國家同步輻射研究中心
National Synchrotron Radiation Research Center

SRF Operation at TLS and Planning of SRF System for TPS

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On behalf of the RF Group
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The Taiwan Light Source (TLS) and the Taiwan Photon Source (TPS)

- Commission in Apr.; open to users in Oct. ‘93
- 1.3 to 1.5 GeV ramping in operation in ‘96
- Machine study of top-up injection in ‘96
- Upgrade booster for full energy injection in ‘00
- 1st cryogenic plant available in ‘04
- SRF cavity in operation in Feb. ‘05.
- Top-up injection routinely operated at 300 mA in Oct. ‘05.
- Successful long term beam tests at 400 mA in ‘07

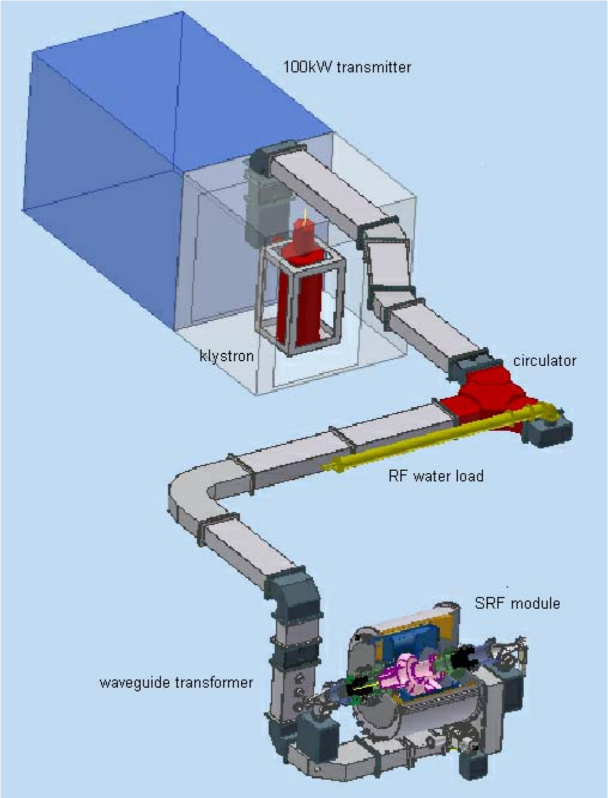
TLS (300mA @1.5GeV)

- Machine energy at 3 and 3.3 GeV;
- Operating beam current of 400 mA;
- Circumference of 518 m;
- Nominal emittance of 1.6 nm-rad;

TPS (400mA@ 3.0-3.3GeV)

The SRF System for Taiwan Light Source (TLS)

- Cornell-type SRF module (x1)
- Home-made klystron-based crow-bar type RF transmitter (x1)
- Analog low-level RF system (PEP-I design) (x1)
- RF feed-line using WR1800 waveguide and AFT circulator

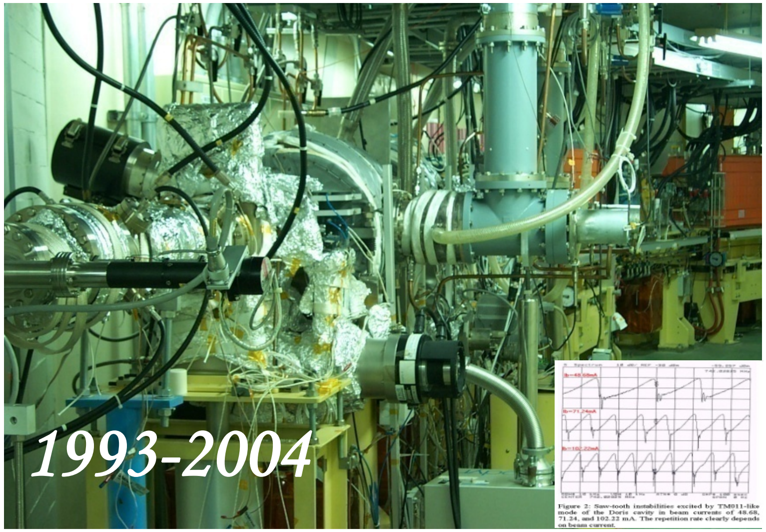


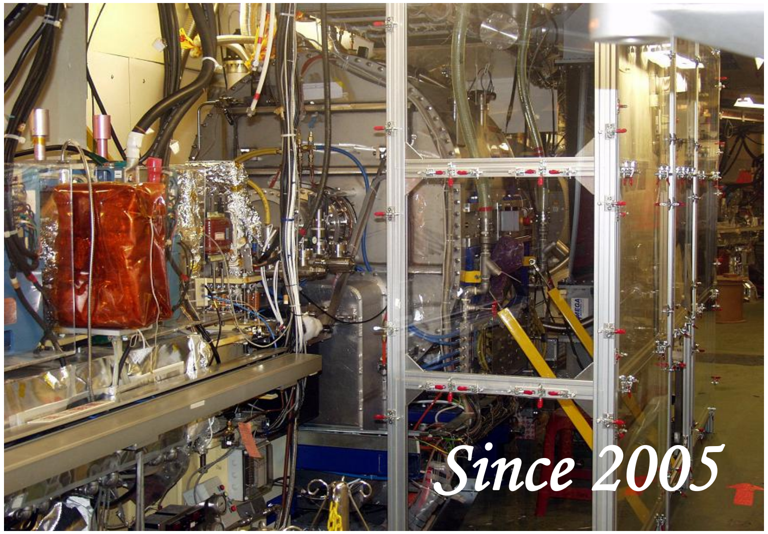
Nominal machine energy	1.5 GeV
Revolution frequency	2.49827 MHz
Maximum beam current	< 500 mA
SR energy loss per turn	<164 keV
RF harmonic number	200
Beam power	< 82 kW
RF frequency	499.654 MHz
RF voltage	1.6 MV
Number of RF cavities	1
R/Q per cell ($V^2/2Pc$)	89/2
External Q	2.2E5
Cryogenic static load	< 30 W @4.5K

TLS (300mA @1.5GeV)

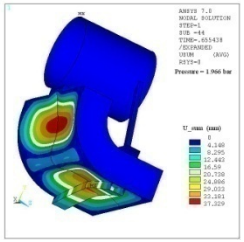
SRF Project Started in End of 97'

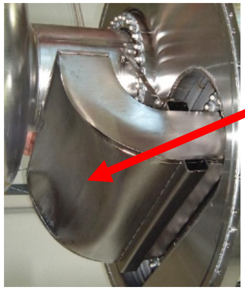
- **Goal:**
  - Increase the maximum operating beam current in a factor of two (from 200 mA to 400 mA) to double the flux of the synchrotron light but keep the synchrotron light even more stable!
- **Solution:**
  - SRF module is quasi-free of coupled-bunch instabilities from the beam-cavity interaction via impedances of cavity's higher-order modes;
  - Replace the two operational Doris cavities with one SRF module of CESR-III design;
- **Challenge: Highly reliable SRF operation**
- **Budget available from 2000 in 4 years;**
  - Routine operation of SRF module since the beginning of 2005 (one year delay).
- **Project goal achieved**
  - in terms of photon flux in winter, 2005;
  - in terms of maximum beam current in summer, 2006;

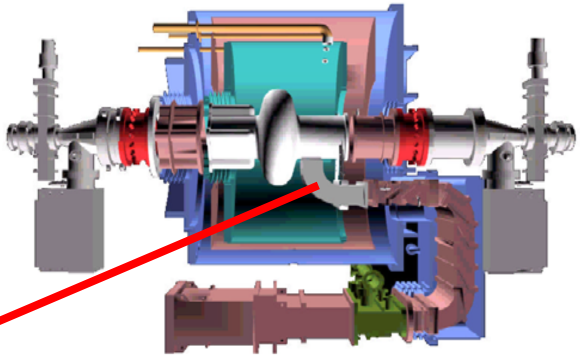




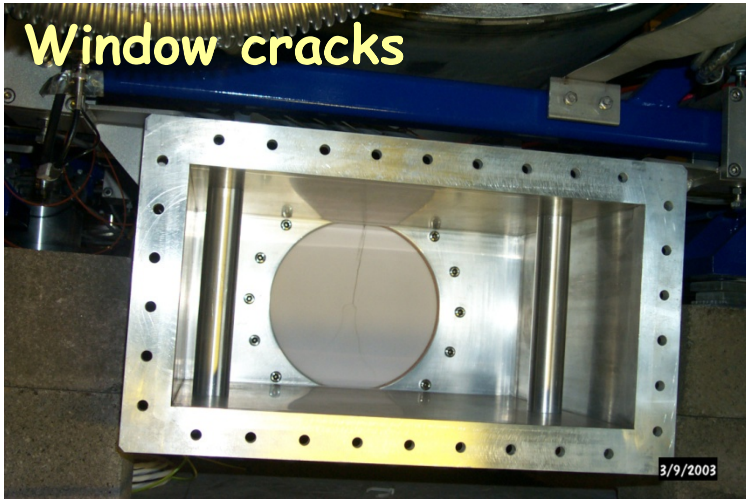
Difficulties during Production of the First SRF Modules S2

