
FCC
SUISSE
FRANCE
Genève
Annecy
LHC

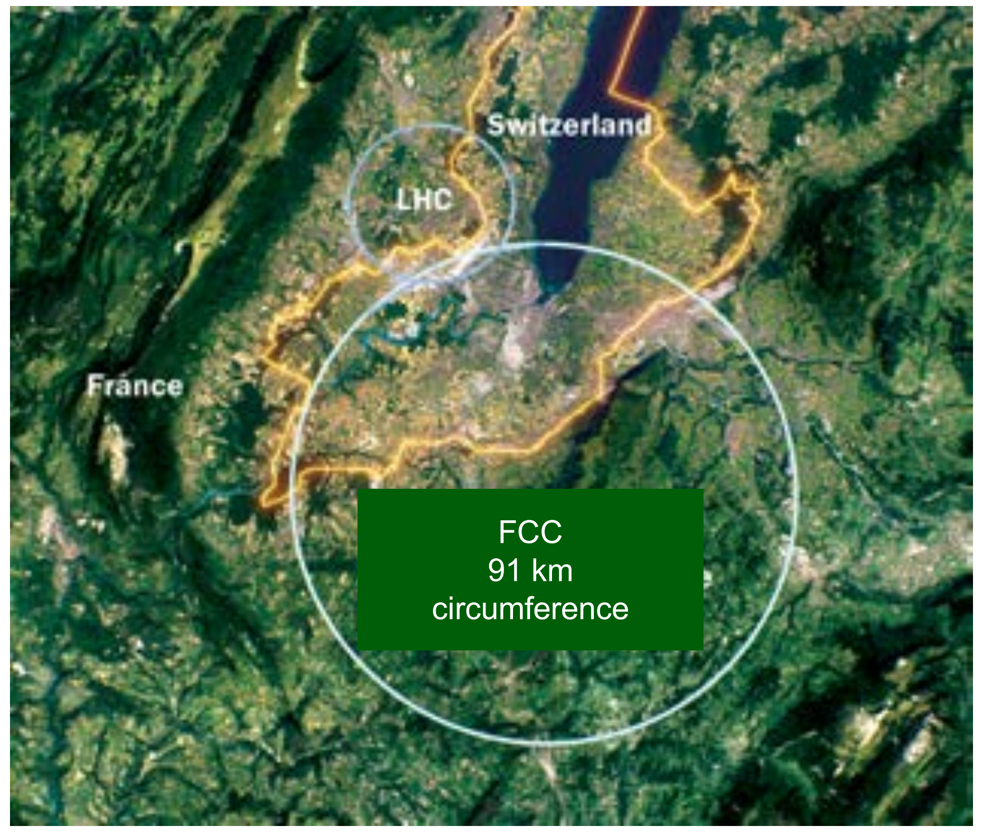
RD-FCC status of international support

- The open symposium of particle physics of partcile physics just ended in Venice
- Inputs callected from European HEP community and from extra-EU collaborators
- Inputs from RD research groups, funding agency, major HEP labs
- good discussion during the symposium to define the basic recommendation for the fiture of high energy collider physics in Europe
- several options have been studied in terms of physics potential, cost, long term vision

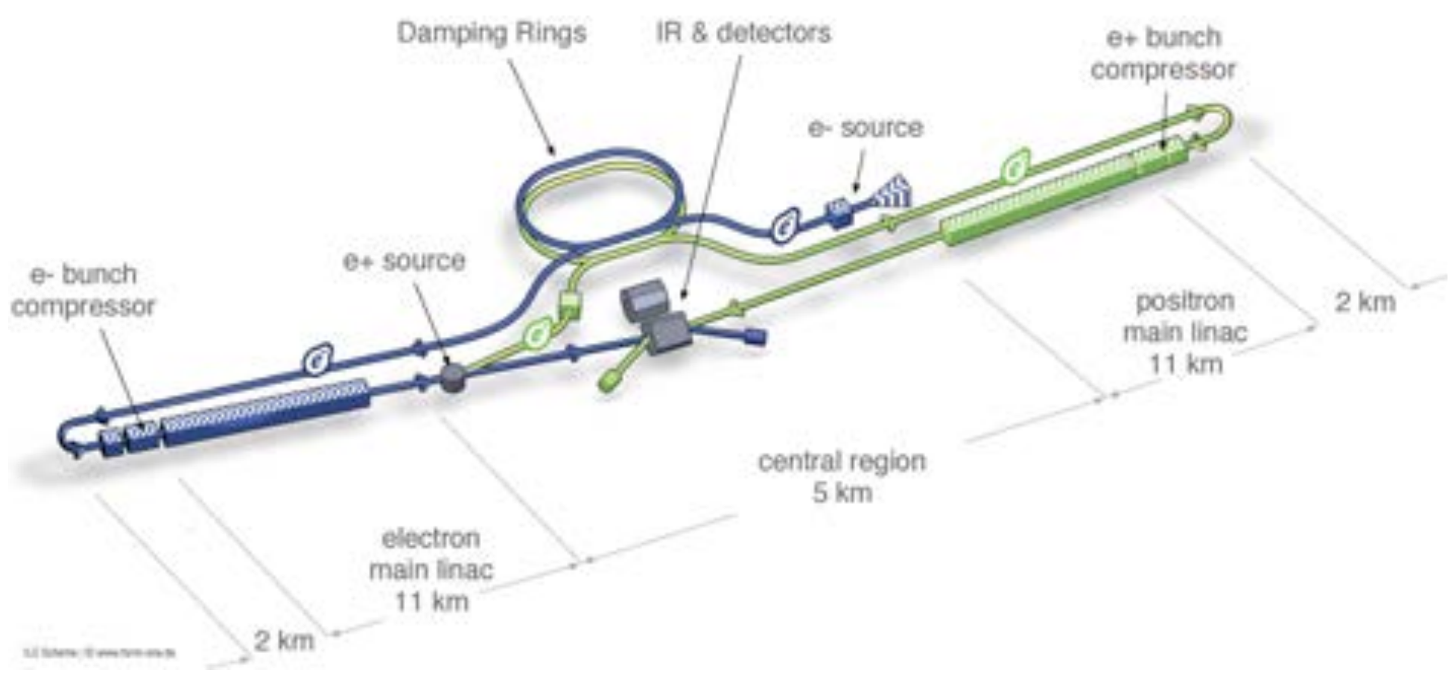
Several options considered including intermediate options in case the best preferred scenario is not favoured due to budget constraints

e^+e^- colliders
("Higgs factories")

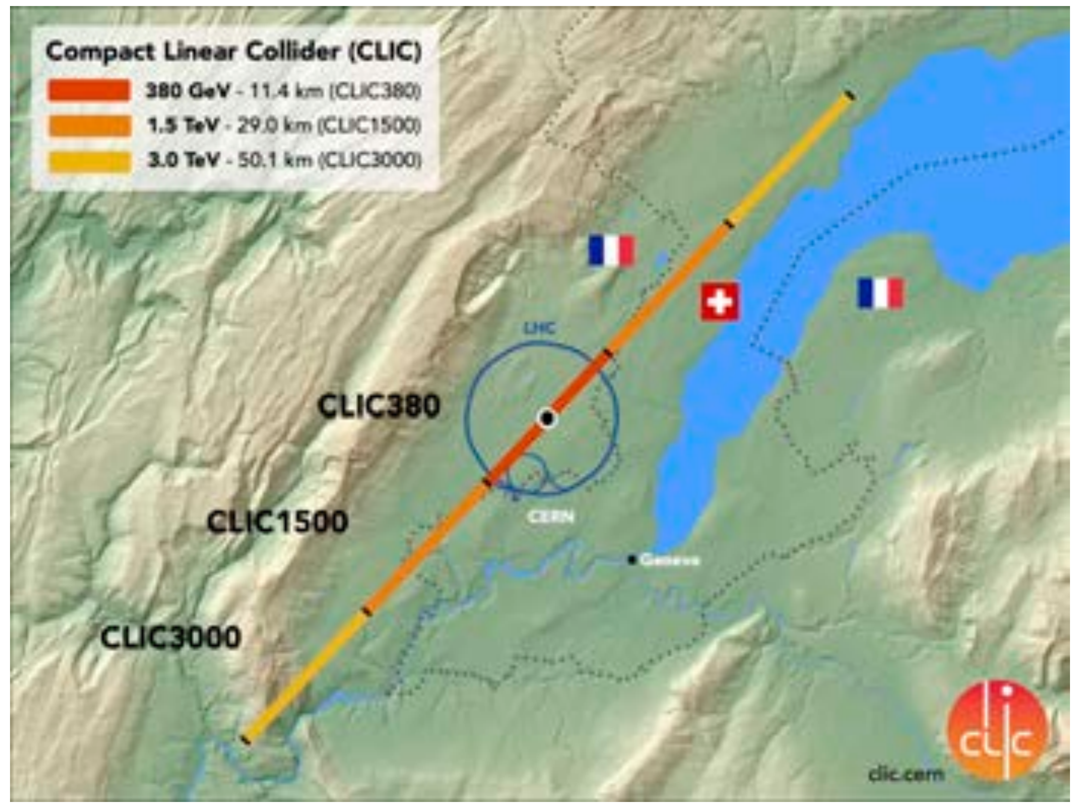
FCC-ee (e^+e^-, circular, 91 – 365 GeV)



LCF (e^+e^-, linear, 91 – 240, 550 GeV)



CLIC (e^+e^-, linear, 380 GeV, 1.5 TeV)

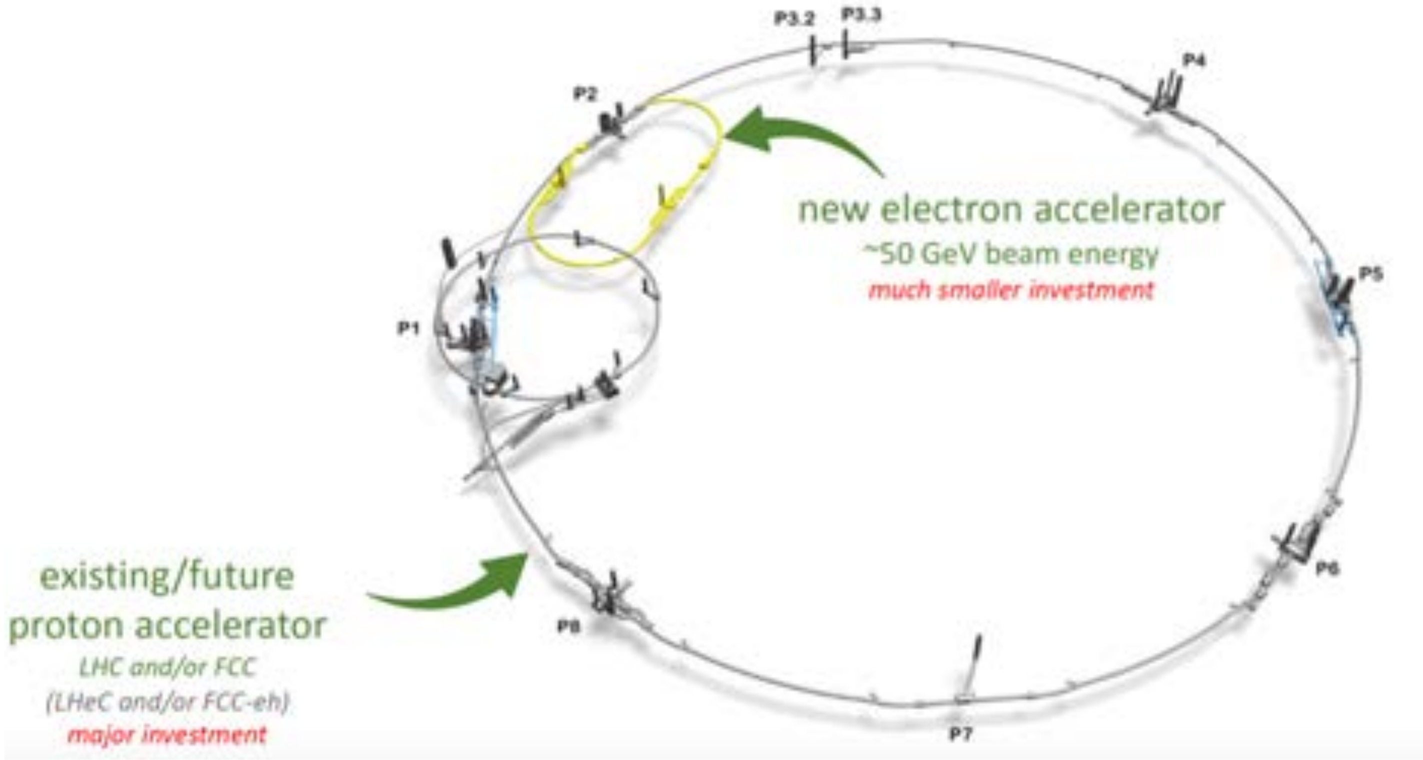


Intermediate projects

(Leave room (time, budget, resources) for further development of THE machine that can probe directly the energy frontier at the 10 TeV parton scale)

