



中国科学院近代物理研究所  
Institute of Modern Physics, Chinese Academy of Sciences

# Robot assisted cavity HPR and assembly at IMP

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On behalf of ADS SRF Team, Institute of Modern Physics, CAS



# Outline

- 1. automation experience at IMP
  - 1.1 overweight cavity
  - 1.2 robot assisting on HPR process
  - 1.3 robot assisting on the strings assembly
- 2. full automated HPR system
- 3. outlook for full automatic cleanroom for CIADS project



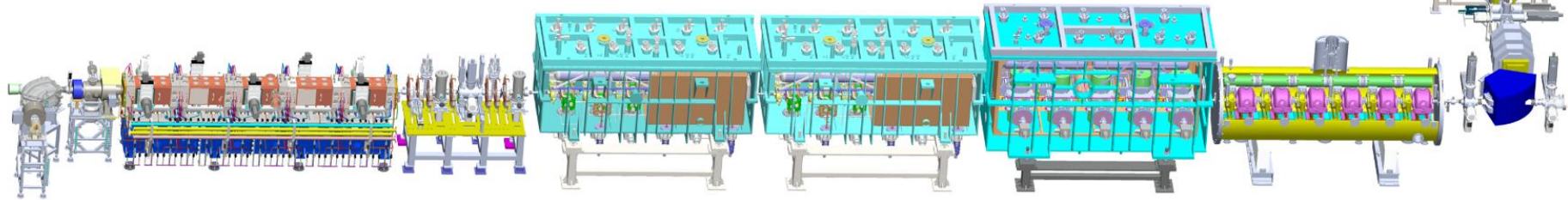
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# The problem of overweight cavity



CiADS front-end demo: 23 cavities, HWR\*17+Spoke\*6

Highest beam: 10 mA (pulsed) 3 mA (cw) p

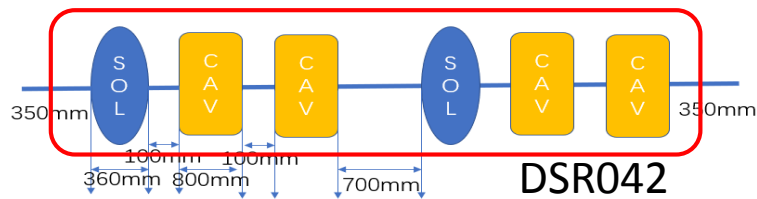
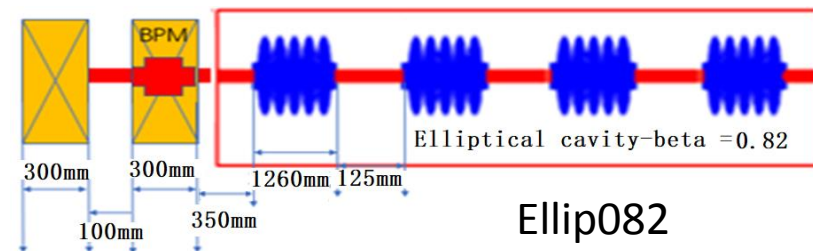
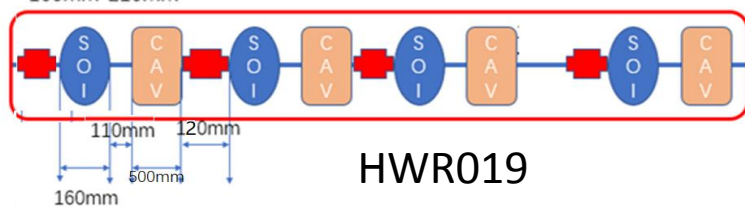
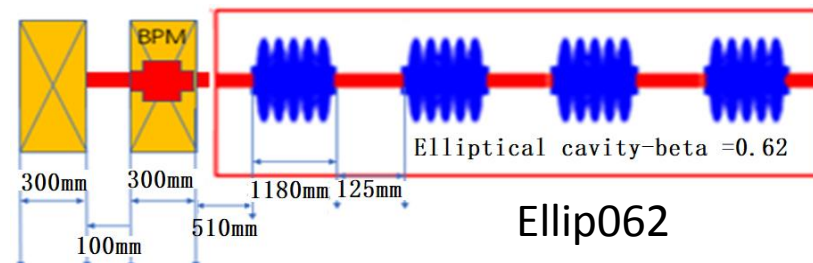
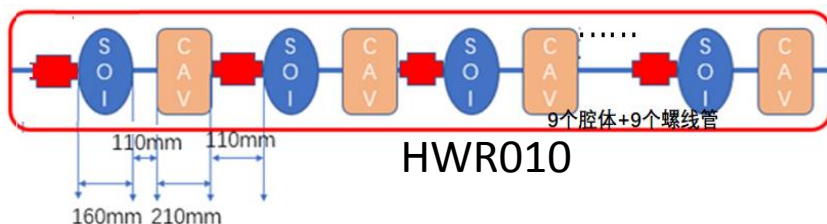
Commissioned in 2017