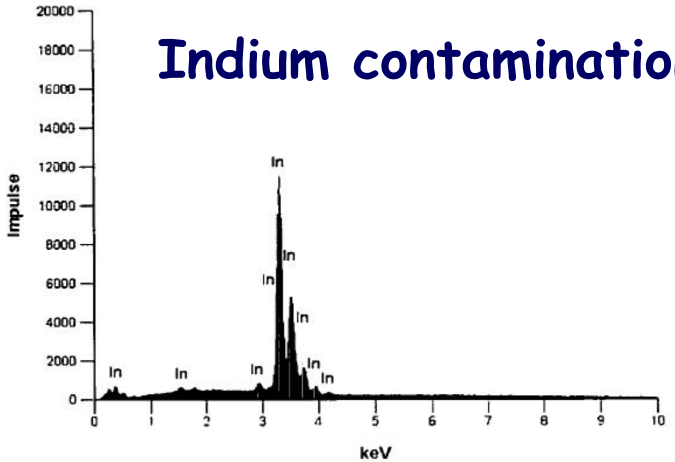




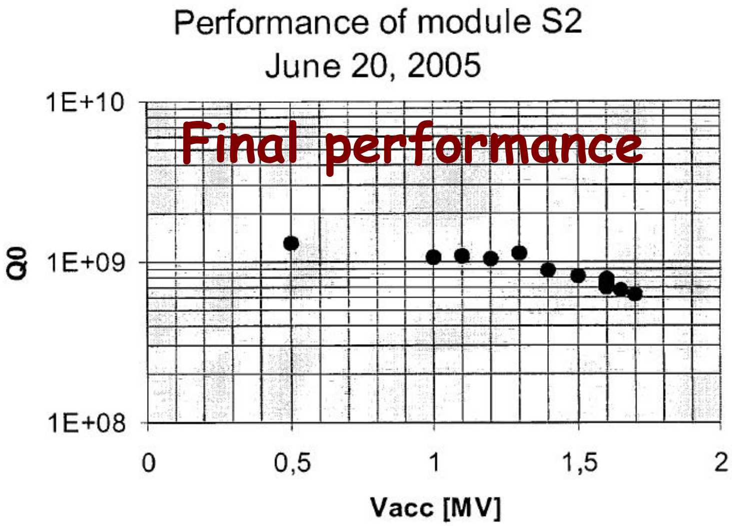


Waveguide buckling

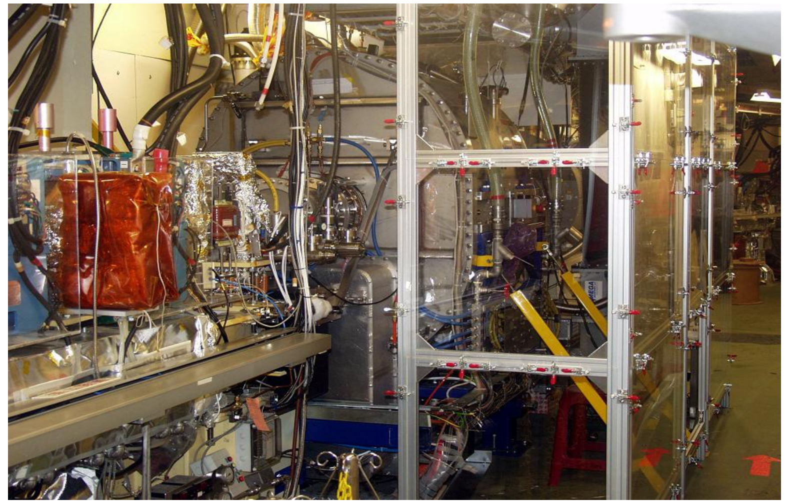


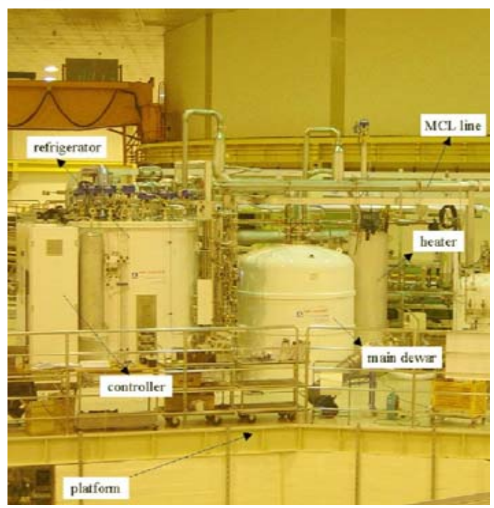


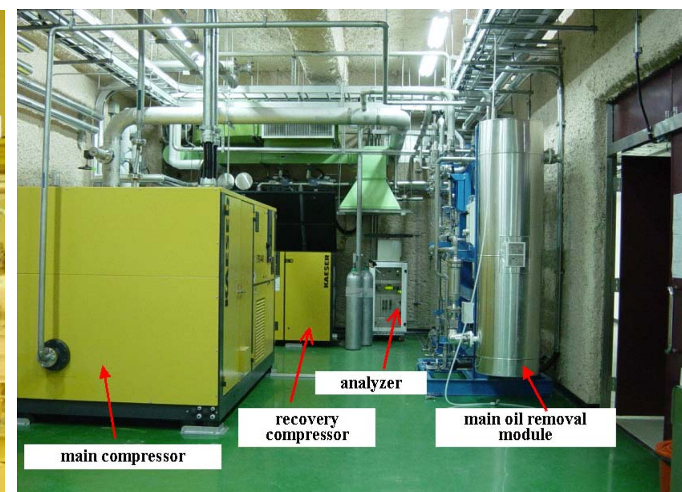
EDX spectrum of the particle found inside the cavity



Specifications and Integrations of Sub-systems in-House



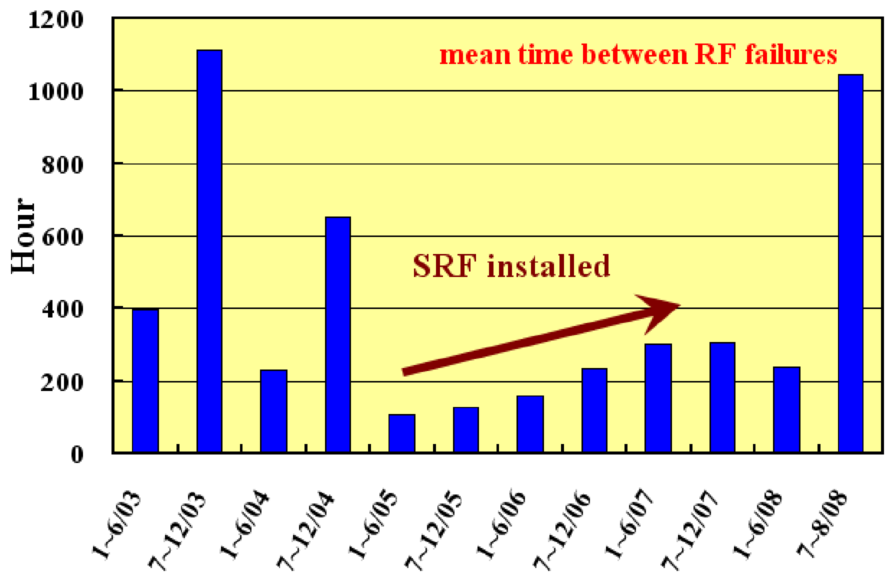


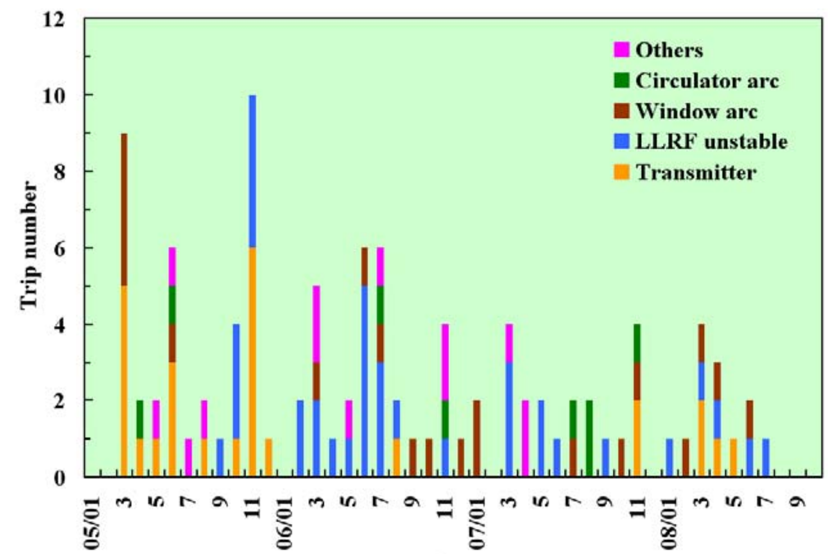


SRF Operation at TLS:

