Acceleratori e CSN1

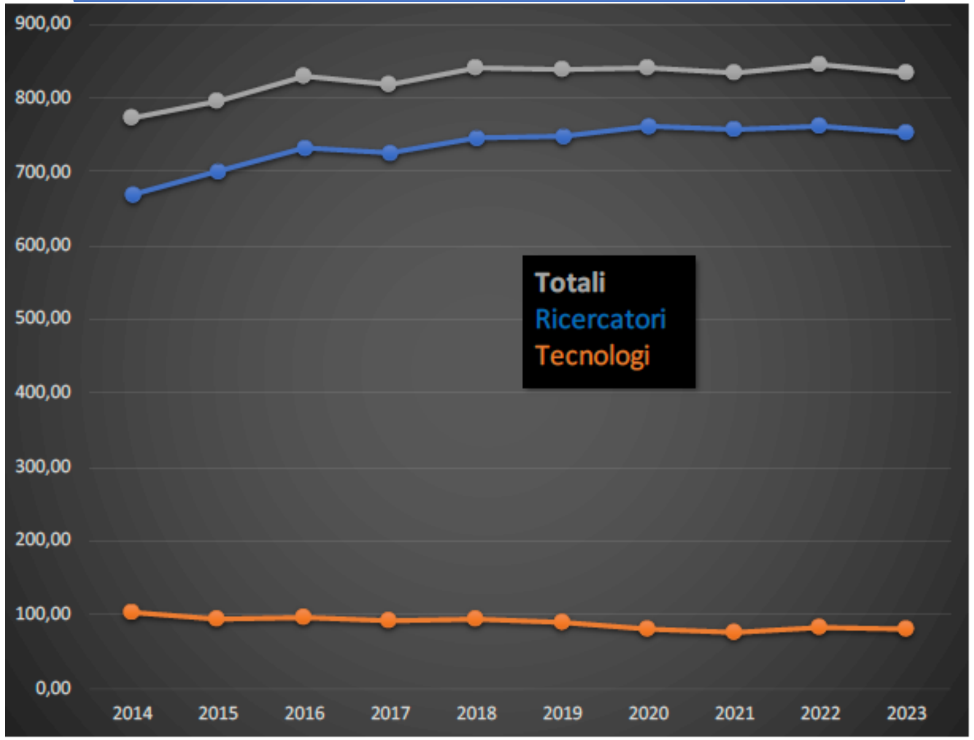
Roberto Tenchini
INFN Pisa

Seconda Giornata Acceleratori
Catania 2-3 marzo 2023

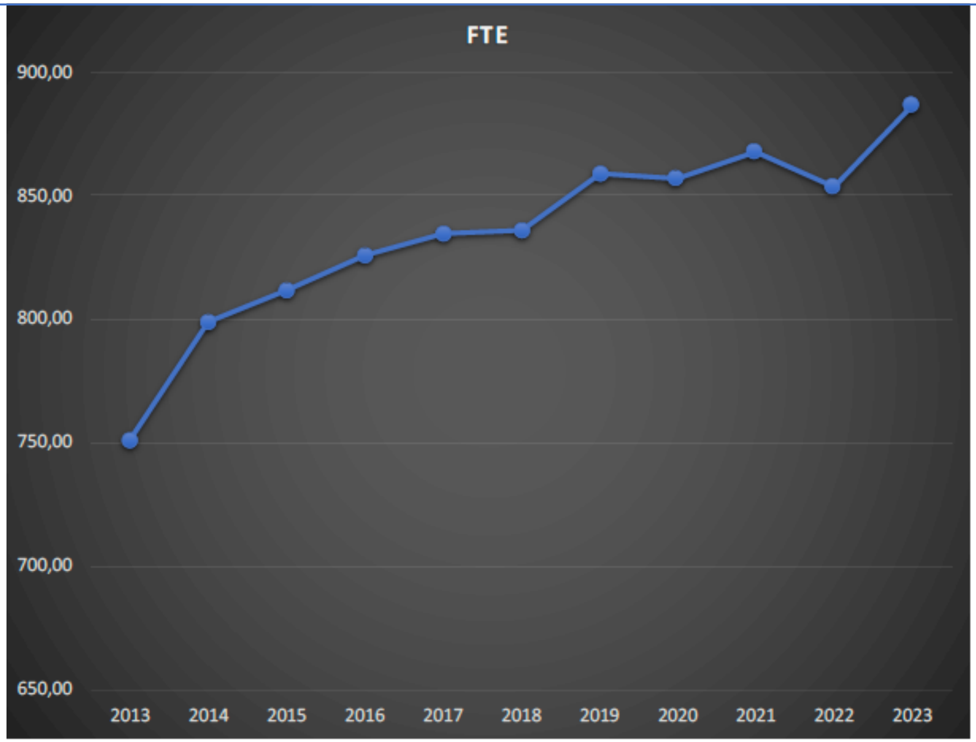
INFN Istituto Nazionale di Fisica Nucleare
SEZIONE DI PISA

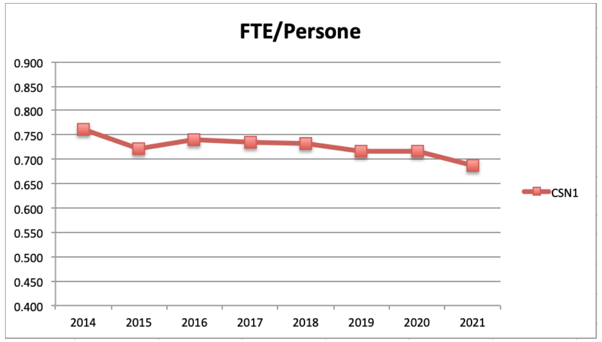
Researchers and technologists affiliated to CSN1

Number of FTEs, CSN1 proper



used for funding: CSN1 + synergic activities

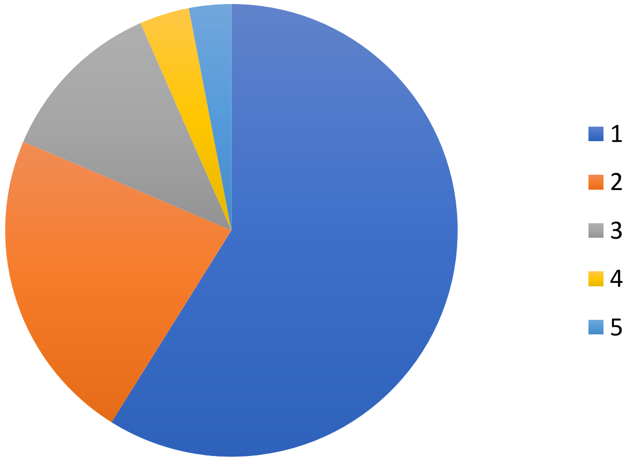




- Number of FTE in 2023 budget requests 833, including synergies 886
- Ratio FTE/people around 70%
- Fraction of women stable ≈ 20 – 21 %

Research lines CSN1	Budget 21 (%)	Budget 22 (%)	Budget 23 (%)
Physics at hadron colliders (LHC)	59,70	58,89	59,74
Flavour Physics (with LHCb)	27,60	22,52	23,5
Charged Lepton Physics	10,80	12,01	10,70
Proton Structure	2,70	3,56	2,76
R&D for exp at Future Accelerators	0,40	3,02	3,30

- Nel 2023 inizia finaziamento specifico triennale per R&D fisica del flavour [300 keu/anno]
- Nel 2023 inizia anche finanziamento specifico quadriennale su IGNITE (elettronica a 28 nm) [300 keu/anno]
    - Review comune CSN1/CSN5



- Nel 2023 aumentano considerevolmente in CSN1 i ricercatori/tecnologi della comunita acceleratori, per un totale di circa 60 persone / 10 FTE
- Finanziamento su acceleratori 2023 ≈ 115 keu
    - Destinato ad aumentare con progetti di R&D di acceleratori per la ESPP (in corso di valutazione da MAC e GE)

(*) 2022 CSN1 Budget 20 M€, does not include the external fund complementing HL-LHC detector construction ≈ 3.5 M€

Future High Energy Physics projects at accelerators with INFN involvement

- **High Luminosity LHC**
  - **ATLAS, CMS phase 2 upgrades (CSN1)**
  - **LHCb phase 2 upgrade (CSN1)**
  - **ALICE phase 2 upgrade (CSN3)**
- **The Future Circular Collider (FCC)**
  - **FCC-ee (CSN1)**
  - **FCC-hh (CSN1)**

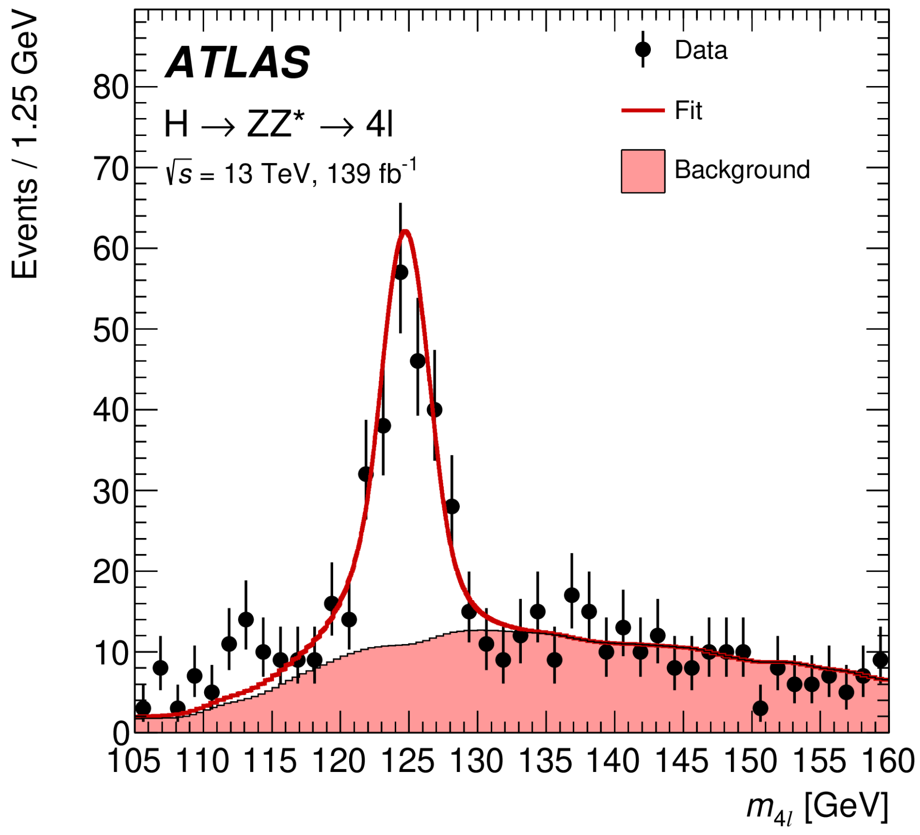
- **The Muon Collider (CSN1)**
- **Electron Ion Collider (CSN3)**
- **The neutrino platform at FNAL (CSN2)**
  - **Short neutrino Baseline (SNB)**
  - **Long neutrino Baseline (LNB)**
- **Hyper Kamiokande (HK) (CSN2)**

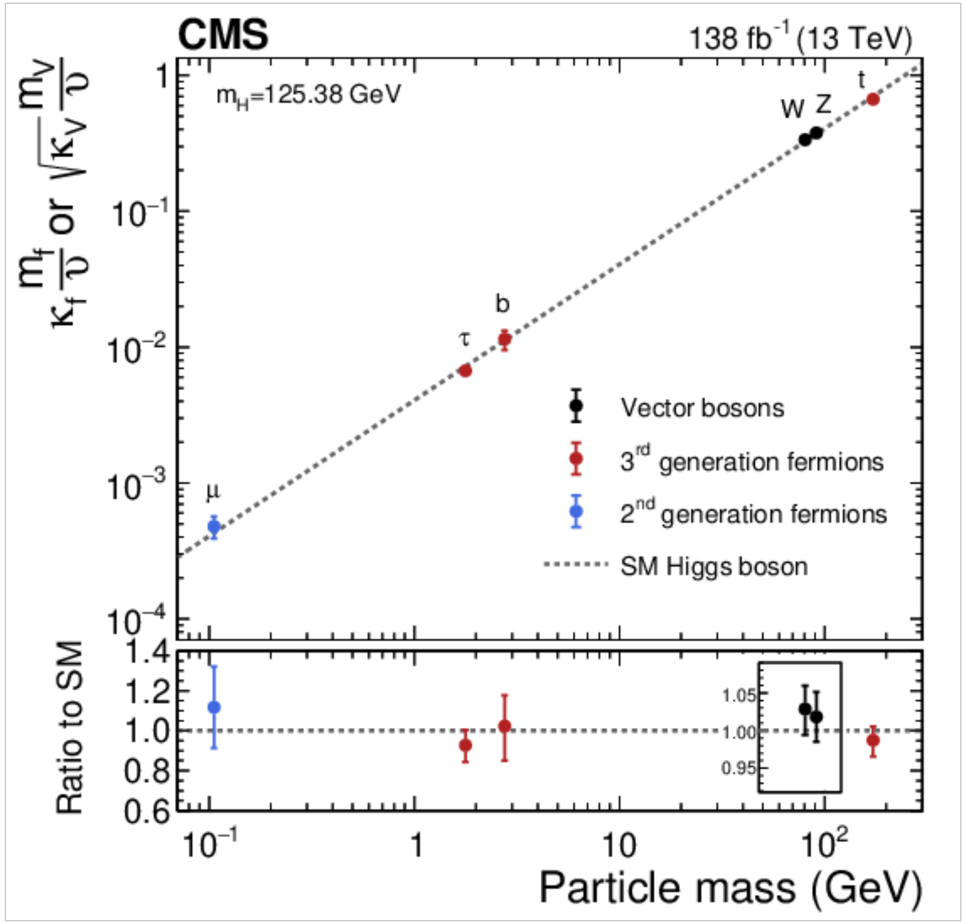
Smaller scale projects: **AMBER, BELLE 2 upgrade, HIKE, LUXE, MEG2, MU2E,** etc.

(approved, under discussion)

- **From the European Strategy for Particle Physics:**

The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.





HL-LHC: the near future

>10x the statistics of the LHC still to be collected!

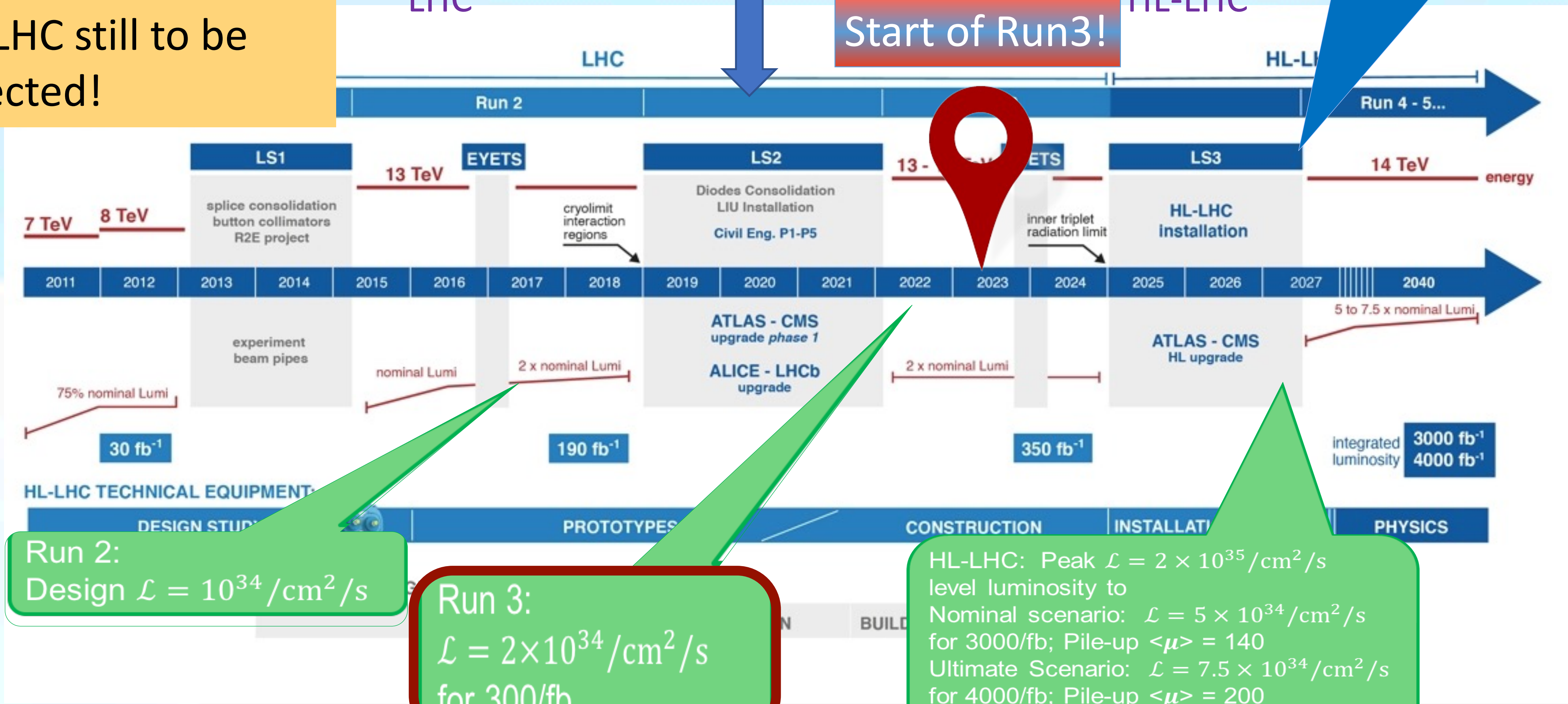
upgrade of injector chain to deliver brighter bunches

new interaction region layout and crab cavity

LHC

HL-LHC

Start of Run3!