Phase-II: 137 cavities, 10 mA cw p beam



# The problem of overweight cavity

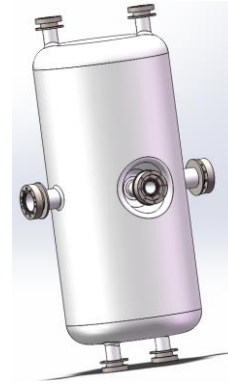
| Cavity   | Quantity of cavities | Quantity of strings |
|----------|----------------------|---------------------|
| HWR010   | 9                    | 1                   |
| HWR019   | 24                   | 4                   |
| DSR042   | 40                   | 10                  |
| Ellip062 | 40                   | 10                  |
| Ellip082 | 24                   | 4                   |





# The problem of overweight cavity

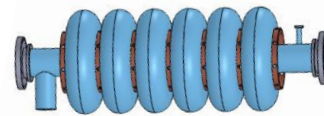
| Cavities type | Weight with helium vessel | Ports number |
|---------------|---------------------------|--------------|
| HWR010        | ~50kg                     | 8            |
| HWR019        | ~180kg                    | 8            |
| DSR042        | ~180kg                    | 8            |
| Ellip062      | ~140kg                    | 4            |
| Ellip082      | ~140kg                    | 4            |



HWR019



DSR042



Ellip062

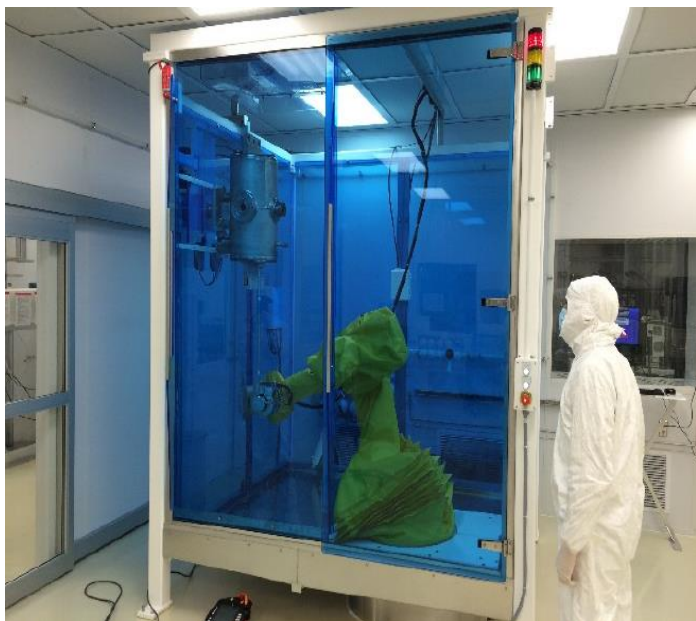
The weight of HWR019, DSR042, Ellip062 and Ellip082 is over the maximum permissible weight to be carried by an adult.

*At 1967, the 'International labor Conference' gave a suggestion of maximum permissible weight to be carried by one worker. The weight is 50kg.*



# Solutions for this problem

- Robotic HPR of SRF cavities in FRIB project.
- Cobotize the nitrogen cleaning of the flange and screw's holes in CEA.



