Two-Dimensional and Wide Dynamic Range Profile Monitor Using OTR /Fluorescence Screens for Diagnosing Beam Halo of Intense Proton Beams

OTR/Fluorescence Beam profile monitor

KEK / J-PARC

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- Motivation
- Concept
- J-PARC and 3-50 Beam Transport Line
- OTR by Low γ : 3GeV Proton Beam
- Large Acceptance Optics & Detector
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- Simultaneous measurement of beam core and beam halo
- Conclusions

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- Motivation

Beam halo : It brings serious activation of the accelerator by beam loss

What to see?

Two-dimensional density distribution from beam core to beam halo of 3GeV Proton Beam.

Beam Intensity ≥ 10^{13} proton/bunch

What kind of instrument?

High Dynamic Range Beam Profile Monitor

Dynamic Range: 10^{6}

What is carried out?

Beam diagnosing for injection beam of J-PARC MR which is extracted beam from RCS.

Evaluation for validity of beam collimation by the collimator

Contents

Concept (1): *Dynamic range*

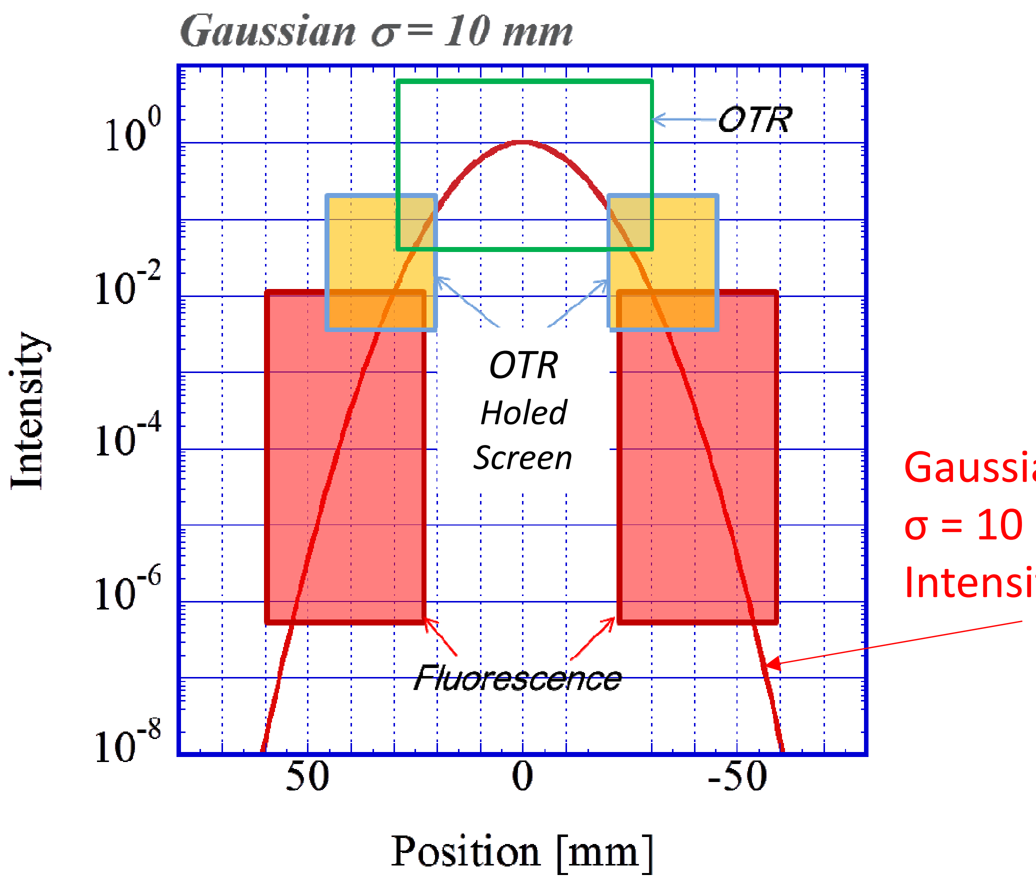
OTR/FLUORESCENCE BEAM PROFILE MONITOR

Combination measurement with OTR and the fluorescence:

Beam core : Measure with OTR from 10 microns titanium foil with smaller beam loss

Beam Halo : Measure with Fluorescence from Chromium doped alumina screen

Adopting Suitable Gain of the Detector: Image Intensifier (II)



Gaussian Beam distribution
σ = 10 mm
Intensity: 10^{13} proton/bunch

Concept (2): *Energy loss in screen*

Combination measurement with OTR and the fluorescence:

Beam core : Measure with OTR from 10 microns titanium foil with smaller beam loss

Beam Halo : Measure with Fluorescence from chromium doped alumina screen

Energy Loss in using material

	Energy Loss [keV/proton]*	Total Energy Loss [J/bunch]**
Titanium Foil 10 micron thick	6.7	9.8e-3
Alumina Ceramics 0.5 mm thick	330	4.7e-1

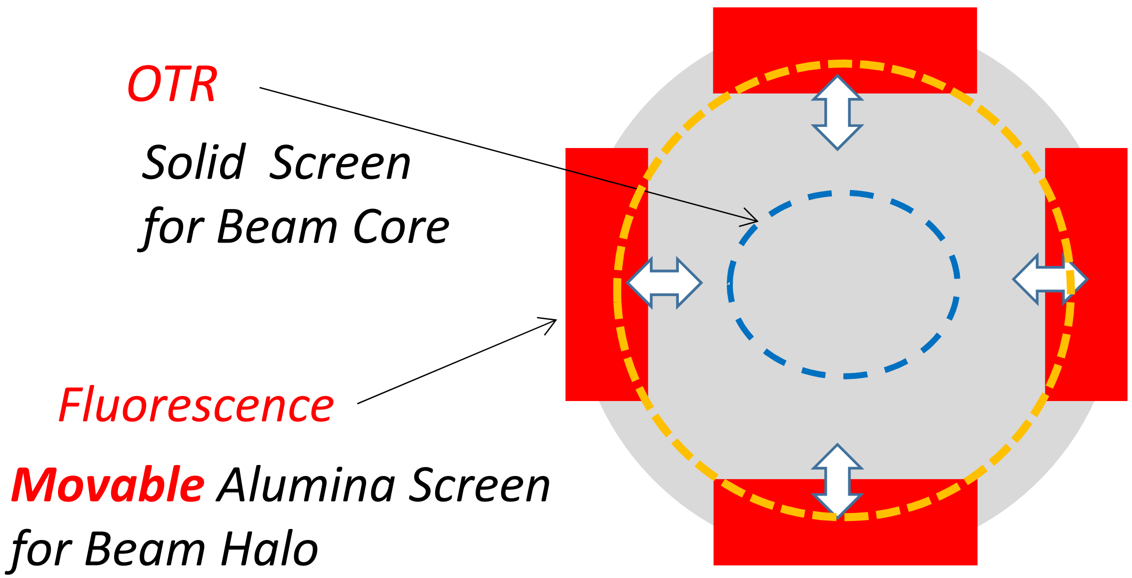
* 3GeV Proton, ** 1e13 proton/bunch

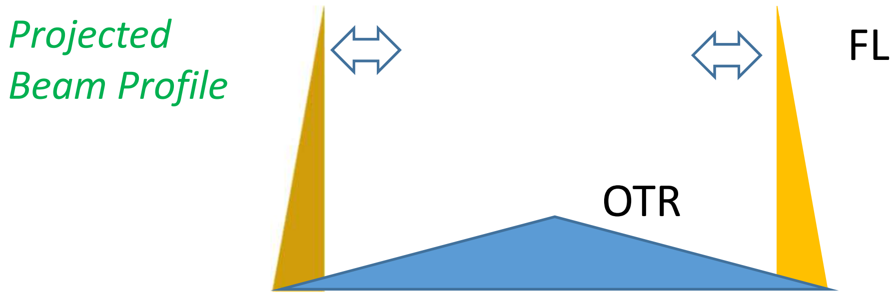
48 times larger than 10 micron Ti

Used in only 10^{-2} region:
4.7 e-3 [J/bunch]
Becomes 1/2 of Ti

Concept (3): *Screen Configuration*

Layout (Front View)





