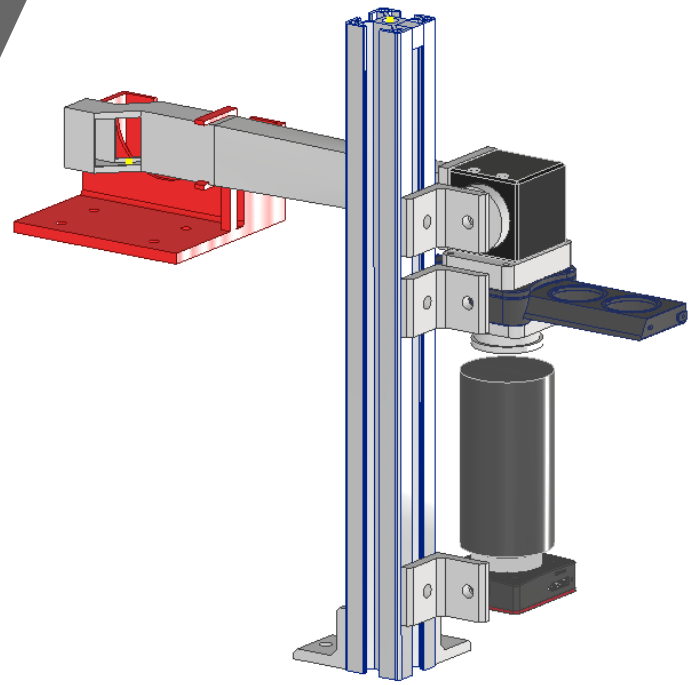
OTR as possible detector for high intensity electron beam profile of T2K's MUMON-EMT test at ELPH



22.02.2023 29. ICEPP Symposium

Oderich Ferdinand Auersperg-Castell
University of Vienna

Exchange semester at
High Energy Physics Tohoku (Tohoku U)

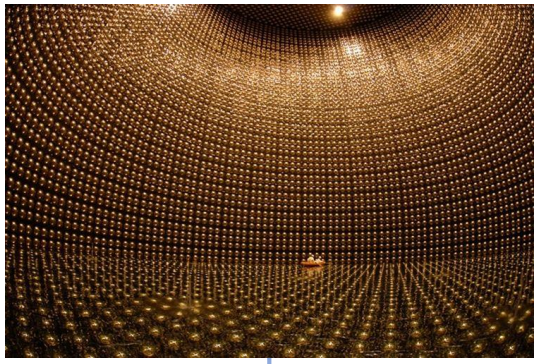
TOHOKU UNIVERSITY

- From **Austria**
- At end of **Physics Master** at **University of Vienna**

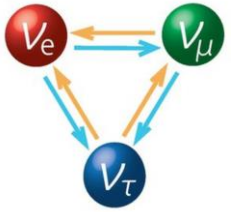
- Exchange semester at **Tohoku University** (winter semester 2022/23)
- At **High Energy Physics Group Tohoku (HEP Tohoku)**
  - Led by **Prof. Atsuko Ichikawa** (Spokesperson of **T2K** for last 4 years)
  - Part of **T2K** Collaboration
  - Other Projects: **HyperK**, **ILC**,
    Search for **Neutrinoless Double Beta Decay** with **AXEL**

T2K

T2K experiment



TOHOKU UNIVERSITY



Super-Kamiokande

Near Detectors

J-PARC

MUMON

Mt. Noguchi-Goro
2,924 m

Mt. Ikeno-Yama
1,360 m

1,700 m below sea level

Neutrino Beam

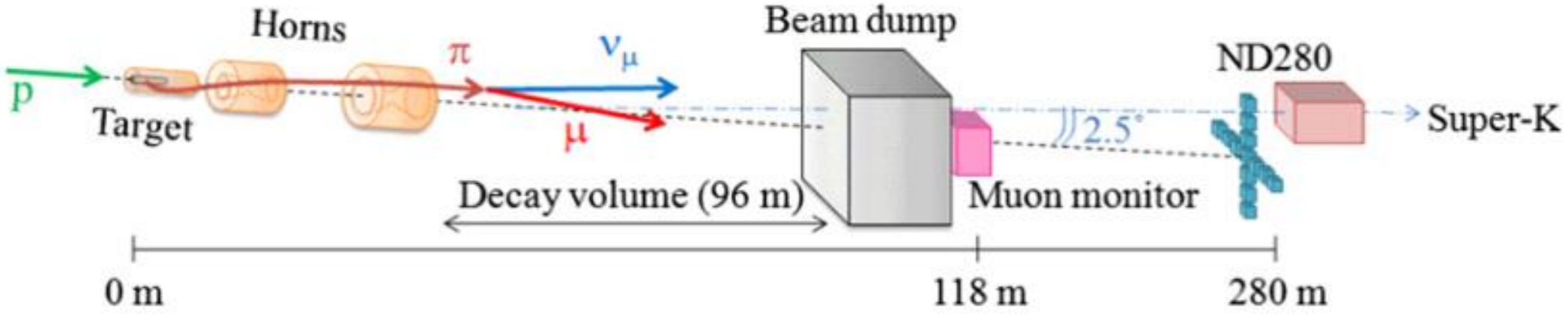
Kamioka

Tokai

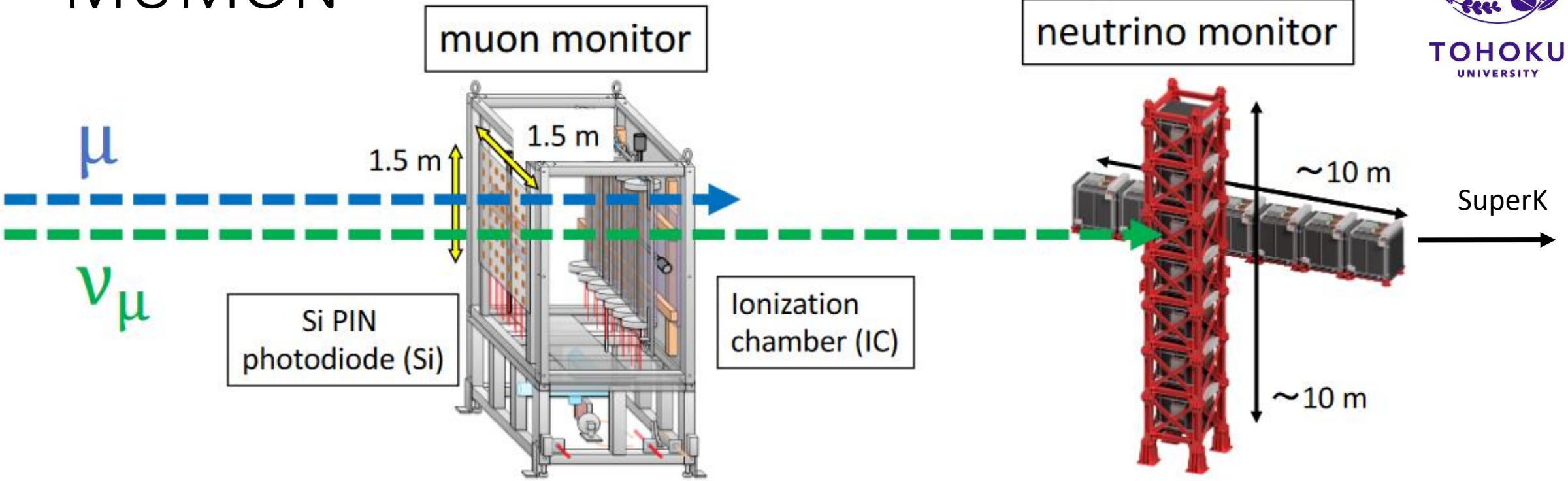
295 km

MUMON

- **MU**on **MON**itor → measures muons that are produced alongside neutrinos
- Located 118m downstream from the target,
- Used to determine the **neutrino beam direction**



MUMON



Monitor muons in **real time**.
Indispensable monitor to **reduce beam loss**
Si is main sensor for monitor.
IC is for cross-check and backup.

Scintillator and Iron plates.
It takes about 1 day to see the profile.