- I. Malloch, et al. "Design and implementation of an automated high-pressure rinse system for FRIB SRF cavity processing" in proc. LINAC2016, East Lansing, MI, USA. Paper TUPRC024.
- II. Berry, et al. "Automatic of Clean Room Work" in proc. TTC meeting 2019, Canada.



# Solutions for this problem

## Robot assisting

Cavity held by robot has been chosen in IMP.  
At 2017, a robot had been introduced.

Parameters of Robot chosen in IMP

|                       |                     |
|-----------------------|---------------------|
| <b>Brand of robot</b> | <b>KUKA</b>         |
| Cleanliness           | ISO4 & ISO5         |
| Rated pay load        | 210 kg              |
| Pose repeatability    | $\pm 0.06\text{mm}$ |
| Number of axes        | 6                   |

Assisting on:

HPR process

Cavity assembly

Strings assembly





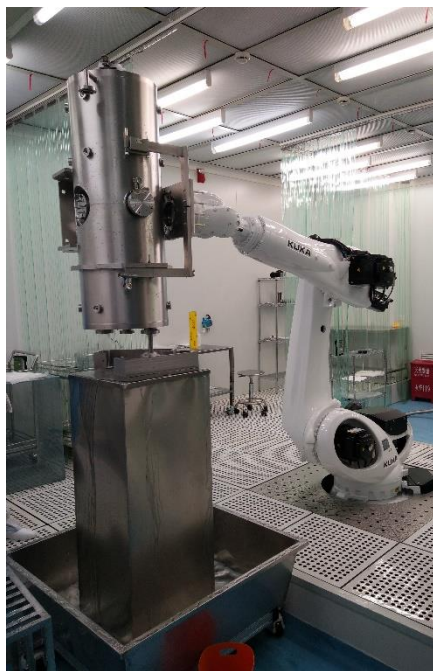


# Robot assisting on HPR process



Horizontal HPR for  
HWR-015 cavities

15 times



Vertical HPR for  
HWR-015 cavities

15 times



HPR for 325MHz  
QWR Nb/Cu cavities

3 times



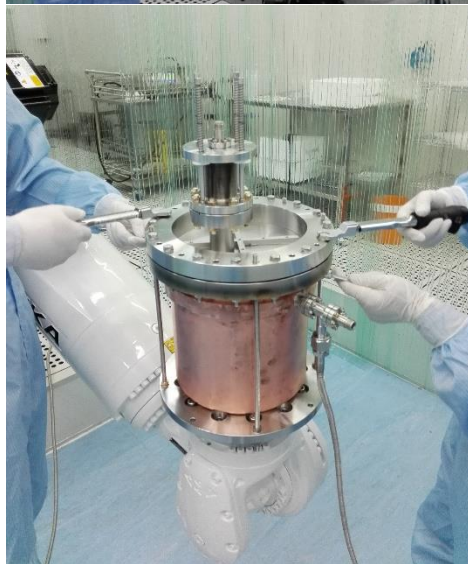
HPR for 1.3GHz  
Elliptical cavities

5 times

| Process                 | Operators (nomal) | Hours (nomal) | Operators (with robot) | Hours (with robot) | Hours saved |
|-------------------------|-------------------|---------------|------------------------|--------------------|-------------|
| HWR-015 cavities<br>HPR | 3                 | 8             | 1                      | 8                  | 16          |



# Robot assisting on cavity assembly



| Cavity            | Ports number |
|-------------------|--------------|
| HWR-010           | 8            |
| HWR-015           | 8            |
| QWR Nb/Cu         | 3            |
| elliptic cavities | 2            |

- Cavity held by robot which has 6 degrees of freedom is easier to be assembled.



