T2K proton beam handling and failure analysis

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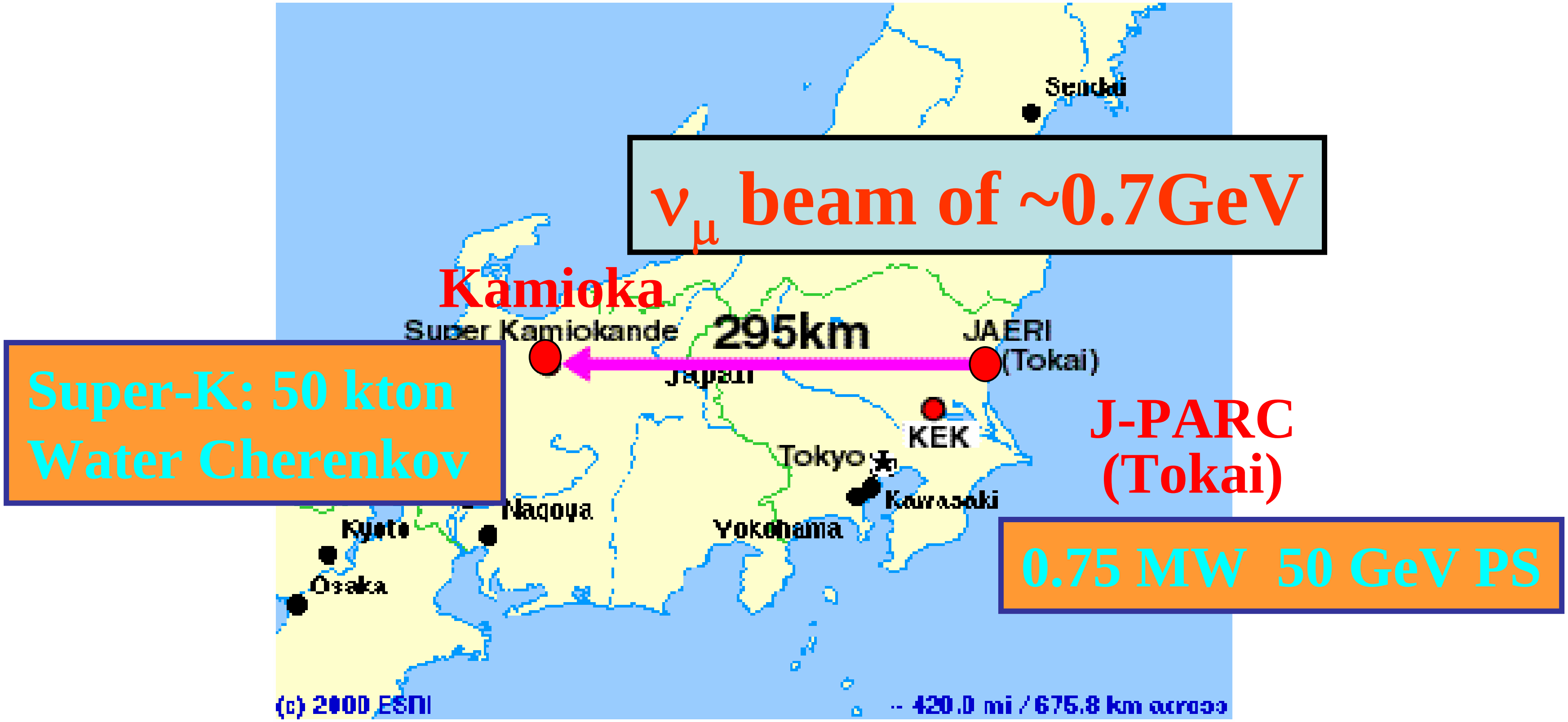
For the T2K collaboration

Introduction

T2K - From Tokai To Kamioka -

→ Next generation long baseline neutrino oscillation experiment



Introduction

T2K proton beam line

Very high-intensity Proton Beam

→ 100 times higher then K2K (750kW)

Employing the Super-conducting magnets for the Arc section
to bend the beam ~85 degree in ~250m

