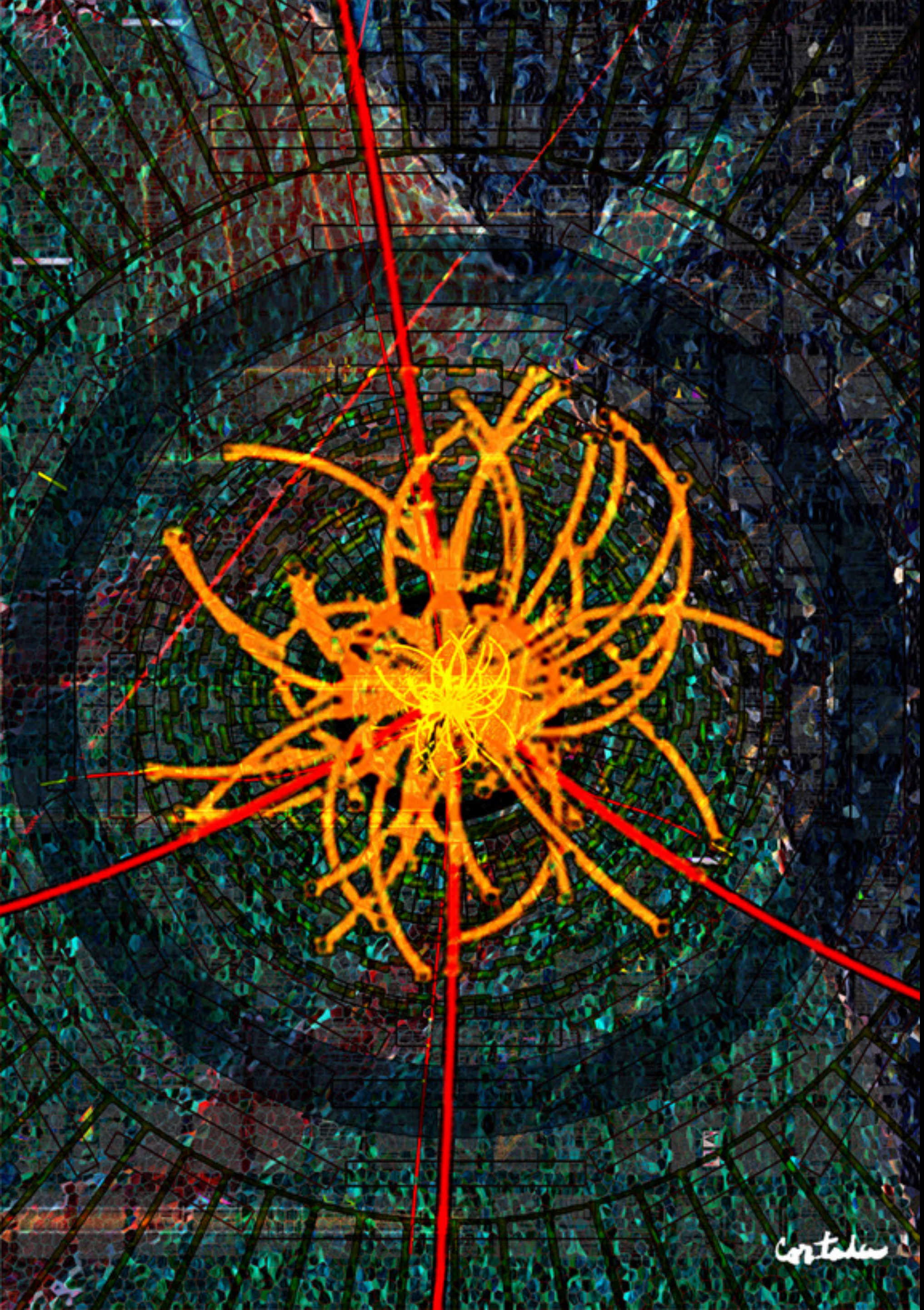
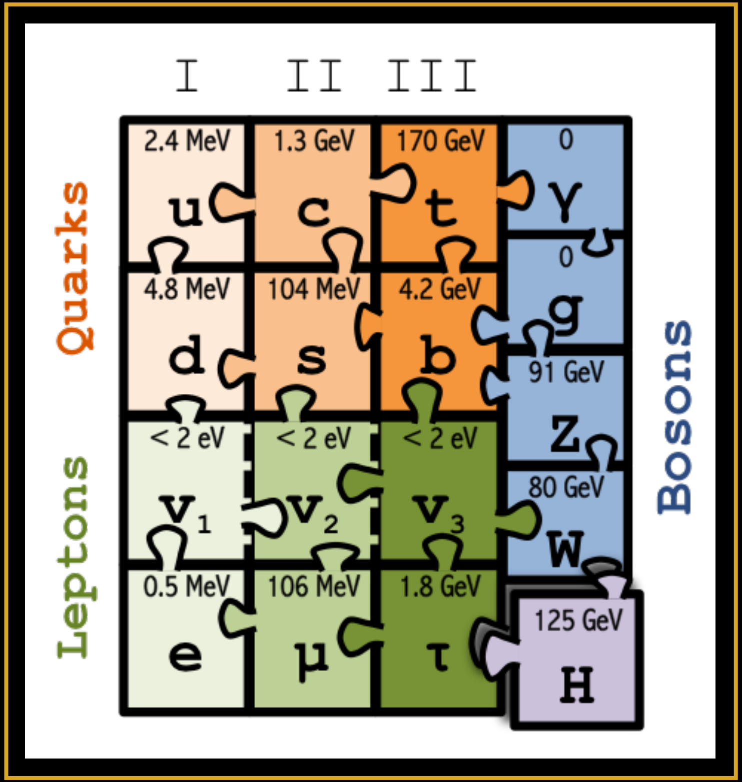
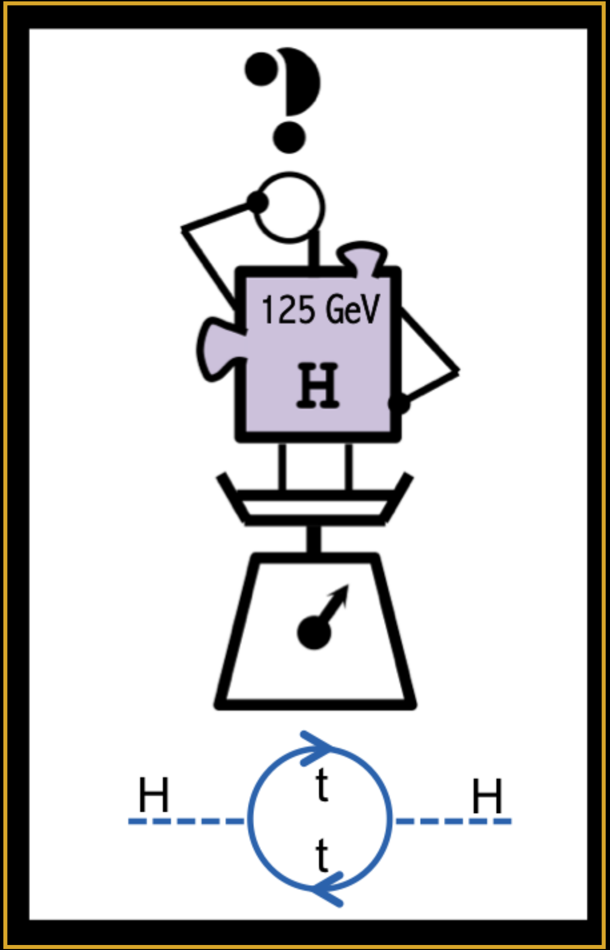


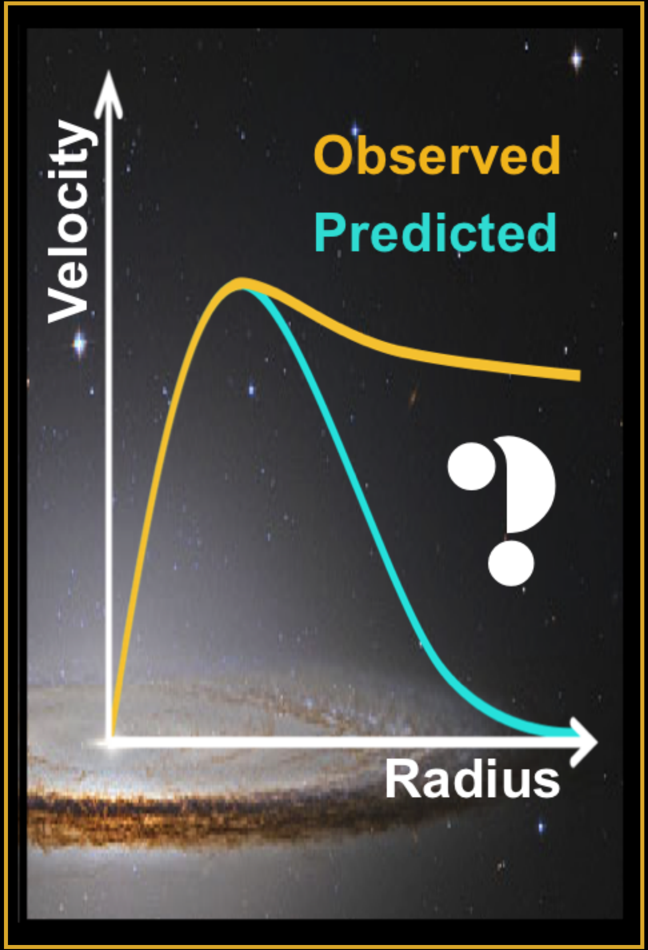
Swiss Particle Physics activities @ CERN

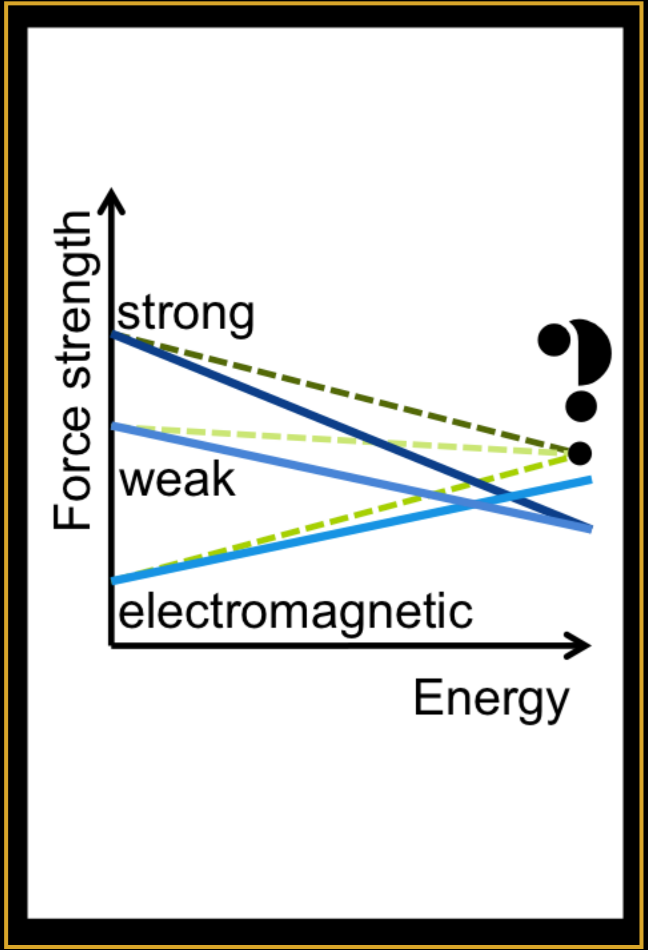
Anna Sfyrla
(University of Geneva)
on behalf of CHIPP

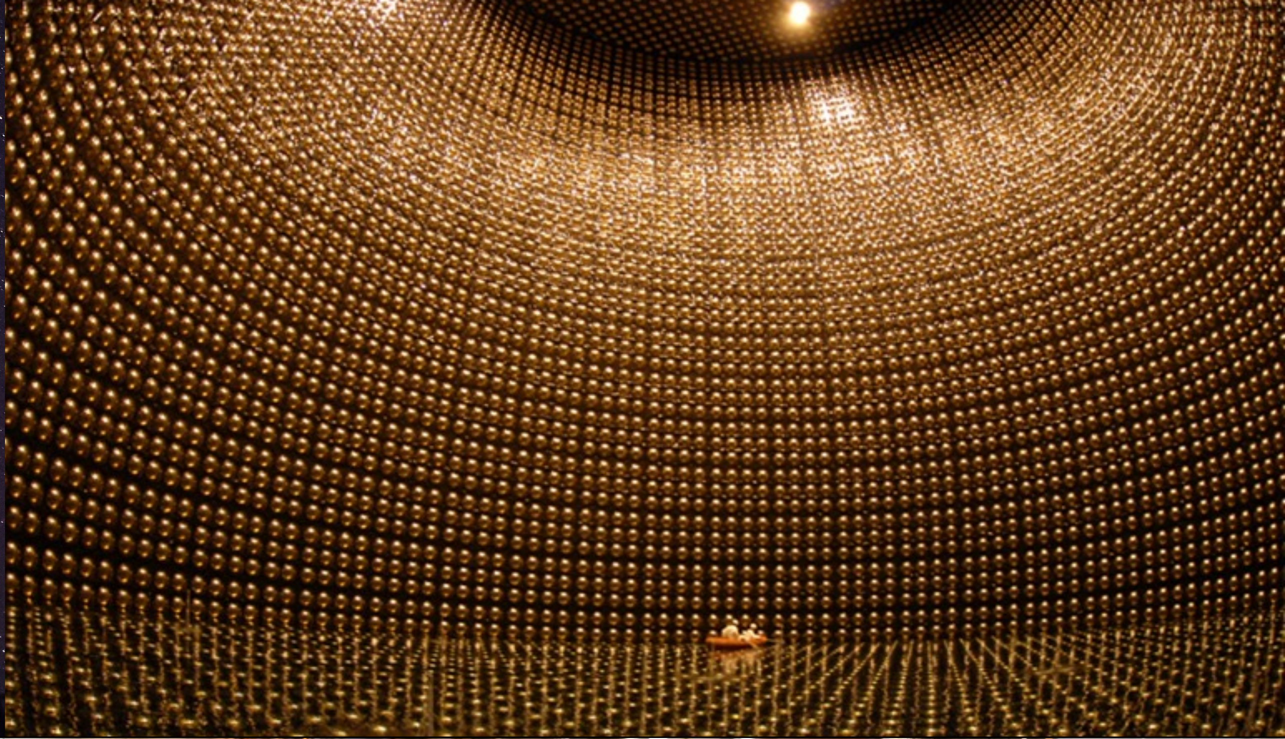
Division II of the SNSF research Council
"extra-muros" meeting at CERN
Oct 19, 2021

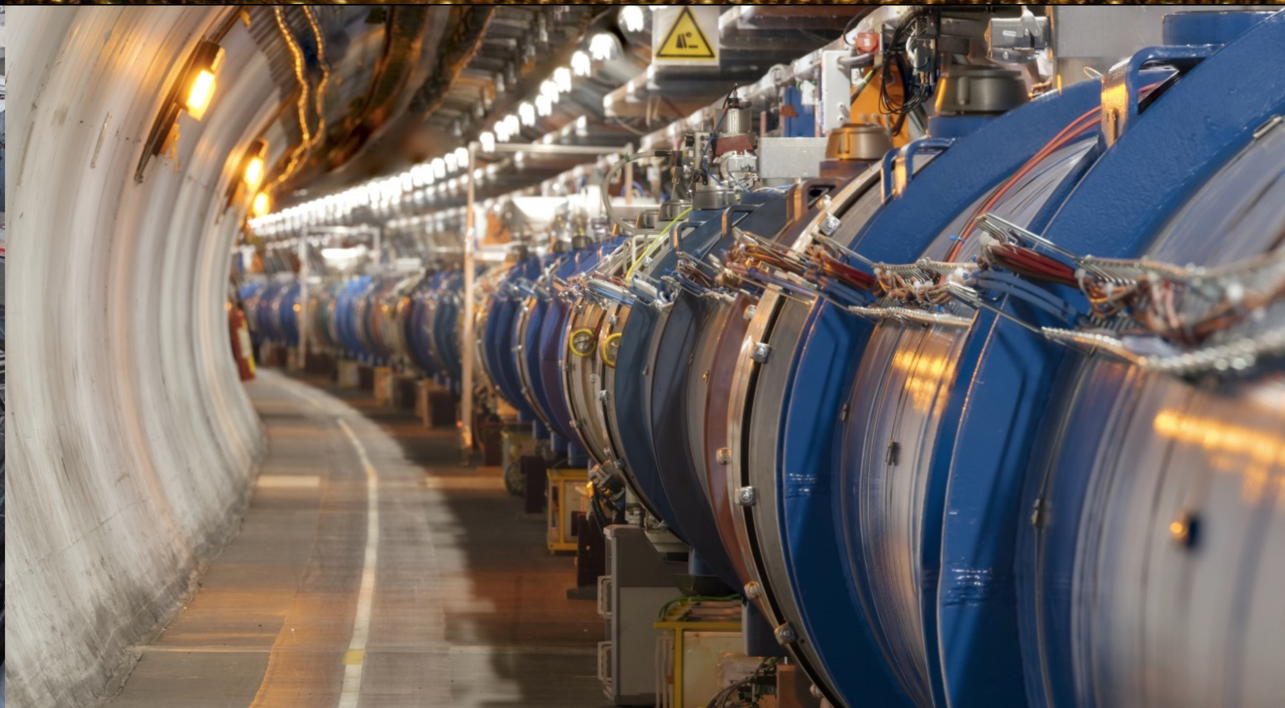

I
II
III
Quarks
Leptons
Bosons
2.4 MeV
u
1.3 GeV
c
170 GeV
t
0
γ
4.8 MeV
d
104 MeV
s
4.2 GeV
b
0
g
91 GeV
Z
< 2 eV
ν1
< 2 eV
ν2
< 2 eV
ν3
80 GeV
W
0.5 MeV
e
106 MeV
μ
1.8 GeV
τ
125 GeV
H

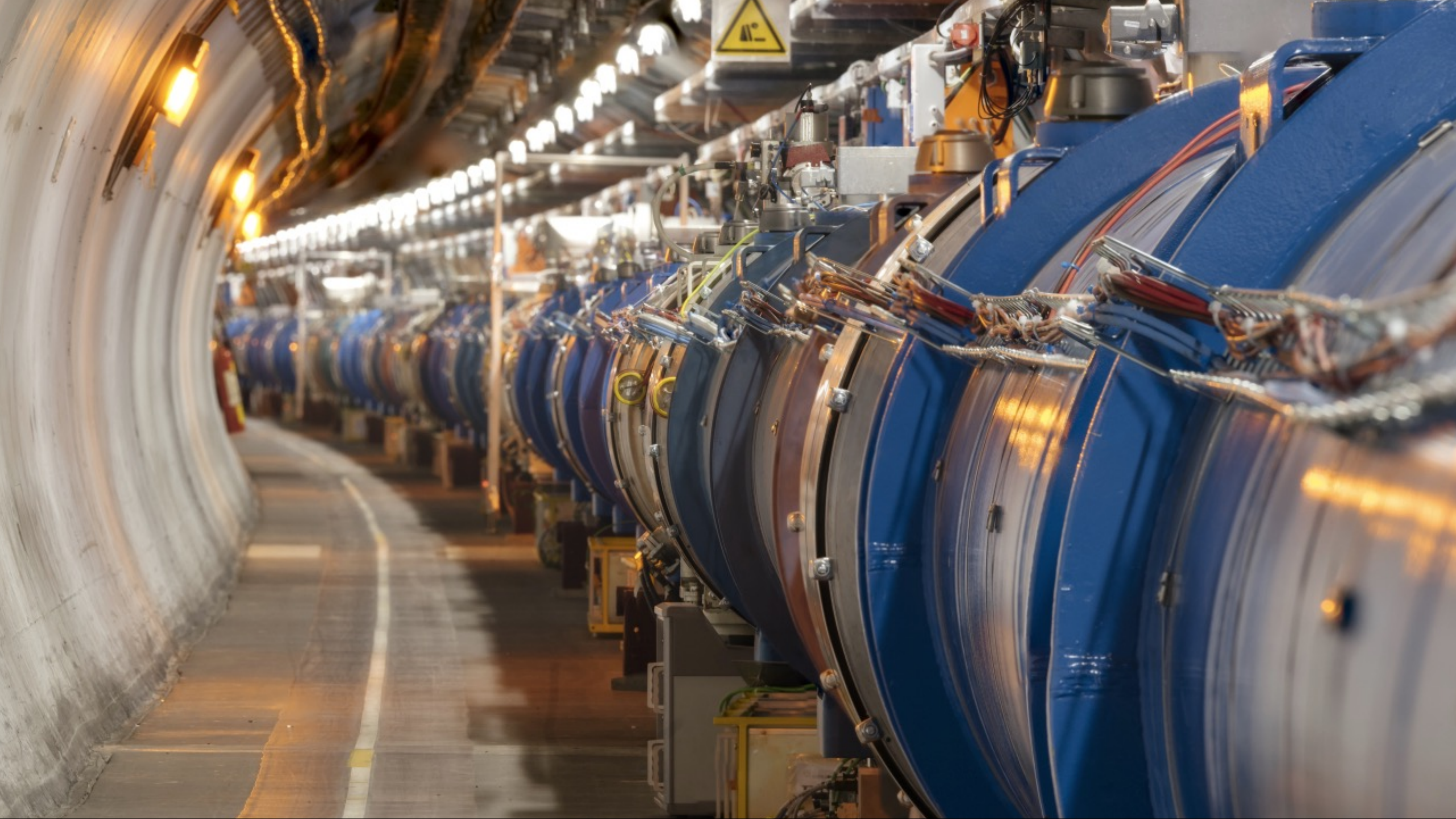

125 GeV
H
H
t
t
H

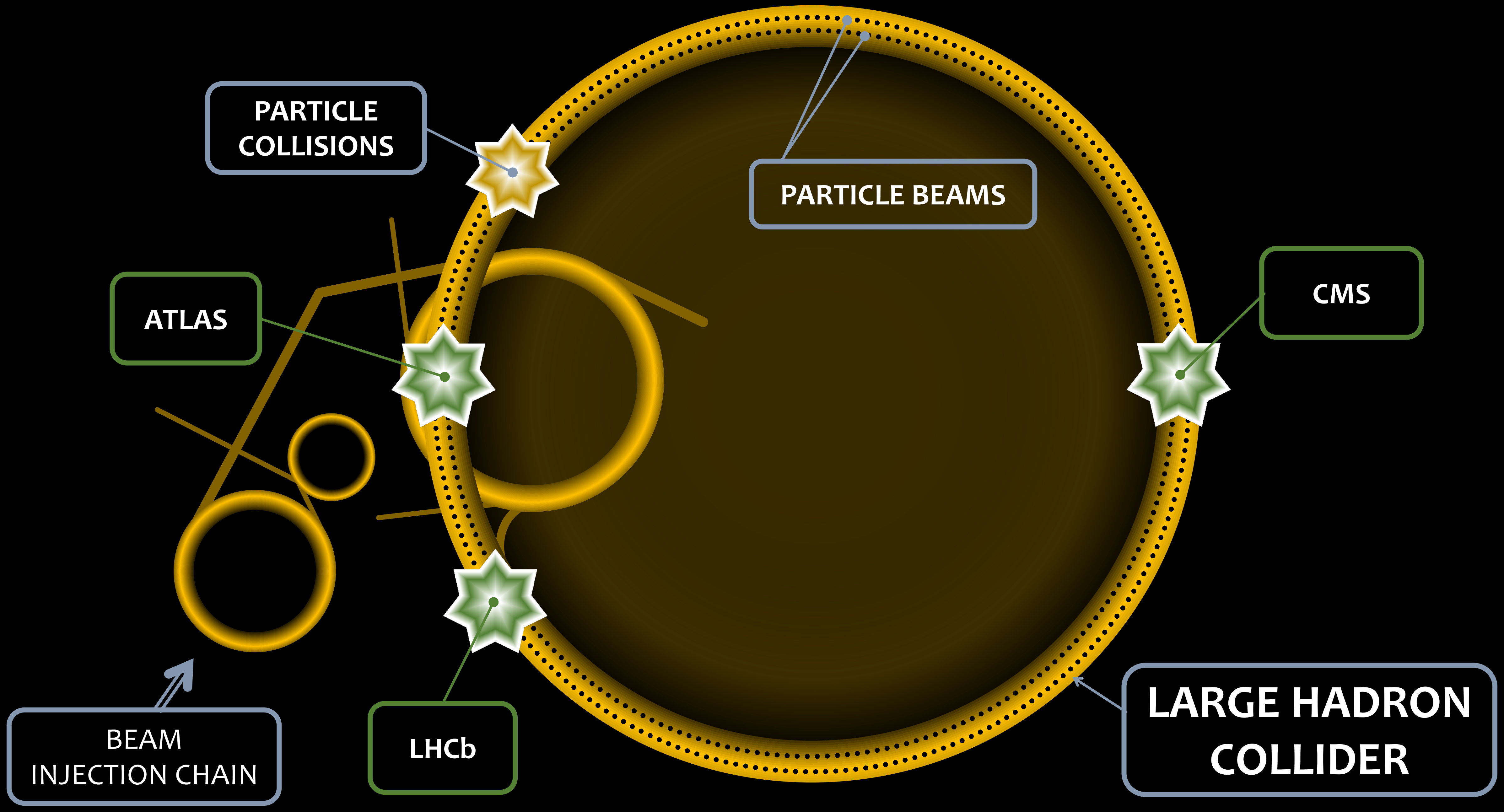

Velocity
Observed
Predicted
Radius


Force strength
strong
weak
electromagnetic
Energy

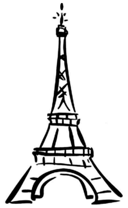








PARTICLE COLLISIONS
PARTICLE BEAMS
ATLAS
CMS
BEAM INJECTION CHAIN
LHCb
LARGE HADRON COLLIDER

Example: The ATLAS detector in numbers

✓ Weights 7 ktonnes ()

