Imperial College London

Science and Technology Facilities Council

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MARIE CURIE ACTIONS

COMET Phase-α Experiment
to Investigate COMET's New Muon Beamline at J-PARC

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On behalf of the COMET collaboration

Lepton Photon 2023, Melbourne, Australia

The 31st International Symposium on Lepton Photon Interactions at High Energies

19th July 2023

COMET Experiment

Tokai, Ibaraki, Japan

Search for μ-e Conversion at J-PARC, Japan (*)

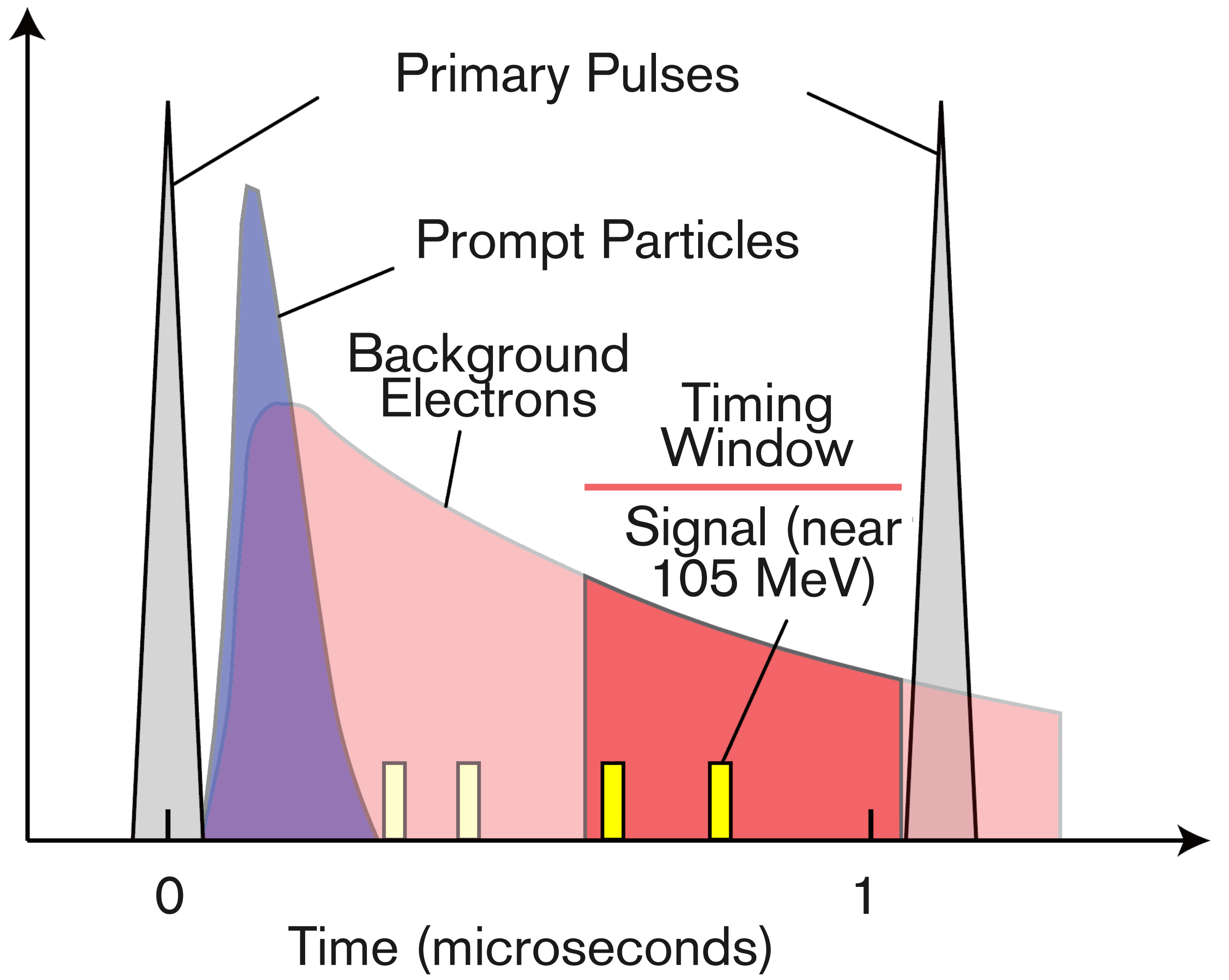
- The final goal: **$O(10^{-17})$ – $O(10^{-18})$** sensitivity.
  - >10, 000 times improvement on the current limit.
  - Two steps: Phase-I and Phase-II
- Building the facility and muon transport line.
  - The beam is key for COMET; its dedicated commissioning is necessary!

Phase-I

- ✓ **Sensitivity $O(10^{-15})$**
- ✓ **Physics measurement by a cylindrical tracker**
- ✓ **Beam & BG measurement by a tracker & ECAL**

Phase-II

- ✓ **Sensitivity $O(10^{-17})$ or better**
- ✓ **Physics measurement by a tracker & ECAL**



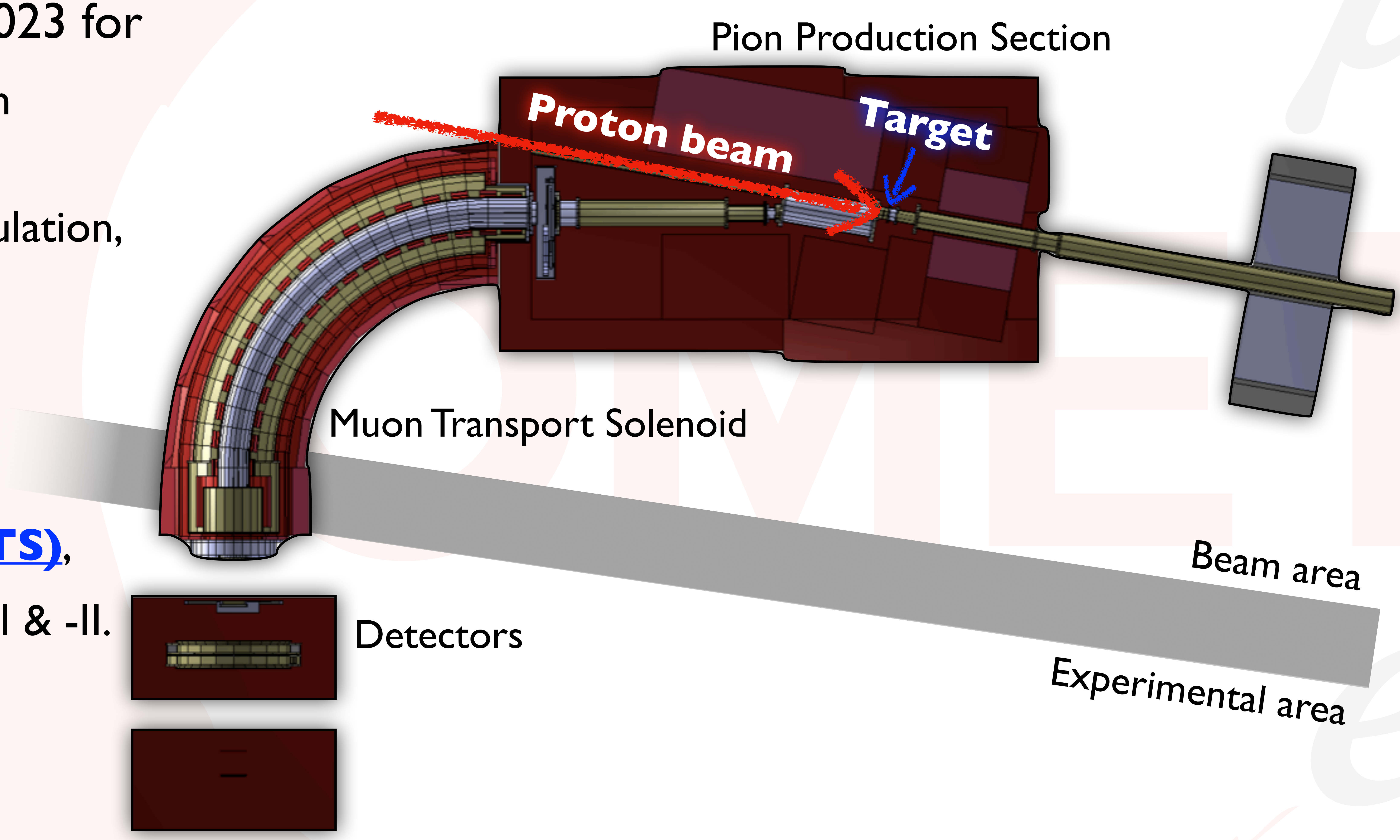
Bunched Beam Structure & Delayed Timing Window

(*) COMET Phase-I Technical Design Report, DOI:10.1093/ptep/ptz125

PHASE-α

Commissioning run to study the new beamline

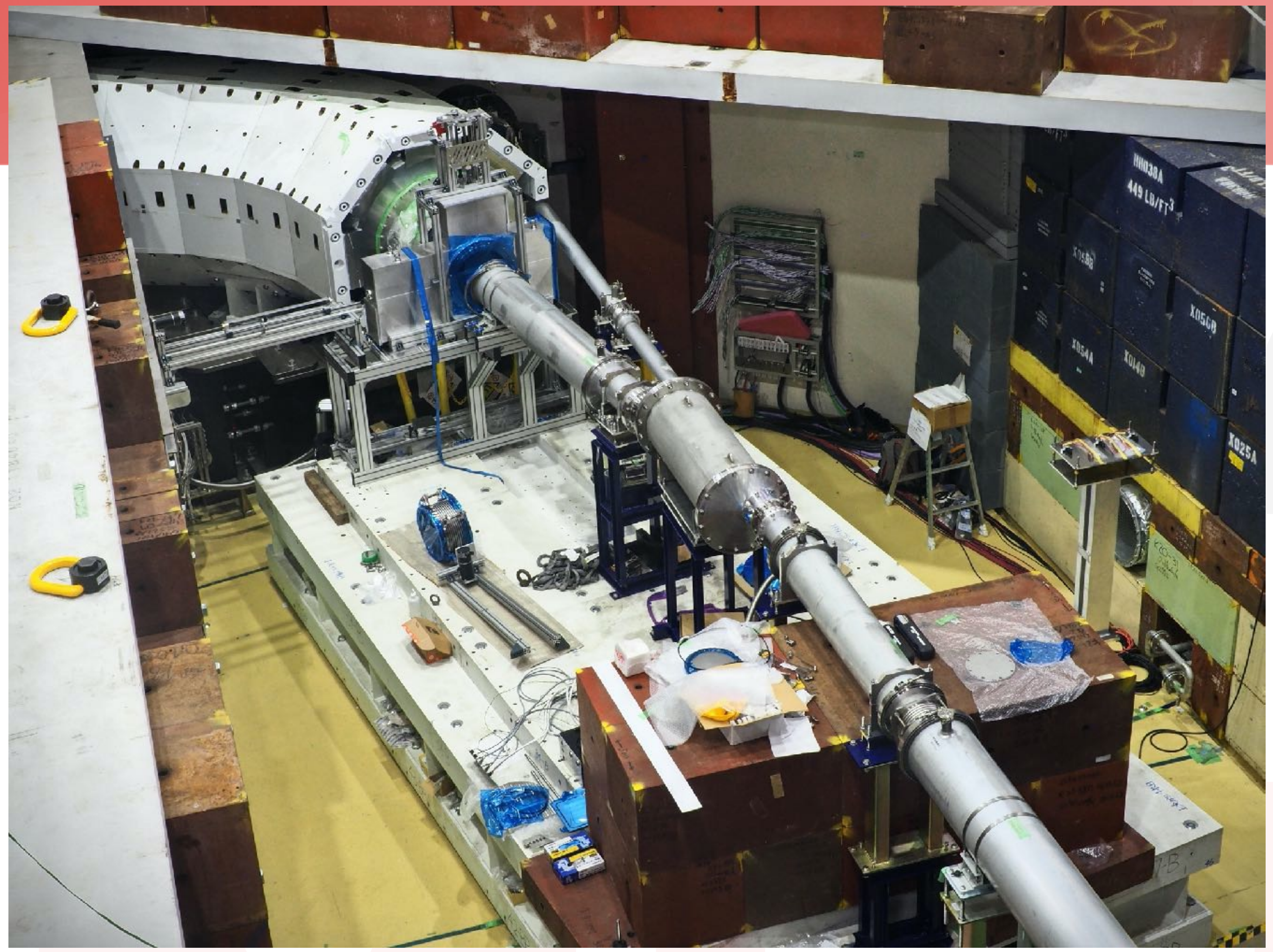
- Performed in February & March 2023 for
  - Investigation of the secondary beam in the experimental area.
  - Comparison between data and simulation, for validation of simulation.
- Used a simpler beamline configuration than Phase-I.
  - Studies of the 90°-curved **Muon Transport Solenoid (TS)**,
  - Only the common part with Phase-I & -II.



