WP4

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.'

FCC Week 2019
June 24th, 2019

The charge of WP4:
Cryogenic Beam Vacuum System

EuroCirCol

Horizon 2020
H2020-INFRADEV-1-2014-1
RIA action, proposal number 654305

The Future Circular Collider study

WP 4: Cryogenic Beam Vacuum System Conception

Objectives
1) Evaluate the impact of the arc design on technology requirements
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
3) Determine the needs for advancing individual technologies to meet the requirements
4) Study synchrotron radiation heat load absorption and mitigation of the photo-electrons generation
5) Consider novel mitigation techniques, e.g. based on frequent discrete photon absorbers
Description of Work
The cryogenic beam vacuum system for the arc dipoles will be designed in close iterative interaction with the magnet cold bore conceptual 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.

Beam induced heat load
Vacuum stability
Impedance
Photo-electrons
cooling
Synchrotron radiation
Mechanical stability
Image current

FCC Week 2019
June 24th, 2019

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

	FCC-hh	Present LHC
Proton energy [TeV]	50	7
Temperature of cold mass [K]	1.9	1.9
Number of bunches at 25 ns	10600	2808
Bunch population [10^{11}]	1	1.15
SR photon flux [ph $s^{-1}m^{-1}$] above cut-off at 4 eV	1.34×10^{17}	2.02×10^{16}
Arc SR heat load per beam [W m^{-1}] * Bending synchrotron emission power	**28.4***	**0.17**
SR critical energy [eV]	**4300**	**44**

E-cloud expected (rows: Number of bunches at 25 ns to SR photon flux)

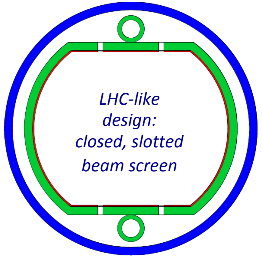
Main issue (rows: Arc SR heat load per beam, SR critical energy)

Required gas density in the arcs < 1×10^{15} H_2/m^3
(equivalent to 100 hrs nuclear beam-gas scattering lifetime)

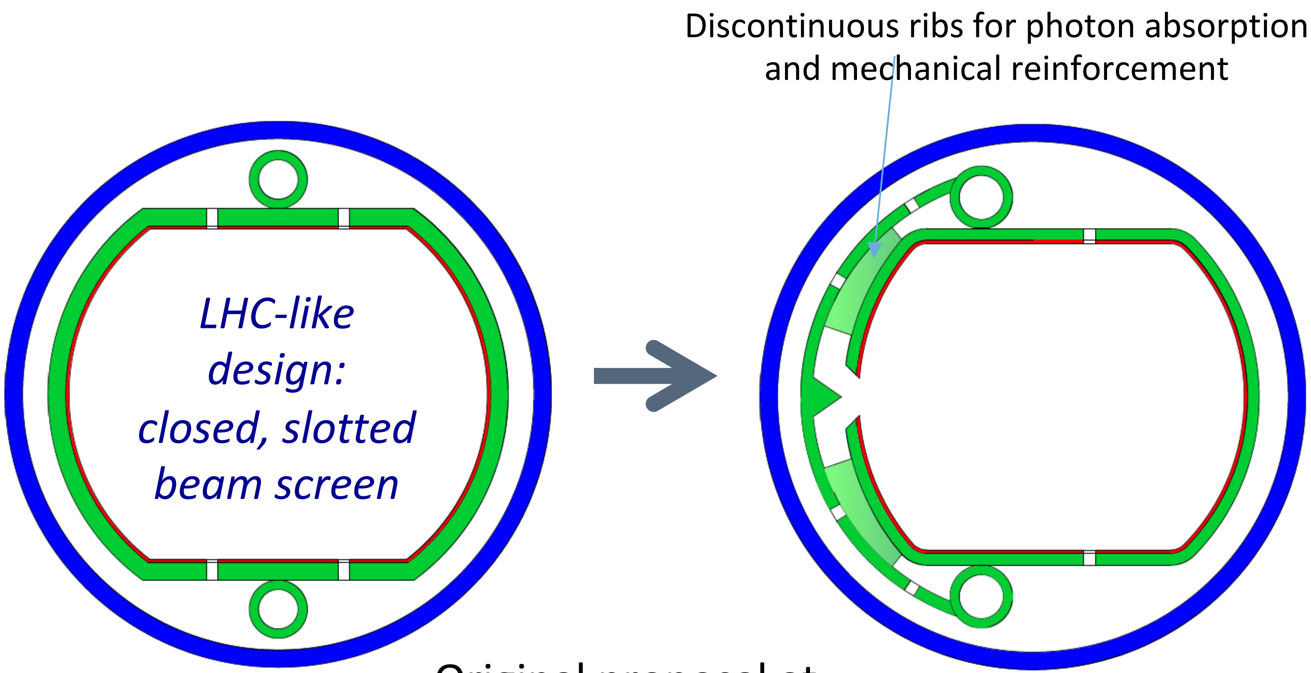
Due to the **higher SR power density:**

- 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 <u>not adapted</u> for the FCC-hh.



