Overview of Current and Future Experiments at the Intensity Frontier

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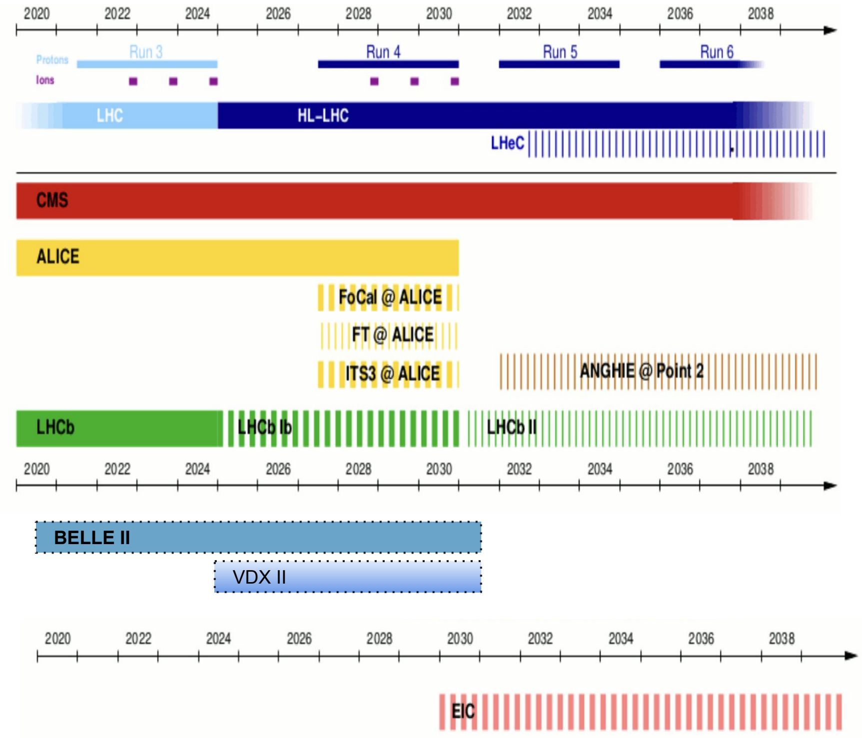
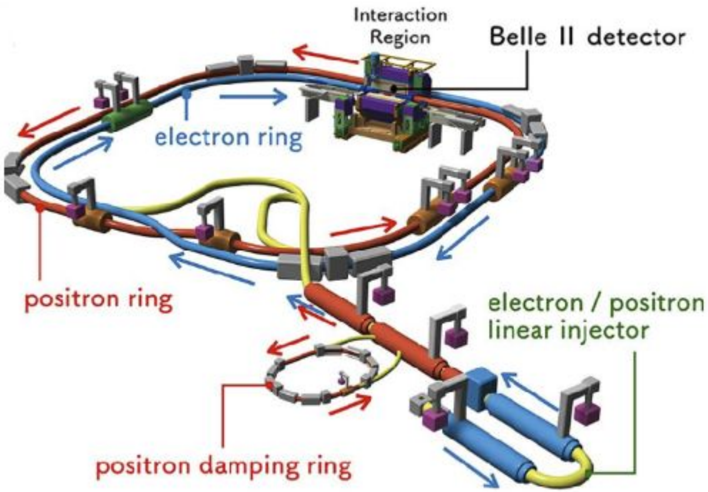
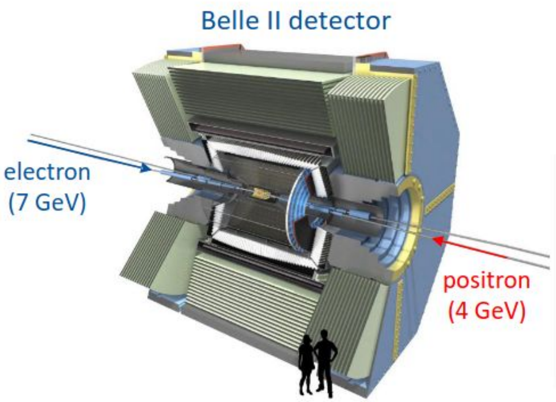
Experiments at colliders

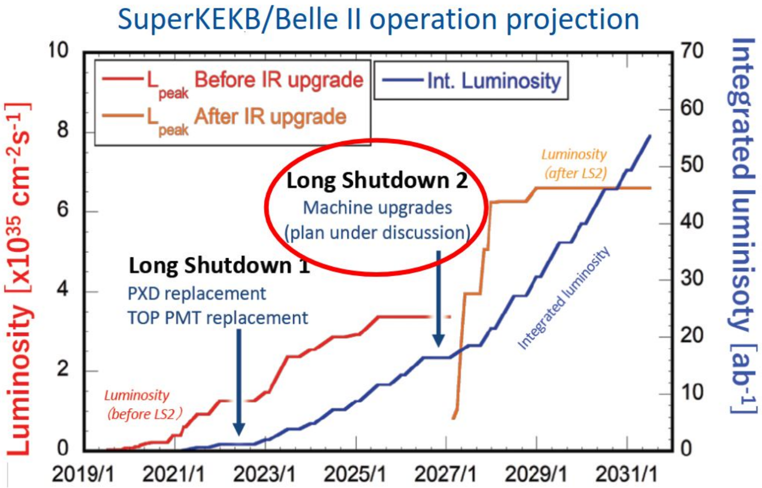
- LHCb experiment at CERN
- Belle II experiment at SuperKEKB
- Future colliders



