

RECENT CMS RESULTS AND PERSPECTIVES ON FUTURE COLLIDERS

FLORENCIA CANELLI

UNIVERSITY OF ZURICH

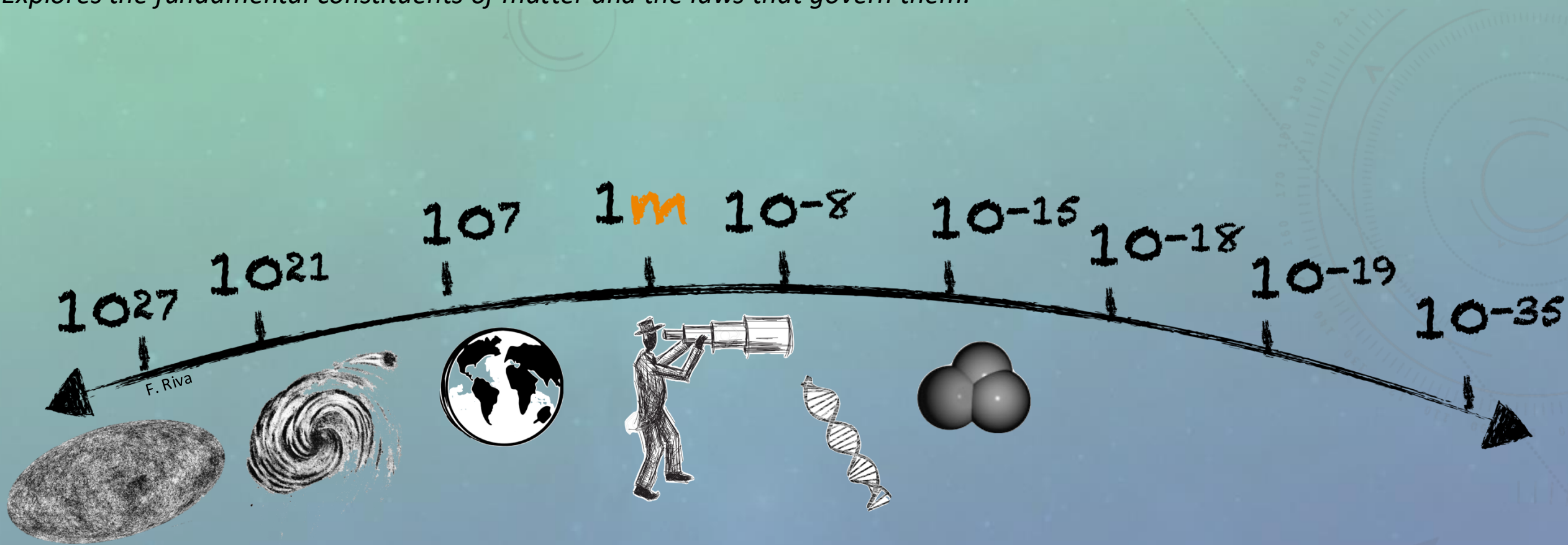
III ICTEA Resarch Days

Instituto de Ciencias y Tecnologías Espaciales de Asturias

JUNE 1, 2026

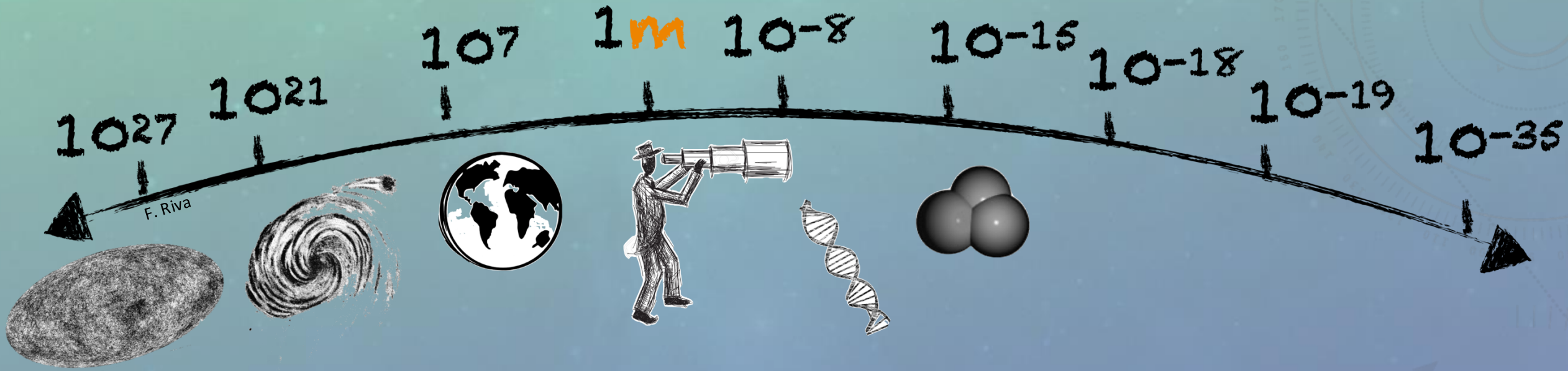
PARTICLE PHYSICS

Explores the fundamental constituents of matter and the laws that govern them.



PARTICLE PHYSICS

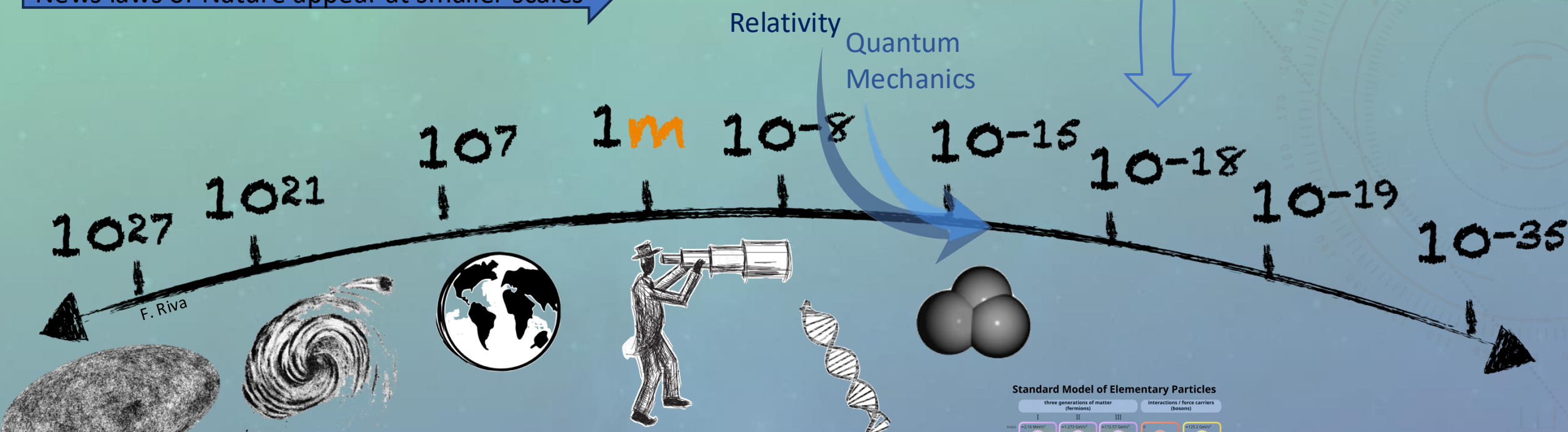
News laws of Nature appear at smaller scales



PARTICLE PHYSICS

News laws of Nature appear at smaller scales →

We are here
LHC @ 13.6 TeV



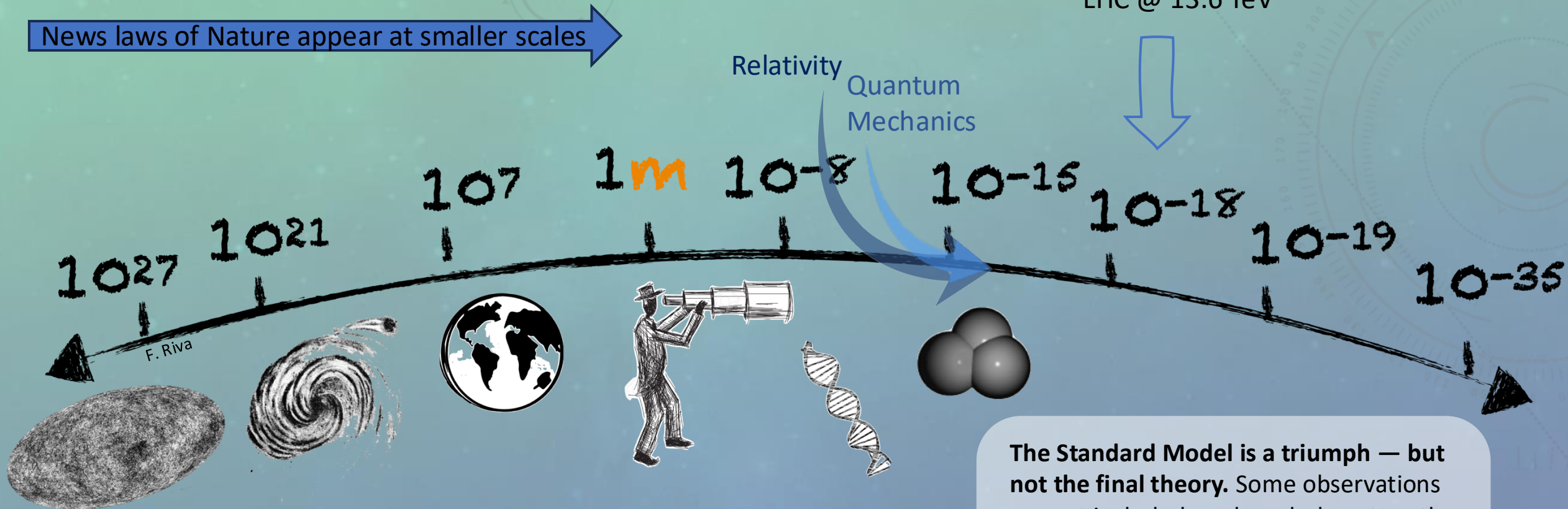
Standard Model of Elementary Particles

	three generations of matter (fermions)			interactions / force carriers (bosons)	
	I	II	III		
QUARKS	$\approx 2.16 \text{ MeV}/c^2$ u up	$\approx 1.273 \text{ GeV}/c^2$ c charm	$\approx 172.5 \text{ GeV}/c^2$ t top	$\approx 8 \text{ GeV}/c^2$ g gluon	$\approx 125.2 \text{ GeV}/c^2$ H higgs
	$\approx 4.7 \text{ MeV}/c^2$ d down	$\approx 93.5 \text{ MeV}/c^2$ s strange	$\approx 4.183 \text{ GeV}/c^2$ b bottom	≈ 0 γ photon	
	$\approx 0.511 \text{ MeV}/c^2$ e electron	$\approx 105.66 \text{ MeV}/c^2$ μ muon	$\approx 1.77693 \text{ GeV}/c^2$ τ tau	$\approx 91.188 \text{ GeV}/c^2$ Z Z boson	
LEPTONS	≈ 0 ν_e electron neutrino	$\approx 0.17 \text{ MeV}/c^2$ ν_μ muon neutrino	$\approx 1.82 \text{ MeV}/c^2$ ν_τ tau neutrino	$\approx 80.385 \text{ GeV}/c^2$ W W boson	

PARTICLE PHYSICS

News laws of Nature appear at smaller scales

We are here
LHC @ 13.6 TeV

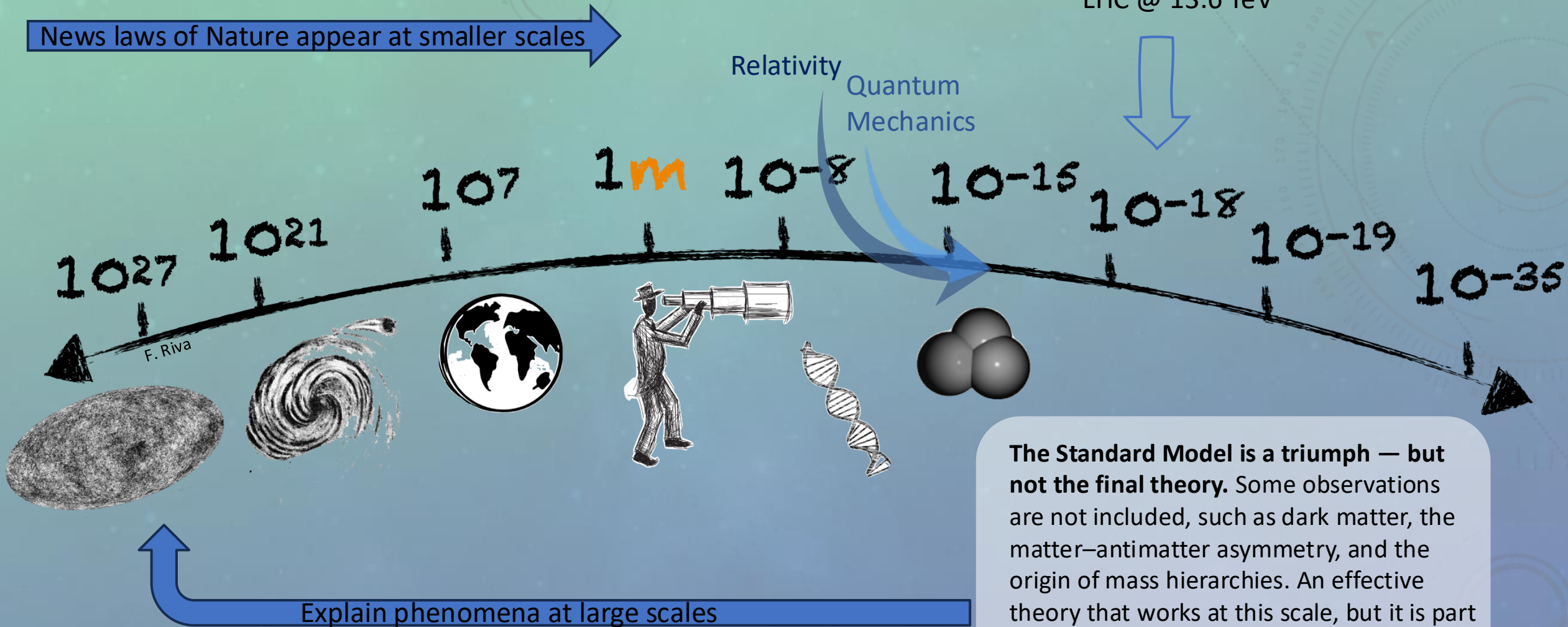


The Standard Model is a triumph — but not the final theory. Some observations are not included, such as dark matter, the matter–antimatter asymmetry, and the origin of mass hierarchies. An effective theory that works at this scale, but it is part of a more fundamental theory of nature.

PARTICLE PHYSICS

News laws of Nature appear at smaller scales

We are here
LHC @ 13.6 TeV

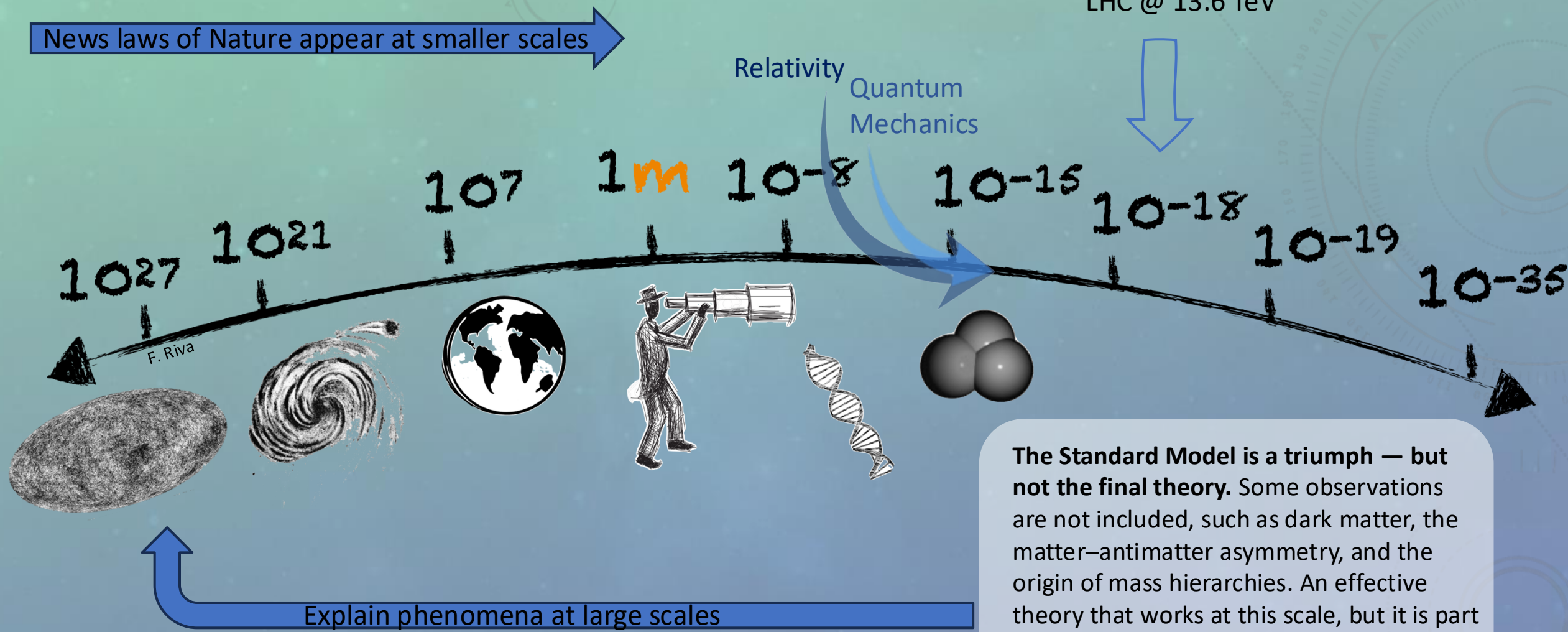


The Standard Model is a triumph — but not the final theory. Some observations are not included, such as dark matter, the matter–antimatter asymmetry, and the origin of mass hierarchies. An effective theory that works at this scale, but it is part of a more fundamental theory of nature.

PARTICLE PHYSICS

News laws of Nature appear at smaller scales

We are here
LHC @ 13.6 TeV



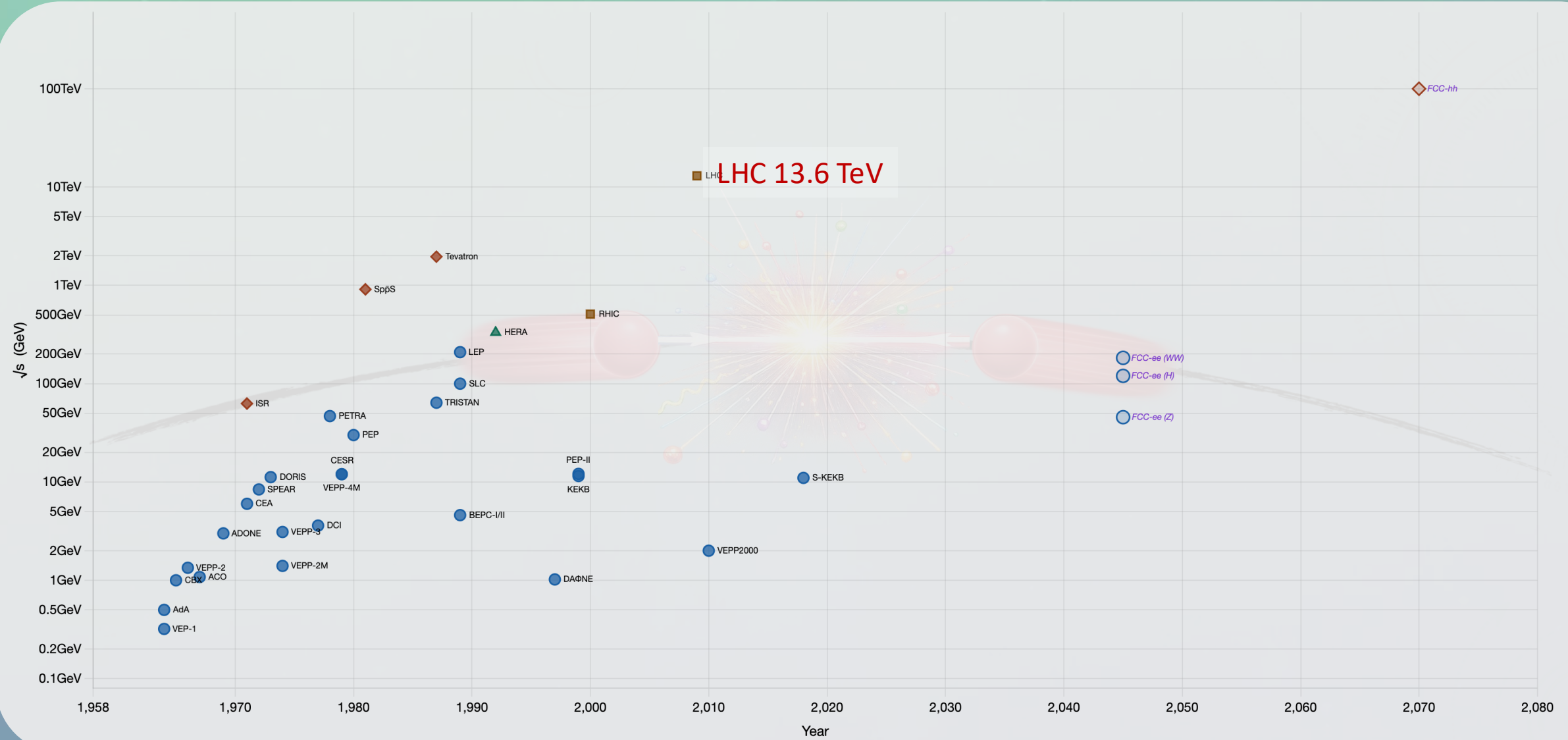
The Standard Model is a triumph — but not the final theory. Some observations are not included, such as dark matter, the matter–antimatter asymmetry, and the origin of mass hierarchies. An effective theory that works at this scale, but it is part of a more fundamental theory of nature.

PARTICLE COLLIDERS



The energy produced is a threshold and a timestamp. It determines which particles can be produced and how close to the Big Bang the collision conditions approach. At 13.6 TeV, we probe energy densities absent from the universe since its first microseconds.

