The LDG RF Activities

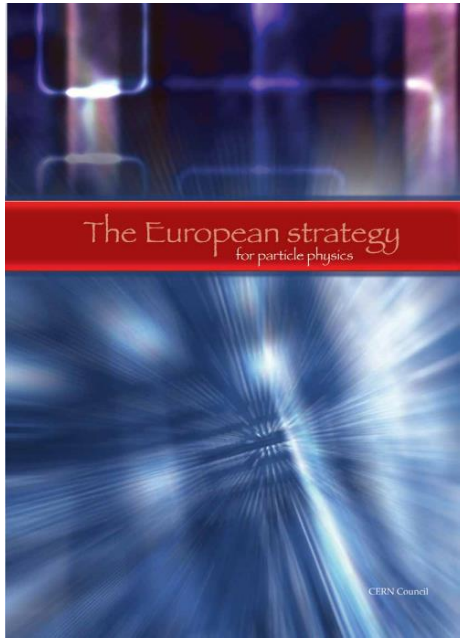
Giovanni Bisoffi, INFN

CLIC Mini Week, CERN

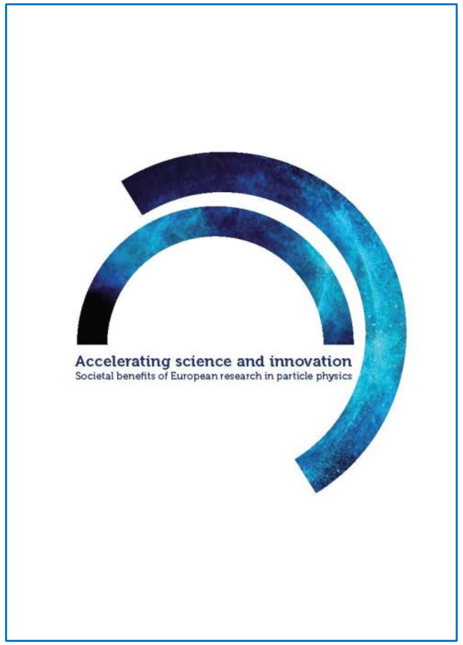
December 12,2023

European Particle Physics Strategy and its updates

"(…) cornerstone of Europe's decision-making process for the long-term future of the field. Mandated by the CERN Council, it is formed through a broad consultation of the grass-roots particle physics community (…) and it is developed in close coordination with similar processes in the US and Japan (…)"



Strategy 14 July 2006



Update 30 May 2013

Update 19 June 2020

European Strategy Group

- ✓ **Chairperson**
- ✓ 1/CERN Member State,
- ✓ 1/lab of the major European Laboratory Directors' Group, **LDG**
- ✓ CERN Director-General,
- ✓ SPC Chairperson,
- ✓ ECFA Chairperson.

Invitees:

- ✓ President of the CERN Council,
- ✓ 1/Associate Member States,
- ✓ 1/Observer State,
- ✓ 1/European Commission, JINR
- ✓ Chairs of ApPEC, FALC, ESFRI, and NuPECC
- ✓ Members of Physics Prep Group

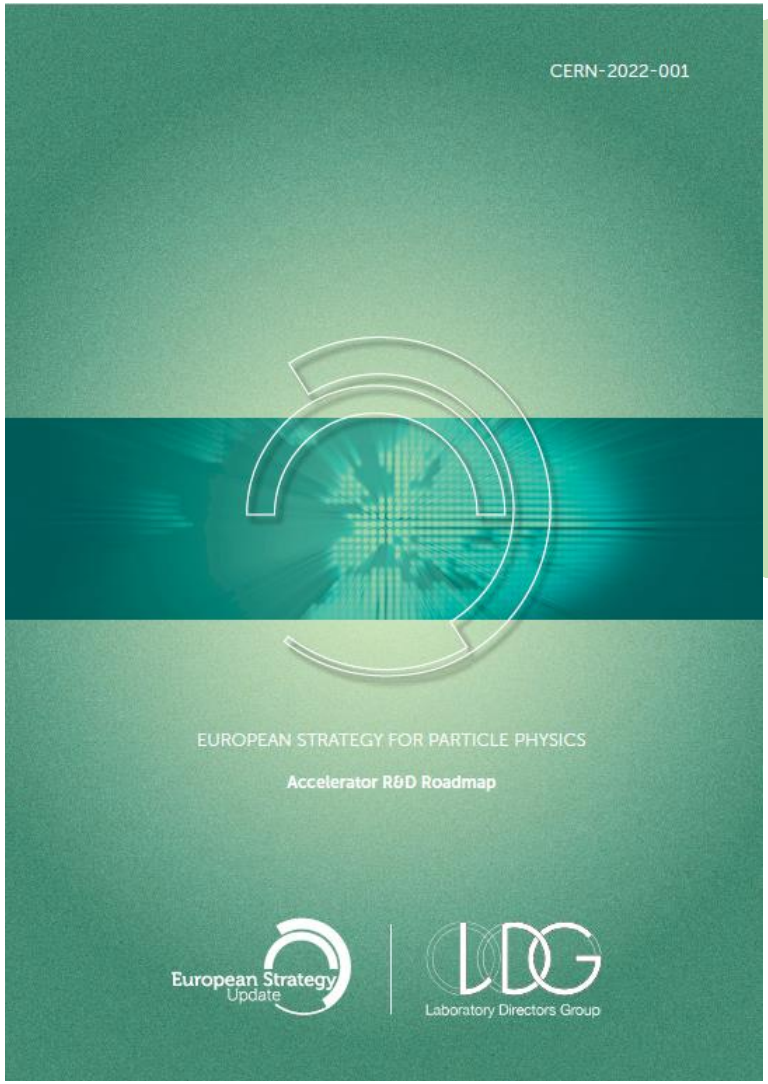
European Laboratory Directors Group (LDG)

Lab representatives from NIKHEF, INFN, STFC, CIEMAT, CERN, DESY, RAL, CNRS, PSI
Standing observers: ECFA Chair, SPC Chair, CERN Directorate

- ✓ Dialogue among Lab Directors and CERN
- ✓ Input to the ESPP, liaise with EU Commission and national funding agencies, institutes and universities
- ✓ Maximise national benefits of investment in fundamental research and in CERN
- ✓ Look at activities outside CERN's Member States, and of other groups in PP and related fields
- ✓ Draw up and maintain a **prioritised accelerator R&D roadmap** towards future large-scale facilities for PP
- ✓ **Coordinate the accelerator R&D activities on the roadmap, until the next SU**

Approved R&D strategy and its implementation

https://doi.org/10.23731/CYRM-2022-001



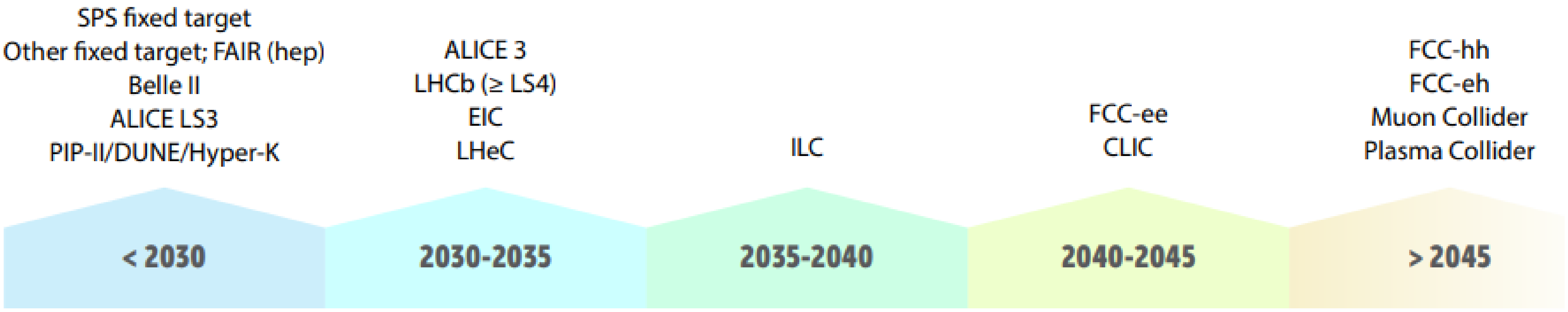
Accelerator R&D Roadmap presented to SPC in March 2022 and adopted by the Council

- ✓Each technology area deeply surveyed
- ✓Key R&D objectives, deliverables (at 5 and 10 years)
- ✓Resource estimates, needed facilities
- ✓Emphasis on: e+e- programme and sustainability

After that: **expert coordination panels**, working with LDG ("extended LDG") and accelerator R&D community to begin **implementation of roadmap recommendations**

Lab representatives from NIKHEF, INFN, STFC, CIEMAT, CERN, DESY, RAL, CNRS, CEA, PSI - **Standing observers**: ECFA Chair, SPC Chair, CERN Directorate
Extended LDG members: on HF-Magnets , Muon C, ERL, Laser Plasma Acc , RF

LDG and the and Acc R&D Coordination panels



(~ feasible start dates)

