High Energy Physics:

fundamental physics w/ the CMS experiment at CERN

Speaker: Mia Tosi mia.tosi@unipd.it int 7064

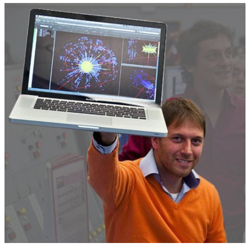
Group: CMS Padova cms-Padova@cern.ch

Site: CMS @DFA e https://cms.infn.it/

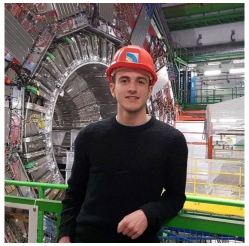
Martino Margoni
Prof. Associato

Patrizia Azzi
Ricercatrice INFN

Marco Zanetti
Prof. Ordinario

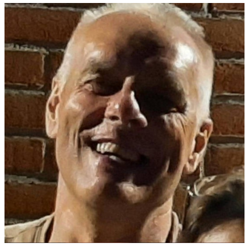


Rocco Ardino
PhD student



Enrico Lusiani
post-doc

Franco Simonetto
Prof. Ordinario



Federica Fanzago
Tecnologa INFN

Sandro Ventura
Tecnologo INFN

Paolo Ronchese
Prof. Associato

Roberto Rossin
Prof. Associato

Paolo Checchia
Emeritus

Jacopo Pazzini
Prof. Associato

Roberto Carlin
Prof. Ordinario

Tommaso Dorigo
Ricercatore INFN

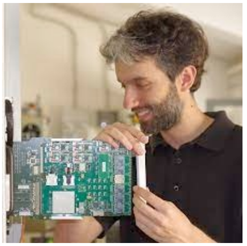
Alberto Zucchetta
Ricercatore INFN

Pierluigi Bortignon
Prof. Associato
@UNICA

Mia Tosi
RTDb

Ugo Gasparini
Prof. Ordinario

Andrea Triossi
Prof. Associato



+

Gabriele Bortolato : PhD student
Nicolo' Lai : PhD student
Sabrina Giorgetti : PhD student
Matteo Migliorini : PhD student
Andrea Bulla : PhD student @UNICA

Nicola Bacchetta : ricercatore INFN
Massimo Benettoni : tecnologo INFN
Antonio Bergnoli : tecnologo INFN
Marina Passaseo : tecnologa INFN
Marco Bellato : tecnologo INFN

Anna Meneguzzo : Emeritus
Dario Bisello : Emeritus
Fabrizio Gasparini : Emeritus

Contacts / website

email to: cms-Padova@cern.ch

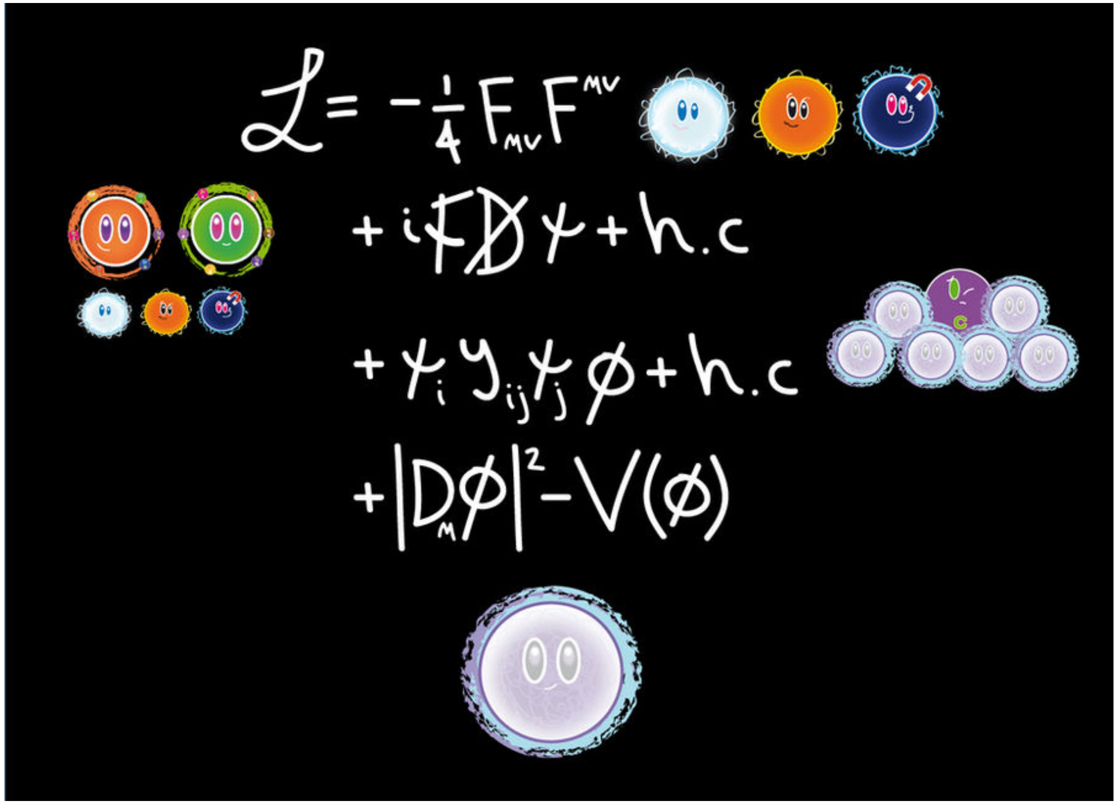
Research Activities

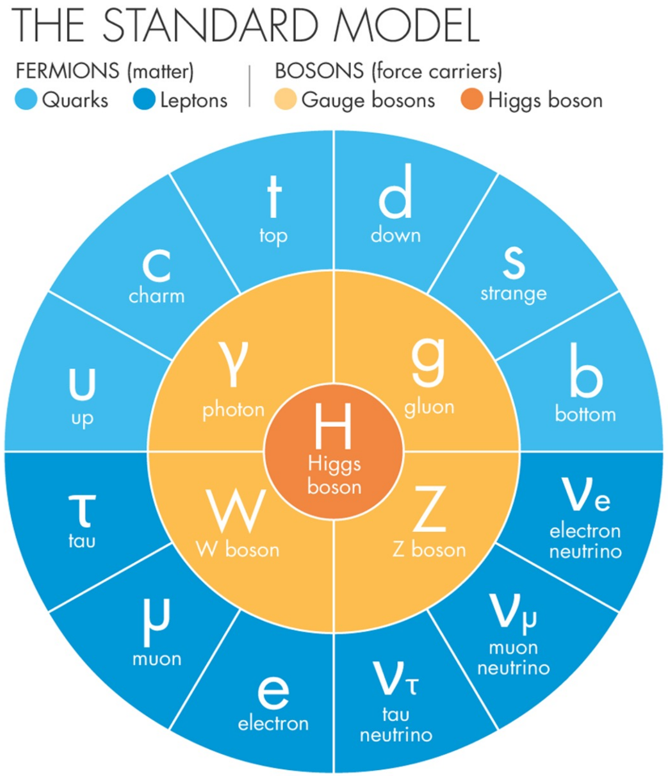
- Flavour Physics
- Physics of the Higgs boson and the Standard Model
- Search for new physics signals
- Advanced statistical methods
- Advanced automatic reconstruction
- Advanced automatic event selection
- Advanced detector R&D

