

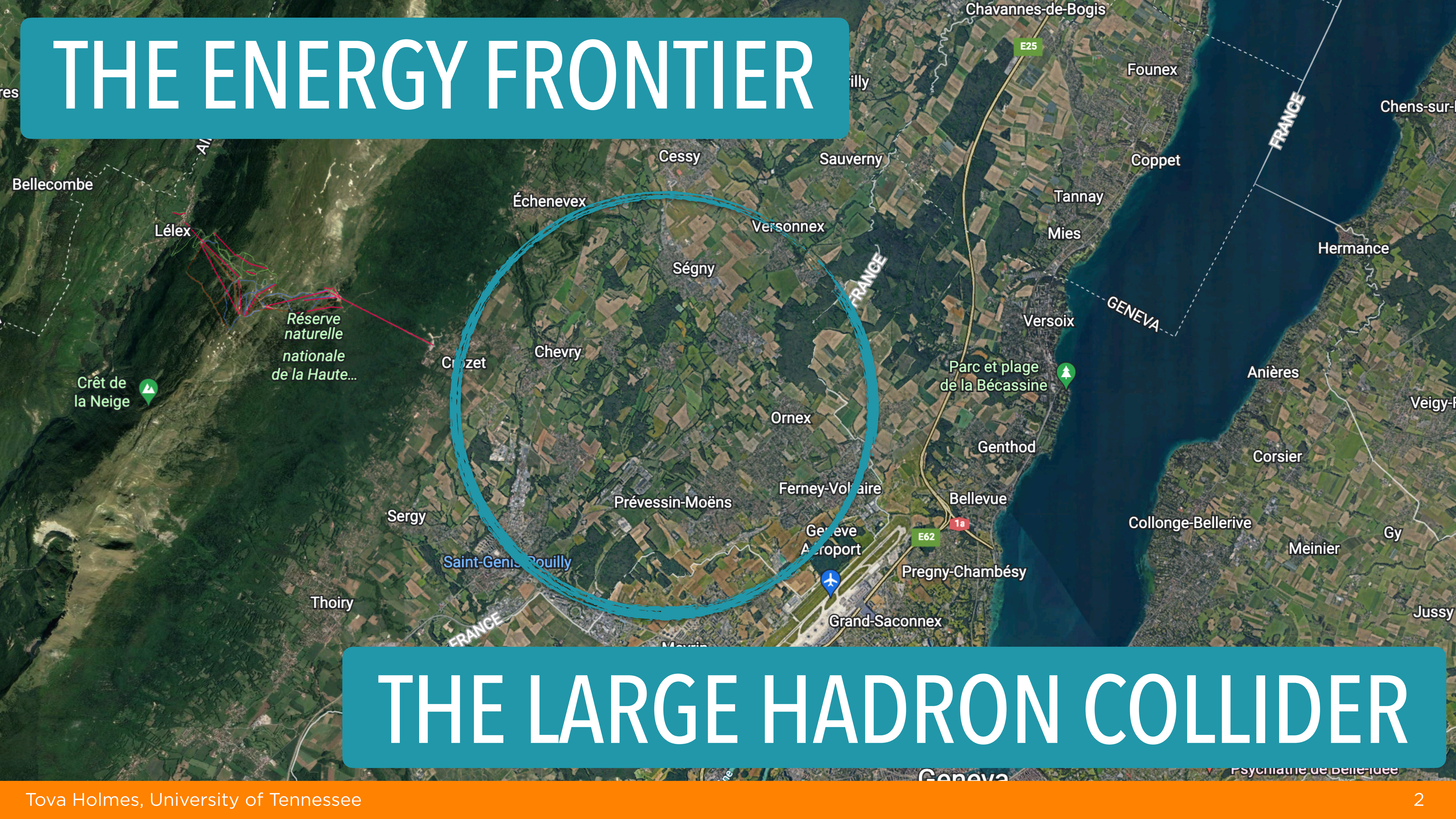
PHYSICS AT THE ENERGY FRONTIER



TOVA HOLMES, UNIVERSITY OF TENNESSEE
55TH ANNUAL FNAL USERS MEETING
JUNE 14, 2022

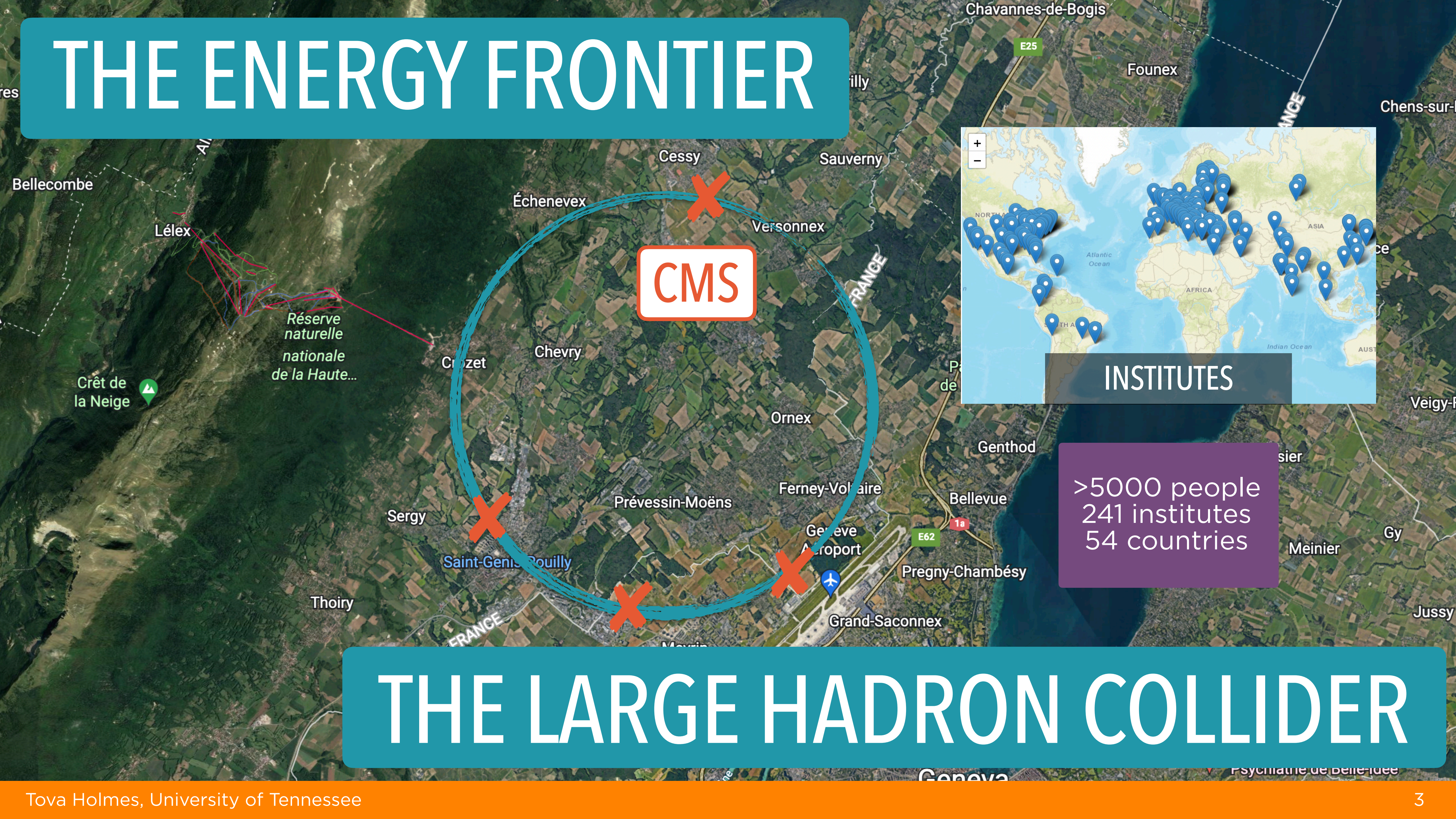


THE ENERGY FRONTIER



THE LARGE HADRON COLLIDER

THE ENERGY FRONTIER



CMS

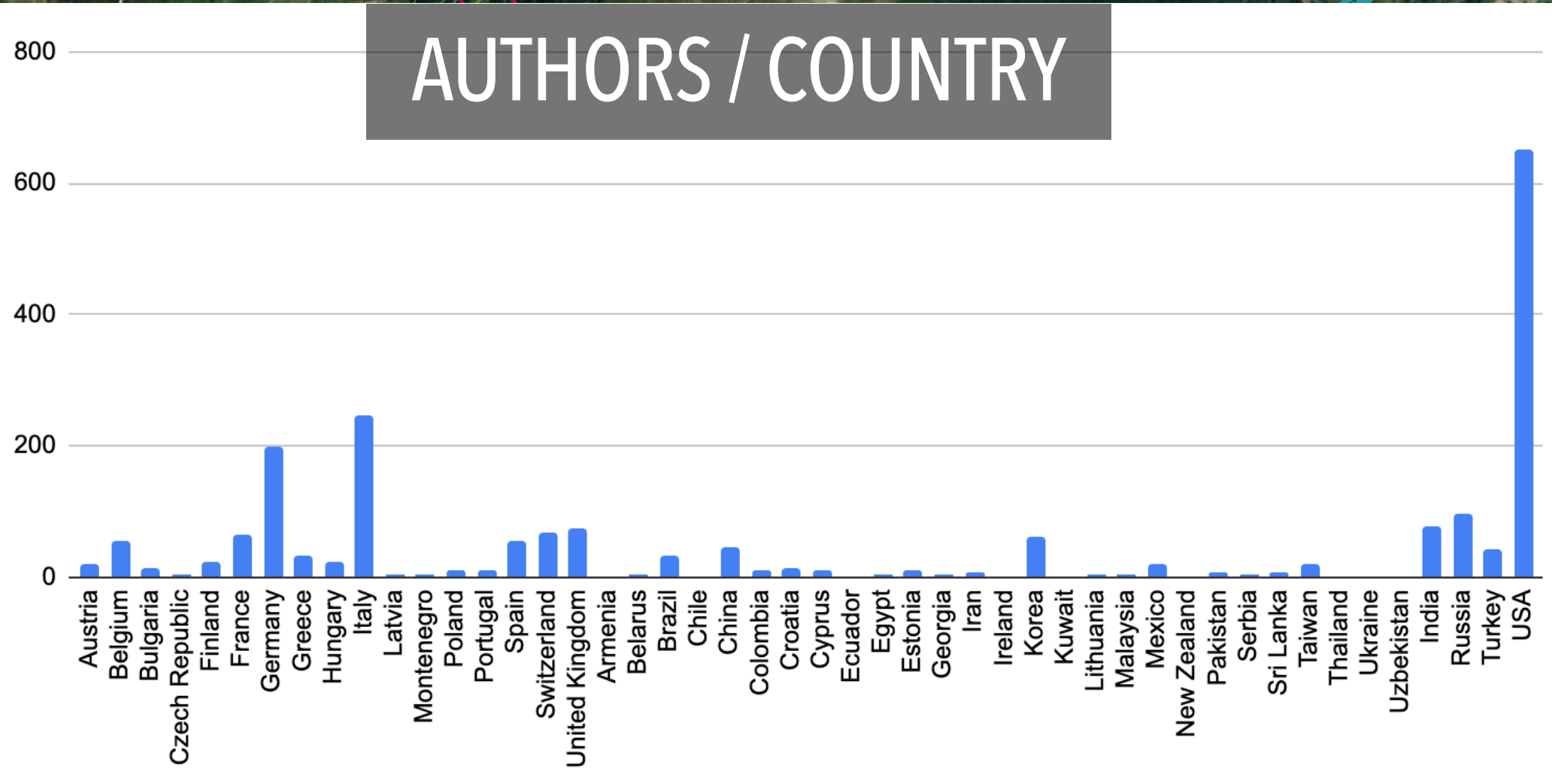


>5000 people
241 institutes
54 countries

THE LARGE HADRON COLLIDER

THE ENERGY FRONTIER

AUTHORS / COUNTRY



CMS



THE LARGE HADRON COLLIDER

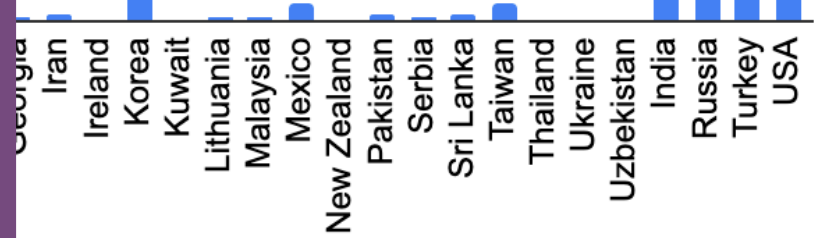
THE ENERGY FRONTIER

AUTHORS / COUNTRY

FNAL:

manages operations and upgrades

hosts ROC, LPC and Tier 1



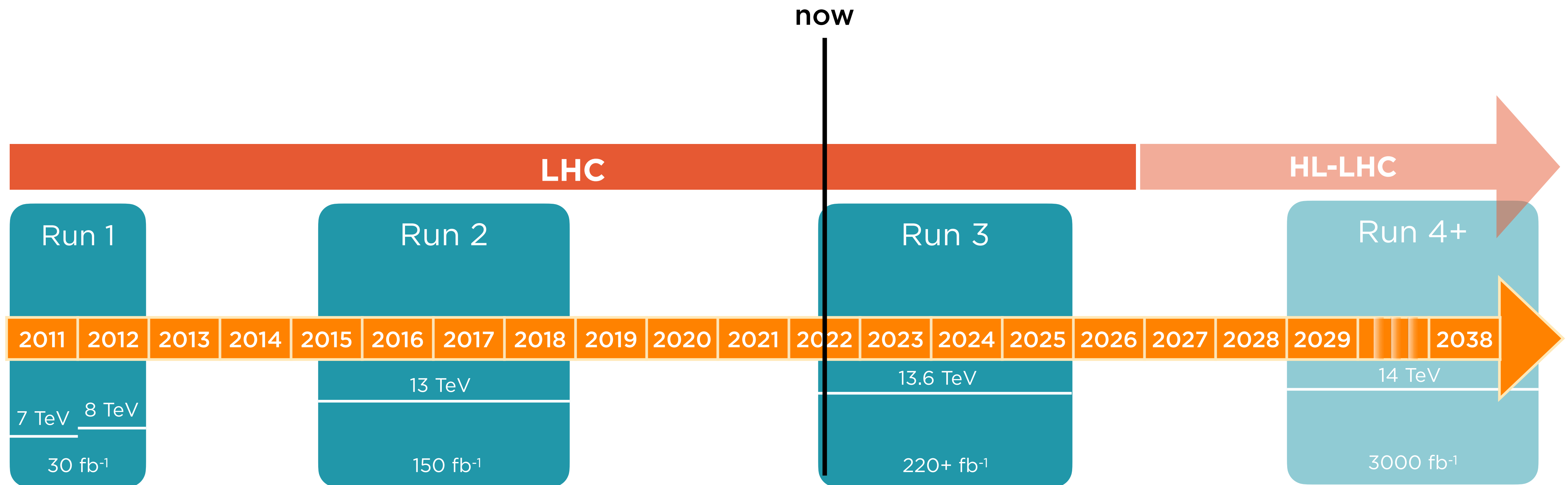
CMS

INSTITUTES



THE LARGE HADRON COLLIDER

WHERE ARE WE NOW?

