The European Laboratory for Particle Physics

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Department Head Experimental Physics, CERN

CERN Cognitive Festival, 24th October 2018, Tbilisi, Georgia

CERN was founded 1954: 12 European States

"Science for Peace"

Today: 22 Member States

- ~ 2500 staff
- ~ 2300 other paid personnel
- ~ 13000 scientific users

Member States: Austria, Belgium, Bulgaria, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden, Switzerland and the United Kingdom

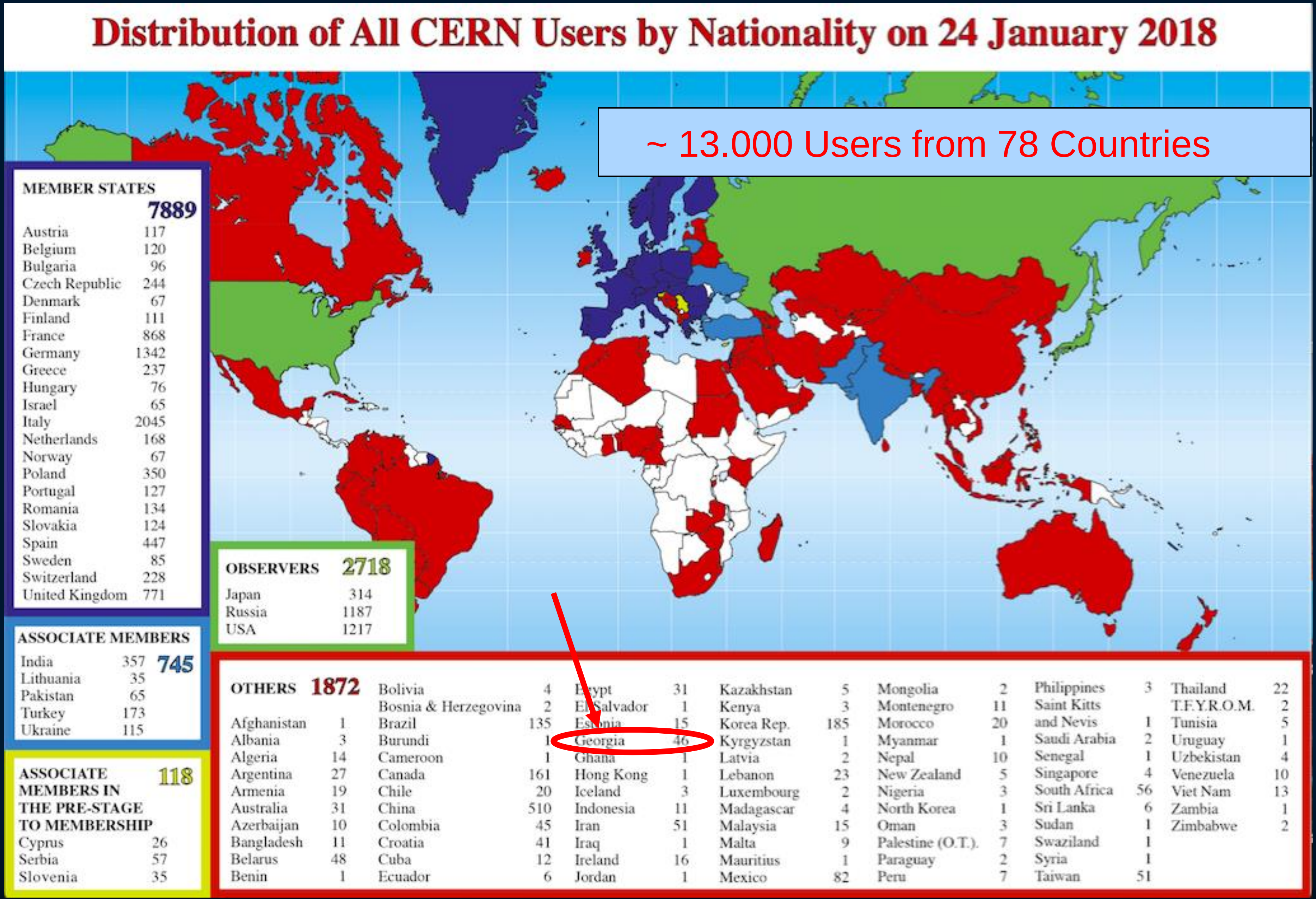
Associate Members in the Pre-Stage to membership: Cyprus, Serbia, Slovenia

Associate Member States: India, Lithuania, Pakistan, Turkey, Ukraine

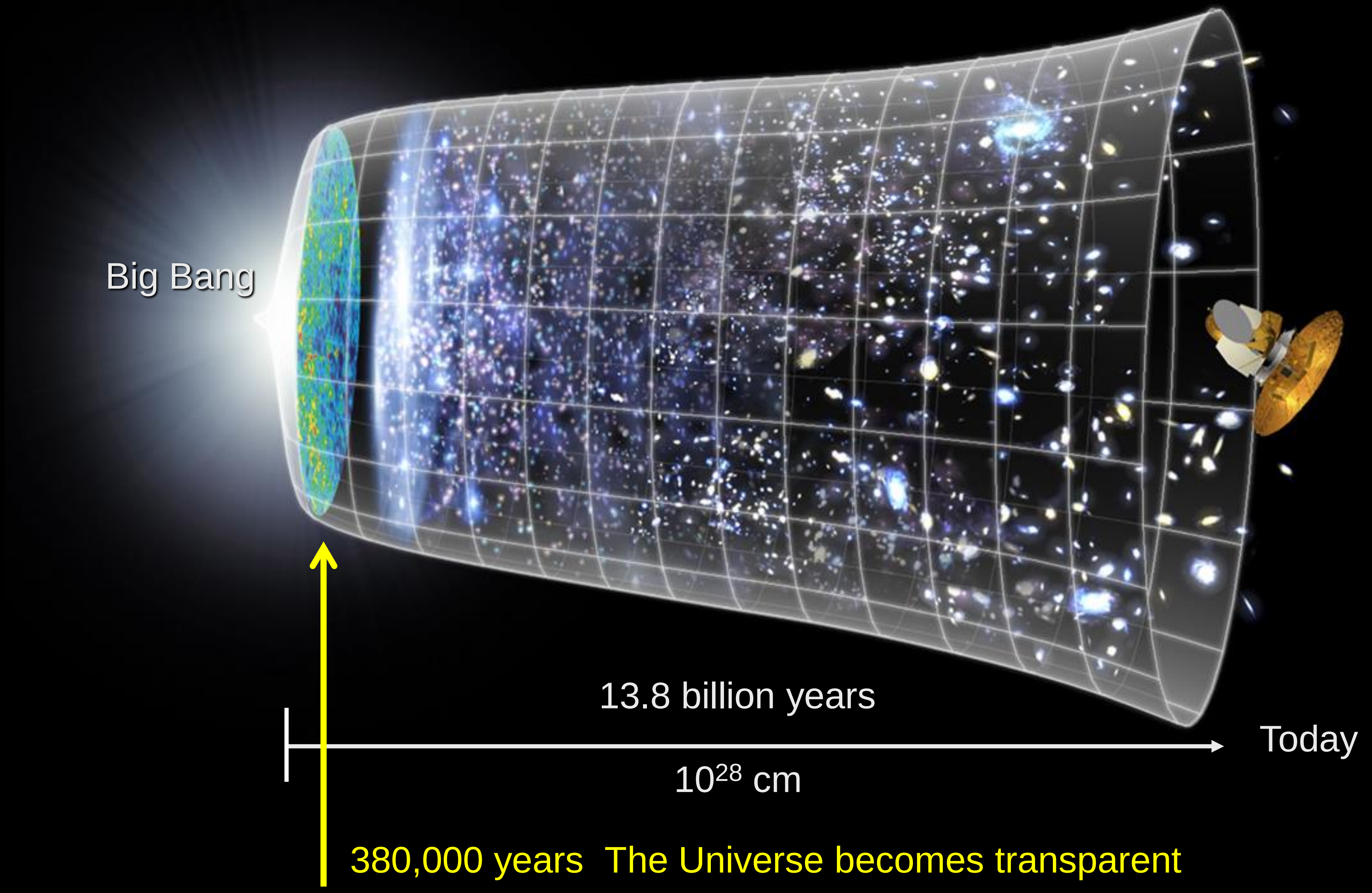
Applicant States for Membership or Associate Membership: Brazil, Croatia

Observers to Council: Japan, Russia, United States of America, JINR, European Commission and UNESCO

Science at CERN is done by scientists from all over the world



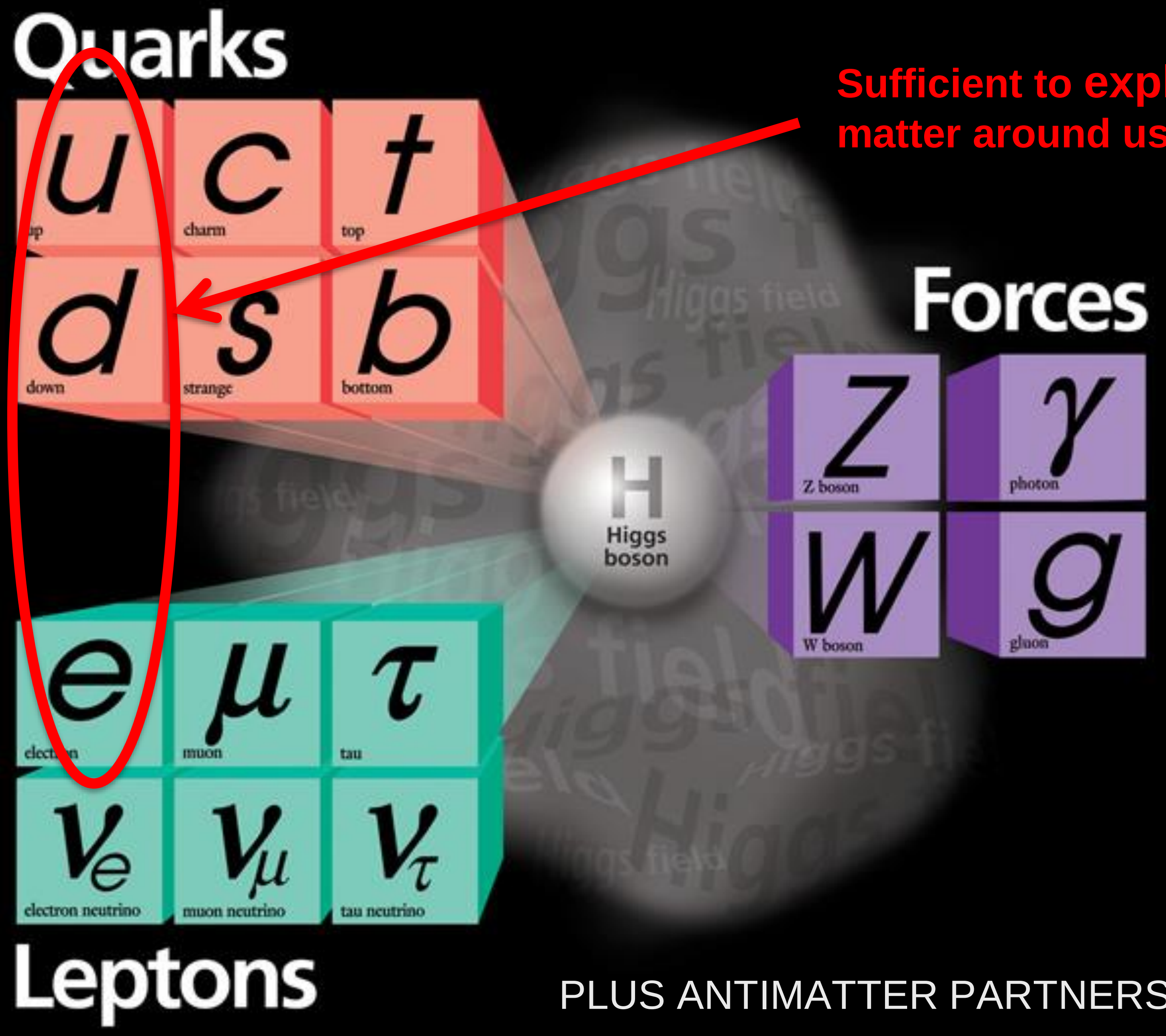
Physics at CERN: Understanding the Universe