PARTICLE COLLIDERS



Future Circular Collider (ee, hh) (future)
91km

Large Electron Positron Collider
Large Hadron Collider (present)
27km

Super Proton–Antiproton Synchrotron Collider (present)
6.9km

Tevatron Proton–Antiproton Collider (past)
6.3km

AdA (past)
1.6m

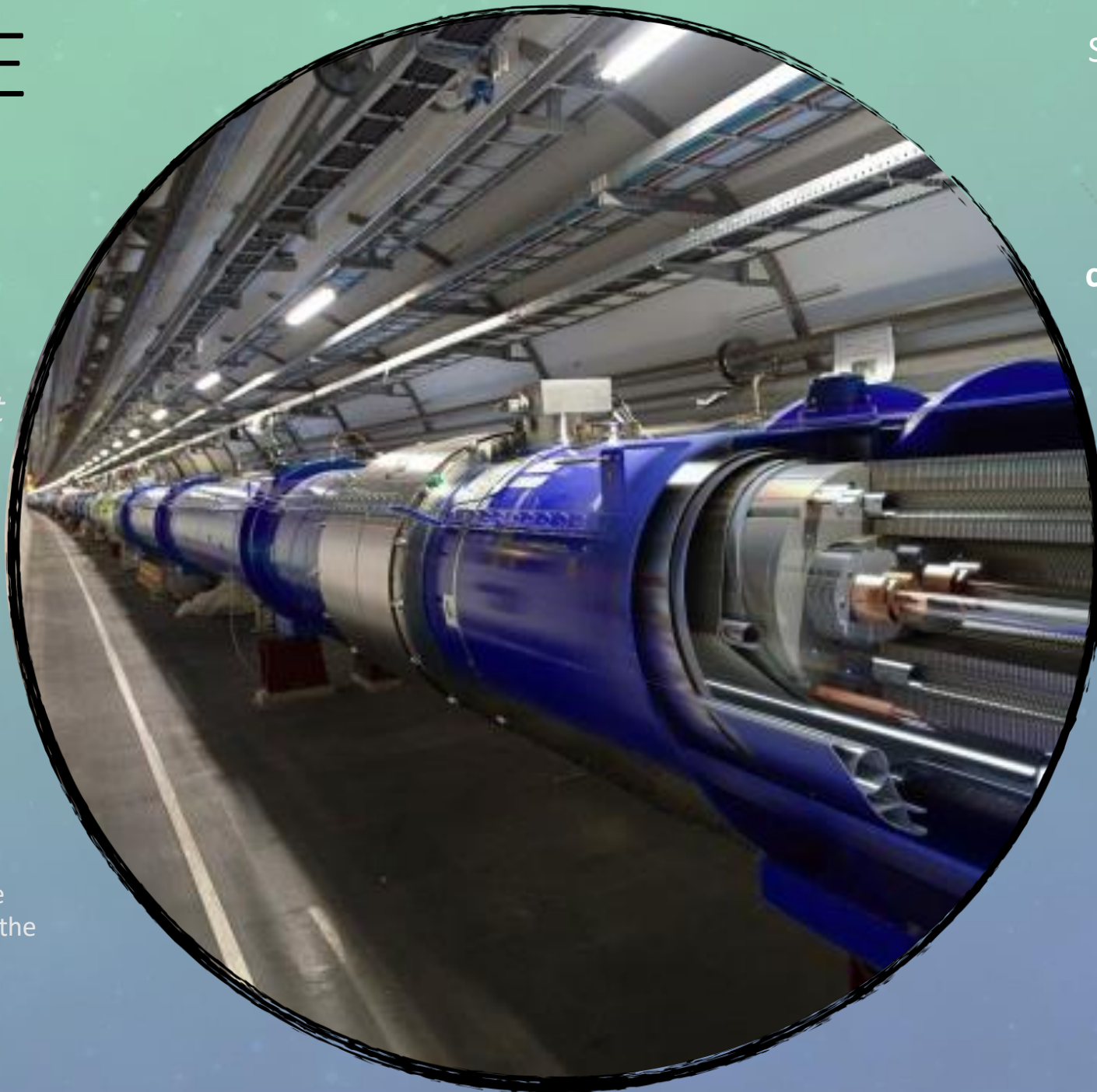
Superconducting Super
Collider (cancelled)
87.1 km

THE LARGE HADRON COLLIDER

World's largest and most powerful particle accelerator

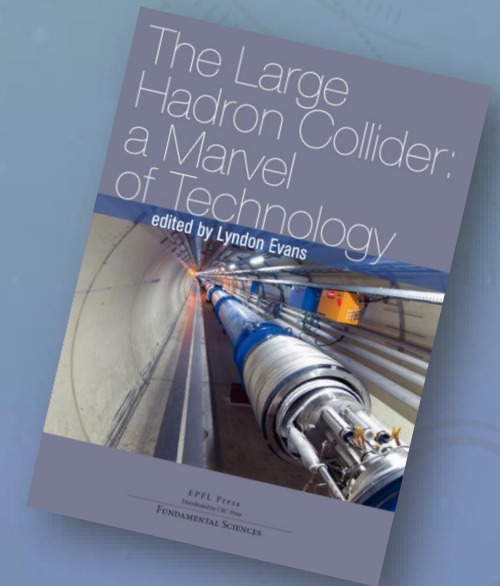
27 Km circumference
100 m underground
~1200 dipoles with 8.4 T

- Protons and ions beams
- Superconducting dipole magnets **bend** the beams
- ~2400 bunches
- Superconducting quadrupole magnets **focus and squeeze** the beams
- Collisions every 25 ns



Separate beam pipes in the same cryomodule
ultra-high vacuum (10^{-10} to 10^{-11} mbar)
Vacuum system at **cryogenic temperatures** (as low as 1.9 K)

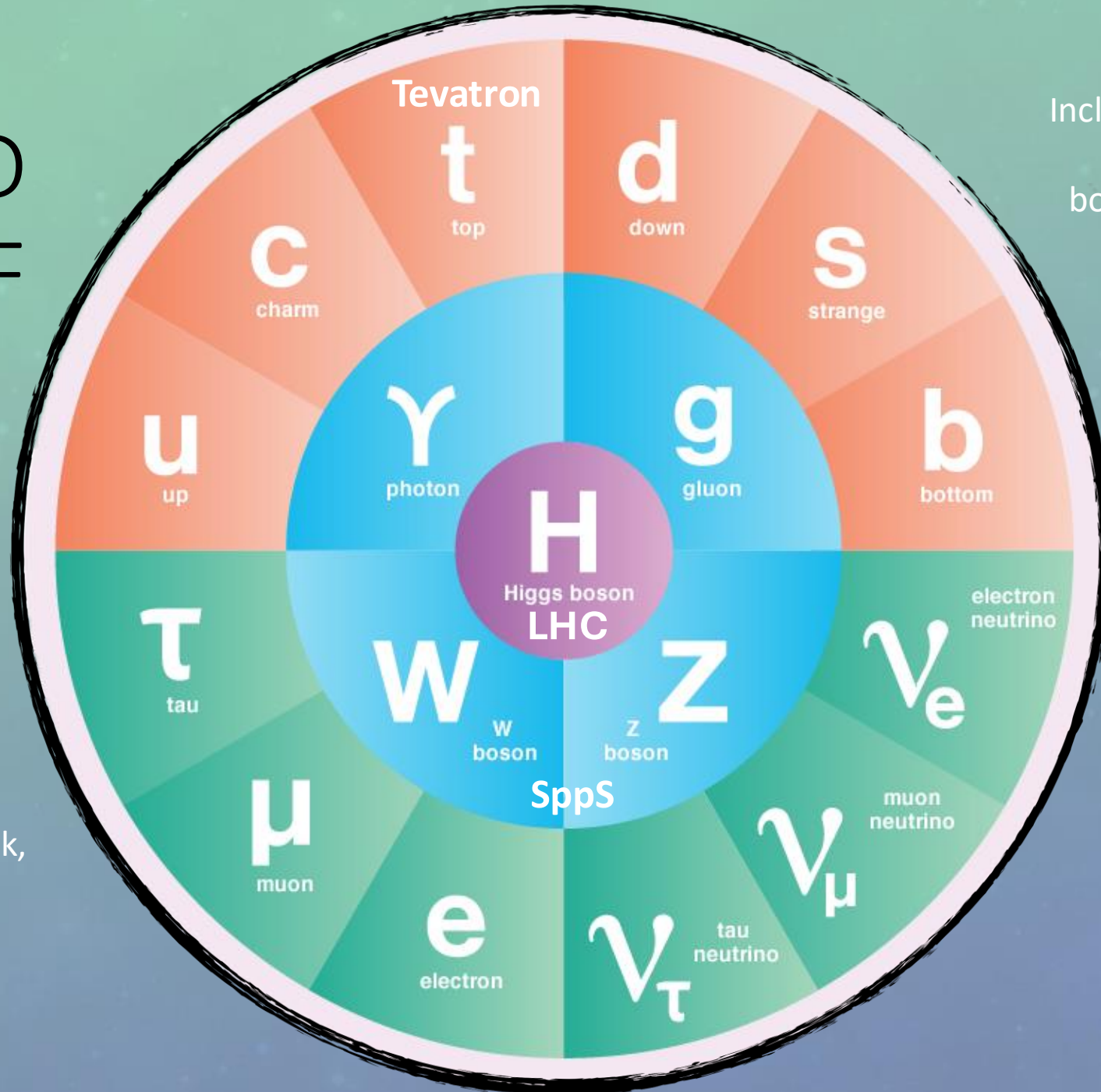
Previous colliders used Nb-Ti conductor at 4.2 K, with dipole fields in the 3.5 to 5 T range



THE STANDARD MODEL OF PARTICLE PHYSICS

Contains the elementary particles that make up all visible matter (5% of the universe)

Describes the strong, weak, and electromagnetic fundamental forces (not gravity)



Includes the Higgs mechanism, giving mass to the gauge bosons and fermions (but not neutrinos)

Tested experimentally with extraordinary precision

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\psi}D\psi + h.c. + \bar{\psi}_i y_{ij} \psi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

“a triumph of reductionist philosophy applied to some of the most fundamental questions in physics.”

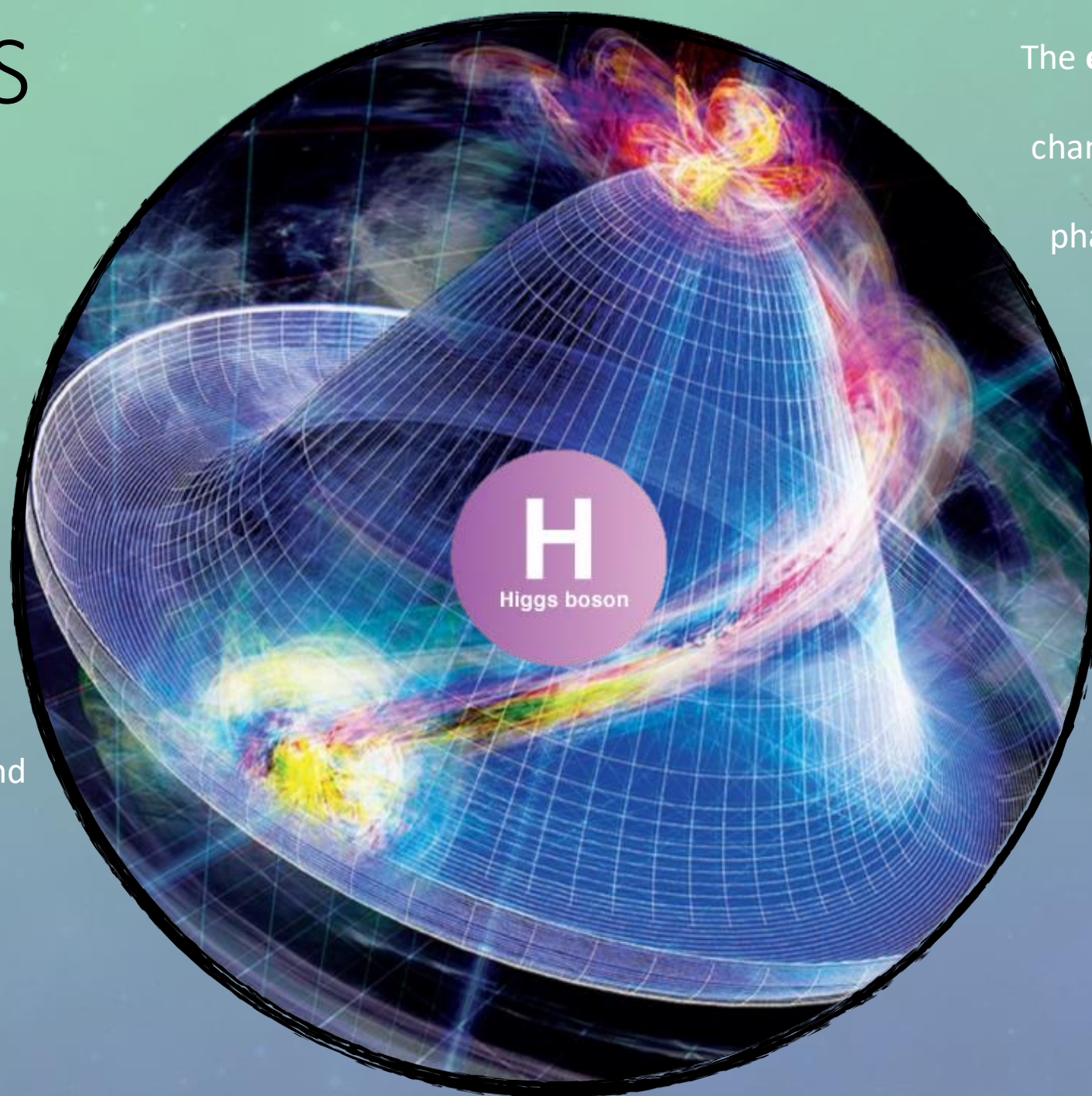
THE HIGGS BOSON

The Higgs boson is the only **fundamental scalar** particle observed so far

Is the Higgs composite? Are there several Higgs bosons?

In the Higgs mechanism, particle masses are proportional to the ground state of the Higgs field

Why is the Higgs mass ~17 orders of magnitude below the Planck scale?



The **electroweak phase transition** describes how the Higgs field changed from a symmetric phase (hot Universe) to the broken phase, where particles get mass (cold Universe).

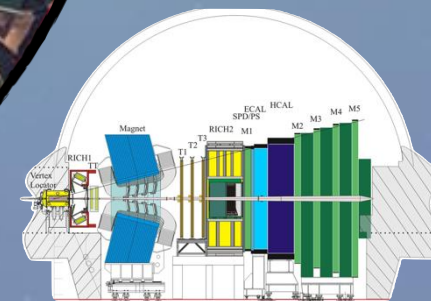
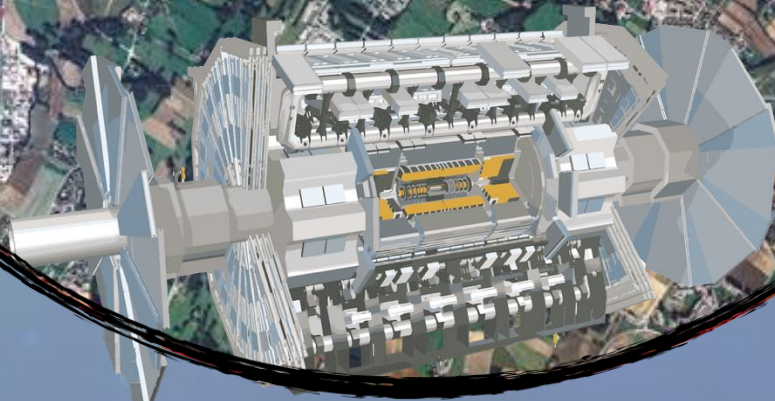
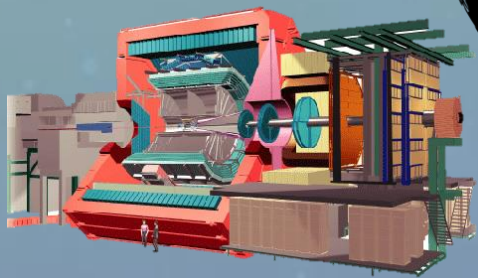
What is the order of the EW phase transition?

What is the role of the Higgs in the EWSB?

The Universe is at the edge between stability and instability

What is the role of the Higgs in the evolution of the cosmos and stability of the Universe?

THE LHC EXPERIMENTS



THE CMS EXPERIMENT



BIRTH CERTIFICATE OF AN EXTRAORDINARY DETECTOR

NAME: **COMPACT MUON SOLENOID (CMS)**

WEIGHT: 14,000 tonnes — heavier than the Eiffel Tower

LENGTH: 21 metres

DIAMETER: 15 metres

SOLENOID: 12 m long, 6 m inner diameter; the largest superconducting solenoid ever built, generating a 3.8 Tesla magnetic field

SILICON TRACKER: The largest silicon tracker ever built — 200 m² of silicon measuring particle trajectories with micrometre precision

ELECTROMAGNETIC CALORIMETER (ECAL): 75,848 lead tungstate crystals measuring electrons and photons with exceptional precision

HADRON CALORIMETER (HCAL): More than 7,000 tonnes of brass and steel measuring the energy of strongly interacting particles

MUON SYSTEM: Detector chambers spread over a volume comparable to a cathedral, designed to identify muons with exceptional accuracy

NERVOUS SYSTEM (CHANNELS): ~140 million individual sensor channels reading out data simultaneously

CIRCULATORY SYSTEM (CABLING): ~250 km of power, signal, and optical cables woven throughout the detector

DATA RATE: ~40 million collisions per second; the trigger system reduces this to ~1,000 events per second worth storing

DATE OF BIRTH: 10 September 2008

BIRTHPLACE: CERN, near Geneva, Switzerland

PARENTS: Thousands of scientists, engineers, technicians, and institutions worldwide

PURPOSE: To explore the fundamental nature of matter, energy, space, and time

EYE COLOUR:
Blue
(The magnetic field lines)



FINGERPRINT:
Event displays from proton collisions



DISTINCTIVE FEATURE:
Built to catch particles that exist for less than a trillionth of a second.





CMS Collaboration

SIGNED BY:
The Global CMS Collaboration

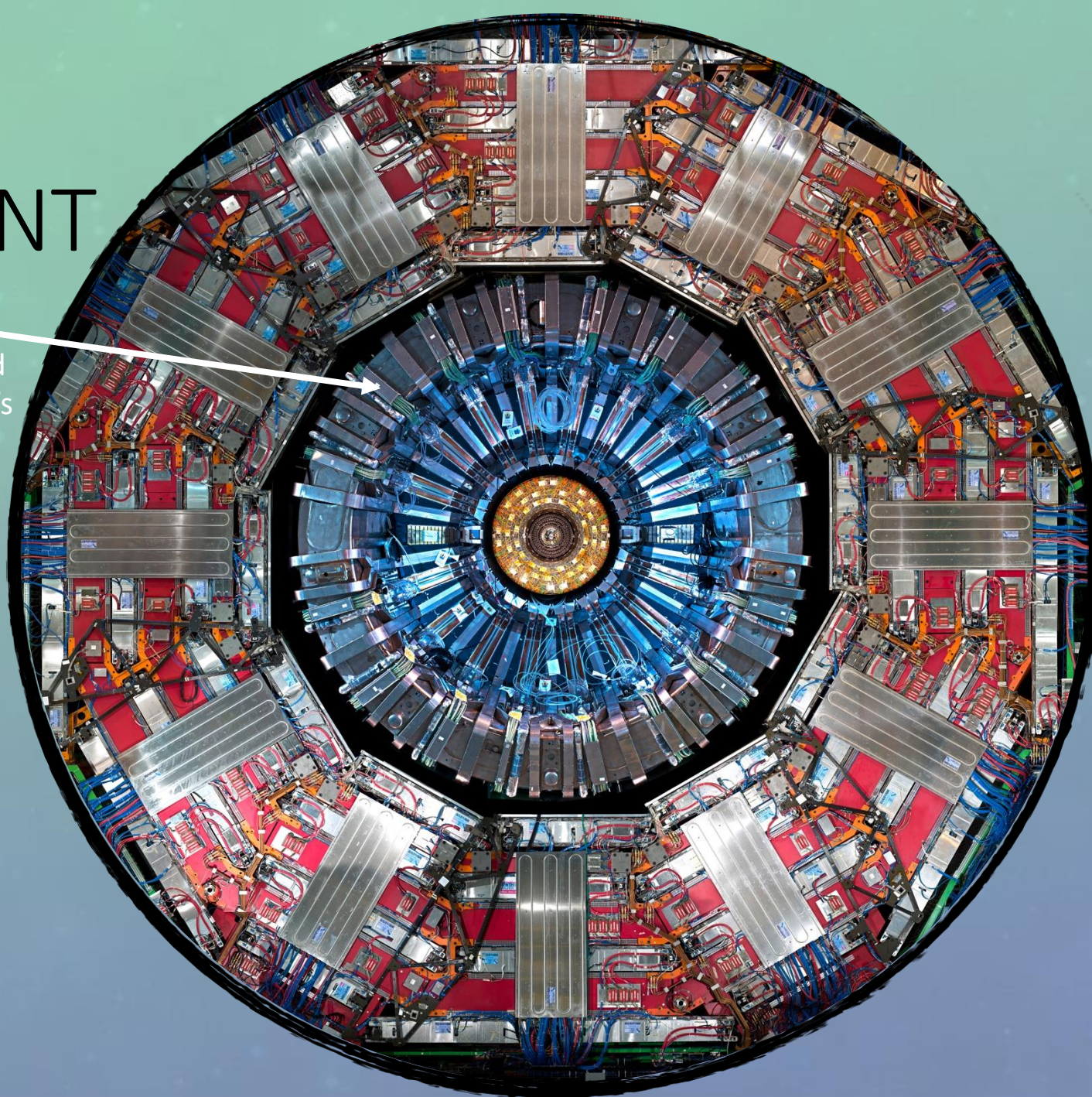
THE CMS EXPERIMENT

Superconducting coil

Concept for the magnetic field as driver of the CMS detector's design

Large bore to accommodate both the tracker and the full calorimetry (η) range

- 1.5 m of iron to saturate the return field, allowing stations of muon chambers to be inserted