The 5 R&D Themes

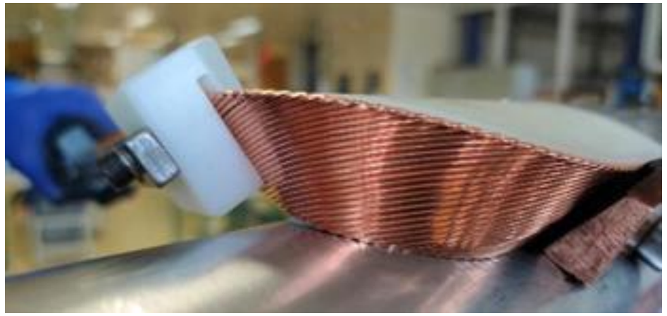
1. High-field magnets
2. High-gradient plasma and laser accelerators
3. Bright muon beams and muon collider
4. Energy Recovery Linacs
5. High-gradient RF structures and systems

Scope
R&D needs
Teams
Time horizon

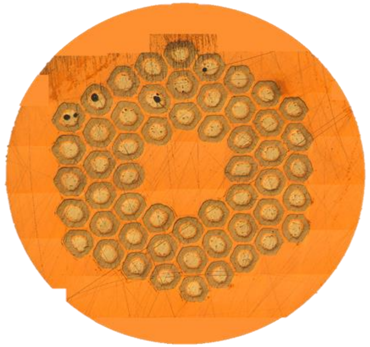
1. High Field Magnets

- HFM Key for new colliders, beyond the LHC

- Goals (on conductor and magnets):
  - ✓ 16 T Nb3Sn technology (large-scale, industry-optimised) for FCC-hh, demonstration before 2026
  - ✓ 20 T at 10÷20K with HTS (proof-of-principle, tapes and cables with industry)
- Decades needed, broad expertise and coordination, infrastructures, industry: CARE, EUCARD, EUCARD2, ARIES, now I-FAST, CERN-High Field Magnet and US-MDP
- **Cross-cutting activities**: materials, powering and protection, infrastructures and instruments, quench detection and protection
- New infrastructures needed!

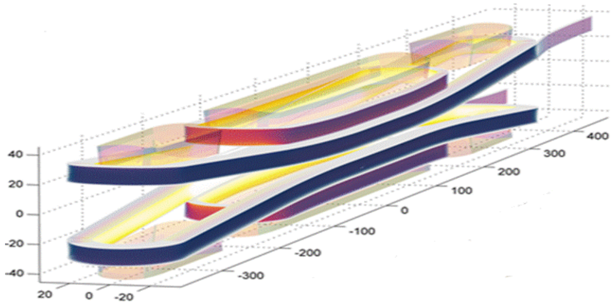


12 T prototypes expected in INFN-Ge and CERN by 2025; CEA: a 16 T prototype plan



Focus on stress/strain sensitivity and degradation of Nb_3Sn: mech. strength, higher J_C, stress-adapted magnet design

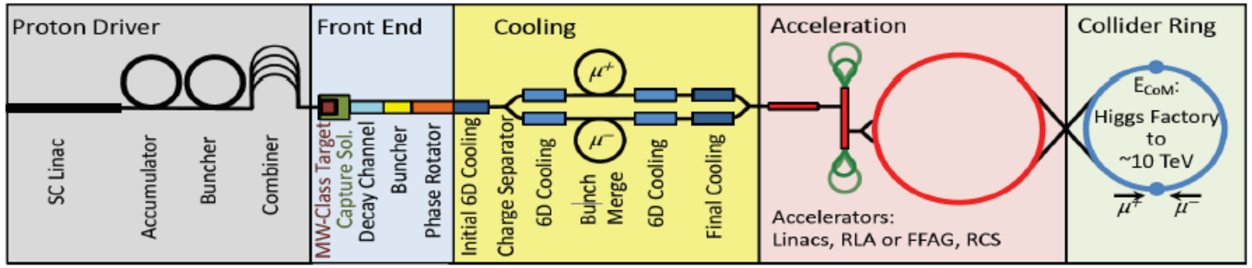
Hybrid LTS/HTS magnets: ReBCO tapes or Bi-2212 cables (still a long way to go for 16 T)



Panel chairs: P. Vedrine, M. Lamont

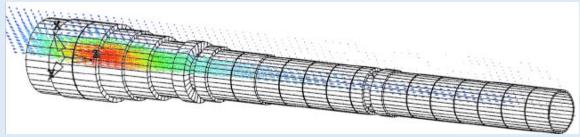
2. Muon Collider

5 GeV p → π → μ, cooled and accelerated at 3/10 TeV



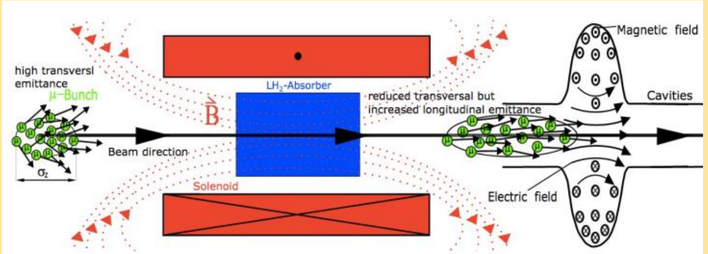
3/10 TeV μ acceleration via RLA/FFAG and RCS (with 14 T Magnets)

- For long-term sustainability of collider physics: strong suppression of synchrotron radiation (μ vs. e) power consumption at 10 TeV lower than CLIC at 3 TeV; $\mathcal{L}/P_{beam}$ increasing with collision energy



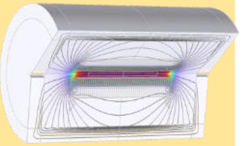
After the target: 200 mm bore 15÷20 T solenoid (synergy with fusion)

- **Needed: a fully integrated design (on target, detector, cooling and accelerator chain)**
- **Needed from RF technology**: e.g. HG room-T cavity in high-field SC solenoid, 20 T solenoids (HFM), ERL linac
- MuCol Collaboration: 32 partners Institutions in Europe, plus USA (waiting for P5), China, India: 7-15 M€ thus far
- After 2026, CDR R&D with a μ-cooling demonstrator



Cooling channel demonstrator is key: HG room-T cavity in high-field SC solenoid

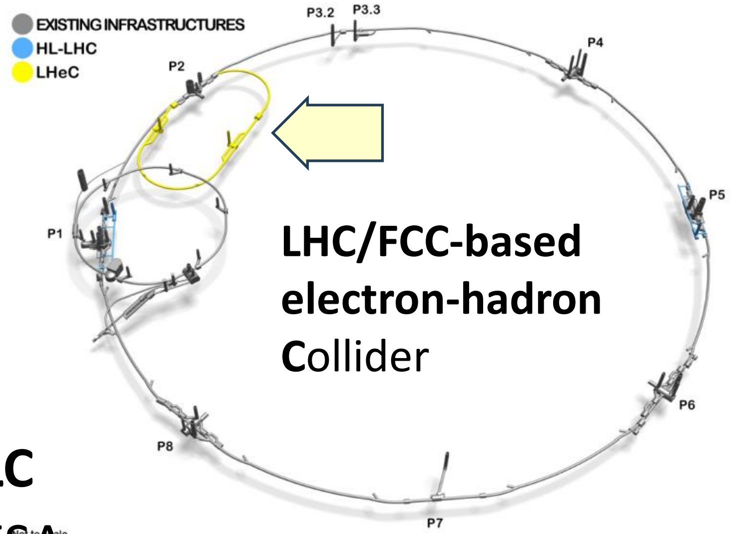
> 40 T, 60 mm



Panel chairs: S. Stapnes, D. Schulte

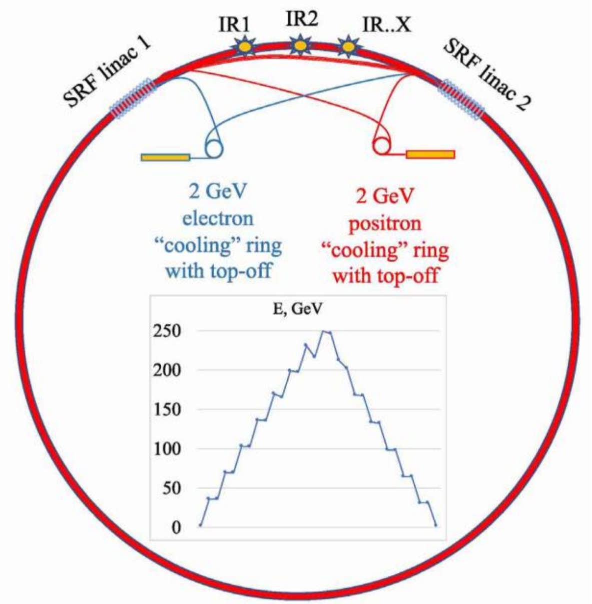
3. Colliders based on Energy Recovery Linacs

- Multipass accel/decel (energy efficient)
- «Linac» beam quality, «ring» high I_{ave}

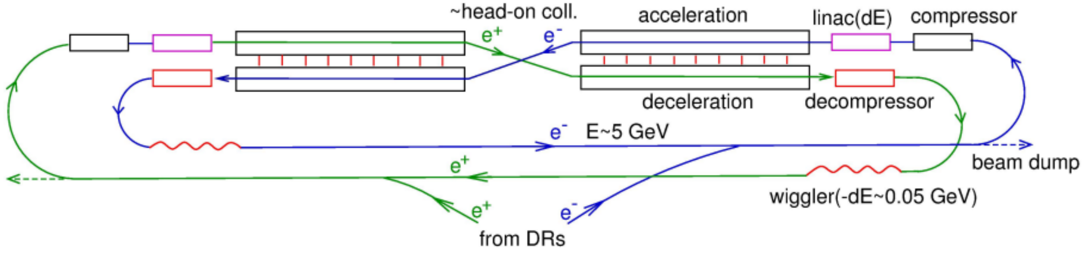


LHC/FCC-based electron-hadron Collider

- **ERL-based colliders: LHeC, FCC-eh, CERC, ERLC**
- Current facilities: S-DALINAC (Darmstadt), MESA (Mainz), CBETA (Cornell, US), cERL (KEK), Recuperator facility (BINP)
- New ERLs: Berlin-PRO, PERLE, CEBAF5, ERL-ecool at EIC
- Collaboration: iSAS project approved (July 10, 2023): 1000 person*months, 12.6 M€, 4 years
- **Needed from SRF technology**: Q~10^{11} at higher T (4K); HOM extraction at high-T; FE-FRT to control transient beam loading and microphonics; dual-axis cavities; ...



