J-PARC neutrino Cryogenics system

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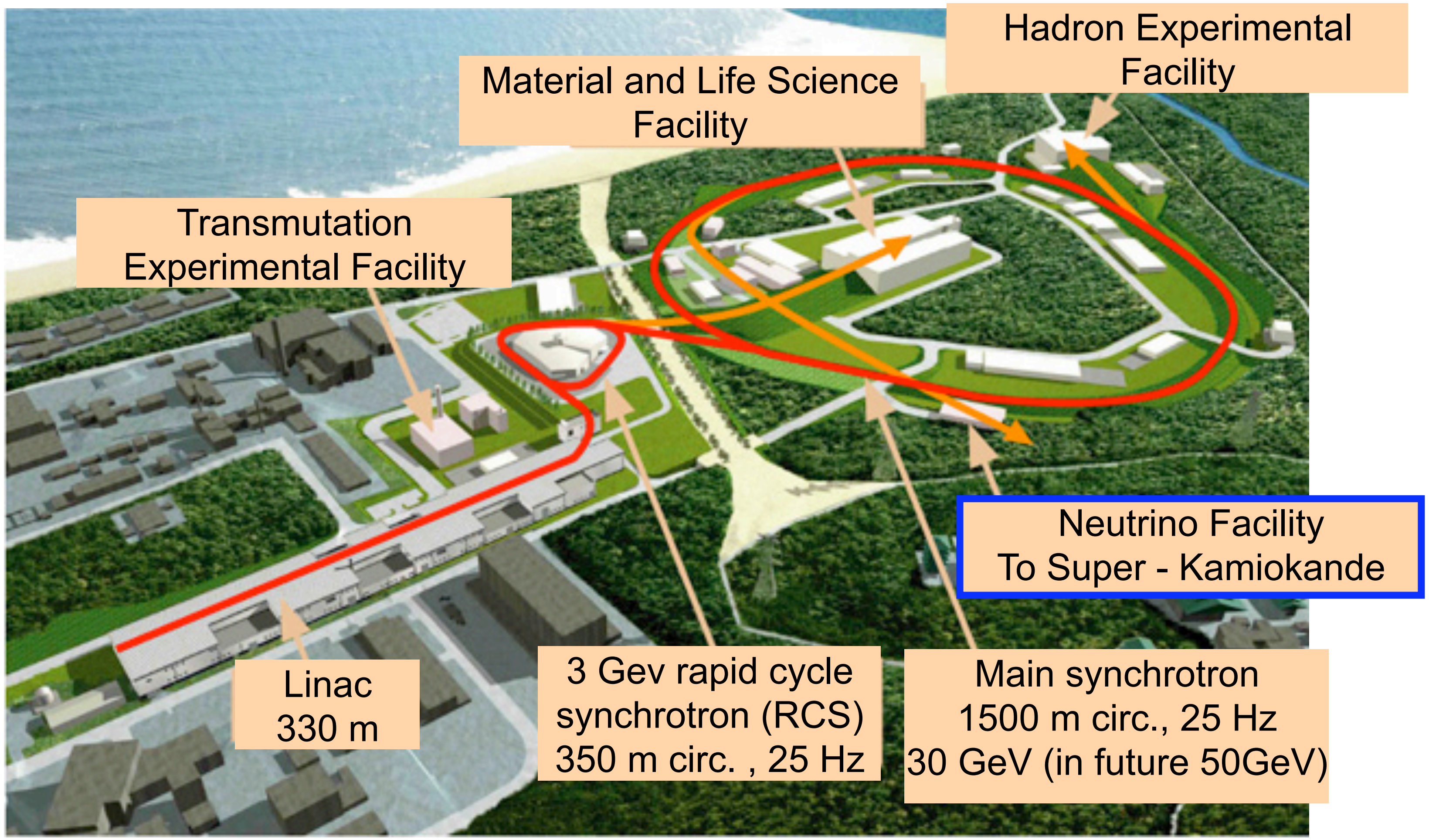
1. Purpose of T2K experiment

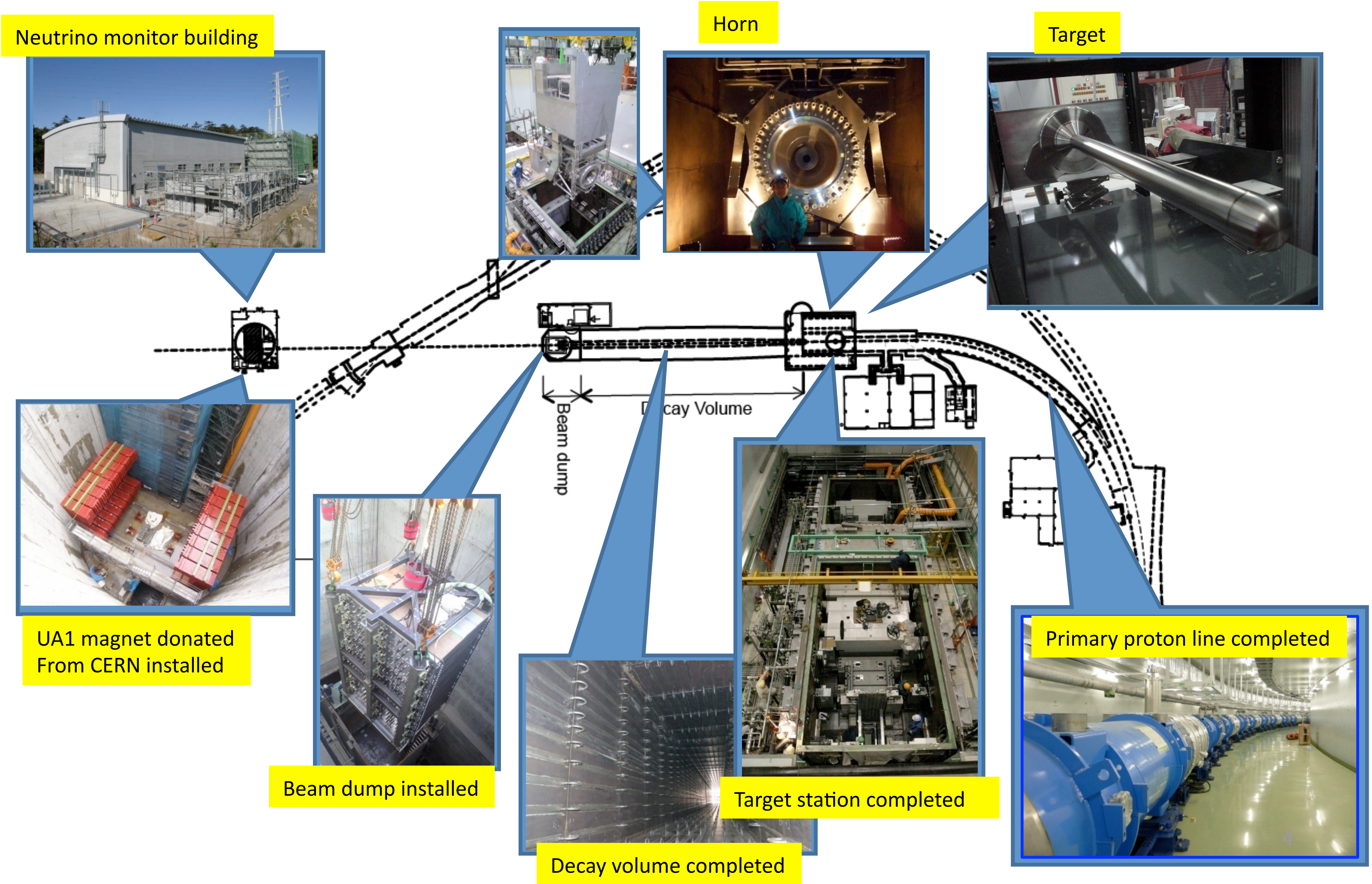
J-PARC (Japan Proton Accelerator Research Complex)



