EuroCirCol WP4
FCC-hh beam vacuum system

Francis Perez (ALBA)
on behalf of EuroCirCol WP4 team

EuroCirCol: 'The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.'
The charge of WP4: Cryogenic Beam Vacuum System

WP 4: Cryogenic Beam Vacuum System Conception

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Description</th>
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<tbody>
<tr>
<td>1) Evaluate the impact of the arc design on technology requirements</td>
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<tr>
<td>2) Develop an overall, integrated design for the cryogenic beam vacuum system consisting of (1) beam-screen, (2) proximity cryogenics, (3) magnet cold bore and (4) vacuum system</td>
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<tr>
<td>3) Determine the needs for advancing individual technologies to meet the requirements</td>
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<tr>
<td>4) Study synchrotron radiation heat load absorption and mitigation for the photo-electrons generation</td>
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<tr>
<td>5) Consider novel mitigation techniques, e.g. based on frequent discrete photon absorbers</td>
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The cryogenic beam vacuum system for the arc dipoles will be designed in close iterative interaction with the magnet cold bore concept and design. The functional and performance requirements need therefore to be continuously re-evaluated and refined. Relevant aspects include beam-induced heat loads including synchrotron radiation, vacuum stability, mechanical performance, beam-screen cooling concept, dynamic effects such as electron cloud multipacting and photo-electrons generation by synchrotron radiation. Image current continuity and impedance are assumed to have significant impacts on the accelerator and magnet design. Optimisation has large performance improvement and cost reduction potentials.
The charge of WP4:
Divided in several tasks

**Coordination**

**Study of beam induced vacuum effects**

**Study of mitigation techniques of e-cloud and ion instabilities**

**Study of vacuum stability at cryogenic temperatures (40-60 K)**

**Develop a mechanical (conceptual) design**

**Prototyping and measurements**
FCC-hh cryogenic beam-vacuum requirement in the arcs

The challenge:

x100+ higher synchrotron radiation power density

<table>
<thead>
<tr>
<th></th>
<th>FCC-hh</th>
<th>Present LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton energy [TeV]</td>
<td>50</td>
<td>7</td>
</tr>
<tr>
<td>Temperature of cold mass [K]</td>
<td>1.9</td>
<td>1.9</td>
</tr>
<tr>
<td>Number of bunches at 25 ns</td>
<td>10600</td>
<td>2808</td>
</tr>
<tr>
<td>Bunch population [10^{11}]</td>
<td>1</td>
<td>1.15</td>
</tr>
<tr>
<td>SR photon flux [ph s^{-1}m^{-1}] above cut-off at 4 eV</td>
<td>1.34x10^{17}</td>
<td>2.02x10^{16}</td>
</tr>
<tr>
<td>Arc SR heat load per beam [W m^{-1}]</td>
<td>28.4*</td>
<td>0.17</td>
</tr>
<tr>
<td>SR critical energy [eV]</td>
<td>4300</td>
<td>44</td>
</tr>
</tbody>
</table>

Required gas density in the arcs < 1x10^{15} H_{2}/m^{3}
(equivalent to 100 hrs nuclear beam-gas scattering lifetime)
Due to the higher SR power density:

- The mass flow of gas in the cooling channel must be increased. The diameter of the channel has to be increased to avoid too high pressure drop.

- The beam screen temperature must be increased in the range 40 to 60 K, as compared to the 5 to 20 K in LHC, to reduce the needed cryogenic power. The higher temperatures have large repercussions on the vacuum due to higher equilibrium vapour pressures.

- There is an increased photo-desorption due to an higher number of photons (x6 above cut-off at 4 eV). Higher effective pumping is needed.

Consequence: The present LHC beam is not adapted for the FCC-hh.
1\textsuperscript{st} proposed design of the FCC-hh arc vacuum system

Original proposal at “FCC Week Conference”, Washington D.C., \textbf{March 2015};

One-slot beam screen with reduced number of pumping slots (source of impedance)

Discontinuous ribs for photon absorption and mechanical reinforcement

- \textit{LHC-like design: closed, slotted beam screen}
Progress with the FCC-hh beam screen design

In the last **four years**, the beam screen design has been modified several times to attain:

- **Improved heat transfer** *(as cold spray copper ring in the outer surface)*
- **Reduced transverse impedance** *(symmetric cross section)*
- **Higher pumping efficiency** *(larger pumping holes)*
- **Easier manufacturing** *(polygonal shape)*
Progress with the FCC-hh beam screen design

Last year a conceptual change was done, by going from Reflection to Absortion concept, in order to reduce the undesired SR scattering and in addition, reduce the head load in the interconnection section.

