Future Circular Collider

Powering tomorrow's discoveries:
INFN Trieste in the European Strategy, Trieste, 20 November 2024

Cobal Marina, Faraj Mohammed, Marafatto Lorenzo, Nitika Nitika, Panizzo Giancarlo, Pinamonti Michele, Pintucci Laura, Ricci Bernardo, Toffolin Leonardo

Università e INFN Trieste/Gruppo collegato di Udine

FUTURE CIRCULAR COLLIDER Innovation Study

INFN

UNIVERSITÀ DEGLI STUDI DI UDINE hic sunt futura

http//cern.ch/fcc

CERN

photo: J.

Overview

- The Future Circular Collider
  - Motivation
  - FCC integrated program
  - Present status
- INFN Udine/Trieste activities
  - Past and present analysis efforts:
    - AFB
  - Detector simulation
    - IDEA detector and Preshower simulation studies

The Future Circular Collider (FCC)

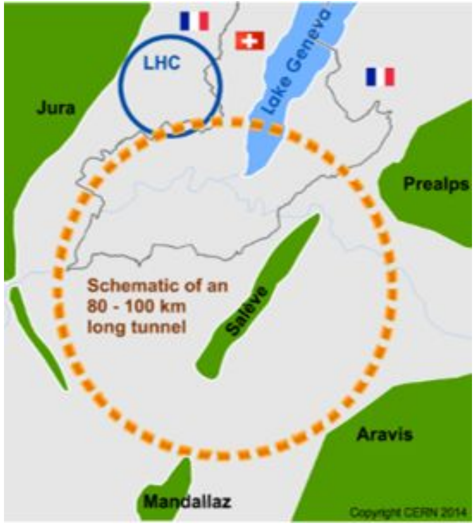
Motivation

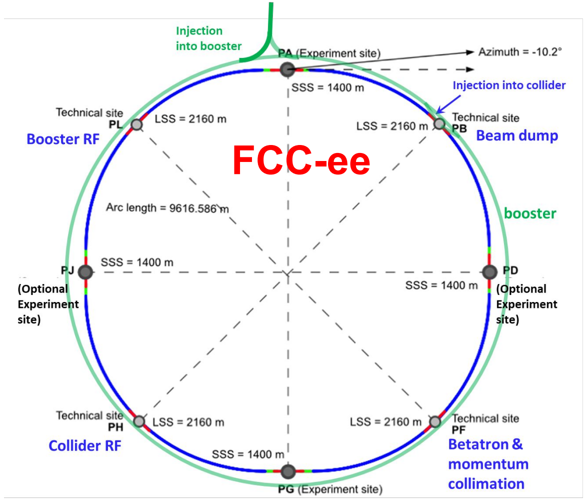
- New physics exists, but there is no clear indication of the energy scale at which it will manifest (see talk by David Marzocca)
- Then we need both
  - A **precision machine** for indirect searches (like LEP, but with much larger statistics): lepton collider
  - A **discovery machine**, taking above inputs (like LHC): hadron collider

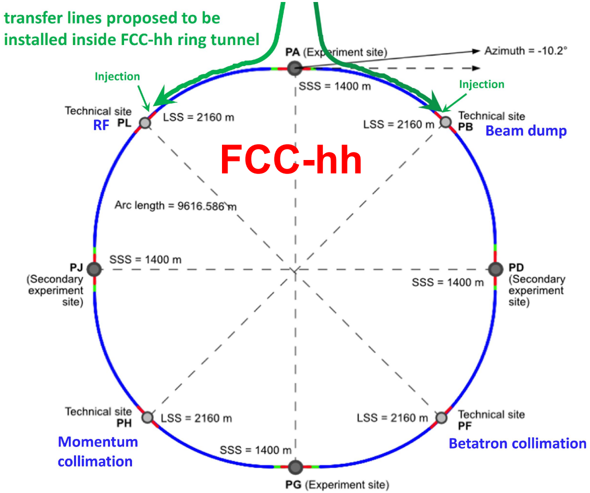
FCC integrated program

comprehensive long-term program maximizing physics opportunities

- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, pp & AA collisions; e-h option**
- highly synergetic and complementary programme boosting the physics reach of both colliders
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows the start of a new, major facility at CERN within a few years of the end of HL-LHC

