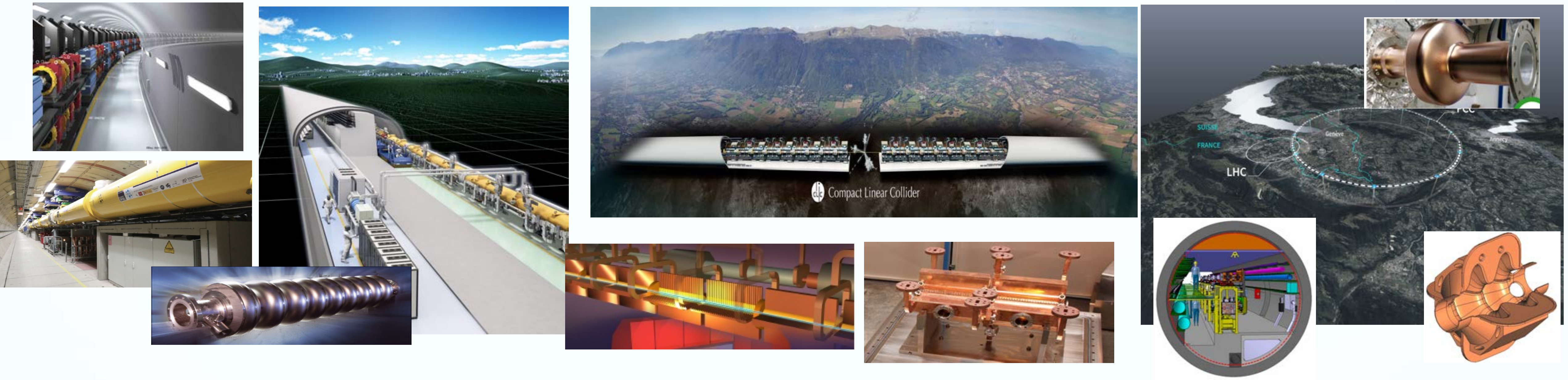


R&D on FCC and Future colliders at IN2P3

FCC-NPC

Institut national de physique nucléaire et de physique des particules

A. Faus-Golfe on behalf FCC-NPC team

Medium Term Plan

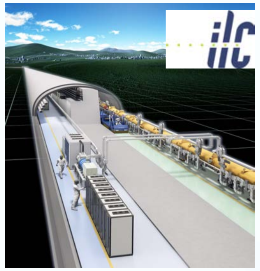
EPPSU | EPPSU | Long Term Plan

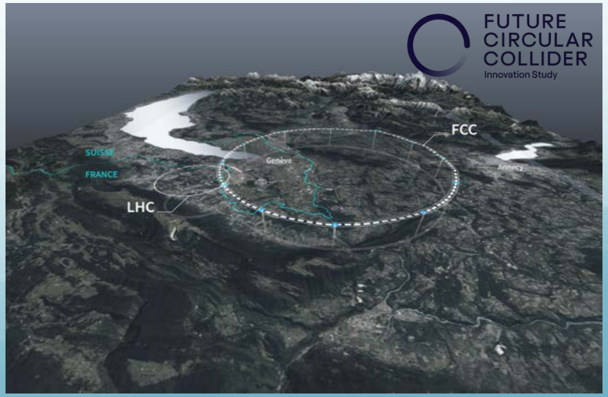
2020 2021 2022 2023 2024 2025 2026 2027 2028 2029 2030 2031 2032 2033 2034 2035 2036 2037

Outline

- **Future Large Accelerator Projects**
  - ESSP & Snowmass context
  - State of the Art and Scientific Issues
- **IN2P3 contribution to future and current**
  - R&D and Projects (2021-2025)
- **Future Perspectives**

Higgs Factories
- Linear: ILC/CLIC
- Circular: FCC-ee





HEP FC Key Technologies

➤ HEP Large Accelerator Projects Key Technologies

IN2P3

			RF cavities						Magnets							
Components			**SCRF**				**NCRF**	**HLRF**	**SC Mag.**		**NC Mag.**	**Vac**	**IRs**	**Injec-e+**	**Sust – C footprint**	**Others**
Techniques			**Design**	**HG/HQ**	**CRYO**	**CRAB**		**HE-Klys**	**Nb_3Tn**	**CRYO**						
PROJECTS	**FCC**	**FCC-hh**				X			X	X		X			X	Integr.
		FCC-ee	X	X	X	X		X			X	X	X	X	X	Integr.
	LC	**ILC**		X	X	X		X					X	X	X	
		CLIC				X	X	X			X		X		X	

e⁺e⁻ Higgs factory technology is ready

Context: FCC - Next Particle Collider

A **rich R&D program** is driving the developing and building of these new facilities. A **strong cooperation** between national institutes, CERN and others global laboratories or collaborations is vital for the **progress of the field** and also for **preserving the expertise**.

In this context the **main goal** of **the FCC-NPC project** is to ensure an **appropriate contribution** to this vibrant and diverse R&D program focusing in where we have already demonstrated our **know-how** and **expertise**:

IN2P3

- Nanobeams handling
- Nanobeam stabilization and positioning techniques
- Luminosity and backgrounds
- High-intensity e+ sources
- e+e- polarimetry
- Dynamics vacuum and material studies
- SRF multipacting and materials

