# 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



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

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# Concept (1): *Dynamic range*

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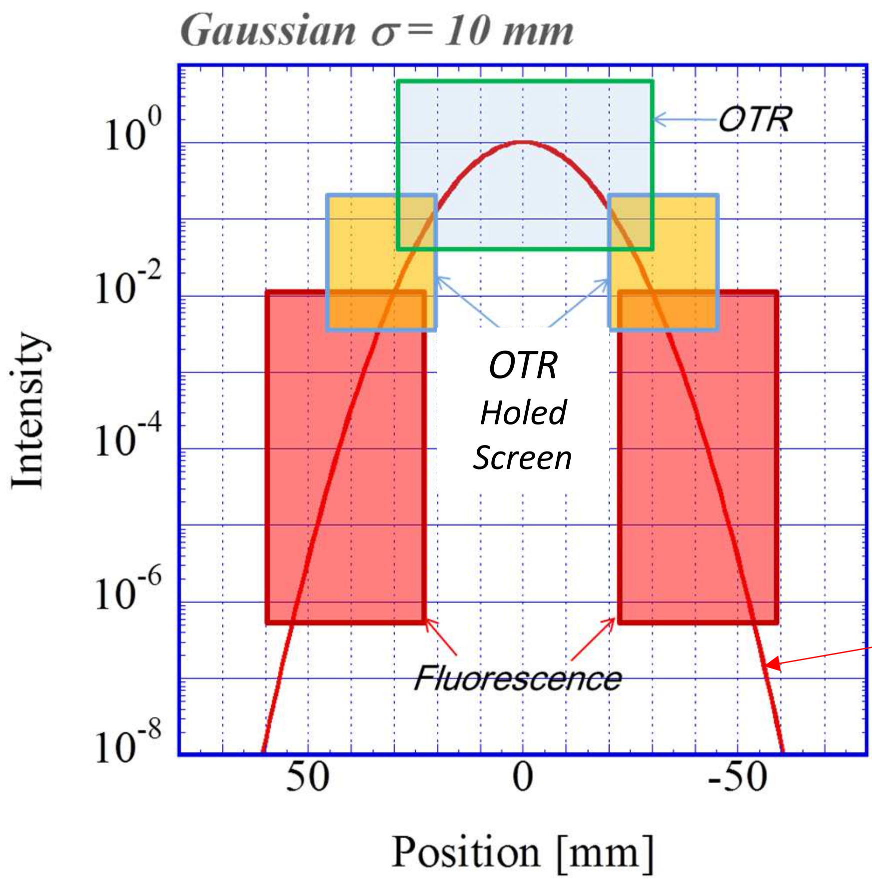
## Combination measurement with OTR and the fluorescence:

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
$\sigma$ = 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

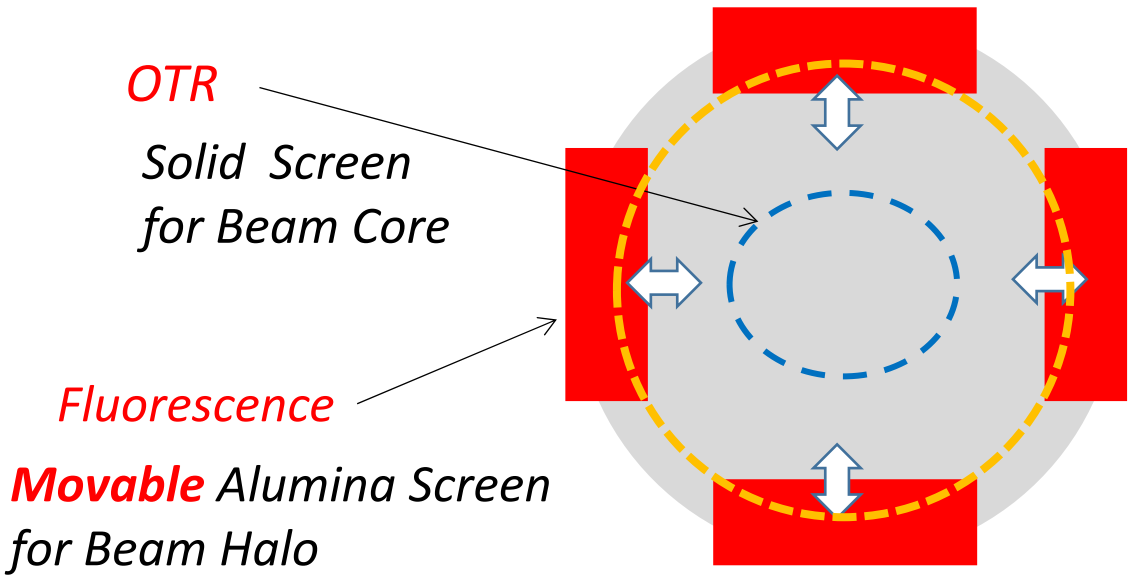
48 times larger than 10 micron Ti

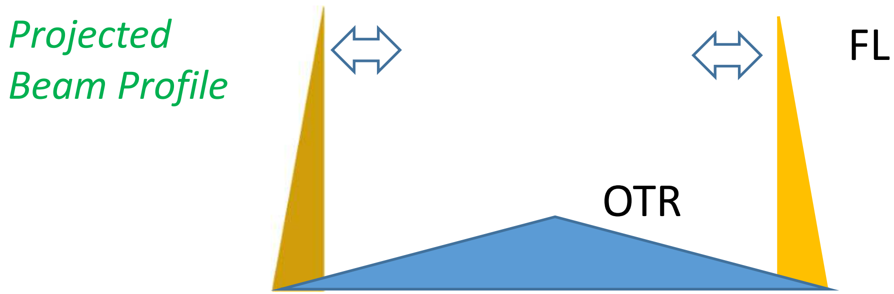
Used in only $10^{-2}$ region:
4.7 e-3 [J/bunch]
Becomes 1/2 of Ti

# Concept (3): *Screen Configuration*



Layout (Front View)



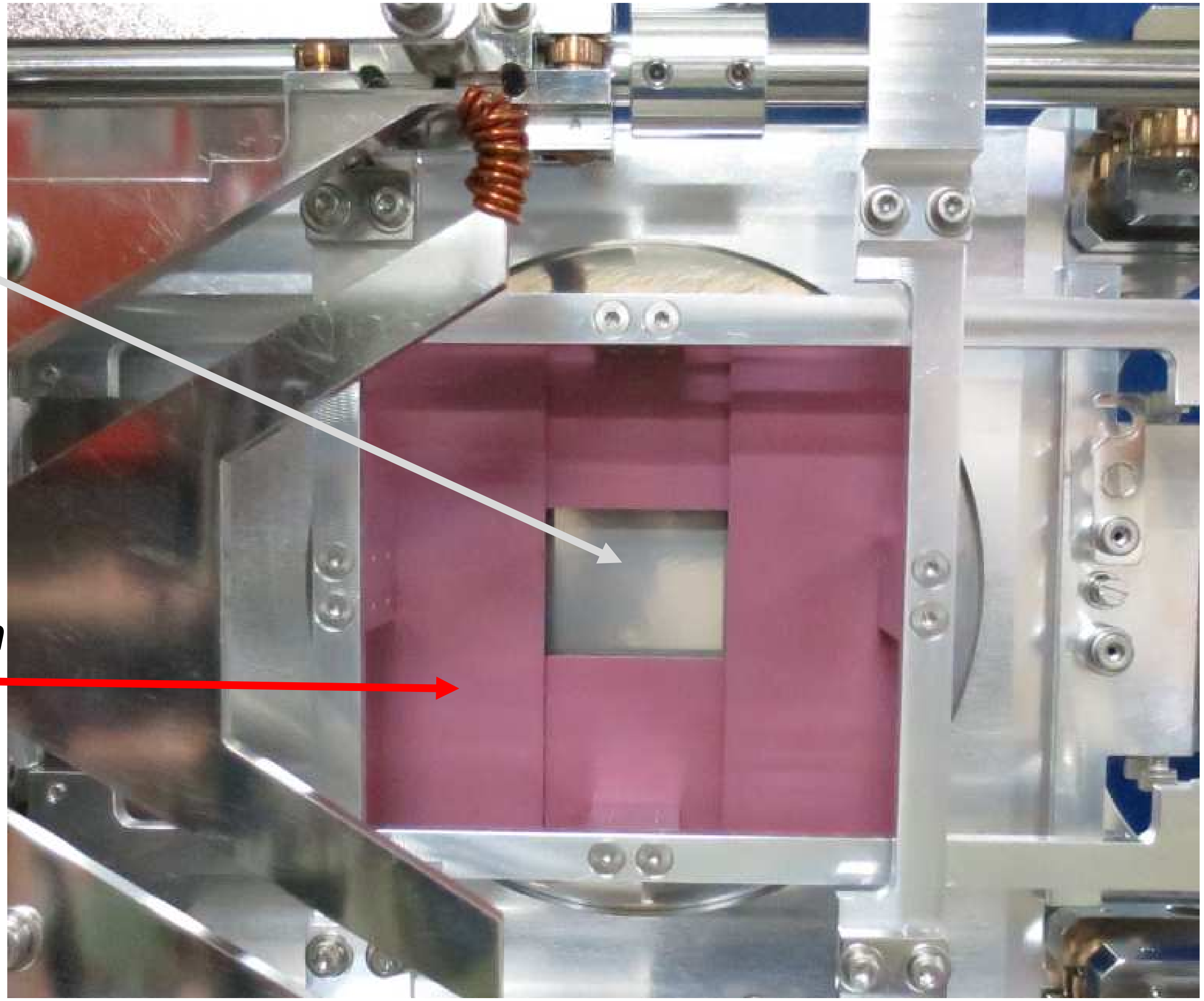
# Concept (4): *Screen photo (front view)*

