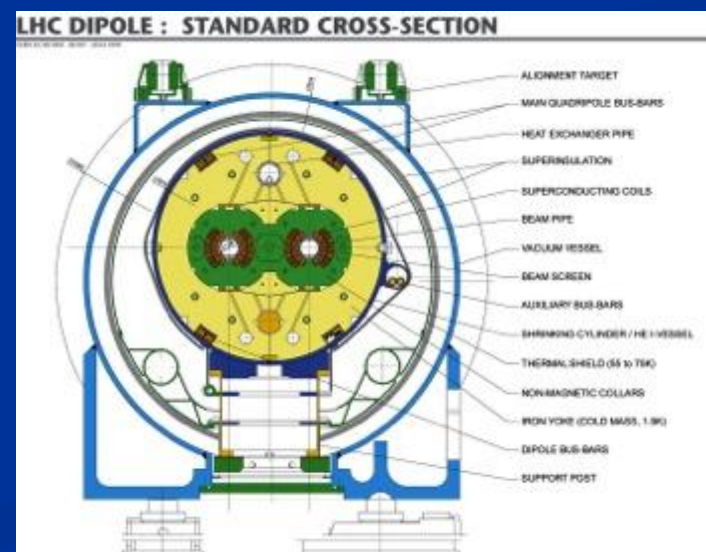
LHC Superconducting Magnets

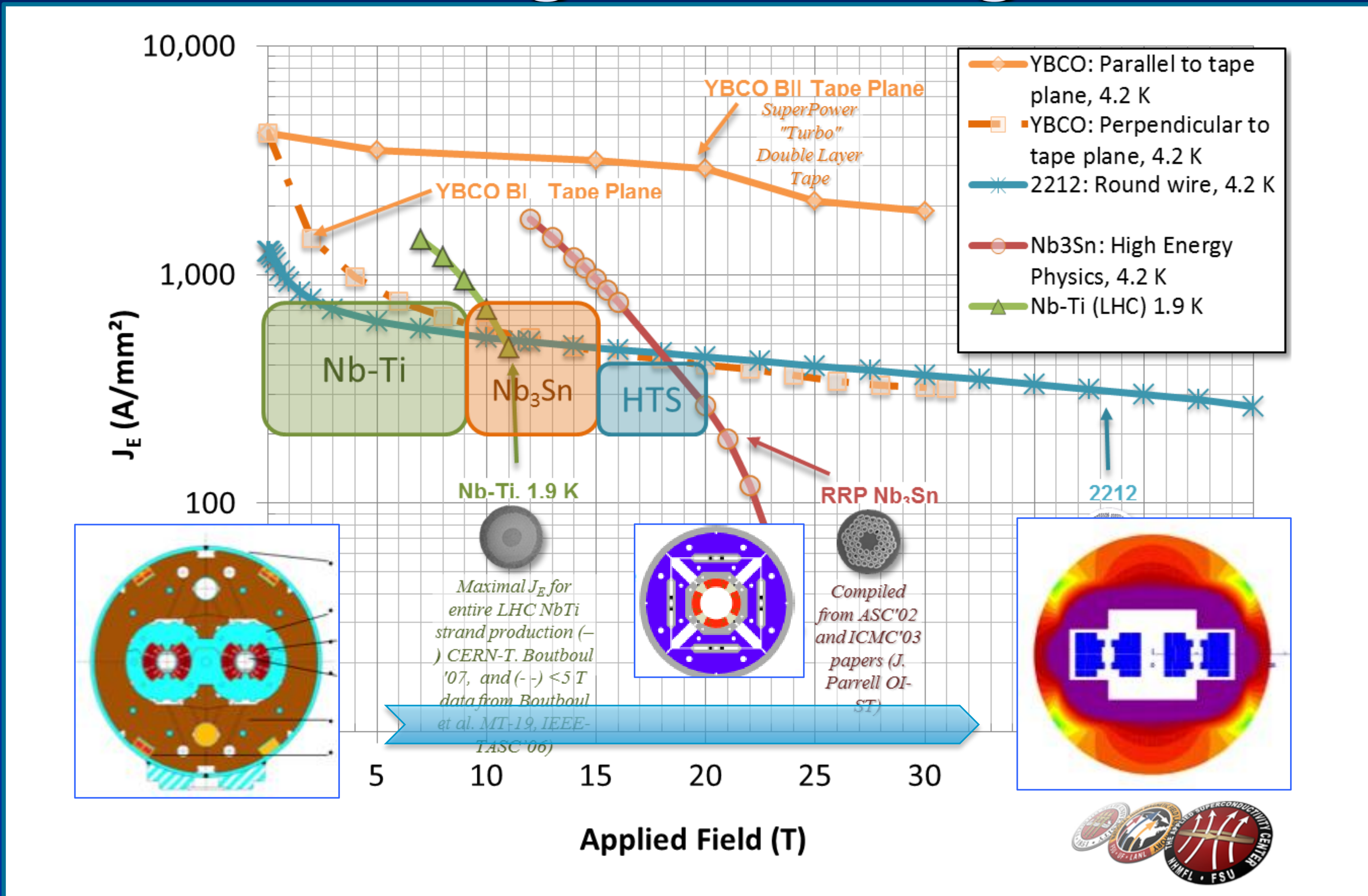
- **Diameter: 27 km**
- **Energy 2 x 7 TeV**
- **SC Magnets 8.4 T**





Superconductor Advanced toward High Field Magnets

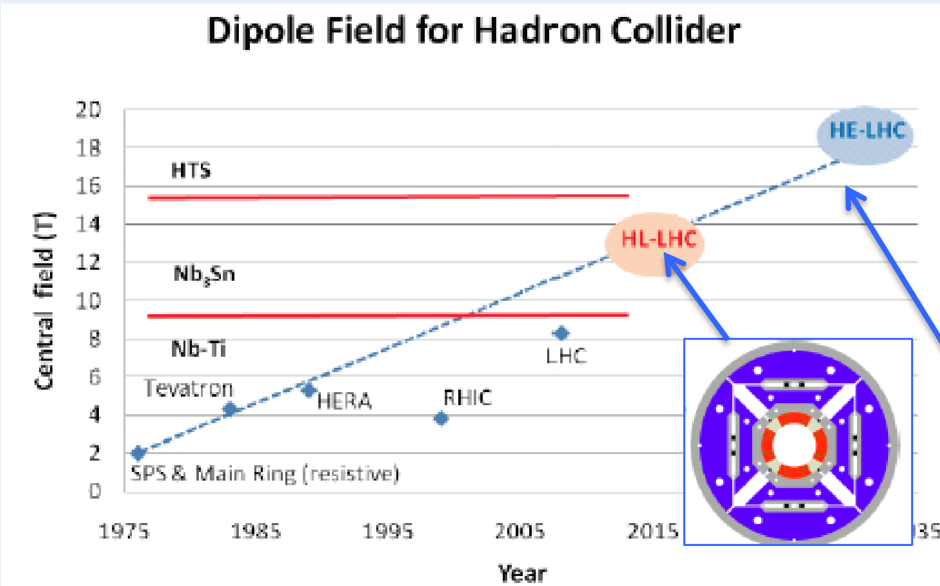
Courtesy: G. Sabbi, L. Rossi

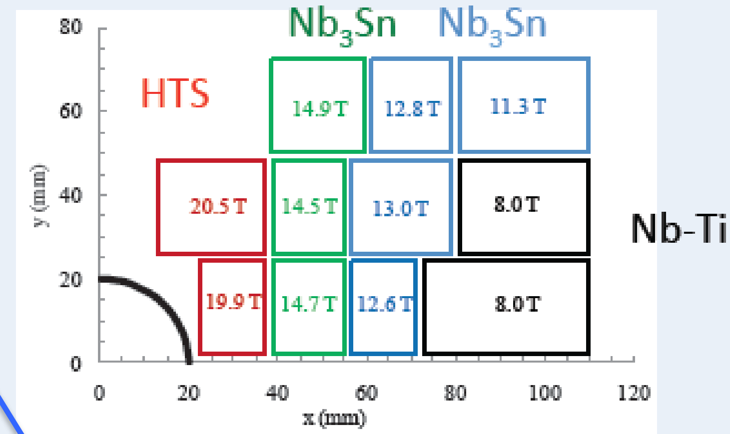


Courtesy:
L. Rossi,

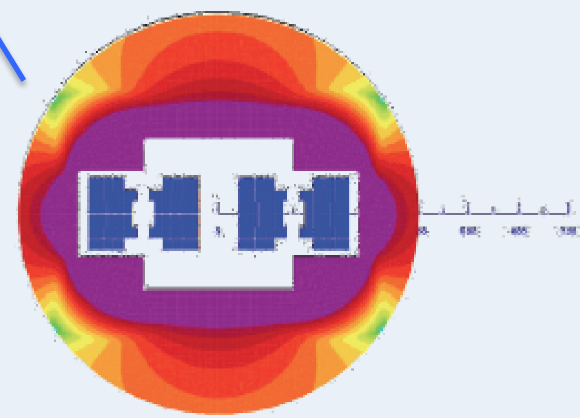
For Higher Energy

Eucard 2 (Lucio Rossi, CERN Edms No. 1152224)





$J_{overall\_HTS}$ = 400 A/mm² @ 20 T



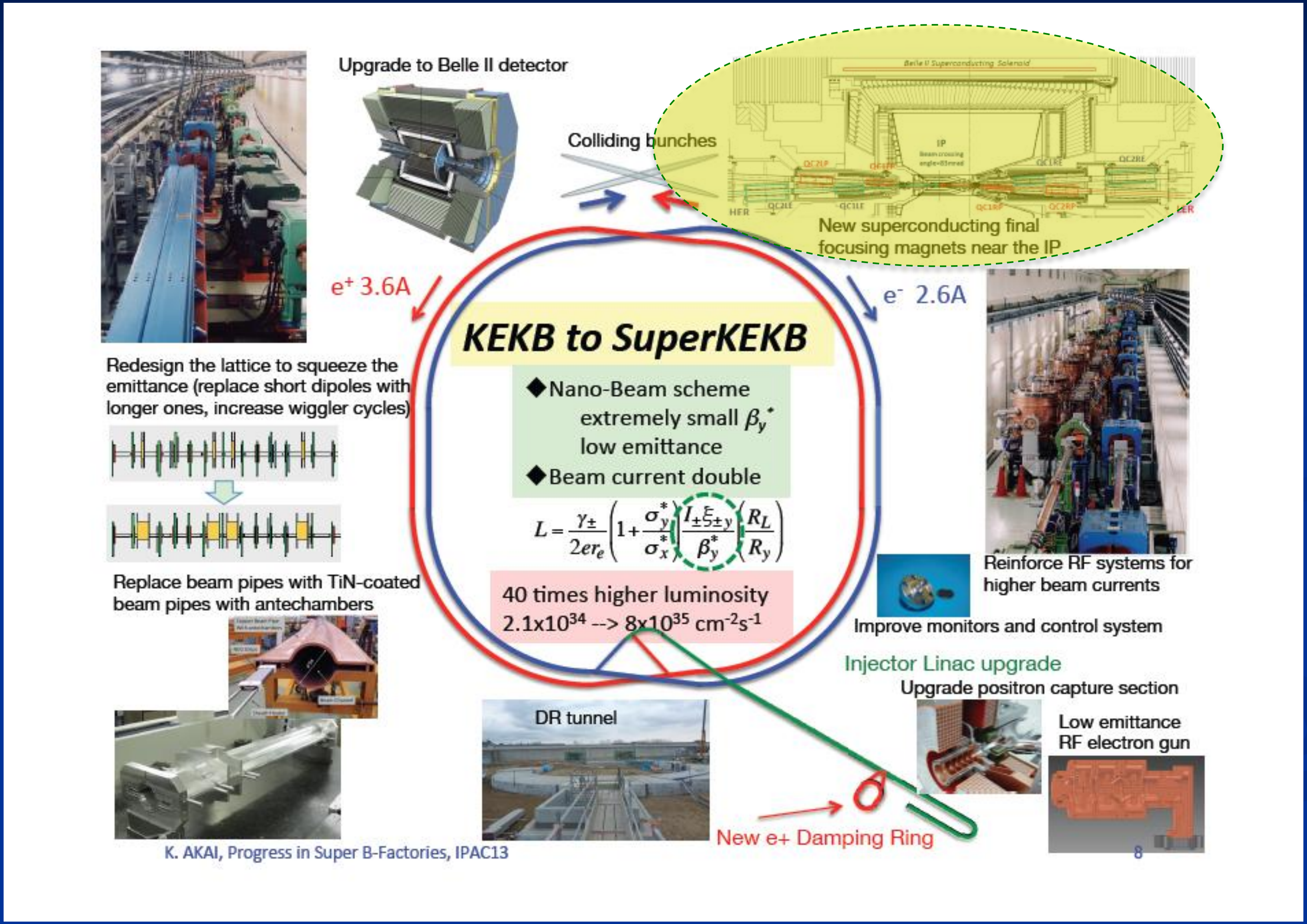
High Energy LHC: 2×16.5 TeV beams

Twin aperture dipole, **20 T**, 15 m long, bore spacing 300 mm, iron diameter 800 mm

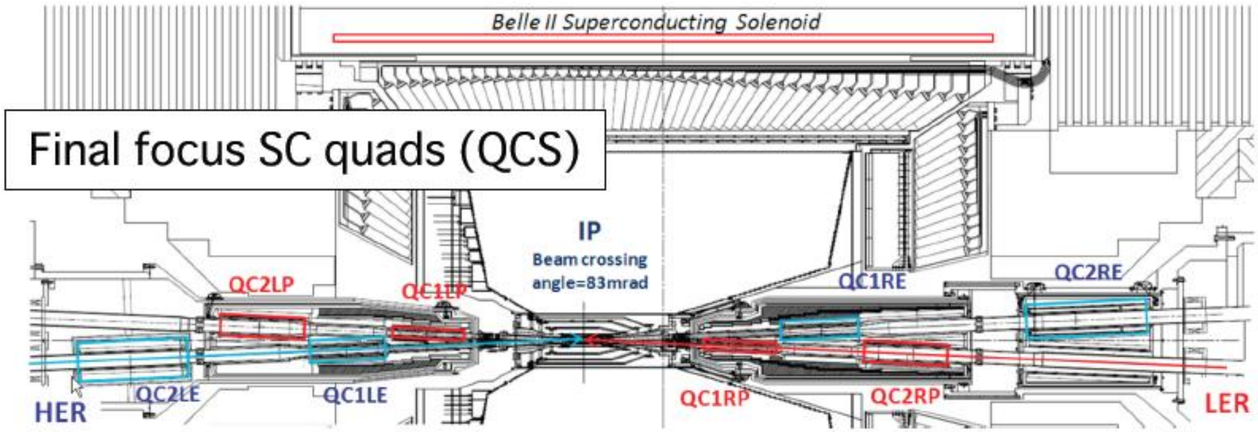
Further Development and Application

- High-precision accelerator magnet technology
  - SuperKEKB final focusing magnets
- Superconducting Power Transmission Technology
- Al-stabilized SC Technology
  - Riken-SRC complex
    - with a unique recent application

Application to Super-KEKB



Super-KEKB Final Focusing SC Quadrupoles (QCS)

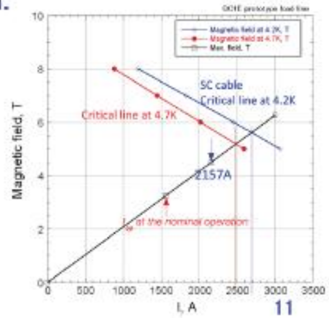


- Eight final focus QCS with 40 corrector coils are to be used.
- Fabrication of QCS-L started in July 2012, and will be completed in JFY2013.
- Fabrication of QCS-R is scheduled in JFY2013 and 2014.
- Prototype magnet was made at KEK. Test results show sufficient margin for operation.
- Corrector coils are being wound at BNL under BNL/KEK collaboration.

QC1LE prototype magnet

Successfully tested without any quench up to 2157A, well over the design current (1560A) for nominal operation.

$I_{4S}/I_{c@4.7K}$ = 62.8%
$I_{12GeV}/I_{c@4.7K}$ = 87.0%
Sufficient margin for operation

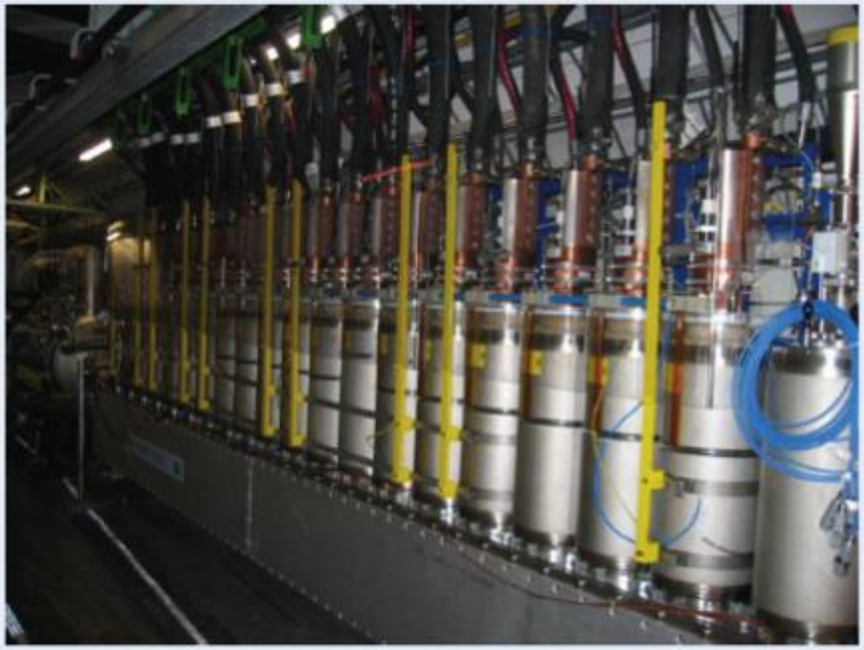


K. AKAI, Progress in Super B-Factories, IPAC13

11

Courtesy: A. Ballarino

HTS Current Leads Application at LHC



Bi-2223 in LHC current leads

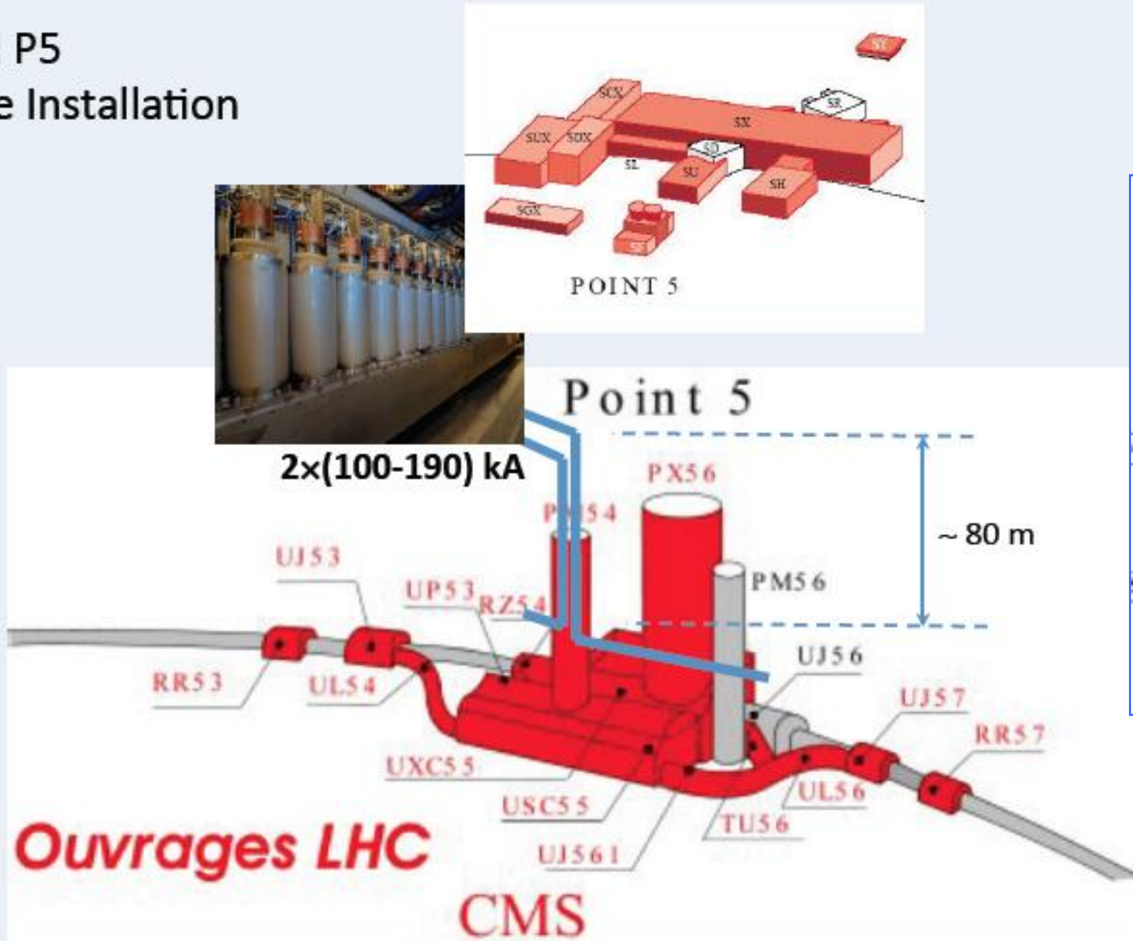
Bi-2223 tape: **31 km** in total
AgAu5 (wt%)
ULs=100...300 m

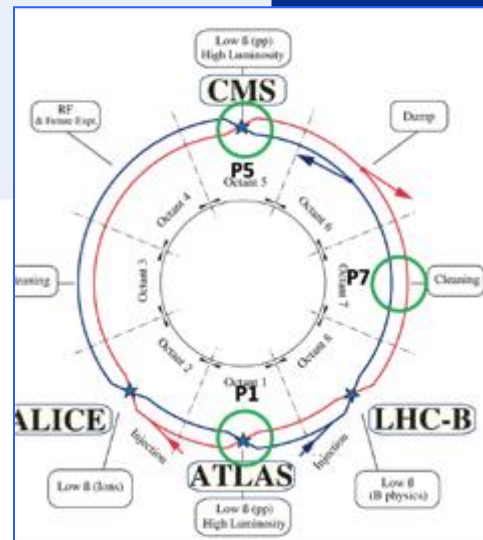
More than **1000 HTS** Current Leads,**1800** Electrical Circuits ~ **3 MA**
Operational in LHC since Nov. 2009. Thousands of electrical cycles

M13, 12 March 2013 A. Ballarino, CERN

HL-LHC Superconducting Link Project

P1 and P5
Surface Installation





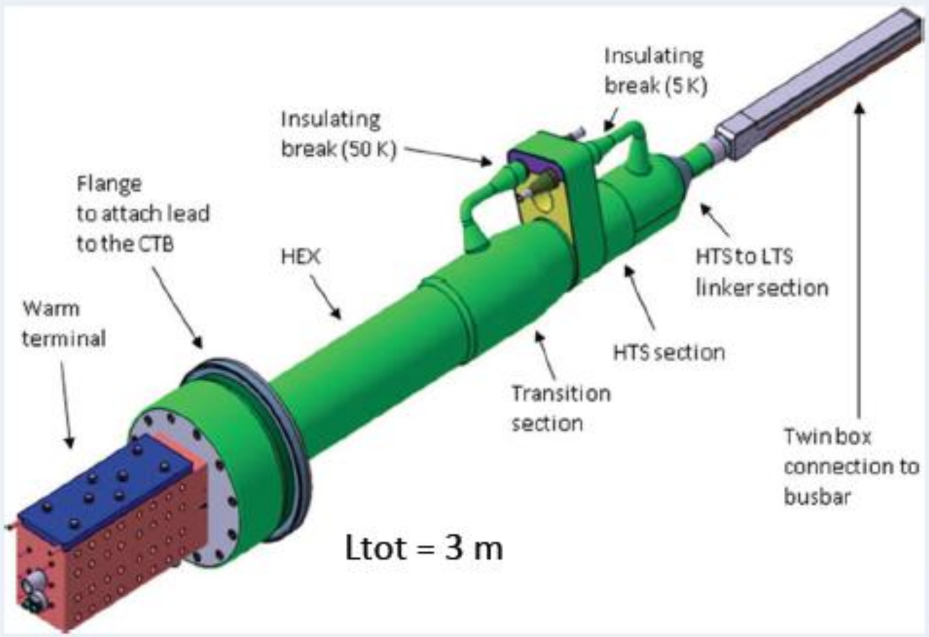
MEM13, 12 March 2013

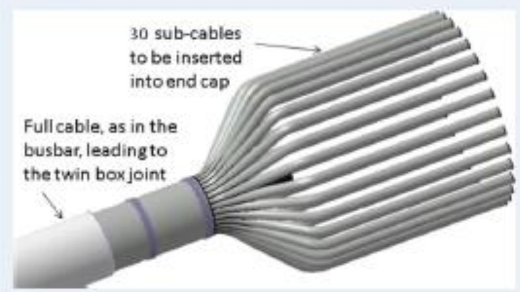
A. Ballarino, CERN

Courtesy: A. Ballarino

Application for ITER Magnet System

Bi-2223 tape
60 HTS Current Leads
68 kA, 55 kA and 10 kA
~ 2.5 MA





Courtesy of P. Bauer and A. Devred and N. Mitchel, ITER-IO

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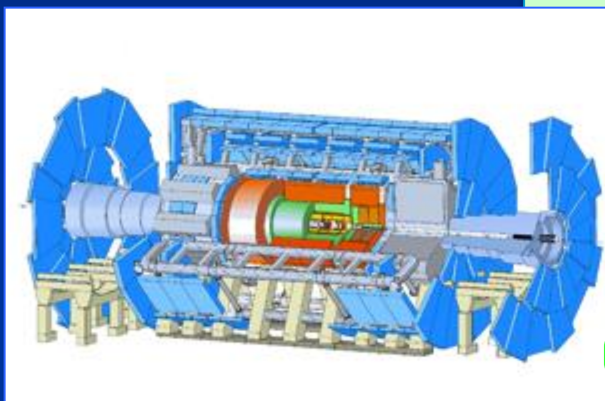
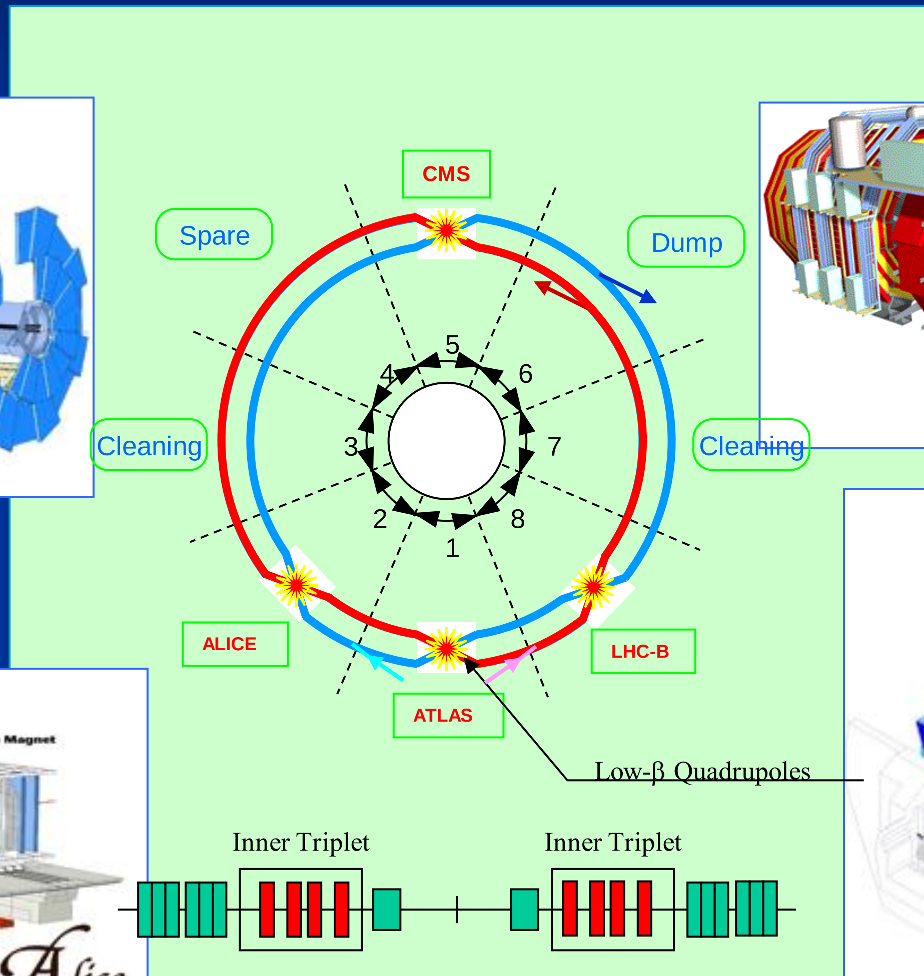
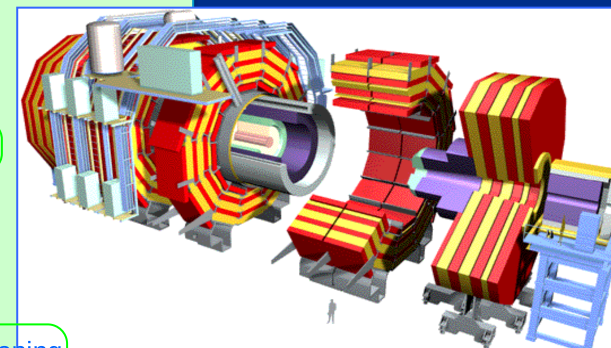
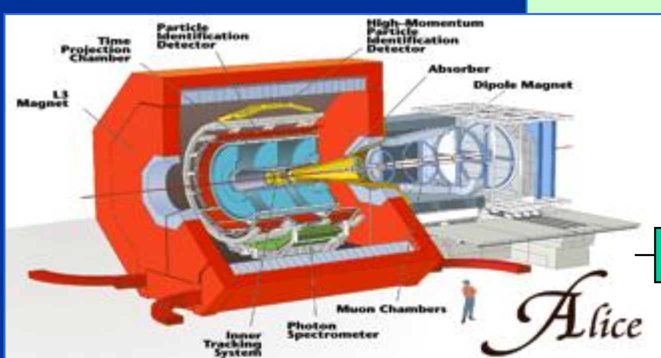
The LHC Experiments