MUMON

150x150cm detector area

Primary sensor array
7x7 Si PIN Photodiodes
→ Half of them have to be replaced every ~100 days due to radiation damage

Secondary sensor array
7x7 Ionisation chambers

Proton beam upgrade and EMT

EMT sensor

Proton intensity will be **upgraded**

This will increase the **muon (and neutrino) flux**

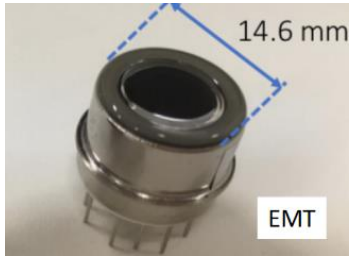
→ from 1.5 x 10^6 muons/cm^2/s to
4.2 x 10^6 muons/cm^2/s

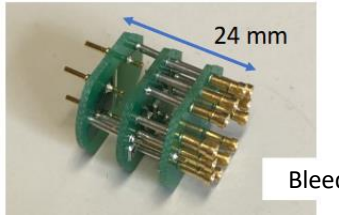
Si PIN Photodiodes will need to be replaced after a month! → new kind of MUMON sensor needed!

with

- High radiation tolerance!
- Real time measurement

EMT – Electron Multiplier Tube
- Same as PMT, but with aluminium cathode instead of photocathode
- Expected to be more radiation tolerant!
- Currently tested outside of J-PARC
- Tested in MUMON during next beam time





EMT performance test at ELPH

Why 4th MUMON-EMT test?

- evaluate **degradation of aluminium cathode**
- To evaluate **degradation of the bleeder circuit**
- Temperature Dependence

Where?

- At **90 MeV electron linear accelerator** of **ELPH** (Tohoku U) in Sendai

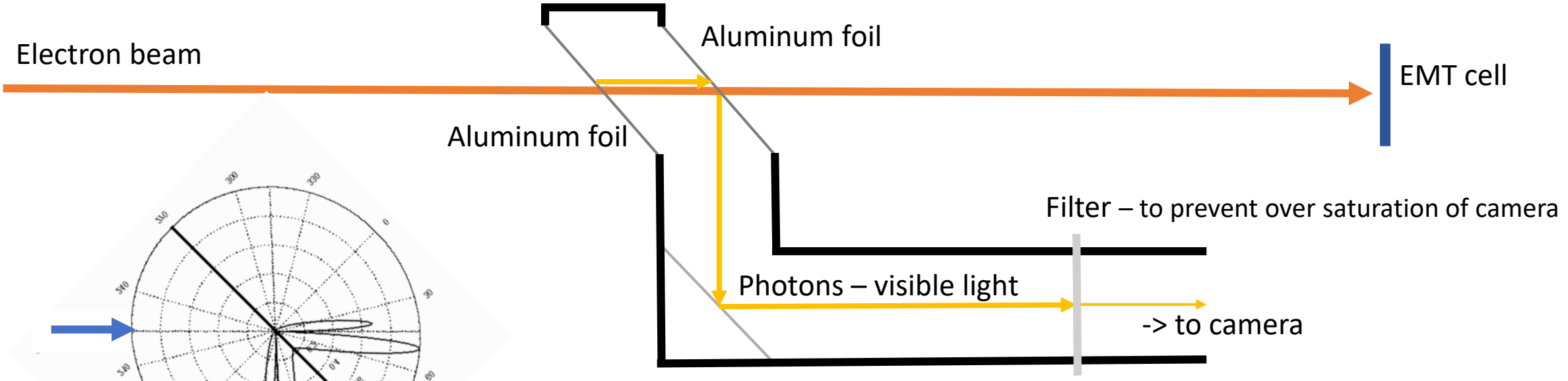
at ELPH

How?

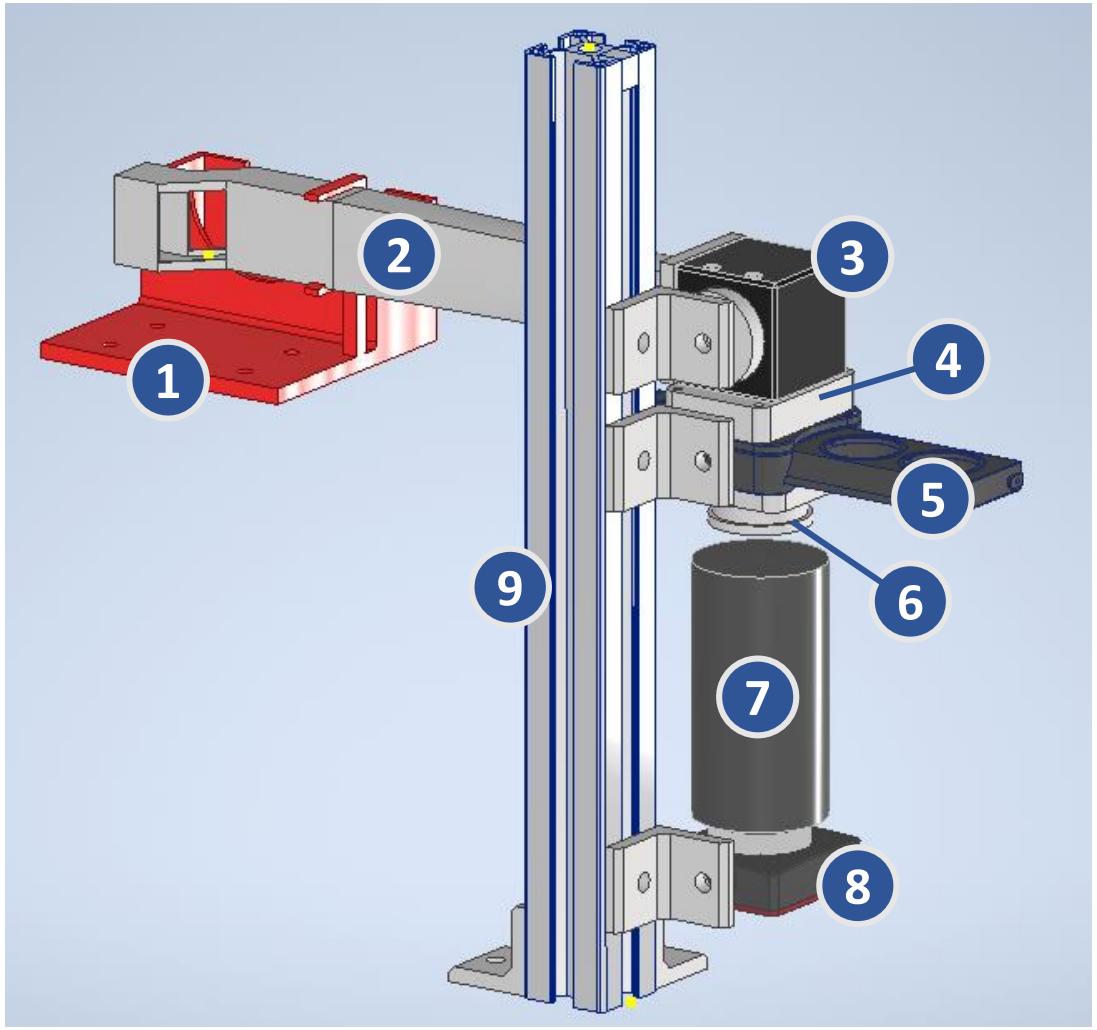
- Low intensity **7pA** (7Hz, 1pC/pulse) electron beam to check the EMT signal
- **High intensity 140nA** (7Hz, 20nC/pulse) electron beam to test EMT‘s **radiation tolerance**
  - EMT cell is moved through electron beam to irradiate it evenly
  - → a detector is needed for the test that can be used for beam monitoring during high intensity → **OTR**

OTR detector– General concept

- **Optical Transition Radiation** - When charged particles (like electrons) pass through the boundary between two media with different electrical properties photons are emitted.