*OTR*

*Solid Screen*
*for Beam Core*

*Fluorescence*

***Movable*** *Alumina Screen*
*for Beam Halo*



# Concept (5): *Two Target Structures*

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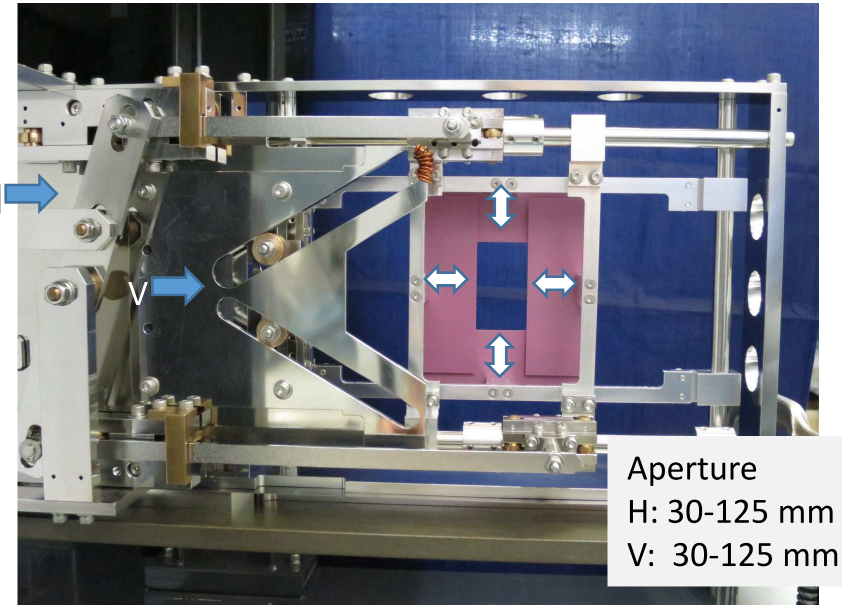
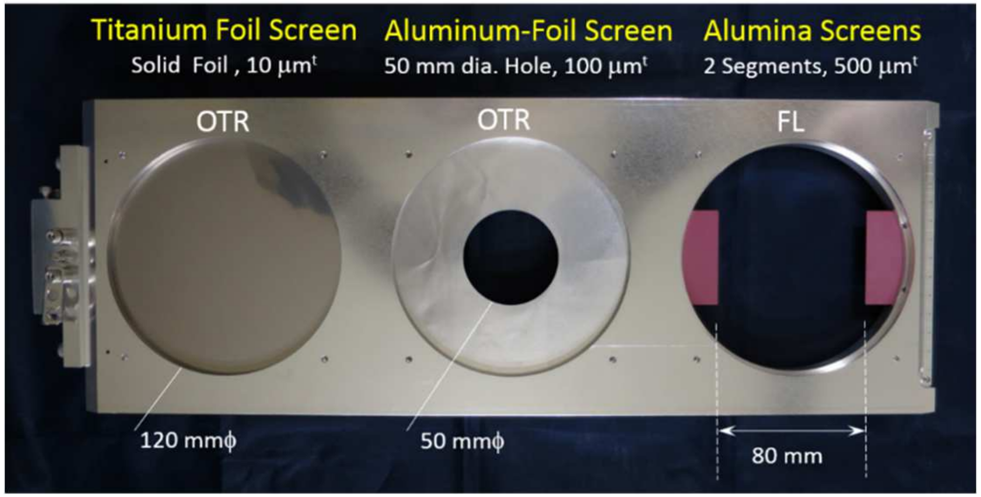
New four-direction alumina screen.




Aperture
H: 30-125 mm
V: 30-125 mm

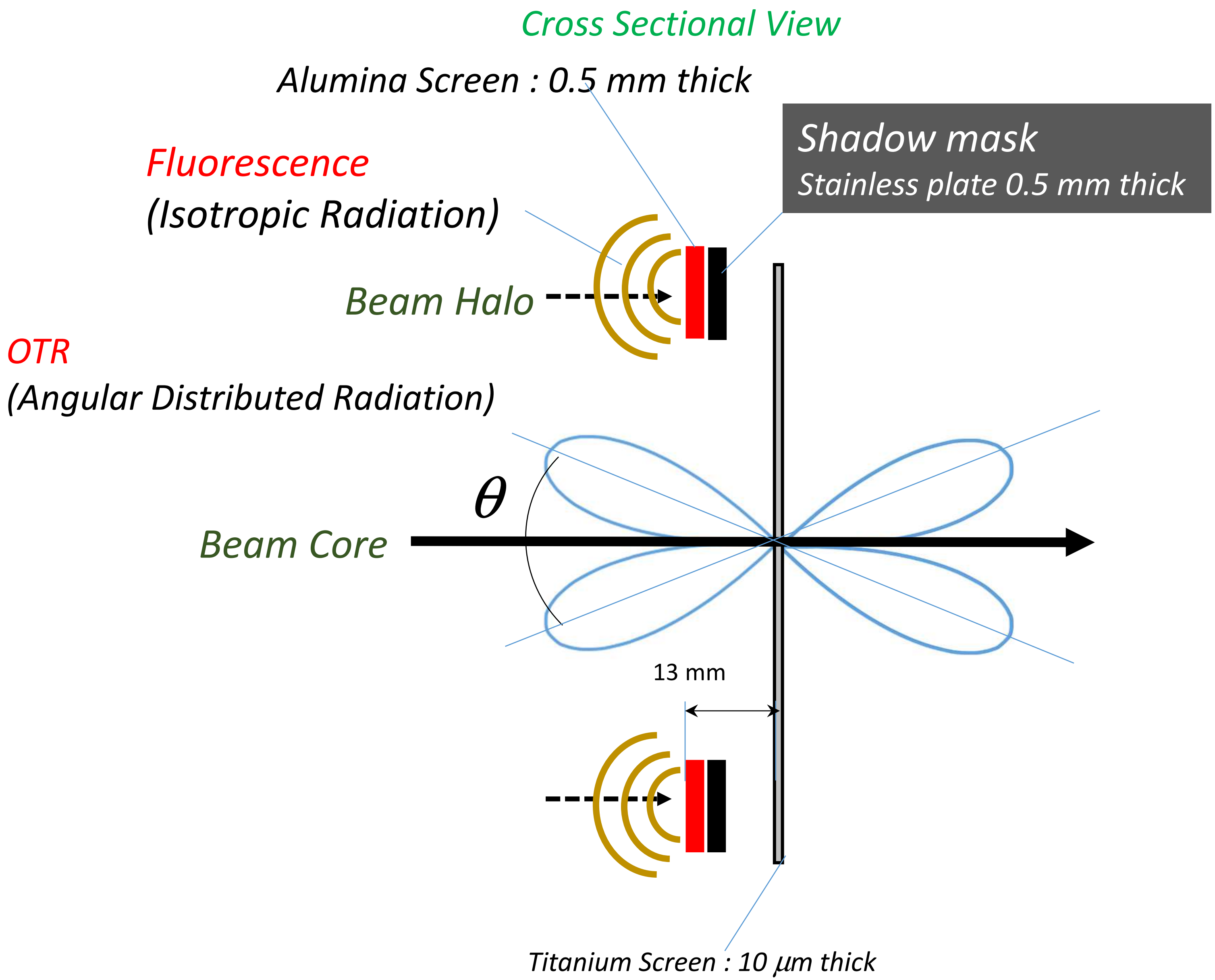
Operate by two horizontal movable shafts.

