FUTURE CIRCULAR COLLIDER

Future Circular Collider

Budúci kruhový urýchľovač

Juraj Smieško (CERN, ÚEF SAV Košice)

70 rokov CERN — Inšpirácia pre budúcnosť

20 Jún 2024

Košice, SK

CERN

CERN

Fotografia pred začatím prvých prác.

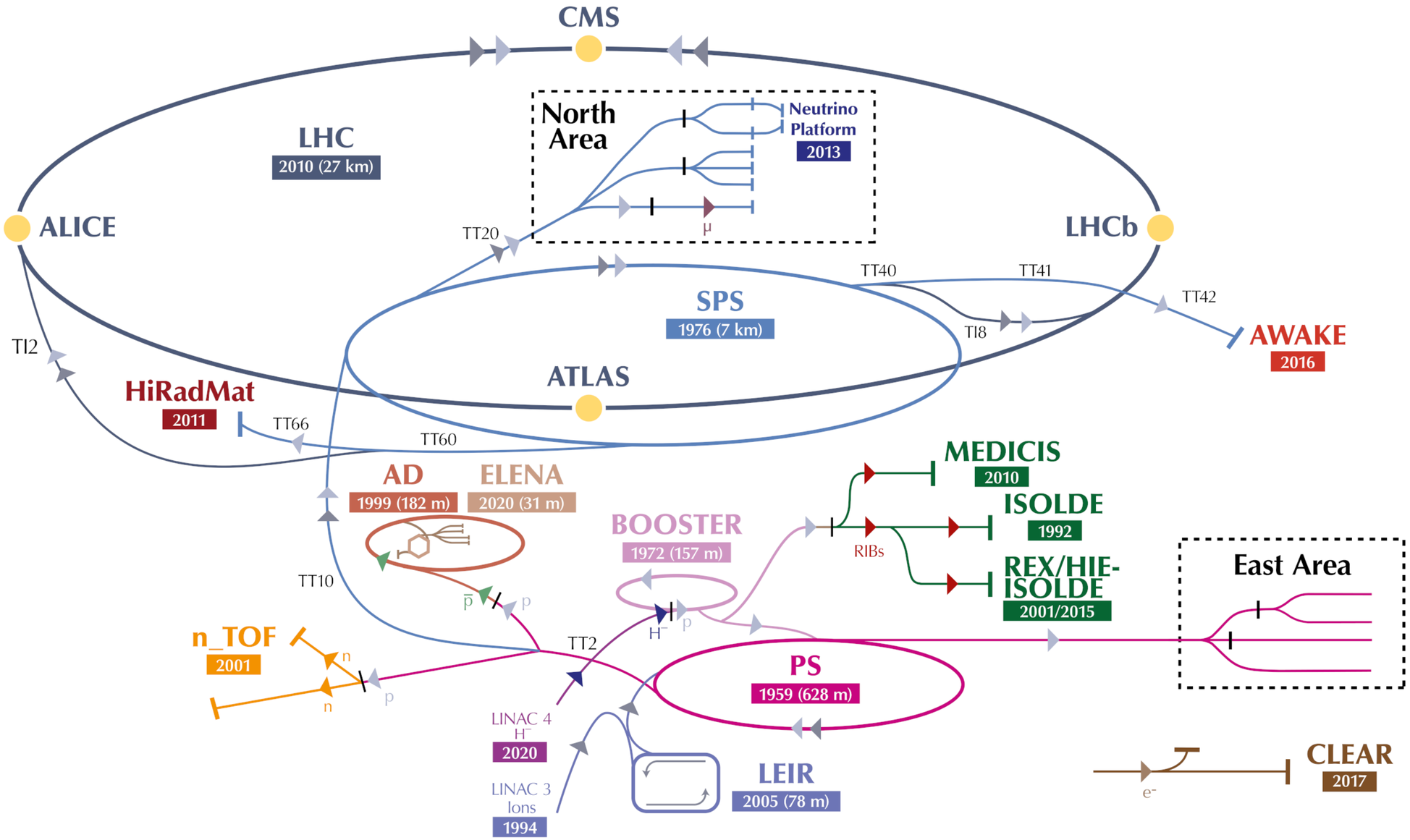
zdroj: The history of CERN

Európska organizácia pre jadrový výskum

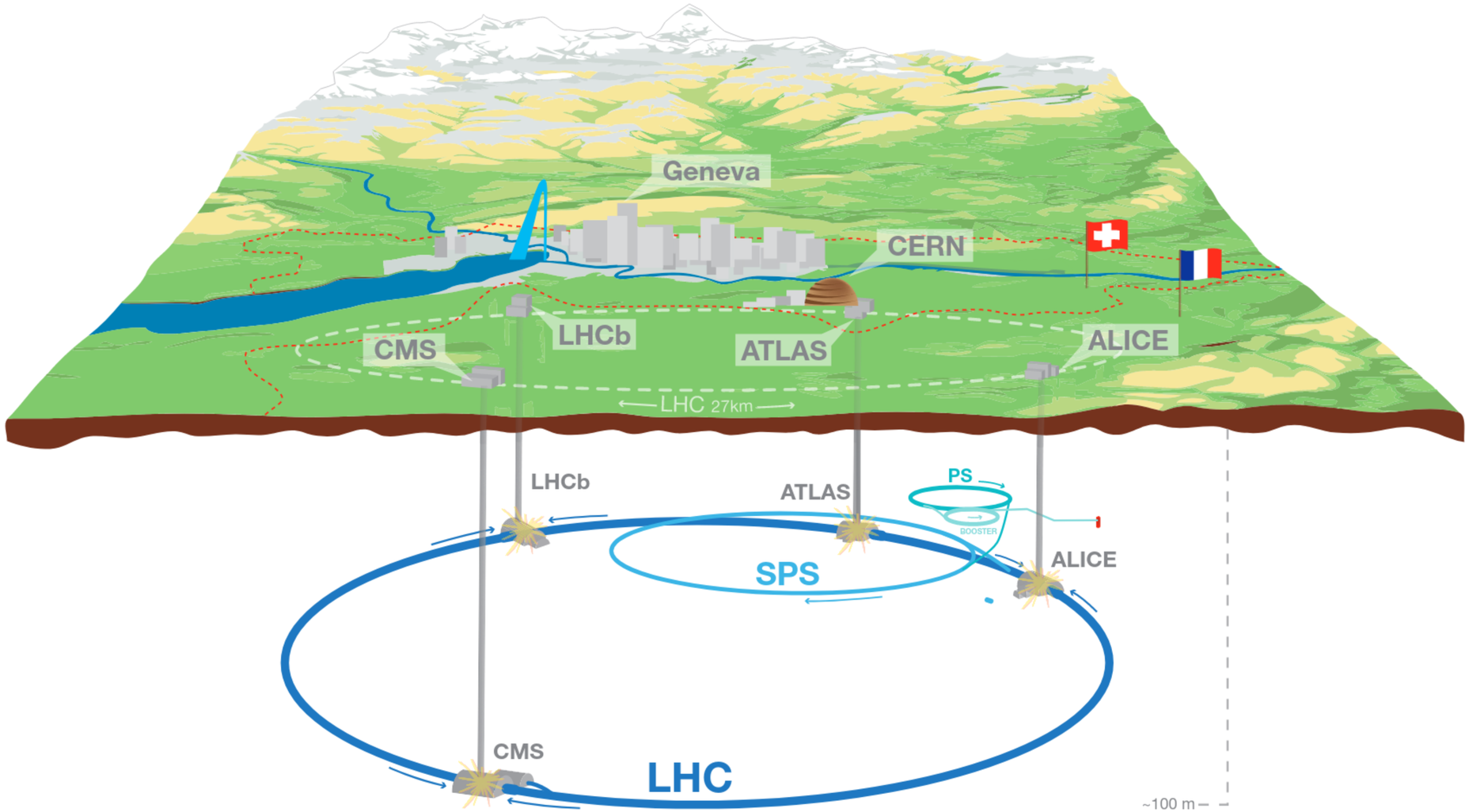
- Založená v roku 1954
  - prvé náznaky od r. 1949
- Sídli v mestečku Meyrin, neďaleko Ženevy
- 23 plných členov a 11 asociovaných
- Slovensko je člen od 1. júla 1993 (spolu s ČR)

