Modeling horn cooling water for fine neutrino flux estimation

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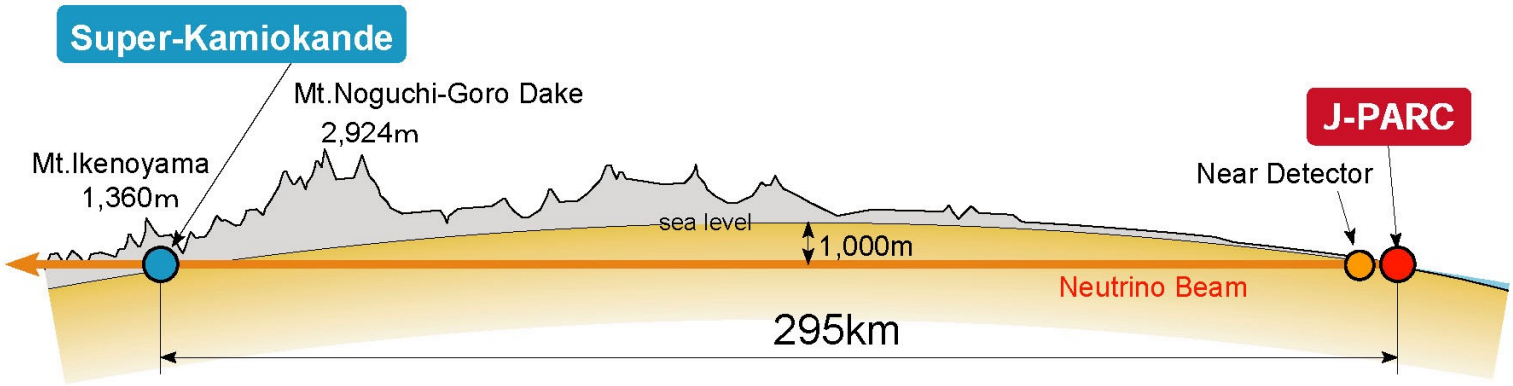
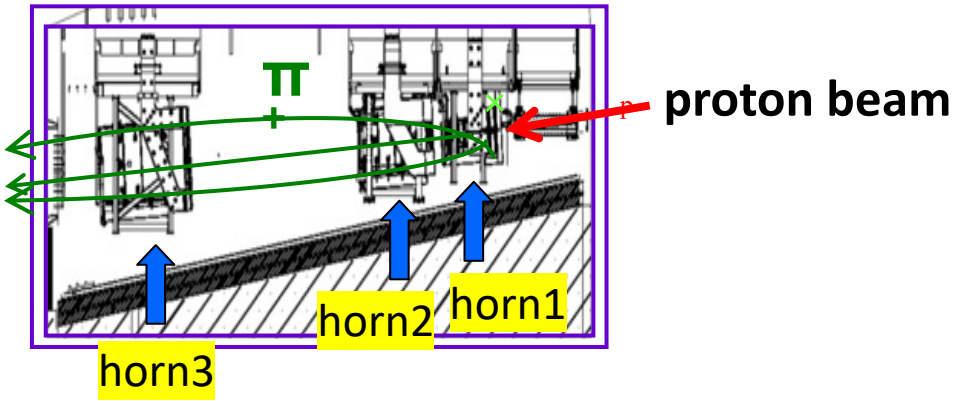
T2K : Long-baseline neutrino experiment

- Search for CP violation in lepton sector by precision measurement of neutrino oscillations.



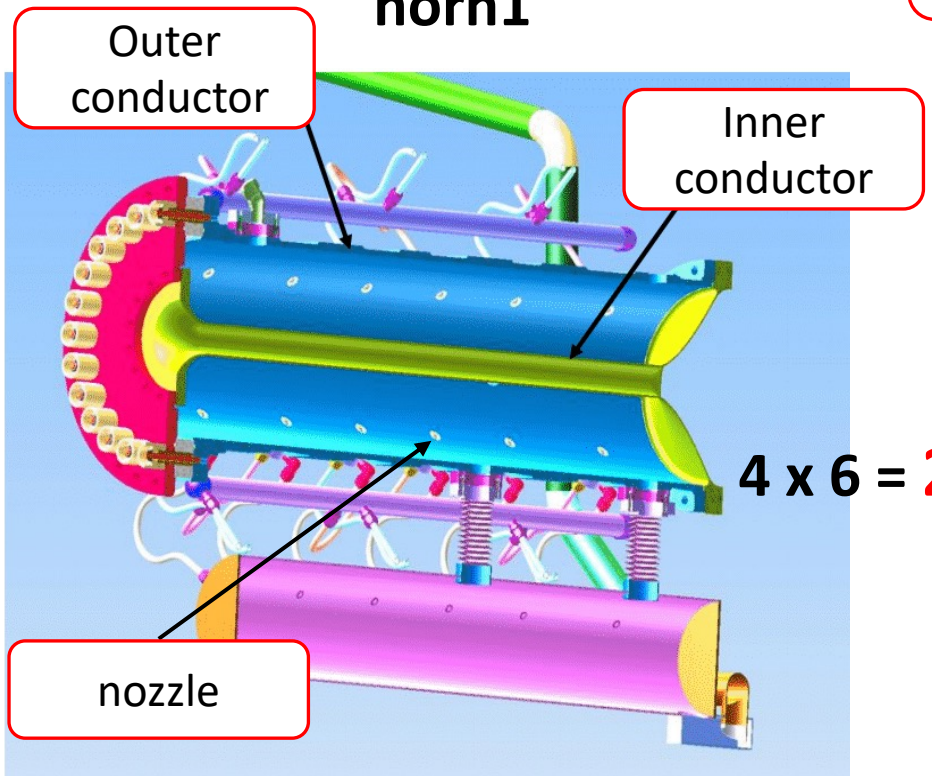
- **There are 3 horns in T2K beamline. (horn 1 - 3)**
- **Create toroidal magnetic field**
  → Pions are focused on the beam axis



