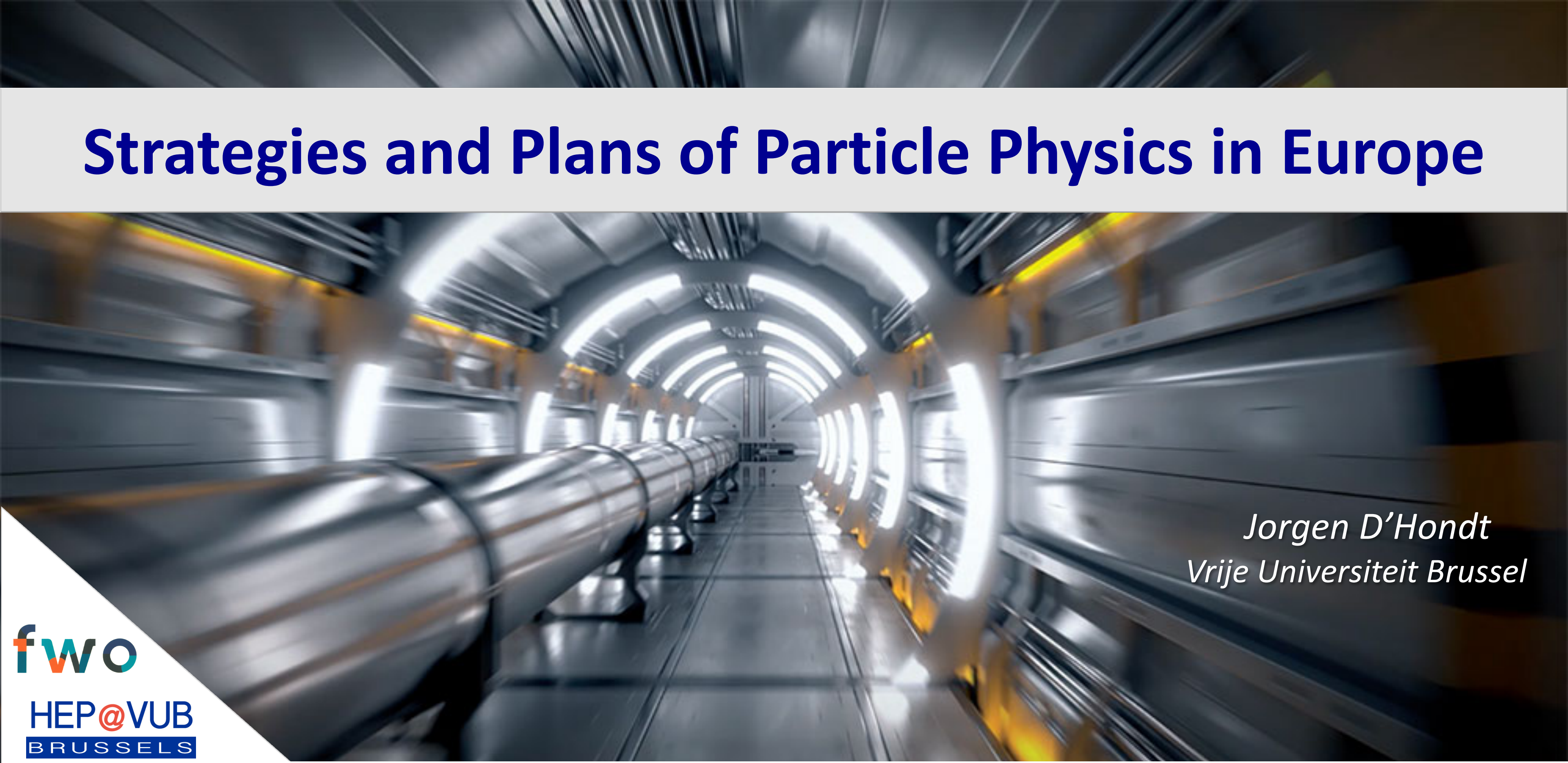
Strategies and Plans of Particle Physics in Europe

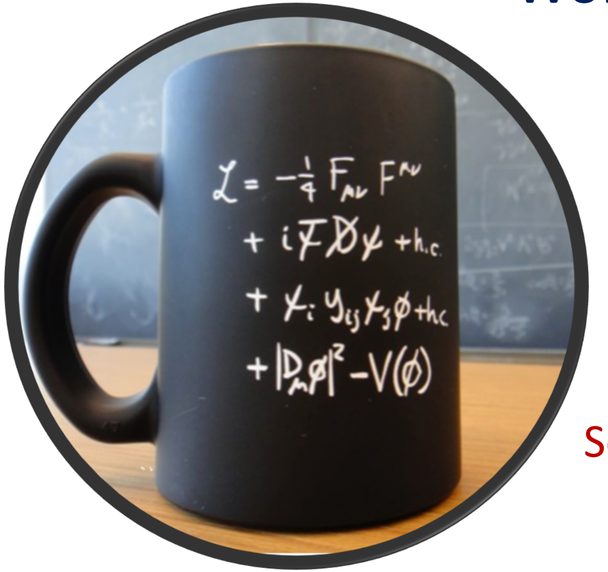


Jorgen D'Hondt
Vrije Universiteit Brussel

HEP@VUB BRUSSELS

Meeting of the Spanish network for future colliders, 6-7 Oct 2020

The quest for understanding particle physics



Picture from Flip Tanedo @ Quantum Dairies

Wonderful description of fundamental interactions

e.g. The Standard Models of Particle Physics and Cosmology
together do not describe all our observations of the universe.

"Problems and Mysteries" [Riccardo Rattazzi]

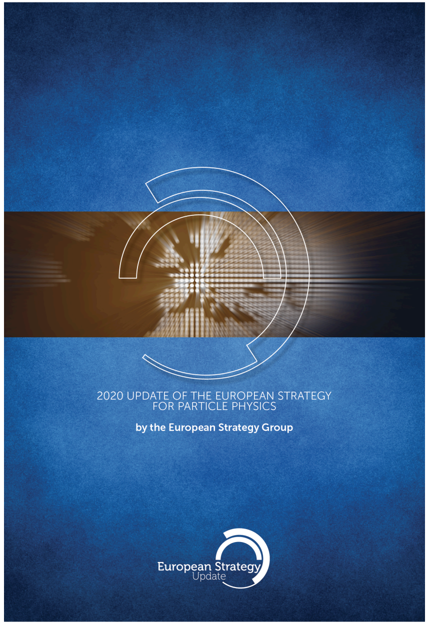
e.g. Abundance of dark matter?
Abundance of matter over antimatter?
Scale of things (EW hierarchy problem / strong CP problem)?
Pattern of fermion masses and mixings?
Dynamics of EW symmetry breaking?...

The search for new knowledge as guidance

Most recent European Strategies

the small …

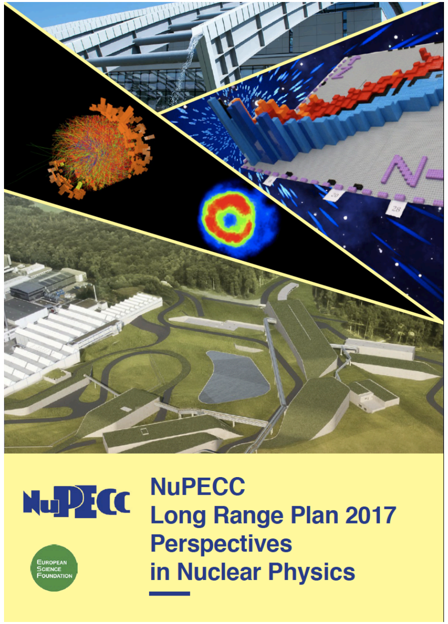
weblink



2020 Update of the European
Particle Physics Strategy

… the connection …

weblink



Long Range Plan 2017
Perspectives in Nuclear Physics

… the large

weblink

2017-2026 European
Astroparticle Physics Strategy

Most recent European Strategies

Community-driven strategies reflecting our coherent ambition to address the open questions in particle/nuclear/astroparticle physics and they serve as guidance for funding bodies to develop resource-loaded research programmes.

the small …

weblink

2020 Update of the European Particle Physics Strategy

… the connection …

weblink

Long Range Plan 2017 Perspectives in Nuclear Physics

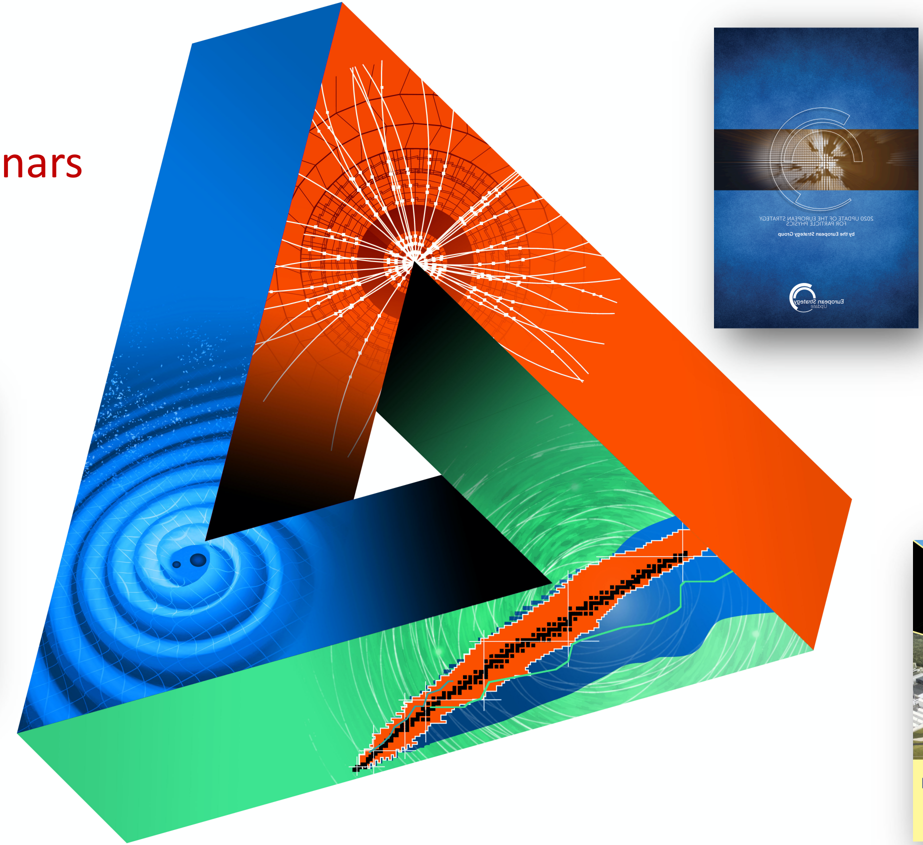
… the large

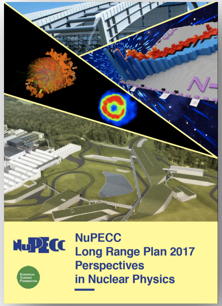
weblink

2017-2026 European Astroparticle Physics Strategy

Exploring and strengthening synergies

Initiated a series of
Joint ECFA-NuPECC-APPEC Seminars
(JENAS)



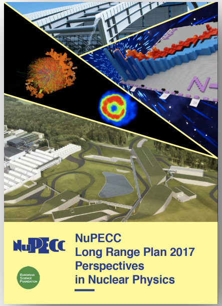


ECFA: European Committee for Future Accelerators
NuPECC: Nuclear Physics European Collaboration Committee
APPEC: Astroparticle Physics European Consortium
First JENAS event at Orsay, 2019: https://jenas-2019.lal.in2p3.fr

Exploring and strengthening synergies

Initiated a series of
Joint ECFA-NuPECC-APPEC Seminars
(JENAS)

ECFA: European Committee for Future Accelerators
NuPECC: Nuclear Physics European Collaboration Committee
APPEC: Astroparticle Physics European Consortium
First JENAS event at Orsay, 2019: https://jenas-2019.lal.in2p3.fr



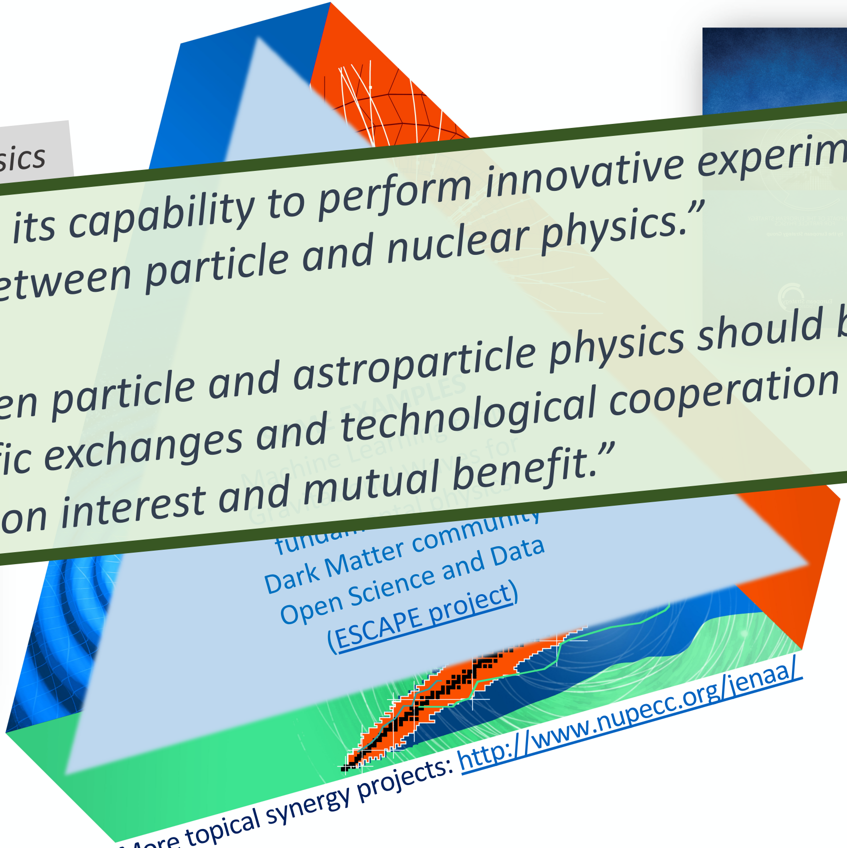
Exploring and strengthening synergies

Initiated a series of
Joint ECFA-NuPECC-AP

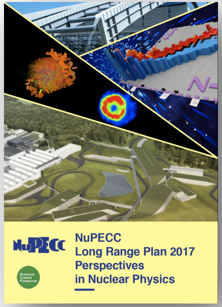
ESPP: European Strategy for Particle Physics

ESPP: “Europe should maintain its capability to perform innovative experiments at the boundary between particle and nuclear physics.”

ESPP: “Synergies between particle and astroparticle physics should be strengthened through scientific exchanges and technological cooperation in areas of common interest and mutual benefit.”



More topical synergy projects: http://www.nupecc.org/jenaa/

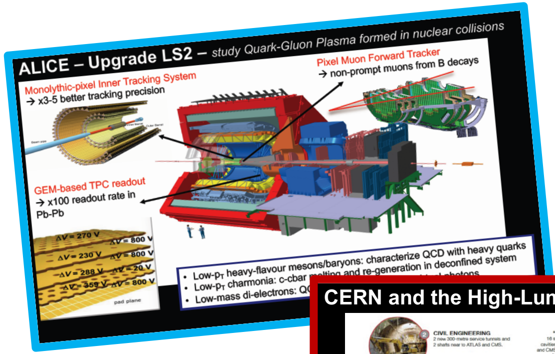


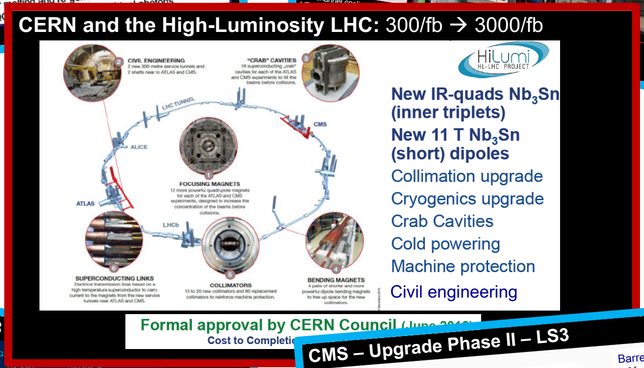
ECFA: European Committee for Future Accelerators
NuPECC: Nuclear Physics European Collaboration Committee
APPEC: Astroparticle Physics European Consortium
First JENAS event at Orsay, 2019: https://jenas-2019.lal.in2p3.fr

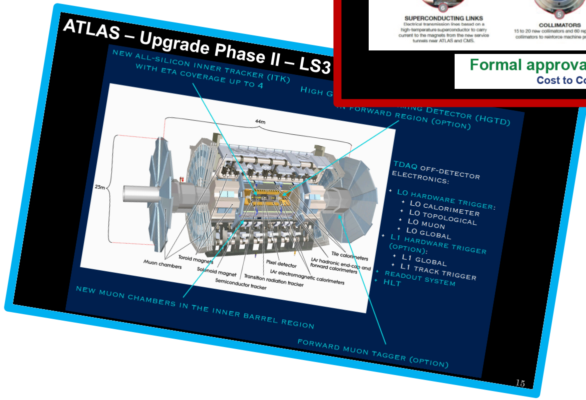
Today's Flagship: from LHC to HL-LHC

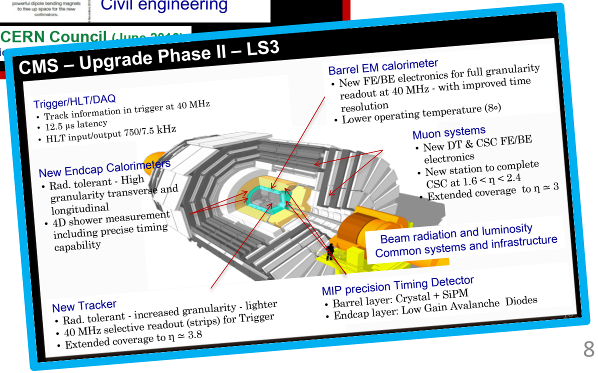
Current flagship (27km)

impressive programme up to 2040





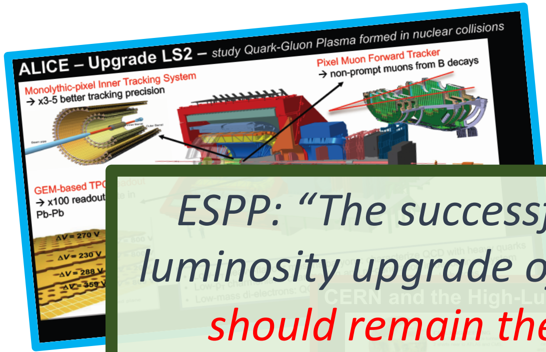


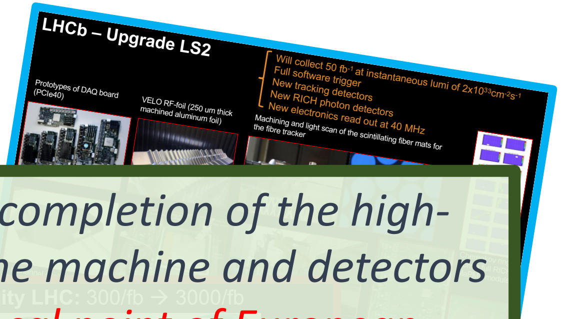


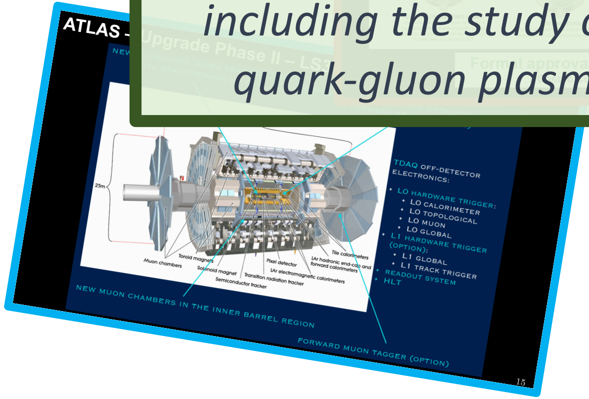
Today's Flagship: from LHC to HL-LHC

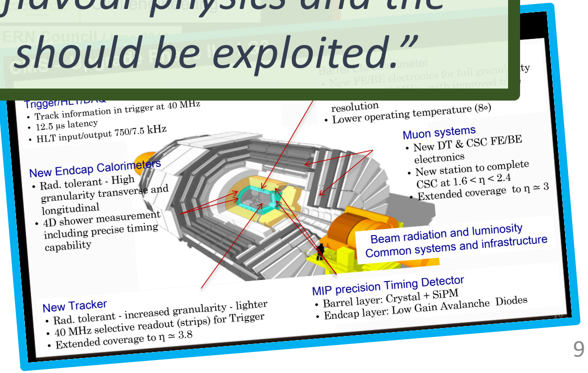
Current flagship (27km)

impressive programme up to 2040









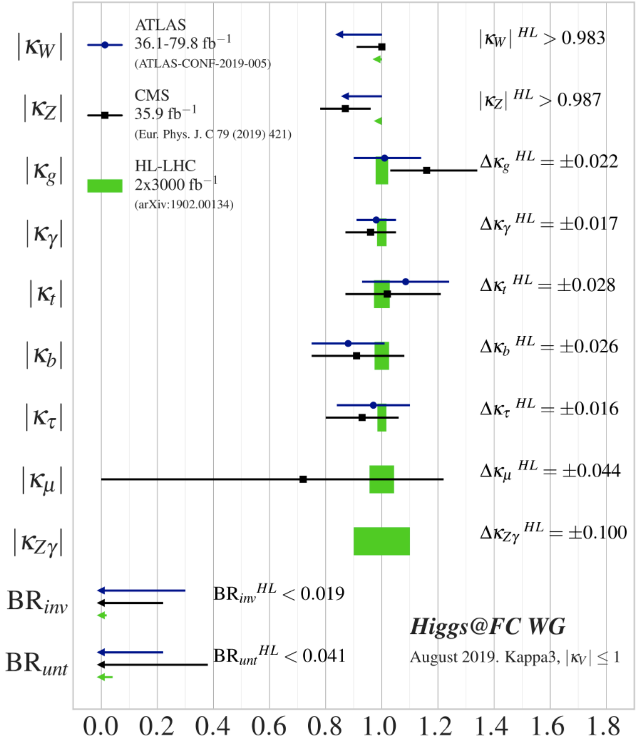
ESPP: "The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques. The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited."