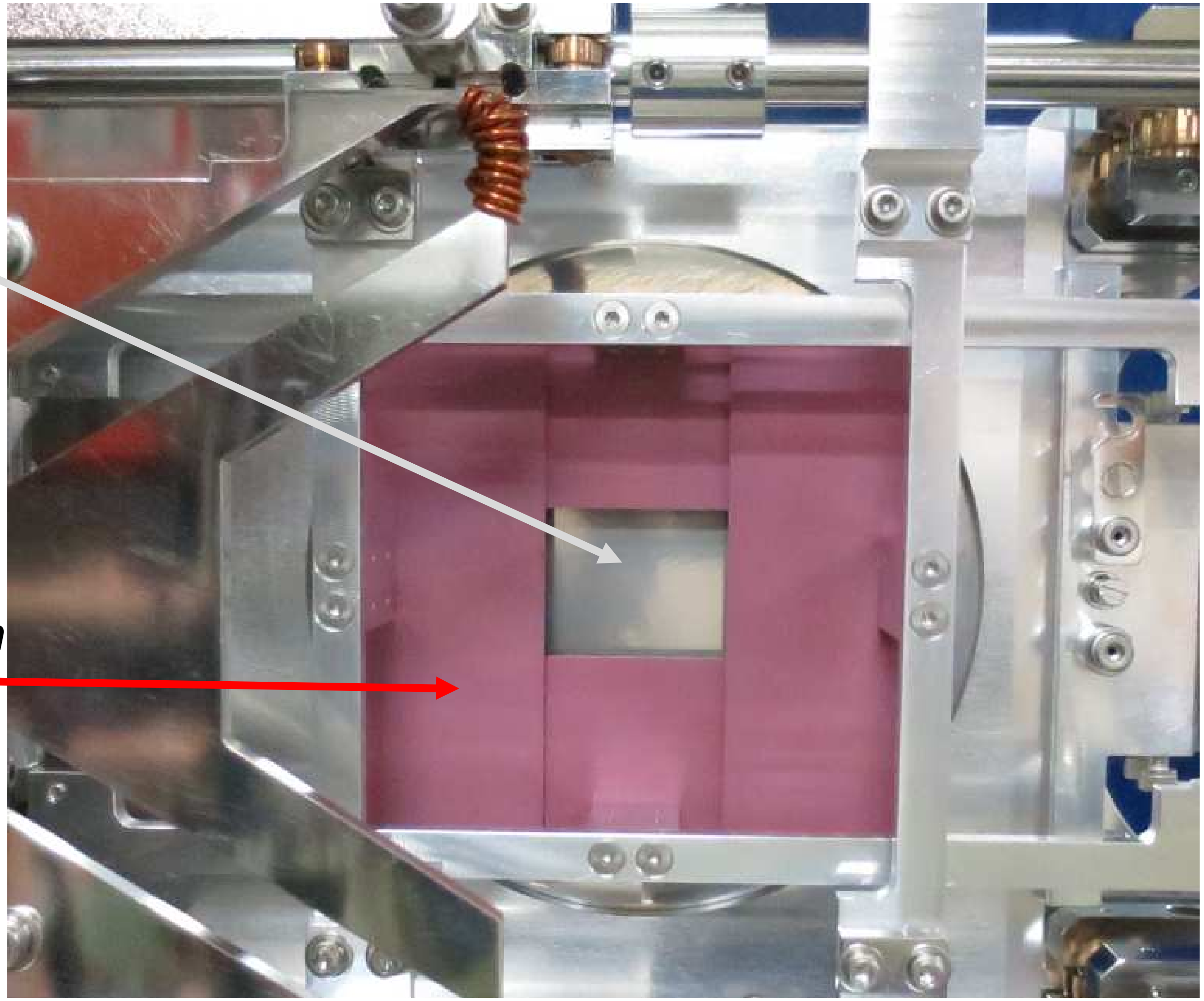
Concept (4): *Screen photo (front view)*

OTR

Solid Screen
for Beam Core

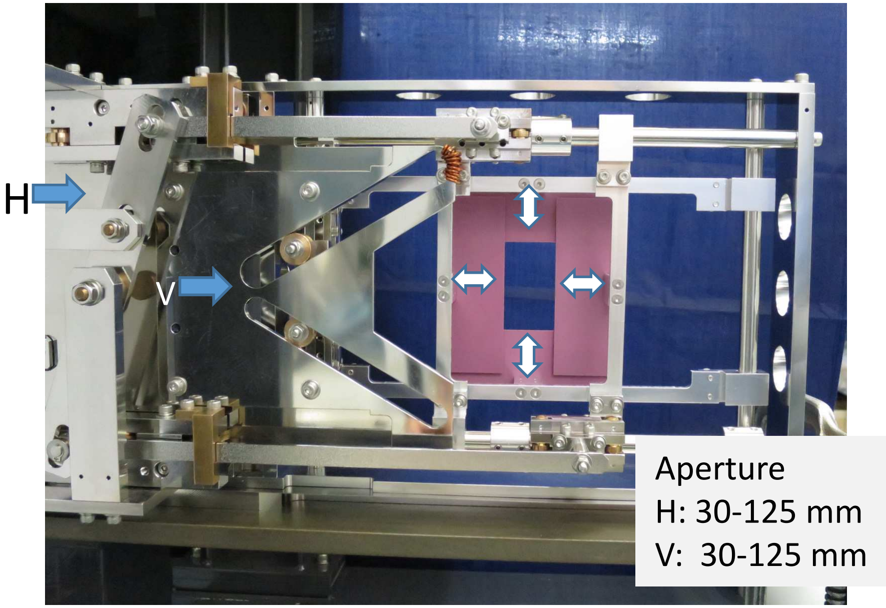
Fluorescence

Movable *Alumina Screen*
for Beam Halo



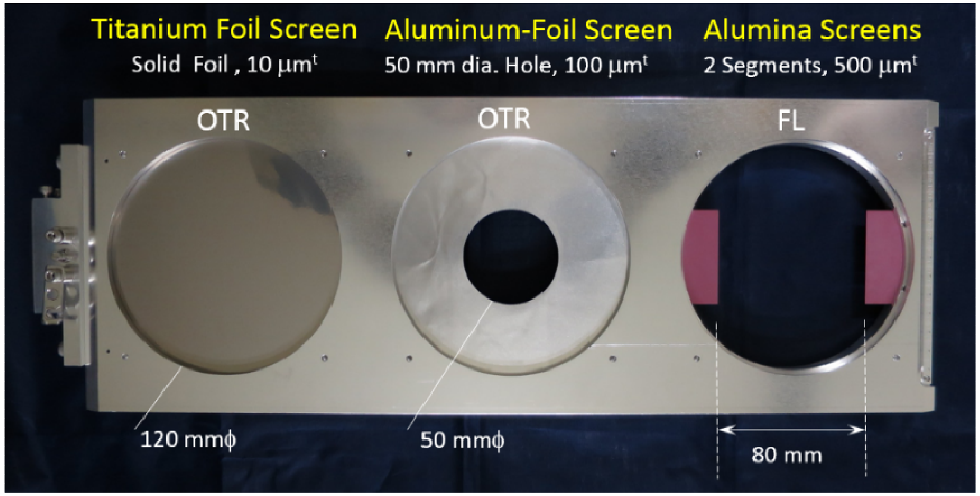
Concept (5): *Two Target Structures*

New four-direction alumina screen.