→ see Marco Zanetti' slides

introduction

- our current description of fundamental phenomena is incredibly accurate, and it is based on the Standard Model of particle physics





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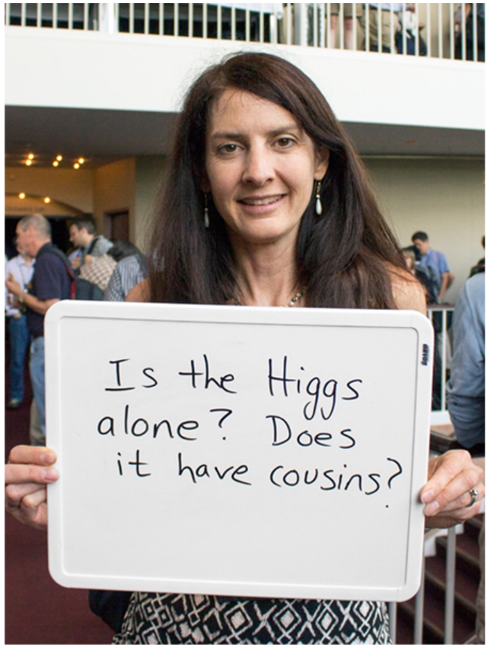
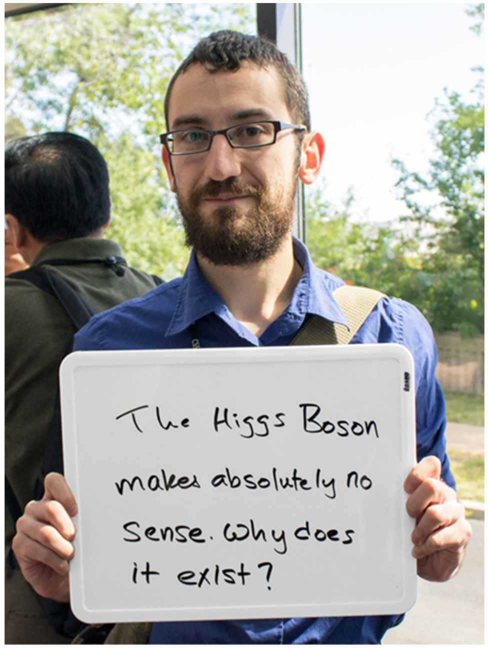
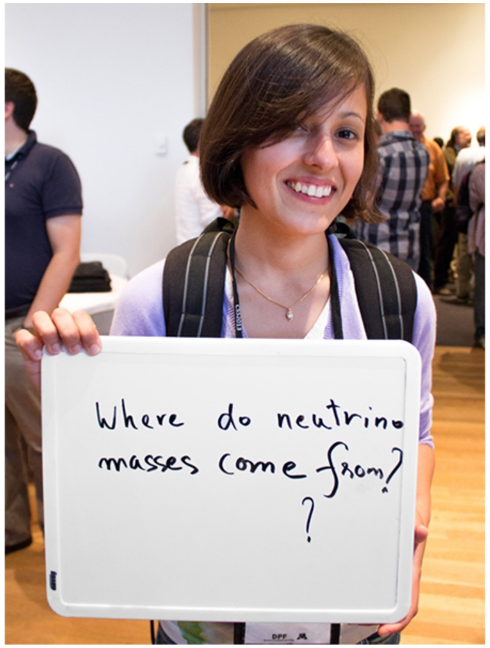
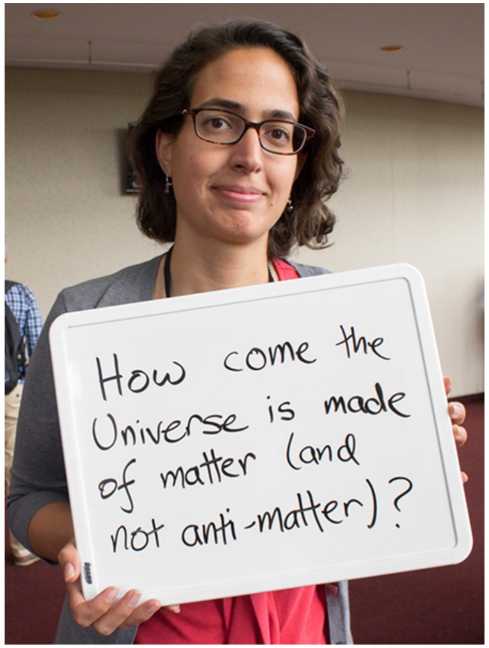
but plenty of unanswered questions !









..any many other questions are still open

introduction

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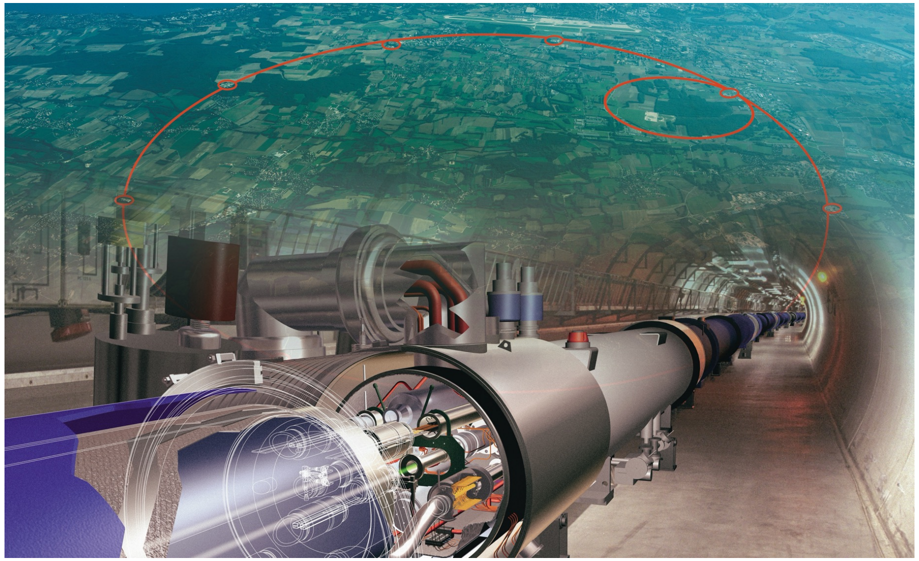
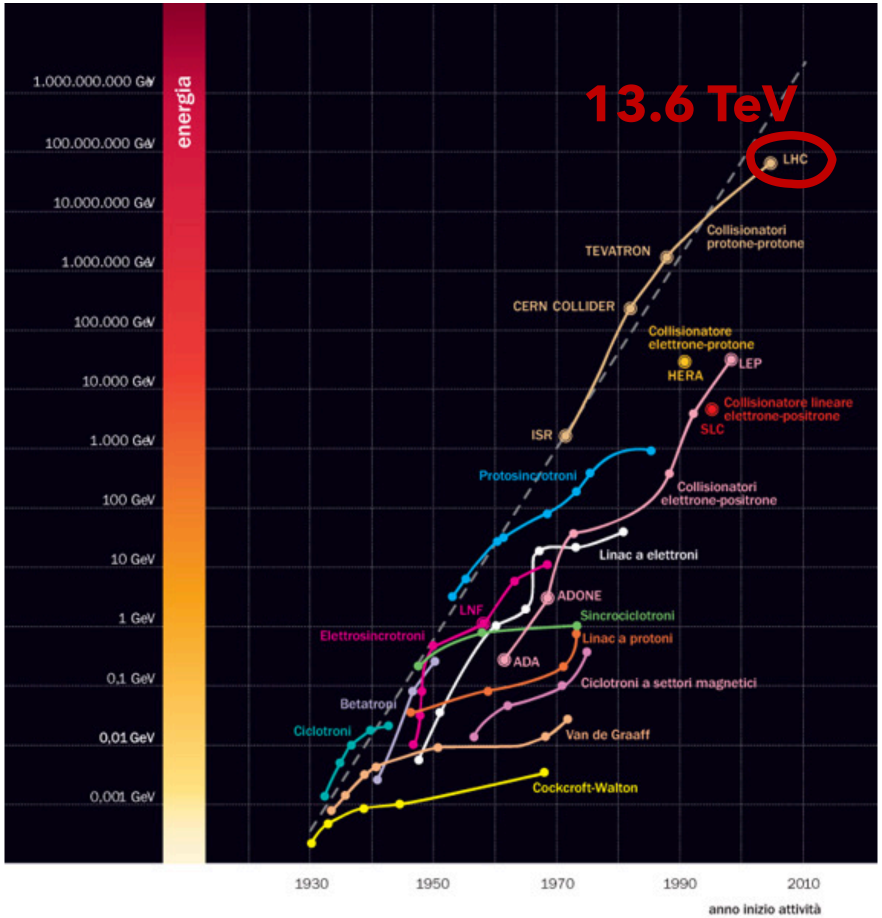
- best tool currently available to look for answers is the **Large Hadron Collider** at CERN