Water cooling of J-PARC horn

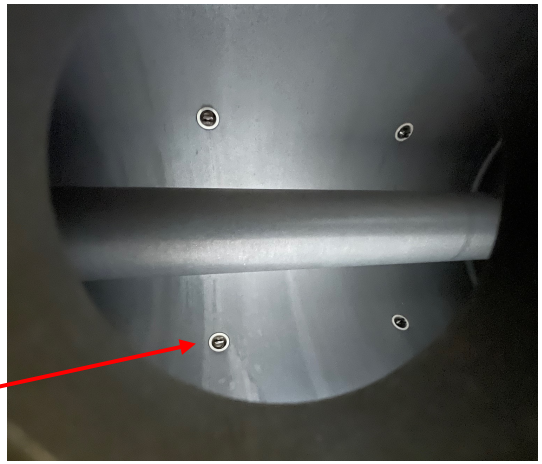
① Heat generated by secondary particles
② Joule heat due to high current (320kA)

horn1



4 x 6 = 24 nozzles

Cooled by water sprayed from attached nozzles

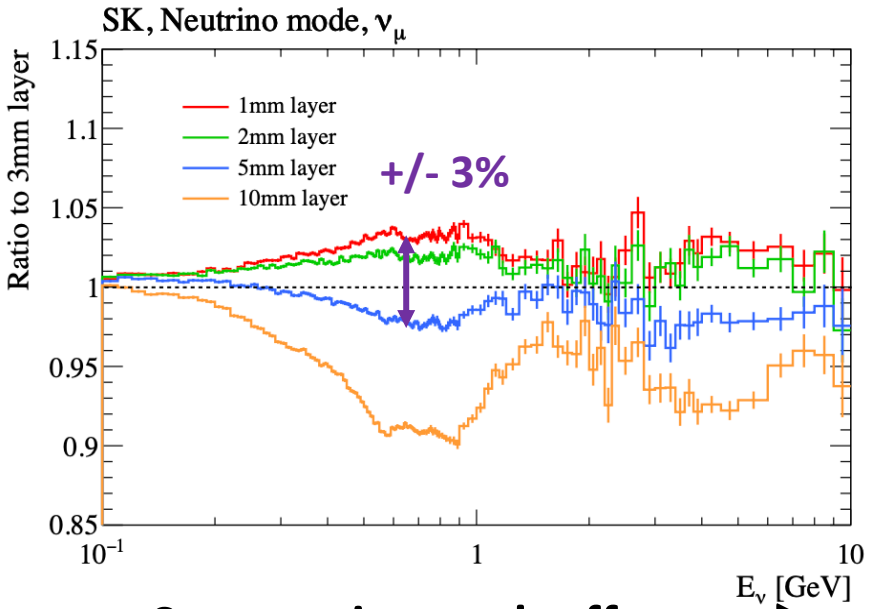


Inside the horn as seen from the viewport

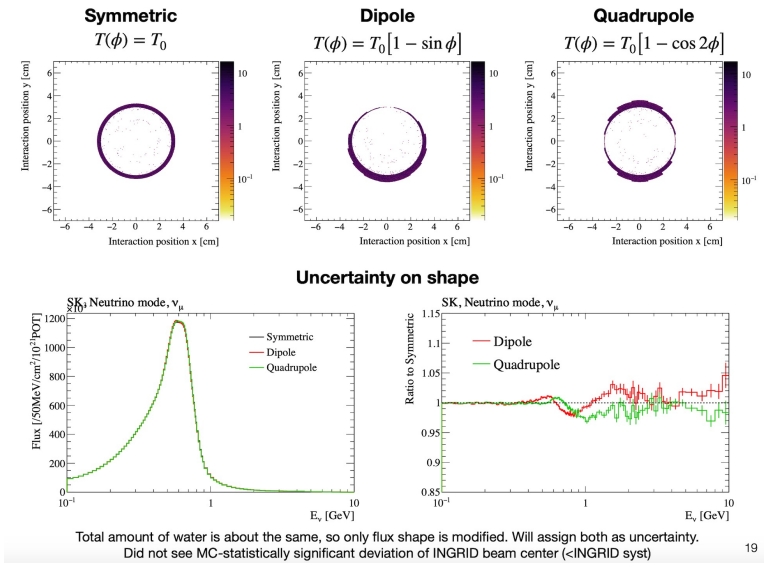
Effect of horn cooling water to neutrino flux

- The flux uncertainty due to horn CW is estimated about +/-3%.
- Based on flux simulation with water layer : 3+/-2mm
  - water parameters are varied conservatively.

Right-sign ν_μ



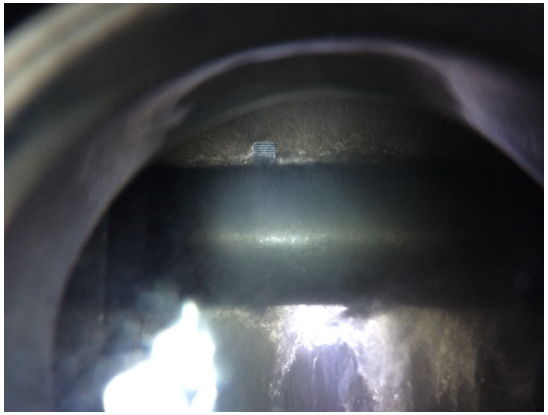
(By Lukas's study)



Symmetric error's effect **>** **Error from non-uniform water shape**

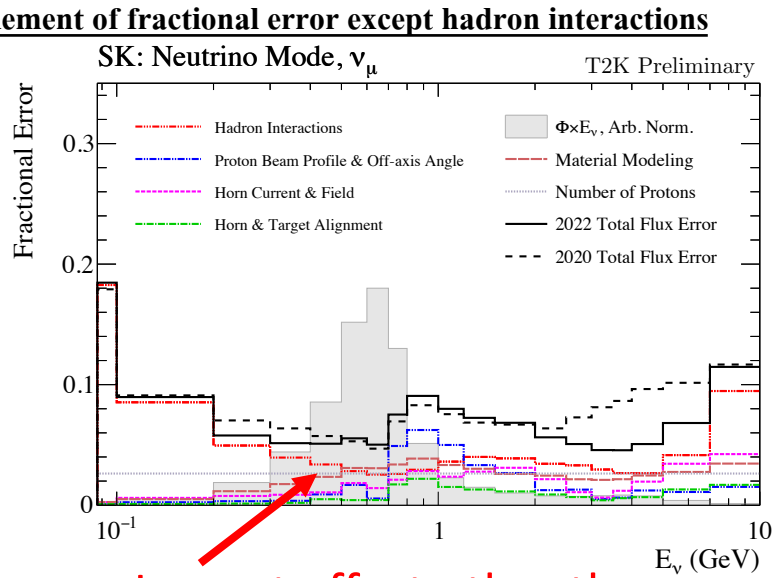
Motivation of this study

- For improving the precision of flux uncertainty, it is important to consider about the distribution of horn cooling water.



