Tuning the HF Calorimeter GFlash Simulation Using CMS Data

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Outline

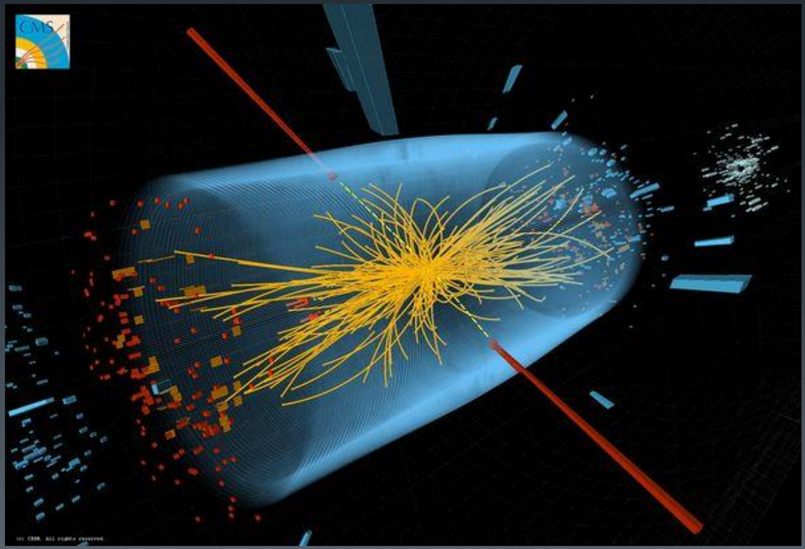
- LHC and CMS Description
- Particle Collisions
- The Higgs Boson
- HF Calorimeter at CMS
- GFlash Speed and Accuracy Tuning
- Future Applications

Large Hadron Collider (LHC)

- Located at CERN in Switzerland
- Four major experiments (CMS, ATLAS, ALICE, and LHCb)
- The LHC is a 27-km ring lined with superconducting magnets

Large Hadron Collider (LHC)

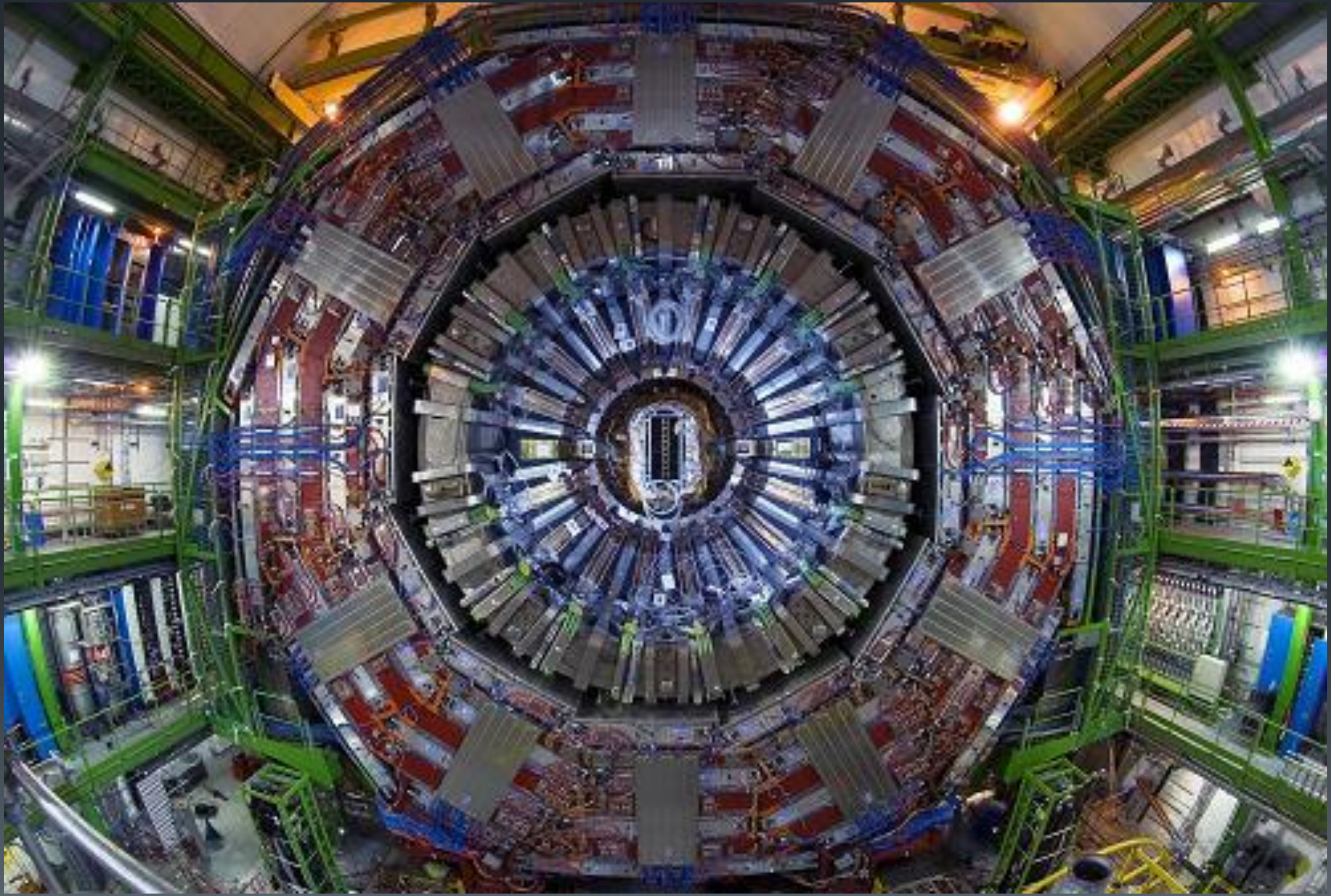
- Two particle-beams are accelerated close to the speed of light
- Collisions between these high-energy beams, create particles that could tell us about the fundamental building blocks of the universe



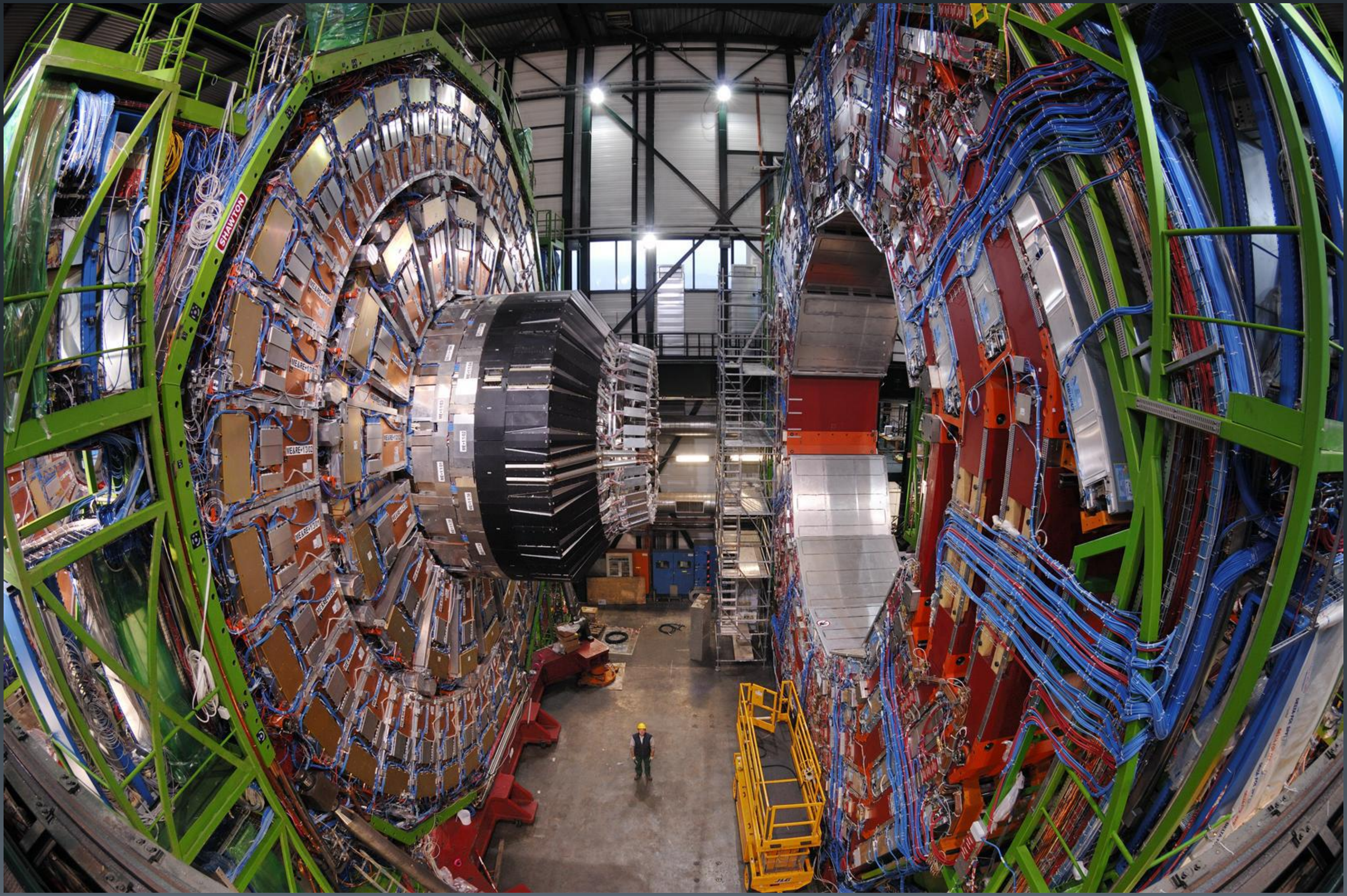
Compact Muon Solenoid (CMS)

- 14,000 Ton Detector
- One of the largest science collaborations in history:
  - 4,300 physicists, engineers, technicians, etc.
  - 182 Universities and institutions
  - 42 countries represented
- 21 meters long
- 15 meters wide
- 15 meters high