IN2P3 FCC-NPC: in a nutshell

FCC - Next Particle Collider

Institut national de physique nucléaire et de physique des particules

2023

Coordinator:
A. FAUS-GOLFE
16.15 FTE/y

WP1 Parameters
0.1 FTE/y

A. FAUS-GOLFE 0.1
L. BRUNETTI
P. BAMBADE
I.CHAIKOVSKA
A.MARTENS
B.MERCIER
Y. GOMEZ-MARTINEZ

ILC-ATF3
CLIC
SuperKEKB
FCCee
HL-LHC

MP-IN2P3

WP2 Nanobeams
3.2 FTE/y

A. FAUS-GOLFE 0.2
G. SIMON (PhD) 1
Z. ZHANG (PhD) 1
R. SOOS (PhD) 1

ILC-ATF3
CLIC
FCCee

MP-IN2P3
FJPPL
FCPPL
EAJADE
MoU FCC

WP3 Stabilisation
3. 6 FTE/y

L. BRUNETTI 0.8
G. BALIK 0.3
NEW ENGINEER 1
A. DOMINJON 0.1
E. MONTBARBON 1
I. de BONIS 0.1
F. POIRIER 0.3

ILC-ATF3
SuperKEKb
FCCee

MP-IN2P3
FJPPL
FCC-IS
EAJADE
MoU FCC

WP4 Luminosity
1.5 FTE/y

P. BAMBADE 0.2
S. WALLON 0.3
M. LI (PhD) 1

SuperKEKB

MP-IN2P3
EAJADE

WP5 Positrons
3.5 FTE/y

I. CHAIKOVSKA 0.6
S. WALLON 0.2
V. KUBYTSKY 0.1
H. GULER 0.1
V. MYTROCHENKO 0.5
F. ALHARTHI (PhD) 1
NEW POSTDOC 1

FCCee
SuoerKEKB
ILC
Muon colliders

MP-IN2P3
IFAST
ANR INSPIRER
EAJADE
MoU FCC

WP6 Polarimetry
0.9 FTE/y

A. MARTENS 0.2
F. ZOMER 0.1
D. NUTARELLI 0.2
Y. PEINAUD 0.1
F. MAWAS (PhD) 0.3

ILC
FCCee
SuperKEkB

MP-IN2P3
FJPPL
EAJADE
MoU FCC *

WP7 Vacuum
1.9 FTE/y

B. MERCIER 0.4
G. SATTONNAY 0.3
E. MISTRETTA 0.1
S. BILGEN 0.6
J. YEMANE 0.2
T. GERARDIN 0.1
NEW POSTDOC 0.2

FCCee
HL-LHC

MP-IN2P3
MoU FCC
MoU HL-LHC*

WP8 SRF
1.45 FTE/y

Y. GOMEZ-MARTINEZ 0.2
F. BOULY 0.1
A. PLACAIS 0.25
M. MEYER (InT) 0.5
D. LONGUEVERGNE 0.1
G. SATTONAY 0.1
A. MIYAKAZI 0.2

FCCee

MP-IN2P3
MoU FCC

* MoU HL-LHC in progress

WP2 Nanobeam size handling

Scientific Issues

$$L = f_{coll} \frac{N_b^2}{4\pi\sqrt{\epsilon_x \beta_x^* \epsilon_y \beta_y^*}}$$

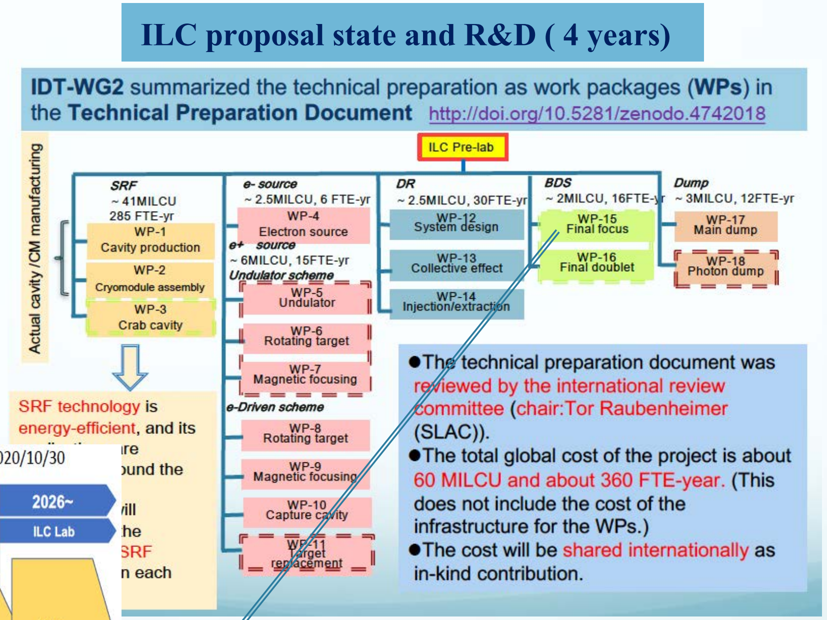
Very **high peak luminosity** needs **nanometre transverse IP beam sizes** (FCC-ee 30-70 nm, ILC 3-8 nm, CLIC 1-3 nm).
To **demagnify** the beams, complex **IR** and **FFS** are designed.

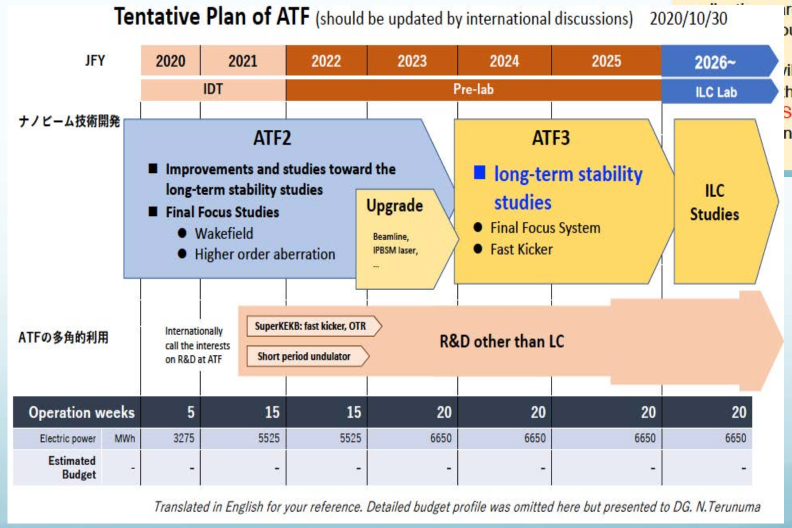
➢ ILC/CLIC scaled FFS: ATF2-3

ATF/ATF2 FFS has verified the **minimal technical feasibility** of ILC/CLIC-FFS, to **maximize** the **luminosity potential of ILC/CLIC** a further investigation of:

- Intensity dependence effects on the IP size
- Optical aberrations specially with smaller β_x^*, design optics (β_x^* x β_y^*)
- Smaller sizes ultra-low β^* (CLIC)

will be pursued in a follow-on upgraded facility **"ATF3"** (ILC-IDT framed).





WP2 Nanobeam size handling

Scientific Issues

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Very **high peak luminosity** needs **nanometre transverse IP beam sizes** (FCC-ee 30-70 nm, ILC 3-8 nm, CLIC 1-3 nm).
To **demagnify** the beams, complex **IR** and **FFS** are designed.

➢ FCC-ee IR studies:

In some "special" IR configurations as **monochomatization** the **energy spread** could be **reduced** to **maximize** the **sensitivity** of certain **physics channels**. Further studies on:

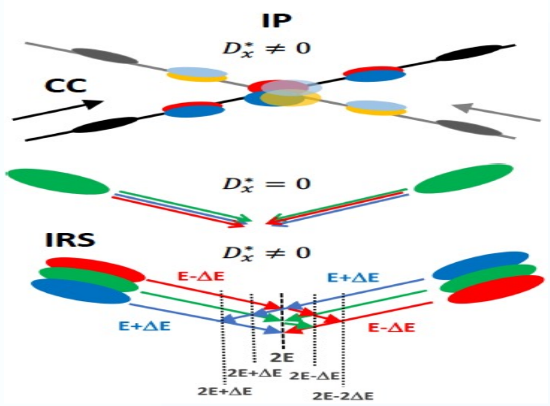
- Parameters including Beamsstrahlung (BS) (increased ε_x σ_b) and crossing angle (Crab Cavities-CC)
- Optics design to generate antisymmetric D_x^* are needed to probe the feasibility of this kind of IR schemes.
- Experimental implementation studies (DAPHNE and SuperKEKB)

