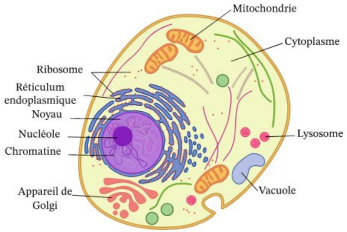
Why the Future Circular Collider ?

Michele Selvaggi (CERN)

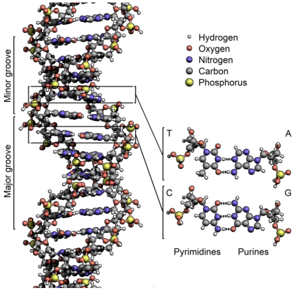
Why colliders (recap from previous talk)

- Particle accelerators and colliders are our **microscopes**
  - Higher Beam Energy → Smaller scale : **E ~ 1 / λ**

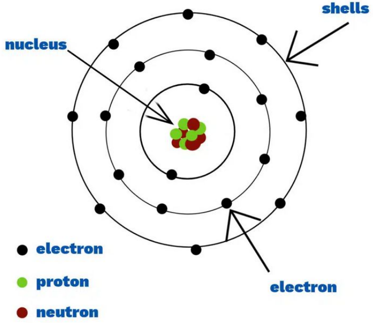
10 cm



10 µm
(0.001 cm)



10 nm
(0.000001 cm)



0.1 nm
(0.0000000001 cm)

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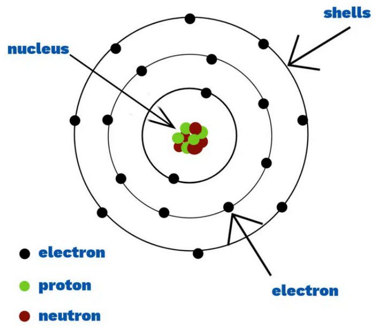

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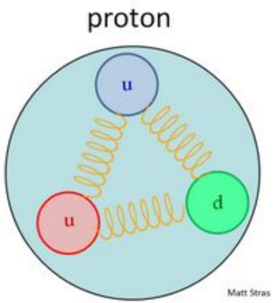
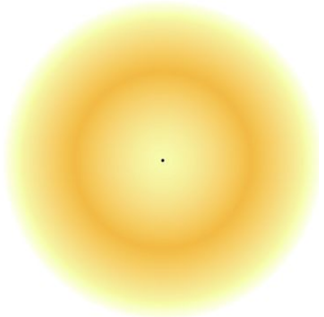


1 fm

10^{-15} m

electron, quark



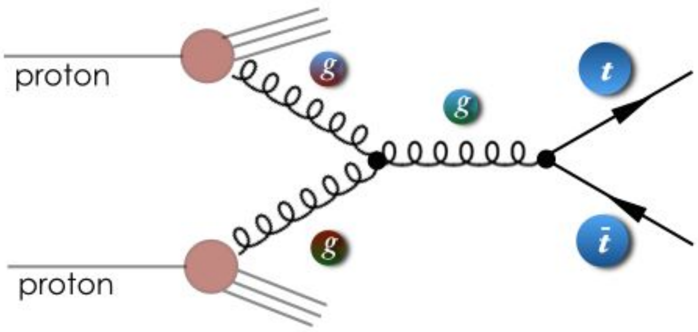
< 0.001 fm

< 10^{-18} m

smallest scale we can probe with the LHC

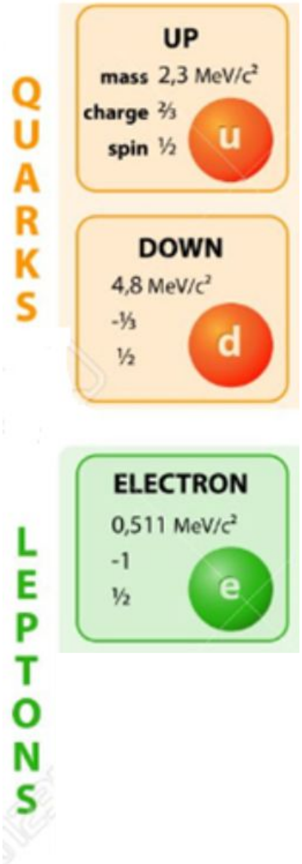
Why colliders (recap from previous talk)

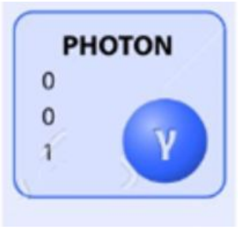
- particle accelerators and colliders can **convert energy** to mass (**E ~ m c^2**)
  - higher beam energy → higher mass particles can be produced



m(proton) ~ 1 GeV
E(proton) = 7000 GeV **<<** **m(top quark) ~ 170 GeV**

Particles and interactions





Explains (most) of the world around us

matter = atoms
atoms = protons, neutrons, electrons
Protons, neutrons = up and down quark

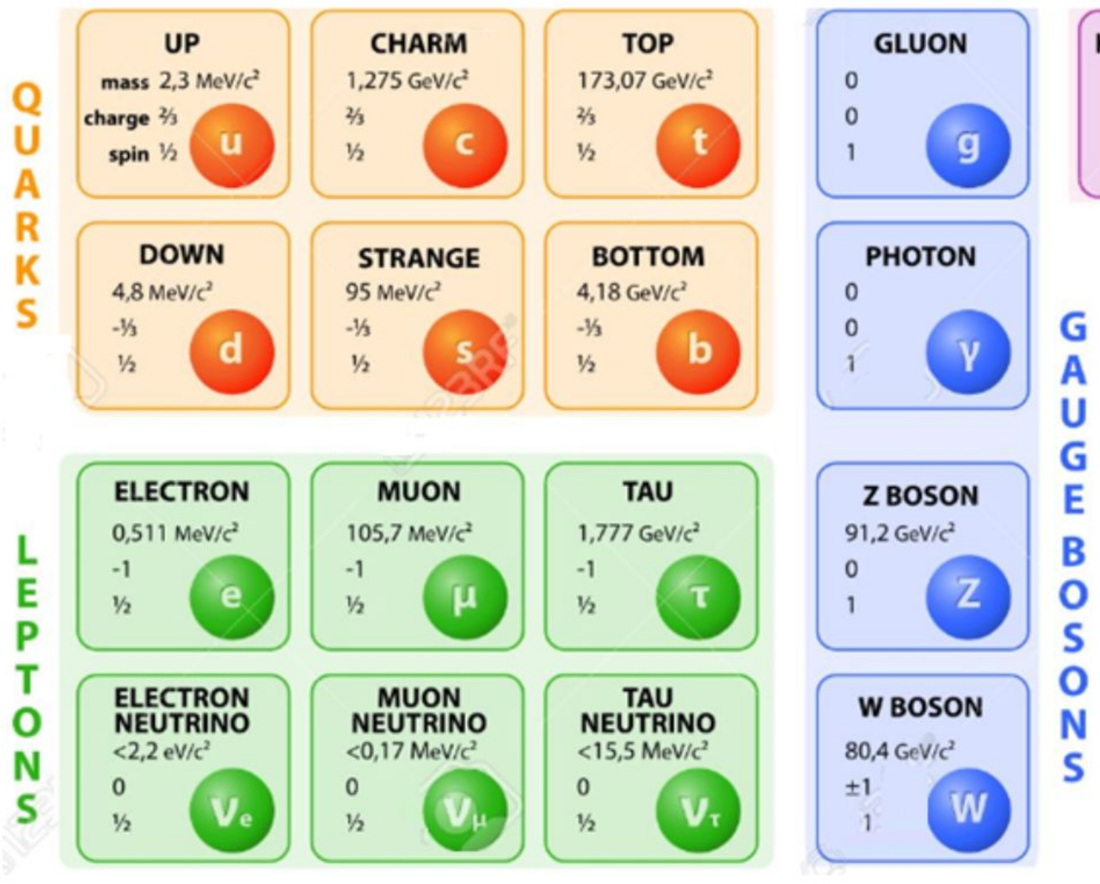
Electromagnetic force = photon
Gravity

What did we know before the LHC?