- Remove the deflector
- Introduce Saw-tooth
- Re-design for simplification (*remove rips, thickness*)
Latest version of the Cryogenic Beam Vacuum System

Wednesday 26th 11:30 - 11:50
Ballroom II (Ground floor)

Update of the design and thermal mechanical study of the FCC-hh beam screen
Marco Morrone

M. Morrone
- At the expense of a higher complexity (translated into a higher, but still affordable, cost) the beam induced vacuum effects are mitigated and the **pumping speed** and cooling capacity have been **considerably increased**

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Francis Perez, on behalf WP4-EuroCirCol: FCC-hh beam vacuum system
Study of beam induced vacuum effects

Expected conditioning achieved in 3-4 months

**Expected conditioning achieved in 3-4 months**

Study on the beam induced vacuum effects in the FCC-hh beam vacuum chamber

Ignasi Bellafont

Wednesday 26th 08:30 - 08:50 Ballroom II (Ground floor)

Study on the beam induced vacuum effects in the FCC-hh beam vacuum chamber

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Study on the beam induced vacuum effects in the FCC-hh beam vacuum chamber

Ignasi Bellafont
To achieve these results and conclusions work in the several tasks have been crucial and have increased our understanding of the involved materials and technologies.
### Study of mitigation techniques of e-cloud and ion instabilities

<table>
<thead>
<tr>
<th>Task</th>
<th>Problem</th>
<th>Solutions</th>
</tr>
</thead>
</table>
| LASE treatment & its optimisation         | Is it possible to achieve $\delta_{\text{max}} < 1$ with other laser than in original invention? | • More than 100 samples produced and characterised, $\delta_{\text{max}} < 1$ in 60%  
• Different lasers can be used for LASE  
  • with different $\lambda$, $f$, $\tau$, power, etc. |
| Surface resistance                        | First LASE samples had surface resistance higher than untreated surface | New LASE combines $\delta_{\text{max}} < 1$ and surface resistance measured at 8 GHz remains the same with and without LASE |
| Thermal outgassing                        | Increased surface area may cause high outgassing                        | No increase in thermal outgassing observed                                 |
| ESD                                       | Would LASE result in higher ESD?                                       | LASE results in the same or reduced ESD                                  |
| Particle generation                       | Possible UFO problem                                                   | • No particles above 25 $\mu$m  
• A number of smaller size particles can be reduced |

**Wednesday 26th. 10:30 - 10:50 Ballroom II (Ground floor)**

**Evaluation of LASER ablated surface engineering of copper and stainless steel for particle accelerators**

Reza Valizadeh
### Study of mitigation techniques of e-cloud and ion instabilities

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</table>
| ESD and pumping             | Is NEG coating works at cryogenic temperatures?                          | For CO:  
  • $\eta$ reduces and $\alpha$ increases  
  For $\text{H}_2$:  
  • $\eta$ and $\alpha$ – small change,  
  • $\eta'$ effect (like at 4.2 K is observed on activated NEG surface) |
| NEG activation with SR      | Would SR induced activation of NEG coating be possible at cryogenic temperatures (like it observed at RT)? | No such effect observed at cryogenic temperature                                                                                            |
| New types of NEG coatings   | Different composition, morphologies                                      | • Columnar and dense films of Ti–Zr–Hf–V, Ti–Zr–V and Zr films have been studied                                                       |

**Recent Results on NEG Coating Characterisation**  
Ruta Sirvinskaite

Wednesday 26th.  
10:50 – 11:10  
Ballroom II (Ground floor)
Study of vacuum stability at cryogenic temperatures (40-60 K)

Material properties of relevance to cryogenic vacuum systems
Luisa Spallino

Wednesday 26th. 08:50 – 09:10 Ballroom II (Ground floor)
**Prototyping and measurements**

**Experiment at KARA-BESTEX**

FCC-hh test area

FCC-hh & KARA set-up:
- Identical power
- Similar ph. Spectrum

SR from KARA’s dipole
Prototyping and measurements

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
**Prototyping and measurements**

**Experiment at KARA-BESTEX**

BESTEX (Beam Screen Testbench Experiment) is an experimental instrument designed to study SR related effects on non-leak tight samples under UHV.

The SR photon beam originated at KARA’s bending magnet is collimated so as to irradiate the samples on their designated region.

**Wednesday 26th. 11:10 – 11:30 Ballroom II (Ground floor)**

**Photodesorption Studies on FCC-hh Beam Screen Prototypes at KARA**

Luis Antonio Gonzalez Gomez
Develop a mechanical (conceptual) design

Quench analysis

\[ F_x(t) \]

\[ j\cdot y(t) \]

\[ B \cdot z (t) \]

Thermal analysis

Max synchrotron radiation power ~ 42 W/m
Beam intensity: 0.5 A, 50 TeV

Installation in cold bore

Week 2019
June 24th, 2019
Francis Perez, on behalf WP4-EuroCirCol: FCC-hh beam vacuum system

Wednesday 26\textsuperscript{th} 11:30 - 11:50 Ballroom II (Ground floor)

