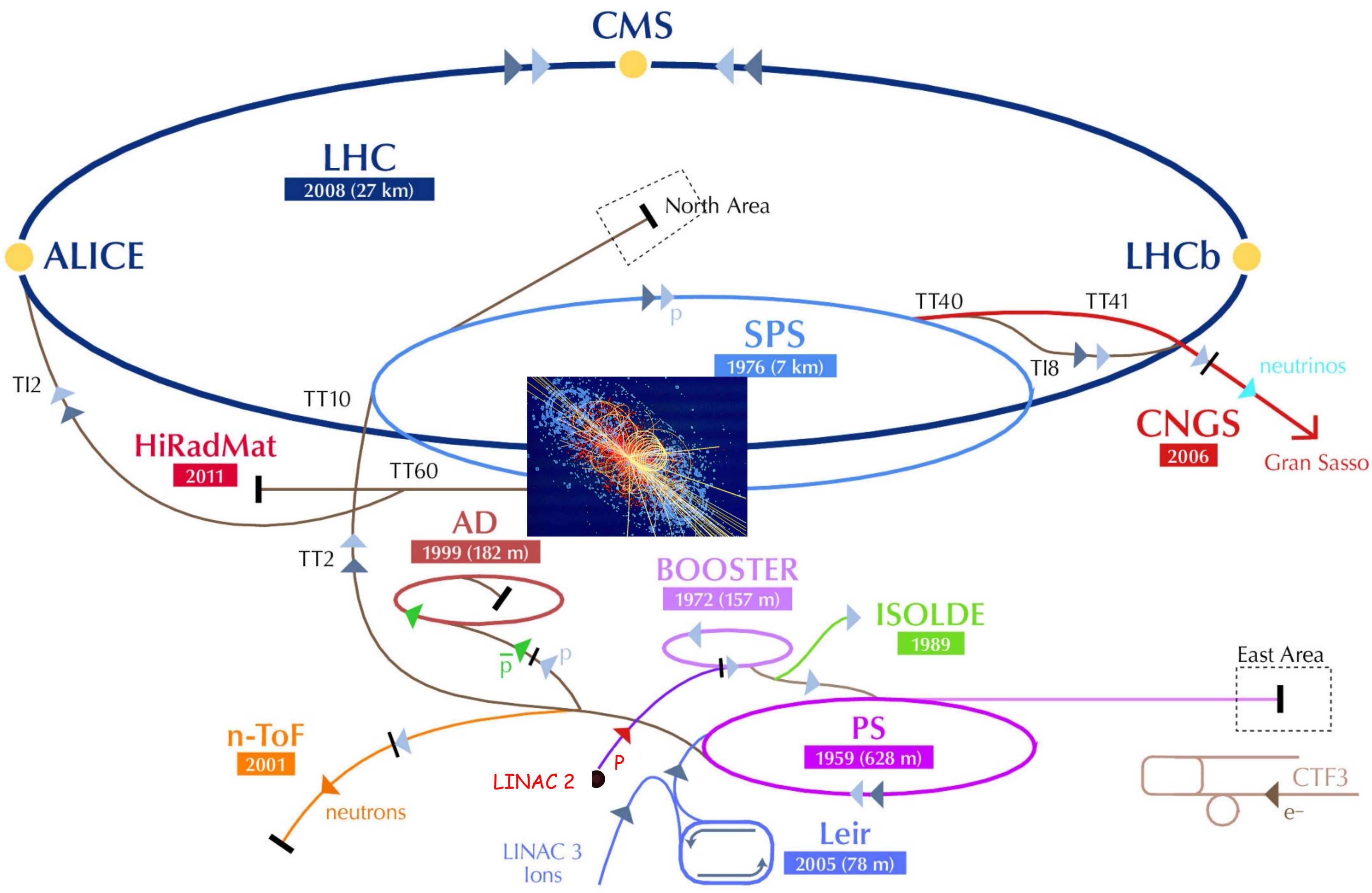
PhD theses on collaborative studies between:

