December 05, 2015
「高密度核物質に挑む実験の将来－施設･装置の観点から」
at Nishina Center

J-PARCハドロン施設のこれまでと今後

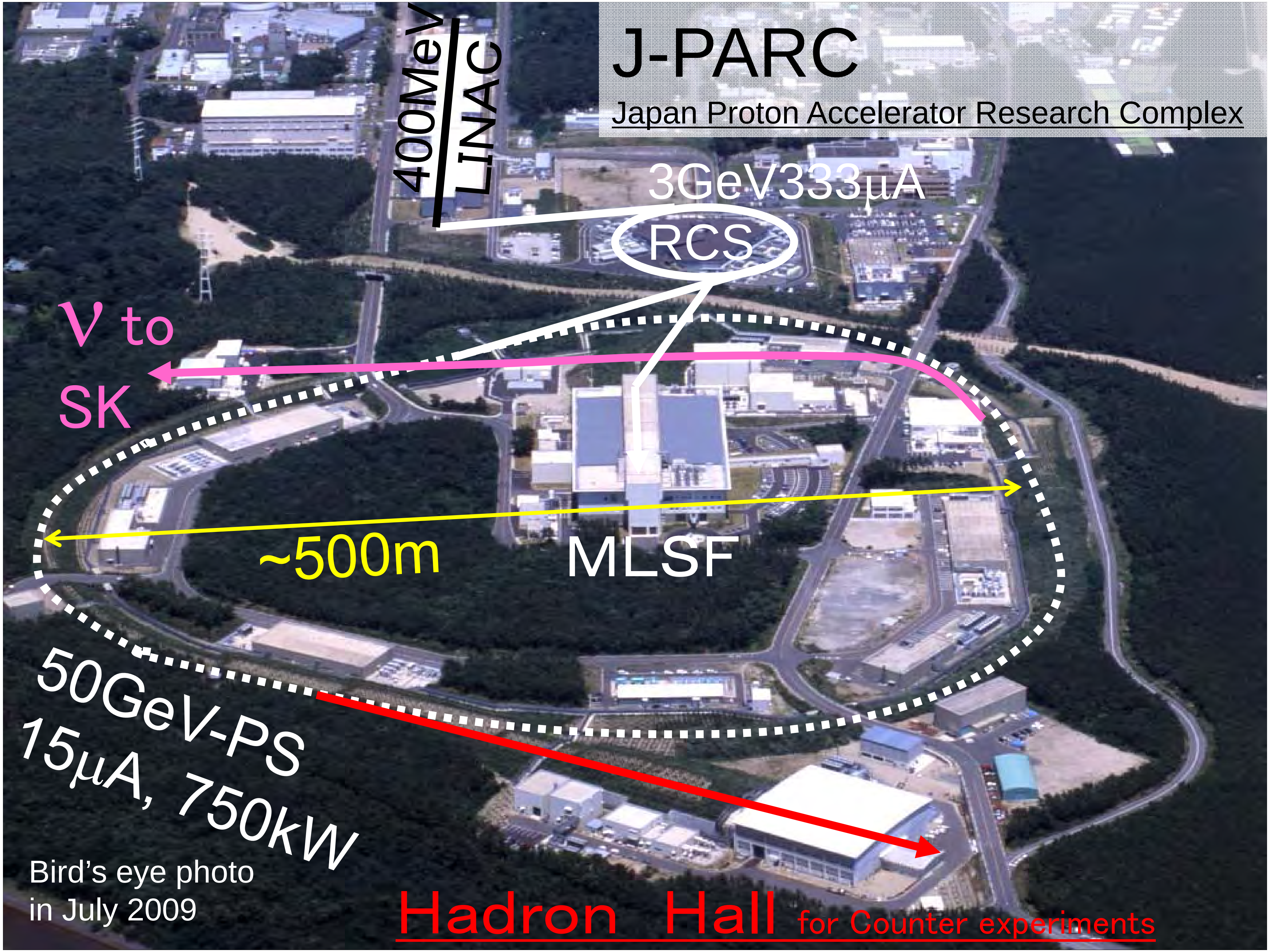
田中　万博

J-PARC Center,
J-PARCセンター素粒子原子核ディビジョン、

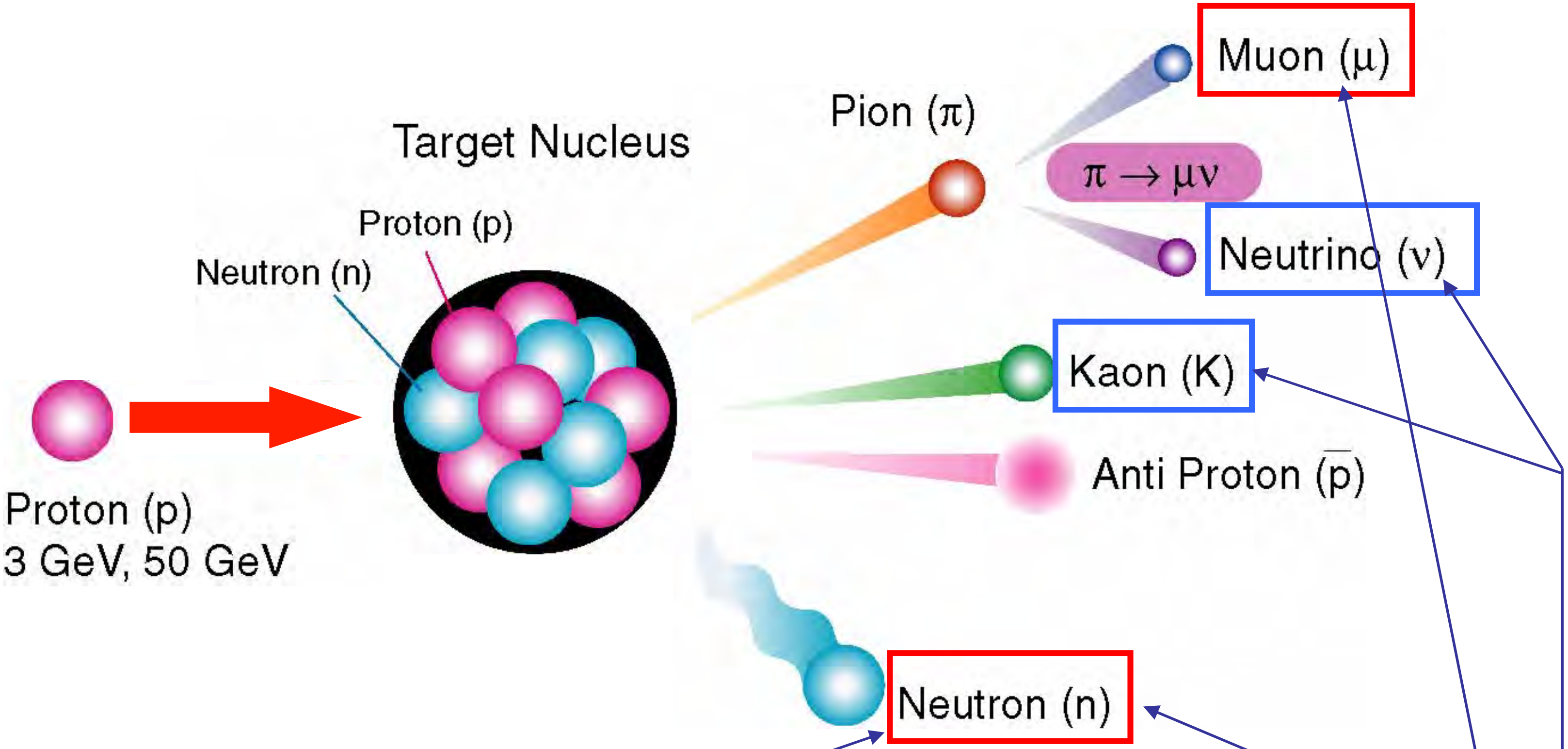
KEK：高エネルギー加速器研究機構、
素粒子原子核研究所、

E-mail: kazuhiro.tanaka@kek.jp


J-PARC
Japan Proton Accelerator Research Complex
J-PARC at Tokai-mura, Ibaraki-ken


J-PARC
Japan Proton Accelerator Research Complex
400MeV LINAC
3GeV333μA
RCS
ν to SK
~500m
MLSF
50GeV-PS
15μA, 750kW
Bird's eye photo
in July 2009
Hadron Hall for Counter experiments

Goals at J-PARC

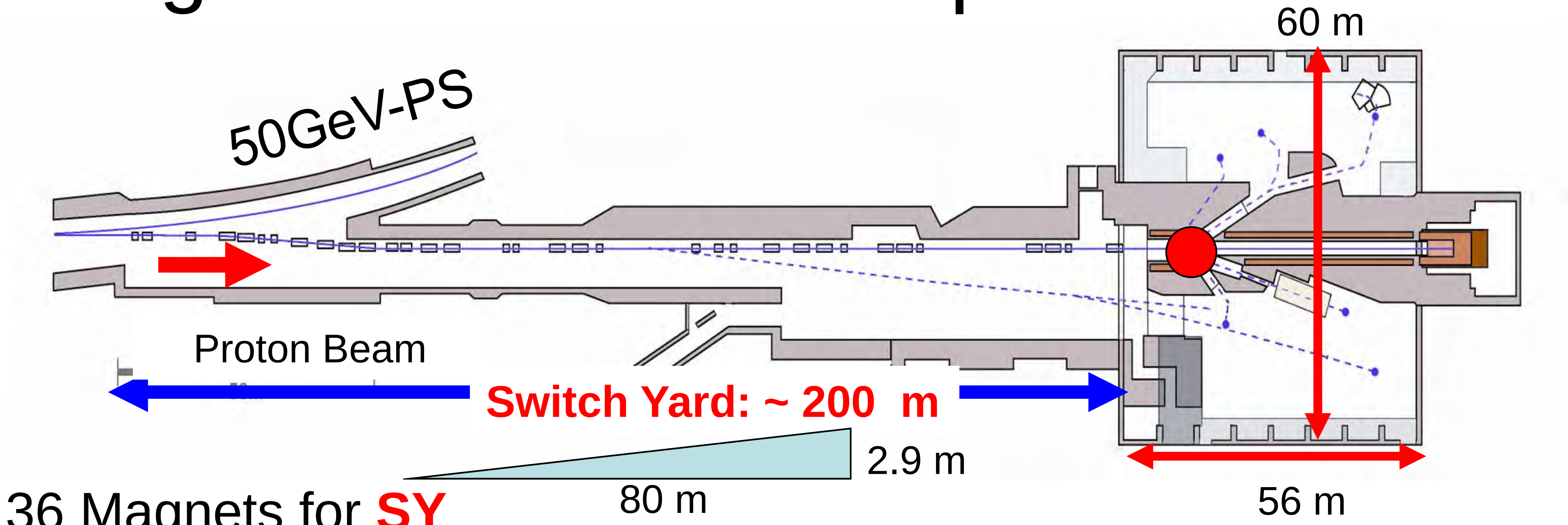


Need to have high-power proton beams

→ MW-class proton accelerator (current frontier is about 0.1 MW)

Materials & Life Sciences at 3 GeV
Nuclear & Particle Physics at 50 GeV
R&D toward Transmutation at 0.6 GeV

Magnets for Hadron Experimental Hall



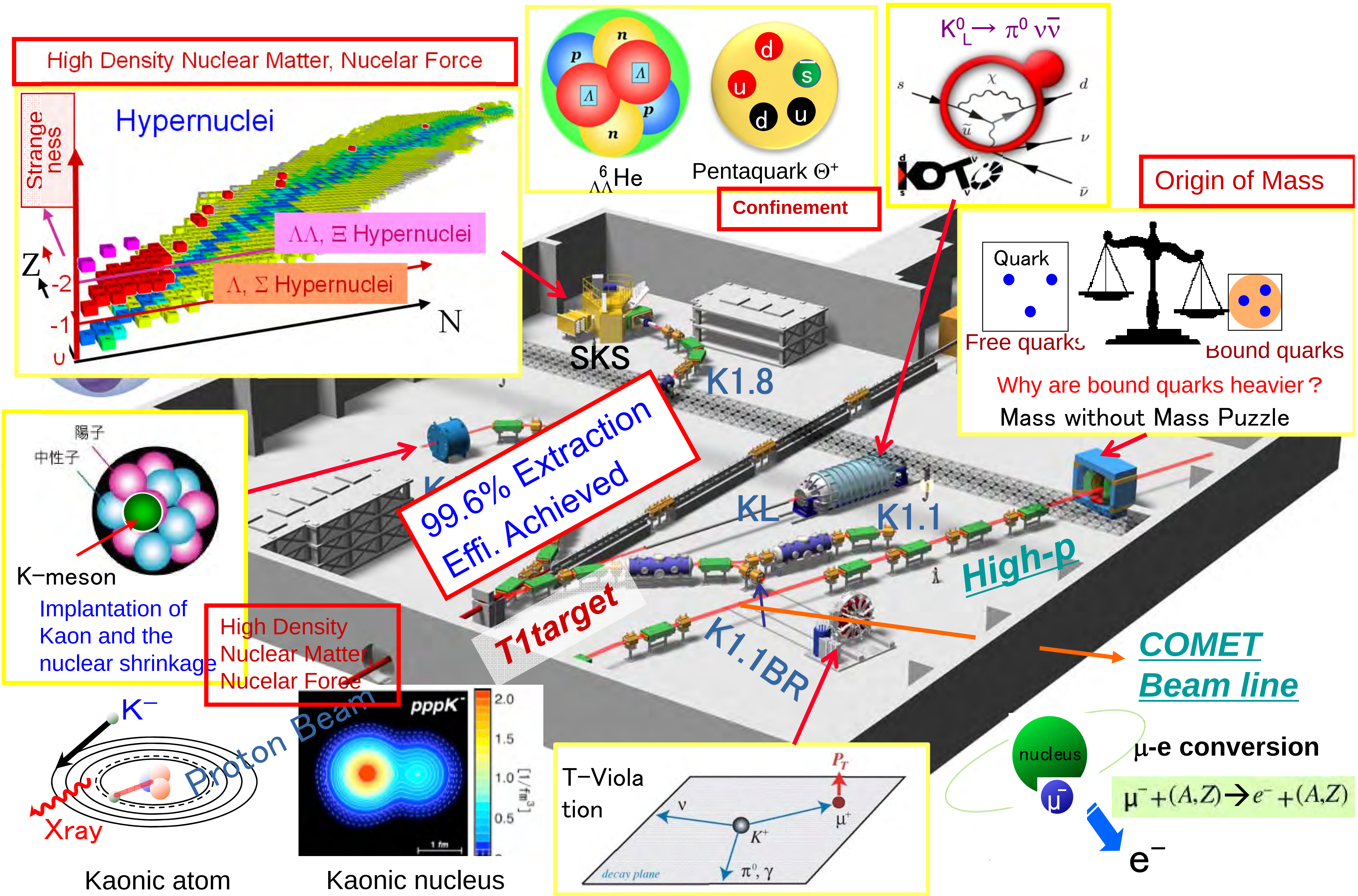
36 Magnets for SY

- 12 Epoxy mags.
- 17 **PI** mags.
- 7 **MIC** mags.
- Semi Remote Handling Sys.

54 Magnets for Hadron Hall

- 4 Epoxy + 27 **PI** mags. for Ordinary Secondary Beam Areas
- 9 **PI** mags. with 2 Chimneys
- 14 **MIC** mags. wiyh 10 Chimneys
- Full Remote Handling with Chimney

Nuclear & Hadron Physics at J-PARC

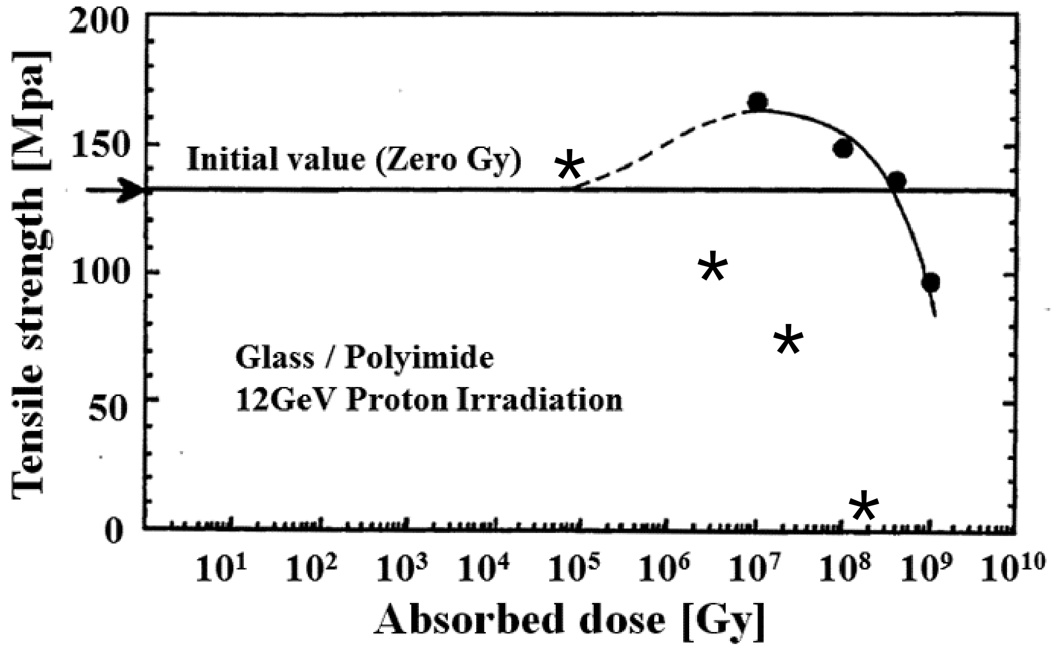


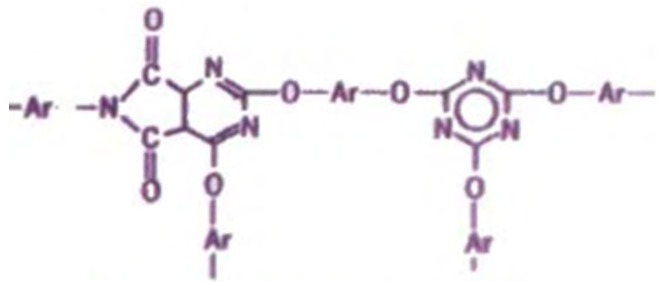
High Intensity Beam Handling

- Magnets etc. should be radiation/heat resistant.
- Magnets etc. should be replaced easily and quickly.
- High Intensity Handling should be considered as a system.
  - Power/water lines,
  - Vacuum line,
  - Daily operation/maintenance,
  - Radiation shields,

R&D of Radiation Resistant Magnets for J-PARC

- Polyimide Resin + Boron Free Glass Tape
  - Tested up to 10^9Gy and usable up to 4×10^8Gy
  - All the J-PARC Accelerator Magnets Employed Polyimide Insulation.





ビスマレイミド・トリアジン樹脂
(BT 樹脂、三菱瓦斯化学)

BT resin

Since 1985

Tensile strength of a cured BT resin reinforced by Boron Free Glass Cloth.

Accelerator Magnets of J-PARC

PI insulation
instead of Epoxy

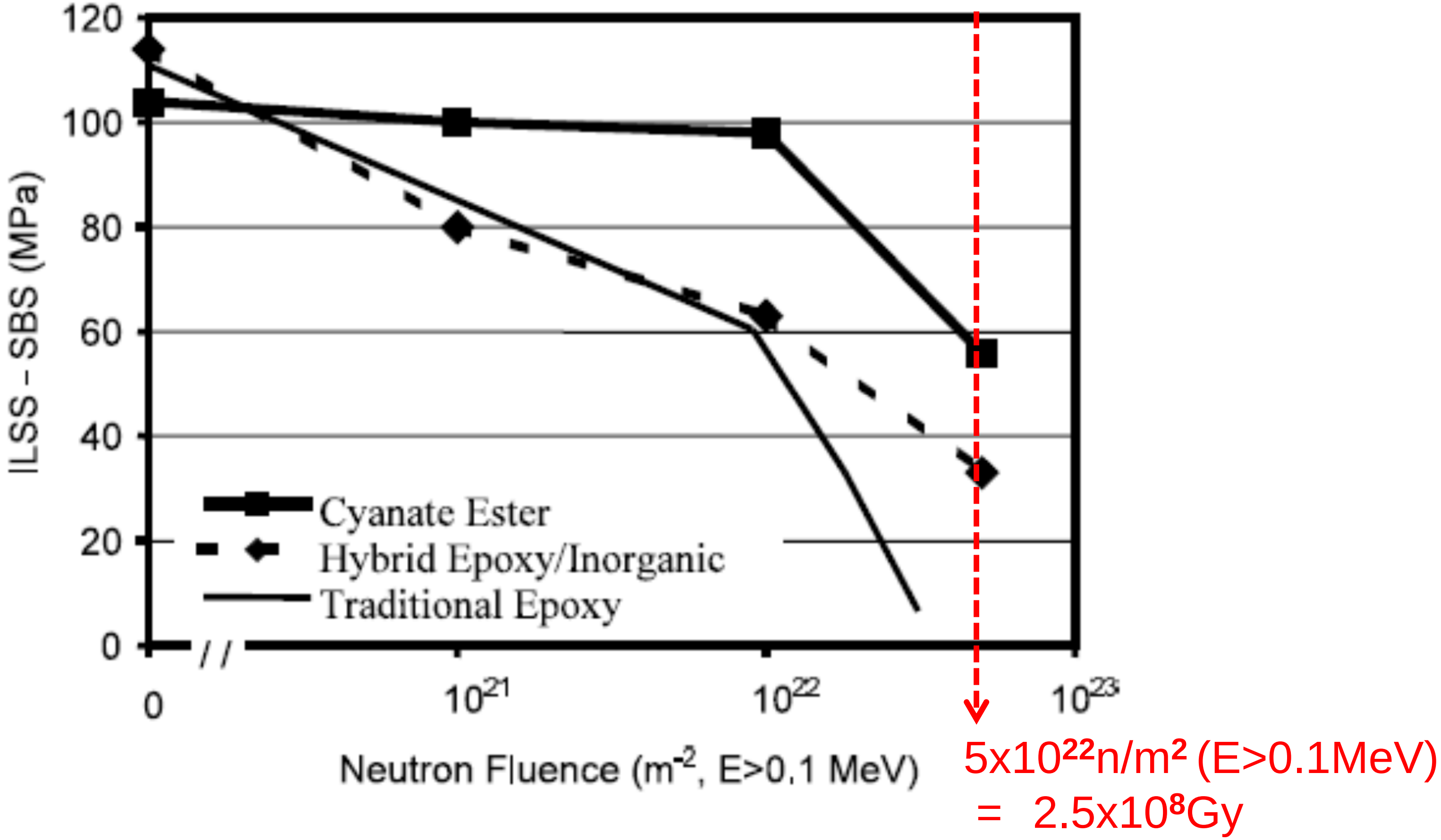
50GeV Synchrotron (1600m)

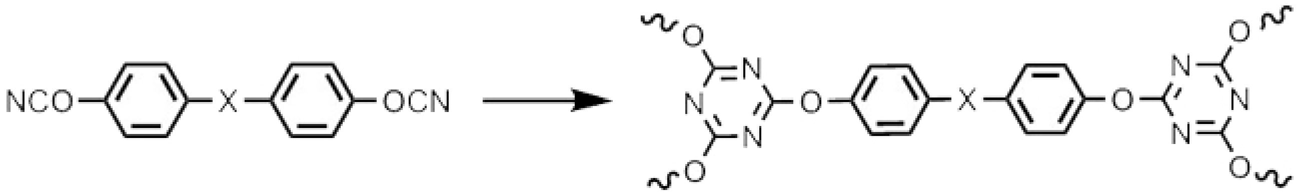
3 GeV Synchrotron (350m)

Q-Magnet for RCS

Beam Transport Magnets of J-PARC

Cyanate Ester resin?