Belle II experiment

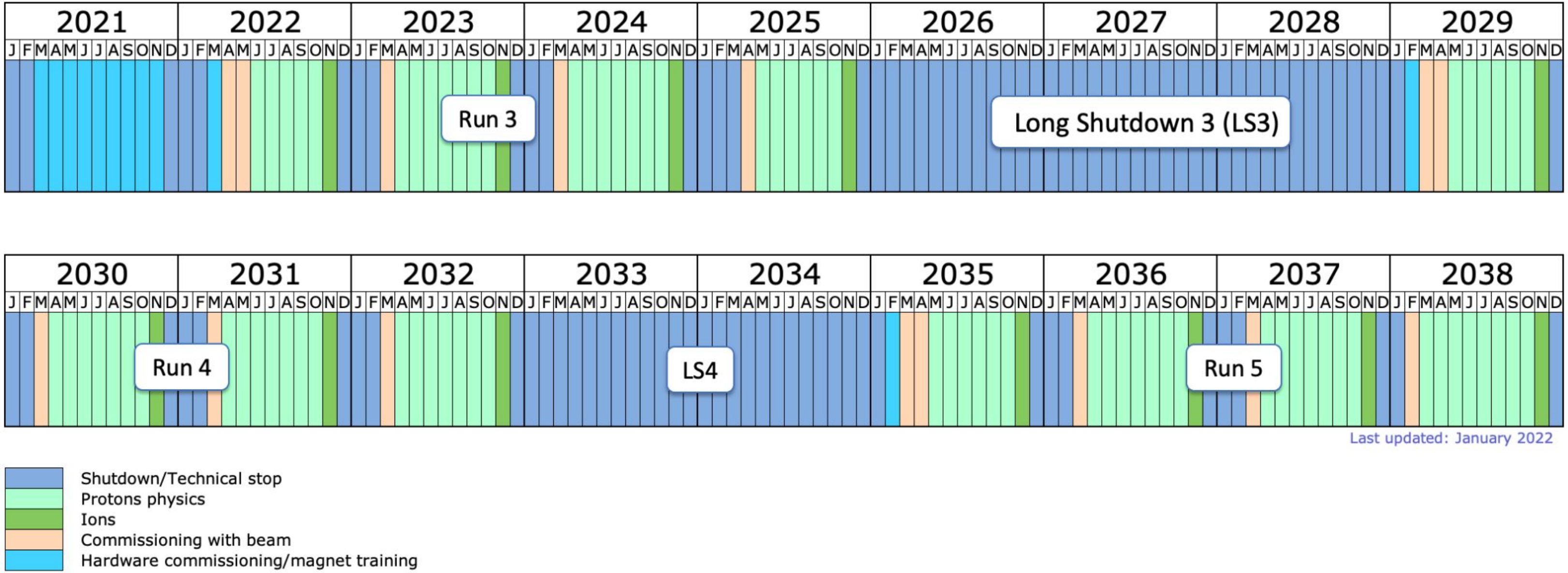






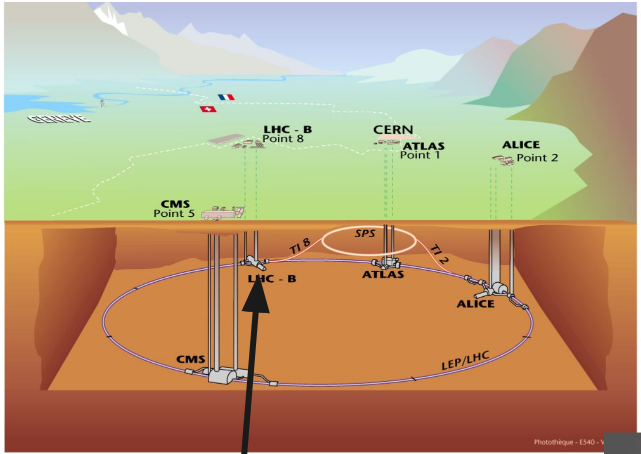
- Belle II upgrade talk from 2021 GDR meeting
- Updates in dedicated talks at this session

LHC schedule

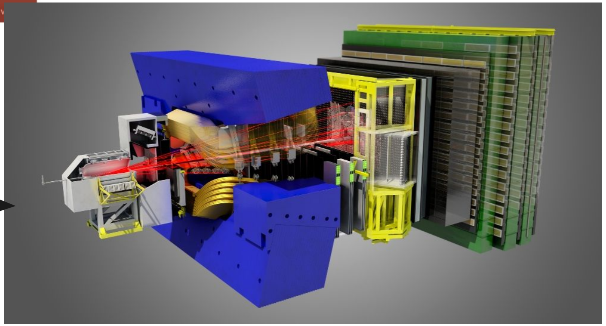


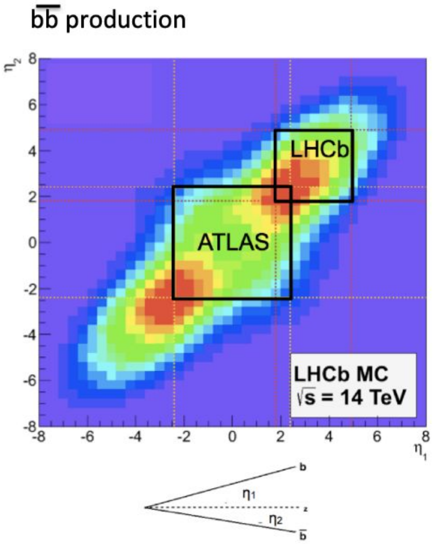
Source: [LHC long term schedule]