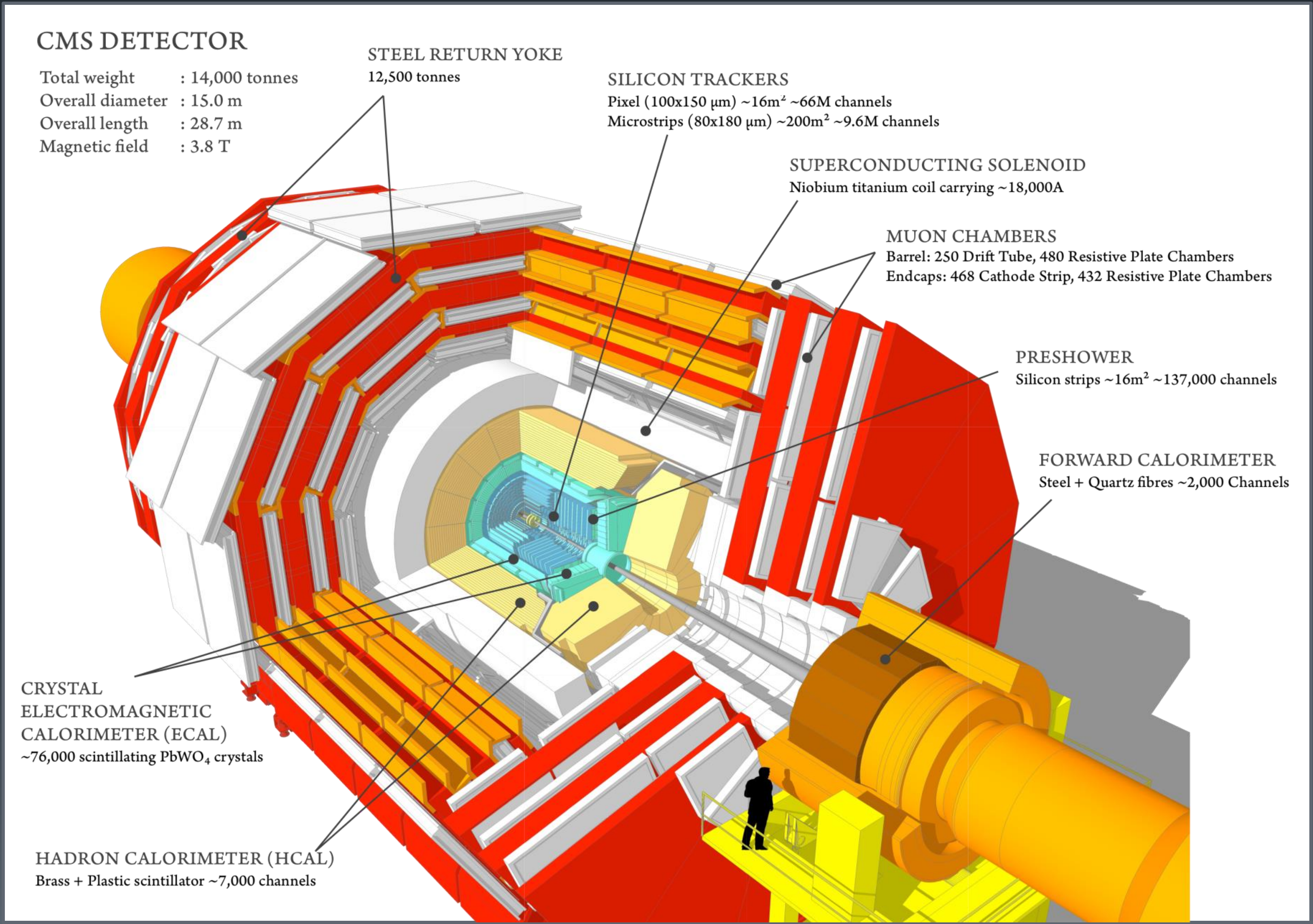
Compact Muon Solenoid (CMS)



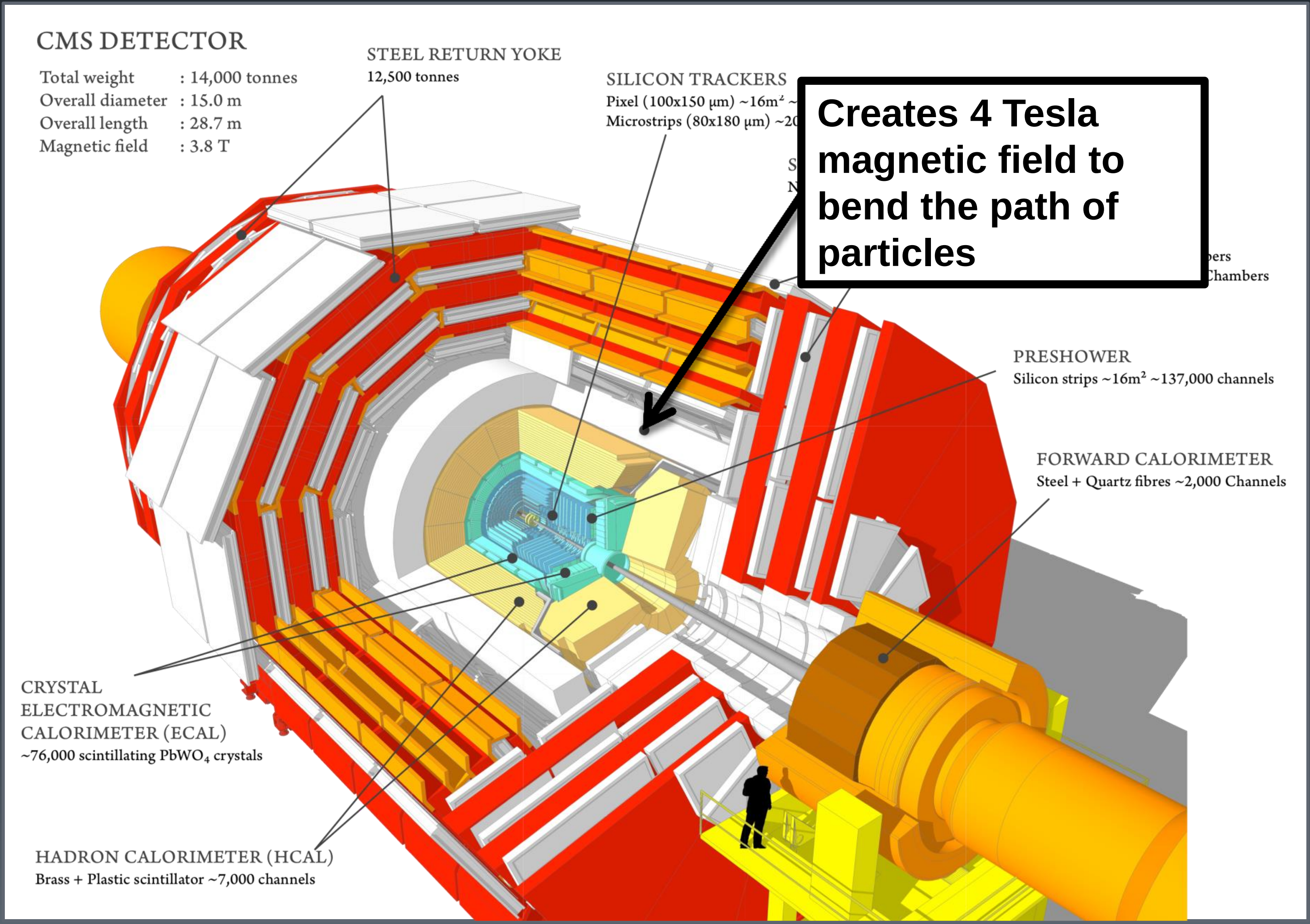
Compact Muon Solenoid (CMS)



Compact Muon Solenoid (CMS)