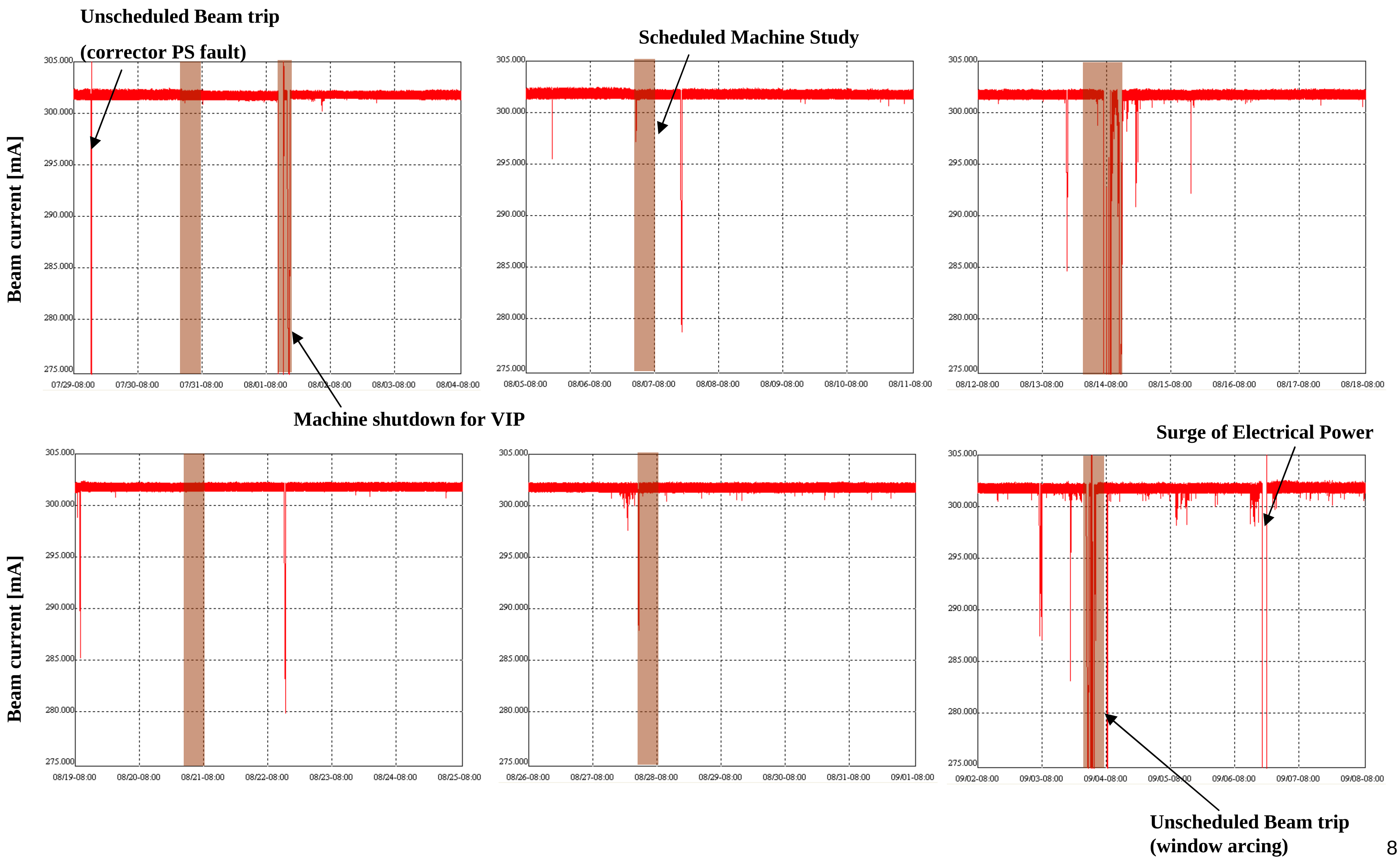
Low RF Power Rating but under Heavy Beam Loading

	Year	Annual Beam Dose (A-hr)	User Time			Opertion Mode	I0 Stability (%) ($\Delta I_0/I_0$<0.2%)
			Annual User Time (hr)	Up-time (%)	MTBF (hr)		
TLS	2002	N.A.	4785	95.8%	154.4	Decay Mode	47%
	2003	897.0	5017	97.2%	313.6	Decay Mode	86%
	2004	772.4	4235	97.5%	69.4	Decay Mode	85%
	2005	943.4	4576	96.8%	83.2	Top-up Mode(3/12)/SRF	76%
	2006	2012.9	5552	96.7%	40.8	Top-up Mode/SRF	99.0%
	2007	1964.7	5219	98.1%	85.6	Top-up Mode/SRF	98.6%
	2008(Jan-May)	N.A.	2272	98.1%	113.6	Top-up Mode/SRF	99.2%
	2008		5656				





SRF Operation at TLS:
713 Hours of Non-interrupted User Beam Time



SRF Operation at TLS:
Heavy Fluctuations of Tuning Angle

- LN2 induced thermal oscillations;
- Fast change of tuning angle in tens of ms range;
  - Microphonics driven by stepping motor;
  - Spontaneous excitation of mechanical vibration at 37 Hz;

SRF Operation at TLS:

LN2 Induced Thermal Oscillations

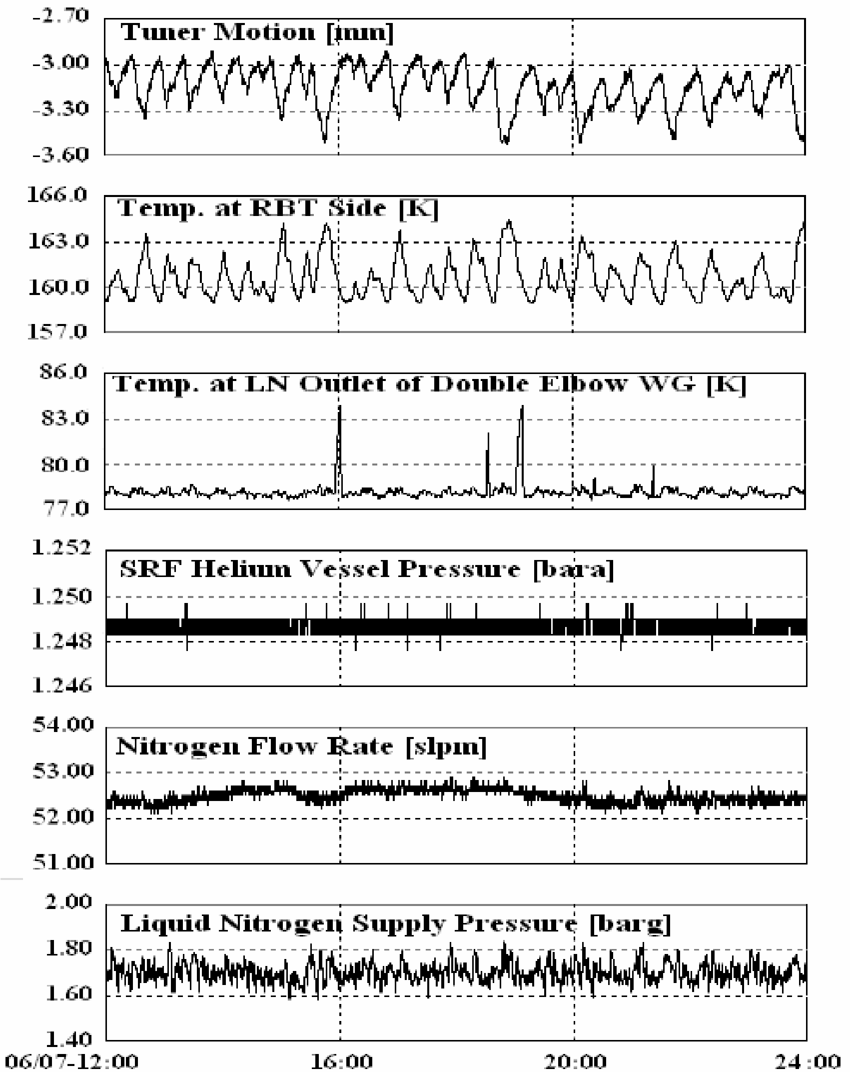
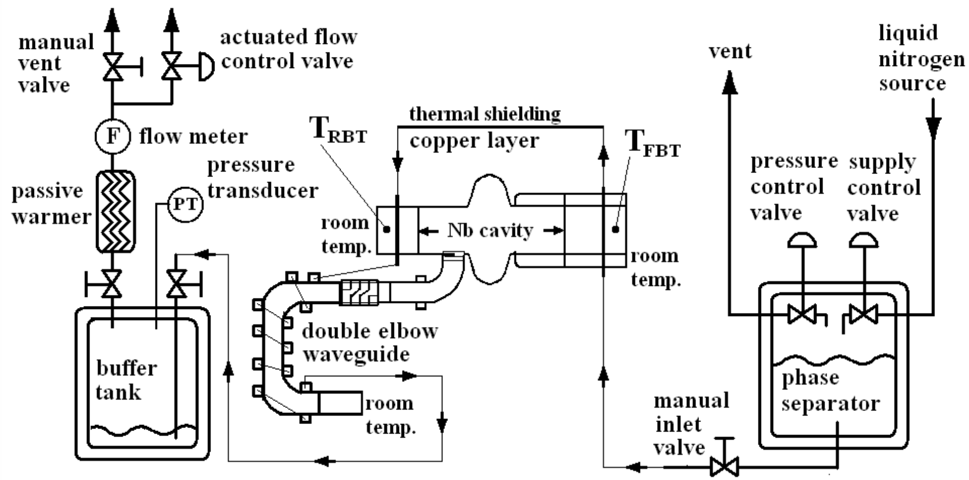


