Journée annuelle de P2I 2024

Développements des accélérateurs pour la physique des particules

27 novembre 2024

Antoine CHANCE IRFU/DACM

Un grand merci à Angeles Faus-Golfe (IJCLab), Walid Kaabi (IJCLac), Jérôme Schwindling (CEA) et Daniel Schulte (CERN) pour leur précieuse aide.

Outline

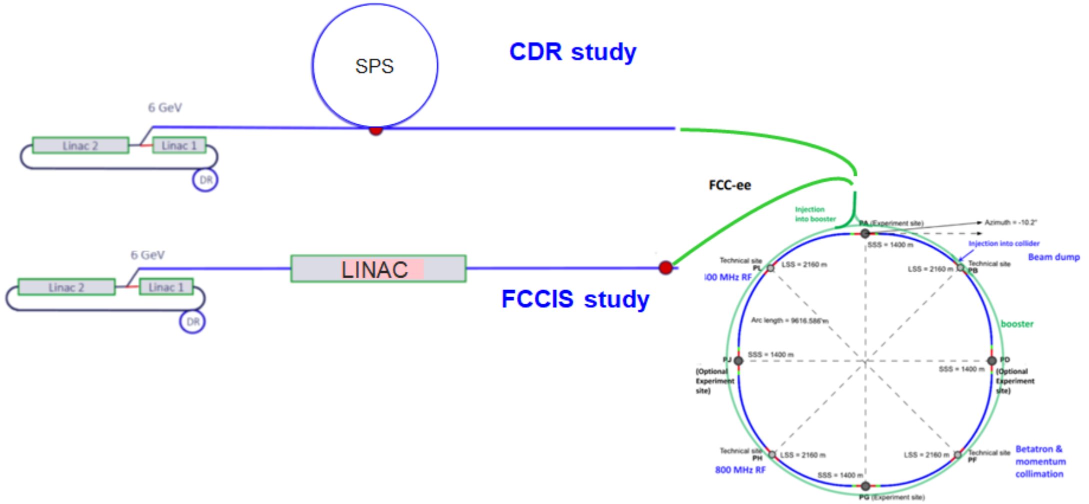
1. **For electron colliders: FCC-ee and ILC/CLIC**
2. **For electron-ion colliders: PERLE**
3. **For muon colliders**
4. **R&D for future colliders**

1. For electron colliders

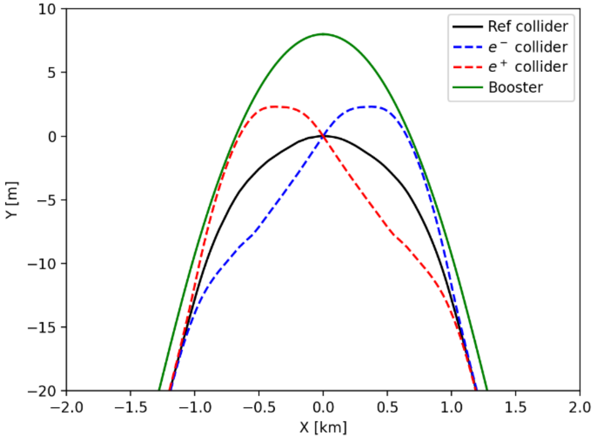
FCC-ee High Energy Booster

- European project H2020 **Future Circular Collider Innovation Study** (FCC-IS).

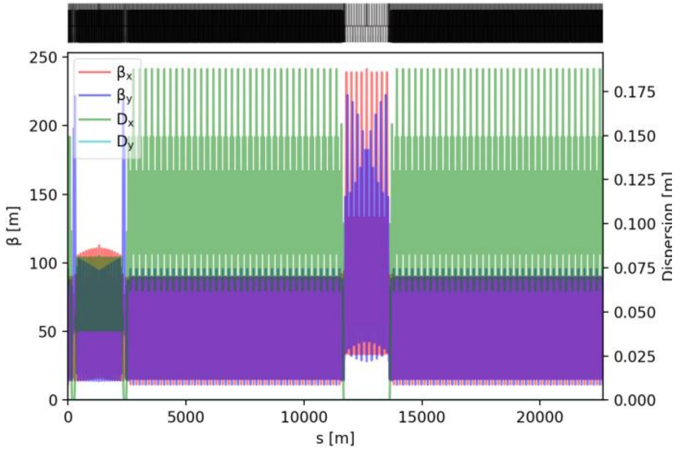
- **CEA in charge of booster task**.
- **Goal**: fukk desing of the booster to accelerate e-/e+ from 20 GeV to nominal colldier energy in the same tunnel of 91 km.



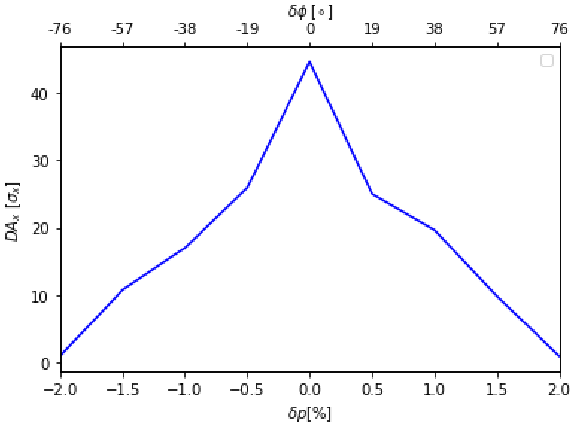
Footprint near experiment



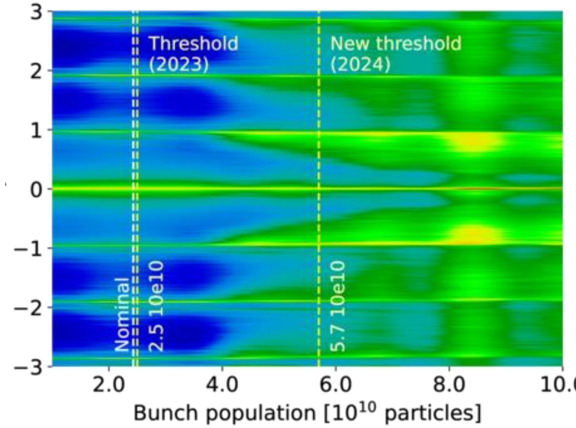
Optics of 1/4 of booster



Booster 6D Acceptance



Example of instability threshold for the Z mode E =20 GeV, σ_z =4 mm, Nb = 15880, Cu beam pipe (R=30 mm).



High-Intensity e+ sources

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 ~$6x10^{12}$ e+/s)

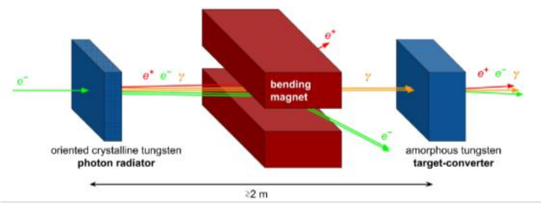
$$L = f_{coll} \frac{N_b^2}{4\pi\sqrt{\epsilon_x \beta_x^* \epsilon_y \beta_y^*}}$$

R&D beyond existing lepton injector technology

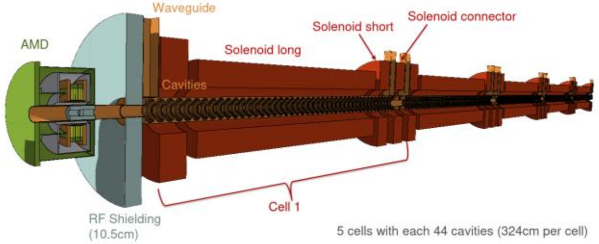
- **Novel types of e^+ source** based on the hybrid scheme (channeling in crystals) with new granular targets.
- **e^+ capture system** based on **SC solenoid** as the matching device for the capture system
- Use of the **Artificial Intelligence** (AI) for global **optimisation** of the e^+ injector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

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

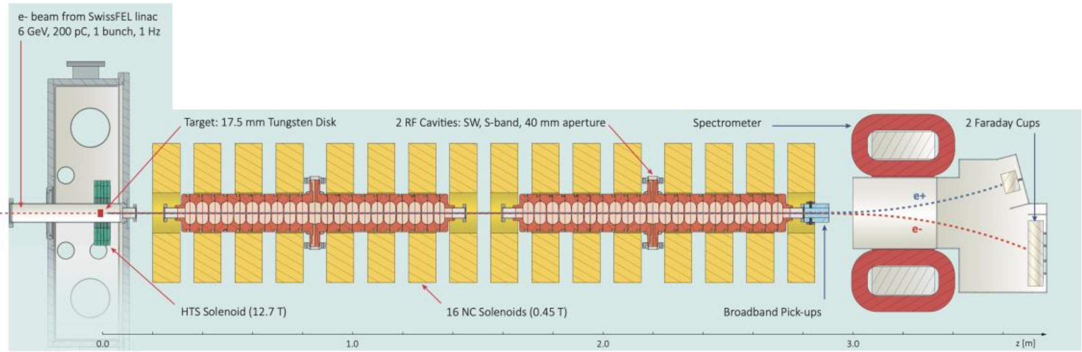
Crystal-based target Hybrid scheme



FCC-ee: Production + Capture System



PoP experiment for novel positron source (P³ à PSI)



Nanobeam size handling

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.

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

ILC/CLIC scaled FFS (Final Focus System)

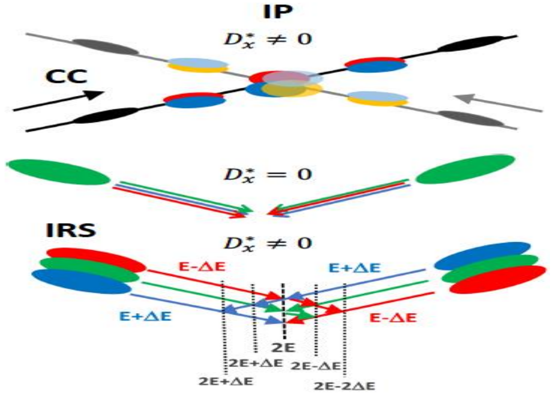
ATF/ATF2 FFS **has verified the minimal technical feasibility of ILC/CLIC-FFS**, to maximize the luminosity potential of ILC/CLIC a further investigation of:

- Intensity dependence effects on the IP size
- Optical aberrations specially with smaller β_x^*, design optics ($\beta_x^* \times \beta_y^*$)
- Smaller sizes ultra-low β* (CLIC)

Will be pursued in a follow-on upgraded facility "ATF3".

$$w = 2E_0 + 0(e)^2$$

Crossing angle monochromatization scheme featuring IP dispersion of opposite signs.



FCC-ee IR (Interaction Region) 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 and crossing angle (Crab Cavities)
- Optics design to generate antisymmetric D_x^* are needed to probe the feasibility of this kind of IR schemes.
- Experimental implementation studies

Realistic IR simulations:

- **Synchrotron Radiation** and Solenoidal detector fields impacts in MAD-X code.
- **Beam-Beam instabilities** studies, including more precise wakefield model and possible experimental studies.

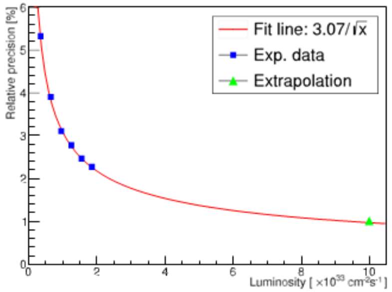
Luminosity and Backgrounds

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** 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 offsets.**
  - **Aberration correction** tuning procedure due to imperfections in the field quality and alignment.
  - **Luminosity optimization studies**, including mechanical vibration near the detector area

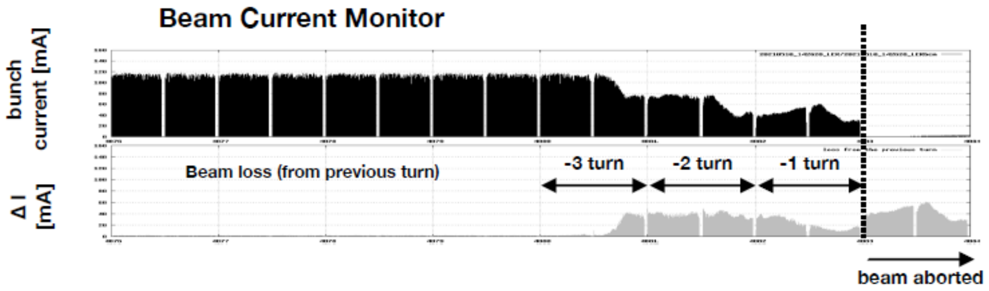
(1% precision at 1 kHz)



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

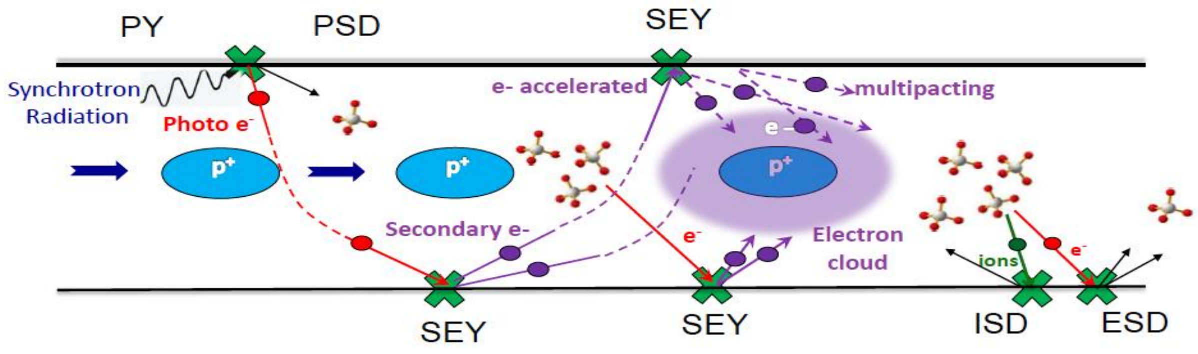


Dynamics Vacuum and Material studies

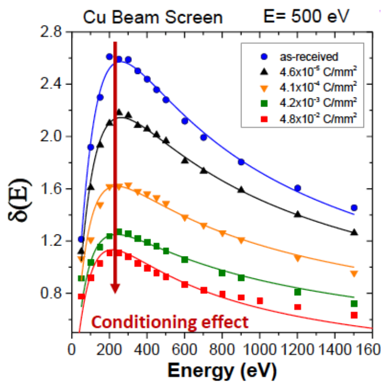
One of the main **potential limitation** in all future colliders is the **dynamic pressure**. Specifications of **vacuum systems** and vacuum studies, including **materials** are of paramount importance.

- **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

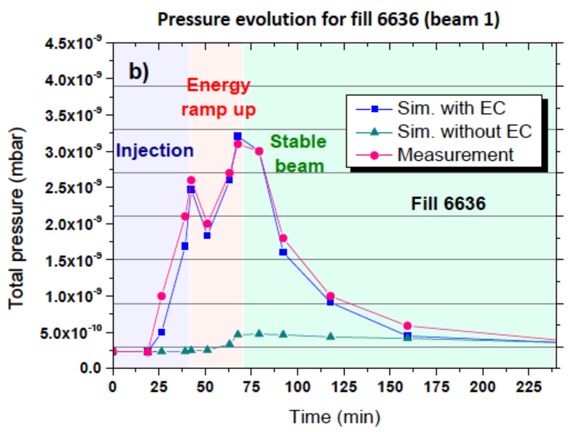
Dynamics Vacuum



SEY measurements



LHC measurements versus DYVACs simulations

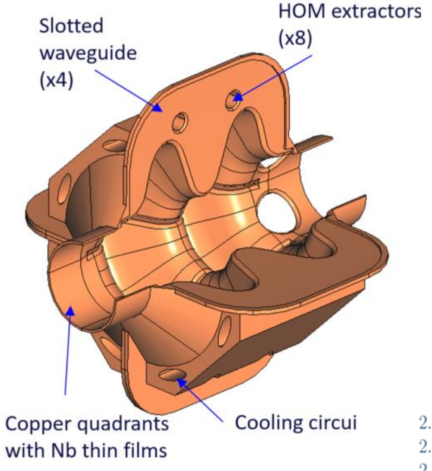


SRF multipacting and materials

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.

