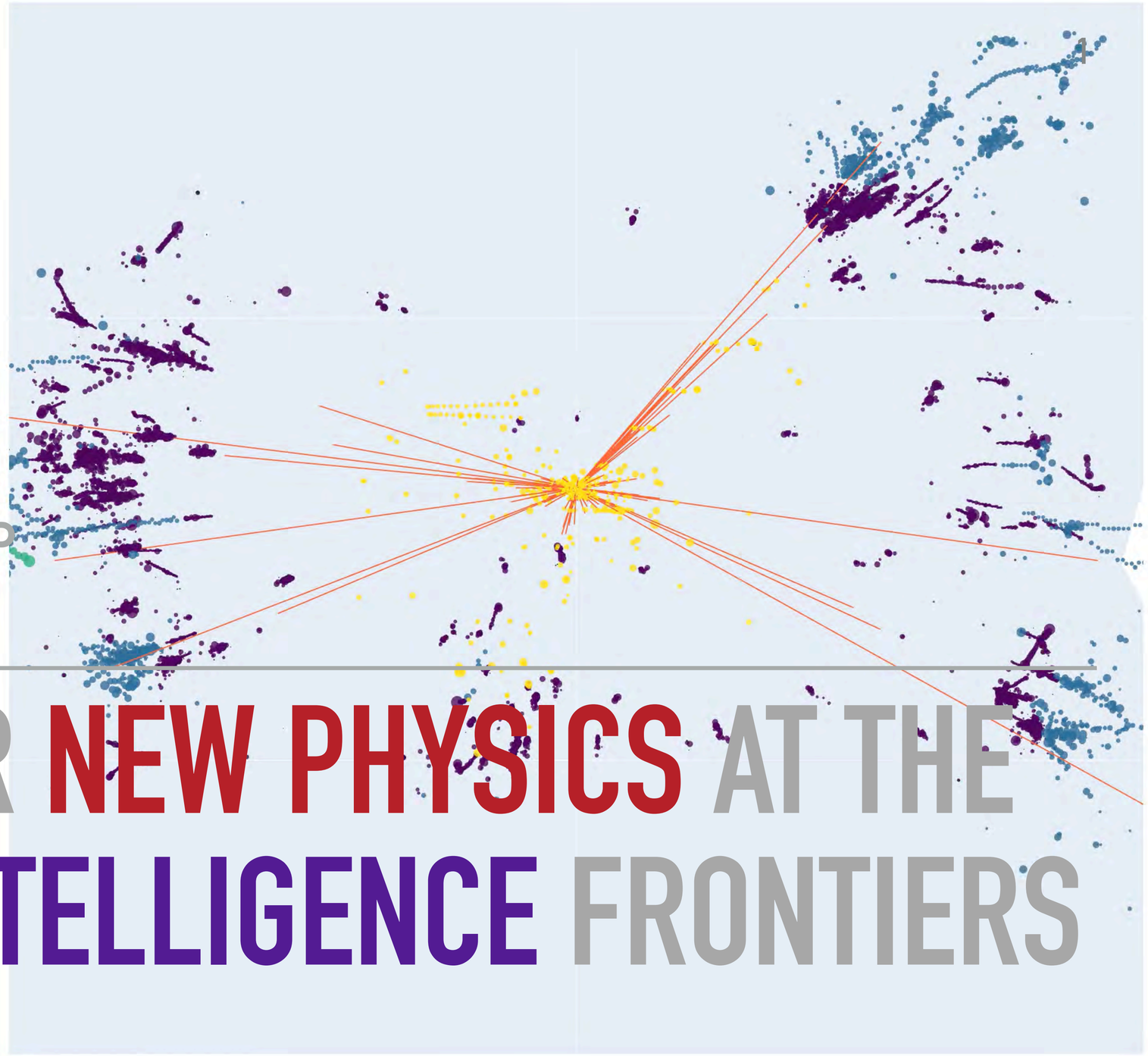


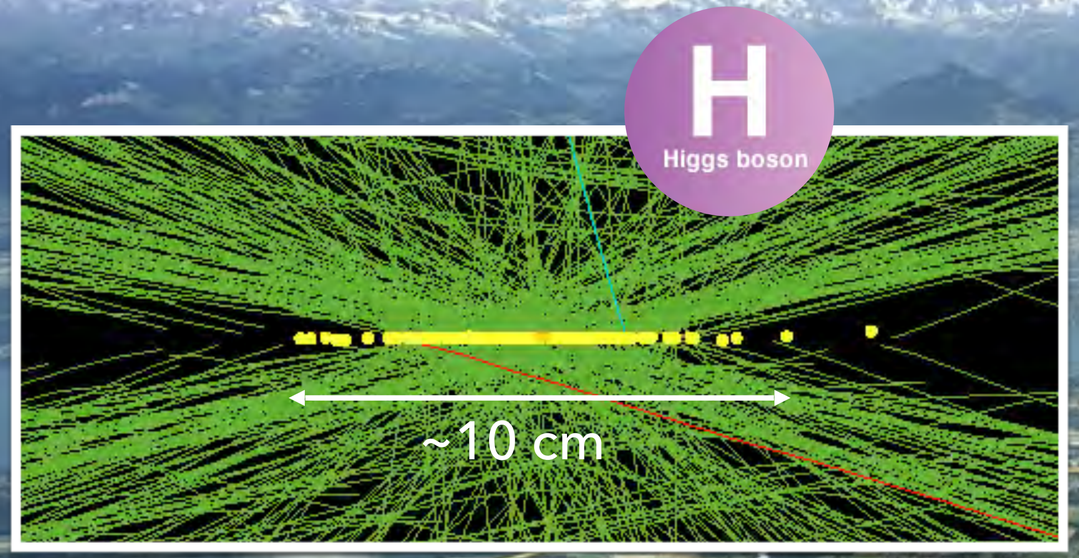
JAVIER DUARTE

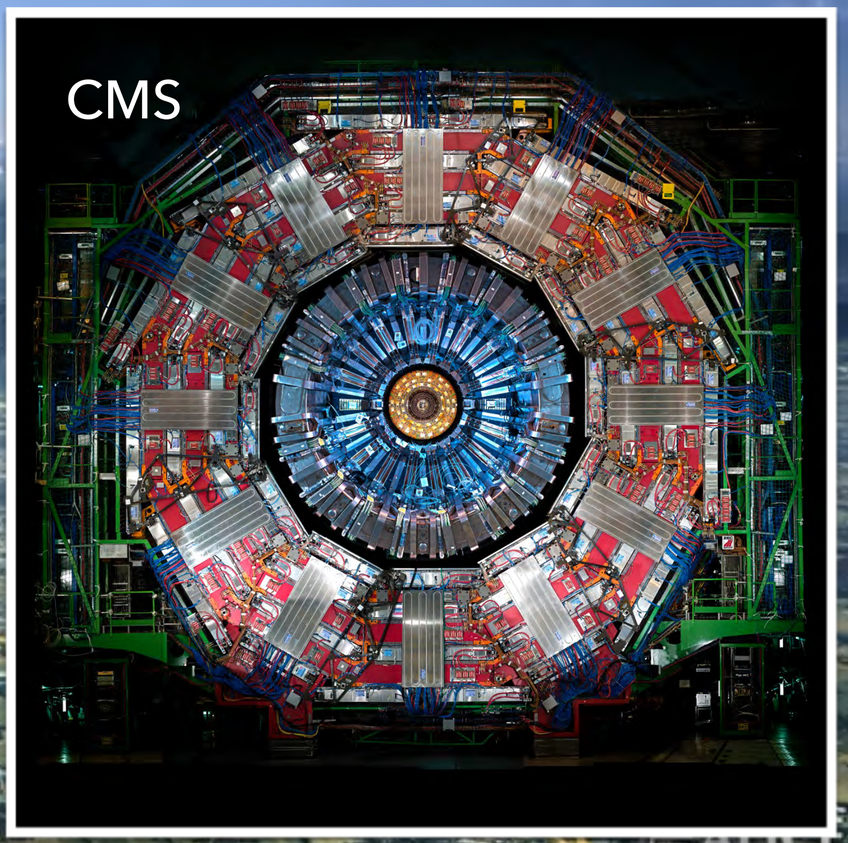
NSF CI COMPASS WORKSHOP

JANUARY 12, 2026

SEARCHING FOR NEW PHYSICS AT THE ENERGY AND INTELLIGENCE FRONTIERS

THE LARGE HADRON COLLIDER





proton-proton collider @ 13.6 TeV center-of-mass energy

4 interaction points

40 million collisions / second

Higgs boson produced 1/10 billion collisions (every 4 minutes)