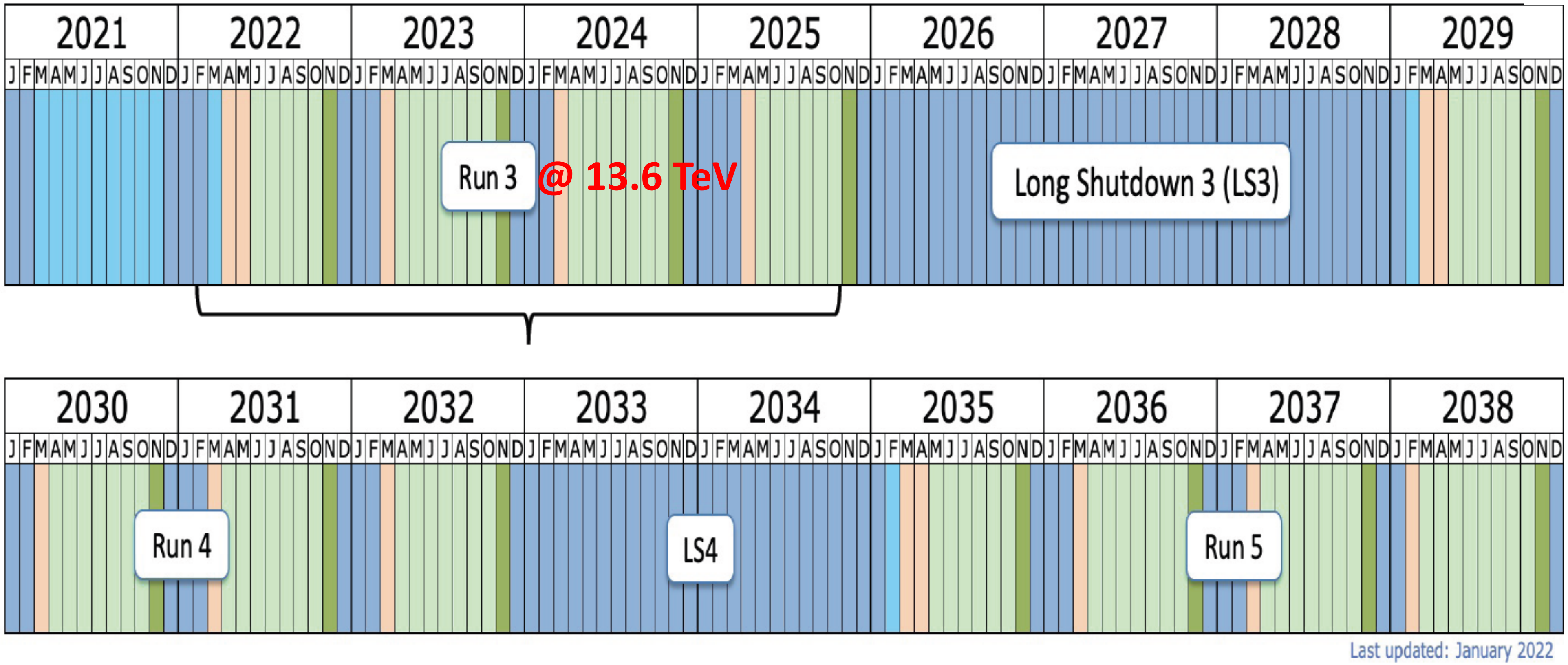


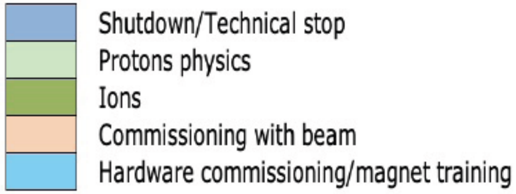
Run 2:
Design $\mathcal{L} = 10^{34}/\mathrm{cm}^2/\mathrm{s}$

Run 3:
$\mathcal{L} = 2{\times}10^{34}/\mathrm{cm}^2/\mathrm{s}$
for 300/fb

HL-LHC: Peak $\mathcal{L} = 2 \times 10^{35}/\mathrm{cm}^2/\mathrm{s}$
level luminosity to
Nominal scenario: $\mathcal{L} = 5 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$
for 3000/fb; Pile-up $\langle\mu\rangle = 140$
Ultimate Scenario: $\mathcal{L} = 7.5 \times 10^{34}/\mathrm{cm}^2/\mathrm{s}$
for 4000/fb; Pile-up $\langle\mu\rangle = 200$
⇒25% increase in integrated lum.

New LHC long term schedule
incorporating delays accumulated for HL-LHC detector construction





Run 3 extended up to 2025

Expected Run 3 Integr. lum. 270fb^{-1} with leveled lum. 2x 10^{34} cm^{-2} s^{-1}

LS3 will start in 2026 with a 3 year duration

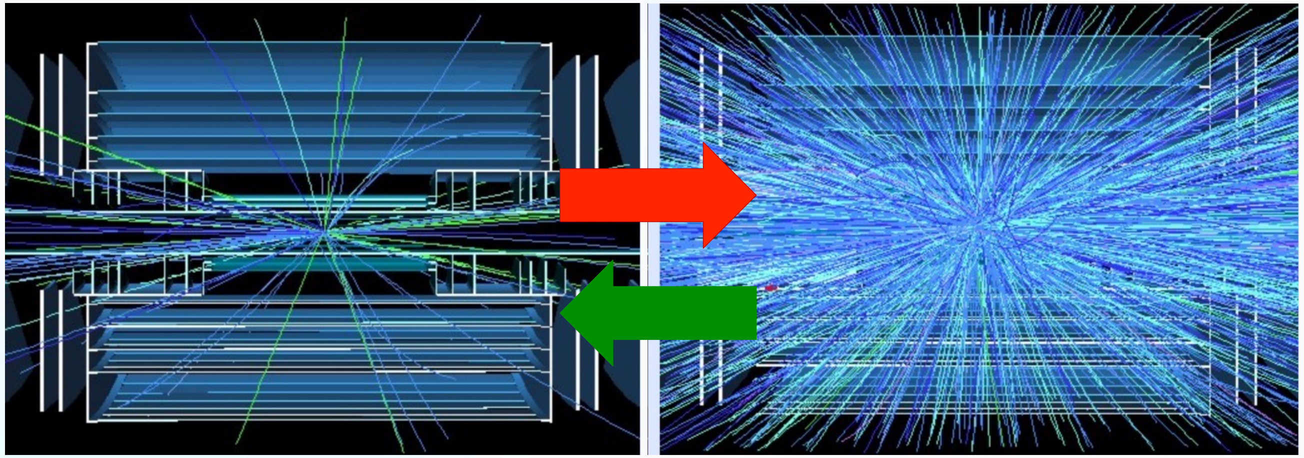
HL-LHC : Run 4 + Run 5, at least 3000 fb-1 delivered tk ATLAS e CMS (*ultimate lumi* 4500 fb-1)

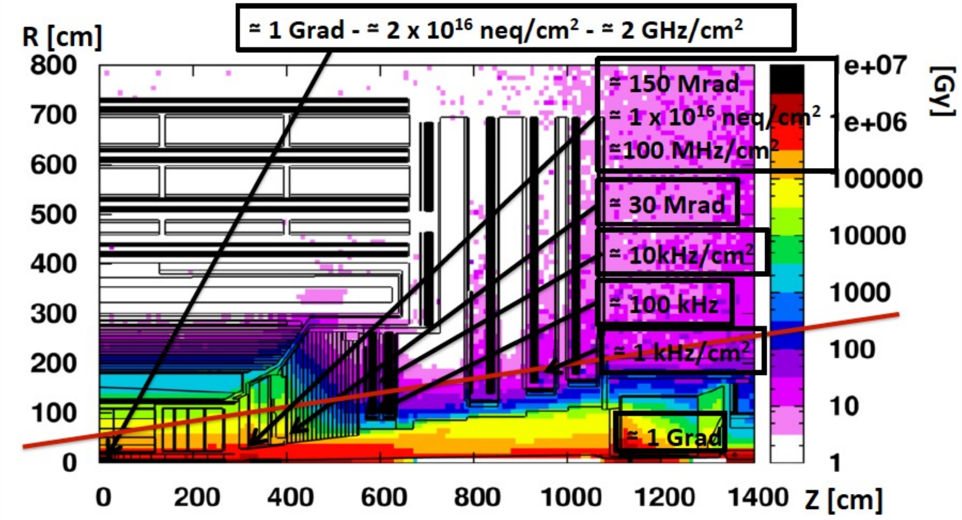
HL-LHC experimental challenges

- **High luminosity ➔ 200 soft pp interactions per crossing**
  - Increased combinatorial complexity, rate of fake tracks, spurious energy in calorimeters, increased data volume to be read out in each event
- **Detector elements and electronics are exposed to high radiation dose : requires new tracker, endcap calorimeters, forward muons, replacing readout systems**
- **Planned detectors shown to be able to successfully operate at the HL-LHC**

25 pileup

200 pileup

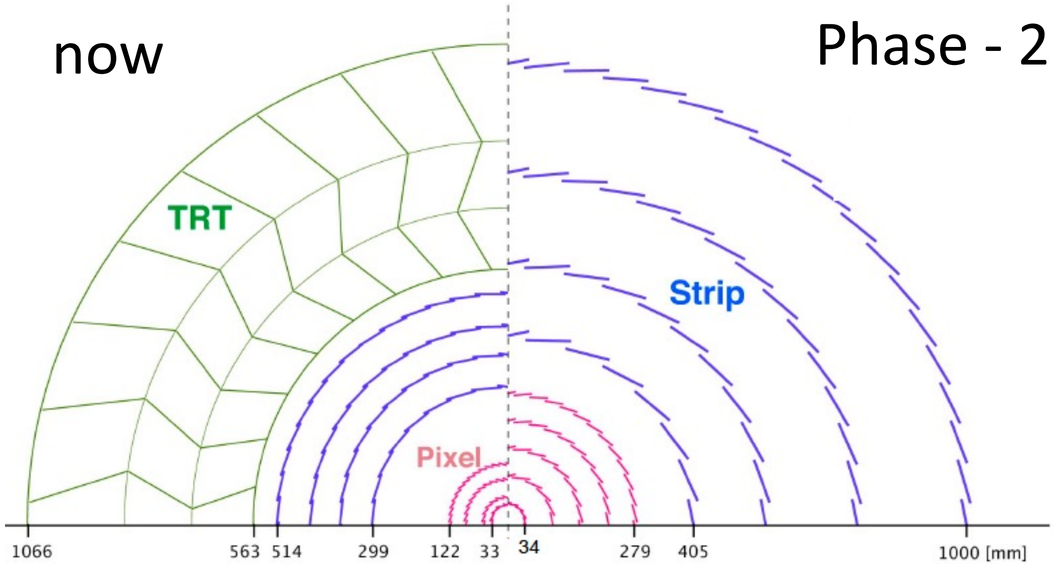




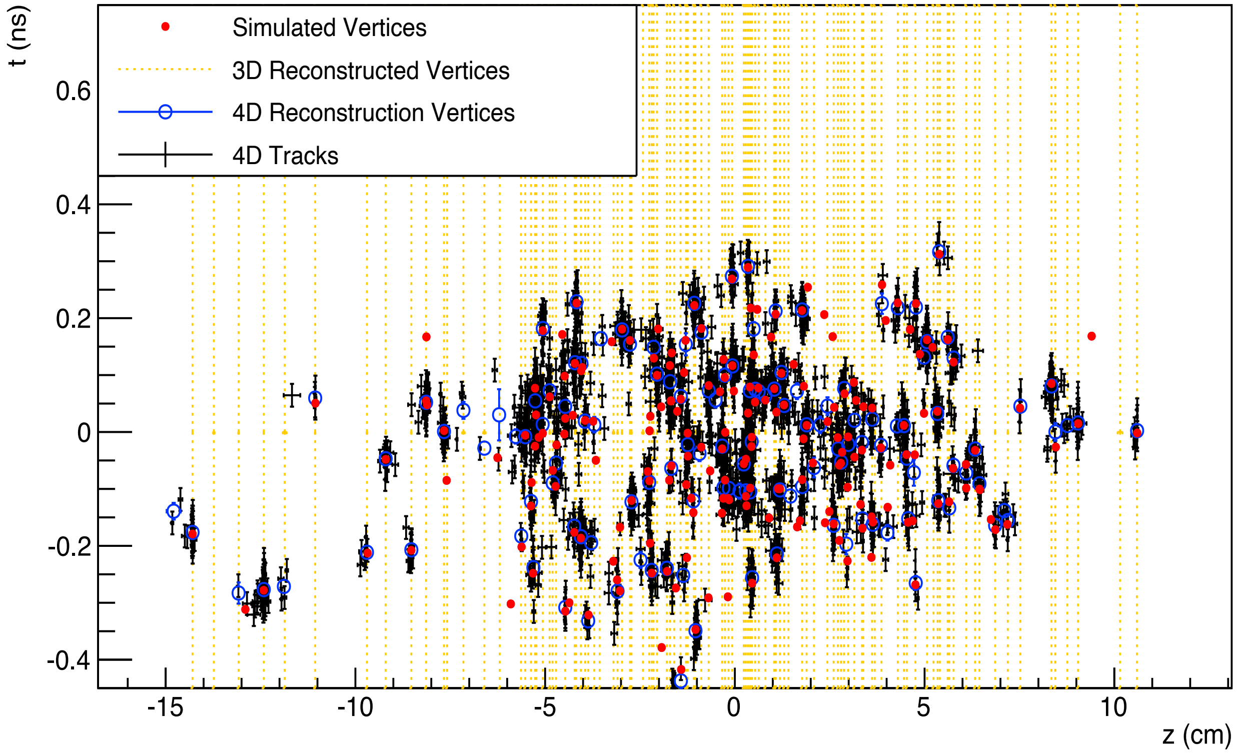
Roughly reaching limits of current techniques in several systems