CERN Accelerator Complex animation - OVERVIEW

zdroj: CERN CDS



zdroj: CERN CDS



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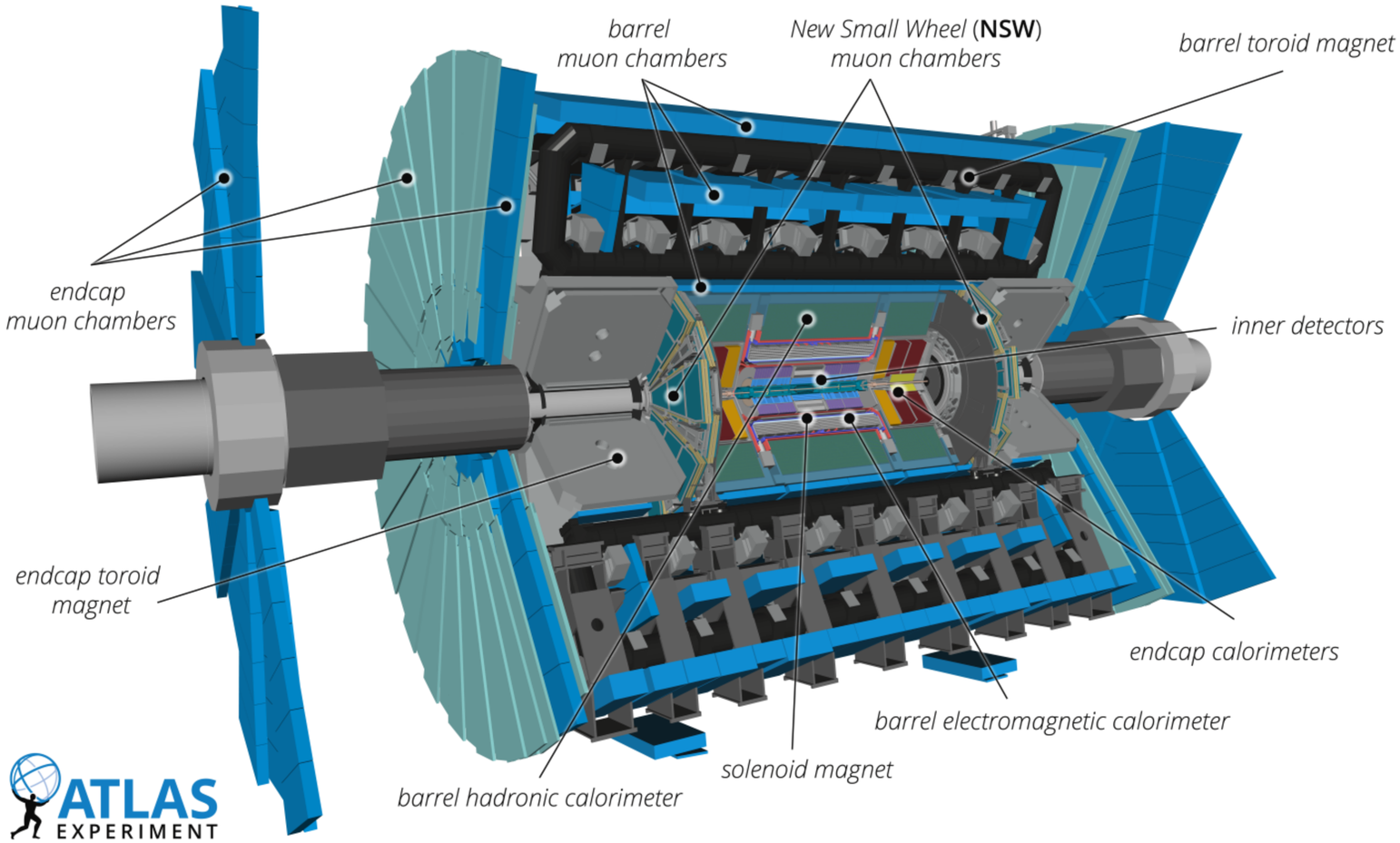

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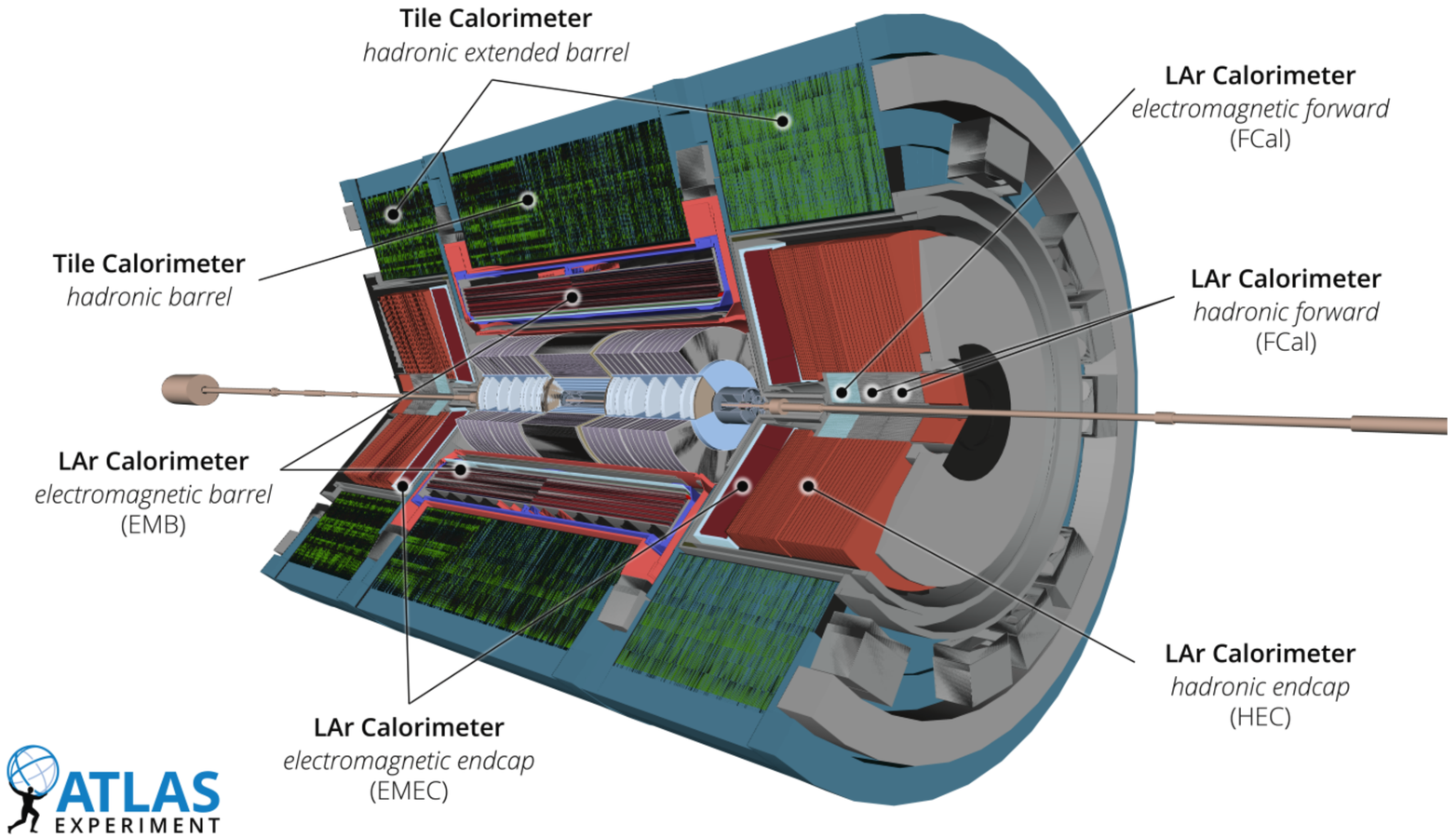