analyze ~1000 collisions / second

COMPACT MUON SOLENOID

100 million channels to measure different particles

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

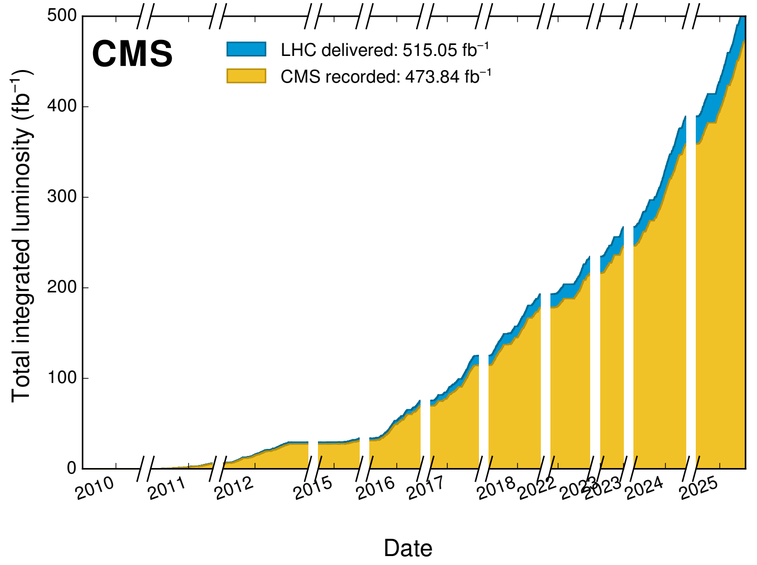
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
Silicon strips ~16m² ~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

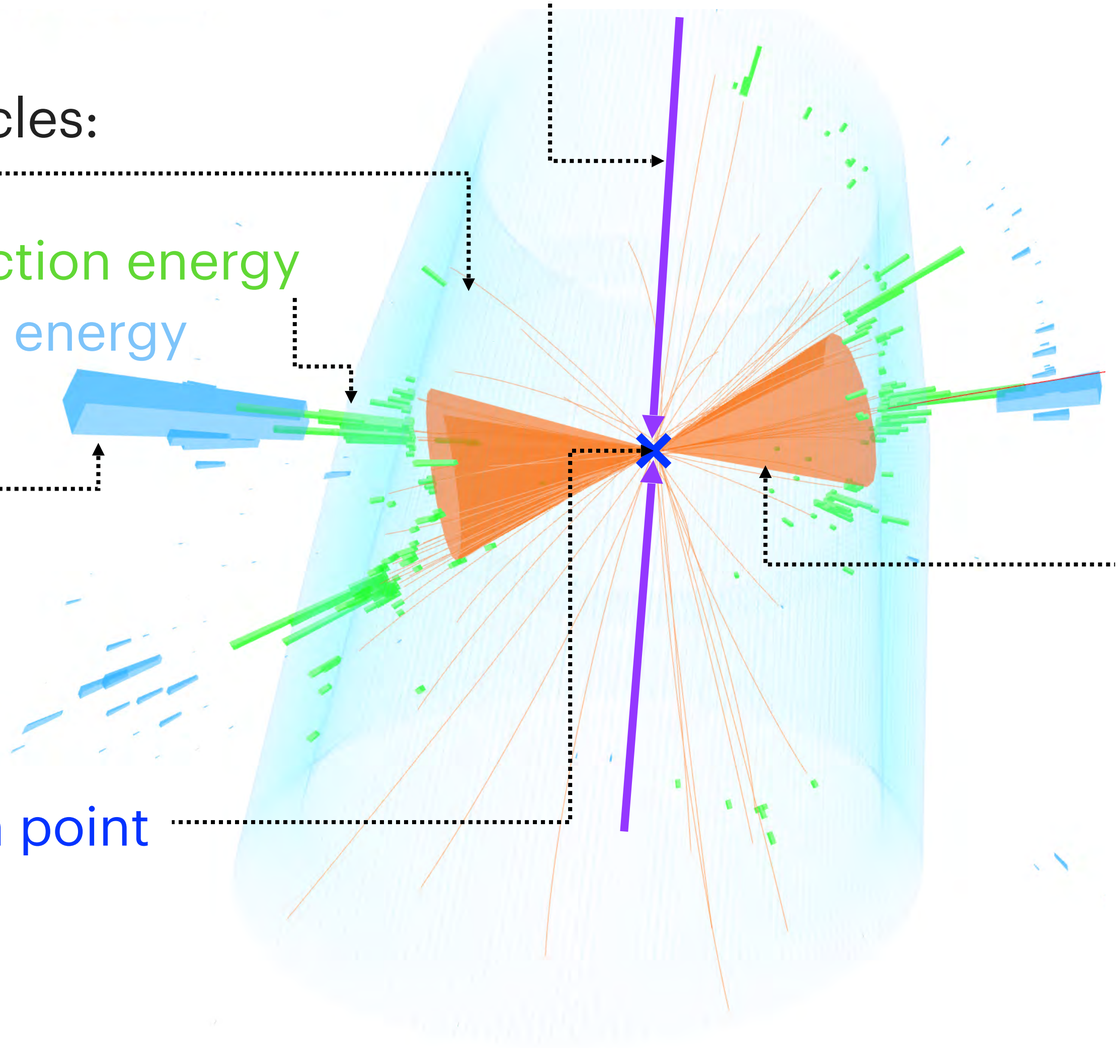
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels



Broad physics program, ranging from measurements of the standard model and the Higgs boson to studies of heavy-ion collisions and searches for new particles and phenomena

AI integrated into almost every aspect from simulation, triggering, reconstruction, and analysis