The Standard Model of Particle Physics

Sufficient to explain the baryonic matter around us

Matter Particles
Quarks and Leptons

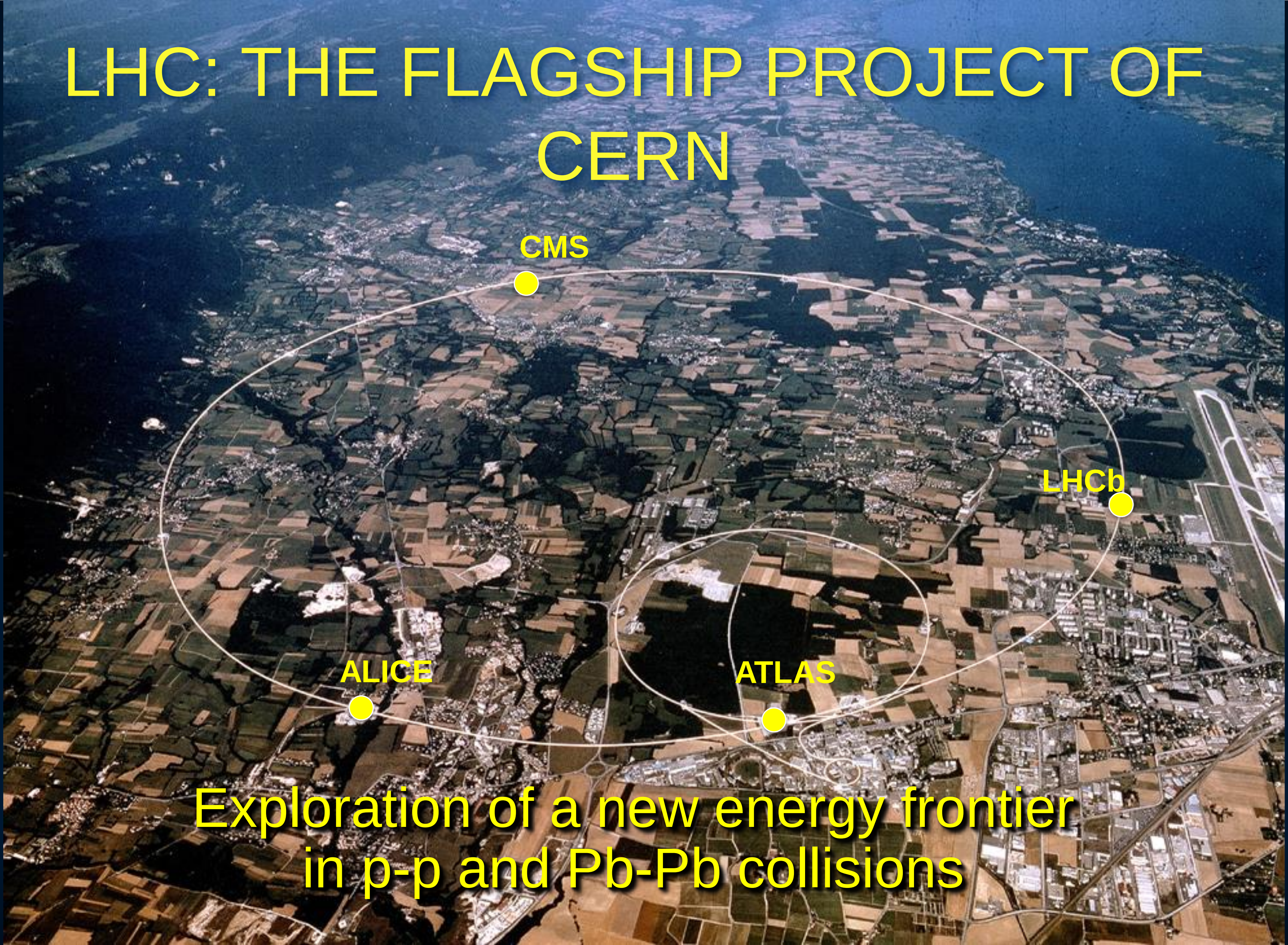


Force Carriers
Bosons

PLUS ANTIMATTER PARTNERS OF EACH PARTICLE

The Physics Program of CERN

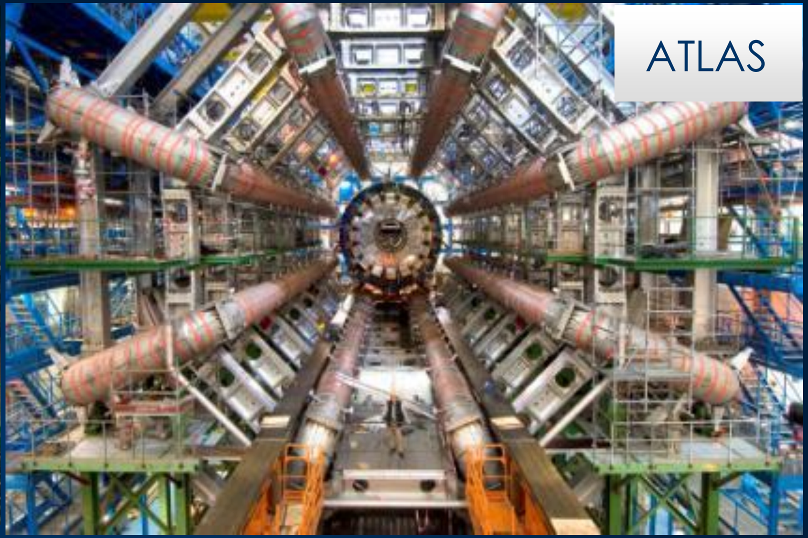
LHC: THE FLAGSHIP PROJECT OF CERN



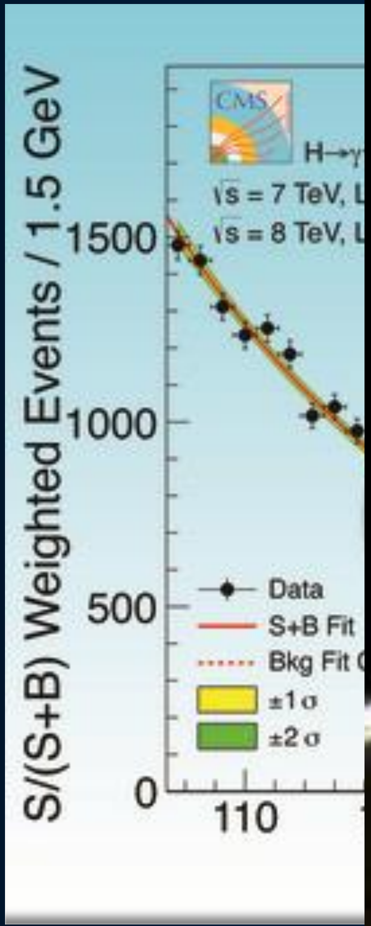
Exploration of a new energy frontier
in p-p and Pb-Pb collisions

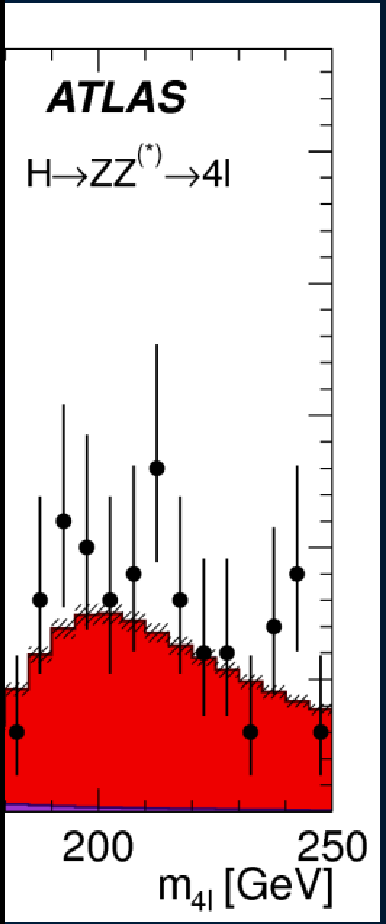
EXPERIMENTS AT THE LHC

Four major experiments + TOTEM, LHCf, MoEDAL



JULY 2012: "ATLAS AND CMS OBSERVE A NEW PARTICLE COMPATIBLE WITH THE HIGGS BOSON"