The LHCb experiment

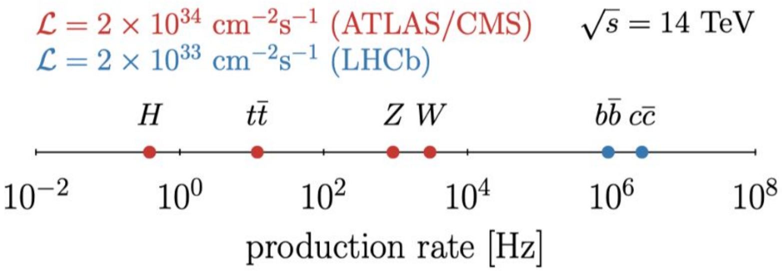


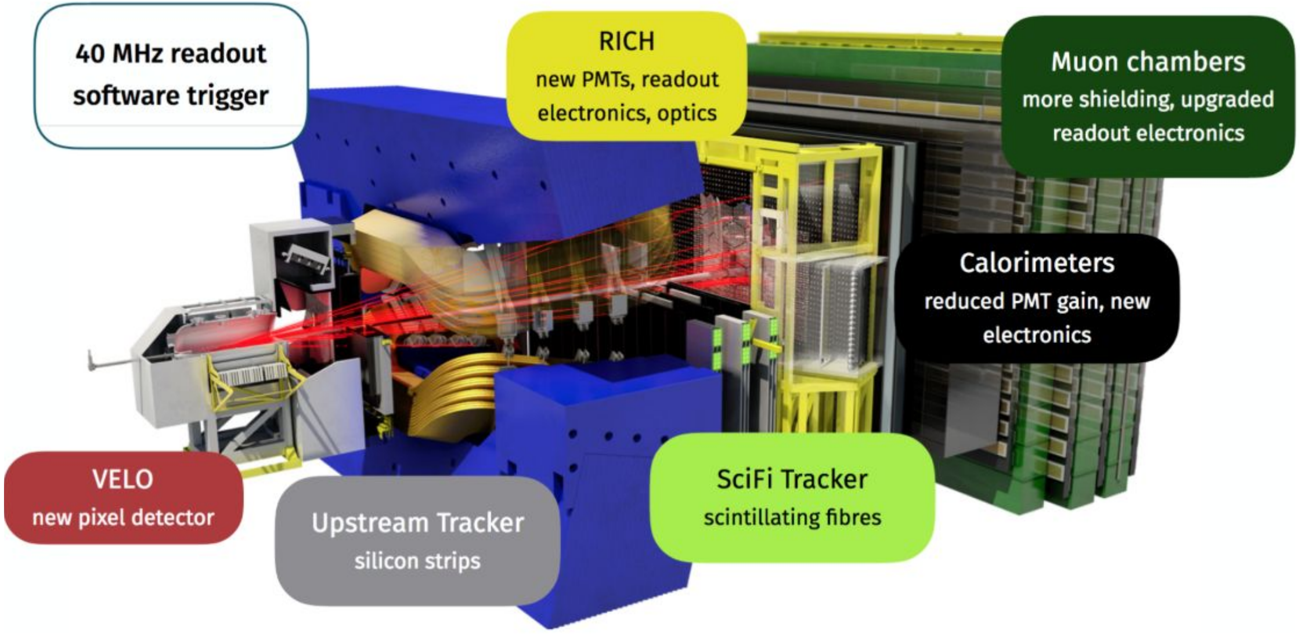
General purpose detector in the forward region specialized in beauty and charm physics





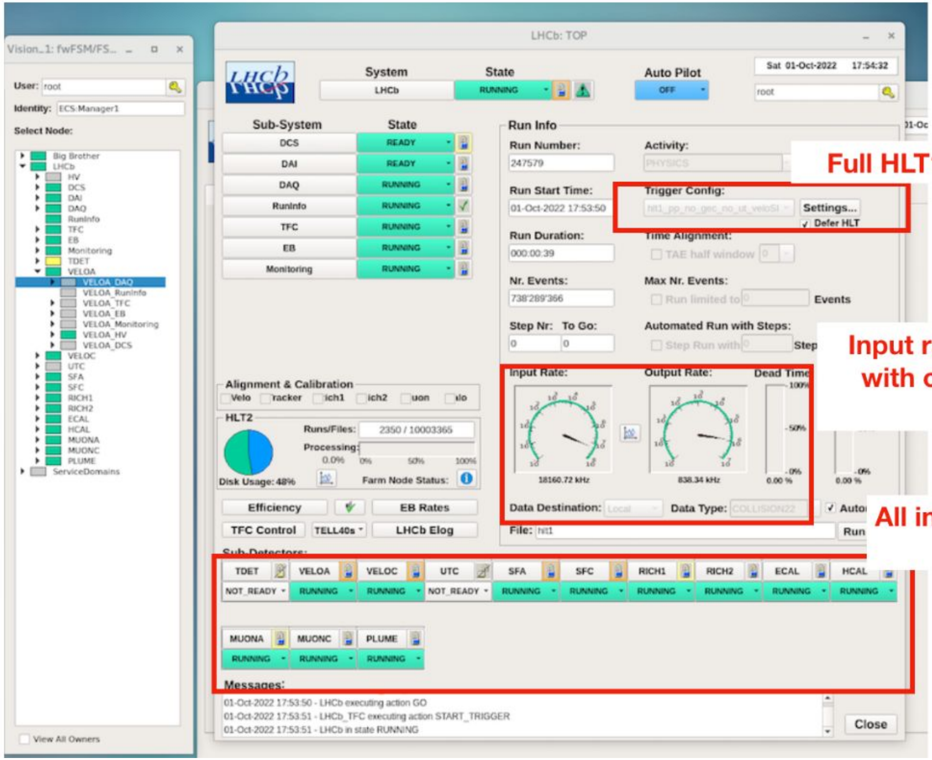
LHCb Upgrade I





LHCb commissioning status

1st October 2022

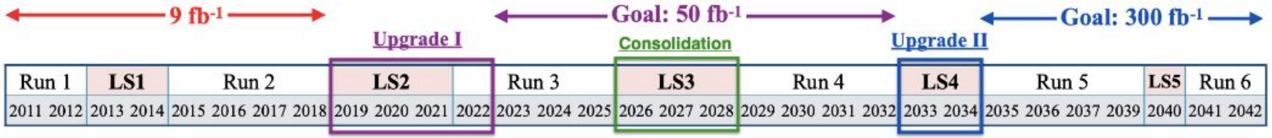


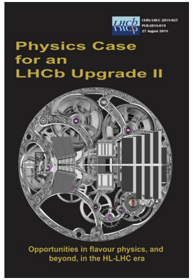
Full HLT1 tracking sequence

Input rate ~20 MHz (max. with current LHC filling scheme)