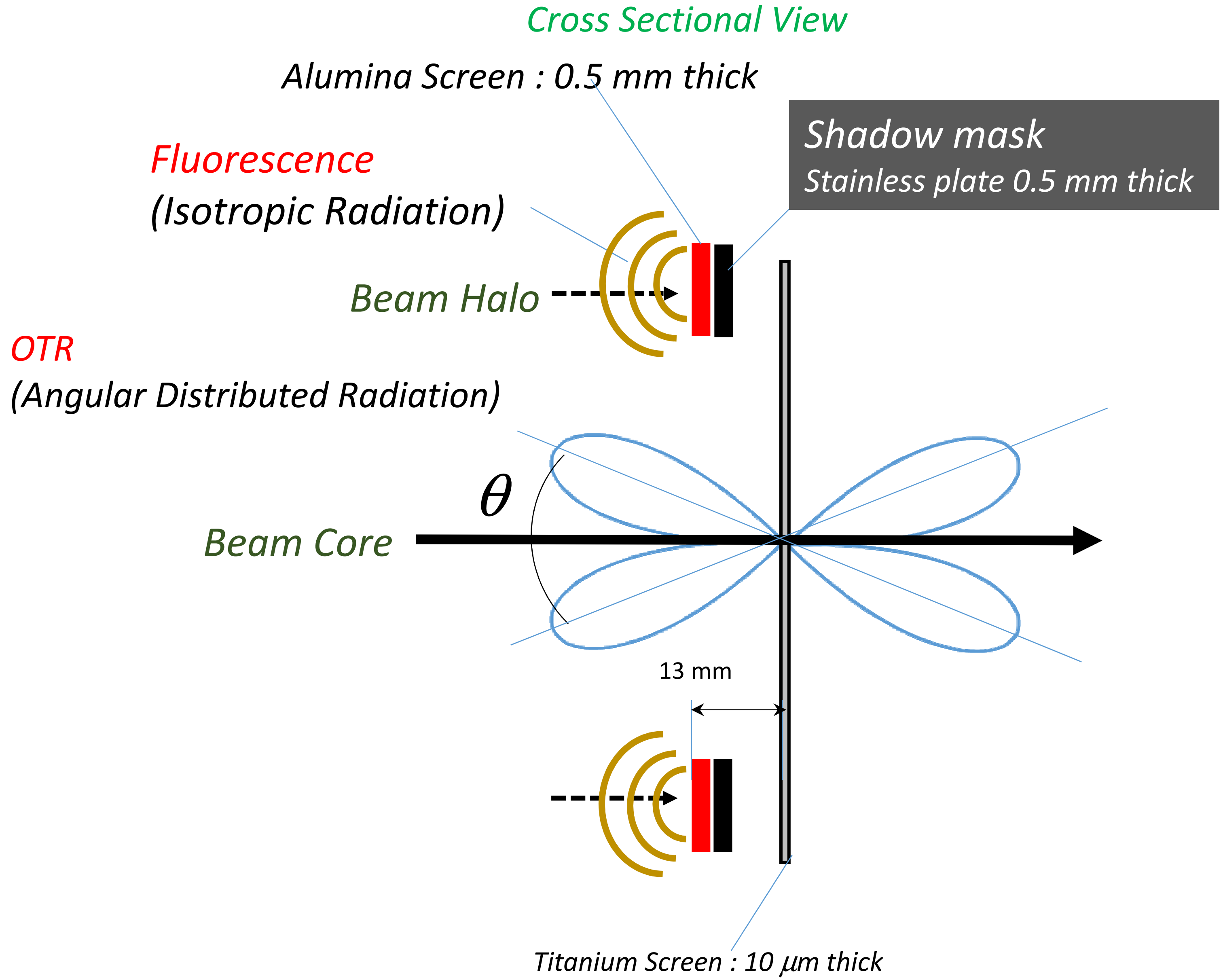


Operate by two horizontal movable shafts.

Pre-existing triple screen
→ Inserted just after four direction screen



Concept (6): *Screen Configuration-2*

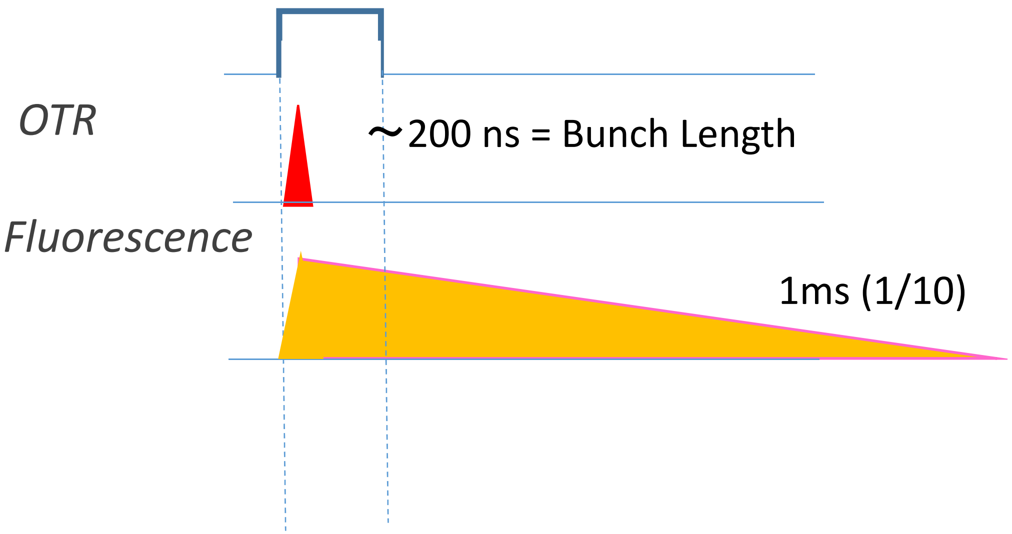


Concept (7): *Fluorescence time*

Light quantity adjustment of the fluorescence from alumina screen
longer fluorescence time of 1ms
⇒Changing the Image Intensifier (II) Gate

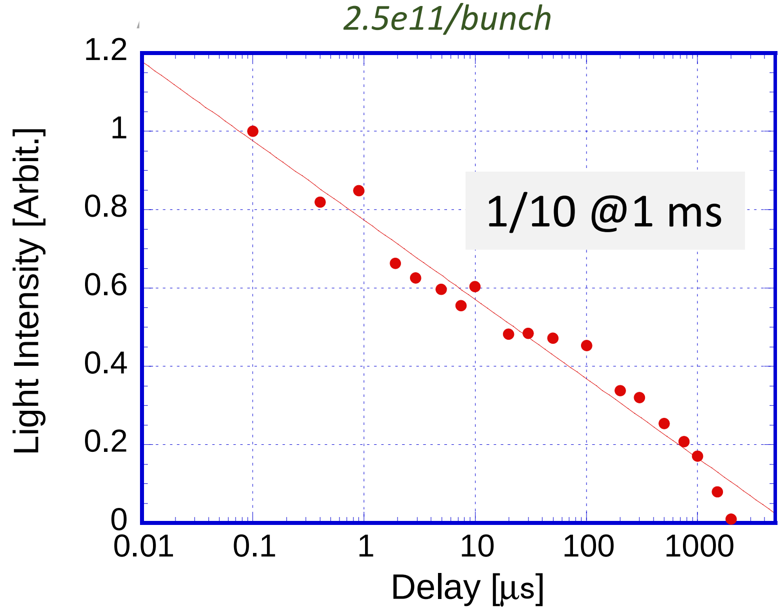
Yield ratio of fluorescence and OTR can be controlled

Exposure (II Gate)



Fluorescence time of Cr doped Alumina Screen

Beam: 3GeV Proton
2.5e11/bunch



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J-PARC and 3-50 BT:

MULTI-SCREEN BEAM PROFILE MONITOR

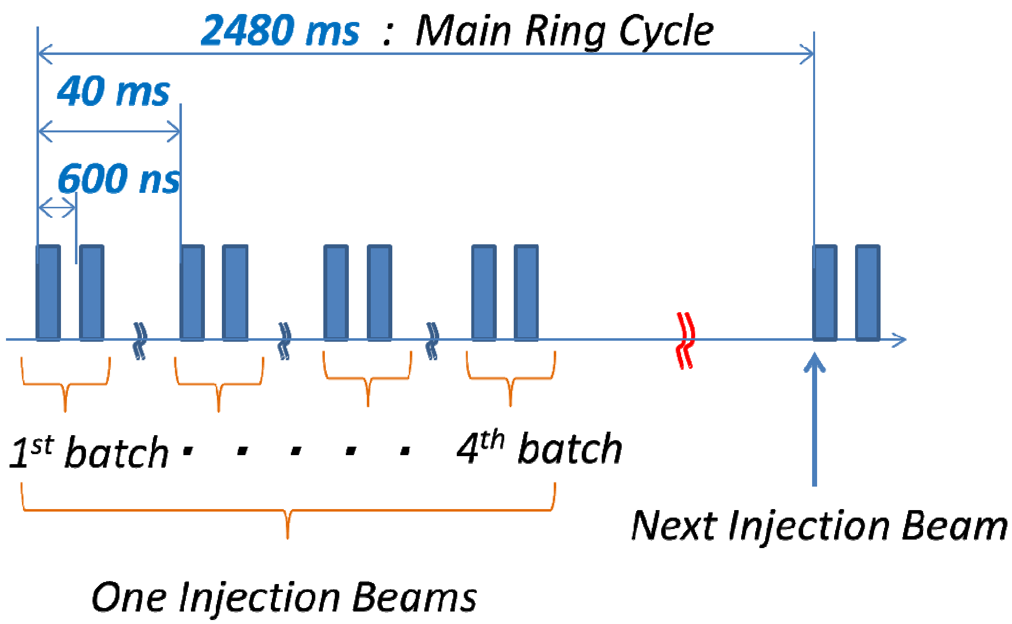
Beam Energy: 3 GeV

Beam Intensity :

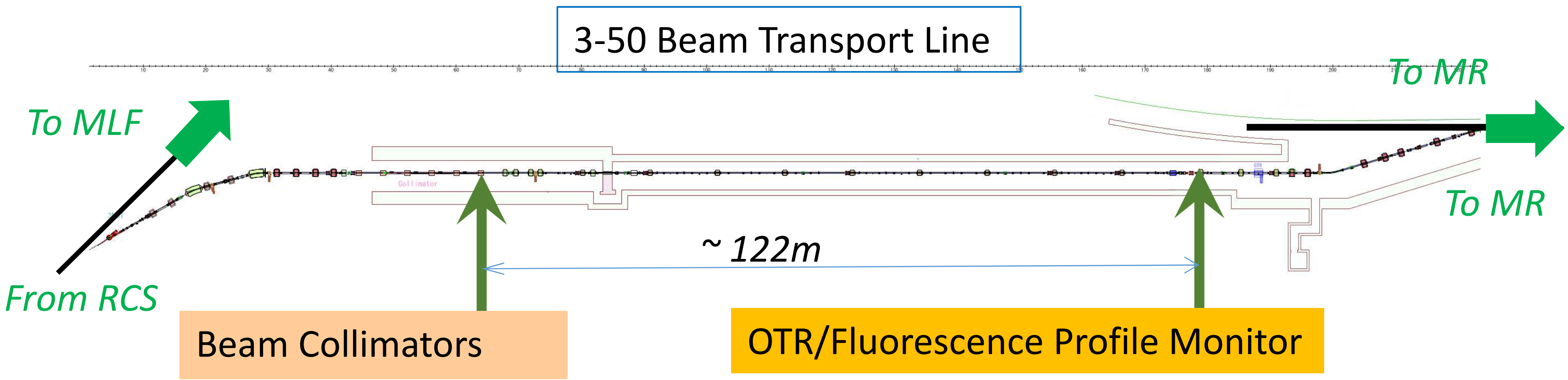
1.6 × 10^{13} proton/bunch

Injection Beam:

2 bunch × 4 batch



- Our monitor usually measured 2bunch (1batch)
- Beam collimators located at 122m upper stream



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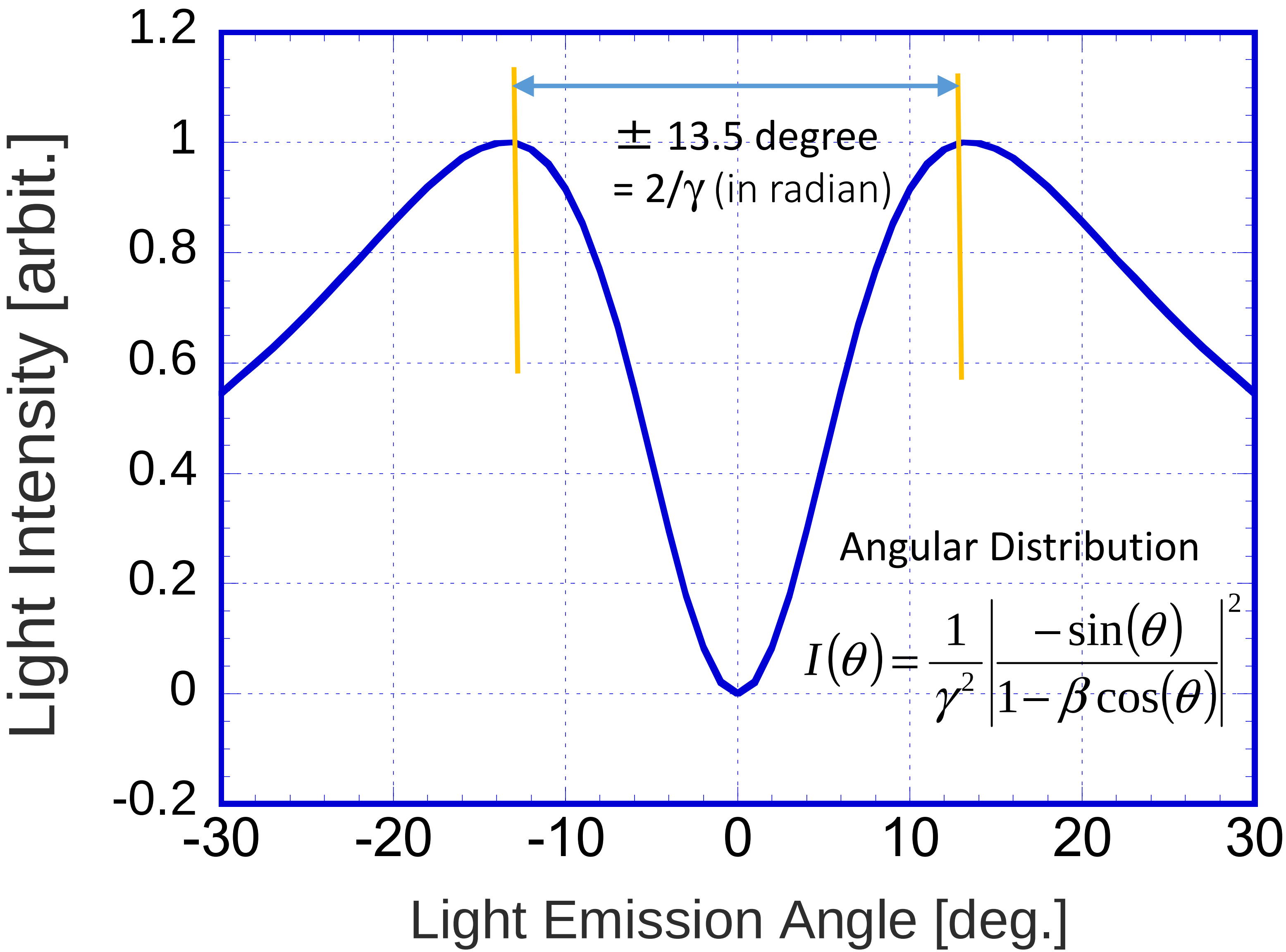
OTR by Low γ : 3GeV Proton Beam:

- Low γ : 4.2 ➔ Larger Angle Spread

MULTI-SCREEN BEAM PROFILE MONITOR



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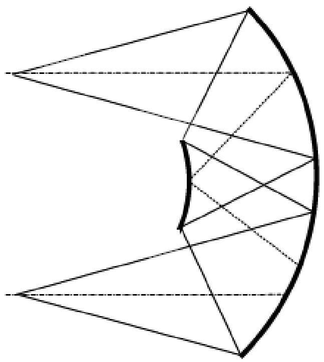
Large Acceptance Optics (1)

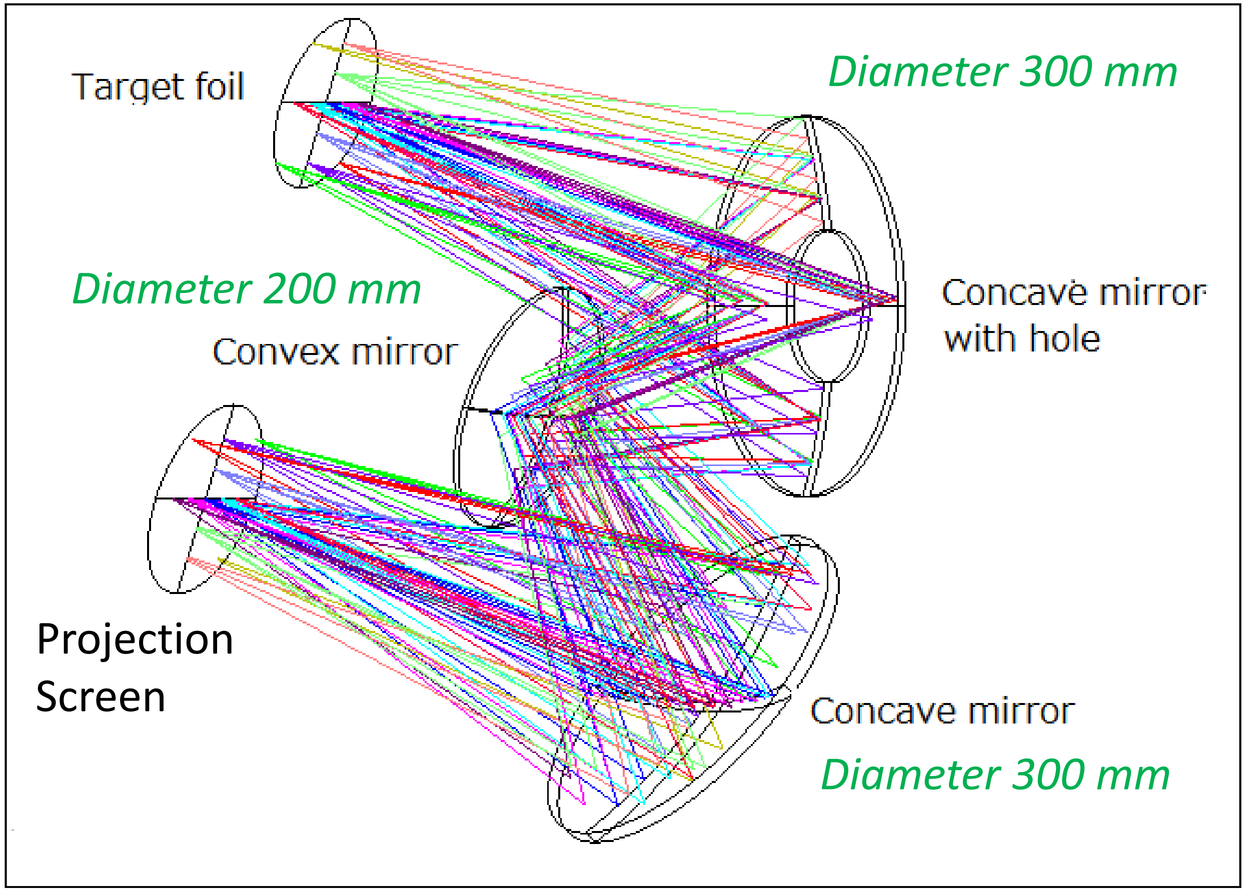
- Large Acceptance (±15 deg.)
- Larger Object Size (100^{H} × 80^{V} mm^{2})
- In vacuum Off-axis Relay Optics