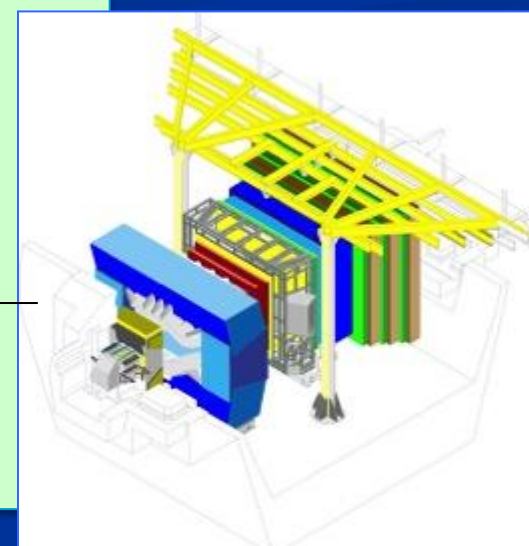
ATLAS, CMS, ALICE, LHCB





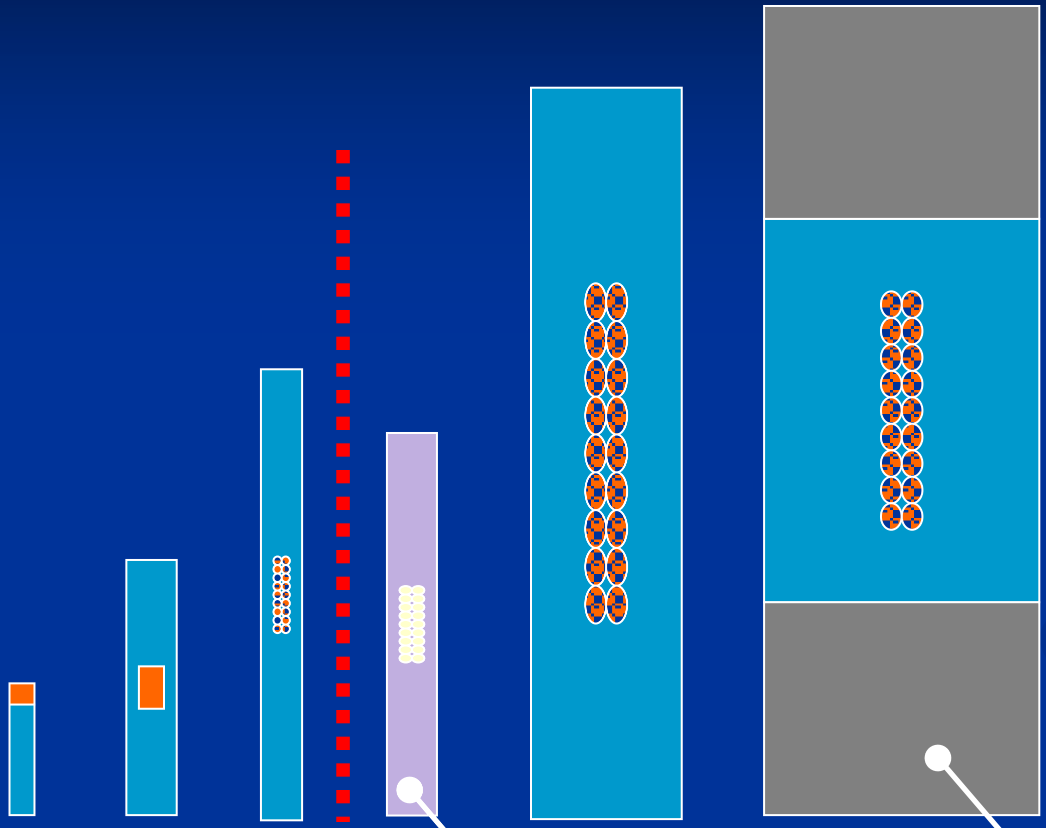






Al-stabilized SC for Detectors

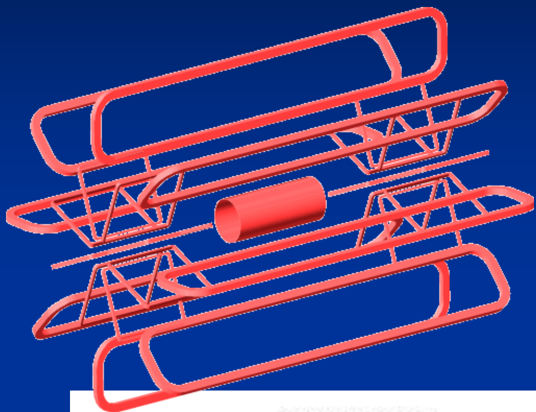
Large Sc: 35 A/mm^2 overall



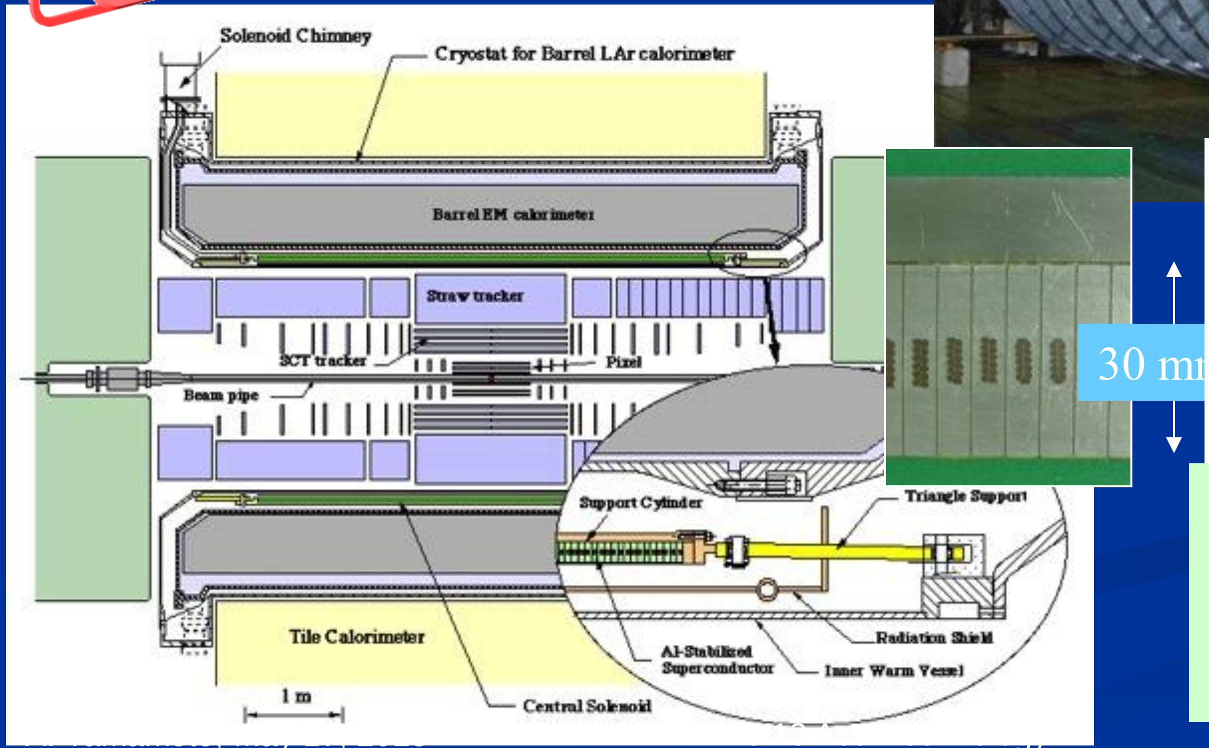
Special Al alloy developed by KEK for Atlas central solenoid

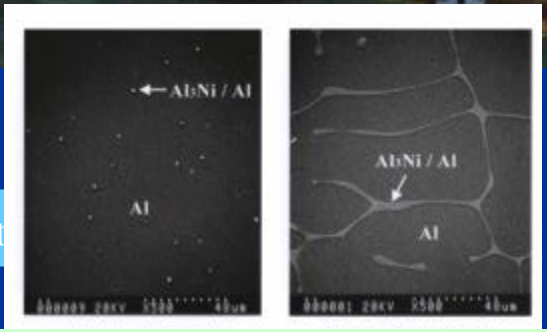
Al alloy reinforced by e-beam, welding, developed by ETHZ-CERN for CMS

ATLAS Central Solenoid



Thin coil
High-strength
Al-stabilizer



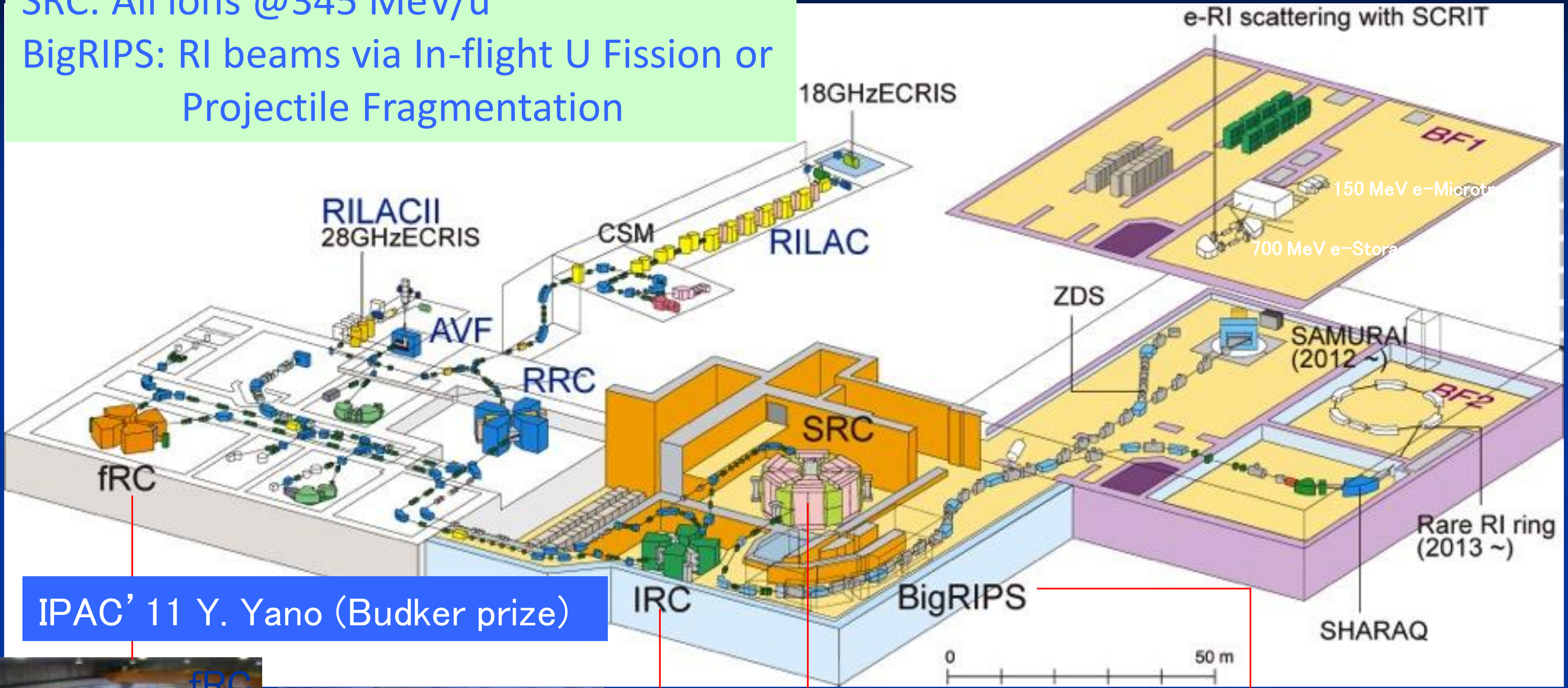


Al_3Ni precipitated
as structural component
Pure-Al region
keep low resistivity

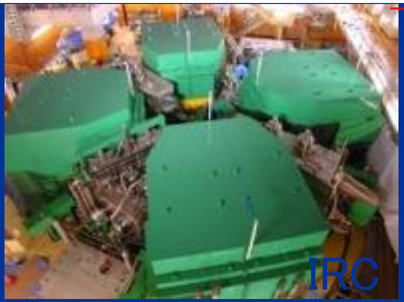
RIBF (RI Beam Factory)

Courtesy:
O. Kamigaito, FRXCB2, IPAC'13

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



IPAC' 11 Y. Yano (Budker prize)

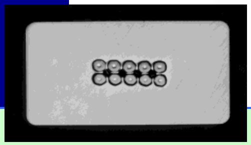


Courtesy: O. Kamigaito, H. Okuno

SRC: the *World's First* Superconducting Ring Cyclotron

K = 2,600 MeV
Max. Field: 3.8T (235 MJ)
RF frequency: 18-38 MHz
Weight: 8,300 tons
Diameter: 19m Height: 8m

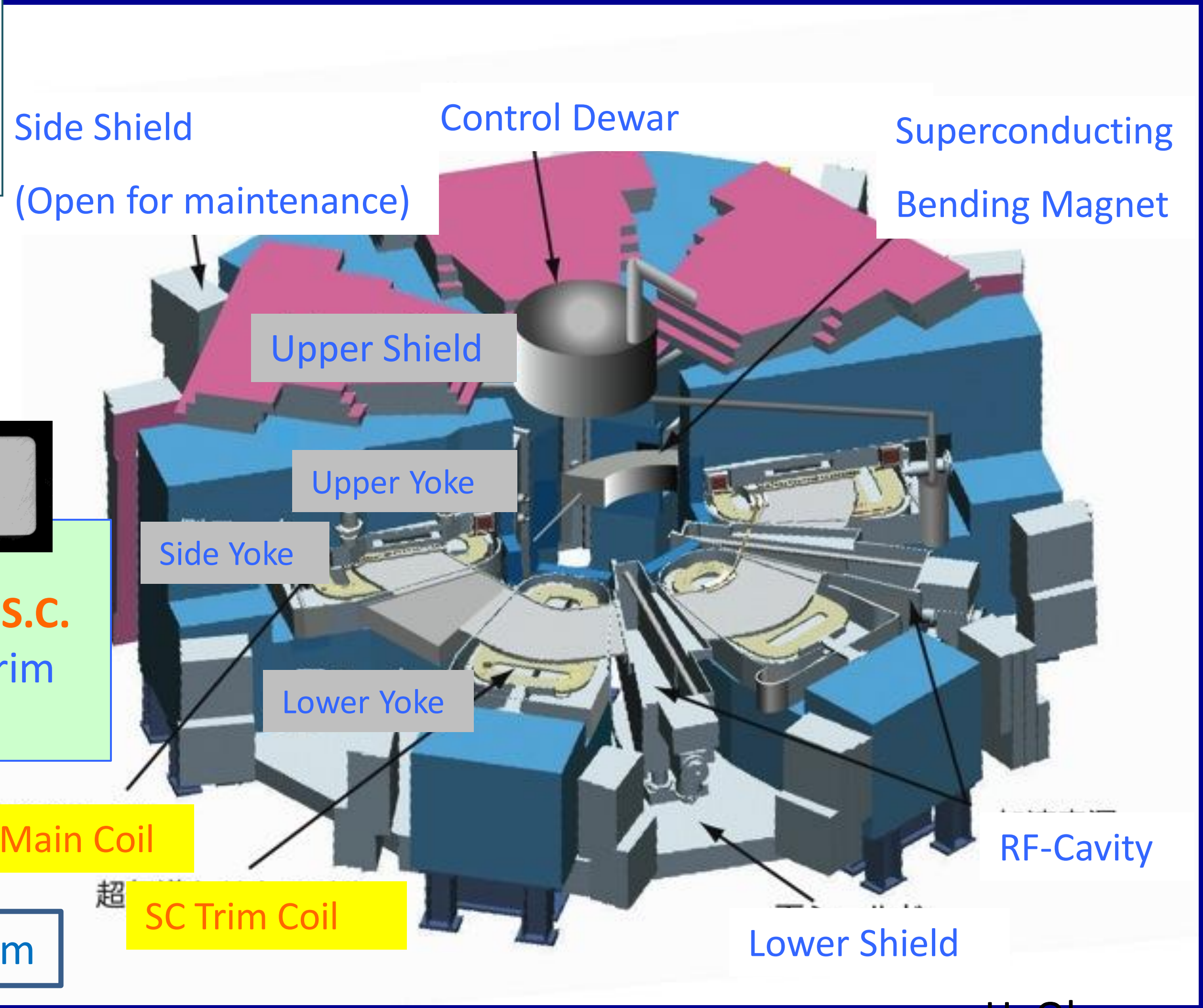
Sector Magnets :6
RF Resonator :4



Key technologies:

- **High-strength Al stabilized S.C.**
- Indirectly cooled thin S.C. trim coils

ATLAS@LHC S.C. magnet system

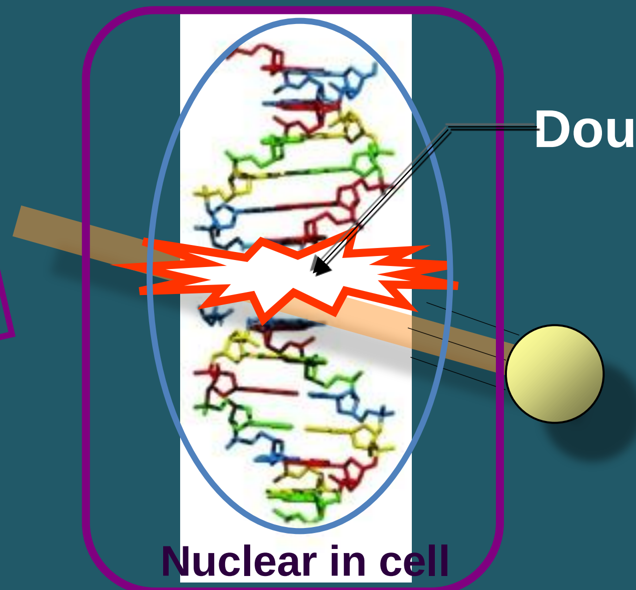


H. Okuno

•Courtesy: T. Abe, Okuno, Kamigaito

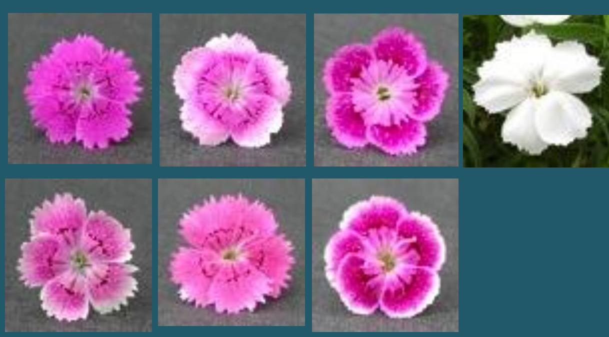
Ion-Beam Breed Development using Heavy-Ion Accelerator

Original
Olivia Red Eye



Lost of function

Mutation in flower color



New cultivar
Olivia pure white

Advantage for ion beam breeding:

1. Ion beam irradiation induces a high mutation rate at low doses without severe growth inhibition,
2. Ion beam irradiation allows isolation of unique mutants,
3. Developmental period of new cultivars is only three years.

Selection of the Salt-resistant Rice in Miyagi Prefecture

C ion beam irradiation at April 2011.

Helping Recovery of TOHOKU from Earthquake

The seedlings were grown in a paddy field at the Miyagi Pregectural Furukawa Agricultural Experiment Station. We obtained 368 M_2 lines for Hitomebore and 351 for the Manamusume.

Salt-resistant Rice

368 lines X16=5888 plants 351 linesX16=5616 plants

We isolated 73 salt-resistant candidate lines from 719 lines.
We will select again salt-resistant plants from 73 lines in 2013.

RIKEN-RIKEN Food Co.Ltd-Iwate Prefecture

Create New “wakame” cultivars in Iwate Prefecture

Helping Recovery of TOHOKU from Earthquake

JPARC:

Courtesy: S. Nagamiya

A World Center for basic Science and Application

- Materials and Life: One of three world centers, in particular, in Asia.
- Hadron physics A unique kaon factory in the world.
- Neutrino physics: As a world leader among the three world centers.

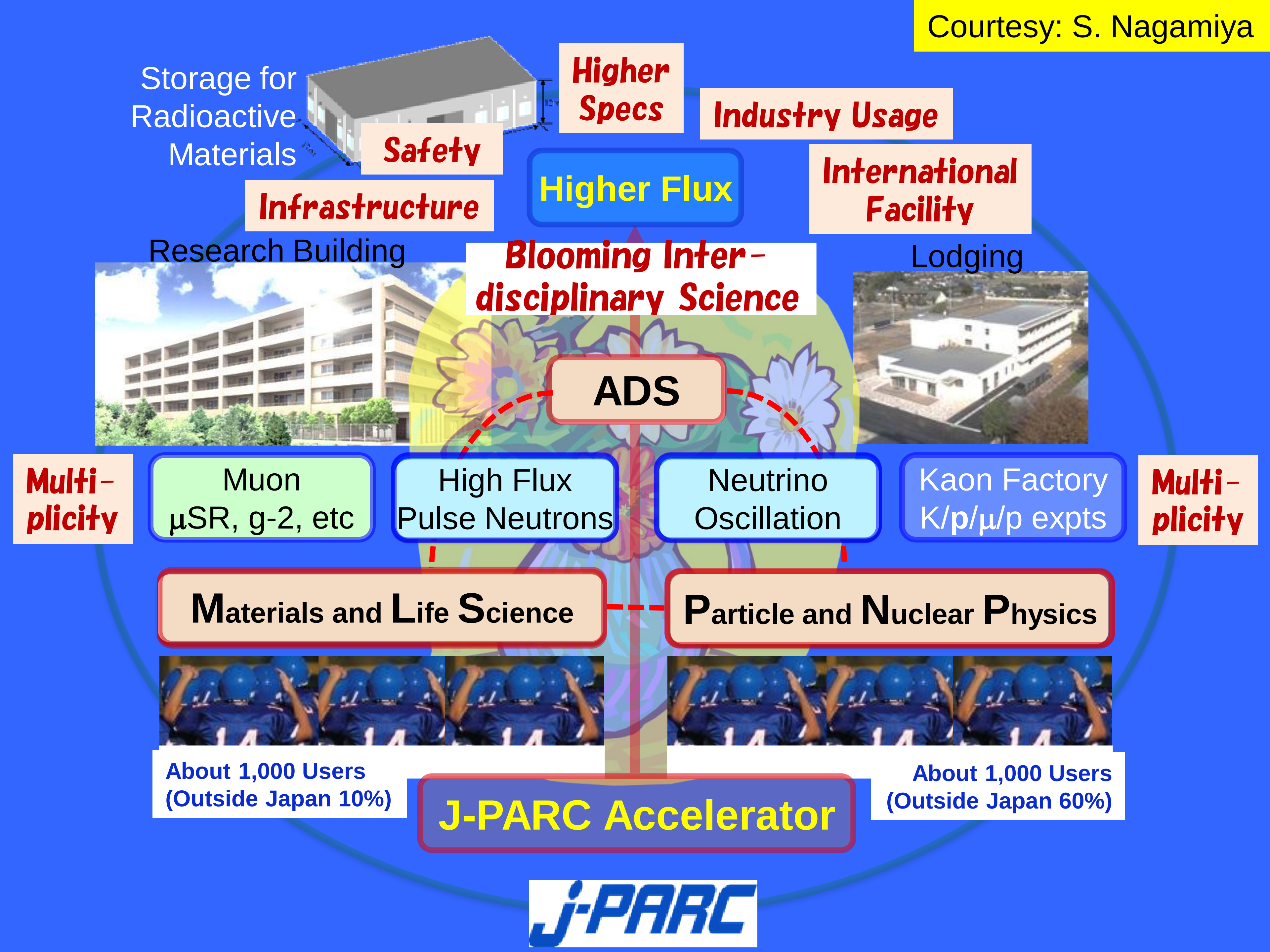
Center in neutrino

Center in neutrons

Hadron (Kaons)

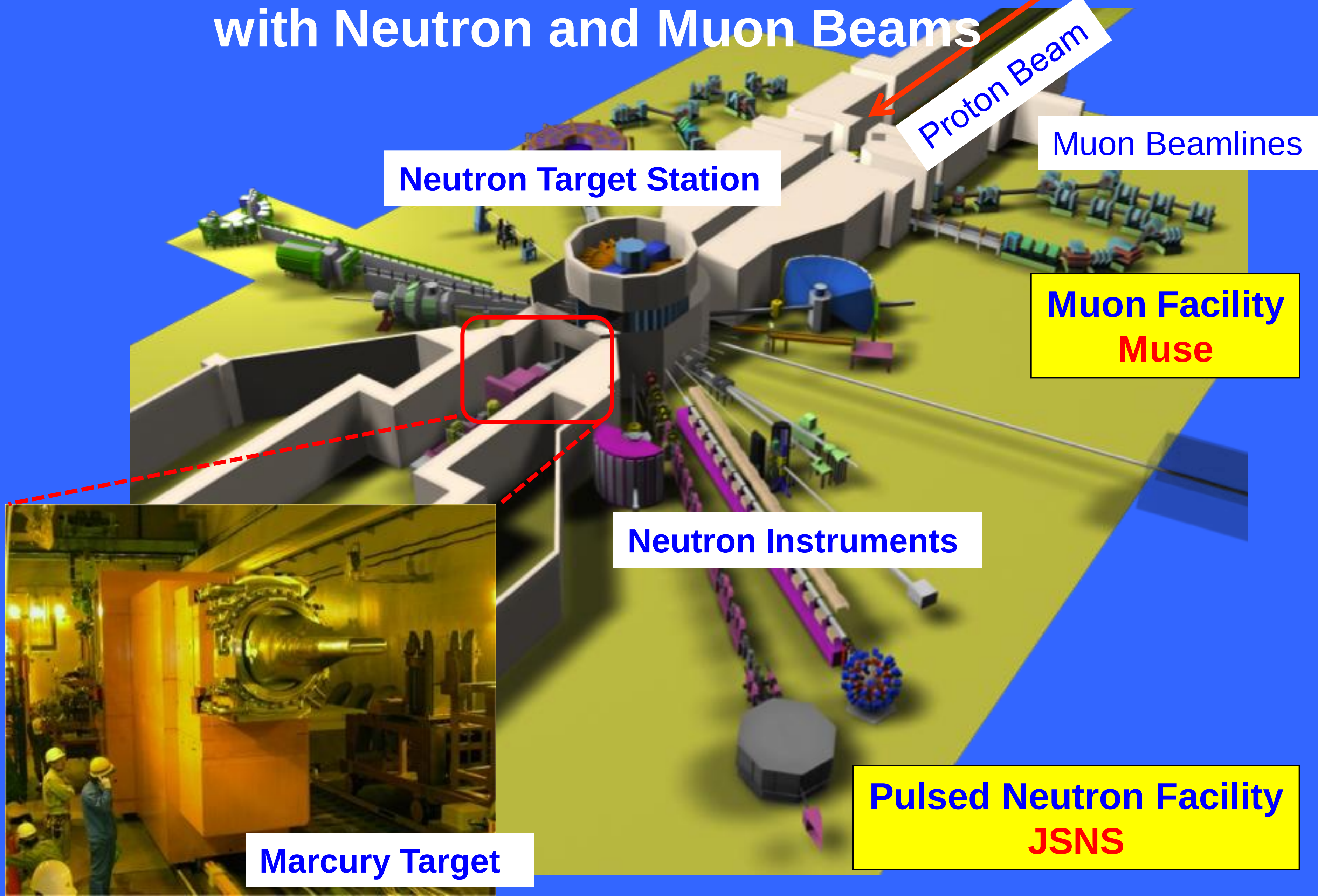
Hadron (antiprotons)

Global Cooperation with ISIS：Neutron Facility in GB、SNS：Neutron Facility, in US
CERN、FNAL、GSI


Courtesy: S. Nagamiya
Storage for Radioactive Materials
Higher Specs
Industry Usage
Safety
Higher Flux
International Facility
Infrastructure
Research Building
Blooming Inter-disciplinary Science
Lodging
ADS
Multi-plicity
Muon
μSR, g-2, etc
High Flux
Pulse Neutrons
Neutrino
Oscillation
Kaon Factory
K/p/μ/p expts
Multi-plicity
Materials and Life Science
Particle and Nuclear Physics
About 1,000 Users
(Outside Japan 10%)
J-PARC Accelerator
About 1,000 Users
(Outside Japan 60%)
J-PARC

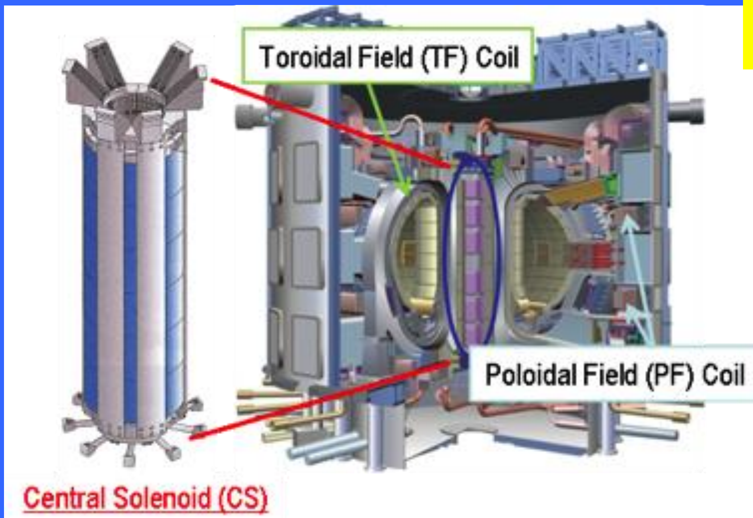
Courtesy: S. Nagamiya

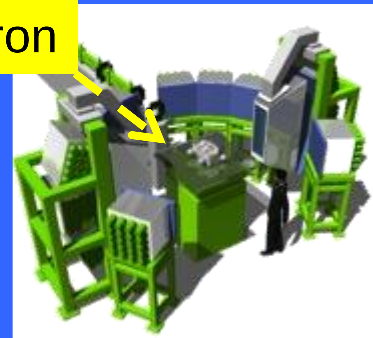
Materials & Life Science Experimental Facility with Neutron and Muon Beams



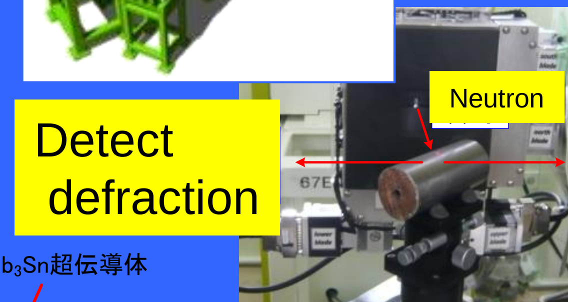
Measurement of Residual Stress in the ITER TF cable

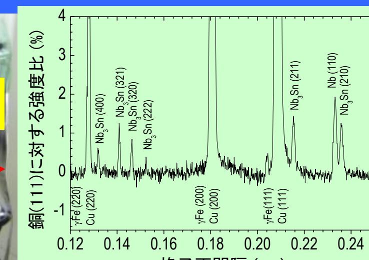
Courtesy: S. Nagamiya





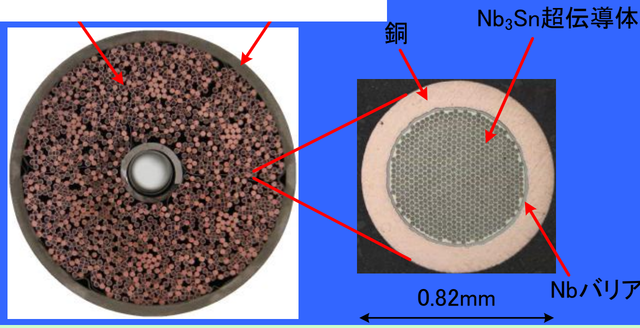
Gauge volume
7×2×15mm^3



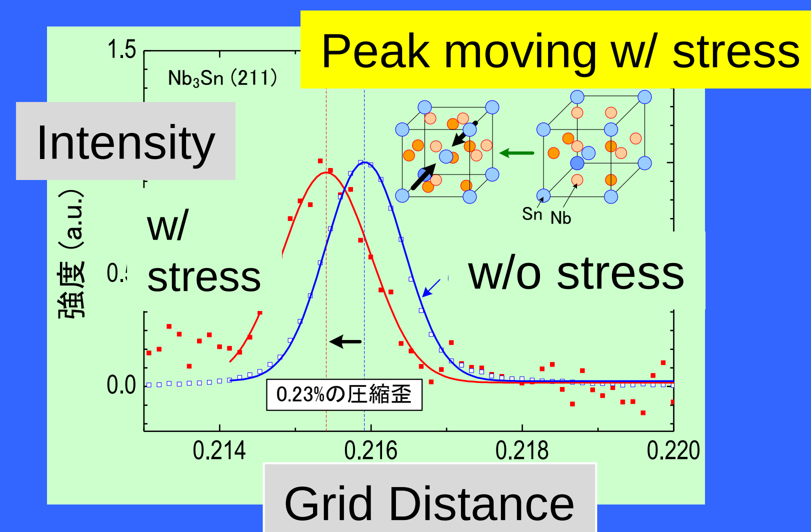


Peaks along axial direct.