1st proposed design of the FCC-hh arc vacuum system



Original proposal at
“FCC Week Conference”, Washington D.C., **March 2015**;
One-slot beam screen with reduced number of pumping slots (source of impedance)

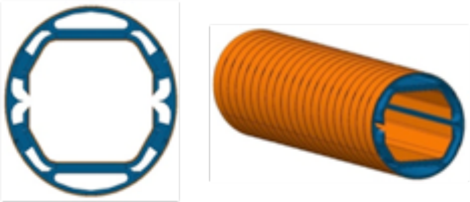
Progress with the FCC-hh beam screen design

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)*

Orsay 09/2015
3th WP4 meeting

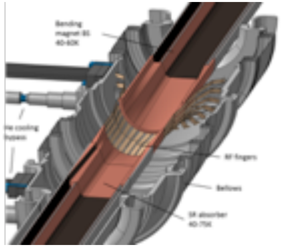
Geneva 06/2016
4th WP4 meeting



Barcelona 11/2016
5th WP4 meeting

Progress with the FCC-hh beam screen design

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

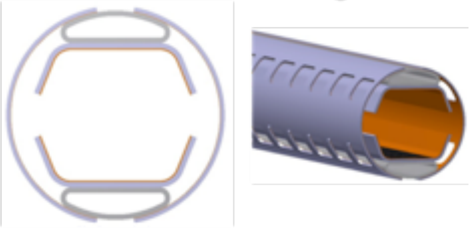


- **Remove the deflector**
- **Introduce Saw-tooth**
- **Re-design for simplification** *(remove rips, thickness)*