✓ 2-4 T superconducting magnets

✓ Position of particles recorded with an accuracy of O(10 µm)

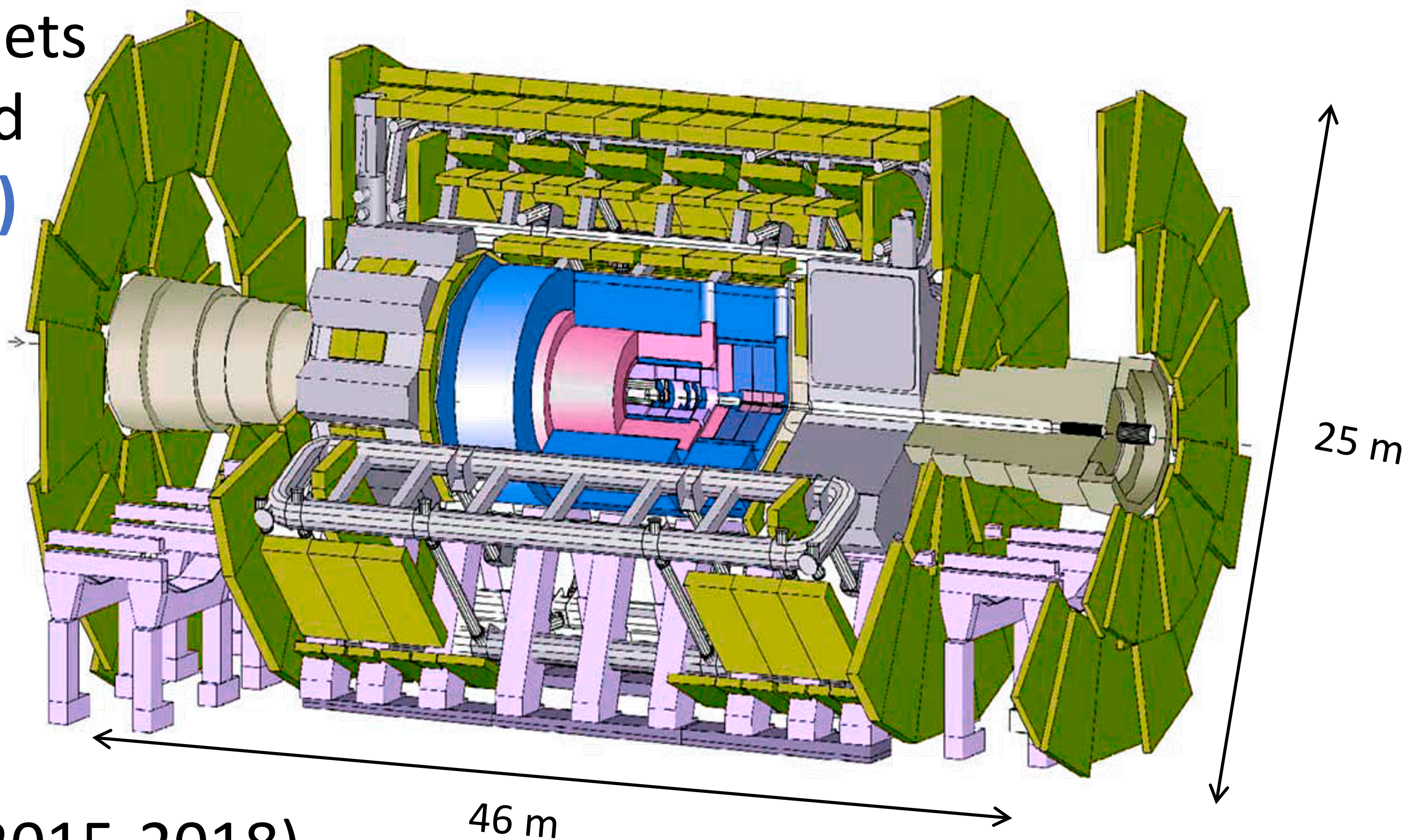
✓ 100 M channels

✓ 1 Giga collisions/second

✓ 1000 events/second stored

✓ 500 PB data on disk & tape

✓ 0.5 M CPU cores used 24/7



✓ 20 billion events collected (2015-2018)

The ATLAS Collaboration

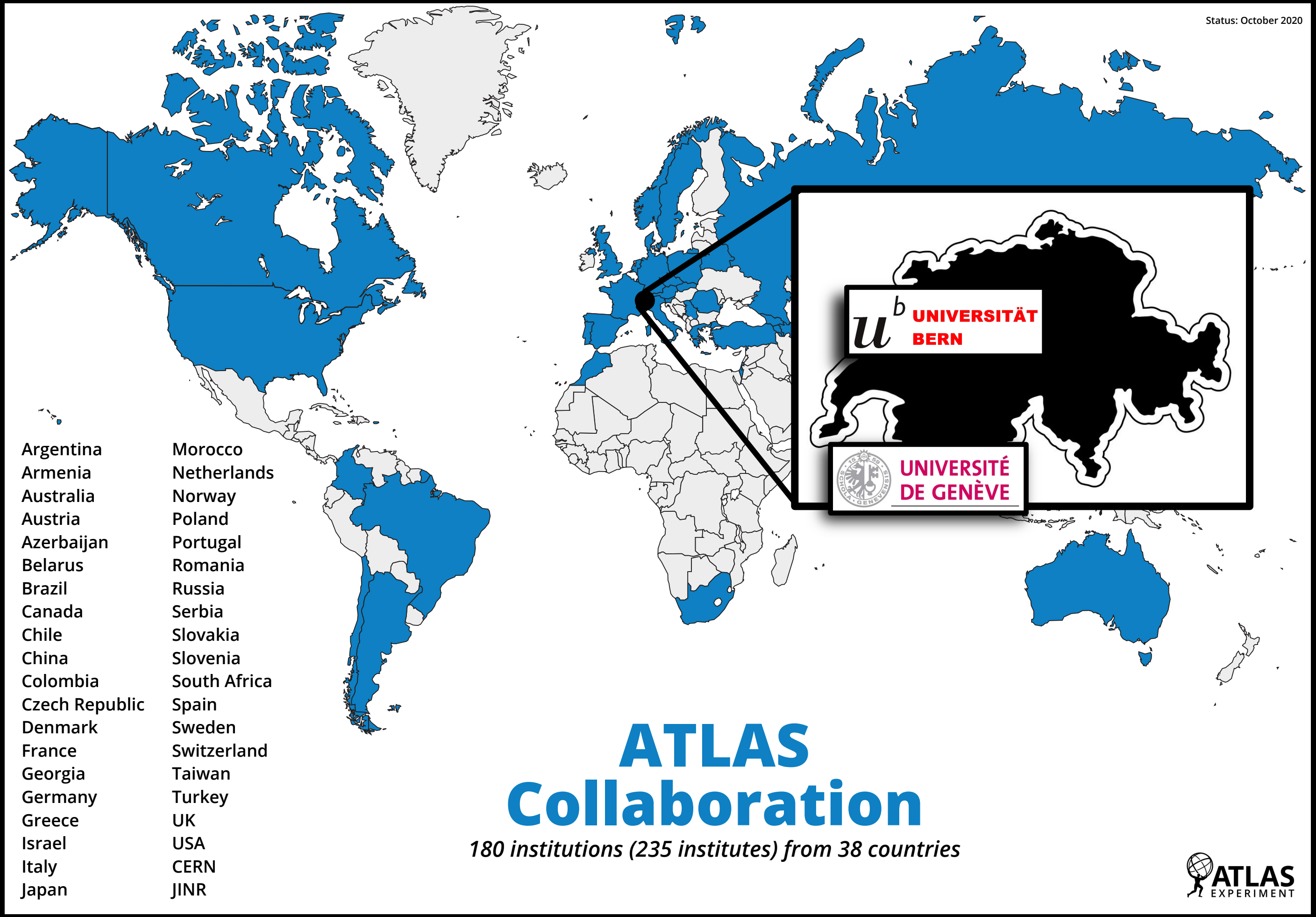
3000
Scientific authors

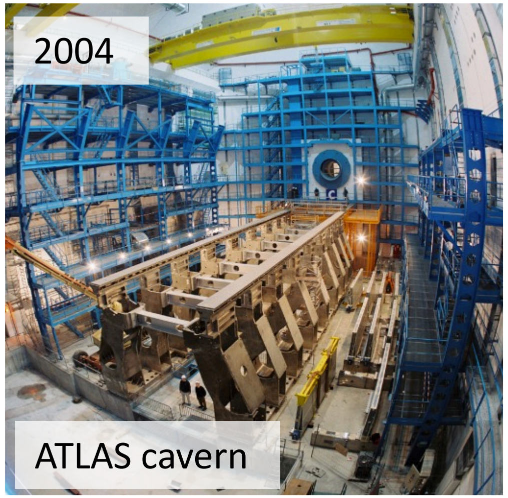
38
Countries

180
Institutions

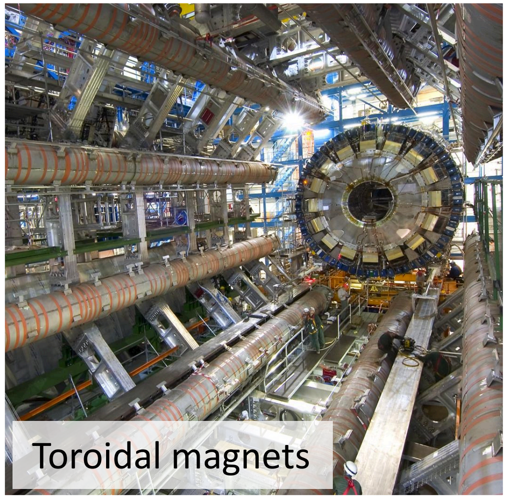
1200
Doctoral students

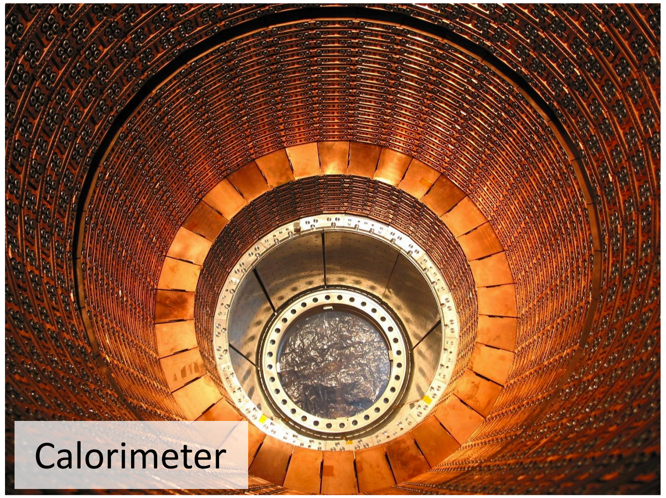
20
Doctoral students



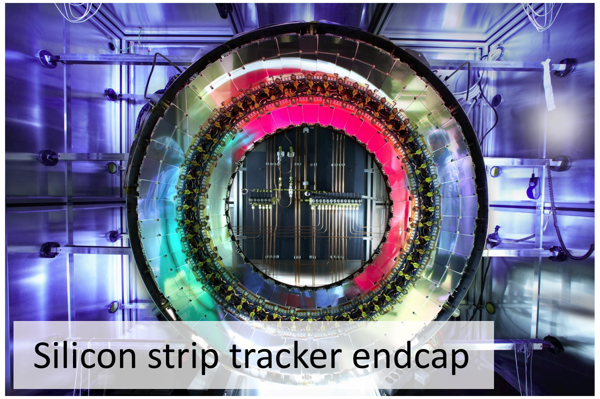


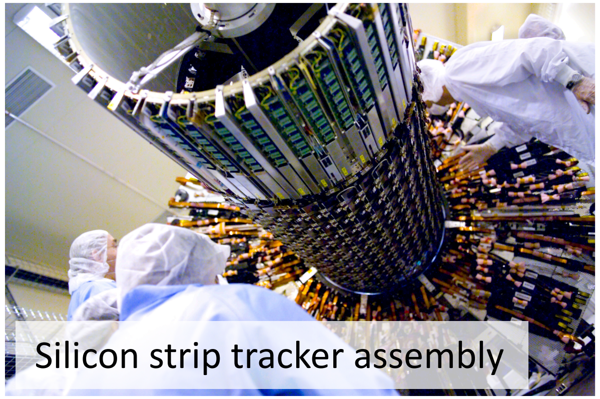
ATLAS cavern

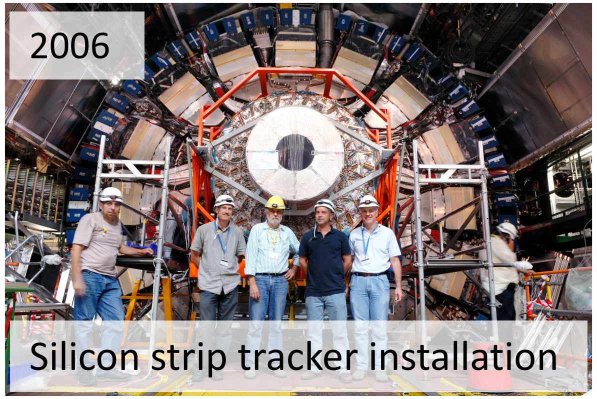

Toroidal magnets


Calorimeter


Pixel tracker


Silicon strip tracker endcap

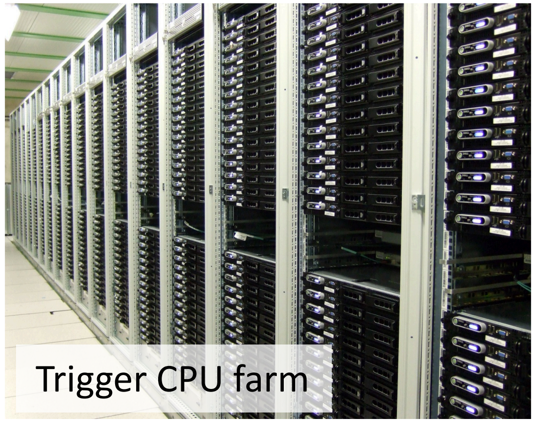

Silicon strip tracker assembly



Silicon strip tracker installation

ATLAS EXPERIMENT

Innermost pixel tracker installation


Trigger CPU farm

<u>**(Aspects relevant for all LHC detectors)**</u>

- Fast and radiation hard sensors
- Stability and accuracy of constructed structures
- Extremely fast readout systems for low latency processing
- Computing infrastructure to process enormous amounts of data

The CMS Collaboration

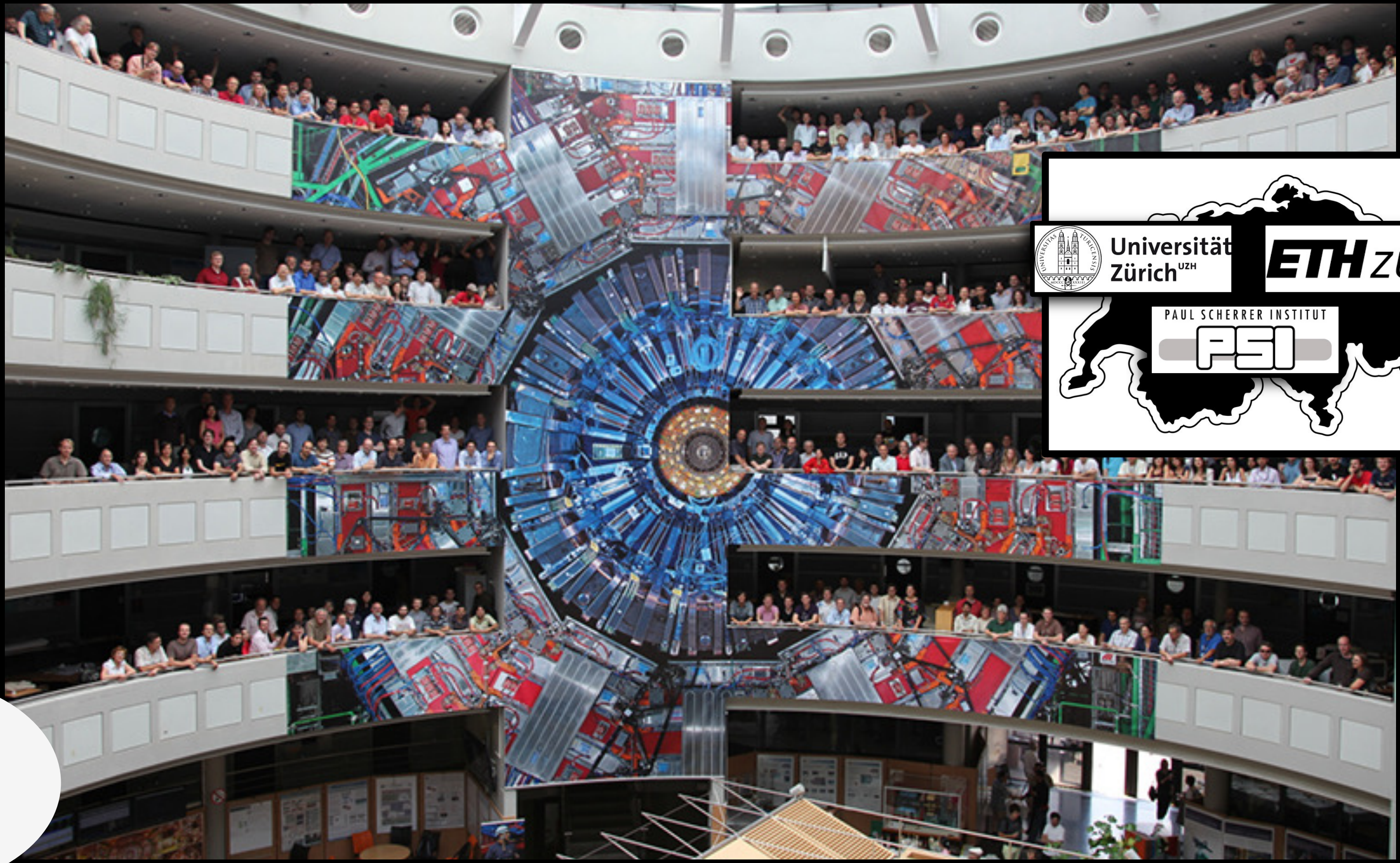
2100
Scientific authors

51
Countries

229
Institutions

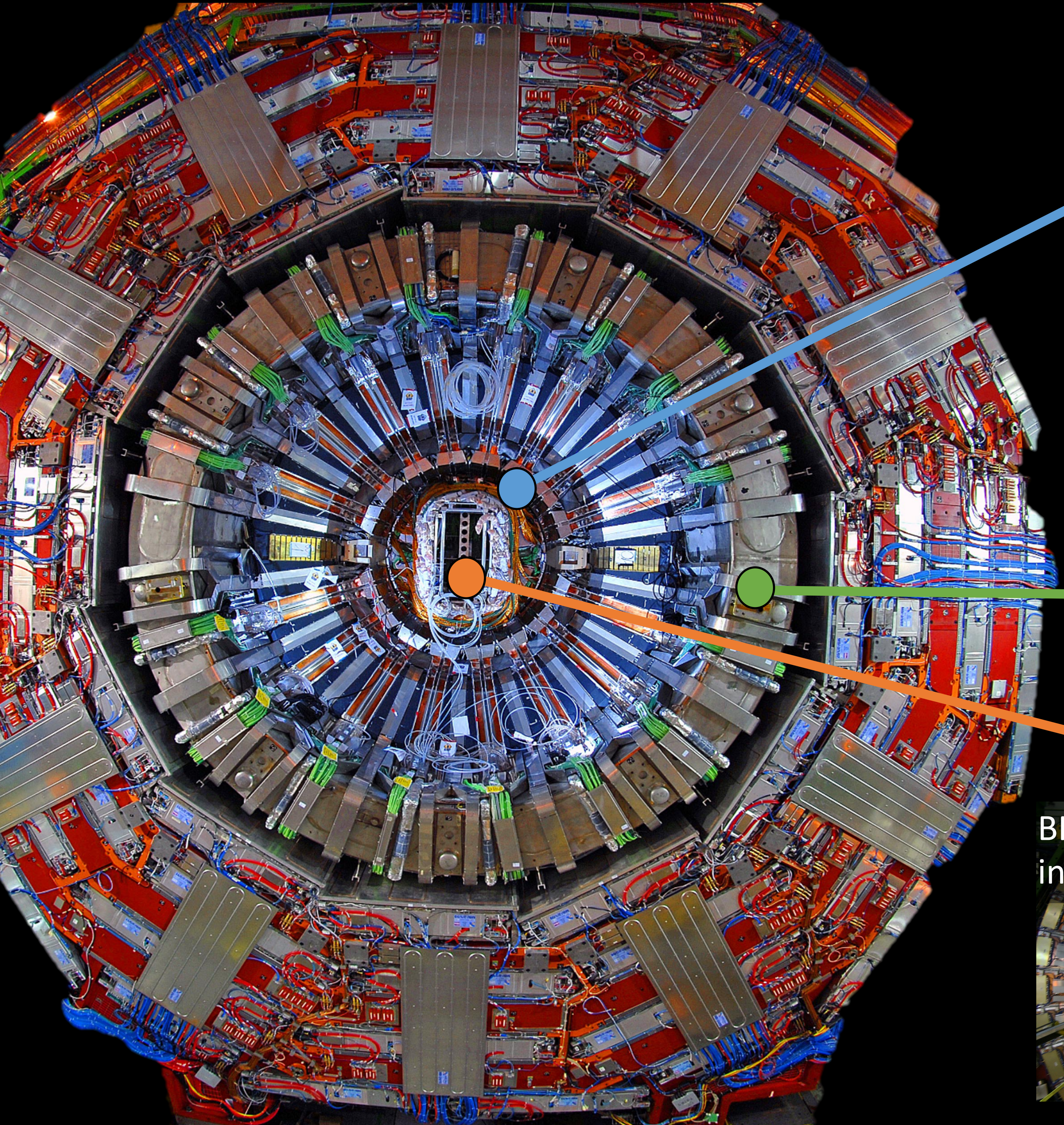
1100
Doctoral students

40
Doctoral students

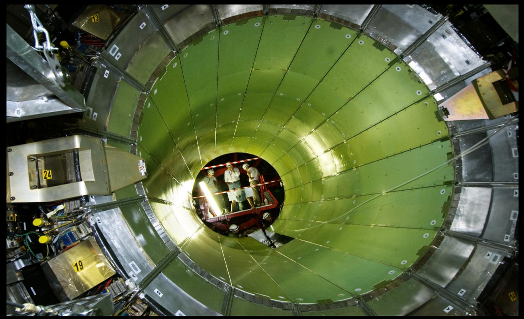


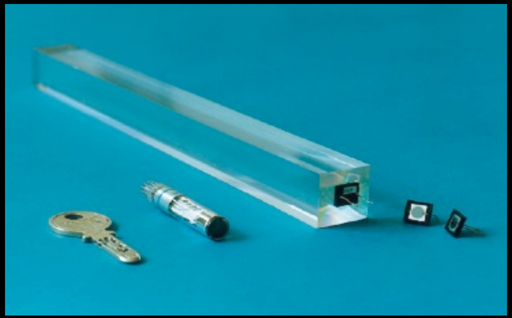
Universität Zürich[UZH]
ETH zürich
PAUL SCHERRER INSTITUT PSI