- 4 fundamental forces
  - electromagnetic (chemistry)
  - weak force (radioactivity, stars)
  - strong force (nuclei bound)
  - gravity

- 3 copies (families) of matter
  - m(III) > m(II) > m(I)

What do we know AFTER the LHC?



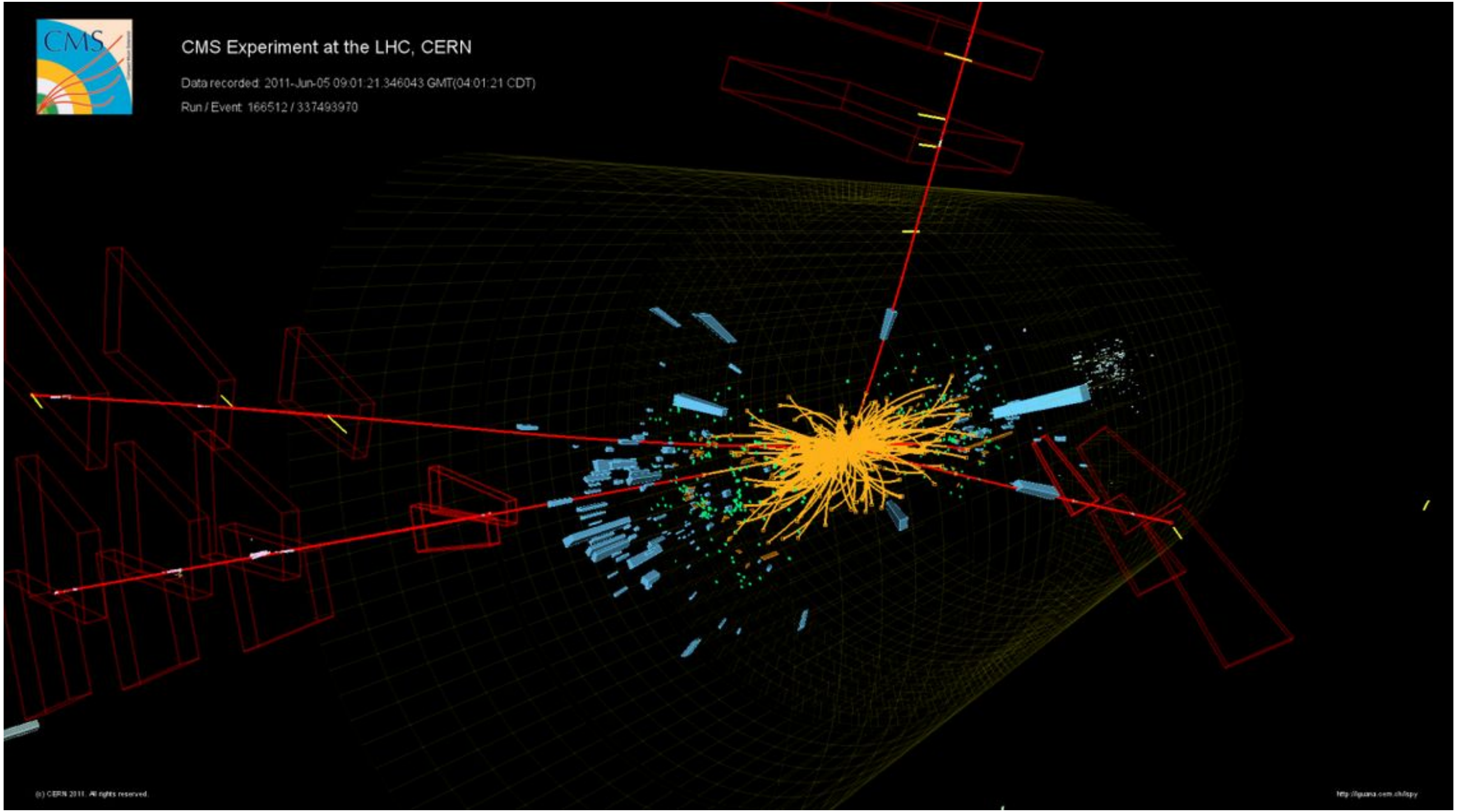
Higgs Particle

We have discovered a **new fundamental particle**

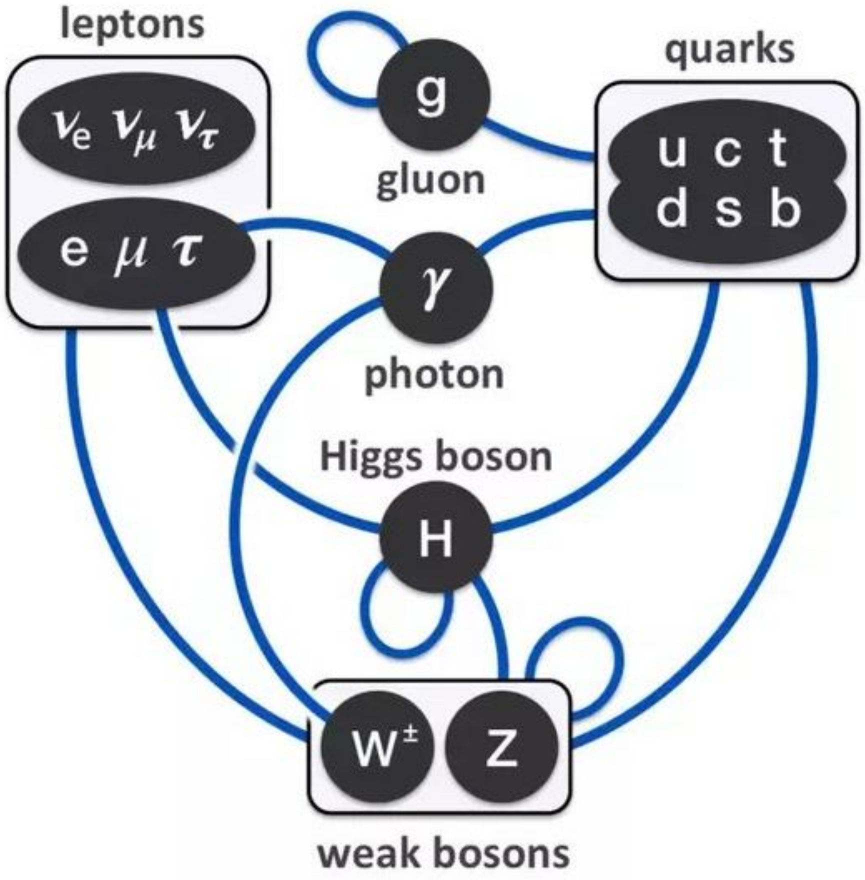
AND

a **5th force** (Yukawa)

A Higgs event: H → μμμμ



Higgs



The Higgs particle interacts with every particle that has a mass > 0

The interaction of particles with the Higgs field explains why they have a mass

Plays a central role in our understanding of nature

Open questions in fundamental physics

Many fundamental **unanswered** questions:

- **Higgs particle elementary or composite ?**
- Why 3 families ?
- What is Dark Matter ?
- Are there **new particles** and **forces**?