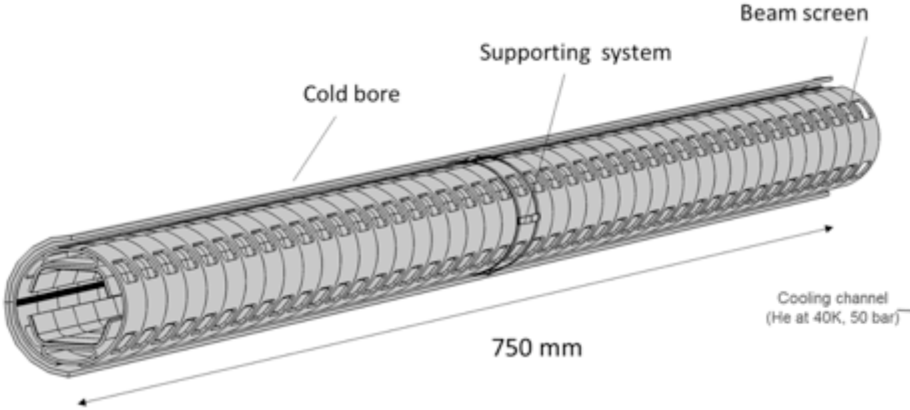
Berlin 05/2017
FCC week

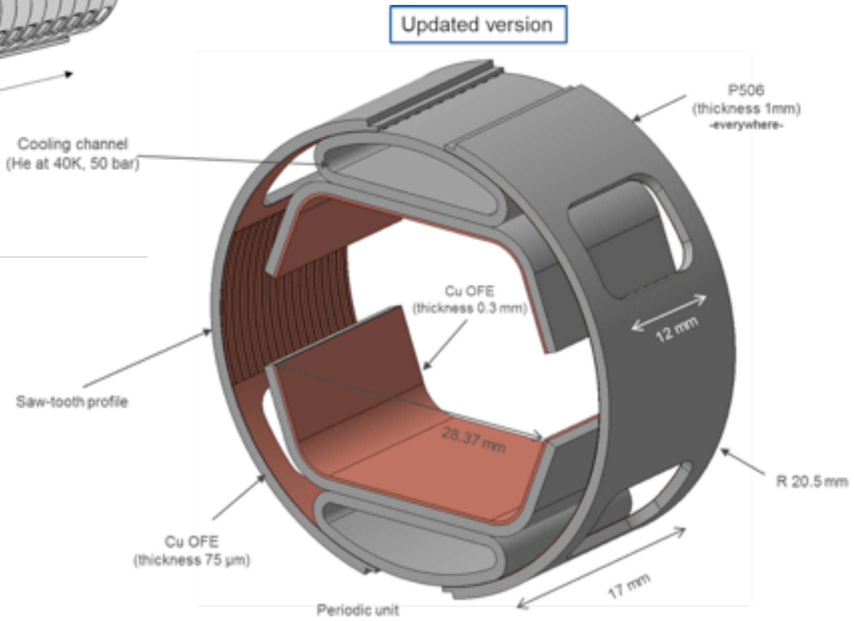
Geneva 10/2017
8^{th} WP4 meeting

Frascati 3/2018
9^{th} WP4 meeting



Latest version of the Cryogenic Beam Vacuum System





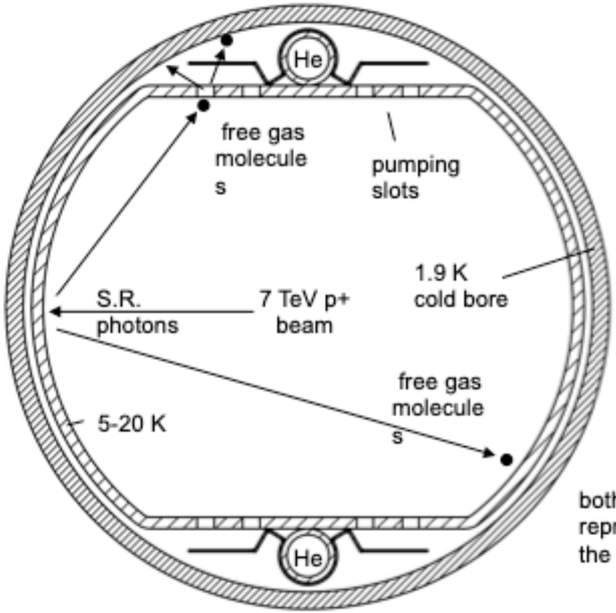
Wednesday 26th 11:30 - 11:50
Ballroom II (Ground floor)

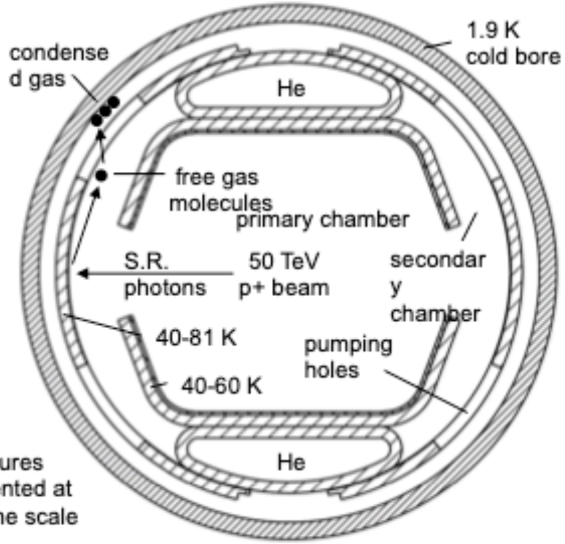
Update of the design and thermal mechanical study of the FCC-hh beam screen

Marco Morrone

M. Morrone

LHC → FCC hh





both figures represented at the same scale

LHC - 173 l/(s·m) for H_2 at 5 K
0.22 W/m emitted SR

FCC-hh - 898 l/(s·m) for H_2 at 40 K
35.4 W/m emitted SR

- 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**

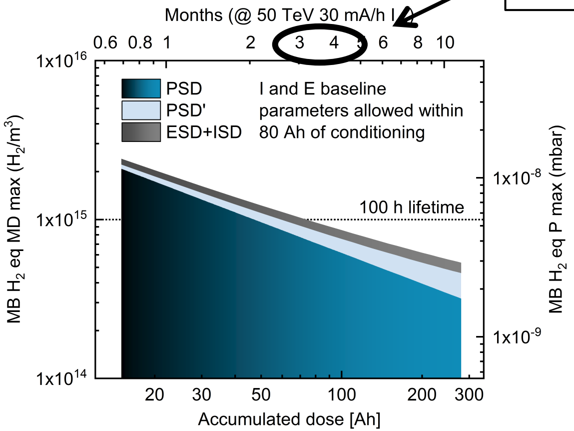
I. Bellafont

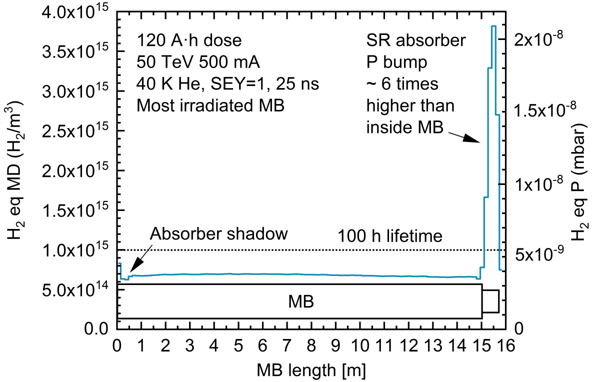
Study of beam induced vacuum effects

FCC hh ee he

EuroCirCol WP4

Expected conditioning achieved in 3-4 months





photon-stimulated desorption (PSD) — *electron-stimulated desorption (ESD)* — *ion-stimulated desorption (ISD)*

$$n = P/kT = Q/SkT = (\eta_{ph} + \eta'_{ph})\,\Gamma_{ph} + (\eta_{e} + \eta'_{e})\,\Gamma_{e} + (\eta_{i} + \eta'_{i})\,\sigma I/e\, n + Aq/$$

Contributions to the total gas load at 36 Ah				
Effect	PSD	PSD'	ESD	ISD
%	80%	10%	8%	< 3%