CH Contributions



EM Calorimeter
76000 $PbWO_4$ crystals **ETH/PSI**





Superconducting Coil
E&I center **ETH**

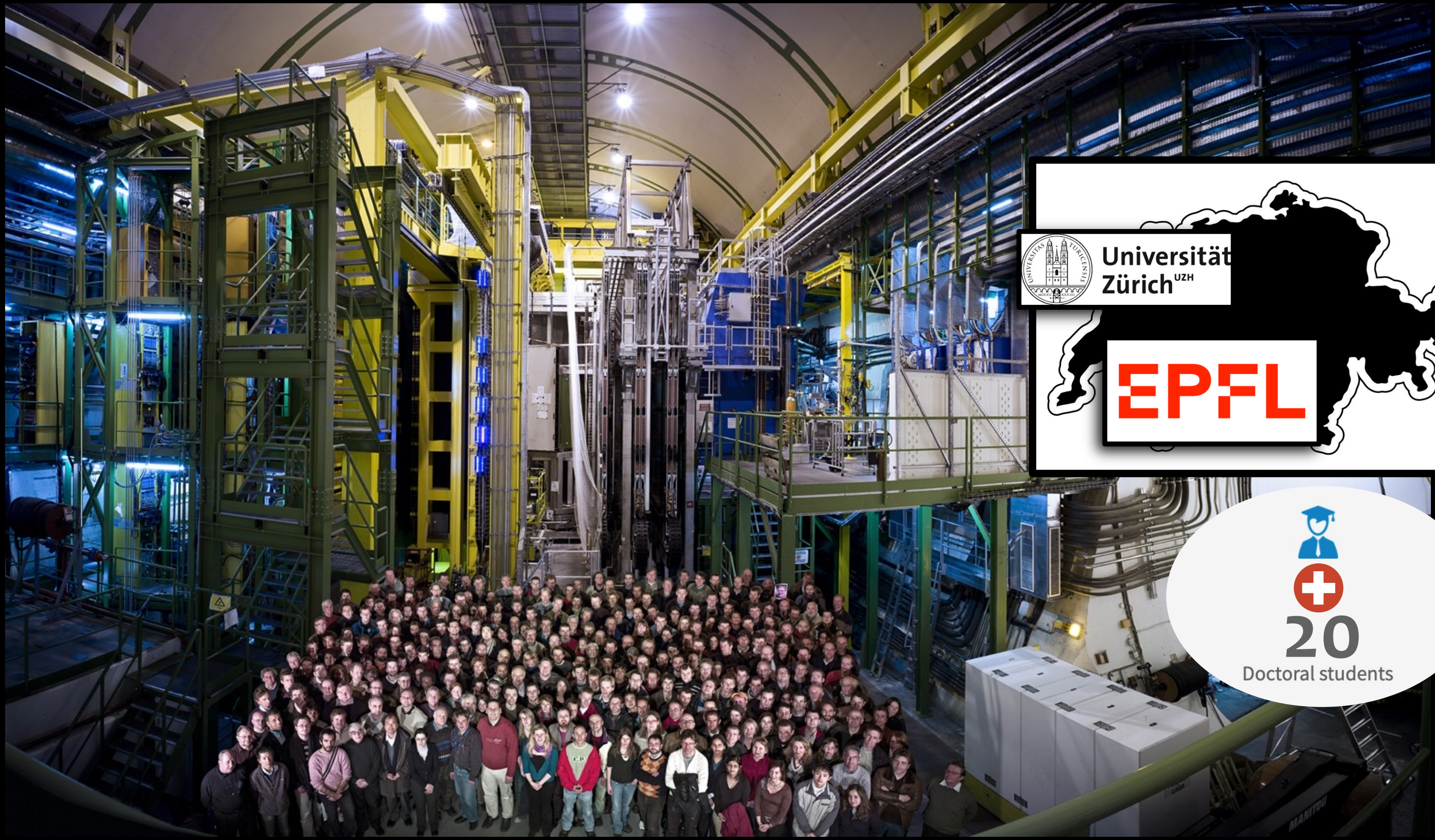
Pixels, Silicon Microstrips
BPIX Phase 0 and Phase I **ETH/PSI/UZH**

The LHCb Collaboration

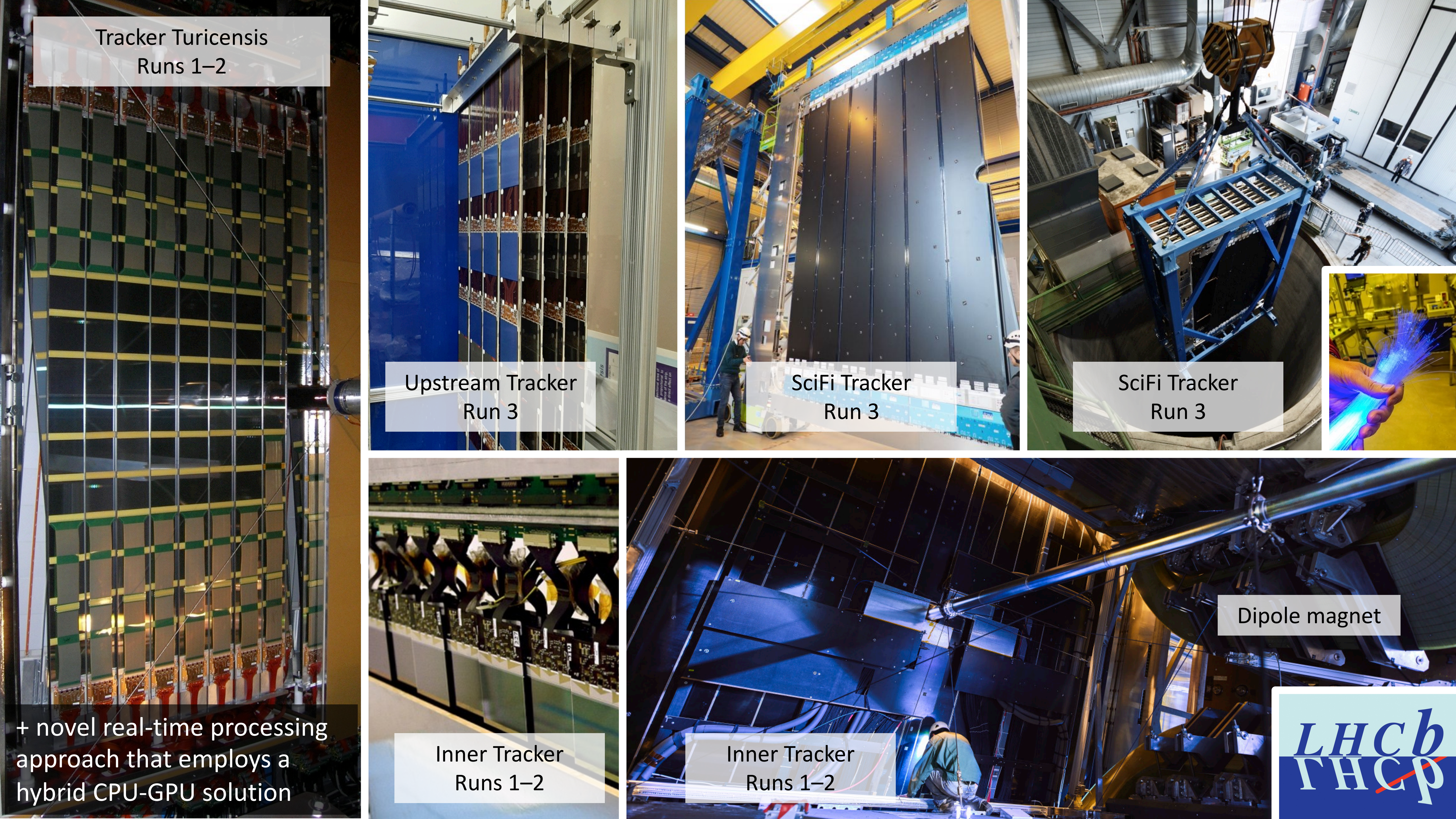
1500
Members

19
Countries

87
Institutions

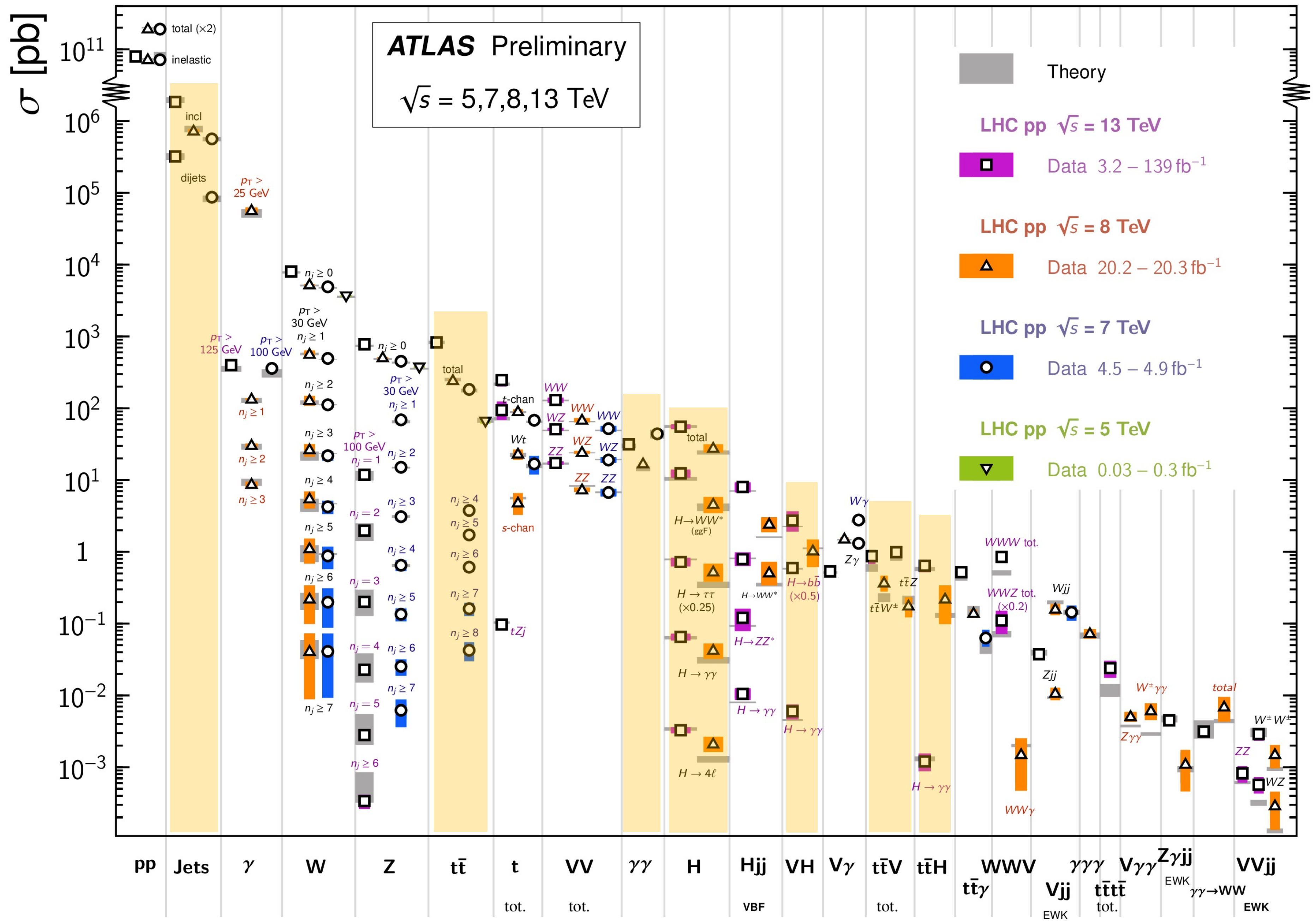


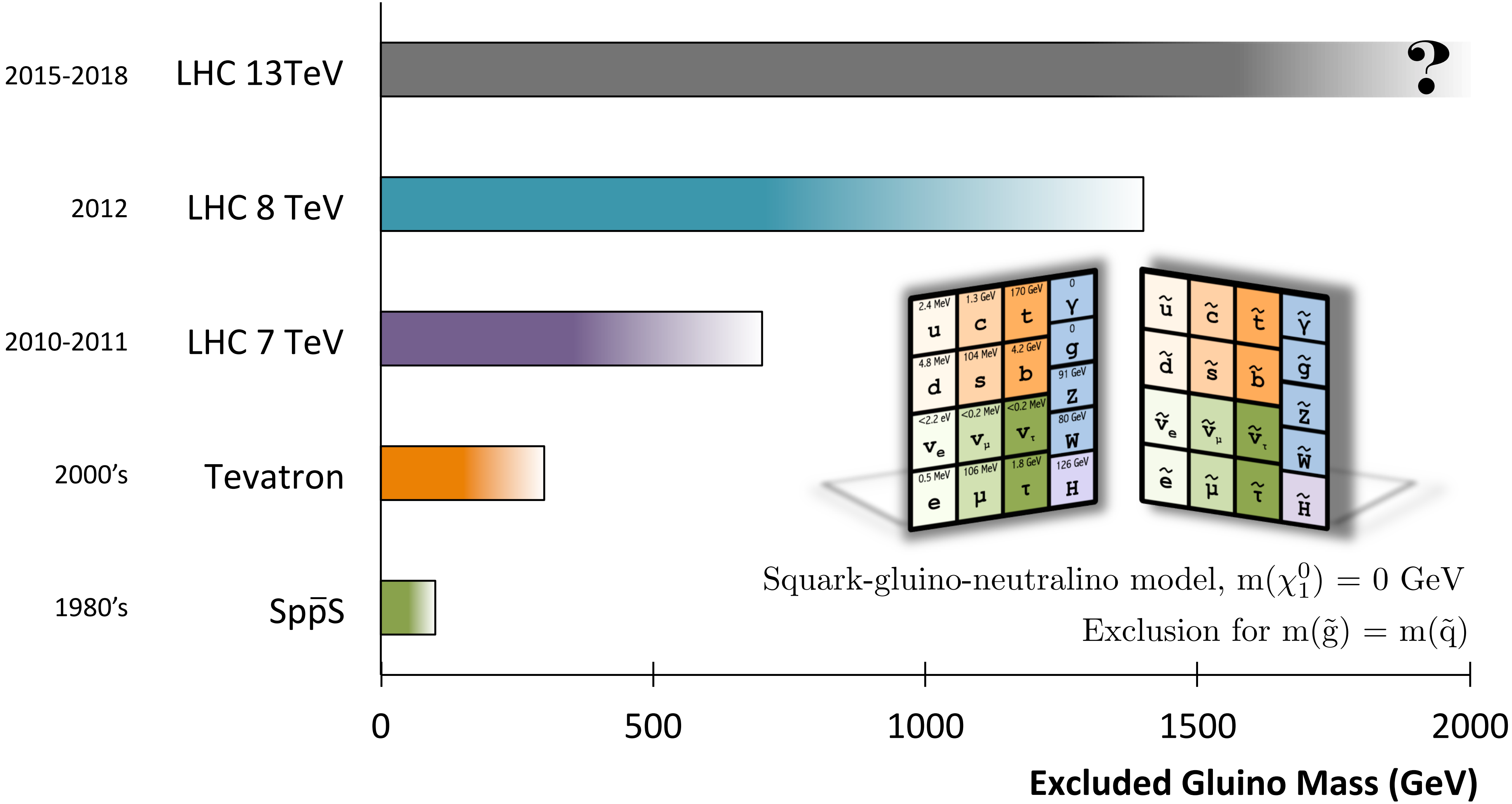
20
Doctoral students

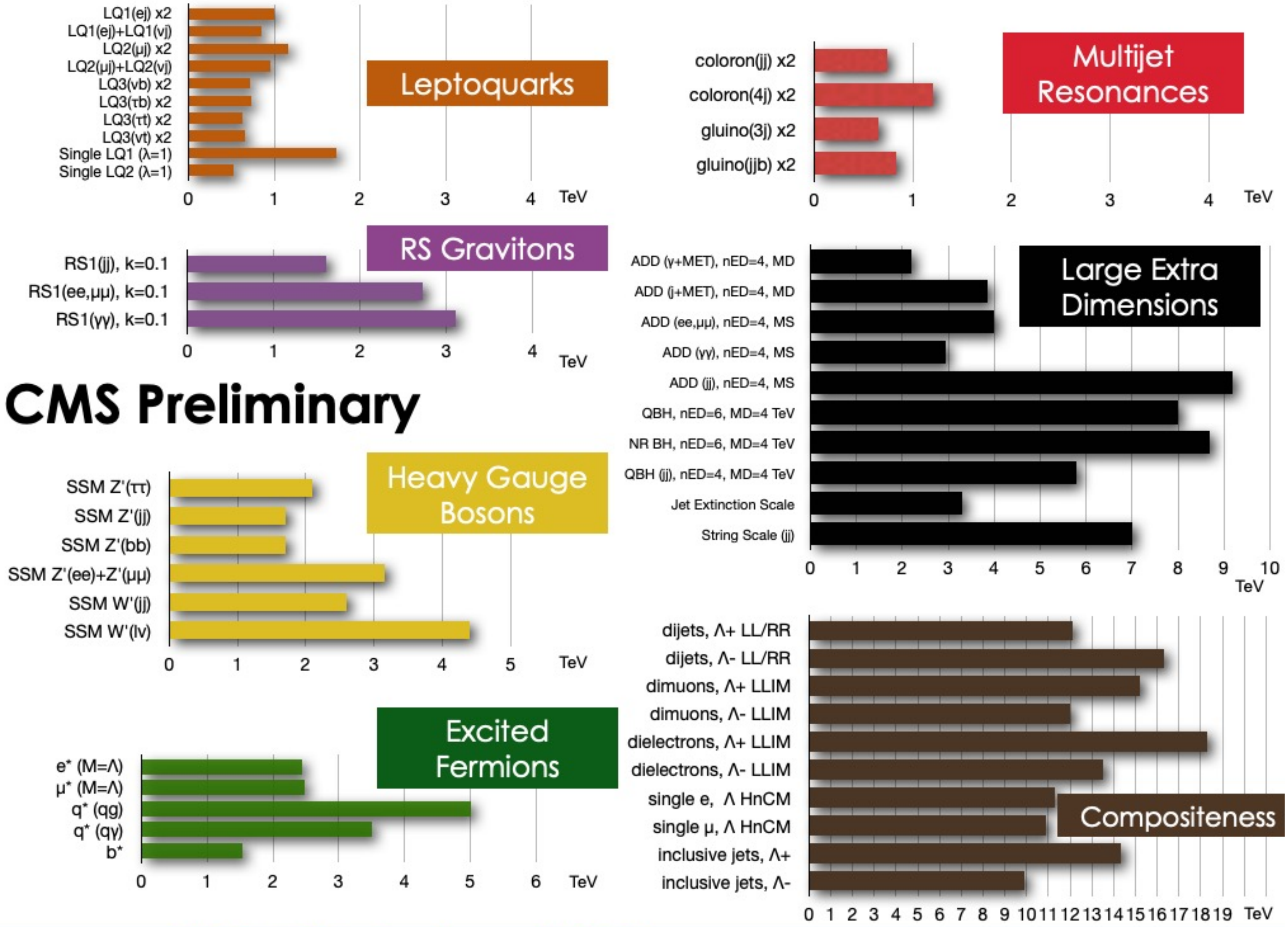

Tracker Turicensis
Runs 1–2
Upstream Tracker
Run 3
SciFi Tracker
Run 3
SciFi Tracker
Run 3
Inner Tracker
Runs 1–2
Inner Tracker
Runs 1–2
Dipole magnet
+ novel real-time processing approach that employs a hybrid CPU-GPU solution
LHCb

