SAPIENZA
UNIVERSITÀ DI ROMA

INFN
Istituto Nazionale di Fisica Nucleare

PARTICLE SOURCES AND TARGETS

LINE OF RESEARCH

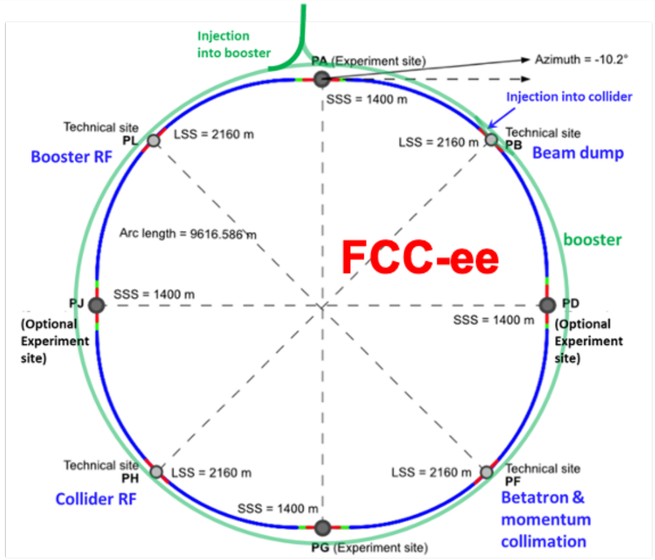
Andrea Ciarma

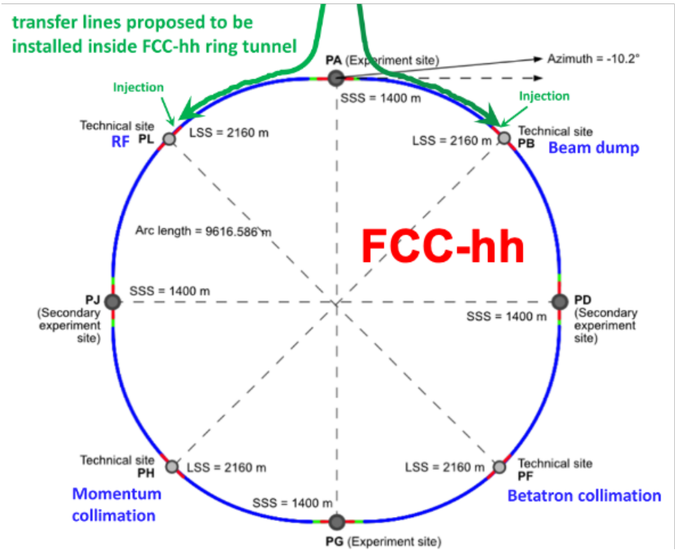
on behalf of: Laura Bandiera, Matteo Bauce, Manuela Boscolo,
Nicola Canale, Gianluca Cavoto, Marco Romagnoni, Alexej Sytov

PARTICLE SOURCES AND TARGETS

Possible topics and areas of interest:

- Future Circular Collider e+e- (FCC-ee)
  - Machine-Detector Interface optimization, background assessment and shielding design
  - luminosity monitoring and control
  - hybrid crystal-based e+ source
- Plasma Wakefield acceleration in nanostructures
- Curved crystals for particle accelerators
- Muon Collider
  - materials for ionization cooling cells





THE FCC INTEGRATED PROJECT

The **Future Circular Collider** (FCC) is a comprehensive **long-term program** aimed at maximizing physics opportunities.

The integrated program envisions **two accelerator machines**:

1st stage: **FCC-ee** (Z, W, H, Top)
- extremely **high luminosity** Higgs factory, EW, top factory

2nd stage: **FCC-hh** (~100 TeV c.o.m. energy)
- natural evolution, pushing the **energy frontier**
- pp and AA collisions, possibility for ep / e-ion

Strong synergy between the two colliders: **common** facilities and infrastructures, **complementary** physics programme.

The FCC Integrated Project allows the start of a **new major HEP programme at CERN** within a few years of the end of HL-LHC.

- Collaboration to FCC funded by INFN, strong Italian team contributing to many key areas
- LNF (solely in INFN) in FCCIS EU-H2020 project, Task Leader in MDI design, 2020-24
- R&D project to build a prototype of the FCC-Interaction Region has just started in Frascati

Contact:
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MACHINE-DETECTOR INTERFACE AT FCC-ee

FCC-ee MDI is a region **dense with elements** – and mechanical constraints!

- L* = 2.2m, 30mrad crossing angle
- **SiW LumiCal** – measure forward bhabhas in **50~100mrad** acceptance
- **-5T anti-solenoid** at s = ±1.23m to cancel **coupling from detector** 2T field
- **Cryostats** for anti-solenoids and SC final focus quadrupoles
- **Central Chamber**: R=10mm, L=18cm
- **Support tube** in carbon fiber for **Vertex/Inner Tracker integration**