LHC RAW DATA TO “PARTICLE" CLOUDS

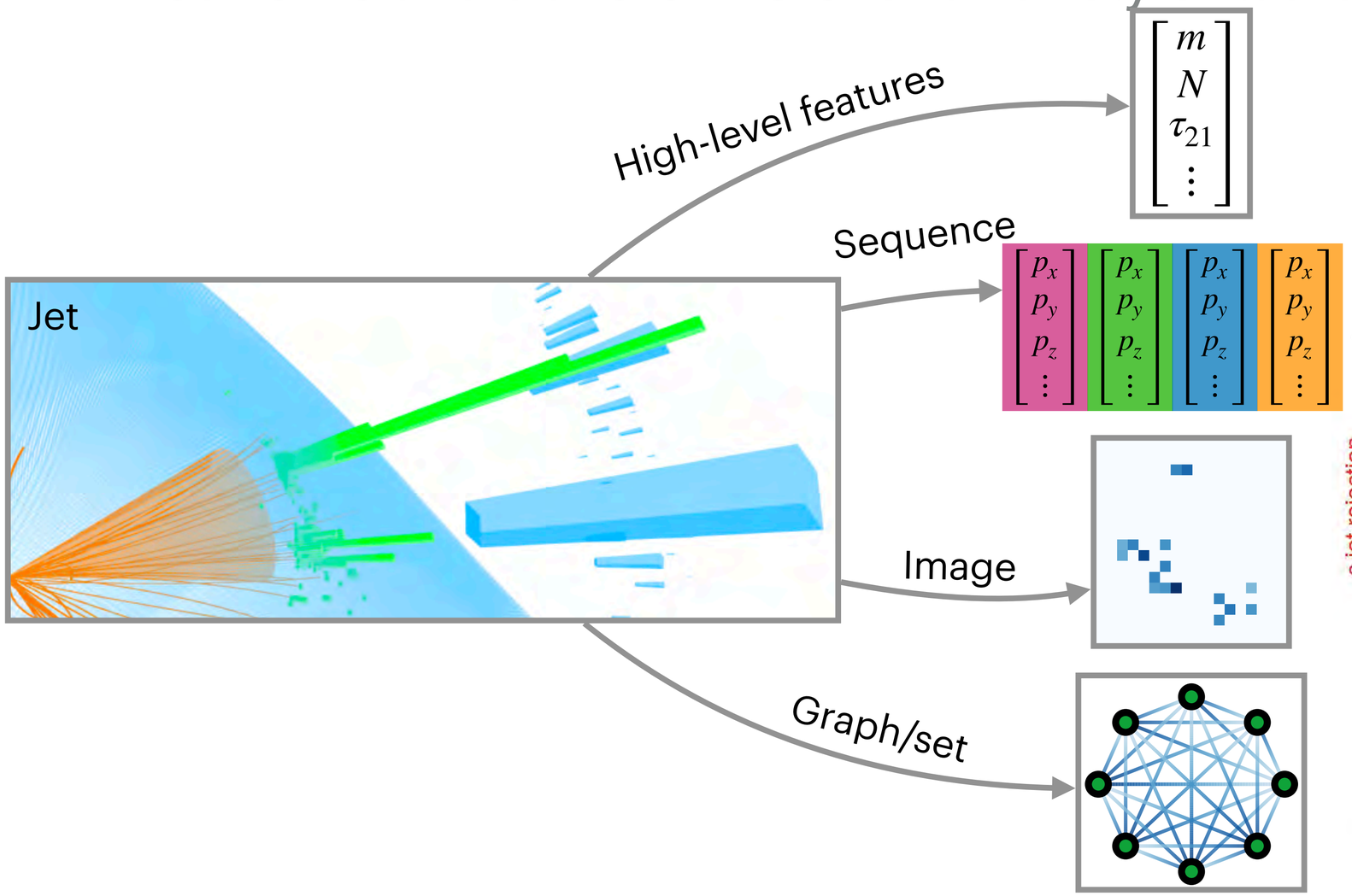


Collision event

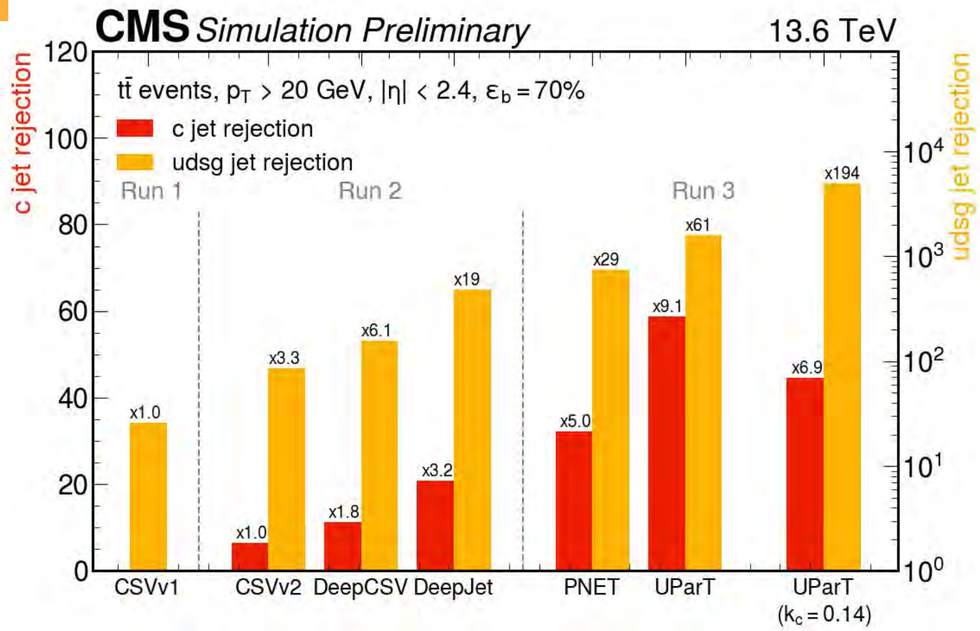
Can artificial intelligence help us?

FROM BDTS TO GNNS AND TRANSFORMERS

- Great strides made to leverage **rich low-level information** with **graph neural networks** and **transformers** for a variety of tasks including **jet classification**

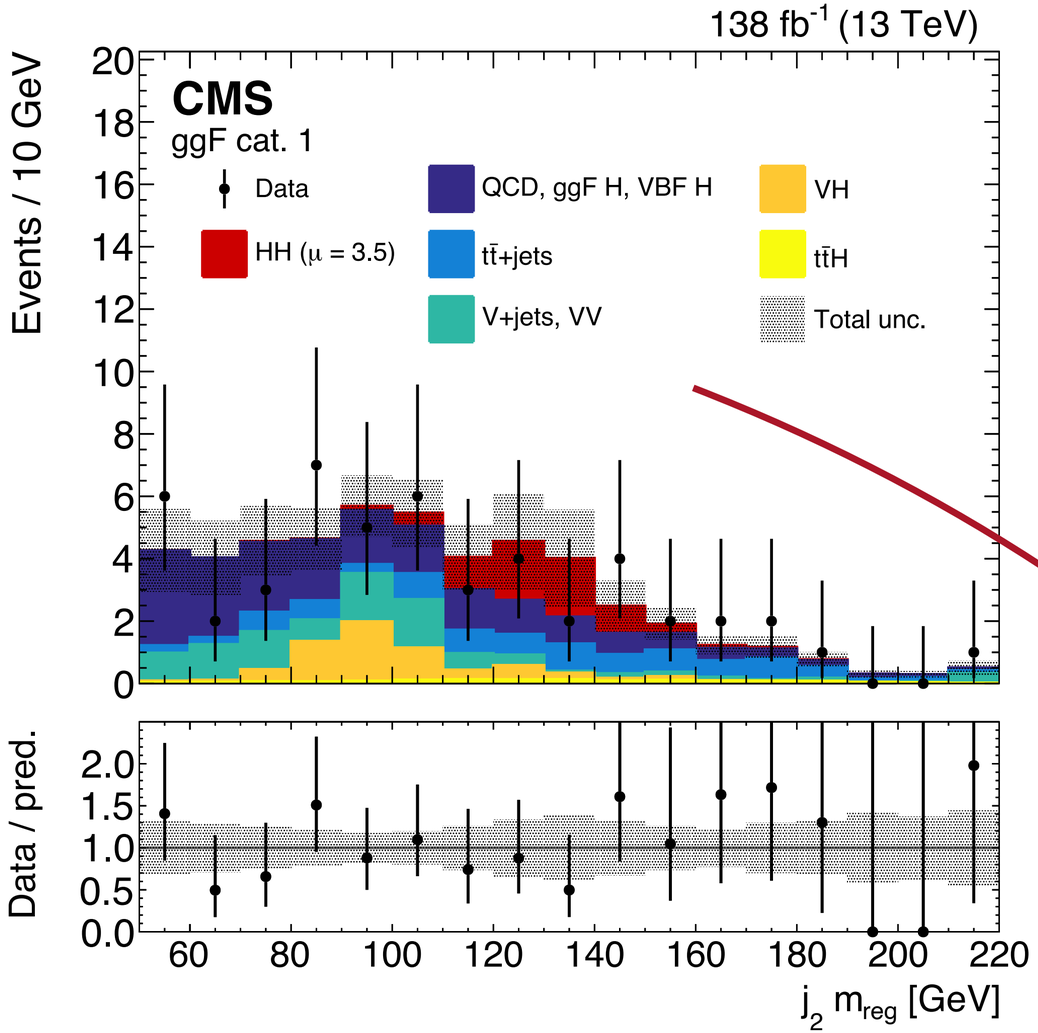


- Major improvements demonstrated in CMS (ParticleNet/Transformer)