Fig. 1. The tuner motion is highly correlated with the temperature fluctuation of the nitrogen-cooled thermal-transition section at the round beam-tube (RBT)



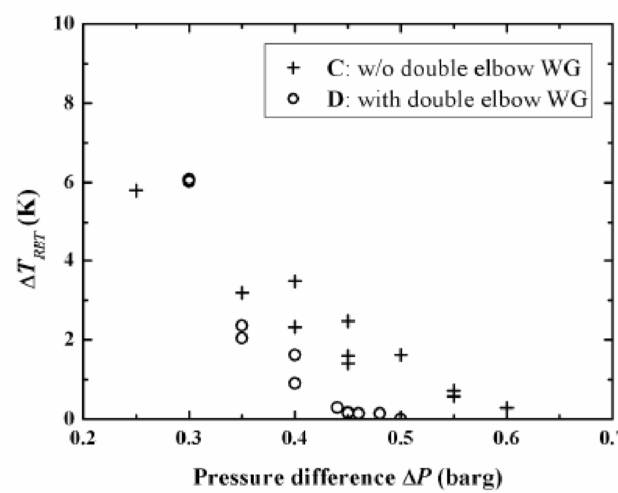
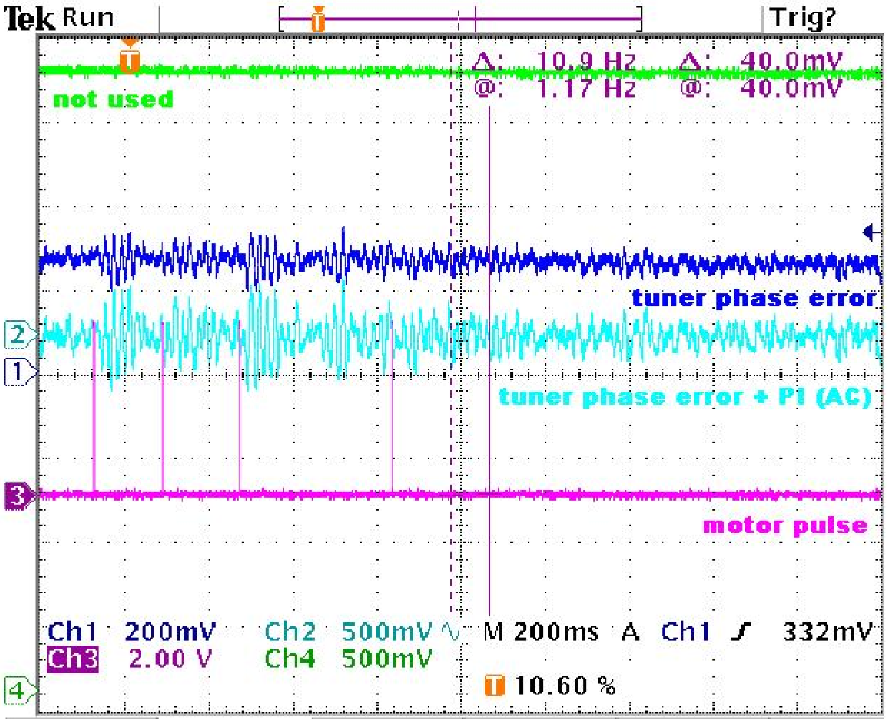
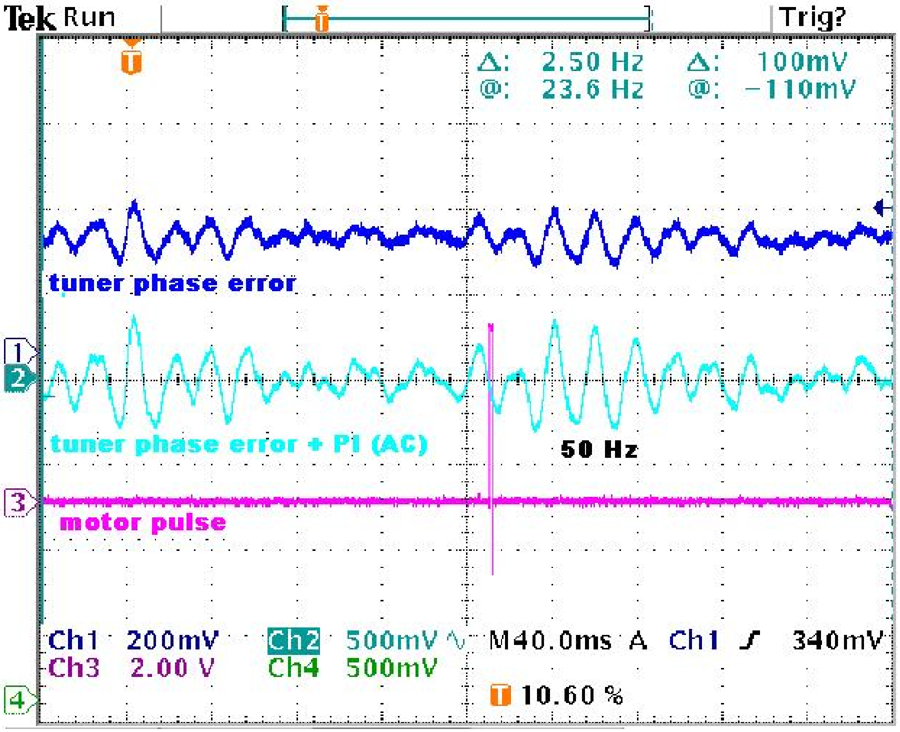


Fig. 7. With a regulated pressure of the buffer tank, the temperature variation ΔT_{RBT} was decreased at large pressure difference between the phase separator and the buffer tank.