Superconducting characters are strongly depend on internal stresses in cables.



ITER-TF Coil conductor/strand



Contraction of 0.23% along axial direct.

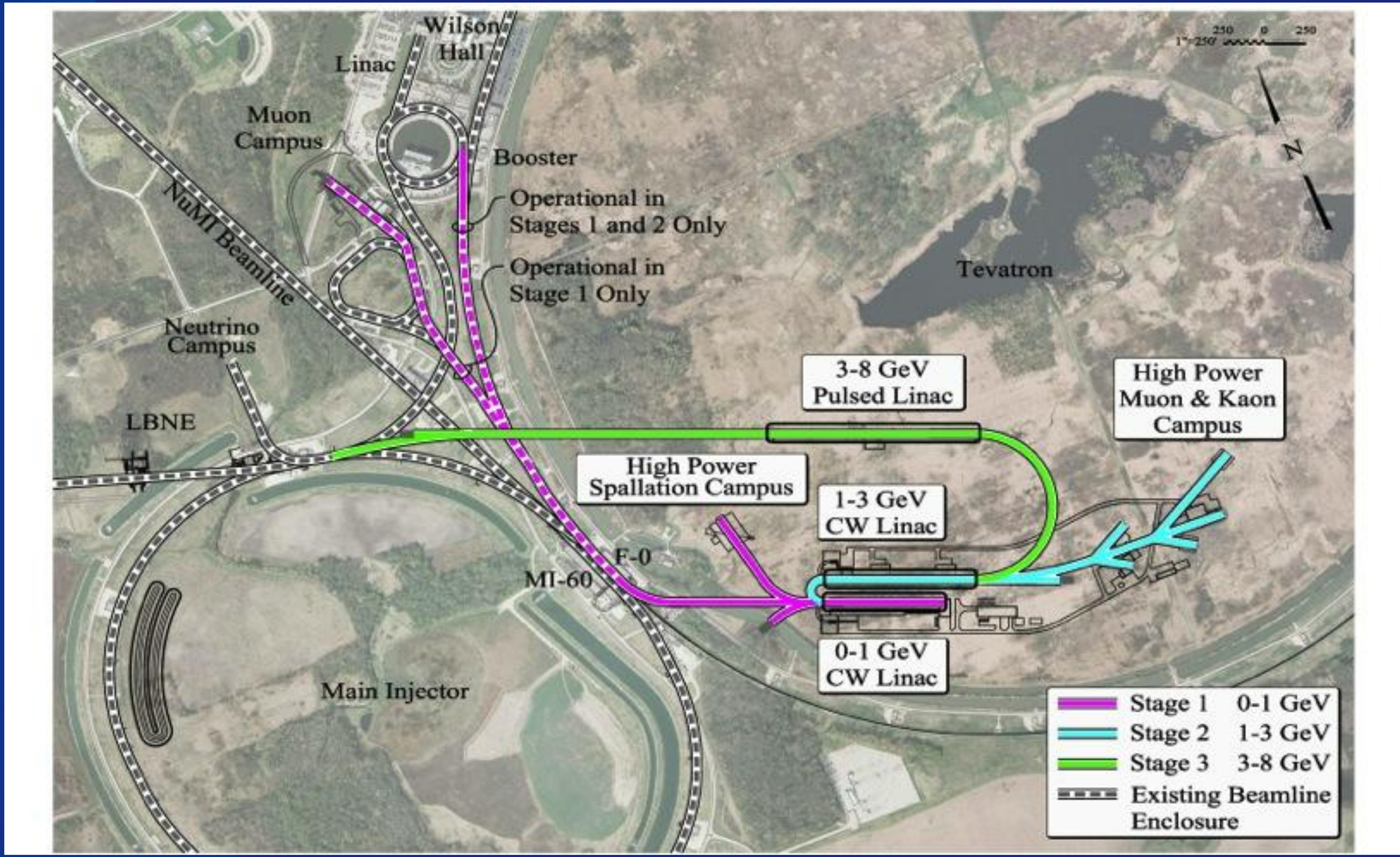
Internal stresses of Nb3Sn successfully observed

- Cable contains only Nb_3Sn of 6%
- neutron transmitted length of 60mm
- good statistics of peaks in several hours at 120kW
- the observation can bring improvements on Nb_3Sn filaments

Courtesy: R. Kephart

Project X

A new high power SRF linac based Proton Source under development for Fermilab



Fermilab

SRF Cavity R&D Program for Project X

- Adoption of a 3 GeV CW linac followed by a 3-8 GeV pulsed linac for Project X results in a very powerful intensity frontier accelerator complex… but presents new challenges
  - Needs six different cavities optimized for changing velocity (β) of Protons
  - Four different frequencies (162.5, 325, 650, 1300 MHz)
  - Five of these cavities are completely new for Project X (vs 2 for SNS, 1 for CBEAF)
  - Requires development of seven different styles of cryomodules
- Requires a major R&D effort

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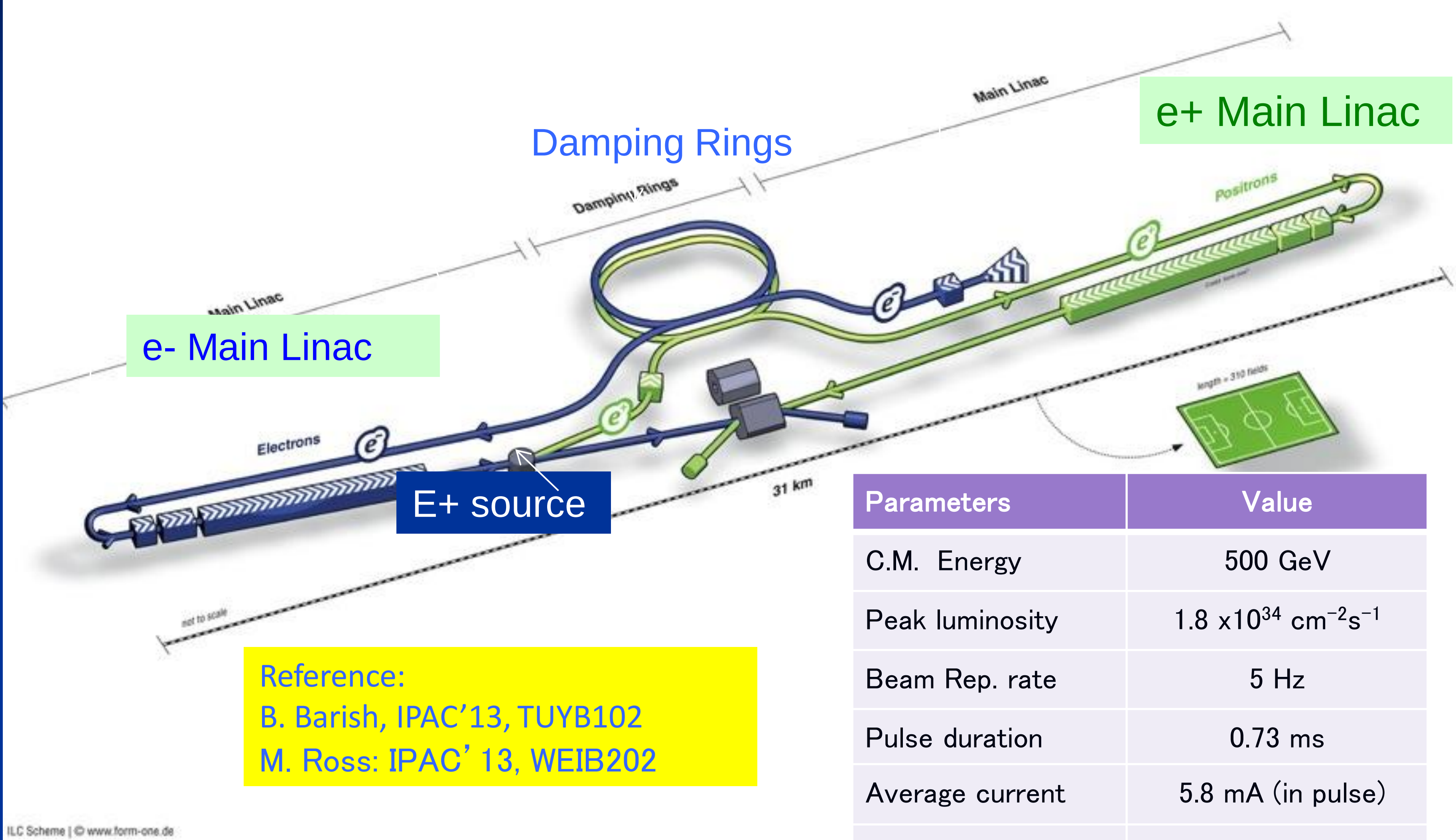
International Linear Collider "proposed"

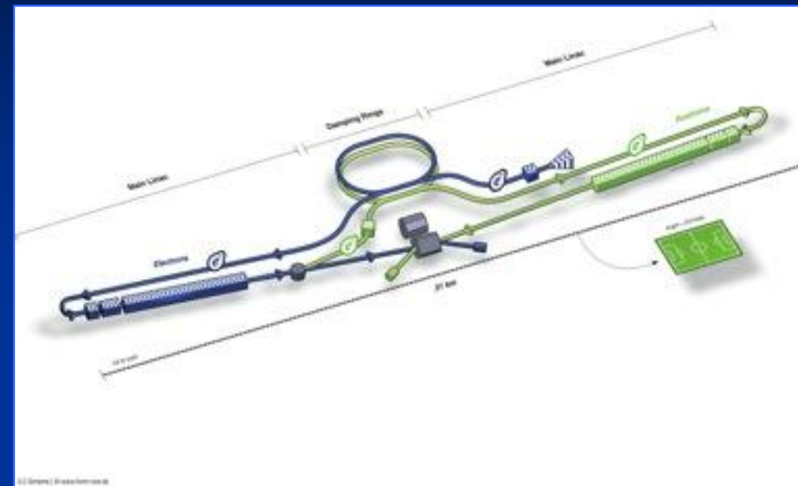


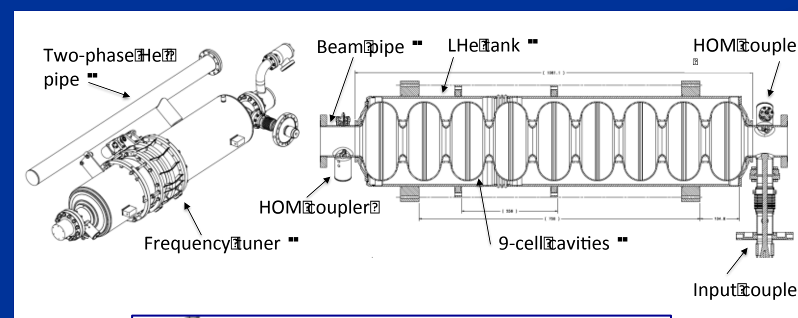
Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.8 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
E gradient in SCRF acc. cavity	31.5 MV/m +/−20% Q_0 = 1E10

Reference:
B. Barish, IPAC'13, TUYB102
M. Ross: IPAC' 13, WEIB202

SCRF Industrialization required

Parameters	Value
C.M. Energy	500 GeV
Peak luminosity	1.5 x10^{34} $cm^{-2}s^{-1}$
Beam Rep. rate	5 Hz
Pulse duration	0.73 ms
Average current	5.8 mA (in pulse)
Av. field gradient	31.5 MV/m +/-20% Q_0 = 1E10
# 9-cell cavity	16024 (x 1.1)
# cryomodule	1,855
# Klystron	~400

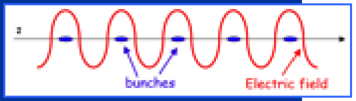


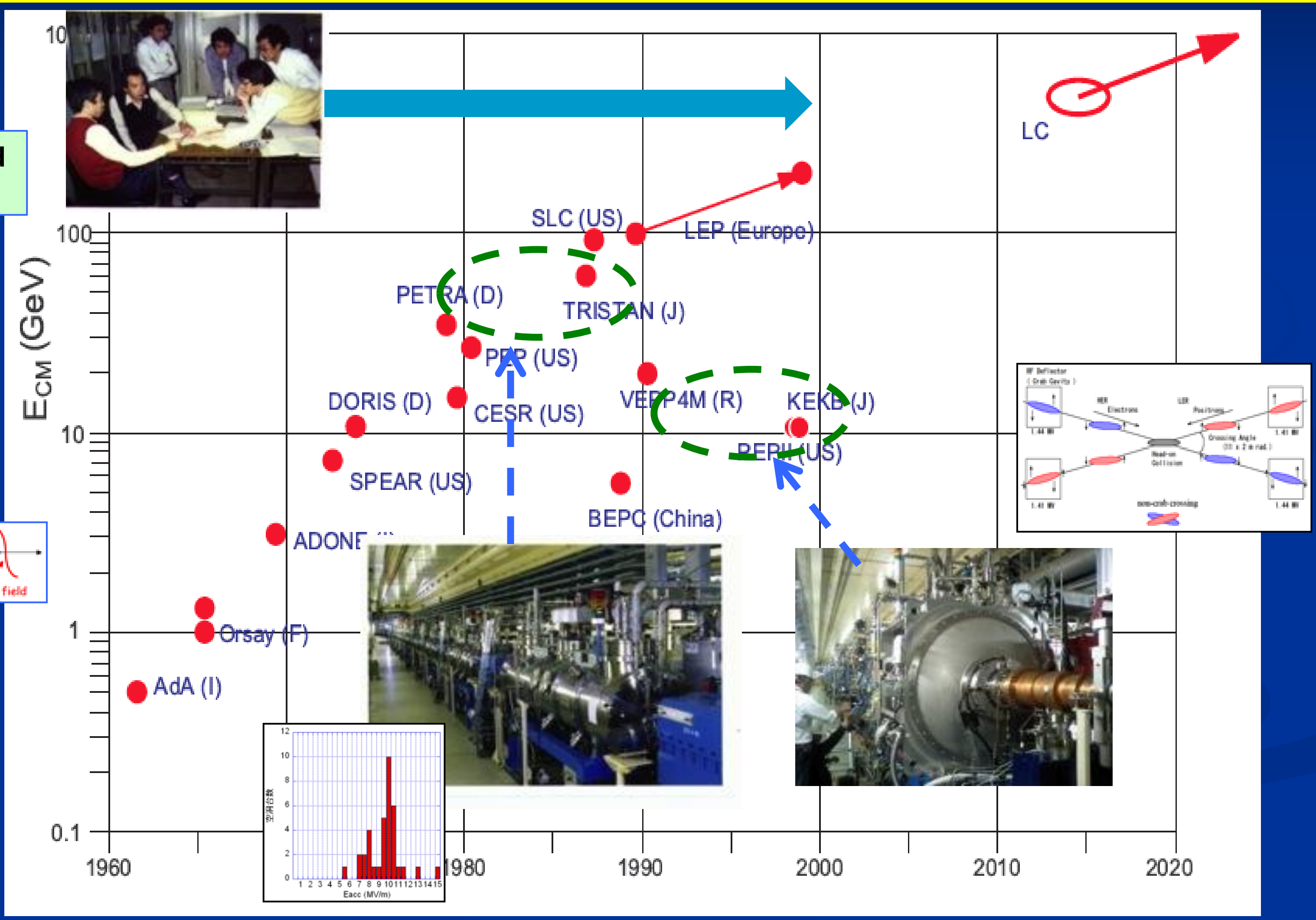


Development of e-/e+ Colliders

KEK' pioneering for SCRF beam acceleration TRISTAN→KEKB

Prof. Y. Kojima led the pioneer work





Progress in cooperation of Laboratories and Industry

year	# 9-cell cavities qualified	Capable Lab.	Capable Industry
2006	10	1 DESY	2 ACCEL, ZANON
2011	41	4 DESY, JLAB, FNAL, KEK	4 RI, ZANON, AES, MHI,
2012	(45)	5 DESY, JLAB, FNAL, KEK, Cornell	5 RI, ZANON, AES, MHI, Hitachi

- Progress in EXFEL (800 cavity construction as of 2012/10):

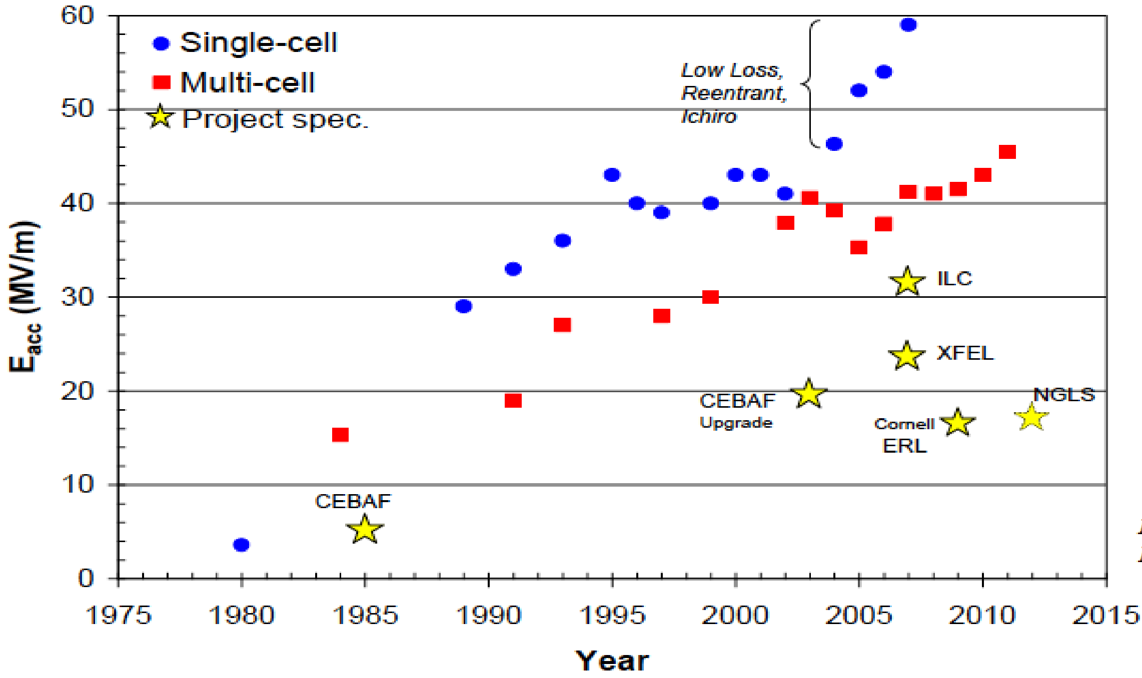
  (courtesy by D. Reschke: the 2nd EP at DESY)

  - RI: 4 reference cavities with Eacc > 28 MV/m, (~ 39 MV/m max.)
  - Zanon: 3 reference cavities with Eacc > 30 MV/m (~ 35 MV/m max.)

Courtesy: G. Ciovati, R. Geng

Progress in Accelerating Gradient,
L-band, β =1 Cavities

Accelerating gradient, L-Band β=1 cavities



G. Ciovati
IPAC'13
THYB201

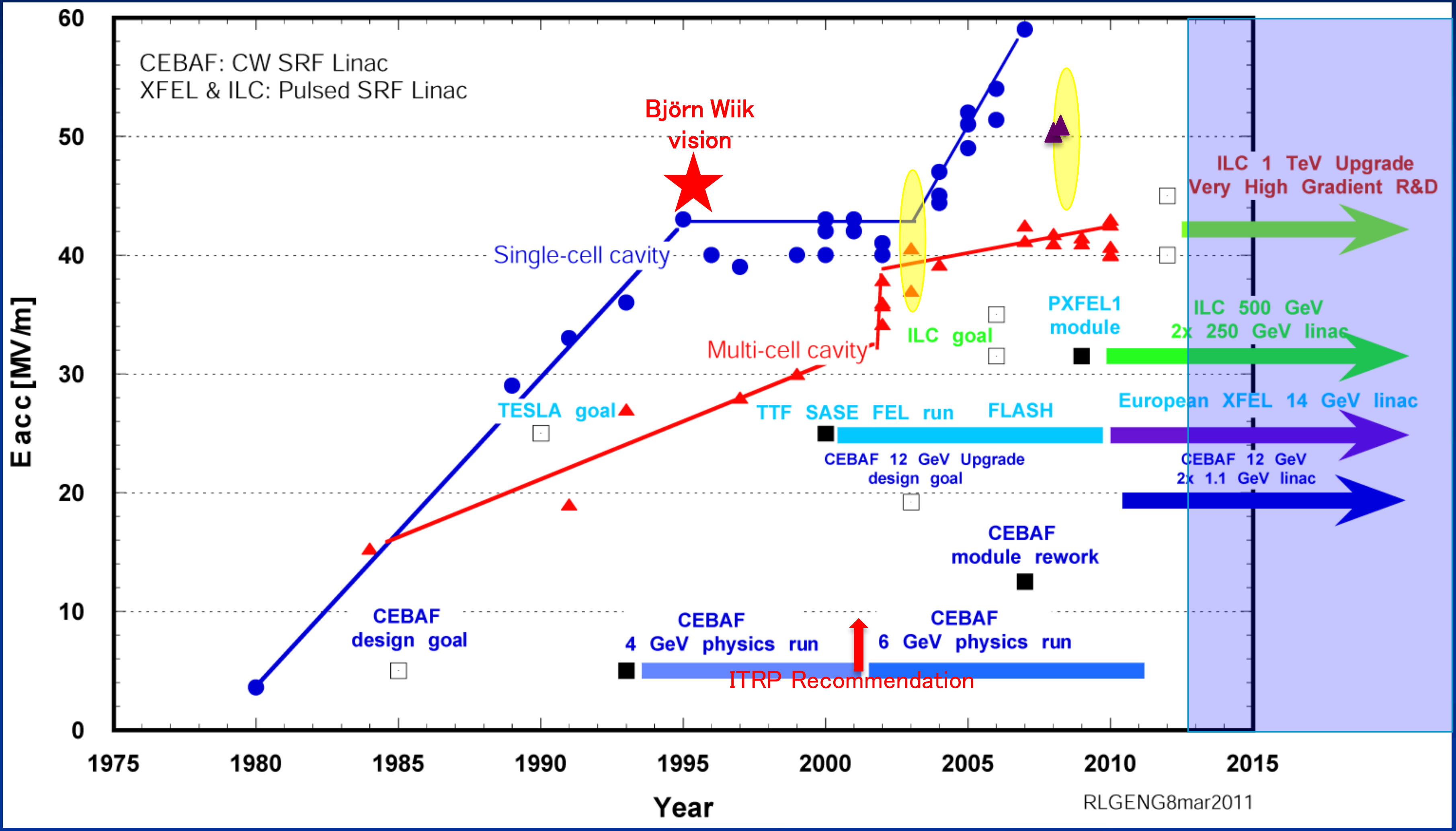
Data is courtesy of R. Geng, JLab

- E_{acc} > 50 MV/m is yet to be achieved in "low B_p" multi-cell cavities
- Average gradient specification of current and future projects is ~20 MV/m

Jefferson Lab   Thomas Jefferson National Accelerator Facility   JSA

Courtesy: R. Geng

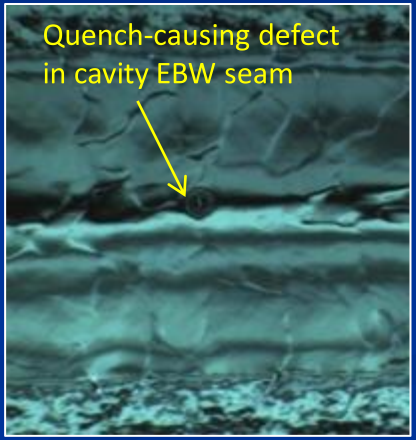
SCRF Cavity Gradient Progress



Courtesy ; A. Hutton

SRF Cavity R&D Effort at JLab

- **Main R&D theme and approach**
  - Understanding and overcoming gradient limitation
    - Quench at low and high field
    - Field emission
  - Instrumented cryogenic RF testing of real multi-cell cavities
  - Closed-loop activities between cavity fab./prep. and testing



- **International collaboration**
  - With other ILC ART members: ANL, Cornell, FNAL
  - With SRF teams in Asia and Europe regions: DESY, IHEP, KEK,

- **Benefits of the JLab gradient R&D results**
  - Raised quality and yield of US industrial SRF cavity fabrication
  - Repeatable cavity proc. procedure for tech transfer to industr
  - Lowering risk and cost for medium SRF gradient projects

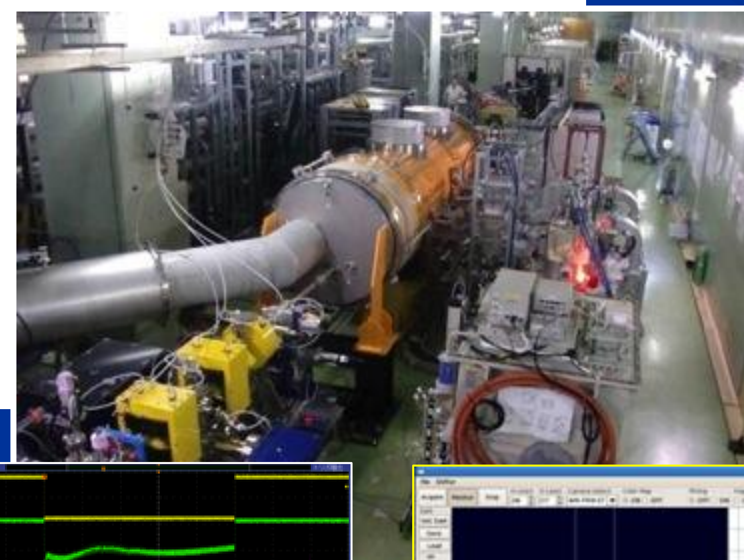
Dr. Zhai Ji Yuan and Cavity IHEP-01 before high pressure water rinsing in class-100 clean room at JLab

Courtesy: J. Urakawa, H. Hayano

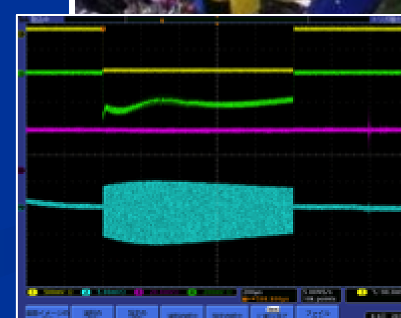
Application for Compact X-ray source

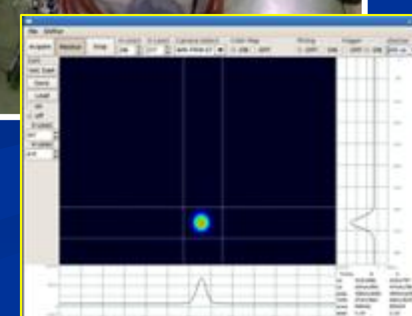
Using SCRF accelerator technology and laser cavity

X-ray by using Inverse-Compton scattering
- 10mA electron beam
- 4-mirror laser resonator cavity
- head-on collision with beam

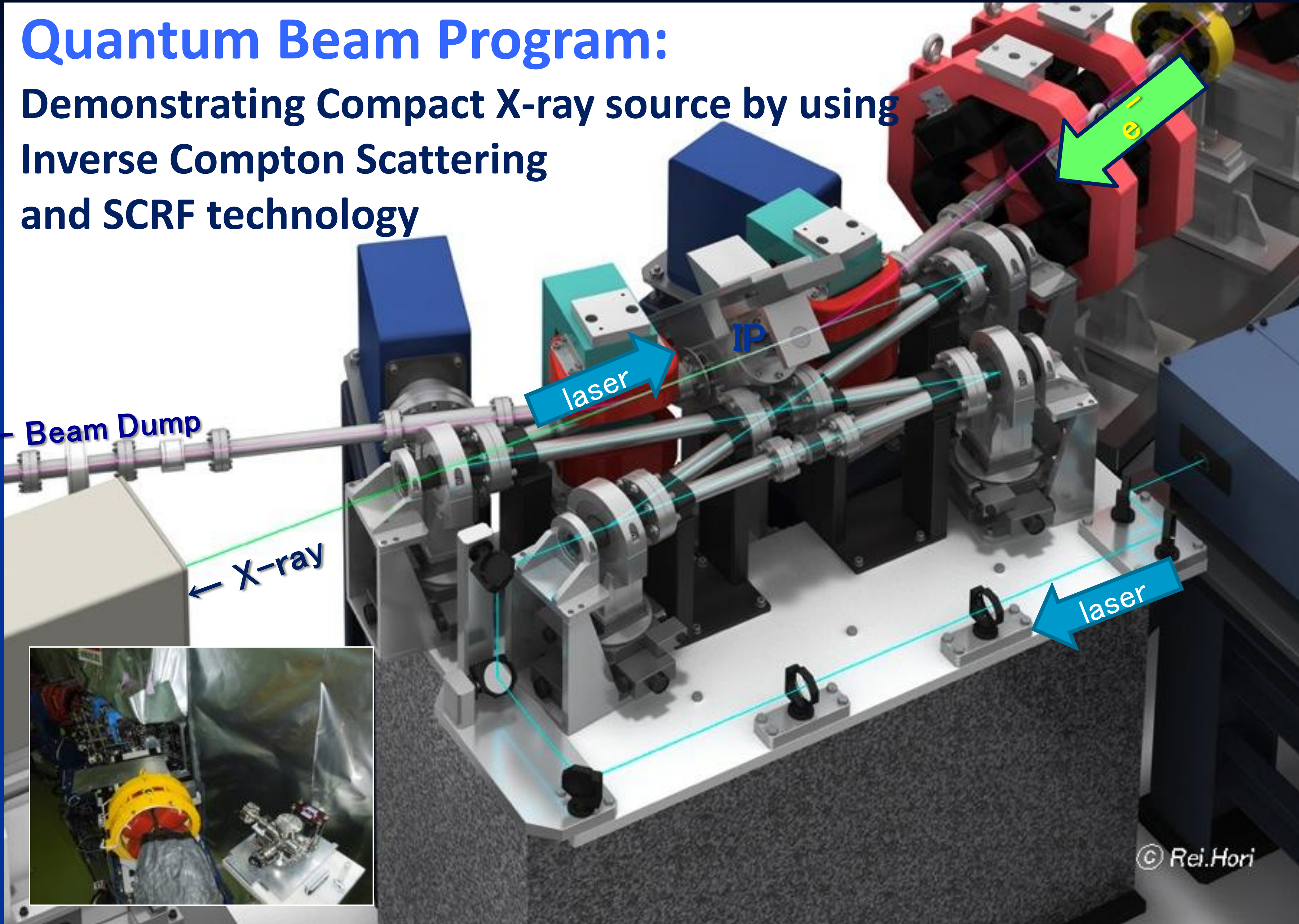
Beam acceleration (40 MV) and transport for 6.7 mA, 1 ms succeeded, at KEK-STF, in 2012