Standard Model Production Cross Section Measurements

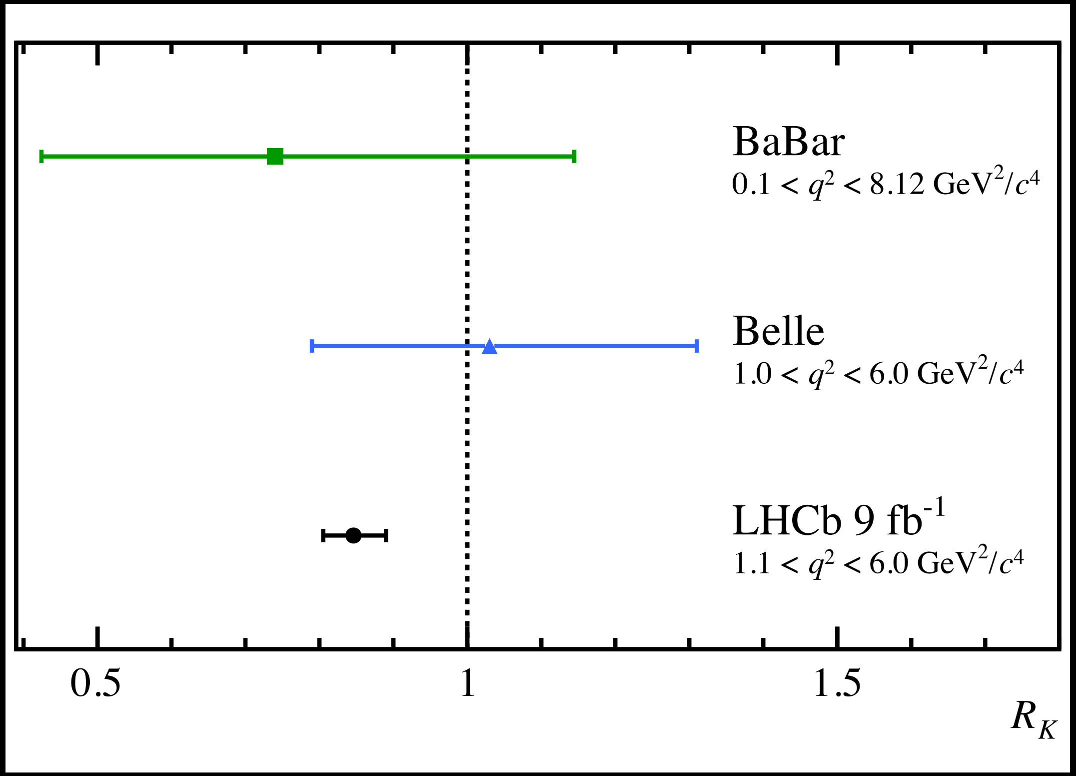
Status: July 2021




2015-2018
LHC 13TeV
?
2012
LHC 8 TeV
2010-2011
LHC 7 TeV
2000's
Tevatron
1980's
Spp̄S
Squark-gluino-neutralino model, $m(\chi_1^0) = 0$ GeV
Exclusion for $m(\tilde{g}) = m(\tilde{q})$
0
500
1000
1500
2000
Excluded Gluino Mass (GeV)



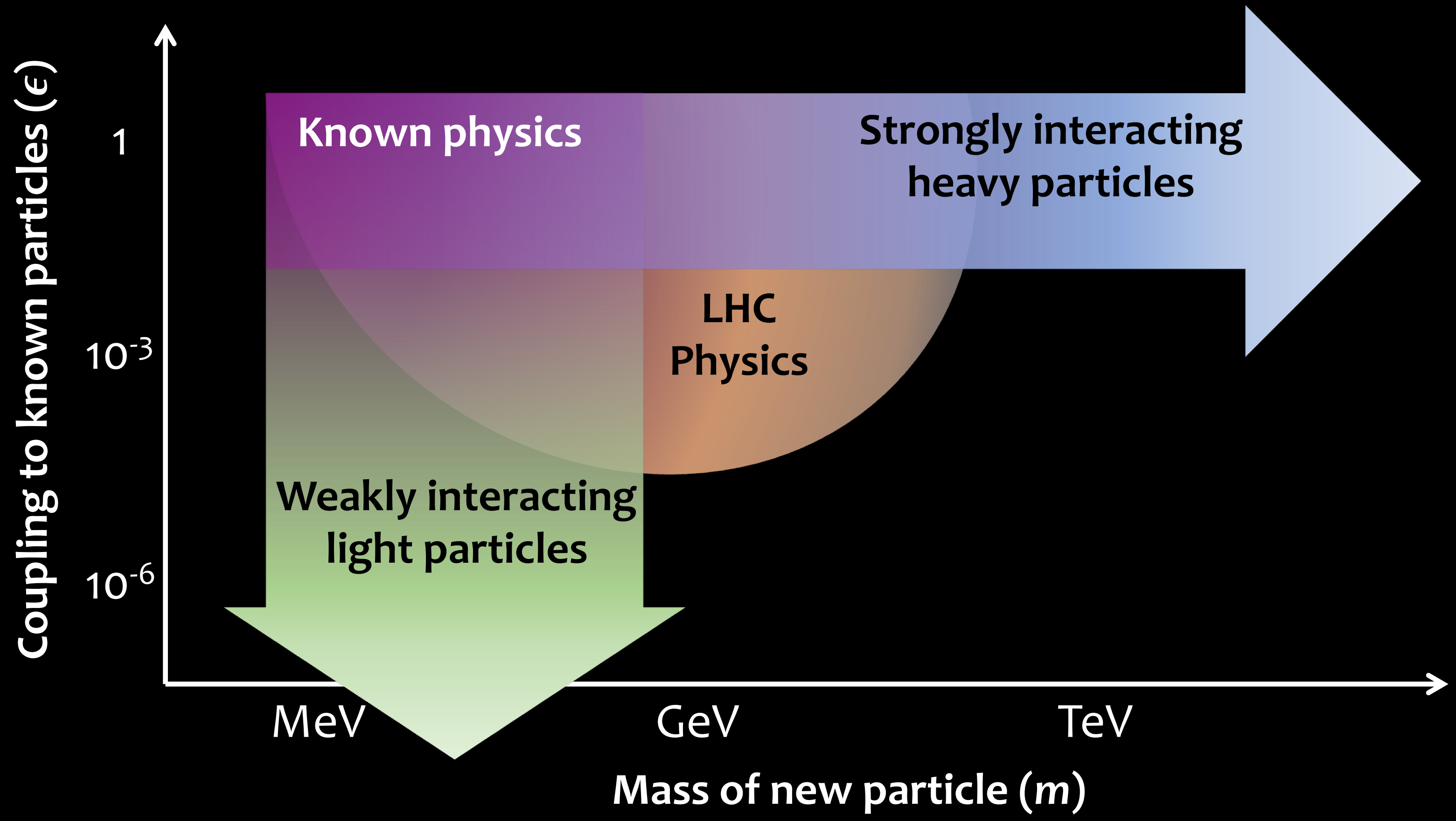
CMS Exotica Physics Group Summary – LHCP, 2016



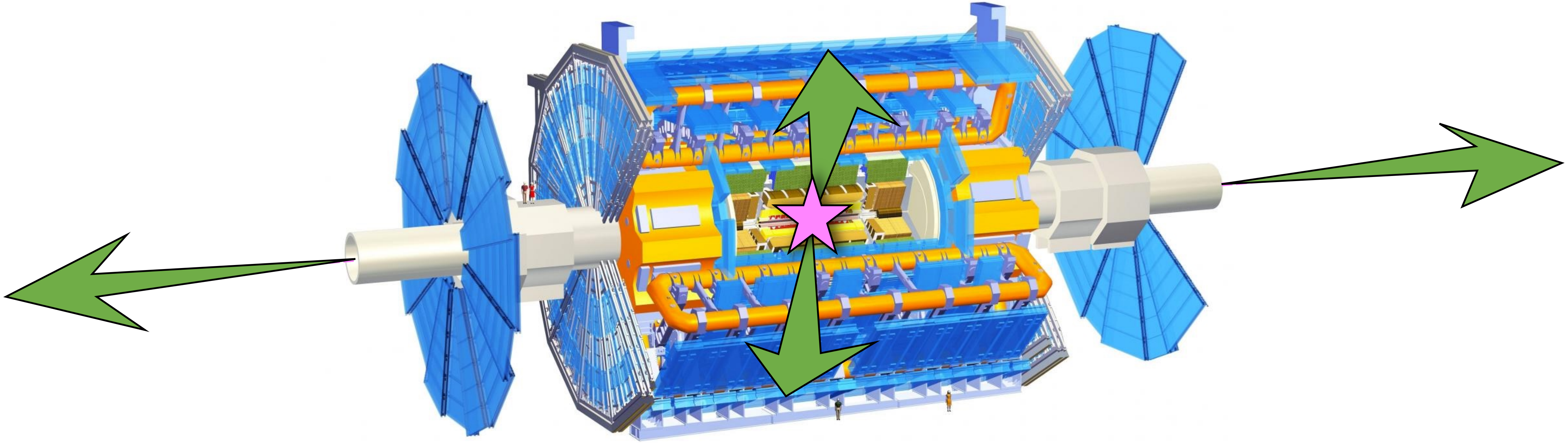
Test of "lepton universality"

$$R_{K^{(*)}} := \frac{\mathcal{B}(B \to K^{(*)}\mu^+\mu^-)}{\mathcal{B}(B \to K^{(*)}e^+e^-)} \overset{\mathrm{SM}}{\cong} 1$$

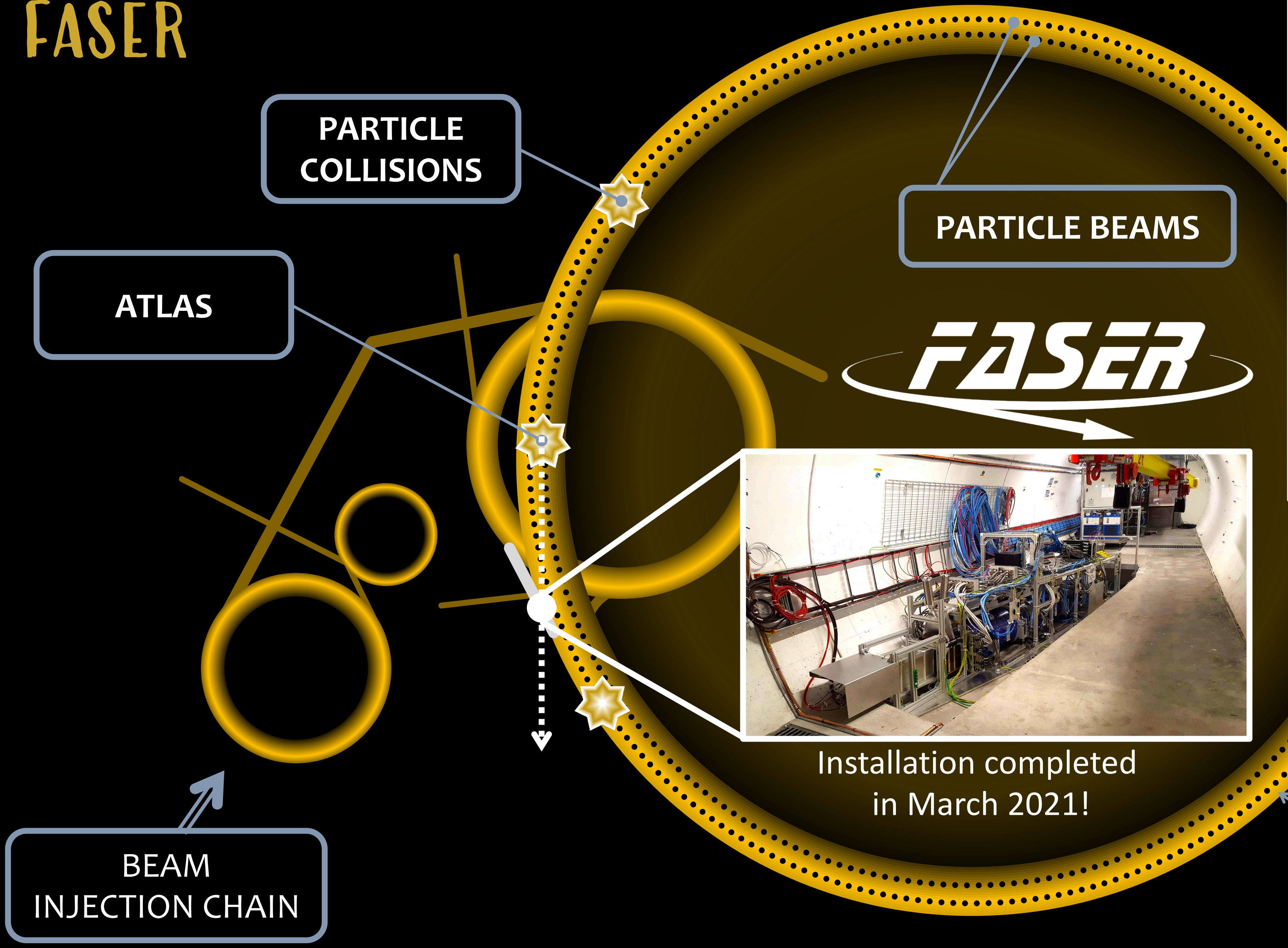
Is new physics around the corner?



- Improve instrumentation / diversify experimental methods
- Get more data
- Look at higher energies



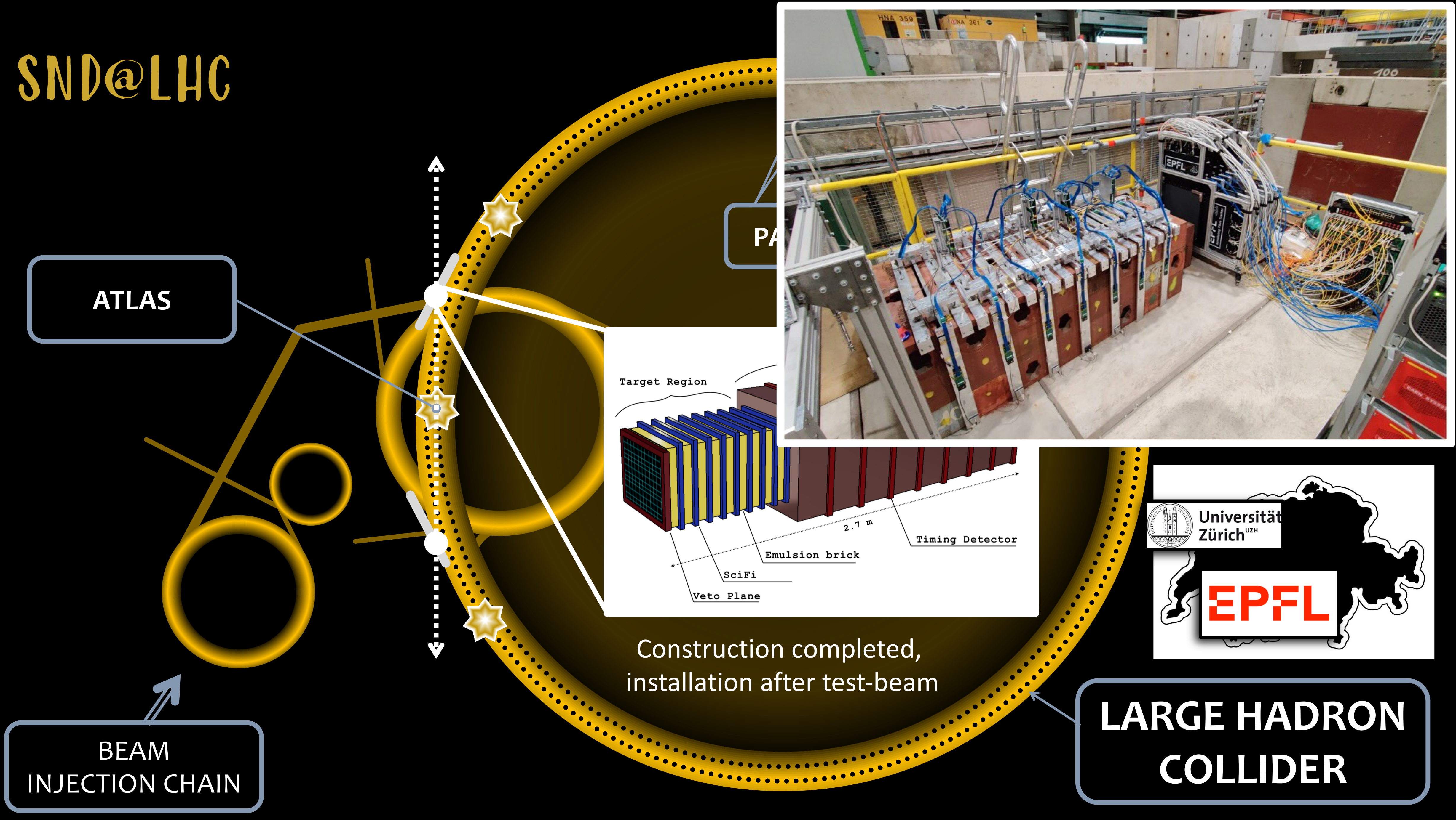
FASER



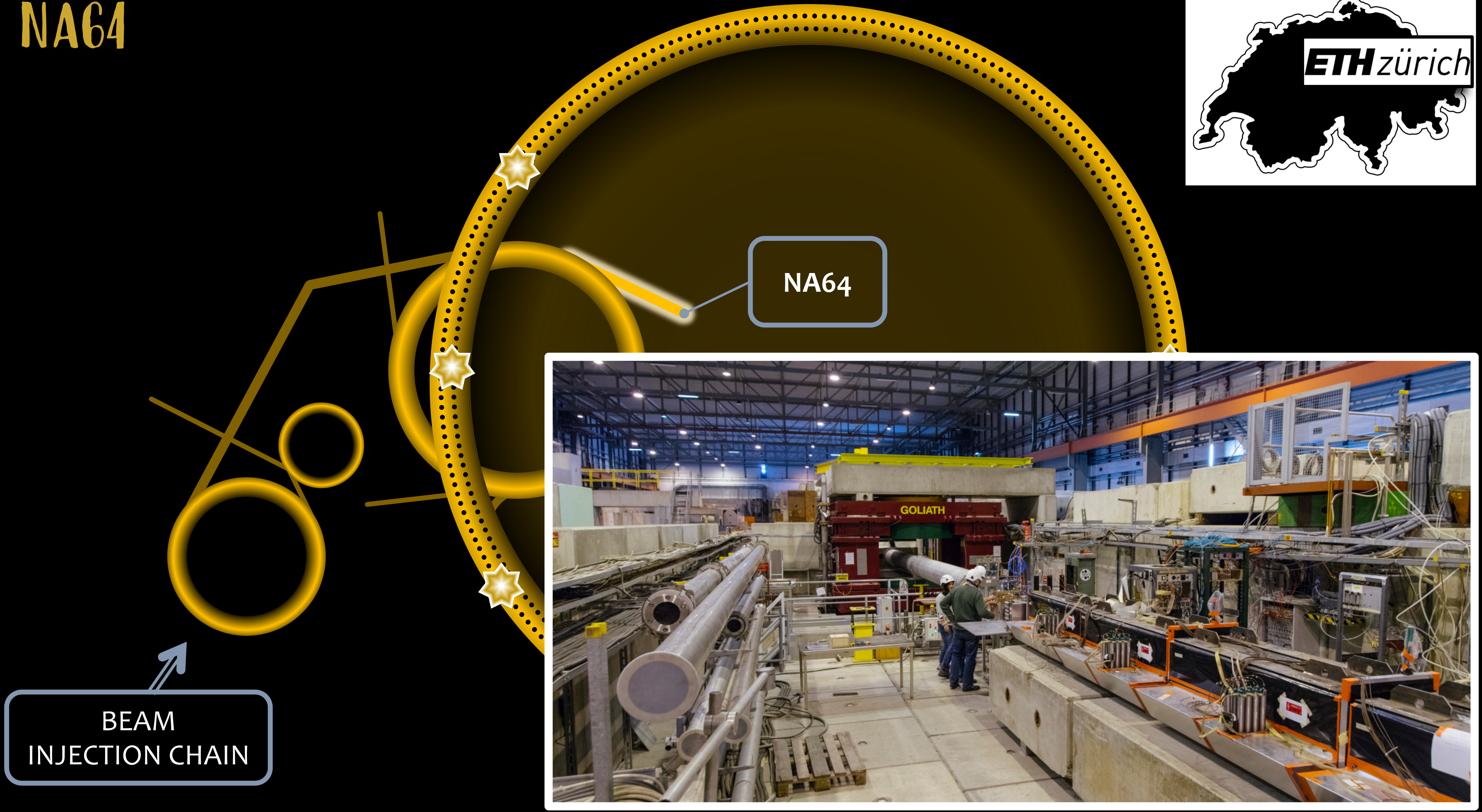
UNIVERSITÄT BERN

UNIVERSITÉ DE GENÈVE

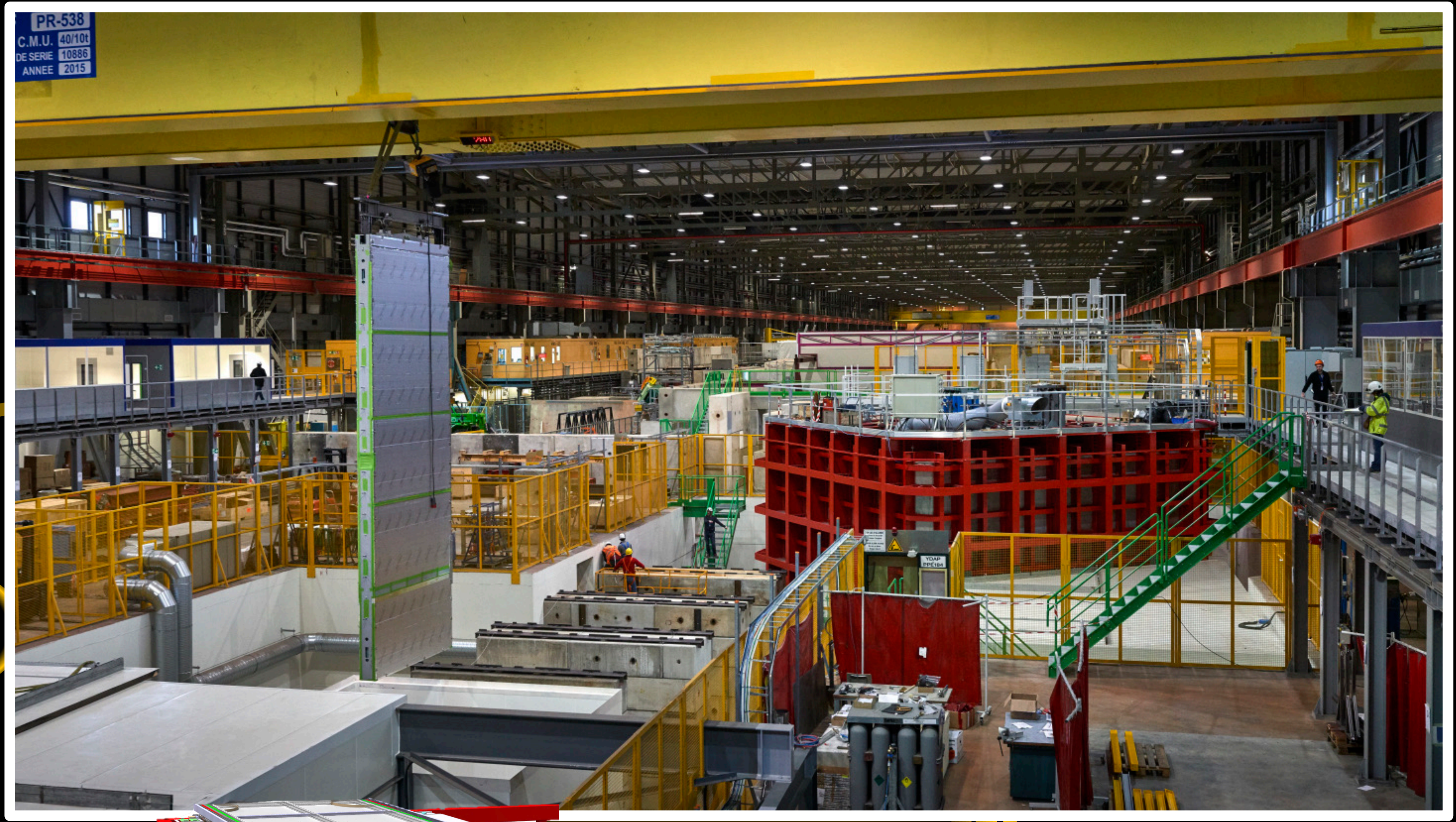
SND@LHC

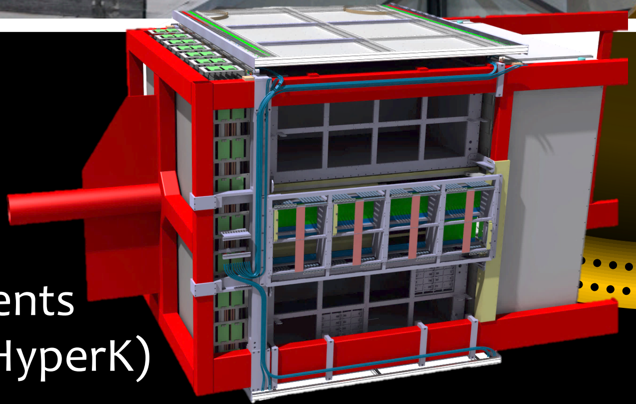

ATLAS
PA
Target Region
2.7 m
Timing Detector
Emulsion brick
SciFi
Veto Plane
Construction completed,
installation after test-beam
Universität Zürich UZH
EPFL
LARGE HADRON COLLIDER
BEAM
INJECTION CHAIN

