

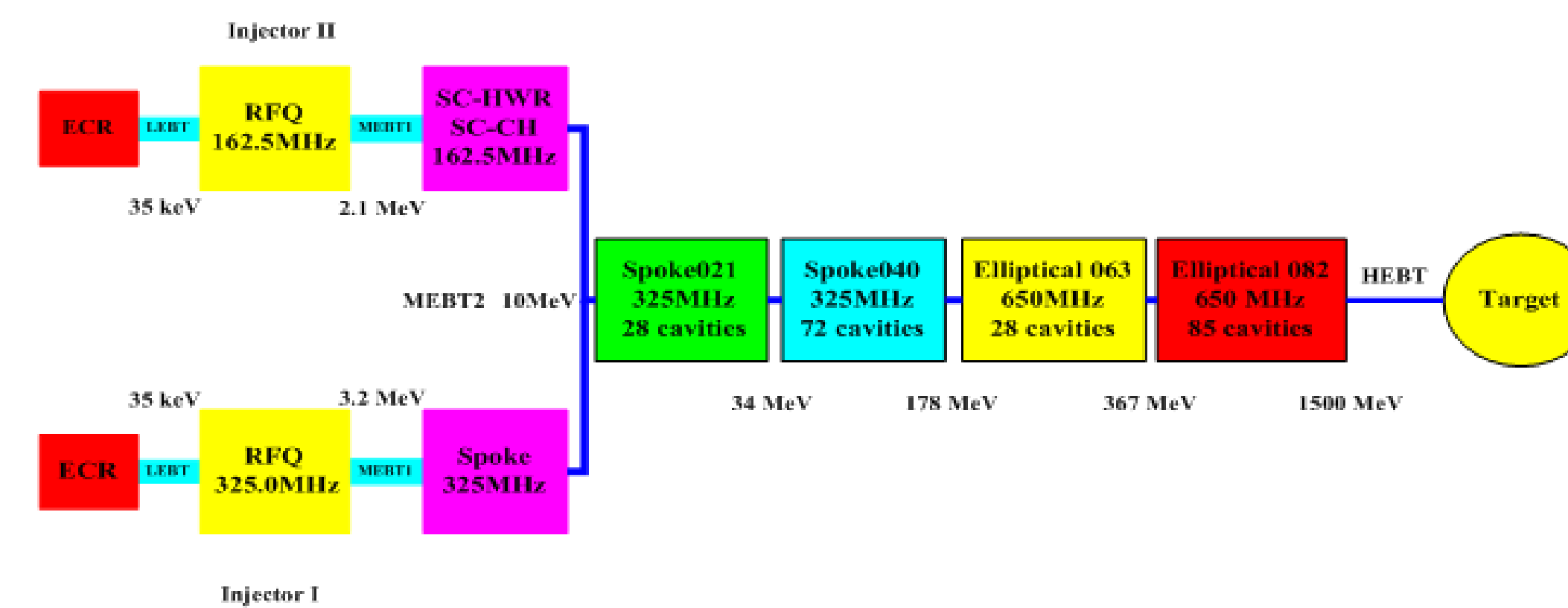
# Overall Design of ADS Injector I Cryogenic System in CHINA

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## Background

Accelerator driven sub-critical system (ADS) in China is a kind of transmutation machine to minimize the nuclear wastes. As one of the important parts in ADS, injector I will be built in IHEP, CAS. Injector I needs two cryomodules operating at 2K cryogenic environment to realize 10MeV proton beam energy. Each cryomodule includes seven Spoke cavities and seven superconducting magnets. This paper describes the overall design of the cryogenic system, including the cooling flow chart, heat loads estimation, the structure of the operation cryomodule and some of the key components.