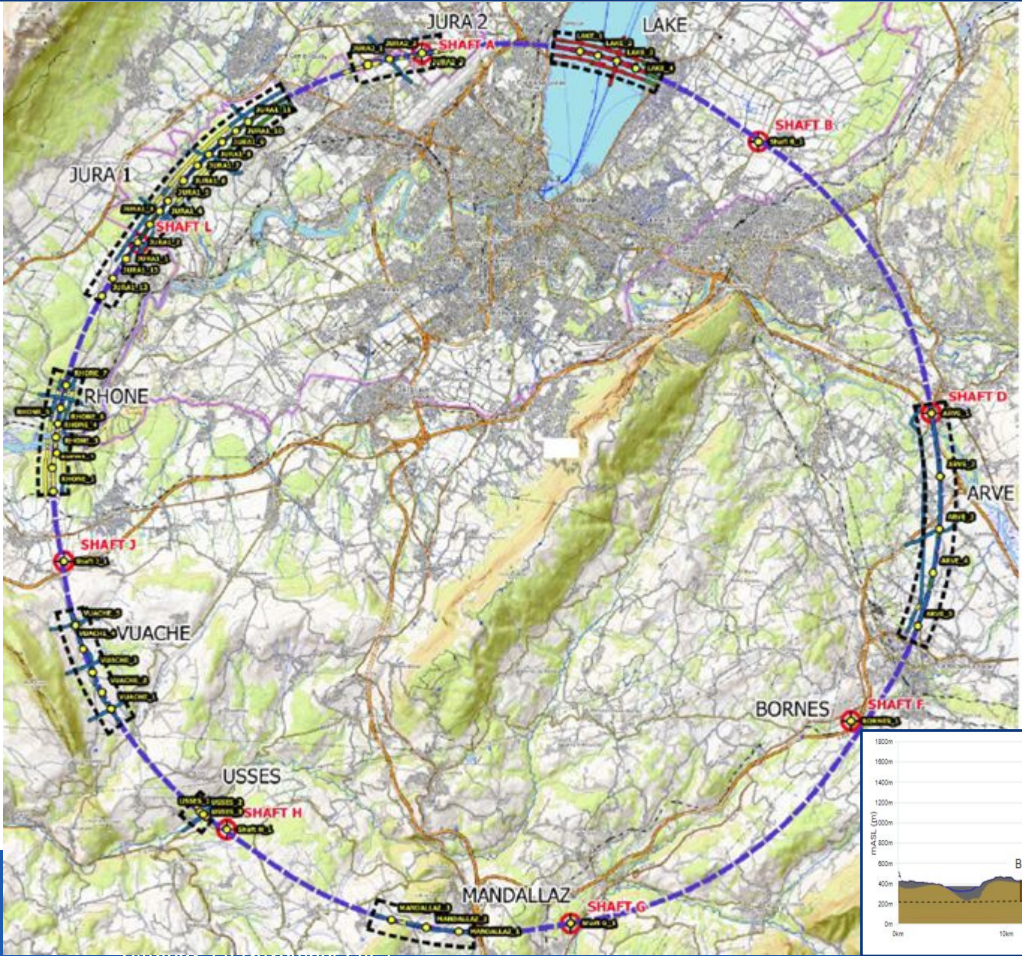






2020 - 2045 | **2045 - 2065** | **2070 -**

Present status: site investigations

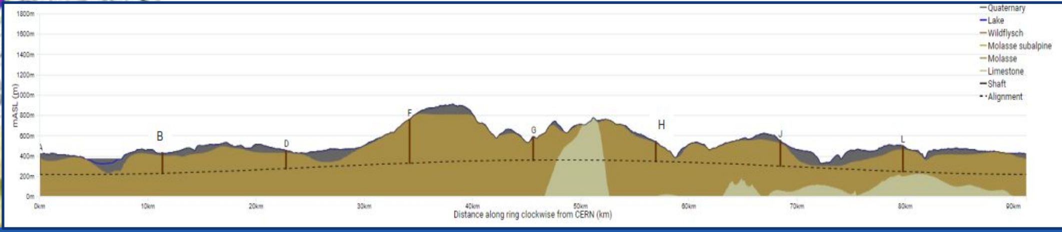


Site investigations to identify exact location of geological interfaces:

- Molasse layer vs moraines/limestone
- ~30 drillings and ~90 km seismic lines

 Vertical position and inclination of tunnel

Sondage A89 (2007) incliné de 45° de 125 ml (surface plateforme estimée : 12 x 12 m soit environ 150 m²)



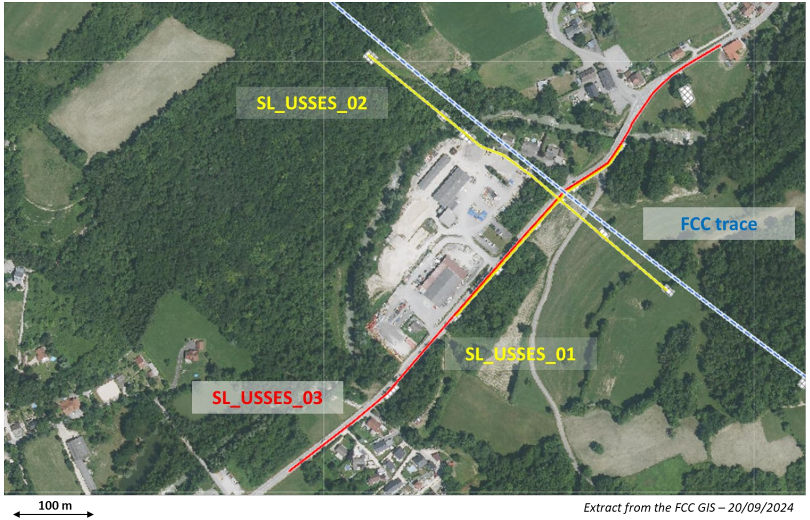
Start of site investigations – seismic investigations

First seismic line :

Seismic line SL_USSES_02 :
Acquisition date : 01/10/2024
Length : 480 meters
Method(s) : Explosive and Seismic gun
Geophones : 96 units (5 meters of spacing)
Shot points : 13 shot points in total

Second seismic line :

Seismic line SL_USSES_01 :
Acquisition date : 02/10/2024
Length : 300 meters
Method(s) : Weight drop
Geophones : 60 units (5 meters of spacing)
Shot points : 15 shot points in total



Extract from the FCC GIS – 20/09/2024

Status of site investigations – drillings

Drilling for first borehole has commenced on 14/10/2024

The drilling (USSES 2) is within the commune of Marlioz

The drill site is located within the storage yard of a private construction company (Besson).