Circular **ER C**ollider



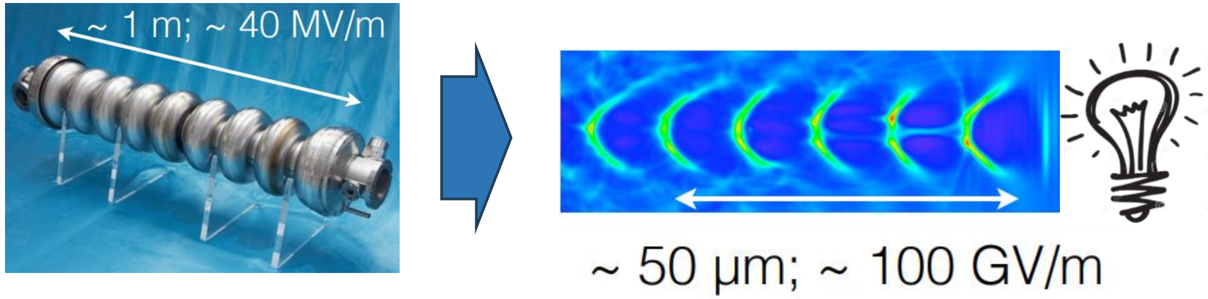
Energy **R**ecovery **L**inear **C**ollider

Panel chairs: J. D'Hondt, M. Klein

4. High-gradient plasma and laser accelerators

Electron bunch or **laser** (v~c) induce wave-like separations of electrons from ions (~ at rest)

Experimental studies on key R&D: e+ bunch acceleration, sufficient bunch charge, nm-scale emittance, staging of multiple structures, spin-polarisation preservation, high rep-rate and power handling, high rep-rate lasers, energy efficiency.

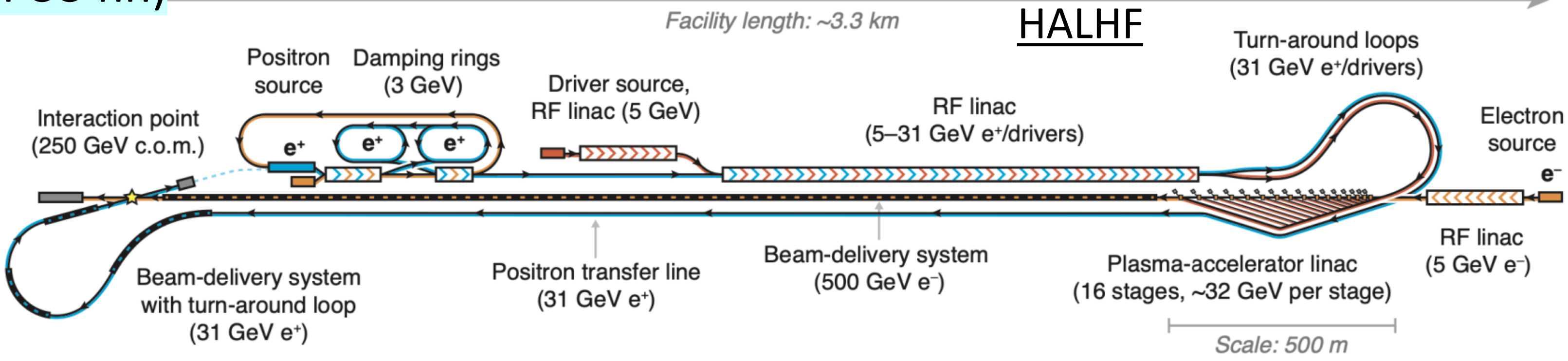


Driving discipline is photon/material science: ELI and EuPRAXIA distributed facilities.
R&D strategies at CERN (AWAKE), CLARA, CNRS, DESY, Helmoltz's, INFN, RAL, and abroad.
HEP-related programmes: EU (EuroNNAc), the US (DOE) and world-wide (ALEGRO).

Pre-CDR and Collider Feasibility Report (**2025**), CDR in 2026-2030 with demo of technical parameters.

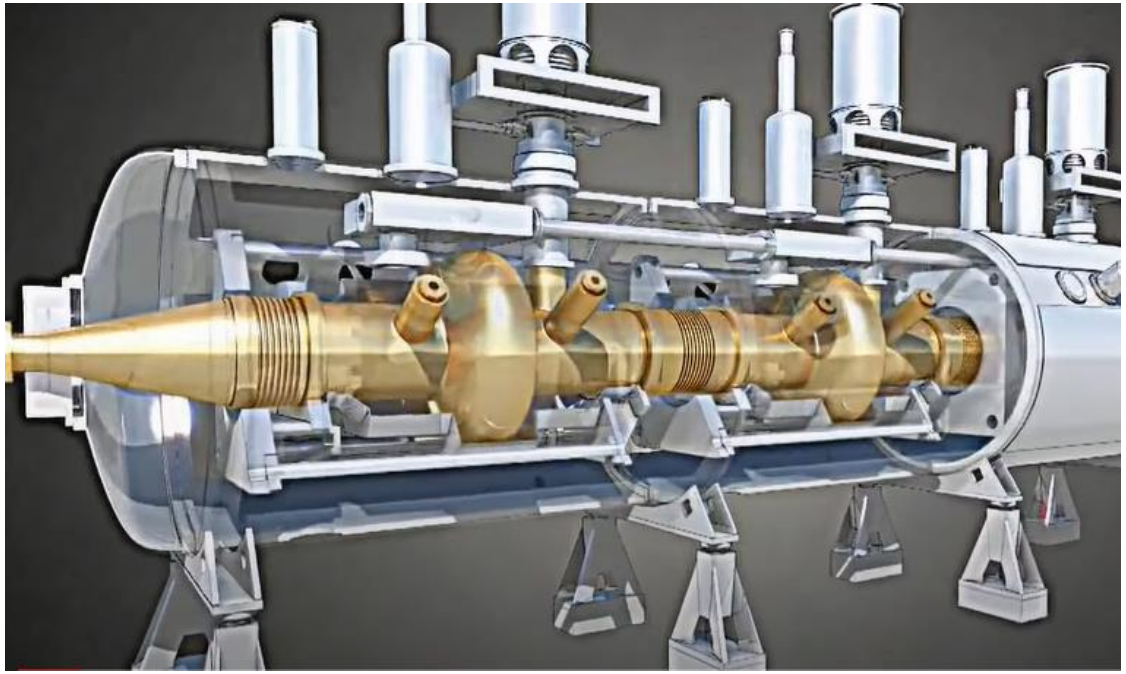
A collider option **beyond 2050** (after FCC-hh)