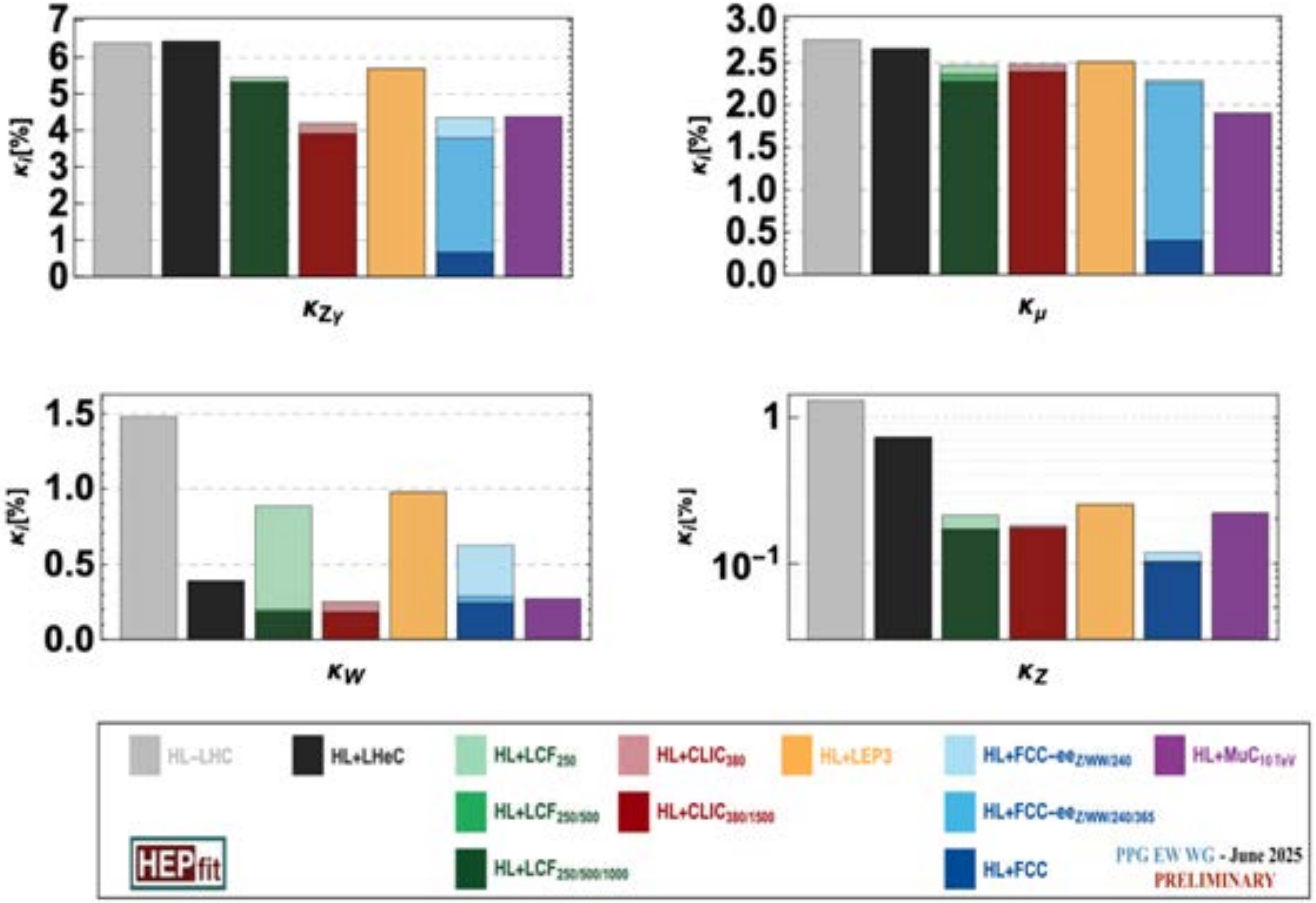
LEP3 (e^+e^-, circular, 91 – 230 GeV)

LHeC (ep, circular, electron ERL, 50 GeV e^-, > 1 TeV ep collisions)

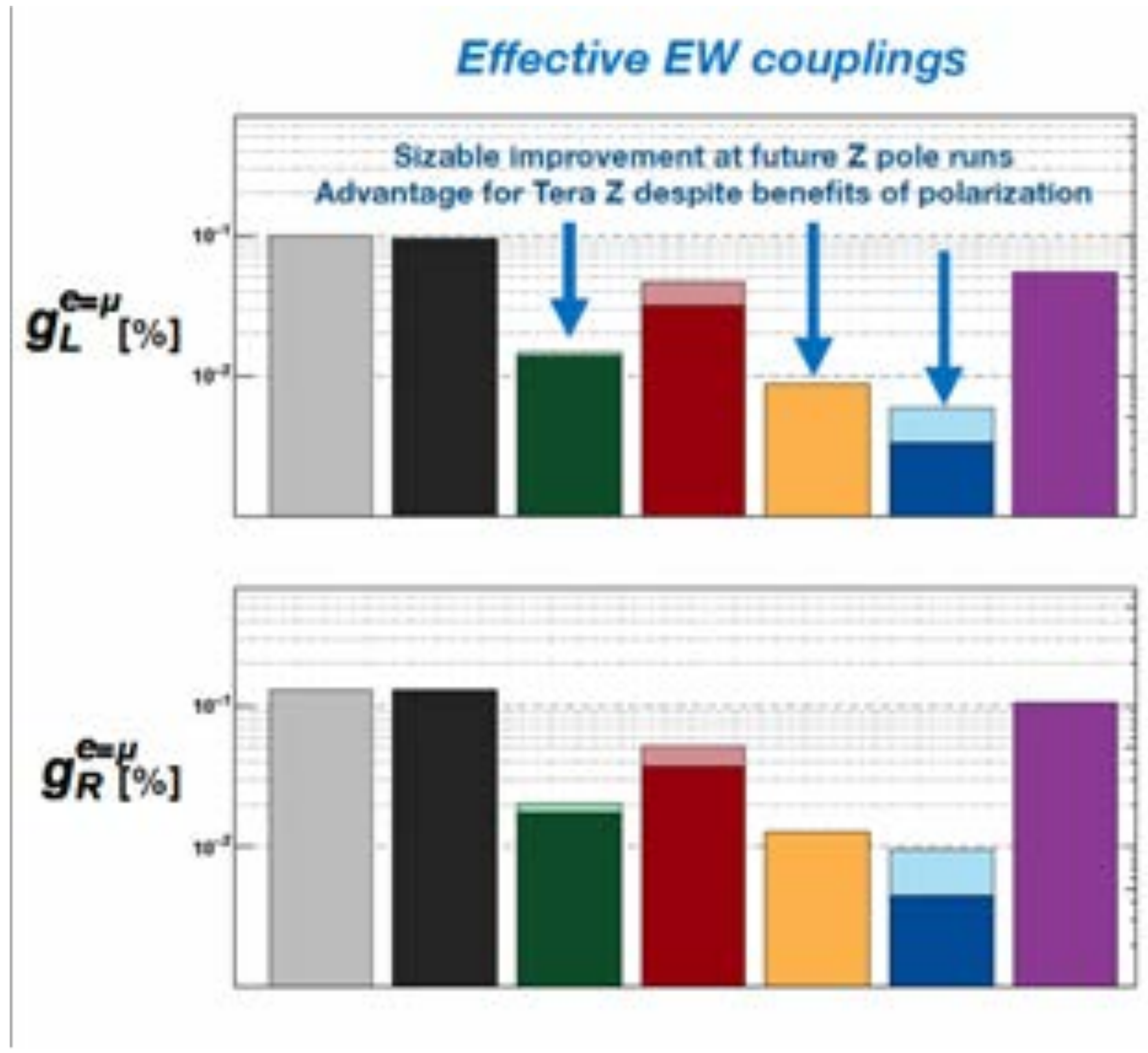


Physics output comparison, H and Z couplings

Higgs physics



Z pole physics

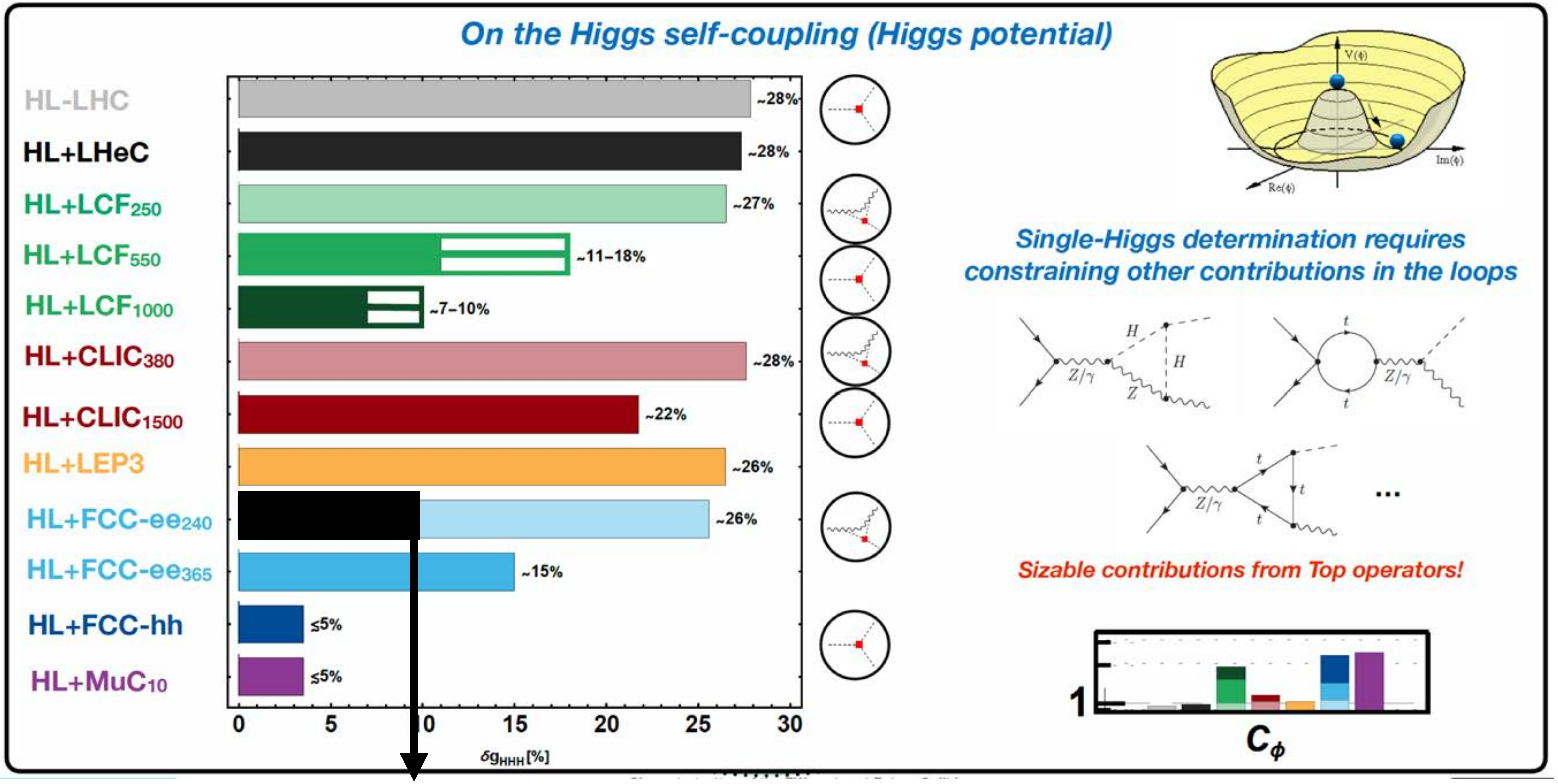


Z pole physics dominated by FCC-ee

Higgs physics dominated by FCC-ee + FCC-hh

(FCC-hh results are typically provieded assuming an FCC-ee collider before it)

Physics output comparison, Higgs boson self-coupling



FCC-ee$_{240}$ under same assumption of FCC-hh result (big misunderstanding here, it should be fixed before the briefing book) - HHH at 10% at FCC-ee under similar assumptions for FCC-ee

Cost comparison

FCC-ee cost estimate (FSR 2025)

Capital cost (2024 CHF) for construction of the FCC-ee is summarised below. This cost includes construction of the entire new infrastructure and all equipment for operation at the Z, WW and ZH working points.

FCC-ee

Domain	Cost [MCHF]
Civil engineering	6,160
Technical infrastructures	2,840
Injectors and transfer lines	590
Booster and collider	4,140
CERN contribution to four experiments	290
FCC-ee total	**14,020**
+ four experiments (non-CERN part)	1,300
FCC-ee total incl. four experiments	**15,320**

Note: Upgrade of SRF (800 MHz) & cryogenics for ttbar operation corresponds to additional cost of 1,260 MCHF

LCF CLIC

Unit: MCHF	LCF 250 (LP)	Δ LCF 550 (FP)	CLIC 380	Δ CLIC 1500
Collider	3864	4204	2471	4684
Main Beam inj./transfer	1181	86	1046	23
Drivebeam inj./transfer	-	-	1060	302
Civil Engineering	2338	0	1403	703
Technical Infrastructure	1109	1174	1361	1404
Sum	**8492**	**5464**	**7341**	**7116**

LEP3

Cost Element	2 new Xpts	2 Exist Xpts
Accelerator	2705	2705
Injectors and Transfer Lines	295	295
Technical Infrastructures	435	435
Experiments	130	60
Civil Engineering	165	165
LHC Removal/LEP3 Installation	140	140
Total CERN (MCHF)	**3870**	**3800**
Experiments non-CERN part	900	270

15 BCHF for FCC-ee, to compare with 8.4 BCHF LCF,
4 BCHF for LEP3 (very preliminary estimate)

FCC-hh
(after FCC-ee)

Cost summary table in 2024 MCHF for the construction of FCC-hh.