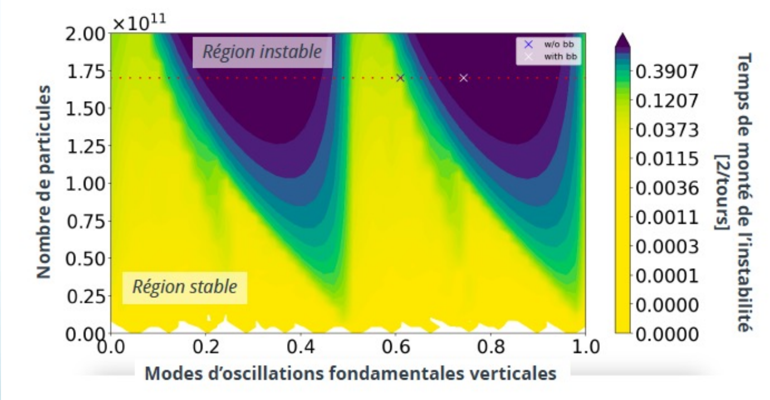
Realistic IR simulations:

- Synchrotron Radiation (**SR**) and **Solenoidal detector** fields impacts in MADX code.
- **Beam-Beam instabilities** studies, including more precise wakefield model and possible experimental studies.

$$w = 2E_0 + 0(\varepsilon)^2$$

Crossing angle monochromatization scheme featuring IP dispersion of opposite signs.





Resonances causing horizontal instabilities after beam-beam interactions with Circulant Matrix Model (CMM) semi-analytical model.

WP2 Nanobeam size handling

Objectives

- **Objective 2.1: ATF3 ILC-CLIC FFS** facility **test optics design**, **long term stability operation** and tuning and **high-order aberration studies** in order to maximize the potential luminosity of ILC.

- **Objective 2.2**: Parametric study of a **monochromatic scheme** to maximize the sensitivity to the Yukawa coupling in **FCC-ee**, including BS and crossing angle effects between others and **IR optics design** implementation and integration of such scheme without luminosity degradation. Possible experimental studies.

- **Objective 2.3: Realistic** simulations of the **FCC-ee IR** including **SR** and **solenoidal detector** field impact in MADX and **beam-beam instabilities** including more precise wakefields model and experimental studies.

WP3 Nanobeam stabilization and Positioning

Scientific Issues

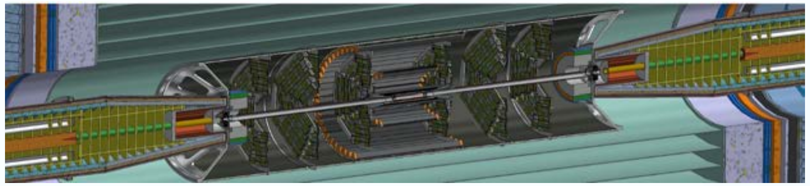
Vibration mitigation and **misalignments control** are crucial to obtain **high luminosity** (CLIC FFS magnet specification displacements 0.2 nm at 4Hz).

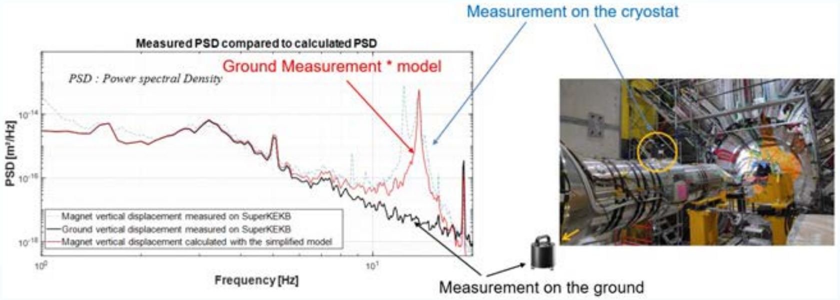
With thousand of magnets**, dynamic positioning approach** by girder is the most effective approach.

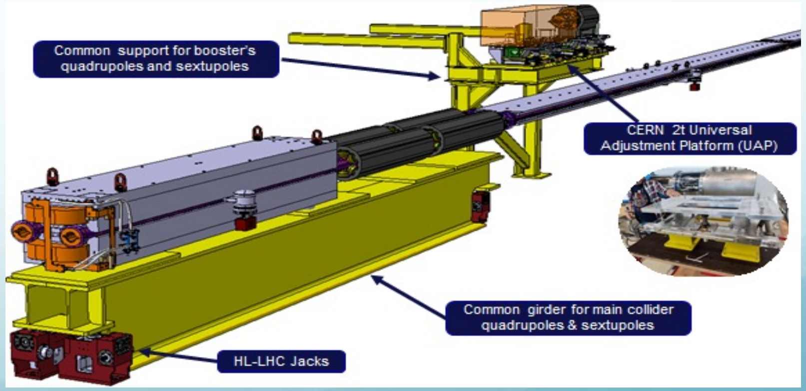
➢ FCC-ee beam stabilization

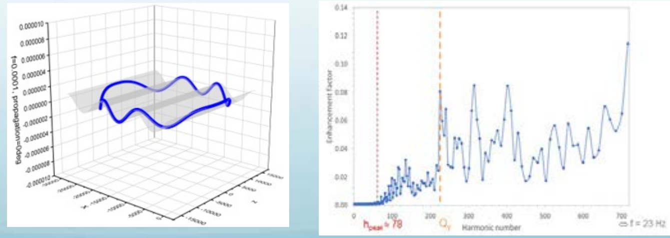
- **FCC-ee MDI:** guarantee the mechanical behavior of the MDI assemblies in integrating the estimated motion of the last focusing magnets into the global optics simulation (MADx)
- **FCC-ee arc-cell prototype:** static and dynamics studies with a special interest on the positioning system
- **FCC-ee uniform waves:** Simulation in function of frequency, phase and direction. Further beam dynamics studies with GND generator.