HALHF, with both RF and PBA:
e- 500GeV electrons onto e+ 31GeV positrons



Panel chairs: W. Leemans, R. Patahill

RF = increase beam energy efficiently and reliably

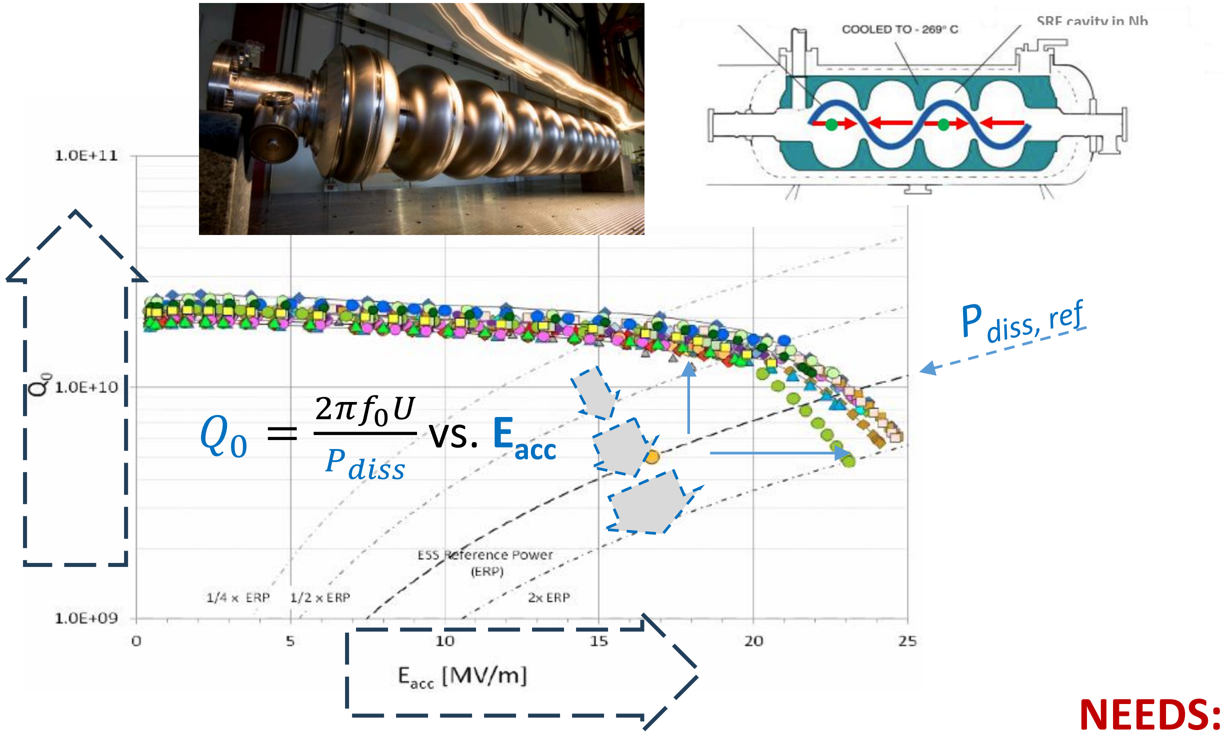


RF Panel coordination		G. Bisoffi INFN-I, P. McIntosh STFC-UK
◆ WG1	Bulk Nb	M. Baylac CNRS-F, C. Madec CEA-F, L. Monaco INFN-I
◆ WG2	Thin films	C. Antoine CEA-F, O. Malyshev STFC-UK
◇ WG3	Couplers	F. Gerick CERN, E. Montesinos CERN, A. Neumann HZB-D
◆ WG4	NC High gradient	W. Wünsch CERN, D. Alesini INFN-I
◇ WG5	RF Power sources	I. Syratchev CERN, G. Burt STFC-UK, M. Jensen ESS-S
◇ WG6	LLRF, AI, ML	Z. Geng PSI-CH, W. Cichalewski U-Lodz-P

GOAL

Per year: 10 M€, 90 FTE (nominal, ~30% higher than actual - ref. Accelerator R&D strategy)

SRF Cavities: reduce operational cost (Q_0 ↑) and capital cost (E_{acc} ↑)



NEEDS:

Higher E_{acc}

ILC – higher E_{acc} ⇒ **smaller linac** (= lower capital **cost**)
MC – **quick acceleration** (vs μ-lifetime)
FCC – **fewer cavities** ⇒ smaller RF installation

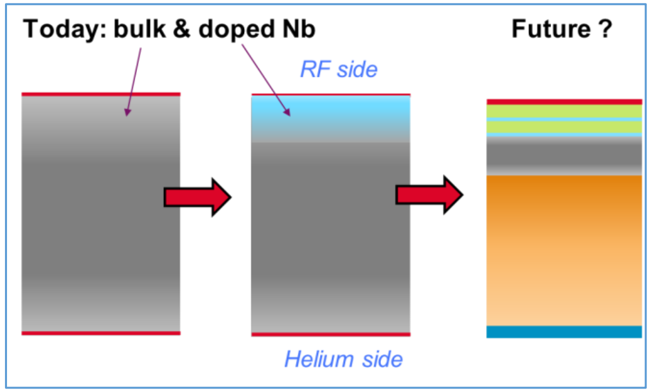
Higher Q_0

FCC, ERL, ILC – lower RF losses, **cryogenic power minimised**.
Others: Reproducibility, cost, industrial manufacturing

Cavity types – mostly elliptical: 1.3 GHz (3.9 GHz), 802 MHz (401 MHz), 704 MHz (352 MHz), 650 MHz (325 MHz).

(mature)

Niobium (T_c=9.2K, T_{cryo}= 2K is mandatory)
E_{acc} > 40 MV/m, Q_0 > 10^{10}
Theoretical limits close? ≤ 57 MV/m s.h. ….



(R&D goal)

Thin films (higher-T_C materials)
E_{acc} x 2 higher than Nb (**≤100 MV/m**); Q_0>10^{10} at **T_{cryo}=4.2K**
(**66% saving in $P_{ele,cryo}$**) – **40% cryo-plant cost saving** (cryocoolers?))

WG1 –Bulk Nb Cavities

M. Baylac (IJCLab), C. Madec (CEA) and L. Monaco (INFN)

1.`Further increase **Q and E_{acc}**: surface polishing, treatment (N doping), low/mid/2-step baking, H degas).

2. Improve **reproducibility** of high-E_{acc} fields: **robots in clean room**, **in-situ** plasma **processing**.

3. Reduce the **cost:** Fine → Medium Grain

4. Risk of losing **manufacturing** capability?

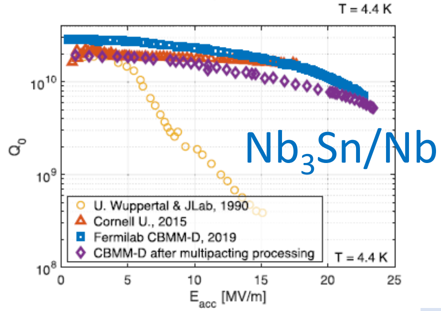
- **Maintain SRF technology skills** in both **labs & industry**.
- Invest in industrial processes (FCC – ~1000 cavities, ILC - 8000 cavities).

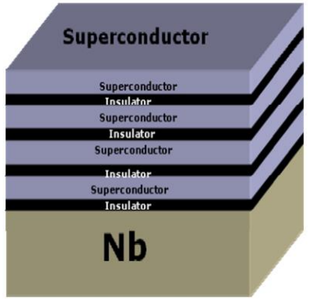
CERN (CH), CEA and IJCLab (F), DESY, HZB, Hamburg-Uni (D), INFN (LASA, LNF, LNL), STFC (UK)

WG2 – Thin film Cavities

C. Antoine (CEA) and O. Malyshev (STFC)

Goals: high Q_0 @ 4.2K; much higher E_{acc}.





A15 materials: Nb_3Sn-on-Nb (USA). **Nb_3Sn-on-Cu** (**IFAST EU project**, on going)

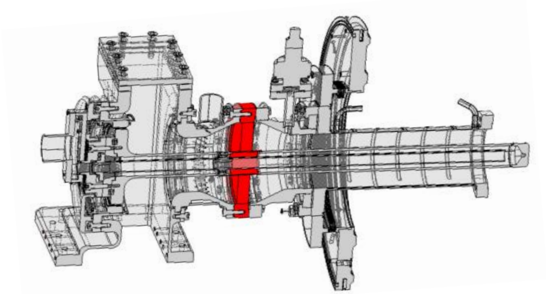
SIS (multi-layer): higher performance, less defect-sensitive (sample→cavity, CEA).

Cu cavity base production R&D: spinning (CERN, INFN), **3D-printing**; **Cu-surface preparation**.

CEA-Saclay, CERN, HZB, HZDR, INFN, STFC, USI, Hamburg U. (DESY), (I.FAST-WP) JLAB, KeK and FNAL

WG3: Fundamental Power Couplers (FPC) and HOM

F. Gerigk (CERN), A, Neumann (HZB) and E. Montesinos (CERN)



Transmitting **hundreds of kW (W's** in the cold mass) reliably **through thin ceramic windows** (diameter ~ 5÷ 50 cm) **into SRF cavities**.

FCCee (Z→W,H → ttb modes): 112→864 couplers, CW, 400-800 MHz, **P = 165 - 900 kW**

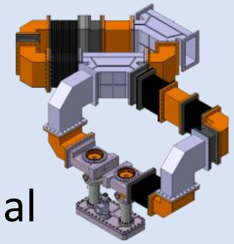
MC (SC driver, NC RF, SC RCS): 250, 7000, 4500 couplers, dc 0.05% → 4%, 325-1300 MHz, **P = 100 - 4000 kW**

(for ILC and CLIC: FP specs achieved)

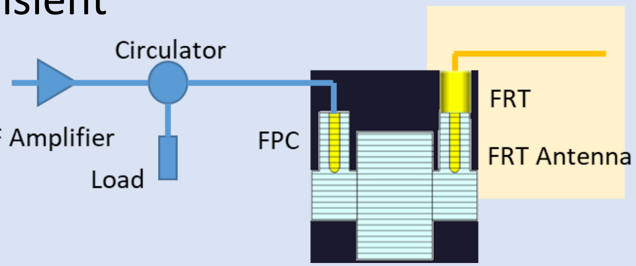
HOMs couplers (see iSAS proposal): R&D on 800, 1300 MHz multicell; ~ kW RF power out of the cold mass

1. Ceramic window! No leak allowed vs. cavity and entire machine, low losses at operating f and T, but brazed, low T-gradient

2. CERN SPS **resonant ring**



3. Fast Reactive Tuners (potential game changer for tuning, transient beam loading, microphonics)



FABRICATION CAPABILITIES, TEST STAND

CERN: **for future colliders, long-term expertise**; couplers for Soleil, ESRF, PERLE, … - **CEA**: couplers on request for XFEL, ESS

DESY: 1.3 GHz CW couplers **RI company**

EIC (USA): couplers with **challenging specs**, developments will **benefit next colliders**.

