Material Science applied to High Energy Physics Accelerators: Status and Prospectives

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(On behalf of IMCA)

thanks to: R. Larciprete, A. Di Trolio, A. Di Gaspare, L. Gonzalez, R. Flammini, V. Corato, U. Gambardella, I. Masullo, V. Vaccaro, M. Migliorati, S. Petracca, A. Grilli, A. Raco, V. Tullio, V. Sciarra, M. Pietropaoli, G. Viviani, A. Balerna, A. Romano, M. Commisso, D. Grosso, V. Nistor, M. Pivi, T. Demma, M. Furmann, V. Baglin, M. Taborelli, P. Chiggiato, F. Zimmerman, M. Benedict, G. Rumolo, G. Iadarola, INFN- group V and NTA, LNF- directors etc

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Status

Starting from the End:

Last **Referee report** of **IMCA** (**I**nnovative **M**aterial and **C**oatings for **A**ccelerators)

(October 2014) By: E. Fagotti (LNL). R. Musenich (Ge) e W. Scandale (LAL).

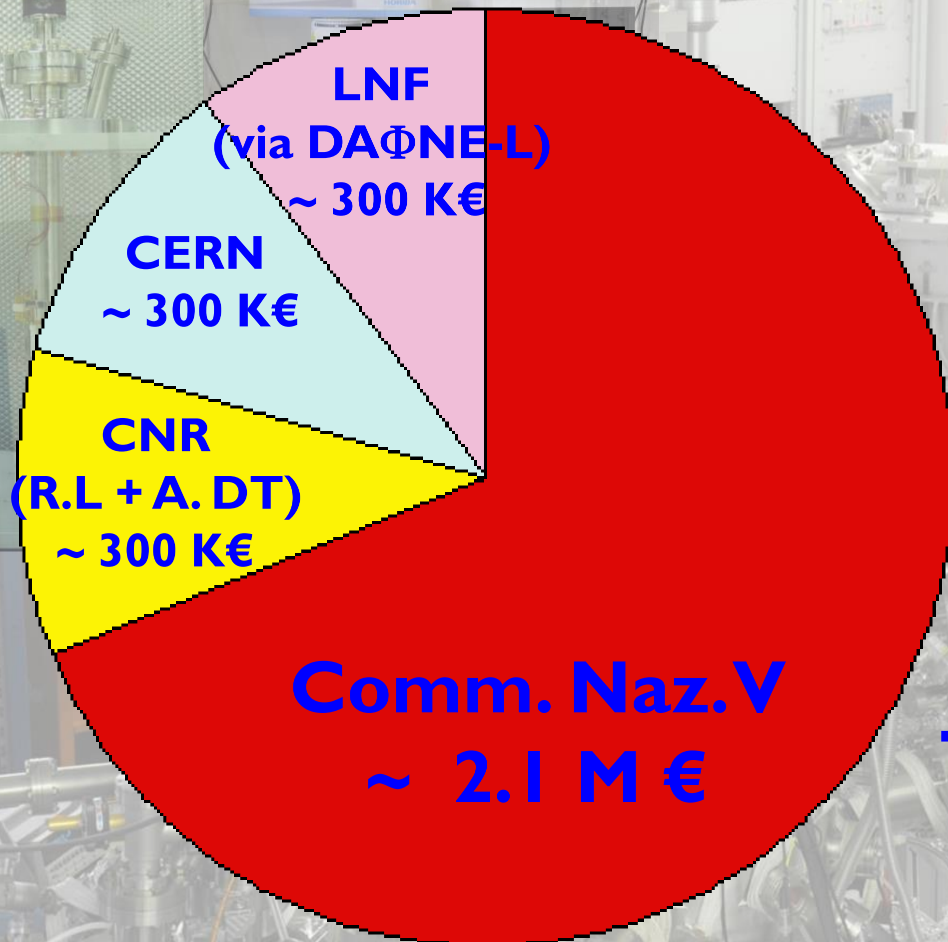
- The experiment IMCA is starting its last year of activity, **but it is clear (and also desirable) that such "historically" consolidated research will not stop at the end of 2015**. The laboratories (in particular that one at LNF) has grown over the years thanks to the strong contributions of CSN5 and **has become an important reference for the study of the interaction between the accelerated particle beams and material surfaces.**
- **The work carried out is certainly important and well-led, of international level, in all its lines of activities. Publications give answers considered relevant by the community of accelerators physicist but also of interest in a much wider context.**
- The referees are suggesting to support the activity also given its future reach. This is why they are proposing the funding of new and "important" equipment even for a closing experiment.
- The reasons for implementing with high technology hardware the LNF laboratory are strong, due to its interest to the community of reference.
- **In this regard, a more profound discussion with the Director of LNF should be undertaken to clarify the extent and form of the LNF contribution and of any external contributions (CSN5, MAC and / or other) to implement / maintain such high standard facility at LNF.**