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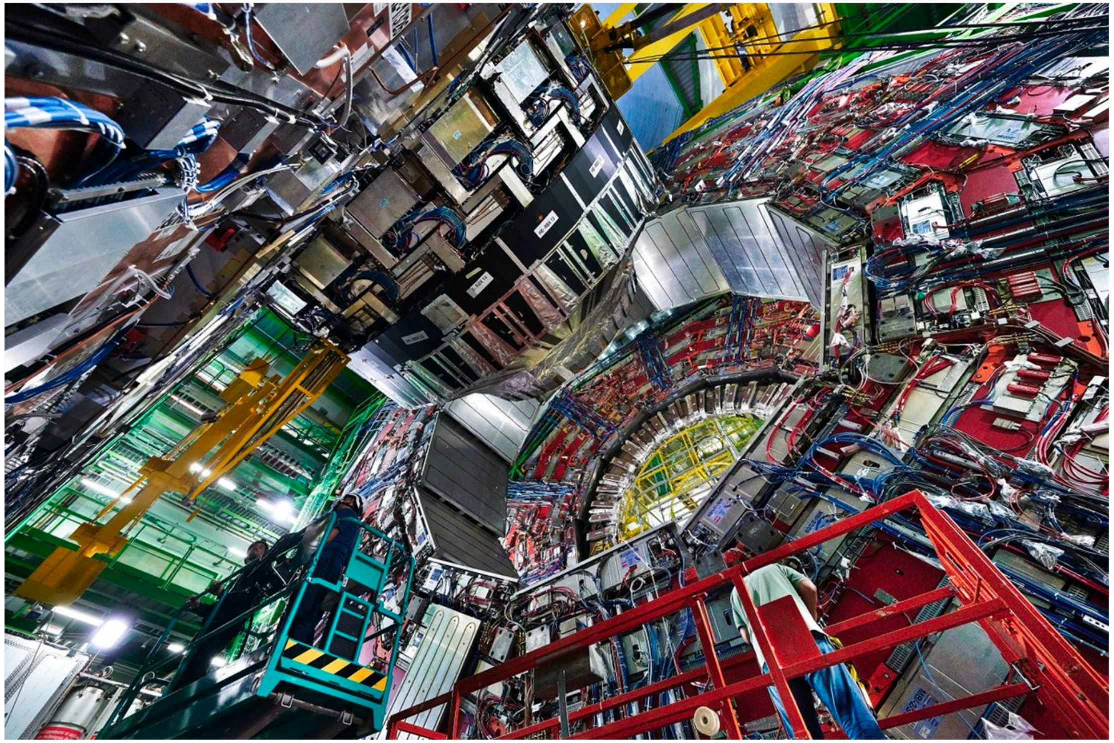
  via the **CMS experiment** and its data

  - *detector to operate*
  - *a new detector to build*
  - *freshly recorded data to be understood and calibrated*
  - *new technologies in the field of Big Data*
  - *lots of exciting physics !*



CMS is a unique opportunity for young physicists !

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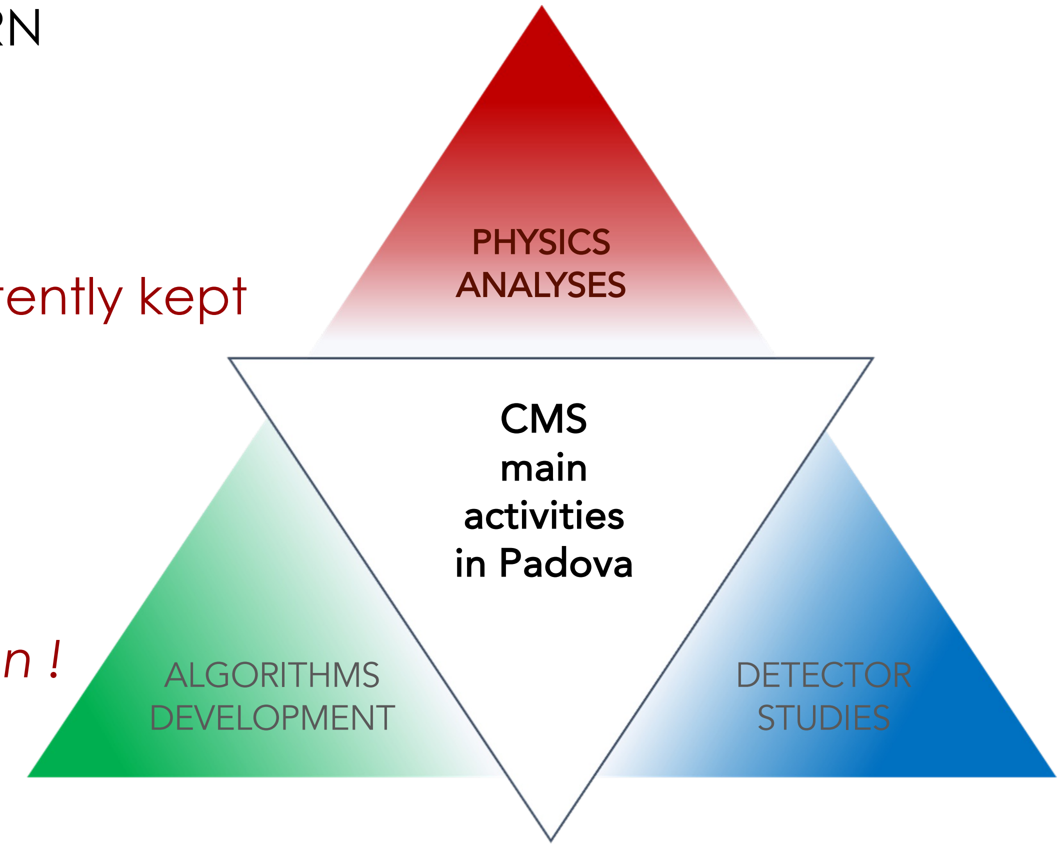
The CMS Padova group has consistently kept a leading role in the experiment w/ many position of responsibilities in **detector construction**, **physics analyses**, **automatic event reconstruction and selection**, *and even providing a spokesperson !*