Drilling Depth = 70m

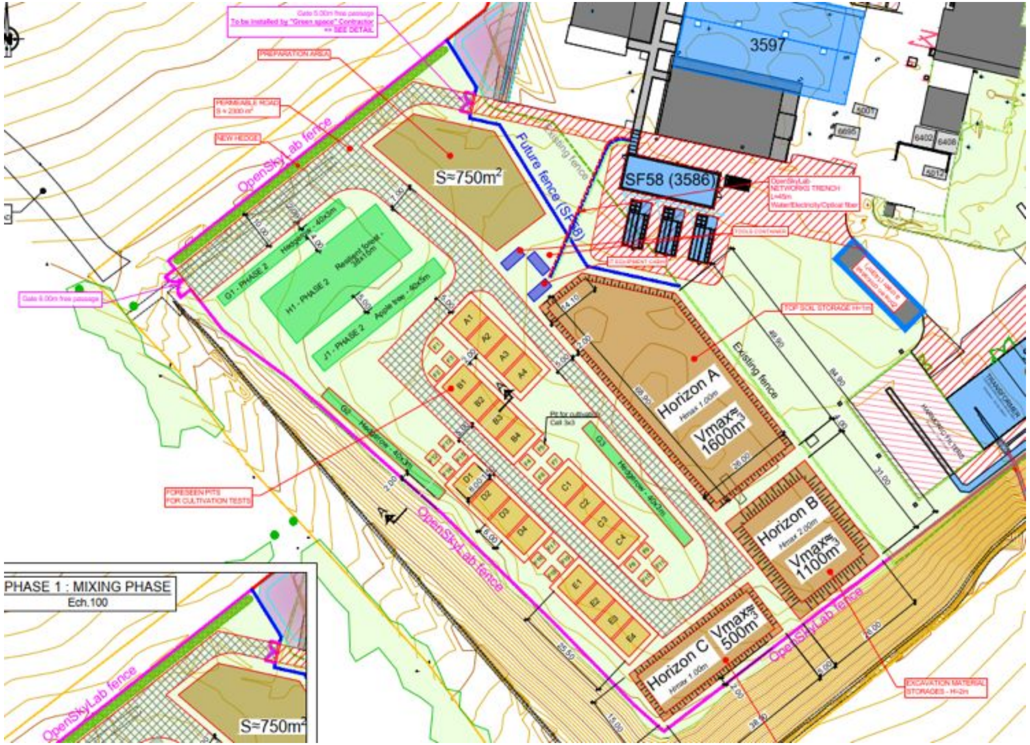
Fully cored recovery

Drill time should be about 2 weeks

Equipped with Piezometer

Development of excavation material re-use opportunities
OpenSkyLab: academic and industrial collaboration @LHC P5 CMS

- **Transformation of Molasse (FCC ~8 Mm^3 volume) into fertile soil for agricultural and other uses**
- **Materials: Molasse from the HL-LHC construction**
- **Duration: 4+ years (2024 -)**
- **Trials with 5 000 t molasse**
  - Soil fertilisation process (micro-organisms, mixing with fertile soil, etc.)
  - Development of fertilisation mix products and quality managed processes
  - Experimental phase with scientific protocol and field monitoring and control system support



OpenSkyLab status and progress

Start of public information & engagement sessions

First public information and discussion meeting at the Science Gateway on the 24th April at CERN.

La Roche-sur-Foron - Haute Savoie international fare April 27 to May 6

Unveiling the science of tomorrow: FCC Study takes centre stage at La Roche-sur-Foron exhibition

The Future Circular Collider team discussed the project's status and aspirations with a large number of attendees

15 MAY, 2024 | By Zoe Nikolaidou

On 15 May, RTS (Radio Télévision Suisse) broadcasted a special program celebrating CERN's 70th anniversary and hosted at CERN's Science Gateway.

Status of FCC global collaboration

Increasing international collaboration as a prerequisite for success:
links with **science, research & development** and **high-tech industry** will be essential to further advance and prepare the implementation of FCC

FCC Feasibility Study:
Aim is to increase further the collaboration, on all aspects, in particular on Accelerator and Particle/Experiments/Detectors

141 Institutes

32 countries + CERN

FUTURE CIRCULAR COLLIDER
Feasibility Study

INFN Udine/Trieste activities: the Steering committe

The FCC International Steering Committee

Function

Under the strategic guidance of the Council, the Steering Committee provides organisational and technical supervision for the execution of the Feasibility Study. Specific tasks include:

- establishing the Feasibility Study work programme
- receiving reports on the progress of the individual work packages;
- evaluating milestones and deliverables to ensure consistency in implementation and compliance with the work plan;

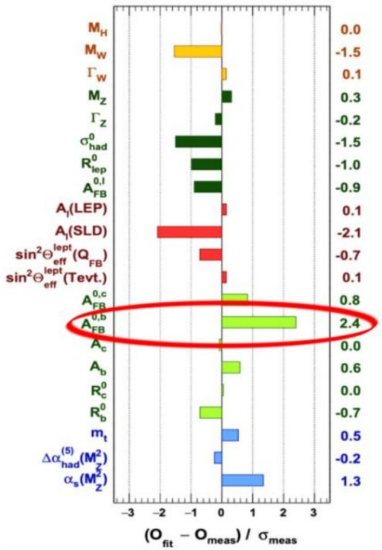
Marina Cobal one of the 12 members

INFN Udine/Trieste activities: analysis, simulation

The Forward Backward Asymmetry of the bottom quark

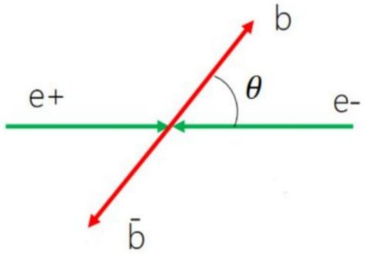
Introduction

- **The goal**:
  - precise measurement of **forward-backward asymmetry** of $b\bar{b}$ in $e^+e^- \rightarrow Z \rightarrow b\bar{b}$ events
  - **>2σ deviation** btw. LEP combination and EW fits
  - ideal **benchmark** measurement for FCC-ee @m_Z



$$\frac{d\sigma_{b\bar{b}}}{d\cos\theta_b} = \sigma_{b\bar{b}}\,\frac{3}{8}\left(1 + \cos^2\theta_b + \frac{8}{3}A^b_{\mathrm{FB}}\cos\theta_b\right)$$