- INFN / Rm1, SBAI and CERN
- INFN / LNF and CERN

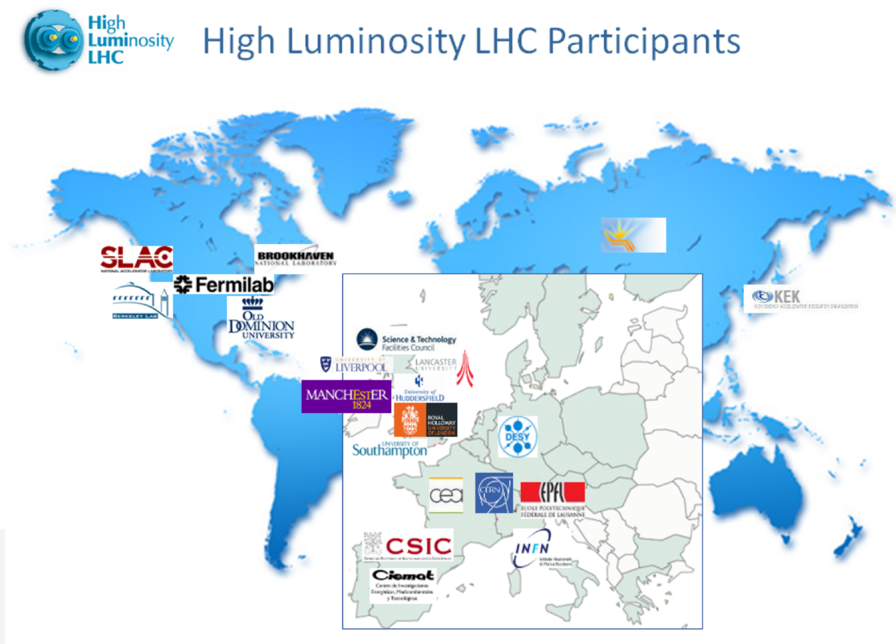
R. Cimino – LNF-INFN

INFN
LNF
Istituto Nazionale di Fisica Nucleare

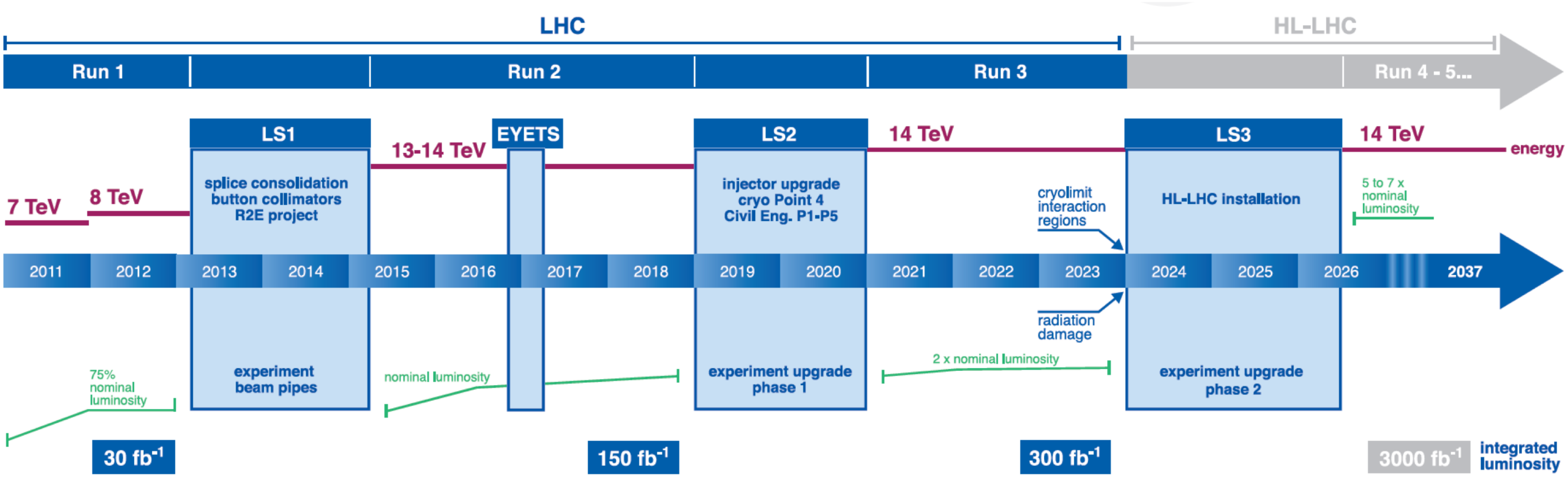
CERN Accelerators Complex



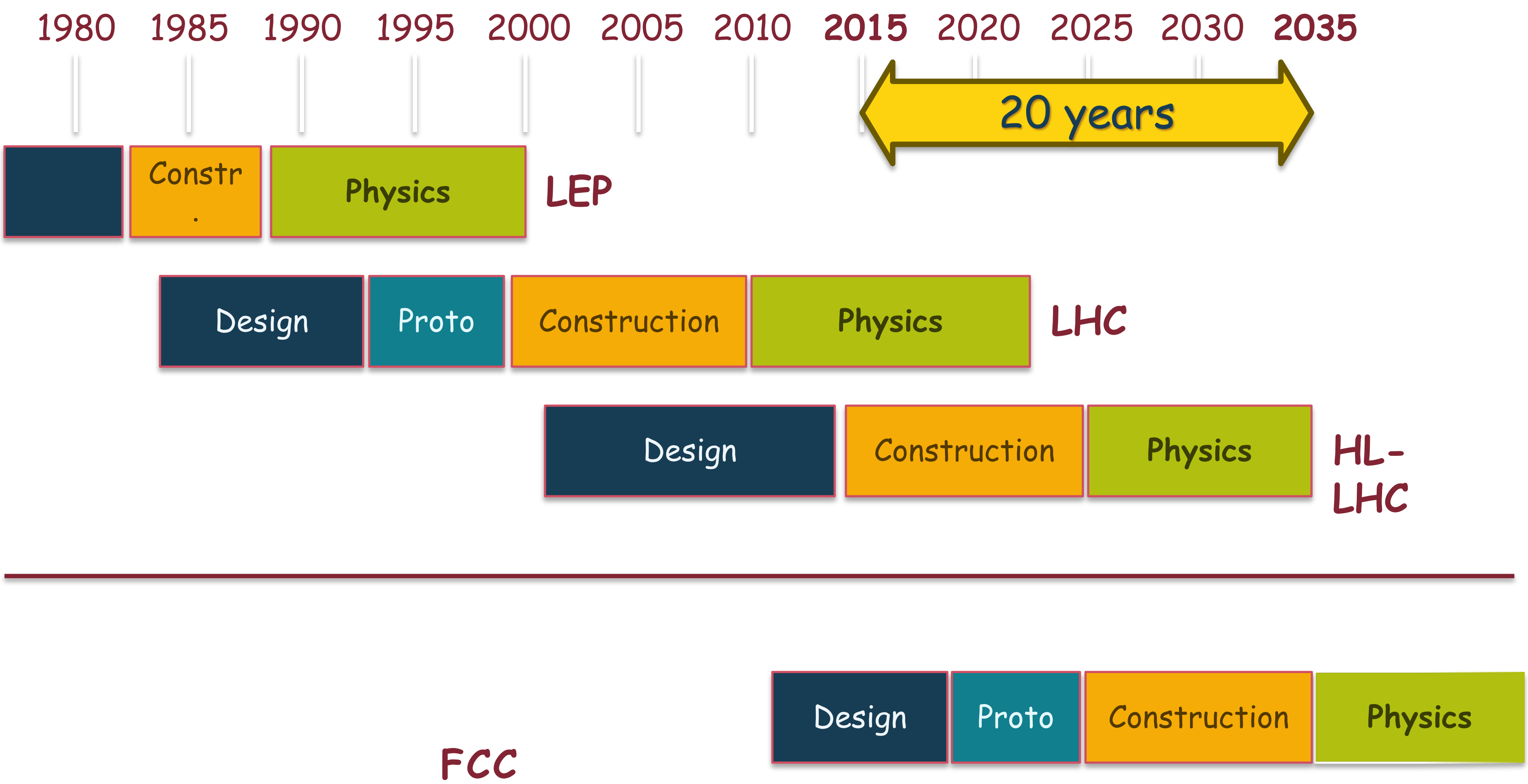
Upgrade of LHC (HL-LHC)



LHC / HL-LHC Plan



The Future Circular Collider project (FCC)



The Future Circular Collider project (FCC)

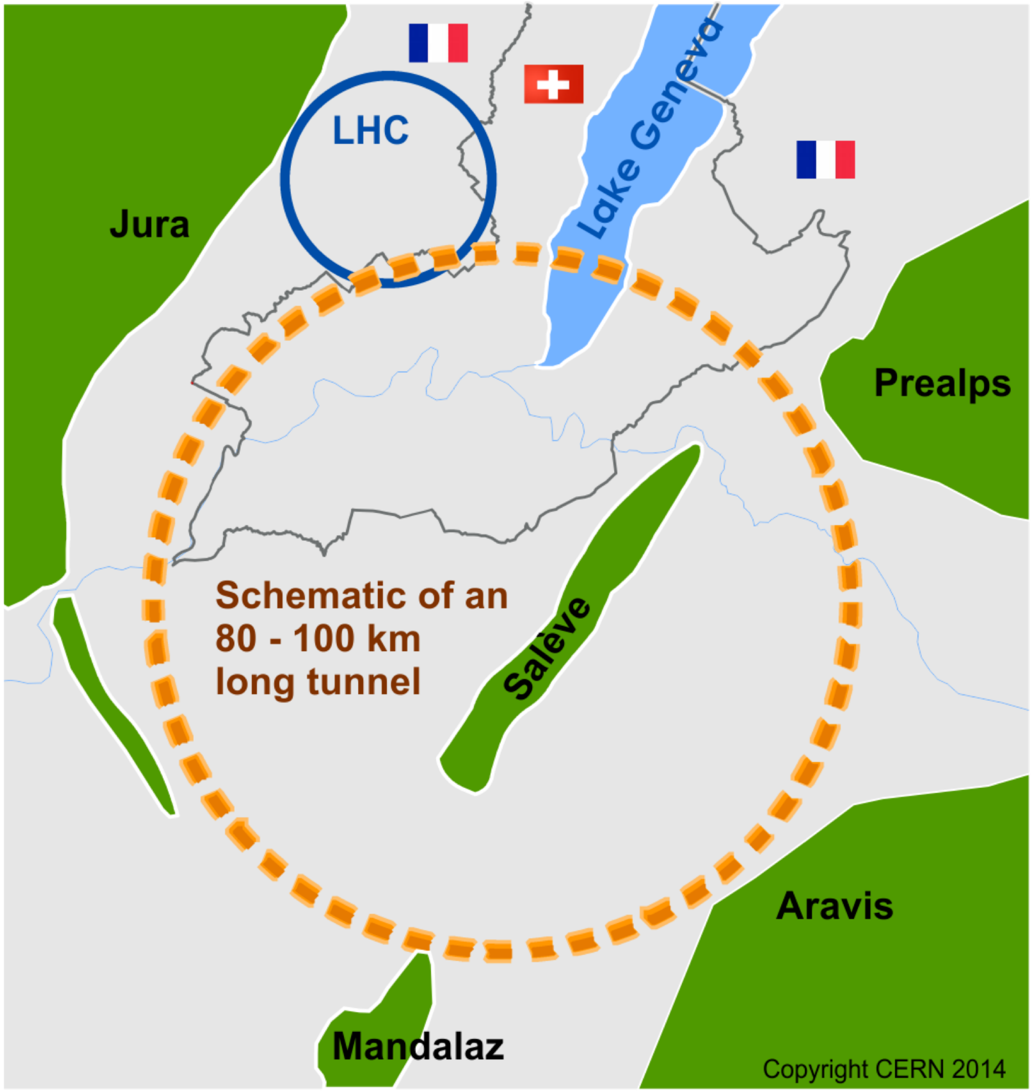
international FCC collaboration to study:

- ***pp*-collider (*FCC-hh*)** → main emphasis, defining infrastructure requirements

- **80-100 km infrastructure** in

~16 T ⇒ 100 TeV *pp* in 100 km

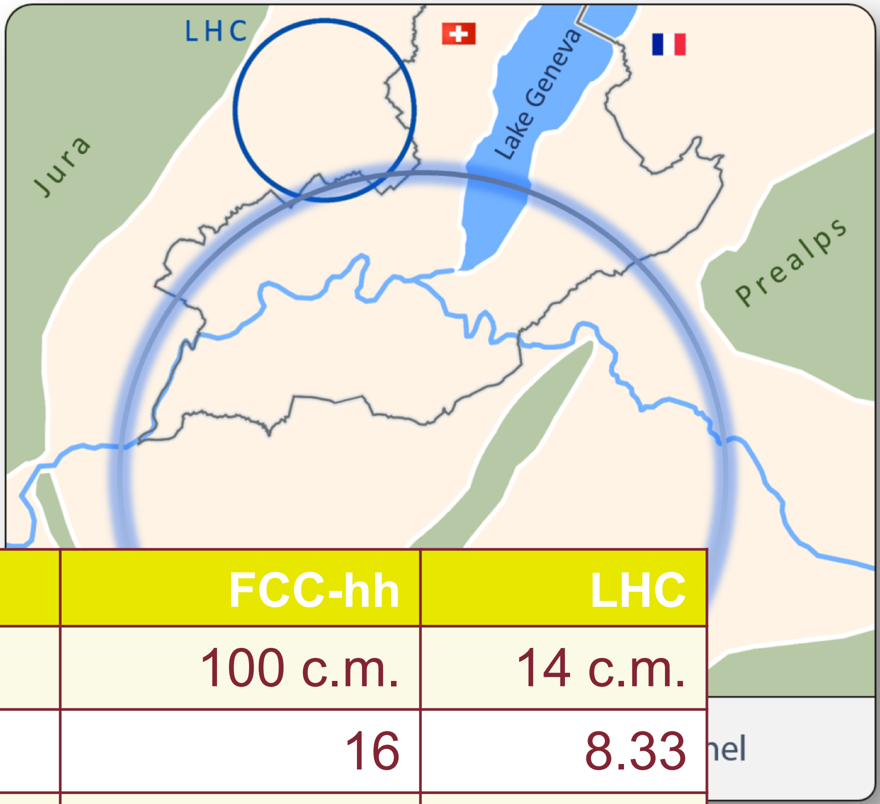
- ***e⁺e⁻* collider (*FCC-ee*)** as potential intermediate step
- ***p-e* (*FCC-he*) option**



FCC-ee
Key Parameters

Parameter	FCC-ee			LEP2
Energy/beam [GeV]	45	120	175	105
Bunches/beam	16700	1360	98	4
Beam current [mA]	1450	30	6.6	3
Luminosity/IP x 10^{34} $cm^{-2}s^{-1}$	28	6	1.8	0.0012
Energy loss/turn [GeV]	0.03	1.67	7.55	3.34
Synchr. Power [MW]	100			22
RF Voltage [GV]	2.5	5.5	11	3.5

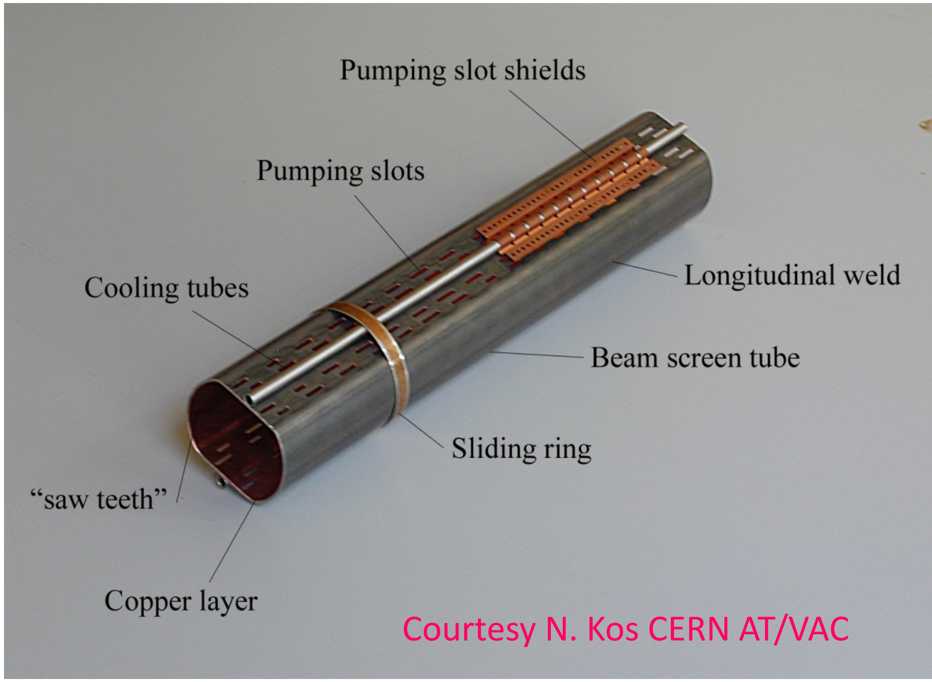
FCC-hh
Key Parameters



Parameter	FCC-hh	LHC
Energy [TeV]	100 c.m.	14 c.m.
Dipole field [T]	16	8.33
# IP	2 main, +2	4
Luminosity/IP$_{main}$ [cm^{-2}s^{-1}]	5-10 x 10^{34}	1 x 10^{34}
Energy/beam [GJ]	8.4	0.39
Synchr. rad. [W/m/apert.]	28.4	0.17
Bunch spacing [ns]	25 (5)	25