NA64



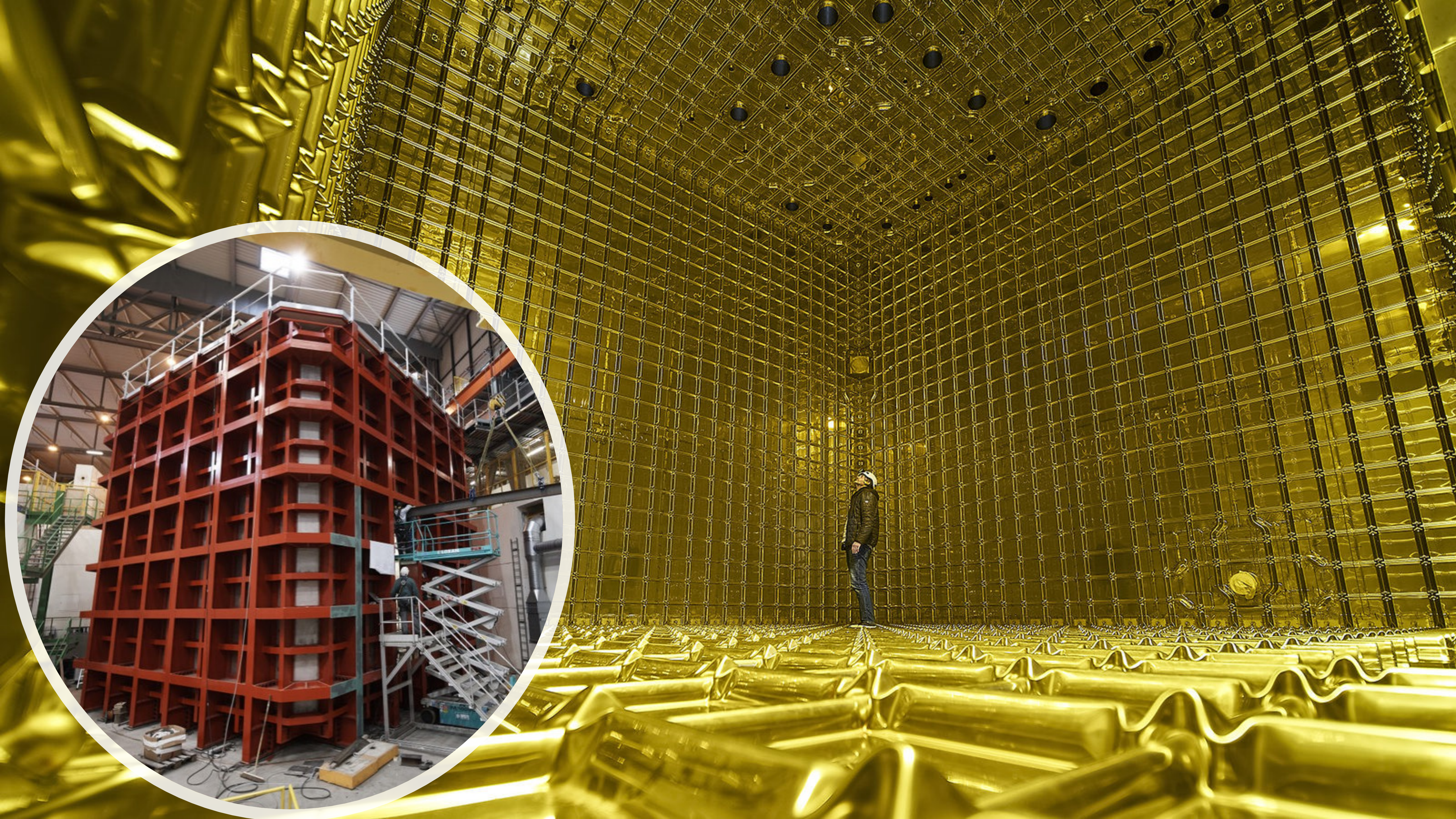
Experimental Facility:
The Neutrino Platform



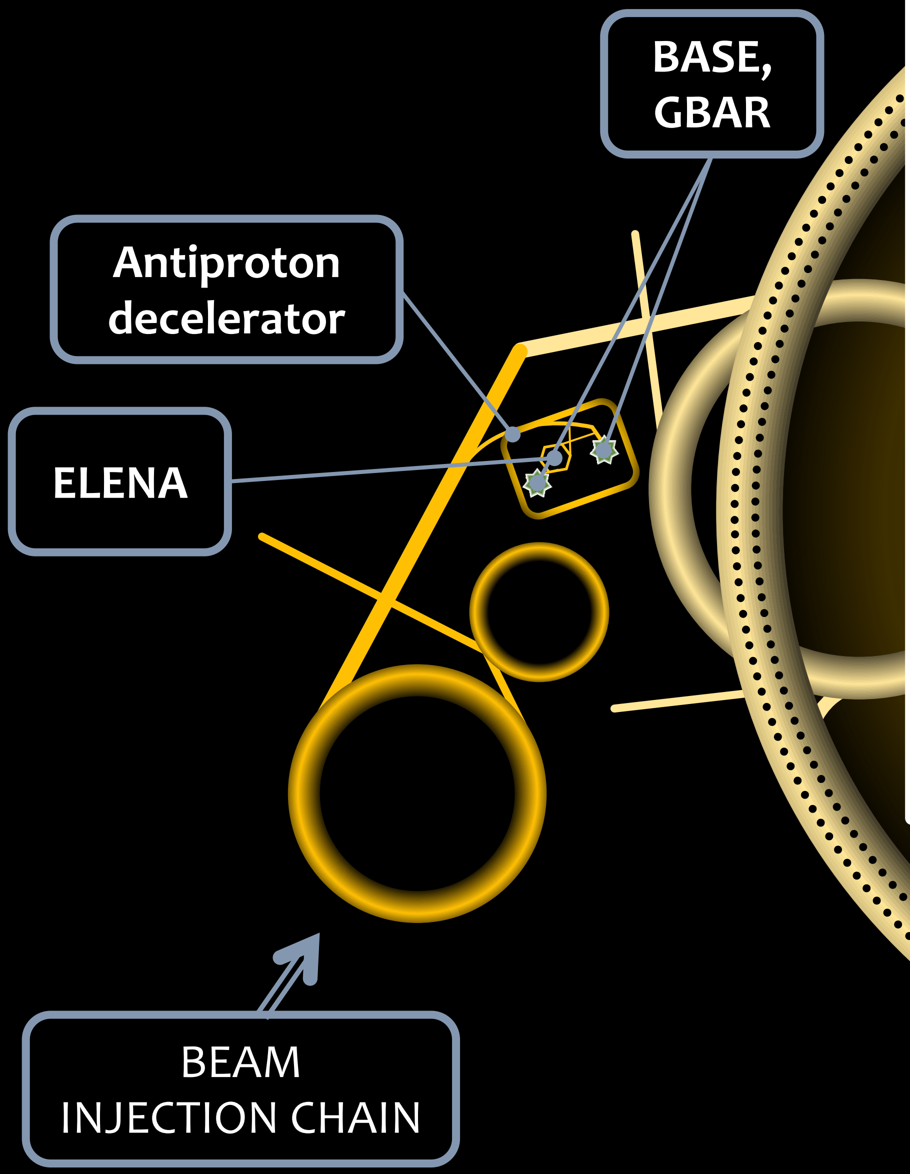


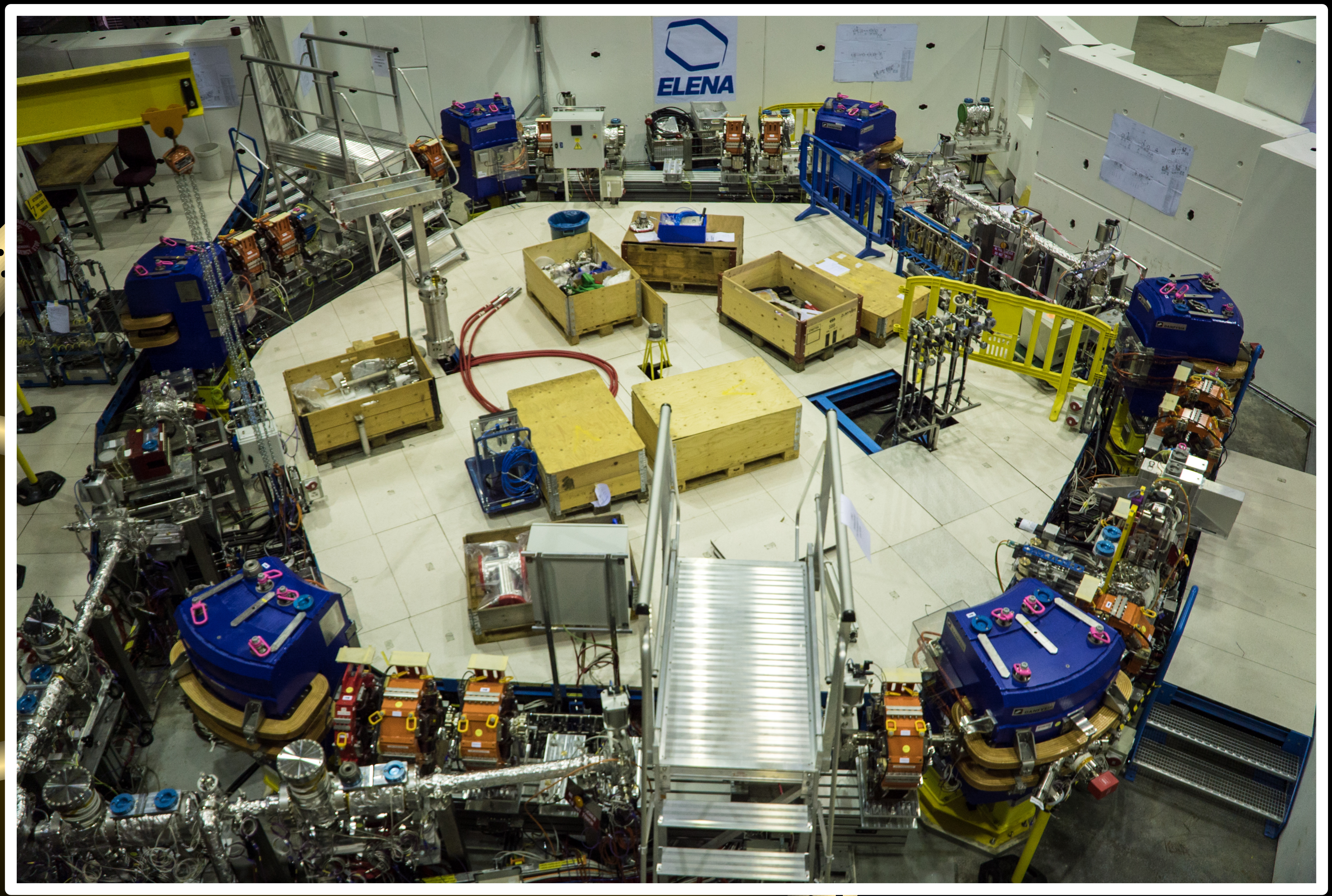
Pathway for neutrino experiments
in the US (DUNE) and Japan (T2K/HyperK)

ETH zürich
UNIVERSITÄT BERN
UNIVERSITÉ DE GENÈVE



Explorations of the properties of ANTI-MATTER



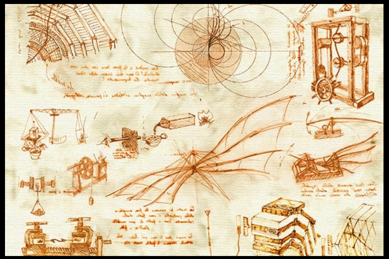


ELENA : Extra Low ENergy Antiproton

A bit of history
using CMS as an example

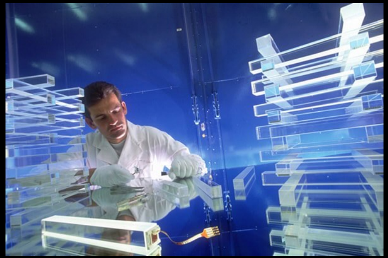
HiLumi HL-LHC PROJECT

1993



APPROVAL OF PROJECT

1993 – 2005

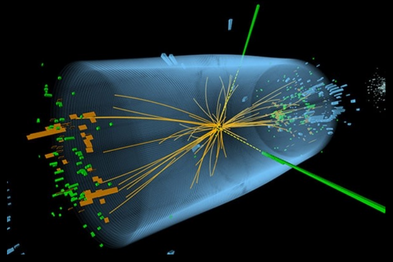


R&D

2010

FIRST PHYSICS DATA

2012



HIGGS DISCOVERY

2013

NOBEL PRIZE

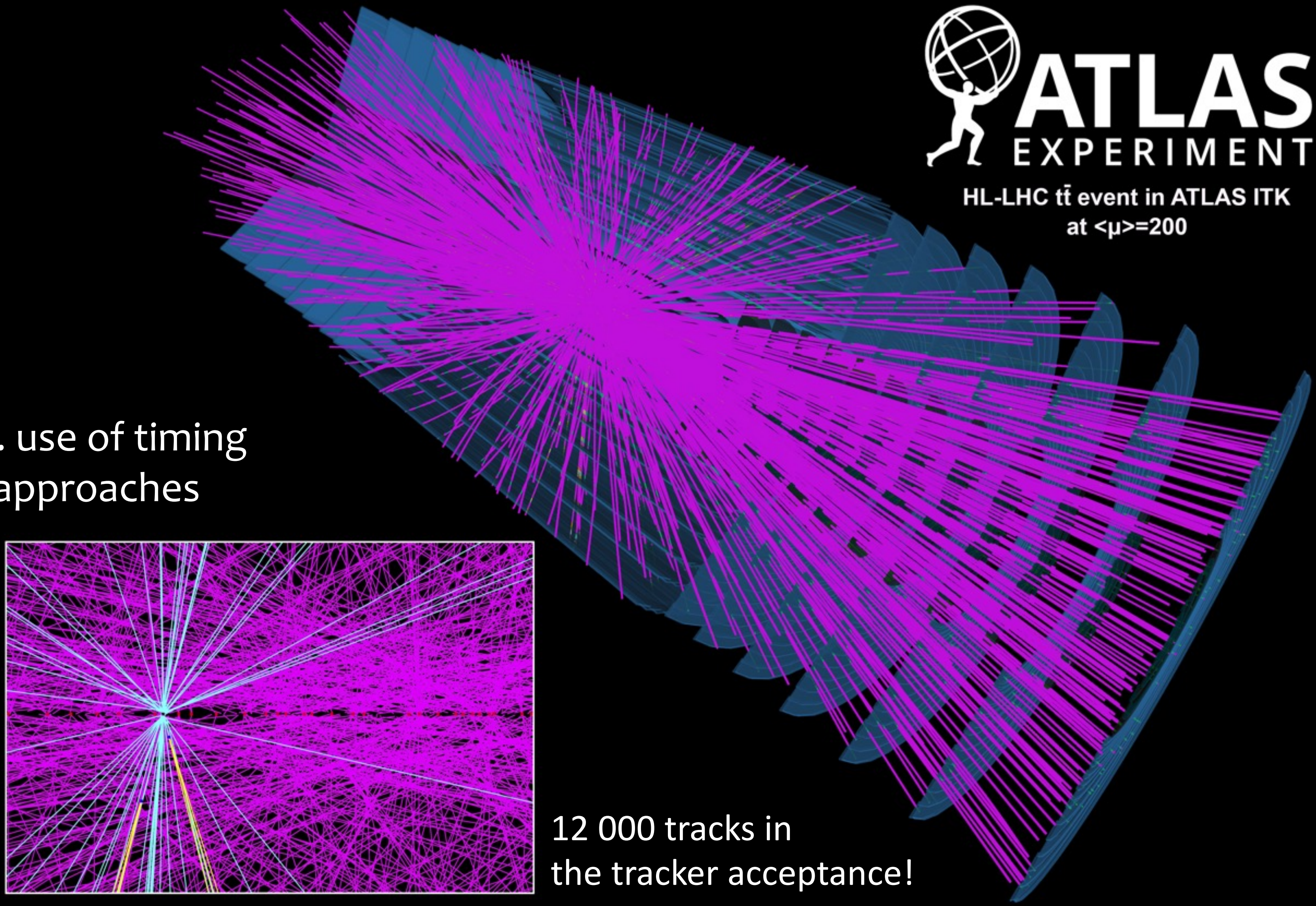
SINCE THEN

MORE DATA
TO PROBE RARE PHENOMENA
& UNRAVEL
NATURE'S SECRETS

Required HL-LHC detector upgrades

Unprecedented challenges :
- amounts of radiation
- data rates
- data volume

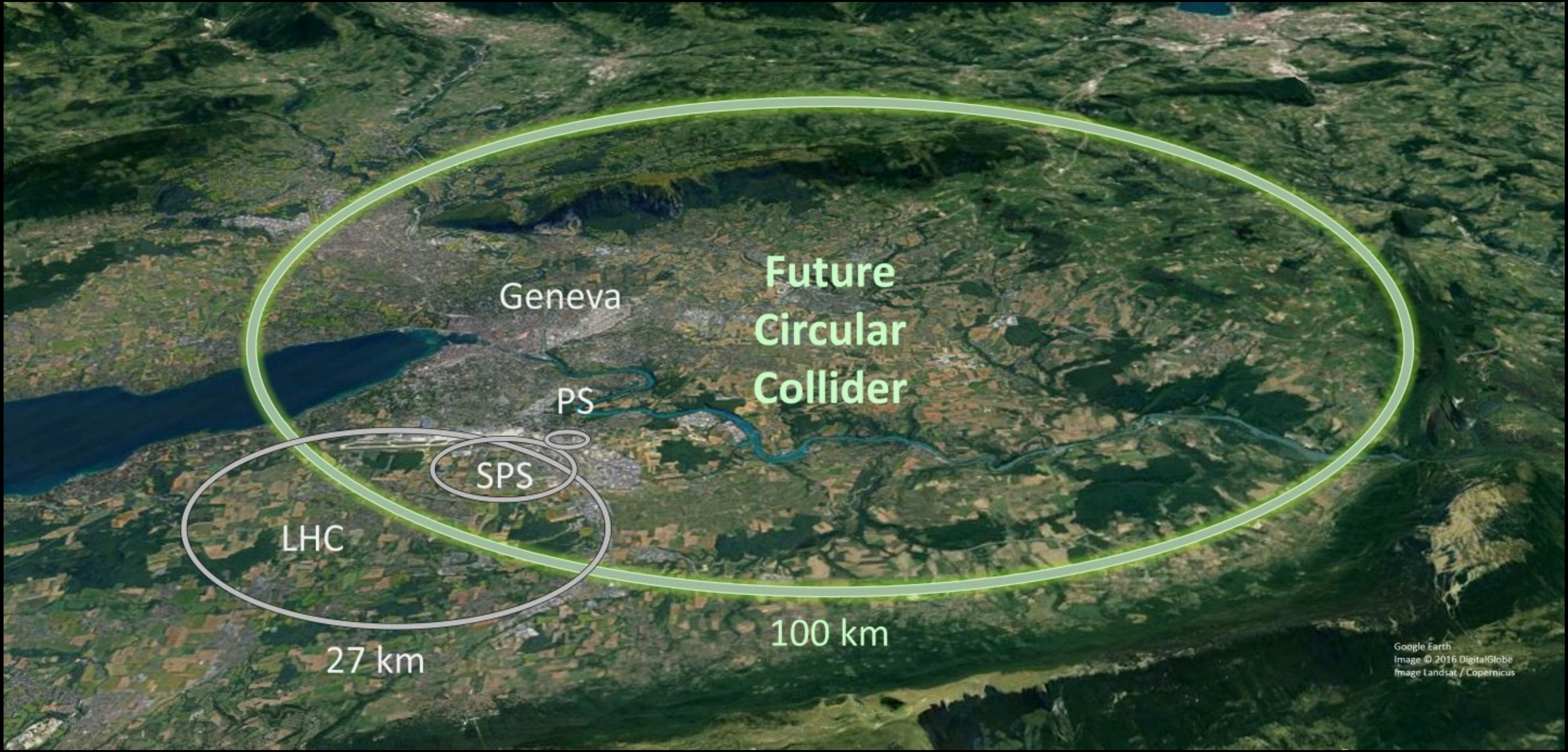
Development of :
- radiation hard detectors
- fast electronics
- new detection methods, e.g. use of timing
- new software & computing approaches



