European Strategy for Particle Physics

Impressions from the ESPPU Open Symposium

https://agenda.infn.it/event/44943/overview

23-27 JUNE 2025 Lido di Venezia

OPEN SYMPOSIUM

European Strategy for Particle Physics

2026 UPDATE

European Strategy
for Particle Physics

Introduction

Background: European Strategy for Particle Physics

- *The **European Strategy for Particle Physics** is a cornerstone of Europe's decision-making process for the long-term future of the field.*
- *Mandated by the CERN Council, the Strategy is formed through a broad consultation of the particle physics communities in the CERN Member and Associate Member States, and beyond.*
- *In the Strategy process recommendations are developed which will be submitted to the CERN Council for an update of the Strategy.*

The European Strategy for Particle Physics is not a project approval process. Projects are approved by the CERN Council through a separate decision process, taking the Strategy recommendations into account.

Original Strategy (2006): LHC, mooting of luminosity upgrade of LHC, R&D in accelerator technologies, coordination with a potential ILC project

1st Update (2013): High Luminosity LHC, need for a post-LHC programme

2nd Update (2020): FCC feasibility study

3rd Update (2026): → recommendation for the next large-scale accelerator project at CERN (reach consensus on the preferred option and possible alternatives)

Remit of the ESPP Update 2026

- *The aim of the Strategy update should be to develop a **visionary and concrete plan** that greatly advances human knowledge in fundamental physics through the **realisation of the next flagship project at CERN**. This plan should attract and value **international collaboration** and should **allow Europe to continue to play a leading role in the field."***

- The ESG should take into consideration:
  - Input of the particle physics community;
  - Status of implementation of the 2020 Strategy update;
  - Accomplishments over recent years

    (Results from the LHC and other experiments and facilities worldwide, progress in the construction of the High-Luminosity LHC, outcome of the FCC Feasibility Study, recent technological developments in accelerator, detector and computing areas)
  - International landscape of the field

- *The Strategy update should include the **preferred option for the next collider at CERN** and **prioritised alternative options** to be pursued if the chosen preferred plan turns out not to be feasible or competitive.*

- *The Strategy update should also **indicate areas of priority for exploration complementary to colliders** and for other experiments to be considered at CERN and at other laboratories in Europe, as well as for participation in projects outside Europe.*

K. Jakobs

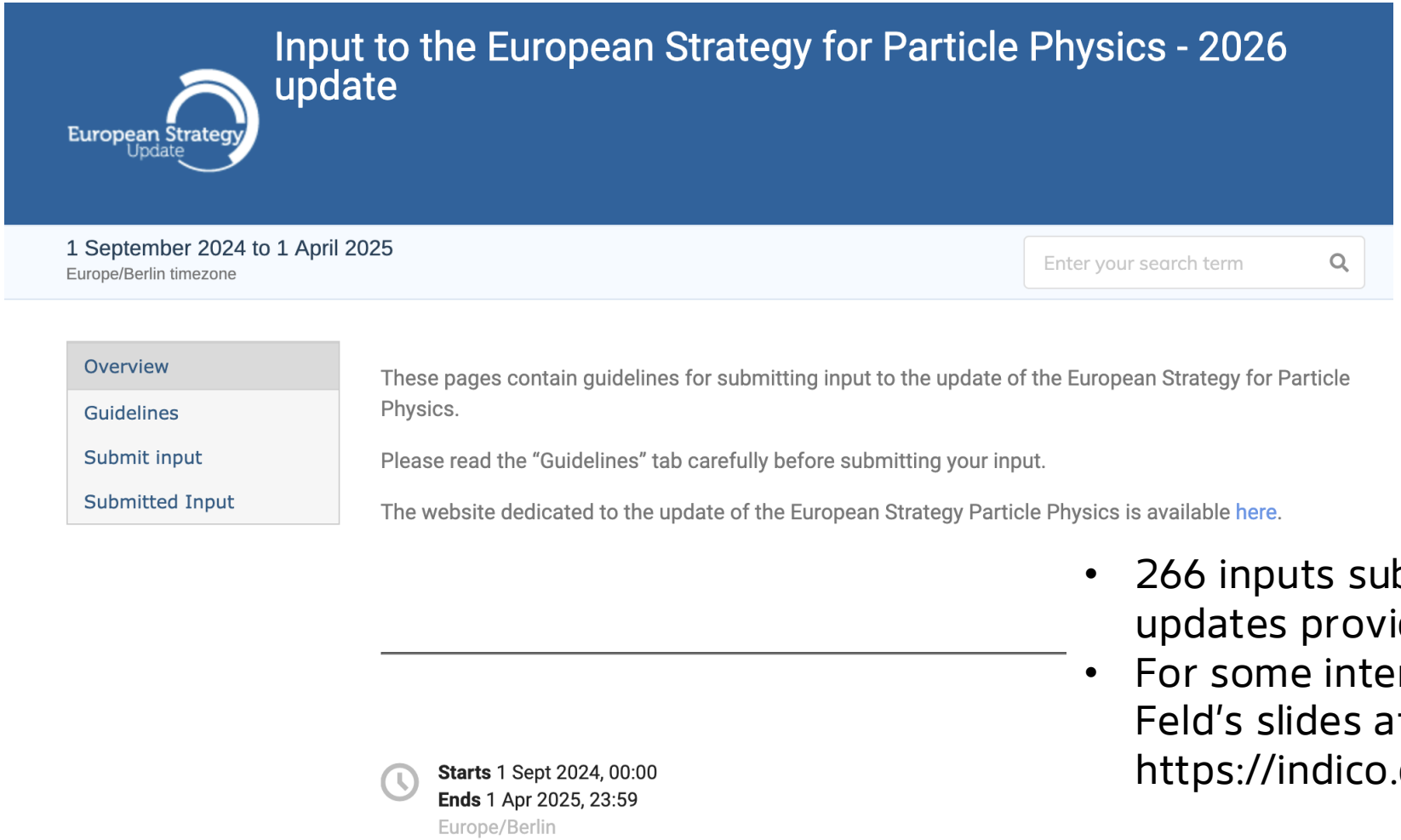
Timeline of the ESPP Update 2026

More details on ESPP web page: https://europeanstrategyupdate.web.cern.ch/

Facts

Input Documents

https://indico.cern.ch/event/1439855/overview



- 266 inputs submitted with deadline 31 March, updates provided in late May.
- For some interpretation and statistics, see Lutz Feld's slides at KET meeting Garching: https://indico.desy.de/event/48080/

