NON-DESTRUCTIVE 2-D BEAM PROFILE MONITOR USING GAS SHEET IN J-PARC LINAC

-overview & hardware construction-

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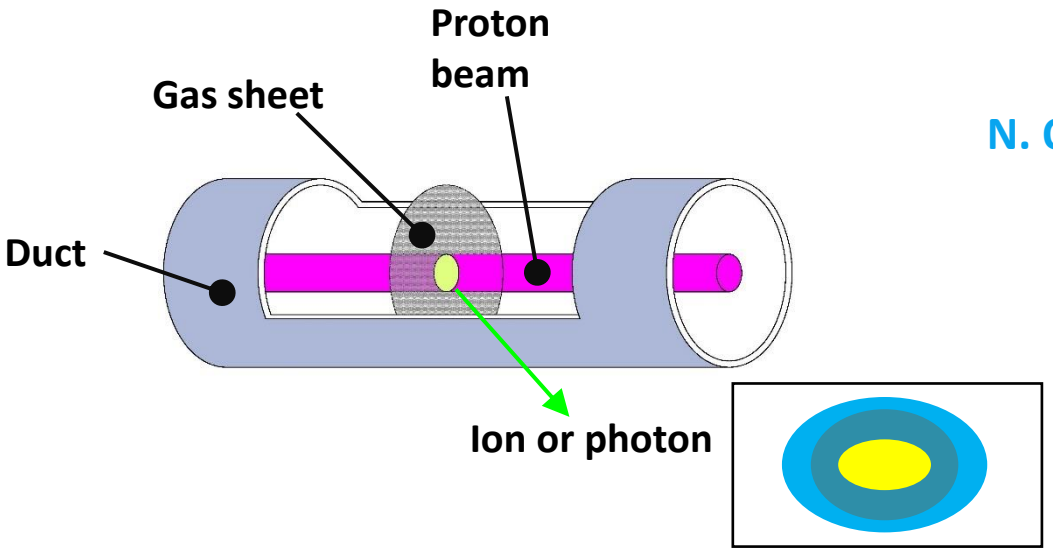
J-PARC / Japan Atomic Energy Agency

Contents

Concept of 2-D beam image monitor using gas distributed in sheet shape "Gas-sheet monitor"

Concept



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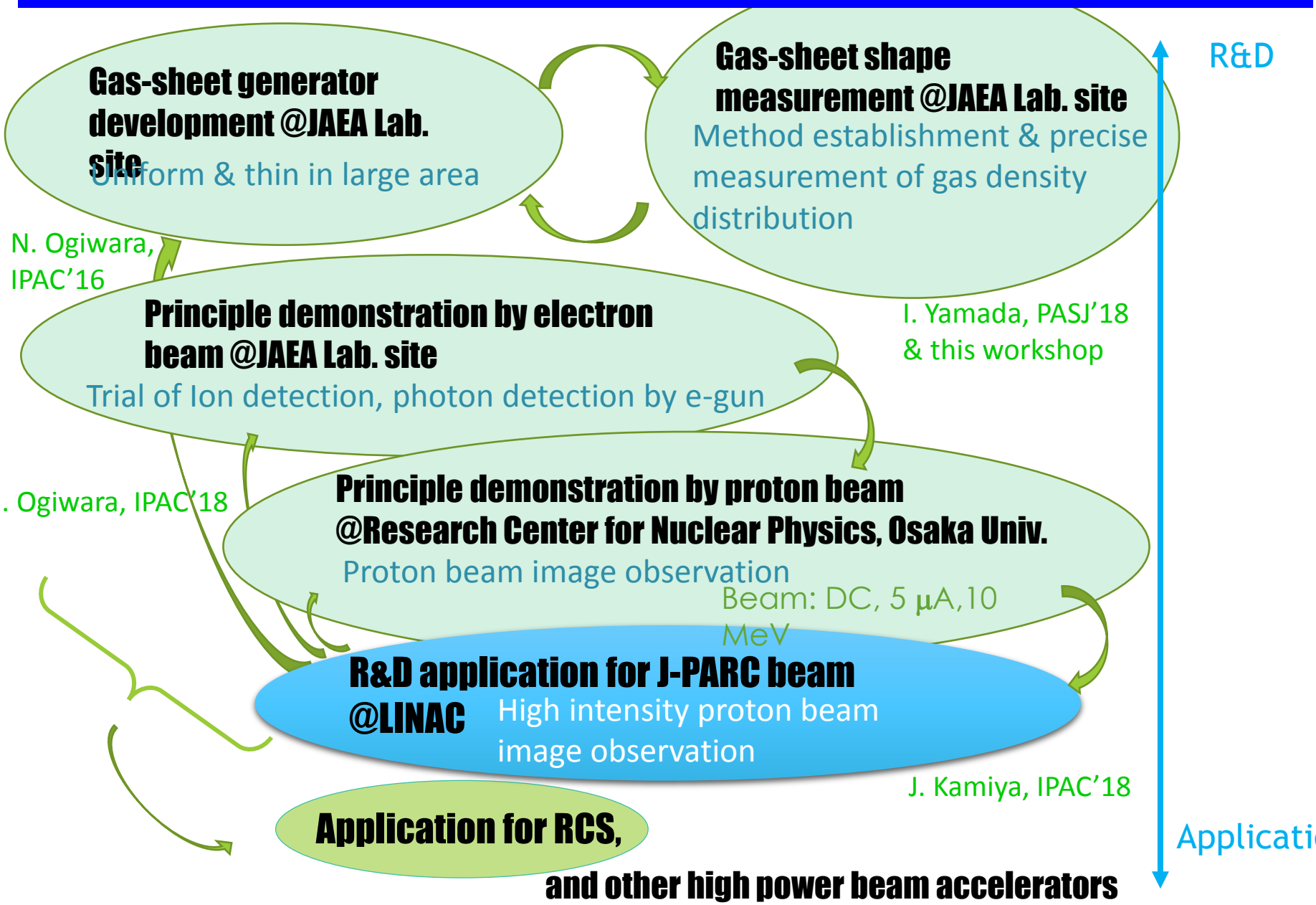
Charactarictics & Merits

- **Non destructive for beam:**
  Possible to work during the user operations.
  Also non-destructive for monitor.
- **Reaction between beam & sheet shaped molecules in a plane:**
  2-D beam image is obtained at an unique position.
- Non-passive gas injection:
  Optimizable for many beam condition.
- Simple system (gas inlet line, vacuum pumps, vacuum gauges, gate valves, detectors) :
  Few special devices make costs lower.

Gas-sheet monitor over view

Strategy for research & developments



Gas sheet generation

- Passing through a slit with very thin (~0.1 mm) and long aperture, gas molecules ejected with directivity (beam effect)
- By optimizing the aperture shape of the slit, the flat and thin distribution of the gas density within the wide area would be obtained.
- Redundant gas, which is injected but finally cut to form the gas sheet, was differentially pumped out.