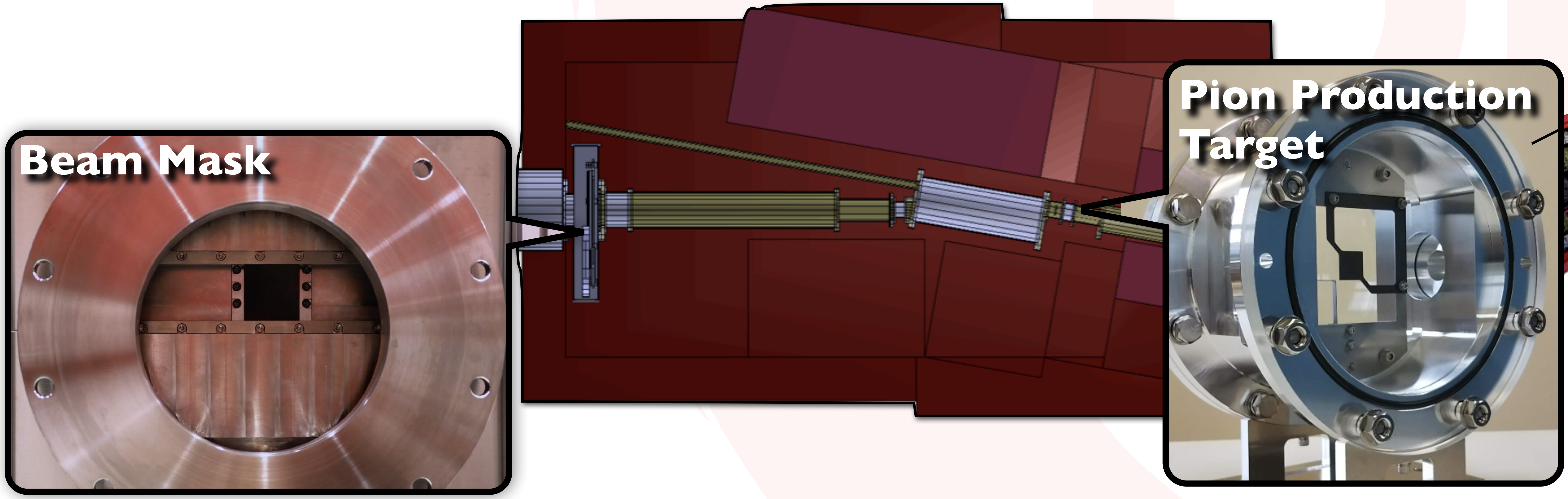
Primary Beamline

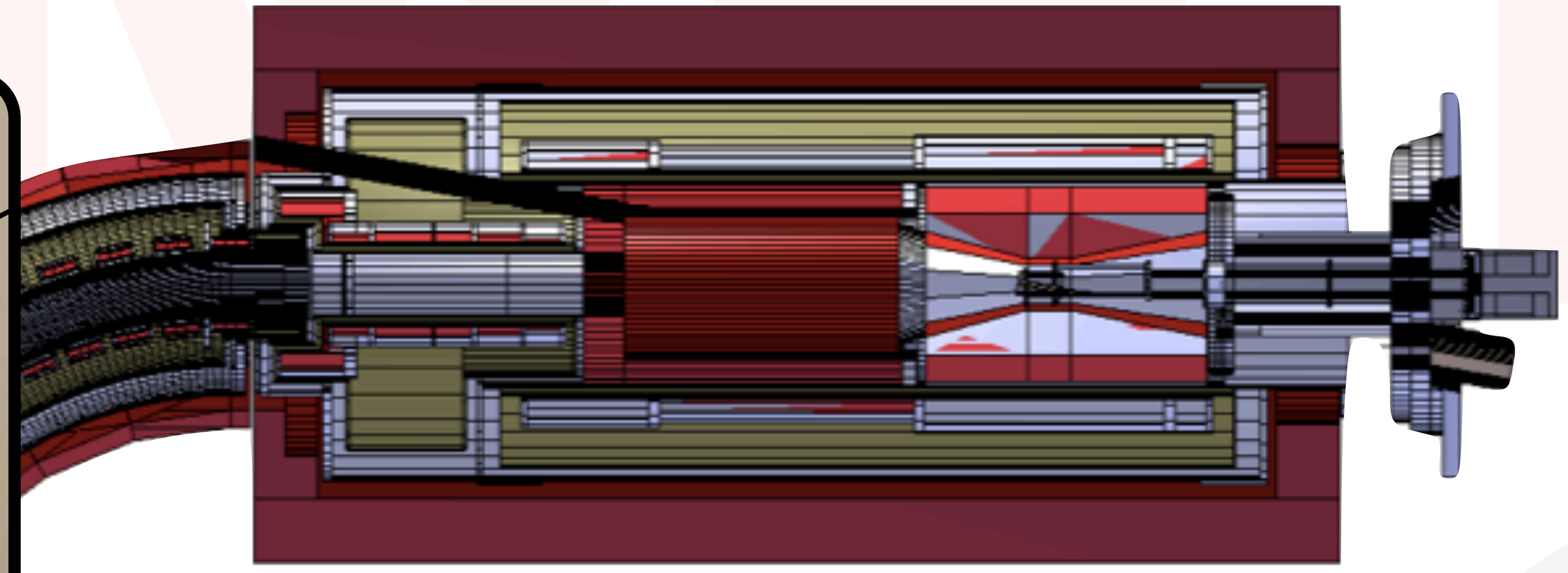
A simpler beamline than Phase-I

- Phase-I / -II Pion Capture Solenoid not present.
- A 1.1 mm-tick C/C composite Pion Production Target
  - ★ A longer graphite target in Phase-I
- A beam mask with two moving collimator slits.
  - ★ To study the transport optics.



Phase-α Primary Beamline



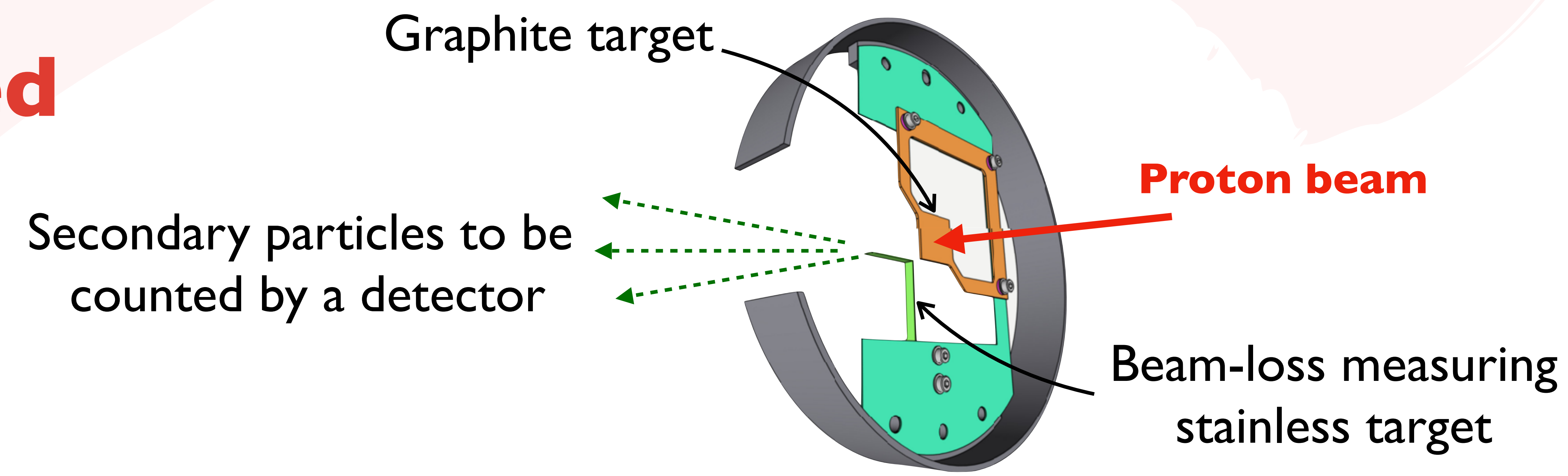


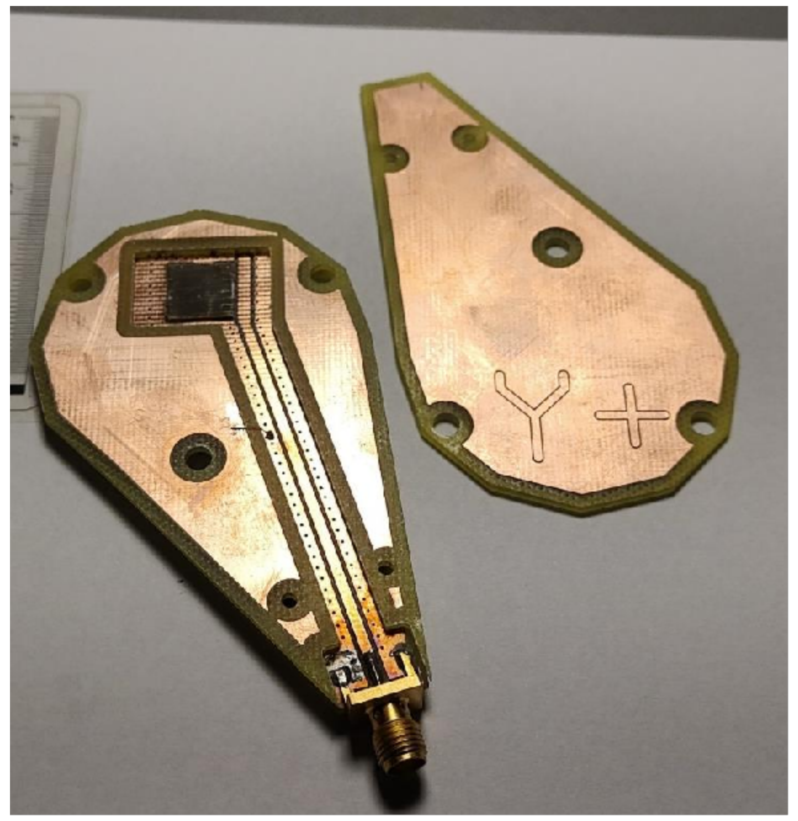
Reference: Pion Capture Solenoid in Phase-I

Proton Beam Extraction

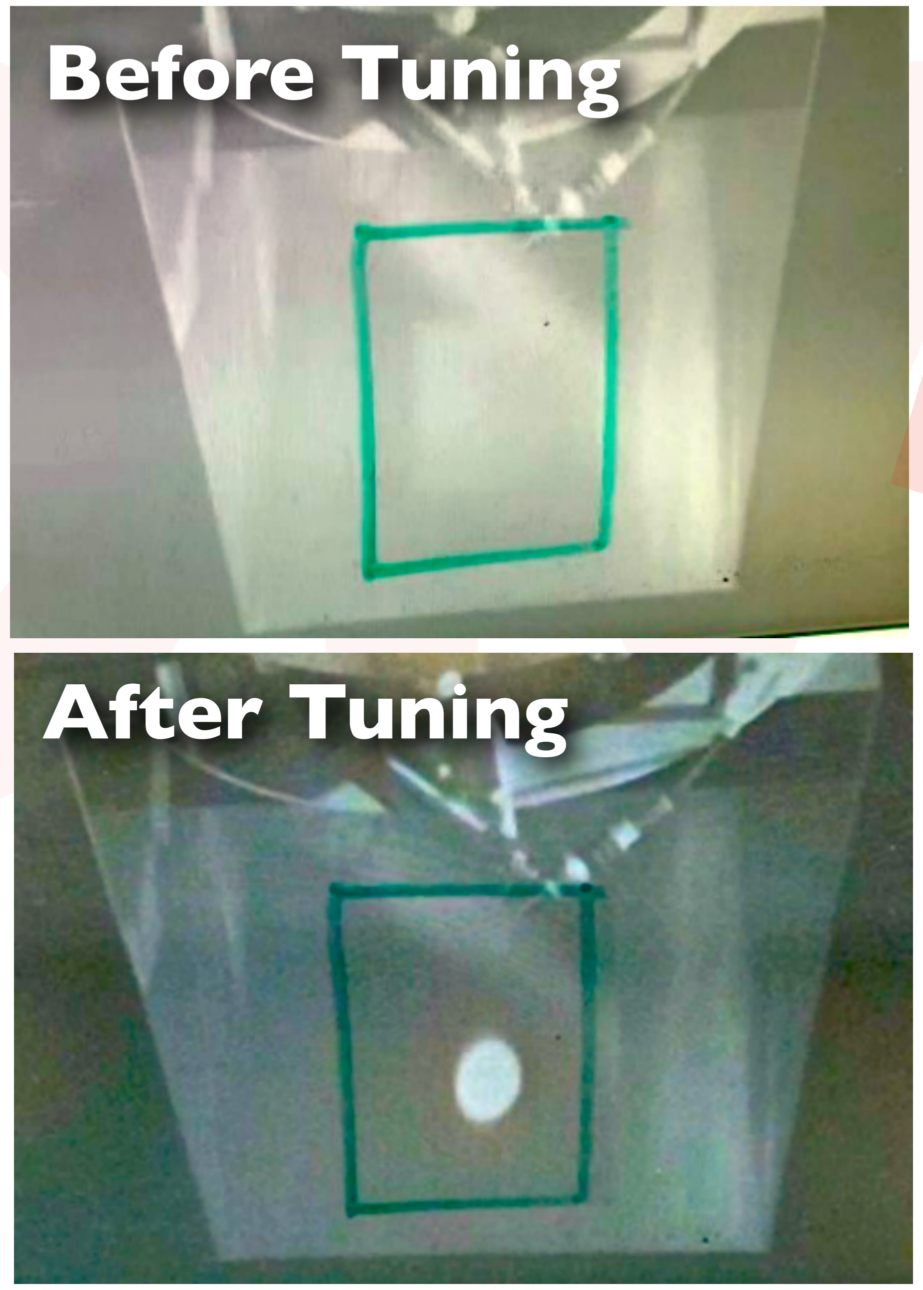
The proton beam successfully extracted

- Slow-extracted & pulsed 8 GeV proton beam
  - Beam power: 260 W (3.2 kW in Phase-I)
  - Beam tuning was well performed.
  - Its beam profile was measured.
- Observed hits on *Proton Beam Monitor*,
  - newly developed TiO_2 sensors
  - doi.org/10.1109/JSEN.2022.3224809

