Development of nuclear emulsion readout system

**HTS (Hyper Track Selector)**

and an application to muon tomography

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Nuclear emulsion

Nuclear Emulsion plate is a 3D tracking detector.
✓ High spatial resolution (more than 1μm)
✓ Possible to record muon tracks
✓ Light weight and compact
✓ Without power supply
✓ No dead time
✓ Without time resolution by itself
✓ Low cost and large area

3 mrad = 0.17°
(300μm thickness)

Microscope image
Progress of readout speed

<table>
<thead>
<tr>
<th>System</th>
<th>Speed in cm²/hour</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS (TTL)</td>
<td>0.003</td>
<td>1983</td>
</tr>
<tr>
<td>NTS (CPLD)</td>
<td>0.082</td>
<td>1994</td>
</tr>
<tr>
<td>UTS (FPGA)</td>
<td>1</td>
<td>1998</td>
</tr>
<tr>
<td>S-UTS (FPGA)</td>
<td>72</td>
<td>2006</td>
</tr>
<tr>
<td>HTS (GPGPU)</td>
<td>~100 times</td>
<td>2011-</td>
</tr>
</tbody>
</table>

Speed in cm²/hour:
- TS (TTL) 0.003
- NTS (CPLD) 0.082
- UTS (FPGA) 1
- S-UTS (FPGA) 72
- HTS (GPGPU) ~100 times

Progress:
- ~4000 m²/year
- ~40 m²/year
- ~4000 m²/year
Applications

Particle physics
- OPERA for neutrino physics
- Directional dark matter search
  - Mid-term target: >1m² (kg)
  - Final goal: >1000m² (t)

Astrophysics
- Gamma-ray telescope (GRAINE)
  - Mid-term target: 25m² in 2014
  - Final goal: several 1000m²/year

Nuclear emulsion

Geophysics
- Muon tomography
  - Large area readout is required for the next applications
  - Scan capacity
    - 160m²/year (SUTSx4)
    - 4000m²/year (HTSx1)
  - 10 - 100m² per 1 measurement
Tracking in the nuclear emulsion plate

Imaging sensor

Microscope Z-axis

Track of charged particle

Output position and angle of tracks by track recognition method

Nuclear emulsion plate

Plastic base layer 210 μm

1st emulsion layer 44 μm

2nd emulsion layer 44 μm
Concept of **HTS**

- Large field of view
- High-speed precision stage
- GPGPU for track recognition

Mosaic Camera

- Using 6 cameras to fill in the gaps

Objective lens

- Normal

FOV of Normal

- ~5mm

FOV of HTS

- ~12mm

X12
Requirements for emulsion readout system

• Stage:
  Positioning accuracy: <0.2μm (1σ)
  Acceptable vibration: <0.2μm (1σ)

• Objective lens:
  Spatial resolution: 0.40μm
  Working distance: ~1mm (depend on emulsion thickness)

• Camera:
  Pixel pitch: 5.5μm
  (0.45μm for x12.2)
  Camera Link cable
  Video capture board

• Processor:
  GPU and CPU

• Storage server:
  Network
Development of the nuclear emulsion readout system HTS... MNR2013 @Tokyo, Japan

May 2013
HTS

Camera 3
Sensor 36

Computer 18
GPGPU board 36
(For track recognition)

High-speed precision stage
5 view/s
Vibration

Driving stage causes vibration of the whole stage.

Following result was measured with images by pattern matching.

By optimizing the acceleration, both high-speed and less vibration were achieved. 5view/s is half speed.
Track reproducibility and Position displacement (HTS-SUTS)

• 500 tracks was scanned with 12 sensors at HTS. These tracks have been analyzed at the other stage (SUTS).

