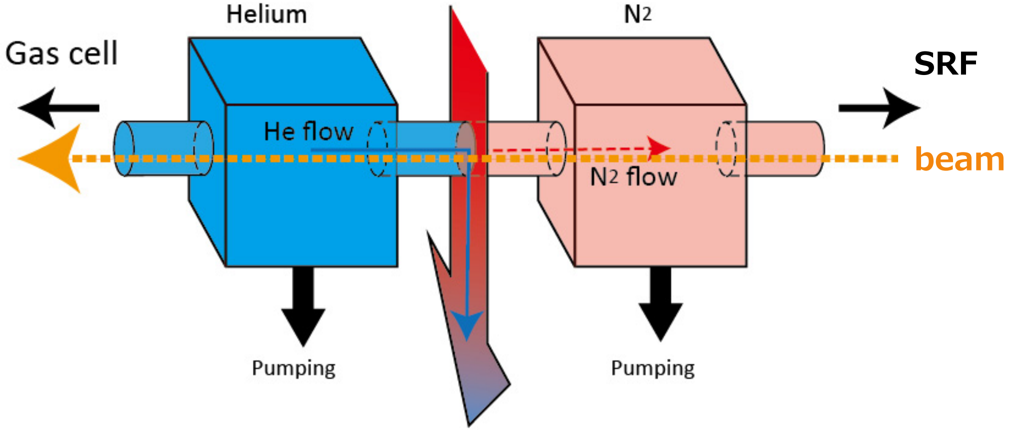
Nitrogen gas-jet curtain for windowless helium gas cell equipped with differential pumping systems



RIKEN Nishina accelerator based science center
Hiroshi Imao

Outline

1. SRILAC and DPS at RIBF

- Introduction of SRILAC
- Differential pumping system for SRILAC

2. N_2 gas-jet curtain

- Concept
- Application in He stripper
- Application in DPS for GARIS

3. Summary and future prospects

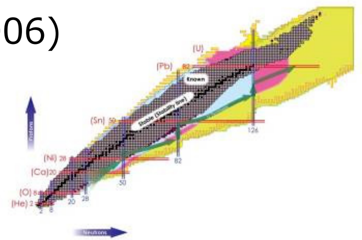
RIKEN RI beam factory (RIBF) and SRILAC

RIBF

Cyclotron-based Heavy-ion accelerator for in-flight RI beams (since 2006)

Super conducting ring cyclotron (SRC) is a main device.

Acceleration of **ALL** ions up to 345 MeV/u (70% of c) in **CW** mode

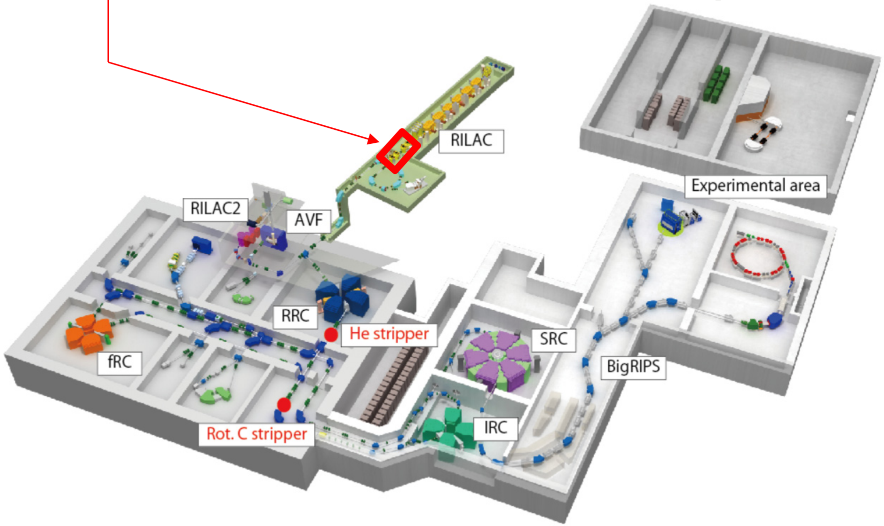


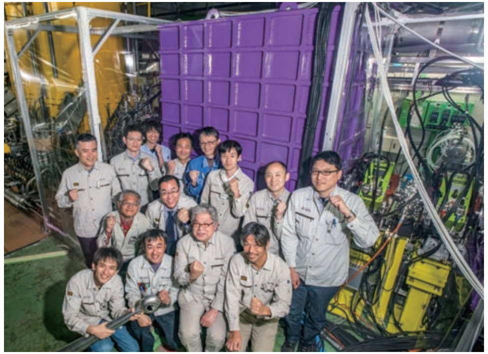
SRILAC

Superconducting linac, SRILAC, has been operated since 2020

Energy upgrade for superheavy element search (**GARISⅢ**) and medical RI productions

Should be installed **in limited space** between existing NC-linac (RILAC) and HEBT



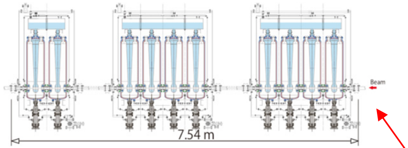


SRILAC parameters	
frequency [MHz]	73
operating mode	C.W.
# of cryomodules	3
# of cavities	10
total length [m]	7.45
E inj [MeV/u]	3.6
E out [MeV/u]	6.5
Eacc [MV/m]	6.8

Configuration of SRILAC and DPSs

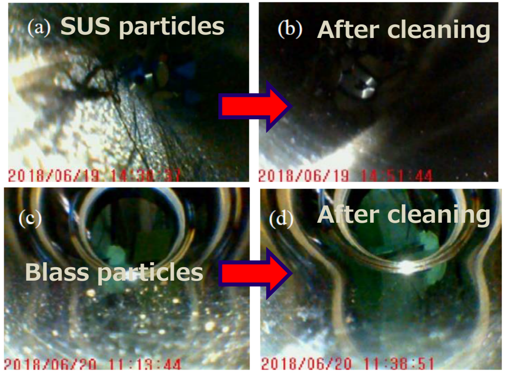
SRILAC

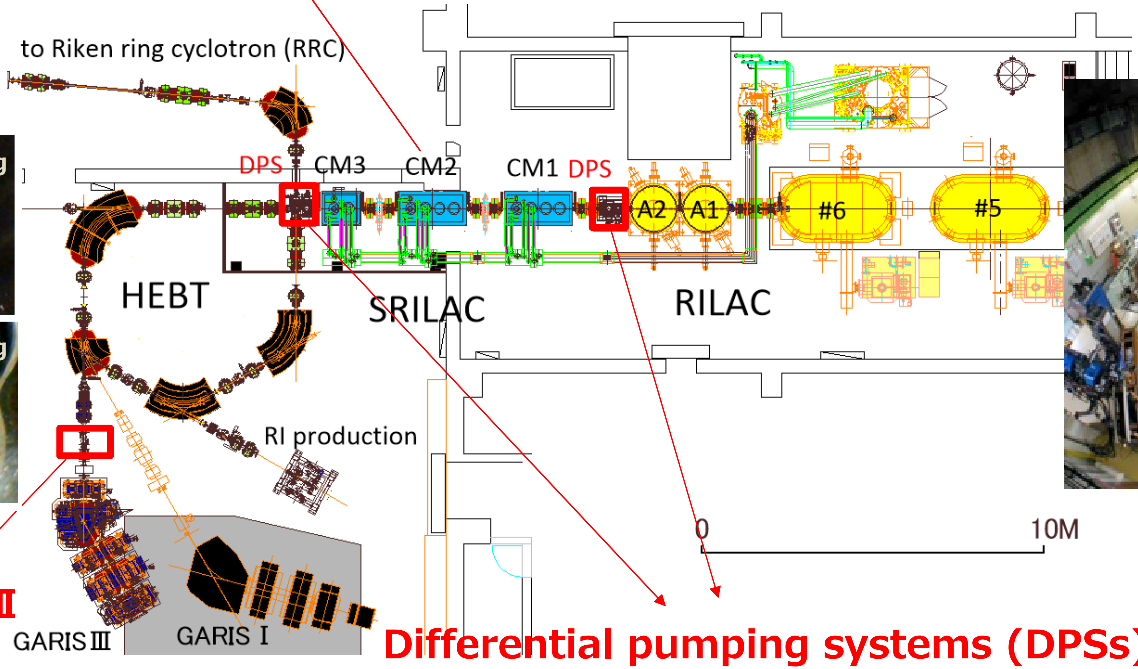
<−10^-8 Pa



RILAC
(40-years old)
10^{-4} Pa∼10^{-6} Pa

HEBT
10^{-4} Pa∼10^{-6} Pa
destructive diag., slits,
C-foil stripper





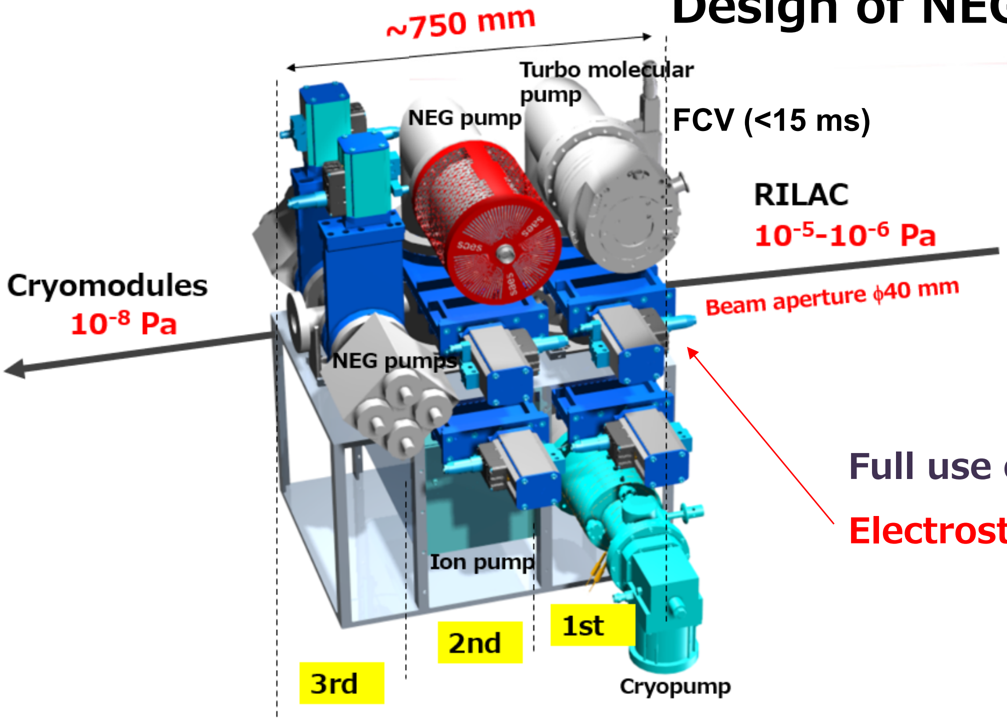
DPS for GARISⅢ

Differential pumping systems (DPSs) for SRILAC

GARISⅢ experiment (SHE #119 and #120)
He gas (∼100 Pa, windowless target)