→ loss limit = 1W/m to avoid quenches

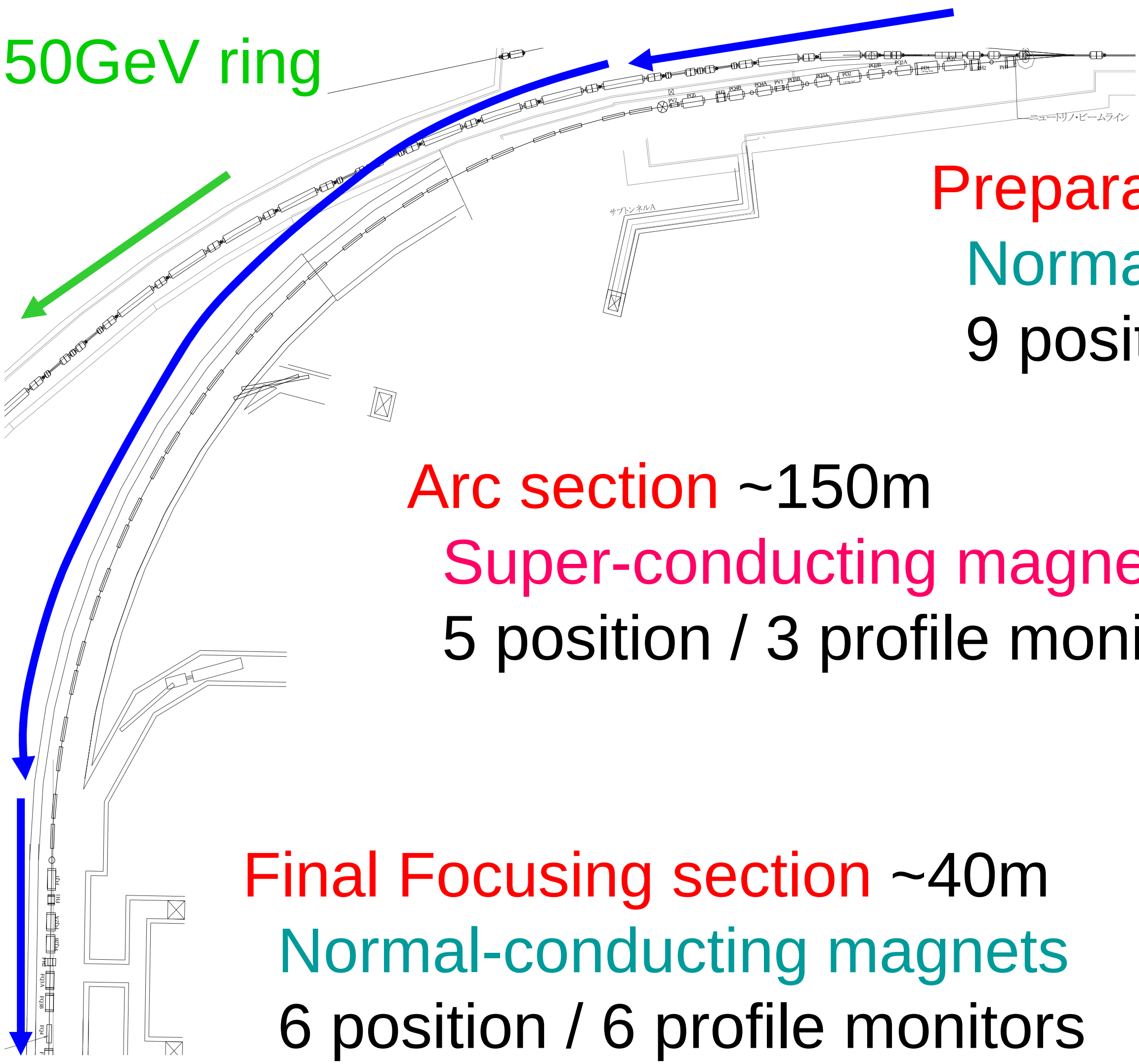
It is important to make sure

1. Can we handle the proton beam well?
2. Is the designed beam line robust?

Contents of this talk

- T2K proton beam line
- Current Status of the beam line components
  - Magnets
  - Beam monitors
- Simulation studies
  - Beam handling
  - Beam line components failure analysis
- Summary

T2K proton beam-line



Preparation section ~50m
Normal-conducting magnets
9 position / 9 profile monitors

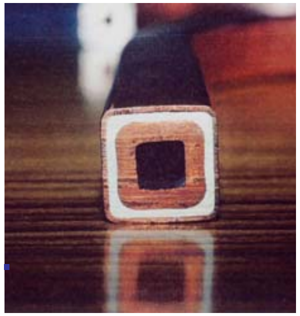
Arc section ~150m
Super-conducting magnets
5 position / 3 profile monitors

Final Focusing section ~40m
Normal-conducting magnets
6 position / 6 profile monitors

Current Status of the beam line components

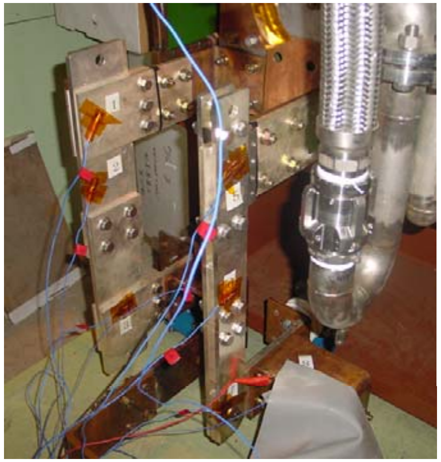
1.Normal-conducting magnets

Designed with
- high radiation-resistance (mineral/polyimide insulation)
- quick cable/pipe connection
- remote installation/de-installation.



Mineral-Insulated Coil

Quick Water-Coupler



Quick Knife-Switch for 3000A

Components developed for hadron beam-line by former KEK-PS beam-channel group.

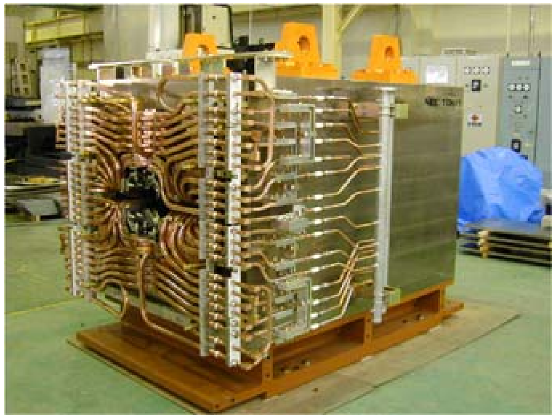
Preparation Section

12 magnets under fabrication (two are recycled ones)
will be installed in July 2007.

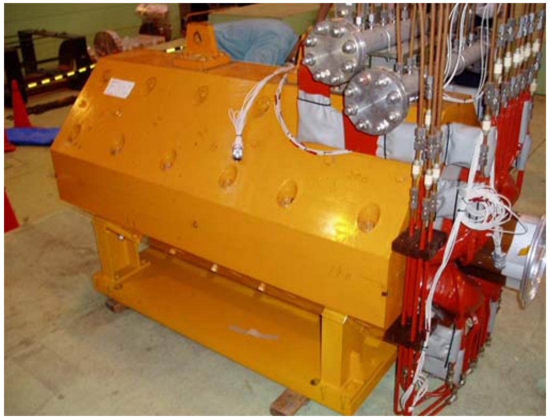
Final-Focus Section

10 magnets (5 are recycled ones)
Machining Iron yokes
will be installed in July 2008.

Cabling, piping, and commissioning will be in 2008.

