TTC2026 Jun.9-12

2 K Static Heat Load Performance for SHINE Cryomodules

Yawei HUANG, Yanfei ZHAI, Sicong GUO, Yiyong LIU, Jinfang CHEN

On behalf of Cryostat Group

SHINE Accelerator Division

2026.06.09

Outlines

- Recent progress for SHINE cryomodules
- 2K thermal performance and analysis
- Conclusions and perspectives

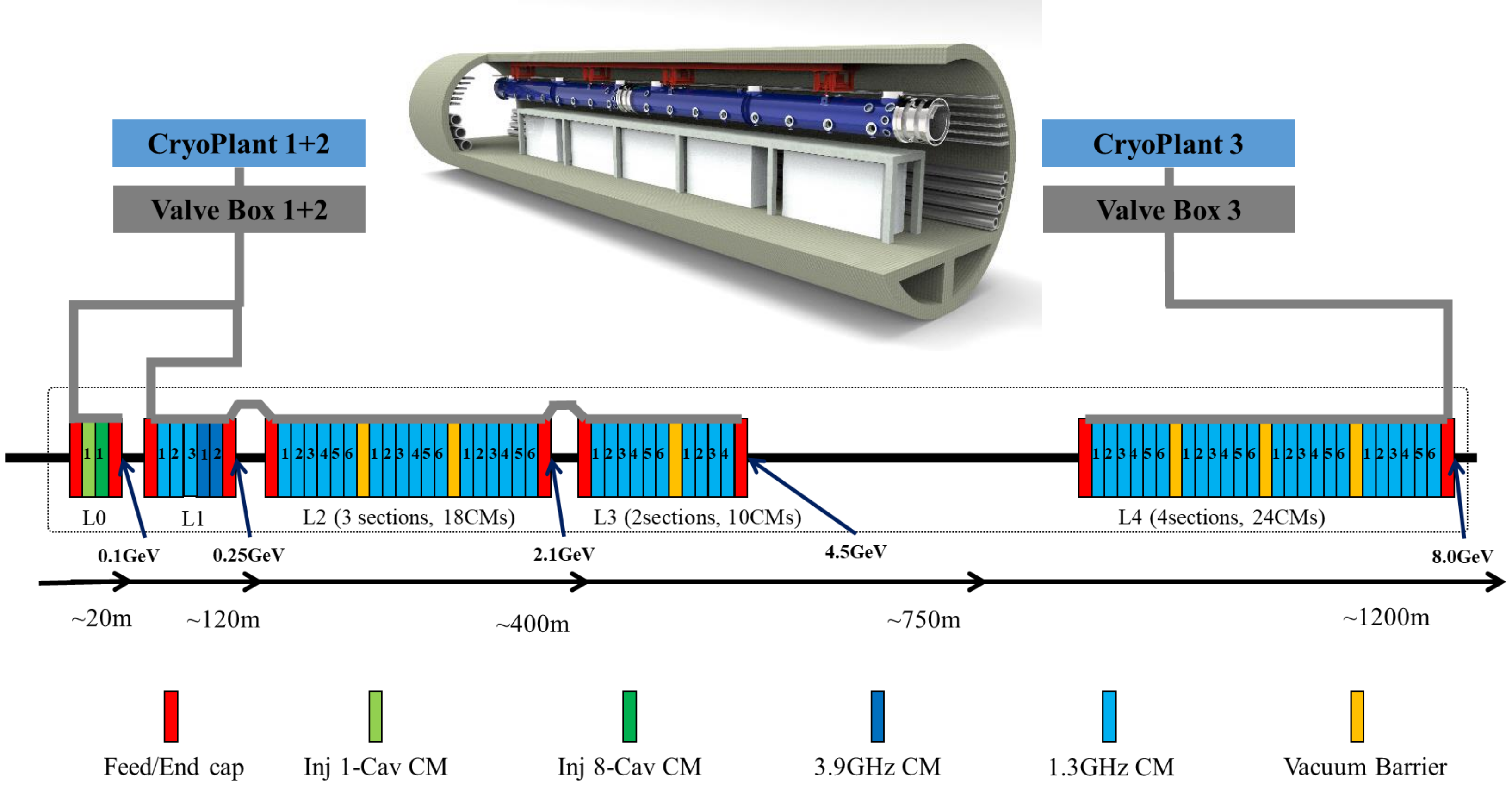
Introduction for SHINE project

- **SHINE = Shanghai HIgh repetitioN rate XFEL and Extreme light facility**
  - Approved in April **2017**, ground-breaking in April **2018**
  - Legal person of SHINE: **ShanghaiTech University (STU)**
  - Joint project teams: **SARI (SSRF), SIOM**
  - Total length **3.1 km**, **29 m** underground
  - SHINE = **8 GeV CW** SC Linac + 2 FEL undulator lines + 2 beam lines + 10 end-stations + PWs laser
  - Photon energy: **0.4 – 25 keV**
  - Rep-rate: **1 MHz**
  - Time resolution: **<10 fs**
  - Cost/schedule: ~**1.3B Euros**, **9 years** (2018-2027)

Introduction for SHINE Linac

- **SHINE Linac @1.4 km= 1** Inj. 1-cav CM + **1** Inj. 8-cav CM + **2** 3.9GHz CMs + **54** 1.3GHz CMs

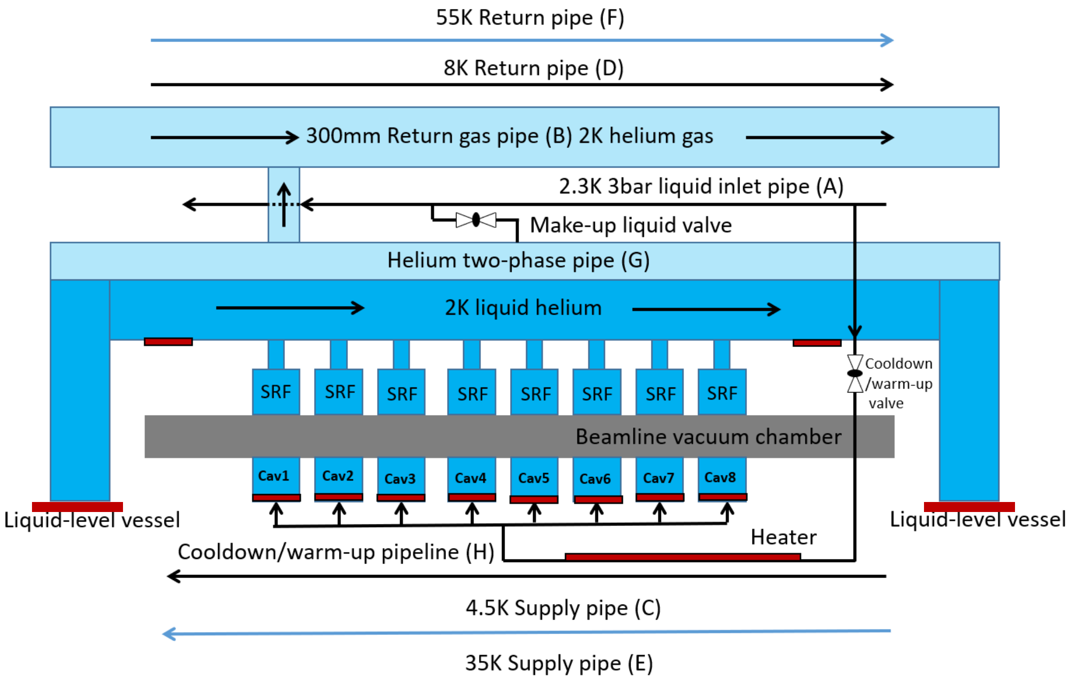
SHINE Linac main parameters	Value
Cavity	TESLA
Operating mode	CW
Operating temp. / K	2.0
Frequency / MHz	1300
Eacc / MV/m	22
Q0	3.0×10^{10}
Number of cavity	450
Cryomodule static heat load	20 W
Cryomodule total heat load @ 166MV	120 W
Beam energy / GeV	8.0
CryoPlant / kW	12



Cryogenic Design for SHINE Cryomodule

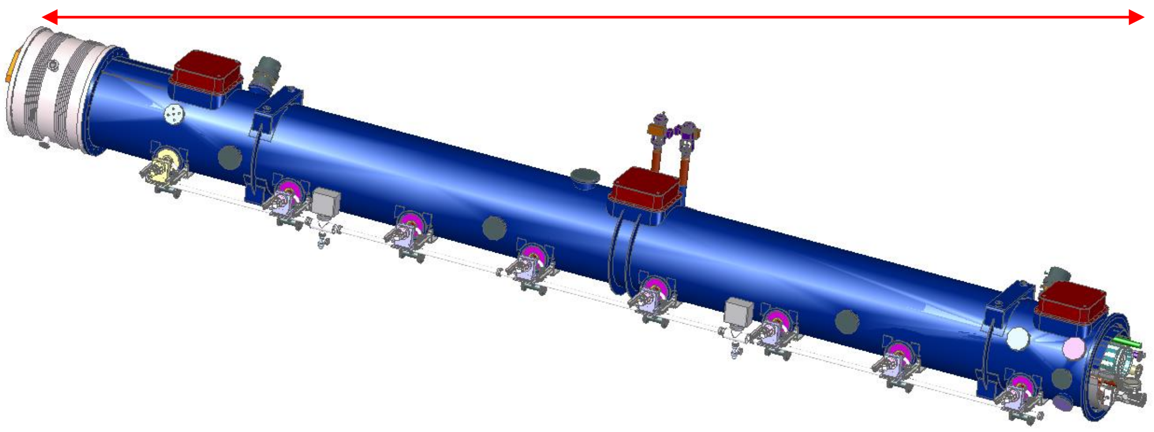
- **Cryogenic design specifications for SHINE cryomodules**
  - **Design specifications:** 2K heat load≤140W， 2K pressure stability≤±10Pa， 45K fast cooling flow≥30g/s， Safe Radial dT on B during cool down **< 15K**——*Boundary conditions for 2K cryogenic system design*
  - **Cryogenic flow chart:** Cavity string @**2K**, Thermal intercept @**5K**, Thermal shield @**45K**