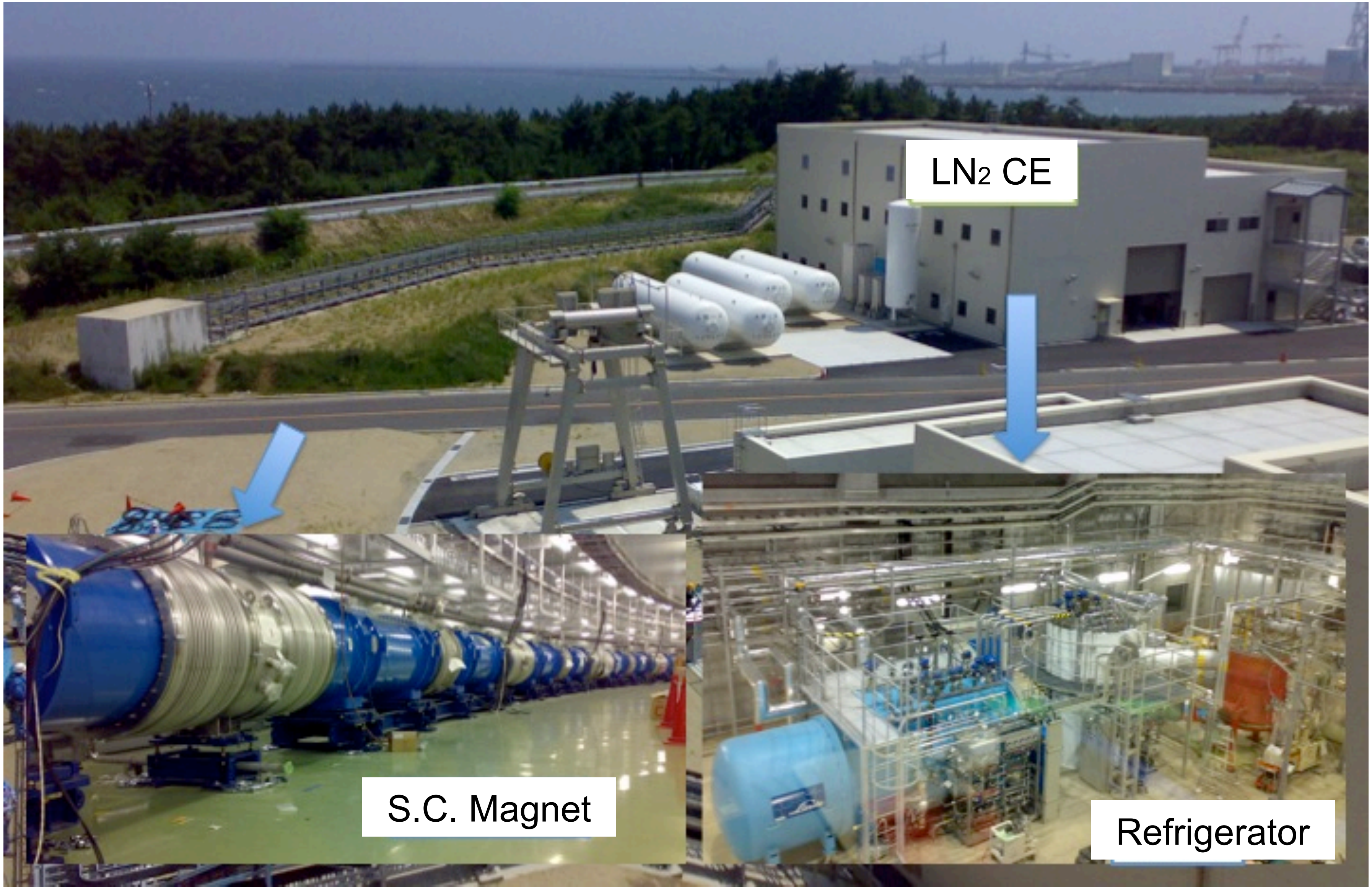
1. Purpose of T2K experiment

Tokai-to-Kamioka (T2K) is long baseline neutrino oscillation experiment

1. Purpose of T2K experiment
T2K neutrino facility construction

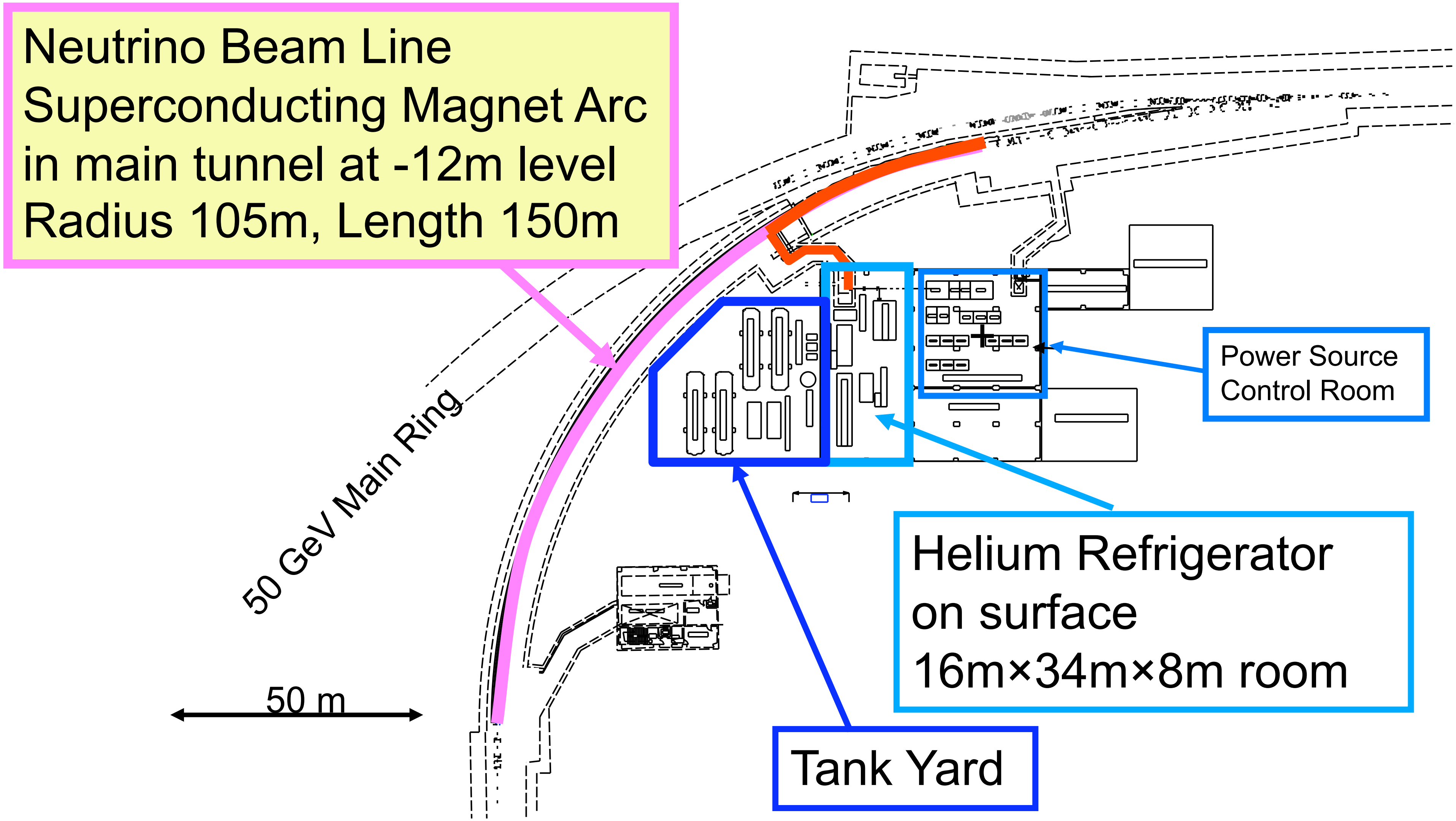


2. Over view of superconducting magnet system