Limited observation only from the view port.

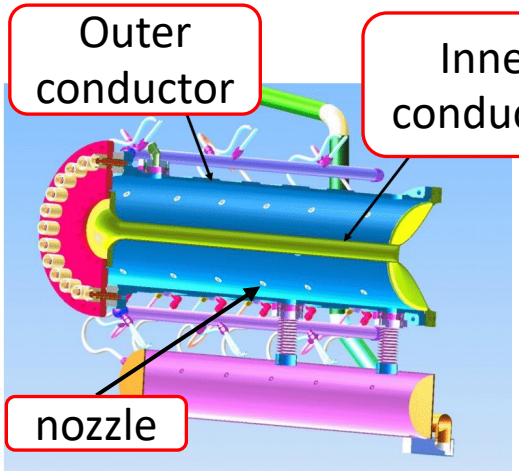
- I decided to make horn's mock-up and to estimate in detail about the water distribution.



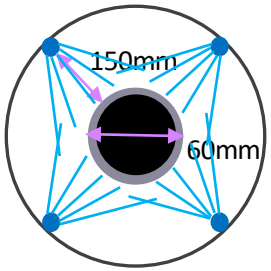
Largest effect other than hadron interactions

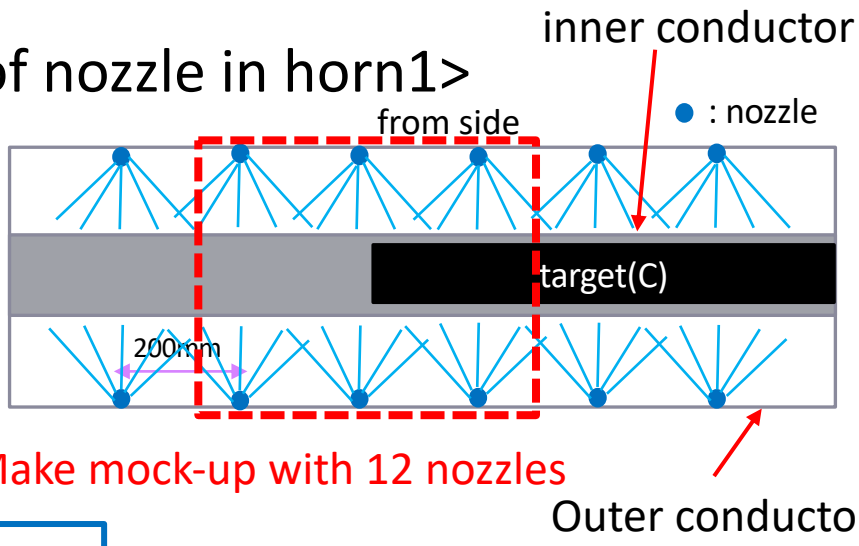
measured in NA61 / SHINE experiment

Overview of horn-1 water splaying mock-up



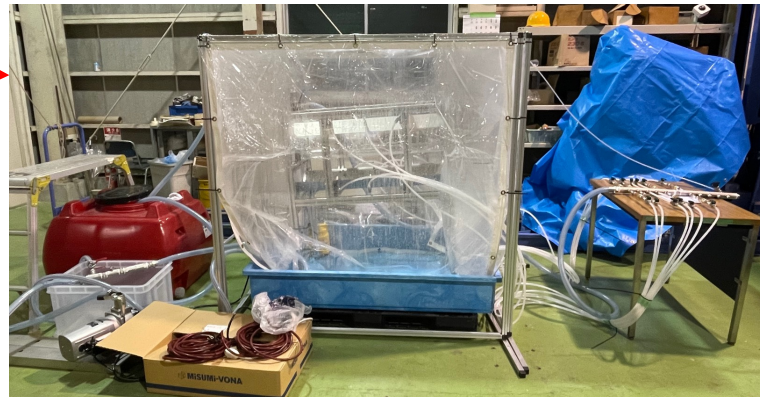
<The place of nozzle in horn1>





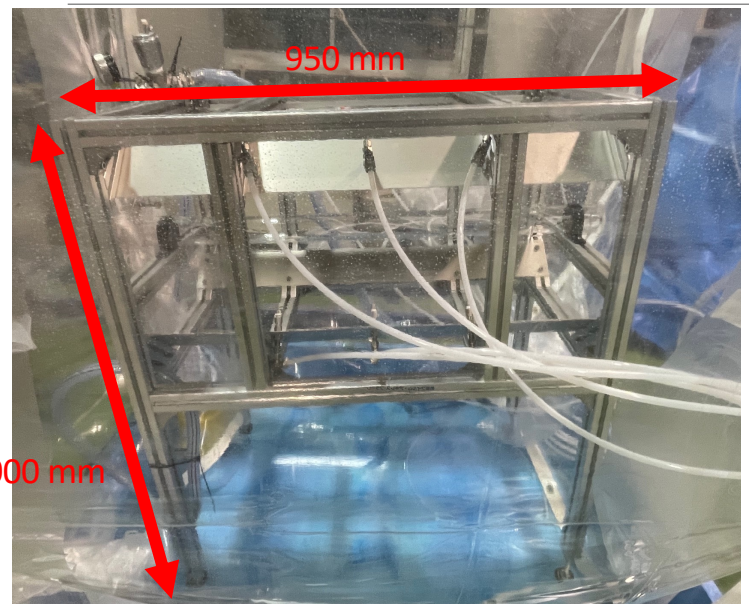
Make mock-up with 12 nozzles

