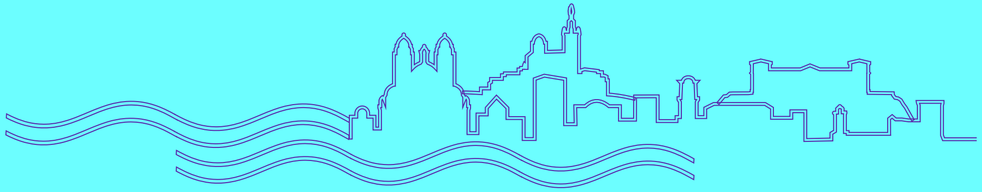
EUROPEAN PHYSICAL SOCIETY

EPS HEP2025 MARSEILLE

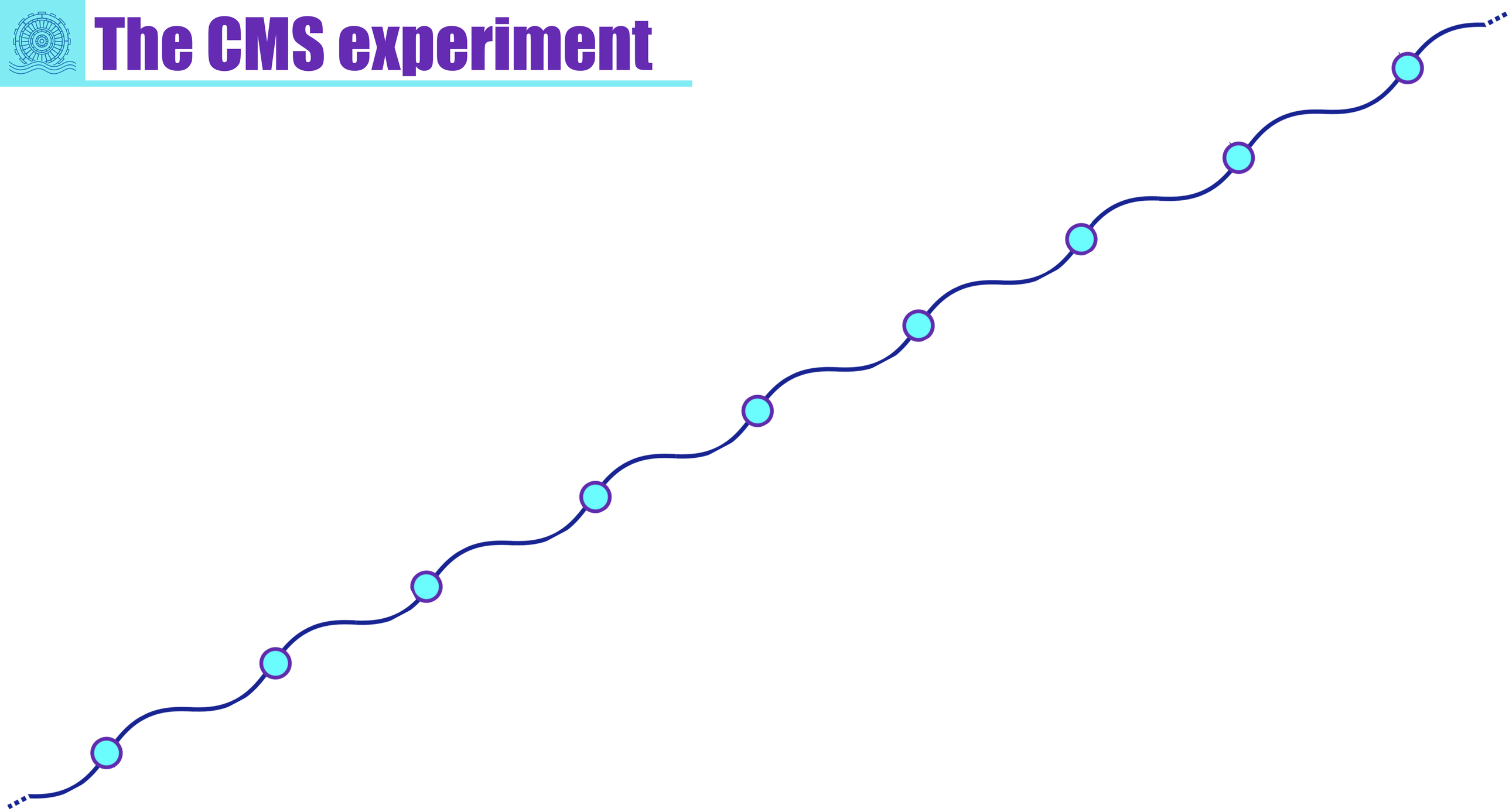


HIGHLIGHTS from CMS

ROBERTO SALERNO

CERN cnrs LLR ÉCOLE POLYTECHNIQUE IP PARIS

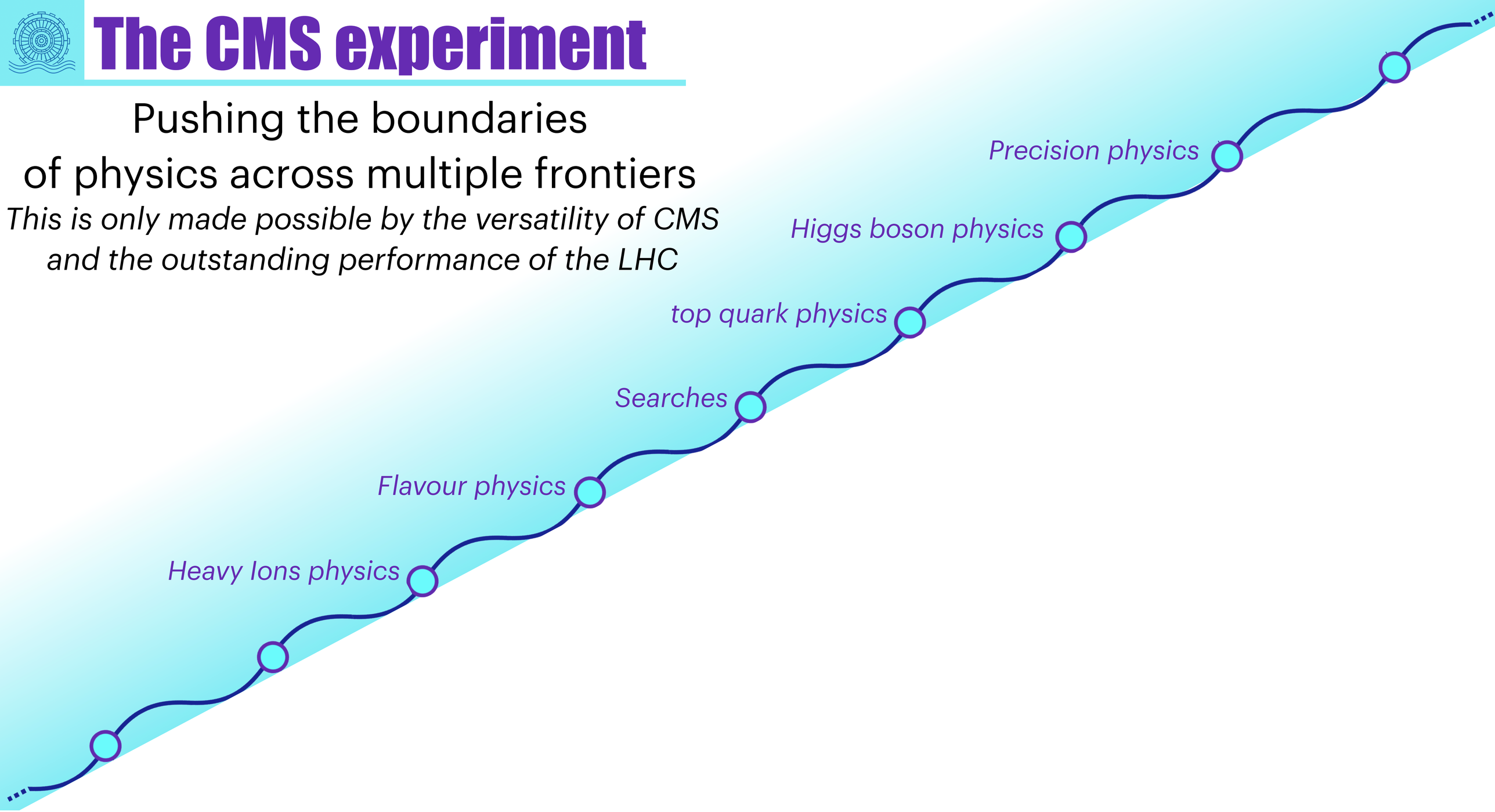
The CMS experiment



The CMS experiment

Pushing the boundaries
of physics across multiple frontiers

This is only made possible by the versatility of CMS and the outstanding performance of the LHC



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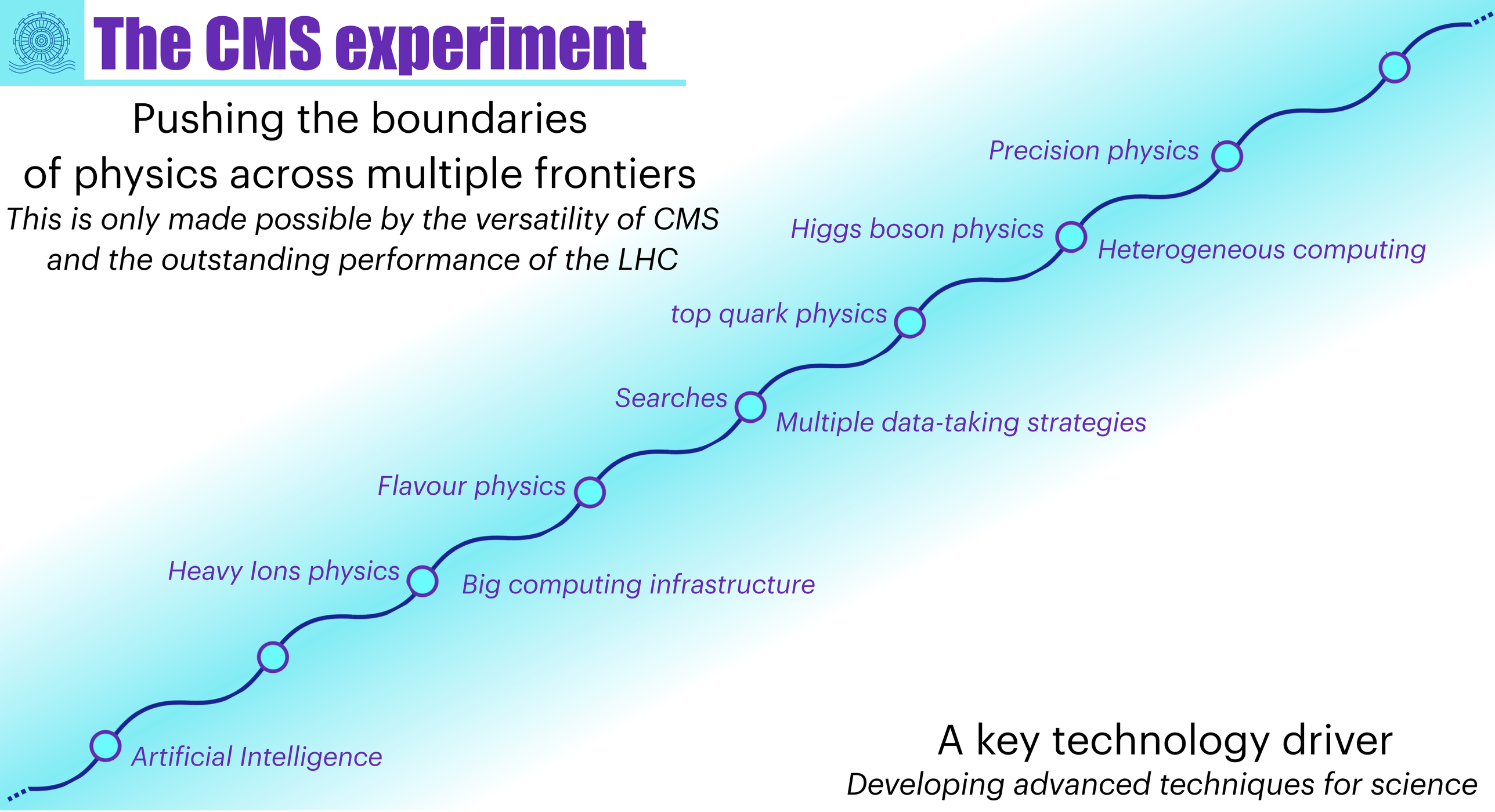
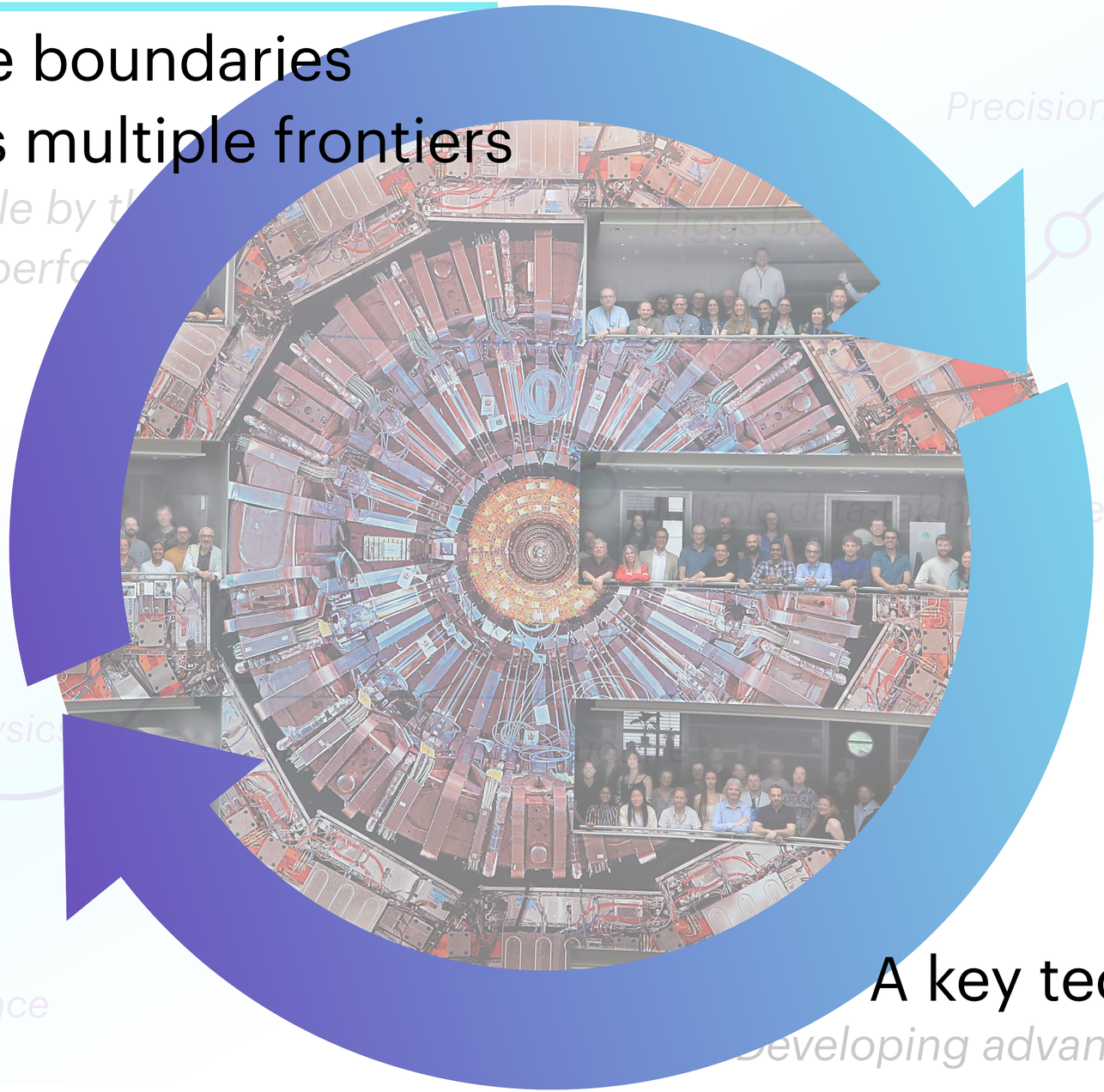


A key technology driver

Developing advanced techniques for science

The CMS experiment

Pushing the boundaries
of physics across multiple frontiers



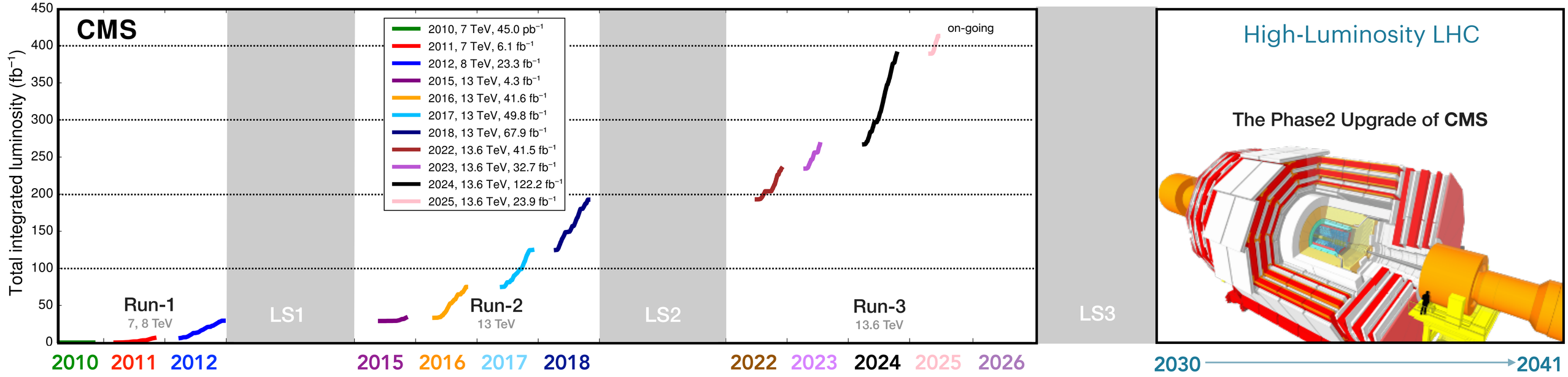
A key technology driver

This is only made possible by t
and the outstanding perfo
Precision physics
Heterogeneous computing
Heavy Ions physic
Artificial Intelligence
Developing advanced techniques for science

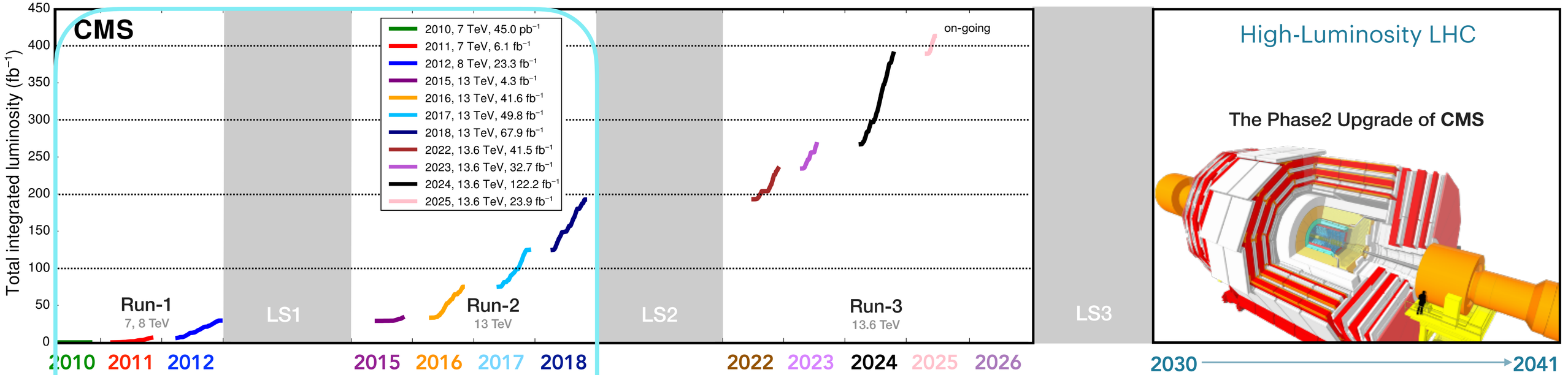
The CMS collaboration

246 institutes from 58 regions ~2300 authors

Midway through a three-decade endeavour



Midway through a three-decade endeavour



A remarkable breadth of physics results

Run-1

Higgs boson discovering

Natural SUSY searches
Exclude large part of parameter space

Probing QGP

Run-2

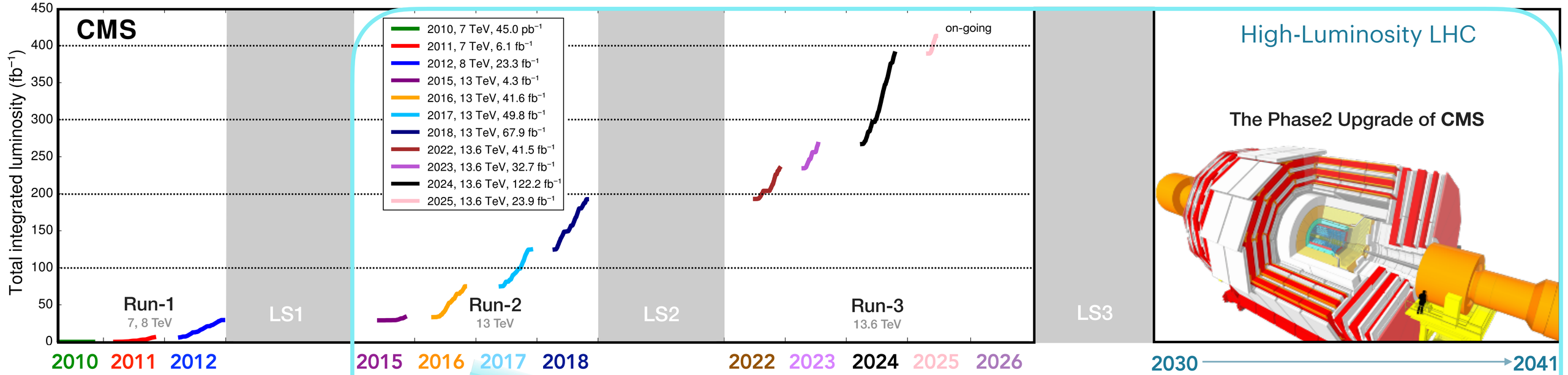
Study of Yukawa coupling
Observation 3rd generation
Evidence 2nd generation