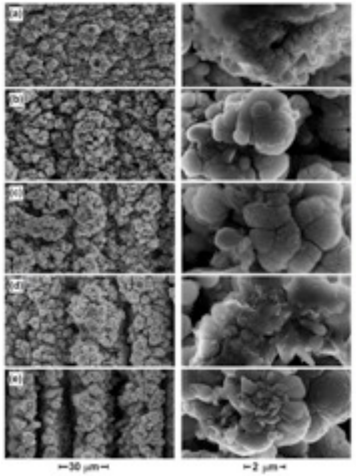
Wednesday 26th 08:30 - 08:50 Ballroom II (Ground floor)

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



Task	Problem	Solutions
LASE treatment & its optimisation	Is it possible to achieve δ_{max} < 1 with other laser than in original invention?	• More than 100 samples produced and characterised, δ_{max} < 1 in 60% • Different lasers can be used for LASE • with different λ, f, τ, power, etc.
Surface resistance	First LASE samples had surface resistance higher than untreated surface	New LASE combines δ_{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 μm • 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

FCC-hh-ee-he
EuroCirCol WP4

STFC ASTeC

Study of mitigation techniques of e-cloud and ion instabilities

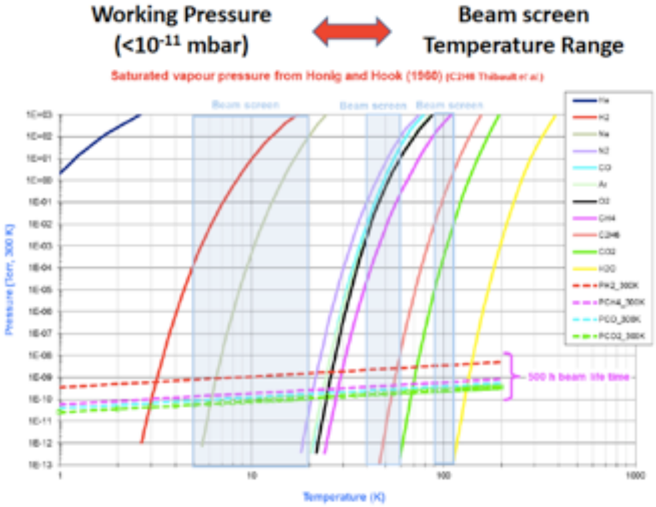
Task	Problem	Solutions
ESD and pumping	Is NEG coating works at cryogenic temperatures?	For CO: • η reduces and α increases For H_2 : • η and α – small change, • η' effect (like at 4.2 K is observed on activated NEG surface)
NEG activation with SR	Would SR induced activation of NEG coating be possible 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 dence films of Ti–Zr–Hf–V, Ti–Zr–V and Zr films have been studied

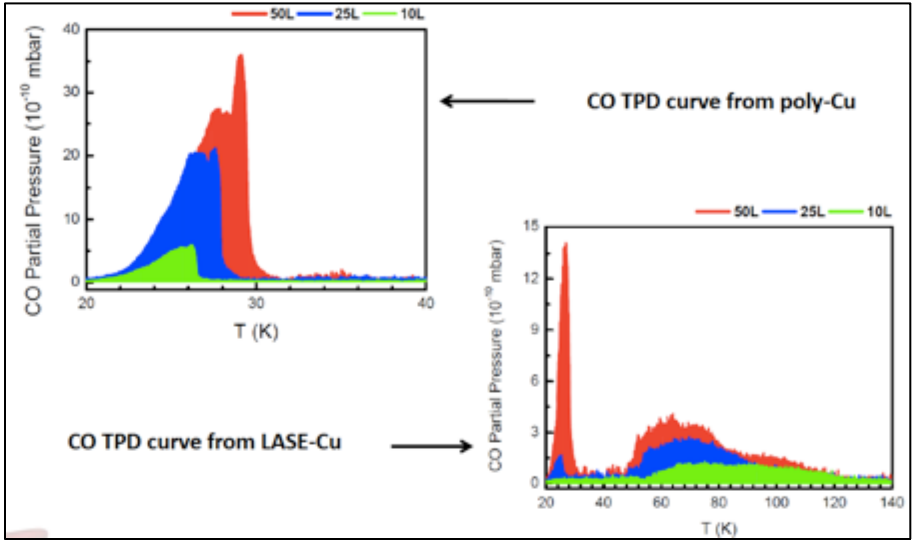
Wednesday 26th. 10:50 – 11:10 Ballroom II (Ground floor)

Recent Results on NEG Coating Characterisation

Ruta Sirvinskaite

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





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

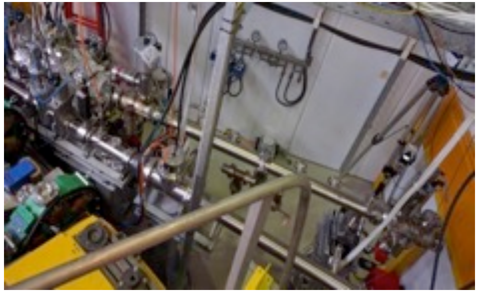
Material properties of relevance to cryogenic vacuum systems