Input Documents

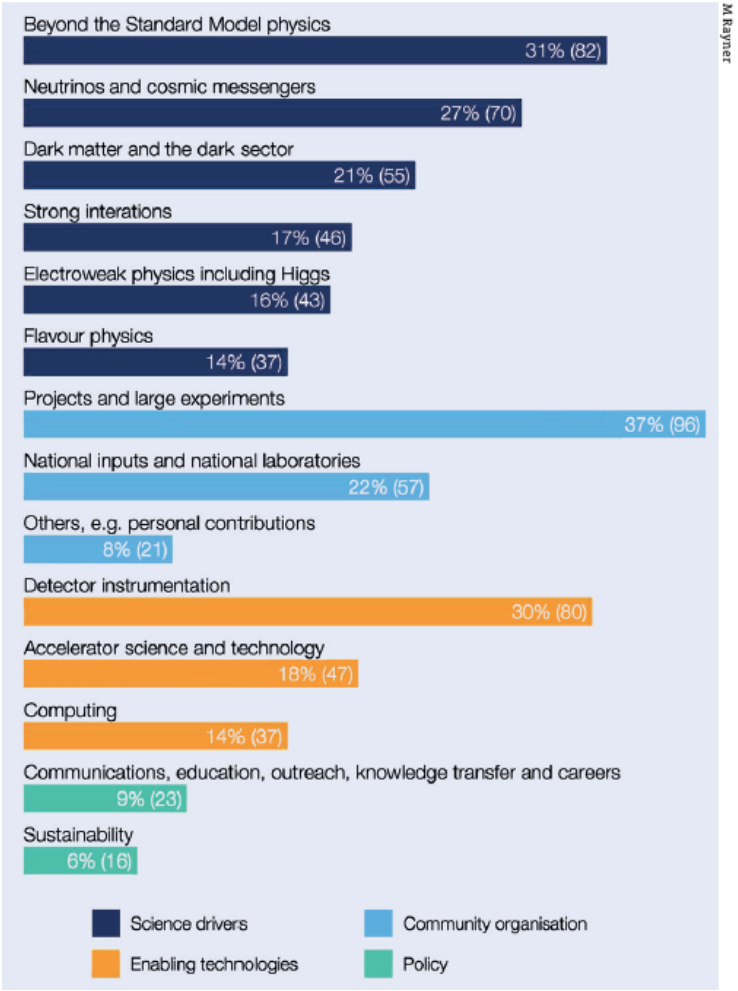
https://indico.cern.ch/event/1439855/overview

- 263 contributions received by 31 March,
  + 3 new contributions + updates by 26 *May*:

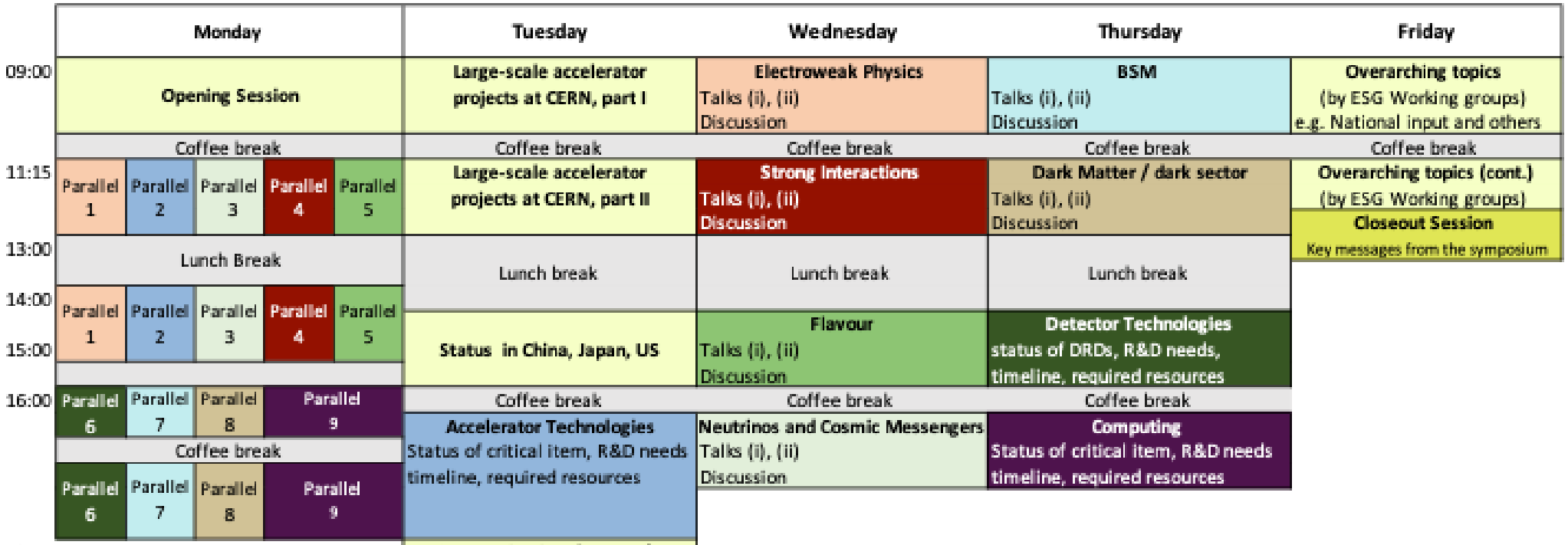
  - *Major flagship projects*
  - *Many projects in other physics areas*
  - *Input from national HEP communities in ECFA countries and beyond*
  - *Input from National European Labs (e.g. DESY, Frascati, …)*
  - *Input from Early Career Researchers (via ECFA ECR panel)*
  - *Input from APPEC, NuPECC, ..*

- All contributions are public:
  https://indico.cern.ch/event/1439855/contributions/
  Alphabetical list:
  https://europeanstrategyupdate.web.cern.ch/sites/default/files/Submitted_Input_2025.03.04.pdf

- These submissions have been analysed by the Physics Preparatory Group (PPG) and ESG working groups;
  They provide the input for the presentations and discussions at this Open Symposium