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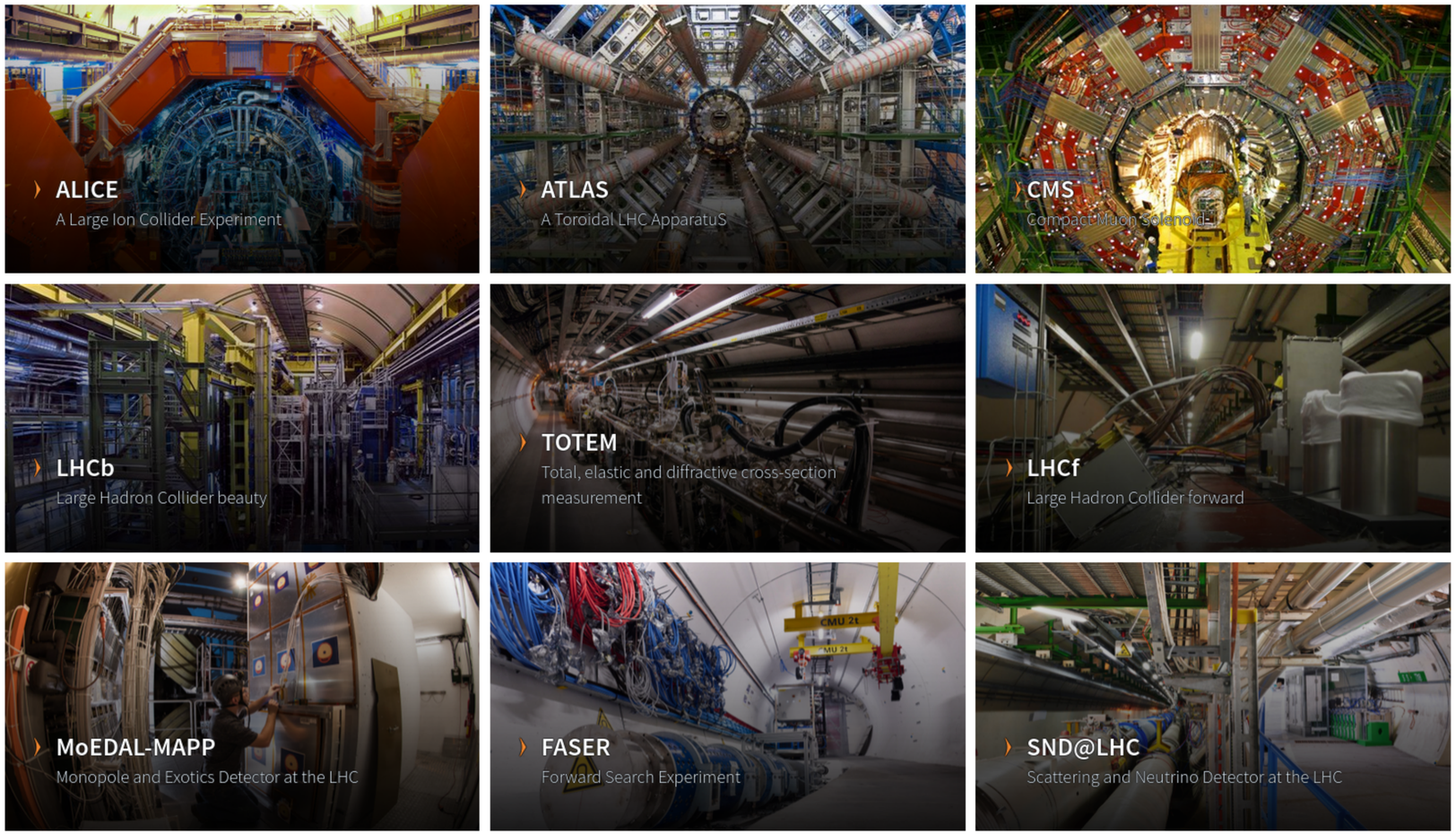
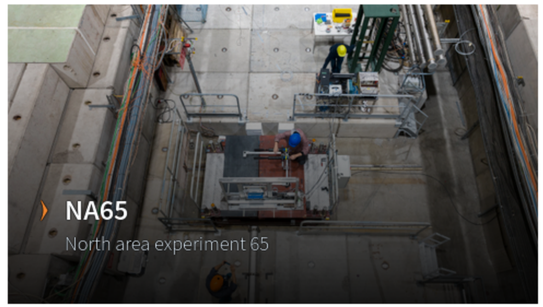
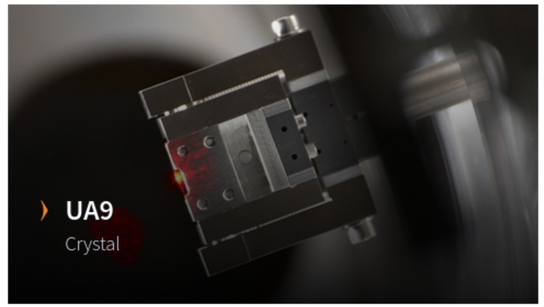