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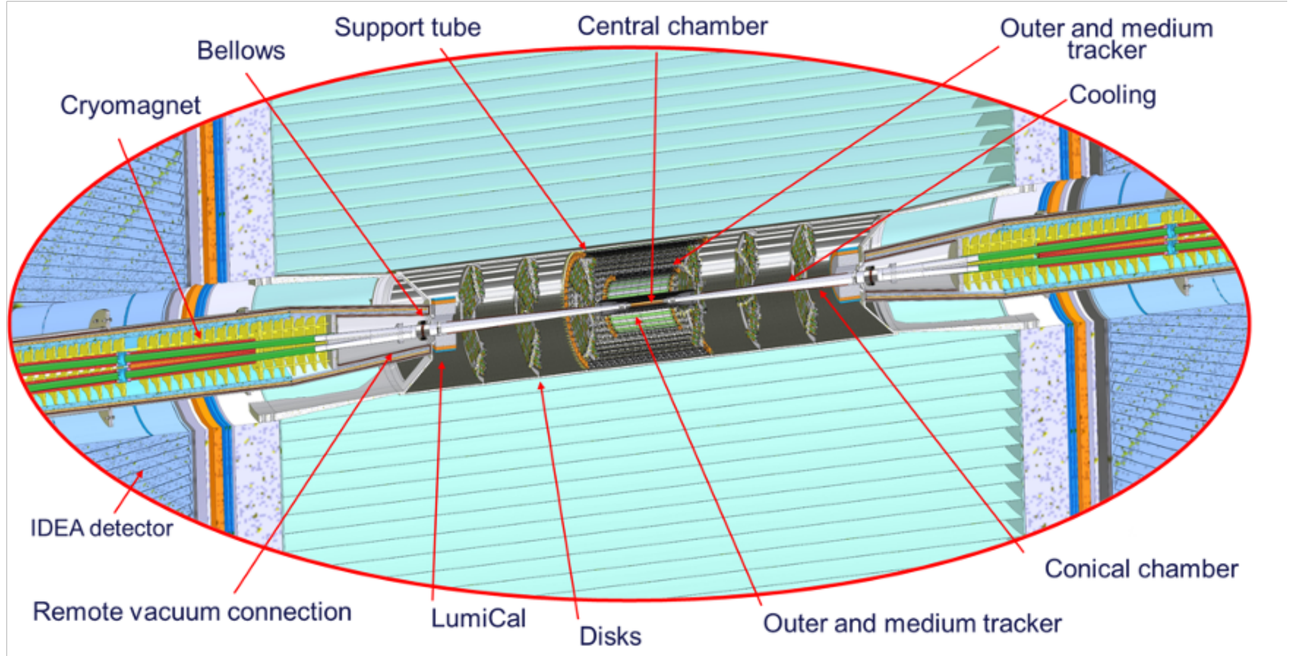

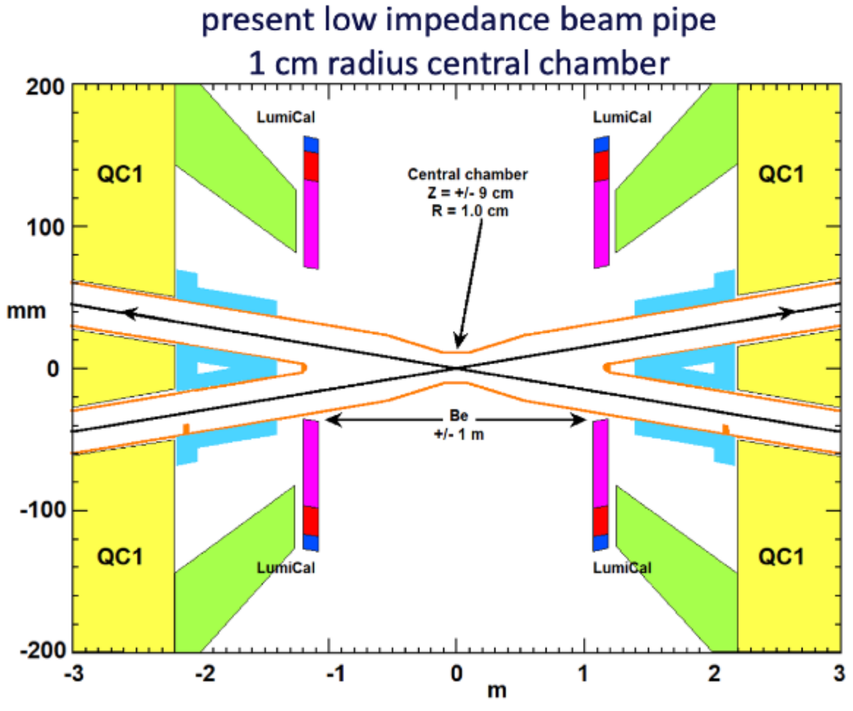

MACHINE-DETECTOR INTERFACE AT FCC-ee

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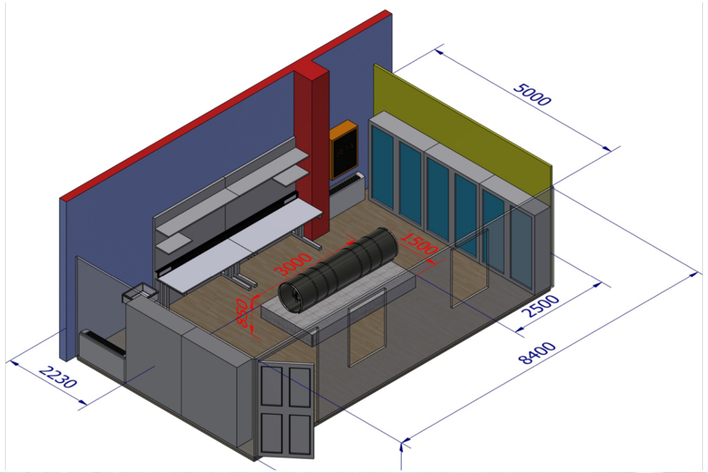
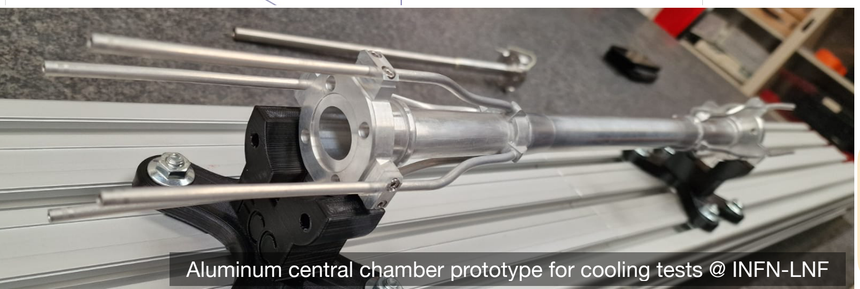
Goals of the research program include:

- optimization of the **FCC-ee interaction region**, considering basic constraints from the detector
- design of **shieldings and absorbers** for the experimental environment
- simulations to assess **detector backgrounds** levels and tolerability
- study **IR optics** with tracking tools (e.g. MAD-X, XSuite) and simulation of **background generation processes**
- **benchmark with existing machines** like SuperKEKB (Tsukuba, Japan) and DAFNE (Frascati)




Aluminum central chamber prototype for cooling tests @ INFN-LNF

Activities on FCC-ee Machine-Detector Interface based at the **INFN Frascati National Laboratories** (INFN-LNF).

- R&D Activity co-funded by INFN & CERN started to build a **IR Mockup** in Frascati for central and conical chambers (±1.2m) and support tube
  - **assembly strategy** feasibility
  - **cooling system** thermal/hydraulical characterization
  - cables and cooling pipes fitting

M. Boscolo, F. Palla, et al., Mechanical model for the FCC-ee MDI, EPJ+ Techn. and Instr., https://doi.org/10.1140/epjti/s40485-023-00103-7
M. Boscolo and A. Ciarma, PRAB 26, 111002 (2023), link
M. Boscolo et al., Status of the IR and MDI of the FCC-ee, IPAC23, 7-12May 2023 https://www.ipac23.org/preproc/pdf/MOPA091.pdf
M. Boscolo, H. Burkhardt, K. Oide, M.K. Sullivan, EPJ+ (2021) https://link.springer.com/article/10.1140/epjp/s13360-021-02031-5

Machine-Detector Interface at FCC-ee: Possible PhD Thesis (1)

Measurement and control of the luminosity at FCC-ee

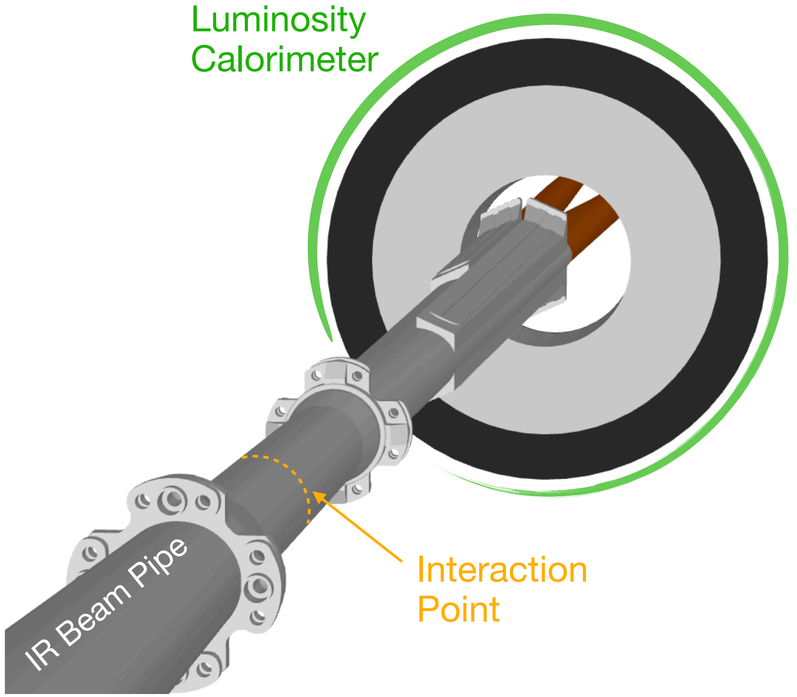
The future circular electron-positron collider at CERN (FCC-ee) aims at unprecedented luminosities obtained with the crab-waist collision scheme.

The thesis will deal with the parameters that determine the **luminosity, its lifetime and control**, as well as the different ways to measure it, **both at the level of the accelerator and the detectors**.

A similar crab-waist scheme has been adopted at the **SuperKEKB** collider at Tsukuba (Japan), where the candidate is expected to be seconded for some short periods to learn "in situ".

The detector **luminosity determination** will use Bhabha scattering process, in which the two emerging leptons will be detector by a calorimeter. The candidate will study the mechanical tolerances and the interaction region layout that are needed to achieve the desired precision.

Activity based at the **INFN Frascati National Laboratories**, in collaboration with CERN(CH), SLAC (US), BNL (US), KEK (JP)



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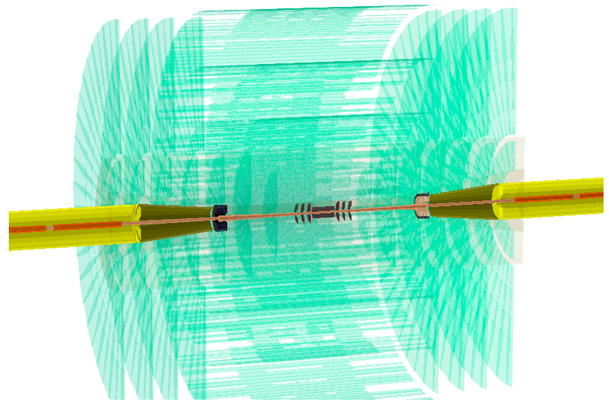
MACHINE-DETECTOR INTERFACE AT FCC-ee: POSSIBLE PHD THESIS (2)