DPSs mitigate sudden changes of vacuum and particle conditions
Allowed space is only 80 cm

Design of NEG-based DPS for SRILAC



NEG: Non-evaporable getter pump

NEG-based 3-stage DPS

1st: TMP+Dry pump & CRP

2nd: Ion pump & HT-NEG

3rd: HV-NEG

Full use of low-particle NEG of **ZAO alloy** (SAES)

Electrostatic particle suppressor at the 1st stage

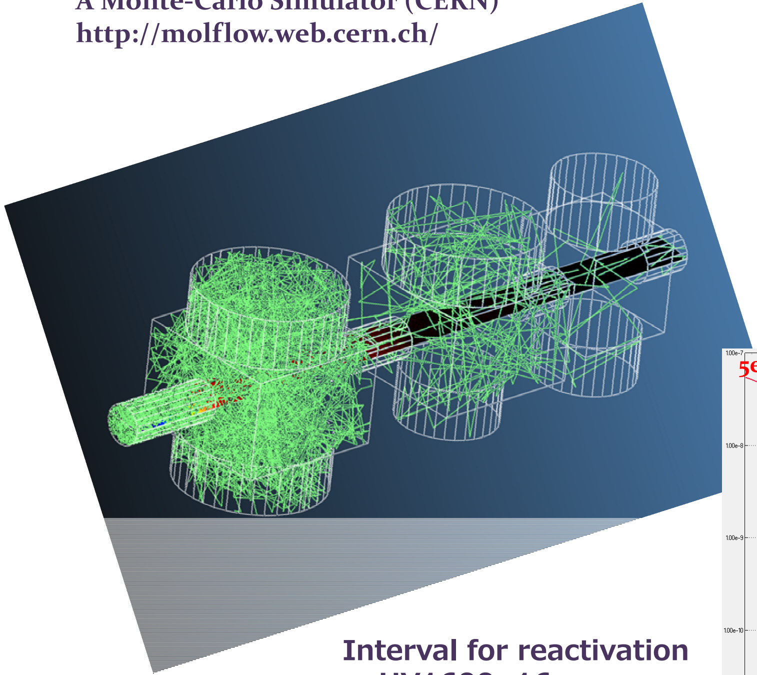
HV1600 (SAES)

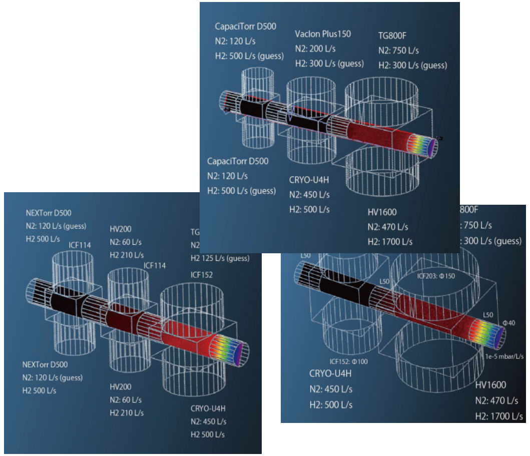
	Type	Model	Vender	Nominal pumping speed
1st. Stage	Turbo Mol. Pump	HiPace700	Pfeiffer	685 L/s (N2) 555 (H2)
5e-7 Pa	Roots Pump	NeoDry30E	Kashiyama	500 L/min (N2)
	Cryo Pump	ULVAC-U6H	ULVAC	750 L/s (N2) 1100 (H2) **2100 (H2O)**
2nd. Stage	High Vacuum NEG	Capacitorr HV1600	SAES	**1700 L/s (H2)** 470 (N2)
5e-8 Pa	Ion Pump	VIP 200 Ion Pump	Agilent	180 L/s (N2) **63 (Ar) ～100 (CH4)**
3rd. Stage	NEG	Capacitorr Z400	SAES	500 L/s (H2) 125 (N2) **210 (CO)**
<1e-8 Pa				4 pumps will be used

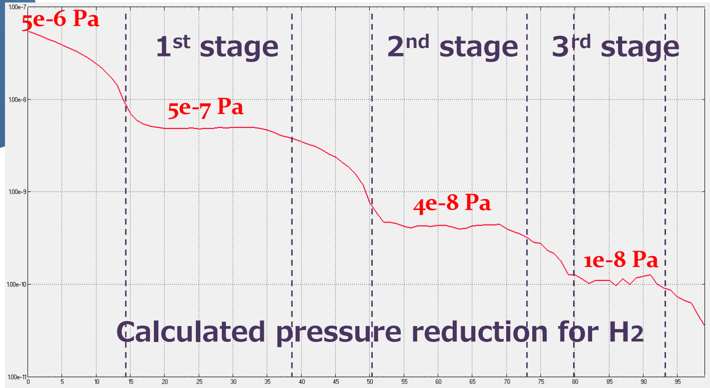
Design optimization with molflow+

molflow+

A Monte-Carlo Simulator (CERN)
http://molflow.web.cern.ch/







Interval for reactivation
HV1600; 16 years
Z400; 1 year

Assembling in clean room (ISO1)

※ISO class1 particles (>0.1um) less than 10/m^3

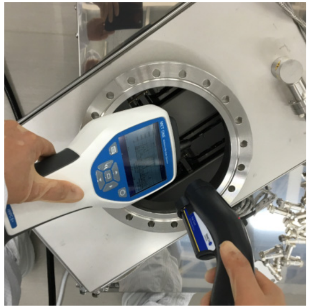
Procedure for cleaning of gate valve)

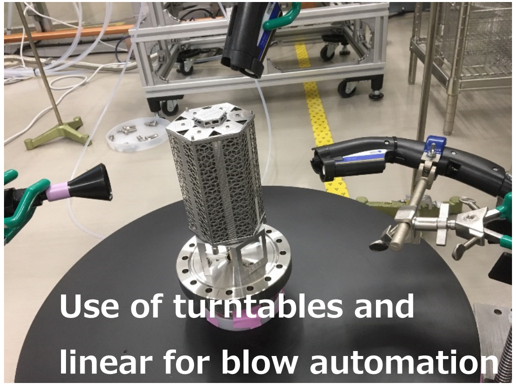
1. Ultra-pure water pouring
2. Ion gun blow
3. Vacuum baking (12h)
4. Ion gun blow
5. Ion gun blow with closed
6. Ion gun blow open with opened

Assembling in clean room (ISO1)