Domain	FCC-hh Cost [MCHF]
FCC-ee dismantling	200
Collider*	13400
Injectors and transfer linear	1000
Civil Engineering	520
Technical infrastructures	3960
Experiments	N/A
Total	**19080**

*target price of 2.0 MCHF per 14.3 m long magnet with 1.0 MCHF of conductor, 0.5 MCHF for assembly, and 0.5 MCHF for components

Muon Collider

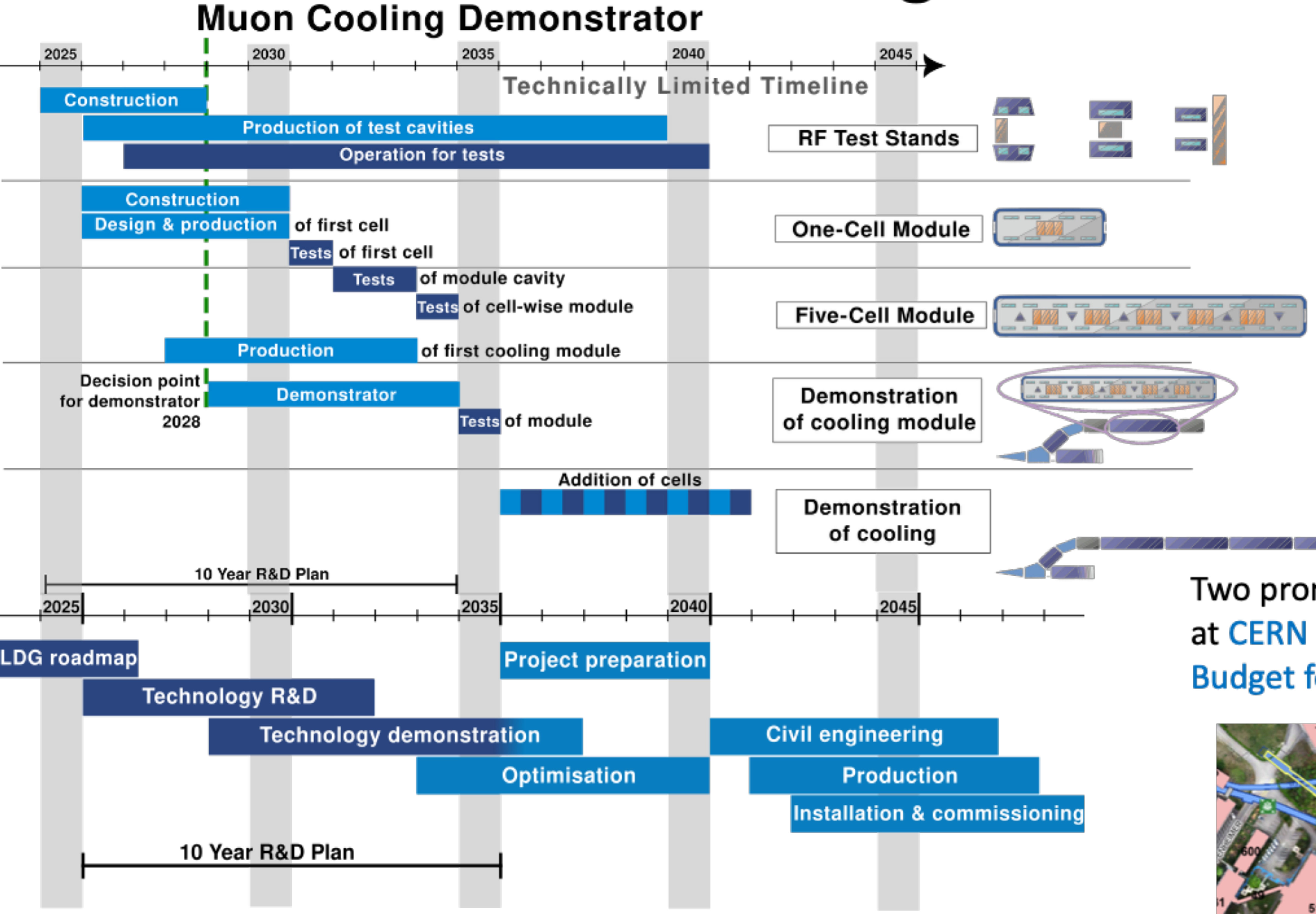
LHeC (cost estimate 2018, 60 GeV e-)

Budget Item	Cost
SRF System	805MCHF
SRF R&D and Proto Typing	31MCHF
Injector	40MCHF
Magnet and Vacuum System	215MCHF
SC IR magnets	105MCHF
Dump System and Source	5MCHF
Cryogenic Infrastructure	100MCHF
General Infrastructure and installation	69MCHF
Civil Engineering	386MCHF
Total	1756MCHF

→ ~2 BCHF (2025)

Muon collider demonstrator timeline

Muon Cooling Demonstrator



D. Schulte, Muon Collider, ESPPU Open Symposium, Venice, June 2025

Launch RF test stands and first module (700 MHz test stand) right away

Important decision in 2028 on sharing of effort and demonstrator location

Two promising demonstrator site studies at at CERN

Budget for site Fermilab study approved

- many aspects need to be demonstrated
  1. muon cooling
  2. magnetic field ramping
  3. stability with respect to electron radiation
  4. magnets and RF cooling and so on
- timeline for R&D set at 2045, when we would actually like to be ready for construction…
- muon collider is on the FCC-hh timescale, it is not an alternative to FCC-ee
- the expectation is an R&D program lead and financed mainly by US

Plan B discussion

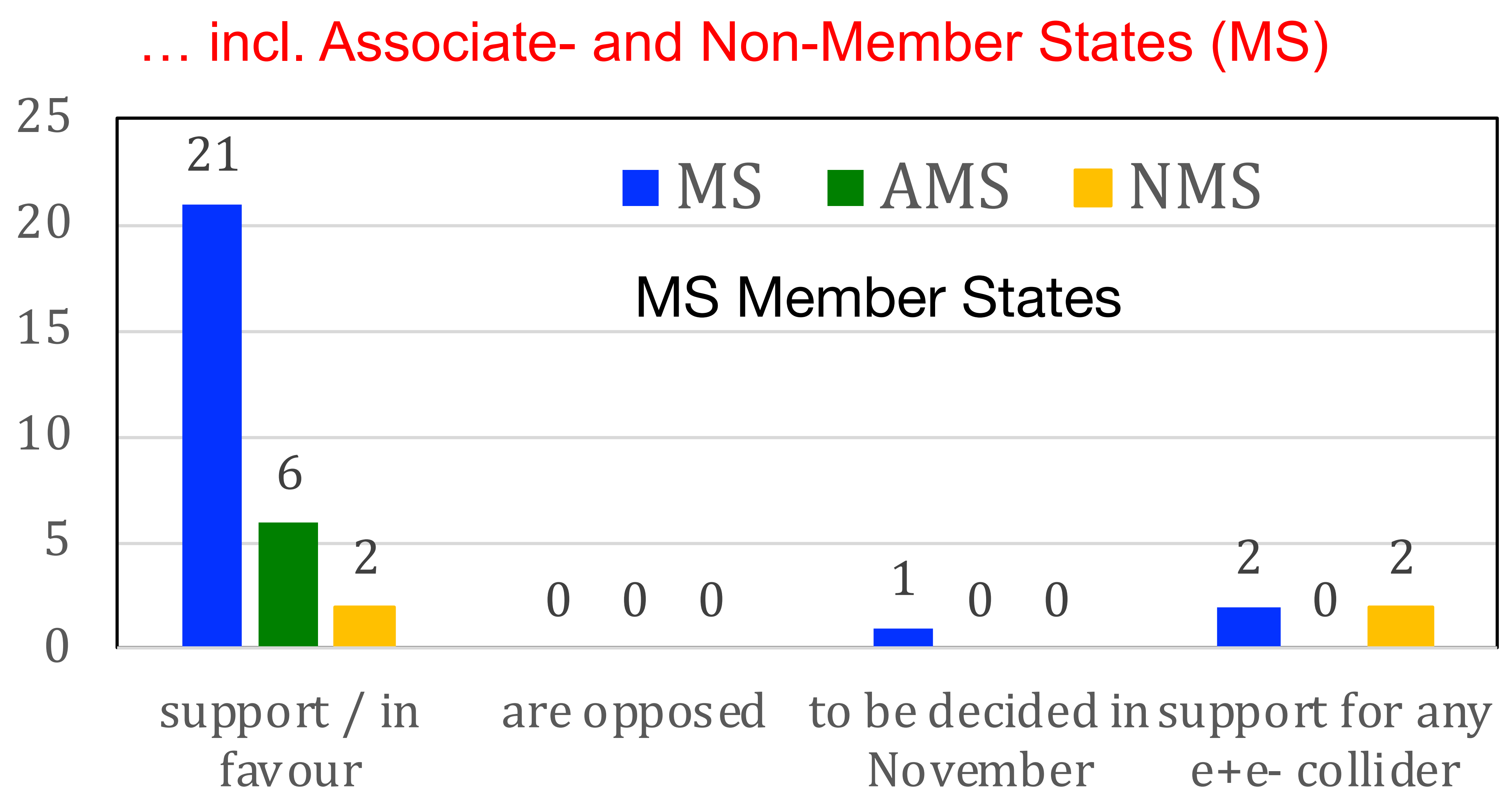
- the ESP asked also for feedback about a possible plan B in case the preferred option could not have been done for budget considerations

The outcome is three possible alternatives

Machine	Pros	Cons
LCF 250	Best Higgs Physics, could be upgraded to higher energies	Z physics a factor 10 worse than LEP3, 2x more expensive than LEP3 (LEP3 cost estimate very preliminary)
LHeC	PDFs for FCChh, access to lepto-quark observables (poorly probed up to now)	cost estimate preliminary, accelerator principle to be demonstrated (recovery energy linac)
LEP3	Z phys at the level of FCC-ee	• we have already seen it, it doesn't look exciting • after that we are again in the condition to chose to move to FCC-ee

National inputs summary

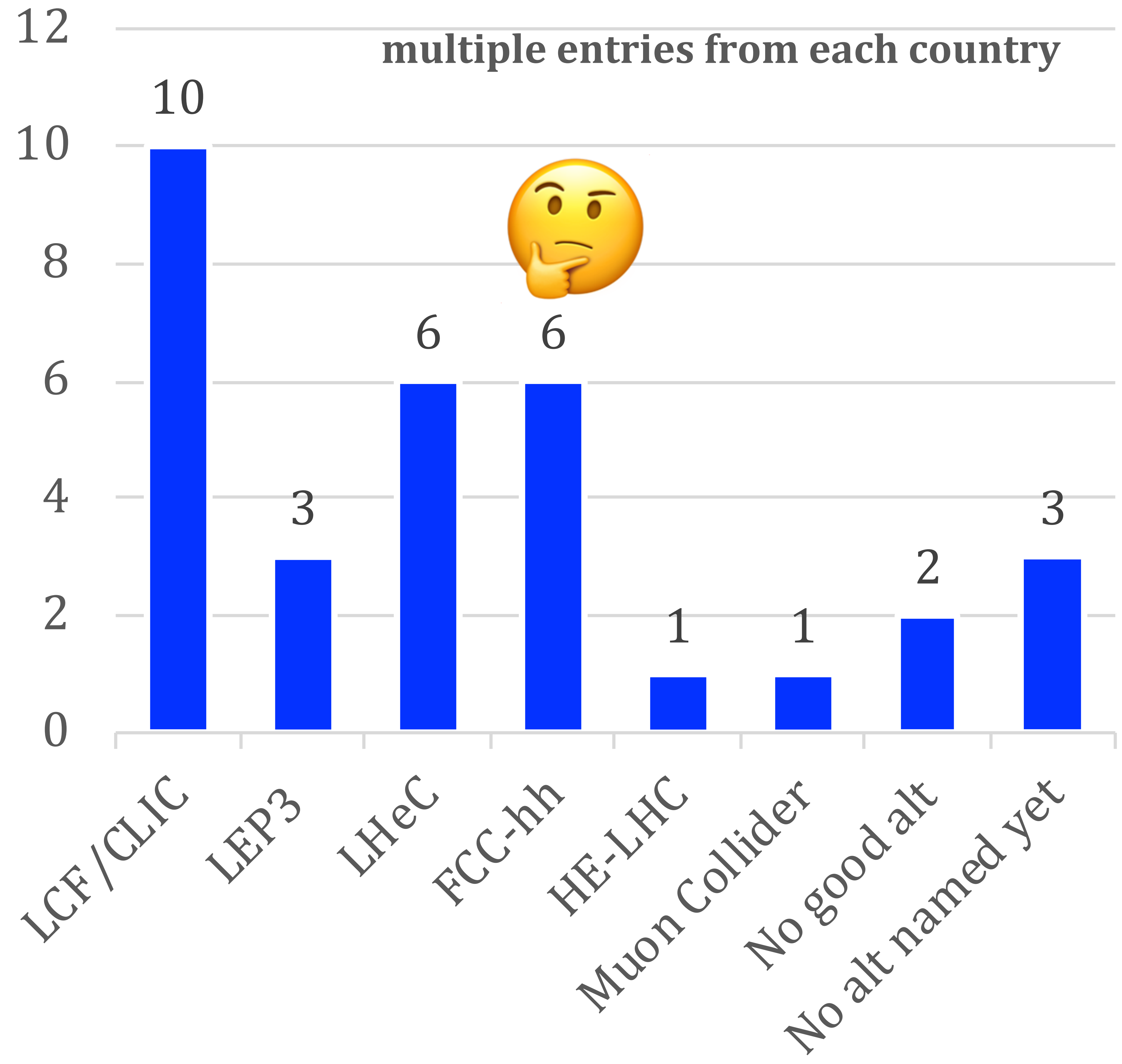
Support for an FCC-ee/hh integrated program



