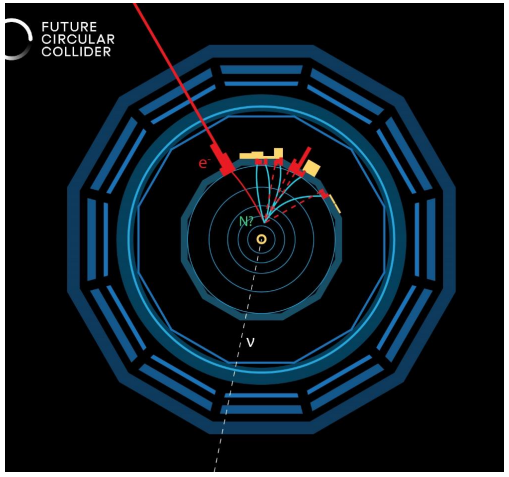
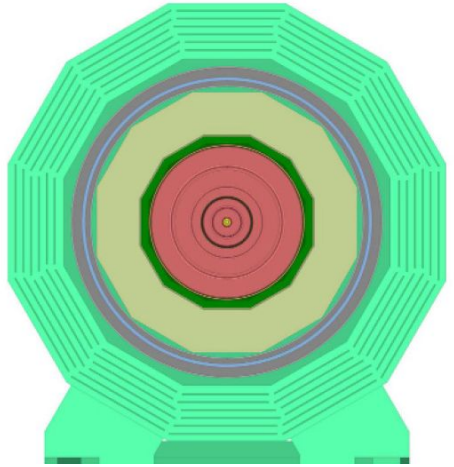
Thoughts on roadmaps

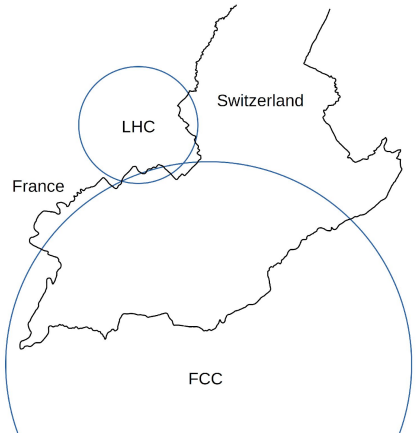
Sarah Eno, U. Maryland

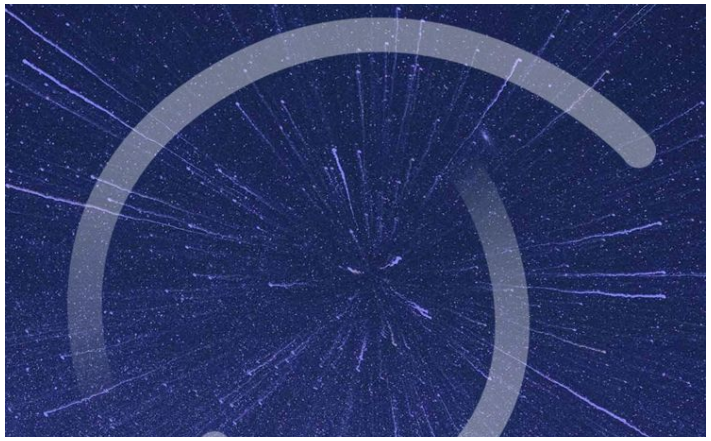
First annual US FCC workshop - BNL

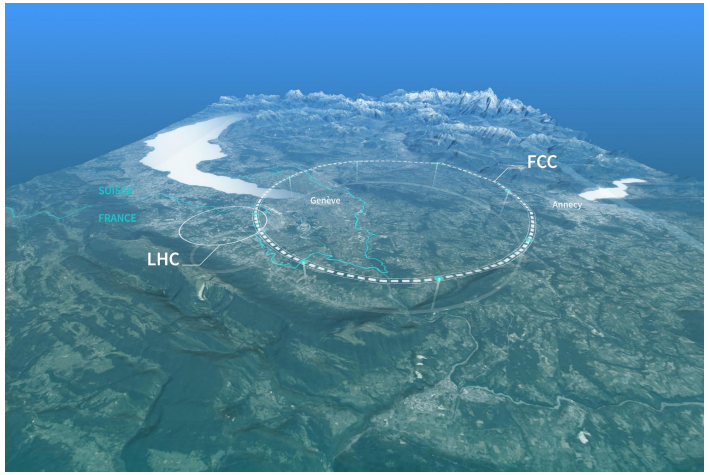
26 April 2023

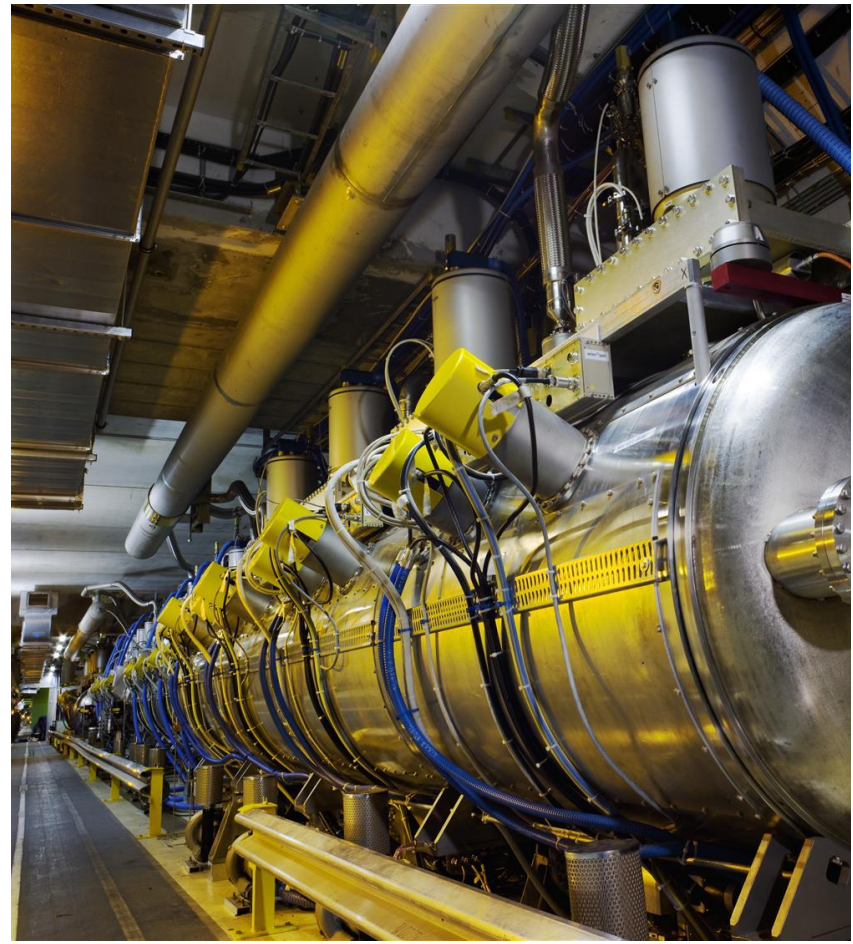










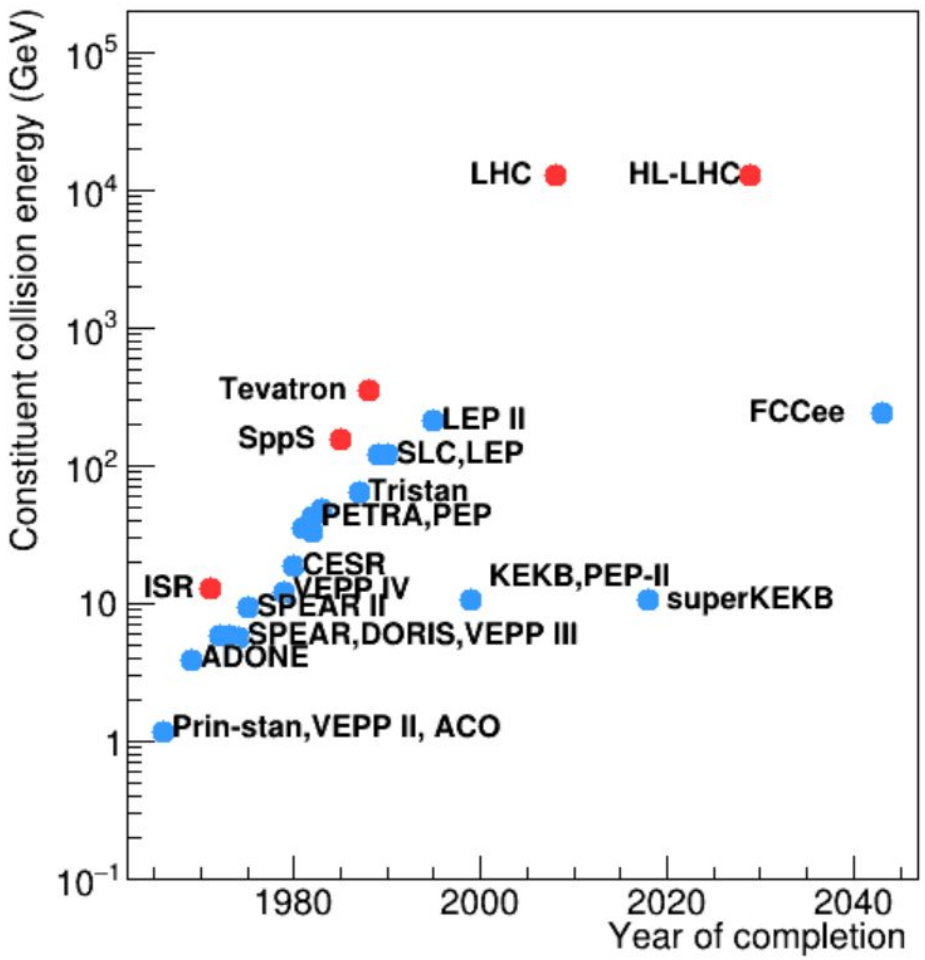


Thank you to BNL

I cannot imagine a better host institution for this first USFCC workshop. The professionalism, meticulous planning, and warm welcome I am sure was felt by all.