All installed sub-detectors included

LHCb Upgrade II

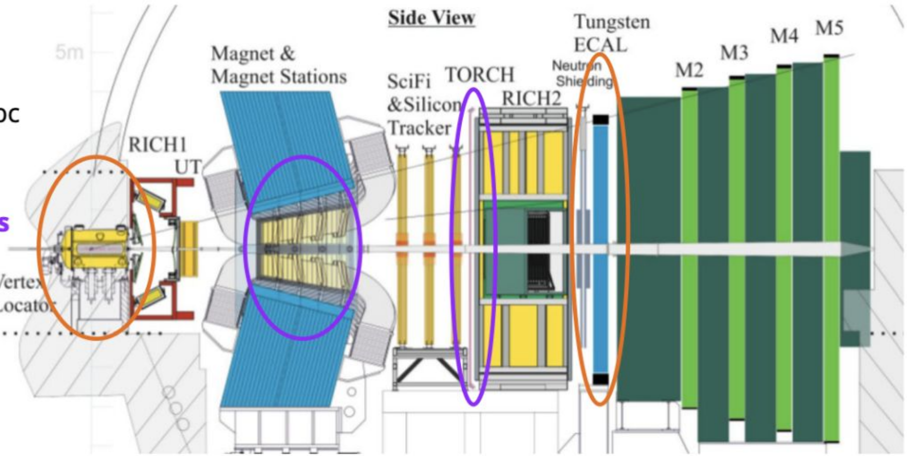




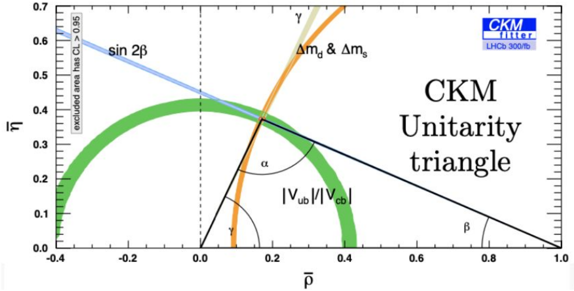
- Precision timing for tracking and PID
- Extreme radiation hardness
- New detectors
- Full heterogeneous software trigger

Timing:
~50 collisions/bc

New detectors

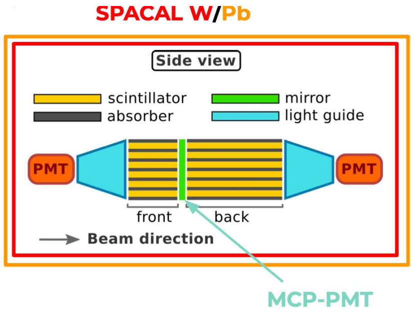


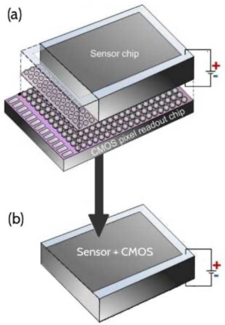
Unprecedented sensitivity for flavor physics



CERN courier article about LHCb Upgrade II to appear in November…

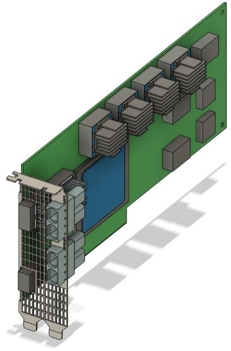
LHCb Upgrade II - French plans

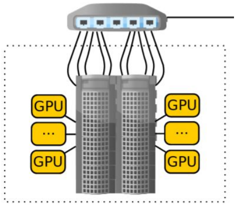




Thinner MAPS sensor

- Calorimeter
  - ECAL2 with 20 ps time resolution from dedicated ASIC
- Tracking detectors
  - Upgrade of UT detector with Monolithic Active Pixel Sensors (MAPS)
  - Micro-channel cooling for tracking detectors
- Data acquisition at 800 Gbit/s
  - Electronics card to receive data from sub-detectors and transfer them to DAQ farm
- Fully heterogeneous real-time analysis at 200 Tbit/s
  - 2nd stage High Level Trigger (HLT2) processed on co-processors (such as GPUs), HLT1 already processed on GPUs in Run 3





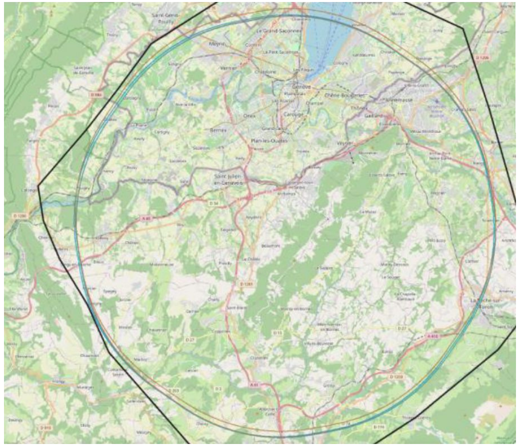
HLT2 compute

LHCb upgrade II talk by P. Robbe at last annual workshop

🇫🇷

Future circular collider (FCC)

	√s	L /IP ($cm^{-2} s^{-1}$)	Int. L /IP(ab^{-1})	Comments
e^+e^- FCC-ee	~90 GeV Z 160 WW 240 H ~365 top	230 x10^{34} 28 8.5 1.5	75 5 2.5 0.8	2-4 experiments Total ~ 15 years of operation
pp FCC-hh	100 TeV	5 x 10^{34} 30	20-30	2+2 experiments Total ~ 25 years of operation
PbPb FCC-hh	$\sqrt{s_{NN}}$ = 39TeV	3 x 10^{29}	100 nb^{-1}/run	1 run = 1 month operation
ep Fcc-eh	3.5 TeV	1.5 10^{34}	2 ab^{-1}	60 GeV e- from ERL Concurrent operation with pp for ~ 20 years
e-Pb Fcc-eh	$\sqrt{s_{eN}}$ = 2.2 TeV	0.5 10^{34}	1 fb^{-1}	60 GeV e- from ERL Concurrent operation with PbPb



- Feasibility Study: 2021-2025
- If project approved before end of decade → construction can start beginning 2030s
- FCC-ee operation ~2045-2060
- FCC-hh operation ~2070-2090++