Today's Flagship: from LHC to HL-LHC

Current flagship (27km)

impressive programme up to 2040

The Higgs couplings are expected to improve significantly with the HL-LHC data



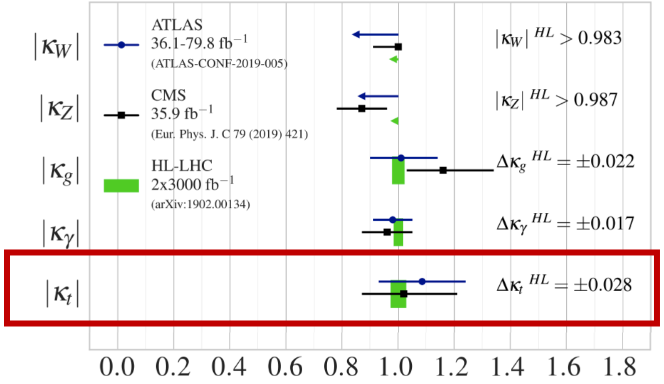
[Physics Briefing Book, http://cds.cern.ch/record/2691414]

Today's Flagship: from LHC to HL-LHC

Current flagship (27km)

impressive programme up to 2040

The Higgs couplings are expected to improve significantly with the HL-LHC data



[Physics Briefing Book, http://cds.cern.ch/record/2691414]

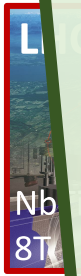
- The estimate made in 2013 for κ_t was a precision of 7-10% with 3000fb^{-1}, while now a value better than 4% seems reachable (for the same integrated luminosity)
- With only 6 years of experimental and theoretical innovations a factor of 2 improvement, and yet 20 years to go into the research program

Today's Flagship: from LHC to HL-LHC

Current flagship (27km)

impressive programme up to 2040

The Higgs couplings are expected to improve significantly with the HL-LHC data



ESPP: "Given the unique nature of the Higgs boson, there are compelling scientific arguments for a new electron-positron collider operating as a "Higgs factory". The vision is to prepare a Higgs factory, followed by a future hadron collider with sensitivity to energy scales an order of magnitude higher than those of the LHC, while addressing the associated technical and environmental challenges."

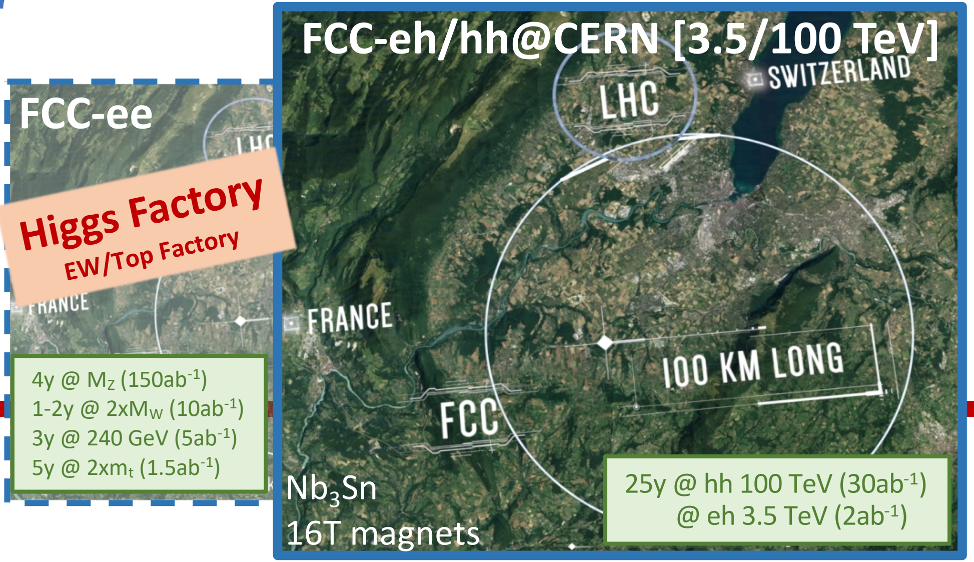
- With only 6 years of experimental and theoretical innovations a factor of 2 improvement, and yet 20 years to go into the research program

Colliders in Europe at the energy & precision frontier

Current flagship (27km)
impressive programme up to 2040

Big sister future ambition (100km), beyond 2040
attractive combination of precision & energy frontier

ep-option with HL-LHC: LHeC
10y @ 1.2 TeV (1ab^{-1})
updated CDR 2007.14491



numbers assume 2 IPs for each collider (only one for FCC-eh)

by around 2026, verify if it is feasible to plan for success (techn. & adm. & financially & global governance)

potential alternatives pursued @ CERN: CLIC & muon collider

Colliders in Europe at the energy & precision frontier

Current flagship (27km)

impressive programme up to 2040

Big sister future ambition (100km), beyond 2040

attractive combination of precision & energy frontier

ESPP: "Europe, together with its international partners, **should investigate the technical and financial feasibility of a future hadron collider at CERN with a centre-of-mass energy of at least 100 TeV and with an electron-positron Higgs and electroweak factory as a possible first stage.** 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."

ESPP: "**CERN should initiate discussions with potential major partners** as part of the feasibility study for such a project being hosted at CERN."

5y @ $2xm_t$ ($1.5ab^{-1}$)

Nb_3Sn
16T magnets

25y @ hh 100 TeV ($30ab^{-1}$)
@ eh 3.5 TeV ($2ab^{-1}$)

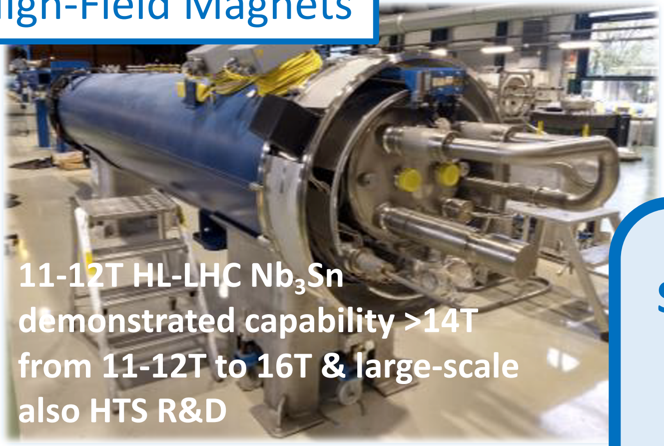
ep-option with HL-LHC: LHeC
10y @ 1.2 TeV ($1ab^{-1}$)
updated CDR 2007.14491

by around 2026, verify if it is feasible to plan for success (techn. & adm. & financially & global governance)

potential alternatives pursued @ CERN: CLIC & muon collider

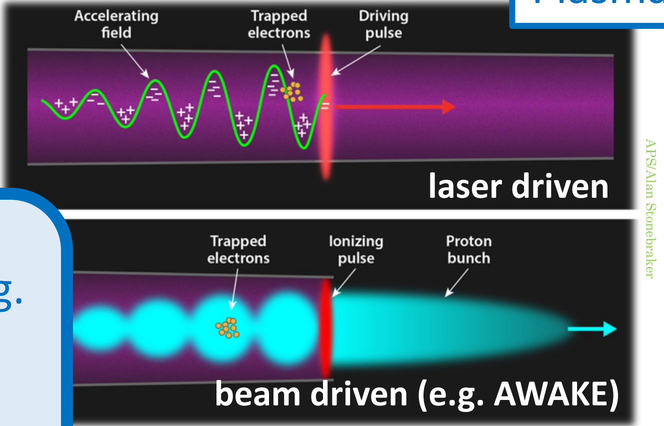
Advancing Accelerator Technologies

High-Field Magnets

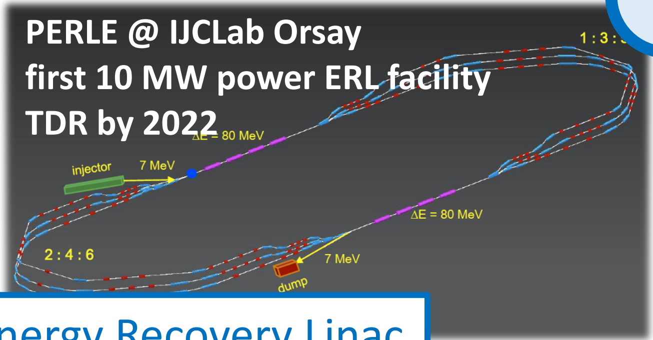


continue the development of CLIC accelerator technology and other high-gradient accelerating structures

Plasma

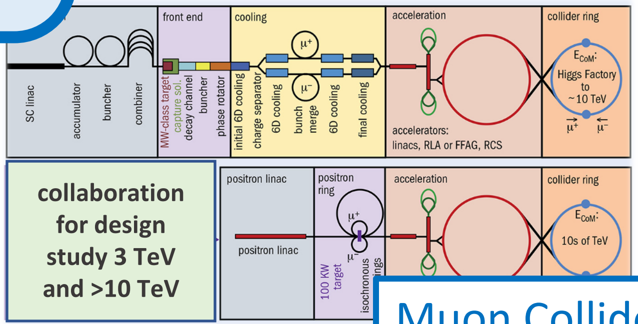


Strong EU support, e.g.
EuPRAXIA, EuroCircol, FCC IS, ARIES, EuCARD, EASITrain, E-JADE, …



Energy Recovery Linac

Accelerator and Detector R&D Roadmaps will be developed (2021)

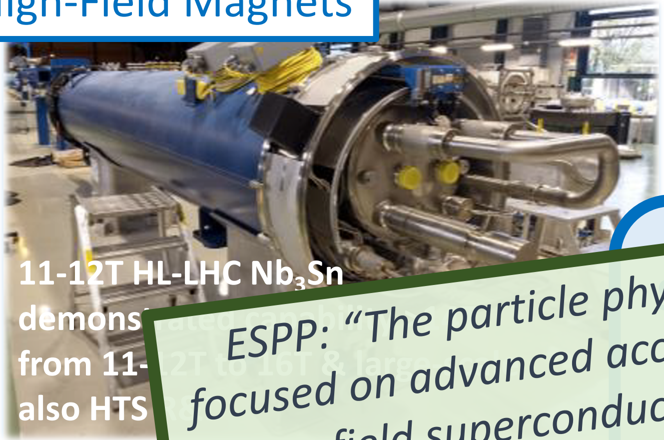


collaboration for design study 3 TeV and >10 TeV

Muon Collider

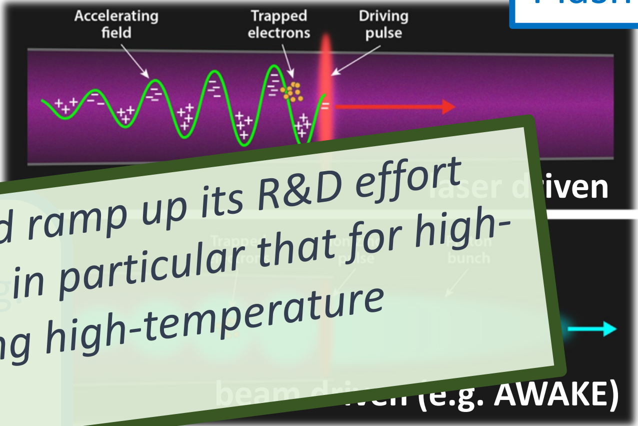
Advancing Accelerator Technologies

High-Field Magnets



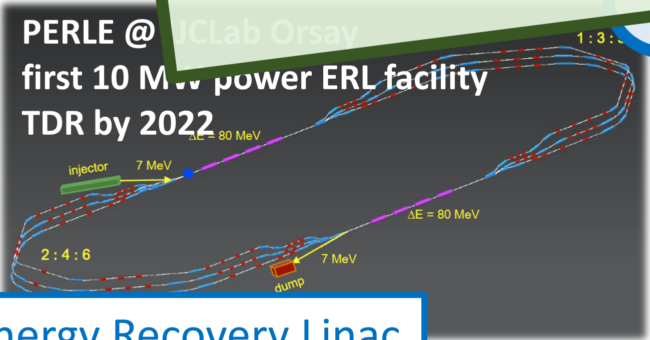
continue the development of CLIC accelerator technology and other high-gradient accelerating structures

Plasma



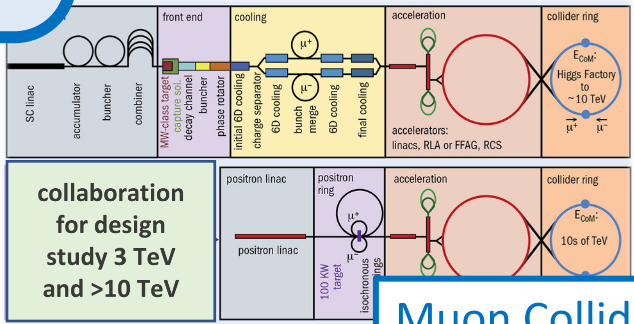
ESPP: "The particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors ."

Energy Recovery Linac



Accelerator and Detector R&D Roadmaps will be developed (2021)

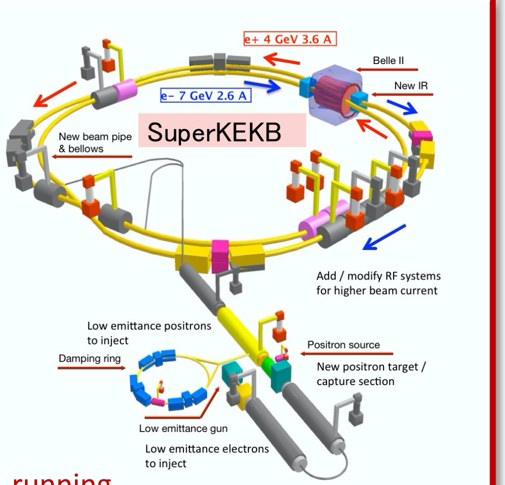
Muon Collider



Europeans at current and future colliders elsewhere

B-factory with e^+e^- at Υ(4S)≈10.5GeV

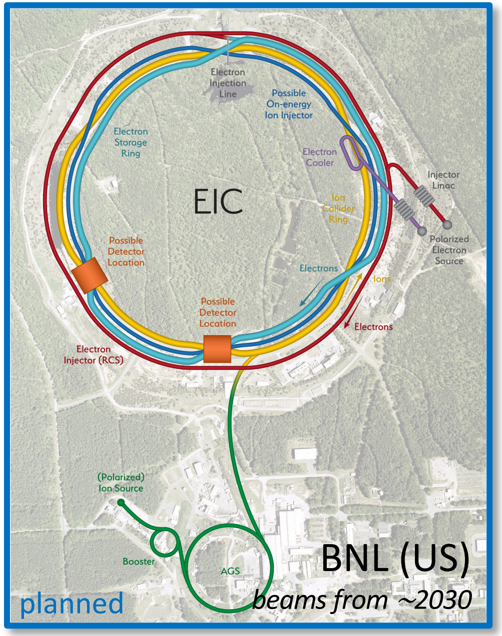
SuperKEKB (Japan)



running

Large European participation in the Belle II experiment

electron-ion collider



BNL (US)

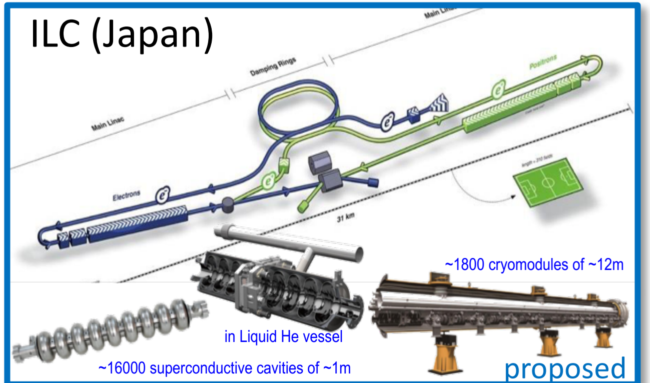
beams from ~2030

planned

Sizeable European fraction in the EIC User Community

e^+e^- Higgs Factory

ILC (Japan)

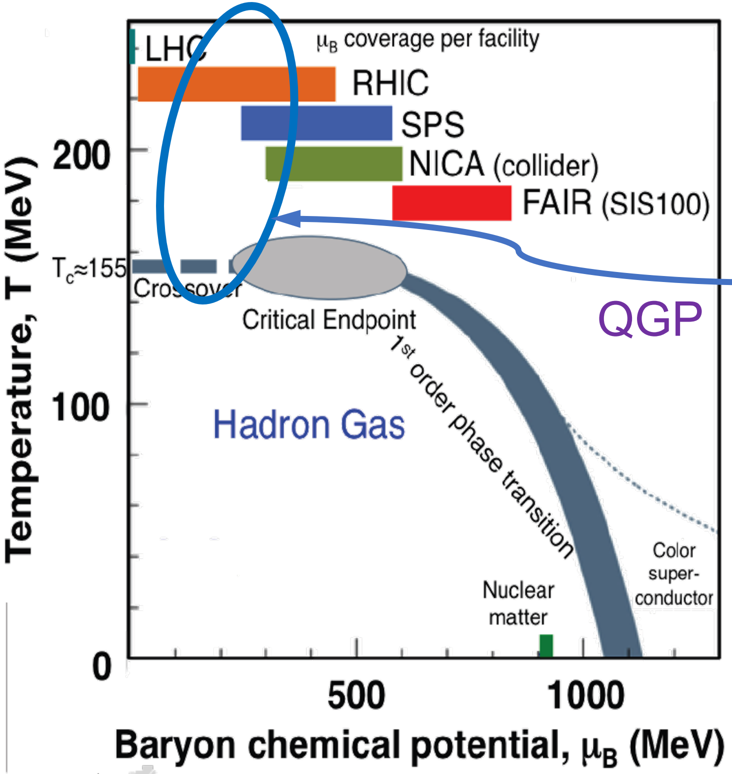


proposed

ESPP: "The timely realisation of the ILC in Japan would be compatible with [the European ambition for a the FCC programme] and, in that case, the European particle physics community would wish to collaborate."