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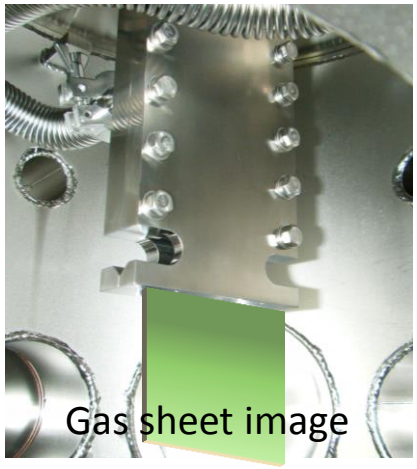
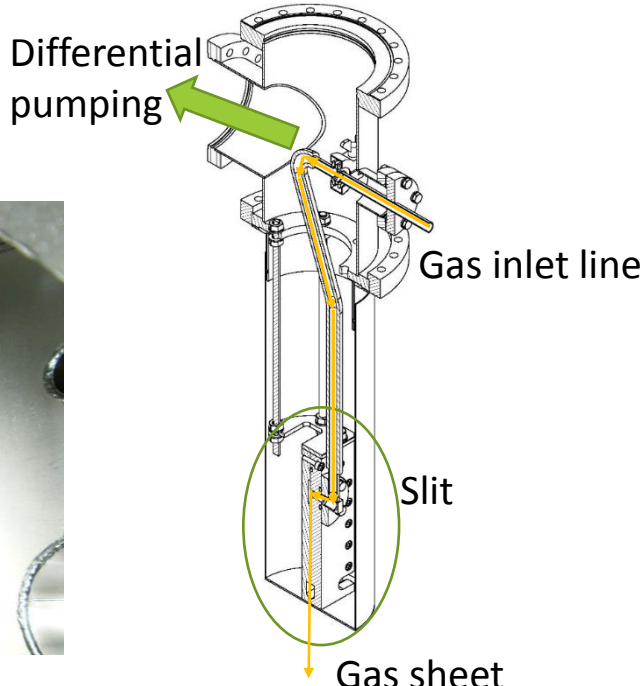
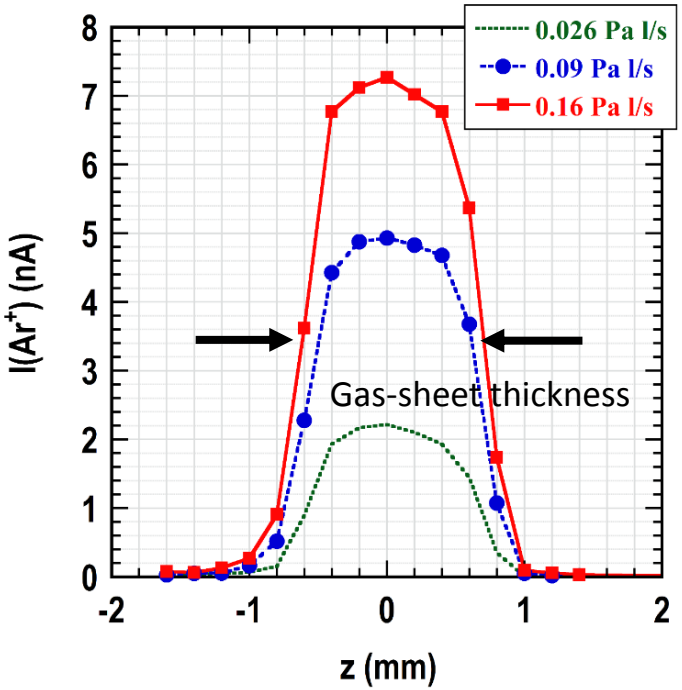




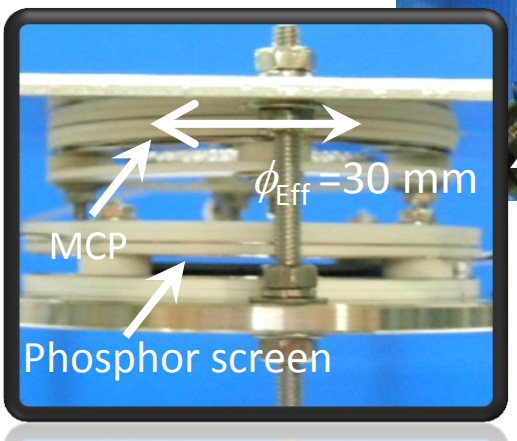
Prototype gas sheet generator

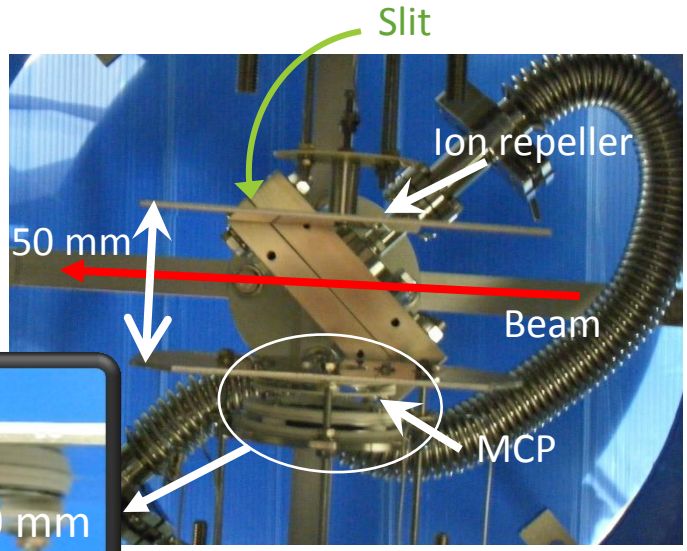


Measured gas density distribution with a prototype slit

Detection technique (ions)

- Gas sheet is generated passing through beam trajectory with an angle.
- Ions, which is the gas molecules ionized by beam, are expelled to the MCP by the electric field.
- Amplified electrons by MCP make the phosphor screen fluorescent.





Camera
(Out vacuum)

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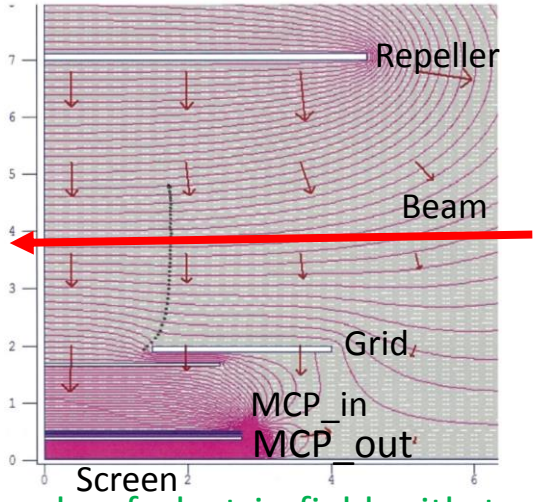
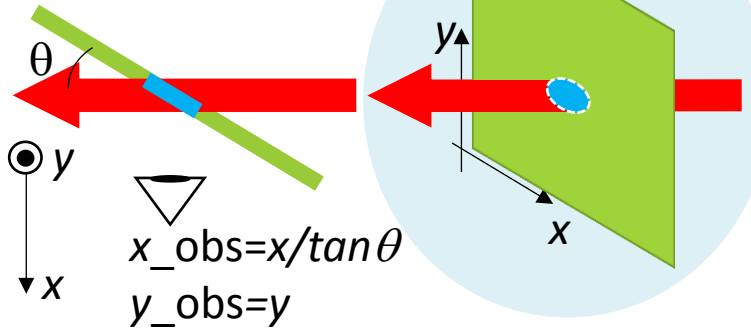
Prototype Detector composition for the ion detection

Voltage (a typical example)

Grid: earth
MCP_in: -900 V
MCP_out: earth
Screen: +3 kV
Repeller: +1-4 kV



Example of electric field with typical applied voltages.