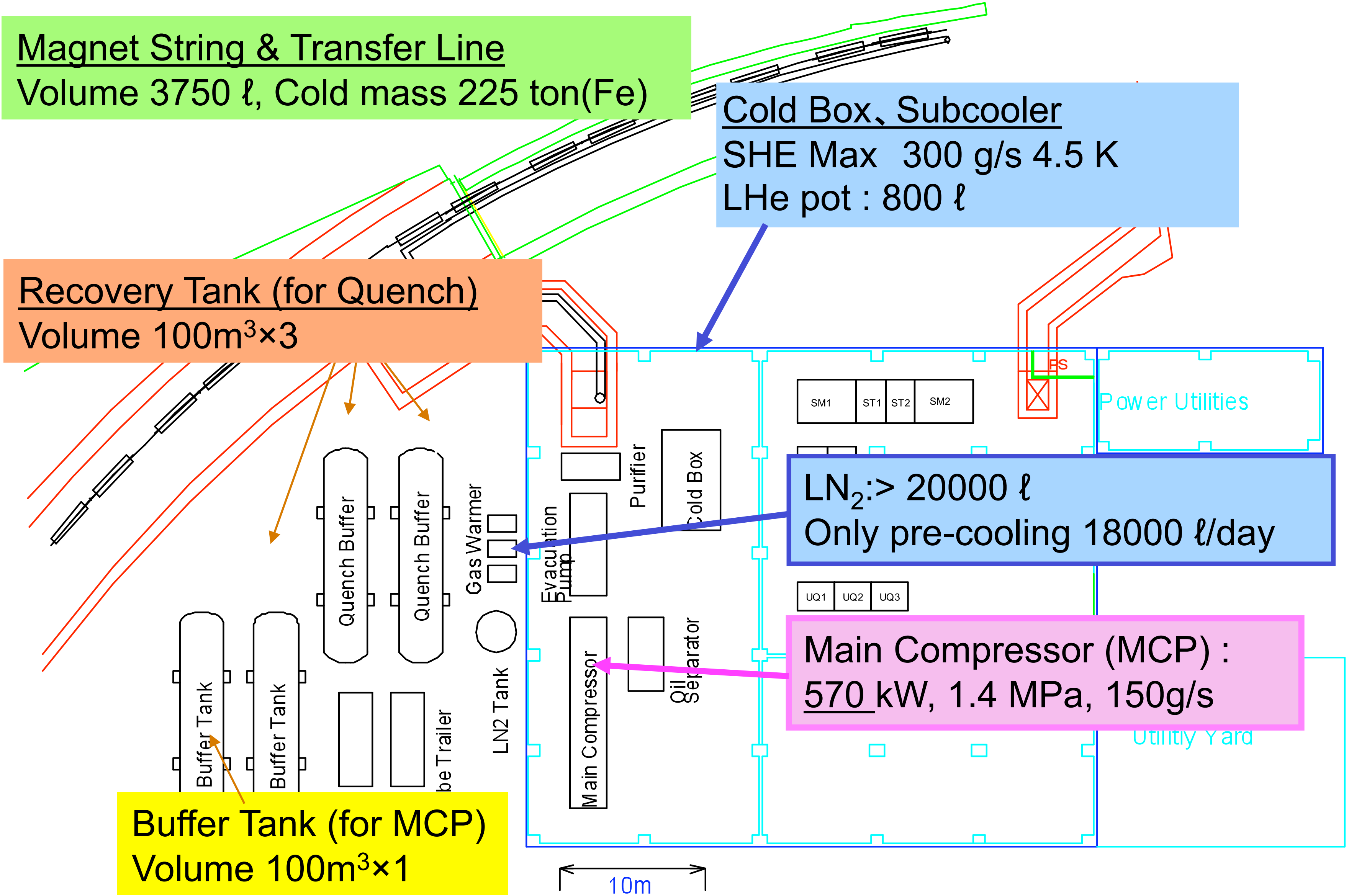


2. Over view of superconducting magnet system

Overall Layout

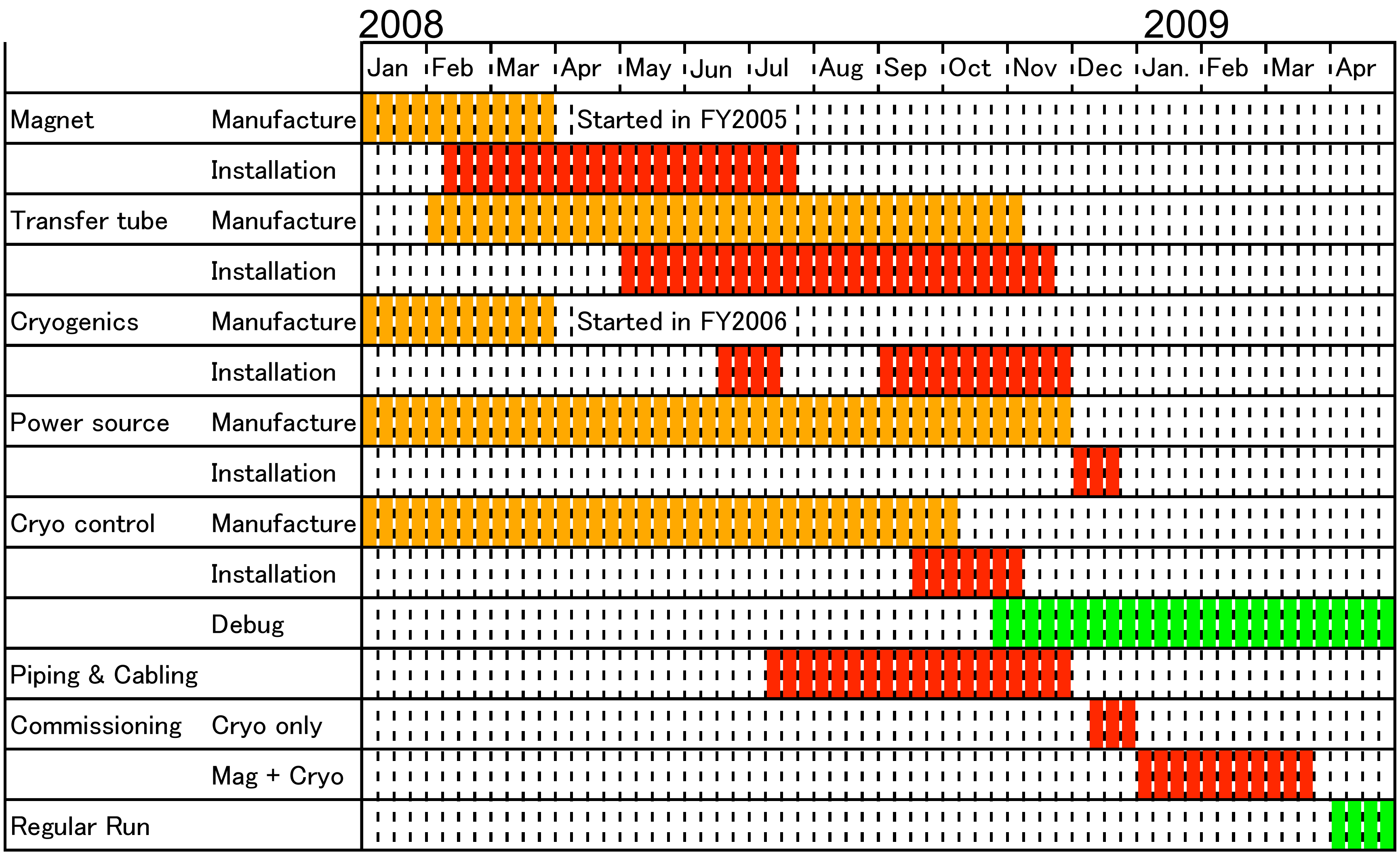


2. Over view of superconducting magnet system
Layout of Cryogenic Components



3. Installation, Construction and Commissioning