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



# Concept (6): *Screen Configuration-2*





# Concept (7): *Fluorescence time*

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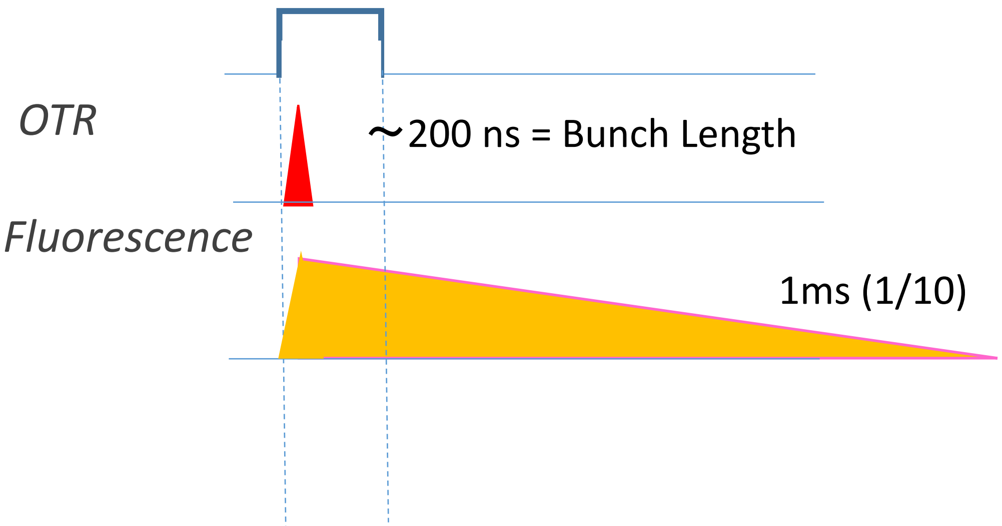
Light quantity adjustment of the fluorescence from alumina screen
longer fluorescence time of 1ms

⇒Changing the Image Intensifier (II) Gate

Yield ratio of fluorescence and OTR can be controlled

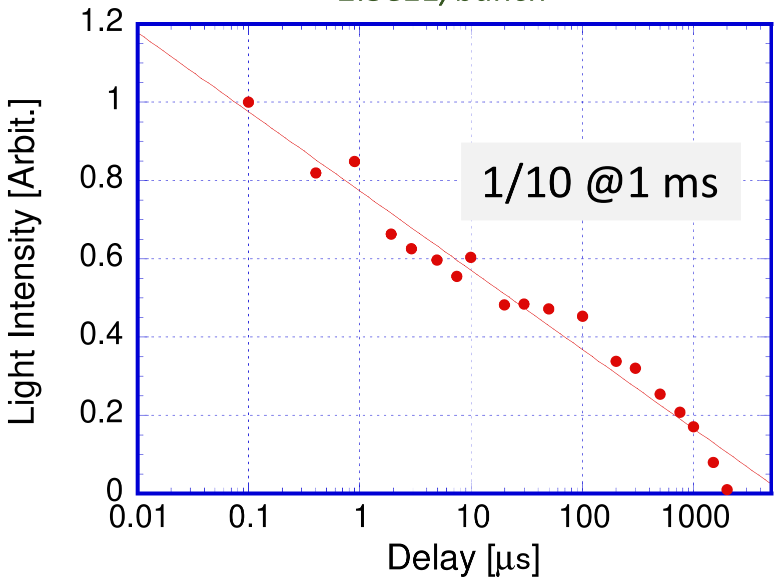
Exposure (II Gate)




*Fluorescence time of Cr doped Alumina Screen*

*Beam: 3GeV Proton*

*2.5e11/bunch*



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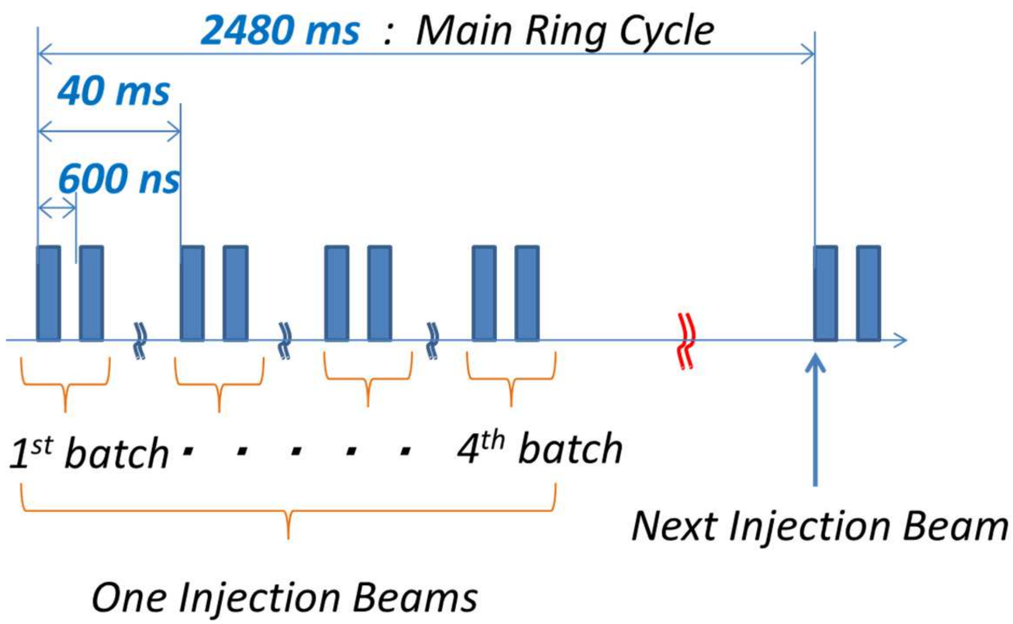
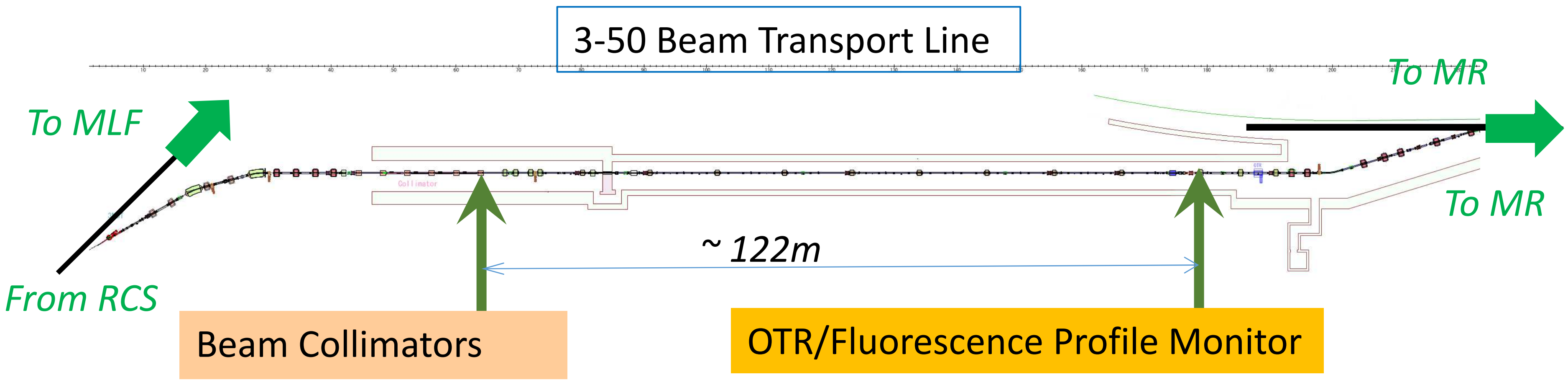
# J-PARC and 3-50 BT:

MULTI-SCREEN BEAM PROFILE MONITOR

Beam Energy: 3 GeV
Beam Intensity :
1.6 $\times 10^{13}$ proton/bunch
Injection Beam:
2 bunch $\times$ 4 batch




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



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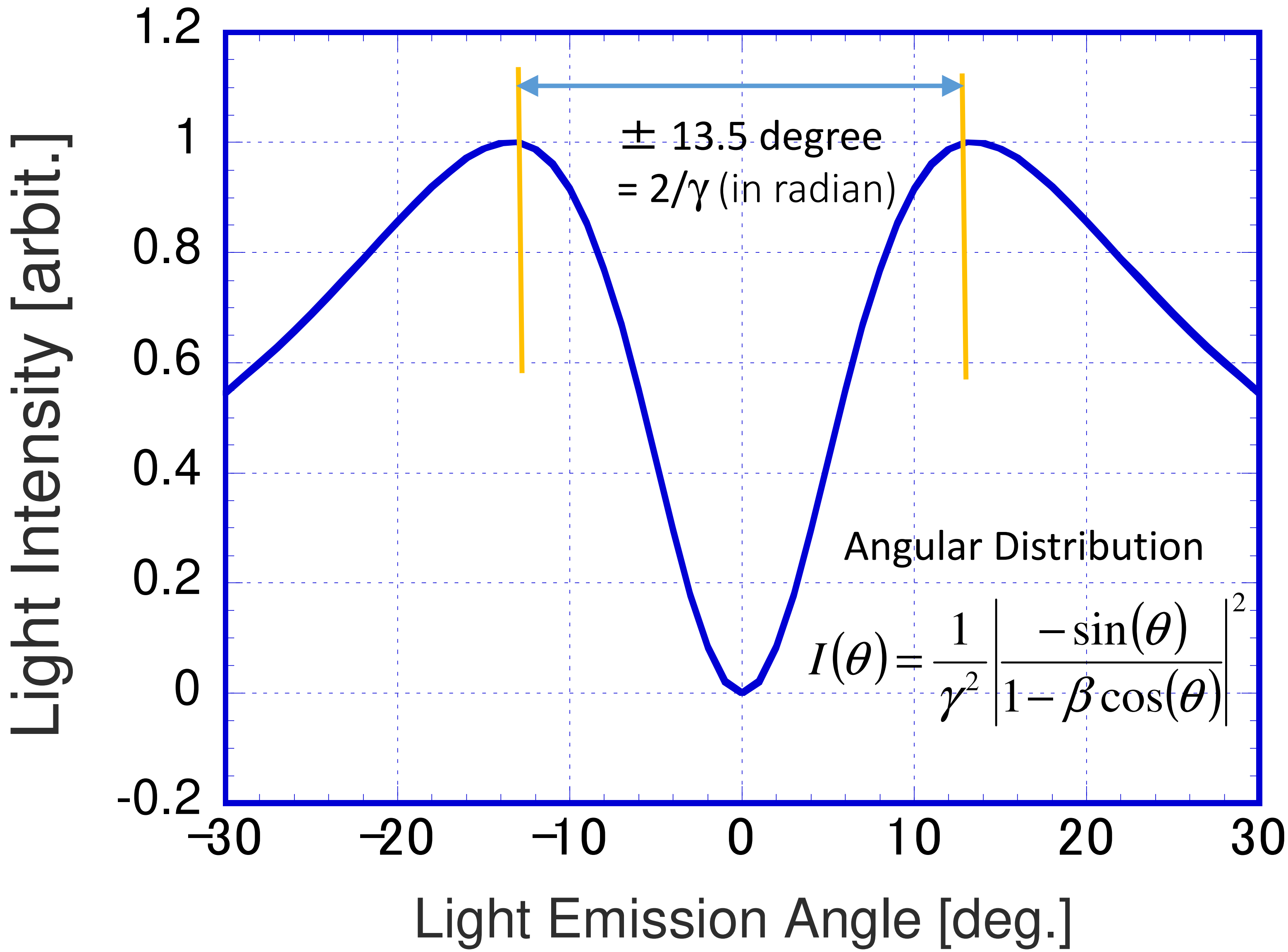
OTR by Low γ : 3GeV Proton Beam:

- Low γ : 4.2 ➔ Larger Angle Spread

MULTI-SCREEN BEAM PROFILE MONITOR



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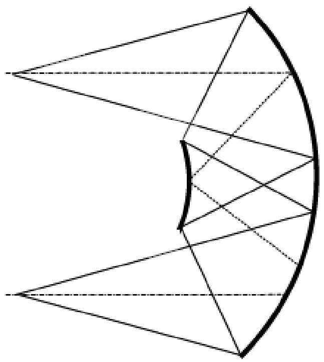
# Large Acceptance Optics (1)

MULTI-SCREEN BEAM PROFILE MONITOR

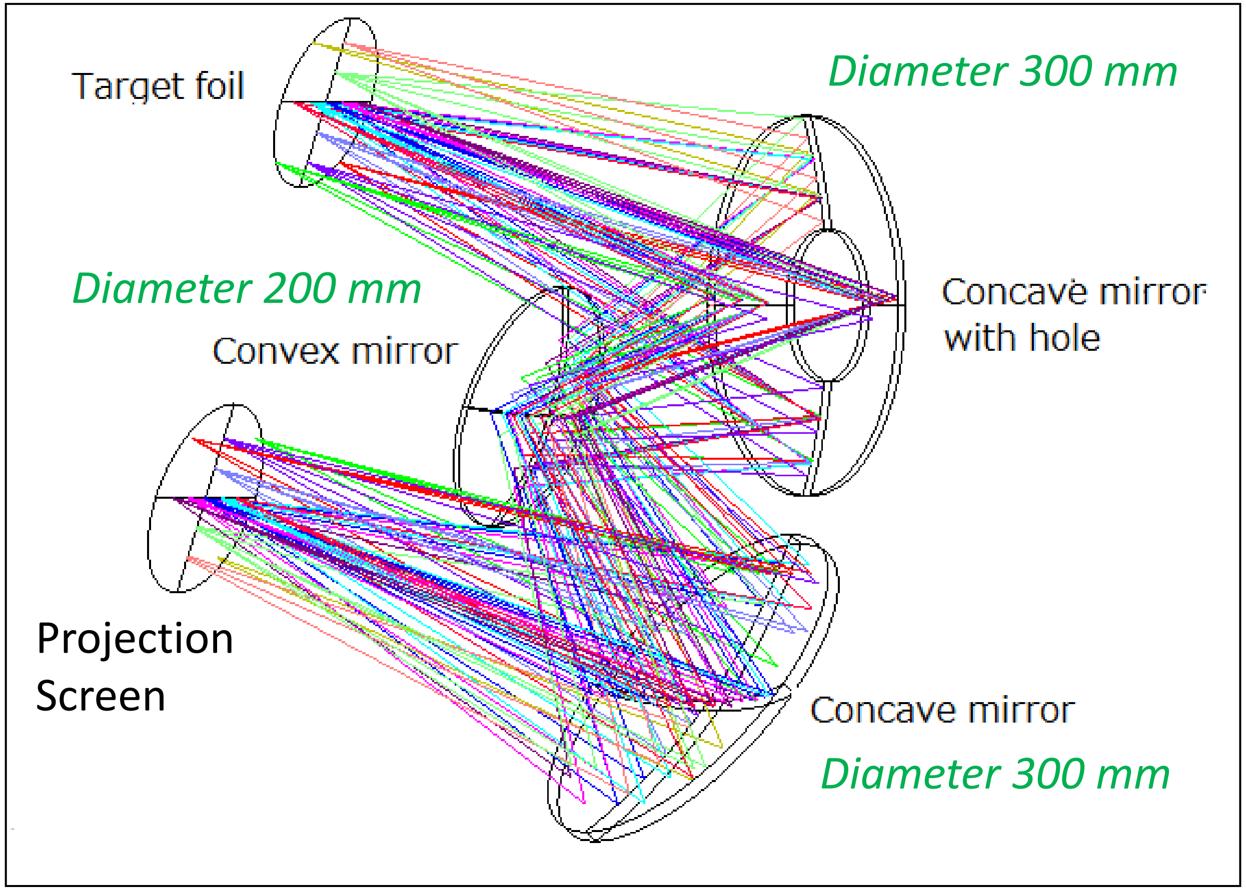
- Large Acceptance (±15 deg.)
- Larger Object Size (100$^H$ × 80$^V$ mm$^2$)
- In vacuum Off-axis Relay Optics

➡ *We employed Offner Optics.*

*Original Offner Scheme*



*Our Scheme*



# Large Acceptance Optics (2)

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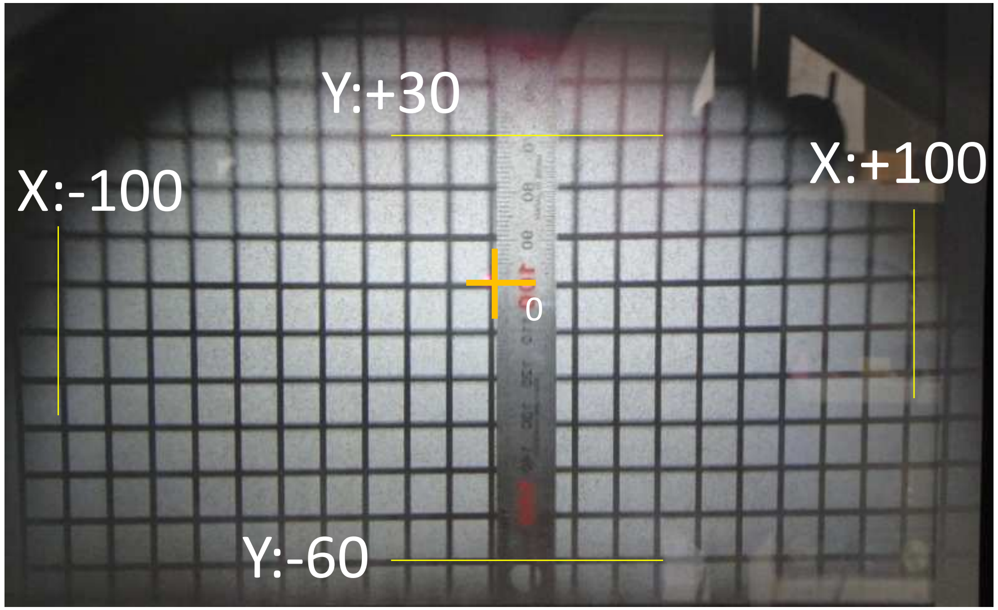
## Clear Aperture