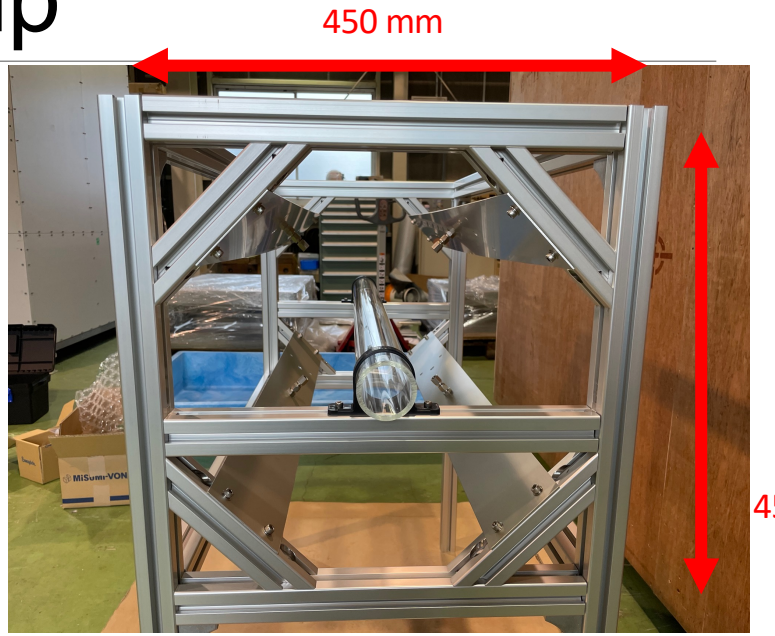
<Actual Horn>
Flow : 2.5L/min/nozzle
Pressure : 3 atmosphere
(in machine room / lifting height : 6.5m)

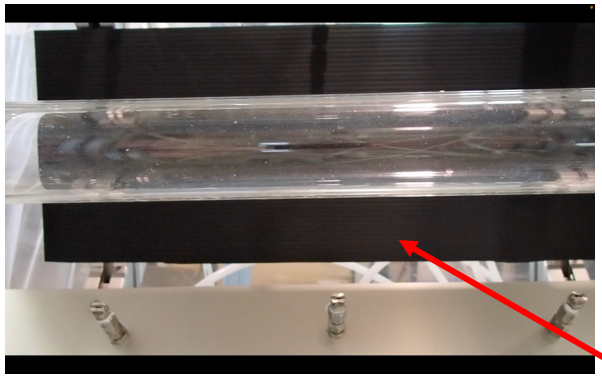


- Dummy inner conductor (acrylic pipe) and 12 water nozzles are located on aluminum structure.

Constructed mock-up

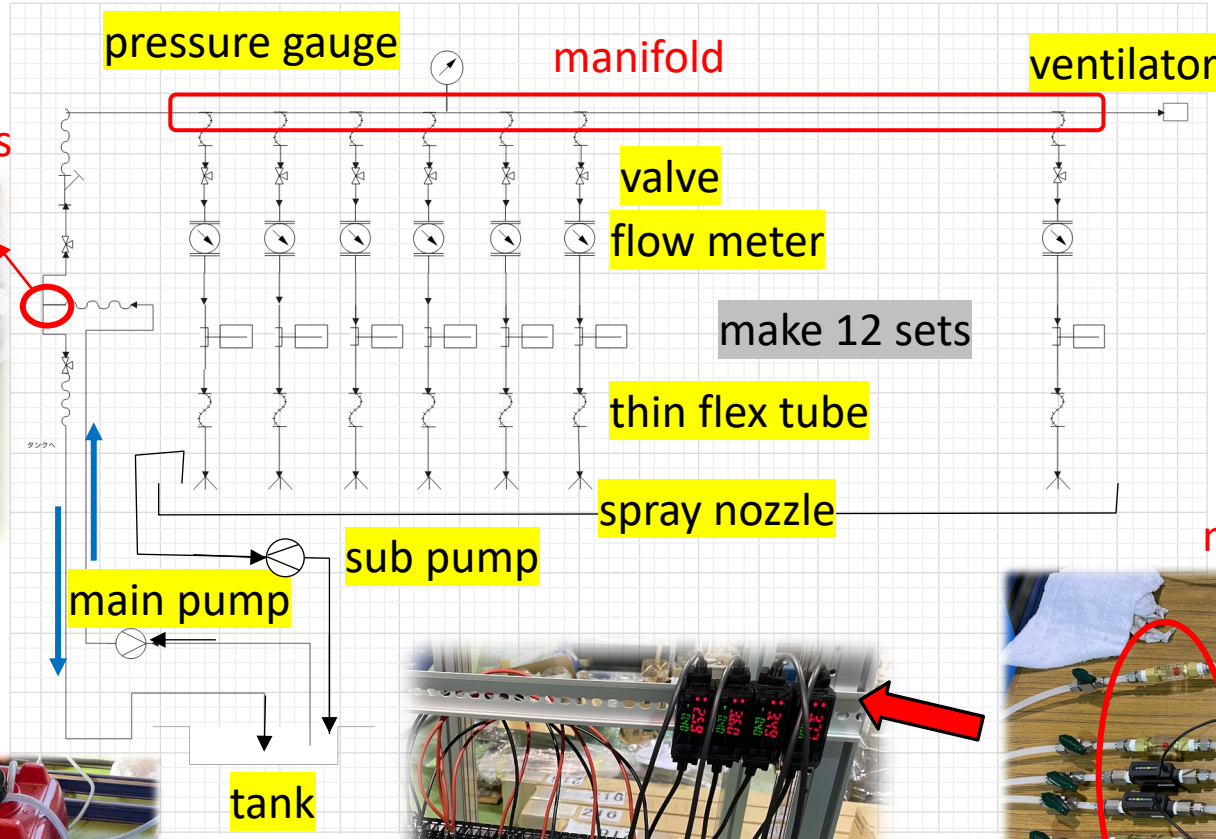






<points>
- Adjustable flow rate
- There are flowmeters for each nozzles.
- Tilted about 3.64 degrees (same as real horn)
- Put black cardboard behind to improve contrast.