Detector answers to the HL-LHC challenge

Example: ATLAS Tracker



Example: CMS Timing layer concept



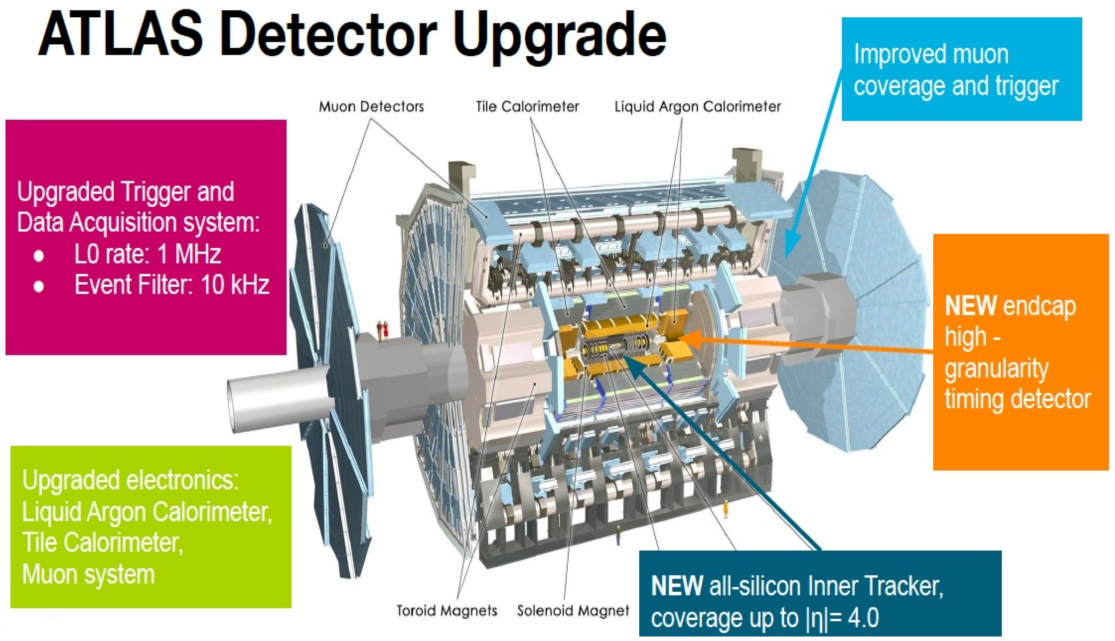
5 cm RMS

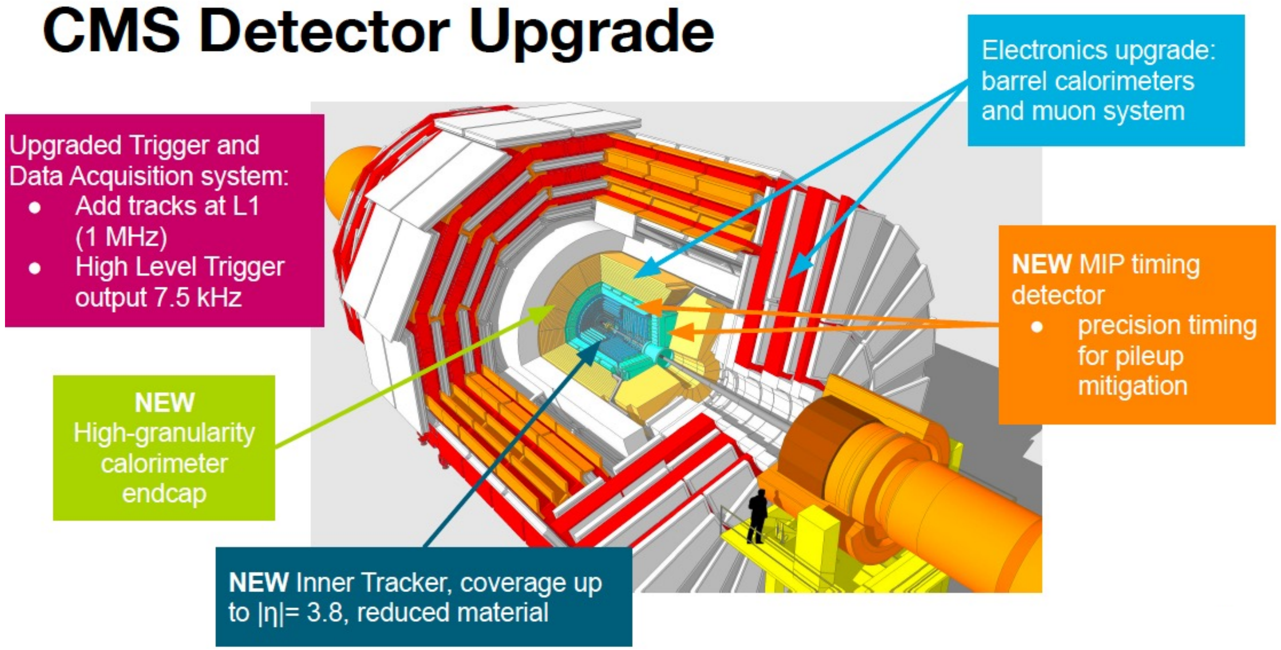
Improve granularity

Add timing information

+ radiation hardness

ATLAS and CMS upgraded detectors (phase 2)





Main INFN INVOLVEMENTS:
- Tracker (ITK)
- Liquid Argon Calorimeter
- Tile Calorimeter
- MUON
- TDAQ

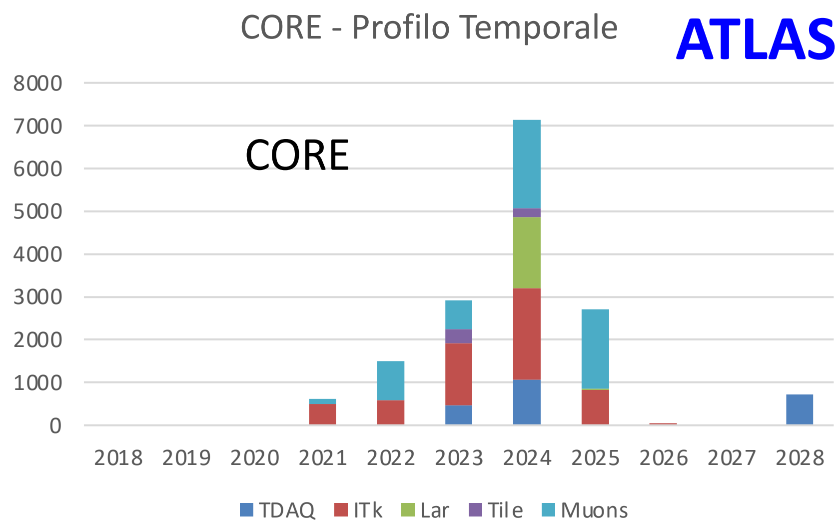
MAIN INFN INVOLVEMENTS:
- Tracker (inner and outer)
- MTD timing layer
- ECAL
- MUON

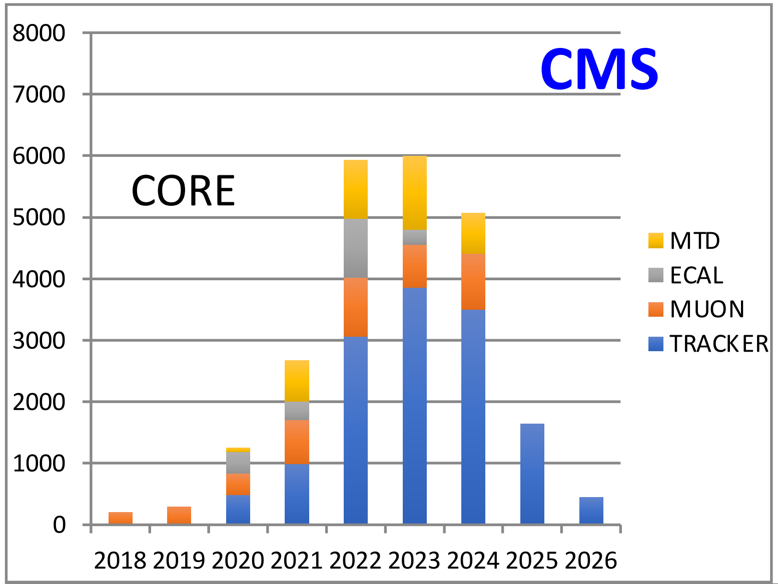
Time profile of INFN contributions to CORE and personnel LHC PHASE 2 – revised schedule (July 2022)

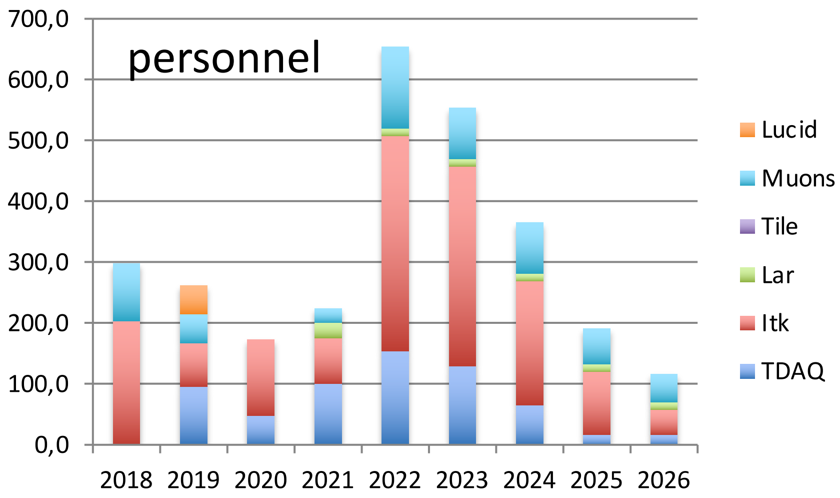
Funding defined in feb 2018 (CTS)

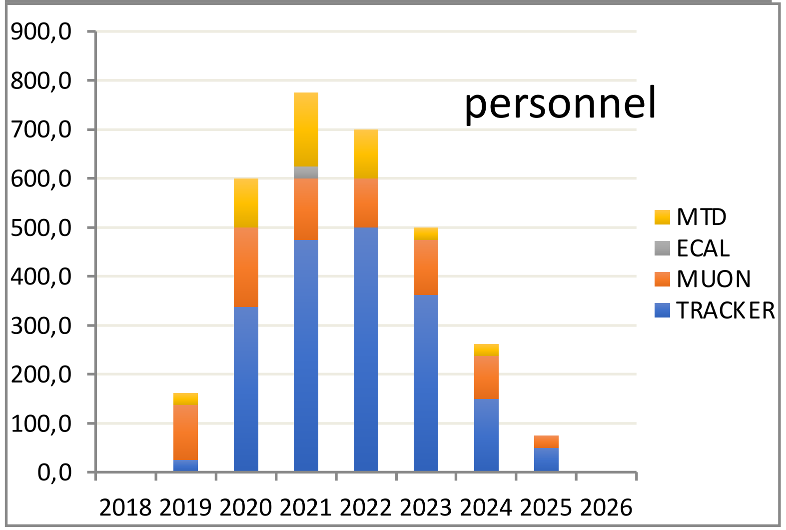
- **CSN1:** 25 M€ in 2018-2025
- **LHC_MIUR:** 31 M€ + 8 M€ contingency
- (computing not included)

- Total cost is bound to increase:
  - **Exchange rate (CHF/EUR)**
  - **Cost of materials**
  - **Russian crisis**





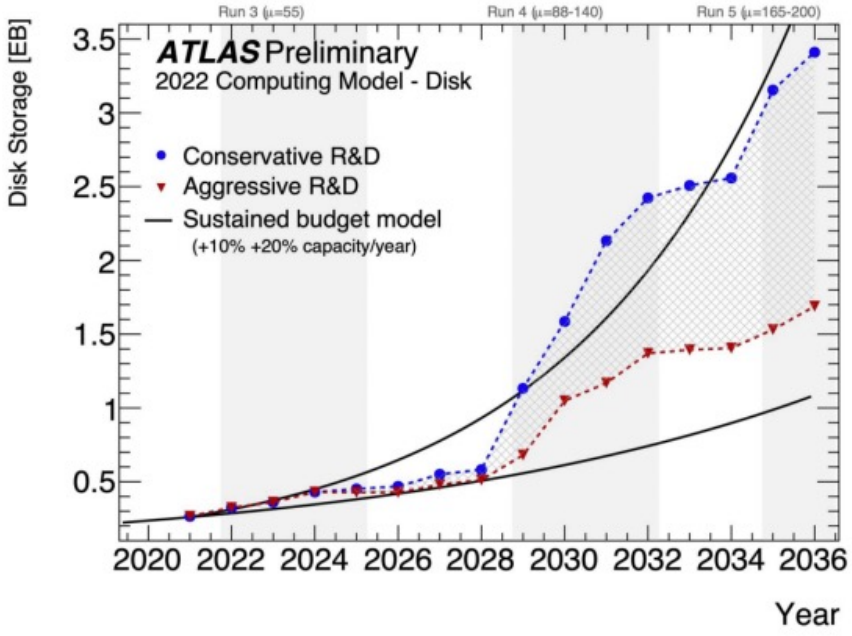


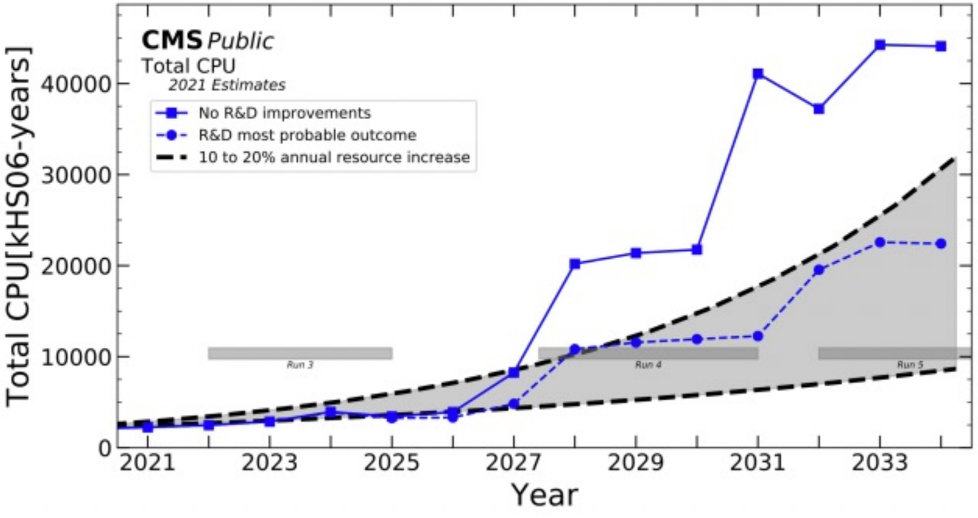


Computing @ HL-LHC (ATLAS+CMS)

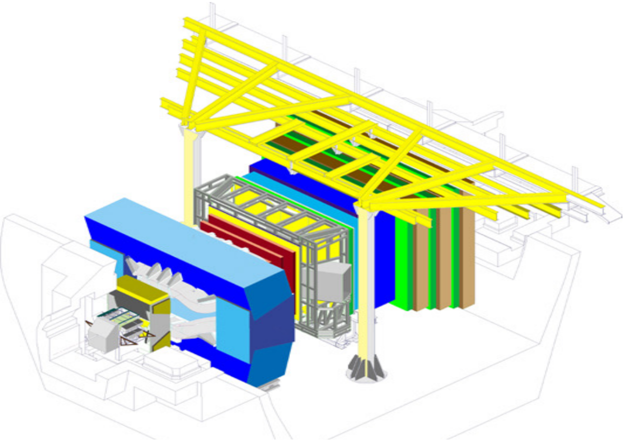
- Initially considered ”impossible” → resources 10-50x in excess of what technology could provide at a fixed price
- Intensive R&D in the last 5+ years, by Experiments, EU + NSF/DOE projects (IRIS, Excalibur, ESCAPE, …), initiatives (HSF, …)
- Tools: HPC, data-lake model, Heterogeneous Computing (GPU, etc.)
- Last extrapolation show a much more optimistic scenario

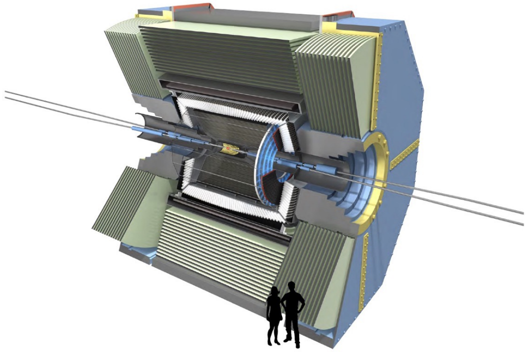
Extrapolations within the two exponentials → fixed budget possible

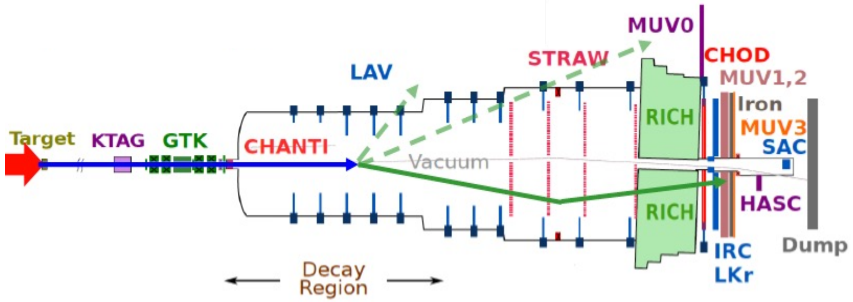




Main players in quark-flavour physics







- ATLAS and CMS : measure some relevant B-physics channels, mainly with muons in the final state, but also new prospects eagerly awaited with parked data → (upgrades already funded)

- LHCb and Belle II: dedicated detectors for flavour physics with wide range of measurements → future upgrades