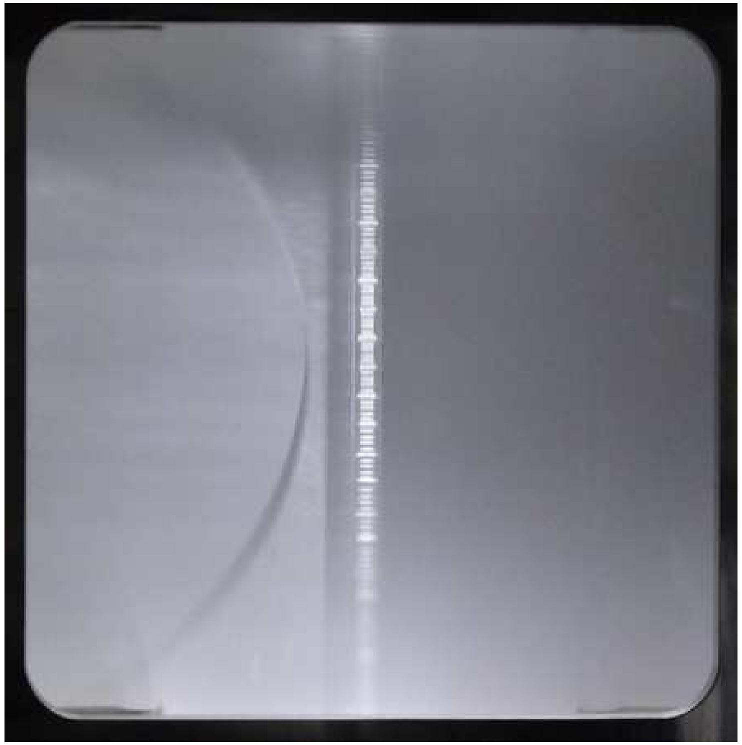
Horizontal: 200 mm

Vertical: 90 mm

*Grid Pattern Test*

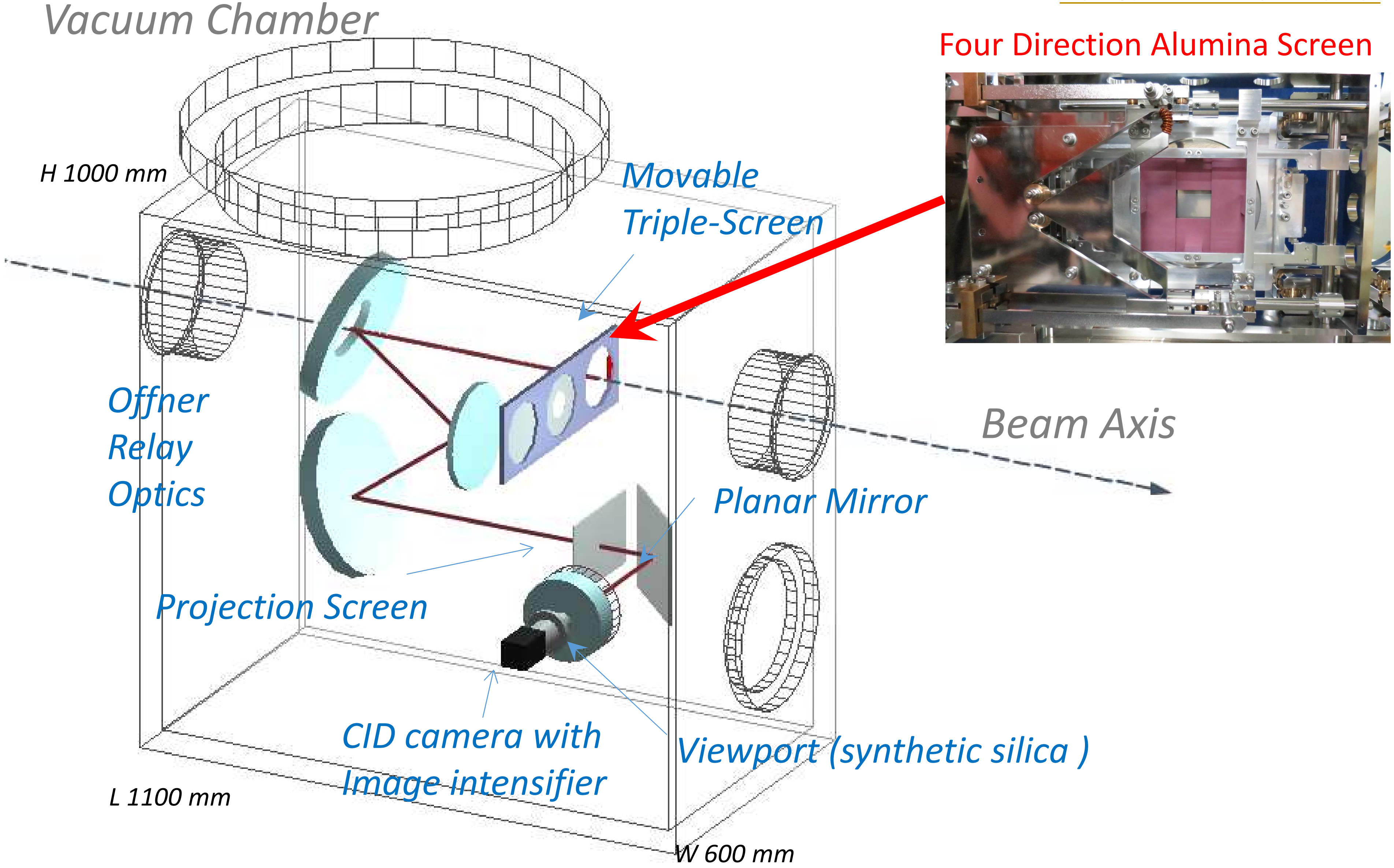



1mm pitch scale is resolved



# Large Acceptance Optics (3)

MULTI-SCREEN BEAM PROFILE MONITOR



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## Scaling for Unified Profile (1)



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/$Y_R$/$G_R$

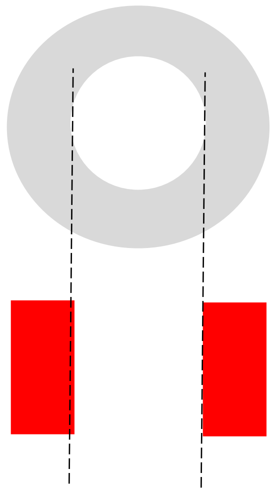
# Scaling for Unified Profile (2)

## *$Y_R$: Yields ratio between Fluorescence/OTR*

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

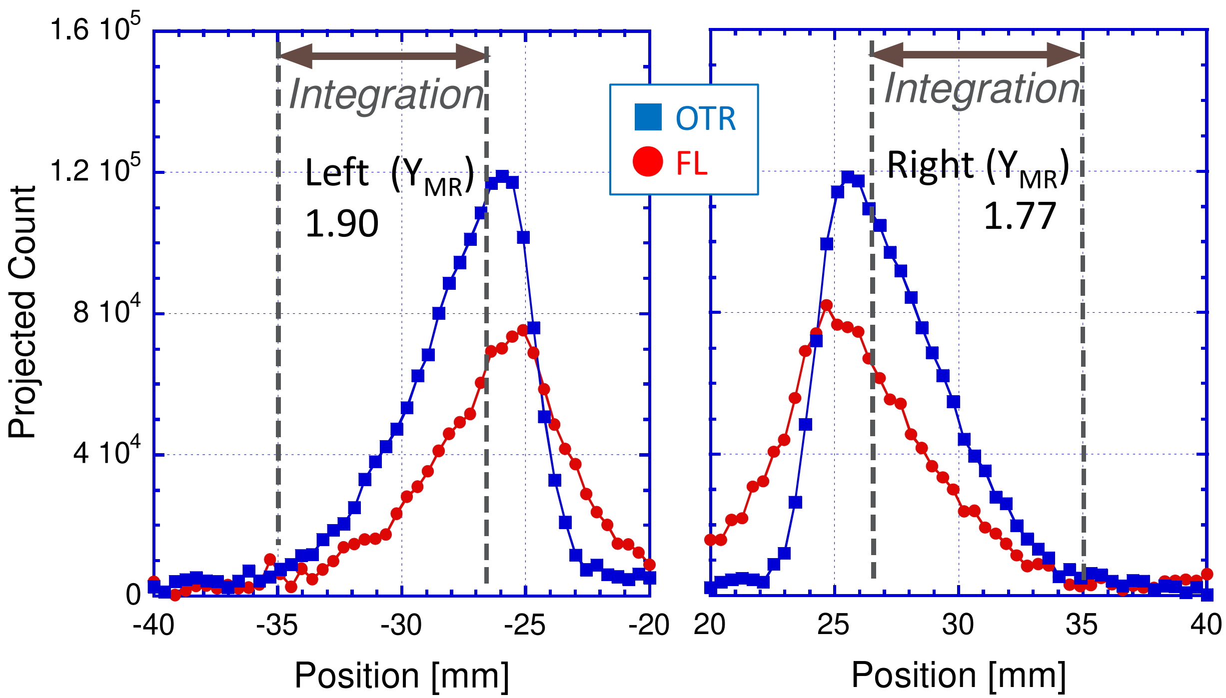
× II gain ratio (714.3)