Shift to precision physics
m_W, m_{top}, $\sin^2\theta_W$

Observation of VBS

Heavy flavour physics
Ultra-rare decay $B_s \to \mu^+\mu^-$

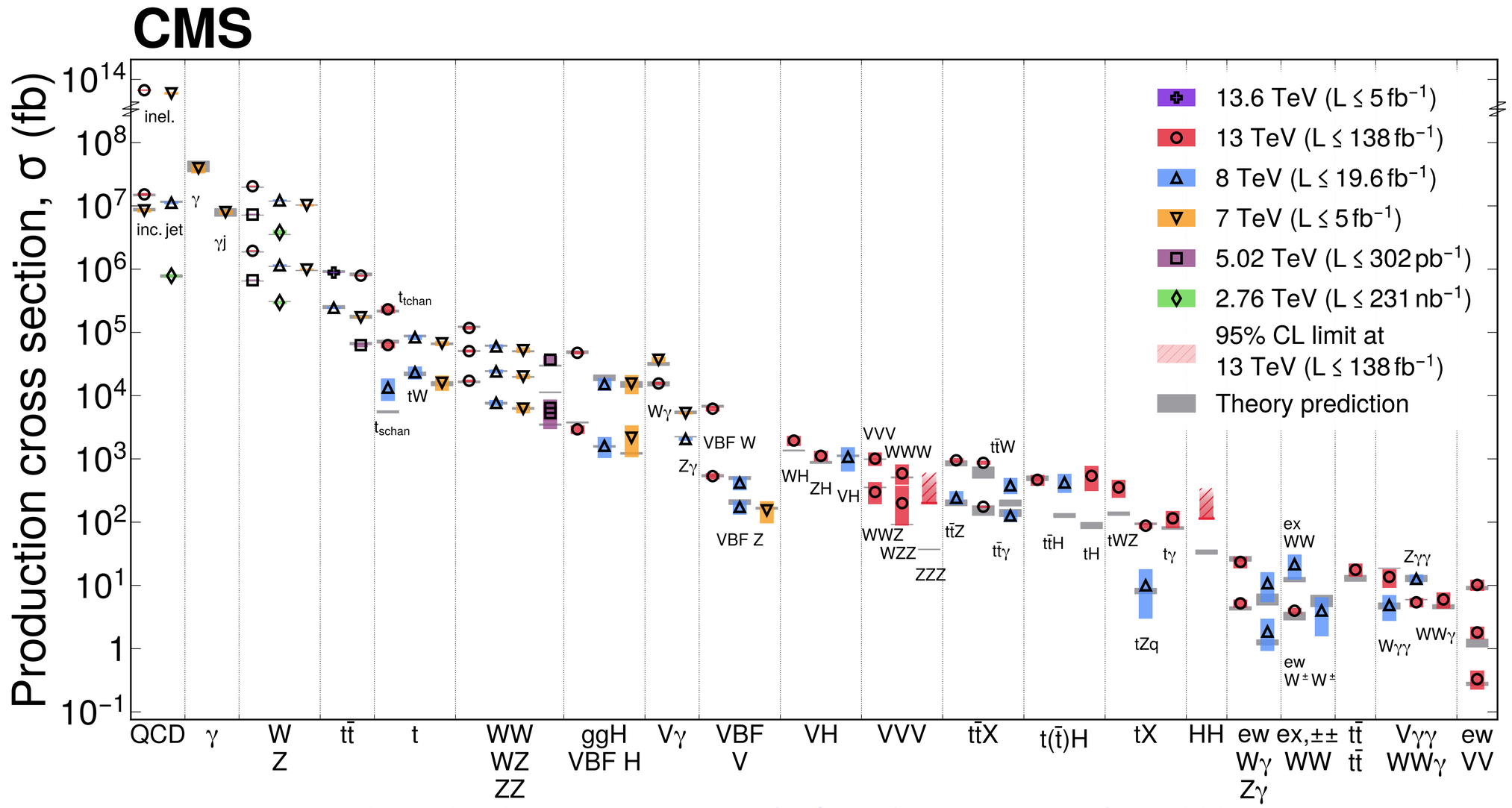
Midway through a three-decade endeavour



Outline

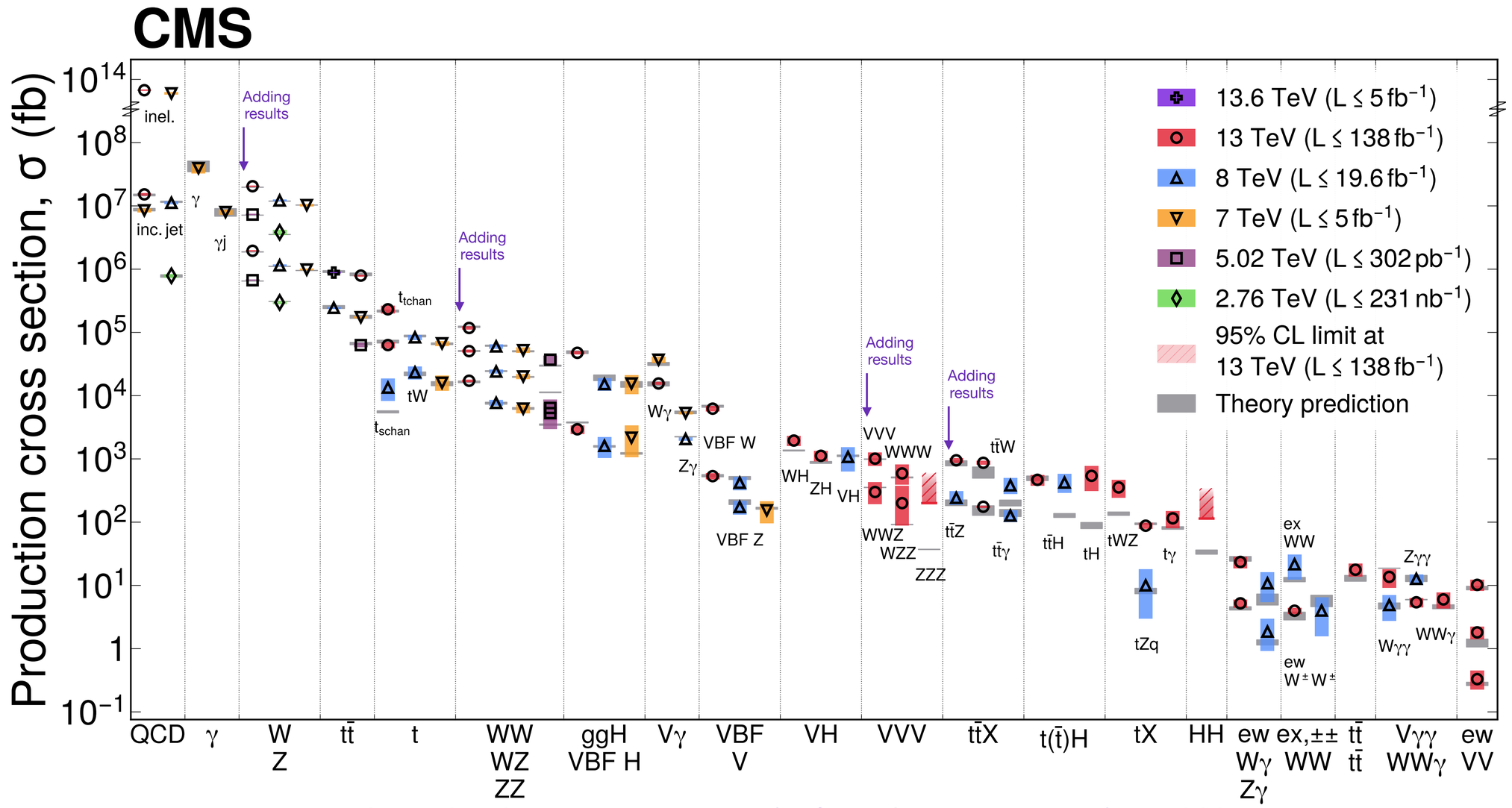
- Recent highlights
  - Run-2
  - Run-3
  - Precision physics
  - Higgs boson physics
  - top quark physics
  - Searches
  - Flavour physics
  - Heavy Ions physics
- Performance in 2025
  - Run-3
- Towards the HL-LHC

From millibarns to femtobarns



Cross-Section measurements of selected processes as of May 2024

From millibarns to femtobarns



Cross-Section measurements of selected processes as of May 2024

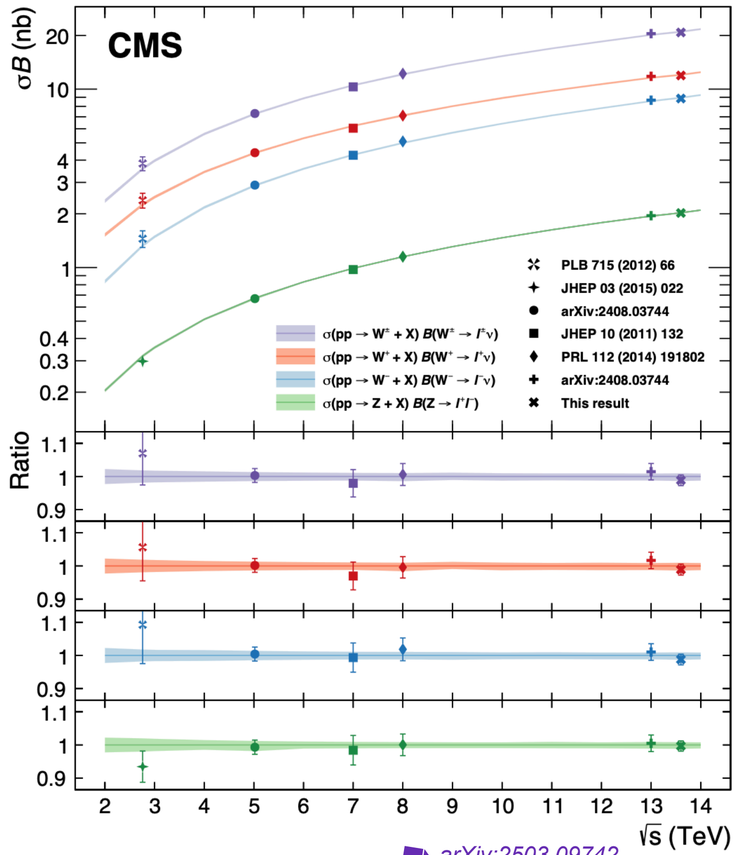
We are continuing the exploration of these processes using Run-3

From millibarns to femtobarns

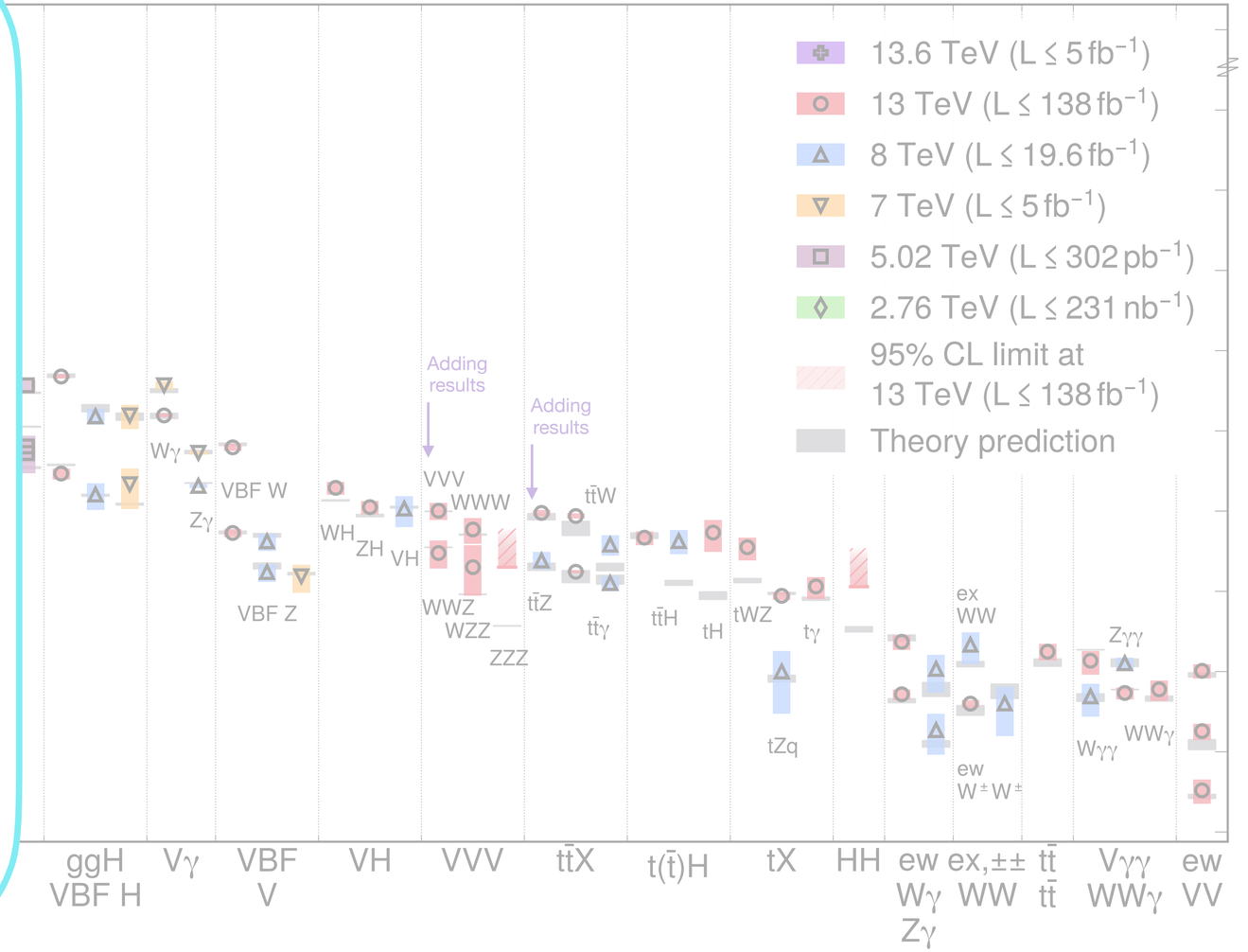
W and Z cross-section

Refinement of PDF's description

Run-3



arXiv:2503.09742
Submitted to JHEP



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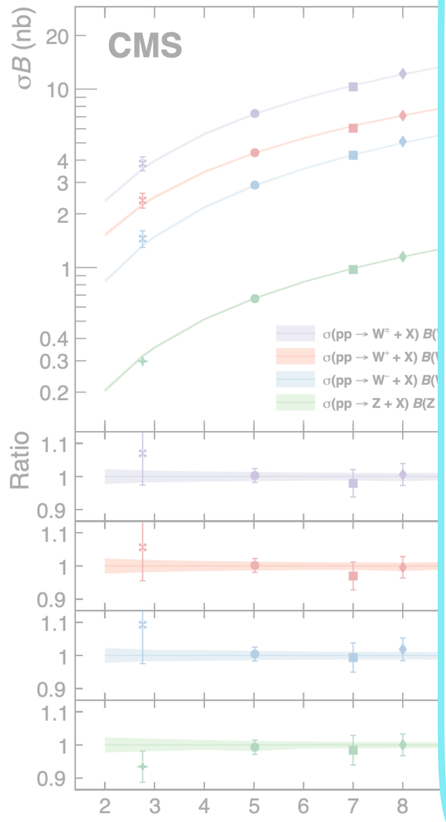
Physics Report 1115 (2025) 3

W and Z cross-sec

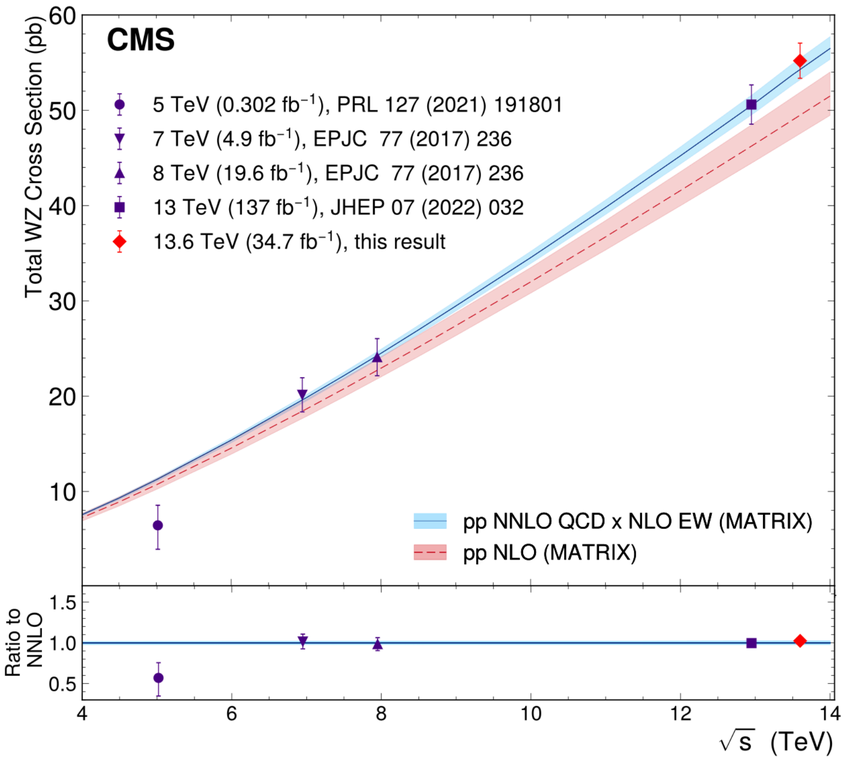
Refinement of PDF's descr



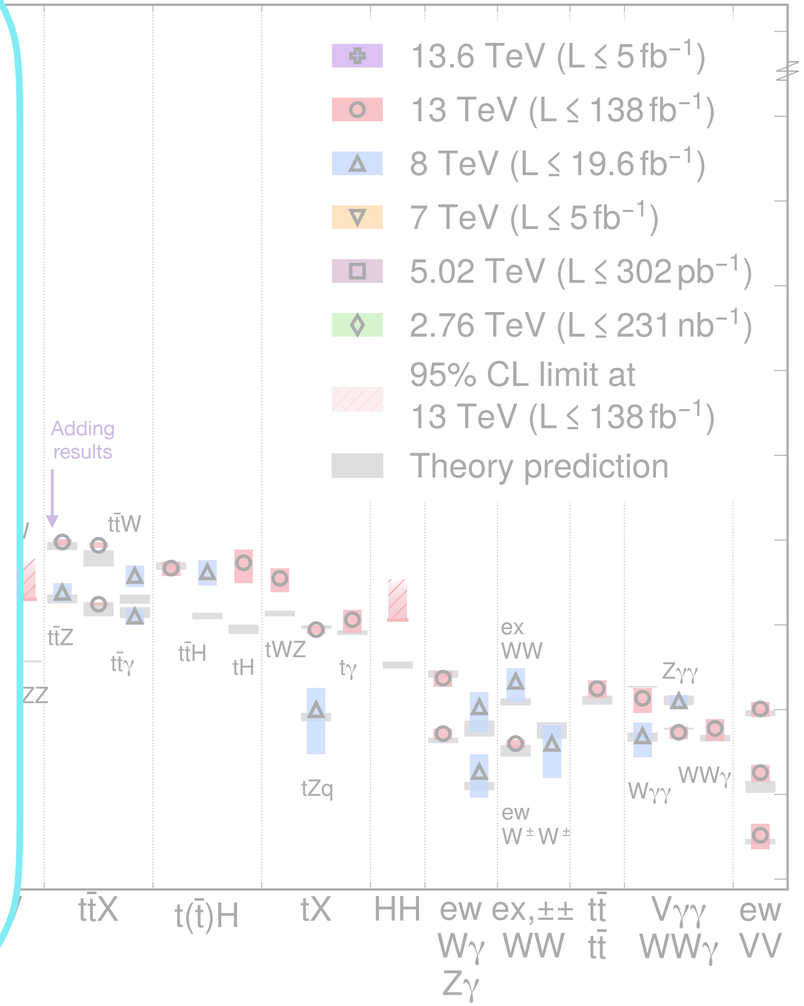
WZ cross-section

Using improved lepton identification

Run-3



JHEP 04 (2025) 115



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Physics Report 1115 (2025) 3

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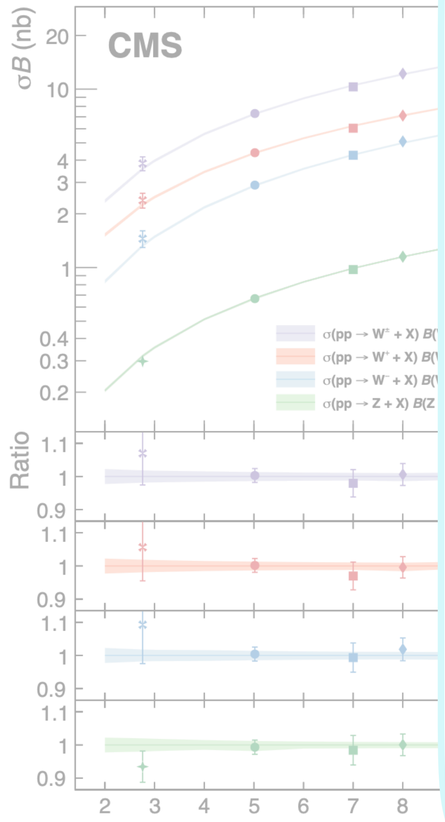
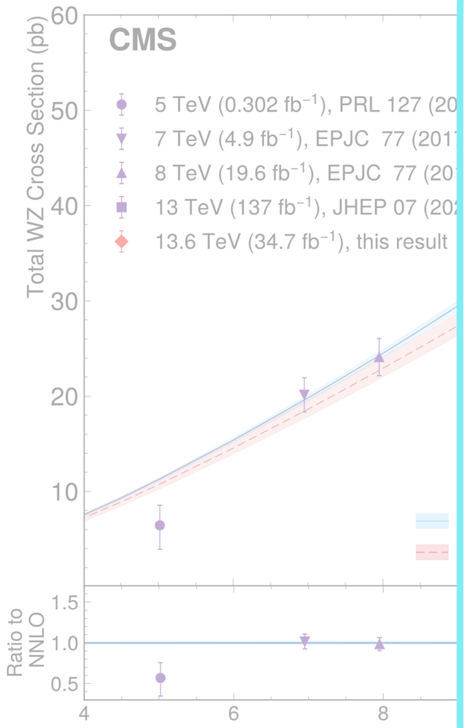


WZ cross-section

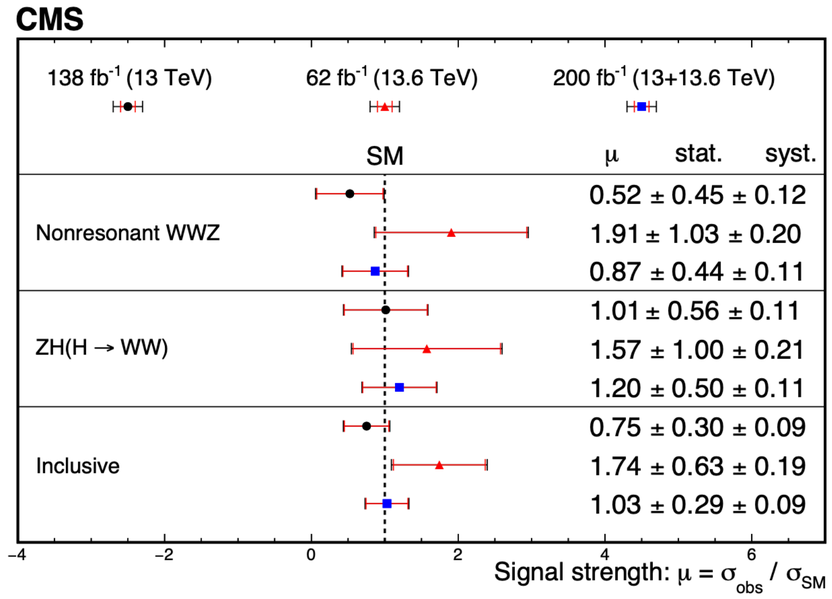
Using improved lepton i



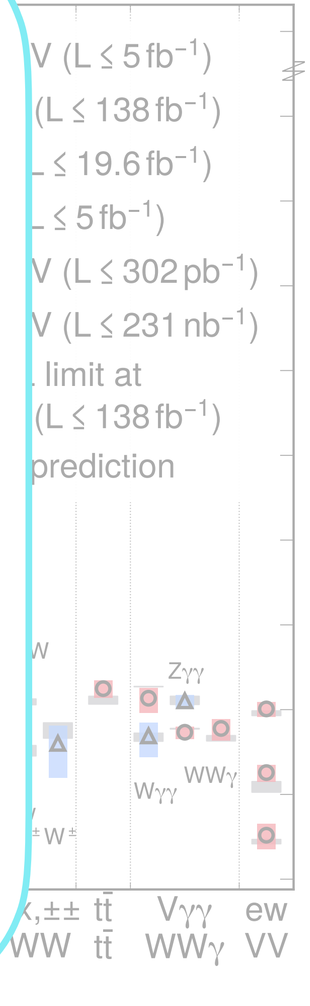
WWZ and HZ cross-sections

Separate and simultaneous measurement of WWZ and HZ

Evidence for triboson production at 13.6 TeV



arXiv:2505.20483
Submitted to PRL



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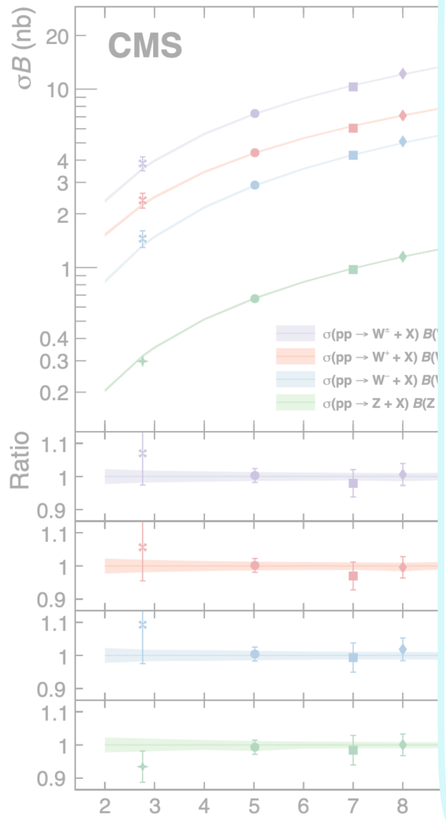
From millibarns to femtobarns

