Results on the FCC-hh Beam Screen prototype at the KARlsruhe Research Accelerator (KARA)

L.A. Gonzalez,¹, ²
M. Gil Costa,³, ² P. Chiggiato,² V. Baglin,² C. Garion,² R. Kersevan,² S. Casalbuoni,⁴ E. Huttel,⁴ I. Bellafont²,⁵ and F. Perez⁶

Task 4.6: Measurements on cryogenic beam vacuum system prototype
Motivation of Experiment

Validation of Simulation Techniques used for the real machine

- PSD
- Reflectivity
- Heat Load
- Photoelectron Generation

<table>
<thead>
<tr>
<th></th>
<th>LHC - 0.58A 7TeV</th>
<th>FCC-hh - 0.5A 50TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR power [W/m]</td>
<td>0.2</td>
<td>35.2</td>
</tr>
<tr>
<td>Flux* ph/m/s</td>
<td>$4.2 \cdot 10^{16}$</td>
<td>$1.5 \cdot 10^{17}$</td>
</tr>
<tr>
<td>Critical Energy</td>
<td>44.2eV</td>
<td>4.3 KeV</td>
</tr>
</tbody>
</table>

*Photon energy above 4eV

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

R. Kersevan; Beam Dynamics meets Vacuum, Collimations, and Surfaces Workshop. KIT, Karlsruhe. March 2017
Samples: FCC-hh Beam Screen Prototypes

Prototype #1  July-Oct '17
#1: Validation of temperature profile and validity of photon reflector

Prototype #2  Jan-May '18
#2: #1 + Electrode for photoelectron current measurements

Prototype #3  June-Aug '18
#3: Surface treatments as for baseline. Updated internal screen and pumping slots. Substitution Reflector for Sawtooth

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring
FCC Week 2018 April 10th
Experiment at KARA

KARA
(KArlsruhe Research Accelerator)

KARA reasonably resembles FCC-hh’s spectrum and linear power, and even at nominal beam energy (2.5 GeV) ANKA’s spectrum is a close match of that of FCC-hh.

Experiment at KARA

BEam Screen Testbench EXperiment

BESTEX (Installation May 2017)
Experiment at KARA

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

Luis Gonzalez
LNF-INFN/CERN TE-VSC

Irradiated length 1.8m

2m FCC-hh Prototype

θ

KARA e-Beam

D-horizontal

D-vertical

2m
Experiment at KARA

After collimation:
83% of Photon Flux Cropped
69% of Photon Power Cropped

<table>
<thead>
<tr>
<th>KARA</th>
<th>FCC-hh</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR Flux</td>
<td>8.7E+16ph/s</td>
</tr>
<tr>
<td>SR Power</td>
<td>32W/m</td>
</tr>
<tr>
<td>Angle of Incidence</td>
<td>18mrad</td>
</tr>
<tr>
<td>Ec</td>
<td>6.2KeV</td>
</tr>
</tbody>
</table>
Experiment at KARA

Ph Flux = 8.73E+16 Ph/s  Normal operation of FCC-hh

Ph Flux = 1.44E+17 Ph/s  Misalignment @ FCC-hh

Ph Flux = 8.73E+16 Ph/s

Injection @ FCC-hh

Ph Flux = 1.44E+17 Ph/s

Injection @ FCC-hh

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring
FCC Week 2018 April 10th
Experiment at KARA

Chimney Connection
• During Irradiation of Geom #1, Dynamic pressure decreases due to conditioning as photon dose increases.
Experiment at KARA

**Experimental Results Prototype #1**

- During Irradiation of Geom #1, dynamic pressure decreases due to conditioning as photon dose increases.
- For doses higher than $1 \times 10^{22}$ ph/m, the normalized pressures decrease linearly.

\[ \eta \propto \Gamma^x \]

Levenberg-Marquardt Algorithm

---

Test of FCC-hh Beam Screen at the ANKA Beamline.

CERN February 20th 2018
# Experiment at KARA

## Experimental Results – Comparison with Calculations

<table>
<thead>
<tr>
<th></th>
<th>2.5GeV/130mA</th>
<th>9.5Ah</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3Ah</td>
<td></td>
</tr>
<tr>
<td>Experiment</td>
<td>Calculations</td>
<td>Rel Discrepancy %</td>
</tr>
<tr>
<td>Middle (mbar)</td>
<td>5.7E-09 ± 15%</td>
<td>6.3E-9</td>
</tr>
<tr>
<td>Front (mbar)</td>
<td>2.9E-09 ± 15%</td>
<td>2.9E-9</td>
</tr>
<tr>
<td>Back (mbar)</td>
<td>2.0E-09 ± 15%</td>
<td>2.8E-9</td>
</tr>
</tbody>
</table>