zdroj: CERN Experiments

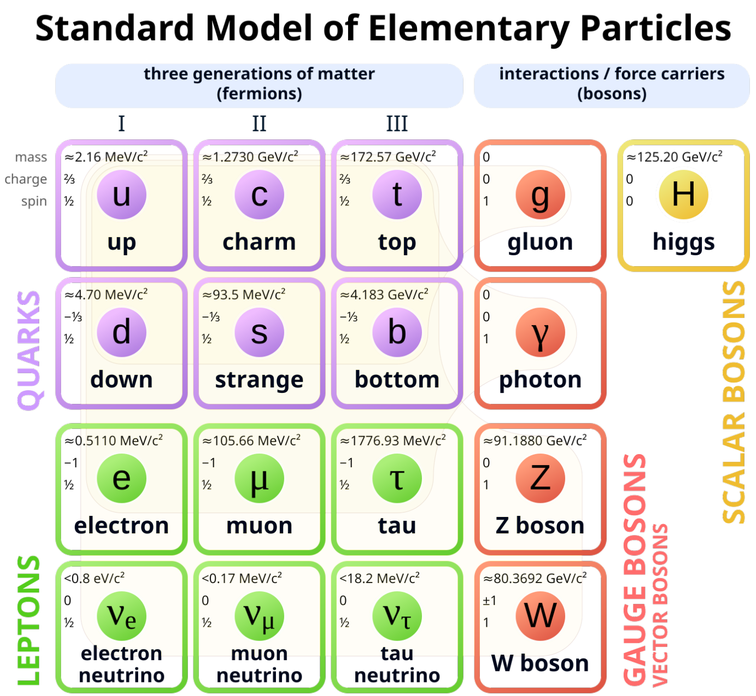


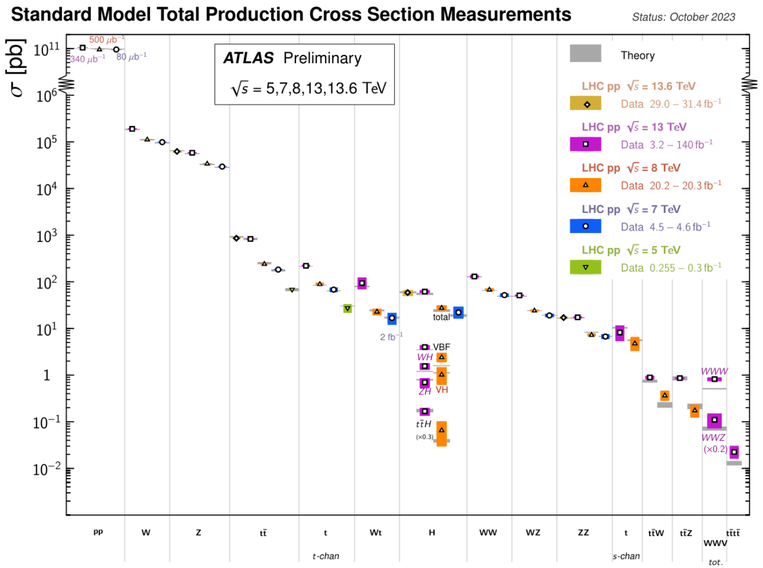


zdroj: CERN Experiments

Čo sme zistili s pomocou LHC

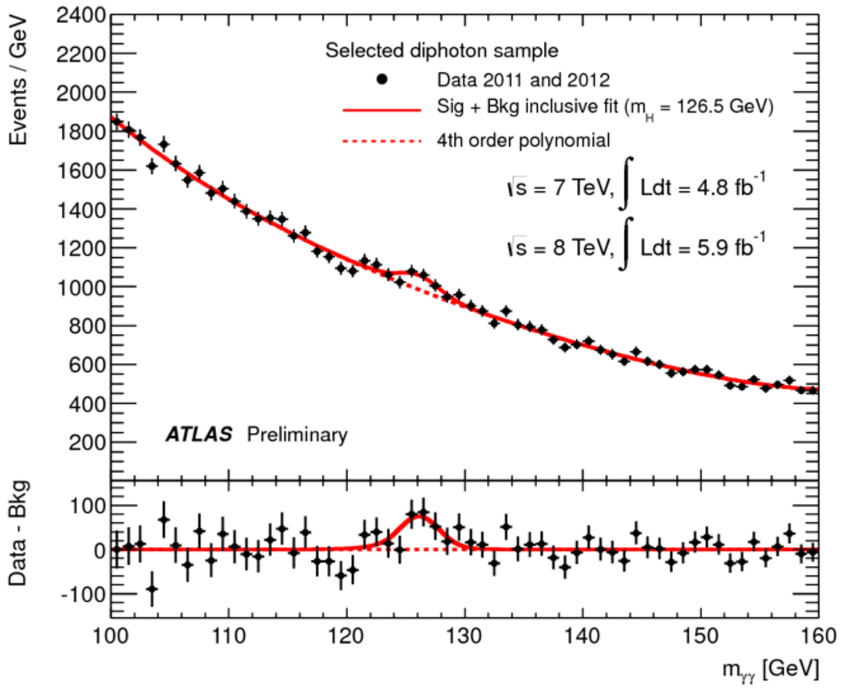
Precízne zmeraný Štandardný model

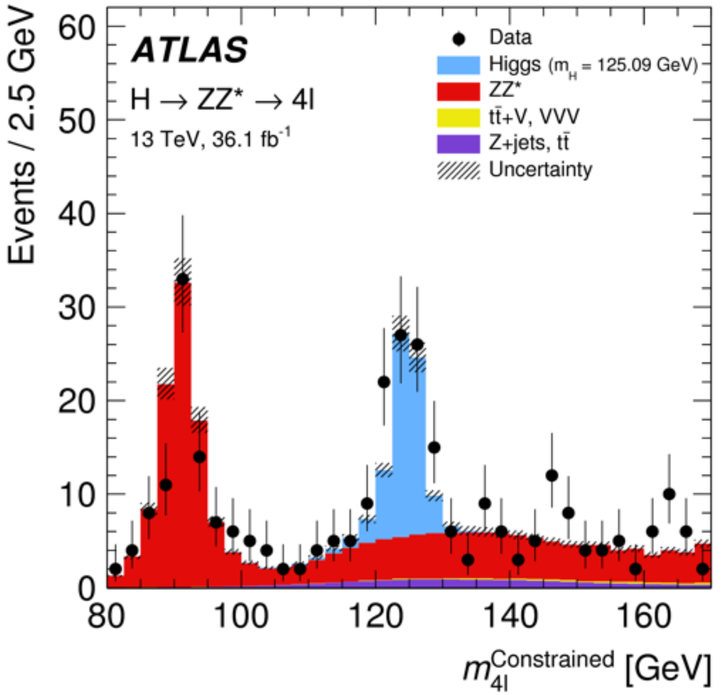




zdroj: Wikipedia, ATLAS Collaboration

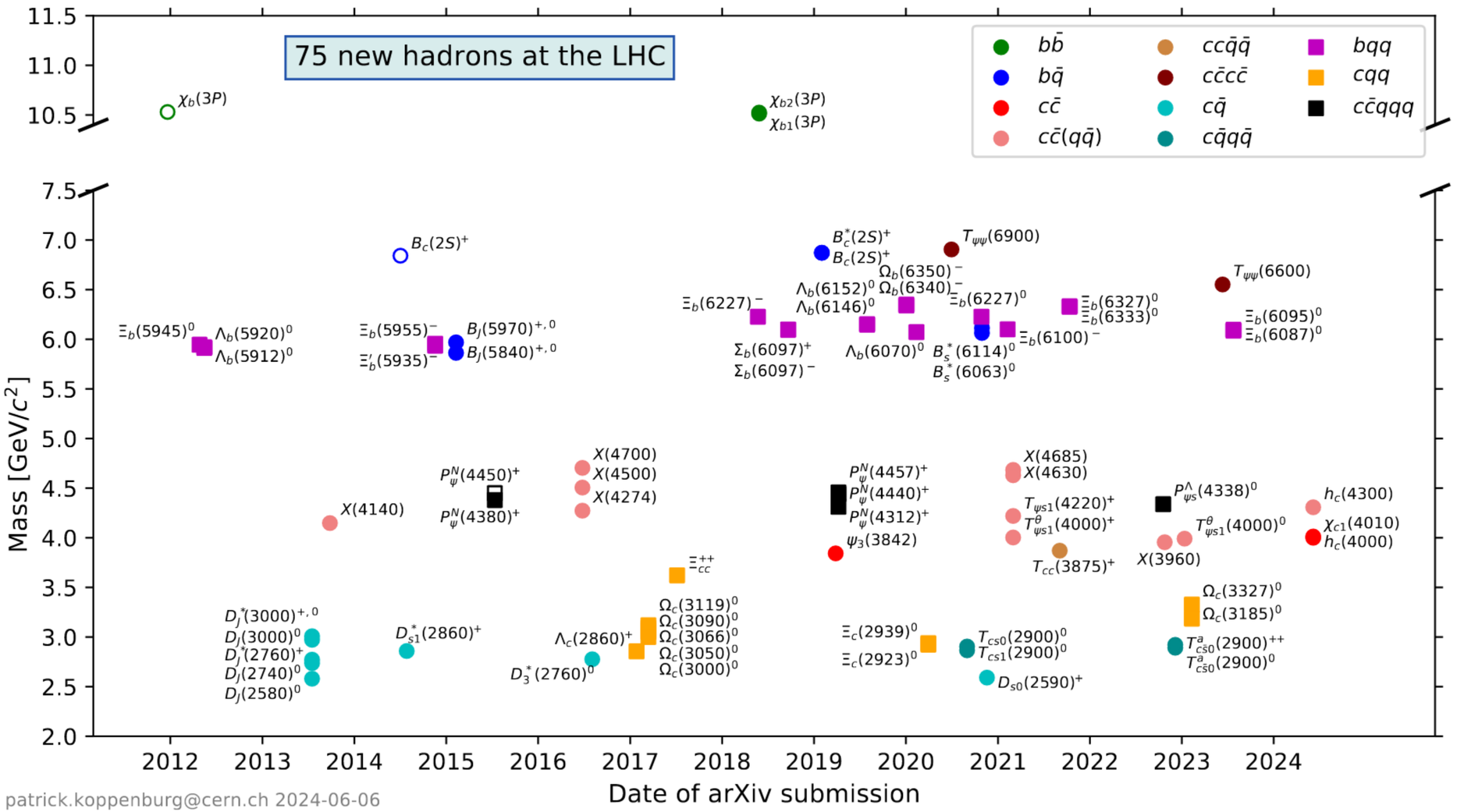
Higgsov bozón





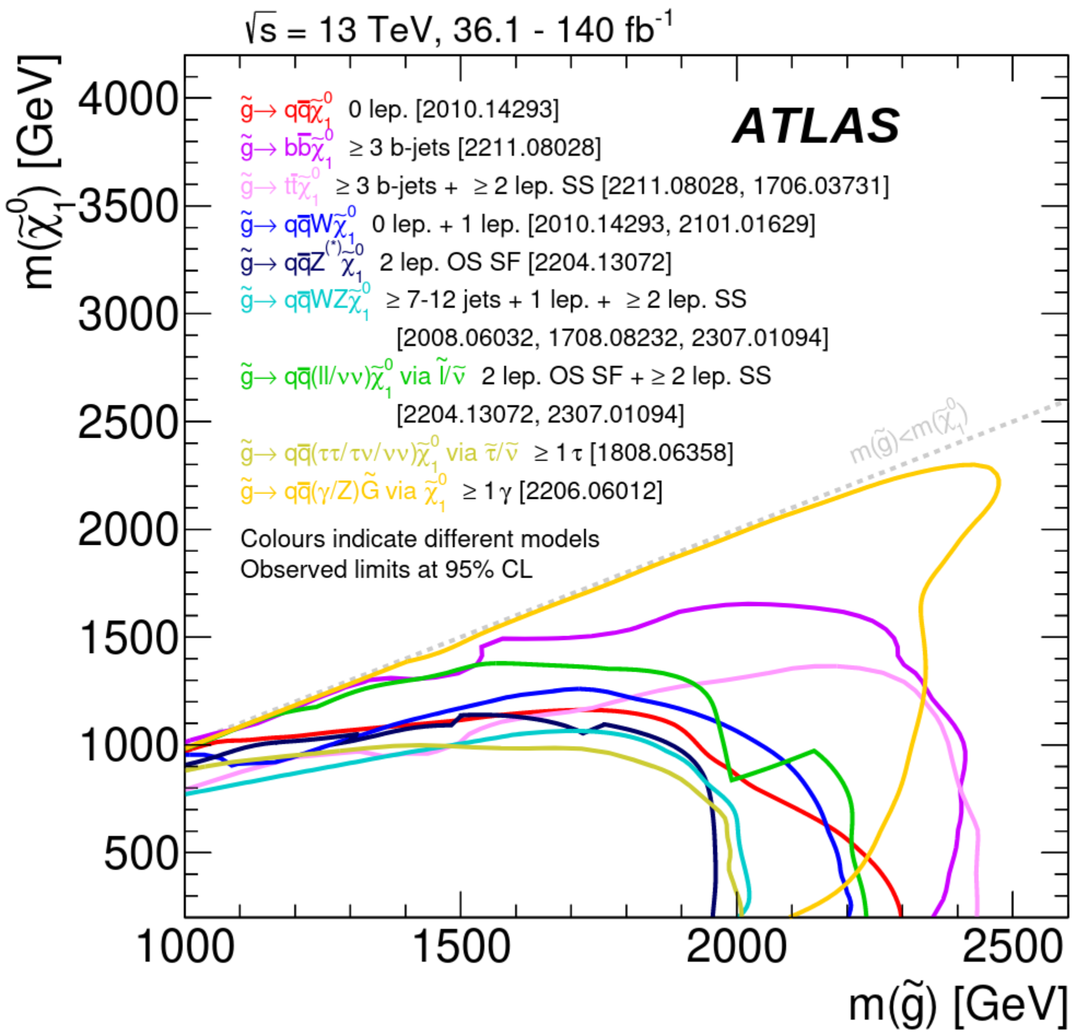
zdroj: ATLAS Collaboration

Nové hadróny



zdroj: New particles discovered at the LHC

Nenašli sme Supersymetriu



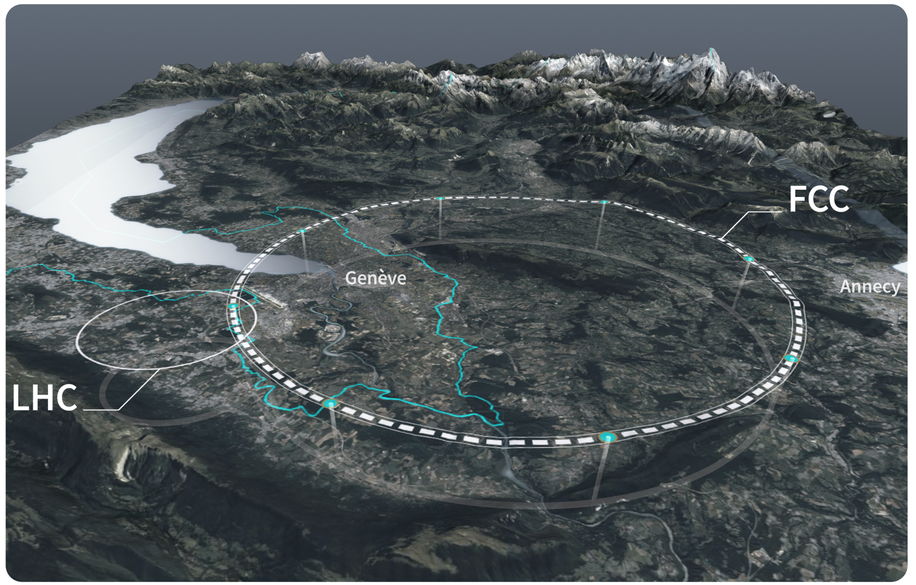
zdroj: ATLAS Collaboration

FCC