Setup of the MDI









Vertical displacement along the collider (frequency at 1Hz)

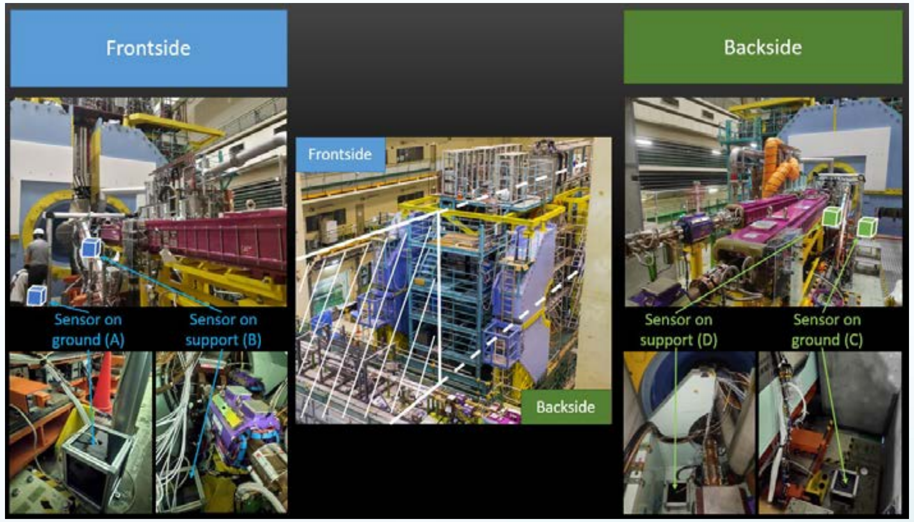
Setup of the arc-cell prototype

WP3 Nanobeam stabilization and Positioning   Scientific Issues

Vibration mitigation and **misalignments control** are crucial to obtain **high luminosity** (CLIC FFS magnet specification displacements 0.2 nm at 4Hz).
With thousand of magnets**, dynamic positioning approach** by girder is the most effective approach.

➢ SuperKEKB stabilization

- Analysis of the **vibrations effects** on **beam parameters** and relevance of the associated optics simulation



4 seismic sensors (2 each side) BELLE II

➢ Positioning

- Development of a **low cost system** dedicated to a **singular magnet** on **two transverse axes**
- Application to **FCCee arc cell** prototype and **ATF3 final focus** magnets

WP3 Nanobeam stabilization and Positioning

Objectives

- **Objective 3.1: FCC-ee Innovation Study MDI** WP leading (Vibrations study and its associated control strategy - Beam optics simulations of vibrations, and impact on beam emittance/luminosity).
- **Objective 3.2:** FCC-ee studies for **static** (uniform waves) and **dynamics** (generator) **vibrations**
- **Objective 3.3: FCC-ee Arc-Cell mock-up**: static and dynamic studies and prospect for positioning.
- **Objective 3.4: SuperKEKB**: analysis of the **vibrations impact** on beam and associated optics simulations

WP4 Luminosity and Backgrounds

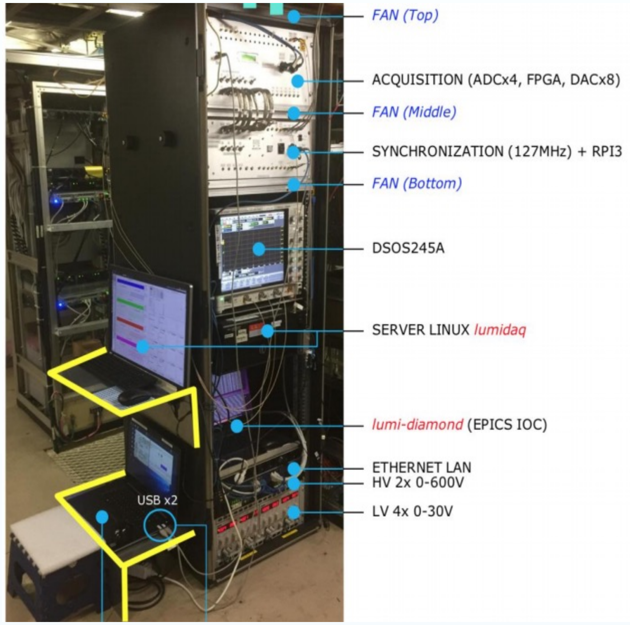
Scientific issues

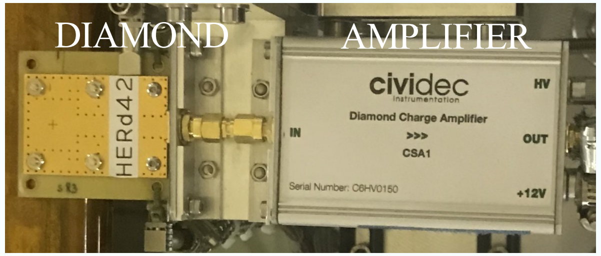
High luminosity implies **continuous correction** of **residual beam offsets and aberrations**, **fast luminosity measurement** are an essential tool. **Background mitigation** is increasingly difficult with **ultra-low β*** and very **high currents**.

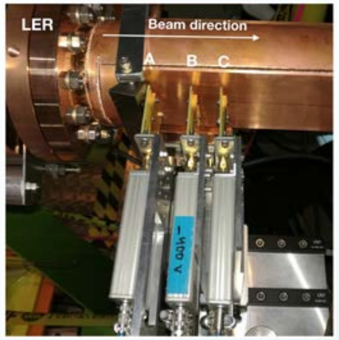
➢ Fast luminosity measurements

Fast luminometers (1% precision at 1 kHz) designed by IJCLab are deployed at SuperKEKB with large dynamic range, bunch-by-bunch and serve also as beam loss monitors. The measurements are inputs for:

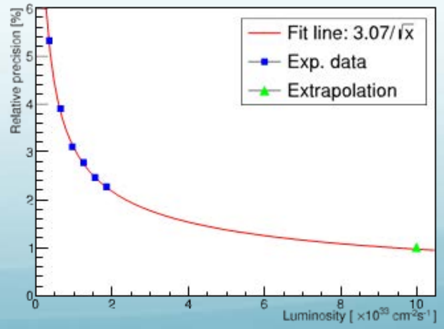
- **Feedback systems** which **stabilize** the **colliding beams** and **minimise** their **residual** horizontal (and vertical) **offsets.**
- **Aberration correction** tuning procedure due to imperfections in the field quality and alignment of magnets.
- **Luminosity optimization studies**, including mechanical vibration near the detector area