OTR Development



* In house 3D print

#	Component	Description
1	CT holder*	Also supports OTR tube
2	OTR tube* + Foil Top* + Cross Top*	Light tight connection between beamline and mirror
3	Mirror	Thorlabs CCM1-E02/M, 45°
4	Adapter*	Between Mirror and Filter slider
5	Filter Slider	Thorlabs CFS1 Filter Mount
6	Black Sheet holder*	Close gap with black sheet
7	Lens	Ricoh FL-BC7528-9M - F2.8/75mm
8	Camera	Thorlabs CS165MU/M
9	Aluminium Frame	25cm, 30x30mm

OTR - Foil top and Cross top

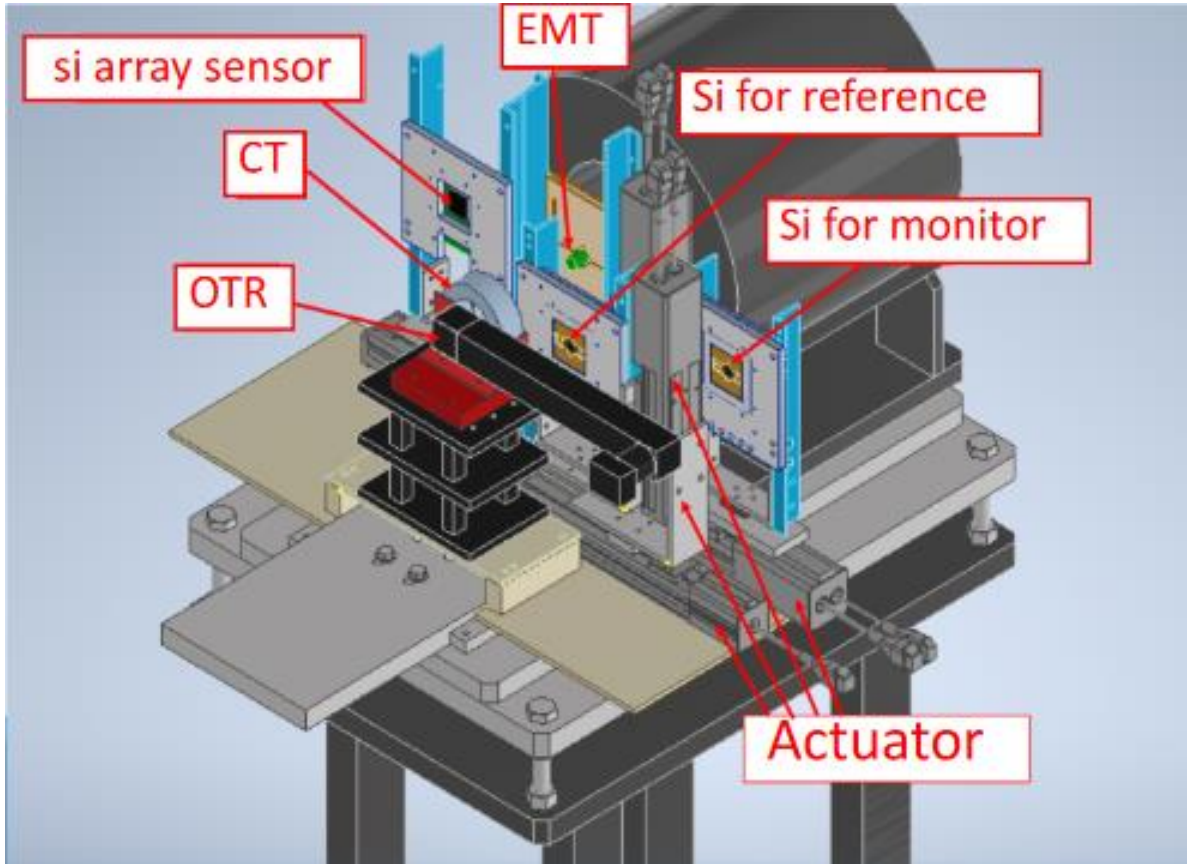
OTR tube

OTR Foil Top

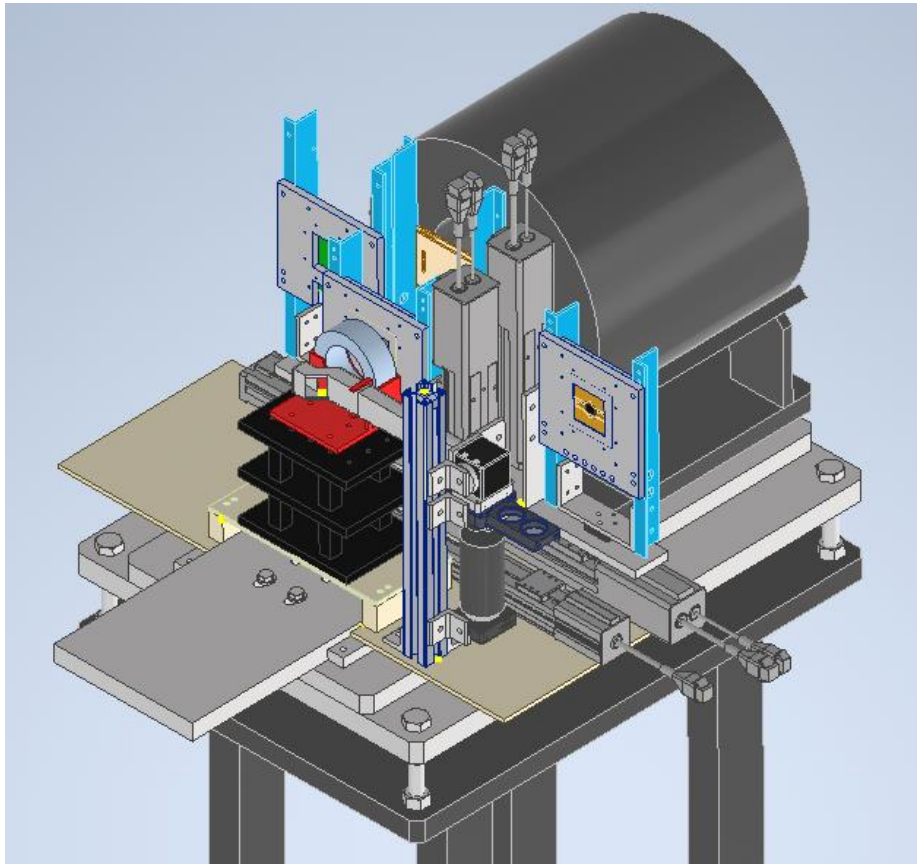
OTR Cross Top

- 2 Foil Tops -> prepare new foils while measurement is running
- To be able to do focussing calibration of camera fast
  -> just change the Top