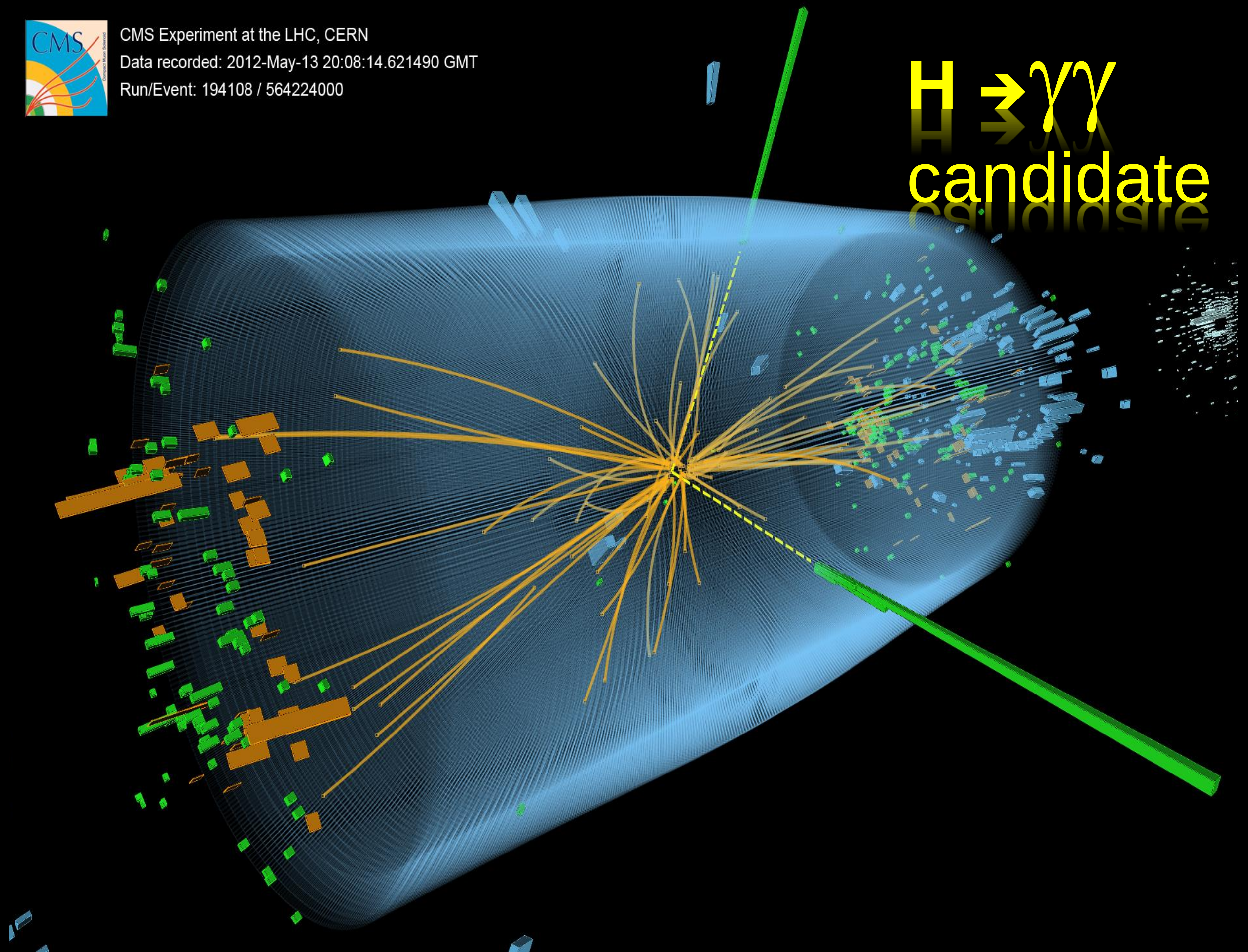
The Nobel Prize in Physics 2013

Photo: A. Mahmoud
François Englert
Prize share: 1/2

Photo: A. Mahmoud
Peter W. Higgs
Prize share: 1/2

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider"*

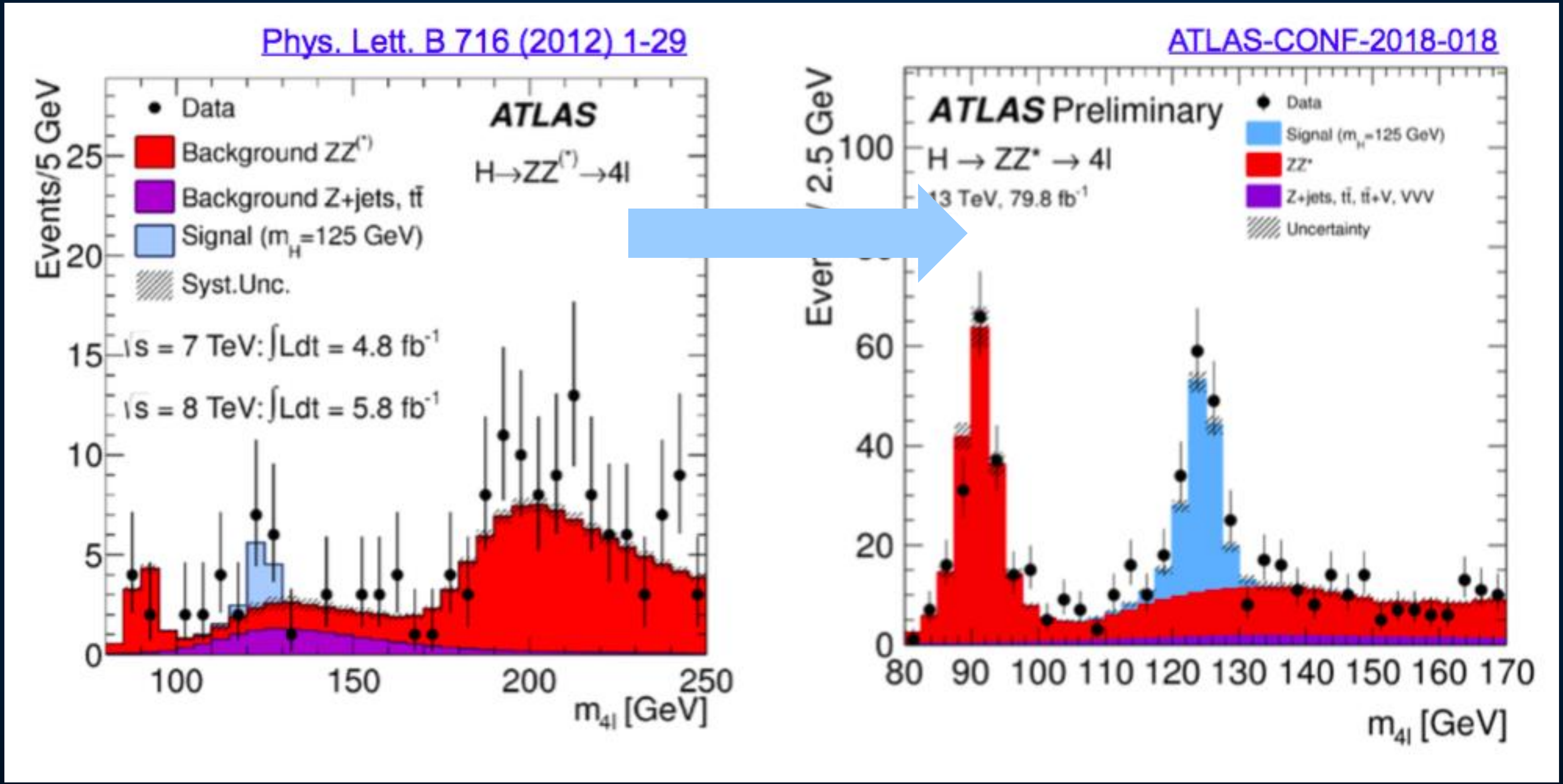
H → γγ candidate



LHC Physics - Higgs

6 years after the discovery – we see the Higgs Boson like other SM particles
Example: H – ZZ* - 4 l channels

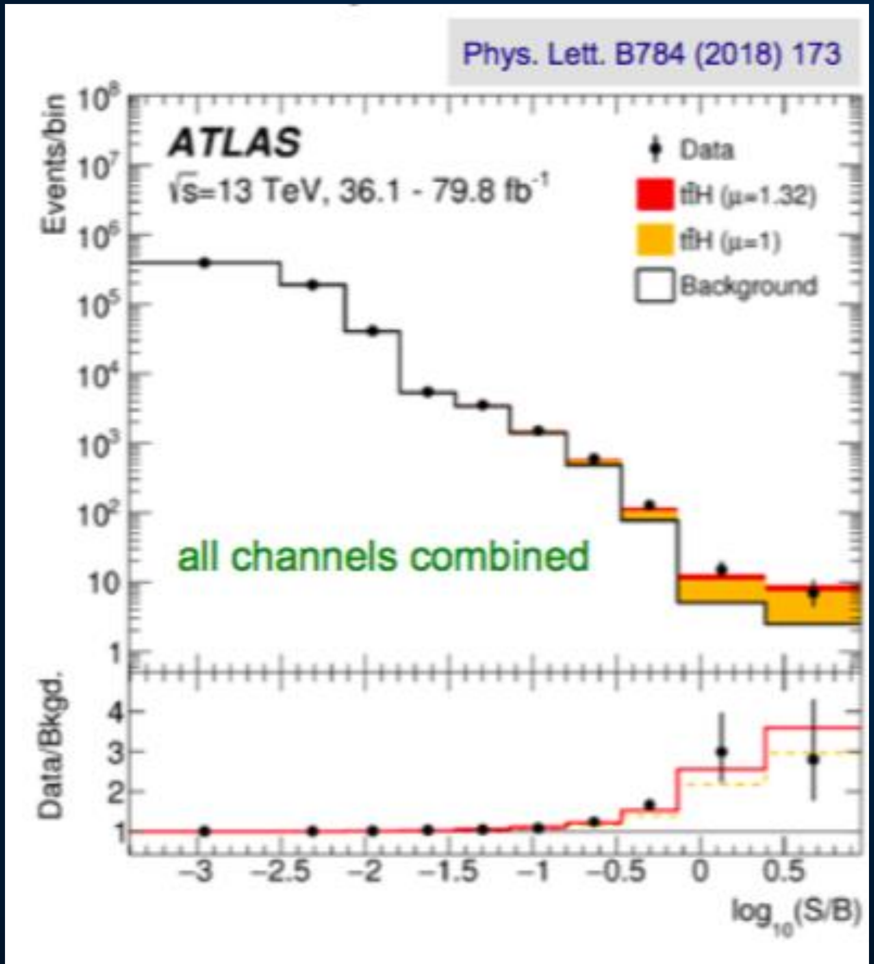
2012 | 2018

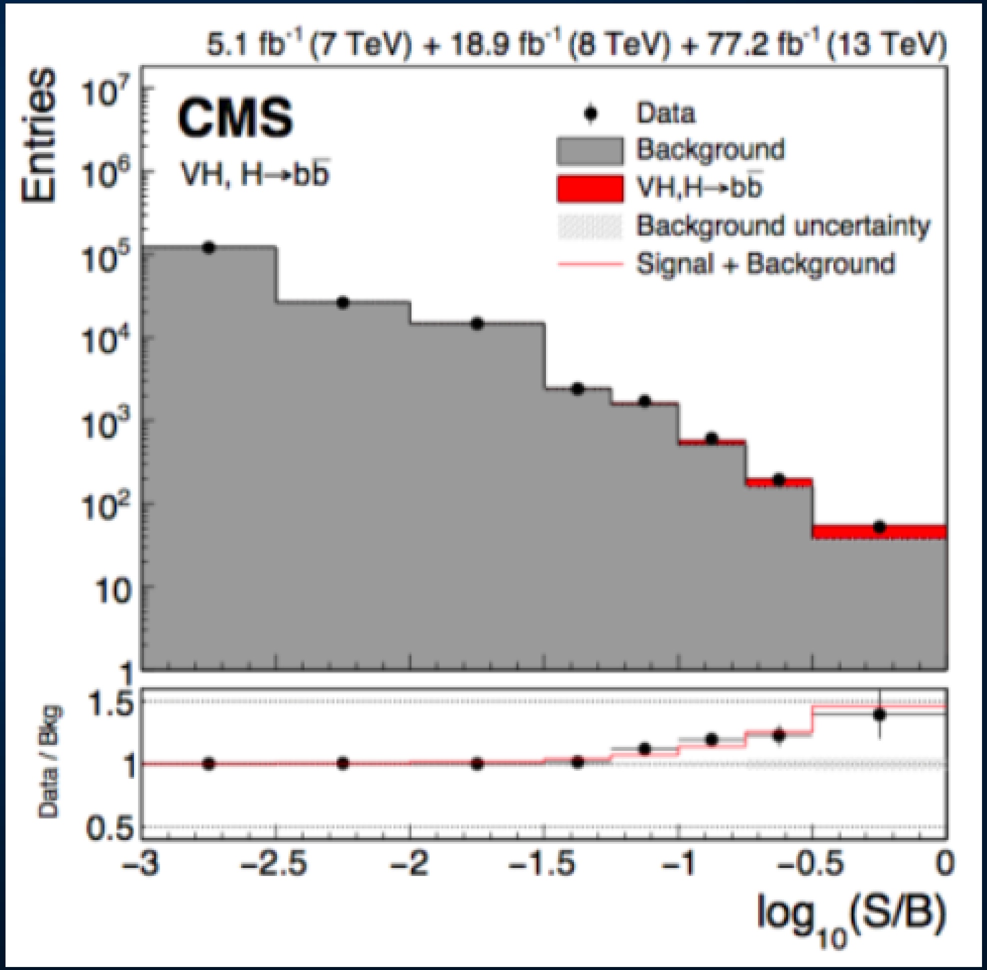


LHC Physics - Higgs

Discovery in Boson channels: 2 Photon, ZZ

2018 the year of the fermionic channels: Coupling to $t\bar{t}$ and $b\bar{b}$ observed by ATLAS and CMS



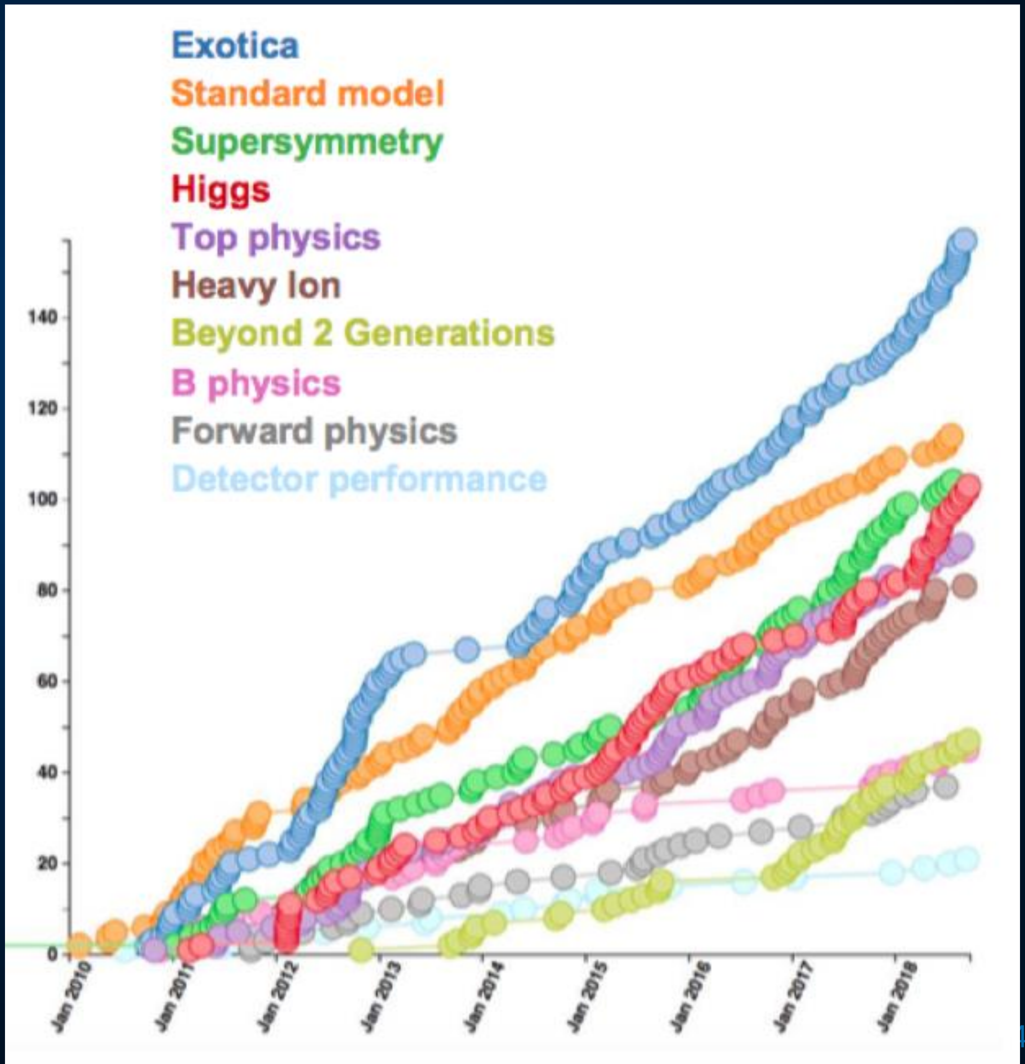


LHC Physics - Overview

Very wide spectrum of physics

- Study of the standard model particles and processes
- Search for hints of physics beyond the standard model “new physics”
- Search for exotic particles
- Heavy ion physics
- And, of course, the study of the Higgs!