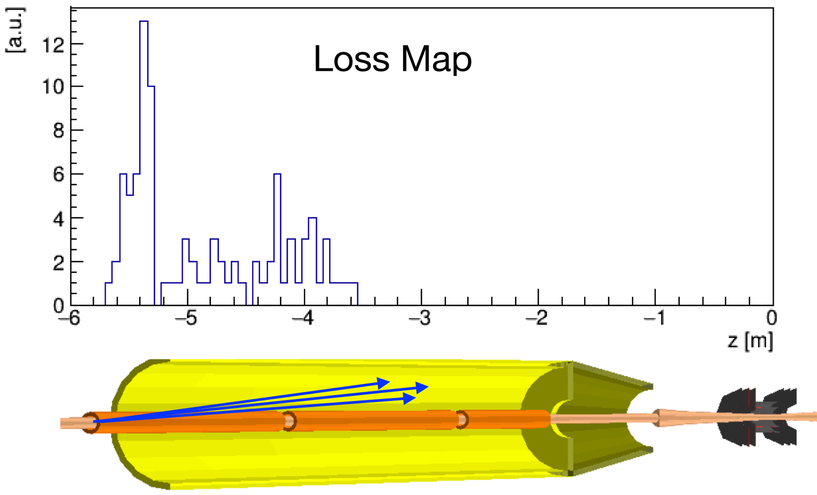


Study of the IR optics and machine related backgrounds at FCC-ee

Several effects are at the origin of the **beam-induced backgrounds** at the interaction region, such as the beam-beam effect, the radiative Bhabha scattering, beam losses from the collimators, synchrotron radiation and beam-gas interactions.

Different machine optics will have different impacts on some of these backgrounds. The student will take confidence on the **beam transport simulations** (MAD-X, XSuite) and **evaluate the backgrounds** in the machine elements as well as in the **detectors** of the experiments, such as the vertex detectors and the drift chambers.

The candidate is expected to be seconded for some short periods to the SuperKEKB collider in Tsukuba (Japan) to learn "in situ" the reduction of the beam-related backgrounds in a running machine.



Activity based at the **INFN Frascati National Laboratories**, in collaboration with CERN(CH), SLAC (US), BNL (US), KEK (JP)

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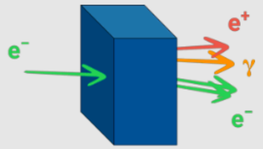
Hybrid crystal-based positron source for the FCC-ee

The **FCC-ee injector complex** foresees **a 2.86 GeV linac**.
Currently **the conventional and hybrid scheme are under study!**

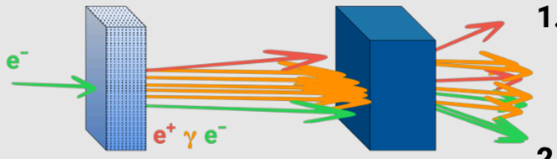
Conventional scheme



Thick amorphous target

- Average energy deposition
  → target heating/melting
- Peak Energy Deposition Density (**PEDD**)
  → Inhomogeneous and instantaneous energy deposition,
  that cause thermomechanical stresses due to temperature gradient

Hybrid positron source *



"Thin" oriented crystalline target (< X_0) **photon radiator**

Amorphous **target-converter**

** Idea of R. Chehab, V. Strakhovenko and A. Variola, NIM B 266 (2008) 3868*

Main advantages of the hybrid source:

1. **Enhancement of photon generation** in crystals in coherent conditions
   → **enhancement of pair production** in the converter target
2. **High rate of soft photons**
   → creation of soft **e^+ easily captured** in matching systems
3. **Decrease of the deposited energy and Peak Energy Deposition Density (PEDD)** in the converter

An hybrid source can be advantageous to future colliders (FCC-ee, CLIC, ILC or CEPC) as well as for current ones (SuperKEK B)

Contact: **L. Bandiera** - INFN Ferrara *bandiera@fe.infn.it*

Collaboration between INFN-Ferrara and IJCLab Paris Orsay to develop hybrid crystal- based positron sources for future colliders.

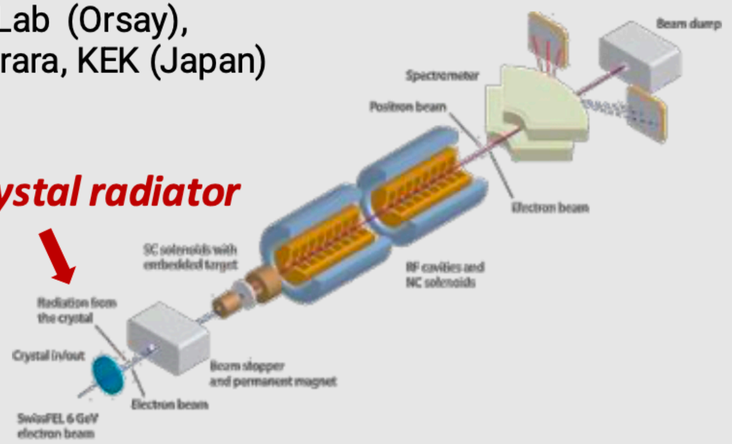
Possibilities of spending period at Paris Orsay.