OTR Implementation

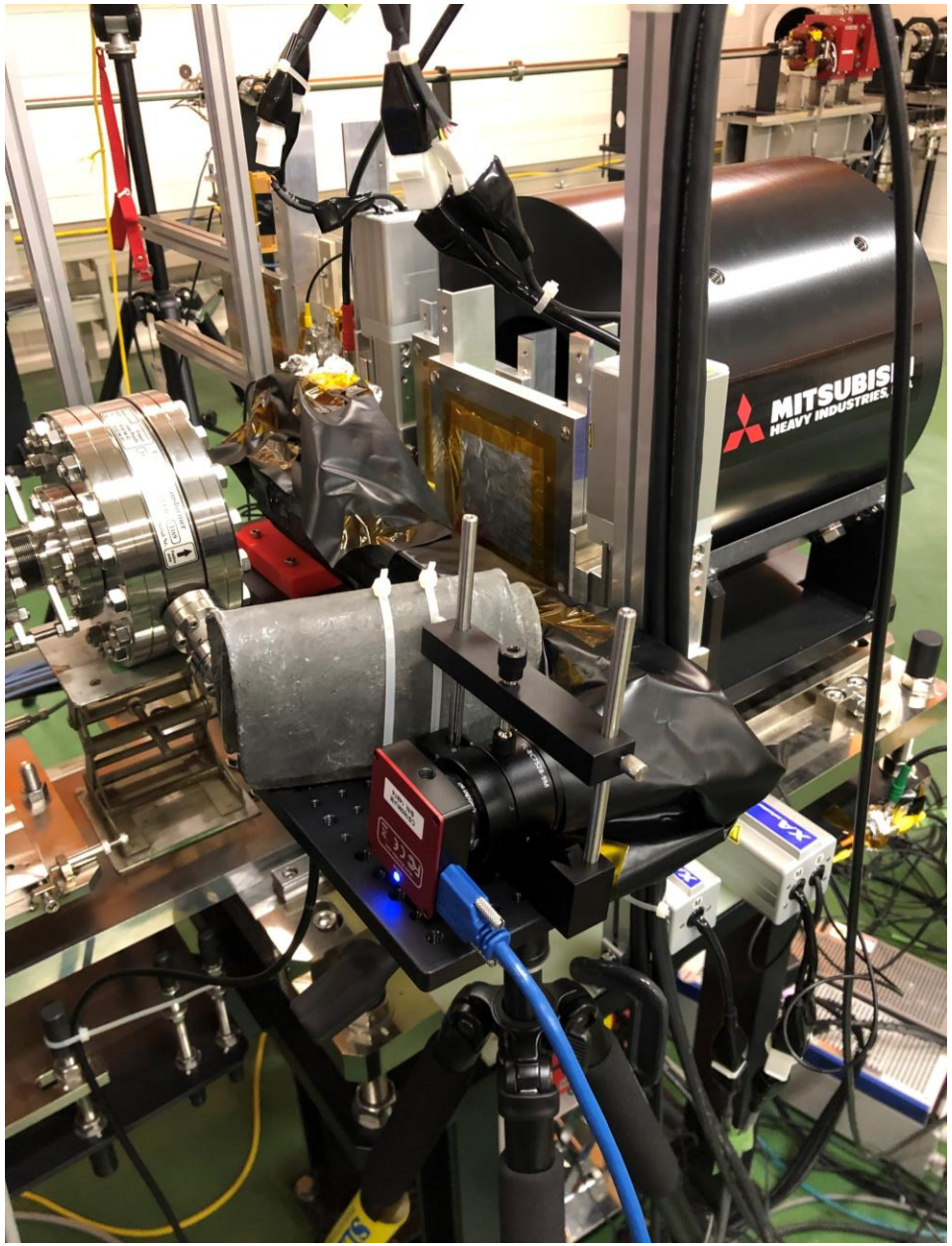


3rd MUMON-EMT test **Nov. 2021**
With simple former OTR setup



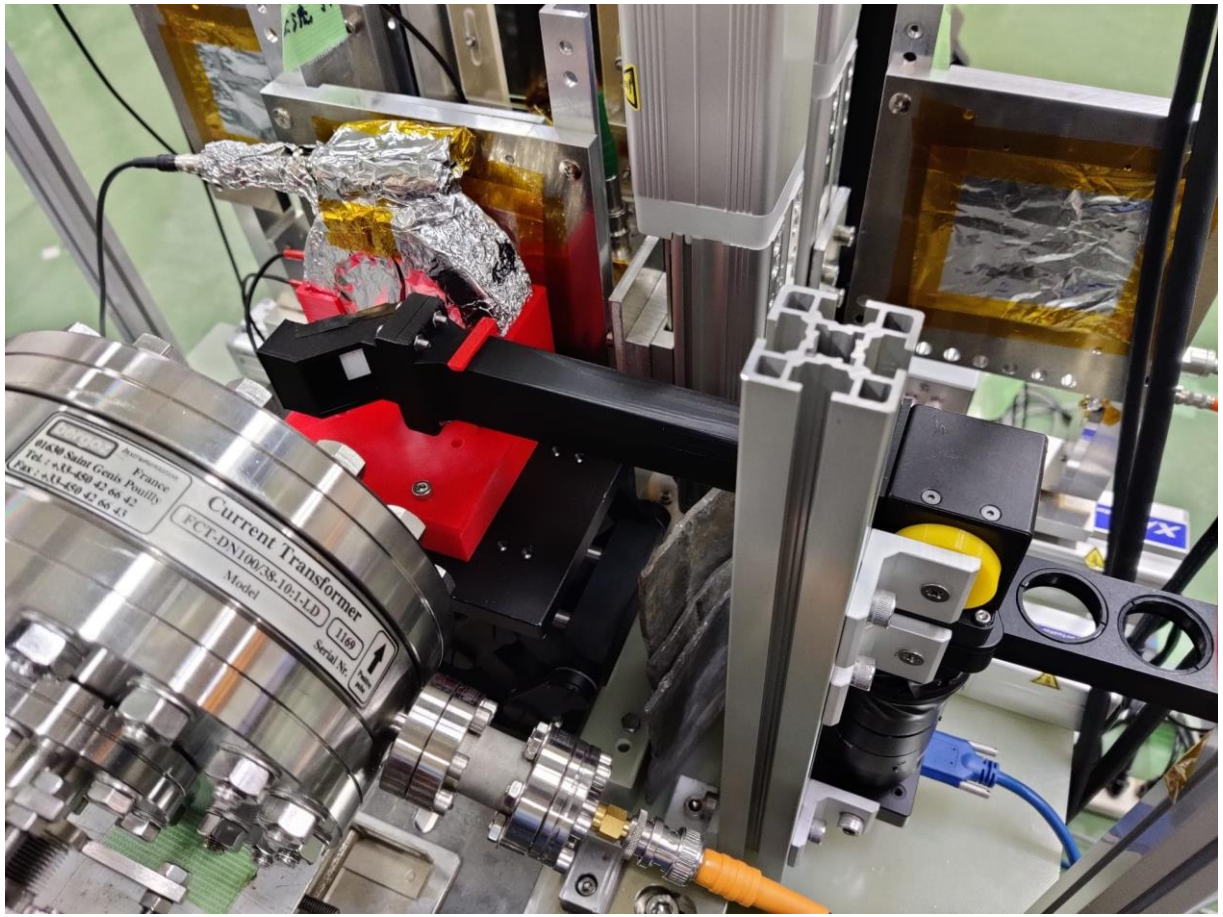
4th MUMON-EMT test **Nov. 2022**
With advanced OTR setup

OTR EXECUTION - Implementation at **ELPH**



3rd MUMON-EMT test

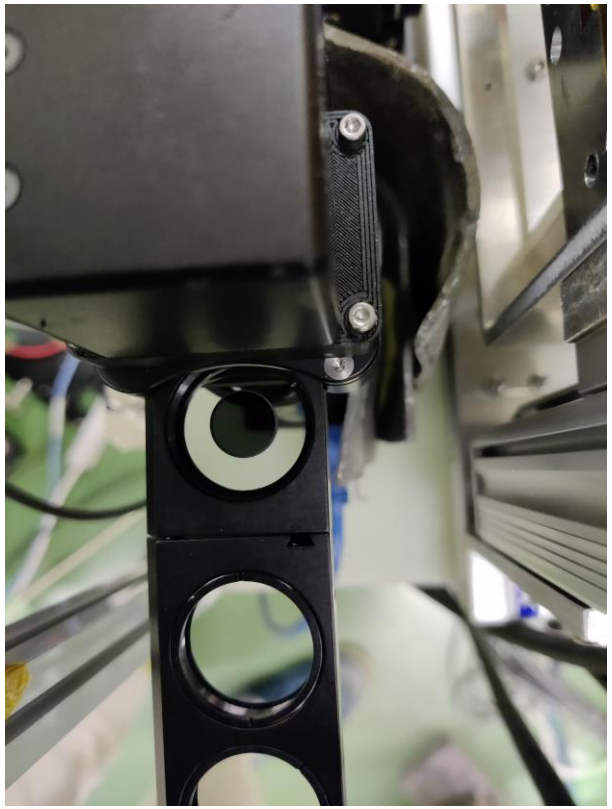
4th MUMON-EMT test



OTR Execution - Intensity adjustment

Neutral density filters:

- 2x ND-2 (50% Transmission)
- ND-4 (25% Tranmission)
- ND-10 (10% Transmission)

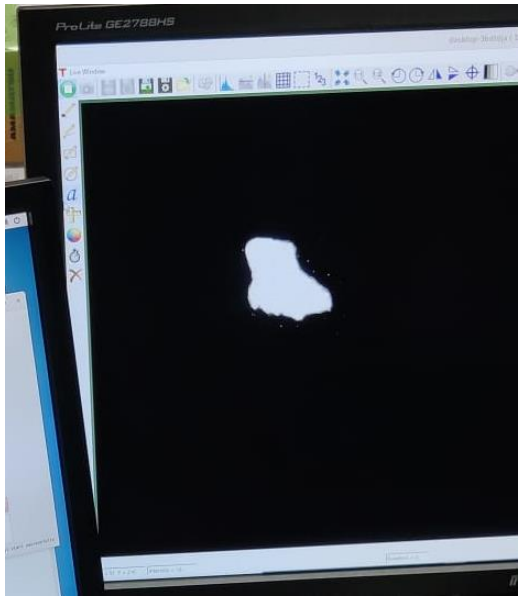


- ND-2 (transparent, fits into the filter slider Insert) filter and
- ND-10 (smaller, dark) filter