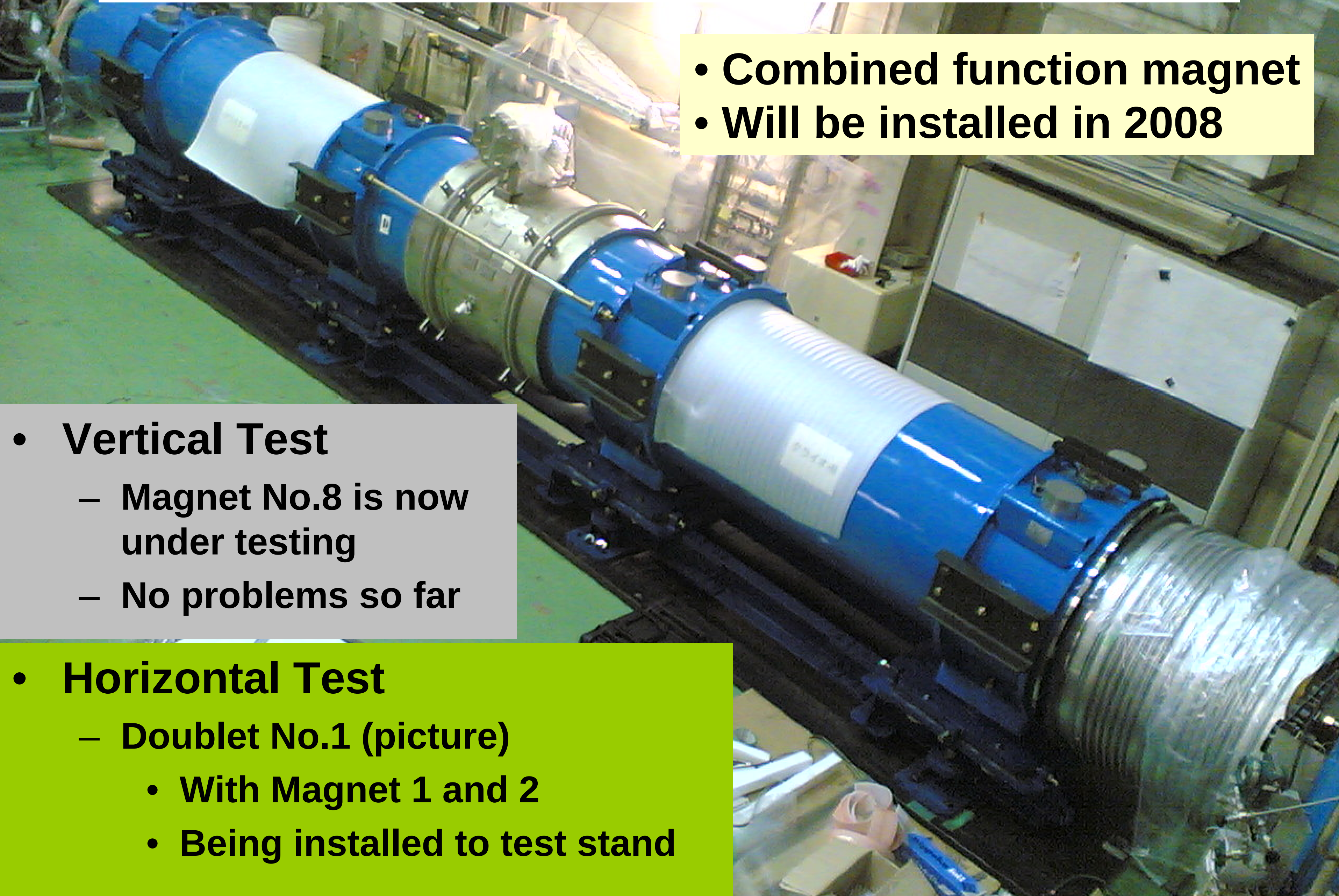


One of the largest Q-magent with MIC



Q-magent to be Recycled

2. Superconducting Magnet

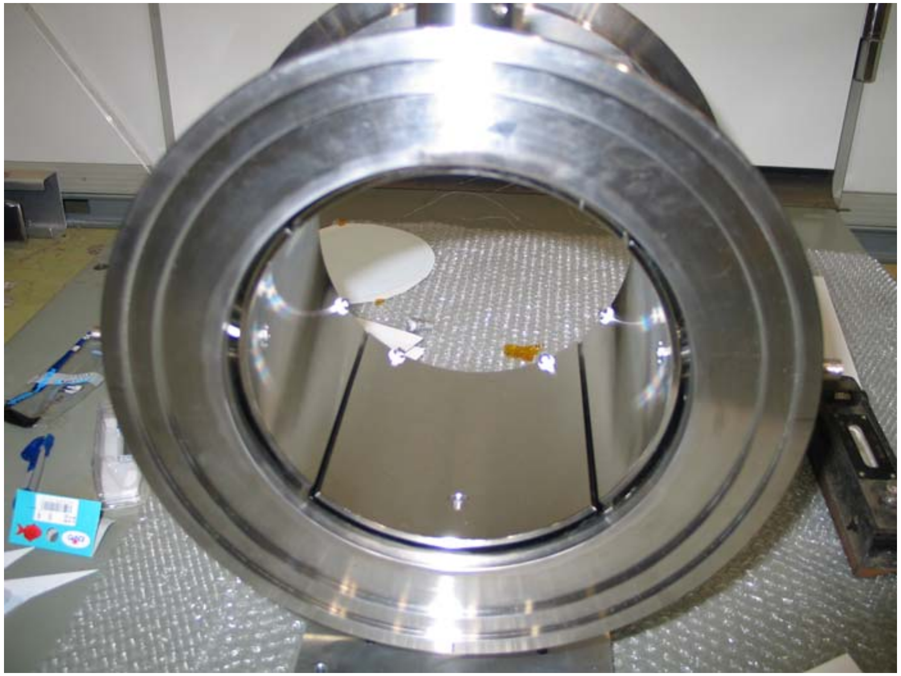


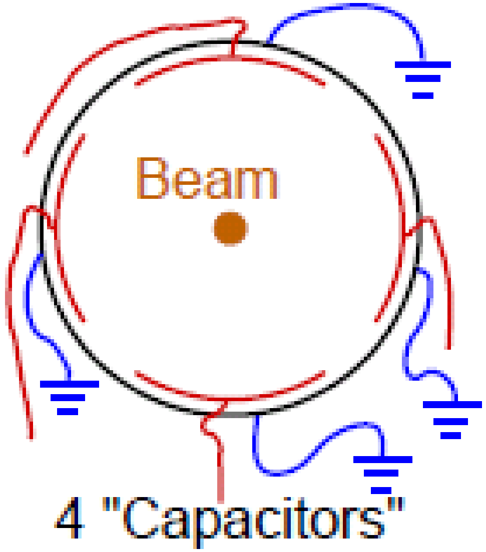
- Combined function magnet
- Will be installed in 2008

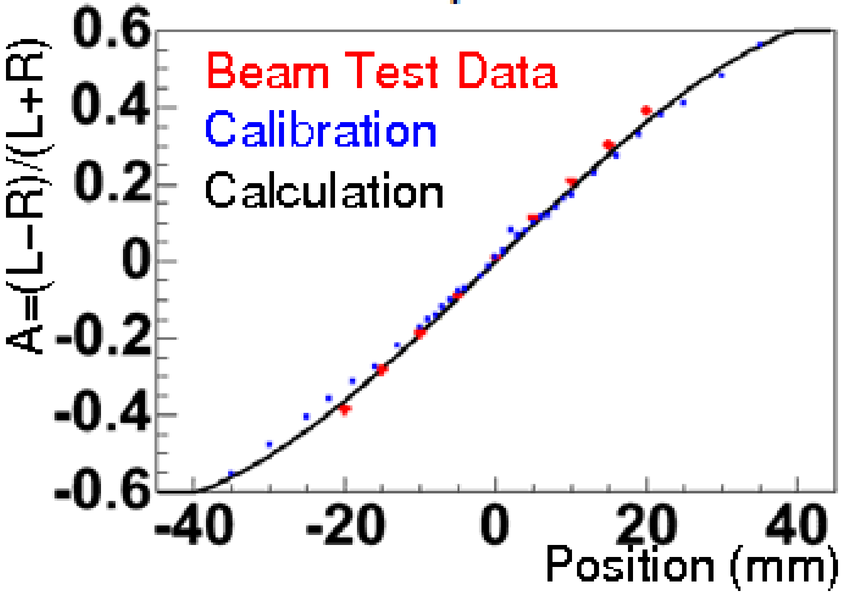
- **Vertical Test**
  - Magnet No.8 is now under testing
  - No problems so far
- **Horizontal Test**
  - Doublet No.1 (picture)
    - With Magnet 1 and 2
    - Being installed to test stand

