CMS and LHC

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August 21 , 2017

A discovery machine

- The Standard Model of particle physics works great
- There must be more!
  - Where did the antimatter go?
  - What are dark matter and dark energy?
  - How do we reconcile gravity and quantum mechanics?

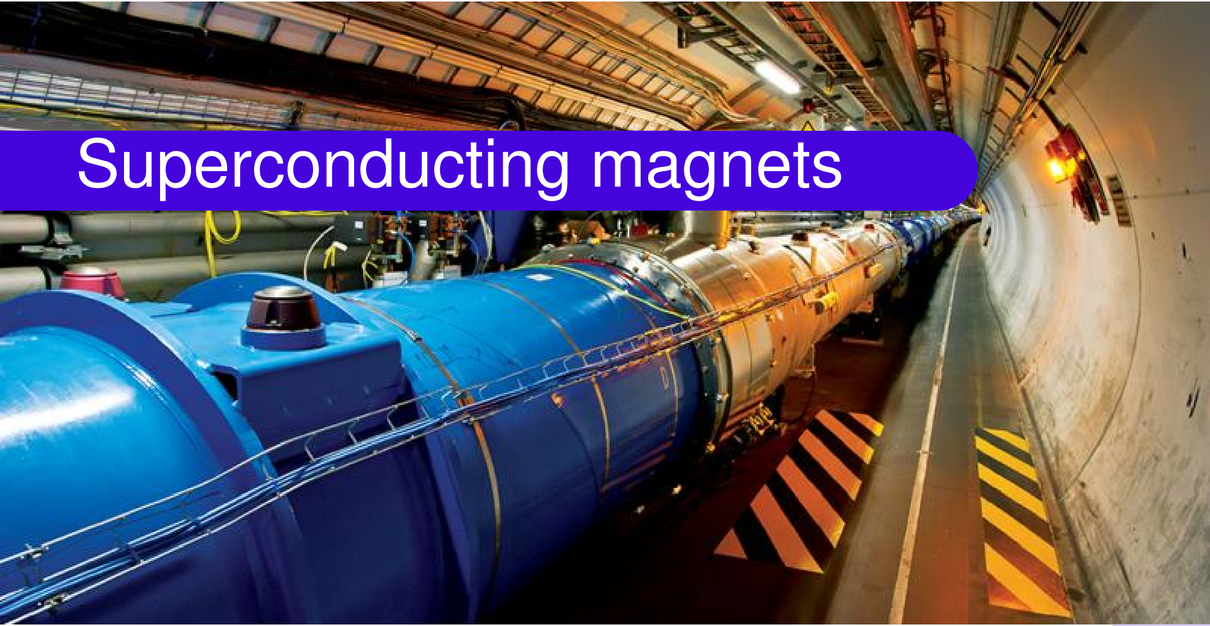
The energy frontier

- Main focus for CMS (and ATLAS) is to probe higher energies
- Mass is energy – to see a new particle produced you need a machine capable of making it
- High energy is difficult – we use some of the most complex machines ever created