Agenda



	Monday	Tuesday	Wednesday	Thursday	Friday
09:00	**Opening Session**	**Large-scale accelerator projects at CERN, part I**	**Electroweak Physics** Talks (i), (ii) Discussion	**BSM** Talks (i), (ii) Discussion	**Overarching topics** (by ESG Working groups) e.g. National input and others
	Coffee break	Coffee break	Coffee break	Coffee break	Coffee break
11:15	Parallel 1 / Parallel 2 / Parallel 3 / Parallel 4 / Parallel 5	**Large-scale accelerator projects at CERN, part II**	**Strong Interactions** Talks (i), (ii) Discussion	**Dark Matter / dark sector** Talks (i), (ii) Discussion	**Overarching topics (cont.)** (by ESG Working groups)
13:00	Lunch Break	Lunch break	Lunch break	Lunch break	**Closeout Session** Key messages from the symposium
14:00	Parallel 1 / Parallel 2 / Parallel 3 / Parallel 4 / Parallel 5				
15:00		**Status in China, Japan, US**	**Flavour** Talks (i), (ii) Discussion	**Detector Technologies** status of DRDs, R&D needs, timeline, required resources	
16:00	Parallel 6 / Parallel 7 / Parallel 8 / Parallel 9	Coffee break	Coffee break	Coffee break	
	Coffee break	**Accelerator Technologies** Status of critical item, R&D needs timeline, required resources	**Neutrinos and Cosmic Messengers** Talks (i), (ii) Discussion	**Computing** Status of critical item, R&D needs timeline, required resources	
	Parallel 6 / Parallel 7 / Parallel 8 / Parallel 9				
19:15		Communicating the case for CERN's next flagship collider			

9:00 - 10:45 Opening Session

Parallel Sessions I - IV
11:15 - 13:00 Parallel I - IV, part I
Lunch Break: 13:00 - 14:00

14:00 - 15:30 Parallel I - IV, part II
Very short break; 15:30 - 15:40 to change rooms
15:40 - 17:00 Parallel V - IX, part I
17:00 - 17:20 Coffee break
17:20 - 19:15 Parallel V-IX, part II

16:45 - 19:15 Accelerator Tech.

For each **Physics Block:**
(i) Status, open questions
(ii) How can they be addressed by the various projects
(iii) Discussion

11:15 - 12:30 ESG Session II
12:30 - 13:30 Closeout session

Future Collider Session

Basically no physics – just the accelerator / collider / CE / costing etc. issues

09:00
- **FCC-ee (incl. common infrastructure)** — *Michael Benedikt (CERN)*
  Sala Perla, Palazzo del Casinò 09:00 - 09:40
- **FCC-hh** — *Frank Zimmermann (CERN)*
  Sala Perla, Palazzo del Casinò 09:40 - 10:10

10:00
- **A Linear Collider at CERN** — *Steinar Stapnes (CERN)*
  Sala Perla, Palazzo del Casinò 10:10 - 10:50
- **Coffee-Break**
  Sala degli Specchi, Palazzo del Casinò 10:50 - 11:20

11:00
- **LEP3** — *Tejinder Virdee (Imperial College London)*
  Sala Perla, Palazzo del Casinò 11:20 - 11:45
- **LHeC** — *Jorgen D'Hondt (Nikhef)*
  Sala Perla, Palazzo del Casinò 11:45 - 12:10

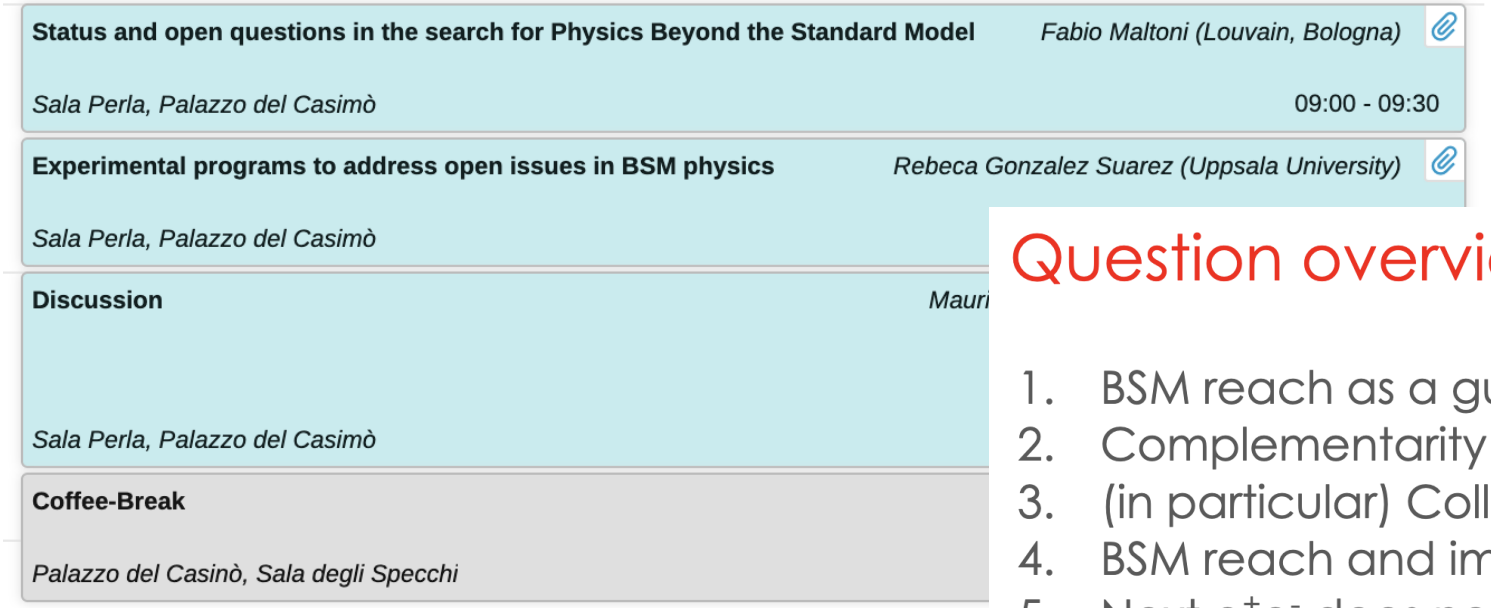
12:00
- **Muon Collider** — *Daniel Schulte (CERN)*
  Sala Perla, Palazzo del Casinò 12:10 - 12:35
- **Linear Collider Vision: future perspectives with advanced technologies** — *Jenny List DESY)*
  Sala Perla, Palazzo del Casinò 12:35 - 13:00

15:00
- **Status and plans for the realisation of the Circular Electron Positron Collider (CEPC) and other large-scale projects in China**
  Yifang Wang (IHEP Beijing)
- **Status and plans for the realisation of the International Linear Collider (ILC) and other large-scale projects in Japan**
  Shoji Asai (KEK)
  Sala Perla, Palazzo del Casinò 15:05 - 15:40
- **Large-scale particle physics projects in the US and plans for participation in projects outside**
  Hitoshi Murayama (Berkeley)

16:00
Sala Perla, Palazzo del Casinò 15:40 - 16:15

Typical Physics / Topical Session Layout

Strongly structured, mostly very well (maybe a bit over-)managed



First answers always to presenters, low (<10) number of questions from audience, few heated discussions.