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i \bar{\psi} \not{D} \psi + h.c. + \psi_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

The Standard Model

New particles could be either:

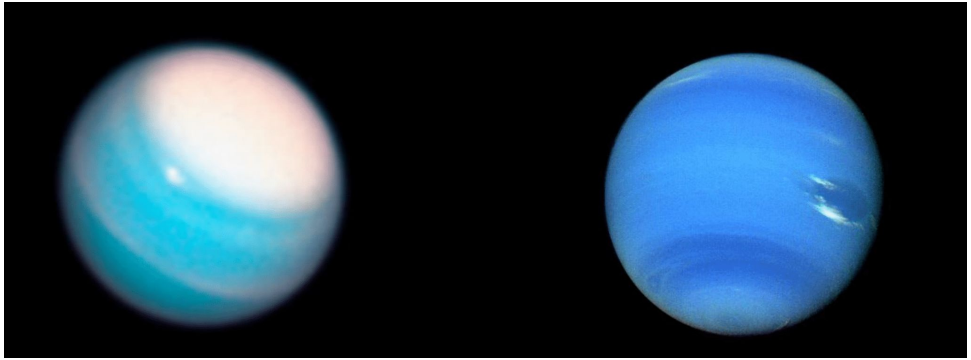
- **too heavy** to be seen with present machines
- **too feebly coupled** to the particles we know of

What do we want from next collider facility

The Quest for **ULTIMATE precision**:

- **measure** more and more precisely the **strengths of the known interactions**, and properties of known particles
- compare to predictions
- gives us **indirect access** to new physics (states and interactions)

Neptune discovery resulted from precision measurement of Uranus orbit deviation from Newton gravitational law



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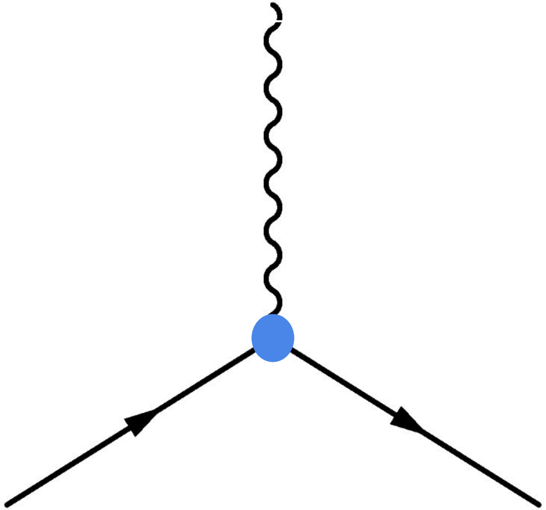
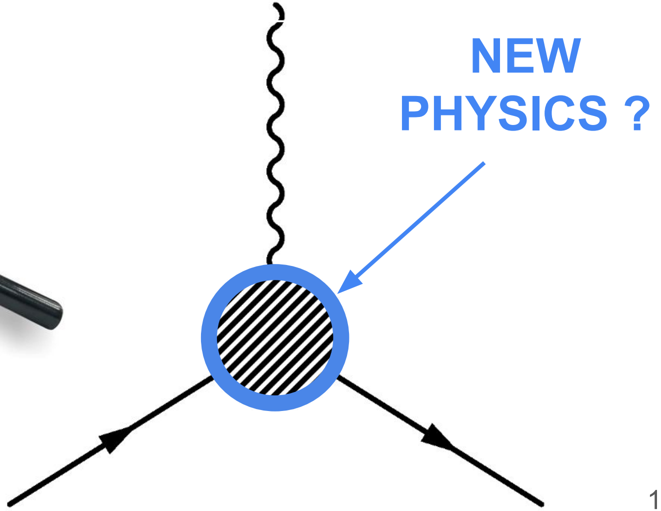
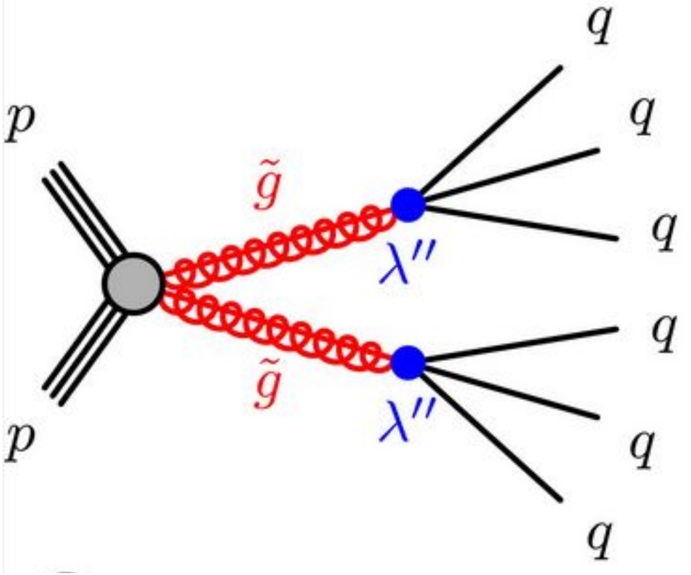


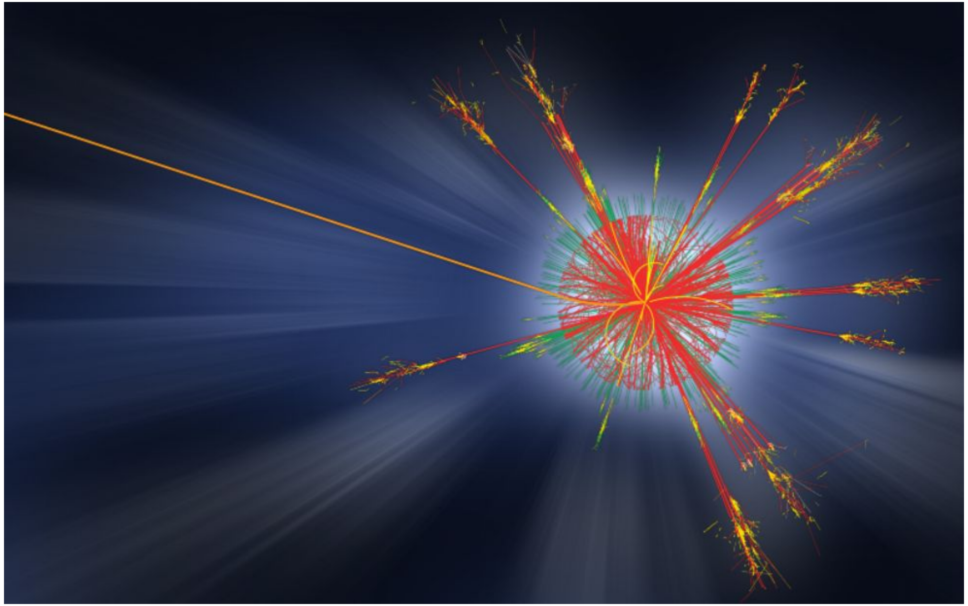


What do we want from next collider facility

The Quest for **ULTIMATE energy**:

- directly produce new HEAVY particles (Dark Matter, Super-symmetric, XYZ)



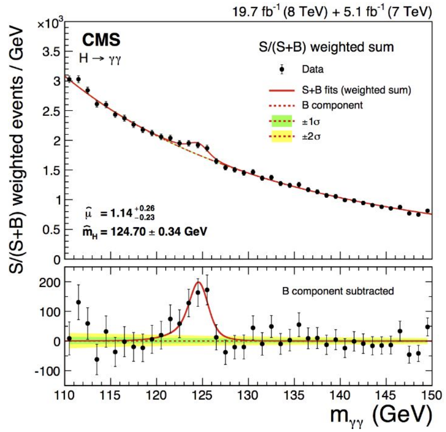


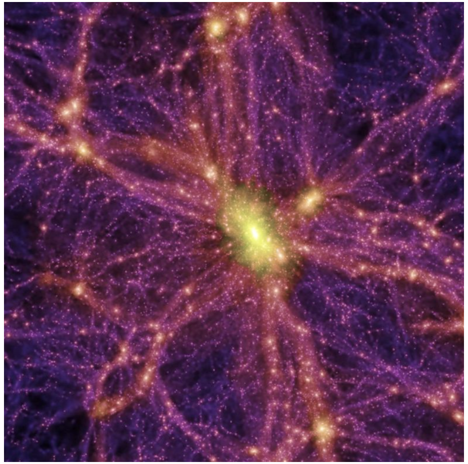
What do we want from next collider facility

FUTURE CIRCULAR COLLIDER

ULTIMATE intensity:

- The Higgs is relatively light M = 125 GeV
  - we produce it at the LHC, but **rare** and **large backgrounds**
  - we want to produce **large amount of Higgs bosons** in a **clean environment**





ULTIMATE ENERGY:

- Reach the **energy frontier** to produce new physics
  - ? Dark Matter, Supersymmetry , Heavy Neutrinos … ?

Possible colliders

e+e-

- "clean" collisions
- **circular**: ***FCC-ee***
  - extreme luminosity for Z,W Higgs production
  - limited to medium energy ~ 200 GeV (Higgs) →
- **linear**: can reach high energies up to 1-3 TeV ILC/CLIC, lower luminosity

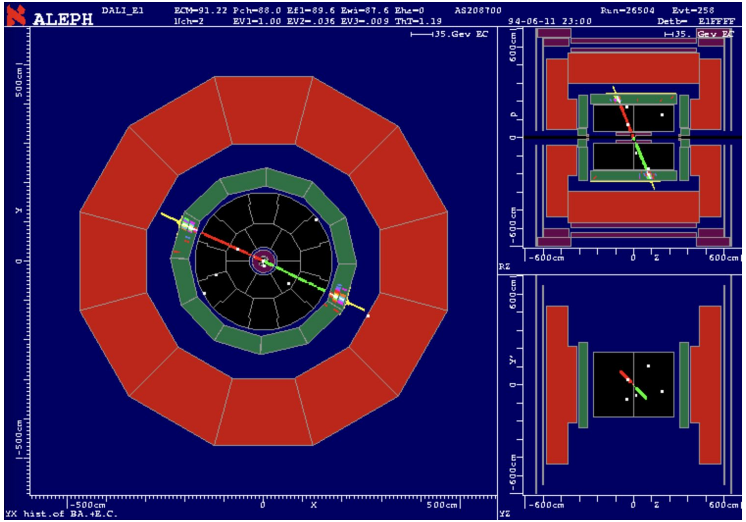
p-p

- complex collisions, large backgrounds
- **circular**: can reach the highest possible energies
  - size of the ring, magnetic field limit the highest achievable energy
  - LHC, ***FCC-hh***
- linear: not interesting (low luminosity and energy)

Large collider ring → highest luminosity in e+e-
highest energy/luminosity for p-p