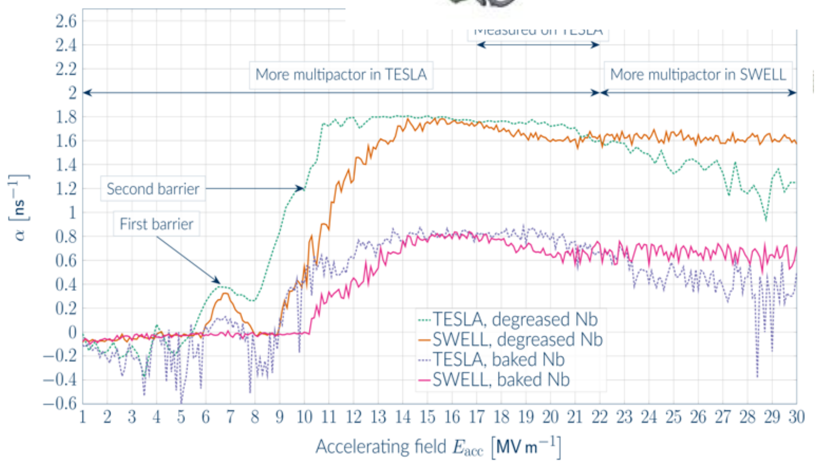
- **Multipacting modelling** in the **SRF SWELL** cavities prototypes for **FCC-ee** (locations, power ranges, level, SEY impact..)
- Participation into **cryogenic RF tests** of SRF **SWELL** at CERN to measure multipacting levels and conditioning capabilities
- Measurement of the **Secondary Emission 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)



SEY measurement set-up at cryogenic temperature @ IJCLab (2024)

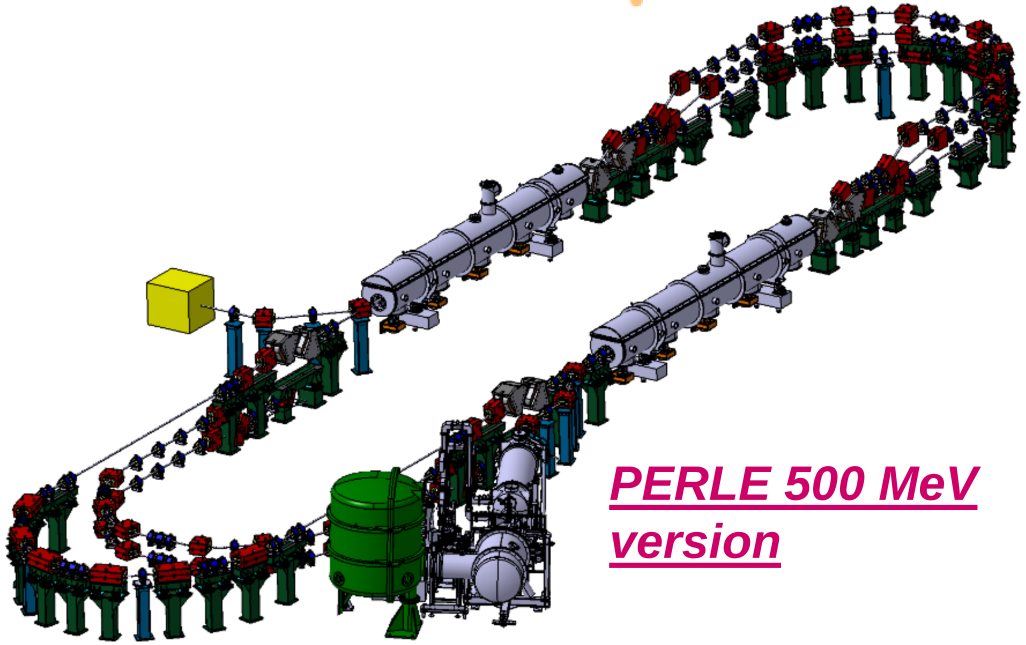
PIC simulations



2. PERLE

PERLE's Impact on ERL panorama

- Demonstrate multi-turn and high current operation → access to unexplored power regimes
- Validation of important technical choices:
  - High-charge electron gun: 500 pC at 40 MHz
  - Optimized 800 MHz SRF system: Maximise the efficiency
  - Common circulation arcs for accelerated and decelerated beams
  - Non-invasive diagnostics
- Host experiments of interest.



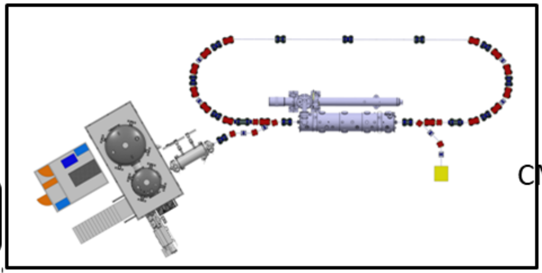
PERLE 500 MeV version

Target Parameter	Unit	Value
Injection energy	MeV	7
Electron beam energy	MeV	500
Normalised Emittance $\gamma\varepsilon_{x,y}$	mm mrad	6
Average beam current	mA	20
Bunch charge	pC	500
Bunch length	mm	3
Bunch spacing	ns	25
RF frequency	MHz	801.58
Duty factor		CW

PERLE Timeline (macroscopic view)

TDR and prototyping

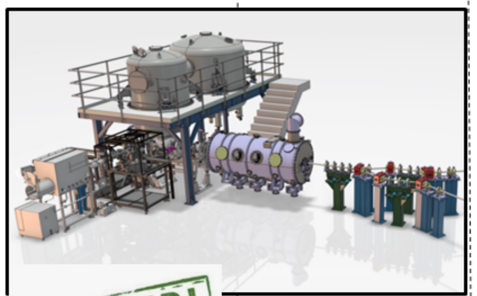
Phase 2: PERLE 1 tour



"Partially" FUNDED!

CM funded by EU Program iSAS
+ Matching funds (IN2P3)

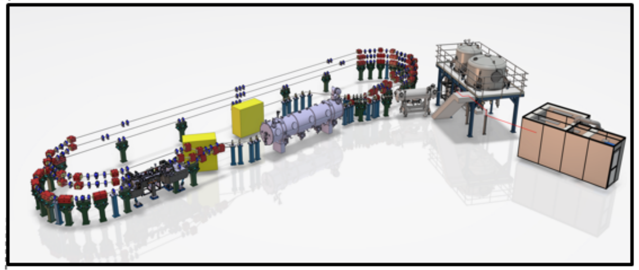
Phase 1: Injection line



FUNDED!

By CNRS National Program RI2

Phase 3: PERLE 250 MeV

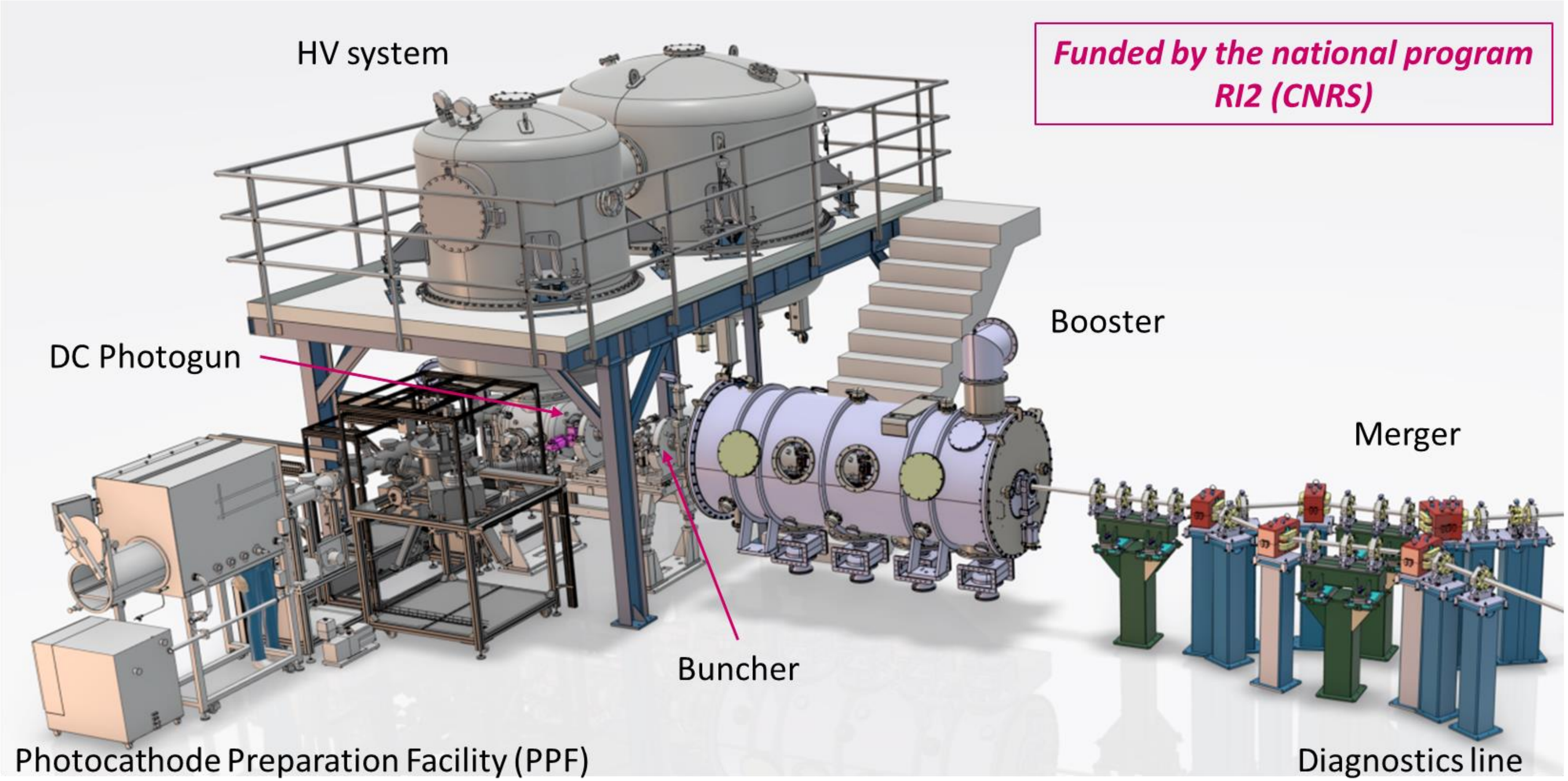


Extra funding needed for 6 arcs configuration

2022	2023	2024	2025	2026	2027	2028	2029	2030	2031

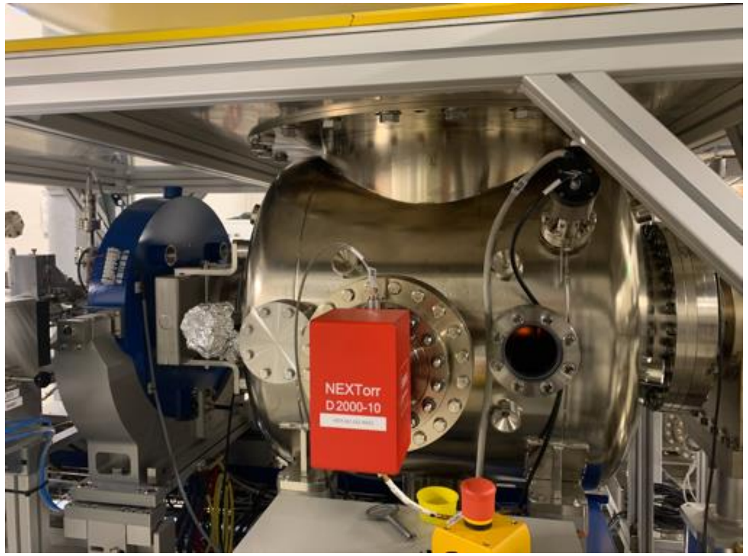
Phase 4: PERLE 500 MeV

The injection line



PERLE electron source

Within a Collaboration Agreement for photoinjector R&D between IJCLab (IN2P3) and Research Instruments GmbH (RI), Hardware of lighthouse project (terminated) transferred to IJCLab for PERLE. The gun was commissioned and tested at high rep rate, at a limited bunch charge. It includes:



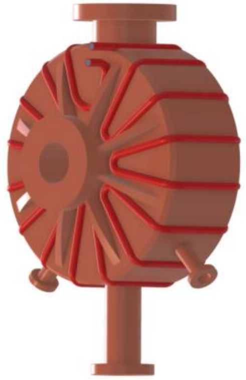
A DC Gun, Cornell design (400 pC, 50 MHz demonstrated), fully equipped (all pumps) in load-lock version

HV power supply suited for high bunch charge (designed for 40 mA, 450 kV)

A Photocathode Preparation Facility (PPF)

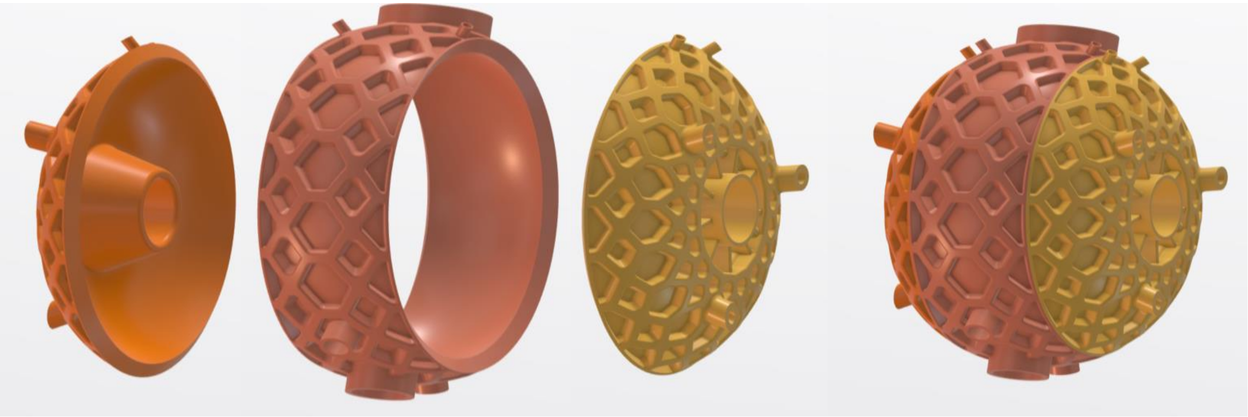
Additive manufacturing proposal for buncher cavity

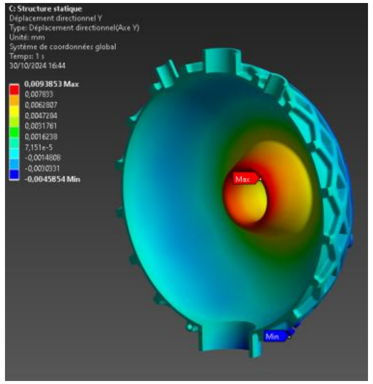
Traditional machining (23kg)

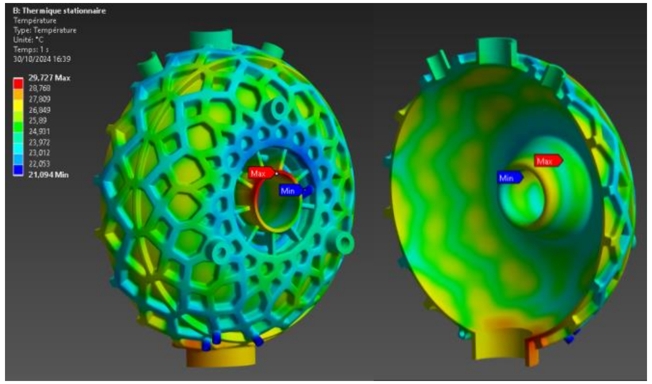


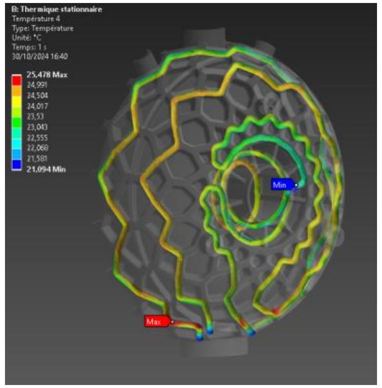
Additive machining (12kg)