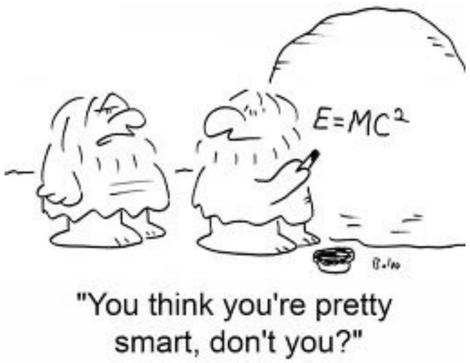


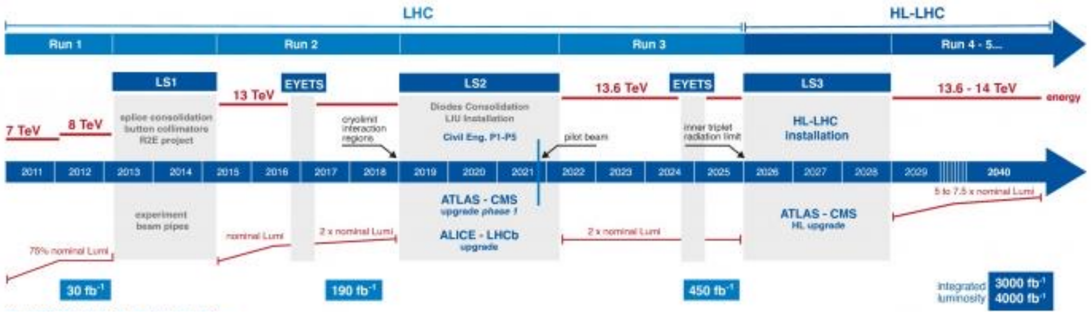
CMS is a unique opportunity for young physicists !

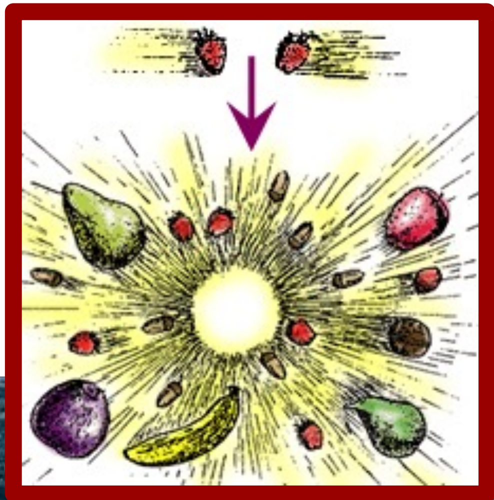
LHC

for observing the Higgs boson
and new physics signals
we need an accelerator which maximizes

- the collisions (centre-of-mass) energy
- the collisions rate



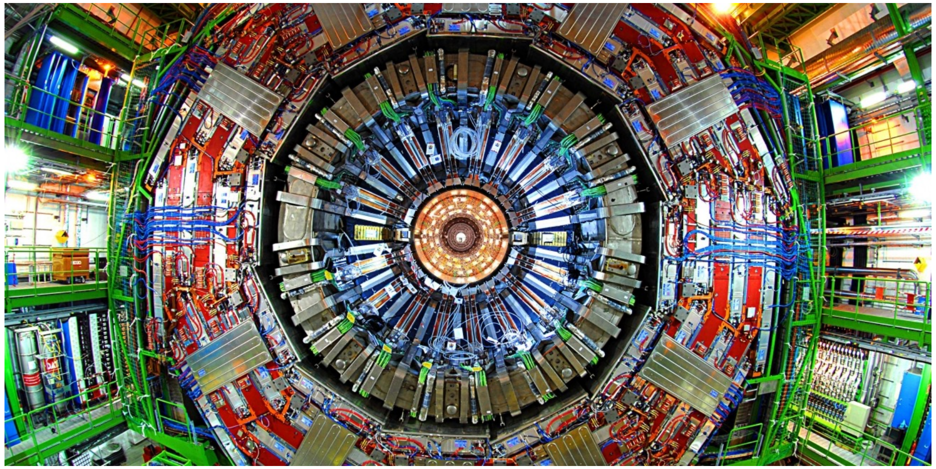




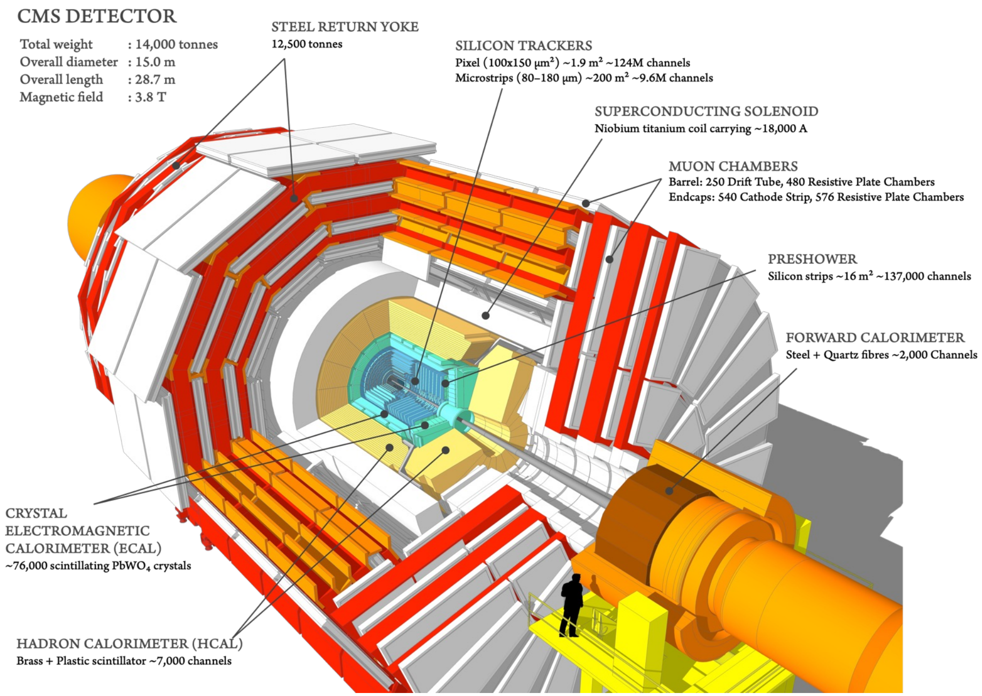
LHC is the biggest and most powerful proton-proton collider in the world