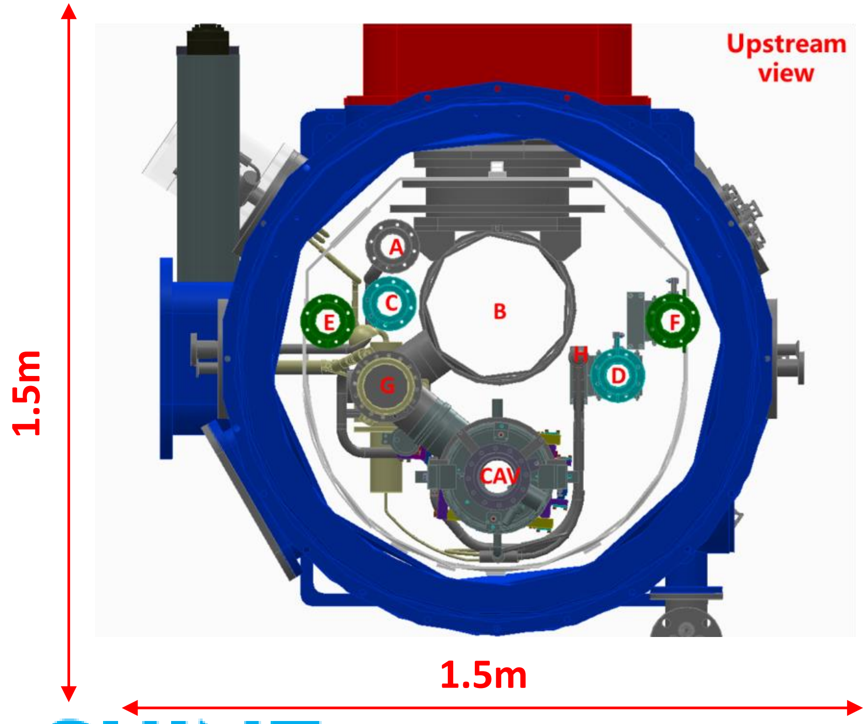
Parameter	Value	Remarks
Static heat load	**≤20 W @2 K**	
Dynamic heat load	**≤120 W** @166MV ≤140 W (Max)	Cav: **3.0E10 @ 20MV/m**
Operating temp.	2.0 K	
Operating pressure	3100 Pa	
Pressure stability	**≤±10 Pa**	Fre. Dev < ±30Hz Peak Detun. (PHe. sens. ~80Hz/mbar)
Fast cooling rate	≥10 K/min	45K ~ 4.5 K
Fast cooling flow	**≥30 g/s**	45K~4.5 K
Cooling/Warm-up rate	**5~10 K/h**	Ins. Vacuum < 1.0E-2Pa
MAX ΔT (Cooling down/Warm up)	< 50 K (Axial) **< 15 K (Radial)**	Ins. Vacuum < 1.0E-2Pa



Cryogenic Design for SHINE Cryomodule

- **Cryogenic structure design for SHINE cryomodules**
  - **Total weight:** ~8.5T
  - **Vacuum chamber:** 12m×1.5m×1.5m
  - **Cryogenic piping:** 3 temp. levels (**2K、5K、45K)**
    8 pipes (from pipe **A** to pipe **H**)

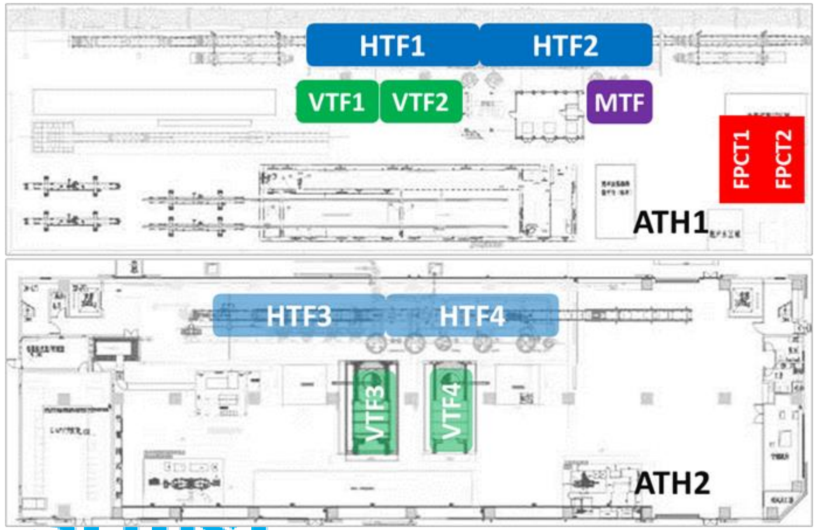


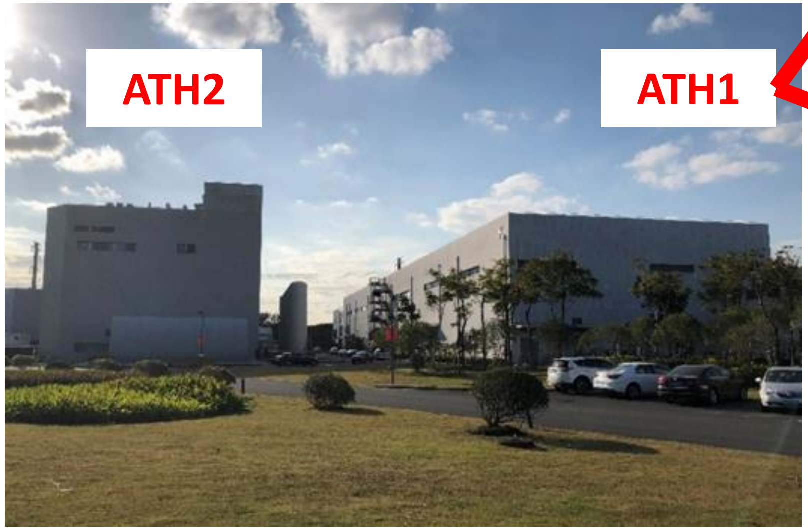


Line	Function	OD/ID (mm)	Operating Temp. (K)	Operating Pressure (barA)	Design Pressure (barA)
A	**2.3K supply**	60.4 / 54.8	2.3-5.5	3.0	15.0
B	**2.0K return**	312 / 300	2.0-4.6	0.031-1.6	4.0
C	**4.5K supply**	60.4 / 54.8	5.5	3.0	15.0
D	**8.0K return**	63.5 / 50.8	7.0	3.0	15.0
E	**35K supply**	60.4 / 54.8	40.0	**18.0**	**23.5**
F	**55K return**	63.5 / 52.5	50.0	**18.0**	**23.5**
G	**2K two-phase pipe**	101.6 / 97.4	2.0-4.6	0.031-1.6	4.0
H	**Cooldown/warm-up line**	42.2 / 38.9	2.0-4.6	0.031-2.6	4.0

Assembly and Test Hall for SHINE Cryomodules

- **SHINE cryomodule assembly and test hall：3 categories, 10 facilities**
  - **Hall 1 (ATH1)** ~ 3000 m2
    - **Horizontal Test Facility × 2** (HTF1/2)：Cryomodules
    - Vertical Test Facility × 2（VTF1/2）：SC Cavities (four-cavity type)
    - Multifunction Test Facility × 1 (MTF1)：SC Magnet, Couplers, Cold BPMs, etc.
  - **Hall 2 (ATH2)** ~ 3000 m2
    - **Horizontal Test Facility × 2**（HTF3/4）：Cryomodules
    - Vertical Test Facility × 2 (VTF3/4)：SC Cavities (two-cavity / four-cavity type)
    - Magnet Test Facility × 1 (MTF2)：SC Magnet