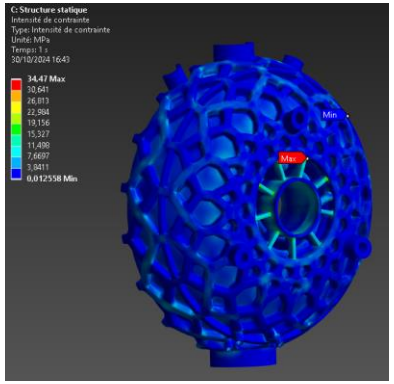
Honeycomb structure
Integration of the cooling circuit





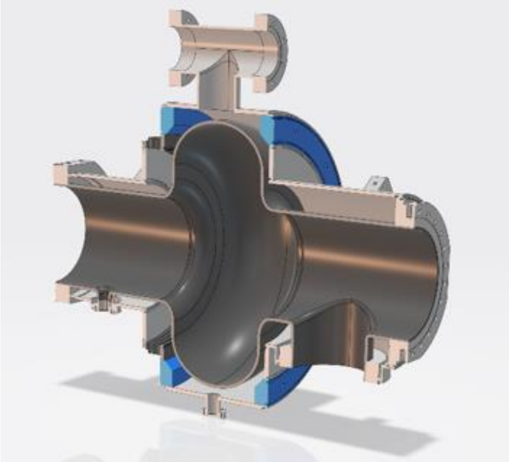


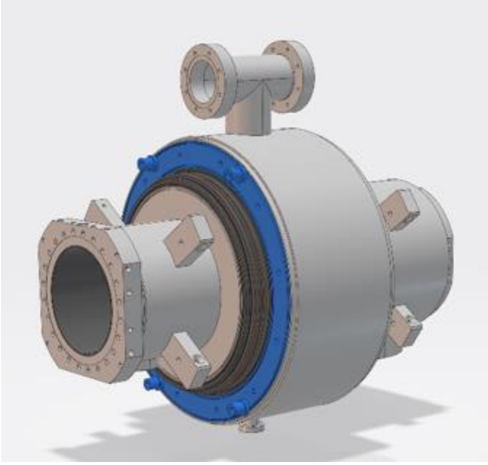


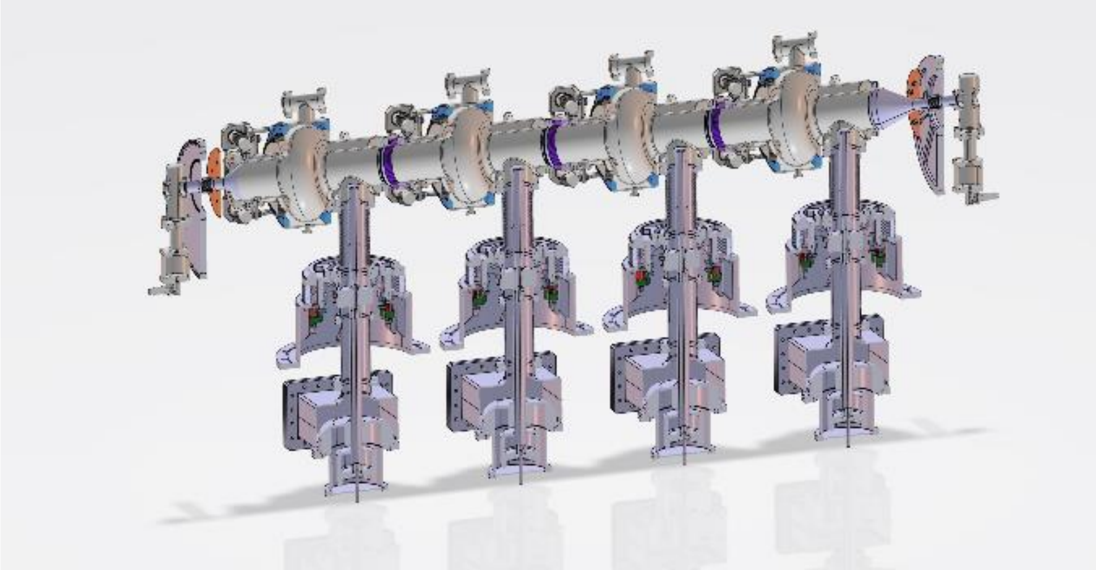


Booster single cell cavity

- The design has been standardized as much as possible w.r to the 5 cell cavity design:
  - RF design from the 5-cell cavity
  - Helium vessel made also of Titanium
  - Same flanges
  - Same coupler port aperture
  - Same bellows
  - Same tuning system
  - ... no HOM coupler ports!
- To be compatible with vertical cryostat configuration for testing at 2K
- Simulations & Injector design optimization studies were performed with different codes (OPAL and Astra)



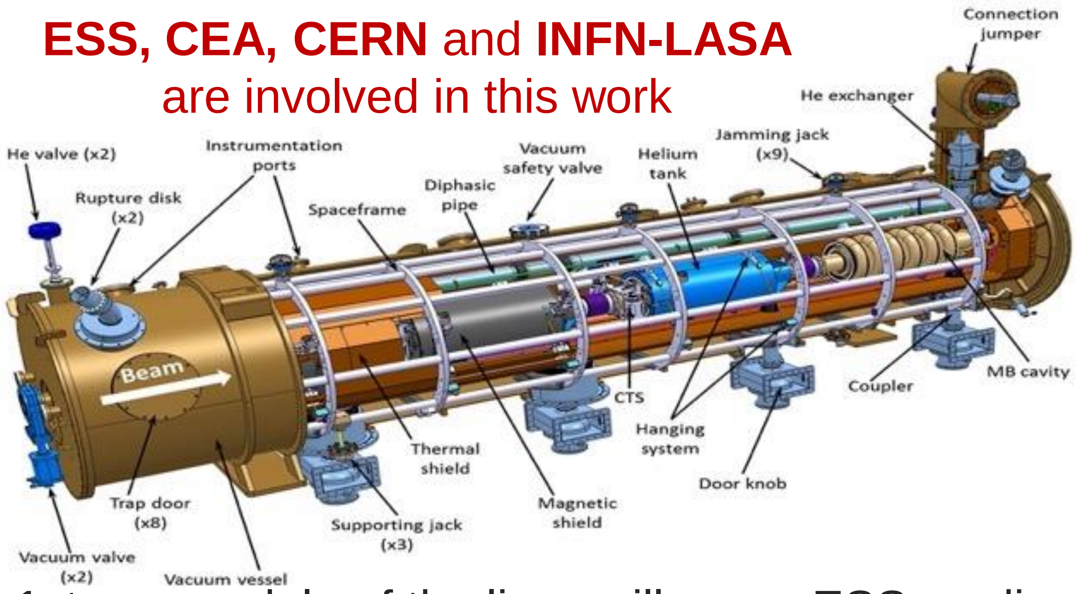


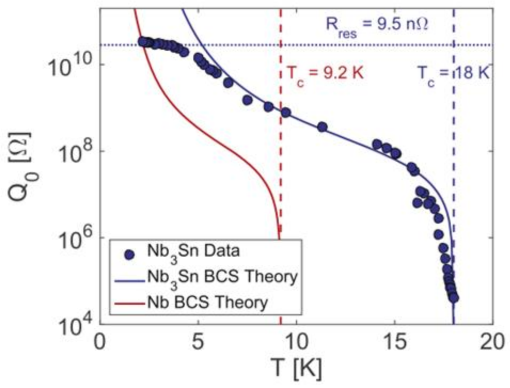


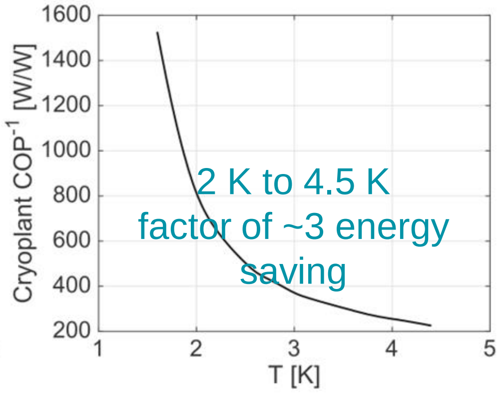
Linac cryomodule design

First cryomodule is adapted from ESS design and will be optimised for efficient high current ERL operation. It will integrate the RF systems (SRF Cavities, HOM couplers & absorbers, Fundamental Power Couplers) optimized and developed within the European project ISAS.

ESS, CEA, CERN and **INFN-LASA**
are involved in this work



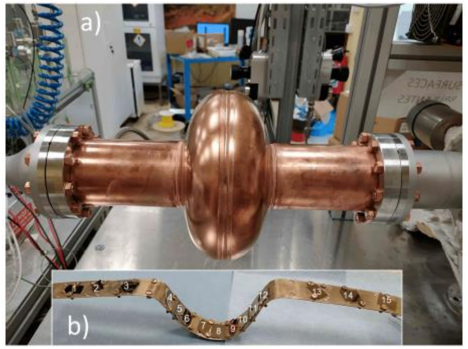




The 1st cryomodule of the linac will reuse ESS medium beta prototype components and will host new optimized components developed within the iSAS project

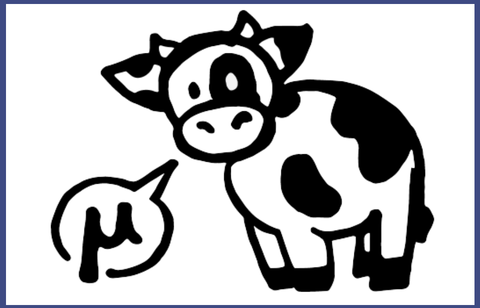
- Cavity string (SRF cavities, RF couplers, Tuning systems, Beam Line Absorbers, HOM couplers...)
- Magnetic shield
- Cryogenics circuit...

Objective = to gp from bulk Nb to Nb3Sn over Cu
Partnairs: INFN, HZB, CEA, UKRI
Expertise Paris-Saclay on thin layer technology and mechanical characterization



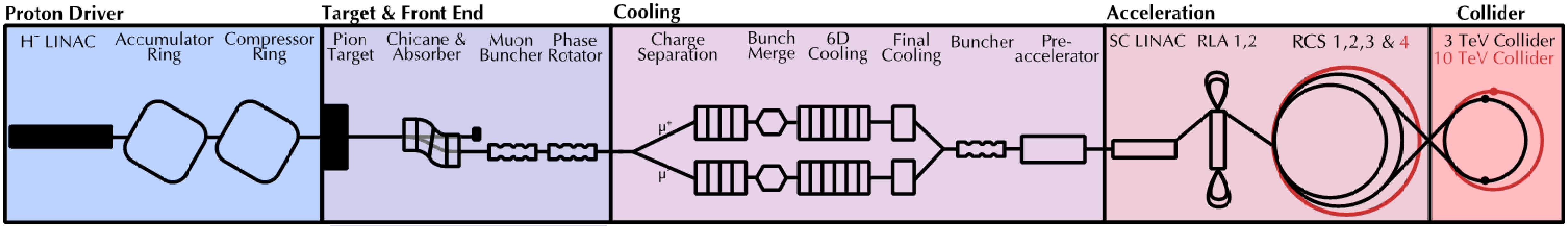
Bancs de dépôts ALD sur cavités et échantillons

3. Muon colliders



Based on MAP
Muon Accelerator Program (2011-2018)

Would be "easy" if the muons did not decay
Lifetime is $\tau = \gamma \times 2.2\ \mu s$ (e.g. 3100 turns in collider ring)



Short, intense proton bunch

Protons produce pions which decay into muons which are captured

Ionisation cooling of muon in matter

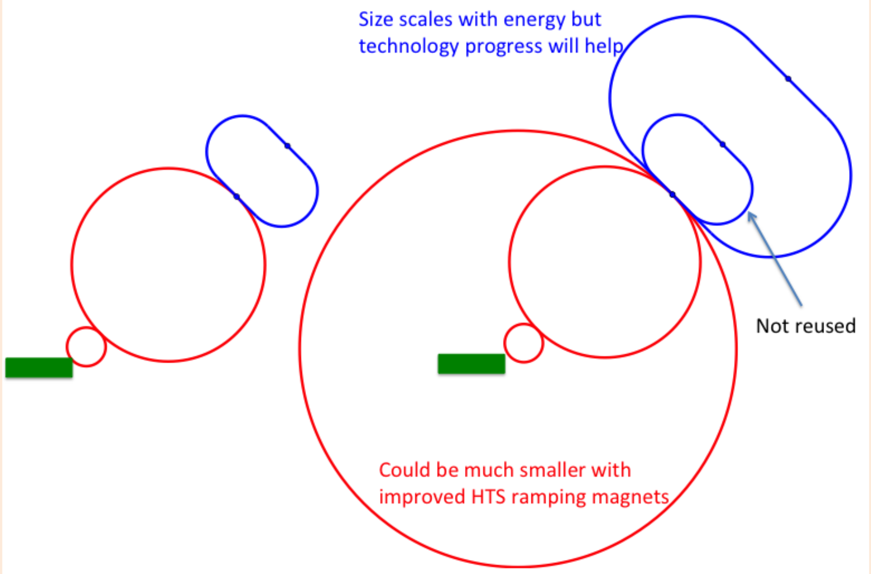
Acceleration to collision energy

Collision

Staging

Expect to be ready for implementation in 15 years

- **Detector**
- **Muon cooling technology**
- **HTS solenoid technology**
- **Nb_3Sn dipoles** for collider ring, maybe lower field HTS
- High field HTS dipoles for collider ring are likely later



Energy staging

- Current 3 TeV, design takes lower performance into account
- Cost split over two stages, little increase in integrated cost

Luminosity staging

- Longer collider ring arcs and less performant interaction region lead to less luminosity in first stage
- Can later upgrade interaction region (as in HL-LHC)
- Full cost at first stage

Parameter	Unit	3 TeV	10 TeV	10 TeV	10 TeV
L	10^{34} $cm^{-2}s^{-1}$	1.8	20	tbd	13
N	10^{12}	2.2	1.8	1.8	1.8
f_r	Hz	5	5	5	5
P_{beam}	MW	5.3	14.4	14.4	14.4
C	km	4.5	10	15	15
<B>	T	7	10.5	7	7

Key Challenges

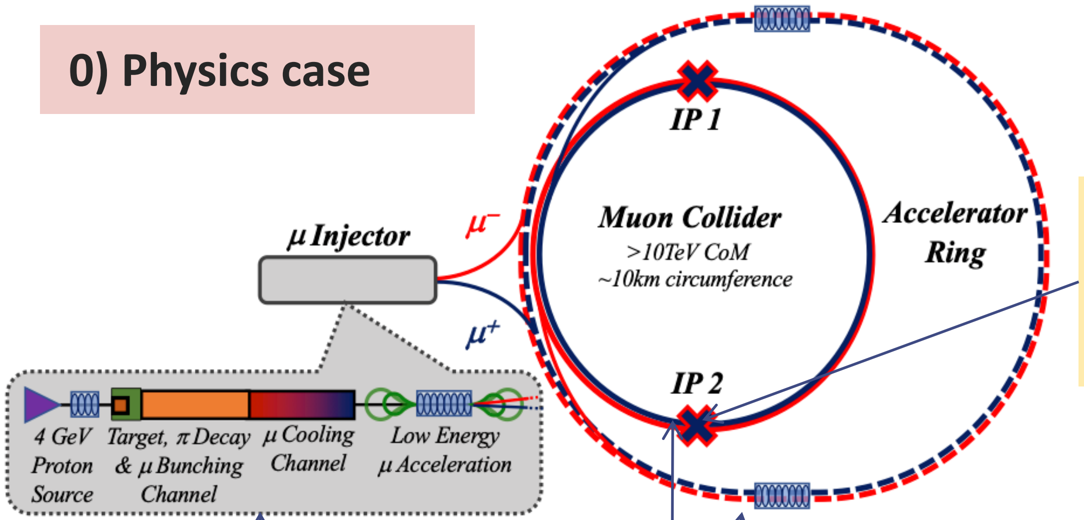
Environmental impact
- Neutrino flux mitigation
- Power, cost, CO_2, …

Key technologies for timeline
- **Magnet technology**
- **Muon cooling technology**
- **Detector**

Other technologies are instrumental for performance, cost, power consumption and risk mitigation
- Accelerator physics, cryogenics, superconducting cavities, ….