My special thanks to Marc-Andre and the program committee.

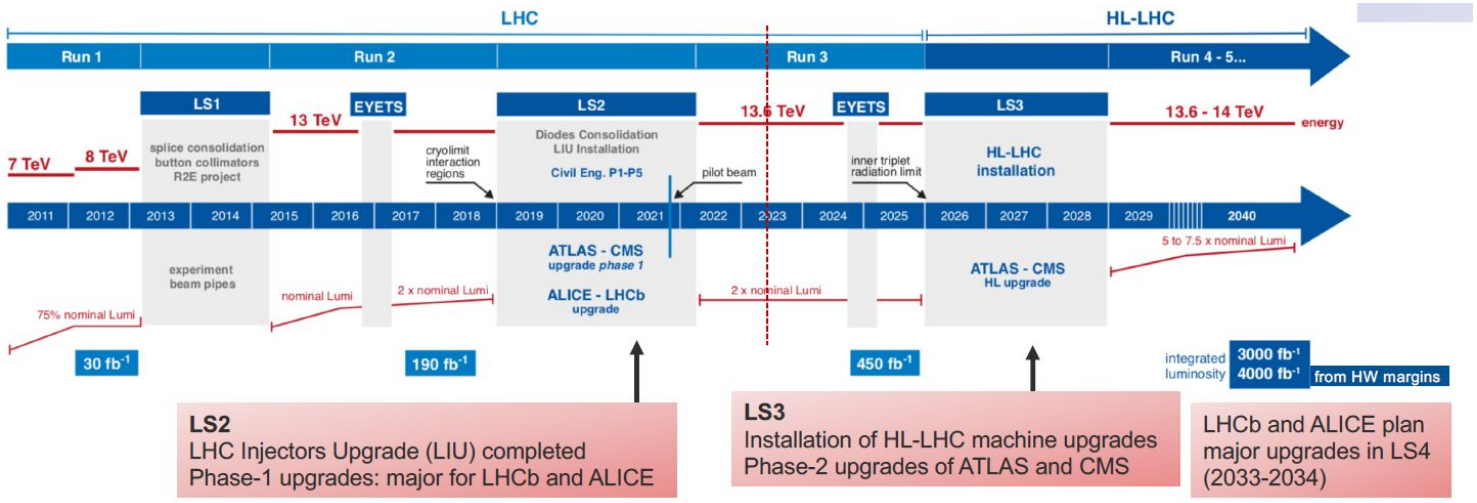
Colliders



We know when the HL-LHC end date is. It is only 20 years in the future. It is essential for our field that we start a new machine very soon after its end. To my mind (and I hope to yours), that machine is FCC-ee.

It is to the H, W, and Z what KEKB, PEP-II, and superKEKB are to the b (and for the b itself, continues their impactful program).

It allows an exciting, perhaps revolutionary, physics program based on current accelerator technology in the 2040s while the accelerator technology for a new energy frontier via a muon collider and FCC-hh are being developed.



You've heard about this exciting accelerator

Relevant US Expertise

	ANL	BNL	FNAL	LANL	LBNL	JLab	SLAC	Universities
SRF cavities/CMs			■			■		Cornell, ODU ...
RF sources/modul.							■	
Copper RF linac	■			■			■	
IR magnets		■	■		■			FSU, TAMU,...
Booster/MR magnets	■	■	■		■			
Beam Optics	■	■	■		■	■	■	Cornell, ...
Collimation		■	■				■	
Polarization		■	■			■		Cornell, UNM, ...
Instrumentation	■	■	■		■	■	■	Many
Infrastructure	■	■	■	■	■	■	■	

Challenge: the FCCee pre-CD2 phase 2024-2033 requires up to ~40FTEs/yr (Sci, Eng, Tech), that is 60-100 qualified people - some of them don't exist, many involved on other projects/ops… other initiatives need the same type of people (ACE, MuColl, C3, GARD) → need a community-wide assessment and planning of the accelerator workforce development (expect P5/EPP to comment)

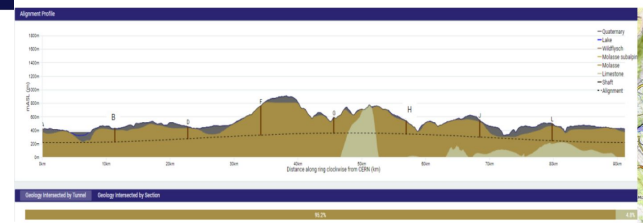
FCC

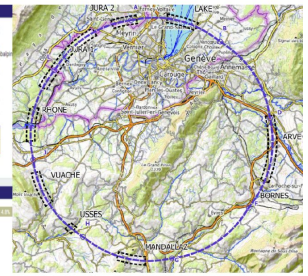
Present US Engagement in FCC Accelerator

- Physics and detector studies (numerous US universities and labs)
- high-field magnet development (FNAL, LBNL, NHFML)
- SRF development (800 MHz 5-cell cavity prototype, JLAB)
- FCC-ee accelerator design: optics and collective effects (SLAC)
- FCC-ee machine detector interface (SLAC, BNL, JLAB)
- FCC-ee interaction-region magnet systems (BNL)
- FCC-ee polarisation and precise energy calibration (FNAL, BNL, Cornell, UNM)
- FCC-EIC collaborations (BNL, JLAB)
- FCC tunnel safety (FNAL)
- FCC civil engineering - surface building design (FNAL)
- SRF 800 MHz bulk Nb cavities with high Q_0 in preparation
- SRF cryomodule design –

FUTURE CIRCULAR COLLIDER

FCC implementation - footprint baseline





present baseline implementation
- **91 km circumference**
- **95% in molasse geology for minimising tunnel construction risks**
- **8 surface sites with ~5 ha area each.**

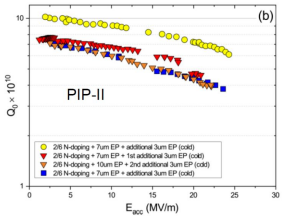
site investigations planned for 2024 and 2025 in areas with uncertain geological conditions:
- **Limestone-molasse border, karstification, water pressure, moraine properties, water bearing layers, etc.**
- **~40-50 drillings, 100 km of seismic lines**

Future Circular Collider Study
Michael Benedikt
US – FCC Workshop, 24.04.2023, BNL

FCC 8

High Q_0 SRF Systems – US expertise

- **LCLS-II developed new N_2 doping approach → is operating cryomodules at 1.3 GHz with Q_0 = 2.7x10^{10} at 16 MV/m**
- **PIP-II is developing high Q cavities at 650 MHz**



- **LCLS-II-HE will build 23 cryomodules with Q0 = 2.7x10^{10} and >21 MV/m**

And seen that it is ripe for key impact by the US

FUTURE CIRCULAR COLLIDER

Mid-Term Review & Cost Review, autumn '23

Mid-term review report, supported by additional documentation on each deliverable, will be submitted to review committees and to Council and its subordinate bodies, as input for the review.

Results of both general mid-term review and the cost review should indicate the main directions and areas of attention for the second part of the Feasibility Study

Infrastructure & placement
- Preferred placement and progress with host states (territorial matters, initial states, dialogue, etc.)
- Updated civil engineering design (layout, cost, excavation)
- Preparations for site investigations

Technical Infrastructure
- Requirements on large technical infrastructure systems
- System designs, layouts, resource needs, cost estimates

Accelerator design FCC-ee and FCC-hh
- FCC-ee overall layout with injector
- Impact of operation sequence: Z, W, ZH, $t\bar{t}$ vs start at ZH
- Comparison of the SPS as pre-booster with a 10-20 GeV linac
- Key technologies and status of technology R&D program
- FCC-hh overall layout & injection lines from LHC and SC-SPS

Physics, experiments, detectors:
- Documentation of FCC-ee and FCC-hh physics cases
- Plans for improved theoretical calculations to reduce theoretical uncertainties towards matching FCC-ee statistica precision for the most important measurements.
- First documentation of main detector requirements to fully exploit the FCC-ee physics opportunities

Organisation and financing:
- Overall cost estimate & spending profile for stage 1 project

Environmental impact, socio-economic impact:
- Initial state analysis, carbon footprint, management of excavated materials, etc.
- Socio-economic impact and sustainability studies

IR Magnets

- Challenging IR magnets embedded in the detector with 2.2 meter L*
- Similar requirements to Linear Colliders
- Small aperture with modest pole-tip field
- Design and requirements have significant impact on detectors

BNL Direct Wind in Action Closeup View

You've heard about the exciting physics

FCC is more than Higgs Factory

F. Gianotti@P5-BNL

	√s	L /IP (cm⁻² s⁻¹)	Int L/IP/y (ab⁻¹)	Comments
e⁺e⁻ FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	182 x 10³⁴ 19.4 7.3 1.33	22 2.3 0.9 0.16	2-4 experiments Total ~ 15 years of operation
pp FCC-hh	100 TeV	5 x 10³⁴ 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	√s_NN = 39TeV	3 x 10²⁹	100 nb⁻¹/run	1 run = 1 month operation
ep Fcc-eh	3.5 TeV	1.5 10³⁴	2 ab⁻¹	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb Fcc-eh	√s_eN = 2.2 TeV	0.5 10³⁴	1 fb⁻¹	60 GeV e- from ERL Concurrent operation with PbPb

A multi-stage facility with immense physics potential (energy and intensity), operating until the end of the century.