CMS SEARCH FOR HH→4B SEARCH

- AI improves search for Higgs boson pair production, which can help to measure the Higgs boson self interaction



Most sensitive HH search in LHC Run 2

bb ZZ
Expected: 40
Observed: 32

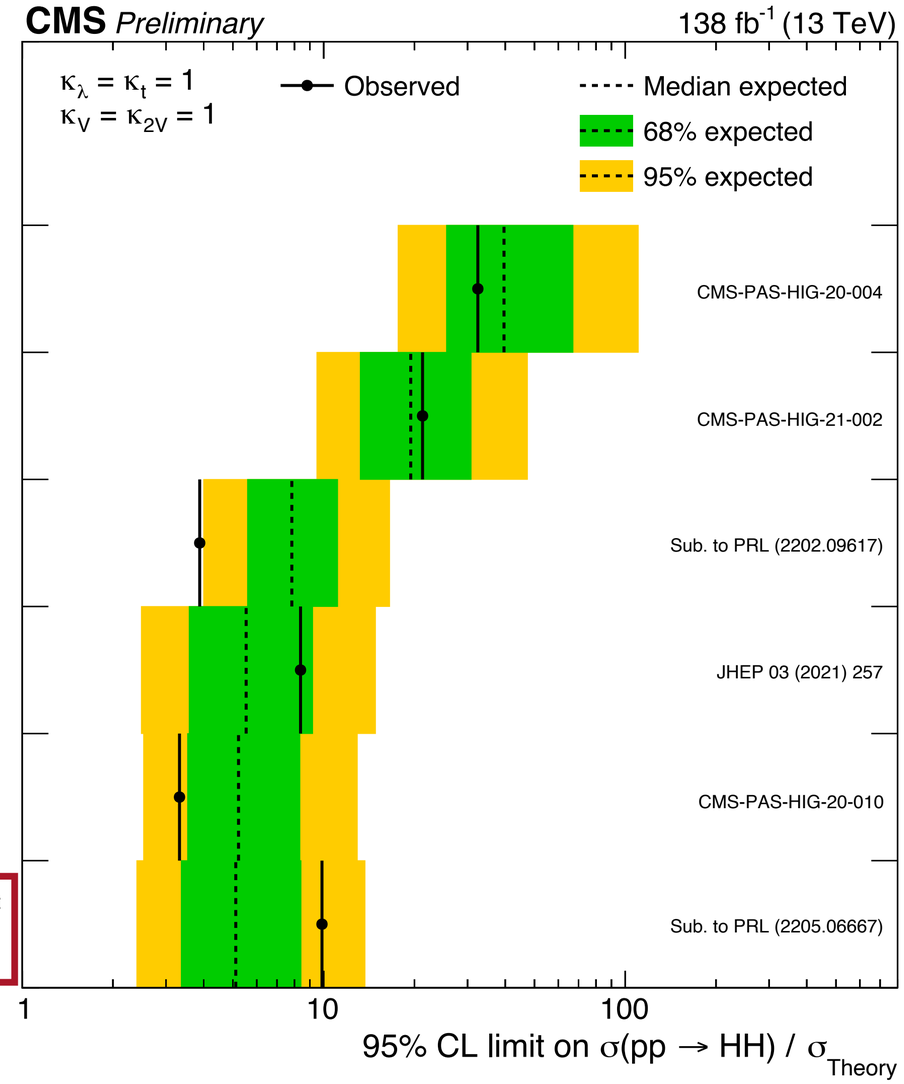
Multilepton
Expected: 19
Observed: 21

bb bb, resolved
Expected: 7.8
Observed: 3.9

bb γγ
Expected: 5.5
Observed: 8.4

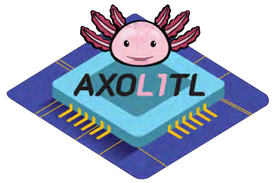
bb ττ
Expected: 5.2
Observed: 3.3

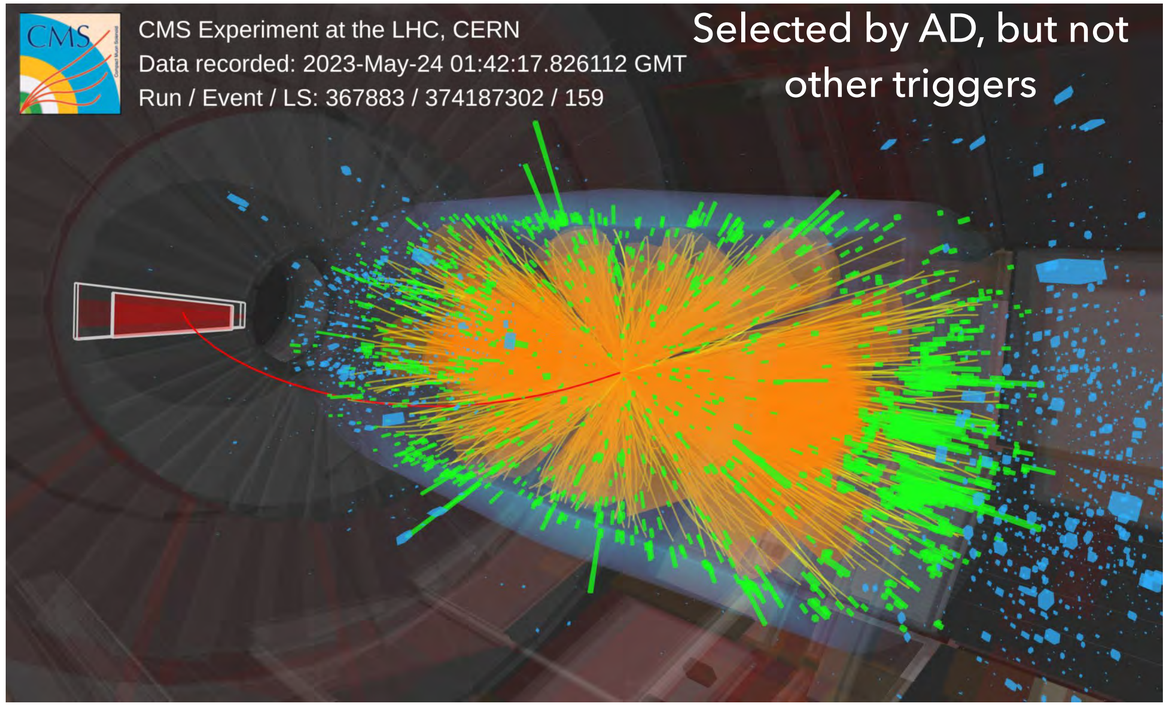
bb bb, merged jet
Expected: 5.1
Observed: 9.9