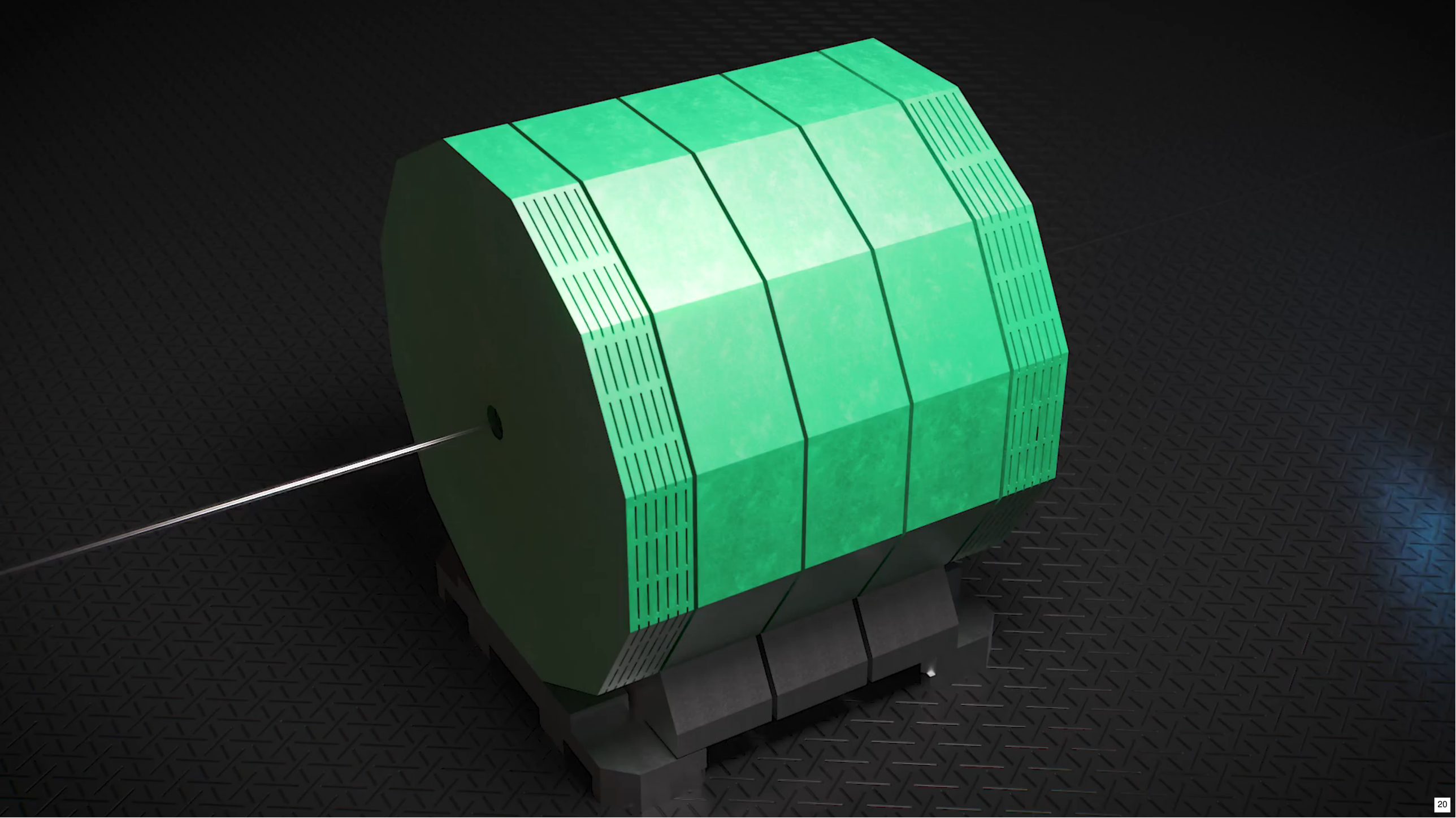
FCC

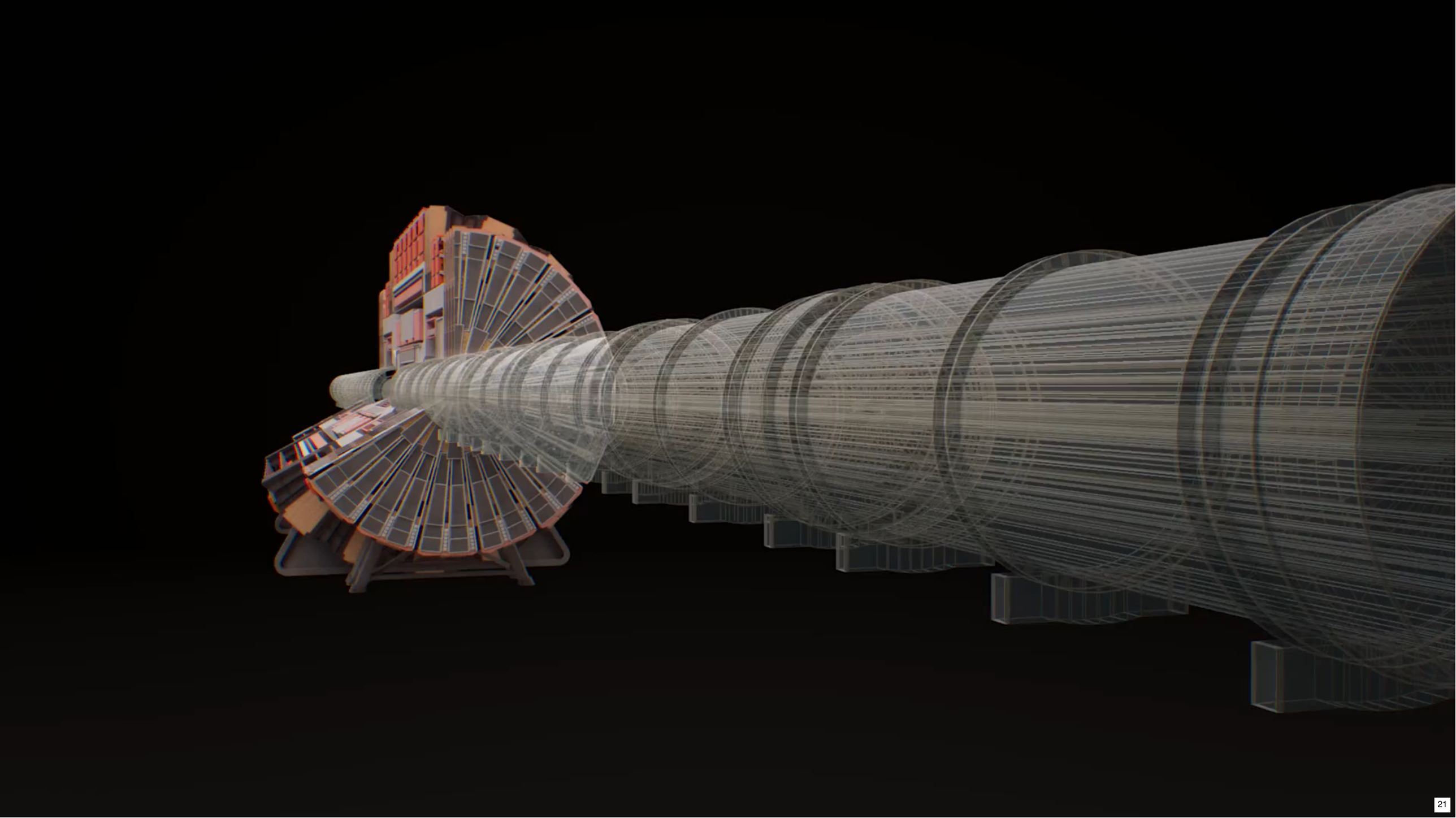
Návrh na urýchľovač novej generácie

- V štádiu skúmania konceptov a technológií
- 91-kilometrový kruhový podzemný tunel popod Francúzsko a Švajčiarsko
- Priemerná hĺbka 200 metrov s ôsmimi povrchovými lokalitami, z toho štyri pre experimenty
- Začiatok prevádzky sa očakáva v polovici 40. rokov
  - Výskumný program potrvá viac ako 70 rokov
- Dve fázy:
  - FCC-ee | elektrón-pozitrónový urýchľovač: poskytne bezprecedentnú presnosť meraní
  - FCC-hh | protón-protónový urýchľovač: nový objaviteľský potenciál
- Zapojených už viac ako 150 inštitútov z viac ako 30 krajín