China has plans for CepC/SPPC similar to FCC

Colliders & fixed-target facilities at the density frontier



BM@N *experiment being prepared at NICA (runs from 2021 onwards)*

Collider experiments @ CERN

- **HL-LHC**: higher luminosity provide new opportunities
- **FCC**: study the QGP at higher energy density and Temp

Fixed-target experiments @ CERN

- **SPS**: QCD at high-μ_B with NA61/SHINE and NA60+
- **(HL-)LHC**: at ALICE and LHCb the most energetic fixed-target experiments to reach quark/gluon high-x PDFs

Facilities @ JINR and FAIR

- **NICA @ JINR**: MPD experiment to start around 2023
- **SIS100 @ FAIR**: CBM & HADES experiments to start around 2025

Nuclotron-based Ion Collider Facility @ JINR

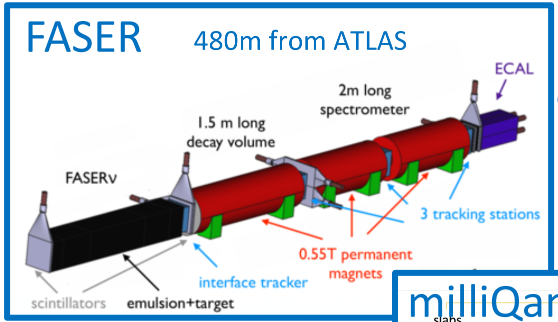
SIS100 @ FAIR

Colliders in Europe at the energy & precision frontier

Current flagship (27km)

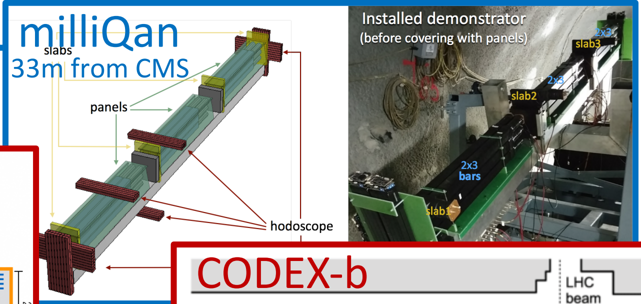
impressive programme up to 2040

Additional opportunities with high-energy proton collisions

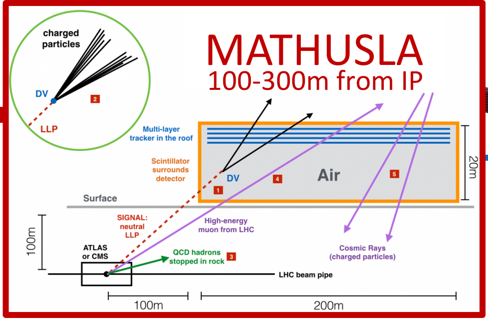


being installed

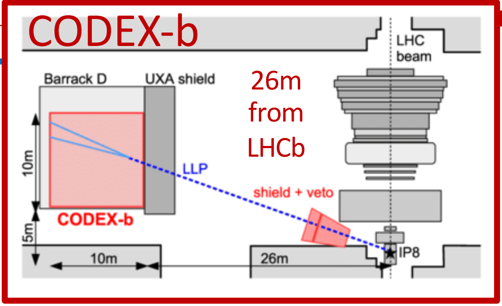
Long Lived Particles
Light & weakly coupling particles
Milli-charged particles
Magnetic Monopoles (MoEDAL)



being demonstrated



proposal

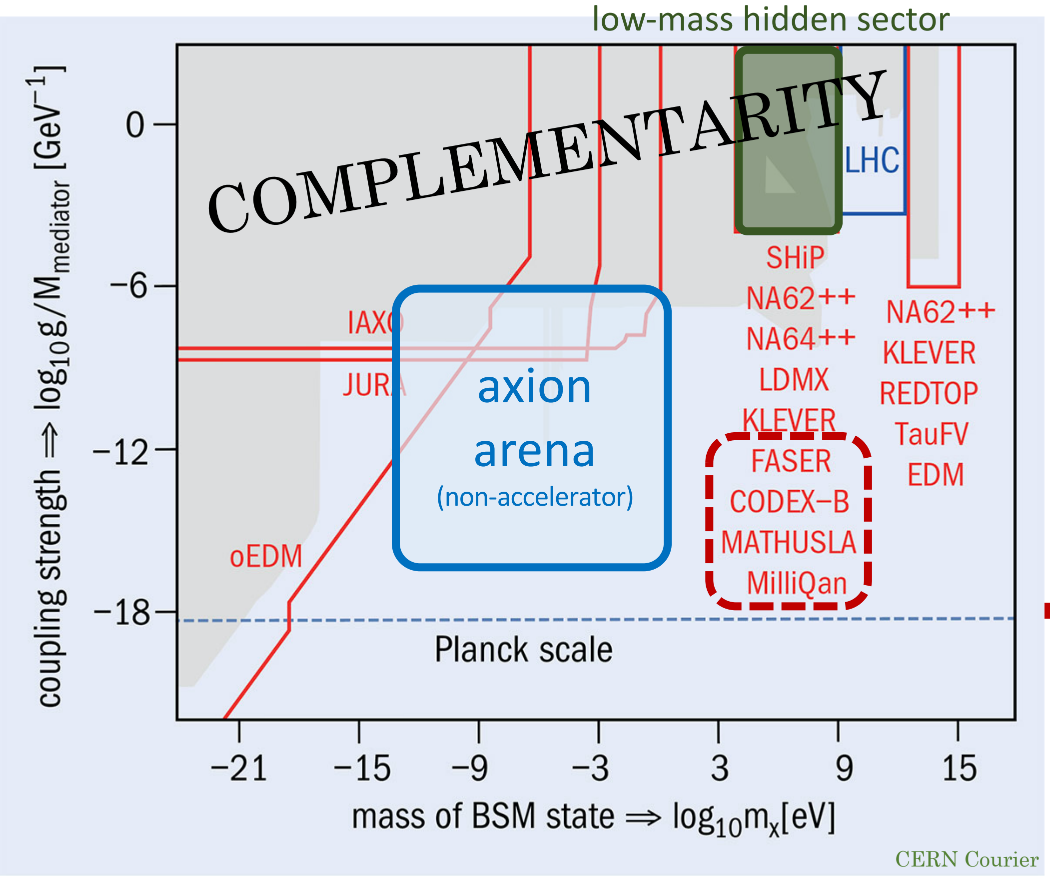


proposal

Colliders in Europe at the energy & precision frontier

Current flagship (27km)

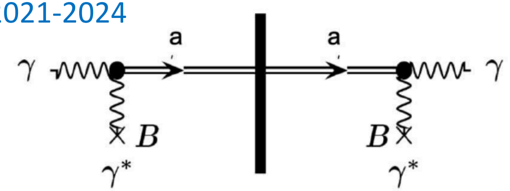
impressive programme up to 2040



"portal" representation of physics potential to demonstrate complementarity

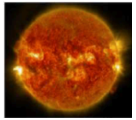
Axion Physics with “old” and new magnets in Europe

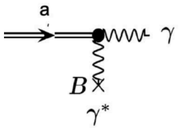
Light-shine-through-Wall
ALPS-II @ DESY
2021-2024

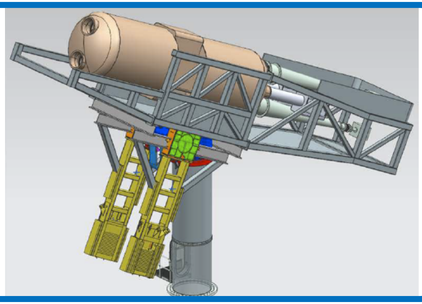


CAST @ CERN
(helioscope)
running

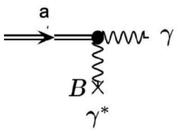
BabyIAXO & IAXO @ DESY
looking at the Sun, helioscope
2024-2030+

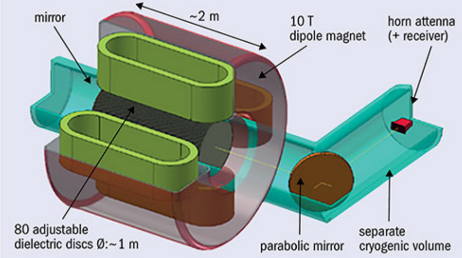


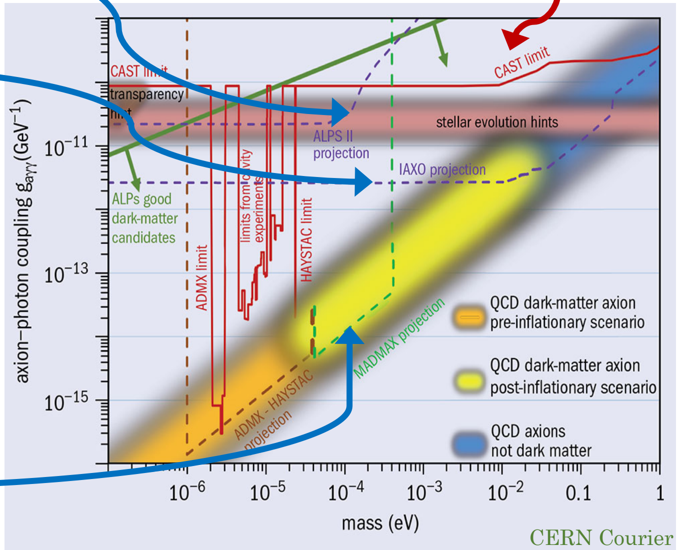




MADMAX @ DESY
looking at the galactic halo, haloscope
2026-2030+

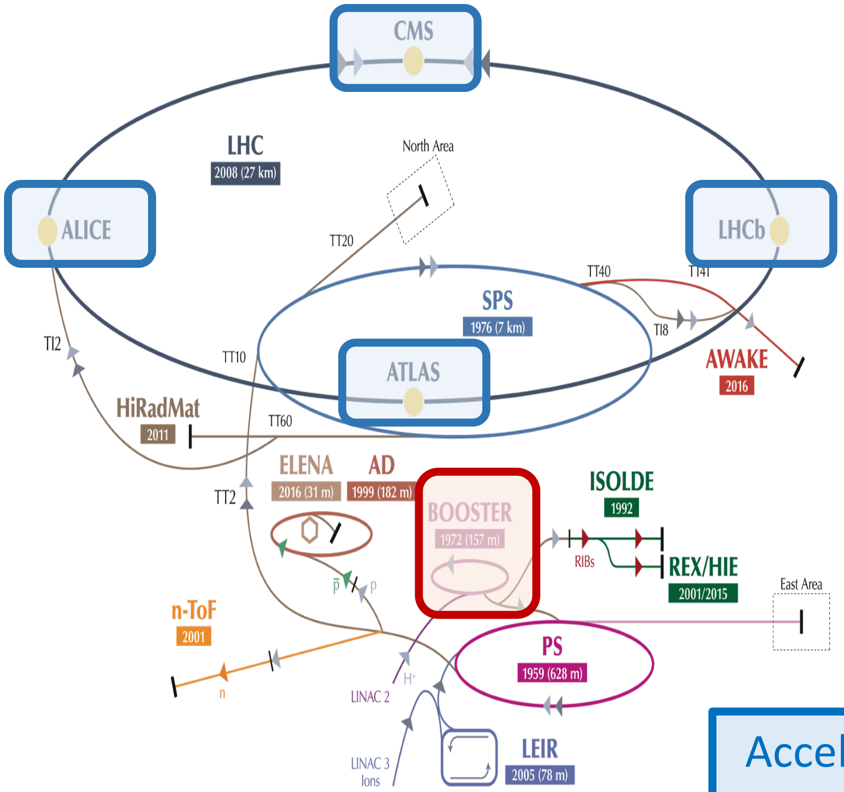


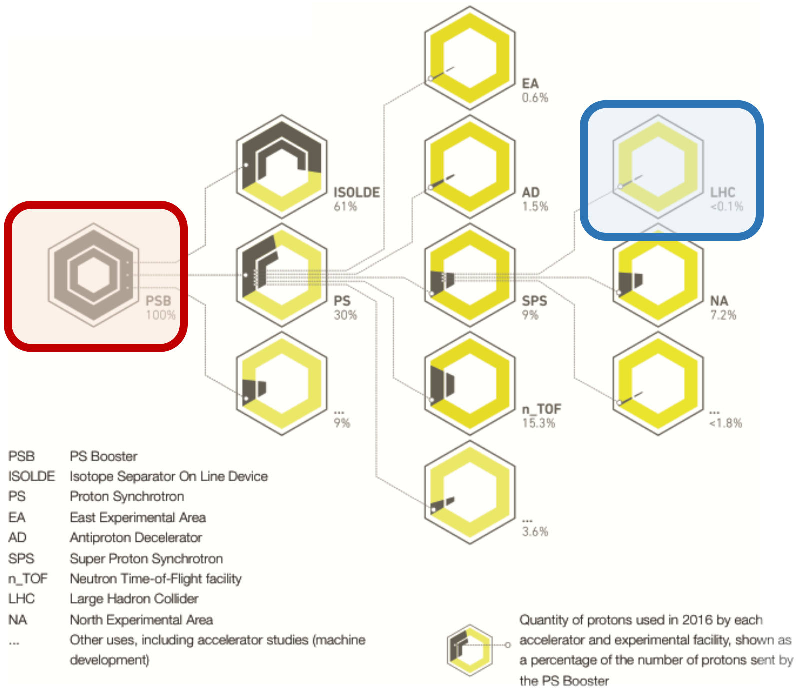




Accelerated Beams (Beyond Colliders) at CERN

The CERN accelerator complex and the LHC – protons from Booster only <0.1% to LHC

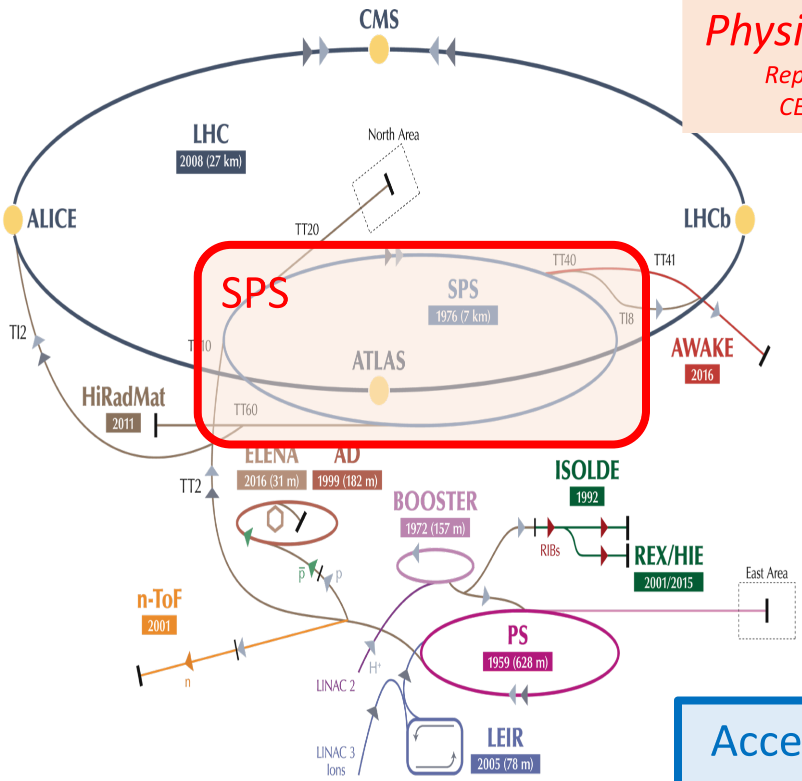




Accelerated beams unlock unique ways to address the open questions with a complementary methodology

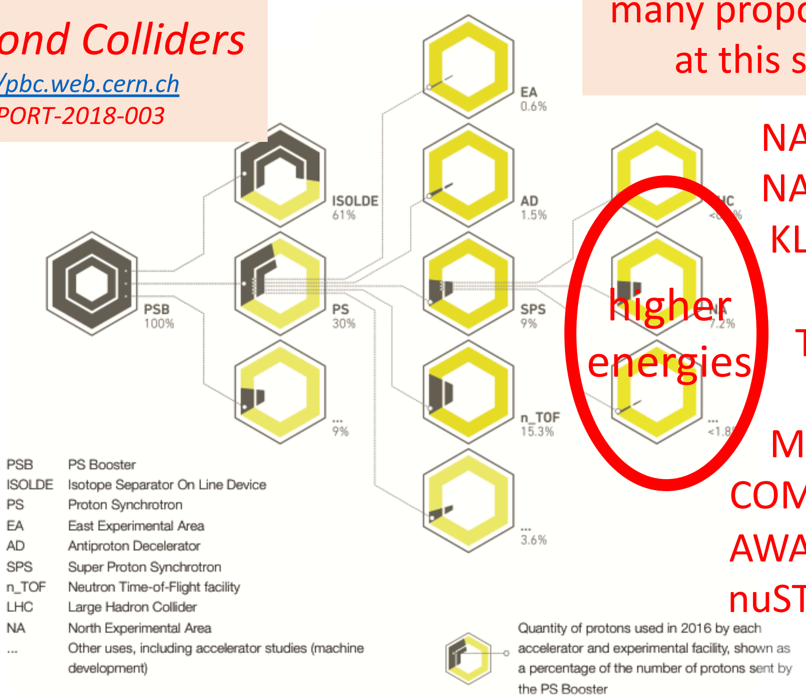
Accelerated Beams (Beyond Colliders) at CERN

The CERN accelerator complex and the LHC – protons from Booster only <0.1% to LHC



Physics Beyond Colliders
Reports: http://pbc.web.cern.ch
CERN-PBC-REPORT-2018-003

many proposals at this stage

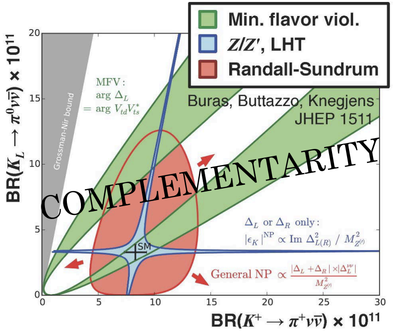


NA62++
NA64++
KLEVER
SHiP
TauFV
eSPS
MUonE
COMPASS
AWAKE++
nuSTORM

Accelerated beams unlock unique ways to address the open questions with a complementary methodology

Kaon physics with NA62 and KLEVER @ SPS-CERN

Flavour physics (CKM and BSM)



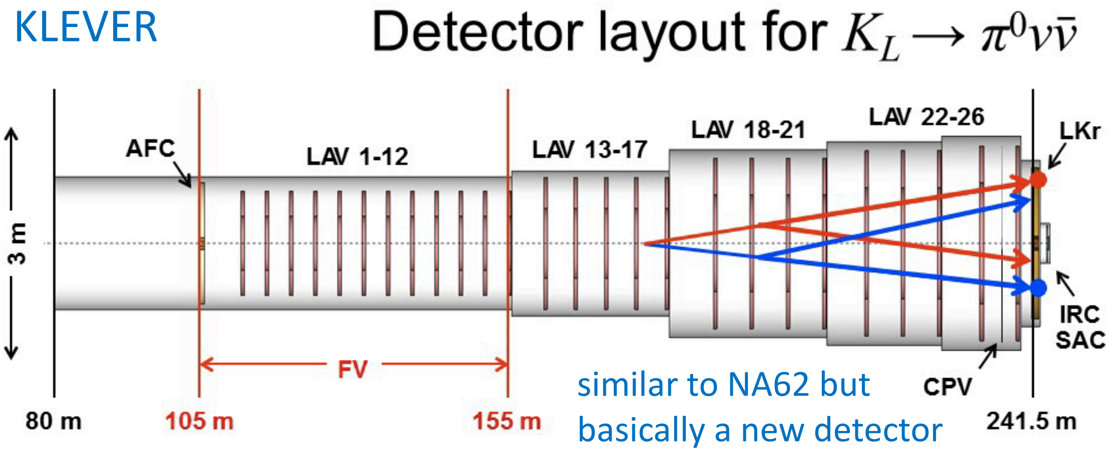
During HL-LHC era

During LHC era

running

NA62++ to run briefly in beam-dump mode (dark sector physics)