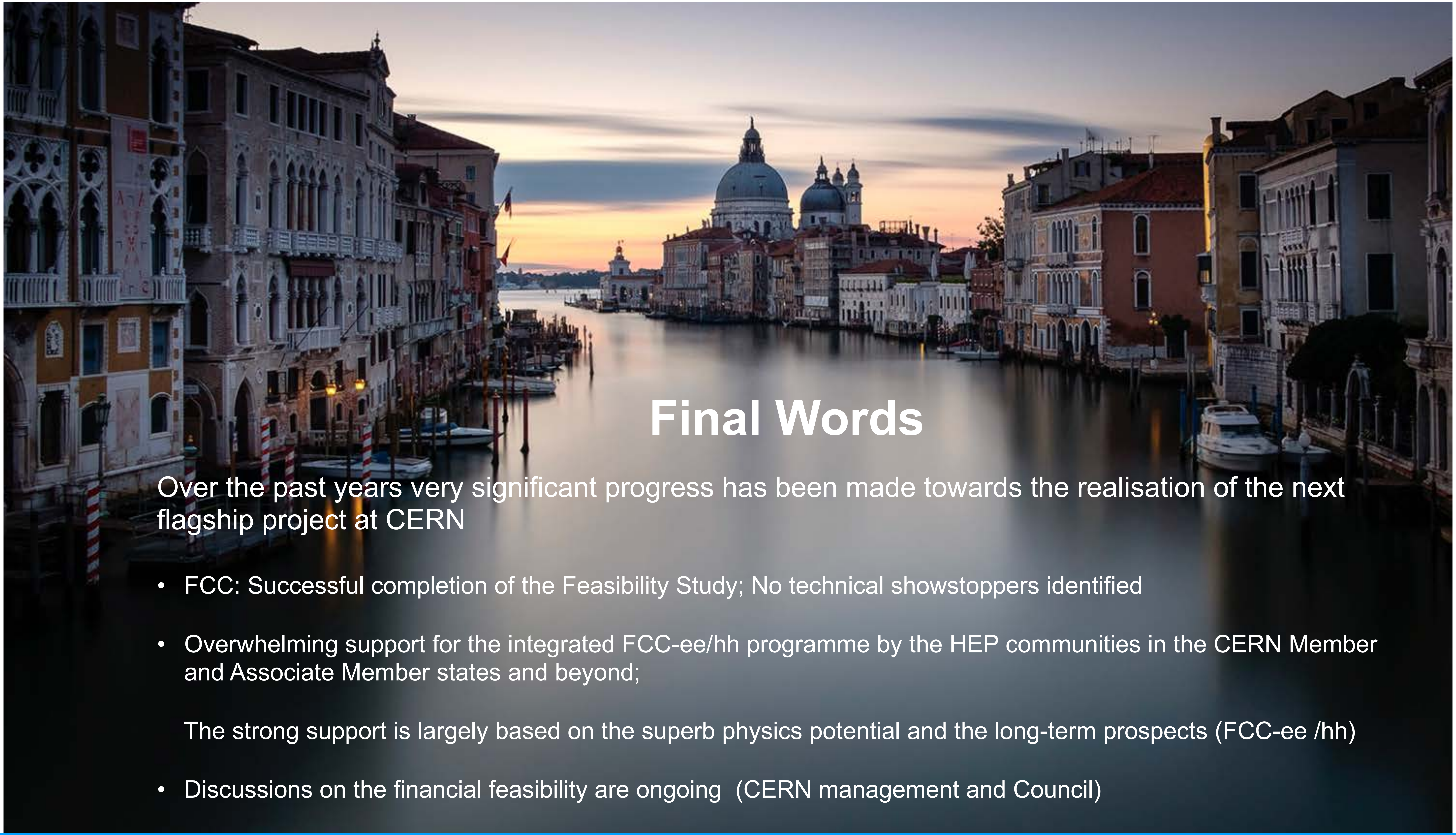
- Support as well from Associate Member states (AMS) and Non-member states (NMS)

Some institutes interpreted “not feasible” in a broad sense, like an e+e- collider in China would stop the plan for the same machine in Europe

What is the best option if the preferred one cannot be realised



Summary from Karl Jakobs



Next steps for RD-FCC

1. disucssion will continue up to the end of the year, possibility to provide further inputs to help summarising the collected inputs so far, national institutes should provide their inputs by the end of this year;

2. I don't expect any change on plan A, but financial feasibility could become more clear, from informal discussions the plan is to get something from European Commission, some extra from the member states and also private income contributions are under evaluation;

3. the decision is ecxpected from the CERN council in the next 2 years, in these two years the plan is to work more on realistic simulation, push forward the R&D of the detector technologies, start building detector collaborations;

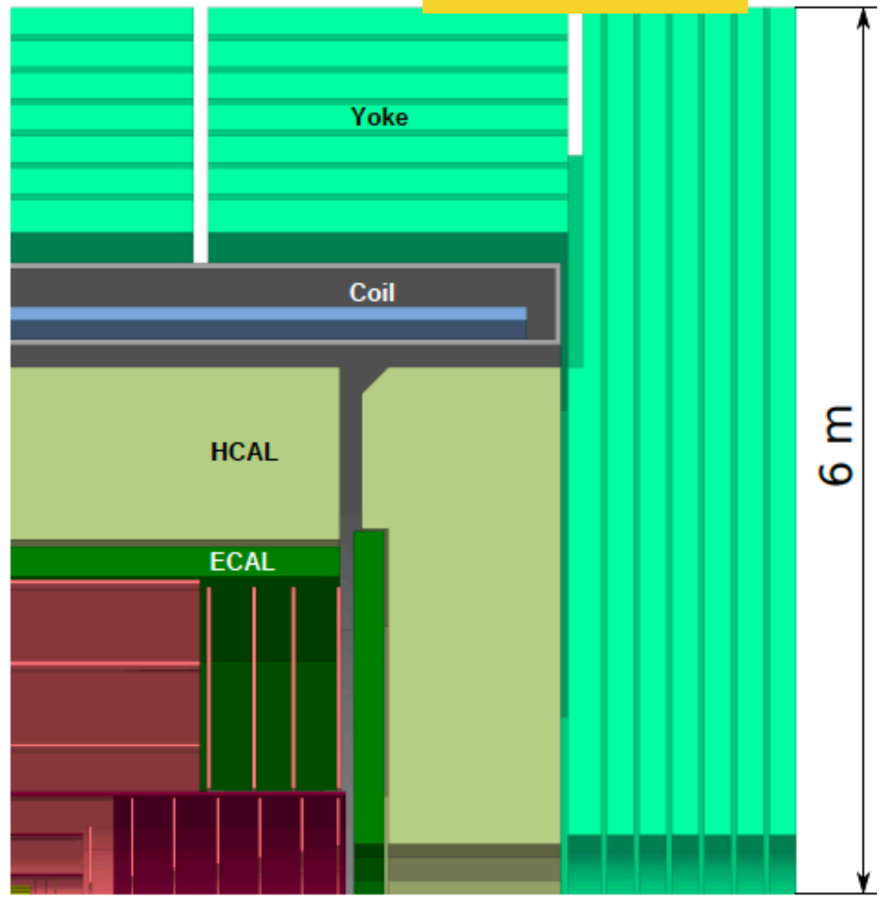
4. at the moment 2 detector prototypes are proposed: IDEA and Allegro, but 4 IPs are considered for FCC-ee, there is room for several technologies to be implemented and specialised for different physics tasks

Detector design

Istituto Nazionale di Fisica Nucleare
Sezione di Pisa

- MicromegaS detectors proposed by Roma-Tre and collaborators for both Allegro and IDEA as an alternative option

CLD (ID#95)



- VTX MAPS
- Main Tracker: Silicon
- Very high granularity (CALICE) inside the Solenoid
  - ECAL Si+W
  - HCAL Fe+scintillator
- PID: RICH and TOF
- Muons ID with RPC

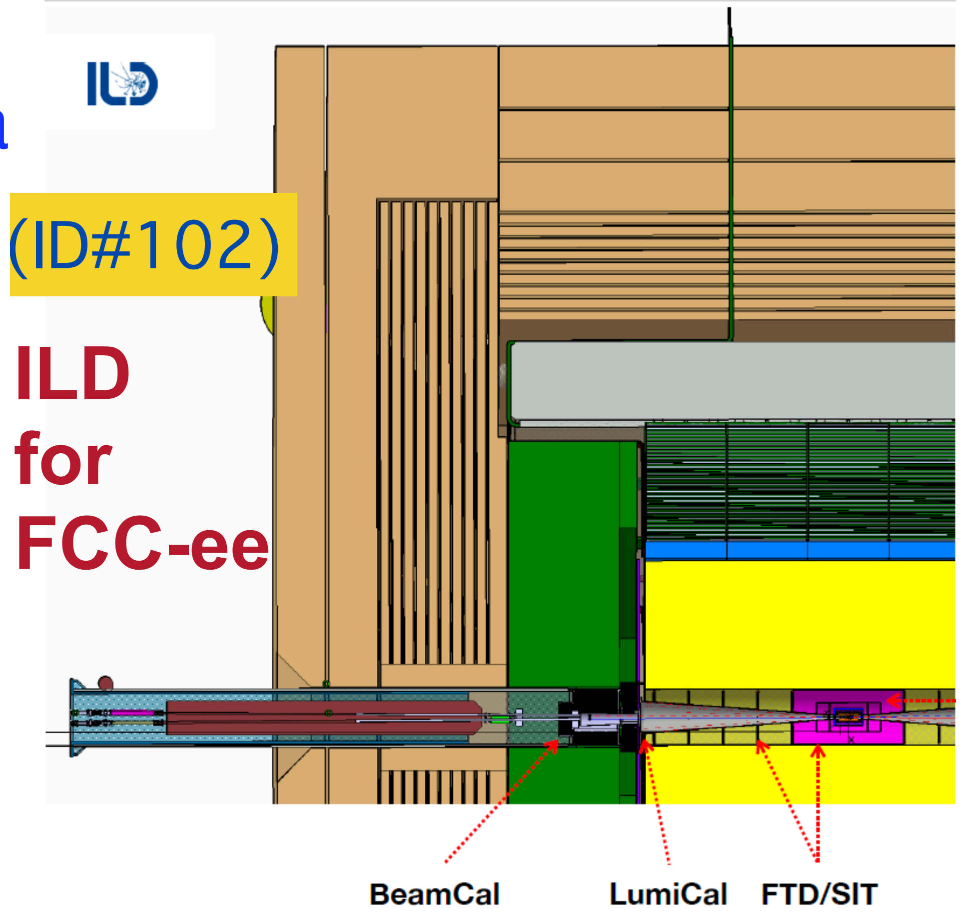
(ID#211) **ALLEGRO**

- VTX MAPS
- Main Tracker:
  - Drift Chamber/Straw/Si
- Si/LGAD wrapper (TOF)
- ECAL: Pb+L-Ar/W-L-Kr
- HCAL: Fe+scintillator outside the Solenoid
- PID: RICH (in case of Silicon main tracker)
- Muons with RPC

- In order to push forward the R&D a minimum fast-sim simulation is needed for both Allegro and IDEA