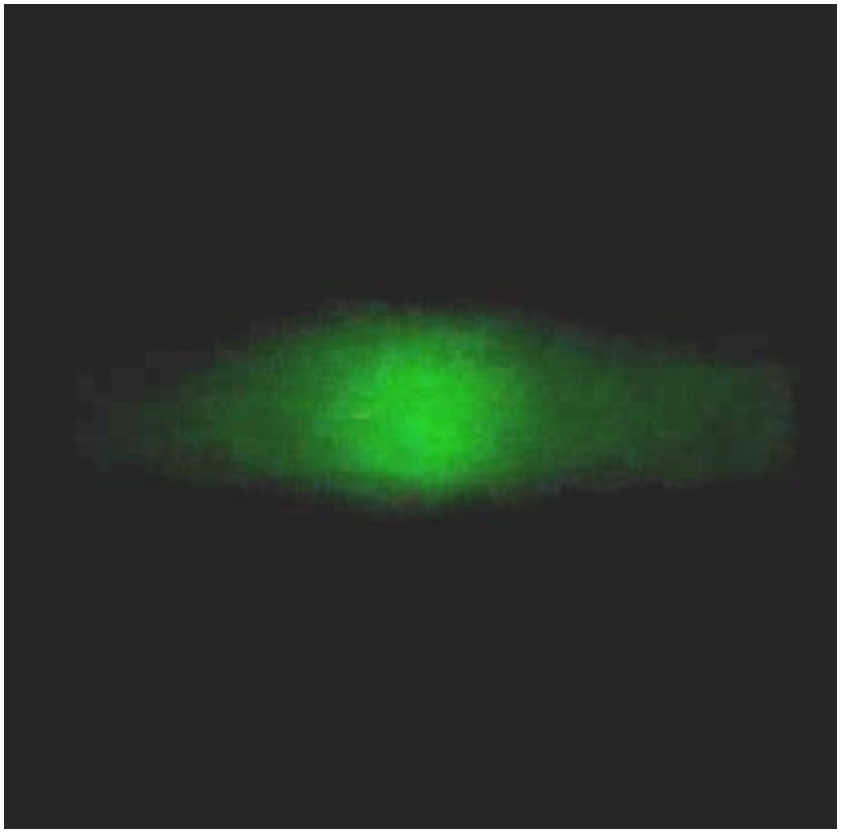


Relation between observed and real scale

Beam images

Proton beam at RCNP, Osaka Univ.

Energy: 10 MeV, Current: 5μA at max, DC

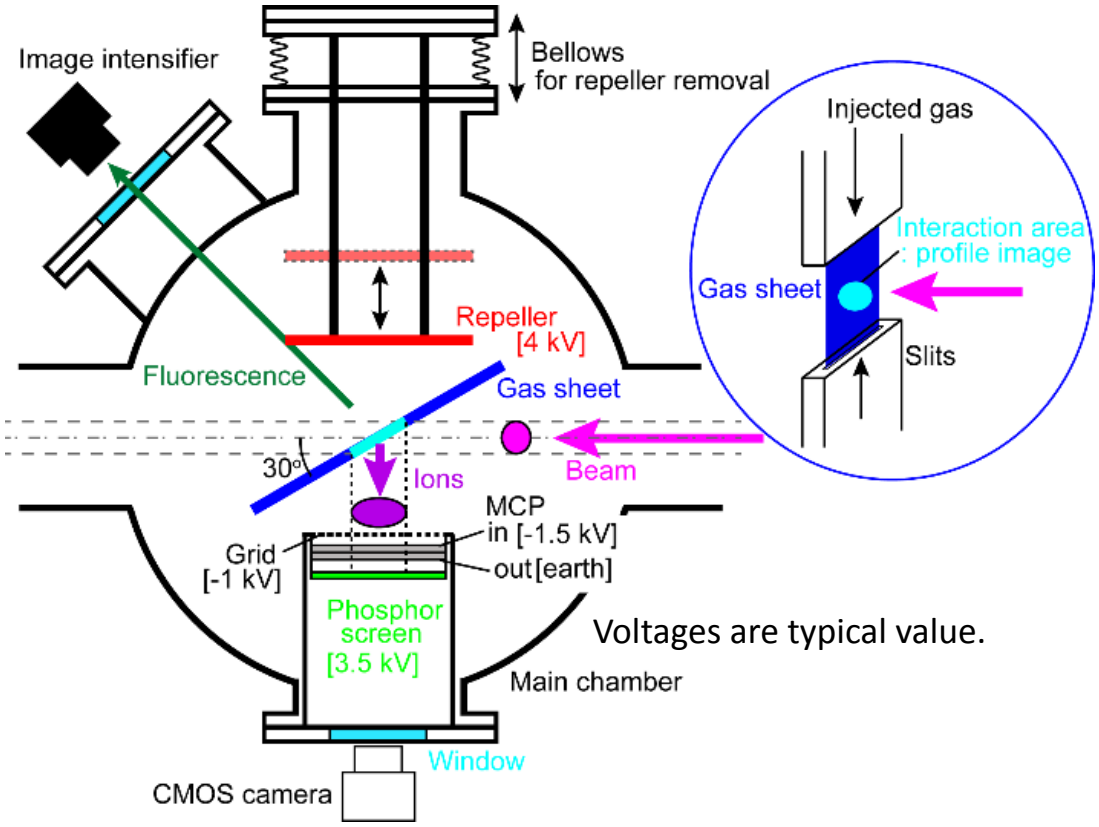


Detection of the beam position change

Detection of the beam shape change (focus-defocus)

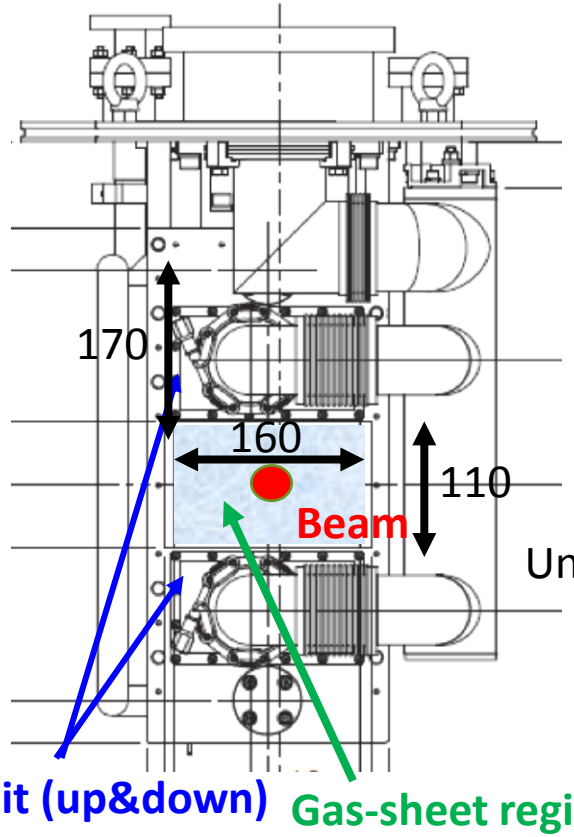
Gas-sheet monitor @J-PARC LINAC

Design concept



Voltages are typical value.