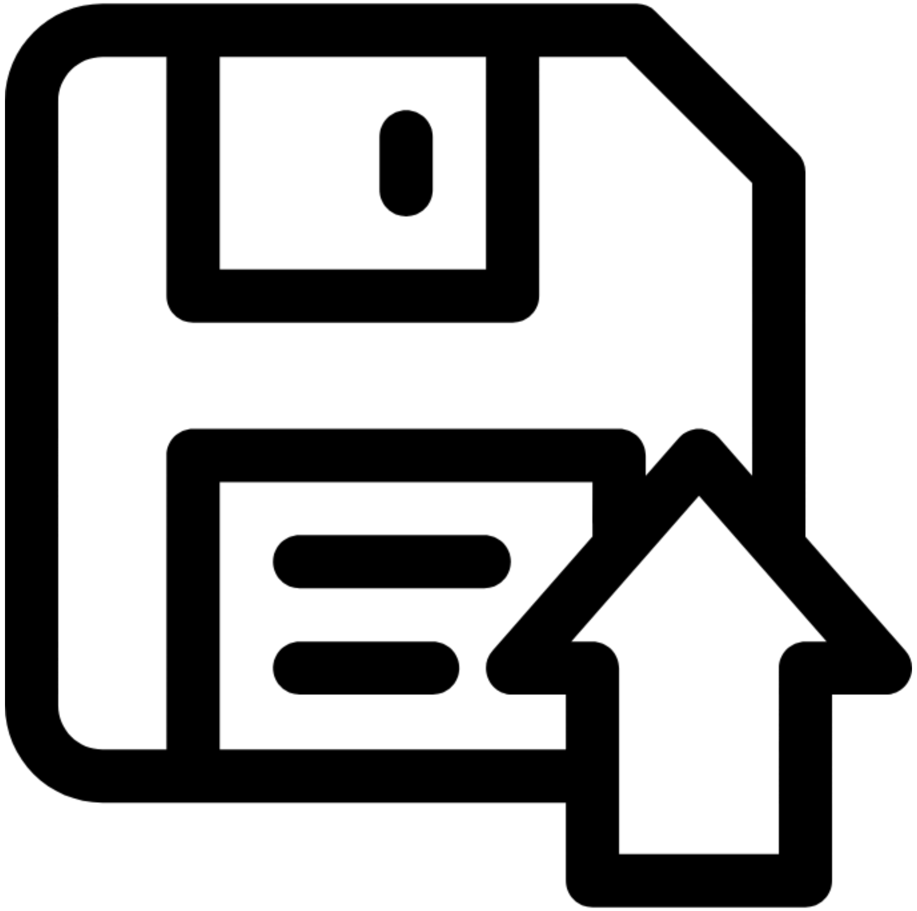
ATLAS EXPERIMENT

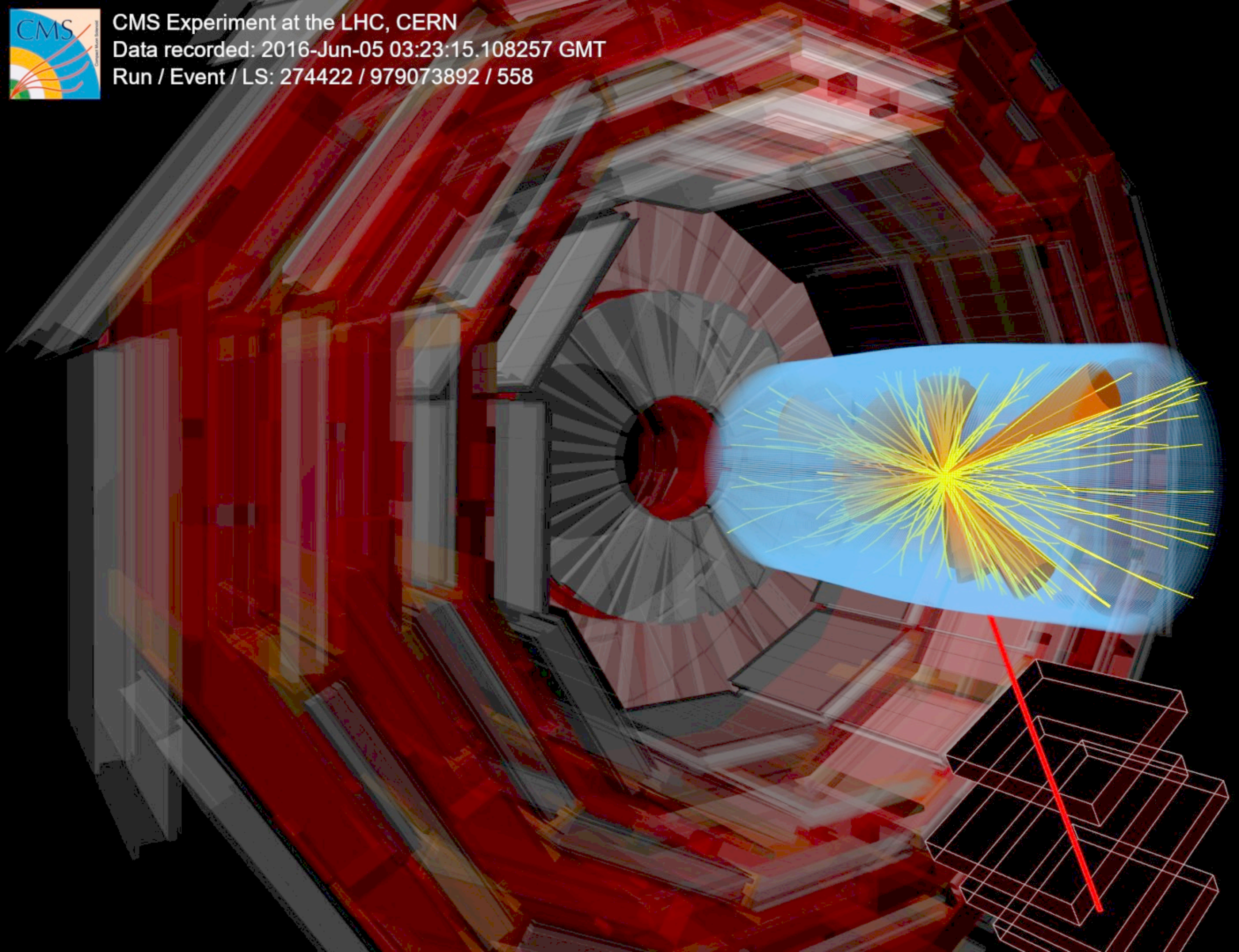
HL-LHC $t\bar{t}$ event in ATLAS ITK at $\langle\mu\rangle$=200

12 000 tracks in the tracker acceptance!


Future
Circular
Collider
Geneva
PS
SPS
LHC
100 km
27 km
Google Earth
Image © 2016 DigitalGlobe
Image Landsat / Copernicus

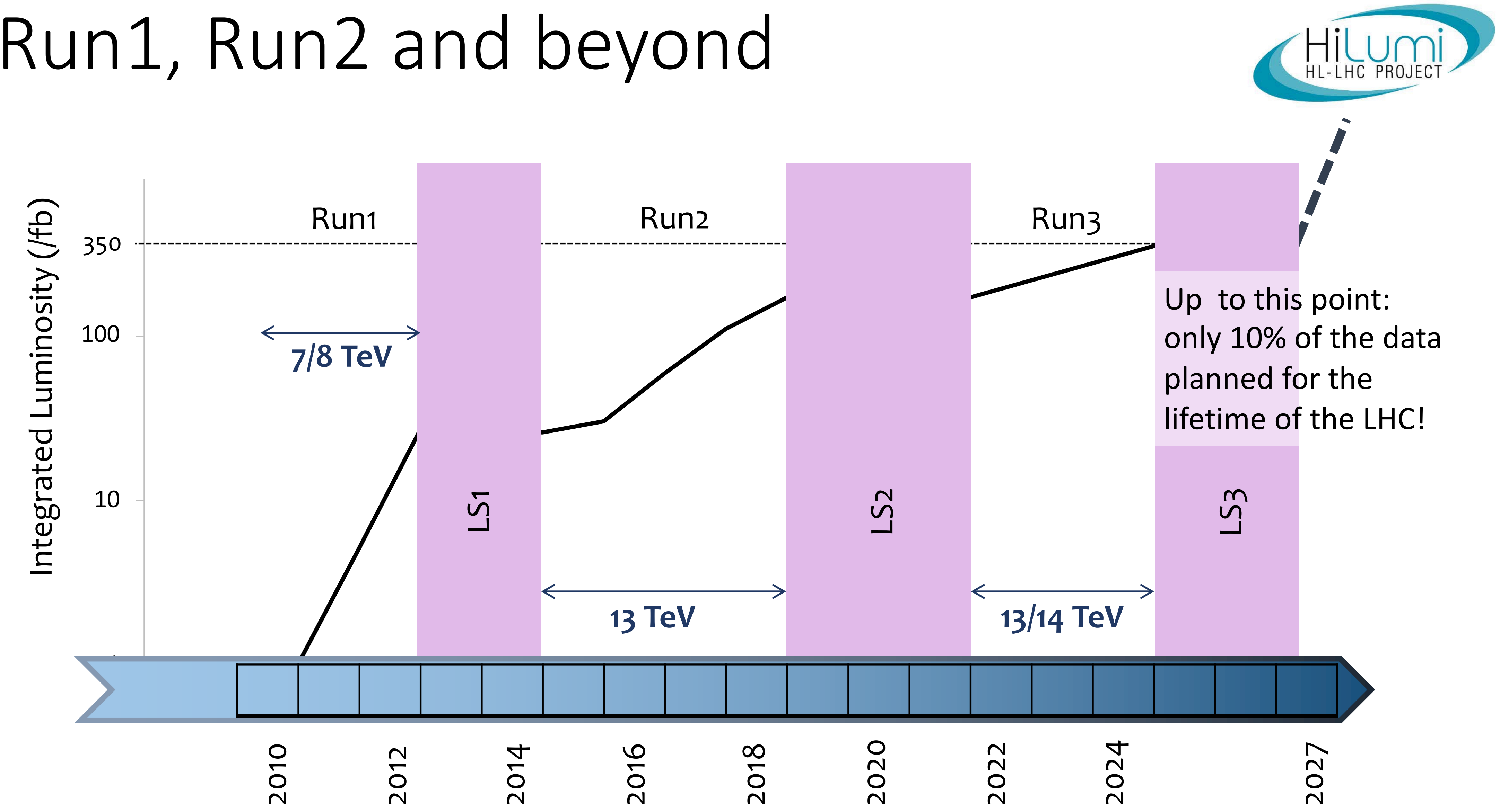

Thank You !



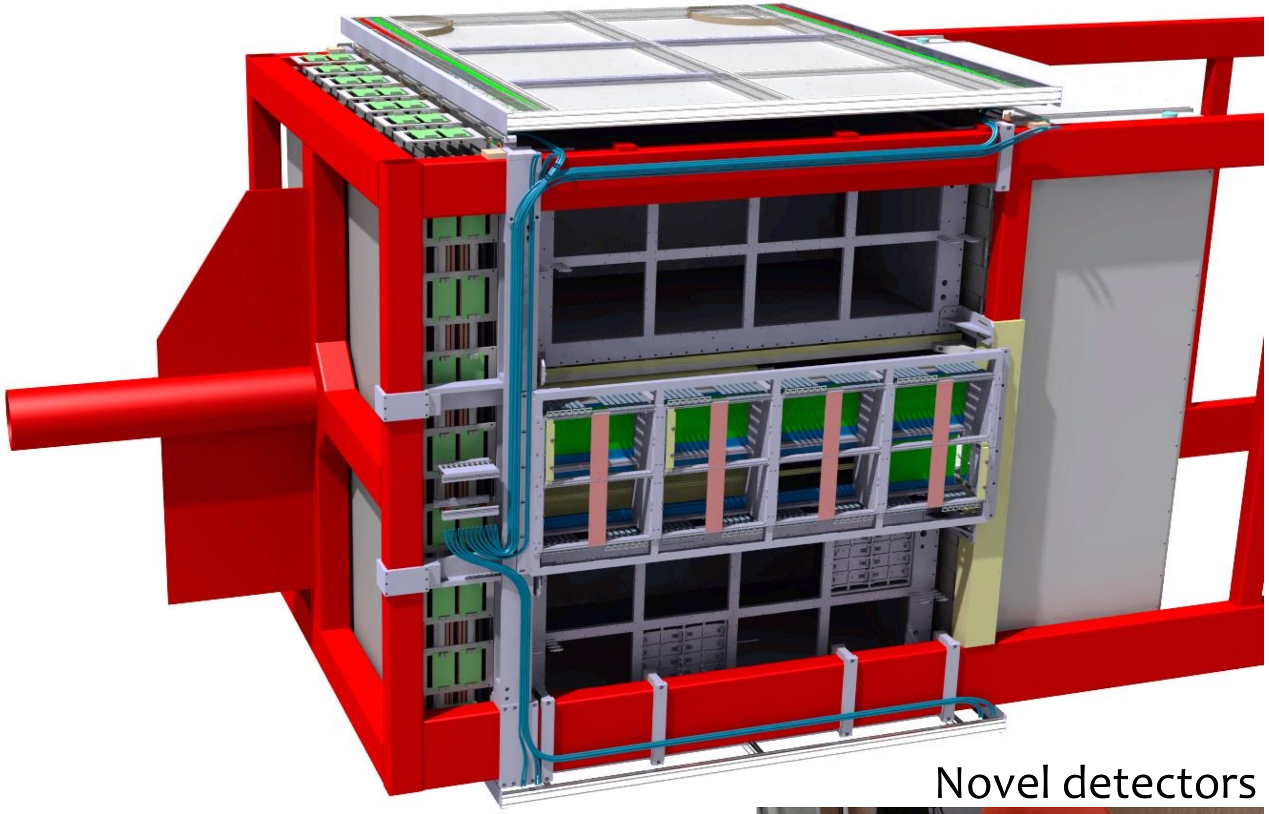


1 OUT OF 20 BILLION EVENTS!

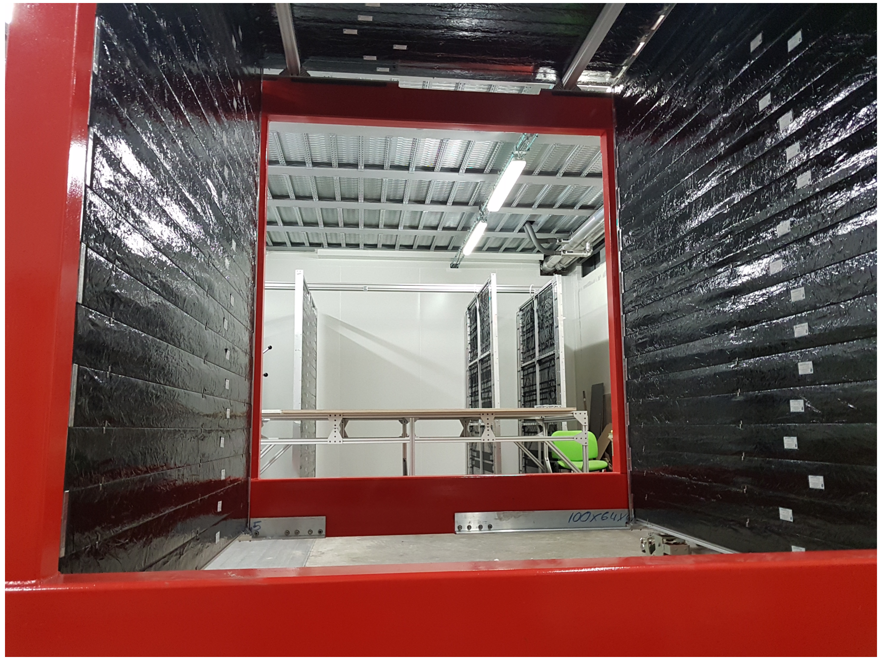
Run1, Run2 and beyond



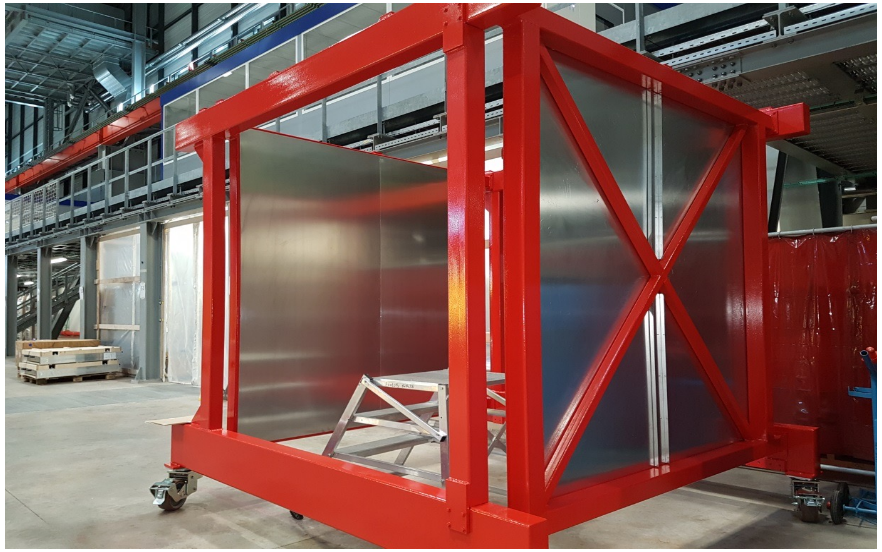
T2K near detector upgrade



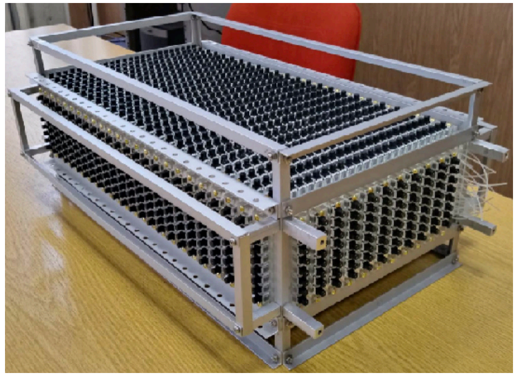
Time of Flight

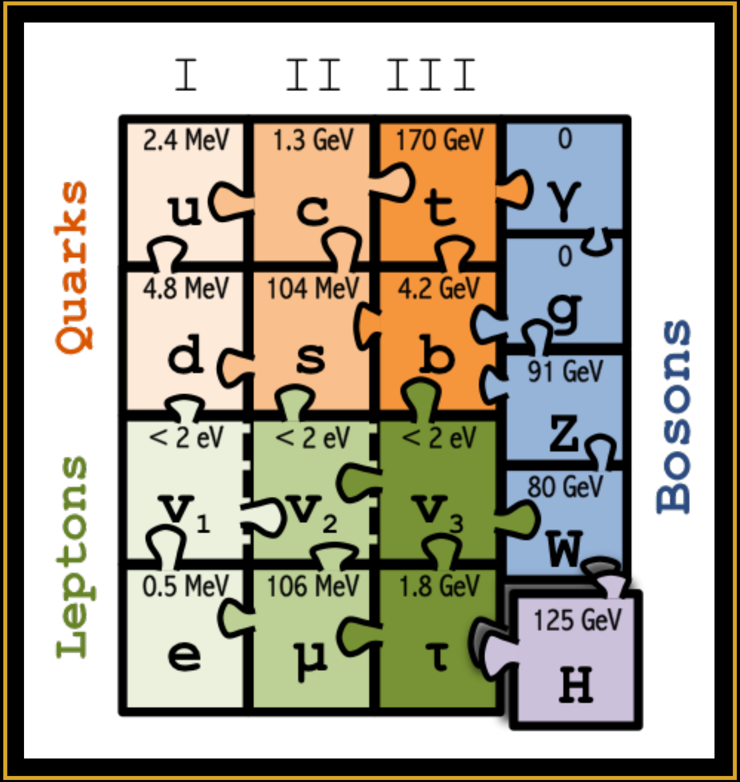


Mechanics



Novel detectors





— Why are there three families of quarks and leptons?

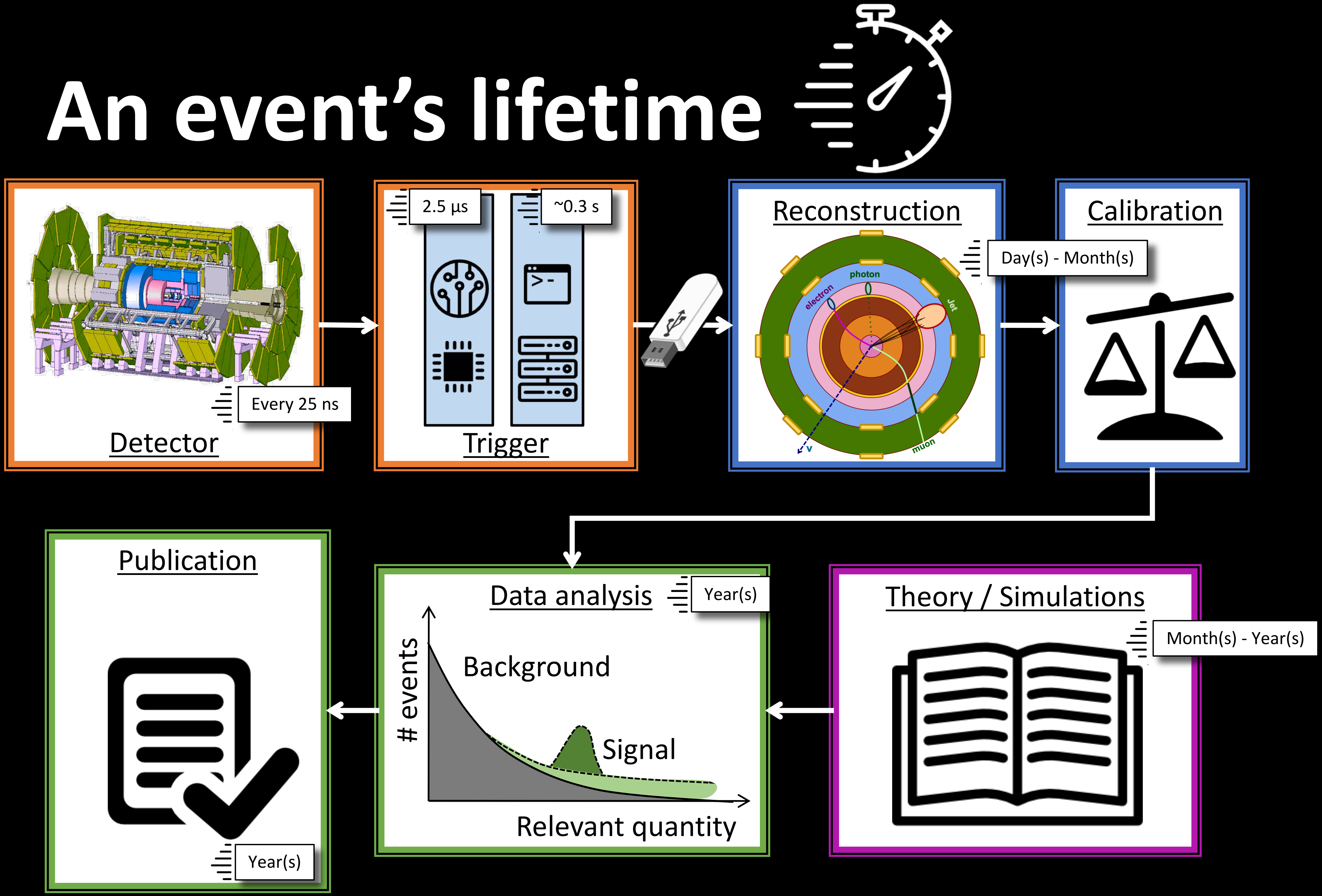
— What is the origin of the different quark and lepton masses?

— Is there a further substructure of fundamental particles?

— Are there more fundamental forces at the microscopic level?

— What is the nature of the Higgs boson?