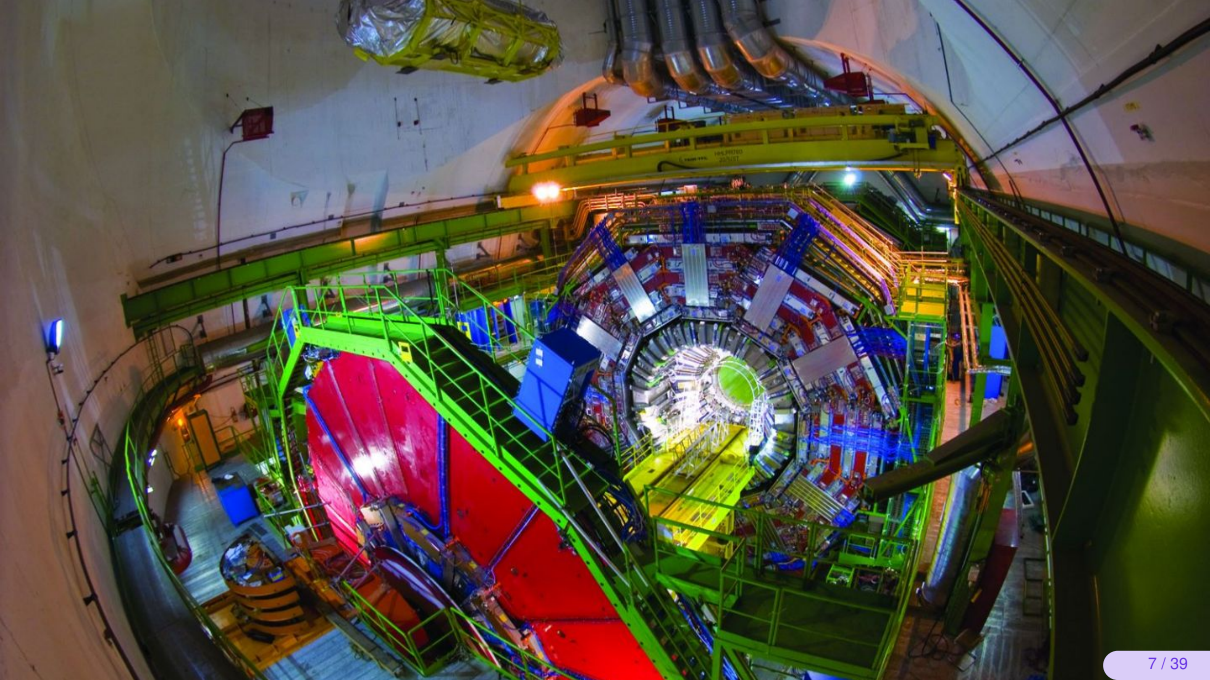
LHC

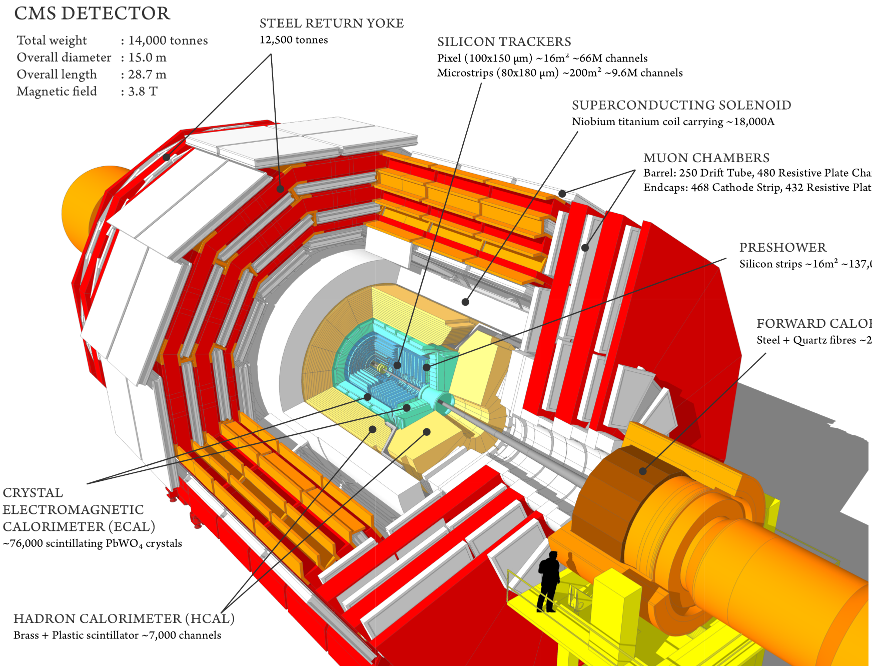

LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
ALICE
CMS
LHC 27 km

Superconducting magnets



Cavern

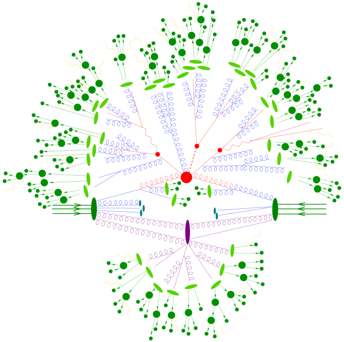




CMS DETECTOR
Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T
STEEL RETURN YOKE
12,500 tonnes
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels
SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~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

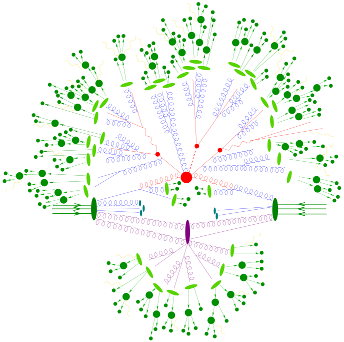
To turn

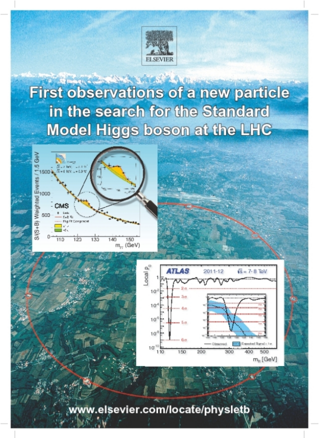
this...



To turn

this...