Physics Report 1115 (2025) 3

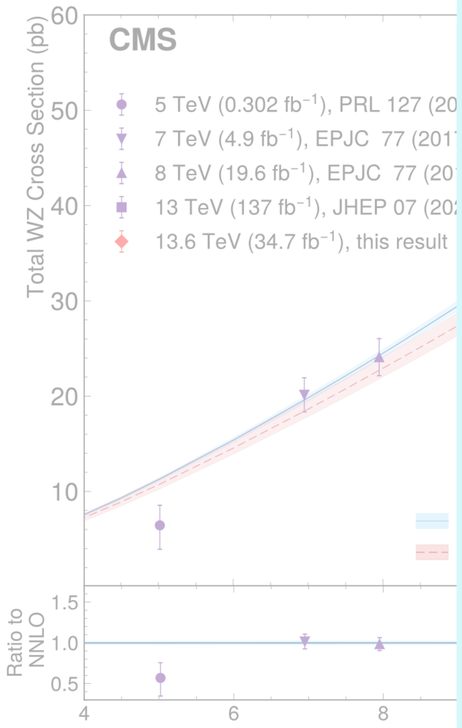
W and Z cross-sec

Refinement of PDF's descr



WZ cross-section

Using improved lepton i



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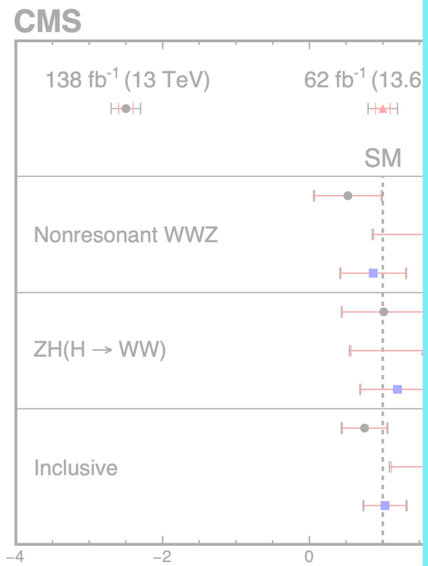
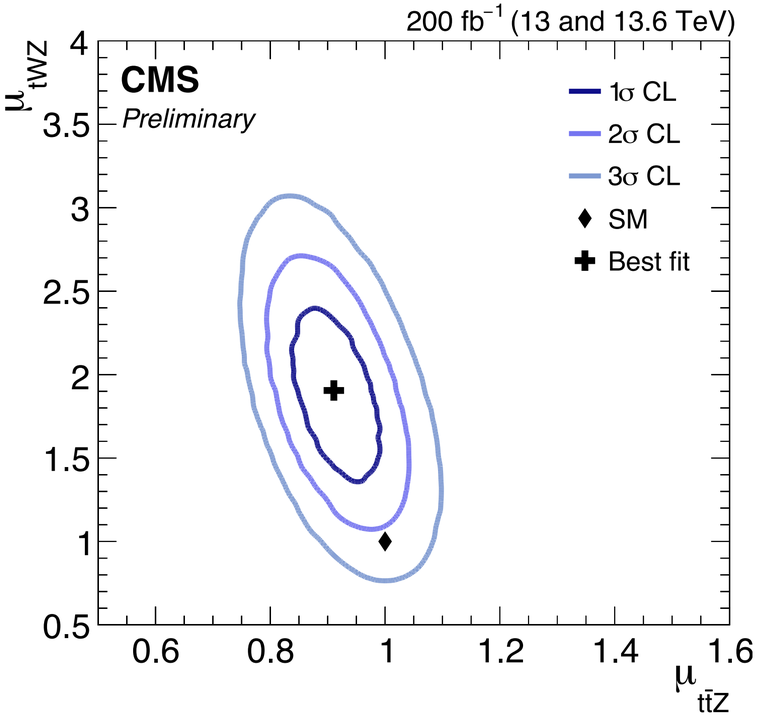


tWZ cross-sections

Run-3

First observation of tWZ

Simultaneous measurement of tWZ and ttZ



TOP-24-009

We are continuing the exploration of these processes using Run-3

Charting the Higgs Sector

Ultimate Precision at 13 TeV

HIG-21-018

Combination of 16 CMS published analyses incorporating

7 decay channels
($\gamma\gamma$, ZZ, WW, bb, $\tau\tau$, $\mu\mu$, Zγ)

6 production channels
(ggH, VBF, WH, ZH, ttH, tH)

Searches for H to invisible

H off-shell production

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H off-shell production

A wide array of the interpretations is provided

Signal strengths
inclusive/production/decay/production×decay

Signal strengths with $\sigma \times \mathscr{B}$

Cross sections
STXS stage 0/STXS stage 1.2

Coupling modifiers
resolved/effective/off-shell/ratio

Higgs self-couplings

SMEFT

Recent Highlights

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  inclusive/production/decay/production×decay
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- Cross sections
  STXS stage 0/STXS stage 1.2
- Coupling modifiers
  resolved/effective/off-shell/ratio
- Higgs self-couplings
- SMEFT

Signal strength inclusive

$$\sigma/\sigma_{\mathrm{SM}} = 1.014\,^{+0.055}_{-0.053}(\text{total}) = 1.014 \pm 0.028\ (\text{stat.})\,^{+0.025}_{-0.024}(\text{exp.})\,^{+0.040}_{-0.039}(\text{theo.})$$

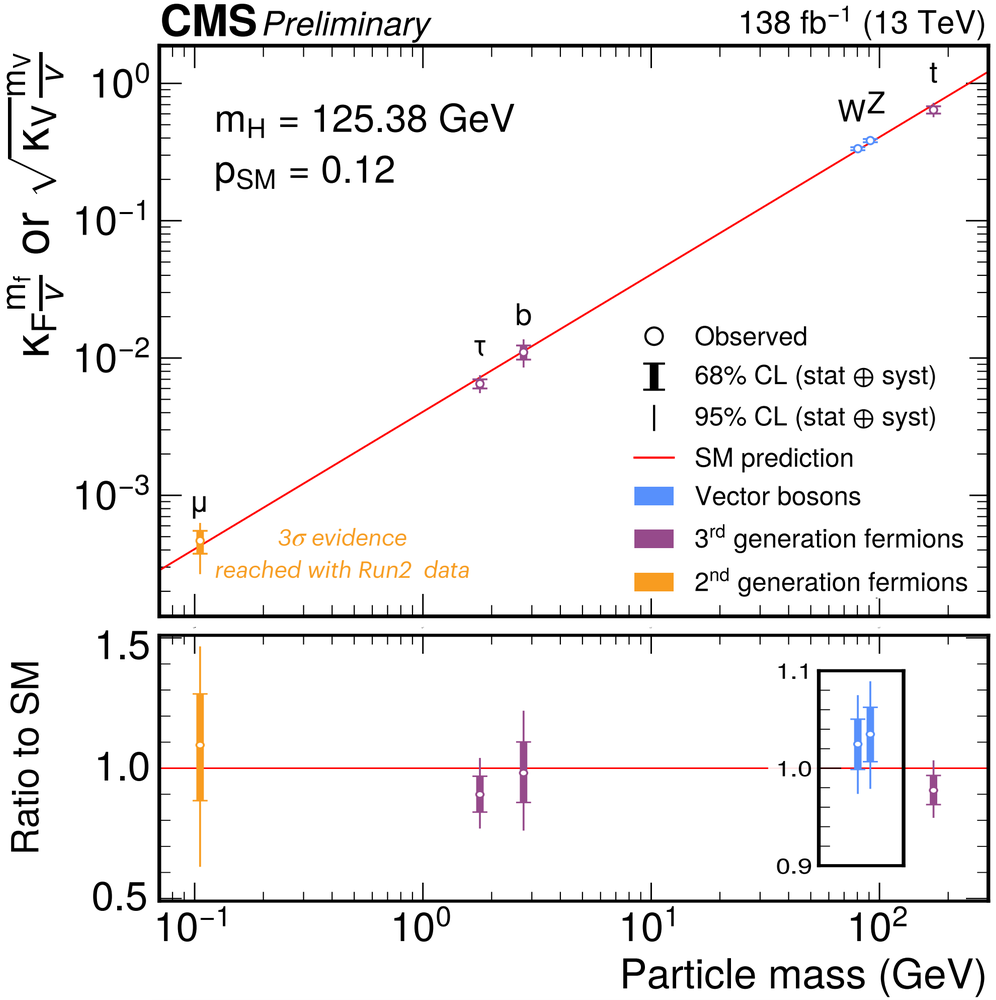
5.4% *2.7%* *2.5%* *3.9%*

Recent Highlights

Higgs boson couplings

Constraints on coupling modifiers

resolved coupling configuration



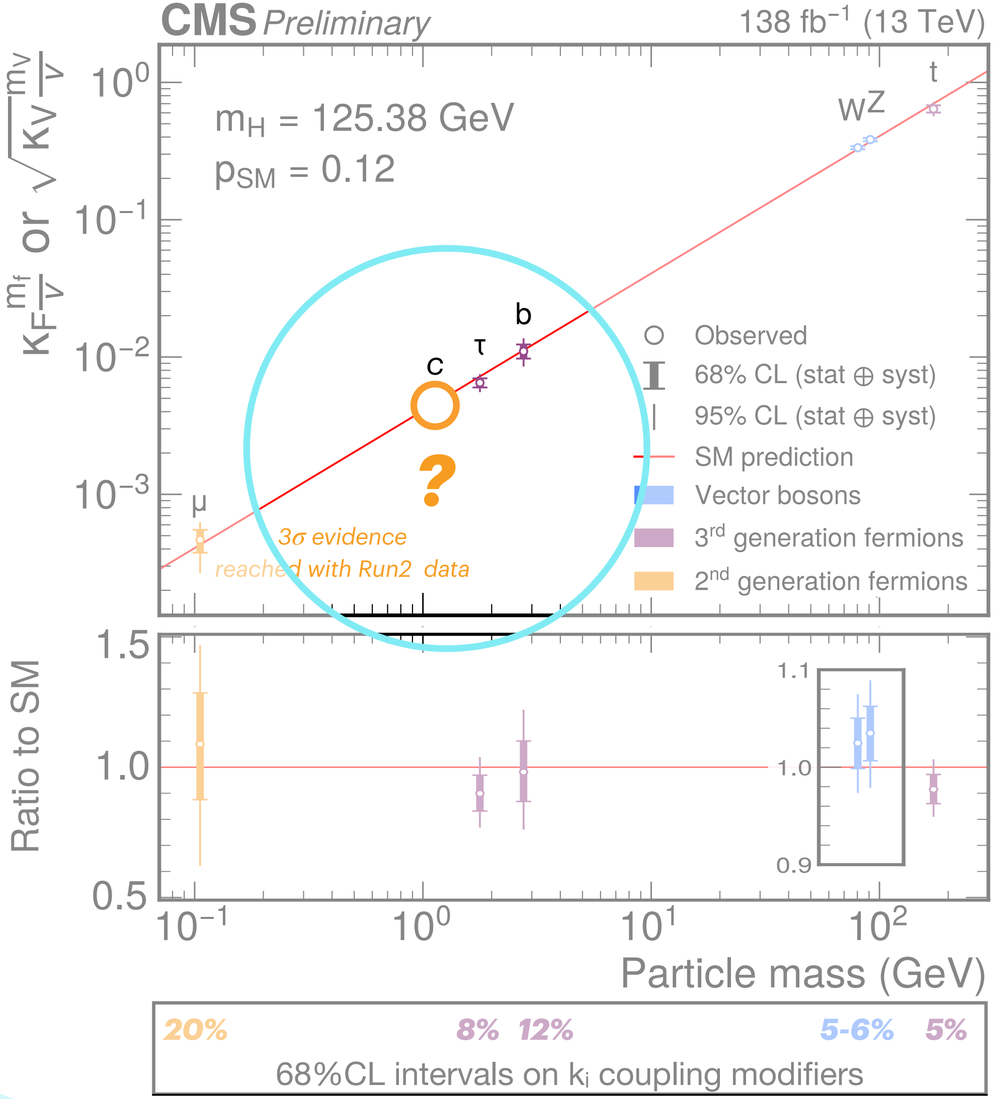
20% **8%** **12%** **5-6%** **5%**

68%CL intervals on k_i coupling modifiers

Higgs boson couplings

Constraints on coupling modifiers

resolved coupling configuration

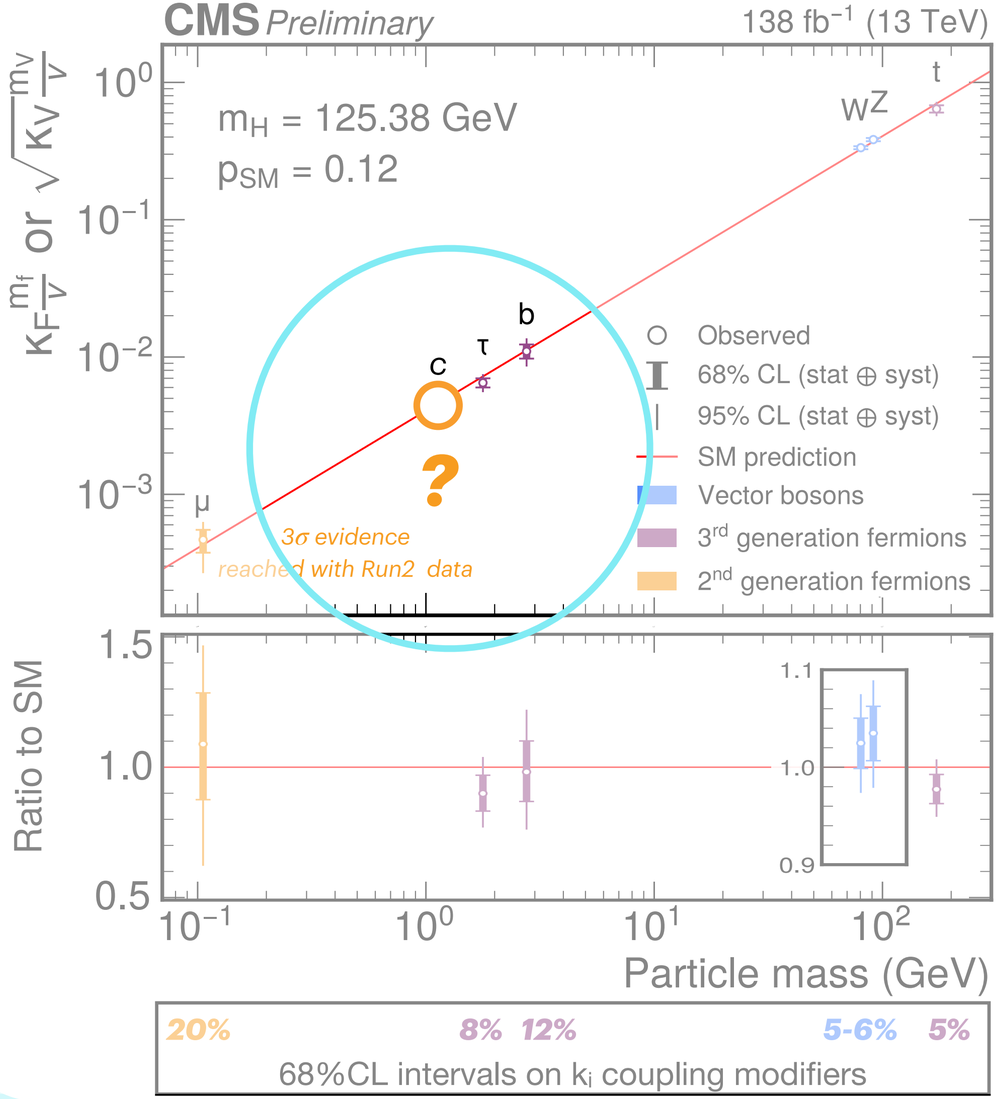


Higgs boson couplings

HIG-21-018
HIG-24-018

Constraints on coupling modifiers

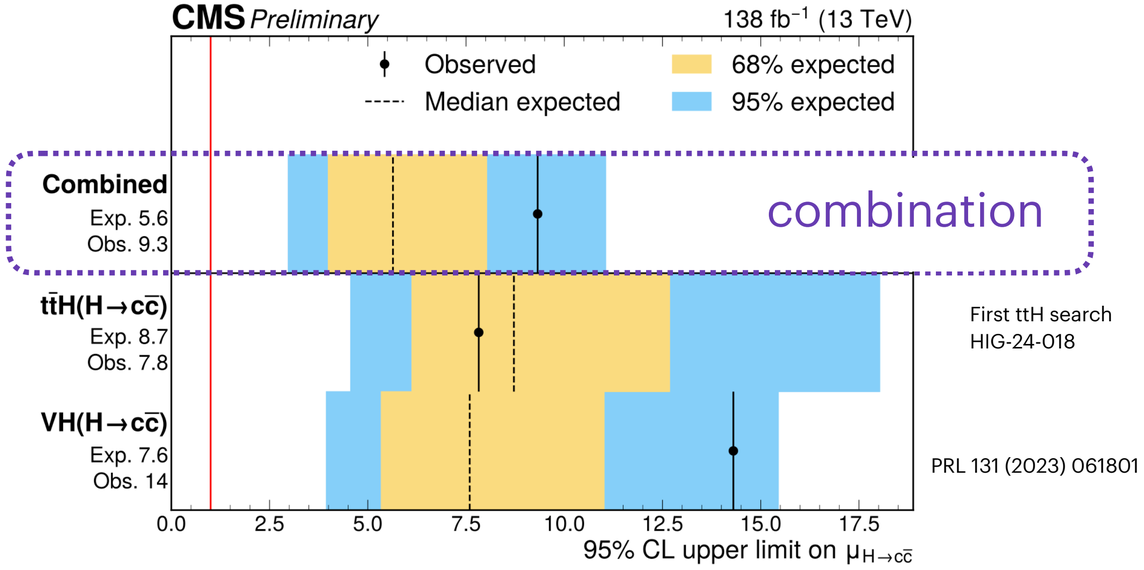
resolved coupling configuration



Probing for $H \to c\bar{c}$

First search in ttH production channel

- Graph convolutional NN for simultaneous ID of b- and c-jets (PNet)
- Multiclass event classifier-based (ParT)



First ttH search HIG-24-018

PRL 131 (2023) 061801

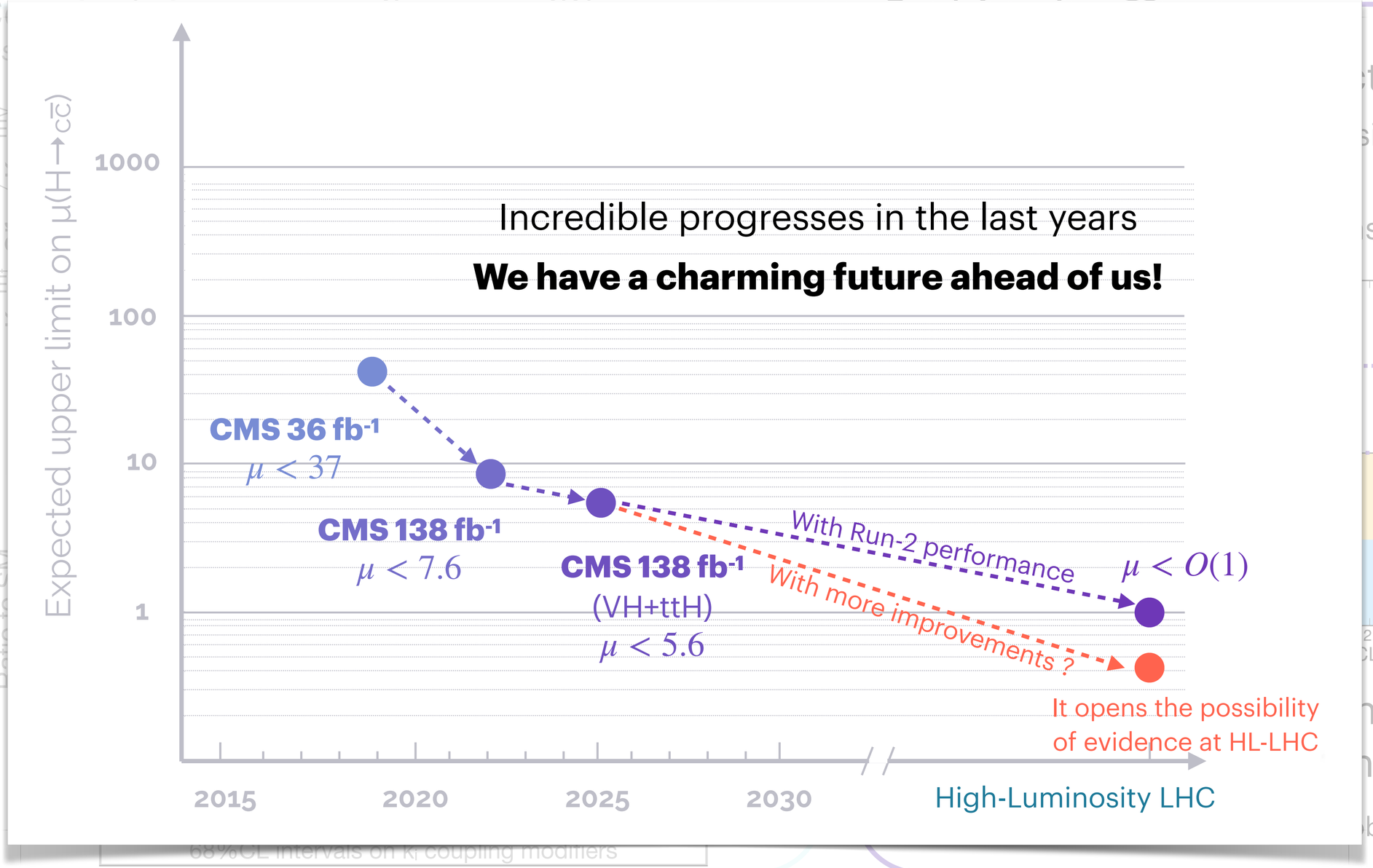
In combination with VH most stringent constraint to date

$$|y_c/y_c^{SM}| \leq 3.5\ (2.7)\ \text{obs. (exp.)}$$

Recent Highlights

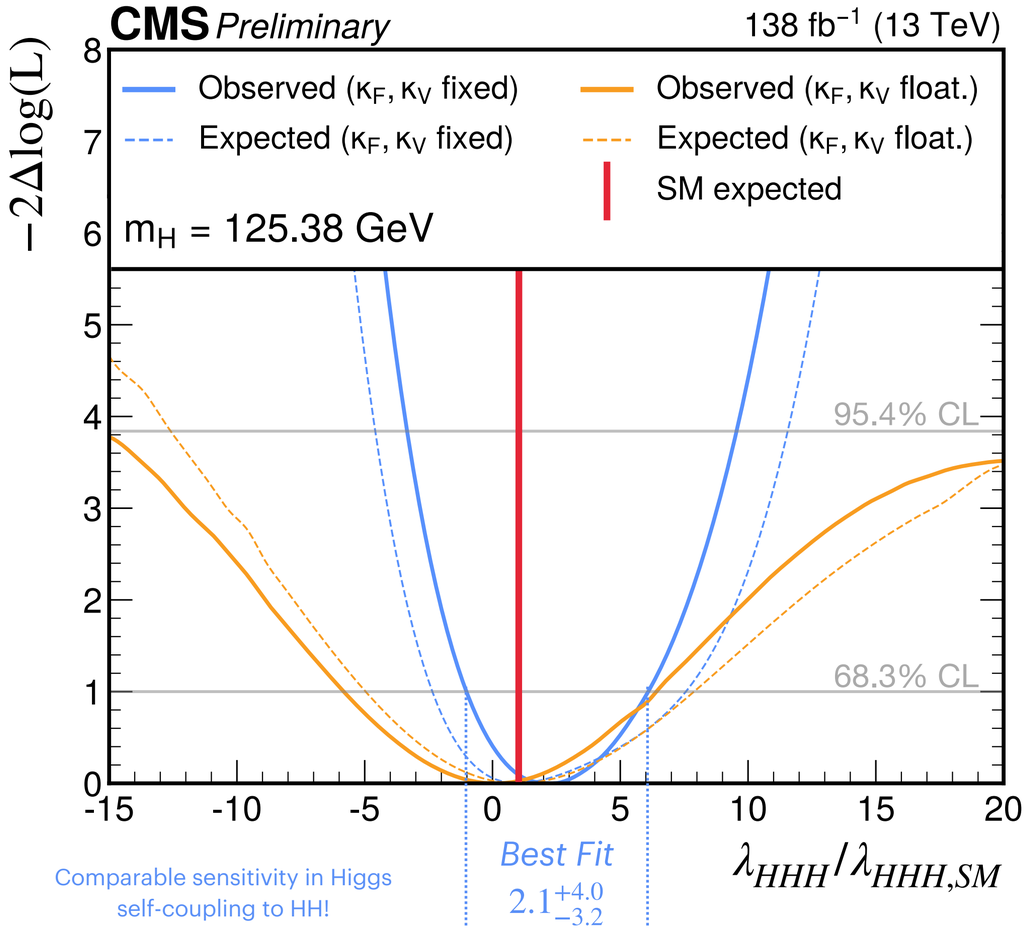
Higgs boson couplings

HIG-21-018
HIG-24-018

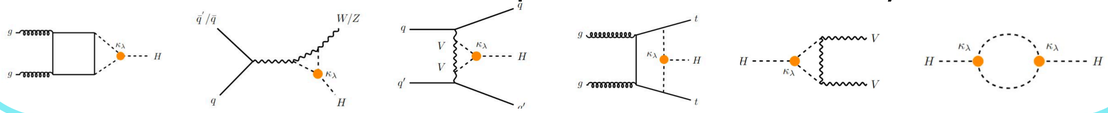


Higgs boson self-coupling

Constraints from single H



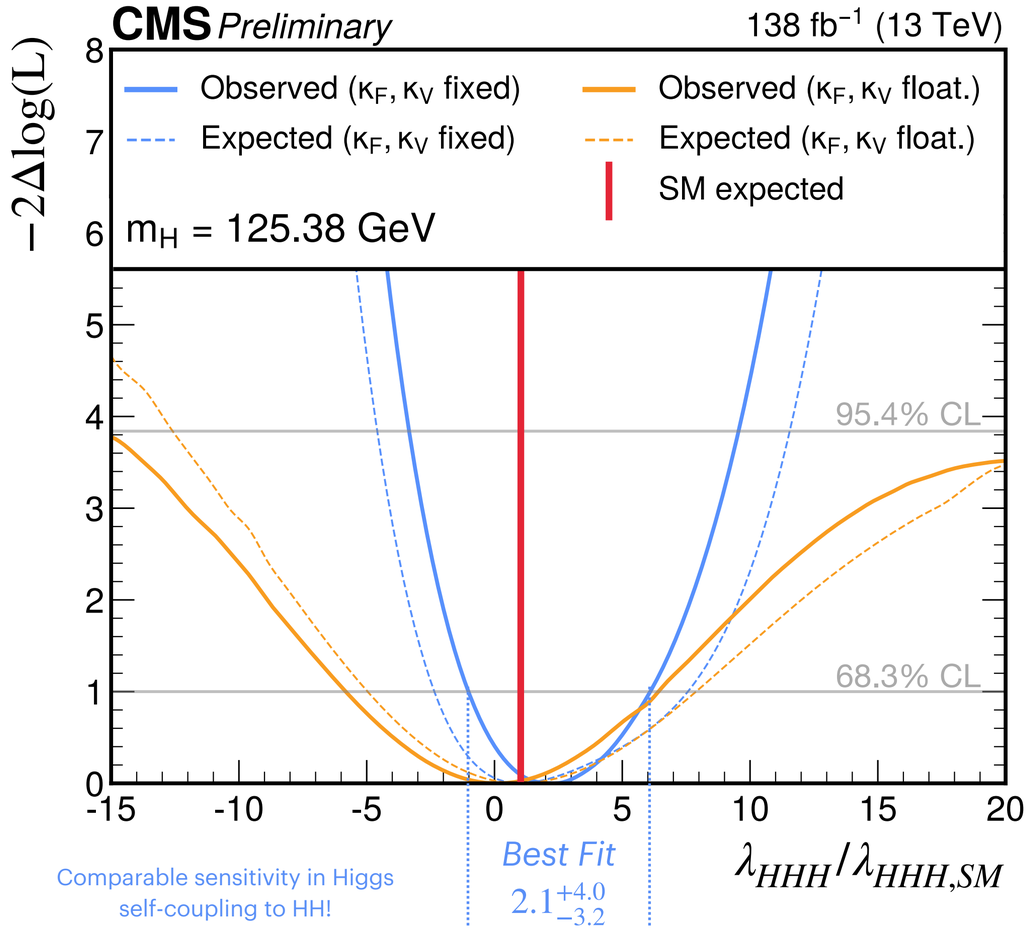
NLO EW corrections to H production and decay rates