Update of the design and thermal mechanical study of the FCC-hh beam screen

Marco Morrone
Develop a mechanical (conceptual) design

Considerations for large scale production of the FCC-hh beam screens

Cedric Garion
In addition, the EuroCirCol WP4 project has created a series of “spin-off” collaborations
Reflectivity studies

Incident Radiation = Transmitted + Reflected + Absorbed

Synchrotron Radiation

Vacuum Chamber Wall

Reflected Radiation

LNF launched a long term proposal (MICA) and received support by INFN and beamtime by the project CALIPSOplus. (under the Grant Agreement 730872 from the EU Framework Programme for Research and Innovation HORIZON 2020)

Wednesday 26th. 09:10 – 09:30 Ballroom II (Ground floor)

Reflectivity and PY from candidate materials for the FCC-hh Vacuum system

Roberto Cimino
### XUV Beamlines

**Three different beamlines**

<table>
<thead>
<tr>
<th>XUV 1 (Low Energy)</th>
<th>XUV 2 (High Energy)</th>
<th>WINDY</th>
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</thead>
<tbody>
<tr>
<td>Small Sample</td>
<td>Small Sample</td>
<td>Long Tube</td>
</tr>
<tr>
<td>From 10 K</td>
<td>From 10 K</td>
<td>From Liquid Nitrogen</td>
</tr>
<tr>
<td>WL and</td>
<td>WL and</td>
<td>Wight Light</td>
</tr>
<tr>
<td>Monochromatic Light</td>
<td>Monochromatic Light</td>
<td>Range Energy:</td>
</tr>
<tr>
<td>Range Energy:</td>
<td>Range Energy:</td>
<td>up to ~200 eV</td>
</tr>
<tr>
<td>from 30 to 150 eV</td>
<td>from 60 to 1000 eV</td>
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**Photo desorption studies at the WINDY set-up at LNF**

Marco Angelucci

Wednesday 26th. 09:30 – 09:50 Ballroom II (Ground floor)
Feasibility of High Temperature Coated Superconductors for the Vacuum Beam Screen

In situ Irradiation and DC resistance testing

Surface resistance vs. B and T

FCC Week 2019
June 24th, 2019

Francis Perez, on behalf WP4-EuroCirCol: FCC-hh beam vacuum system
Feasibility of High Temperature Coated Superconductors for the Vacuum Beam Screen

Wednesday 26th. 14:10 – 14:30
Clarity (8th floor)

RF Characterisation of HTS-CC Tapes as Alternative Coating for the FCC-hh Beam Screen
Patrick Krkotić

Wednesday 26th. 14:30 – 14:50
Clarity (8th floor)

REBa2Cu3O7 coated conductors as a beam screen coating: Using the classical rigid-fluxon model to link surface resistance to microstructure
Artur Romanov

POSTERS Klimt (Ground floor)

HTS REBaCuO coated conductors for the FCC-hh beam screen: Performance under photon irradiation at the ALBA Synchrotron Light Source
Patrick Krkotić

Coating the FCC-hh beam screen chamber with REBa2Cu3O7-x coated conductors
Joffre Gutierrez Royo
Conclusions

1. Design of the beam screen concept has required several iterations.

2. The optimisation of the beam screen is completed; thermal, mechanical and vacuum behaviours are fully simulated.

3. The dipole-end photon absorber has been optimised and engineering design is in progress.

4. At the KARA-BESTEX set-up, three prototypes have been measured and an upgrade for testing with LN2 is in progress.

5. The optimisation of the laser treatment for the mitigation of electron cloud have been broadly investigated, further analysis including the impedance resistance is in progress.

6. Study of gas adsorption effects on SEY has been done. Further test at the new set-ups are in progress.
Future R&D

1. Perform further photo desorption studies at LN2 temperature
   • KARA - BESTEX.
   • LNF - WINDY
2. Perform quench test of a 2 meter prototype to test the mechanical stability.
3. Further optimization of the beam screen large scale production.
4. Investigate other surfaces:
   • amorphous carbon coating.
   • high temperature coated superconductors.
5. Measurements of the surface impedance of the different materials.
6. Improve the computational models with the new data.
7. ...
The charge of WP4:
Cryogenic Beam Vacuum System

Successfully done!

Francis Perez, on behalf WP4-EuroCirCol: FCC-hh beam vacuum system
Thanks to the team!

Paolo Chiggiato
Roberto Kersevan
Vincent Baglin
Olivier Brunner
Cedric Garion
Sergio Calatroni

Roberto Cimino
Marco Angelucci
Luis Antonio Gonzalez Gomez
Luisa Spallino
Marco Morrone

Anke-Susanne Mueller
Erhard Huttel
Sara Casalbuoni

Miguel Gil Costa
Javier Fernandez Topham

Oleg Malyshev
Reza Valizadeh
Peter McIntosh
Taaj Sian
Ruta Sirvinskaite

Francis Perez
Carles Colldelram
Raquel Monge
Joan Casas
Ignasi Bellafont
Thanks for your attention!
EuroCirCol: 'The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.'