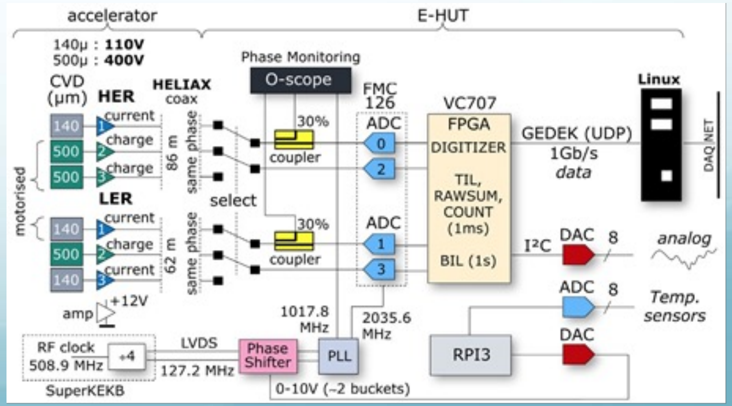






Measured 1 kHz relative luminosity precision versus luminosity





WP4 Luminosity and Backgrounds — Scientific issues

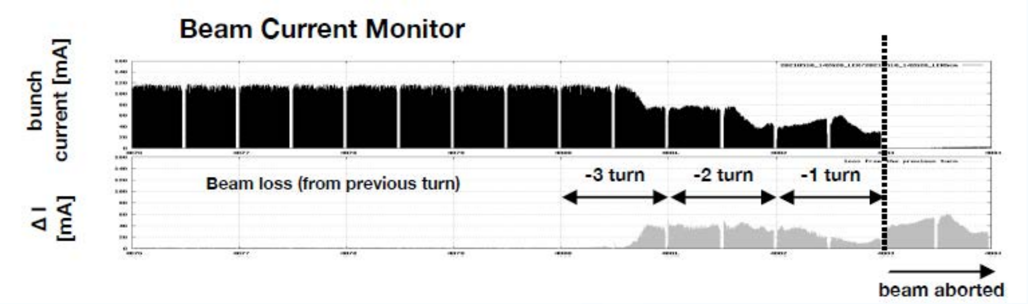
High luminosity implies **continuous correction** of **residual beam offsets and aberrations**, **fast luminosity measurement** are an essential tool. **Background mitigation** is increasingly difficult with **ultra-low β*** and very **high currents**.

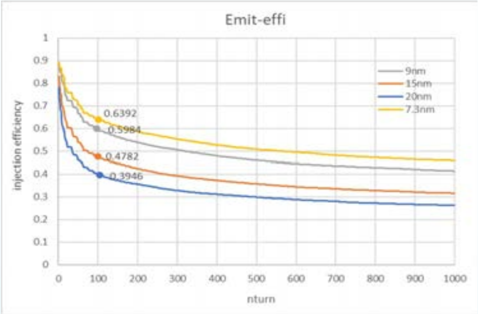
➢ Backgrounds

Simulation and **experimental** studies on beam loss backgrounds from continuous top-up injection system:

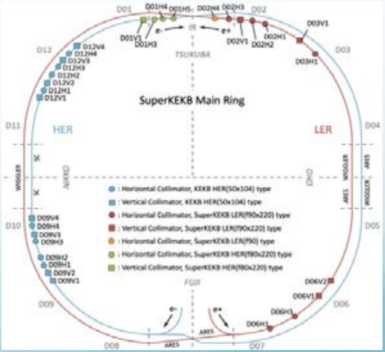
- **Beam dynamics studies** including: collimators and septum aperture, Dynamic aperture DA (beam-beam, crab waist), optics mismatchs, Injection angle and offset, coupling… of HER injection efficiency cooperating with SuperKEKB injection task force at KEK

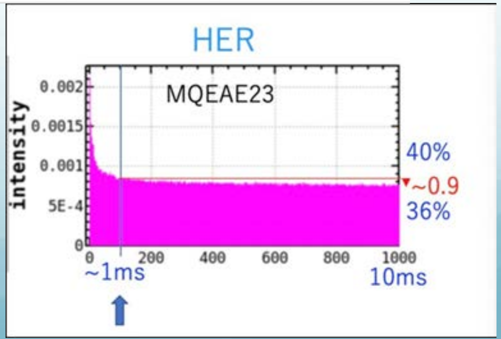
Major current issue : sudden beam loss beyond threshold





Effect of increased input emittance





WP4 Luminosity and Backgrounds

Objectives

- **Objective 4.1**: Conducting dedicated **experiments** at the **SuperKEKB** collider aiming at **maximizing luminosity performance** and **mitigating beam-induced backgrounds**, including specific tests and validations of concepts and methods proposed / under development for future e^+e^- high-energy colliders, based on operating the LumiBelle2 fast luminosity monitor, on the Belle II and **SuperKEKB** loss monitors, including comparing with LAPP mechanical vibration monitors near the IP, and supplemented by suitable simulation efforts.

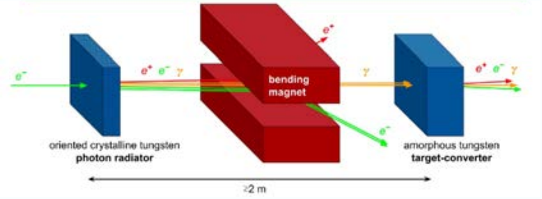
WP5 High-Intensity e⁺ sources

Scientific issues

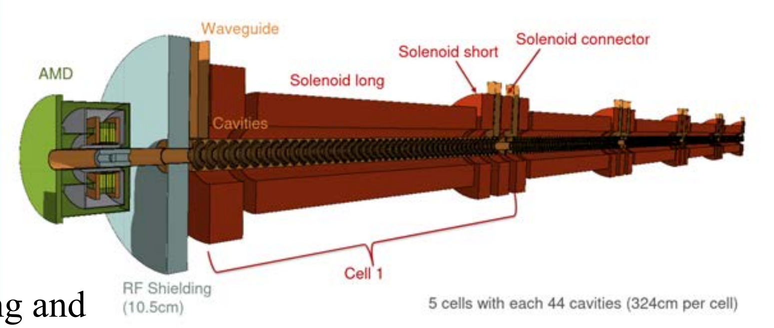
$$L = f_{coll} \frac{N_b^2}{4\pi \sqrt{\epsilon_x \beta_x^* \epsilon_y \beta_y^*}}$$

High-beam intensity and **low emittance** **e⁺** are necessary to achieve high-luminosity
(ILC/CLIC 10^{14}-10^{15} e⁺/s, FCC-ee ~10^{13} e+/s while demonstrated @SLC ~6×10^{12}e+/s)

Crystal-based target Hybrid scheme



FCC-ee: Production + Capture System



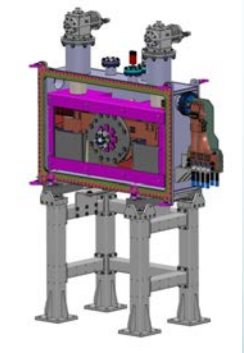
➢ Novel types of e⁺ sources

R&D beyond existing lepton injector technology :

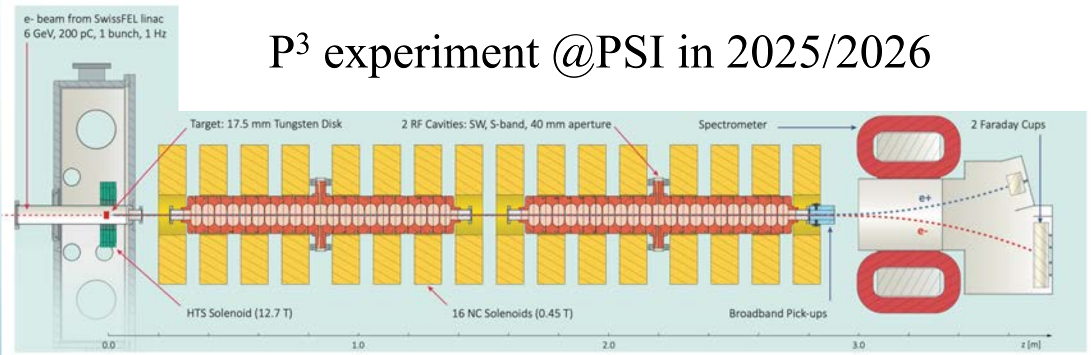
- **Novel types of e⁺ source** based on the hybrid scheme (channeling in crystals) with new granular targets.
- **e⁺ capture system** based on **SC solenoid** as the matching device for the capture system
- Use of the **Artificial Intelligence** (AI) for global **optimisation** of the e⁺ injector parameters