**$Y_R$=1314.6**



OTR
50 mm dia. -Hole
Target

Fluorescence
Alumina Target
Edge: ±25 mm



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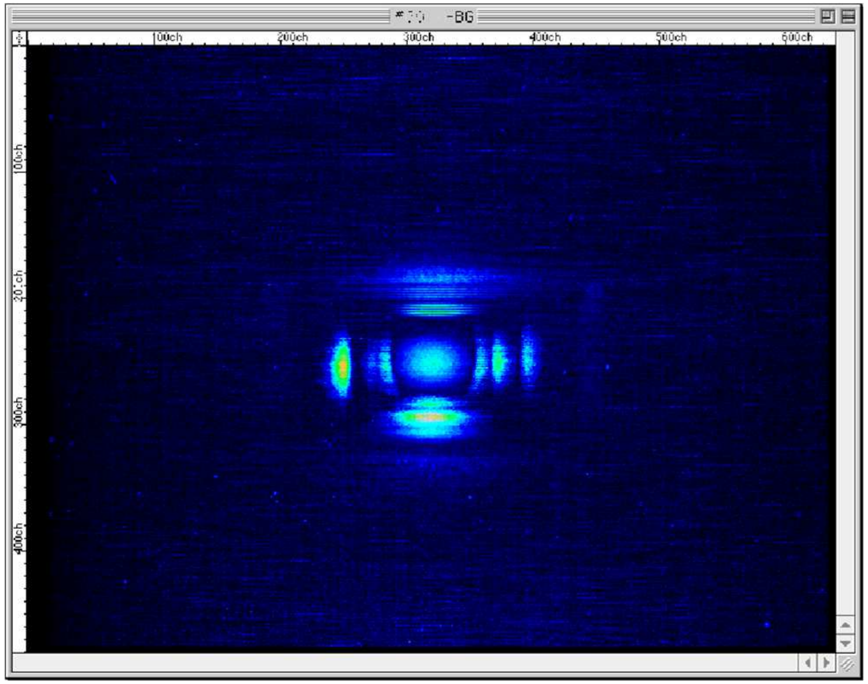
# Effect of the beam cut by 3-50 BT collimator (1)

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)



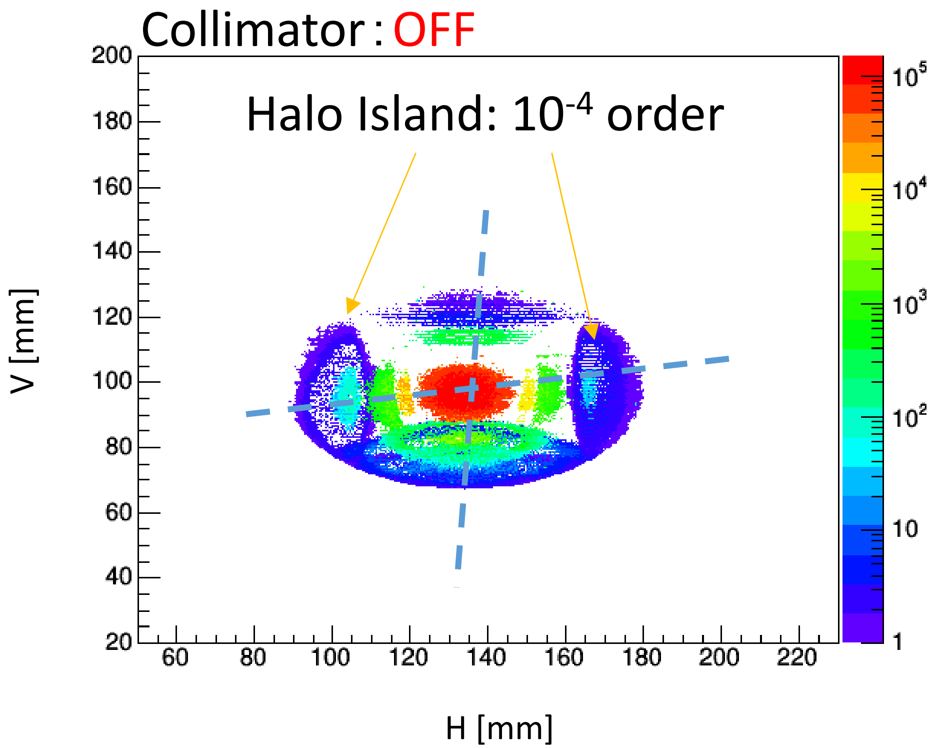

Scaling

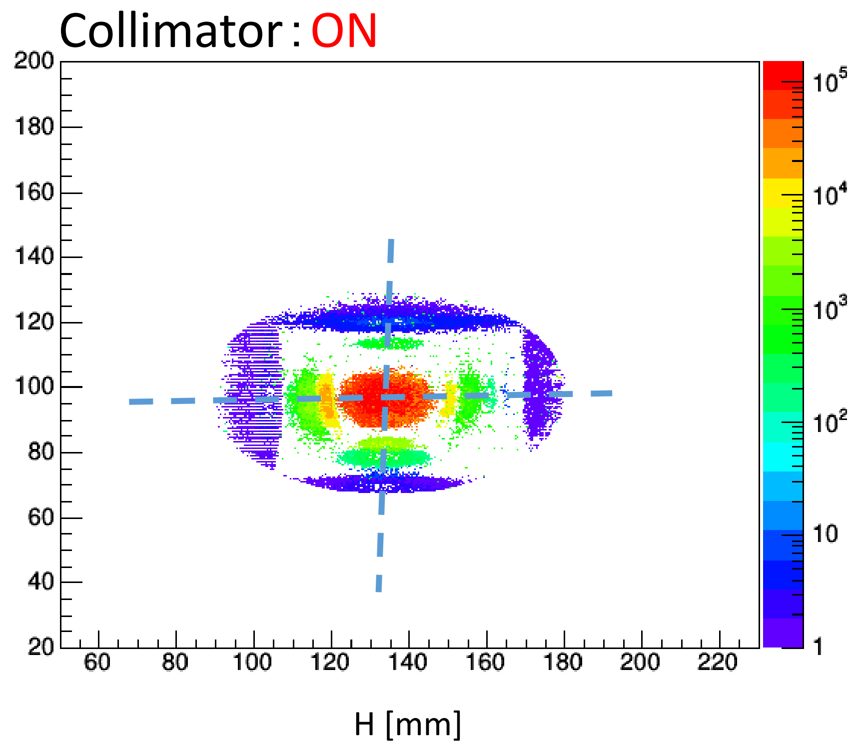
# Effect of the beam cut by 3-50 BT collimator (2)



## 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.



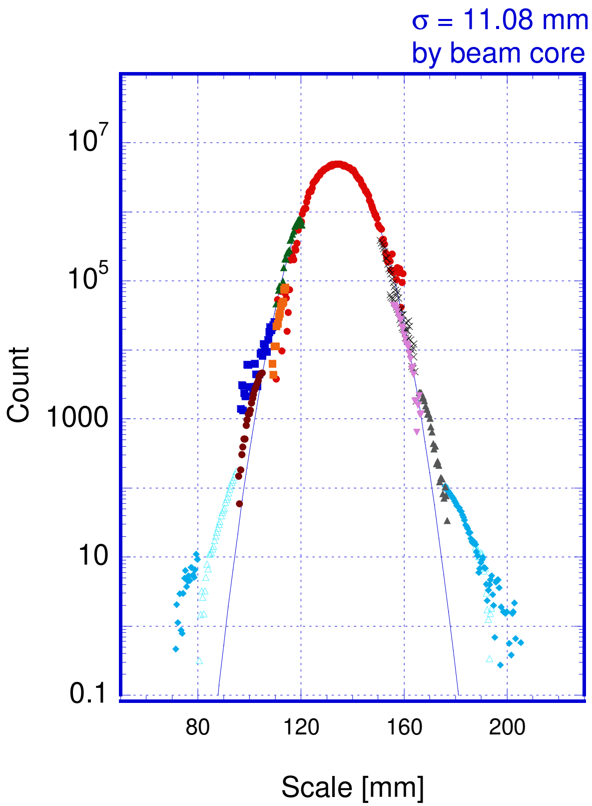
Effect of the beam cut by 3-50 BT collimator (3)

## Horizontal Projection

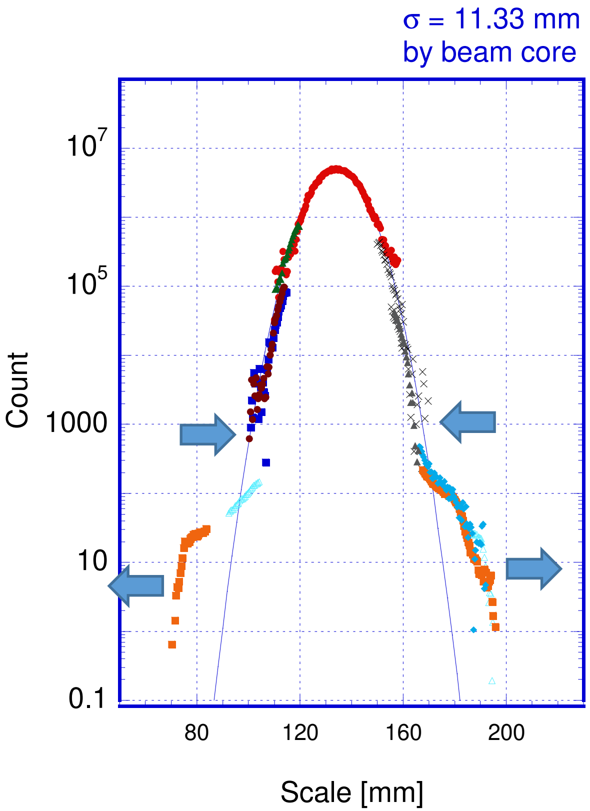
Dynamic Range :More than six order obtained
Beam Size: More than 120 mm at $10^{-6}$ order