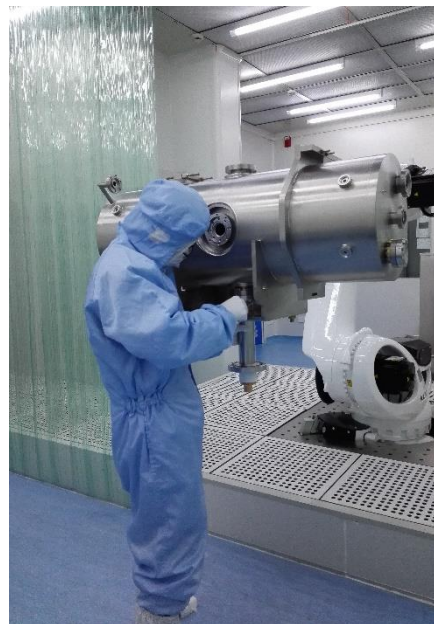
# Robot assisting on string assembly



Cavities moving and fixing on the bracket



Solenoid assembly and fixing on the bracket



Coupler assembly assisting



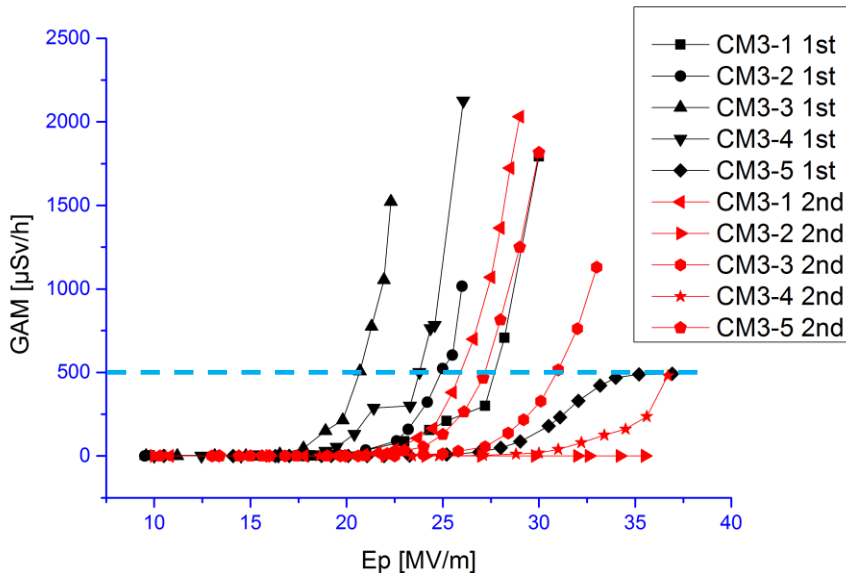
Nitrogen cleaning assisting

◆ Alignment between flange to flange is easier with robot assisting



# Robot application in IMP cleanroom

Cavity online RF result compared between CM3 1<sup>st</sup> and CM3 2<sup>nd</sup>  
 All cavities in CM3 1<sup>st</sup> and CM3 2<sup>nd</sup> have similar FE onset in vertical test.



| Cavity number | FE Onset (1st) | GAM<500 μSv/h(1st) | FE Onset (2nd)        | GAM<500 μSv/h(2nd) |
|---------------|----------------|--------------------|-----------------------|--------------------|
| CM3-1         | 23MV/m         | 28MV/m             | 21MV/m                | 26MV/m             |
| CM3-2         | 19MV/m         | 25MV/m             |                       | 36MV/m             |
| CM3-3         | 16MV/m         | 20MV/m             | 25MV/m                | 31MV/m             |
| CM3-4         | 18MV/m         | 24MV/m             | 29MV/m                | 36MV/m             |
| CM3-5         | 26MV/m         | 36MV/m             | 22MV/m                | 27MV/m             |
| Average       | 20.4MV/m       | 26.6MV/m           | 24.2MV/m (4 cavities) | 31.2MV/m           |

## CM3 1st

- Hard alignment between flange to flange
- Assembled 5 times due to vacuum leak
- 3 operators needed on assembly and disassembly process

**contaminated**

improvement



## CM3 2nd

- Easy alignment between flange to flange with robot assisting
- Assembled only one time
- 1 operators needed on assembly and disassembly for HPR process

Improved by robot assisting



# Experiences learned

1. Robot assisting can better solve the problem of “over weight” which is caused by heavy cavities.
2. Robot assisting could not reduce the cavities RF performance compared with former process.
3. Robot assisting can save labors in cleanroom



# What are the next steps ?

1

Full automated HPR system



2

Automated assembly

An automatic  
production line  
for SRF cavity  
strings.