- NA62: measure the SM branching fraction of $K^+ \to \pi^+ \nu\nu$ with 10% precision → future upgrades involve K^+ and K^0 rare decays (HIKE)

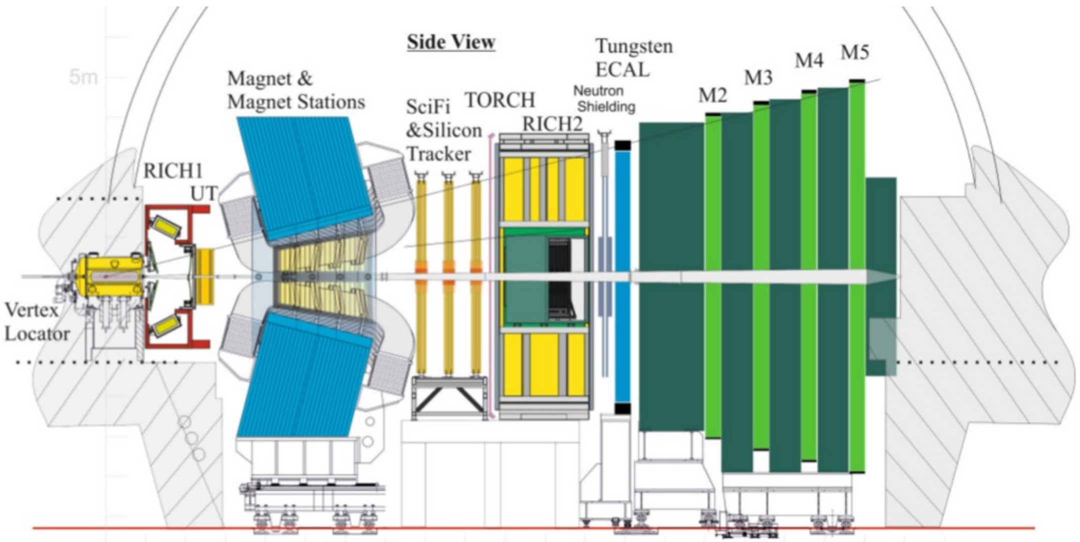
- FCC-ee : very relevant B physics perspectives by running at the Z at 10^5 times LEP luminosity

For all of them strong INFN involvement, specific resources for R&D added in 2023-2025 under "RD_flavour"

LHCb Upgrade II : The detector challenge

Q1

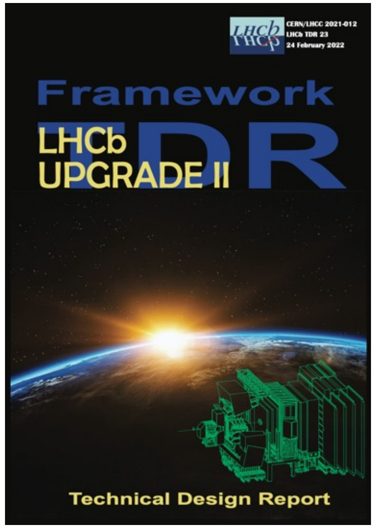
Targeting same performance as in Run 3, but with pile-up ~40!



Same spectrometer footprint, innovative technology for detector and data processing

Key ingredients:

- granularity
- fast timing (few tens of ps)
- radiation hardness

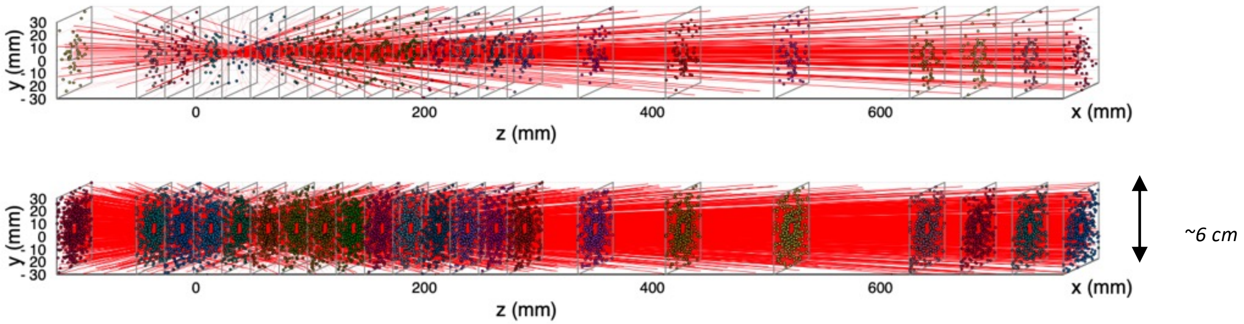


Approved March 2022
R&D programme,
scoping document followed by sub-system TDRs

VErtex LOcator (VELO)

Run 3: pile-up ~6

Upgrade II: pile-up ~42



Q1

Cost of LHCb upgrade II

Detector	Baseline (kCHF)
VELO	14800
UT	8900
Magnet Stations	2300
MT-SciFi	22400
MT-CMOS	19500
RICH	15600
TORCH	9900
ECAL	34800
Muon	7100
RTA	17400
Online	8900
Infrastructure	13500
Total	175100

- FTDR describes baseline detector and areas of descope for investigation
- Cost range 175-130 MCHF

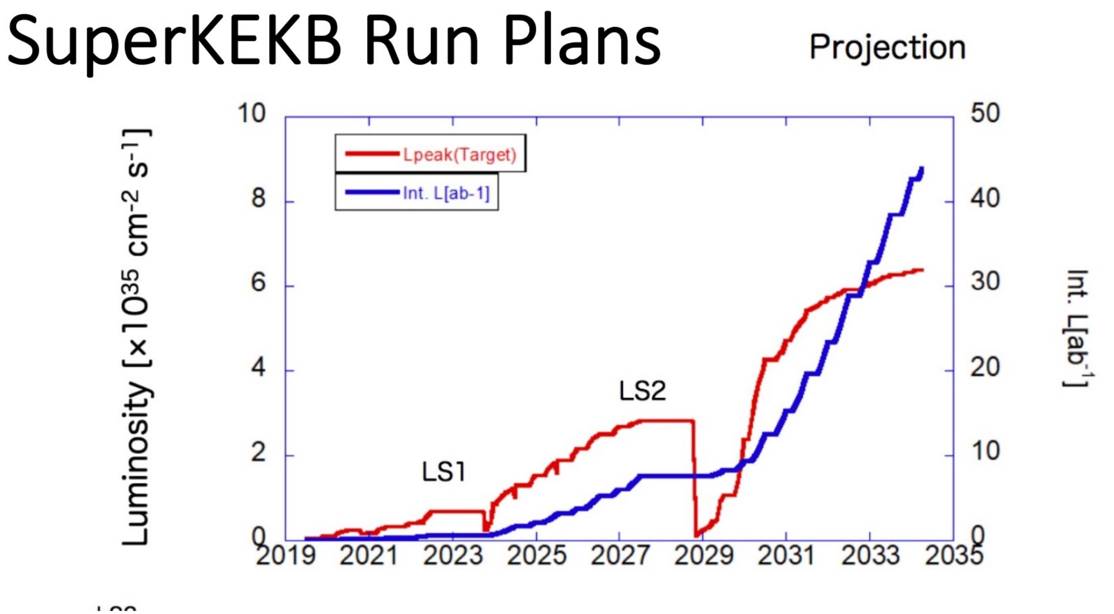
Descope examples driven by physics or technology

system	what	cost reductio n	impact/comments
RTA	reduce peak luminosity	8 MCHF	Reduce data taken
ECAL	single readout on outer region	13 MCHF	Reduced physics performance
TORCH	reduce coverage	3.5 CHF	Reduced physics performance
MT-CMOS	reduce CMOS pixel area	7 MCHF	Driven by technology and algorithm development

Request funding agencies decision on participation with time scale ~ 2 years
→ Toward TDR and Money MatrixItalian community very interested and already involved: 16% in the current LHCb Collaboration

Belle 2 and future upgrades

- SuperKEKB: new record of instantaneous luminosity (June '22): **L_{peak} = 4.7 10^{34} $cm^{-2}s^{-1}$** 'crab waist scheme': 1300 mA (LER), 1040 mA (HER)
- Excellent performance of the detector, several publications and new results at ICHEP 2022
- Machine far from the target luminosity, long shutdown foreseen in 2026-7 (LS2) to upgrade final focus and for other interventions
- **LS2 in 2026-7 is an important opportunity for a detector upgrade that improves robustness (vs BKG) and performance**



Submitted to the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021)

Snowmass Whitepaper:
The Belle II Detector Upgrade Program

Belle II Collaboration

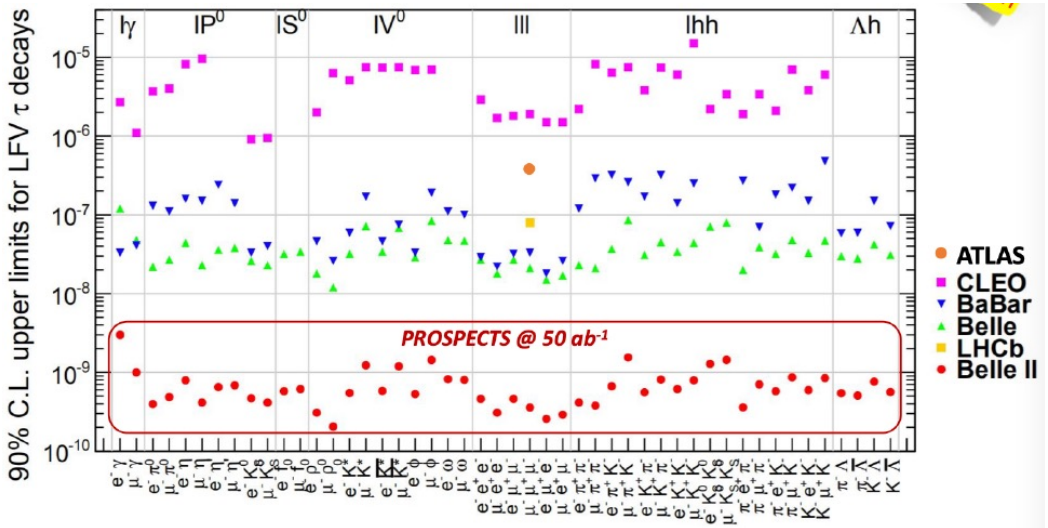
March 23, 2022

Abstract

We describe the planned near-term and potential longer-term upgrades of the Belle II detector at the SuperKEKB electron-positron collider in Tsukuba, Japan. These upgrades will allow increasingly sensitive searches for possible new physics beyond the Standard Model in flavor, tau, electroweak and dark sector physics that are both complementary to and competitive with the LHC and other experiments. We encourage the instrumentation-frontier community to contribute and study upgrade ideas as part of the Snowmass process.

arxiv:2203.11349

Example of physics case for tau physics



Belle 2 and future upgrades

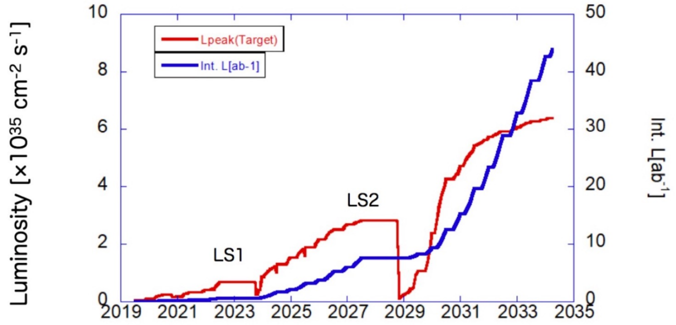
Q1

SuperKEKB ha una lunga lista di contromisure alle limitazioni di luminosità osservate: buona parte si stanno implementando durante LS1

	Aim	Possible countermeasures	
(1)	· Increase injection power (efficiency)	Linac upgrade to designed specification	
		Large physical aperture at electron injection point (HER)	During LS1
		Linac upgrade beyond designed specification	
(2)	· Relax beam-beam effect · Expand dynamic aperture	Utilizing rotatable sextuplole magnets (LER)	Done before LS1
		"Perfect matching"	Under consideration
		QCS modification (Option#1): Move QC1RP to the far side of IP	(It was found that it is not easy.)
		Larger scale QCS modification (Option #8)	Under consideration
(3)	· Suppress BG · Expand physical aperture	QCS cryostat front panel modification and additional shield to IP bellows	During LS1
		Optimization of collimator location	Done before LS1
		Enlargemen of QCSR beam pipe (Option#3)	Under consideration
(4)	· Relax TMCI limit	"Non-linear collimator"	During LS1
(5)	· Improve stability	Robust collimators	During LS1 (Partially)
		Upgrade of beam abort system and loss monitor system	During LS1 (Partially)
(6)	· Anti-aging measures	Preparation of standby machines and spares, repair of facilities, etc.	During LS1 (Partially)

SuperKEKB Run Plans

Projection

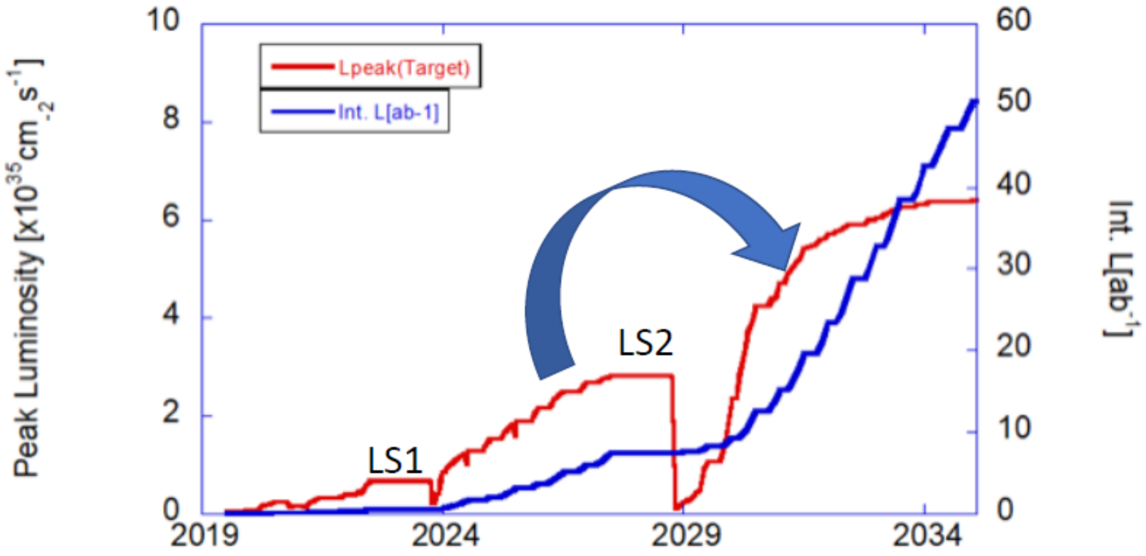


Piani per l'upgrade

Nel Run II SuperKEKB punta a raggiungere $L_{peak} = 2.4 \times 10^{35}\ cm^{-2}\ s^{-1}$.

Per poter integrare 50 ab-1 sarà poi necessario raggiungere $L_{peak} = 6 \times 10^{35}\ cm^{-2}\ s^{-1}$

A questo scopo sarà probabilmente necessario un ridisegno della regione di interazione e forse un upgrade di tutto il sistema di iniezione.
Fondamentale il run 2024 per precisare queste idee.



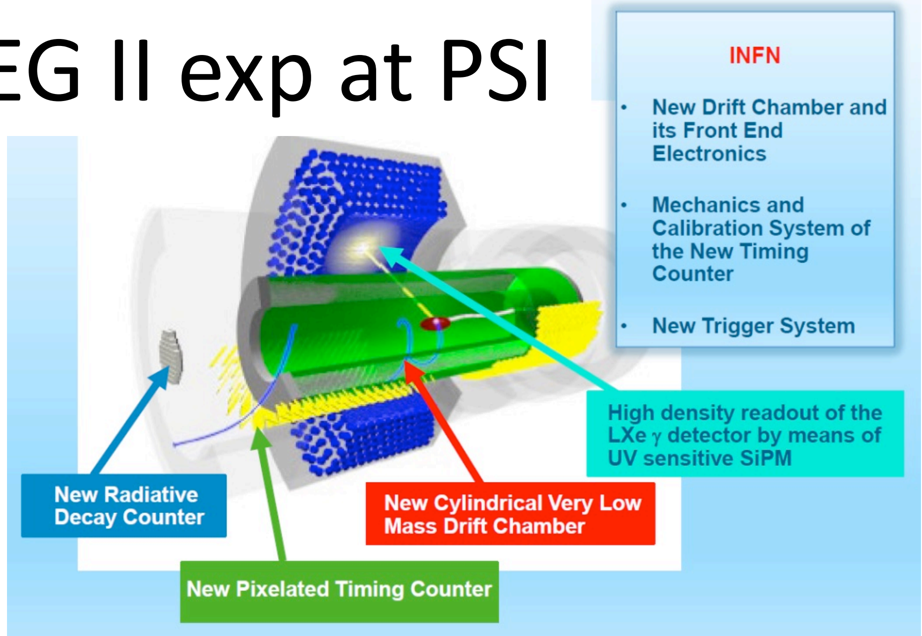
Simili interventi richiederanno un LS2 di durata > 1 anno (2027-28) e una ripartenza molto «ripida» per recuperare la luminosità non integrata durante LS2.
Una International task force sta studiando i possibili scenari di upgrade per SuperKEKB: la partecipazione di fisici di macchina italiani sarebbe molto importante.