- FCC-ee : highest luminosities at Z, W, ZH of all proposed Higgs and EW factories; indirect discovery potential up to ~ 70 TeV
- FCC-hh: direct exploration of next energy frontier (~ x10 LHC) and unparalleled measurements of low-rate and "heavy" Higgs couplings (ttH, HH)
- Also heavy-ion collisions and, possibly, ep/e-ion collisions
- Synergistic programme exploiting common civil engineering and technical infrastructure, building on and reusing CERN's existing infrastructure

- 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

LHC@15 reinforced the need for

- a TeraZ factory
- a MegaH factory
- a $\sqrt{\hat{s}} \sim$10 TeV factory

FCC emerges as the natural project

FCC-ee will provide results in EW/Flavour/Higgs that will remain *state-of-the-art* well beyond FCC-hh

"FCC-ee+FCC-hh » ILC+FCC-hh"

C. Grojean & P. Janot — 9 — US FCC, April 24, 2023

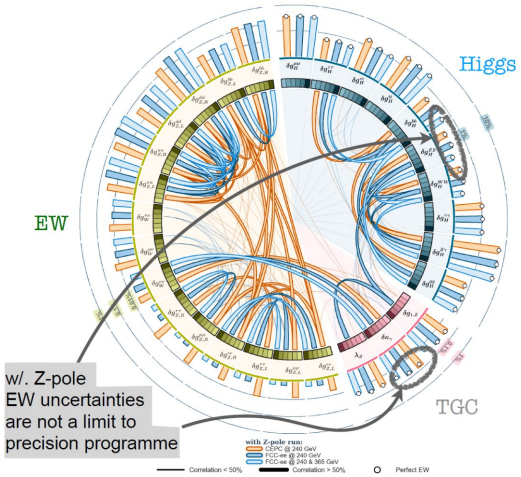
The alignment of stars towards FCC

P. Janot @ CERN-SPC

- **Discovery of a light Higgs boson – m_H = 125 GeV, just above LEP limit**
  - Higgs boson can be produced at e⁺e⁻ centre-of-mass energies accessible at circular colliders
- **Progress in e⁺e⁻ circular collider technology (B factories)**
  - Makes it possible to exceed 10^{35} cm⁻²s⁻¹ at the e⁺e⁻ → ZH_{125} cross section max. (~240 GeV)
- **No BSM physics found (yet) in the TeV range at LHC (+ ttH/HH sensitivity at HL-LHC)**
  - Greatly limits the physics potential of TeV-class e⁺e⁻ linear colliders
  - Forces to think differently about BSM physics to explain the big open questions
    - Dark matter, Neutrinos, BAU, Flavour, Hierarchy problem, …
  - Solutions to these open questions can be at even higher energy
    - Higgs compositeness is among the most popular avenues
  - But often include light and very-weakly-coupled structures
    - Axion-like particles, dark photons, heavy neutral leptons, long-lifetime particles

Impact of Z-pole on Higgs measurements

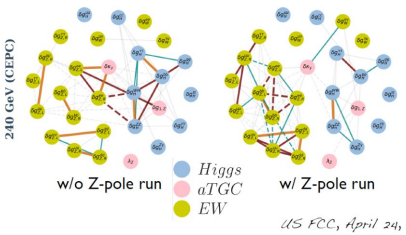
J. De Blas et al. 1907.04311



Contamination EW/TGC/Higgs can be understood by looking at correlations

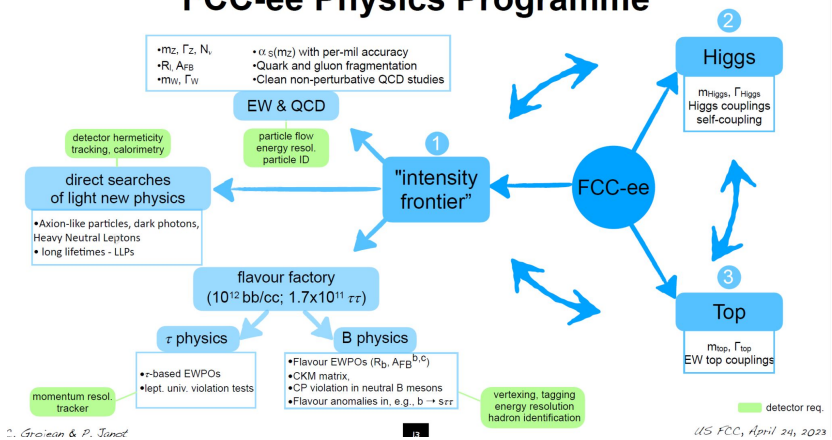
With Z-pole runs, only correlations between EW and TGC remain

Z-pole runs at circular colliders isolate EW and Higgs sectors from each others



C. Grojean & P. Janot — 32 — US FCC, April 24, 2023

FCC-ee Physics Programme



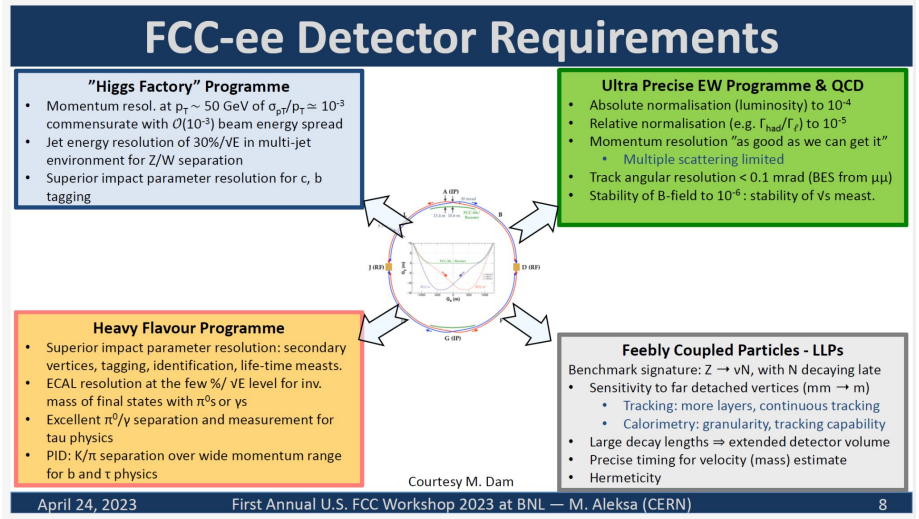
C. Grojean & P. Janot — 15 — US FCC, April 24, 2023

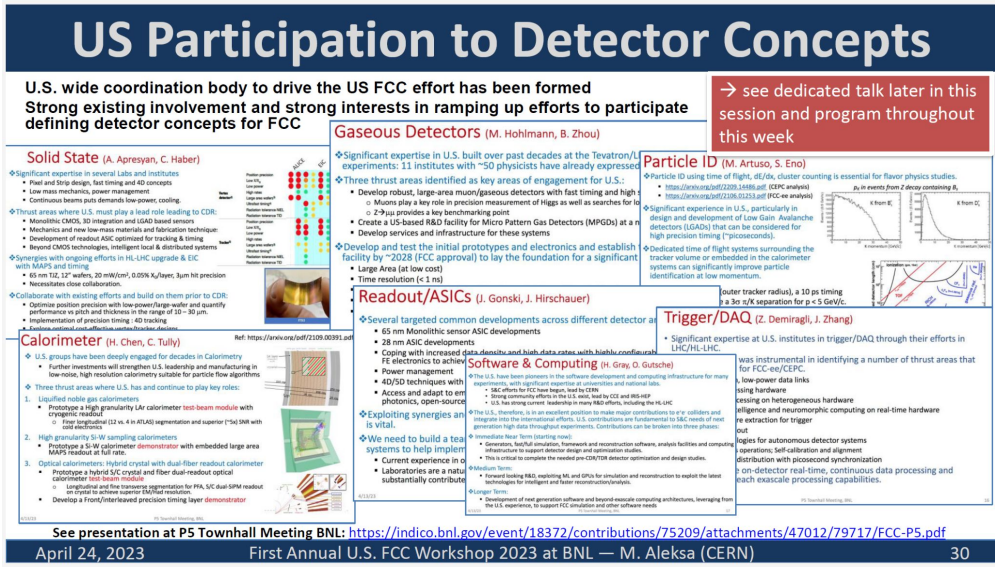
And seen that it is ripe for key impact by the US