➡ *We employed Offner Optics.*

<u>*Original Offner Scheme*</u>



<u>*Our Scheme*</u>



Large Acceptance Optics (2)

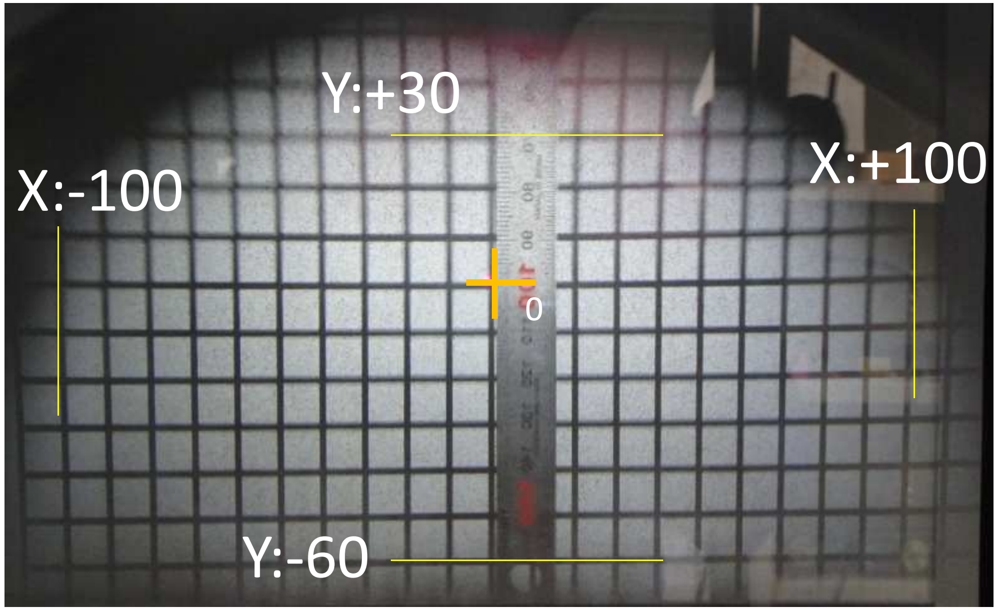
OTR/FLUORESCENCE BEAM PROFILE MONITOR

Clear Aperture

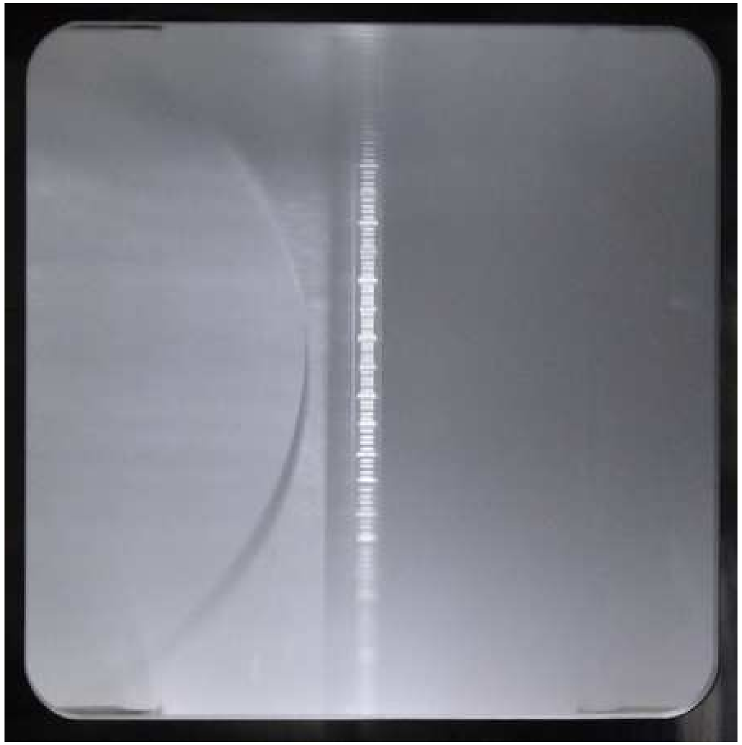
Horizontal: 200 mm

Vertical: 90 mm

Grid Pattern Test



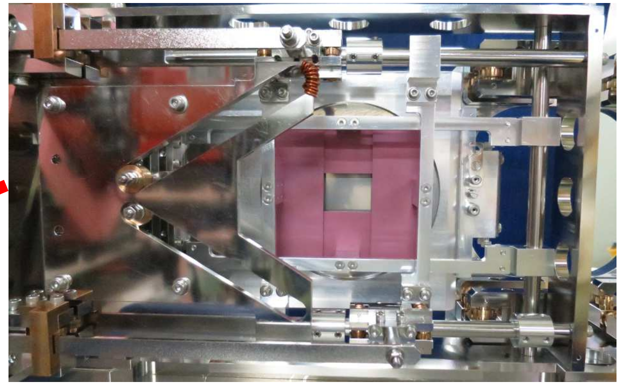
1mm pitch scale is resolved

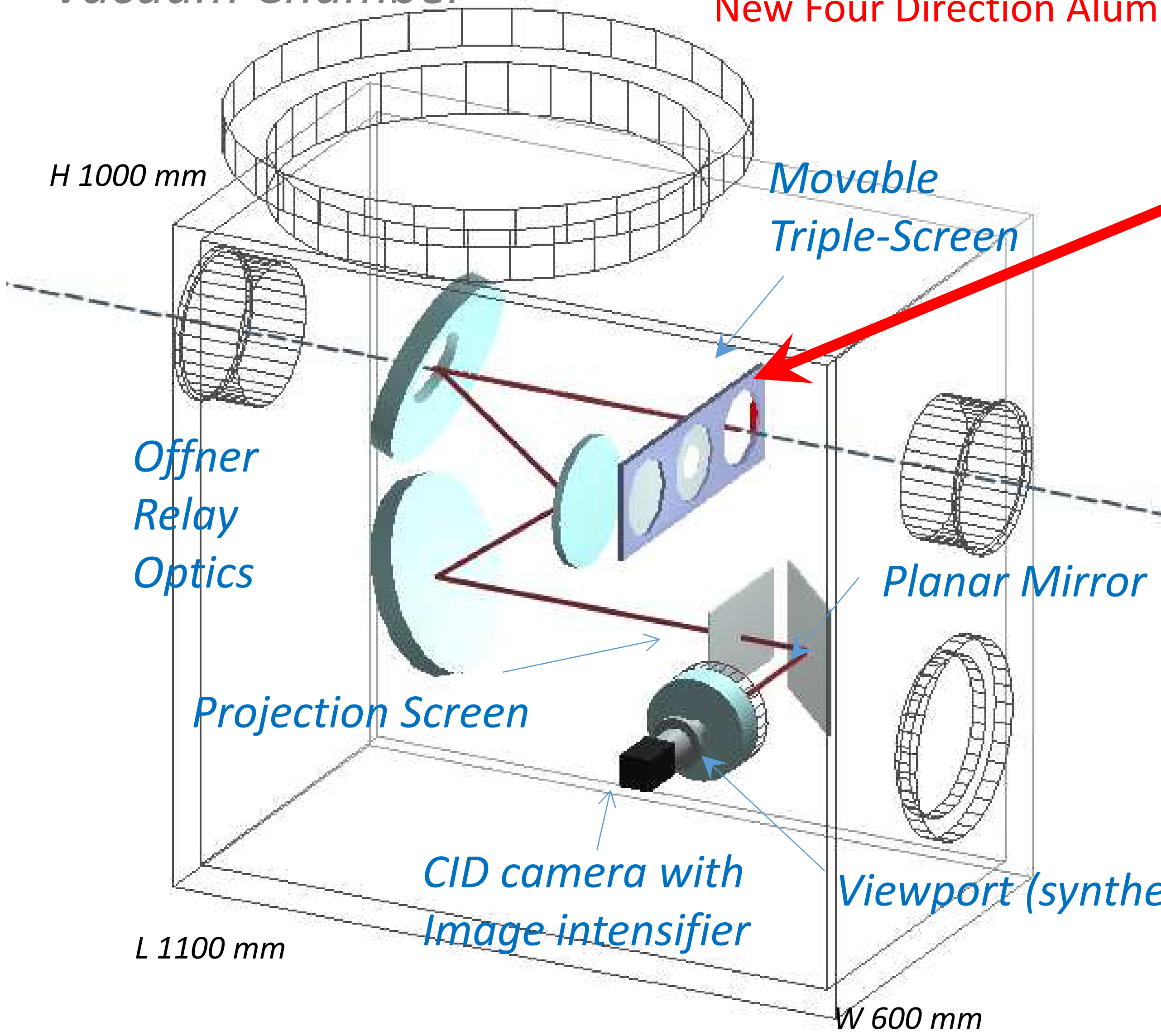


Large Acceptance Optics (3)