Question overview

1. BSM reach as a guidance for next collider choice
2. Complementarity to other programs
3. (in particular) Colliders vs Fixed Target/Forward detectors
4. BSM reach and impact of new technologies
5. Next e^+e^- does not see a discrepancy: what next?
6. Next e^+e^- does see a discrepancy: what next?

If time allows:

7. Impact of PDFs
8. Role of theory uncertainties for BSM program
9. How e^+e^- and next-to-next colliders address HEP big questions

„Outcomes"
Summary Talks Arduini / Jakobs

Future Colliders Comparison

"Future Colliders Comparison" Working group established by CERN Directorate in June 2023, involving Project Leaders of main projects and other experts

Goal: **compare FCC** and **alternative scenarios** in a consistent way, using common assumptions and methodology, in view of the ESPP Update 2026

Deliverables:

- **Summaries of FCC-ee and alternative options for implementation at CERN**
- **Metrics for comparison**
- Comparative evaluation of the potential options for **realization at CERN**
- Credible and consistent **timelines** for implementation and time to first physics
- Summary of options considered elsewhere in the world that could be realized within the given time frame

Working Group report submitted as input to ESPP2026 on 26/5/2025
https://indico.cern.ch/event/1439855/contributions/6542430/

For projects to be considered for realisation as the next flagship project at CERN, several aspects need to be thoroughly evaluated and compared. Two ESG sub-groups tasked:

- 2a) Project assessment
  - Technical feasibility, required R&D
  - Risks
  - Timeline
  - Costs and human resources (including estimates for the associated detectors)
  - Environmental impact
- 2b) Physics potential

Two WG2a meetings held, so far:

- Assigned "reviewers" for the large-scale project proposals submitted to the ESPP2026
- Discussion on the report of the Future Collider Comparative Evaluation WG

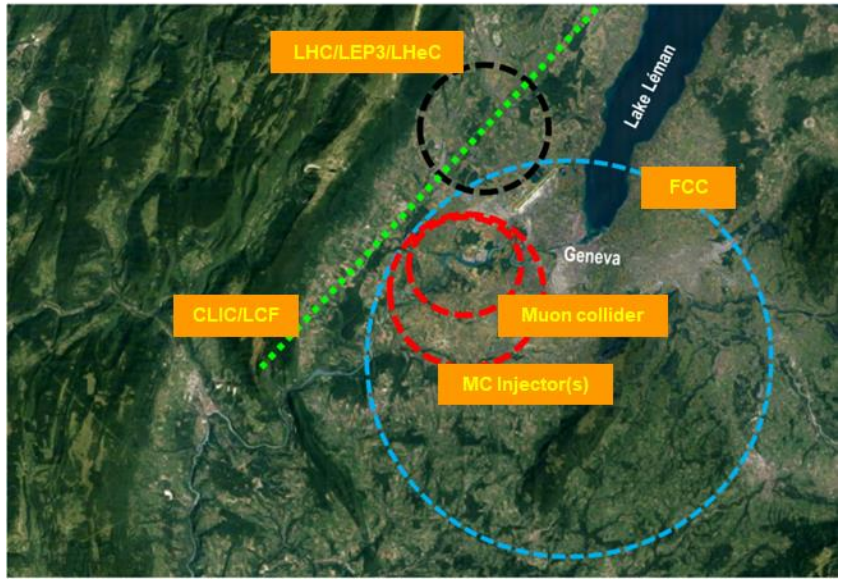
"FCC and alternatives at CERN"

Within the time frame of operation starting in mid-2040s
- CLIC 380 GeV
- FCC-ee
- LCF@CERN 250 GeV

… and their evolution (**outside the above time frame**):
- CLIC energy upgrades
- FCC-hh
- LCF@CERN energy upgrades

Muon collider (outside the above time frame)

Also included:
- Proposed reuse the LHC tunnel (LEP3, LHeC)
- International landscape (CEPC, ILC 250 GeV in Japan)



Key aspects analysed (comparison methodolgy):
- **main parameters** and performance
- **environmental** aspects (carbon footprint)
- **technical readiness**
- **material costs** for accelerator and experiments construction and installation
- human resources for accelerator construction and installation
- **project timeline**
- material and personnel costs for operation

Contributed to standardise/normalise the input provided by the projects to the ESPP2026

Selection of Results

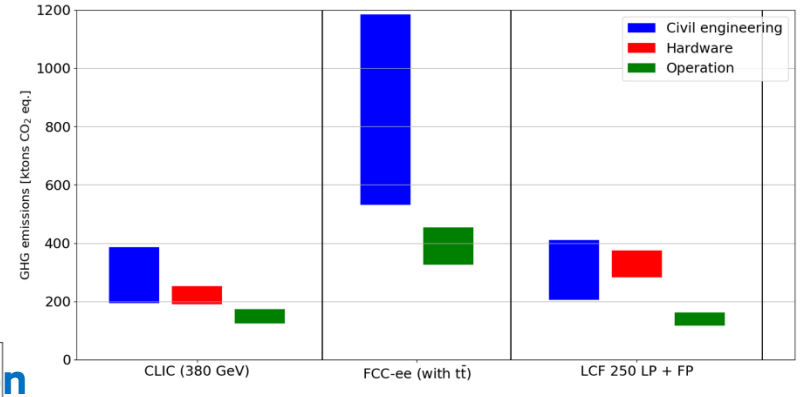
Annual resource requirements

	CLIC 380 GeV	FCC-ee 91.2 – 365 GeV	LCF 250 GeV LP – FP
Maintenance and replacement material cost [MCHF/y]	137	200[a]	170[b]
Electricity cost [MCHF/y]	63	92 – 146	61 – 77
Personnel for operation of the future collider accelerator complex [FTE/y]	650	950	800