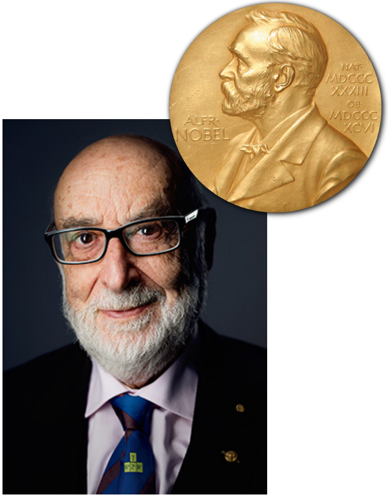




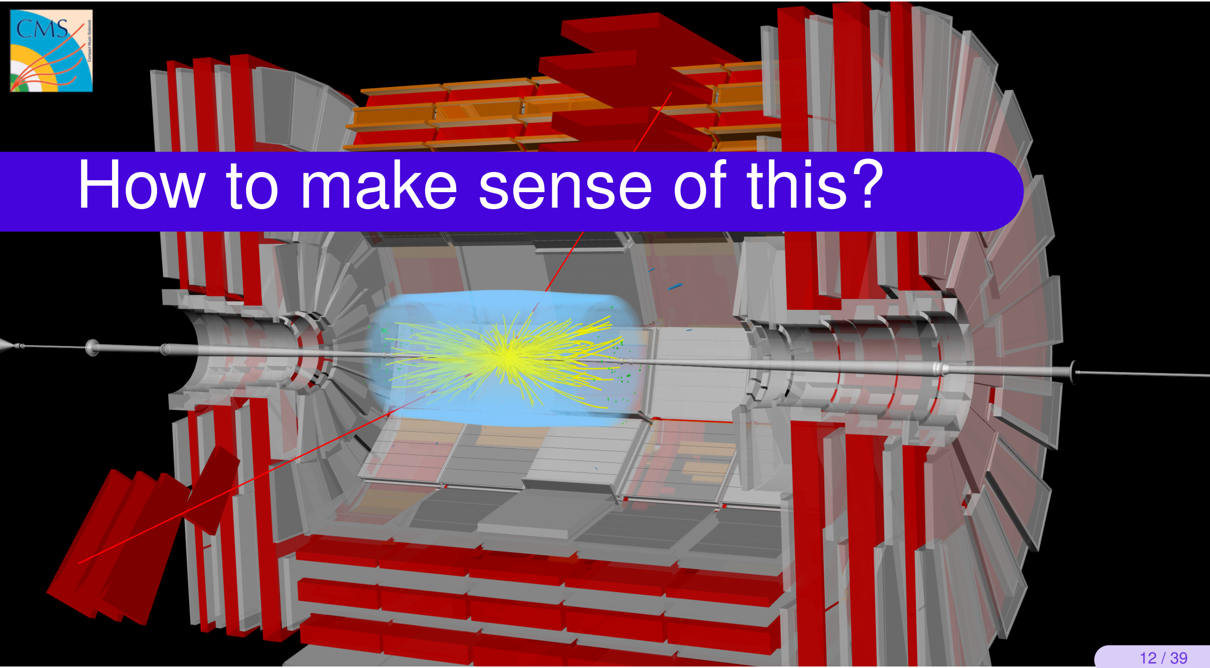
...into this

And this


ALFR·
NOBEL
NAT·
MDCCC
XXXIII
OB·
MDCCC
XCVI


ALFR·
NOBEL
NAT·
MDCCC
XXXIII
OB·
MDCCC
XCVI

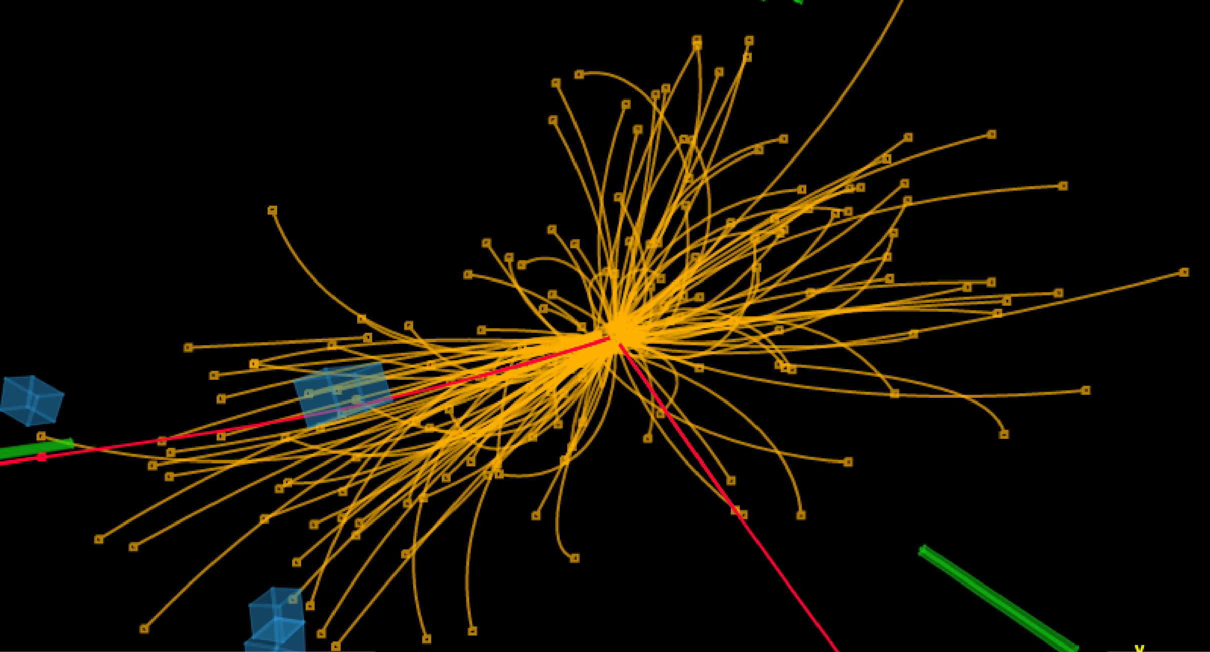
How to make sense of this?

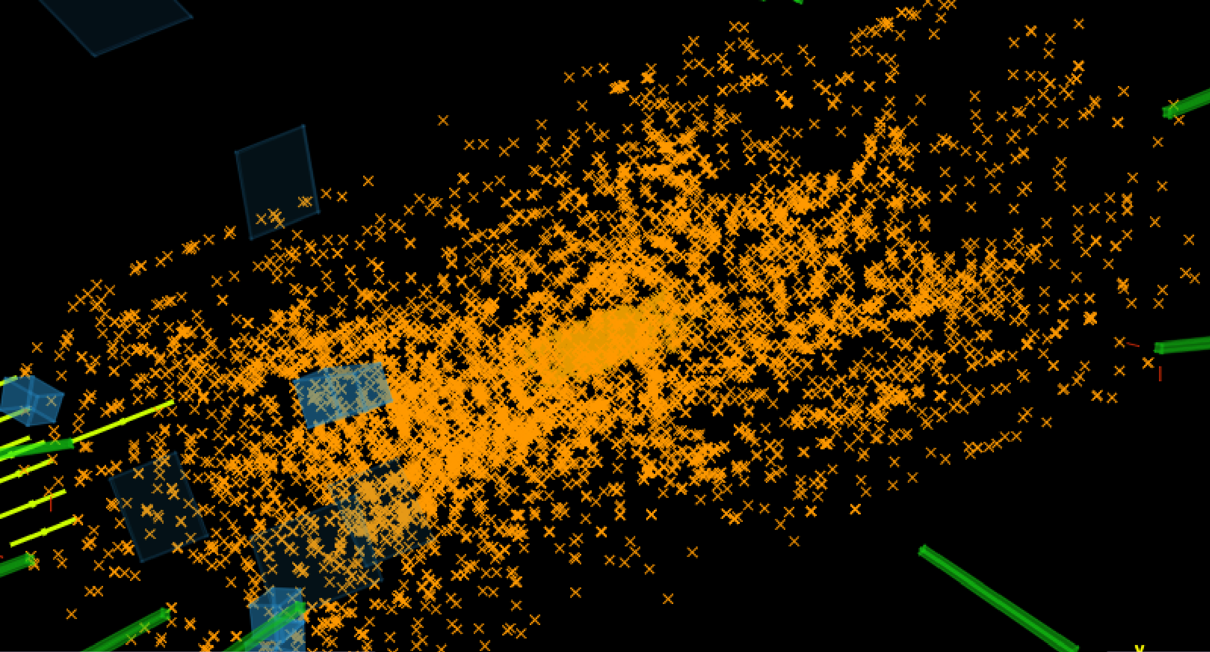


What do we need to know?