- **The measurement**:
  - $A^b{}_{FB}$ can be extracted from ***cosθ(b)*** distribution
  - experimental distinction between b and $\bar{b}$ needed ⇒ quark **charge** determination



b-quark charge determination

- Two classes of **methods**:

1. **Jet charge**:
    - charge of jet obtained as weighted **sum** of charges of constituent **tracks**
    - can be applied to all jets ⇒ maximal efficiency
    - relatively low purity
    - strong dependence on jet shape and hadronization

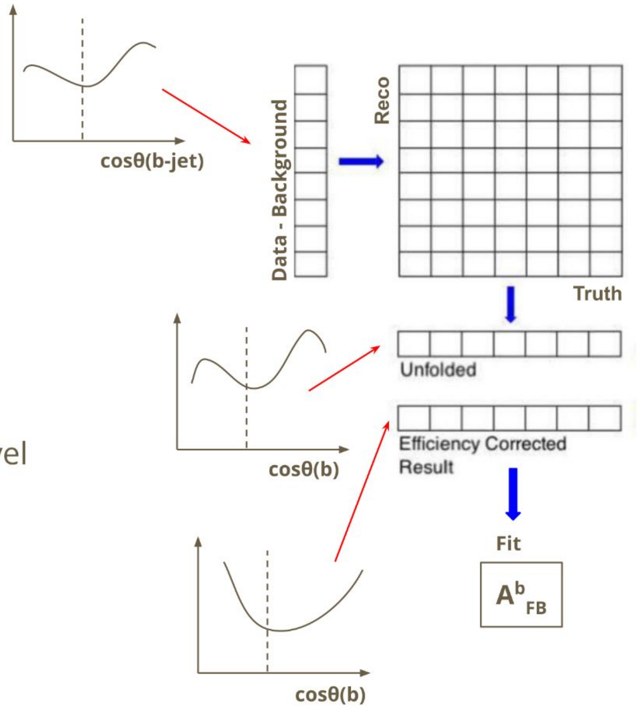
2. **Soft lepton tagging**:
    - charge of *b* inferred from charge of e or μ in ***B*-hadron semileptonic decay**
    - relatively low efficiency (restricted to semileptonic decays)
    - better purity
    - highly sensitive to *B*-hadron decay modelling

The Forward Backward Asymmetry of the bottom quark

Analysis strategy

- **Investigated workflow**:

    1. build **reco-level observable** using:
        - jet direction
        - charge determined with one of the two methods (studies in parallel)
    2. perform **unfolding** from reco-level to parton-level
    3. extract A^b_{FB} from **fit** to unfolded distribution

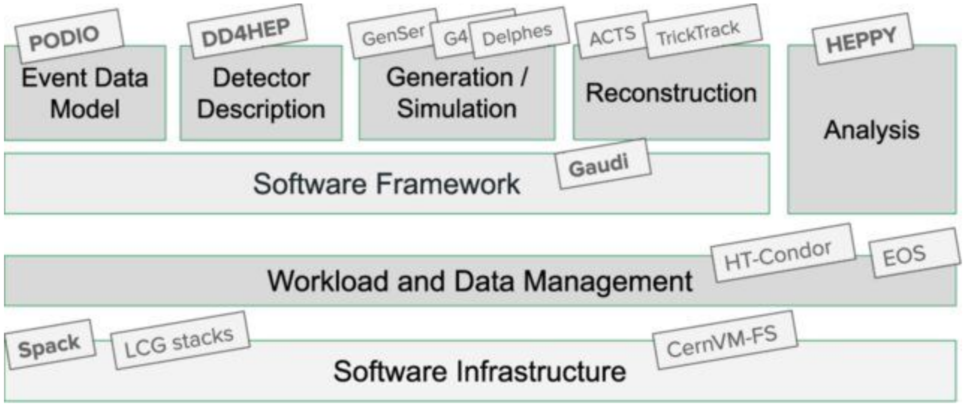


Key4hep & DD4hep

Key4hep

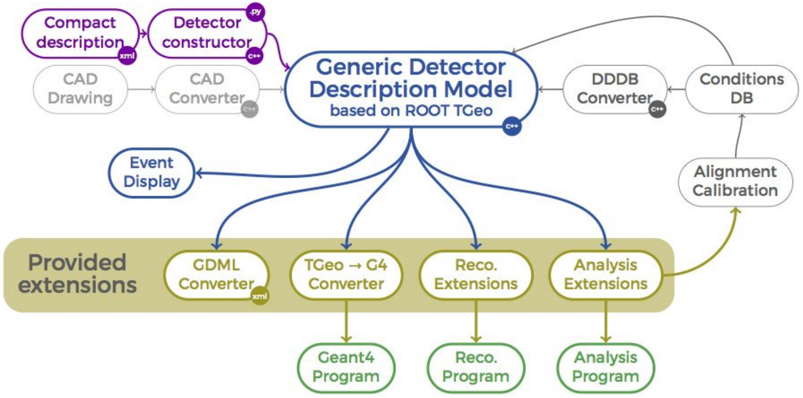
The turnkey software stack for FCC and all other future colliders

- ❖ The high-energy physics (HEP) community decided to create a software ecosystem that integrates the best software components in an optimal way, providing a ready-to-use, full-fledged solution for data processing in future collider experiments
- ❖ This effort involves contributions from various communities, including CEPC, CLIC, EIC, FCCee, FCChh, ILC, LUXE, Muon Collider.