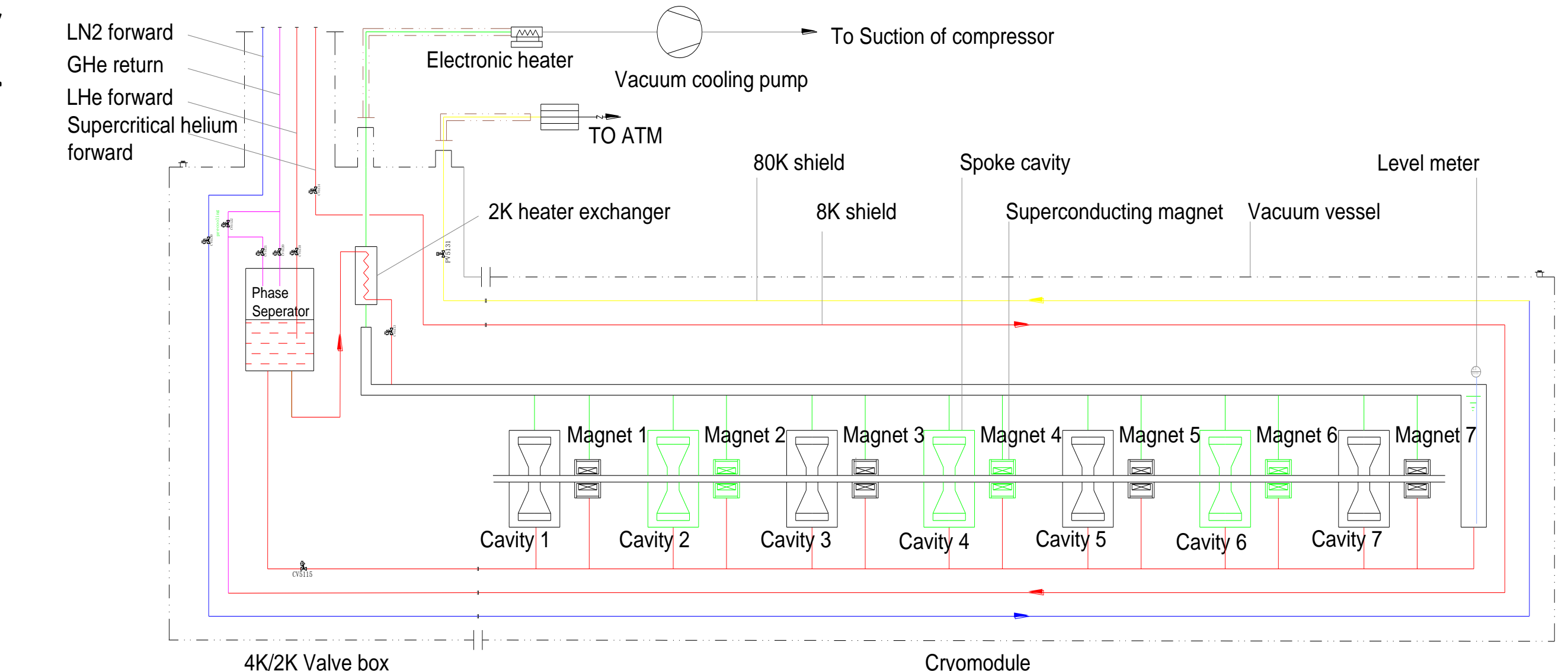
Conceptual design of ADS proton superconducting linac accelerator

## Flow chart design of the superconducting devices

The cooling down for superconducting devices has two steps. Firstly, the superconducting devices are cooled by mixture of 300K and 40K helium. Secondly, the mixture of 40K and 4.5K helium is used to cool the devices to 4.5K. After that, 4.5K liquid helium goes to 2.0K by the heat exchanger, JT valve and the pumping system. When operating, the superconducting cavities and magnets are immersed in the 2.0K superfluid helium.

The vapor pressure for 2.0K saturated liquid helium is about 3130Pa which is obtained by a set of pumps. Pump unit pumps gas helium from the vessels through the pipe of about 50 meters long. The pumped-out gas helium goes directly to the suction of the main compressor, so a closed cycle is completed. When the system is cooling down or warming up, the returning gas can either go to the compressor or to the gas bag. Impure gas helium in the gas bag must be purified and then return to the cycle.