An event's lifetime



Why? Guarantee openness and preservation of experimental data

New open data policy in support of open science from CERN & the LHC experiments

Peer-reviewed publications

- Open Access
- Followed by detailed data related to the results, available at hepdata.net

Purpose: Communicate results and maximize their scientific value

Reconstructed & calibrated data

- Followed by related metadata
- Accompanied by appropriate simulated data samples

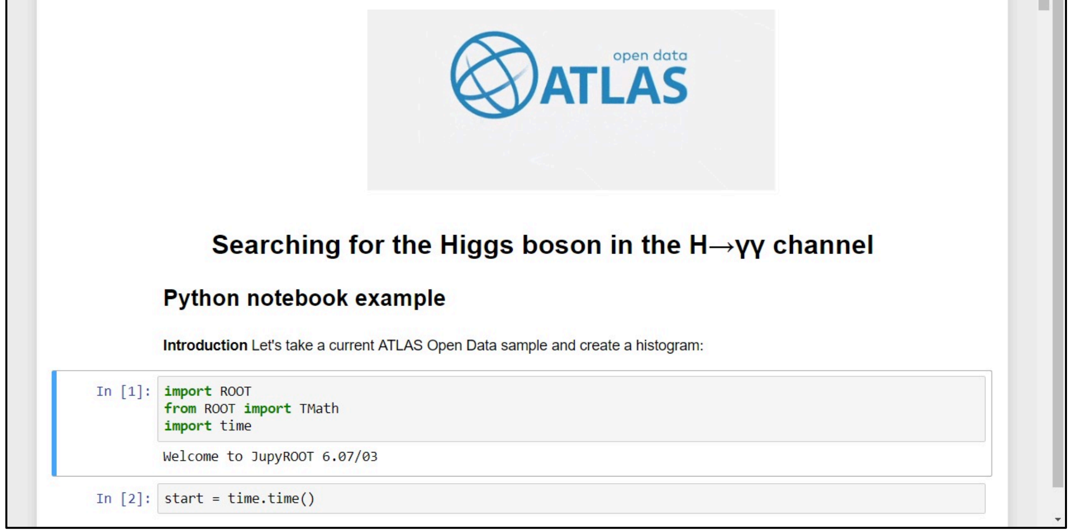
Purpose: Algorithmic, performance and physics studies

Data for outreach and education

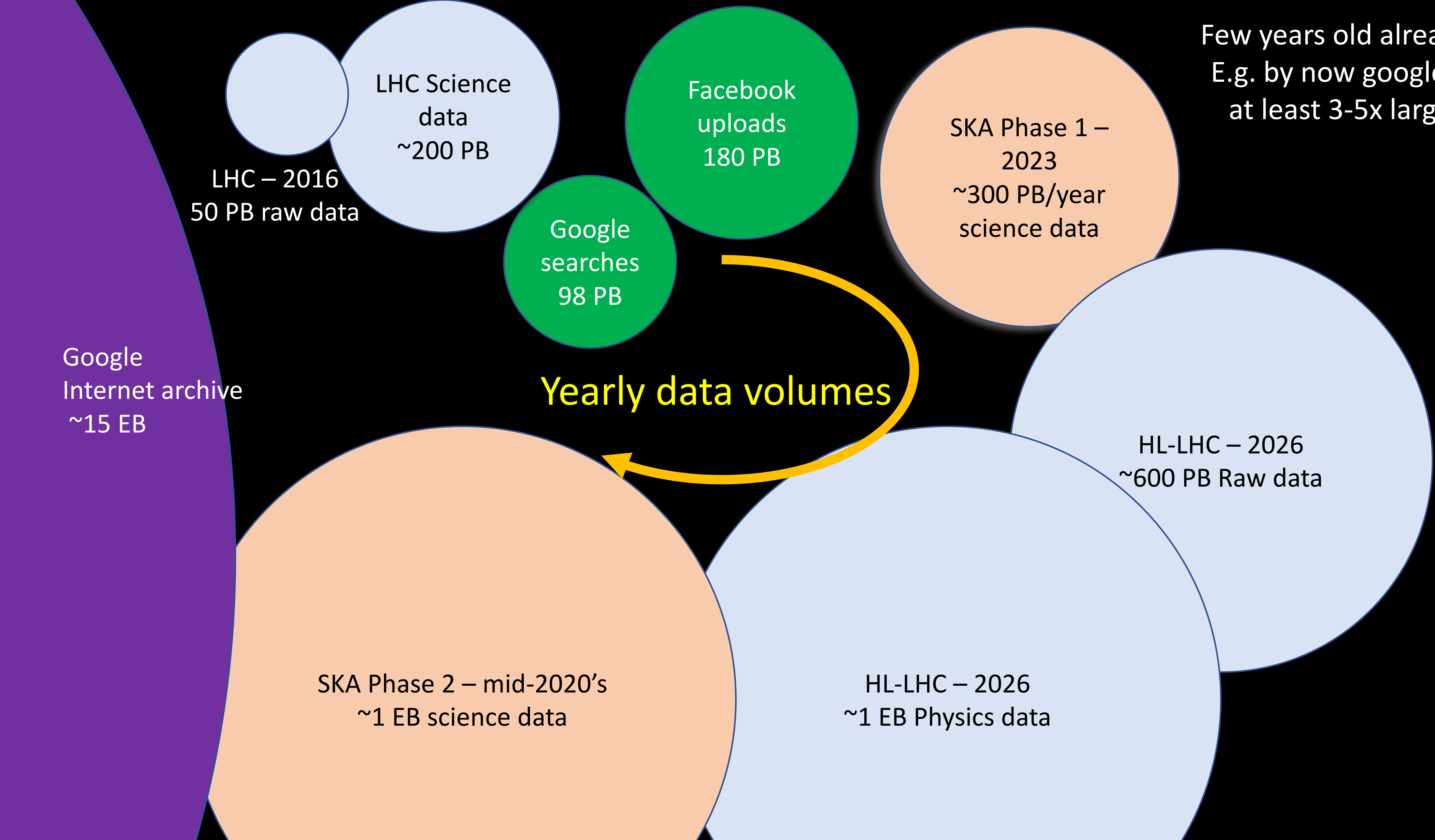
- Selected and formatted (“light”) datasets
- Examples available in Jupyter notebooks
- Used in university classes, in growing numbers

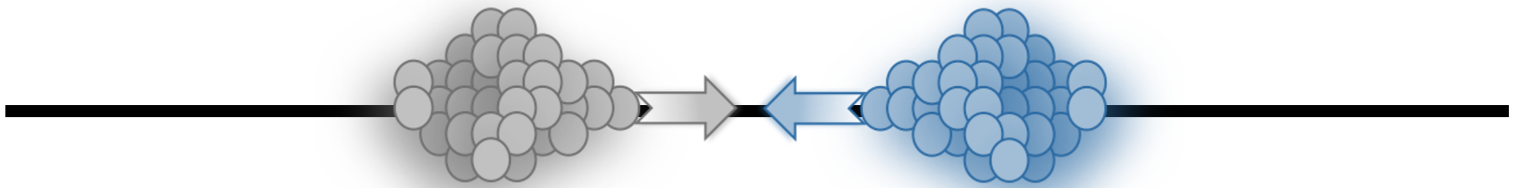
Purpose: Maximize educational impact

More info: https://atlas.cern/resources/opendata

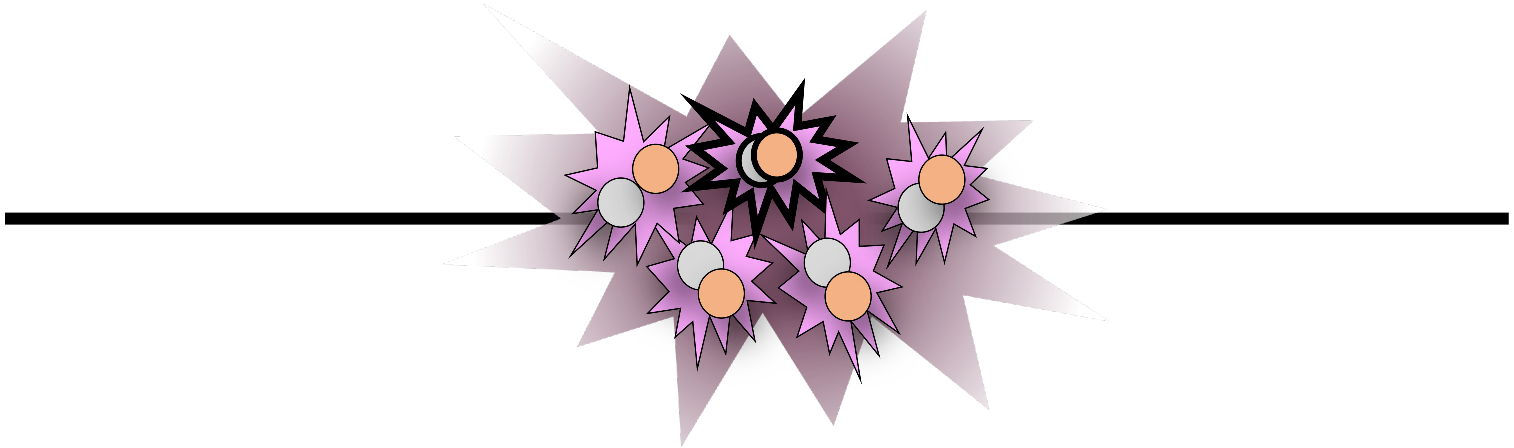


Few years old already
E.g. by now google is
at least 3-5x larger!



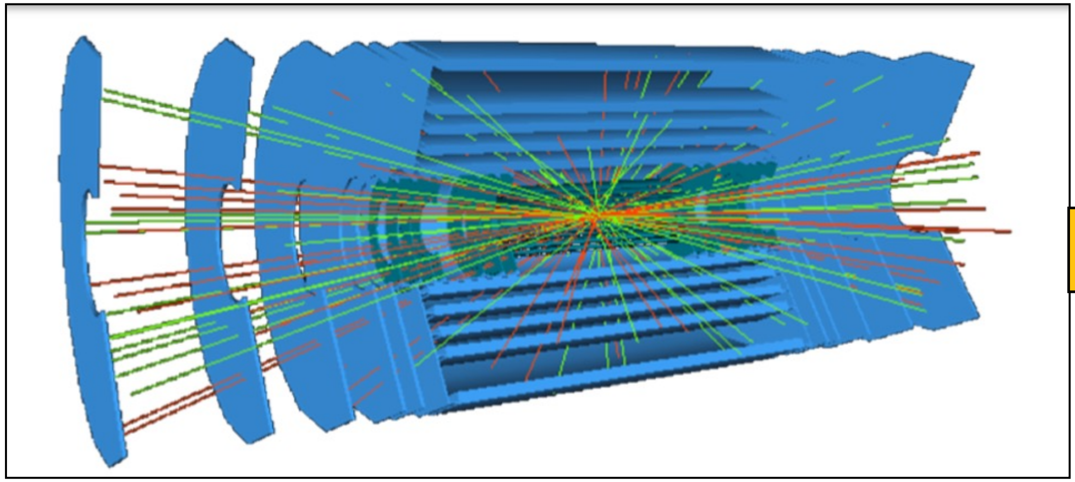


Proton bunches
>10^{11} protons/bunch
(colliding at **~30MHz in Run2)**

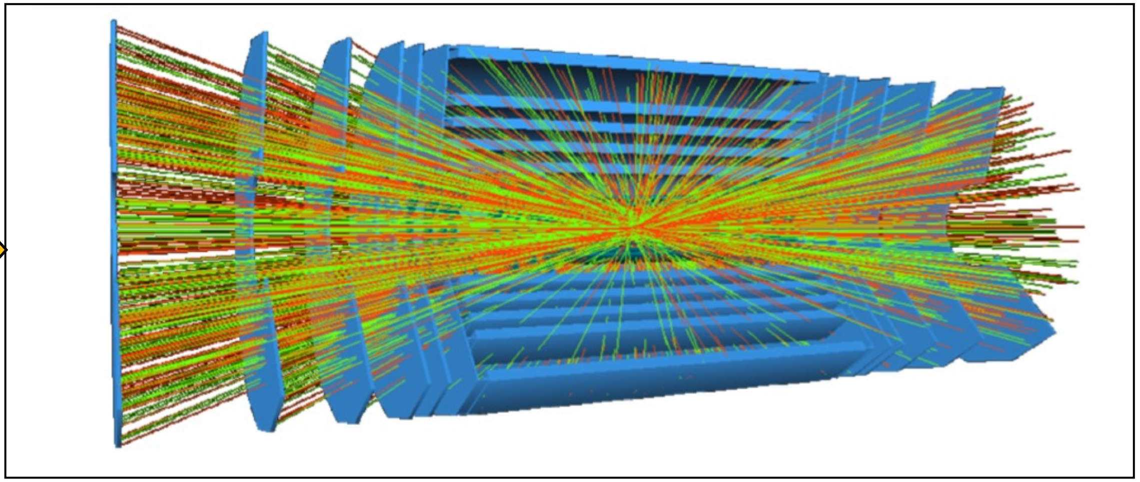


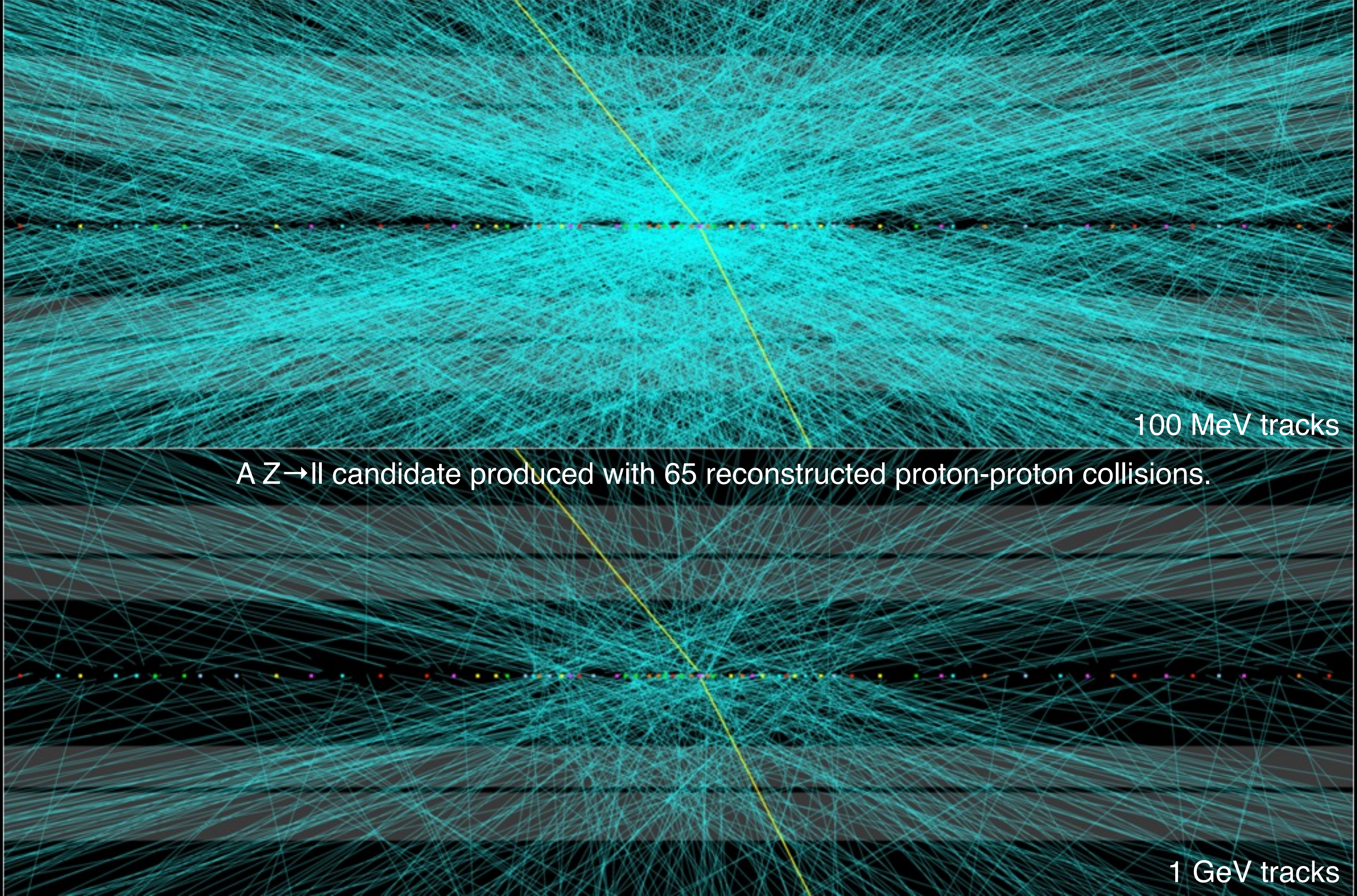
Up to 60 p-p collisions / bunch crossing

LHC: ~ 30 evts/x-ing



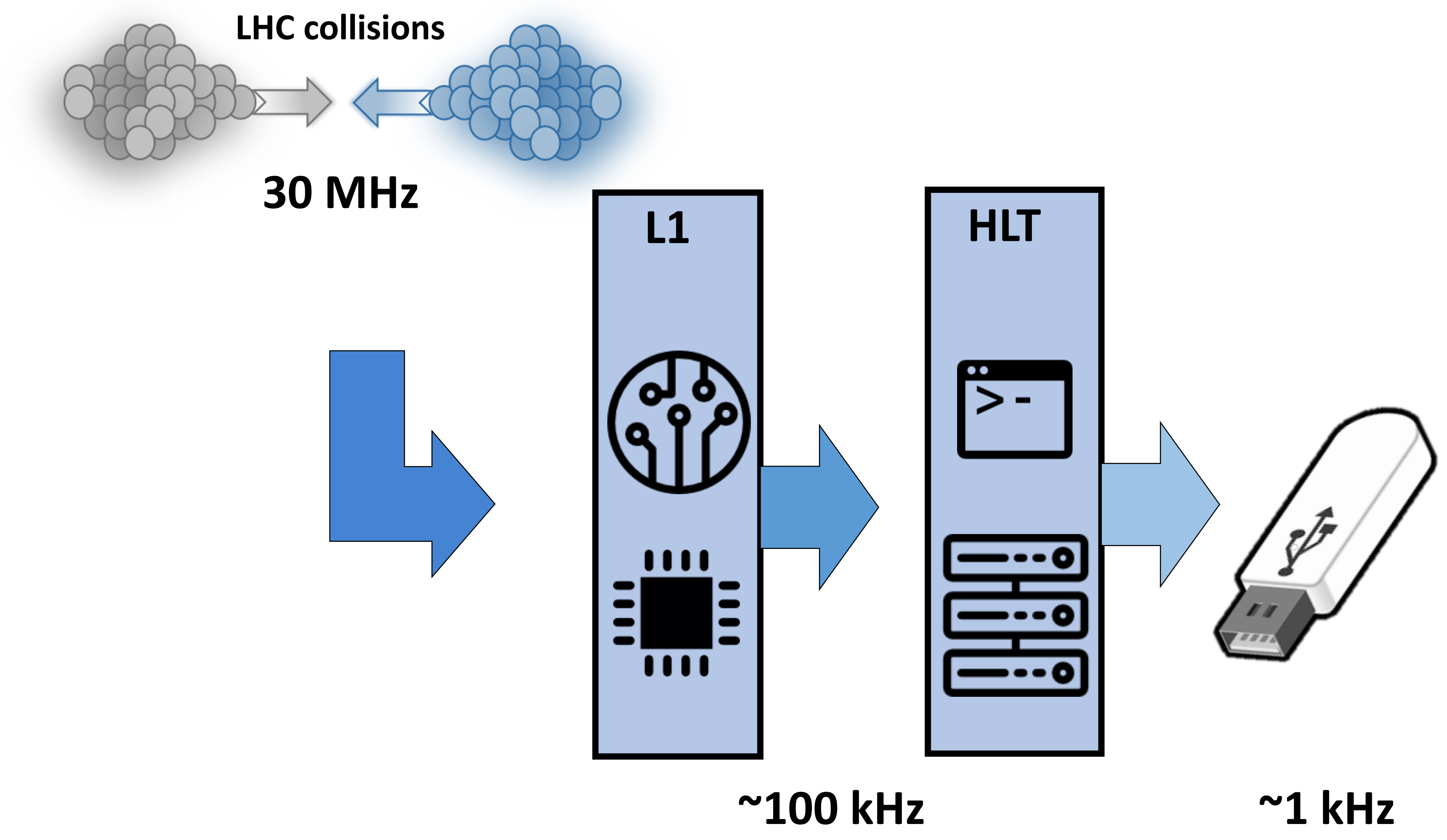
HL-LHC: ~ 140-200 evts/x-ing





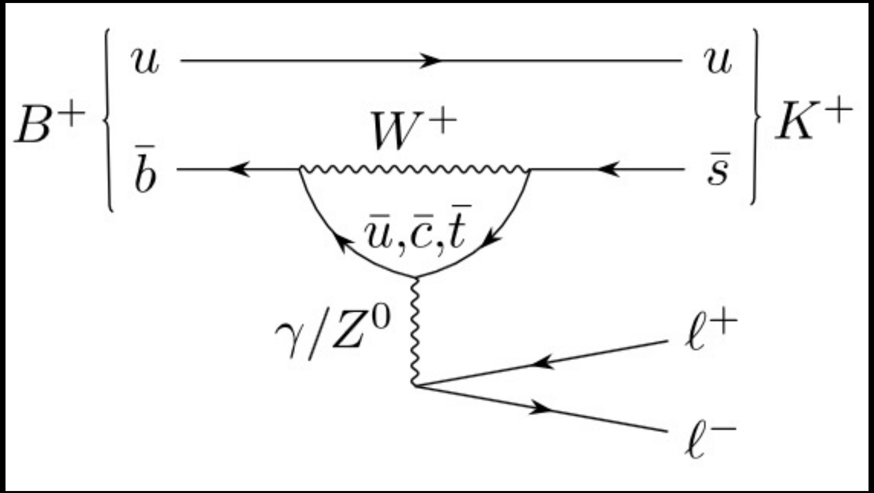
A Z→ll candidate produced with 65 reconstructed proton-proton collisions.

Triggering on physics

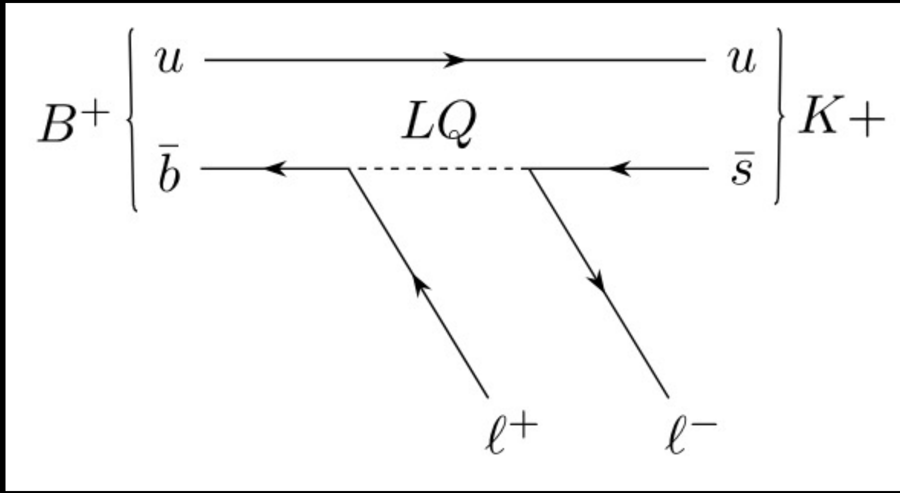


R_K

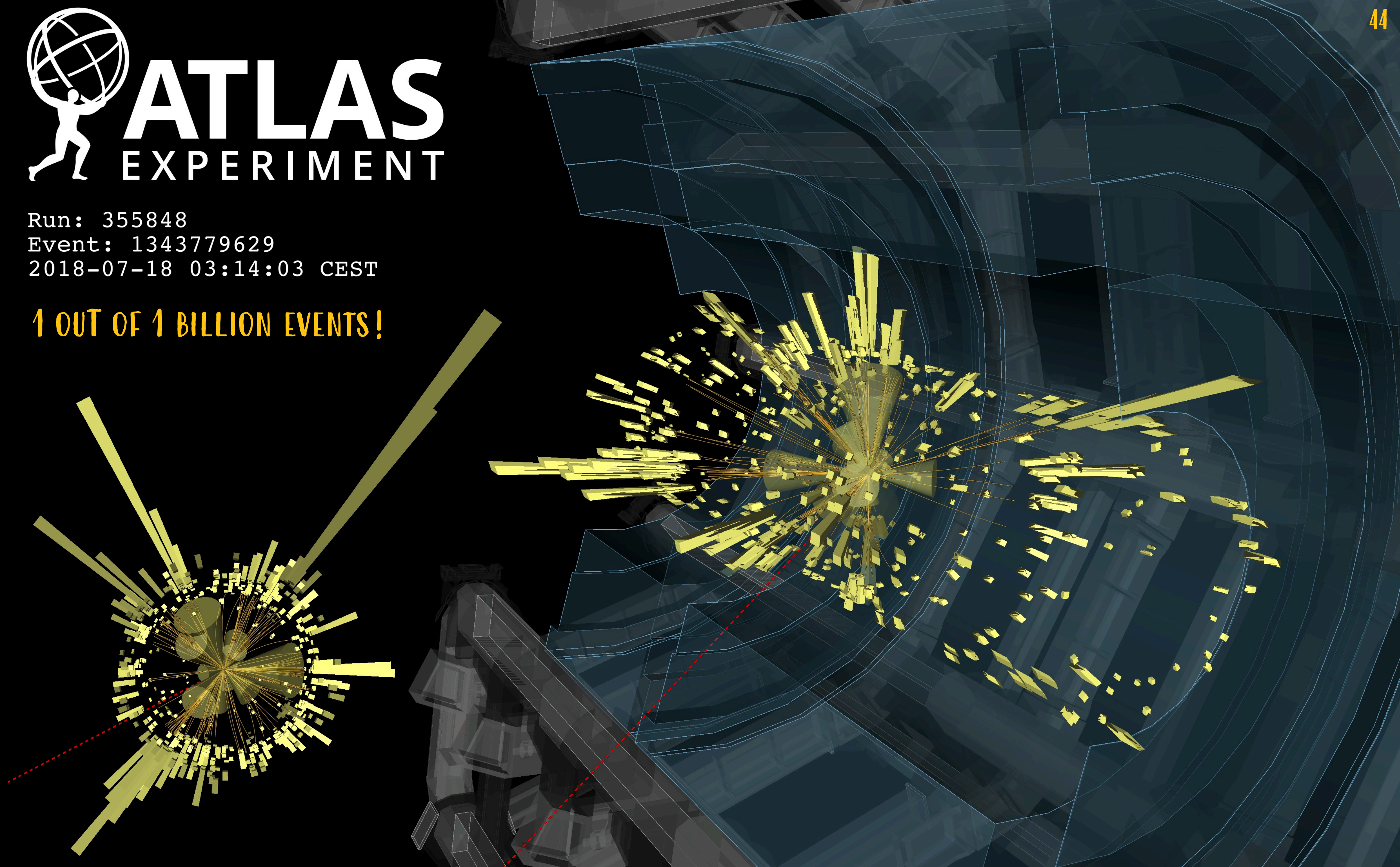
Standard Model



New physics example



- R_K : how often a B^+ meson decays to a charged kaon and either a positive and a negatively charge muon ($K^+\mu^+\mu^-$) or a positron-electron pair ($K^+e^+e^-$).
- These decays are extremely rare, occurring at a rate of only one in two million B^+ meson decays.