Mock-up cooling water system diagram



adjust flow using a bypass

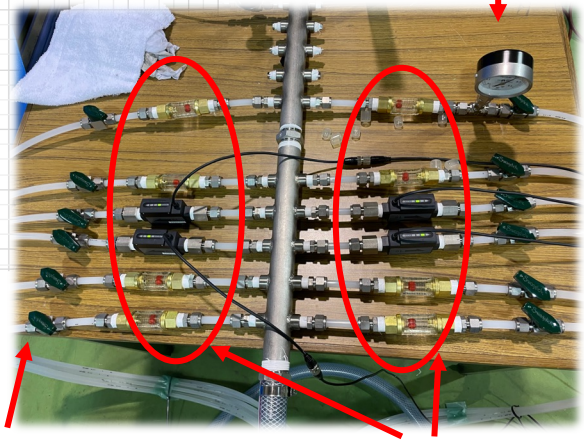
tank

pump

4 digital flow meter

pressure gauge

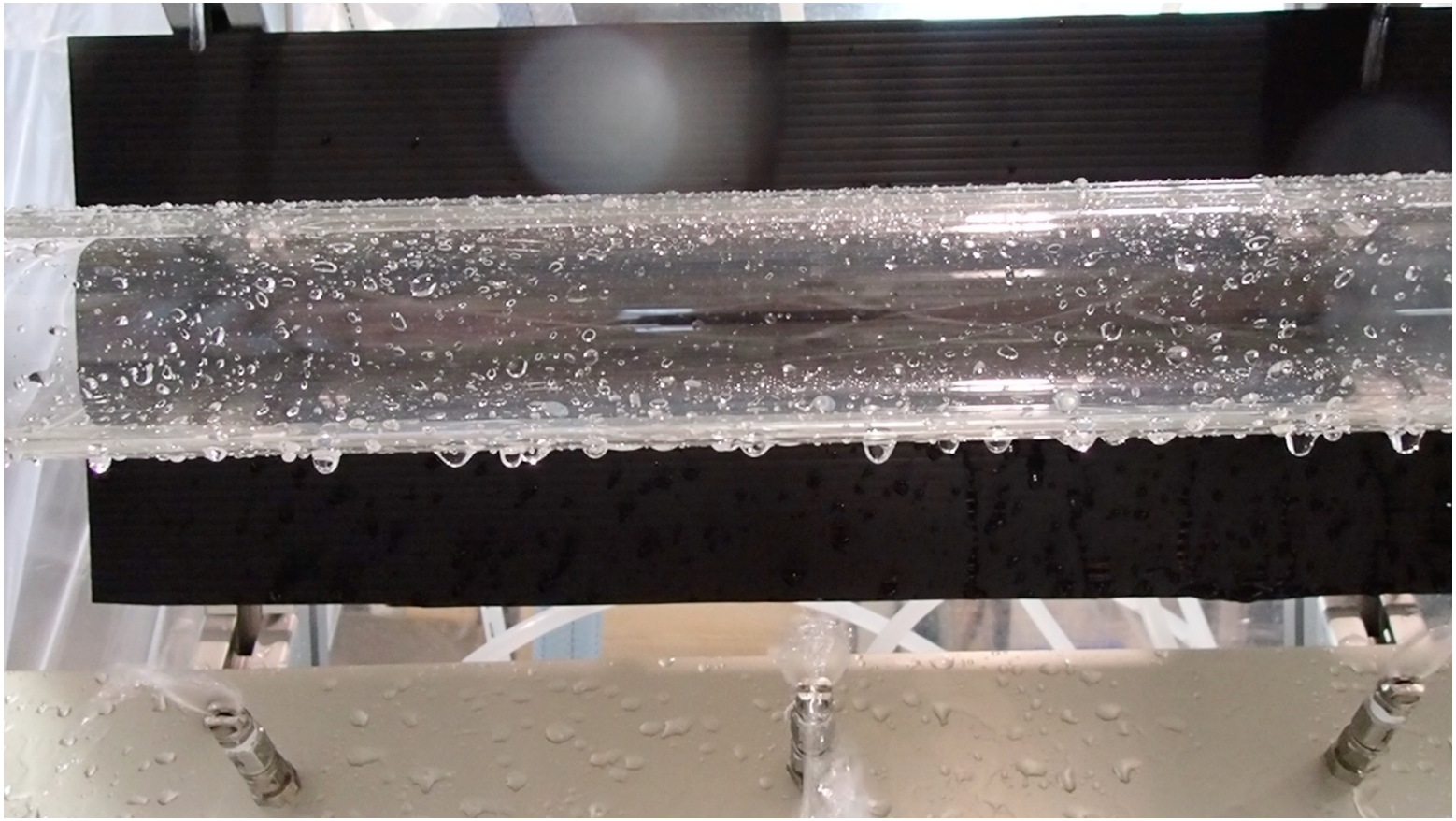
manifold



valve

Flowmeters

Water behavior observed in the mock-up

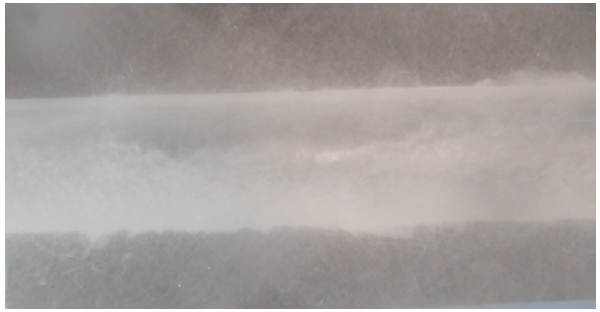


It is necessary to model the water distribution although its shape fluctuates constantly.