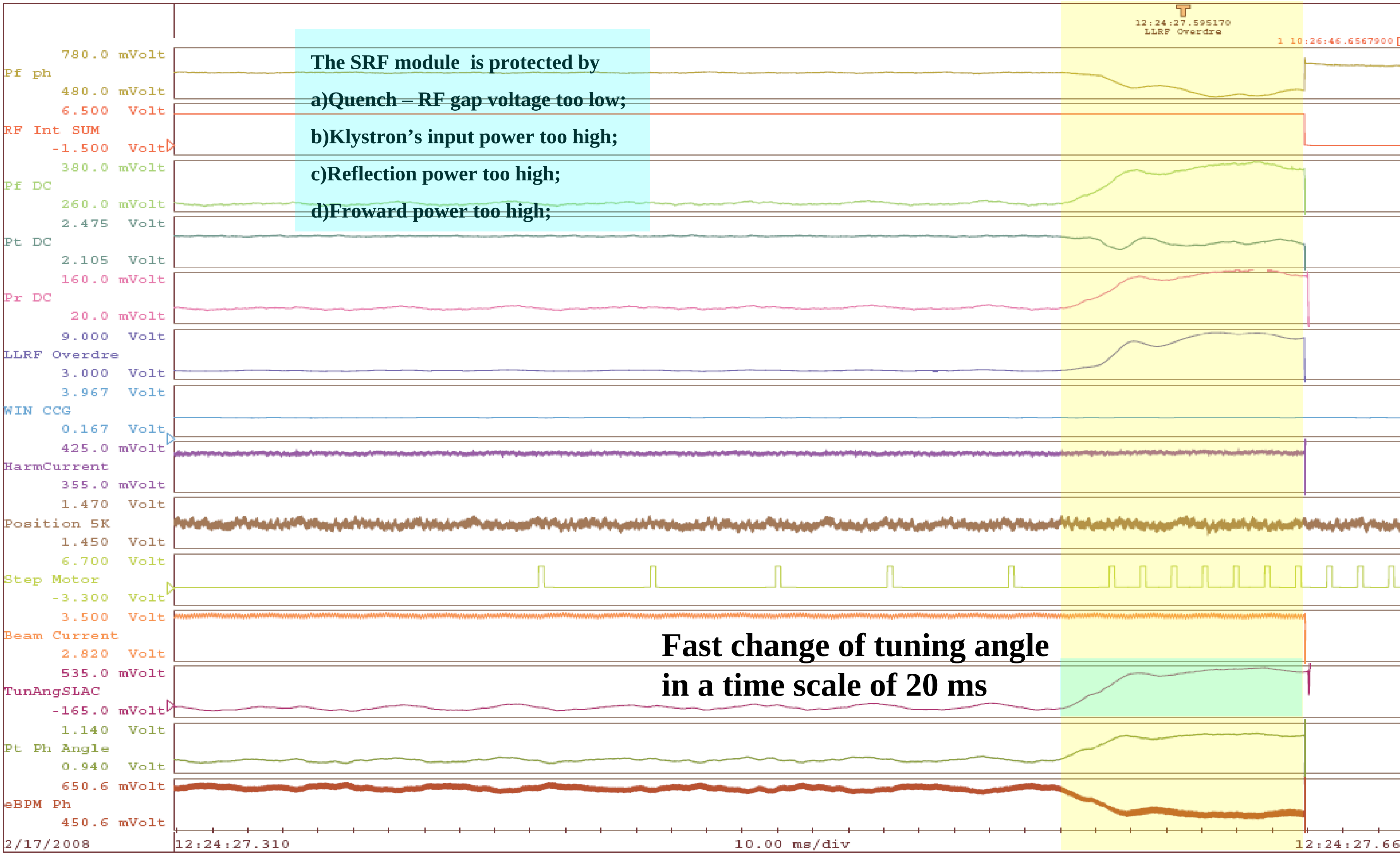
(MC Lin, 2008)

SRF Operation at TLS:
Microphonics Driven by Pulse of Stepping Motor

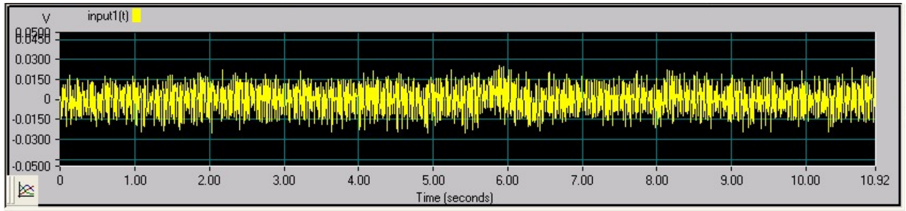


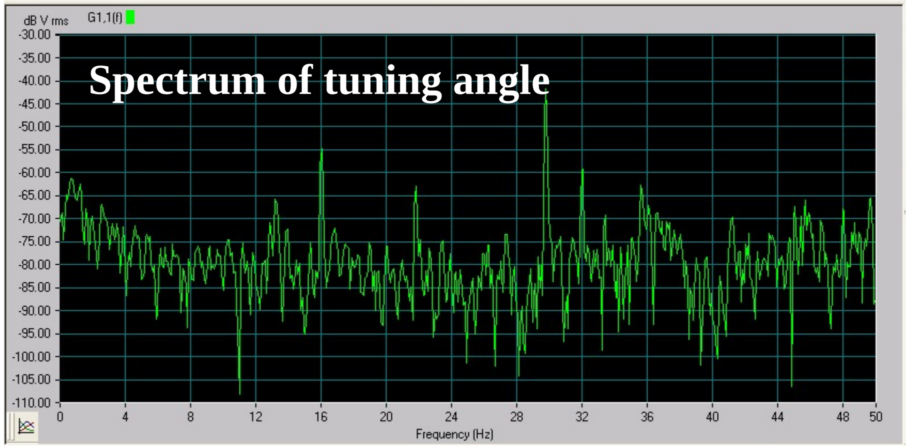


SRF Operation at TLS:
Fast Change of Tuning Angle

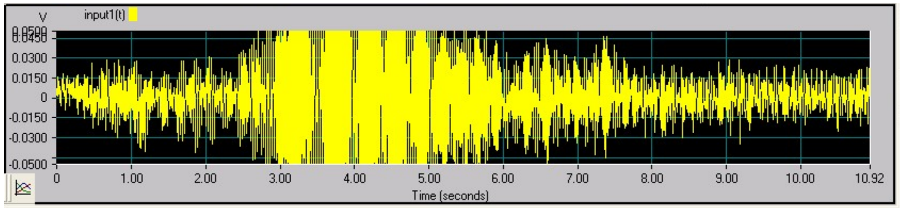


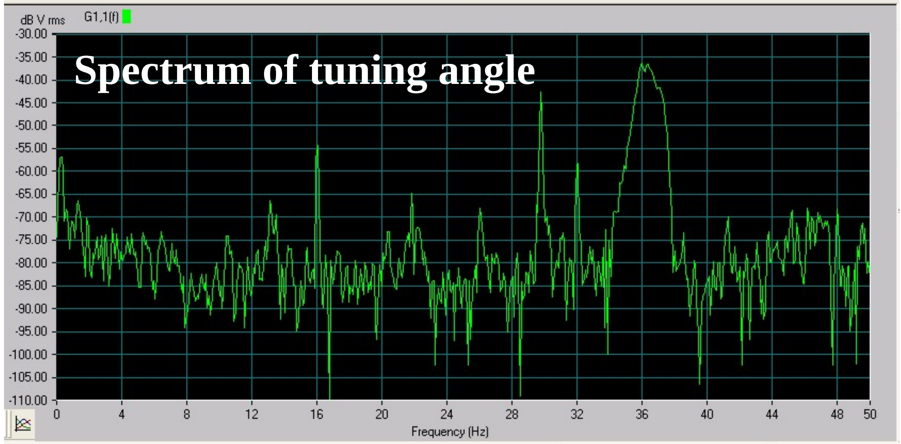
SRF Operation at TLS:
Spontaneous Mechanical Vibrations at 37 Hz

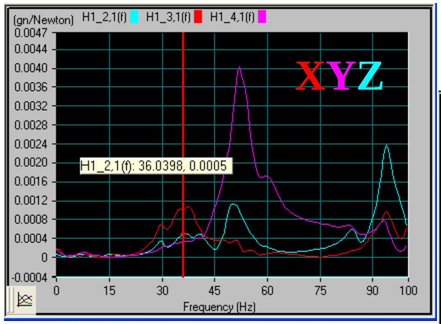


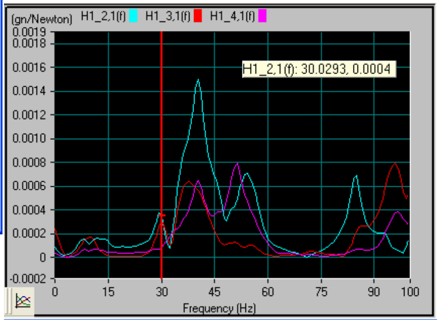


- Strong mechanical vibrations at around 37 Hz observed;
- Possible reason to cause LLRF unstable;
- A false quench with insufficient Robinson phase margin;
- Similar observation at DLS and CLS during SRF processing
- Mechanical vibration mode of LHe tank or SRF cavity?