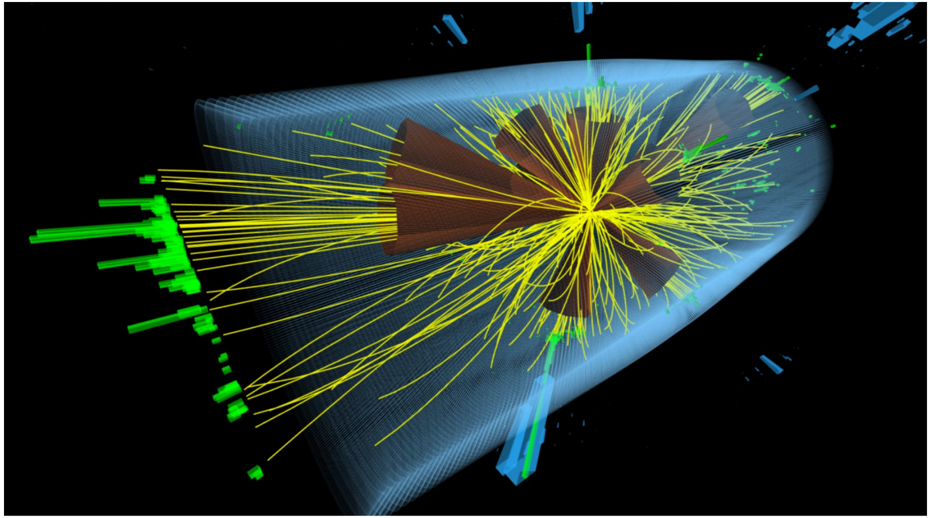
Possible colliders

e+e-



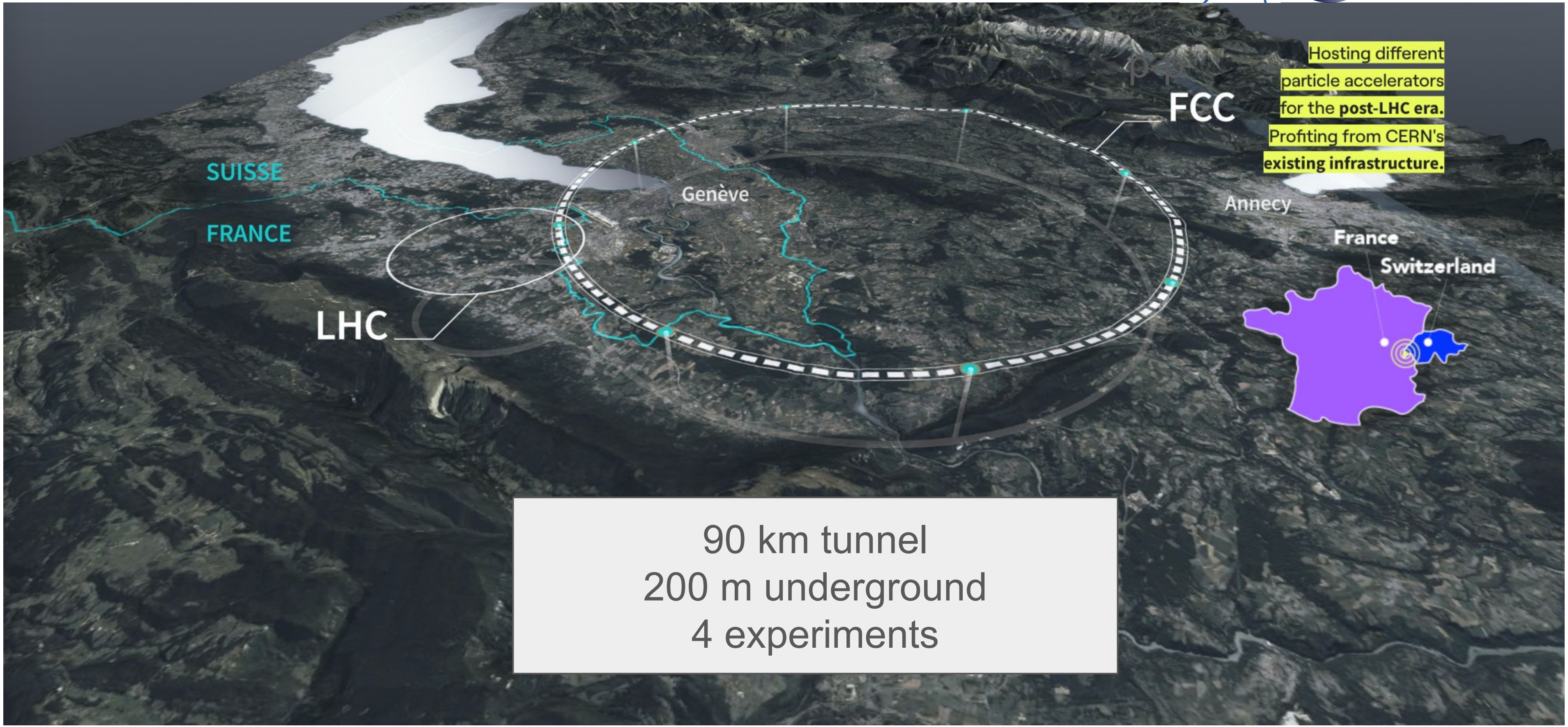
"clean"

p-p



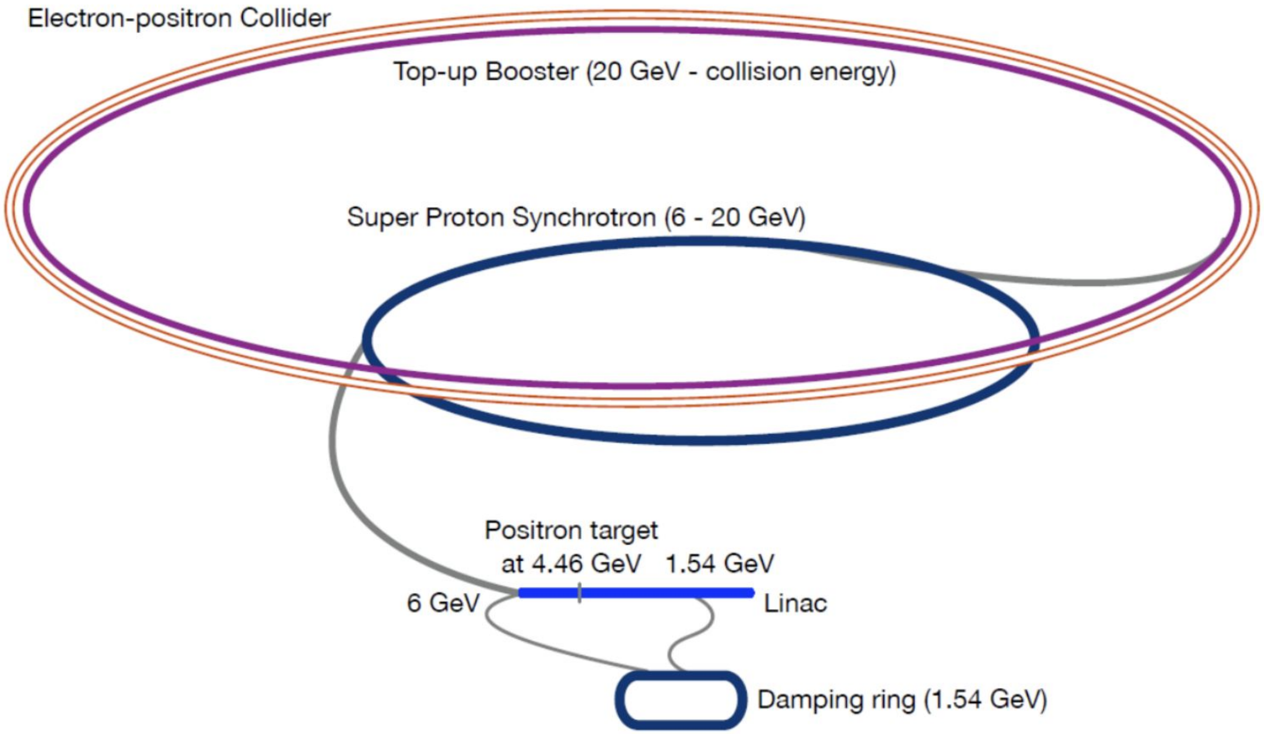
"messy"

FCC



SUISSE
FRANCE
Genève
LHC
FCC
Annecy
France
Switzerland
Hosting different
particle accelerators
for the **post-LHC era.**
Profiting from CERN's
existing infrastructure.
90 km tunnel
200 m underground
4 experiments

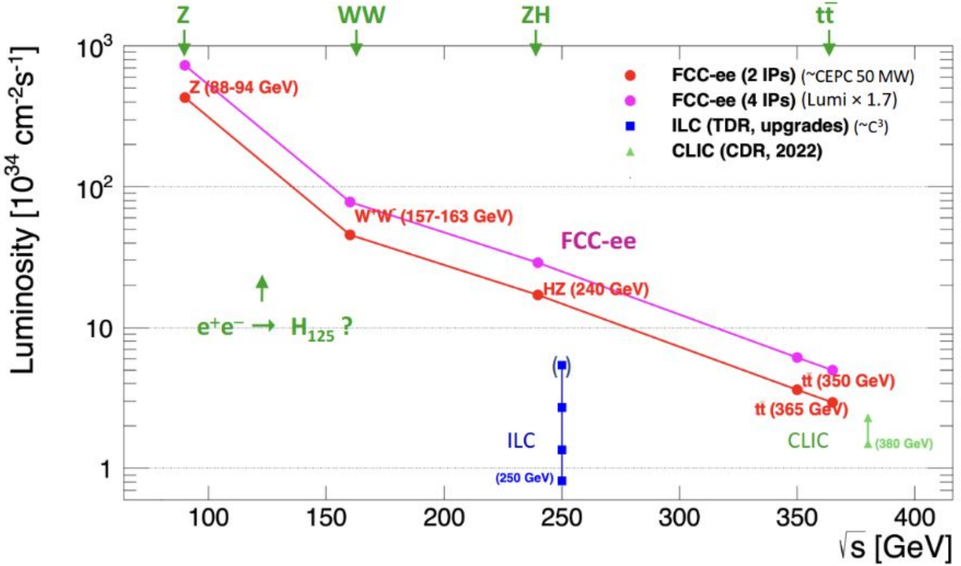
FCC-ee


Electron-positron Collider
Top-up Booster (20 GeV - collision energy)
Super Proton Synchrotron (6 - 20 GeV)
Positron target
at 4.46 GeV
1.54 GeV
6 GeV
Linac
Damping ring (1.54 GeV)