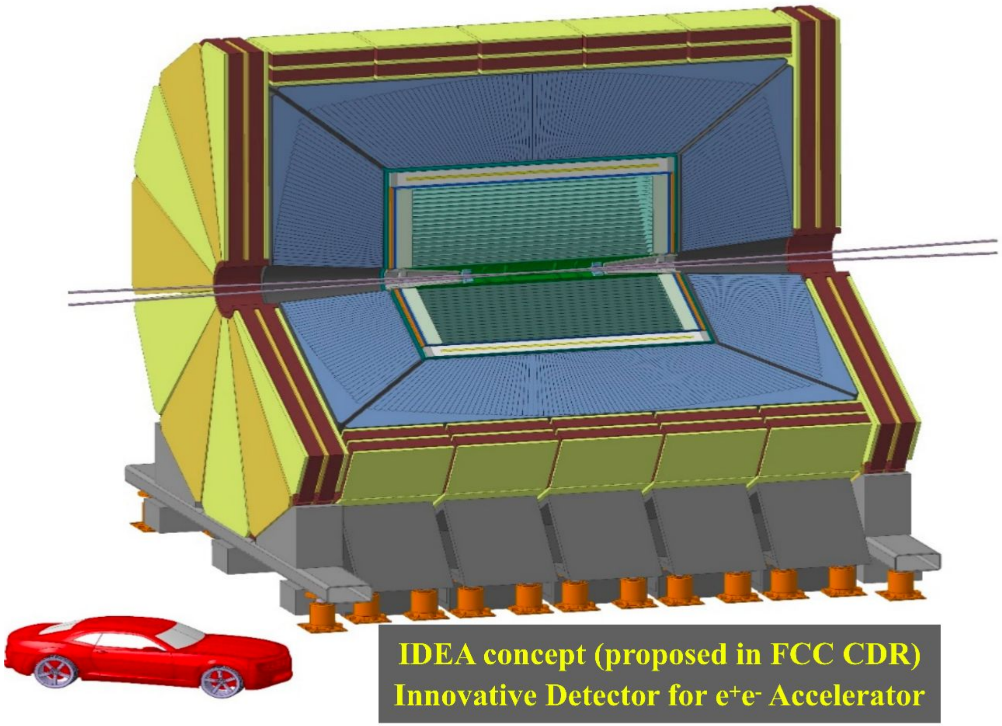
DD4hep geometry toolkit

- ❖ supporting the full life cycle of the experiment
- ❖ this package serves as a single source of information for full simulation, reconstruction, alignment, visualization, and analysis used by CEPC, CLIC, CMS, EIC, FCC, ILC, LHCb, and other projects
- ❖ all future Higgs factory detector simulation models in one package https://github.com/key4hep/k4geo
- ❖ can use plug-and-play for sub detectors to study detector variants



https://dd4hep.web.cern.ch/page/about/

IDEA detector, preshower



- **New, innovative, possibly more cost-effective concept**
  - Silicon vertex detector
  - Short-drift, ultra-light wire chamber
  - Dual-readout calorimeter
  - Thin and light solenoid coil *inside* calorimeter system
    - Small magnet   small yoke
  - Muon system made of 3 layers of μ-RWELL detectors in the return yoke

https://pos.sissa.it/390/

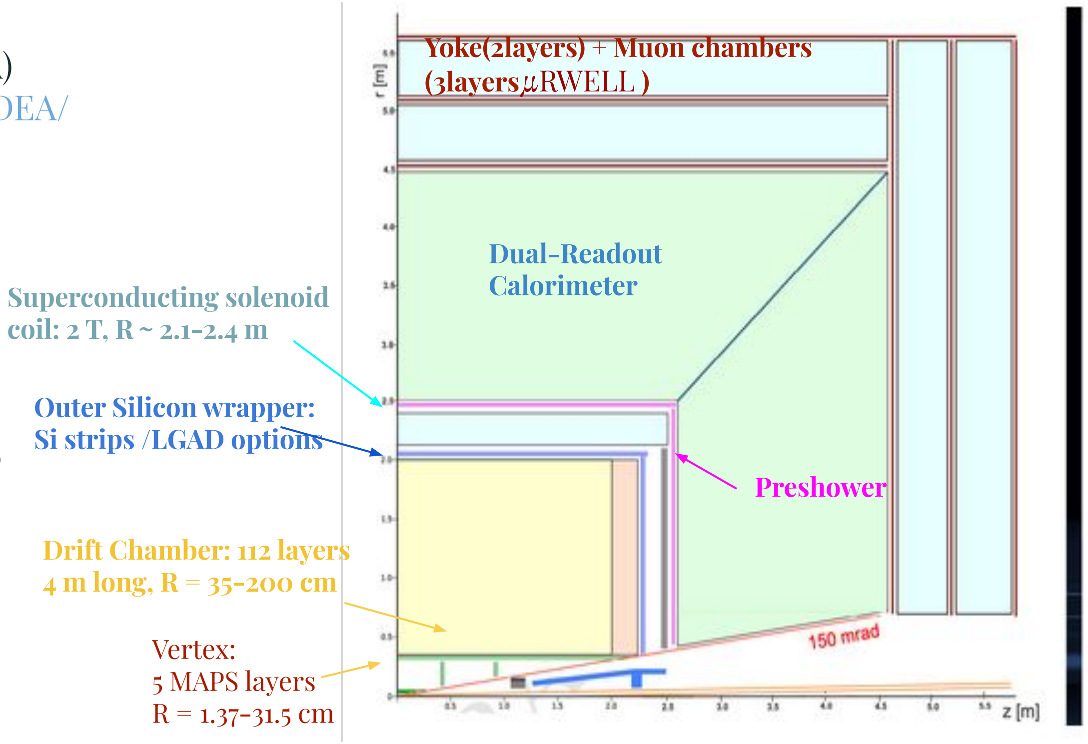
04/11/2024 FCC project in Italy - Paolo Giacomelli 3