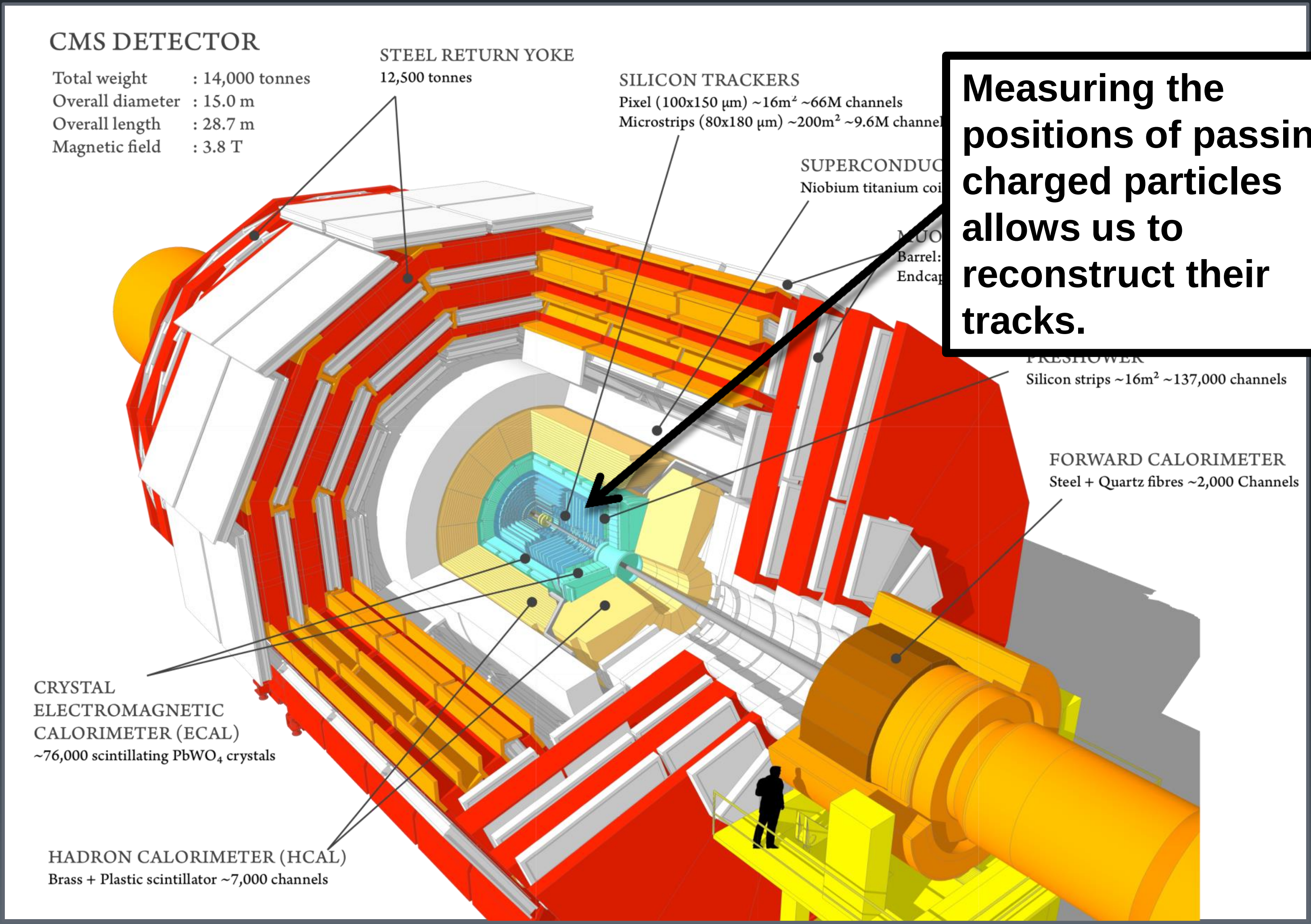


Solenoid



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
Creates 4 Tesla magnetic field to bend the path of particles
PRESHOWER
Silicon strips ~16m² ~137,000 channels
FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels
CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating PbWO4 crystals
HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels

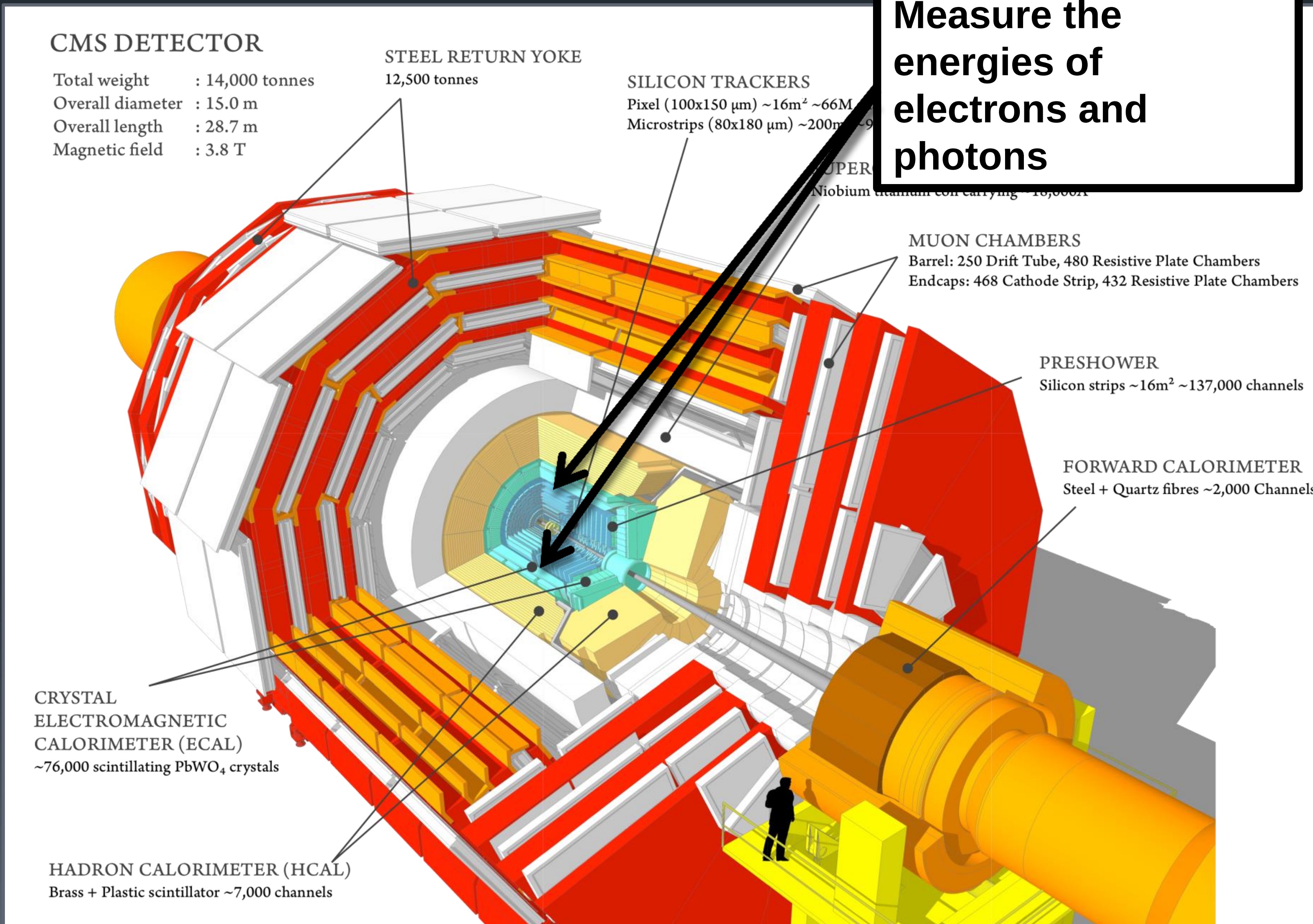
Silicon Tracker



Measuring the positions of passing charged particles allows us to reconstruct their tracks.