# Outline

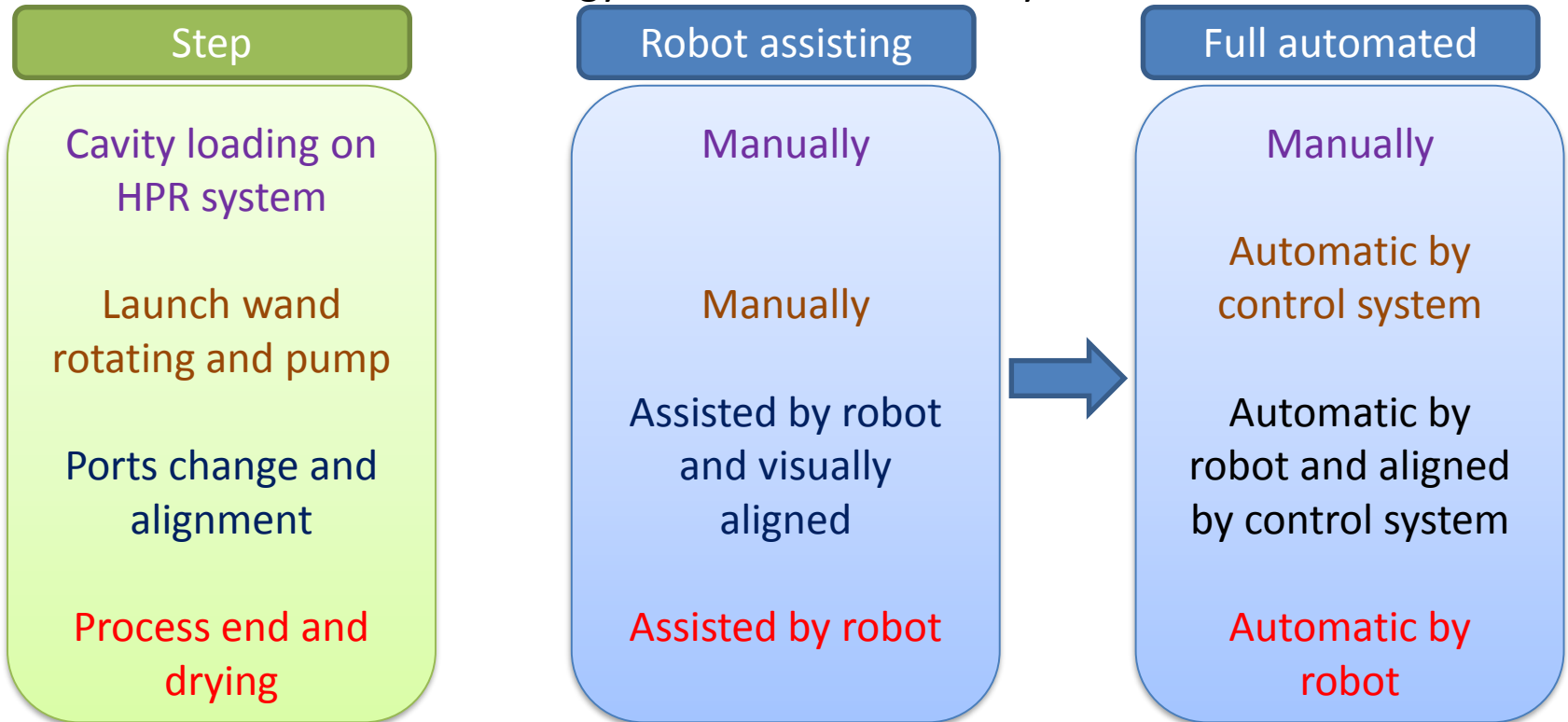
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# The design of automated HPR system

Based on robot technology, full automated HPR system is feasible.