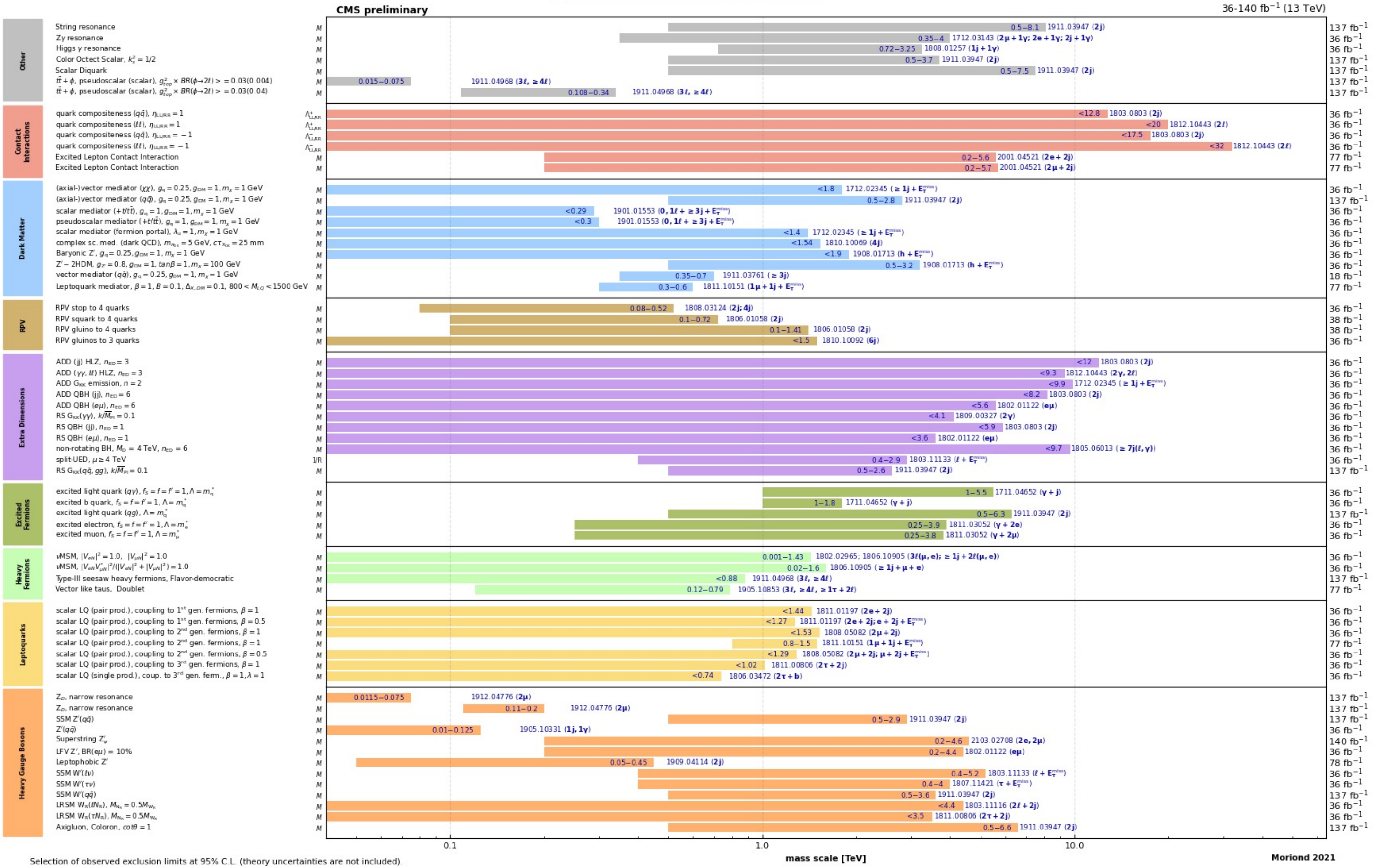

ATLAS
EXPERIMENT
Run: 355848
Event: 1343779629
2018-07-18 03:14:03 CEST
1 OUT OF 1 BILLION EVENTS!

The many other applications of accelerators.

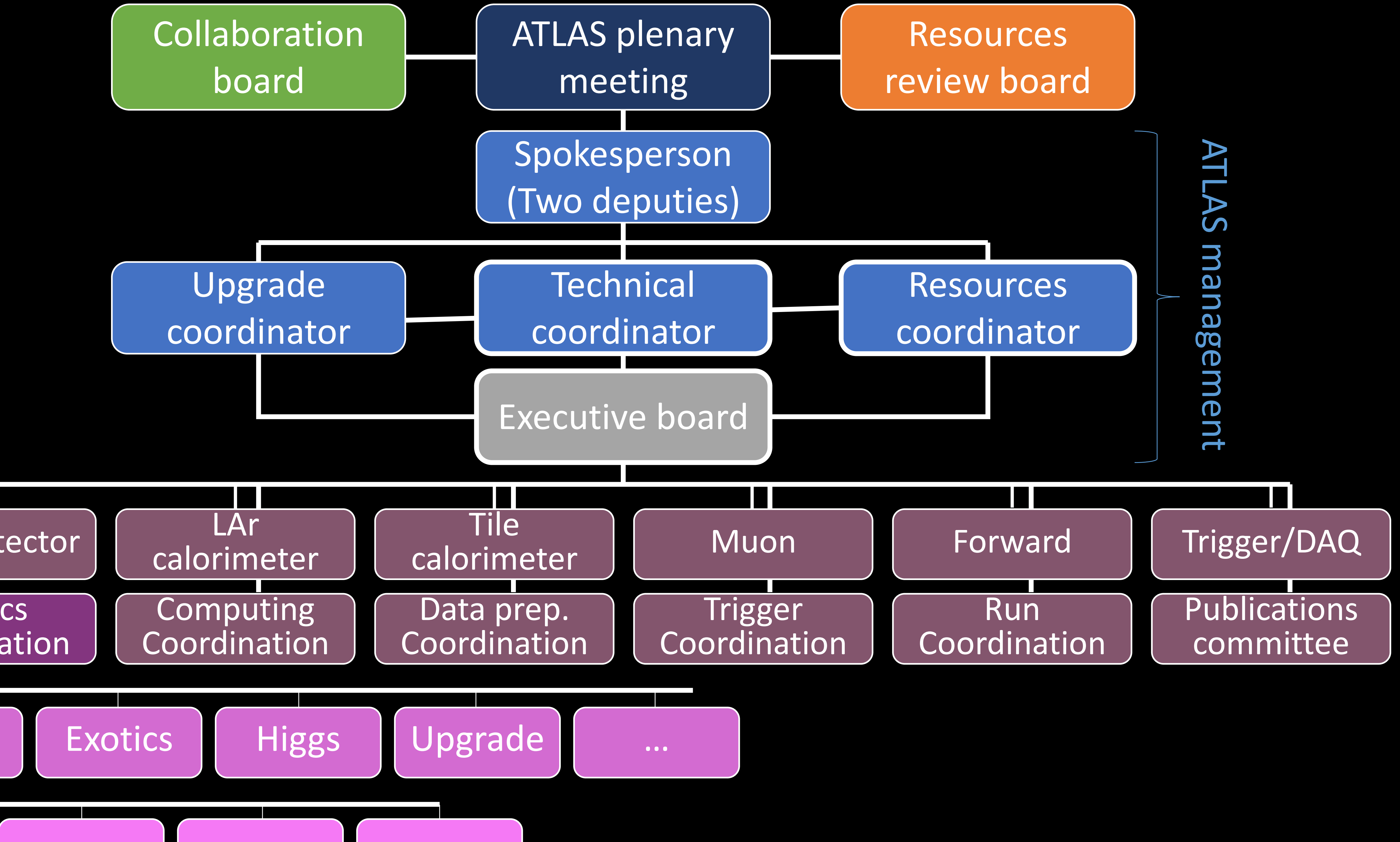
- The giant research accelerator like CERN's Large Hadron Collider in Geneva, with its 27 km is only the tip of the iceberg
- An accelerator can shrink a tumor, produce cleaner energy, spot suspicious cargo, make a better radial tire, clean up dirty drinking water, map a protein, study a nuclear explosion, design a new drug, make a heat-resistant automotive cable, diagnose a disease, reduce nuclear waste, detect an art forgery, implant ions in a semiconductor, prospect for oil, date an archaeological find, besides discovering the secrets of the Universe
- Medical and industrial markets exceed $3.5 billion/y, and are growing at more than ten percent annually. Digital electronics now depend on particle beams for ion implantation, creating a $1.5 billion annual market for ion-beam accelerators. All the products that are processed, treated or inspected by particle beams represent a collective annual value of more than $500 billion.

C. Rubbia @ The 50th Anniversary of Hadron Colliders at CERN

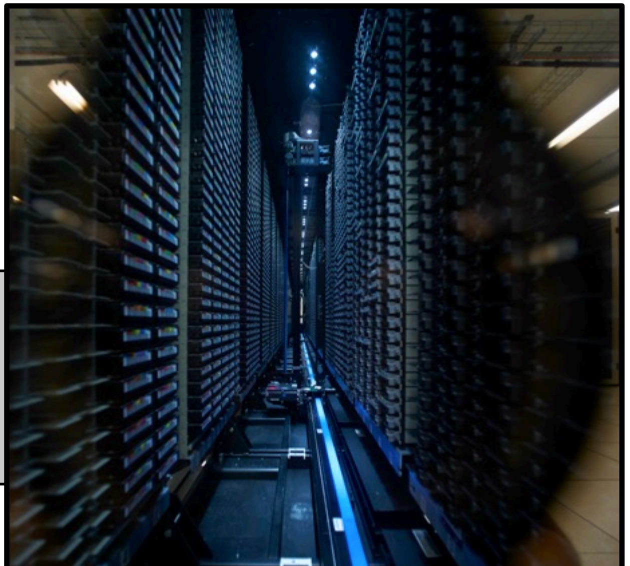
Overview of CMS EXO results



ATLAS Organization model simplified



Hardware


Magnetic tapes, retrieved by robotic arms, are used for long-term storage

Storage

Tape (at CERN) about 270 PB	• Most reliable and cost-effective technology for large-scale archiving • Data stored there infinitely
Disk about 200 PB	• Data for initial processing • Copies for further processing / user analysis • Data in disks gets staged from tape, on demand

Processing power

CPUs	• Mainly GRID • About 400k cores
GPUs	• Mostly for RnD • Few 10s *Also considering for the future: FPGA accelerators*
Opportunistic resources	• Online farm, 100k cores • High Performance Computers, primarily in the US • Volunteer computing (see later talk)

Nvidia GeForce

LHC@home Volunteer computing for the LHC

Software

athena
Project ID: 53790

70,356 Commits | 34 Branches | 1,374 Tags | 2.6 GB Files | 2.6 GB Storage | 124 Releases

The ATLAS Experiment's main offline software repository

- **All software organized in packages in Git.** For example:
  https://gitlab.cern.ch/atlas/athena

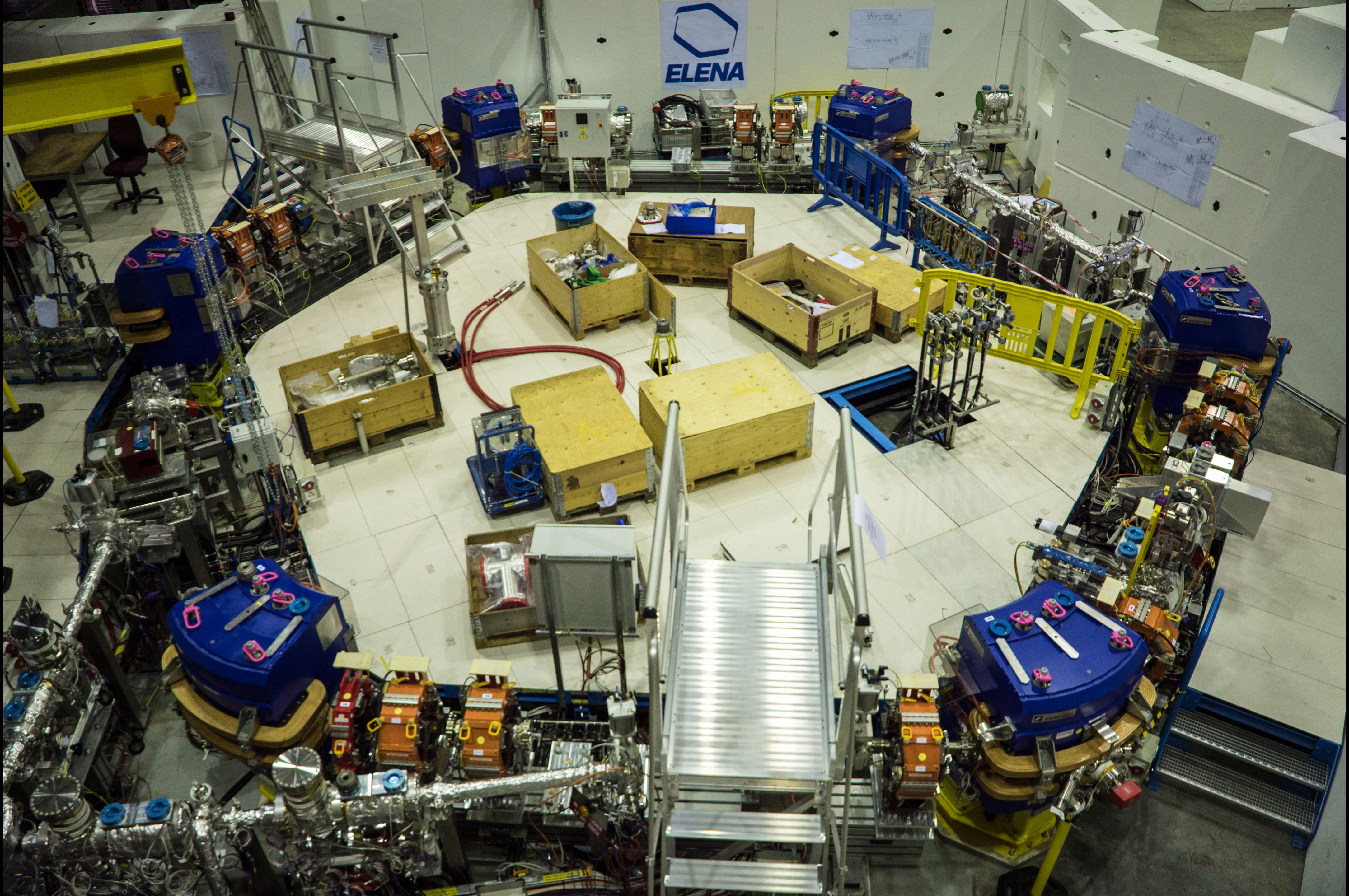
- **All software open source, copyrighted and licenced (Apache 2)**
  - "Copyright (C) 2002-2020 CERN for the benefit of the ATLAS collaboration"
  - For open use – but also for crediting developers who move out of academia

- **Thorough tracking of software developments a key of success**
  - Via the Jira software, supported by CERN IT Jira Software
  - Multiple releases exist for merging of new code with existing one
  - Automated tools run nightly to verify code sanity & performance
  - Globally the software projects are coordinated with careful planning

- **Software Tools**
  - Databases
  - Analysis tools: ROOT is the workhorse!

ROOT
Data Analysis Framework

- **Analysis-specific software developed by teams available to whole collaboration!**



ELENA : Extra Low ENergy Antiproton

NA64

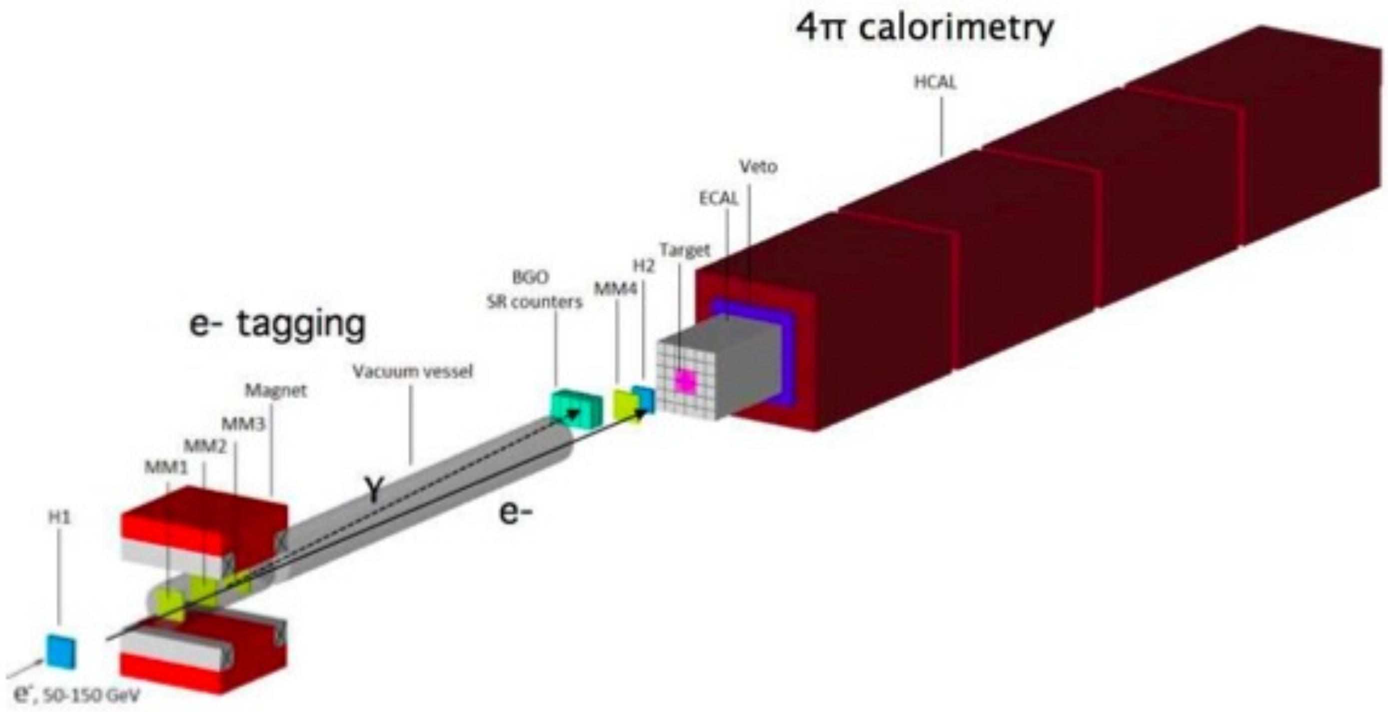


Table 1. Main characteristics of sub-detectors used in the experiment

1. Electromagnetic calorimeters ECAL + Preshower
• module design: (1.5 mm Pb + 1.5 mm Sc) × 150 layers
• purpose: energy measurements, shower profile measurements, e/π separation
• performance: energy resolution $\Delta E/E \simeq 0.18/\sqrt{E}$, X,Y resolution $\simeq$ 3 mm,$e/\pi \lesssim 10^{-2}$
• event rate: up to 10^6 e^- per spill, $10^{12} - 10^{13}$ e^- in total run
2. Hadronic Calorimeter HCAL, 4 modules
• module design: (25 mm Fe+ 4 mm Sc) × 48 layers
• purpose: secondary energy detection, π, p, n detection
• performance: energy resolution $\Delta E/E \simeq 0.62/\sqrt{E}$, π-hermeticity $\simeq 10^{-9}$
• event rate: up to 10^6 π per spill, $10^{10} - 10^{11}$ in total run
3. Beam counters S1,S2 and Hodoscopes H1,H2
• design: Sc 1mm hodoscopes
• purpose: e^-e^+ pair hits, track detection and T_0
• performance: spacial resolution $\simeq$ 1 mm, 2 tracks separation $\Delta R \gtrsim$ 1 mm
• event rate: up to 10^6 e^- per spill
4. Veto counter
• design: plastic scintillator, 5 cm x 60x 60 cm^3
• purpose: low energy charged track detection
• performance: mip inefficiency $\lesssim 10^{-3}$
• event rate: up to 10^5 hits per spill
5. Synchrotron radiation counter, BGO array
• design: diam 60x200 mm thick BGO crystal
• purpose: γ ray energy mesurements in the range 1-30 MeV
• performance: energy resolution $\Delta E/E \simeq$ 3% at 1 MeV, time resolution $\simeq$ 2 ns.
• event rate: up to 10^6 1-30 MeV γ per spill, $\simeq 10^{11}$ for full run
6. Decay volume
• design: diameter $\simeq$30 cm × 15 m length, filled with He or vacuum $\lesssim 10^{-5}$ Torr
• purpose: minimize secondary particles interactions
7. Micromegas tracker, 4 chambers
• design: diam 80 mm
• purpose: e- track measurement
• performance: momentum resolution at 100 GeV $\Delta P/P \simeq$ 2%.
• event rate: up to a few 10^5 per spill
8. Straw tube chambers, 4 chambers
• design: 200x200 mm^2, thickness $\simeq$ 200 μm thick, straw tube diameter 2 and 6 mm