• tight environment
• high radiation area
• non-serviceable area
• passive components
• optics only, no active electronics
• transmit image through flexible fiber bundle
Optical Diagnostics

glass imaging fiber bundle
Core size: 12 µm, diameter: 1/8”

SMD camera
CCD size: 13.4 x 13.4 mm
Pixels: 960x960
Single frame: 240x240 pixels
Reduced pixel size: 56 x 56 µm

Total fiber counts ~50,000 in 3.17 mm diameter
Imaging ~243 x 243 fibers on 960 x 960 CCD array

~1 imaging fiber on ~4x4 pixels on full frame
~1 imaging fiber on ~1 pixel on a single frame
Optical Diagnostics

etroreflected illumination

Spherical mirror

laser illumination

image collection

cm scale

test target

Works OK in this tight environment
Optical Diagnostics
An optical chopper in motion @ 4 kHz

Velocity @ ~40 m/s

Stationary image

100 µs/frame

10 µs/frame

1 µs/frame
Optical Diagnostics

optical design in secondary containment

One set of optics per viewport

Conceptual design completed
Irradiation Studies of Optical Components - I

CERN, ~ April 15-24, 2005
1.4 GeV proton beam
4 \times 10^{15} \text{ proton}
Irradiation dose: equivalent to
40 pulses of 24 GeV proton beam
28 TP/pulse
total of $1.2 \times 10^{15} \text{ proton}$

Received radiation dose:
3231 Gy, ~ 323 krad

Before irradiation April, 2005

Schott glass imaging fiber
not good

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13-Jul-2005</td>
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<tr>
<td>2</td>
<td>Results of optical components irradiated at CERN on April 15, 2005</td>
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<tr>
<td>3</td>
<td>proton beam energy: 1.4 GeV</td>
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<tr>
<td>4</td>
<td>no. of protons: $4 \times 10^{15}$</td>
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<td>5</td>
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<td>6</td>
<td>transmitance and reflectance measured at the HeNe wavelength</td>
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<td>7</td>
<td>item #</td>
<td>components</td>
<td>before</td>
<td>after</td>
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<tr>
<td>8</td>
<td>2</td>
<td>Large gold mirror reflectance</td>
<td>0.910</td>
<td>0.920</td>
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<td>9</td>
<td>3</td>
<td>Small gold mirror reflectance</td>
<td>0.930</td>
<td>0.940</td>
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<td>10</td>
<td>4</td>
<td>50/50 beam splitter: transmittance</td>
<td>0.450</td>
<td>0.360</td>
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<tr>
<td>11</td>
<td>4</td>
<td>50/50 beam splitter: reflectance</td>
<td>0.530</td>
<td>0.423</td>
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<tr>
<td>12</td>
<td>5</td>
<td>imaging lens: transmittance</td>
<td>0.890</td>
<td>0.610</td>
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<tr>
<td>13</td>
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<td>1-mm thick sapphire plate</td>
<td>0.853</td>
<td>0.867</td>
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<td>14</td>
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<td>1-mm thick fused silica</td>
<td>0.914</td>
<td>0.859</td>
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<td>15</td>
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<tr>
<td>16</td>
<td>1</td>
<td>3-fleet long imaging fiber</td>
<td>0.394</td>
<td>0.000</td>
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</tbody>
</table>

After irradiation July 13, 2005
Irradiation Studies of Optical Components - II

CERN, ~ Oct. 24, 2005
1.4 GeV proton beam
5 x 10^{15} proton
Irradiation dose: equivalent to 40 pulses of 24 GeV proton beam
total of 5 x 10^{15} proton

Sumitomo fused silica imaging fiber
is good
Sumitomo imaging fibers

**Product Lineup**

<table>
<thead>
<tr>
<th></th>
<th>IGN-02/03</th>
<th>IGN-028/06</th>
<th>IGN-035/06</th>
<th>IGN-037/10</th>
<th>IGN-051/10</th>
<th>IGN-08/30</th>
<th>IGN-15/30</th>
<th>IGN-20/50</th>
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</thead>
<tbody>
<tr>
<td>Number of picture elements</td>
<td>3,000</td>
<td>6,000</td>
<td>6,000</td>
<td>10,000</td>
<td>10,000</td>
<td>30,000</td>
<td>30,000</td>
<td>50,000</td>
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<tr>
<td>Jacketing diameter (um)</td>
<td>200</td>
<td>280</td>
<td>350</td>
<td>370</td>
<td>500</td>
<td>800</td>
<td>1,500</td>
<td>2,000</td>
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<tr>
<td>Picture elements area diameter (um)</td>
<td>180</td>
<td>252</td>
<td>315</td>
<td>333</td>
<td>450</td>
<td>720</td>
<td>1,350</td>
<td>1,800</td>
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<tr>
<td>Coating diameter (Primary) (um)</td>
<td>250</td>
<td>340</td>
<td>420</td>
<td>450</td>
<td>590</td>
<td>960</td>
<td>1,800</td>
<td>2,400</td>
</tr>
<tr>
<td>Coating diameter (Secondary) (um)</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>2,600</td>
<td>3,000</td>
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<tr>
<td>Circularity</td>
<td>&gt;= 0.93</td>
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<tr>
<td>Core material</td>
<td>GeO2 Containing Silica</td>
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<tr>
<td>Cladding material</td>
<td>F Containing Silica</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Coating material</td>
<td>Silicone</td>
<td></td>
<td></td>
<td>Silicone + PFA</td>
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<td></td>
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<tr>
<td>Numerical aperture</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
<td>0.30</td>
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<tr>
<td>Lattice defect (%)</td>
<td>&lt;= 0.1</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Allowable bending radius (mm)</td>
<td>10</td>
<td>15</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>40</td>
<td>75</td>
<td>100</td>
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<tr>
<td>Allowable max temp. (°C)</td>
<td>150</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Cost per foot: $78, $158, $305
- Cost in 10 meter: $2574, $5214, $10065
- Total cost for 4 fibers (40 meter): $10.3k, $20.8k, $40.3k