## Important aspects to take into account for a realistic model
- Not leak tight Chimney
- Rounded reflector
- ...

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

Luis Gonzalez
LNF-INFN/CERN TE-VSC
**Experiment at KARA**

- At Geom #2 photon dose increases irradiating new areas away from the effect of the reflector - Normalized pressure increases

- At Geom #3 normalized pressure continue the decreasing rate observed at #2 – Preconditioning of the inner chamber due to reflected photons

- Back to Geom #1 the normalized pressure recovers the original decreasing trend

---

**Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring**

FCC Week 2018 April 10th
At Geom #4, the pressure evolution indicates preconditioning of the inner chamber due to reflected photons during previous geometries.
Experiment at KARA

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

**PSD Studies**

**Experimental Results Prototype #2**

- At low doses, normalized pressure is about 100 times higher than for Proto#1 - Effect ascribed to the cold sprayed Cu and ceramics
- The pressure increase at Geoms #2 and #3 is negligible
- The effect of a large amount of photons reflected into the main chamber is now visible due to the presence of clearing electrode and ceramics
- Back to Geom #1 the normalized pressure recovers the original decreasing trend
Test of FCC-hh Beam Screen at the ANKA Beamline.

Experiment at KARA

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

Luis Gonzalez
LNF-INFN/CERN TE-VSC

PSD Studies
Experimental Results Prototype #2

- At low doses, normalized pressure is about 100 times higher than for Proto#1 - Effect ascribed to the cold sprayed Cu and ceramics
- The pressure increase at Geoms #2 and #3 is negligible
- The effect of a large amount of photons reflected into the main chamber is now visible due to the presence of clearing electrode and ceramics
- Back to Geom #1 the normalized pressure recovers the original decreasing trend

\[ \eta \propto \Gamma^x \]

Levenberg-Marquardt Algorithm

Sample#1 \( X=-0.54 \pm 0.01 \)
Sample#2 \( X=-0.98 \pm 0.01 \)

Dynamic Pressure (mbar/A)

Dose (Ph/m)
Experiment at KARA

Reflectivity Studies
Experimental Equipment

\[ RI = \frac{I_{\text{Reflection}}}{I_{\text{Straight Through}}} \times 100 \]

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Experiment at KARA

Reflectivity Studies
Experimental Results Prototype #1

Photoelectron current measured at electrode

Comparison: Straight vs Reflection

\[ R_l = \frac{I_{\text{Reflection}}}{I_{\text{Straight Through}}} \times 100 \]

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Experiment at KARA

Photoelectron current measured at electrode

Comparison: Straight vs Reflection

\[ RI = \frac{I_{\text{Reflection}}}{I_{\text{Straight Through}}} \times 100 \]

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

The surface roughness and their aspect ratios were measured at different parts of the sample

Stainless Steel
AR \sim 0.06

Electrodeposited Cu
AR \sim 0.5
Calculation* of photons reaching photon cup

\[ RI = \frac{I_{\text{Reflection}}}{I_{\text{Straight Through}}} \times 100 \]

Comparison: Straight vs Reflection

\[ R\Gamma = \frac{\Gamma_{\text{Reflection}}}{\Gamma_{\text{Straight Through}}} \times 100 \]

Comparison: Straight vs Reflection

The surface roughness and their aspect ratios were measured at different parts of the sample.

Electrodeposited Cu
AR ~ 0.5

Stainless Steel
AR ~ 0.06

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Calculation* of photons reaching photon cup

\[ RI = \frac{I_{\text{Reflection}}}{I_{\text{Straight Through}}} \times 100 \]

Comparison: \(\text{Straight vs Reflection}\)

<table>
<thead>
<tr>
<th>Geom</th>
<th>(R\Gamma) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>1.3%</td>
</tr>
<tr>
<td>#2 and #3</td>
<td>1.2%</td>
</tr>
<tr>
<td>#4</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

RI = \(\frac{I_{\text{Reflection}}}{I_{\text{Straight Through}}} \times 100\)

Comparison: \(\text{Straight vs Reflection}\)

The surface roughness and their aspect ratios were measured at different parts of the sample.