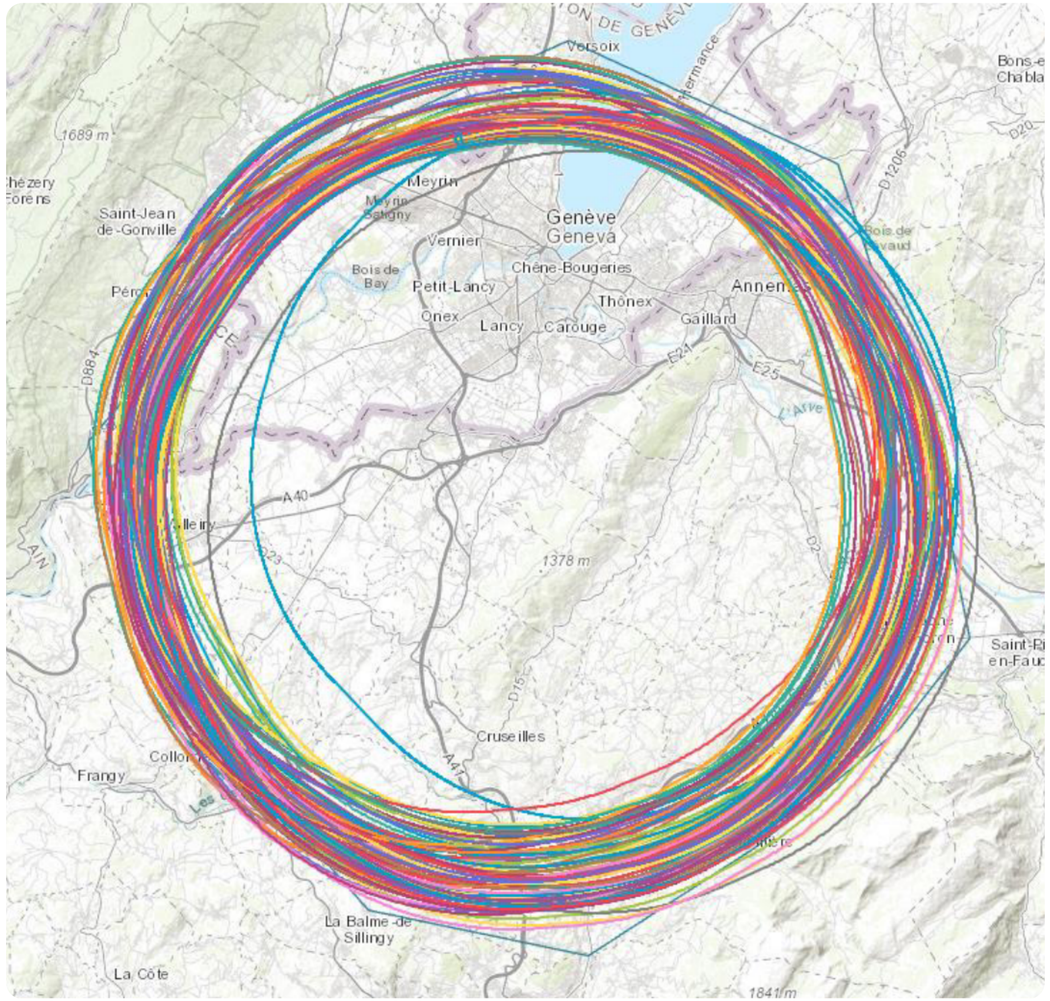


zdroj: FCC Layout — Aerial View



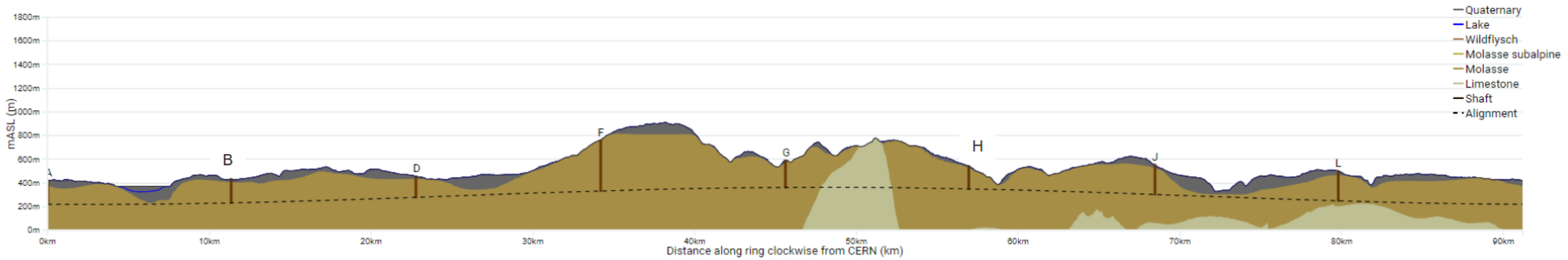


Umiestnenie



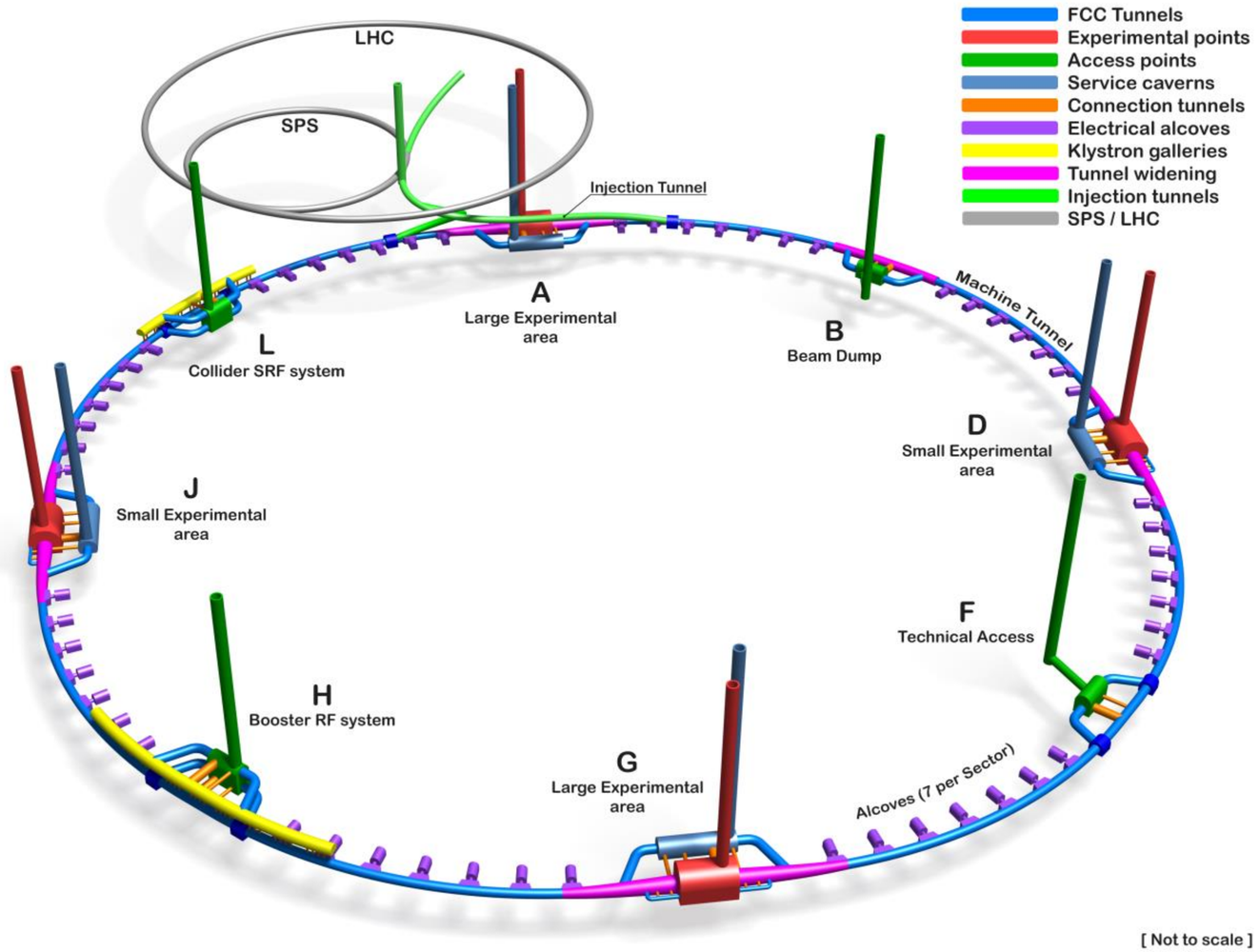
zdroj: FCC Week 2023 | J. Gutleber

Umiestnenie



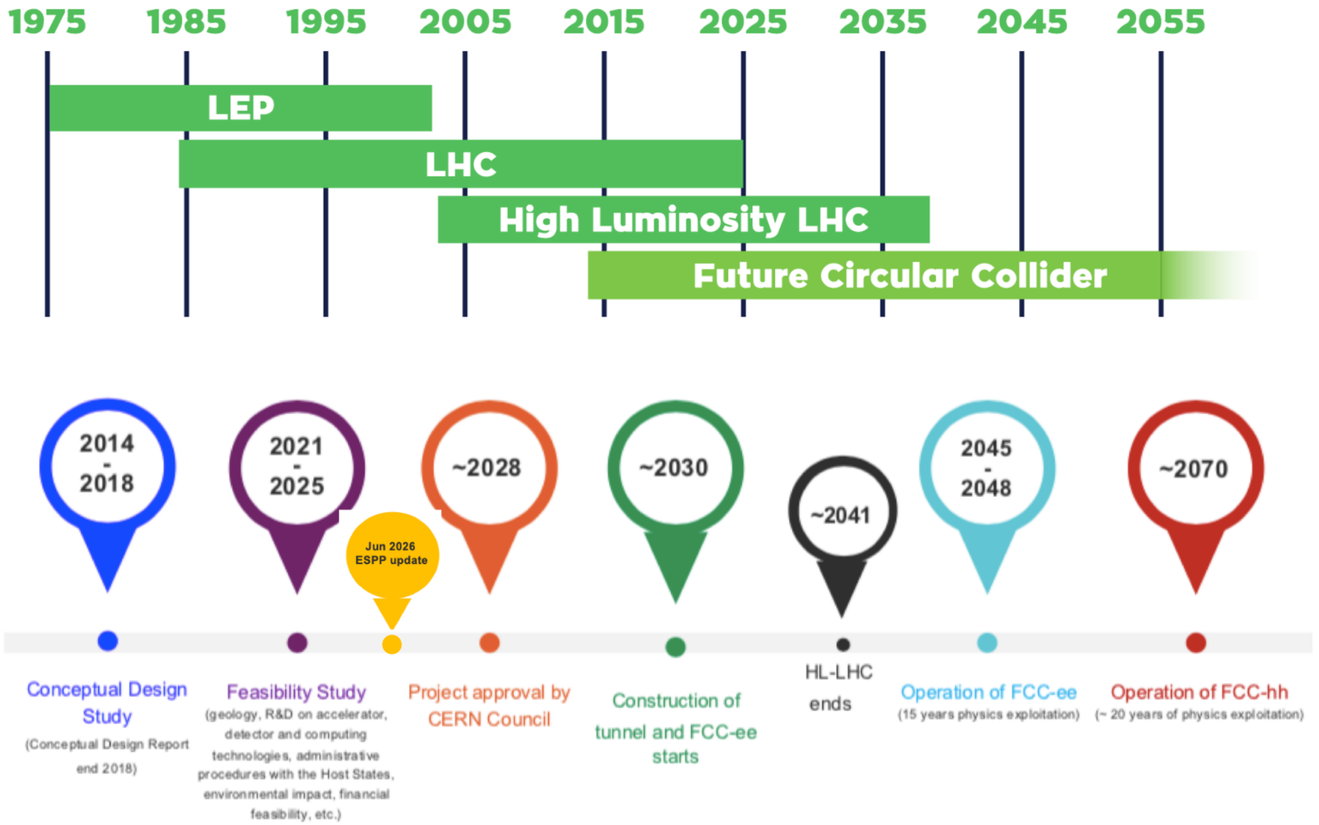
zdroj: FCC Week 2023 | T. Watson

Tunel



zdroj: FCC Week 2024 | T. Watson

Časový harmonogram



zdroj: FCC Week 2024 | F. Gianotti, FCC Poster

Parametre FCC-ee

Parameter	Z	WW	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1280	135	26.7	5.0
number bunches/beam	10000	880	248	36
bunch intensity [10^{11}]	2.43	2.91	2.04	2.64
SR energy loss / turn [GeV]	0.0391	0.37	1.869	10.0
total RF voltage 400/800 MHz [GV]	0.120/0	1.0/0	2.08/0	4.0/7.25
long. damping time [turns]	1170	216	64.5	18.5
horizontal beta* [m]	0.1	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horizontal geometric emittance [nm]	0.71	2.17	0.64	1.49
vertical geom. emittance [pm]	1.42	4.34	1.29	2.98
horizontal rms IP spot size [μm]	8	21	14	39
vertical rms IP spot size [nm]	34	66	36	69
luminosity per IP [10^{34} $cm^{-2}s^{-1}$]	182	19.4	7.3	1.33
total integrated luminosity / year [ab^{-1}/yr] 4 IPs	87	9.3	3.5	0.65
beam lifetime (rad Bhabha + BS+lattice)	8	18	6	10
	4 years 5 x 10^{12} Z LEP x 10^{5}	2 years > 10^{8} WW LEP x 10^{4}	3 years 2 x 10^{6} H	5 years 2 x 10^{6} tt pairs

Currently assessing technical feasibility of changing operation sequence (e.g. starting at ZH energy)

- ❑ x 10-50 improvements on all EW observables
- ❑ up to x 10 improvement on Higgs coupling (model-indep.) measurements over HL-LHC
- ❑ x10 Belle II statistics for b, c, τ
- ❑ indirect discovery potential up to ~ 70 TeV
- ❑ direct discovery potential for feebly-interacting particles over 5-100 GeV mass range