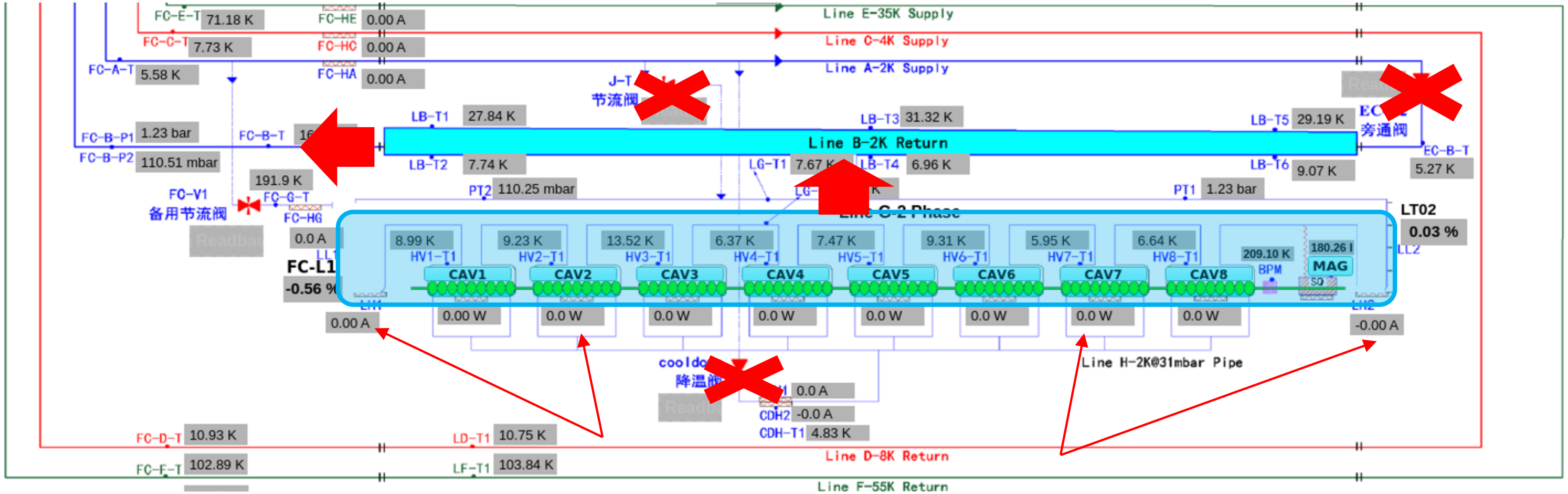


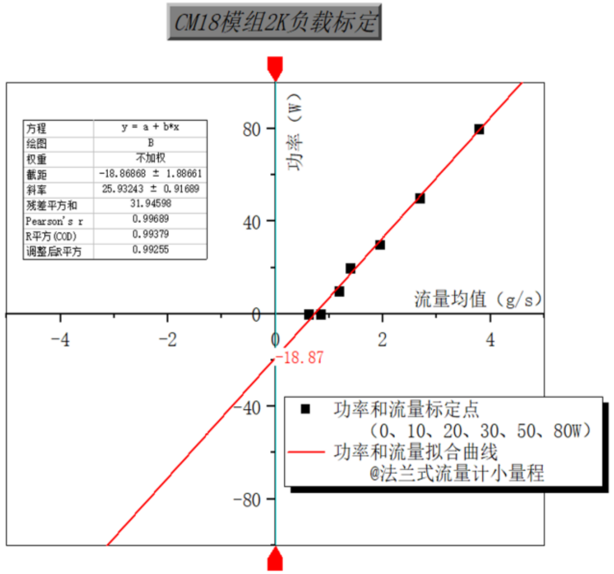


- ATH = Assembly and Test Hall
- HTF = Horizontal Test Facility
- VTF = Vertical Test Facility
- MTF = Multifunction/Magnet Test Facility

2 K Static Heat Load Measurements

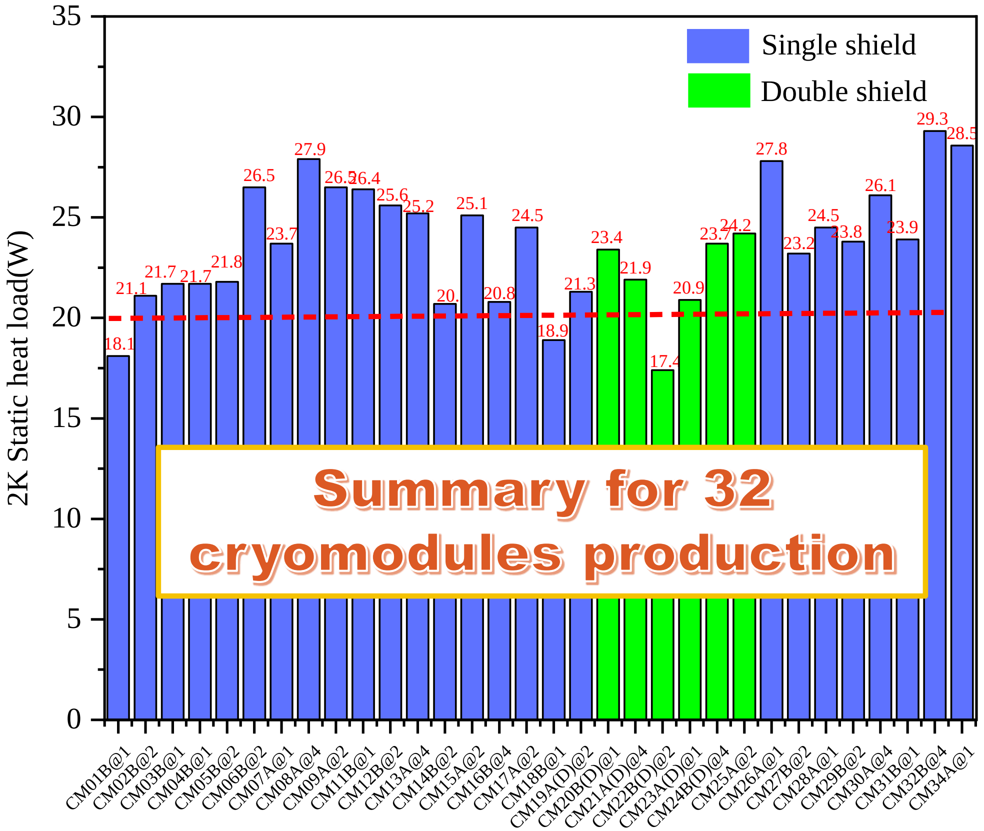
- **Mass Flow-rate Method:** The two-phase pipe is accumulated to the target liquid level. **Close the liquid inlet valve and keep the return gas valve fully open**. Apply a certain heat load, such as a heater or cavity power, to evaporate the liquid. **Stabilize the pressure at 31 mbar**, and continuously **record the room-temperature pump flow rate** for at least 10 minutes after it becomes stable. Then perform **data processing and calibration**.
  - $H_{stat} + H_{dyn} = \dot{m}_{He} h_{lg}$
  - $\rightarrow H_{dyn} = h_{lg}\dot{m}_{He} - H_{stat}$





2 K Static Heat Load for Recent Production

- **2K Static Heat Load Summary for 32 Prod. Cryomodules**
  - **Measurement approach：**
    - ➢ **Test system:** 2K Warm pump + Mass flow meter (Flange ~**4.5g/s**)
    - ➢ **Mes. range：0 ~ 90W** (corresp. ~4g/s)
    - ➢ **Mes. deviation：~10%**
  - **2K static heat load values** (inc. test stand)
    - ➢ Average for **All** cryomodules = 32: **23.6 W**
    - ➢ Average for **Single Shield** cryomodules =26: **24.1 W**
    - ➢ Average for **Double Shield** cryomodules = 6: **21.4 W**
    - ➢ **Two levels** of 2K thermal performance：1^{st} level~ **20.0W±2.0W** (10%), 2^{nd} level ~ **26.0W±3.0W** (10%)
  - Preliminary analysis for CM **structure and assembly：**
    - ➢ Different **MLI** installation on the LHe piping ➔ **30 layers better**
    - ➢ Different **type** of cryostat (w/t OR w/o **JT valve**) ➔ **No Difference**
    - ➢ Different **test stand** contribution ➔ ATH2 > ATH1 **~2.5W**

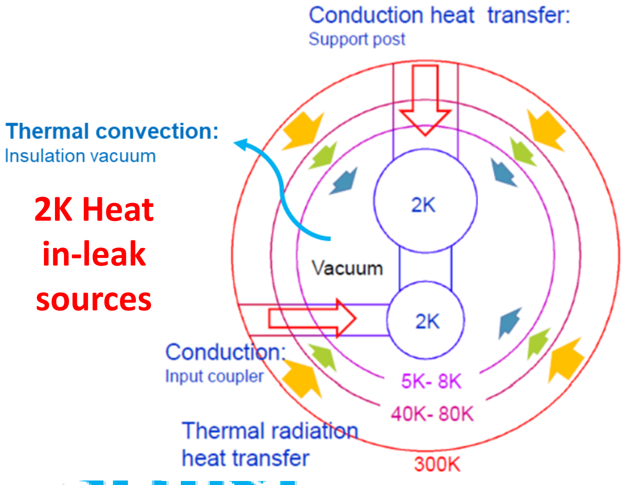


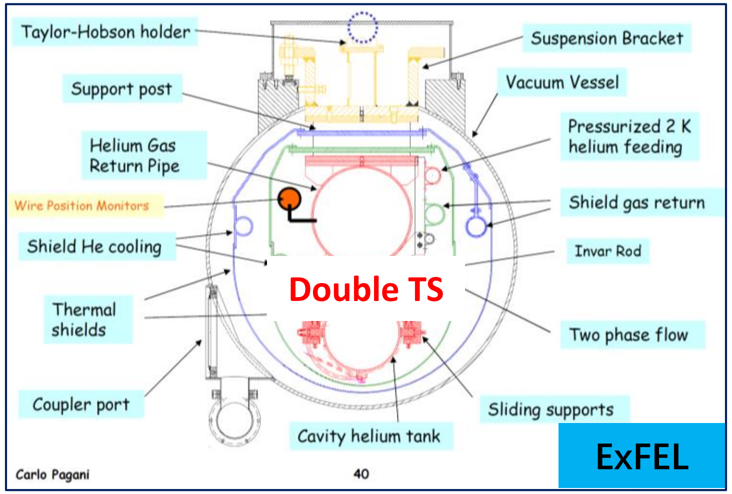
SHINE

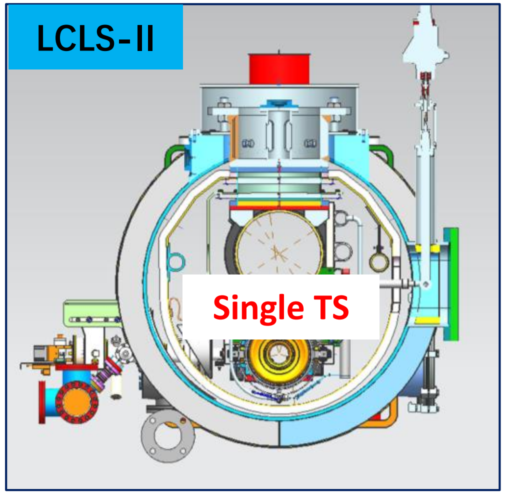
2 K Thermal Performance for SHINE Cryomodules