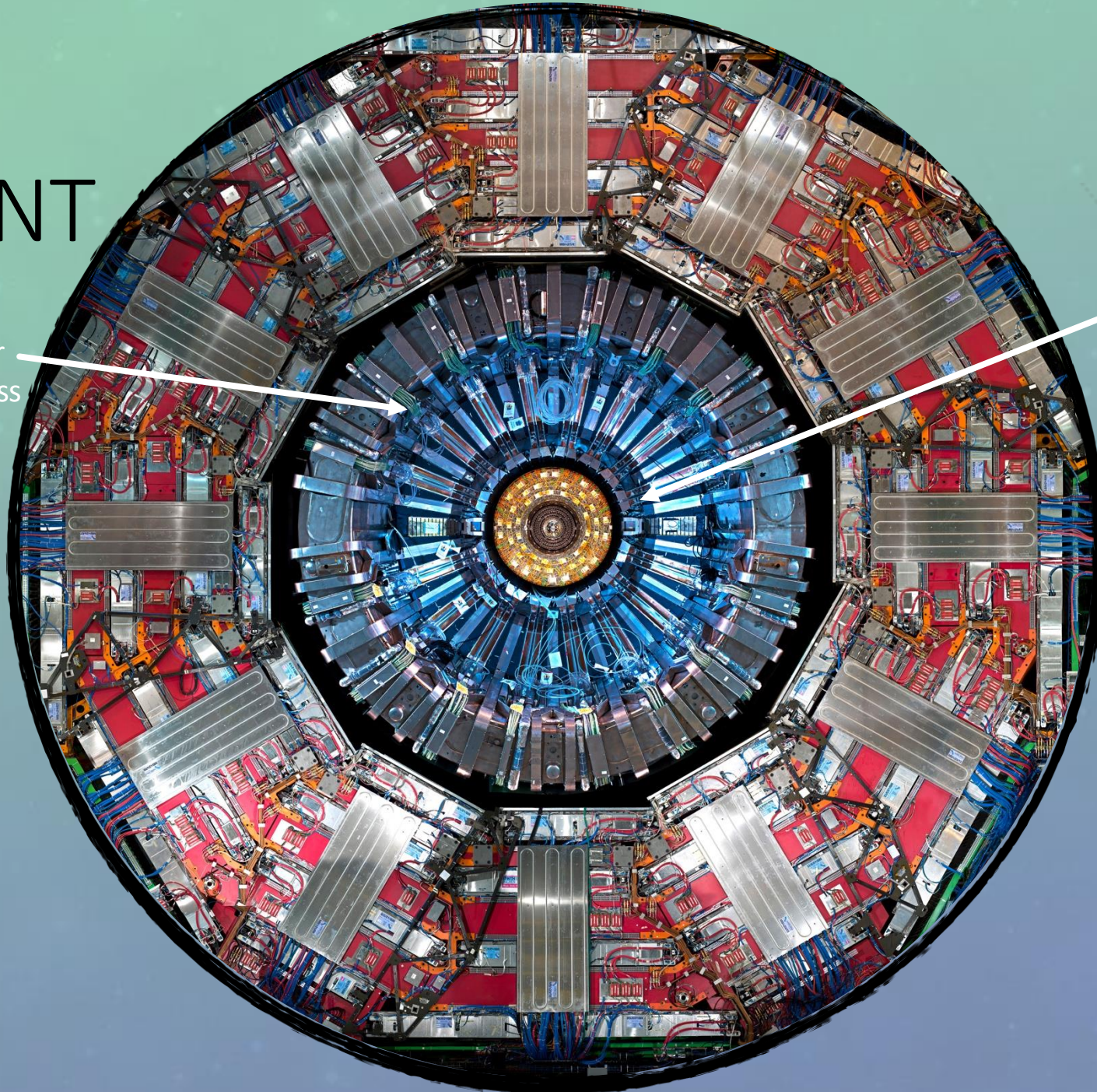


THE CMS EXPERIMENT

Hadronic calorimeter

Hermetic Sampling Calorimeter
More than 7,000 tonnes of brass
and steel

- An active sampler (low Z) to measure shower content
- A dense absorber (high Z) to build-up shower
- Limited energy resolution
- Shower information from longitudinal information



Electromagnetic Calorimeter

Compact, homogenous,
and hermetic crystal
calorimeter

- Detection of scintillation light produced in 75,848 lead tungstate crystals, each grown to sub-millimetre precision
- Excellent energy resolution
- No information on longitudinal shower shape

THE CMS EXPERIMENT

Muon detectors

Early design choice (~1990):
muon chambers with
standalone triggering
capabilities inside the magnet
yoke.

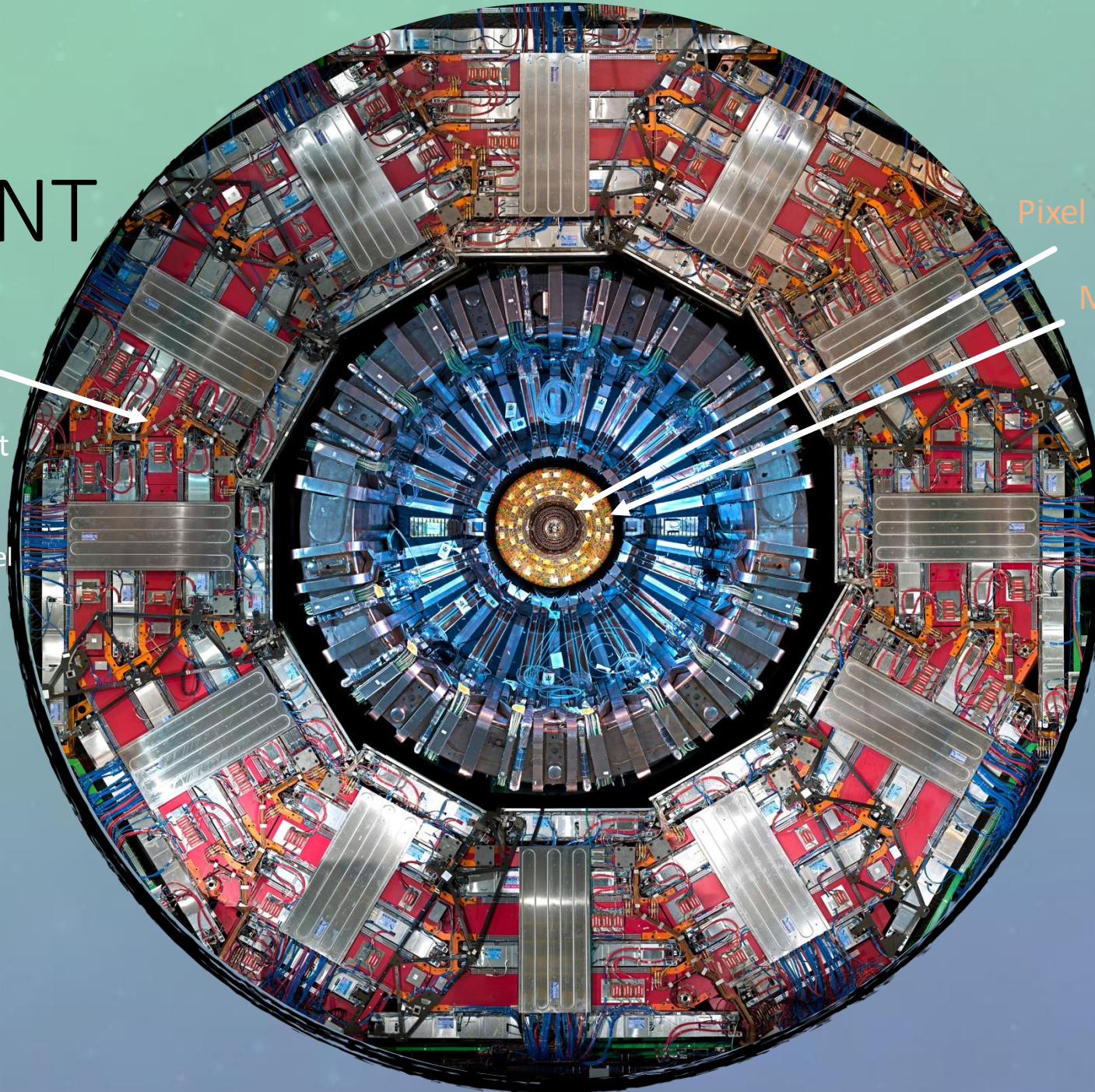
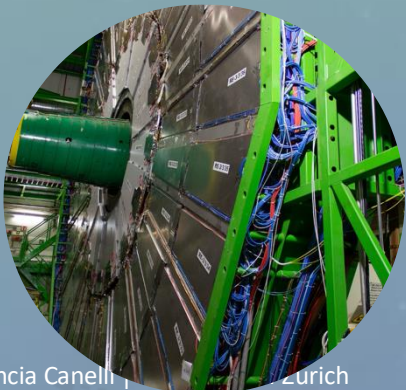
Four detectors:

DT: precision tracking in the barrel

CSC: precision tracking in the
endcaps

RPC: fast triggering throughout
CMS

GEM: high-rate triggering and
tracking in the forward region



Pixel detector

Microstrip tracker

Tracker detector

Early design choice (~1990):
full silicon tracker

- **Pixel detector** over a large surface area for reconstruction of primary and secondary vertices: 124 million pixels: $100 \times 150 \mu\text{m}^2$
- **Microstrip tracker** relies on relatively few high-precision points: 10 million microstrips: $80 \mu\text{m} - 200 \mu\text{m}$ pitch and ~ 13 precise position measurements ($15 \mu\text{m}$) per track up to $\eta = 2.5$
- *High B field reducing occupancy at larger radii*
- Robust and efficient pattern recognition

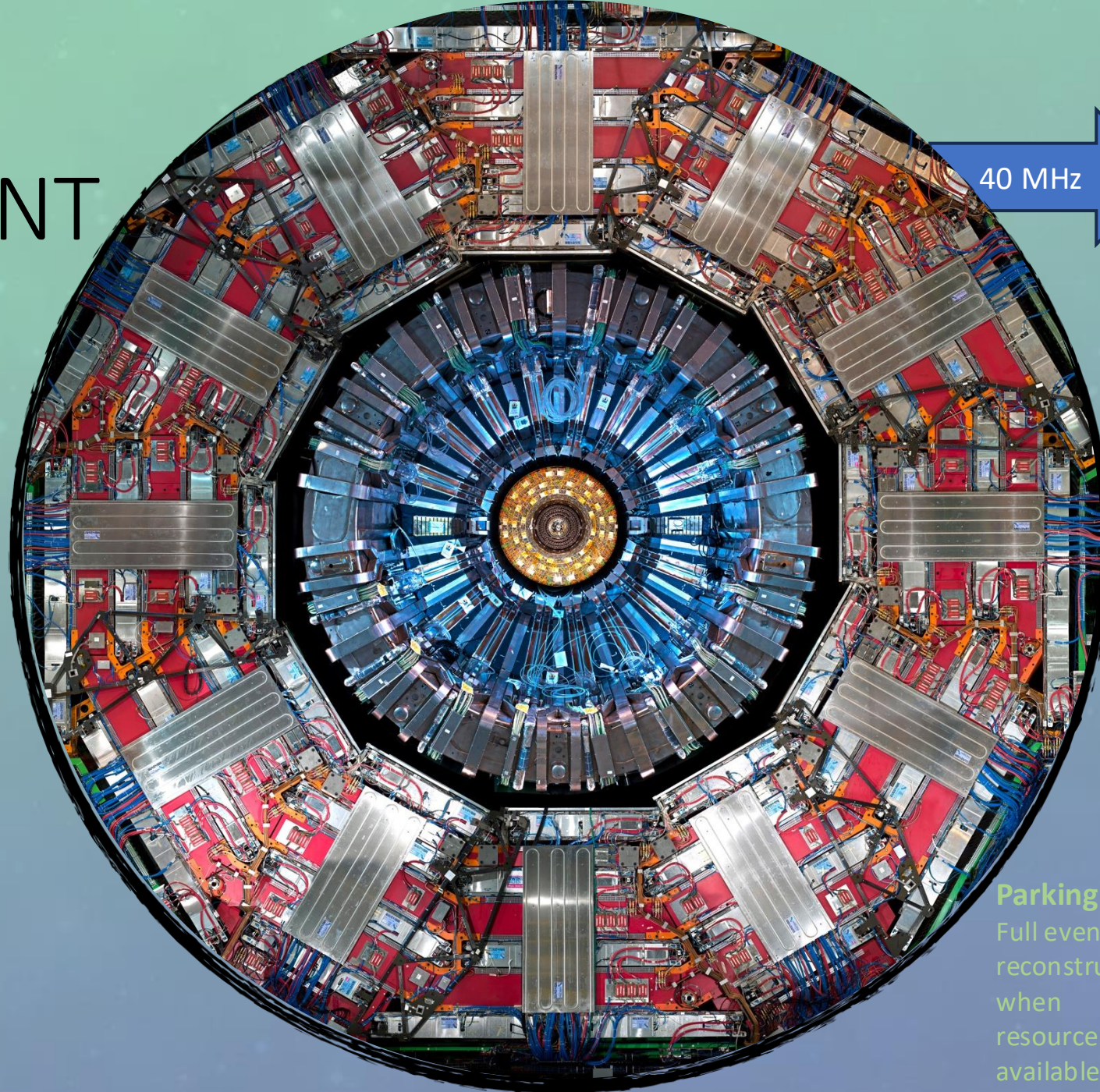


THE CMS EXPERIMENT

~ 50 TB/s \Rightarrow can't write to tape (100MB/s ~ "reasonable rate")

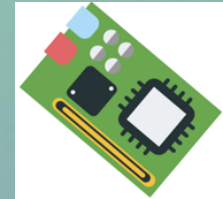
Processes of interest having very small rates - e.g. Higgs $\sim 10^{-2}$ Hz vs inelastic collision 108 Hz at $\mathcal{L} = 2 \times 10^{33} \text{ cm}^{-2} \text{ s}^{-1}$

Varying accelerator conditions, varying detector conditions



40 MHz

Trigger system



Level 1 Trigger

100 MHz



High-Level Trigger

Scouting
Reduced
data format

1 kHz
1 MB/event

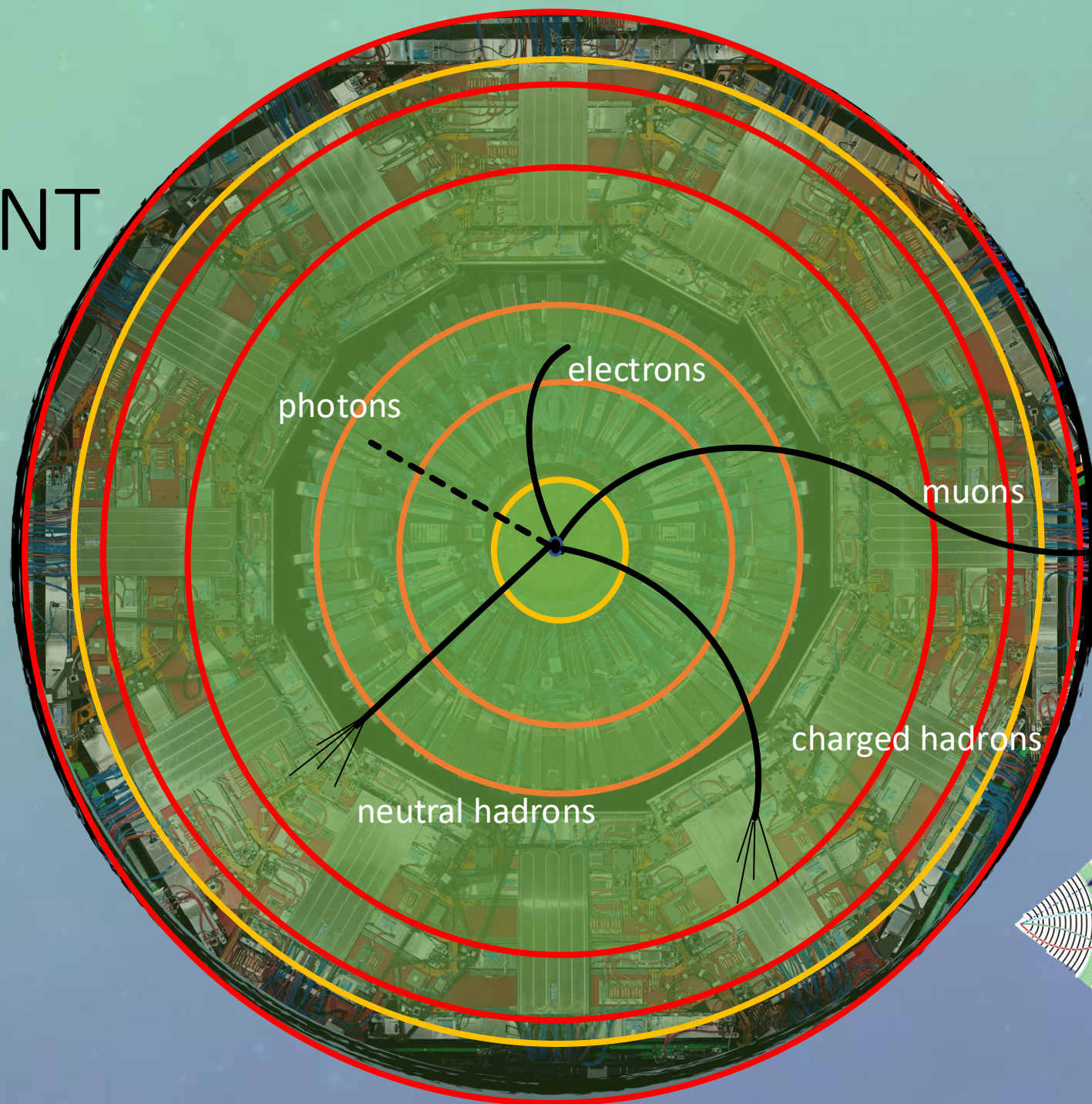


Storage

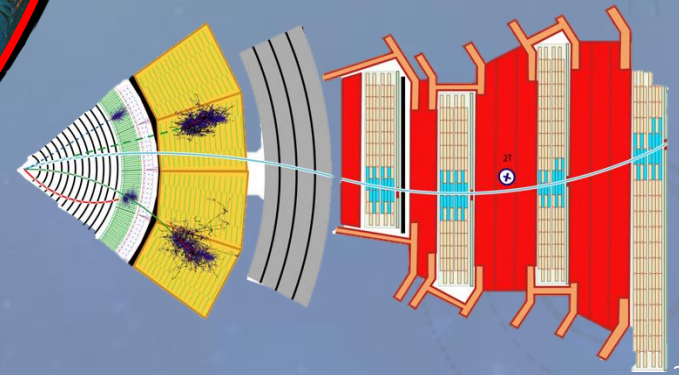
Parking
Full event
reconstructed
when
resources are
available

Standard
Full event
reconstructed
at Tier0 after
48 hours

THE CMS EXPERIMENT

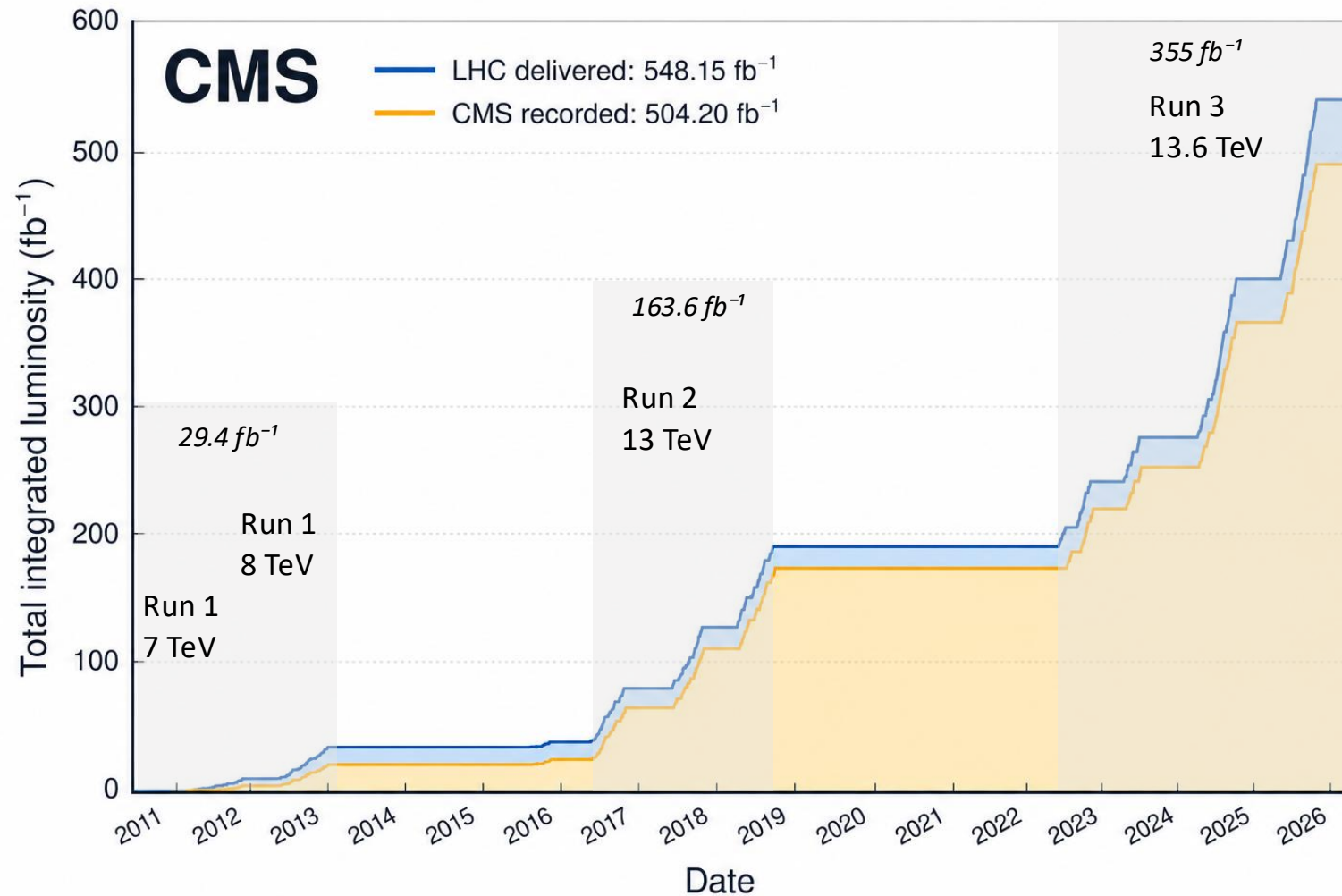


Physics output relies on a deep understanding of the detector and reconstruction performance, including calibration, triggering, and object identification



THE LHC AND CMS

31.6 M Higgs bosons
982 M top quarks
114 B W bosons



500 (fb⁻¹)

(0.5 ab⁻¹)

Last data taking
for LHC
scheduled on
June 11, 2026

CROSS SECTIONS

Perform precision measurements by increasing statistics and reducing uncertainties with auxiliary measurements.