※ISO class1 particles (>0.1um) less than 10/m^3

Continue to blow inside the ion pump for two days

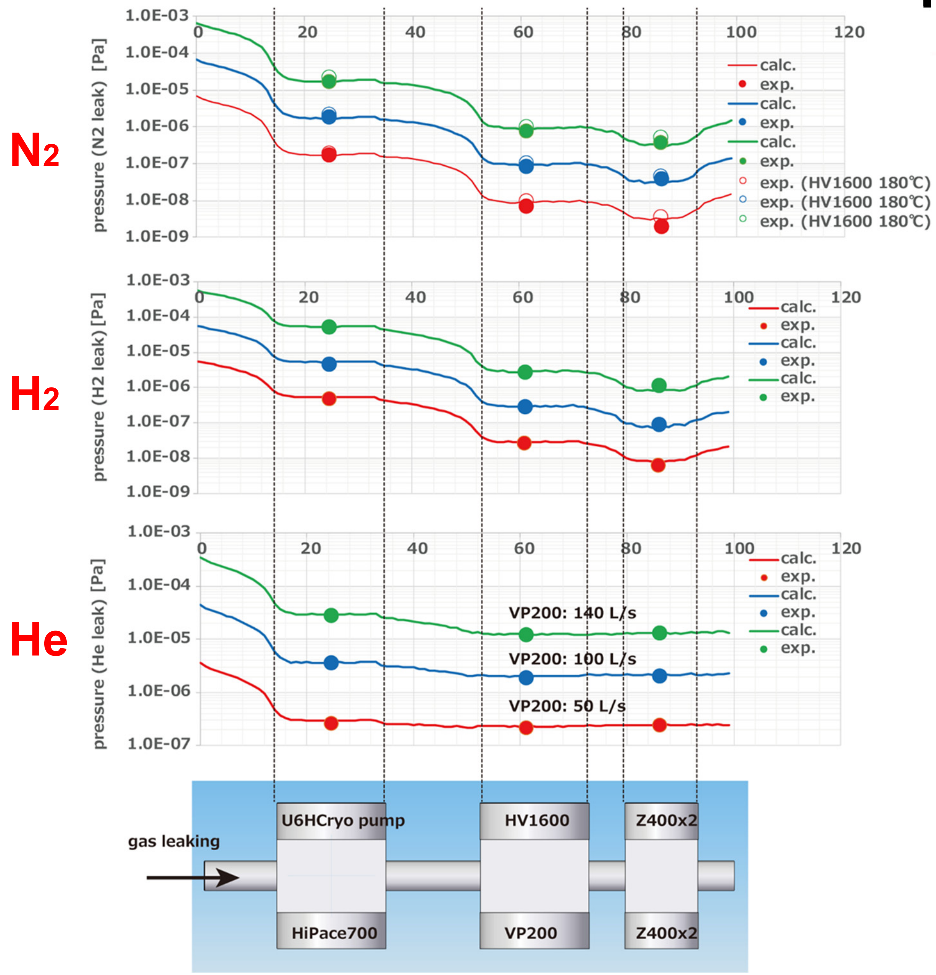




Use of turntables and linear for blow automation

Leak test with He gas

Results of performance test



Achievable vacuum ~$2x10^{-9}$ Pa

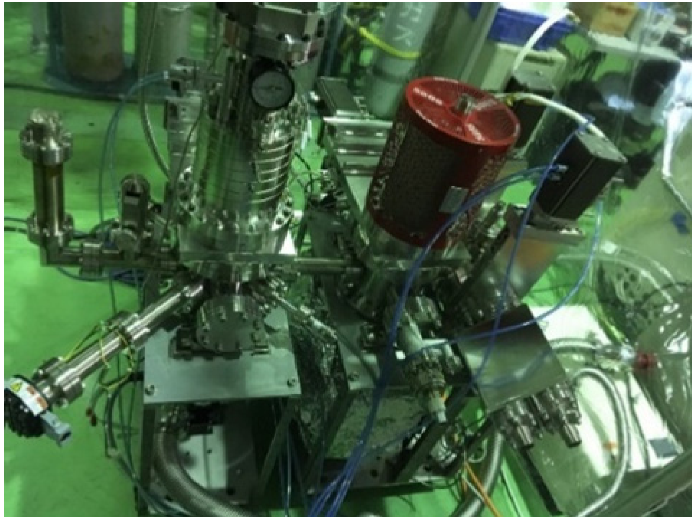
The 3rd stage pressures when ambient pressure of 10^{-5}-10^{-6} Pa

N_2: ~$2x10^{-9}$ Pa

H_2: ~$6x10^{-9}$ Pa

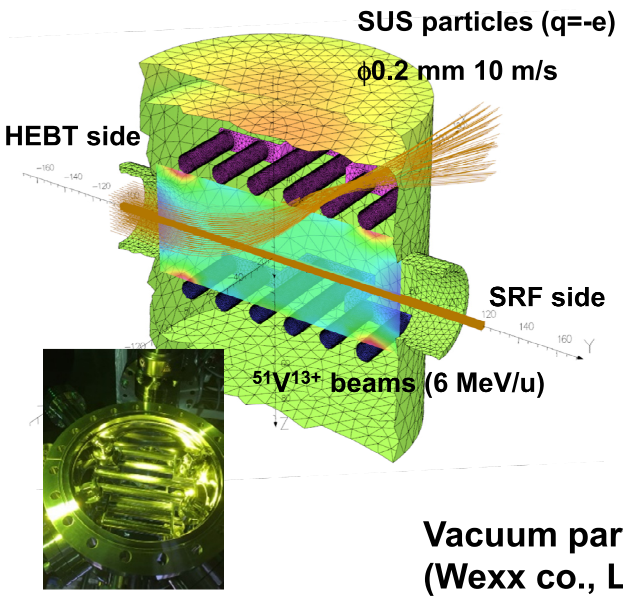
He: ~$2x10^{-7}$ Pa

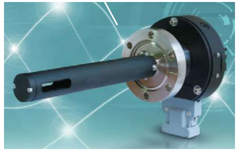
(NEG is almost no pumping power for He)



Original electrostatic particle suppressor (EPS)

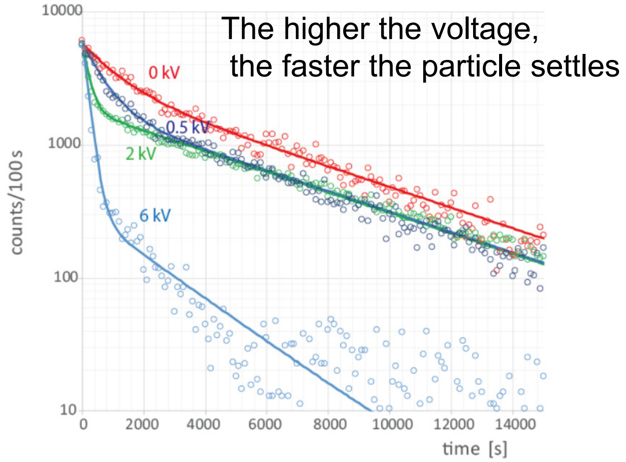
The EPS consists of two electrodes, each of them consists of 6 stainless steel bars.
We can apply high voltage up to ±10 kV on both electrodes.



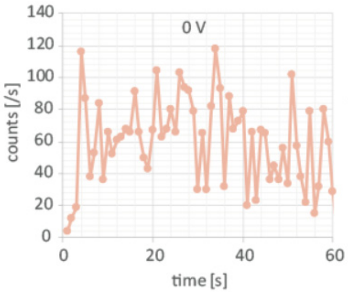


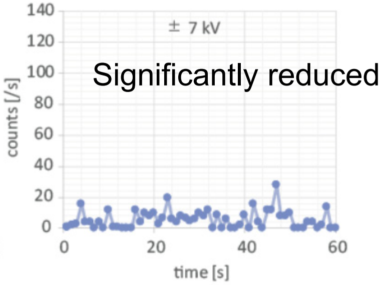
Vacuum particle sensor (Wexx co., Ltd)

The EPS can reduce the particle transport to the SRF



Dependence of particle counts (> 0.3 μm) on the voltages after the fast venting

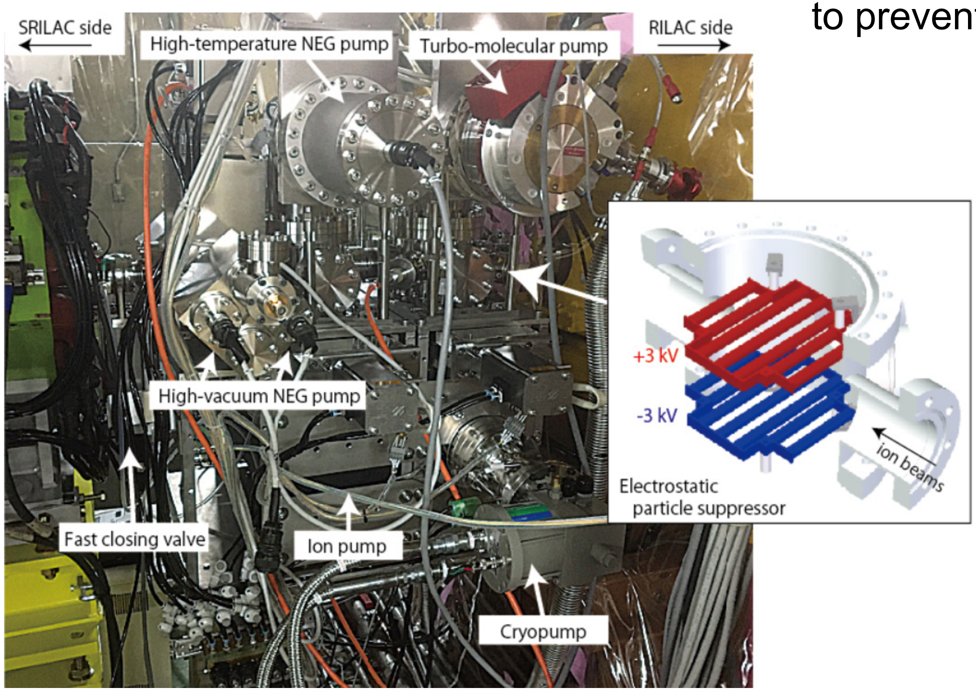


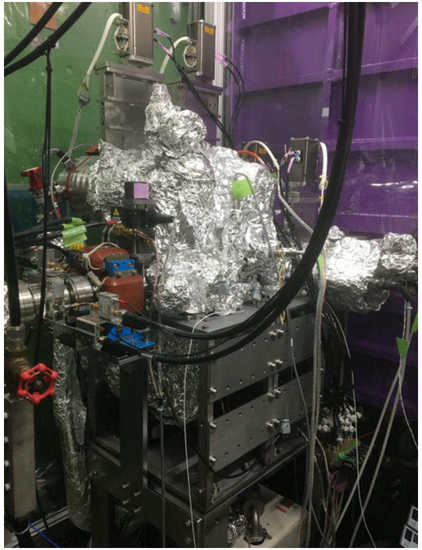


Particle counts (> 0.3 μm) when the ceramic block was scraped in vacuum

Installation on site

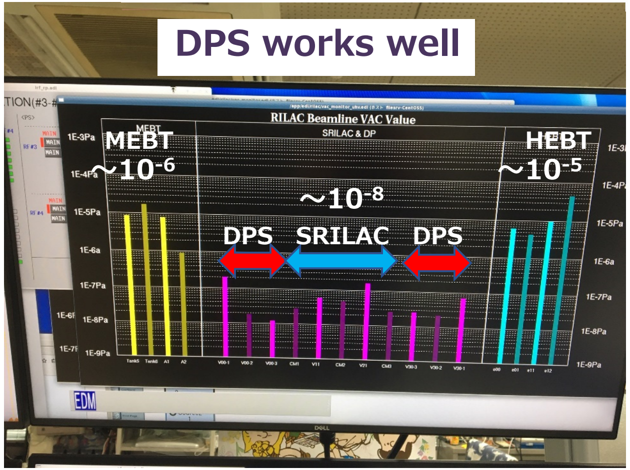
A simple clean booth was set up on site and connected while internally pressurized with argon gas to prevent particle contamination