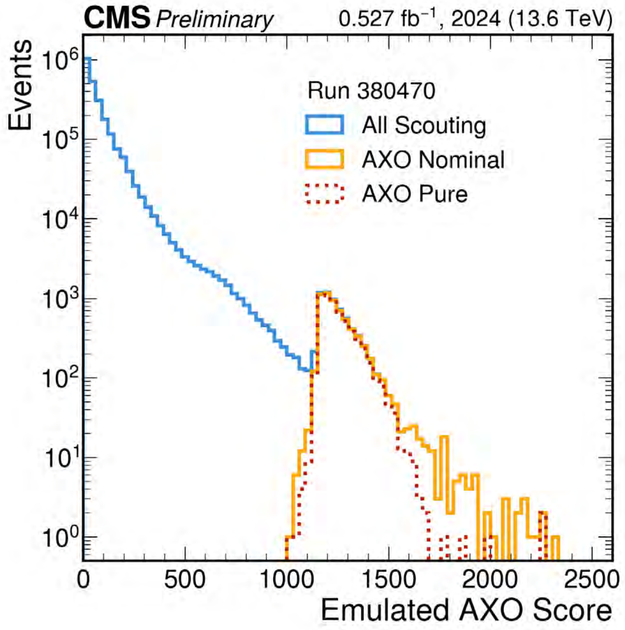


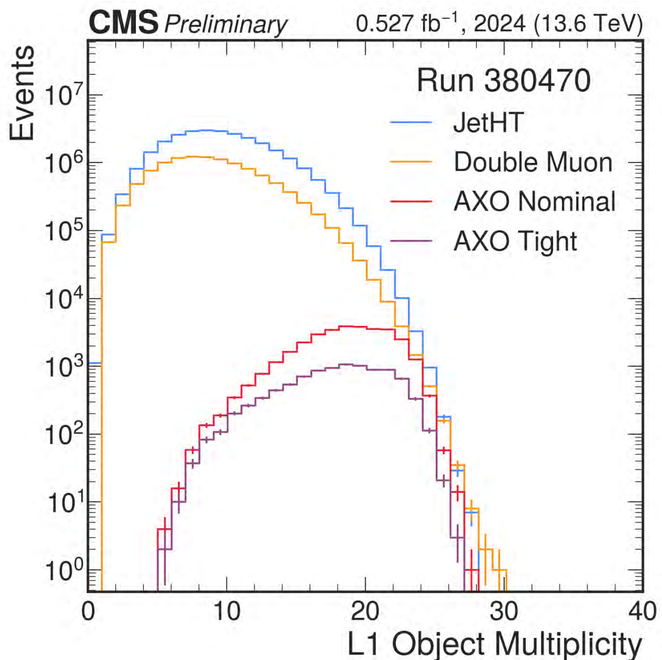
REAL-TIME ANOMALY DETECTION

- Real-time anomaly detection algorithm deployed in FPGAs based on a variational autoencoder
- Selects unique events relative to existing triggers
- Preference for high multiplicity events



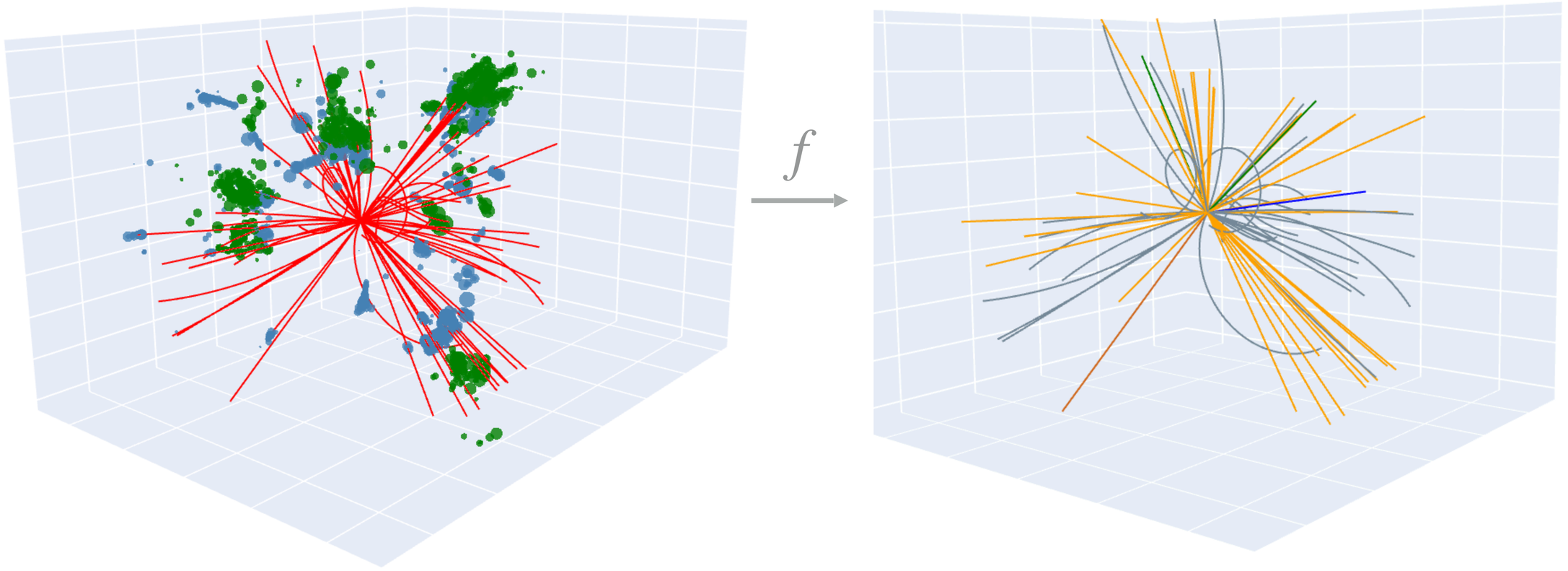






PARTICLE RECONSTRUCTION AS AN AI TASK

- Formulate particle reconstruction as an AI task (naturally "tunable" through re-training and portable to new hardware)
- Learn a "set-to-set" function $f: X \rightarrow Y$, where $\{\text{tracks, energy clusters}\} \in X$ and $\{\text{particles}\} \in Y$