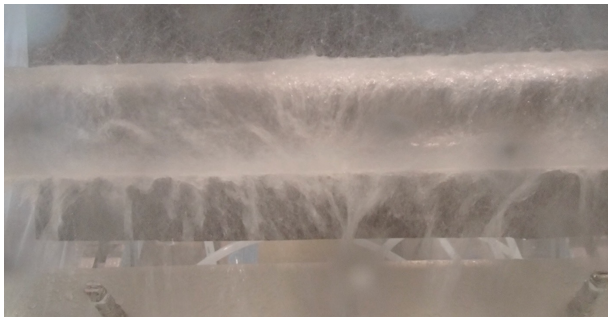
Location of cameras

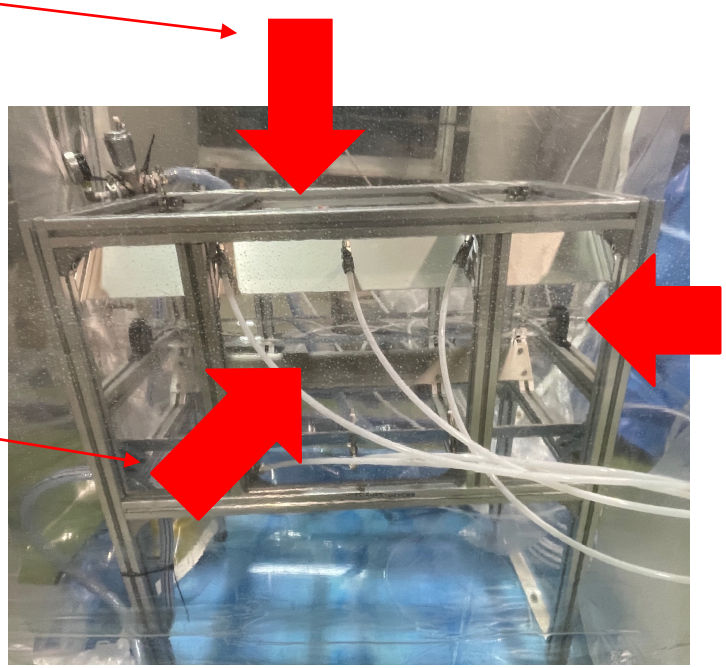
Shooting a video
→ Extracting images from the video

from top



from side



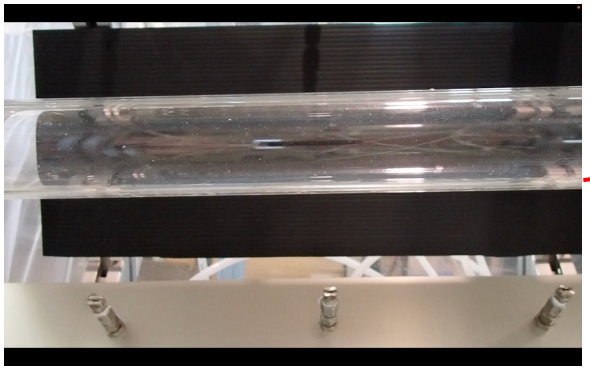


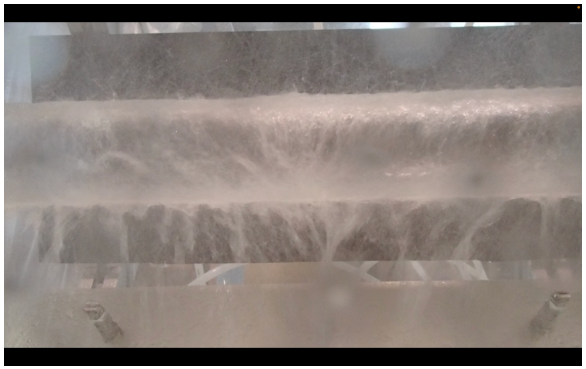
from front(beam axis)

Pictures from up and side are used for image analysis.
Pictures from front is not clear.

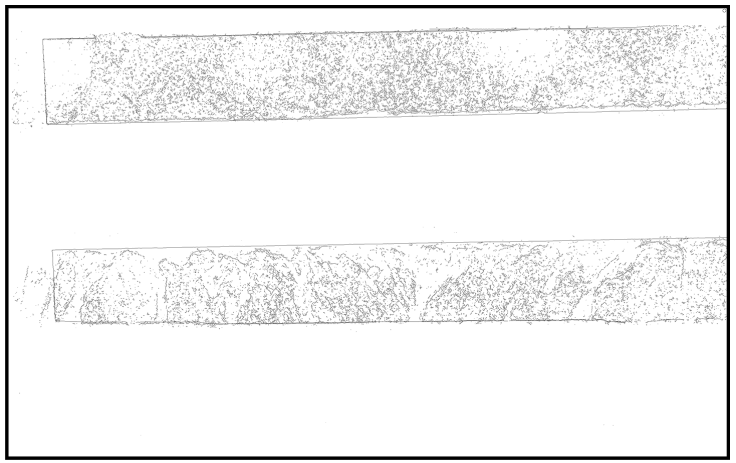
Image analysis method

- **Canny method** : Detect and dot the edges of the image (areas of strong color change).
- Overlay images with and without water flow.





Overlay



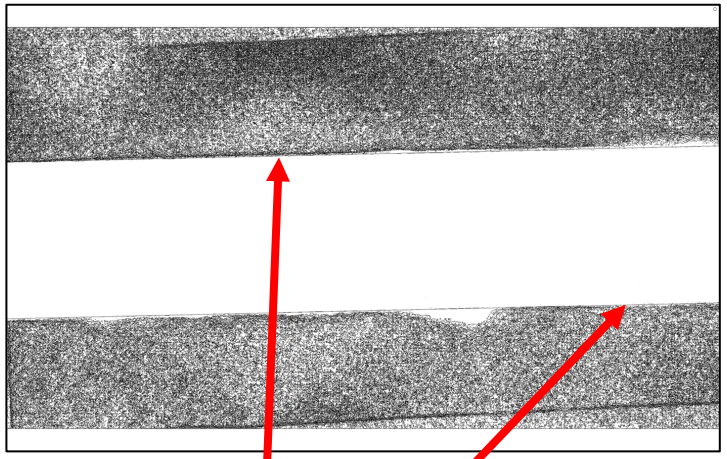
Flow : About **2.5 L/min/nozzle**
Pressure : About 1 atm.