Gas-sheet generator



- Installed in L3BT (LINAC to 3-GeV Synchrotron Beam Transport Line): 400 MeV, H^-
- Slit size: 160 mm^w × 170 mm^h, 0.1 mm^t , 110 mm between up and down slits.
- Gas species N_2 (based on actual performance in energy of 10 MeV, stable for ion pumps, intense luminescence)
- Designed mainly for ion detection, but possible for trial to photon detection.

Concept of the vacuum system design

If the vacuum design is poor,

- Large background pressure makes S/N for the gas sheet worse. → Poor monitor performance.
- Injected gas makes the beam line pressure increase.
- Maintenance of the monitor takes long time.

→ Bad effect on the accelerator operation.

ex) Cavity discharge, long machine-stop period, etc.

Vacuum design concept

- Injected gas for the gas sheet should be pumped out in the monitor chamber or nearby.
- Maintenance for only the gas-sheet monitor should be performable.
- Additional system should be consistent with the existence LINAC vacuum system.

J-PARC LINAC gas-sheet monitor
Vacuum system

Pumping system

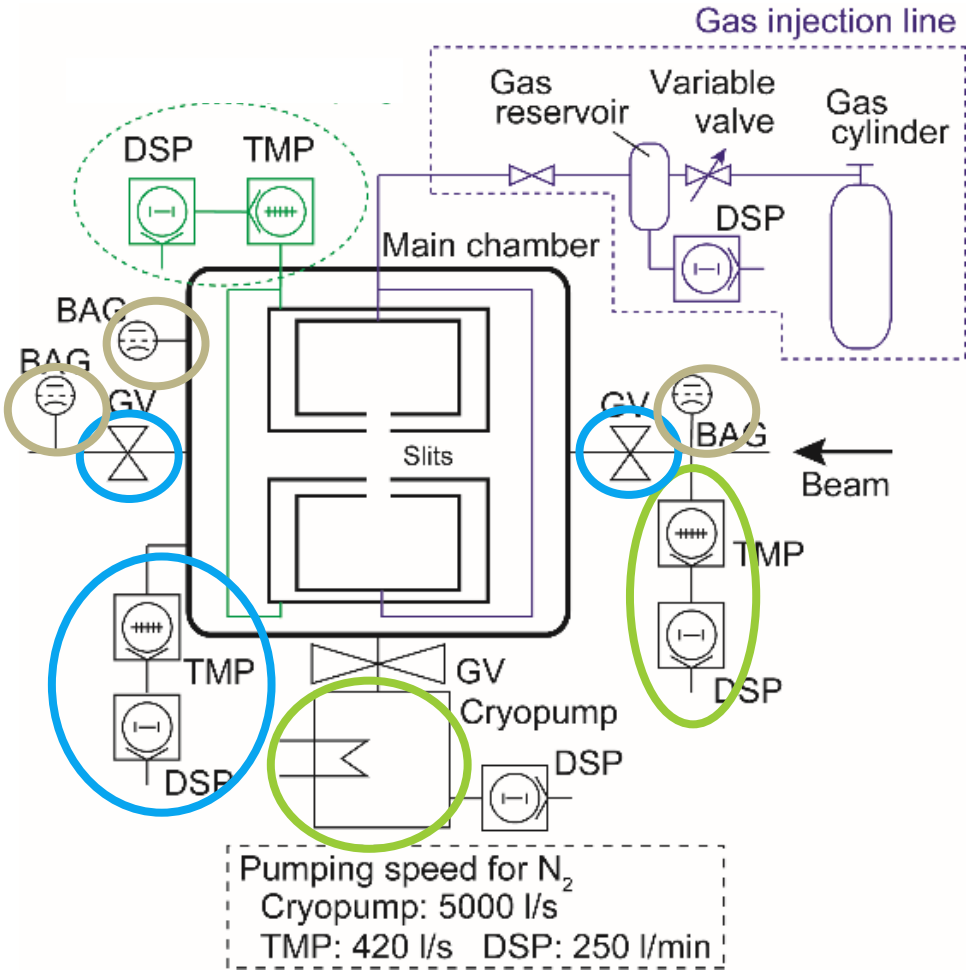
- Cryo-pump as main: Largest pumping speed with an aperture.
- Turbo molecular pump (TMP) as differential pumping in the beam line: To suppress the pressure increase at the upstream cavity.

Maintenance

- Beam line gate vales (GV): To purge only the chamber of the gas-sheet monitor.
- TMP as backup pump: To ensure UHV even in the main pump trouble case.

Consistency with the existence system

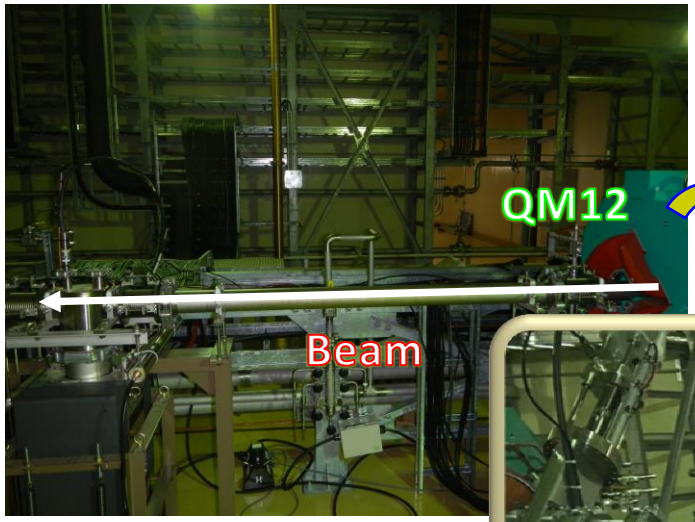
- B-A gauges (BAG) up/down-stream of GV
- FL-net: Link all the information with the existence system.