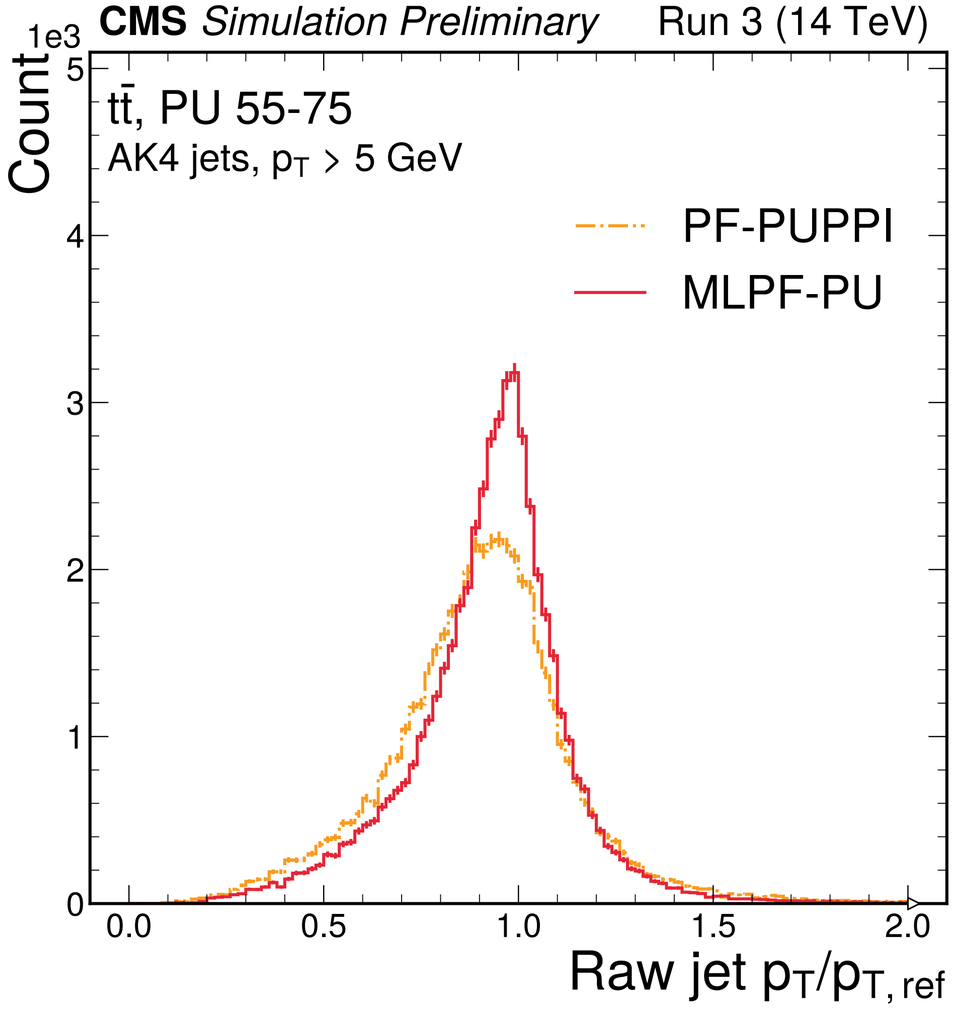


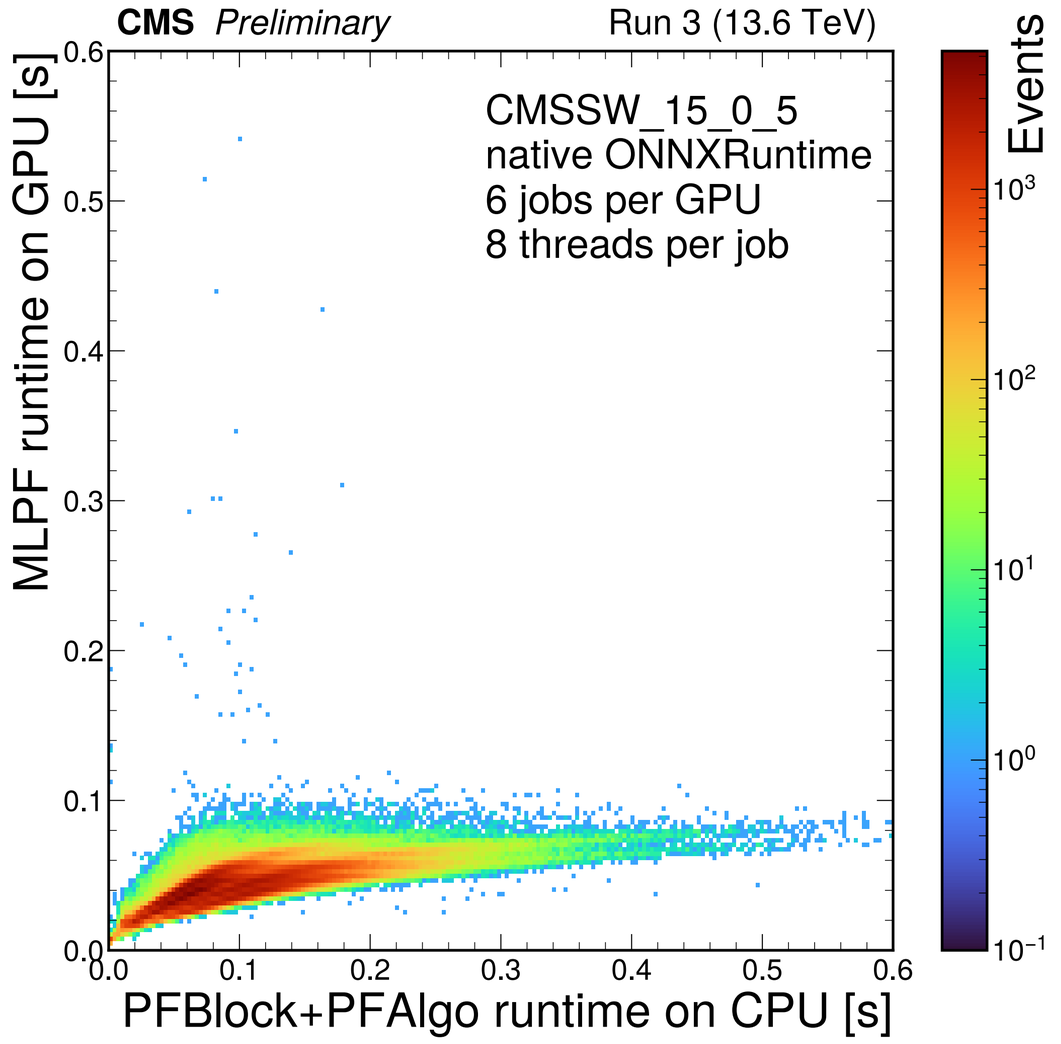
$\{\text{tracks, energy clusters}\} \in X$

$\{\text{particles}\} \in Y$

PARTICLE RECONSTRUCTION WITH AI

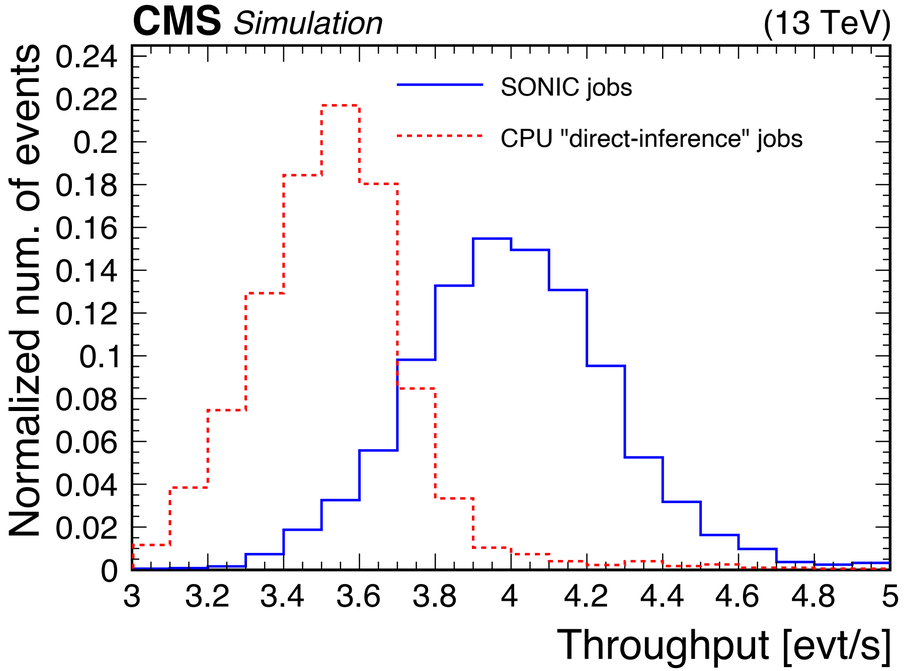
- Improved physics performance and computational scaling with AI-based algorithm