Up to 4 interaction points → robustness, statistics, possibility of specialised detectors to maximise physics output

zdroj: FCC Week 2024 | F. Gianotti

Parametre FCC-hh

parameter	FCC-hh	HL-LHC	LHC
collision energy cms [TeV]	81 - 115	14	
dipole field [T]	14 (Nb_3Sn) - 20 (HTS)	8.33	
circumference [km]	90.7	26.7	
arc length [km]	76.9	22.5	
beam current [A]	0.5	1.1	0.58
bunch intensity [10^{11}]	1	2.2	1.15
bunch spacing [ns]	25	25	
synchr. rad. power / ring [kW]	1020 - 4250	7.3	3.6
SR power / length [W/m/ap.]	13 - 54	0.33	0.17
long. emit. damping time [h]	0.77 – 0.26	12.9	
peak luminosity [10^{34} $cm^{-2}s^{-1}$]	~30	5 (lev.)	1
events/bunch crossing	~1000	132	27
stored energy/beam [GJ]	6.1 - 8.9	0.7	0.36
Integrated luminosity/main IP [fb^{-1}]	20000	3000	300

If FCC-hh after FCC-ee: significantly more time for high-field magnet R&D aiming at highest possible energies (HTS) and lowest electricity consumption

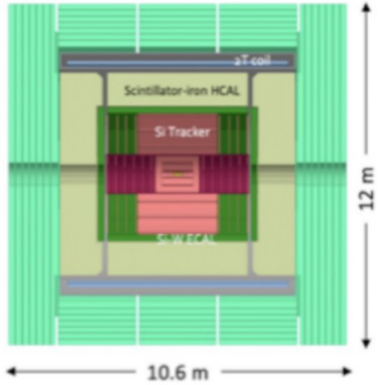
Formidable challenges:
- ❑ high-field superconducting magnets: 14 - 20 T
- ❑ power load in arcs from synchrotron radiation: 4 MW → cryogenics, vacuum
- ❑ stored beam energy: up to 9 GJ → machine protection
- ❑ pile-up in the detectors: ~1000 events/xing
- ❑ energy consumption: 4 TWh/year → R&D on cryo, HTS, beam current, …

Formidable physics reach, including:
- ❑ Direct discovery potential up to ~ 40 TeV
- ❑ Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- ❑ High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays ($\gamma\gamma$, $Z\gamma$, μμ)
- ❑ Final word about WIMP dark matter
- ❑ Insight into EW phase transition in early universe

zdroj: FCC Week 2024 | F. Gianotti

Detektorové koncepty pre FCC-ee

CLD

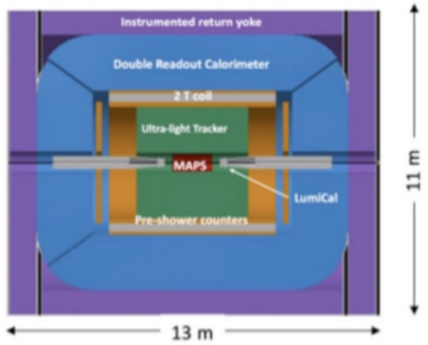


Design (ILC/CLIC/Calice)