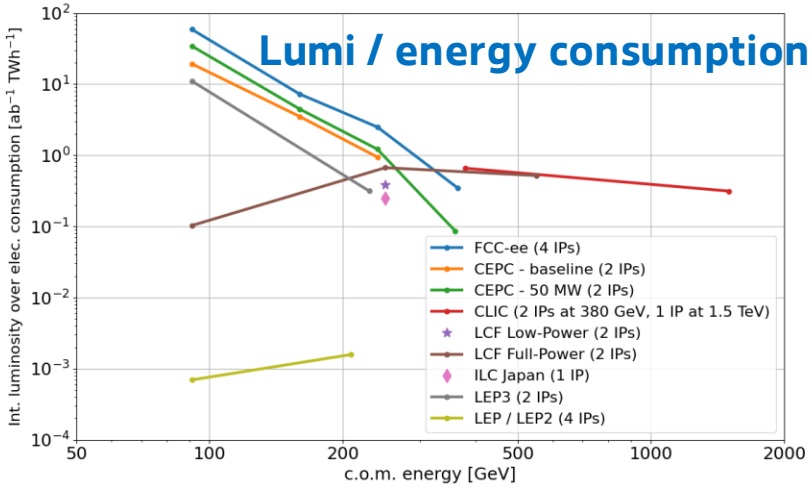
[a] Average of the costs for the different energy configurations.
[b] Average of the costs for the LP and FP configurations.

Table 4.12: Annual resource requirements for the operation of the acc e^+e^- colliders at CERN.

GHG emissions



Lumi / energy consumption



Timeline

Milestone	FCC-ee
Conceptual Design Study	2014 – 2018
Definition of the placement scenario	2022
Preliminary implementation with the Host states	2024 – 2025
Feasibility Report ready	2025
Earliest Project Approval[a]	2028
Environmental evaluation & project authorisation processes	2026 – 2031
Main technologies R&D completion[b]	2031
Technical Design Report ready[c]	2032
Civil engineering	2033 – 2041
TI installation	2039 – 2043
Accelerator installation	2041 – 2045
HW commissioning	2042 – mid 2046
Beam commissioning – collider	mid 2046 – 2047
Physics operation start	2048

Timeline

	CLIC	LCF
Design Report	2004 – 2012	2002 – 2007
for ILC 500 GeV		2007 – 2013
n Plan, Readiness Report	2013 – 2025	
and Prelab planning		2013 – 2025
ase 1	2026 – 2028	
Definition of the placement scenario Design optimisation and finalization Main technologies R&D conclusions Technical Design Report - two IPs at CERN		
Project Preparation Phase 2	T_0 – (T_0+5)	
Site investigation and preparation Implementation studies with the Host states Environmental evaluation & project authorisation processes Industrialisation of key components Engineering design completion		
Construction Phase (from ground breaking)	T_1 – (T_1+10)	
Civil engineering Construction of components Installation and hardware commissioning		
Beam commissioning and physics operation start	T_1+11	

Cost Estimates

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

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)

The View of the National Communities

- **Completing the full HL-LHC programme** is essential and must remain a high priority for CERN;

  It is paramount to fully exploit the High-Luminosity LHC (HL-LHC) to maximise scientific returns

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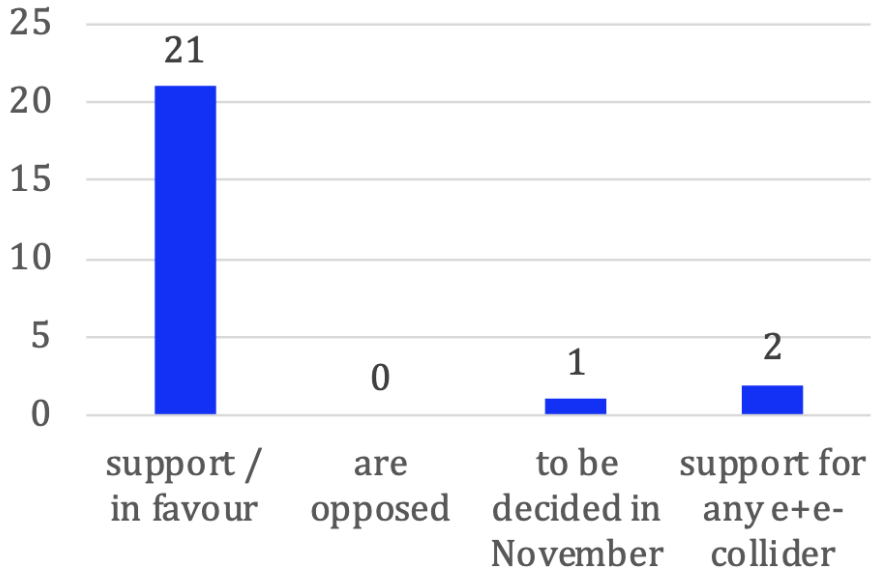
- It is important that the **next flagship collider supports a broad physics programme**, given that it is not clear where new physics will show up.

- Should a dedicated energy-frontier collider or a high-luminosity e^+e^- machine not prove feasible or face significant delays, **intermediate collider projects** such as LHeC and LEP3 are recognised as strategically valuable by some member-states HEP communities

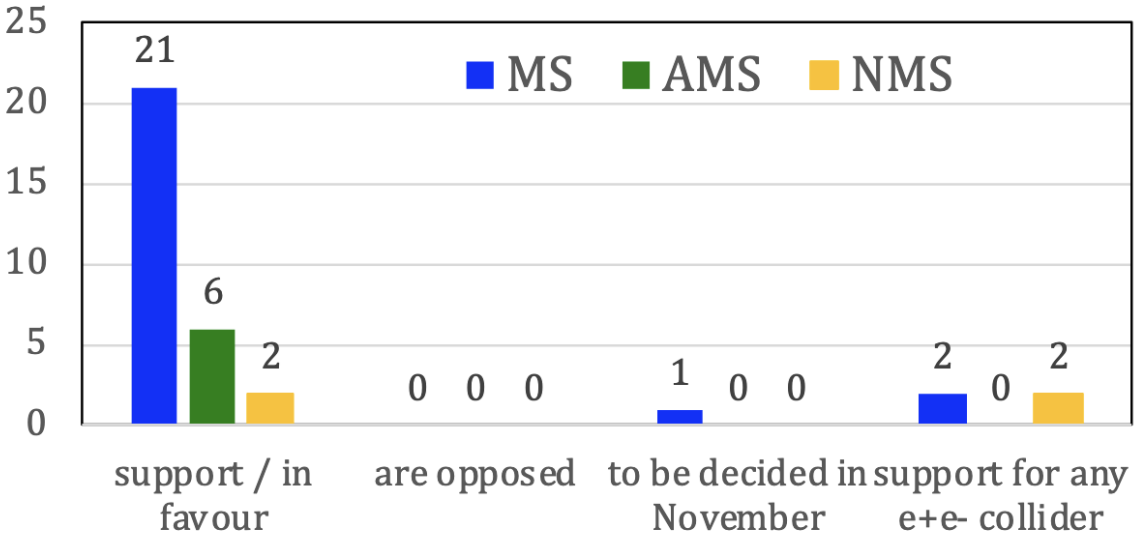
The View of the National Communities

What is the preferred large-scale accelerator for CERN

CERN Member States (MS)