CMS – Compact Muon Solenoid

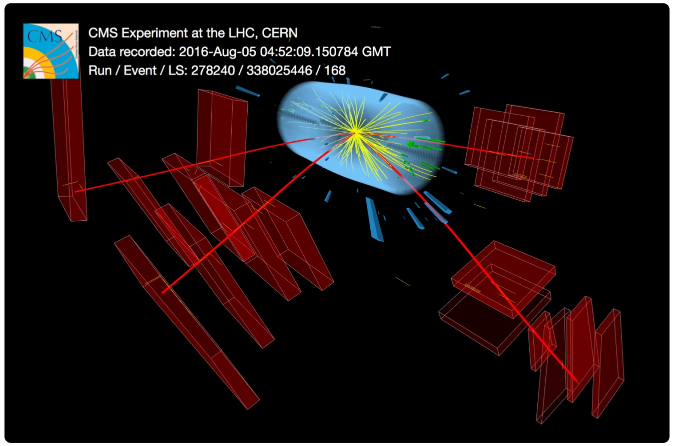
multi-porpoise HEP detector

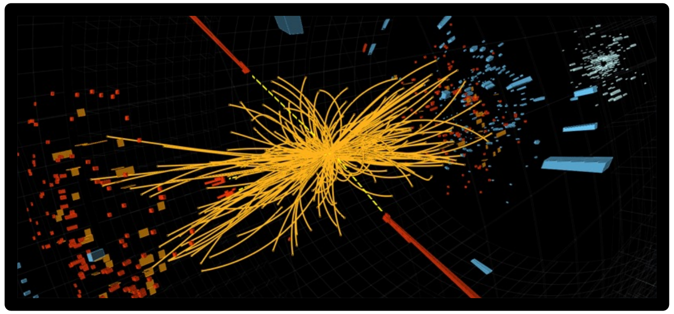


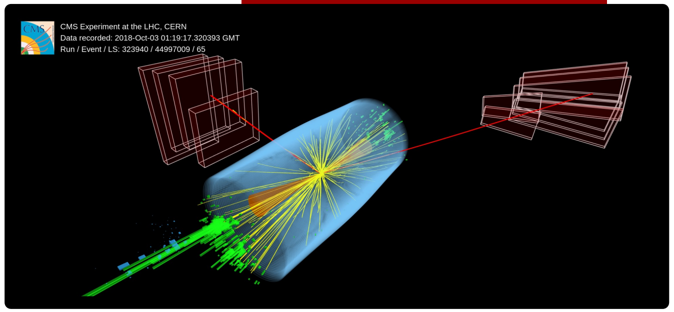
- hermetic
- large acceptance
- very strong magnetic field (3.8 T)
- very precise
  particles trajectory measurement
- excellent electromagnetic
  energy resolution
- excellent muon reconstruction

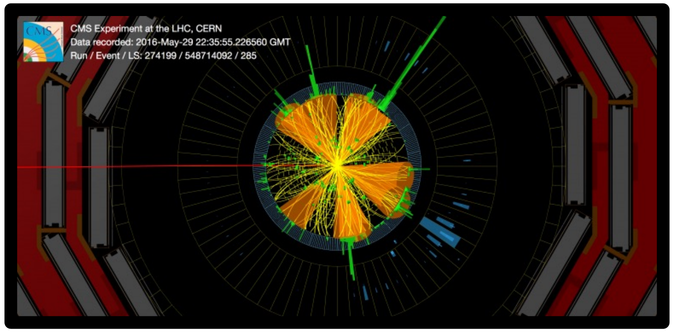


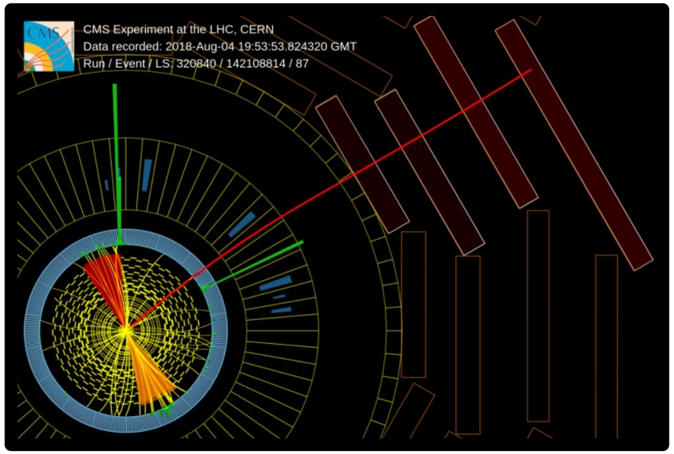
What do we see ?