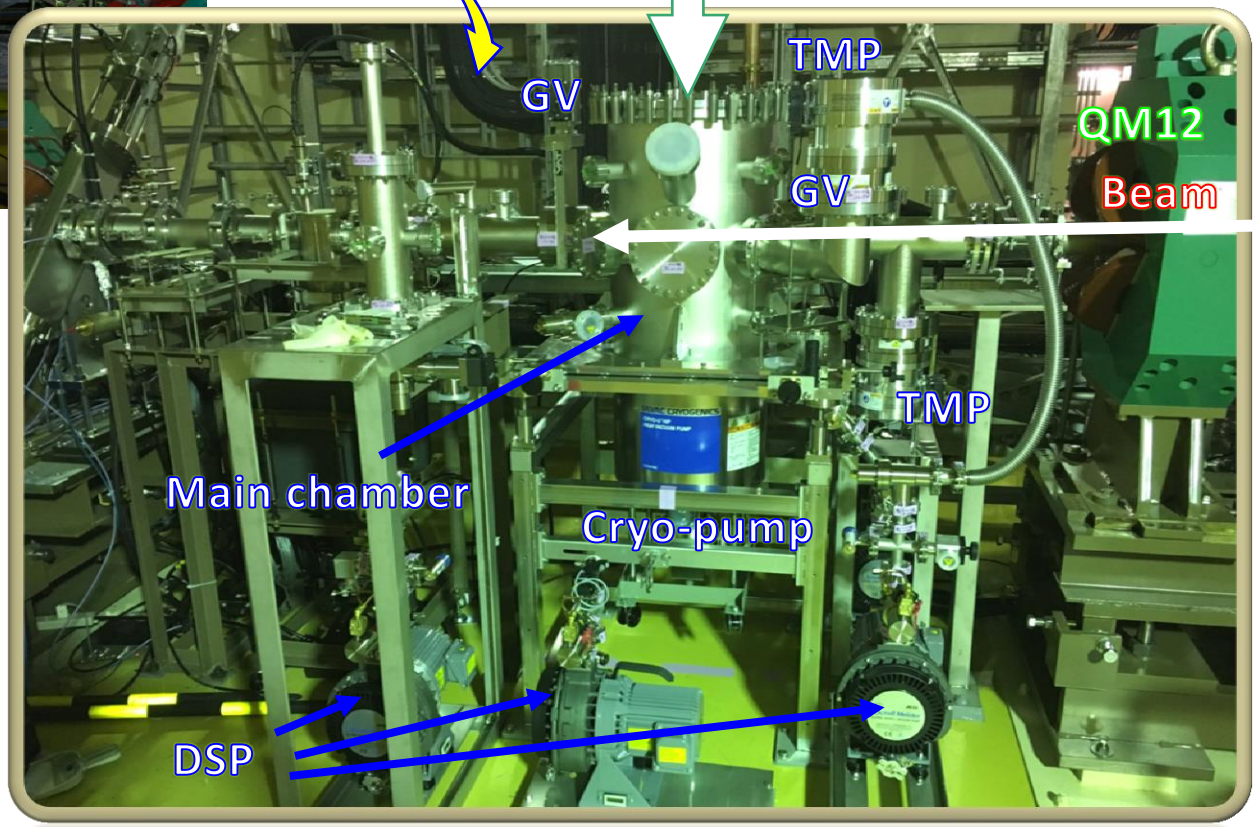


J-PARC LINAC gas-sheet monitor

System overview

Drift space between quadrupole magnets



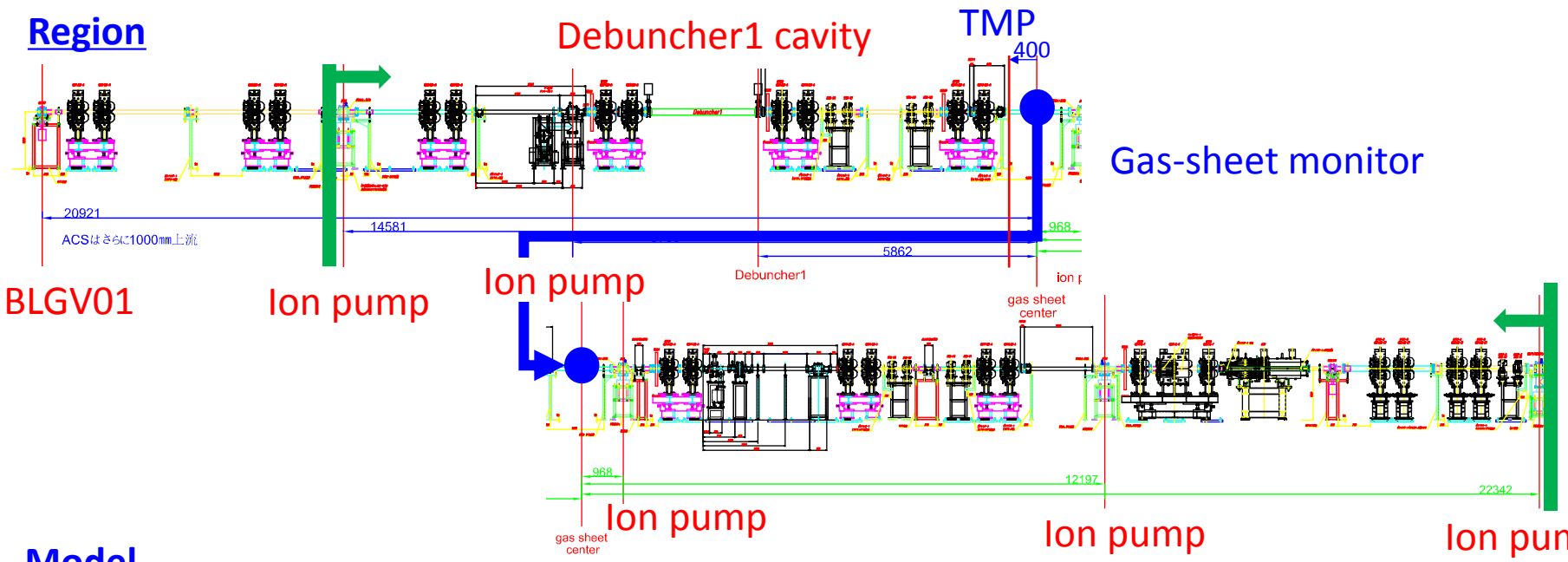


J-PARC LINAC gas-sheet monitor

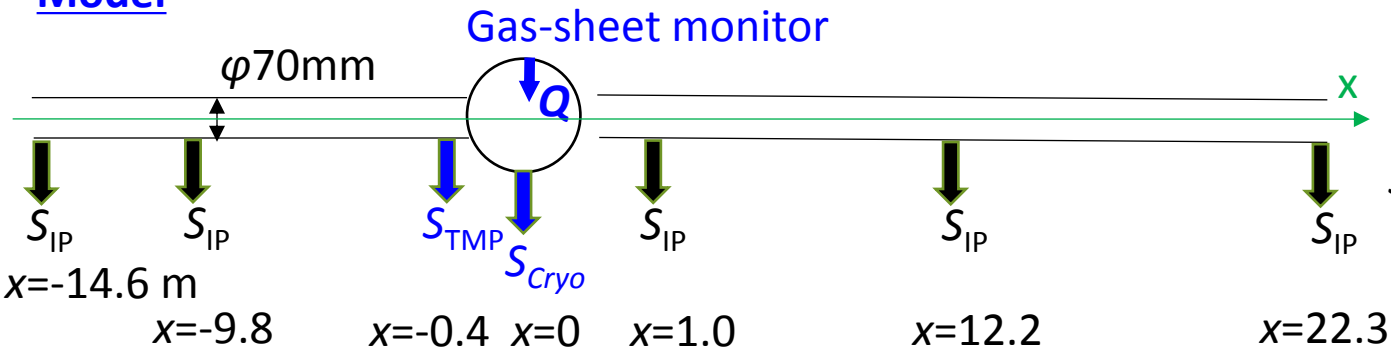
Pressure distribution estimation

Purpose Confirm that the injected gas does not make a harmful effect on the beam line, especially cavity.