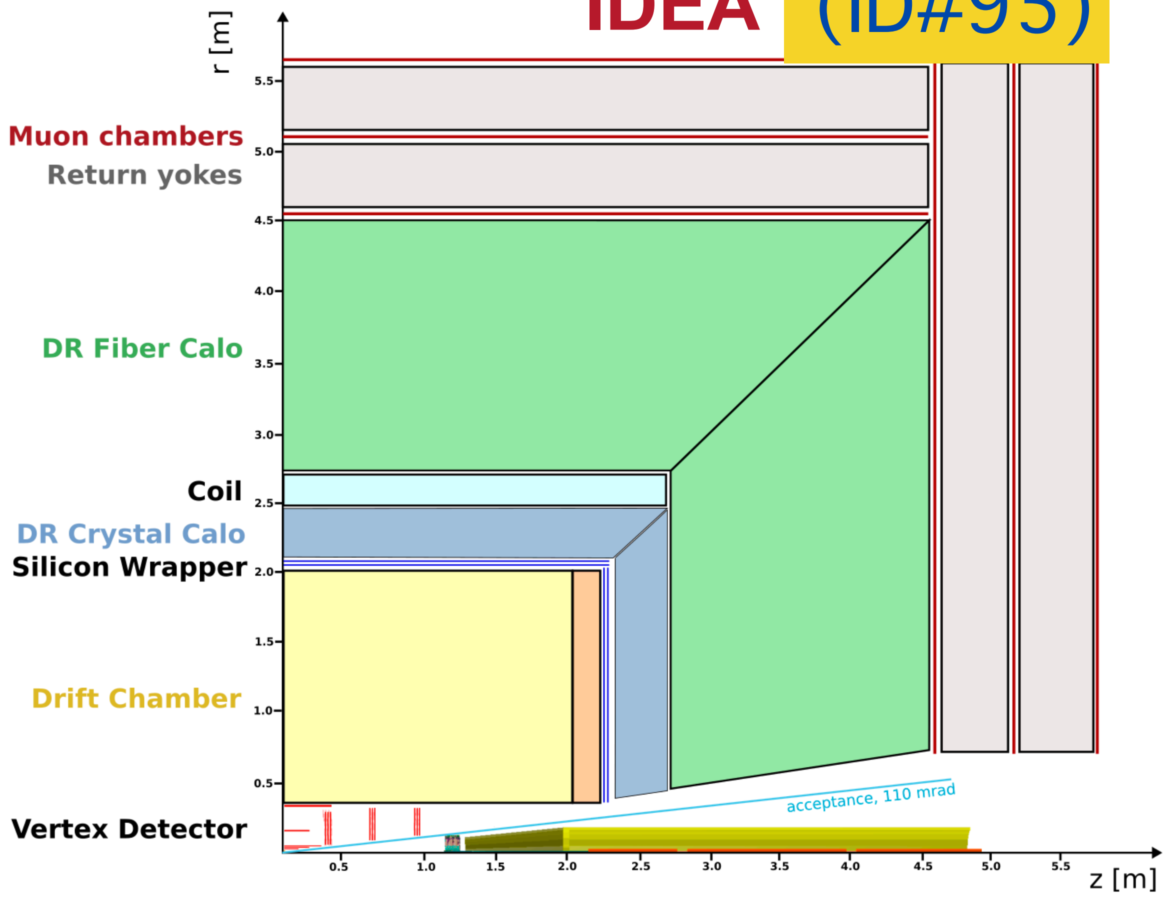
(ID#102)

ILD for FCC-ee



- VTX MAPS
- Main Tracker: TPC
- Very high granularity (CALICE) inside the Solenoid
  - HCAL Fe+scintillator
  - ECAL Si-W
- Muons with scintillator

IDEA (ID#95)



- VTX MAPS
- Main Tracker:
  - He+Isob drift chamber
- Si/LGAD wrapper (TOF)
- DR calorimetry (fibres):
  - ECAL: Crystals
  - HCAL: Iron **outside** the Solenoid
- HTS Solenoid (up to 3T)
- Muon ID: μ-RWELL

Particle flow for dual readout in IDEA

- the nominal calorimeter for IDEA is a dual-readout spaghetti-copper calorimeter;
- main difficulties is to recover the bad electromagnetic resolution of usch devices with respect to homogeneus electromagnetic calorimeter;
- a NN approach (Roma Tre) was implemented using different configurations, using the dual-readout information, the fiber-level cluster information, the fiber-level energy
- unfortunately no - improvement over standard electron reconstruction was observed, main limiting factors was the hardware setup in the training: unoptimised training algorithm, limited GPU memory and absence of GPU parallelisation;
- we installed in the new cluster a full cluster of GPU based on an obsolete PowerPC controlled architecture but much more powerful than what we had up to now;
- R. Di Nardo implemented Tensorflow on this setup
- With Ada, Michela and Roberto trying to powerup the training using the new hardware to probe more complex NN configurations

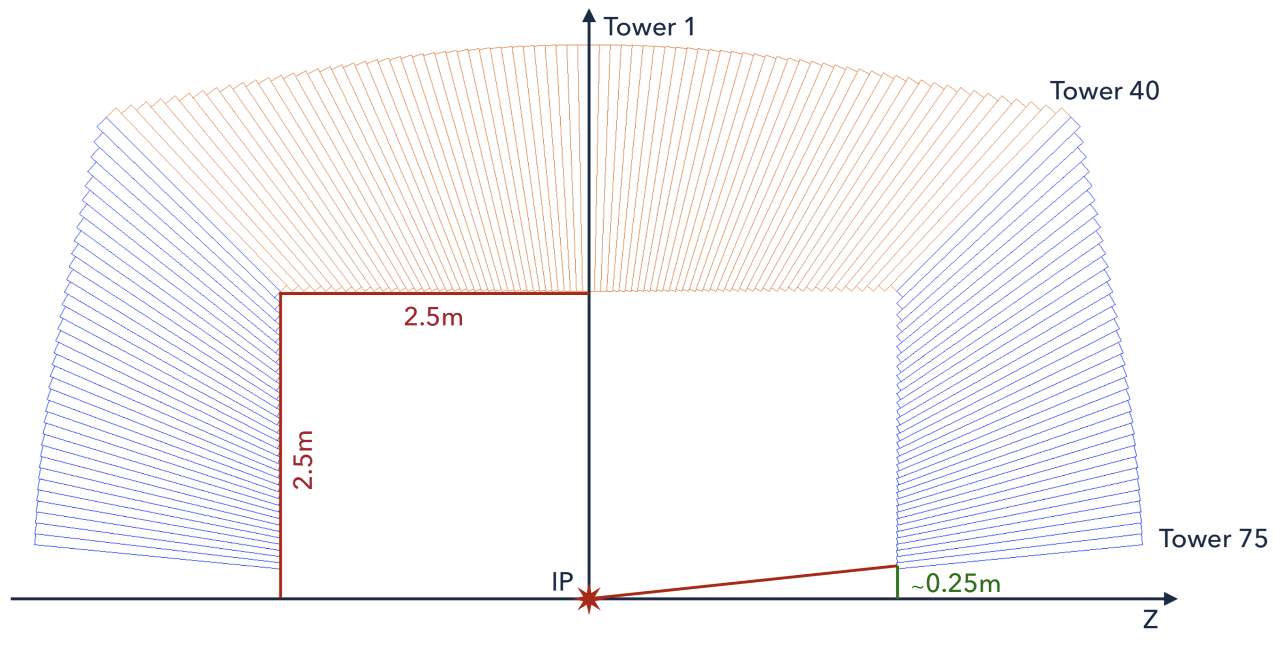
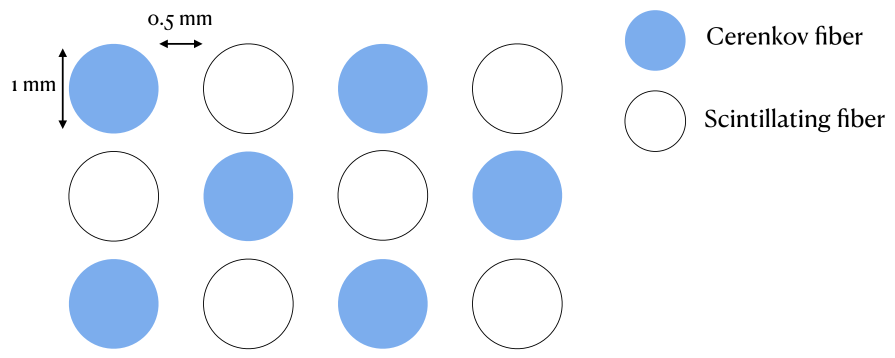
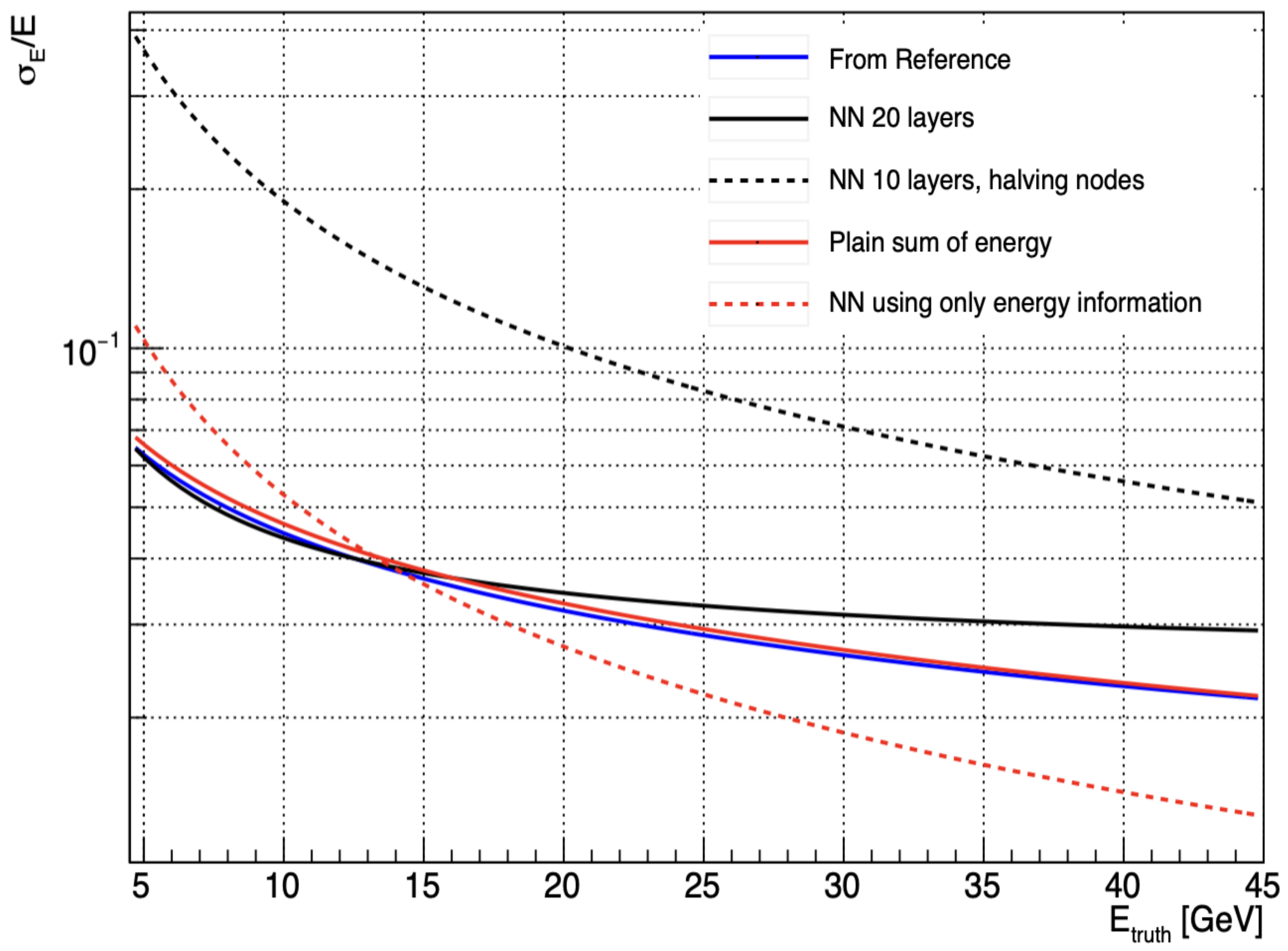
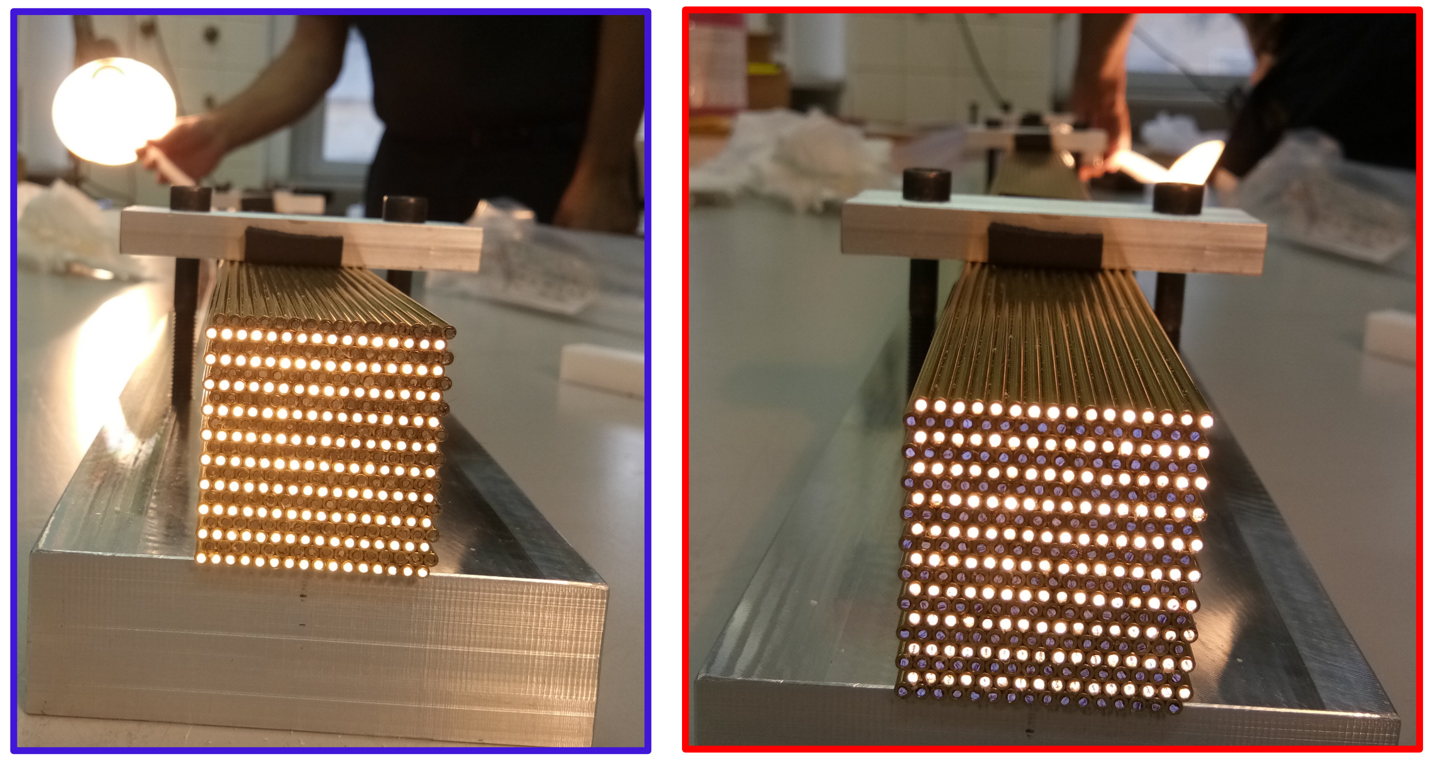


Figure 1: Sketch of a single slice of the IDEA calorimeter.