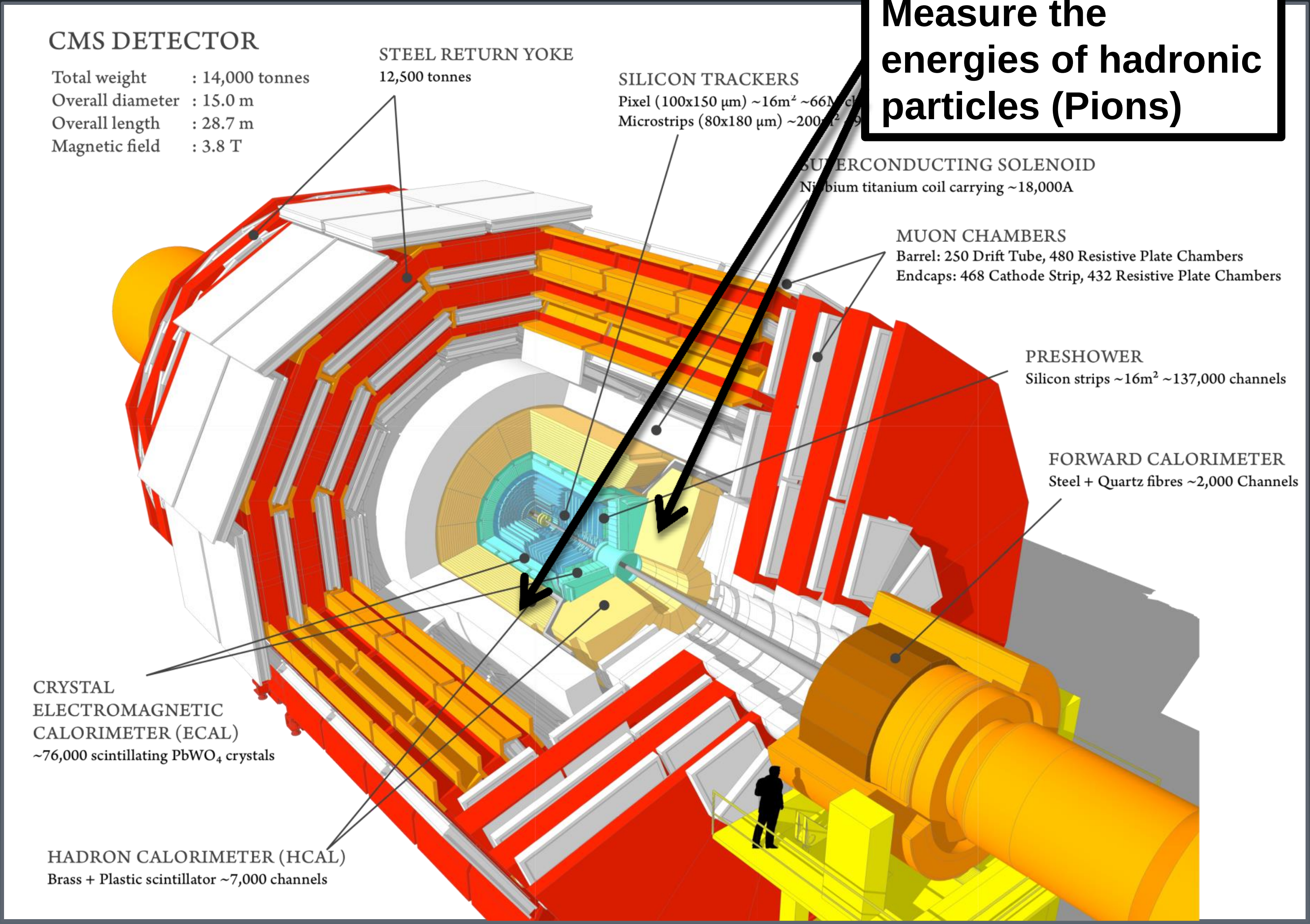
Electromagnetic Calorimeter

Measure the energies of electrons and photons

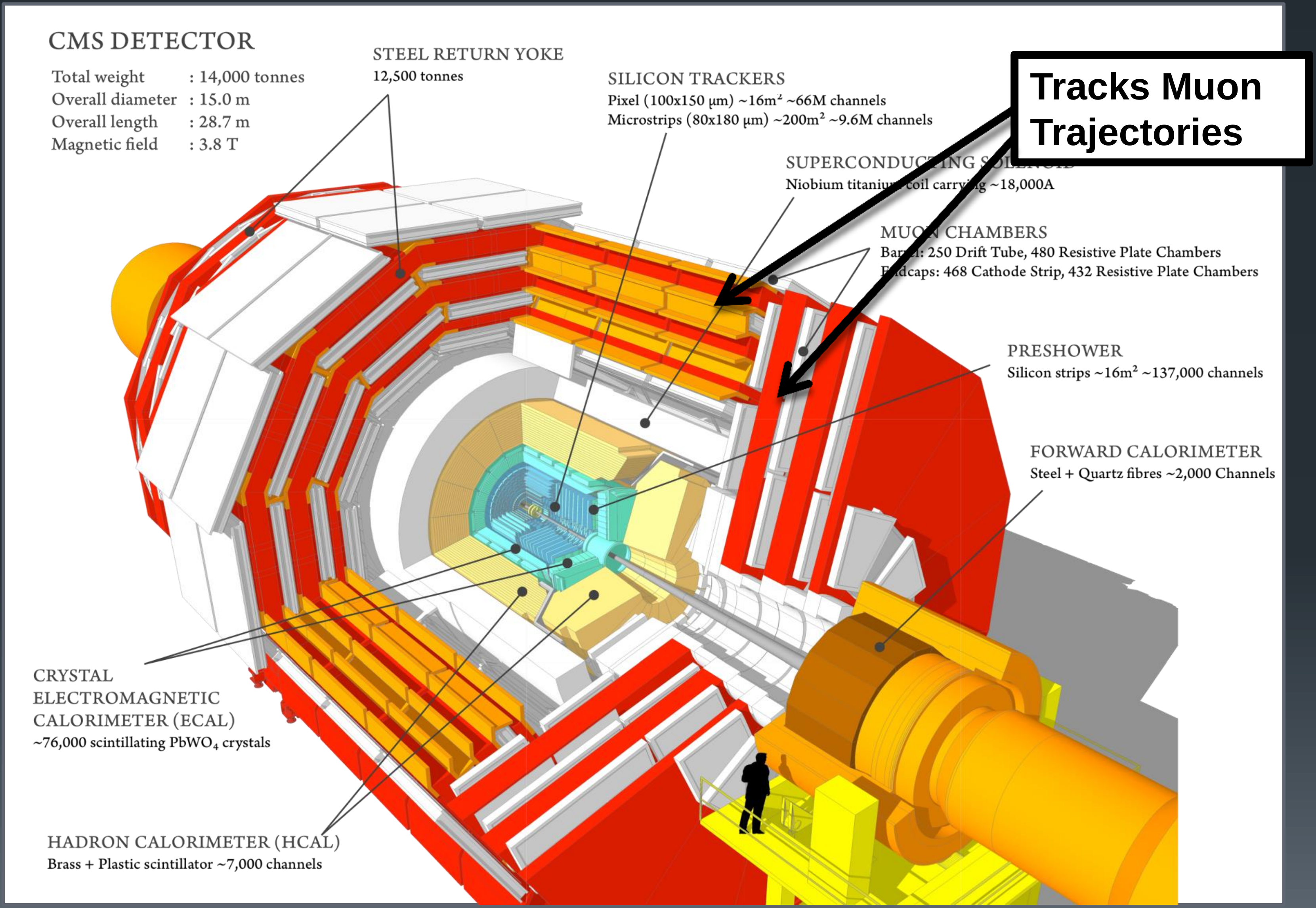


Hadronic Calorimeter

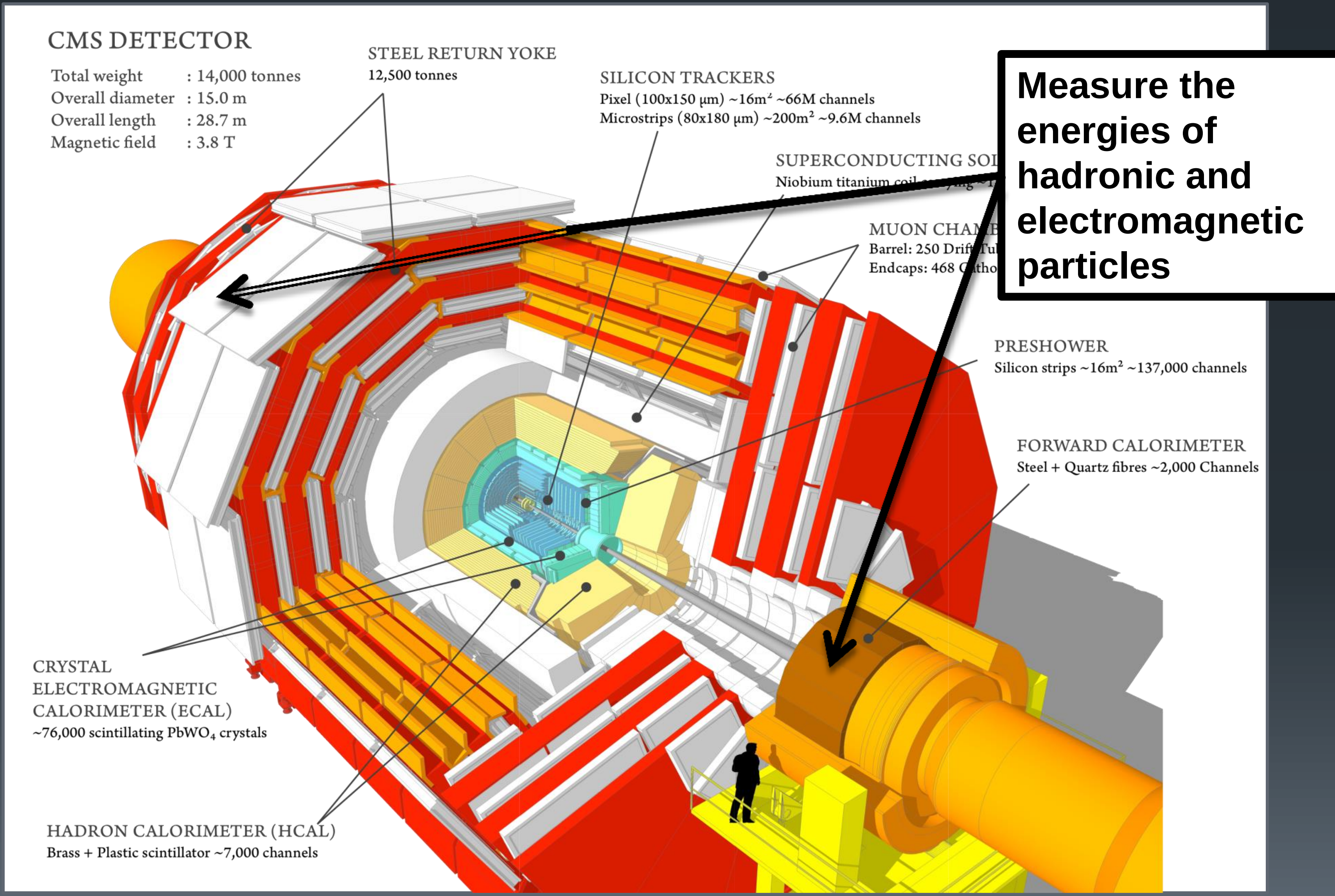
Measure the energies of hadronic particles (Pions)



Muon Chambers



Hadronic Forward Calorimeter

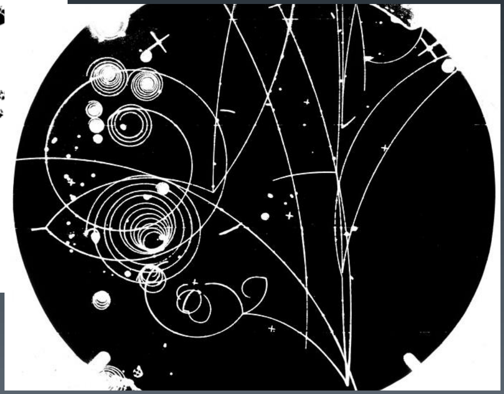


How do we detect particles?

"Just as hunters can identify animals from tracks in mud or snow, physicists identify subatomic particles from the traces they leave in detectors"

-CERN

- Accelerators
- Tracking Devices
- Calorimeters
- Particle ID Detectors

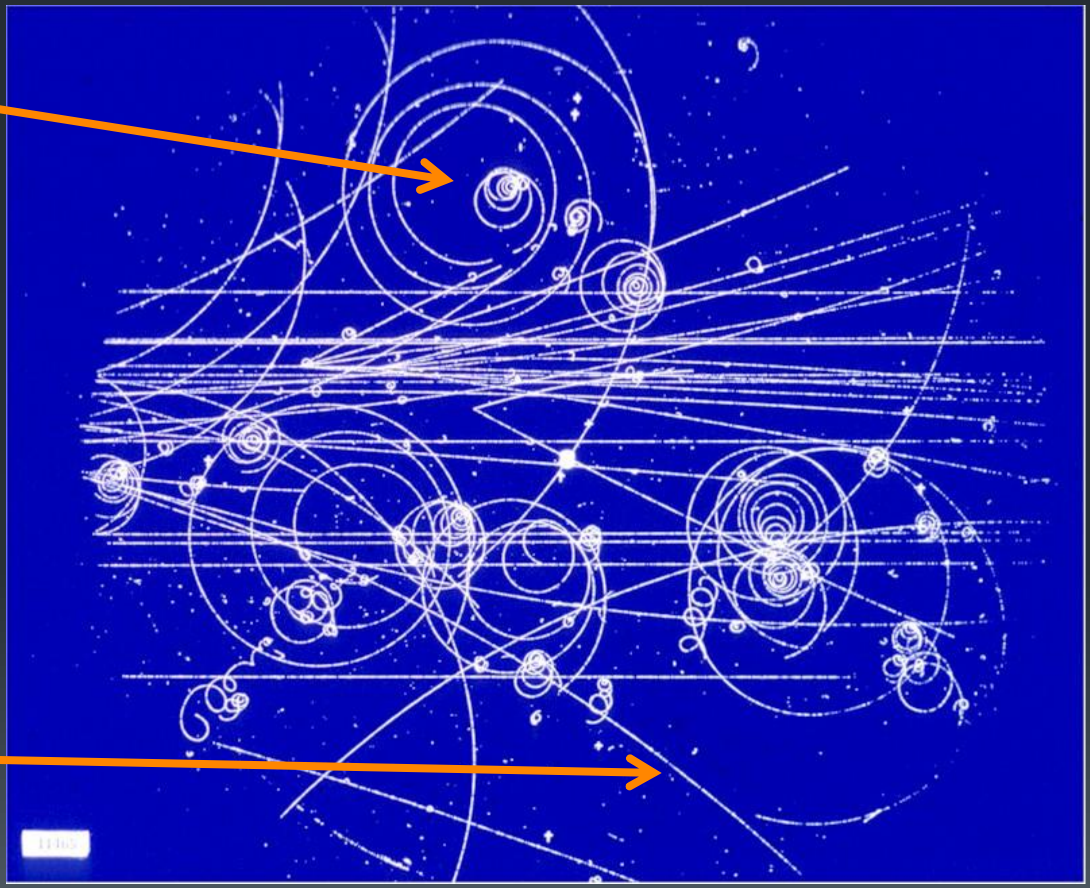


Step-by-Step Collision

1. Accelerate particles to near the speed of light using electromagnetic fields.
2. Physicists can bend the beam using superconducting magnets.
3. Collide particles in four specific locations. Sub-atomic particles are ejected.
4. Normally particles travel in a straight line. Using magnetic fields, the particle paths can be curved. (Only for charged particles)