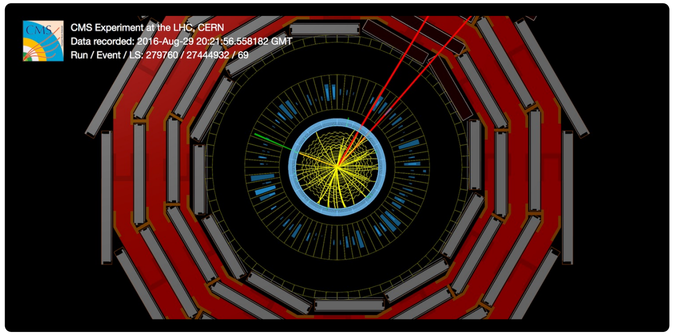


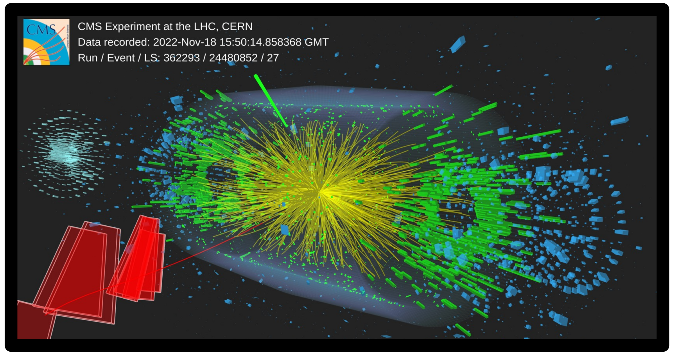


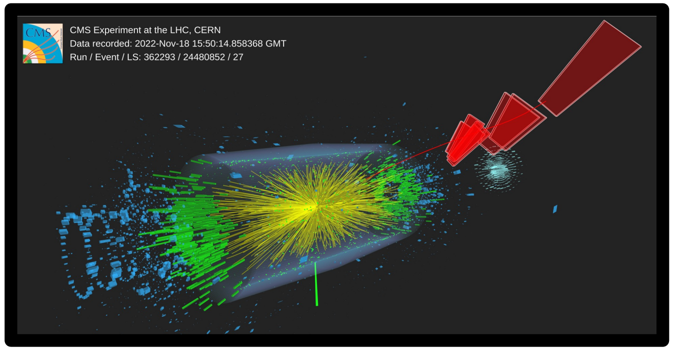








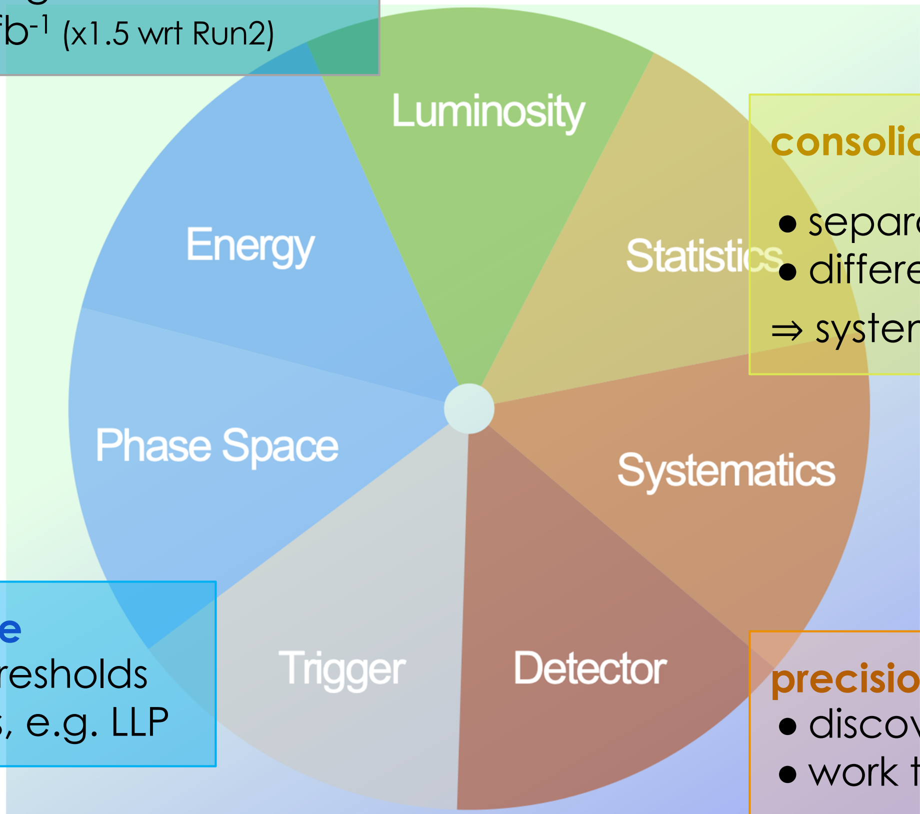




opportunities

energy and luminosity

- 13 → 13.6 TeV: higher mass reach
- additional 200 fb^{-1} (x1.5 wrt Run2)



consolidate Run2 observations

e.g. H→ff, VH, ttH, VV, VBS, tttt, ..

- separately in different channels
- differential measurements

⇒ systematics becoming relevant

new phase space

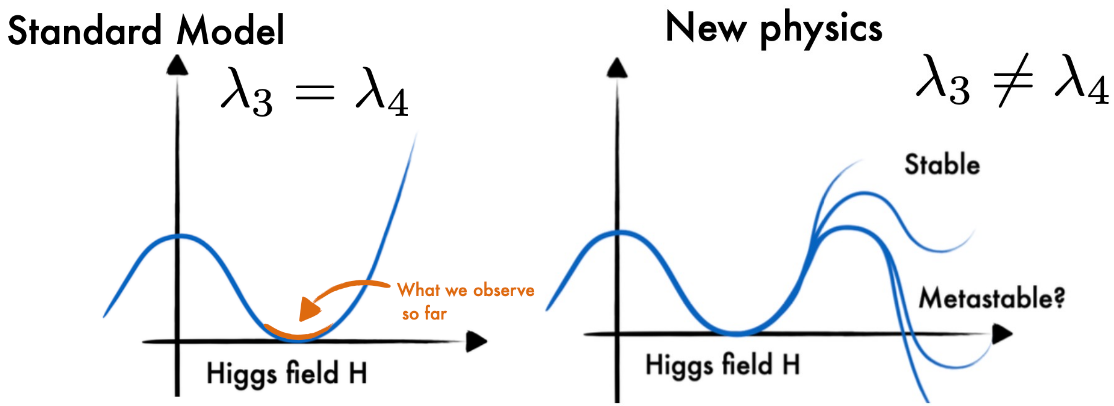
- push for low thresholds
- new signatures, e.g. LLP

precision

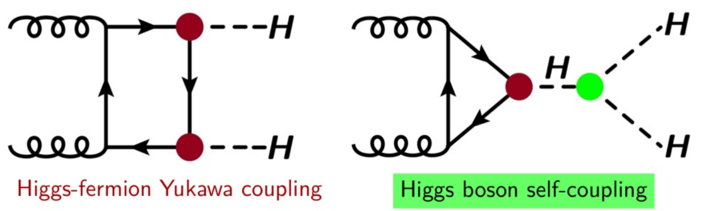
- discovery-through-precision
- work to improve systematics (calibrations and methods)
- better detector towards HL-LHC

Some examples : di-higgs

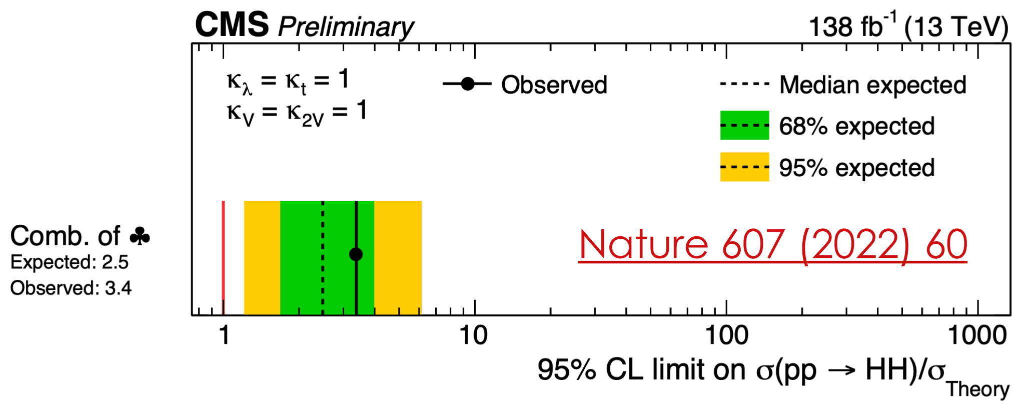
- the nature of the Higgs boson is still not completely understood and its potential is not completely known !
- **quantum corrections may change the Higgs potential shape**
  including quantum corrections to the Standard Model couplings, the vacuum might have a second minimum (metastable state)



⇒ search for the **double Higgs** production :
direct access to Higgs self-coupling strength (λ)



- **challenge** :
  very small SM cross sections
- **opportunity** :
  very large *statistics* (Run2+Run3)
  + *advanced analyses techniques*