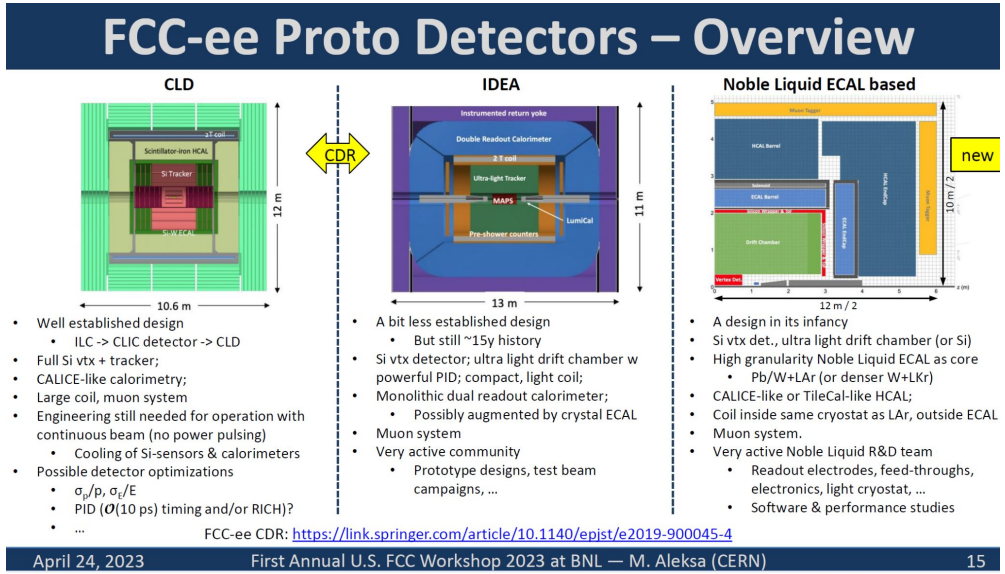
You've heard about the exciting detectors

Intra-Collider Synergies

- Current/near-future:
  - Si-based Calorimetry: Calice & CMS HGCal
  - Scintillator-tile-based calorimetry: CMS HGCal & EIC
  - LGADs: HL LHC ATLAS & HL LHC CMS & EIC
- Future:
  - MAPS: will be ubiquitous; low mass, high granularity, can include fast timing: HL LHC & EIC, FCC-ee, ILC, MuC
  - Standard silicon tracking:
  - Calorimetry: PF and Dual Readout, different materials and technologies: many commonalities among different colliders
  - Gaseous detectors: applications in tracking, calorimetry, muon detection
  - Radiation hardness: FCC-hh & MuC
  - Many other synergies: ASICs, readout electronics, TDAQ, on-detector AI/ML

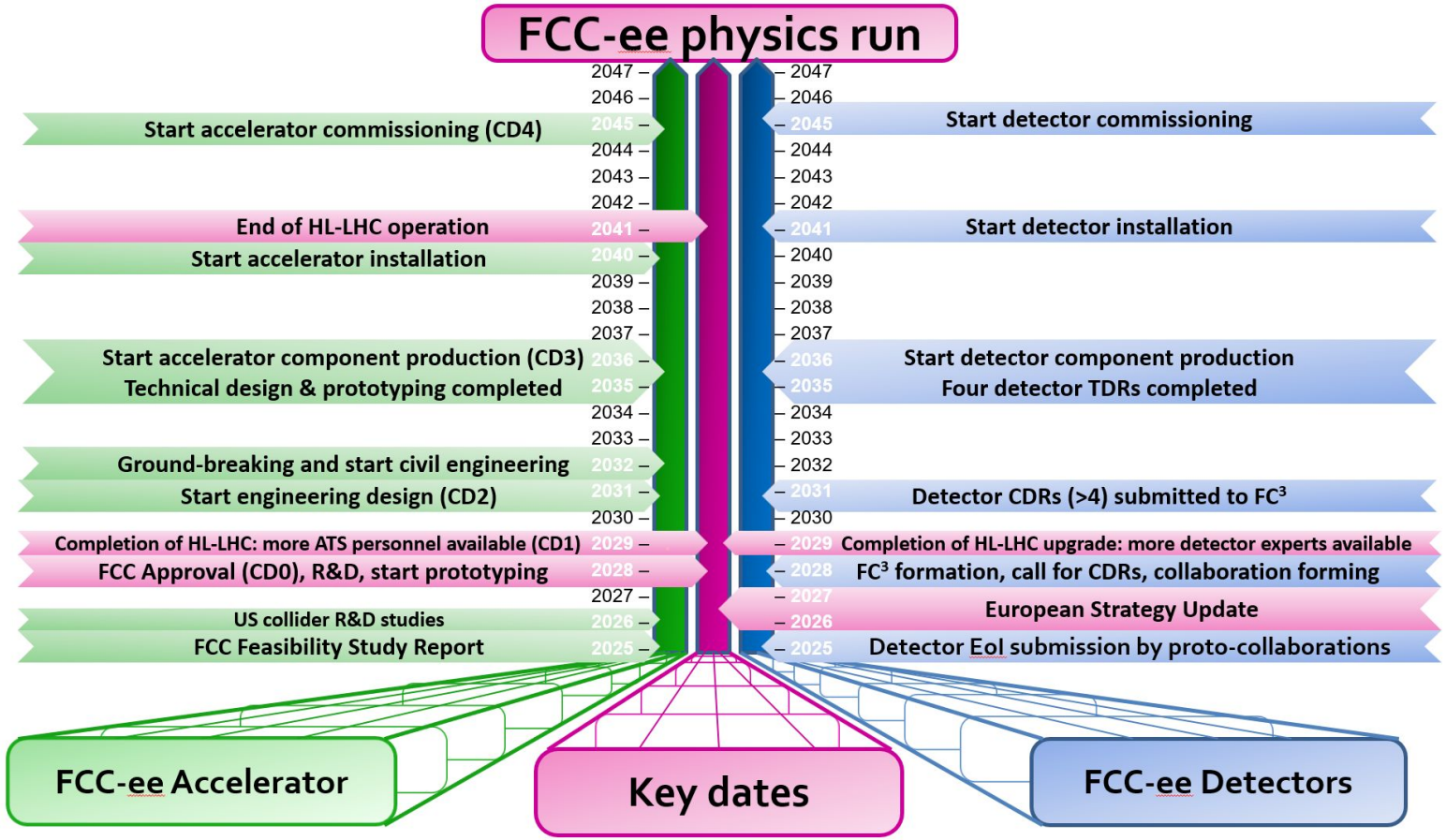






And seen that it is ripe for key impact by the US

Time is short



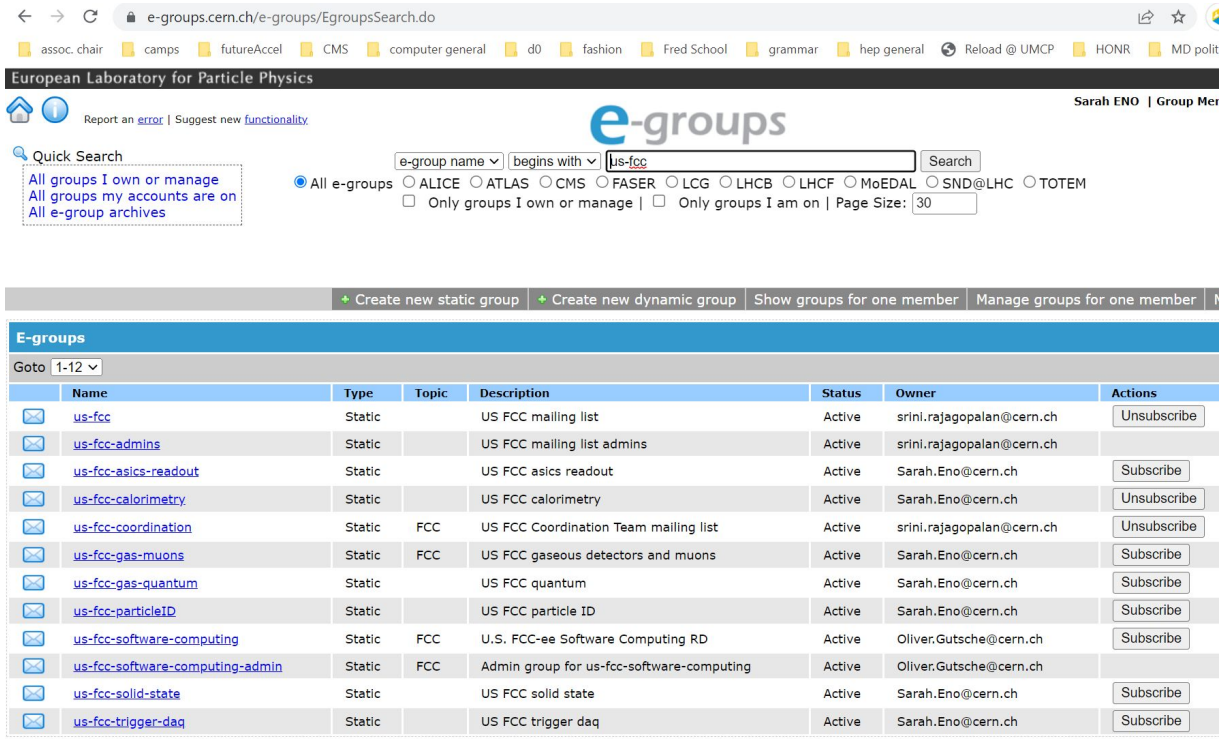
An aggressive but feasible timeline. But for this to happen, we need to push!

- 2028 formulation of collaborations. That's five years from now!!
- 2031 detector CDR's (4!) that's eight years from now
- 2041 installation (18 years)
- CD0 in 2028???
- CD1 at time of CDR?

What are the next steps forward?