Other important timeline considerations are
- Civil engineering
- Decision making

0) Physics case



2) Beam-induced background

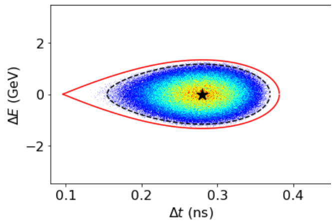
4) Muon production and cooling drives the **beam quality**
MAP put much effort in design
optimise as much as possible

1) Dense neutrino flux mitigated by mover system and **site selection**

3) Cost and **power** consumption limit energy reach
e.g. 35 km accelerator for 10 TeV, 10 km collider ring
Also impacts **beam quality**

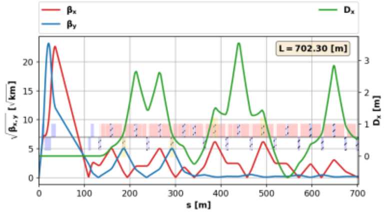
Facility Design

Good progress in the different system designs
- Proton complex, muon production and cooling, acceleration and collider ring, collective effects, …



Preliminary design of **cooling chain** advanced
- 24 to 30 um transverse emittance
- Goal 22.5 um, MAP achieved 55 um

Collider ring lattice design
- Achieve beta-function
- Need to improve energy acceptance (2-3 x)



Subsystem	Energy	Length	Achieved Transm.	Achieved μ^-/bunch	Target μ^-/bunch
	GeV	m	%	10^{12}	10^{12}
Proton Driver	5 (p^+)	1500	–	500 (p^+)	
Front End	0.17	150	9	45.0	
Charge Sep.	0.17	12	95	42.8	
Rectilinear A	0.14	363	50	21.4	
Bunch Merge	0.12	134	78	16.7	
Rectilinear B	0.14	424	32	5.3	
Final Cooling	0.005	100	60	3.2	
Pre-Acc.	0.25	140	86	2.8	4.0
Low-Energy Acc.	5	–	*90**	2.5	
RLA2	62.5	∘2430	90	2.3	
RCS1	314	∘5990	90	2.1	
RCS2	750	∘5990	90	1.9	
RCS3	1500	∘10700	90	1.7	
3 TeV Collider	1500	∘4500	–	1.7	2.2
RCS4	5000	∘35000	90	1.5	
10 TeV Collider	5000	∘10000	–	1.5	1.8

Preliminary **muon transmission** estimate
- 1.5 x 10^{12} muons at IP (goal 1.8 x 10^{12})
- Cooling transmission below target
- High-energy complex is above (would like to reduce for cost)

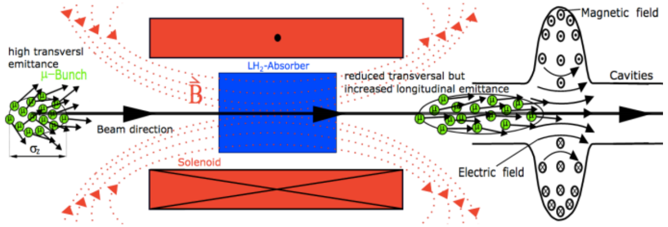
Need resources to improve system design

Will study higher power target (graphite or liquid metal)

Time to **increase design effort** to cover and integrate all systems (“**start-to-end simulation**”), improve codes, performances and consider alternatives

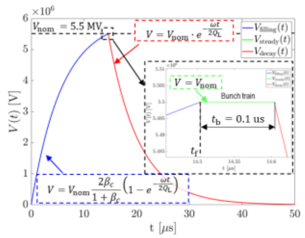
Muon Production and Cooling

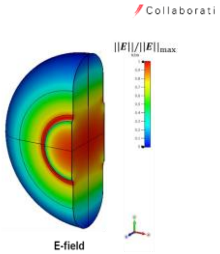
Muon cooling technology and **demonstrator**
- Most integrated technology
- Operational demonstrator in O(10 years), with enough resources
- Allows to perform final optimization of cooling technology



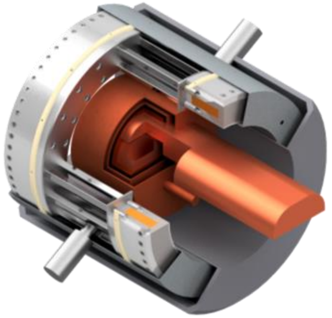
Very bright muon beam challenges **absorbers** and **windows**
- First tests of absorber windows performed

Strong theoretical and experimental programme required



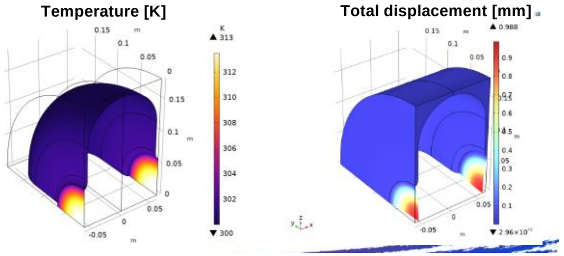


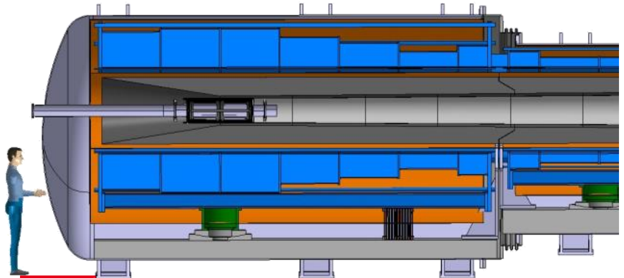
Engineering **module design** started
Including solenoid



Contribution of CEA

RF design ongoing



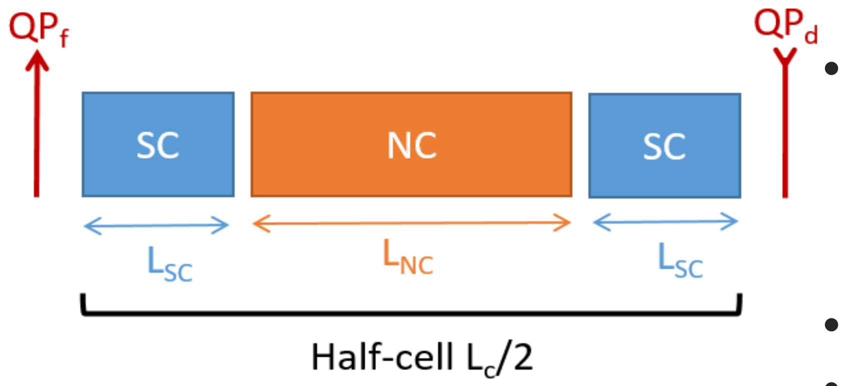


2 MW graphite target looks very promising
- Some work on windows remains

Will study alterative higher power (4 MW) target
- Graphite, liquid metal, fluidized tungsten

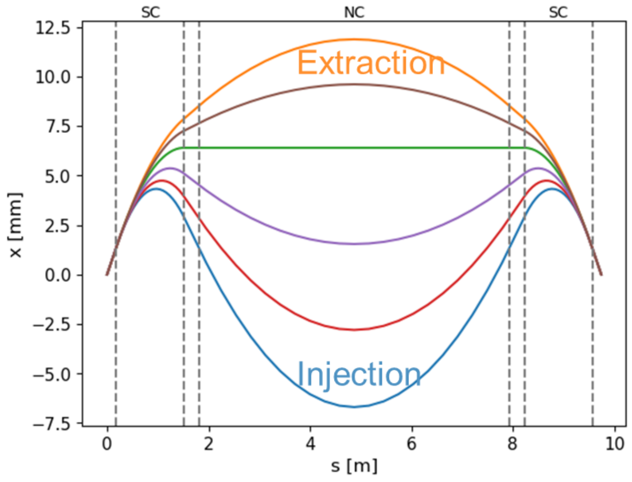
Ready to **widen effort**, in particular beam dynamics, prototyping and experimental work

Fast muon acceleration

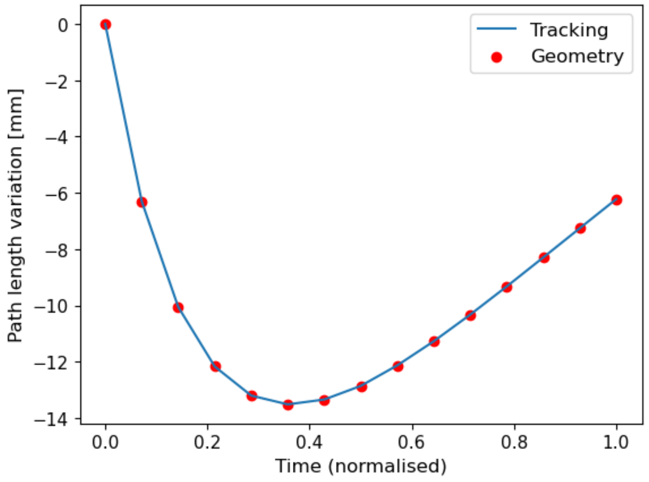


- Hybrid Synchrotron (**never operated configuration**):
  - Static SC magnets → High mean field → comâct synchrotron
  - Pulsed magnets → fast acceleration
- Very large cavity number: voltages above 10 GV.
- Challenge: accelerate **in a few milliseconds** muons with efficent way and keeping beam quality.

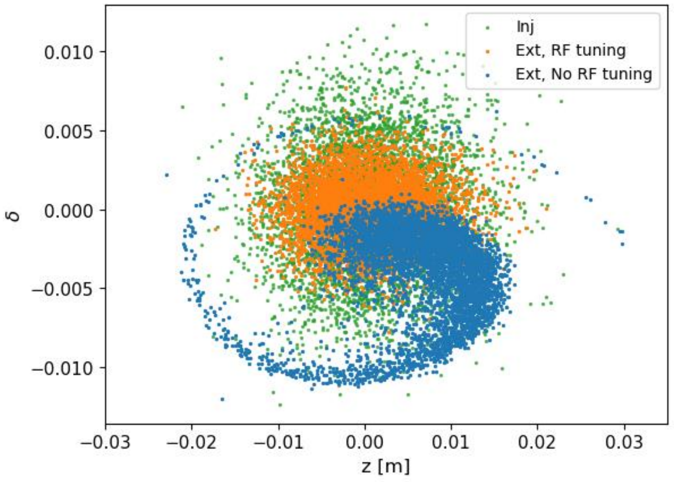
Trajectories from injection to extraction



Path length variation



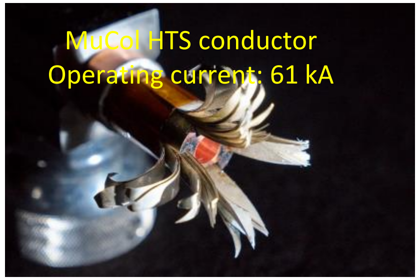
Longitudinal Transport

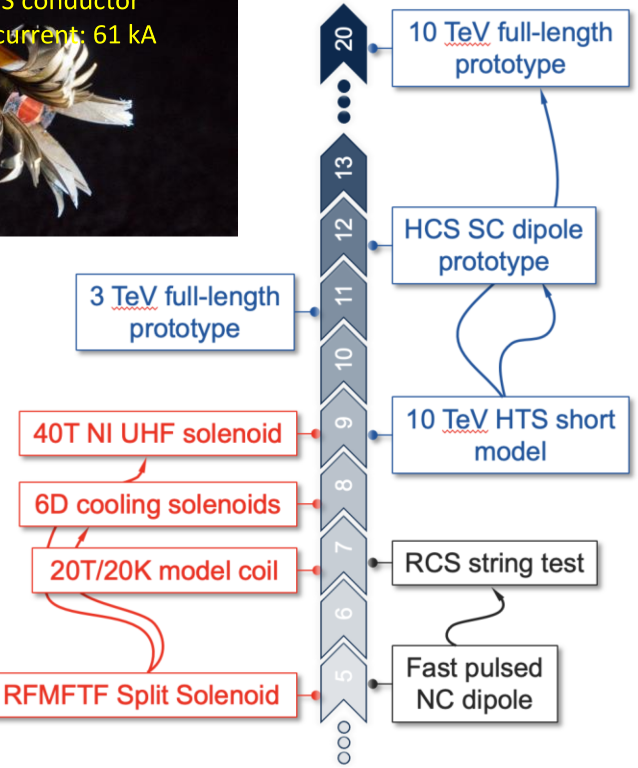


Magnets

Systematic **dipole performance prediction** for **LTS** and **HTS**
- Aperture, field, cost, stress, loadline, protection, …

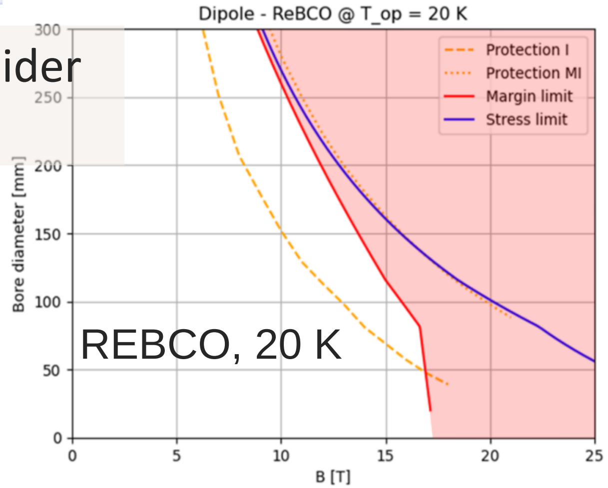
HTS solenoid designs (6D cooling, final cooling, target)
Normal-conducting **fast-pulsed dipoles** (HTS as alternative)
Technical timeline



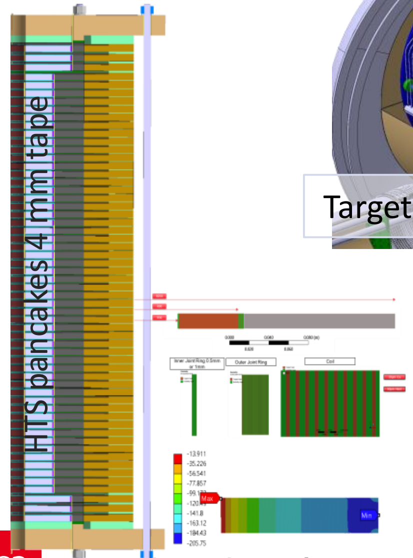


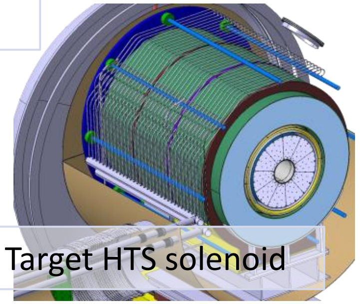
First **HTS winding tests**

Will slightly adjust collider ring field for cost



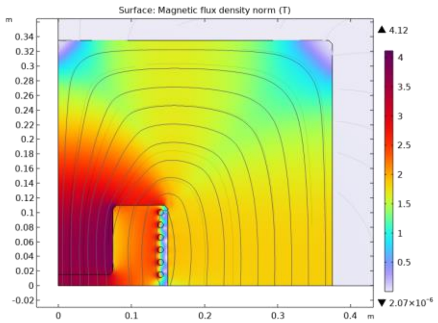
HTS final cooling solenoid mechanical design





Target HTS solenoid

Normal-conducting RCS **pulsed magnets**



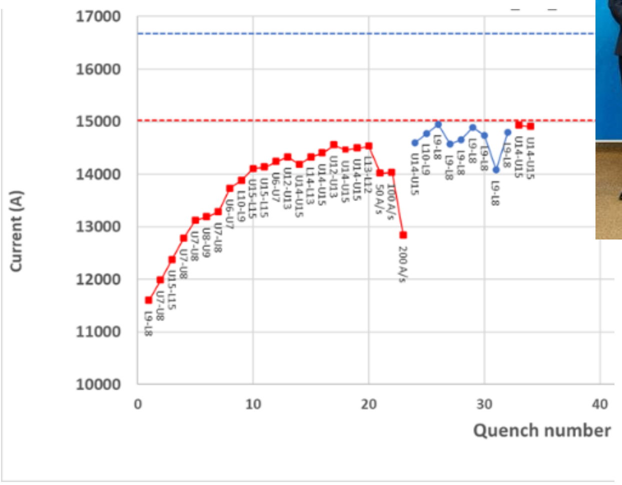
Opportunity to **ramp up** effort
- Engineering designs
- Tests of cables, building models, …

With sufficient resources **HTS solenoids** and **Nb_3Sn dipoles** could be **ready for decision in 10-15 years**
HTS dipoles likely take longer