IDEA

Innovative Detector for e+ e− Accelerator (IDEA)
https://fcc-ee-detector-full-sim.docs.cern.ch/IDEA/

IDEA detector concept consists of:

- ❖ Silicon pixel vertex detector.
- ❖ Large-volume extremely light drift wire chamber.
- ❖ Surrounded by a layer of silicon micro-strip detectors.
- ❖ Dual readout crystal calorimeter.
- ❖ Thin low-mass superconducting solenoid coil.
- ❖ Pre-shower detector based on μRWELL.
- ❖ Dual readout fiber calorimeter.
- ❖ Muon chambers based on μRWELL technology inside magnet return yoke.



IDEA Detector

Our group involved in simulation of pre-shower

Summary

- FCC in our futures, a present reality
- Udine/Trieste active in
  - Management
  - Analysis and software
  - Preshower simulations
- … we need you!

Thanks!

BackUp

FCC-ee main machine parameters

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45.6	80	120	182.5
beam current [mA]	1270	137	26.7	4.9
number bunches/beam	11200	1780	440	60
bunch intensity [10^{11}]	2.14	1.45	1.15	1.55
SR energy loss / turn [GeV]	0.0394	0.374	1.89	10.4
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.1/0	2.1/9.4
long. damping time [turns]	1158	215	64	18
horizontal beta* [m]	0.11	0.2	0.24	1.0
vertical beta* [mm]	0.7	1.0	1.0	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.71	1.59
vertical geom. emittance [pm]	1.9	2.2	1.4	1.6
vertical rms IP spot size [nm]	36	47	40	51
beam-beam parameter ξ_x / ξ_y	0.002/0.0973	0.013/0.128	0.010/0.088	0.073/0.134
rms bunch length with SR / BS [mm]	5.6 / 15.5	3.5 / 5.4	3.4 / 4.7	1.8 / 2.2
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	140	20	≥5.0	1.25
total integrated luminosity / IP / year [ab^{-1}/yr]	17	2.4	0.6	0.15
beam lifetime rad Bhabha + BS [min]	15	12	12	11

	Z	WW	H (ZH)	ttbar
	4 years 5 x 10^{12} Z LEP x 10^5	2 years > 10^8 WW LEP x 10^4	3 years 2 x 10^6 H	5 years 2 x 10^6 tt pairs

Design and parameters to maximise luminosity at all working points:

- allow for 50 MW synchrotron radiation per beam.
- Independent vacuum systems for electrons and positrons
- full energy booster ring with top-up injection, collider permanent in collision mode

- ❑ x 10-50 improvements on all EW observables
- ❑ up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- ❑ x10 Belle II statistics for b, c, τ
- ❑ indirect discovery potential up to ~ 70 TeV
- ❑ direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

Up to 4 interaction points □ robustness, statistics, possibility of specialised detectors to maximise physics output

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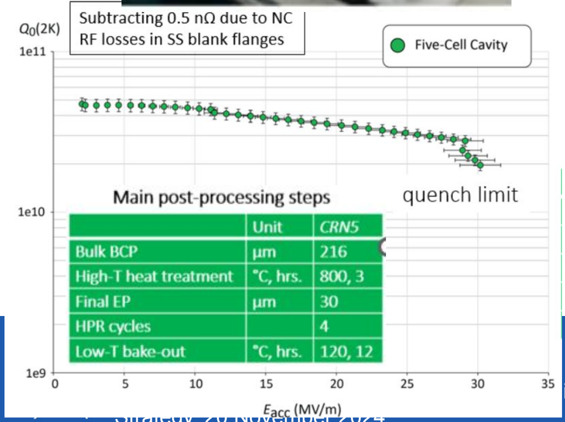
RF R&D activities

RF system R&D is key for increasing energy efficiency of FCC-ee

- Nb on Cu 400 MHz cavities (KEK as R&D partner), seamless cavity production, coating techniques
- Bulk Nb 800 MHz cavities, surface treatment techniques
- RF power source R&D in synergy with HL-LHC.

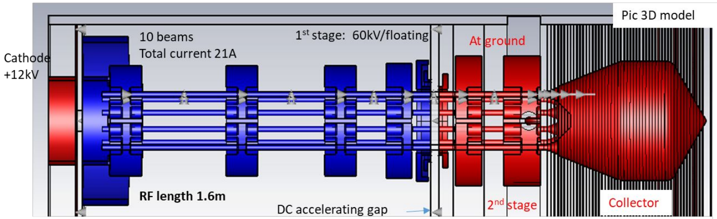
5-cell 800 MHz cavity development collaboration with JLAB

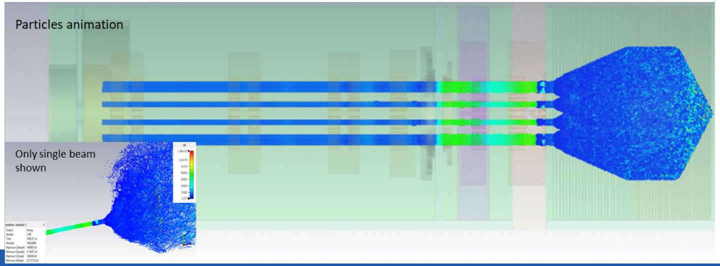


	Unit	CRN5
Bulk BCP	µm	216
High-T heat treatment	°C, hrs.	800, 3
Final EP	µm	30
HPR cycles		4
Low-T bake-out	°C, hrs.	120, 12