3. Beam Position Monitor

ESM: Electrostatic Monitor



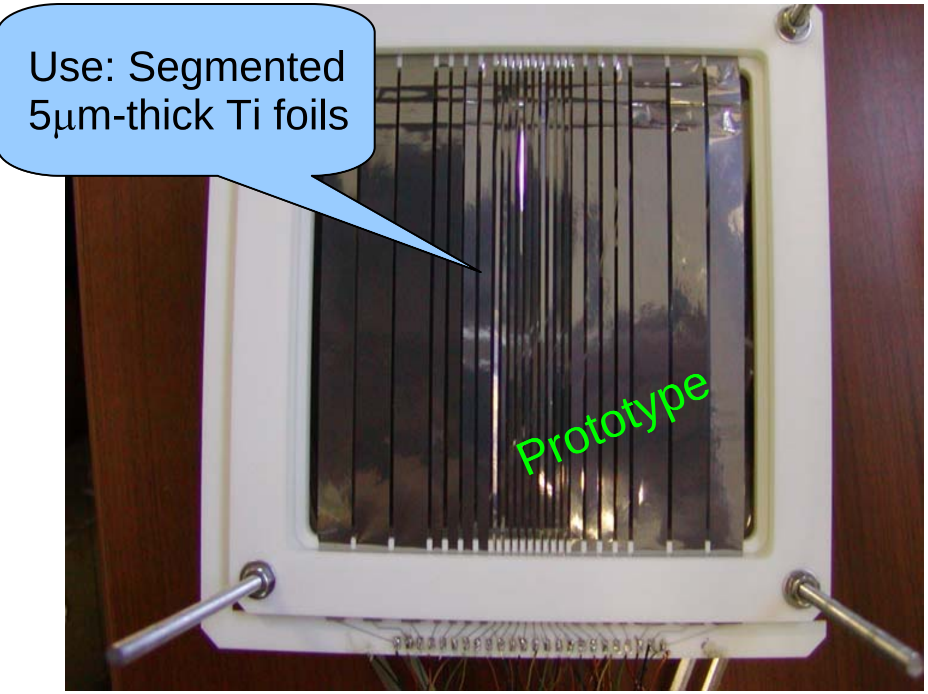


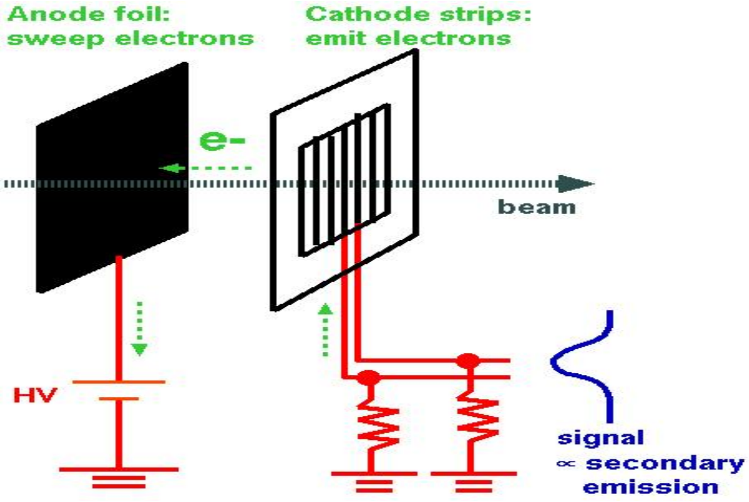


- Non-destructive
- Simple structure
- Resolution at T2K ~0.24mm

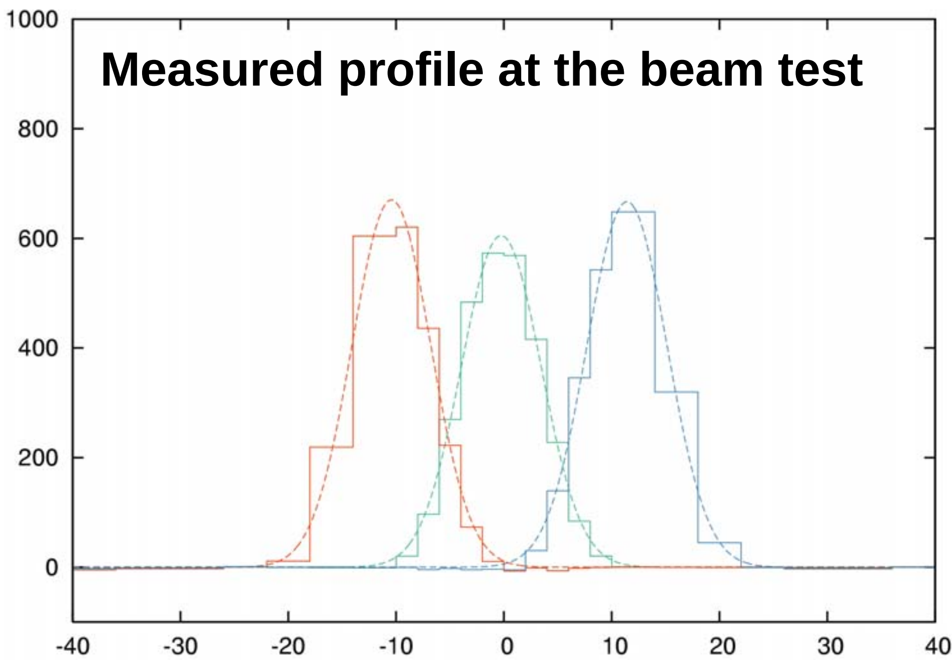
4.Beam profile monitor

SSEM: Segmented Secondary Emission Monitor





- Not the non-destructive type
  → Only for the beam tuning
- Simple structure
- Beam width resolution at T2K
  ~3.5% of the beam size
  (0.18-0.60 mm)



Simulation Studies

1. Beam handling

Here we want to make sure if the current monitor configuration can handle the proton beam well.

Beam tuning strategy

At first, deliver the beam to the target. Then adjust the size.