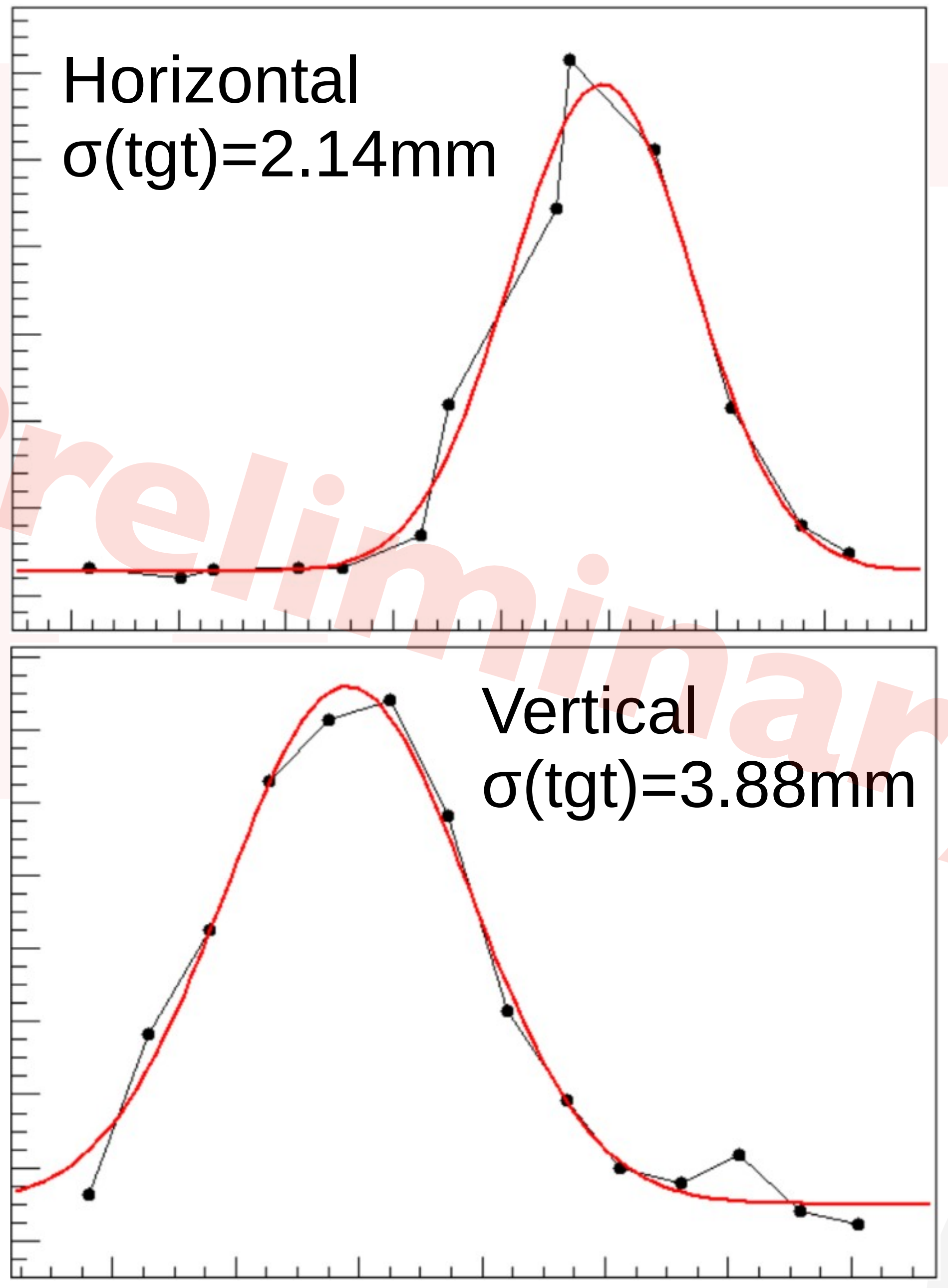




TiO_2 Sensor for Proton Monitor



Phosphor plate response before and after beam tuning

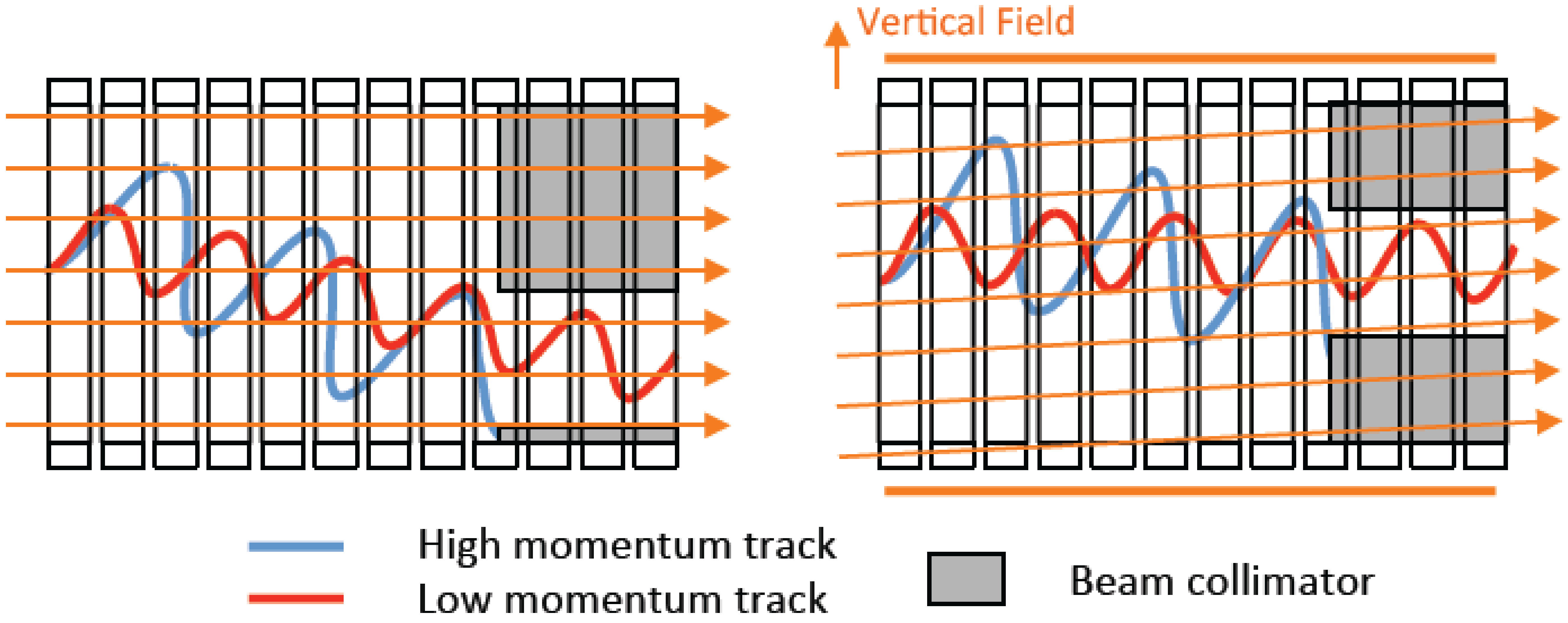


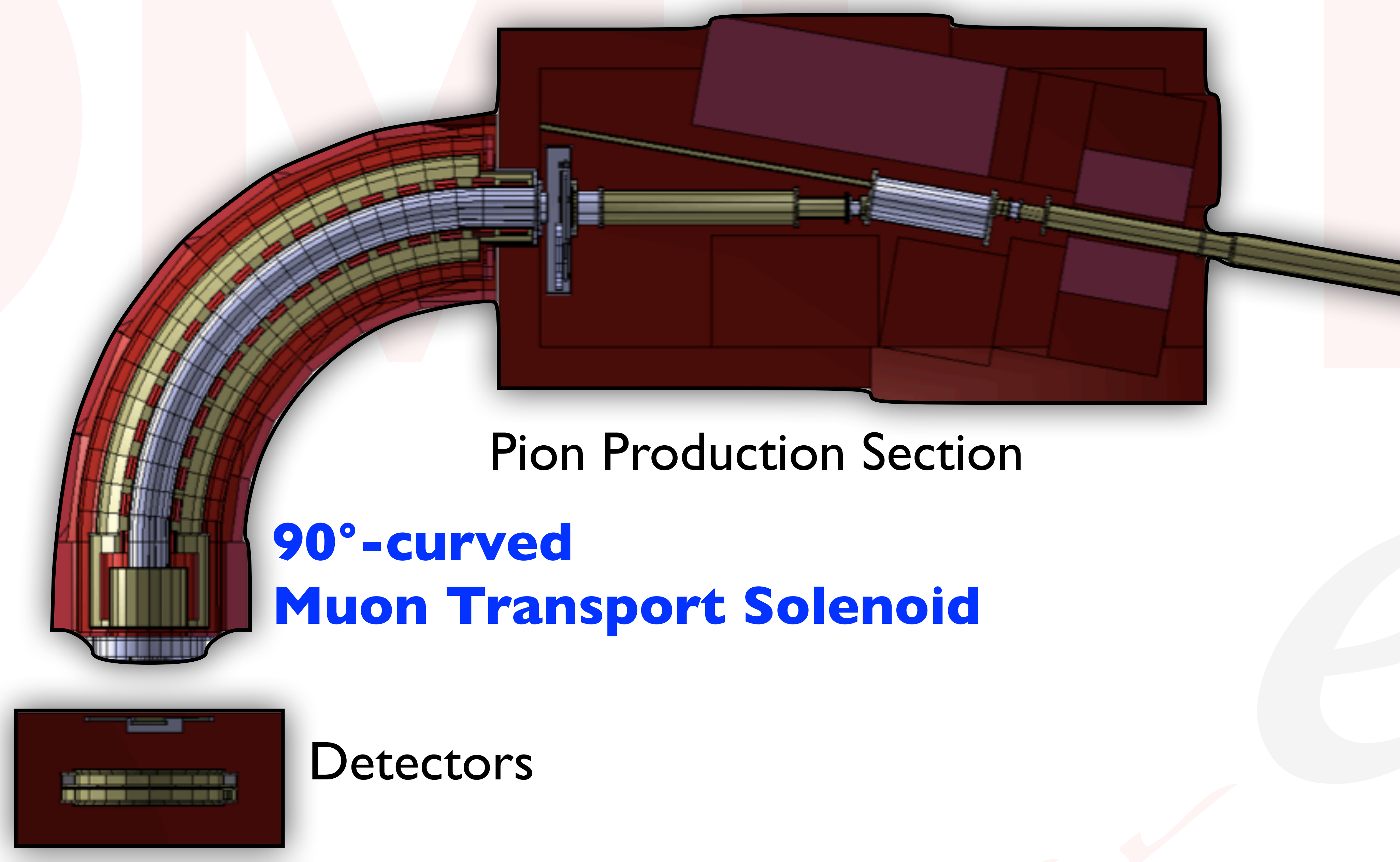
Measured beam dimensions

Muon Transport Solenoid

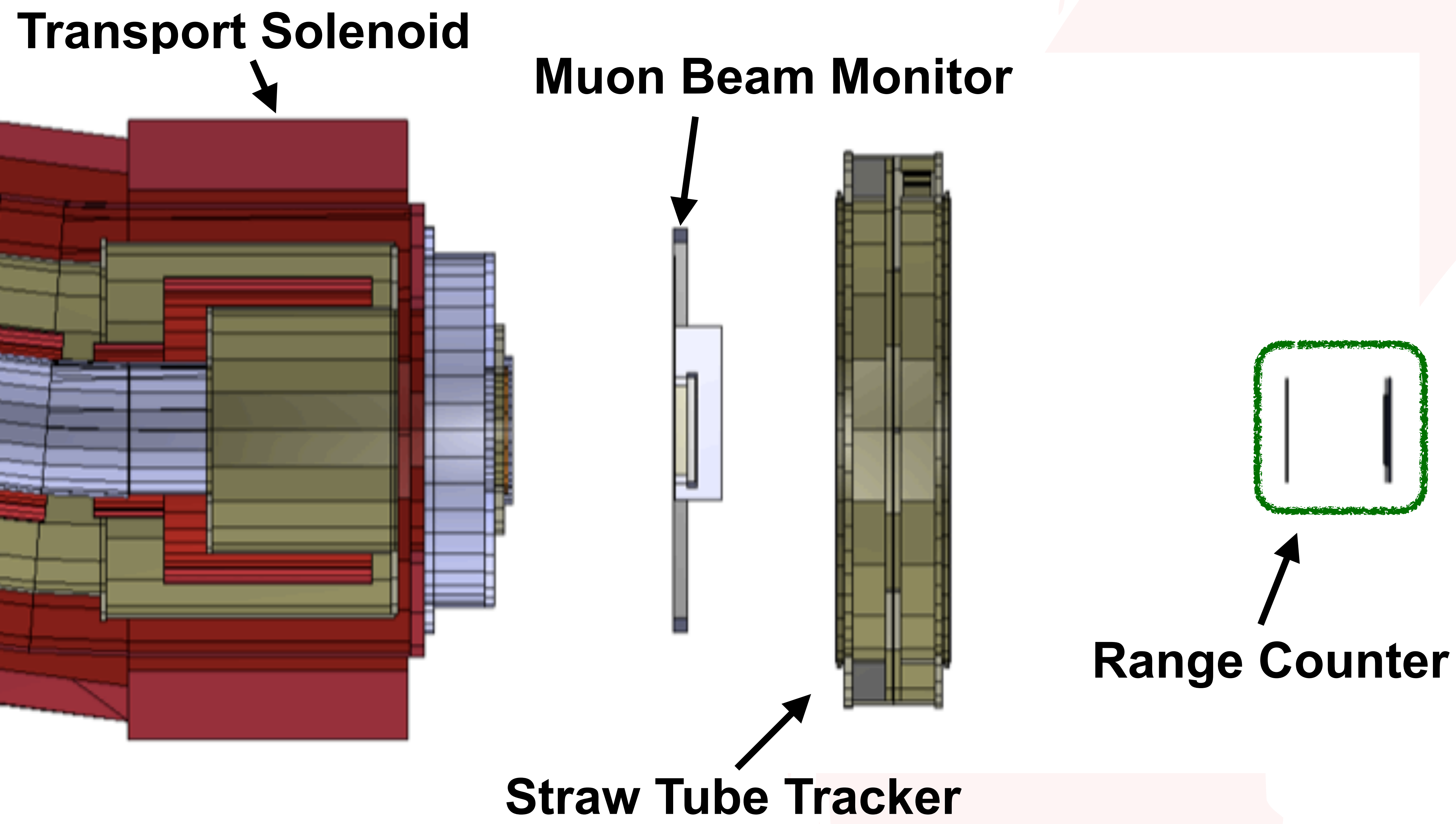
Curved Muon Transport Solenoid

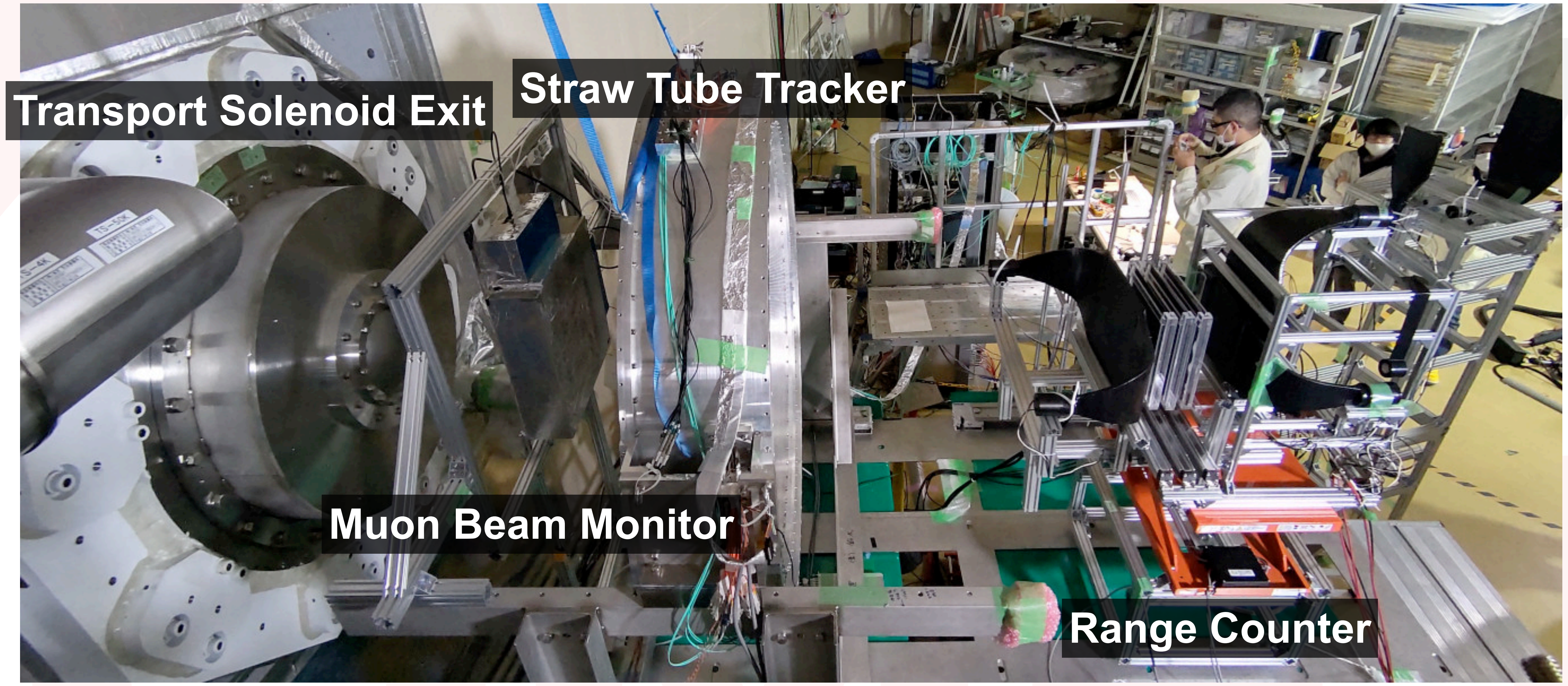
- Curved solenoids have the ability to select momentum and sign of charge.
  - ★ Charged particle trajectories drift vertically depending on their charge and momentum.
  - ★ A dipole magnetic field compensates the drift of targeted charge and momentum.