| Process                  | Operators (robot assisting) | Hours (robot assisting) | Operators (full automated) | Hours (full automated) | Hours saved |
|--------------------------|-----------------------------|-------------------------|----------------------------|------------------------|-------------|
| HPR                      | 1                           | 8                       | 1                          | 1                      | 7           |
| Cavity moving and drying | 1                           | 1                       | 0                          | 0                      | 1           |



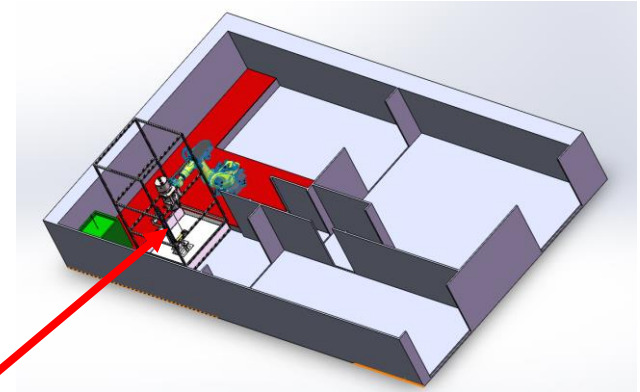


# The design of automated HPR system

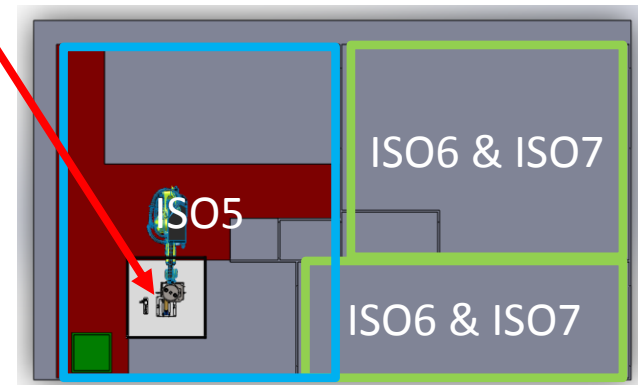
Some of main design goals for the automated HPR system:

- Rated payload: >200 kg
- Ingress protection: IP67
- Cleanliness: ISO class 5
- Stroke of wand: 1300 mm
- Length of wand: 1400 mm
- Diameter of wand: 12 mm
- **Cavity type: Suit for all cavity type with ports diameter greater than 25mm**