- sign up on US-FCC and FCC mailing lists
- Become an official FCC institution by signing an MOU (okay, I haven't done that yet)
- Get familiar with the existing documentation and structures
- Start to participate in some aspect as your current commitments allow. Even one meeting a month is enough to prepare for a bigger impact later.
- Try to send somebody from your group either to the winter "PED" meeting or to the June "FCC" meeting (which has strong accelerator-community attendance) or our new annual USFCC meeting..
- Think bold. Bored of what you are doing? Now is the opportunity to make a change. Why not think about drift chambers? cherenkov counters? doing flavour physics? doing precision measurements of the W, top, or Z mass? It can be fun to explore these things with undergrads. There are a few years here where you can get up to speed to make a course change
- Form a community to help ourselves make an impact despite our limited resources
- **and above all, get ready for a lot of fun!!**

sign up usfcc and FCC



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✉	us-fcc-admins	Static		US FCC mailing list admins	Active	srini.rajagopalan@cern.ch	
✉	us-fcc-asics-readout	Static		US FCC asics readout	Active	Sarah.Eno@cern.ch	Subscribe
✉	us-fcc-calorimetry	Static		US FCC calorimetry	Active	Sarah.Eno@cern.ch	Unsubscribe
✉	us-fcc-coordination	Static	FCC	US FCC Coordination Team mailing list	Active	srini.rajagopalan@cern.ch	Unsubscribe
✉	us-fcc-gas-muons	Static	FCC	US FCC gaseous detectors and muons	Active	Sarah.Eno@cern.ch	Subscribe
✉	us-fcc-gas-quantum	Static		US FCC quantum	Active	Sarah.Eno@cern.ch	Subscribe
✉	us-fcc-particleID	Static		US FCC particle ID	Active	Sarah.Eno@cern.ch	Subscribe
✉	us-fcc-software-computing	Static	FCC	U.S. FCC-ee Software Computing RD	Active	Oliver.Gutsche@cern.ch	Subscribe
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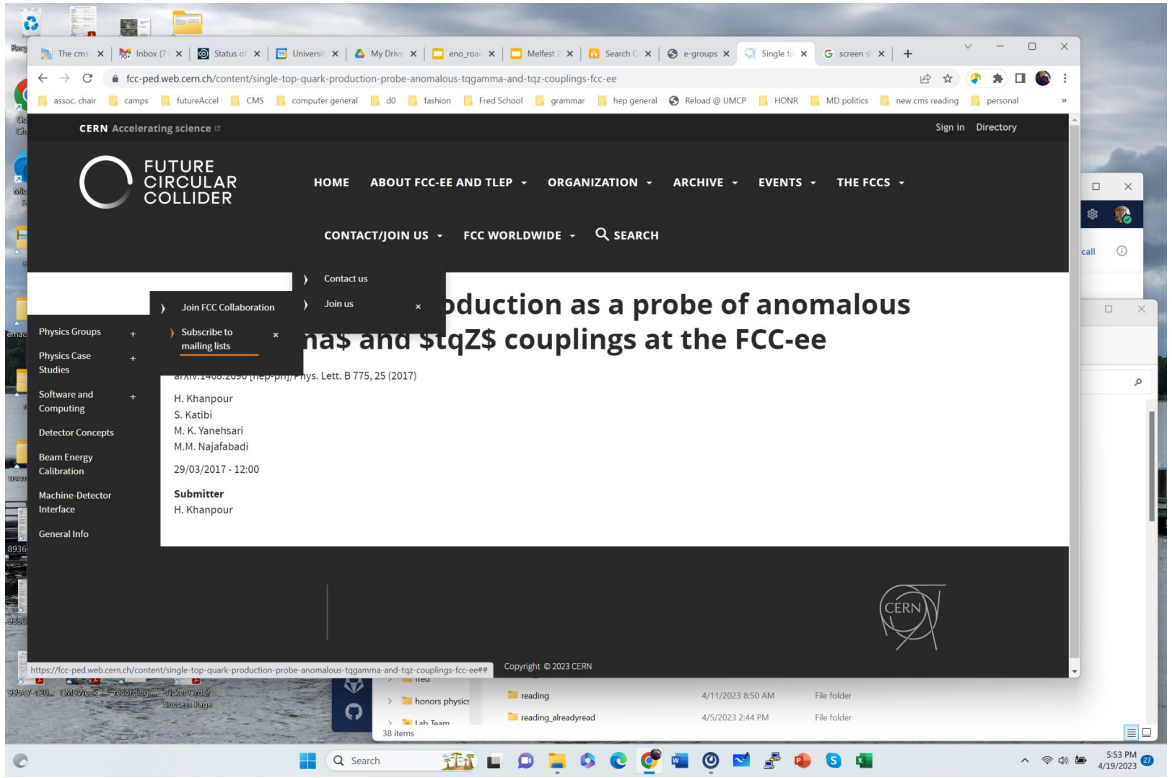


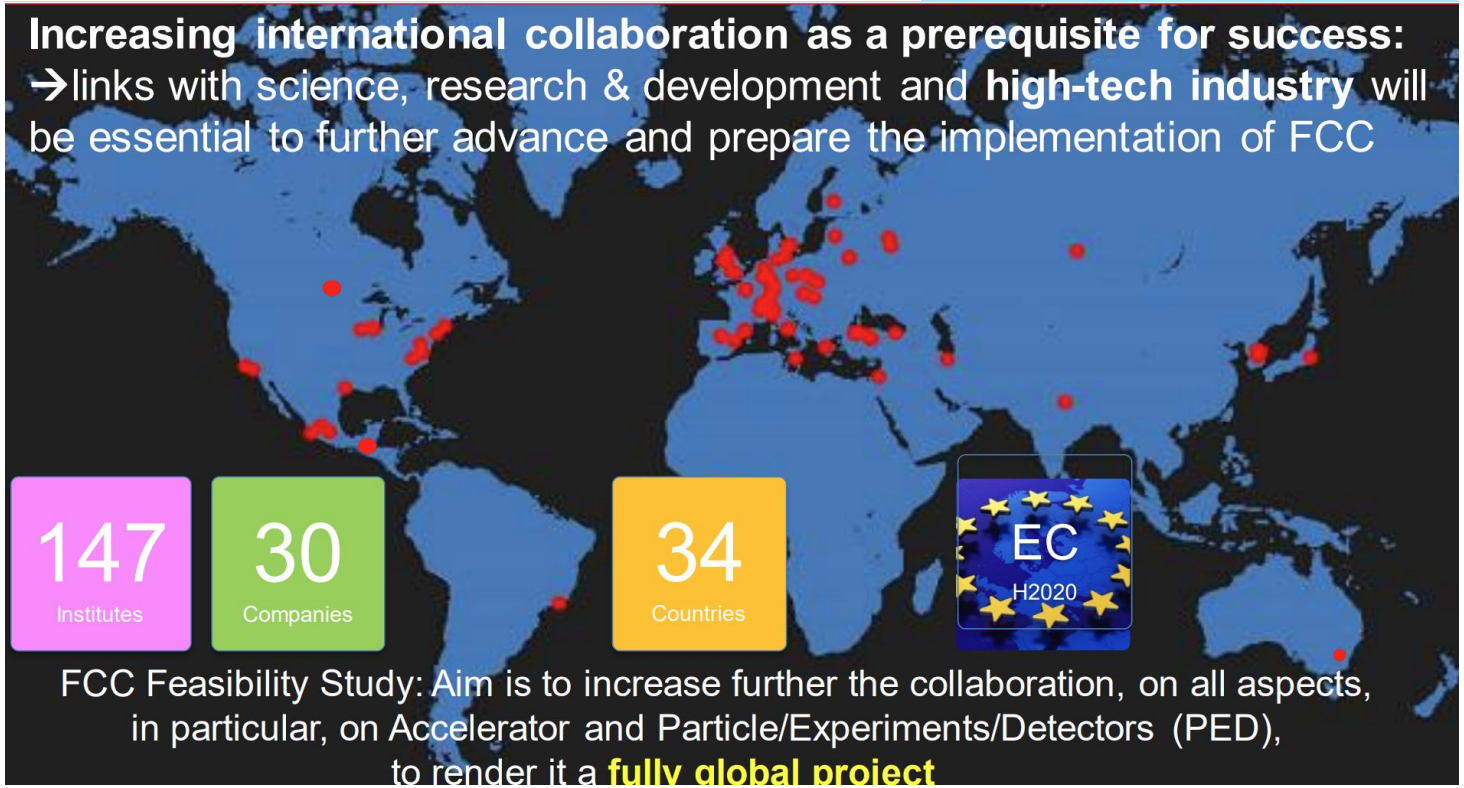
MOU

Step 1: Sign the Memorandum of Understanding

- Identify the organisation's legal authorised representative for the signature
- Download the **FCC MoU TEMPLATE** or the **FCC MoU for Companies Template**
- Put the legally authorised signatory's name and function in the template