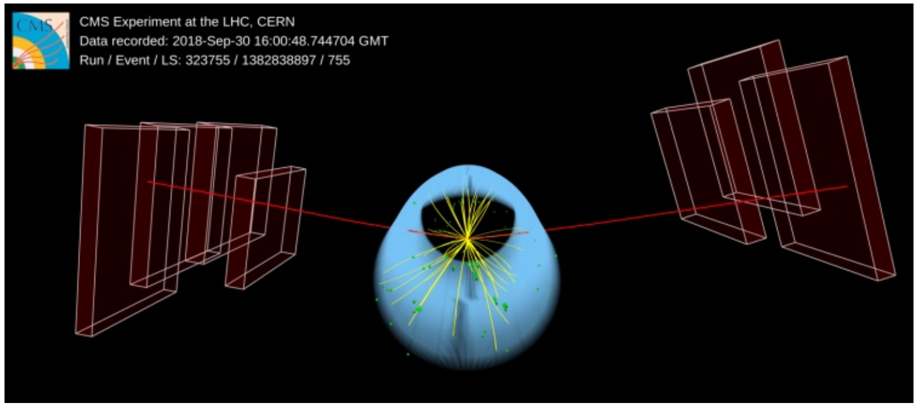


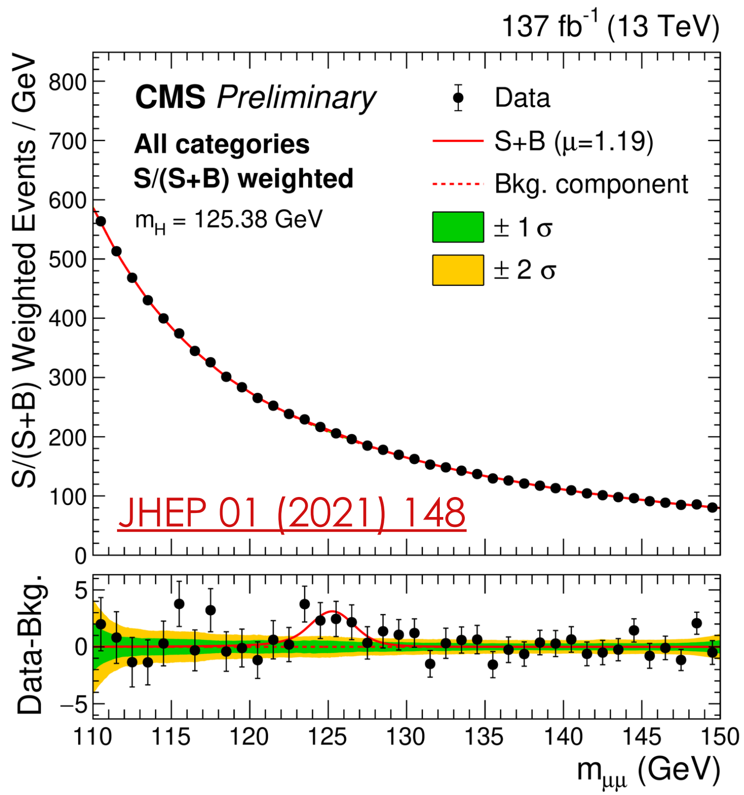
Some examples : H coupling

by measuring the Higgs boson decay rate to a particle,
we infer the interaction strength between
the Higgs field and that particle
⇒ these measurements directly **test the predicted mechanism by which particles acquire mass**

⇒ observe the **Higgs** decay **into muons** :
is the next experimental frontier (so-far untested mass scale)

- **challenge** :
  very rare SM process (1/5000 Higgs)
  very large SM background (S/B ~ 1/1000)
- **opportunity** :
  very large *statistics* (Run2+Run3)
  + *advanced analyses techniques*

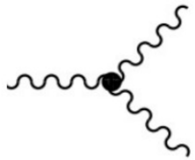


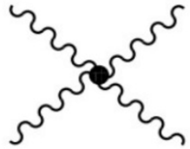


Some examples : VBS (and VBF)

Trilinear and Quartic Gauge Couplings (TGC, QGC)
precisely determined by SU(2) x U(1) gauge symmetry

- Neutral coupling forbidden.
- TGC:
  - VBF and VV production.
- QGC:
  - VBS and VVV production.



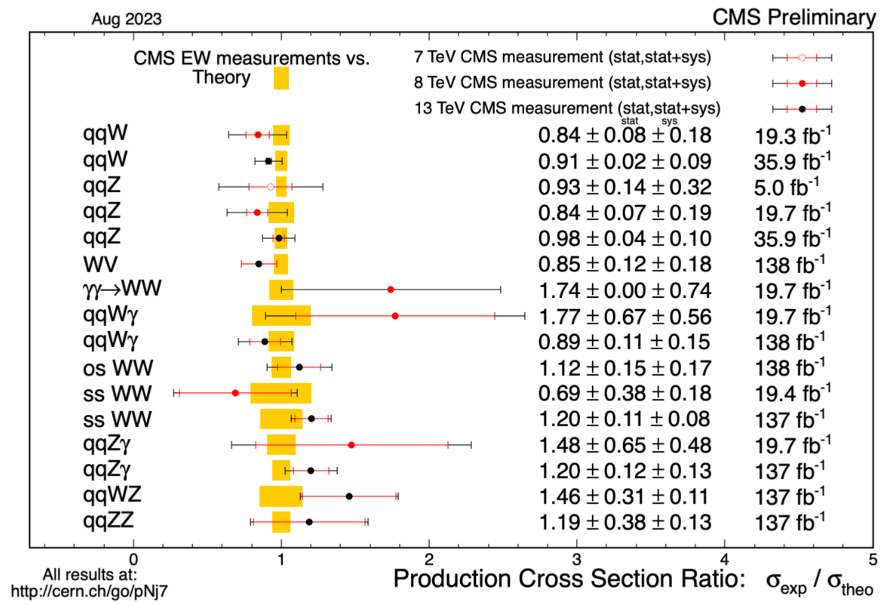


Anomalous Gauge Coupling would result in different
- production cross-section
- differential cross-section

⇒ **Vector Boson Scattering** at **13.6 TeV**:

is a key test of the SM and a possible means for highlighting new physics

- **challenge** :
  very rare SM process
  complex event topologies
- **opportunity** :
  new strategy for enhancing statistics
  liaison w/ theory model