*The first version design of this system has been finished in mid-June.*



Automated HPR system

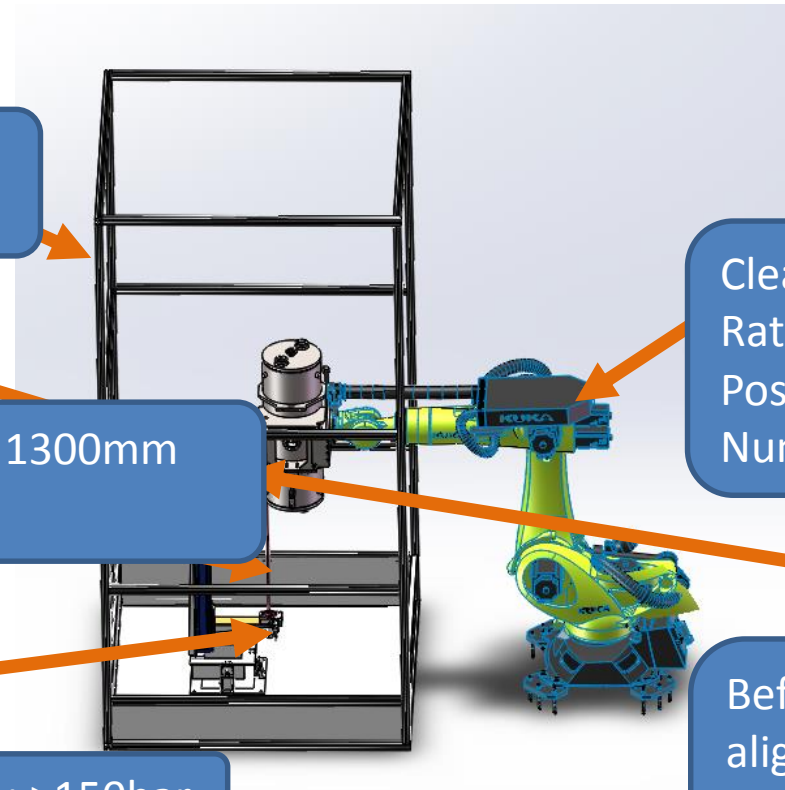


*The layout of IMP cleanroom and the position of automated HPR system*



# The design of automated HPR system

## The detail design of automated HPR system



Water shelter frame

Covered by Anti-static plastic

Linear motion system

Stroke length, maximum: 1300mm  
Ingress protection: IP67

Length: 1400mm  
Diameter: 12mm

feedthrough

Maximum water pressure: >150bar

Cleanroom robot

Cleanliness: ISO4 & ISO5  
Rated payload: 210 kg  
Pose repeatability:  $\pm 0.06\text{mm}$   
Number of axes: 6