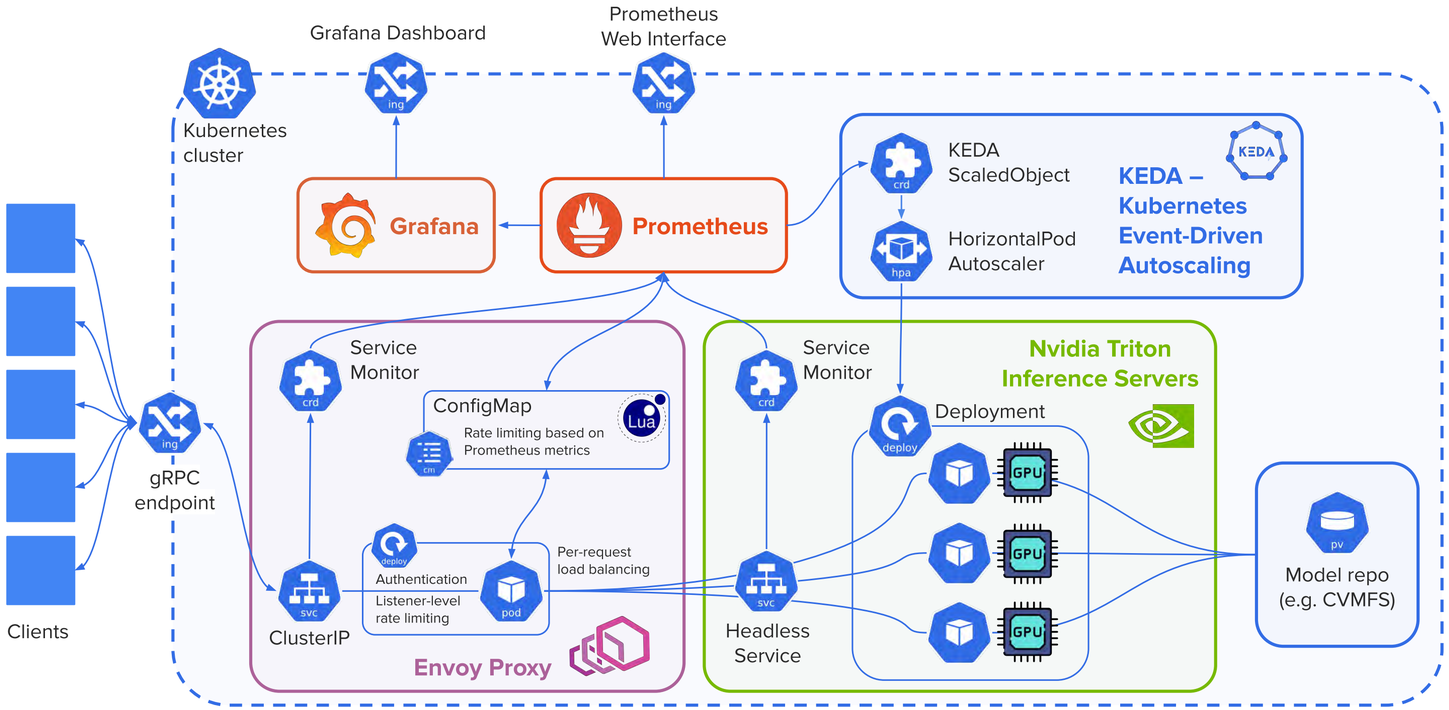


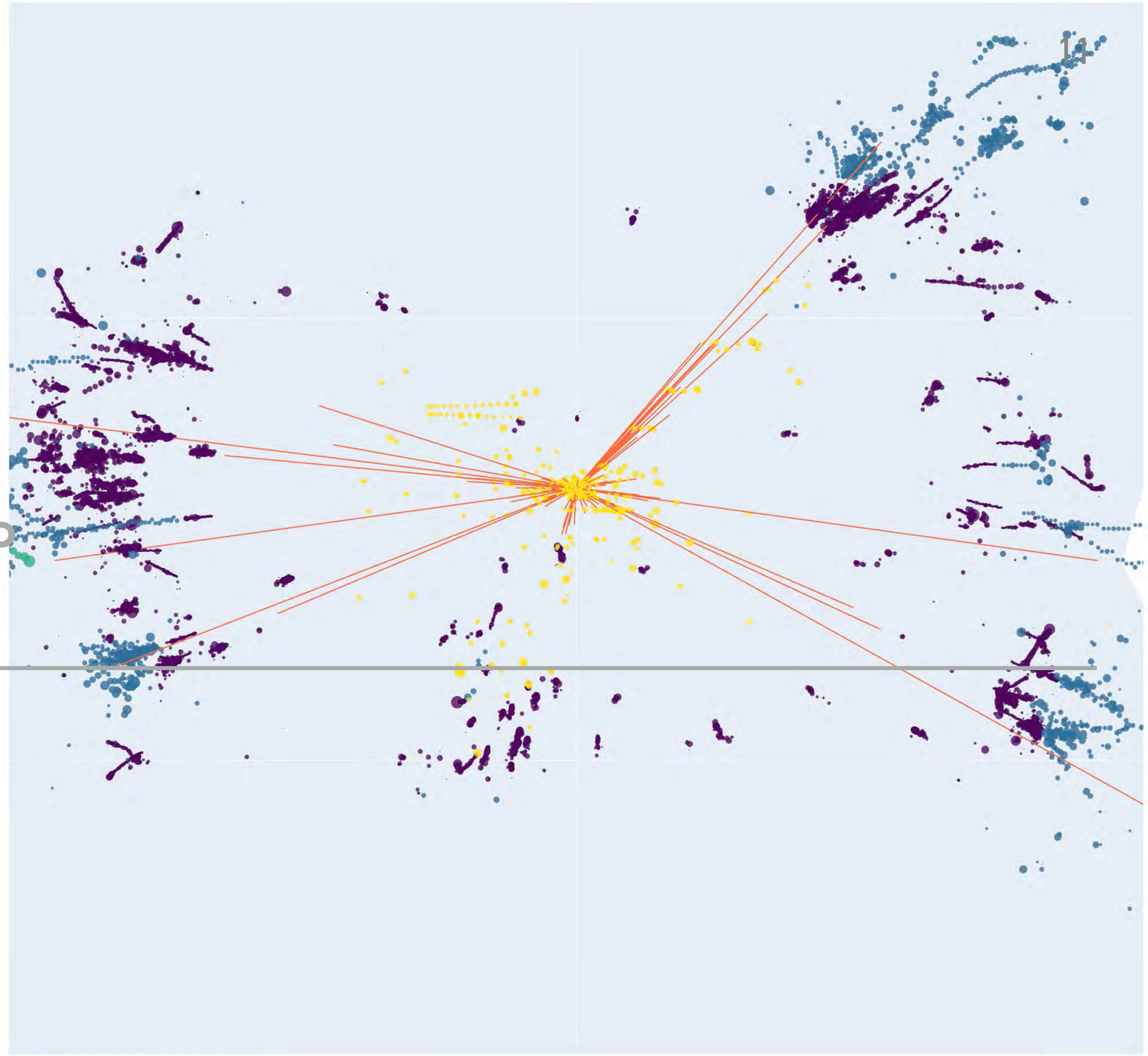


ACCELERATED INFERENCE AS A SERVICE

- Services for optimized network inference on coprocessors (SONIC) and SuperSONIC projects implements server infrastructure for inference-as-a-service applications in large experiments
  - Designed for deployment at Kubernetes clusters equipped with GPUs