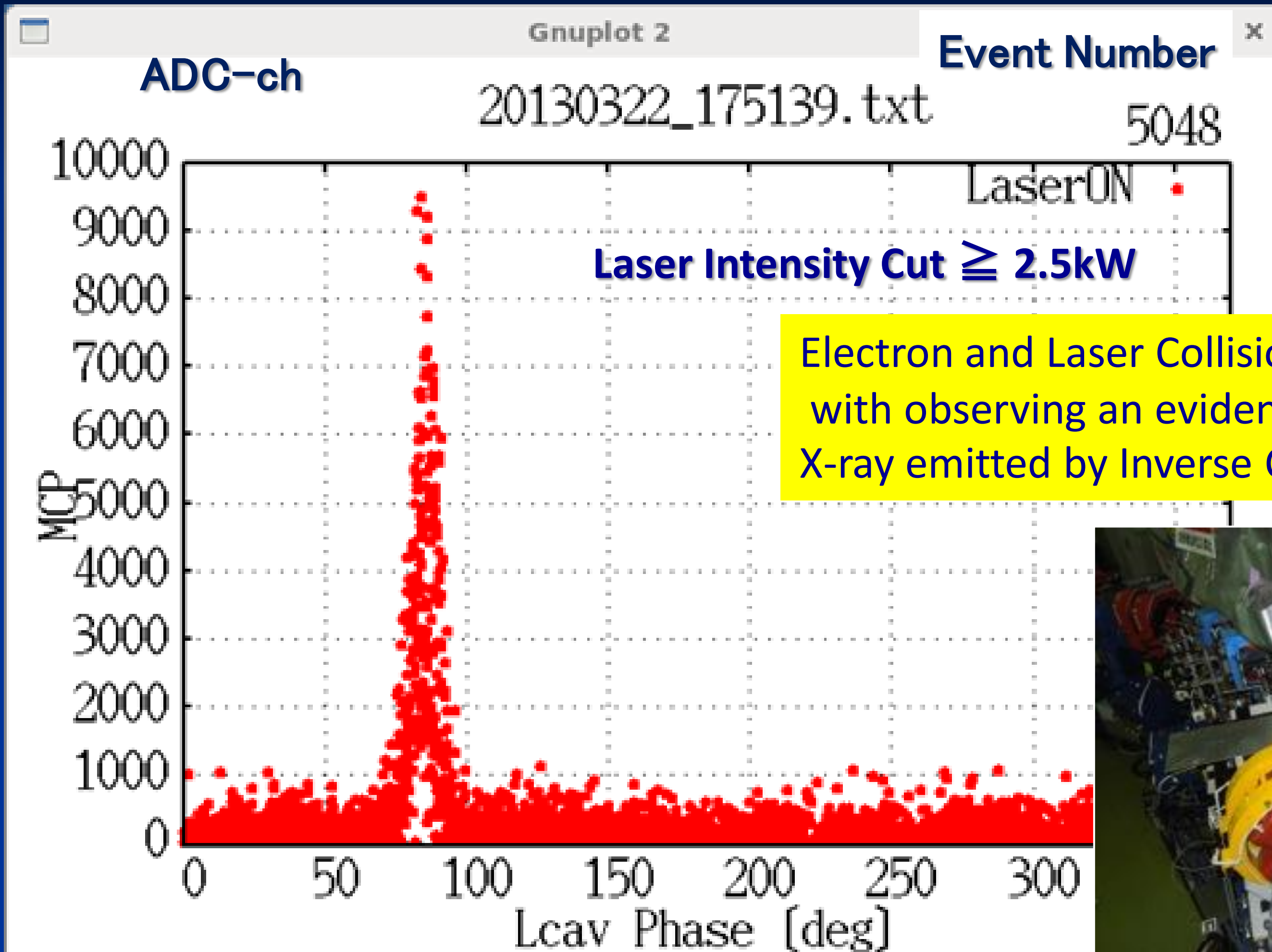


Quantum Beam Program:

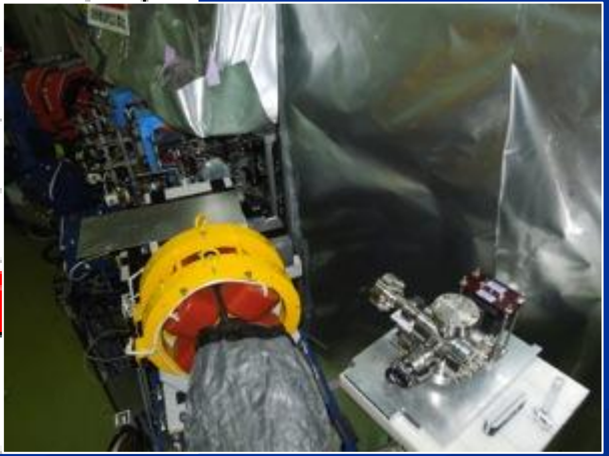
Demonstrating Compact X-ray source by using Inverse Compton Scattering and SCRF technology



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

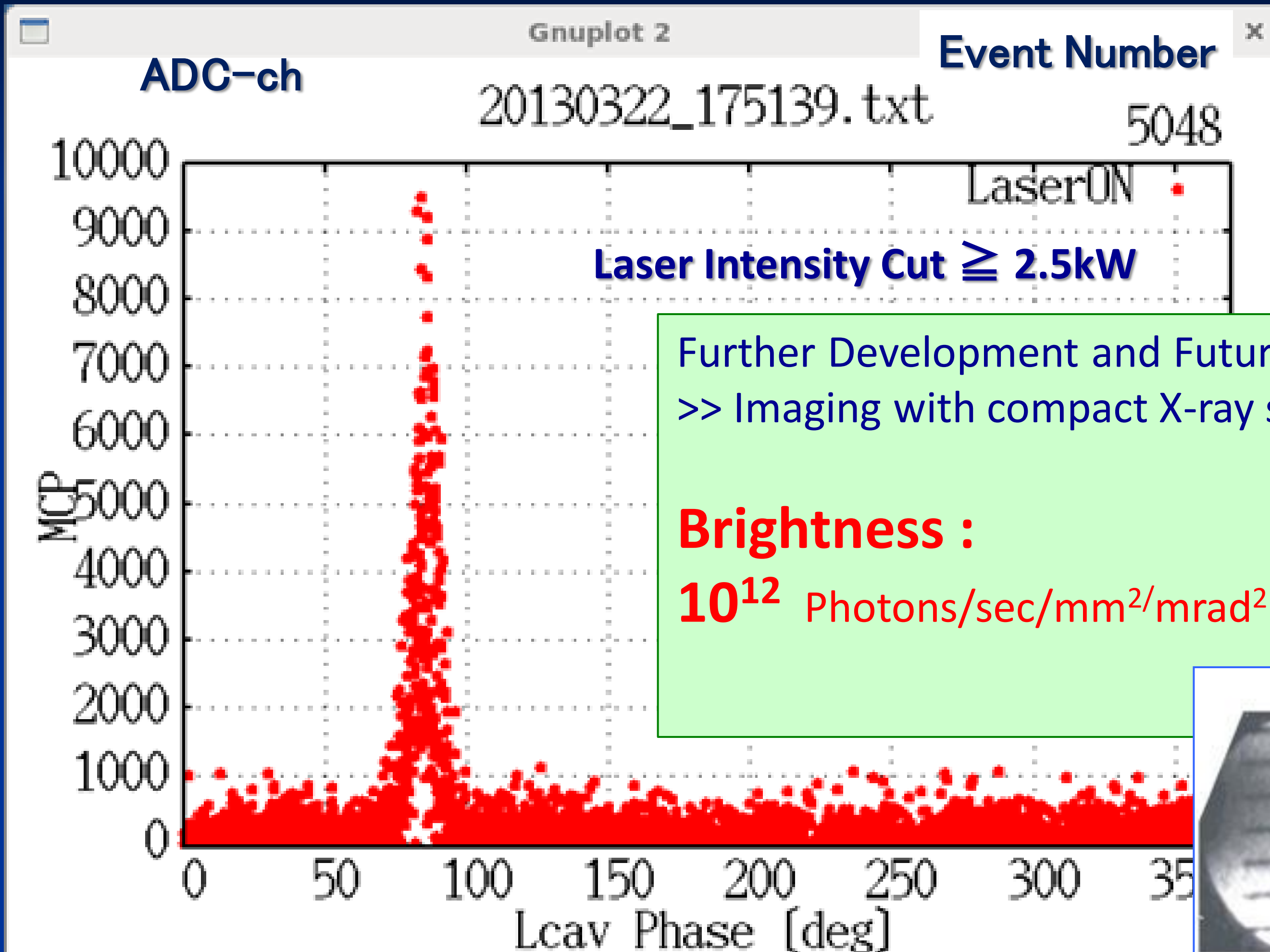


Electron and Laser Collision confirmed
with observing an evidence using MCP :
X-ray emitted by Inverse Comption scattering



Laser beam (Ext. Cavity) not synchronized with STF clock (162.5MHz)
Horizontal Axis: Phase defference of laser beam from STF RF
Specific MCP count clearly excessed

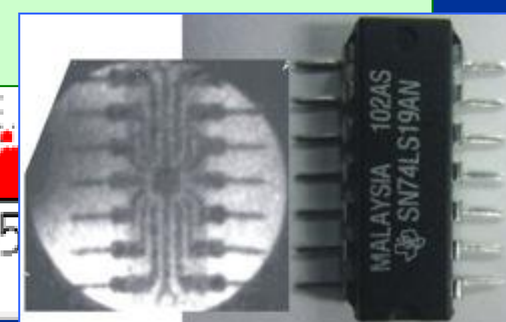
X-ray observed (w/ MCP, 22^{nd} Mar.2013)



Further Development and Future Scope
>> Imaging with compact X-ray source with

Brightness :

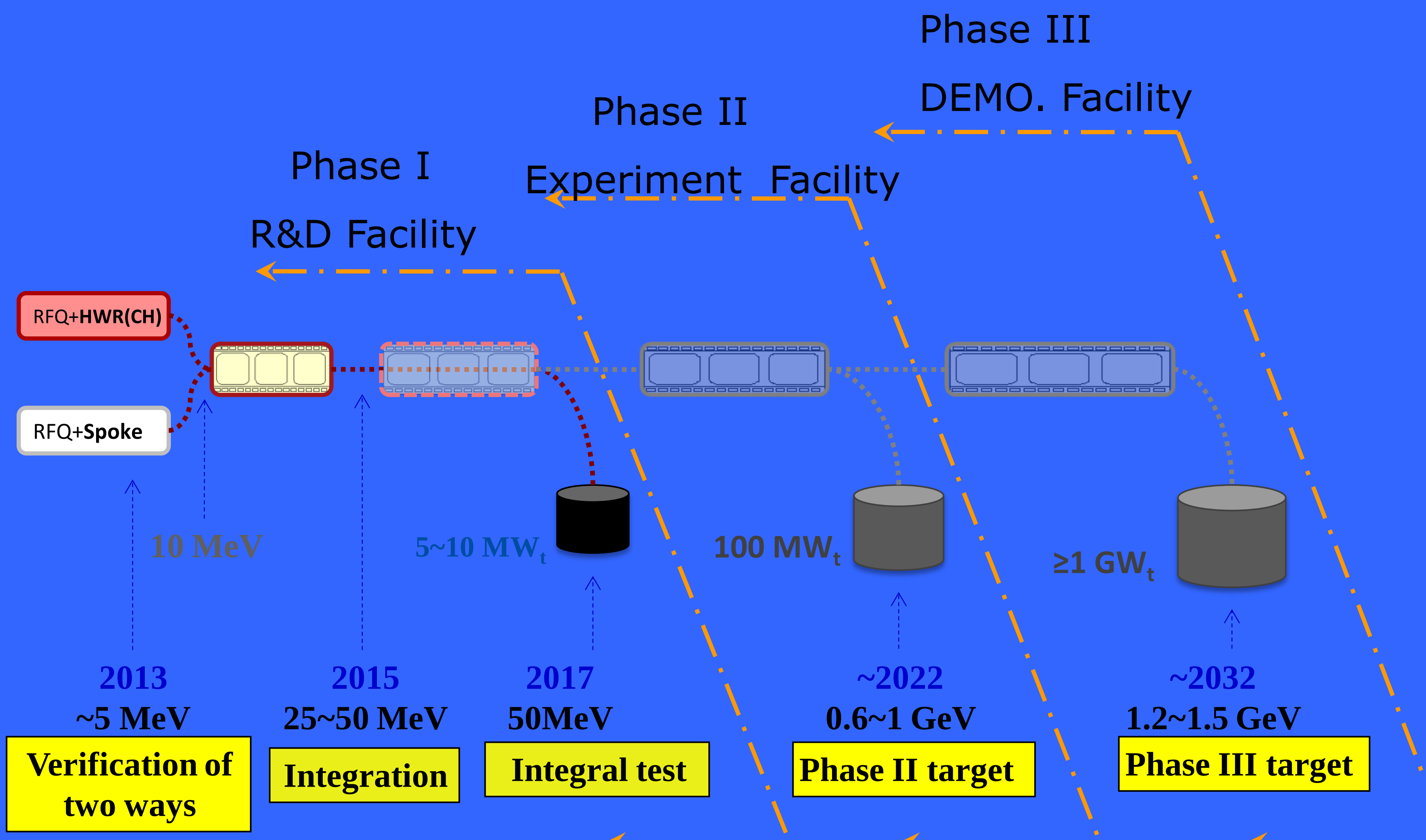
10^{12} Photons/sec/mm^{2}/$mrad^{2}$ in 0.1%b.w.



Laser beam (Ext. Cavity) not synchronized with STF clock (162.5MHz)
Horizontal Axis: Phase defference of laser beam from STF RF
Specific MCP count clearly excessed

An important Future Application: ADS Roadmap in China

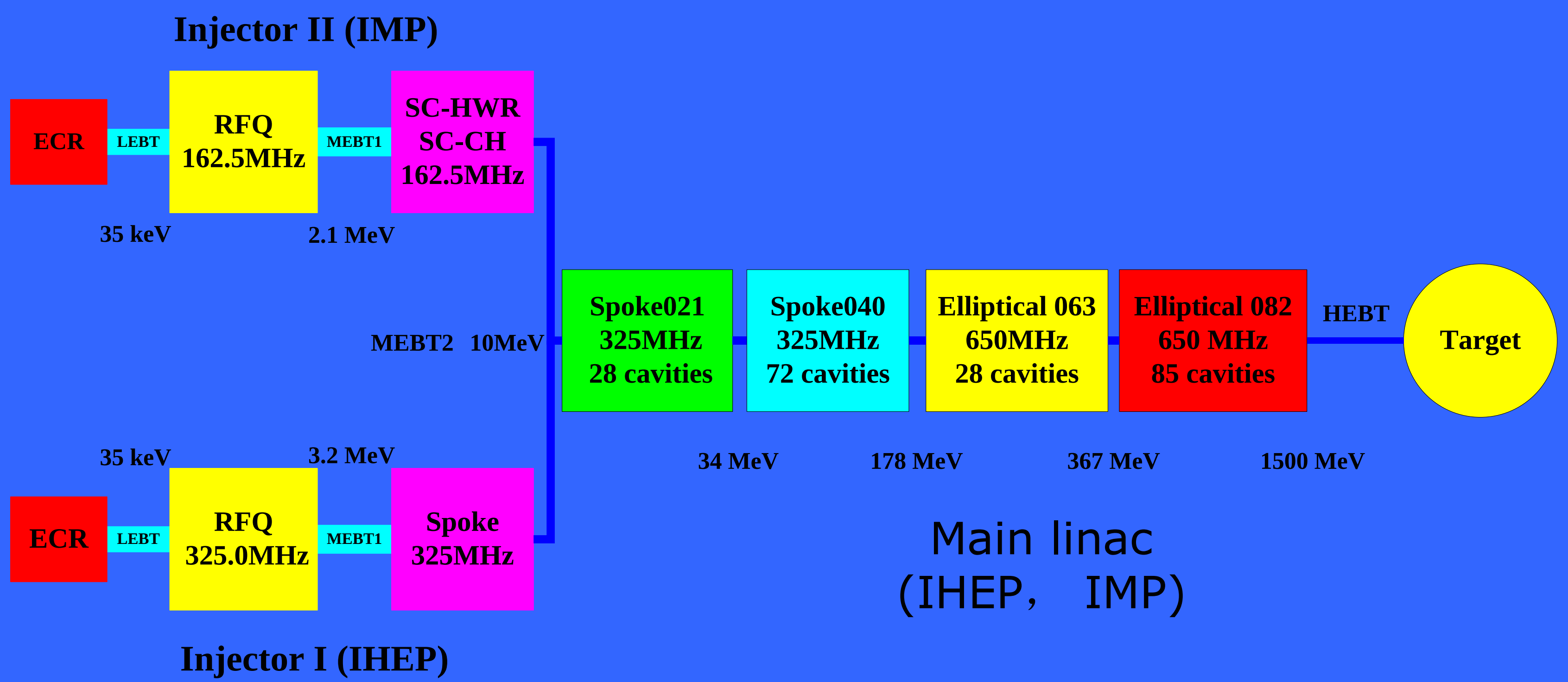
Courtesy:
W. Pan, J. Gao



Layout of ADS Accelerator in China

Courtesy:
W. Pan, J. Gao

•The proton accelerator is being built by IHEP and IMP together.
•This project has begun from early 2011.



Outline

- Introduction
  - Progress in particle accelerators
- Accelerator technologies from "Big Projects" and "Applications"
  - LHC: Superconducting magnet technology
  - JPARC: A research complex
  - EXFEL and ILC: superconducting RF technology
- General applications
  - Photon science, Medical application, and others
- Summary

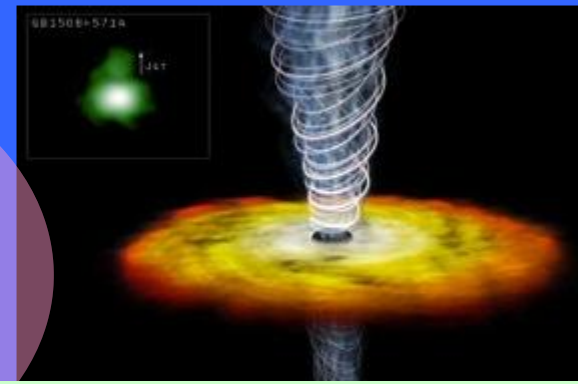
Courtesy: Y, Murakami, H. Kawata

Main Synchrotron Radiation Facilities of the world

	ESRF	SPring-8	APS
	European Synchrotron Radiation Facility	Super Photon ring-8GeV	Advanced Photon Source

XFEL explores new worlds of science

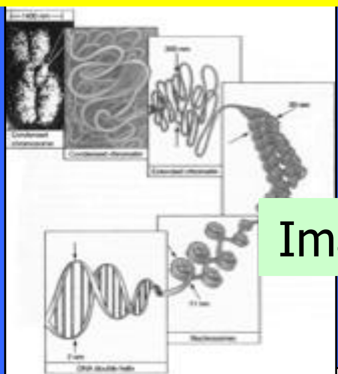
Courtesy:
Hanaki, YABASHI and Yamauchi



NL & Quantum X-ray Science
High Energy Density Science

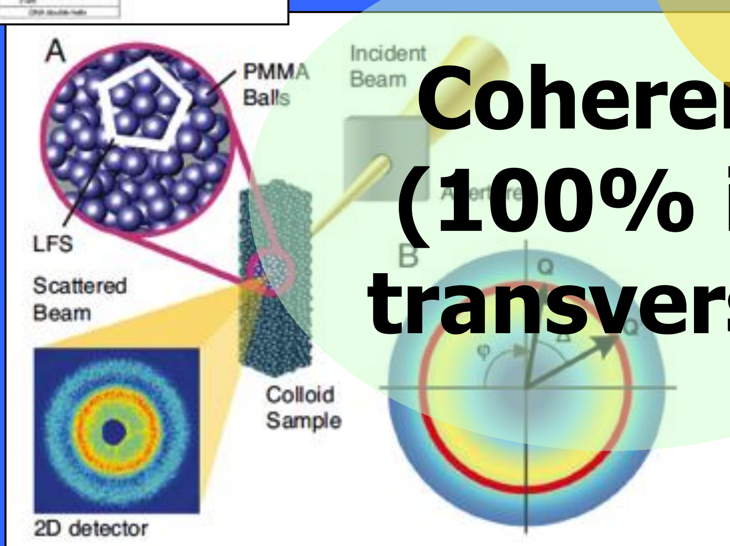
Brilliance ($X10^9$)

XFEL



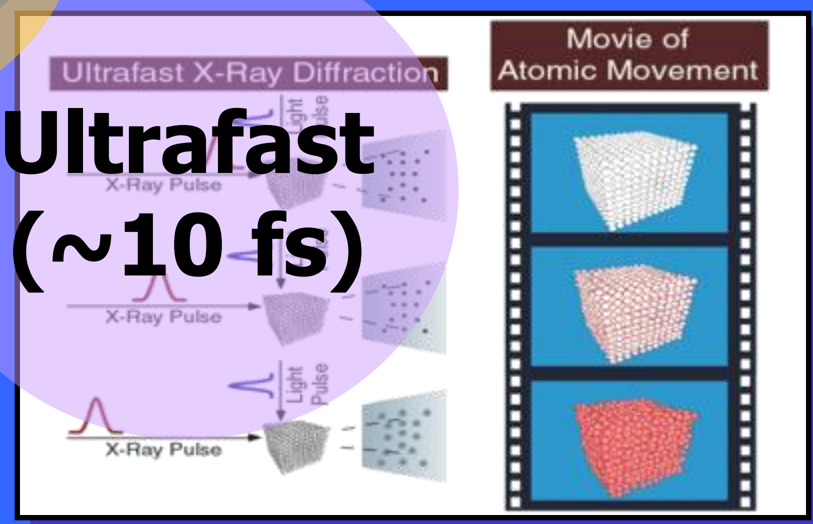
Imaging Biology

Ultrafast Materials Science
Serial Femtosecond Crystallography



Coherent (100% in transverse)

Ultrafast (~10 fs)



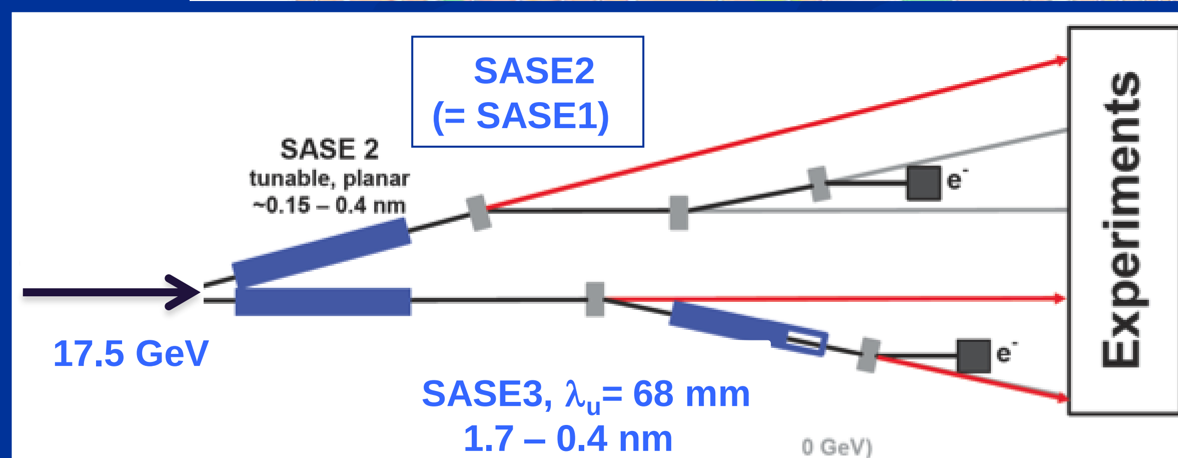
Courtesy: H. Weise, M. Heuning, J. Sekutowicz

The European XFEL

Specifications

- Photon energy 0.3–24 keV
- Pulse duration ~ 10–100 fs
- Pulse energy few mJ
- Superconducting linac. 17.5 GeV
- 10 Hz (27 000 b/s)
- 5 beamlines / 10 instruments
  - Start version with 3 beamlines and 6 instruments
- Several extensions possible:
  - More undulators
  - More instruments
  - …….
  - Variable polarization
  - Self-Seeding
  - CW operation

First beam late 2015

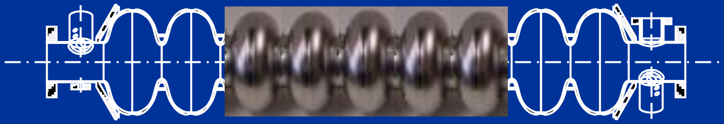


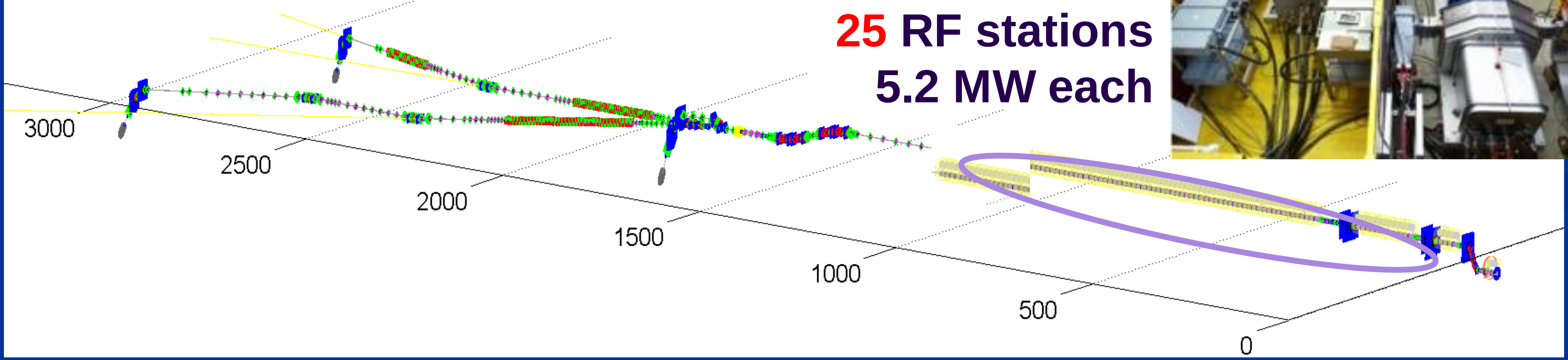
EXFEL: SCRF Accelerator Complex

providing a reference for ILC Project “anticipated”

100 accelerator modules

800 accelerating cavities
1.3 GHz / 23.6 MV/m





25 RF stations
5.2 MW each

Undulators another very important technology

- Series production of 90 undulators started
  - Today 22 tuned, 18 ready for installation
- Focusing quadrupoles manufactured and precision fiducialization
- Series production of intersection components started

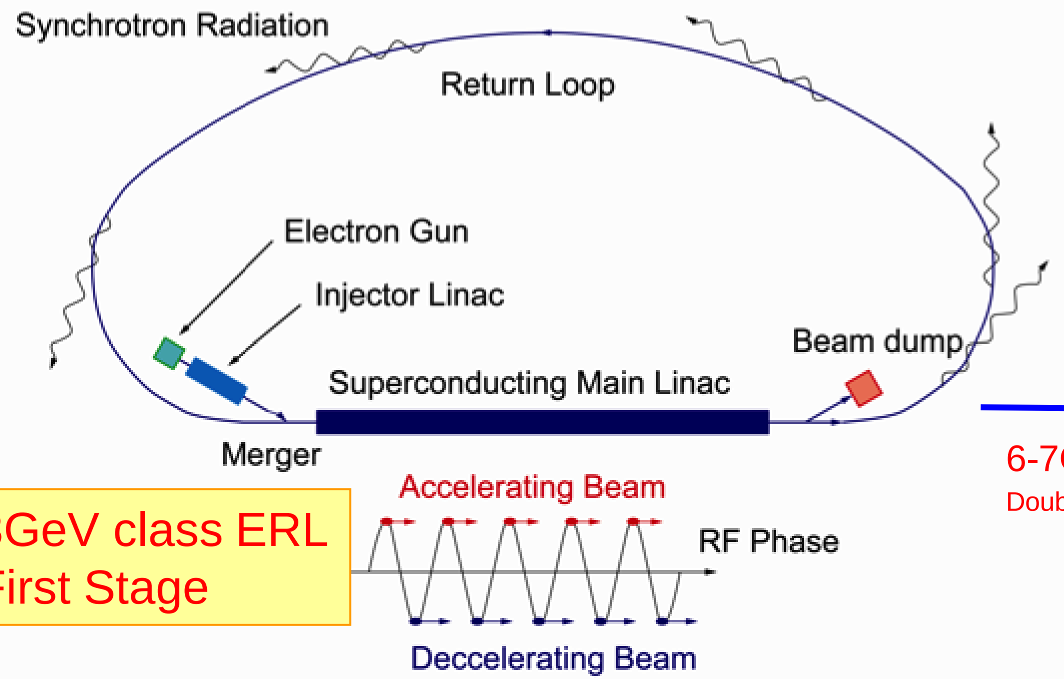
Courtesy: Y. Murakami,H. Kawata

Future light source of the Photon Factory

Users' demands : both cutting edge and workhorse
To realize a sustainable society.
Ultra-fast phenomena, nano-meter scale, Nondestructive measurements, high rep rate, soft and hard X-ray
Ample possibilities for future expansion

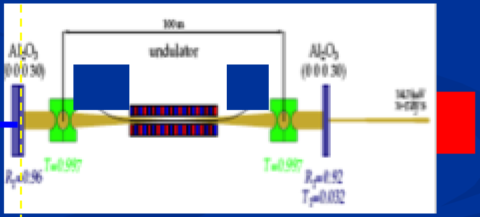
3GeV ERL proposed

3 GeV Energy Recovery Linac (ERL) and Resonant type of XFEL (XFEL-O)



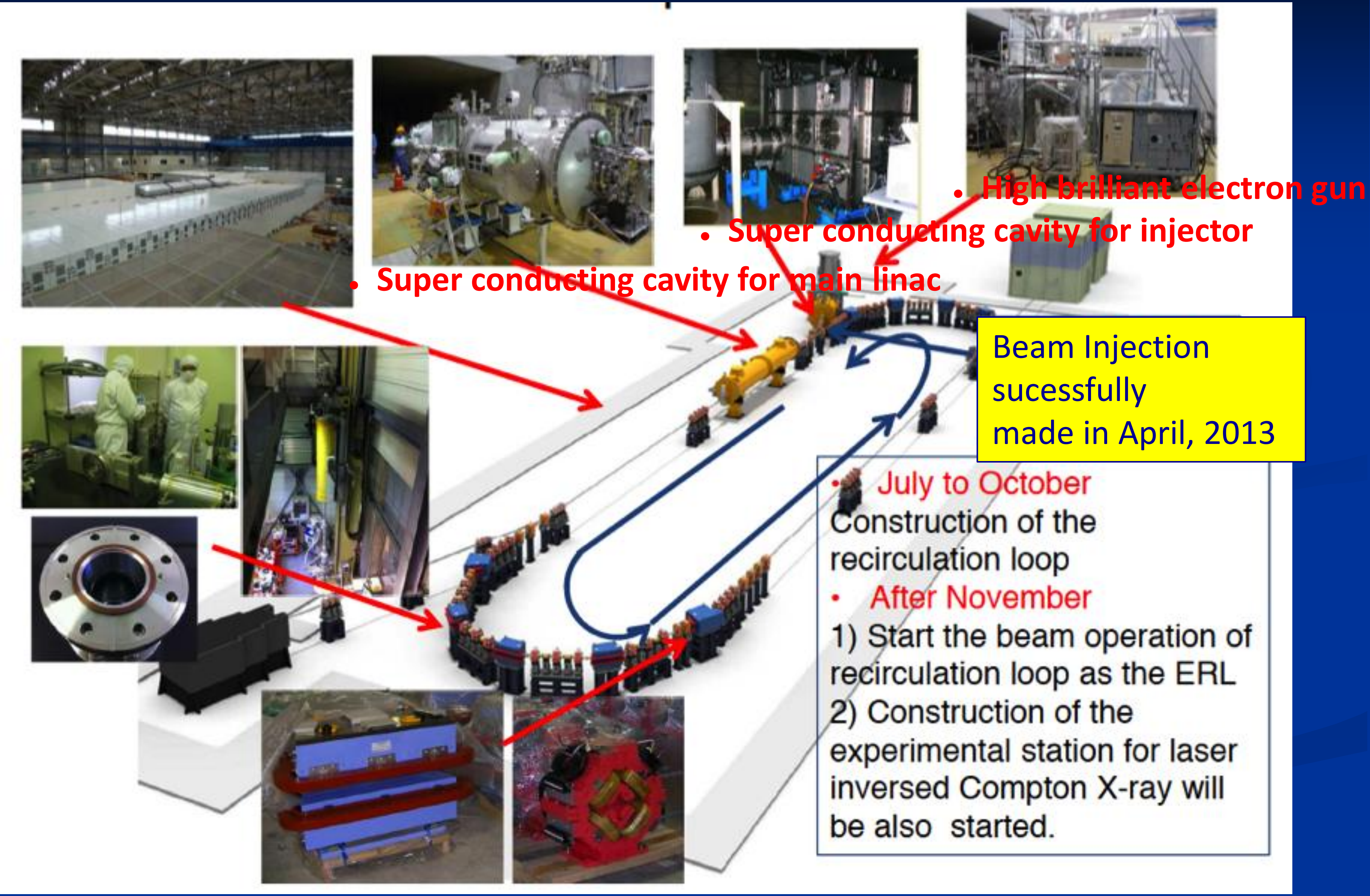
3GeV class ERL First Stage

6-7GeV
Double Acc.