E.g. Scientific output of CMS:
800 physics paper submitted (September 2018)

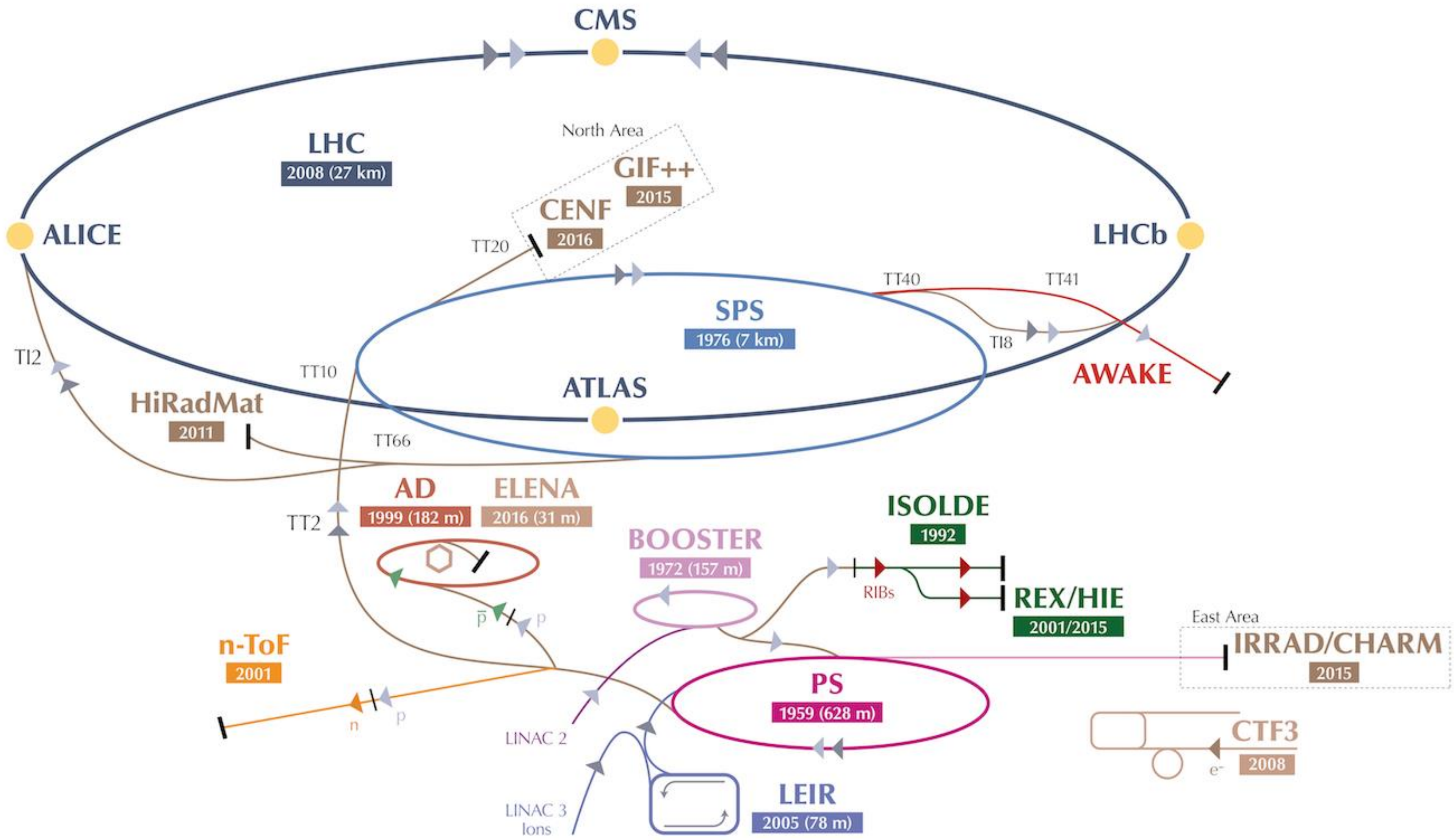


CERN is not only LHC

3 main pillars of the scientific strategy of CERN:

- Full exploitation of the LHC including upgrades and HL-LHC
  - Plan to operate the LHC until 2037
- A scientific diversity programme
  - Experiments exploiting the accelerator complex at CERN
  - Non-Accelerator experiments using CERN technologies (CAST, OSQAR)
  - Participation in accelerator-based neutrino projects outside Europe
- Preparing CERN's future
  - Studies for future accelerators: CLIC, FCC
  - Studies for CERNs future diversity programme: "Physics beyond colliders"
  - R&D on accelerator and experimental techniques

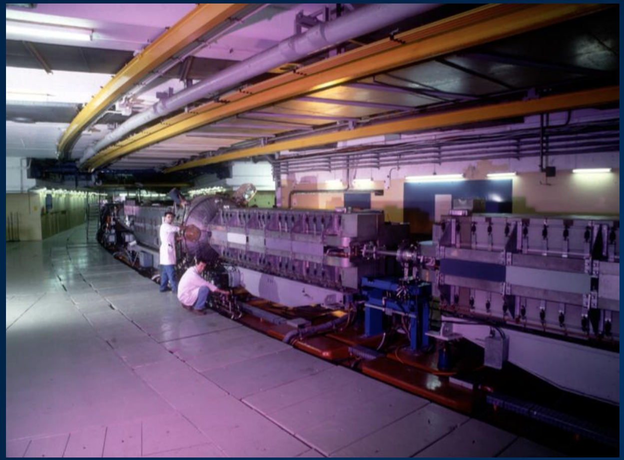
CERN ACCELERATOR CHAIN



Fixed Target Physics

Lower energy experiments using the injector accelerators PS or SPS (in 1-100 GeV range)
Allow precision measurements and comparison with theory

Proton Synchrotron (1959)
14 – 26 GeV, max. 1.4×10^{13} protons per pulse



Super Proton Synchrotron (1976)
Protons up to 400 GeV, max. 9.5×10^{9} p per bunch

Fixed target experiments:

- NA58 (COMPASS): muon spin physics, hadron spectroscopy
- NA61 (SHINE): strong interaction (onset of deconfinement), neutrino and cosmic ray program
- NA62: rare K decays BR($K^+ \rightarrow \pi^+ \nu \bar{\nu}$)
- NA63: electromagnetic processes in strong crystalline fields
- NA64: search for dark photons in missing energy events

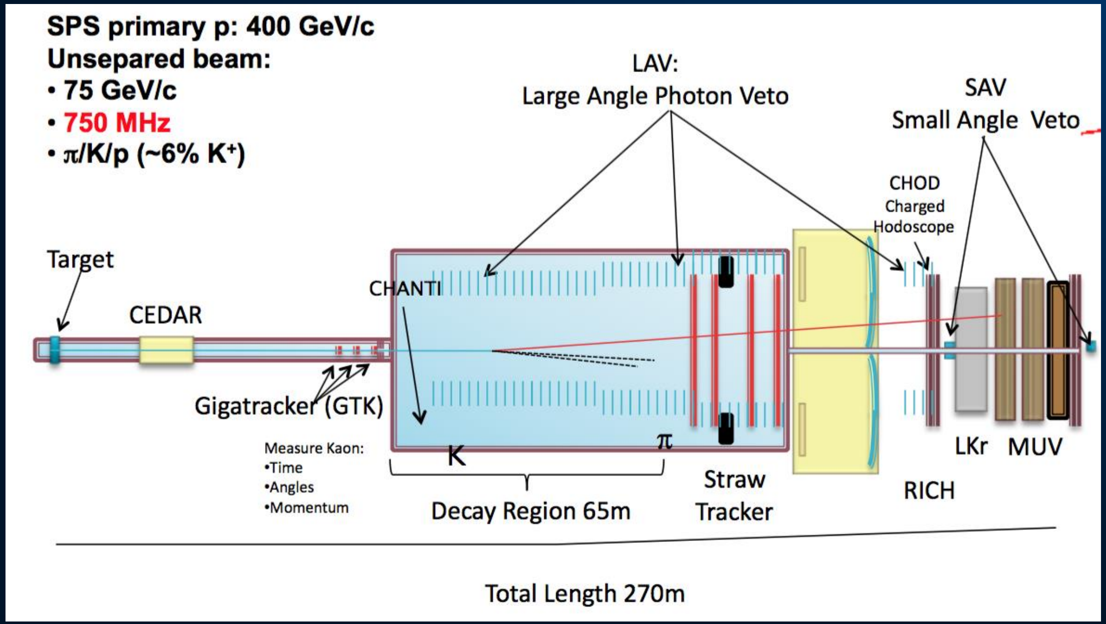
Fixed Target Physics – NA62

Search for very rare decays: BR($K^+ \rightarrow \pi^+ \nu\bar{\nu}$) predicted by theory to be (8$\pm$1)x10^{-11} (Buras et al. 2015)

And much more, e.g. Precision measurements of dominant Kaon BRs

- Precision test of lepton universality $R_K = \Gamma(K \rightarrow e\nu(\gamma)) / \Gamma(K \rightarrow \mu\nu(\gamma))$
- Searches for lepton flavour or number violation $K^+ \rightarrow \pi^+ \mu e, K^+ \rightarrow \pi^- \mu^+ e^+$, $K^+ \rightarrow \pi^- l^+ l^+$
- Searches for heavy neutrinos $K^+ \rightarrow l^+ \nu_h$
- Searches for long-lived dark sector particles: dark photons, axion like particles produced in target
- π^0 decays $\pi^0 \rightarrow invisible, 3\gamma, 4\gamma$