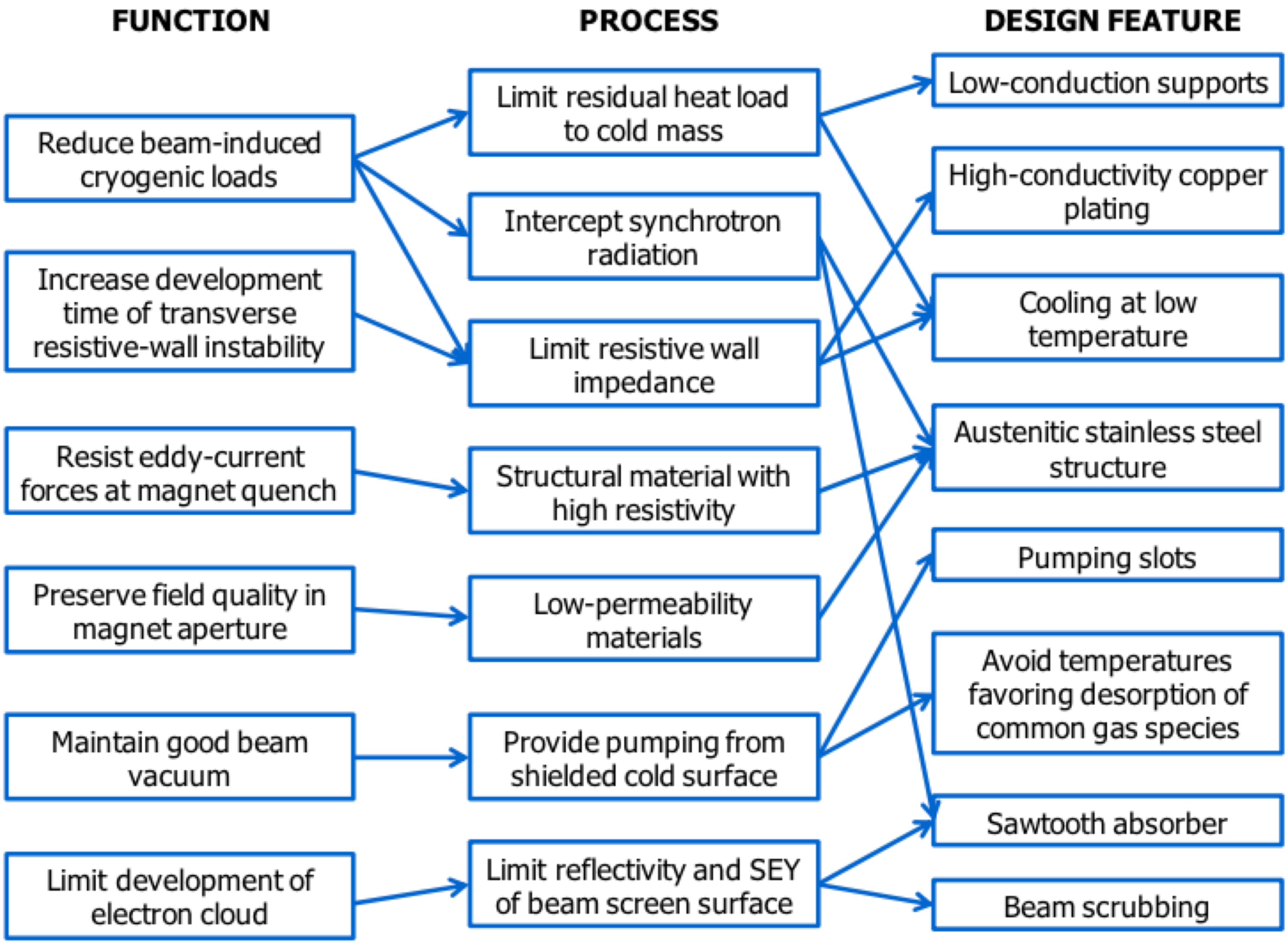
LHC Beam Screens Functionalities

- Intercept the heat load induced by the circulating beam (impedance, synchrotron radiation, electron cloud)
- Operate between 5 and 20 K
- Non-magnetic stainless steel substrate to withstand quench forces (few tons) and to ensure a good field quality
- Copper colamination onto non-magnetic stainless steel to reduce impedance



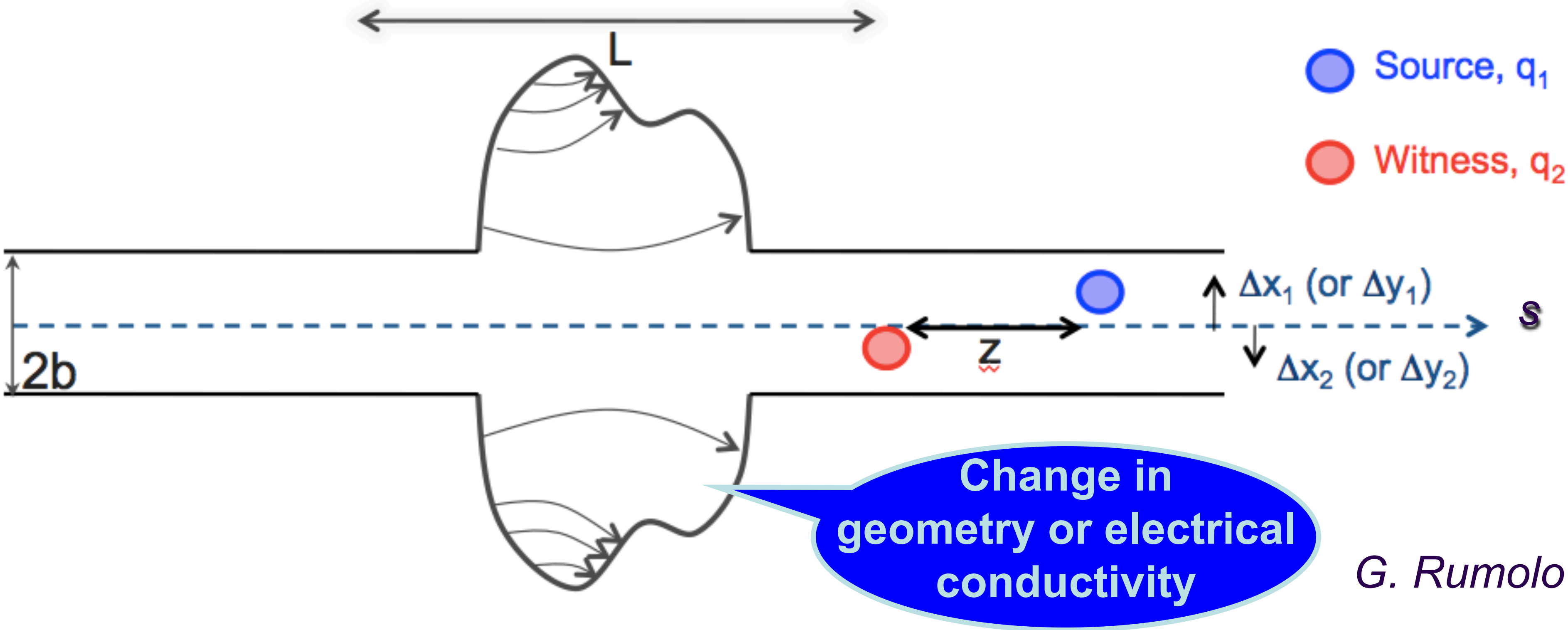
- **Pumping holes to control the gas density**
- **Rounded pumping slots to reduce electromagnetic leakage towards the cold bore held at 1.9 K or 4.5 K**
- **Electron shield to protect the cold bore from the heat loads induced by the electron cloud**
- **Saw teeth to reduce photoelectron yield and forward reflectivity of photons to decrease the seed of electrons**

Any adopted solution for the Beam screen has to compel with many other requirements and boundary conditions.