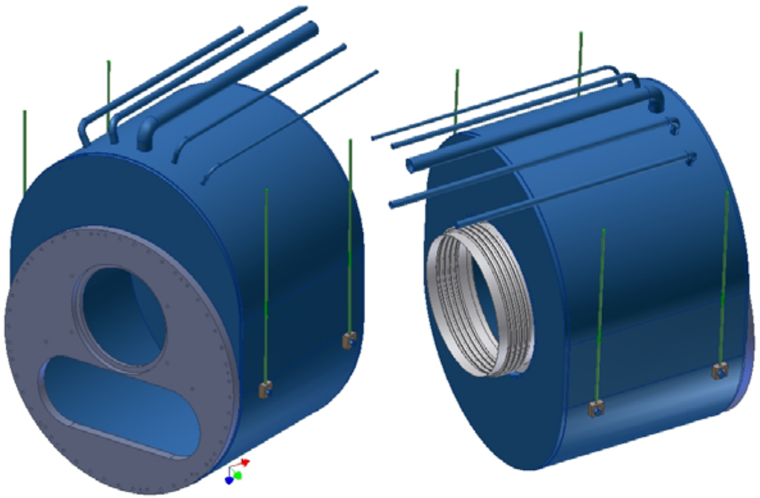


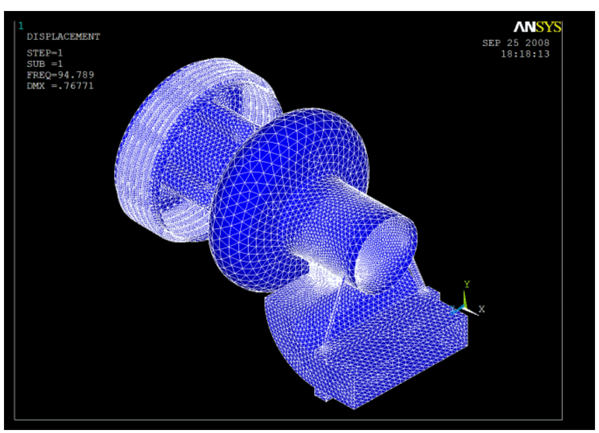
Measured transfer functions of mechanical vibration modes

SRF Operation at TLS:
Spontaneous Mechanical Vibrations at 37 Hz

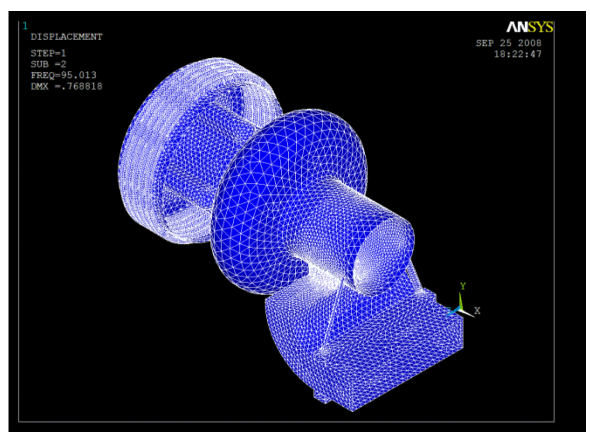
- According to the preliminary ANSYS simulation, the suspension system (with 4 long invar rods) of the LHe vessel is more likely responsible for the mechanical vibration at a low frequency of 37 Hz.

$$f \propto \sqrt{\frac{k}{m}} \propto \sqrt{\left(Y\frac{A}{L}\right)\cdot\frac{1}{m}}$$

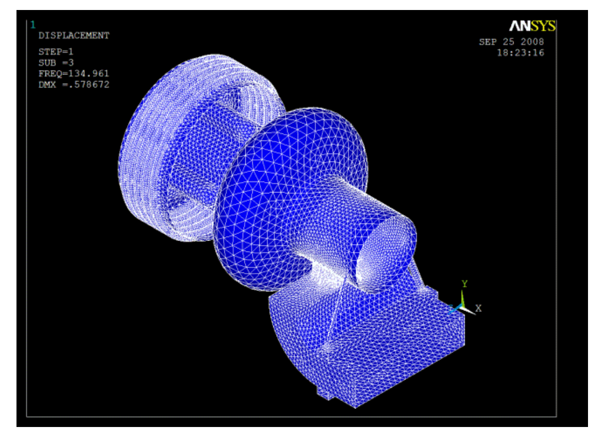




~ 95 Hz



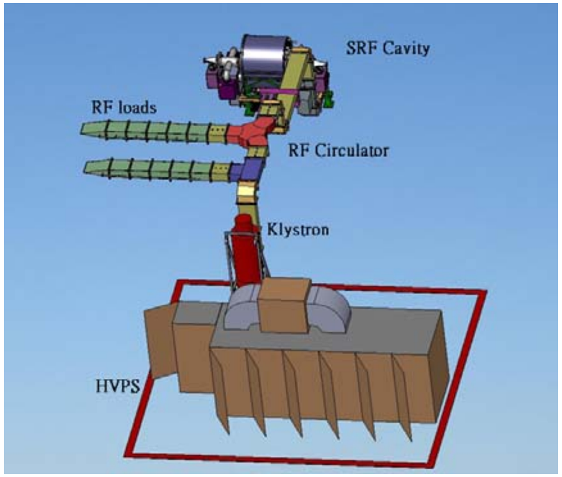
~ 95 Hz



~ 135 Hz

The SRF System for Taiwan Photon Source (TPS)

- Cornell-type (x4) or KEKB-type SRF modules (x3)
- Klystron-based Thales/Thomson RF transmitters (x2)
- Solid-state RF transmitters (x2?)
- Analog low-level RF systems (x4)
- RF feed-line using WR1800 waveguide and AFT circulators



Machine Energy	3 GeV
Maximum beam current	400 mA
RF frequency	499.65 MHz
Radiation loss – bending magnets	341 kW
Radiation loss – insertion devices	423 kW
Total beam power	725 kW
Total accelerating voltage	~3.5 MV

TPS (400mA@ 3.0-3.3GeV)

Requirements of SRF System for TPS

- Final Goals:
  - Beam power of more than 725 kW;
  - Total RF gap voltage of around 3.5 MV;
    - Build-up of RF voltage is not a problem but delivery of beam power is a challenge.
    - The operational Qext will be extremely low because of the low total RF gap voltage.

- Commissioning Goals:
  - Many uncertainty owing to budget constraint;
  - Many comment/suggestion from the external review committee for # of SRF cavity in operation;

- Configuration of RF plant
  - Each RF plant includes one klystron, one RF transmitter (300 kW), and one SRF module;
  - Switching type HVPS for RF transmitter;
  - Analog low-level RF system (PEP-I/SLAC scheme with new RF chips);

- Time schedule:
  - Project from 2007-2013
  - Groundbreaking in spring, 2009 (hopefully)
  - Commissioning done before end of 2013
    - Stand-alone horizontal test stand to be available before end of 2009;
    - 300 kW klystron-based, switching type, RF transmitters (x2) in procurement stage;
    - Contract of SRF modules to be signed before end of 2009;
    - Delivery of SRF modules before end of 2011 (24 vs. 33 months);
    - Acceptance test of SRF modules successful before end of 2012;

Tough Challenge of Highly Reliable SRF Operation for TPS…

$$\text{trip rate} \propto \frac{\text{\# of SRF modules}}{\text{Safety factor}}$$

Successful SRF operation at TLS does NOT provide any warranty for a highly reliable SRF operation for TPS, because the RF power loading on the SRF modules will be increased significantly at TPS. And, this might make the SRF modules not reliable…

Cornell-type or KEKB-type SRF Module?

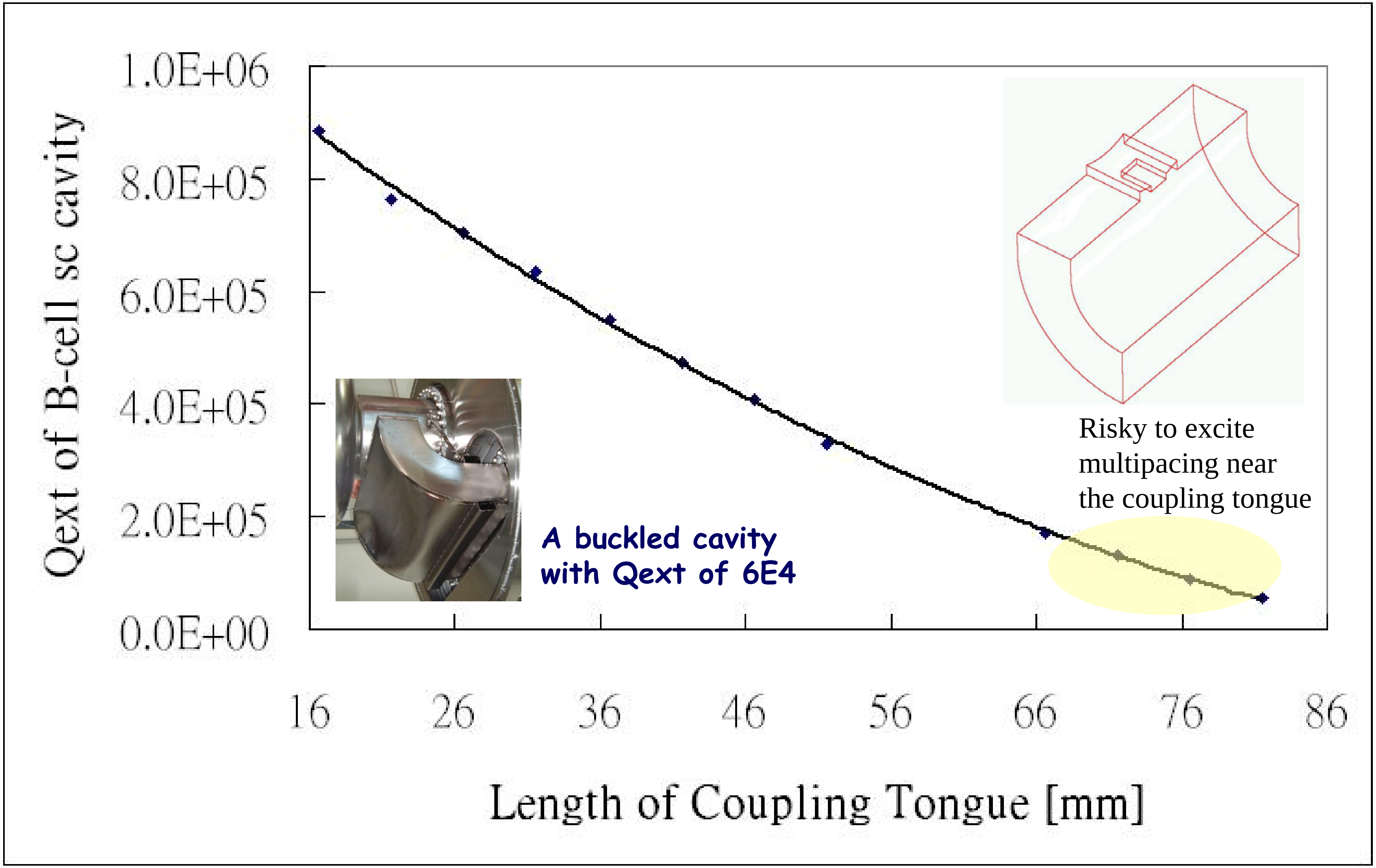
- **Concerns on reliable SRF operation at a high RF power (> 180 kW)**
  - Solution to waveguide multipacting
    - CLS/DLS experience: Excellent low-level rf system + beam processing?
  - Anonymous beam/vacuum trip: DLS's experience?