Target rare processes and challenging signatures by pushing experimental sensitivity.

Design measurements to constrain theory and modeling systematics, improving future precision.

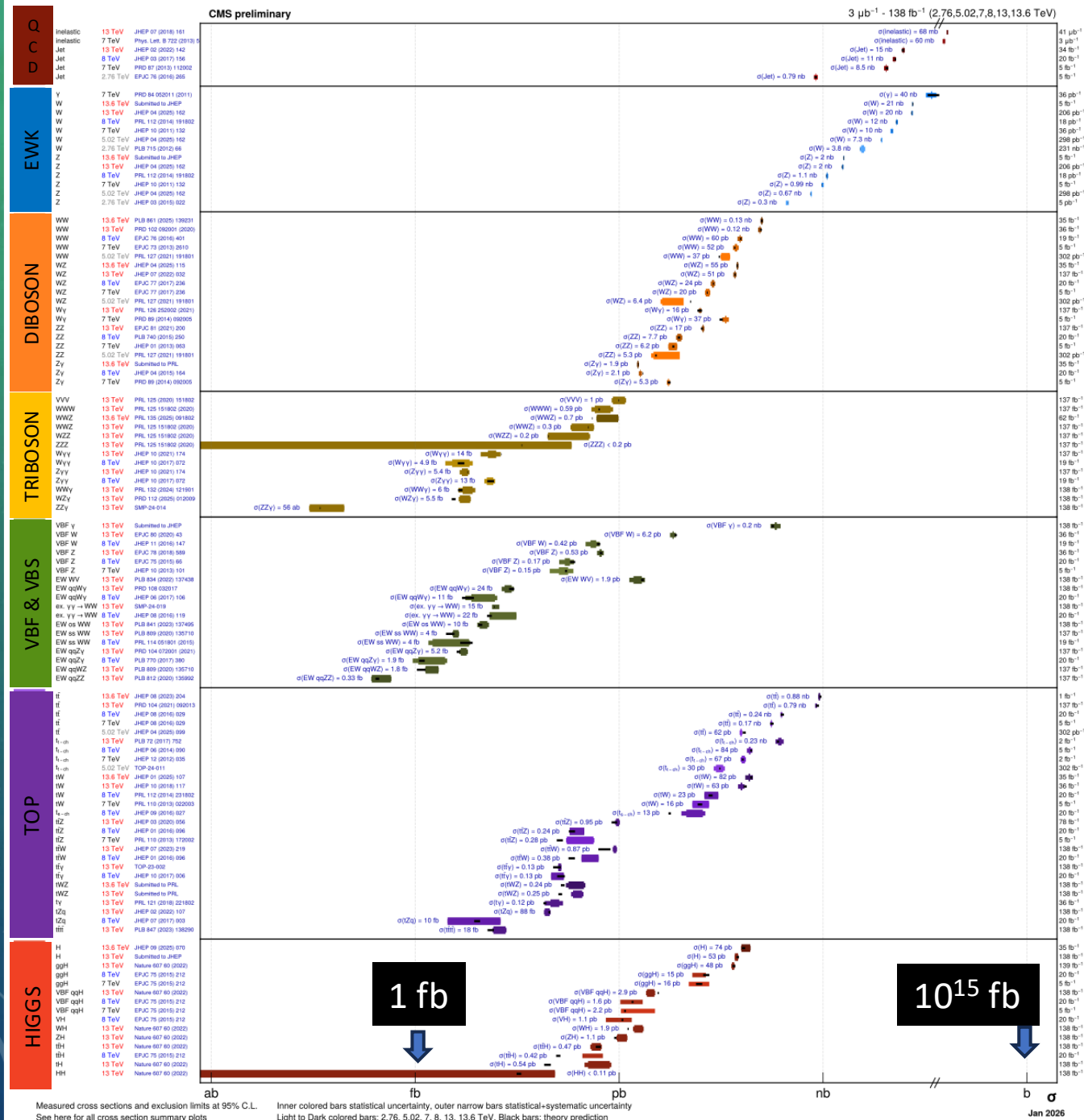
At 13.6 TeV, recent efforts focus on re-establishing the SM.

Building on the experience from Runs 1 and 2, analyses extend and refine methods.

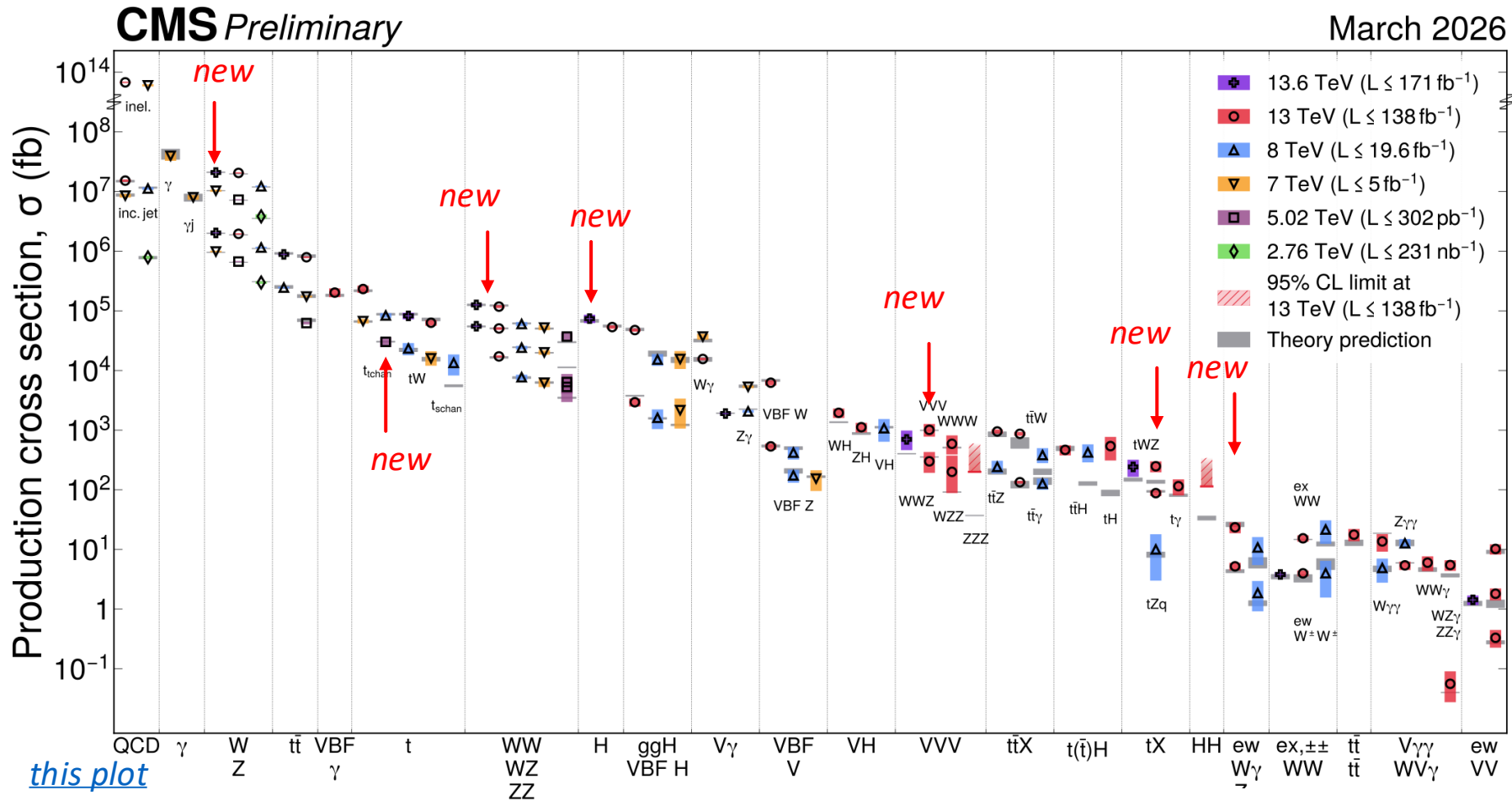
..... Bands: experimental result

---- Black lines: theoretical prediction

this plot includes access to each entry



CROSS SECTIONS

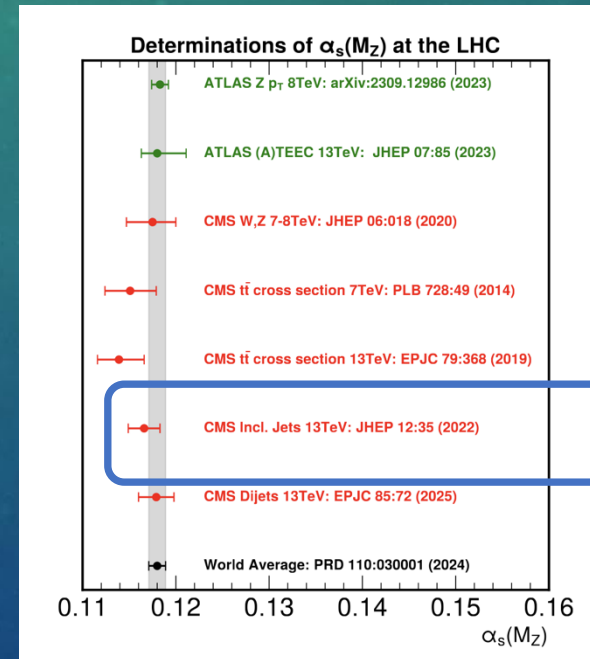
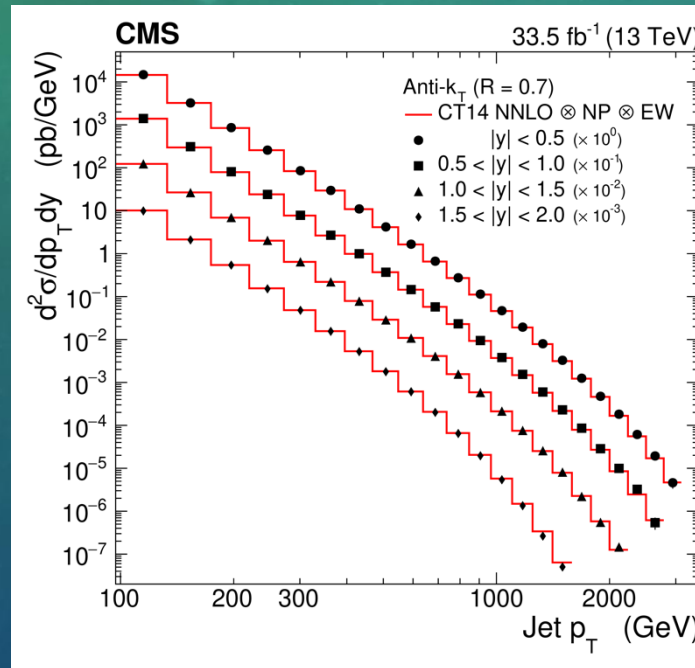
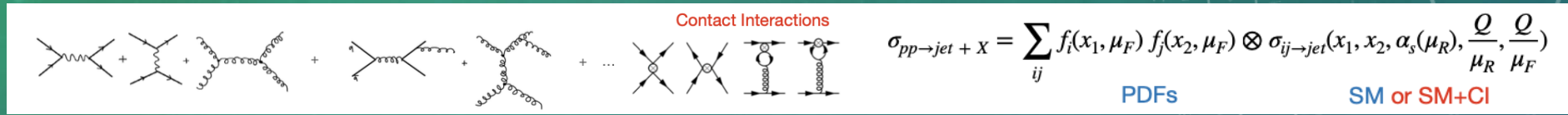


10¹¹ (pb)

10⁻³ (pb)

Jet CROSS SECTIONS

Jet production in pp collisions sensitive to parton distribution functions (PDFs), α_s , new physics

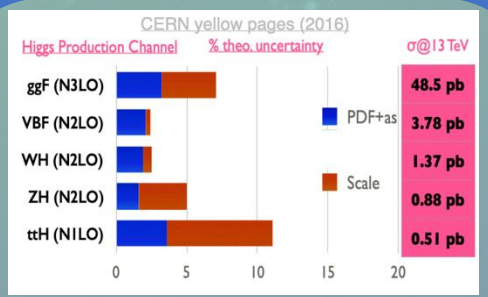


Simultaneous fit of PDF and at NNLO and constraints on contact interactions (CI)

$\alpha_s(m_Z) = 0.1166 \pm 0.0017$

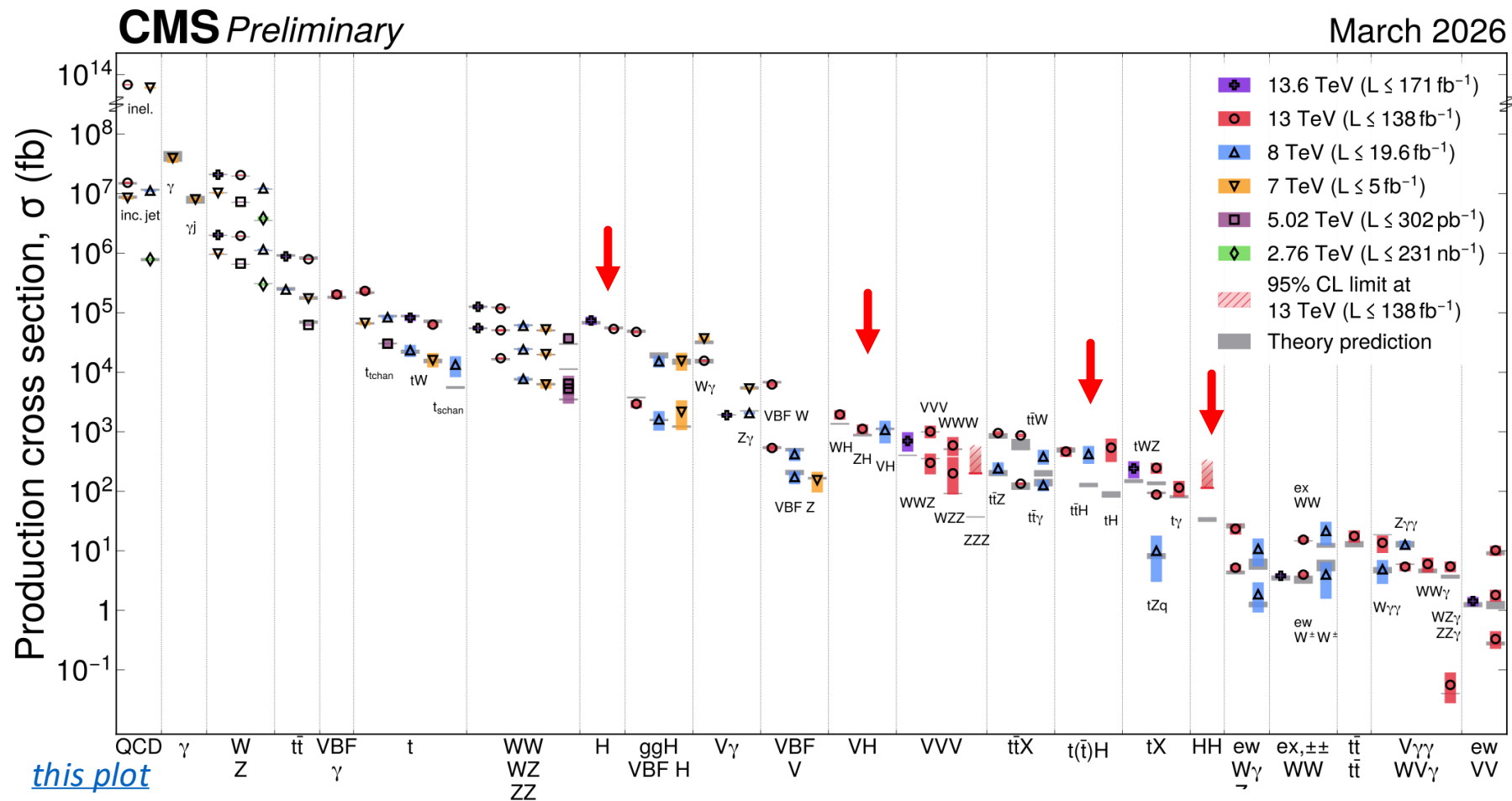
Precise PDF are essential: they set the theoretical floor for BSM sensitivity and determine the reach of direct searches for new heavy particles.

Reduction in $\delta\alpha_s$ uncertainty directly propagates into cross-section predictions — limiting factor for Higgs coupling measurements at HL-LHC precision targets



Higgs CROSS SECTIONS

Many production modes for the Higgs boson, spanning a few orders of magnitude



Physics Report 1115 (2025) 3

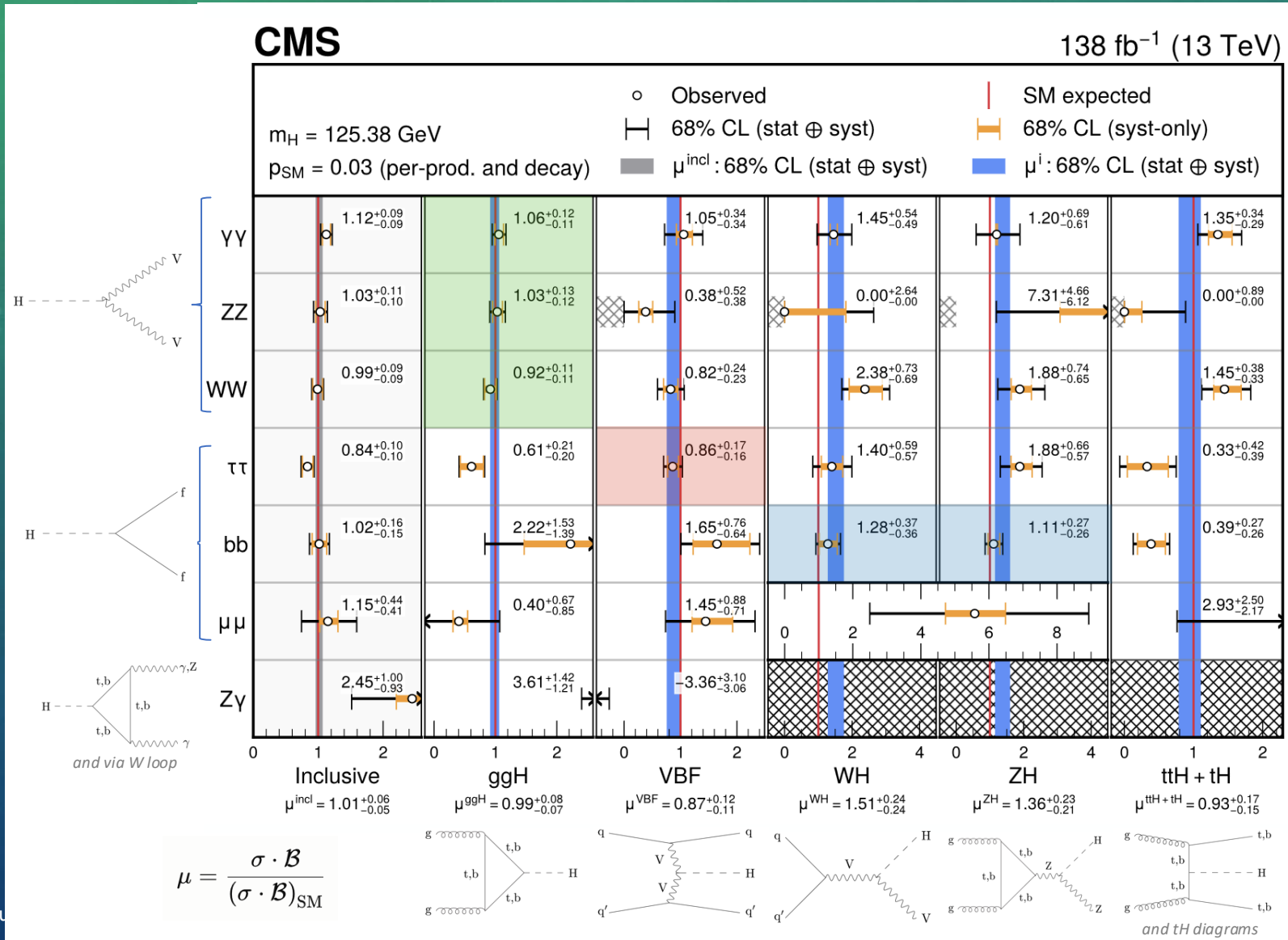
Higgs CROSS SECTIONS

Ultimate precision at 13 TeV: combination of 16 CMS published analyses (all major decay and production modes)

High-resolution channels

Larger BR but more challenging final states

Rare decay modes



Up to O(100) cross sections measured simultaneously in ~1k channels

5% precision, theoretical component leading the uncertainty.

Higgs CROSS SECTIONS and properties

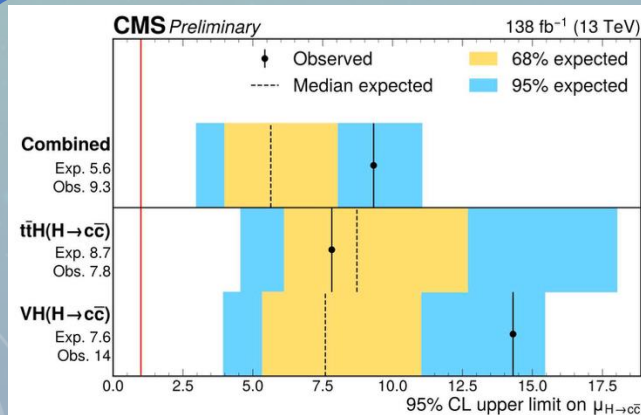
Ultimate precision at 13 TeV: combination of 16 CMS published analyses (all major decay and production modes)

Wide array of interpretations and constraints on BSM Higgs decays, the Higgs width, and SMEFT operators.