Our Material Science Laboratory

- Our laboratory is devoted **to the growth** of thin and ultrathin films of interest for the high energy particle accelerators and of nanomaterials important for the development of new detectors and devices **and to the study of their chemical, structural and electronic properties.**
- We have two ultra-high vacuum systems equipped with several growth facility (Chemical Vapour Deposition, physical evaporation, magnetron sputtering) and with **in-situ, UHV, electronic diagnostics** (**Low Energy Electron Diffraction, X-ray and UV Photoelectron Spectroscopy, Secondary Electron Yield and Raman Spectroscopy**) and scanning probe microscopy (**variable temperature Scanning Tunneling Microscopy also recently implemented for UHV use**).
- **One of the system is equipped with a low temperature (~ 7 K) manipulator**.
- In the laboratory there is also a set-up dedicated to the growth and characterization of graphene layers including an atmospheric pressure furnace and a Raman microscope. (See Rosanna talk)
- We are a leading international laboratory for the growth and/or characterization of technical samples coming from high energy accelerators with the aim to investigate the relation between their surface state and secondary emission properties.
- Our research activity includes the study of carbon based materials with a special attention to graphene and low dimensionality structures. (See Rosanna talk)

Our Material Science Laboratory

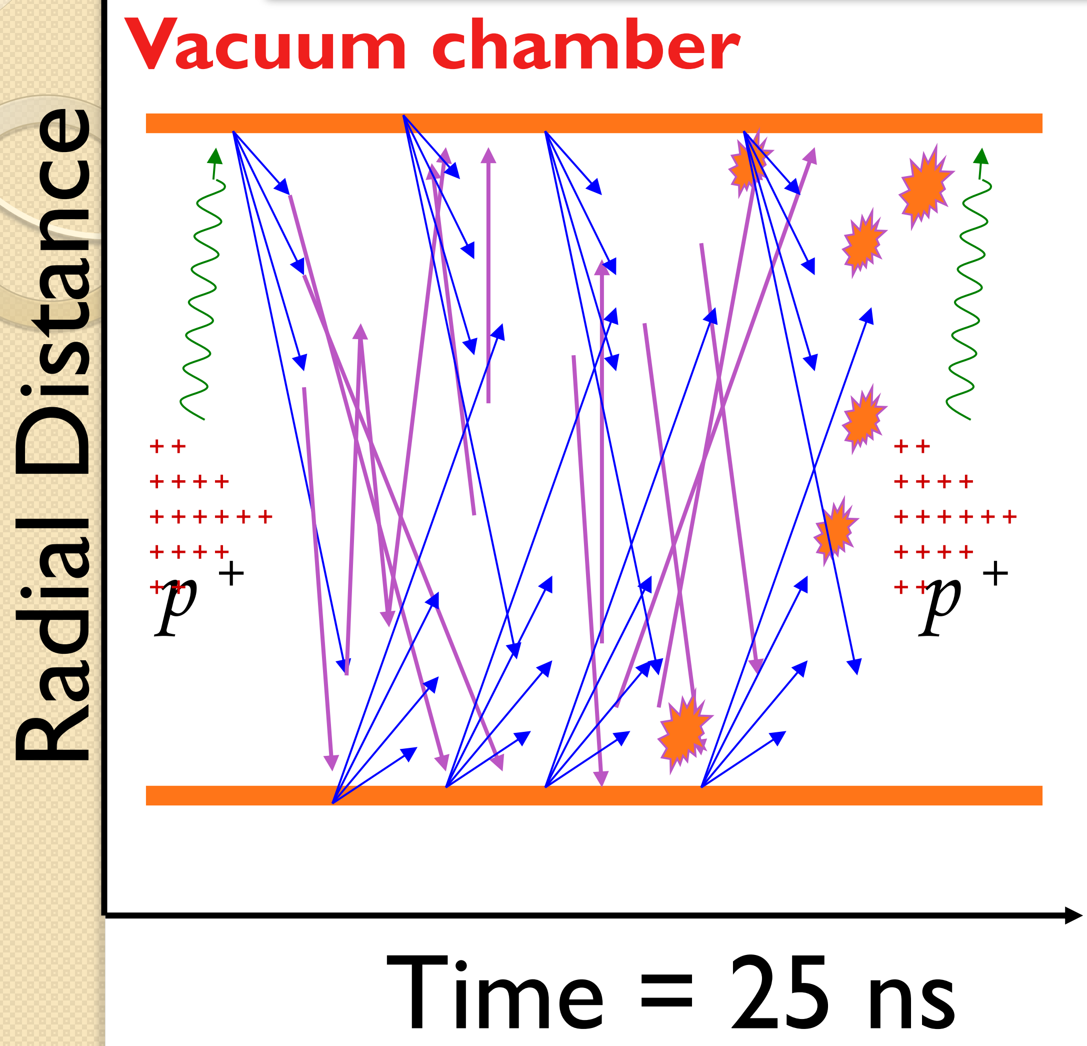
Contributors (over the last 20 years):



Total invested
~ 3 M €

+ Two Beamlines ~ 1.5 M€ (from 2003 via DAΦNE-L&LNF)

The "e-cloud" phenomenon (in pils)



The accelerated particle beam produces SR and/or e⁻ that, by hitting the accelerator's walls generate photo-e⁻ or secondary-e⁻.