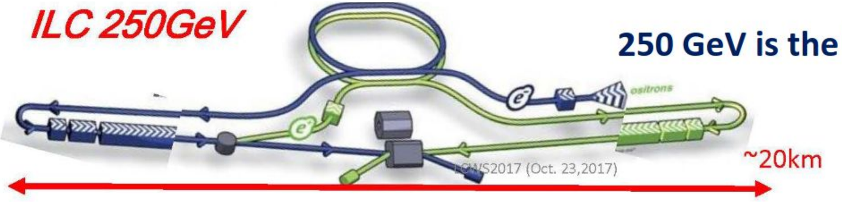
FCC Conceptual Design Report

Source: F. Gianotti, FCC week 2022

International Linear Collider (ILC)

Source: ILC TDR

Energy	Reaction	Physics Goal
91 GeV	$e^+e^- \to Z$	ultra-precision electroweak
160 GeV	$e^+e^- \to WW$	ultra-precision W mass
250 GeV	$e^+e^- \to Zh$	precision Higgs couplings
350–400 GeV	$e^+e^- \to t\bar{t}$	top quark mass and couplings
	$e^+e^- \to WW$	precision W couplings
	$e^+e^- \to \nu\bar{\nu}h$	precision Higgs couplings
500 GeV	$e^+e^- \to f\bar{f}$	precision search for Z'
	$e^+e^- \to t\bar{t}h$	Higgs coupling to top
	$e^+e^- \to Zhh$	Higgs self-coupling
	$e^+e^- \to \tilde{\chi}\tilde{\chi}$	search for supersymmetry
	$e^+e^- \to AH, H^+H^-$	search for extended Higgs states
700–1000 GeV	$e^+e^- \to \nu\bar{\nu}hh$	Higgs self-coupling
	$e^+e^- \to \nu\bar{\nu}VV$	composite Higgs sector
	$e^+e^- \to \nu\bar{\nu}t\bar{t}$	composite Higgs and top
	$e^+e^- \to \tilde{t}\tilde{t}^*$	search for supersymmetry

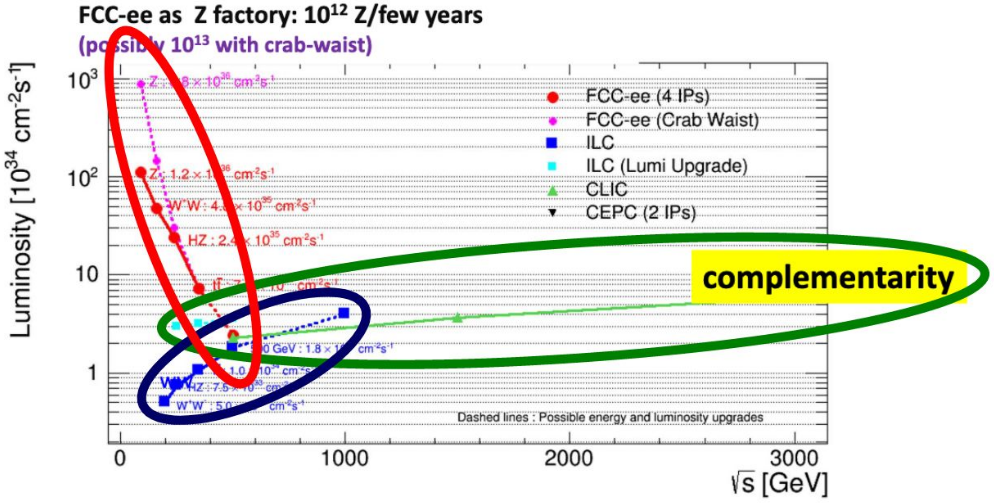


250 GeV is the baseline for initial implementation

but considerations for future options
(Z pole and energy upgrades)
now officially encouraged

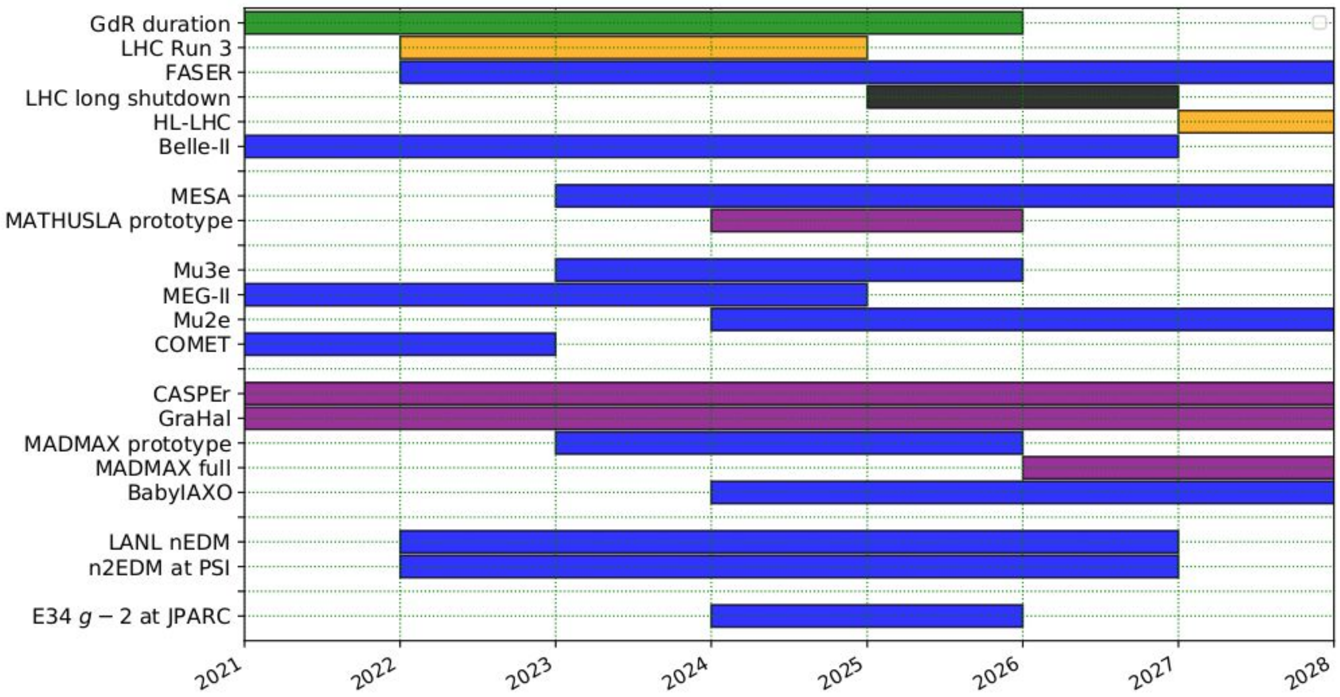
Complementarity of FCC and ILC

- FCC-ee: largest luminosity
  - Electroweak physics
  - Flavor physics
  - Low-energy Higgs physics
  - Top mass and electroweak couplings
- ILC: largest energy
  - Top physics
  - High-energy Higgs physics
  - BSM physics