History of manufacture, installation and commissioning



3. Installation, Construction and Commissioning Photos

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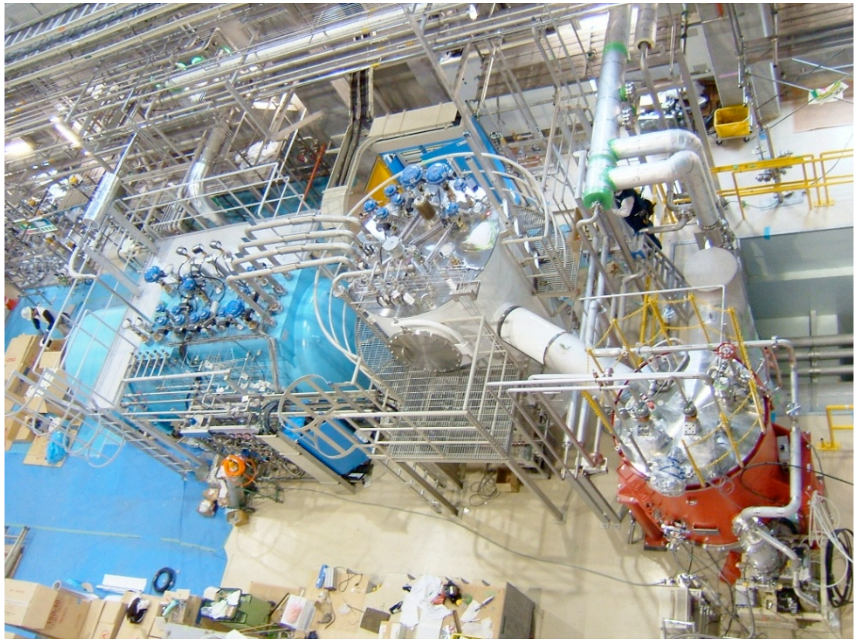
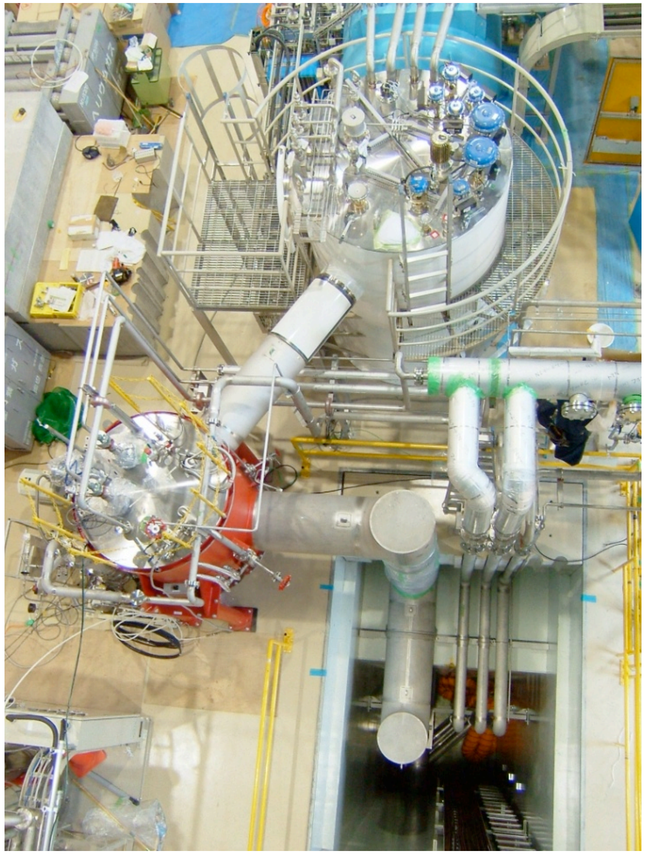
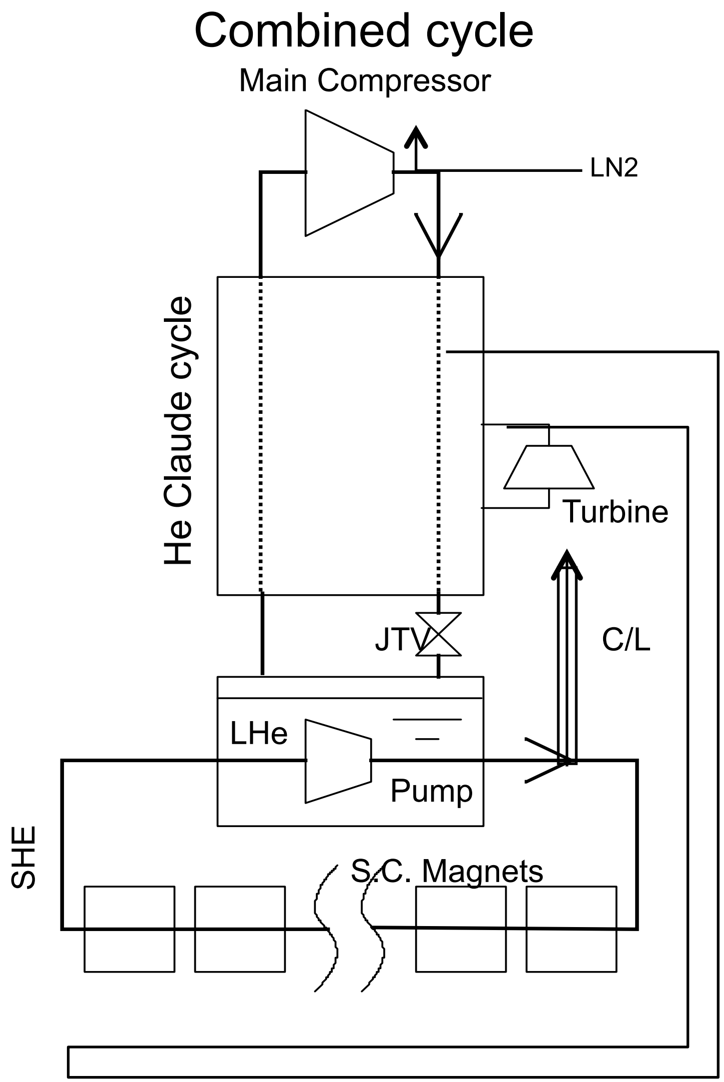