FCC-ee

Phase I: FCC-ee (~ 15 years operations)

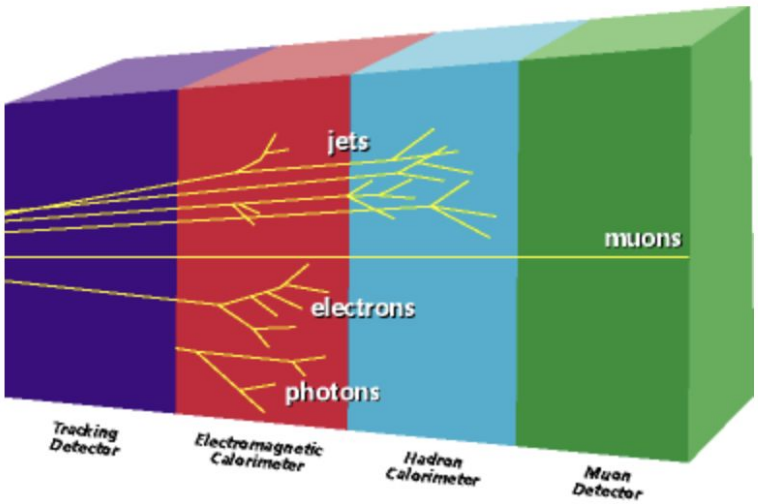
- extreme luminosity **e+e- machine**
  - **10000x more luminosity** than LEP
- measure the Higgs/Electroweak/Top sector properties to extreme precision
  - **> 10-100x more precise** than current
- probe New feebly interacting states (Heavy neutrinos)

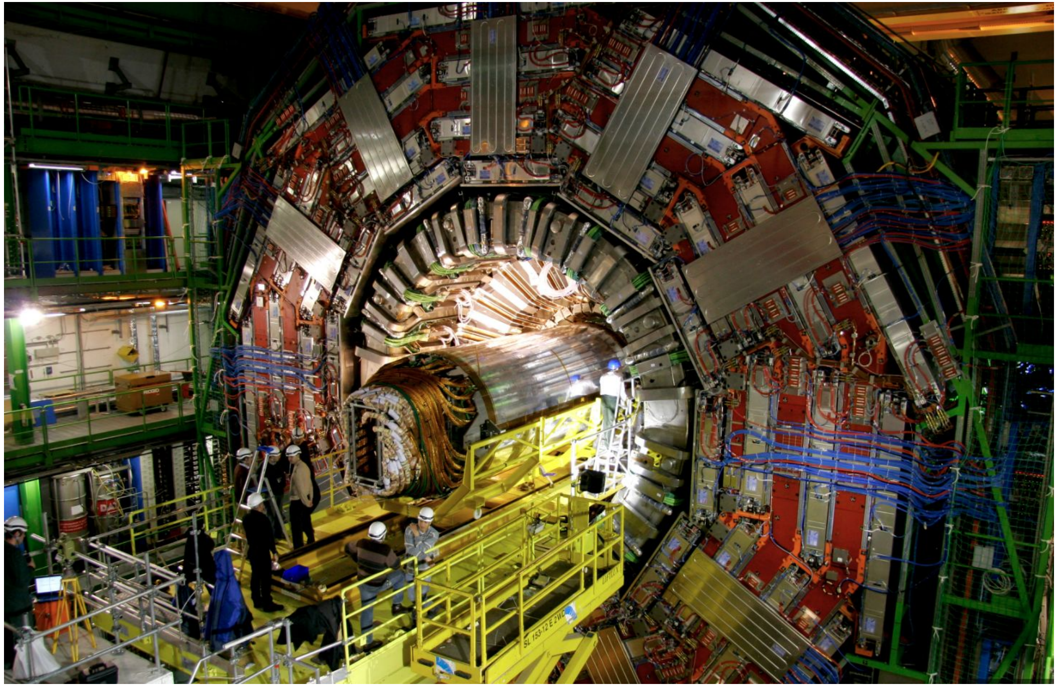


Exquisite luminosity allows for ultimate precision:

- 100K Z bosons / second
  - LEP dataset in 1 minutes
- 10k W boson / hour
- 2k Higgs bosons / day
- 3k tops / day

Detectors


jets
muons
electrons
photons
Tracking Detector
Electromagnetic Calorimeter
Hadron Calorimeter
Muon Detector

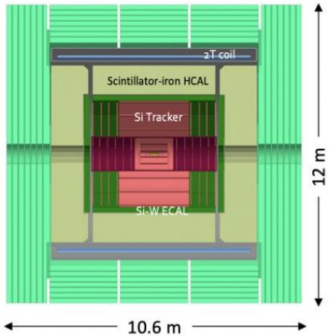


FCC-ee detectors

CERN FUTURE CIRCULAR COLLIDER

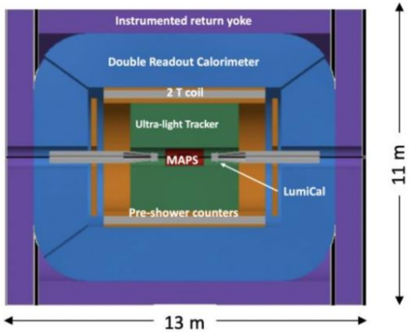
CDR

CLD



- Well established design
  - ILC -> CLIC detector -> CLD
- Full Si vtx + tracker;
- CALICE-like calorimetry;
- Large coil, muon system
- Engineering still needed for operation with continuous beam (no power pulsing)
  - Cooling of Si-sensors & calorimeters
- Possible detector optimizations
  - σ_p/p, σ_E/E
  - PID ($\mathcal{O}$(10 ps) timing and/or RICH)?

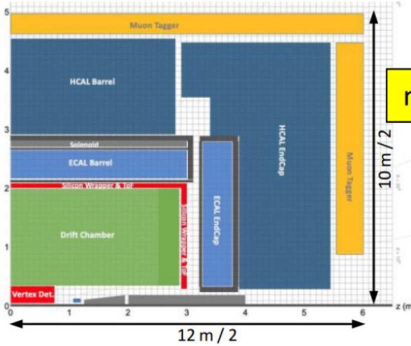
IDEA



- A bit less established design
  - But still ~15y history
- Si vtx detector; ultra light drift chamber w powerful PID; compact, light coil;
- Monolithic dual readout calorimeter;
  - Possibly augmented by crystal ECAL
- Muon system
- Very active community
  - Prototype designs, test beam campaigns, ...