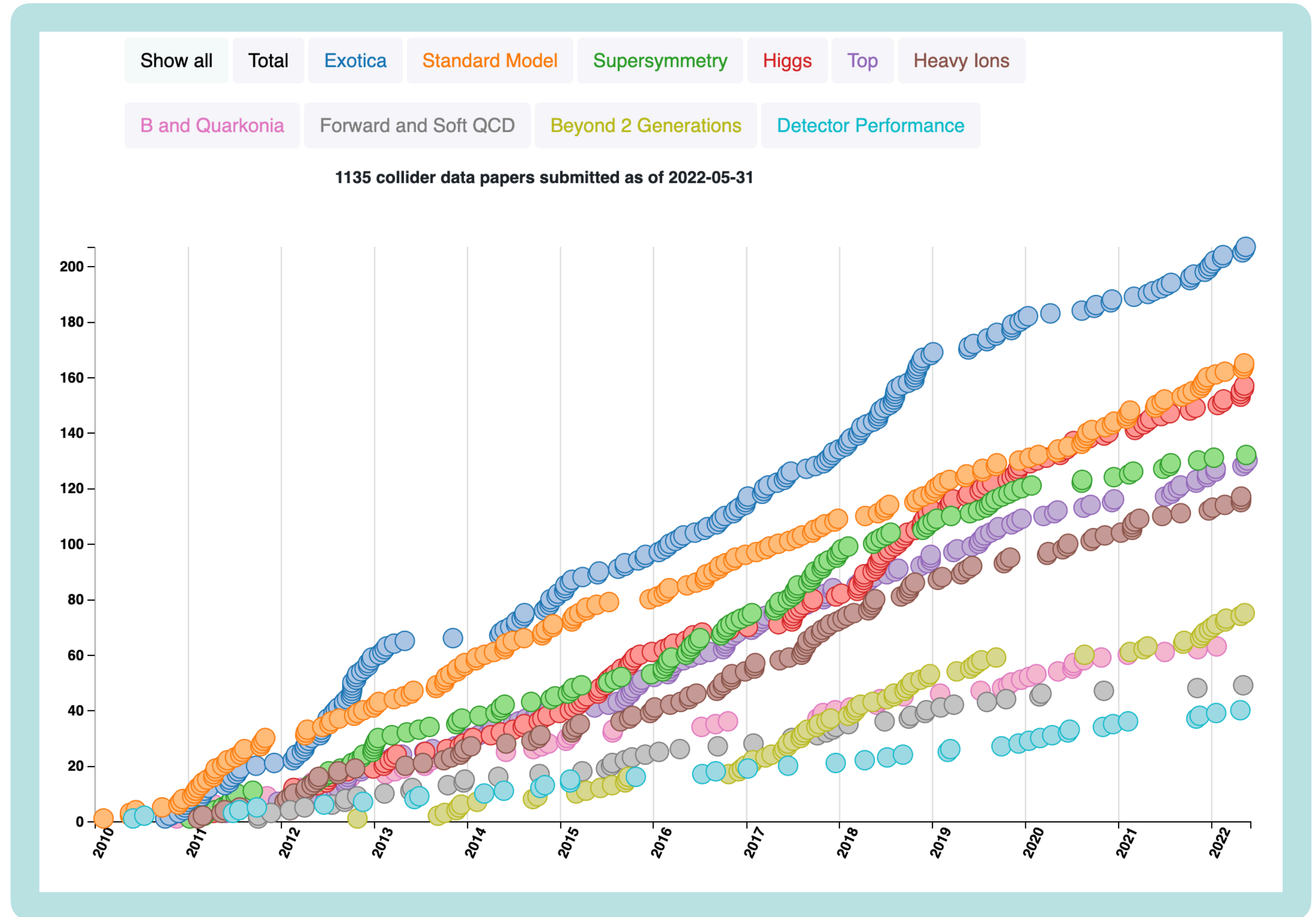


only collected 5% of total data

WHAT HAVE WE LEARNED SO FAR?

QUITE A BIT:

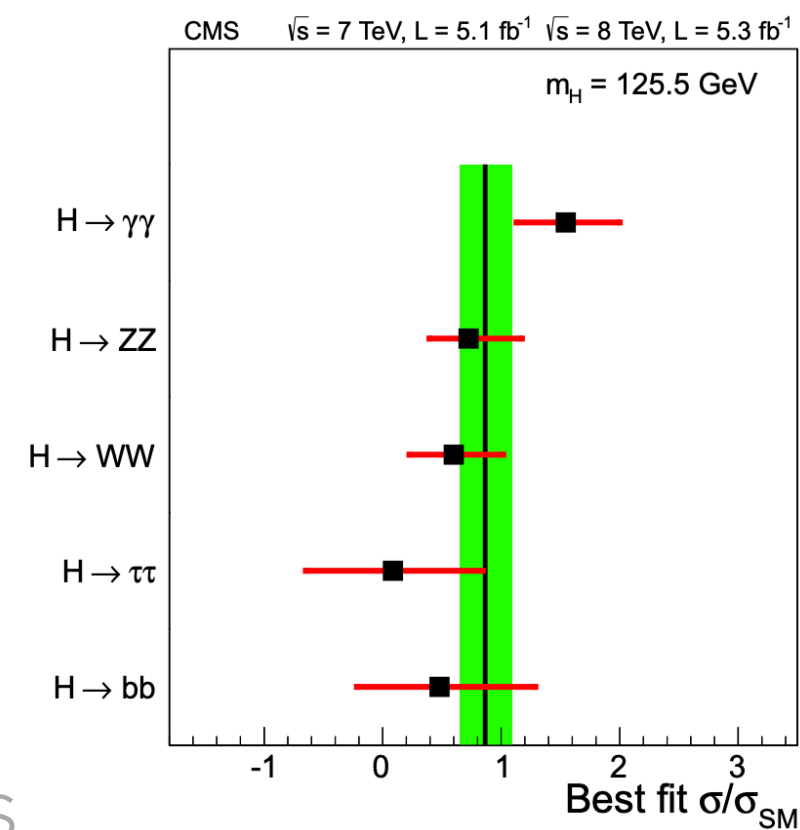
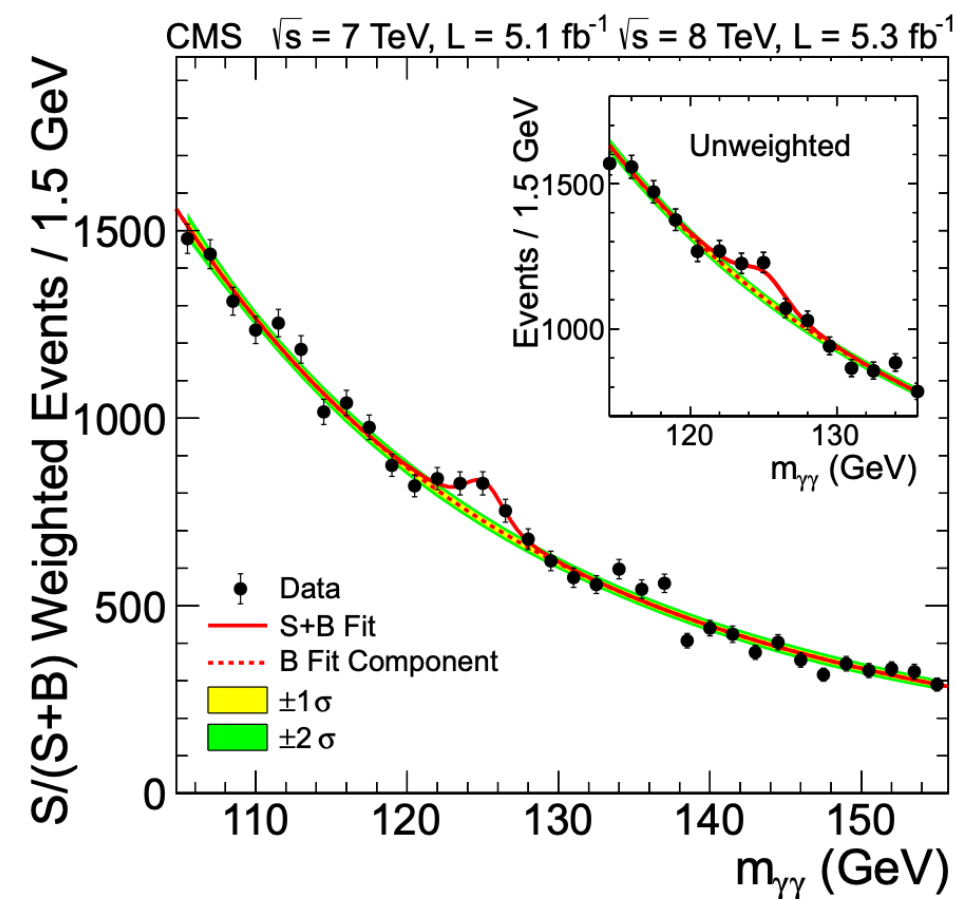
- 1135 papers total
- Detectors: 40
- Standard Model: 564
- Heavy Ions: 117
- Beyond SM: 414



HIGGS DISCOVERY

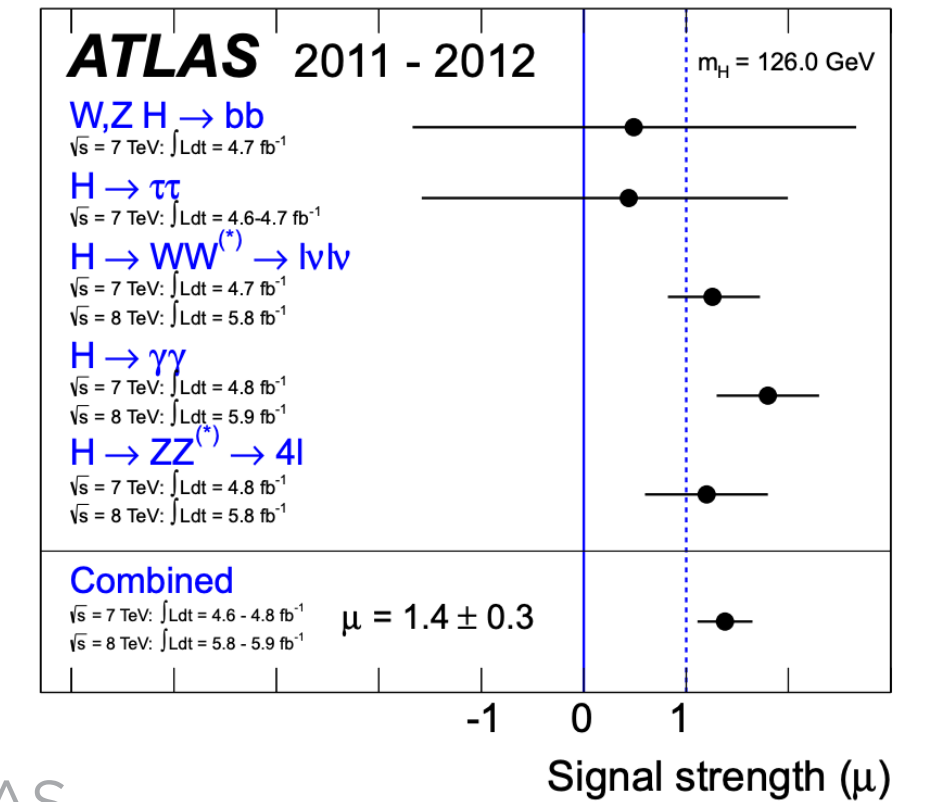
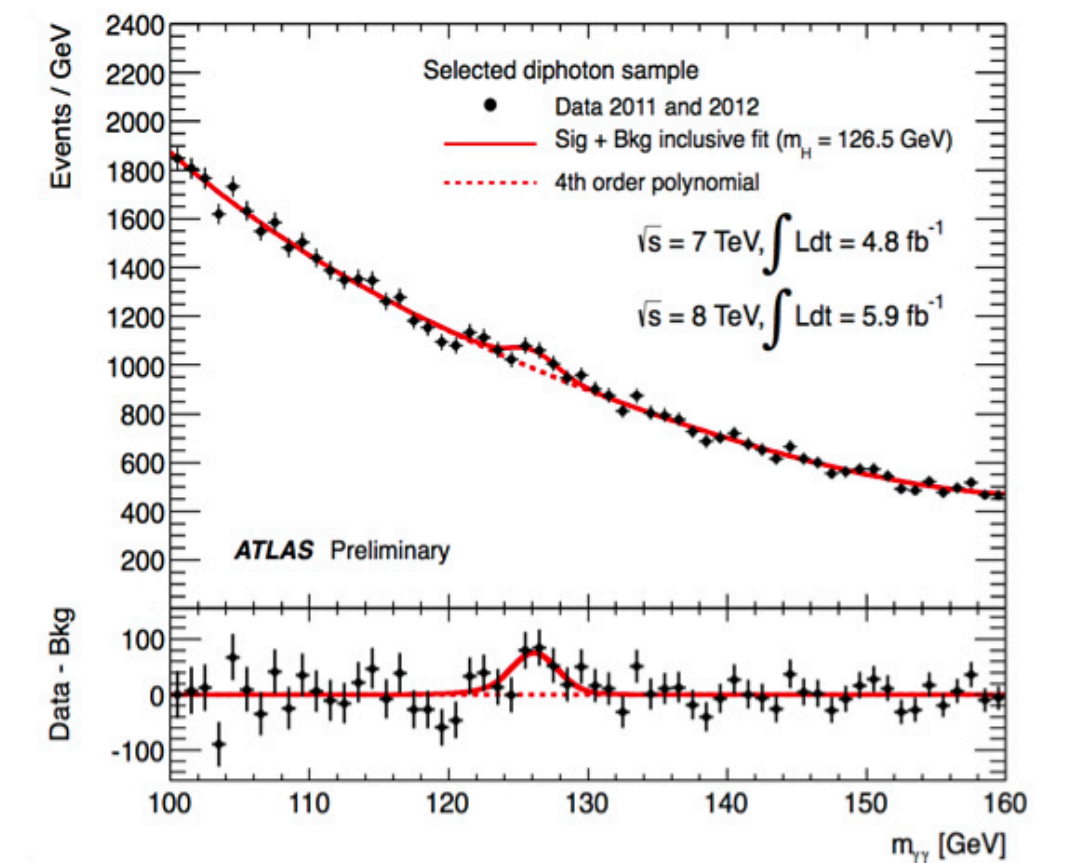