Design studies for the FCC-ee are ongoing and well advanced (input for the FCC mid term project review)

18.2 T @15K@2kA reached
for stack of 4 coils



PoP experiment for novel positron source (P³)



P³ experiment @PSI in 2025/2026

WP5 High-Intensity e^+ sources

Objectives

- **Objective 5.1:** Deep investigation of the positron source performances, with a focus on production target and capture systems suitable for applications in current and future accelerators. Approach the **e^+ production** rate **10^{15}-10^{16} e^+/second** requested by the future collider. Exploit Artificial Intelligence (**AI**) techniques for the start-to-end optimization studies of positron injectors.
- **Objective 5.2:** Participation in the **PoP e+ exper**iment in PSI (P^3).

Scientific issues

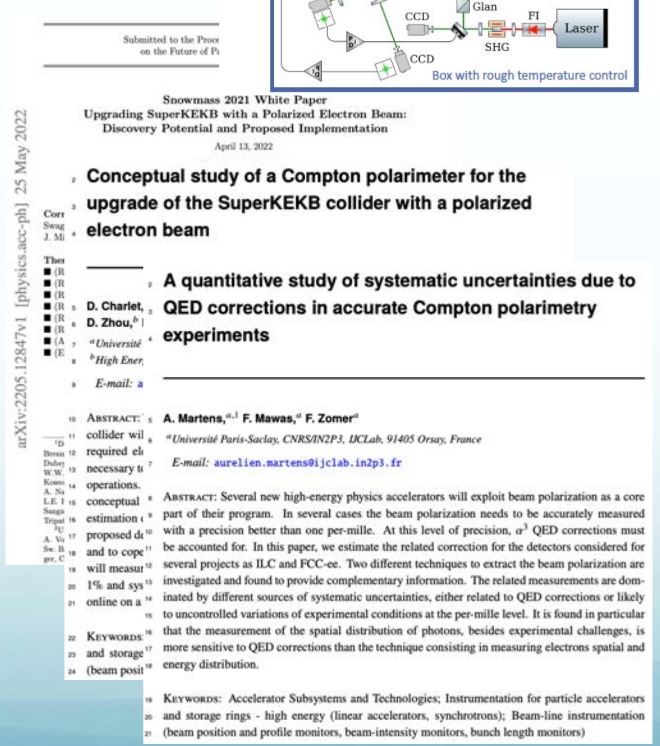
To optimize collision of polarized beams, **rapid measurements of polarization** are a key ingredient. **Accurate energy measurements** thanks to resonant depolarization is **critical for physics.**

➢ Compton polarimetry

R&D on:

- **Laser systems:** specific design for real time monitoring of the laser-beam polarization (unavoidable systematic uncertainty on longitudinal polarization); critical for ILC, FCC-ee; goal: per-mille accuracy.
- **Photon detectors:** design and development towards real time monitoring (funding requested to ANR for SuperKEKB); useful for EIC too.
- **Pixelized detectors:** conceptual design studies for FCC-ee

Recent highlights:
- Snowmass21 paper, https://arxiv.org/abs/2205.12847
- QED corrections for Compton polarimetry under review
- paper dedicated to Compton polarimeter design submitted


Snowmass 2021 White Paper
Upgrading SuperKEKB with a Polarized Electron Beam: Discovery Potential and Proposed Implementation
April 13, 2022

Conceptual study of a Compton polarimeter for the upgrade of the SuperKEKB collider with a polarized electron beam

A quantitative study of systematic uncertainties due to QED corrections in accurate Compton polarimetry experiments

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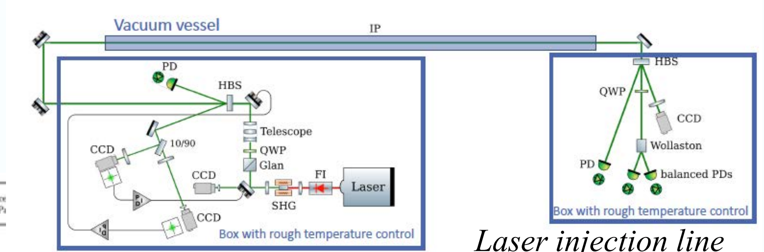
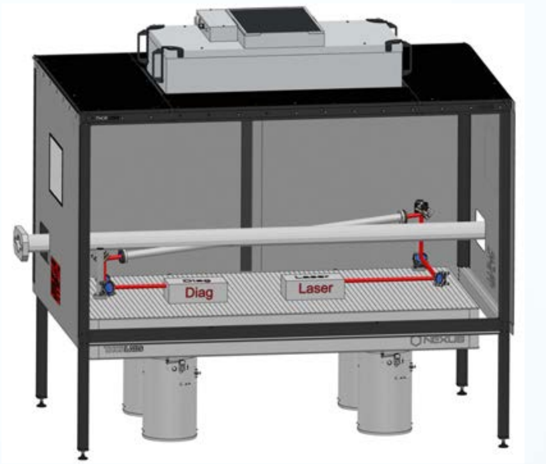
E-mail: aurelien.martens@ijclab.in2p3.fr

Abstract: Several new high-energy physics accelerators will exploit beam polarization as a core part of their program. In several cases the beam polarization needs to be accurately measured with a precision better than one per-mille. At this level of precision, α^3 QED corrections must be accounted for. In this paper, we estimate the related correction for the detectors considered for several projects as ILC and FCC-ee. Two different techniques to extract the beam polarization are investigated and found to provide complementary information. The related measurements are dominated by different sources of systematic uncertainties, either related to QED corrections or likely to uncontrolled variations of experimental conditions at the per-mille level. It is found in particular that the measurement of the spatial distribution of photons, besides experimental challenges, is more sensitive to QED corrections than the technique consisting in measuring electrons spatial and energy distribution.