Higgs boson self-coupling

HIG-21-018
HIG-20-011

Constraints from single H



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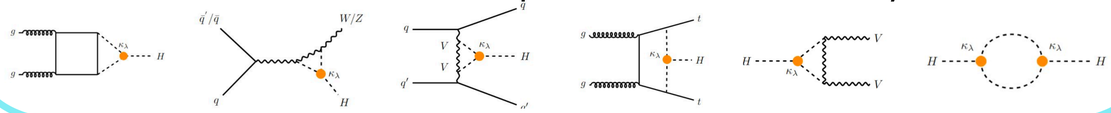
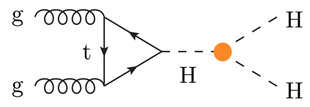
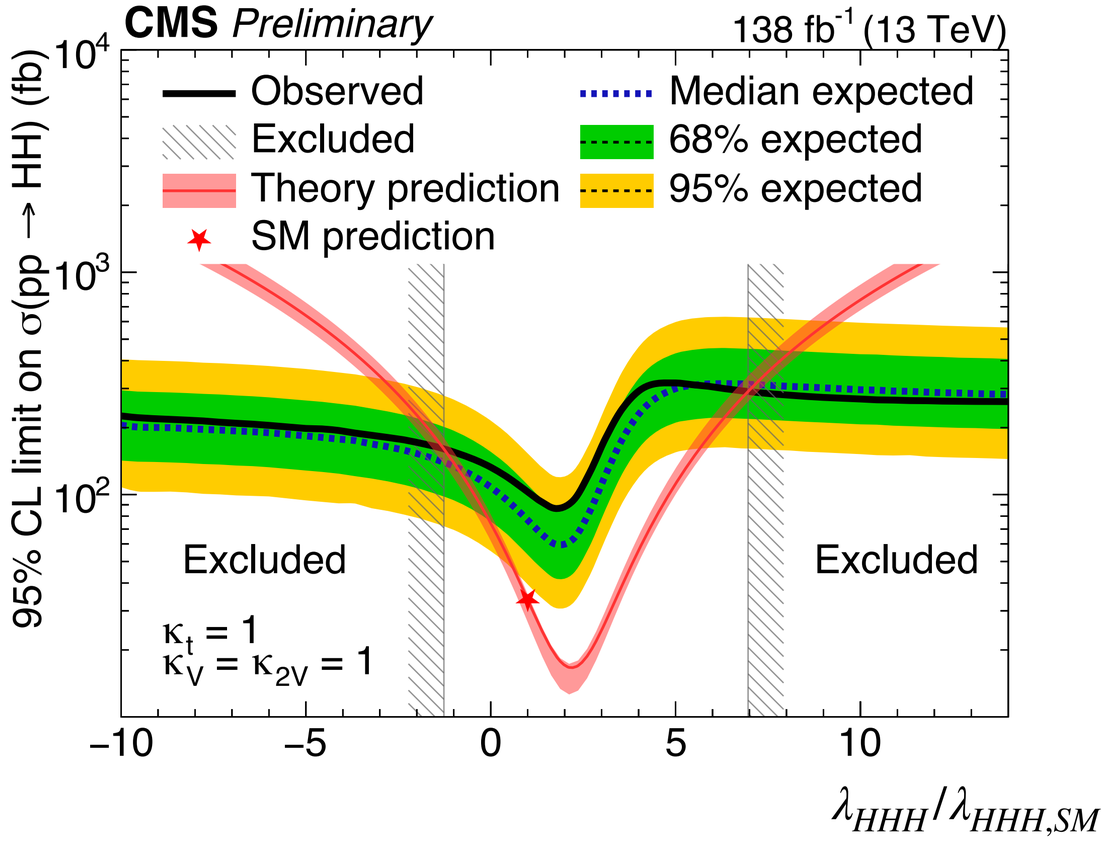


HH searches

Combination of 11 analyses





95% CL UL on σ/σ_{HH}^{SM} is 3.5 (2.5) obs. (exp.)

Recent Highlights

Top quark-antiquark excess

arXiv:2503.22382
Submitted to ROPP

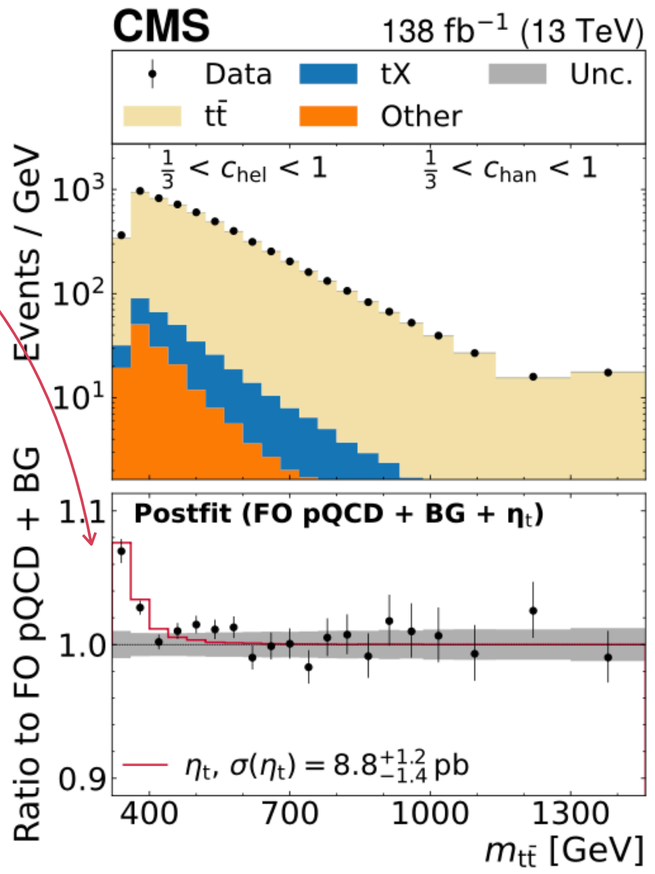
In the search for H/A resonances into $t\bar{t}$ observed an excess of data at threshold

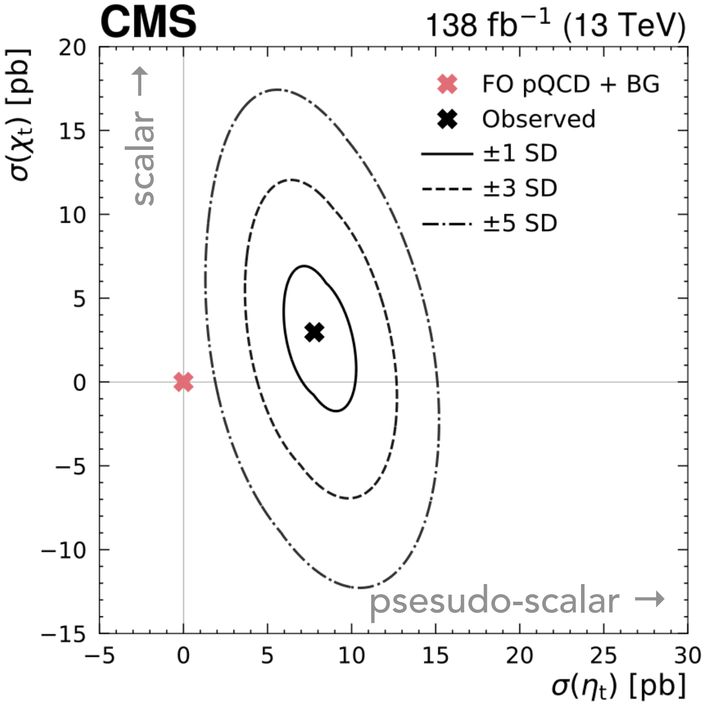
Measured cross section of a quasi-bound

$$\sigma(\eta_t) = 8.8^{+1.2}_{-1.4}\,\text{pb}$$

Compatible with NRQCD prediction $\sigma(\eta_t) = 6.4$ pb

arXiv:2102.11281 arXiv:2401.08751





Excess compatible with pseudo-scalar hypothesis

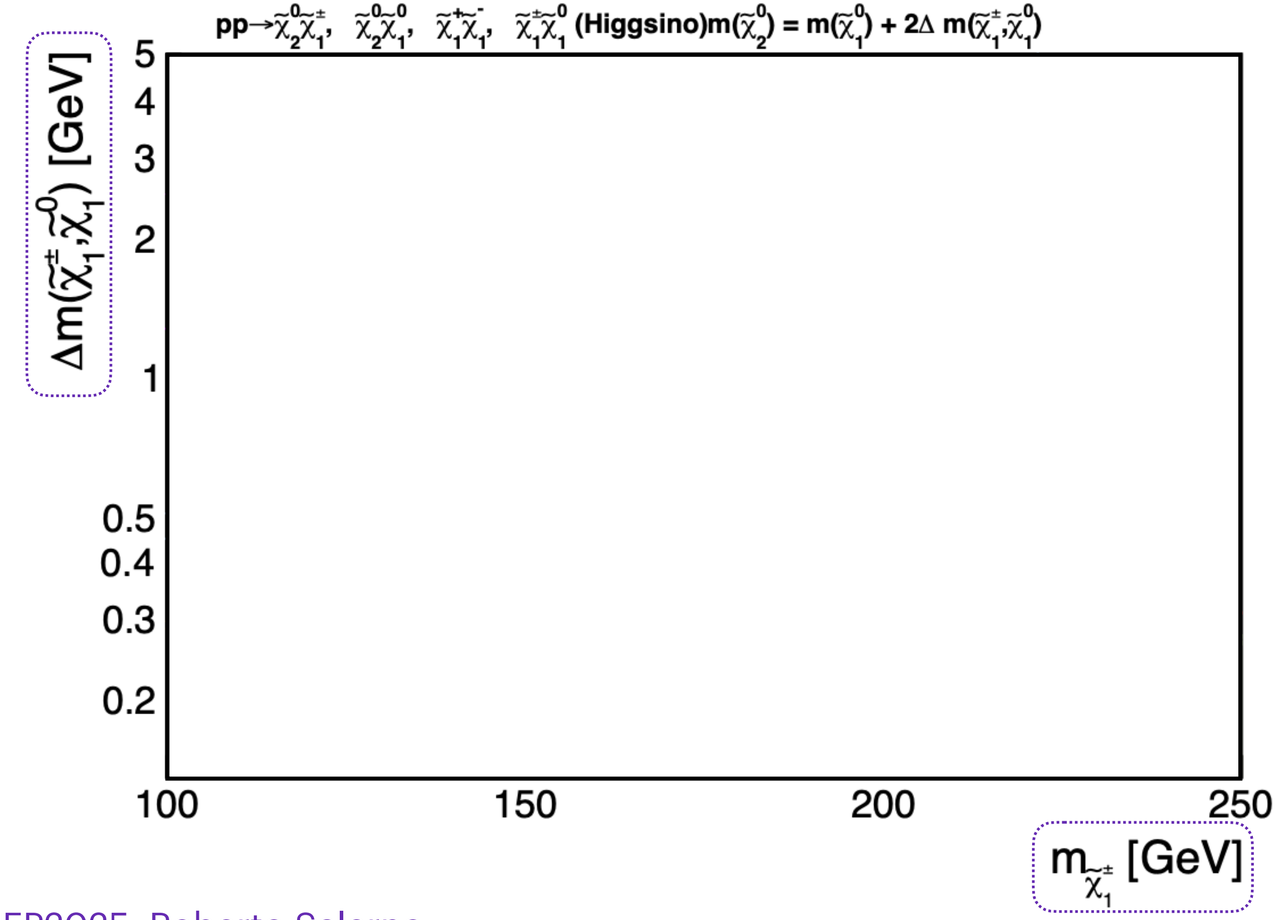
Observation of a NRQCD effect is a great triumph.

Modelling of the $t\bar{t}$ threshold region is challenging and requires further theoretical investigation

Cornering natural SUSY

Experimental data has sign of large part of the natural SUSY parameter space from stops and gluinos searches

Extend searches to natural models with light higgsino and light wino and bino super partners so they can reproduce the measured relic density.



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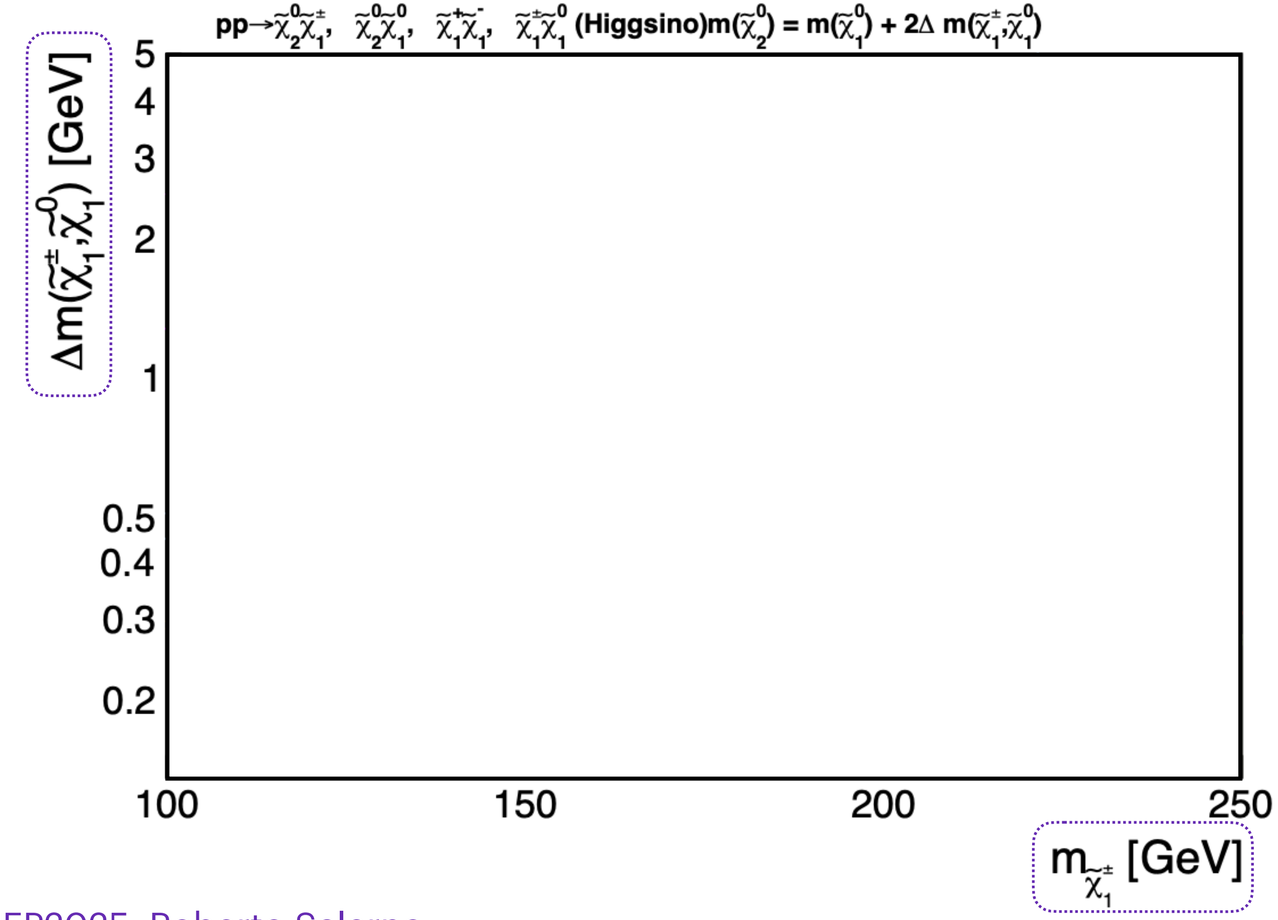
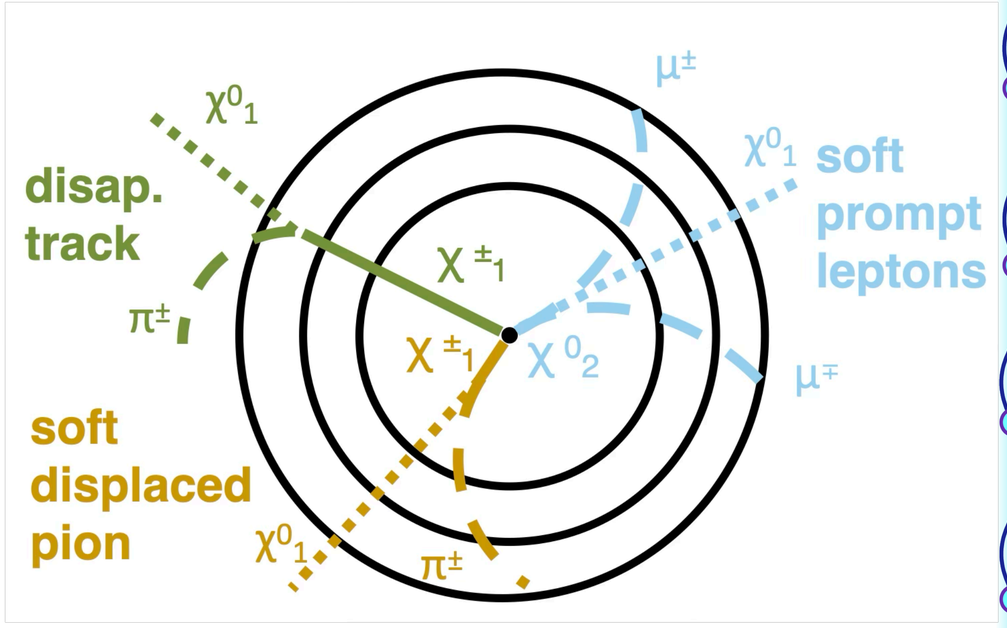


Experimental challenging analyses with soft lepton and tracks



Cornering natural SUSY

EXO-23-017 SUS-24-012
SUS-24-003 PRD 109 (2024) 072007

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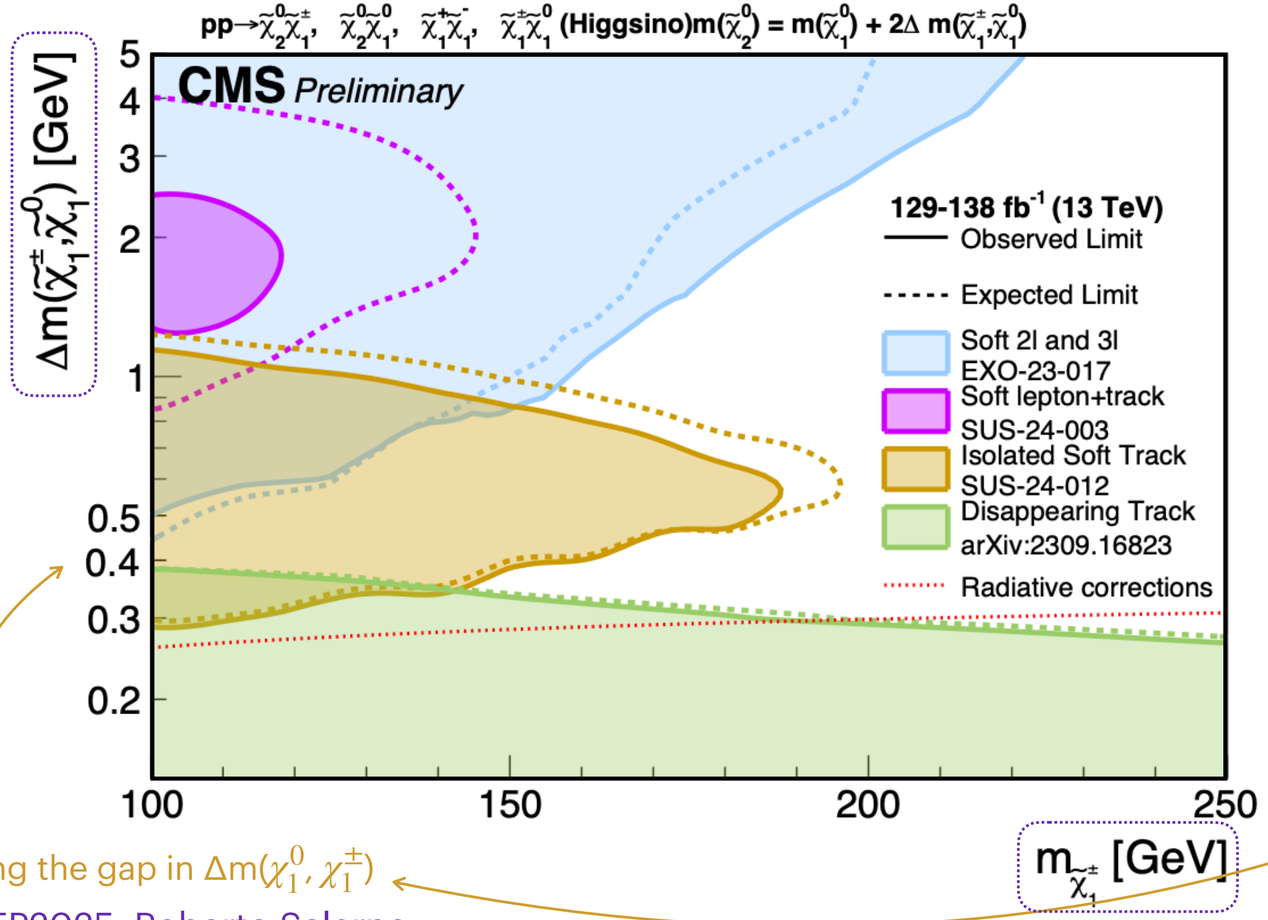
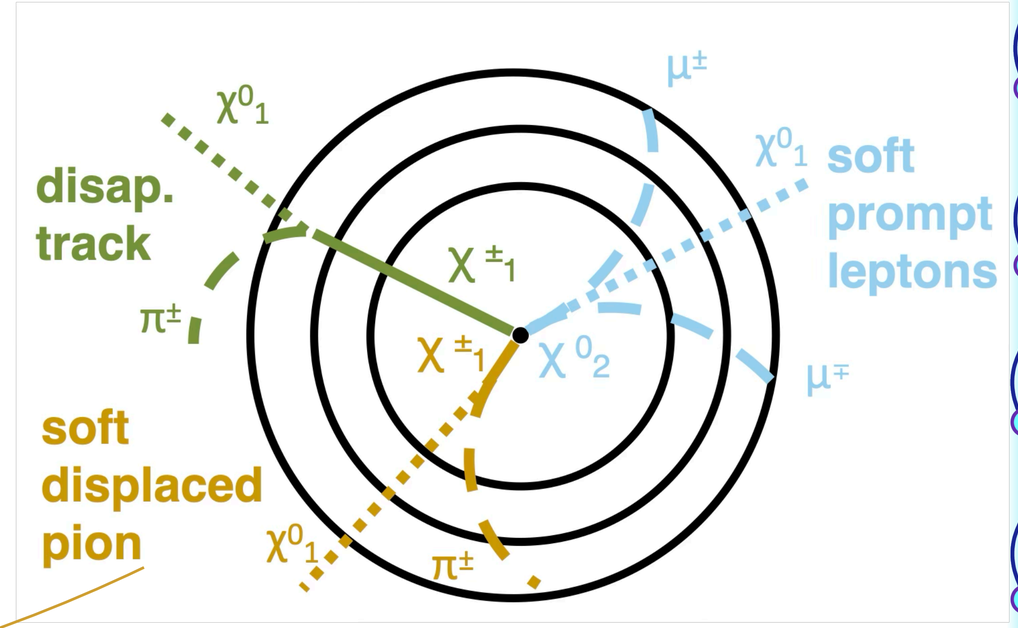