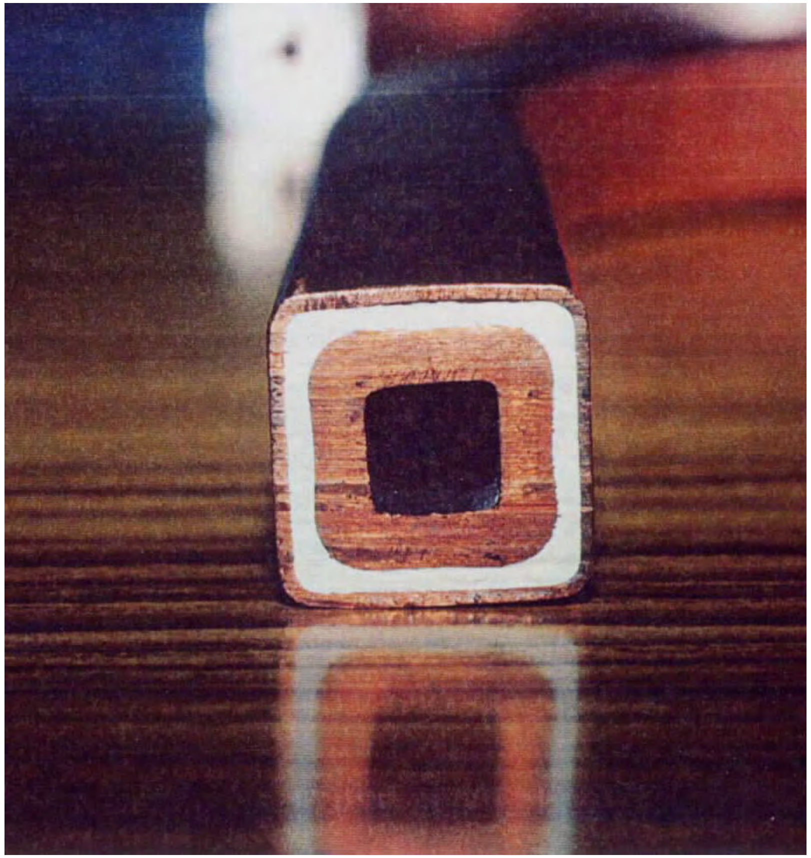


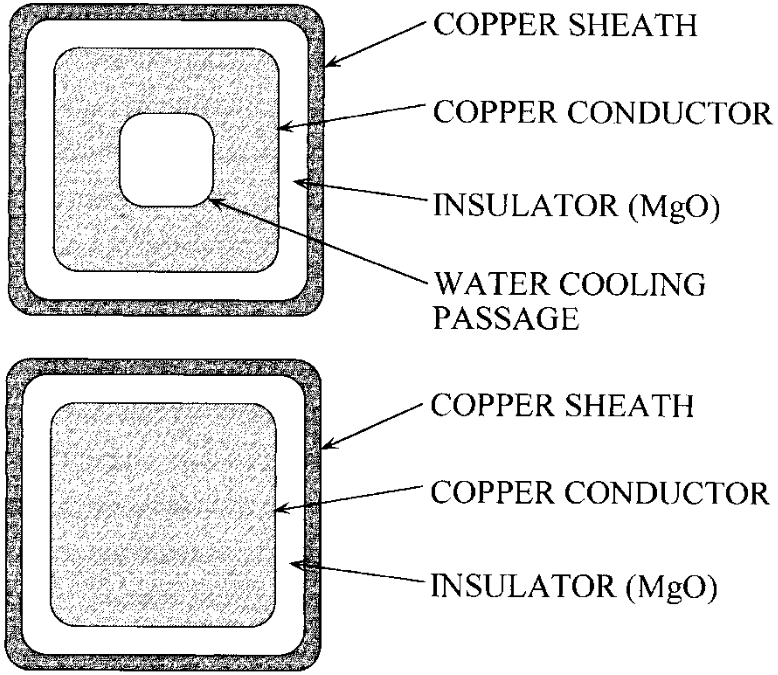


CYTESTER®, Mitsubishi Gas Chemical

P.E. Fabian et al., Fusion Engineering and Design 61-62 (2002) pp795

HC-MIC and SC-MIC since 1990

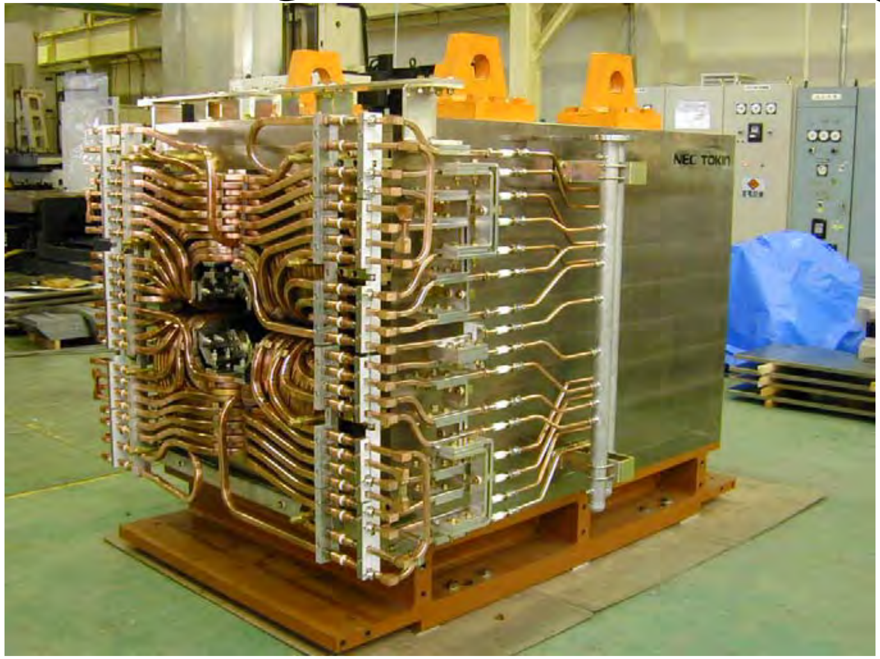


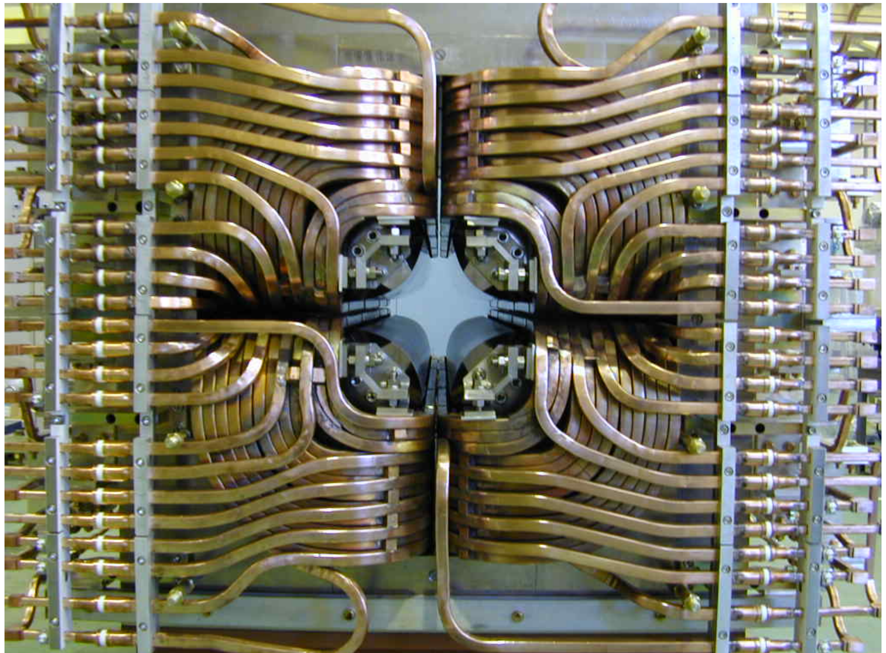


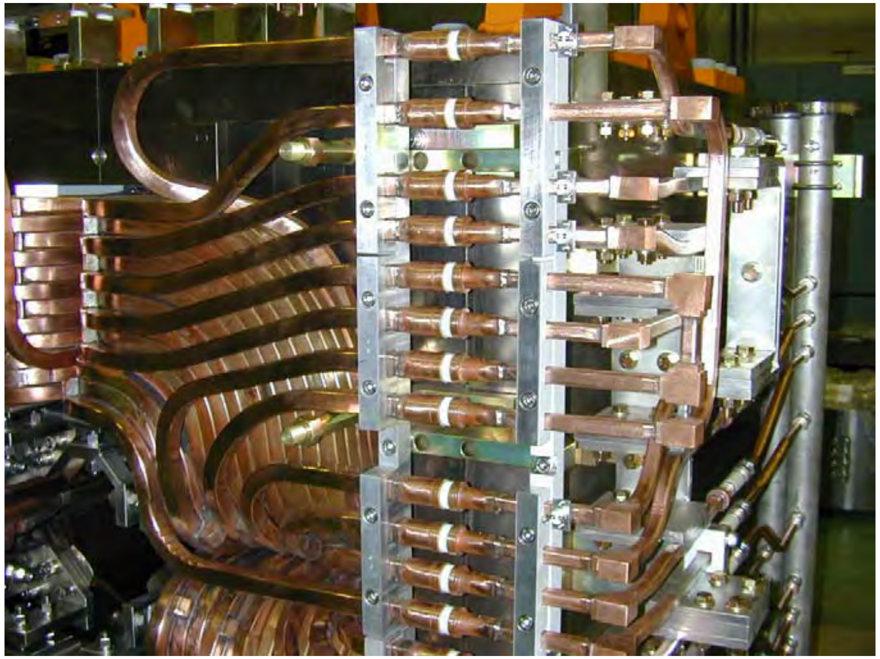
Nominal Current (A)	2000	2500	3000	1000*	2000*
Dimmensions (mm)					
A: Outward Size	20.0	23.8	28.0	18.0	14.0
B: Insulator Size	18.0	21.6	25.0	16.6	12.6
C: Conductor Size	14.6	18.0	20.0	13.2	9.2
D: Hollow Size	7.4	10.0	10.0	--	--
Cross Section (mm^2)					
Conductor	150.9	211.7	293.1	168.4	78.8
Insulator	117.7	153.2	227.4	106.6	79.4
Seath	73.4	95.3	150.6	47.8	36.6

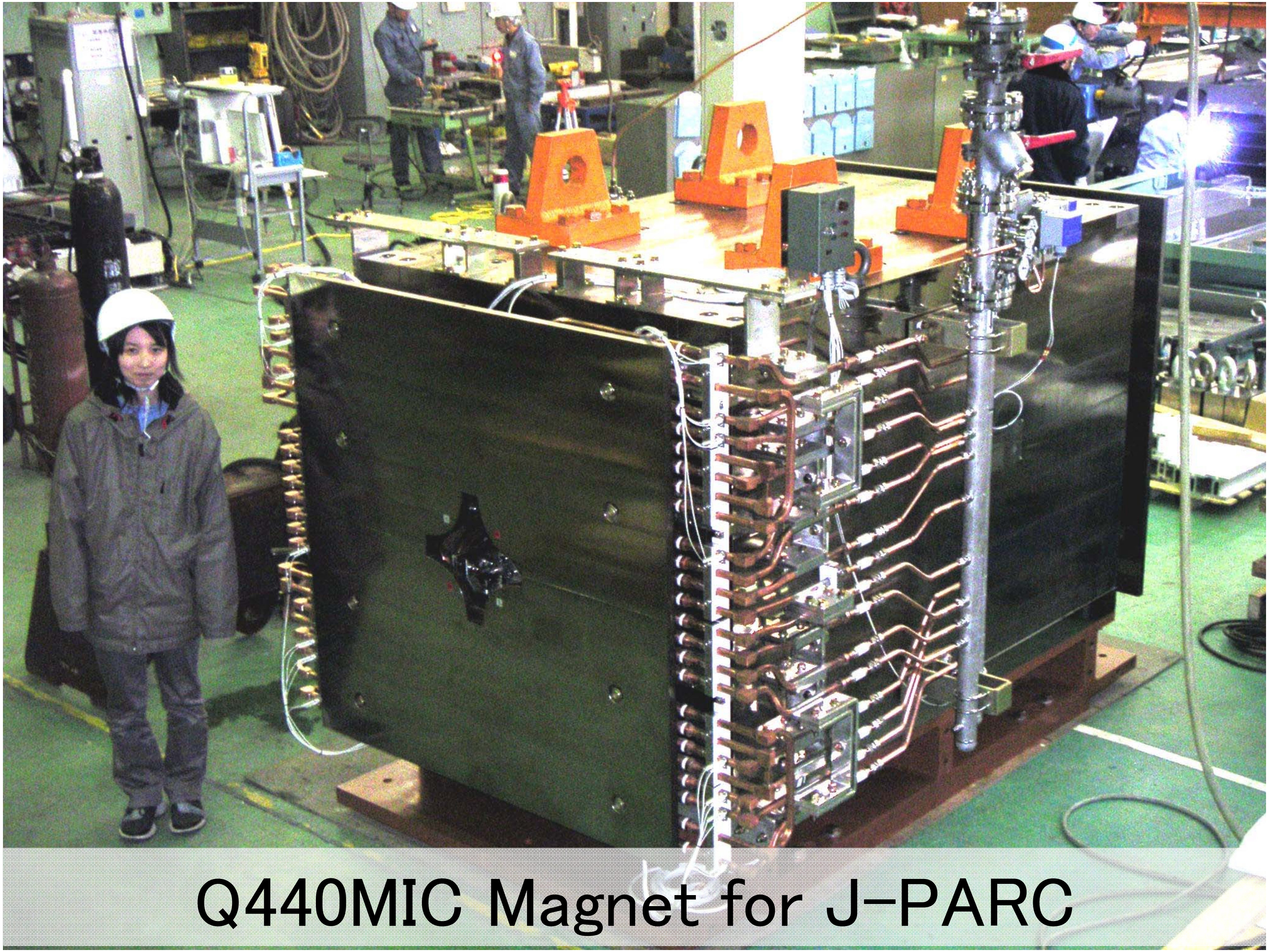
* indicates Solid Conductor MICs. No hollow is in Cu conductor.

Q440MIC Magnet with HC-MIC





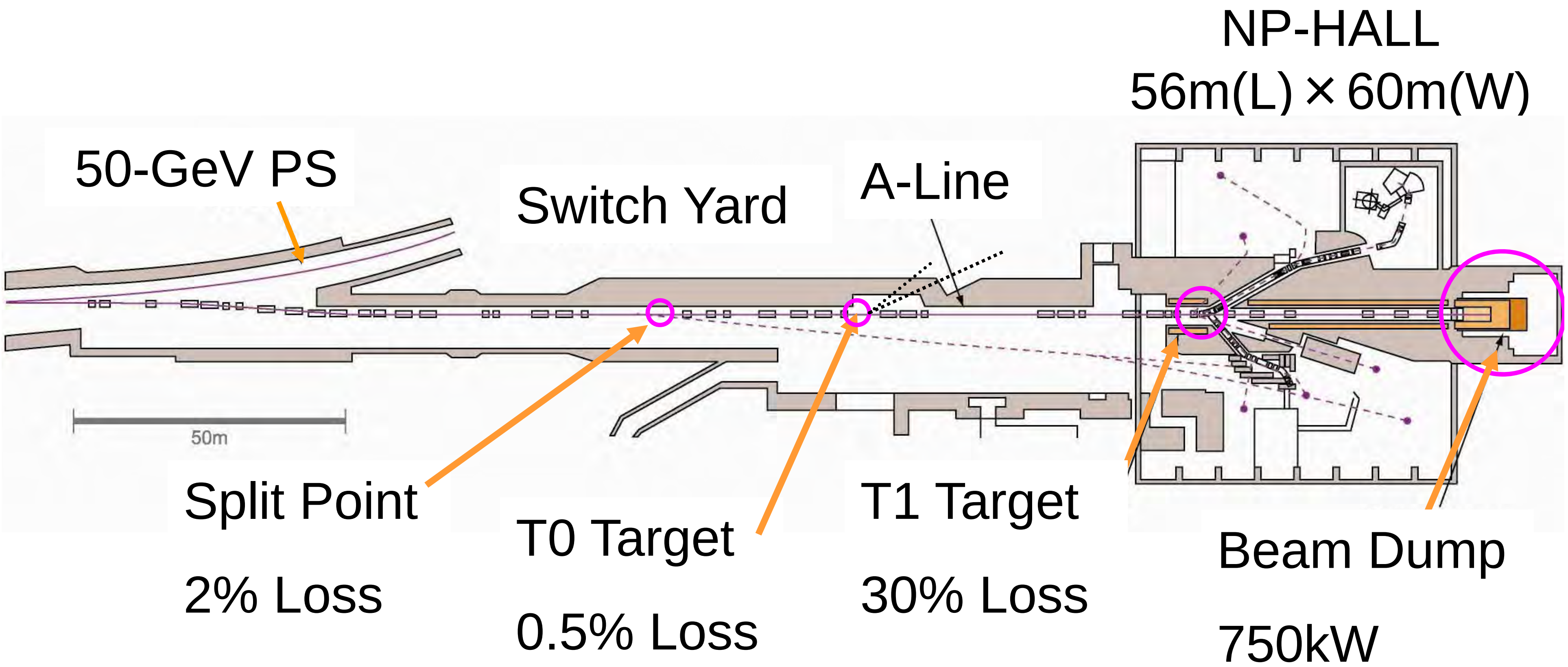




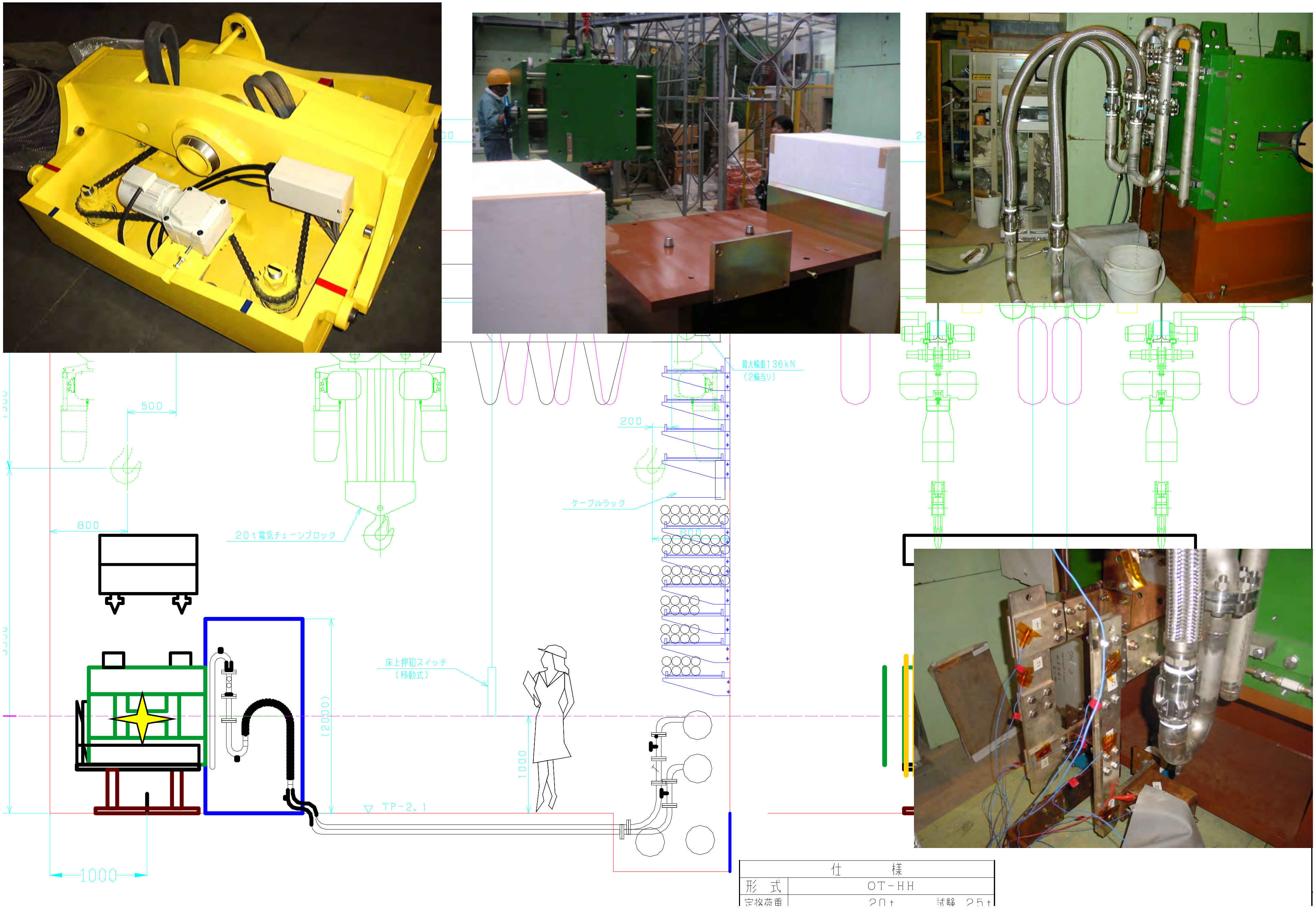
Q440MIC Magnet for J-PARC

Slow Extraction Beam Line (Phase I)