Such e⁻ can interact with the beam (most efficiently for positive beams) and multiply, inducing additional heat load on the walls, gas desorption and may cause severe detrimental effects on machine performance.

The Surface Science Actors:

Secondary Electron Yield (SEY)

(the number of electrons created after bombardment of a single electron)

Photoelectron Yield (PY)

(the number of electrons created after bombardment of a single photon)

Photo-reflectivity (R)

(the number of photons reflected by the surface)

And their dependence on:

material, energy, angle, temperature, magnetic field, Conditioning etc etc….

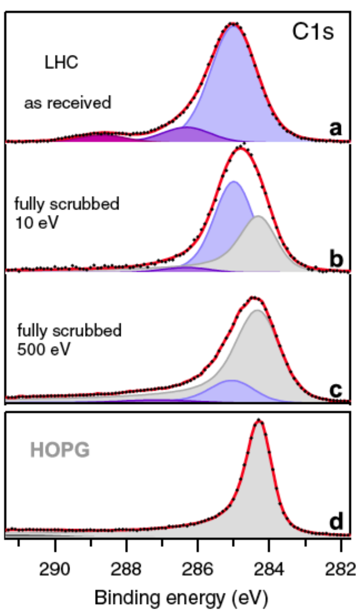
Their detailed study is essential for:

- ✓ Producing realistic input parameters
- ✓ Understanding their physical origin
- ✓ Than, proposing mitigation mechanisms.

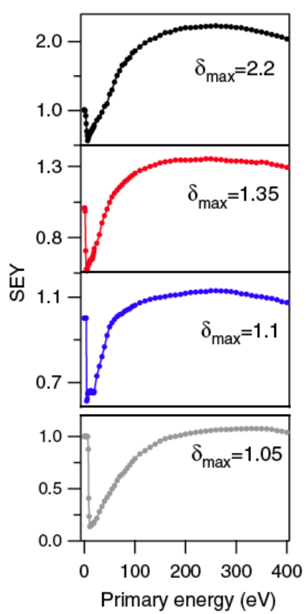
Their study bring us towards mitigation strategies….

- ✓ We measure and feed material parameters (R, PY, and SEY) into simulations.
- ✓ Understand their profound nature to:
- ✓ Optimize chemical (mechanical) process to reduce their detrimental influence on beam.
- ✓ Search for new material / coatings with intrinsically "good" parameters.

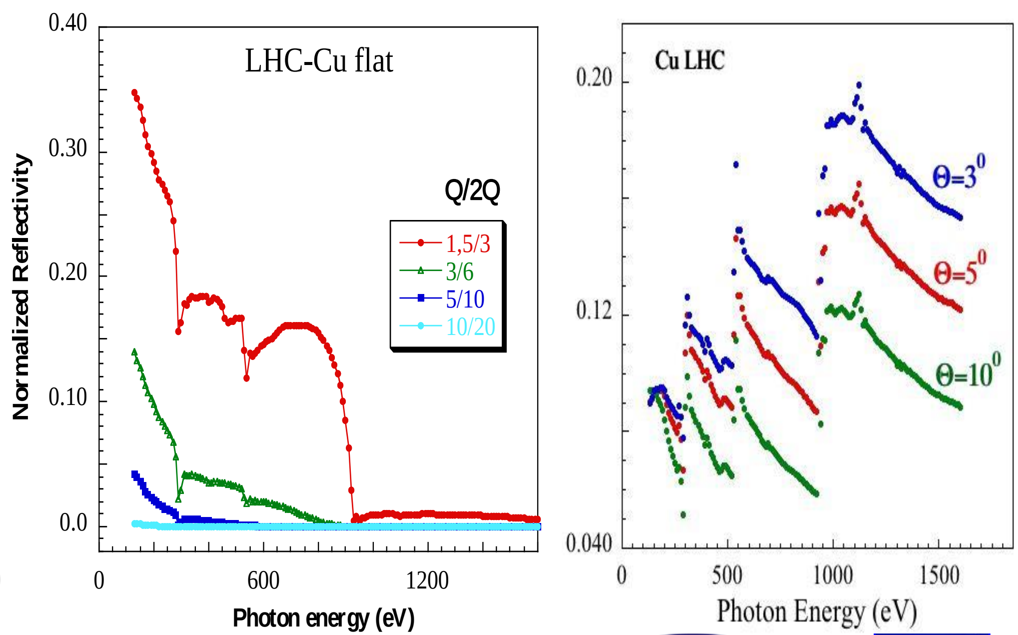
XPS



SEY



SR Reflectivity and PY (@BESSY-II)



We were the first ones (in 2004) to develop a technique to measure SEY at very low impinging energies.

VOLUME 93, NUMBER 1 PHYSICAL REVIEW LETTERS week ending 2 JULY 2004

Can Low-Energy Electrons Affect High-Energy Physics Accelerators?