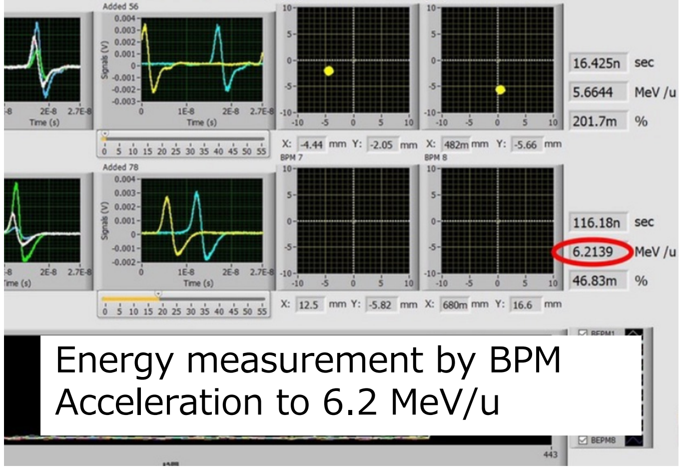




First beam acceleration

First beam acceleration achieved by the end of January 2020



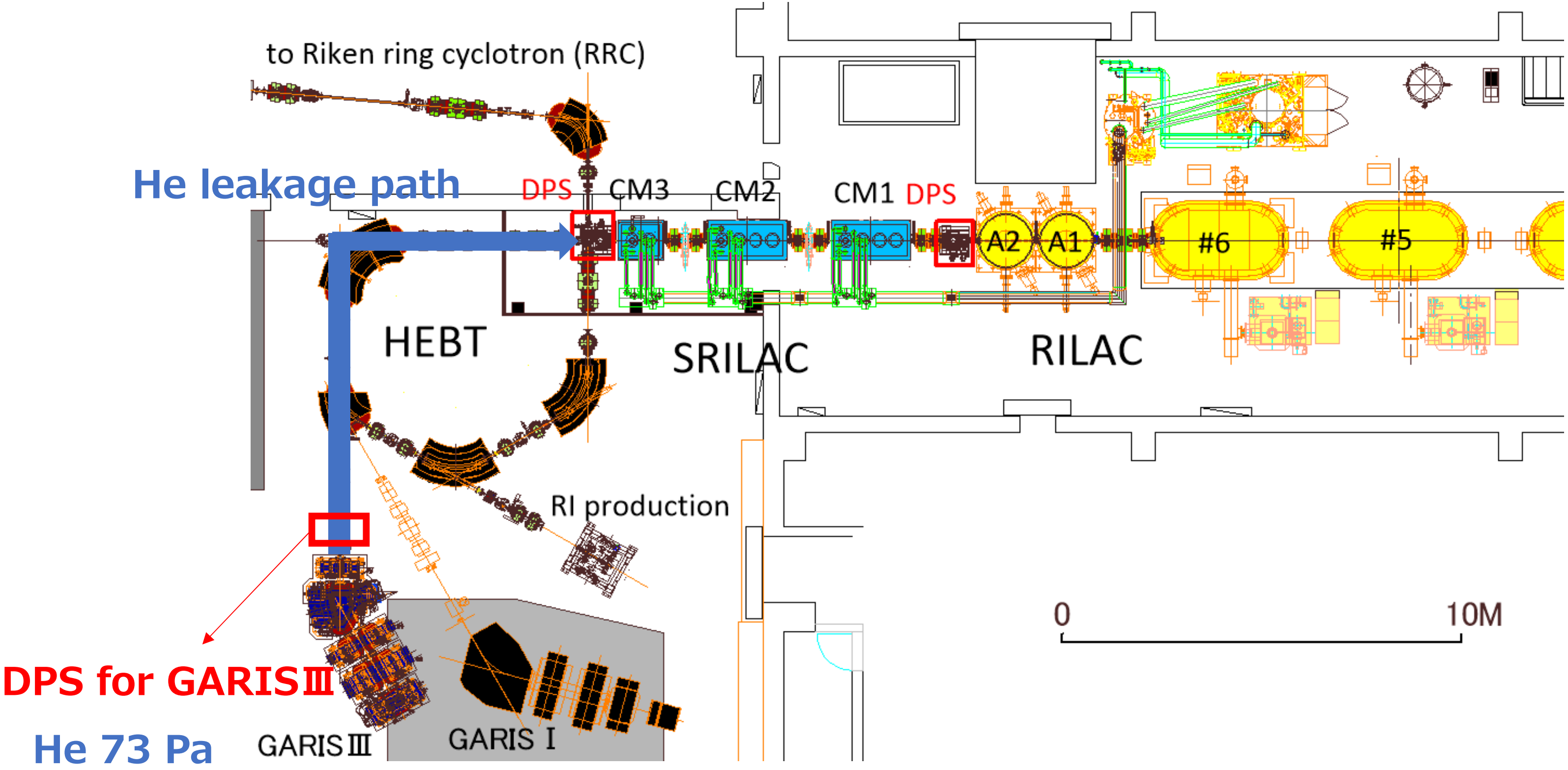


Successful acceleration of Ar13+ to 6.2 MeV/u

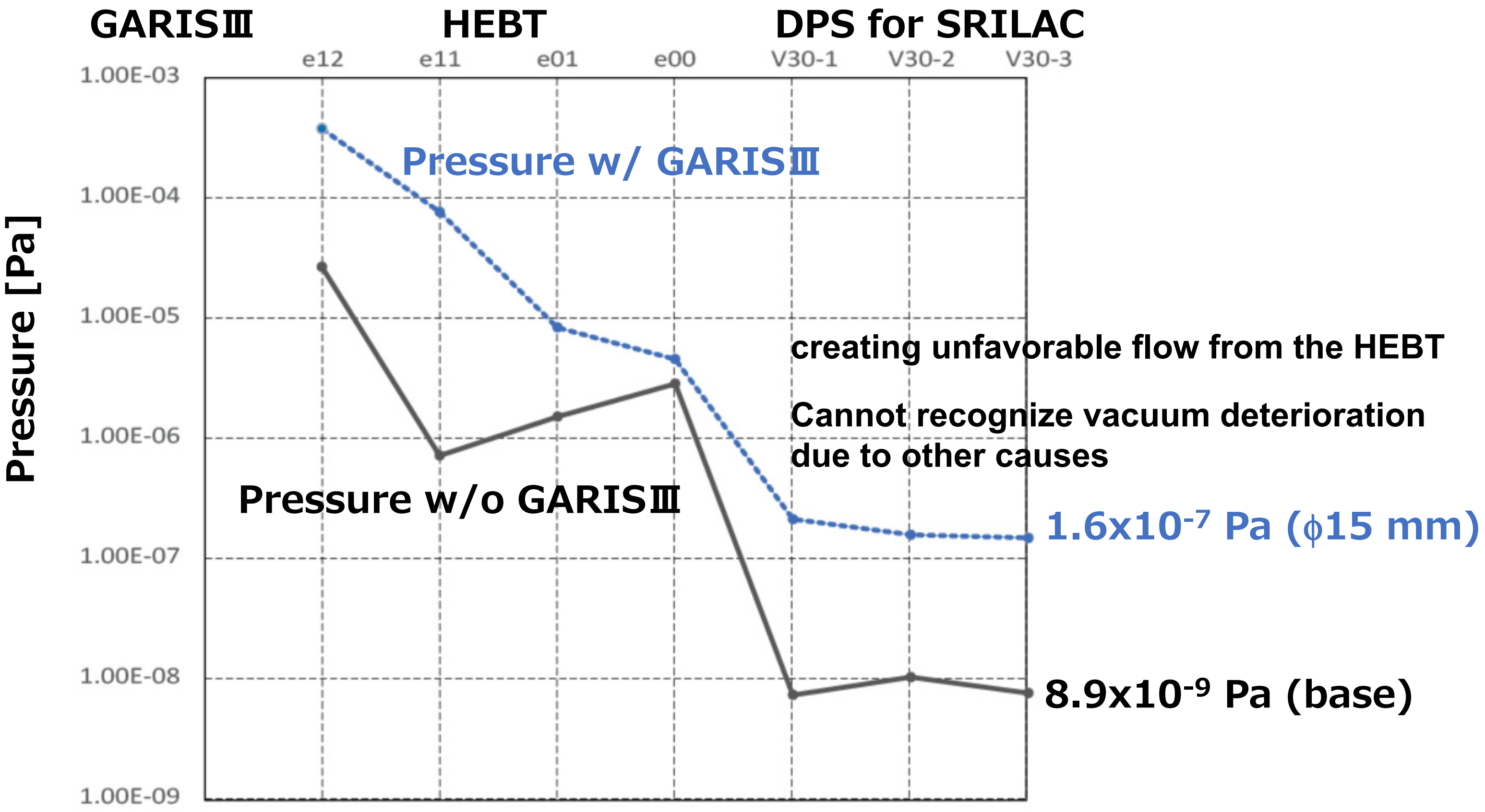
No serious degradation of the SRFs

He leakage from GARISⅢ

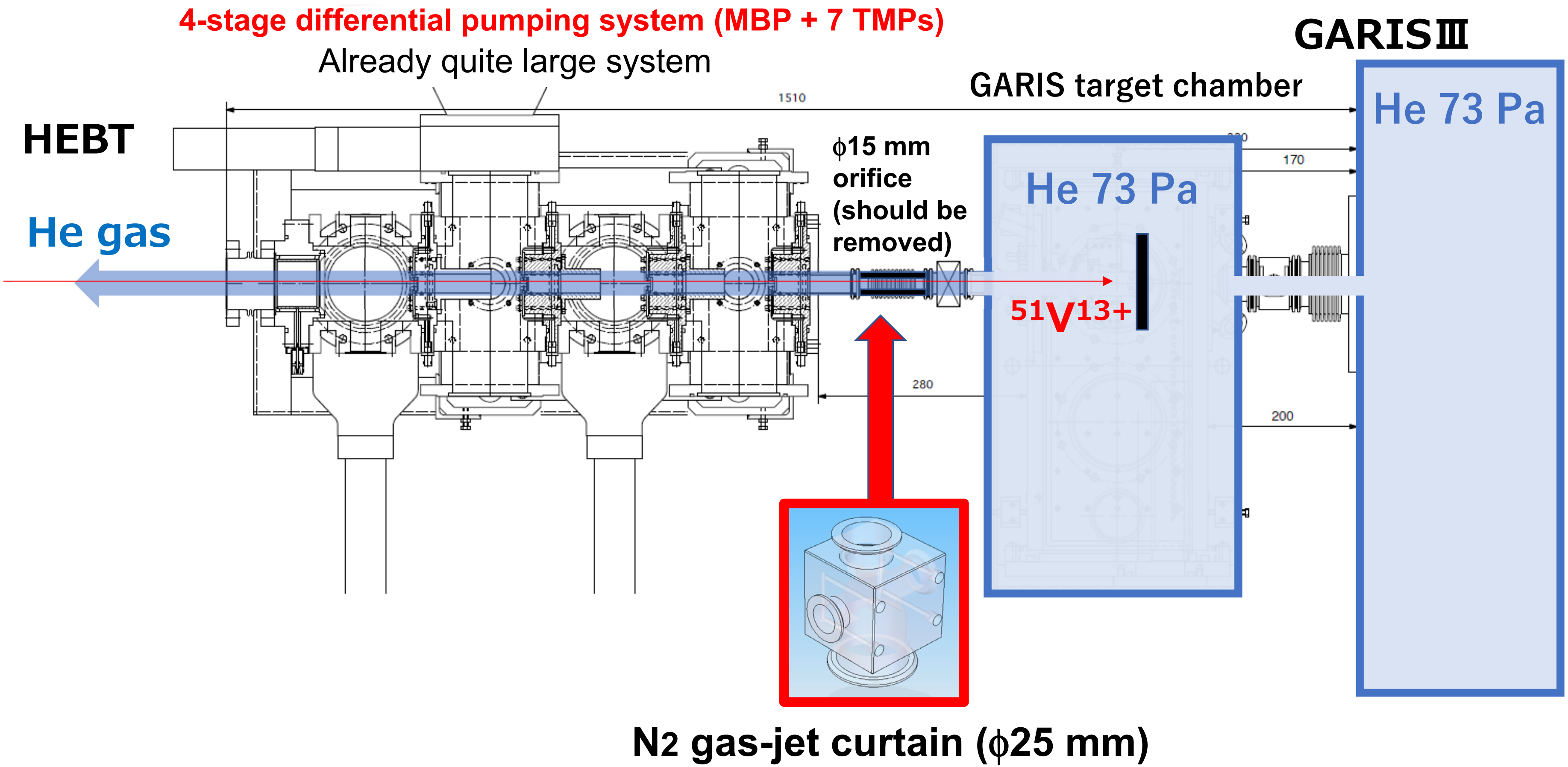
He gas used in the GARISⅢ experiment was leaking through the DPS to the SRILAC