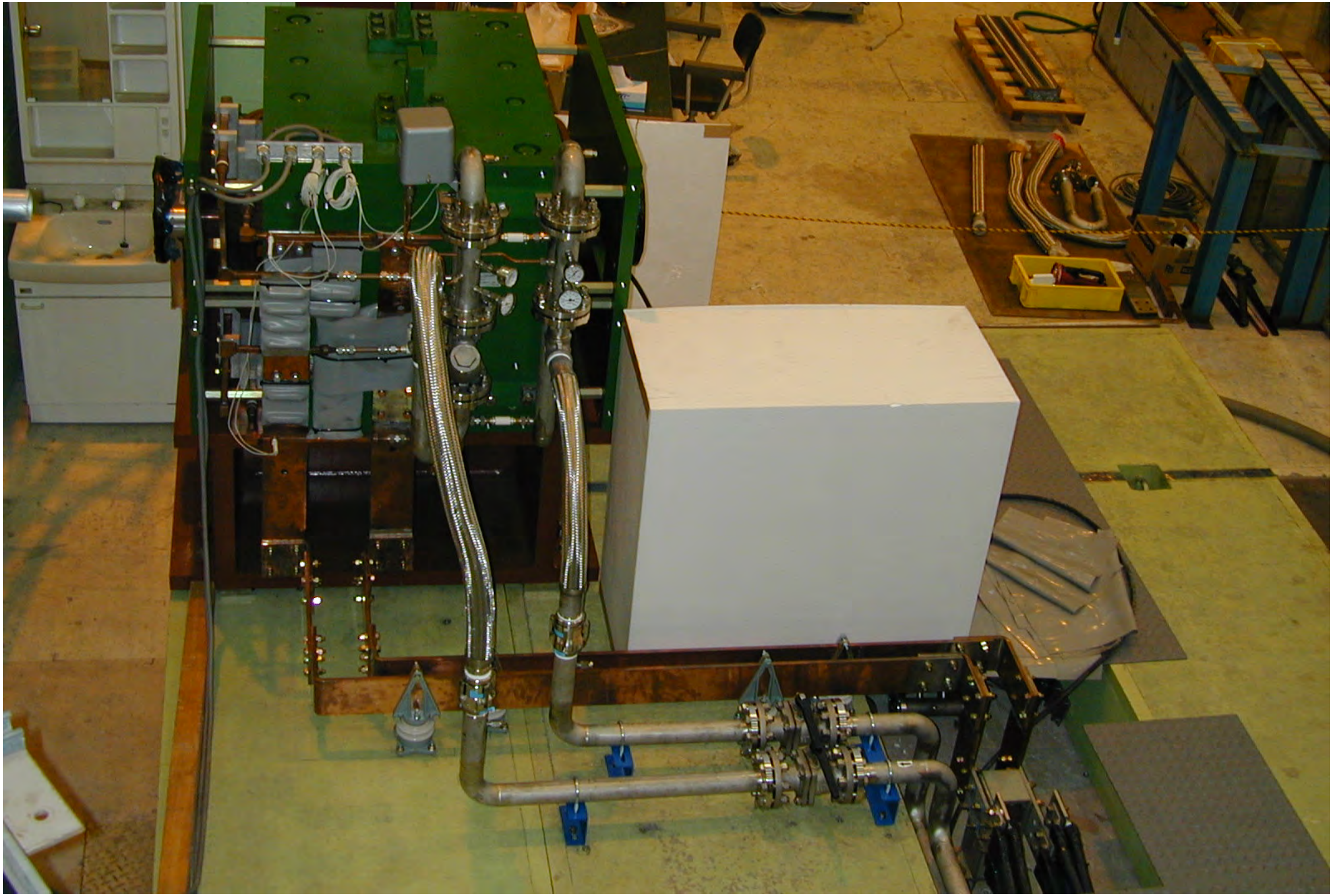
Semi Remote Maintenance at Switch Yard



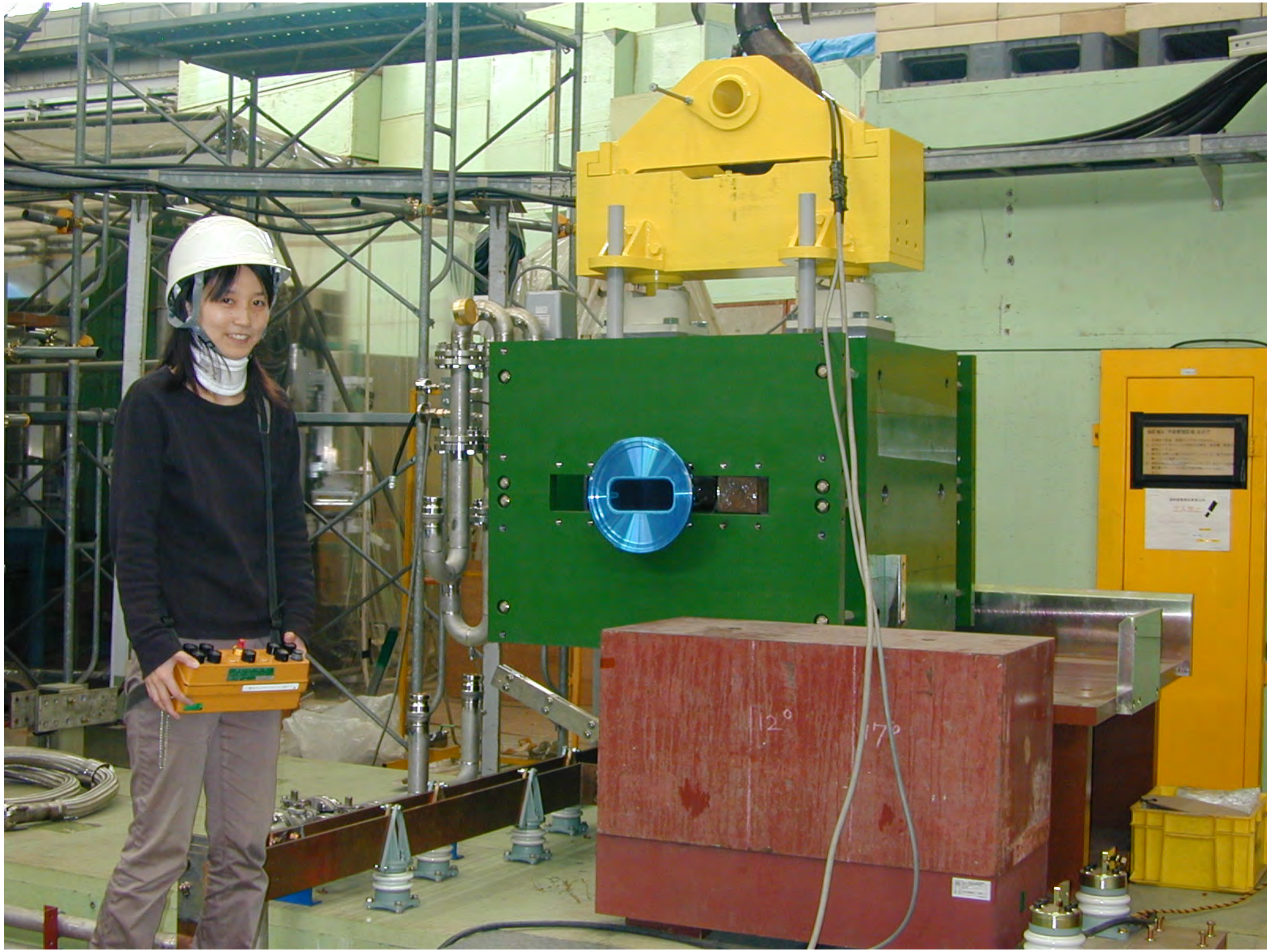
Cross Section of Switch Yard



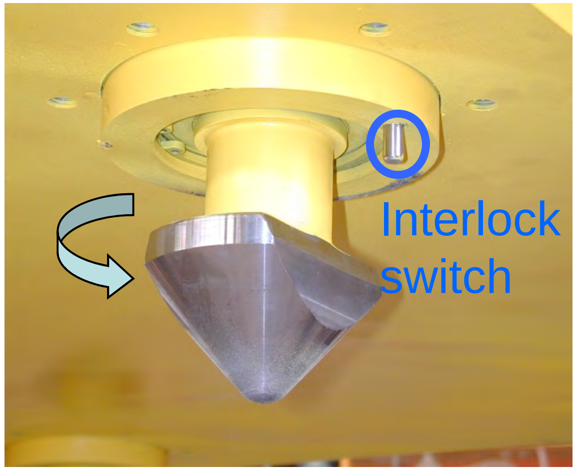
Mock Up of Hadron-SY & Neutrino



Automated magnet lifting for 20 ton load

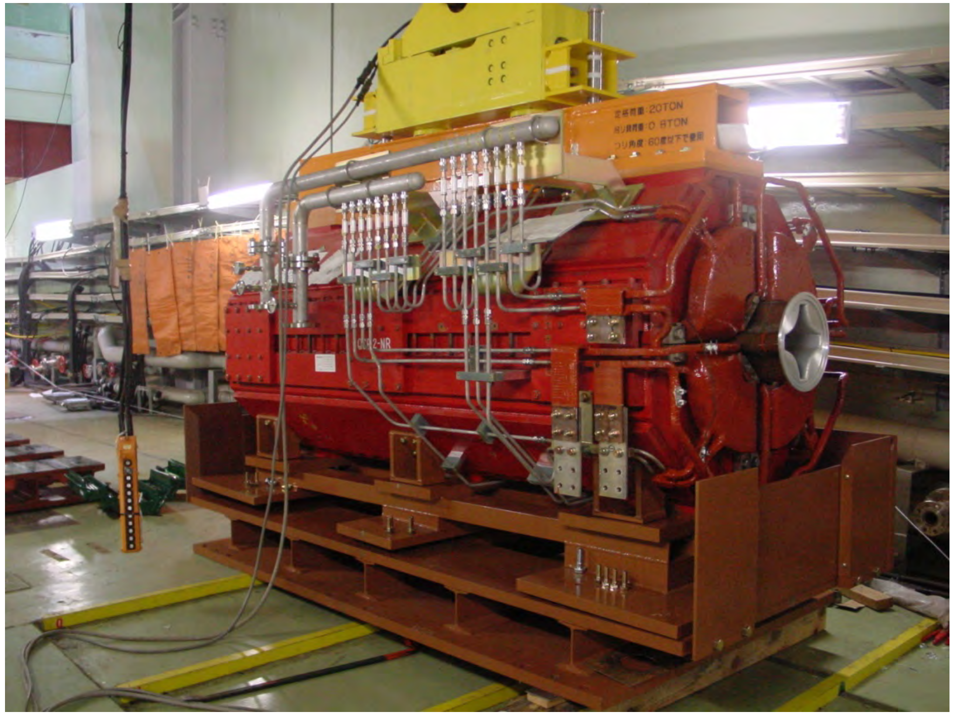


Automated magnet lifting for 20 ton load



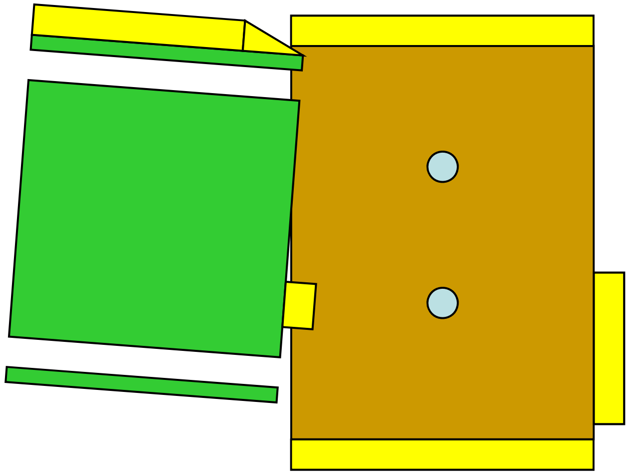
Twist lock

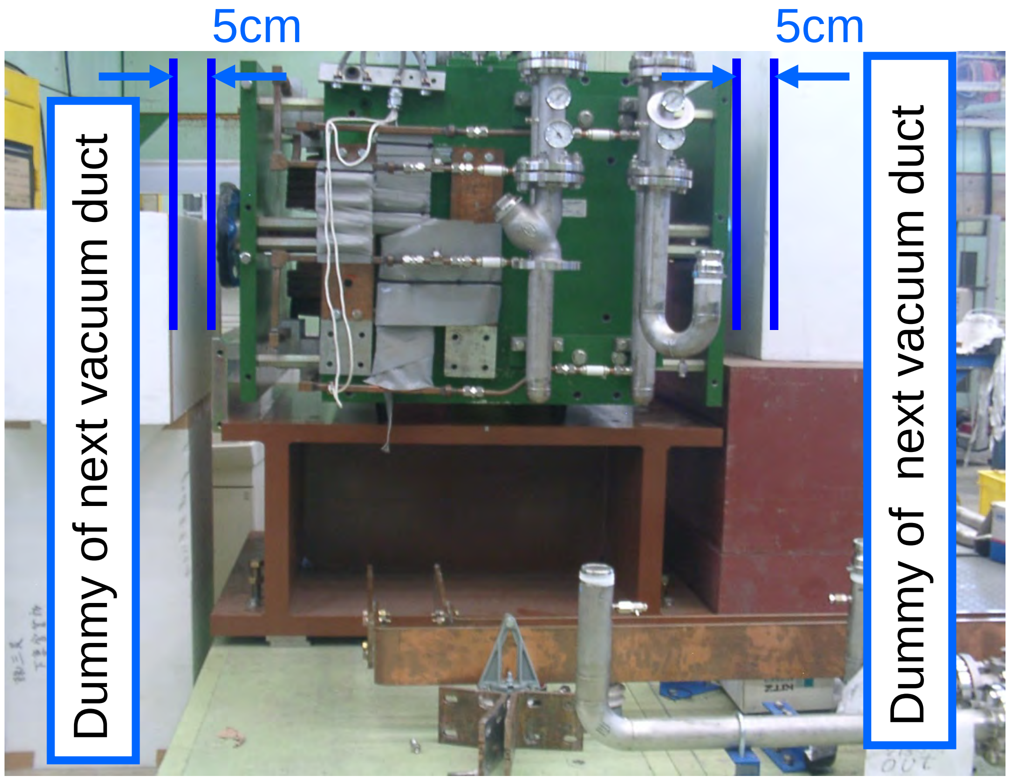
Corner fitting



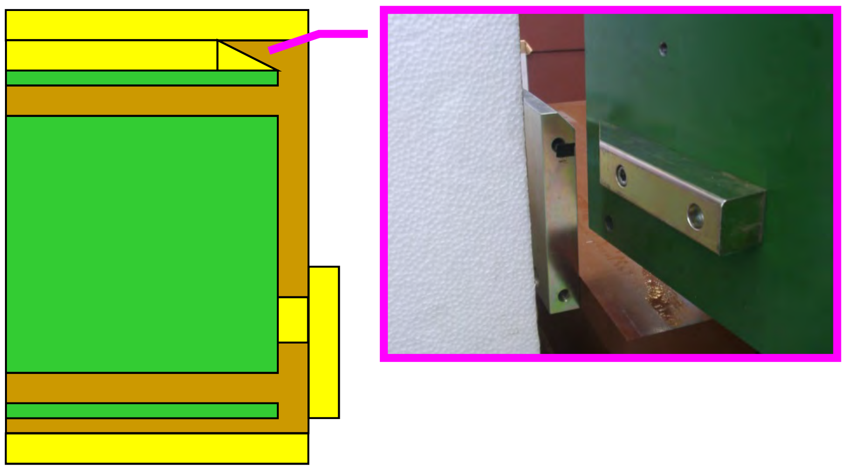
Quick alignment guide

①

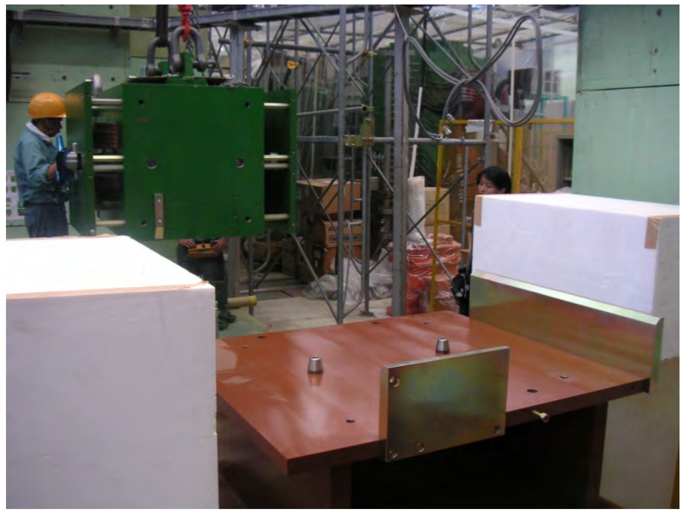


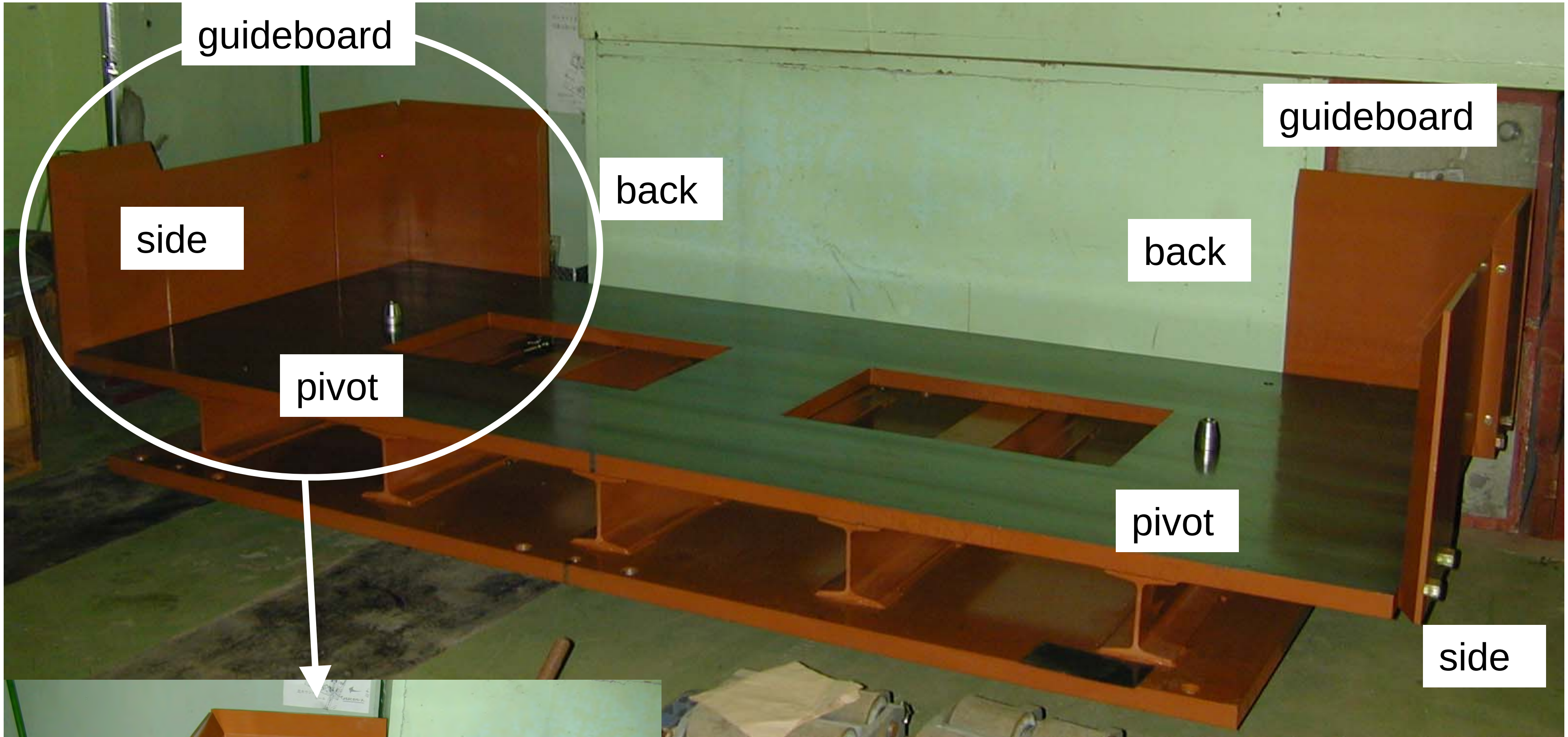


②



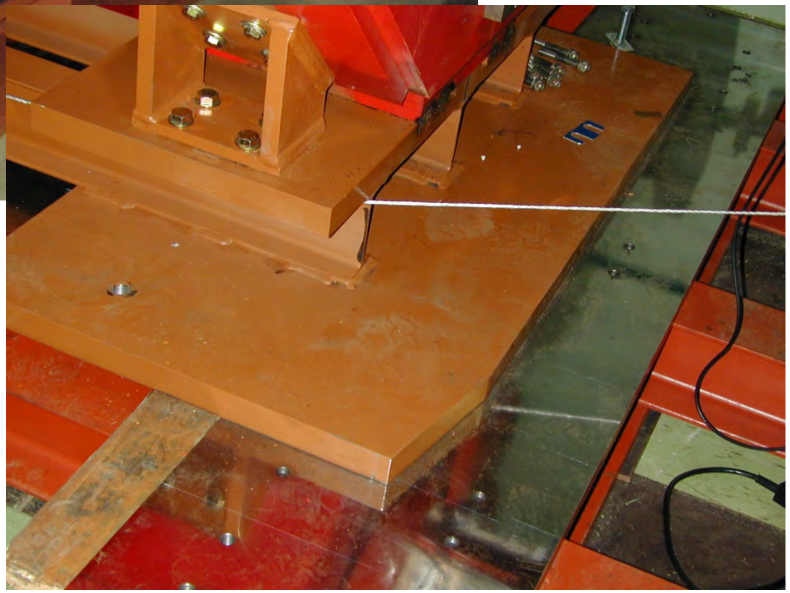
Mechanical support





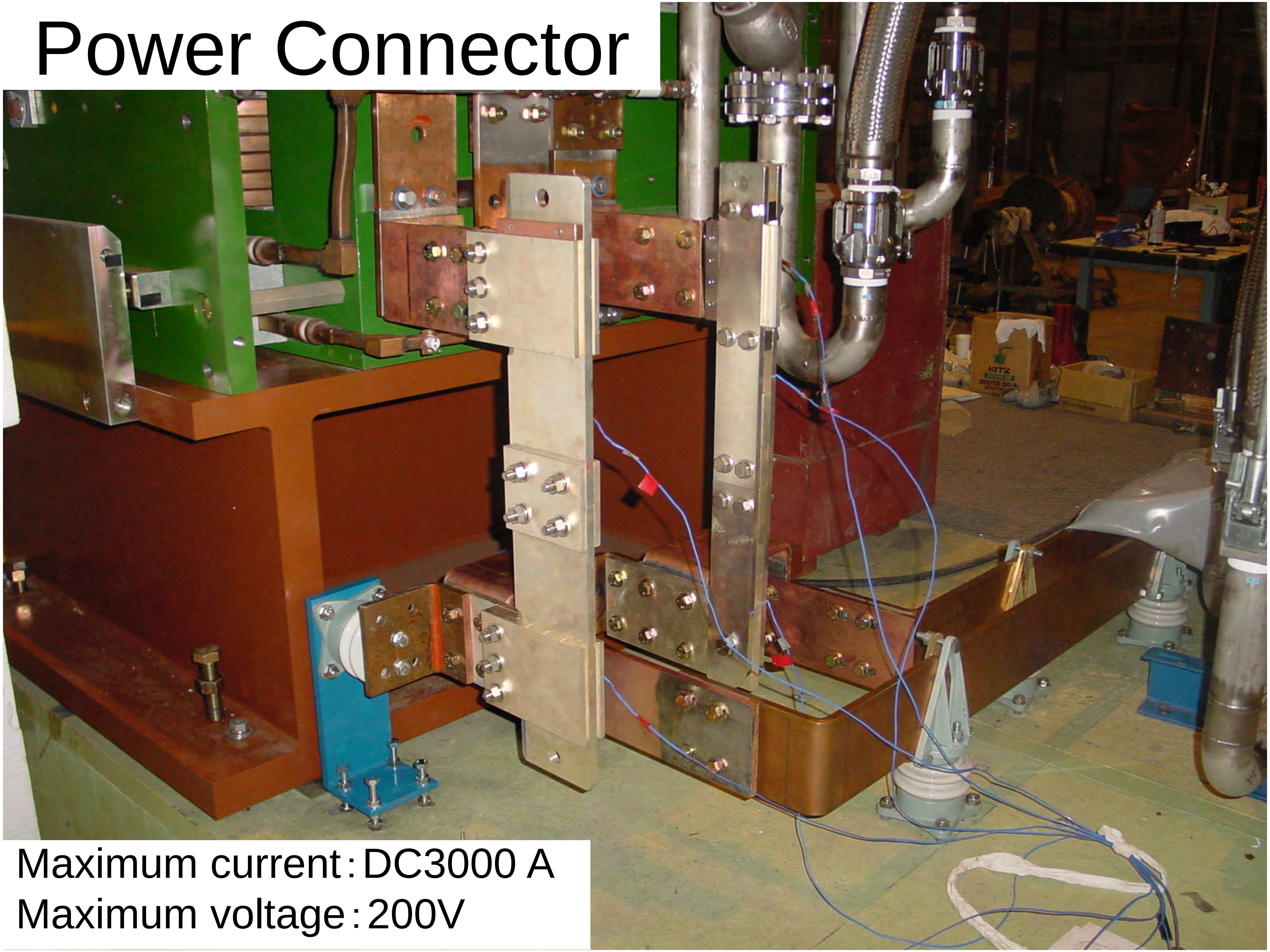
Quick alignment guide

Mechanical support with pivots and guideboards



Quick alignment guide
Magnet with hitting boards

Power Connector

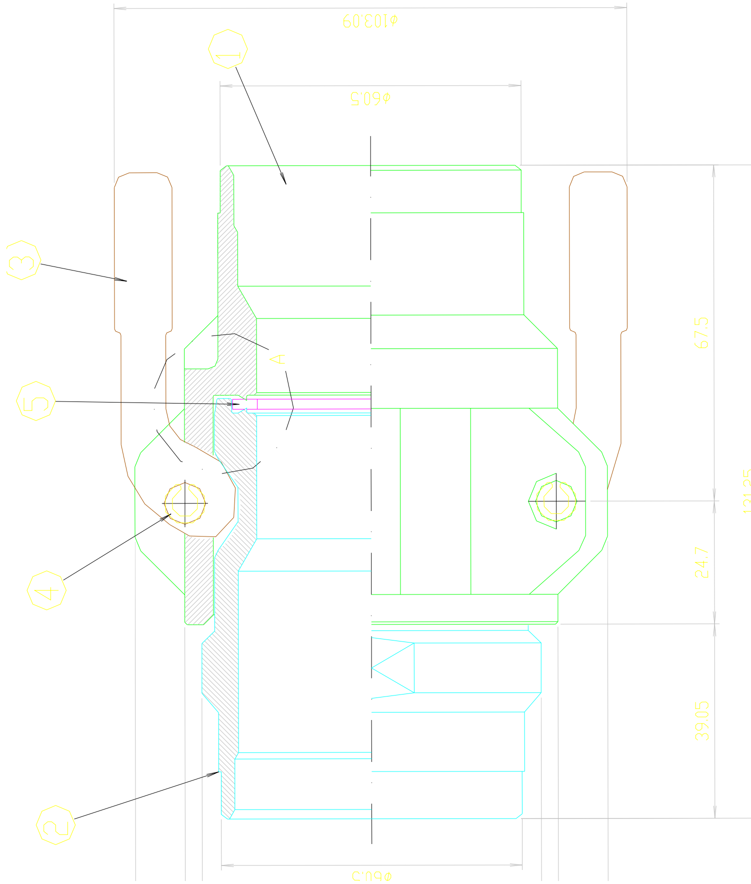


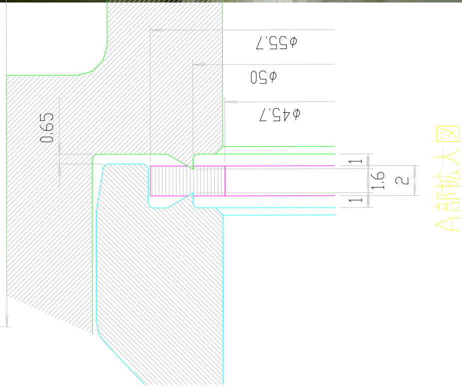
Maximum current：DC3000 A
Maximum voltage：200V

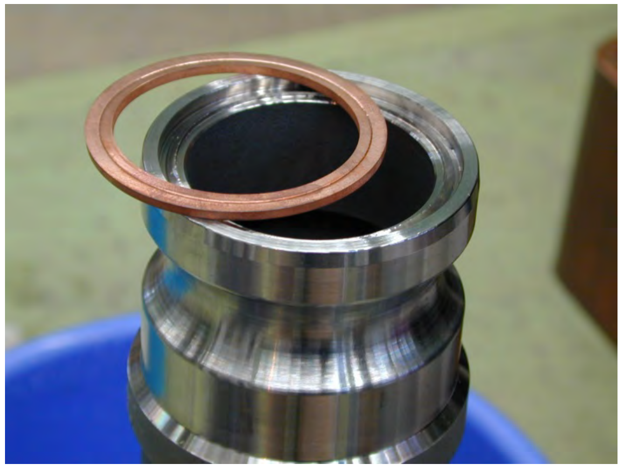
Remote Handling 3

Metal sealed lever coupler

- Normal operation with 2MPa
- Normal operation temperature : 15～80℃
- Two inch. Diameter
- Cu-ring annealing @750℃
- Deficit depth > 0.2mm