WG4: HG Normal-Conducting RF

W. Wuensch (CERN) and D. Alesini (INFN)

CLIC

- **HG (70 to 100 MV/m),** X-Band with **very low breakdown rate,** key for **cost** (linac length) and **efficiency** (BD).
- **Good alignment** mitigates **HG/BD interplay (**wakefields)**.**

Muon Collider

- Muon capture: **HG with high external magnetic field**.

FCC-ee 20 GeV **NC injector; FCC-hh E-separators (**S and C-Band).

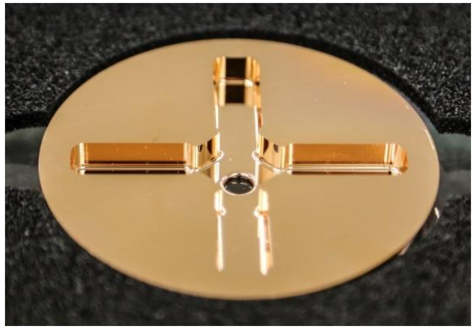
Synergic with applications outside HEP (60 - 70 MV/m)

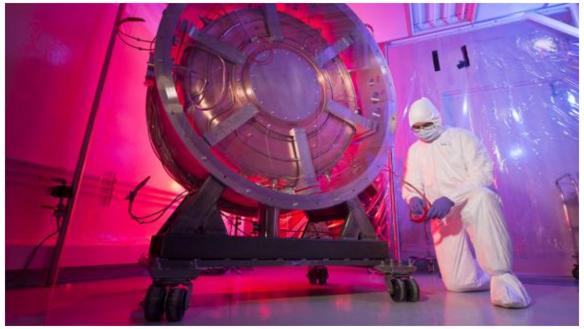
Operational test infrastructures: CERN (n.3, 50 MW, 12 GHz), **Trieste** (45 MW, 3 GHz), **Valencia** (7.5 MW, 3 GHz), **Frascati** (50 MW, 12 GHz), **Uppsala** (cryo pulsed DC sys)

X-band linearizers and deflectors: PSI, DESY, STFC

Linac design, operation: INFN (Roma and LNF), CERN, PSI, Eindhoven, Elettra, Medical VHEE, FLASH

- **Achieved: Gradient; understanding** of fundamentals physics; **industry** on NC RF components/systems; **synergies** (XFEL, Eupraxia, ICS, medical, plasma accelerator, RFQ, …)
- **Generated: dielectric structures**, short pulse acceleration and HT superconductors.
- **Required: systems engineering, integration**, mechanics R&D, design, **μm-level alignment.**
- **Fundamentals of breakdown**: on materials, plasma, surface physics, …





WG5: High Efficiency Amplifiers

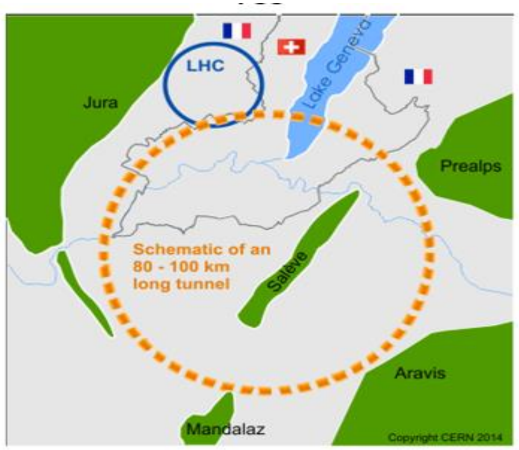
I. Syratchev (CERN), G. Burt (Lancaster U) and M. Jensen (ESS)

- **High efficiency RF power sources** for future large-scale particle accelerators (**LHC** and **FCC$_{ee}$** first)
- **In collaboration with industry to secure** to ensure decades of industry support.

Only large projects can afford R&D costs and risks, which benefit many applications; for small labs energy savings are not worth R&D investment.

Klystrons (**CERN, Lancaster,** ESS, CEA): **R&D expensive, today done solely with industry (3 qualified vendors!)**. 50-100% cost increase in last ~5 yrs. **SSPA** (**CERN, Uppsala, CEA Saclay, INFN-Legnaro, NCBJ (Swierk), CIEMAT**): **industry on transistor (and** η) **R&D**; **labs** contribute with **combination/matching** techniques

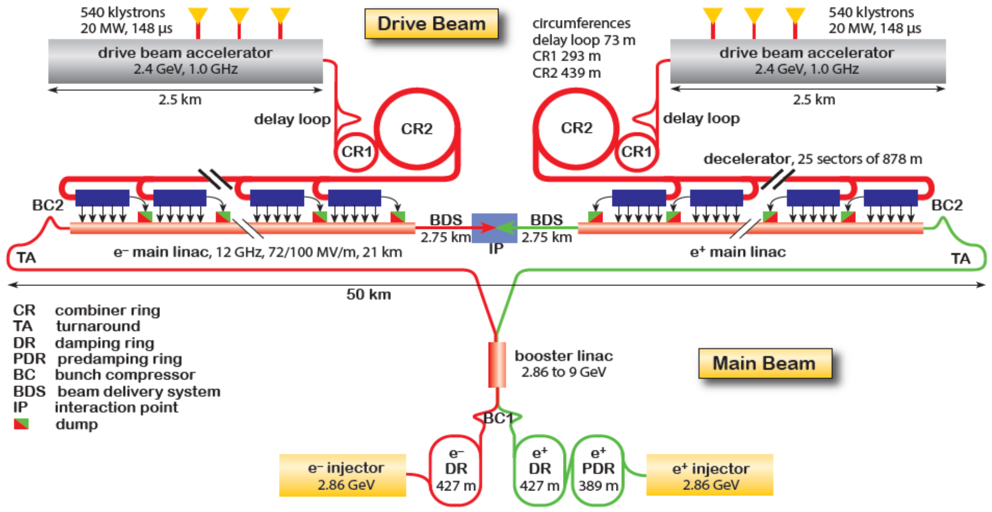
FCCee



FCC ee: CW, 0.4/0.8 GHz, P_{RF} total= 110 MW

105 MW

from **380** klystrons and **600** SSPAs



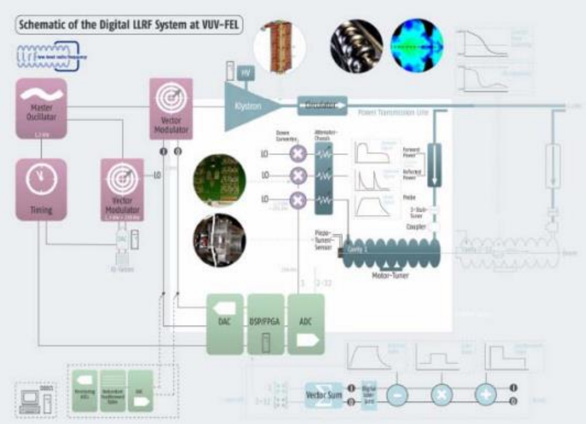
3.0 TeV CLIC^{e+e-} ; pulsed, 1.0 GHz, $P_{RF,\ total}$ = **180 MW**

WG6: RF Control – LLRF, ML and AI

G. Zheqiao (PSI) and W. Cichalewski (DMCS)

Comprehensive, intelligent, highly automated, and standardised LLRF system is essential for the success of the RF systems of future colliders.

- **Accelerator sections** with **different beam patterns** and f_{RF} high-level AI automation/optimisation.
- **ILC/FCC/MC SC RF cavities** → RF **control vs. vibrations and heavy BL**
- **Lower energy consumption** → **RF/operation control**
- **Long construction and operation cycles** → **optimal architecture** and framework suited for long-term standardised HW/SW



RF stability figures achieved! (FEL specs ~ 0.01 % amplitude and 0.01° phase; ILC: 0.07 % and 0.24°); real-time stabilization with AI automation/optimization alogorithms (telecom industry providing high-res fast ADCs and high-performance DSPs.

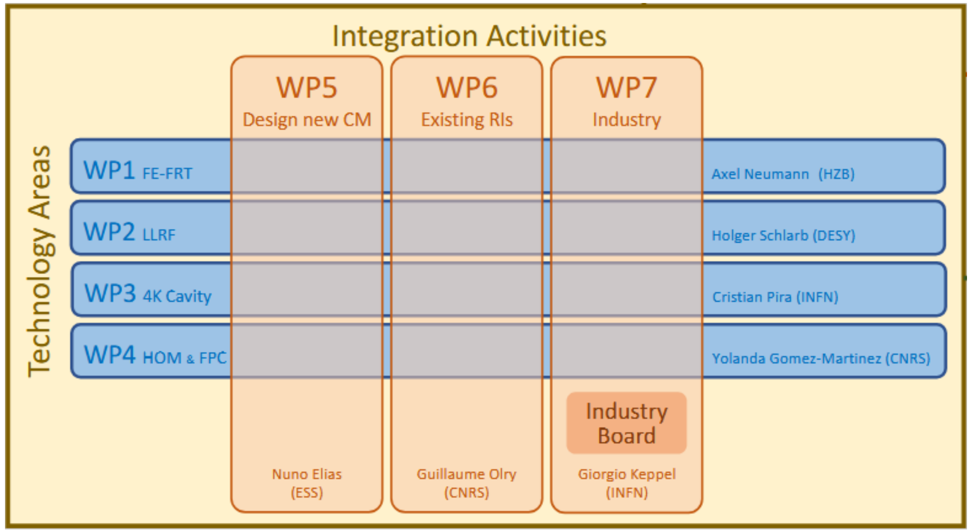
Availability, reliability and operability (FCC, ILC, MC, …) with **many RF stations & cavities** (ILC, > 560 RF stations and 14500 cavities), **ML algorithms** will decrease operation/maintenance costs.