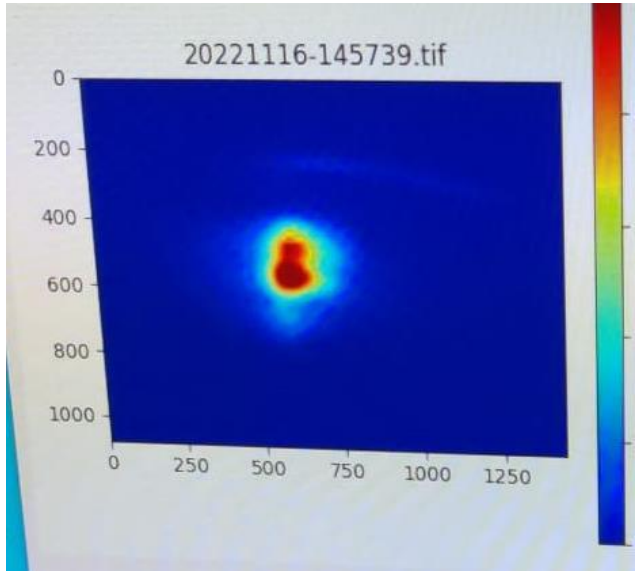
- ND-2 (lower, black) filter and
- ND-4 (upper, silver) filter

OTR Execution - Data taking

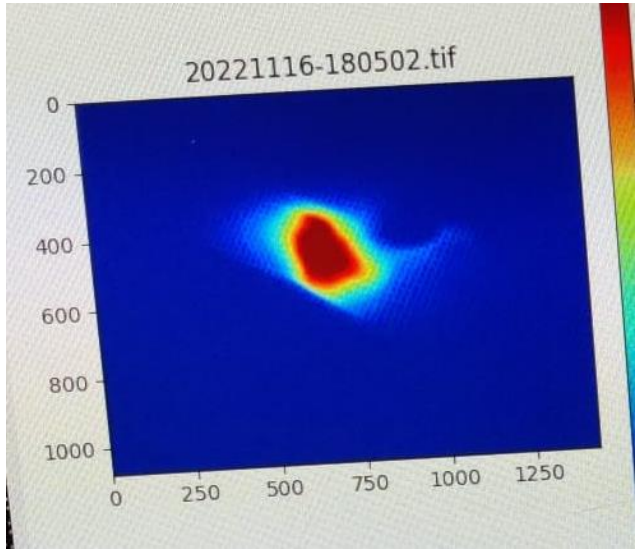
15.11.2022
2 foils



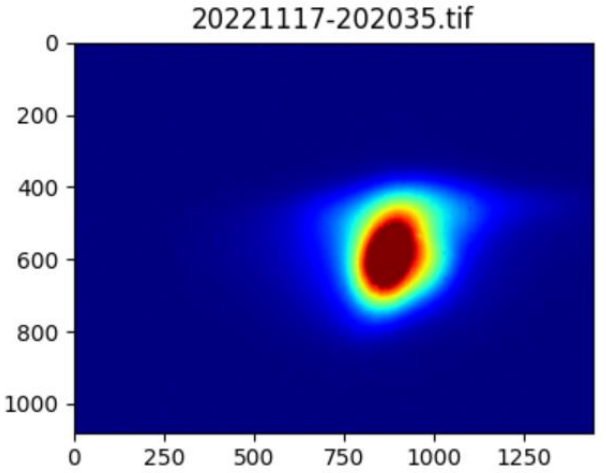
16.11.2022
2 foils



16.11.2022
2 foils

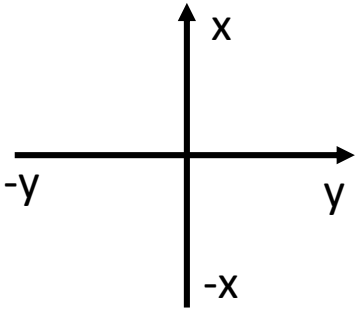


17.11.2022
1 foil

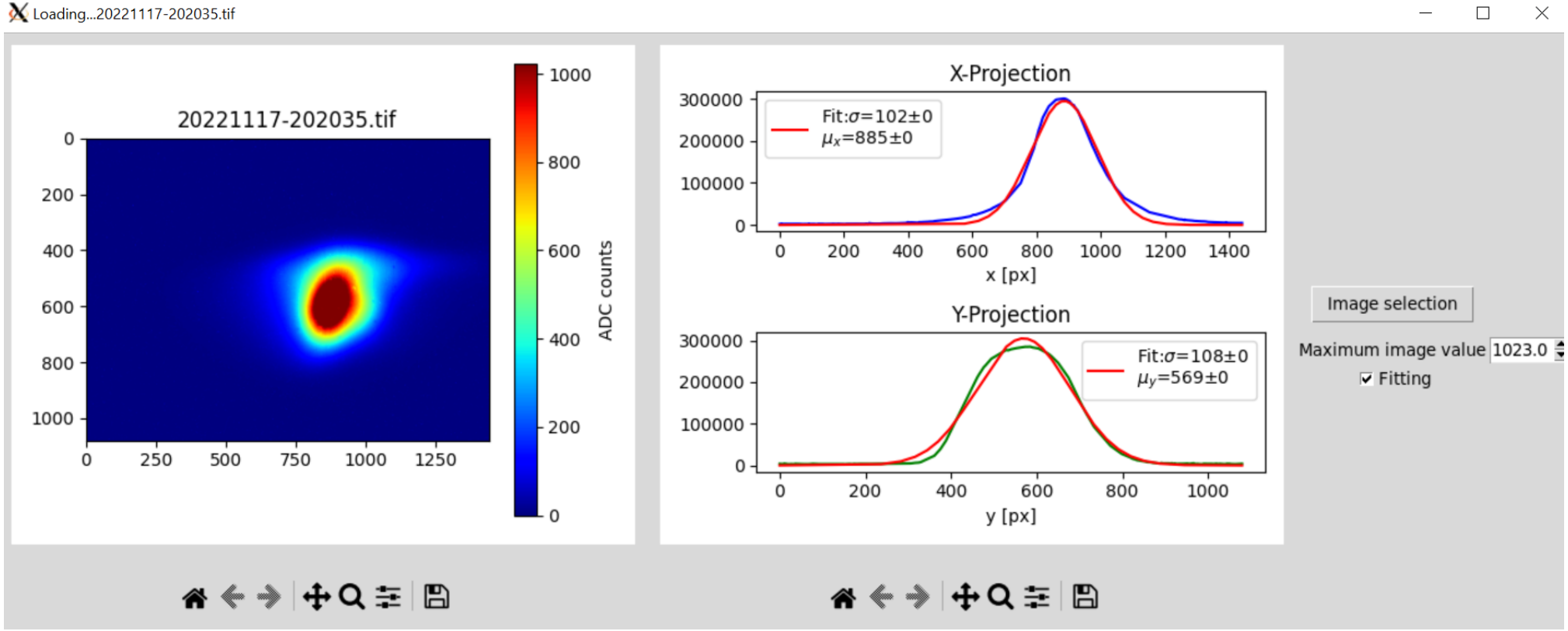


- **High intensity beam**
- All filters used except in first case (no ND-10)
- On 15. and 16.11.2023 OTR with 2 foils
- On 17. OTR with 1 foil.