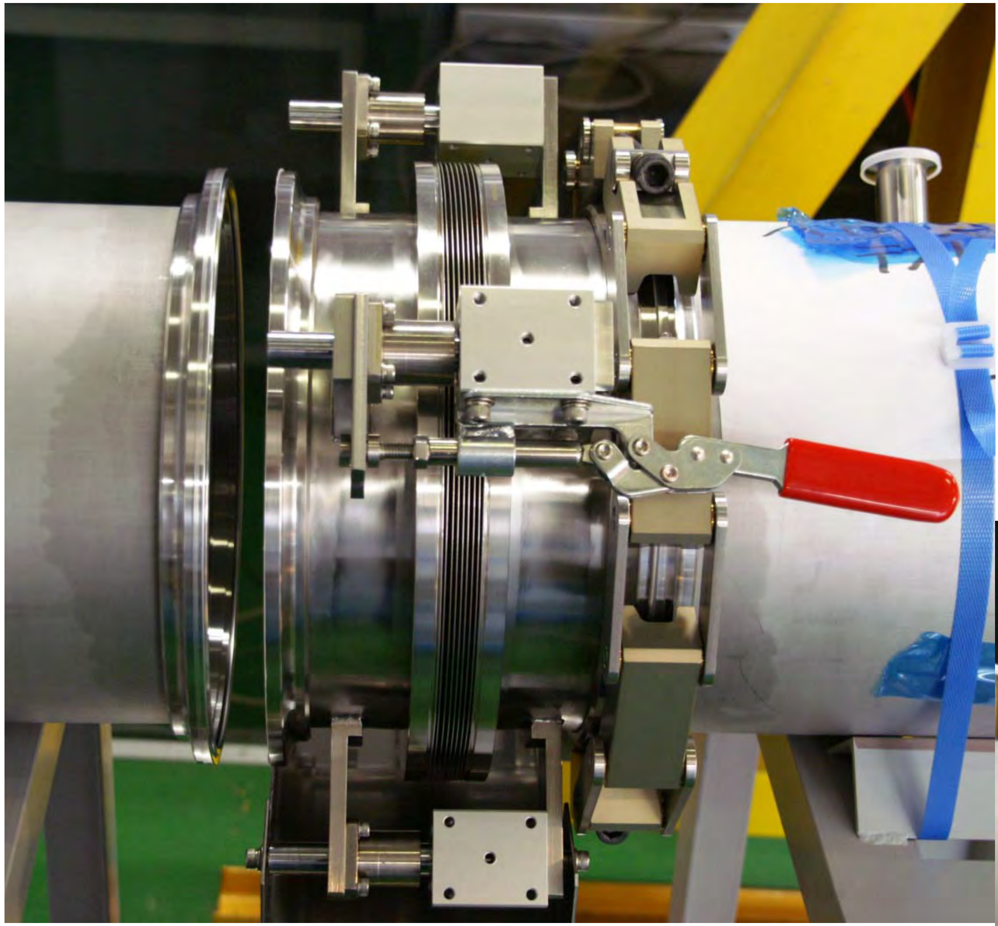


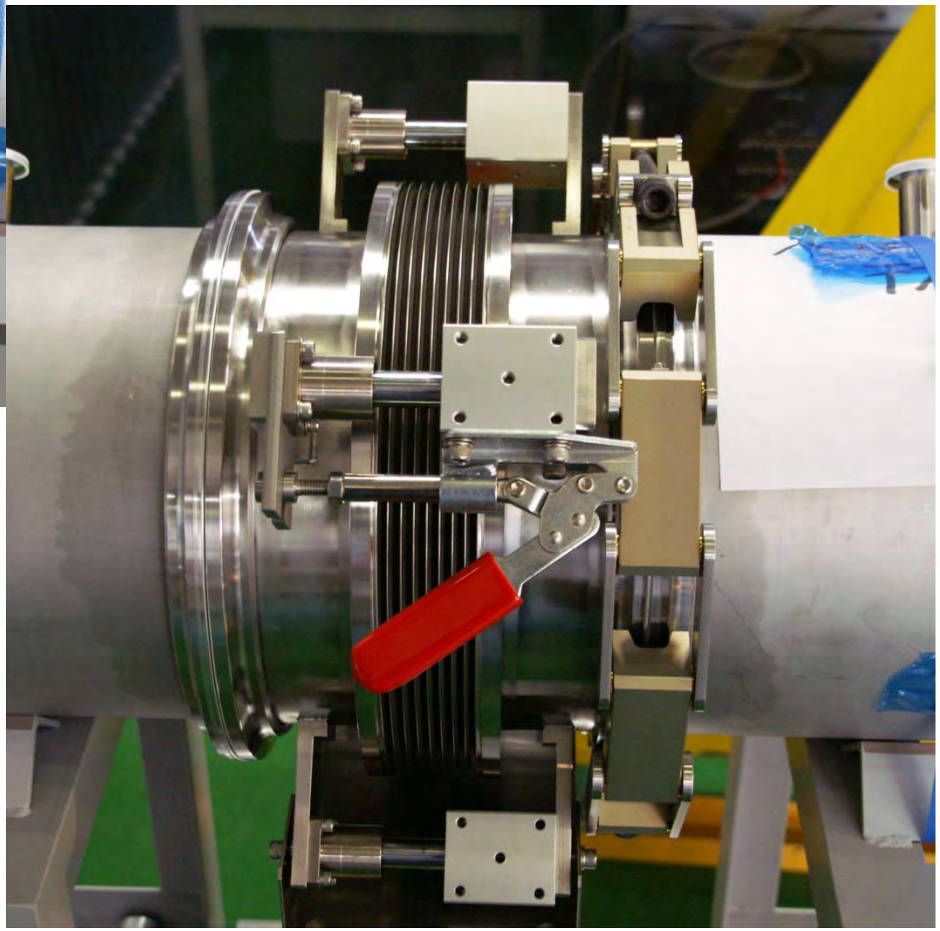


Remote Handling

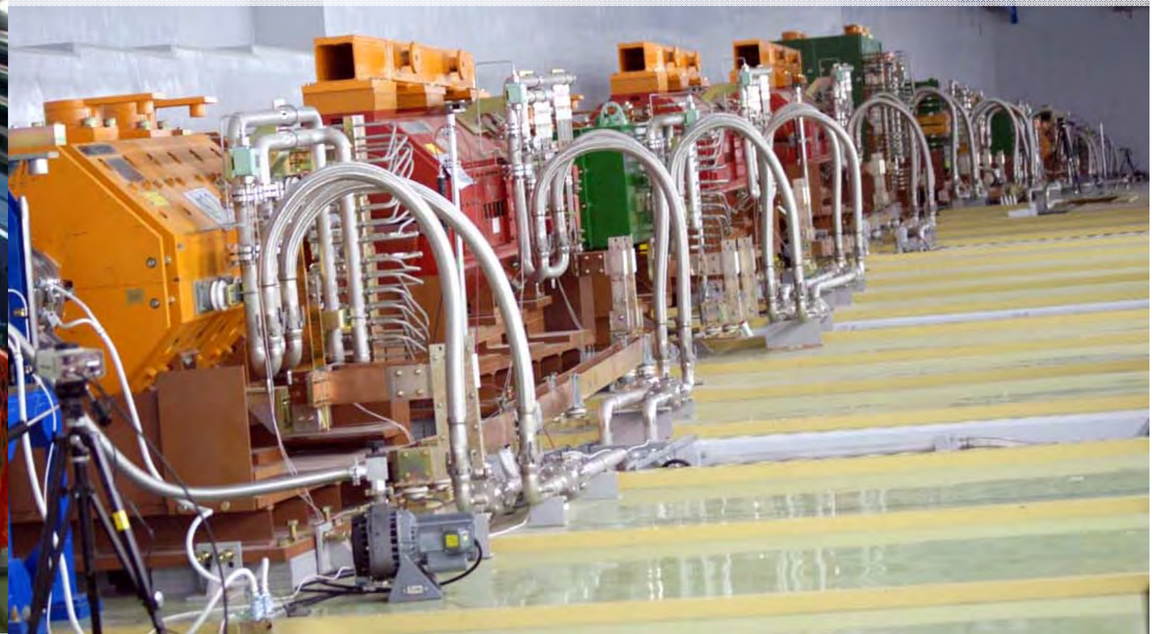
Quick connection

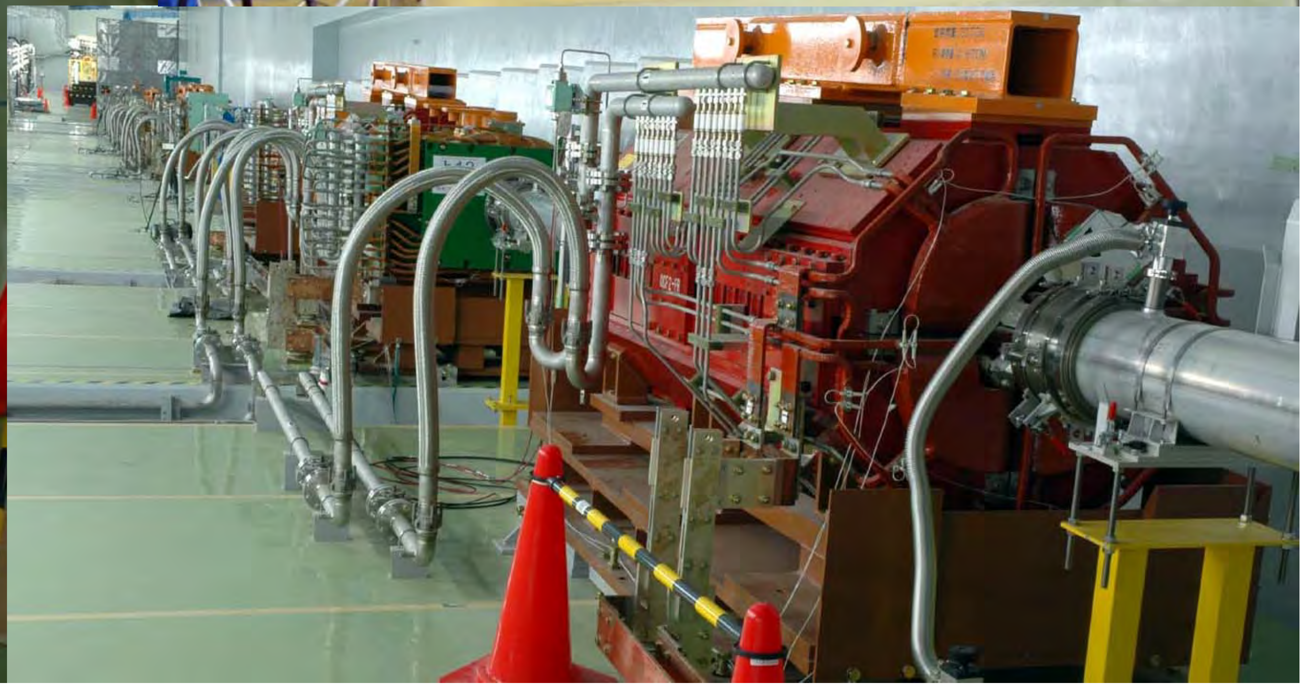
bellows





Switch Yard: Nov. 2008

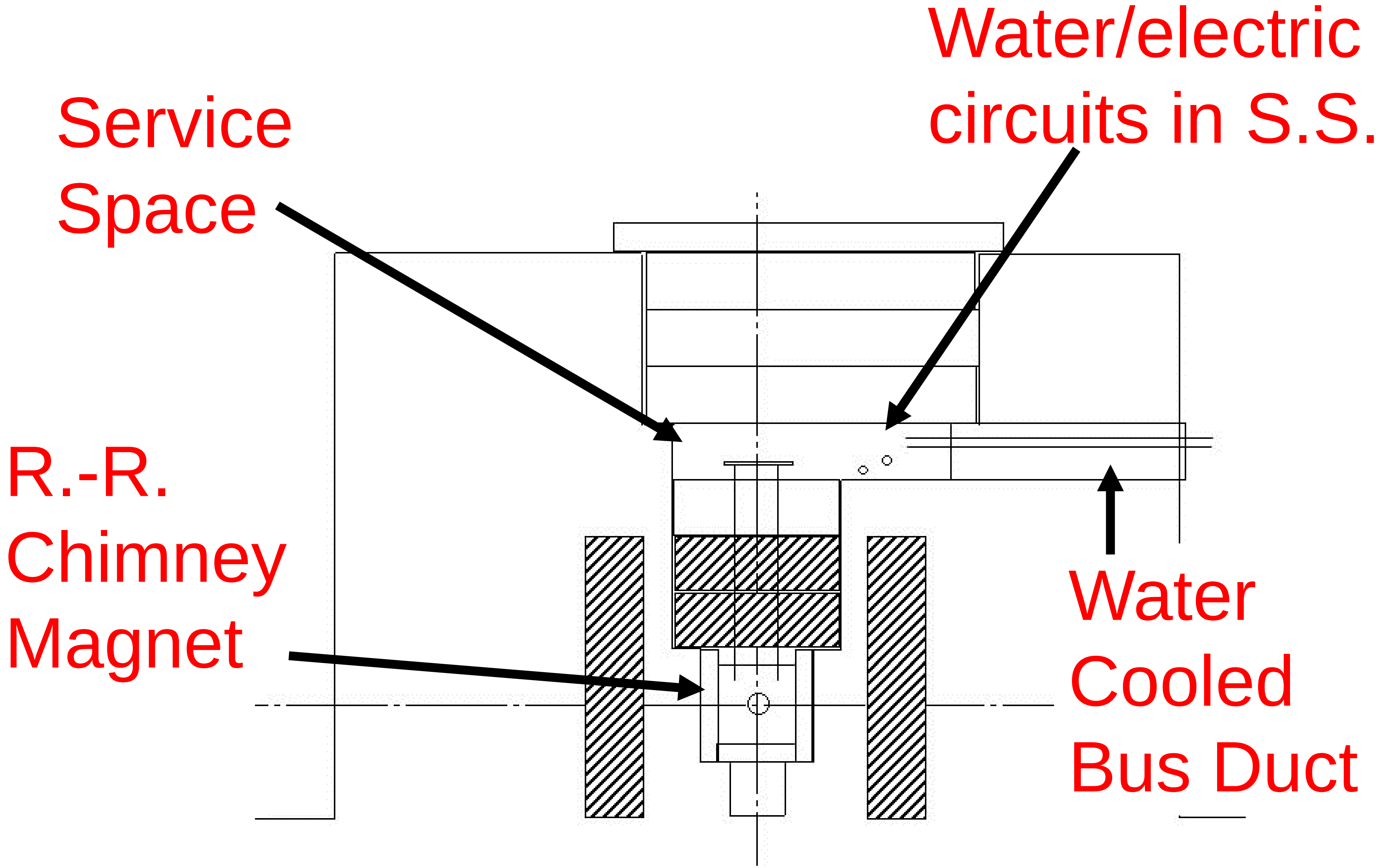




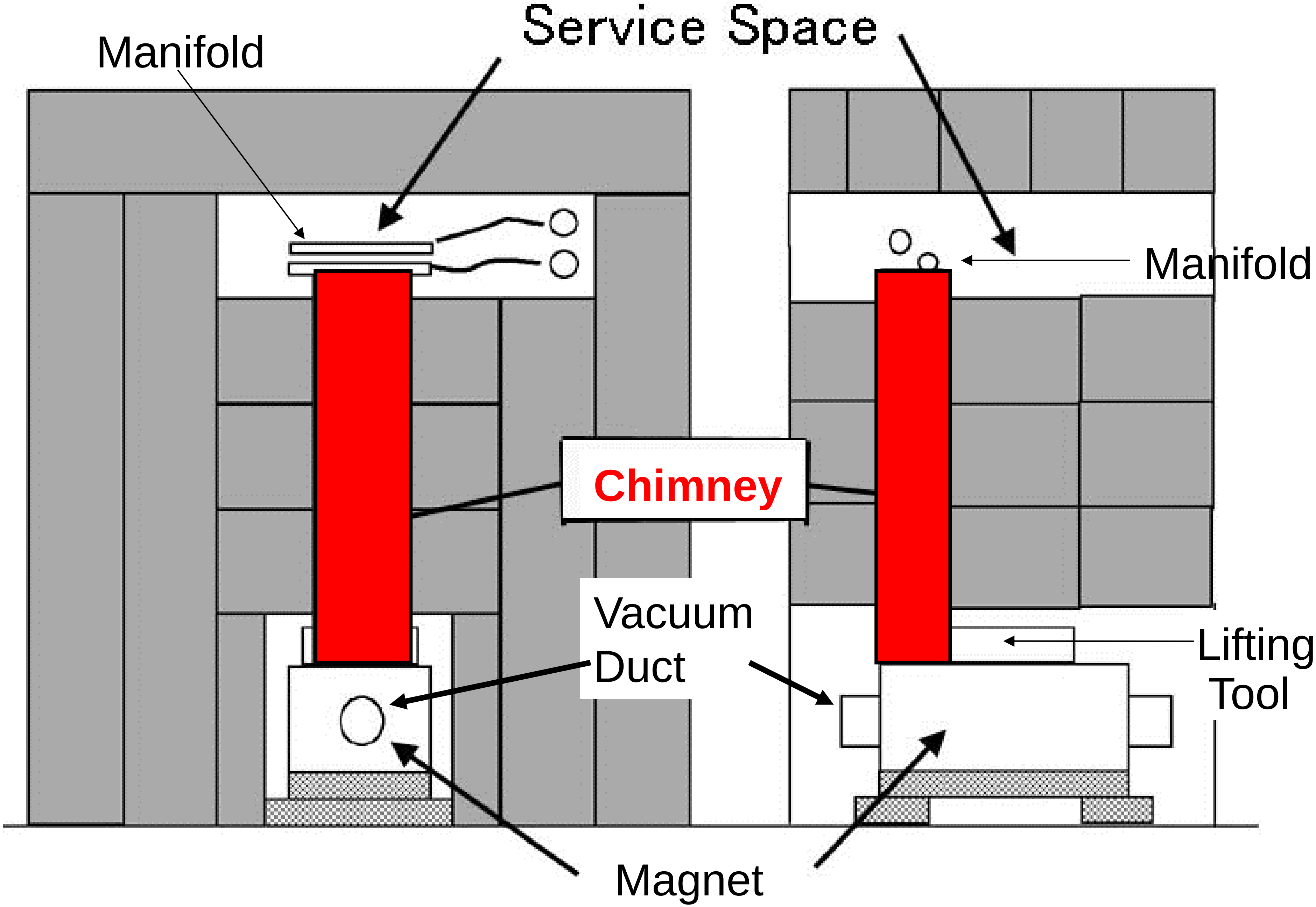
Hadron Experimental Hall

Remote Maintenance

Hadron Hall Systematization; Chimney as High Power Beam Facility



Chimney for Hadron-Hall Magnets



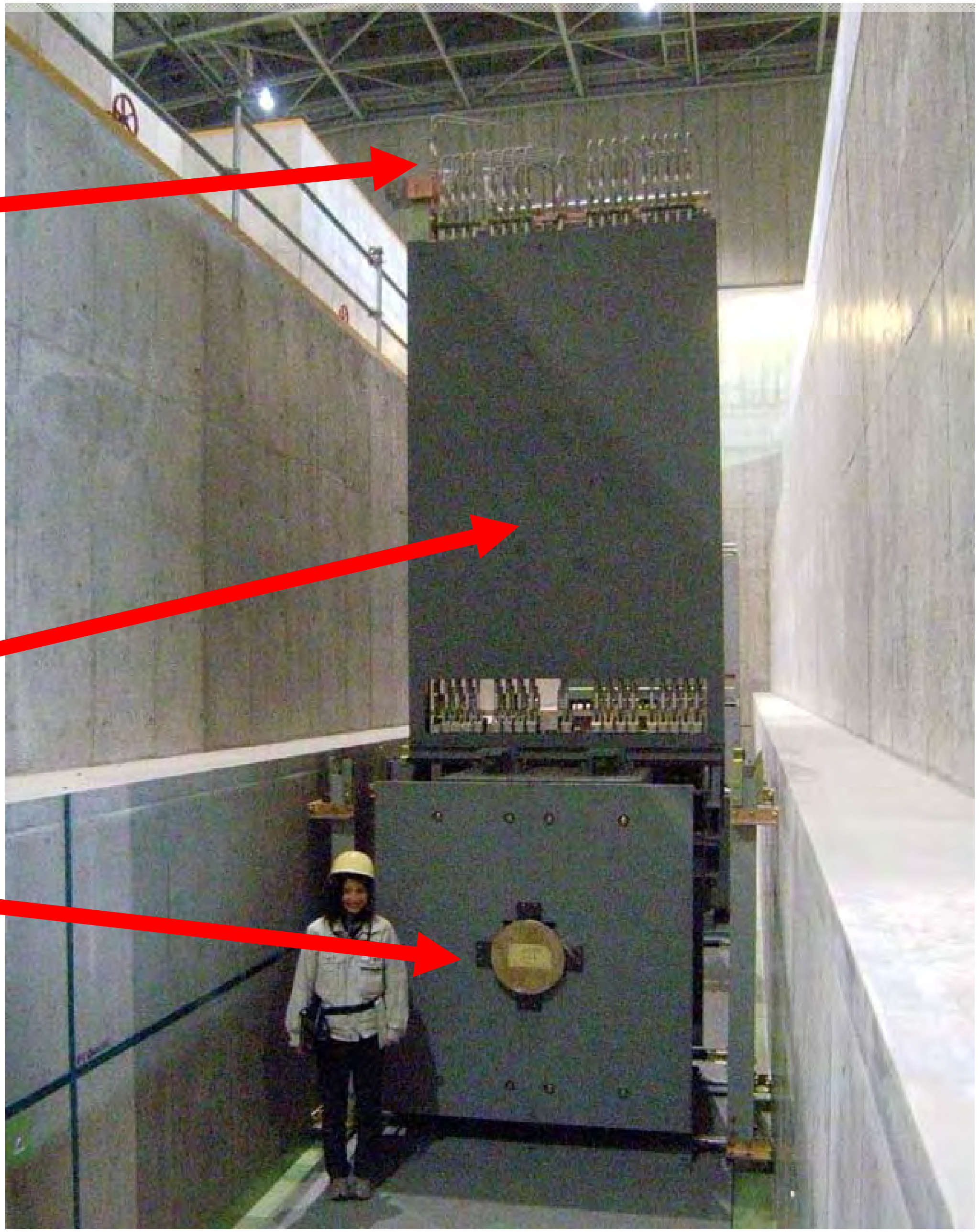
Radiation Resistant Chimney Magnet

Water Manifold &
Electric Connection
at Service Space Level

Completely Inorganic

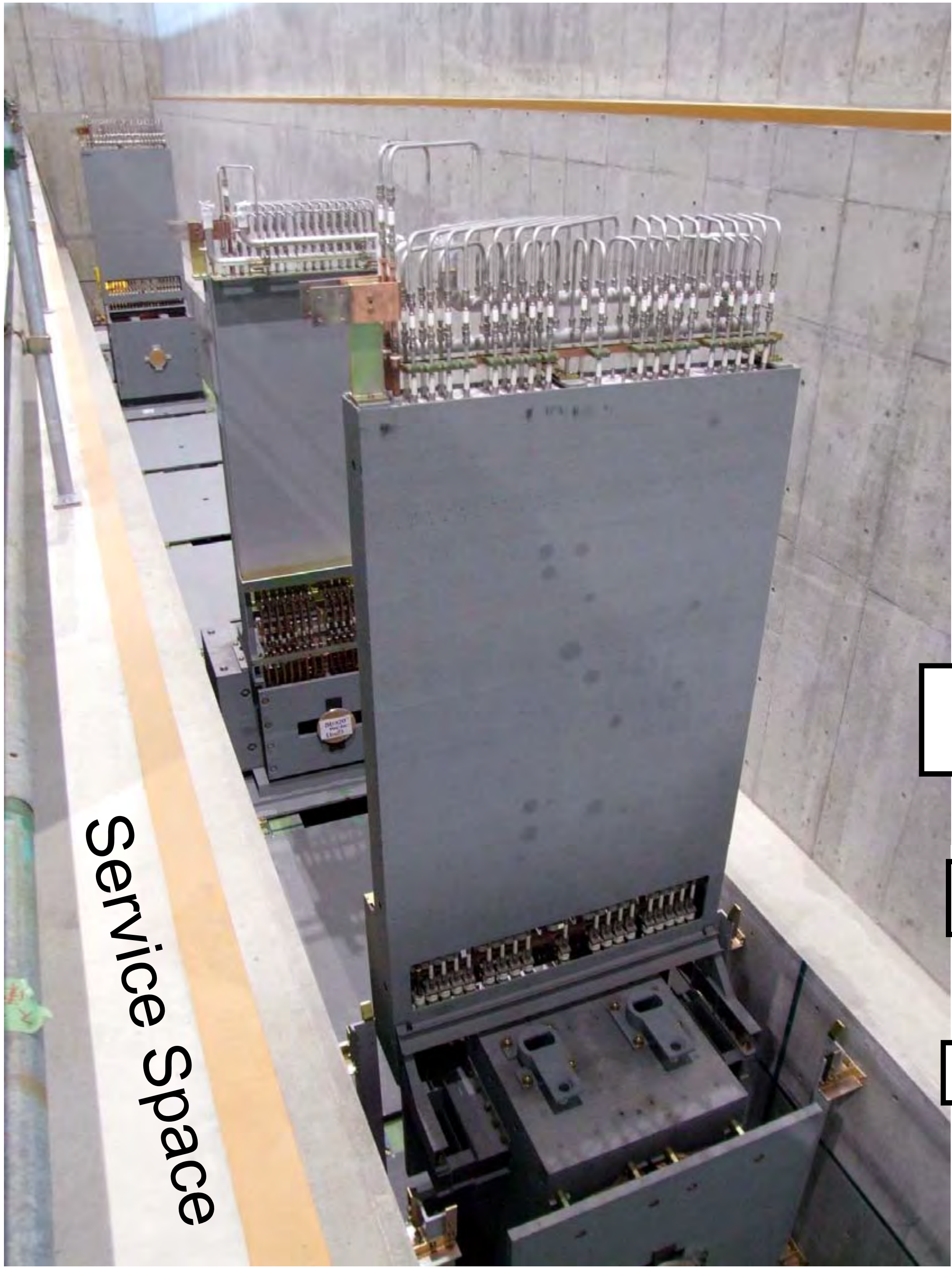
Chimney

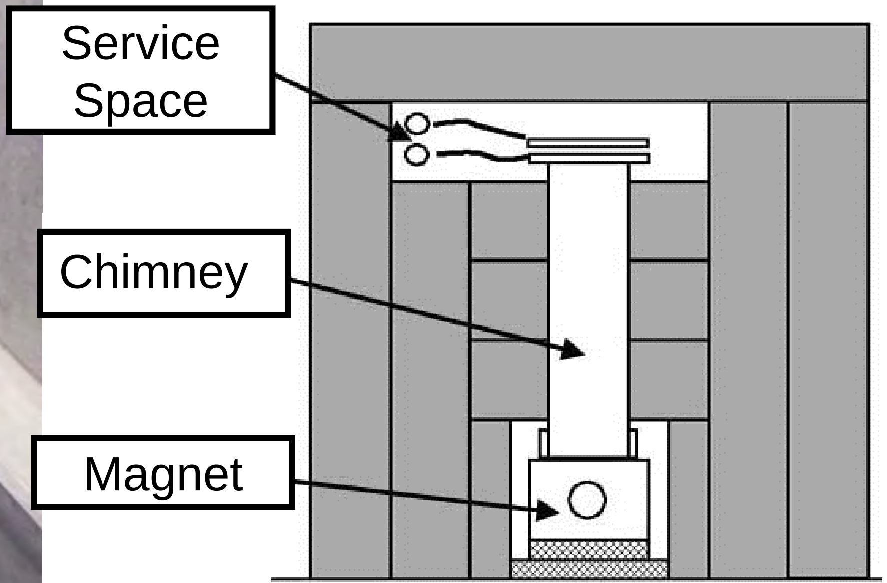
MIC Magnet



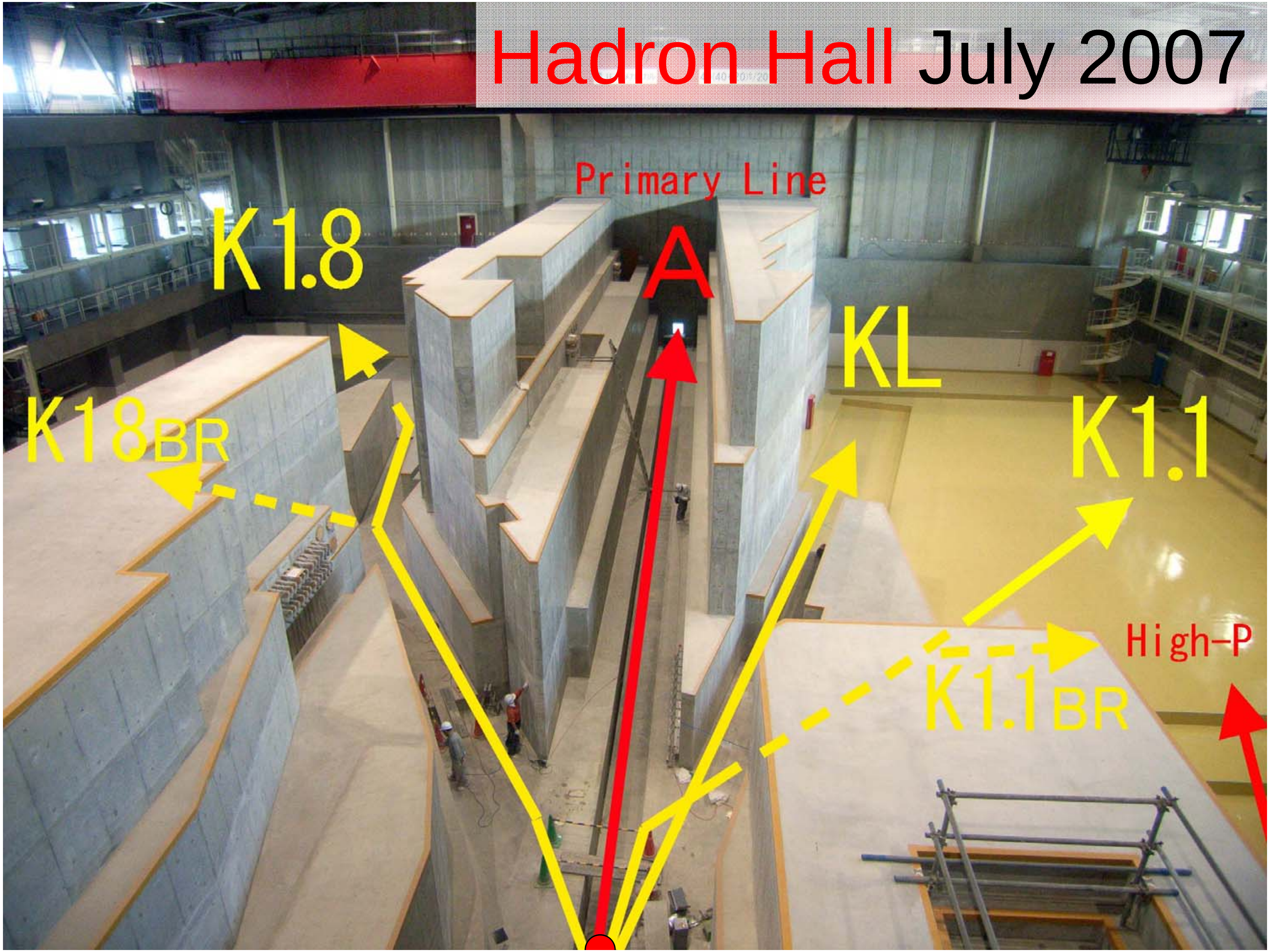
Chimney magnets tested at Tsukuba

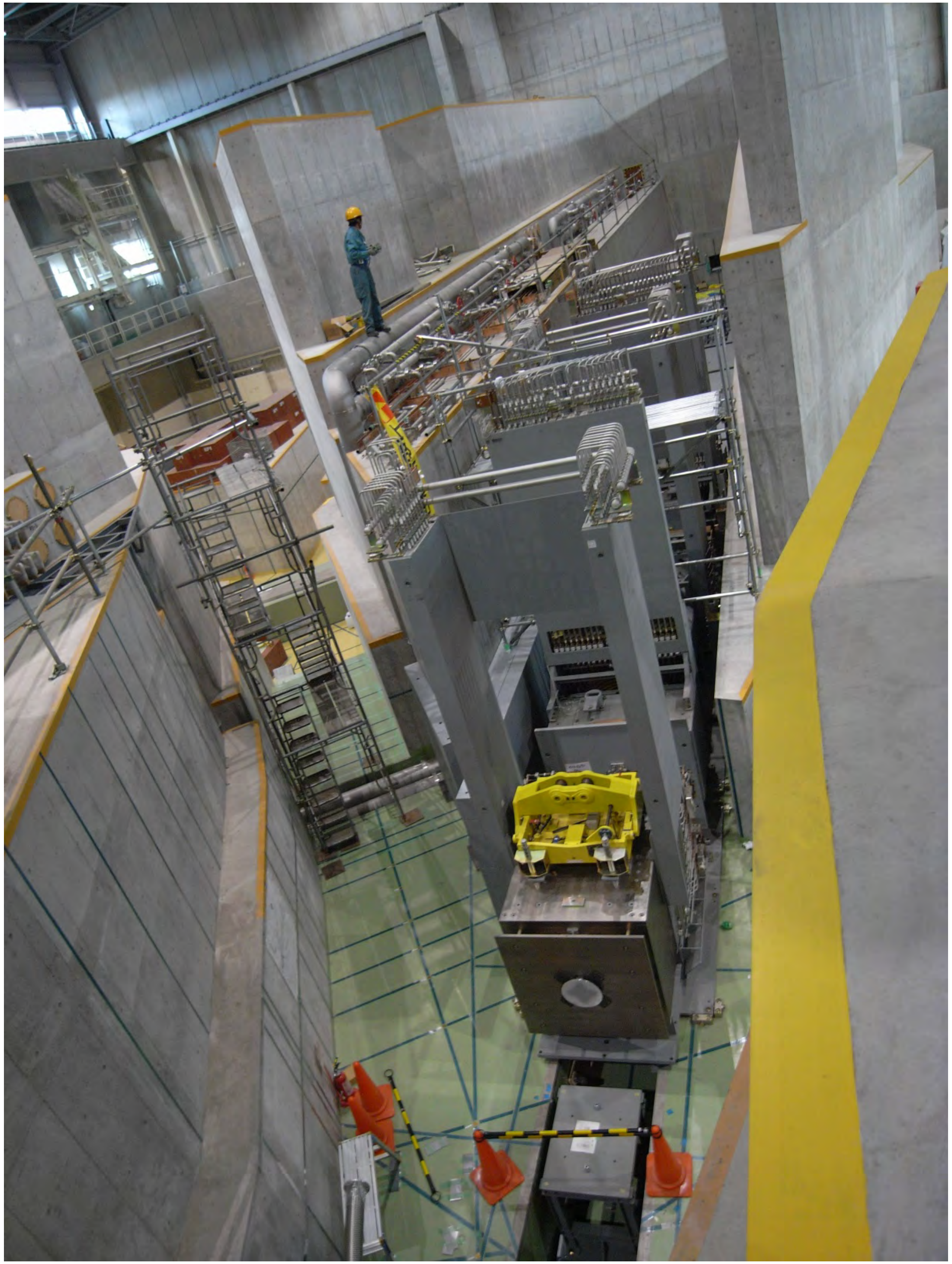
Chimney magnets aligned on line at Hadron Hall