I. Chaikovska *et al.*, **JINST 17 (2022) P05015.**

Recently added at the **CHART project on the FCCee Injection System**: Collaboration between PSI and CERN with external partners: CNRS-IJCLab (Orsay), INFN-LNF, INFN-Ferrara, KEK (Japan)

CHART
Swiss Accelerator Research and Technology

Crystal radiator



- Optimization of the capture section of pre-injector still ongoing.
- Integration studies with potential proof-of principle at P3 experiment @ PSI (and future CHART projects)

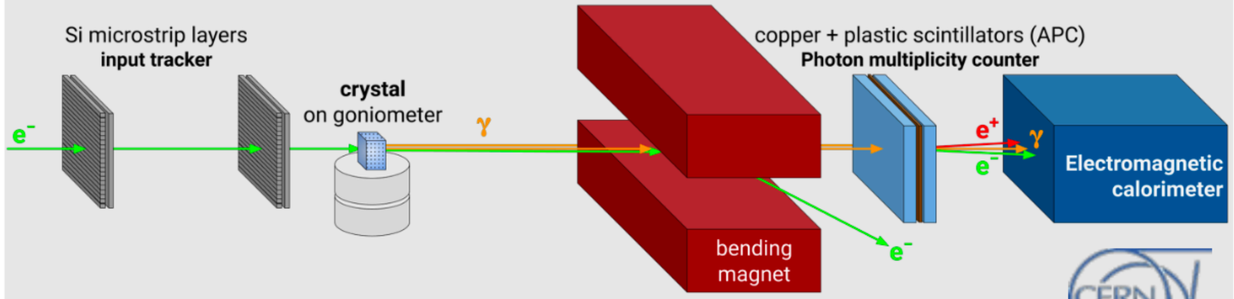
Possible PhD thesis

Activities:

Experimental tests on the targets

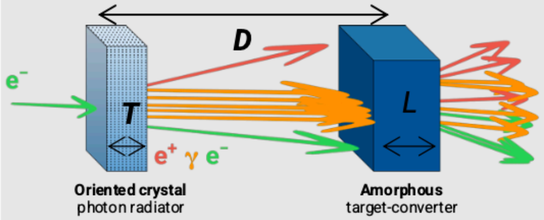
e+BOOST PRN2022-2022Y87K7X | Bando PRIN 2022 | Finanziato dall'Unione europea NextGenerationEU | Ministero dell'Università e della Ricerca | Italiadomani | INFN FERRARA

Setup at CERN PS extracted lines Electron energy of 2.86 GeV (forseen FCC e⁻ linac)

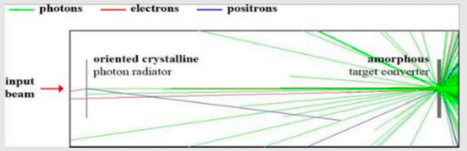


L. Bandiera *et al.*, **EPJC 82**, 699 (2022)

MC with Geant4 for the source optimization



Positron yield, energy deposit and Peak Energy Deposition Density can be modified by tuning radiator *thickness (**T**), amorphous thickness (**L**)* and the distance between them (***D***).



*M. Soldani et al., **NIM A**, 1058, 168828 (2024)*

- Optimization of the capture section of pre-injector
- Simulation of the full positron source
- Integration studies of the proof-of principle at P3 experiment

Contact: **L. Bandiera** - INFN Ferrara *bandiera@fe.infn.it*

In Collaboration with IJCLab (leader I. Chaikovska)

Curved crystals for particle accelerators

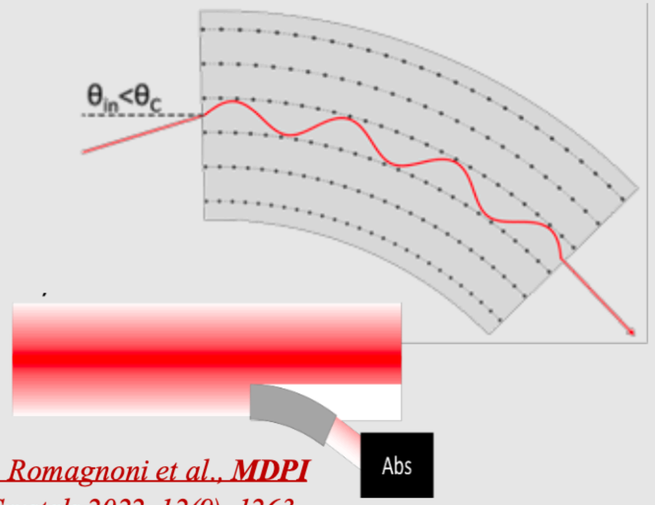
Possible PhD thesis

Curved crystals can act as **waveguide** for charged particle beams through the phenomenon of **channeling**, achieving steering power **larger than 1000 T** magnetic dipoles.

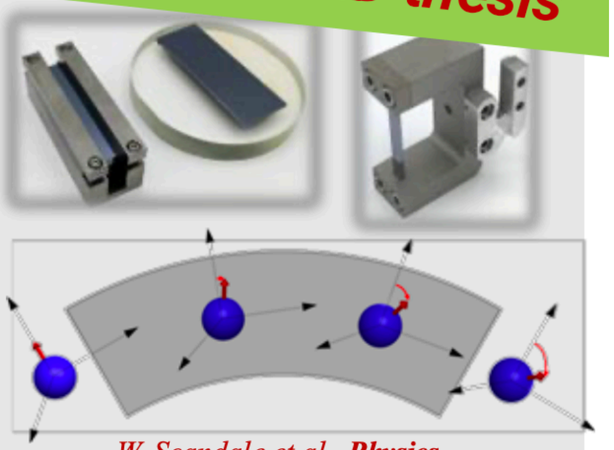
This effect can be exploited in accelerators for:
- Collimation/extraction of beam halo
- Protection of insertion devices in accelerators (beam shadowing)
- Spin precession of fast decaying particles

INFN Ferrara is currently involved in several projects:
- **Mu2e** proton beam extraction at Fermilab
- Collimation of **Muon Collider**
- Spin precession of charmed baryons in **LHC**
- Desing and manufacture of crystal for channeling experiments

- Geant4-based simulation of channeling in bent crystals **for Muon Collider collimation** optimization