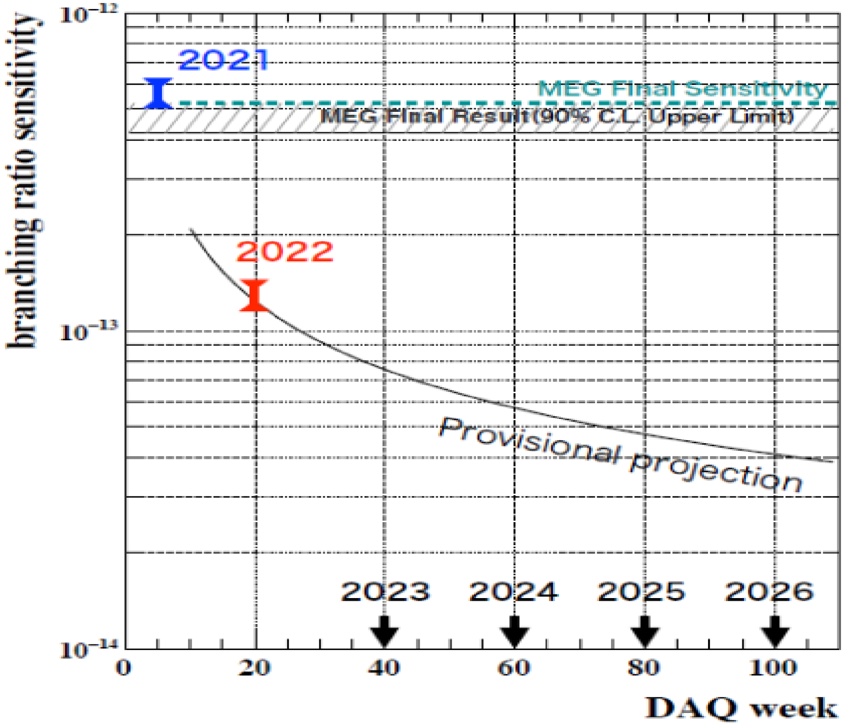
Ovviamente l'upgrade di macchina ha impatto sul detector, non solo per le modifiche di IR ma anche per l'aumento della rate di acquisizione e del background

The MEG II exp at PSI

Q1

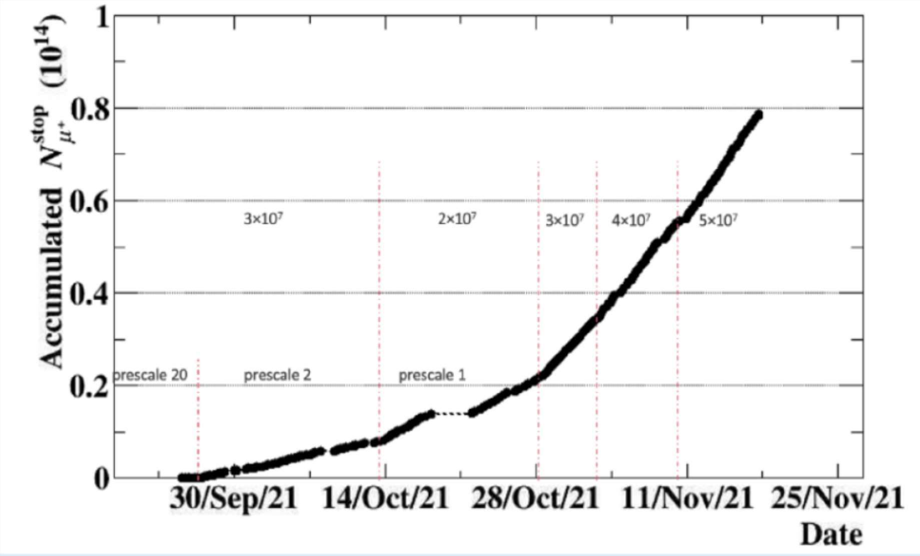
Search for $\mu \rightarrow e\gamma$ decays



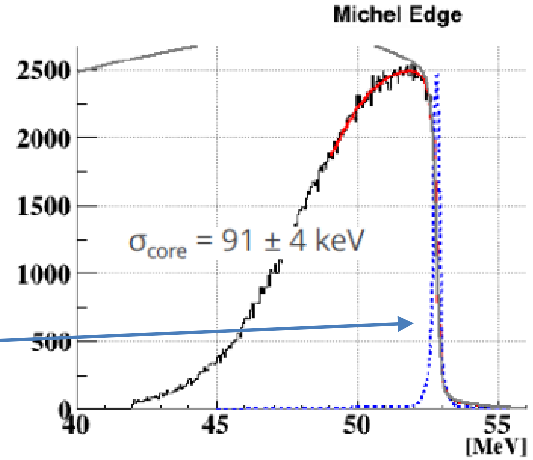


- Provisional projection curve based on expected detector performance ("Updated(2021)" in summary table)
- (20 DAQ weeks for 6 month beam time) per year
- DAQ time 2021 with correction for fraction of physics run

"Luminosity" accumulated during first physics run

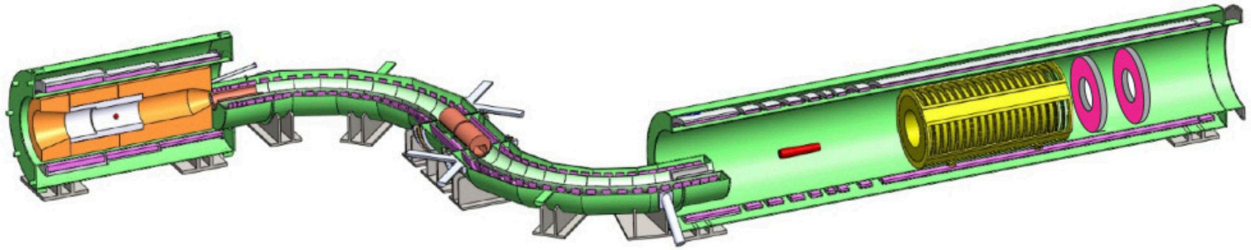


Performance of drift chamber is very good, already with initial alignement momentum resolution improved by a factor of 4 w.r.t. MEG I

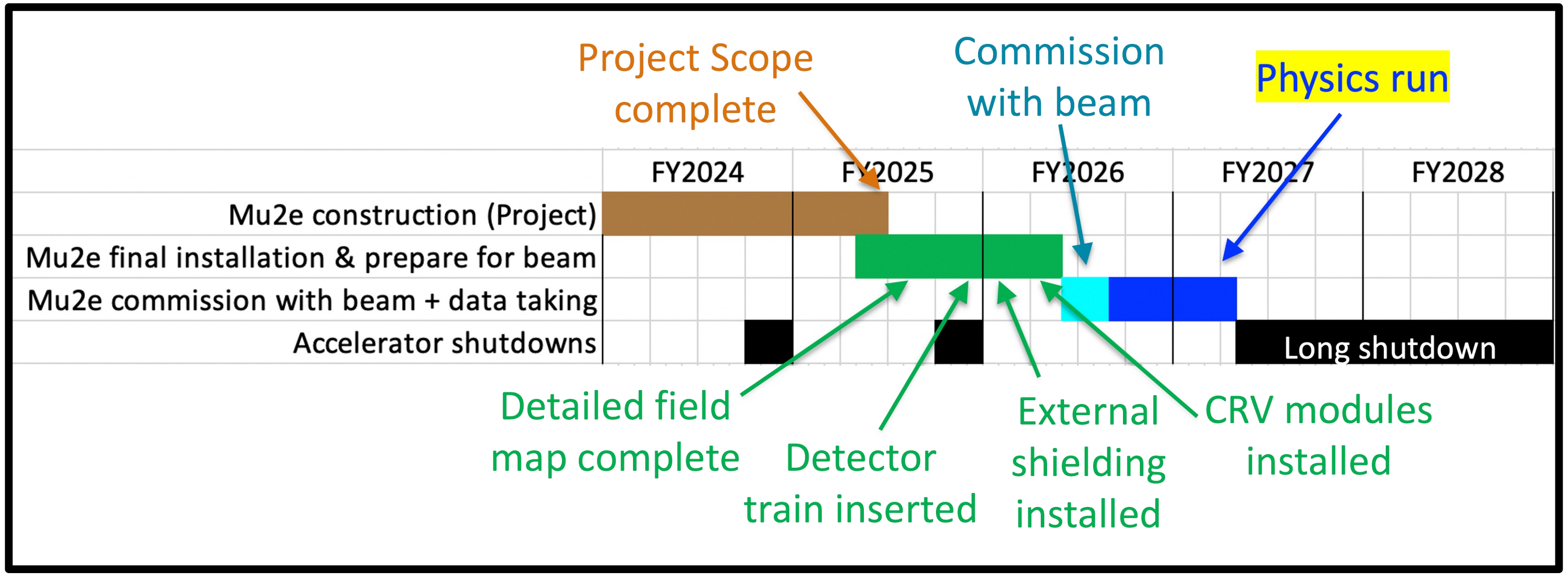


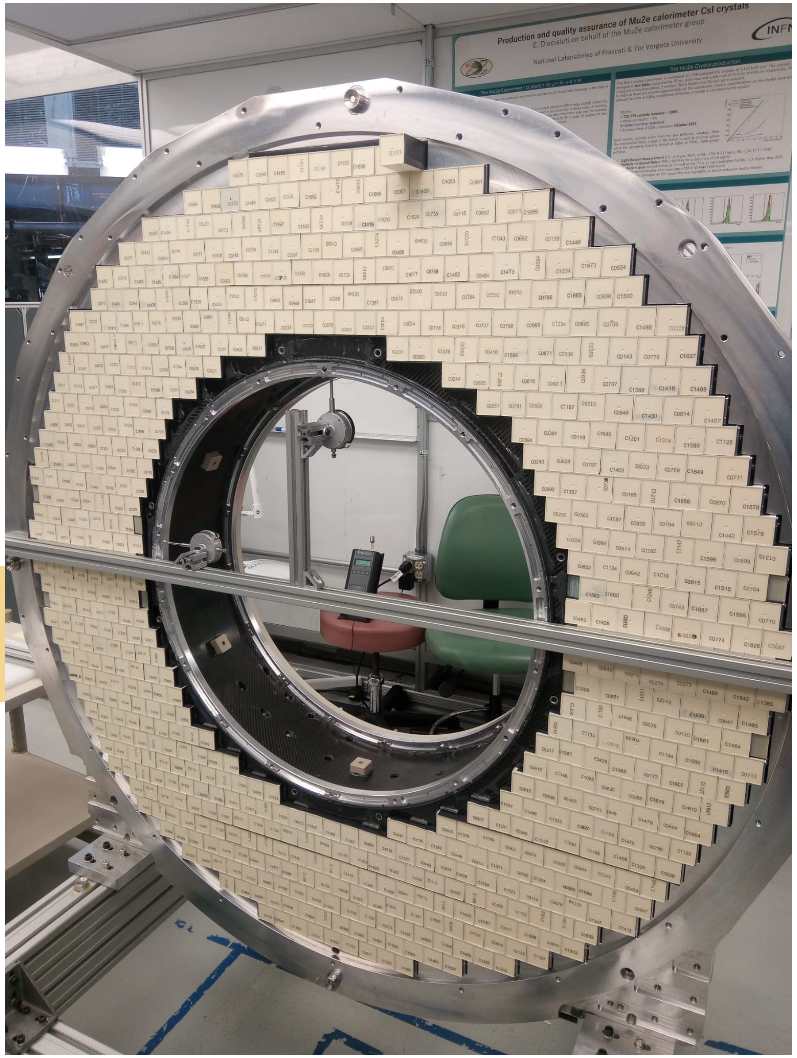
The Mu2e experiment at Fermilab

Searching for muon-to-electron conversion in a thin aluminum stopping target



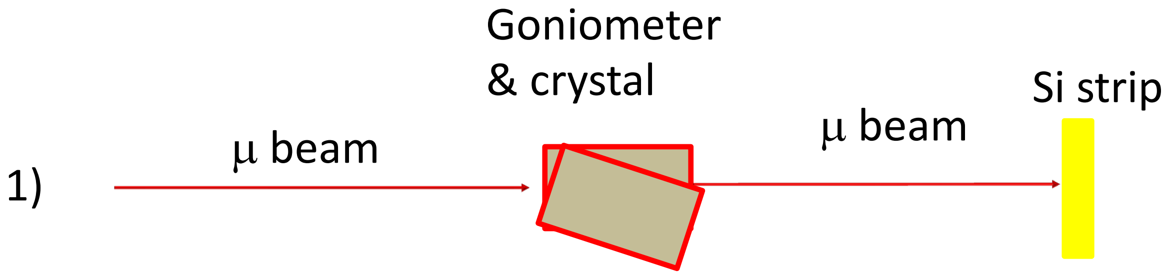
Mu2e progresses 2022: Critical path still driven by Solenoids +1.5 year Delay due to Covid → REBASELINED by DOE in Sept 2022.

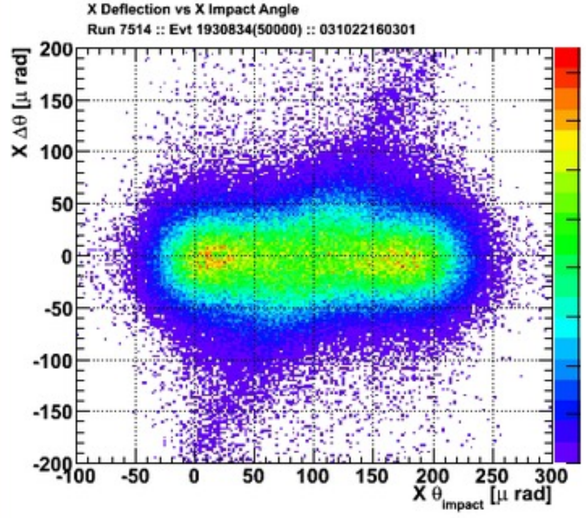




Calorimeter disk assembled with crystals (INFN responsibility)

UA9 : Cristalli per manipolazione e ricombinazione fasci

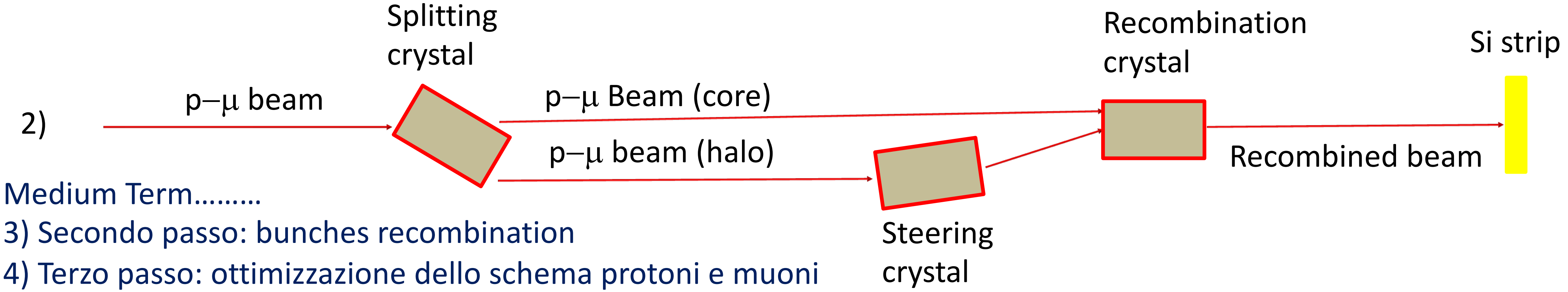




Primo scopo è quello di fornire due fasci sincronizzati da ricombinare

Short Term, 2023

1) Test dei cristalli Aplyx nel nuovo bender realizzato da Roma1
2) Primo passo: test di allineamento della configurazione a tre cristalli (de-bunched).