- How many particles pass through?
- What direction are they going?
- What is their momentum or energy?
- What kind of particles are they?

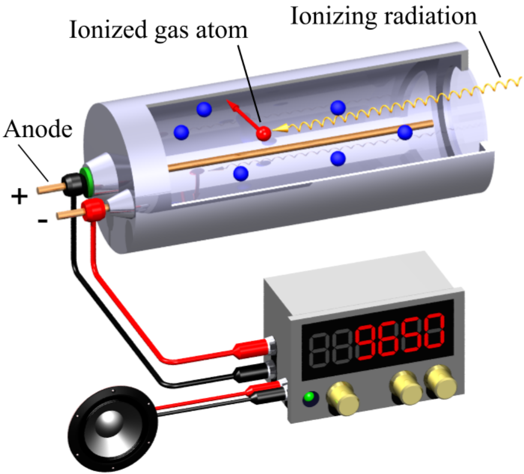
How does it work?



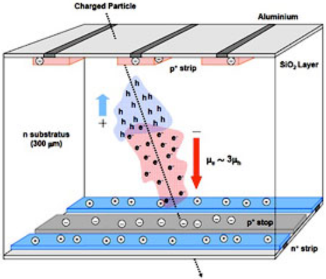


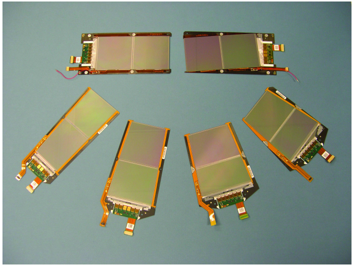
https://www.i2u2.org/elab/cms/event-display/

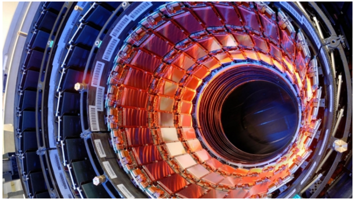
Geiger counter



Silicon tracking

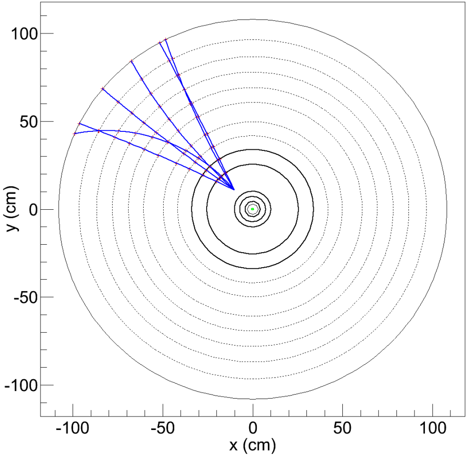


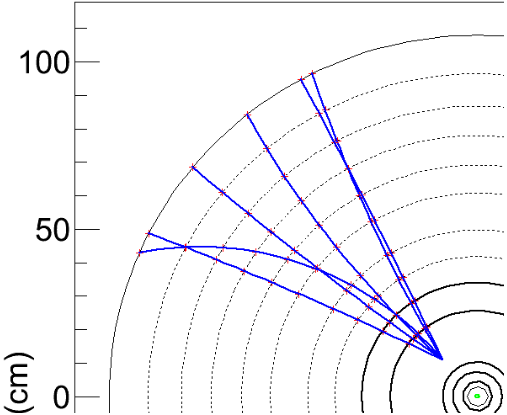




Tracking

Connect the dots

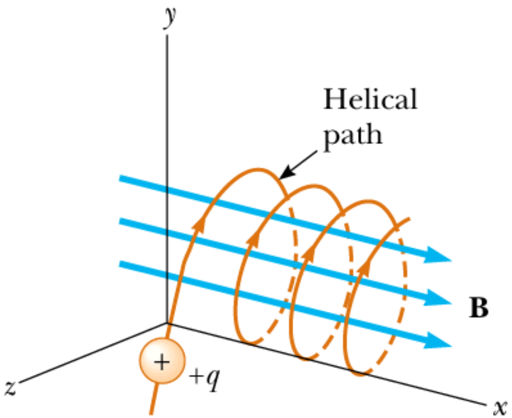




Momentum

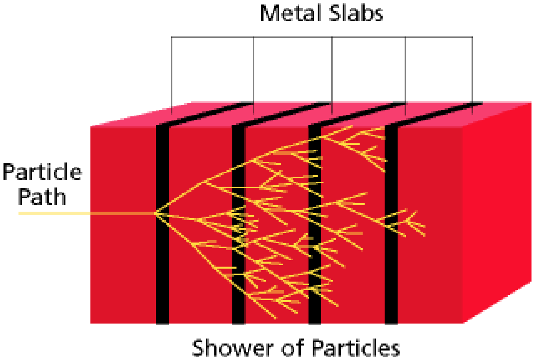
- Trajectories tell us where charged particles went
- Magnetic field causes curvature
- Curvature gives momentum