Prep section : Measure beam emittance and Twiss parameter

→ Optics tuning to adjust the beam size at the Arc section

Arc section : Monitor the beam position / size

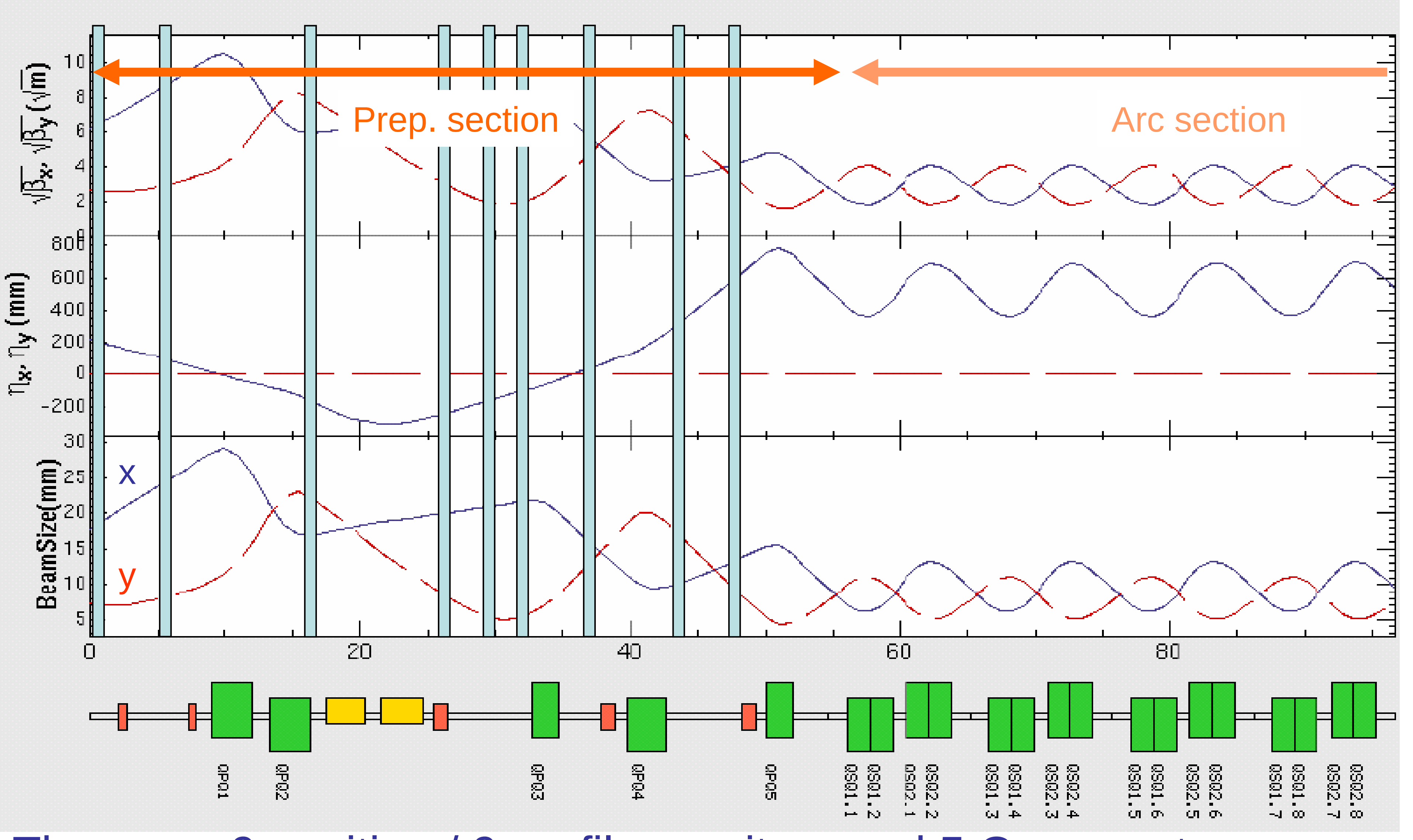
FF section : Extract the beam position and width at the target

→ Optics tuning to adjust the beam size at the target

In this study, we estimate

1. Expected beam emittance and Twiss parameter resolutions at the Prep. section
2. Expected beam position and width resolutions at the target

1. Emittance / Twiss parameter measurement at the Prep. section



There are 9 position / 9 profile monitors and 5 Q-magnets

Emittance / Twiss parameter measurement at the Prep. section

Using the 9 monitors, we measure the beam parameters. (emittance and Twiss parameters)

Here we assume the profile monitor (SSEM) resolution of ~3.5% of the beam size (0.18mm – 0.60mm)

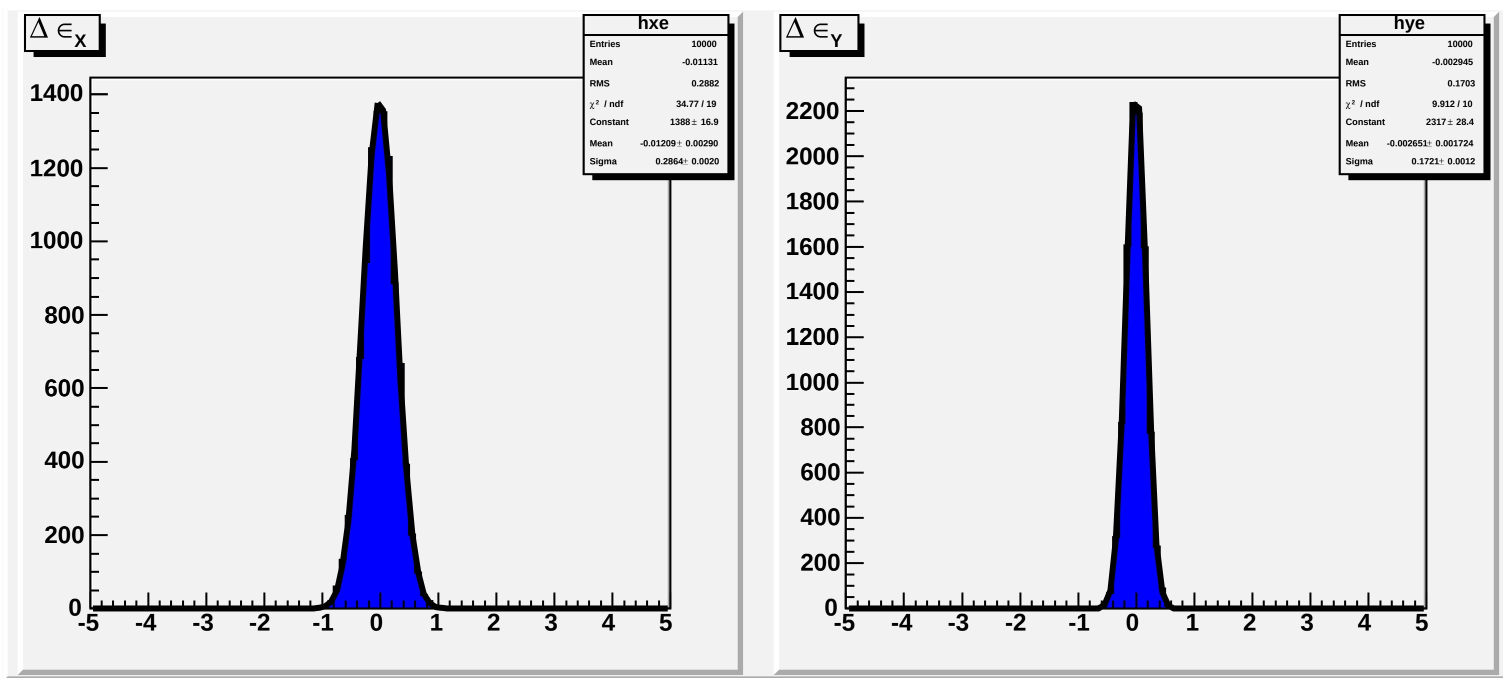
1. Simultaneous fit of the beam parameters (beam emittance and Twiss parameter. Field of Q-magnets are fixed)

2. Simultaneous fit of the beam parameters and field of Q-magnets (Here we can fit 1st , 2nd, and 4th magnets)

Beam parameter resolutions

Profile monitor resolution 0.18 – 0.60 mm
Q-magnets values are fixed

Emittance



$\Delta\varepsilon(x) \sim 4\%$ $\Delta\varepsilon(y) \sim 2\%$

Twiss parameters $\Delta\alpha(x) \sim 4\%$ $\Delta\alpha(y) \sim 12\%$

$\Delta\beta(x) \sim 3\%$ $\Delta\beta(y) \sim 3\%$

Simultaneous fit of the beam parameters and Q magnets

We can perform the simultaneous fit of beam parameters and Q-magnet field values (1st, 2nd and 4th magnets)