FROM CMS



CMS

FROM ATLAS



ATLAS

10 YEARS
AGO

- discovered Higgs primarily through di-photon channel
- signal strengths in each channel had O(1) uncertainties

SOLVED ONE PROBLEM CREATED ANOTHER

FERMIONS		BOSONS	
LEPTONS	e	μ	τ
	ν_e	ν_μ	ν_τ
QUARKS	u	c	t
	d	s	b
GAUGE BOSONS	γ	H	SCALAR
	g		
	W		
	Z		

resolved the puzzle of how to incorporate the known masses of standard model particles

our standard model tells us that if this is all there is, the Higgs mass should be about 15 orders of magnitude larger

$$\Delta m_H^2 \sim \frac{y^2}{16\pi^2} \Lambda^2 \sim 10^{34} \text{ GeV}^2$$

SOLVED ONE PROBLEM CREATED ANOTHER

this on top of the many other
standard model problems:

dark matter

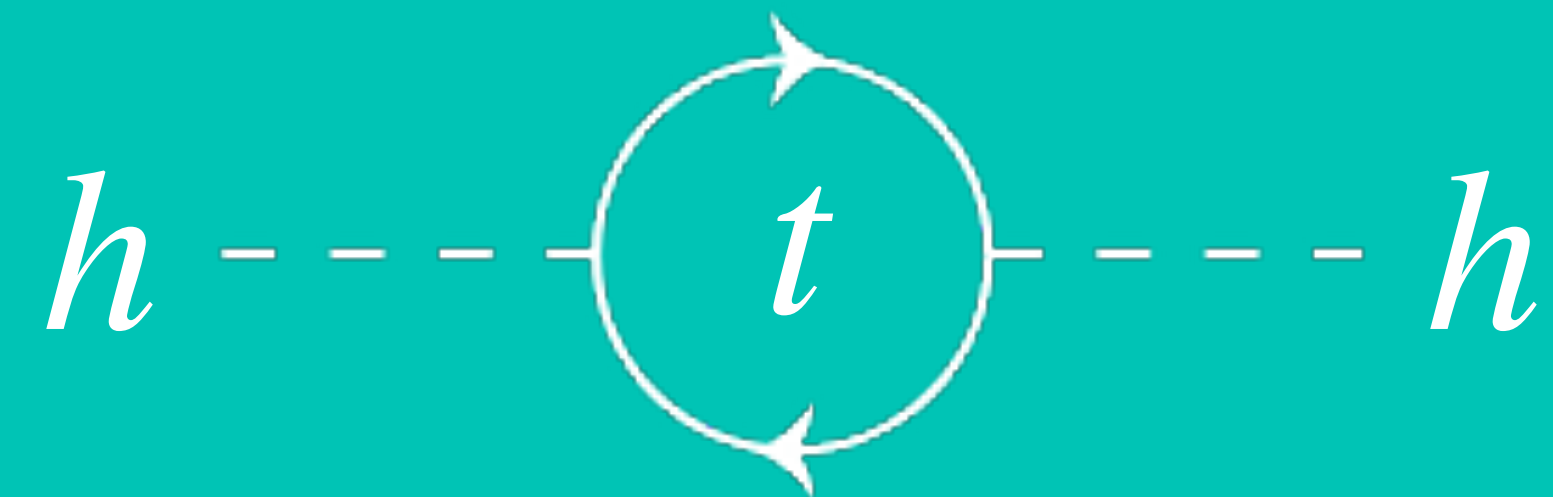
neutrino mass

matter-antimatter asymmetry

strong CP problem

...etc!

where do we look?

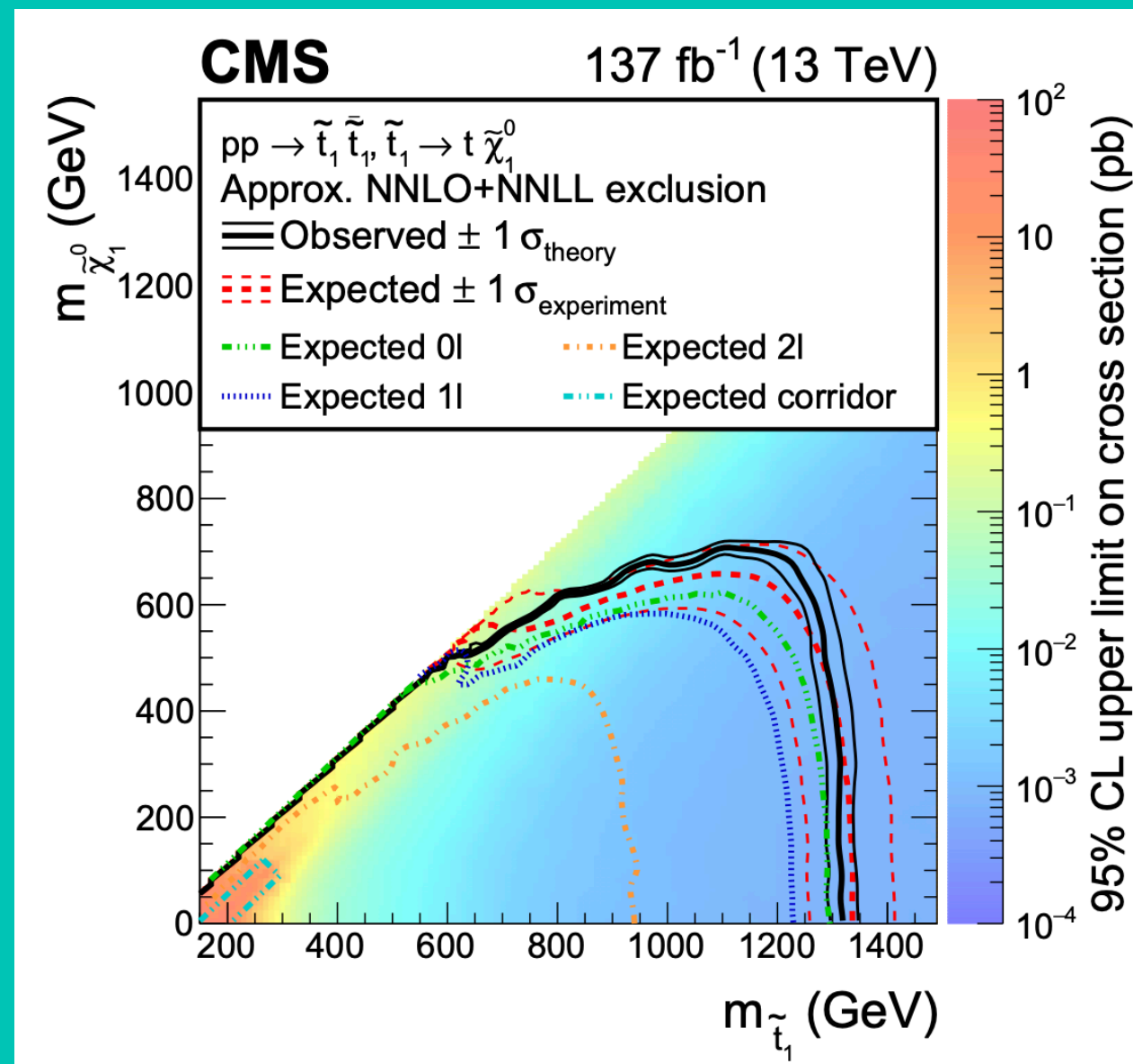


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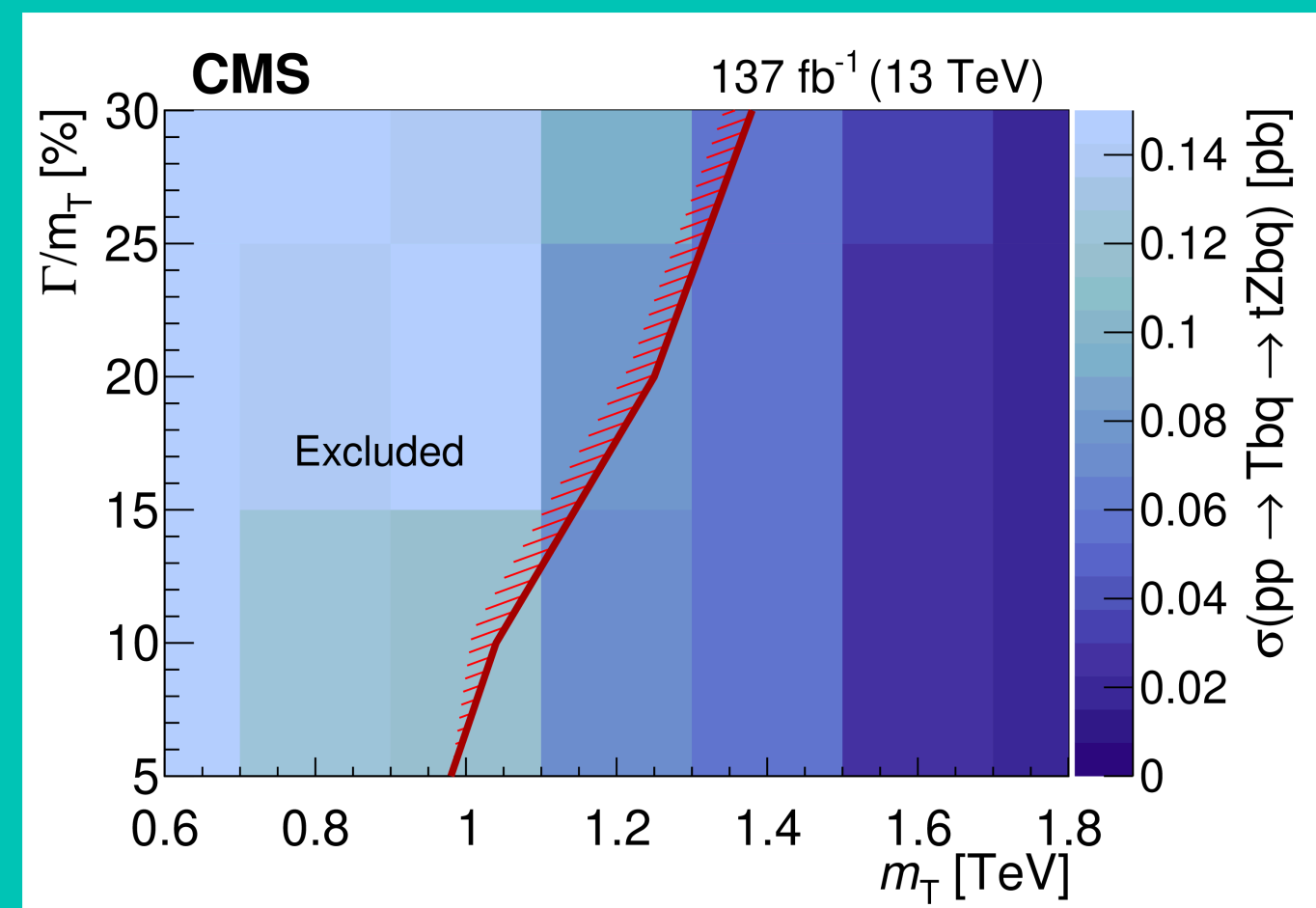
IN SEARCH OF NEW PHYSICS