KLEVER



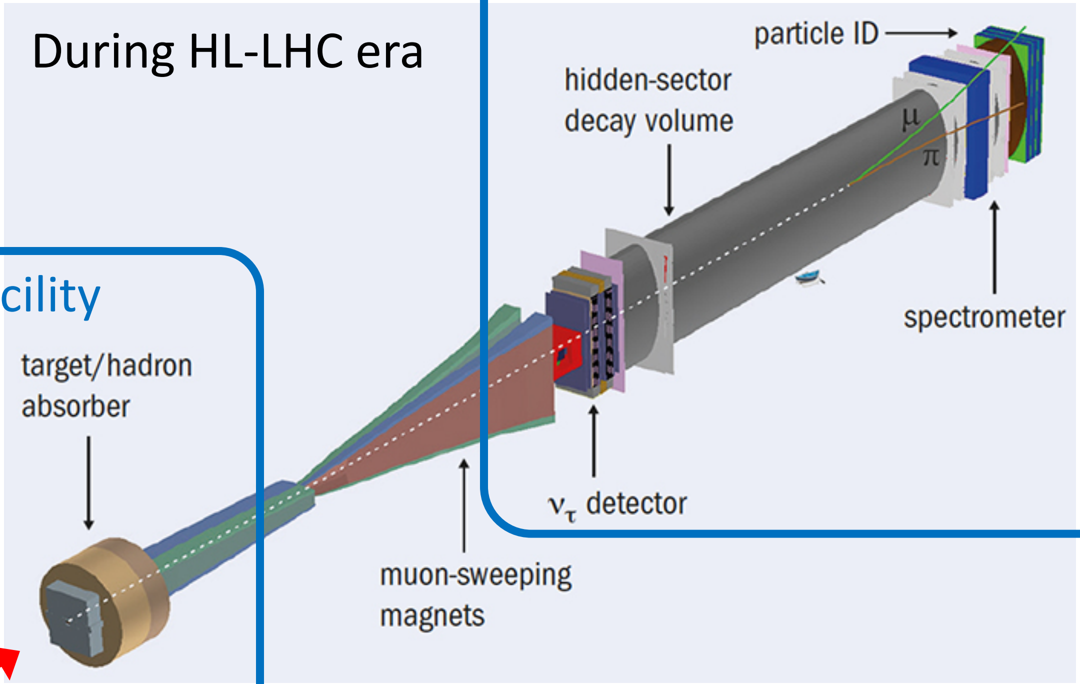
similar to NA62 but basically a new detector

proposal

Beam Dump Facility @ SPS-CERN

Intensity Frontier & Hidden Sectors

During HL-LHC era



SHiP

reconstruct decays of hidden particles in order to reject background to quasi zero

beyond NA62, to reach the charm & beauty mass decay acceptance domain

TauFV

$\tau \rightarrow \mu\mu\mu$ and other rare τ decays on the 10^{-10} level

proposal

Beam Dump Facility

target to contain most of the cascade generated by the primary beam interactions

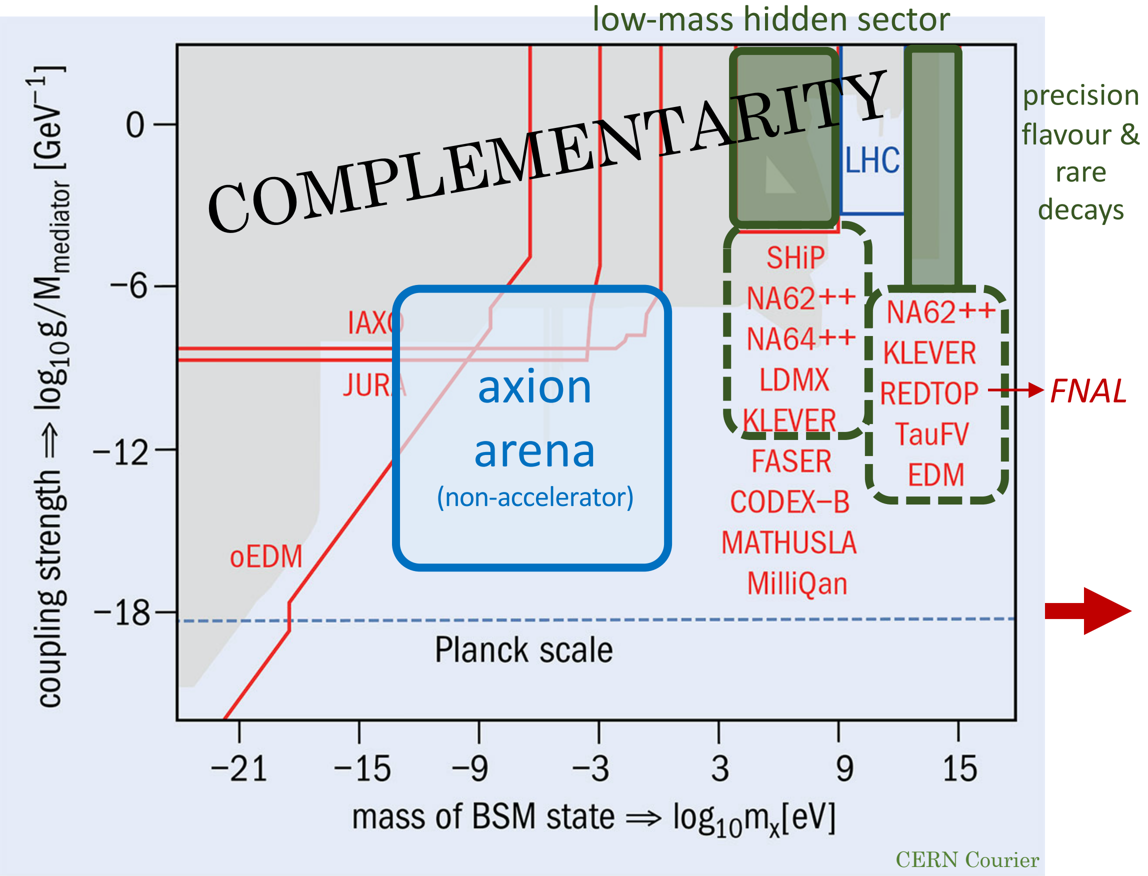
$PoT/y = 4 \times 10^{19}$

400 GeV protons

proposal (towards CDR)

Accelerated Beams (Beyond Colliders) at CERN

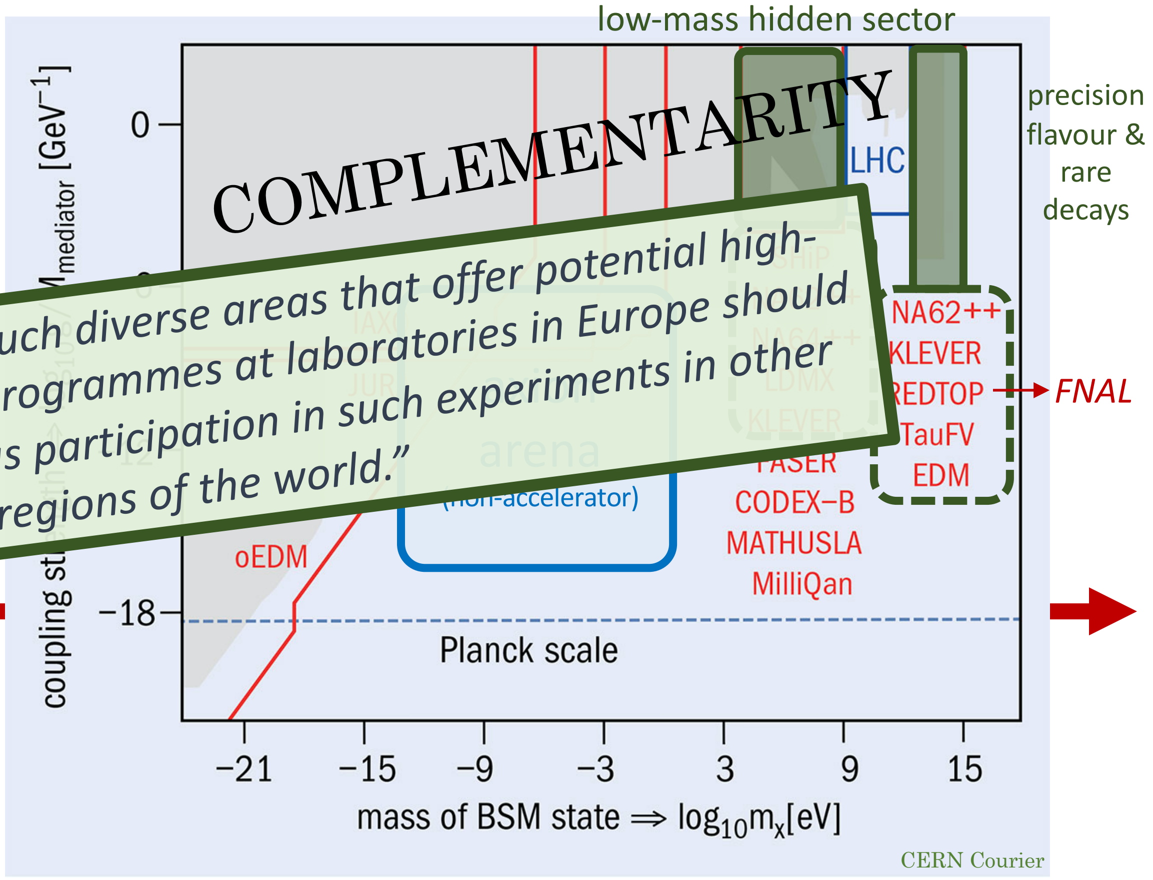
Flavour Physics
Intensity Frontier



“portal” representation of physics potential to demonstrate complementarity

Accelerated Beams (Beyond Colliders) at CERN

Flavour Physics
Intensity Frontier



ESPP: "Experiments in such diverse areas that offer potential high-impact particle physics programmes at laboratories in Europe should be supported, as well as participation in such experiments in other regions of the world."

"portal" representation of physics potential to demonstrate complementarity

Charged-Particle EDMs (CPEDM & JEDI Collaborations)

Towards a prototype storage ring – Flavour Physics & Axion Physics via oscillating EDMs

Feasibility studies

Extensive EDM activity throughout Europe

Neutrons: (~ 200 ppl.)
- Beam EDM @ Bern
- LANL nEDM @ LANL
- nEDM @ PSI
- nEDM @ SNS
- PanEDM @ ILL
- PNPI/FTI/ILL @ ILL
- TUCAN @ TRIUMF

Storage rings: (~ 400 ppl.)
- CPEDM/JEDI
- muEDM @ PSI
- g-2 @ FNAL
- g-2 @ JPARC

Atoms: (~ 60 ppl.)
- Cs @ Penn State
- Fr @ Riken
- Hg @ Bonn
- Ra @ Argonne
- Xe @ Heidelberg
- Xe @ PTB
- Xe @ Riken

Molecules: (~ 55 ppl.)
- BaF (EDM^3) @ Toronto
- BaF (NLeEDM) @ Groningen/Nikhef
- HfF+ @ JILA
- ThO (ACME) @ Yale
- YBF @ Imperial

https://www.psi.ch/en/nedm/edms-world-wide

Ultimate goal of a dedicated storage ring with 400-500m circumference is pEDM sensitivity down to 10^{-29} e cm

(today 10^{-26} e cm)

Opportunity to modify the COSY storage ring at the Forschungszentrum Jülich (Germany) towards a demonstrator and R&D for small EDMs

Charged Lepton Flavour Violation

Towards the MEG-II and Mu3e experiments @ PSI (Switzerland)

Flavour Physics

Mu3e experiment

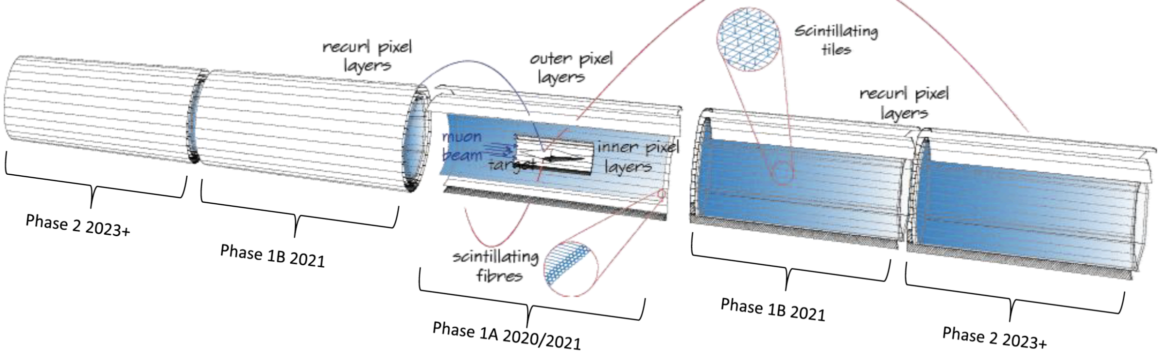
search for $\mu^+ \to e^+e^-e^+$

new beamline in next 5-10 years with most intense muon beam with >10^9 muons/s decaying in the Mu3e detector

sensitivity to BR($\mu^+ \to e^+e^-e^+$) ~ 10^{-16}
(10^4 improvement)

being installed

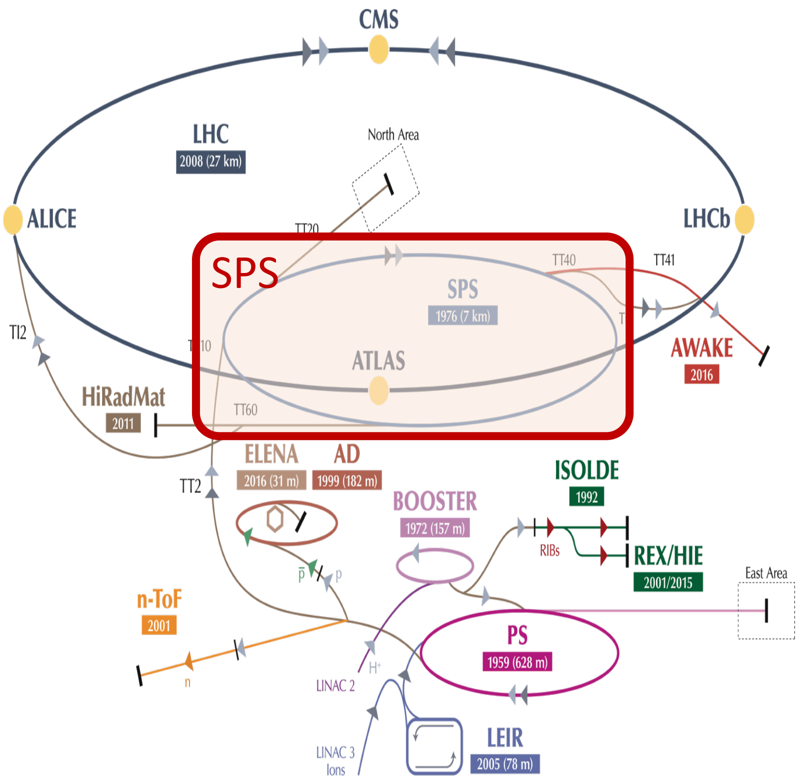
magnet arrival – July 2020



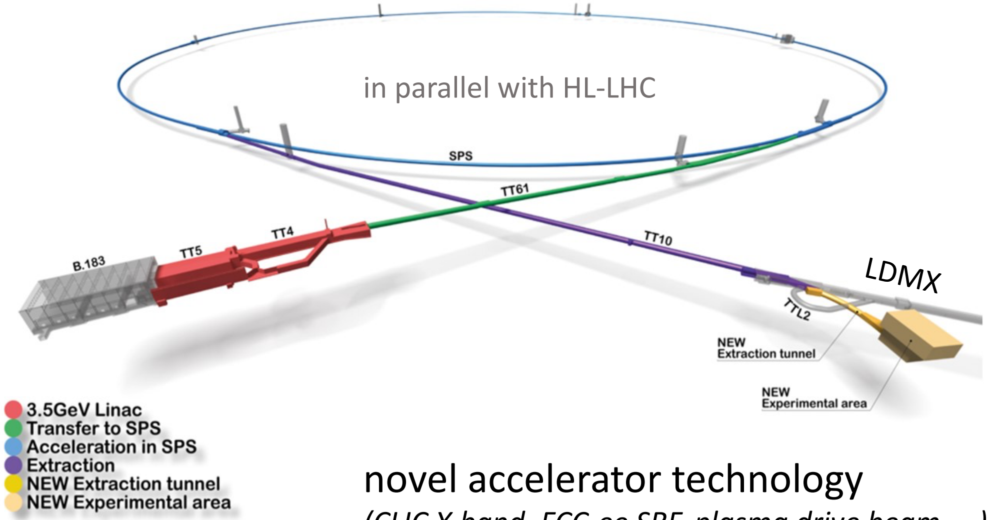
Technical Design: https://arxiv.org/abs/2009.11690

Accelerated Beams (Beyond Colliders) at CERN

The CERN accelerator complex and the LHC – from protons to electrons in the SPS



eSPS accelerator
&
Light Dark Matter eXperiment (LDMX)

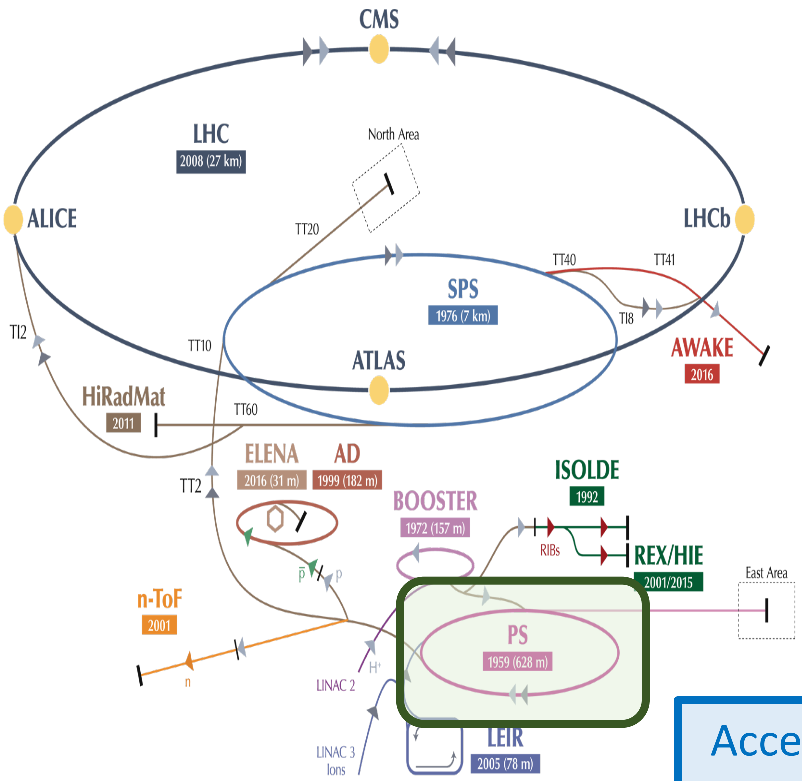


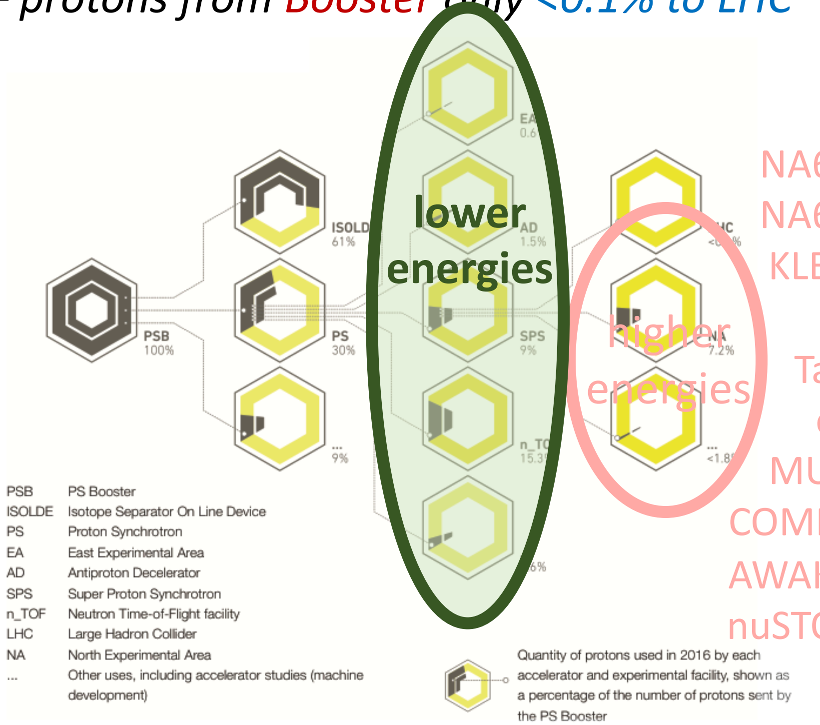
novel accelerator technology
(CLIC X-band, FCC-ee SRF, plasma drive beam, …)

proposal, CDR just submitted

Accelerated Beams (Beyond Colliders) at CERN

The CERN accelerator complex and the LHC – protons from Booster only <0.1% to LHC