Stainless Steel
AR ~ 0.06

Electrodeposited Cu
AR ~ 0.5

Experimental results are in good correlation with Calculations

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring
FCC Week 2018 April 10th

**Reflectivity Studies**
Experimental Results Prototype #1

Luis Gonzalez
LNF-INFN/CERN TE-VSC
Experiment at KARA

Heat Load Studies
Experimental Equipment

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Experiment at KARA

Heat Load Studies
Experimental Results Prototype #2

Calculation

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Experiment at KARA

Cold Sprayed Isolated Electrode

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Experiment at KARA

Photoelectron Generation Studies
Experimental Results – Prototype #2

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

Luis Gonzalez
LNF-INFN/CERN TE-VSC

Photon Flux
- 75.4% Increase

Photoelectrons
- 23.7% Increase
Experiment at KARA

Effect of the surface conditioning is visible

Photoelectron Generation Studies
Experimental Results – Prototype #2

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

Luis Gonzalez
LNF-INFN/CERN TE-VSC

23
Summary and Conclusions

• After installation of BESTEX at KARA, experimental data has been obtained for the first two prototypes.
• Experiments have been carried out in different irradiation configurations, in order to mimic the different scenarios at FCC-hh
• Sample #1 shows a satisfactory behavior under SR in terms of vacuum
• Sample #2 shows a large amount of photoelectrons reflected towards the BS’s main chamber
• Reflectivity measurements show an unforeseen decrease of the amount of reflected photons for the misalignment case. Effect ascribed to the roughness of electrodeposited Cu at the BS’s main chamber.
• Calculations were compared to experimental results:
  • PSD calculations were compared to experimental results and tuned by using more realistic models. Discrepancies remain below 30% in all cases.
  • Temperature distribution calculations are in good agreement with experiment.
  • Experimental reflectivity results are in good correlation with calculations
• Measurements on Photoelectron generation inside the BS have been performed.
• Instation of Sample #3 (Sawtooth profile) and test to be carried out from June 2018
Thank You
Fluorescent Screen Information

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Fluorescent Screen Information

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Fluorescent Screen Information

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring
FCC Week 2018 April 10th
Alignment

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th
Alignment

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

Luis Gonzalez
LNF-INFN/CERN TE-VSC
Alignment

3D Model Calculations

Footprint

Irradiated Fluorescent Screen

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

FCC Week 2018 April 10th

Luis Gonzalez
LNF-INFN/CERN TE-VSC
Experiment at KARA

Levenberg-Marquardt Algorithm

\[
\begin{align*}
\text{Middle} & \quad x = -0.16 \pm 0.01 \\
\text{Front} & \quad x = -0.02 \pm 0.01 \\
\text{Back} & \quad x = -0.23 \pm 0.01
\end{align*}
\]
Experiment at KARA

PSD Studies
Experimental Results

Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring
FCC Week 2018 April 10th

Lower starting point lower conditioning rate.
Indicates pre-conditioning of the Geometry #4 region due to scattered photons

Middle $X = -0.16 \pm 0.01$
Front $X = -0.02 \pm 0.01$
Back $X = -0.23 \pm 0.01$

Levenberg-Marquardt Algorithm
Results on the FCC-hh Beam Screen prototype at the KIT electron storage ring

Luis Gonzalez
LNF-INFN/CERN TE-VSC

FCC Week 2018 April 10th
## ANKA Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>2.5</td>
<td>GeV</td>
</tr>
<tr>
<td>Emittance</td>
<td>50</td>
<td>nm</td>
</tr>
<tr>
<td>Circumference</td>
<td>110.4</td>
<td>m</td>
</tr>
<tr>
<td>Current</td>
<td>200</td>
<td>mA</td>
</tr>
<tr>
<td>Optics</td>
<td>4x2</td>
<td>DBA</td>
</tr>
<tr>
<td>DP-Field</td>
<td>1.5</td>
<td>T</td>
</tr>
<tr>
<td>DP SR Power</td>
<td>18</td>
<td>W/mrad</td>
</tr>
<tr>
<td>DP SR Photon Flux</td>
<td>$6 \times 10^{19}$</td>
<td>Ph/(s mrad)</td>
</tr>
<tr>
<td>$E_{\text{crit}}$</td>
<td>6.2</td>
<td>KeV</td>
</tr>
</tbody>
</table>

## FCC Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP SR Power</td>
<td>32</td>
<td>W/m*</td>
</tr>
<tr>
<td>DP SR Photon Flux</td>
<td>$1 \times 10^{17}$</td>
<td>Ph/(s m*)</td>
</tr>
</tbody>
</table>

## BESTEX Parameters (at ANKA after collimation)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP SR Power</td>
<td>32</td>
<td>W/m*</td>
</tr>
<tr>
<td>DP SR Photon Flux</td>
<td>$5 \times 10^{16}$</td>
<td>Ph/(s m*)</td>
</tr>
<tr>
<td>Incident angle</td>
<td>18</td>
<td>mrad</td>
</tr>
</tbody>
</table>

*m: irradiated length