4. Cryogenic system design & performance

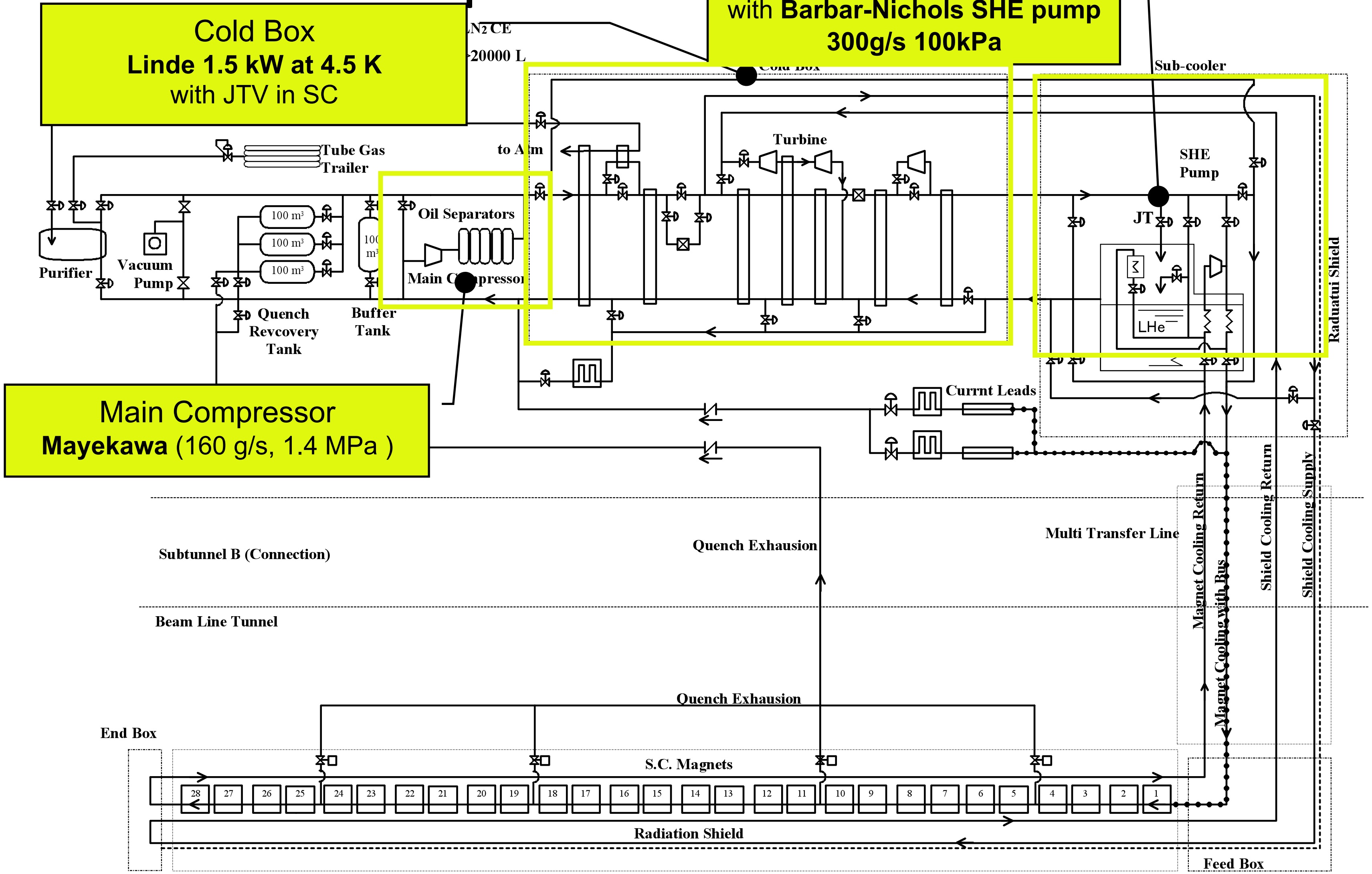
Required Cooling Capacity

SHE Flow Rate	**max 300 g/s**
SHE Condition	**0.4 MPa(A), 4.5 K**
SHE Return	**4.9 K**
Thermal Load to SHE Flow	**410 W**
Pressure Head of SHE	**85 kPa**
C/L cooling gas	**1.1 g/s (1 pair)**
Shield Temperature	**60～100 K**
Shield Cooling	Cold Helium Gas
Thermal Load to Shield Line	1710 W
Shield Cooling Gas Condition	Not specified
LN_2 usage	Only Pre-cooling and re-cooling after quench
Pre-cooling duration	< 20 days
Re-cooing duration	<6 hours (30GeV operation)



4. Cryogenic system design & performance

Conceptual Flow



4. Cryogenic system design & performance

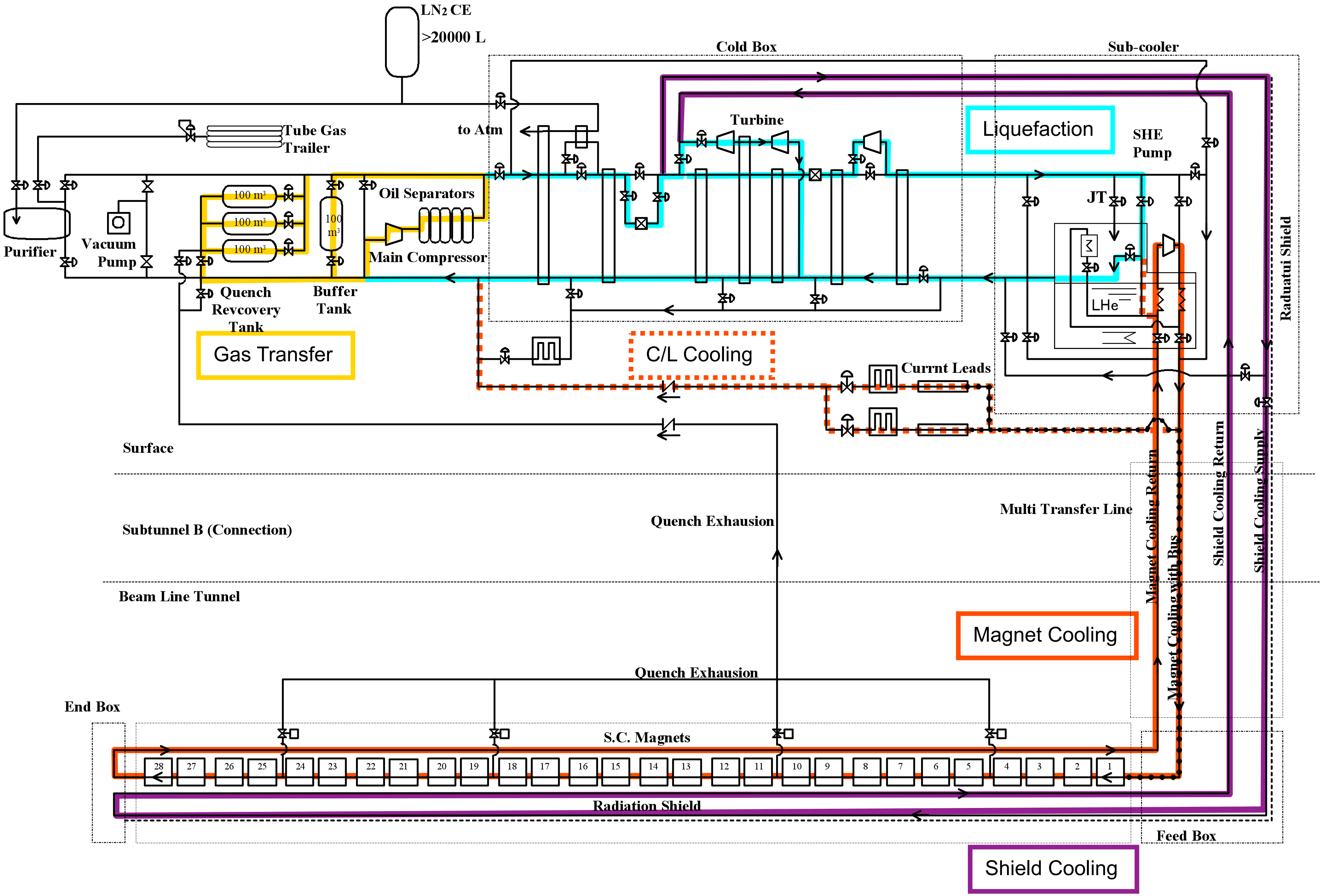
Required Refrigeration Capacity – Maker Design

		4.5 K Level	60-100 K Level
KEK Requirement	Magnet & Transfer Line	**410 W + 1.1 g/s**	**1710 W**
	SHE Flow Imedance	**Max 300 g/s, 4.5 K, 0.4 MPa Head 85 kPa**	
Contractor Design	SHE Pump Load	330 W	
	Sub-cooler, Transfer Line b/w CB	150 W	250 W
	Required Refrigeration	890 W + 1.1 g/s → 1.0 kW	1960 W → 2 kW
	+ 20 % Margine	1.2 kW	2.4 kW
Measured Performance		1.5 kW (For SHE load 1163 W) Pump Efficiency 66.7 %	2.4 kW

Taiyo-Nissan Co. in the business collaboration with LINDE won the bid.