Horizontal

Collimator OFF




Collimator ON




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

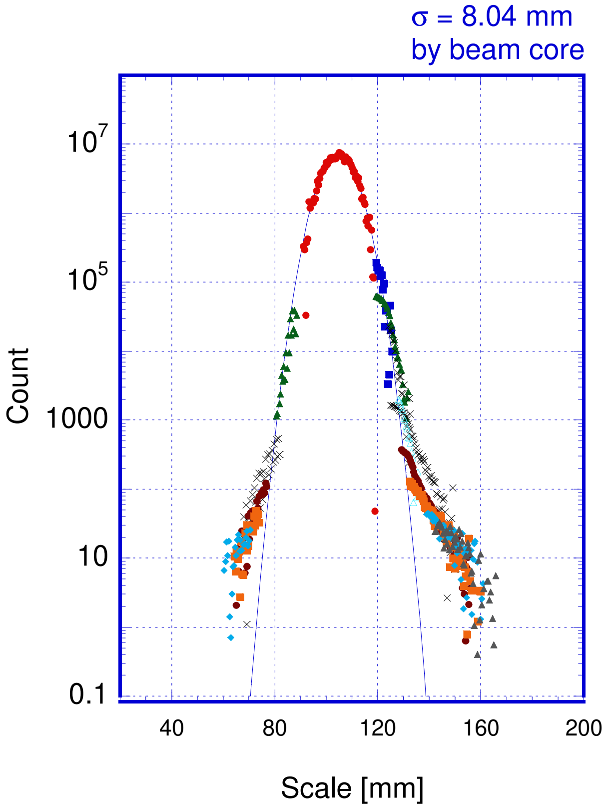
Effect of the beam cut by 3-50 BT collimator (4)



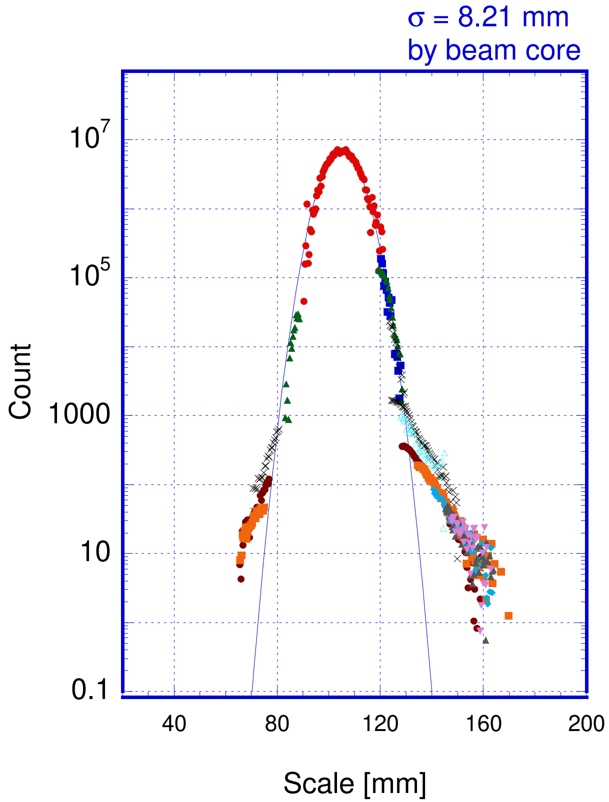
Vertical

## 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

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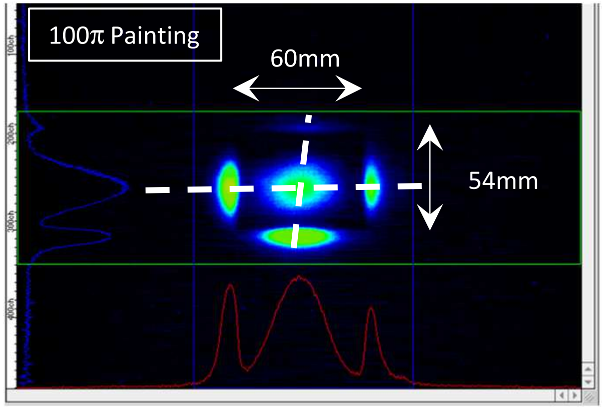
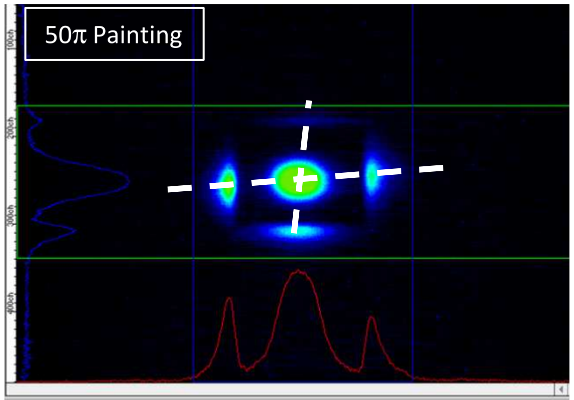
Difference by Painting Area of RCS Injection of 100 π and 50 π [mm.mrad]

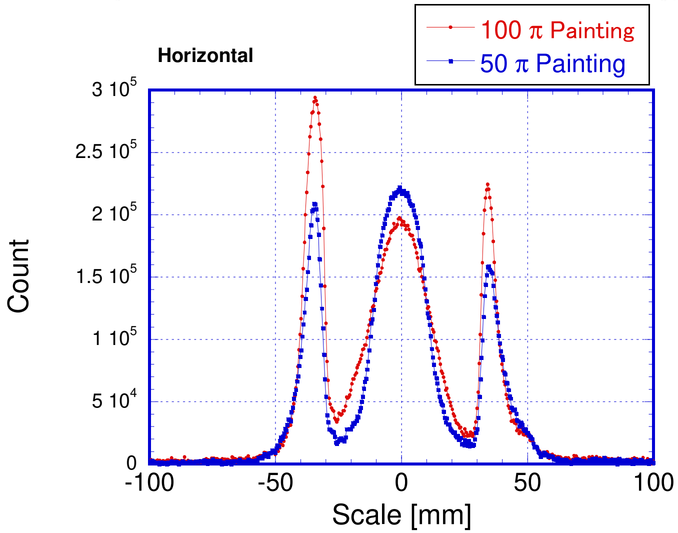
Beam Intensity: 2.99e13/2bunch   5 times averaged

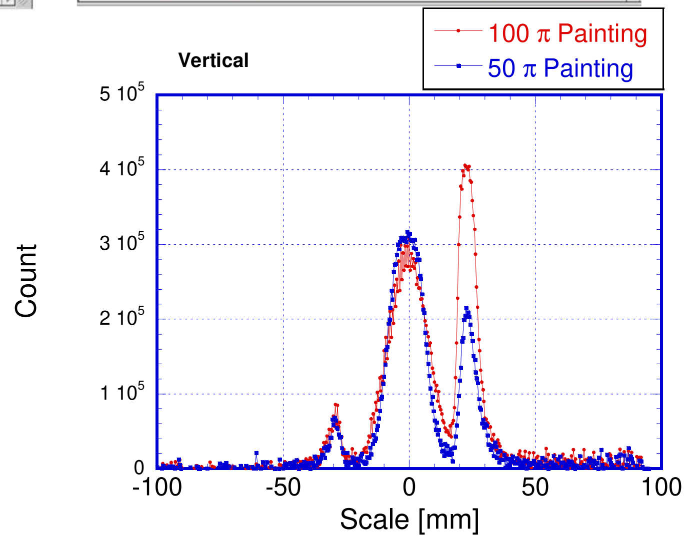



50 π Painting

- Smaller Beam Size
- Halo Rotation

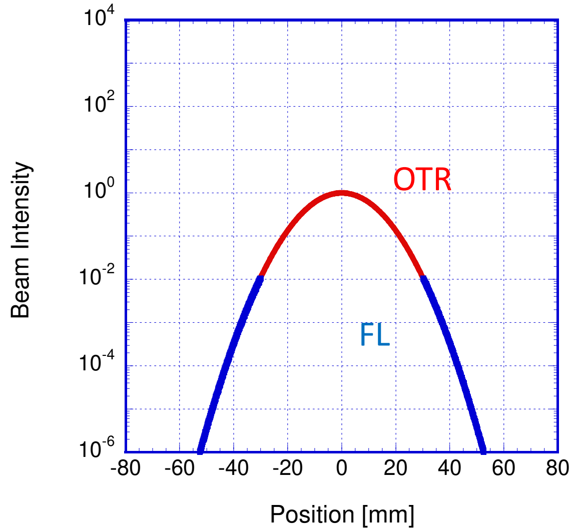


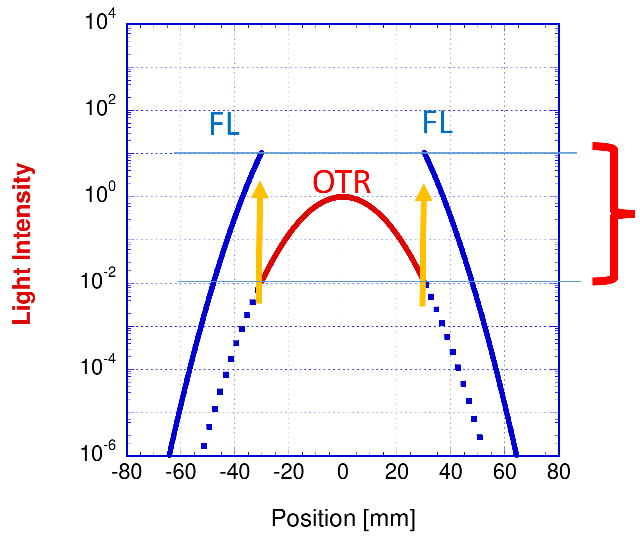



Simultaneous measurement of beam core and beam halo (2) :
as possible as seamlessly (Next step)