- **Phase-α tested a 90°-curved solenoid for the first time.**
  - ★ A 36°-curved solenoid was the longest one prior to it.
- Operated at 1.5 T solenoidal field & 0.05 T dipole field in Phase-α.





DETECTORS





Muon Beam Monitor

- Measure beam position

Straw Tube Tracker

- Measure beam position and direction

Range Counter

- Identify negative muons and
- Generate trigger signals.

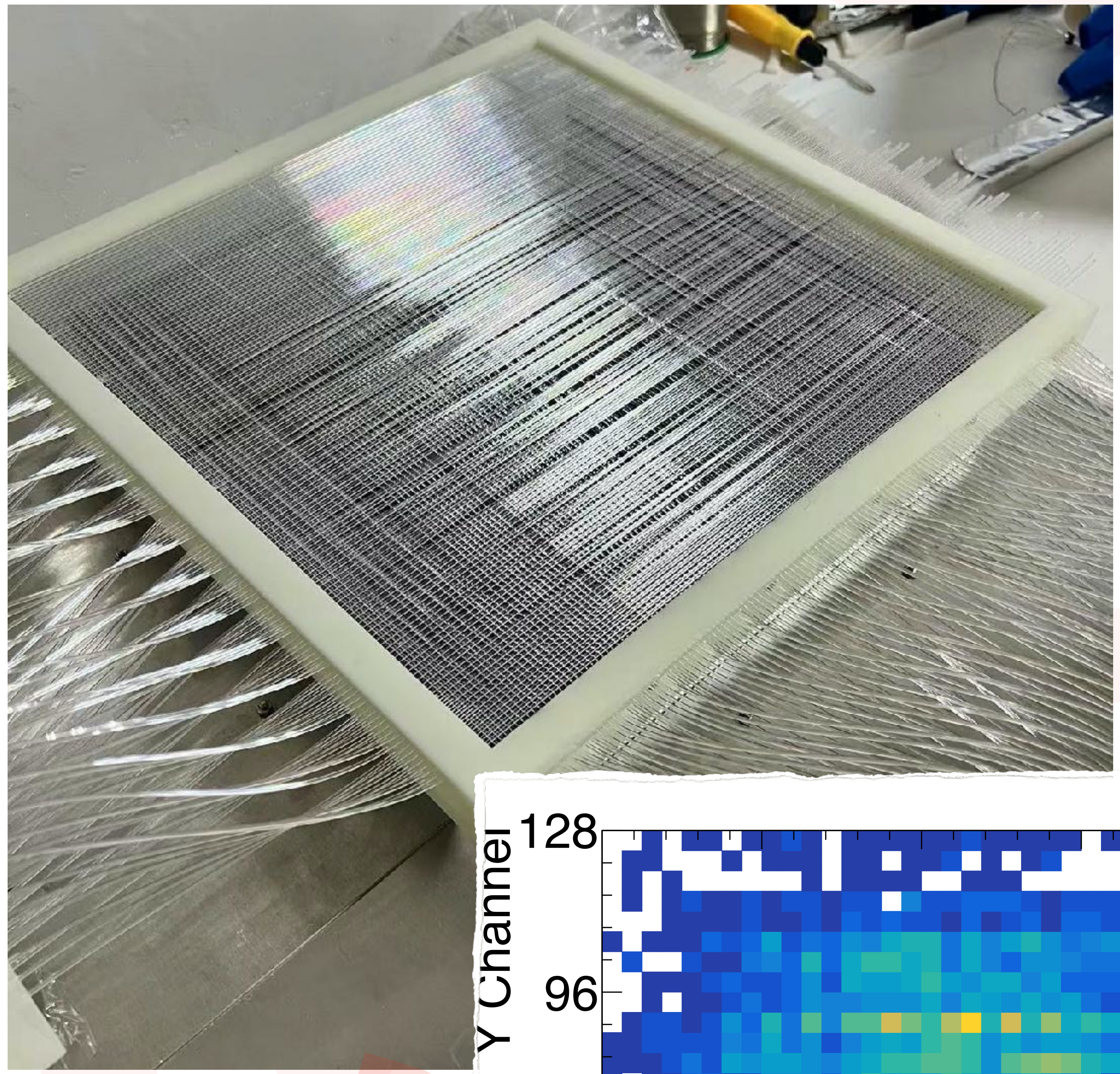
Muon Beam Monitor

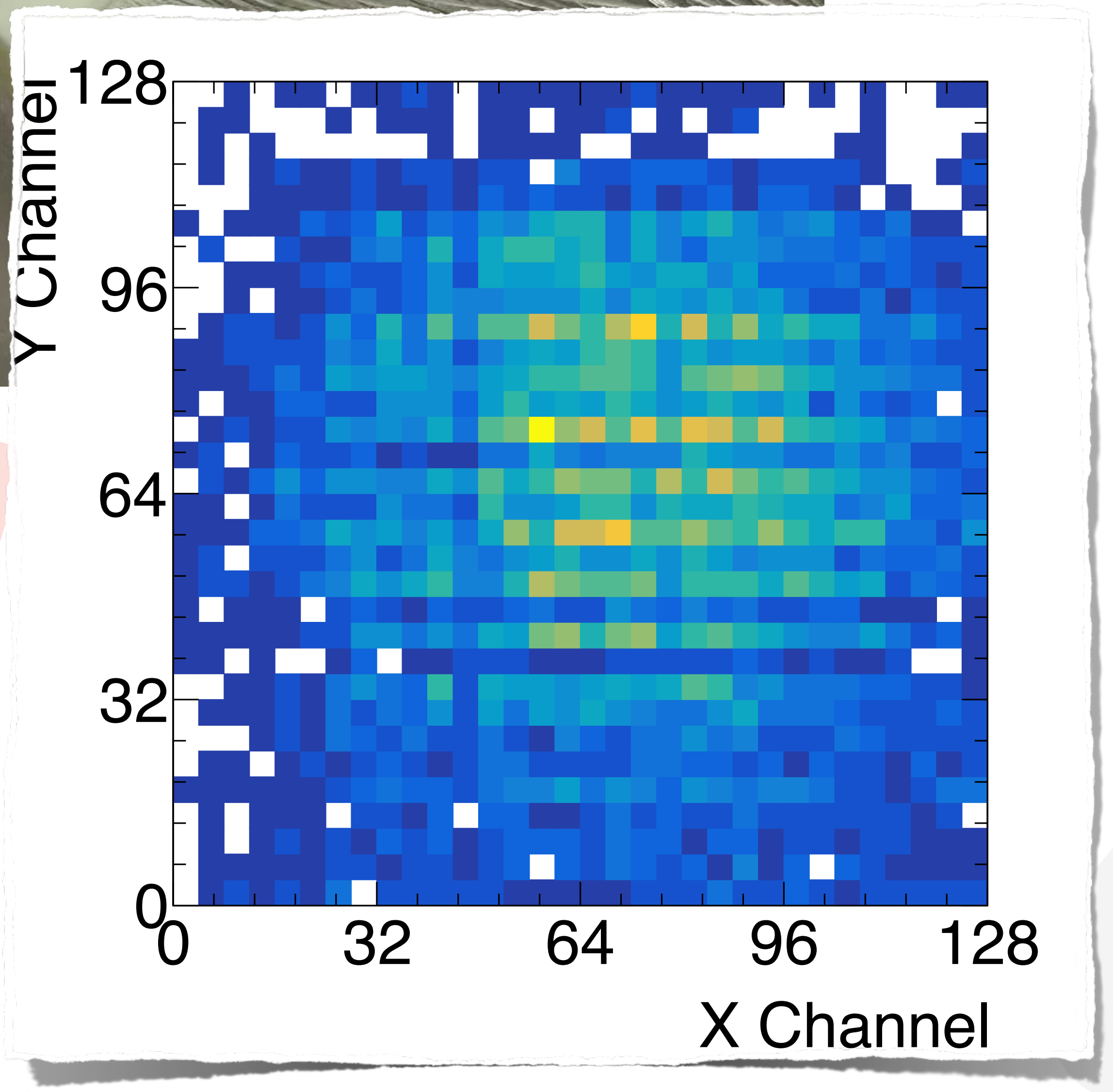
Scintillating fibre hodoscope

- Hodoscope detector with 1 mm² plastic scintillating fibres, readout by SiPMs.
- 30×30 cm² area holds 128+128 fibres aligned to form a plane.