<Actual Horn>
Flow : 2.5L/min/nozzle
Pressure : 3 atmosphere
(in machine room)

Result

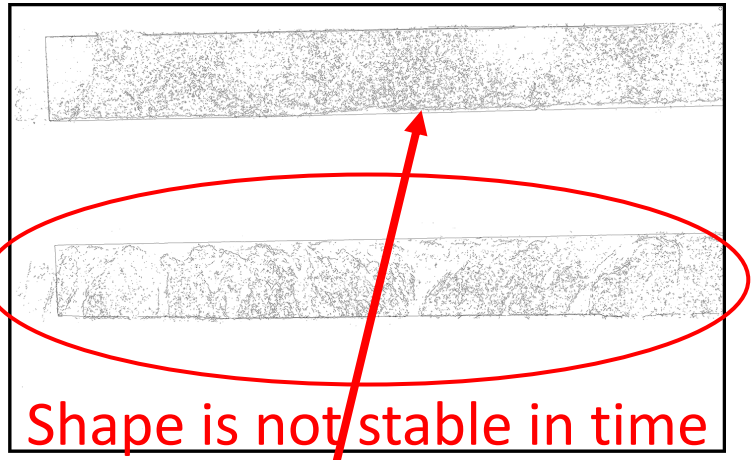
Flow : About 2.5L/min
Pressure : About 1 atm.

from top overlapping 5 images



about 1.0~3.5 mm

from side



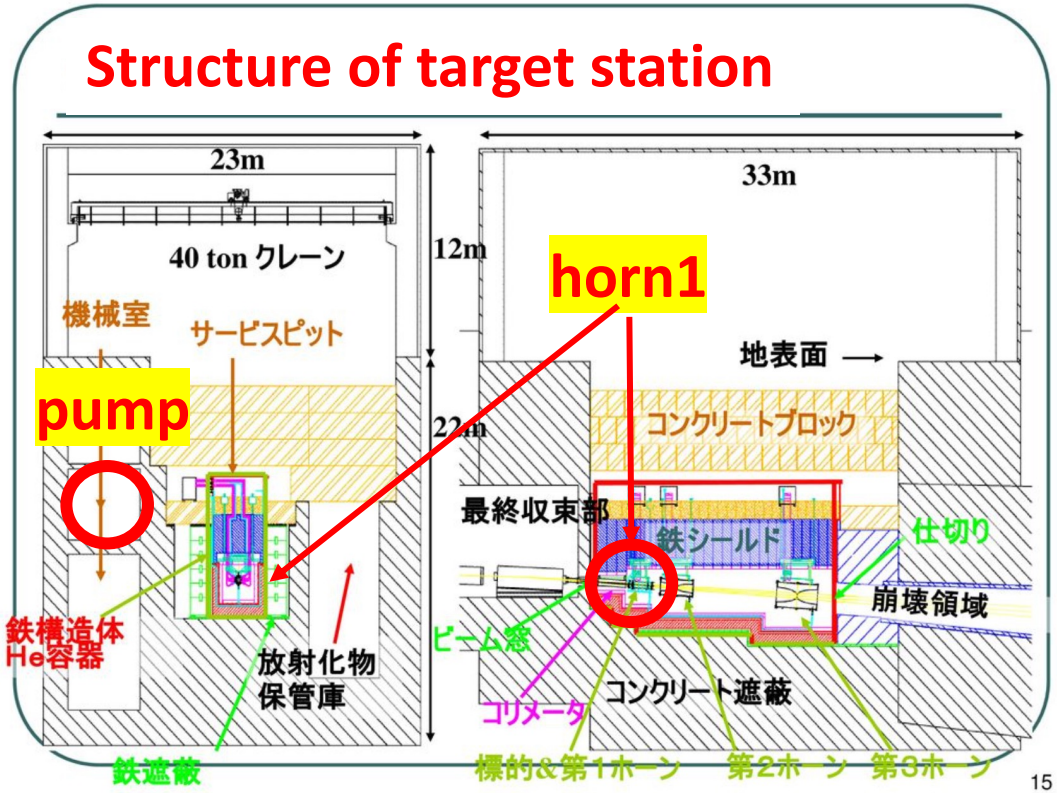
about 1.5~4.0 mm

The thickness of the water was measured using the thickness of the pipe as a reference (6 cm).

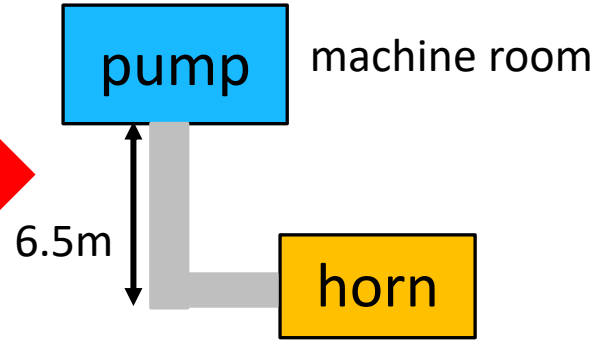
Water thickness : Almost same as current thickness used in the simulation (3 +/- 2 mm).
We should consider about the bottom side water.