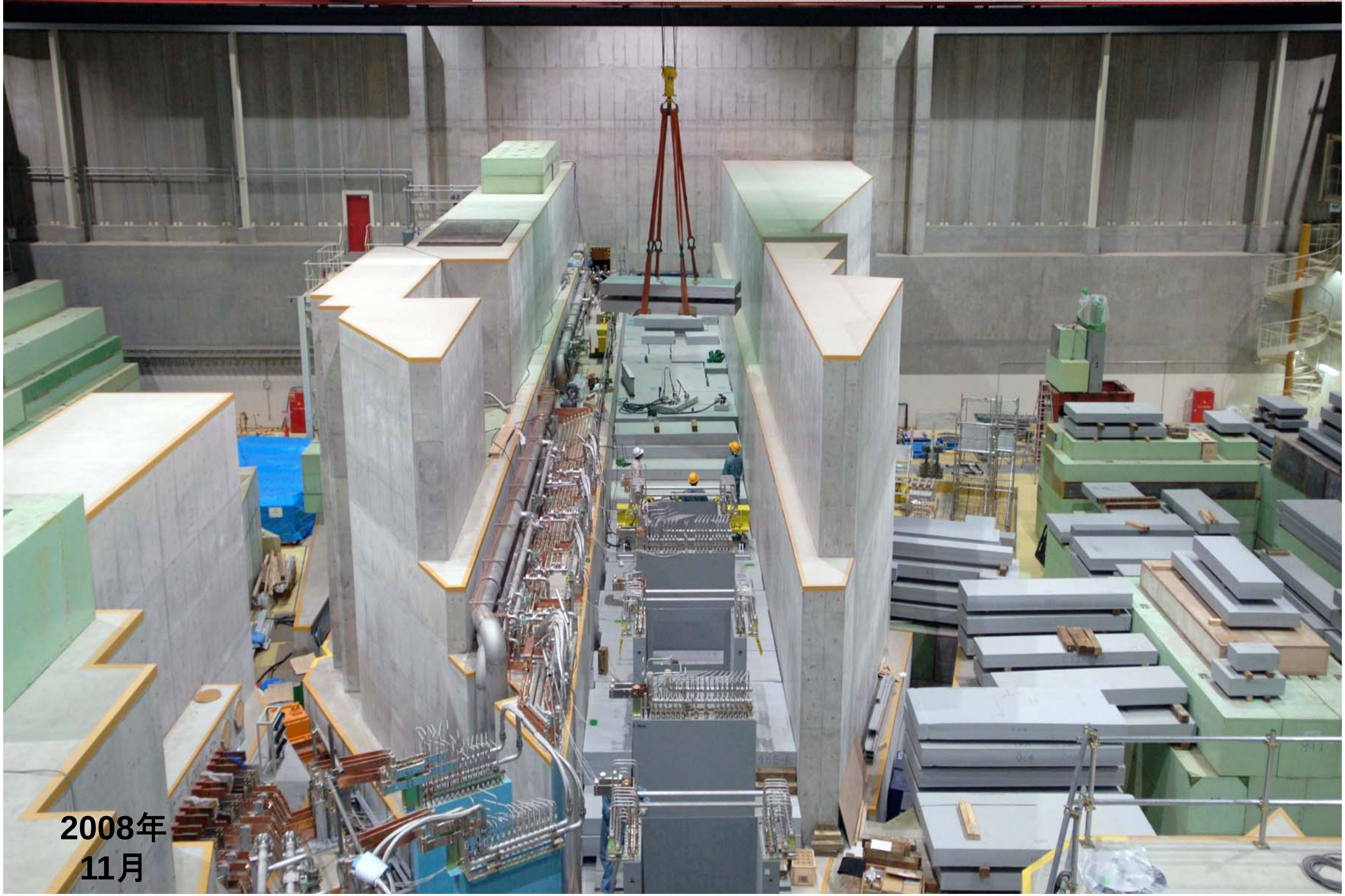


Hadron Hall July 2007


Hadron Hall July 2007
Primary Line
A
K1.8
K18BR
KL
K1.1
High-P
K1.1BR



Hadron Hall Nov. 2008



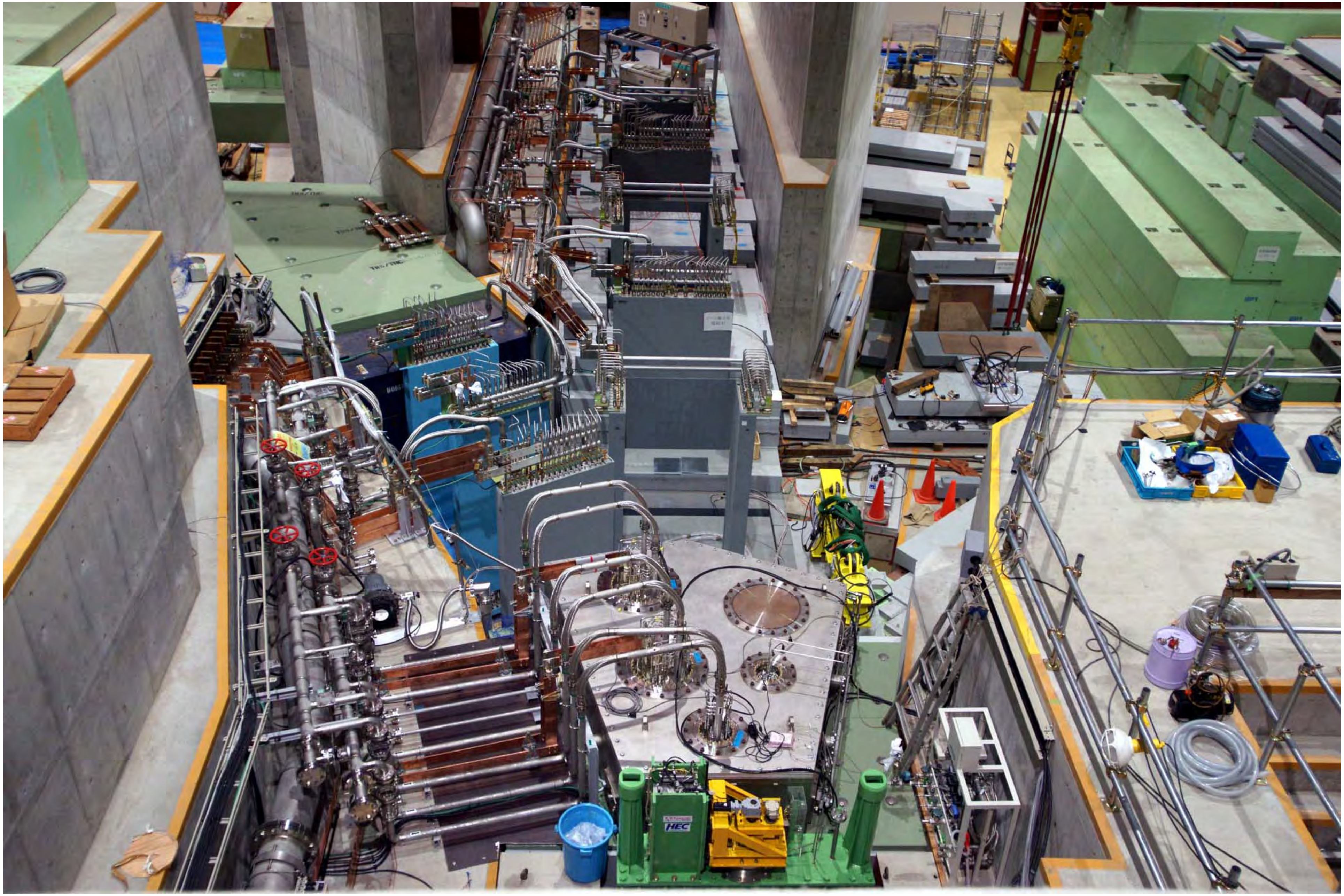
Hadron Hall Nov. 2008

Hadron Hall Nov. 2008

Hadron Hall Nov. 2008

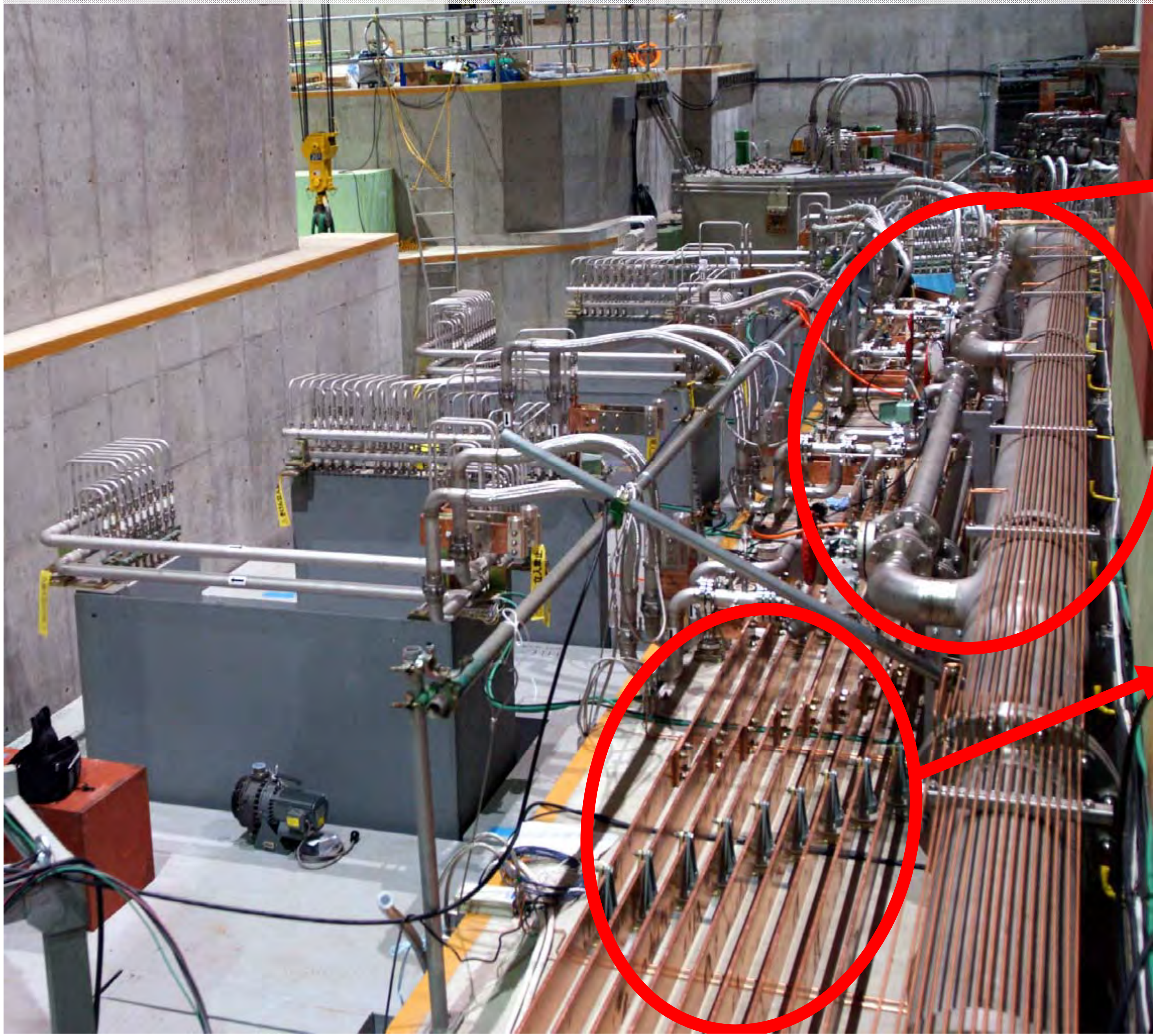
2008年
11月

Chimney magnets near T1



Chimney magnets near T1 (side view)

Service Space; Water/Electric circuits



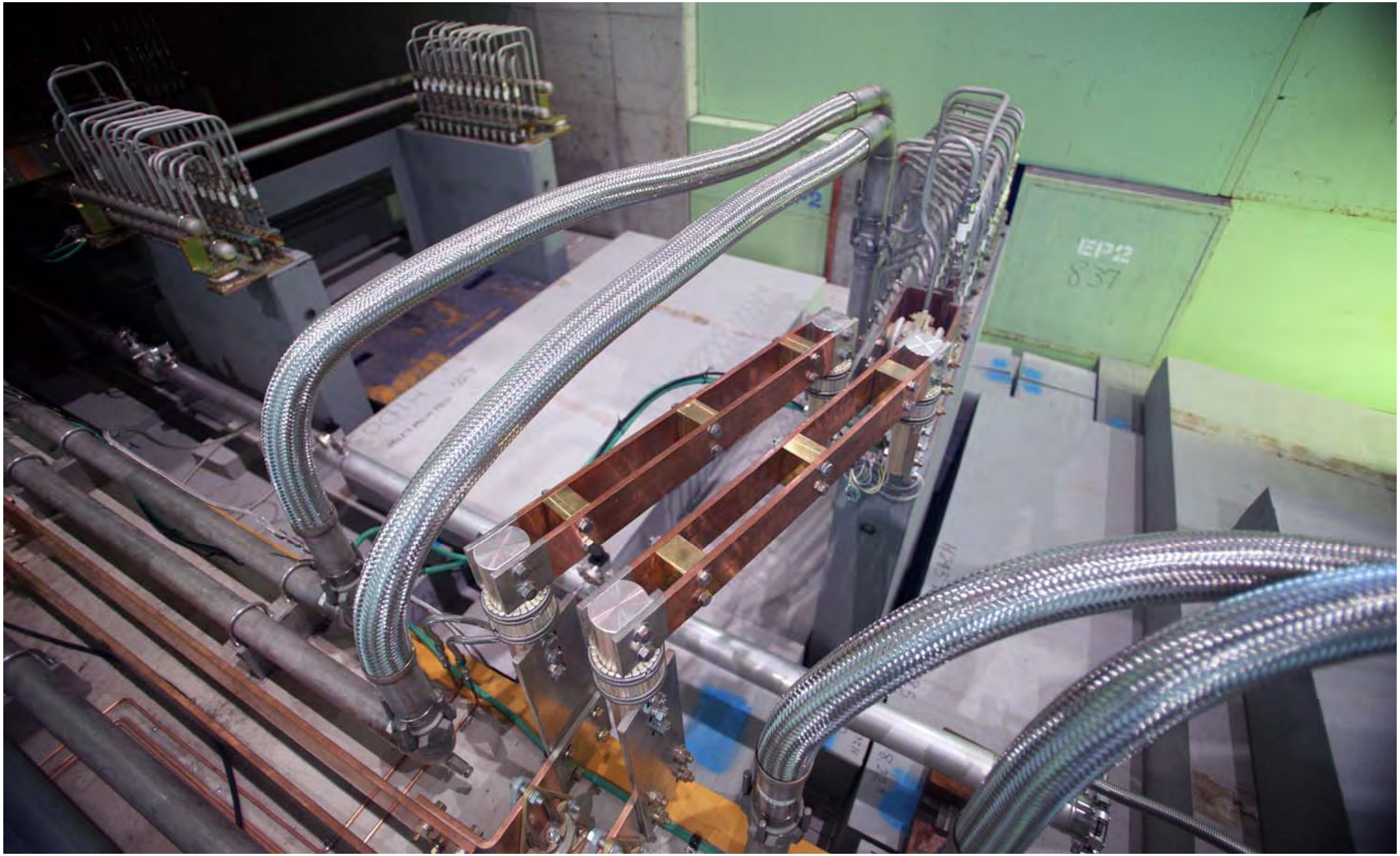
Water Piping

Inorganic; using steam piping technology

Electric Circuits

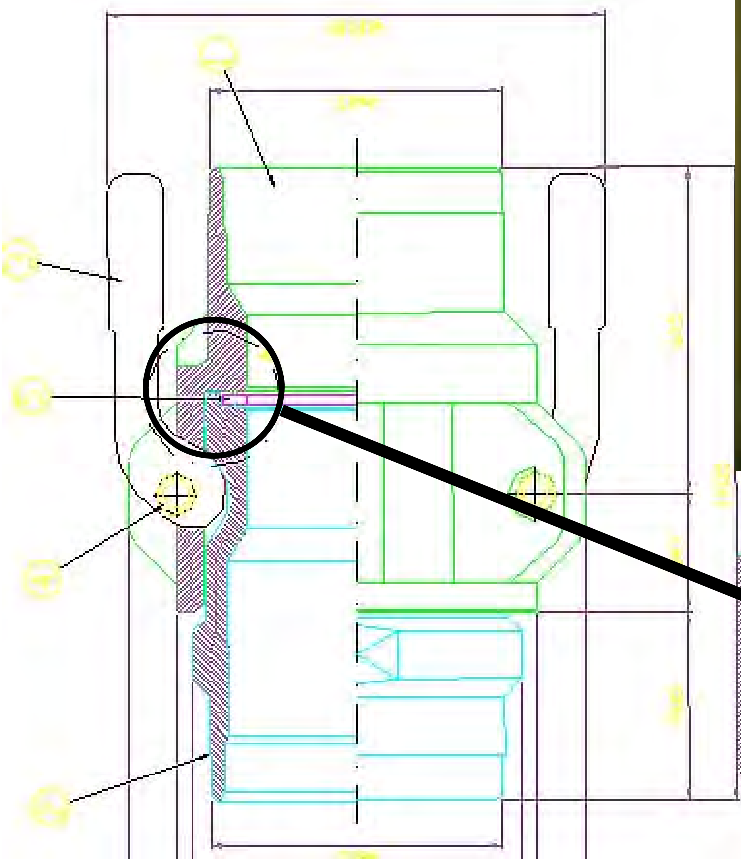
Inorganic; using Cu B.B.

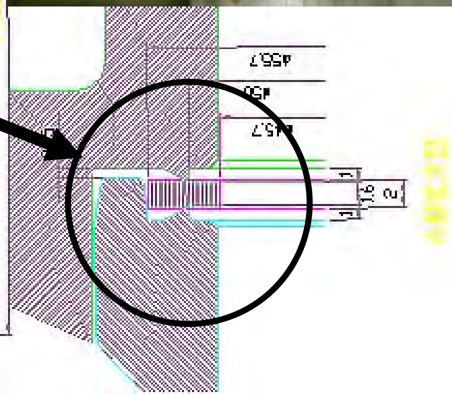
Bridges for Water & Electric Power; Quick Disconnect System

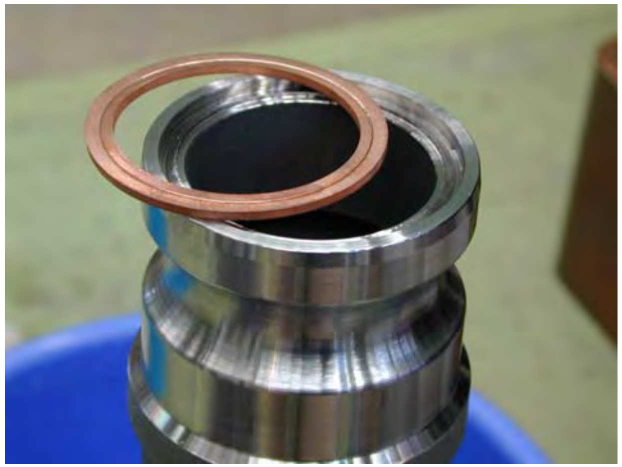


Water Connector
Metal sealed lever coupler

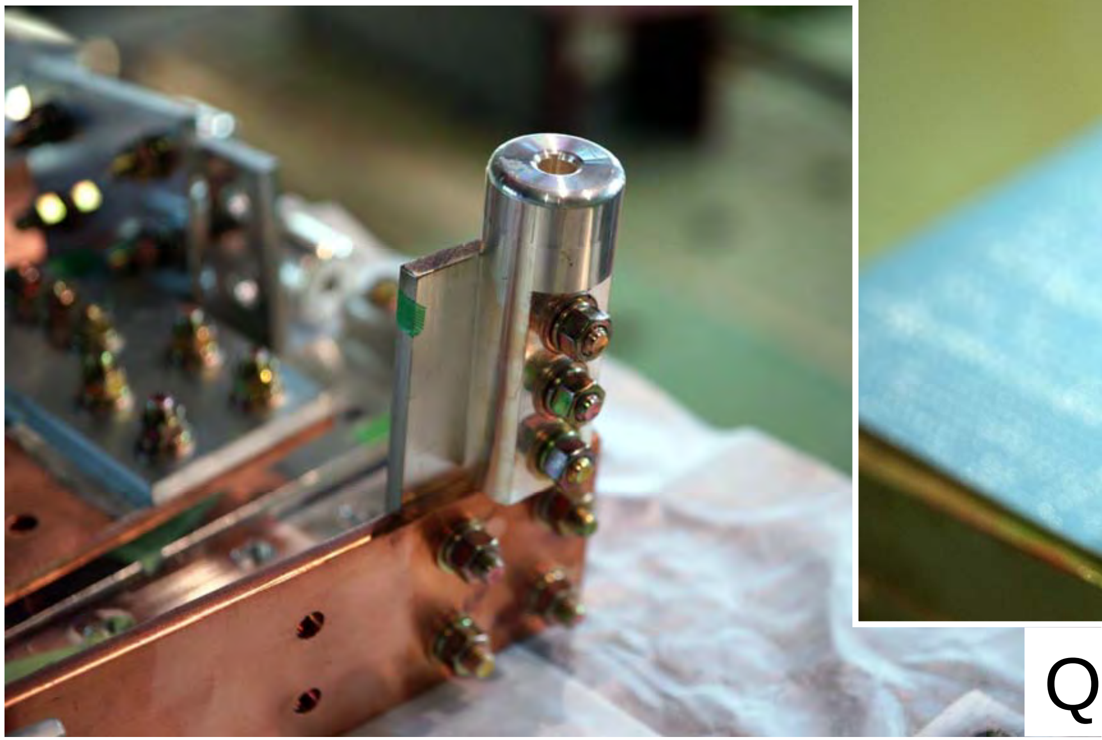
- Normal operation with 2MPa
- Normal operation temperature : 15～80℃
- Two inch. Diameter
- Cu-ring annealing @750℃
- Deficit depth > 0.2mm

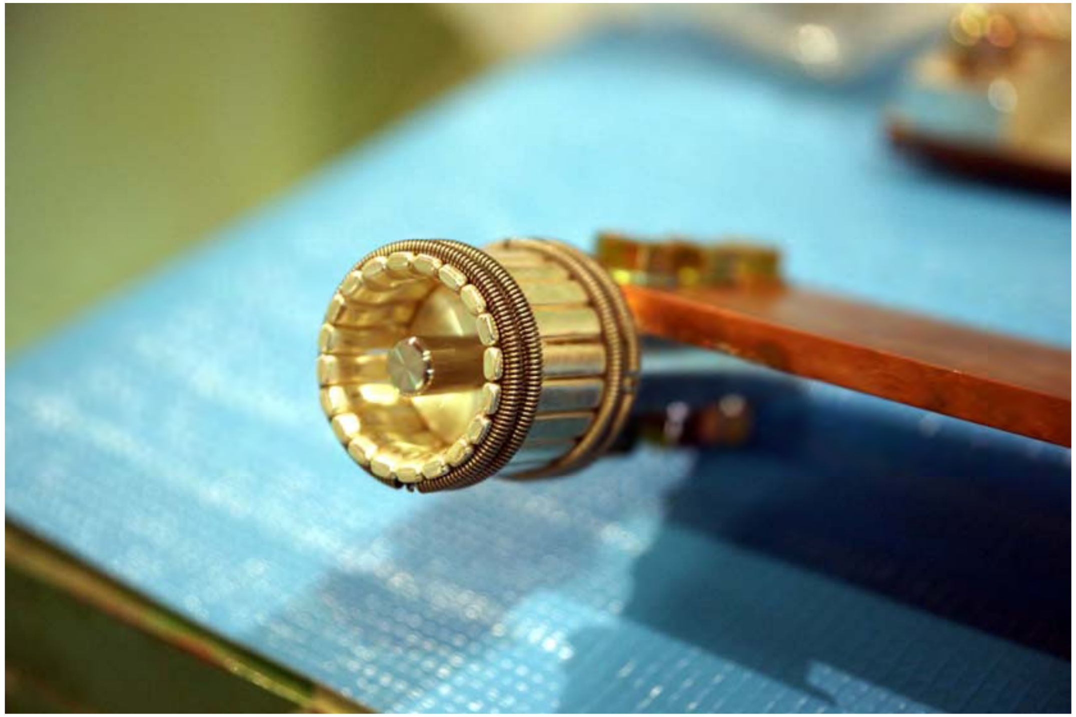




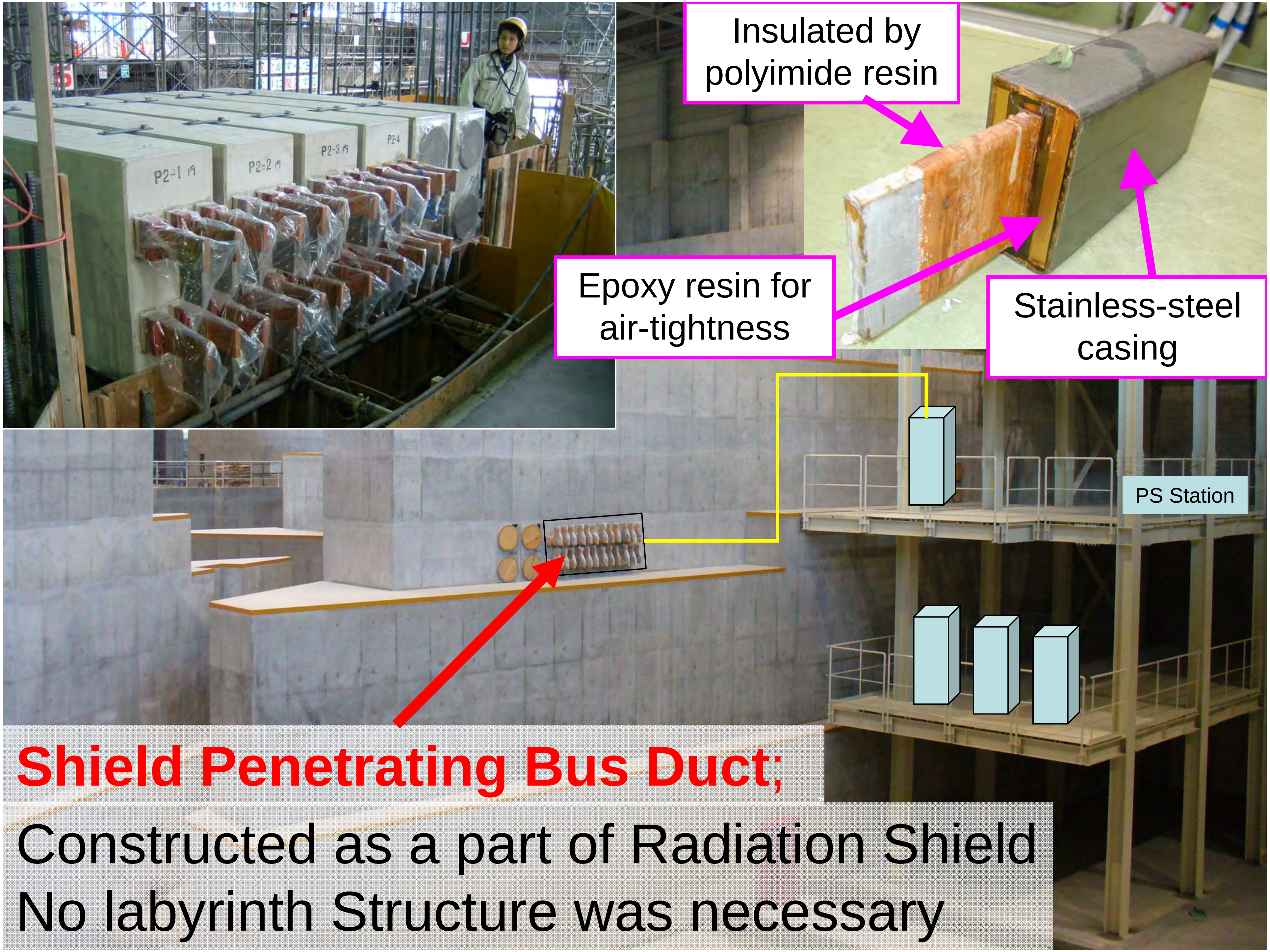


Q.D. Electric Power Connector

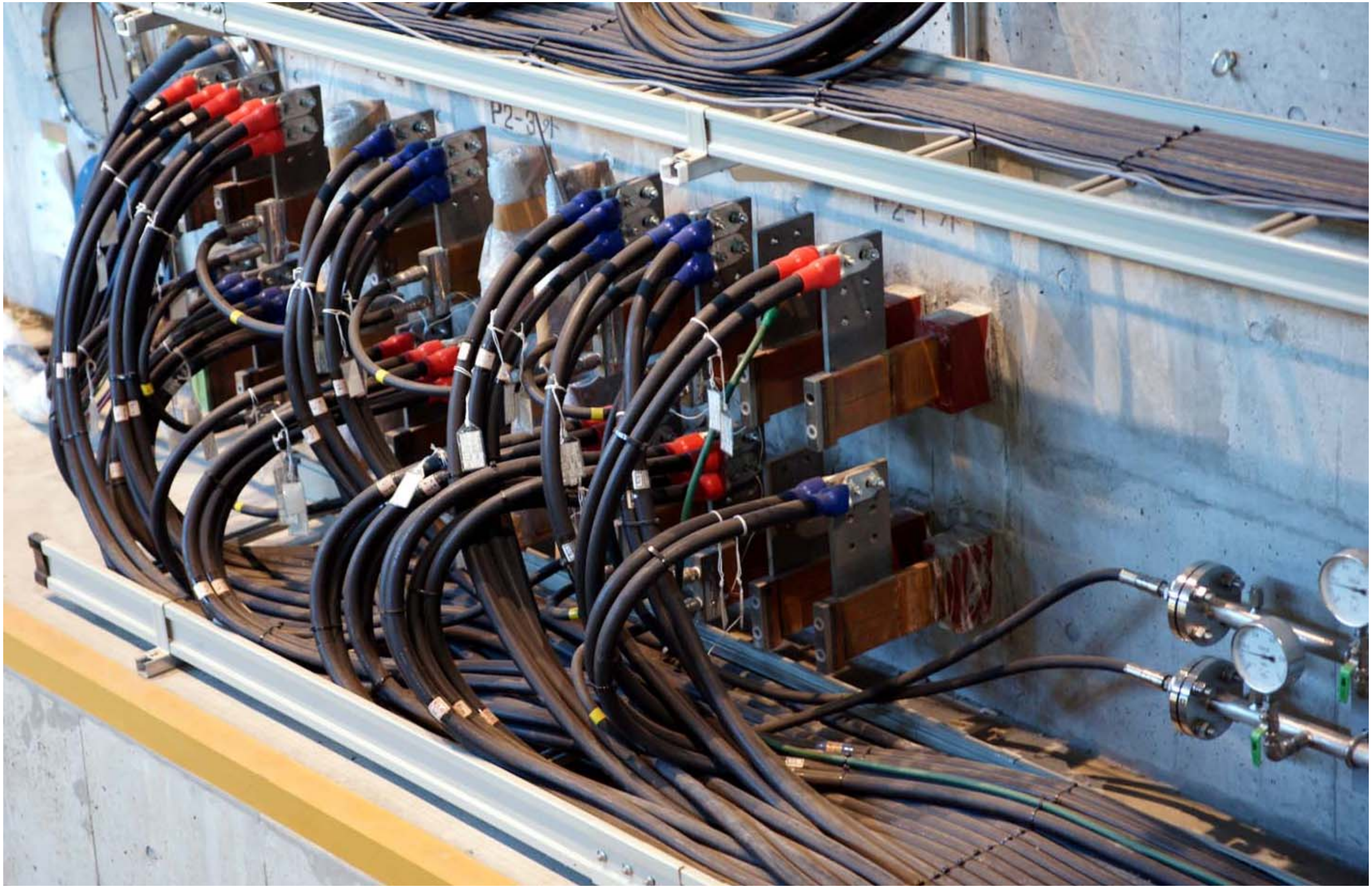




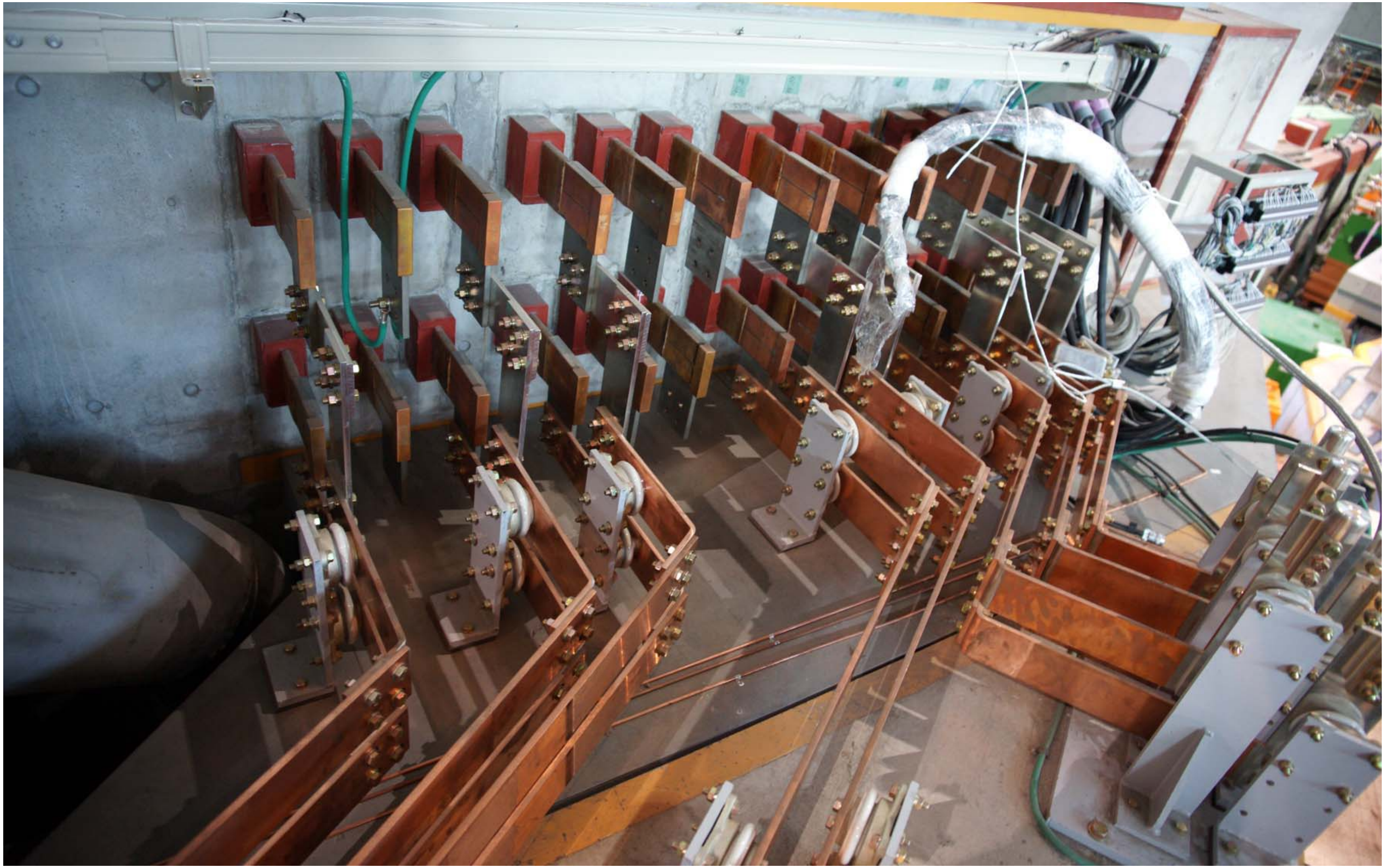
Quick Disconnect device


Insulated by polyimide resin
Epoxy resin for air-tightness
Stainless-steel casing
PS Station
Shield Penetrating Bus Duct;
Constructed as a part of Radiation Shield
No labyrinth Structure was necessary