**Ign-08/30 Sample**
- 0.3-meter
- 30,000 pixels

**Facet #1**
- Illumination uniformity

**Rad-hard to 1 Mrad**

Cost in 10 meter:
- Continuous 10-20 meter available
- Continuous 10 meter maybe available

**Price Quote**
Fujikura imaging fibers

Table 3

<table>
<thead>
<tr>
<th>Item</th>
<th>FIGH-30-850N</th>
<th>FIGH-50-1100N</th>
<th>FIGH-70-1300N</th>
<th>FIGH-100-1500N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of picture elements(nominal)</td>
<td>30,000</td>
<td>50,000</td>
<td>70,000</td>
<td>100,000</td>
</tr>
<tr>
<td>Image circle diameter (um)</td>
<td>790 ± 50</td>
<td>1,025 ± 80</td>
<td>1,200 ± 100</td>
<td>1,400 ± 120</td>
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<tr>
<td>Fiber diameter (um)</td>
<td>850 ± 50</td>
<td>1,100 ± 80</td>
<td>1,300 ± 100</td>
<td>1,500 ± 120</td>
</tr>
<tr>
<td>Coating diameter (um)</td>
<td>950 ± 50</td>
<td>1,200 ± 100</td>
<td>1,450 ± 100</td>
<td>1,700 ± 150</td>
</tr>
<tr>
<td>Minimum bending radius (mm)</td>
<td>90°±50°</td>
<td>110°±80°</td>
<td>150°±100°</td>
<td>200°±130°</td>
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<tr>
<td>Coating material</td>
<td>Silicone resin</td>
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<td></td>
</tr>
<tr>
<td>Lattice defect (%)</td>
<td>&lt; 0.1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncircularity (%)</td>
<td>&lt; 5</td>
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</tr>
<tr>
<td>length/pc</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Cost per foot

| Cost in 10 meter           | $2805        | $8250         | $17.8k        |
| Total cost for 4 fibers (40 meter) | $11.2k       | $33k          | $71.8k        |

unofficial price info

Cost/foot | $210 | $371.4
Cost in 10 meter | $6,935.65 | $12,256.7
Cost in 20 meter | $15,607.9
Total cost for 4 fibers (40 meter) | $27,742.6 | $49,026.8
30,000 picture elements

NO significant difference in the uniformity of imaging fibers
Image quality comparison

25 cm long

Fujikura  FIGH-30-850N

30,000 pixels, 1-mm diameter

Sumitomo  IGN-08/30

30 cm long

$210/foot  delivery in 3 months

$78/foot  delivery in 4 weeks

camera SMD illumination
NIR pulse, 10 us/frame

NO significant difference in image quality
Should go with Sumitomo fibers
(20 meters have been ordered)
All-in-one optical setup

Grin objective lens
imaging fiber – 1 mm
illumination fiber
fiber holder

implementation depends on the radiation hardness test on the Grin objective lens
All-in-one images

Sumitomo IGN-08/30

0.1 ms NIR pulse

Fujikura FIGH-30-850N

0.01 ms NIR pulse
CCD cameras

**SMD 64KIM camera**
- CCD size: 13.4 x 13.4 mm
- Pixels: 960x960
- Single frame: 240x240 pixels
- 57,600 picture elements
- Frame rate: 16 frames up to 1 µs/frame

**FastVision**
- CCD size: 15.4 x 12.3 mm
- Pixels: 1280x1024
- Single frame: FPGA programable
- 1.3 M picture elements
- Frame rate: 500/s @ full resolution
  - 2500/s @ 200x1280
- Shutter speed down to 1 µs
- Storage of 800 frames @ full resolution

**CERN Olympus Encore PCI 8000S**
- 4 kHz recording rate, 25 µs electronic shutter
Laser sources

Laser diode, SLI 15-W, Class IV
Power = 15 Watts
$I_{th} = 4.5$ Amp
$\lambda = 808$ nm

JDS Uniphase
Laser diode, SDL-2300-L2
Power = 1 Watts
$I_{th} = 0.3$ Amp
$\lambda = 850$ nm

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>25</td>
<td>°C</td>
</tr>
<tr>
<td>Rated power</td>
<td>20</td>
<td>W</td>
</tr>
<tr>
<td>Current at rated power</td>
<td>35.38</td>
<td>A</td>
</tr>
<tr>
<td>Maximum current</td>
<td>41.63</td>
<td>A</td>
</tr>
<tr>
<td>Threshold current</td>
<td>6.2</td>
<td>A</td>
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<tr>
<td>Center wavelength</td>
<td>888.6</td>
<td>nm</td>
</tr>
<tr>
<td>Linewidth FWHM</td>
<td>2.64</td>
<td>nm</td>
</tr>
</tbody>
</table>
1. Passive optical components
2. Image transmit through 10-meter long flexible rad-hard imaging fiber bundle
3. Laser illumination through spherical retroreflecting mirror
4. 4 sapphire viewports, 6-inches apart
5. 1 fast (1 µs/frame) CCD camera, ~3 slower (250 µs/frame) camera
6. New laser and optics have potential to illuminate all viewports with one laser
7. A mark-up run will be assembled in May 2006