Step-by-Step Collision

- Particles that curve a lot have low momentum.
- Particles that curve just a small amount have very high momentum



(Old Bubble Chamber Method)

Step-by-Step Collision

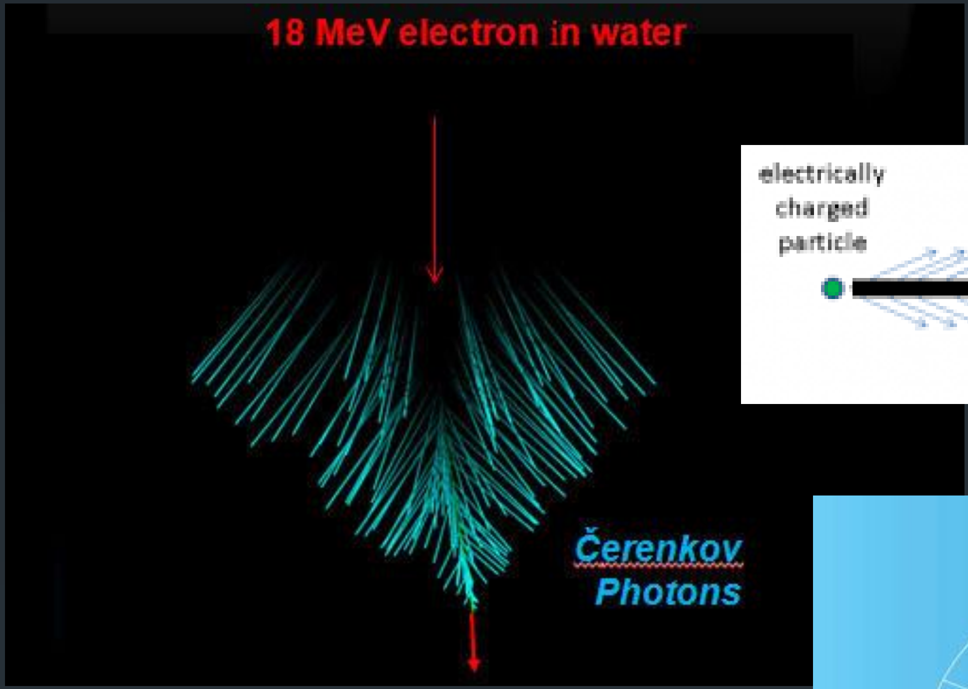
1. Sub-atomic particles also enter calorimeters.
2. These are designed to absorb and measure the energy of particles.
3. Made from high-density materials.
4. Electromagnetic Calorimeters can identify electrons and photons.
5. Hadronic Calorimeters can identify particles made from quarks (pions, neutrons, protons)

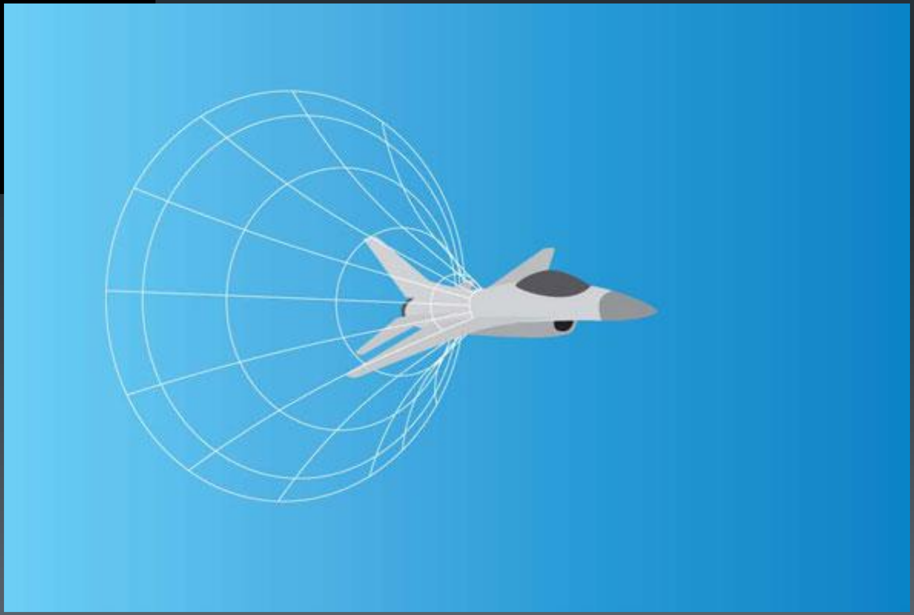
Step-by-Step Collision

1. Physicists can also measure Cherenkov light from particles to help determine their momentum.
2. In a vacuum, nothing moves faster than the speed of light. However, in other materials (like water), high-energy particles can travel faster than light.
3. "*It is the optical equivalent to a sonic boom*"

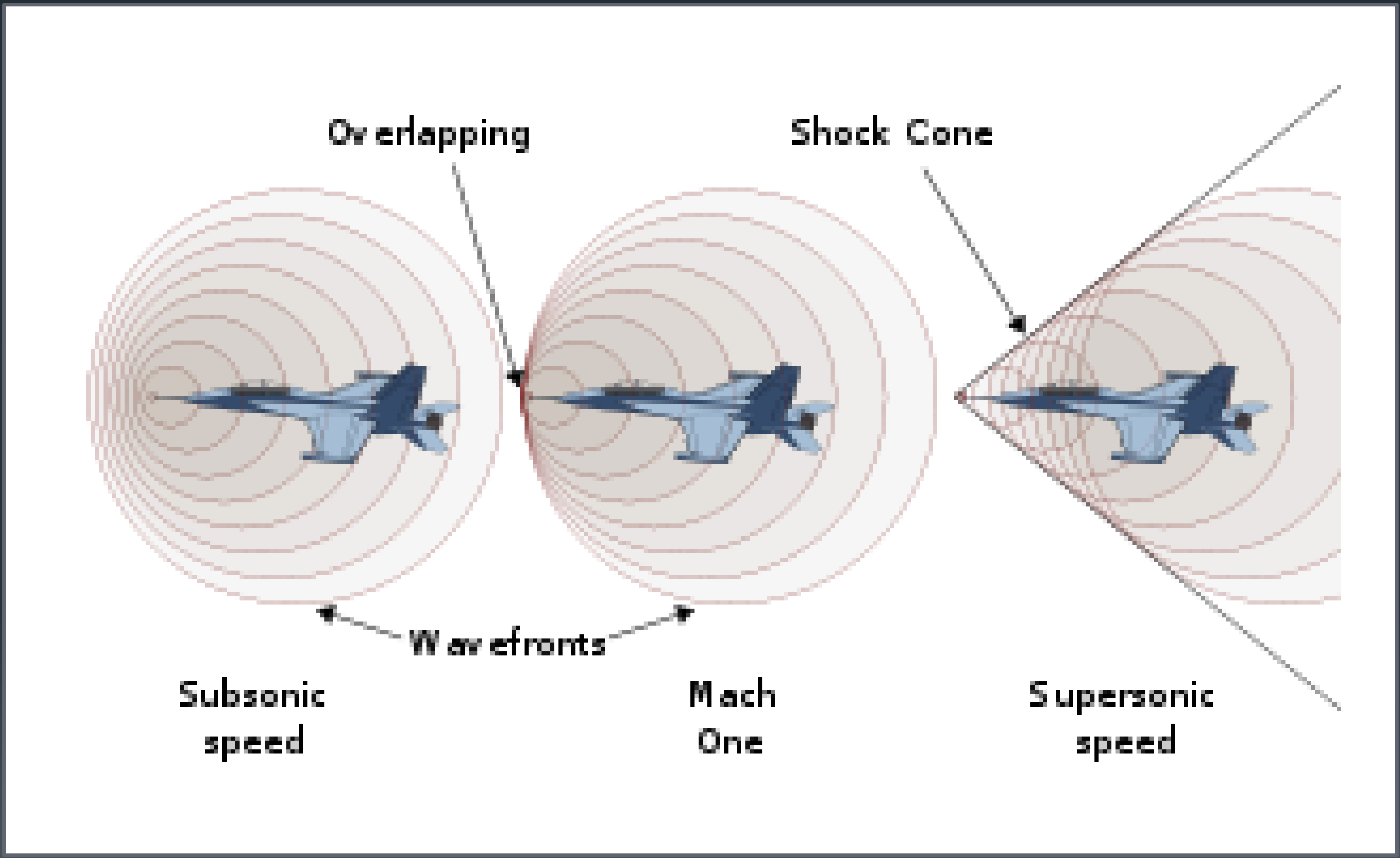
- Explain it in 60 Seconds (Symmetry Magazine)