*M. Romagnoni et al., **MDPI** Crystals 2022, 12(9), 1263*



*W. Scandale et al., **Physics Reports** 2019, 04 003*

- Fabrication and characterization of crystals for **beam shadowing** in the **Mu2e** experiment
- Development of **advanced crystal bending techniques** for charmed baryon spin precession experiments
- Sample characterization at **synchrotron facilities**
- **Beam line experiments** on bent crystals

Fermilab ESRF mami DESY. CERN

Contact: **A. Mazzolari, M. Romagnoni** – INFN Ferrara mazzolari@fe.infn.it and rmgmrc@unife.it

Advanced Particle-In-Cell simulations of laser-driven plasma wakefield acceleration

This research focuses on the simulation **of laser-driven plasma wakefield acceleration** (LWFA) in dense materials, in particular solid-state targets and **carbon nanotubes** (CNTs) *C. Bontoiu et al. **Scientific Reports** 13, 2845 (2023)*

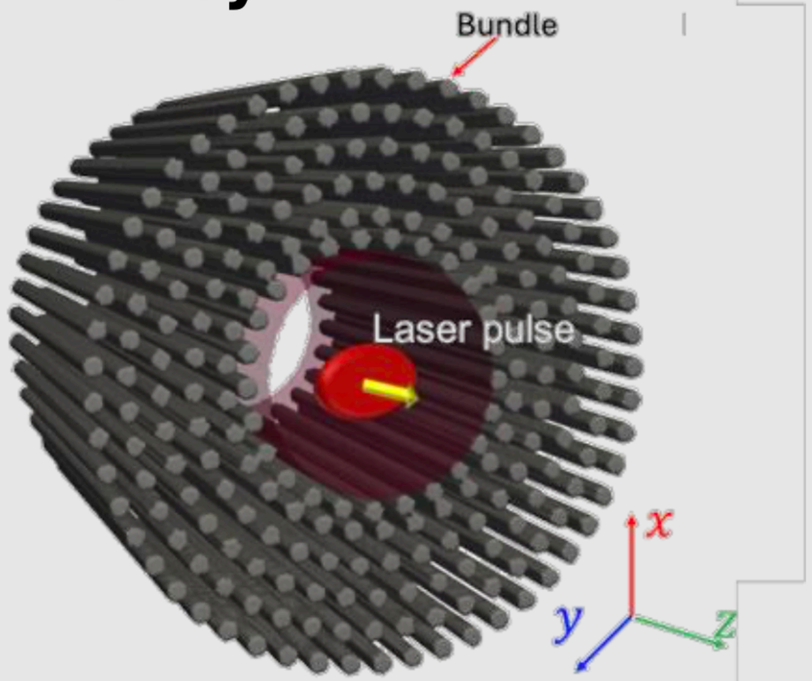
Plasma wakefield acceleration in such materials offers the potential for producing extremely high-gradient acceleration and highly intense particle beams, critical for next-generation accelerators.

Using CNTs as the target medium, this study aims to optimize key parameters, such as laser intensity, plasma density, and beam-plasma interactions, to maximize the beam quality and charge. Additionally, the research explores methods for the production and preparation of CNT targets for LWFA, addressing challenges in target fabrication.

Contact: **A. Sytov** – INFN Ferrara sytov@fe.infnit

Possible PhD thesis

CNT array



Monte Carlo modeling of laser-driven plasma wakefield acceleration in dense materials

MUON COLLIDER AT A GLANCE

International MUON Collider Collaboration

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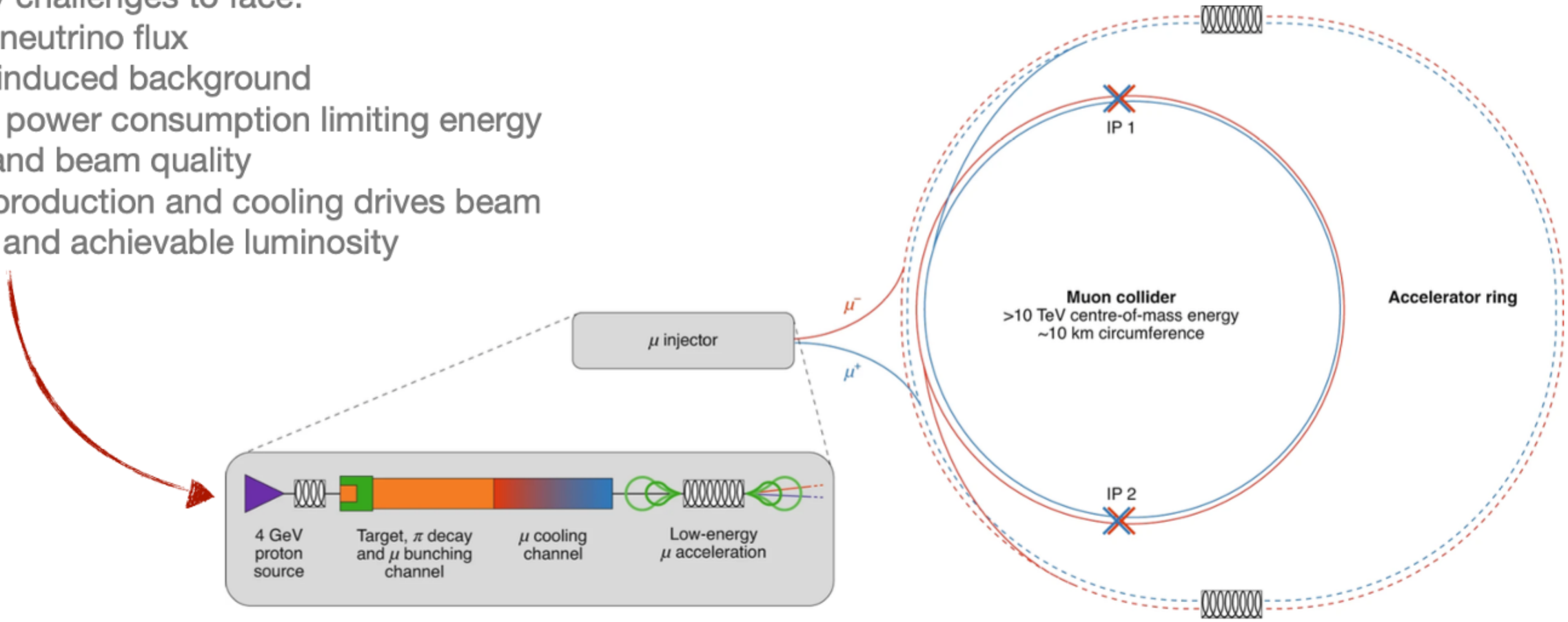
Many key challenges to face:

- Dense neutrino flux
- Beam-induced background
- Cost & power consumption limiting energy reach and beam quality
- Muon production and cooling drives beam quality and achievable luminosity



LIGHT-MATERIAL ABSORBERS FOR MUON COOLING

Contact:
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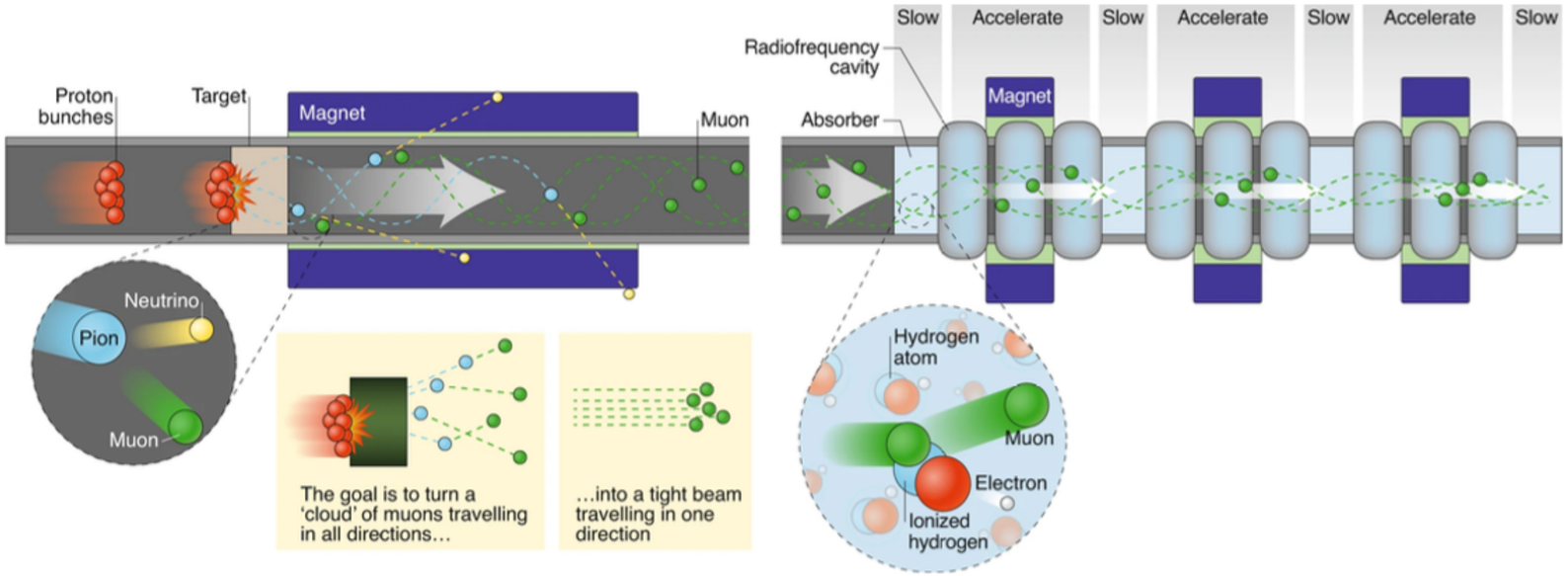
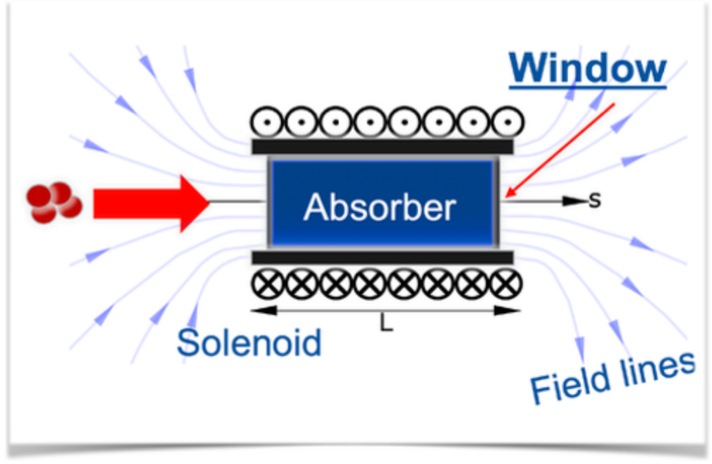
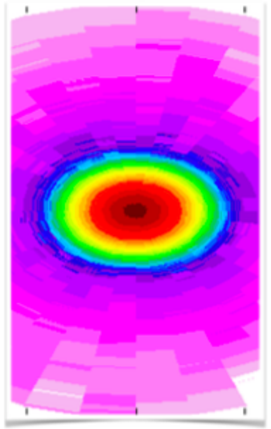