- **Tunability of Qext**
  - Maximum required RF power will be increased slowly – optimal Qext different in the commissioning phase and in the machine mature phase;
    - **CESR experience: using waveguide transformer for Qext tuning.**
    - **TLS experience: window broken.**
    - **CESR experience: re-optimize the window location at the standing wave minimum voltage position.**
    - **Using waveguide transformer with a correction factor of N**
      - **In-vacuum one: no effects on RF window;**
      - **In-air one: loading on the RF window will be increased in a factor of**
        - » **N, if RF window is located at minimum standing wave position;**
        - » **N^2, if not**

- **Achievable Qext?**
  - 1.5E5 or 0.5E5?

- **# of RF cavities required for machine operation**
  - Two to three for KEKB cavities (350 kW routinely operated at KEKB);
  - Three to four for Cornell cavities (250 kW maximum given by ACCEL);

Qext of Cornell-Type SRF Cavity



KEKB-type or Cornell-type SRF Module?

- 500 MHz version of KEKB SRF modules (x2) is now operated at IHEP, Beijing.
  - Width of cavity equator extended to lower the cavity frequency;
  - Doorknob modified for a better RF matching;
  - HOM loads re-produced;
  - Multipacting behavior at coaxial power coupler is different
    - HV bias is required for routine operation;
- Risk of vacuum leaks of SRF module after initial thermal cycling;
- Semi-laboratory product and Japanese business style vs. 100% industrial product and western business style;
- Maintenance challenge;

In-House R&D Project:
Cryostat Assembly of 500 MHz SRF Module

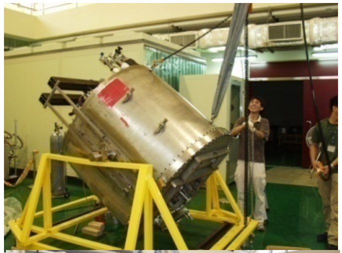
Cavity assembly


Cavity assembly


LN2 Cold Shock for vacuum leak check



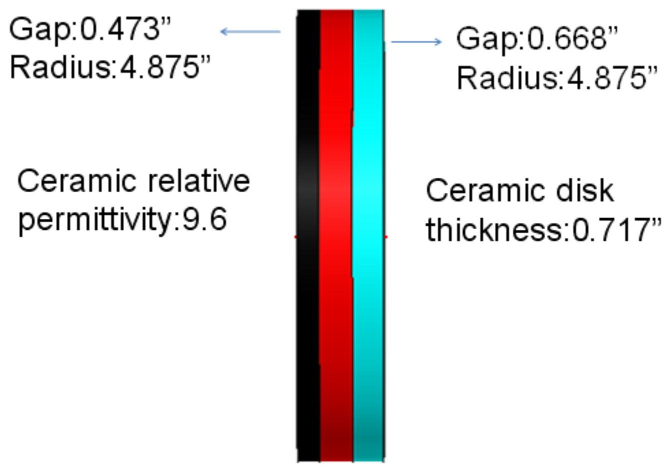
Cryostat assembly

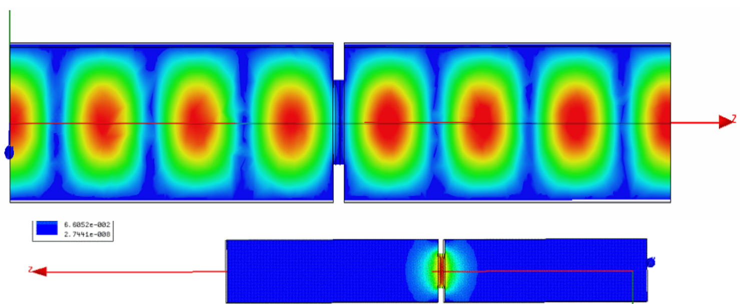


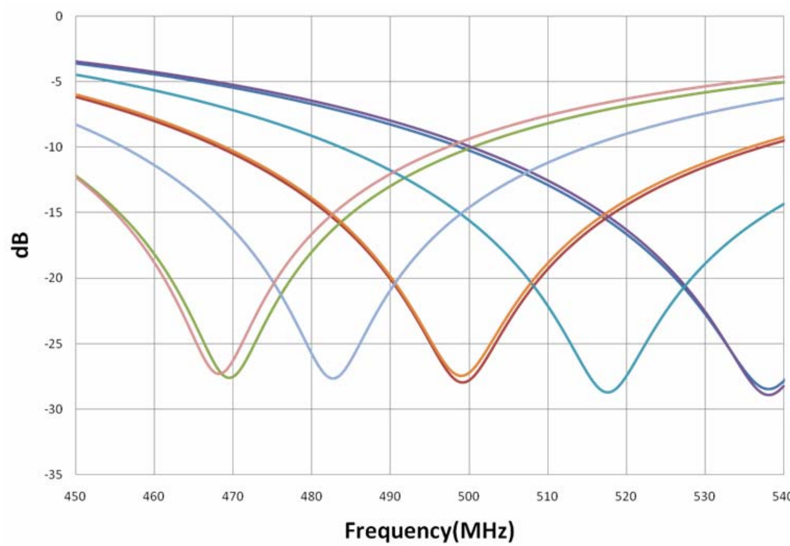

Leak Checks

In-House R&D Project:
500 MHz PEP-II Type RF Window

1. PEP-II type pre-stressed “traveling wave type” RF window (without matching posts);
2. Manufacture will be started in 2009.
3. Technical transfer of PEP-II RF cavity from SLAC was received in 2006.