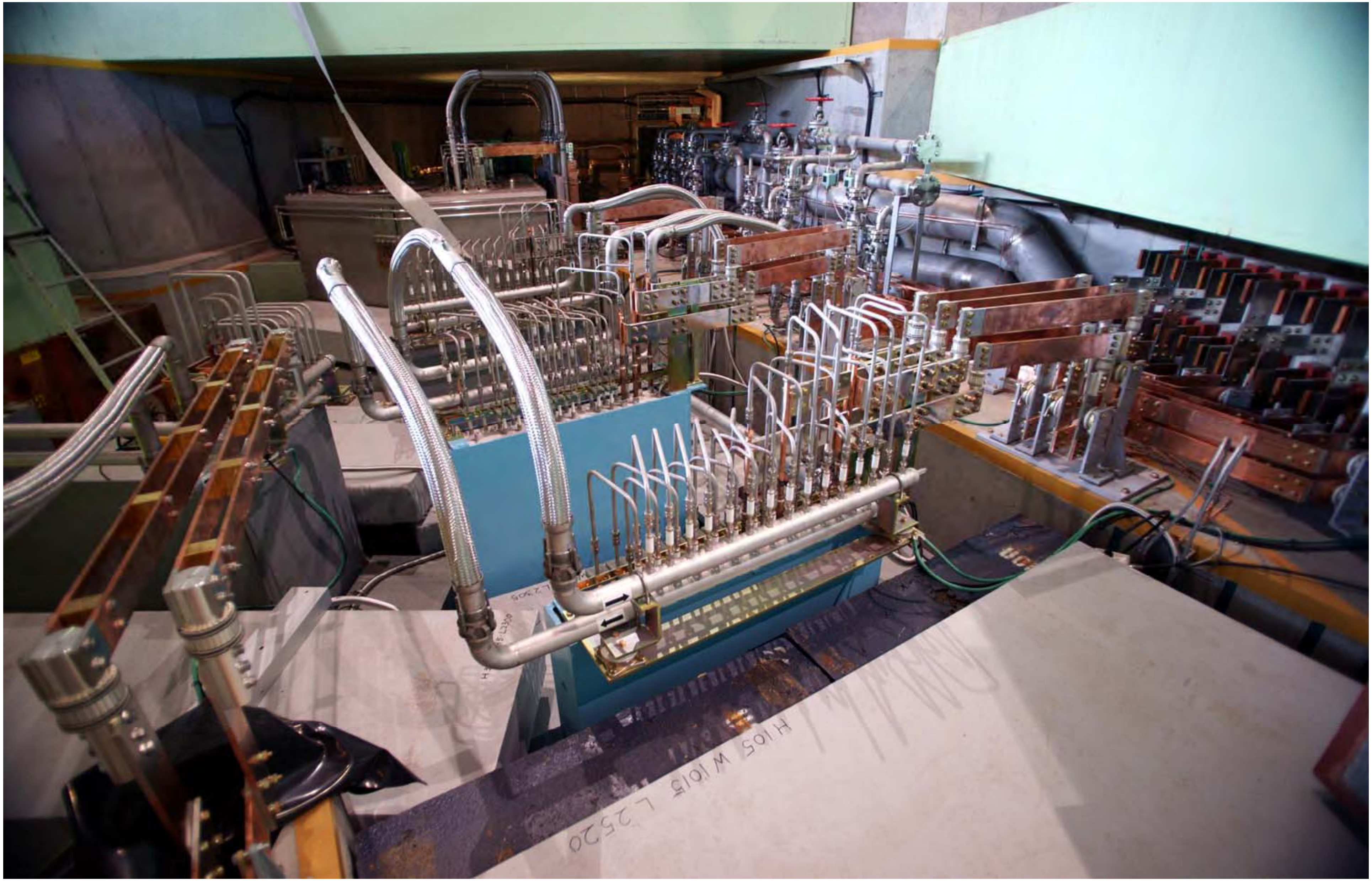
Shield Penetrating Bus Duct (Outside)



Shield Penetrating Bus Duct (Inside)

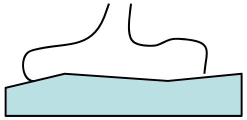


Service Space near T1 Target

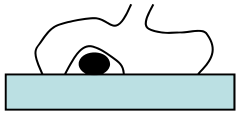


Pillow Seal for Vacuum Connection

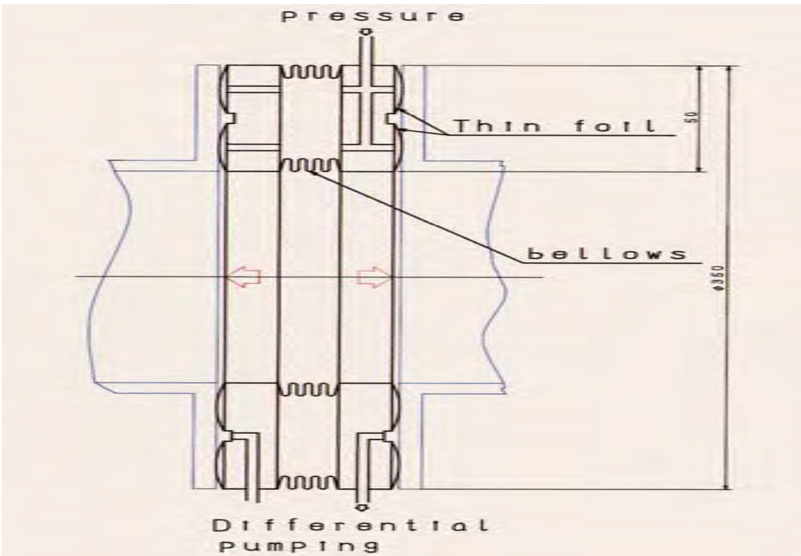
Our first one (1989) for KEK-PS
Effective Dia. = 30cm, Leak rate ~10^{-8}Pa・m^3/s



On non-flat…

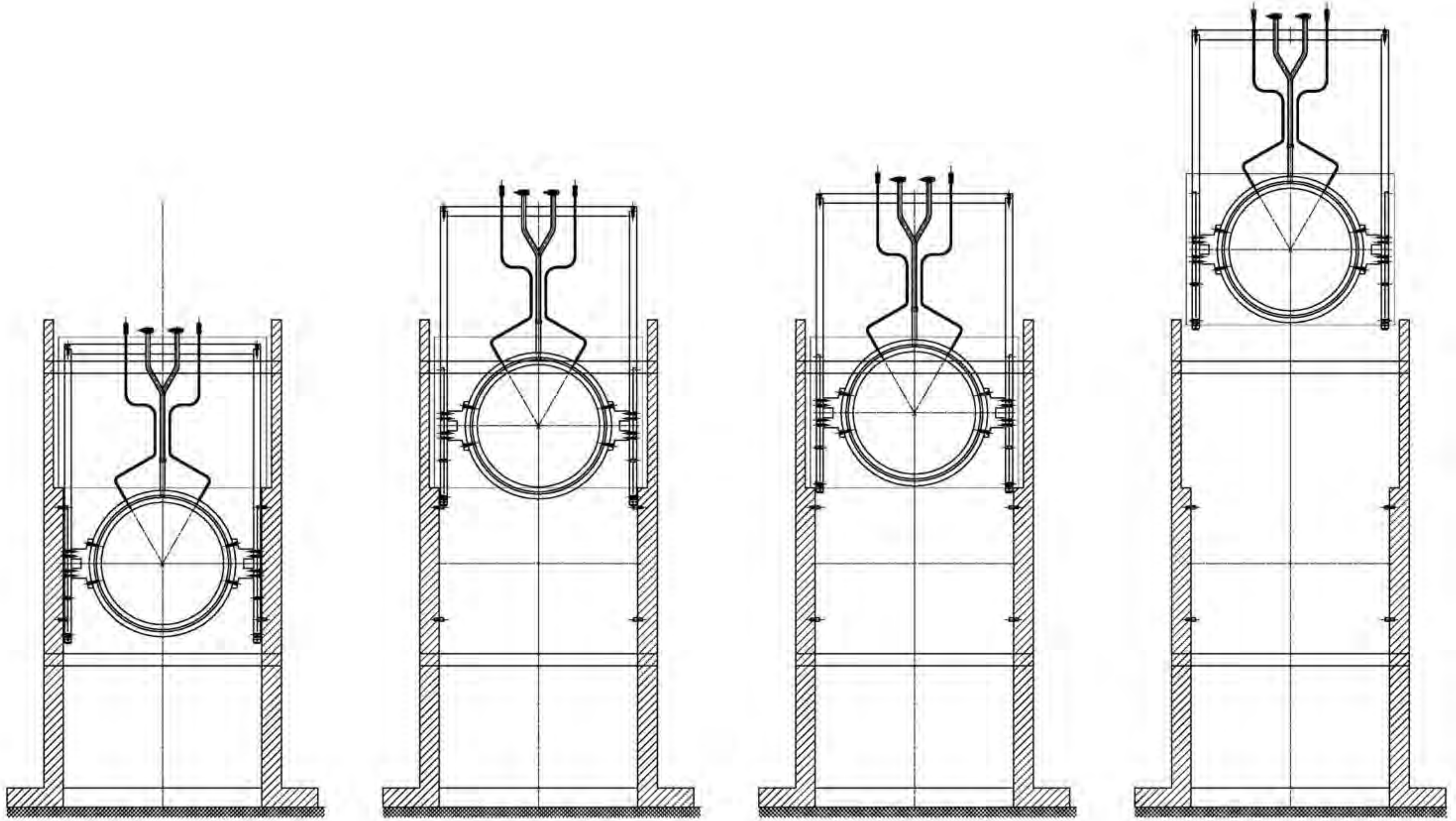


On dust….



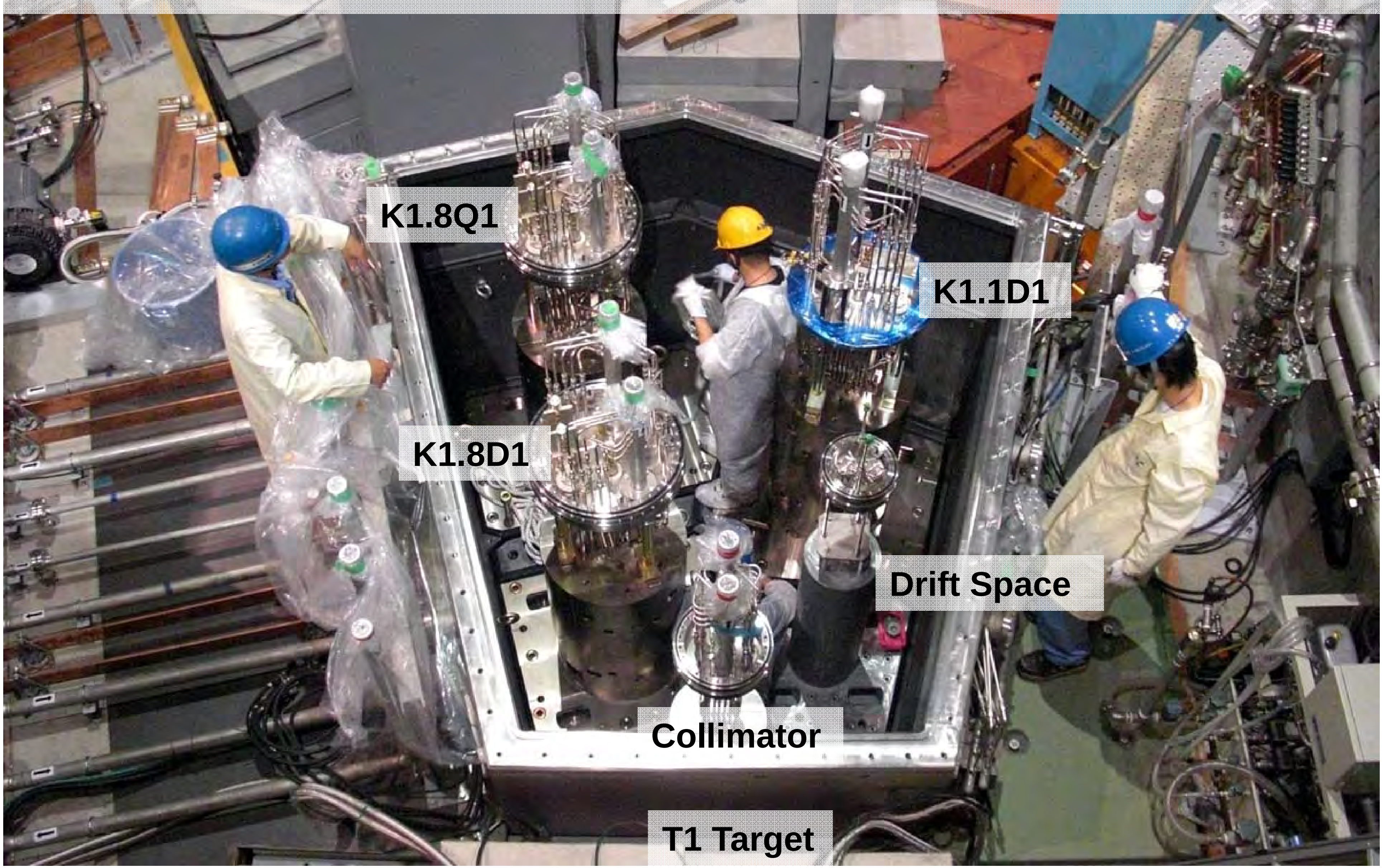
- Now, Leak rate is ~4×10^{-12}Pa・m^3/s
- Effective Dia. >50cm

Pillow Seal for Vacuum Connection

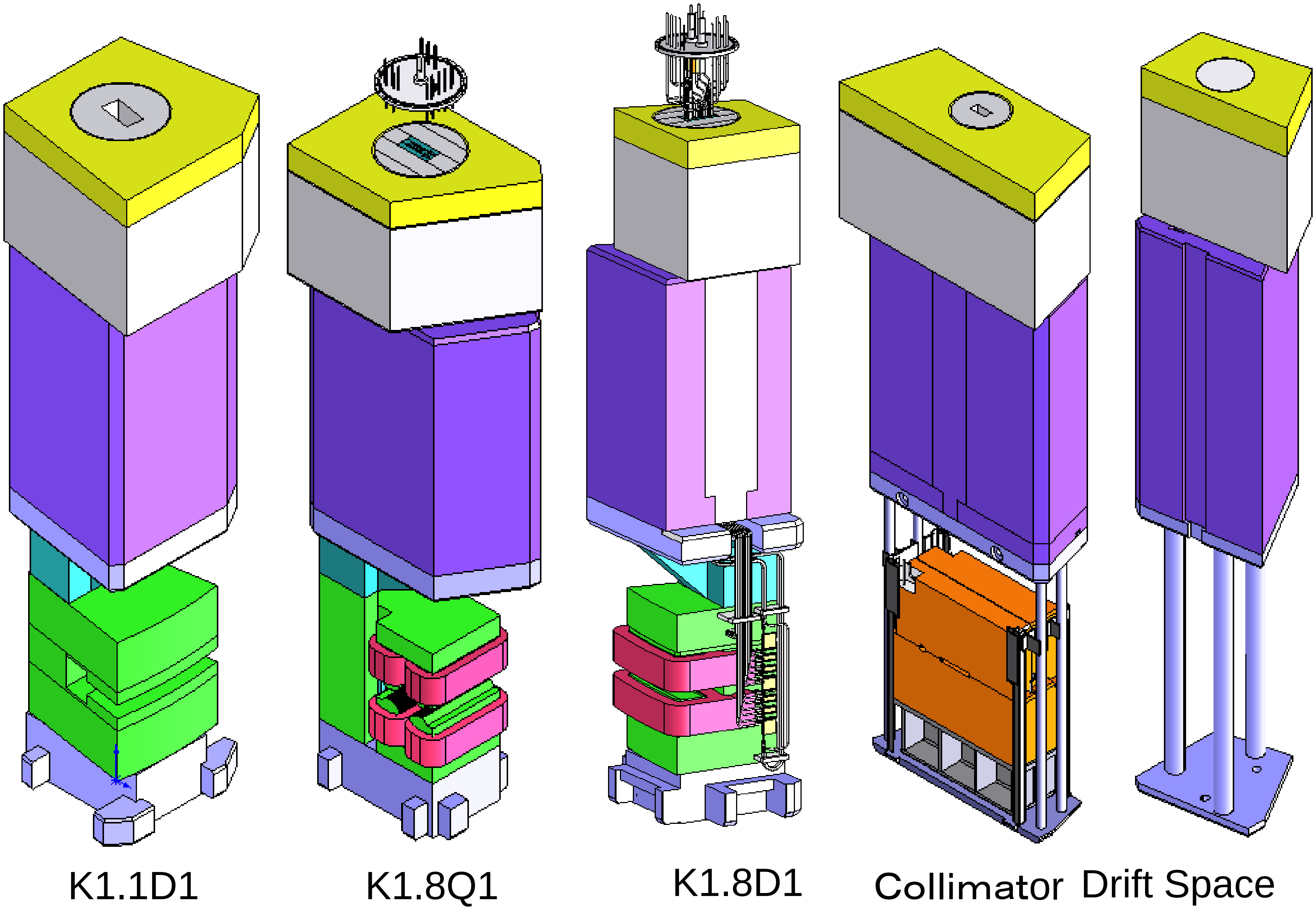


Special System for T1 Area

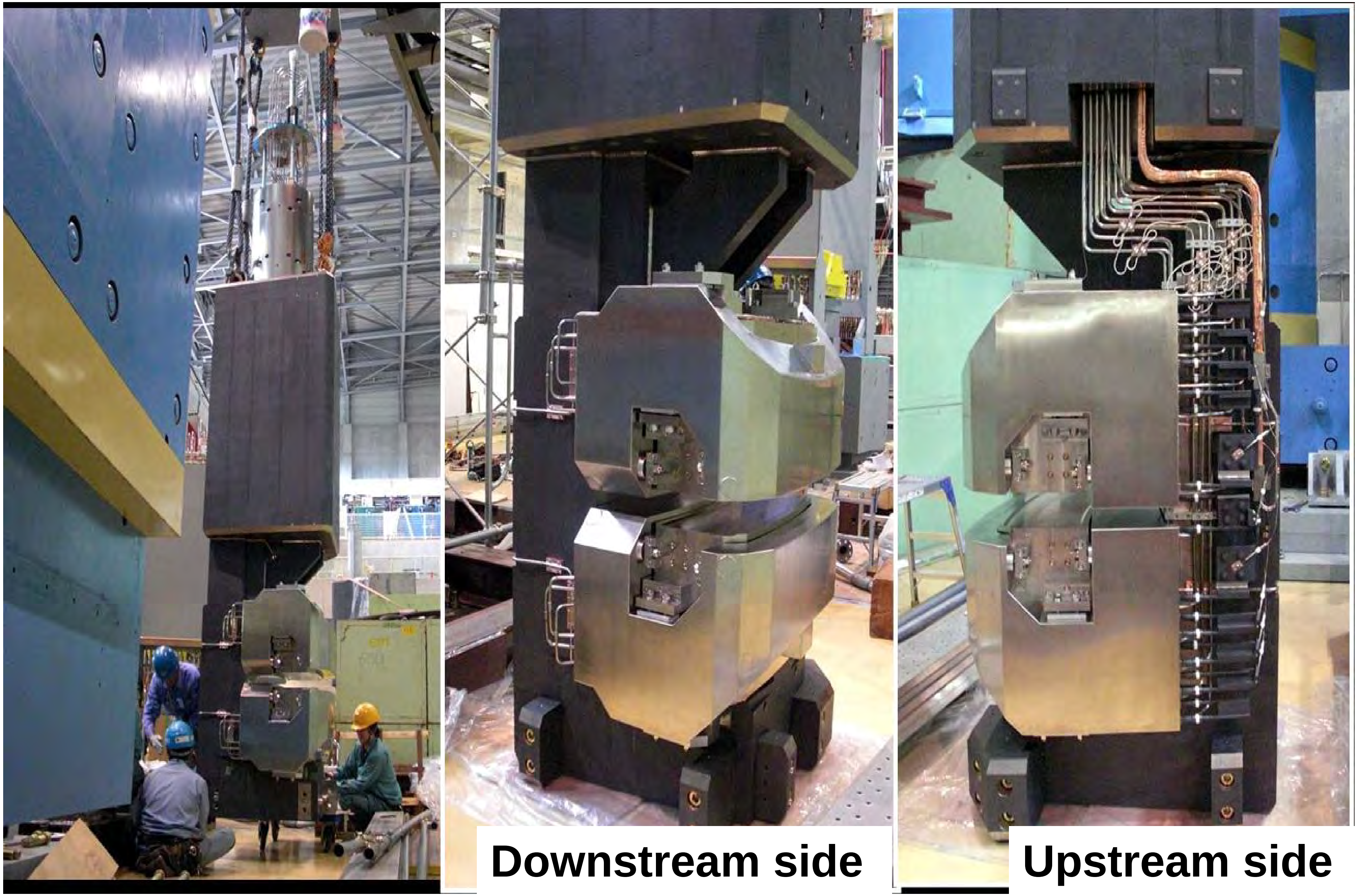
The most upstream part of K1.1



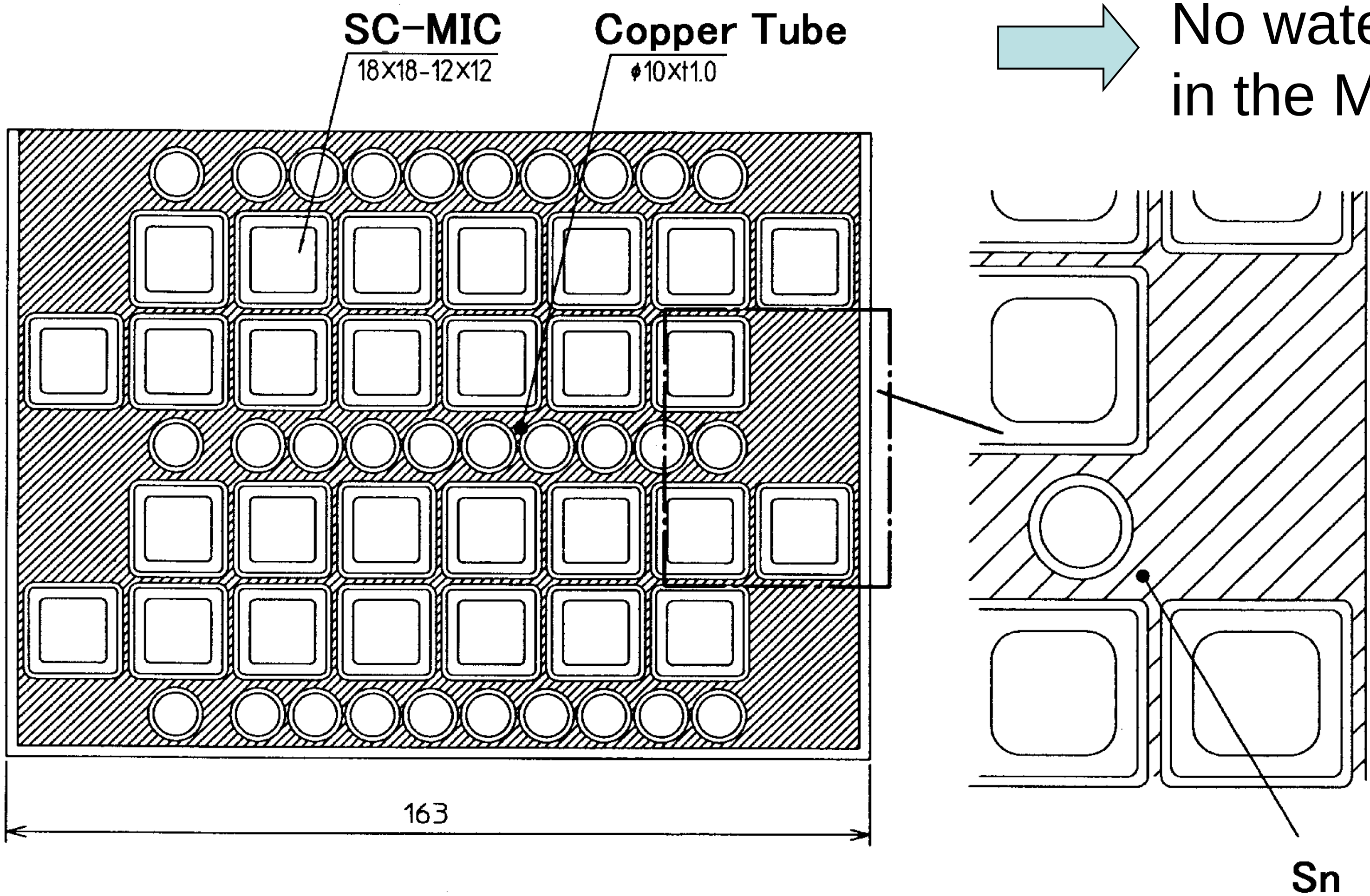
Modules



Super Radiation Hard Magnet: K1.1D1



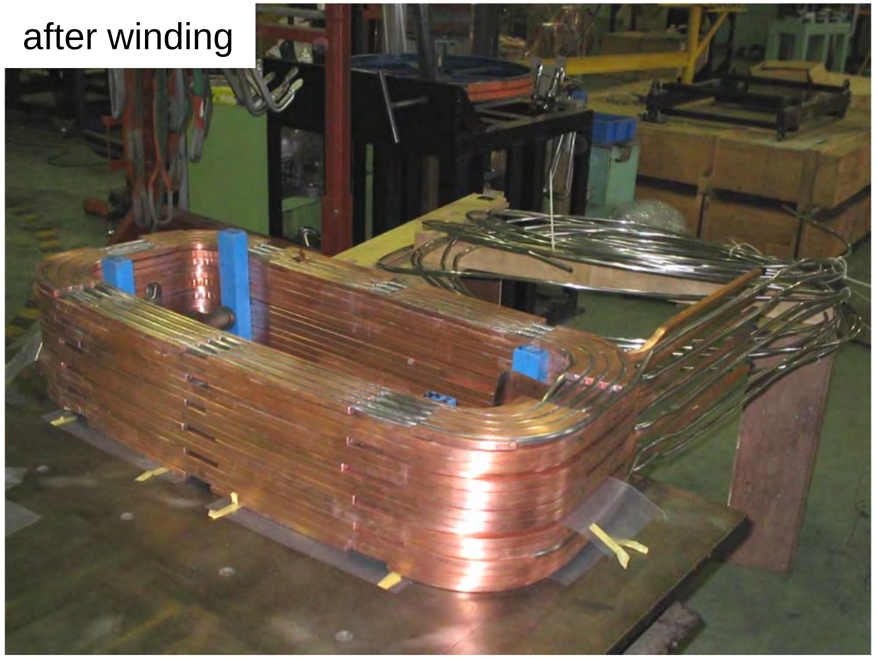
Solid MIC with Indirect Water Cooling

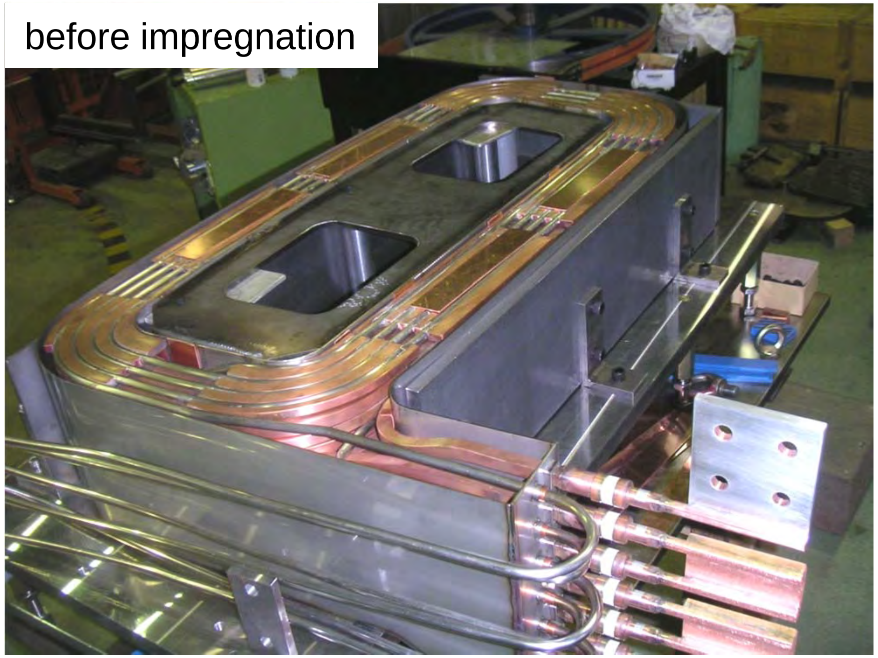


No water Leak in the Magnet

- SC-MIC is sandwiched by cooling tubes.
- Whole coil is impregnated by tin.