Probing the Higgs couplings to particles: 3 orders of magnitude in particle masses

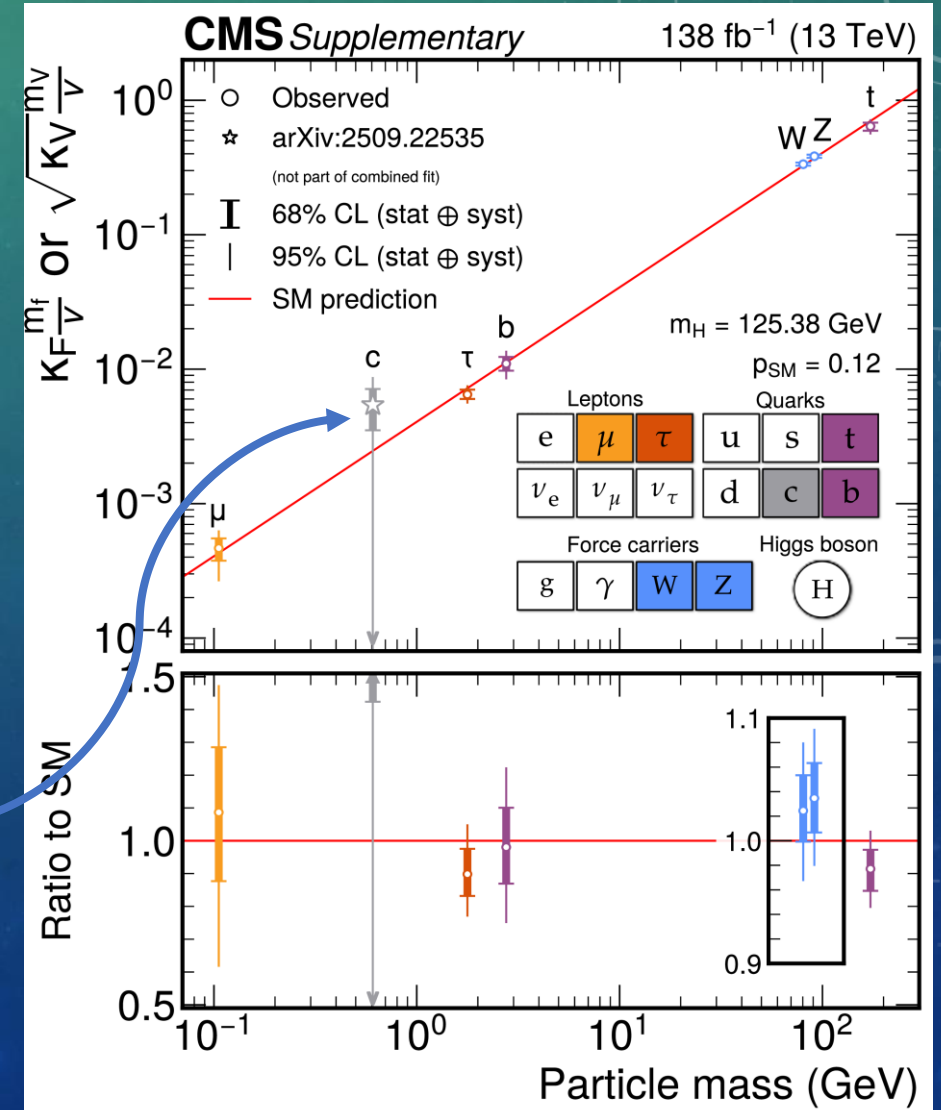
Higgs couplings to vector bosons and third-generation fermions are tested at the few-percent level.

$$\kappa_i = \frac{g_{HXX}}{g_{HXX}^{SM}} \quad g_{HXX} \text{ is the coupling of the Higgs to particle } X$$



$|\kappa_c| < 3.5$ at 95% CL
 $\mu(ttH, H \rightarrow c\bar{c}) = -1.6 \pm 4.5$
 (stat-dominated)

Opens possibility of $\mu(ttH+VH, H \rightarrow c\bar{c}) < O(1)$ with HL-LHC.

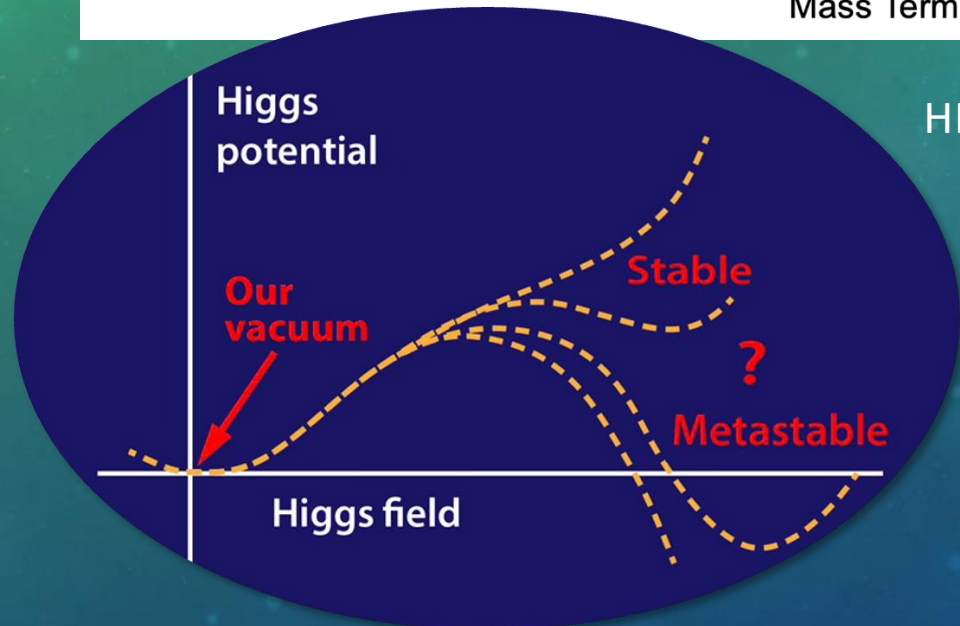


HH CROSS SECTIONS *and properties*

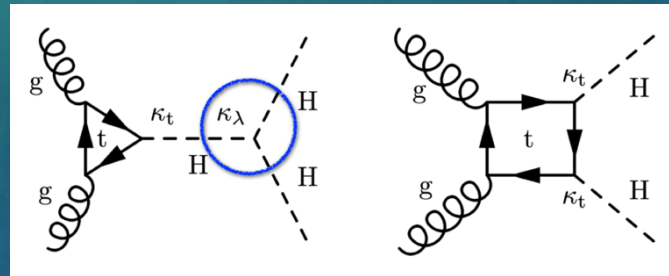
Higgs potential — probing the shape λ_{HHH} fixes the curvature at the minimum \rightarrow first handle on whether EWSB is really SM-like

The SM prediction of V :
(expansion at the minimum)

$$V(h) = V_0 + \underbrace{\frac{1}{2}m_H^2 h^2}_{\text{Mass Term}} + \underbrace{\lambda_{hhh} v h^3}_{\text{HH production}} + \underbrace{\frac{1}{4}\lambda_{hhhh} h^4}_{\text{HHH production}}$$

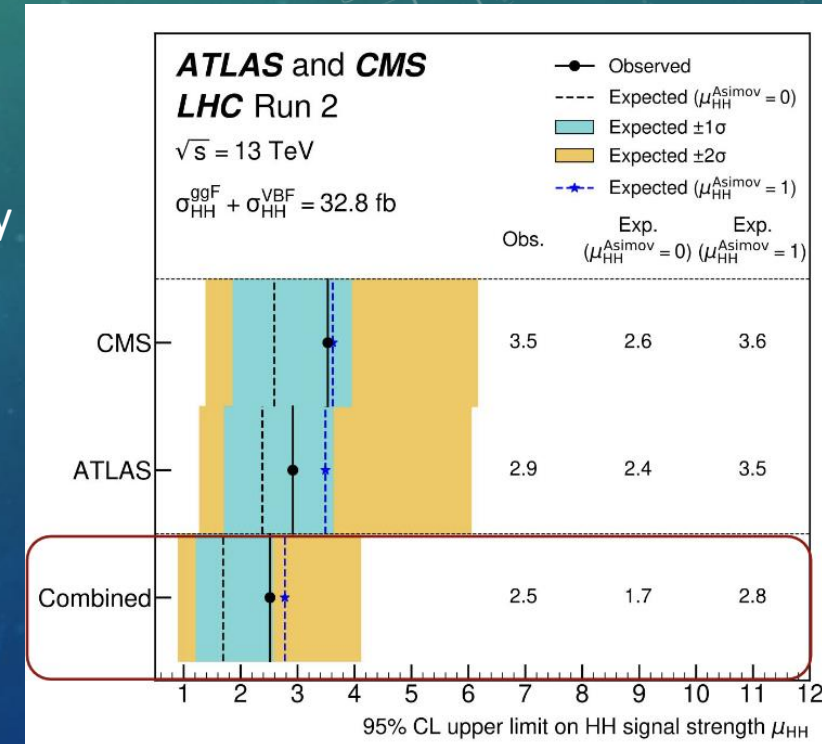


HH production is sensitive to λ_{HHH} directly



HH x1000 smaller rate than single Higgs production

Constraints on λ_{HHH} directly impact:
electroweak phase transition,
extended Higgs sectors,
baryogenesis-motivated models.



Expected: $-1.3 \leq \kappa_\lambda \leq 6.7$
Observed: $-0.71 \leq \kappa_\lambda \leq 6.1$

HH CROSS SECTIONS *new results*

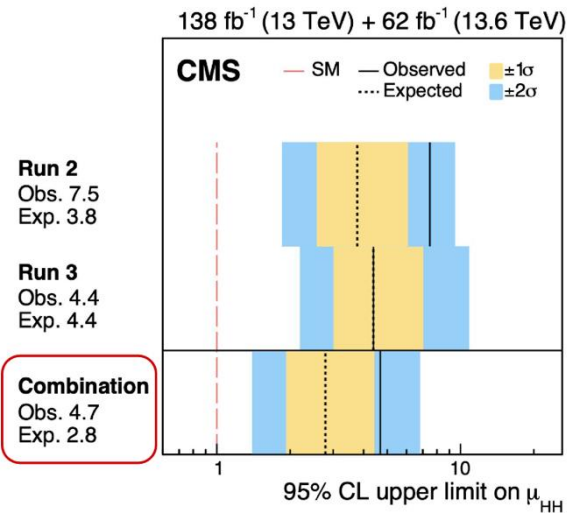
Higgs potential — probing the shape λ_{HHH} fixes the curvature at the minimum \rightarrow first handle on whether EWSB is really SM-like

Multi-channel strategy: channels: $b\bar{b}\gamma\gamma$, $b\bar{b}\tau^+\tau^-$, $b\bar{b}WW^*$, $b\bar{b}b\bar{b}$, $b\bar{b}\ell\ell$ — combined power

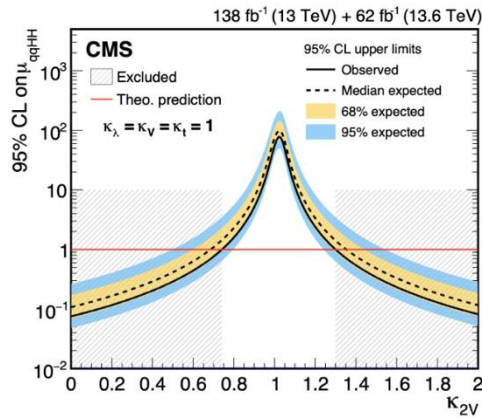
Analysis methods: ML-based signal extraction, improved b- and γ -tagging

4b candidate events now resolved with new flavour-tagging techniques

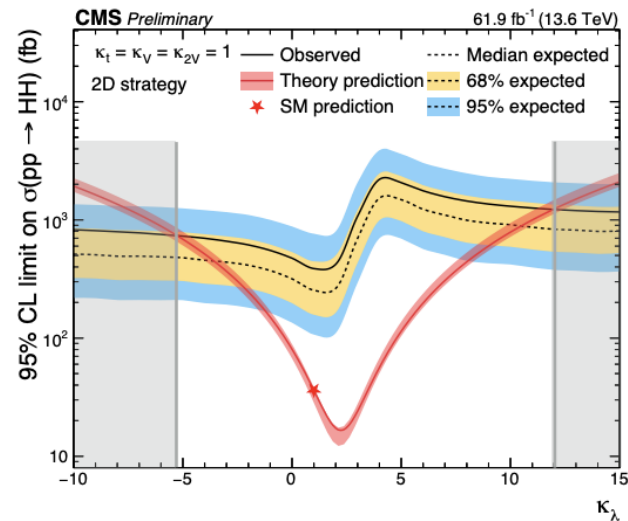
HH \rightarrow bbbb



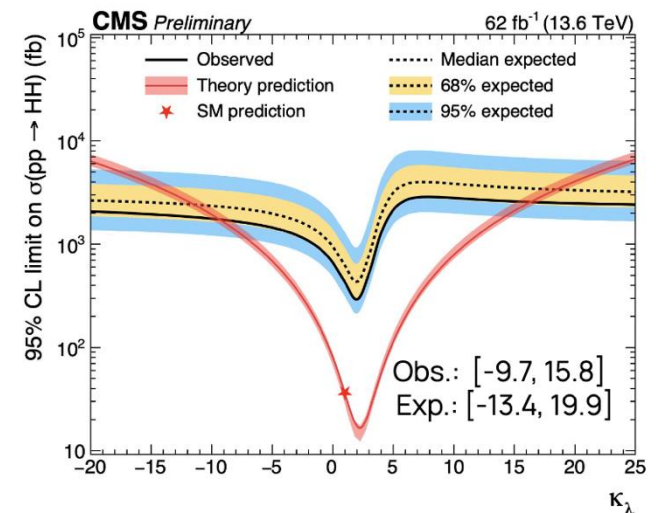
Observed: $0.74 < \kappa_{2V} < 1.30$
Expected: $0.69 < \kappa_{2V} < 1.35$



HH \rightarrow bb $\gamma\gamma$

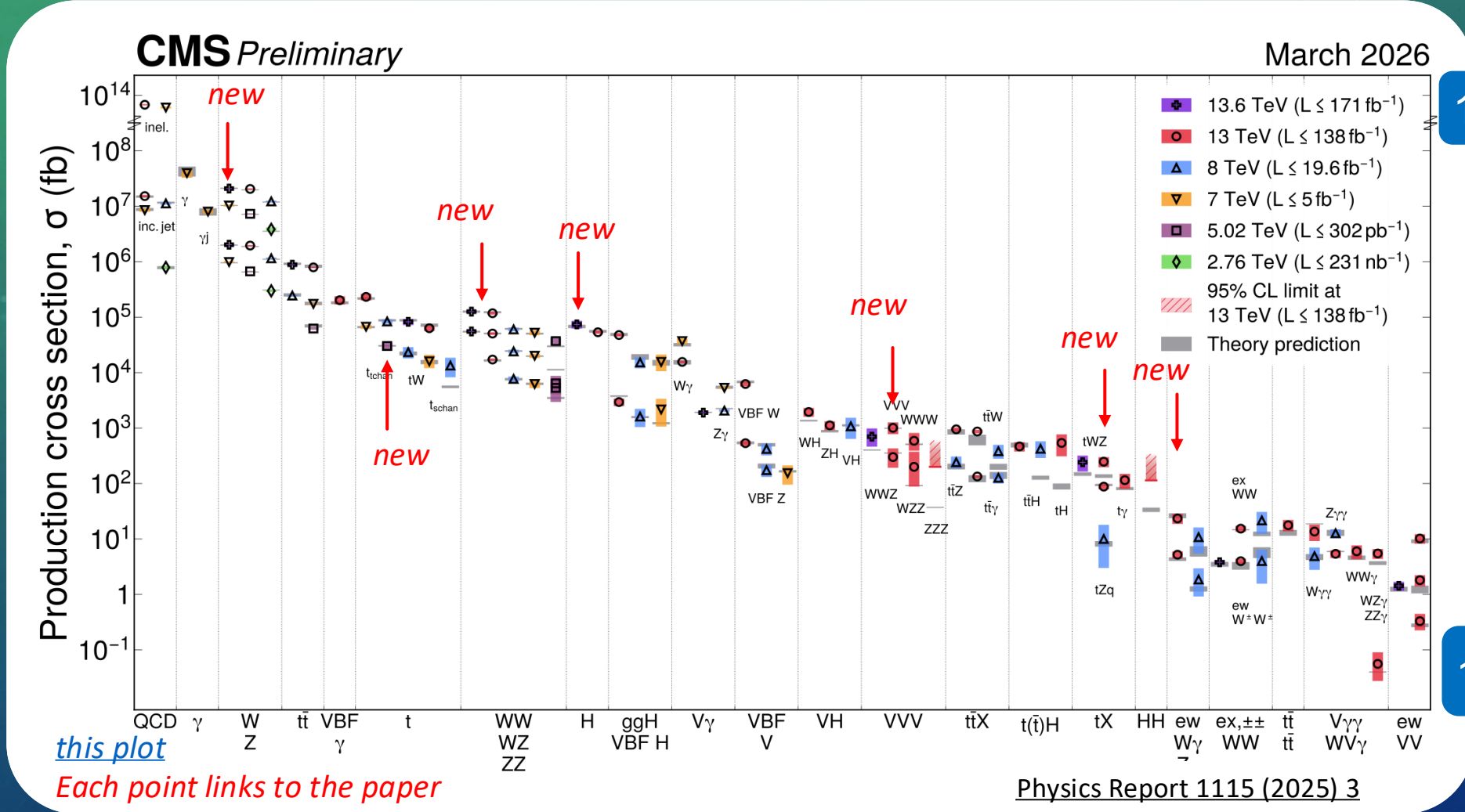


HH \rightarrow bbWW



Each new result is ~better than the ATLAS+CMS Run 2 combined one!

smallest CROSS SECTIONS



[this plot](#)
Each point links to the paper

10¹¹ (pb)

10⁻³ (pb)

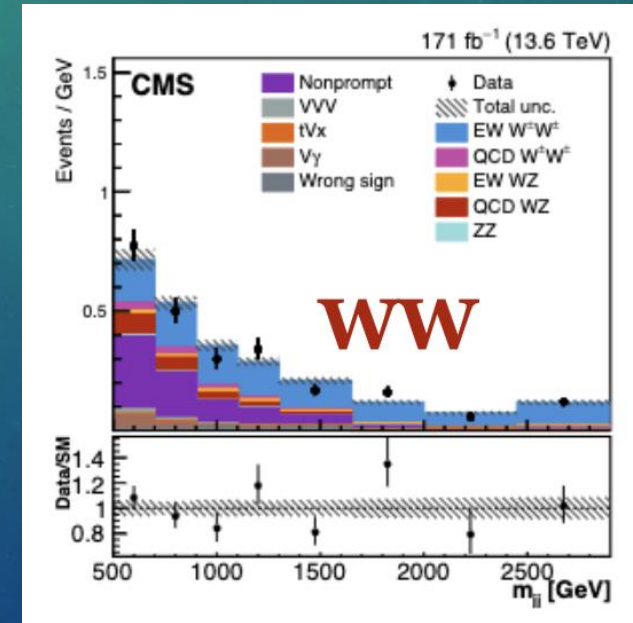
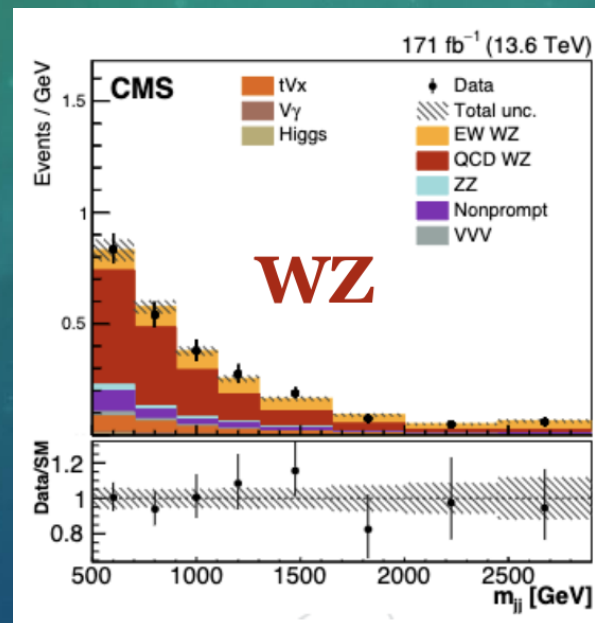
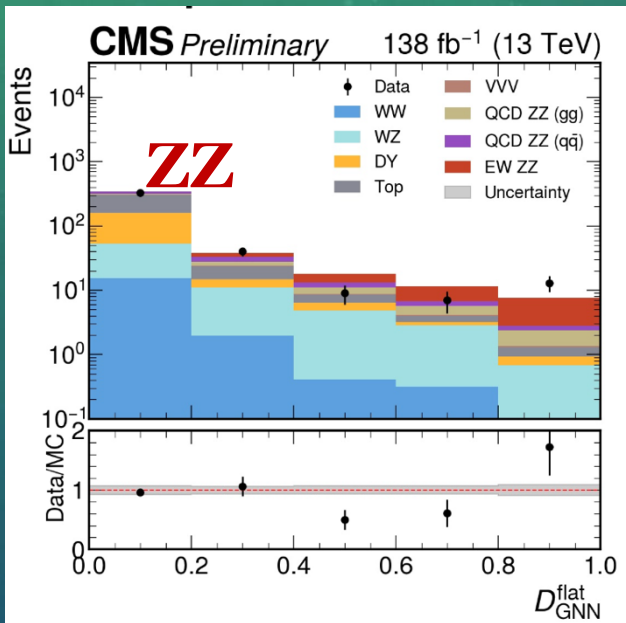
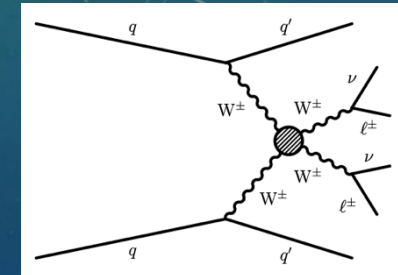
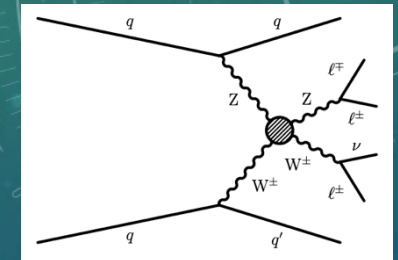
smallest CROSS SECTIONS *new results*

Vector boson scattering — the smallest cross sections we measure Pure electroweak production, forward jets + multileptons → rare, but a direct test of EW gauge structure and Higgs unitarization

Evidence for VBS ZZ (2l2ν);

Observation of VBS ZZ (4l+2l2ν)

VBS: first observations in Run3 (2022-2024)



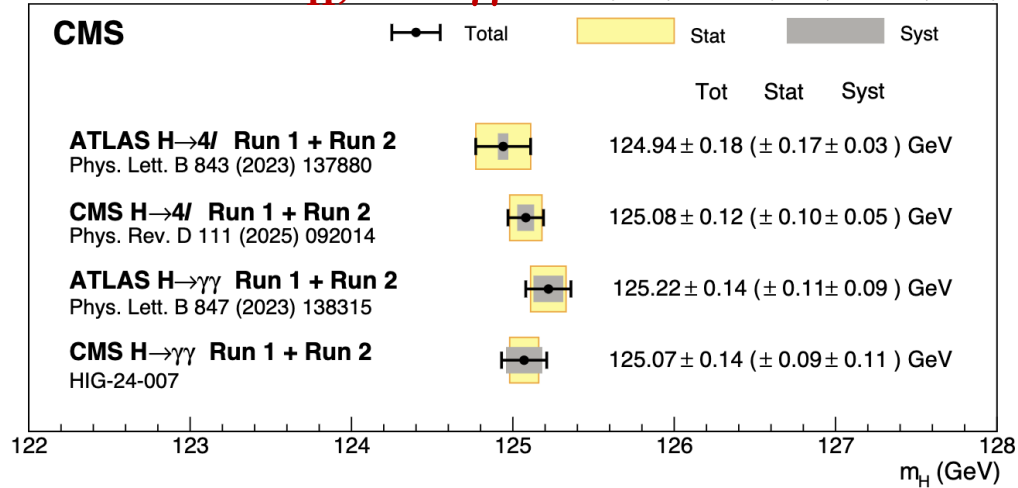
10⁻³ (pb)

Channel	Expected	Observed
4ℓ	3.5σ	4.0σ
2ℓ2ν	2.8σ	3.1σ
4ℓ + 2ℓ2ν	4.5σ	5.0σ

...and first differential distributions!

precision INPUTS TO THE SM

CMS: new m_H , $H \rightarrow \gamma\gamma$ 5.1 fb⁻¹ (7 TeV) + 19.7 fb⁻¹ (8 TeV) + 138 fb⁻¹ (13 TeV)



ATLAS+CMS combination is ongoing, in the meantime.