Noble Liquid ECAL based

new



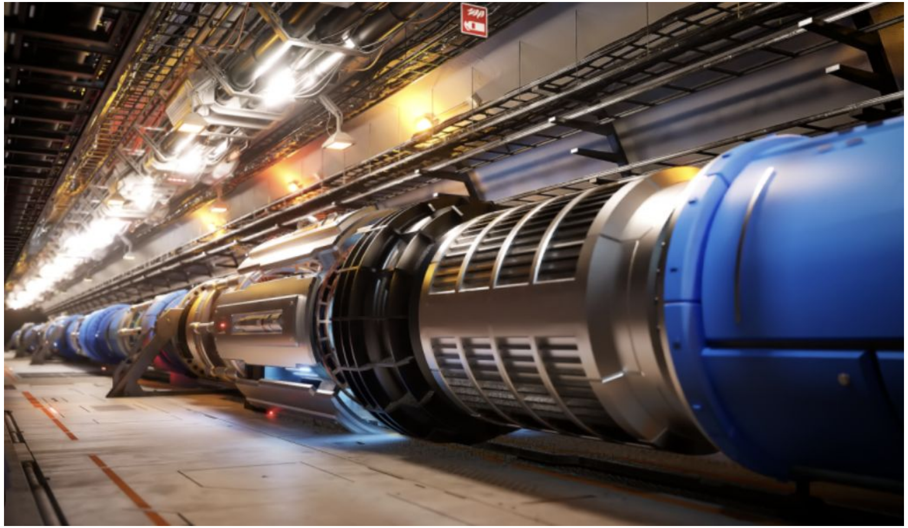
- A design in its infancy
- Si vtx det., ultra light drift chamber (or Si)
- High granularity Noble Liquid ECAL as core
  - Pb/W+LAr (or denser W+LKr)
- CALICE-like or TileCal-like HCAL;
- Coil inside same cryostat as LAr, outside ECAL
- Muon system.
- Very active Noble Liquid R&D team
  - Readout electrodes, feed-throughs, electronics, light cryostat, ...
  - Software & performance studies

At the 4 interaction points, we record data with particle detectors

FCC-hh

Phase II: FCC-hh (~ 20 years operations)

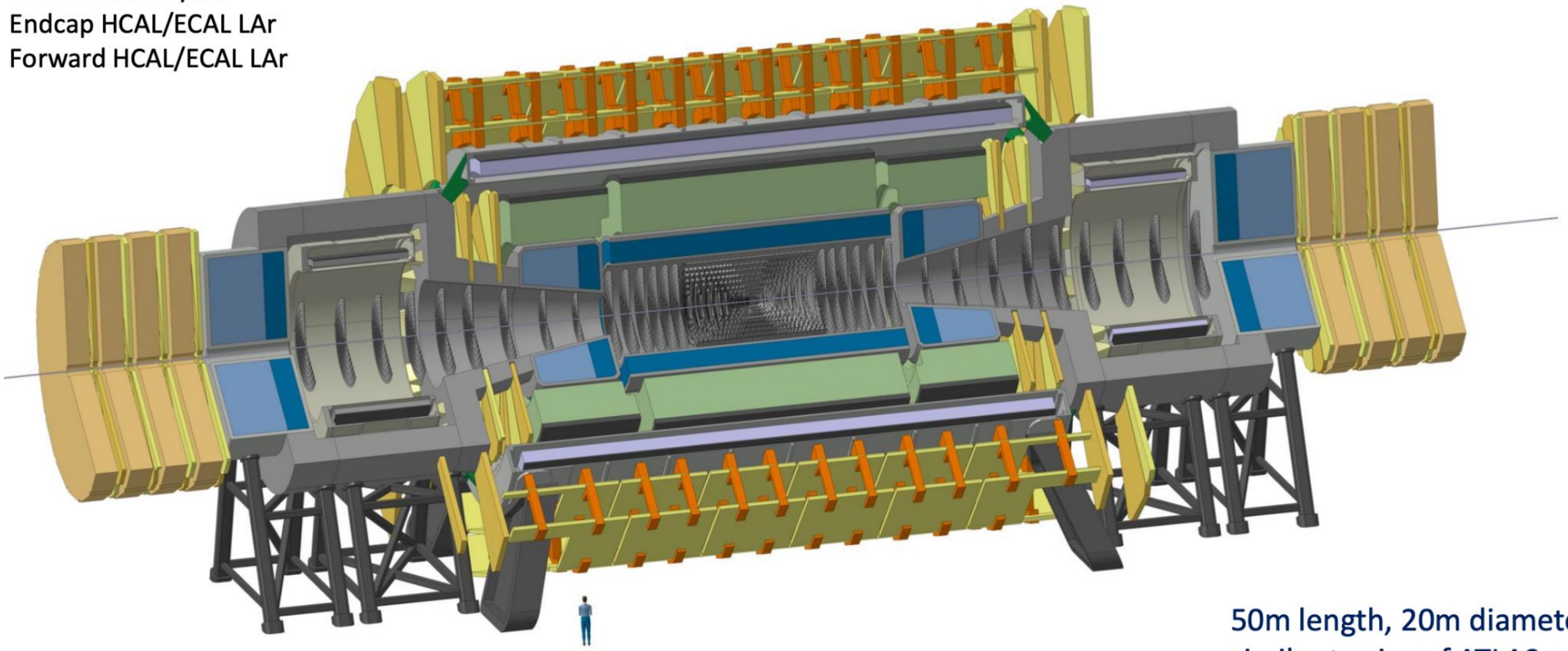
- extreme energy proton collisions (100 TeV)
    - **7x more energy than LHC**
- **directly search** for new physics
    - e.g Dark Matter
- allows to directly **very rare Higgs** production and decay modes
    - The Higgs self-coupling
- **complementary program to FCC-ee**



Requires development of high field magnets !

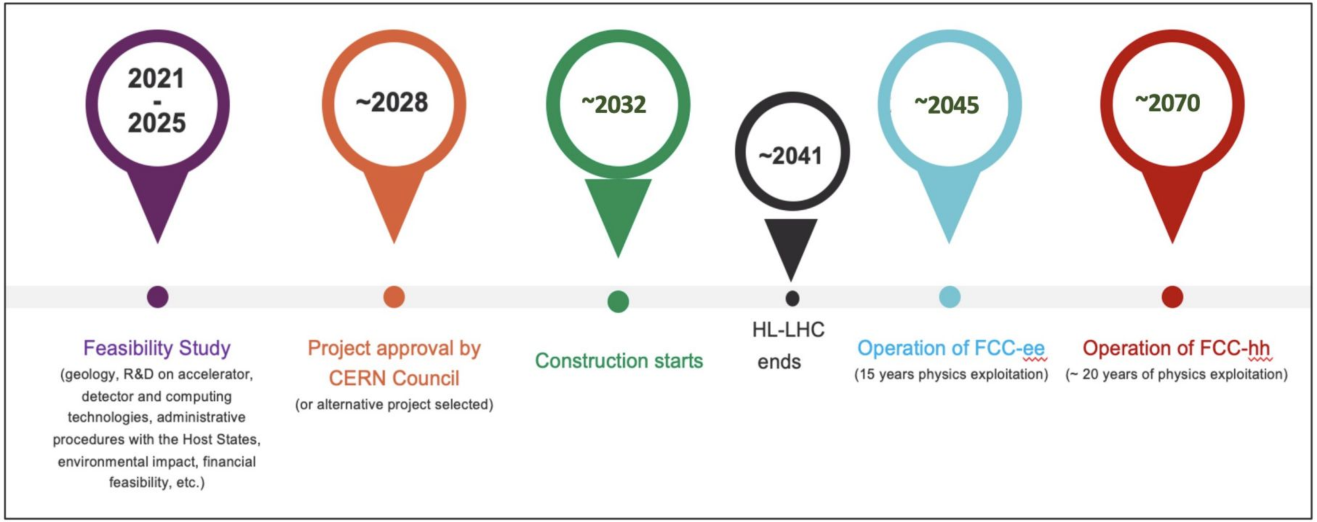
FCC-hh detector

4T, 10m solenoid, unshielded
Forward solenoids, unshielded
Silicon tracker
Barrel ECAL LAr
Barrel HCAL Fe/Sci
Endcap HCAL/ECAL LAr
Forward HCAL/ECAL LAr