Supersymmetry

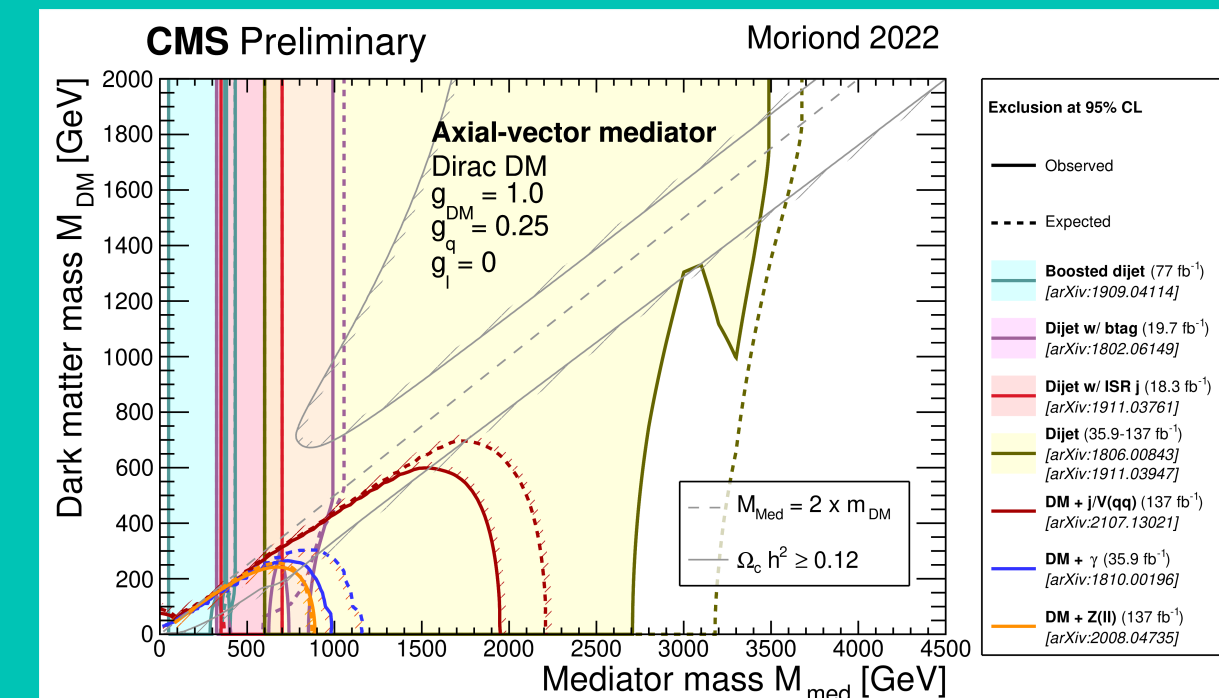


Direct Searches

Vector-like Quarks

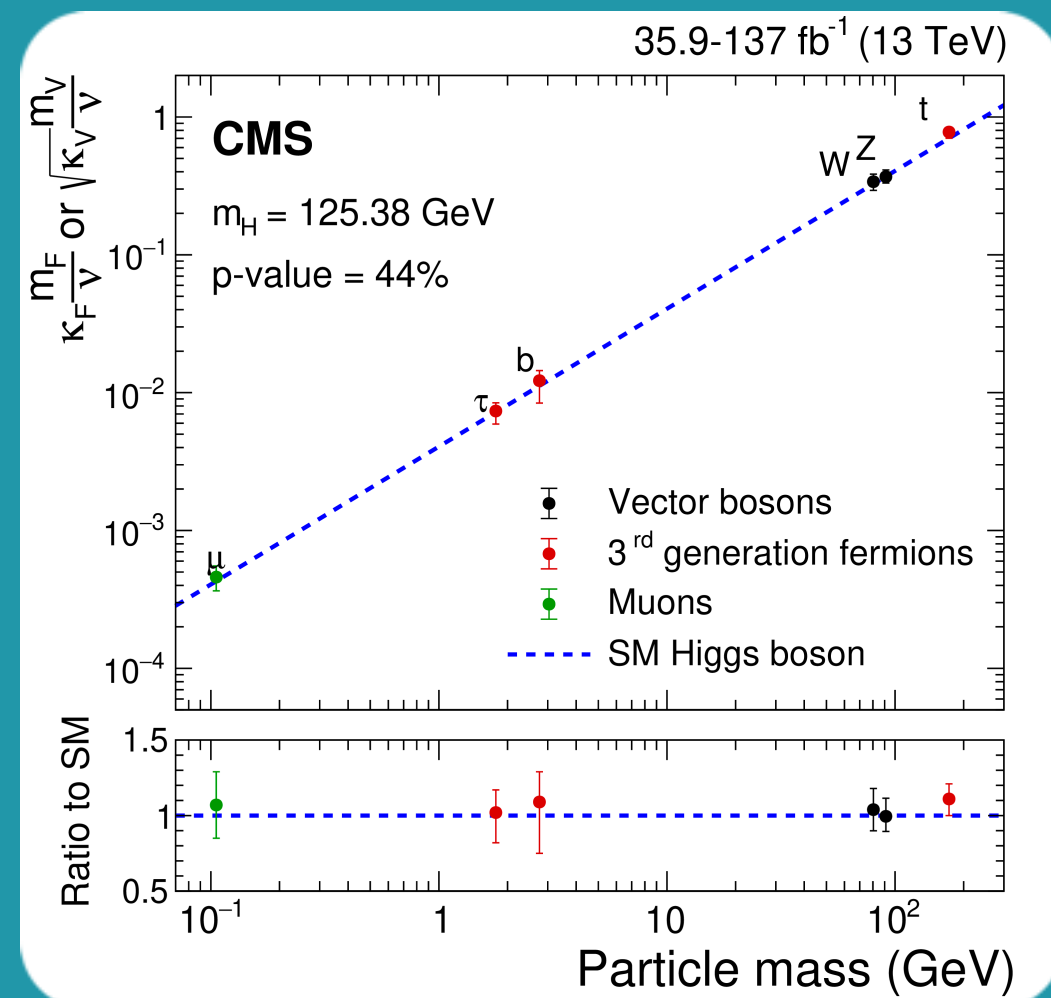


Dark Matter Searches



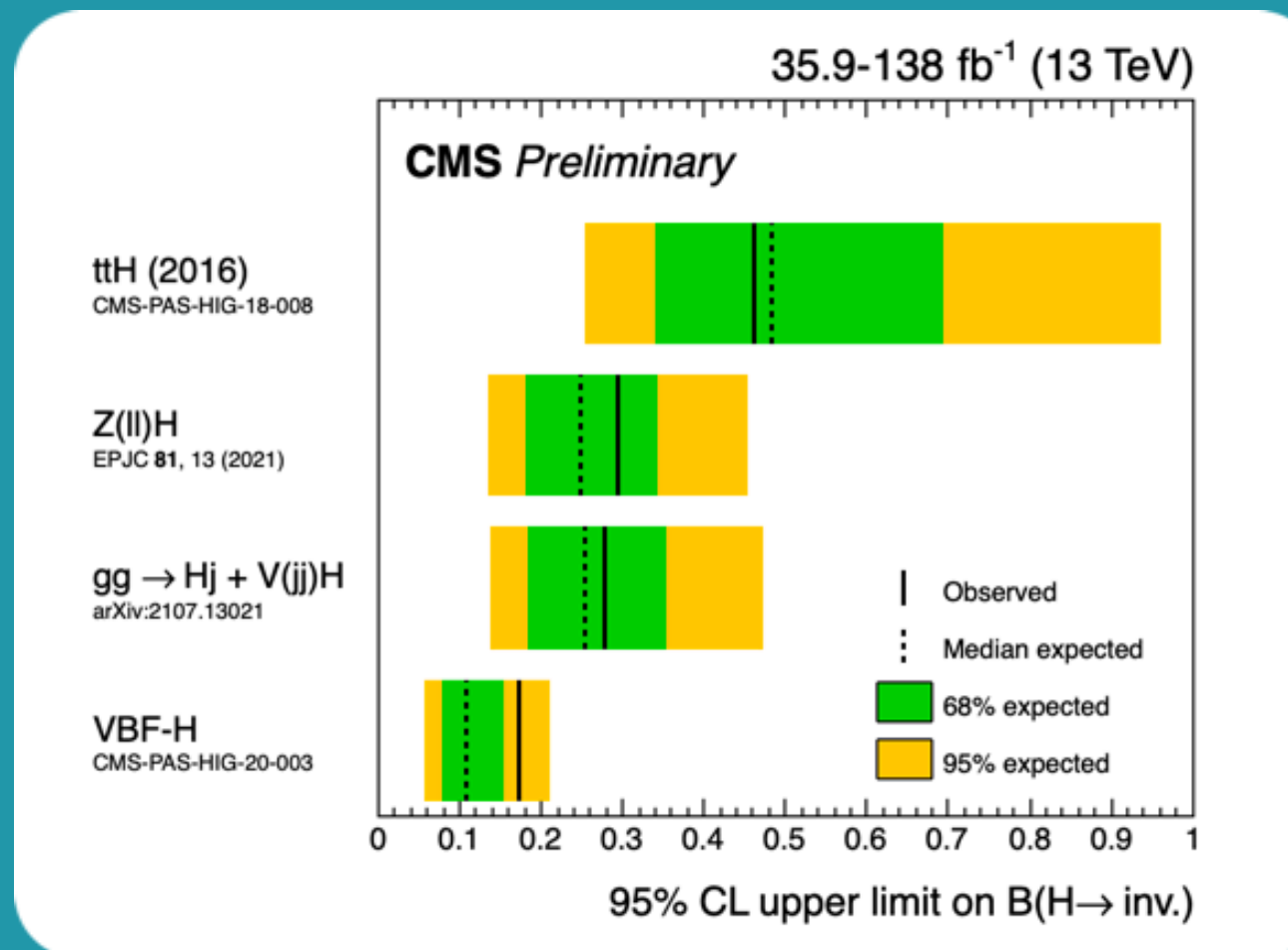
IN SEARCH OF NEW PHYSICS

Couplings to SM particles

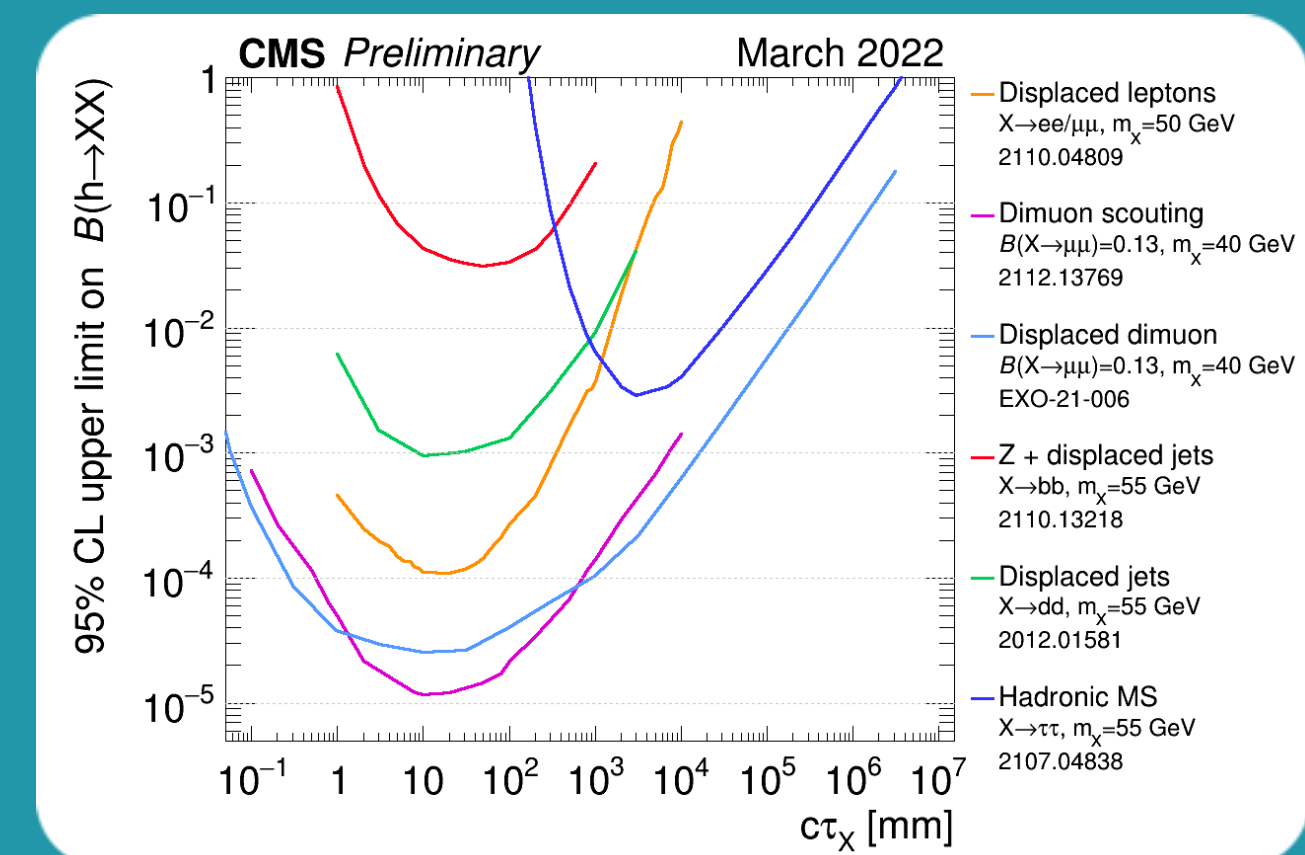


Studying the Higgs

Decays to Invisible Particles



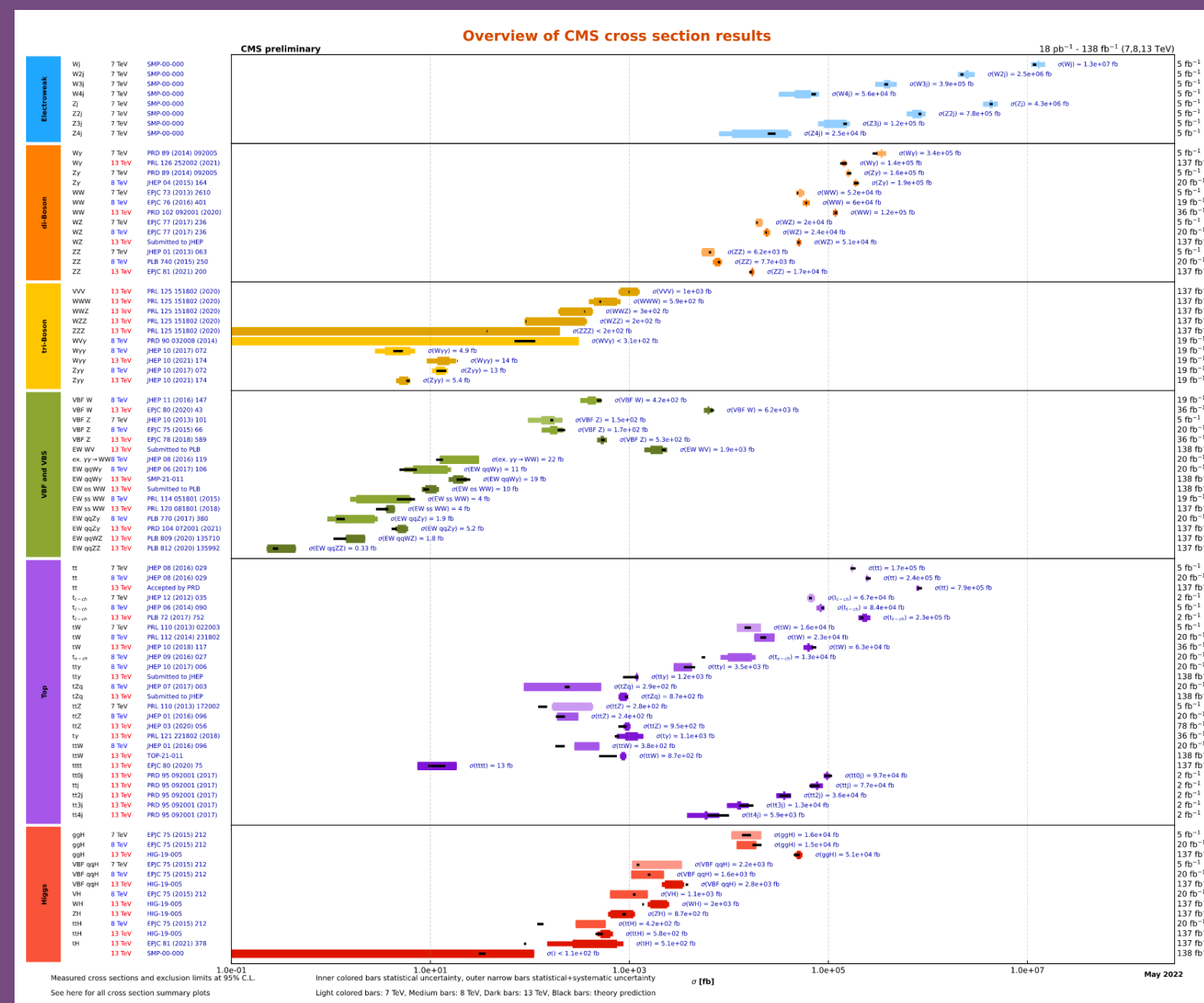
Decays to Long-lived Particles



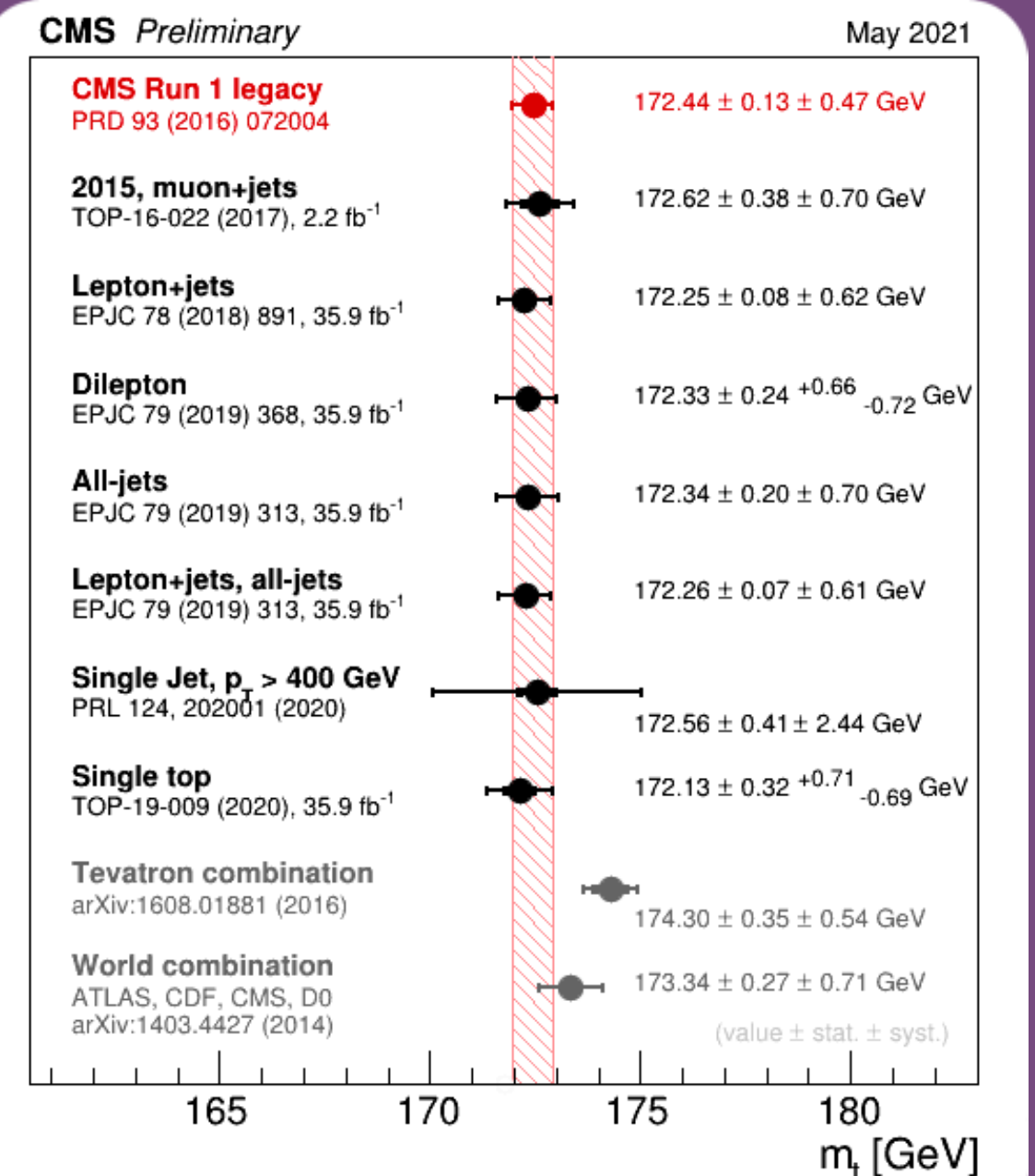
IN SEARCH OF NEW PHYSICS

Precision Measurements

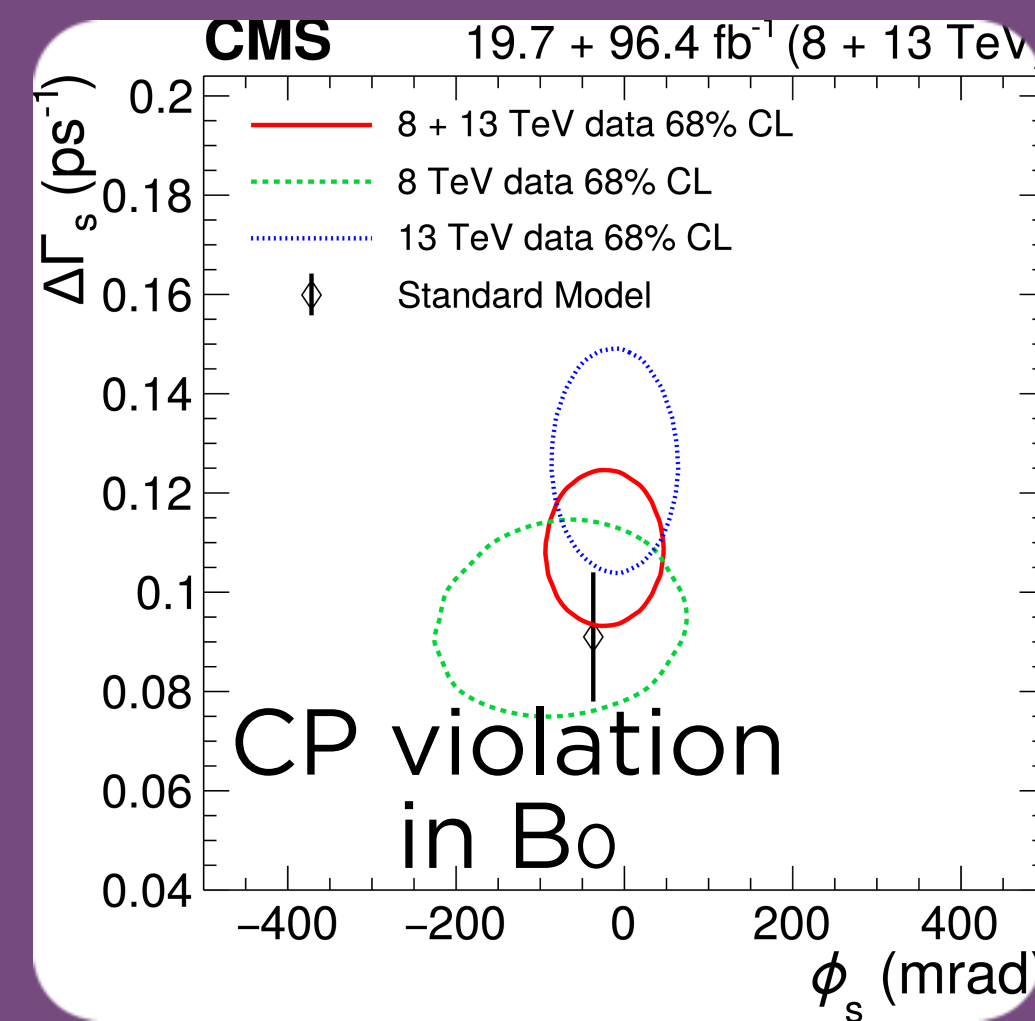
Cross-sections for SM Processes



Top Measurements