Medium Term………

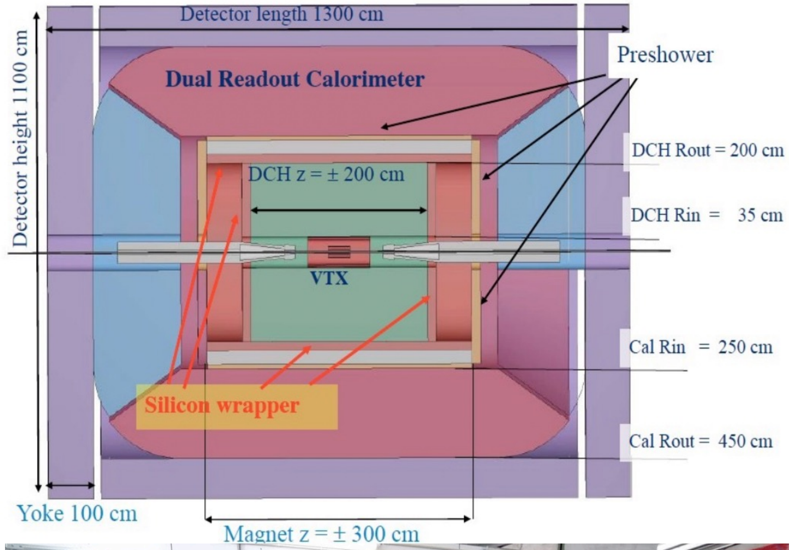
3) Secondo passo: bunches recombination
4) Terzo passo: ottimizzazione dello schema protoni e muoni

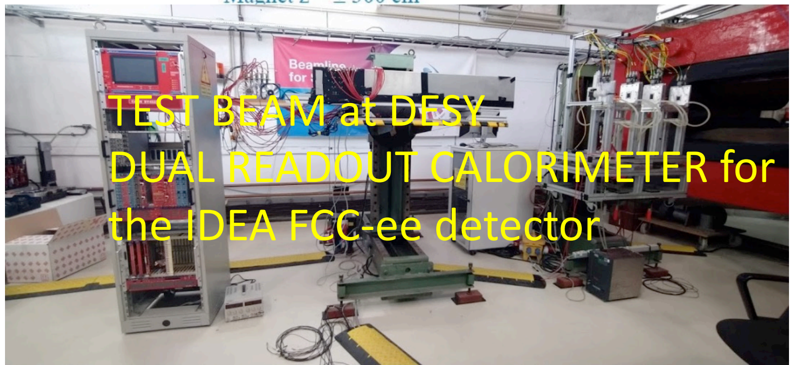
Preparing the future: FCC and Muon Collider

CSN1: RD_FCC

2022: 105 scientists/15.3 FTE

~ 6-700 k€/yr (CSN1 & EU grants)

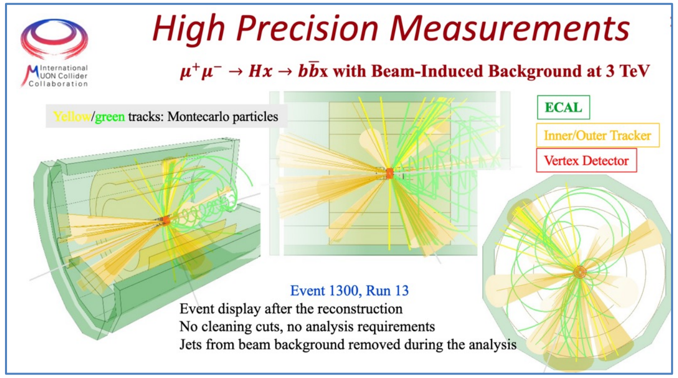


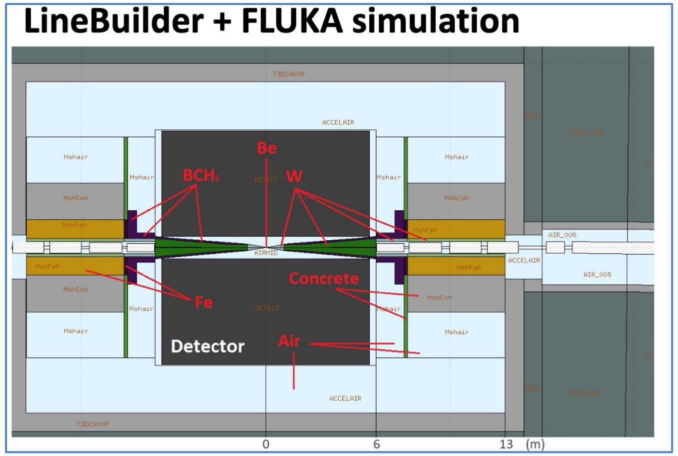


CSN1: RD_MUCOL

2022: 97 scientists/15.7 FTE

~ 300+X k€/yr (CSN1 & EU grants)





Coordinating the efforts to boost participation and include the INFN accelerator community, in synergy with other projects

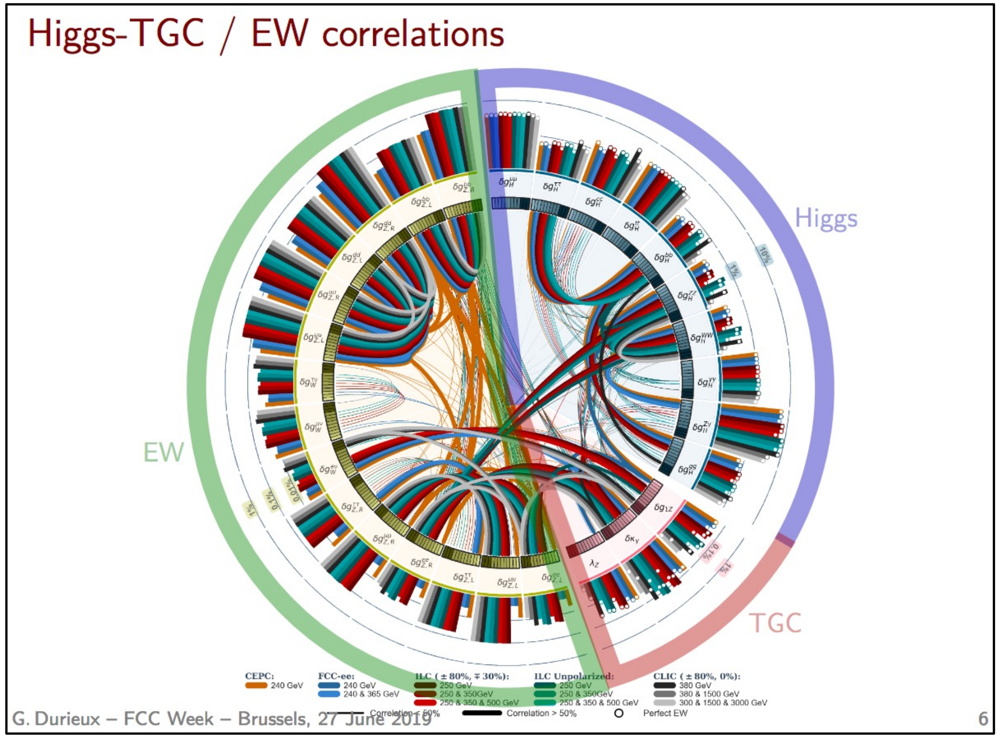
- SC magnets
- RF cavities
- etc

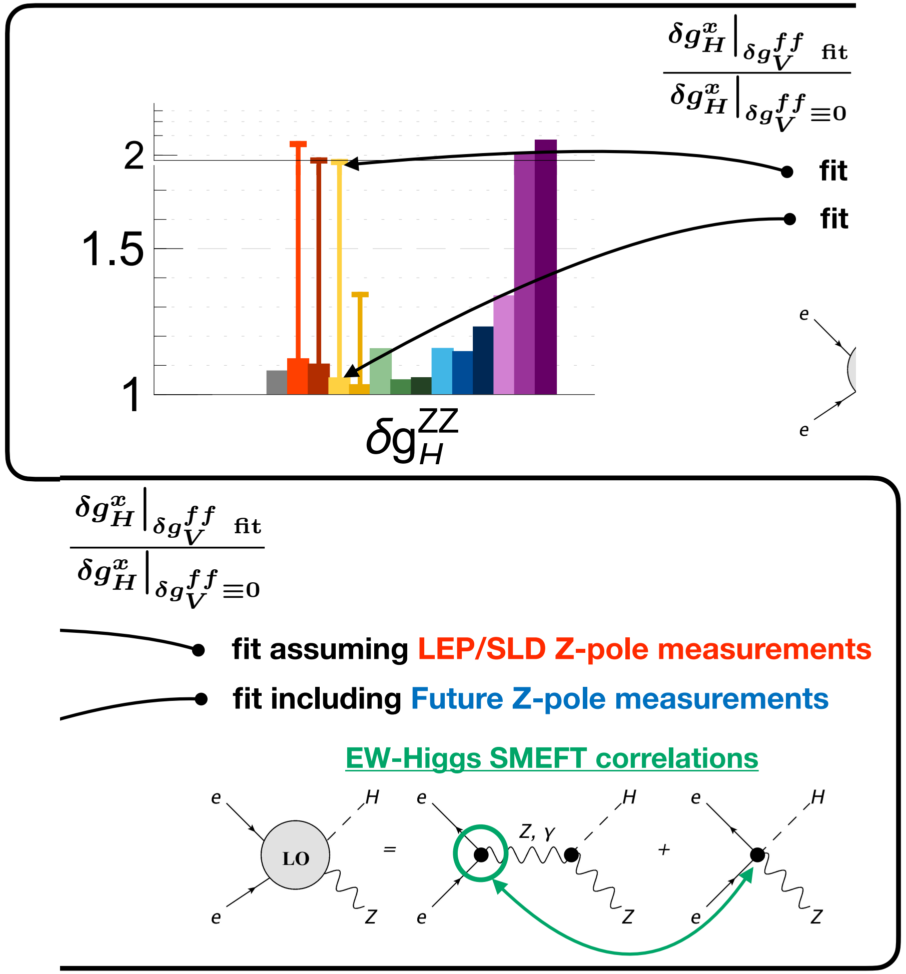
Beyond Standard Model, Precision Measurements, Discoveries: un programma di ricerca indirizzato alle prossime decadi non deve essere indirizzato al pennacchio di fumo, ma all’intero panorama per scoprire gli edifici che formano la nuova fisica

Beyond Standard Model, Precision Measurements, Discoveries: un robusto programma di ricerca a medio/lungo termine deve affrontare gli aspetti e correlazioni delle misure di precisione e delle ricerche dirette.

Esempio: incertezze Higgs couplings senza e con nuove misure alla Z

Correlazioni tra osservabili Higgs, Z e W a futuri acceleratori

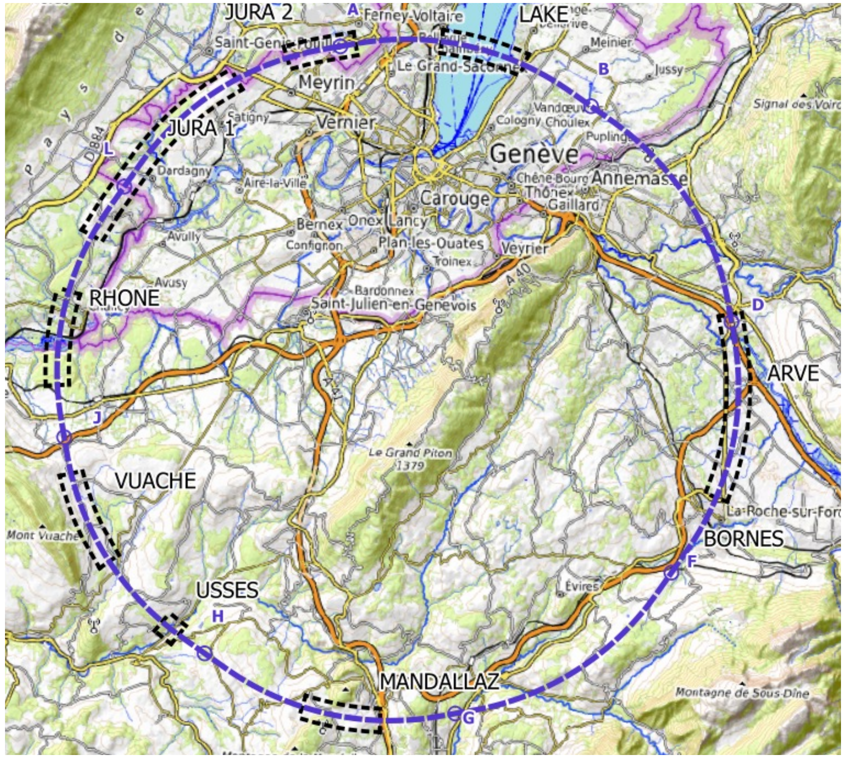




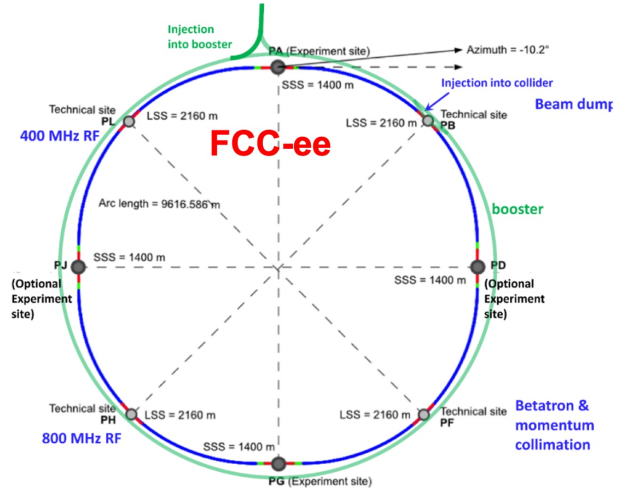
After HL-LHC: the FCC integrated project

Comprehensive long-term program maximizing physics opportunities

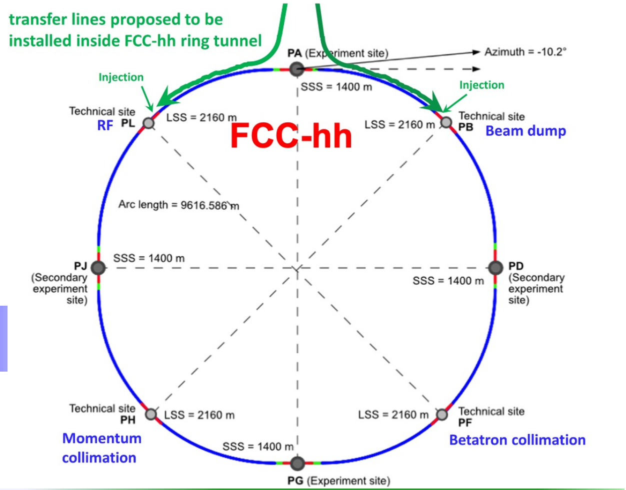
- **stage 1: FCC-ee (Z, W, H, $t\bar{t}$) as Higgs factory, electroweak & top factory at highest luminosities**
- **stage 2: FCC-hh (~100 TeV) as natural continuation at energy frontier, with ion and eh options**
- complementary physics
- common civil engineering and technical infrastructures, building on and reusing CERN's existing infrastructure
- FCC integrated project allows seamless continuation of HEP after completion of the HL-LHC program



Infrastructure preparation 2020 - 2040



2045 - 2060



2065 - 2090

A first class infrastructure to maintain the leadership of European research in particle physics over the 21st century

FUTURE CIRCULAR COLLIDER

FCC Feasibility Study status summary

Following 2020 European Strategy Update, **organisation structure and major milestones & deliverables for the FCC Feasibility Study (FCC FS) approved by CERN Council in June 2021.** Entire **FCC government structure (**members of **SC, CB, SAC, CG) established (summer 2022).**

Main activities: **developing & confirming concrete implementation scenario,** in collaboration **with host state authorities**, including **environmental impact analysis**, and accompanied by **machine optimisation, physics studies and technology R&D - via global collaboration,** supported by **EC H2020 Design Study FCCIS and Swiss CHART. Goal: demonstrate feasibility by 2025/26**

Next milestone is the mid-term review, autumn 2023.