Region



Model



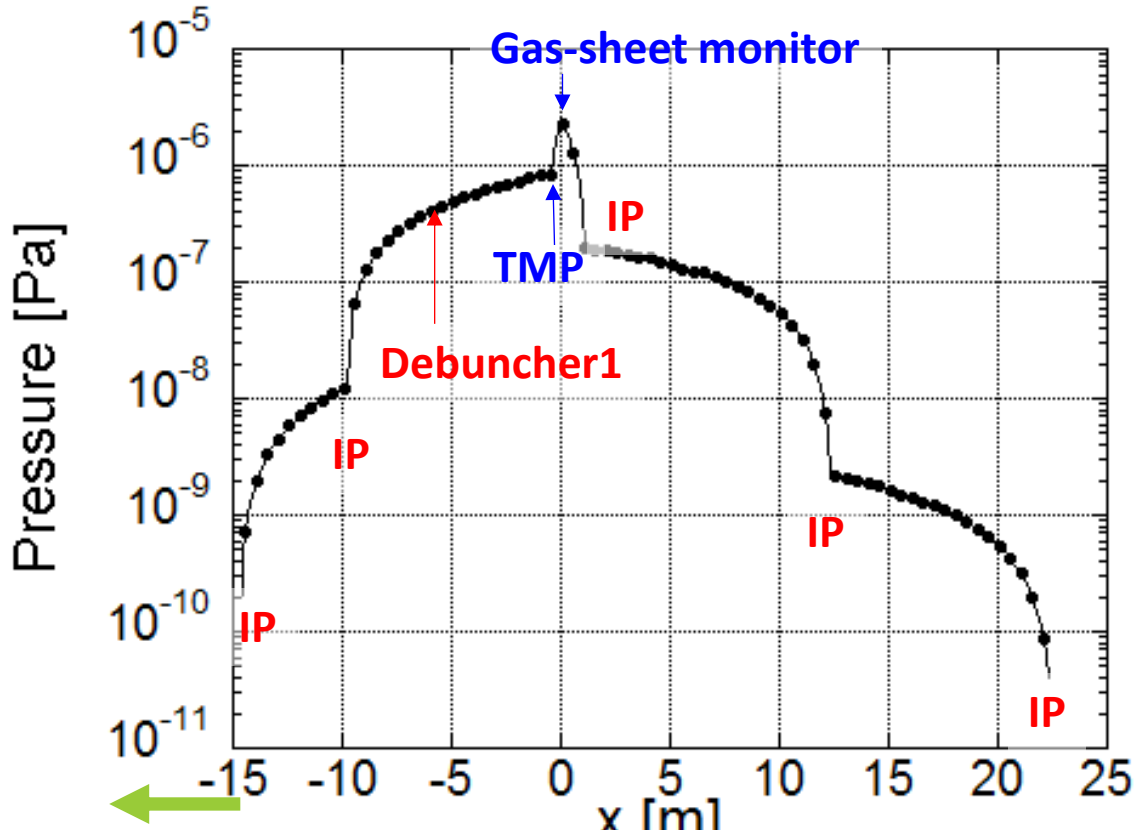
Q: Inlet gas flow
1.42e-5 Pam^3/s
Q_{max} at RCNP

$S_{IP(TMP, Cryo)}$: pumping speed
IP: 0.5 m^3/s
TMP: 0.2 m^3/s
Cryo: 6 m^3/s

J-PARC LINAC gas-sheet monitor

Pressure distribution estimated result

Pressure increase by the injected gas (Δ*P* from the static pressure)



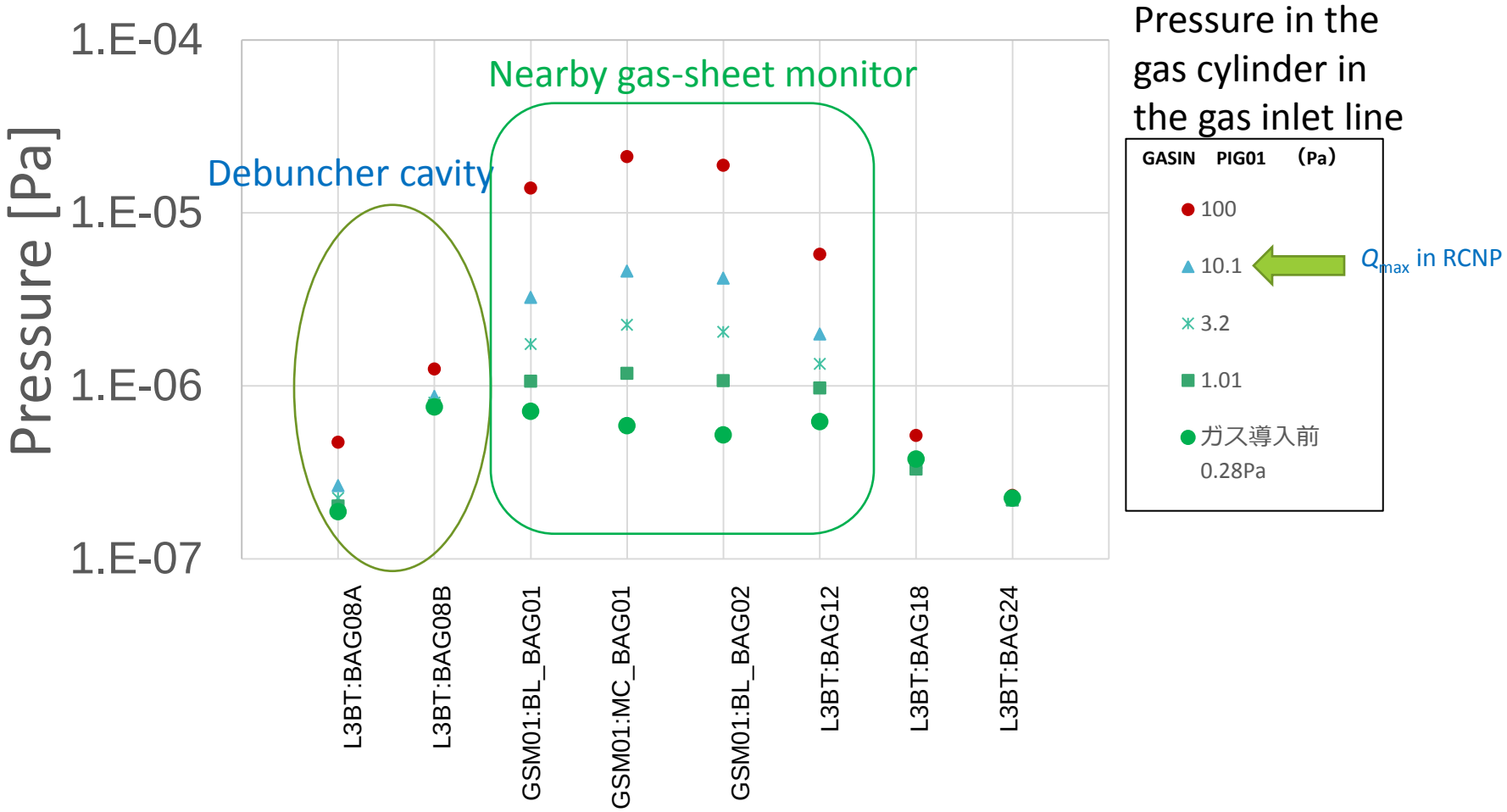
ACS 7.3 m upstream from hear

- Injected gas has negligible effect on pressure in the cavities.
- Δ*P* is in the order of only 10^{-7} Pa or less through all the beam line .