$$\text{radius} = \frac{p}{qB}$$

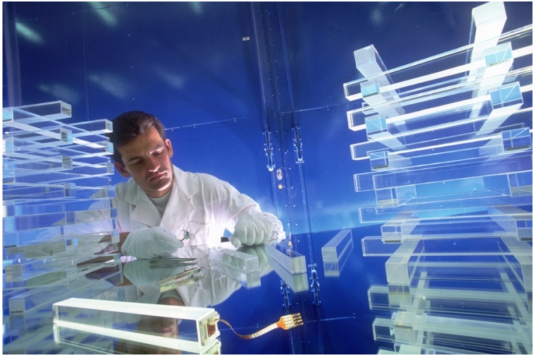


Energy

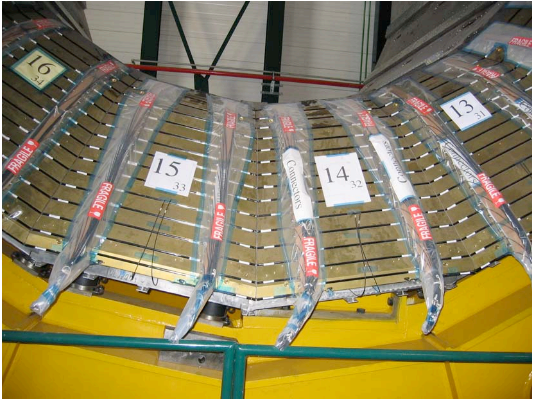
- Design a calorimeter to cause lots of interaction and stop the particle
- Creates many new particles (a shower)
- Goal is to measure how much energy deposited



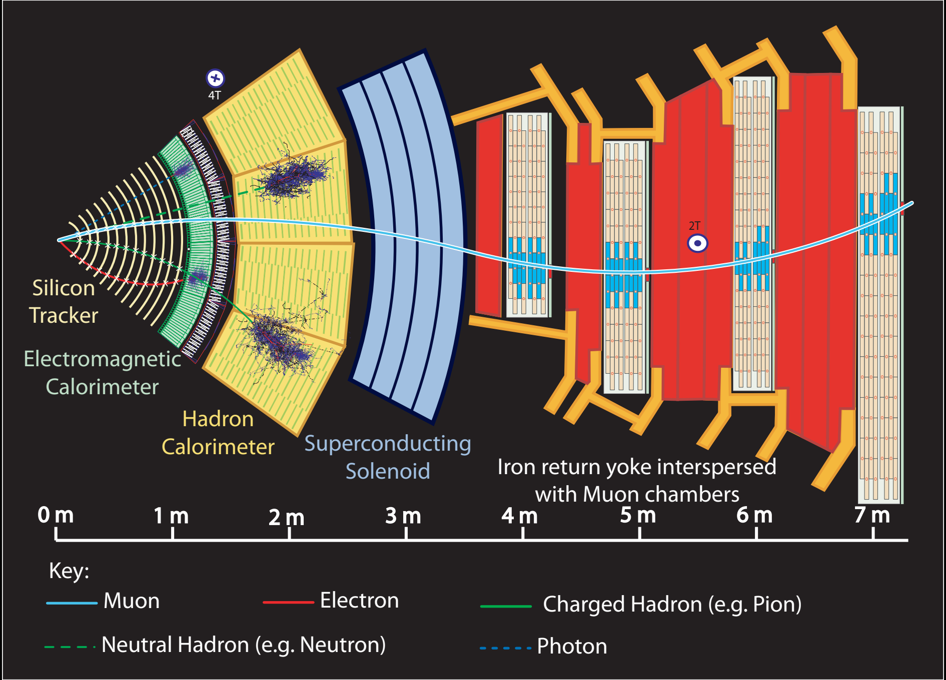
Calorimetry



ECAL crystals



HCAL stack

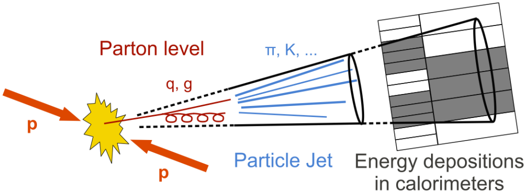


4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
0 m
1 m
2 m
3 m
4 m
5 m
6 m
7 m
Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon

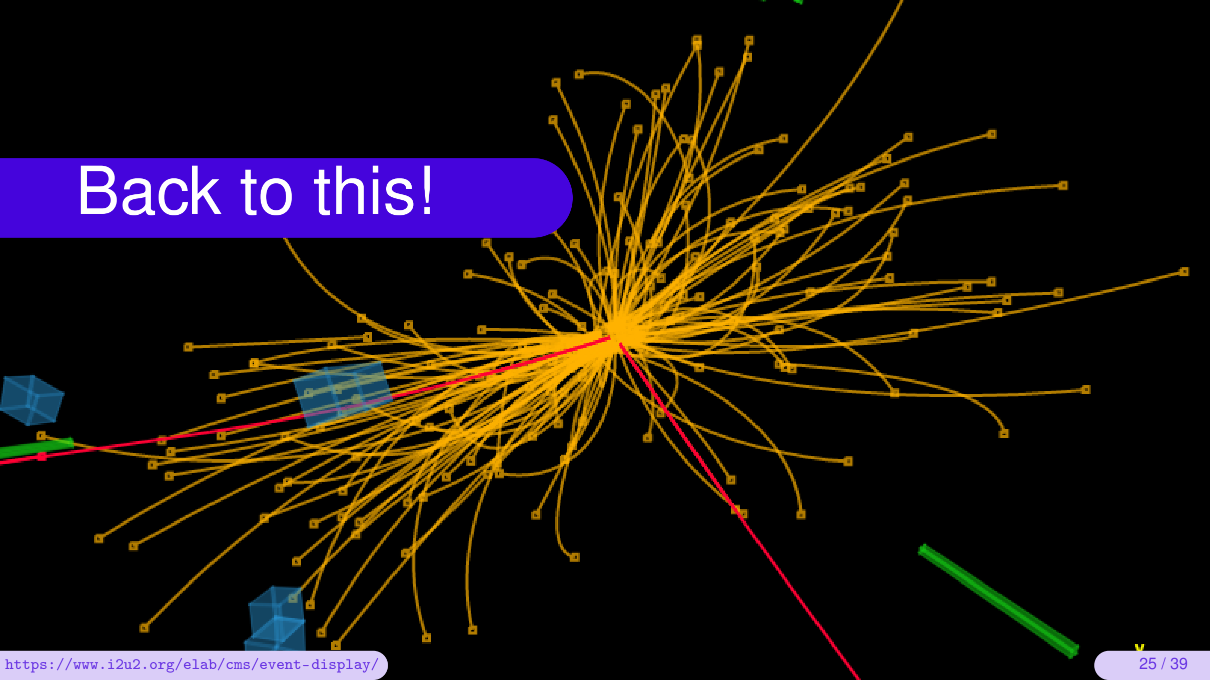
Jets

A different kind of “particle”

- Often we want to measure a quark or gluon
- But when these are produced with lots of energy you get a “jet” of nearby particles
- Most basic thing to do is add up measurements for everything inside a cone



Back to this!



What we get out

After a lot of complicated software processing

- Lists of “objects”:
  - Electrons
  - Photons
  - Muons
  - Jets
- Their properties:
  - p_{T}: momentum tranverse to beam direction
  - ϕ: azimuthal angle around the beam
  - η[1]: $0 =$ perpendicular, $\infty =$ parallel to beam
  - What kind of particle we think it is

[1] $\eta = -\log(\tan(\theta/2))$

Adding particles together

- Heavy particles decay
- Can only be detected by their decay daughters!
- In special relativity, if you know the momentum and energy (or mass) of the daughters, you can calculate the mass of the parent

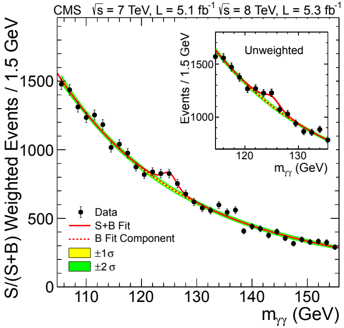
A particle physics "search"

1. Pick a decay signature, e.g. two photons
2. Scan through events looking for it
3. Calculate the mass

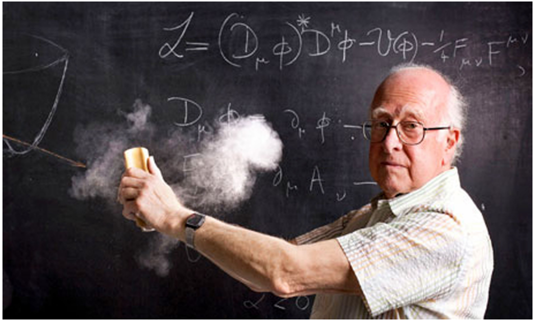
Search for the Higgs

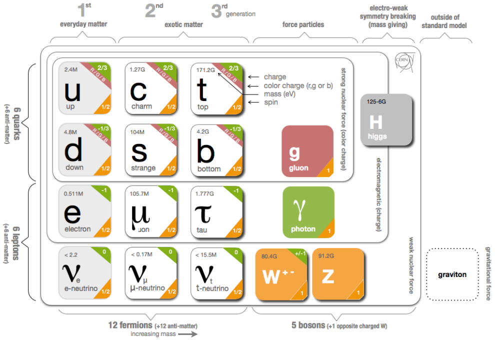
`https://twiki.cern.ch/twiki/pub/AtlasPublic/HiggsPublicResults//Hgg-FixedScale-Short2.gif`

`https://twiki.cern.ch/twiki/pub/CMSPublic/Hig13002TWiki/HZZ4l_animated.gif`



So we're done right?



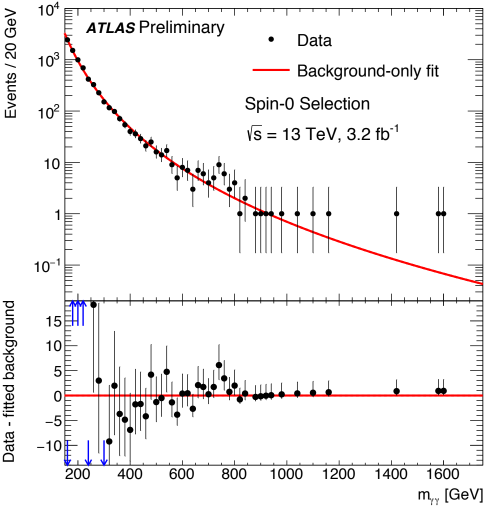


What's left to do?

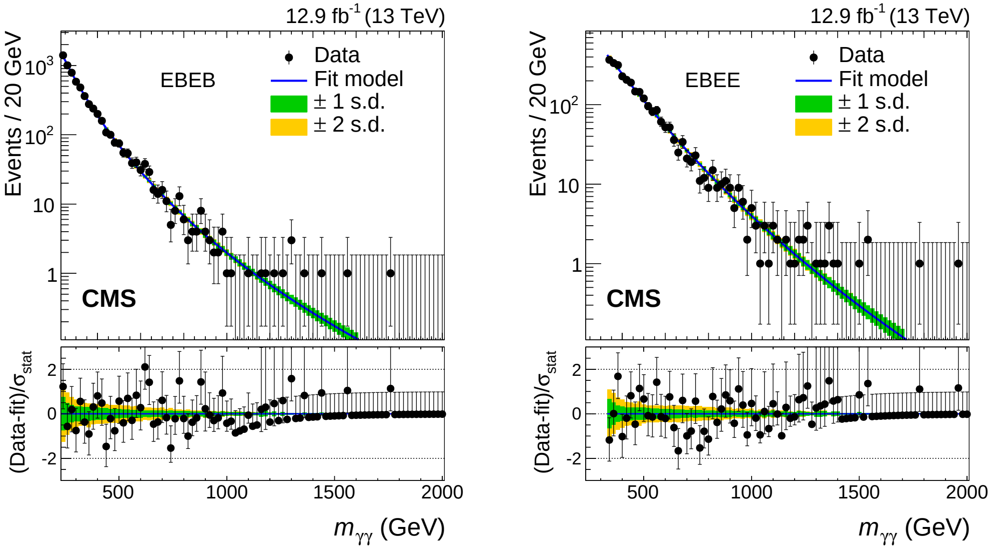
Search for new physics!