… incl. Associate- and Non-Member States (MS)

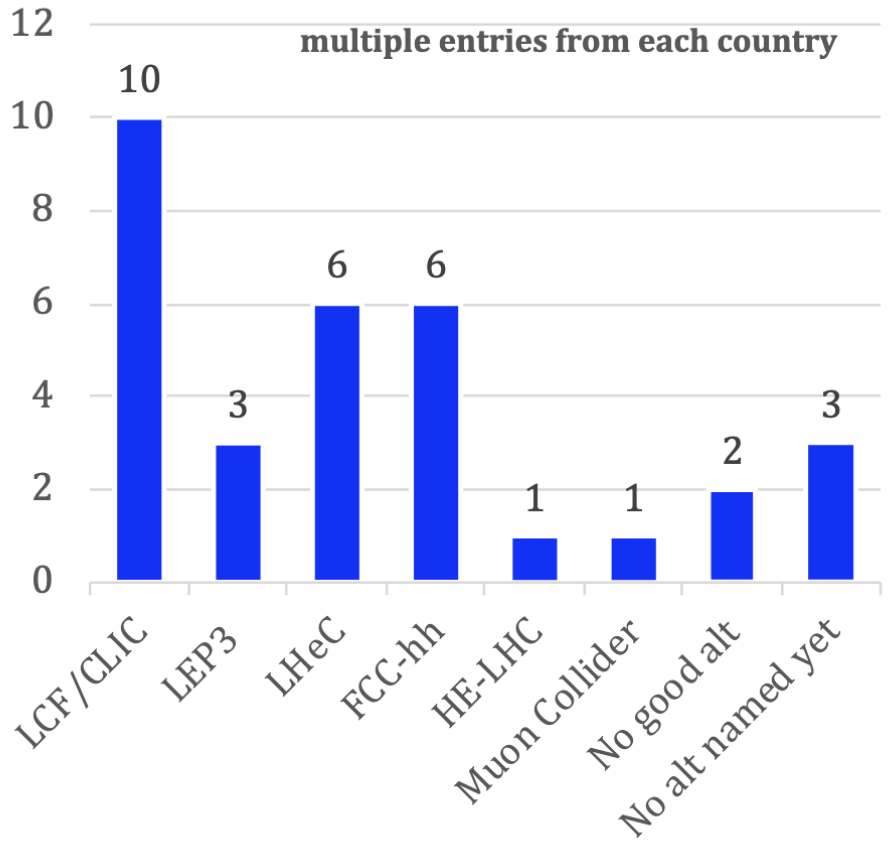


- Overwhelming support (21/24 CERN MS HEP communities) in favour of the integrated FCC-ee/hh programme

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

The View of the National Communities

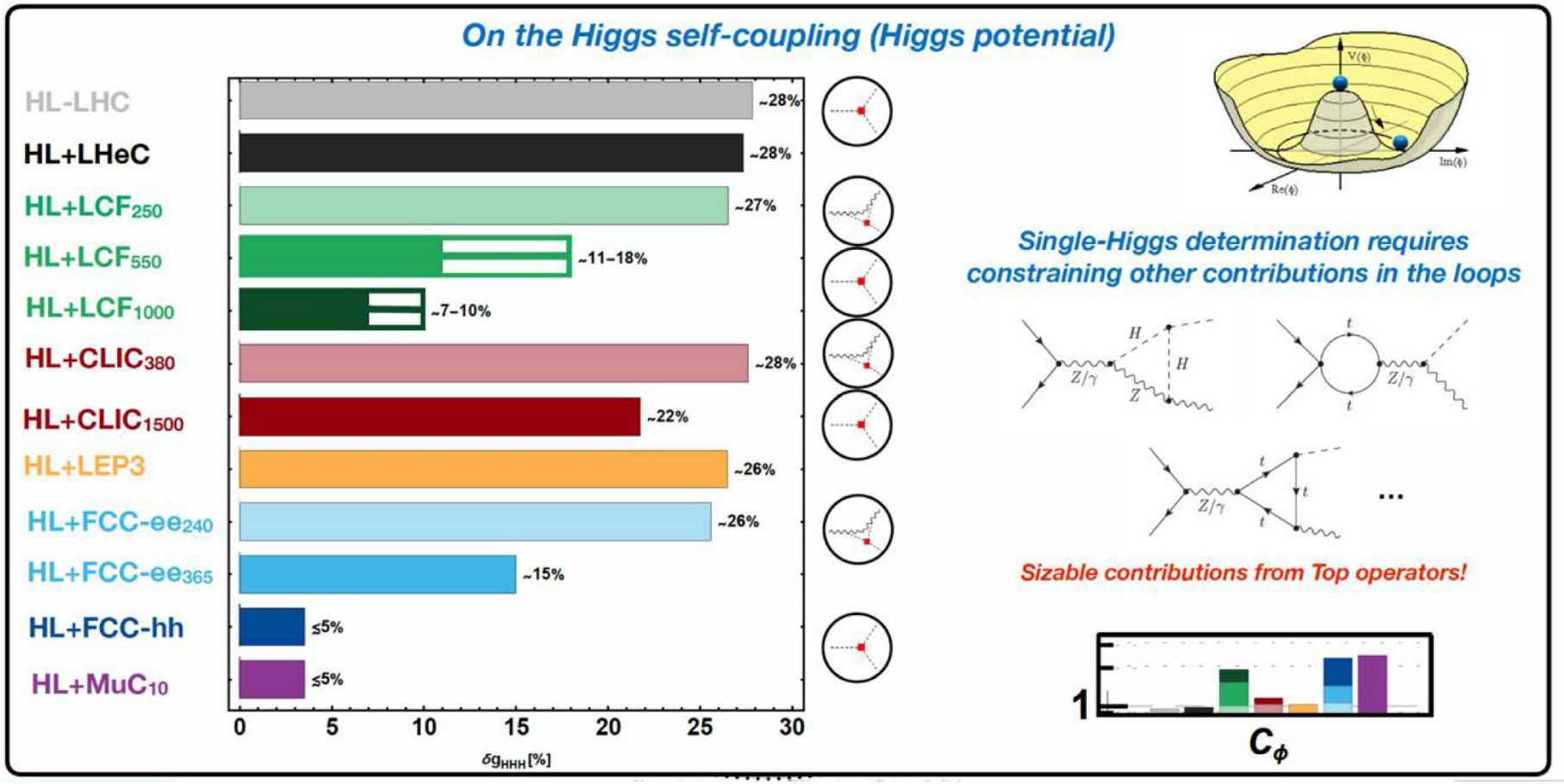
What is the alternative if the preferred option is not feasible?