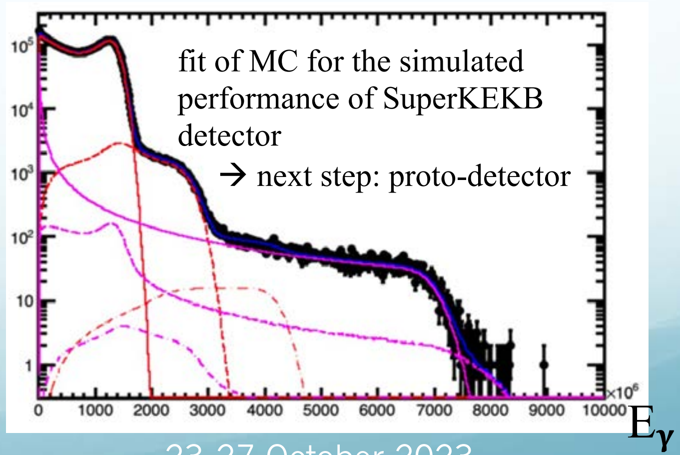
Keywords: Accelerator Subsystems and Technologies; Instrumentation for particle accelerators and storage rings - high energy (linear accelerators, synchrotrons); Beam-line instrumentation (beam position and profile monitors, beam-intensity monitors, bunch length monitors)



Laser injection line



Conceptual implementation for SuperKEKB



Objectives

- **Objective 6.1:** Design and optimization of **laser systems** for the **Compton polarimeters**, including the implementation and the laser beam transport for **SuperKEKB** and **ILC** and for resonant depolarization at **FCC-ee**. In particular for the ILC and FCC-ee to obtain the required **one** (or below for FCC-ee) **per-mille precision** on the determination of the **laser polarization** in the accelerator, in a reliable and reproducible way, which otherwise may become a limiting systematic uncertainty.

WP7 Dynamics Vacuum and Material studies

Scientific Issues

One of the main **potential limitation** in all future colliders is the **dynamic pressure**. Specifications of **vacuum systems** and vacuum studies, including **materials** are of paramount importance.

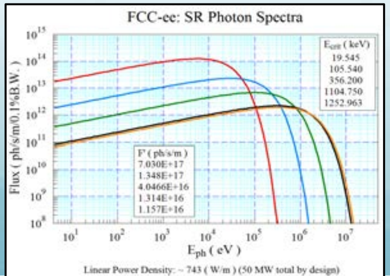
➢ Dynamics Vacuum and Materials studies

Experimental and **Simulation** studies on:

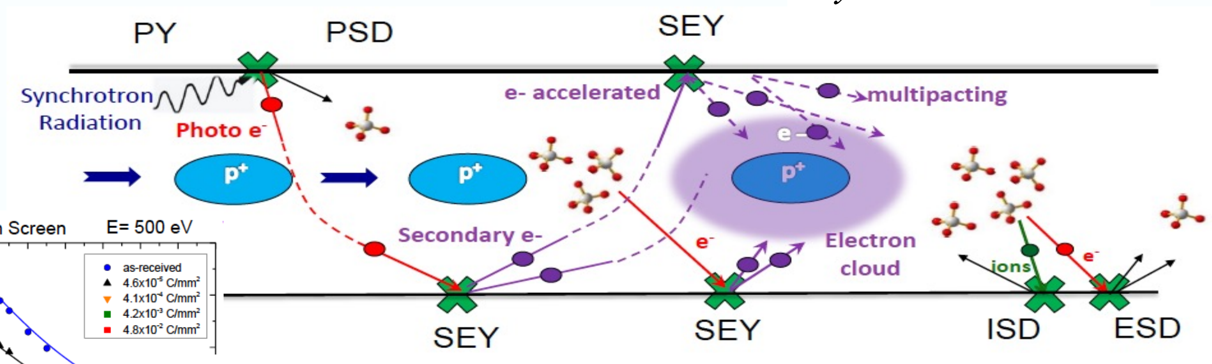
- Measurement of the **Secondary Emission Yield** (SEY) (multipacting)
- **Surface analysis** of materials
- In situ **measurements** of **pressure** and development of the **Dynamic pressure simulation** (DYVACS)
- **Ion Stimulated Desorption** (ISD) experimental studies at **yields of production for the conditioning surfaces** of FCC-ee
- **Electron Stimulated Desorption** (ESD) experimental measurement using the same electron energy as that of Compton electrons

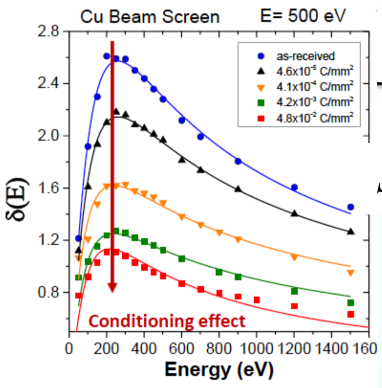
E=182 Gev

Energie critique ~ 1.2Mev !!!



Dynamics Vacuum

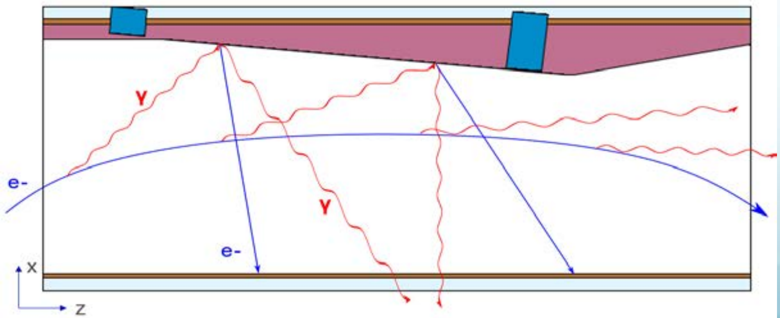




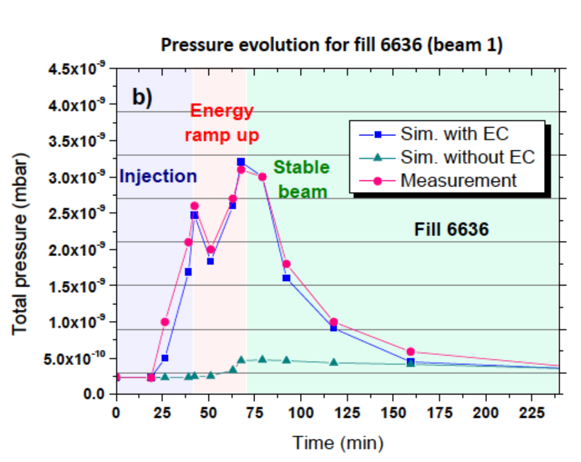
SEY measurements

LHC measurements versus DYVACs simulations

Compton scattering in a beam pipe



Compton scattering: photon collides with electron and is scattered into a different direction, dominant in the MeV range



WP7 Dynamics Vacuum and Material studies

Objectives

- **Objective 7.1**: Study and measurement of **SEY, ESD** and **ISD** for materials relevant for **FCC-ee** (low desorption yield, low SEY, fast conditioning, weak magnetic permeability, with a pumping action..)
- **Objective 7.2**: Development of the Dynamic pressure simulation (**DYVACS**) for **FCC-ee**

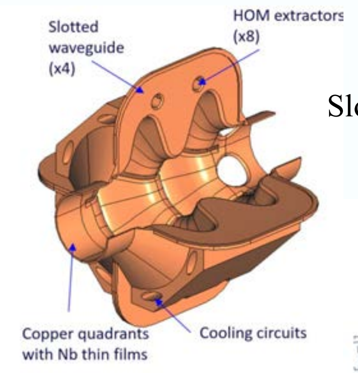
WP8 SRF multipacting and materials   Scientific Issues

Multipactor phenomena is triggered by the electromagnetic fields present in RF devices under vacuum such as SRF cavities. This phenomena is one of the potential limitation in in SRF cavities for future e^+e^- colliders.