Dedicated SiPM control & readout electronics

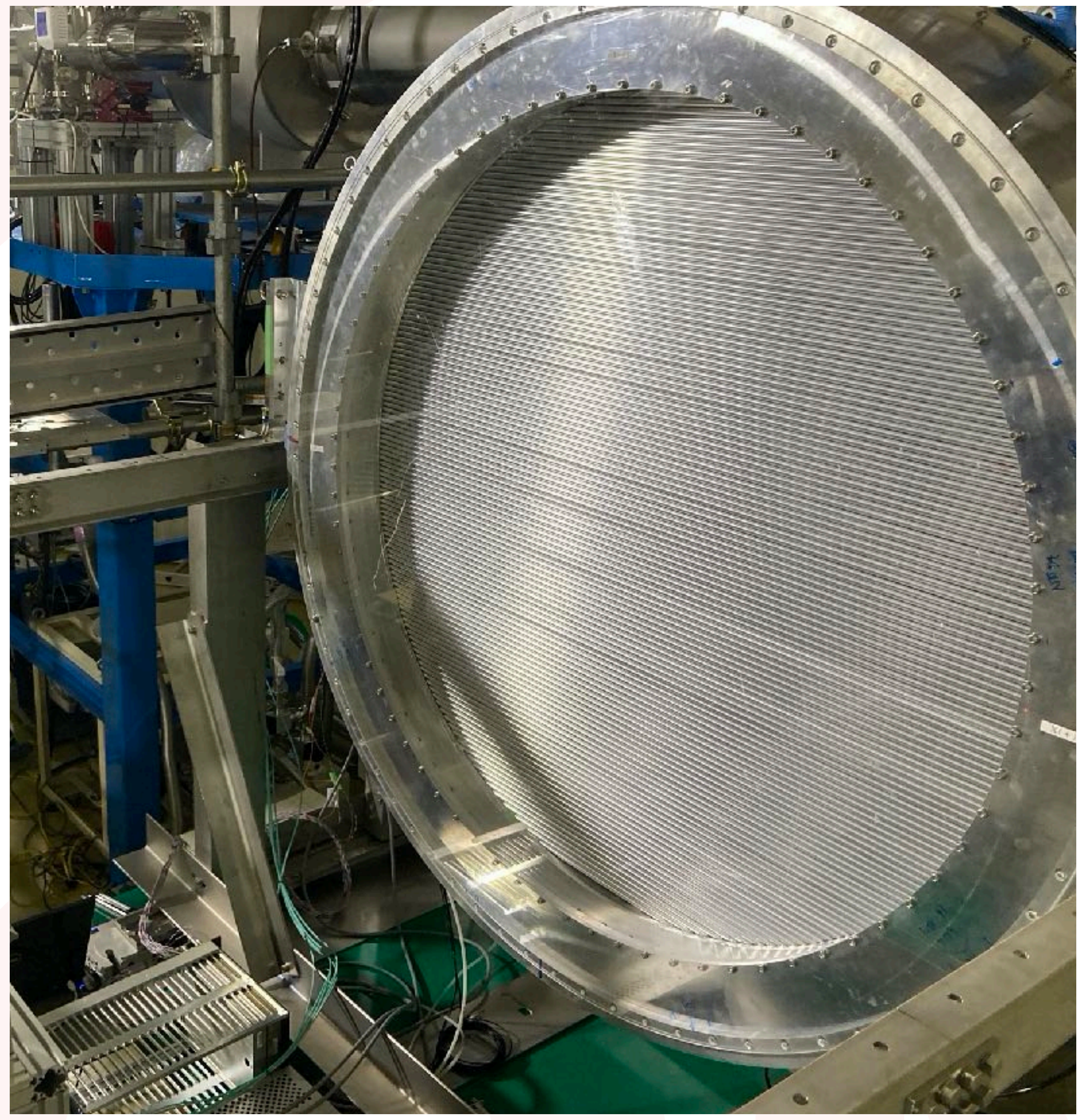
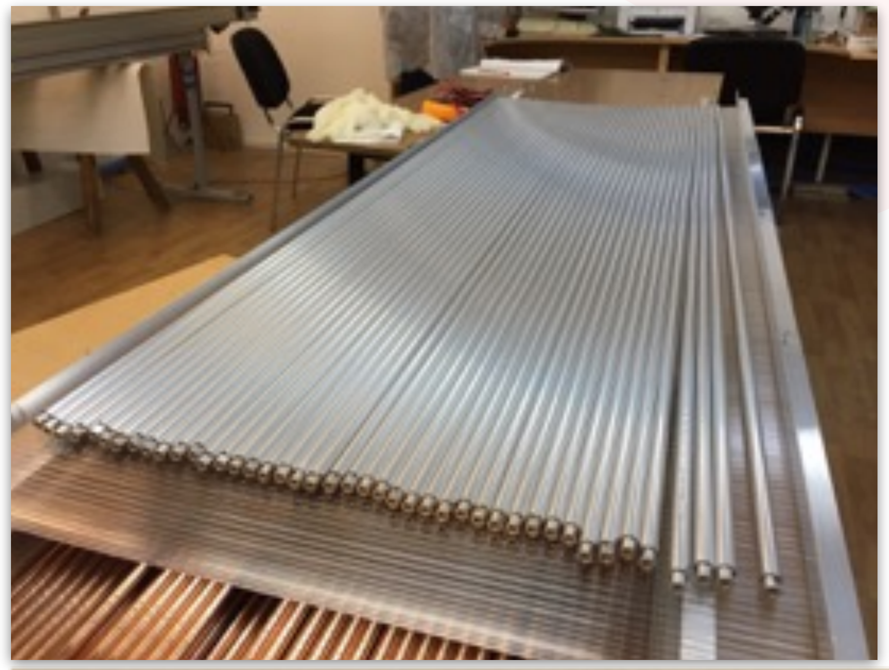
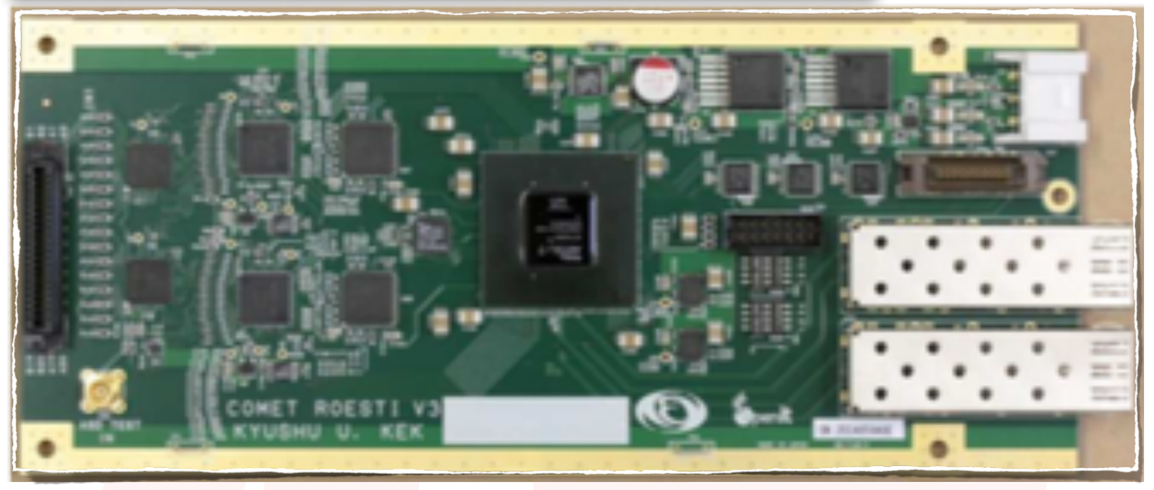
- 3.3 nsec time resolution.
- Good hit rate tolerance and capability for the experiment.





Beam profile associated with trigger

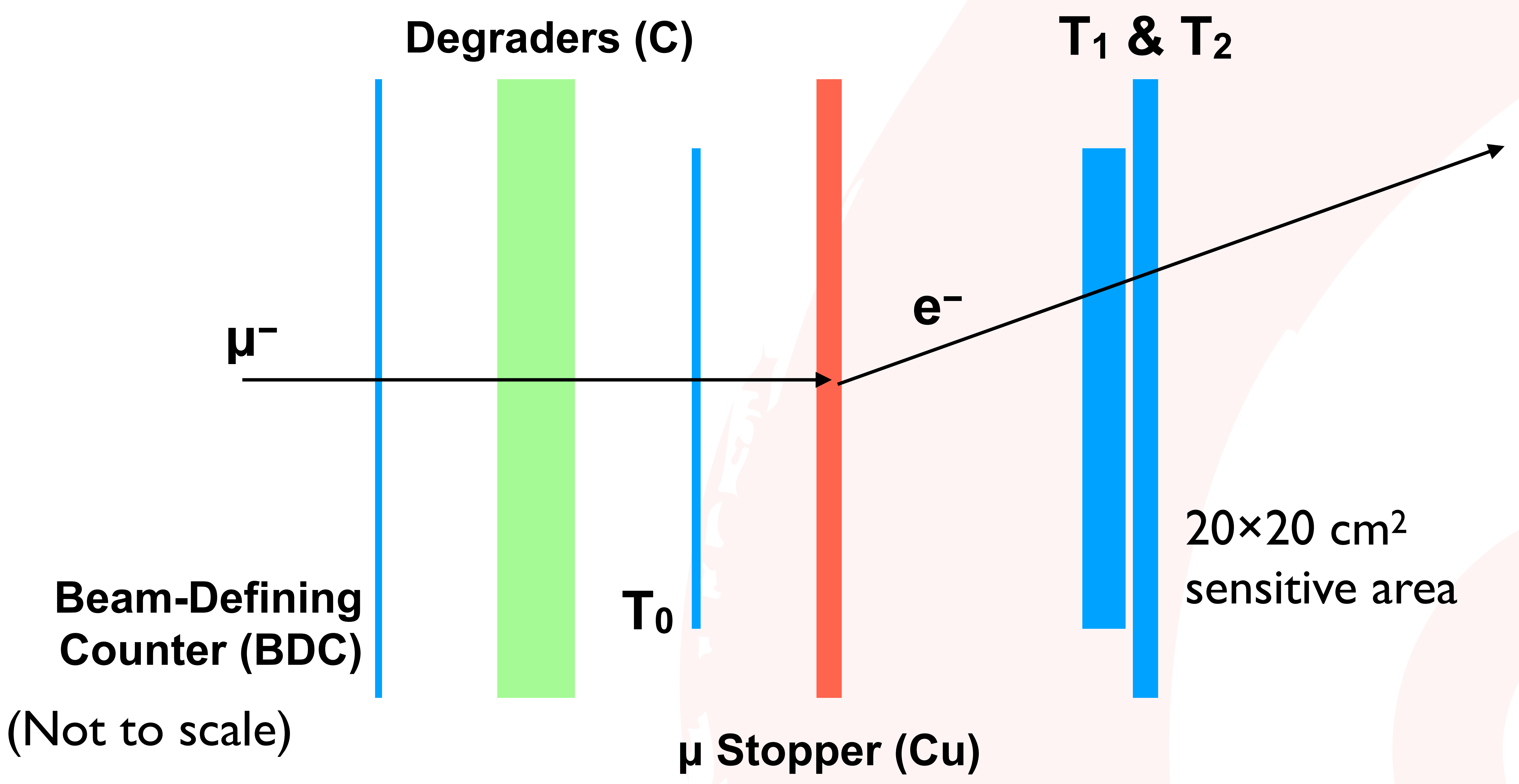
Straw Tube Tracker

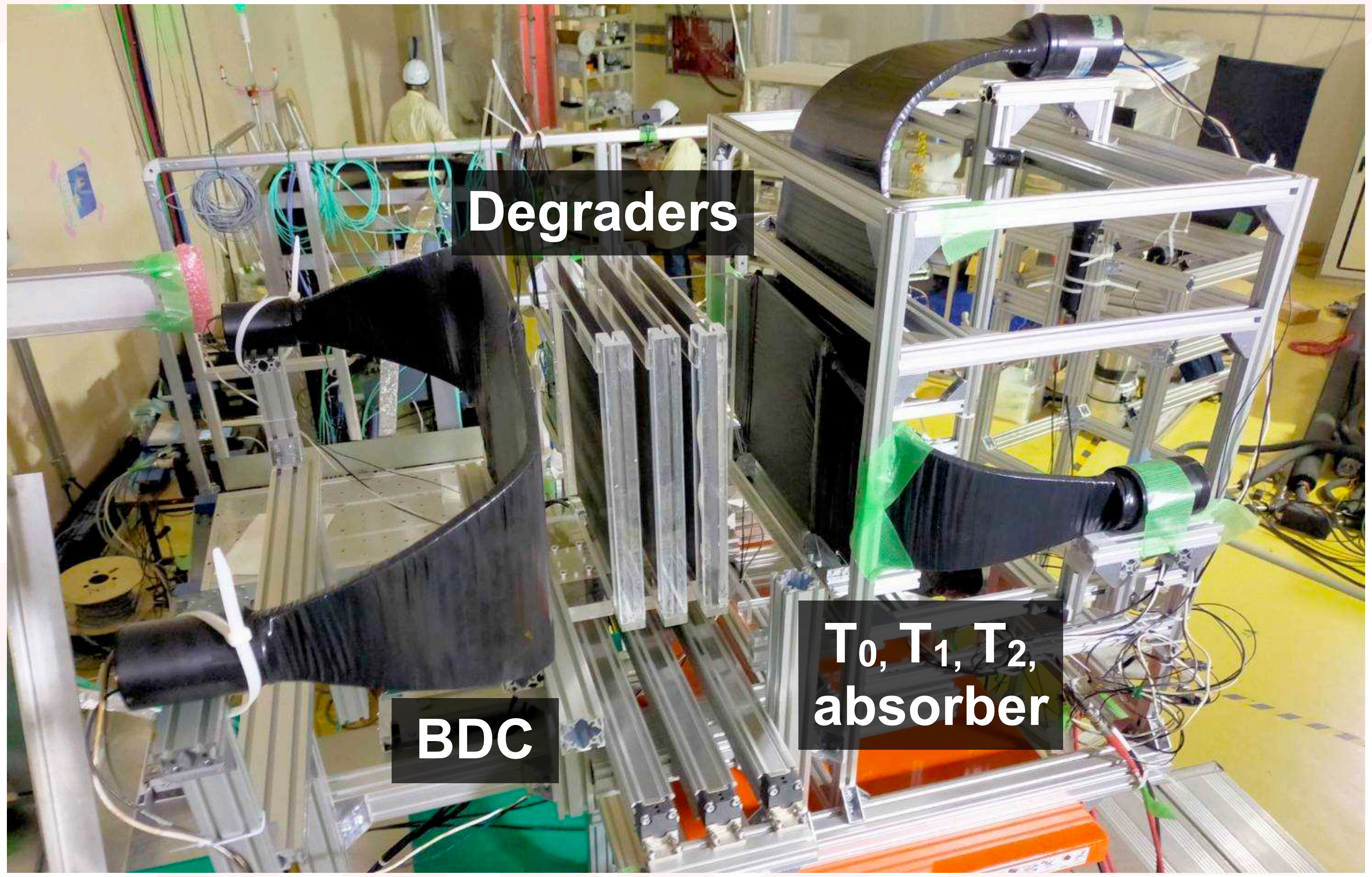





A single Phase-I straw 'station' was assembled for Phase-α.