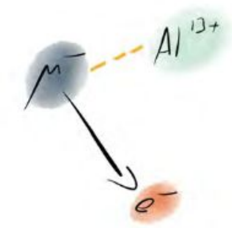
Source: P. Janot, 3rd FCC Physics Workshop

Experiments at accelerators



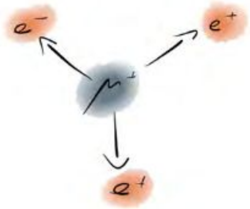
Source: [GDR Intensity Proposal for Renewal]

Charged Lepton Flavor Violation



$\mu^- N \rightarrow e^- N$

$\mu^+ \rightarrow e^+ \gamma$



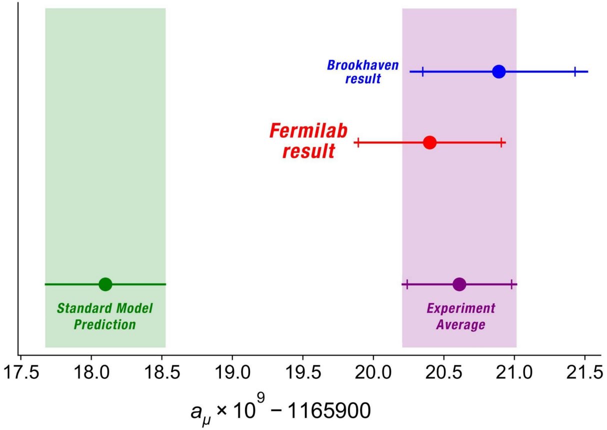
$\mu^+ \rightarrow e^+ e^- e^+$

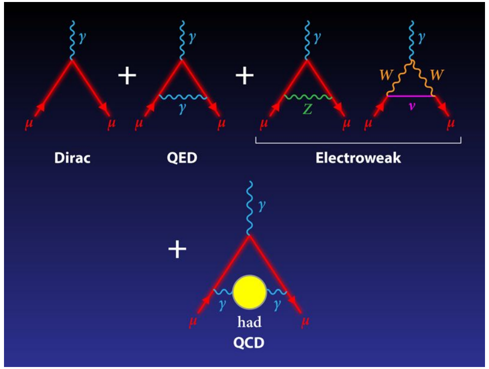
- Branching ratio suppressed to below 10^{-54} in the standard model
- Mu3e at PSI: $\mu \rightarrow$ eee
  - 10^8 - 10^9 muons on target, TDR, BR sensitivity to 10^{-16}
- MEG-II at PSI: $\mu \rightarrow$ eγ
  - 10^7 - 10^8 muons/s on target, Design of MEG II, BR sensitivity to 10^{-14}
- $\mu \rightarrow$ e near nuclei
  - Mu2e at Fermilab: Aluminum target, 10^{17} muons/year, BR sensitivity to 10^{-17}
  - COMET at J-PARC, Aluminum target, 10^{16} muons on target in phase 1, TDR, final BR sensitivity to 10^{-16}

Muon anomalous magnetic moment

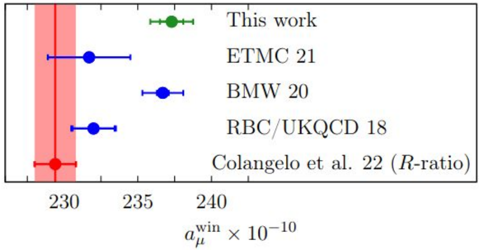
Source: FNAL news

- Fermilab g-2
  - 2021 results confirm long-standing discrepancy between theory and experiment at 4.2 σ
- E-34 at J-PARC
  - Will measure g-2 and electric dipole moment (EDM)
  - Different technique than Fermilab experiment, using ultracold muons
- Ongoing work in theory community to understand hadronic vacuum polarization contribution
  - Recent lattice calculations of hadronic vacuum polarization significantly reduce tension



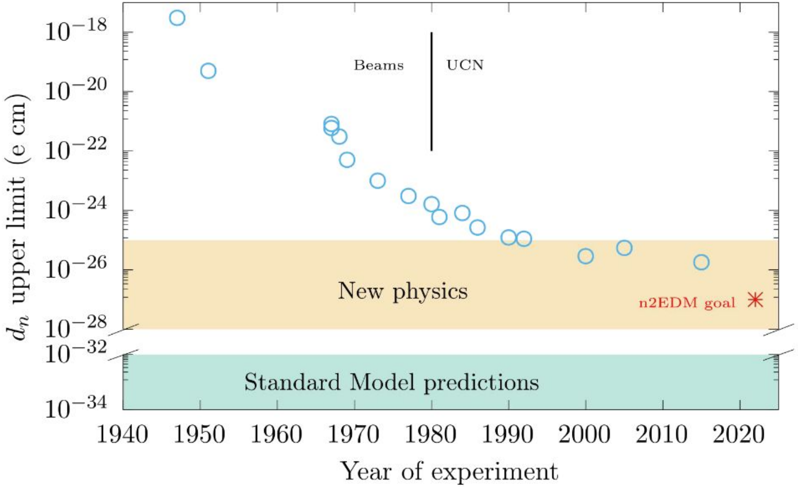


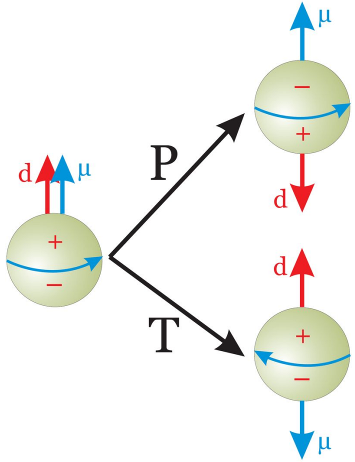
arXiv:2206.06582



Neutron Electric Dipole Moment (nEDM)