CERN Member States (MS) (multiple entries allowed)

- 10 MS HEP communities list a Linear Collider (LCF, CLIC) as second best choice
  (LCF is preferred to be realised with 550 GeV)
- 3 MS HEP mention LEP3 as a genuinely less costly alternative to FCC-ee
- 6 MS HEP communities support LHeC
- 6 MS HEP communities support a lower-energy hadron collider
- 2 MS HEP see no reason for another option, as they would be equally costly.

Physics Considerations



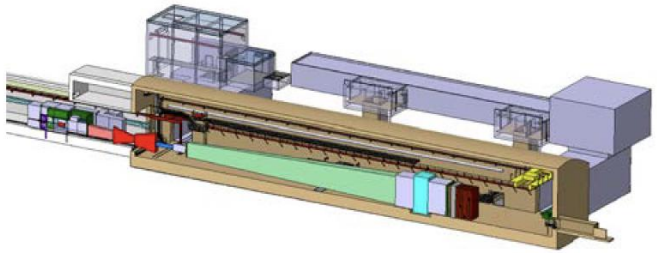
Diversity

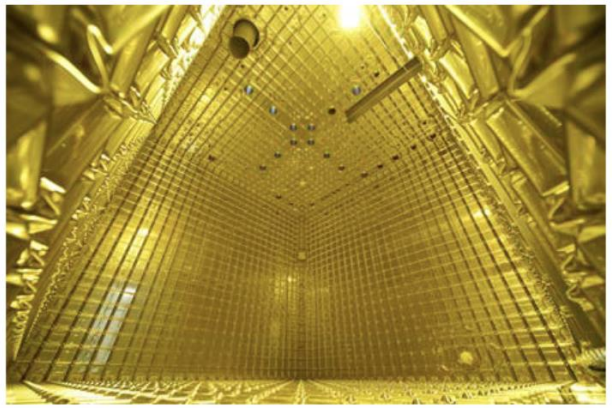
Diversity in the Physics Programme

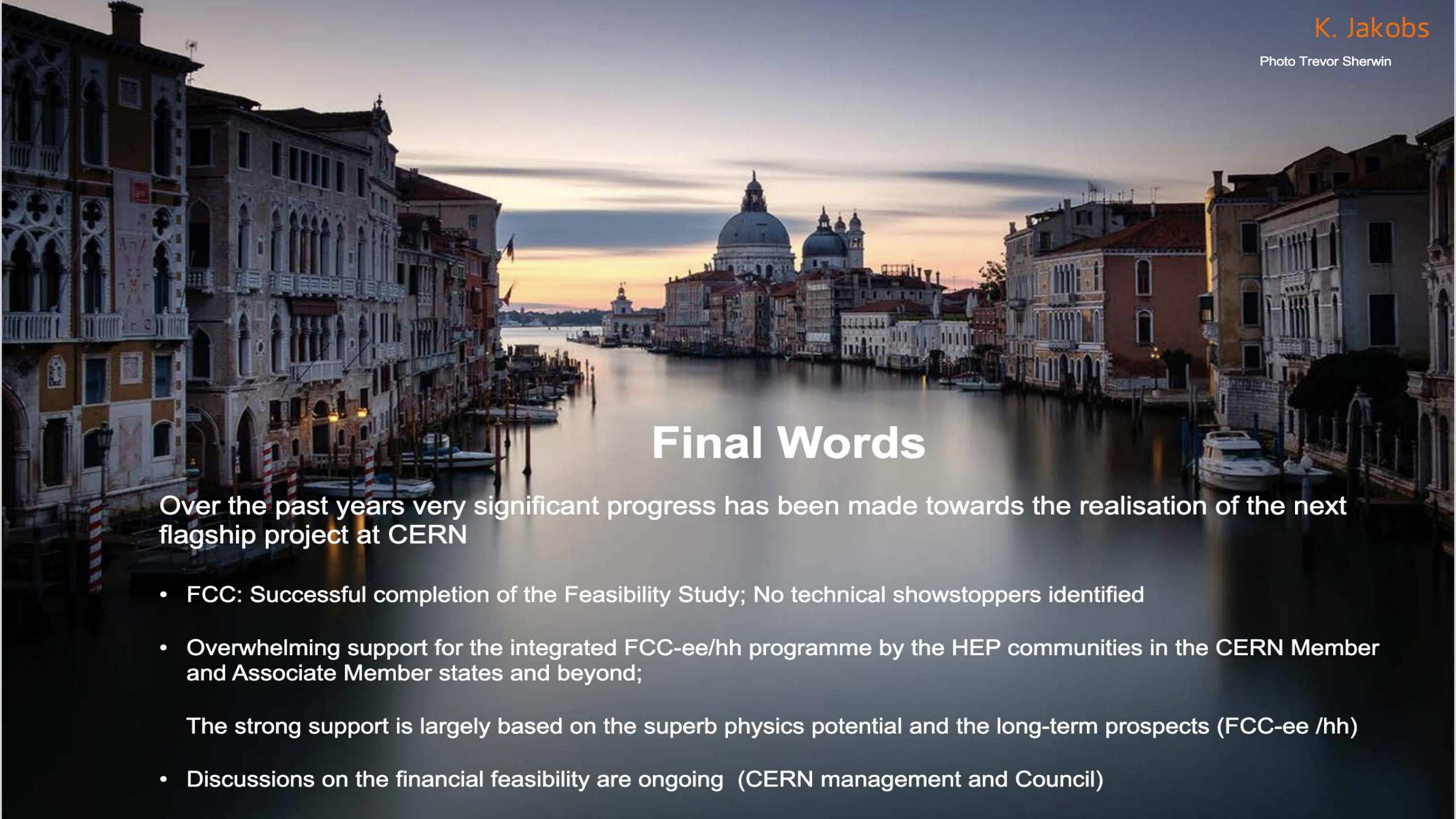
Keeping **diversity in the particle physics** programme is essential: the next collider project should not come at the expense of a diverse scientific programme in Europe in terms of resources.