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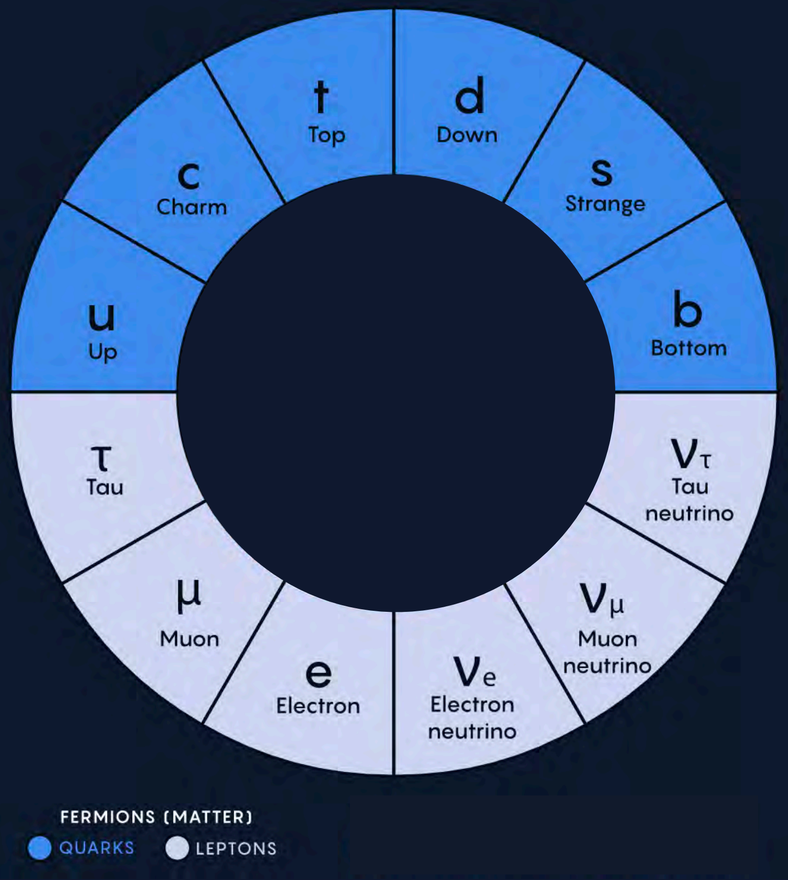
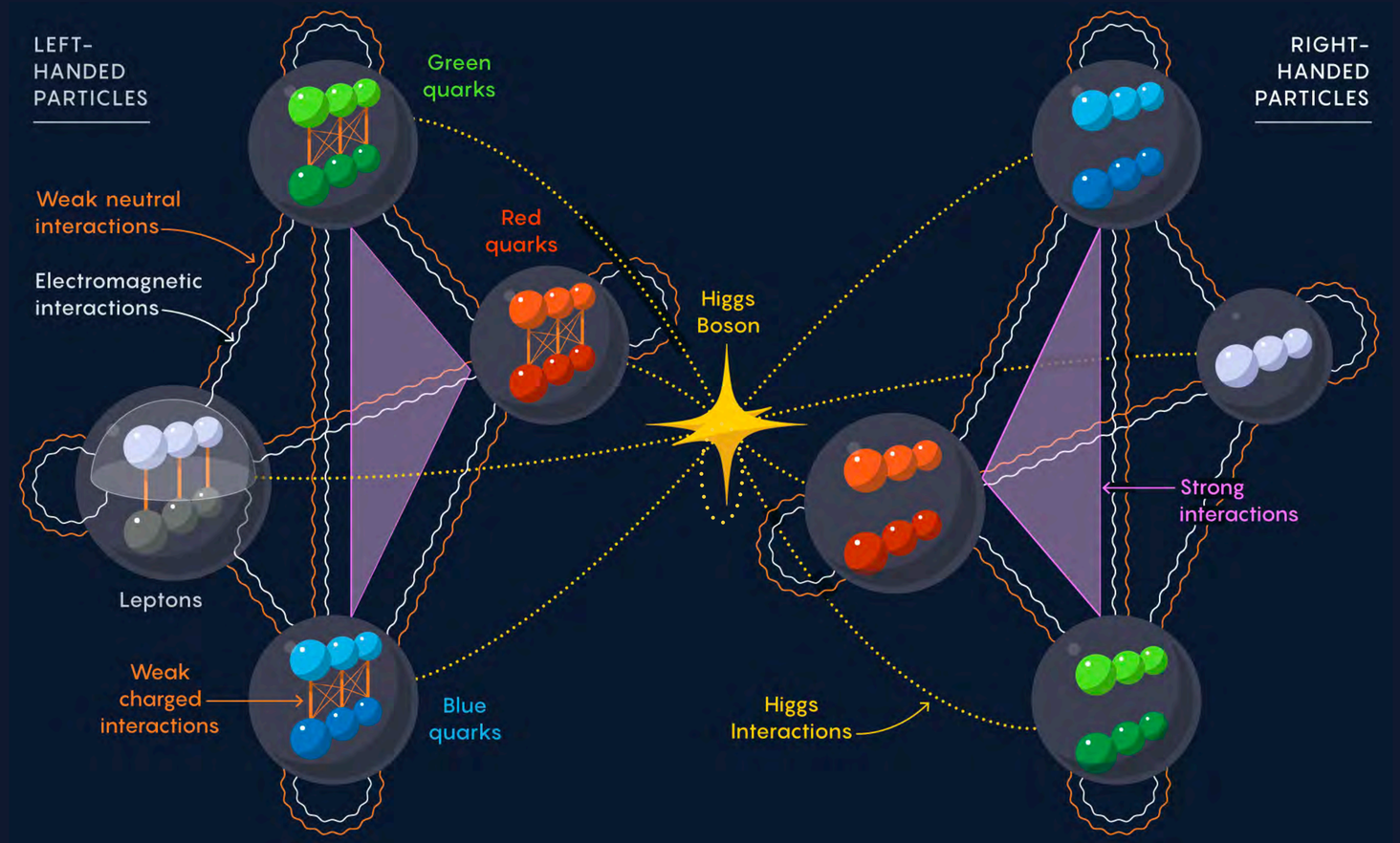
BACKUP

THE STANDARD MODEL

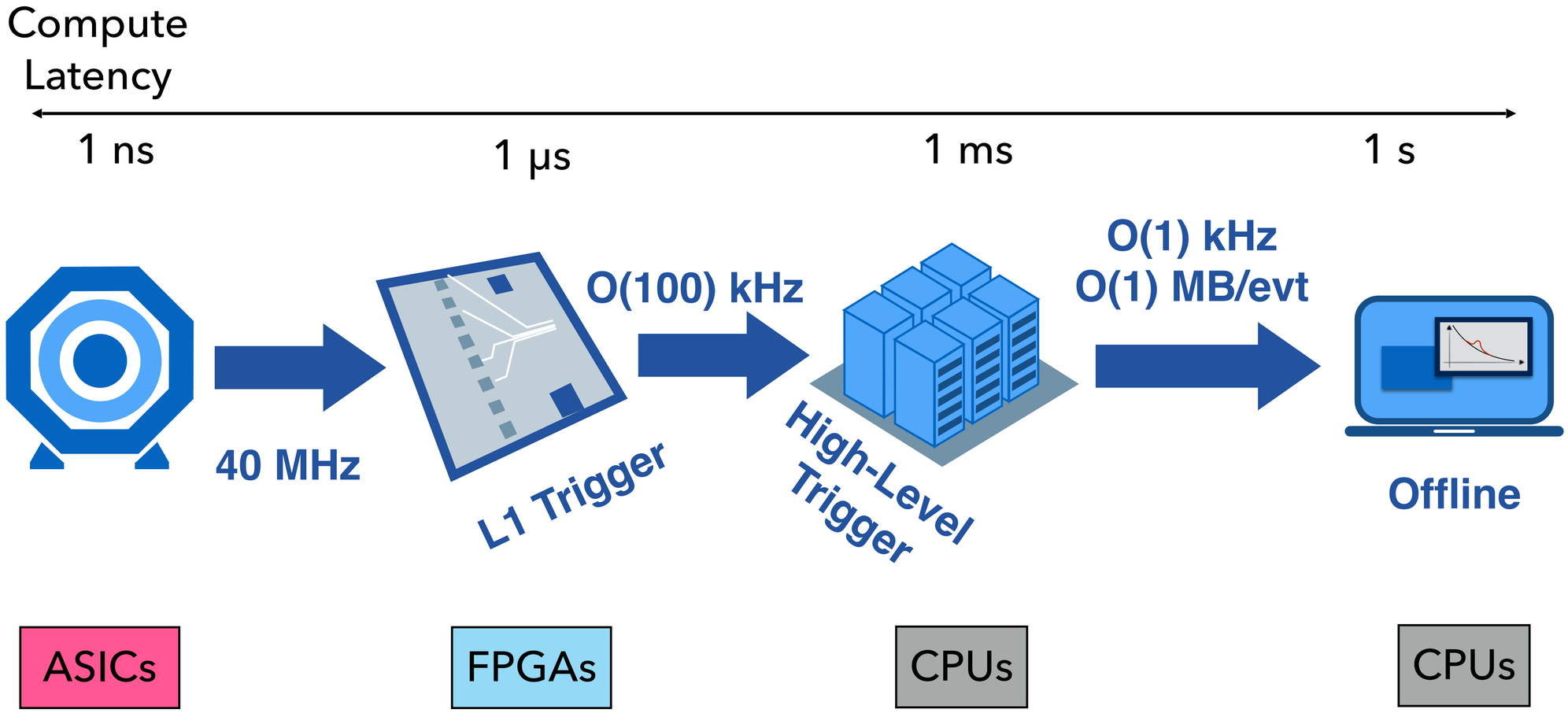
Image: https://www.quantamagazine.org/a-new-map-of-the-standard-model-of-particle-physics-20201022/





- But there has to be more to it! SM does not answer all our questions
- Higgs is a ***centerpiece:*** Mechanism by which particles ***acquire mass***
- Measuring its couplings to other particles (and to *itself*) may give insight into BSM physics

LHC EVENT PROCESSING



Challenges:

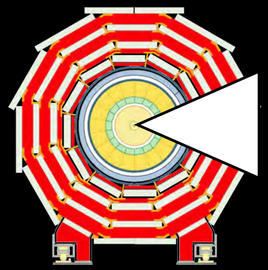
Each collision produces O(10^3) particles

The detectors have O(10^8) sensors

Extreme data rates of O(100 TB/s)

Exabyte-scale datasets

MULTILAYERED DETECTORS, E.G. CMS



Current and future multilayered detectors…

Require complex pattern recognition