Closing the gap in $\Delta m(\chi_1^0, \chi_1^\pm)$

Experimental challenging analyses with soft lepton and tracks



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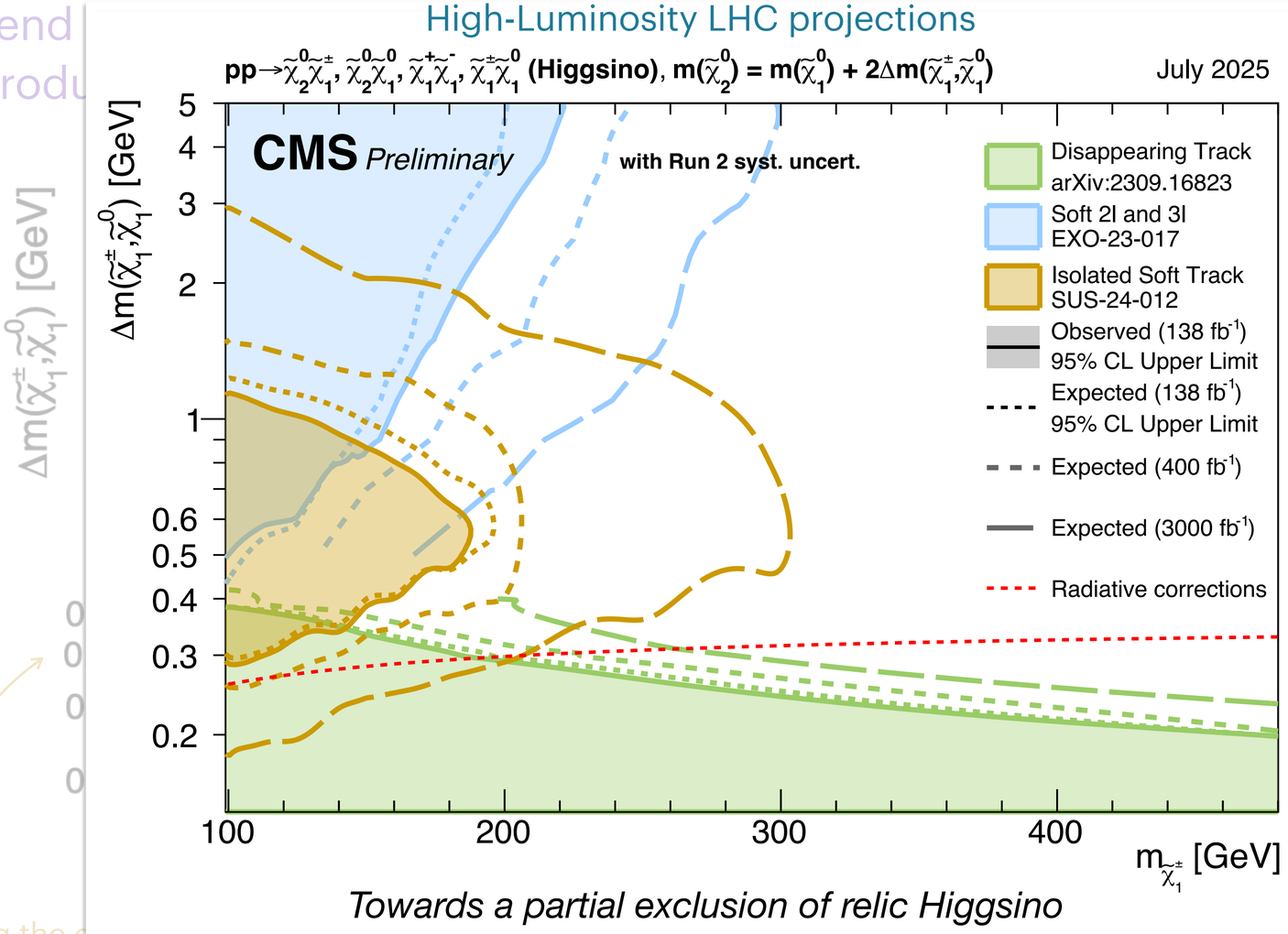
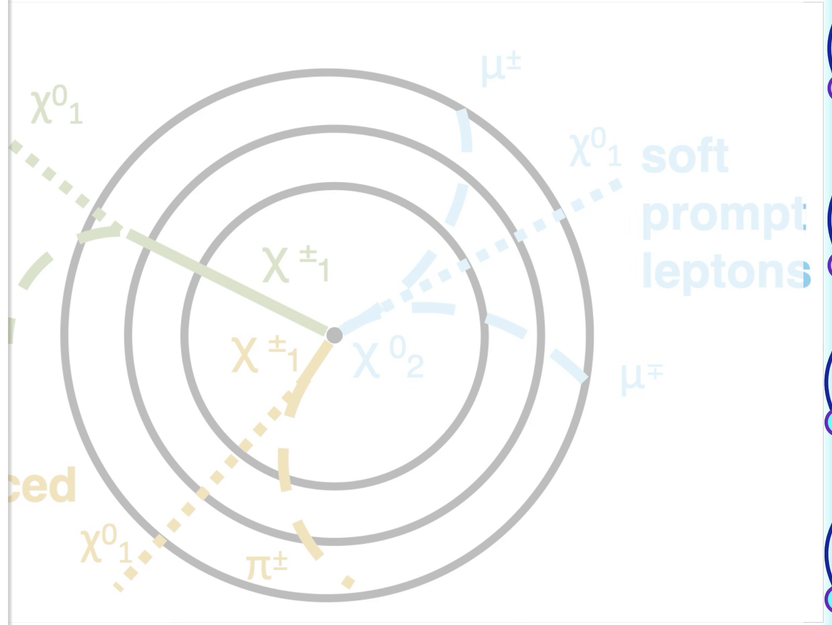
Extend … d bino super partners so they can reprodu…

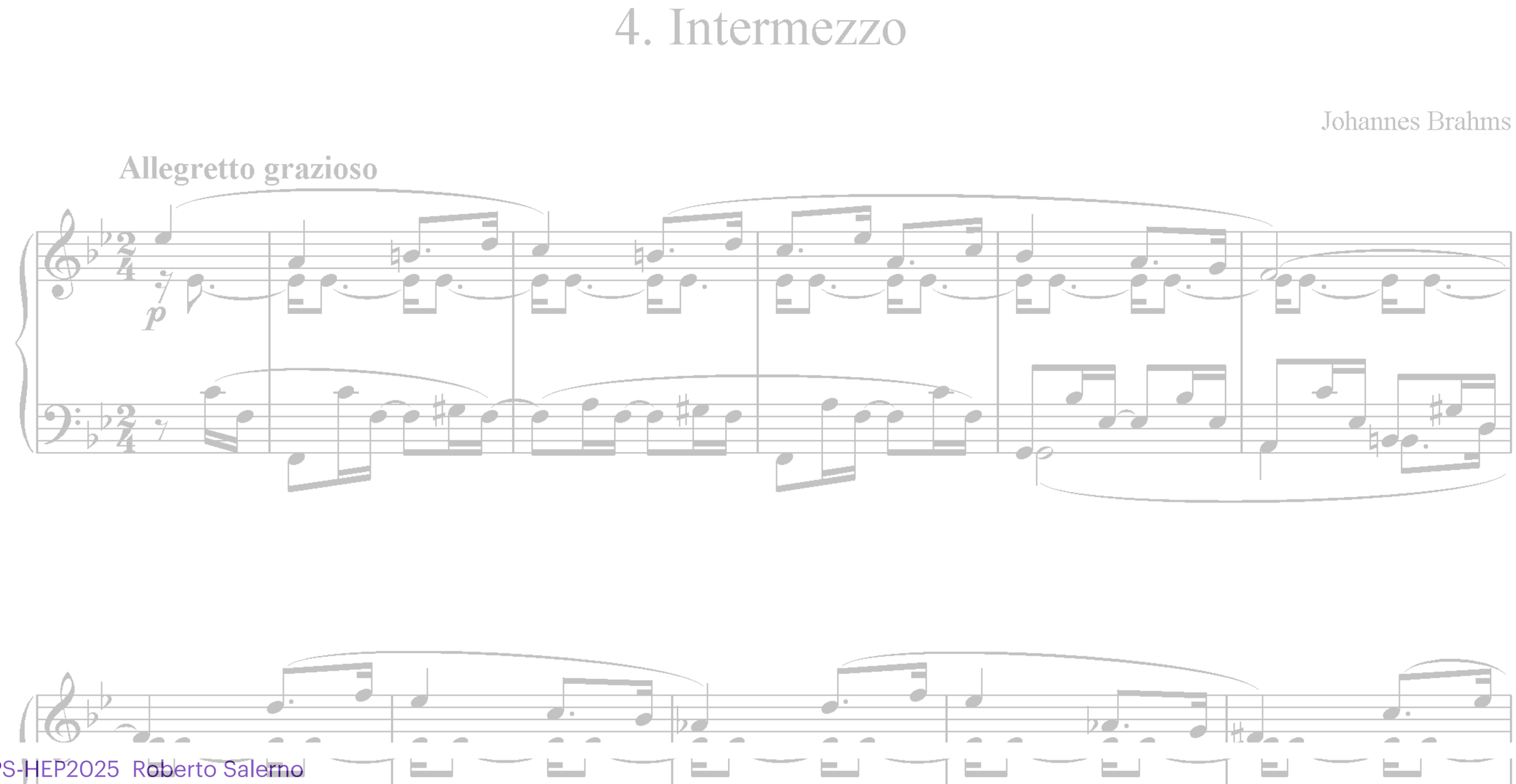
…mental challenging analyses …th soft lepton and tracks





Closing the g…

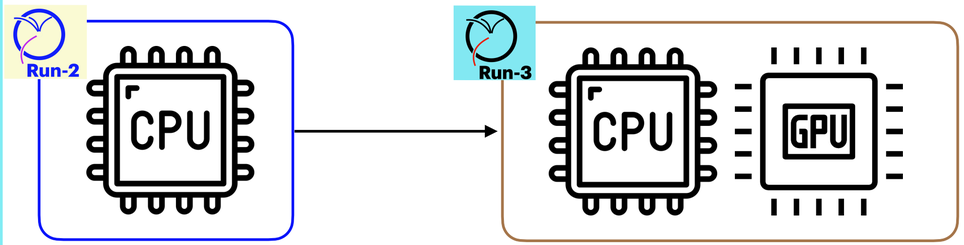
CMS as a technology driver



CMS as a technology driver

Heterogeneous computing

Successful R&D effort to run the High-Level Trigger reconstruction on heterogeneous hardware in production since the start of Run-3



Faster and more power-efficient HLT reconstruction

- **+50%** event processing throughput
- **+15-25%** performance per kW

Portable heterogeneous software (Alpaka) deployed

- same code base can run seamlessly on CPUs and GPUs

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CMS-DP-2024-082
CMS-DP-2025-034

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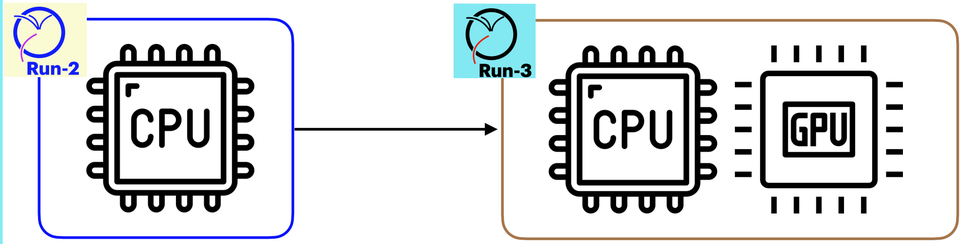

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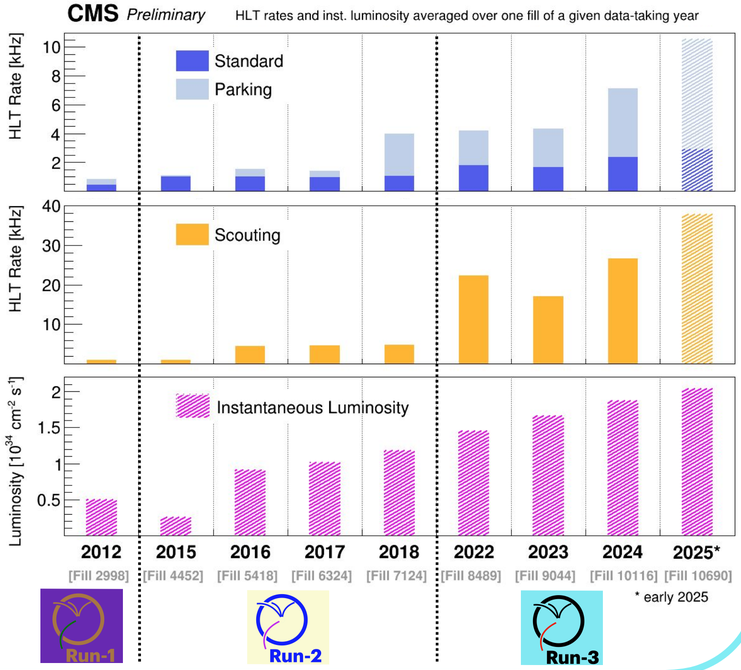
"Standard", "Parking" and "Scouting" pushing CMS trigger coverage far beyond Phase-1 design values

Parking is now integral to the core physics program (Higgs, searches, etc.), and opens large phase space for flavour physics.

HLT scouting runs at ~30 kHz (1/3 of accepted L1T events)

- Using HLT objects for physics analyses in an even wider phase space



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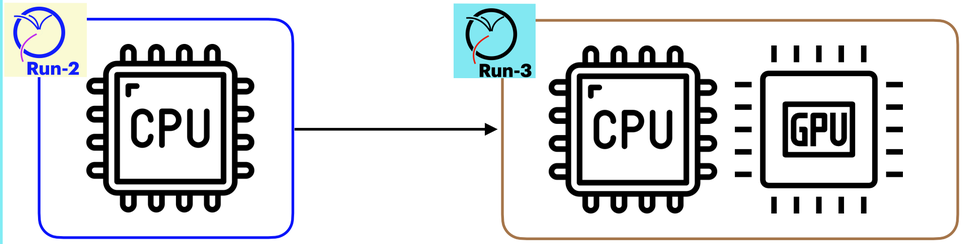

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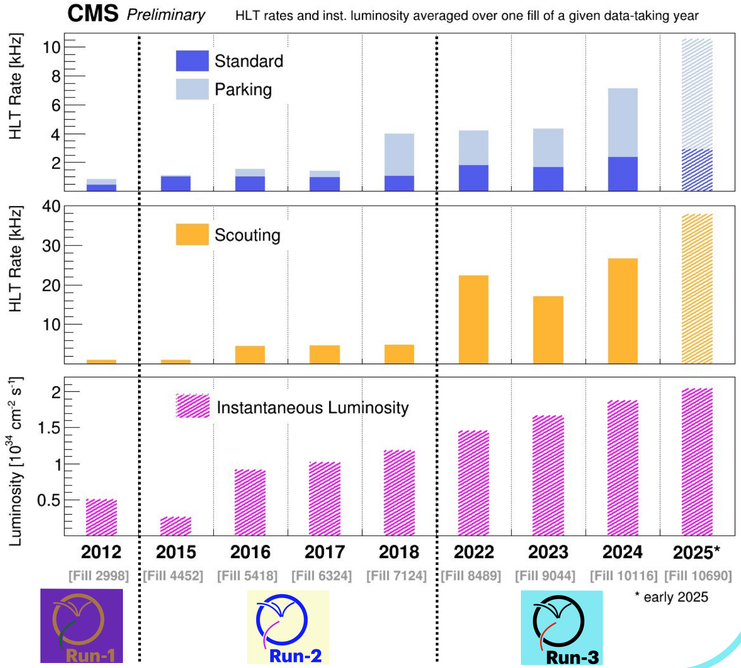
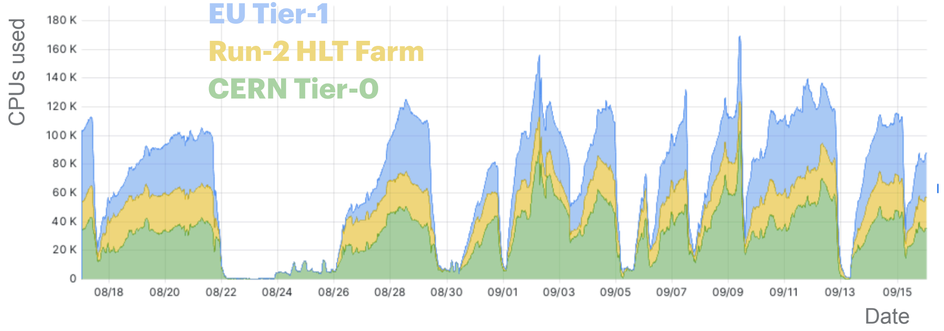


Big computing infrastructure

Parking data is processed quickly without delaying, using also the Run-2 HLT Farm and European Tier-1 for prompt reconstruction



Opportunistic resources, as High-Performance Computing (HPC) facilities, are used for MC production.

In 2024, CMS can generate 1.5B events per week.

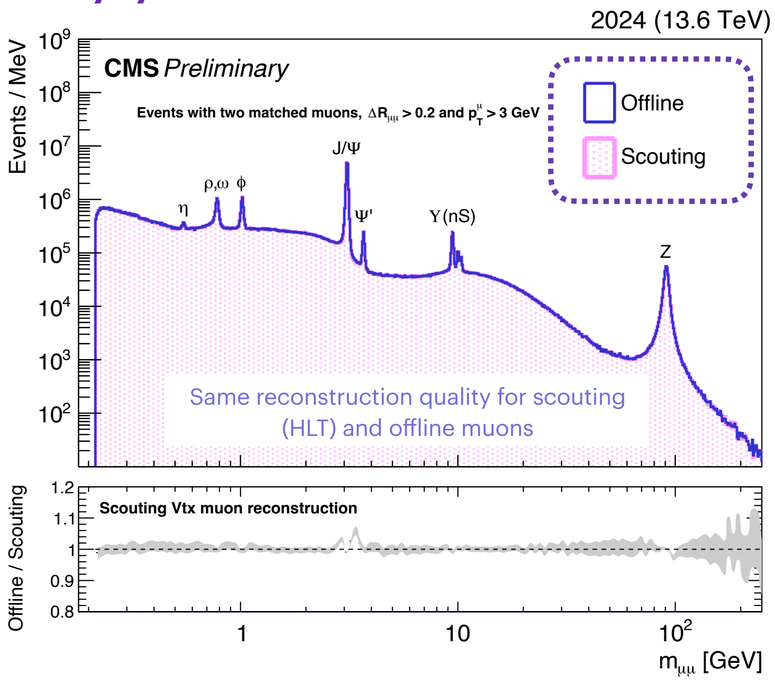
Low mass searches

EXO-24-016

Scouting data set Run-3

Going beyond the designed trigger constraints with the scouting data set. Record reduced information at high rates, opening up otherwise inaccessible low-mass phase space

$\mu\mu$ resonances



CMS-DP-2025-029

Recent Highlights

Low mass searches

EXO-24-016

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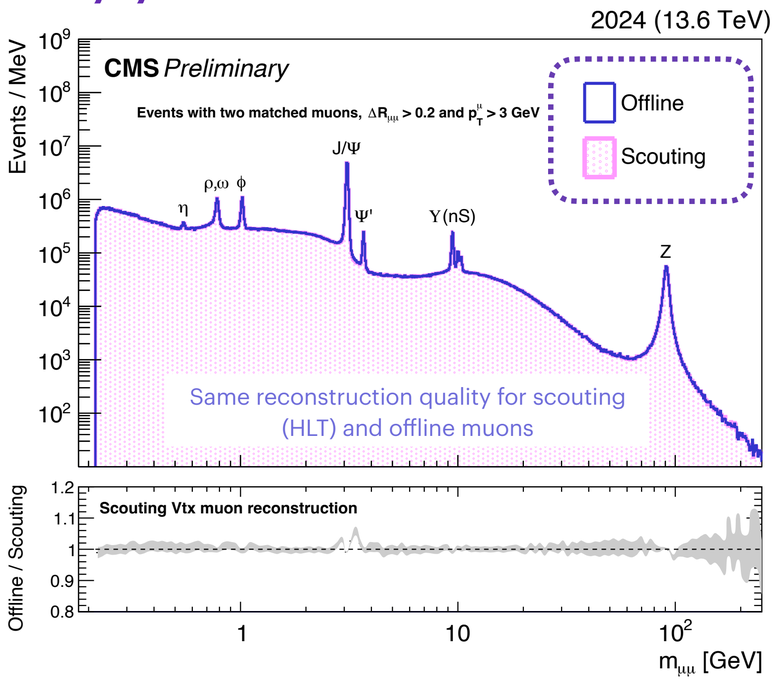

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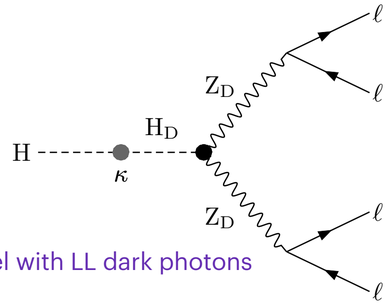
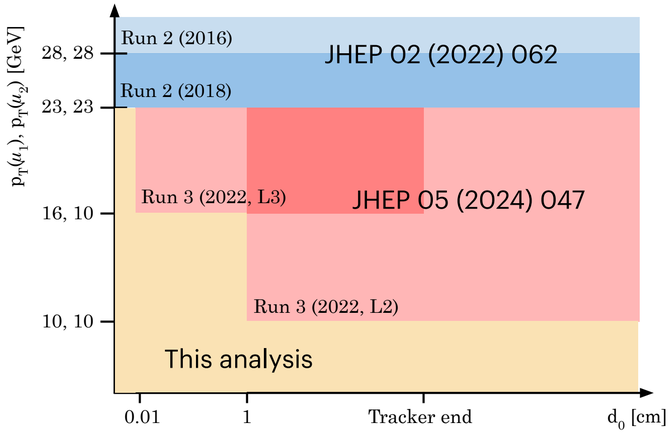


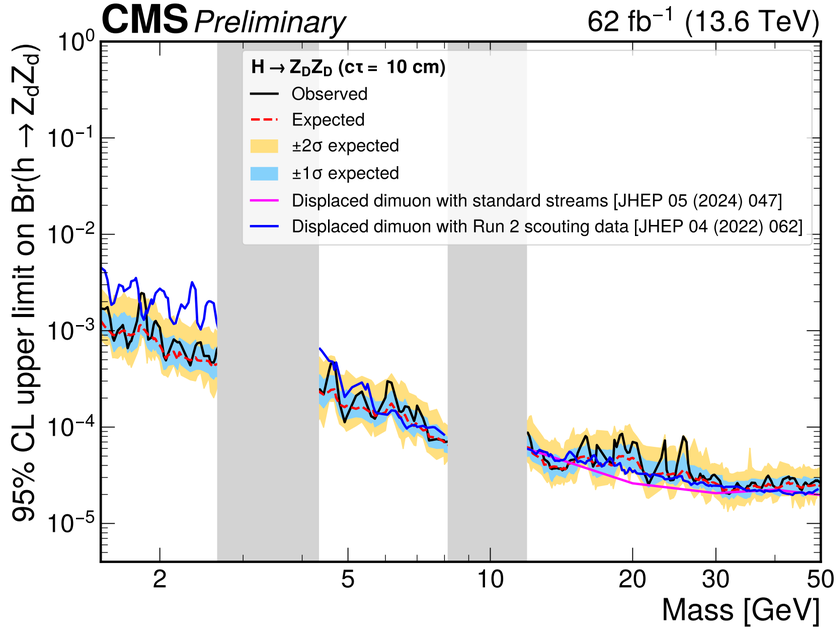
HADH model with LL dark photons

H decays to long lived dark particles with muons in the final state

Extending the reach wrt previous analysis



Lower lepton p_T lower masses can be probed



Recent Highlights

Low mass searches

$\tau\tau$ resonances

EXO-24-012

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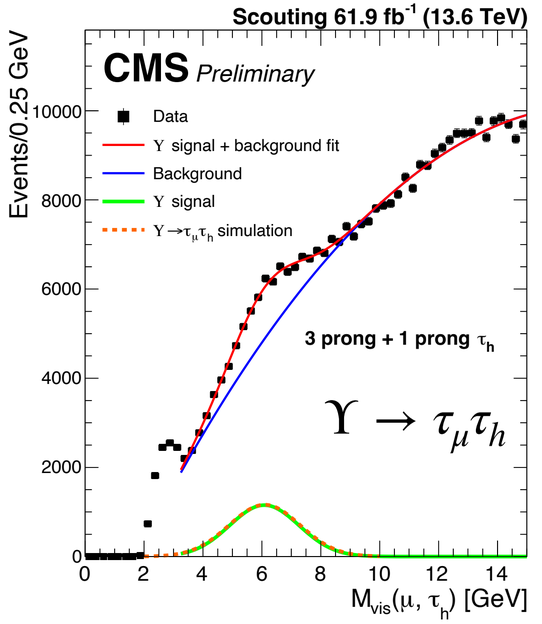
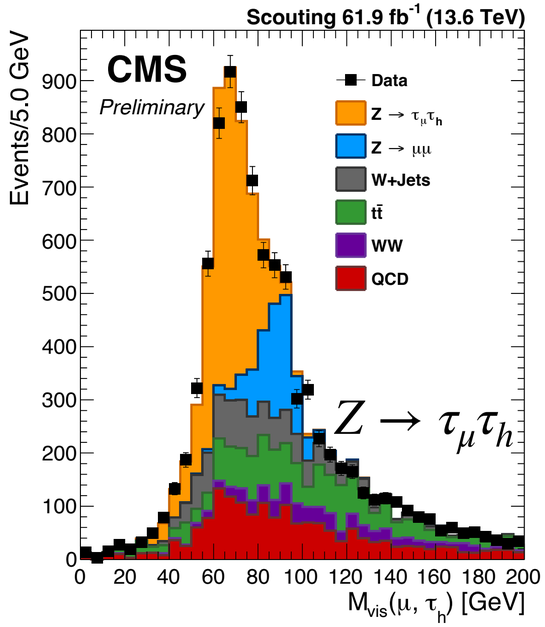
SM candles