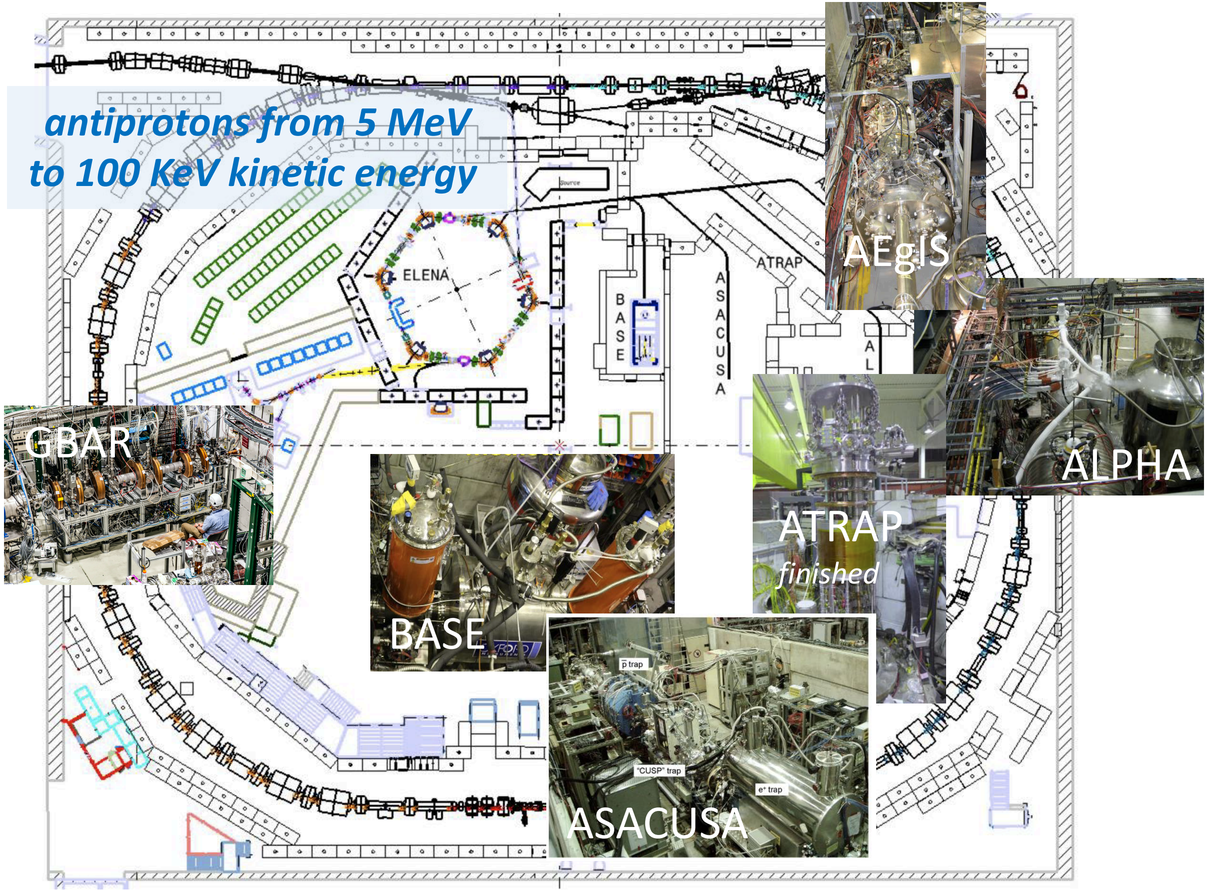




NA62++
NA64++
KLEVER
SHiP
TauFV
eSPS
MUonE
COMPASS
AWAKE++
nuSTORM

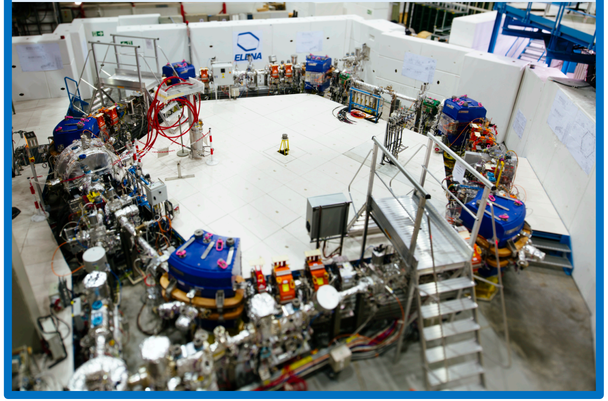
Accelerated beams unlock unique ways to address the open questions with a complementary methodology

Precision physics with antimatter @ CERN



Devoted to antiproton and antihydrogen properties

ELENA secures antimatter physics for the next decade



AEgIS – Antihydrogen Experiment: Gravity, Interferometry, Spectroscopy
ALPHA – Antihydrogen Laser PHysics Apparatus
ASACUSA – Atomic Spectroscopy And Collisions Using Slow Antiprotons
ATRAP – Antihydrogen TRAP
GBAR – Gravitational Behaviour of Antihydrogen at Rest
BASE – Baryon Antibaryon Symmetry Experiment

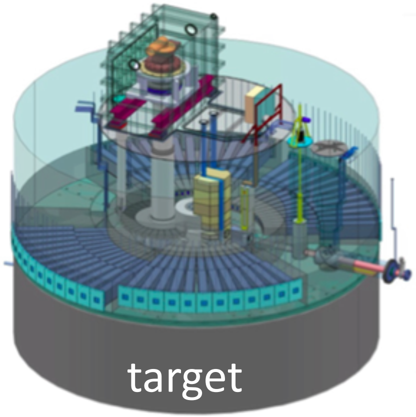
European Spallation Source (ESS) at Lund (Sweden)

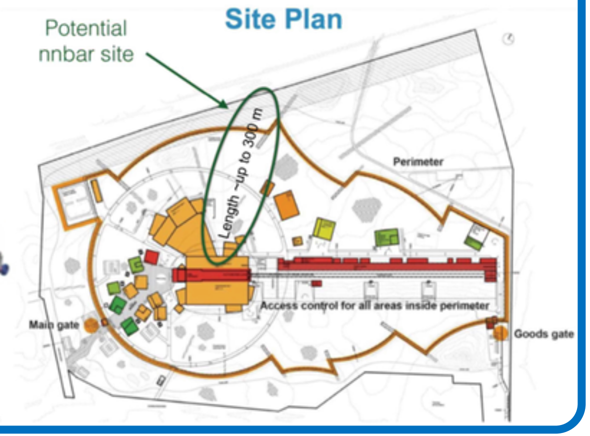
Fundamental Physics Beamline – Physics with Cold Neutrons

NNBAR experiment – from 2030 onwards

Baryon Number Violation with neutron-antineutron oscillations (up to 300m)

(3 orders of magnitude more sensitivity)





proposal

Linear Accelerator producing up to 5 MW beam of 2 GeV protons

(first science from 2023, full operation 2026)

Other particle physics proposals @ ESS: ANNI, HIBEAM, ESSνSB, CEνNS

Neutrino beams in Japan and in the US

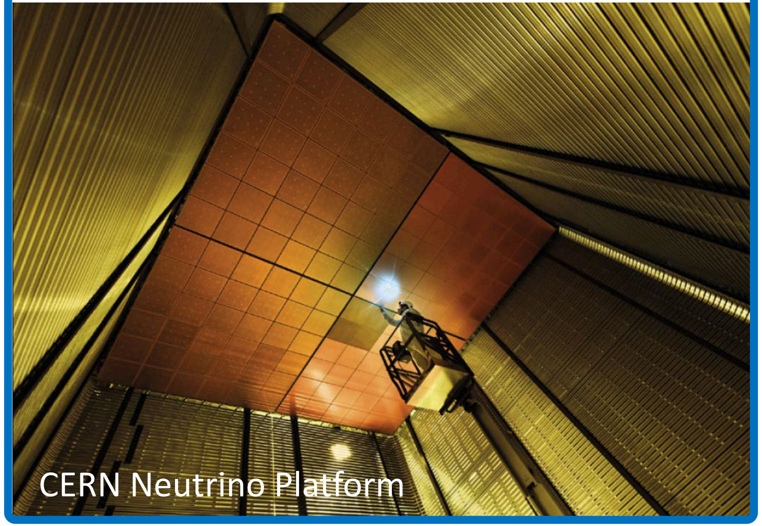
CERN's Neutrino Platform in LBNF & DUNE, and in T2K

Leptonic CP violation, neutrino mass hierarchy, sterile neutrino's, …

DUNE @ LBNF

also JINR

Prototype dual-phase Liquid-Argon TPC



BabyMIND @ T2K (near detector)

Prototype for Magnetised Iron Neutrino Detector

ESPP: "[…] continue to support long baseline experiments in Japan and the US.
In particular […] towards the successful implementation of LBNF and DUNE."

Neutrinos

Experiments at reactors

From very short to long baseline

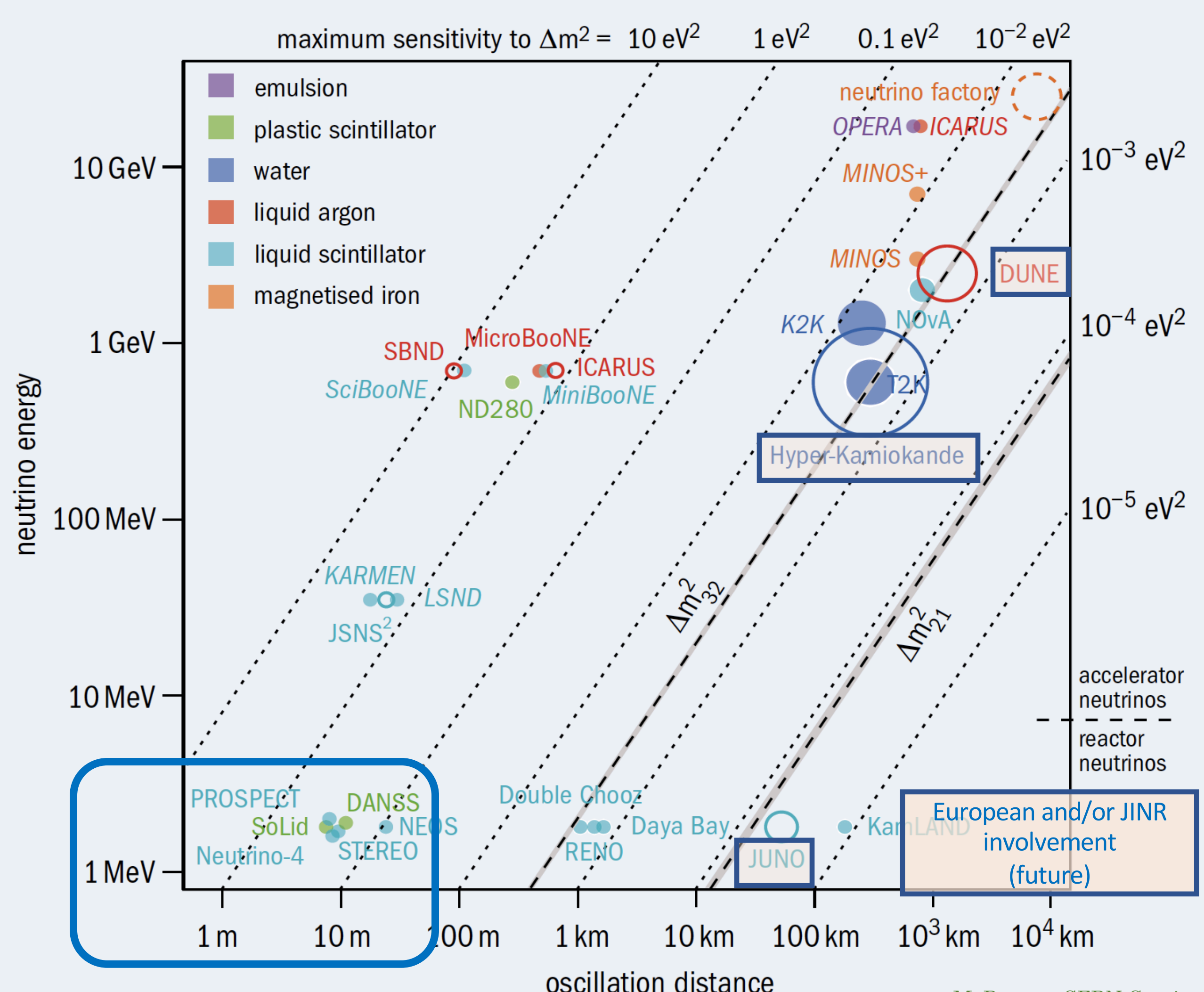
Running in Europe/Russia

- *DANSS (Russia)*
- *Neutrino-4 (Russia)*
- *SoLid (Belgium)*
- *STEREO (France)*

Zooming into anomalies

Sterile neutrinos

Neutrino-oscillation experiments using neutrinos from nuclear reactors or accelerator beams, as a function of the distance from source to detector and the peak energy of the neutrinos. Open markers indicate future projects (for detectors in excess of 5 kton, the area of the marker is proportional to the detector mass) and italics indicate completed experiments. The experiments are coloured according to target material. The "magic-baseline" neutrino factory proposed in the 2011 international design study is plotted for reference.



M. Rayner, CERN Courier

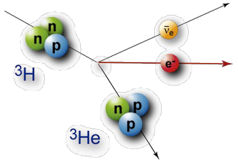
The absolute mass of the neutrino (ν_e)

KATRIN experiment at KIT (Germany) – a 70m long experimental setup

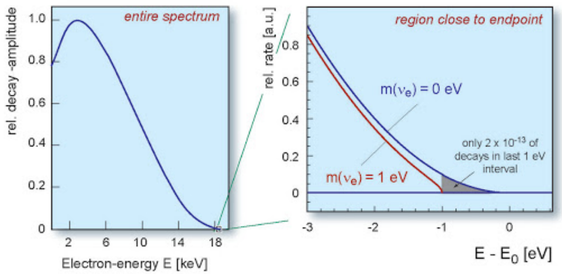
KATRIN

spectroscopic energy measurement of the β-electrons from ^{3}H β-decay

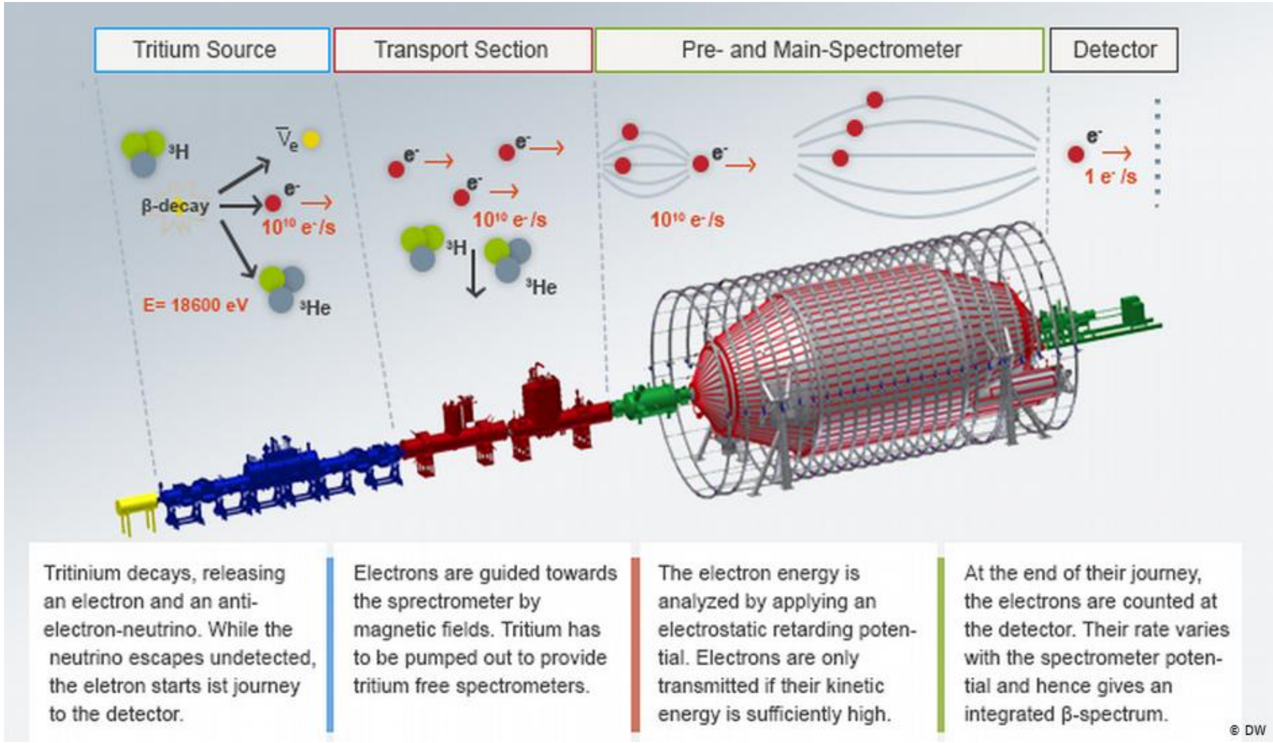
sensitivity down to about 0.35 eV (5σ)



kinematic parameters
&
energy conservation



running



Major underground Facilities in Europe

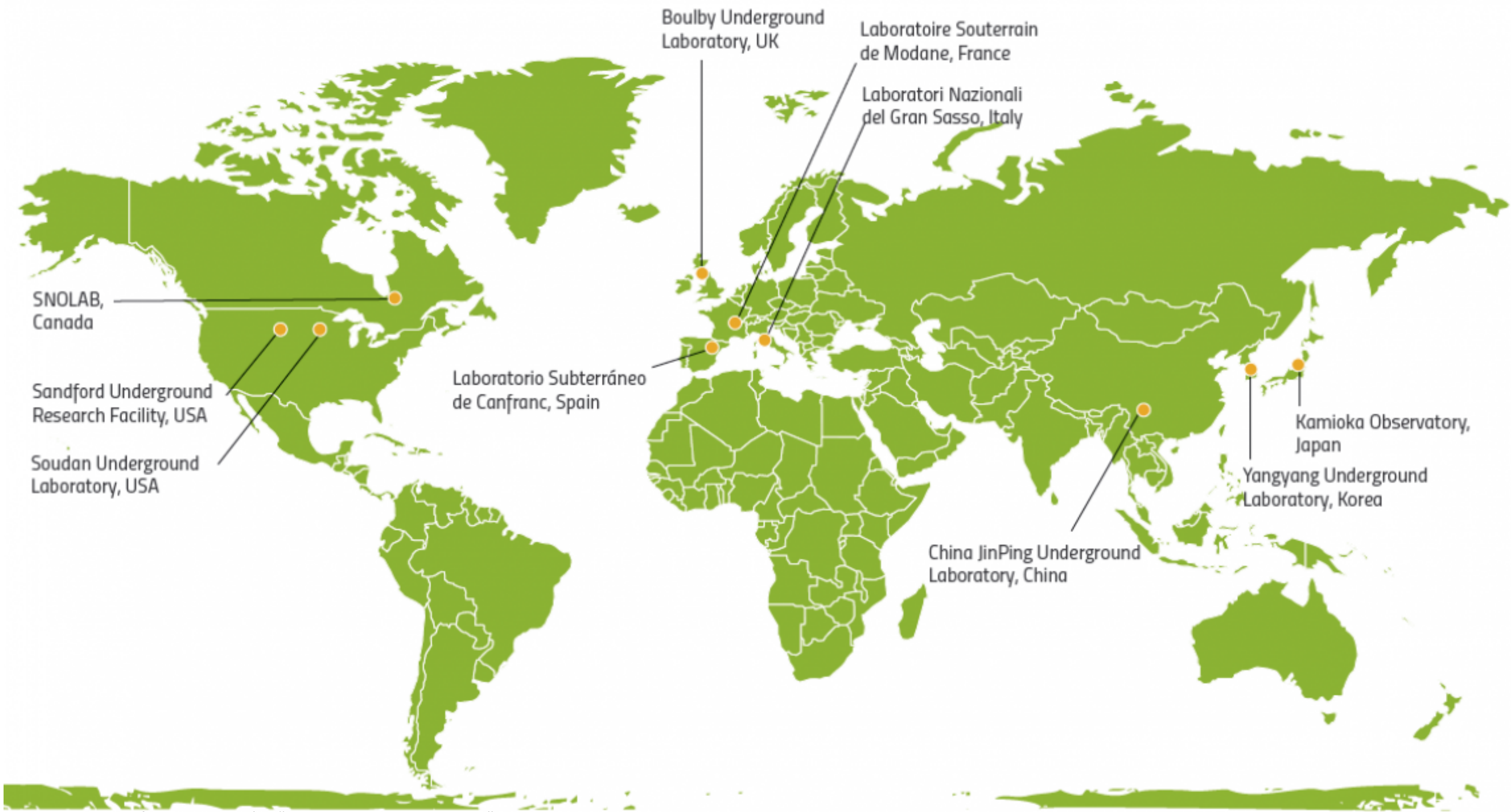


image courtesy of Susana Cebrián, "Science goes underground"