Chi-square combination

$$m_H = 125.09 \pm 0.07$$

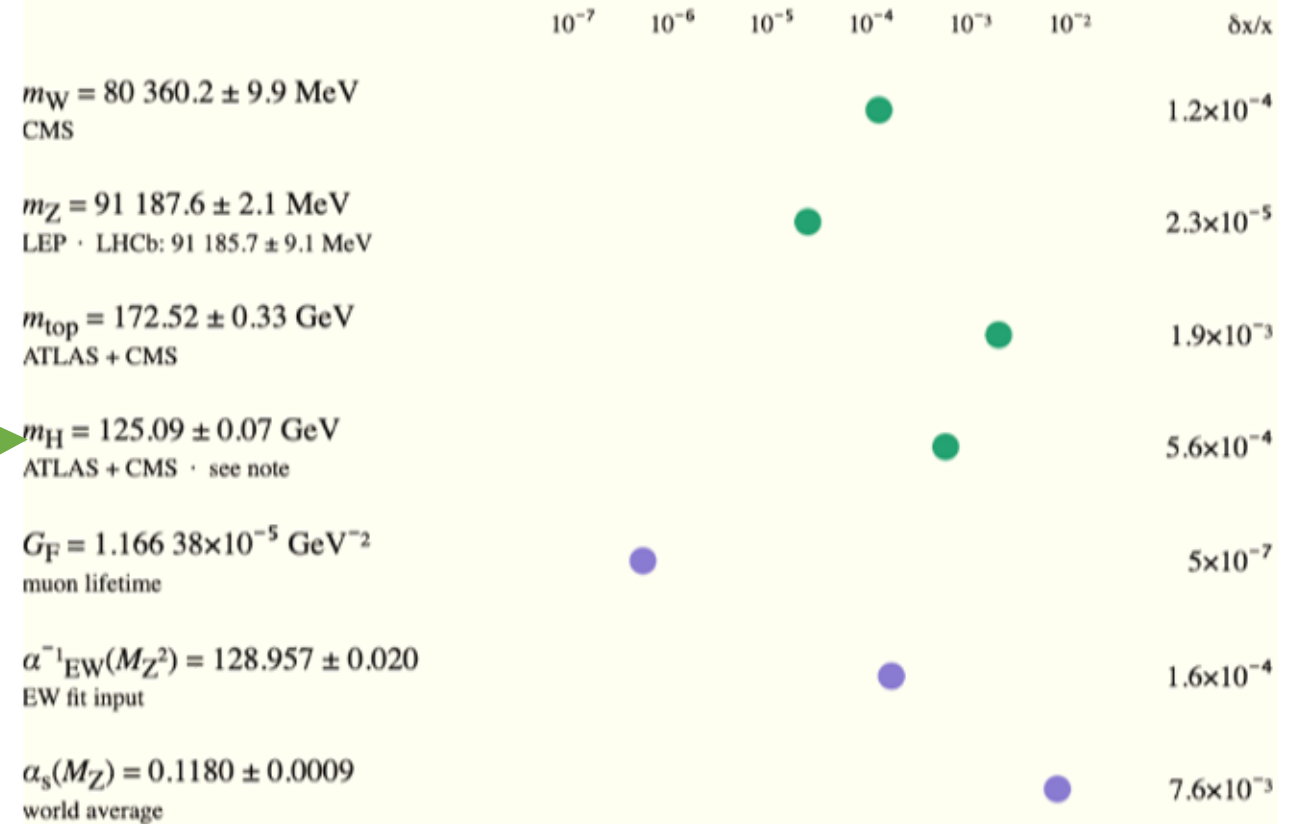
0.6‰ of precision

A. Tarabini, C. Mariotti @ LHCP26

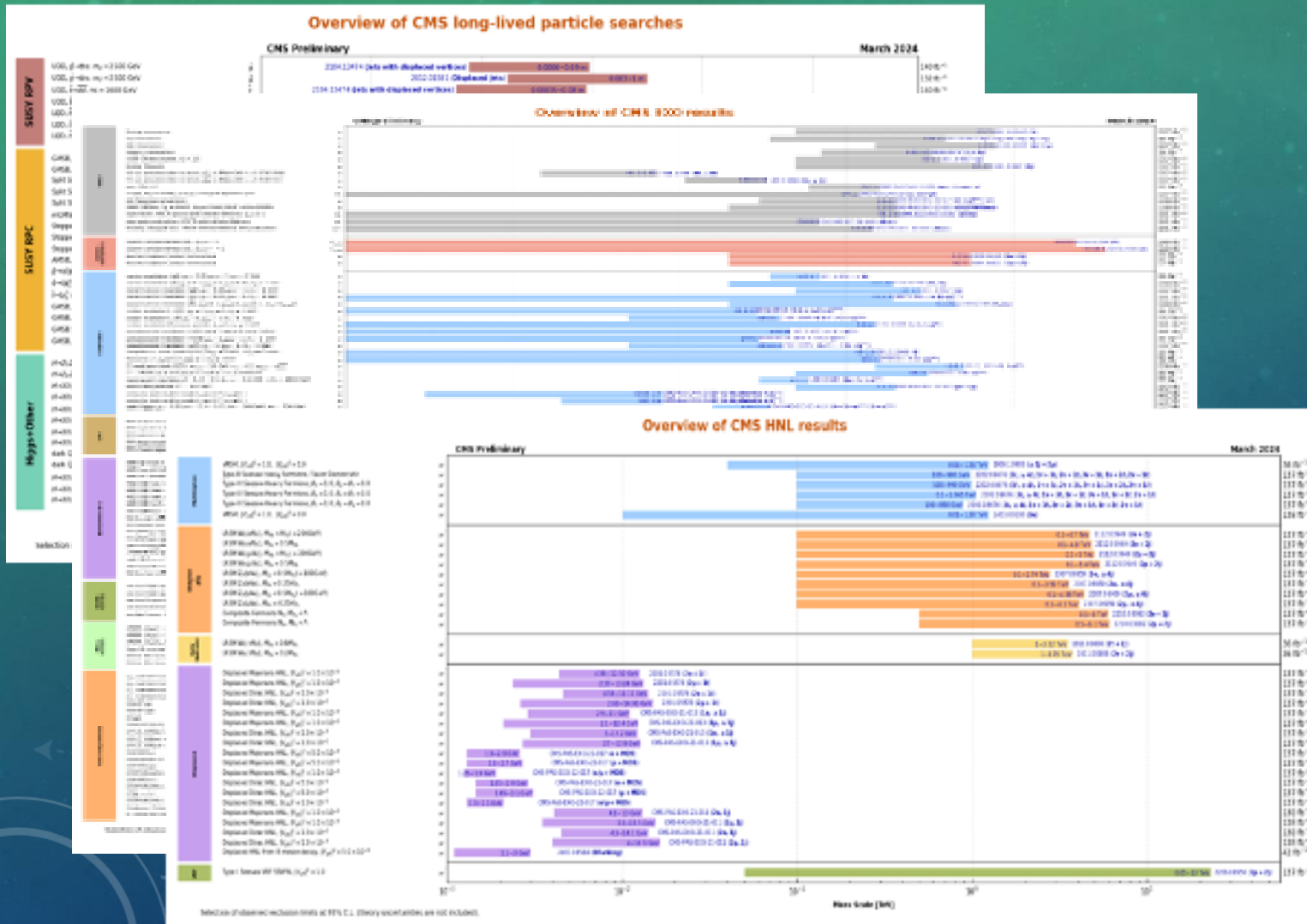
Standard Model input parameters — current precision

Relative uncertainty $\delta x/x$, logarithmic scale

● Masses ● Couplings



directly SEARCHING FOR BSM



Direct searches — probing > 10 TeV

What's driving the reach:

- More luminosity, new energy
- New Run 3 triggers
- Dedicated reconstruction & data processing
- Improved analysis techniques

What we see:

- A few intriguing events/excesses — no discovery yet
- Mostly exclusions

2 Examples of new searches opening a new region of exploration



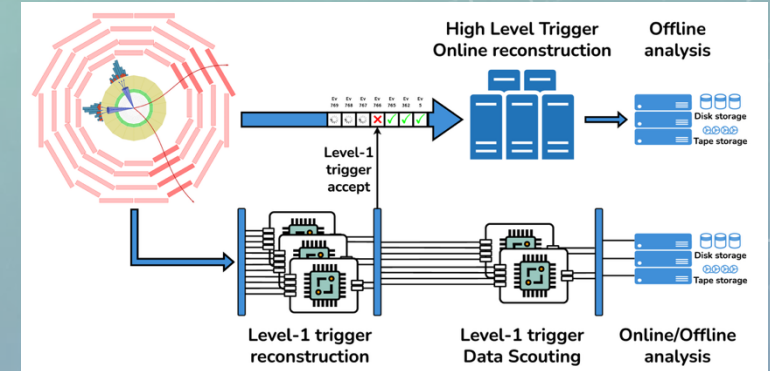
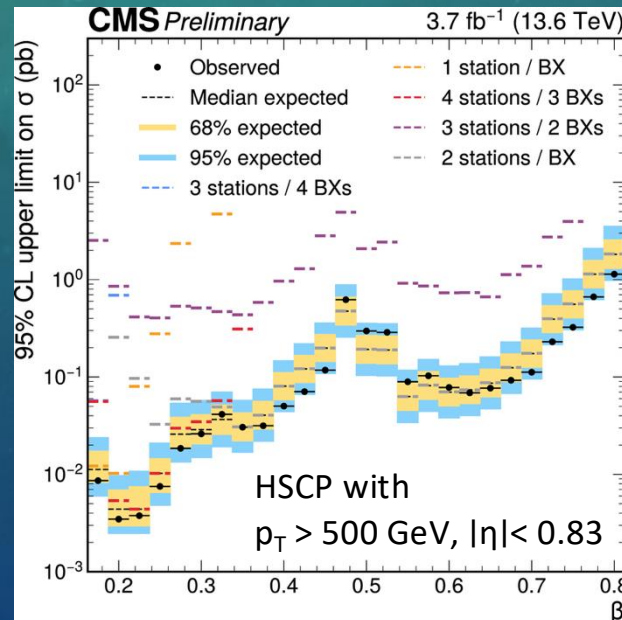
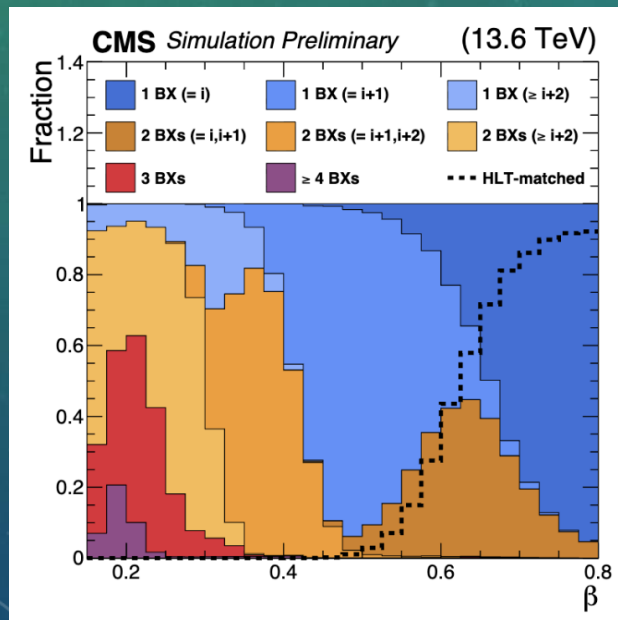
directly SEARCHING FOR BSM

Heavy Long Lived Charged Particles search with L1 scouting — new long-lived phase space

HSCPs slow enough to cross muon chambers over **several bunch crossings** and evade all standard triggers.

Uses Level-1 scouting demonstrator data taken in 2024.

Extends the sensitivity to HSCPs with β as low as 0.15!



Demonstrator of Phase-2 L1 scouting, collecting data now.

No L1 trigger required: data collection at 40 MHz!

Will improve significantly in HL-LHC: full event reconstruction including tracks at L1!

Set 95% CL limits on: $Z' \rightarrow \tau\tau'$ production and gluino R-hadron production.

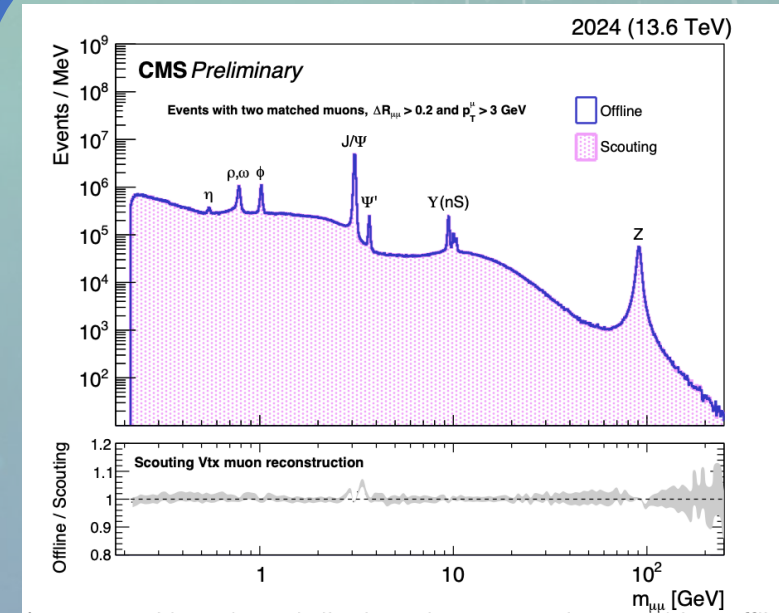
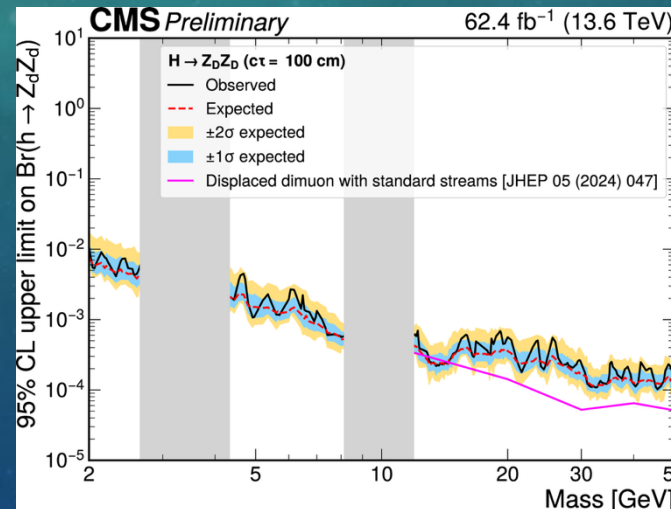
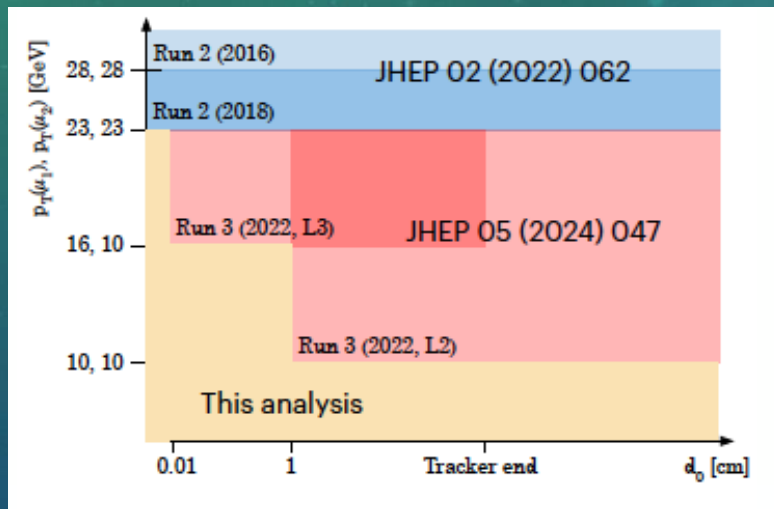
directly SEARCHING FOR BSM

Long-lived particles with low-mass - muons with dimuon scouting

Targets ($\approx 0.4\text{--}50$ GeV) region of displaced dimuon and four-muon resonances with transverse decay lengths up to 1m.

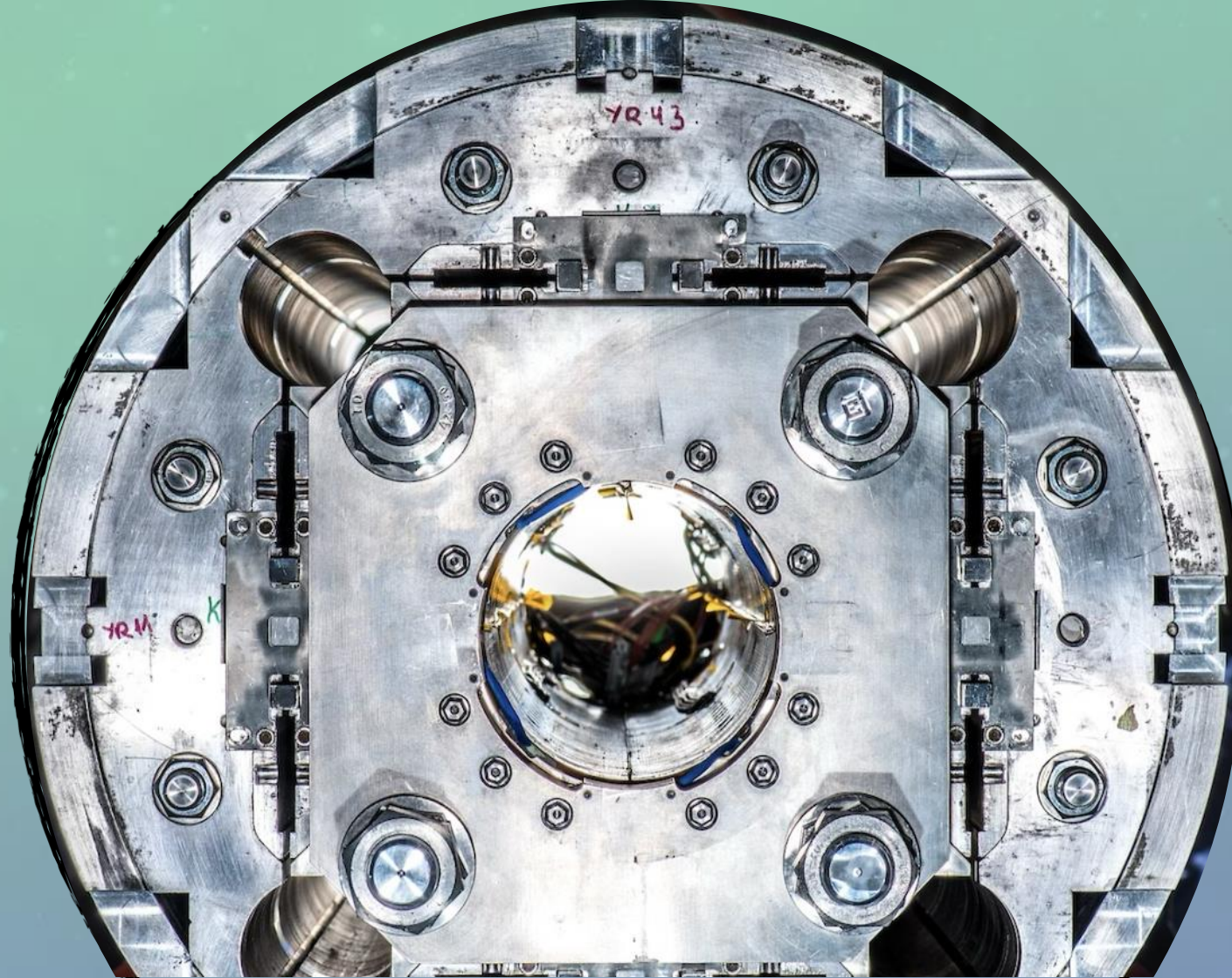
Use a dedicated **scouting trigger** to record events at kHz rates with reduced event content, otherwise inaccessible

Search extended to low mass and large displacement region.



