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

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Contents

- Motivation
- Concept
- J-PARC and 3-50 Beam Transport Line
- OTR by Low $\gamma$: 3GeV Proton Beam
- Large Acceptance Optics & Detector
- Scaling for Unified Profile
- Combination Measurement with OTR and Fluorescence
- 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 $\geq 10^{13}$ 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*

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)

![Graph showing Gaussian Beam distribution with OTR and Fluorescence measurements.](image)

- Gaussian Beam distribution $\sigma = 10 \text{ mm}$
- 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

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Titanium Foil 10 micron thick</td>
<td>6.7</td>
<td>9.8e-3</td>
</tr>
<tr>
<td>Alumina Ceramics 0.5 mm thick</td>
<td>330</td>
<td>4.7e-1</td>
</tr>
</tbody>
</table>

* 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*

**Screen Configuration**

**Layout (Front View)**

- **OTR**
  - **Solid Screen for Beam Core**
  - **Fluorescence**
  - **Movable Alumina Screen for Beam Halo**

**Projected Beam Profile**
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.

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

Operate by two horizontal movable shafts.
Concept (6): *Screen Configuration-2*

Cross Sectional View

- **Alumina Screen**: 0.5 mm thick
- **Fluorescence** *(Isotropic Radiation)*
- **Beam Halo**
- **OTR** *(Angular Distributed Radiation)*
- **Shadow mask**: Stainless plate 0.5 mm thick
- **Titanium Screen**: 10 μm thick
- **Beam Core**: 13 mm
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)**

- **OTR**
  - ~200 ns = Bunch Length

- **Fluorescence**
  - 1ms (1/10)

![Fluorescence time of Cr doped Alumina Screen](image)

**Beam:** 3GeV Proton
:**2.5e11/bunch**

**Light Intensity [Arbit.]**

- 1.2
- 1
- 0.8
- 0.6
- 0.4
- 0.2
- 0.01
- 0.1
- 1
- 10
- 100
- 1000

**Delay [μs]**

- 1/10 @1 ms
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J-PARC and 3-50 BT:

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

- Our monitor usually measured 2 bunch (1 batch)
- Beam collimators located at 122m upper stream
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OTR by Low $\gamma$: 3GeV Proton Beam:

- Low $\gamma$: 4.2 → Larger Angle Spread

\[ I(\theta) = \frac{1}{\gamma^2} \left| -\sin(\theta) \right|^2 \left| 1 - \beta \cos(\theta) \right| \]

Angular Distribution

± 13.5 degree

= \frac{2}{\gamma} \text{ (in radian)}
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Large Acceptance Optics (1)

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

We employed Offner Optics.

**Our Scheme**

**Original Offner Scheme**

**Diameter 300 mm**

**Target foil**

**Diameter 200 mm**

**Convex mirror**

**Projection Screen**

**Concave mirror with hole**

**Concave mirror Diameter 300 mm**
Large Acceptance Optics (2)

Clear Aperture
Horizontal: 200 mm
Vertical: 90 mm

**Grid Pattern Test**

1mm pitch scale is resolved
New Four Direction Alumina Screen was installed in 2014
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Scaling for Unified Profile (1)

For obtaining an **UNIFIED** profile: *Scaling*

Gain ratio of the image intensifier: $G_R$

$$G_R = \frac{G_{1000}}{G_{SET}}$$

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 $\Rightarrow$ data/$G_R$

FL data $\Rightarrow$ data/$Y_R/G_R$
Scaling for Unified Profile (2)

\( Y_R \): Yields ratio between Fluorescence/OTR

Integration Ratio (avg.)
\[ Y_{MR} = 1.84 \pm 0.07 \] (\( \pm 3.8\% \))

\( Y_R = 1314.6 \)

OTR
50 mm dia. -Hole Target
Fluorescence Alumina Target
Edge: \( \pm 25 \) mm
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Effect of the beam cut by 3-50 BT collimator (1)

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
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

Horizonatal  | Collimator OFF  | Collimator ON

![Graphs showing beam size and dynamic range with and without collimator.](image)

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

\[ \sigma = 8.04 \text{ mm by beam core} \]

Count

Scale [mm]

Collimator ON

\[ \sigma = 8.21 \text{ mm by beam core} \]

Count

Scale [mm]
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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 $\pi$ and 50 $\pi$ [mm.mrad]

Beam Intensity: $2.99\text{e}13/2\text{bunch}$ 5 times averaged

50 $\pi$ 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

Exposure (I.I. Gate)

Three Orders: Measure with 60 ~ 70dB CMOS Camera
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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 dynamic range.

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!