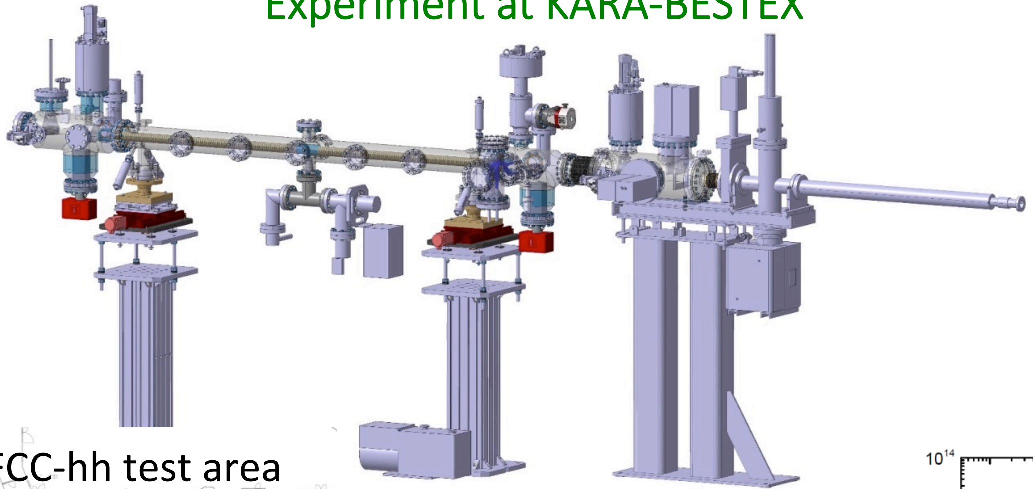
Luisa Spallino

WP4

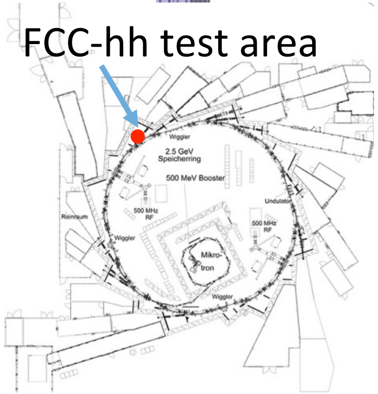
Prototyping and measurements

Experiment at KARA-BESTEX



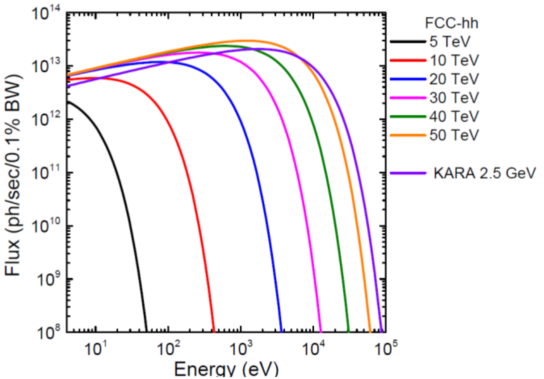


SR from KARA's dipole



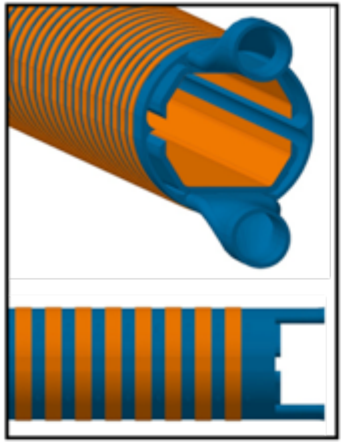
FCC-hh & KARA set-up:

- **Identical power**
- **Similar ph. Spectrum**



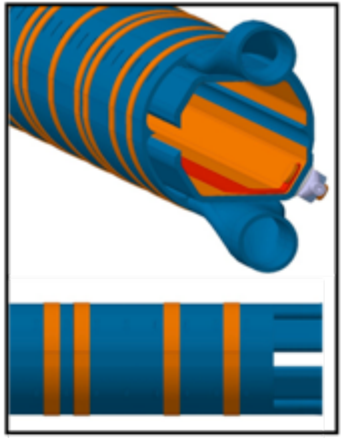
Prototyping and measurements

Prototype #1 *July- Oct '17*



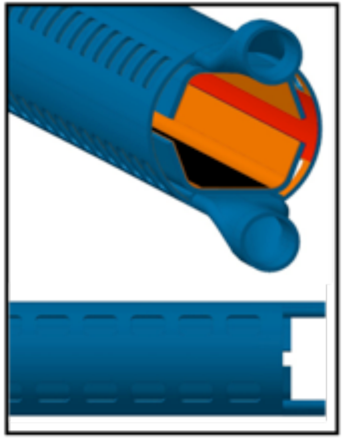
#1: Validation of temperature profile and **validity of photon reflector**