Vacuum deterioration due to the GARISⅢ

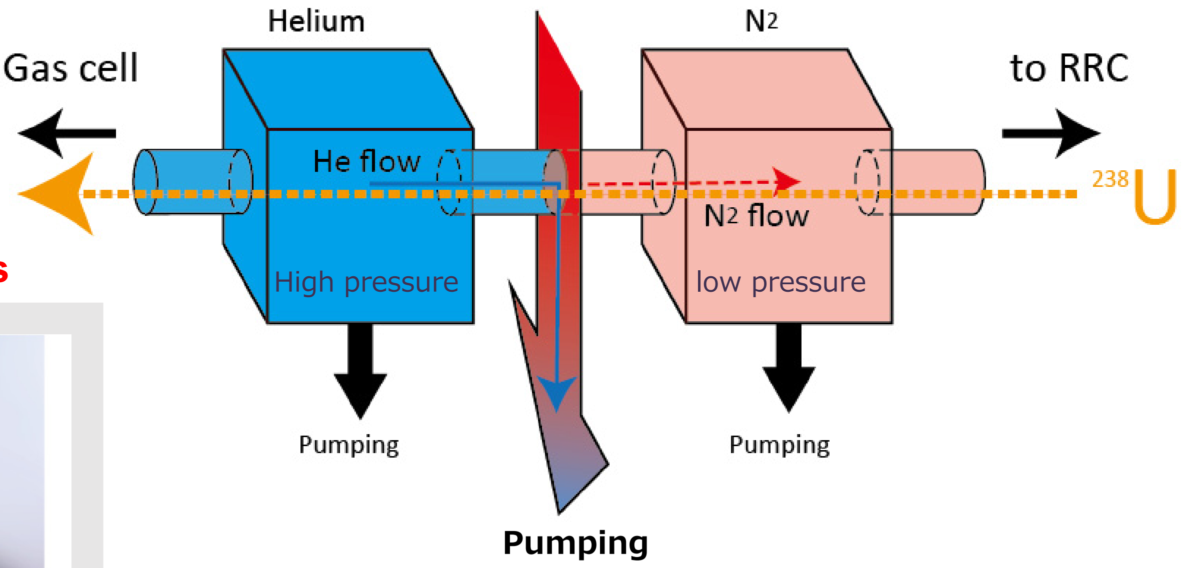


DPS for GARISⅢ



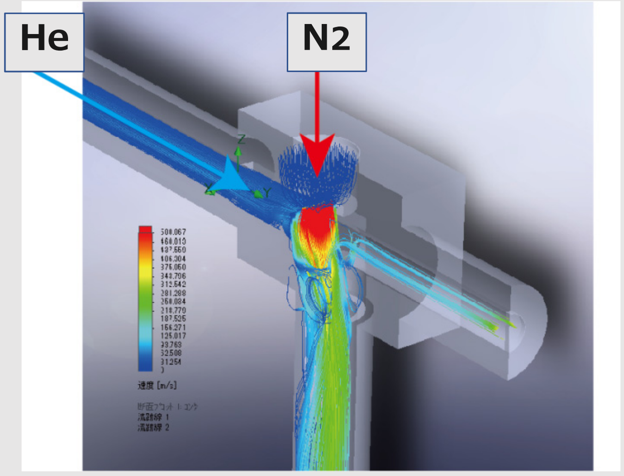
Concept of gas jet curtain

Curtain-like nitrogen-gas jet



First used in He strippers

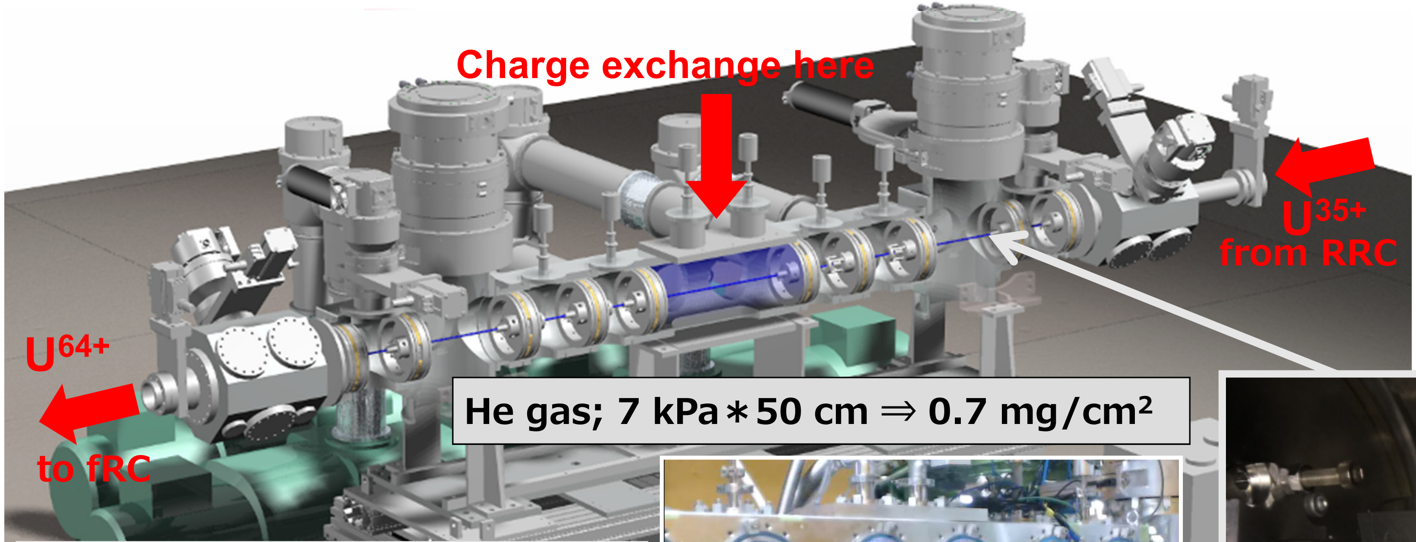
CFD simulation of N_2 gas jet



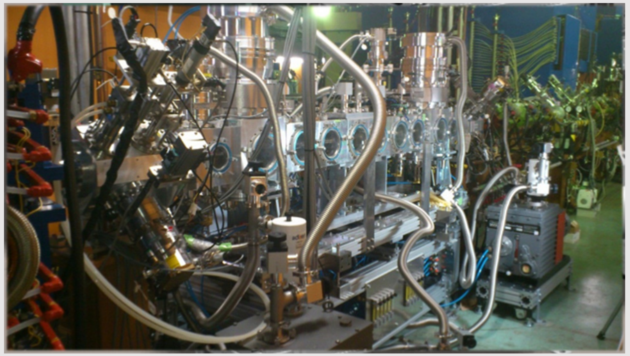
Block He flow and exchange leaked gas species

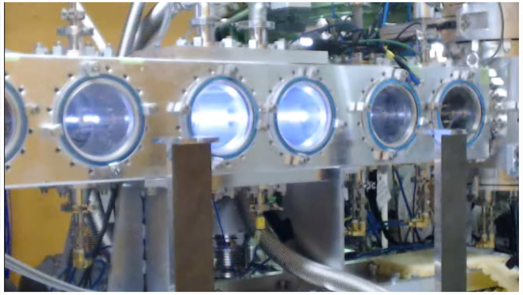
N_2 gas can be easily evacuated by vacuum pumps