Functional design map of beam screen

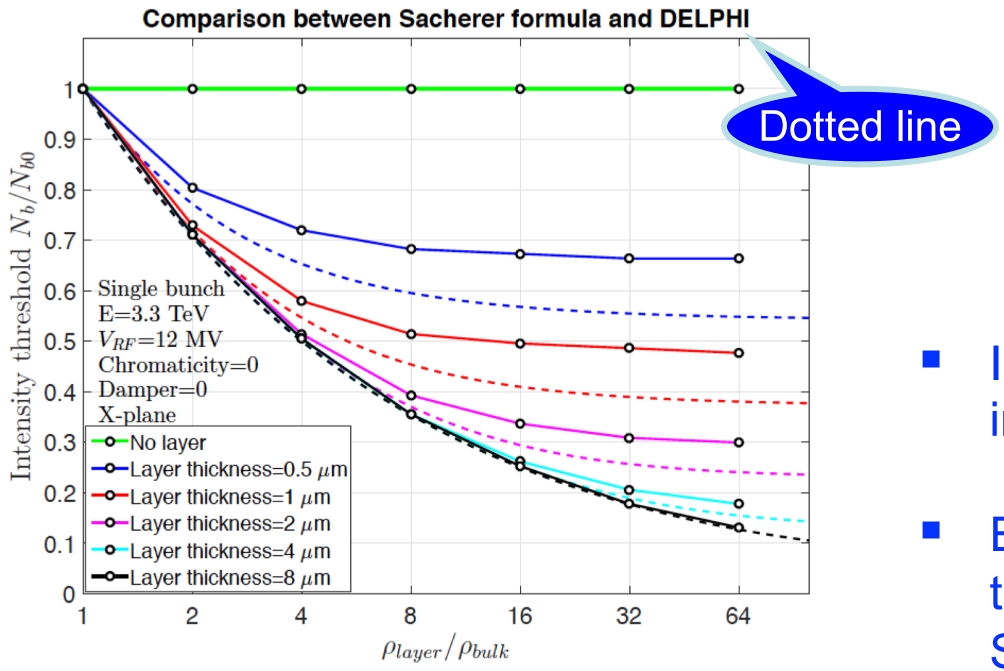
IMPEDANCE



- Wake field = Electromagnetic field generated by the beam interacting with its surroundings (vacuum pipe, etc.)
  - Power loss
  - Beam instabilities
- Impedance = Fourier transform of the wake field (wake function)

IMPEDANCE

- The impedance is a complex function of frequency and at least 5 contributions are needed to correctly characterized an equipment
  - Longitudinal impedance
  - Horizontal dipolar/driving impedance
  - Vertical dipolar/driving impedance
  - Horizontal quadrupolar/detuning impedance
  - Vertical quadrupolar/detuning impedance



An example:

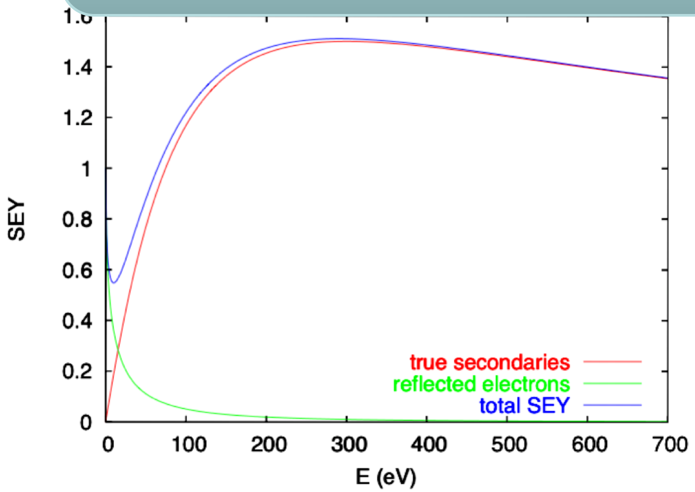
COATING (e.g. a-C) OR SURFACE TREATMENT (e.g. LESS) TO FIGHT AGAINST E-CLOUD

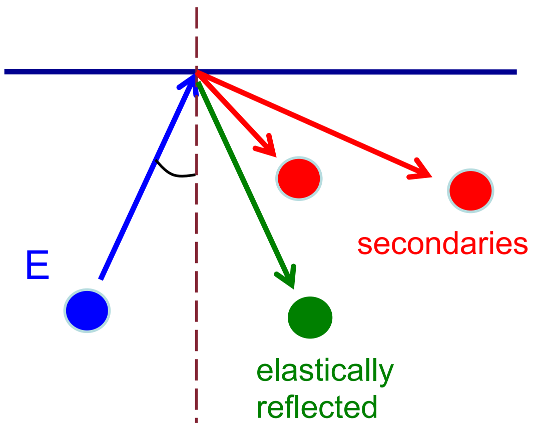
- Increase of imaginary part of transverse impedance at high frequency
- Example case of FCC-hh, where laser treatment was proposed as baseline for SEY reduction

Electron cloud formation in a vacuum pipe

Generation of electrons inside the vacuum chamber
(primary, or seed, electrons)

- Acceleration of primary electrons in the beam field
- Secondary electron production when hitting the wall