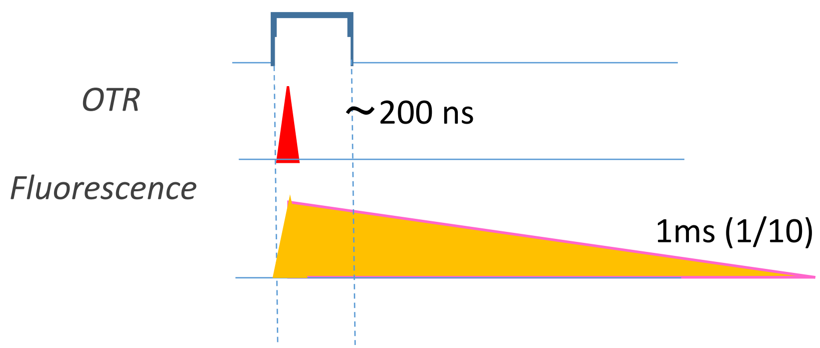
## Light Yield Ratio : Fluorescence /OTR →1000




Three Orders:
Measure with
60～70dB CMOS
Camera

## Exposure (I.I. Gate)



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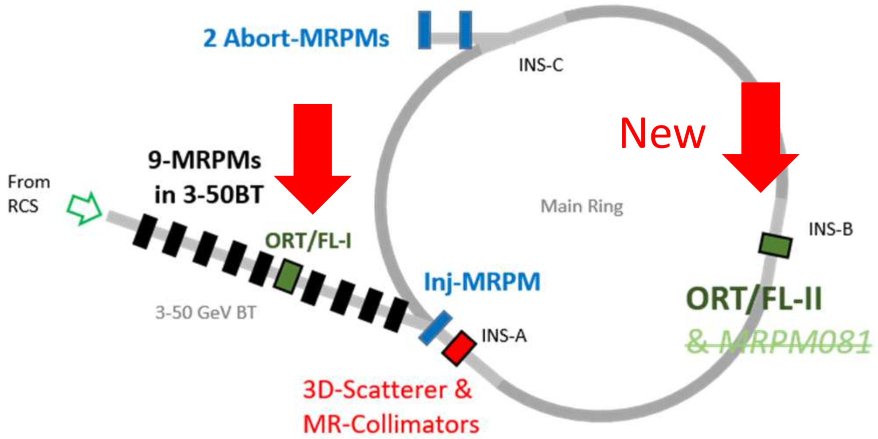
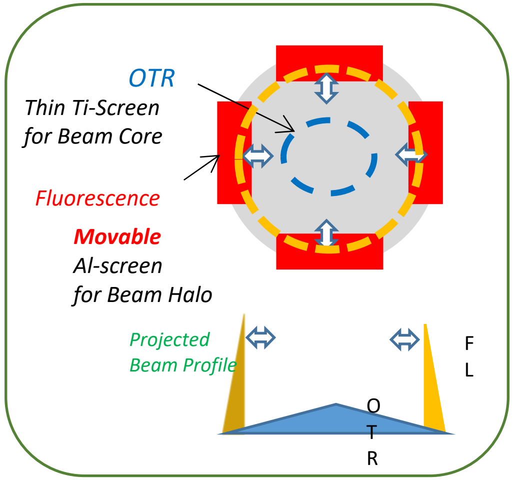
# New OTR/FL-II in MR (on going construction)






**New Halo Monitor at MR**

- 2D beam profile from the beam core to the beam halo with a dynamic range of 6 digits for each pulse for a beam of about 20 turns after beam injection.

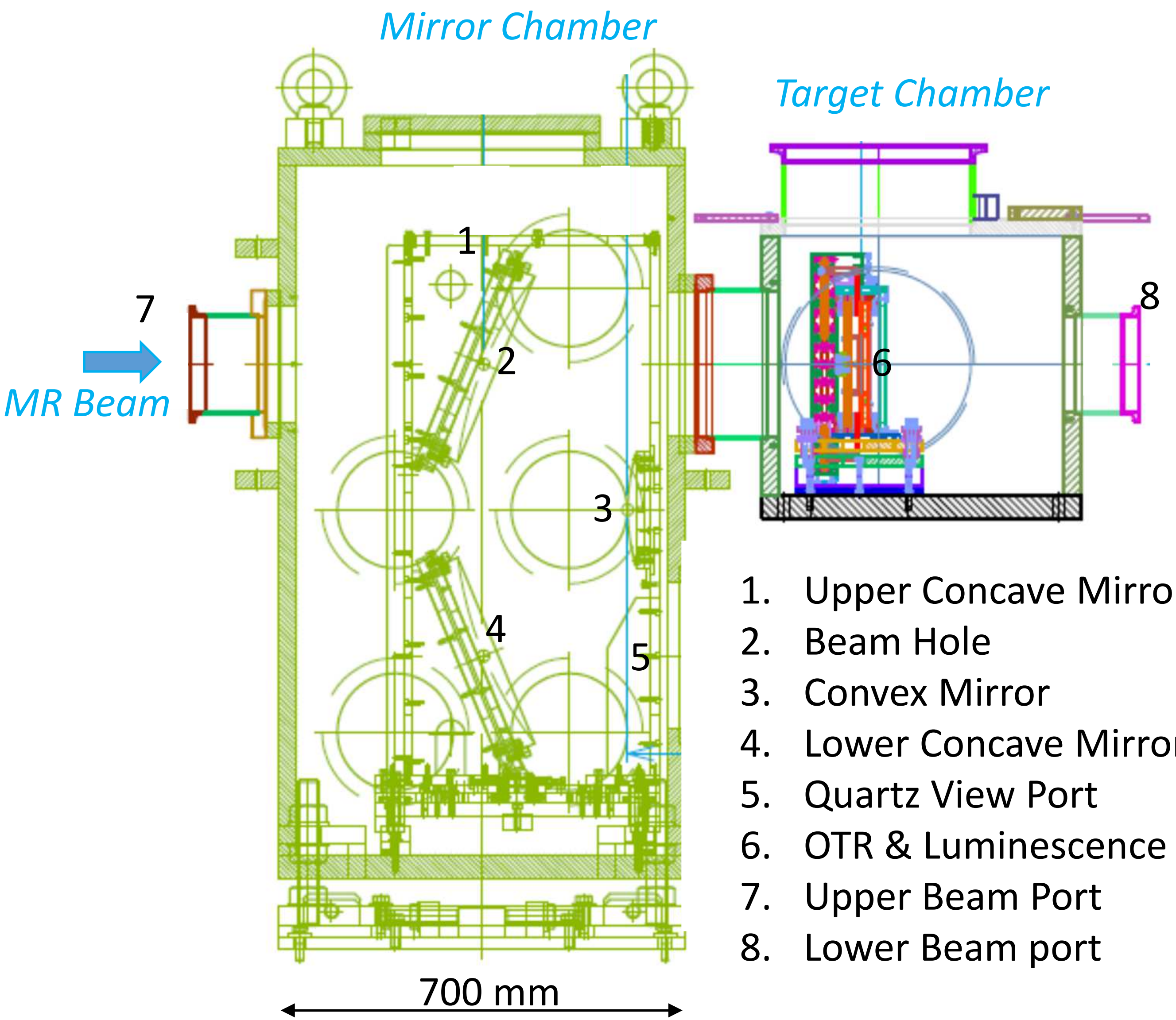
**Operational goal (combinational operation with OTR/FL-1 at 3-50 BT etc. )**:

- Understanding 4D (xx'yy') of MR incident beam-> Advanced simulation model
- Halo cut optimization of both 3-50 BT and MR beam collimator
- Optimization of beam halo suppression parameters

**Issue**:

- Coupling impedance

# OTR/FL-II : Equipment( Side Cross-sectional View)




1. Upper Concave Mirror
2. Beam Hole
3. Convex Mirror
4. Lower Concave Mirror
5. Quartz View Port
6. OTR & Luminescence Screens
7. Upper Beam Port
8. Lower Beam port

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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 !*