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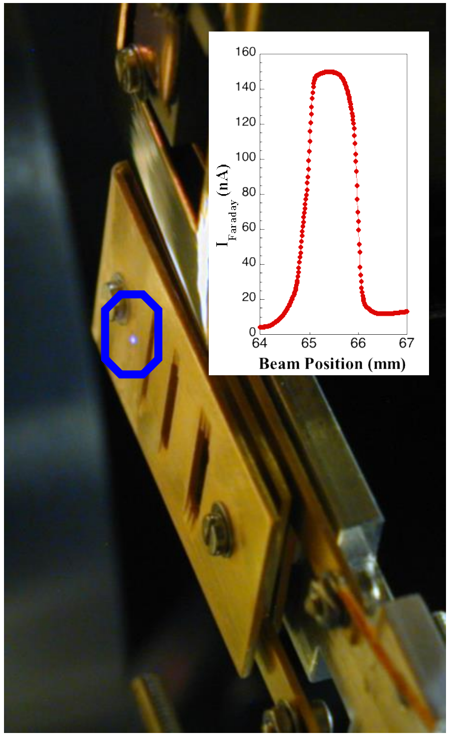
(Received 10 February 2004; published 29 June 2004)

Present and future accelerators' performances may be limited by the electron cloud (EC) effect. The EC formation and evolution are determined by the wall-surface properties of the accelerator vacuum chamber. We present measurements of the total secondary electron yield (SEY) and the related energy distribution curves of the secondary electrons as a function of incident-electron energy. Particular attention has been paid to the emission process due to very low-energy primary electrons (<20 eV). It is shown that the SEY approaches unity and the reflected electron component is predominant in the limit of zero primary incident electron energy. Motivated by these measurements, we have used state-of-the-art EC simulation codes to predict how these results may impact the production of the electron cloud in



We recently confirm its validity (after some debate) (… submitted To Phys Rev Special Topics)

Detailed Investigation of the Low Energy Secondary Electron Yield of Technical Cu and its Relevance for the LHC

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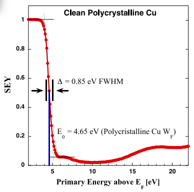
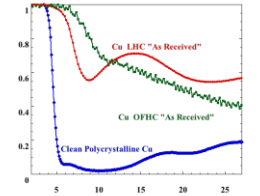
(Dated: February 3, 2015)

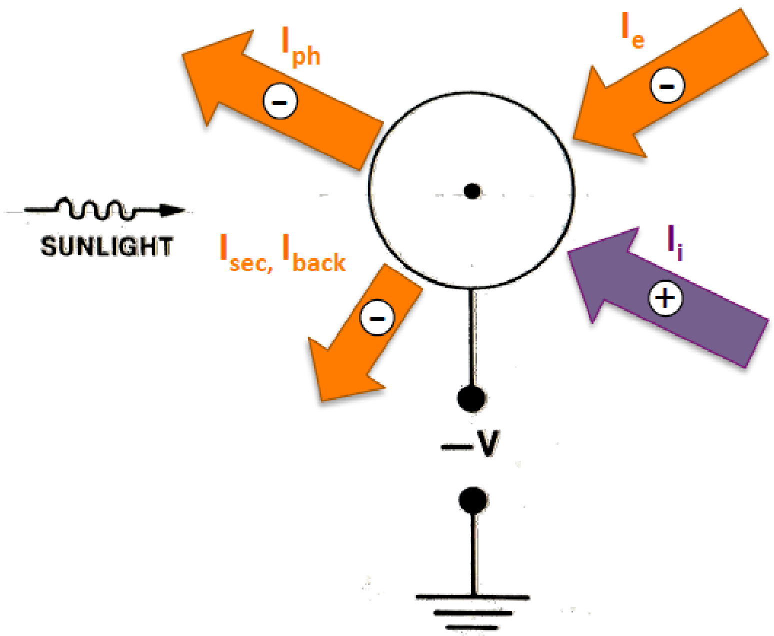




Such material properties are essential input parameters also in other fields of research.

Spacecraft charging is the result of a current balance:

$$\sum I = 0 \quad \rightarrow \quad I_e(V) - I_i(V) - I_{ph}(V) - I_{sec}(V) - I_{back}(V) = 0$$



I_e: Net incoming electron current

I_i: Net incoming ion current

I_{ph}: Net emitted photoelectron current

I_{sec}: Net secondary electron current

I_{back}: Net backscattered electron current

In spacecrafts, two materials with different SEY, PE and R can charge differently and cause disruptive discharge. (20% SC failure!)

Some recent publications on international journals:

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Effect of the surface processing on the secondary electron yield of Al alloy samples

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(Received 7 May 2012; published 28 May 2013)

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **16**, 011002 (2013)

Secondary electron yield of Cu technical surfaces: Dependence on electron irradiation

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PRL **109**, 064801 (2012) PHYSICAL REVIEW LETTERS week ending 10 AUGUST 2012

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Evolution of the secondary electron emission during the graphitization of thin C films

CrossMark

Rosanna Larciprete[a,b,*], Davide Remo Grosso[b], Antonio Di Trolio[c], Roberto Cimino[b]
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IEEE TRANSACTIONS ON PLASMA SCIENCE 1

Detailed Investigation of the Low-Energy Secondary Electron Yield (LE-SEY) of Clean Polycrystalline Cu and of Its Technical Counterpart

Roberto Cimino, Alessandra Di Gaspare, Luis Antonio Gonzalez, and Rosanna Larciprete