- 480 straw tubes (narrow drift chambers) alined in total on the X & Y axes.
  - Ar & C_2H_6 (50:50) gas mixture
- Phase-α was the first opportunity for commissioning a Phase-I detector!
  - Full readout chain was tested.
  - Five stations will be used in Phase-I.

Range Counter

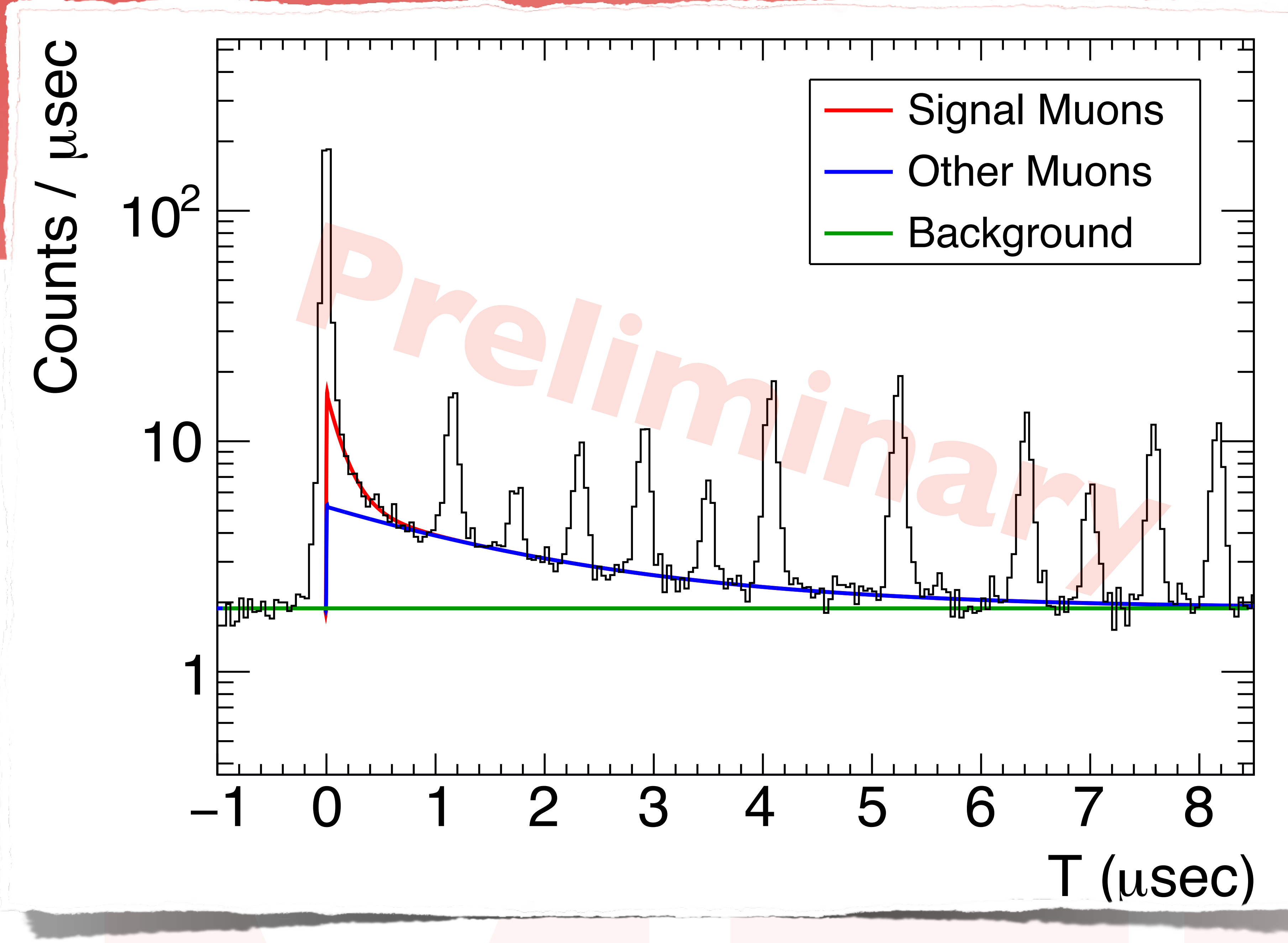




Multi-layered plastic scintillating counters measuring muon decay time

- Change the momentum range to measure with different thicknesses of a graphite degrader.
- Reconstruct the number of muons stopped in a copper muon stopper.
  - Negative muon's life time in copper is about 160 ns compared to about 2 μs in lighter materials.
- Generated trigger signals when a particle hits *BDC* & T_0 with no simultaneous hits in T_1 / T_2.

RESULTS (1)



Muon decay spectrum

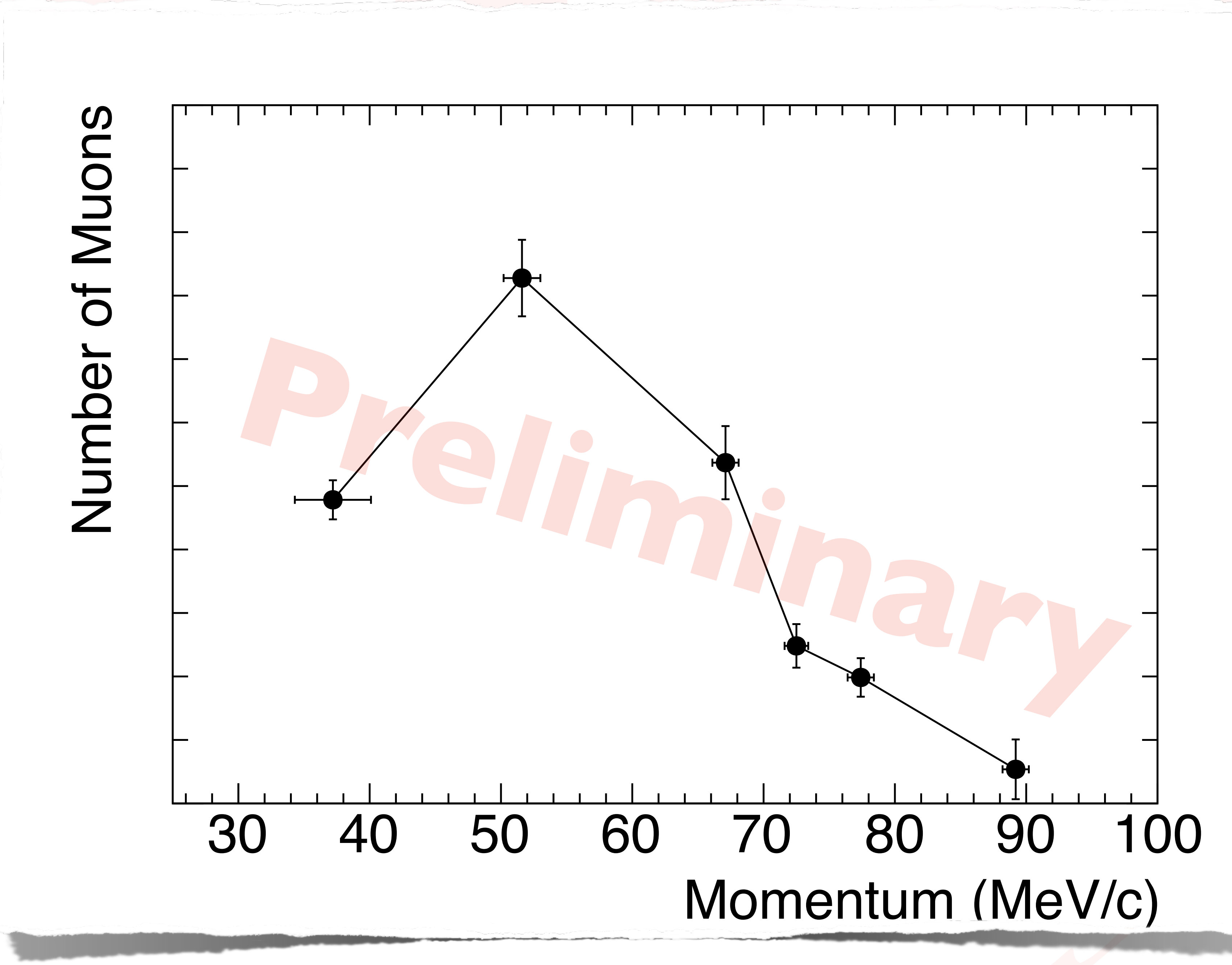
- ✦ The signal 'short' muon decay component was observed.
  - ★ **Negative muons transported via the 90°-curved Transport Solenoid!**

Muon momentum spectrum

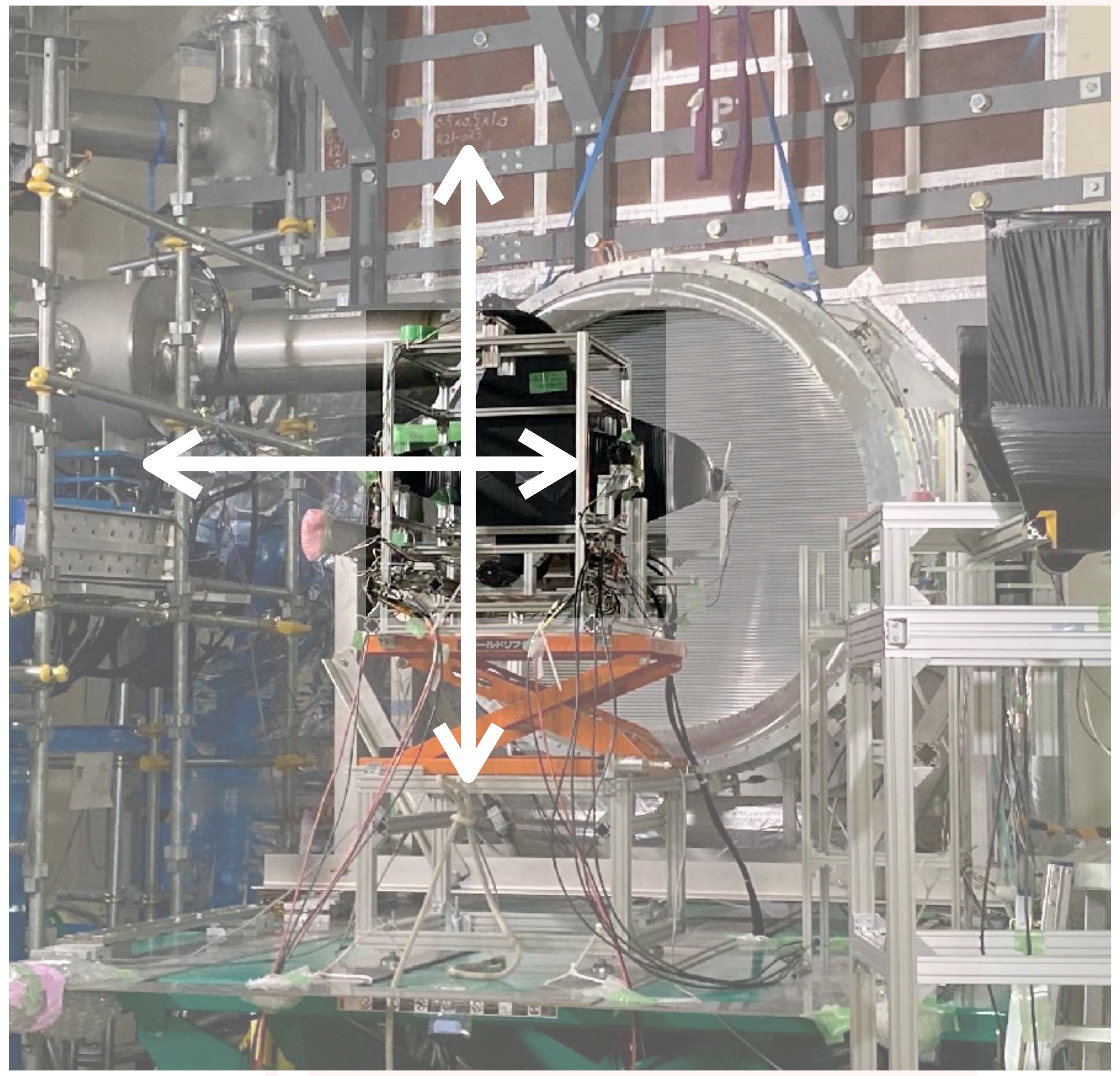
- ✦ Reconstructed the number of negative muons stopped in the muon stopper from the fitted value.
  - ★ Only statistical uncertainties plotted.
- ✦ The spectrum shape is close to our expectation from the design.