Structure at the Υ mass



Reached offline-like resolution

Low mass searches

$\tau\tau$ resonances

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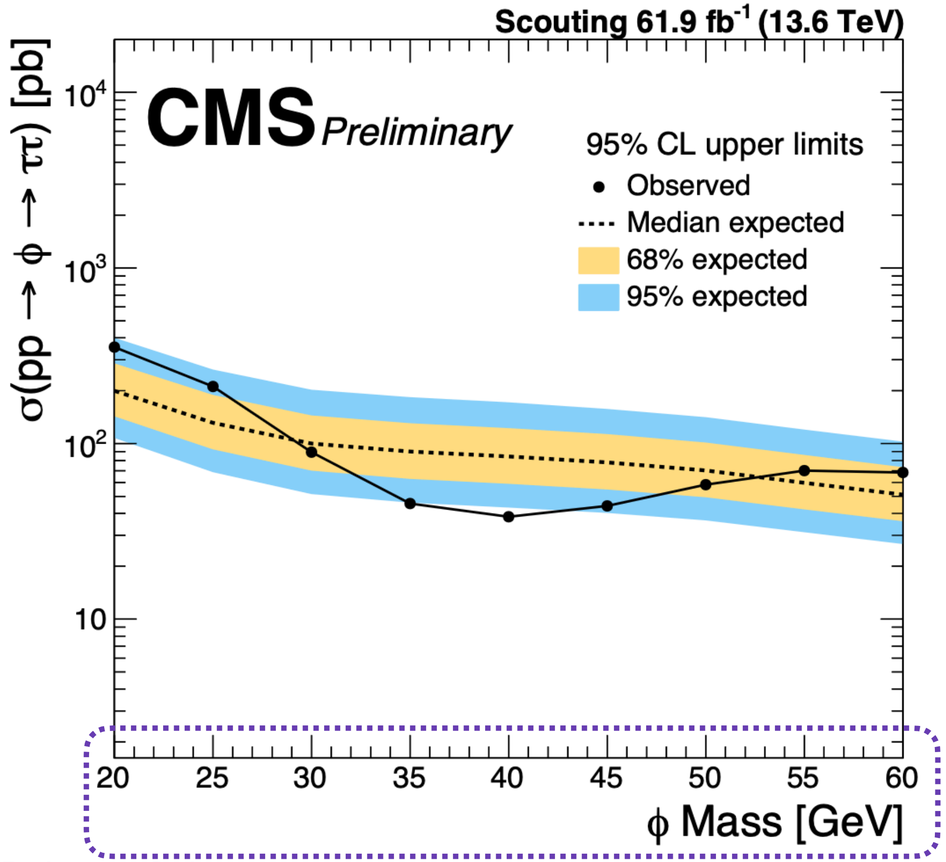

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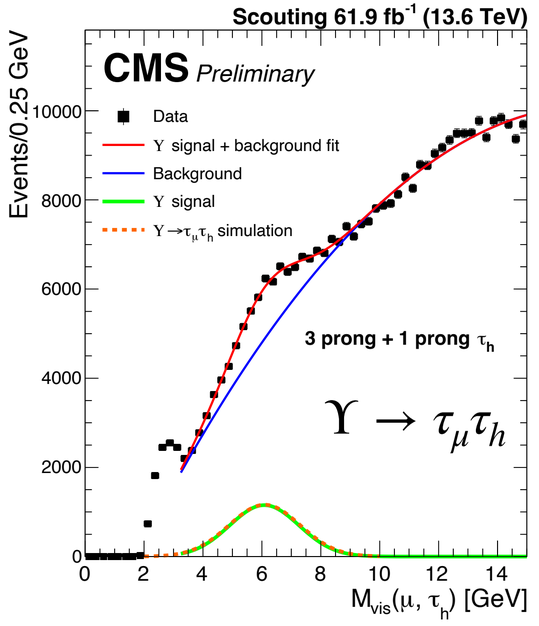

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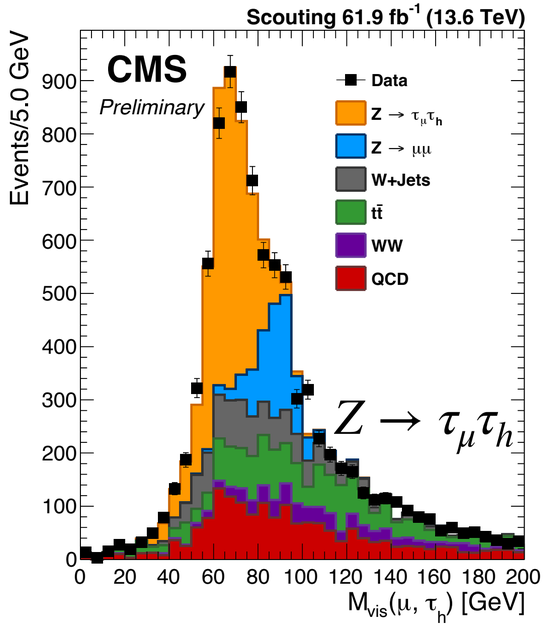


Reached offline-like resolution

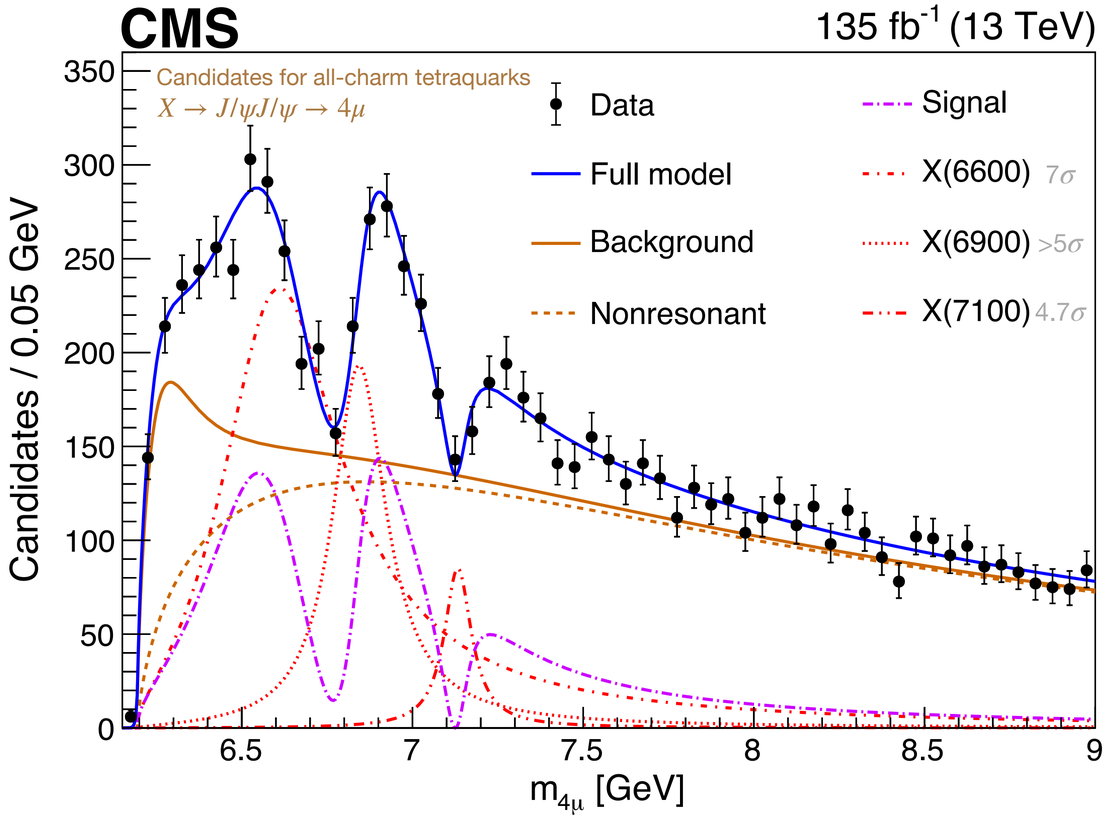
First time masses <60 GeV explored at hadron colliders

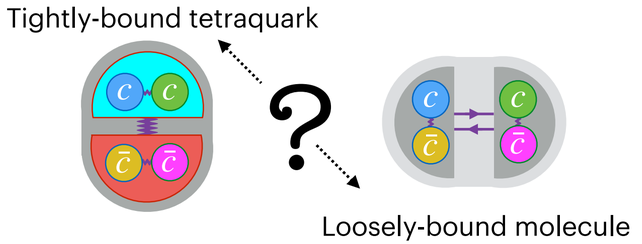
Determination of J^{CP} all-charm tetraquarks

arXiv:2506.07944
Submitted to Nature

Observation of 3 X states in the $J/\psi J/\psi$ final state

Mass spacings following a radial Regge trajectory plus interference pattern
→ the 3 X particles form a family of cccc states with **same quantum numbers**





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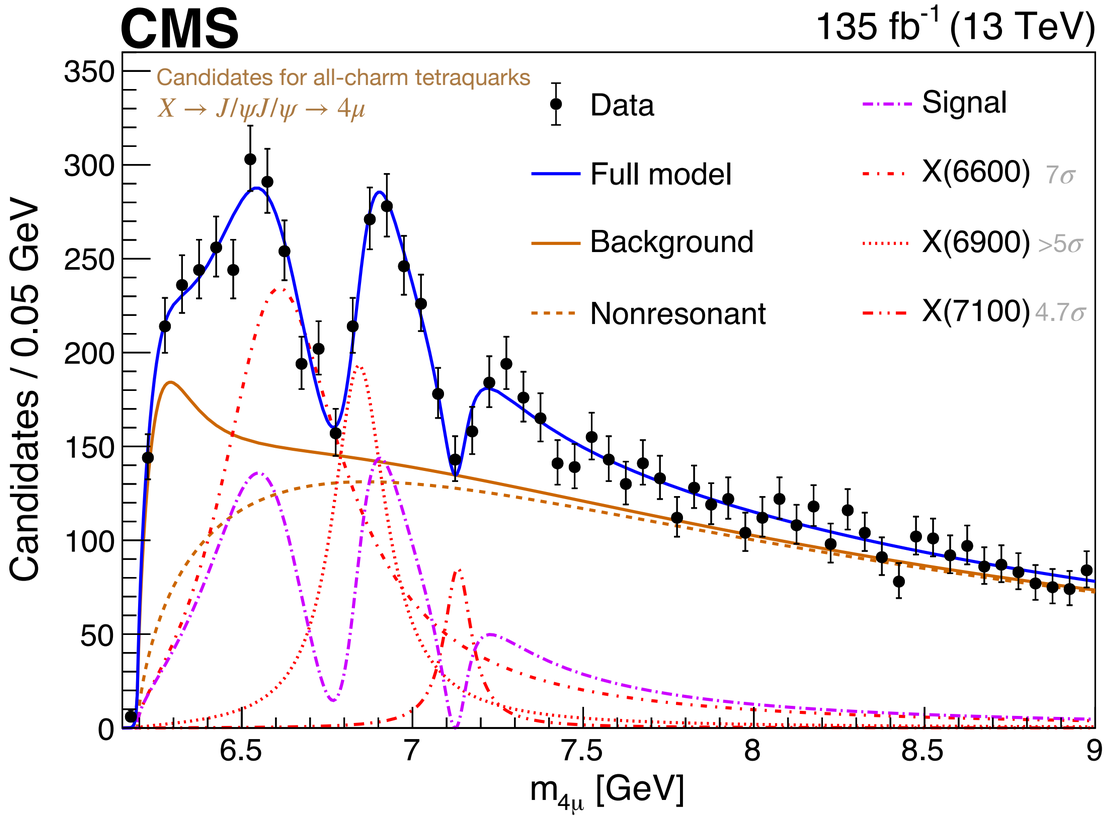

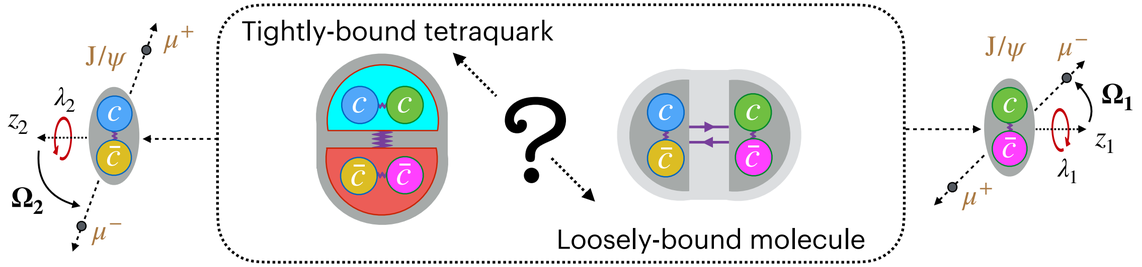

J^{CP} can be inferred from the polarizations of the mesons
→ angular distributions of the decay muons

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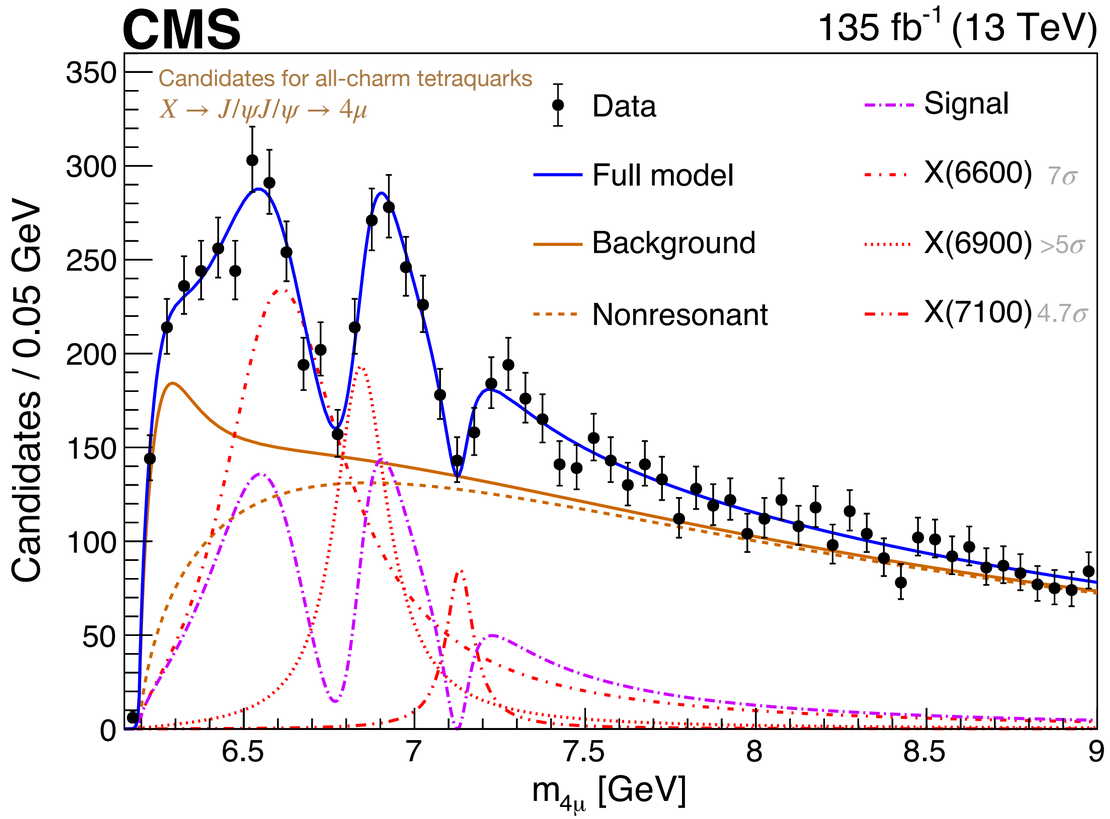

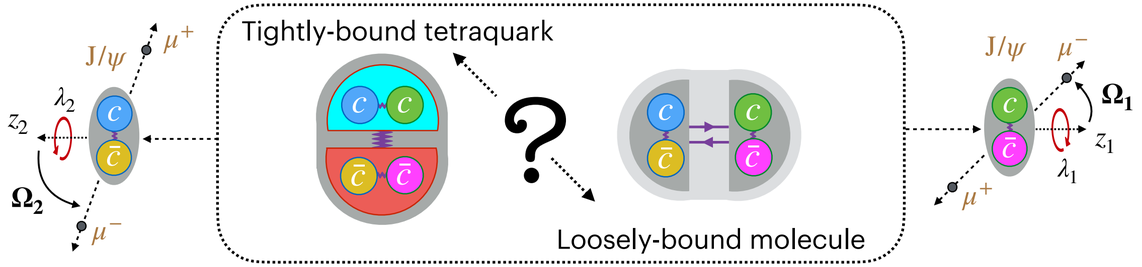

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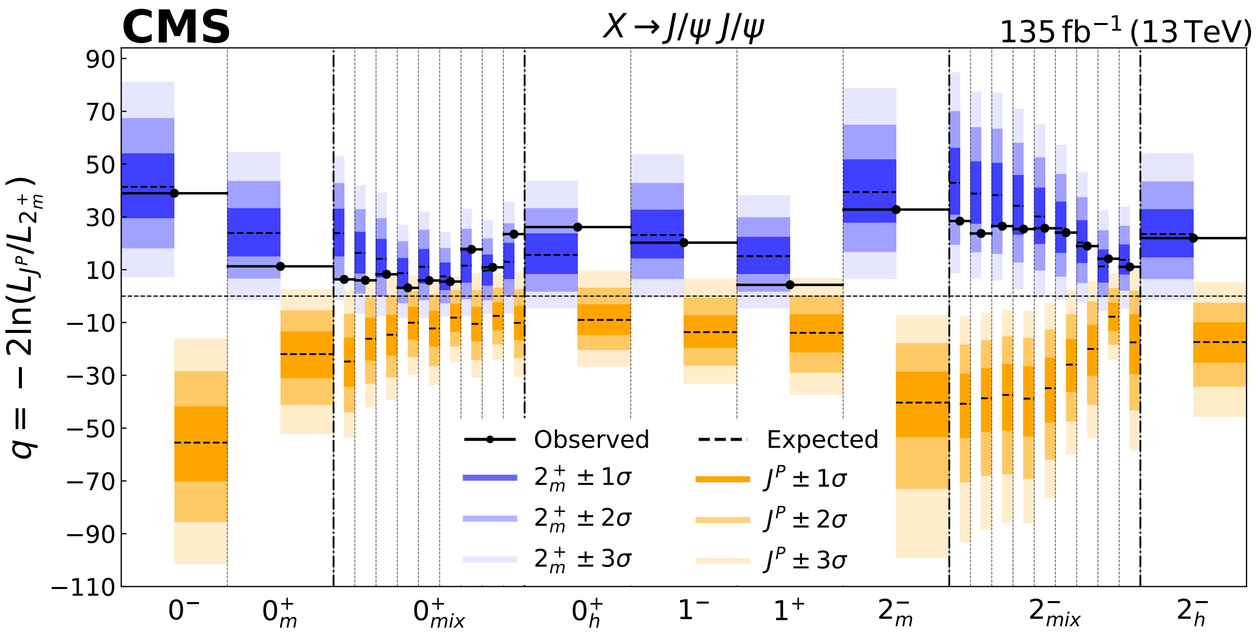

CP = ++ established

Data consistent with 2+ (bound tetraquark) and inconsistent with others

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Mass spacings following a radial Regge trajectory plus interference pattern
→ the 3 X pa

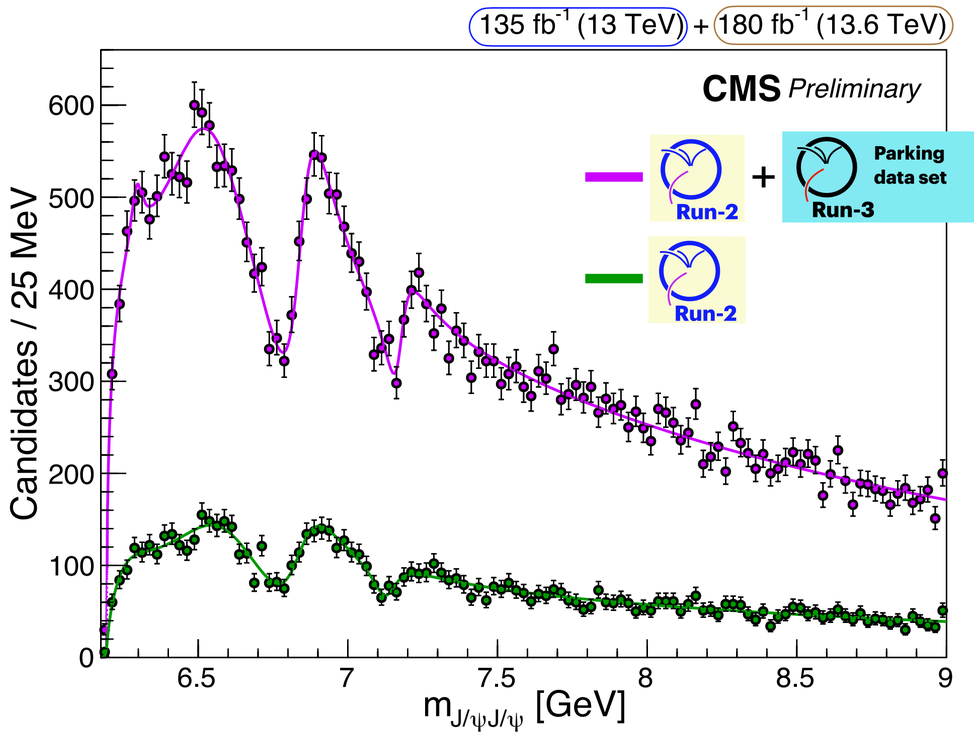
Tightly-bound tetraquark

BPH-24-003

Run-3 will bring significantly larger sample statistics thanks to parking data stream

3.6 times more $J/\psi J/\psi$ pairs

Expect more detailed studies of X family with enhanced dataset available



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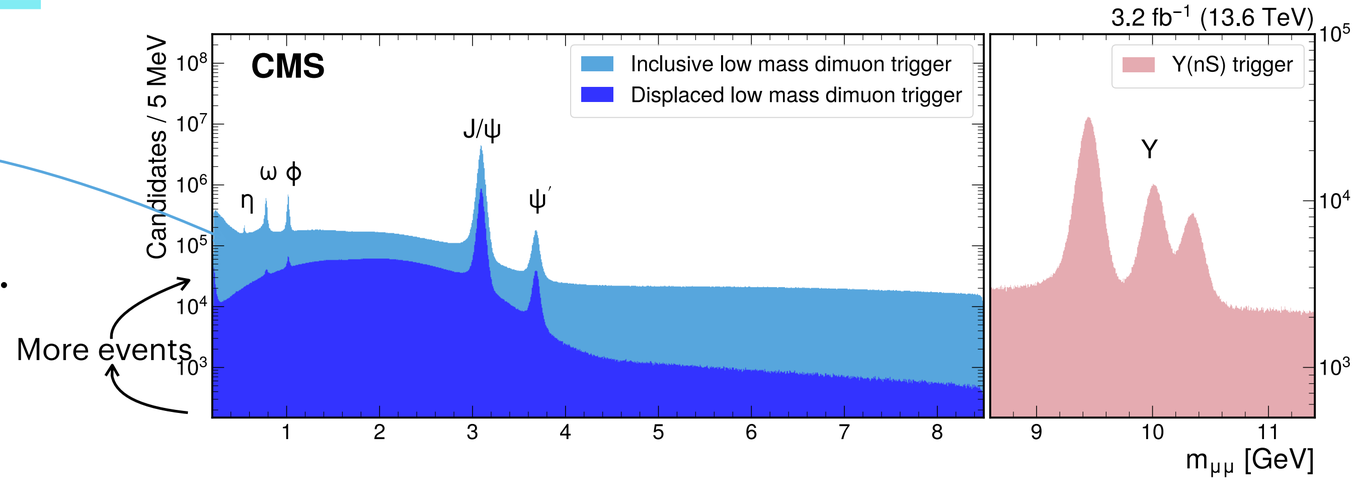
Recent Highlights

Search for rare D⁰ decay

arXiv:2506.06152
Submitted to PRL

Parking data set Run-3

In Run-3 using a new inclusive dimuon trigger,
the low-mass coverage below 8.5 GeV is extended.
Crucial for future low-mass flavor physics studies.