New particle?

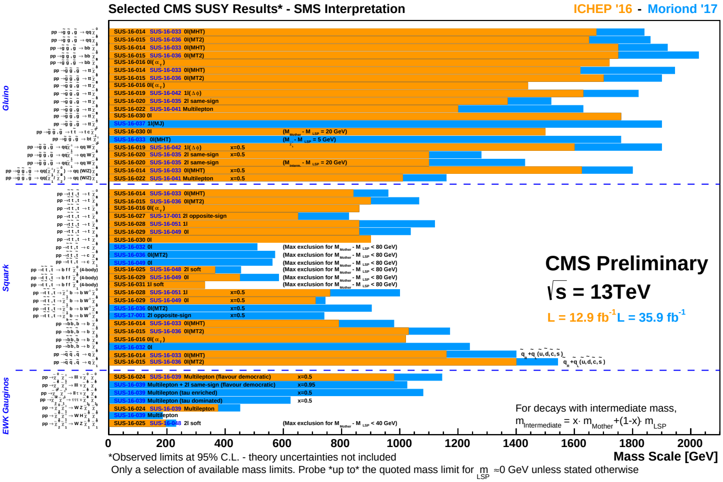
Atlas and CMS diphoton results



More data says no

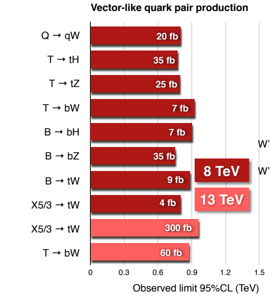


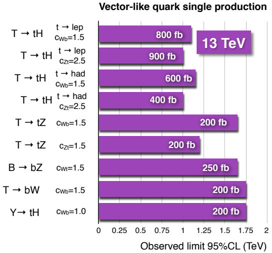
Searching...

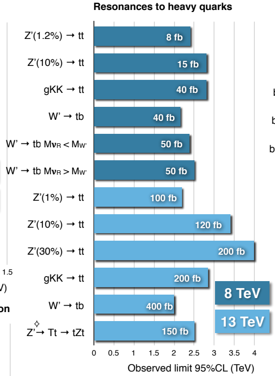


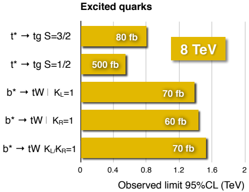
Selected CMS SUSY Results* - SMS Interpretation
ICHEP '16 - Moriond '17
Gluino
Squark
EWK Gauginos
CMS Preliminary
$\sqrt{s}$ = 13TeV
L = 12.9 fb^{-1} L = 35.9 fb^{-1}
For decays with intermediate mass,
$m_{Intermediate} = x \cdot m_{Mother} + (1-x) \cdot m_{LSP}$
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Mass Scale [GeV]
*Observed limits at 95% C.L. - theory uncertainties not included
Only a selection of available mass limits. Probe *up to* the quoted mass limit for $m_{LSP} \approx 0$ GeV unless stated otherwise

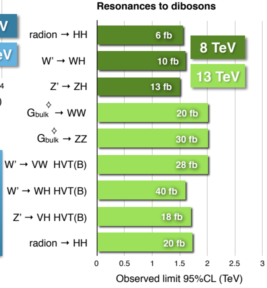
...and searching...









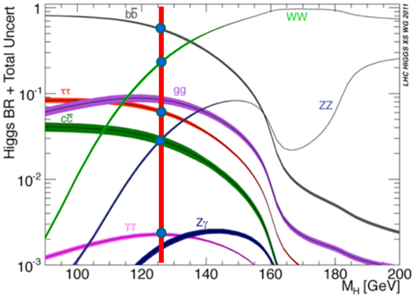


B2G
new physics searches with heavy SM particles

Studying properties

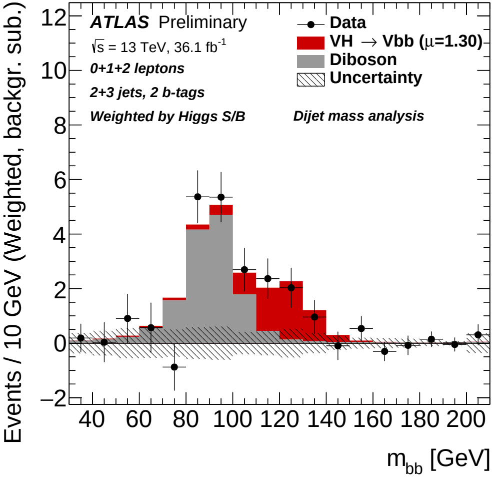
Is the Higgs really the Higgs?

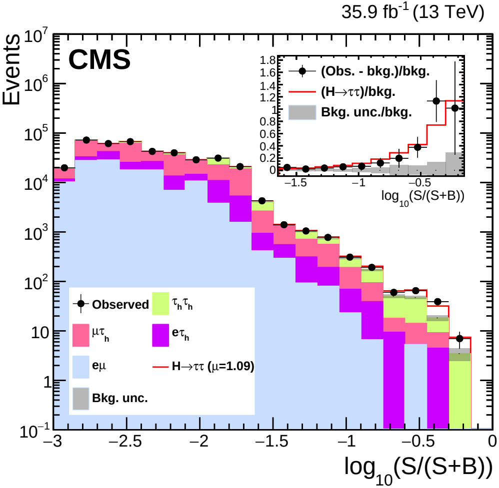
- Does it have spin-0? ✓
- Does it decay into the particles we expect? ✓
- At the right rates?
- Produced in the amount expected?