- n2EDM experiment being installed at Paul Scherrer Institute (PSI), TDR
- Use Ultracold Neutron Source (UCN) -> dedicated talk in this session
- Expected sensitivity: 10^{-27} e cm in 500 days of data-taking, one order of magnitude improvement
- nEDM violates P, T and CP symmetry -> Tight constraints on BSM models

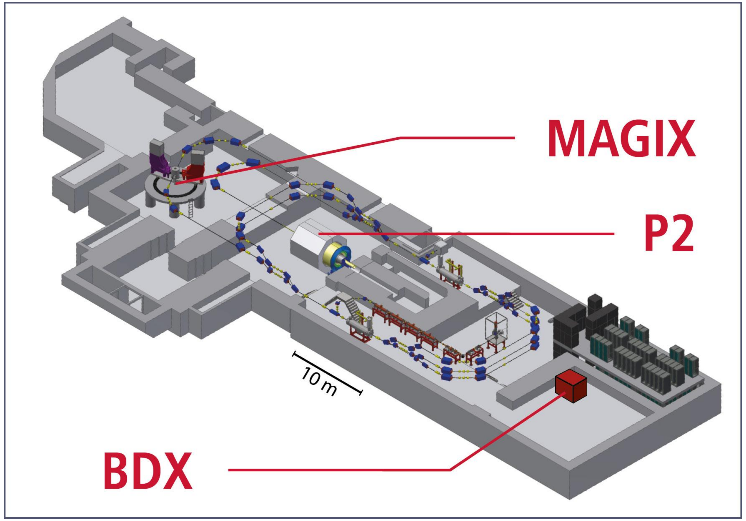




Source: Wikipedia nEDM

Talk by W. Saenz at 2020 annual workshop

MESA accelerator in Mainz

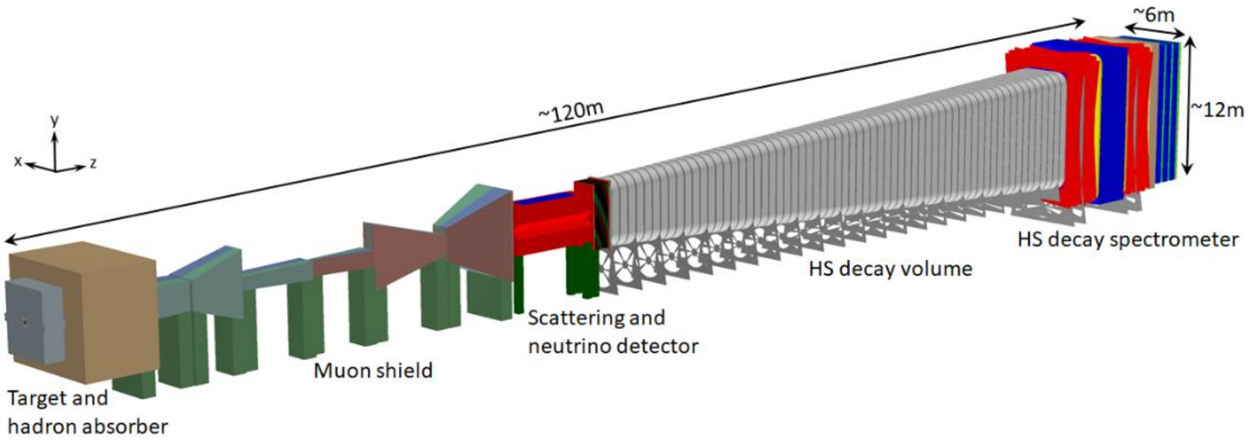


Source: [MESA website]

- High intensity beam (150 μA) of 155 MeV electrons
- P2 experiment
  - Measurement of weak mixing angle with 0.1% precision
- MAGIX:
  - Proton form factor measurement at lowest impulse transfer rate -> proton radius puzzle
- BDX: Beam dump experiment for dark matter searches
  - Mass sensitivity in MeV range with 10^{22} electrons on target

SHiP beam dump experiment @ SPS

- Sensitive to particles in MeV - GeV range
- Very weakly interacting long-lived particles
- Heavy neutral leptons, dark photons, light scalars, pseudoscalars (ALPs), supersymmetric partners
- 10^{19} protons per year

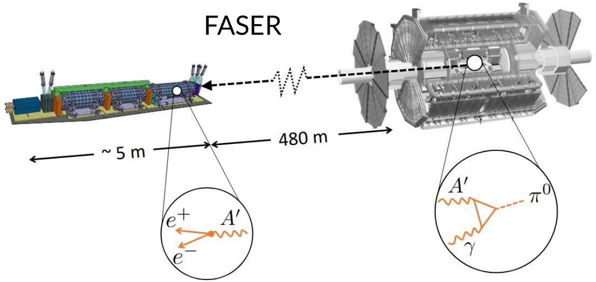


arXiv:2112.01487

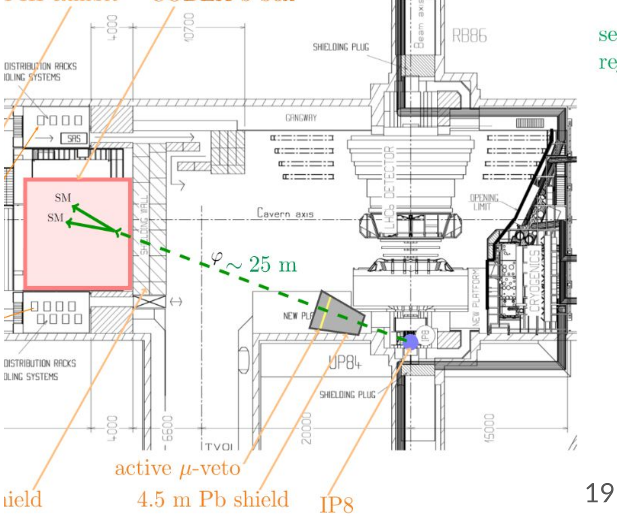
Long-lived particles produced in LHC collisions