Major underground Facilities in Europe – $0\nu\beta\beta$

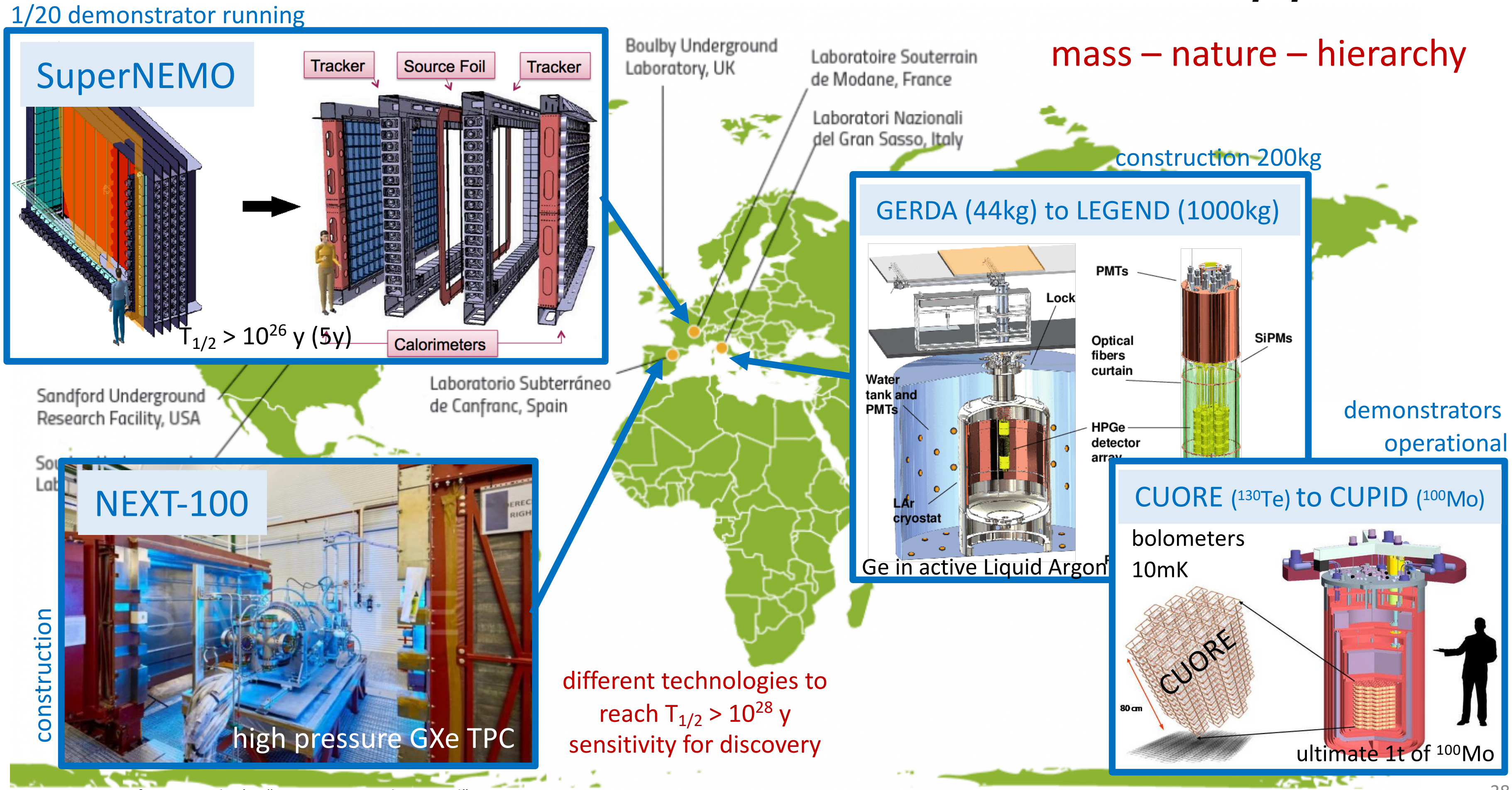
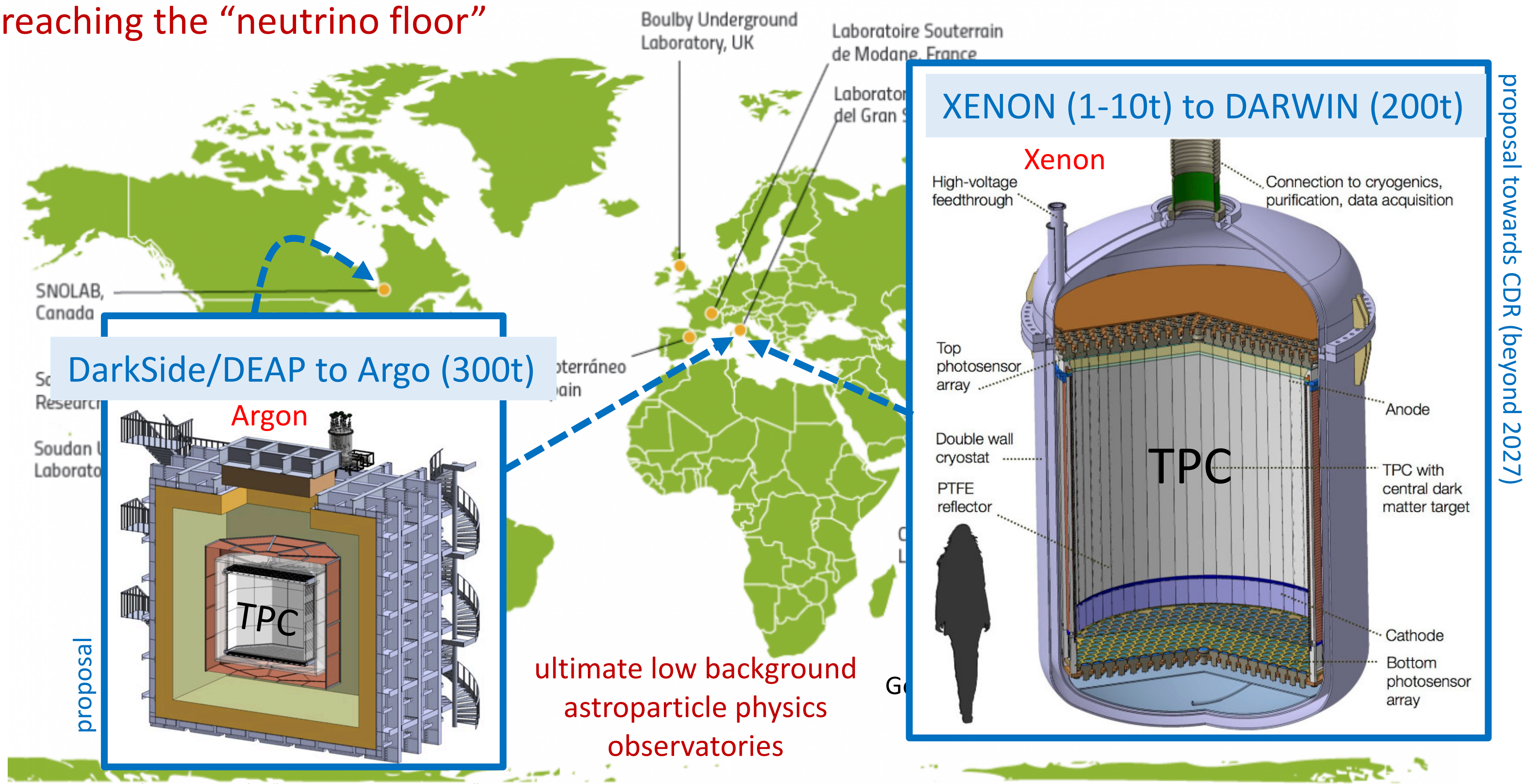


image courtesy of Susana Cebrián, "Science goes underground"

Major underground Facilities in Europe – Dark Matter

reaching the “neutrino floor”

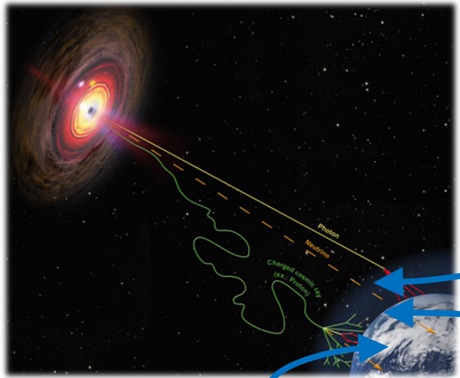


ultimate low background astroparticle physics observatories

image courtesy of Susana Cebrián, “Science goes underground”

Major Cosmic Particle Facilities in Europe

advance our major participation outside Europe: Pierre Auger Observatory, IceCube(-Gen2), …



observatory in orbit

AMS-2

anti-matter in cosmic rays

assembled at CERN

data taking

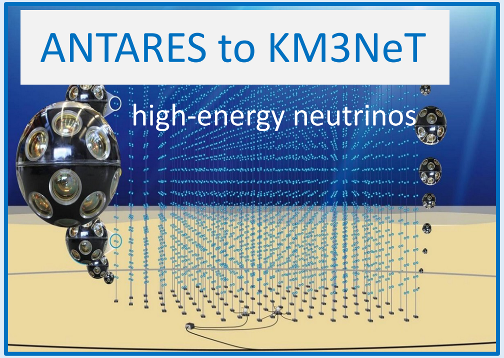
observatory on the surface

H.E.S.S./MAGIC/VERITAS to CTA

high-energy gamma-rays

construction, start observations >2022

observatory below surface



ANTARES to KM3NeT

high-energy neutrinos

construction, partially operational

BAIKAL-GVD

high-energy neutrinos

construction, partially operational

Gravitational Wave Facilities in Europe

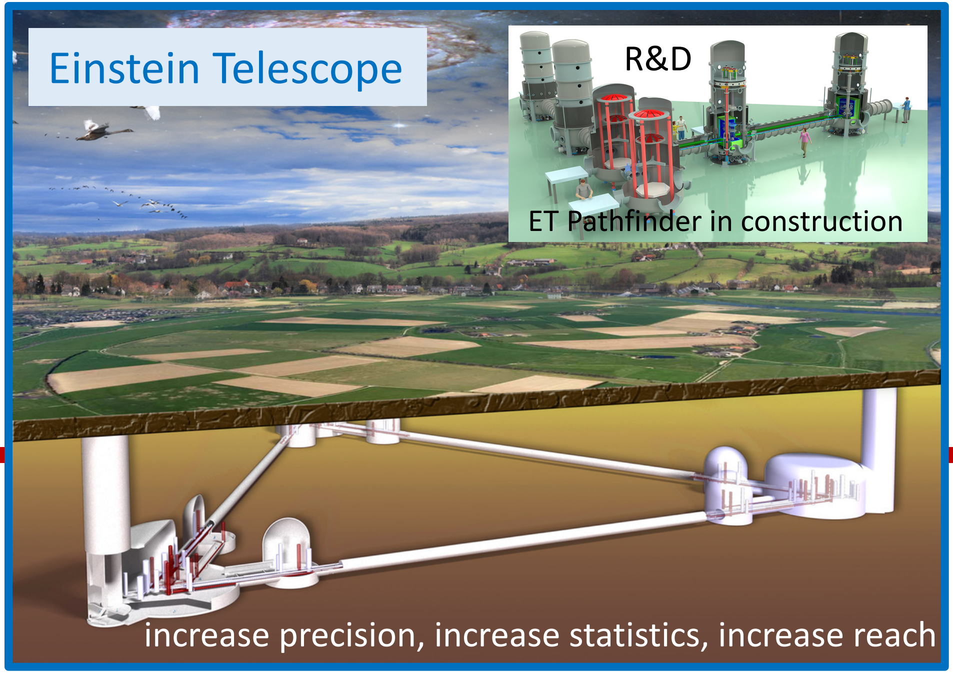
Current flagships

Advanced & Plus upgrades up to 2035

into the Multi-Messenger Realm for Astronomy

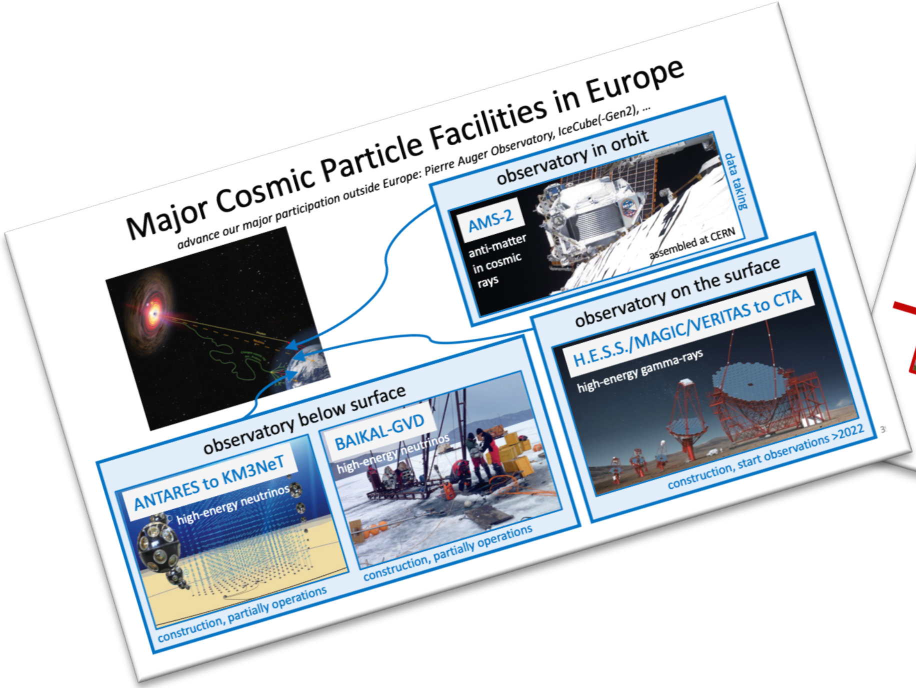
3rd generation interferometer, beyond 2035

underground – triangle (10km arms) – cryogenic



application to ESFRI Roadmap (EU) (European Strategy Forum on Research Infrastructures)

complementary: LISA (ESA) to be launched around 2034



into the global Multi-Messenger Realm for Astronomy

Updated European Strategy: "The ground-breaking discovery of gravitational waves has occurred since the last Strategy update, and this has contributed burgeoning multi-messenger observations of the universe. "

Vast portfolio to unlock new avenues to address the puzzling unknowns in fundamental physics

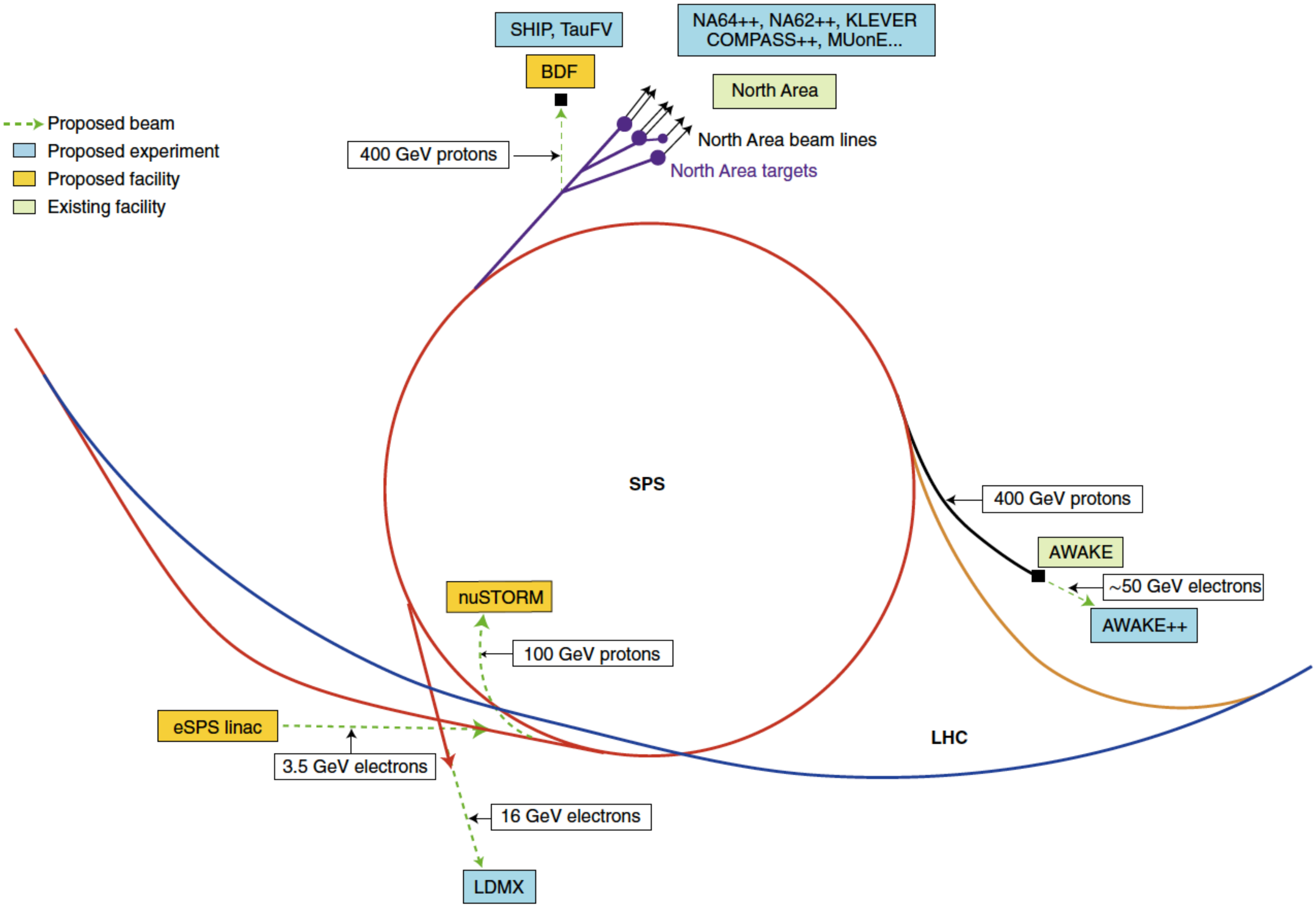
∾ *leave no stone unturned* ∾

These strategies are now a coherent basis for funding bodies to develop resource-loaded programmes

ESPP: "The implementation of the Strategy should proceed in strong collaboration with global partners and neighbouring fields."

Thank you for your attention!