Application in He stripper

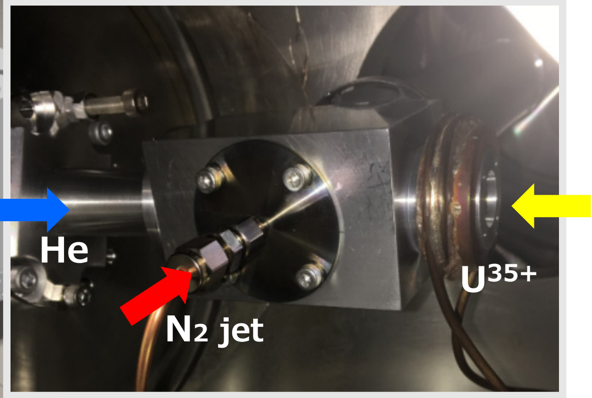


He gas; 7 kPa∗50 cm ⇒ 0.7 mg/cm^2





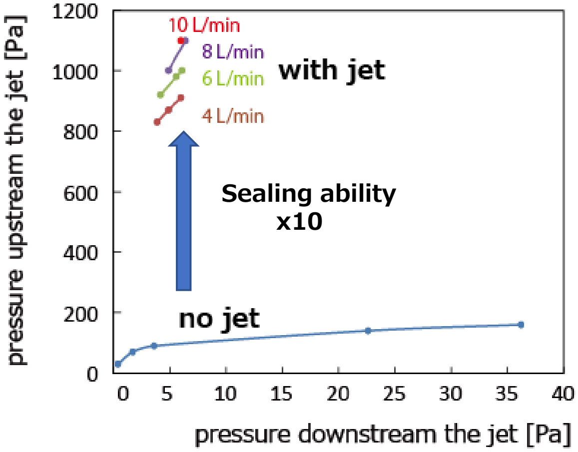
N$_2$ gas jet curtain

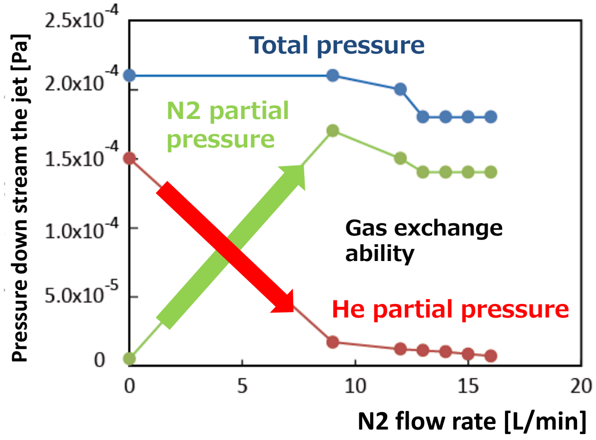


- 5-stage diff. pumping; 26 pumps
- 8 order pres. reduction; 7 kPa⇒10^{-5} Pa
- Large beam aperture; >Φ12 mm
- He gas flow; 300 m^3/day

Performance of N_2 gas-jet curtain for He stripper

Performance of N_2 gas-jet curtain for He stripper excellent (patented)



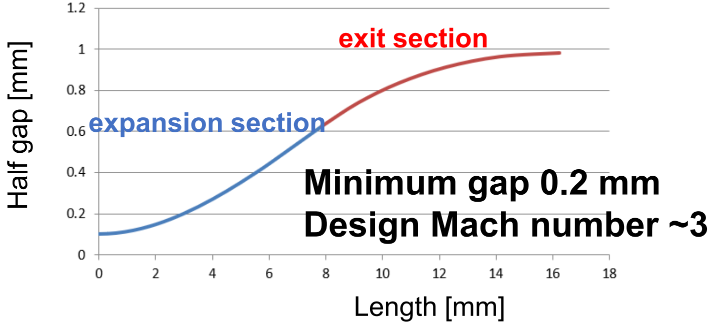


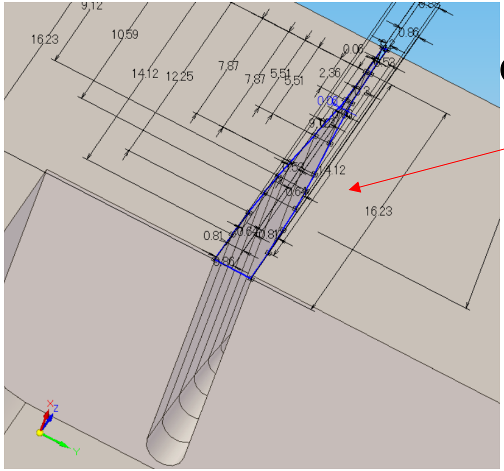
We can accumulate He gas at **10 times** the pressure without changing downstream pressure by using the gas-jet curtain

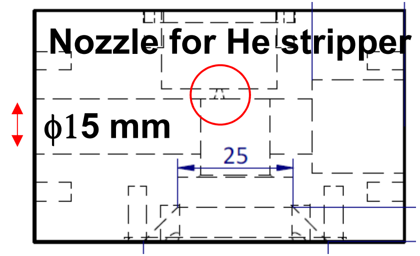
The gas leaked to downstream was successfully **exchanged to N_2** as we desired

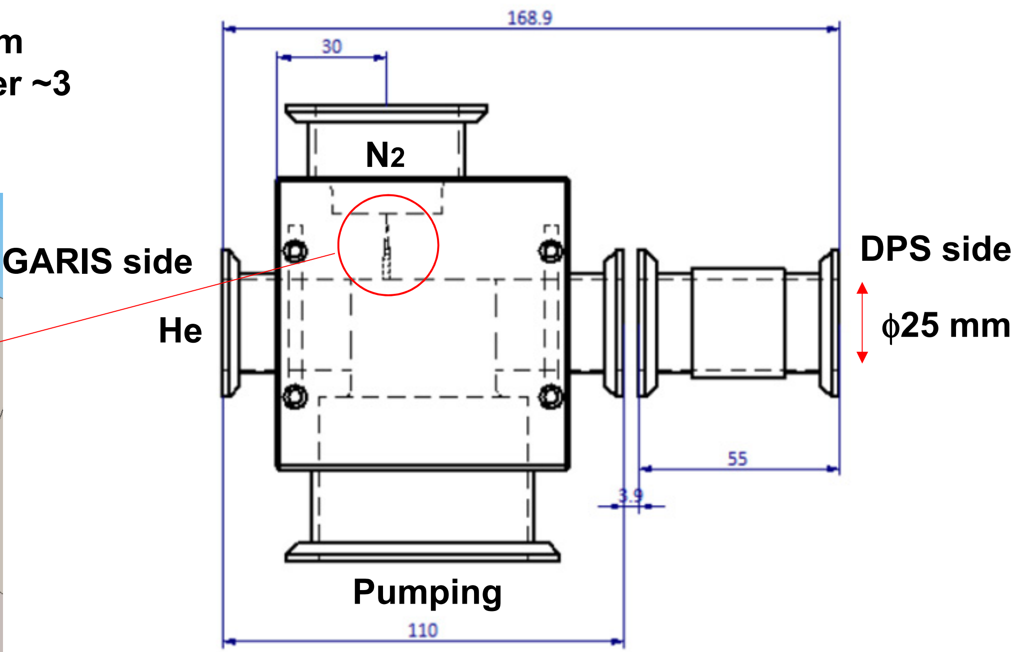
Nozzle design of gas jet curtains for GARISⅢ

2-D Laval nozzle to increase the jet velocity
(ref. **NASA Technical note 1651**)