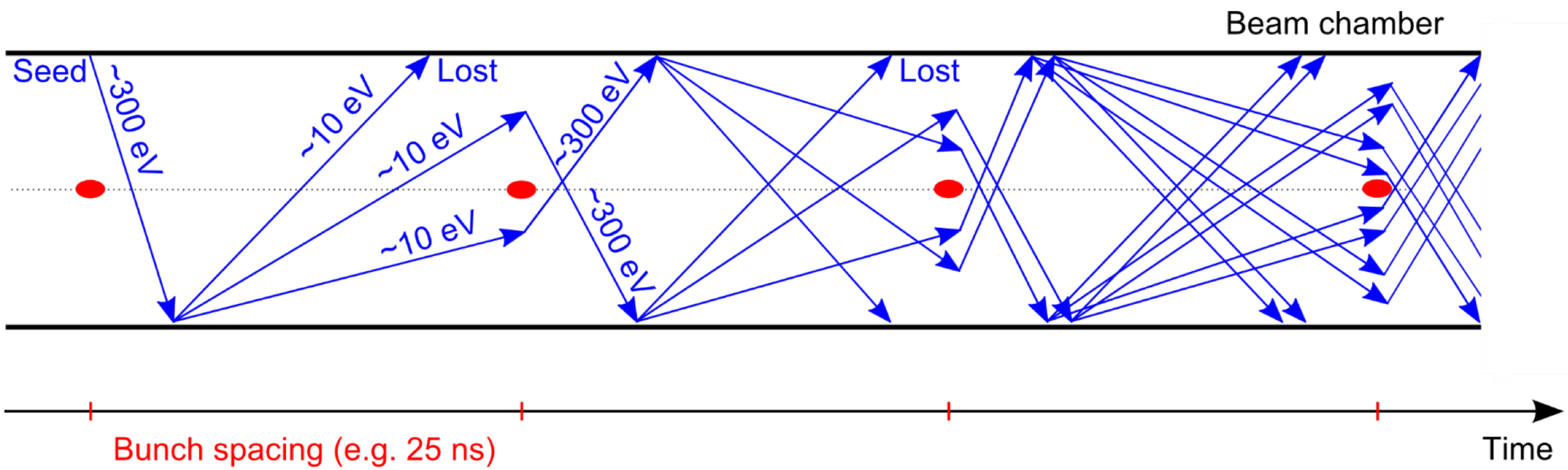




Electron cloud formation in a vacuum pipe

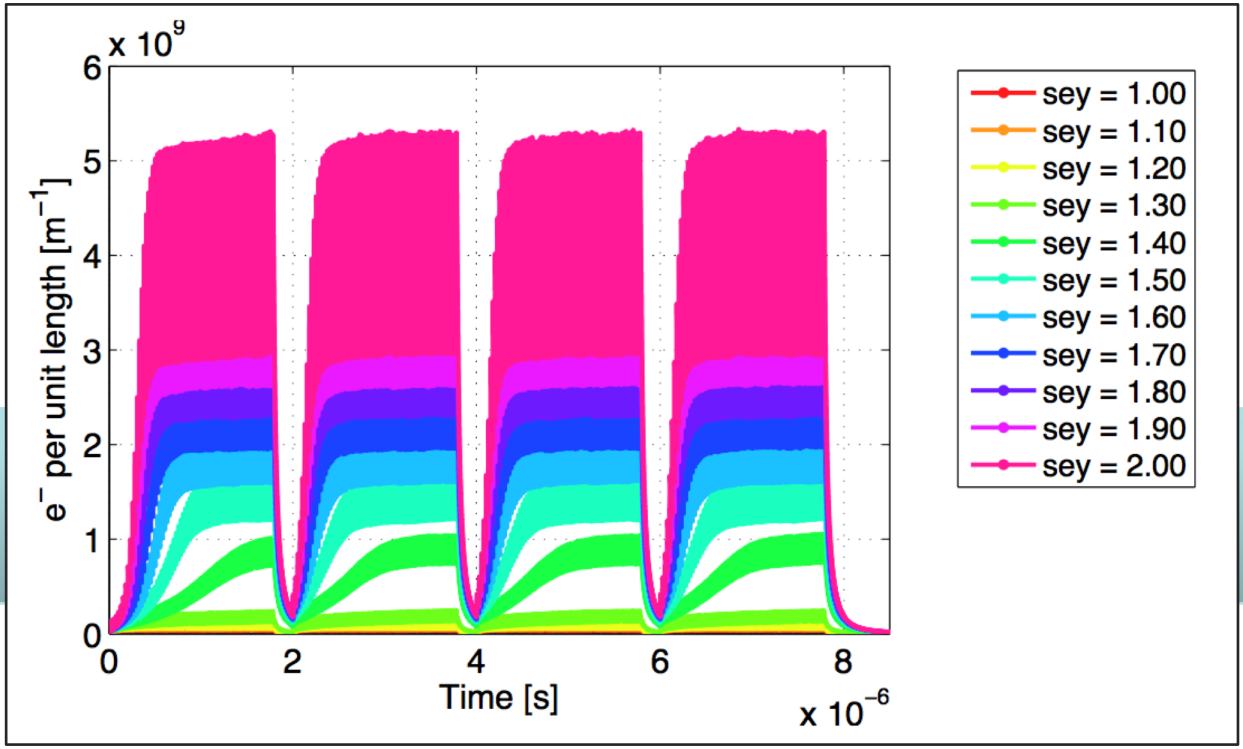
Generation of electrons inside the vacuum chamber (primary, or seed, electrons)

- **Acceleration of primary electrons in the beam field**
- **Secondary electron production when hitting the wall**
- **Avalanche electron multiplication**



Electron cloud formation in a vacuum pipe

Could be simulated with SEY curve (and δ_{max}) as input parameter



After the passage of several bunches, the electron distribution inside the chamber reaches a stationary state (electron cloud)

→ Several effects associated

Effects of the electron cloud

The presence of an e-cloud inside an accelerator ring is revealed by several **typical signatures**

- ✓ Fast pressure rise, outgassing
- ✓ Additional heat load (LHC has cold Dipoles)
- ✓ Baseline shift of the pick-up electrode signal
- ✓ Tune shift along the bunch train
- ✓ Coherent instability
  - ○ Single bunch effect affecting the last bunches of a train
  - ○ Coupled bunch effect
- ✓ Beam size blow-up and emittance growth
- ✓ Luminosity loss in colliders
- ✓ Energy loss measured through the synchronous phase shift
- ✓ Active monitoring: signal on dedicated electron detectors (e.g. strip monitors) and retarding field analysers

Machine observables (first three items)

Beam observables (tune shift through energy loss)

PhD thesis in this research framework
and
in collaboration with CERN :

Beam dynamics and collective effects for the upgrade program of LHC and FCCee
(contact: mauro.migliorati@uniroma1.it)

- **HiLumi LHC**, is the major funded upgrade to increase LHC luminosity by a factor of 10 beyond its design value. The project is co-funded by the EU and implies significant upgrades not only for LHC but for all the machines in the injection chain (LIU project).

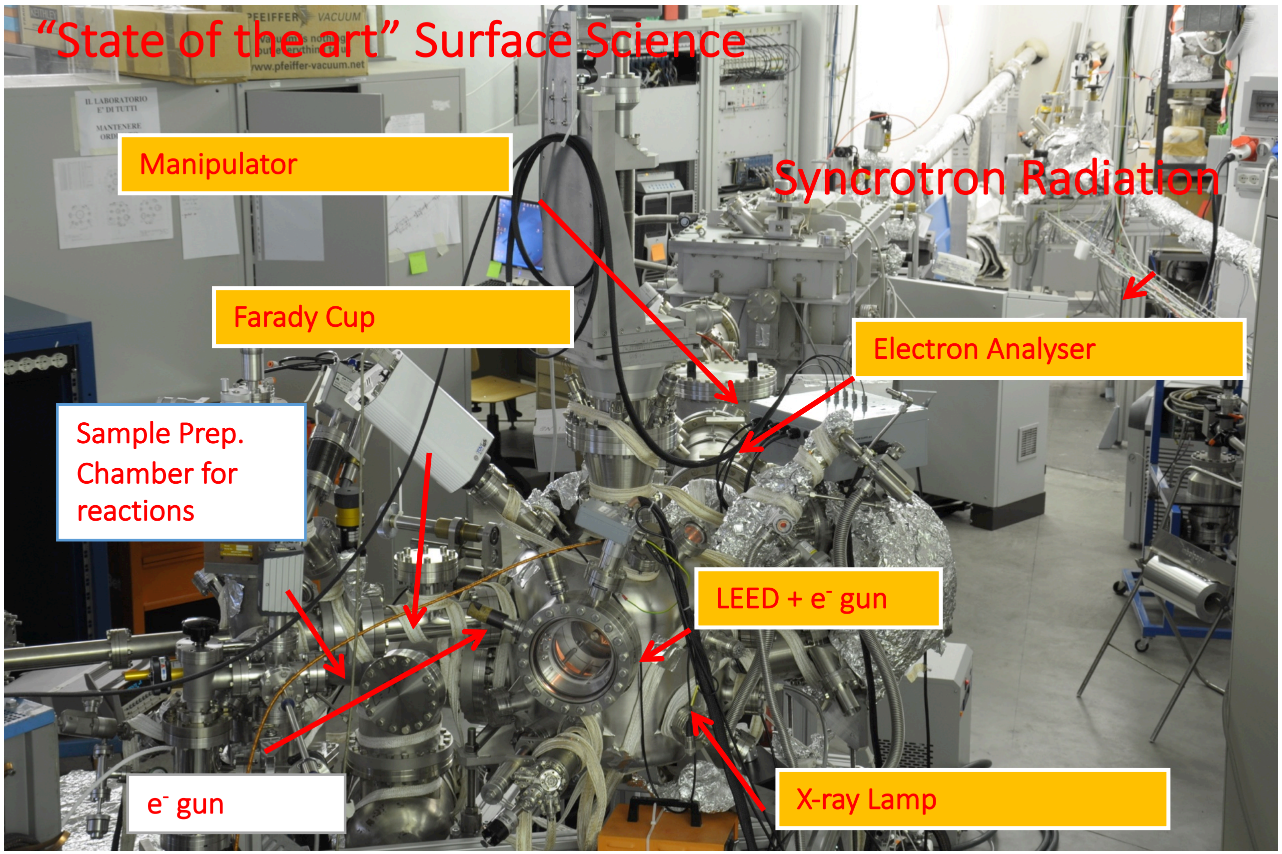
- **FCC (Future Circular Collider)**: is a global effort (lead by CERN) to study a post-LHC particle accelerator in a worldwide context. The project is co-funded by the EU and it is exploring the potential of hadron and lepton circular colliders, considering the technology R&D programs that would be required to build them.

The goal of the PhD work is to predict the behaviour of these future accelerators in terms of beam stability due to the increase of beam intensity that could lead to undesirable collective effects, triggered by self-induced em fields, which may play an important role in the machine performance.

The thesis activity is based at the Department of Basic and Applied Science for Engineering of La Sapienza, but some periods at CERN for impedance measurements and for discussions are foreseen.