First data with completed detector in 2016, 3x10^{12} K^+ collected in 2017



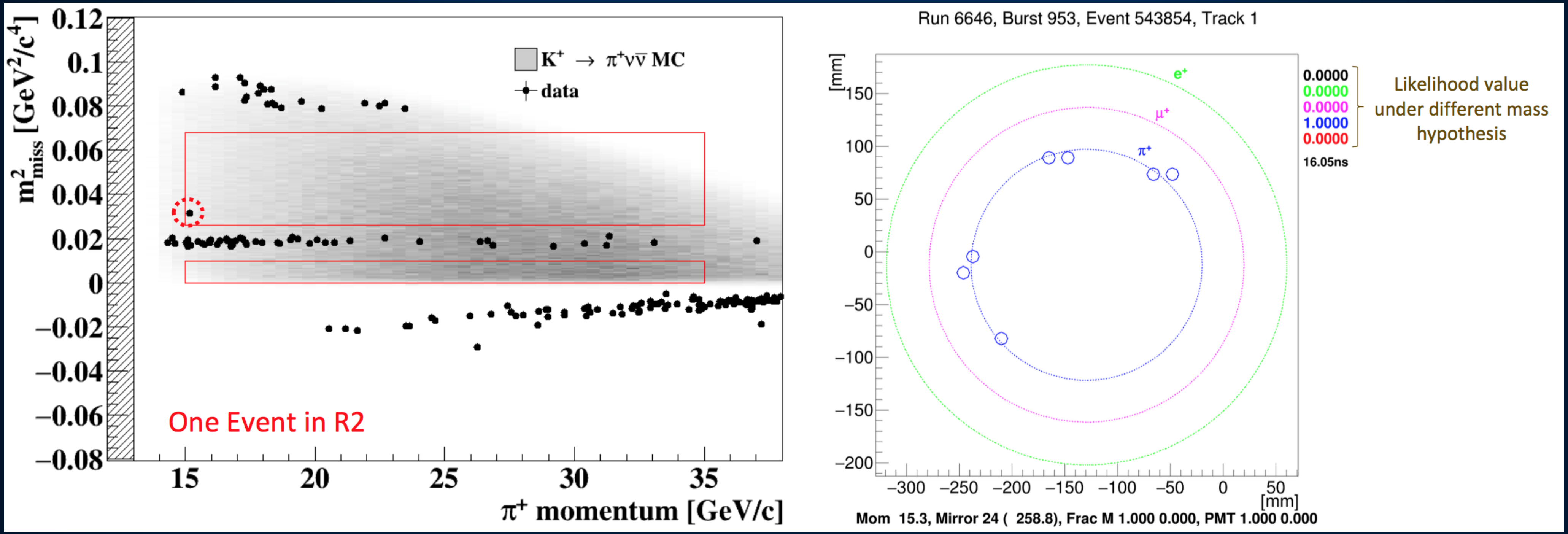
(60 m long)

Fixed Target Physics – NA62

2016 comissioning and physics run (30 days of running, ~50K good bursts)

First event observed in 2016 data - The new NA62 decay in flight technique works!

2017 Successful physics run (160 days, 2018 run ongoing (217 days scheduled), $3x10^{12}$ K^+ collected



Presented at Moriond2018, publication in preparation.

With the data from 2017 and 2018 expect order of 20 events.

Nuclear Physics: ISOLDE

ISOLDE: radioactive ion beams

- Nuclear structure
- Fundamental interactions
- Nuclear Astrophysics
- Applications (Medicine, Material Science)

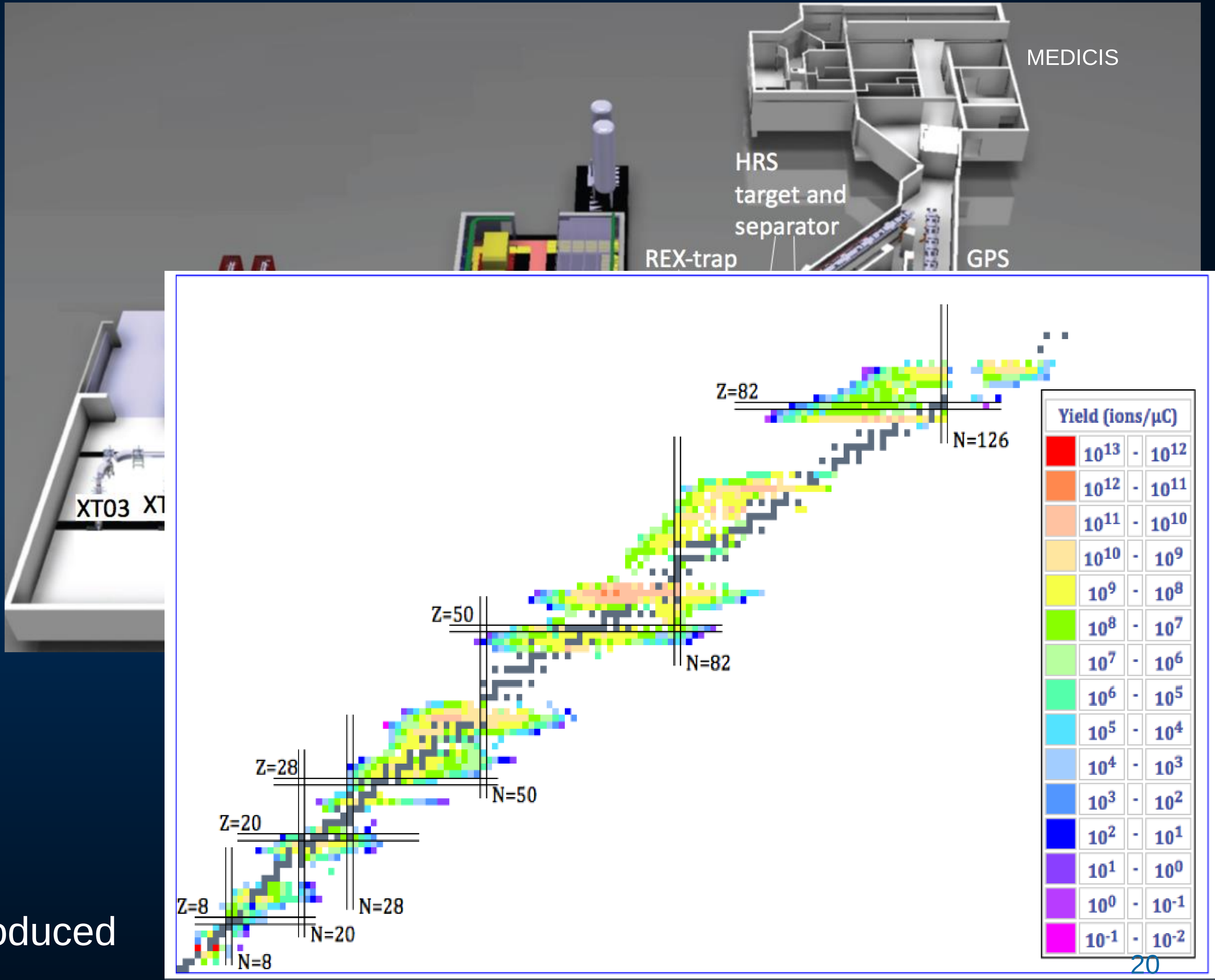
HIE-ISOLDE: post acceleration up to 10 MeV/nucleon since 2018

Over 20 Target materials:
carbides, oxides, solid metals, molten metals and molten salts (U, Ta, Zr, Y, Ti, Si, …)

3 types of ion sources: surface, plasma, laser

Charge breader for post acceleration

- 1000 isotopes of 75 chemical elements produced



Nuclear Physics: nTOF

nTOF (neutron time-of-flight) a spallation source using 20 GeV/c protons from the PS

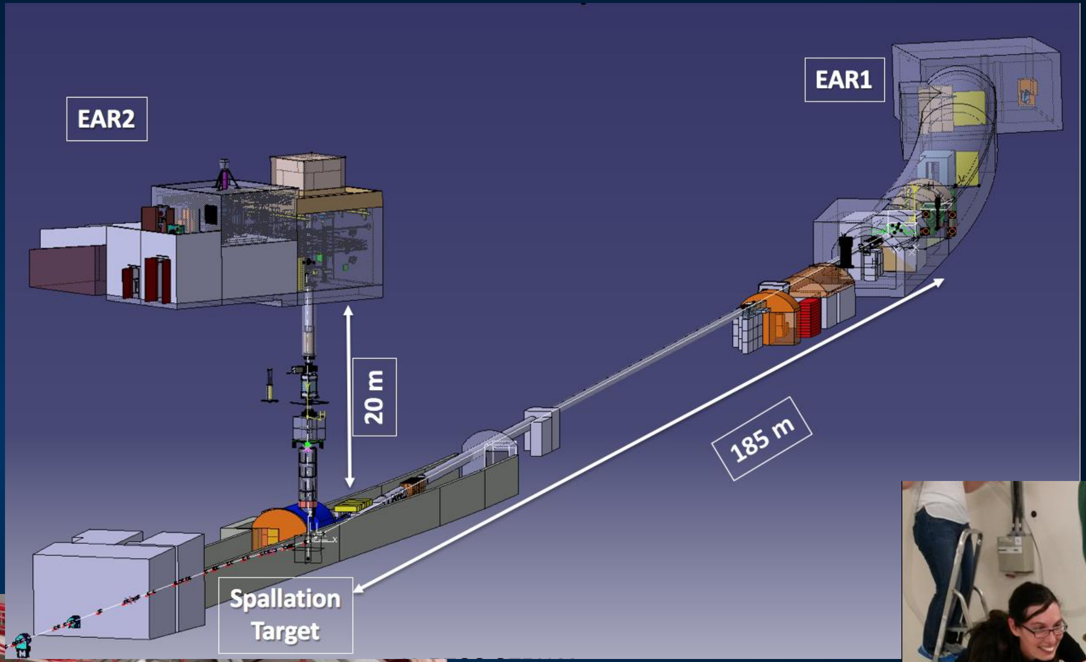
Neutron cross-section measurements

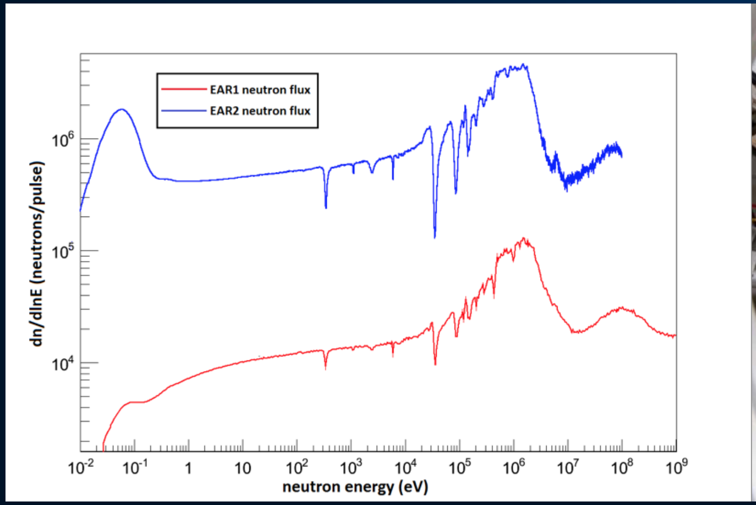
- Astrophysics
- Nuclear Physics
- Medical Applications
- Nuclear Waste Transmutation

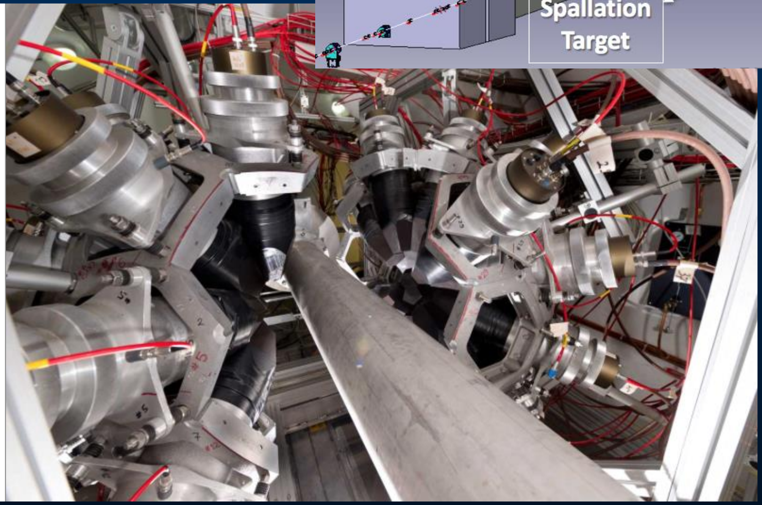
2 experimental areas EAR1 and EAR2

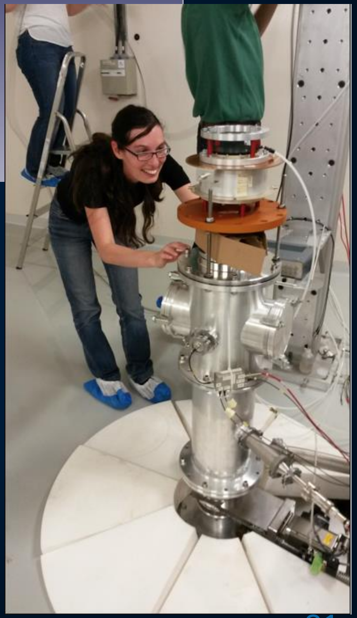
High instantaneous neutron flux (10^5/cm^2/pulse)