J-PARC LINAC gas-sheet monitor

Measured beam line pressure

Measured beam line pressure when the gas flow was increased.



■ No harmful effect by the gas injection on the beam line pressure

Trial beam profile measurement

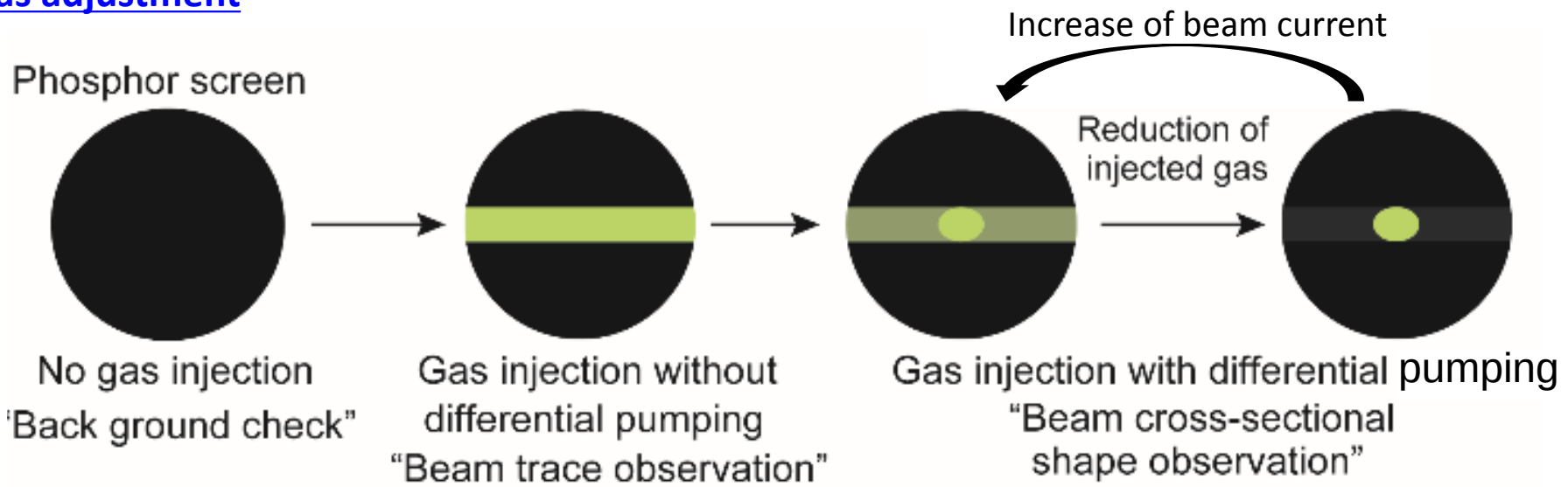
Beam condition

Energy: 191 MeV
Beam current: 5-50 mA
Repetition: 2.5 Hz
Macro bunch width: 100 μm
chop: no-chop

For the first trial, the condition, in which ions are generated as many as possible, are selected.

No beam loss signal increase during the test.
→Surely, non-destructive.

Gas adjustment



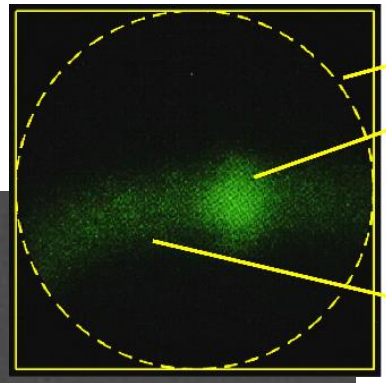
Actual performances

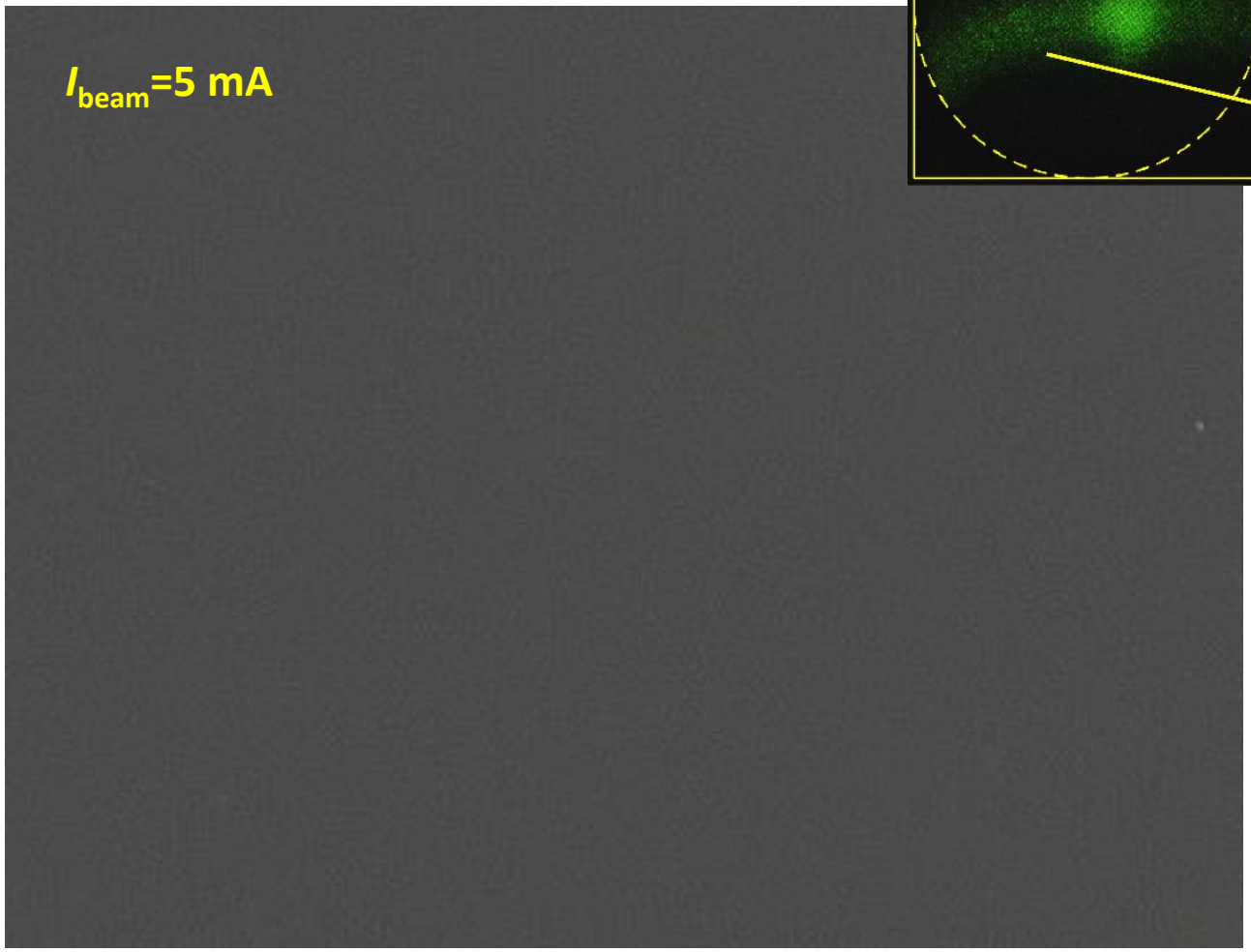
I_{beam}=5 mA	I_{beam}=50 mA	
P_{in}: 10 Pa	P_{in}: 1 Pa	*Amount of the injected gas is very low for the high beam current.
P_{main}: 5.3×10^{-6} Pa	P_{main}: 7.2×10^{-7} Pa	