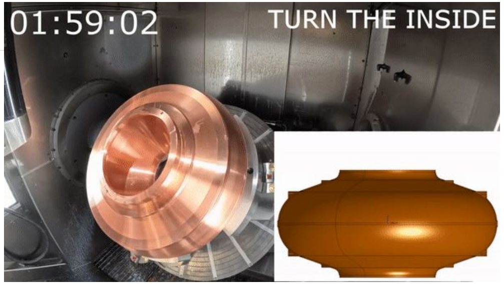
high-efficiency klystron R&D

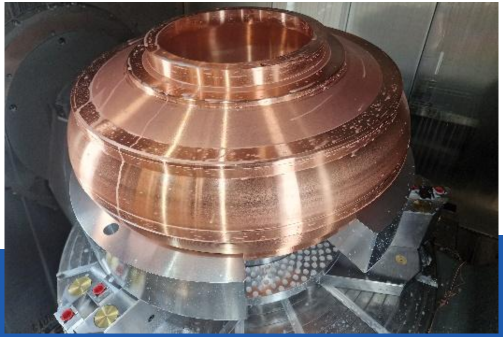
Novel two-stage MBK klystron: CW, 400MHz, 1.28MW.





400 MHz monoblock prototype





Interaction region mock up at INFN-LNF (Frascati)

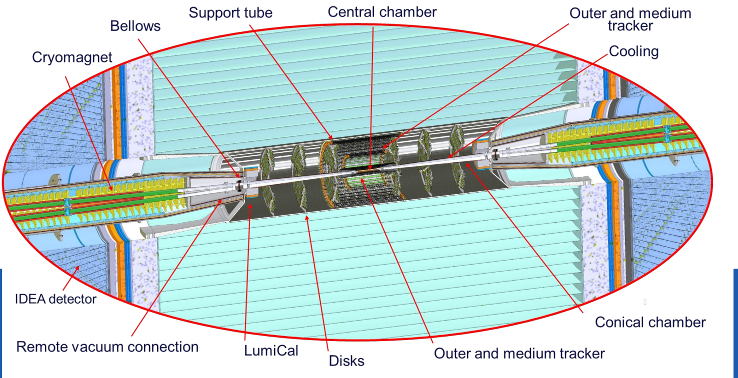
INFN-LNF, CERN and INFN-Pisa collaboration

Assembly & test lab in Frascati

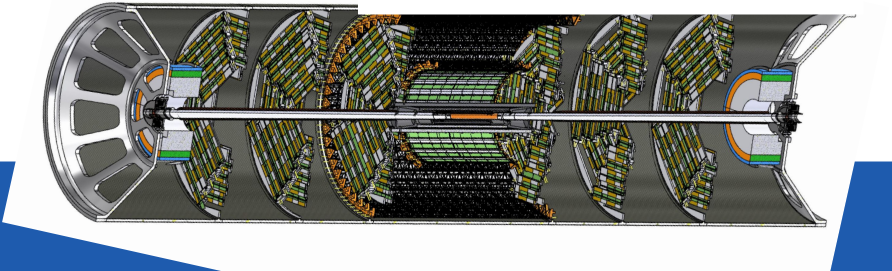
B. 5/a Serv. ing. mecc. (SIM) div.acc.

- Central chamber with paraffin cooling **in production** – **Tests starting end of Oct.**

  Conical chamber(s) with water cooling **~ to be ordered** – **Delivery end of the year**
- Vertex mechanical structure Carbon fibre foils **arriving**
- Vertex air cooling tunnel – **orders placed** – **assembled Q1 2025**
- Support tube - **orders expected Q1-2025**
- Bellows **~ design almost finished, to be ordered**
- Integration & overall assembly **Q4-2025**



M. Boscolo,
F. Fransesini,
F. Palla



Other FCC-ee science applications under study

→ **Workshop on "Other Science Opportunities at the FCC-ee"**
28-29 November at CERN, https://indico.cern.ch/event/1454873/

for example:

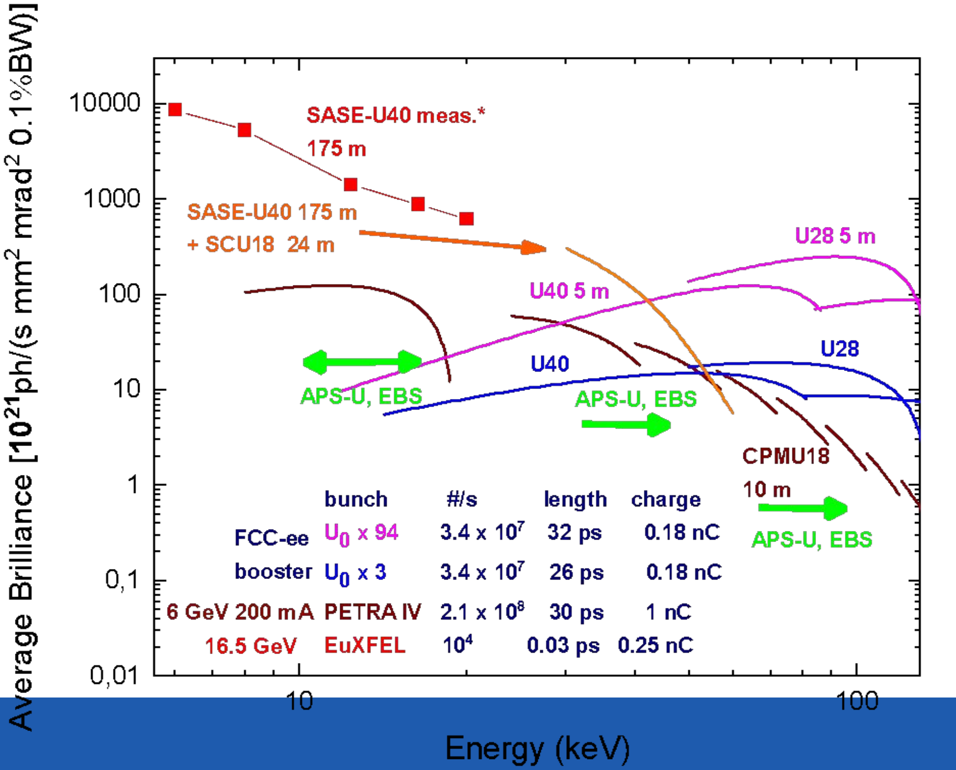
FCC-ee booster as diffraction limited storage ring with coherent synchrotron radiation down to 0.1 Å