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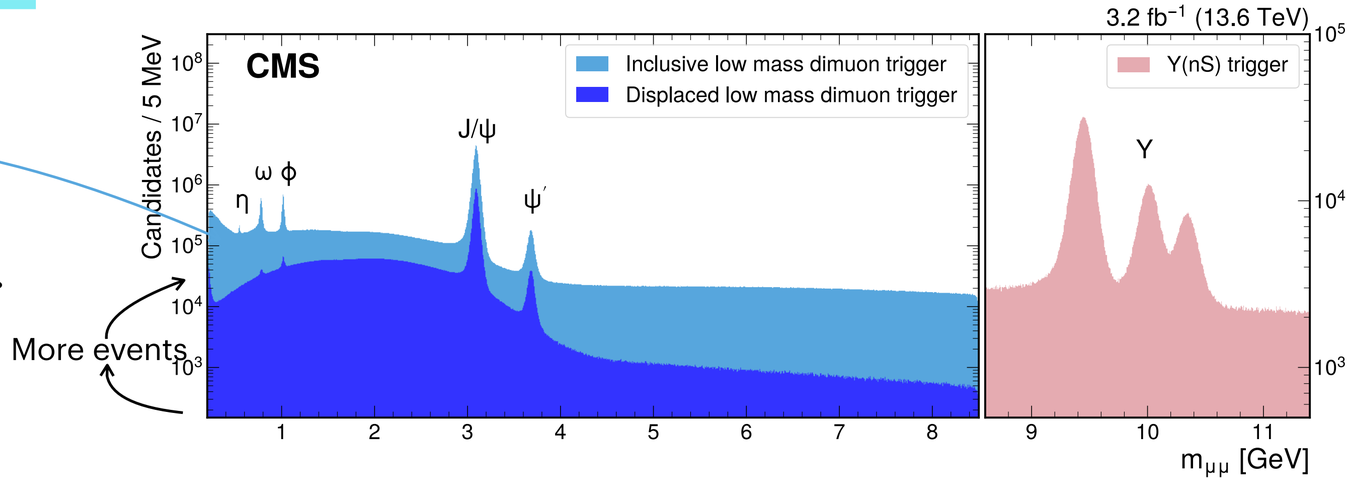


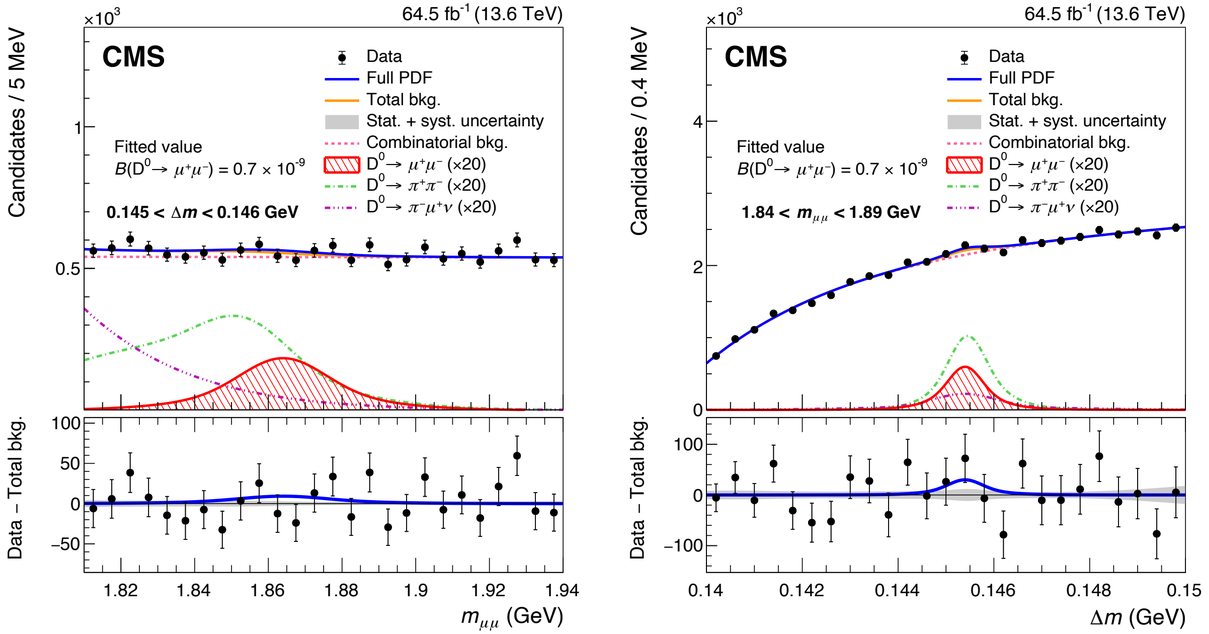
Study of the rare D⁰ decays mediated by flavor changing neutral currents

Rare decays of charmed hadrons via c → u process

$$\mathcal{B}(\mathrm{D}^0 \to \mu^+\mu^-) < 2.1\,(2.4) \times 10^{-9} \text{ at } 90\,(95)\%\ \mathrm{CL}$$

Setting the most stringent limit on flavor changing neutral currents in the charm sector

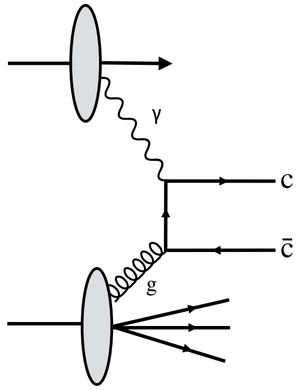
2D unbinned maximum likelihood fit $m_{\mu\mu}$ and $\Delta m = m_{D^{0*}} - m_{D^0}$

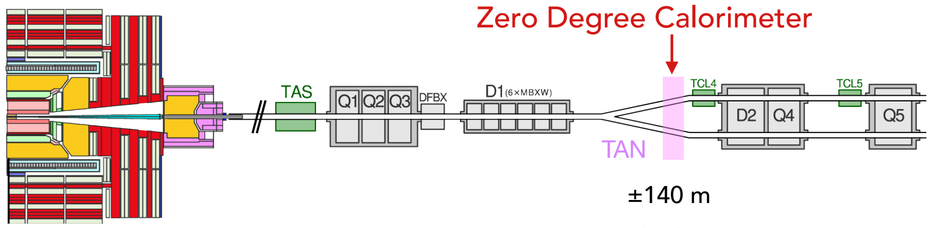


Measurement of D^0 in UPC

arXiv:2507.nnnnn
Submitted to PRL

Photonuclear D^0 meson production in ultraperipheral lead-lead collisions





covers $|\eta| > 8.3$

Usage of Zero Degree Calorimeters to identifies forward neutrons from nuclear breakup

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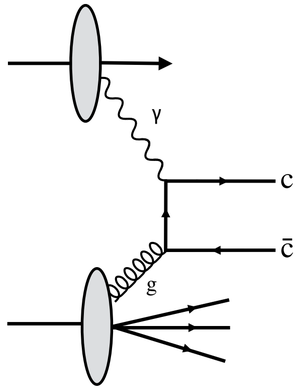

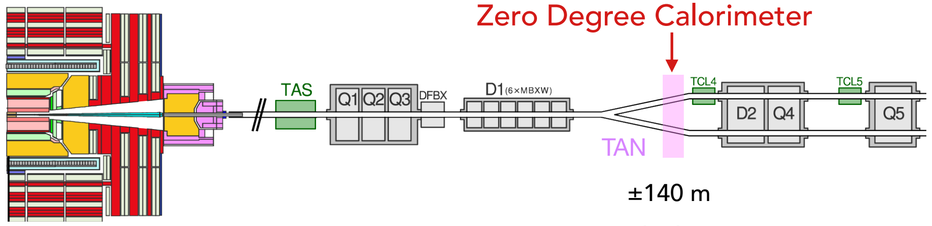

±140 m

covers $|\eta| > 8.3$

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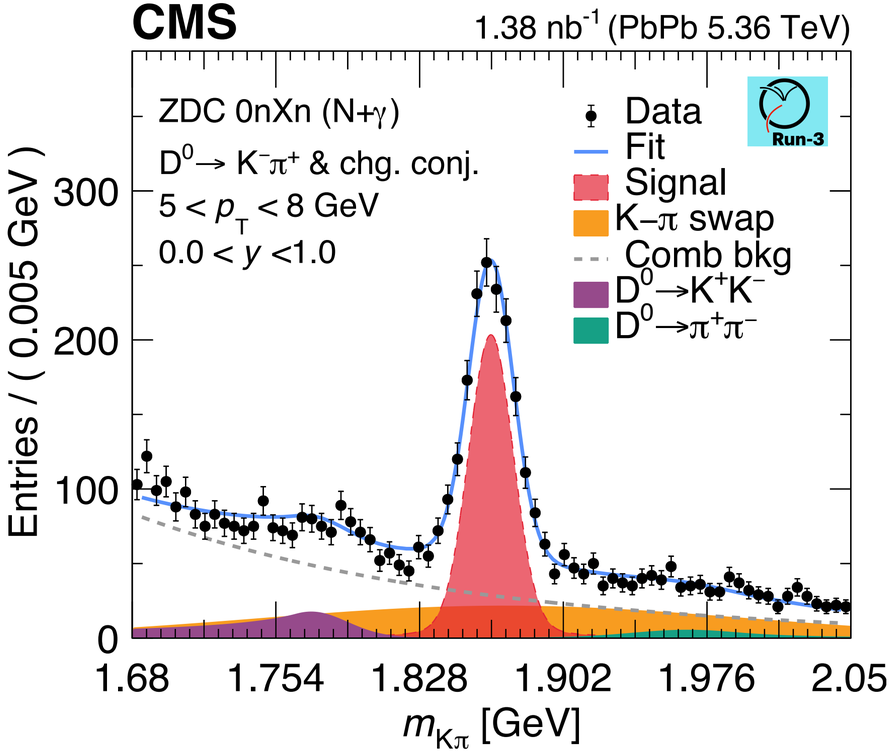
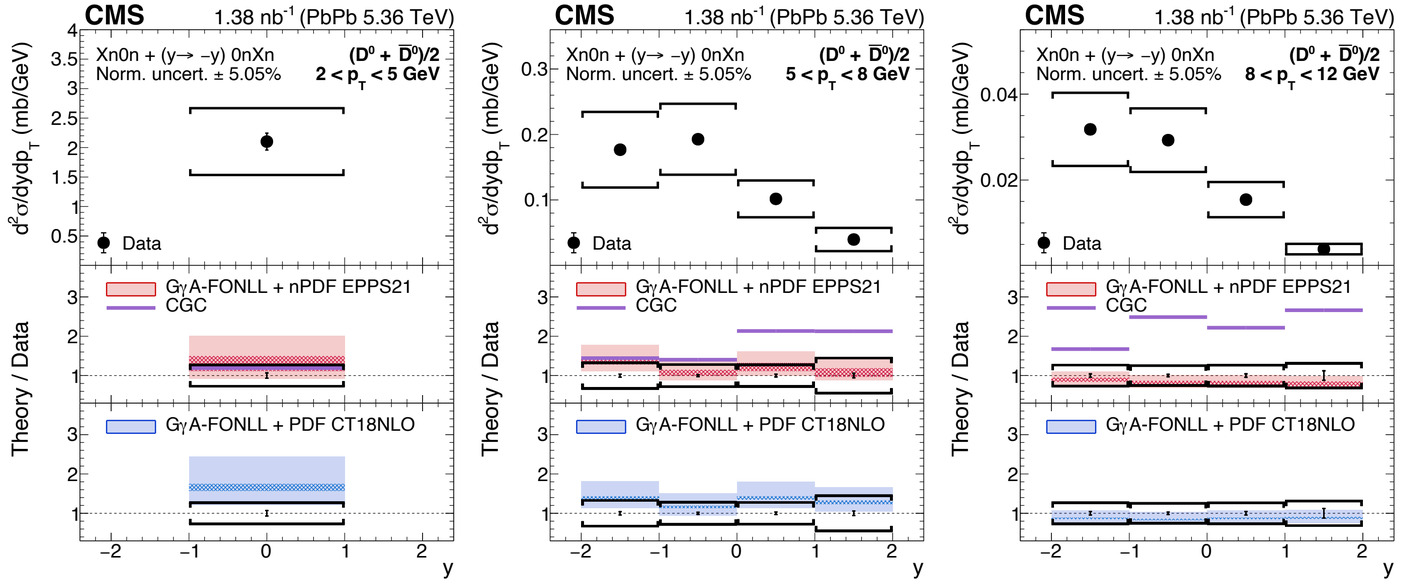
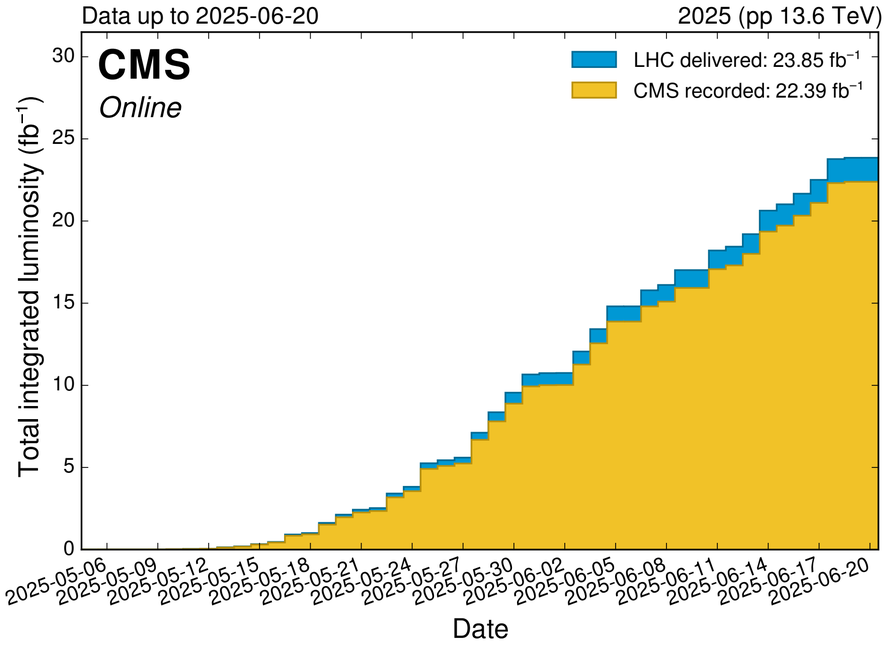




New constraints on nuclear parton distribution functions in the clean environment provided by photonuclear collisions

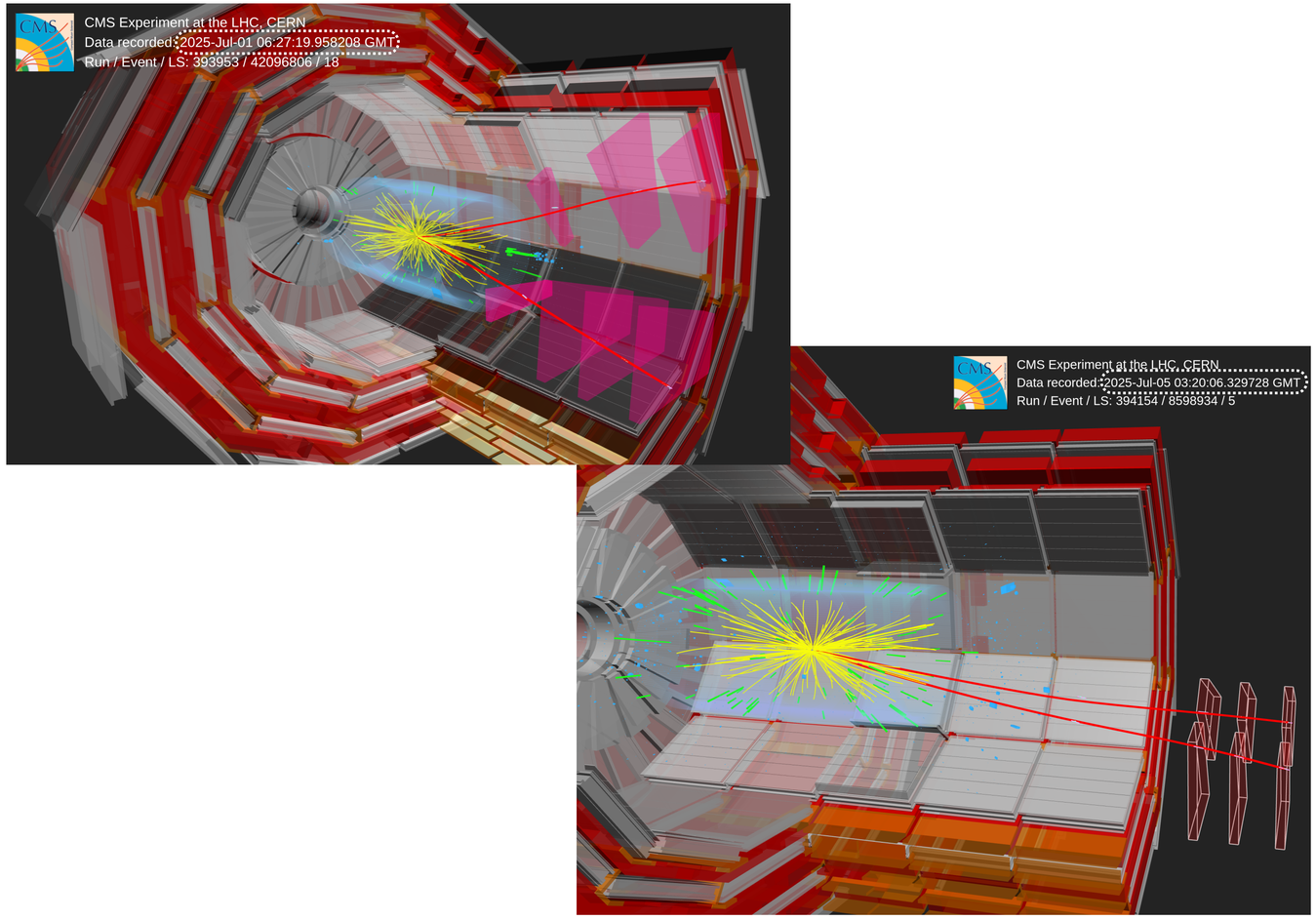
2025 data taking

proton-proton collisions



Cumulative day-by-day integrated luminosity, 2025

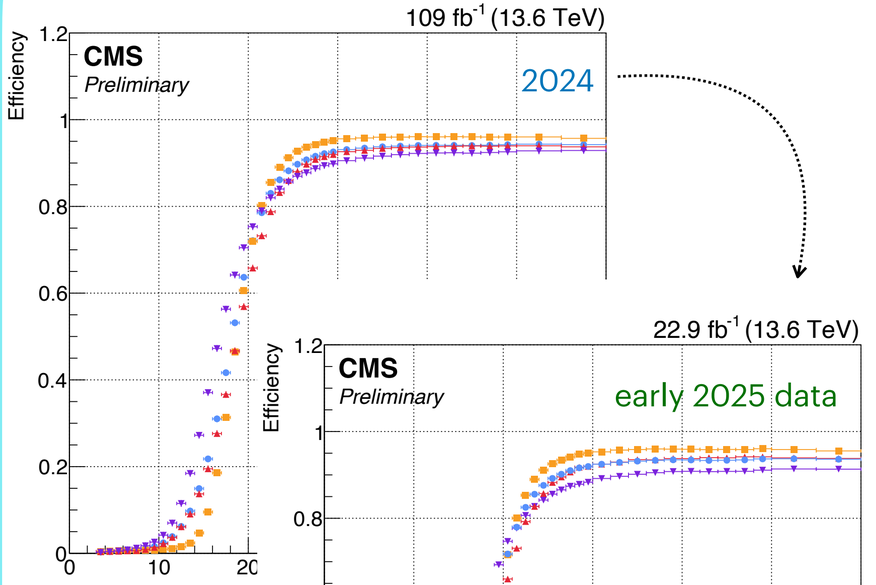
proton-Oxygen and Oxygen-Oxygen collisions

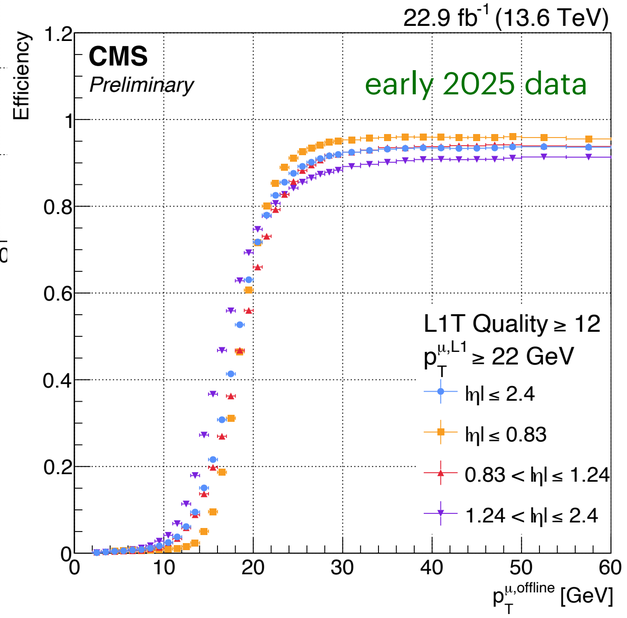


The DAQ system allows CMS to collect data during HI collisions with ~100% HLT efficiency (throughput of up to 32 GB/s)

Performance in 2025

Muon trigger performance





Similar L1 muon efficiencies in **2024** as in **early 2025 data**

Performance in 2025

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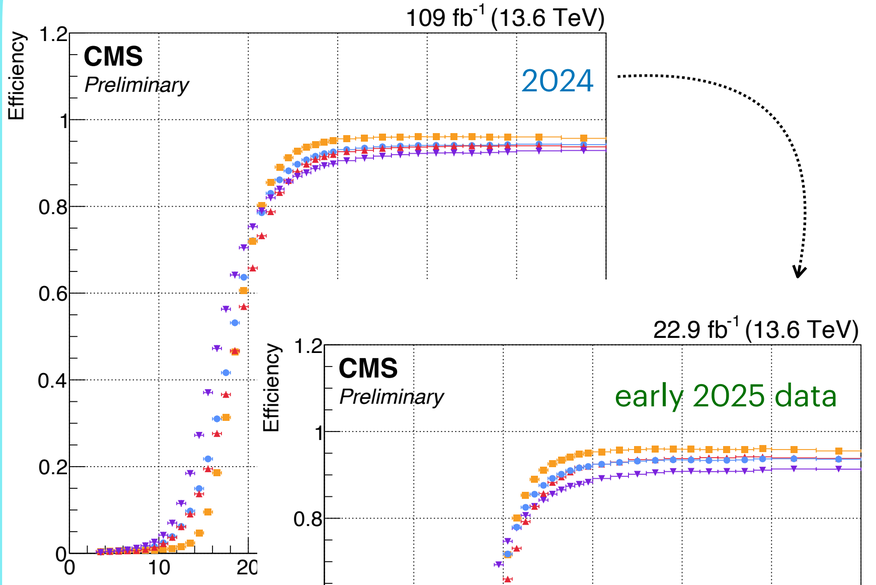