Flavor Sector



CP violation in B_0

The diagram features two teal rectangular boxes with white text, connected by a light blue, curved, hourglass-shaped band. The left box contains the text '125 GEV HIGGS' and the right box contains 'STANDARD MODEL HOLDING STRONG'. The band is wider at the ends near the boxes and narrows in the center, visually representing the tension between the two observations.

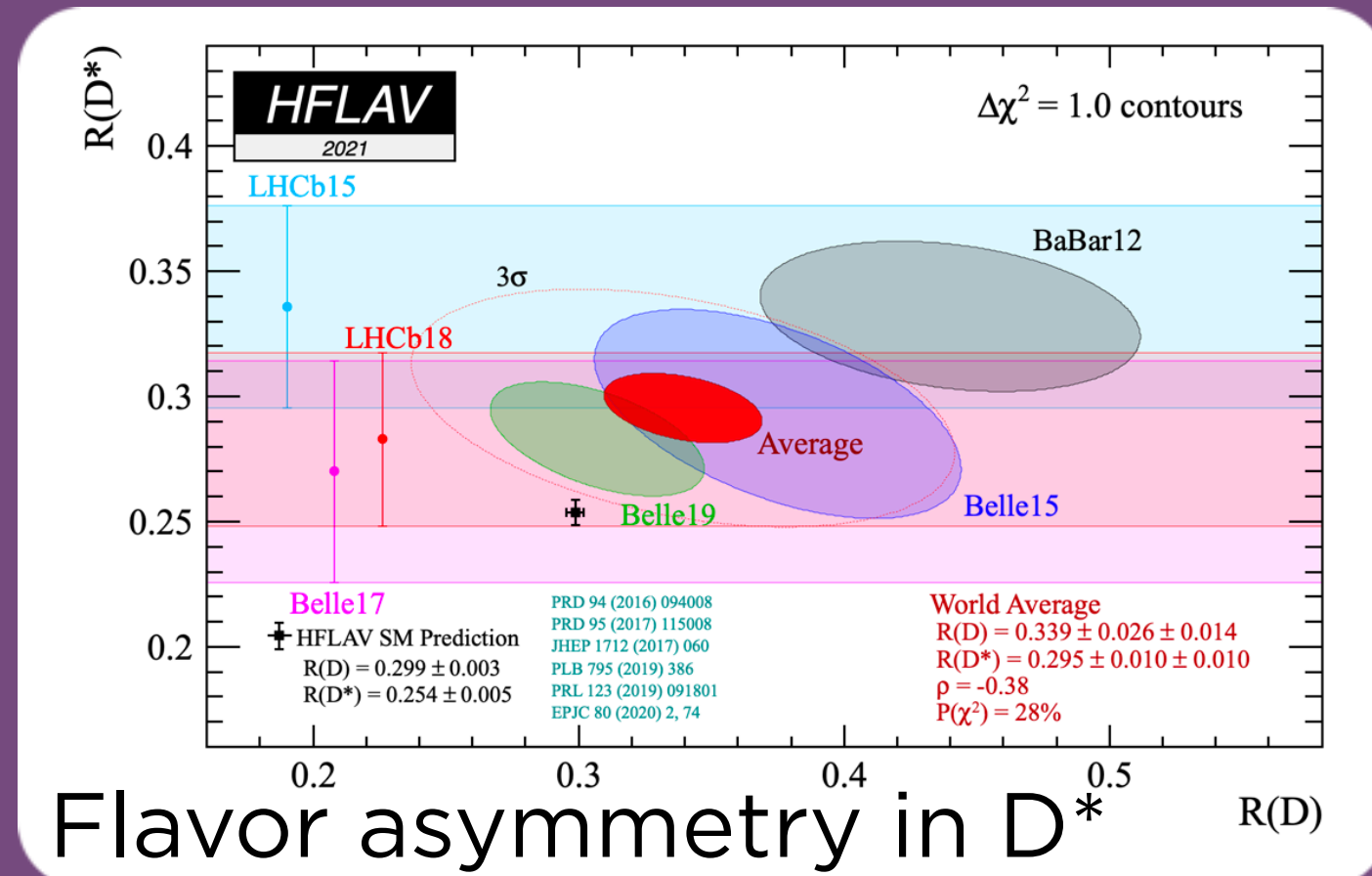
125 GEV
HIGGS

STANDARD
MODEL
HOLDING STRONG

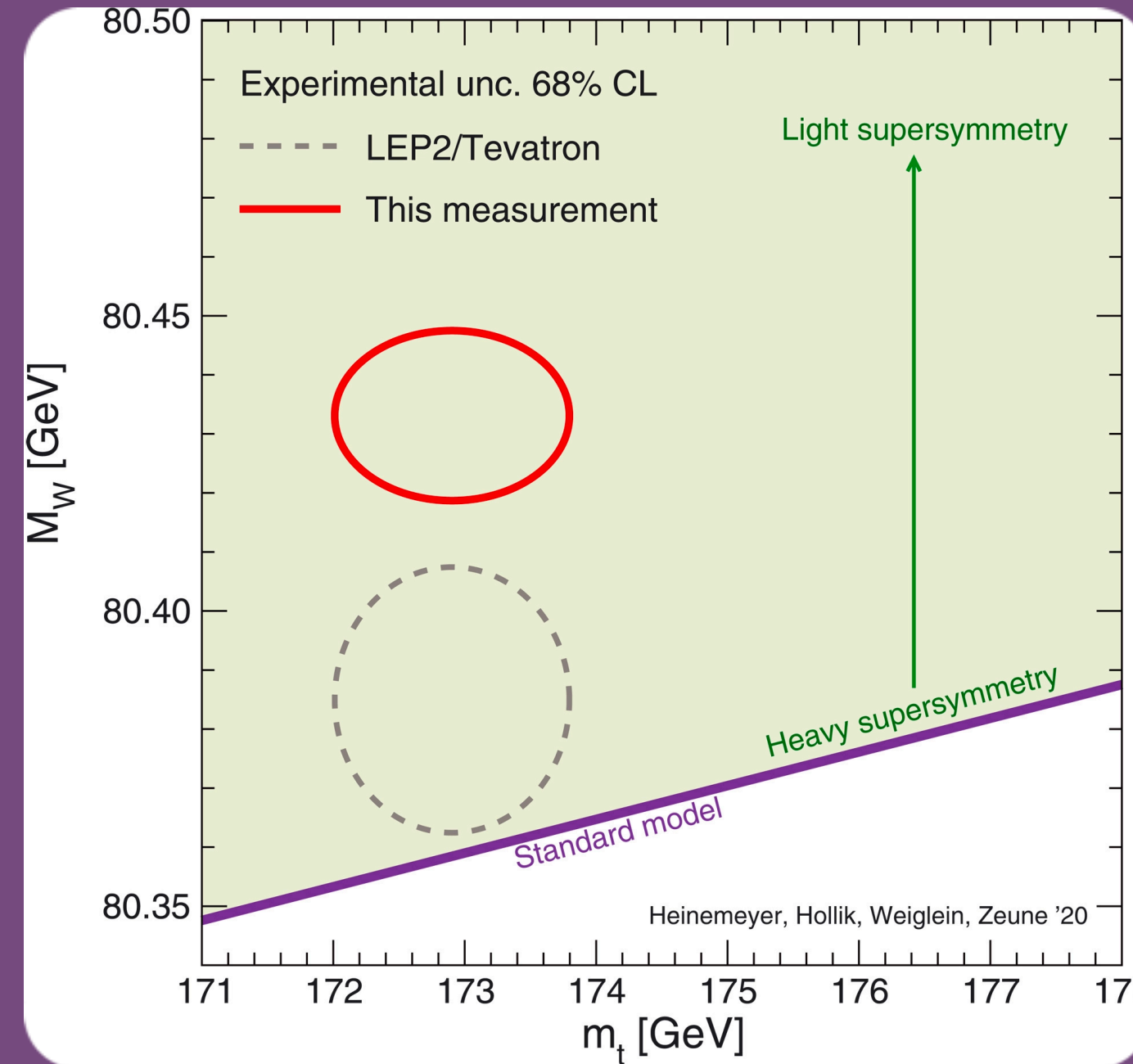
Tension is increasing between these
two observations — hope for discovery
just out of reach.