→ Can check the Q-magnets and measured emittance values

1. Q-magnets values are all fixed

   $\Delta\varepsilon(x)$ 4% $\Delta\varepsilon(y)$ 2%

2. Simultaneous fit of beam parameters + PQ2 + PQ4

   $\Delta\varepsilon(x)$ 5% $\Delta\varepsilon(y)$ 2% ΔPQ2 0.6% ΔPQ4 1.0%

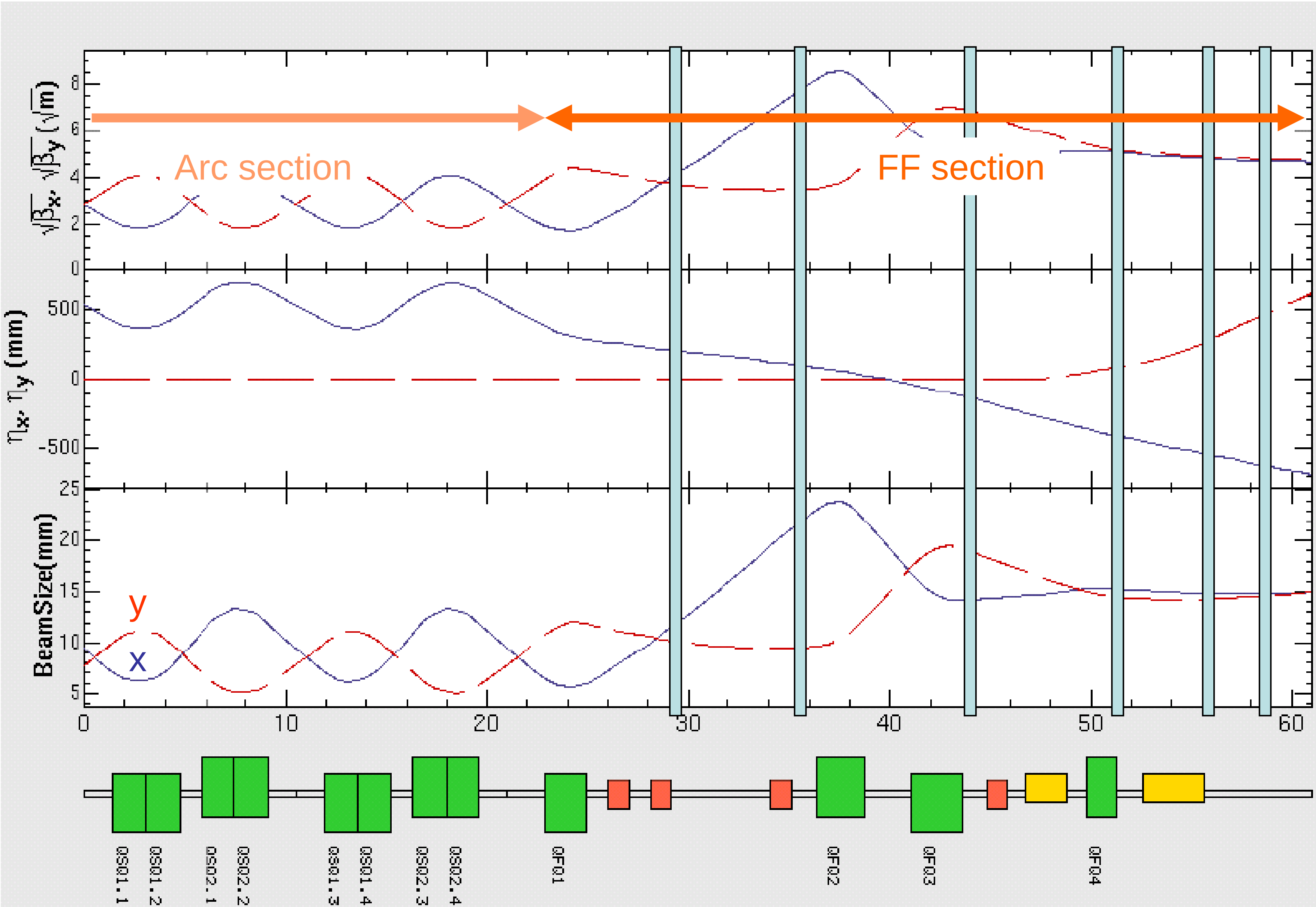
3. Simultaneous fit of beam parameters + PQ1 + PQ4

   $\Delta\varepsilon(x)$ 6% $\Delta\varepsilon(y)$ 2% ΔPQ1 1.6% ΔPQ4 1.0%

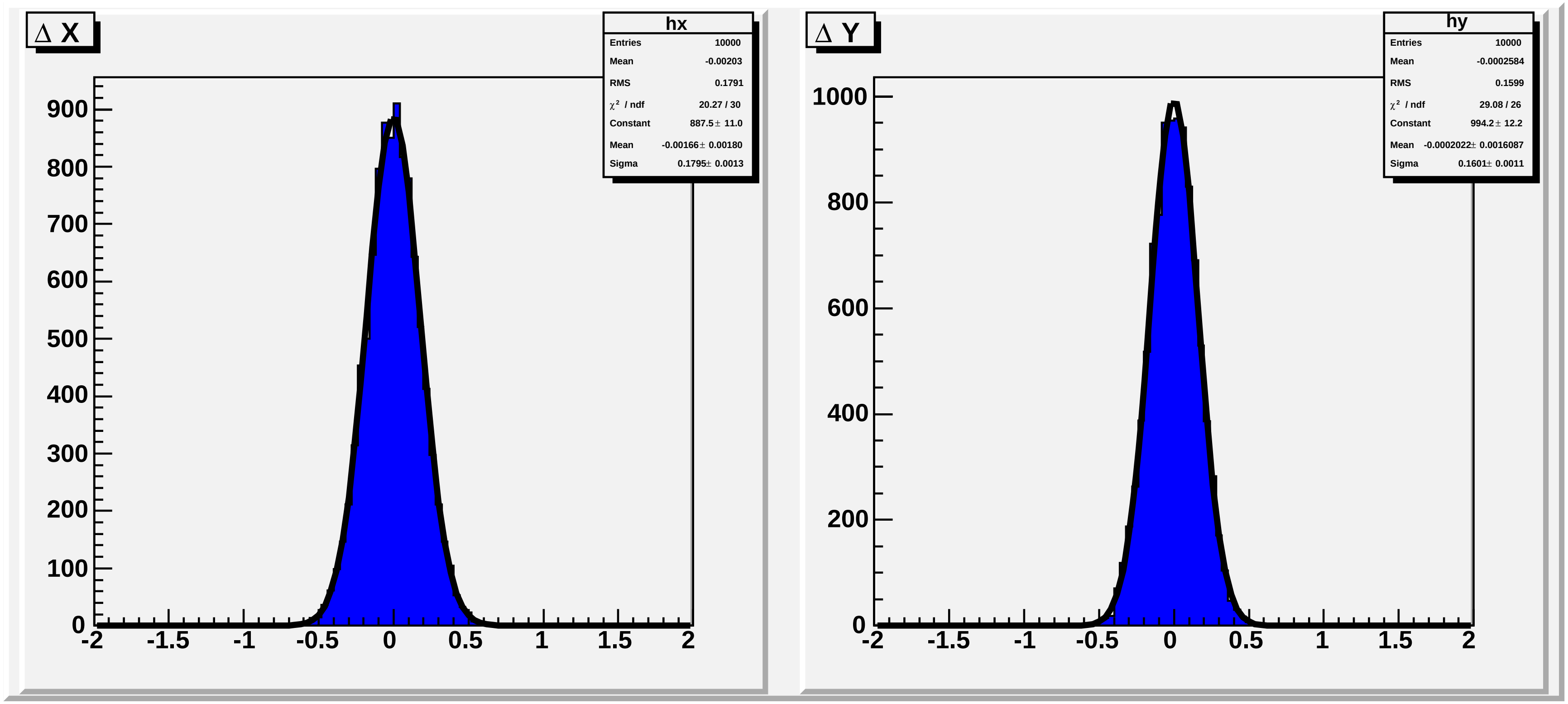
Using the simultaneous fit, we can check the Q magnets with 0.6 – 1.6% accuracy