4. R&D

Magnets Programme Nb3Sn 16 T

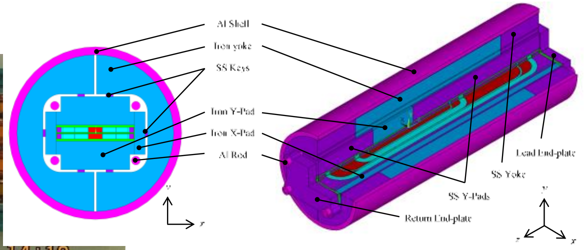
- Short coil SMC (=Short Model Coil)
  - 2 model coils built in CEA
  - Tested at CERN
  - **Reached 95% and 99% of estimated limit !**



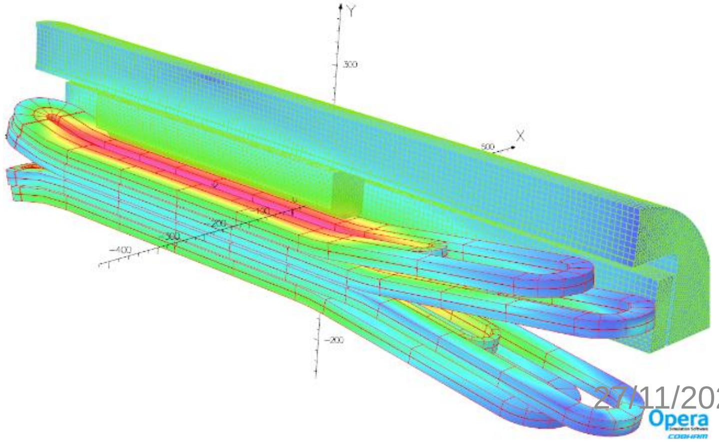
Signature in April 2023 of a new agreement CERN – CEA for 5 years

- Magnet project R2D2
  - Demonstrator magnet of 12 T
  - First coils Nb3Sn ongoing
  - Magnet assembly scheduled mid-2025

R2D2



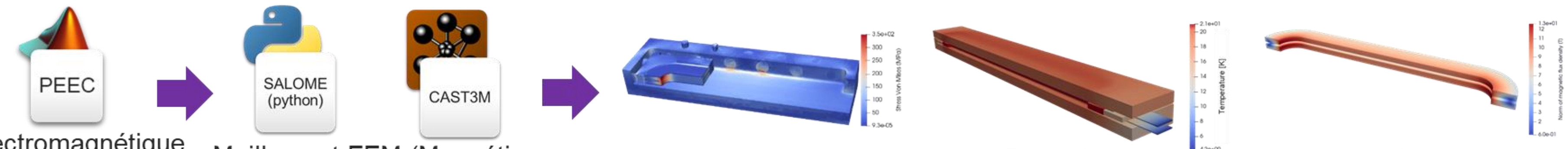
- Future magnet project F2D2
  - Short model of 16 T, aperture of 50 mm
  - Concept model approved,
  - Start of the detailed design



Magnet developpement HTc REBCO 16 T+

Signature en mai 2023 d'un nouvel accord CERN – CEA pour 2 ans

- Racetrack modelisation and multi-racetrack « Metal Insulated » (MI)



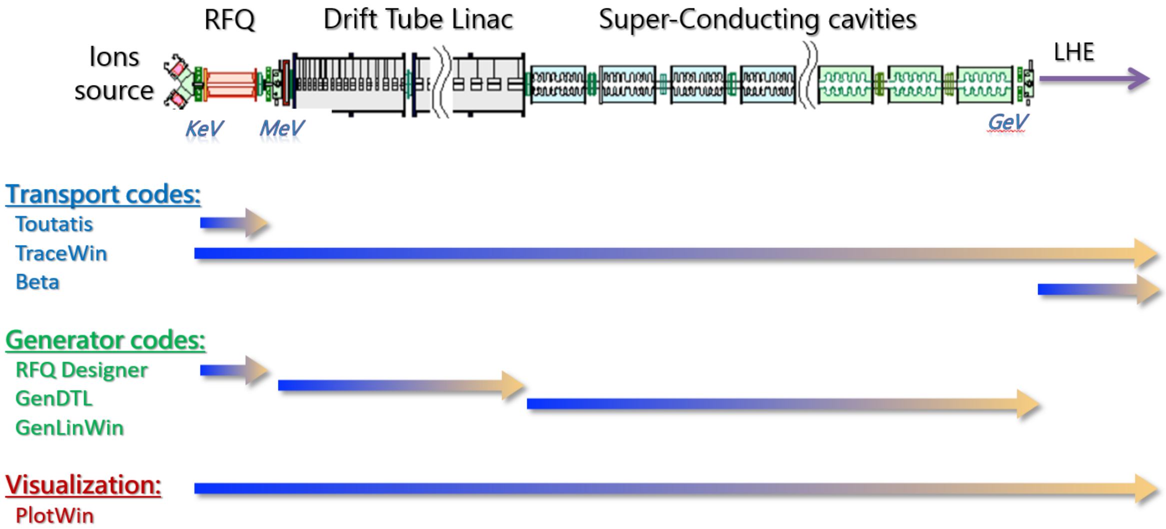
Electromagnétique + Thermique — Maillage et FEM (Magnétique, thermique, mécanique) — Mécanique — Thermique — Magnétique

- Prototyping project multi-racetracks (no aperture)
  - Racetrack MI (length 600 mm)
  - Assembly of 2 to 4 racetracks
  - Inductance > 6 T
  - Design of tooling and structure ongoing
- Magnet EuCARD2 cosθ (cable Roebel REBCO)
  - SCB03 issues during tests in 2022
  - New assembly SMB02 (SCB01 and SCB02) ongoing
  - Tests at CERN in 2025

Bobineuse HTS - Building 392

Simulation codes: more than 1000 licences sold

https://irfu.cea.fr/Phocea/Vie_des_labos/Ast/ast.php?t=fait_marquant&id_ast=5281



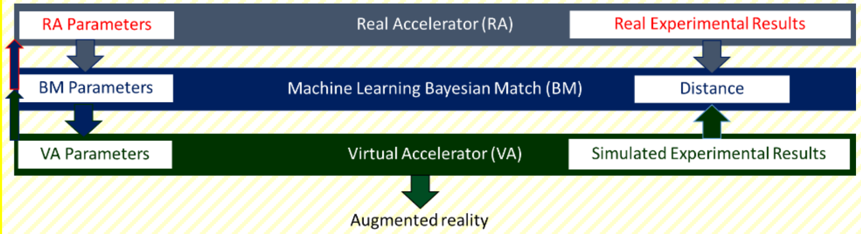
Domaine d'application des logiciels en fonction des différentes parties d'un accélérateur linéaire typique

Cartes de répartition des codes de simulation du DACM : en bleu, les codes actuellement utilisés, et en rouge, ceux ayant été utilisés. La représentation inclut 92 laboratoires scientifiques et 30 entreprises privées répartis dans 30 pays

Artificial Intelligence

Operation

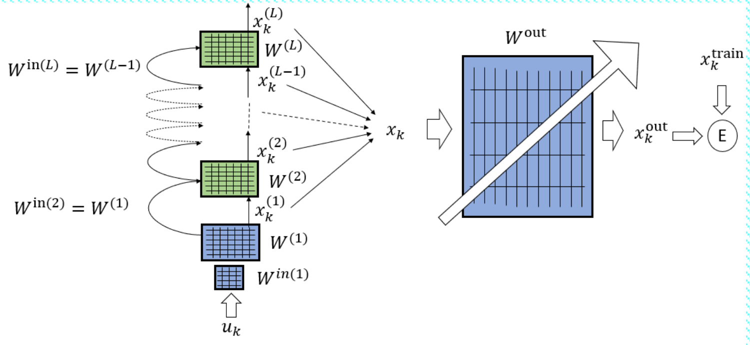
Improvement of an accelerator « digital twin » using Machine learning Bayesian inference methods



Machine operated by a Digital Twin

Modeling

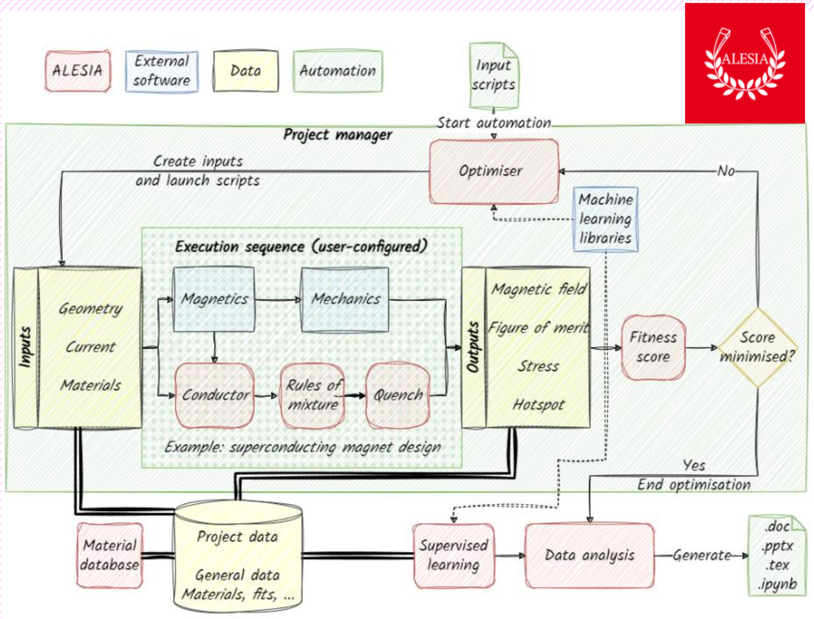
Optimization of optics design and beam measurements of present and future accelerators



- ESN for DA prediction, M. Casanova, B.Dalena et al. , Eur. Phys. J. Plus (2023) **138**: 559

Technology

Superconducting magnet design through multi-physics optimization



- Participation in **M4CAST** (French network of AI for Accelerators)
- Contribution to **InTheArt** seminars (DRF/CNRS network on transverse applications of AI)

Merci

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France

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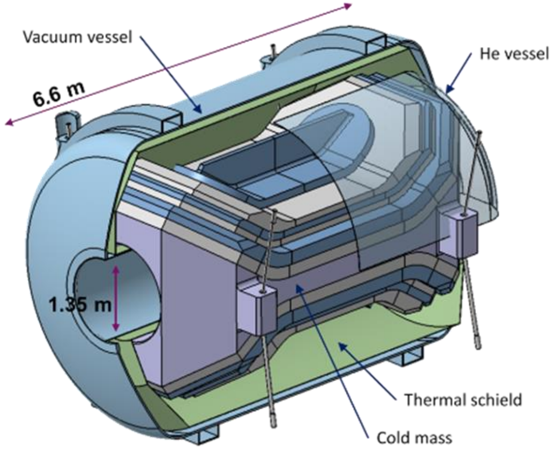
Phone: +33 1 69 08 17 19

Bibliography

- “R&D on FCC and Future colliders at IN2P3” de Angeles Faus-Golfe à CEPC2024, 23-27 octobre 2024
- “PERLE Status and Plans” de Walid Kaabi à ERL 24 Workshop
- “Muon Collider Progress” de Daniel Schulte à PECFA, Novembre 2024
- « Développements Accélérateurs au CEA » de Jérôme Schwindling à Rencontres Accélérateurs de la SFP 2024

De la station d'essais JT-60SA-CTF à la nouvelle station MATTRICS
(MAgnet Technology Testing Research InfrastruCtureS)

Cryostat MATTRICS : 12 x 7 x 1,8 m



10 T NbTi coils

Objectif :

Préparer les tests futurs:

- le détecteur MADMAX (« *very large-scale dipole for dark matter experiment* »)
  - Conception en cours du Démonstrateur MACUMBA
- La faisabilité de démonstrateurs avec des aimants à haute température (HTS) PEPR Suprafusion

Scientific Highlights

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.**

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

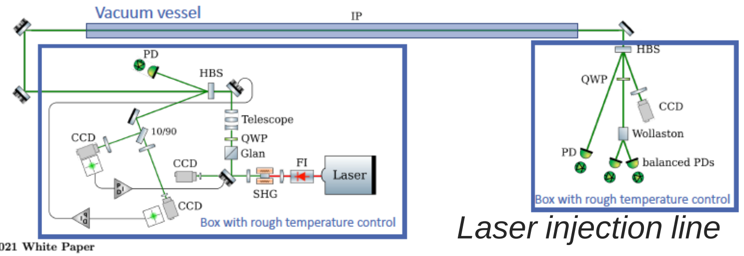
➢ Compton polarimetry

R&D on:

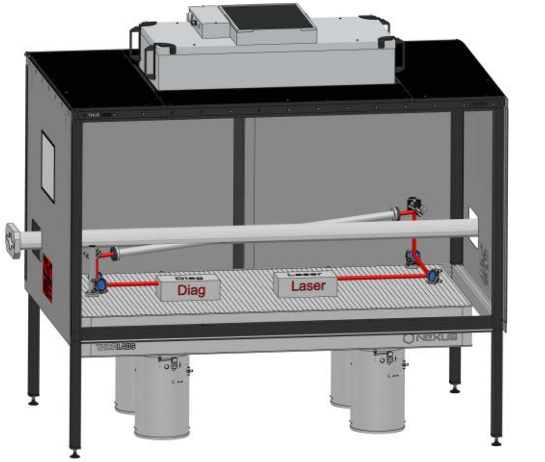
Laser systems: specific design for real time monitoring of the laser-beam polarization (unavoidable systematic uncertainty on longitudinal polarization); critical for ILC, FCC-ee; goal: per-mille accuracy.

Photon detectors: design and development towards real time monitoring (funding requested to ANR for SuperKEKB); useful for EIC too.

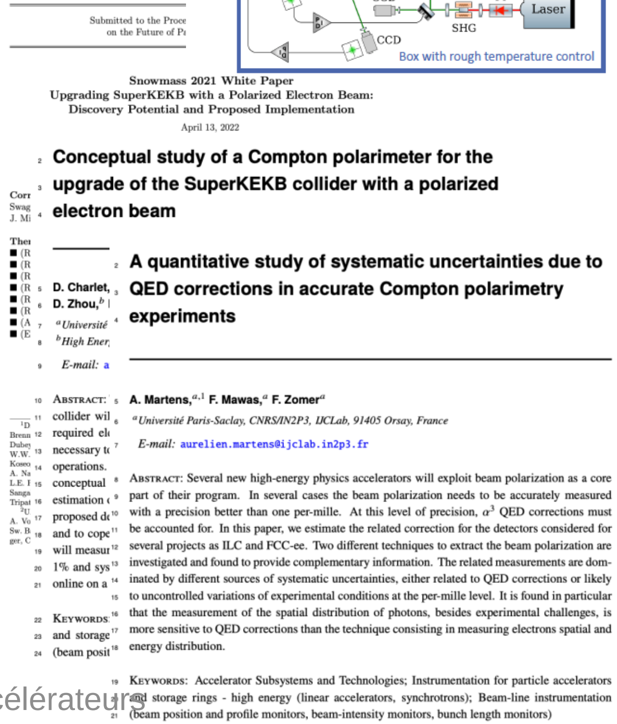
Pixelized detectors: conceptual design studies for FCC-ee



Laser injection line



Conceptual implementation for SuperKEK



Submitted to the Proce... on the Future of P...

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

arXiv:2205.12847v1 [physics.acc-ph] 25 May 2022

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

D. Charlet, D. Zhou

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

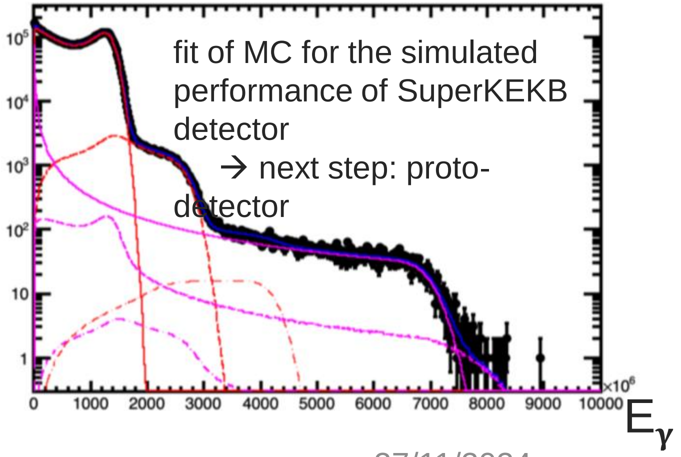
A. Martens,[a,1] F. Mawas,[a] F. Zomer[a]

[a]Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

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 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.