XFEL-O Second Phase

Development of c-ERL at KEK



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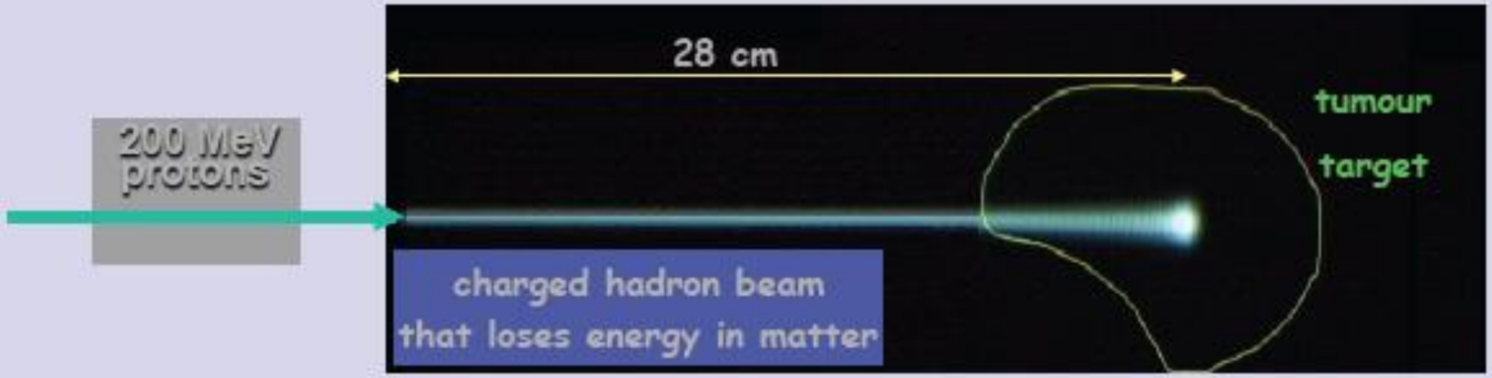
- Summary

Courtesy: K. Noda, H. Tsuji

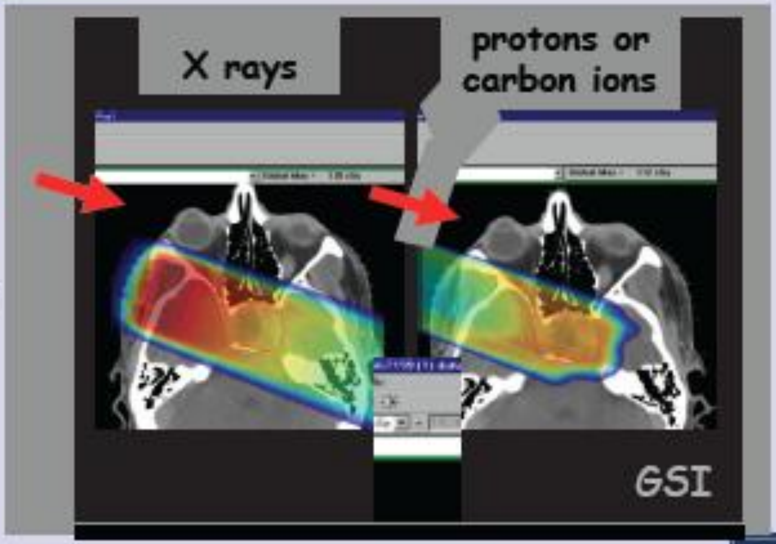
Medical Application:

Hadron Therapy - The Principle (U. Amaldi)



Hadron beams provide new treatment opportunities for deep-seated tumours.

Hadron beams are more effective than X-rays in destroying tumours while sparing healthy tissues nearby.

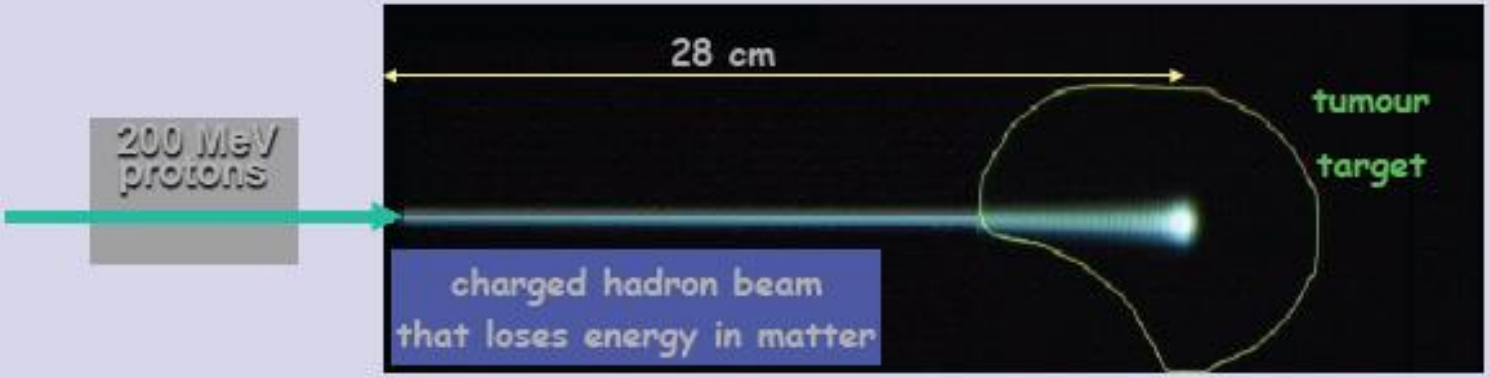


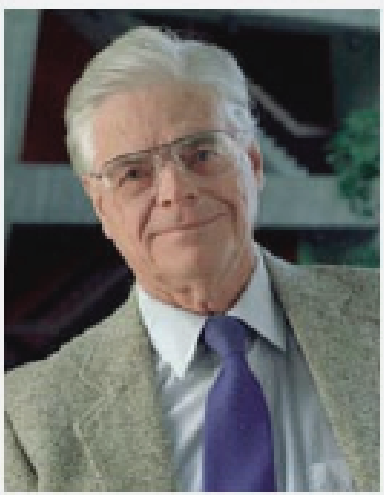
ENLIGHT

Courtesy: K. Noda, H. Tsuji

Medical Application:

Hadron Therapy - The Principle (U. Amaldi)





Founder and first

All started in 1946 ....

Robert Wilson :

- Protons can be used clinically
- Accelerators are available
- Maximum radiation dose can be placed into the tumour
- Proton therapy provides sparing of normal tissues

(*) Wilson, R.R. (1946), "Radiological use of fast protons," Radiology 47, 487.

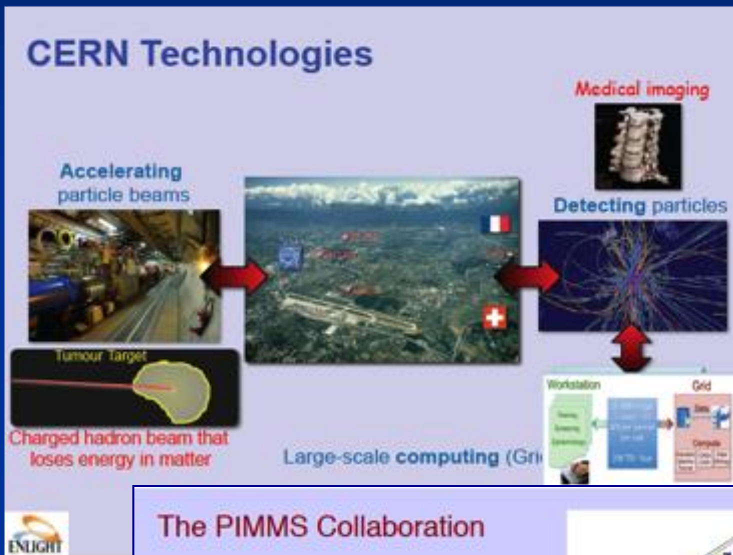
Courtesy: K. Noda, See more in Appendix

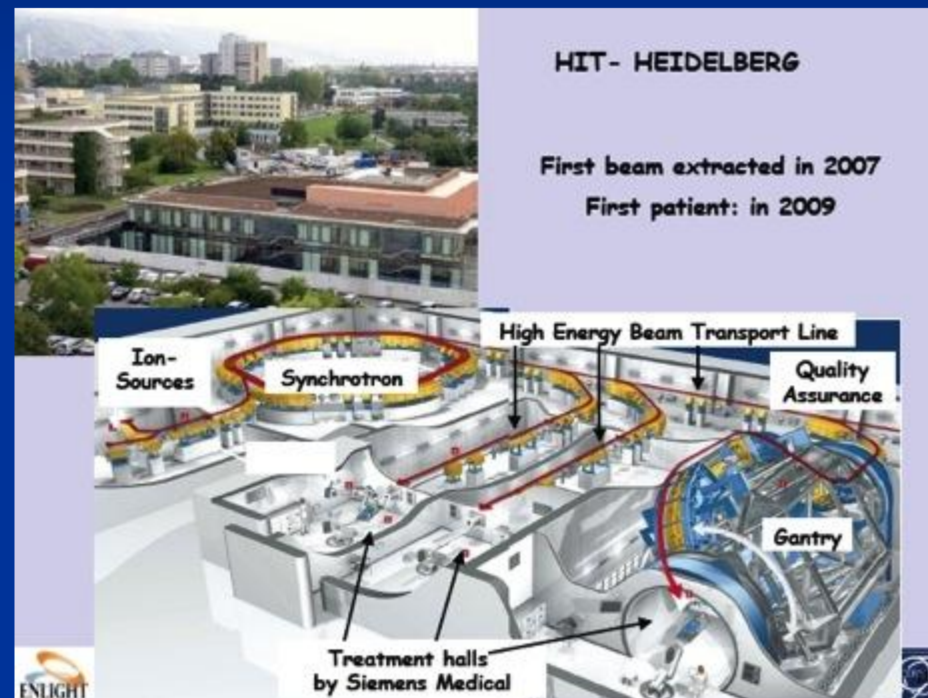
Outline of Carbon Facilities in Worldwide Operation

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

Courtesy: M. Dosanih, L. Rossi,

Accelerator Technology Contributing Dedicated Medical Accelerators





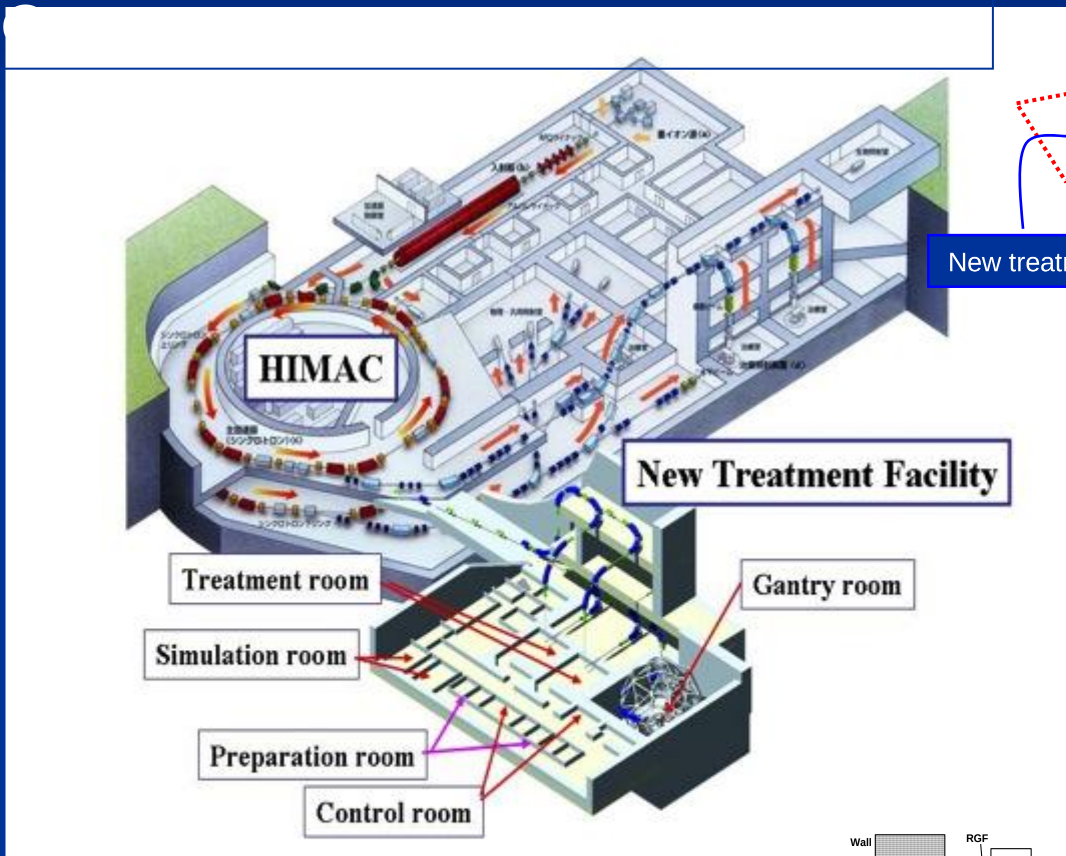
Heavy Ion Beam Accelerator at Heidelberg

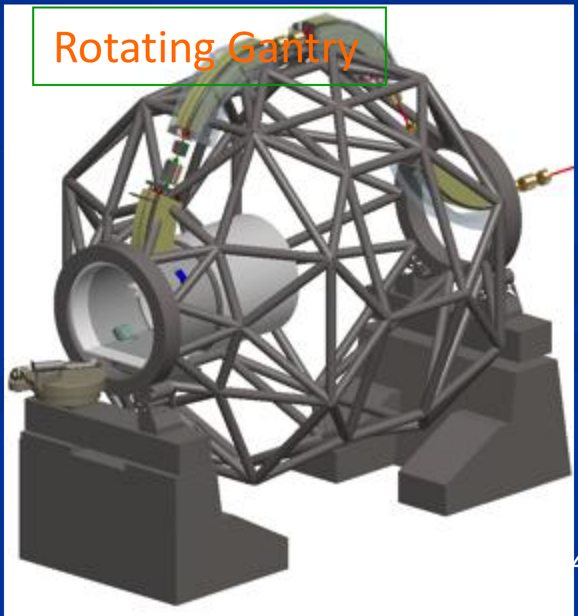
Ref: T. Haberer, IPAC'13, THB201

Development of New Treatment Research Facility at NIRS, Japan

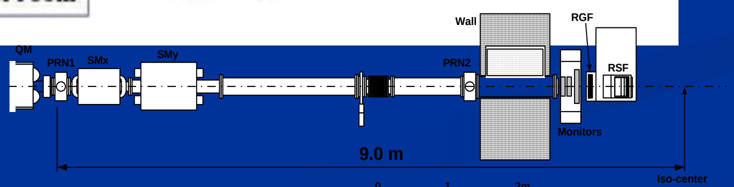
Courtesy: Y. Iwata, T. Ogitsu

○3D Scanning with Gating (H&V): 2 rooms



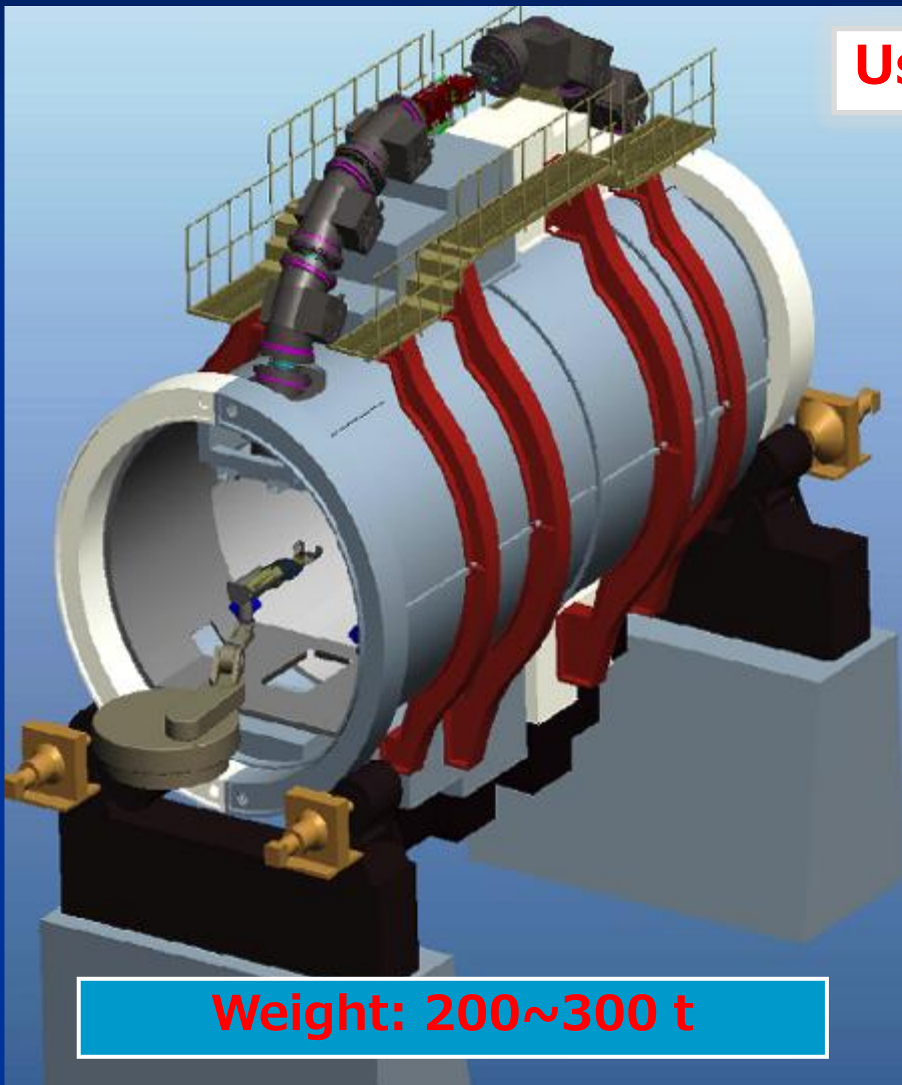


3D Scanning



Courtesy: Y. Iwata, T. Ogitsu

Superconducting rotating-gantry



Use of superconducting magnets

Ion kind : ^{12}C
Irradiation method: 3D Scanning
Beam energy : 430 MeV/n
Maximum range : 30 cm in water
Scan size : □200×200 mm^2
Radius : 5.5 m
Length : 13 m

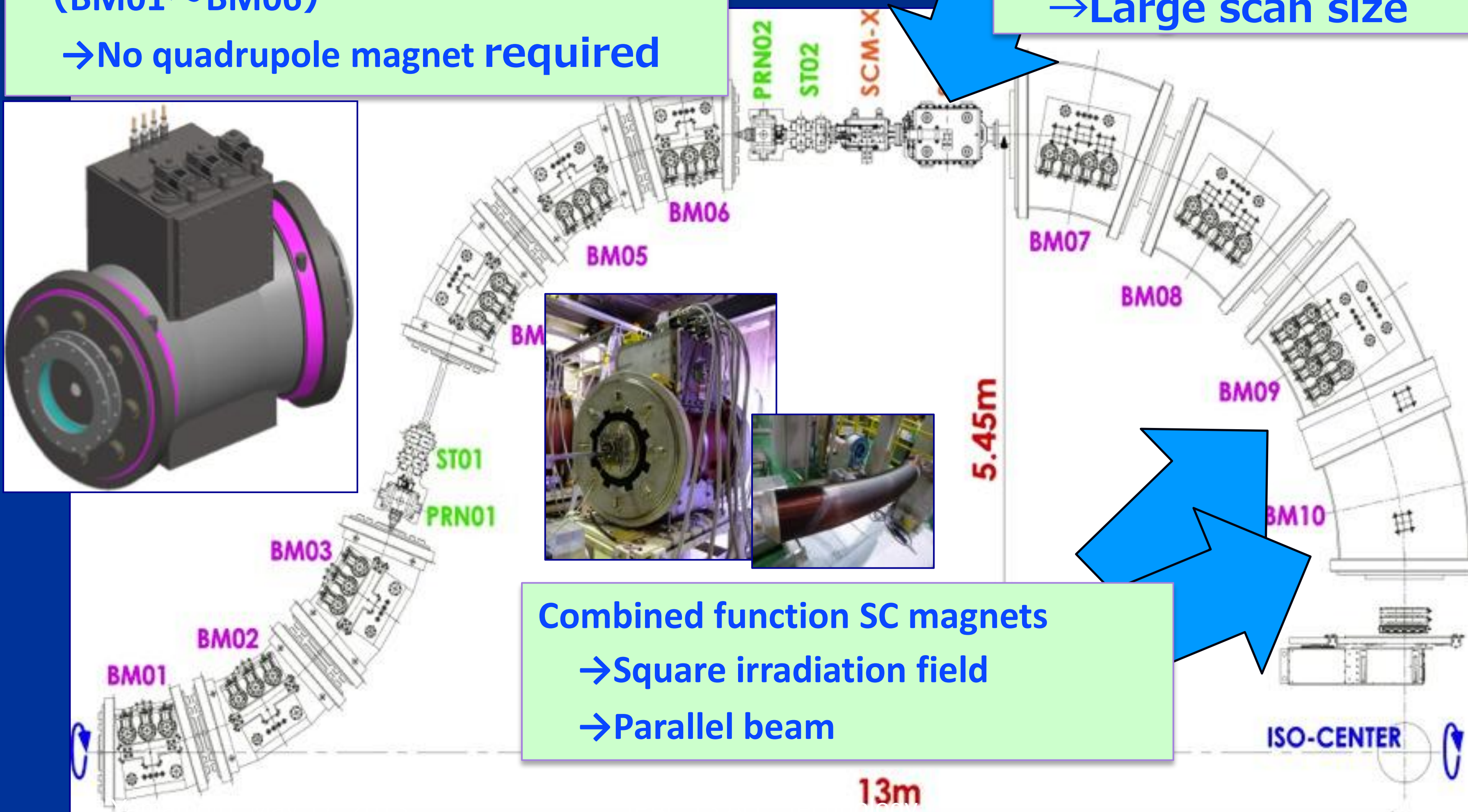
The size and weight are comparable to those of proton gantries!

Courtesy: Y. Iwata, T. Ogitsu

Layout of the SC gantry
(under construction)

Combined function SC magnets
（BM01～BM06）
→No quadrupole magnet required

Scanning magnets on top
→Large scan size



Combined function SC magnets
→Square irradiation field
→Parallel beam

Courtesy: M. Matsuoka and Y. Kamino

Image Guided , Dynamic Tumor Tracking Radiation Therapy System

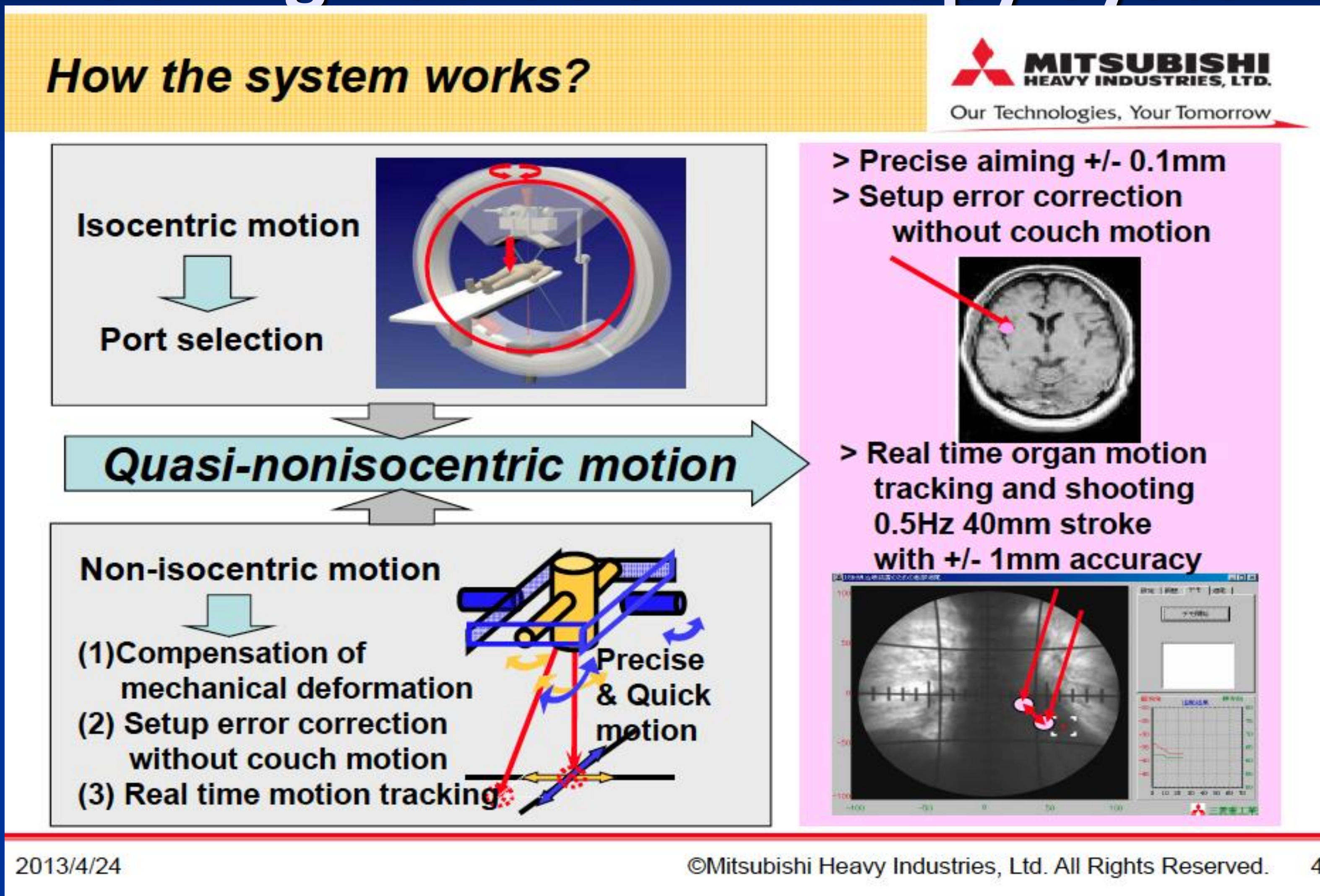
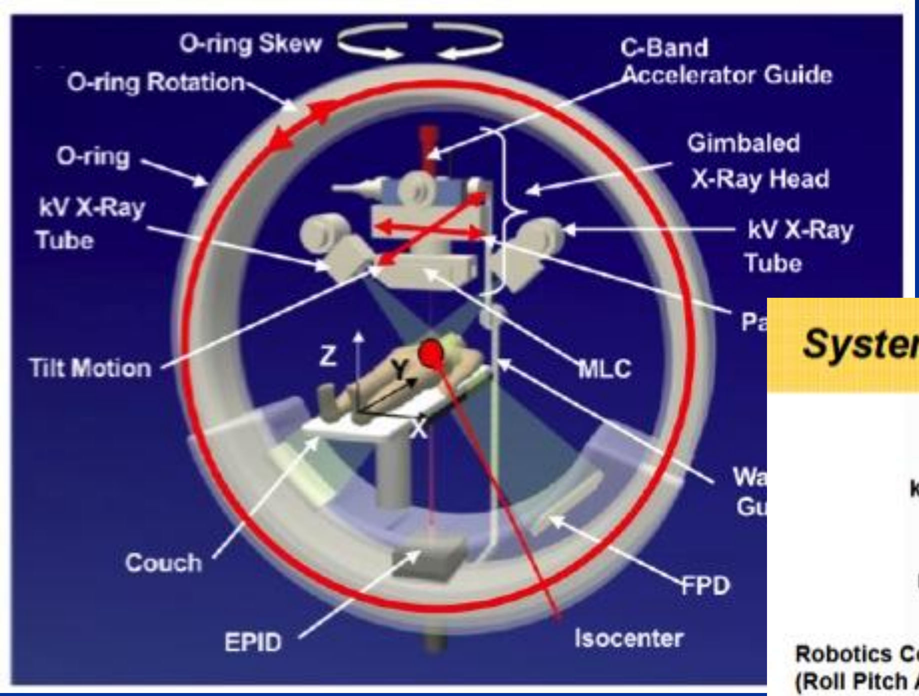
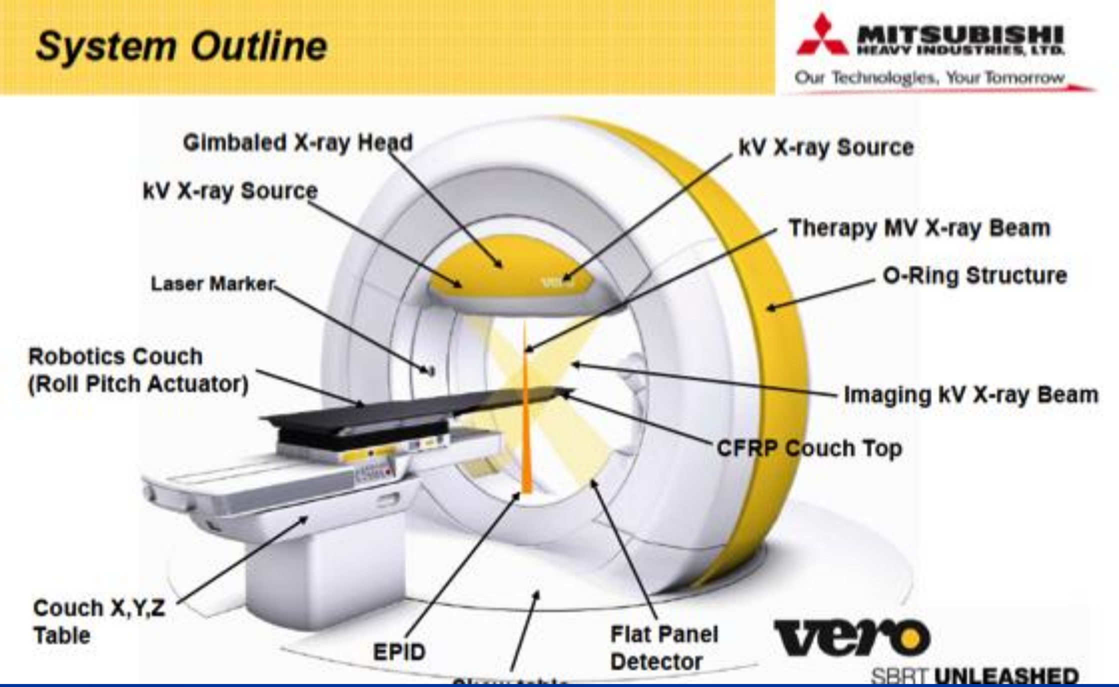