To be improved in this study

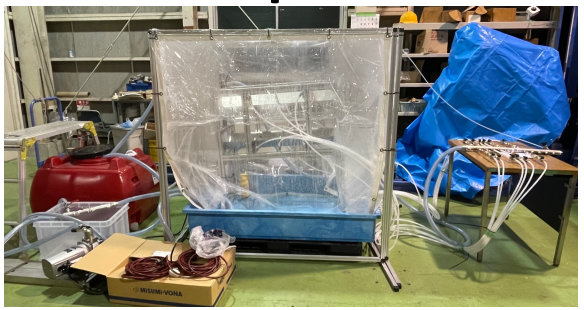
① Adjustment of water flow and pressure



<Actual horn>



<Mock-up>



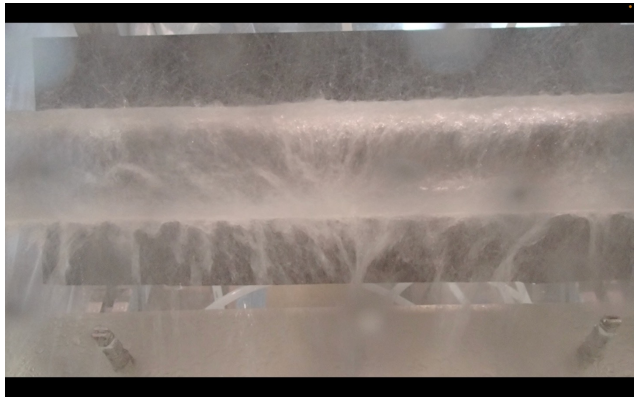
lifting height : 0m

The lifting height is different

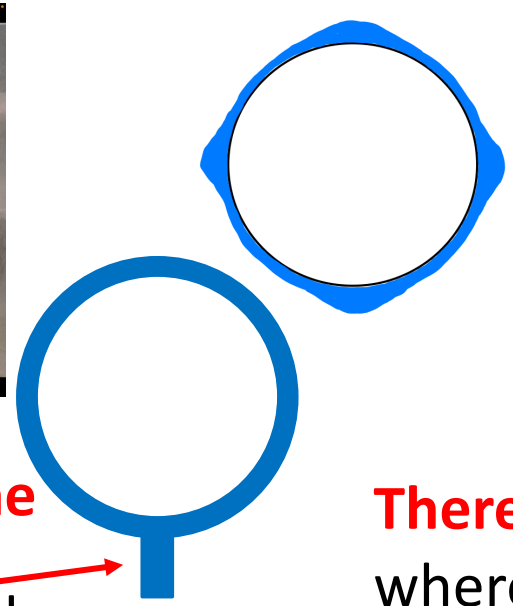
→ Pressure condition should be adjusted in mock-up

To be improved in this study

② Treatment of bottom-side water

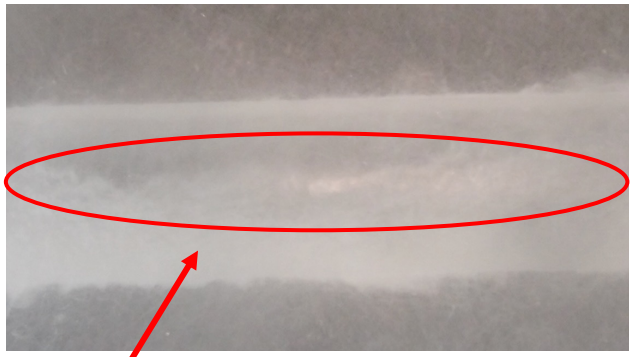


Shape is not stable in time



Approximate to rectangle

③ Treatment of the characteristic shape



There is a line-shape structure where the water spray from two nozzles are overlapping.

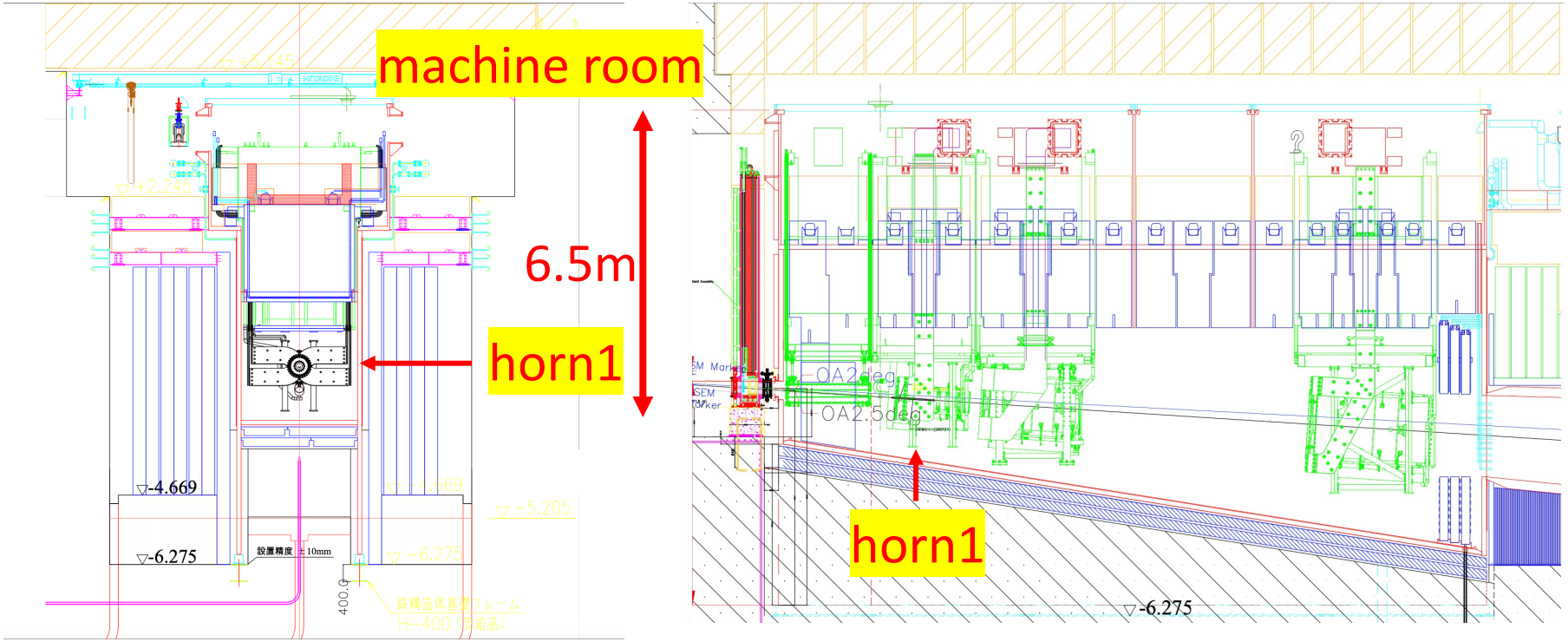
evaluate errors using simulation

Summary

- For improving the precision of flux uncertainty, we have made the horn-1 mock-up to observe cooling water behavior inside horn.
- In the mock-up test, we have established the method to evaluate water layer of inner conductor by image analysis (canny method).
  - The water thickness (image analysis results) : 1.0 ~ 4.0 mm
  - this is almost same as current expected value (expected from the observation via viewport).
- We have some improve points.
  - Adjustment of pressure condition
  - Treatment of complicated water shape

Back up

The place of horn1 in the target station



the detail of water layer

	Horn 1 cooling water layer	
	Nominal	**Uncertainty**
Old (13a)	0 mm	±(1mm – 0mm)
New (21a)	3 mm	±2mm ±(dipole – symm) ±(quadrupole – symm)