Low- p_T dimuon scouting trigger
Same reconstruction quality for scouting (HLT) and offline muons

Set 95% CL limits exotic Higgs decays ($H \rightarrow Z_D Z_D$) to long-lived dark photons and dark showers.



New Nb₃Sn inner-triplet quadrupoles to squeeze the beams into a smaller spot (first Nb₃Sn in an accelerator)

New superconducting crab cavities to rotate each bunch to restore full overlap at the crossing angle

LHC

HL-LHC (3000 fb⁻¹, 6 x LHC)

2030

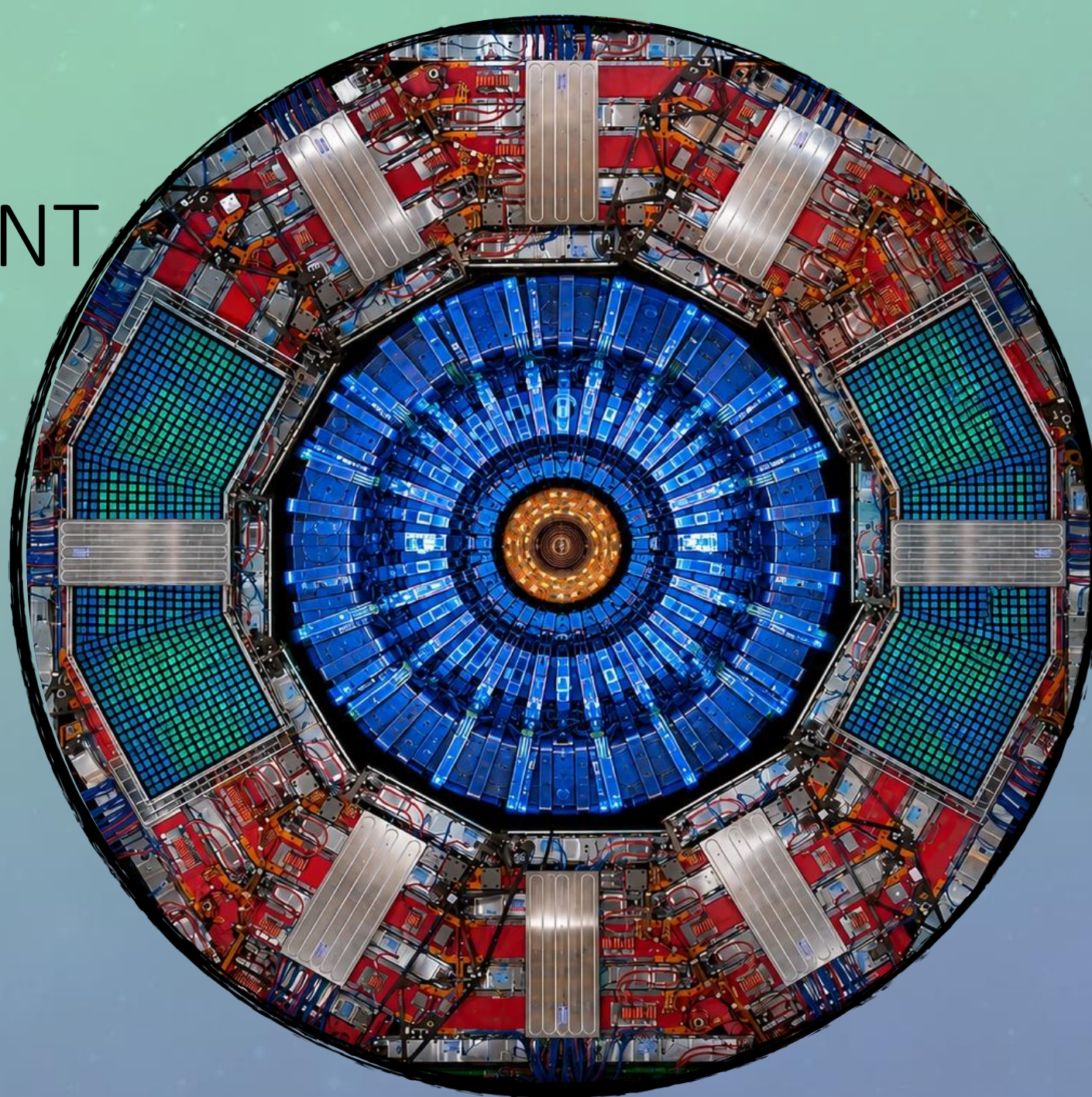
~ 2040

We are here

THE CMS EXPERIMENT AT HL-LHC

CMS is engaged in **one of the most ambitious undertakings** in experimental particle physics

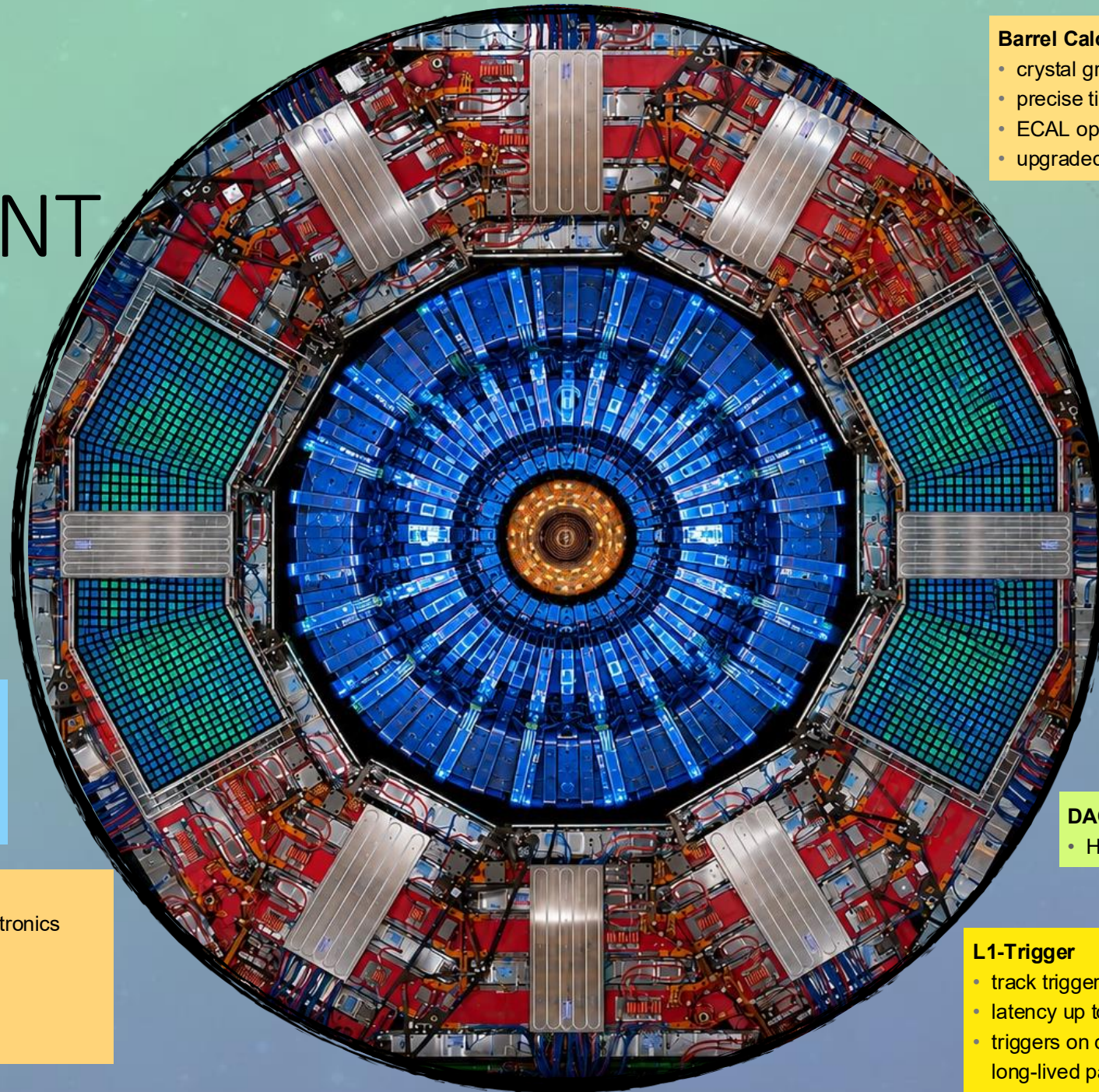
At HL-LHC:
High intensity beams
Up to 200 collisions /
bunch crossing
10 years of operations
High level of radiation



- Higher granularity
- Precision timing
- Radiation hardness
- Capacity for a higher data rate
- Extended geometrical coverage

THE CMS EXPERIMENT AT HL-LHC

CMS is engaged in one of the most ambitious undertakings in experimental particle physics



Barrel Calorimeters

- crystal granularity readout at 40 MHz
- precise timing for $e/\gamma > 30$ GeV
- ECAL operation at low temperature (10°)
- upgraded laser monitoring system

A MIP Timing Detector (MTD)

- precision timing on single charged tracks (30 to 40 ps resolution)
- Barrel (BTL): LYSO crystals + SiPMs
- Endcaps (ETL): Low Gain Avalanche Diodes

Tracker

- all silicon (strips and pixels)
- higher granularity ($>2B$ channels)
- less material
- coverage extended to $|\eta| = 4$

BRIL

- BCM/PLT refit
- new T2 tracker

DAQ/HLT

- HLT output at 7.5 kHz

L1-Trigger

- track trigger at L1 (40 MHz)
- latency up to $12.5 \mu\text{s}$
- triggers on displaced muons and long-lived particles

Endcap Calorimeter (HGCAL)

- silicon pixels (EM) and scintillators + SiPMs (HAD)
- 3D shower reconstruction with precise timing

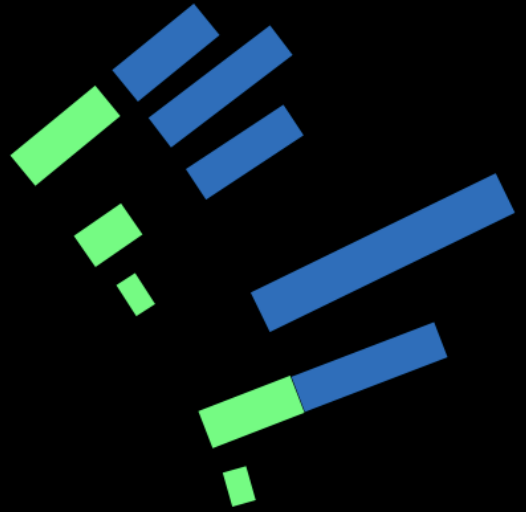
Muon Detectors

- DTs & CSCs: new FE/BE readout electronics
- RPCs: new electronics
- new GEM/iRPC chambers
- extended muon coverage to $|\eta| = 3$

THE CMS LEVEL 1 TRIGGER TODAY



TRACKER

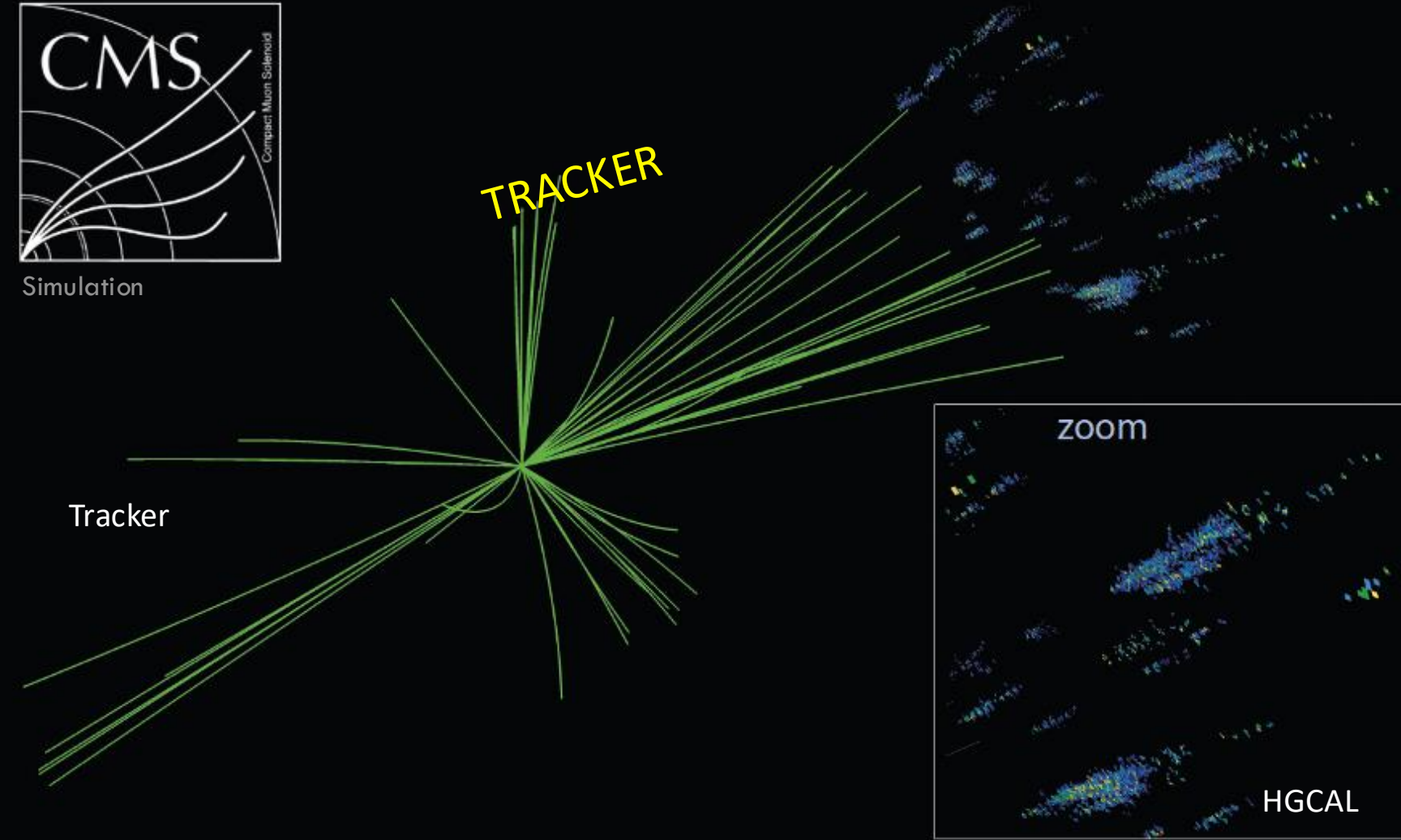


CAL

THE CMS LEVEL 1 TRIGGER AT THE HL-LHC



Simulation



Tracker

TRACKER

CAL

zoom

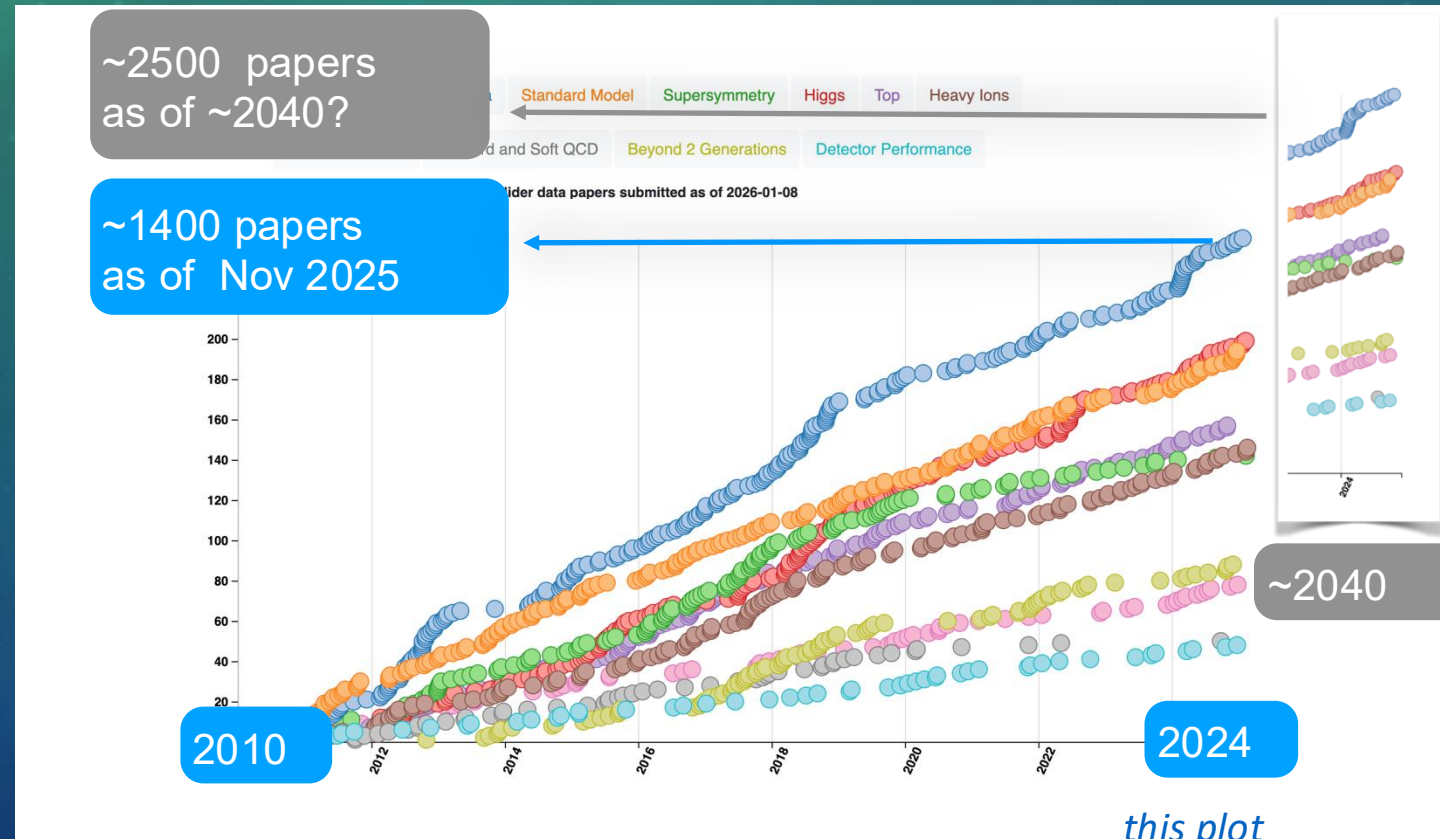
HG CAL

Tracker at L1 Trigger

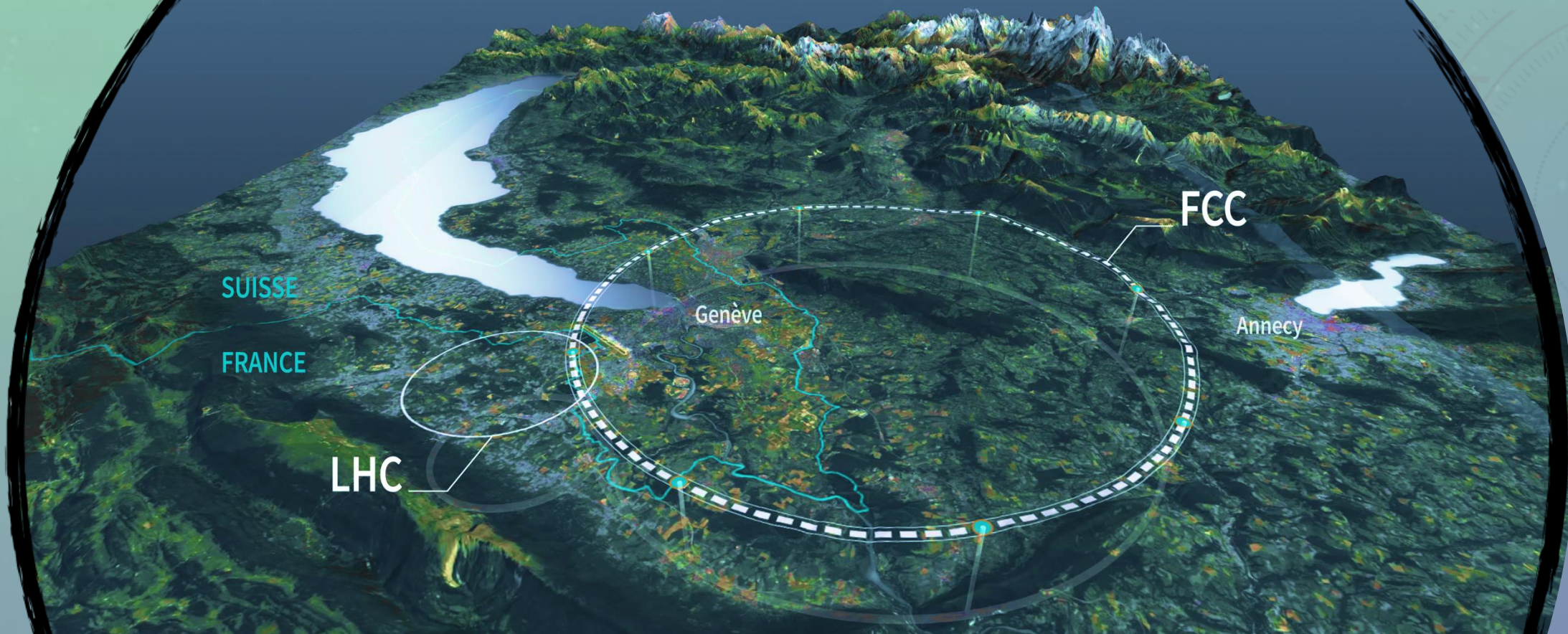
High-granularity calorimetry at L1 Trigger

PHYSICS LANDSCAPE AT THE HL-LHC

- A new-generation CMS — novel detector technologies plus AI/ML at every stage, from trigger to reconstruction - **extending the precision and discovery reach of physics** into currently inaccessible territory
- Unprecedented proton-proton dataset collected at ~ 14 TeV - *the last pp dataset available till the next collider operates* (~ 2070 ?)



THE FUTURE CIRCULAR COLLIDER



LHC

HL-LHC

2030

FCC-ee

~ 2045

FCC-hh

~ 2070

~ 2090

We are here

THE EUROPEAN STRATEGY FOR PARTICLE PHYSICS

September 2024: the community called to develop a visionary and concrete plan that advances human knowledge in fundamental physics through the realization of the next flagship at CERN.