- All silicon tracker (pixels + strips)
- Si-W EM calorimeter
  - $22X_0$, 40 long. layers.
- Steel-Scintillator hadronic calo.
  - SiPM readout
- Solenoid outside calorimeter
- RPC based Muon system

https://arxiv.org/pdf/1911.12230.pdf

IDEA



- MAPS based vertex detector (1% X_0)
- High-precision low-mass drift chamber with surrounding Si microstrip (t_d < 400 ns).
- pre-shower with MPGD readout
- Lead-Fiber dual readout calorimeter
- Sensitive to both Sci/Cerenkov
  - Hybrid with crystal EM?
- large μ-Rwell muon chambers

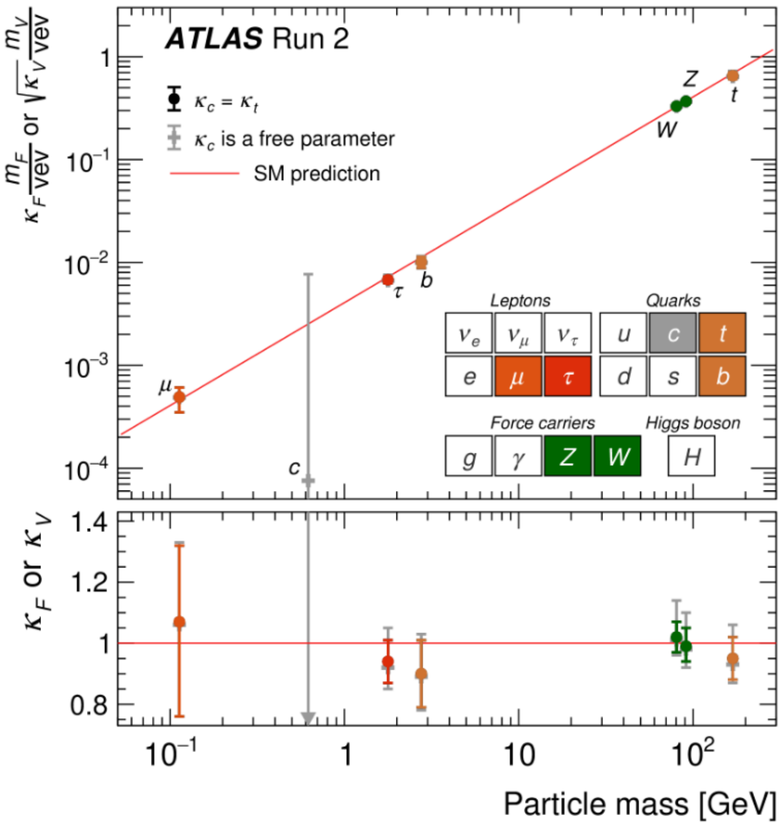
https://inspirehep.net/files/49ec726758c422bc454e270a71f6e59f

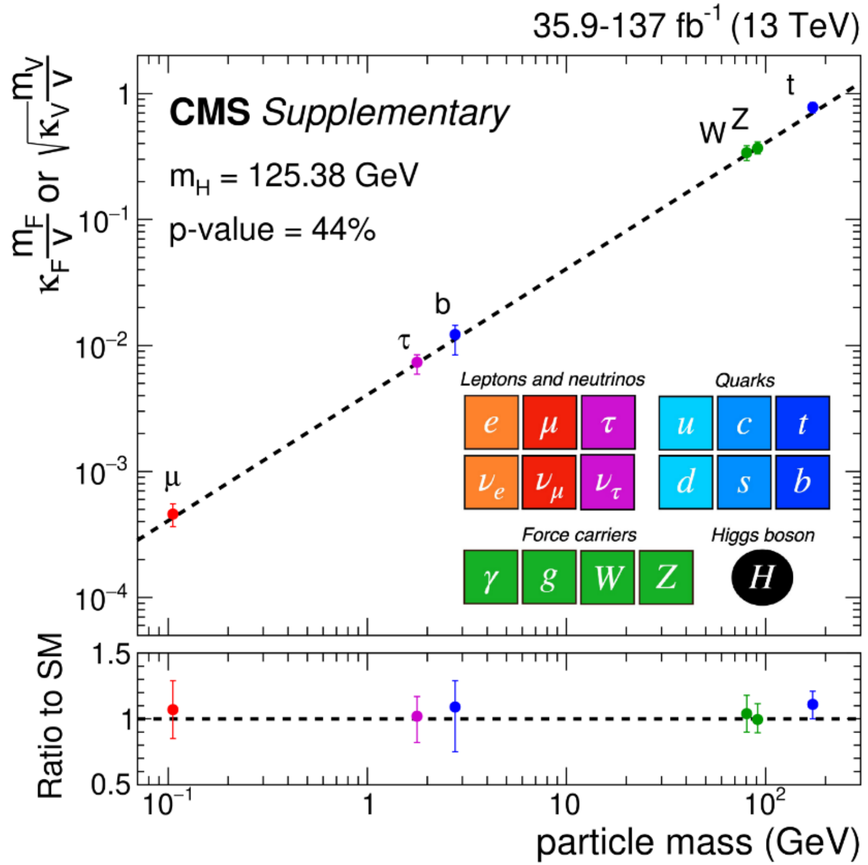
Allegro

- Includes a highly granular noble liquid calorimeter
- Possible design being explored are lead/steel absorbers (RM ~4 cm), stacked azimuthally inclined at 50° wrt radial axis with LAr as the active medium.
- Other considerations include Tungsten absorbers and/or Liquid Krypton.
- https://arxiv.org/pdf/2109.00391.pdf

zdroj: FCC Week 2024 | JA. Hewett

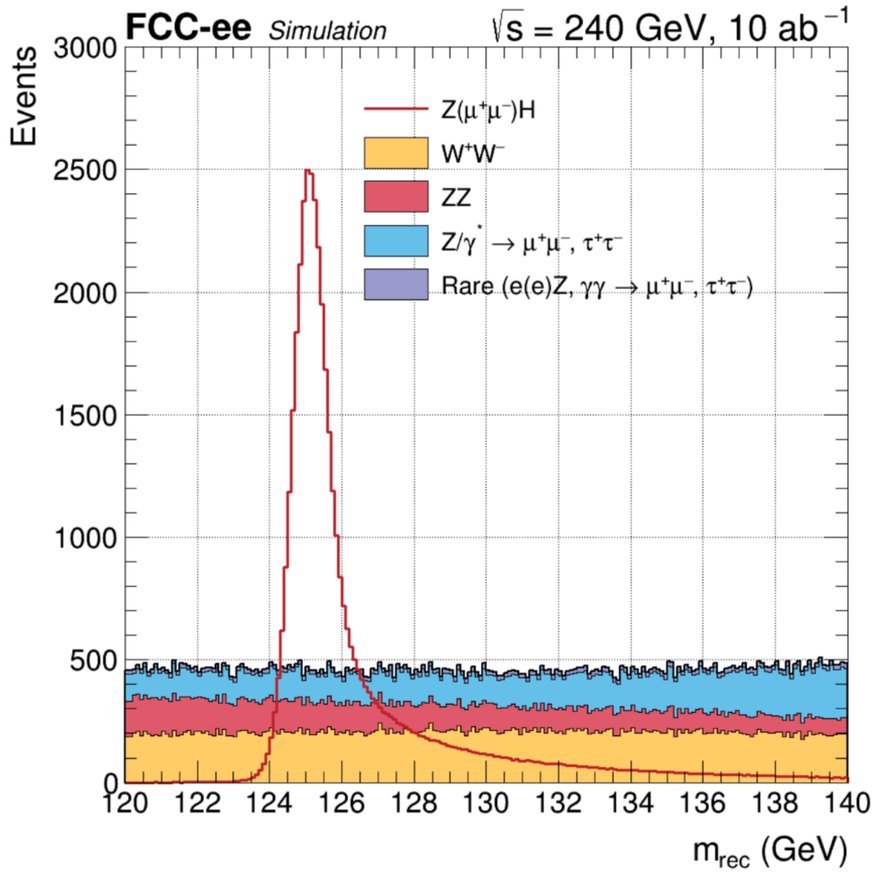
Vlastnosti Higgsovho bozónu





zdroj: ATLAS Collaboration, CMS Collaboration

ZH recoil



$$M^2_{recoil} = (\sqrt{s} - E_{l\bar{l}})^2 - p^2_{l\bar{l}} = s - 2E_{l\bar{l}}\sqrt{s} + m^2_{l\bar{l}}$$

zdroj: L. Portalès

Future Circular Collider - Expanding our Horizons