Review

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Electron cloud in accelerators

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[4]*DESY, Notkestrasse 85, 22603 Hamburg, Germany*
(Received 7 May 2012; published 28 May 2013)

IEEE TRANSACTIONS ON PLASMA SCIENCE 1

Detailed Investigation of the Low-Energy Secondary Electron Yield (LE-SEY) of Clean Polycrystalline Cu and of Its Technical Counterpart

Roberto Cimino, Alessandra Di Gaspare, Luis Antonio Gonzalez, and Rosanna Larciprete

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **16**, 011002 (2013)

Secondary electron yield of Cu technical surfaces: Dependence on electron irradiation

R. Larciprete,[1,2] D. R. Grosso,[2] M. Commisso,[2] R. Flammini,[3,2] and R. Cimino[2]

Review

Applied Surface Science 328 (2015) 356–360

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc

Evolution of the secondary electron emission during the graphitization of thin C films

Rosanna Larciprete[a,b,*], Davide Remo Grosso[b], Antonio Di Trolio[c], Roberto Cimino[b]

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Some recent publications on international journals:

Review

International Journal of Modern Physics A
Vol. 29, No. 17 (2014) 1430023 (65 pages)

DOI: 10.1142/S0217751X14300233

World Scientific
www.worldscientific.com

Electron cloud in accelerators

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Visibility in Italy:

From a single topic and single starting UNIT @ LNF we are now studying a much higher number of materials and material properties in accelerators (Impedance, Impact on collective effects, new materials like HTSC, Sponges… etc) and the Collaboration is now actively including:

INFN - Na (I. Masullo, V. Vaccaro etc) Impedence & coll. effects

INFN – Rm 1 (A. Mostacci, M. Migliorati, etc) Impedence

INFN - Sa (S. Petracca, U. Gambardella, etc) Impedence & HTC

CNR – ISC (R. Larciprete, A. Di Trolio) S.S. & film growth & HTC

ENEA – Frascati (V. Corato) HTC

International Visibility:

At CERN:

- Close collaboration on LHC: restart @ 25 ns – collective effects.
- Close collaboration on HL-LHC (approved) collective effects.
- Close collaboration on future projects – collective effects, new materials, surface science, vacuum…

Worldwide:

Organization of international conferences:

R.C. Co-chair of Ecloud-12

Participation to International conferences: Invited and /or contributed (IVC, IPAC, and also on Space charge satellites).

Invited Talks and seminars in different Universities/Iinstitutions/ laboratory (Princeton, Lal, etc)

Invited to contribute to CAS (CERN Accelerator School)

Material Science applied to High Energy Physics Accelerators: Status and Prospectives

Prospectives

European Strategy Update 2013

Design studies and R&D at the energy frontier

- "….invite to propose an ambitious **post-LHC accelerator project at CERN** by the time of the next Strategy Update" in 2018.

FCC-Future Circular Colliders

- CERN should undertake design studies for accelerator projects in a global context
  - with emphasis on proton-proton and electron-positron high-energy frontier machines
  - coupled to a vigorous accelerator R&D programme, including high-field magnets and high-gradient accelerating structures
  - in collaboration with national institutes, laboratories and universities worldwide.

Without entering into priorities:

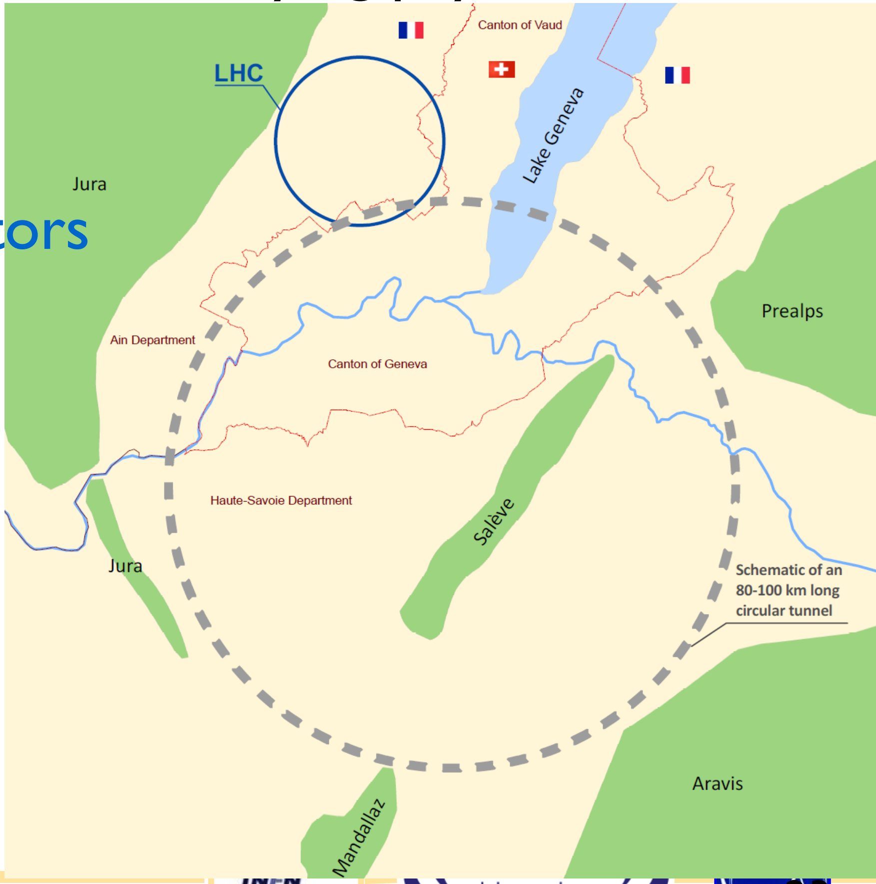
- FCC
- Linear accelerators (CliC, ILC…)
- Plasma Accelerators
- Foreseen and prevent Earthquakes, Hurricanes…
- Allow "some" football players to play 20 more Years
- ….