Image Guided , Dynamic Tumor Tracking Radiation Therapy System



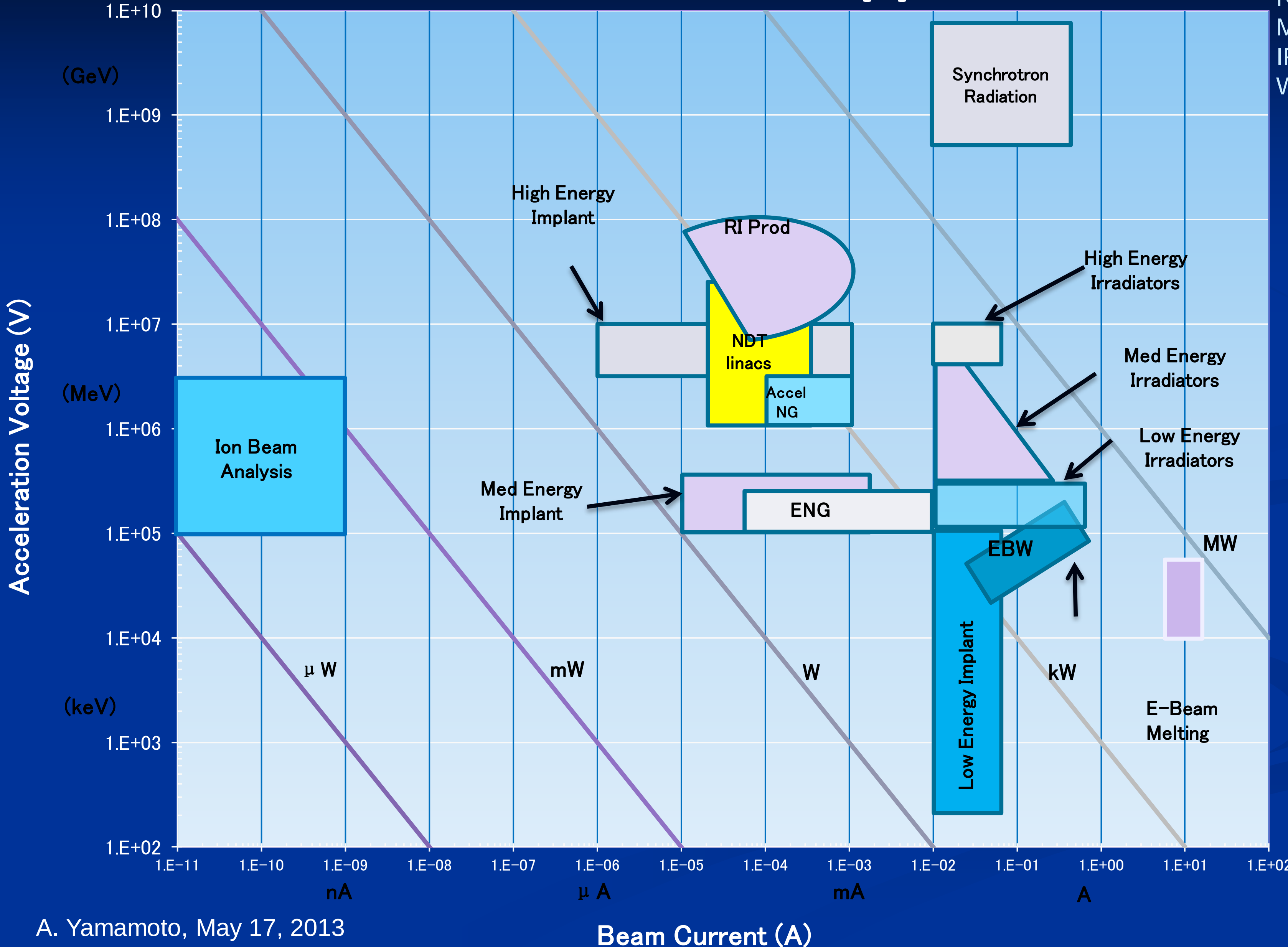
C-band Accelerator Technology Contributing
with MHI and KEK cooperation



Courtesy: R. Hamm, S. Henderson

Industrial Accelerator Applications

Ref:
R. Hamm
M. Hamm
IPAC'13
WEIB201



Summary

- Accelerator technology is highly motivated and progressed with "big accelerator projects"
- It is leading broad accelerator science and medical/life and industrial application
- Advanced accelerator technology needs to be extended and transfer to our next generation

Acknowledgements

- *I would thank:*
  - *L. Rossi,A. Ballriono, M. Dosanih (CERN)*
  - *G. Sabbi (LBNL)*
  - *R. Kephart, S. Henderson (Fermilab)*
  - *R. Geng, G. Ciovati, J. Hogan, A. Hutton (JLab)*
  - *H Weise, M. Heuning, J. Sekutowicz*
  - *B. Barish, M. Ross, N. Walker (ILC-GDE)*
  - *J. Kerby (ANL)*
  - *T. Haberer 8HIT)*
  - *K.Noda, H. Tsujii, Y. Iwata (NIRS)*
  - *M. Matsuoka, Y. Kamino (MHI)*
  - *R. Hamm (R&M Technical Enterprise)*
  - *S. Nagamiya (JAEA/KEK)*
  - *K. Akai, J. Urakawa, H. Hayano, T. Ogitsu (KEK)*
- *For their cooperation to prepare for this talk.*

Backup

ILC Time Line

1980' ~ Basic Research and Design Study

2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013

ILC-GDE

LCC

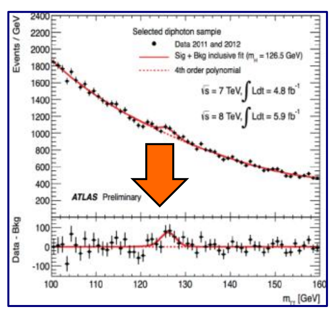
Ref. Design (RDR)

Tech. Design : TDP1

TDP 2

Selection of SC Technology

LHC

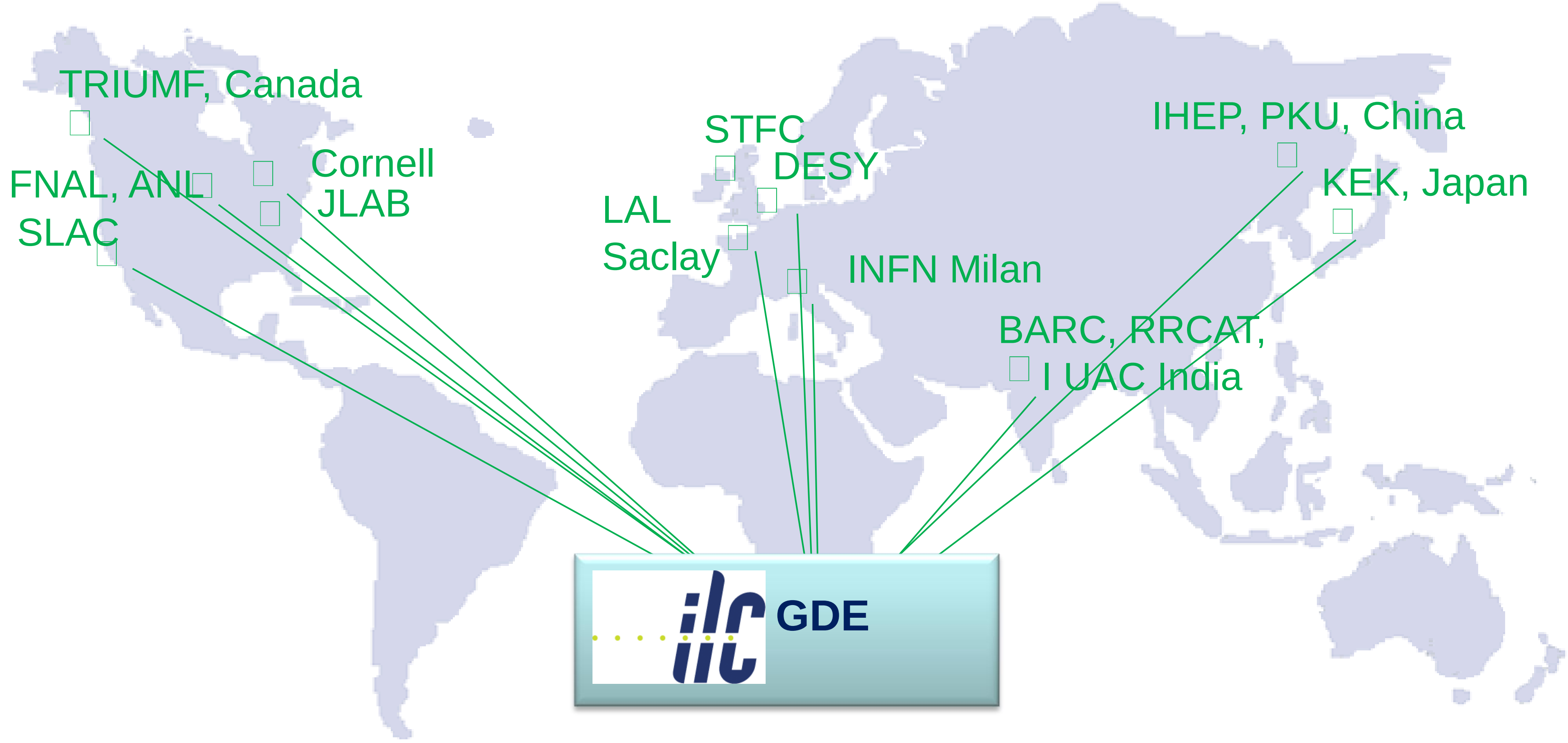


126 GeV

Higgs particle discovery

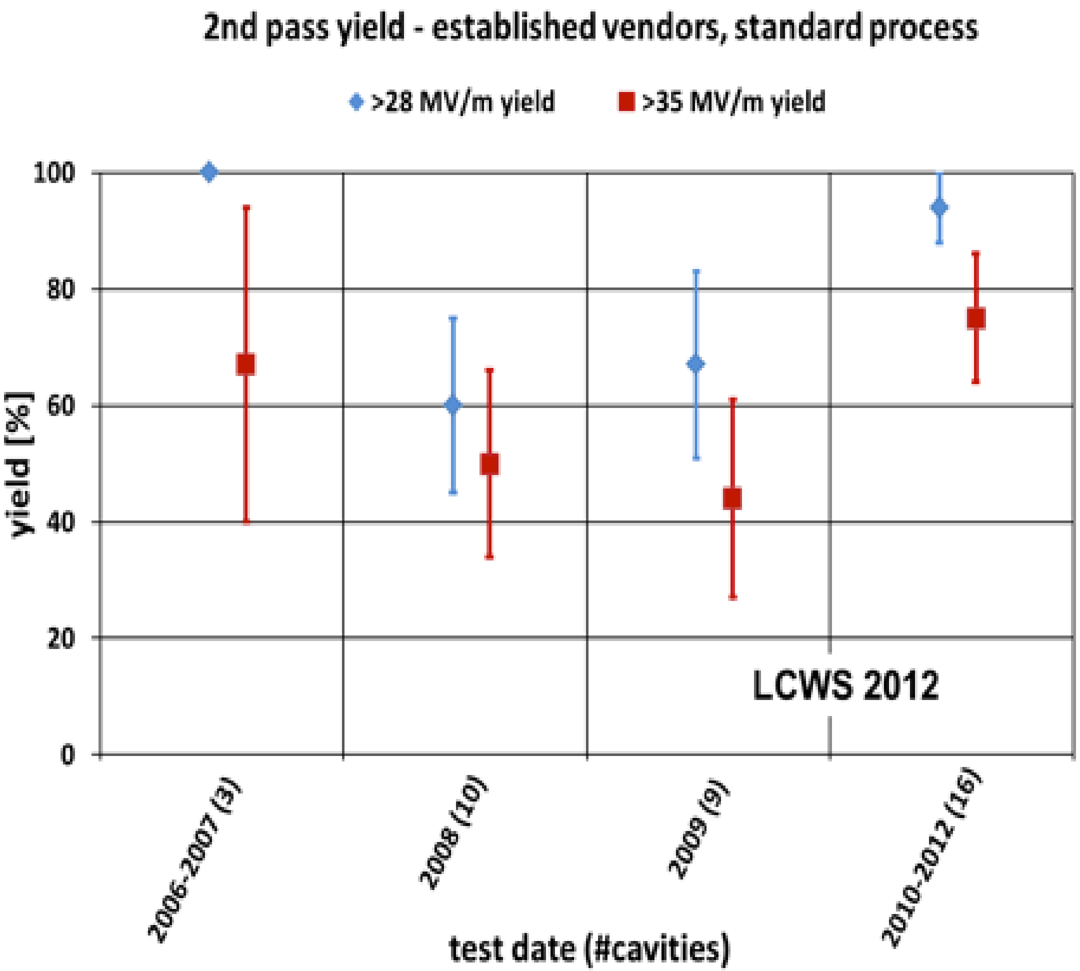
TDR completion

ILC R&D: Global Collaboration



We would thank the global effort effectively carried out

Progress in SCRF Cavity Gradient

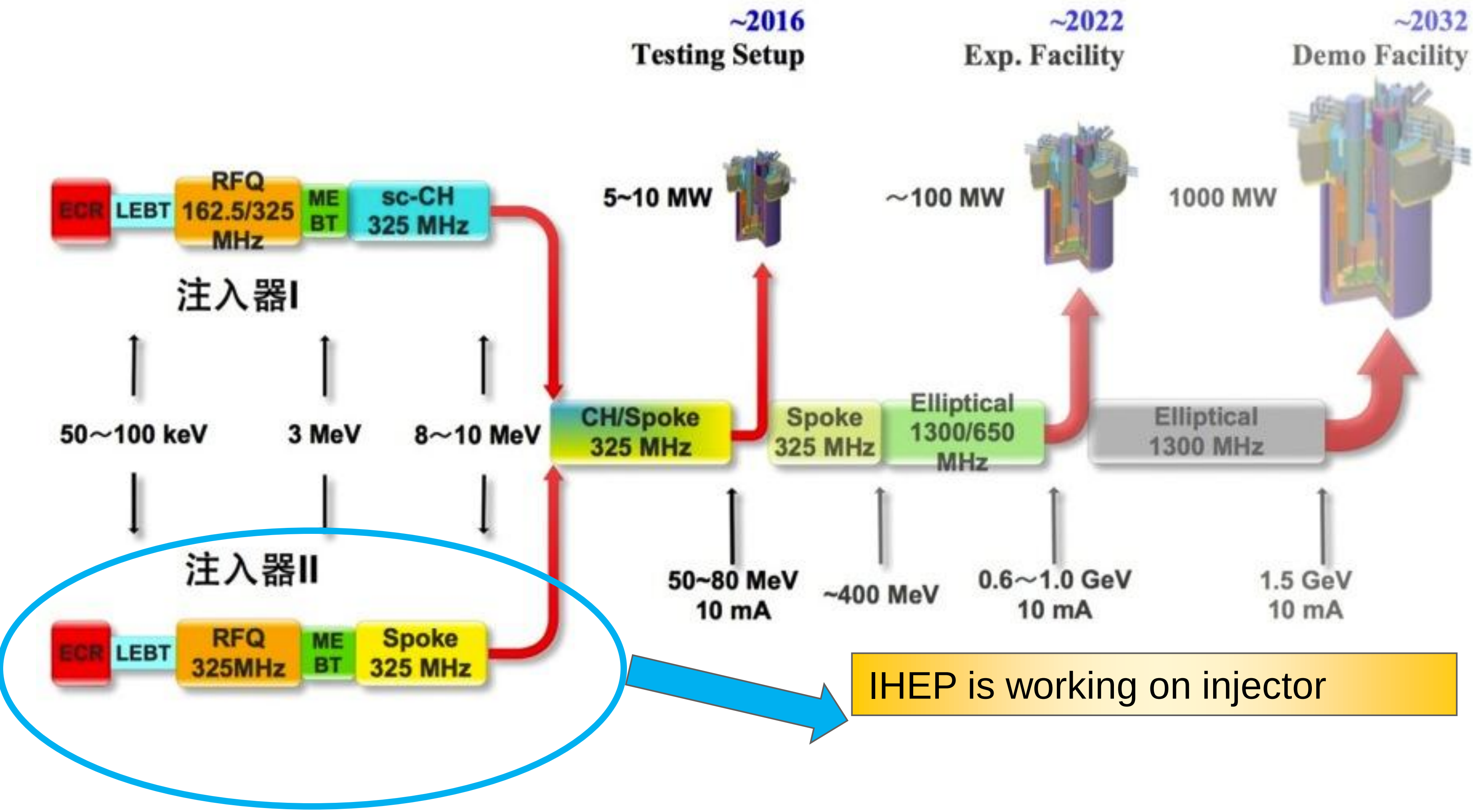


Production yield:
94 % at > 28 MV/m,

Average gradient:
37.1 MV/m

reached (2012)

CSNS



IHEP is working on injector

SPring-8 Upgrade Plan ~ towards diffraction lir

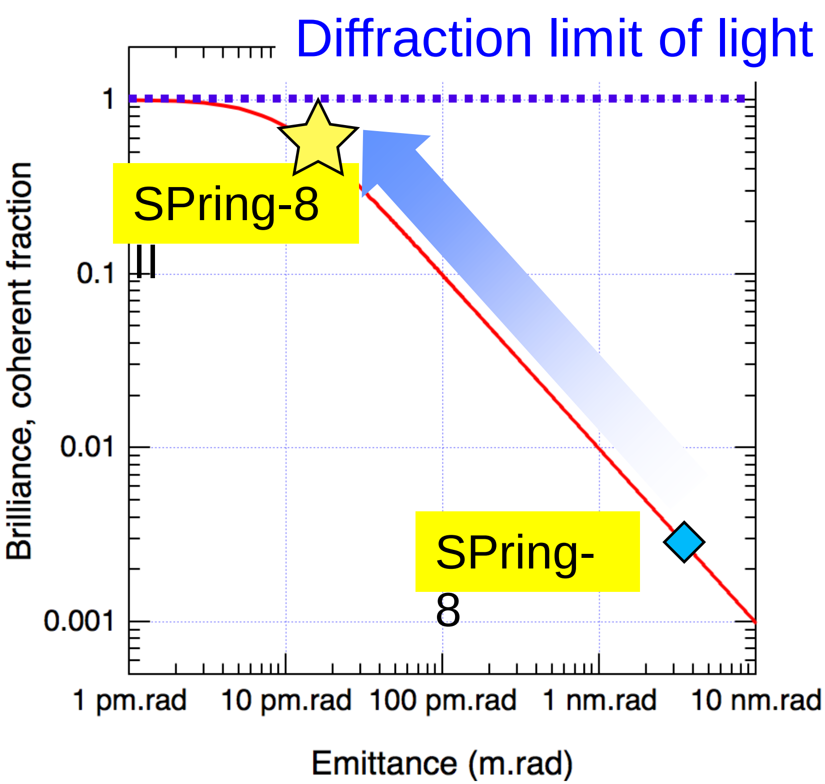
Courtesy:
H. Hanaki

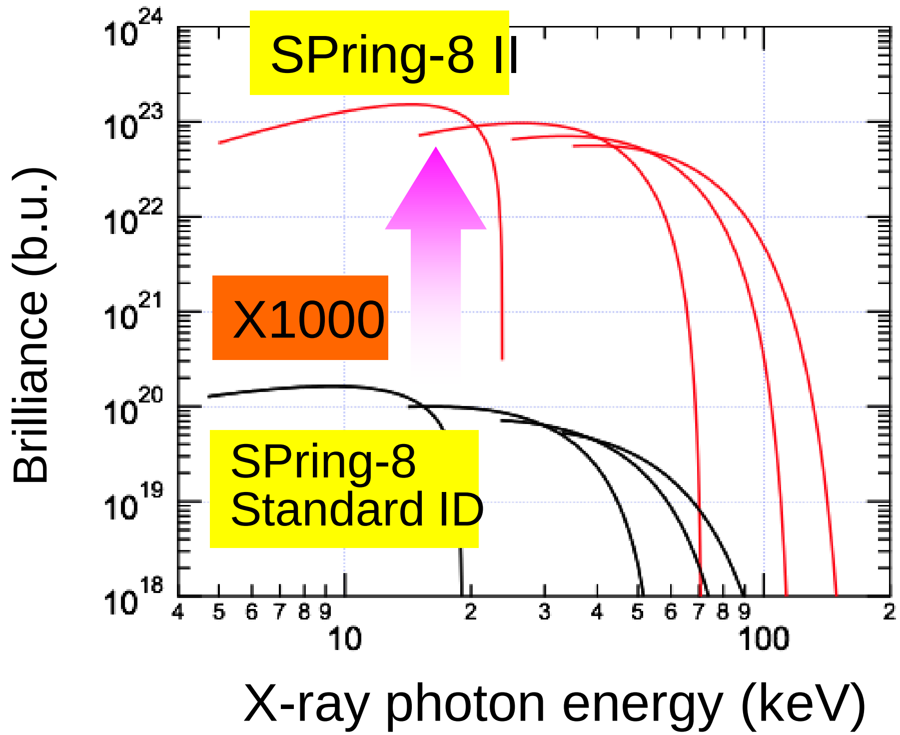
In 2020(?), one-year shutdown, to replace the existing ring

Electron beam emittance → Diffraction limit of light

ϵ → $\lambda / 4\pi$

via multi-bend lattice and more





Preliminary Report: www.spring8.or.jp/en/about_us/whats_sp8/spring-8_II

SPring-8, a storage ring for photon scie

Courtesy: H. Hanaki

> SPring-8 = 8 GeV storage ring + 8 GeV booster + 1 GeV linac

Energy 8GeV, Emittance 3.4 nm.rad

> Major upgrade plan

Replace the existing ring

In 2020 (planned) with one-year shutdown

To achieve extremely small emittance ~ diffraction limit of X-ray

For 10 keV, diffraction limit = 10 pm.rad (challenging goal)

via multi-bend lattice and more...

> 1,000 times higher brilliance = Big impacts on photon science

\+ open new fields of applications

(high-energy science etc)

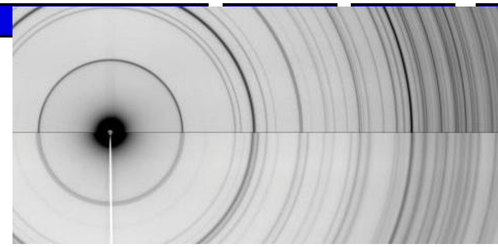
Enables to observe dynamics of inhomogeneous systems
(i.e., real material and life systems) by coherent intense X-ray

Coherent X-rays

Courtesy:
H. Hanaki

SPring-8

X-ray structural analysis



Homogeneous system
by incoherent X-ray

Periodicity and
homogeneity assumed

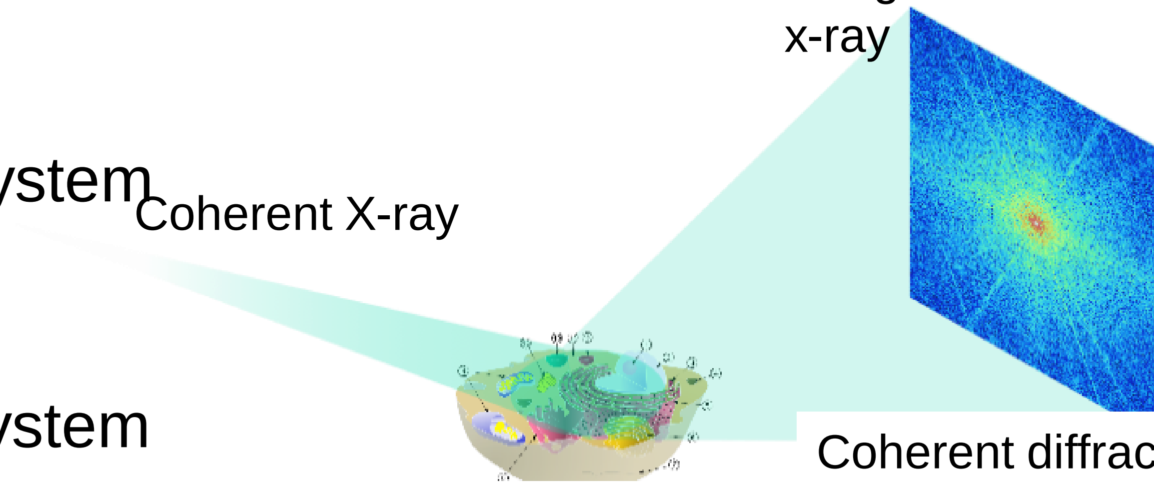
SPring-8 II

Inhomogeneous system
by coherent X-ray

Non-periodic and
inhomogeneous system

Hierarchy, structural
dynamics

Nano-resolution and
large-field observation
using intense coherent
x-ray



Coherent diffraction
pattern

Sample (biological,
organic and inorganic)

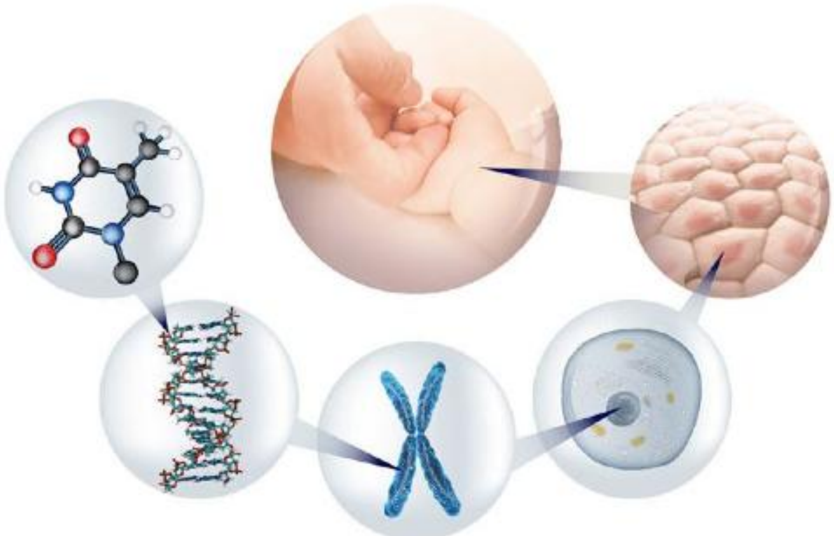
Preliminary Report: www.spring8.or.jp/en/about_us/whats_sp8/spring-8_II

Scientific targets

Courtesy: H. Hanaki

Bridge between molecular structure and macroscopic functions

Hierarchy in biological systems



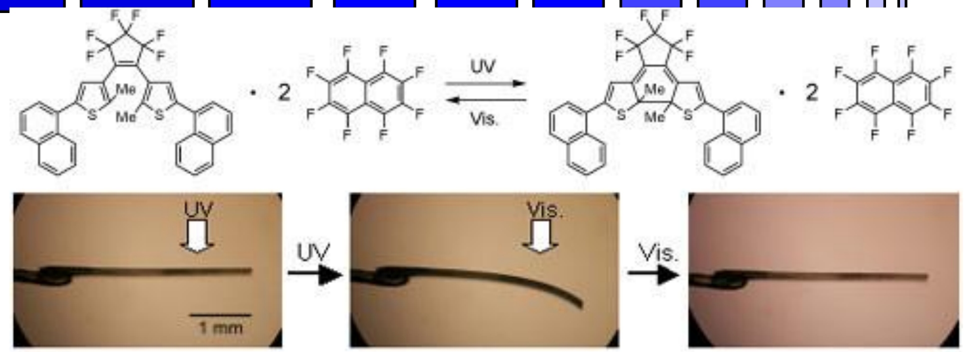
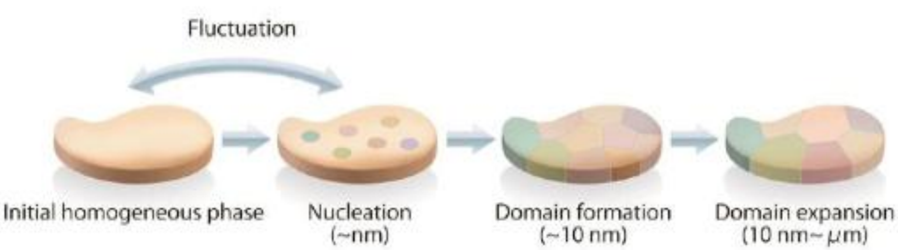
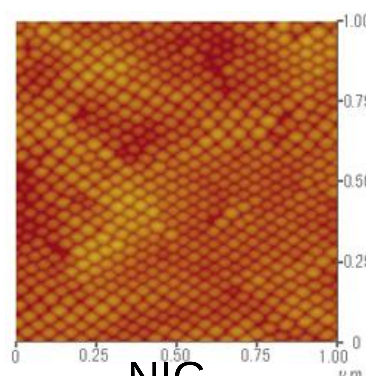