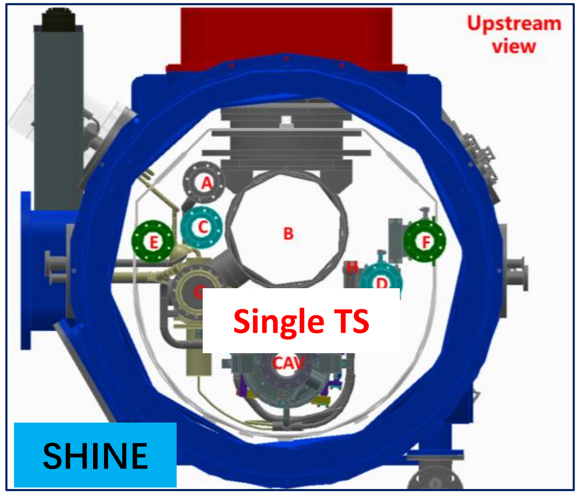
- **TESLA Type Cryomodule:** 2K static heat load estimation
  - **2K Heat in-Leak Sources:** thermal conduction, thermal convection, thermal radiation

2K heat in-leak	Temp. Level	ExFEL~6W	LCLS-II~16W	SHINE~20W
Conduction	300K-2K	MPC, Post support	MPC, Post support, CryoValve manifolds	MPC, Post support, CryoValve manifolds
	45K-2K	—	He tank inlet pipe, Cryocables	He tank inlet pipe, Cryocables
	5K-2K	He tank inlet pipe, Cryocables	—	—
Convection	300K-2K	＜1.0E-3Pa	＜1.0E-2Pa	＜1.0E-3Pa
Radiation	45K-2K	-	Cavity string, 2K piping	Cavity string, 2K piping
	5K-2K	Cavity string, 2K piping	—	—





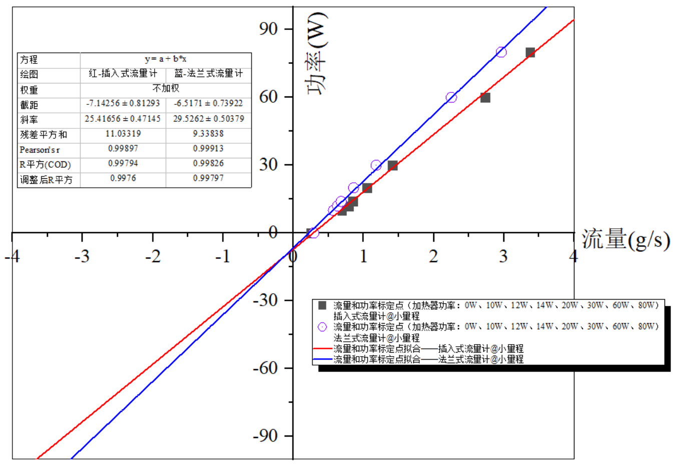




Analysis from Pre-Development Experience

- **2 K static heat load distribution analysis for SHINE CMs:**
  - **Test system:** 2K static heat load mes. system is already calibrated and optimized for production CMs, with Cap contrib. estim. ~**1W**.
  - **Conduction:** total contribution ~**2W**
    - **MPC** ×8: ~**0.4W** (num. analy. ~0.05W/MPC based on the exp. data)
    - **Post support** ×3: ~**0.52W** (num. analy. based on the exp. data)
    - CryoValve mes. **< 1W** (with thermal intercept estim.~0.57W)
    - ~~CryoManifolds mes. ~8W~~ (avoided by assembly procedure control)
  - **Convection:** total contribution ~**0W**
    - SHINE prod. CM Insulating Vacuum~**5.0E-4Pa** @2K (effective thermal conductivity min. ≪**1.0E-2Pa**)
  - **Radiation: non-study yet during pre-development stage for SHINE (2021~2024)**
    - To apply the ExFEL empirical flux density of **0.05W/m2 @10 MLI ➔** contrib. ~**1.5W @2K**
    - Study on **Single/Double thermal shield difference** on 2K static heat load: addition of 5K thermal shield inside SHINE 1.3GHz CM

VTF2 小量程下流量计校核时流量和功率拟合



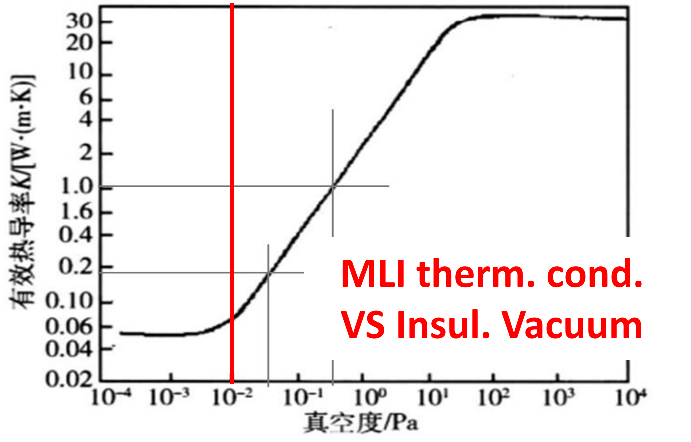


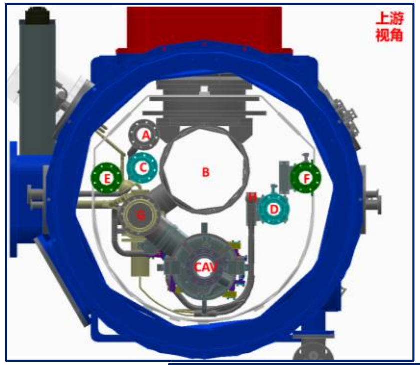
图 1 多层绝热的表观真空度与有效热导率的关系 [1]

Fig. 1 Effective thermal conductivity as a function of apparent vacuum

Thermal Radiation Experiment for Cryomodule

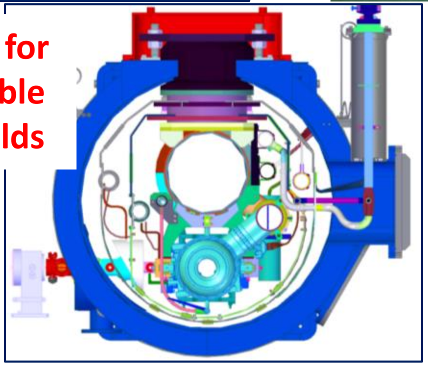
- **Trials for improving 2K static heat load:** Double thermal shields assembly and test based on the **BCPed CM**
  - Addition of **5K thermal shield**, including **8K pipe** (Al6061) with **welding plate** and **10 MLI** on the 5K shield
  - **Remake of 45K** shield (for enlarging inner space) and cryogenic piping flange (for horizontal test stand connection)
  - **2K tests** (LHe Level Method +Mass Flow Method) for comparing before/after double shield remake——**First batch production:** double thermal shield already planned for **CM19-CM24**
    - **Liq Level Method**： 2025 double TS < 2025 single TS ~**1.6W**； 2025 double TS < 2022 single TS ~**7.5W**
    - **Mass Flow Method**： 2025 double TS < 2025 single TS ~**3.4W**

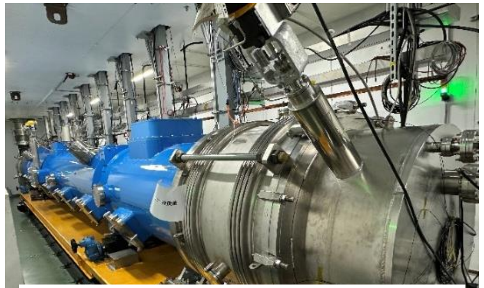
Test Stand	Test Method	Test Period	CM Structure	Pressure (mbar)	Results (W)	Difference (W)
HTF2	Liq Level	2022.06	**Single TS**	31±0.2 (C.C.)	**23.4**	**7.5**
HTF1	Liq Level	2025.06	**Double TS**	31±0.1 (W.P.)	**15.9**	**1.6**
		2025.08	**Single TS**	31±0.1 (W.P.)	**17.5**	
	Mass Flow	2025.06	**Double TS**	31±0.1 (W.P.)	**21.2**	**3.4**
		2025.08	**Single TS**	31±0.1 (W.P.)	**24.6**	