Large energy range (25 meV – 1 GeV)







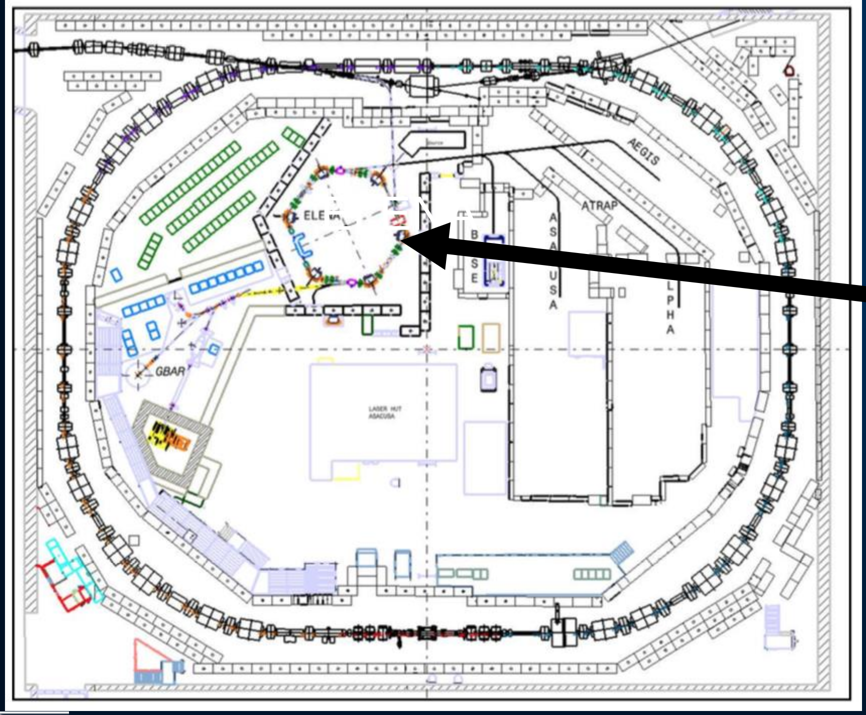


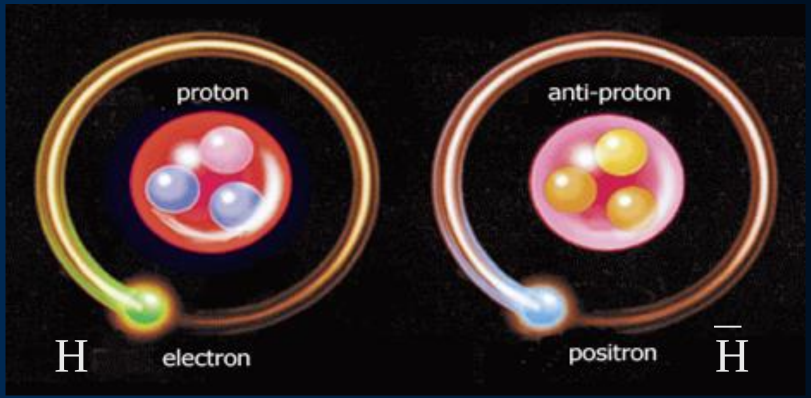
Antiproton & Antihydrogen Physics

Matter-Antimatter comparison

- Test CPT invariance, the most fundamental Symmetry in relativistic quantum field theory
- Test of the Weak Equivalence Principle by measuring the gravitaional behavior of antimatter
- Measurements of “antihydrogen”-like systems: antiprotonic helium, positronium, protonium

The Antiproton Decelerator (AD): antiprotons at 5.3 MeV





In commissioning ELENA
Extra Low Energy Antiprotons
at 100 keV
→10-100 x larger trapping efficiency
→ Parallel running of experiments

Antiproton & Antihydrogen Physics

6 experiments connected to the AD/ELENA:

ATRAP spectroscopy and magnetic moment of the antiproton

With a single trapped antiproton: $\mu_{p(bar)} / \mu_p$=-1.000000+-5 x 10^{-6} *Phys. Rev. Lett. 110, 130801 (2013)*

BASE magnetic moment of the antiproton

Trapped antiprotons and stored them for >400 days

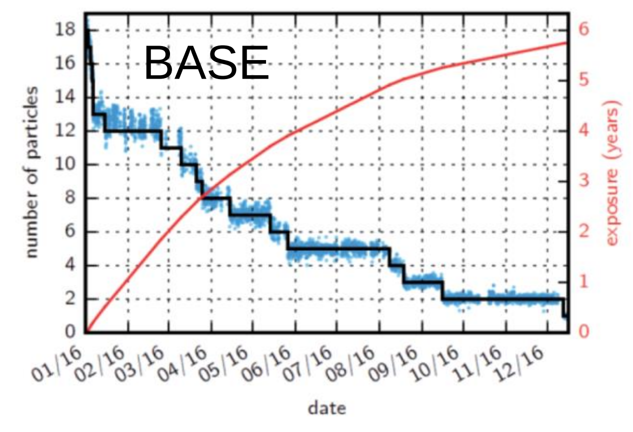
Improvement of precision by a factor of 350: $\mu_{p(bar)}$ = -2.7928473441 (42) μ_N *Nature 550, 371 (2017)*

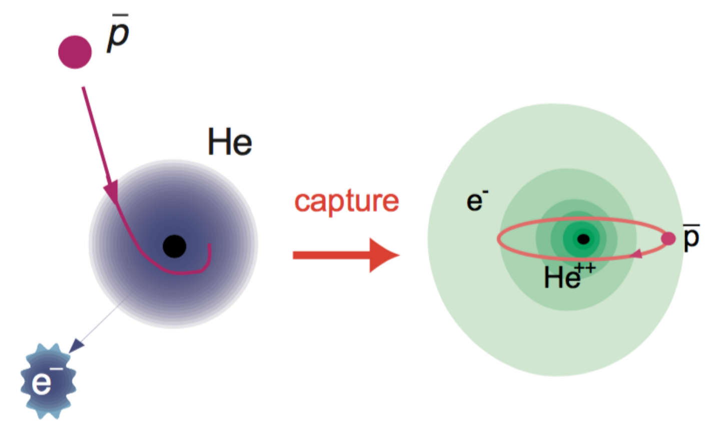
ASACUSA spectroscopy of exotic atoms

antiprotonic Helium p(bar)He^+, H(bar) ground state hyperfine splitting

Measurement of the ratio of $m_{p(bar)} / m_e$, agrees to measured m_p / m_e within 8 x 10^{-10}

Science Vol. 354, Issue 6312, pp. 610-614 (2016)





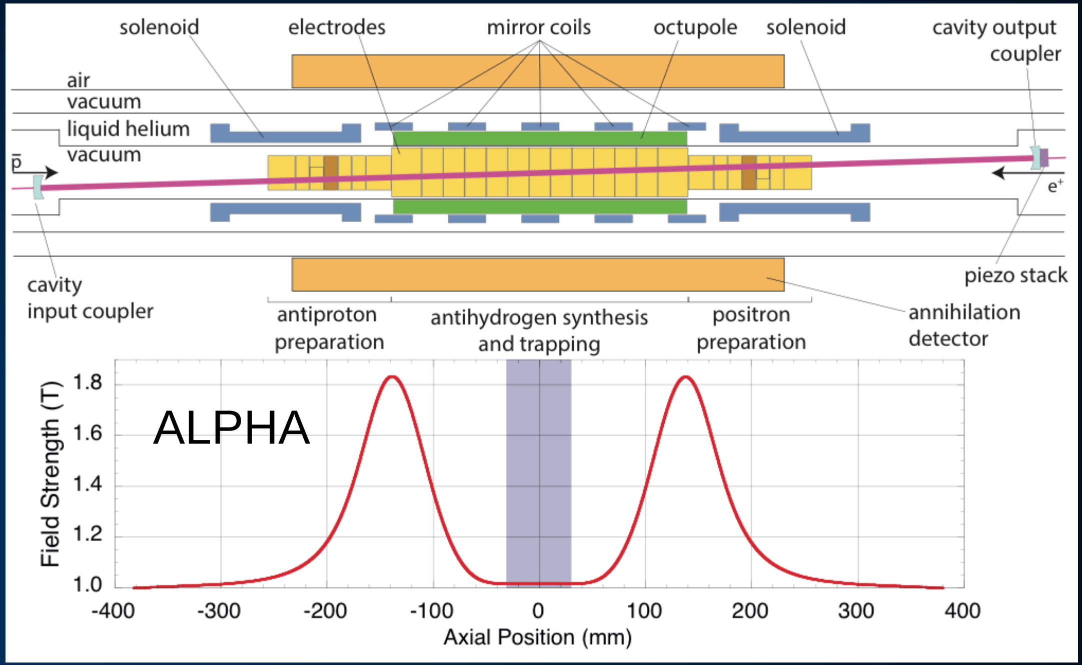
Antiproton & Antihydrogen Physics

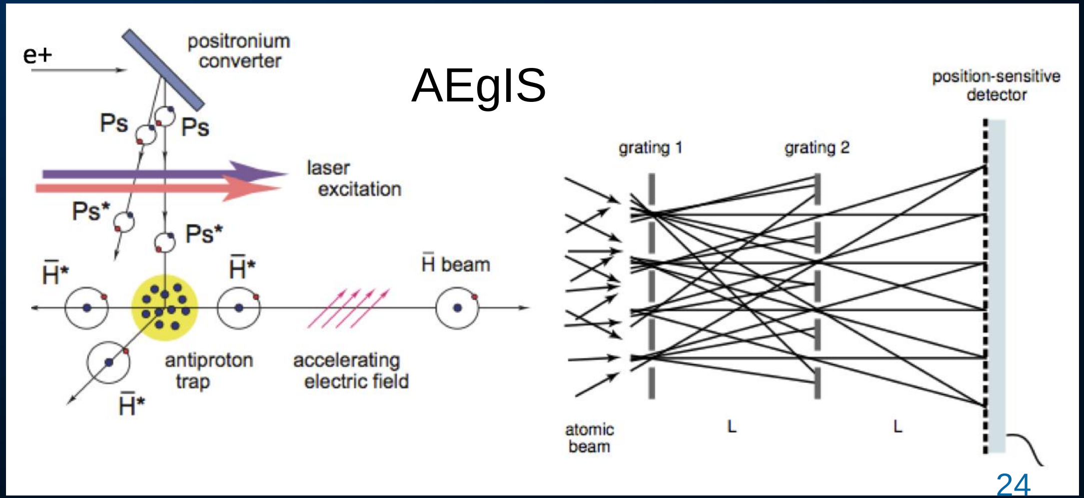
ALPHA/ALPHA-g spectroscopy and gravity

- 1st measurement of 1s – 2s transition in anti-H to 10^{-10}
  Nature 541, 506-510 (2017)
- 1st observation of the hyperfine spectrum of anti-H
  Nature 548, 66-70 (2017)
- 1st observation of the Lyman-α electron transition (1S-2P)
  Nature 561, 211-215 (2018)

AEgIS spectroscopy, antimatter gravity experiment

GBAR (will start in 2017 connected to ELENA)
antimatter gravity experiment





Environmental Physics

CLOUD - Study effect of cosmic rays on cloud formation

Clouds created in a large climatic chamber

Study influence of natural and man made aerosols on the development of clouds, cosmic rays “simulated” by PS beam.

Ultra clean, can simulate temperature conditions anywhere in the atmosphere, equipped with a wide range of instruments for monitoring and analysis.

The CLOUD experiment has gathered experimental data to model aerosol production solely based on laboratory measurements.