MULTI-SCREEN BEAM PROFILE MONITOR

New Four Direction Alumina Screen was installed in 2014





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Scaling for Unified Profile (1)

MULTI-SCREEN BEAM PROFILE MONITOR

For obtaining an *UNIFIED* profile : *Scaling*

Gain ratio of the image intensifier: G_R

$G_R = G_{1000}/G_{SET}$ by Gain curve of the Image Intensifier

G_{1000} : Gain at MCP1000V (Maximum)

G_{SET} : Gain at MCP set voltage at Measurement

Yields ratio Fluorescence/OTR: Y_R

OTR data → data/G_R

FL data → data/Y_R/G_R

Scaling for Unified Profile (2)

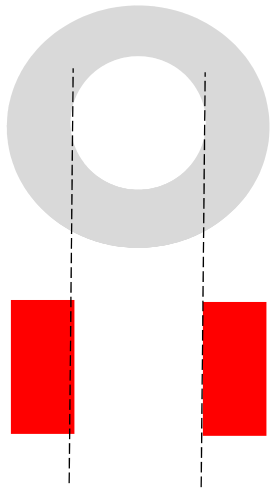
Y_R: Yields ratio between Fluorescence/OTR

MULTI-SCREEN BEAM PROFILE MONITOR

Integration Ratio (avg.)
= Y_{MR}
=1.84 ±0.07
(±3.8 %)

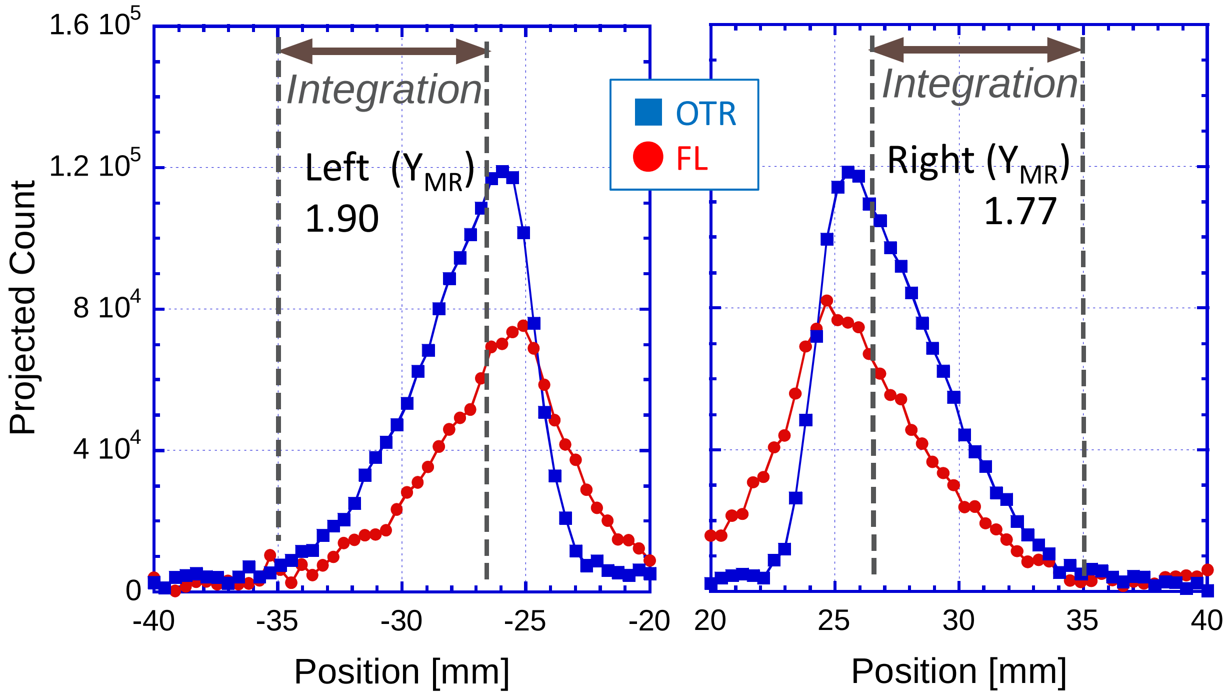
×II gain ratio (714.3)

Y_R=1314.6



OTR
50 mm dia. -Hole
Target

Fluorescence
Alumina Target
Edge: ±25 mm



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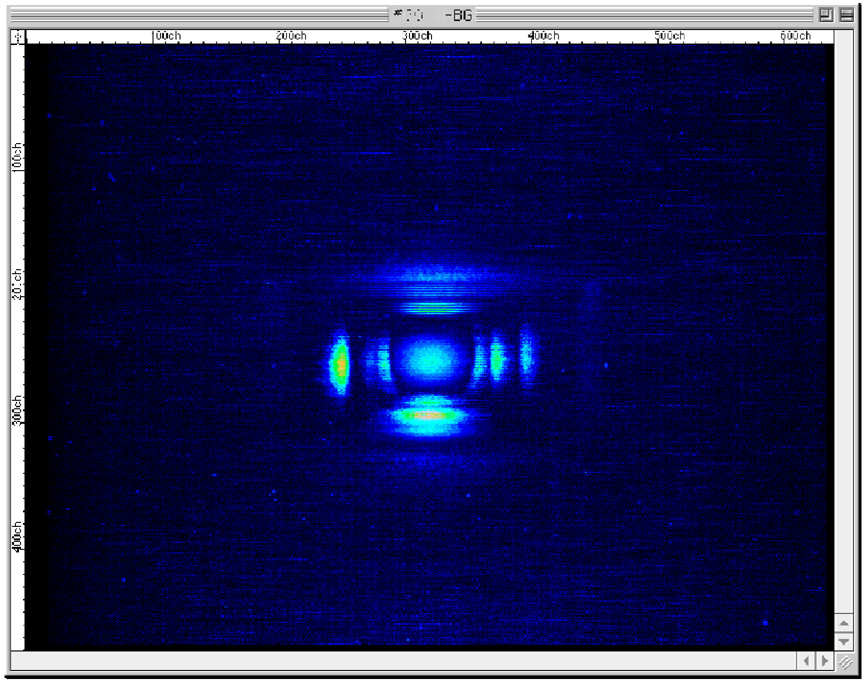
Effect of the beam cut by 3-50 BT collimator (1)

OTR/FLUORESCENCE BEAM PROFILE MONITOR

Halo Measurement by 25 times Changing Position of Alumina Screen
Gain of II : optimized in each step
Superimposed Image (5 times averaged each)
Beam Condition :Intensity 1.5e13 p/bunch, 50 π painting at RCS Injection

Raw data (superimposed)



