Results on the FCC-hh Beam Screen at the KIT Electron Storage Ring KARA

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Task 4.6: Measurements on cryogenic beam vacuum system prototype
FCC - Future Circular Collider

- Proposed as successor of the LHC among others: CLIC, HE-LHC...

- Three versions* FCC-hh FCC-ee FCC-he

<table>
<thead>
<tr>
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<th>FCC-hh</th>
<th>LHC</th>
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<tbody>
<tr>
<td>Energy collision [TeV]</td>
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<td>Perimeter [km]</td>
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<tr>
<td>Dipole field [T]</td>
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<td>8.3</td>
</tr>
<tr>
<td>Arc SR Photon Flux** [ph/s/m]</td>
<td>$1.34 \times 10^{17}$</td>
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<td>SR Heat load [W/m]</td>
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<td>SR Critical Energy [eV]</td>
<td>4300</td>
<td>44</td>
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** Energy above cut-off at 4 eV

*Please attend: THYGBD1: FCC: Colliders at the Energy Frontier, Michael Benedikt
Present LHC BS Design

**FCC-hh BS** must be redesigned in order to guarantee:

- Higher cooling capacity
- Higher pumping speed
- Higher working temperatures 40-60K

-Proposed as successor of the LHC among others: CLIC, HE-LHC...

-Three versions*: FCC-hh  FCC-ee  FCC-he

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O. Gröbner, Vacuum 60 (2001) 25-34
FCC-hh BeamScreen Designs

Present LHC BS Design

First FCC-hh BS Design

Last FCC-hh BS Design (Base Line)

O. Gröbner, Vacuum 60 (2001) 25-34

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FCC-hh BeamScreen Designs

Present LHC BS Design

First FCC-hh BS Design

Last FCC-hh BS Design (Base Line)
Motivation

Perform Studies on FCC-hh BS prototypes

Obtain relevant experimental data on
- PSD
- Reflectivity
- Heat Load
- Photoelectron Generation

Validation of Simulation Techniques used for the real machine

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Samples: FCC-hh Beam Screen Prototypes

Prototype #1  
*July- Oct ‘17*

#1: Commissioning of BESTEX. Validation of temperature profile and validation 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. Substitution Reflector for Sawtooth. Test of Complete design

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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

Irradiated length 1.8m

KARA e-Beam

D-horizontal

D-vertical

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8
Experiment at KARA

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

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<thead>
<tr>
<th></th>
<th>KARA</th>
<th>FCC-hh</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR Flux</td>
<td>8.7E+16ph/s</td>
<td>1.5E+17ph/s</td>
</tr>
<tr>
<td>SR Power</td>
<td>32W/m</td>
<td>32W/m</td>
</tr>
<tr>
<td>Angle of Incidence</td>
<td>18mrad</td>
<td>&lt;2 mrad</td>
</tr>
<tr>
<td>Ec</td>
<td>6.2KeV</td>
<td>4.2KeV</td>
</tr>
</tbody>
</table>

Beam Direction

Results on the FCC-hh Beam Screen at the KIT Electron Storage Ring KARA
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Experiment at KARA

Experimental Configurations

Ph Flux = 8.73E+16 Ph/s

Geometry #1

Normal operation of FCC-hh

Ph Flux = 1.44E+17 Ph/s

Geometry #2

Injection @ FCC-hh

Ph Flux = 8.73E+16 Ph/s

Geometry #4

Misalignment @ FCC-hh

Ph Flux = 1.44E+17 Ph/s

Geometry #3

Injection @ FCC-hh

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Experimental Results
Chimney Connection
(Allows pressure measurements inside of BS)
Experiment at KARA

PSD Studies

Experimental Results Prototypes #1 & #2

- At low doses, normalized pressure for proto #2 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 visible for proto#2 due to the presence of clearing electrode and ceramics
- Back to Geom #1 the normalized pressure recovers the original decreasing trend
### Experiment at KARA

#### Experimental Results – Comparison with Calculations

<table>
<thead>
<tr>
<th></th>
<th>2.5GeV/130mA</th>
<th></th>
<th>9.5Ah</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3Ah</td>
<td>9.5Ah</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experiment</td>
<td>Calculations</td>
<td>Discrepancy %</td>
<td>Experiment</td>
</tr>
<tr>
<td>Middle (mbar)</td>
<td>5.7E-09 ± 15%</td>
<td>6.3E-9</td>
<td>9%</td>
<td>3.0E-09 ± 15%</td>
</tr>
<tr>
<td>Front (mbar)</td>
<td>2.9E-09 ± 15%</td>
<td>2.9E-9</td>
<td>1%</td>
<td>2.0E-09 ± 15%</td>
</tr>
<tr>
<td>Back (mbar)</td>
<td>2.0E-09 ± 15%</td>
<td>2.8E-9</td>
<td>29%</td>
<td>1.0E-09 ± 15%</td>
</tr>
</tbody>
</table>

### Important aspects to take into account for a realistic model

- Not leak tight Chimney
- Rounded tip of reflector
- ...

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Results on the FCC-hh Beam Screen at the KIT Electron Storage Ring KARA
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Experiment at KARA

Reflectivity Studies
Experimental Equipment

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

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#1 #2 #3 #4
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 at the KIT Electron Storage Ring KARA

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Photoelectron current measured at electrode

**Comparison:**

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

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

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

Comparison: Straight vs Reflection

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

Stainless Steel
AR ~ 0.06

Electrodeposited Cu
AR ~ 0.5

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

Comparison: Straight vs Reflection

Photoelectron current measured at electrode

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Experiment at KARA

Comparison:

**Straight vs Reflection**

Photoelectron current measured at electrode

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

<table>
<thead>
<tr>
<th>Geom #1</th>
<th>( R\Gamma = 1.3% )</th>
</tr>
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<tbody>
<tr>
<td>Geom #2 and #3</td>
<td>( R\Gamma = 1.2% )</td>
</tr>
<tr>
<td>Geom #4</td>
<td>( R\Gamma = 0.3% )</td>
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Experimental results are in good correlation with Calculations

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

Stainless Steel
AR \( \sim 0.06 \)

Electrodeposited Cu
AR \( \sim 0.5 \)
Experiment at KARA

Heat Load Studies
Experimental Equipment

Results on the FCC-hh Beam Screen at the KIT Electron Storage Ring KARA

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Experiment at KARA

Heat Load Studies
Experimental Results Prototype #2

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Experiment at KARA

Cold Sprayed Isolated Electrode

Photoelectron Generation Studies
Experimental Equipment
Experiment at KARA

Photoelectron Generation Studies
Experimental Results – Prototype #2

Photon Flux 75.4% Increase
Photoelectrons 23.7% Increase
Summary and Conclusions

- After installation of BESTEX at KARA, experimental data have 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, and give us confidence at using simulations for predicting the behaviour of the whole FCC-hh machine.
- Measurements on Photoelectron generation inside the BS have been performed.
- Installation of Sample #3 (Sawtooth profile) and test to be carried out from June 2018.
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