Additional Slides



Jaeckel, J., Lamont, M. & Vallée, C. The quest for new physics with the Physics Beyond Colliders programme. *Nat. Phys.* **16**, 393–401 (2020). https://doi.org/10.1038/s41567-020-0838-4

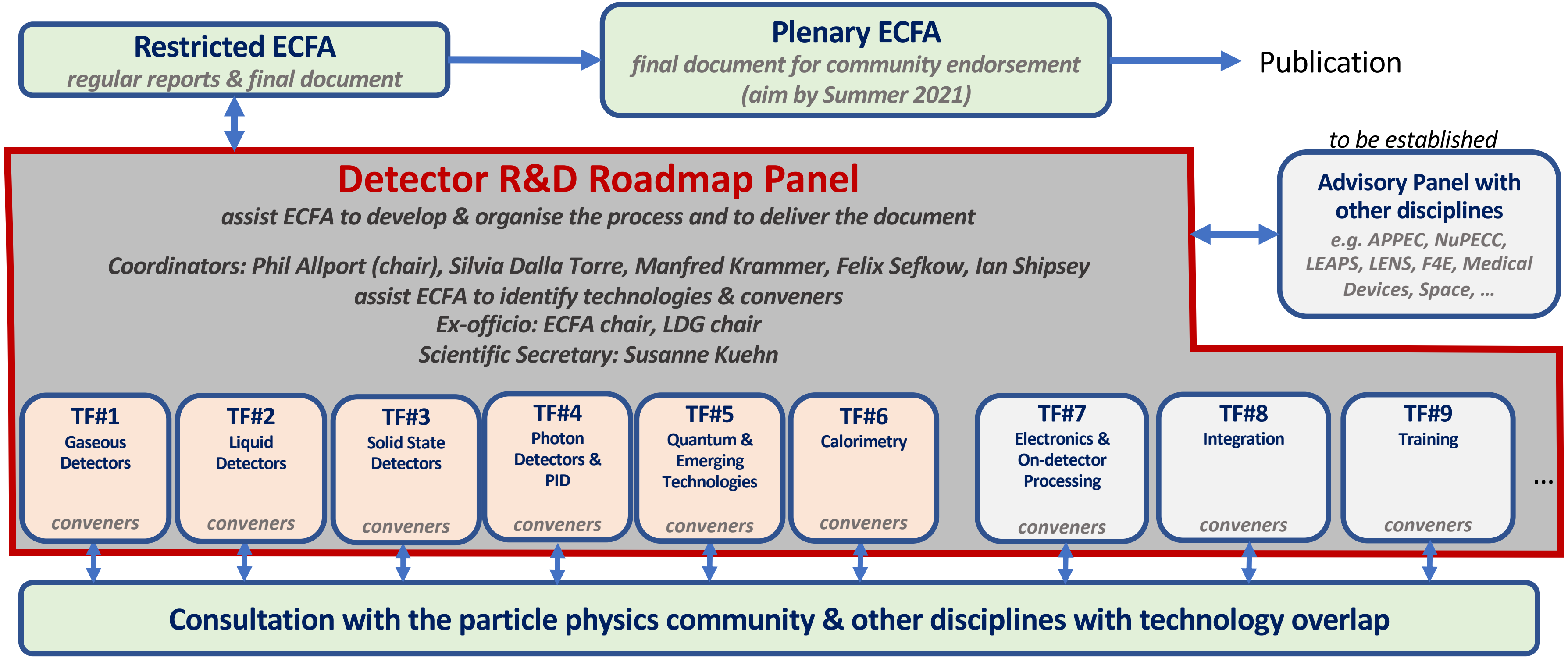
Jaeckel, J., Lamont, M. & Vallée, C. The quest for new physics with the Physics Beyond Colliders programme. *Nat. Phys.* **16**, 393–401 (2020). https://doi.org/10.1038/s41567-020-0838-4

Table 1 | List of projects submitted to the PBC study group

Experiment	Physics case	Status	Time scale
NA61++	Charm in QCD phase transition	Operational/upgrade studies	Near
NA60++	Caloric curve of QCD phase transition	Feasibility study	Medium
DIRAC++	QCD with pionic and kaonic atoms	Feasibility study	Medium
COMPASS++	QCD dynamics	Operational/upgrade studies	Near
MUonE	Hadronic vacuum polarization for $(g-2)_\mu$	Prototype/tests with beam	Near
LHC FT (gas storage cell)	QCD dynamics and phase transition	Installation/further studies	Near
LHC FT (bent crystal)	Magnetic and electric dipole moment of short-lived baryons	Prototype planned/studies	Medium
KLEVER	Ultra-rare decays of neutral kaons	Feasibility studies	Medium
TauFV	Ultra-rare decays of tau leptons	Design study in progress	Long
REDTOP	Ultra-rare decays of eta meson	Proposal	Medium
NA64++	Dark photon searches with electron and/or muon beam dump	Operational/upgrade studies	Near
LDMX	Dark photon searches	Design study in progress	Medium
AWAKE++	Dark photon searches	Exploratory studies	Long
NA62++	Dark sector searches with proton beam dump	Beam dump option studies	Near
SHiP	Dark sector, study of tau neutrinos	Design study complete	Medium
BabyIAXO/IAXO	Axion search (helioscope)	Conceptual design/ prototyping	Medium
JURA	Axion and axion-like particle searches	Exploratory studies	Long
VMB@CERN	Vacuum magnetic birefringence	Letter of intent/studies	Medium
Facility	**Beam type**	**Status**	**Time scale**
BDF	High intensity 400 GeV protons for SHiP and TauFV	Design study complete	Medium
eSPS	16 GeV electrons	Design study in progress	Medium
nuSTORM	Neutrino beam from a muon storage ring for cross-section measurements	Feasibility study complete	Long
EDM ring	Polarized proton storage ring for EDM measurement	Feasibility study complete	Medium
Gamma Factory	High intensity gamma-ray beam	Design study in progress	Long

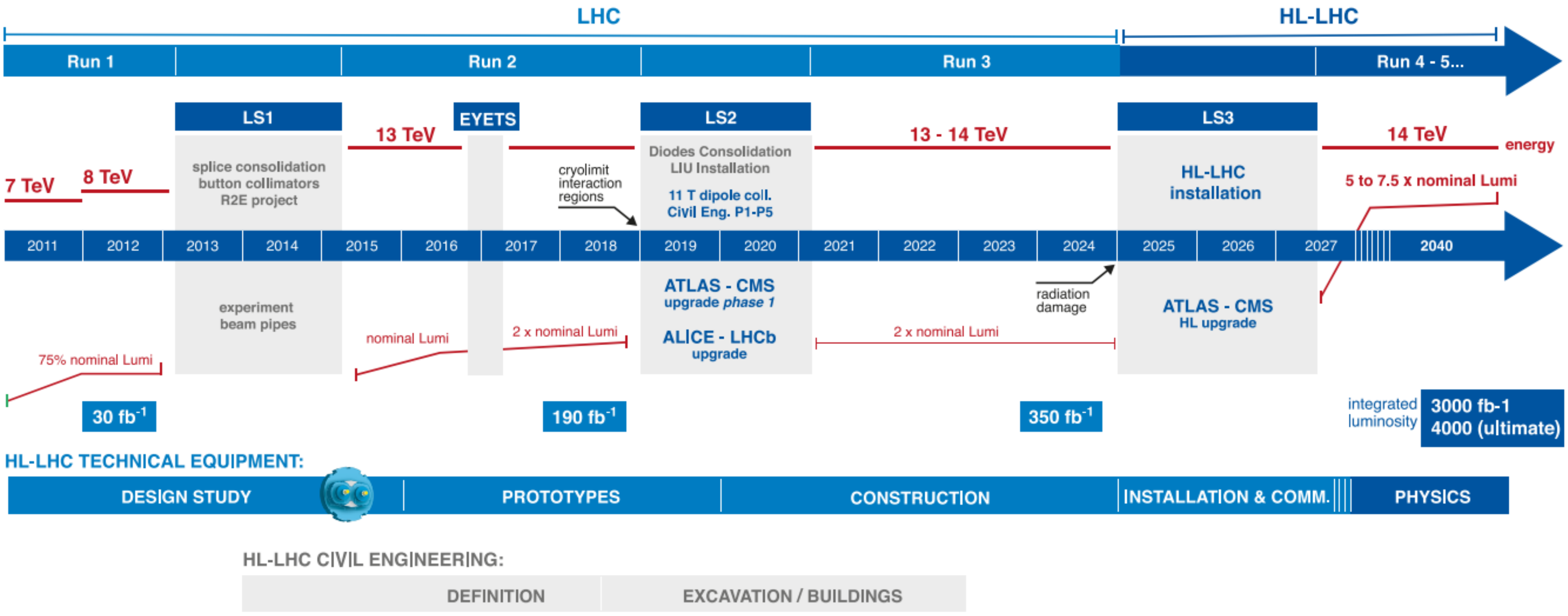
The level of maturity (status) and approximate time-line (time scale) for each experiment/facility is indicated as in ref. [1]: near term, before 2025; medium term, 2025–2030; long term, after 2030. See main text for discussion of the individual projects.

Detector R&D Roadmap – preview of organisation



in the process of selecting conveners

From the LHC to the High-Luminosity LHC @ CERN



From the LHC to the High-Luminosity LHC @ CERN

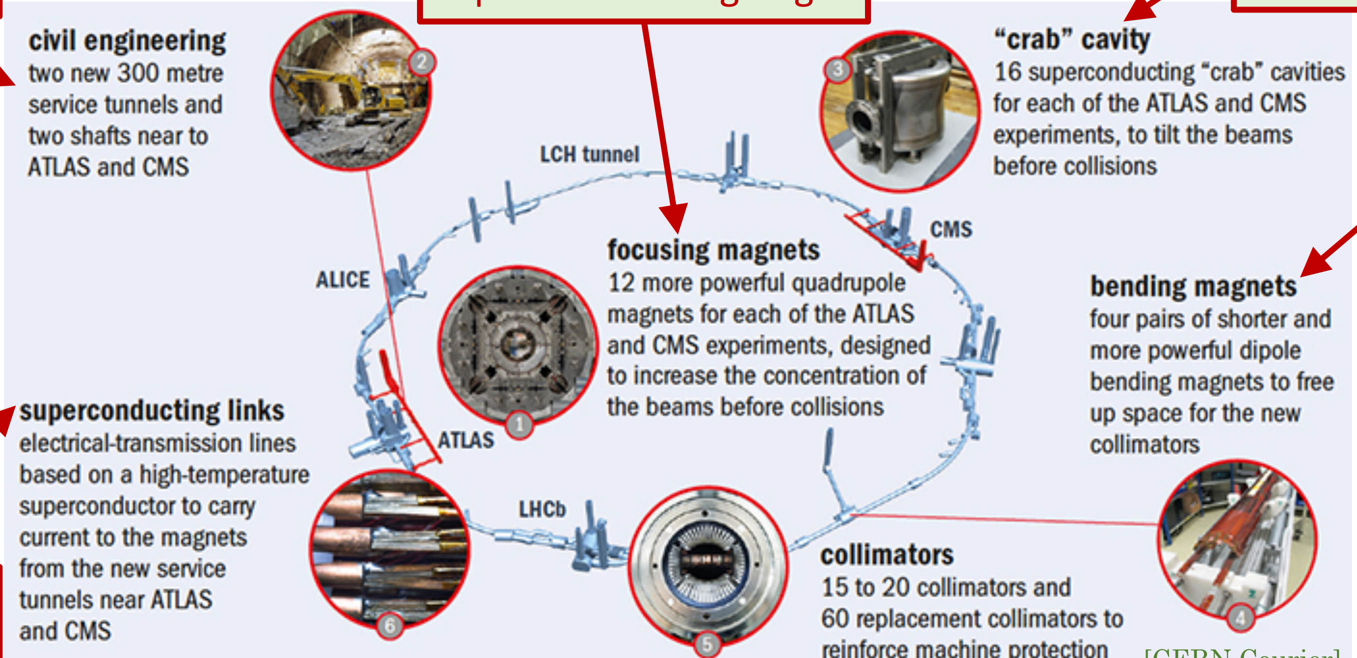
excavation mostly done

successfully tested (US) production ongoing

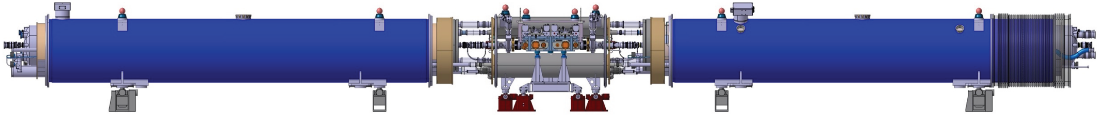
successfully tested at SPS (CERN)

ongoing tests on bench, some qualified (CERN)

60m system demonstrator successful (CERN)



[CERN Courier]



e^+e^- Higgs Factories (incl. B/c/τ/EW/top factories)

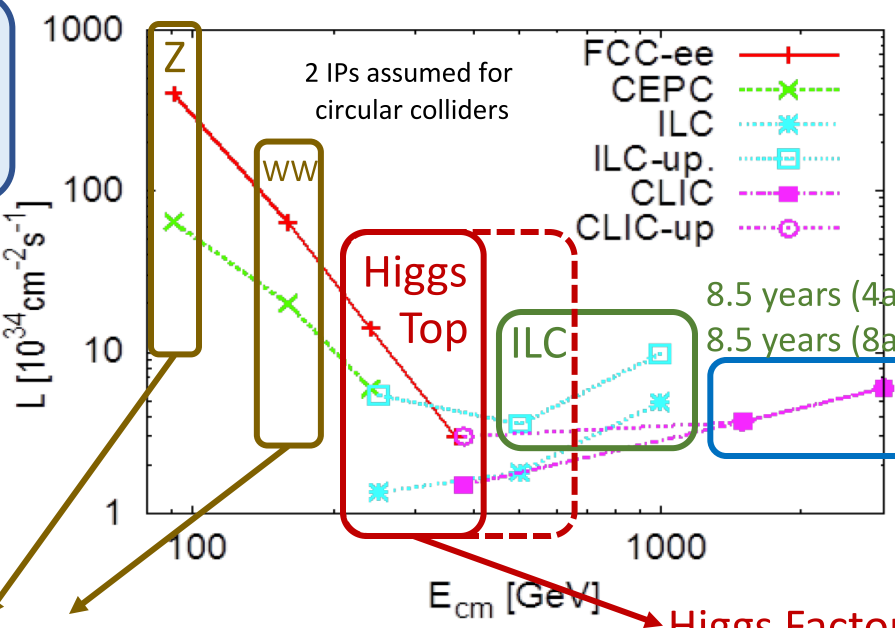
precision frontier

circular colliders

synchrotron radiation

for the same power, less luminosity at higher E_{cm}

(Energy Recovery Linac technology might mitigate this & allow to go to higher E_{cm})



linear colliders

energy frontier

8.5 years (4ab^{-1} @ 0.5 TeV)

8.5 years (8ab^{-1} @ 1 TeV)

7 years (2.5ab^{-1} @ 1.5 TeV)

8 years (5ab^{-1} @ 3 TeV)

B/c/τ/EW Factories

per detector in e^+e^-	# Z	# B	# τ	# charm	# WW
LEP	4×10^6	1×10^6	3×10^5	1×10^6	2×10^4
SuperKEKB	-	10^{11}	10^{11}	10^{11}	-
FCC-ee	2.5×10^{12}	7.5×10^{11}	2×10^{11}	6×10^{11}	1.5×10^8

Higgs Factories with complementarity

- g_{HZZ} (250GeV) versus g_{HWW} (380GeV)
- top quark physics
- beam polarization for EW precision tests

(transverse polarization in circular e^+e^- colliders only at lower E_{cm} while longitudinal polarization at linear colliders)

Zooming into the Higgs sector with colliders

Complementarity between e^+e^- and proton colliders

(Higgs coupling strength modifier parameters κ_i – assuming no BSM particles in Higgs boson decay)
(expected relative precision)

the coupling we looked at on the previous slide

kappa-0-HL	HL+FCC-ee$_{240}$	HL+FCC-ee	HL+	ee/hh	HL+FCC-eh/hh	HL+FCC-hh	HL+FCC-ee/eh/hh
κ_W[%]	0.86	0.38	0.23	0.27	0.17	0.39	0.14
κ_Z[%]	0.15	0.14	0.094	0.13	0.27	0.63	0.12
κ_g[%]	1.1	0.88	0.59	0.55	0.56	0.74	0.46
κ_γ[%]	1.3	1.2	1.1	0.29	0.32	0.56	0.28
$\kappa_{Z\gamma}$[%]	10.	10.	10.	0.7	0.71	0.89	0.68
κ_c[%]	1.5	1.3	0.88	1.2	1.2	–	0.94
κ_t[%]	3.1	3.1	3.1	0.95	0.95	0.99	0.95
κ_b[%]	0.94	0.59	0.44	0.5	0.52	0.99	0.41
κ_μ[%]	4.	3.9	3.3	0.41	0.45	0.68	0.41
κ_τ[%]	0.9	0.61	0.39	0.49	0.63	0.9	0.42
Γ_H[%]	1.6	0.87	0.55	0.67	0.61	1.3	0.44

adding 365 GeV runs

adding FCC-ep

ALL COMBINED

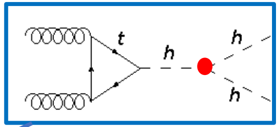
only FCC-ee@240GeV

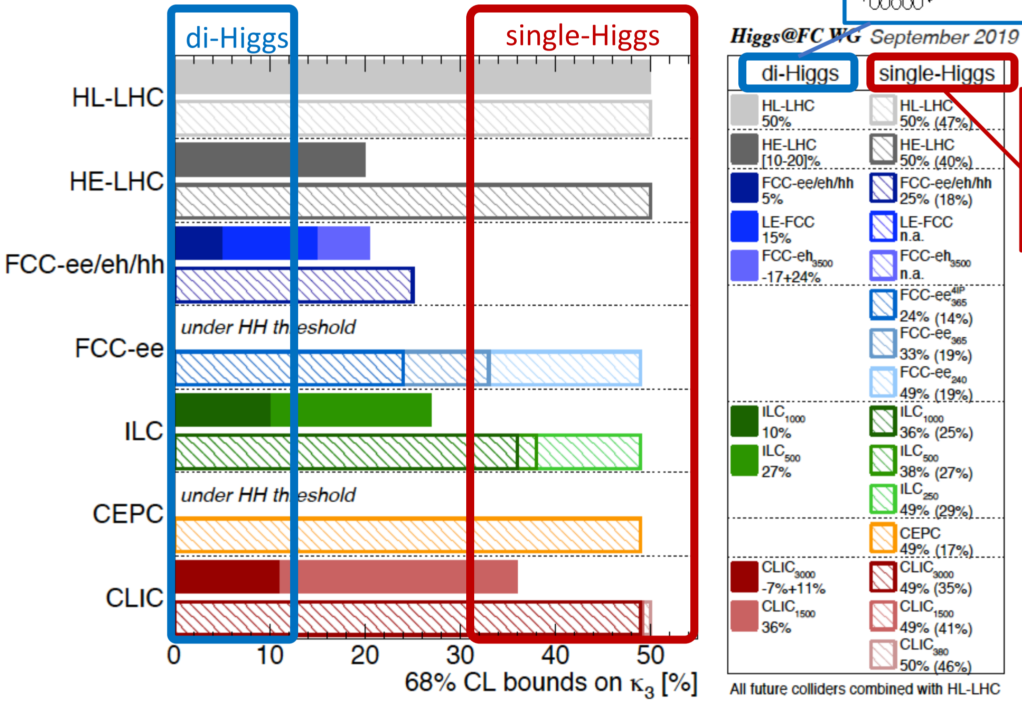
only FCC-hh

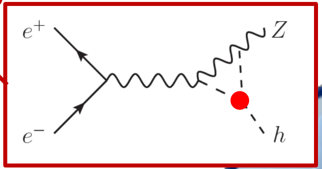
[J. de Blas et al., JHEP 01 (2020) 139]

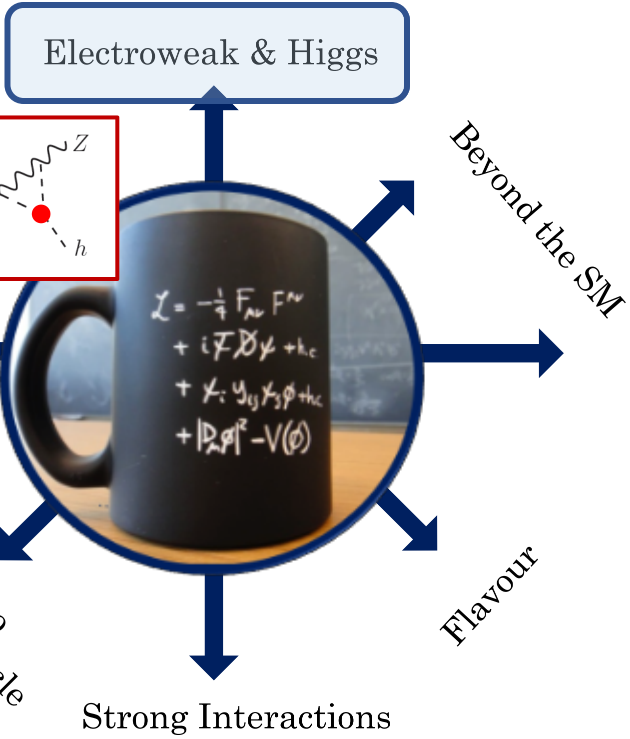
Zooming into the Higgs sector with colliders

The Higgs boson cubic self-coupling (κ_3)









Physics themes of the Open Symposium of the European Strategy for Particle Physics in Granada

[J. de Blas et al., JHEP 01 (2020) 139]

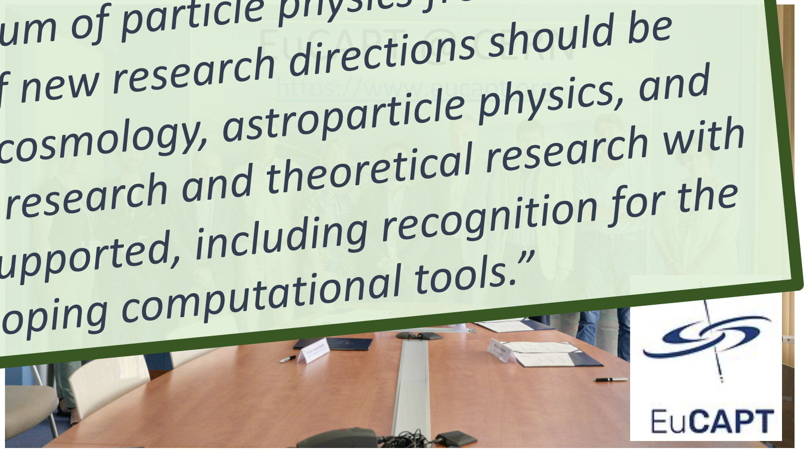
Essential: the Theory backbone in Europe

Theoretical research continues to motivate (new) experimental searches and provides crucial tools in support of the empiric exploration. A broad programme from abstract to phenomenological topics and from small to large scales is on the

ESPP: "Europe should continue to vigorously support a broad programme of theoretical research covering the full spectrum of particle physics from abstract to phenomenological topics. The pursuit of new research directions should be encouraged and links with fields such as cosmology, astroparticle physics, and nuclear physics fostered. Both exploratory research and theoretical research with direct impact on experiments should be supported, including recognition for the activity of providing and developing computational tools."