Photo-induced shape modification in a molecular crystal

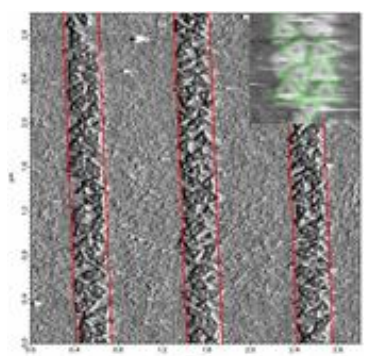
Developing process of self-assembled d

Phase transition: nucleation and fluctuation





NICT



IBM

Preliminary Report: www.spring8.or.jp/en/about_us/whats_sp8/spring-8_II

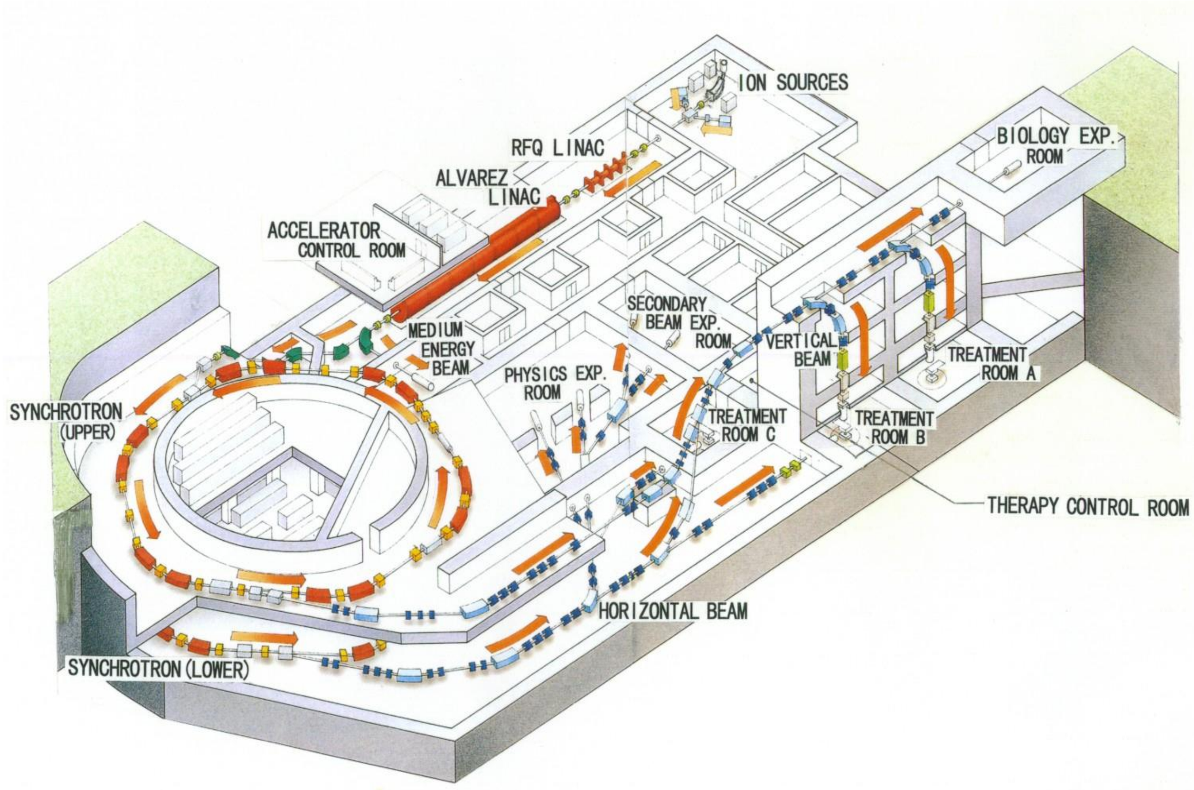
Courtesy: K. Noda

Outline of facilities under Construction or Planning

Institute /Hospital	Location Country	Start year	Ion	Room	Irradiation method	Max. Energy MeV/u
Fudan University	Shanghai China	2013	C P	3	Scanning	430 (C) 250 (p)
SAGA-HIMAT	Saga Japan	2013	C	3	Wobbler / Scanning	400 (C)
EBG MedAustron	Wiener Neustadt Austria	2015	C P	3	Scanning	400 (C)
iROCK Kanagawa CC	Kanagawa Japan	2015	C	4	Wobbler / Scanning	400 (C)
PTC UKGM	Marburg Germany	2013 ?	C P	4	Scanning	430 (C) 250 (p)
ETOILE	Lyon France	2016 ?	C	3	Wobbler	400 (C)
KIRAMS	Pusan Korea	2016 ?	C	3	Scanning	400 (C)

HIMAC (Heavy-Ion Medical Accelerator in Chiba)

- Ion species: High LET (100keV/μm) charged particles He, C, Ne, Si, Ar
- Range: 30cm in soft tissue 800MeV/u (Si)
- Maximum irradiation area: 22cmΦ
- Dose rate: 5Gy/min
- Beam direction: horizontal, vertical



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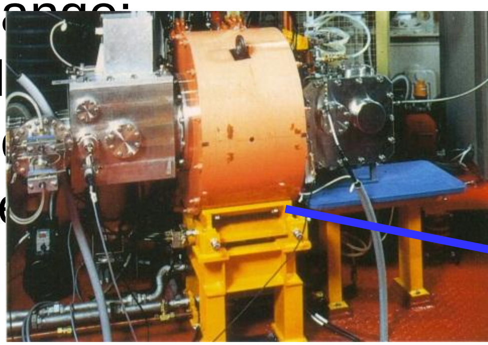

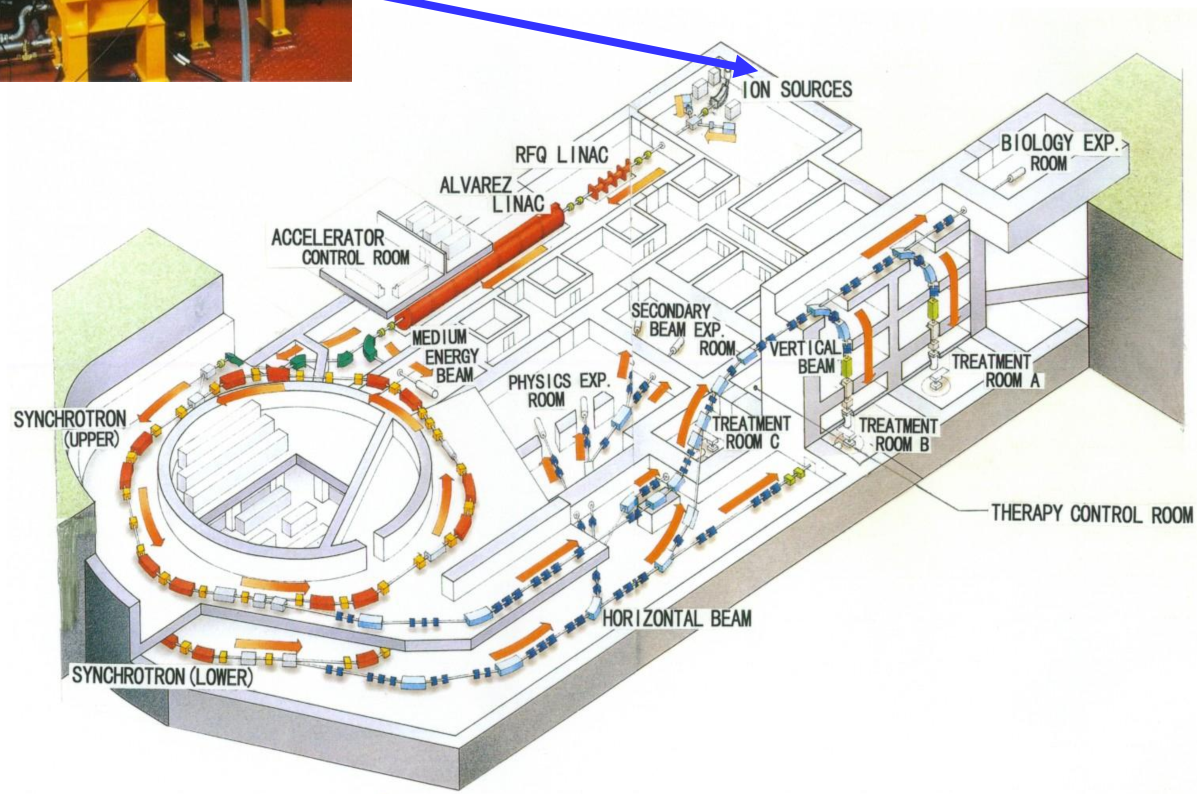

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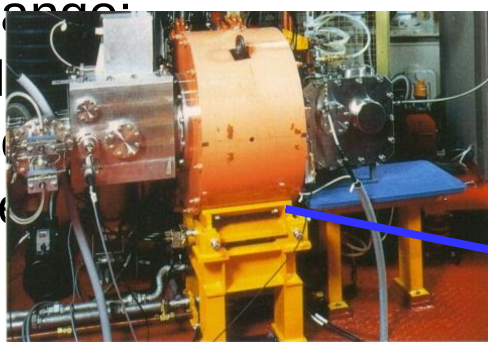

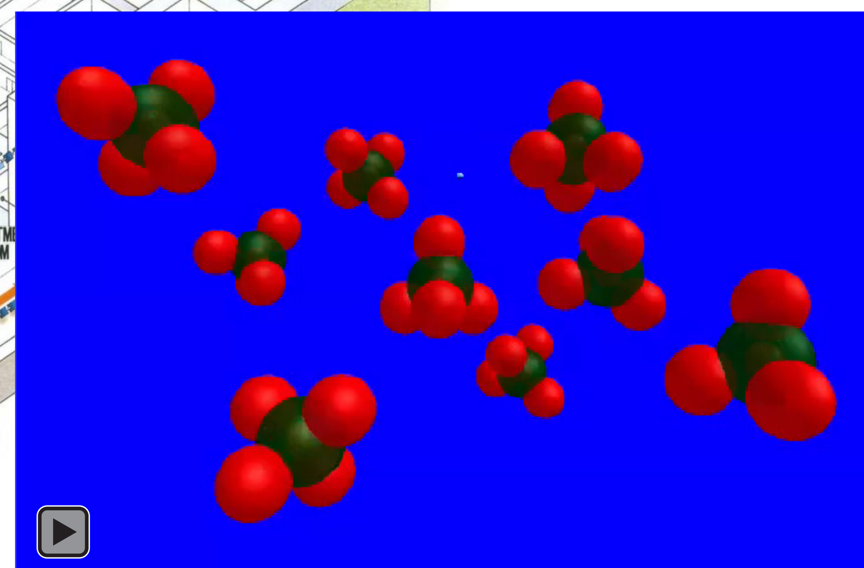

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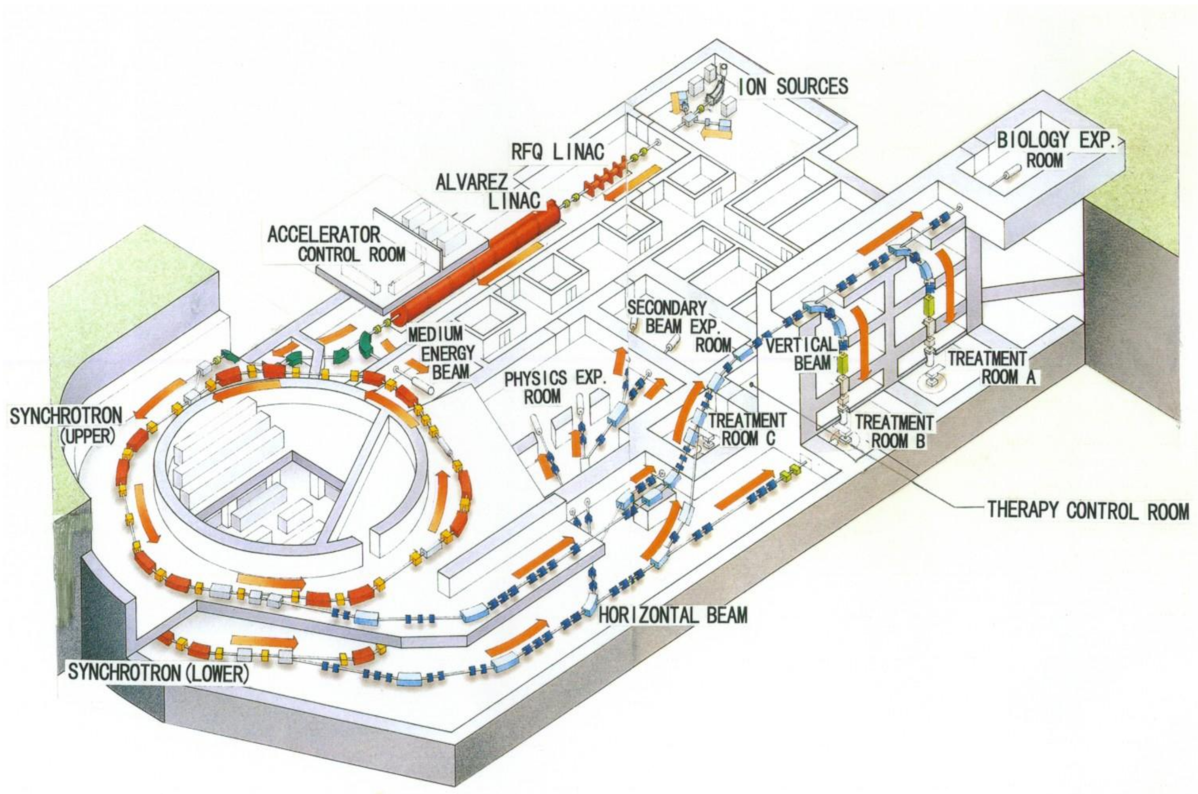

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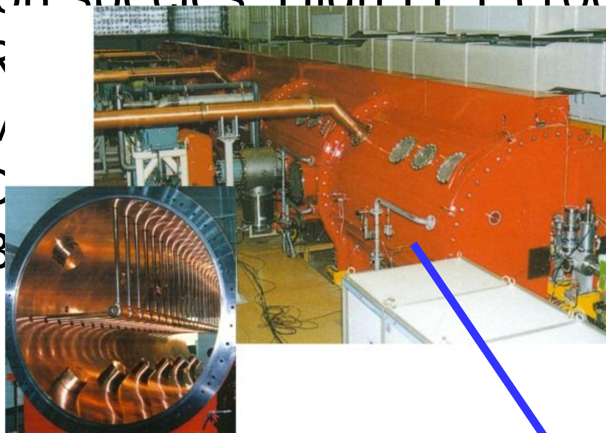

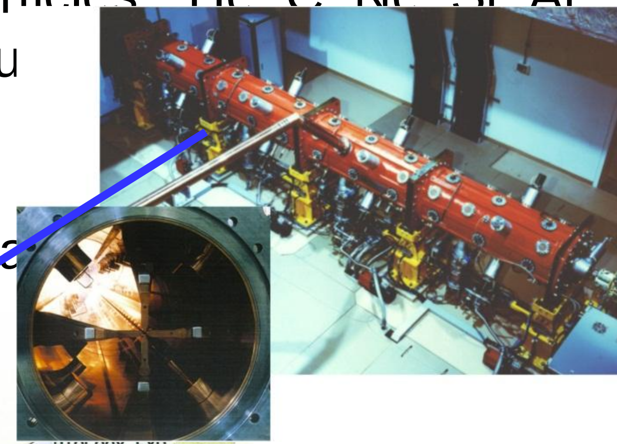

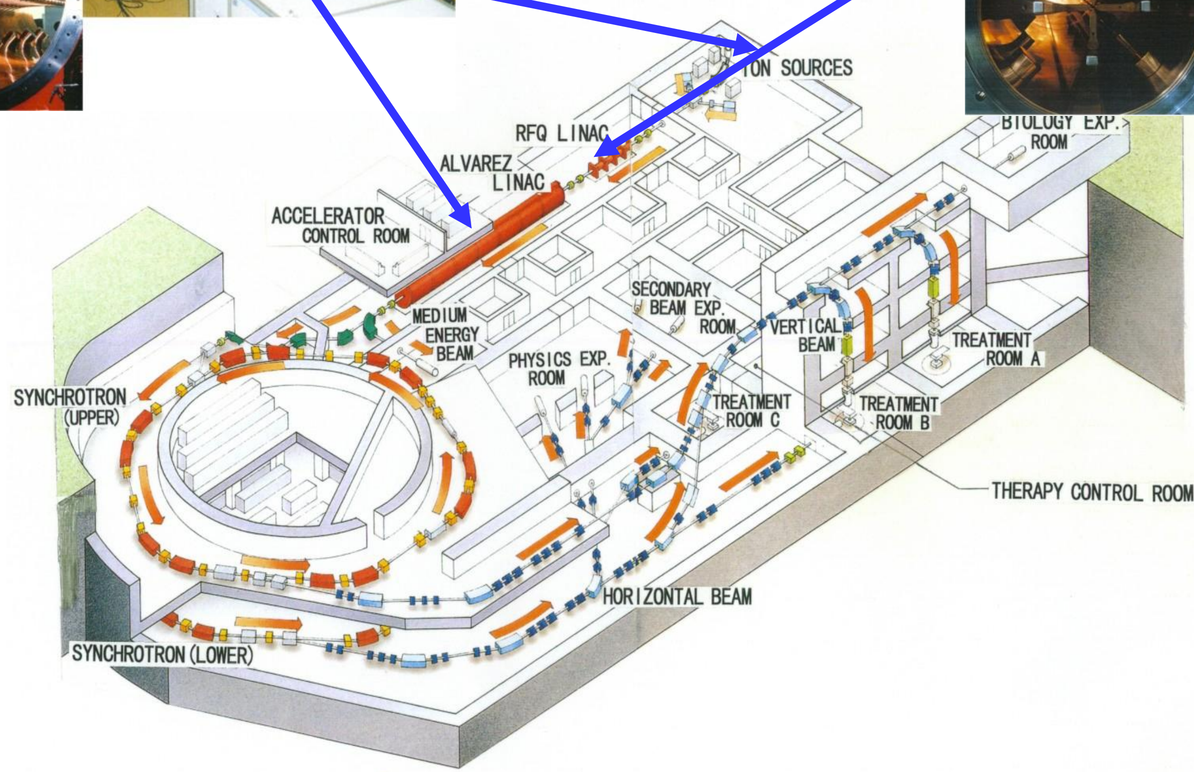

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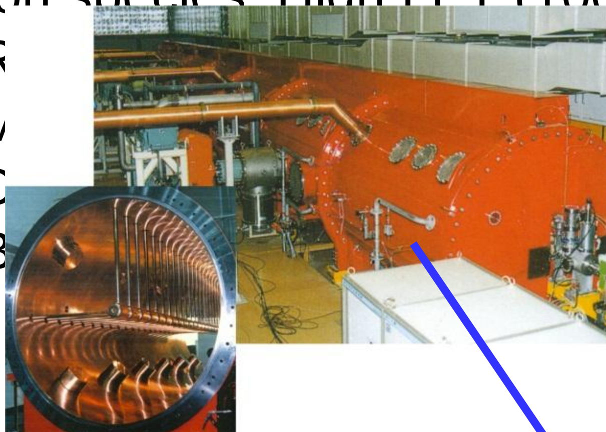

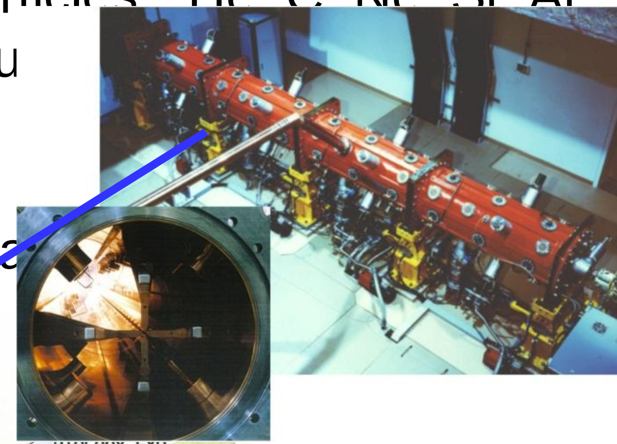

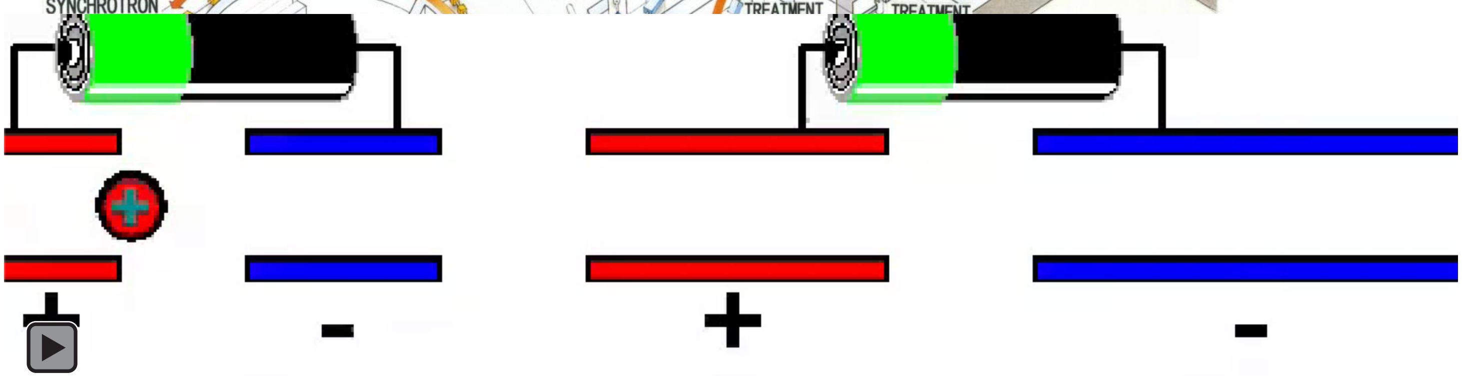

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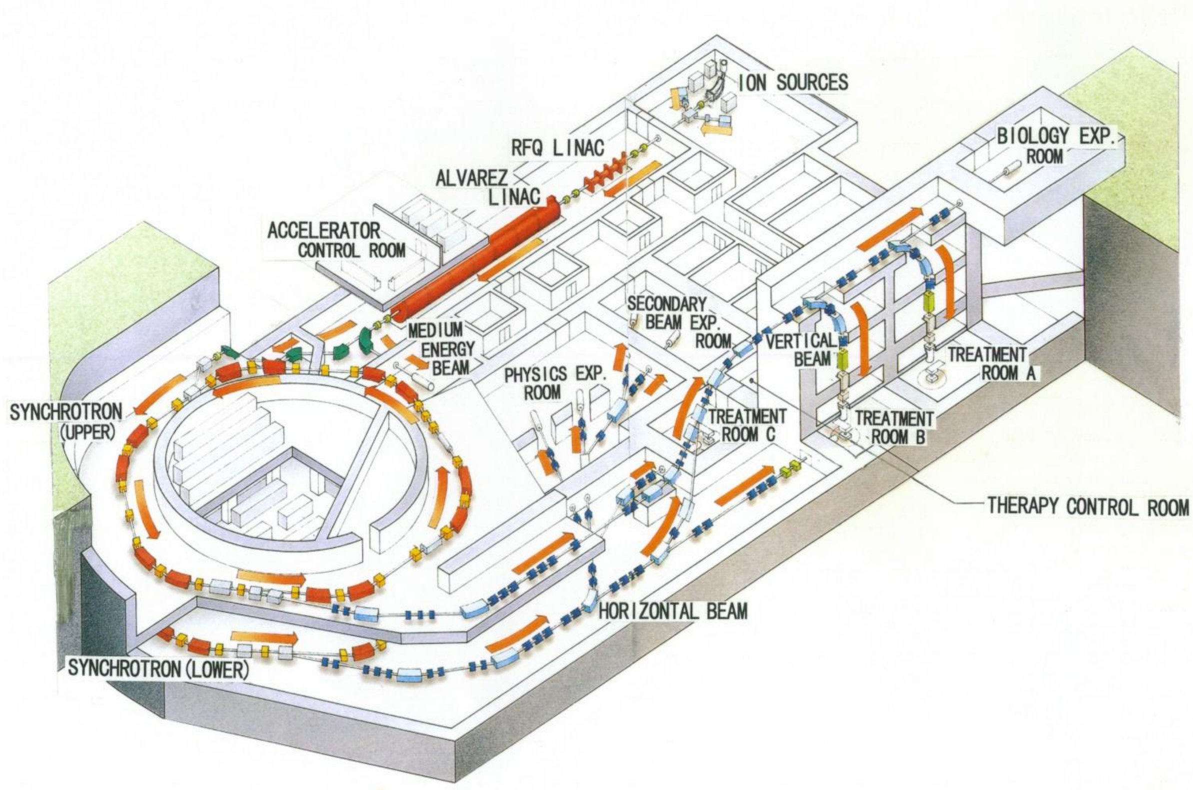

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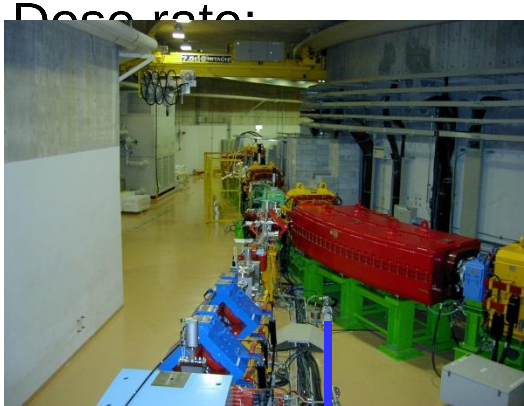

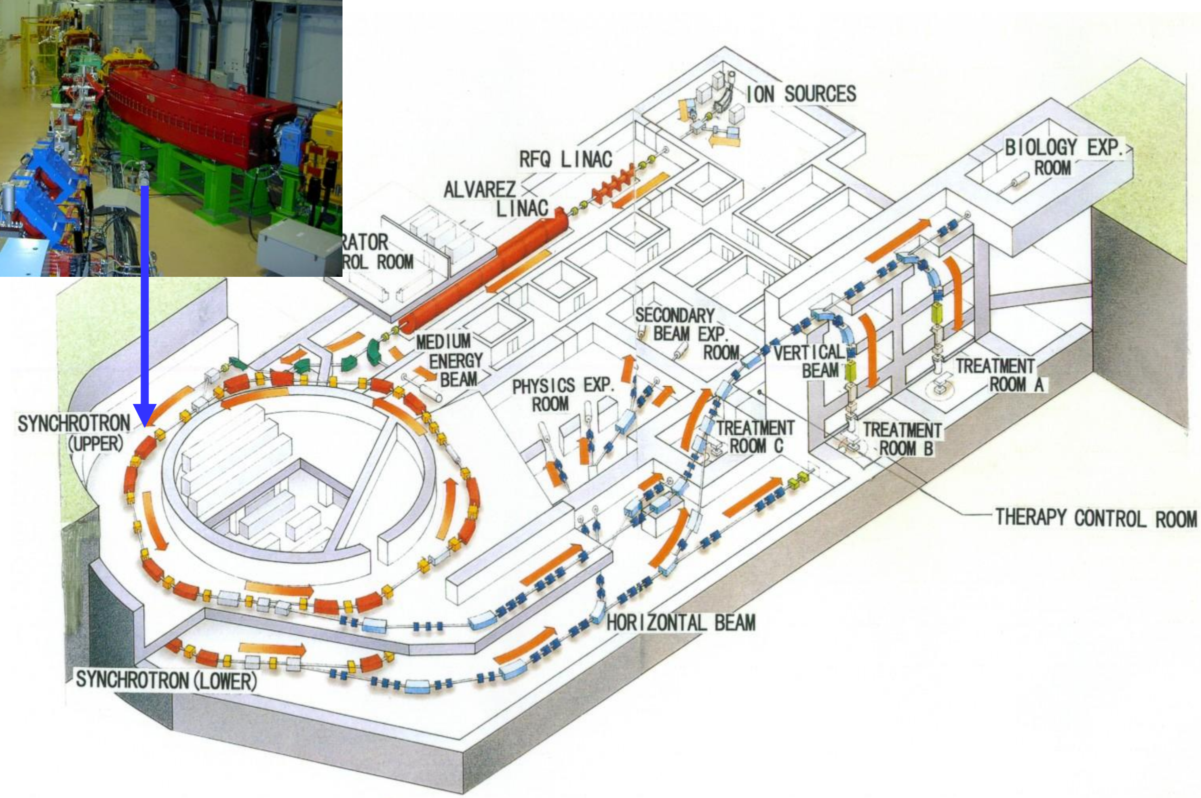

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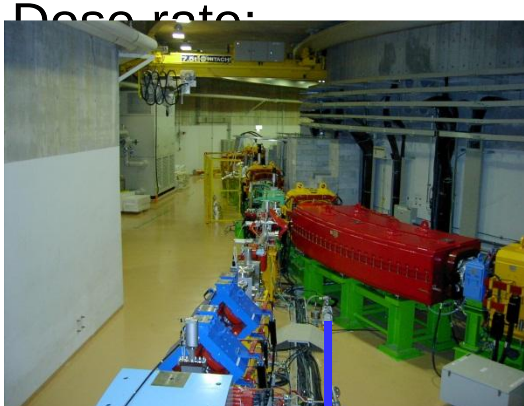
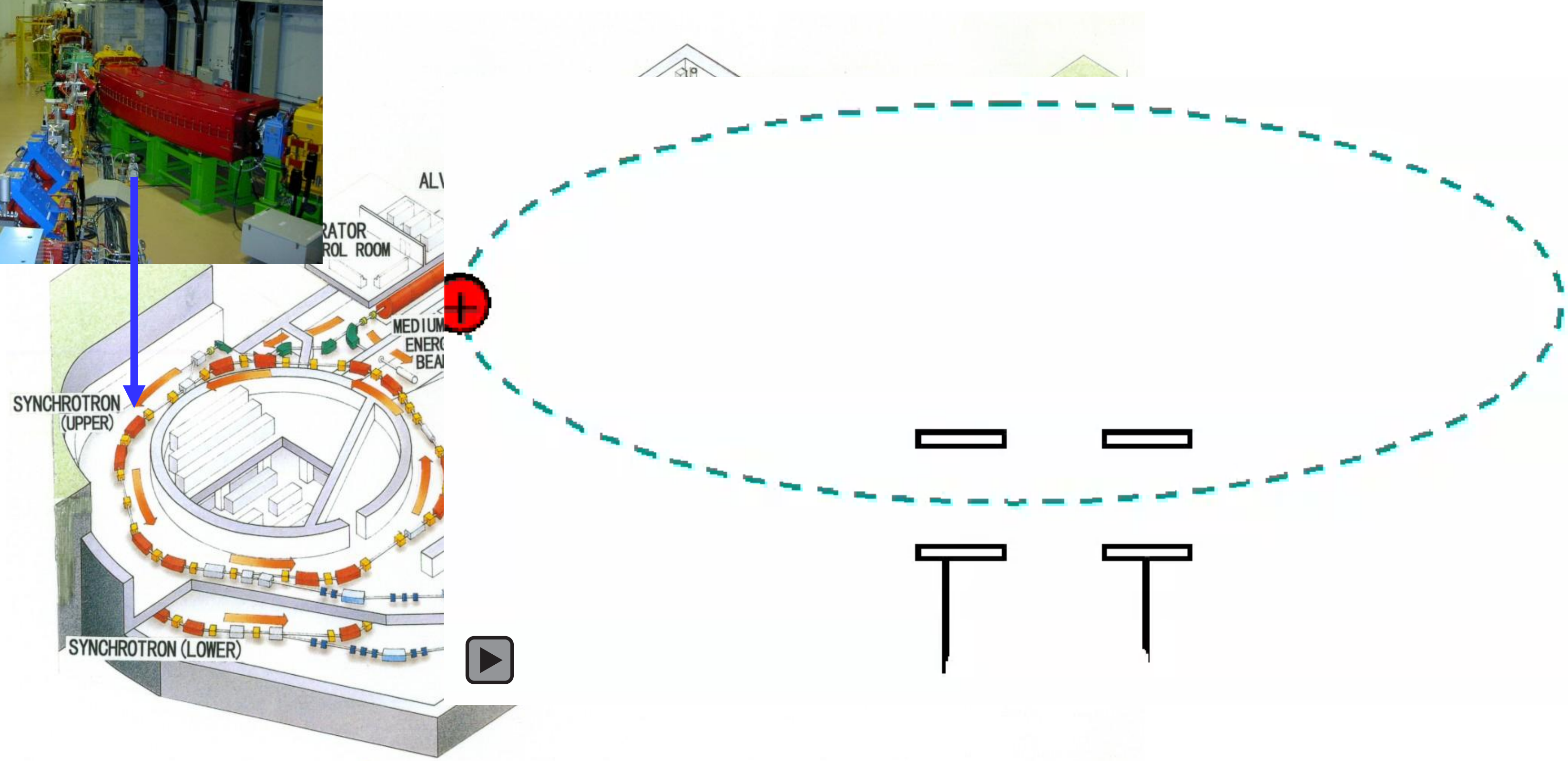
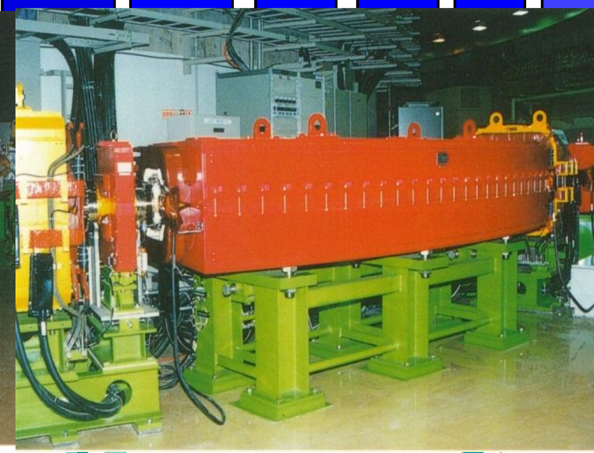