In order to improve the production efficiency of 2K liquid helium, there is a phase separator and a 2K low pressure heat exchanger in the 4K/2K valve box. The two-phase helium which comes from the distribution valve box is separated into liquid and gas helium in the phase separator. 4.2K saturated liquid helium goes through the heat exchanger and is cooled down to about 2.3K by the returning 2K gas helium and then throttled to the pressure 3130Pa which realized by the pumps. The production efficiency of the 2K liquid helium can be more than 85%.

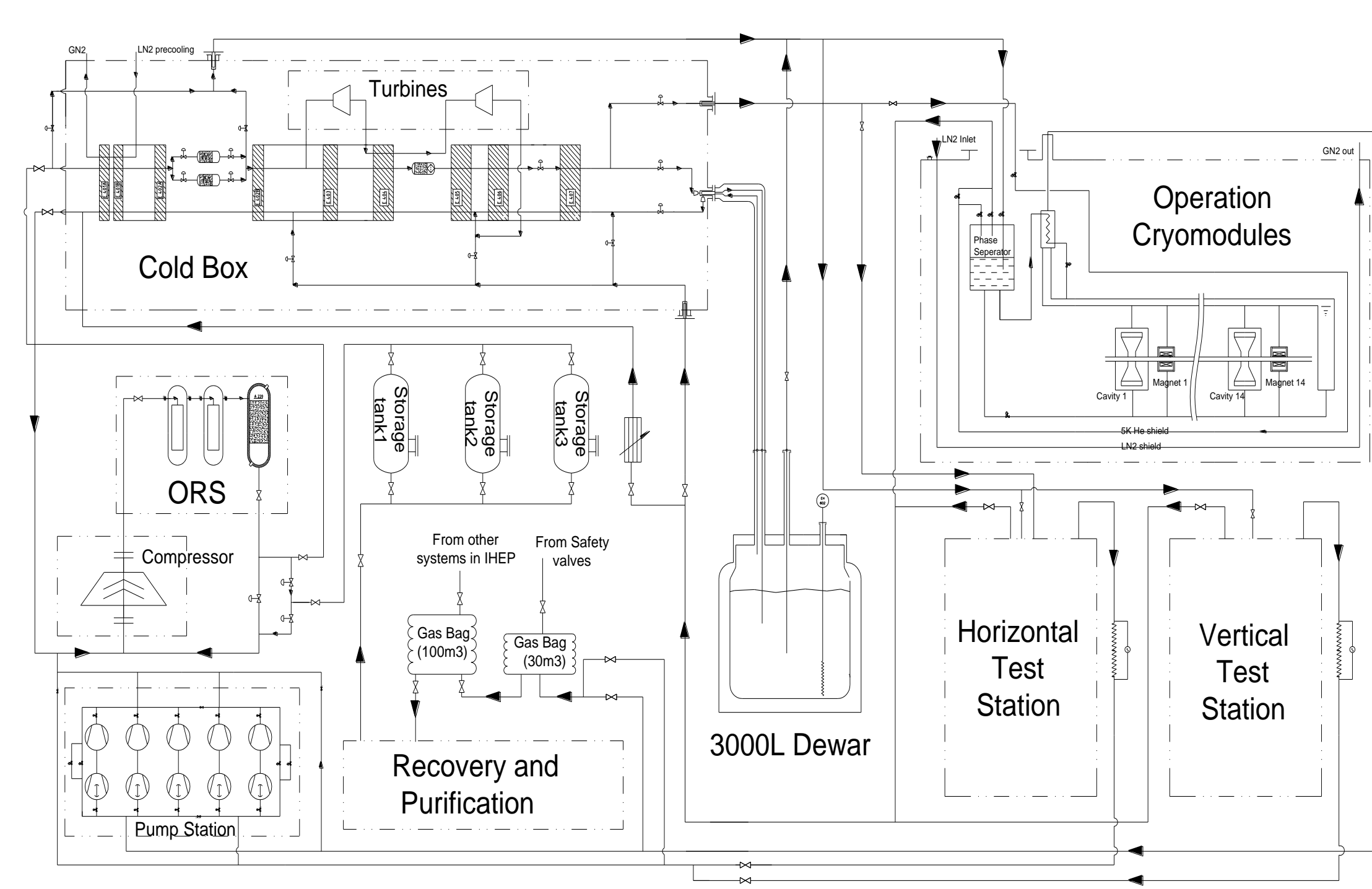


Flow Chart of Operation Cryomodule and its valve box

## Overall Design

ADS injector I cryogenic system mainly includes the refrigerator, cryogenic distribution valve boxes, superconducting devices, 2K pumping system, recovery and purification system.