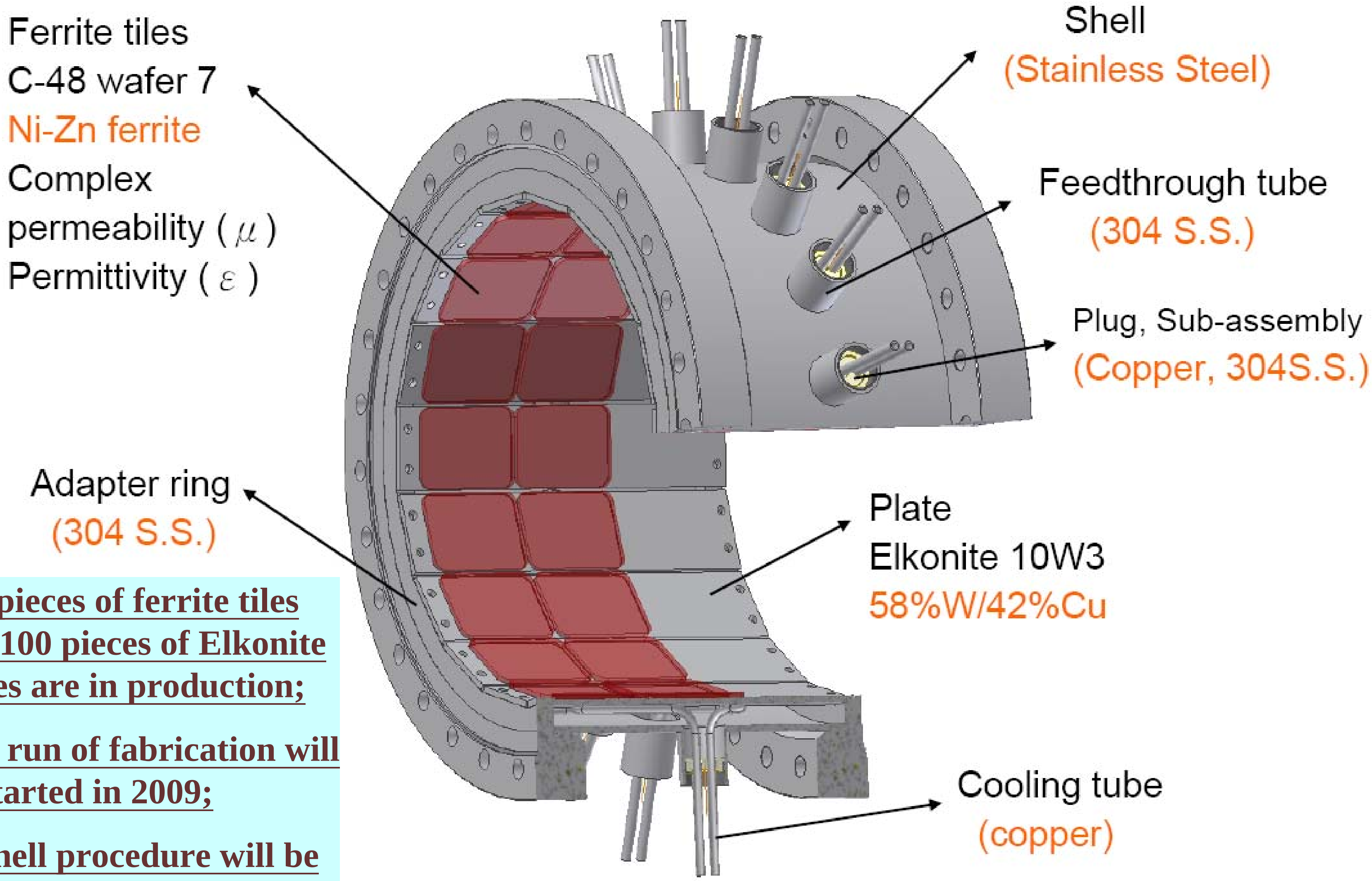



Ghost mode at 518 MHz



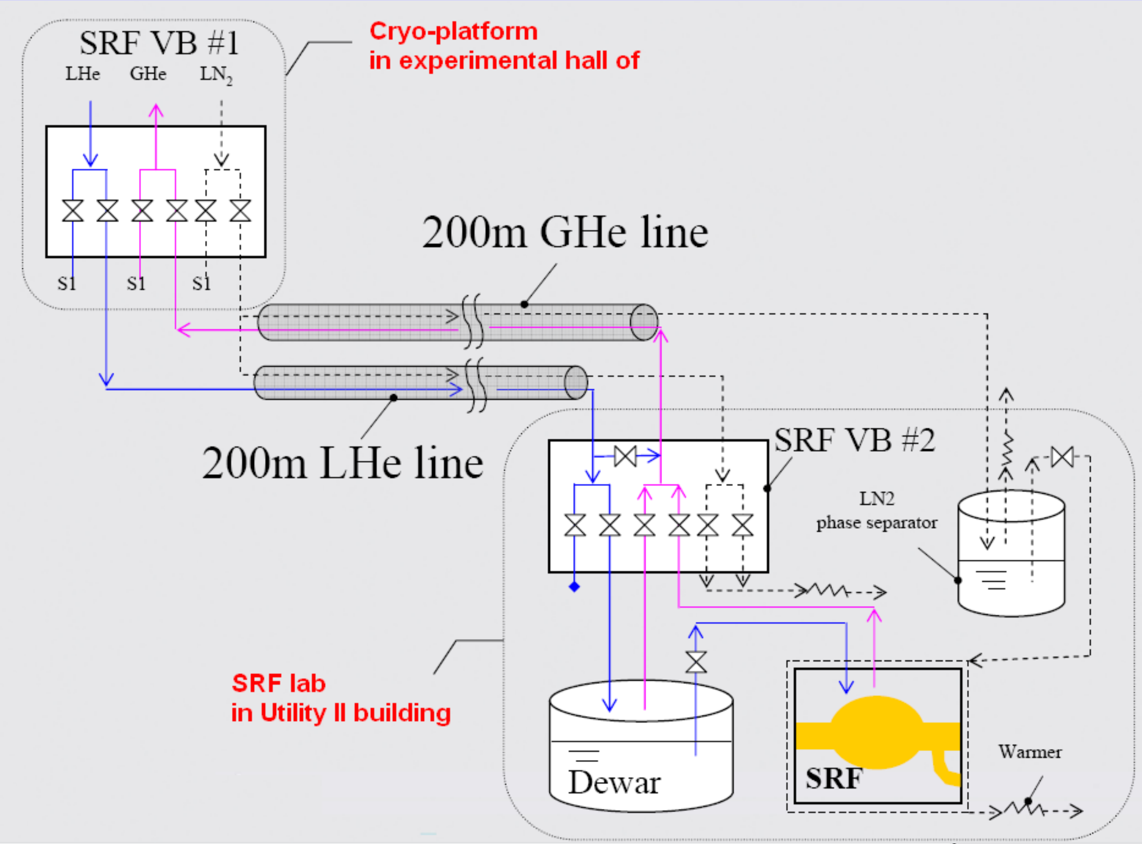
(NSRRC+NTHU)

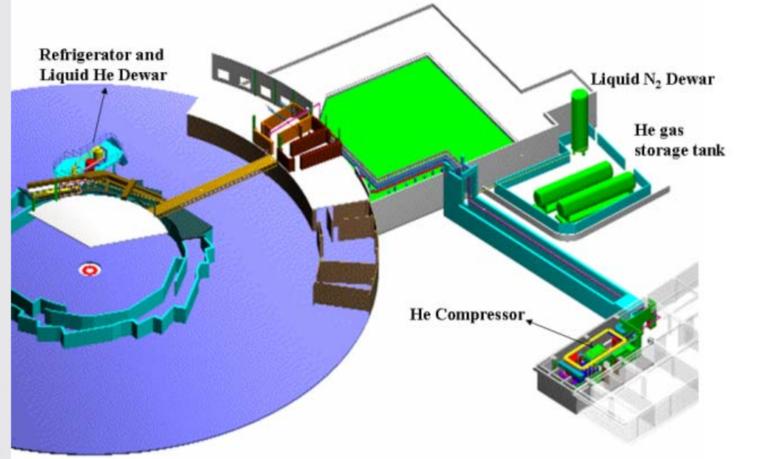
In-House R&D Project:
Manufacture of HOM Load



1. **200 pieces of ferrite tiles and 100 pieces of Elkonite plates are in production;**
2. **Test run of fabrication will be started in 2009;**
3. **Cornell procedure will be followed.**

In-House Engineering Project:
Horizontal Test Stand at SRF Lab





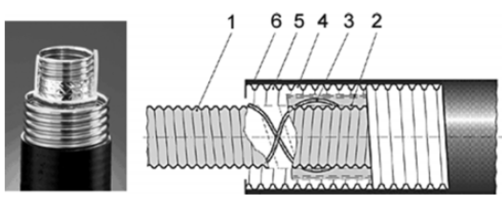
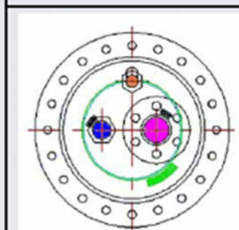
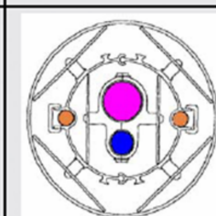


Fig. 2. This shows the cross section of a flexible cryostat. 1-Inner corrugated stainless steel tubing, 2-Multi layer insulation (MLI), 3-Polymer support and spacing material, 4-Vacuum space, 5-Outer corrugated stainless steel tubing, 6-Outer cable sheathing.

		NSRRC (DeMaCo)	KEK	CERN & BESSY (Nexans)
				
Dia	LHe	17.27 mm	17.3 mm	21.0 mm
	GHe	29.97 mm	34.0 mm	39.0 mm
cryogenic heta loss		0.3 W/m (69W for 230m)	0.05 W/m (11.5W for 230m)	0.06 W/m (21W for 230m)

Summary

- NSRRC made a critical decision of selecting SRF Technology for our 3rd generation light source, TLS in 1999.
- We demonstrated the operation of light source with SRF modules can meet the performance requirement of a light sources at a high beam current.
- Most recent commissioned light sources selected SRF modules as their accelerating cavities. We will adopt SRF modules for our constructing 3GeV new light source, TPS, too.
- We appreciate the strong technical support on the SRF technology from Cornell and KEKB in last years.

Thank you very much for your attention!