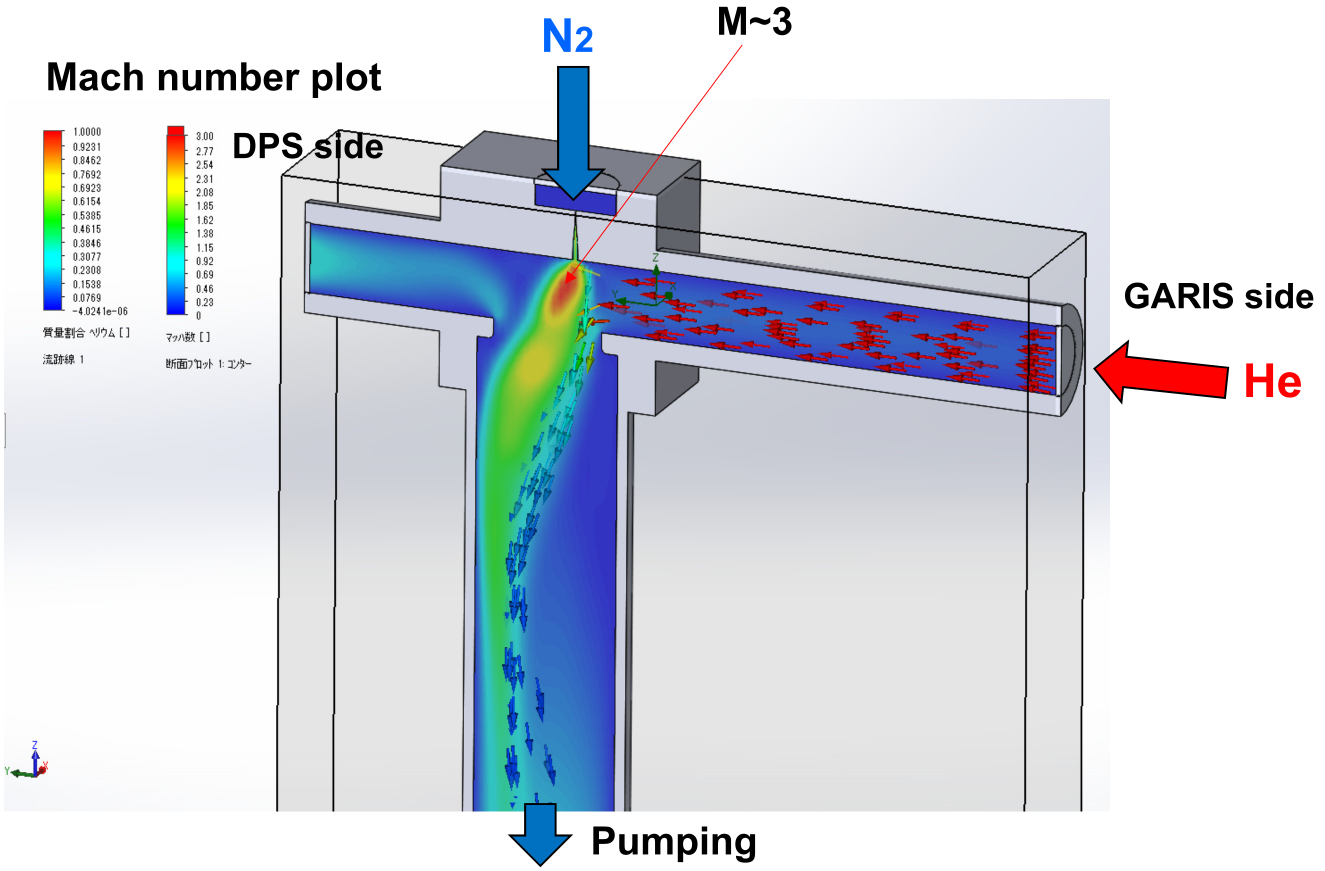








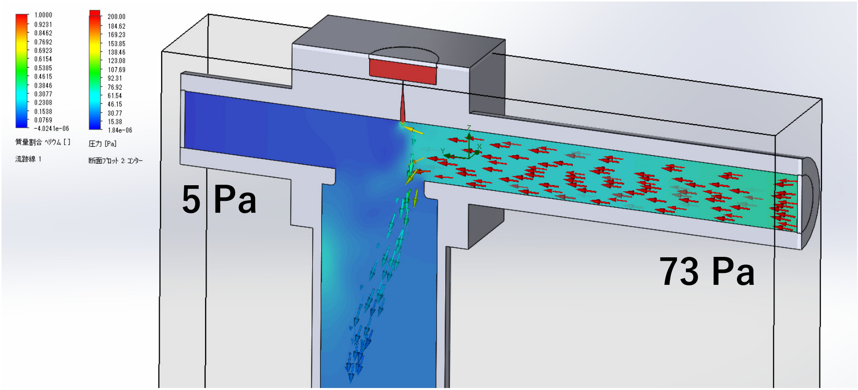
CFD calculations



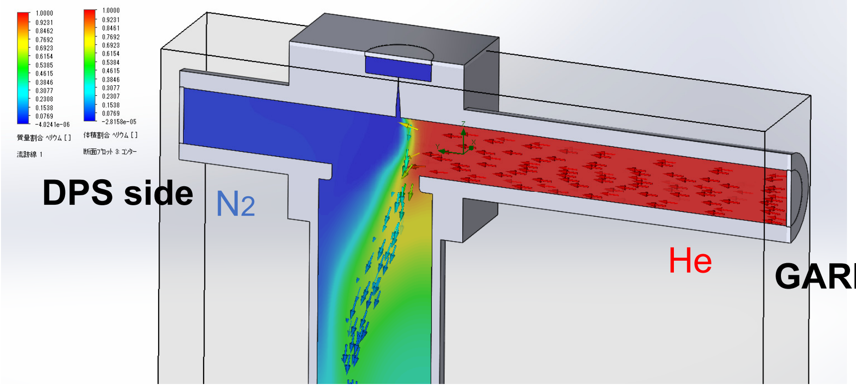
CFD simulation by using **SOLIDWORKS Flow Simulation**

CFD calculations

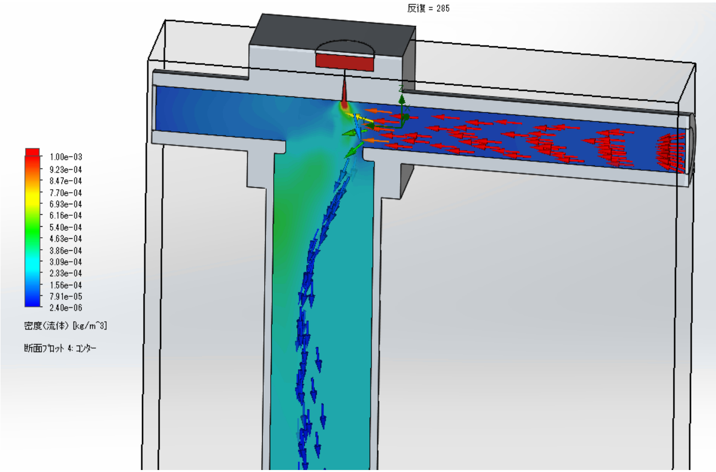
Pressure



Ratio of N_2 to He gas

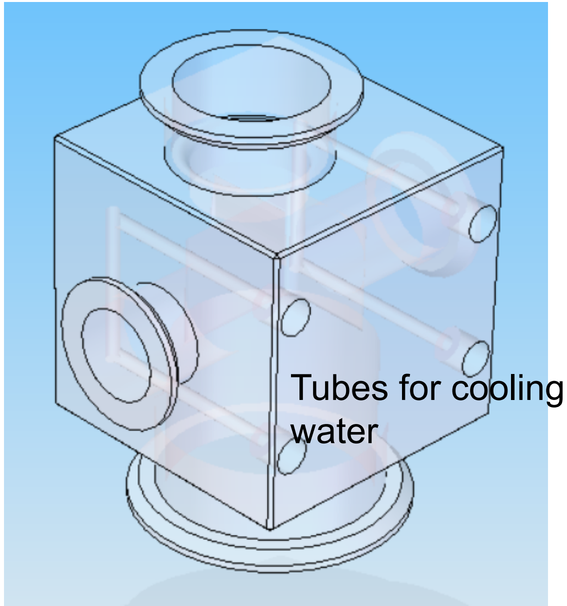


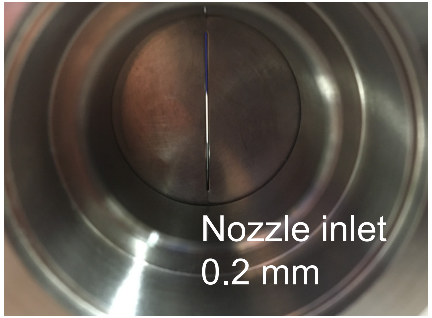
Density



Gas thickness is ~1 ug/cm^2
Energy deposition of $^{51}V^{13+}$ (6MeV/u) is ~22 keV
The effect on the beam is almost negligible