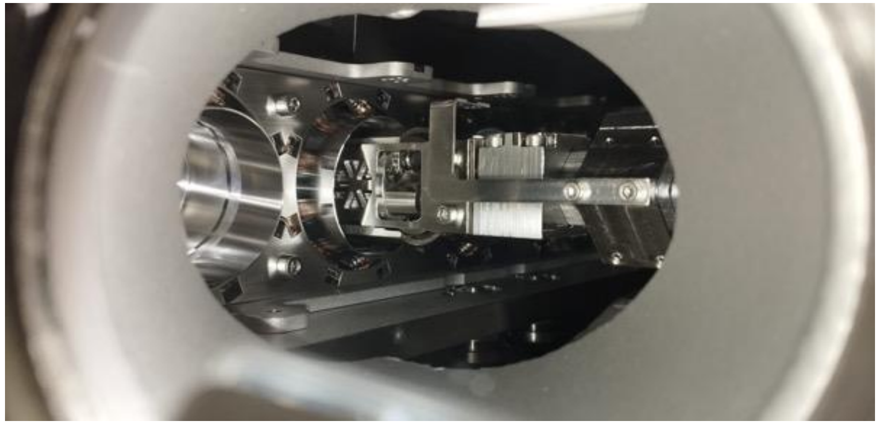
Keywords: Accelerator Subsystems and Technologies; Instrumentation for particle accelerators and storage rings - high energy (linear accelerators, synchrotrons); Beam-line instrumentation (beam position and profile monitors, beam-intensity monitors, bunch length monitors)

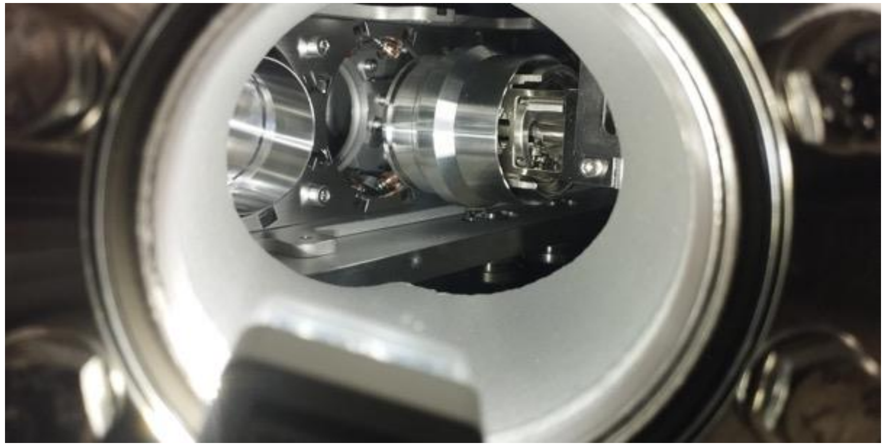


fit of MC for the simulated performance of SuperKEKB detector
→ next step: proto-detector

Avancement Technique: Photocathode Production Facility

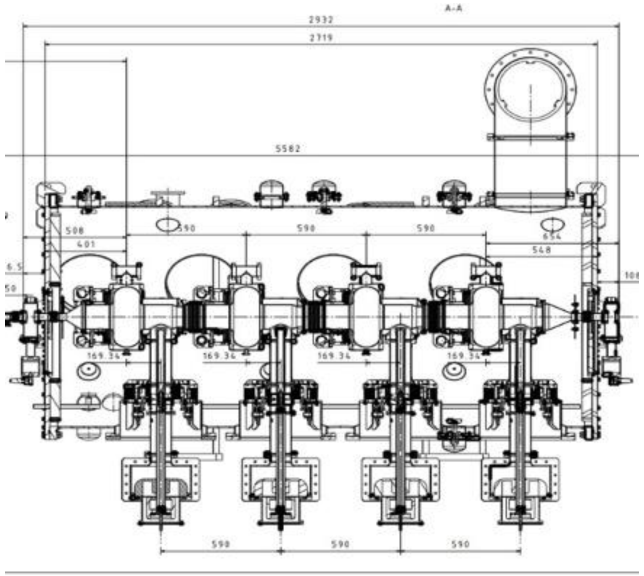
Courtesy to Denis Reynet- Sylvain Brault et al.





Booster specifications and possible design investigation

The booster study just started this summer, the specifications are

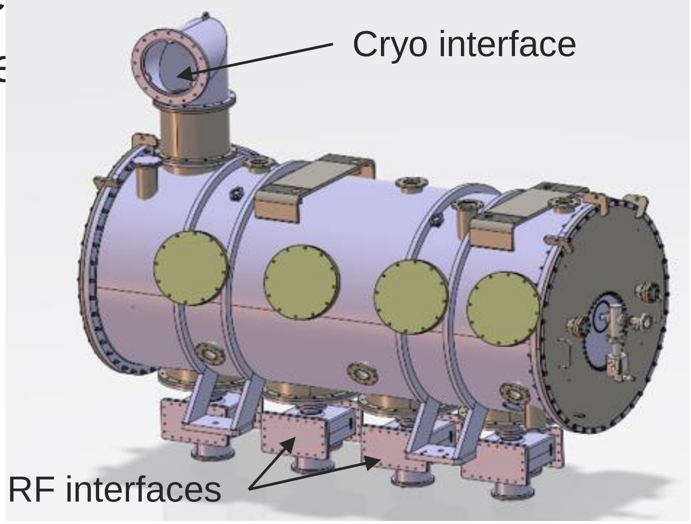


Bring the beam energy up 7 MeV:

- x4 single cell SRF cavities, Qo > 3E+10 @ 10 MV/m
- T= 2K (dynamic losses < 5W /cavity)
- F = 801.58 MHz
- RF Power/cavity~40kW
- No HOM couplers but absorbers needed

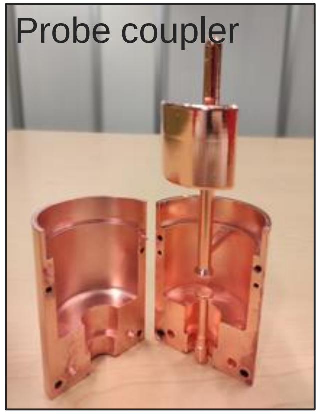
Adapt as much as possible the Linac cryomodule design to the booster requirements:

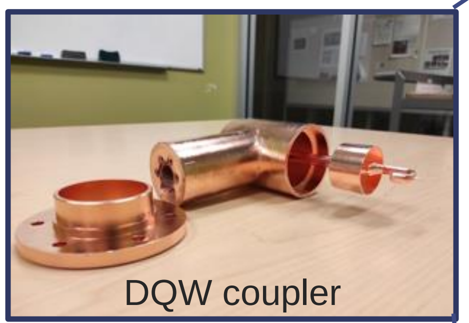
- Same vacuum vessel type (same diameter, alignment supports, ope ...)
- Same cryogenic interface (jumper connection)
- Same interface to the RF network
- Same tuning systems



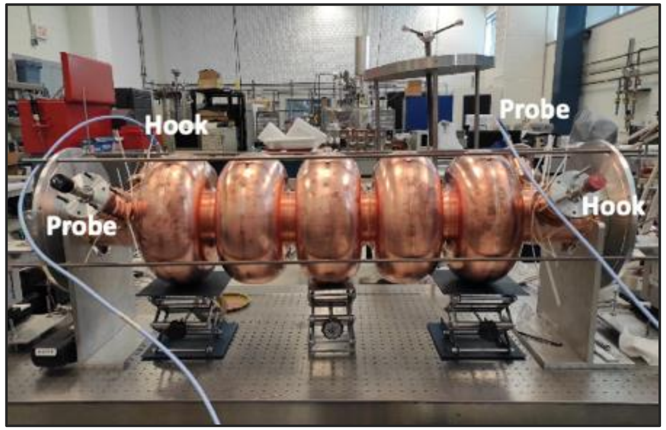
Status of HOM studies :

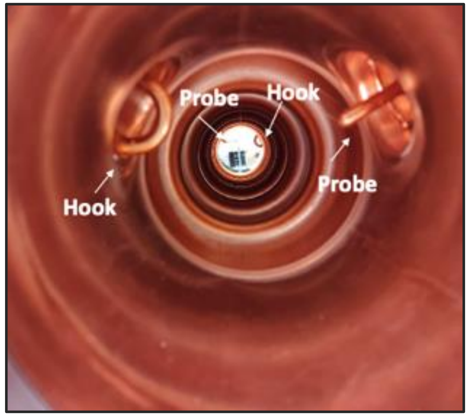
From RF design to performance measurements: **Successful collaborative effort between IJCLab, Jefferson Lab & CERN**

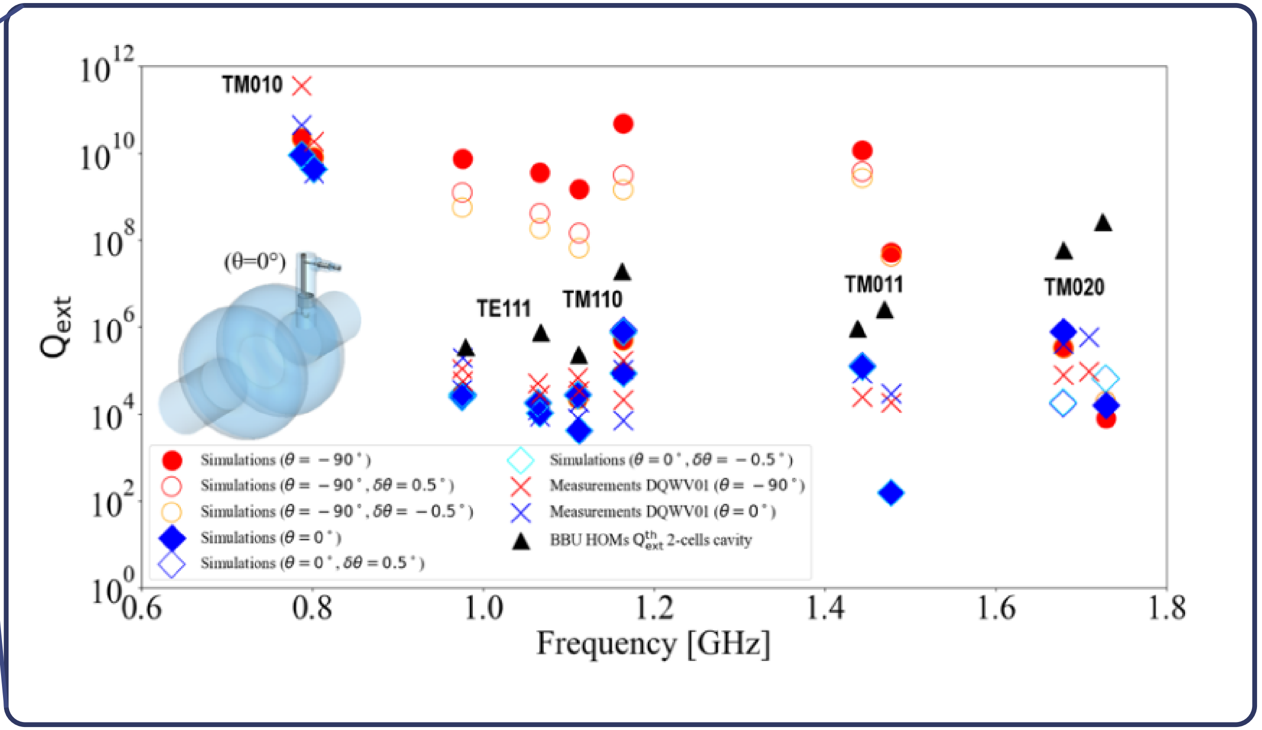




3D-printed prototype (Epoxy Accura 48) copper-coated @CERN



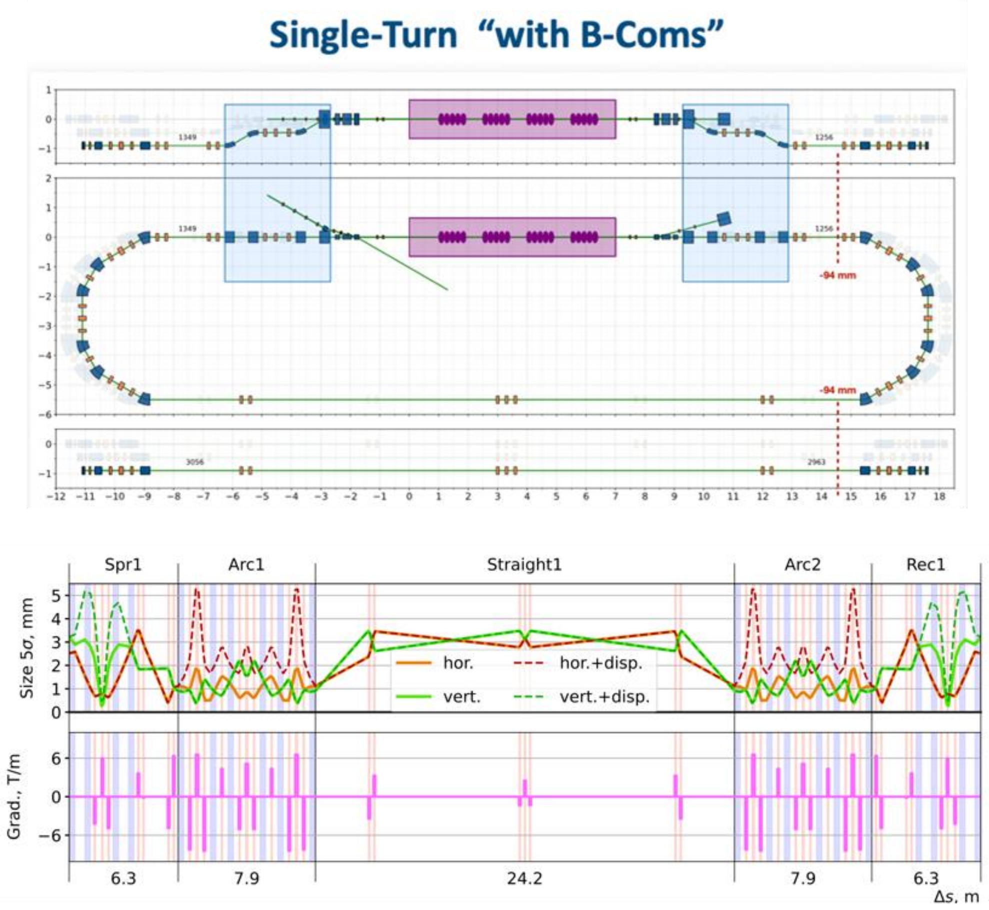


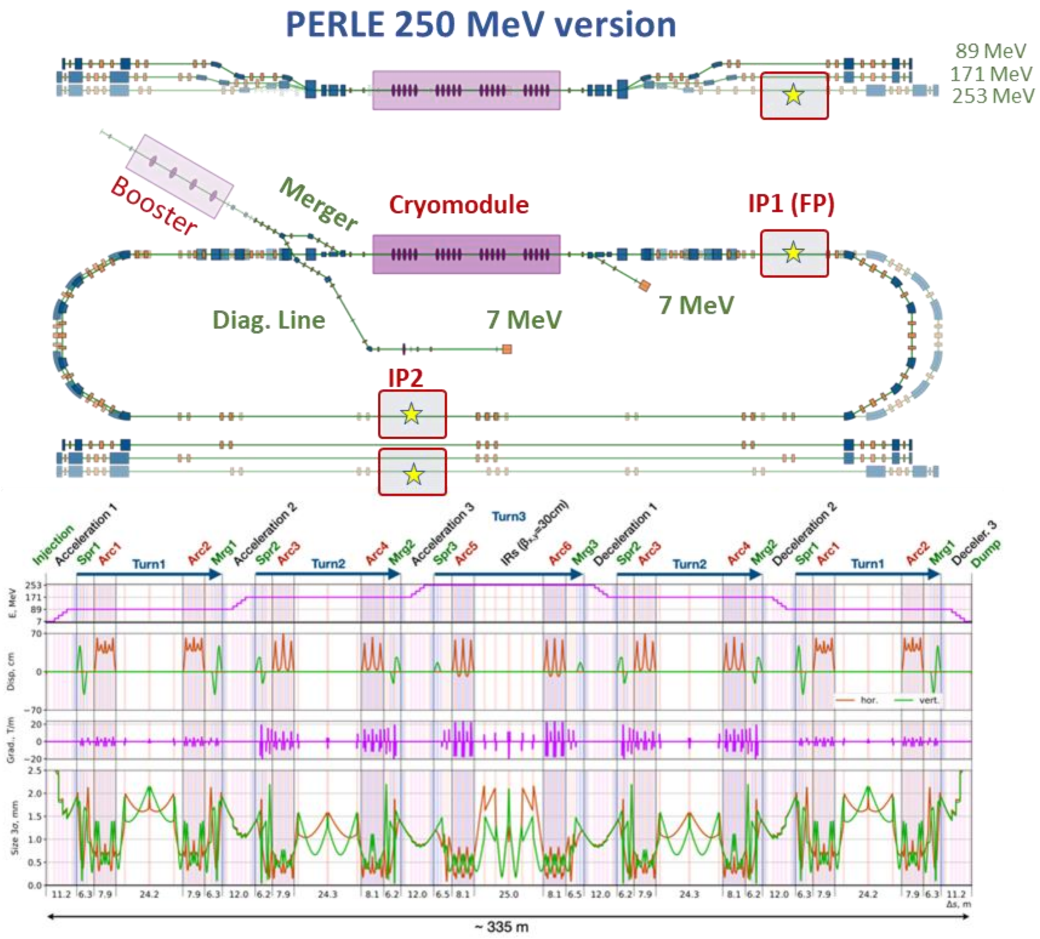


Ultimately, we aim to produce Nb HOM couplers with optimised design and to install them on a new Nb 5-cell PERLE cavity with optimised end groups. **The Production of 4 cavity scheduled within the ISAS program**