Fabrication for double thermal shields

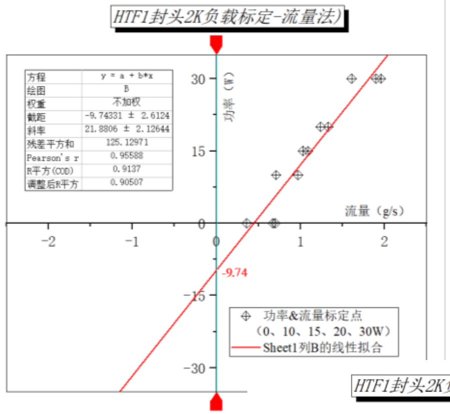
TDR for double shields

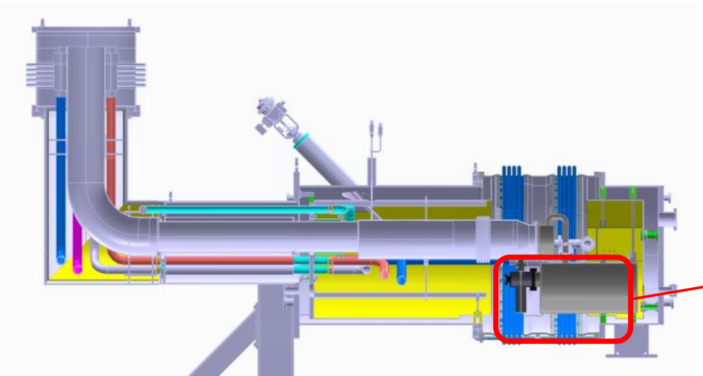



2K test for double shields

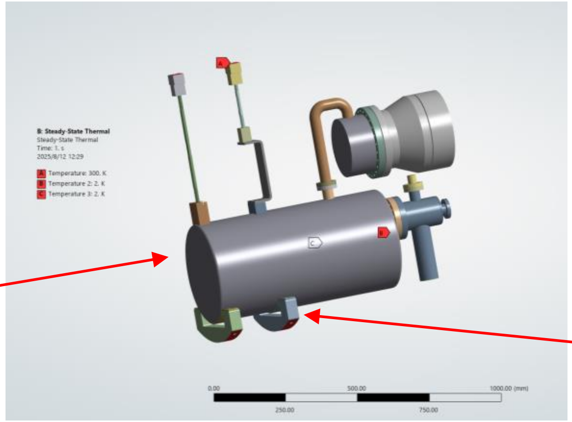
Dummy Experiment for Test stand

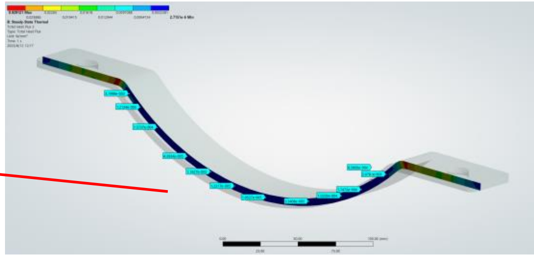
- **Dummy experiment with only Caps for the Test Stand HTF1 at 2K**
  - **Test preparation**
    - **HTF1 condition:** The cryomodule already warmed-up to room temperature. The cryomodule, Faraday cup, and related downstream support components are removed from the HTF1.
    - **Test fixture preparation:** An external **liquid helium vessel**, equipped with an internal heater and liquid-level gauge, is installed. A **pressure sensor** is installed at the Feedcap as well as **six additional temperature sensors** added. An **aviation plug** is also added at the Endcap for the extra cryogenic measurement.
  - **Test results**
    - 2K heat in-leak estim. for **inner support fixture**: 6.2W @2K
    - 2K heat in-leak mes. for **Test Stand**: 7.8W@LiqLevel, 9.7W@MassFlow
    - 2K heat in-leak mes. for **Test Stand pure**: **1.6W @LiqLevel, 3.5W @MassFlow**



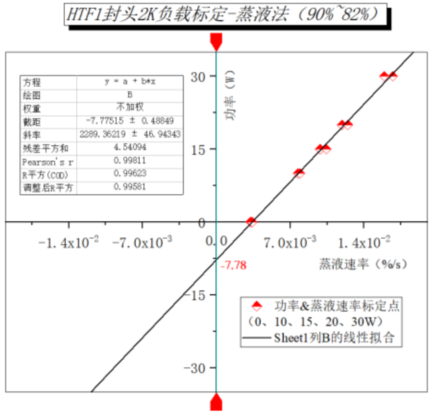


Dummy test for HTF1





Estimation for test fixture



2 K Thermal Performance Analysis

- **Summary for 2K static heat load contribution from three heat transfer ways**
  - All measurement for analysis are based on the **Mass Flow Method**

NO.	Heat Transfer	CM component	2K static heat load Estim.（W）	2K static heat load Mes.（W）	Note
1	**Conduction**	Post support	0.12	0.52	
2		MPC	0.44	0.40	Suspect: 0.049W/MPC =f(Cu coating)
3		CryoValvel	1.14	~1.0	0.57W/CryoValve
4		Others (e.g Cables)	~1.0	?	Unknown: 24.1W - 10.5W = 13.6W (RF cable, Tuner cable, Cryocable)
6	**Convection**	Insulating Vacuum	0	0	~5.0E-4Pa
7	**Radiation**	45K Shield	1.5	5.0	Estim. vs Mes.: 0.05W/m2 vs 0.15W/m2
8	**Test stand**	Entire	~1.0	3.5	Faraday Cup not included
9		Faraday Cup	—	0.05	
10	**Total**		**5.2**	**24.1**	26 CMs with **Single Shield**

SHINE

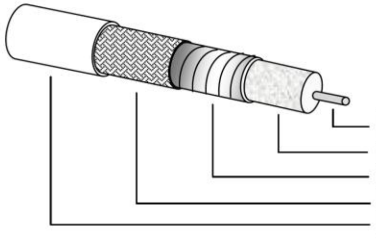
Next plan：Find the X-man!

- **Simulation for the 2K heat in-leak from SHINE RF cables (for Cav. HOM/PU feedthroughs)**
  - 2K static heat load estimation ~**0.2W** /RF cable even with good thermal intercept at 5K level

No.	Name	Wire Diameter (inch)	Wire Diameter (mm)	Cross-sectional Area (mm2)	Total Cable Length (m)	Length from Thermal Intercept at 10K to 2K End (m)	Material	Thermal Conductivity (W/m.K)
1	Center Cond	0.0641	1.62814	2.082	2.5	0.5	Sliver-plated copper (RRR100)	400-2400：2-100K 400：100-300K
2	Dielectric	0.208	5.2832	19.840	2.5	0.5	PTFE	0.25
3	Outer Cond	0.222	5.6388	3.050	2.5	0.5	Sliver-plated copper (RRR100)	400-2400：2-100K 400：100-300K
4	Outer Shield	0.249	6.3246	6.444	2.5	0.5	Sliver-plated copper (RRR100)	400-2400：2-100K 400：100-300K
5	Jacket	0.27	6.858	5.523	2.5	0.5	White fluoropolymer (ETFE)	0.25

	Thermal Intercept Temperature on Pipe（K）	Total Heat Load per Cable at the Thermal intercept on Pipe D（W）	Total Heat Load per Cable at 2K（W）
Heat Load Analysis	10	8.68E-01	0.2
	20	2.56E-01	0.7
	30	-4.37E-01	1.3
	40	-9.79E-01	1.7
	50	-1.35E+00	2.0

RF cable 401



Center Conductor	0.0359"	Silverplated Copper
Dielectric	0.118"	Solid PTFE Dielectric
Outer Conductor	0.126"	Silver Plated Copper
Outer Shield	0.139"	Silver Plated Copper Braid
Jacket	0.160"	White Tefzel

Mechanical Characteristics

Diameter:	0.165" nominal
Minimum Bend Radius	0.625" nominal
Operating Temperature*	-200^0 to +125^{0}C
Weight	31-lbs/1000 ft

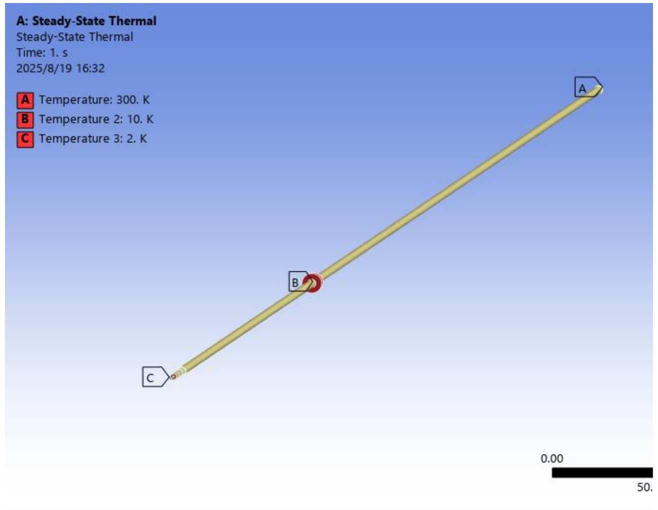
Optional Print: "TFLEX-402 COAXIAL CABLE T TIMES MICROWAVE SYSTEMS 68999 PH +1(203)949-8400 DD/MM/YY ftftft "

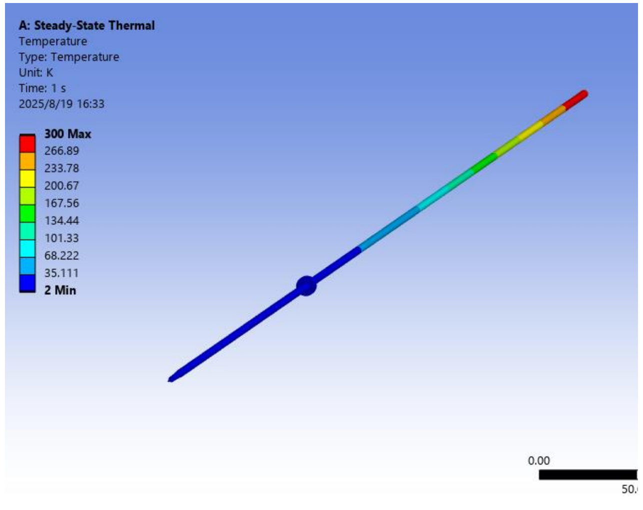
* The minus 200^0 C temperature limit is for static installations only.