Observed image

Observed "raw" image

Among 60 fps, those synchronized with the 2.5 Hz beam shows the beam image.



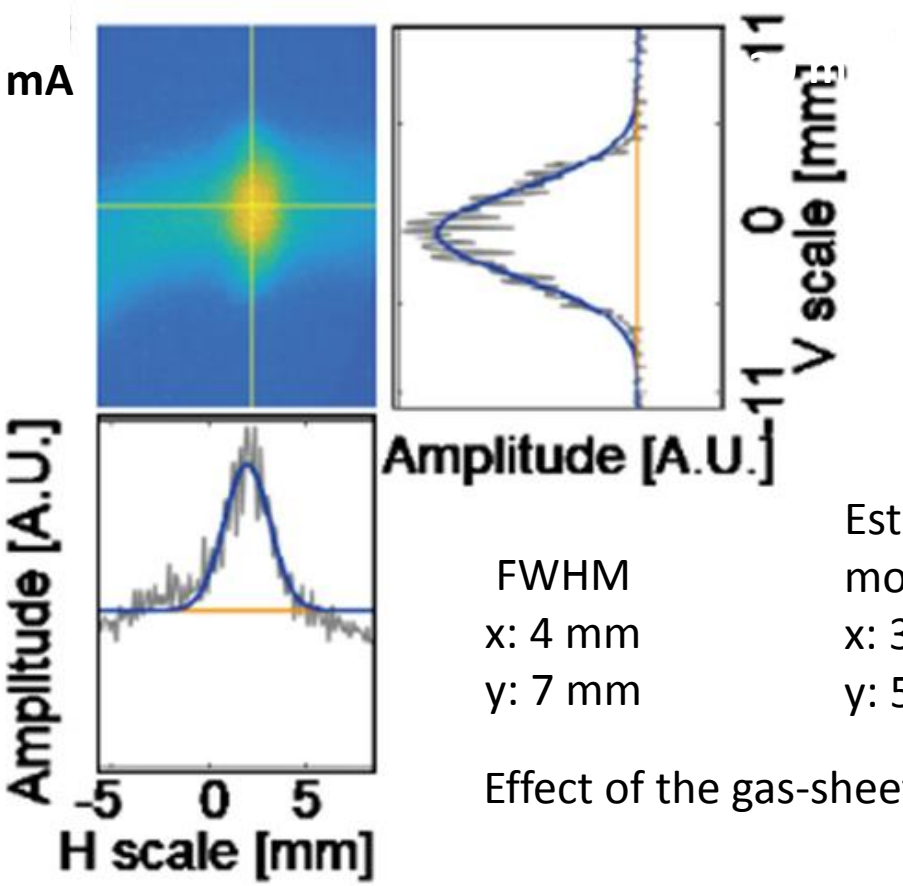


Beam profile analysis

Image analysis

- Flames synchronized with the 2.5 Hz beam was manually selected and averaged in the software.
- Gas-sheet angle to the beam was corrected.

Beam cross-sectional shape



FWHM	Estimation from wire-scanning monitor at gas-sheet position
x: 4 mm	x: 3 mm
y: 7 mm	y: 5 mm

Effect of the gas-sheet thickness and electric field.

Towards the real beam image observation

Ion detection "Image observed. But, is it real image?"

- Gas density distribution in the gas sheet → Measurement method under development
- Electric field by repeller, grid , MCP
- Electric field by beam potential

→ Depending on calculation
Difficult to trace back to real beam image.

I. Yamada, PASJ'18
& this workshop

"Make things simpler."

Photon detection "Easy?, Not."

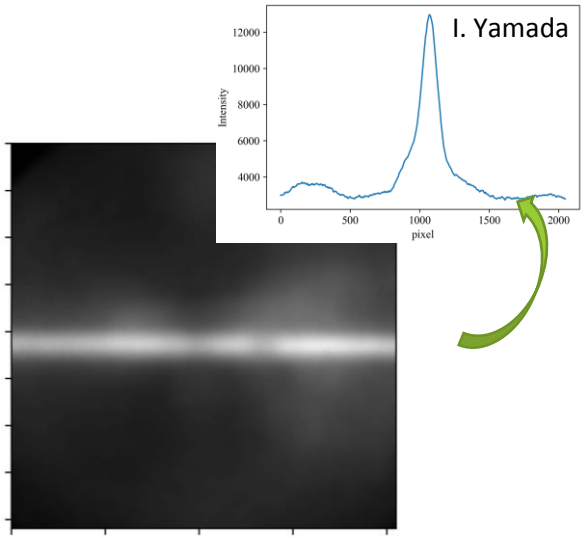
- No effect by electric field.
- Small cross-section for fluorescence.

Low energy experiment, where the cross-section is larger, is ongoing.

- Electron beam experiment @JAEA Lab. site.
- Proton measurement at 10 MeV @RCNP, Osaka Univ.

J-PARC beam: pros & cons

- Higher energy: Lower cross-section.
- Vast number of protons: large fluorescence.



Electron beam 3 keV
Atmosphere gas 10^{-4} Pa (N_2)
Detector: Image intensifier

This Oct., we will see some results…

Summary

- 2-D beam image monitor using gas sheet is under developing with comprehensive strategy.
- **The gas-sheet monitor as a R&D application for the J-PARC LINAC beam was constructed.**
  - Improved gas-sheet generator was designed.
  - Ion detection technique, which was demonstrated in low energy test, was applied.
  - Vacuum system was carefully constructed based on the concept to obtain both high performances for monitor and accelerator.
- 2-D image of LINAC beam was observed by detecting ions.
- Developments towards the reliable beam image observation by photon detection is ongoing.