CRACKS STARTING TO SHOW

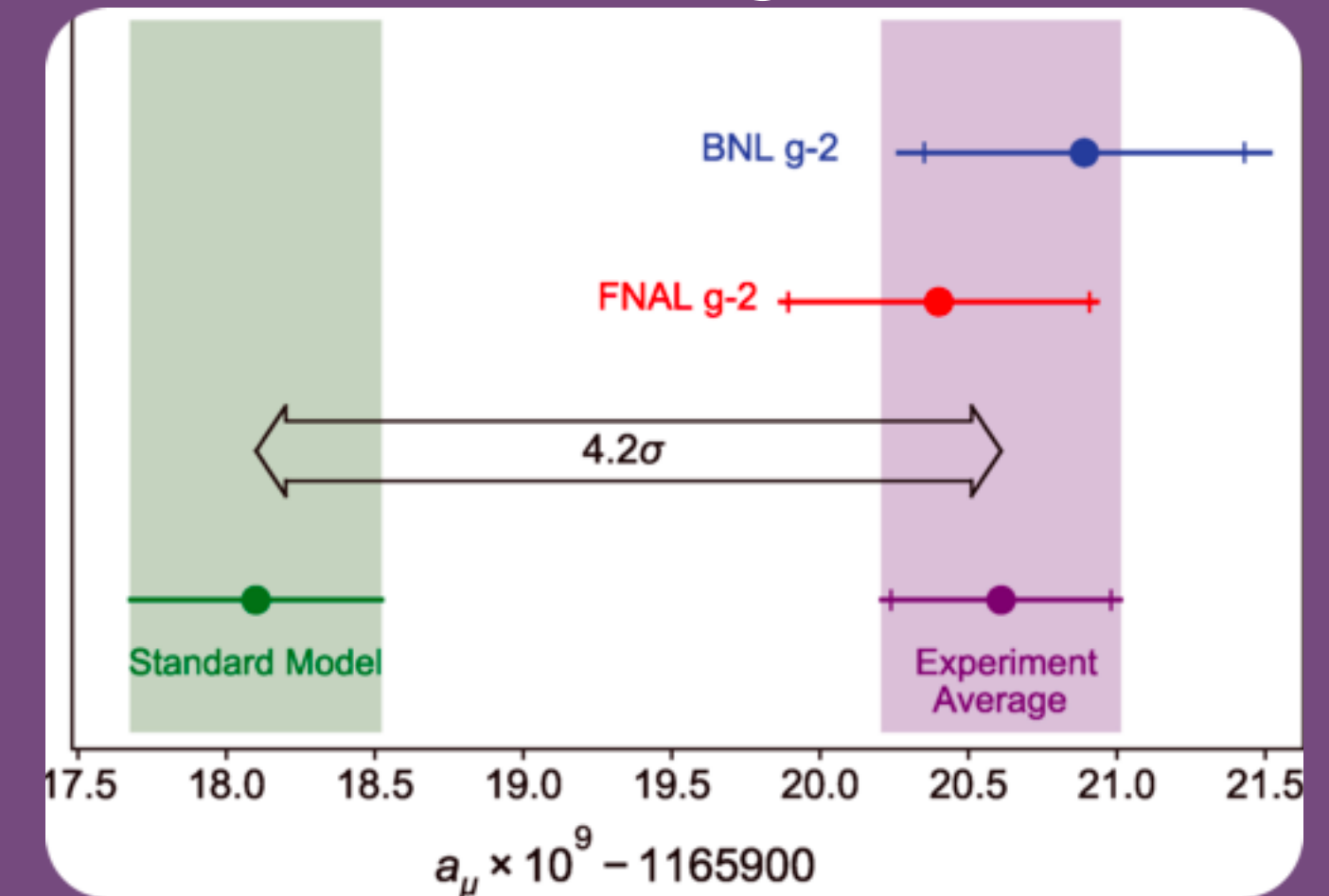
Flavor Anomalies



W Mass Measurement



Muon g-2

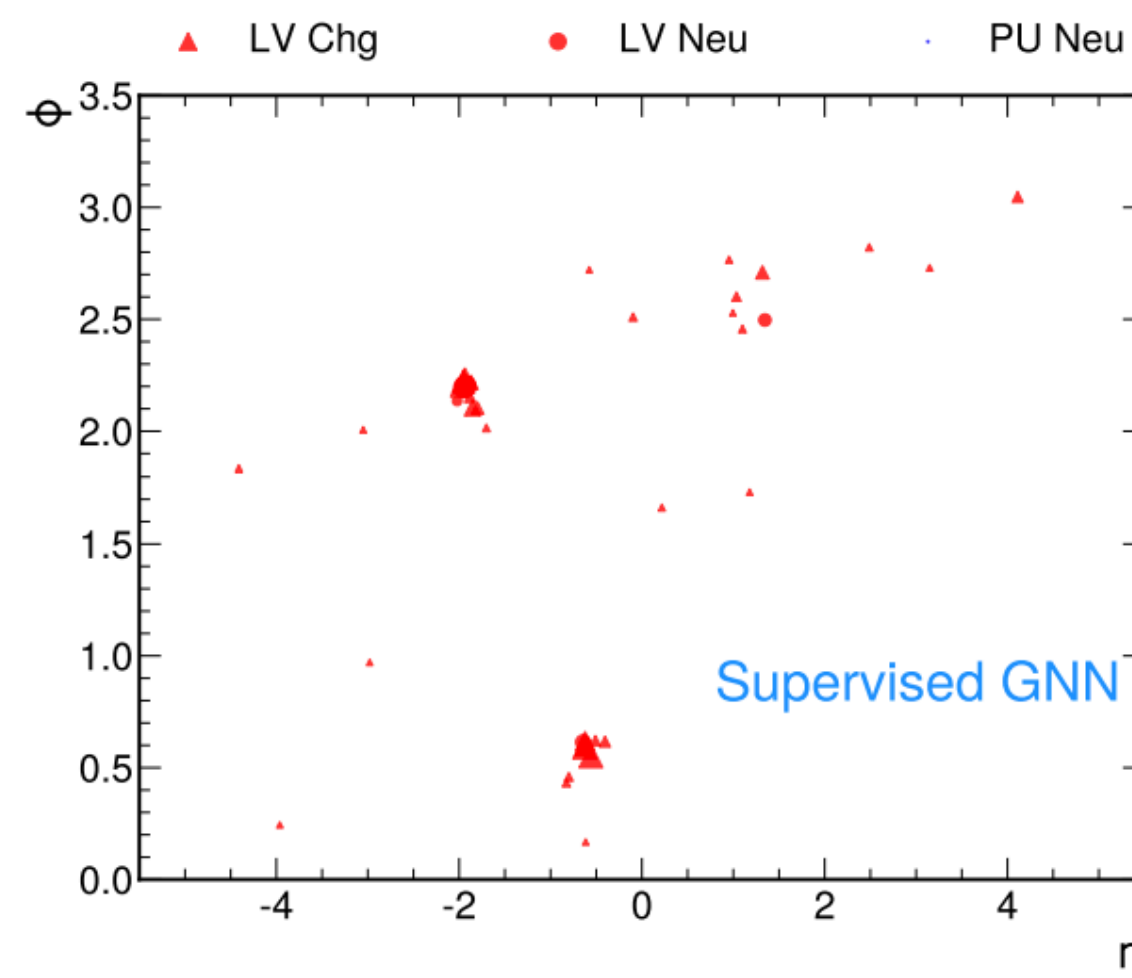
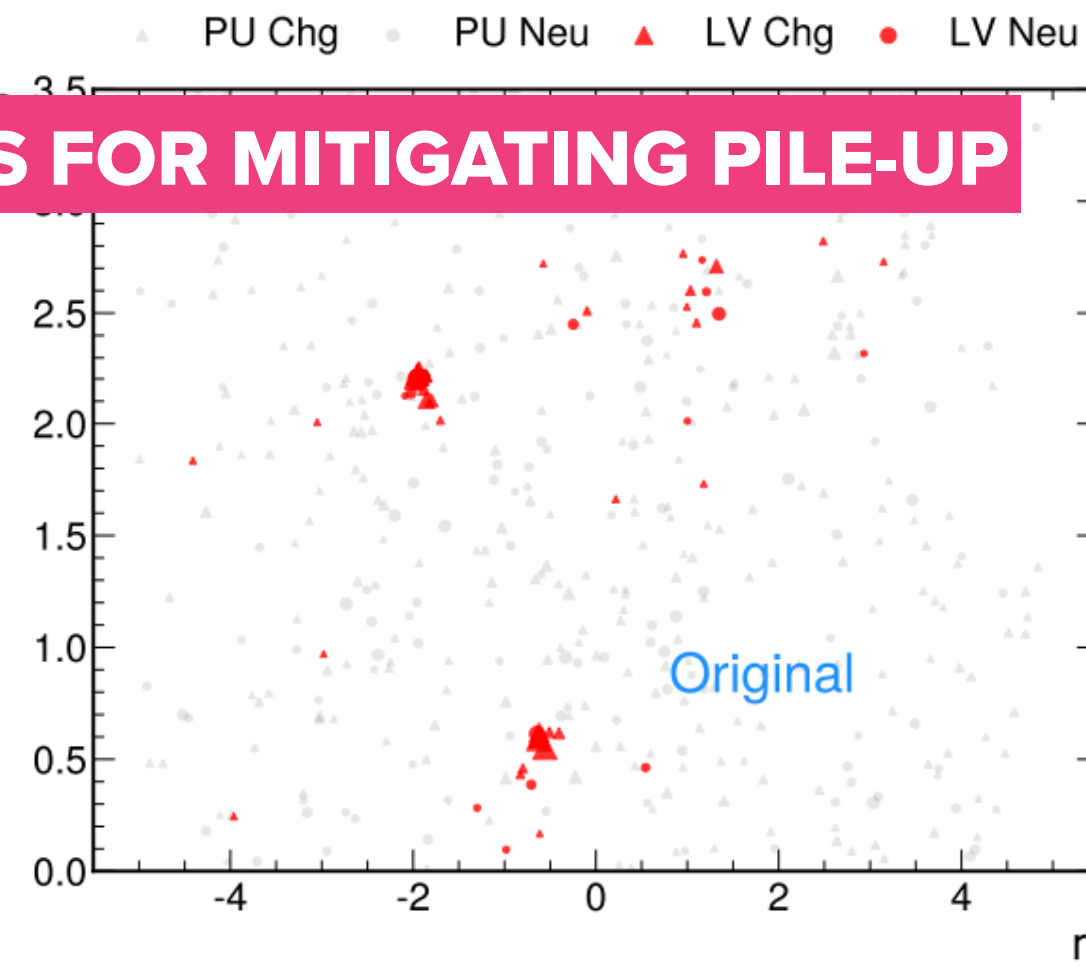


Need EF to directly access particles that could cause these deviations

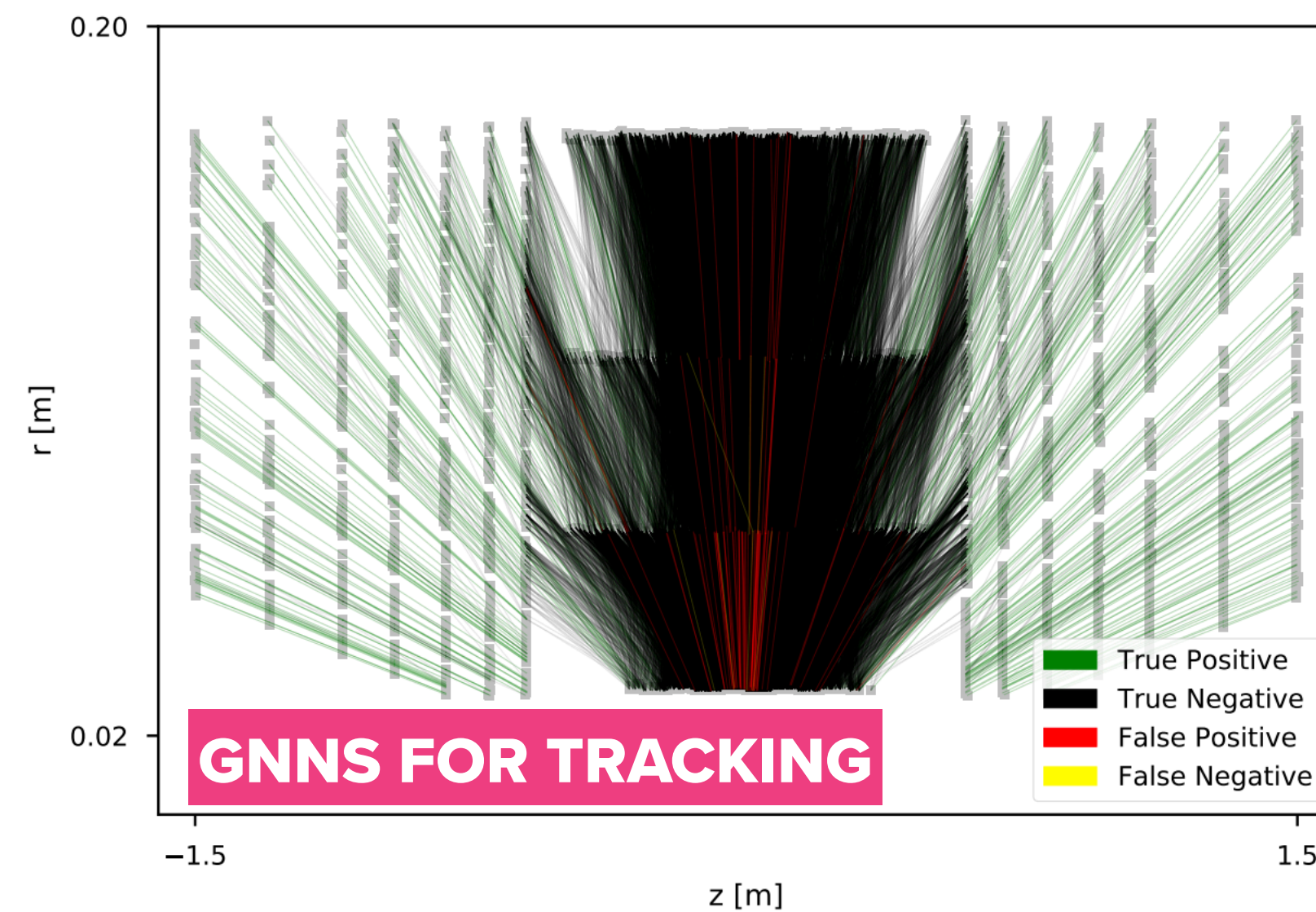
WHAT DO WE DO NOW?