Comparison with simulation

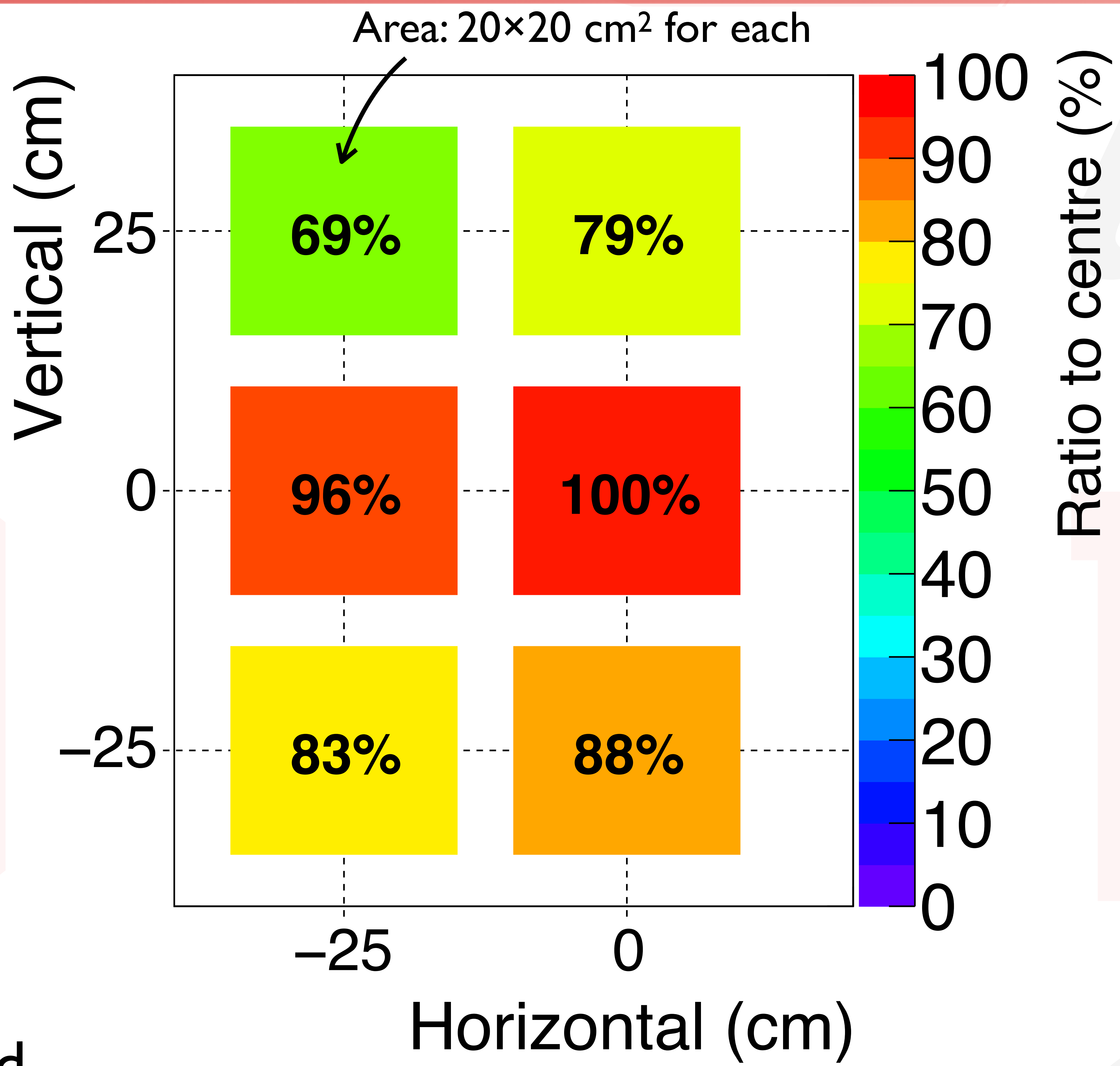
- ✦ These measurements contribute to our hadron production model studies.
  - ★ The model reproducing the data will be chosen for simulation studies for Phase-I & -II.



Results (2)



Seen from downstream



Relative difference of number of muons stopped in the muon stopper among the positions.

Muon beam 2D profile

- Moved the Range Counter two-dimensionally by 25 cm step.
- Muons with a momentum of around 40 MeV/*c* were measured.
- Muons in this momentum range are expected to concentrate around the centre in the vertical direction.

Summary and Future

Studied the COMET muon transport at Phase-α.

- Beam time: February & March 2023
- Simple beamline and detectors were developed.
- **Proton beam was successfully extracted into the COMET beam hall.**
- **Achieved the first observation of beam particles (muons) successfully transported via a 90°-curved Muon Transport Solenoid.**
- Expected muon momentum spectrum and beam profile were observed.

In the future?

- More analysis to research the muon transport optics, too, by combining all detector data.
- Measure the backward π/μ production cross-section.
- The COMET simulation software (hadron production model) will be validated.
- Further Phase-α data-taking requested.
- Move towards the Phase-I experiment!

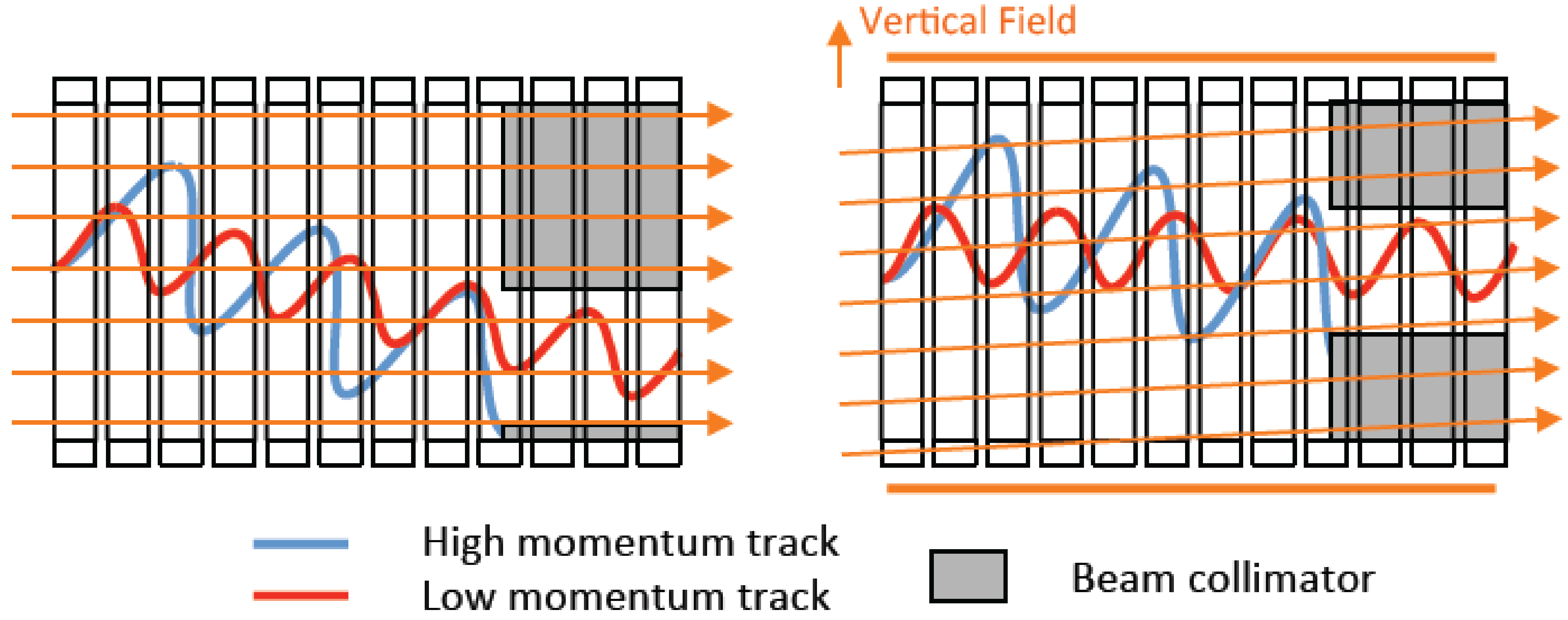
Thank you for listening

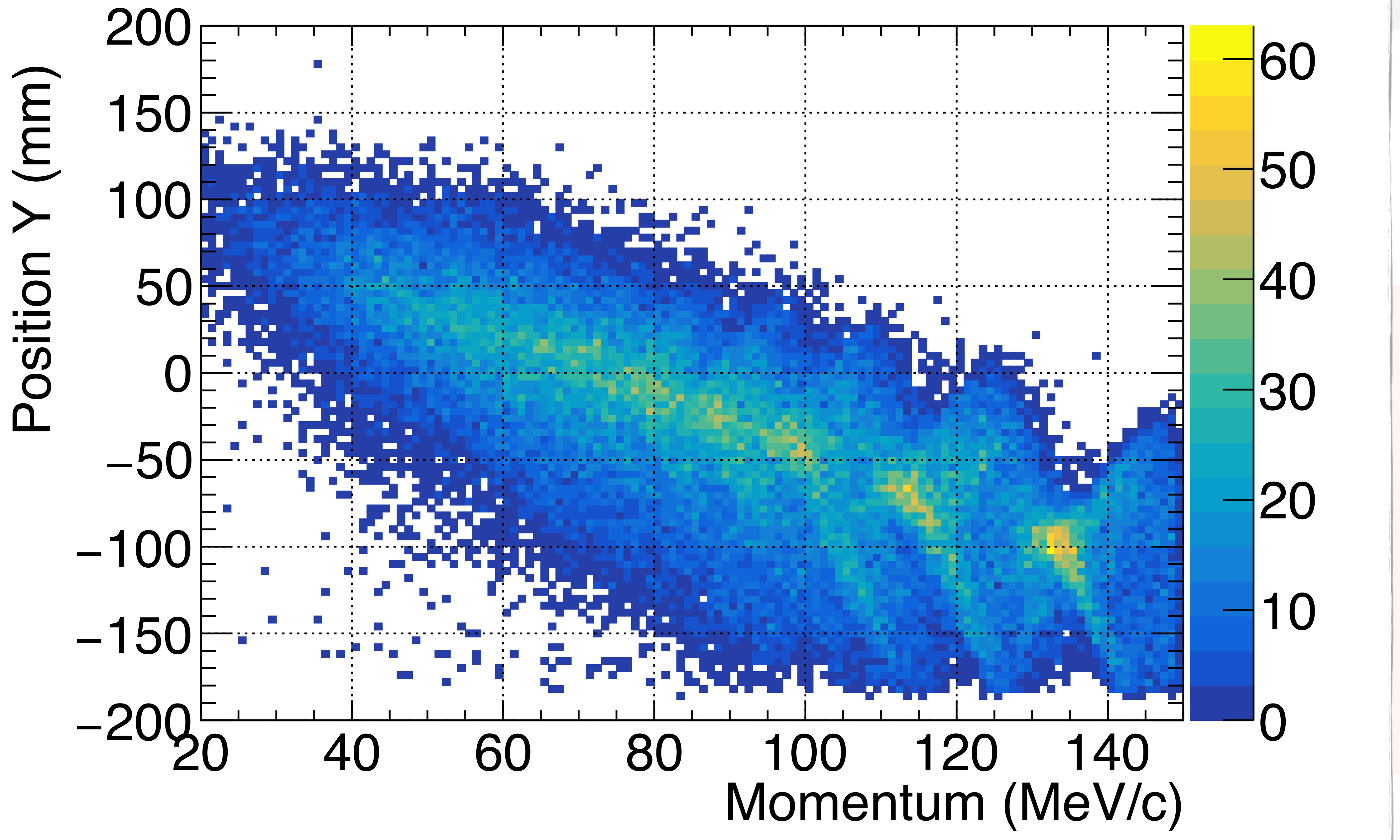
Backup

Drift in Transport Solenoid

- Drift (D) is described by

$$D = \frac{1}{qB}\left(\frac{s}{R}\right)\frac{p_L^2+\frac{1}{2}p_T^2}{p_L},$$
$$= \frac{1}{qB}\left(\frac{s}{R}\right)\frac{p}{2}\left(\cos\theta+\frac{1}{\cos\theta}\right)$$