**Track reproducibility rate 94.2%**

cf. SUTS-SUTS 95%

Sensor No. 1

dx 0.76μm (1σ)

cf. SUTS-SUTS
dx 0.85μm
Angle displacement (HTS-SUTS)

Sensor No. 1

0 – 100 [mrad]

200 – 500 [mrad]

100 – 200 [mrad]

dax

0 – 100  4.0mrad (1σ)
100 – 200  4.1mrad
200 – 500  6.0mrad

cf. SUTS-SUTS
0 – 100  3.5mrad
100 – 200  3.6mrad
200 – 500  5.6mrad
## Results of 12 sensors

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>94.2</td>
<td>0.76</td>
<td>5.2</td>
</tr>
<tr>
<td>2</td>
<td>95.2</td>
<td>0.86</td>
<td>5.5</td>
</tr>
<tr>
<td>3</td>
<td>93.6</td>
<td>0.80</td>
<td>5.2</td>
</tr>
<tr>
<td>4</td>
<td>93.6</td>
<td>0.79</td>
<td>5.6</td>
</tr>
<tr>
<td>5</td>
<td>94.6</td>
<td>0.78</td>
<td>5.5</td>
</tr>
<tr>
<td>6</td>
<td>93.6</td>
<td>0.87</td>
<td>5.3</td>
</tr>
<tr>
<td>7</td>
<td>93.0</td>
<td>0.82</td>
<td>5.9</td>
</tr>
<tr>
<td>8</td>
<td>93.8</td>
<td>0.83</td>
<td>5.3</td>
</tr>
<tr>
<td>9</td>
<td>94.8</td>
<td>0.78</td>
<td>5.2</td>
</tr>
<tr>
<td>10</td>
<td>92.6</td>
<td>0.81</td>
<td>5.5</td>
</tr>
<tr>
<td>11</td>
<td>95.0</td>
<td>0.83</td>
<td>5.6</td>
</tr>
<tr>
<td>12</td>
<td>93.0</td>
<td>0.82</td>
<td>5.6</td>
</tr>
<tr>
<td><strong>Aver.</strong></td>
<td><strong>93.8</strong></td>
<td><strong>0.81</strong></td>
<td><strong>5.5</strong></td>
</tr>
</tbody>
</table>

- These results doesn’t depend on the location of each sensor.
- The position and angle accuracy are enough to take muon tomography.
High-speed precision stage
5 → 10 view/s

HTS

Camera 3 → 6
Sensor 36 → 72

Computer 18 → 36
GPGPU board 36 → 72
(For track recognition)

Present → Goal
**Schedule**

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Camera and Stage speed</td>
<td>1/4 (25%)</td>
<td>1/4 (25%)</td>
<td>1/2 (50%)</td>
<td>1/1 (100%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(already achieved)</td>
<td></td>
</tr>
<tr>
<td>Track recognition speed</td>
<td>1/6 (13%)</td>
<td>1/2 (50%)</td>
<td>1/1 (100%)</td>
<td>1/1 (100%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(already achieved)</td>
<td></td>
</tr>
<tr>
<td>Scanning tested done</td>
<td>1/12 (9%)</td>
<td>1/4 (25%)</td>
<td>1/1 (100%)</td>
<td>1/1 (100%)</td>
</tr>
<tr>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- **Rate [%]**: Present
- **Limit speed of stage**

**Analysis target**

- **10 - 100 m²**: Muon tomography / 1 measurement.
- **25 m²**: Gamma-ray telescope (GRAINE) in 2014.

*Welcome to the use of your measurements.*
Summary

• Parameter adjustment made it possible to drive stage at 5 view/s.
• The performance of optical system was checked.
• Track reproducibility is 93.8% and angle repro. is 5.5 mrad (0.32°).
• Half of the total cameras is installed and speed of the stage is a half. Total throughput is quarter at the present moment.
• Scan speed will be 4500 cm²/hour (half) this fiscal year by installing full image sensors.
Thank you for your attention.

- staff
  Toshiyuki Nakano
- graduate students
  Ryosuke Komatani
  Masahiro Yoshimoto
  Hideharu Miyashita