Beam coordinates in the OTR pictures:



OTR Execution – **Results and Evaluation**



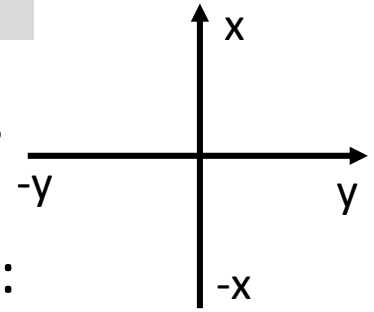
Readout Values:

- X-Axis: $\boldsymbol{\sigma_x = 102\ pixels}$
- Y-Axis: $\boldsymbol{\sigma_y = 108\ pixels}$

Camera resolution:

- Camera X-Axis: **1440 pixels**
- Camera Y-Axis: **1080 pixels**

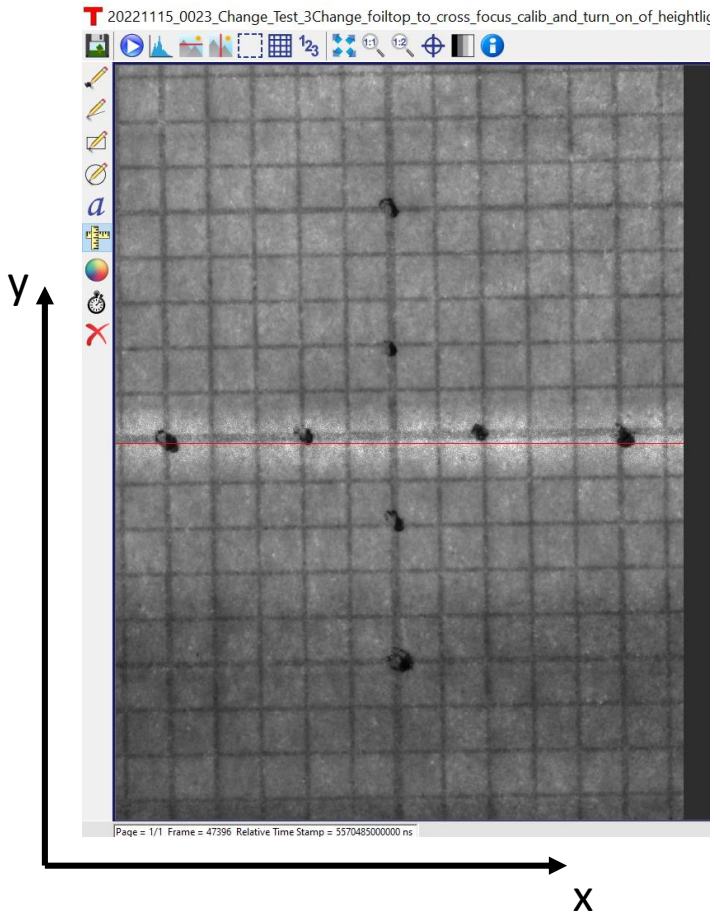
Beam coord. in the OTR pictures:



OTR Execution – Results and Evaluation

Camera pictures transformed into Beam coordinates

Calibration picture



Camera **screen size:**
- X-Axis$_{Beam}$: **12.50 mm**
- Y-Axis$_{Beam}$: **16.75 mm**

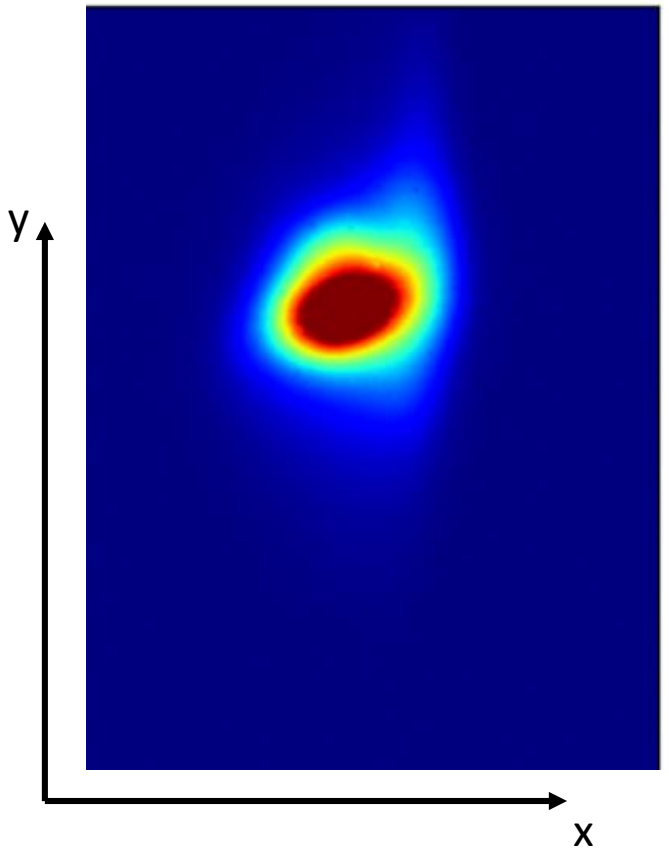
Camera **resolution**:
- X-Axis$_{Beam}$: **1080 pixels**
- Y-Axis$_{Beam}$: **1440 pixels**

→ **Pixel size: (0.0116 mm)²**

Preliminary result for beam width:

$$\sigma_x \approx 1.23mm$$
$$\sigma_y \approx 1.18mm$$

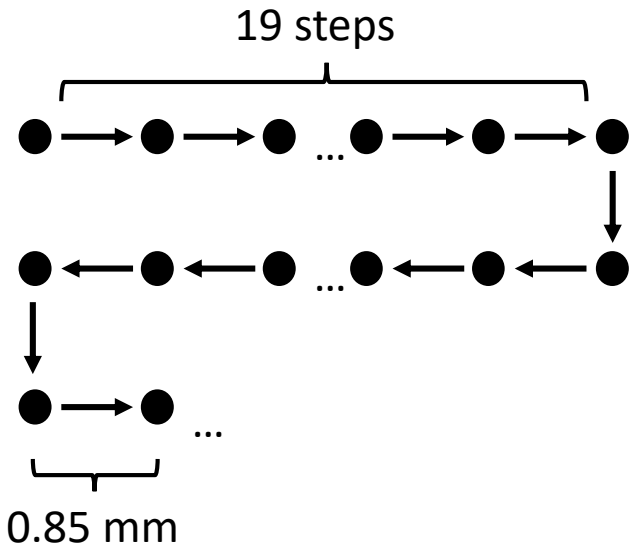
Beam profile picture



OTR Execution – Results and Evaluation

We want to **irradiate the EMT cell evenly**

Electron beam is narrow
-> move EMT through beam



Step size of EMT actuator movement

16x16mm area

20x20 locations

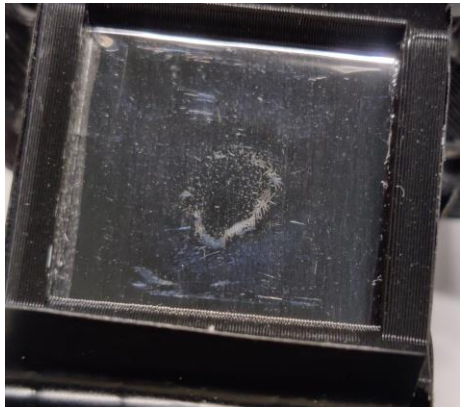
→**Step size** = 16 mm/19 = **0.85 mm**

Beam Size
$\sigma_x \approx 1.23mm$
$\sigma_y \approx 1.18mm$

This result indicates that the EMT cell was successfully irradiated evenly

OTR - Additional measurements

- Open questions for me
  - What influence does the flatness of the foils have
    → Measurements with different tilts
  - Does the beam cause a radiation damage on the foils?
    If yes, does it affect the performance of the detector?
    →Measurements with same beam intensity over longer time
  - Why is there a camera saturation despite using so many filters and despite the change to single foil?
    Is the range the filters are effective on wrong?
    →Filter on different positions.
    →Change to single foil on 17.11.22



Observed damage on 1. foil (replaced after 1 day on 16.11.23 at 17:30,)

まとめ – Summary

- **Muon monitor** is measuring the beam direction in the T2K experiment.
  → **indispensable for T2K beam operation**
- **Upgrade of proton intensity** for T2K neutrino production
  → **new MUMON sensor** with **better radiation robustness**
- **EMT cells** are developed as new sensors.
- EMTs are tried in **MUMON-EMT tests.** Recently **4th test** in November 2023 at **ELPH** (Sendai) for
  - **Degradation** of cathode aluminium and the bleeder circuit.
  - **Temperature dependence**.
- **High intensity e- beam** → Use **OTR** for beam profile monitoring
- First analysis shows **satisfactory beam behaviour** (diameter and position) → OTR works well
  - Further data evaluation for **exact beam profile**
    → Short exposure measurement series
  - Determine reliability of OTR results with additional measurements

Master Thesis

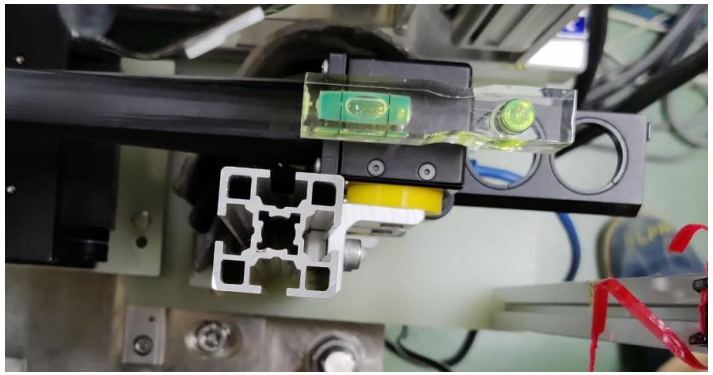
Thank you very much for your Attention!