The R&D connected to FCC is:

- One of the approved research lines at CERN and H2020 (It is well within the int. context)
- It is absolutely worth doing and rich of intriguing and cross fertilizing items!

Scope of FCC study (within 2018)

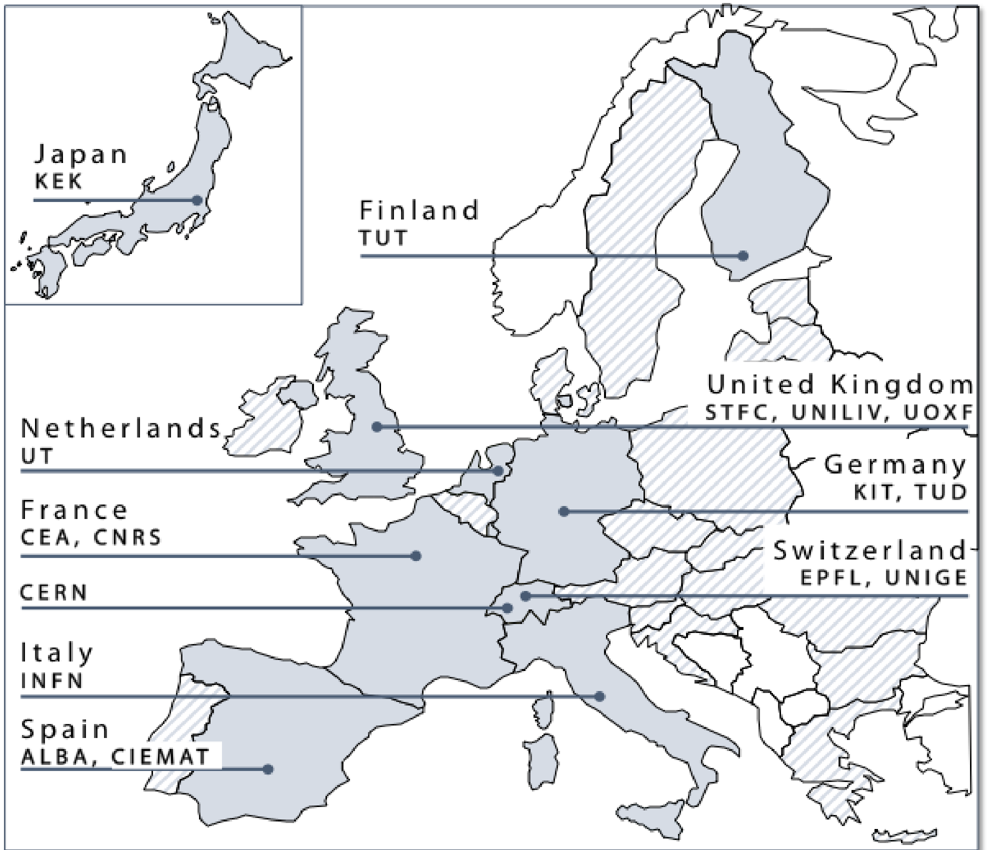
- The main emphasis of the conceptual design study shall be the long-term goal of a hadron collider with a centre-of-mass energy of the order of 100 TeV in a new tunnel of 80 - 100 km circumference for the purpose of studying physics at the highest energies.
- **Will also include:**
- A lepton collider and its detectors (as an intermediate step)
- Options for e-p scenarios
- Cost and energy optimisation,
- Industrialisation aspects
- Implementation scenarios,
- Schedule and cost profiles



We (LNF) are in!

EuroCircol (R&D on FCC-HH) H2020 project has been approved (top rated)!