MORE SOPHISTICATED ANALYSIS

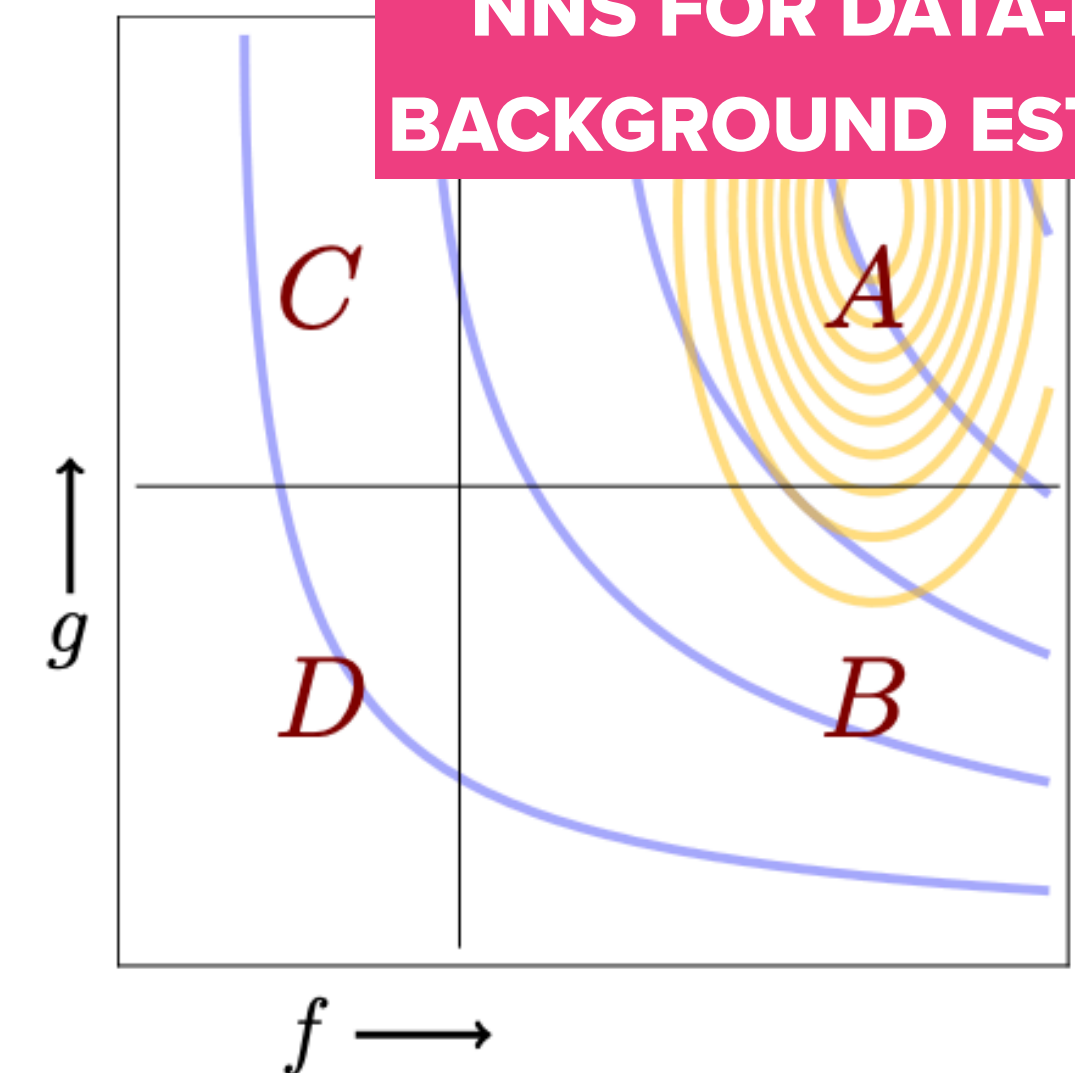
GNNs FOR MITIGATING PILE-UP



The complexity of LHC data necessitates advanced ML strategies
CMS is at the cutting edge



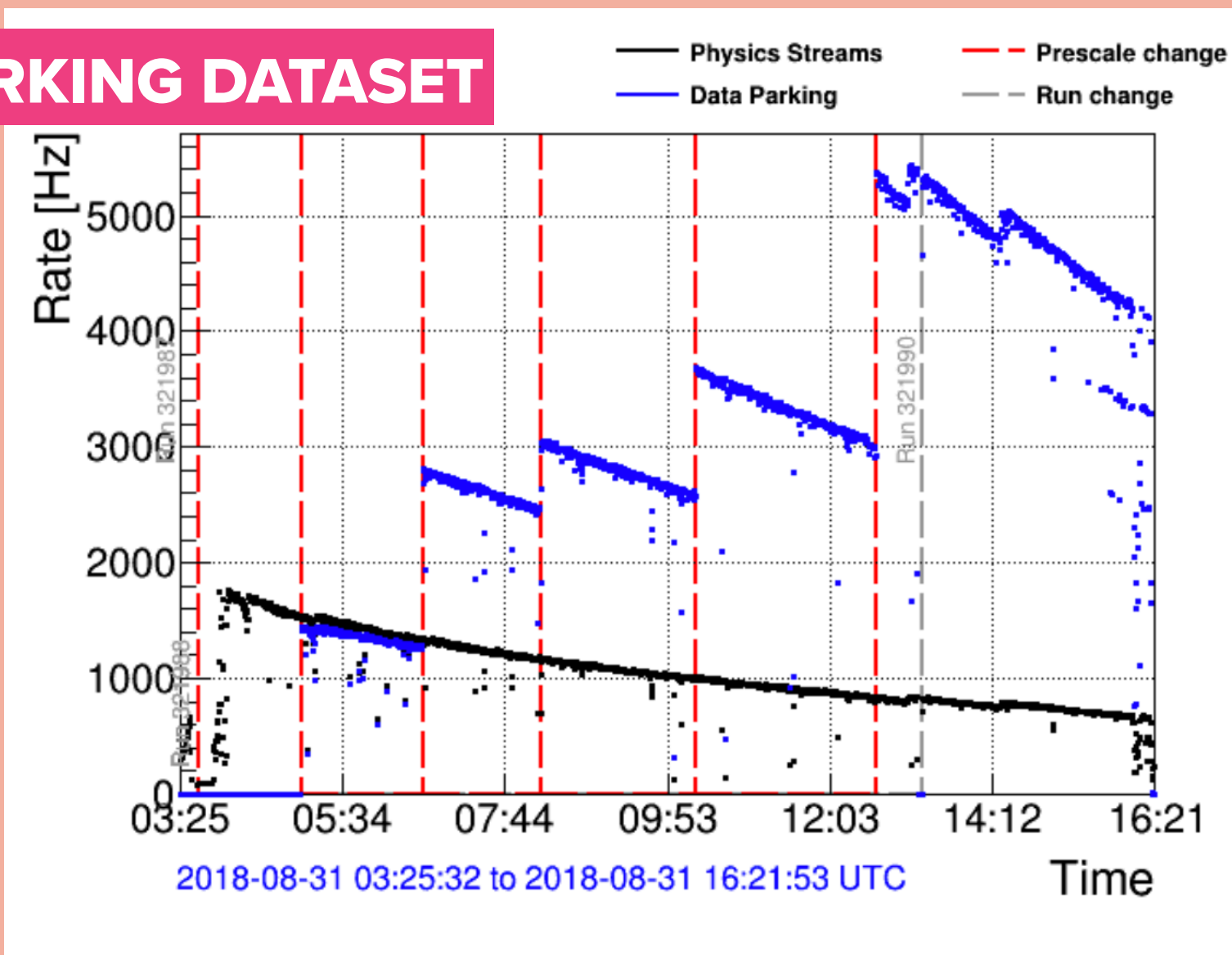
NNS FOR DATA-DRIVEN BACKGROUND ESTIMATION



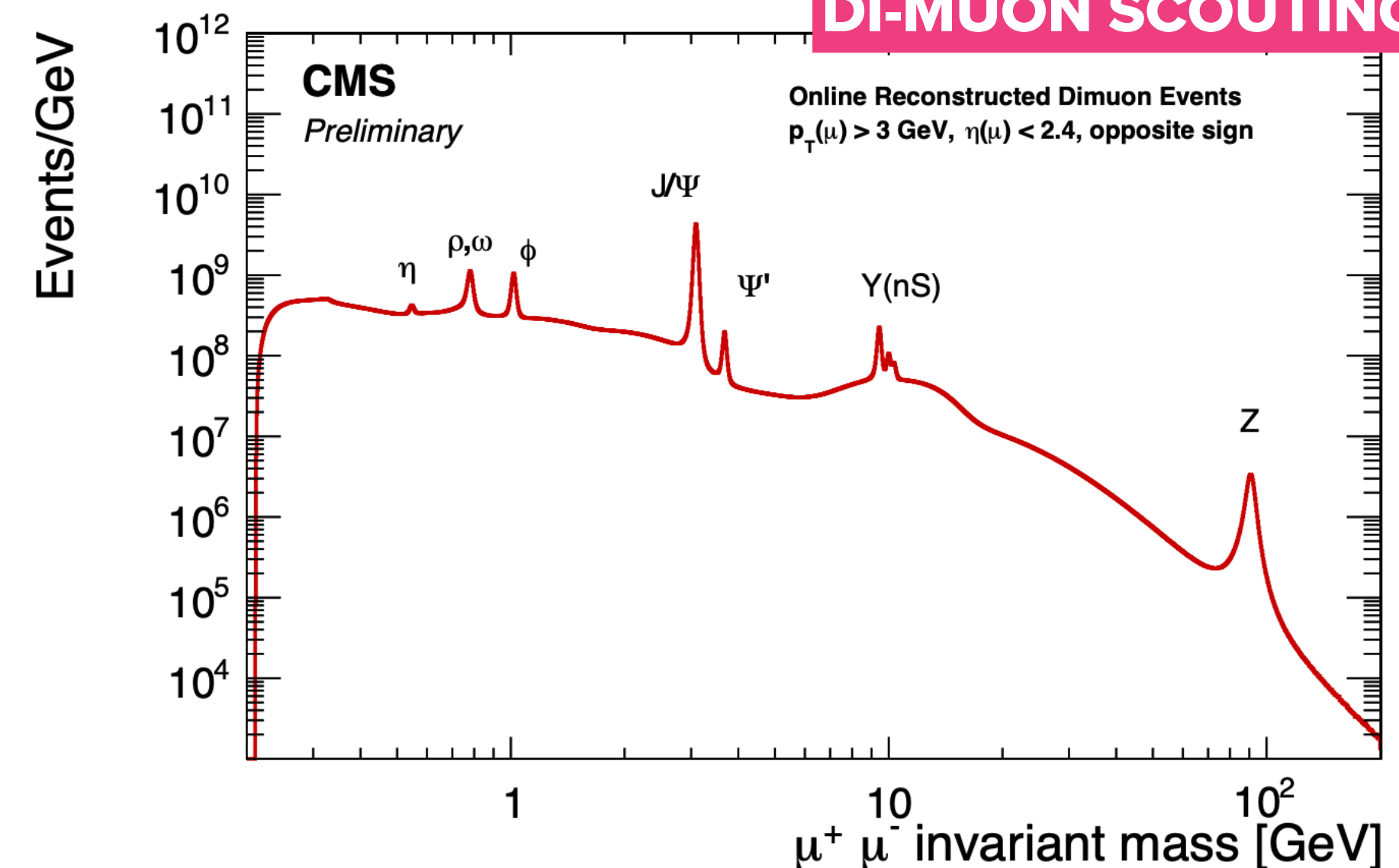
NEW PHASE SPACE

Conventional trigger strategies keep $\sim 0.0025\%$ of events
circumventing this constraint \rightarrow a brand new dataset