Theory center at DESY to be added

increase exchange
and
help scientists



European Consortium for Astroparticle Theory
bring together the European community of theoretical astroparticle physicists and cosmologists

Advancing Accelerator Technologies

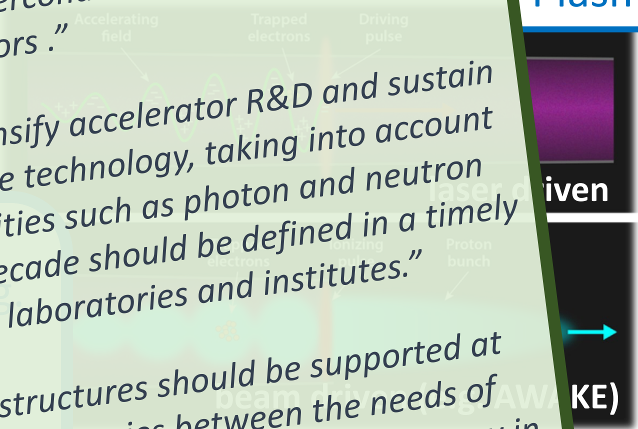
ESPP: "The particle physics community should ramp up its R&D effort focused on advanced accelerator technologies, in particular that for high-field superconducting magnets, including high-temperature superconductors ."

ESPP: "The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes."

ESPP: "Detector R&D programmes and associated infrastructures should be supported at CERN, national institutes, laboratories and universities. Synergies between the needs of different scientific fields and industry should be identified and exploited to boost efficiency in the development process and increase opportunities for more technology transfer benefiting society at large. Collaborative platforms and consortia must be adequately supported to provide coherence in these R&D activities. The community should define a global detector R&D roadmap that should be used to support proposals at the European and national levels."

High-Field Magnets

Plasma



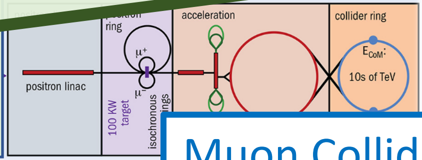
Energy Recovery Linac

PERLE @ IJCLab Orsay
first 10 MW power ERL facility
TDR by 2022

developed
(by Summer 2021)

Muon Collider

for design study 3 TeV and >10 TeV



AstroParticle Physics European Consortium

APPEC

- ***The General Assembly :*** strategic, decision making and supervisory body. Chair: TM (UniGeneva), Deputy Chair C. Stegmann (DESY), General Secretary: Job De Kleuver (NWO)
- ***The Scientific Advisory Committee:***
  Chair: S. De Jong (RadboudU)
  vice-Chair: S. Pascoli (DurhamU)
- **The Joint Secretariat** running the functional centres (currently DESY, NWO, KIT, APC, EGO)

21 funding agencies in 17 countries in the General Assembly

CAMK, Poland; CEA & CNRS, France; DESY & KIT, Germany; FNRS & FWO, Belgium;

FCT, Portugal; IEAP-CTU, Czech Republic; IFIN-HH, Romania; INFN, Italy

JINR, Dubna, Russia; LSC, Spain; MTA, Hungary; NOA, Greece

NWO, the Netherlands, HIP, Finland, SNF; Switzerland, STFC, United Kingdom; VR, Sweden; CSF/HRZZ Croatia soon back in APPEC!

APPEC Observers: CERN, ECFA, NuPPEC, ESO, ASTRONET

Teresa.Montaruli@unige.ch
APPEC GA Chair

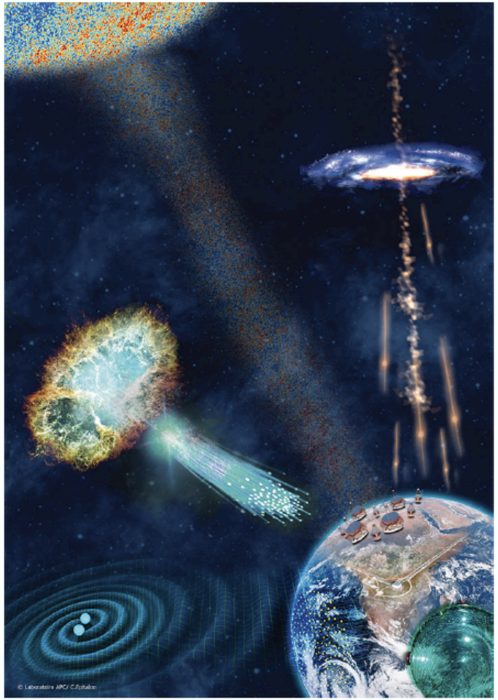
Berrie Giebels (CNRS) is APPEC representative in the Snowmass21 process.

APPEC Prioritization process

https://www.appec.org/roadmap

- 21 recommendations in 'resource-aware' **2017-2026 Roadmap**

- APPEC **EPPSU** *input # 84 (order not prioritized) focused on:*
  i) ***dark matter searches***
  ii) ***multi-messenger astronomy,*** *and in particular the* **3G GW** experiments (Einstein Telescope in Europe)
  iii) ***neutrino physics***
  iv) the exploitation of the ***European Center for AstroParticle Theory (EuCAPT)***

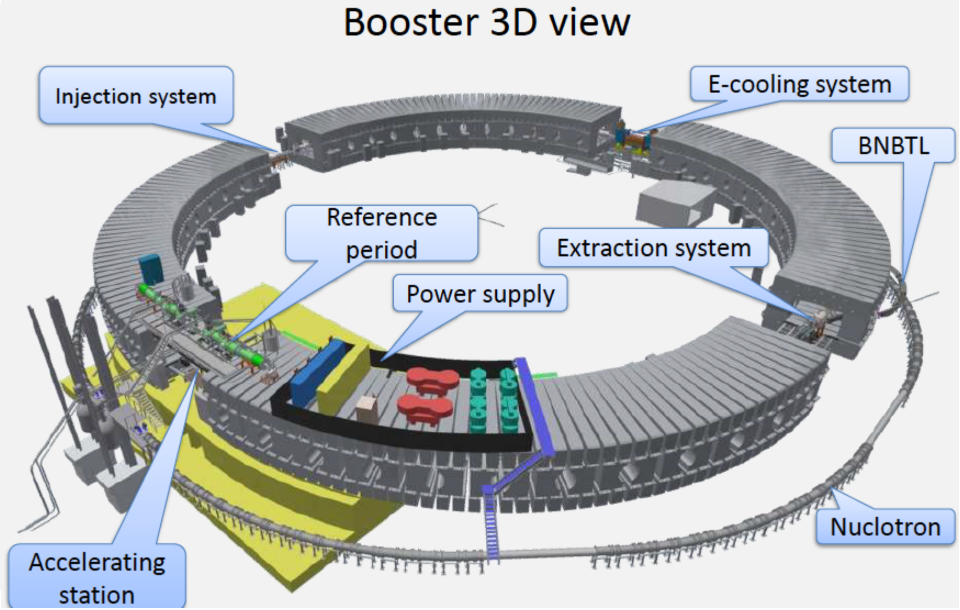


Now, APPEC is working on the **consolidation** and **implementation** of its Roadmap, which for some cases **require cooperation with US**, such as for Multi-Messenger science (CTA, Gravitational Waves, Global Neutrino Network and in particular IceCube, Pierre Auger,…), DM (next generation experiments: DARWIN, ARGO), $0\nu\beta\beta$ next generation experiments (CUPID, LEGEND, NEXT), LBL (DUNE, HPK), CMB S4 & LITEBIRD.

Message from JINR (Dubna, Russia)

- Although the pandemic situation caused a two-month, the tests of the main Booster systems were completed.

- August 2020: Booster commissioning with beam
- September 2020: Delivery of Booster-Nuclotron transport line
- End 2020: First operation Booster+ Nuclotron
- Summer 2020: start collider assembly



NICA: Infrastructure Developments

Infrastructure Developments

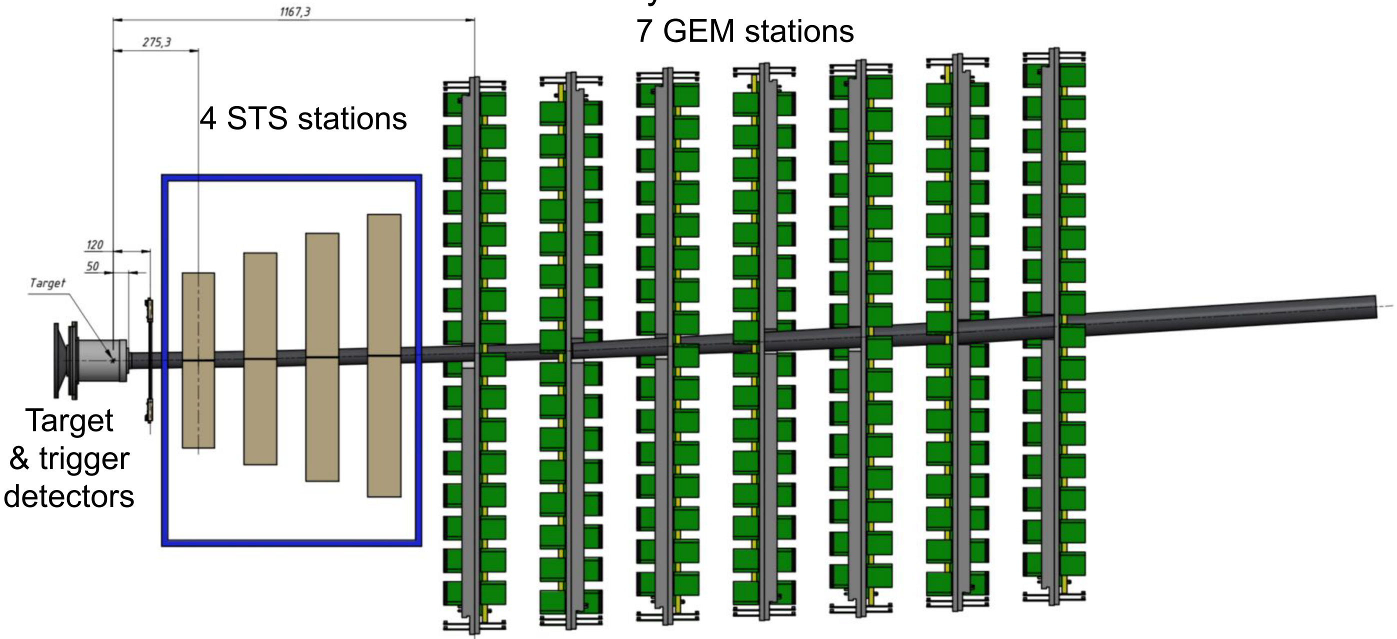
- for 2021

BM@N experiment at NICA

- Upgrading detector for the heavy-ion physics runs planned in 2021 and beyond and on the analysis of the data collected with carbon and argon beams on fixed targets. The results obtained with the C and Ar beams will be published soon

Hybrid central tracker for heavy ions: STS + GEM

Beam intensity of a few 10^6 Hz



JINR in Daya Bay and JUNO

- **Daya Bay and JUNO**

- JUNO is aimed primarily at determining the hierarchy of neutrino masses with high sensitivity and at measuring lepton mixing parameters with sub-percent precision level.
- The contributions of the JINR group to both experiments made in many important systems of the detectors are acknowledged and imprinted in the structure of the collaboration management.
- The JINR team will continue the oscillation analysis and searches for sterile neutrinos in the Daya Bay experiment and will contribute to the development, construction and commissioning of various parts of the JUNO project. The JINR data centre is expected to be one of three European centres managing JUNO data.

JINR in NovA and DUNE

❑ NOvA / DUNE

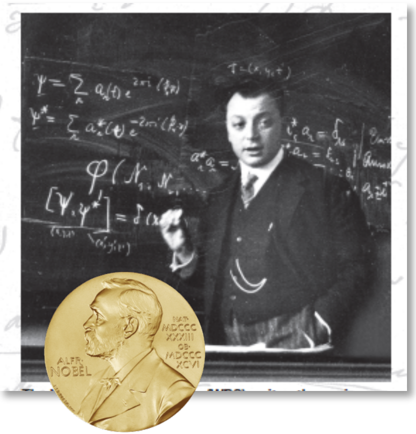
- Since 2014 the JINR group has made significant hardware contributions to the NovA experiment. The team members are also well involved in the ongoing neutrino oscillation analyses and in the studies of supernova and atmospheric neutrinos, as well as in monopole searches. JINR personnel also serve in various leading roles, as Detector Simulation convener, Offline and DAQ Software Release Managers, DAQ, DDT and ROC experts.
- The JINR group also presented its plans for the future LBNF/DUNE neutrino project at Fermilab/SURF, with a gradual increase of their participation expected to start after completion of NOvA. Their first commitments are for the light collection system in the liquid argon TPC for the Near Detector, the preparation of computer resources at JINR and the development of data analysis tools.

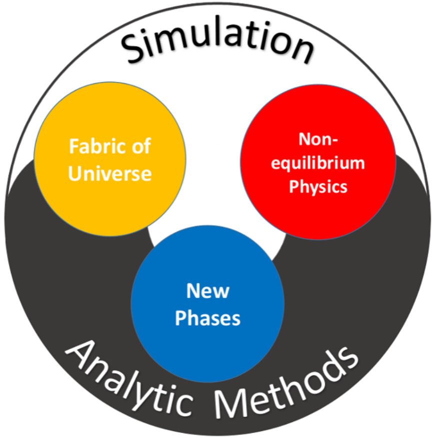
Wolfgang Pauli Centre (WPC) – a joint initiative of DESY and University of Hamburg

The Wolfgang Pauli Centre for theoretical physics *pursues and promotes interdisciplinary research to address the fundamental challenges in our understanding of matter, materials and the universe …*

… fosters international cooperation and a vivid dialogue between theory and experiment.

[from mission statement]





WPC rests on five interdisciplinary **scientific pillars**

- Fabric of the Universe
- New Phases and Phase Transitions
- Non-equilibrium Physics
- Exact and analytical Methods
- Simulation and Numerical Methods

Why "Wolfgang Pauli"?

During Pauli's years in Hamburg (1922-1928), he pioneered work on the anomalous Zeeman effect, electron spin and Pauli equation, and the electron gas in metals. In 1925, Pauli published his work on the "exclusion principle," for which he was later awarded the Nobel prize.

Eine Partnerschaft der
Universität Hamburg und DESY

The Wolfgang Pauli Centre

Central measure is construction of new building to host **offices & co-working spaces for theory departments & guest scientist program** including

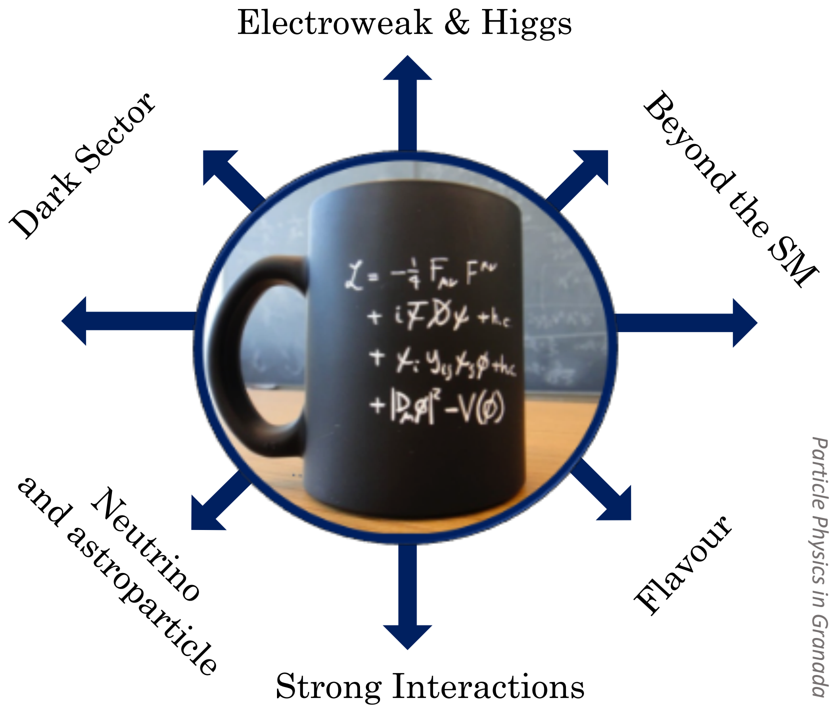
- *Thematic Institutes, workshops and conferences*
- *Research hotel* hosting long term guests and young investigator groups. ....

2020	Scientific evaluation of WPC concept (completed)
2021	Contracts and Financing (around 20 Mio Euros)
2022 - 2025	Construction of building (around 5000 sqm)
	Inauguration of WPC building in spring of 2026

The quest for understanding particle physics

Through theoretical research the many open questions in particle physics can be related to a large variety of observable phenomena that can be captures in some principle categories

Seeking new knowledge requires a profound empiric exploration with colliders at the intensity and energy frontier, primary and secondary beams at accelerators, storage rings, high-power lasers, precision instrumentation, nuclear reactors, underground facilities, interferometers, cosmic sources, detectors in orbit, …



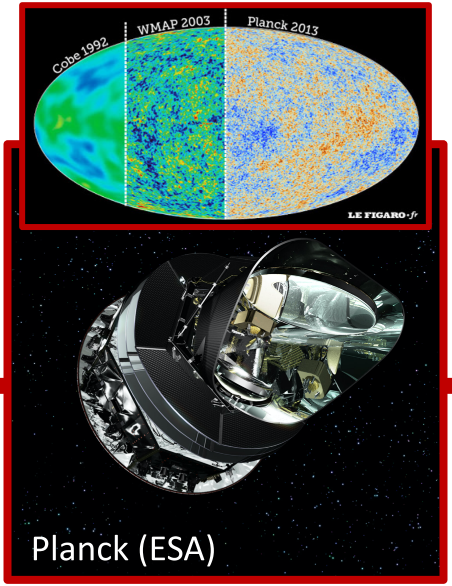
As an example the physics themes of the Open Symposium of the European Strategy for Particle Physics in Granada

This vast portfolio calls for coherent and community-wide Strategies

The cosmic frontier: CMB precision physics

Previous flagship

impressive science



completed

Next generation "Dark Universe" flagship

>30 M spectroscopic redshifts with 0.001 accuracy up to z ~2
to measure the acceleration of the universe

ESA: European Space Agency

Essential: the Theory backbone in Europe

Theoretical research continues to motivate (new) experimental searches and provides crucial tools in support of the empiric exploration.

Wolfgang Pauli Centre – new building by 2026

interdisciplinary research to address fundamental challenges in our understanding of matter, materials and the universe

European Consortium for Astroparticle Theory

bring together the European community of theoretical astroparticle physicists and cosmologists

Essential: the Theory backbone in Europe

Theoretical research continues to motivate (new) experimental searches and provides crucial tools in support of the empiric exploration.

ESPP: "Europe should continue to vigorously support a broad programme of theoretical research covering the full spectrum of particle physics from abstract to phenomenological topics."

Wolfgang Pauli Centre – new building by 2026

interdisciplinary research to address fundamental challenges in our understanding of matter, materials and the universe

European Consortium for Astroparticle Theory

bring together the European community of theoretical astroparticle physicists and cosmologists

ESPP: "The CERN theory department acts as a focus point for research, both within Europe and worldwide."