Short Name	Country
CERN	IEIO
TUT	Finland
CEA	France
CNRS	France
KIT	Germany
TUD	Germany
INFN	Italy
UT	Netherlands
ALBA	Spain
CIEMAT	Spain
STFC	United Kingdom
UNILIV	United Kingdom
UOXF	United Kingdom
KEK	Japan
EPFL	Switzerland
UNIGE	Switzerland

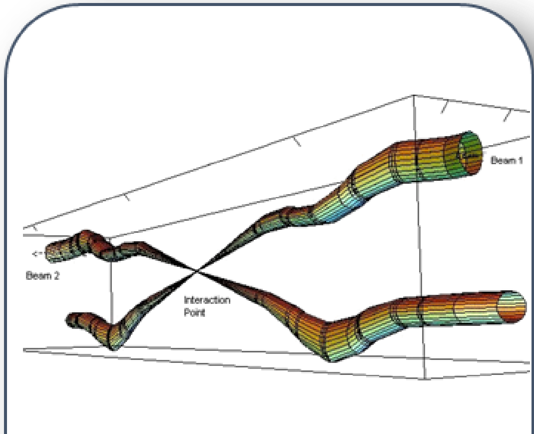


EuroCirCol consortium, federating 16 partners, 1 from Japan and 1 IEIO

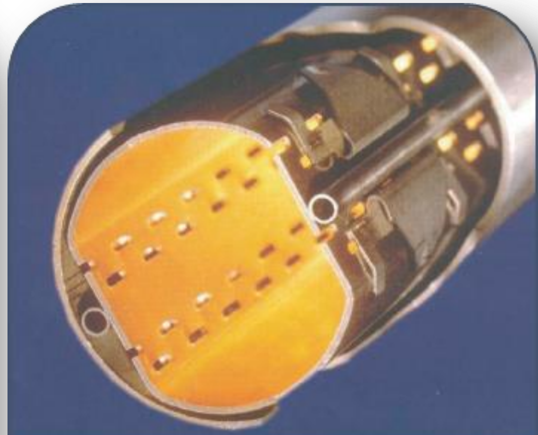
EuroCircol

Coordinated by CERN. More than 400k€ to INFN (Ge–LNF–Mi) (2nd biggest contribution)

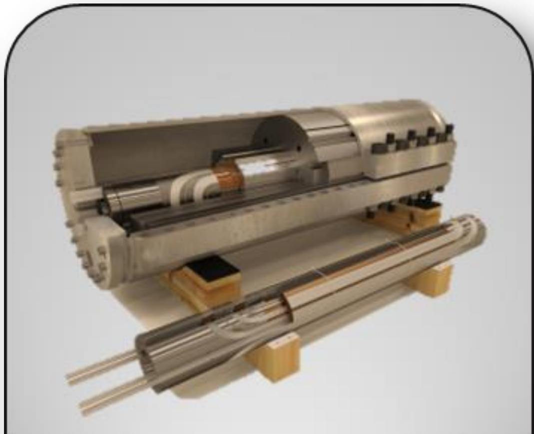
Different tasks:
machine-detector interface - vacuum - magnets



EIR Design



Cryo Beam Vacuum



High Field Magnet

@ LNF ~ 160K€ from EU (for personnel)

Work Unit: Cryo-magnet beam pipe system for FCC-hh (INFN-HH-2)	
Reference	1.2.3.16 Vacuum System requirements and conceptual design
Objectives:	Studies vacuum stability at cryogenic temperature, in particular adsorbtion isotherms at different beam screen operating temperature ranges, and beam induced stimulated desorption phenomena by photons, electrons and ions.
Participant Work unit Contact	Roberto Cimino (Roberto.cimino@lnf.infn.it)
CERN Work unit contact:	Paolo Chiggiato (Paolo.chiggiato@cern.ch)
Work Unit Deliverable: design of cryo beampipe system for FCC-hh	
Identifyer/Type	**INFN-HH-@.1/Document**
Participant's Deliverable:	Provide input to document on FCC-hh cryo-vacum system design. Results of vacuum stability analysis and desorbtion studies.

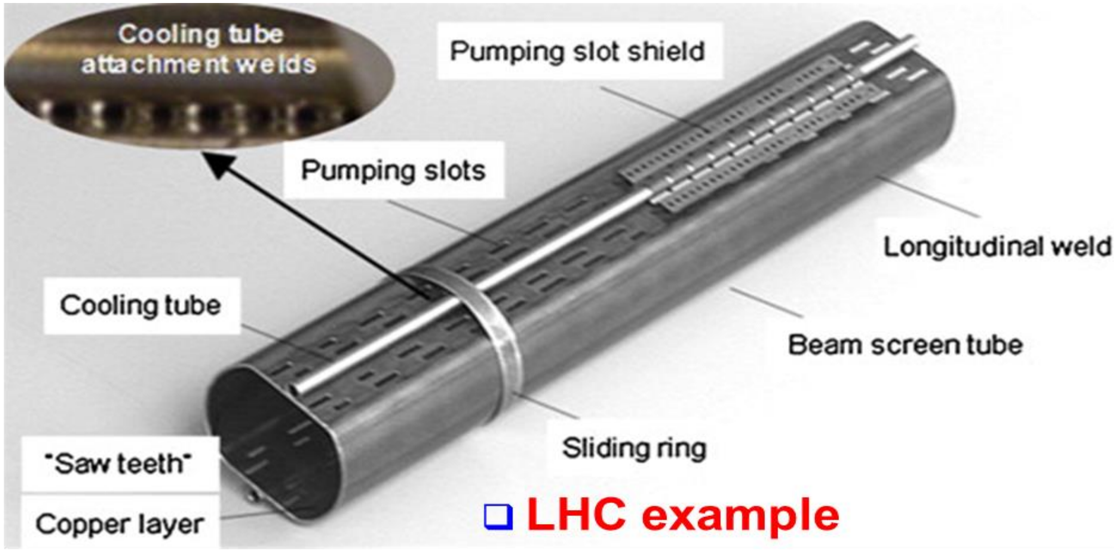
FCC Special Technologies: *Cryogenics and vacuum WP4 (EuroCirCol)*