Electrical Characteristics

Characteristic Impedance	50 Ohms nominal
Velocity of Propagation	70% nominal
Capacitance	29.4 pf/ft nominal
Delay	1.45 nsec/ft nominal
Shielding	-90 dB minimum
Insertion Loss	0.66 dB/Ft @ 18 GHz

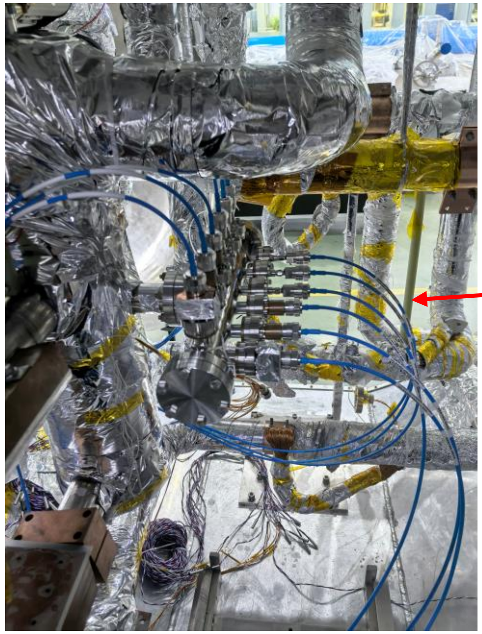
To calculate Insertion Loss for other Frequencies Use:
IL =0.3324 x√ Freq*+ 0.001191 x Freq*(*MHz) dB/100ft

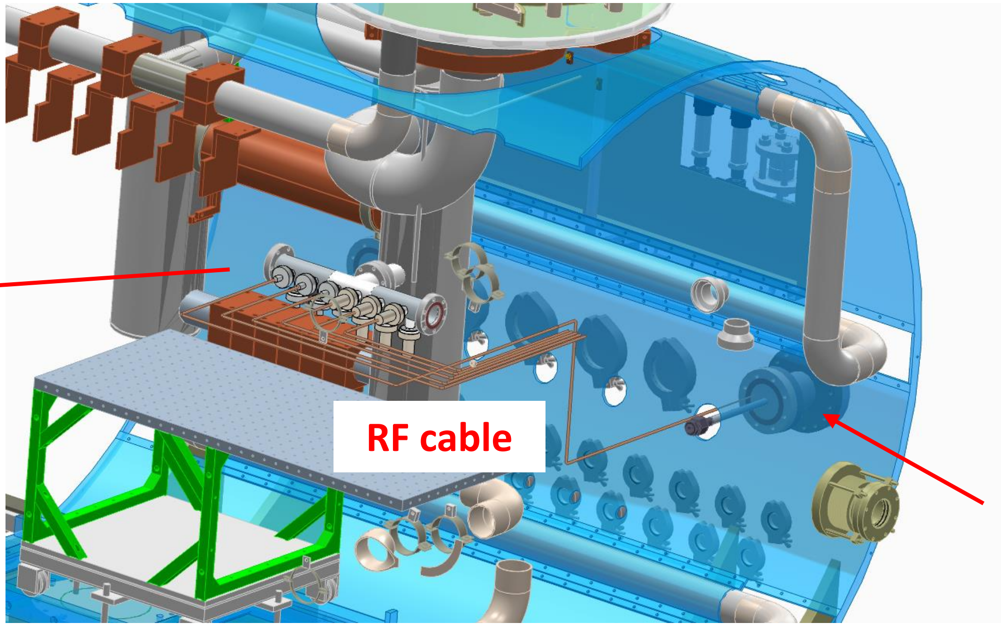




Next plan: Find the X-man!

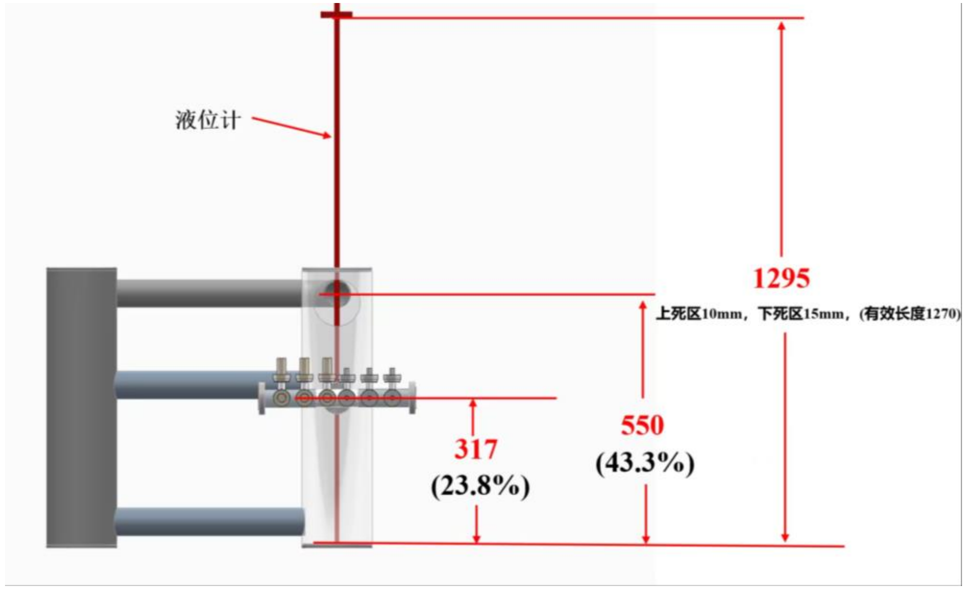
- **Cryogenic Experiment for RF Cables**
  - **Preparation** both from cryogenic & RF sides
    - To take advantage of the SHINE **test stand MTF** with LiqLevel Method at 4K
    - To customize a **test fixture** for connecting all the RF cables used in the SHINE cryomodule
    - To add **cryogenic heaters** at the Level can
    - **RF cables with FT and connection ports**: 6 for HOM and 6 for Pick up, with N/SMA type and CF100 flange for VT
  - **Experiment plan**: measurement with RF cables type 401, no thermal intercept from cryogenic end to warm end along the 2.5m, normal signal transmission.



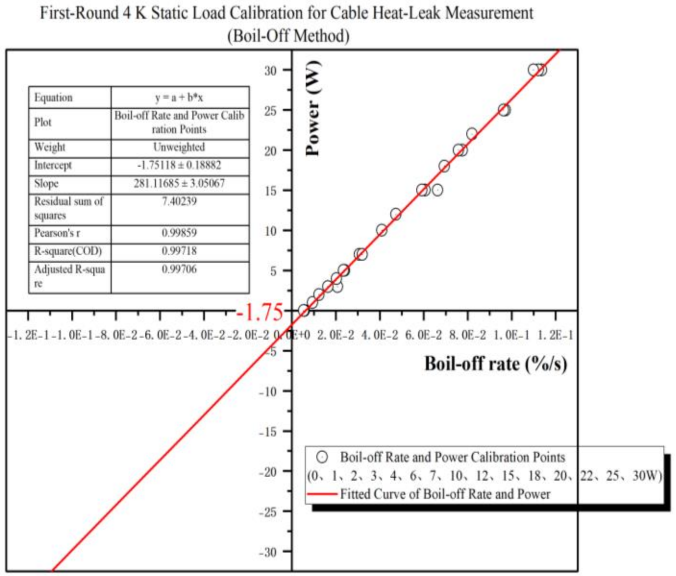


Next plan：Find the X-man!

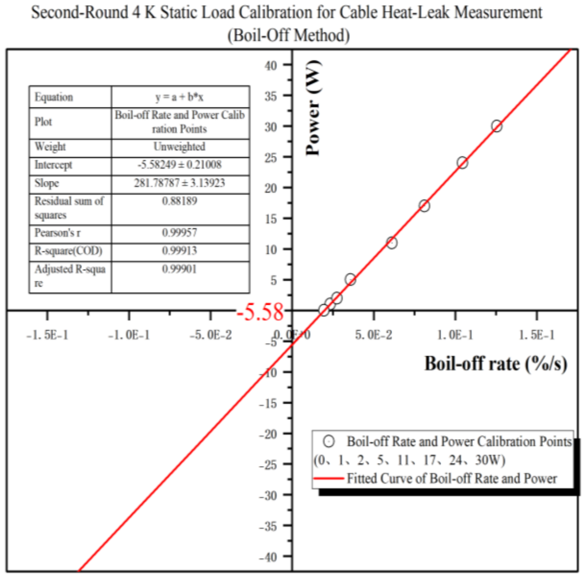
- **2K Static heat load measurement for RF cables: 6 months (2025.11~2026.05)**
  - **Execution plan**: Functional verification of the MTF ➪ Platform modification ➪ Installation test: Test with fixture only, Test with cables 401 (incl. fixture), Test with fixture only
  - Static heat load at 4K: 12 RF cables total **~3.85W (~0.33W /cable** with type 401 @2.5m without thermal intercept)



LiqLevel diagram
for Test Fixture



Test with fixture only



Test with cables 401

Conclusions and Perspectives

- **Summary on the 2 K static heat load for 32 SHINE cryomodules**
  - **Test period** : ~**2.5 years**
  - **Test approach**: Mass flow rate measurement for Prod. cryomodules 2K horizontal test
  - **Test uncertainty**: ~**10%**
  - **Contribution level**: Conduction~**80%** **>** Radiation~**20%** **>** Convection~**0%**
  - **Other contribution**: Test stand (Feedcap + Endcap, Faraday Cup, etc) ~**3W**, Mass flow meter calibration~**3W** (more than Liquid Level Method)
  - **Correction** for single shield prod. cryomodules: **24.1W → 18.1W**
- **Perspectives:**
  - To complete the **verification of the cables contribution** on 2K static heat load for other conditions (cable 402, thermal intercept, etc.)
  - To find the **systematic difference** between **Liq Level Method** & **Mass Flow Rate Method** = f (Test Stand):
    - ~3W in ATH1
    - ~8W in ATH2
  - To **improve** the 2K thermal performance as much as possible, at least **before the Last ONE CM**
  - To complete the **final 20 prod. cryomodules** measurement and give a full analysis for SHINE