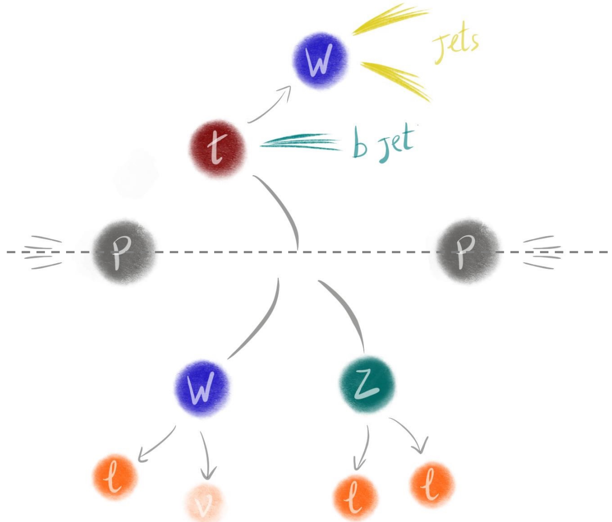
Some examples : rare process

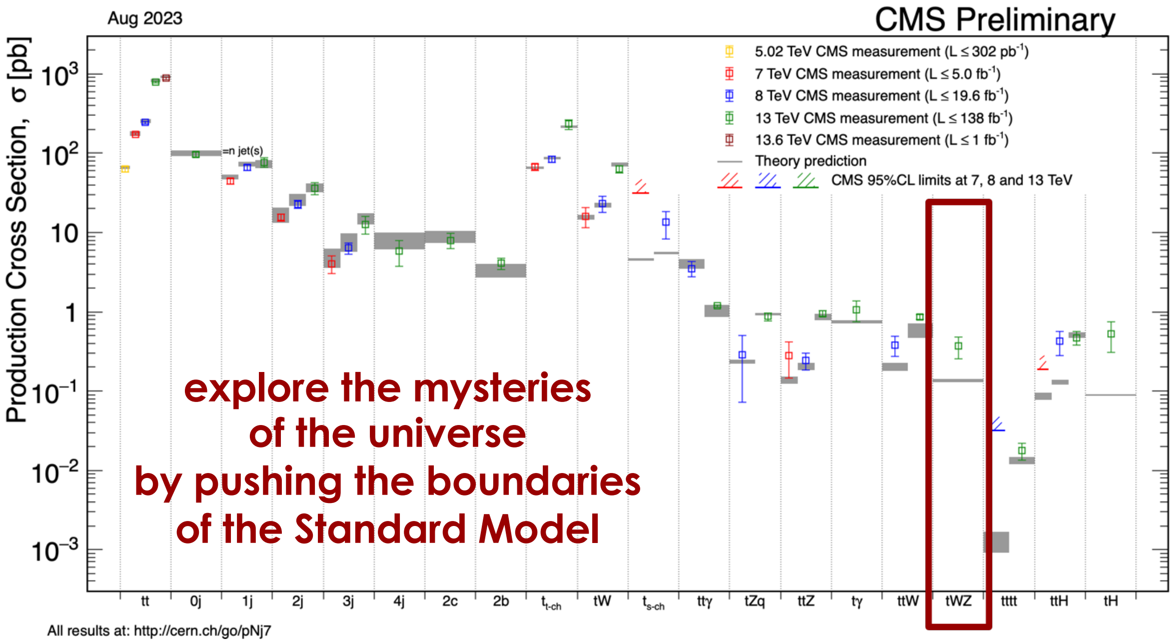
new heavy particles can affect some interactions
and make them deviate from the Standard Model prediction

⇒ production of a **top quark w/ a W boson and a Z boson** (tWZ)

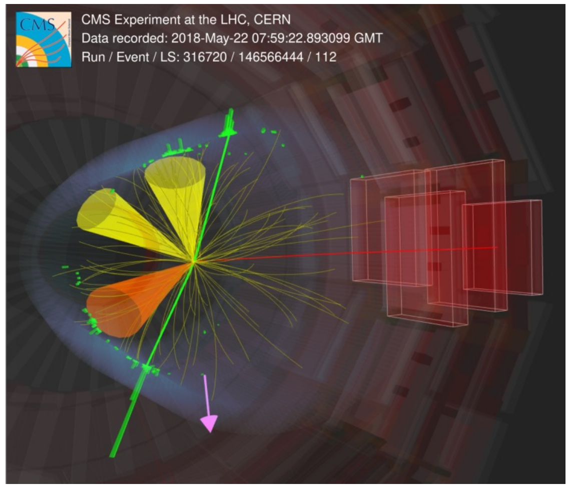
sensitive to the presence of new particles

- **challenge** :
  very low cross-section in the SM
- **opportunity** :
  clean signature
  large statistics in Run3
  liaison w/ theory model





explore the mysteries of the universe by pushing the boundaries of the Standard Model



Some examples : matter-antimatter puzzle

- the charge-conjugation and parity-reversal (CP) symmetry is a symmetry between matter and antimatter

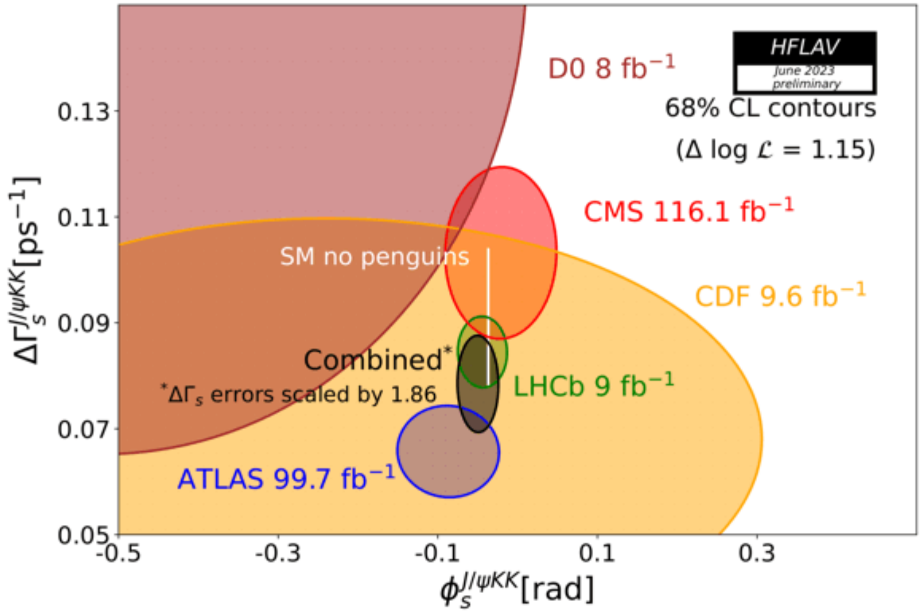
  → violation of this CP symmetry was first observed in 1964

  → Sakharov proposed that *CP violation is necessary to explain the observed imbalance of matter and antimatter in the Universe*

  but the **amount of CP violation as predicted by the Standard Model** as well as the observed so far in experiments **is too small to explain the cosmic imbalance**

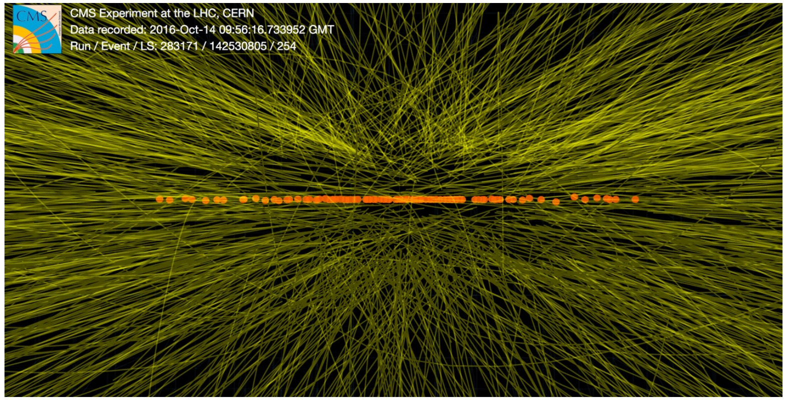
  ⇒ there is an as-yet-unknown sources of CP violation beyond the Standard Model

CP-violating phase in the B_s system (ϕ_s) is predicted in the Standard Model and the effects of new physics could change its value significantly



Some examples : the future

The High-Luminosity LHC (**HL-LHC**), due to start in 2029,
will deliver about **x10 data** than has been accumulated so far
⇒ to exploit the HL-LHC physics potential,
the CMS collaboration is building **an optimised detector that pushes technologies to new heights**



→ sustain the increased luminosity
(greater radiation damage and higher particle rates)
→ *new tracker*
→ *new MIP precision timing detector* (30 ps)
→ almost all the existing *electronics replaced*

High granularity
the key to achieving the necessary HL-LHC performance
is to *enhance the granularity of the detector*
⇒ reduce the maximum occupancy per readout cell
while considerably increasing the readout bandwidth
and processing power of the trigger system
⇒ **full particle-flow reconstruction at the hardware-based trigger** (at 40 MHz)
⇒ **precision timing information**, which contributes to the high-level-trigger,
is exploited by highly optimised software mostly running on GPUs

Contacts

Speaker: Mia Tosi
Office n. 144 edificio Marzolo
Email mia.tosi@unipd.it

Group: CMS Padova cms-Padova@cern.ch