Current goal:
beam aperture: 2x13mm
Causing intrinsically high impedance
magnet aperture: 2x20mm
Space for shielding and cooling 7mm
Synchrotron radiation in arcs:

28 W/m/beam - 16T Ɛc~4 KeV

44 W/m/beam - 20T Ɛc~5 KeV

Total 4.8-5.8 MW



❑ **LHC example**

SR power mostly cooled at beam screen temperature; part going to magnets at 2-4 K

options:

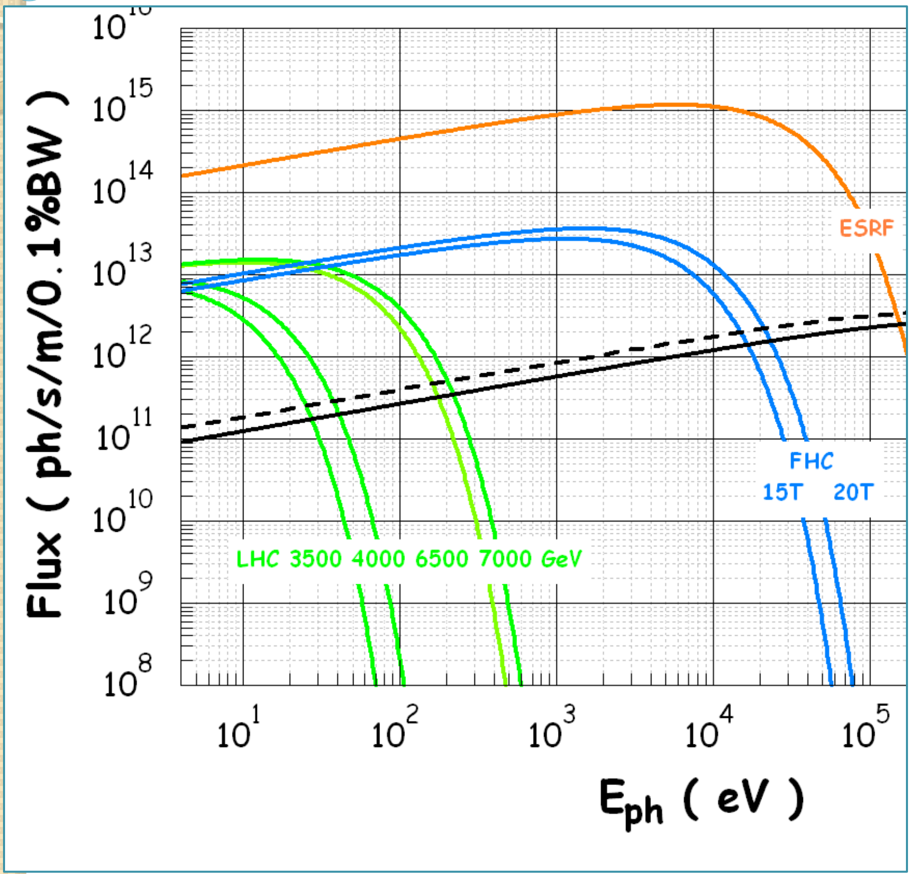
- LHC-type copper coated beam screen (baseline)
- LHC-type beam screen coated with HTS (L. Rossi)
  + novel cryogens (*He-Ne* mixtures)
- photon stops at room temperature

D. Schulte,
M. Jimenez et al.

FCC Special Technologies: *Cryogenics and vacuum WP4 (EuroCirCol)*

Studies as a function of:

- **Beam screen proposed working Temperature**
- **Beam screen Bulk and coating Material (Cu, HTC, a-C……), shape, and (micro/macroscopic) mechanical properties, impedance, etc.**



On:
adsorbtion isotherms of residual gas at different beam screen operating temperature

- SR power deposition
- SR induced stimulated desorption
- SR induced photo yield
- SR Reflectivity

- e^- power deposition (e^- cloud)
- e^- induced stimulated desorption
- e^- induced Secondary yield (SEY)

- Ion induced stimulated desorption

This is Surface Science, SR studies, Vacuum, material and thin films science……

We are proposing, for FCC-hh 28/44 W/m Heat load a promising (solution) research line based on our experience in the specific fields of Surfaces and SR:

"Potential countermeasures against the very large SR heat load in FCC-hh"

Conclusions:

✓ In nearly 20 years of activity we show that “state of the art” material science, if well focused, is not just “compatible” with INFN mandate, BUT it is essential!

✓ We have now a powerful and “well booked” lab with major potentialities and future activities.

✓ We will need continuous support from the Lab (and/or MaC) and the Nat. Committee and we are open to new collaborators and collaborations.

✓ With such a support we can attract ext. resources to consolidate / potentiate our facility at LNF.