”The aim of the Strategy update should be to develop a visionary and concrete plan that greatly advances human knowledge in fundamental physics through the realization of the next flagship project at CERN. This plan should attract and value international collaboration and should allow Europe to continue to play a leading role in the field.”

The Ascona / Monte Verità recommendations: [Link](#)

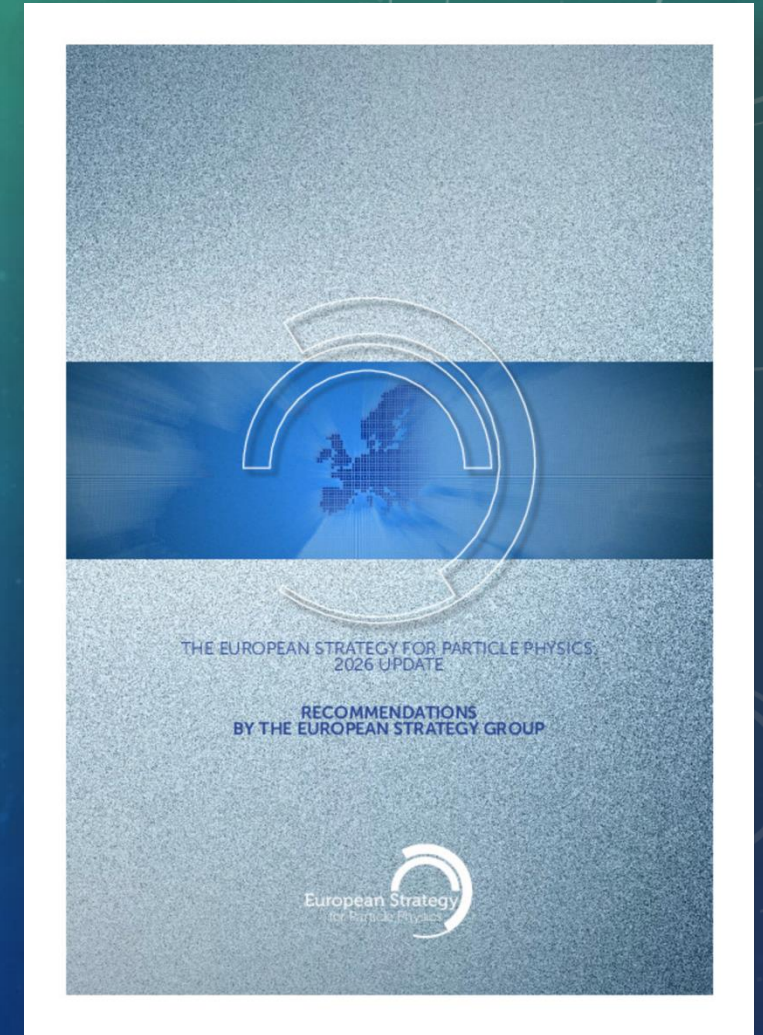
i. The electron–positron Future Circular Collider (FCC-ee) is recommended as the preferred option for the next flagship collider at CERN.

*ii. A descoped FCC-ee is the preferred alternative option for the next flagship collider at CERN. Although the suggested descoping measures would have a significant impact on the breadth of the physics programme and the precision achieved, the descoped FCC-ee would still provide a **very strong physics programme** and a **viable path towards high energies**, compared to the alternative collider options.*

At this stage, without knowing the reasons for which the FCC-ee would not be feasible, other alternative options are not ranked.

The chosen path: FCC-ee → FCC-hh

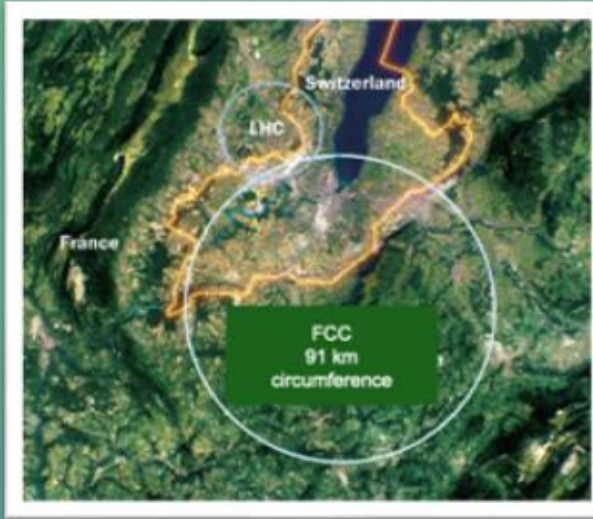
How did we get here?



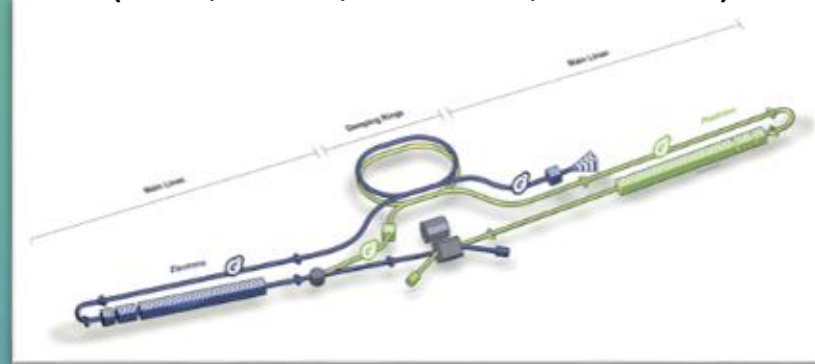
PROPOSED LARGE-SCALE PROJECTS AT CERN, ~ 2045

e+e- colliders
("Higgs factories")

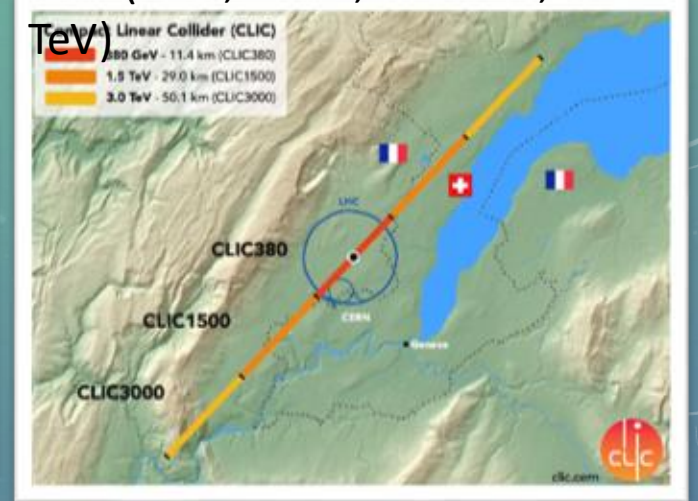
FCC-ee (e+e-, circular, 91 – 365 GeV)



LCF (e+e-, linear, 91 – 240, 550 GeV)



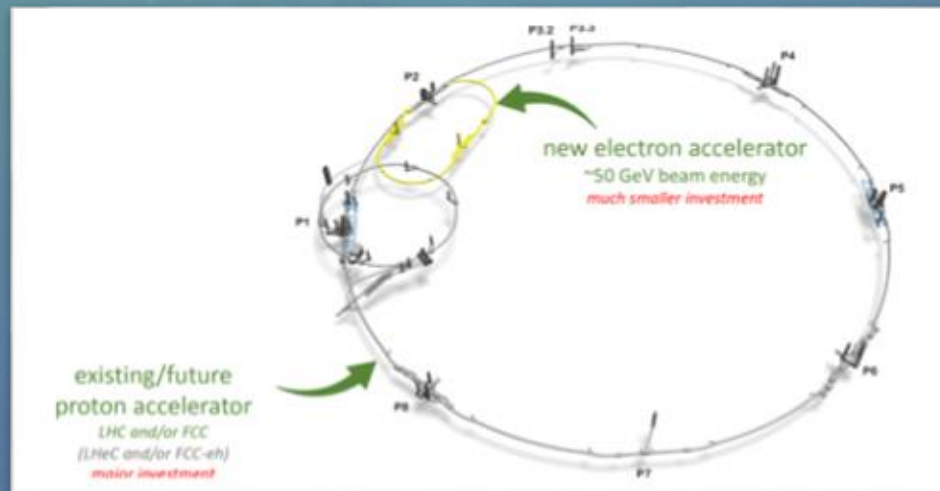
CLIC (e+e-, linear, 380 GeV, 1.5 TeV)



Intermediate projects

(Leave room (time, budget, resources) for further development of THE machine that can probe directly the energy frontier at the 10 TeV parton scale)

LEP3 (e+e-, circular, 91 – 230 GeV)



LHeC (ep, circular, electron ERL, 50 GeV e-, > 1 TeV ep collisions)



PROPOSED LARGE-SCALE PROJECTS AT CERN, ~ 2045

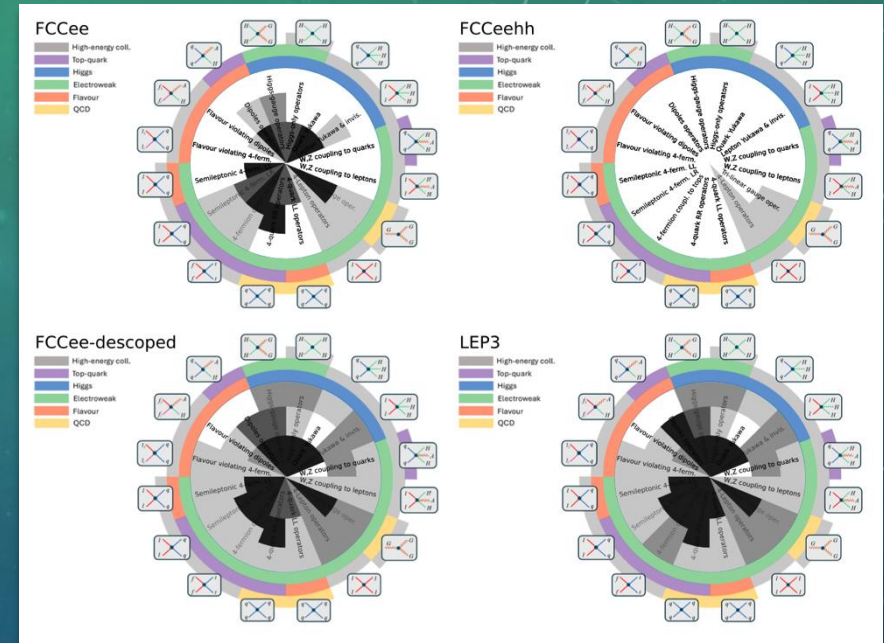
Overall comparisons

Machine	Precision Physics	BSM physics	Physics vs CEPC	Technical readiness	Constr. cost (BCHF)	Time scale	Path to ≥ 10 TeV
FCC-ee	22	23			15.3	2046-2060	
Descoped FCC-ee	15	17			12.9	2046-2055	
LCF550	15	17			14.8	2045-2065	
CLIC1500	14	18			14.6	2045-2066	
LCF250	10	16			9.4	2045-2053	
CLIC380	10	16			7.5	2045-2054	
LEP3	15	17			4.1	2047-2062	
LHeC	8	7			2.1	2044-2051	

Physics: from WG2b: sum of precision/BSM physics Phys vs CEPC: competitiveness, assuming CEPC is running in parallel
 Tech readiness: from WG2a
 Construction cost: from proponents + exp. (CERN part)

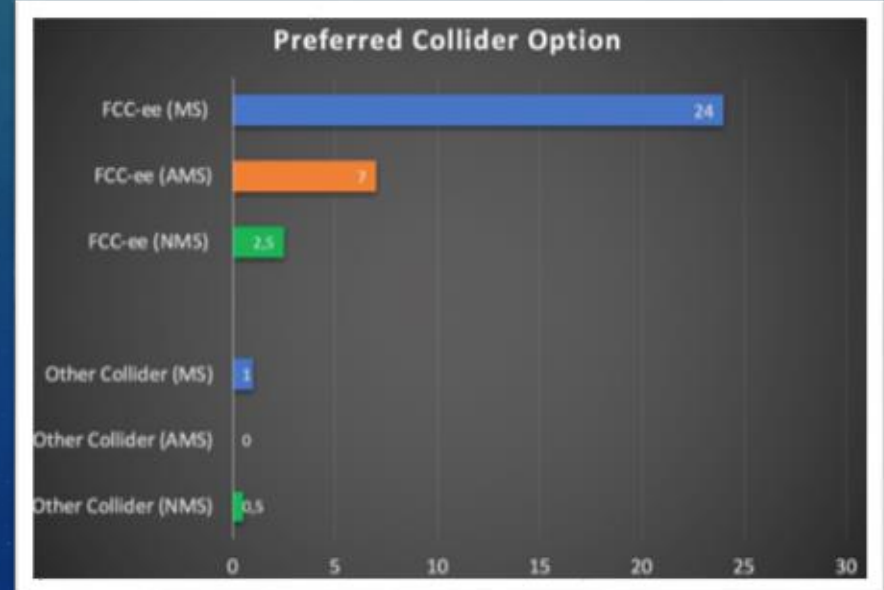
Physics comparisons

Potential of each collider for all sectors/rings. HL-LHC performance is used as a reference



Community survey

What is the preferred large-scale post-LHC accelerator at CERN?



THE FCC-ee



Machine parameters

- 91 km circular ring · 4 interaction points · 15 years of operation
- Peak luminosity: $144 \times 10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ at Z pole — one LEP1 every few mins.
- Continuous beams, no pile-up · Energy consumption 1.2–1.9 TWh/year

Running modes

- Z pole (91 GeV), WW threshold (160 GeV), ZH threshold (240 GeV), $t\bar{t}$ threshold (365 GeV)
- Quasi-total flexibility in the order of operating points
- Clean environment: $\sim 10\times$ more bb and cc pairs than total Belle II design statistics

Targets to deliver

- 3 million Higgs bosons · 2 million top quarks
- 240 million WW events · 6×10^{12} Z bosons
- B hadrons at \sim current LHCb statistics — all in a much cleaner environment

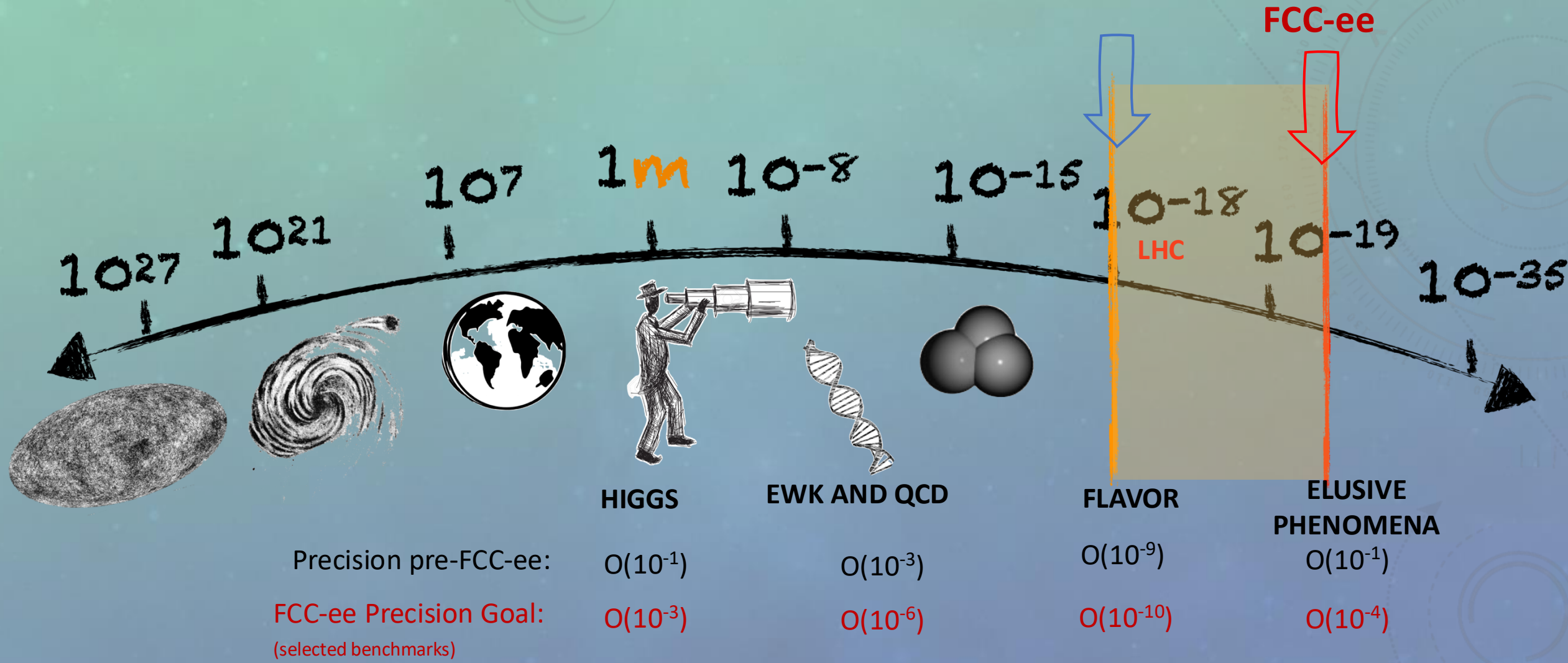
FCC-ee at the intensity frontier

- Ultimate precision machine — far beyond a Higgs factory
- $\times 50$ –2000 improvement on all EW observables; up to $\times 30$ –100 on Higgs observables
- Indirect sensitivity to new physics at the O(100) TeV scale

PARTICLE PHYSICS

Explores the fundamental constituents of matter and the laws that govern them.

We are here
LHC @ 13.6 TeV

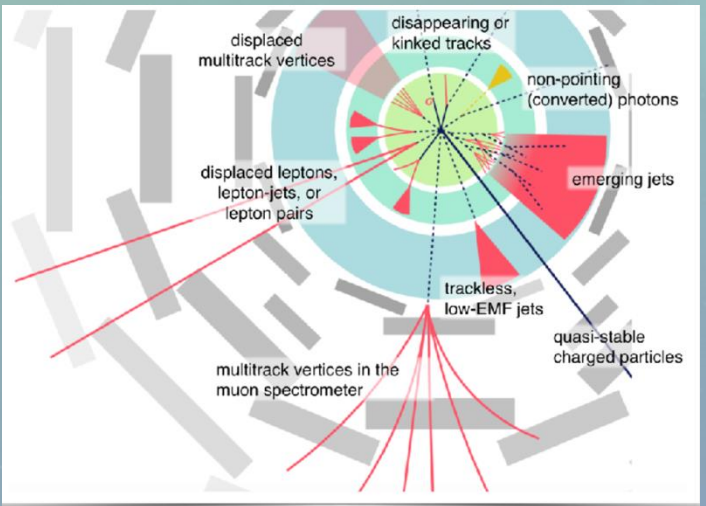


SURPRISES ARE POSSIBLE

The LHC continues to deliver surprises even in well-studied final states and new analysis techniques and methods are opening new windows

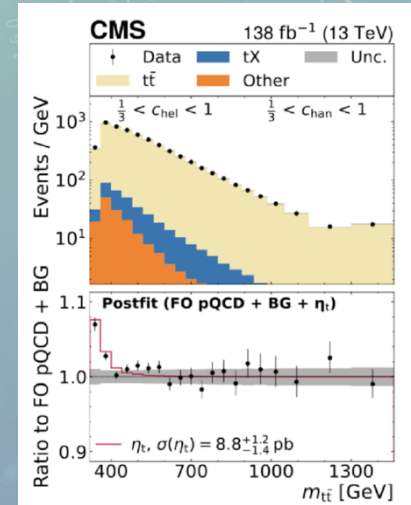
Exploring new physics possibilities

At lower energies and smaller couplings through **unconventional signatures** at the LHC, TLA, and **data scouting ideas** and **new collider experiments**, FASER and SND!



$t\bar{t}$ resonances and the 'toponium' signature

- Color-singlet quasi-bound $t\bar{t}$ state (pseudo-scalar-like) near threshold
- Subtle effect of the strong interaction predicted in non-relativistic QCD models
- Observed by CMS and confirmed by ATLAS: seen as a feature in the $m_{t\bar{t}}$ spectrum around 340–350 GeV



Quantum entanglement in $t\bar{t}$ production

- At threshold, the $t\bar{t}$ pair is produced in a Bell state: $(1/\sqrt{2})(|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$
- Used to probe quantum entanglement — first observation at a hadron collider
- New window on quantum information in QFT — observed by both ATLAS and CMS

With $\times 20$ more data, many more such surprises are expected

SUMMARY

A Scientific Mission for the 21st Century

LHC Runs 1–3 — harvest the attobarn era ($\sim 0.5 \text{ ab}^{-1}$ / experiment)

- Not just accumulating statistics — the program keeps outperforming expectations
- New measurements and analysis ideas continue to emerge from the data in hand
- Reach already exceeds what these datasets were designed to deliver

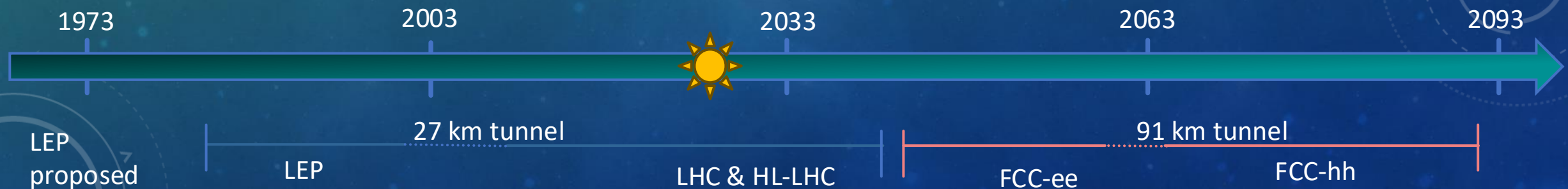
HL-LHC — open new phase space

- Upgraded detectors + matched computing reach regions and processes inaccessible today
- Higher luminosity, 6x LHC

FCC-ee — the next 2 years are decisive

If it proceeds, the bar rises across the board:

- Theory: predictions at unprecedented accuracy
- Detectors: extraordinarily granular, efficient, reliable
- Simulation & data processing: scale by orders of magnitude





Thanks for your attention