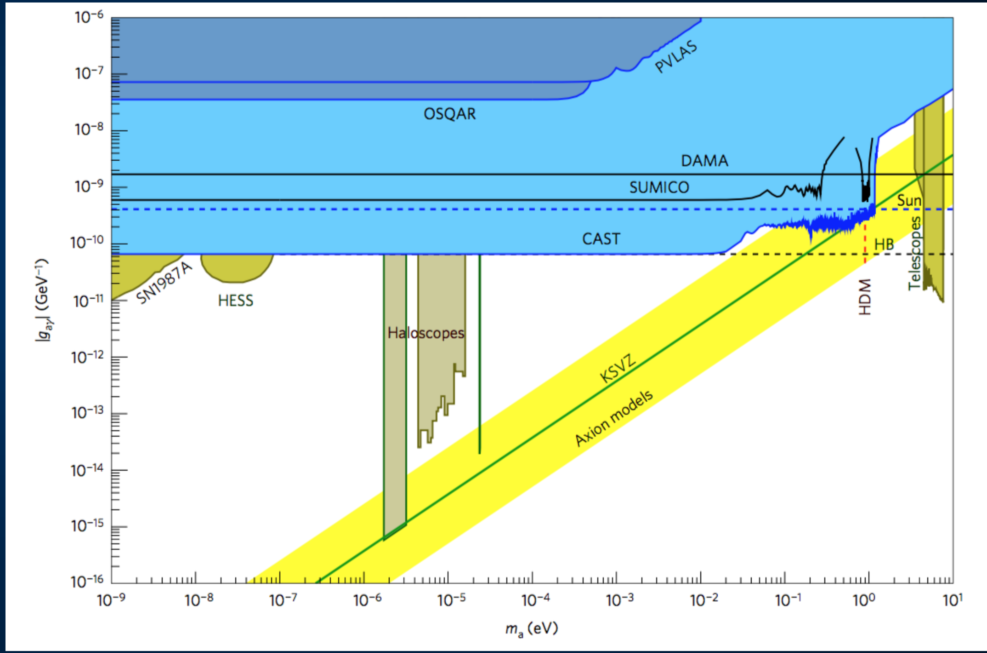
Science 10.1126/science.aaf2649 (2016)

Non Accelerator Experiments

CAST: The CERN Axion Solar Telescope (using a LHC test magnet)

- Search for solar axions
- Search for dark matter axions from the galactic halo
- Search for solar chameleons

Constraints on Axion-Photon coupling:

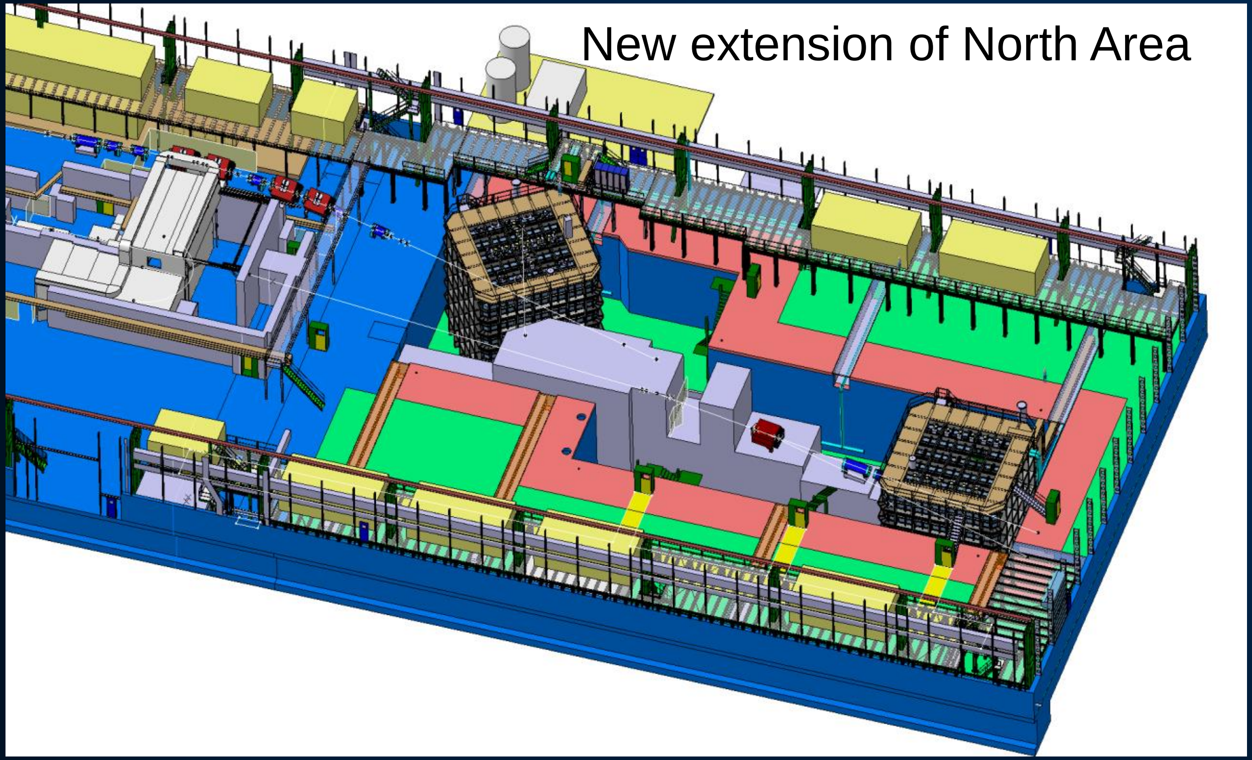


Nature Physics 13, 584-590 (2017)

OSQAR: Search for Axions through “Light shining through wall experiments” and search for Chameleons “inverse Primakoff conversion – afterglow” Using LHC prototype dipole magnet

Neutrino Physics

Neutrino Platform at CERN:
Support for the European Neutrino Community, test area with charged beams for neutrino detectors (e.g. R&D for large liquid argon detectors)

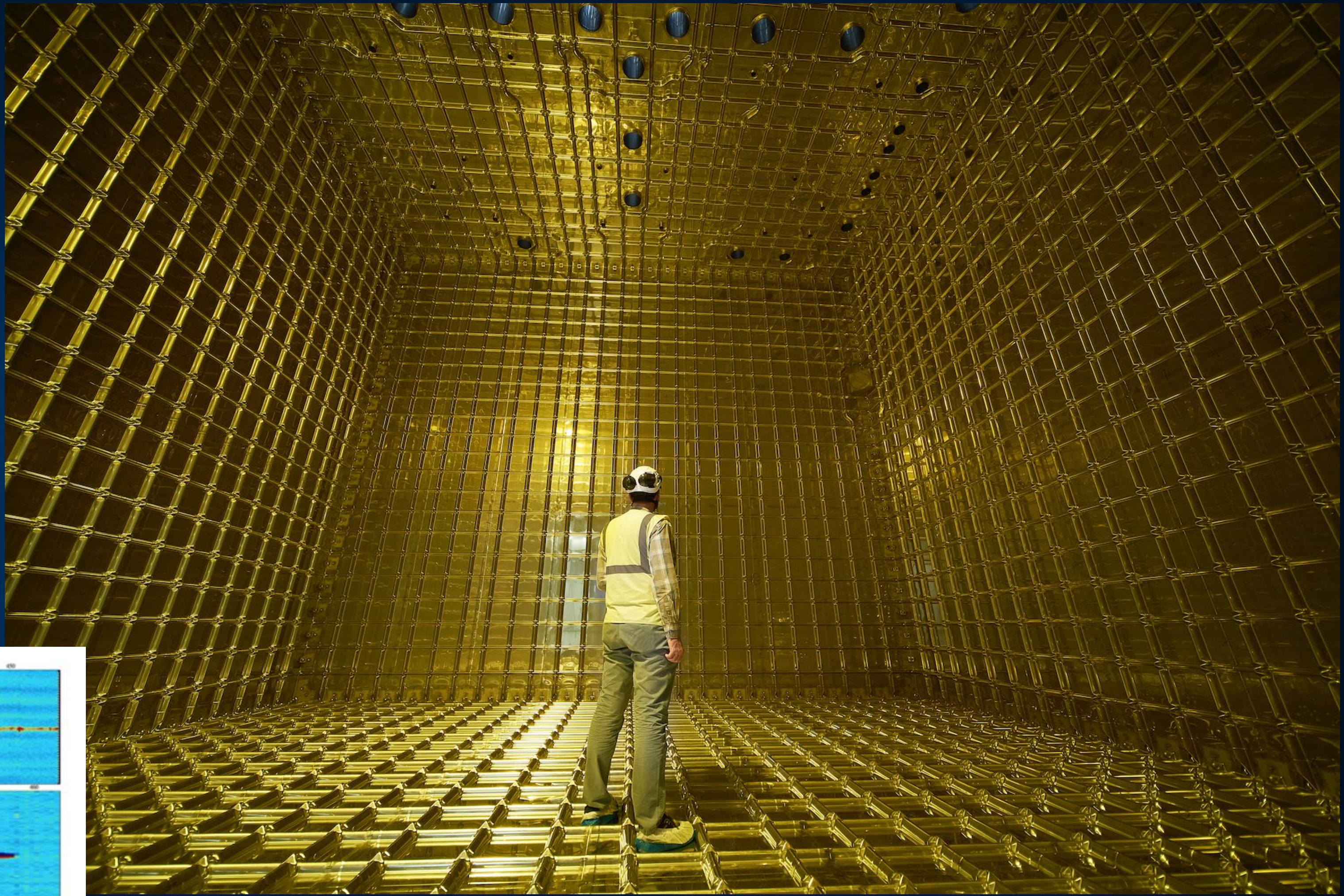


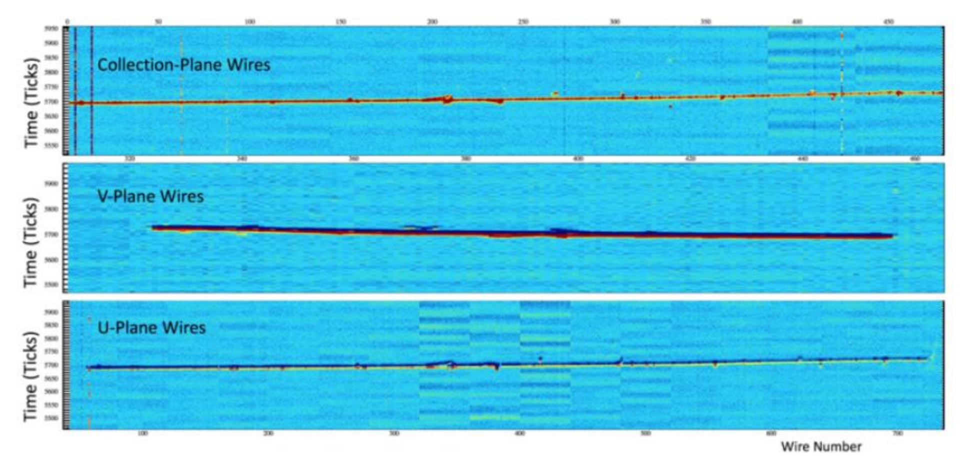
At present 5 projects/activities part of the platform:

- Refurbishment of ICARUS, a short base line detector – done
- Construction of two large LAr Prototypes for DUNE (Single phase and double phase). Test with charged beams planned for end of 2018.
- Baby MIND a magnetized iron spectrometer for a JPARC experiment - done
- PLAFOND framework for generic R&D

Proto DUNE Single Phase

- Liquid Argon Time Projection Chamber
- New type membrane cryostat technology
- ~800 ton LAr at ~89 K temperature
- Cold electronics, photon detection system
- Active volume 6x7x7.2 m^3
- Drift distance between cathode and anode plane is 3.6 m
- 180 kV, 500 V/cm drift field