Standardise LLRF system design and gain **long-term industry support to labs** (**HW/SW platforms** like VME, ATCA to MicroTCA, System-on-Chip): it will **facilitate in-kind** for large scale projects

RF-to-ERL Panel link

M. Baylac (CNRS)

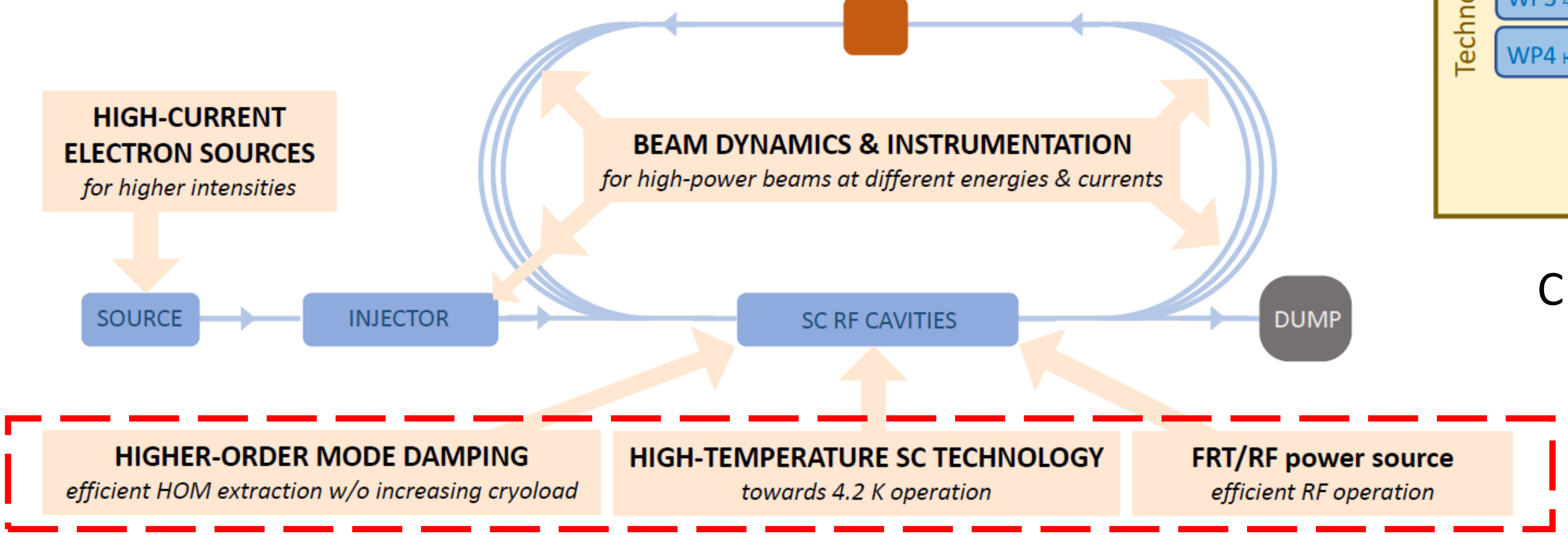
ERL/RF Panel collaboration: iSAS project 1000 person*months, 12.6 M€, 4 years (Approved July 10, 2023, Start March 1, 2024):



Identified the key aspects for an Energy Recovery accelerator

towards high-energy & high-intensity beams to be used at particle colliders

The Development of Energy-Recovery Linacs
arXiv:2207.02095, 237 pages, 5 July 2022



RF items

CNRS, CERN, ESS, DESY, VUB, CEA, HZB, INFN

(**WG2**-Thin films, **WG3**-Couplers, **WG5**-Power Sources, **WG6**-LLRF, ML and AI)

RF-to-MC link: high E_a in high B

G. Burt (STFC)

(**WG4**-NC High Grad, **WG5**-Power Sources)

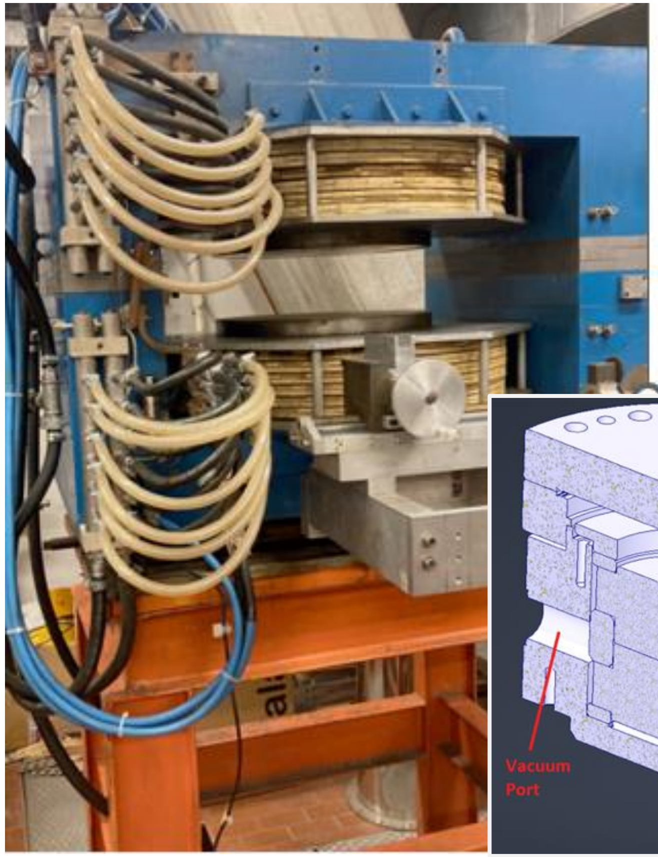
Study of RF breakdown (BD) under strong magnetic fields for muon ionisation cooling

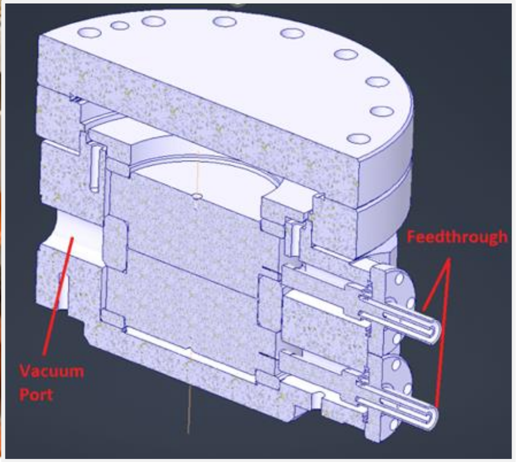
So far (FNAL): 50 MV/m at 3 T

Four test stands being considered:

- ✓ **UHF test facility** (CEA)
- ✓ **Higher frequencies - 3 GHz, 12 GHz** (INFN, CERN and Cockcroft): smaller, quicker, act as guideline
- ✓ **DC field breakdown test stands** (CERN, Cockroft, Uppsala): cheaper, compact, short gap
- ✓ **New compact klystrons** (with WG5)

MC/RF Panel coordination → survey sent to each institute involved, responses awaited on capabilities and physics targeted by each facility; joint meeting to follow





Outlook - Progress of the LDG RF Panel

Nov22 – Mar23: watch future collider needs and RF goals

From Apr23:

✓ Outreach (Community Forum-July 2023; special session at HG2023), **priorities revised**

\+

Apr23 – Oct23:

✓ Who is doing what/**progress on the Roadmap milestones: survey of national teams**

✓ Continue coordination with ERL and MC panels

=

Jan-Jun 24:

✓ **Coordinate teams vs priorities, explore funding routes: national and EU**

✓ Zoom meeting with RF coordinators in **Snowmass-P5** (February 2024)

✓ **Promote RF developments/needs** towards HEP-physicists and funding agencies

✓ Idea, a superWP on RF in **I.FAST2** ← EU funds, national matching funds, more cohesion in the RF community at large

Jul-Dec 24, … : **report on progress** in the field and impact of above actions

Spare slides

Outlook - lobbying for more funds

How to address the funding agencies after the survey?

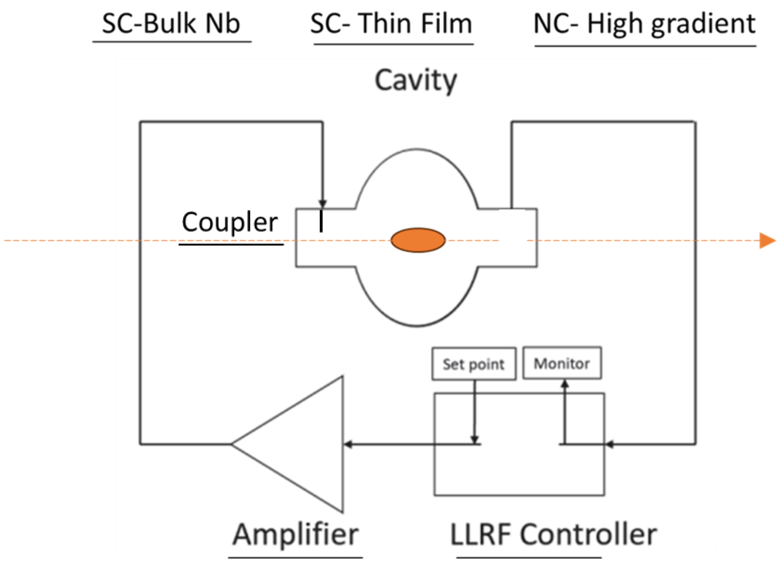
- ✓ Highlight **priority areas;** identify **best lab candidates to address them**
- ✓ Elaborate a **overall investment proposal**
- ✓ Coordinate within the **extended-LDG** on the overall **fund requests** to the funding agencies

«IFAST-2»

Initial contacts to develop a **super-workpackage** clustering several R&D activities **in RF** (*now in I.FAST: thin films, HE power sources, C-guns, AM*).