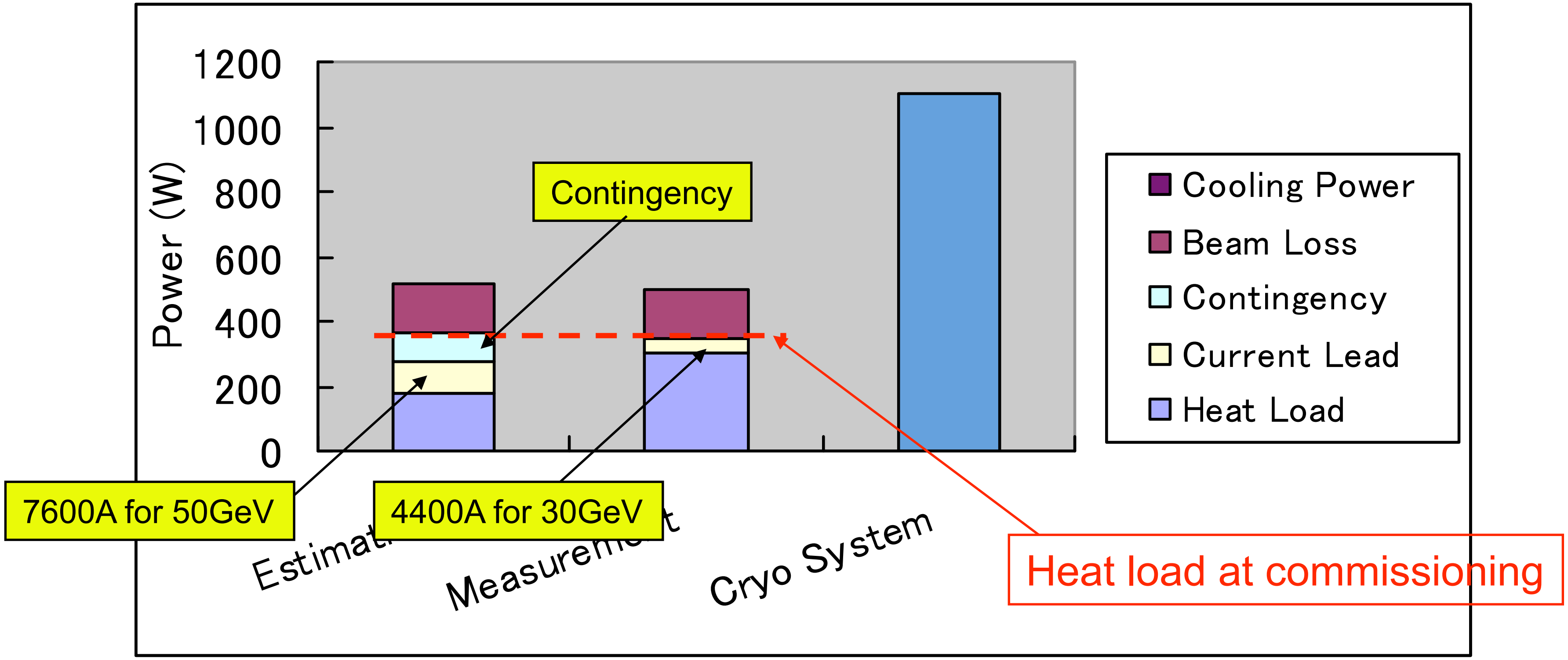
4. Cryogenic system design & performance

Operation – Magnet Excitation (Steady state)



4. Cryogenic system design & performance

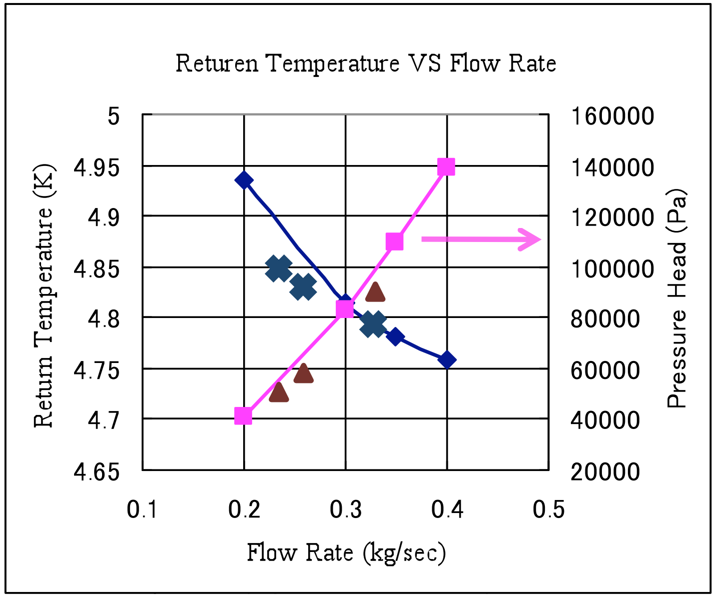
Estimated heat load and actual heat load VS. Cooling capacity

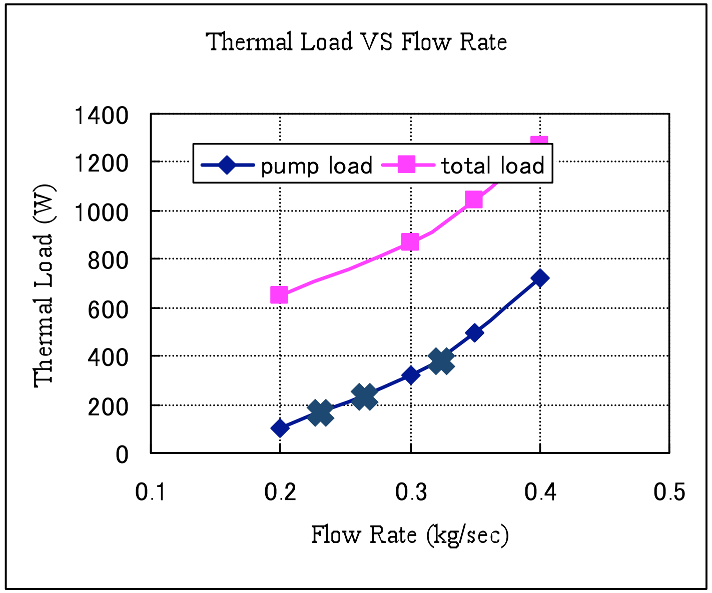


Larger heat load at magnets are covered by smaller CL flow and contingency.

4. Cryogenic system design & performance

Required Coolig Capacity - Estimation





▲ Measured Pressure Head (Drop)
✖ Measured Return Temperature

✖ Measured Pump Load

$$PressureHead = 1.5 f \frac{L}{D_h} \frac{\rho u^2}{2}$$

f : Friction Coefficient, L : Length, D_h : Hydraulic Diameter, u : Flow Velocity

+ 50 % contingency

$$TotalLoad = [Mag \& Trans.T + 20\%] + [PumpLoad] + [Sub-coolerLoad : 143W]$$

$$PumpLoad = \frac{\Delta P \dot{M}}{\rho \eta}$$

Flow Rate : 300 g/s → Pump Load : < 300 W
Mag. Temp. : ~ 4.8 K

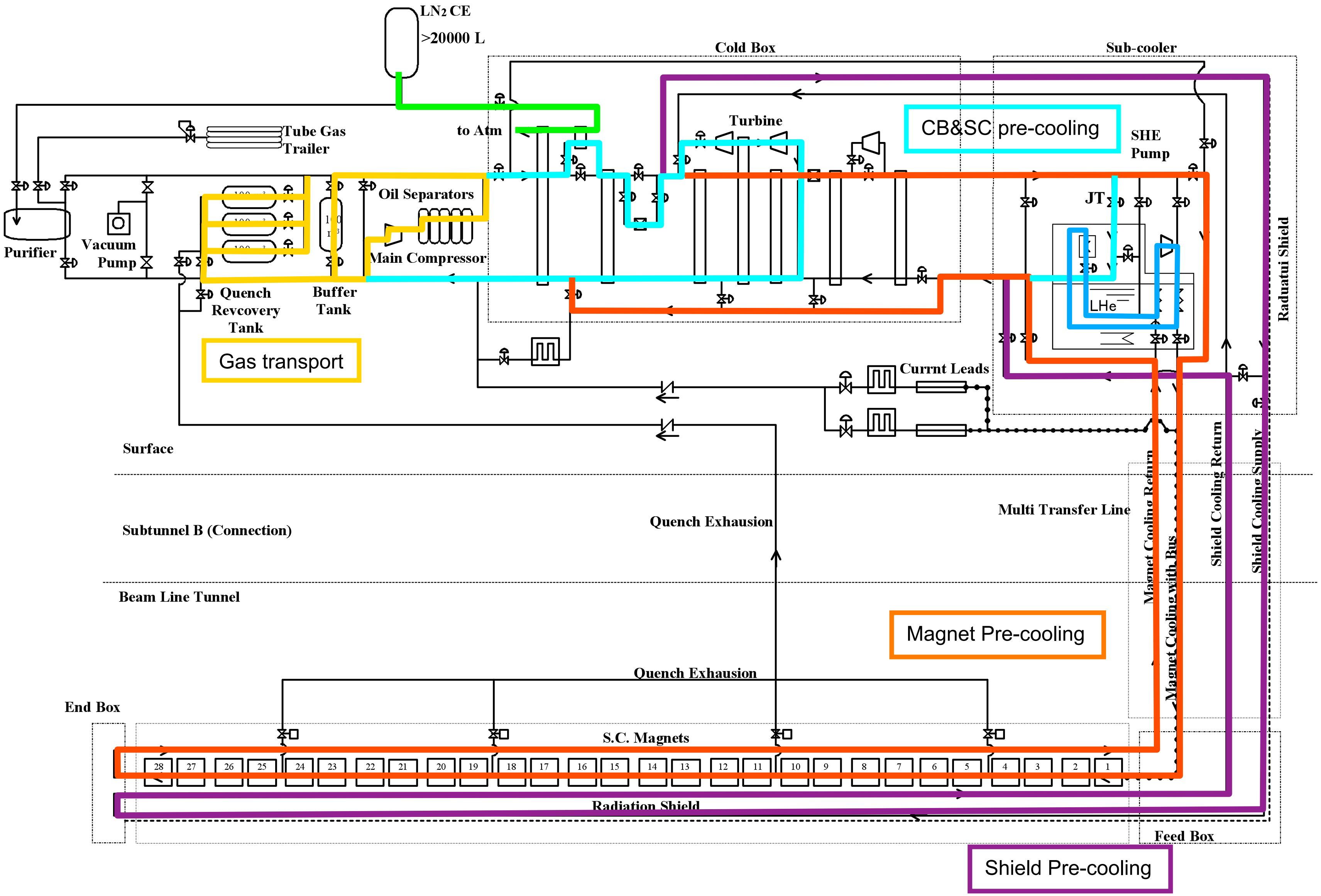
4. Cryogenic system design & performance