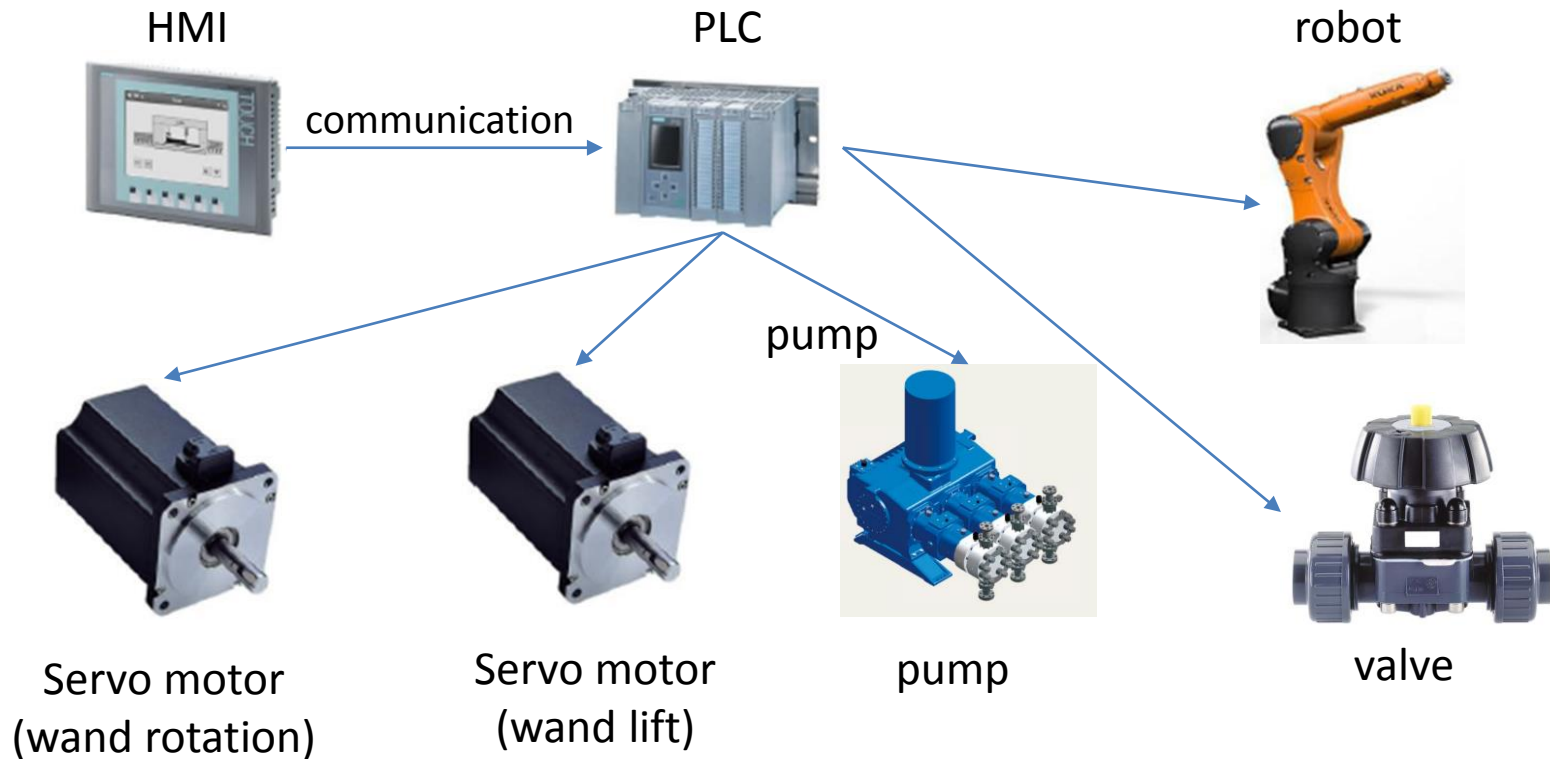
Alignment system

Before every process, alignment system will check the status of cavity which could avoid cavity damage by spray wand.



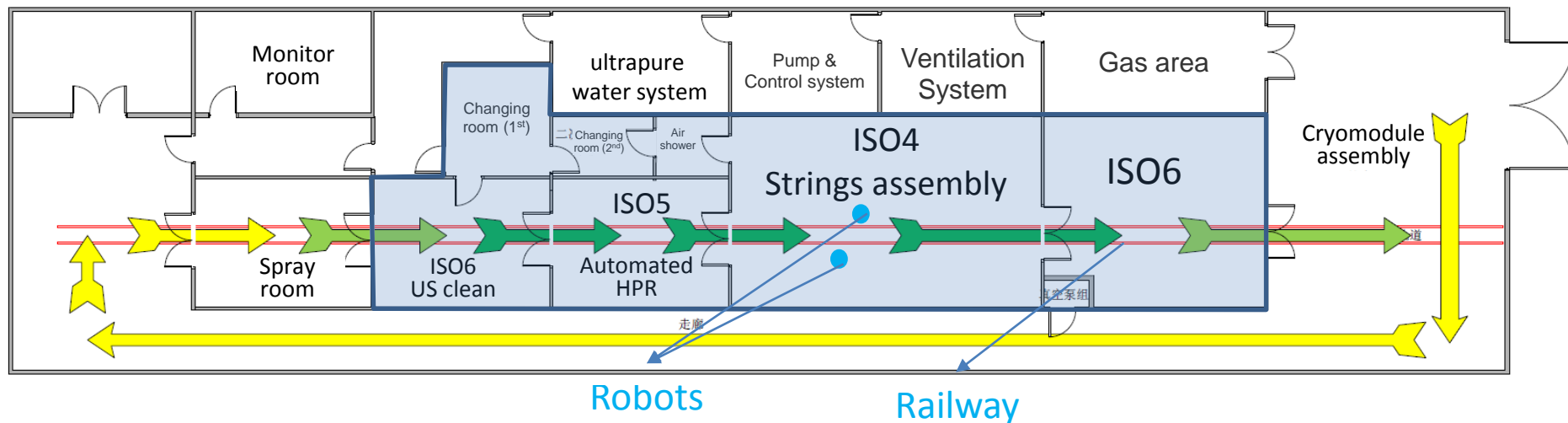
# The design of automated HPR system

The control system design of automated HPR system





# The new automatic cleanroom for SRF cavities



- The cavities will enter cleanroom from one side and become strings to other side.
- An automatic railway will be used for carry cavities and other components.
- A special facility will assist operator to move the cavity into ultrasonic cleaner.
- For HPR process, an automated system will finish it without operators.
- For strings assembly, two robots will assist operators to finish cleanroom alignment and assembly.

Operators needed in cleanroom

| Step             | Nomal cleanroom | Automated cleanroom |
|------------------|-----------------|---------------------|
| US clean         | 2               | 1                   |
| HPR              | 3               | 0                   |
| Strings assembly | 3               | 2                   |

*Only 3 operators needed in the whole cleanroom process*



Thank you for  
your attention