Cherenkov Radiation





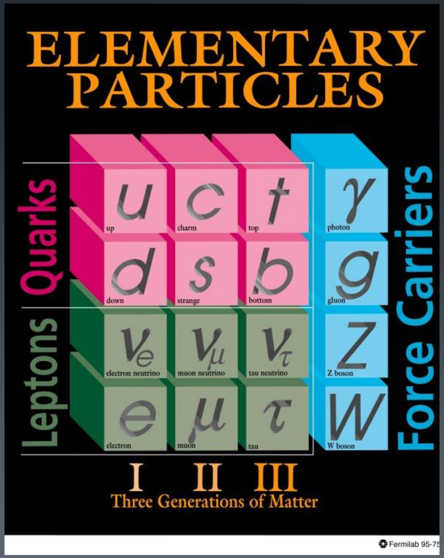
Cherenkov Radiation



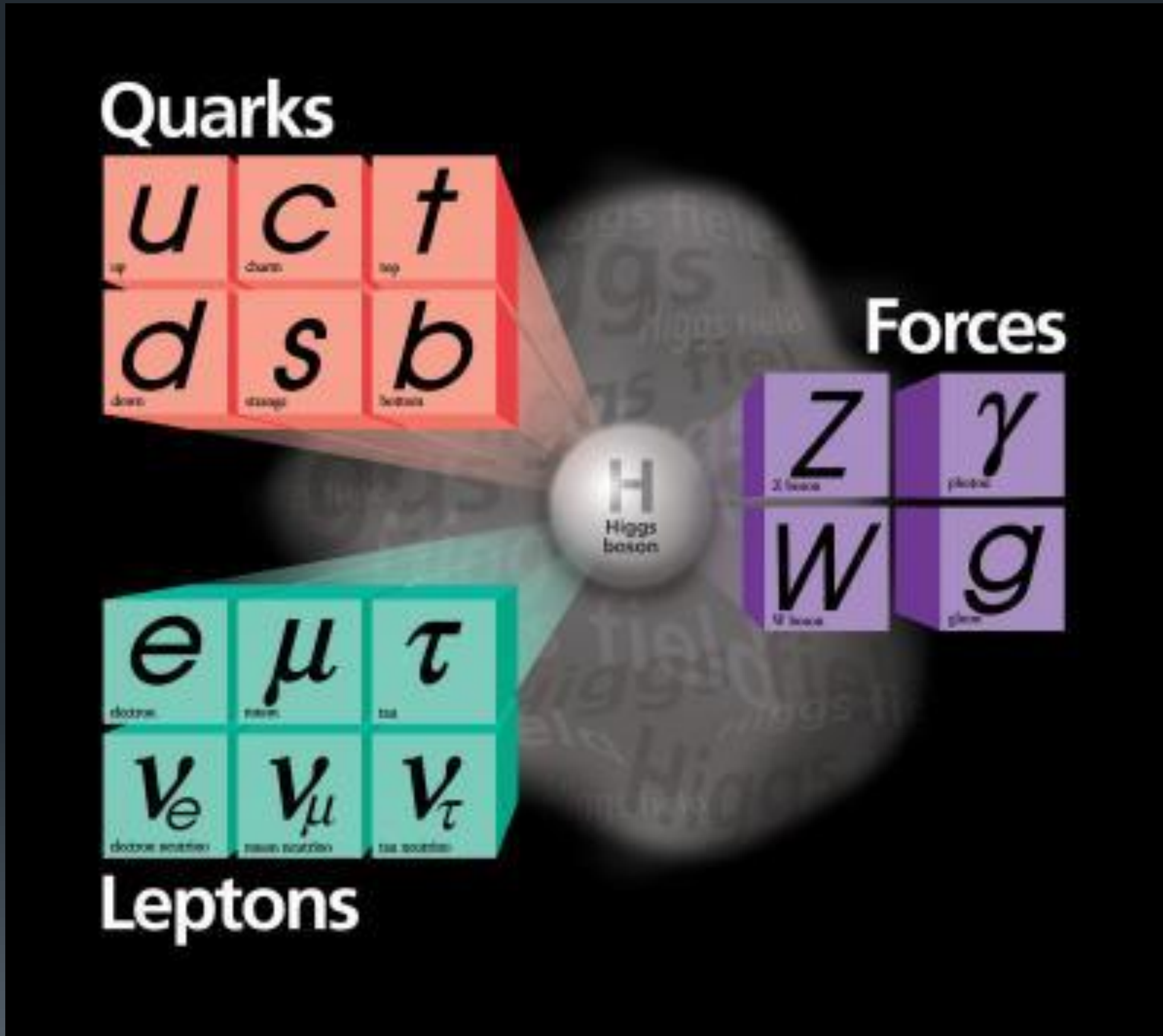
Cherenkov Radiation

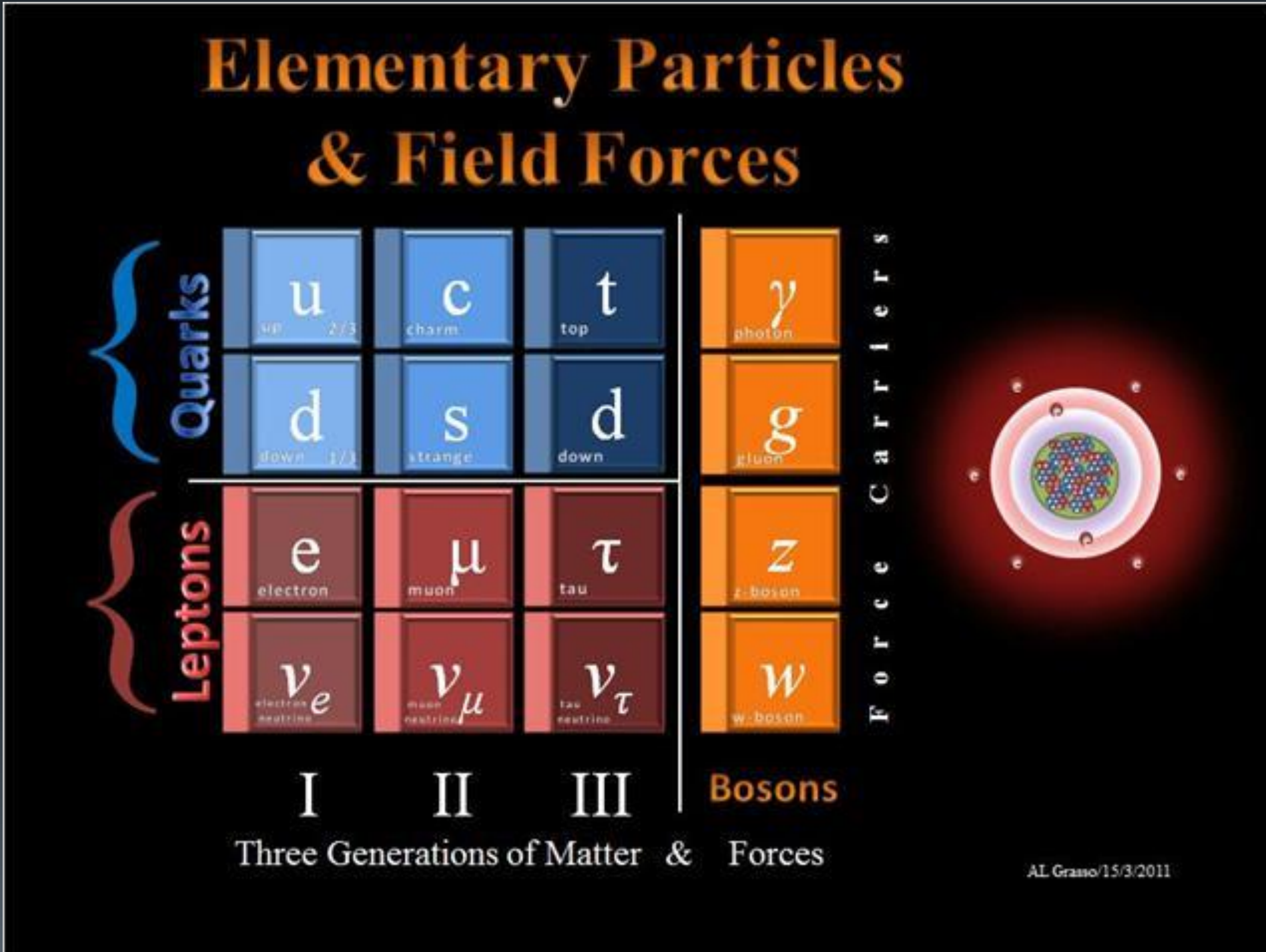
Combining Results

- Physicists use the combination of all these methods to learn about the fundamental building blocks of the universe.
- Discoveries on many particle accelerators and detectors in the past have led to the **Standard Model.**