Long term goal: **world-leading HEP infrastructure for 21st century** to push particle-physics **precision and energy frontiers** far beyond present limits

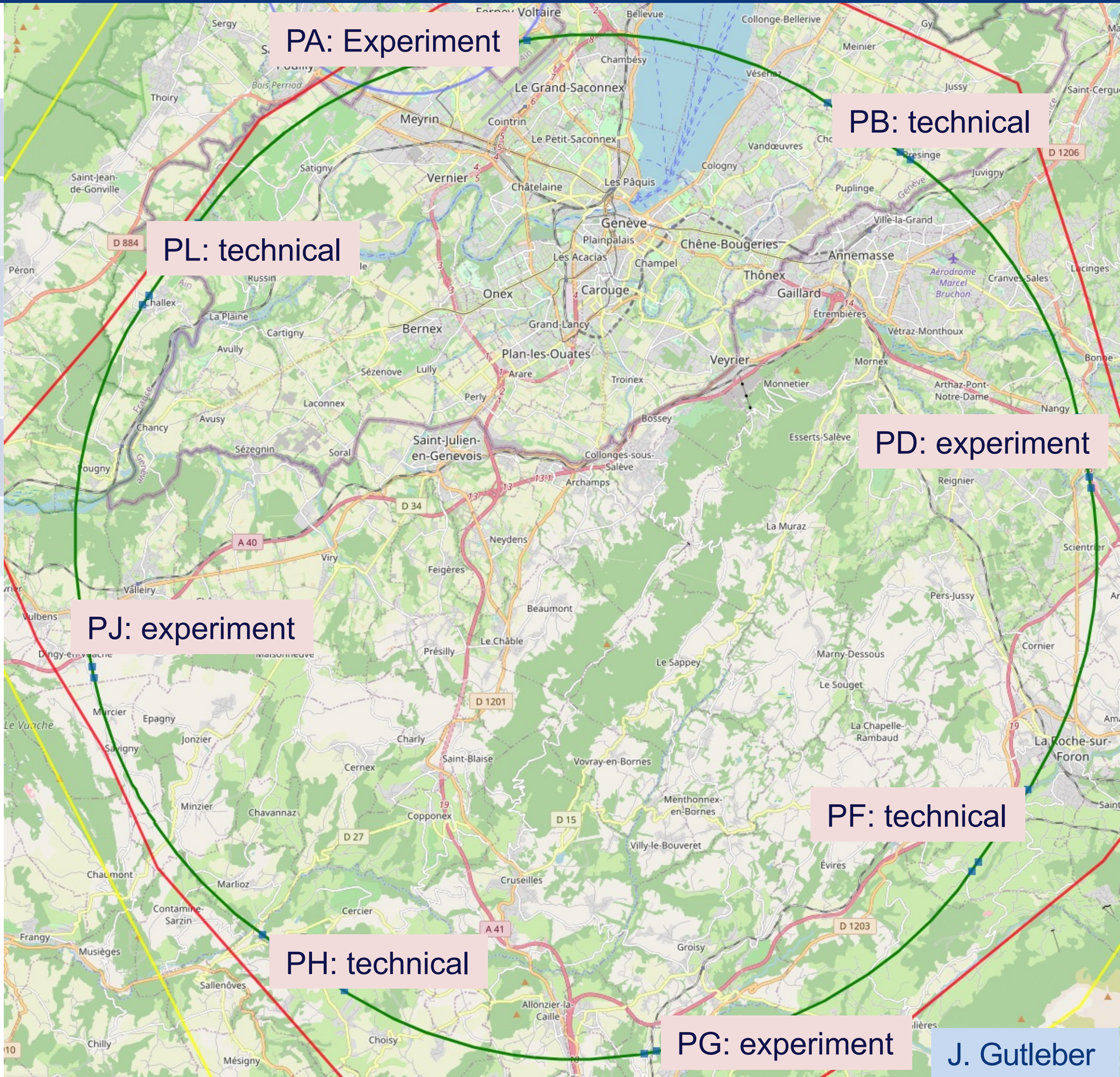
FUTURE CIRCULAR COLLIDER

optimized placement and layout

8-site baseline “PA31-3.0”

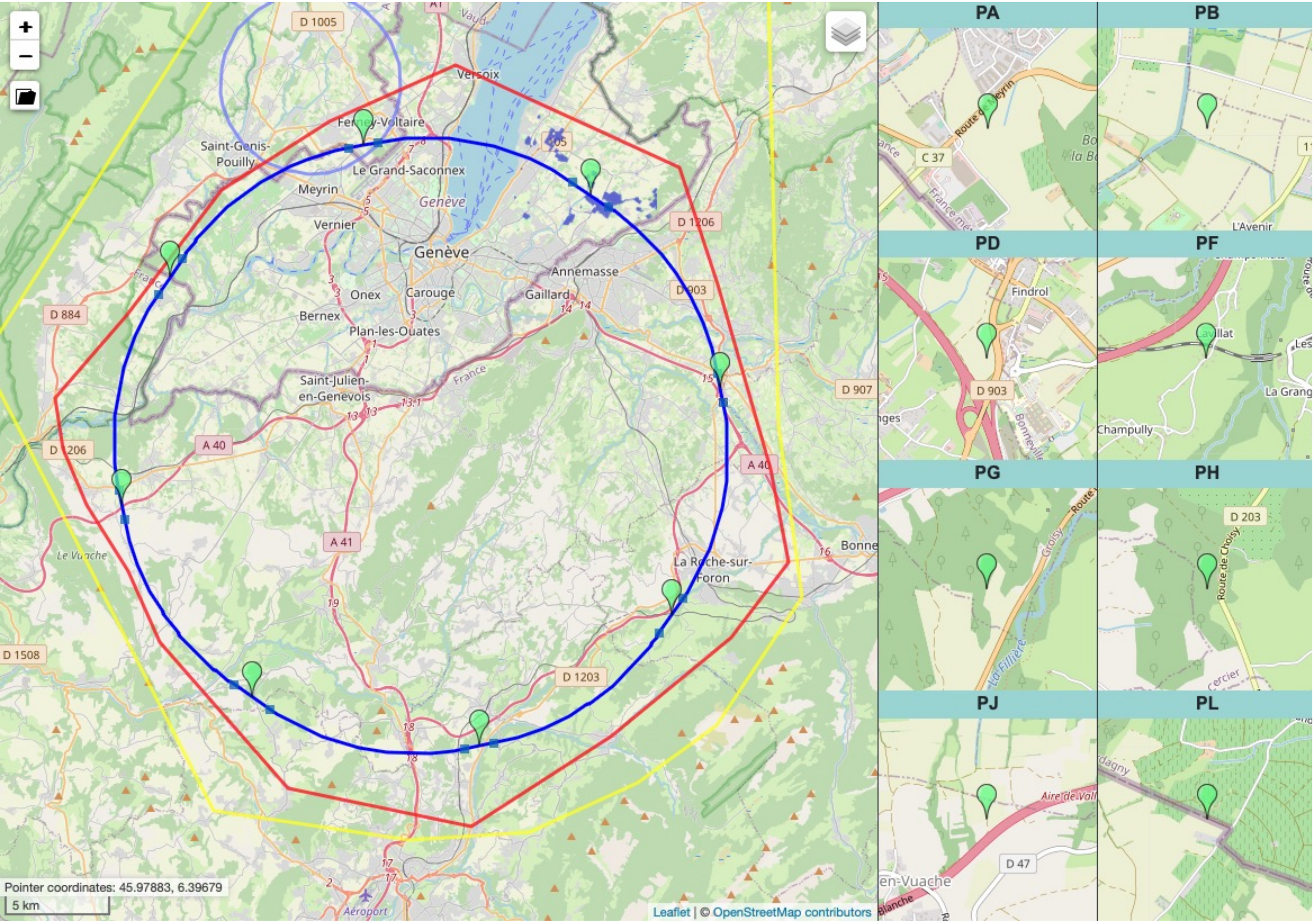
Number of surface sites	8
LSS@IP (PA, PD, PG, PJ)	1400 m
LSS@TECH (PB, PF, PH, PL)	2032 m
Arc length	9.6 km
Sum of arc lengths	76.9 m
Total length	**90.6 km**

- 8 sites – less use of land, <40 ha instead 62 ha
- Possibility for 4 experiment sites in FCC-ee
- All sites close to road infrastructures (< 5 km of new road constructions for all sites)
- Vicinity of several sites to 400 kV grid lines
- Good road connection of PD, PF, PG, PH suggest operation pole around Annecy/LAPP
- **Exchanges with ~40 local communes in preparation**



J. Gutleber

Progressi rilevanti nel progetto di ingegneria civile, nelle discussioni coi governi e comunita locali



FUTURE CIRCULAR COLLIDER

FCC – SYNTHESE DES CONTRAINTES ET OPPORTUNITES D'IMPLANTATION

FCC-2107150900-CER

Date : 07/02/2023

Grant Agreement number: 951754 — FCCIS — H2020-INFRADEV-2018-2020 / H2020-INFRADEV-2019-3

FCC
Futur Collisionneur Circulaire

RAPPORT LIVRABLE

SYNTHESE DES CONTRAINTES ET OPPORTUNITES D'IMPLANTATION

Identifiant du document	FCC-2107150900_Synthese_implantation_territoriale_V0100.docx
Autre identifiant	10.5281/zenodo.7614421
Date de la version	07/02/2023
Groupe de travail	FCCIS – WP3 Intégrer l'Europe
Organisation	Cerema - CERN
Version	V 1.1
Statut	Version publiée
Domaine	Implémentation
Mots clés	FCC, implémentation, impacts environnementaux, opportunités territoriales

Primi scavi di test 2023 !!

Page 1 sur 505

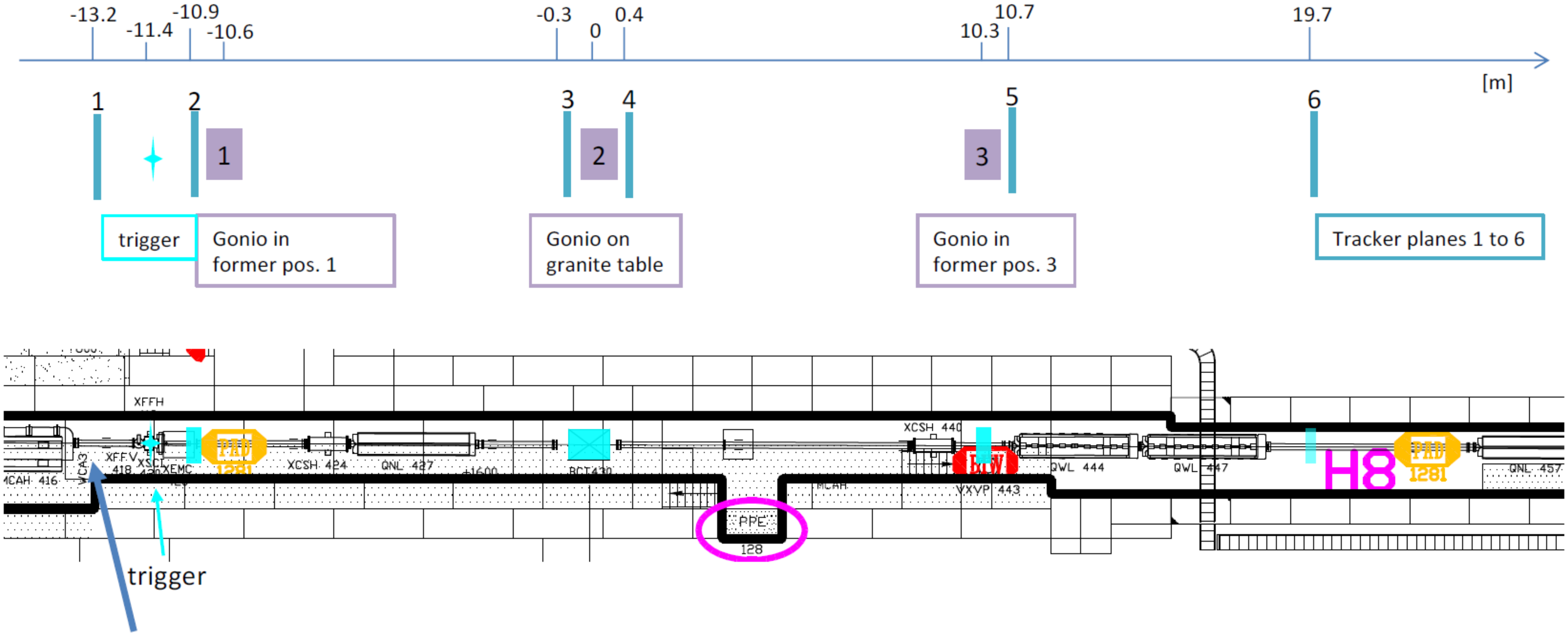
Final comments

- Strong **CSN1** involvement in HEP experiments with **accelerators** at the **intensity and energy frontiers**
- **At present** most of the budget focused on projects at CERN
  - **LHC experiments upgrade taking most of the effort**, both from the personnel and financial point of view
  - **Concerns (and mitigating actions) due to international crises** (war, cost of materials / components)
- Significant resources dedicated also to other activities:
  - Special focus on **flavour** (new dedicated funds) and **lepton sector**
  - New experiments started or in preparation (SND, AMBER, LUXE, MUonE, MU2E)
- Special attention dedicated to the preparation for the future of our field
  - Focusing on the **feasibility of FCC** (FCC-ee followed by FCC-hh): **«A first class infrastructure to maintain the leadership of European research in particle physics over the 21st century»**
    - Seeking green light at next ESSP
    - Construction in the next decade to be ready to operate soon after the end of LHC
  - We support studies for the **Muon Collider** a splendid tool for energy frontier if technologically demonstrated
- In 2022 and 2023 we stregthened the links between CSN1, CSN5 and the INFN accelerator community: in my opinion this path should be further pursued.

Additional Information

UA9 2023 Layout

3 gonios, 6 tracker planes, ~33m

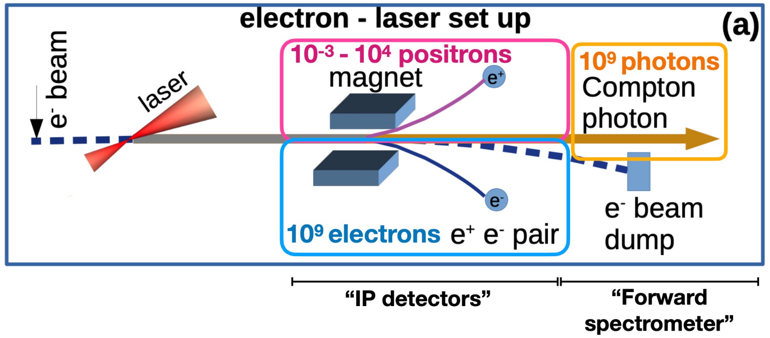


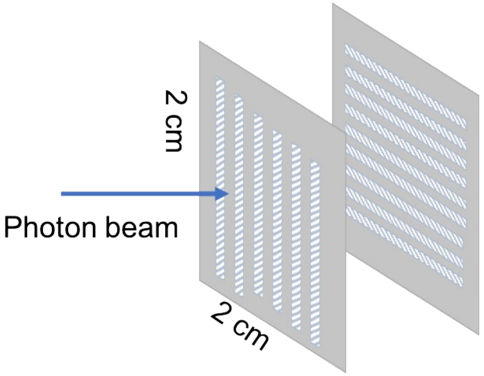
- Requires new opening of vacuum at plane 1 (already confirmed)
- Single station position might float by up to 0.5m

Q6a

Luxe at the DESY Eu.XFEL

- XFEL and high-power LASER electron beam collisions
  - Investigating QED in regimes beyond the Schwinger limit by XFEL electron scattering on photons from a very high power laser (100 TW)..
- Collaboration 90 members (26 institutes)
- INFN grups: Bologna, Padova
- INFN proposed contribution : beam profile measurement with a detector made with strips on sapphire