- ✓**Additional funds** for RF by EU
- ✓National FAs to add **matching funds**.
- ✓**It encourages** RF coordination across Europe → **one** community

Outlook



Done:

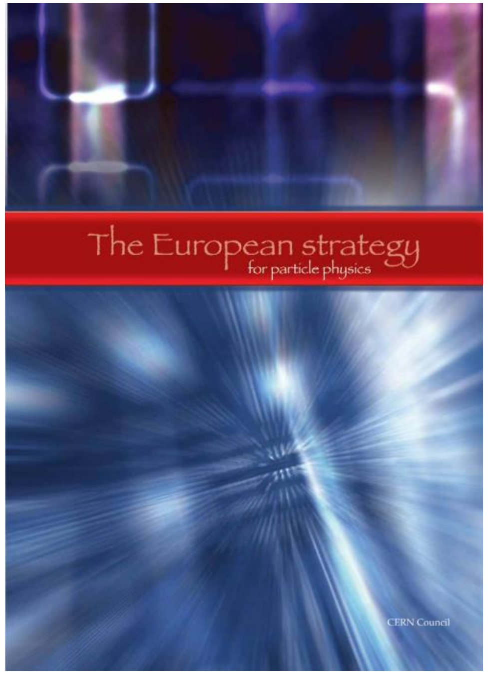
- Future collider RF needs well focused
- European contributing teams identified, along with available infrastructures; Progress/challenges in RF theme areas followed up

Next:

- The Nov-2023 progress report to the CERN council, as basis for periodic updates
- Correlate needs - candidate labs to fulfill them → coordinate (at LDG level) towards national funding agencies
- Elaborate on a super-RF-WP in the "I.FAST2" proposal

European Particle Physics Strategy and its updates

"(…) cornerstone of Europe's decision-making process for the long-term future of the field. Mandated by the CERN Council, it is formed through a broad consultation of the grass-roots particle physics community (…) and it is developed in close coordination with similar processes in the US and Japan (…)"



Strategy 14 July 2006

Update 30 May 2013

Update 19 June 2020

European Strategy Group (ESG)

- ✓ **Chairperson**
- ✓ 1/CERN Member State,
- ✓ 1/lab of the major European Laboratory Directors' Group, **LDG**
- ✓ CERN Director-General,
- ✓ SPC Chairperson,
- ✓ ECFA Chairperson.

Invitees:

- ✓ President of the CERN Council,
- ✓ 1/Associate Member States,
- ✓ 1/Observer State,
- ✓ 1/European Commission, JINR
- ✓ Chairs of ApPEC, FALC, ESFRI, and NuPECC
- ✓ Members of Physics Prep Group

European Laboratory Directors Group (LDG)

Remit by CERN Council:

- Dialogue among Lab Directors and CERN
- Input to the ESPP, liaise with EU Commission and national funding agencies, institutes and universities
- Maximise national benefits of investment in fundamental research and in CERN
- Look at activities outside CERN's Member States, and of other groups in PP and related fields
- Draw up and maintain a **prioritised accelerator R&D roadmap** towards future large-scale facilities for PP
- **Coordinate the accelerator R&D activities on the roadmap, until the next SU**

- S. Bentvelsen (NIKHEF)
- F. Bossi (LNF)
- J. Clarke (DL)
- N. Colino (CIEMAT)
- F. Gianotti (CERN)
- B. Heinemann (DESY)
- D. Newbold (RAL)
- E. Previtali (LNGS)
- F. Sabatie (IRFU)
- M. Seidel (PSI)
- A. Stocchi (IJCLab)

Standing observers

- K. Jakobs (ECFA Chair)
- M. Lamont (CERN Directorate)
- J. Mnich (CERN Directorate)
- H. Montgomery (SPC Chair)

Secretary

- E. Tsesmelis (CERN)

Extended LDG members

- G. Bisoffi (**for RF**) + P. Macintosh
- W. Leemans (**for LPA**) + R. Patahill
- S. Stapnes (**for Muons**) + D. Schulte
- J. D'Hondt (**for ERL**) + M. Klein
- P. Vedrine (**for HFM**) + M. Lamont

European Strategy Update and Accel R&D

Key questions during the 2020 Strategy Update on **R&D for future collider options**:

- What R&D? which priorities?
- How long might it take? How much will it cost?
- Which science with demonstrators, or intermediate-scale facilities?
- Which new infrastructures?

Large-scale **accelerator R&D** plan to inform and support future decision-making in the field

1. HF magnets
2. HG RF structures and systems
3. HG plasma and laser accelerators
4. Muon colliders,
5. Energy Recovery Linacs

⇒

Superconducting RF: bulk niobium cavities, surface preparation, thin films

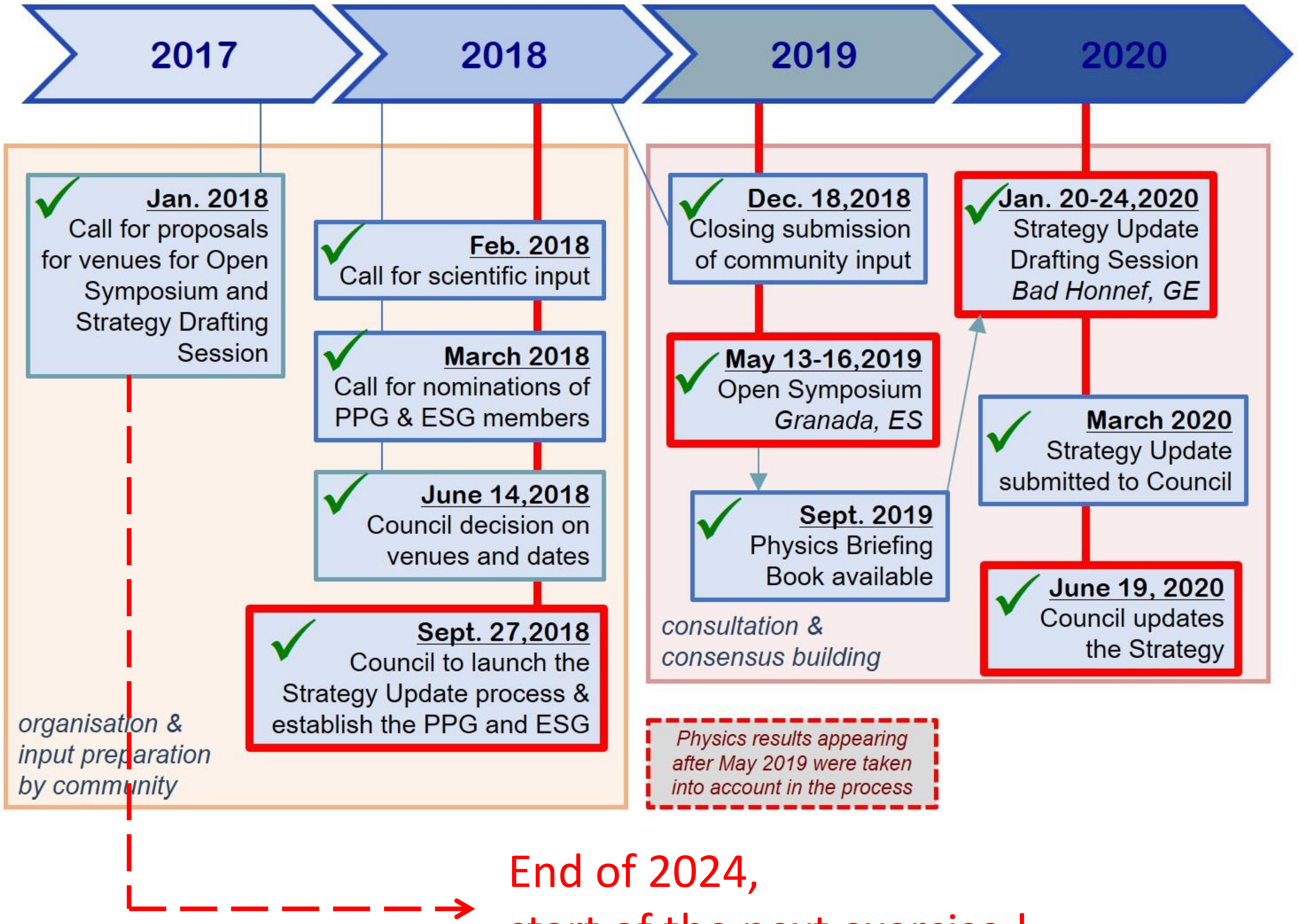
NC structures: fundamental limitations, surface preparation, manufacturing techniques

High power RF sources, accelerating structures ancillaries (couplers, tuners…), LLRF and AI

Authors of RF R&D strategy:
S. Bousson (IJCLab), Hans Weise (DESY). G. Burt (Lancaster University); G. Devanz (CEA); A. Gallo (INFN LNF); F. Gerigk (CERN); A. Grudiev (CERN); D. Longuevergne (IJCLab); T. Proslier (CEA); R. Ruber (Uppsala University), plus added experts

European Paricle Physics Strategy *Update*

→ 2020÷2027



End of 2024,
start of the next exercise !