Experimental investigation on relevant material properties for FCC & Hi Lumi LHC

- **Surface properties of Carbon and Cu Surfaces for HL-LHC (INFN project)**
- **Vacuum stability at FCC-hh (EU / INFN Project)**
- **Synchrotron radiation material studies (MoU with CERN/ INFN)**



These PhD thesis foreseen experimental studies (with SR and Surface Science techniques) on material properties of interest to the accelerator community.

The interested candidate will work in an international contest, within various international collaborations and will be mainly performing experiments in Frascati National Lab but also in various Facilities around Europe.

Tesi da svolgere presso il Laboratori Nazionali di Frascati dell'INFN
Contact person: R. Cimino (roberto.cimino@lnf.infn.it)

Synchrotron radiation desorption studies of candidates materials to be used for the High Luminosity upgrade for the LHC at CERN

This thesis work will be done in close collaboration with CERN and is finalised to the optimization of the LHC upgrade. New vacuum chambers with integrated tungsten-shielded beam-screen (BS) will have to be installed. A thorough characterization of the surface properties of the BS needs to be done. In particular for the co-laminated copper with different surface treatment for electron cloud mitigation, like amorphous-carbon (a-C) thin film and laser-structured surfaces, with potential applications also for the Future Circular Collider (FCC) design study.

In addition, recent studies have pointed out that the heat load transferred by electron clouds to the LHC arcs' cryogenic systems will remain a subject of concern also in the HL-LHC era, when the number of SR photons will double. A better understanding of the role of synchrotron radiation in the electron cloud built-up process is essential.

Tesi da svolgere presso il Laboratori Nazionali di Frascati dell'INFN

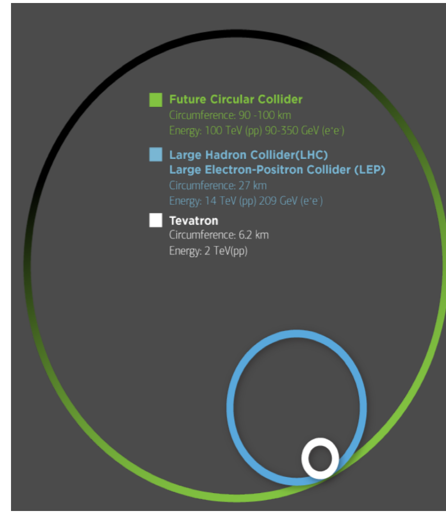
Contact person: R. Cimino (roberto.cimino@lnf.infn.it)

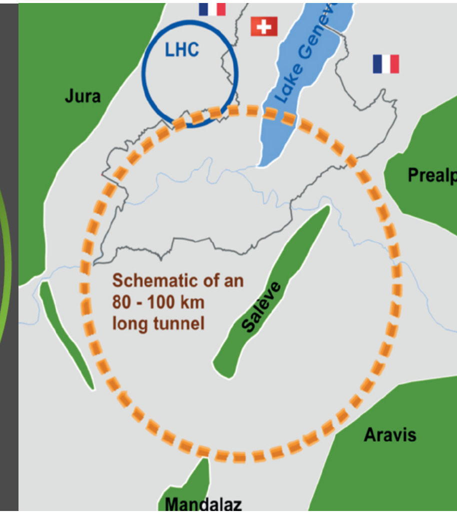
Search of passivating coatings for ultimate performances Vacuum chambers

This thesis work will use the laboratory facilities to study surface preparation/modification apt to produce a vacuum chamber with minimal desorption properties, especially during photon or electron irradiation. The laboratory is equipped with all the technologies and instruments to study thermal, electron and photon stimulated desorption, and some facilities to produce specially designed surfaces and coatings.
Surface morphology modifications, thin film Carbon films, up to Graphene-like coatings, and NEG coatings will be studied to define, at least in principle the way to produce as inert as possible surfaces for Ultra high vacuum applications.

Tesi da svolgere presso il Laboratori Nazionali di Frascati dell'INFN
Contact person: R. Cimino (roberto.cimino@lnf.infn.it)

Vacuum stability studies at cryogenic temperature of candidates materials to be used for the FCC-hh project at CERN





This thesis work will be done in close collaboration with CERN, and is finalised to the study of potential solutions for the vacuum chamber systems for the Future Circular Collider (FCC-hh), the new highest energy and intensity accelerator proposed to be built at CERN. In the framework of the European EuroCirCol collaboration, different groups are producing design studies and prototypes for the beam-screen of FCC-hh. Its design, operating temperature and structure must fulfil a number of different technical requirements. Among such requirements, vacuum stability at cryogenic temperatures needs to be studied in details. The objective of this thesis work is to test and validate the various material surfaces proposed to be used. The candidate will access two dedicated UHV systems to study gas adsorption/desorption processes at cryogenic temperature.

Tesi da svolgere presso il Laboratori Nazionali di Frascati dell'INFN

Contact person: R. Cimino (roberto.cimino@lnf.infn.it)

One word on technological research:

- It qualifies you for jobs in many field of research and in industry (not necessarily accelerator’s related);
- I makes accelerators work!
- It can be fun and have impact on more academic studies:

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Home » Highlights » Interstellar ice in accelerators

INTERSTELLAR ICE IN ACCELERATORS

20 September 2018 Highlights, News

Image credits: Vinicio Tullio

The study of ice forming at low temperature on the interstellar dust at the origin of the planetary systems has been carried out by a collaboration among the LERMA Laboratory (Sorbonne, Paris), the CNRS "Laboratoire de Chimie Physique" of the Paris-Saclay University, the CERN of Geneva and the **INFN Frascati National Laboratories**.

Specifically, the LNF researchers, Marco Angelucci and Roberto Cimino, are involved in this investigation, together with the CERN, studying the behaviour of the gases absorbed by the cold walls of the Large Hadron Collider (LHC) and of the future large accelerators. The analysis of these ice and their behaviour, whether irradiated by a different wavelength light, is of great value in astrophysics, since the parameters governing ice desorption and emission are at the basis of databases used to study the Universe.

This work is one example of how detailed and state-of-the-art studies about issues technologically relevant can have a significant impact in scientific areas which are not directly related to them. This investigation is funded both by the **INFN**, at national level, and by **EuroCirCol**, in the framework of **Horizon 2020**, at European level.

The importance and innovativeness of the work has meant that the results were published last **16th of July** on the "Nature Astronomy" magazine with an article titled "X-ray photodesorption from water ice in protoplanetary disks and X-ray-dominated regions". The work presents the first quantitative measurement (performed at the French synchrotron Radiation Facility "Soleil") of the desorption stimulated using synchrotron radiation at the oxygen K edge (~ 520 eV), from water ice. Photons of this energy are present on the outer layers of protoplanetary disks of interstellar dust and must be taken into account for a correct evaluation of many of the parameters derived from the experimental observations of the Universe. Photons of this energy are also present in the existing accelerating machines or in the ones currently being designed and their impact on vacuum and on particle beam dynamics will require further detailed studies, pushing to maintain and strengthen the synergy between accelerator physicists and astrophysicists.

nature astronomy
LETTERS
https://doi.org/10.1038/s41550-018-0532-y

X-ray photodesorption from water ice in protoplanetary disks and X-ray-dominated regions

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Proposed theses arguments with SBAI/RM1/LNF

Innovative accelerating structures for future LINACS in X and W band (contact: bruno.spataro@lnf.infn.it)

In the last century accelerators played a key role and we expect they will certainly continue playing a key role also in the coming decades not only for fundamental researches. More than 15,000 accelerators, but this number is certainly underestimated, are in use around the world and more than 97% of the accelerators are used for different industrial applications. As an example, electron linacs for radiotherapy represent one third of all the existing accelerators. This thesis proposal looks at the R&D of key components of the next generation of accelerators as the RF cavities. The construction of future accelerators starts from the R&D of electromagnetic linear accelerator operating in X (11.424 GHz) and W (100 GHz) band structures for high gradients. The mandatory condition to achieve the goal is the availability of reaching well above 120 MeV/m in X band and 400 MeV/m in W one. However, this research, fundamental for the next accelerating techniques is just at the early stage for real applications. To achieve the multi-TeV energies of the future linear colliders and the extraordinary x-ray FEL sources devoted to interdisciplinary researches such as nano-technology, protein crystallography or imaging of viruses, new emerging technologies have to be setup.