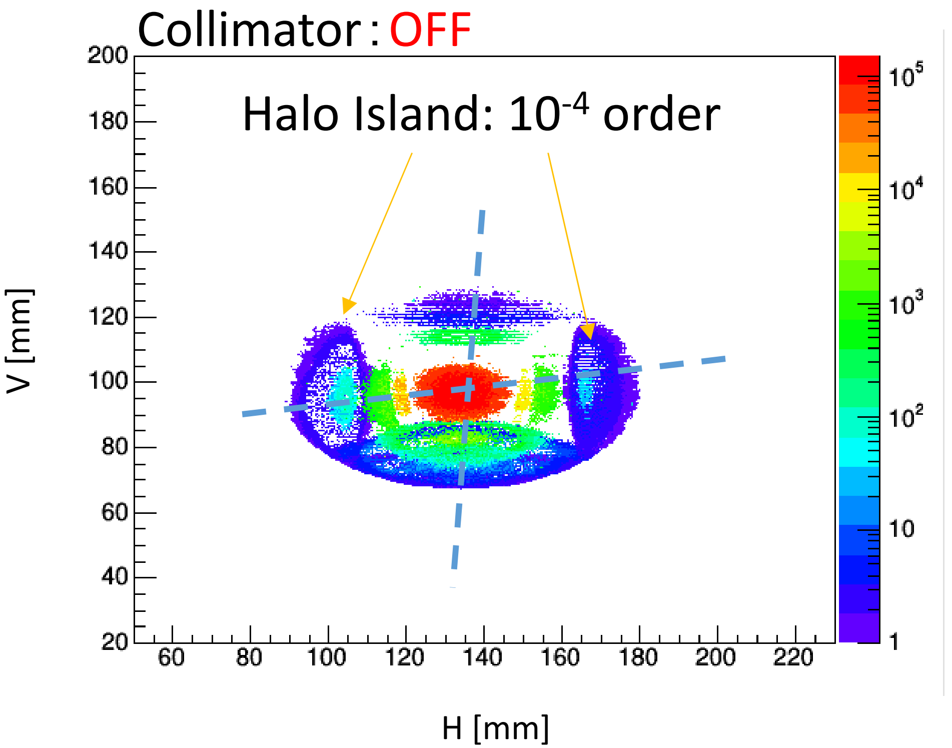
Scaling

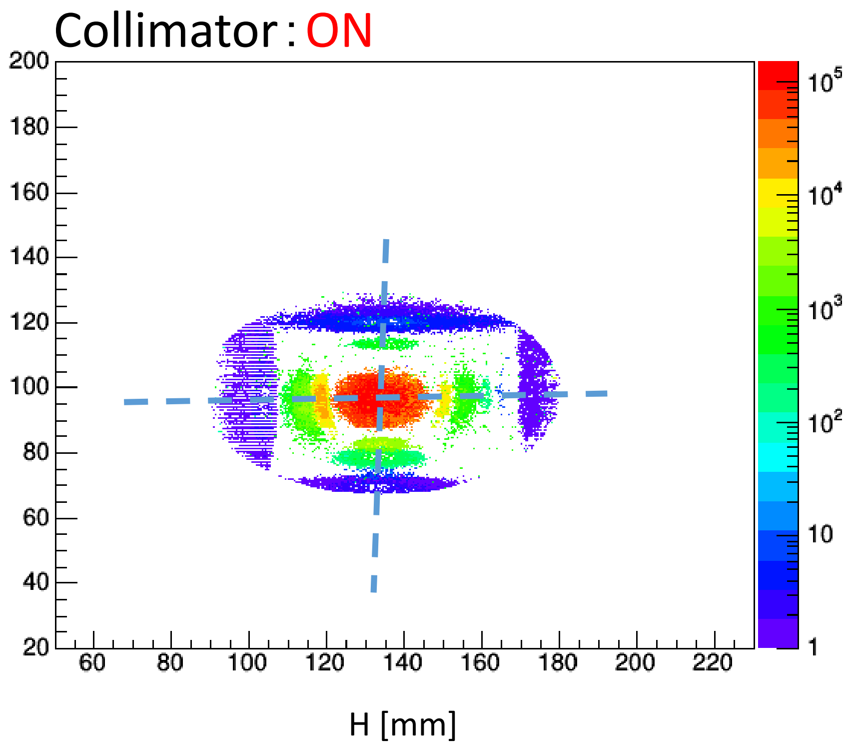
Two-Dimensional Halo Distribution

Dynamic Range of Light Intensity: 4 to 5 order obtained.

Halo Island at Minus fourth order disappeared by Collimator ON

Left and Right Halo distribution has asymmetry.





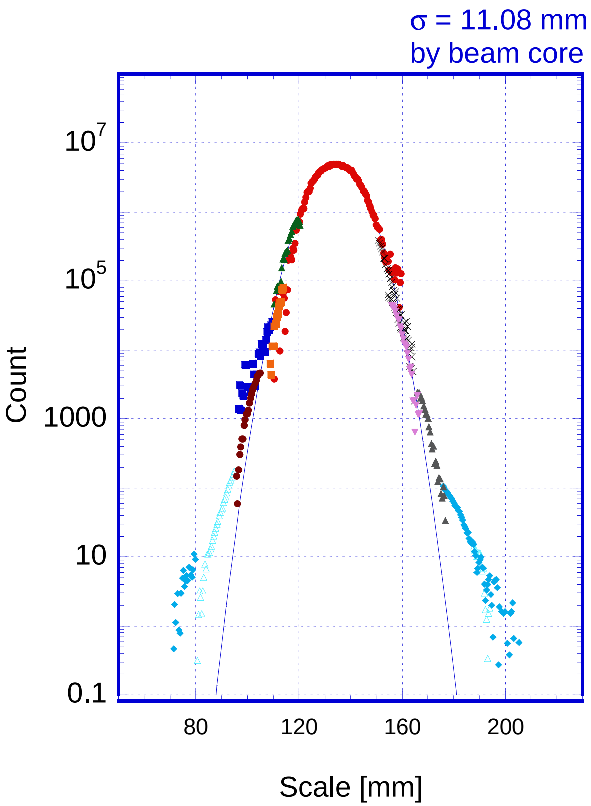
Effect of the beam cut by 3-50 BT collimator (3)

Horizontal Projection

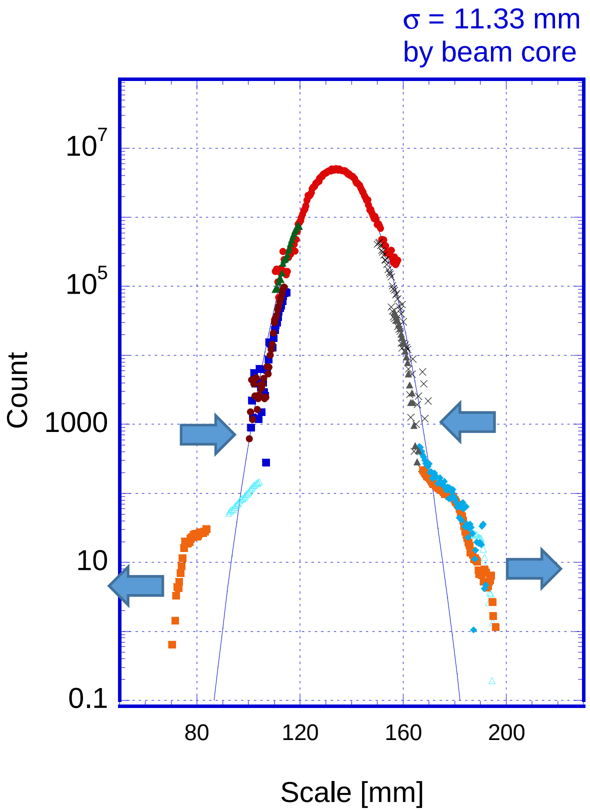
Dynamic Range :More than six order obtained
Beam Size: More than 120 mm at 10^{-6} order

Horizontal

Collimator OFF



Collimator ON



Collimator-ON
Waist appears at 10^{-4}
Expansion at 10^{-6}

Effect of the beam cut by 3-50 BT collimator (4)