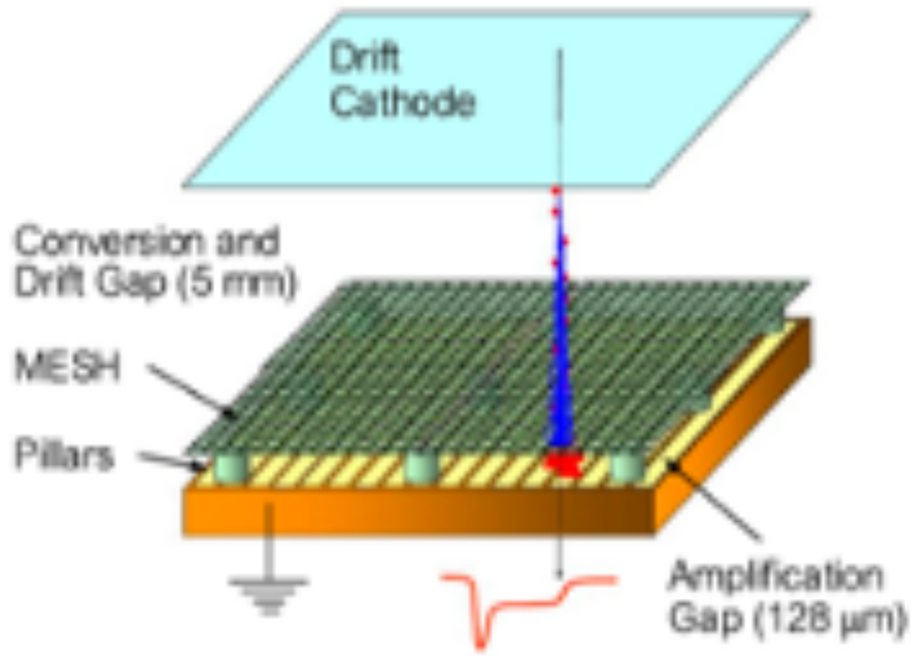




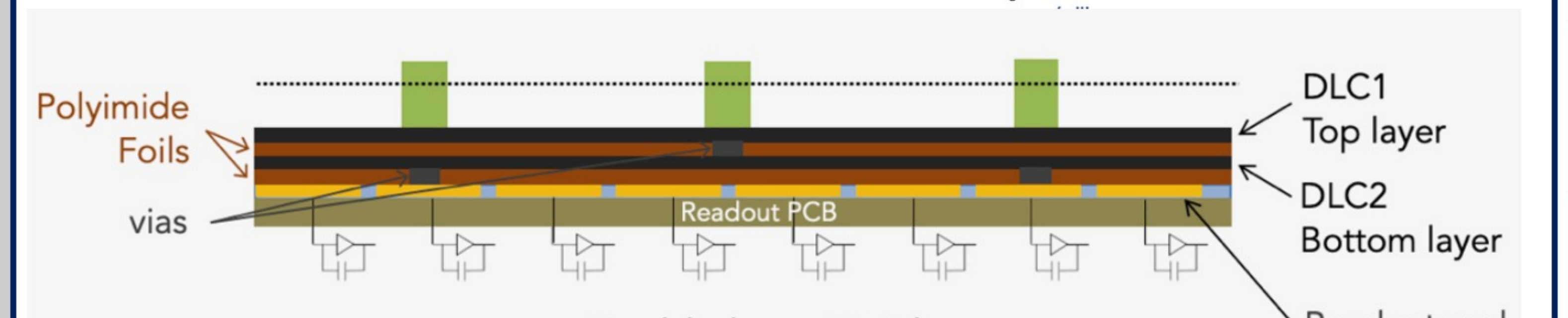
Scintillation fibers Cherenkov fibers

Micromegas R&D 1/2

Initial development since 2015 in CSN5 (MPGD_NEXT, RHUM)



Double DLC Uniform resistive layer



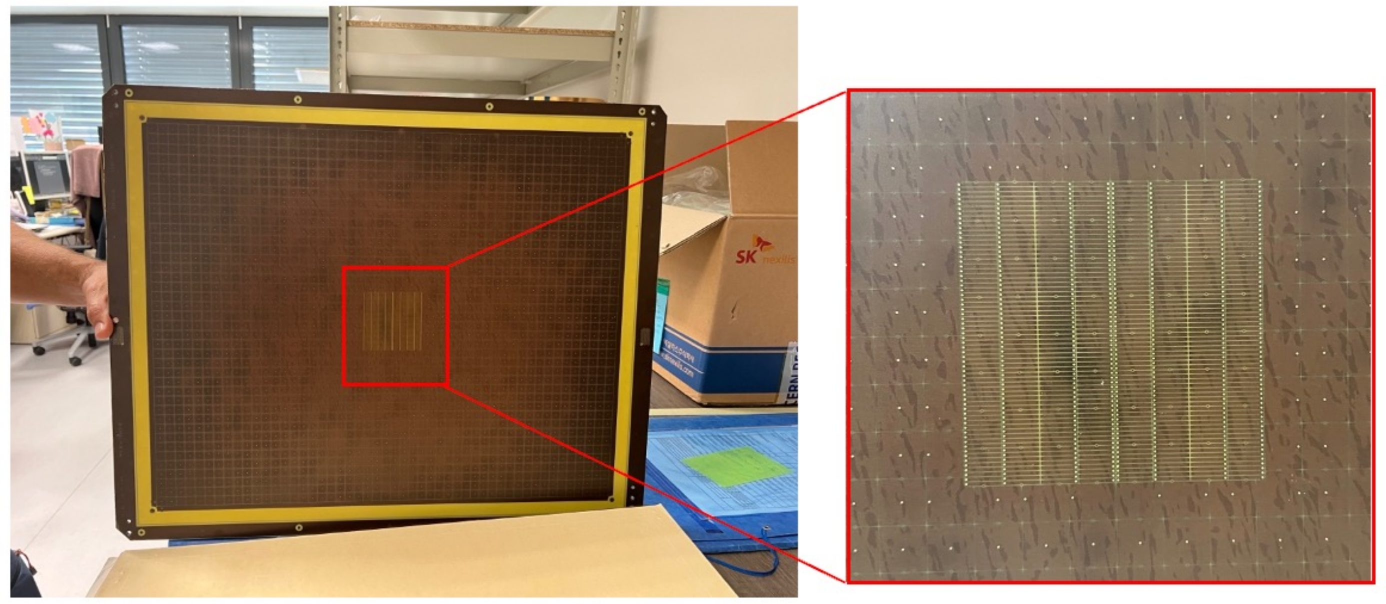
Double-layer DLC layout

- Uniform double DLC layer with DOT grounding connections (every ~8 mm)
- Sequential Build-Up technique implemented in recent years

Excellent performances obtained with double-resistive layer configuration with DLC, recently published in:

M. Alviggi et al.
"Resistive fine granularity Micromegas: characterization and performance for different spark protection resistive schemes" 2025 JINST 20 P01012

2024-2025 Large Area Detector Development



High-rate configuration
DOUBLE DLC LAYER
Fine granularity readout in the centre, 1 cm^2 pads elsewhere (for practical reasons – number of channels)

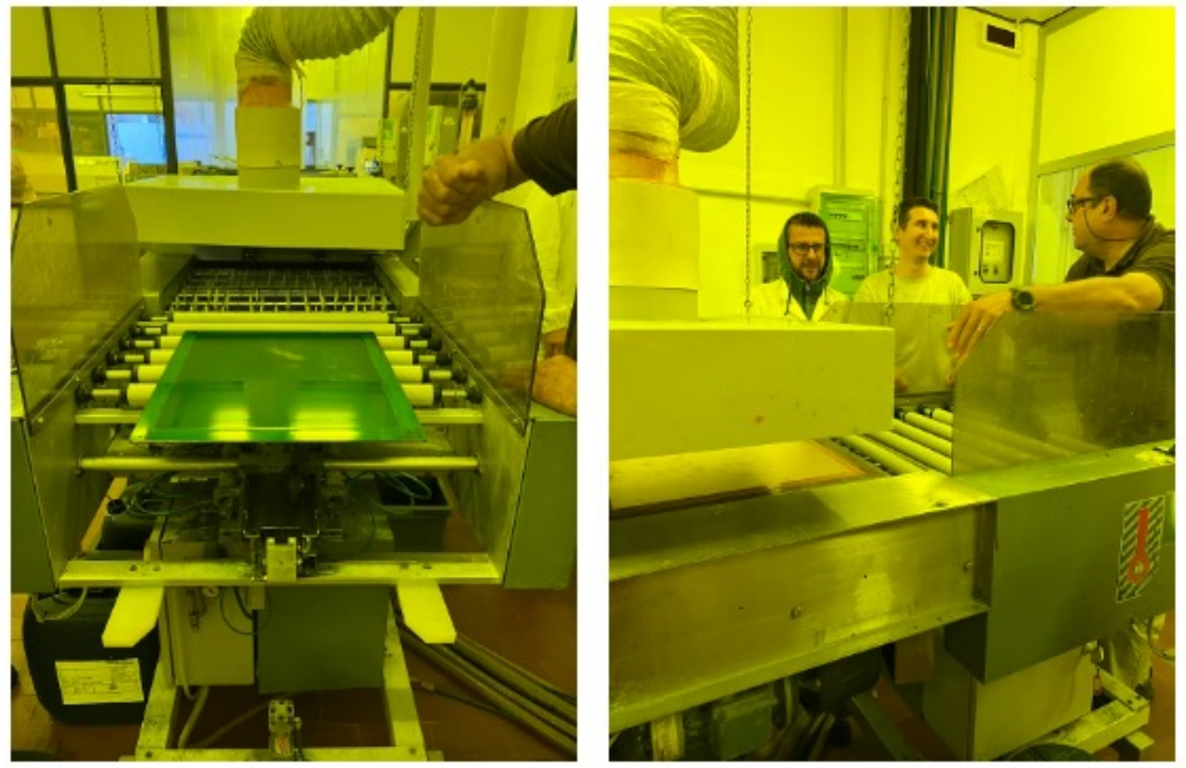
Central region
6.4x6.4 cm^2
with1x8 mm^2 pads

Hirose connectors on the back
Central region readout through 4 connectors
Full detector readout out by 20 hybrids

Industrialisation at ELTOS

Bulking - development

Transport in a diluted soda Solvay bath



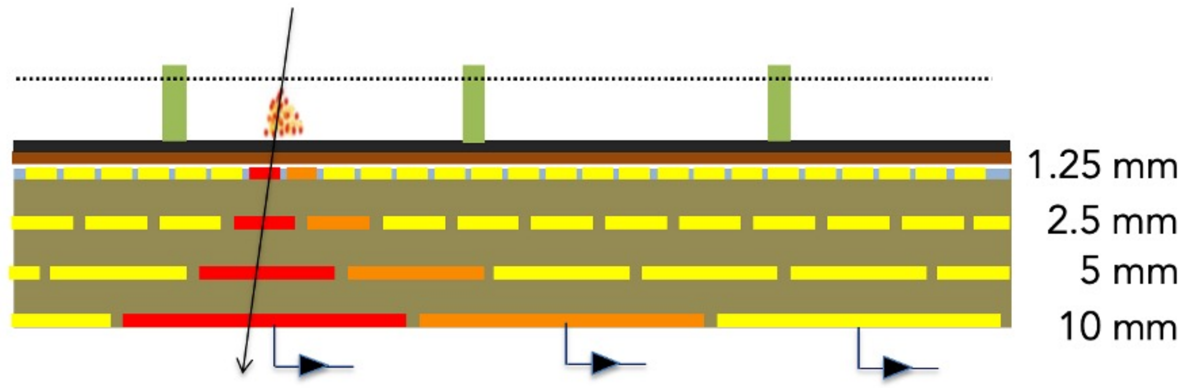
Development for application to a muon system at FCC-ee

Leverage high-rate experience to create robust, simplified resistive Micromegas for **medium/low-rate environments** and large areas, like the FCC-ee muon system, at a reduced cost.