First tracks seen Sept. 2018

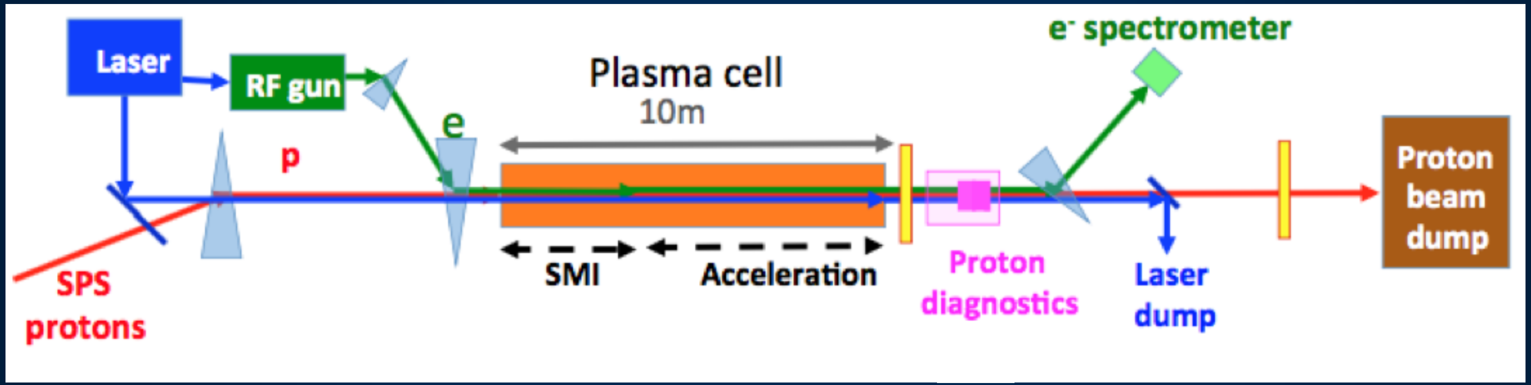
AWAKE

Advanced Proton Driven Plasma Wakefield Accelerator Experiment

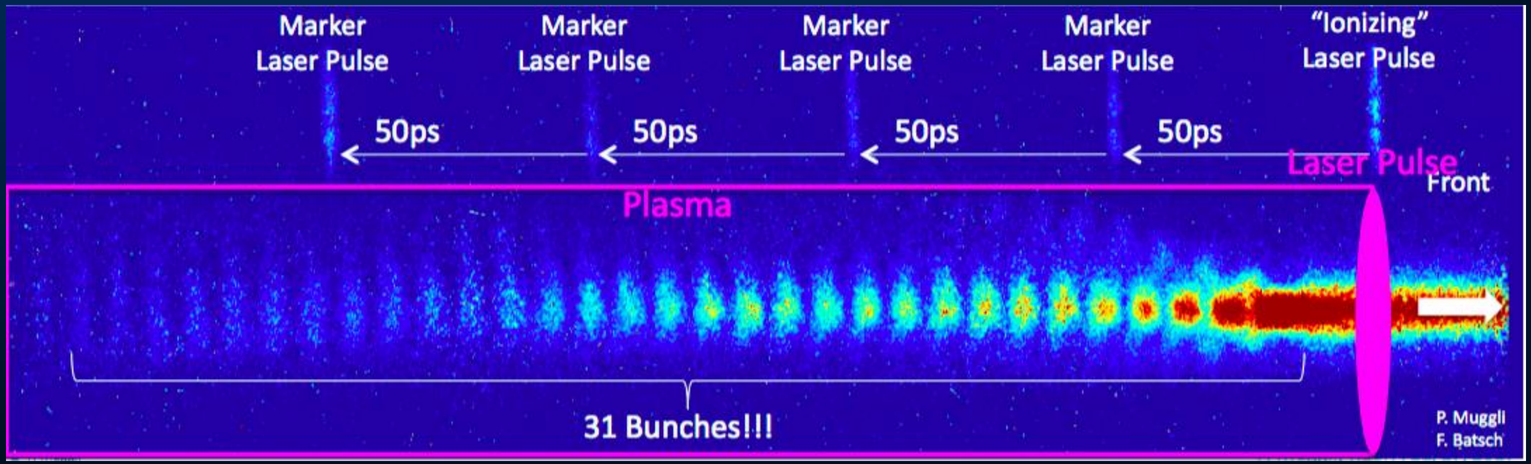
R&D experiment to demonstrate novel accelerator technique:

400 GeV proton beam generates strong electromagnetic field in plasma,

e^- beam to be accelerated in the wake of the p beam – aim for accelerator gradients of ~GeV/m



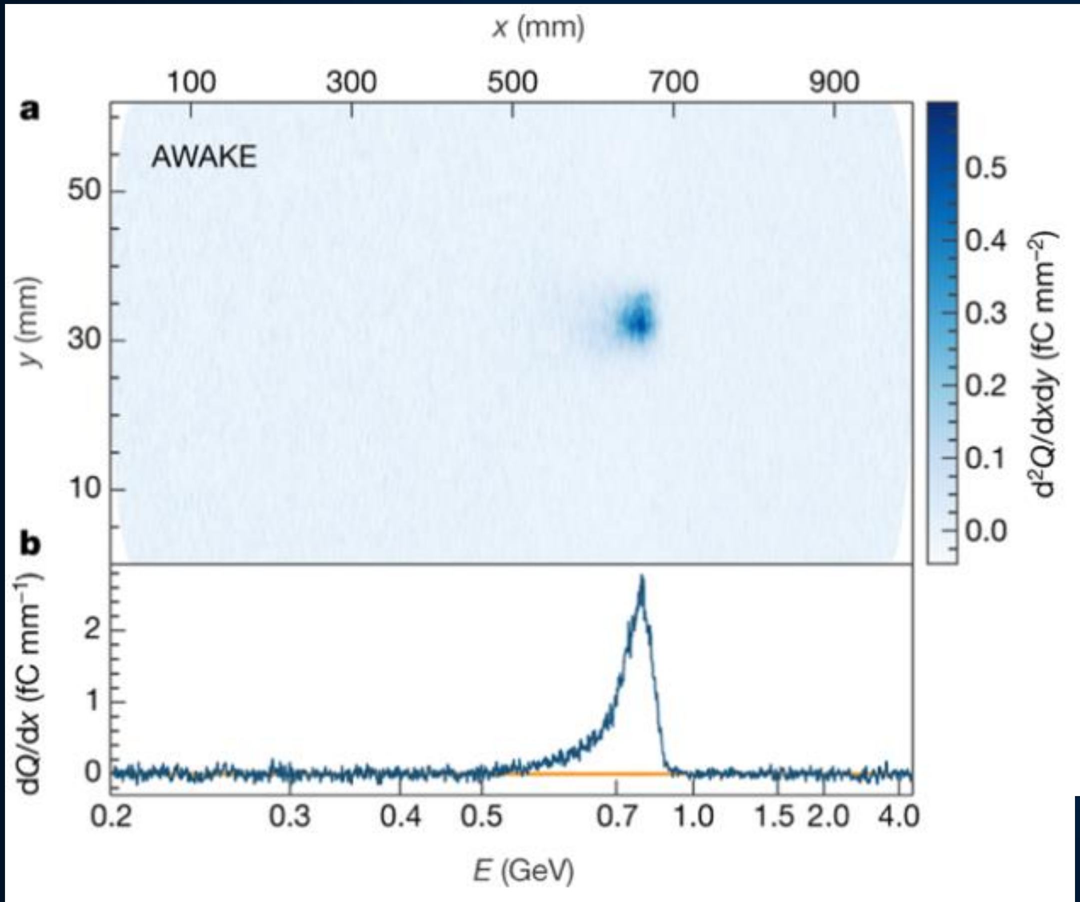
2017: Observation of beam induced self modulated instabilities

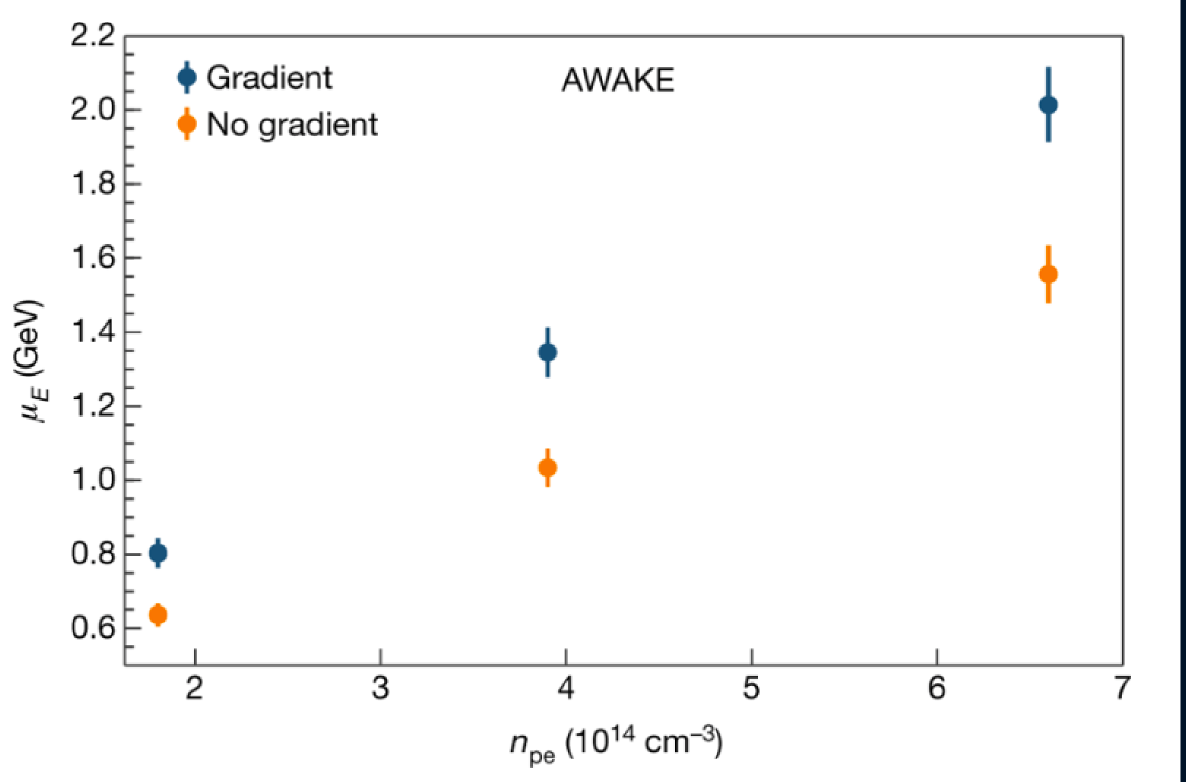


AWAKE

2018: First demonstration of proton driven plasma wakefield acceleration of externally injected electrons

Nature 561, 363-367 (2018)





Up to 2 GeV in 10 m plasma
Average gradient of 200 MV/m!

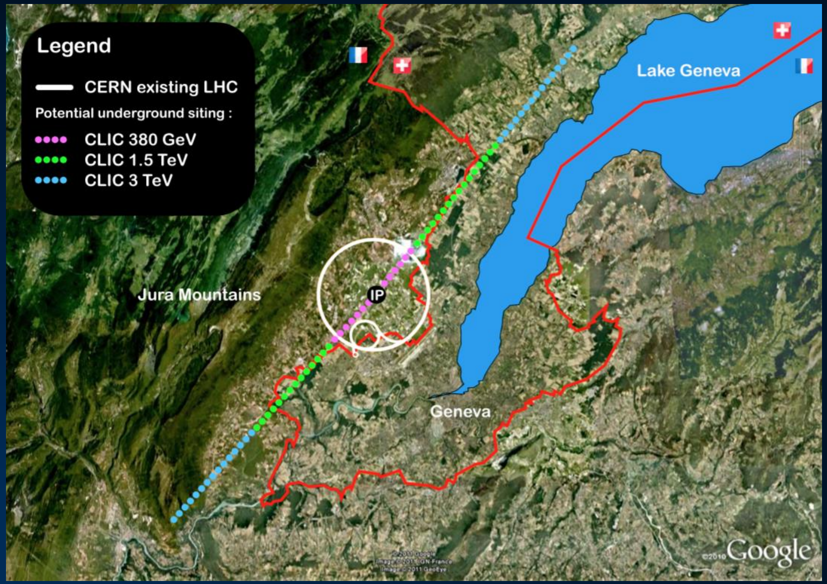
Studies for Future Facilities

LHC, and its upgrade to higher luminosity, is central to CERN program for next decade(s)

But Europe need to prepare for what will come after, so future accelerators and experiments are under study

- CLIC – Compact Linear Collider
  Study of the design for a possible future e^+e^- linear collider up to 3 TeV, starting at 380 GeV
- FCC – Future Circular Collider
  Study of a 100 km circumference machine for pp collisions at 100 TeV, as well as e^+e^-, option for ep
- Physics beyond Colliders
  Study to explore possibilities using the non-collider part of the CERN accelerator complex

Discussion on next update of the European Strategy has started, conclusion in May 2020.



Thank you for your attention !