Parameters:
- 20 to 5 MeV cooling
- 4e12 muons/pulse
- 5 Hz repetition rate
- σ_{RMS}=0.6 mm

- *Low-Z* and *thin* absorbers (LiH, H_2,…) to minimize beam Multiple Scattering
- Thin windows to contain liquid absorbers (Be, Si_3N_4, SiC, C

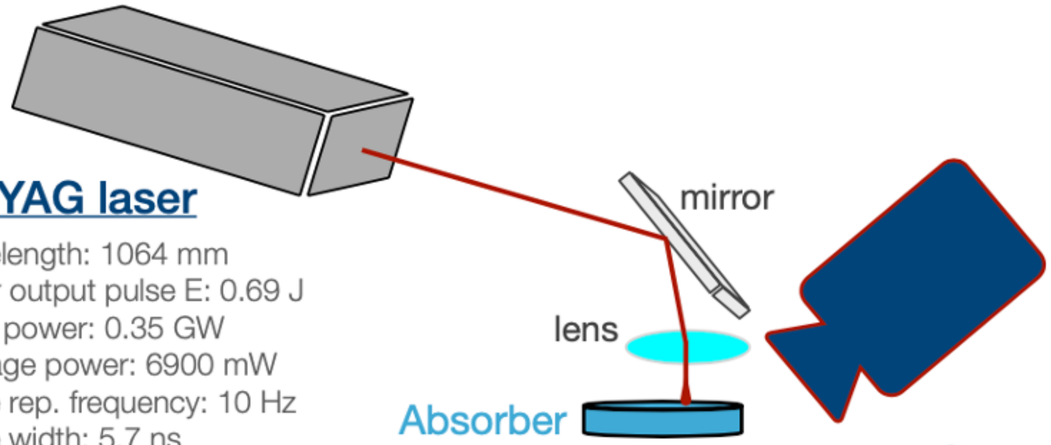




ABSORBER MATERIAL CHARACTERISATION

Target crash test with photons

Ex ante ex post characterisation

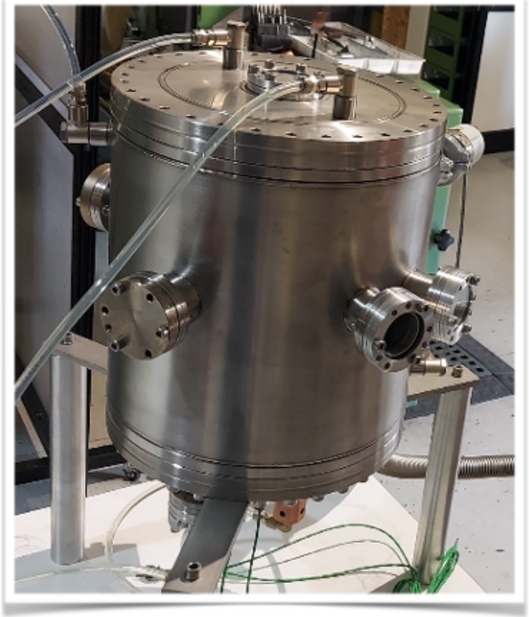


Nd:YAG laser

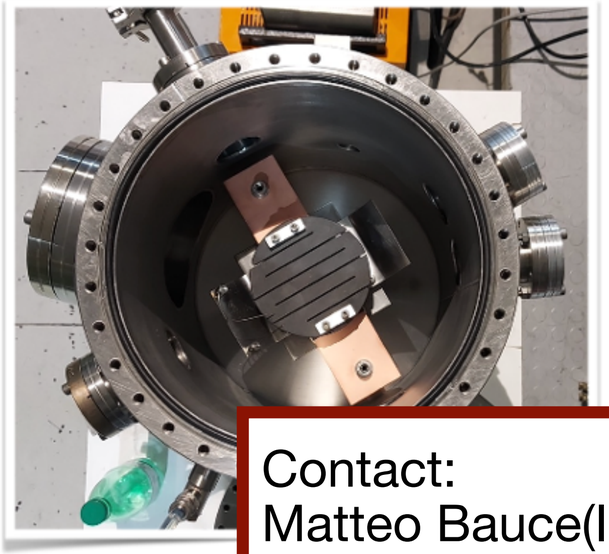
Wavelength: 1064 mm
Laser output pulse E: 0.69 J
Peak power: 0.35 GW
Average power: 6900 mW
Pulse rep. frequency: 10 Hz
Pulse width: 5.7 ns

Infrared Camera
FLIR X6901sc SLS

Optic: 17 mm, calibrated in the range [-80 °C, +300 °C]



vacuum chambers for thermal measurements



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SUMMARY LIST OF PHD THESIS PROPOSALS

Contact	Thesis Topic	Research Area	email
Manuela Boscolo	**Measurement and control of the luminosity at FCC-ee**	Future e+e- collider FCCee	manuela.boscolo@lnf.infn.it
	Study of the IR optics and machine related backgrounds at FCC-ee		
Laura Bandiera	**Hybrid Crystal-based Positron Source: experimental tests on the targets**		bandiera.fe.infn.it
	Hybrid Crystal-based Positron Source: MC with Geant4 optimization of the source		
Marco Romagnoni Andrea Mazzolari	**Curved crystals for particle accelerators**	Mu2e / Muon Collider	rmgmrc@unife.it mazzolari@fe.infn.it
Alexei Sytov	**Advanced Particle-In-Cell simulations of laser-driven plasma wakefield acceleration**	Plasma Wakefield Acceleration	sytov@fe.infn.it
Matteo Bauce	**Study of thermal stress for absorber materials in the Muon Collider Ionization cooling cells**	Muon Collider	matteo.bauce@roma1.infn.it