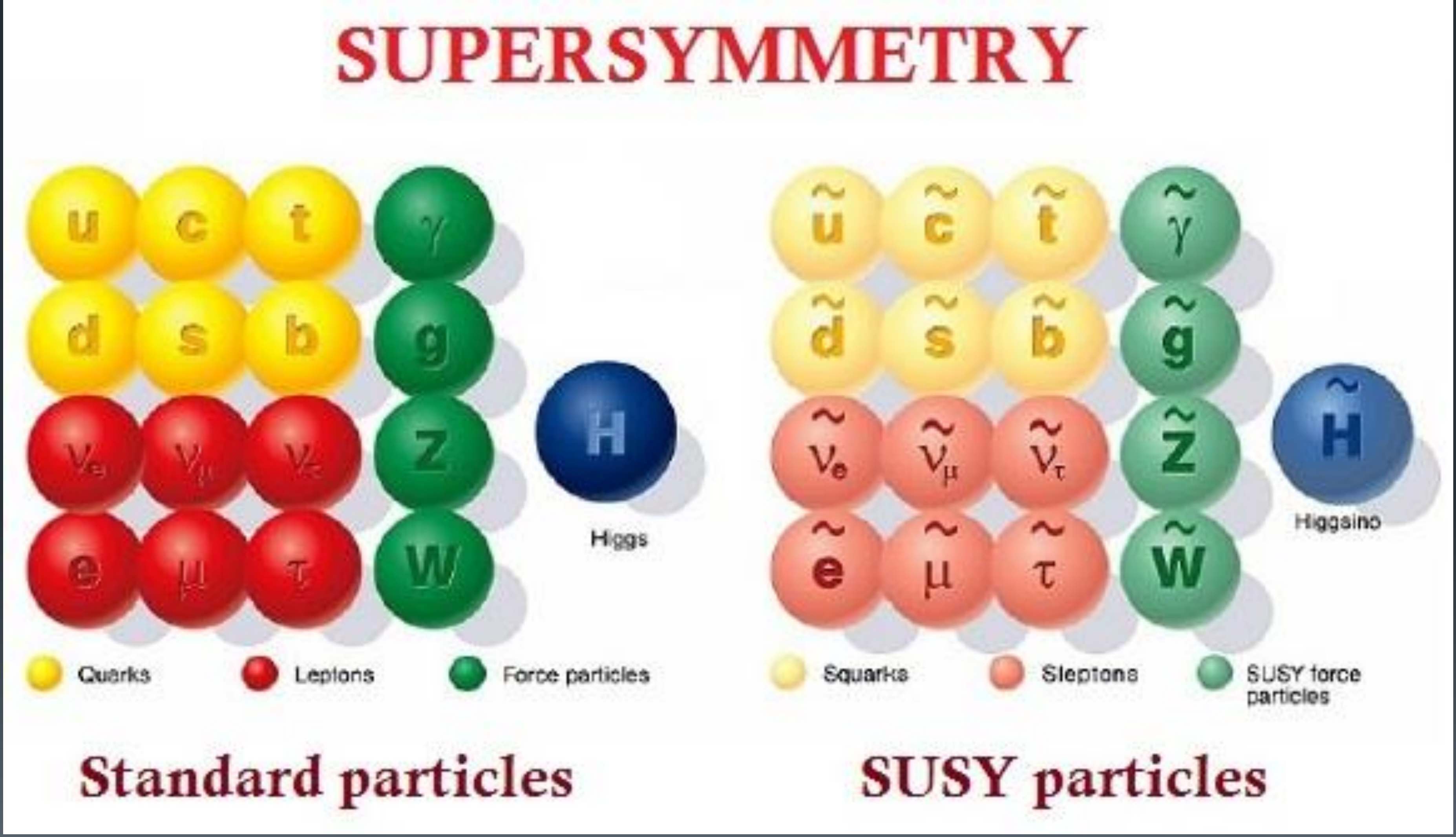
The Standard Model



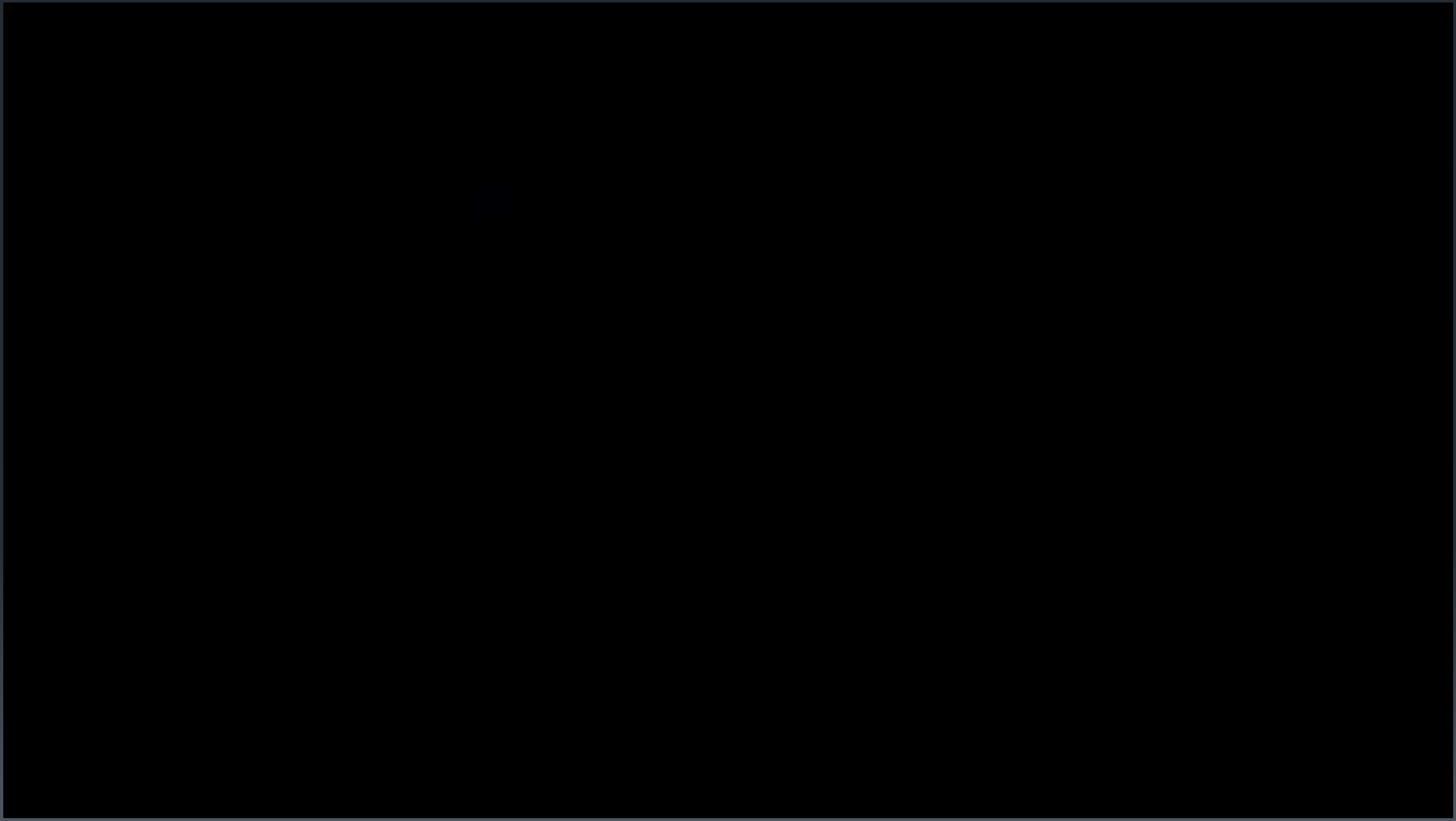


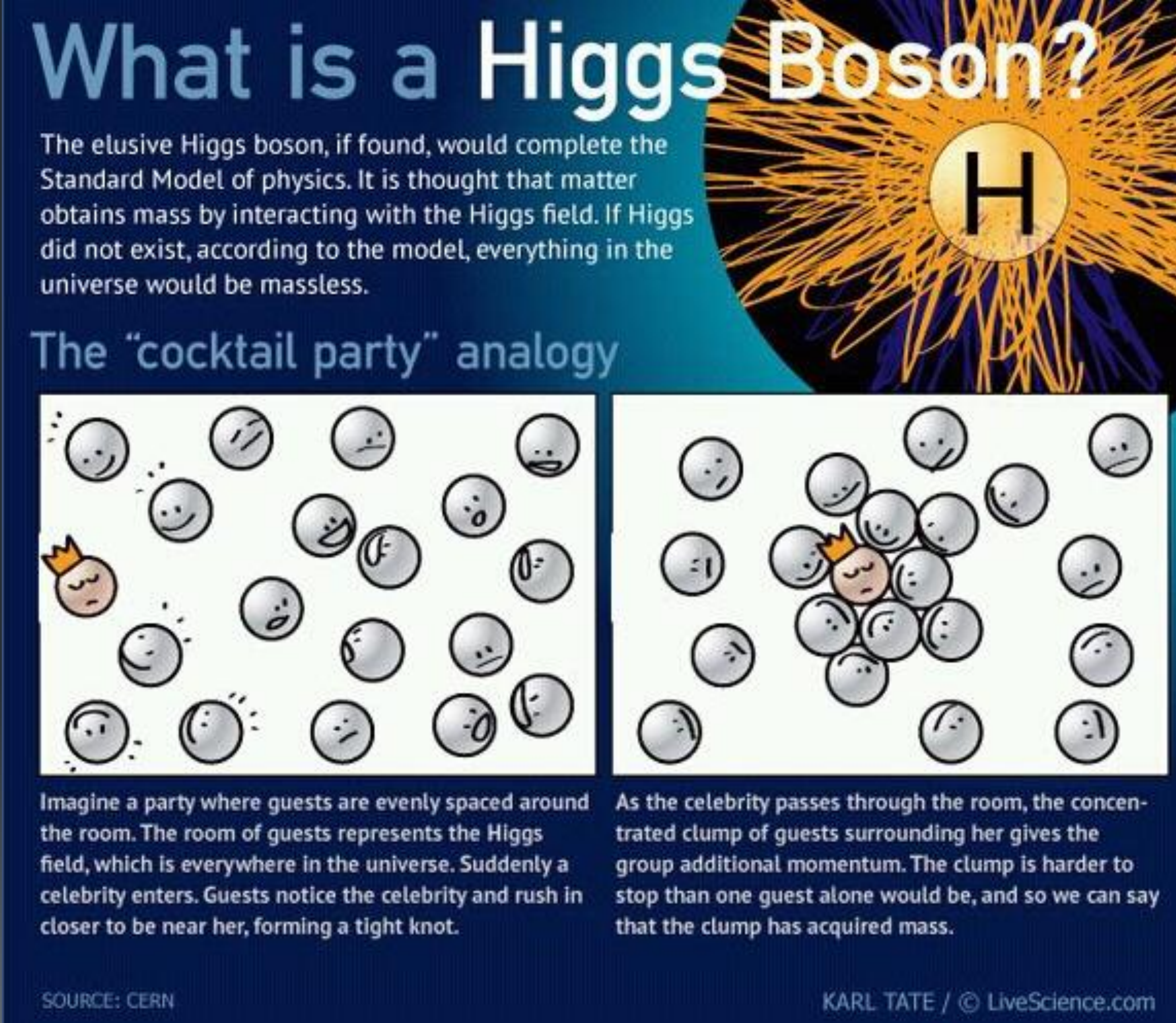
Elementary Particles
& Field Forces
Quarks
Leptons
u
up
2/3
c
charm
t
top
d
down
1/3
s
strange
d
down
e
electron
μ
muon
τ
tau
ν_e
electron neutrino
ν_μ
muon neutrino
ν_τ
tau neutrino
γ
photon
g
gluon
z
z-boson
w
w-boson
Force Carriers
I
II
III
Bosons
Three Generations of Matter & Forces
AL Grasso/15/3/2011

More To Be Discovered?