Prototype #2 *Jan- May '18*



#2: #1 + Electrode for **photoelectron current measurements**

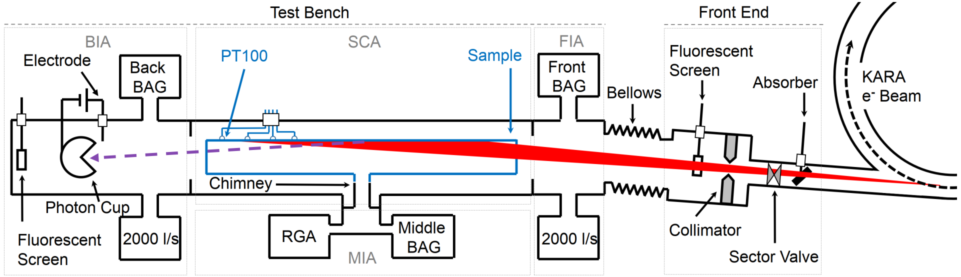
Prototype #3 *June-Aug'18*

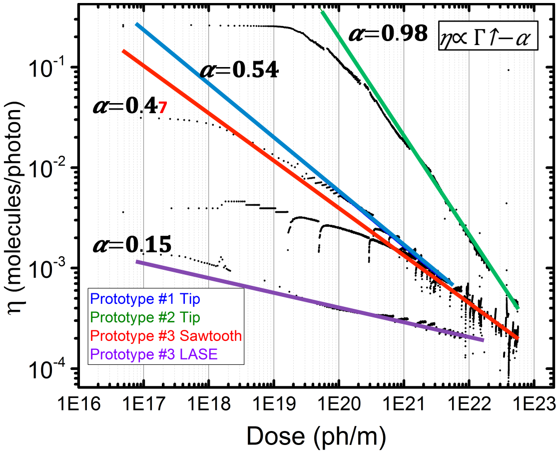


#3: Surface treatments **as for baseline**. Updated internal screen and pumping slots. **Substitution Reflector for Sawtooth**

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

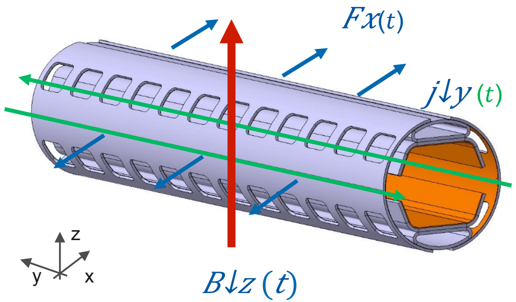
Wednesday 26th. 11:10 – 11:30 Ballroom II (Ground floor)

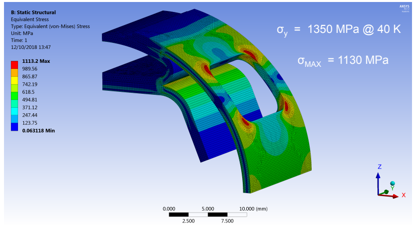
Photodesorption Studies on FCC-hh Beam Screen Prototypes at KARA

Luis Antonio Gonzalez Gomez

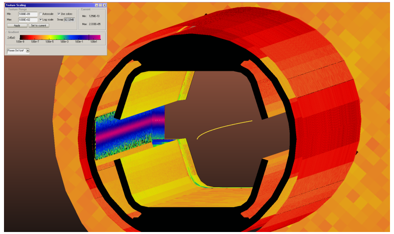
Develop a mechanical (conceptual) design

Quench analysis

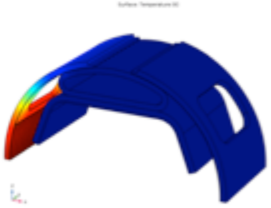




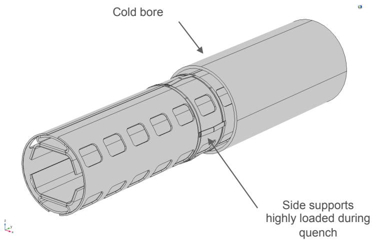
Thermal analysis

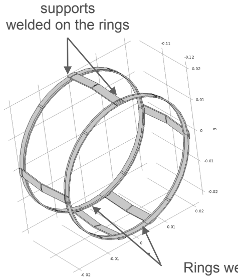


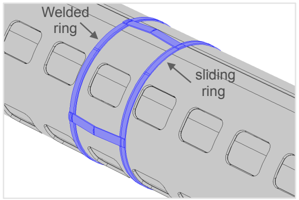
Max **synchrotron radiation** power ~ 42 W/m
Beam intensity: 0.5 A, 50 TeV