Ensuring a diverse and comprehensive physics programme is crucial for addressing fundamental physics questions, including fixed-target, neutrino, flavour, astroparticle and nuclear physics experiments

We do not know where new physics might be hiding → potential for groundbreaking discoveries







K. Jakobs

Photo Trevor Sherwin

Final Words

Over the past years very significant progress has been made towards the realisation of the next flagship project at CERN

- FCC: Successful completion of the Feasibility Study; No technical showstoppers identified
- Overwhelming support for the integrated FCC-ee/hh programme by the HEP communities in the CERN Member and Associate Member states and beyond;

  The strong support is largely based on the superb physics potential and the long-term prospects (FCC-ee /hh)
- Discussions on the financial feasibility are ongoing (CERN management and Council)

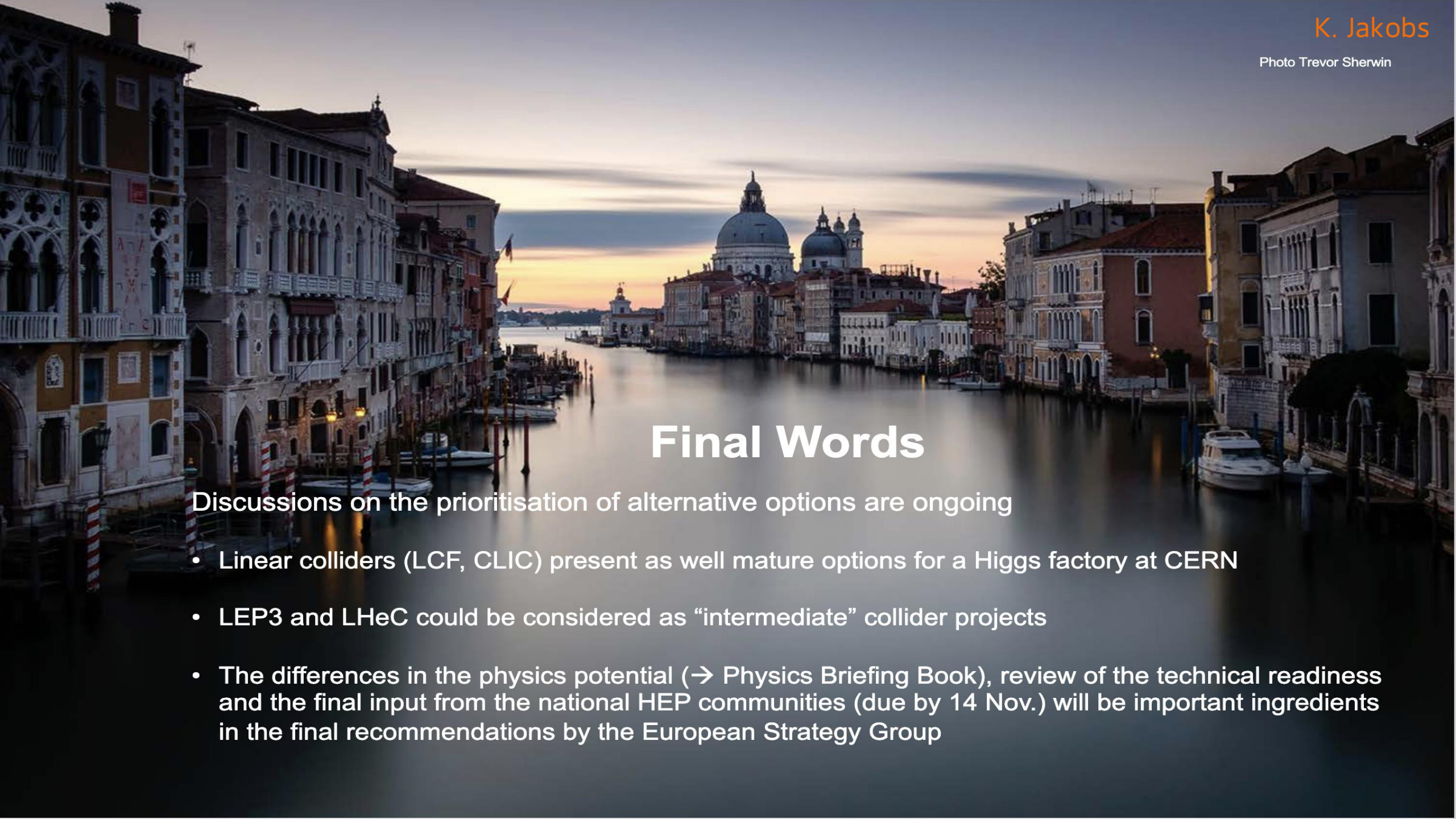


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Photo Trevor Sherwin

Final Words

Discussions on the prioritisation of alternative options are ongoing

- Linear colliders (LCF, CLIC) present as well mature options for a Higgs factory at CERN
- LEP3 and LHeC could be considered as “intermediate” collider projects
- The differences in the physics potential (→ Physics Briefing Book), review of the technical readiness and the final input from the national HEP communities (due by 14 Nov.) will be important ingredients in the final recommendations by the European Strategy Group

Personal Impressions Summary

18:03 5G 67

Lido di Venezia

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Impressions and Summary (1)

This might still be uncontroversial?

- A very strongly structured and managed event, with all good and bad consequences
  - A very clear difference to Grenada …
- FCC accepted – be it happily or with clenched teeth – by everybody as “plan A”.
  - See national inputs, see Arduini’s slide title
  - Discussions in coffee breaks on “plan B”
- From national inputs, linear colliders as second-most mentioned option.
- LEP3 as a serious contender (but clearly not ”an intermediate project”?)
- China: expect decision on CEPC within next 12 months or so
  - Y. Wang: Will no pursue if CEPC if Europe builds FCC

Impressions and Summary (2)

Very strictly personal – probably nuch more controversial

- I find the inconsistencies and contradictions that form part of many arguments for a new machine hard to bear.
  - Especially the mix of very different argument categories obscures the discussion (cost vs scientific merit vs impact on community vs diversity programme vs innovation vs international competition vs keeping the community together vs keeping CERN alive vs …)
    → source of a lot of unnecessary emotions
  - Interesting notion: "post-normal science" (Wikipedia: https://en.wikipedia.org/wiki/Post-normal_science)
- I personally don't believe in a linear machine in Japan anymore.
- I personally think a new machine must be financially feasible within the CERN budget (construction and operation) and must by no means (and be it by its continency) eat up a scientifically diverse programme or fix a community to one project beyond technological development cycle timescales