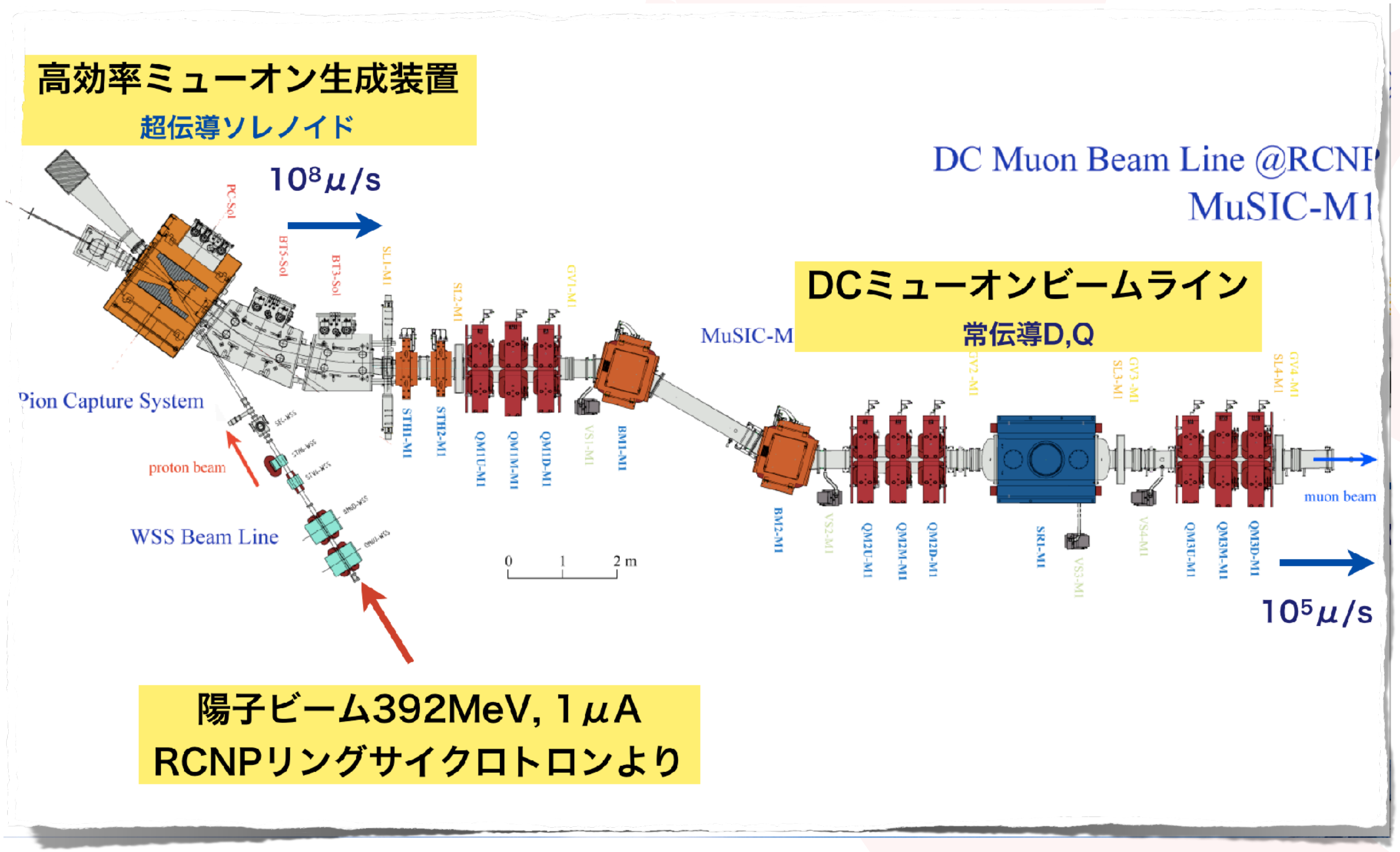


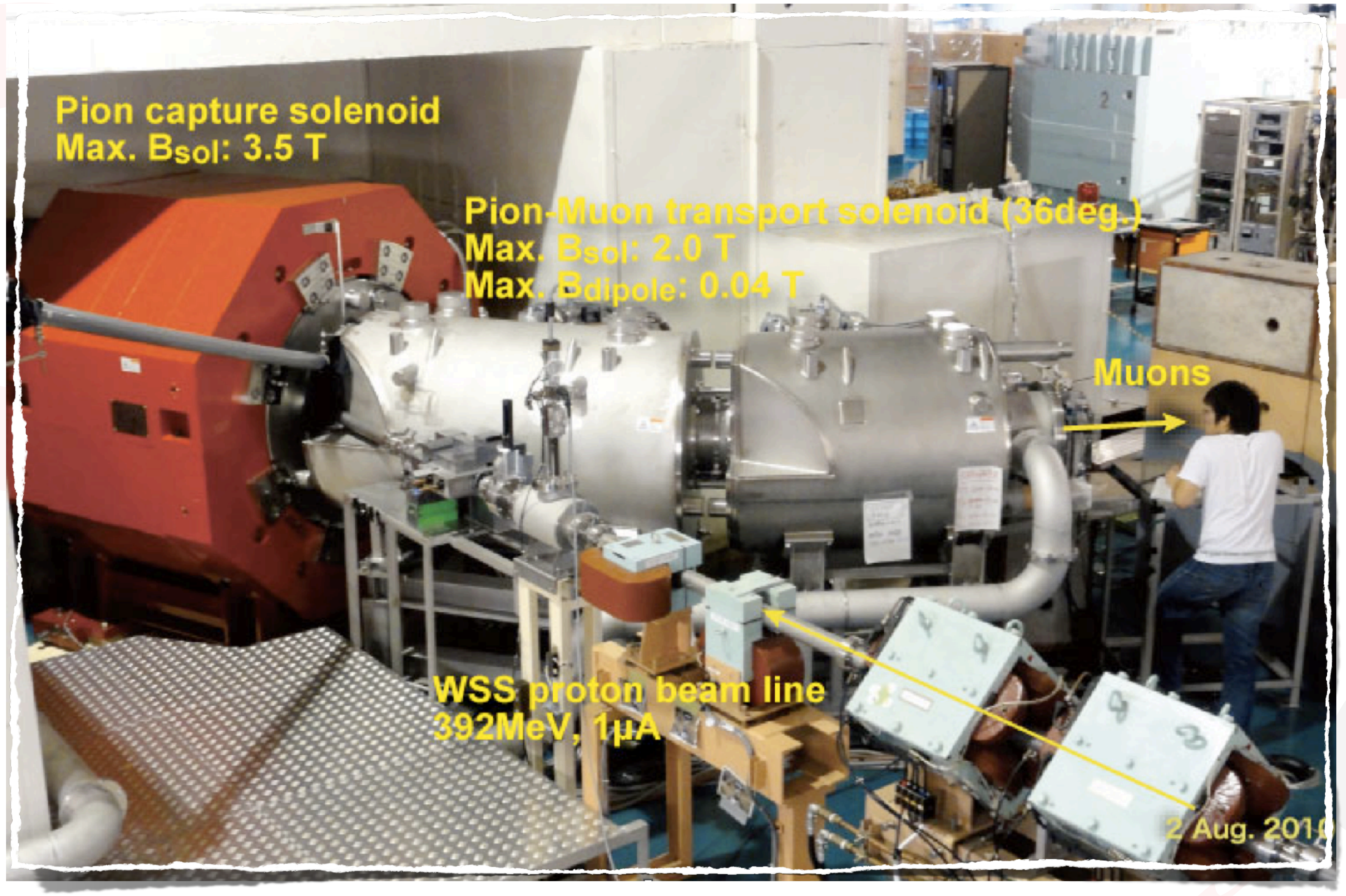
Correlation of the vertical position and momentum of negative muons reaching the end of the Transport Solenoid (3 T solenoidal field & 0.05 T dipole field)

Another Transport Solenoid

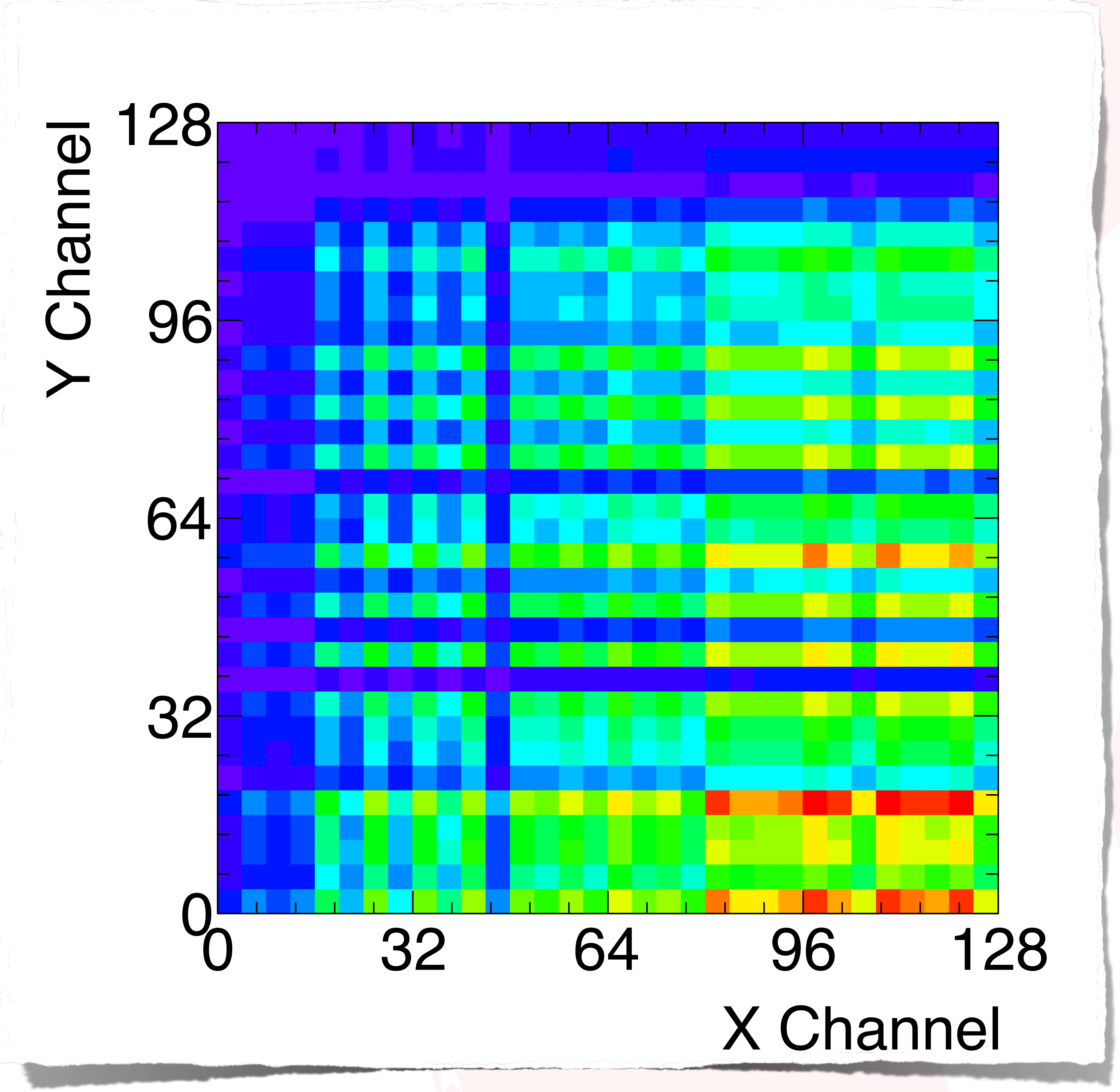
MuSIC – A pre-existing muon transport beamline

- DC Muon Beamline at RCNP, Osaka University, Japan
- Proof of concept for pion production and muon transport in COMET.
- 36°-curved muon transport solenoid (90° in COMET Phase-I, and 180° in Phase-II)

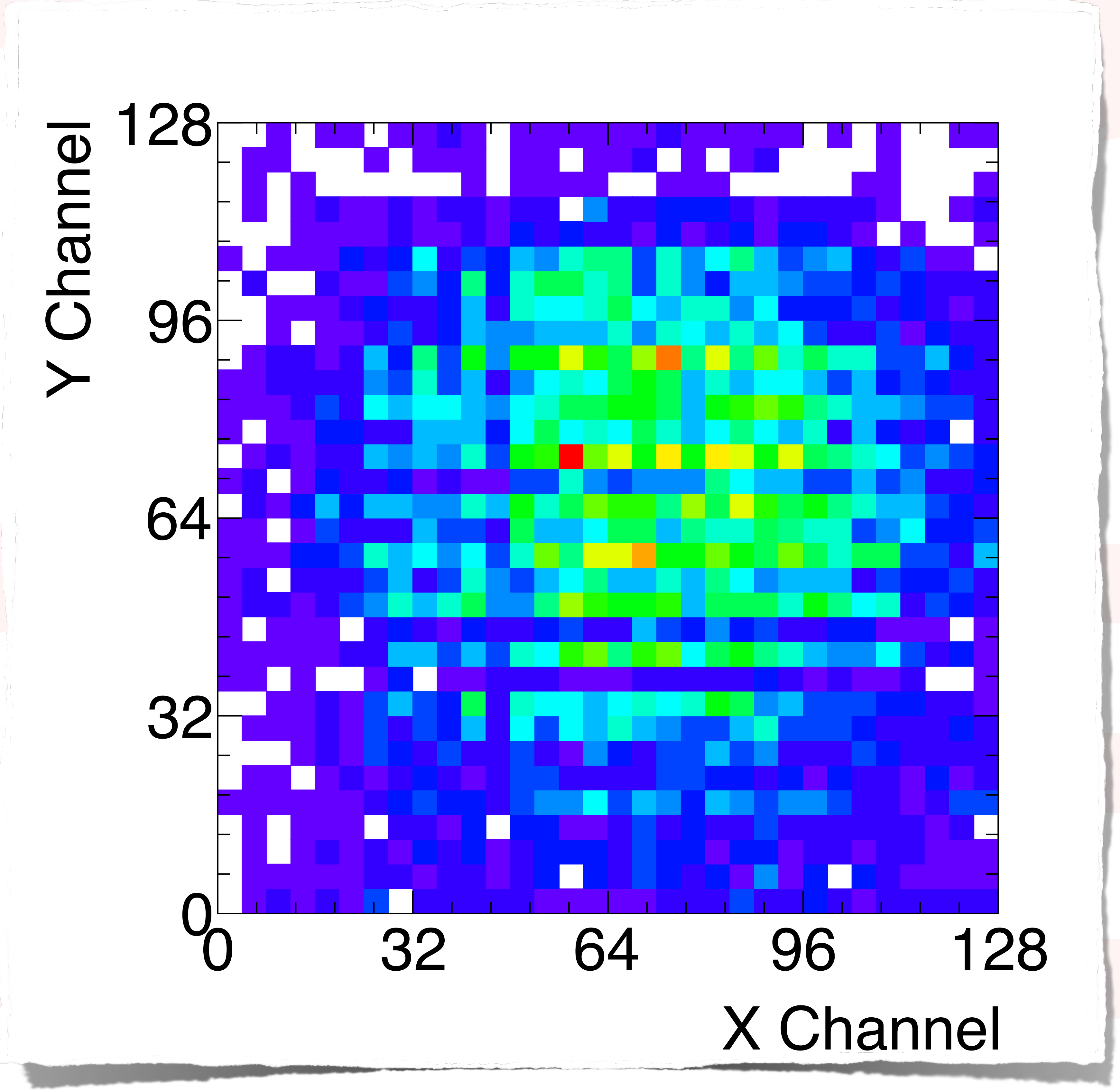




Beam profile (MBM)



All (unassociated with trigger)



Associated with trigger

- The Muon Beam Monitor measured beam profiles being not associated with the trigger signals generated by the Range Counter, too.
- Many high-momentum particles are supposed to concentrate on the bottom because of the curved solenoidal field.