CERN Council: decision making body, coordinating particle physics in Europe (23 Member States)

Example: INFN-Projects for ESPP Accelerator R&D

1. Damping Ring and Transfer Lines for FCC-ee Injector
2. FCC-ee IR and MDI full-scale experimental validation
3. Muon Collider R&D activities
4. High-Q/high-G SRF R&D
5. SRF R&D for FCC-ee
6. HFM Italy
7. GANDALF (GaN-baseD AmpLiFier)

Approved (*) [items 2–5]

On-hold [items 6–7]

(*) Allocated funds (for **3 years**, 2023-2026): **4929 k€**

- 2125 k€ (of which RF: 1730 k€)
- Temporary personnel 552k€ p (of which RF: 288 k€)
- 2252 k€ staff

US Snowmass Implementation Task Force: Th. Roser, R. Brinkmann, S. Cousineau, D. Denisov, S. Gessner, S. Gourlay, Ph. Lebrun, M. Narain, K. Oide, T. Raubenheimer, J. Seeman, V. Shiltsev, J. Straight, M. Turner, L. Wang et al.

International MUON Collider Collaboration

	CME [TeV]	Lumi per IP [$10^{34}cm^{-2}s^{-1}$]	Years to physics	Cost range [B$]	Power [MW]
FCC-ee	0.24	8.5	13-18	12-18	290
ILC	0.25	2.7	<12	7-12	140
CLIC	0.38	2.3	13-18	7-12	110
ILC	3	6.1	19-24	18-30	400
CLIC	3	5.9	19-24	18-30	550
MC	3	1.8	19-24	7-12	230
MC	10	20	>25	12-18	300
FCC-hh	100	30	>25	30-50	560

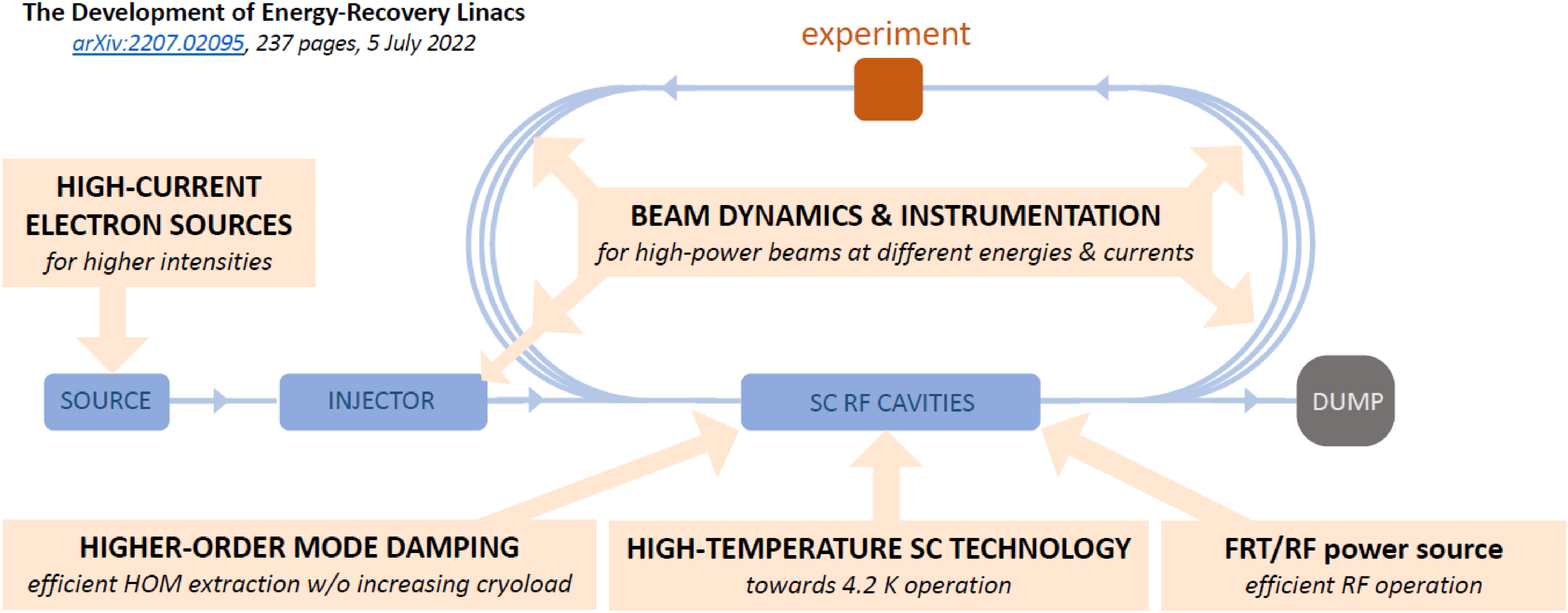
Judgement by ITF, take it *cum grano salis*

ERL RF topics

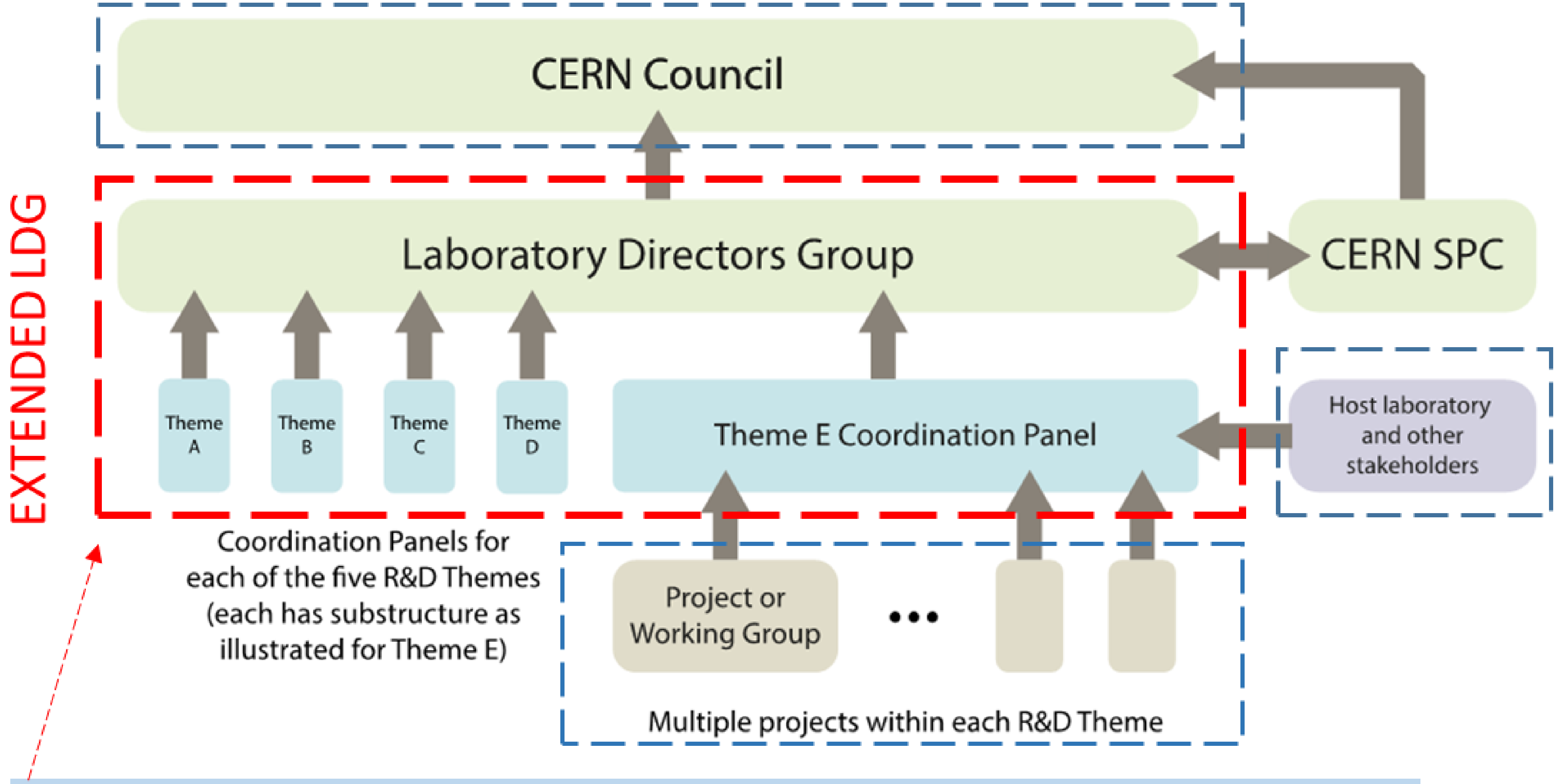
Identified the key aspects for an Energy Recovery accelerator

towards high-energy & high-intensity beams to be used at particle colliders

The Development of Energy-Recovery Linacs
arXiv:2207.02095, 237 pages, 5 July 2022



Extended LDG role



The RF Coordination Panel is one of the Theme Coordination Panels A-E