Summary of Load (Magnet & Transfer Lines) to Cryogenic System

	4.5 K Level		80 K Level	
	Estimation	Measurement	Estimation	Measurement
Coolant	SHE		He Gas	
Heat Load Estimation	**180 W** + 150 W (beam loss)	**300W** + 150 W (beam loss)	1419 W	
Current Lead	1.0 g/s @7600 A	0.6 g/s @4400 A	-	
+ 20 % Contingency	**403 W + 1.1 g/s**		**1703 W**	
Cold Mass	204 ton Iron basis		6.8 ton Aluminum basis 2.5 ton Iron basis	
+ 10 % Contingency	**225 ton**		7.5 ton Aluminum basis 2.8 ton Iron basis	
Inventory	3550 ℓ	3750 ℓ	1620 ℓ	
+ 10 % Contingency	**3900 ℓ**		**1780 ℓ**	
Pressure Drop	**84 kPa** **(@300 g/s, 400 kPa, 4.5 K)**	85 kPa	**36 kPa** (@ 40 g/s, 80 K, 1.35 MPa)	
Design Pressure	**>1.8 MPa(G)**	2.0 MPa	**>1.8 MPa(G)**	2.0 MPa

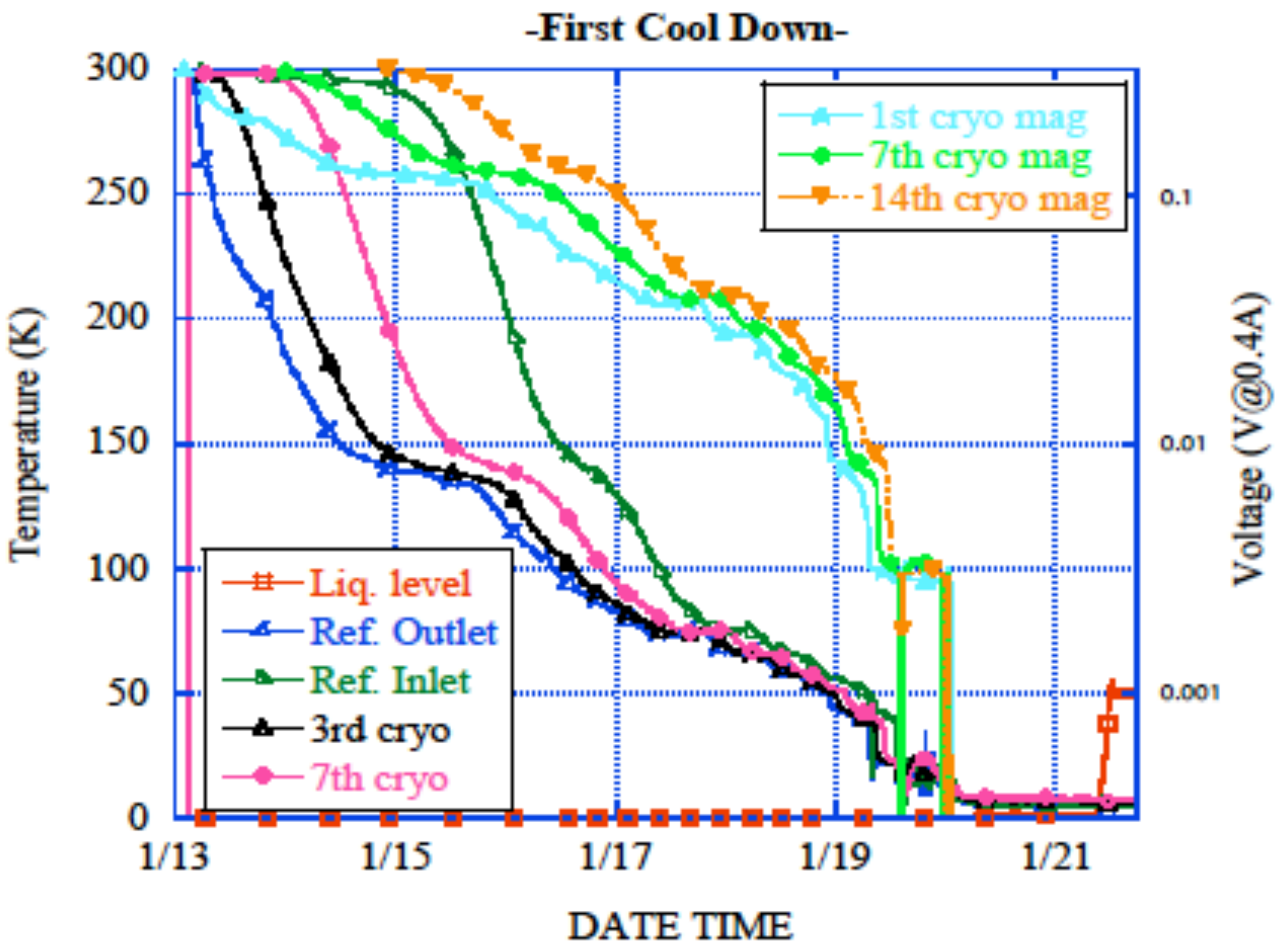
4. Cryogenic system design & performance