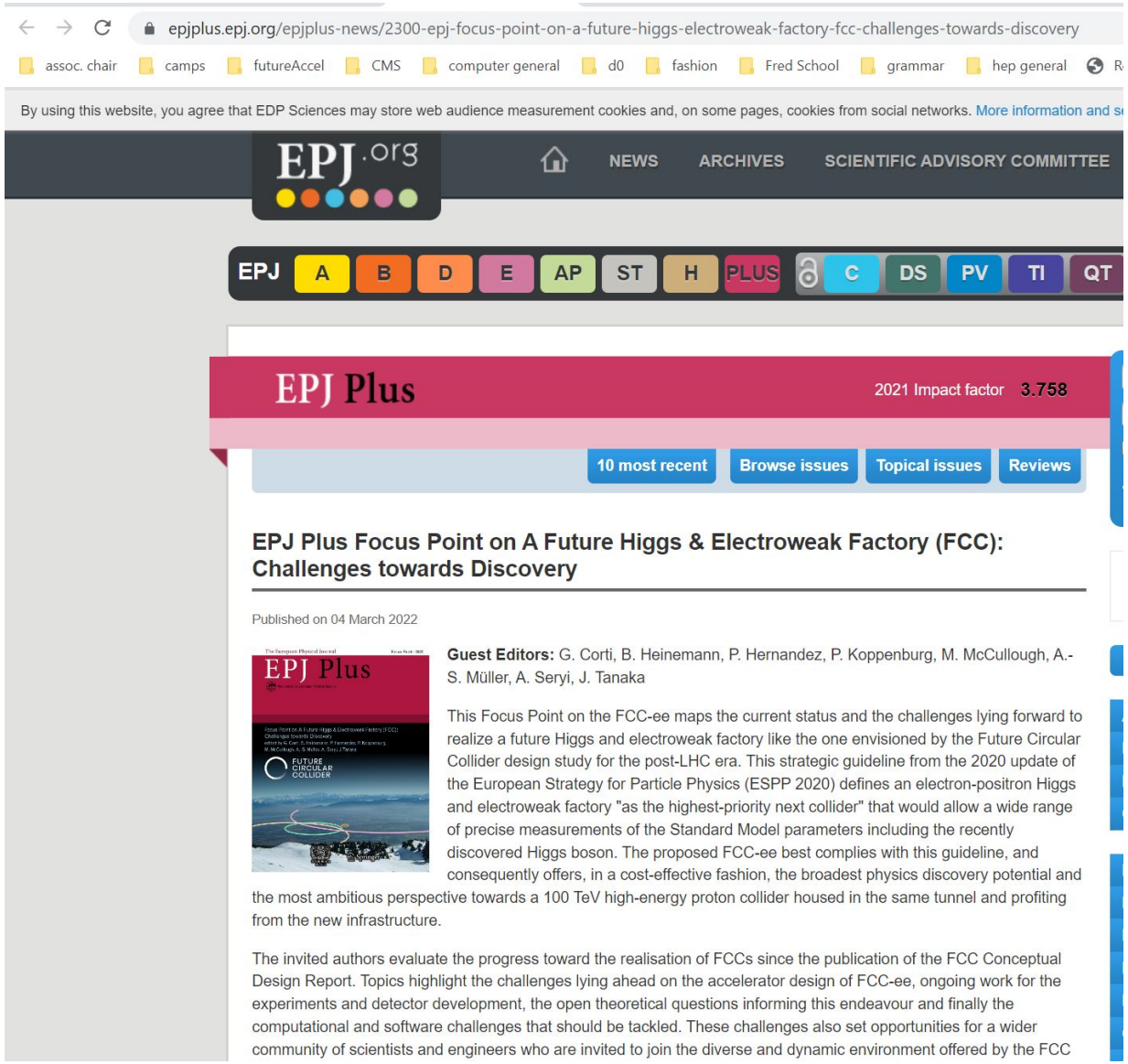
- Print the document twice (one side printing)
- Have both copies signed by the legally authorised representative
- Send the two signed copies by postal mail to **CERN - FCC Study Office - P.O. Box M22110 - 1211 Geneva 23, Switzerland**

https://twiki.cern.ch/twiki/pub/FCC/FCCMoU/FCC-2109140000-CERN_FCCMoUTemplate_V0200.pdf



existing documentation

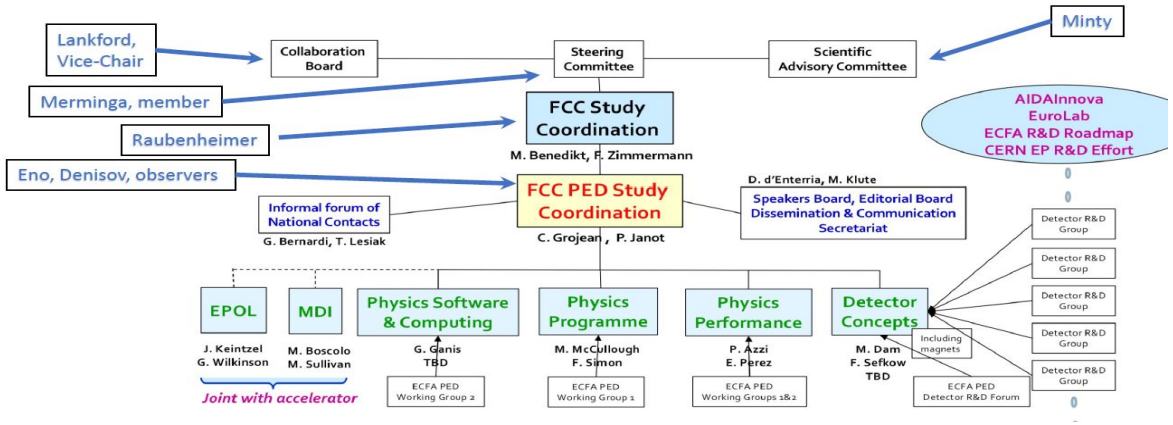
perhaps a nice place to start?

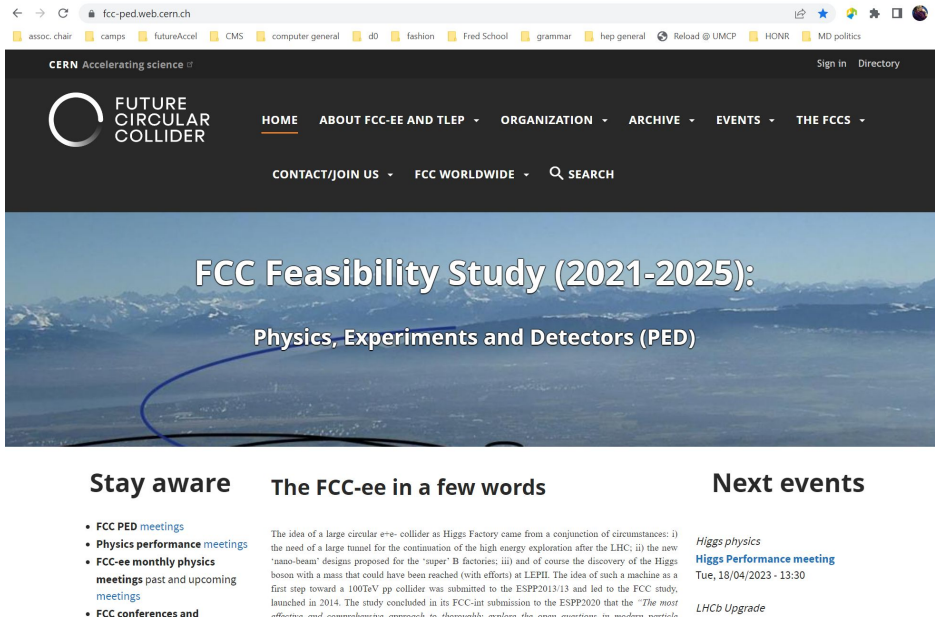


Some other literature

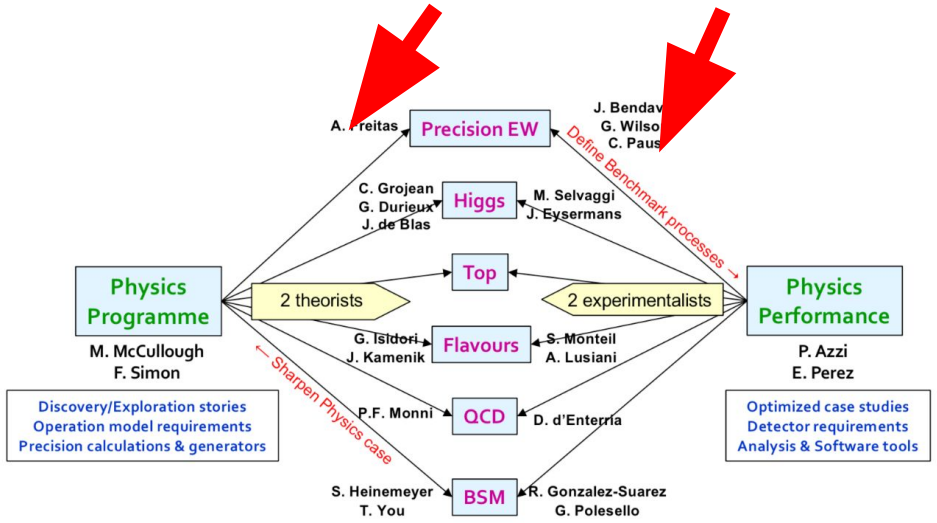
- Snowmass white paper https://arxiv.org/abs/2203.06520
- FCCee CDR https://link.springer.com/article/10.1140/epjst/e2019-900045-4
- Detector Challenges at FCC-ee https://fcc-ee-conference.web.cern.ch/database/conference/960/presentation/1036/
- Particle identification at FCC-ee https://link.springer.com/article/10.1140/epjp/s13360-021-01810-4
- FCC-ee: Your Questions Answered https://arxiv.org/abs/1906.02693