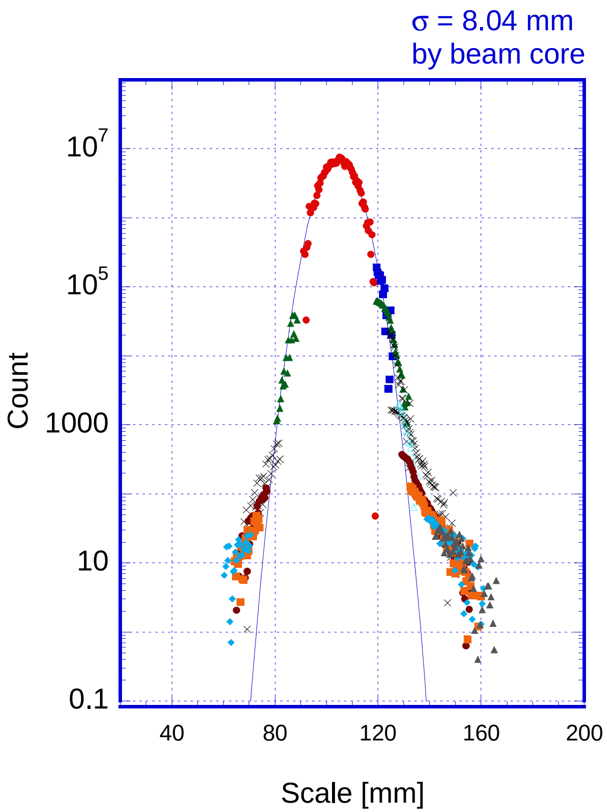
J-PARC

OTR/FLUORESCENCE BEAM PROFILE MONITOR

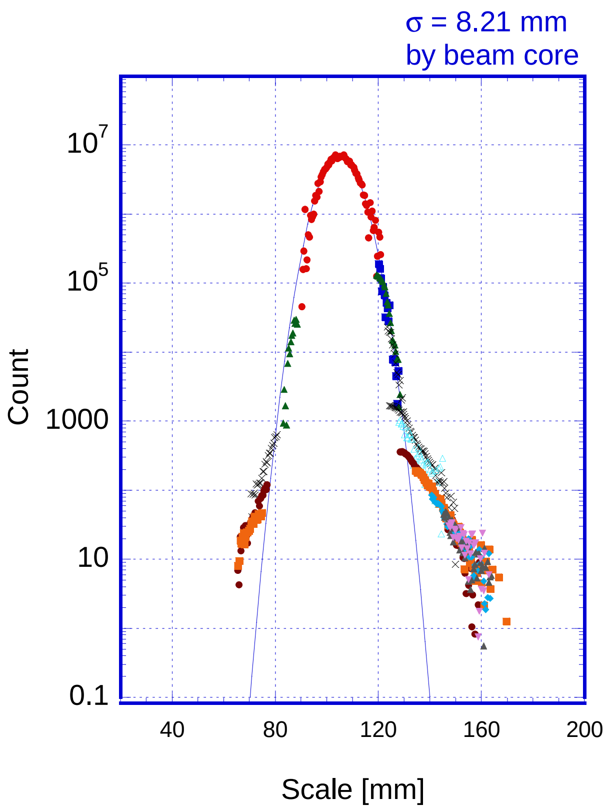
Vertical

No Significant Difference

Collimator OFF



Collimator ON



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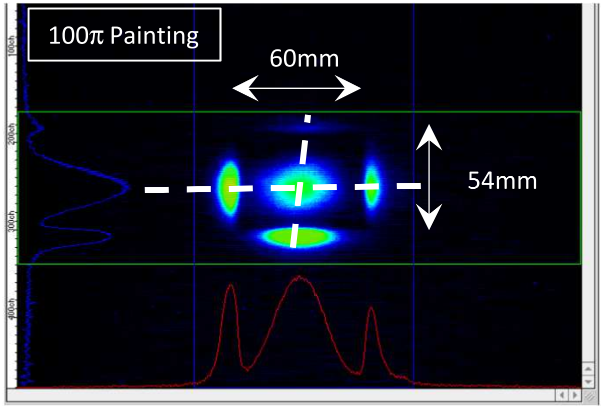
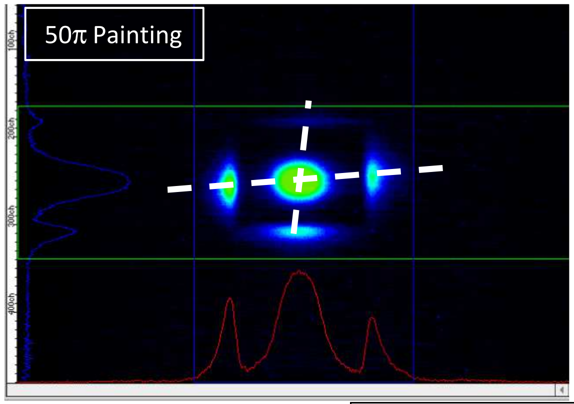
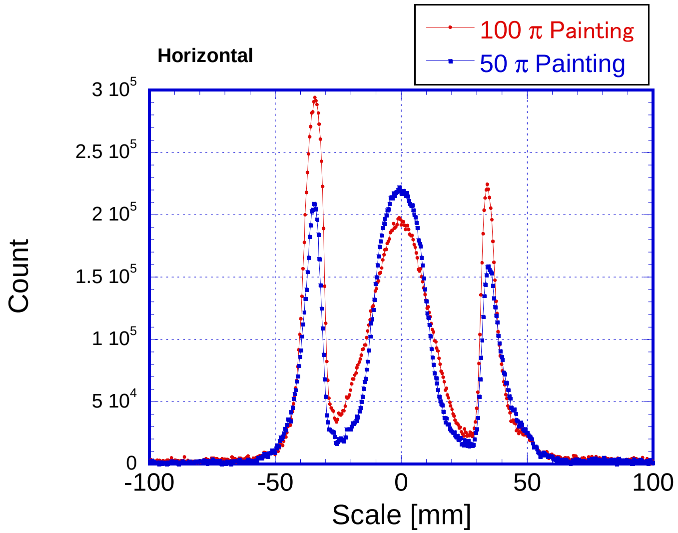
Simultaneous Measurement of Beam Core and Beam Halo (1)
Alumina Edge Position : Halo of 10^{-4} order

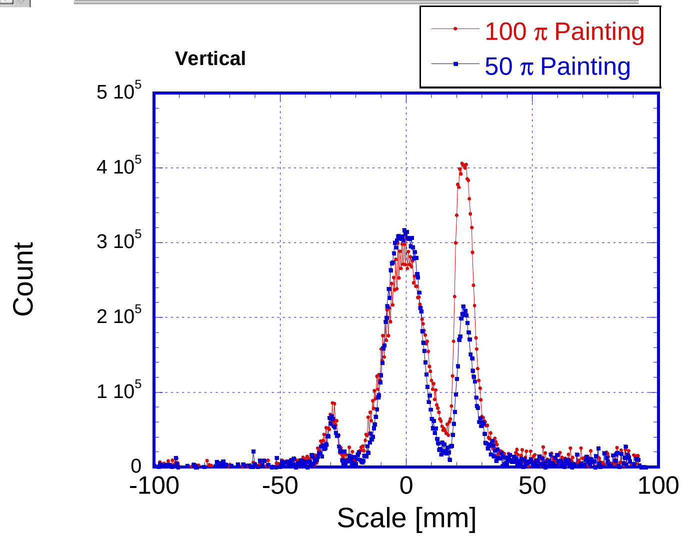
Difference by Painting Area of RCS Injection of 100 π and 50 π [mm.mrad]

Beam Intensity: 2.99e13/2bunch   5 times averaged





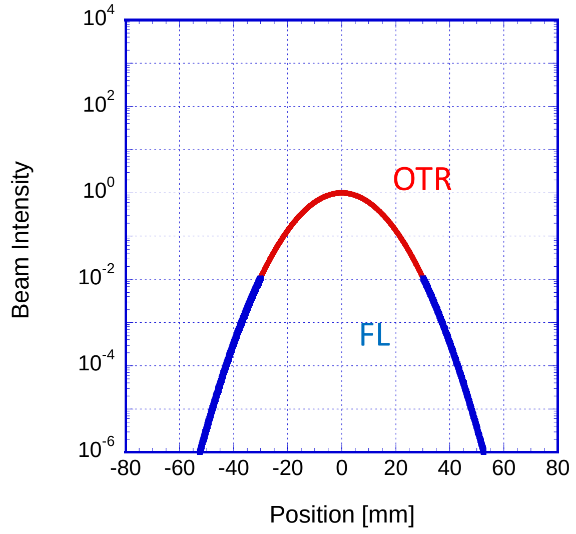


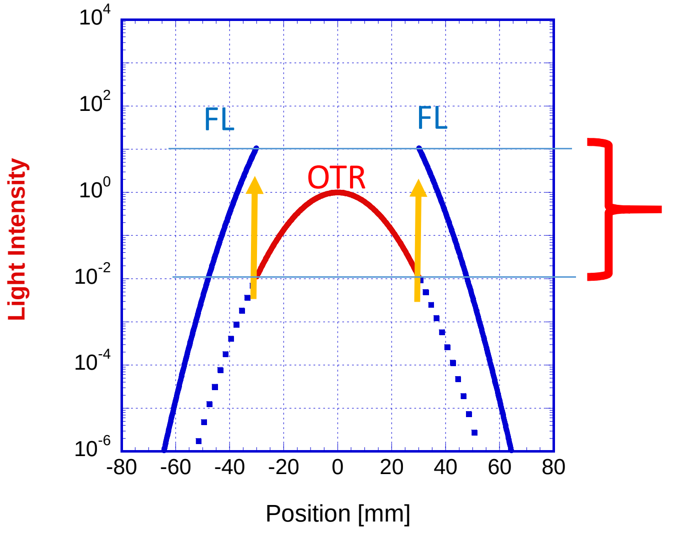


50 π Painting
- Smaller Beam Size
- Halo Rotation

Simultaneous measurement of beam core and beam halo (2) :
as possible as seamlessly (Next step)

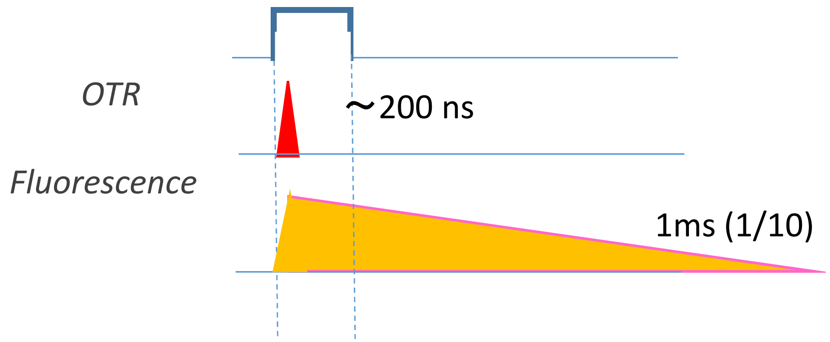
Light Yield Ratio : Fluorescence /OTR →1000





Three Orders:
Measure with
60～70dB CMOS
Camera

Exposure (I.I. Gate)



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Conclusions :

1. By using combination measurement of the OTR from the titanium foil screen and the fluorescence from the alumina screen, we developed two-dimensional and high dynamic-range profile monitor.

2. On the projection profiles, we obtained the beam profile of the core and the halo with around six-orders dynamicrange.

3. It was shown that the beam asymmetry or the rotation were measured with this instrument as advantage of a two-dimension.

4. These results greatly benefit to investigation of beam dynamics.

Thank you very much for your attention !