Operation – Pre-cooling



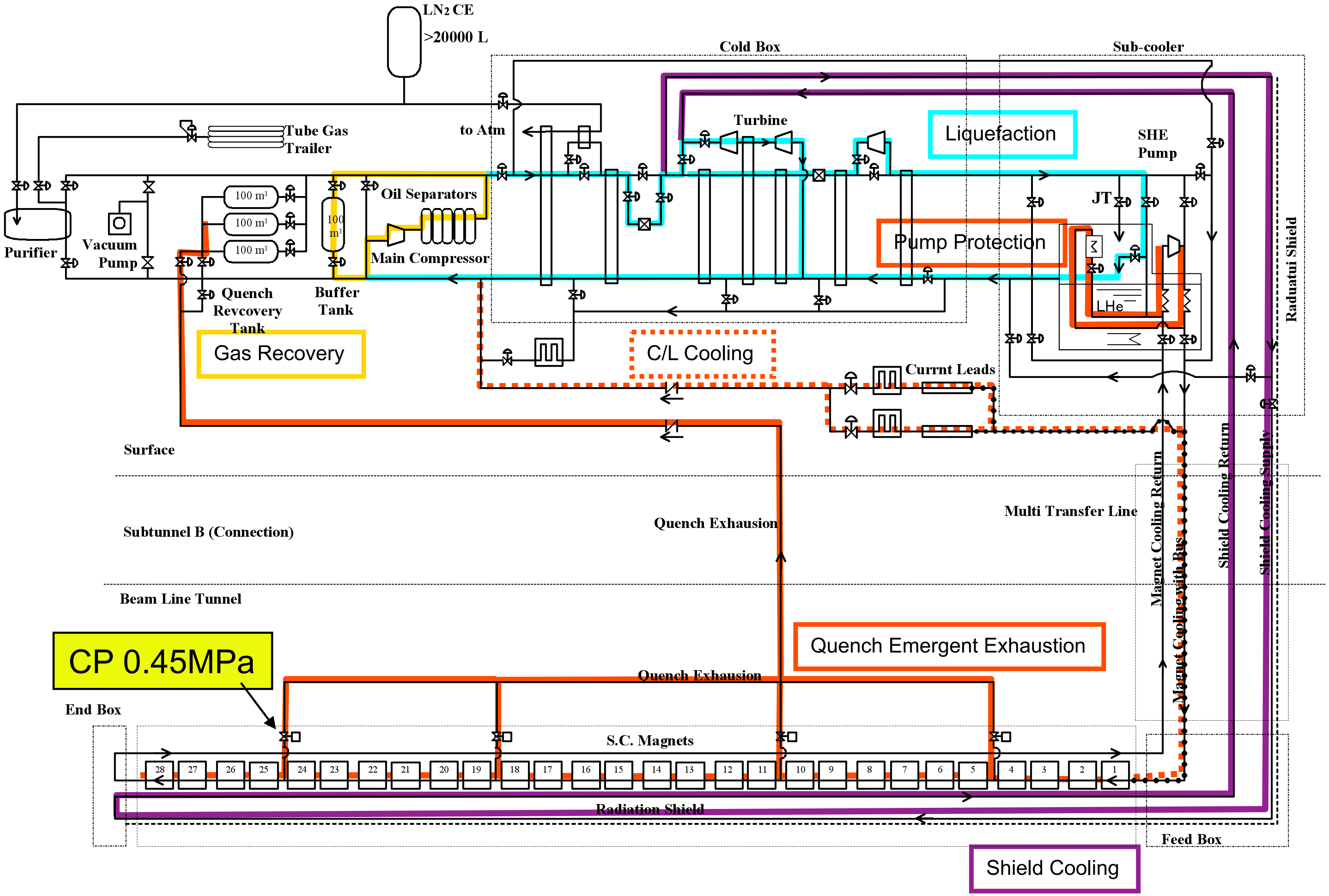
4. Cryogenic system design & performance

Pre-cooling in 9 days



4. Cryogenic system design & performance

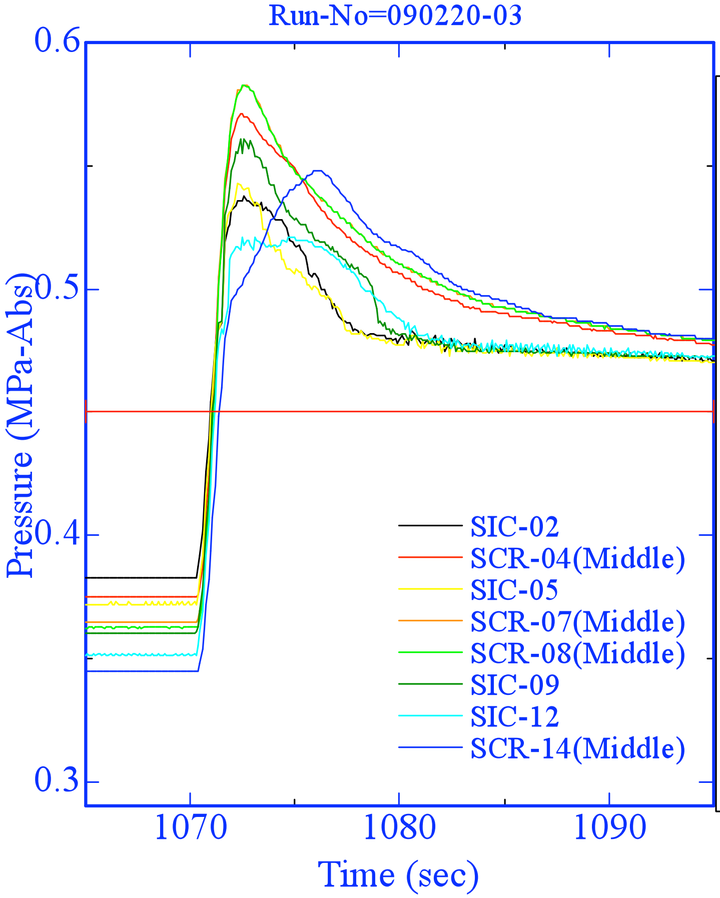
Operation - Quench



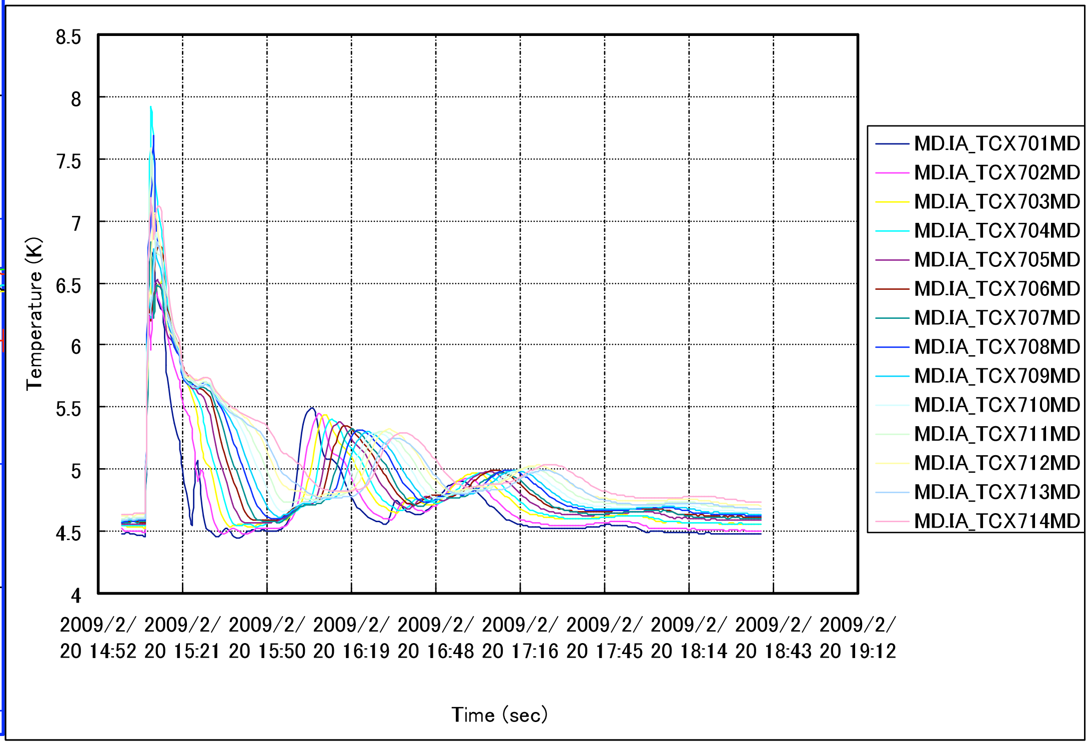
4. Cryogenic system design & performance

Quench Protection and Re-cooling(1)

All magnet heater quench test



Current=4400A
QPHs(A) are fired.
All Magnets are Quenched.
Setting Pressure of QRValve=0.45 MPa-Abs
All QRValves at SIC-2,5,8,12 are opened.



4. Cryogenic system design & performance
Summary

- COP (coefficient of performance)

  1500 W (4.5 K) / 570 kW (300 K) = 0.0026

- FOM (figure of merit)

  COPi = 0.015 FOM = COP/COPi = 17 %

- Running cost at steady operation

  Electric 570 kW , 10 yen / kWh => 4,100,000 yen/month

  Liquid Nitrogen 0 ℓ

- Comparison with another system
  - BELLE cryogenics (240 W)

    Electric 240 kW, 10 yen / kWh = 2,160,000 yen/month

    Liquid Nitrogen 50000 ℓ/month, 40 yen/ℓ

    COP = 0.001, FOM = 6.5 %

- Cryogenic system has enough cooling power for magnet load including future beam halo.