Installation in cold bore







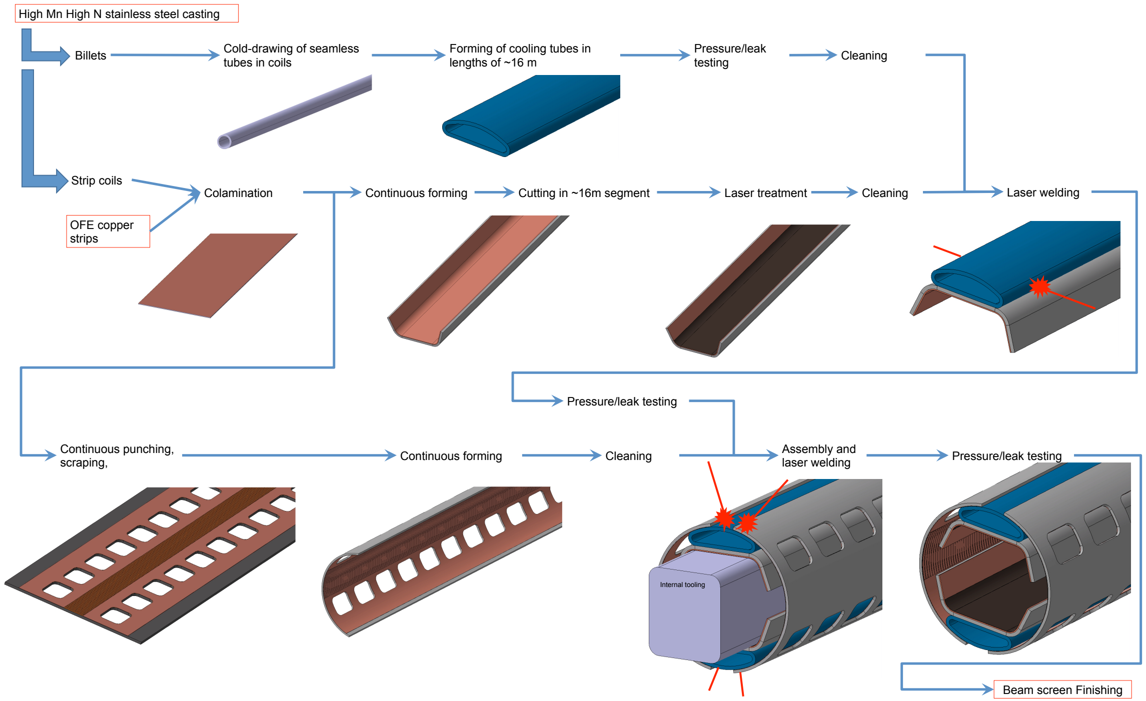
Rings welded as two half shells on the BS

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

Develop a mechanical (conceptual) design



POSTER

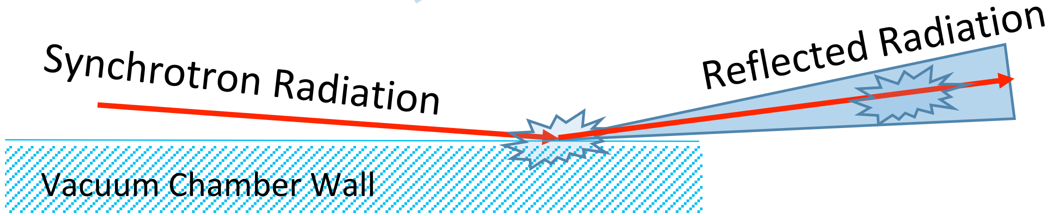
Considerations for large scale production of the FCC-hh beam screens

Cedric Garion

In addition,
the EuroCirCol WP4 project
has created
a series of "spin-off" collaborations

Reflectivity studies

Incident Radiation = ~~Transmitted~~ + Reflected + Absorbed



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

WINDY set-up

XUV Beamlines

Three different beamlines

XUV 1 (Low Energy)

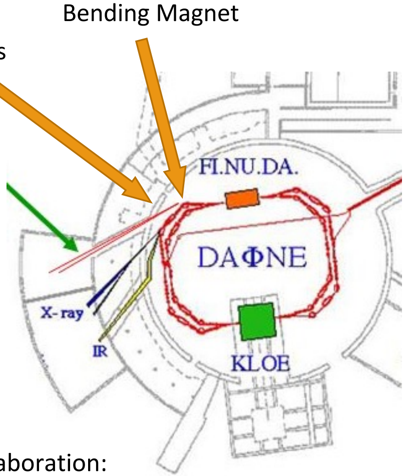
- Small Sample
- From 10 K
- WL and Monochromatic Light
- Range Energy: from 30 to 150 eV

XUV 2 (High Energy)

- Small Sample
- From 10 K
- WL and Monochromatic Light
- Range Energy: from 60 to 1000 eV

WINDY

- Long Tube
- From Liquid Nitrogen
- Wight Light
- Range Energy: up to ~200 eV



CERN collaboration:
K E 3 7 2 4 / T E / H L - L H C - Addendum N o. 4 to Agreement TKN3083

Wednesday 26th. 09:30 – 09:50 Ballroom II (Ground floor)

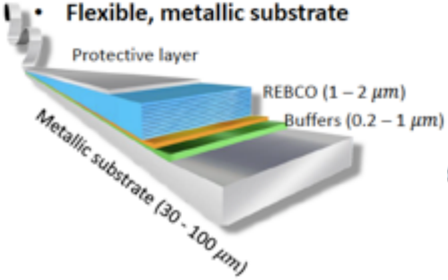
Photo desorption studies at the WINDY set-up at LNF

Marco Angelucci

Feasibility of
High Temperature Coated Superconductors for the Vacuum Beam Screen

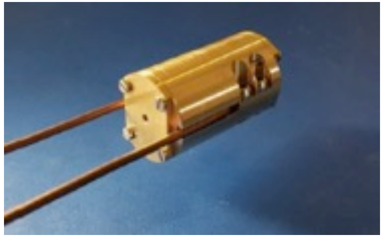
REBCO coated conductors are layered structures consisting of:

- Multifunctional oxides
  - HTS $REBa_2Cu_3O_7$
  - Buffers that allow epitaxial growth
- Flexible, metallic substrate



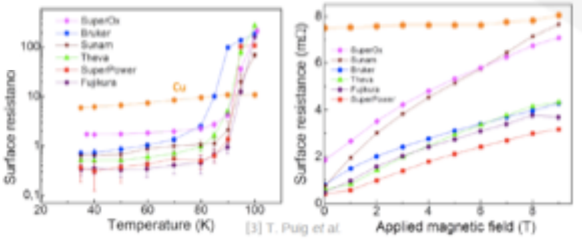
Commercially available in km length (≈5000 km/a).

Participating manufacturers in FCC study: SuNAM, Bruker, SuperOx, Fujikura, THEVA, SuperPower



Surface resistance vs. B and T

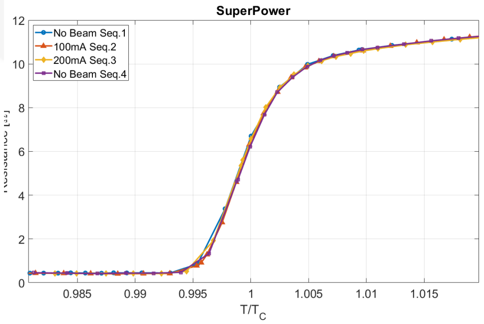
…that close to FCC conditions (40-60 K, 8 GHz, 0-9 T), HTS surface … lower than that of copper for most manufacturers.



Surface Resistance

Normal Conductor	vs	Superconductor
$R_{S_{Cu}} \propto \sqrt{f}$		$R_{S_{SC}} \propto f^2$

In situ Irradiation and DC resistance testing



Feasibility of High Temperature Coated Superconductors for the Vacuum Beam Screen

WP4

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

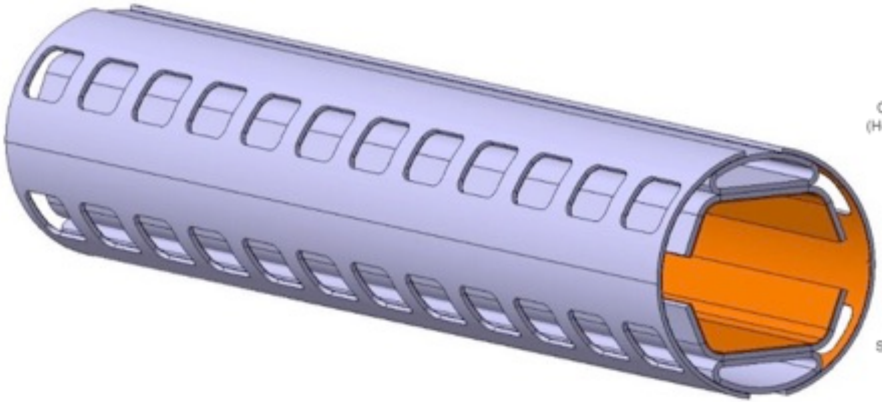
Conclusions

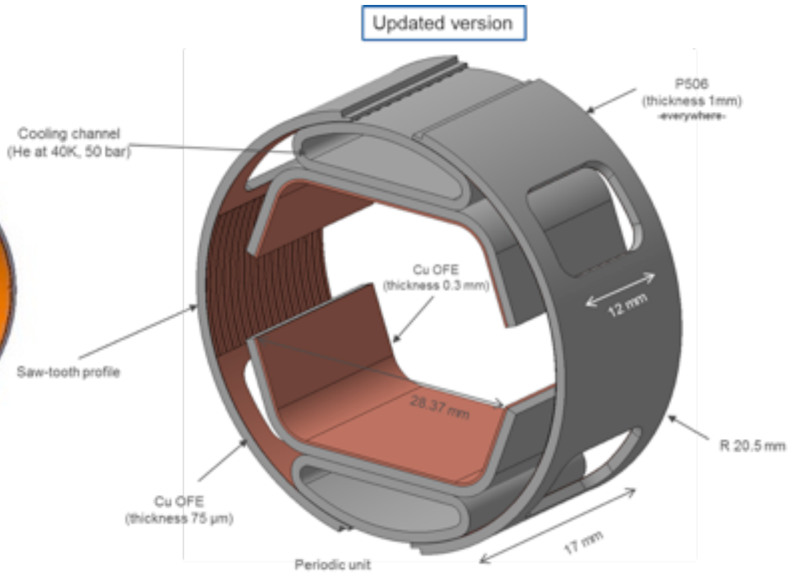
1. Design of the beam screen concept has required **several iterations.**
2. The optimisation of the **beam screen is completed**; thermal, mechanical and vacuum behaviours are fully simulated.
3. The **dipole-end photon absorber** has been optimised and engineering design is in progress.
4. At the **KARA-BESTEX 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 impredance 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!

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
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Thanks for your attention!

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