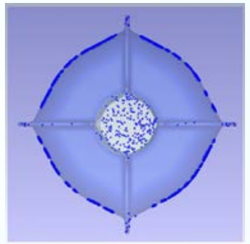
➢ SRF multipacting and materials

Further studies on :

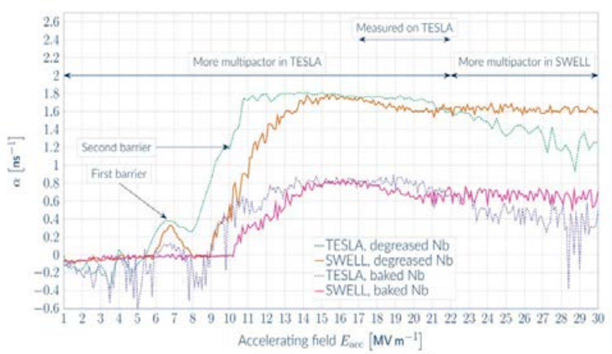
- **Multipacting modelling** n the **SRF SWELL** cavities prototypes for **FCC-ee** (locations, power ranges, level, SEY impact..)
- Participation into **cryogenic RF tests** of SRF **SWELL** at CERN to measure multipacting levels and conditioning capabilities
- Measurement of the **Secondary Emission Yield** (SEY) on samples representative of SWELL cavity surface (at room and cryogenic temperatures).
- Fundamental understandings of **frequency dependence** of the **SRF cavities**
- Study on **thermoelectric current** that degrades **SRF performance**



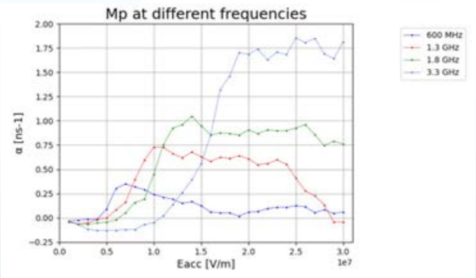
Slotted Waveguide Elliptical cavity (SWELL)

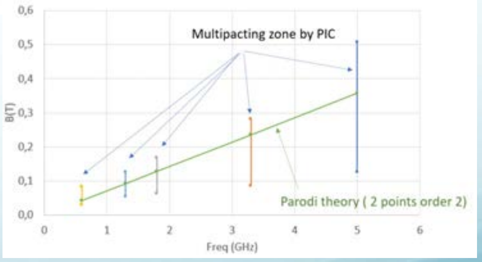


Multipactor locations



PIC simulations



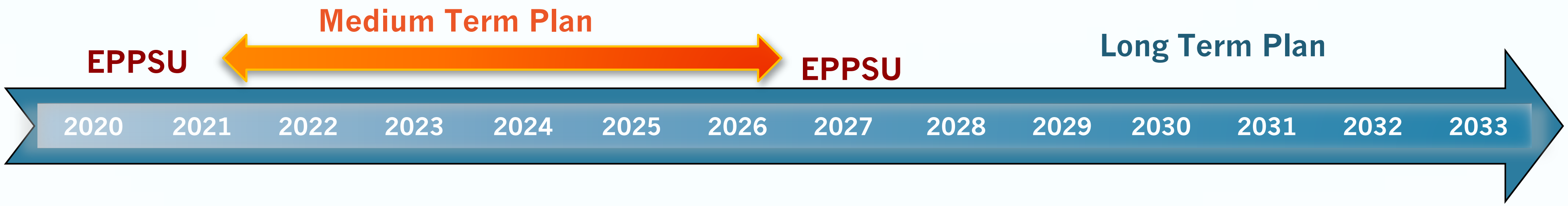


WP8 SRF multipacting and materials

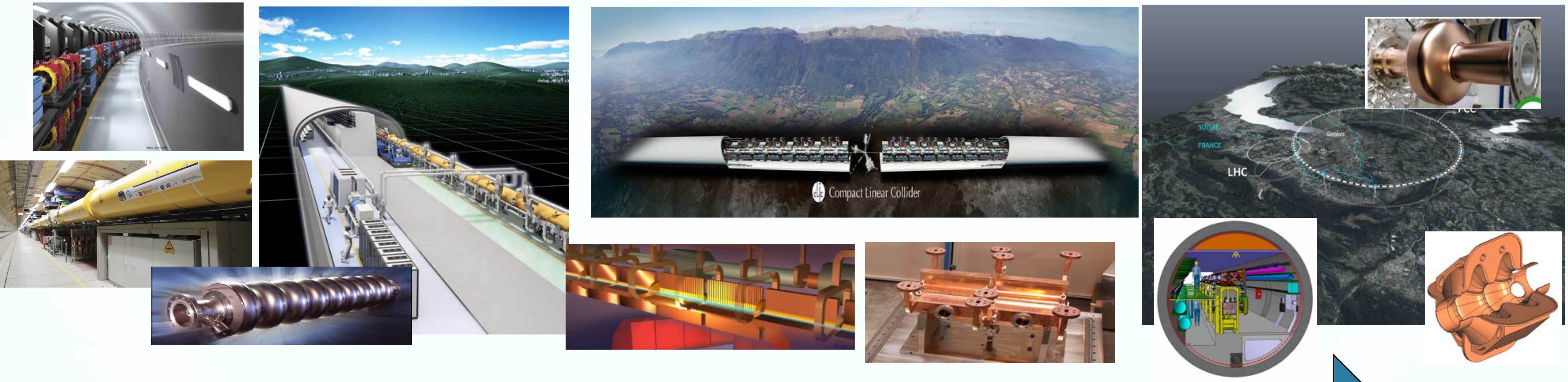
Objectives

- **Objective 8.1**: **Multipacting simulati**ons and **experimental benchmarking** of the SRF **SWELL** cavity prototypes for **FCC-ee**
- **Objective 8.2**: **SEY measurements** on samples representative of SRF **SWELL** cavity surfaces for **FCC-ee**
- **Objective 8.3 : Measurements on frequency dependence** of SRF surface resistance
- **Objective 8.4 : Simulation and analysis of thermoelectric current in bi-metal structure** of SRF cavities

FCC-NPC
R&D Teams evolution



PROJECTS R&D	Present	MT Future	
	B Factories	Higgs Factories	
	SuperKEKB	ILC/CLIC	FCC-ee
Nanobeams & IRs		X	X
Nanobeam stabilization & Monitoring	X	X	X
Luminosity & Backgrounds	X		
e+ sources		X	X
e+e- Polarimetry	X	X	X
Vacuum & Materials			X
SRF Cryo & Materials			X



Thanks for your attention