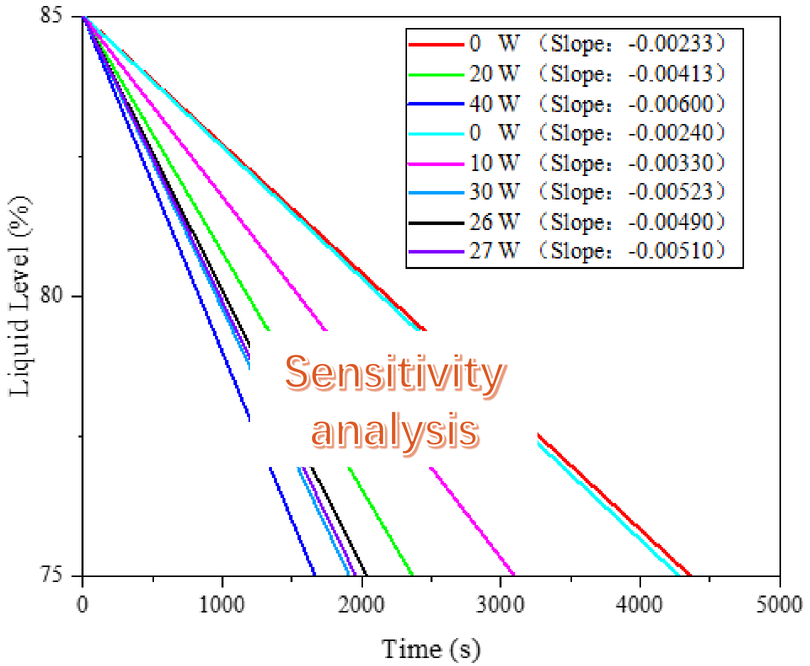
Thank you!
Merci!

Back-up

High-Q cryomodule: 2K heat load measurement

- **Uncertainty analysis：**
  - Main sources: heaters power, liquid level sensor reading, time resolution
  - Main parameters:
    - 1、heater power accuracy~0.5% (40W, 10W)
    - 2、density, thermal capacity set as zero
    - 3、time resolution set as 0.5% (5s difference within 1000s)
    - 4、liquid level sensor accuracy ~0.5%, Lhe volume measurement accuracy~0.5%
  - Theoretical uncertainty range: **~±2%**
- **Sensitivity analysis: ~1W** @ liquid level method
- **Repeatability analysis: ~5%**
- **Pressure stabilization analysis:**
  - ~2mbar → ＜0.5mbar：**~10% contribution**

$$\boldsymbol{P_{stat} + P_{dyn} = \frac{\rho_{He} \cdot \Delta V \cdot h_{lg}}{\Delta t} \propto \alpha \frac{\Delta LL}{\Delta t}}$$



Sensitivity analysis

测试日期：2022.05.21

BCP模组2K静态负载测试：液位法 @ 0W		
参数	数值	备注
温度(K)	2.00	
压力(mbar)	31.63	30.66 mbar - 32.6 mbar
氦体积(m3)	0.024	估算值（液位高度：85%-77.5%）
氦密度(kg/m3)	145.66	1068.874675
氦汽化潜热(J/kg)	23041.85	
氦质量(kg)	3.50	
氦汽化热量(J)	80550.40	
汽化时间(s)	3140	液位曲线：2022.05.21 11[illegible] 77.5%（两侧[illegible]
2K总负载(W)	**25.65**	加热器：~0[illegible]
2K静态负载(W)	**25.65**	加热器：~0 W

Repeatability analysis

测试日期：2022.05.22

BCP模组2K静态负载测试：液位法 @ 0W		
[illegible]	数值	备注
[illegible]	1.99	
[illegible]	30.36	30.74 mbar - 29.98 mbar
[illegible]	0.024	估算值（液位高度：85%-77.5%）
[illegible]g/m3)	145.64	1093.057862
[illegible]化潜热(J/kg)	23056.43	
氦质量(kg)	3.50	
氦汽化热量(J)	80588.97	
汽化时间(s)	3072	液位曲线：2022.05.22 16:03:09 85% - 16:54:21 77.5%（两侧液位）
2K总负载(W)	**26.23**	加热器：~0 W
2K静态负载(W)	**26.23**	加热器：~0 W

测试日期：2022.06.10

BCP模组2K静态负载测试：稳压液位法 @ 0W		
参数	数值	备注
温度(K)	2.01	
压力(mbar)	32.00	31.8 mbar - 32.2 mbar (0.4mbar)
氦体积(m3)	0.023	估算值（液位高度：85%-77.5%）
氦密度(kg/m3)	145.67	1032.845264
氦汽化潜热(J/kg)	23037.01	
氦质量(kg)	3.29	
氦汽化热量(J)	75839.14	
汽化时间(s)	3249	液位曲线：2022.06.10 14:54:40 85[illegible] 15:48:49 77.5%（两侧液[illegible]
2K总负载(W)	**23.34**	加热器：[illegible]
2K静态负载(W)	**23.34**	[illegible]
BCP模组2K静态负载测试：稳压[illegible]		
参数	数值	[illegible]
温度(K)	2.01	
压力(mbar)	32.05	31.9 mb[illegible]
氦体积(m3)	0.023	估算值（[illegible]
氦密度(kg/m3)	145.67	1.[illegible]
氦汽化潜热(J/kg)	23036.34	
氦质量(kg)	3.29	
氦汽化热量(J)	75837.39	
汽化时间(s)	1748	液位曲线：2022.06.[illegible]% - 20:17:54 77.5%（[illegible]液位）
2K总负载(W)	**43.39**	加热器：~20 W (LH1=10 W, LH2=10 W)
2K静态负载(W)	**23.39**	±0.34W

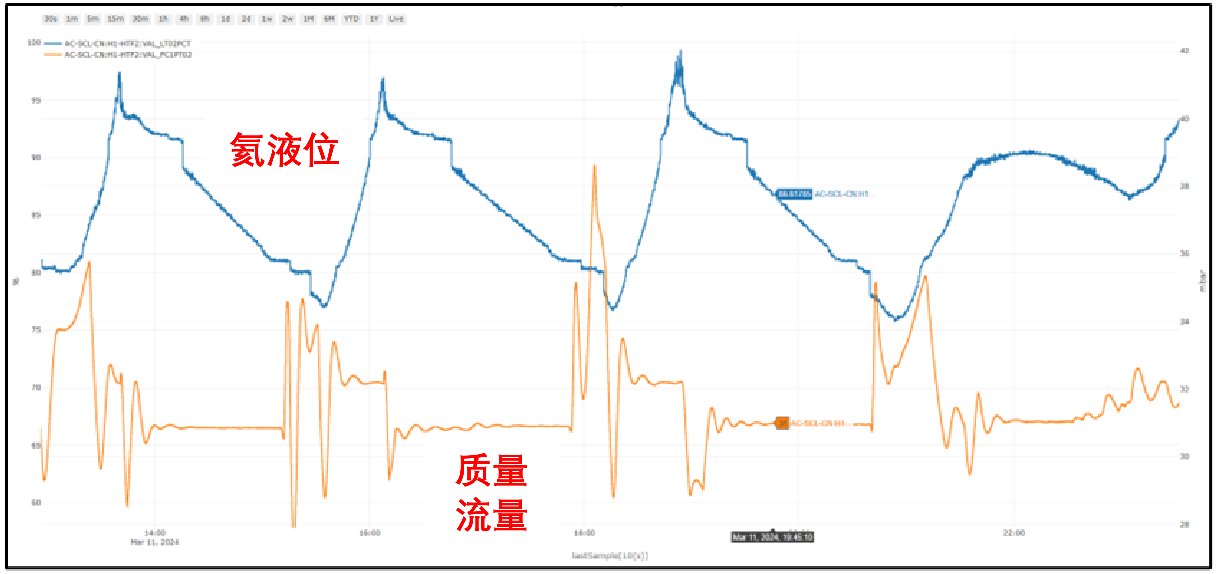
测试日期：2022.05.21

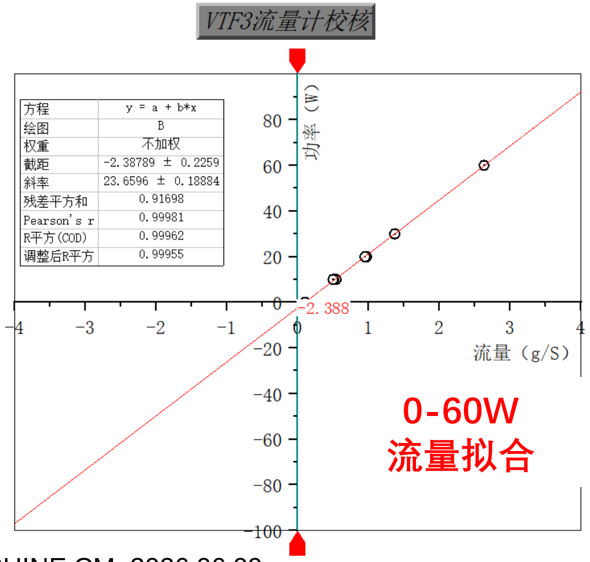
BCP模组2K静态负载测试：液位法 @ 0W			偏差度	
参数	数值	备注		
温度(K)	2.00			
压力(mbar)	3[illegible]	30.66 mbar - 32.6 mbar (2mbar)		
氦体积(m3)	[illegible]	估算值（液位高度：85%-77.5%）		
氦密度(kg/m[illegible]	[illegible]	1068.874675		
氦汽化[illegible]	[illegible]			
[illegible]	[illegible]			
[illegible]	[illegible]			
[illegible]	[illegible]	[illegible]线：2022.05.21 11:16:59 85% - [illegible]09:19 77.5%（两侧液位）	109	3.4%
[illegible]	[illegible]	加热器：~0 W		
[illegible]	[illegible]	±0.18W	2.31	9.9%
[illegible]液位法 @ 20W				
[illegible]	[illegible]	备注		
[illegible]	[illegible]			
[illegible]	[illegible]1.90	31.80 mbar - 31.99 mbar (0.19mbar)		
[illegible]	0.024	估算值（液位高度：85%-77.5%）		
[illegible]m3)	145.66	1918.73483		
[illegible]潜热(J/kg)	23038.35			
氦质量(kg)	3.50			
氦汽化热量(J)	80540.81			
汽化时间(s)	1749	液位曲线：2022.05.21 15:36:00 85% - 16:05:09 77.5%（两侧液位）	-1	-0.1%
2K总负载(W)	**46.05**	加热器：~20 W (LH1=10 W, LH2=10 W)		
2K静态负载(W)	**26.05**	±0.36W	2.66	11.4[illegible]