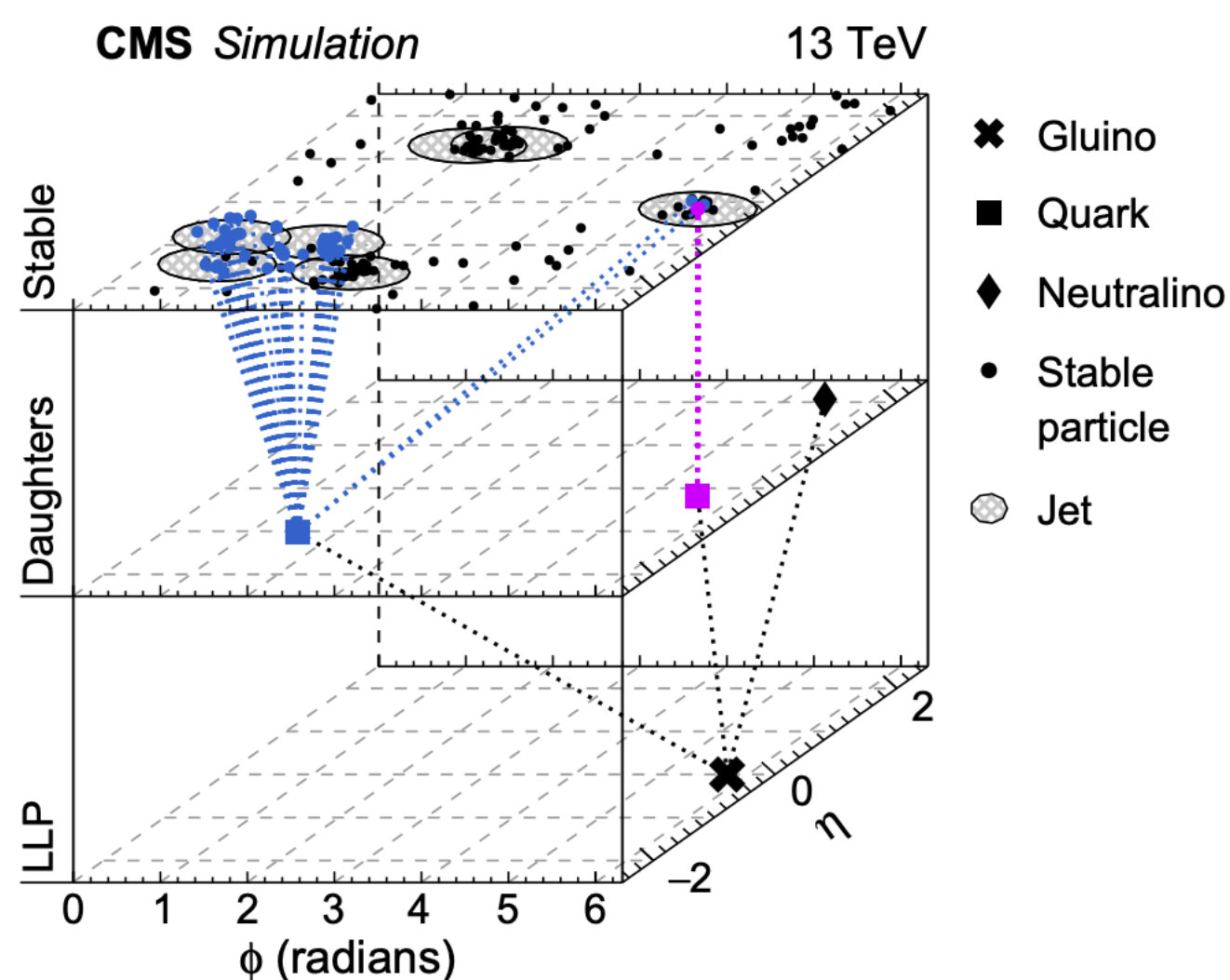
B-PARKING DATASET



DI-MUON SCOUTING DATASET

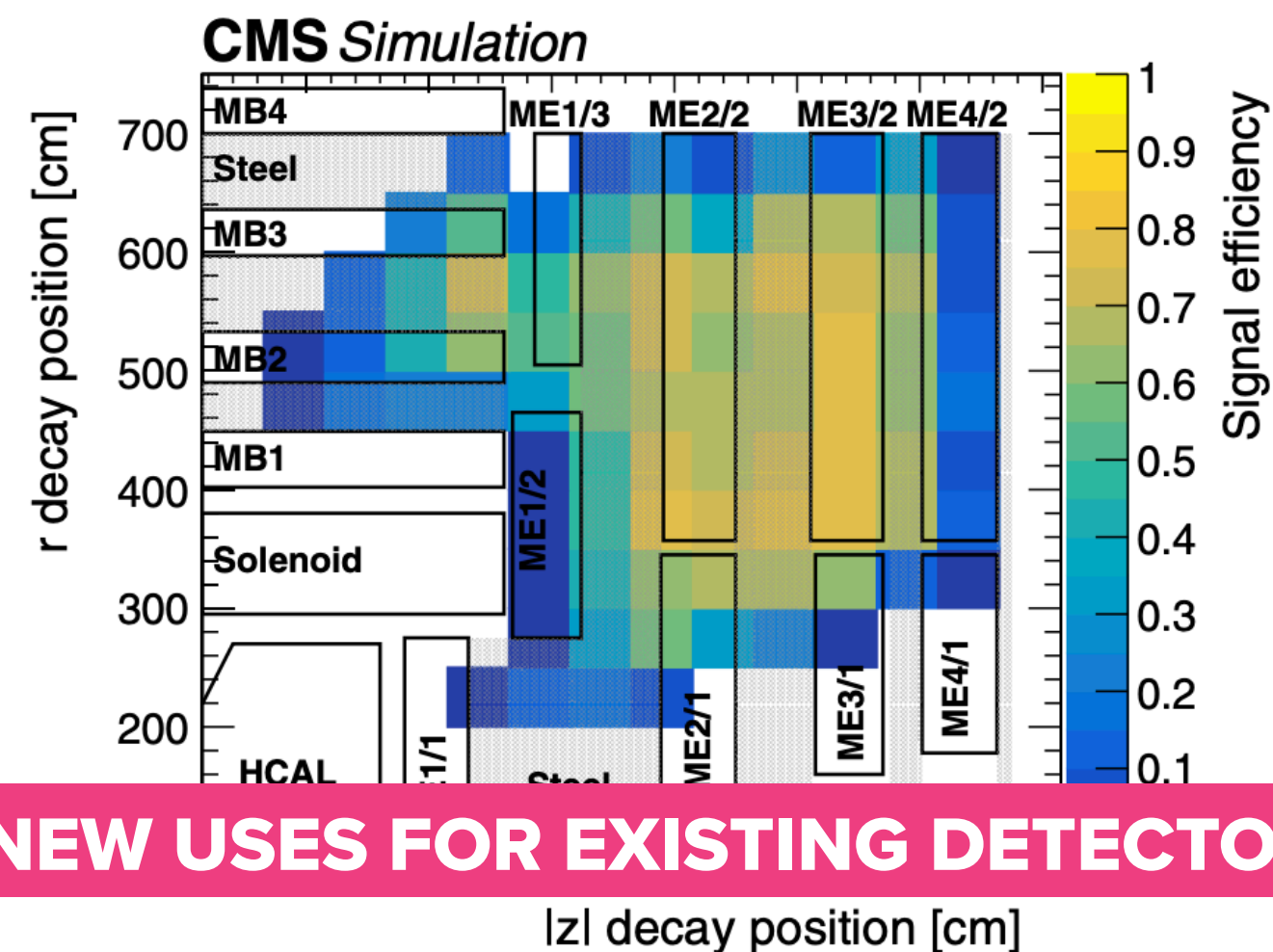
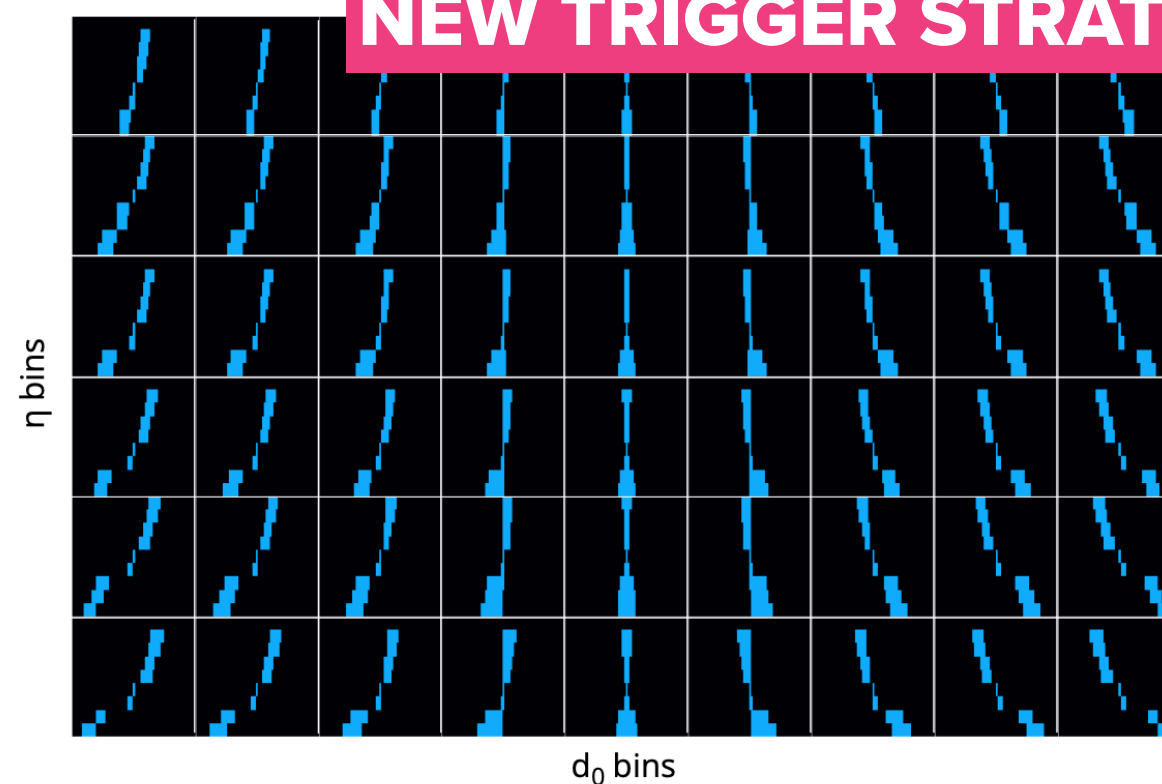


NEW PHASE SPACE



APPLYING ML TO UNCONVENTIONAL SIGNATURES

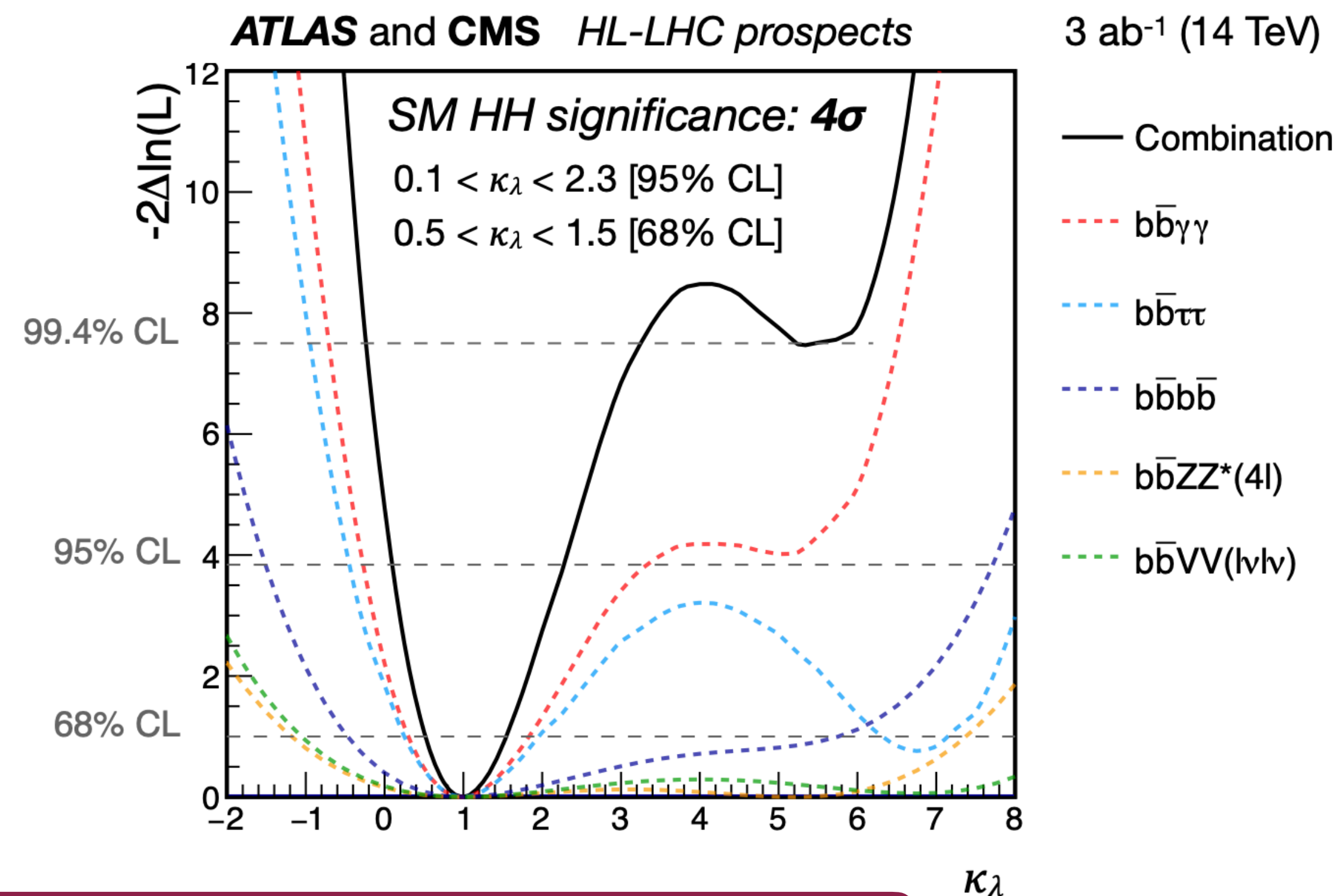
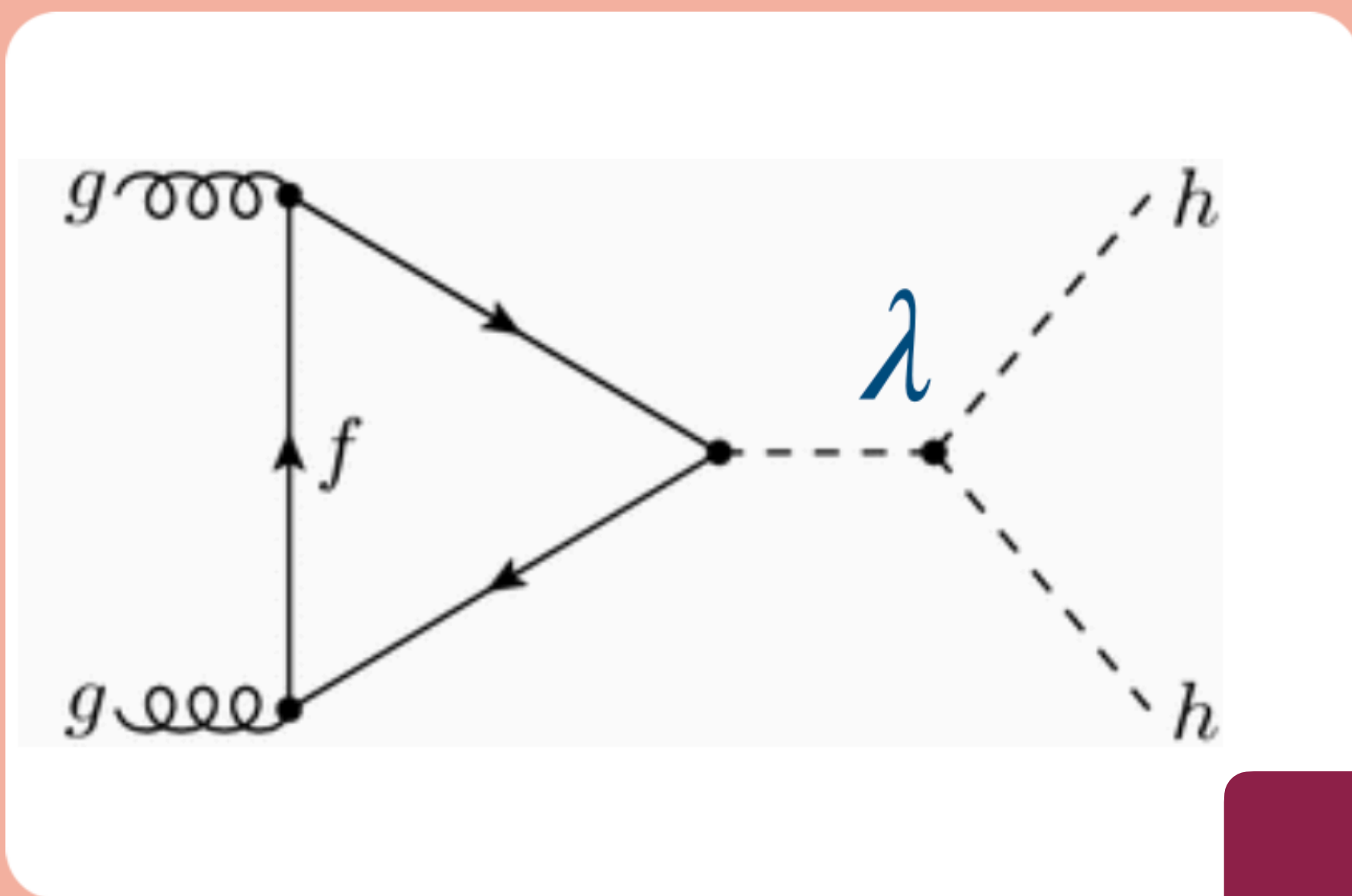
NEW TRIGGER STRATEGIES



Uncovered territory in long-lived particles

MORE DATA: THE HL-LHC

1000x fewer HH events than H



expect 50% uncertainty on κ_λ
 4-sigma evidence for HH production

EF BIG QUESTIONS

AND MUCH,
MUCH MORE!

Evolution of early universe
Matter antimatter asymmetry
Nature of dark matter
Origin of neutrino mass
Origin of EW scale
Origin of flavor

Exploring the unknown

Huge breadth of physics reach

95% of data left to gather

answers may lie in that data,
if we can just figure out how to
look in the right places

THANK YOU!



THE UNIVERSITY OF
TENNESSEE
KNOXVILLE



U.S. DEPARTMENT OF
ENERGY

Office of
Science