C. Barbagallo et al. "First RF measurements of coaxial HOM coupler prototypes in a copper cavity for the PERLE project"- IPAC'23- MOPA025

Further design and beam dynamics studies ongoing

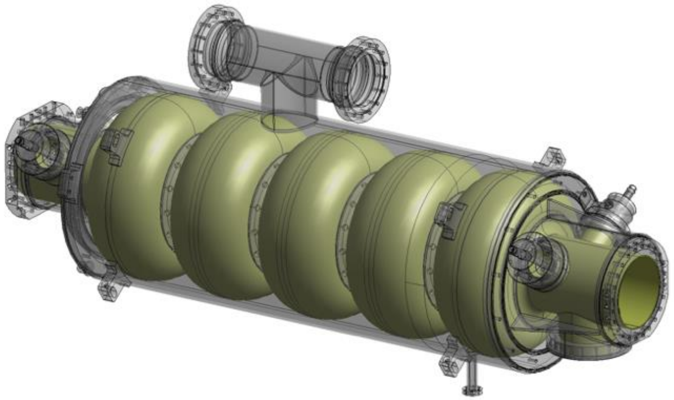




SRF cavity : latest news

With the results of the previous studies, we complete the design of the 5-Cell cavity by adapting and integrating:

- A helium jacket made of Titanium (including the beam pipes)
- 4 HOM couplers and the fundamental power coupler to the end-groups
- A “classical” tuning system as the one developed for the ESS Spoke cavities
- A BLA (very preliminary design) between cavities
- A “cold” magnetic shield



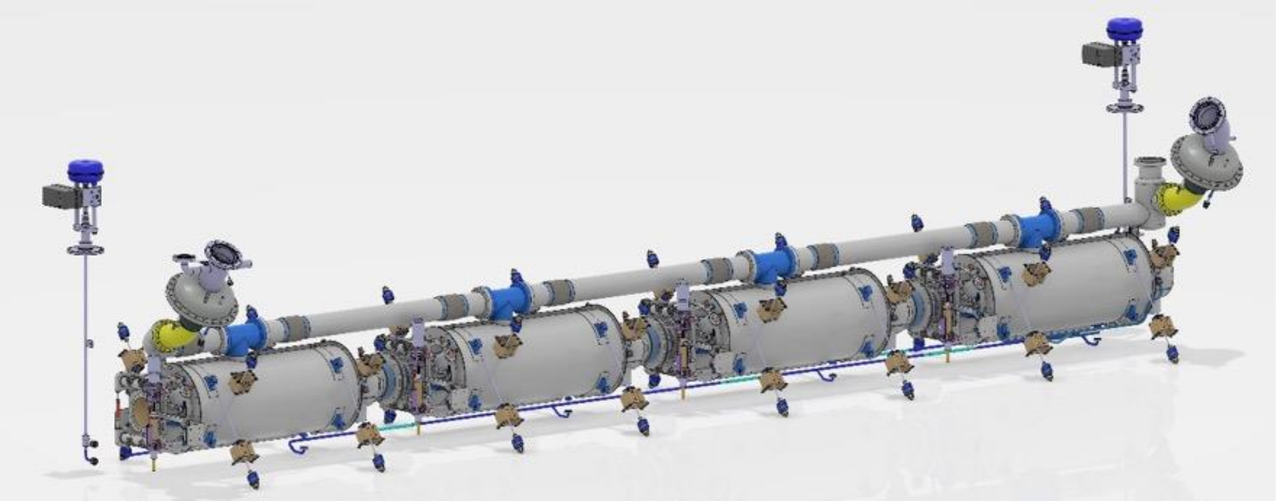
A review meeting on the cavity post-production processes recipes (EP, BCP, Mid-T baking…) was organised end of March with international experts.

→ An R&D program ongoing for recipe optimization (Coll. IJCLab, Jlab, Fermilab, CERN and KEK)

Within iSAS program:

→ The Nb procurement procedure is lunched (for single and multi-cell cavities).

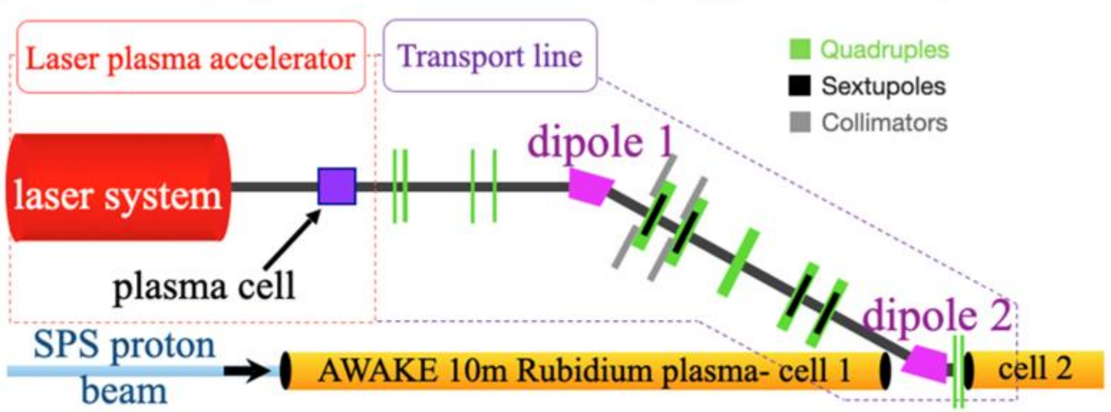
→ It is foreseen to lunch the procurement procedure of 4 cavities also before end of the year.



Accélération laser - plasma

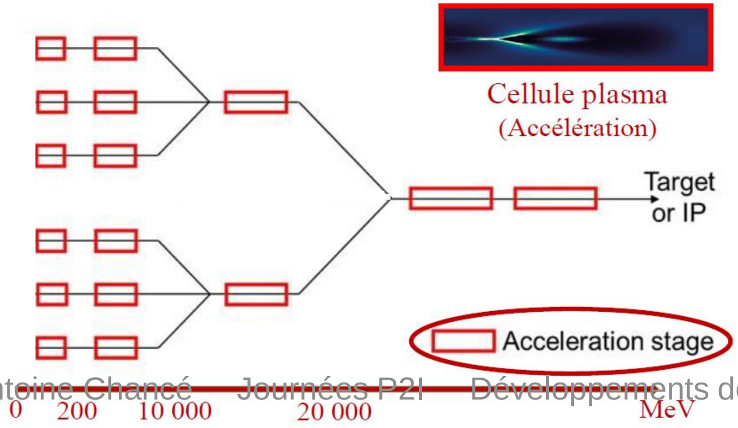
Conception et modélisation d'un injecteur d'électrons

- Simulation de la cellule plasma et de la ligne de transport, étude d'erreurs, chiffrage
- Satisfait aux exigences d'un injecteur pour AWAKE
- https://irfu.cea.fr/Phocea/Vie_des_labos/Ast/ast.php?t=fait_marquant&id_ast=5282



Mesure et transport d'un faisceau produit par LWPA pour des expérience d'irradiation d'échantillons biologiques

- Conception d'une ligne de transport
- Mesures du faisceau sur UHI100 (collaboration avec CEA/IRAMIS)



Etude d'une structure avancée d'accélérateurs laser-plasma à faisceau de haute énergie, haute intensité et haute qualité

- Système d'accélération laser plasma multi-étages
- Augmentation de la charge et de l'énergie du faisceau
- Optimisation des lignes de transport pour tenter de conserver une bonne qualité de faisceau (émittance, $\delta p/p$)

Etudes de réduction du claquage pour les cavités des cellules de refroidissement

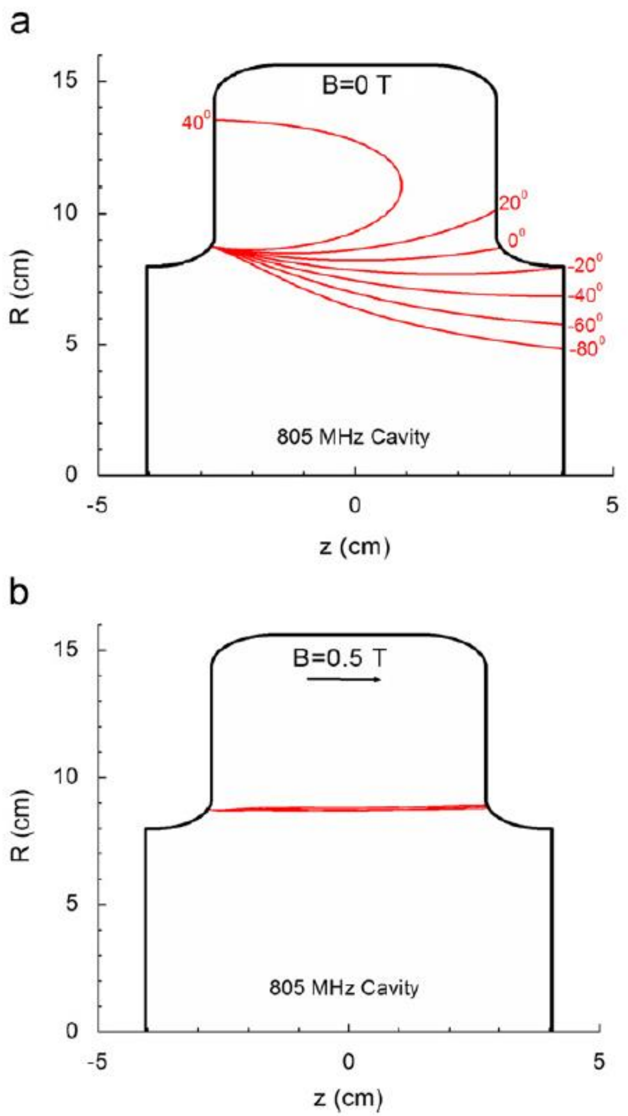
Responsable de la tâche: Guillaume Ferrand

Contribution du LISAH – Cavités RF :

- Simulation de l'émission de champ dans une cavité RF, avec effet du champ magnétique. Simulations avec CST, analyse des effets thermomécaniques.
- Comparaison des résultats avec les expériences précédentes/bibliographie.
- Chiffrage d'un banc de test de cavités sous champ, en utilisant les sources ESS 704, et un aimant prêté par un autre labo (UKRI, INFN ?).

Rapport final à rendre en 2026. (+ rapports annuels).

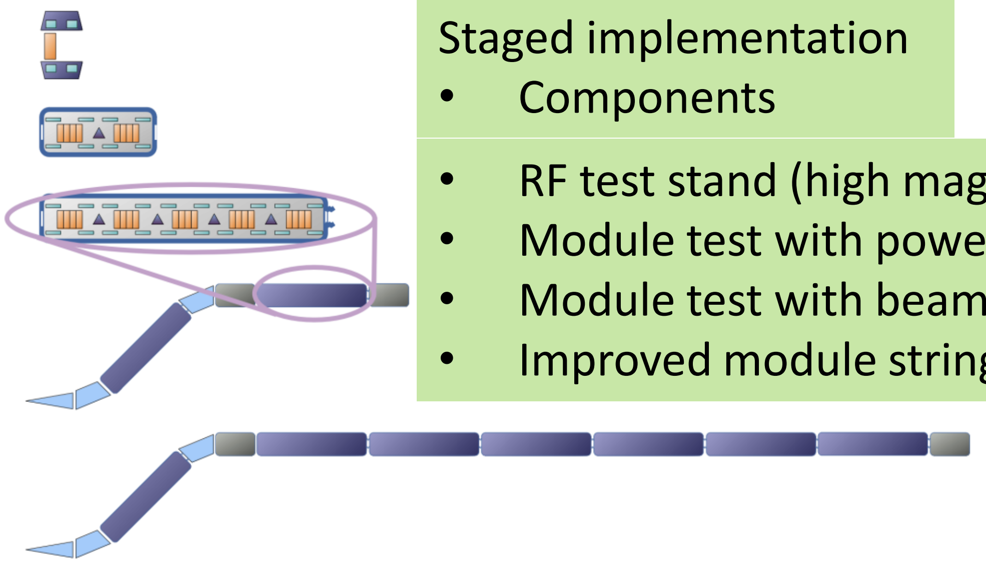
Financement pour un CDD 24 mois.



Demonstrator

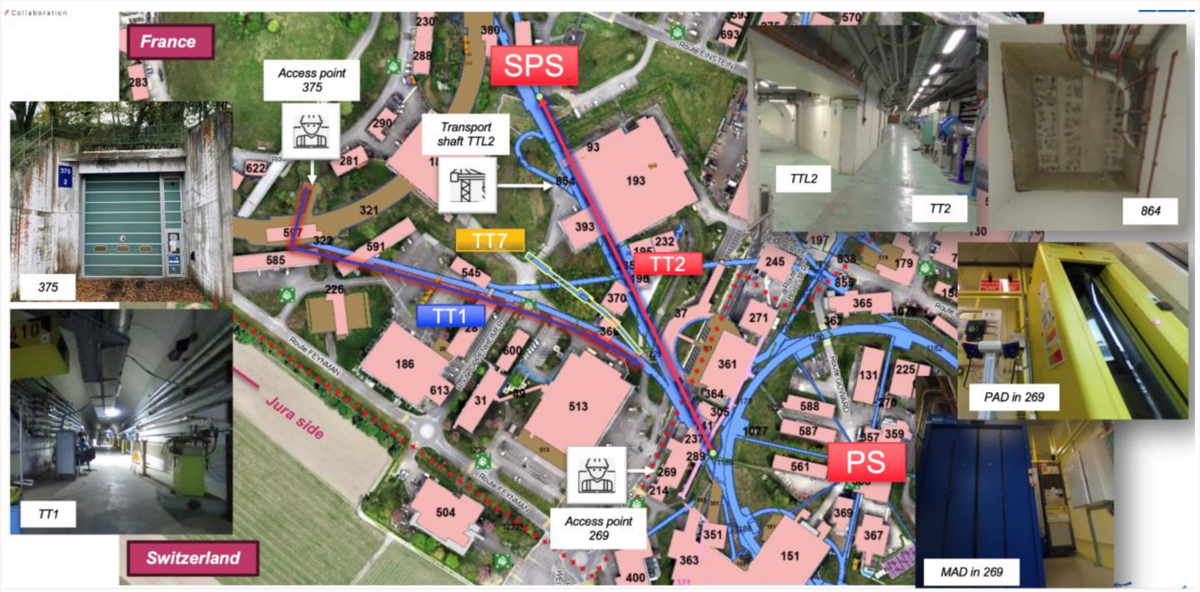
Ultimate **6D cooling technology integration**