4th MUMON-EMT test at ELPH

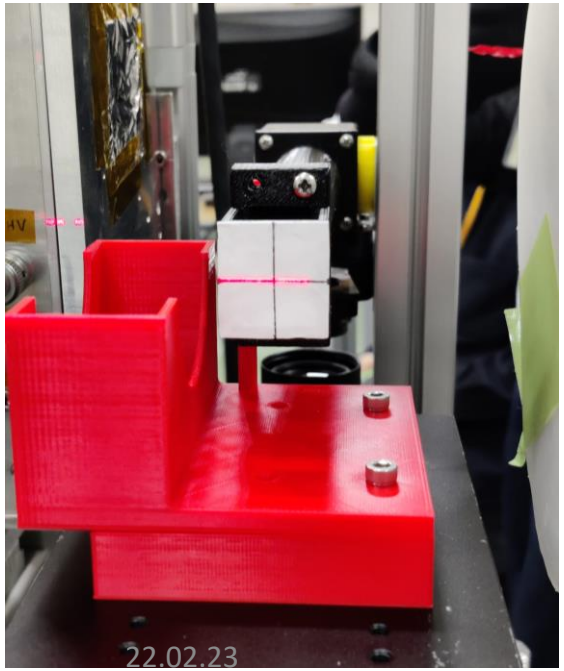
Back Up

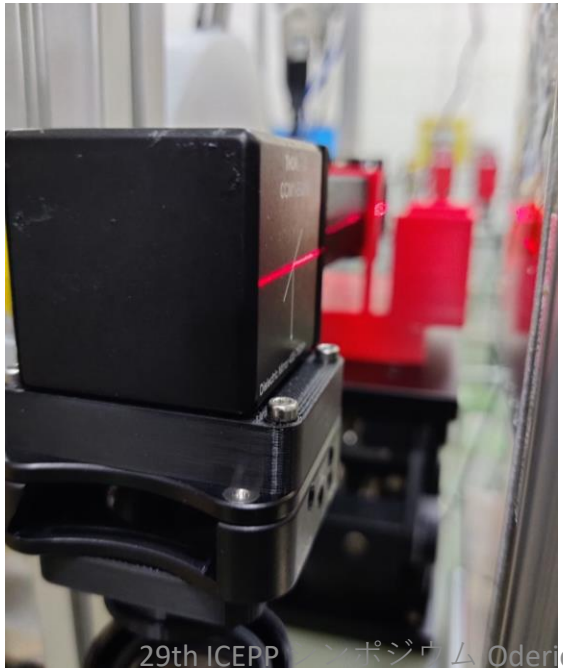
OTR Calibration

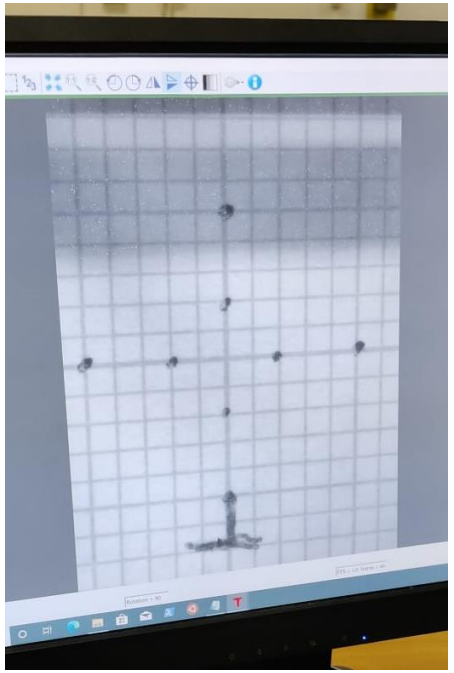
Focusing

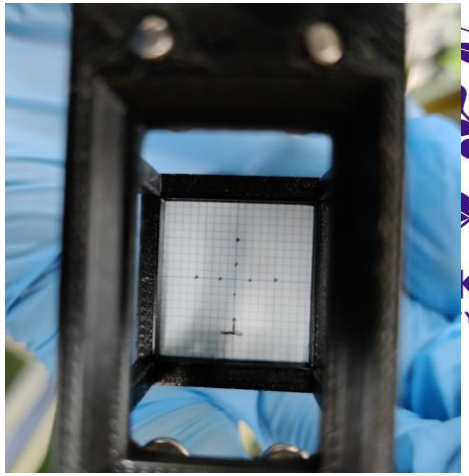


Alignment and height correction (done with laser)

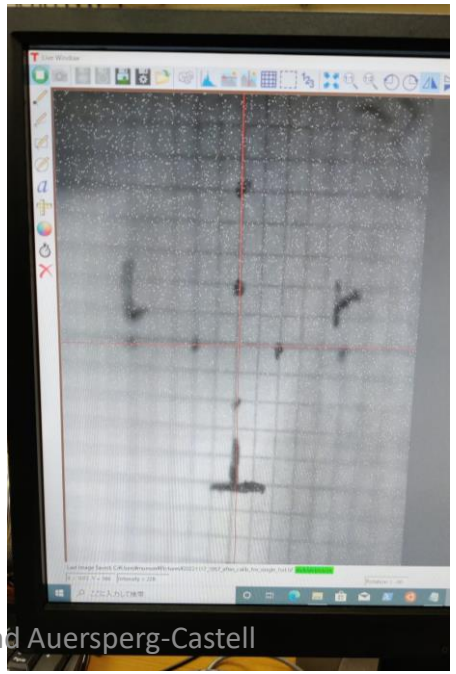


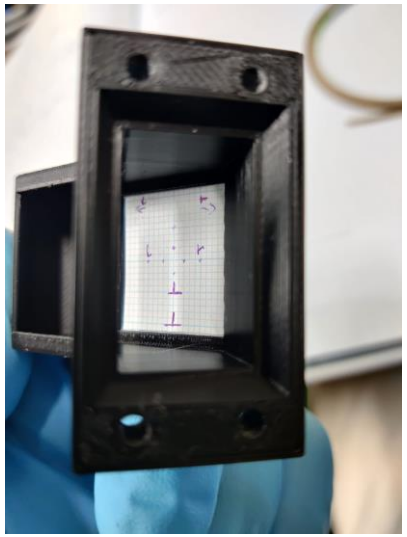






Focusing for two foils setup (length of foiltop is chosen to represent distance to inbetween the foils.)





Focusing for single foil setup (cross is put where the foil would be.)