Innovative accelerating structures for future LINACS in X and W band
(contact: bruno.spataro@lnf.infn.it)

In the framework a collaboration between INFN-SLAC-KEK- UCLA aims to:

1) design and construction of dedicated standing wave (SW) structures operating at F=11.424 GHz and F=100 GHz in order to study breakdowns discharges due to high electric field and thermal stress or to pulse heating effects;

2) identify manufacture technologies to achieve accelerating structures with high surface quality;

3) test of materials with a high melting point such as Mo and Ru sputtered on Cu and characterization of smart coatings through morphological and structural techniques.

R&D activities will aim to the realization of novel RF accelerating structures of SW type in order to:

1) promote the acquisition of innovative technologies based on new materials raising the threshold for the electric discharge;

2) generate spin-off of these technologies for compact industrial-grade devices;

3) develop alternatives to normal colliders based on superconductive technologies;

4) manufacture simple and compact structures to generate high brightness electron beams such as those required by proposed X-FEL. In this framework, a dedicated design of the mode launcher for feeding the structure with no multi-polars RF components is required, too.

Innovative accelerating structures for future LINACS in X and W band: thesis (contact: bruno.spataro@lnf.infn.it)

1) X band mode launcher (normal conducting)

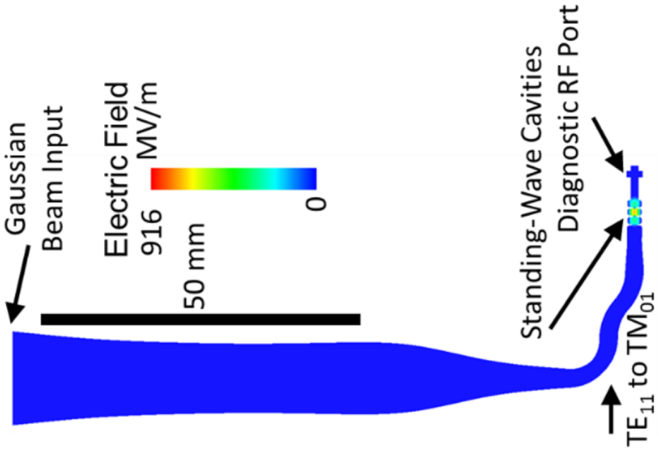
Recent studies of RF breakdown in cryogenic copper structure have shown a strong increase in the operating gradient and the surface electric field that can be attained. The RF photo-injector of future generation will use this increase in surface electric field to create an ultra-high brightness cryogenic normal conducting photo-injector. The brightness is expected to increase by over un order of magnitude. This RF photo-injector is fed by a dedicated mode launcher with no multipolar components in order to avoid an undesirable emittance growth in the electron beam launched from the RF photoinjector. In the frame of the collaboration INFN-LNF/SLAC-UCLA (USA), the goal of this work, is to design and fabricate a compact X band mode launcher in order to remove the multipolar RF components.

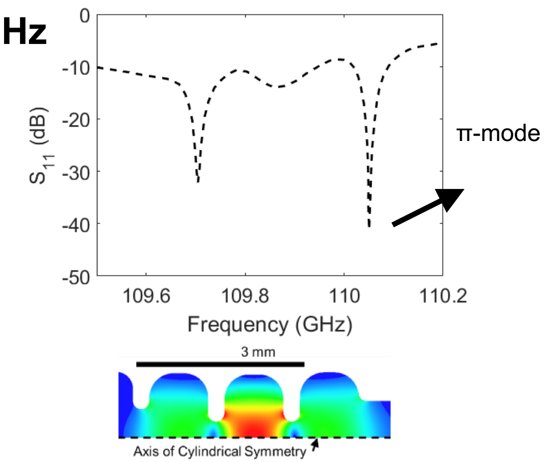
2) X band Open Split Structure (normal conducting)

Accelerating structures are usually manufactured by precision turning of individual cells, and combined with precision milling for complex parts such as RF power couplers. These multiple parts are brazed into a complete structure. An alternative approach is the use of precision milling to cut cells into metal blocks that comprise either halves or quarters of the complete structure. One of the main motivations for this work is to study the high gradient performance of accelerating structures made with novel manufacturing methods (or milled out of two halves and brazed together) in order to reduce the fabrication cost

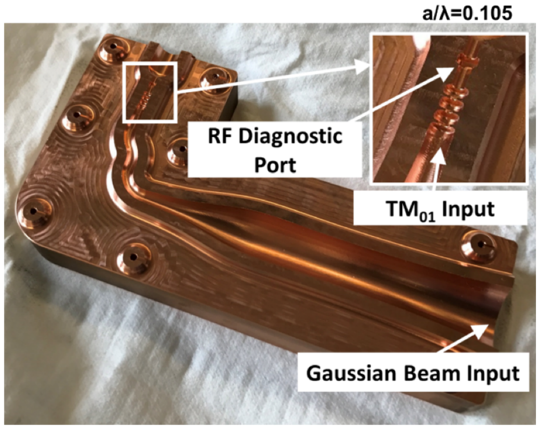
Innovative accelerating structures for future LINACS in X and W band: thesis (contact: bruno.spataro@lnf.infn.it)

3) Design and tests of a high gradient accelerating structure operating a 110 GHz





Accelerating Structure



Split-Cell Structure with Mode Converter and Cavities

In the frame of the collaboration INFN-LNF/SLAC(USA) we are studying and improving the performance of the accelerator structure operating at 110 GHz (mm wave). The purpose of this work is to study the basic physics of ultra high vacuum RF breakdown in high-gradient RF accelerators to be tested at SLAC and MIT.

The goal is to design a innovative mode launcher and single-cell accelerating structure. Preliminary testing results for single-cell accelerating structures intended for high-gradient testing at 110 GHz are in progress at SLAC, too.

The thesis activity is based at the Department of Basic and Applied Science for Engineering of La Sapienza.

Metallic films: conductivity properties vs. work function.
New opportunities for accelerator and other technological applications
(contact: bruno.spataro@lnf.infn.it)

Technological activities to design, manufacture and test new accelerating devices using different materials and methods are under way all over the world. The main goal of these researches is to increase the accelerating gradients minimizing the probability of RF breakdown. Among the possible options, experimental results point out that relatively thick metallic coatings of Transition Metal (TM) atoms may improve the properties of standard materials like copper, in particular, the breakdown rate. As a consequence of the relationship between defects and work function, many transition metal (TM) oxides tend to have decreased work functions near a metal/metal-oxide interface, a behavior useful to tune the work function and the field emission, if the TM oxide and the metallic substrate is properly selected.

- The thesis activity is based at the Department of Basic and Applied Science for Engineering of La Sapienza in collaboration with INFN-LNF.

Conclusion

- Phd Thesis is a very important transition from students to researchers
- One of the important skills you are supposed to have and develop is: choosing on what and with whom you want to work!
- So: read carefully, study, look on google scholar publication lists, check for grants available and capabilities of thesis proposers, talk to people, visit labs ... (Supervisors, ex-students, etc.)
- You need to choose where and with whom to spend your next 3 years.
- Take your time!