- Components: Magnets, RF systems, absorbers, vacuum, instrumentation, cryogenics, …
- Integration, operation, performance with beam
- Gradual upgrades as cell design evolves, confidence grows
- Will be important part of commissioning preparation after the decision to build the muon collider



Staged implementation

- Components
- RF test stand (high magnetic field)
- Module test with power
- Module test with beam
- Improved module string



Detailed studies of site at CERN ongoing, considering TT7 tunnel
US plan to start detailed study at FNAL

Effort **ramp-up** in several stages
Modular plan will allow quickly moving forward

- adjust to developments in Europe and the US

Other R&D Programme

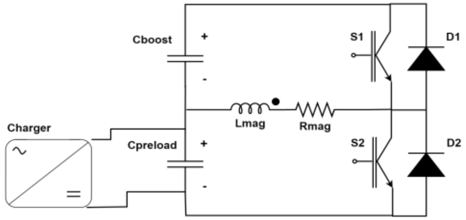
R&D on other technologies also needed
Power converter, high-field superconducting cavities, efficient RF power sources, cryogenics (e.g. **liquid hydrogen**), instrumentation, …

Most important is training of **young people**
- Strong interest by early career experts
  - e.g. https://indico.cern.ch/event/1422393/
- Motivating challenges
- Most important resource

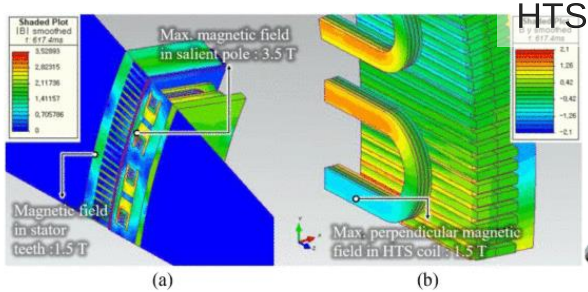
Exploit synergies with other fields (technology and physics)
- Strong **synergy** with **LDG HFM** and **RF**

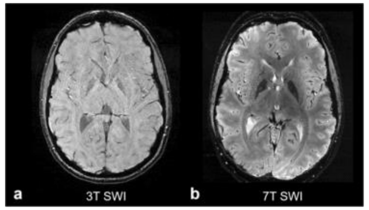
HTS solenoids have important potential
- Fusion
- Power generators for windmills and motors
- Life sciences
- Important step toward FCC-hh HTS dipoles
- …

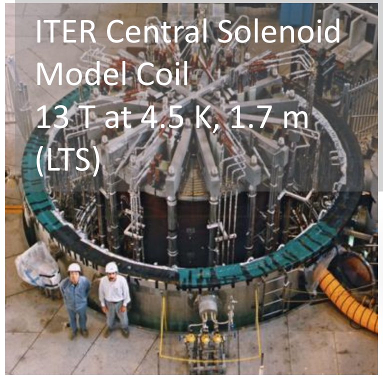
Detector technology development
- AI, ML, …



Design of 10 MW HTS wind generator





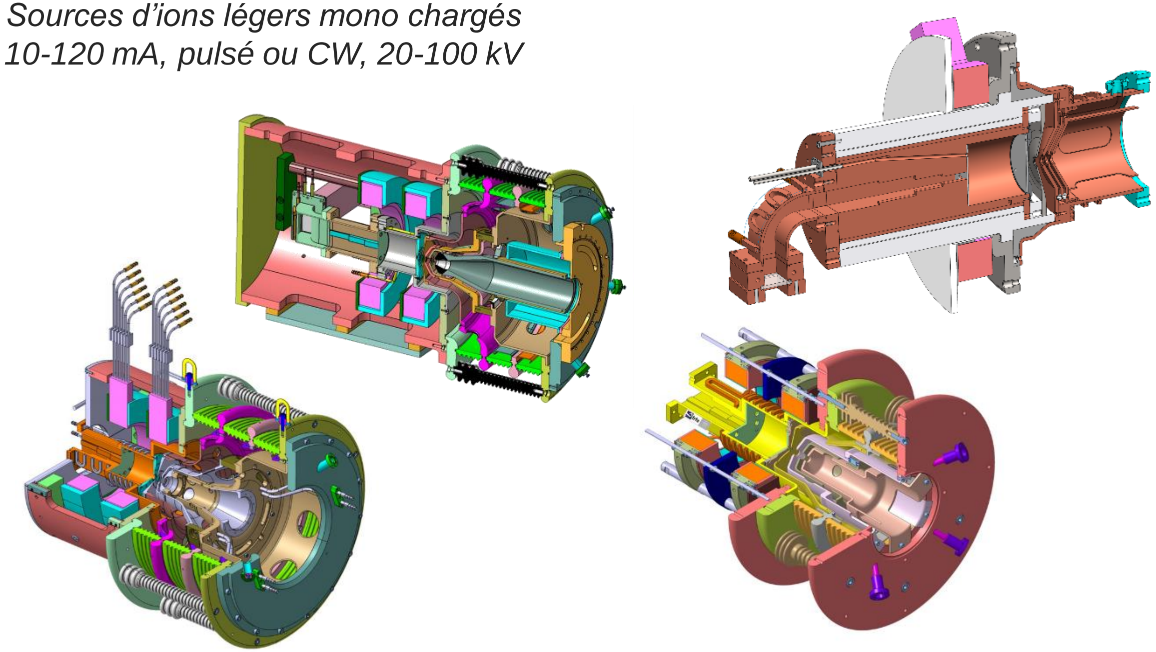


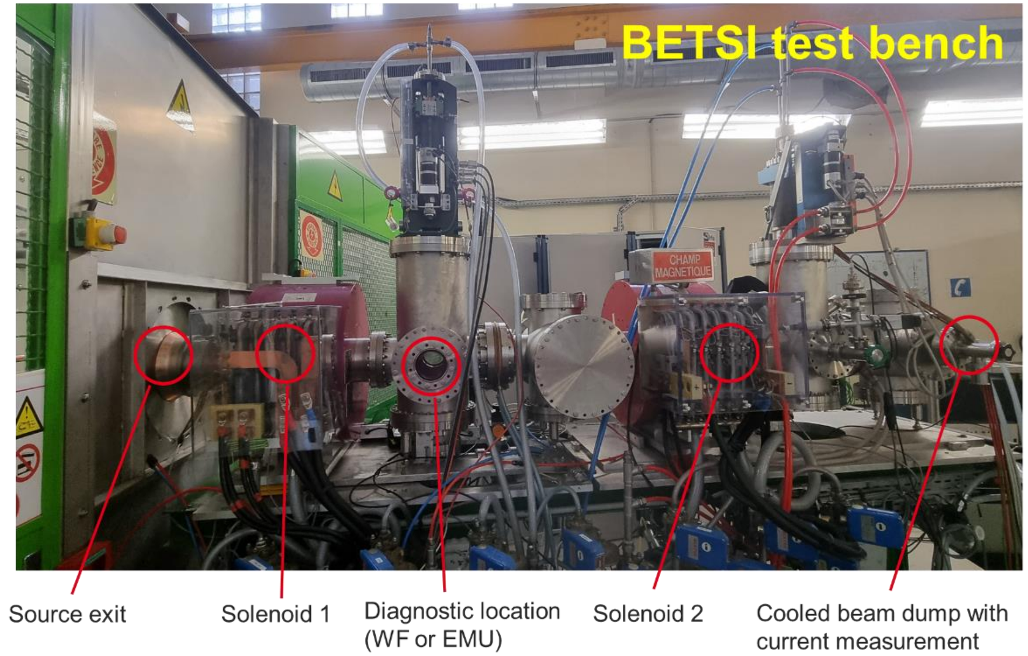
28.2 T LTS+HTS, 54 mm

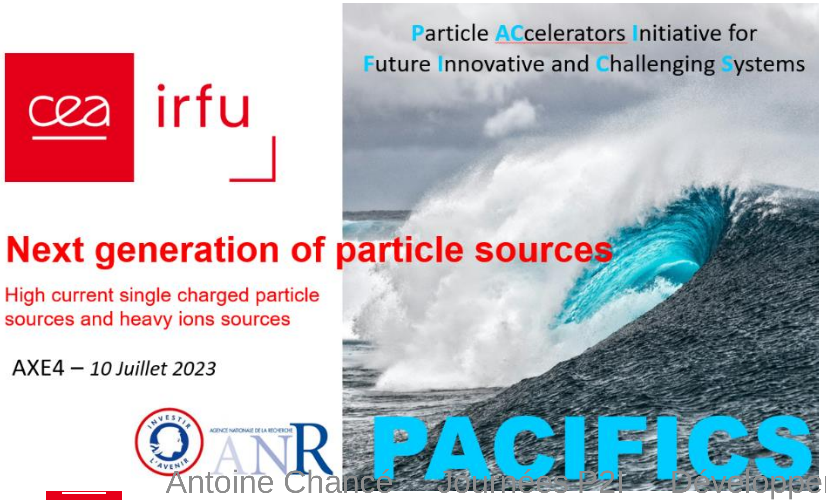
Opportunities to profit from synergies
Attract young generation
R&D programme can be distributed world-wide

Bancs de test de sources d’ions

Sources d’ions légers mono chargés
10-120 mA, pulsé ou CW, 20-100 kV

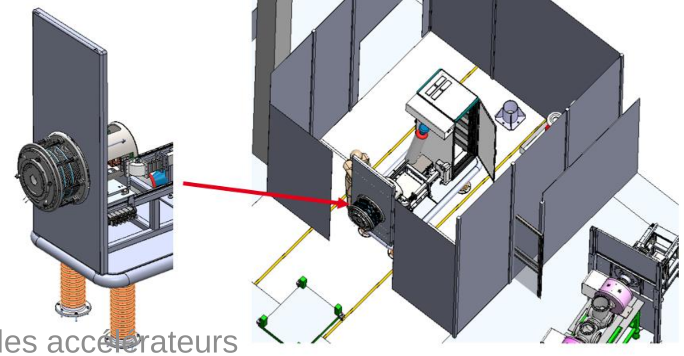


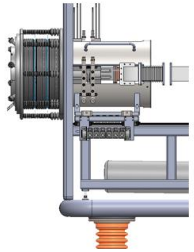


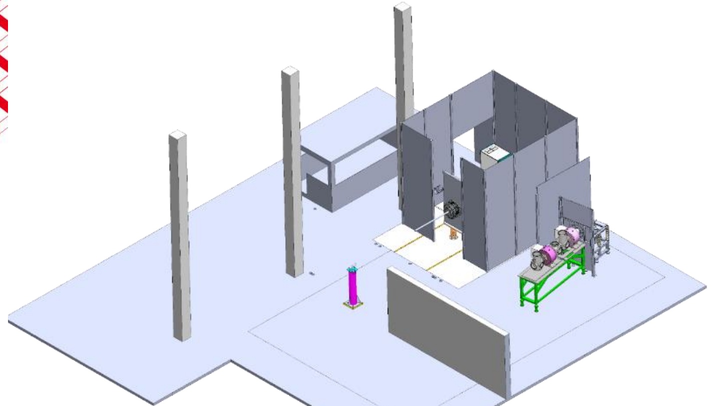


Définition de la nouvelle infrastructure

Implantation PACIFICS dans le Hall 4^{E} à côté du banc BETSI







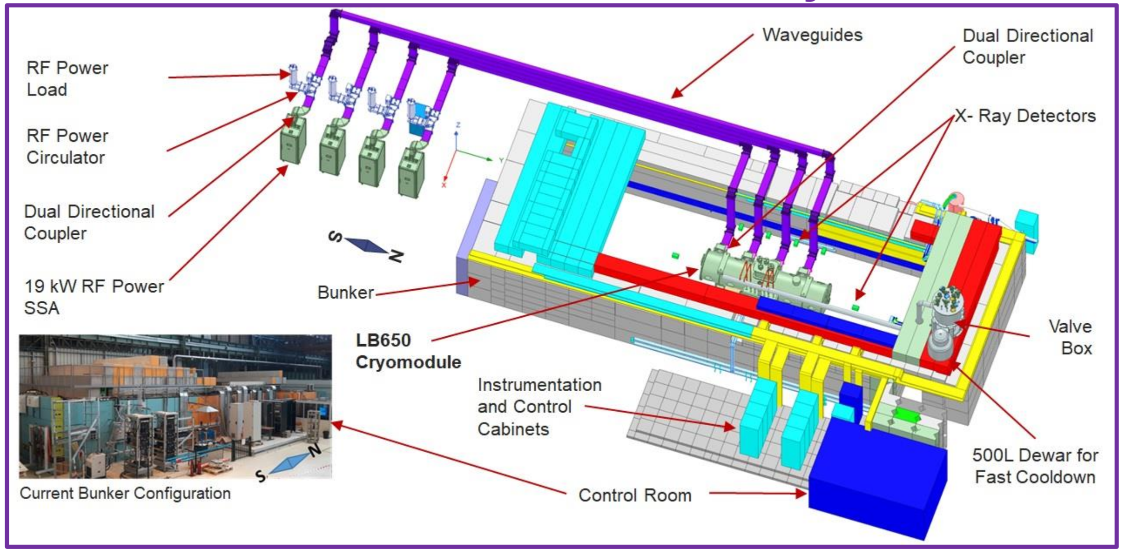
Infrastructure dédiée aux cryomodules

Hall d'assemblage (x2)
~3000 m²

Salle blanches
~300 m²

Préparation chimique
BCP + EPV

Infrastructure de test de cryomodules



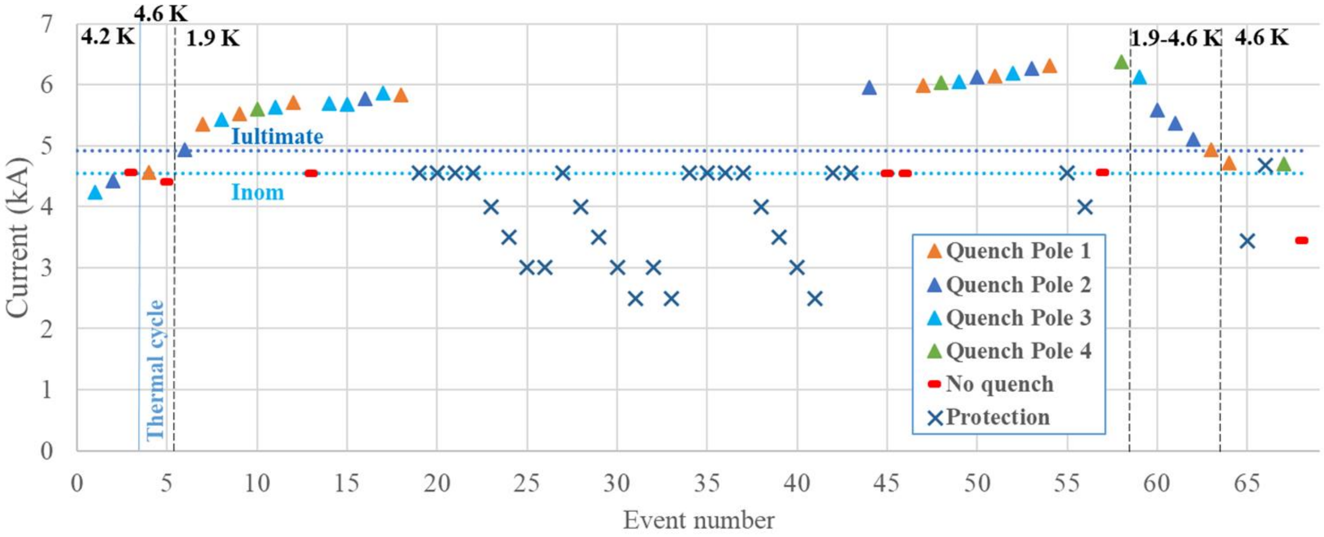
Stations de test R&D

2 HPRs

Station d'essais STAARQ
(Station de Test pour Aimants d'Accélérateurs Quadrupôles)

Station conçue pour tester des aimants quadrupôles pour le LHC.

Très bons résultats obtenus en 2024 sur MQYYM:
Cryogénie performante
Aimant a supporté ~60 quench



Test de l'aimant MQYYM réalisé de mi juin à mi-juillet 2024

Main parameters
- Pressurized LHe bath at 1.9K (cryogenic power :45 W)
- I max: 13 kA
- Liquefier: 65 l/h
- Numerical // Analogical MSS
- Weight max magnet: 12 t
- Useful diameter: 640 mm
- Useful Length : 5.2 m