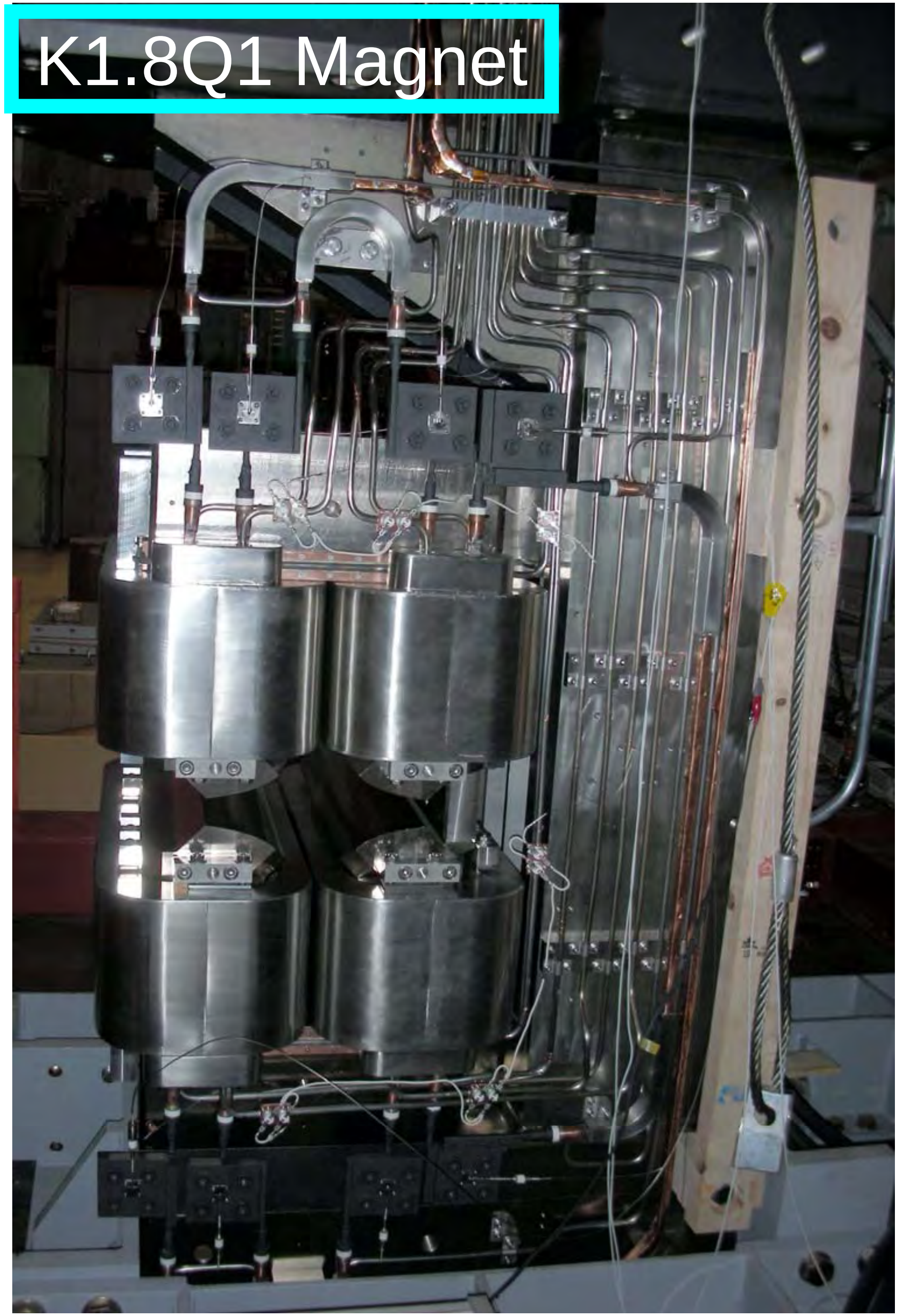
Manufacturing SC-MIC Coil for K1.8D1


after winding

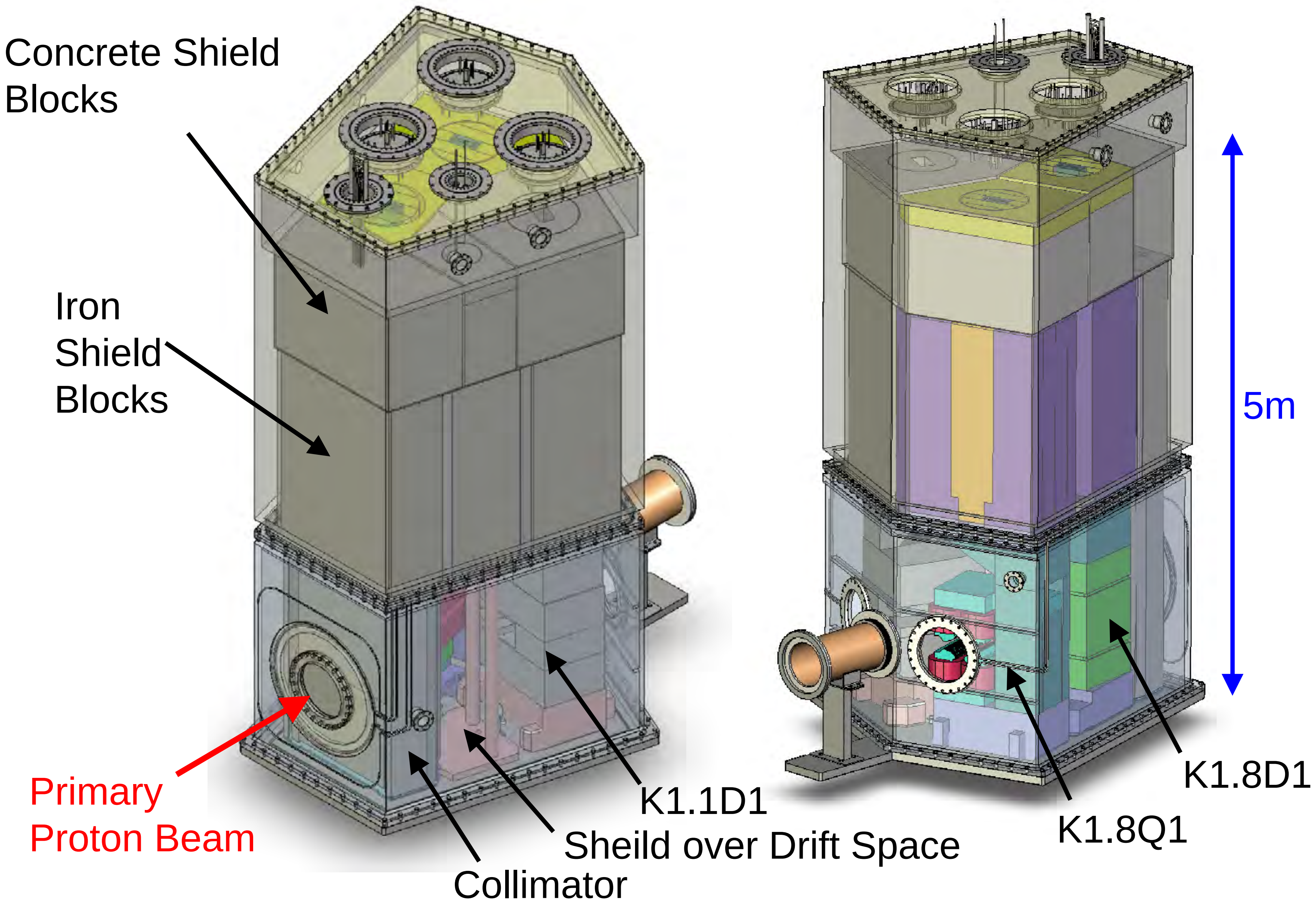

before impregnation


after impregnated by solder


before welding lid to stainless-steel casing


K1.8Q1 Magnet

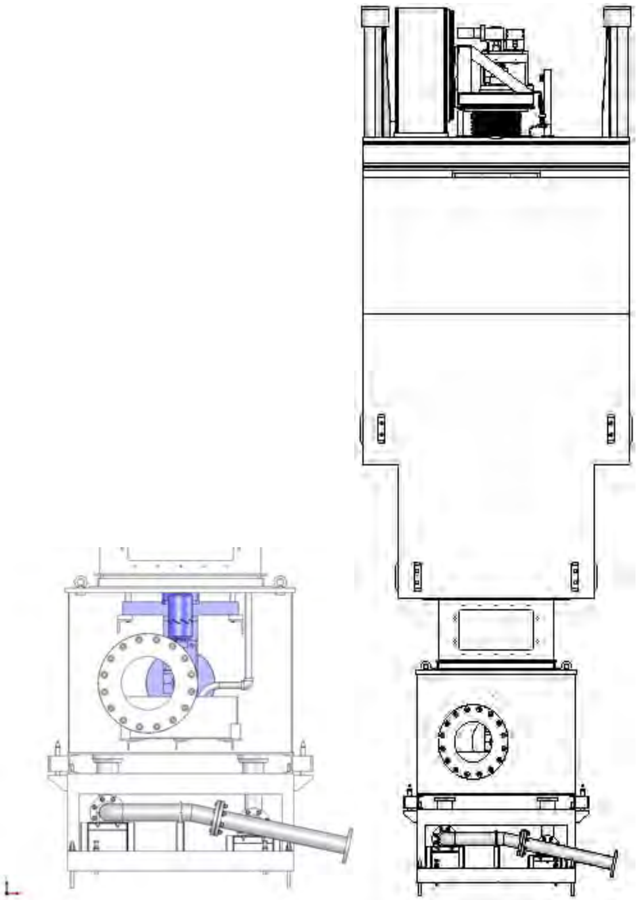
Vacuum Chamber



Central Vacuum Chamber

주식회사 지 엠
GOOD MORNING ENGINEERING CO. LTD

T1 Target Area

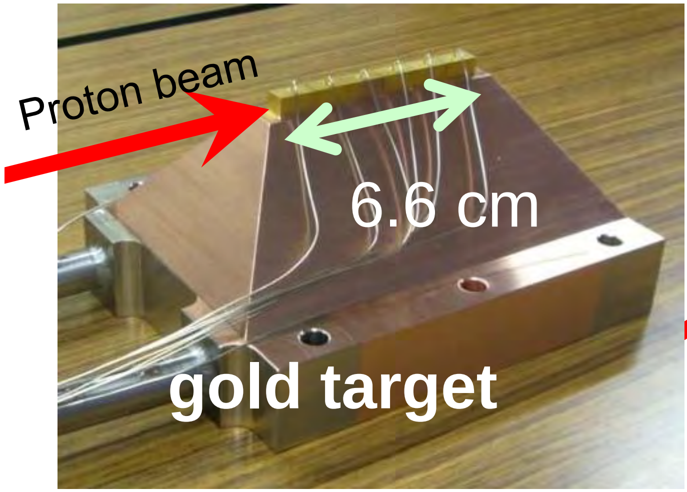


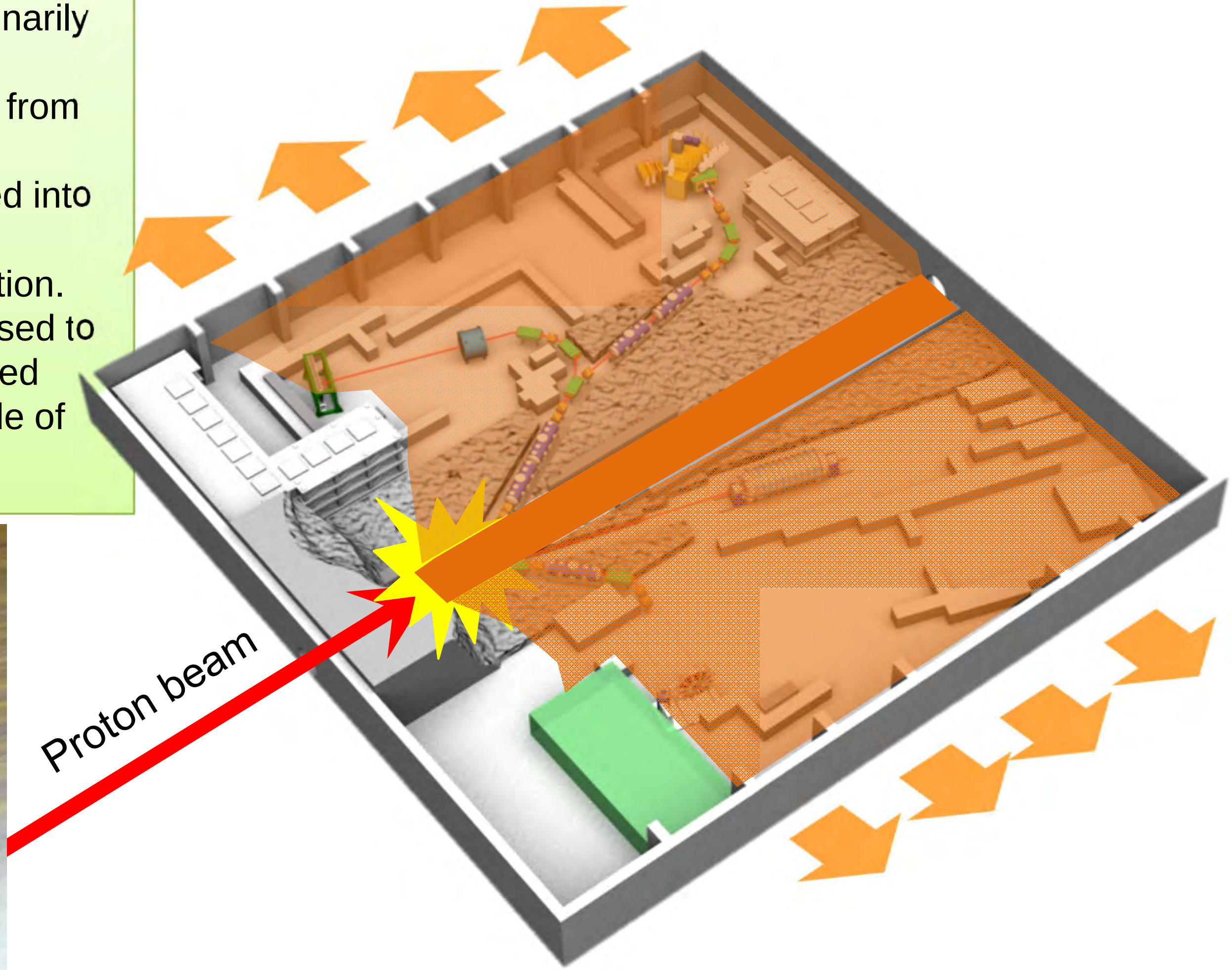
Target and Hadron Hall Incident

Radioactive Materials Leak Incident

11:55 on May 23, 2013

- An abnormal proton beam was injected to the gold target.
- The target heated up to a extraordinarily high temperature.
- Radioactive material was released from the target.
- The radioactive material was leaked into the HD hall.
  → Workers were exposed to radiation.
- The radioactive material was released to the outside of the radiation controlled area and to the environment outside of the HD hall.

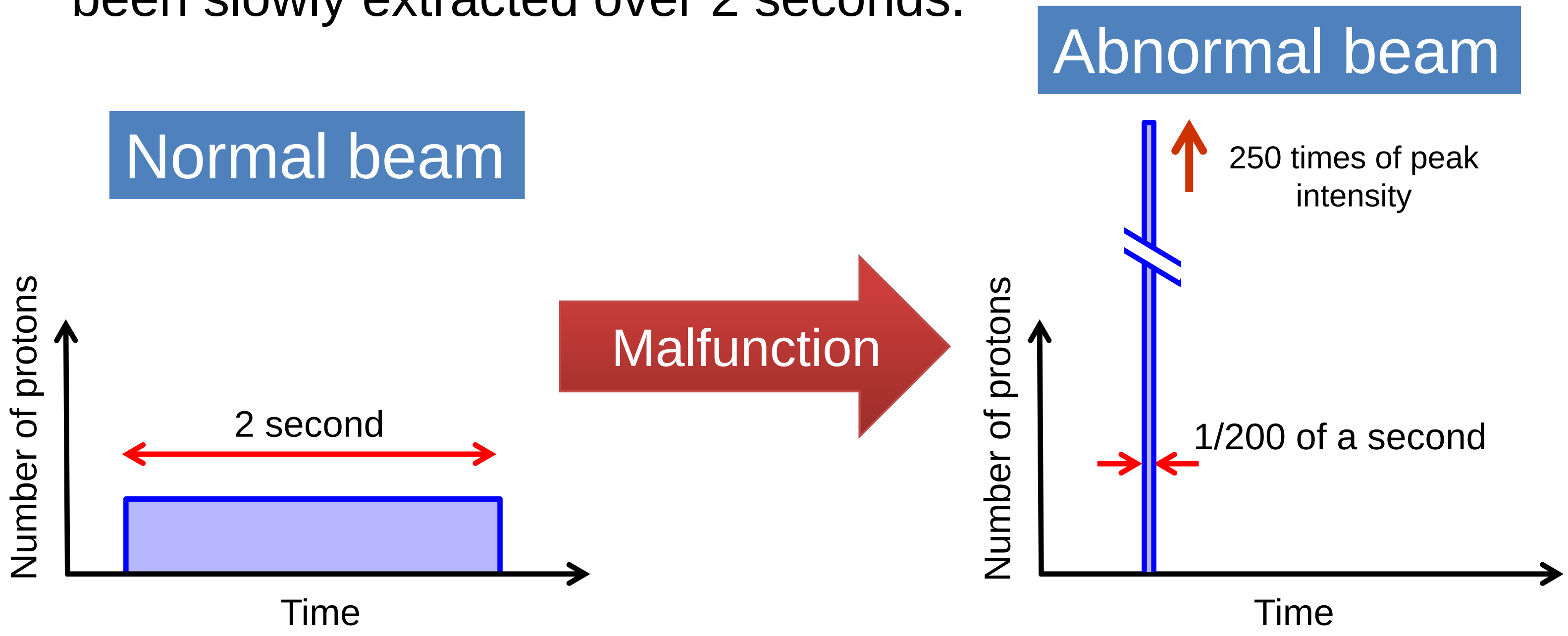




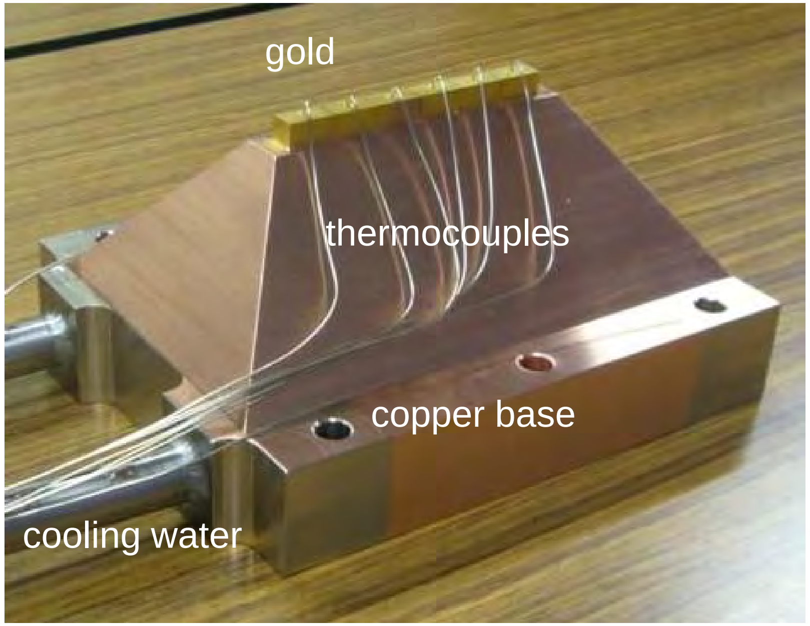
Abnormal Beam

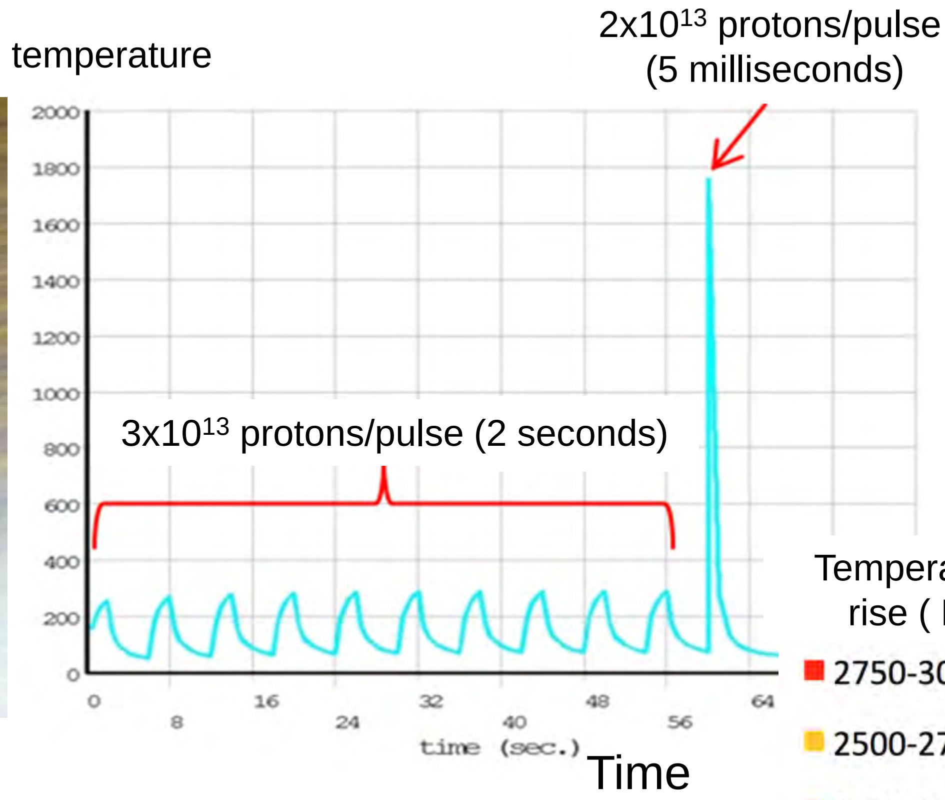
- At around 11:55 on May 23, the power supply system of a special magnet in the 50 GeV Synchrotron malfunctioned.

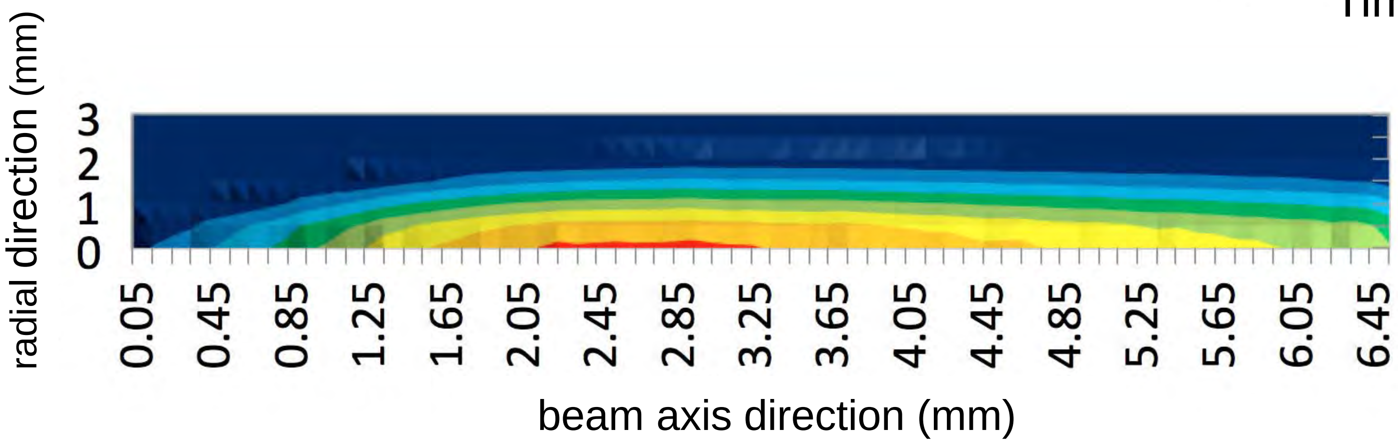
→ $2x10^{13}$ protons were extracted in a very short period of 5 milliseconds, while in normal operation $3x10^{13}$ protons should have been slowly extracted over 2 seconds.



Target Temperature（Simulation Results）



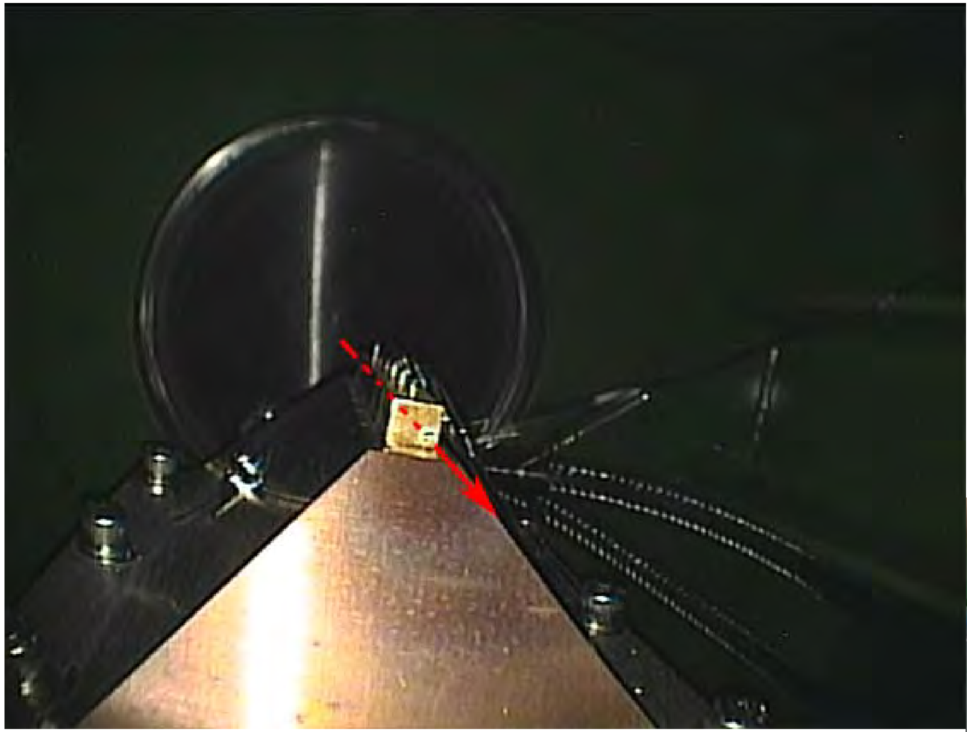




Temperature rise (K)

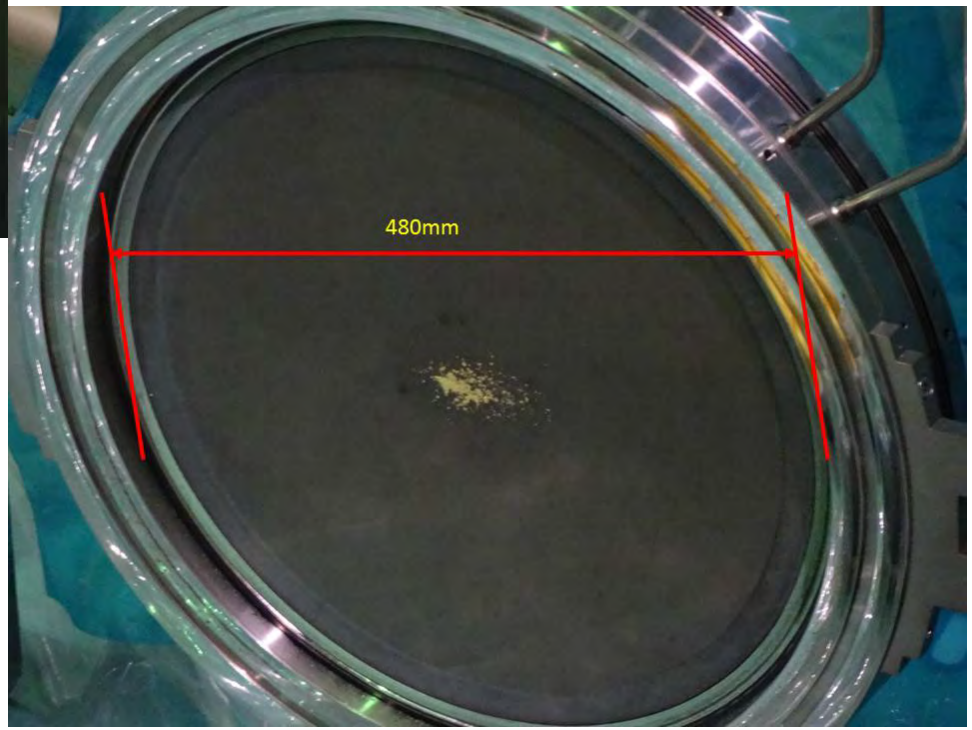
- 2750-3000
- 2500-2750
- 2250-2500
- 2000-2250
- 1750-2000
- 1500-1750
- 1250-1500
- 1000-1250

Observed Au Target



Au target observed from the downstream: a 1mm in diameter hole was seen at the downstream end.