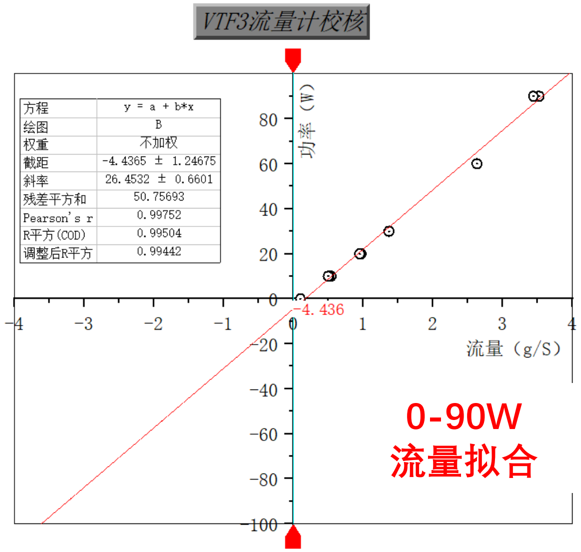
Pressure stabilization analysis

2 K Static Heat Load Measurements

- **SHINE工程模组2K热负载测量：方法校准**
  - **测量系统**：2K系统常温泵 + 液位计 + 流量计
  - **测试工况**：水平工位 (模组)、垂测工位 (超导腔)
  - **校准目标**：流量法的测量偏差
  - **校准方法**：
    - 规整的**蒸液**区间：两相管、垂测杜瓦
    - 稳定的**压力**区间：31mbar ±0.1mbar
    - 适配的**加热器**负载：0-90W
    - 两套**数据**读取：液位计、流量计
  - **校准结果**：
    - **流量法**：0-60W测量偏差~5%，60-90W测量偏差~15%（相对理论偏差）
    - **流量法**：垂测工位拟合斜率23.6~26.5J/g，水平工位拟合斜率27.4~28.5J/g（参考：2K超流氦理论潜热~23.0J/g）
    - **流量法**：重复性最大偏差~0.15g/s（~3W）

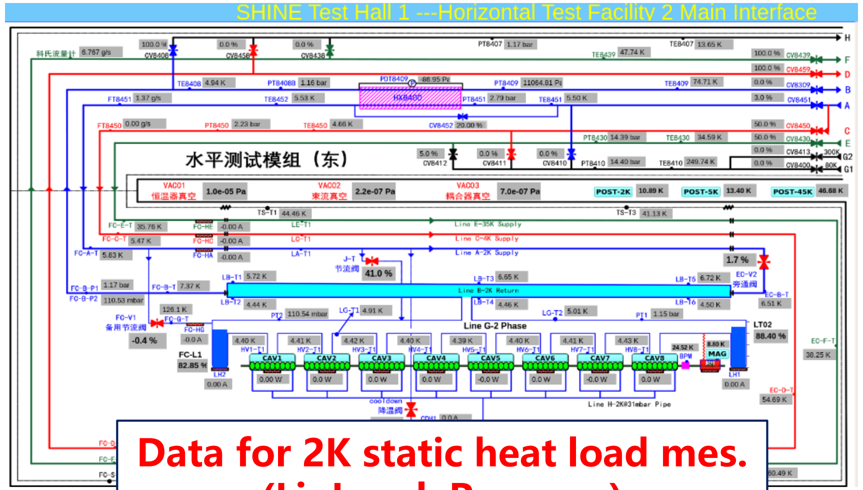




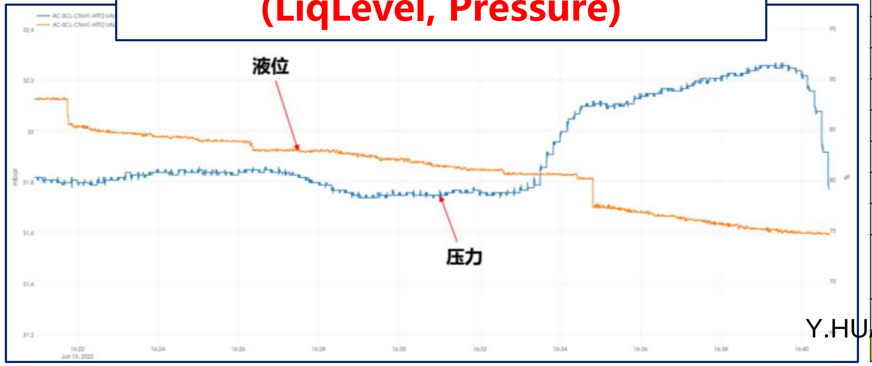


Experiment plan： LiqLevel + MassFlow

- **Double shield BCPed CM：** 2K static heat load comparison measurment
  - **Original data**: Cold Comp. + LHeLevel, mes.~**23.4W** @2K
  - **Retest data** for 2K heat in-leak:
    - To apply an entire CM as for SHINE prod. CM = **Cav. ×8 + MPC ×8**
    - To apply 2K test system for SHINE prod. CM = **warm pump + MassFlow / LHeLevel**



Data for 2K static heat load mes.
(LiqLevel, Pressure)

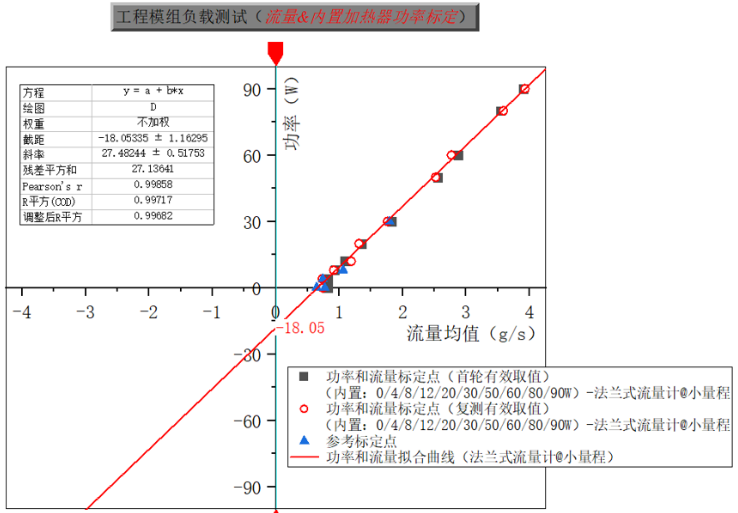


测试日期：2022.06.10

BCP模组2K静态负载测试：稳压液位法 @ 0W		
参数	数值	备注
温度(K)	2.01	
压力(mbar)	32.00	31.8 mbar - 32.2 mbar (0.4mbar)
氦体积(m3)	0.023	估算值（液位高度：85%-77.5%）
氦密度(kg/m3)	145.67	1032.845264
氦汽化潜热(J/kg)	23037.01	
氦质量(kg)	3.29	
氦汽化热量(J)	75839.14	
汽化时间(s)	3249	液位曲线：2022.06.10 14:54:40 85% - 15:48:49 77.5%（两侧液位）
2K总负载(W)	23.34	加热器：~0 W
2K静态负载(W)	23.34	±0.17W

BCP模组2K静态负载测试：稳压液位法 @ 20W		
参数	数值	备注
温度(K)		
压力(mbar)		mbar (0.3mbar)
氦体积(m3)		：85%-77.5%）
氦密度(kg/m3)	145.67	1919.700664
氦汽化潜热(J/kg)	23036.34	
氦质量(kg)	3.29	
氦汽化热量(J)	75837.39	
汽化时间(s)	1748	液位曲线：2022.06.10 19:48:46 85% - 20:17:54 77.5%（两侧液位）
2K总负载(W)	43.39	加热器：~20 W (LH1=10 W, LH2=10 W)
2K静态负载(W)	23.39	±0.34W

CC+LiqLevel Method



Warm pump +Mass Flow Method

Next plan

- **Study for RF cables heat in-leak experiment**
  - No direct experiment data for single cable heat in-leak at 2K
  - Some estimations and simulations

Heat Load	2K （one cable / sum）		占比	备注
KEK-STF	Module-A 1 cavity cable	0.14W / 5.6W	2.50%	Mes.+Simu. （based on the temp. distribution)
	Module-B 1 cavity cable	0.17W / 6.1W	2.79%	
	Module-C 4 cavity cable	3.65W / 9.8W	37.24%	
TTF-CRY3	Cabling (TTF-CDR)	**2.4W / 2.8W**	85.71%	Estim.
TTF	Instrumentation cable	**0.13W / 1.74W**	7.47%	Estim.
LCLS-II	HOM coupler (cables)	0.9W / 30W	3.00%	Estim.
IHEP-TCM	BPM cables Other cables	1.3W / 4.37W	29.75%	Simulation
KEK-S1-G	Module-A (HOM RF cables, Piezo cables, etc)	2.08/4.8W	43.33%	Estim.
	Module-B (HOM RF cables, Piezo cables, etc)	0.05/1.3W	3.85%	
DALS-TFCP	HOM coupler (cables)	0.17/7.2W	2.36%	Estim.

SHINE