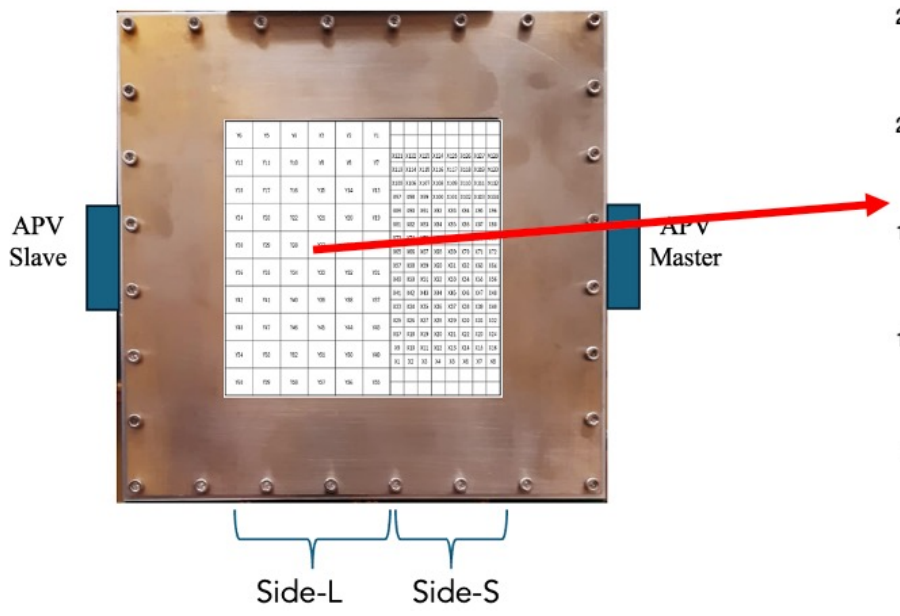
Medium/Low-rate Version – Capacitive Sharing

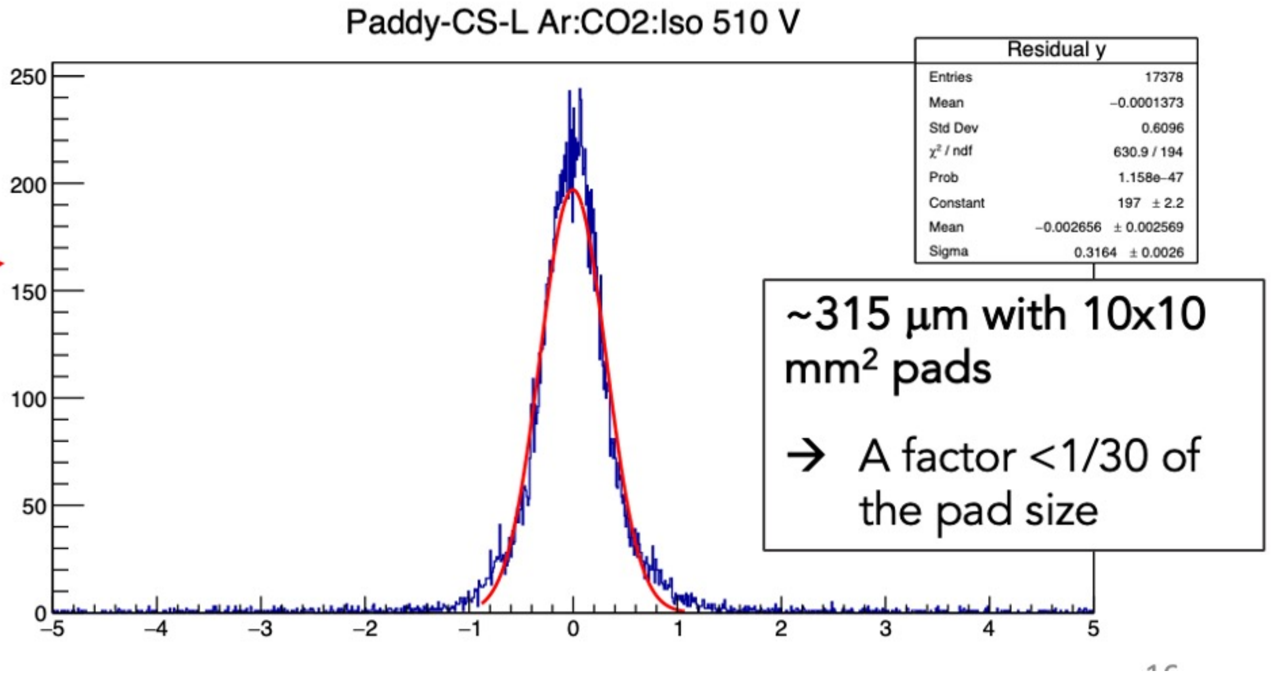
Concept from R. De Oliveira and K. Gnanvo et al., NIMA 1047 (2023) 167782)

SINGLE LAYER DLC Layout implementing the "capacitive sharing" concept, aiming at preserving good spatial resolution with a reduced number of readout channels:
Charge shared in large readout pads through the capacitive coupling between stack of layers of pads.

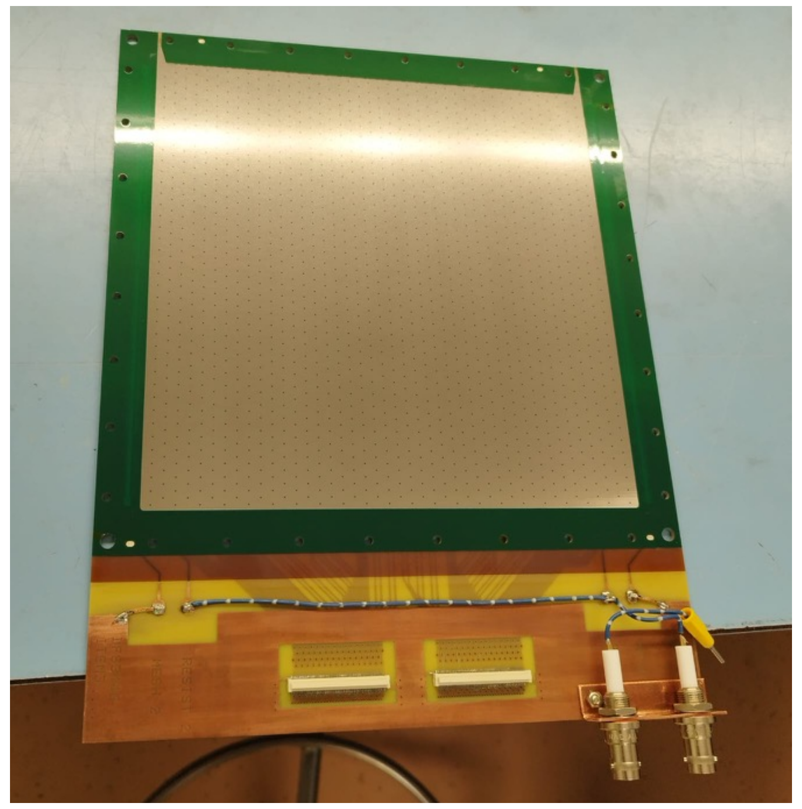


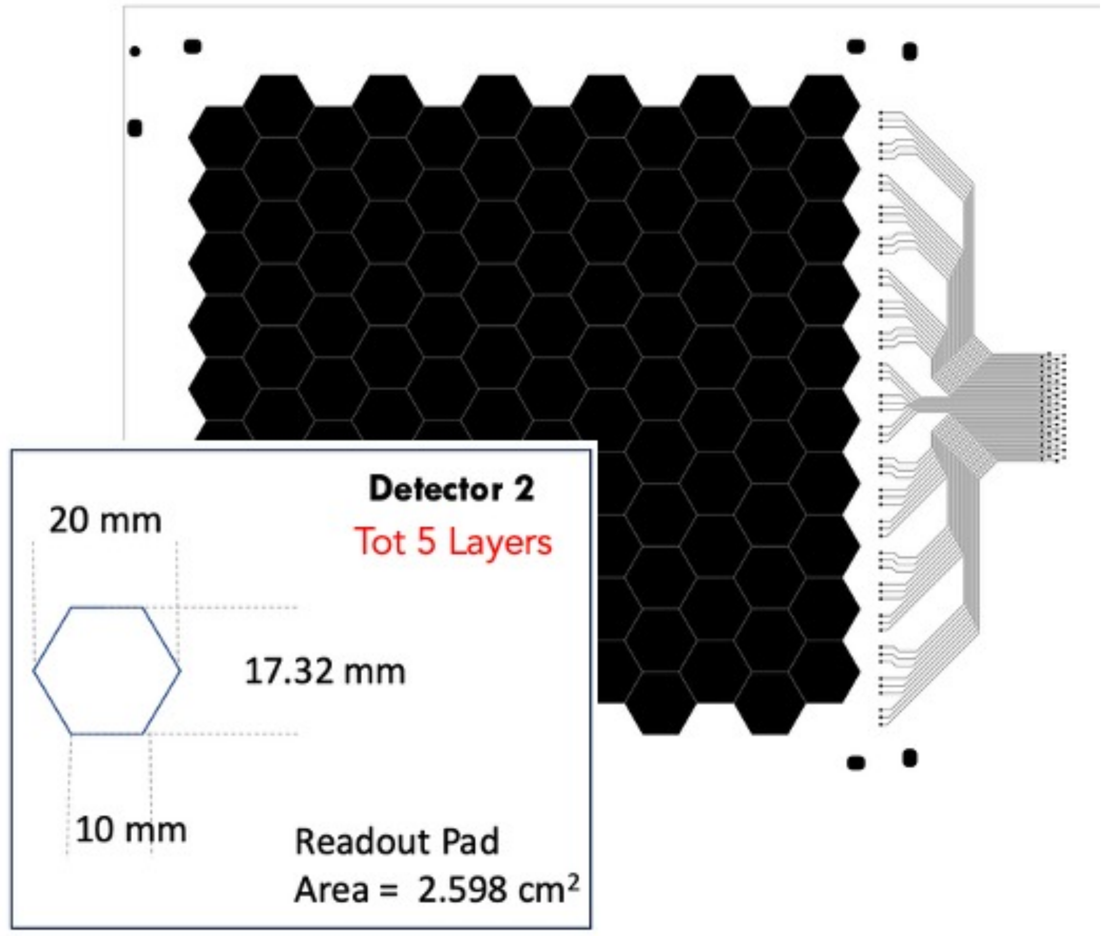
First Micromegas Prototype Built implementing the Capacitive Sharing layout





- Aiming to further investigate the potentiality of the capacitive sharing for 2D pad readout we launched the production of two new detectors, with 4 and 5 layers of hexagonal pads





("diameter" internal layer: 1.25 mm)