Beam position / size extraction at the Target

Using 6 position/profile monitors at the FF section and the measured ε, we extract the beam position and width at the Target



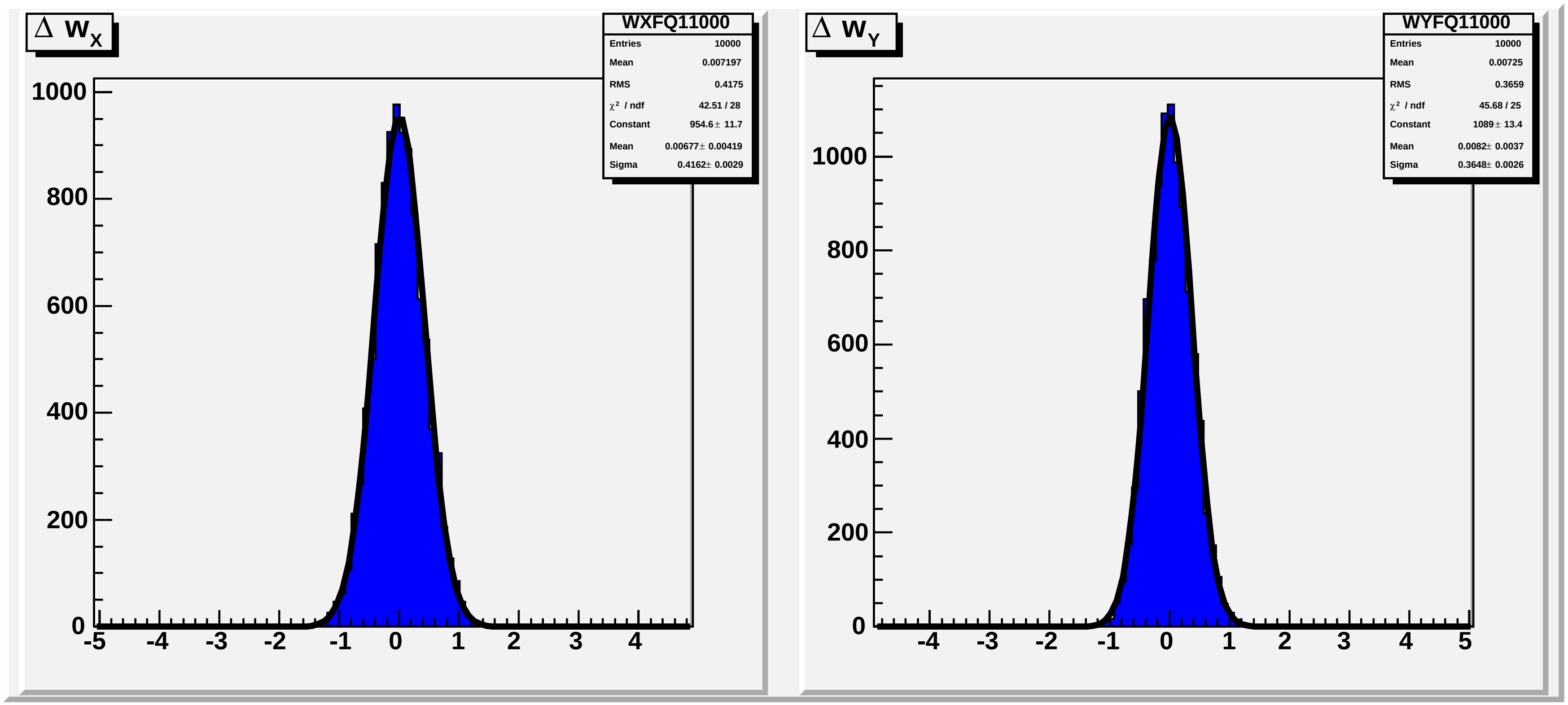
Beam position extraction resolution
(assumed ESM resolution .. 0.25mm)



Δx = 0.18mm　　　　Δy = 0.16mm

Required position resolution is 1mm.

Beam size extraction resolution
(assumed SSEM resolution .. 3.5% of the beam size)



$\Delta\sigma(x) = 0.36$mm $\Delta\sigma(y) = 0.30$mm

(Simultaneous fit $\Delta\sigma(x) = 0.63$mm $\Delta\sigma(y) = 0.48$mm

$\Delta\varepsilon(x) = 15\%$ $\Delta\varepsilon(y) = 6\%$)

Compared to the beam size of 15.0mm at the target

Simulation Studies

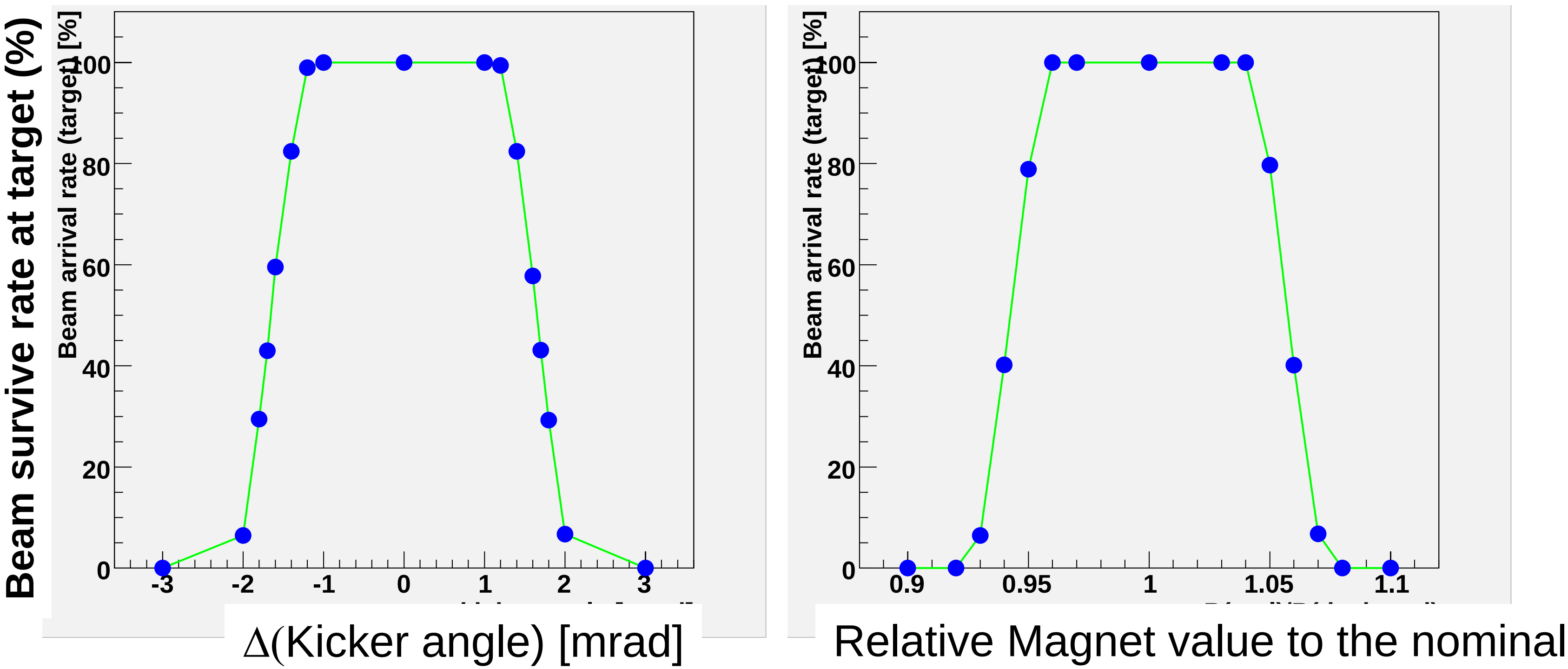
2. Beam line components failure analysis