Decay to b and τ

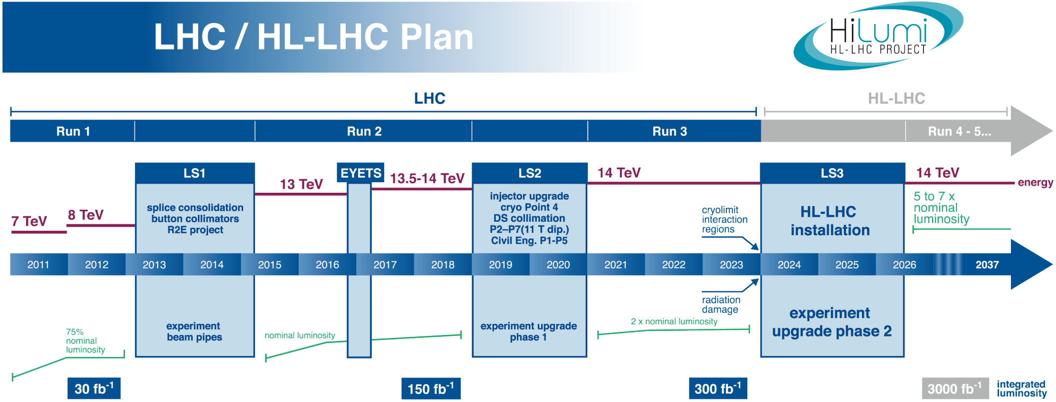
Most recent results





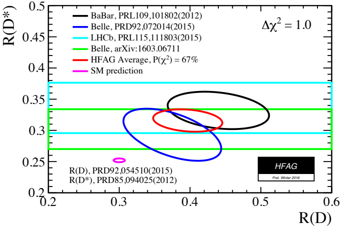
Into the future

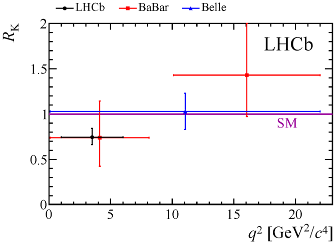
- Need to probe Higgs properties with an uncertainty less than 5%
- Will need lots more data, fortunately there is a plan:

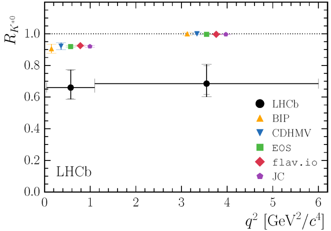


Precision *b*-physics

Maybe LHCb will be the discovery machine?





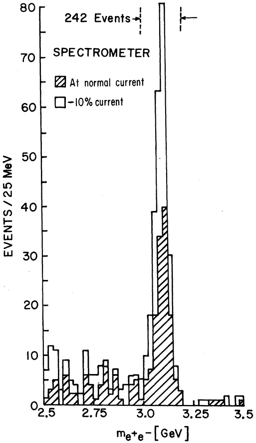


Are there new differences between leptons?

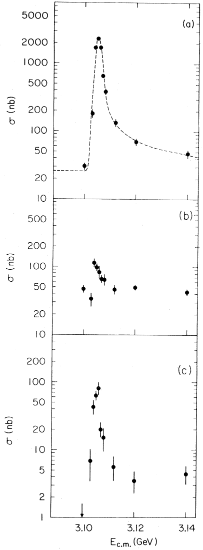
Conclusion

Backup

How do we know we measure things co

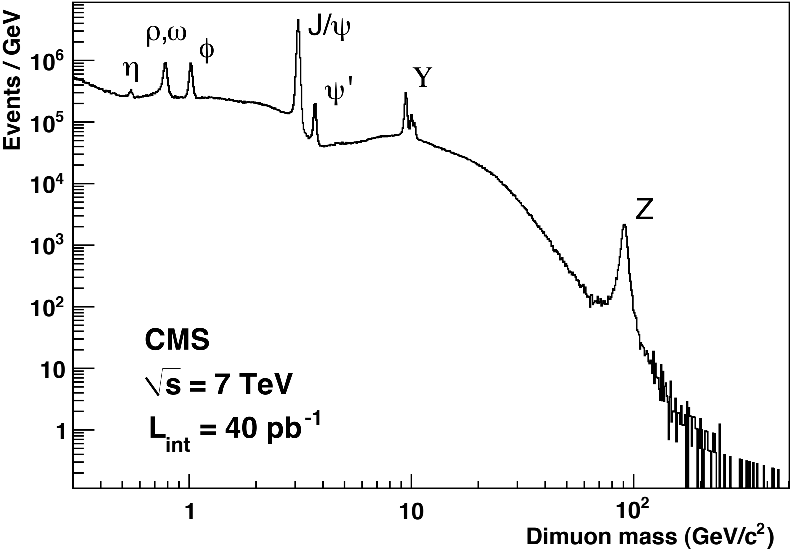

242 Events
SPECTROMETER
At normal current
-10% current
EVENTS / 25 MeV
0
10
20
30
40
50
60
70
80
2.5
2.75
3.0
3.25
3.5
$m_{e^+e^-}$ [GeV]

J


(a)
(b)
(c)
σ (nb)
σ (nb)
σ (nb)
5000
2000
1000
500
200
100
50
20
10
500
200
100
50
20
10
200
100
50
20
10
5
2
1
3.10
3.12
3.14
$E_{c.m.}$ (GeV)

ψ

Calibrate with known particles



Effects of trigger