50m length, 20m diameter
similar to size of ATLAS

Timeline



This collider will start to take data in your 30's

You have the opportunity to join participate in the design/construction/commissioning and PHYSICS

Contact

Who am I?

- PhD and PostDoc in Belgium (Antwerp and Louvain)
- Joined CERN as a Fellow in 2016
- CERN Physics Research Staff (since 2019) in the Experimental Physics Department

What do I do?

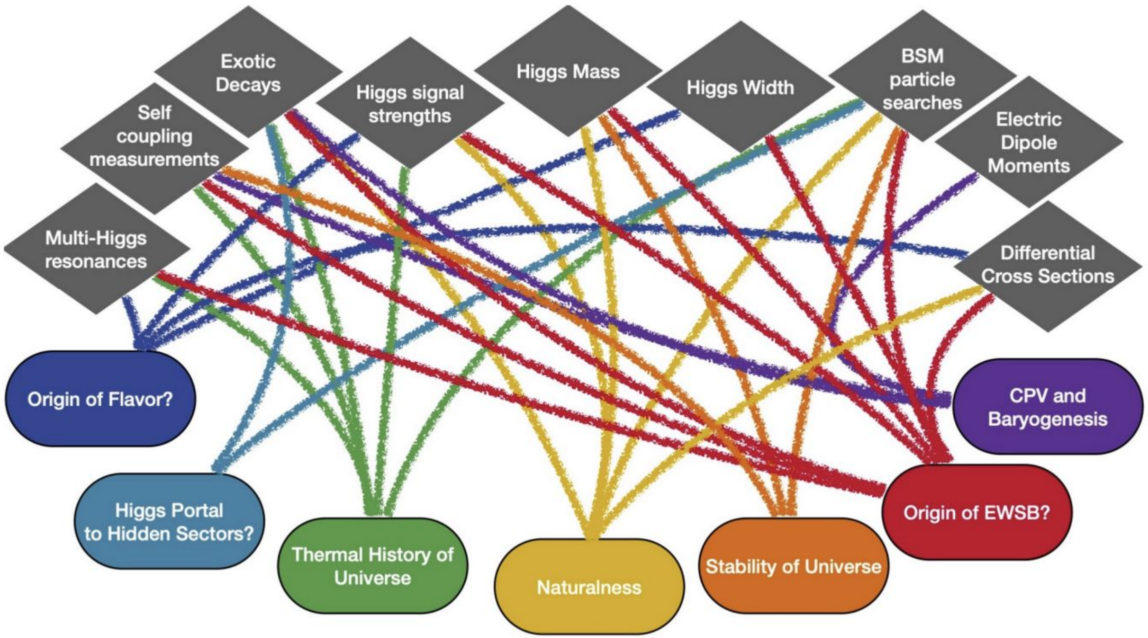
- I am a member of the CMS collaboration (study Higgs properties)
- I coordinate the Physics Performance Studies for the FCC
  - Goal: define and design detectors that maximise the physics reach of the FCC

Feel free to contact me at:

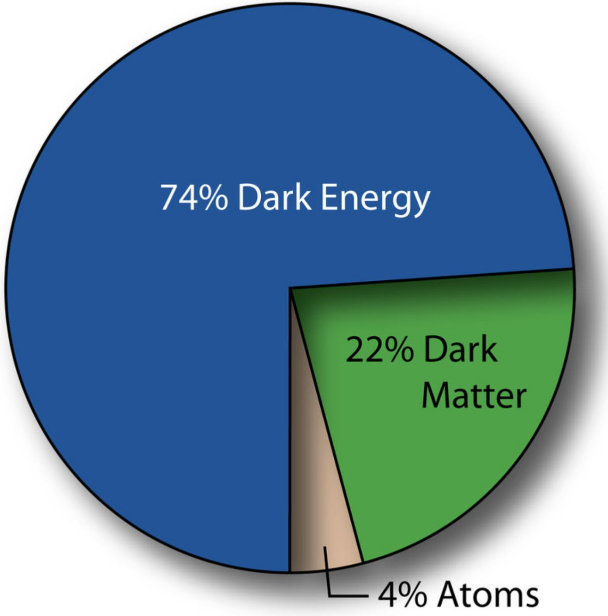
michele.selvaggi@cern.ch

Many thanks for the attention!

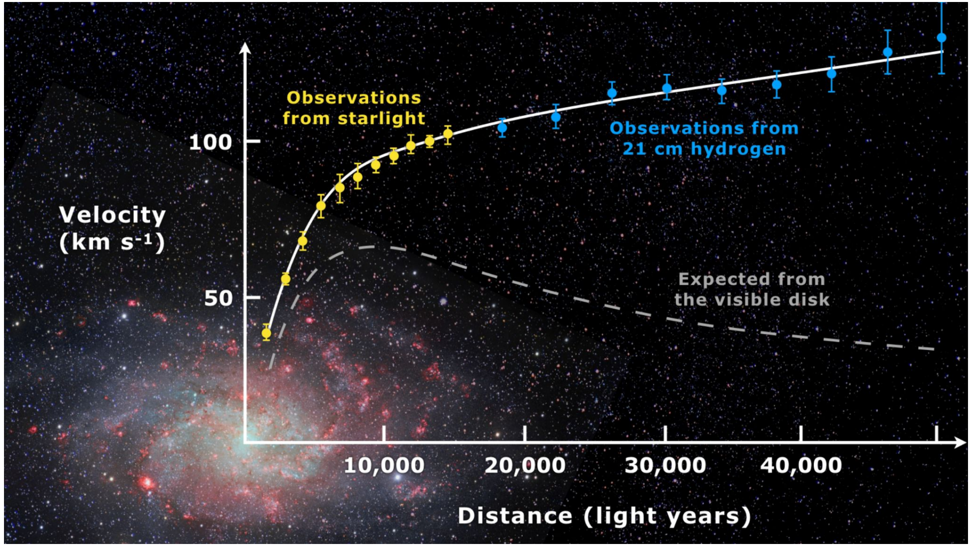
Higgs precision to probe new Physics



Dark Matter



74% Dark Energy
22% Dark Matter
4% Atoms



Observations from starlight
Observations from 21 cm hydrogen
Velocity (km s-1)
100
50
Expected from the visible disk
10,000
20,000
30,000
40,000
Distance (light years)