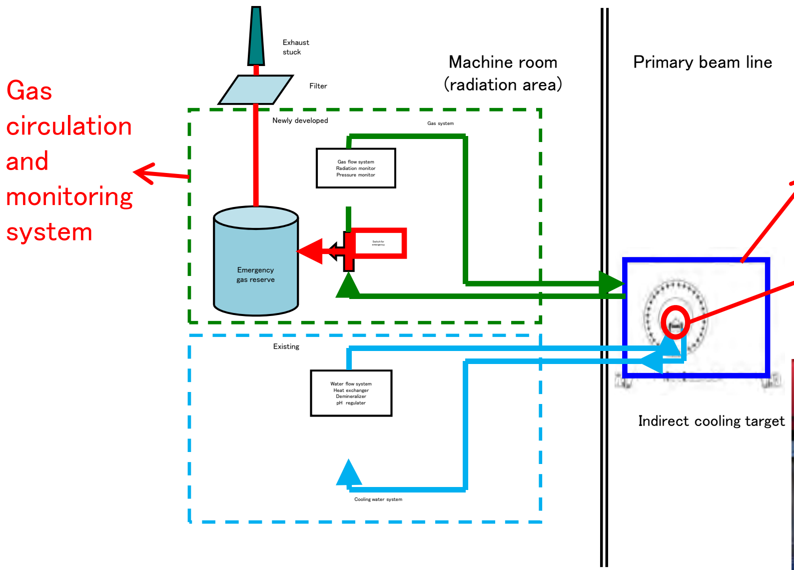
Traces of sprayed-out melting gold at the Be window at the downstream

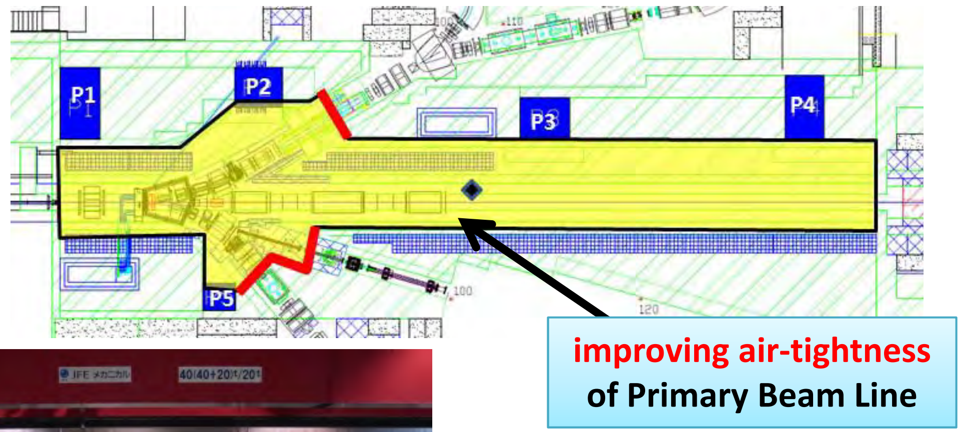


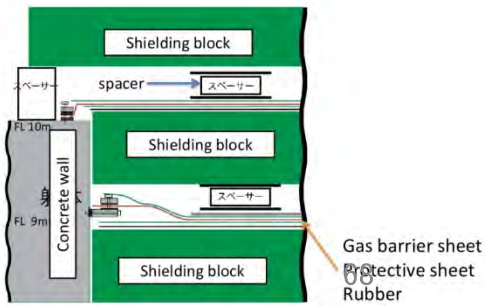
These observations well match with our simulation results.

Countermeasures

- Hardware:
  - Strengthen interlocks including the accelerator side
  - Airtight target chamber and gas circulation system
  - Reinforced airtightness of the primary beam line
  - Air exhaust system and monitors at the Hadron Hall
- Software: organization, manuals, etc.

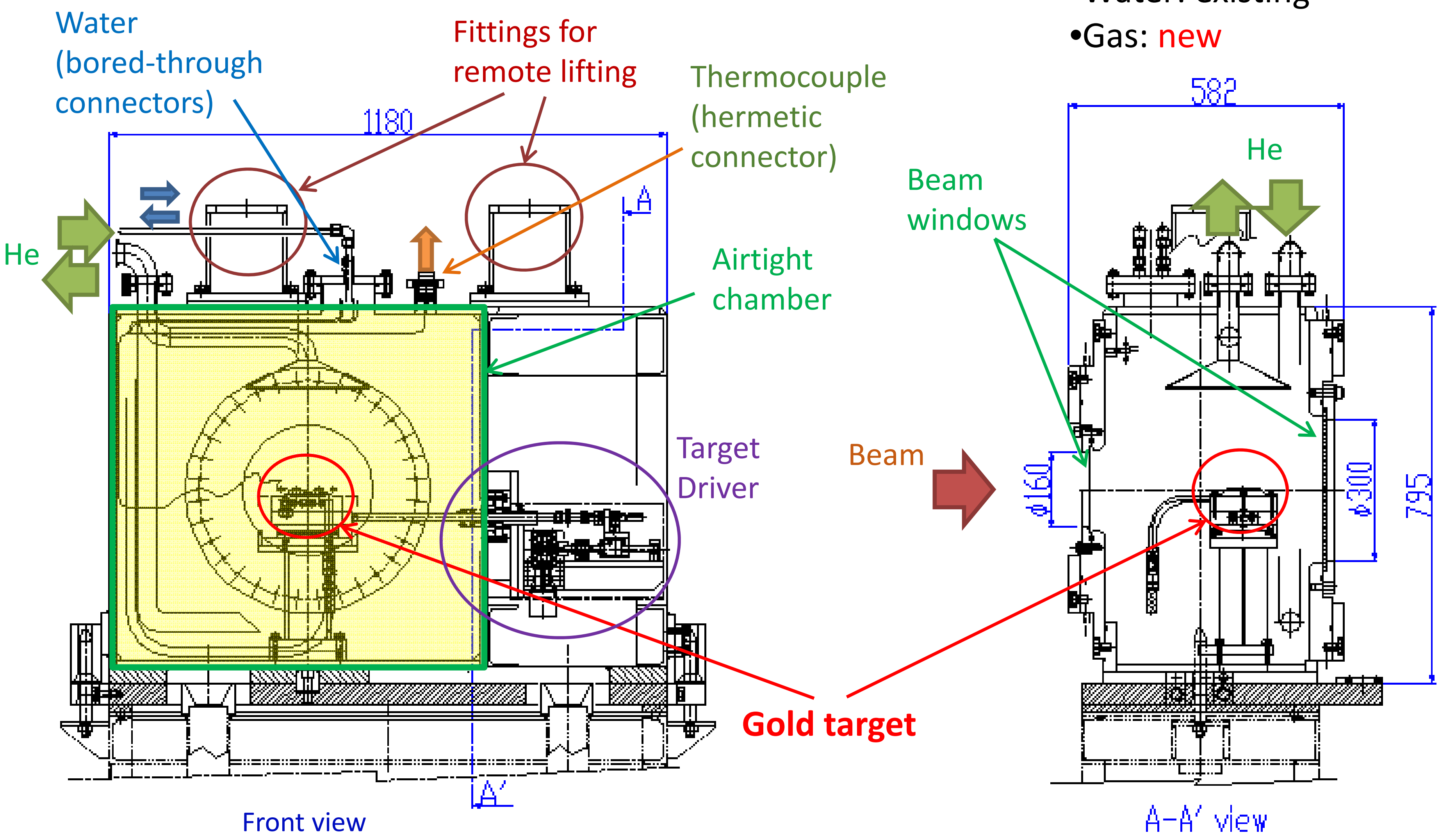






Structure of New Target chamber

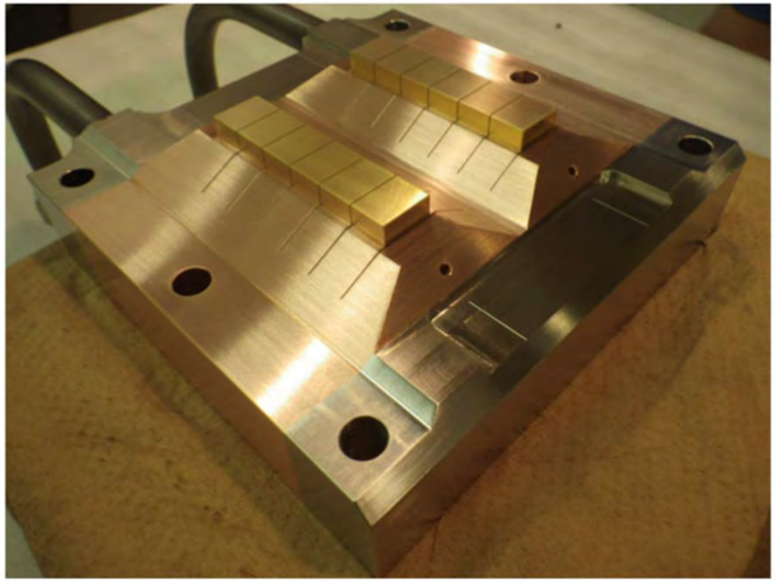
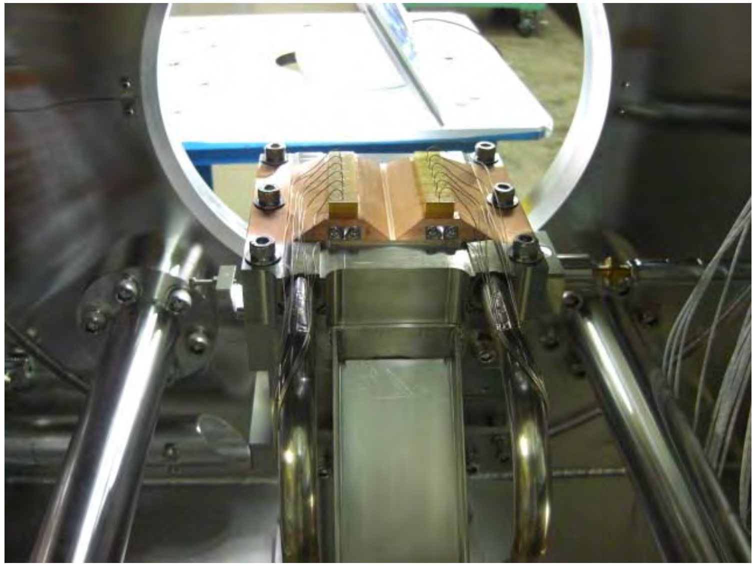
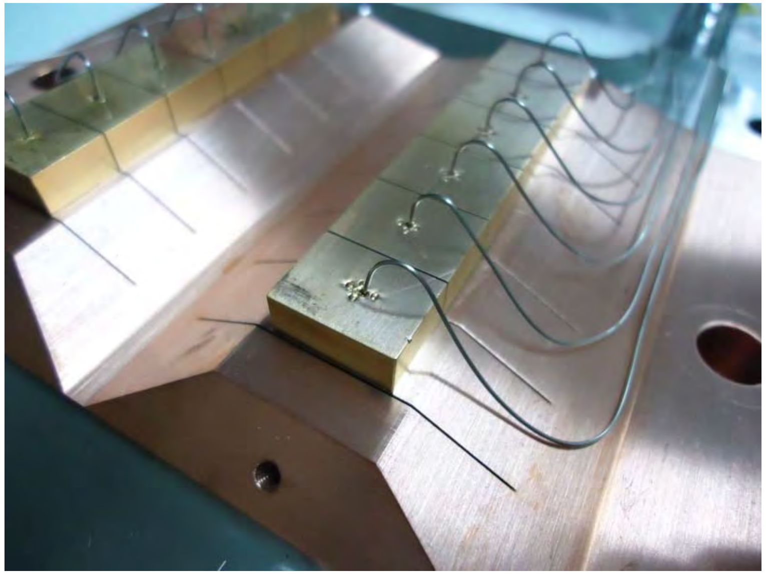
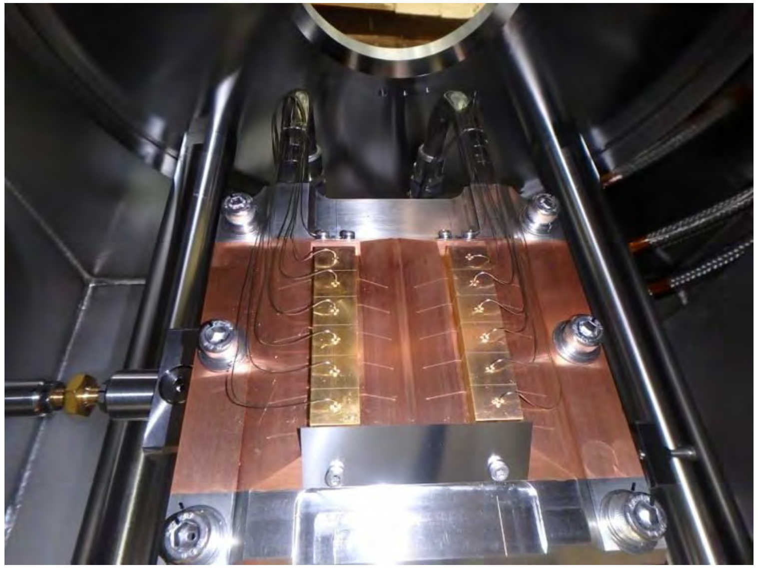
Circulation System
- •Water: existing
- •Gas: new



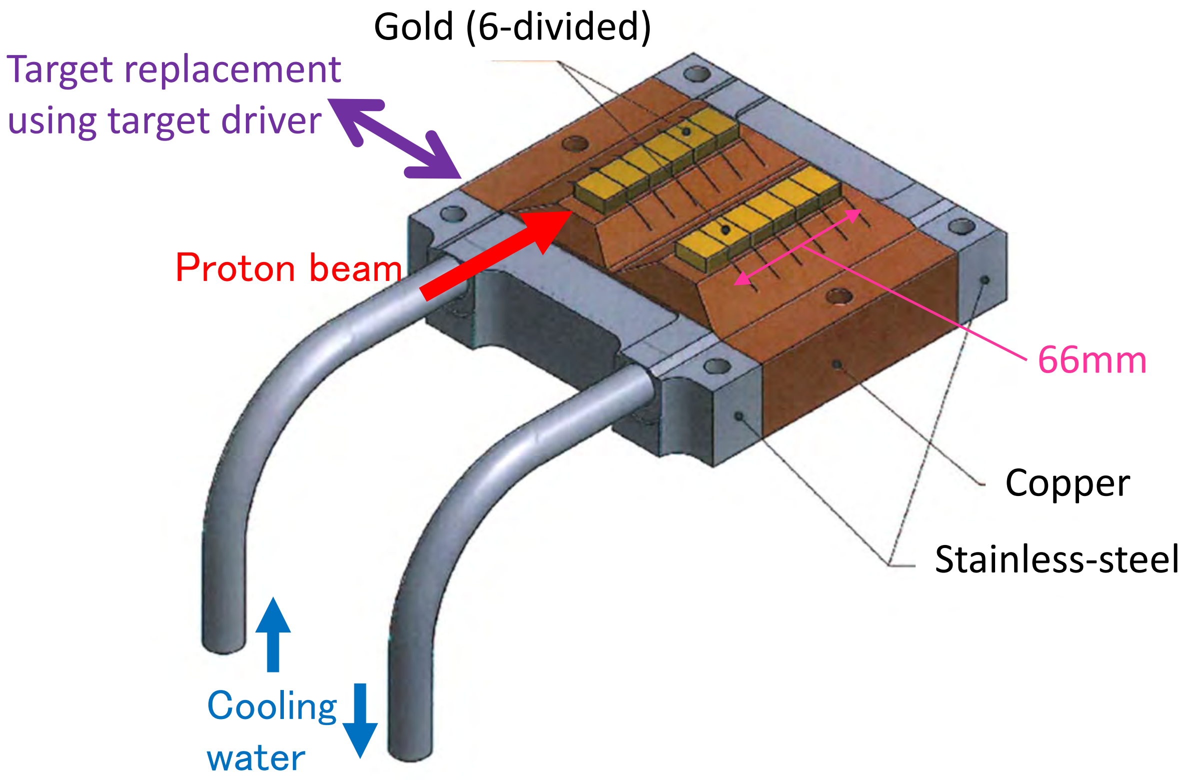
Since the beam windows are always exposed to a primary beam directly,
we designed the windows to keep their soundness even in the case of 5-μs pulse beams.

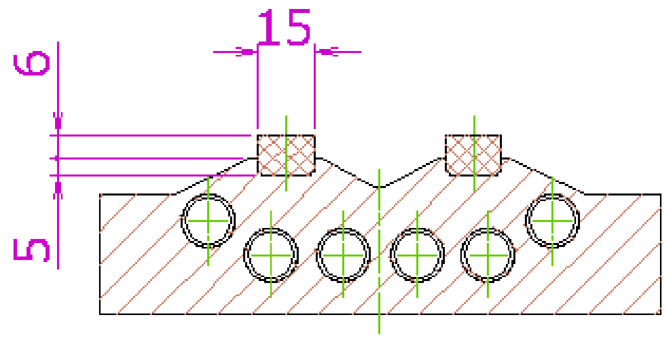
* 5-μs = revolution of Main Ring

2519 標的組込作業写真

Structure of New Target





Cross-sectional view

*Gold, copper, and stainless-steel are bonded by **HIP (Hot Isostatic Pressing)**

Improvements

- Gold is partially sunk in copper block to avoid instantaneous separation of gold from copper.
- Cooling pipes are located closer to gold for efficient cooling.
- Width of gold is incleased (6 => 15) for wider beam.
- 2-headed structure for quick and remote replacement of target.

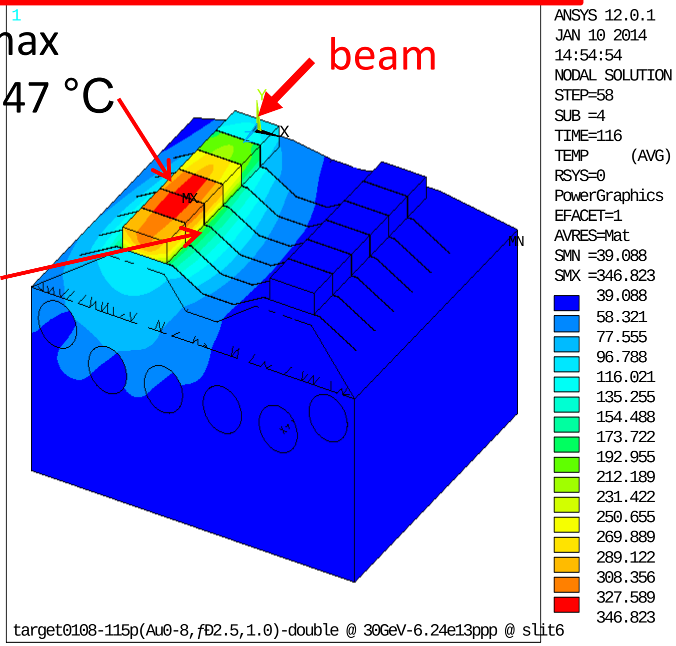
Result of Thermal Analysis of Target (50kW)

In normal operation (2-sec extraction)

max
347 °C

beam

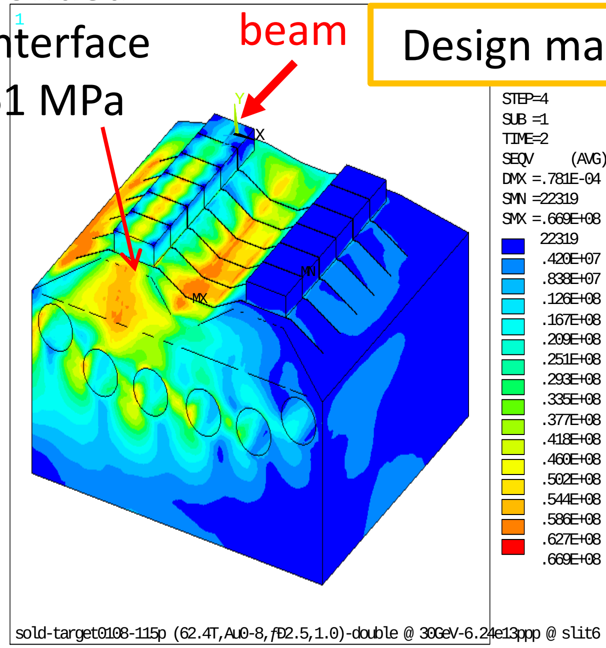
Bonded
interface
225 °C



Bonded
interface
61 MPa

beam

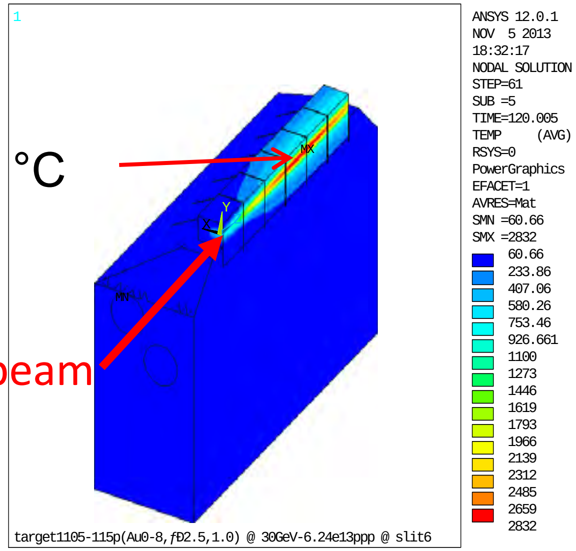
Design margin: 2.1



In accident (5-msec extraction)

max.
2832 °C

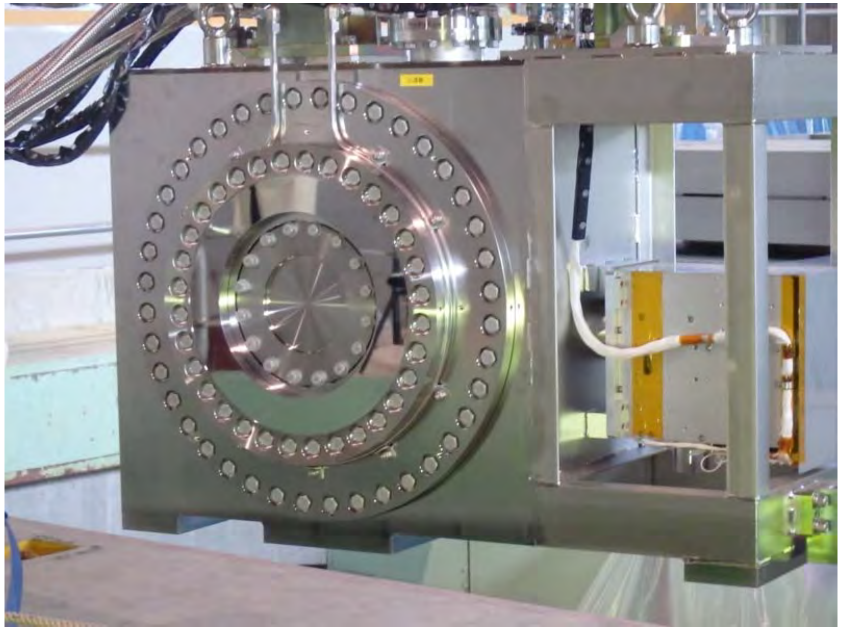
beam

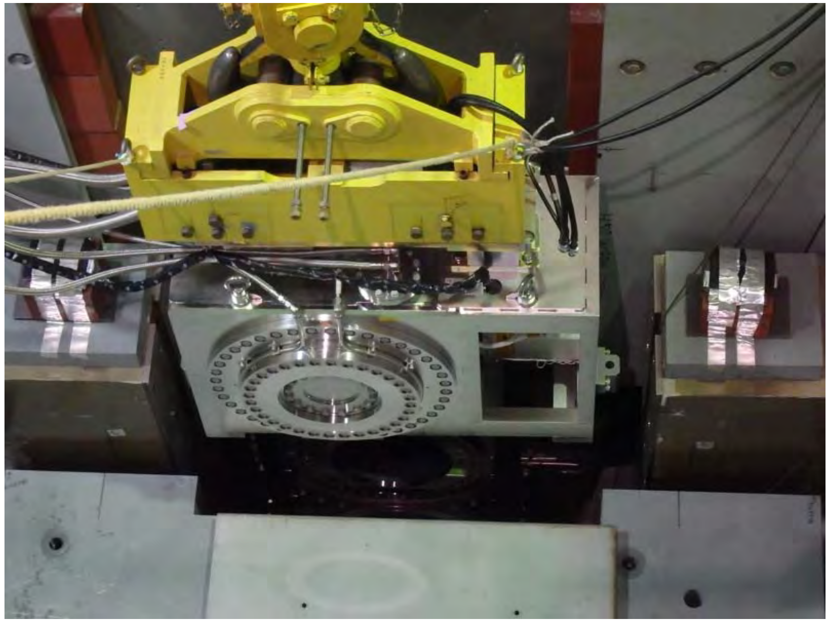


Bonding strength:
171MPa(@25°C)
137MPa(@200°C)
76MPa(@400°C)
linear interpolation:
129MPa(@225°C)

*Latent heat and radiation cooling are not included.

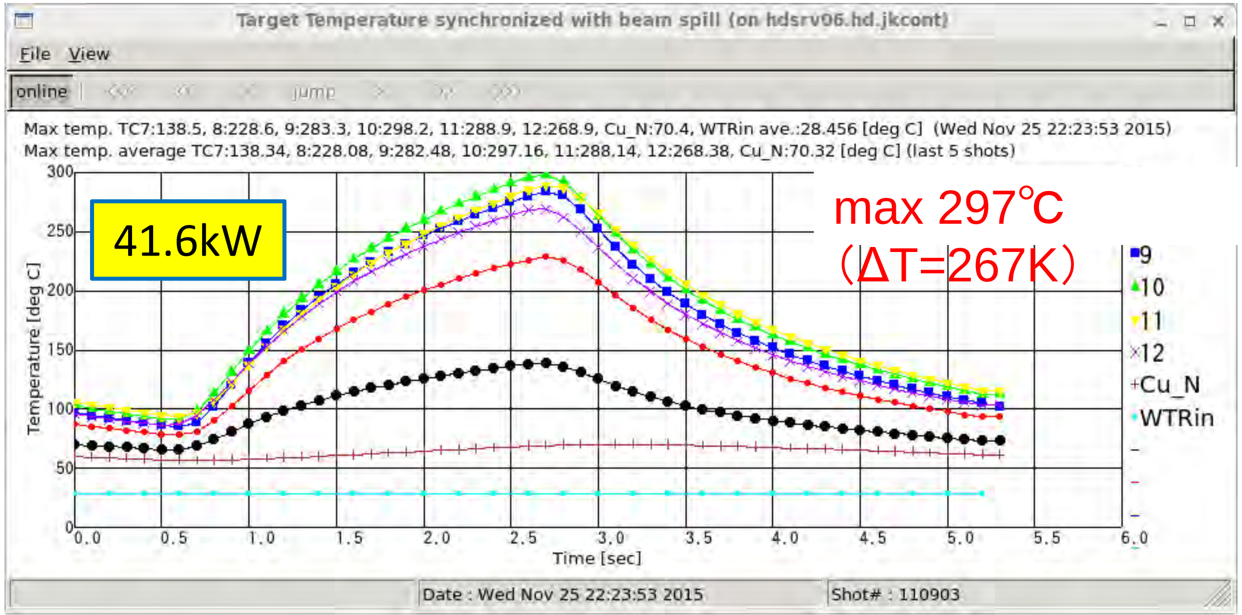
New Chamber Installation

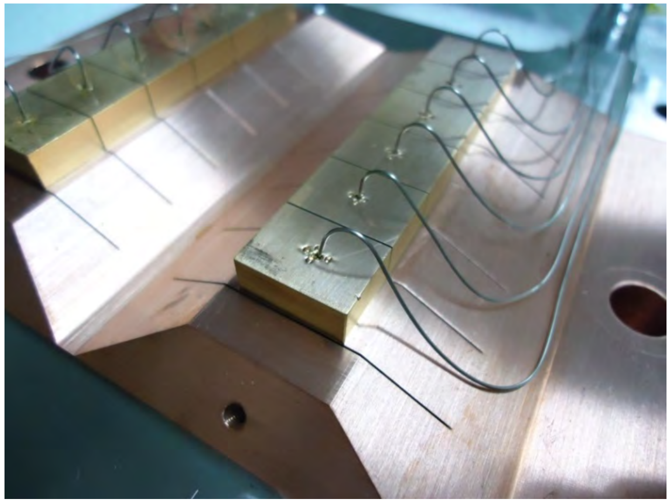


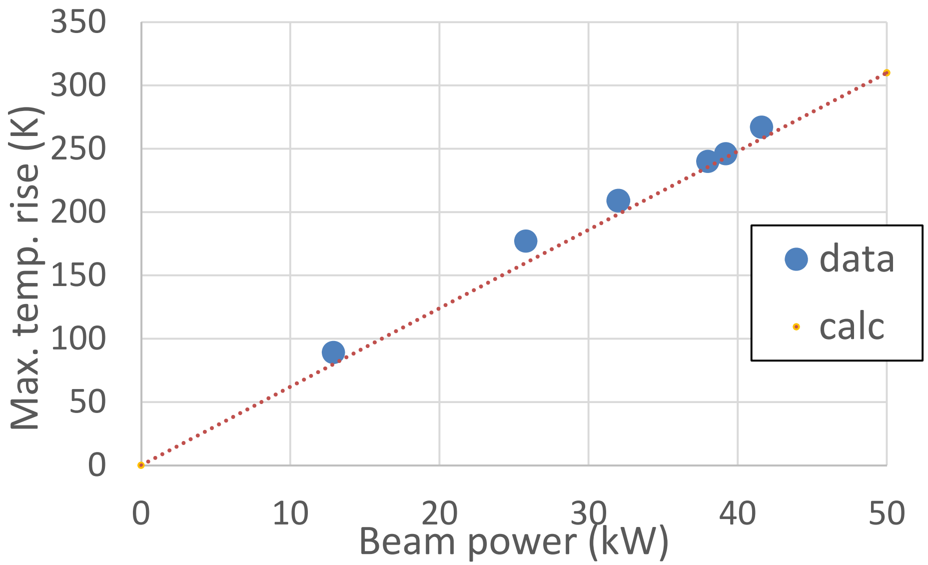


Sept 30, 2014

T1 Target Temperature (41.6kW, 5.52s-cycle)







Restart of Hadron Facility User Run, 2015 April 24.