FCC-ee injector as the world's **ultimate positron source** for material studies and paving a path towards the first **Bose-Einstein condensation of Ps** (511-keV gamma-ray laser)

using beamstrahlung for **radionuclide production**

e^- beam driven **neutron source**

etc.



FUTURE CIRCULAR COLLIDER

FCC-hh main machine parameters

parameter	FCC-hh	HL-LHC	LHC
collision energy cms [TeV]	81 - 115	14	
dipole field [T]	14 - 20	8.33	
circumference [km]	90.7	26.7	
arc length [km]	76.9	22.5	
beam current [A]	0.5	1.1	0.58
bunch intensity [10^{11}]	1	2.2	1.15
bunch spacing [ns]	25	25	
synchr. rad. power / ring [kW]	1020 - 4250	7.3	3.6
SR power / length [W/m/ap.]	13 - 54	0.33	0.17
long. emit. damping time [h]	0.77 – 0.26	12.9	
peak luminosity [10^{34} cm^{-2}s^{-1}]	~30	5 (lev.)	1
events/bunch crossing	~1000	132	27
stored energy/beam [GJ]	6.1 - 8.9	0.7	0.36
Integrated luminosity/main IP [fb^{-1}]	20000	3000	300

With FCC-hh after FCC-ee: significant amount of time for high-field magnet R&D, aiming at highest possible collision energies

- Target field range for cryo-magnet R&D

❑ high-field superconducting magnets: 14 - 20 T
❑ power load in arcs from synchrotron radiation: 4 MW □ cryogenics, vacuum
❑ stored beam energy: ~ 9 GJ □ machine protection
❑ pile-up in the detectors: ~1000 events/xing
❑ optimization of energy consumption: □ R&D on cryo, HTS, beam current, …

h, including:

❑ Direct discovery potential up to ~ 40 TeV
❑ Measurement of Higgs self to ~ 5% and ttH to ~ 1%
❑ High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays (γγ, Zγ, μμ)
❑ Final word about WIMP dark matter

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Progress on international collaboration

Joint Statement of Intent between The United States of America and The European Organization for Nuclear Research concerning Future Planning for Large Research Infrastructure Facilities, Advanced Scientific Computing, and Open Science

The United States and CERN intend to:

- Enhance collaboration in future planning activities for large-scale, resource-intensive facilities with the goal of providing a sustainable and responsible pathway for the peaceful use of future accelerator technologies;
- Continue to collaborate in the feasibility study of the Future Circular Collider Higgs Factory (FCC-ee), the proposed major research facility planned to be hosted in Europe by CERN with international participation, with the intent of strengthening the global scientific enterprise and providing a clear pathway for future activities in open and trusted research environments; and
- Discuss potential collaboration on pilot projects on incorporating new analytics techniques and tools such as artificial intelligence (AI) into particle physics research at scale.

Should the CERN Member States determine the FCC-ee is likely to be CERN's next world-leading research facility following the high-luminosity Large Hadron Collider, the United States intends to collaborate on its construction and physics exploitation, subject to appropriate domestic approvals.

26 April 2024

White House Office of Science and Technology Policy Principal Deputy U.S. Chief Technology Officer Deirdre Mulligan signed for the United States while Director-General Fabiola Gianotti signed for CERN.

EU Competitiveness Report

edited by Mario Draghi, and officially handed over to Ursula von der Leyen in September 2024

https://commission.europa.eu/topics/strengthening-european-competitiveness/eu-competitiveness-looking-ahead_en

"One of CERN's most promising current projects, with significant scientific potential, is the construction of the Future Circular Collider (FCC): a 90-km ring designed initially for an electron collider and later for a hadron collider..

Refinancing CERN and ensuring its continued global leadership in frontier research should be regarded as a top EU priority*, given the objective of maintaining European prominence in this critical area of fundamental research, which is expected to generate significant business spillovers in the coming years."*

Supporting statements at CERN's 70 anniversary

"….No European country alone could have built the world's largest particle collider. CERN has become a global hub because it rallied Europe and this is even more crucial today.

I am proud that we have financed the feasibility study for CERN's Future Circular Collider (FCC). This could preserve Europe's scientific edge and could push the boundaries of human knowledge even further. *And as the global science race is on, I want Europe to switch gears. To do so, European unity is our greatest asset. …."*

Ursula von der Leyen, President of the European Commission

Possible timeline till start of construction