Thickness: 0.1 mm
Pitch: 0.1 mm
200+200 Readout channels

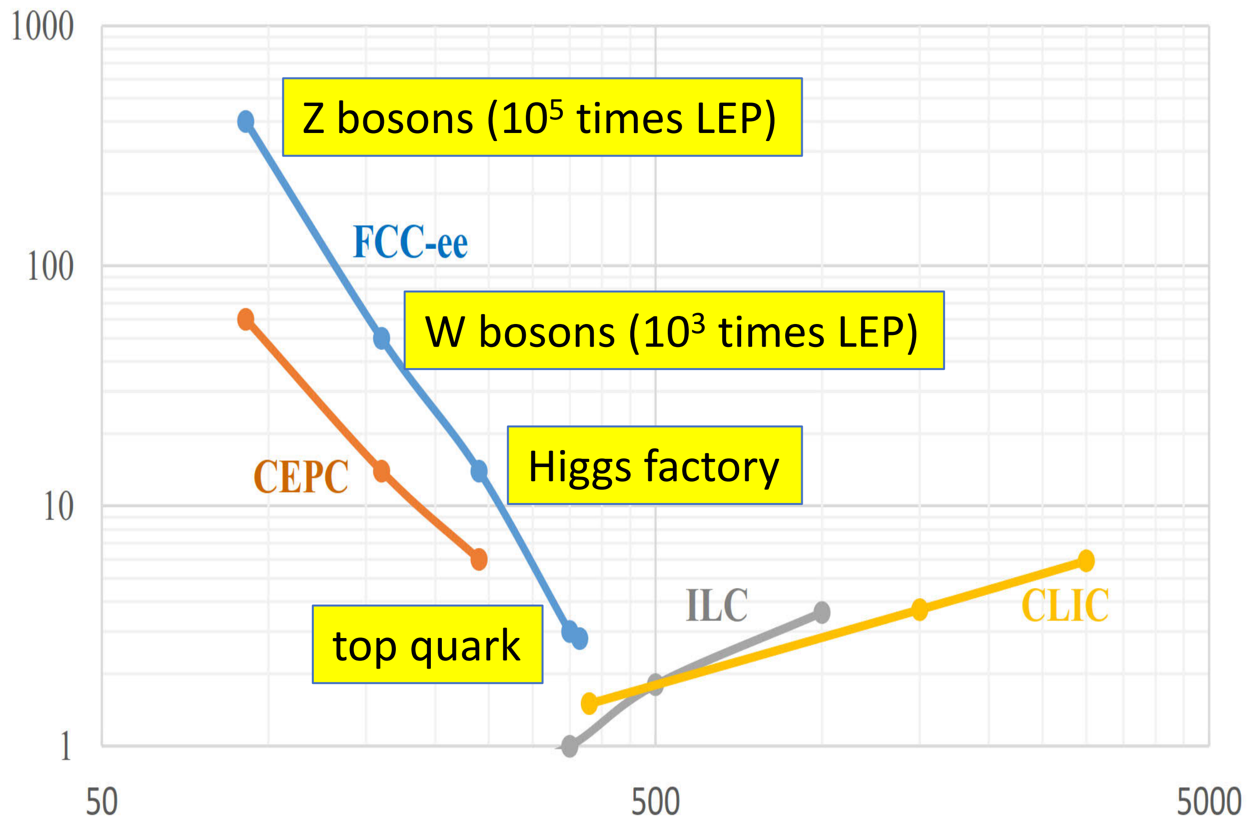
		2021				2022				2023				2024				2025				2026			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Photon Profiler	Procure detector prototypes and test																								
	Test beam at ELBE/FRASCATI/XFEL																								
	LUBPRO design, production																								
	Movable support mechanics design, production																								
	Detector installation/commissioning																								
	Detector ready for data-taking																								

- **From the European Strategy for Particle Physics (2019):**

*Europe, together with its international partners, should **investigate the technical and financial feasibility of a future** <u>**hadron collider at CERN with a centre-of-mass energy of at least 100 TeV**</u> **and** <u>**with an electron-positron Higgs and electroweak factory as a possible first stage**</u>. Such a feasibility study of the colliders and related infrastructure should be established as a global endeavour and be completed on the timescale of the next Strategy update.*

Where nature decided to put stuff (the electroweak playground)

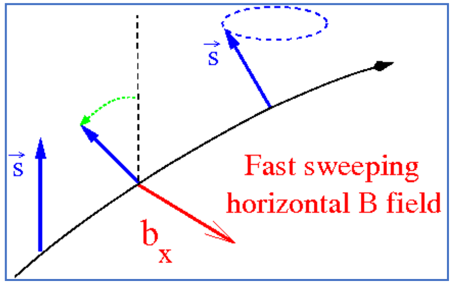
total luminosity [10^{34} cm^{-2}s^{-1}]

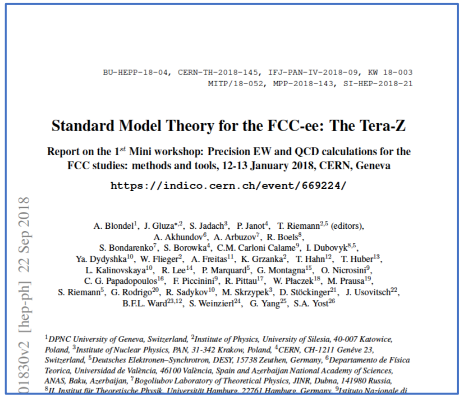


c.m. energy [GeV]

Some key points about FCC

- **FCC-ee is not just about brute-force luminosity**
  - Continuous calibration of centre-of-mass energy (e.g. 100 keV at the Z) with resonant depolarization
  - Direct measurement of parameters, which were computed until now (e.g. direct measurement of α_{QED} running)
- **There is a well-defined theory effort, to successfully use data in a meaningful way (e.g. 3-loop calculations)**
- **It has been shown in various ways (e.g. EFT analyses) that a jump in precision in Z, W, H, top measurements is required for a comprehensive interpretation of the electroweak sector**
  - A deviation of a single coupling or operator will not provide the full picture
- **FCC-hh is eventually required to precisely investigate the Higgs self-coupling, to close important chapters (e.g. WIMP interpretation of Dark Matter) and to significantly extend direct searches**





BU-HEPP-18-04, CERN-TH-2018-145, IFJ-PAN-IV-2018-09, KW 18-003
MITP/18-052, MPP-2018-143, SI-HEP-2018-21

Standard Model Theory for the FCC-ee: The Tera-Z

Report on the 1st Mini workshop: Precision EW and QCD calculations for the FCC studies: methods and tools, 12-13 January 2018, CERN, Geneva

https://indico.cern.ch/event/669224/

A. Blondel[1], J. Gluza[*,2], S. Jadach[3], P. Janot[4], T. Riemann[2,5] (editors), A. Akhundov[6], A. Arbuzov[7], R. Boels[8], S. Bondarenko[7], S. Borowka[4], C.M. Carloni Calame[9], I. Dubovyk[8,5], Ya. Dydyshka[10], W. Flieger[2], A. Freitas[11], K. Grzanka[2], T. Hahn[12], T. Huber[13], L. Kalinovskaya[10], R. Lee[14], P. Marquard[5], G. Montagna[15], O. Nicrosini[9], C. G. Papadopoulos[16], F. Piccinini[9], R. Pittau[17], W. Płaczek[18], M. Prausa[19], S. Riemann[5], G. Rodrigo[20], R. Sadykov[10], M. Skrzypek[3], D. Stöckinger[21], J. Usovitsch[22], B.F.L. Ward[23,12], S. Weinzierl[24], G. Yang[25], S.A. Yost[26]

[1]DPNC University of Geneva, Switzerland, [2]Institute of Physics, University of Silesia, 40-007 Katowice, Poland, [3]Institute of Nuclear Physics, PAN, 31-342 Krakow, Poland, [4]CERN, CH-1211 Genéve 23, Switzerland, [5]Deutsches Elektronen–Synchrotron, DESY, 15738 Zeuthen, Germany, [6]Departamento de Física Teorica, Universidad de València, 46100 València, Spain and Azerbaijan National Academy of Sciences, ANAS, Baku, Azerbaijan, [7]Bogoliubov Laboratory of Theoretical Physics, JINR, Dubna, 141980 Russia,

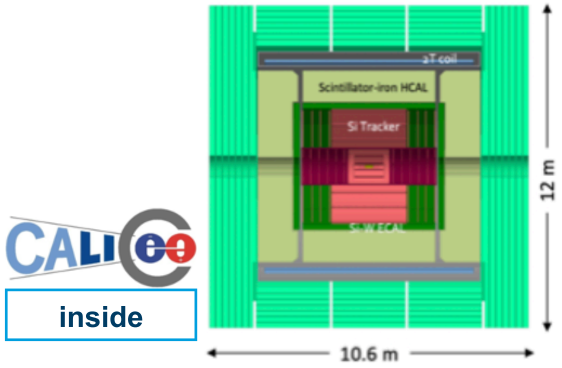
01830v2 [hep-ph] 22 Sep 2018

	# Higgs pairs to bbγγ
LHC: 14TeV 300fb^{-1}	36
HL-LHC: 14TeV 3ab^{-1}	360
FCC: 100TeV 20ab^{-1}	92 x 10^3 ← percent precision physics

Detector Concepts

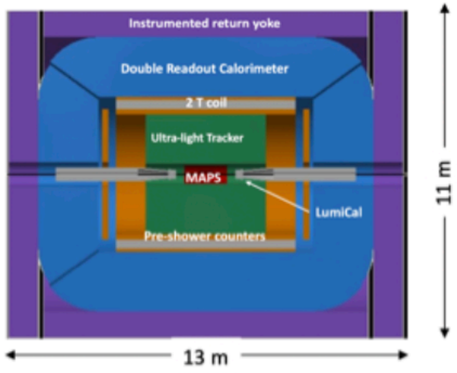
In a Nutshell

CLD



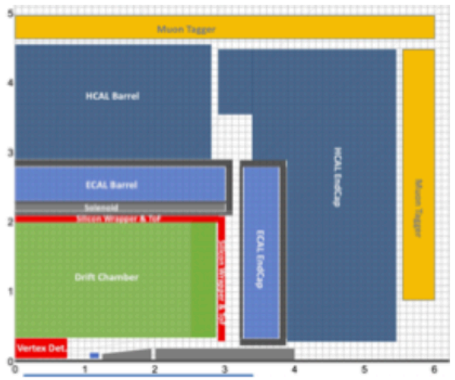
- Well established design
  - ILC -> CLIC detector -> CLD
- Engineering needed to make able to operate with continous beam (no pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations?
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?
  - …
- Robust software stack
  - Now ported (wrapped) to FCCSW

IDEA



- Less established design
  - But still ~15y history: 4th Concept
- Developed by very active community
  - Prototype construction / test beam compains
  - Italy, Korea,…
- Is IDEA really two concepts? Or will it be?
  - w, w/o crystals
- Software under active development
  - Being ported to FCCSW

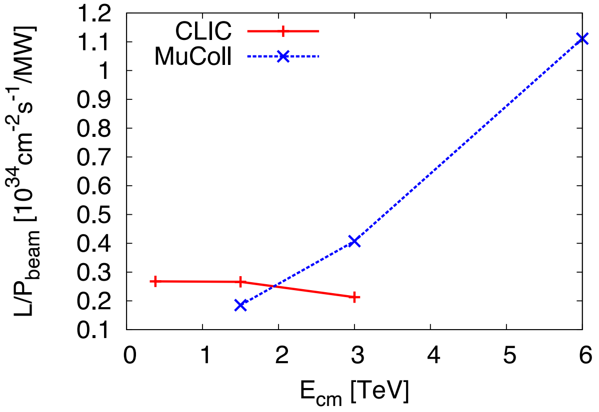
Noble Liquid ECAL based



- A design in its infancy
- High granul Noble Liquid ECAL is the core
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, …
  - Software & performance studies
- Full simulation of ECAL available in FCCSW

Mogens Dam

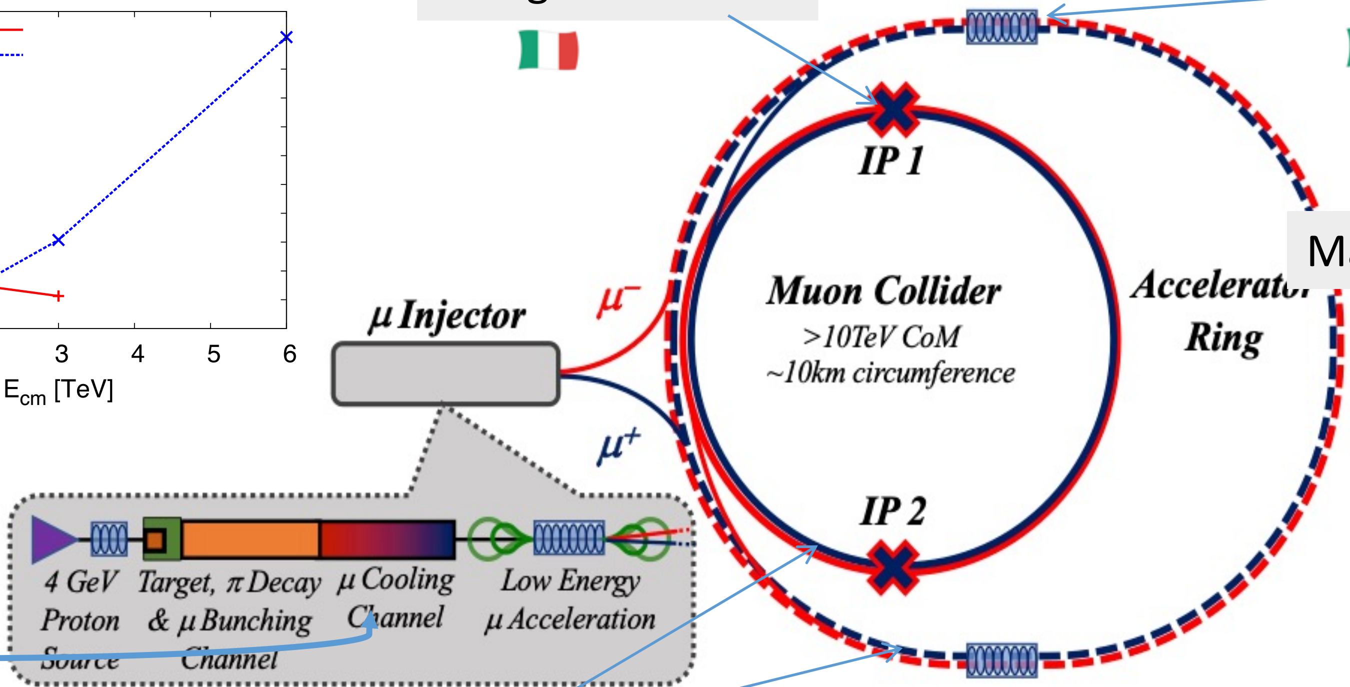
Muon Collider



Beam induced background

MDI and Detector design

Magnets &RF



Cooling cell prototyping

Cost and **power** consumption drivers, limit energy reach e.g. 30 km accelerator for 10/14 TeV, 10/14 km collider ring

ASSUMPTION/IP

$\mathcal{L} = (E_{CM}/10\text{TeV})^2 \times 10\ ab^{-1}$

@ 3 TeV 1 ab^{-1} /5 years

@ 10 TeV 10 ab^{-1} /5 y

@ 14 TeV 20 ab^{-1} /5 y

1st stage a muon cooling demonstrator to be built in 2030+

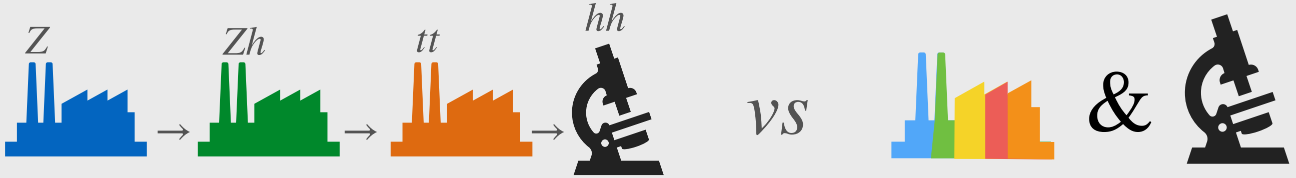
Conclusions

- dedicated e^+e^- factory stages prove to be the "easiest" factories to operate (and to interpret) when it comes to precision measurements ($\delta m_W, \delta m_t, \delta m_Z, \ldots$)

- high-energy machines (pp or $\mu\mu$) can often probe the microscopic phenomena that motivate the precision measurements and often surpass it by far (see t_R compositeness example, EWPT in SMEFT)

- in many instances the $\mu\mu$ collider can play the role of the hh in finishing the job started by ee with the bonus of potentially being run in the same years while also contributing as a "multiplex"-factory)

- well motivated scenarios require <u>inputs from all projects to reach a conclusion</u> ($h \to \phi\phi$ for ϕ driving EWpt, mechanism**s** for neutrino mass, …)

- interactions between timelines of the projects is highly non-trivial
  - 

  - during the <u>long time from now to the next collider</u> results from outside highest-energy colliders might give a strong hint of where BSM might lie (e.g. for WIMPs, flavor, GWs, EDMs)