- Three modes of the cold box: refrigeration mode, liquefaction mode and mixed mode;
- Refrigerator capacity: 1000W @ 4.5K at refrigeration mode and 284L/h at liquefaction mode with LN2 precooling;
- Three outputs: 300K&40K mixture output, supercritical helium output and two-phase helium output;
- Capacity of the 2K pumping system: 8000m<sup>3</sup>/h@31mbar;
- Recovery and purification system with purification pressure 20MPa and purification flow rate 105Nm<sup>3</sup>/h;
- The purity of helium after purification: 99.999%

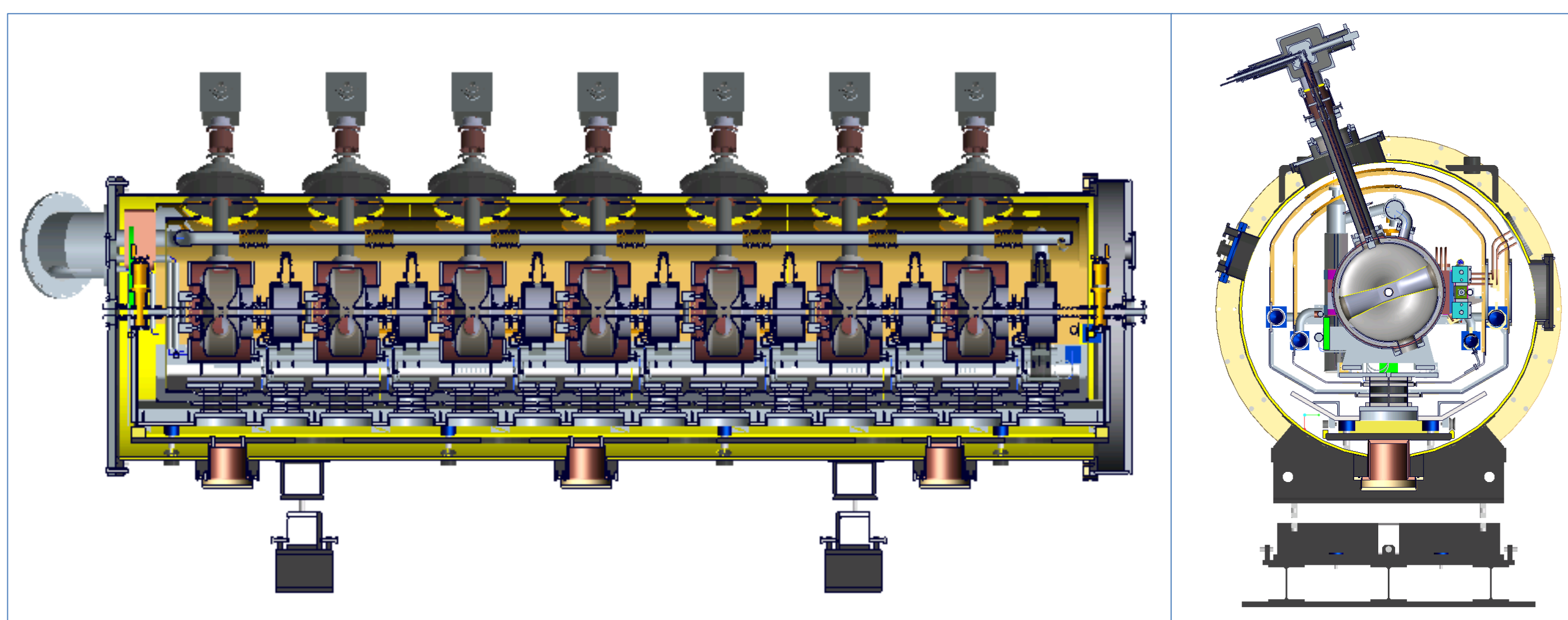


Simplified flow chart of ADS injector I cryogenic system

## Cryomodule and Heat Load Estimation

### Cryomodule of superconducting devices

- Seven spoke012 cavities, seven solenoid magnets, seven beam position monitors;
- Operate at 2K, lower loss of cavities;
- 80K liquid nitrogen shield and 5K helium shield;
- Adjustable bottom supports;
- Length: 5485mm, diameter: 1400mm.



3D Design of the Cryomodule

### Heat loads of cryomodule

The estimation of dynamic and static heat loads of one cryomodule is shown in the following table.

Dynamic and Static Heat loads of one Cryomodule

IHEP-ADS CM1#(7-Spoke,7-solenoid)	Quantity	Heat loads @80K(W)	Heat loads @5K(W)	Heat loads @2K(W)
Supports for the magnets	7	19.56	2.18	0.27
Supports for the cavities	7	23.47	2.61	0.32
Dynamic heat load of spoke012 cavities	7	--	--	10.50
Couplers for the cavities	7	169.96	29.47	2.21
Current leads for the magnets	14	51.24	47.04	5.60
Beam pipe	2	1.70	--	0.22
BPM cables	28	--	--	2.94
Supports for 2K cryogenic pipes	--	--	--	0.34
Temperature and other cables	0.62	0.027	0.054	--
Heat radiation	19.00	1.50	--	--
<b>Total</b>		<b>285.55</b>	<b>82.83</b>	<b>22.45</b>

- (1) Dynamic heat loads of Spoke012 cavities estimation is according to the frequency of 325MHz, R/Q: 142Ω, Vc: 0.8MV, Q value: 3 × 10<sup>9</sup>.
- (2) Current leads for magnets according to 200A / unit;