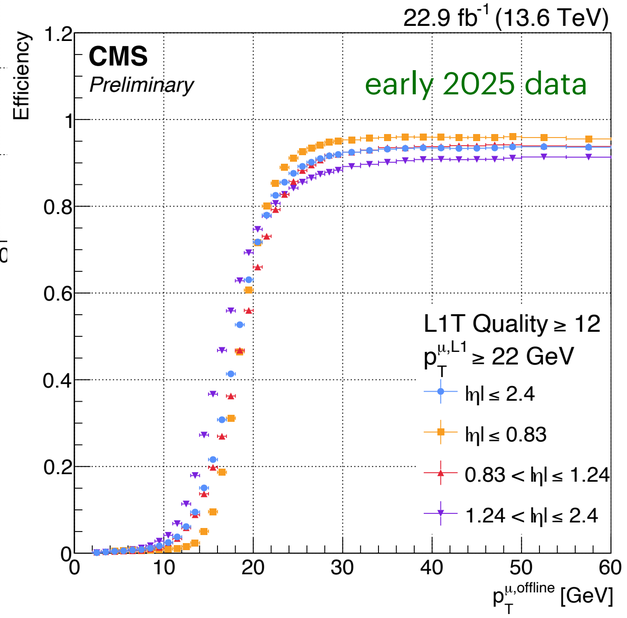

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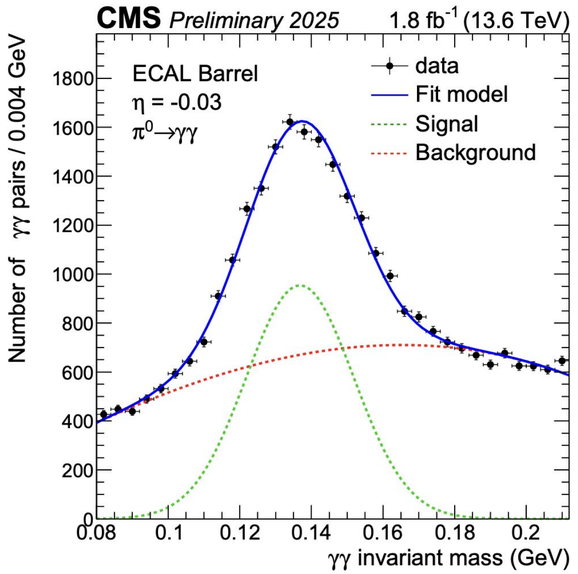
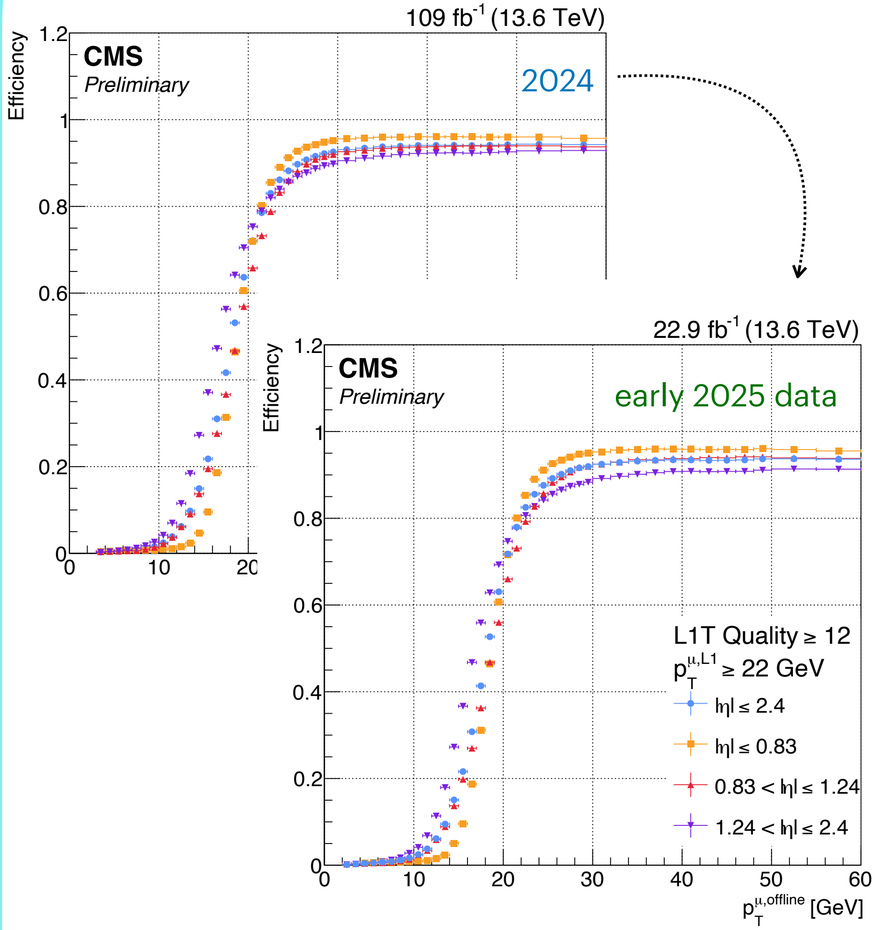


ECAL π^0 monitoring

Events used as prompt feedback to monitor the laser calibrations

Performance in 2025

Muon trigger performance



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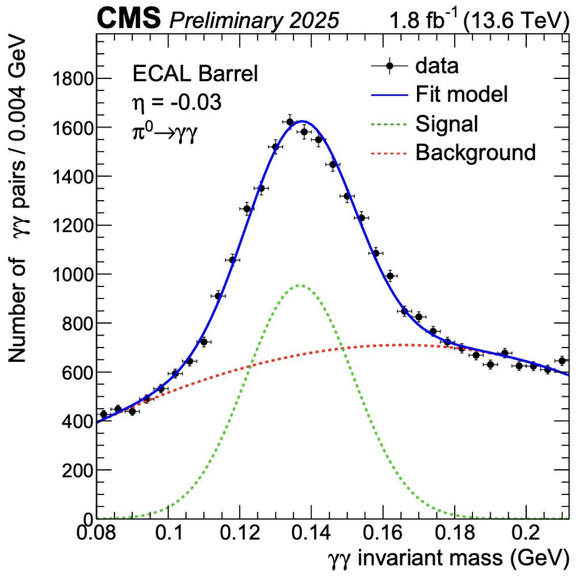

ECAL π^0 monitoring

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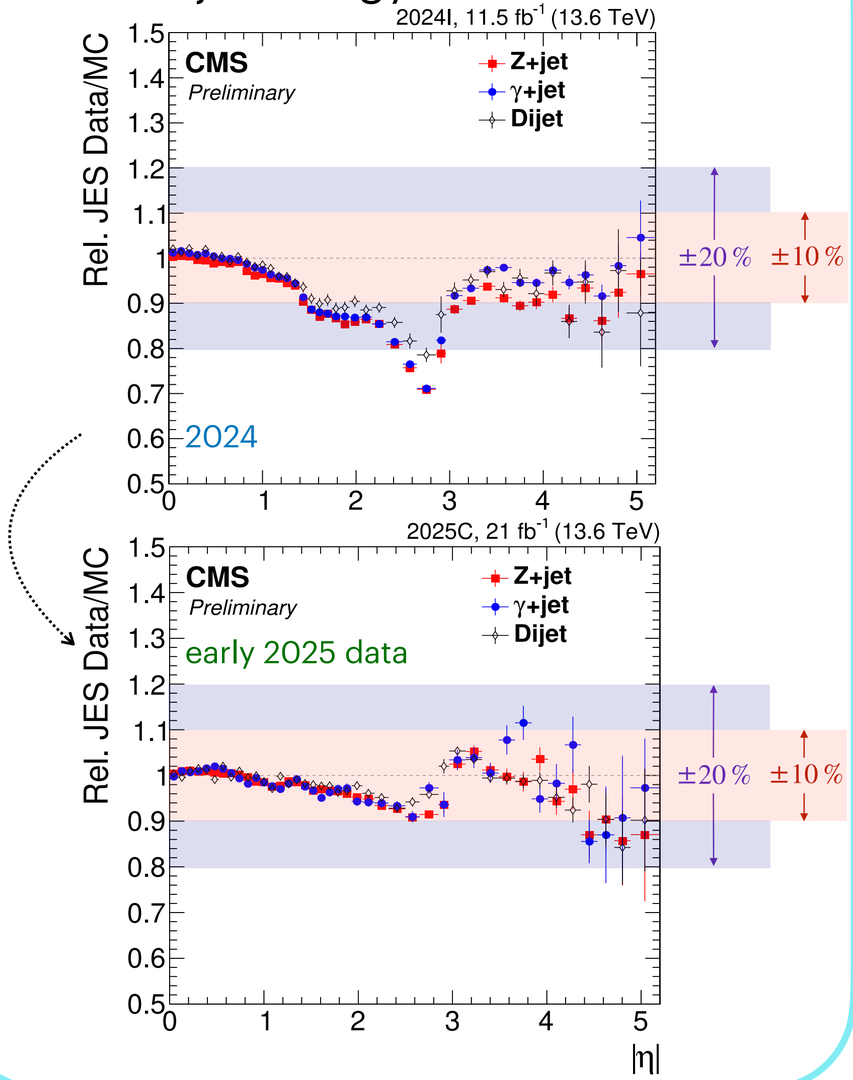
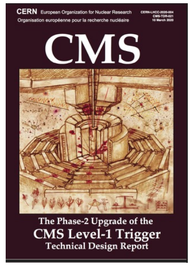
Jet reconstruction performance

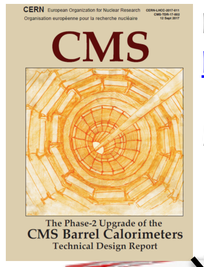
Reduced jet energy scale variations



CMS Upgrade Projects



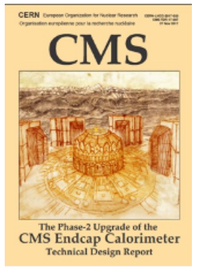
L1-Trigger
https://cds.cern.ch/record/2714892
- Tracks in L1-Trigger at 40 MHz
- Particle Flow selection
- 750 kHz L1 output
- 40 MHz data scouting

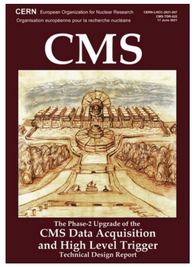


Barrel Calorimeters
https://cds.cern.ch/record/2283187
- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

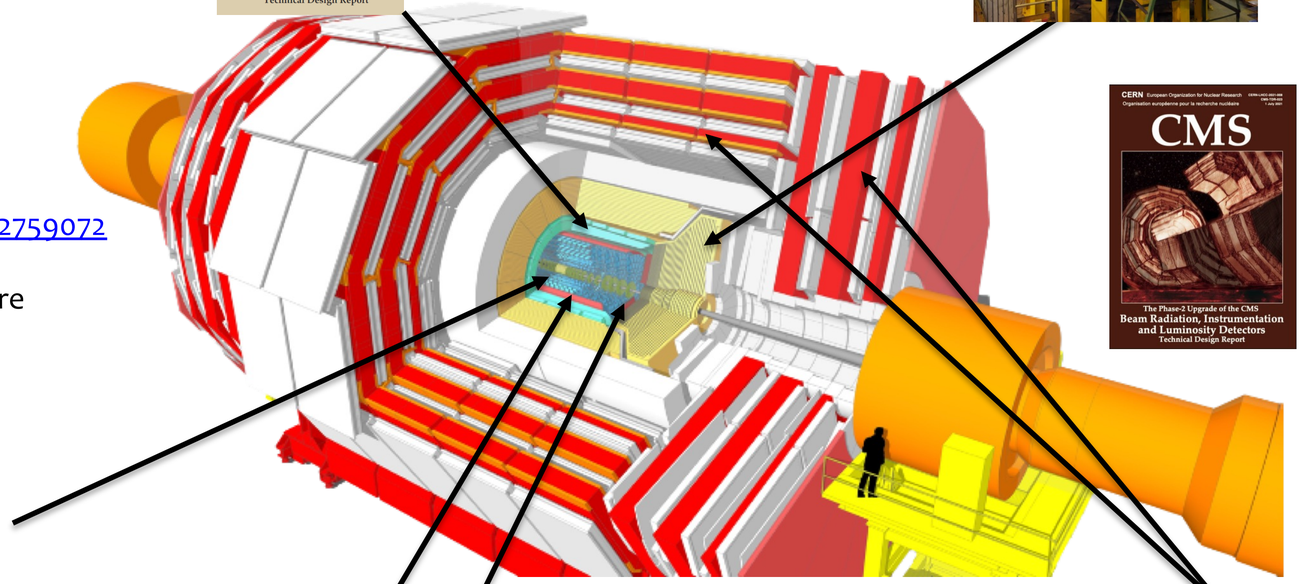
Absorber (~1 endcap)

Calorimeter Endcap (HGCal)
https://cds.cern.ch/record/2293646
- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS



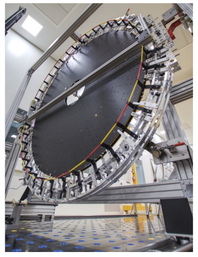


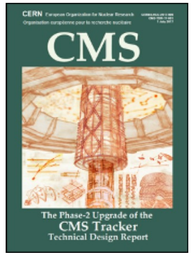
DAQ & High-Level Trigger
https://cds.cern.ch/record/2759072
- Full optical readout
- Heterogenous architecture
- 60 TB/s event network
- 7.5 kHz HLT output



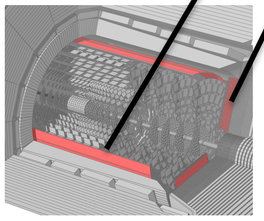
Beam Radiation Instr. and Luminosity
http://cds.cern.ch/record/2759074
- Beam abort & timing
- Beam-induced background
- Bunch-by-bunch lumi: 1% offline, 2% online
- Neutron and mixed-field radiation monitors

First double disk

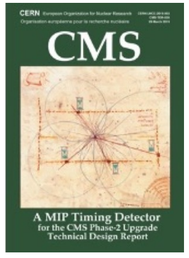


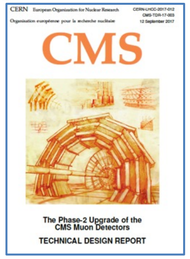


Tracker
https://cds.cern.ch/record/2272264
- Si-Strip and Pixels increased granularity
- Design for tracking in L1T
- Extended coverage to $\eta \simeq 3.8$



MIP Timing Detector
https://cds.cern.ch/record/2667167
Precision timing with:
- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes

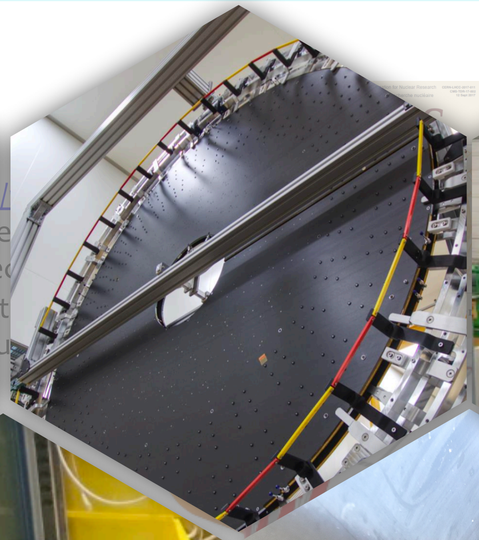


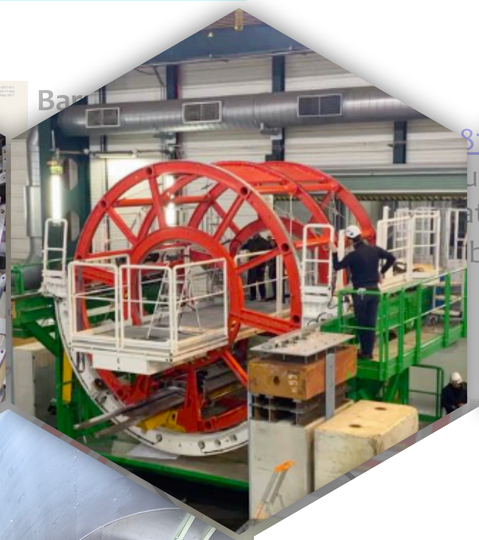


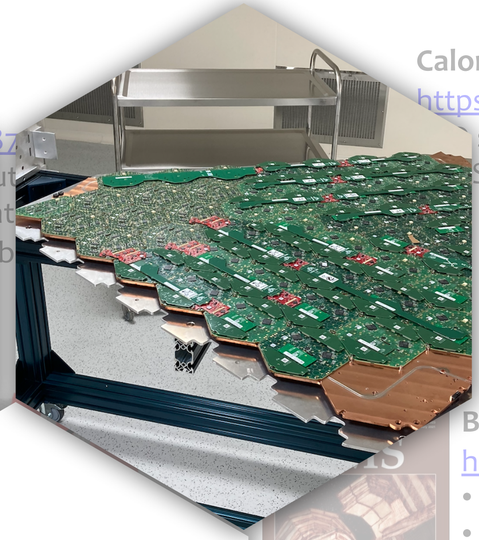
Muon systems
https://cds.cern.ch/record/2283189
- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

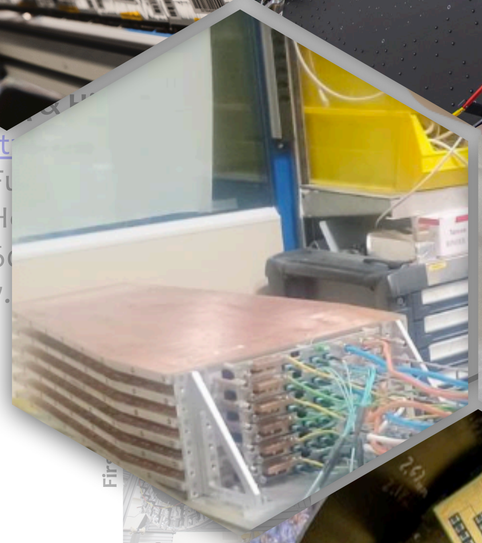
Towards the HL-LHC

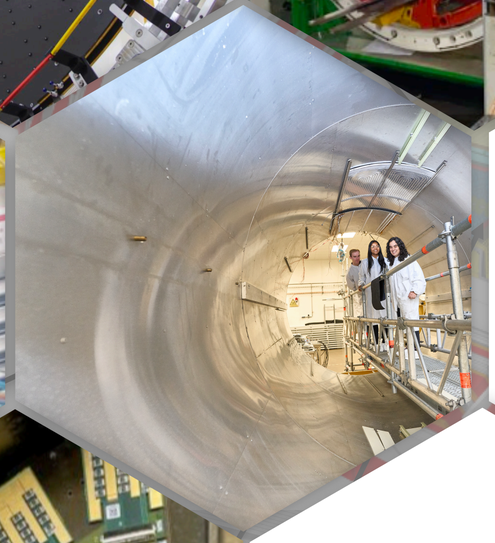
CMS Upgrade Projects



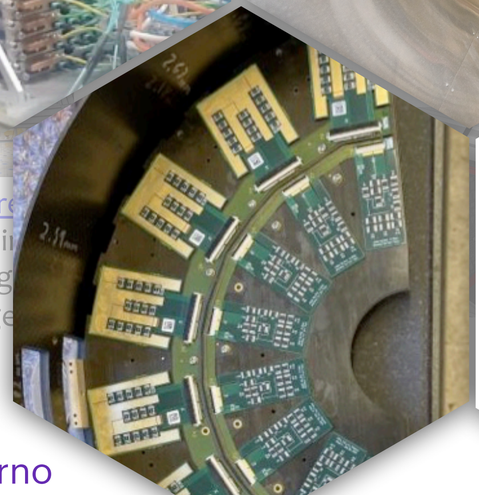








All projects on track!



Majority of ingredients in production, several finished, several procurements to finish

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Scint+SiPM in Pb/W-SS

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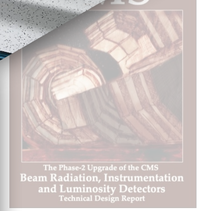
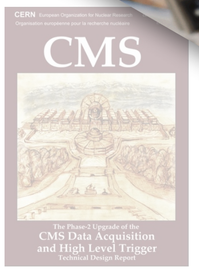
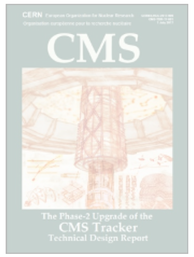




Tracker
https://cds.cern.ch/re
- Si-Strip and Pixels i
- Design for tracking
- Extended coverage



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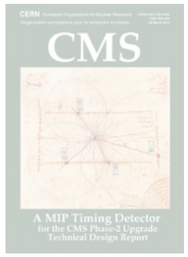

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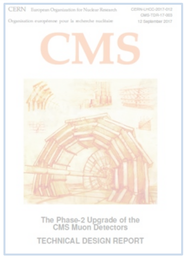

Towards the HL-LHC

A flood of new public results…

… and today just a few recent highlights have been shown

In first half of 2025

- 92 New Physics Results
- 22 New Physics Briefings
- 35 New DPS notes
- 39 New Publications submitted

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39 New Publications submitted

of which the results premiering at EPS

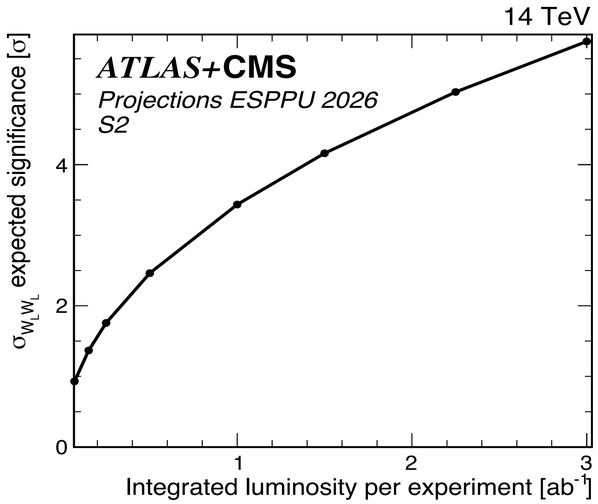
TRK-20-002	Operation and performance of the CMS silicon strip tracker	Jindrich Lidryc	link to parallel talk
EGM-24-002	Highly boosted dielectron identification	RaffaellaTramontano	link to parallel talk
EXO-23-016	Long-lived particle triggers at CMS: Strategy and performance during early LHC (Run 3)	Eric Chabert, Celia Fernandez	link to parallel talk
SMP-22-003	Simultaneous **measurements** of a basis of N-subjettiness observables in boosted hadronic top quark and W boson decays, and in light jets	Patrick Connor	link to parallel talk
SMP-24-012	**Measurement** of jet mass distributions of boosted W bosons	Patrick Connor	link to parallel talk
SMP-24-019	**Measurement** of the photon-induced production of a pair of W bosons	Zongsheng He	link to parallel talk
TOP-24-011	**Measurement** of the t-channel single top quark cross section at $\sqrt{s}$ = 5.02 TeV	Enrique Palencia	link to parallel talk
HIG-24-006	**Constraints** on anomalous Higgs boson couplings to vector bosons and fermions in the $\gamma\gamma$ final state	Dermot Moran	link to parallel talk
HIG-24-019	**Measurement** of the charge asymmetry in WH production in the $H \rightarrow \tau\tau$ decay channel	Ralf Schmieder	link to parallel talk
HIG-24-003	**Search** for associated production of a Higgs boson and of two vector bosons via vector boson scattering	Ralf Schmieder	link to parallel talk
HIG-24-015	**Search** for triple Higgs production using 4b2γ final state	Jin Wang	link to parallel talk
B2G-23-007	**Search** for a heavy scalar resonance X decaying to a Higgs and Higgs-like boson in the Lorentz-boosted $H \rightarrow bb$ and $Y \rightarrow 4q$ final state	Ilias Zisopoulos	link to parallel talk
EXO-24-016	**Search** for long-lived particles decaying into muons using the scouting data sets (Run3)	Celia Fernandez	link to parallel talk
EXO-24-033	**Search** for long-lived particles using displaced vertices with low-momentum tracks and missing transverse momentum	Eric Chabert	link to parallel talk
EXO-24-034	**Search** for light scalar particles from Higgs boson decay in exclusive final states with two muons and two hadrons	Eric Chabert	link to parallel talk
EXO-24-020	**Search** for the pair production of long-lived supersymmetric partners of the tau lepton	Eric Chabert	link to parallel talk
EXO-24-025	**Search** for H decaying to two pseudoscalars (A) with one merged and one resolved diphoton final state	Abhirami Harilal	link to parallel talk
SUS-23-013	**Search** for dark matter produced in association with a resonant bottom quark pair	Sushil Chauhan	link to parallel talk
SUS-21-005	**Search** for new physics using single-lepton events with large jet and b-jet multiplicities	Sezen Sekmen	link to parallel talk

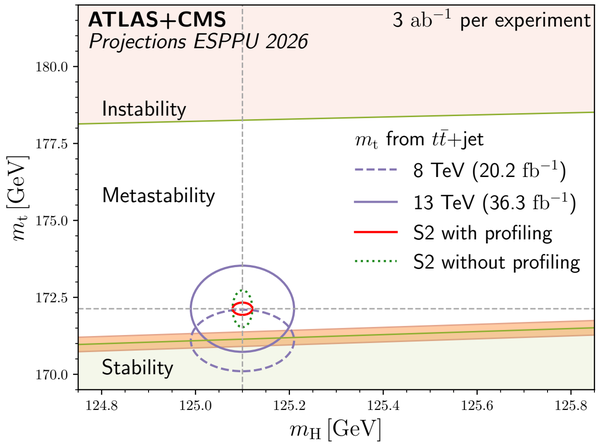
Additionally many more CMS results in plenary talks of Timothy Gershon, Emanuele Di Marco, Josh Bendavid, Francesco Prino, Tamara Vazquez Schröder

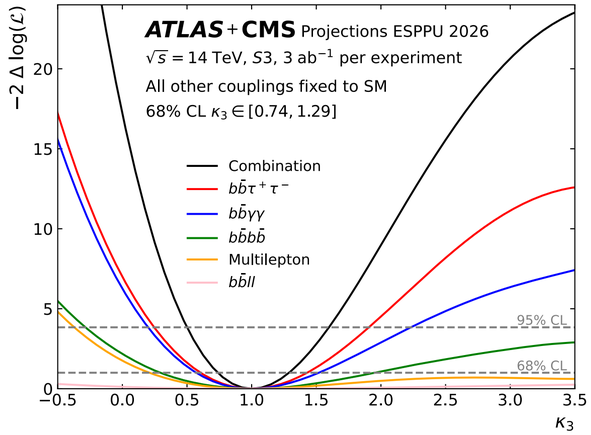
Conclusions: an outlook for the future

CMS is continuously pushing the boundaries of physics, exploring new frontiers and driving technological innovation.

With the upgraded detector we will deliver major physics results at the HL-LHC







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Thanks for listening, enjoy our results!