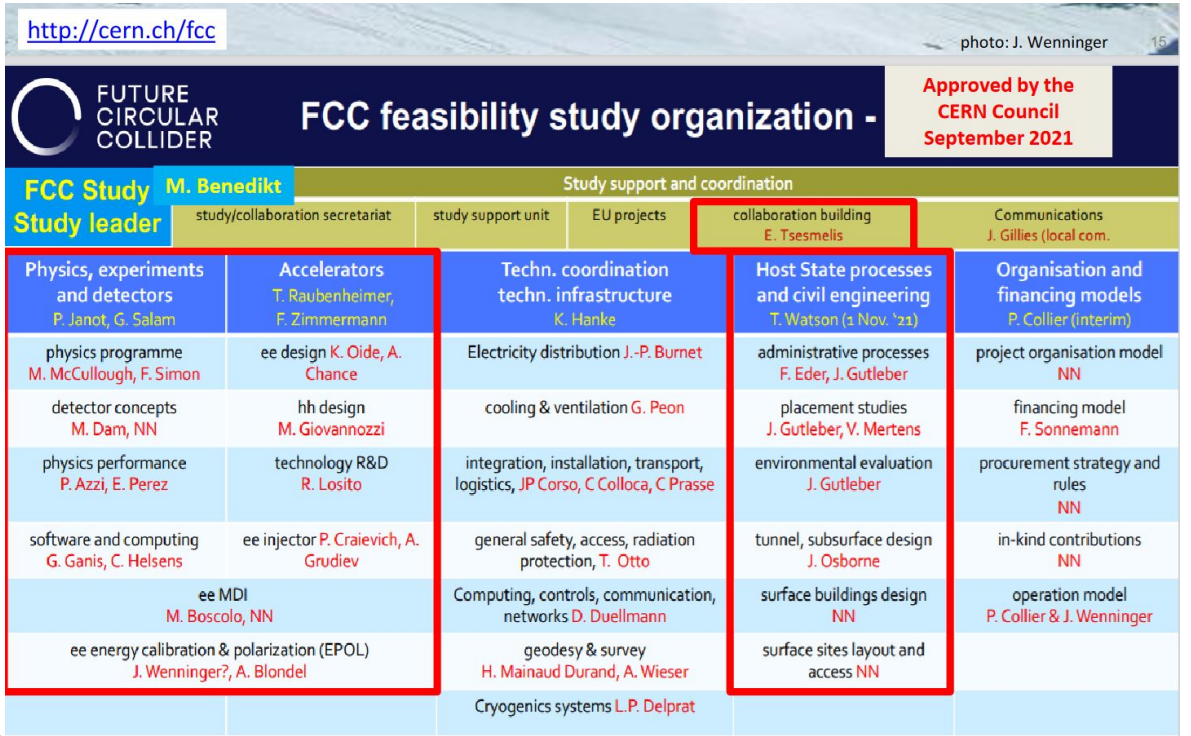
existing structures



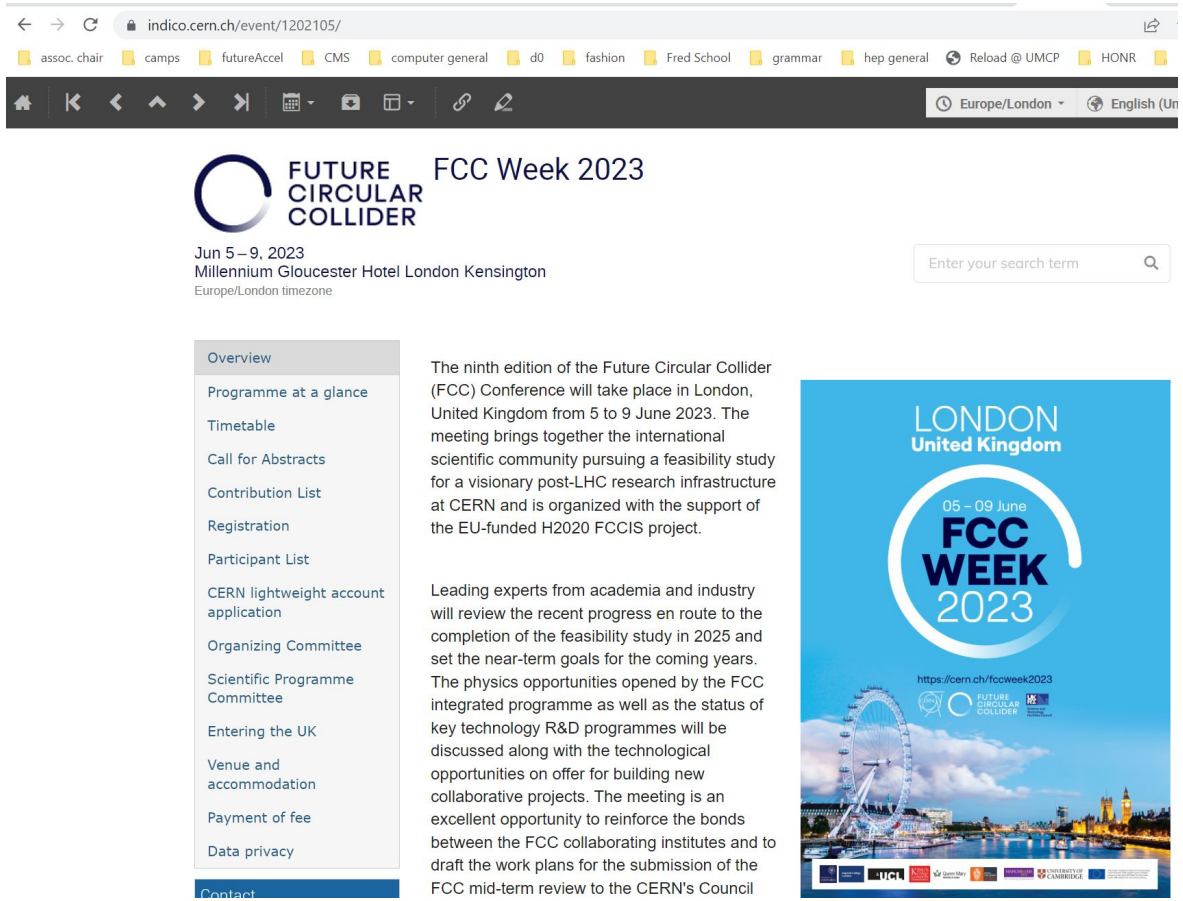


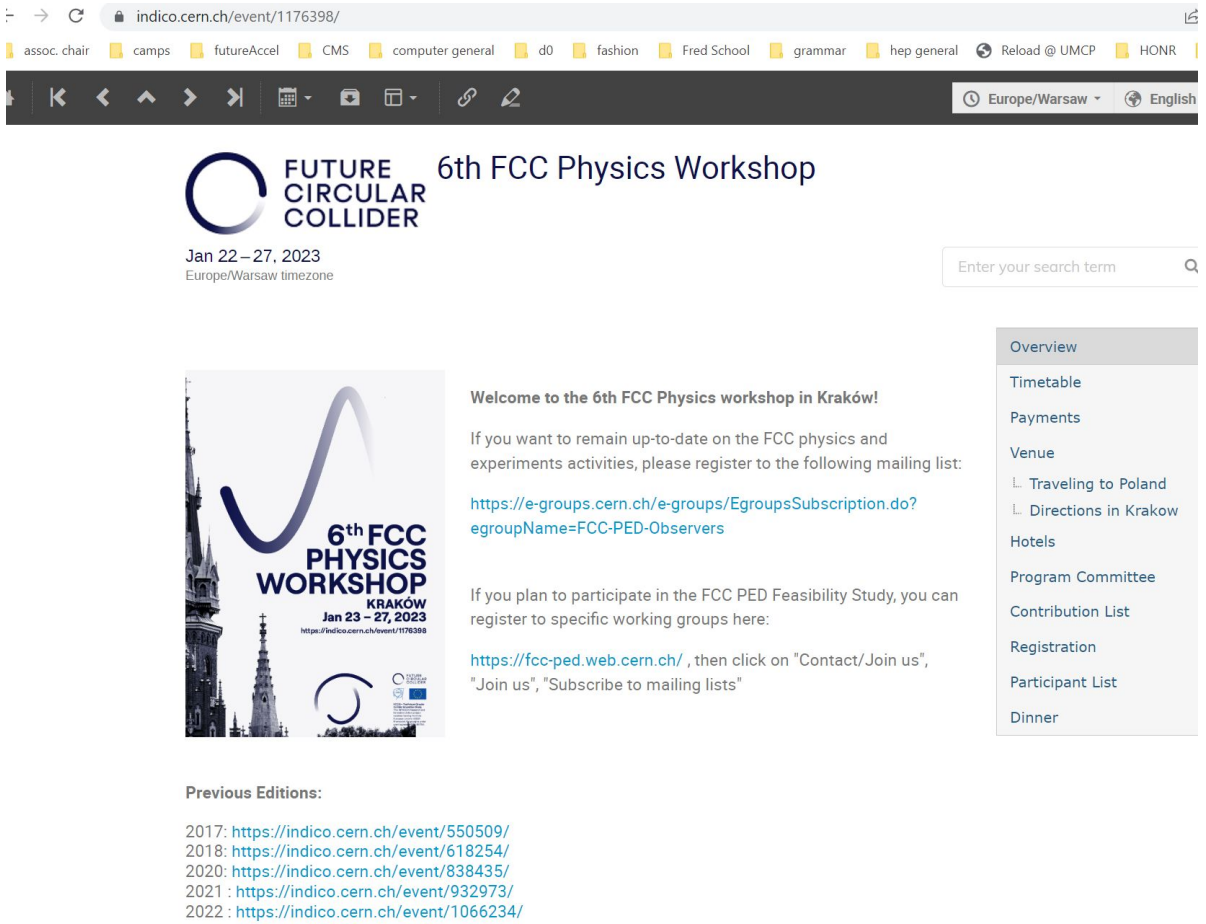
We hope to announce more US names soon





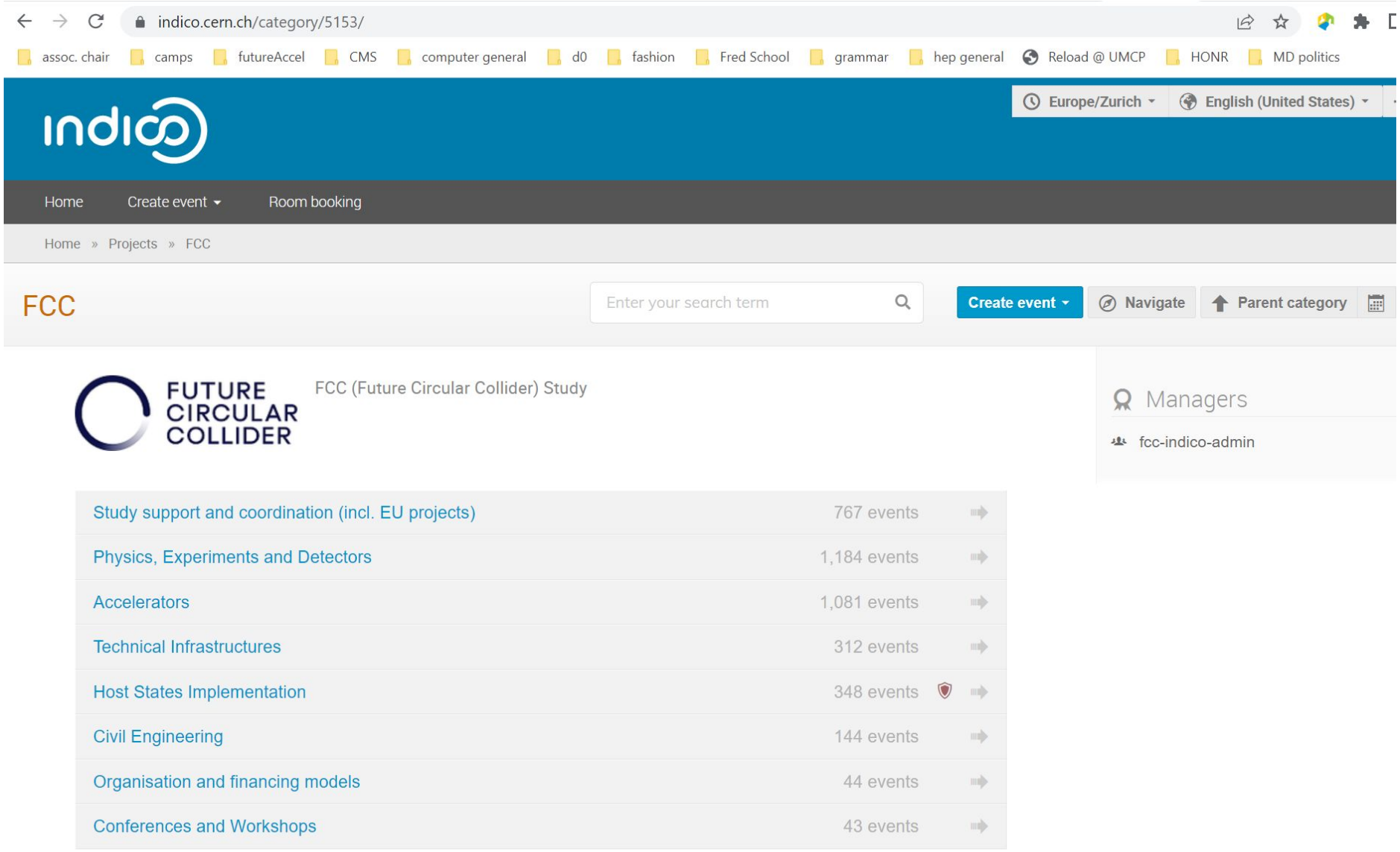
attend an FCC general meeting





And next year’s annual USFCC meeting

meetings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English (United States)
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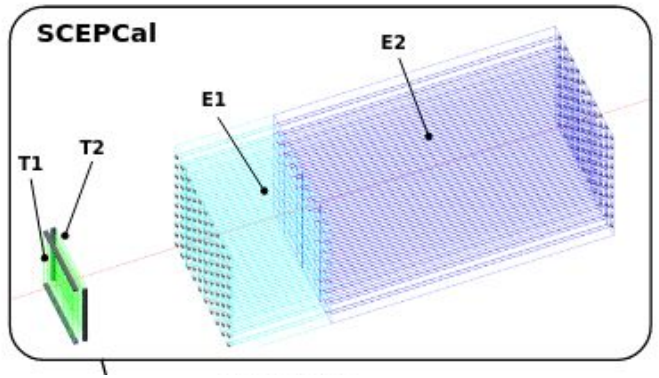
Create event
Navigate
Parent category
FUTURE CIRCULAR COLLIDER
FCC (Future Circular Collider) Study
Managers
fcc-indico-admin
Study support and coordination (incl. EU projects) 767 events
Physics, Experiments and Detectors 1,184 events
Accelerators 1,081 events
Technical Infrastructures 312 events
Host States Implementation 348 events
Civil Engineering 144 events
Organisation and financing models 44 events
Conferences and Workshops 43 events

think bold

For CMS, I do radiation damage in plastic scintillators. There is no need for that at FCCee. So working with colleagues at a variety of institutions, I've pivoted to dual readout calorimetry.

You have a year or so before work gets serious. Think about trying something new. That's why we got into physics, right?



work collaboratively

We are all very busy. We are operating our detectors for the current run, analyzing last and this run's data, and building for HL-LHC. Who has time to do even a little for FCC-ee?

We have been here before. We know the solution. We can do it if we work together.

USCMS meeting Princeton 2004

Letter from Tevatron Groups

A group of 9 University faculty on D0/CDF and CMS wrote to Mike, asking that he strongly support the LPC during the coming 3 years (2004,2005,2006) because we saw no other way we could possibly maintain the level of manpower we need on the Tevatron experiments while insuring we will be ready to do physics on Day 1 on the new energy frontier machine (LHC).

"Sold" LPC as a way to ensure a smooth transition between Tevatron/LHC and to maintain manpower on the Tevatron experiments as LHC turn-on becomes imminent. As a way to allow postdocs to work on both experiments at the same time.

Similar process occurred in ATLAS

Letter

Dear Colleagues:

I am writing to respond to your letter concerning the LHC Physics Center at Fermilab. In that letter you expressed interest in the development of such a center and stated how important it would be for U.S. university groups to take full part in research with the CMS data sample.