- (3) Dynamic heat loads of couplers are under 15KW RF power.

### Heat loads of the whole system

Besides the cryomodules, heat loads of the whole system also include the heat loads of liquid helium dewar, cryogenic transfer lines and the valve boxes, etc. The result of the heat loads estimation is an important data for choosing the capacity of the refrigerator and pump system.

- The results are as follows:  
701.55W @ 80K;  
271.42W @ 5K;  
45.80 W @ 2K .

Then the basic liquefaction capacity needed for operating the system is about 170L/h. The refrigerator still has a 40% margin when operating two cryomodules.

Cryomodules operation heat loads

	Quantity	Heat loads @80K(W)	Heat loads @5K(W)	Heat loads @2K(W)
3000L Dewar	1	--	8.00	--
Single-channel liquid helium transfer lines	54m	--	27.10	--
Single-channel liquid nitrogen transfer lines	62m	28.02	--	--
Multi-channel cryogenic transfer lines	72m	72.00	36.00	--
4K main distribution valve box	1	15.10	25.03	--
Cryomodules	2	571.10	165.65	44.90
4K-2K valve box	1	15.33	9.64	0.90
<b>Total for system operation</b>		<b>701.55</b>	<b>271.42</b>	<b>45.80</b>

Static heat loads of the test stations

	Quantity	Heat loads @80K(W)	Heat loads @5K(W)	Heat loads @2K(W)
2K horizontal test valve box	1	15.82	9.64	0.90
2K horizontal test cryostat	1	37.57	3.03	0.33
2K vertical test valve box	1	10.34	6.45	--
2K vertical test cryostat	1	172.62	12.07	0.49
<b>Total for test Stations</b>		<b>236.35</b>	<b>31.19</b>	<b>1.72</b>

## Proceedings

After many discussions and optimization, the design of ADS injector I cryogenic system has been completed.

Construction of the system is undergoing now. Installation of the main equipment such as the refrigerator, pump station, recovery machines and storage tanks has already done. The refrigerator and pumps are under commissioning.

The cryogenic valve boxes and cryostats are under manufacturing.