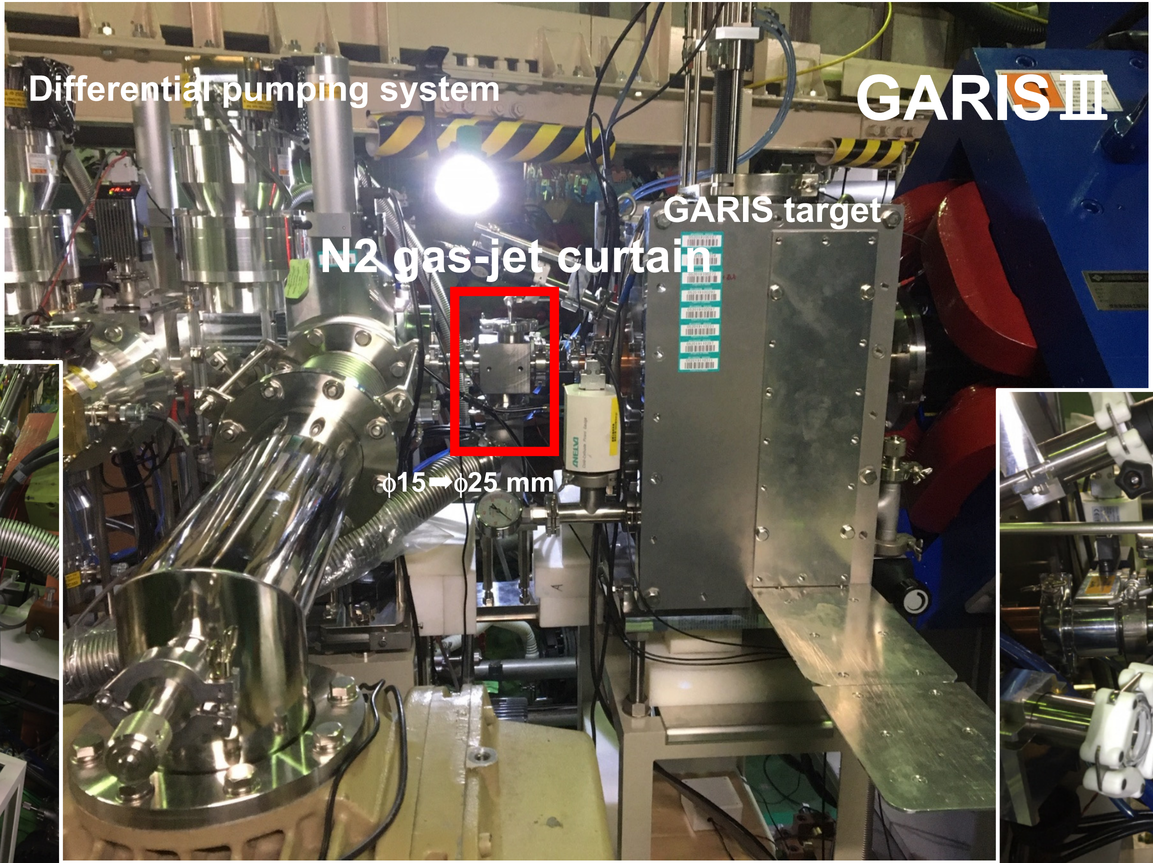
Production of actual apparatus

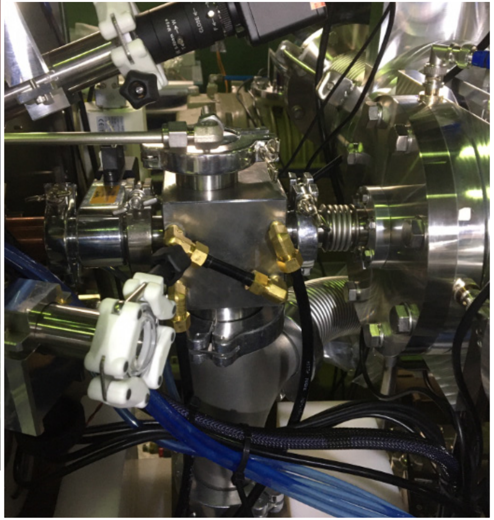




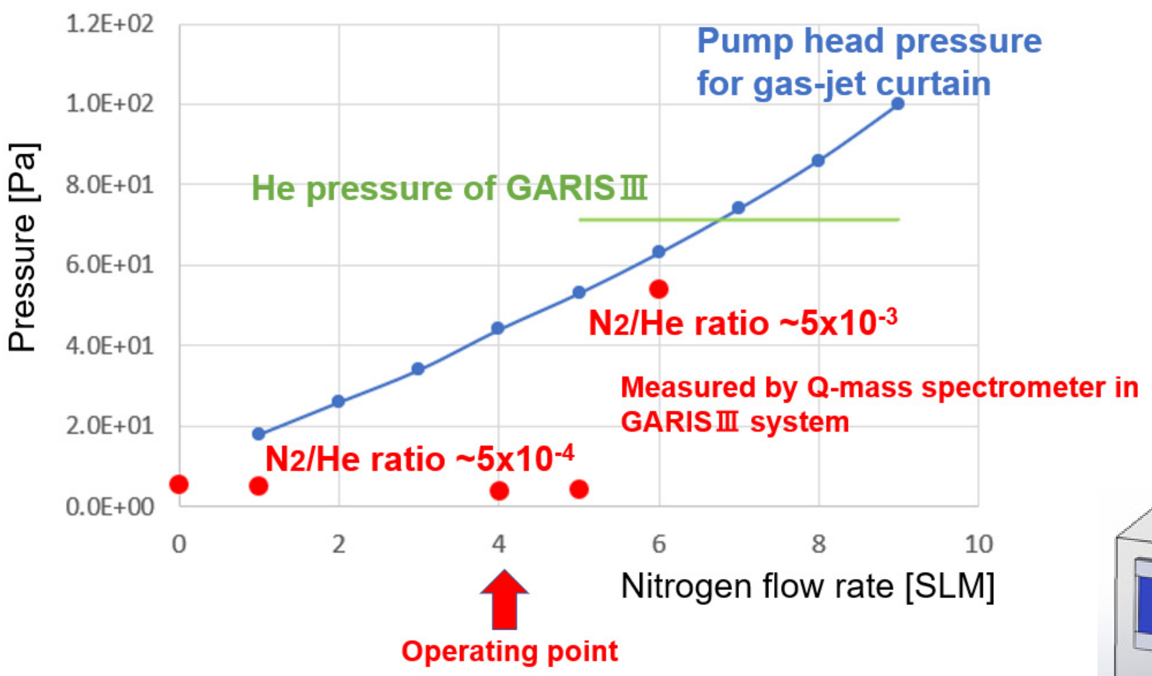
The nozzle has a half-split structure and is fabricated by electrical discharge machining.

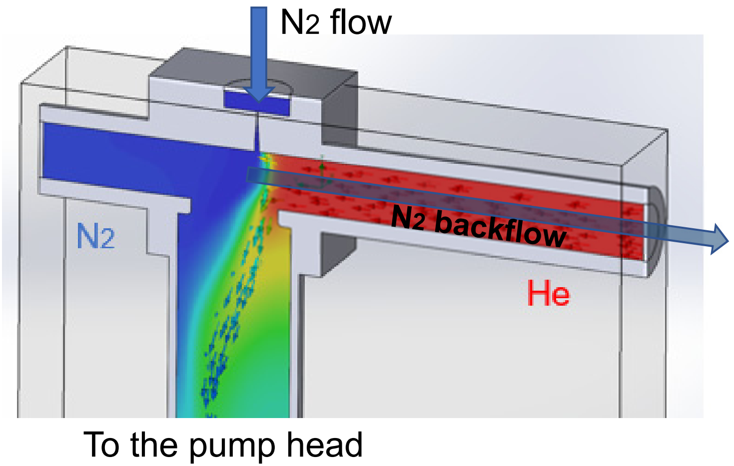
Installation of gas-jet curtain



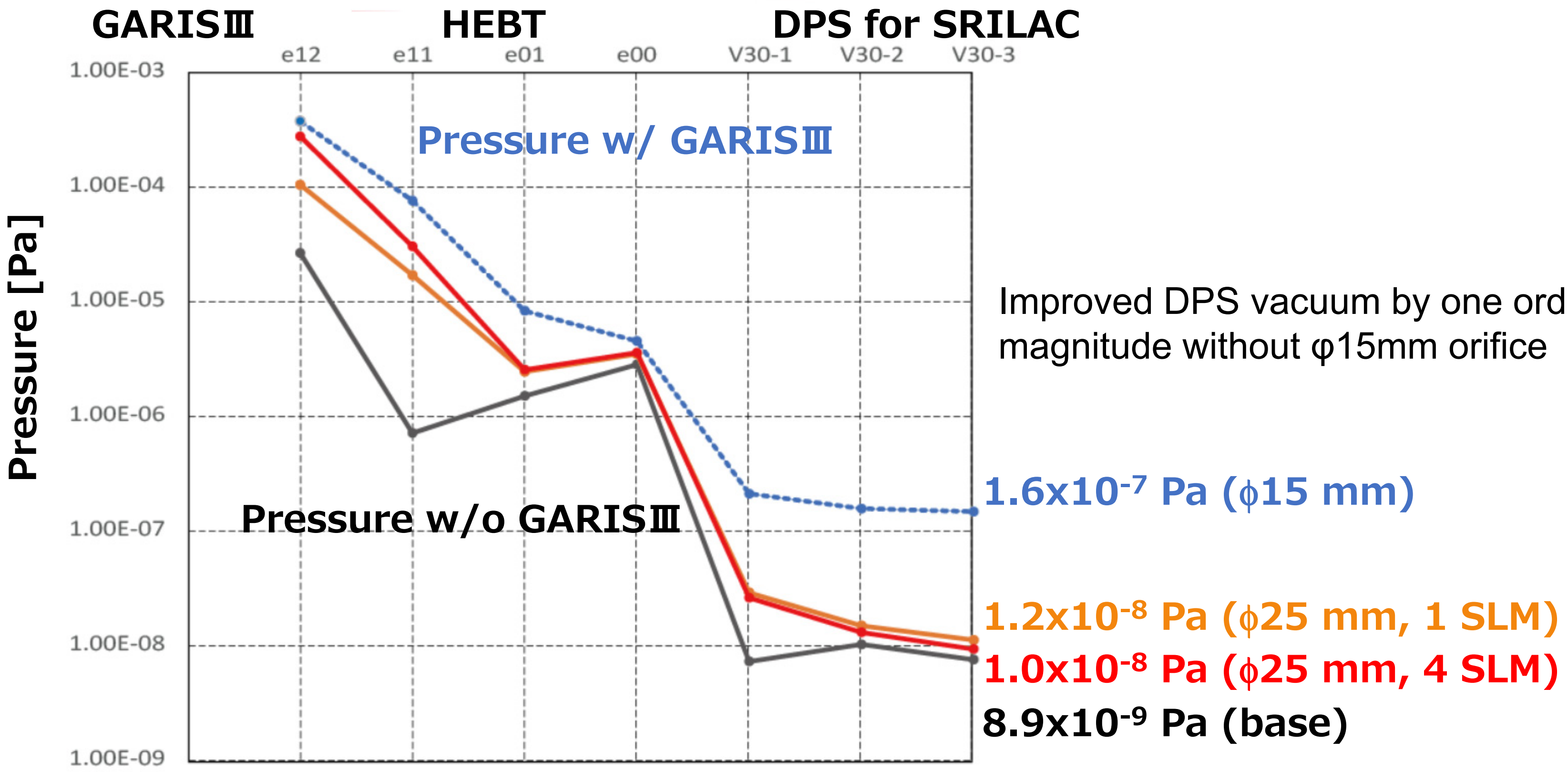


N_2 backflow into GARISⅢ





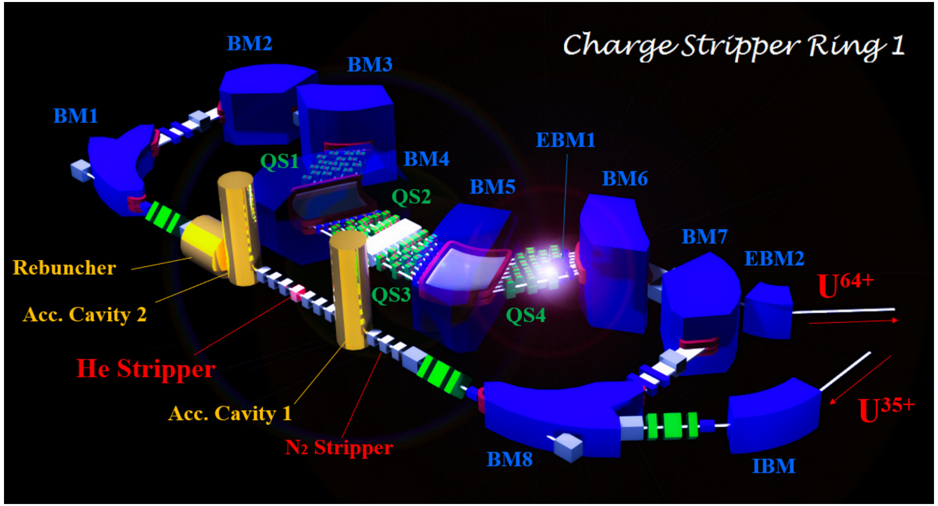
Performance of gas-jet curtain



The 3rd stage pressure of DPS was drastically reduced when we turned on the gas jet curtain.
We also confirmed that there was no effect on the beam when we used gas-jet curtain.

Summary and future prospects

- **SRILAC** has been operating successfully since 2020.
- Compact and powerful **NEG-based DPSs** were developed.
- **Nitrogen gas-jet curtain** method was applied to solve the problem of He leakage from GARIS III.
- All system has been running without major problems for nearly two years of intermittent operation.
- Future plans for the RIBF include a **charge stripper ring (CSR)**, where the gas-jet curtain method will also be applied.



charge stripper ring (CSR)

H. Imao, Charge Stripper Ring for RIKEN RI Beam Factory, **JINST 15 (2020) P12036.**

H. Imao et al., The present status and future plan with charge stripper ring at RIKEN RIBF, **IPAC2022, TUIYGD2.**