Here we want to make sure if our beam line is robust against the beam line components failure.

- In this study, we use full simulation code (GEANT4)
- Vary magnet values / kicker bending angle and see the beam failure effect (estimate the tolerance to deliver the beam core)
- Estimate the effect of the beam line damage due to the beam failure

Beam line components tolerance to deliver the beam core

Vary magnet values / kicker bending angle and estimate how many particles can reach to the target plane (beam core)



<u>Estimated tolerance to deliver the beam core to the target</u>

Kicker : 1 mrad

Arc. section magnet : ~3%

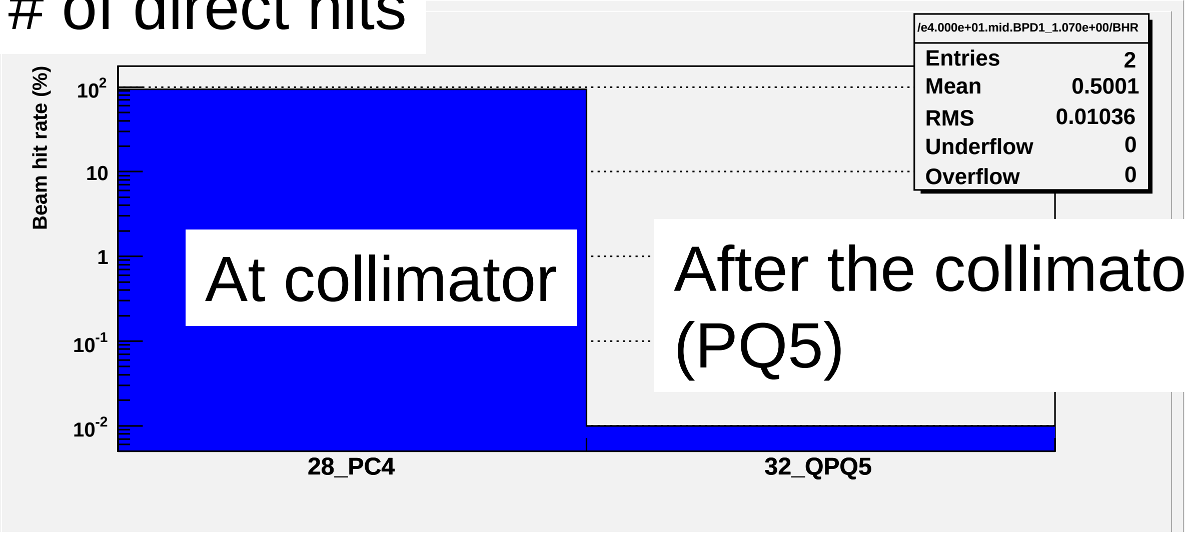
Prep. section magnet : ~5%

FF section magnet: ~25%

Beam failure effect

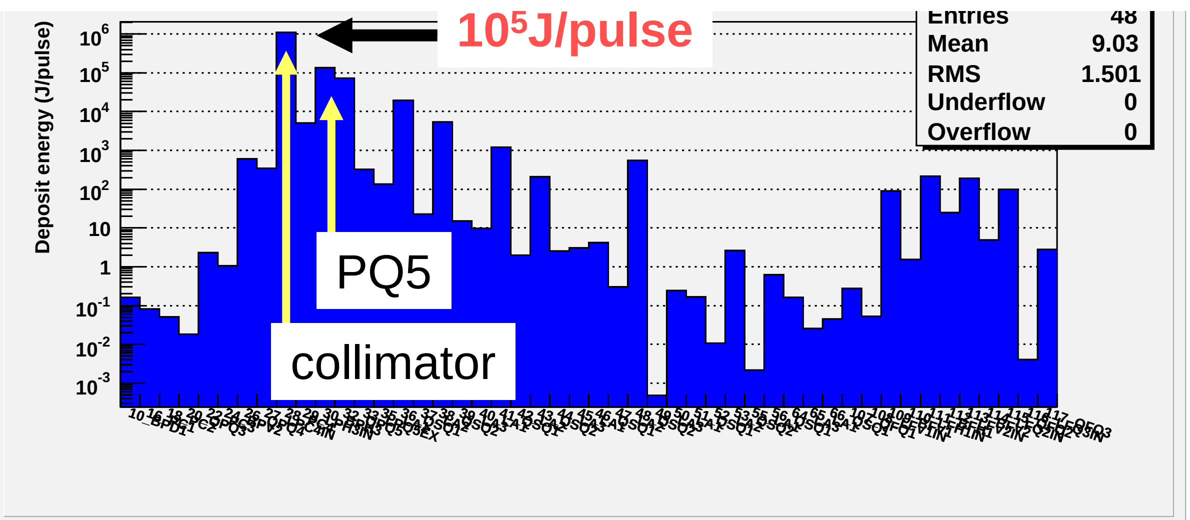
Vary 7% of the prep. section magnet value
(which is over the tolerance of 5%)

of direct hits



Collimator can absorb ~99.99% of the direct hits

Energy deposit (including the secondary particle hits)



But it makes secondary showers…

Summary

Beam line components (magnets, monitors) are
under construction / ready for the production

Several simulation studies has been done

1. With the current monitor configuration, accuracy of the beam parameter measurements are

   $\Delta\varepsilon(x)$ = 4% $\Delta\varepsilon(y)$ = 2%

   Beam position at the target : 0.2mm(x) 0.2mm(y)

   Beam size at the target : 0.4mm(x) 0.3mm(y)

2. Estimate the tolerance of the beam line components to deliver the beam core to the target