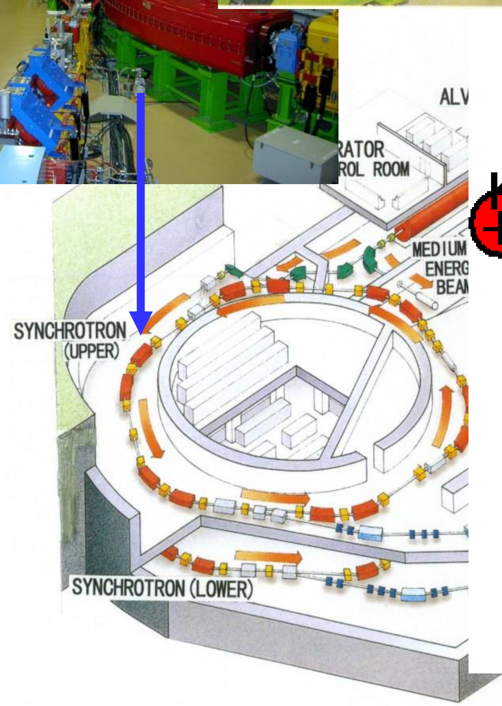


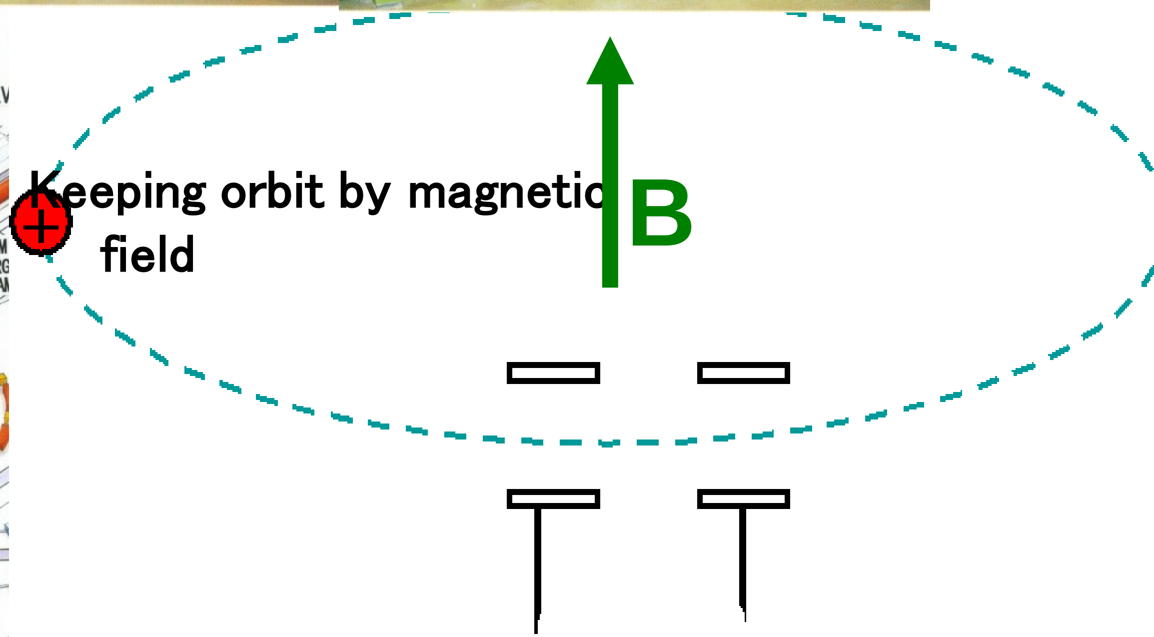
Courtesy: K. Noda

HIMAC
(Heavy-Ion Medical Accelerator in Chiba)

- Ion species: High ... Si, Ar
- Range: ... 0MeV/u (Si)
- Maximum irradia...
- Dose rate:
-







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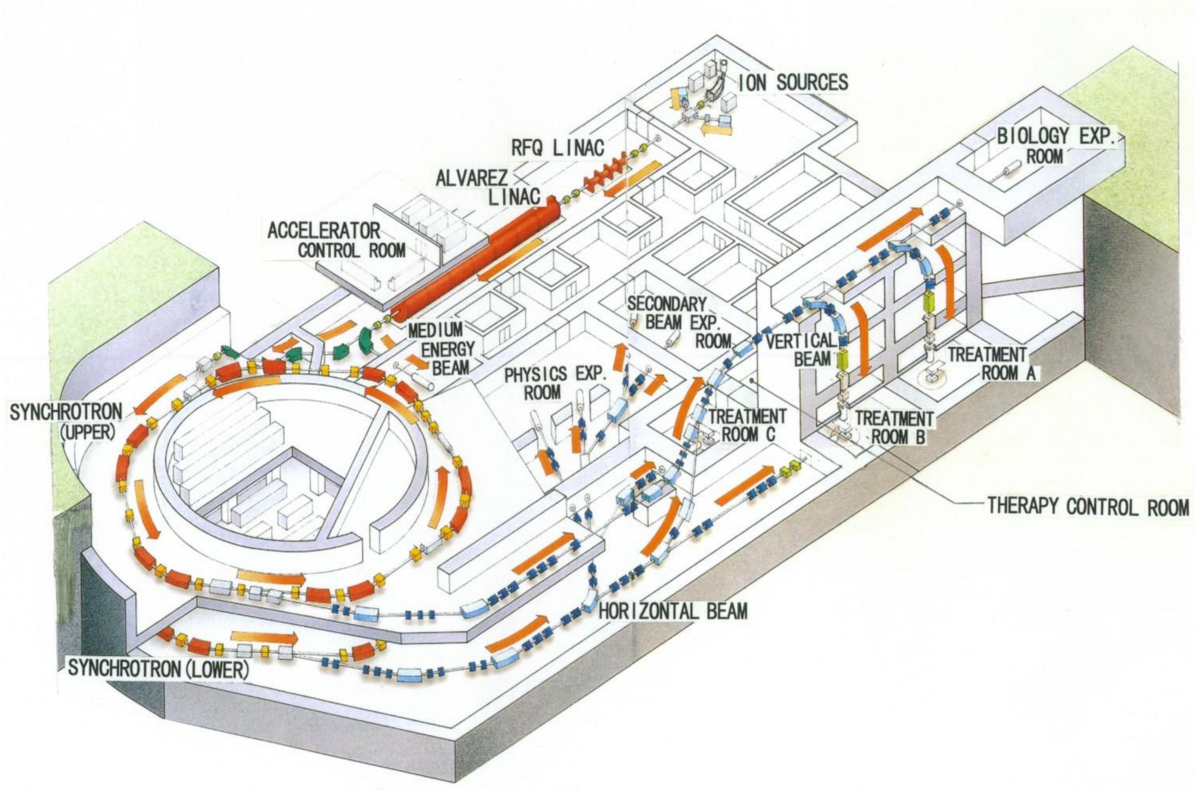

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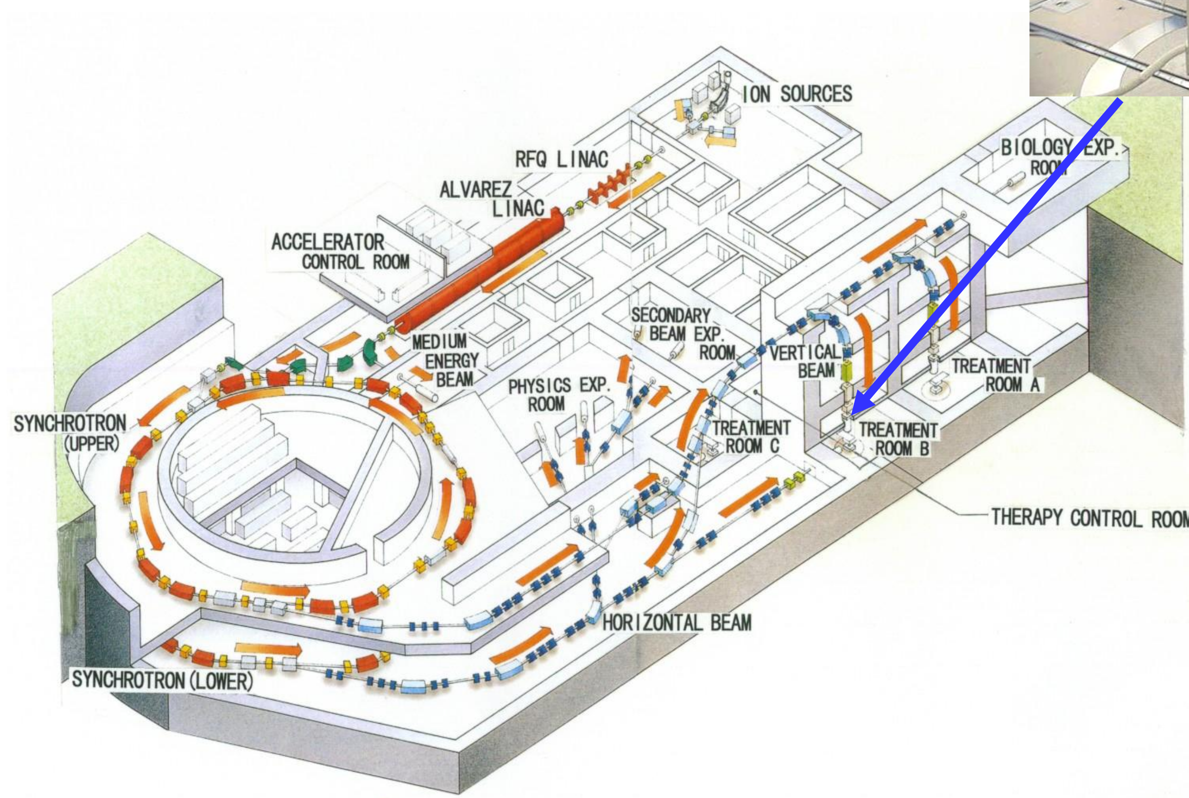
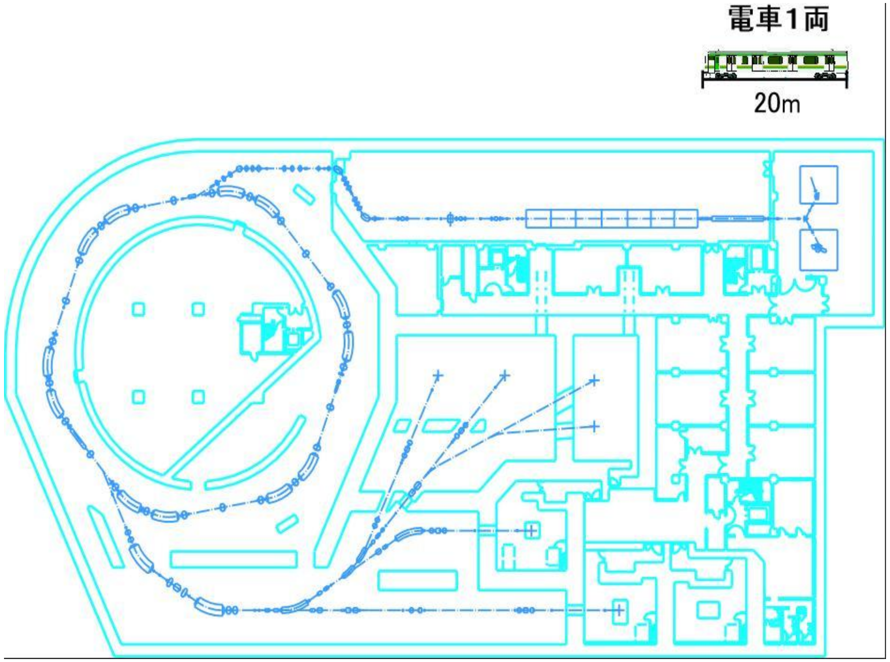


Design and R&D for Standard Type of C-ion RT in Japan

Courtesy: K. Noda



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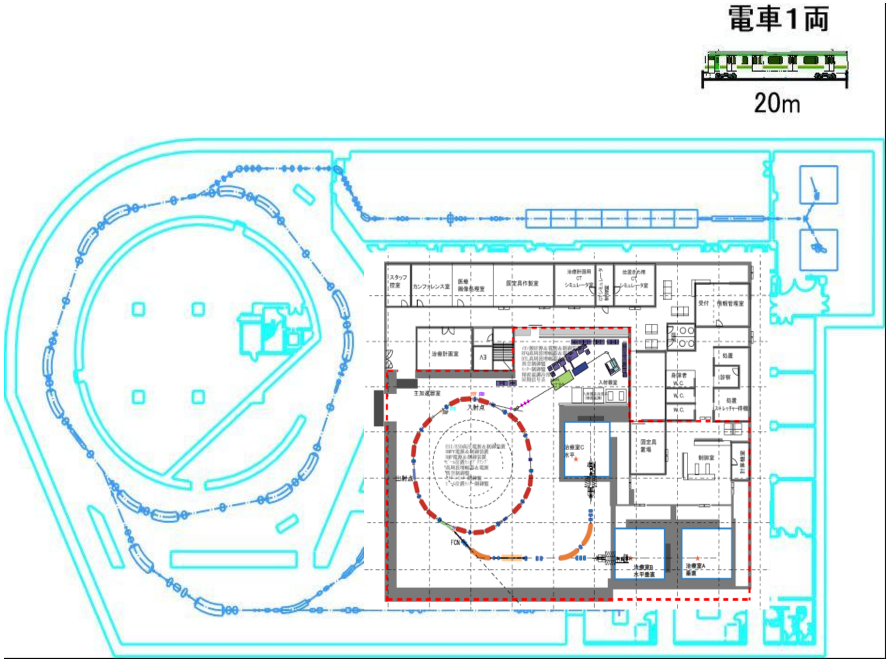

Design and R&D for Standard Type of C-ion RT in Japan

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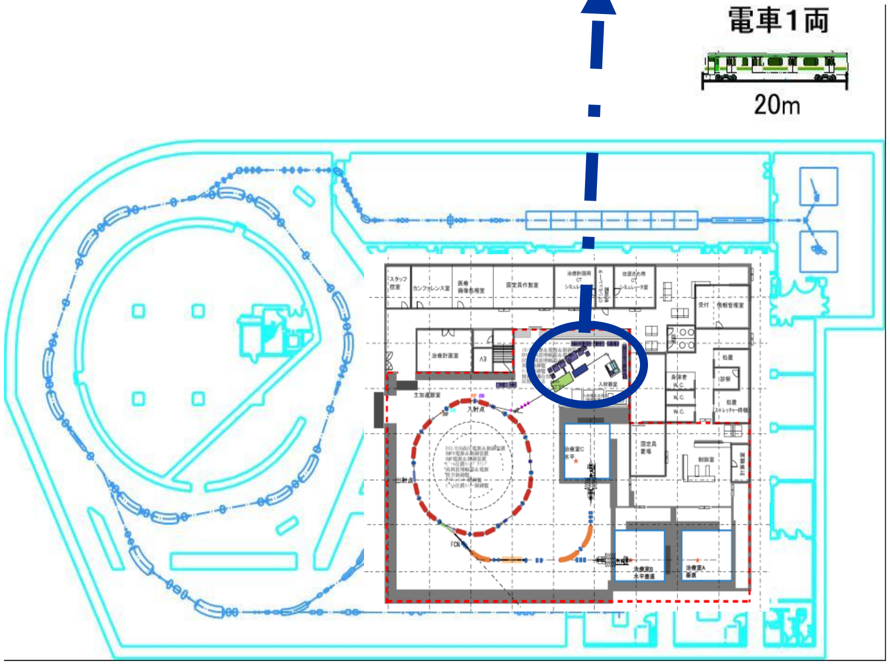
Compact Injector
RFQ + APF-IH



Design and R&D for Standard Type of C-ion RT in Japan

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Compact RF-cavity

Compact Injector
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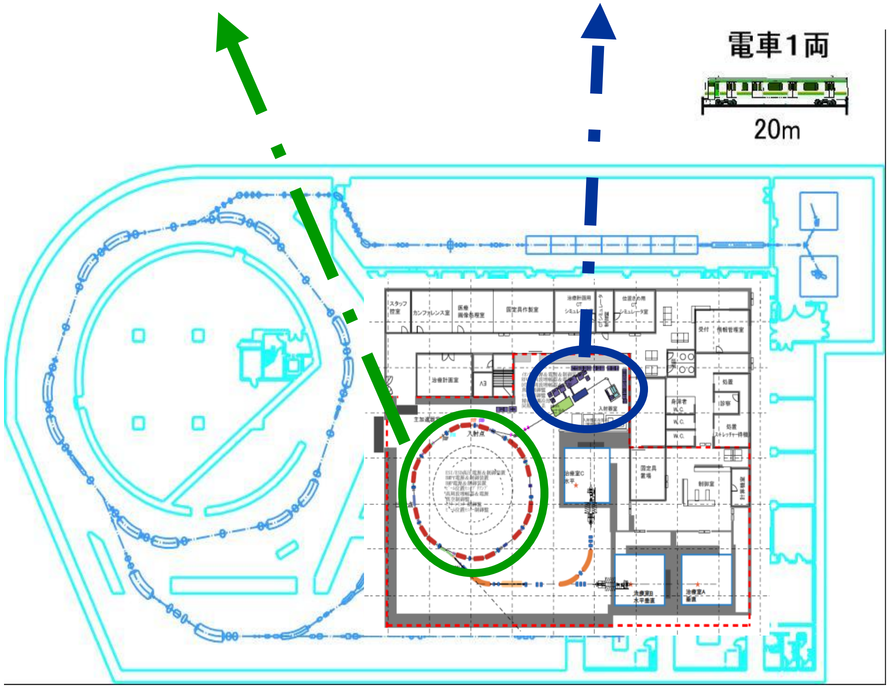

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Compact RF-cavity

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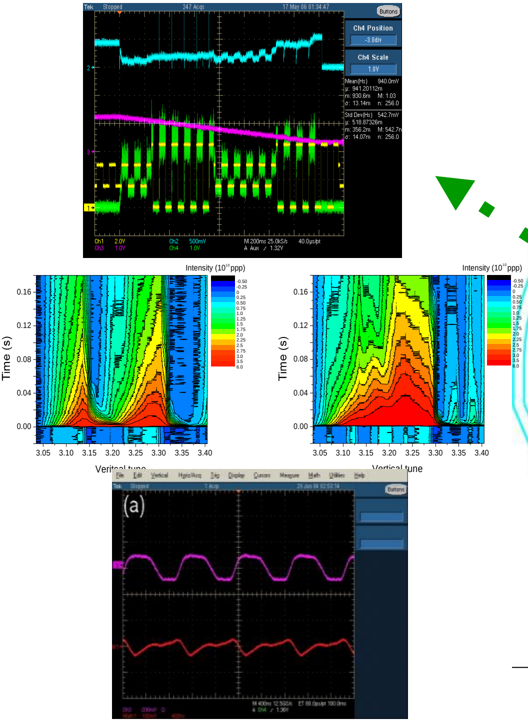
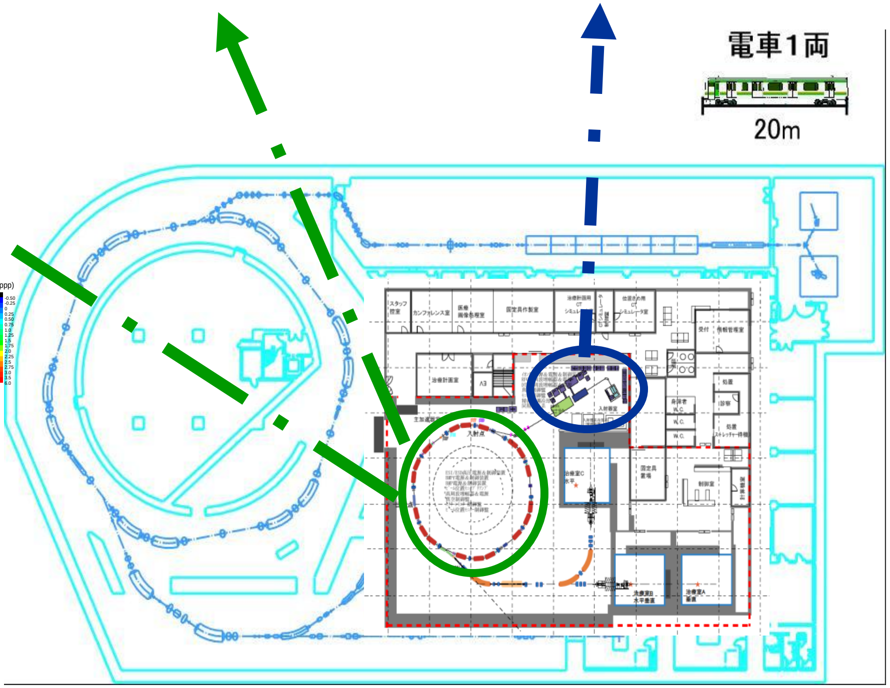
Beam Study





Design and R&D for Standard Type of C-ion RT in Japan

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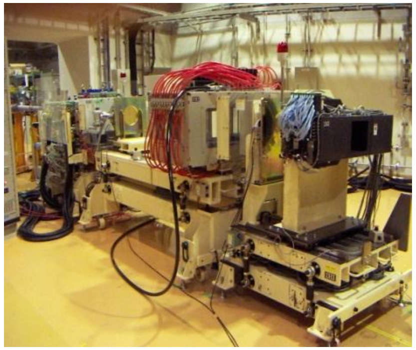
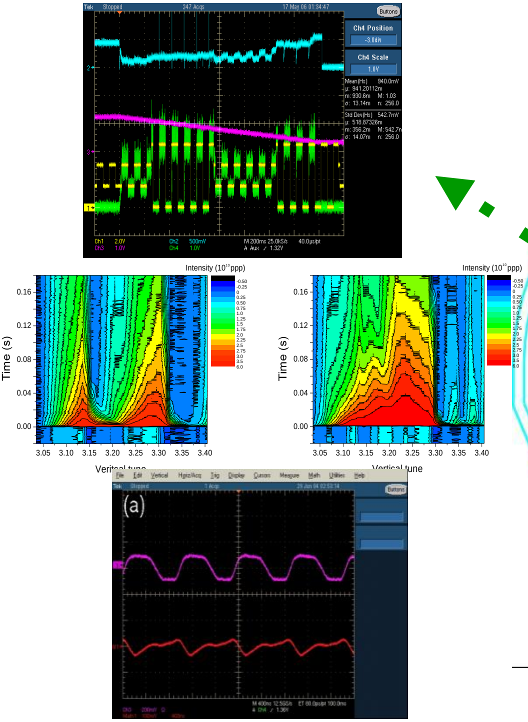
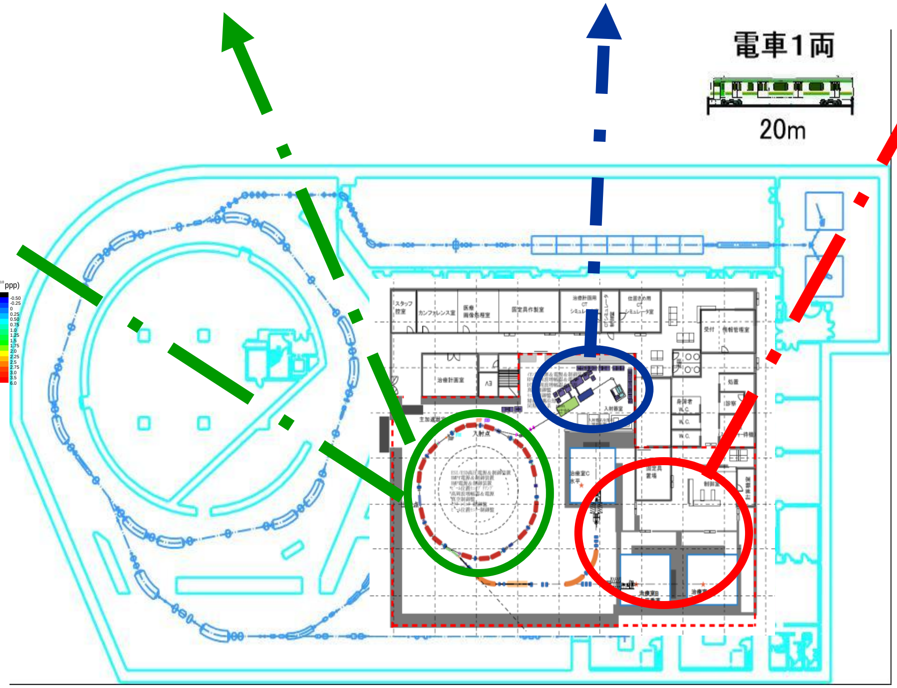


Development Irrad. Tech.

Beam Study





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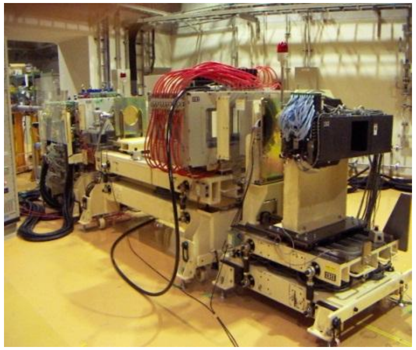

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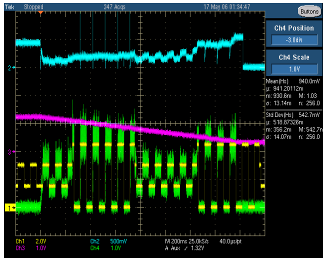

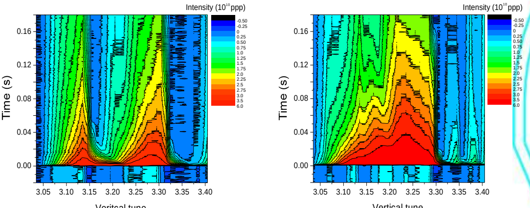

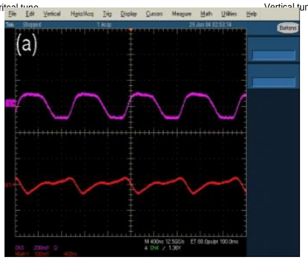

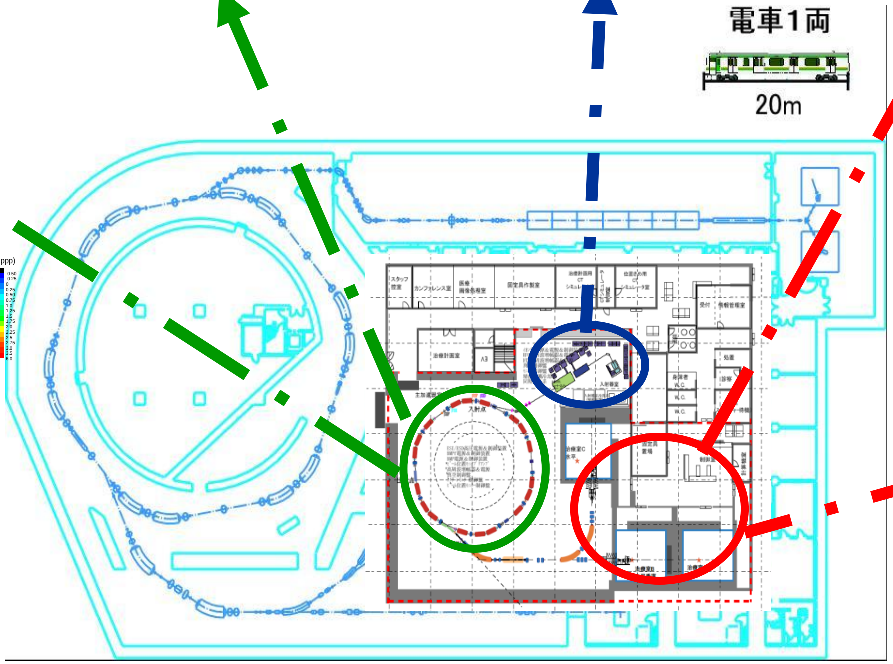

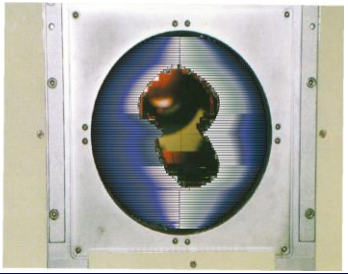

High-Precision MLC

Courtesy: K. Noda

Annual Patient Accrual for Carbon Ion Therapy at NIRS (Treatment: June 1994～ February 2013)