- FASER, [TDR]
  - 480 m downstream of ATLAS experiment
  - 10^{16} pions / year
- CODEX-b, [EOI]
  - 25 m from LHCb experiment
  - Masses from MeV to TeV probed
- MATHUSLA, [LOI]
  - Above CMS detector
  - Masses above GeV range

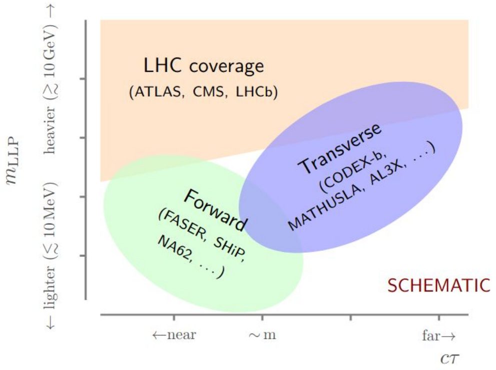
FASER



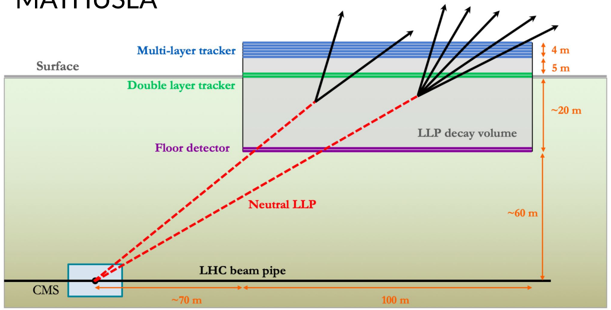
CODEX-b



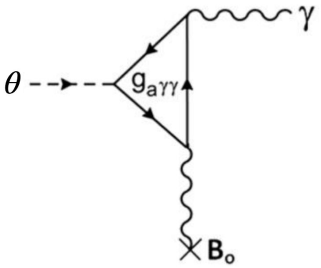
arXiv:1911.00481

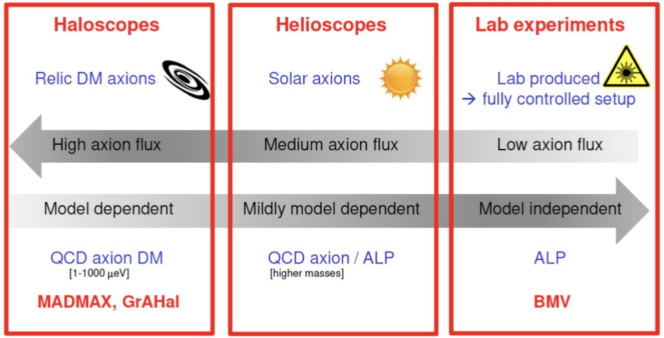


MATHUSLA

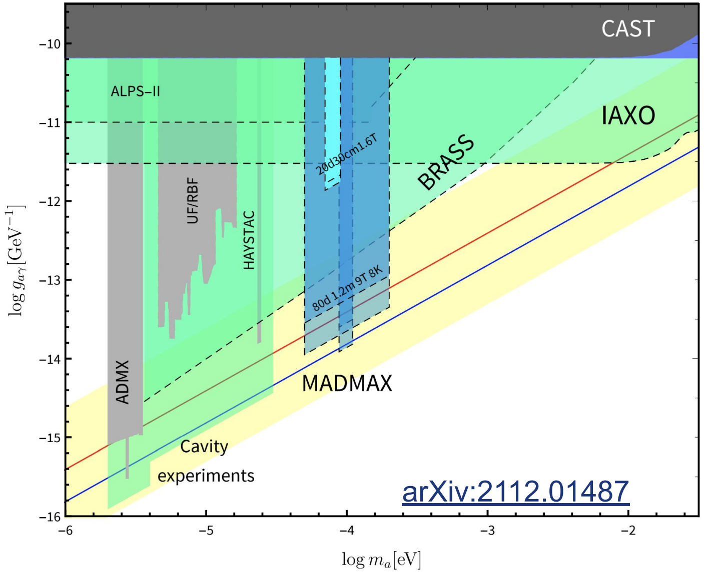


Axion searches





Source: MESA website

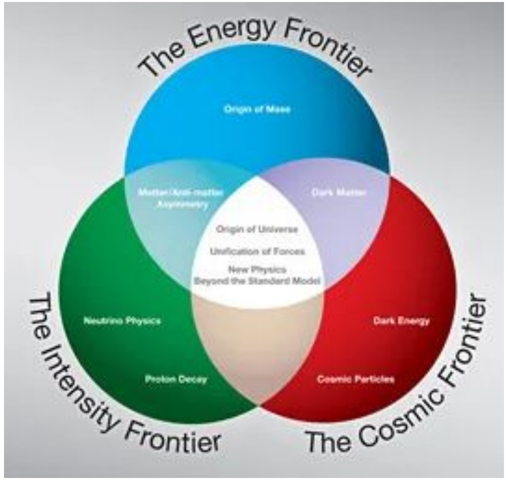


Grenoble hybrid magnet

- Axion search based on photo-conversion with interaction with static magnetic field.
- Three experimental approaches: holoscopes, helioscopes, lab experiments
- Many facilities to measure axions in the future:
  - MADMAX: tests performed with CERN's Morgot magnet, full detector to be built in the coming years
  - JURA: evolution of OSQAR + ALPS @CERN
  - GraHal: based around the Grenoble hybrid magnet which will be operant in 2023

Conclusions

- Intensity frontier is very active field of research
- Expect LHCb Run 3 and Belle II results within the next years
- Upgrade program at colliders up to ~2030
- R&D for FCC and ILC continuing in parallel
- Wide range of smaller experiments with high intensities
- French contributions mostly in nEDM, ALP and long-lived particle searches



INTENSITY frontier GDR-InF