Both Fermilab and the leadership of the US-CMS research program have also expressed support for the LHC Physics Center (LPC) . One goal of the center is the one you articulated, that is, to make it possible for U.S. physicists working on CMS to be innovative leaders in LHC physics. The other is that Fermilab remain an intellectual center for collider physics in the LHC era. I think that both of these goals serve the larger purpose of advancing particle physics in the U.S.

A broad group of the involved parties recognizes the need of a transition period in which physicists will share effort between CDF or D0 and one of the LHC experiments. This sharing will make it possible to sustain the needed effort to operate CDF and D0 effectively, at the same time that it brings a lot of experience from the Tevatron program to the LHC. At our Annual Program Review, both CDF and D0 said that they are moving to make it easier for scientists to be an active member of their collaborations while sharing time with CMS or ATLAS. P.K. Williams expressed to me his encouragement of the LHC Physics Center here as an effective way of sharing university physicists between CDF or D0 and CMS.

I want to make the LHC Physics Center into one of the leading centers in the world for producing particle physics results, and am ready to commit resources to that end. In planning this startup we will work closely with you and with leadership of the US-CMS research program to make sure that we are establishing an institution that serves all of the interested parties well.

US FCC

Work with us to advocate for what we need to succeed

The US FCC Coordination Team

Solid State	Artur Apresyan (Fermilab), Carl Haber (LBNL)
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Particle ID	Marina Artuso (Syracuse), Sarah Eno (Maryland)
Readout/ASICs	Julia Gonski (Columbia), Jim Hirschauer (Fermilab)
Trigger/DAQ	Zeynep Demiragli (Boston), Jinlong Zhang (ANL)
Software/Computing	Heather Gray (Berkeley), Oliver Gutsche (Fermilab)
Quantum	Marcel Demarteau (ORNL), Cristian Pena (Fermilab), Si Xie (CalTech)
Advisers	Karl Jakobs (ECFA), Andy Lankford (ILC)
ex-officio	Abid Patwa (DOE), Helmut Marsiske (DOE), Jonathan Asaadi (CPAD)
Chair	Srini Rajagopalan (BNL)

Thank you

- My sincere thanks to everybody for taking the time to come to this workshop
- I know how stretched we all are, time-wize, financially, etc
- I see this meeting as a key investment in our future, something that will be celebrated 20 years in the future, at FCC-ee turn-on, as the beginning of strong US participation in a new machine.
- But more than that, you are going to be glad you came here, because this is the start of a whole lot of fun!