OTR – Exchange Semester tasks

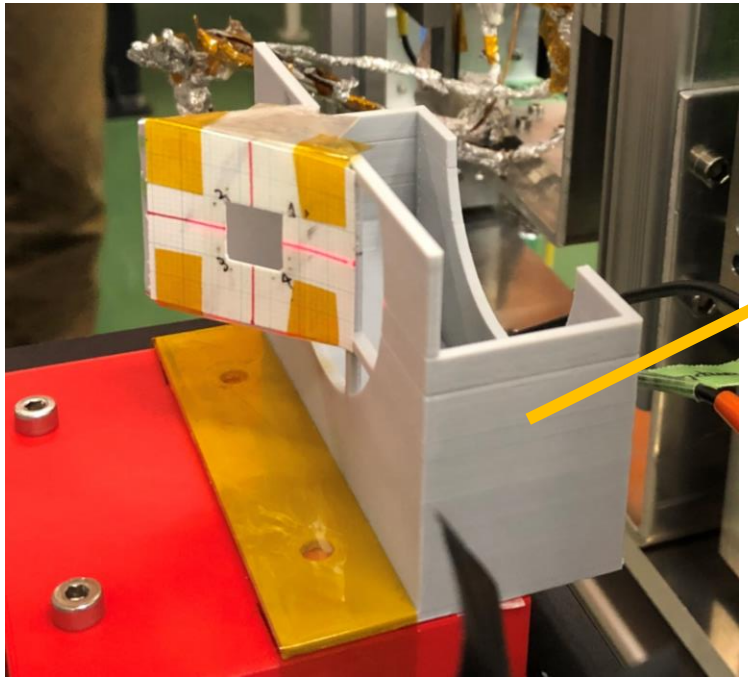
Only 1 semester time → OTR development very fitting task

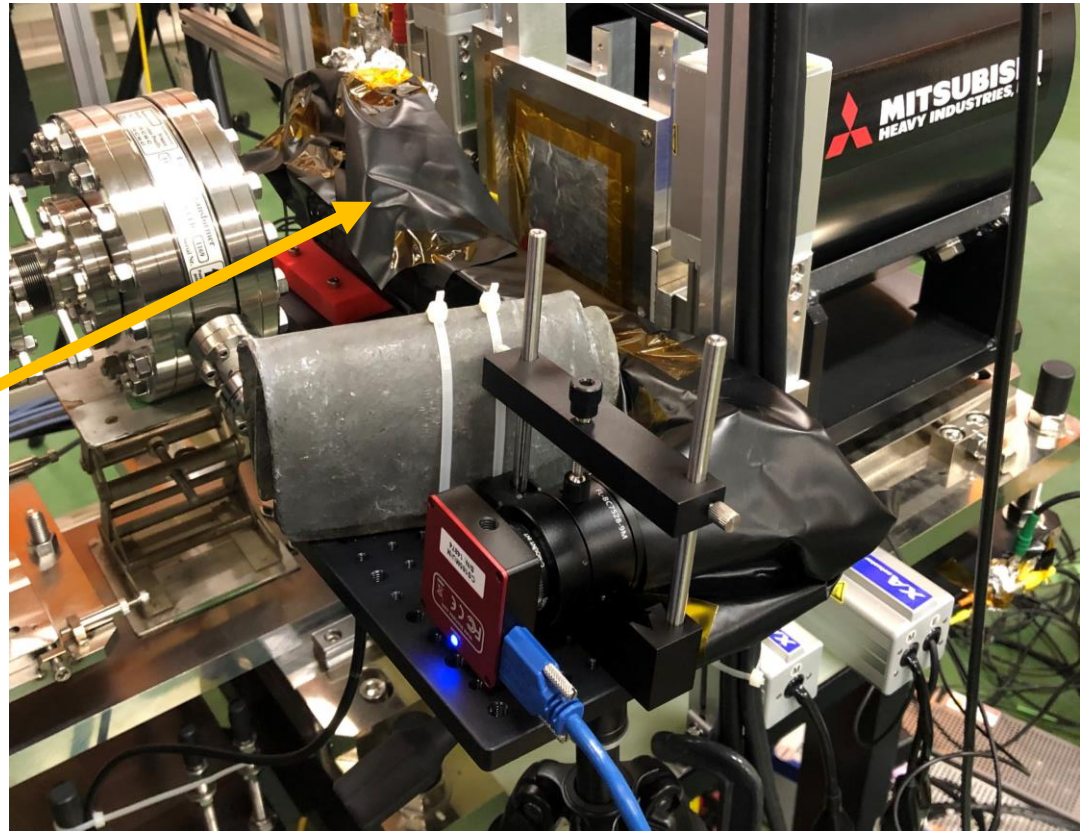
Develop construction which

- **fits** on the **experiment table** with the rest of the instruments
- allows to have the **camera be focused** on the foil/the point in between the foils which is/are located in the beamline
- can be used for **high and low intensity beam** -> be able to exchange filters
- is **simple and easy** to set up
- is **completely dark** on the inside (to minimize noise on the camera)
- ideally is **easily accessible** to do calibration and exchange foils

Old OTR → Motivation for **new OTR**

OTR version at last test (Nov. 2021, 2. MUMON Test)

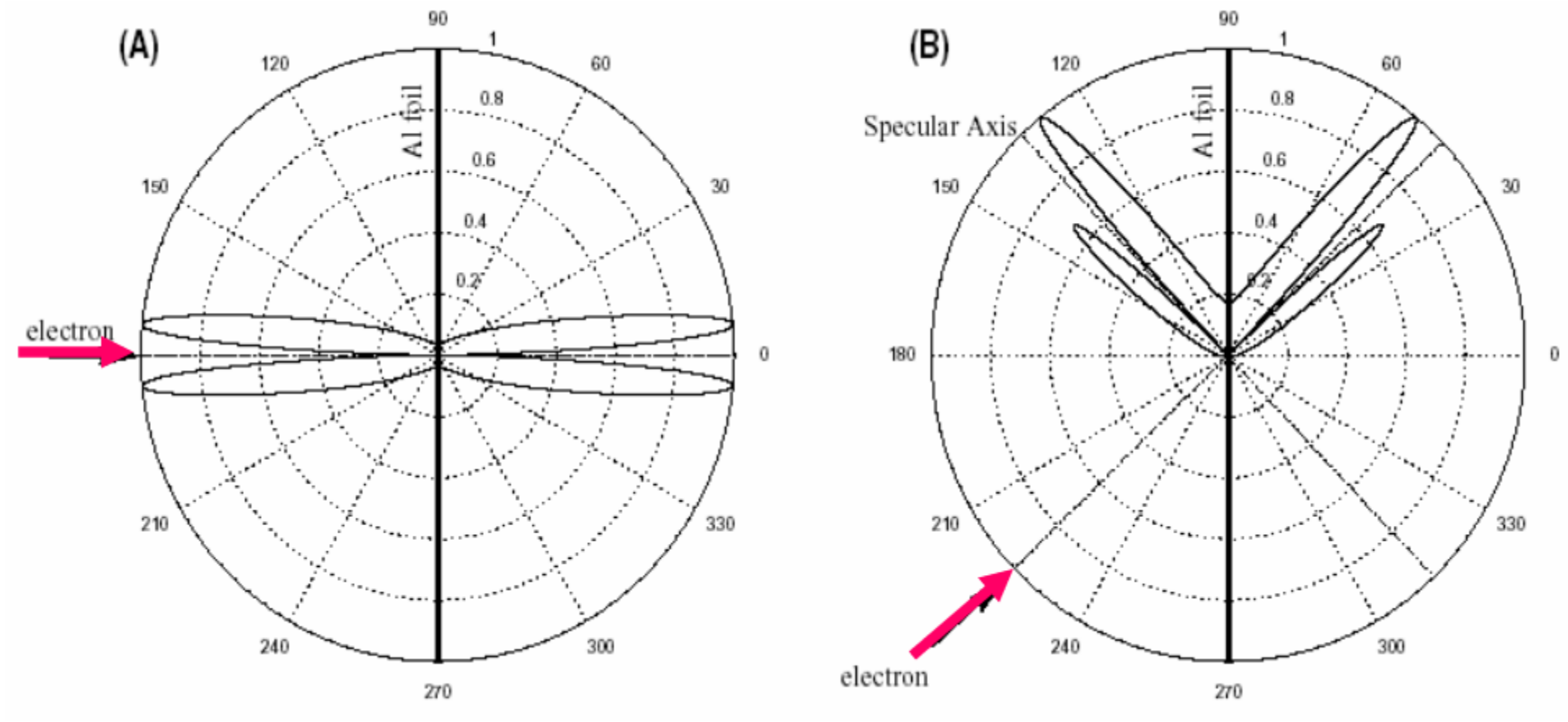




- **Single Foil**
- Rather **spontaneous set up idea**
- **Camera** was put on **tripod** next to experiment table

- Setup had to be **wrapped in black foil** since it was **open**
- It was **hard to keep camera focused** because the setup was only loosely connected to the rest of the experiment

OTR - physics


(A)
90
1
120
60
0.8
Al foil
0.6
150
30
0.4
0.2
electron
0
180
210
330
240
300
270
(B)
Specular Axis
electron