- Delivered at CERN last week
- Under assembly and test

MicromegaS current activities

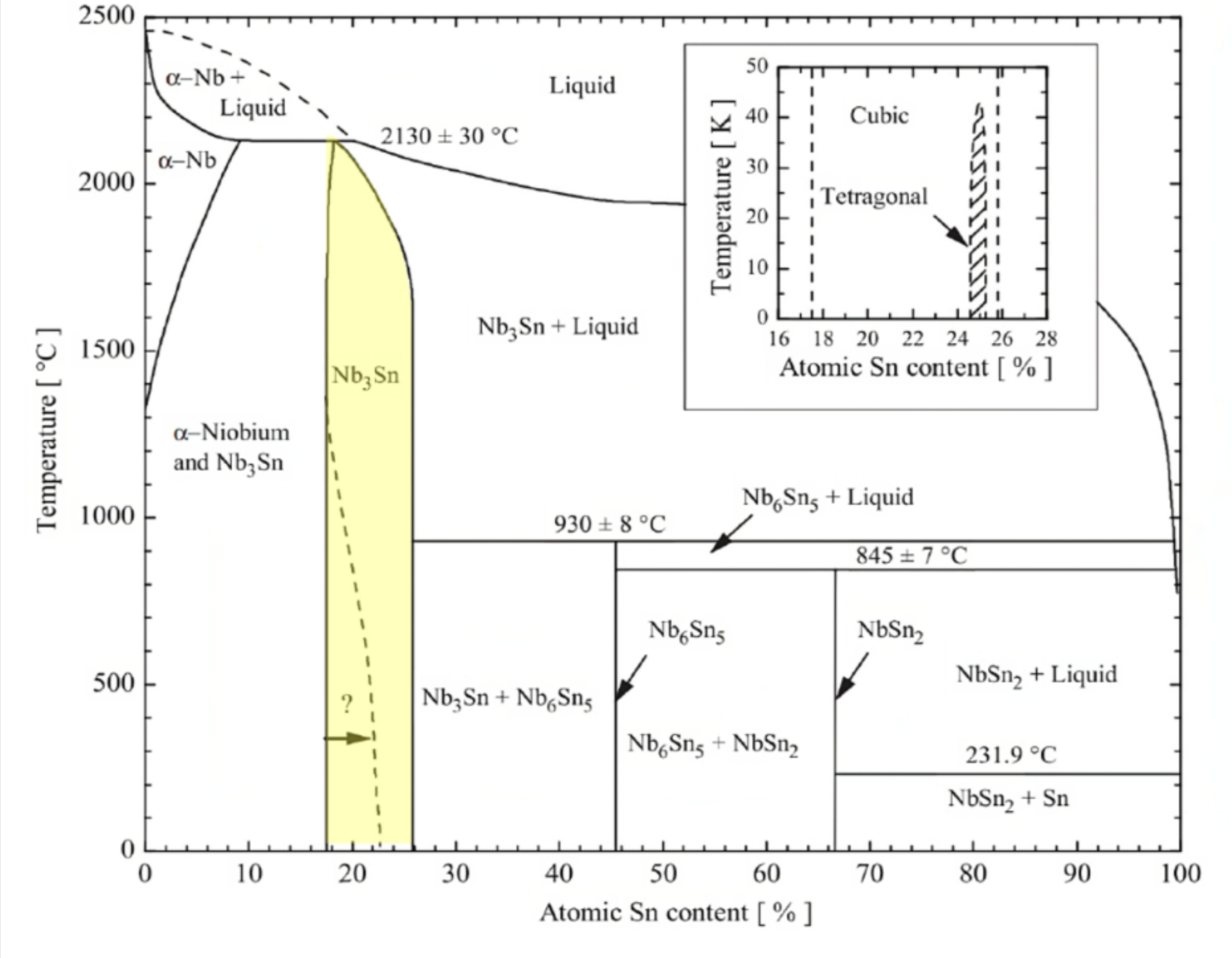
- Test of new detectors with capacity sharing (2 modules 50x40 cm^2 + 2x 20x20 cm^2 with 4 layers with exagonal pads)
- Under construction a setup for the placement of 6 micromegas detectors 50x40 cm^2 for the CERN Test Beam in November (2 weeks)
- Production and test improvement construction procedure with ELTOS
  - 2 modules 20x20 cm2 by November
  - New production and test of production chain in 2026
- Transition from current electronic (APV25 chip) to a new generation one (VMM chip)

New activity: study of cavity coating with NbSn compounds

FCC-ee cavity will be subject to high electric fields, high frequency, high energy dissipation from photon radiation.

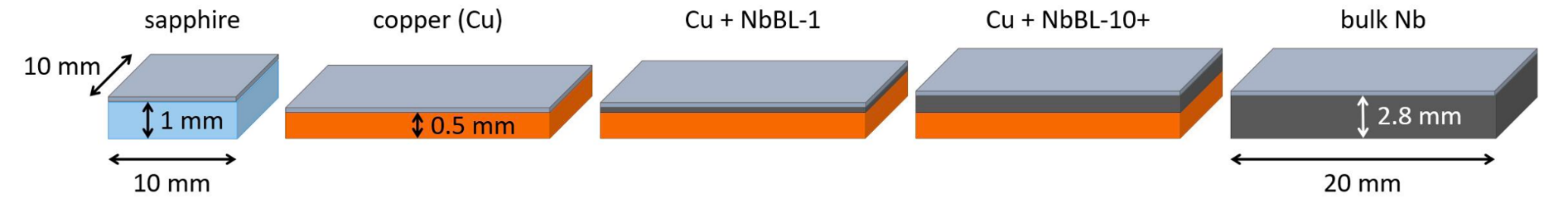
The aim of the project is to provide studies on the surface of different cavities using several NbSn compouns

Nb-Sn possible compounds



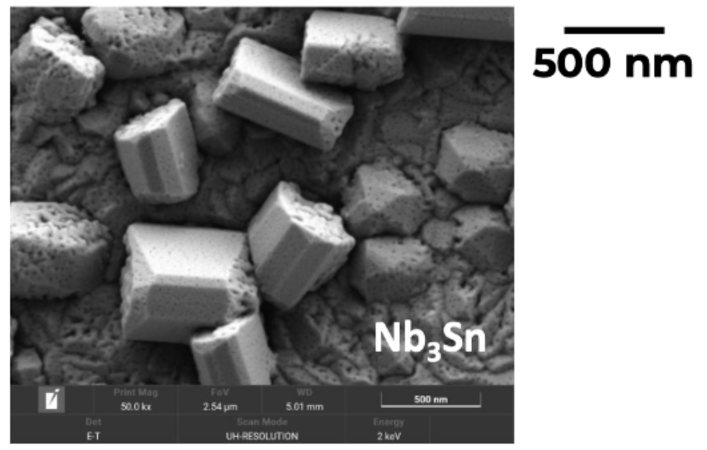
[1] A Godeke 2006 *Supercond. Sci. Technol.* 19 R68

Nb_3Sn/Cu by Magnetron Sputtering

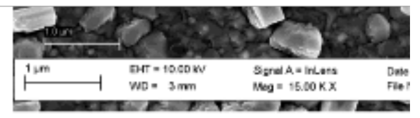


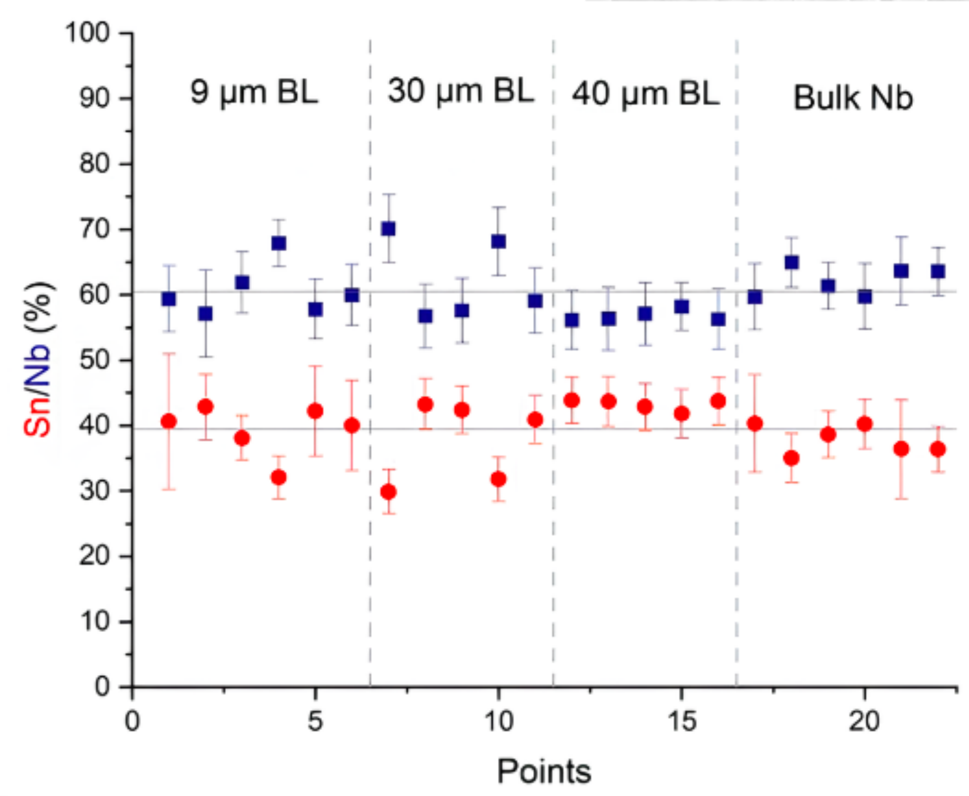
When Nb_3Sn is grown on bulk Nb or Al_2O_3 the structure of the film is characterized by the presence of cluster of material with different stoichometry

Nb_3Sn/bulk Nb



Cluster composition





INFN RM3 collaboration:

- **Investigation of cluster composition and localization through ToF- SIMS technique**
- **local quantitative composition analysis**
- **investigation for spurious phases**
- **homogeneity of SC phase across film/island interface**
- **size change/effect due to the heating of the substrates (possible)**
- **verify/falsify nucleation dependence from deposition times**

L. Tortora, A. Passeri, V. Graziani (INFN - Roma Tre)

C. Pira, D. Fonnesu (INFN - LNL)

Roma Tre - activity prospects

1. contribution to the EPS strategy through to phenomelogical interpratation of results and comparison with different setup (in particular Higgs self-couplings and Higgs couplings)

2. development of analysis using full detector simulation with different detector configurations (in particular testing the MicroemgaS implementation in the muon system)

3. Finalising the Dual Read Out calorimeter reconstruction studies using NN;

4. R&D on MicromegaS detector and simulation inside IDEA and Allegro

5. Studying different FCC-ee cavity coating material

RD-FCC FTE and requests

Name	FTE-RDFCC
B. Di Micco	0.2
M. Biglietti	0.3
K. Chimiel (PhD)	0.2
R. Di Nardo	0.2
A. Farrilla	0.1
M. Iodice	0.3
R. Orlandini (PhD)	0.1
A. Passeri	0.1
L. Tortora	0.2
A. Budano	0.15
F. Montereali (post-doc)	0.15
Tot	2

Financial requests			
		request	sub iudice
	Metabolismo per 2 FTE	2.5 k€	
RF cavity surface tests	Travels to LNL	3 k€	
	ToF-SiM - Cs, Bi ion sources replacement (consumable)	10 k€	
	Transport of samples to LNL	1 k€	1 k€
MicromegaS activity	Prototype 50x40 cm^2 construction with ELTOS	7.5 k€	
	Readout electronics for constructed prototypes - 10 VME (0.8 k€) FEC board (1.5 k€)	7.5 k€	
	Test at GDD lab (CERN)	2 k€	
	Test Beam (sub iudice approvazione)		3 k€
	Travels to ELTOS	2 k€	
	Travels to ELTOS if DRD1 common project proposal is approved (sub iudice)		2 k€
Totale		35.5 k€	6 k€

Total FTE 2.0 allowing to open a budget label

Servicies (m.u.)	
Computing (GPU setup and assistance)	2
Electronic (for MicormegaS)	2
Mechanic (for MicromegaS)	2

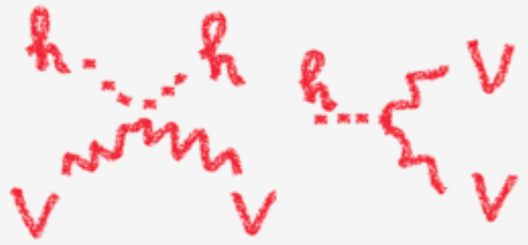
RD MUCOL

R. Franceschini , W. Xing

Higgs, and its couplings

SM and SM+SMEFT

$h \to ZZ, WW$ TREE-LEVEL COUPLING FROM $|D_\mu H|^2$



$h \to \gamma\gamma, \gamma Z$ LOOP-LEVEL COUPLING FROM $H X_{\mu\nu} X^{\mu\nu}$

Usually these contact interactions are probed (only) by Higgs couplings measurements

IN SMEFT
WARSAW BASIS

$\frac{H^2}{\Lambda^2} W_{\mu\nu} W^{\mu\nu}$ $\frac{H^2}{\Lambda^2} B_{\mu\nu} B^{\mu\nu}$

$\frac{H \sigma^a H}{\Lambda^2} W^a_{\mu\nu} B_{\mu\nu}$

δg_{hVV} $\frac{v}{\Lambda^2} \cdot hVV$

$\supset h \to \gamma\gamma$
$h \to \gamma Z$
$h \to VV$

modification of Z boson coupling to f

Multibody processes at muCol and FCChh can probe these operators at large momentum transfer

with Barcelona, Granada, Roma I, Trieste

possible flavor violation

with Maryland, soon on arXiv

Possible sensitivity to $\Lambda >$ few TeV to compete with Higgs couplings and go beyond $\Lambda \gg$ few TeV

Higgs, but no couplings at the Higgs pole

SM and SM+SMEFT

IN SMEFT
WARSAW BASIS

$\frac{H^2}{\Lambda^2} W_{\mu\nu} W^{\mu\nu}$ $\frac{H^2}{\Lambda^2} B_{\mu\nu} B^{\mu\nu}$

$\frac{H \sigma^a H}{\Lambda^2} W^a_{\mu\nu} B_{\mu\nu}$

δg_{hVV} $\frac{v}{\Lambda^2} \cdot hVV$

$\supset h \to \gamma\gamma$
$h \to \gamma Z$
$h \to VV$

Multibody processes at muCol and FCChh can probe these operators at large momentum transfer

with Pisa

COMPUTE DEPENDENCE ON $C_{\phi W}$ $C_{\phi B}$ $C_{\phi WB}$

Possible sensitivity to $\Lambda >$ few TeV to compete with Higgs couplings and go beyond $\Lambda \gg$ few TeV

Person	FTE-RDMuCOL
R. Franceschini	0.1
W. Xing	0.1

Financial	bdg	s.i.
Mission	3 k€	2 k€

Travels needed for W. Xing work at CERN with R. Franceschini (located at CERN in first half of 2026)

Participaion to Muon Collider collaboration meetings and conferences