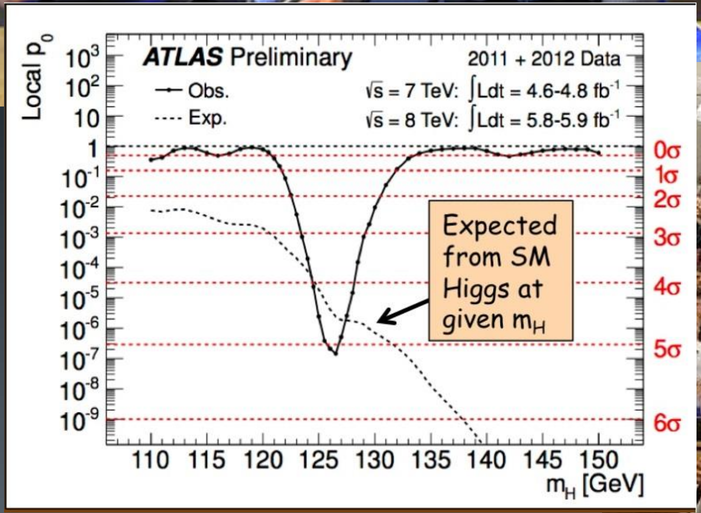
What about the Higgs Boson?




What is a Higgs Boson?
The elusive Higgs boson, if found, would complete the Standard Model of physics. It is thought that matter obtains mass by interacting with the Higgs field. If Higgs did not exist, according to the model, everything in the universe would be massless.
H
The "cocktail party" analogy
Imagine a party where guests are evenly spaced around the room. The room of guests represents the Higgs field, which is everywhere in the universe. Suddenly a celebrity enters. Guests notice the celebrity and rush in closer to be near her, forming a tight knot.
As the celebrity passes through the room, the concentrated clump of guests surrounding her gives the group additional momentum. The clump is harder to stop than one guest alone would be, and so we can say that the clump has acquired mass.
SOURCE: CERN
KARL TATE / © LiveScience.com

What about the Higgs Boson?

July 4, 2012



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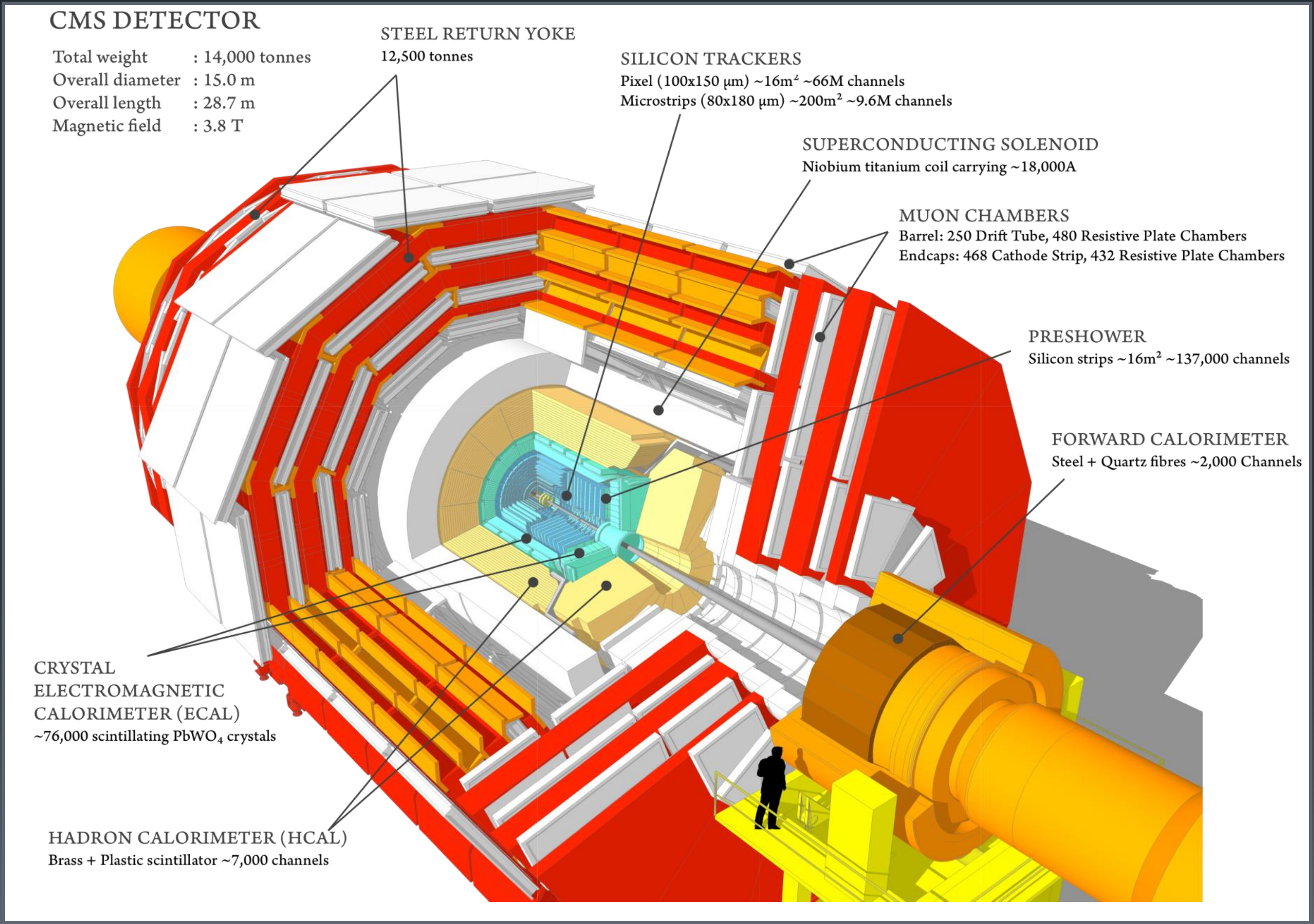
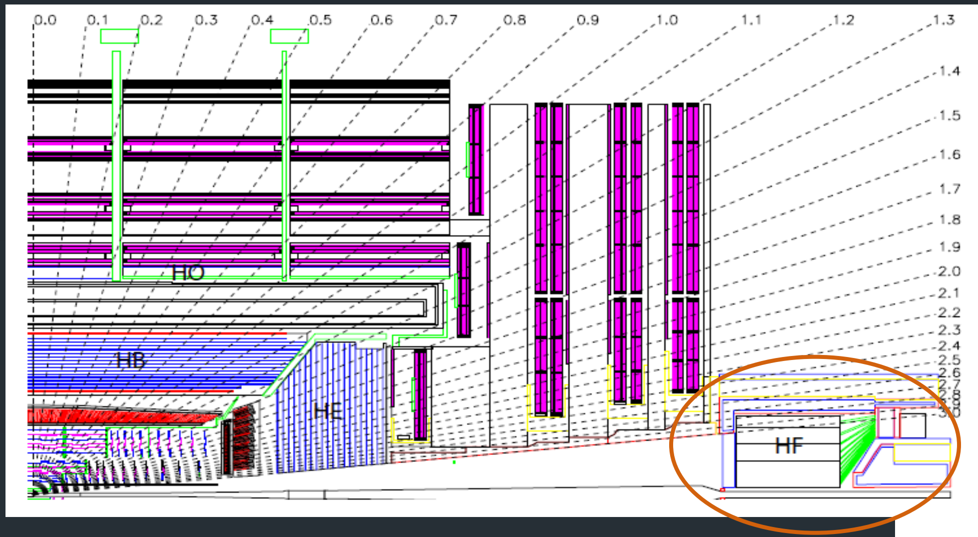
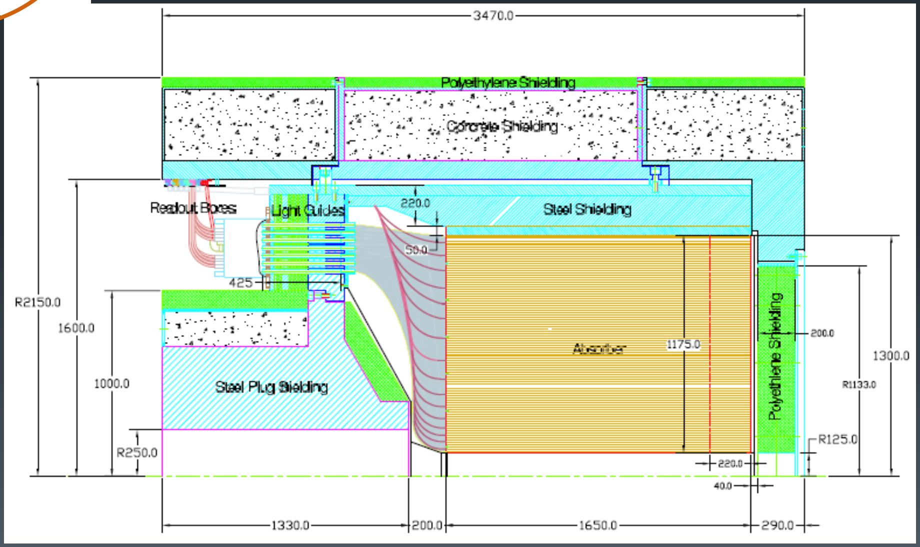


Hadronic Forward Calorimeter (HF)



Hadronic Forward Calorimeter(HF) is placed about 11 m from interaction point and has 3 <|η|< 5. There is no other calorimeter in front of HF so that HF is a very good place to study Gflash.



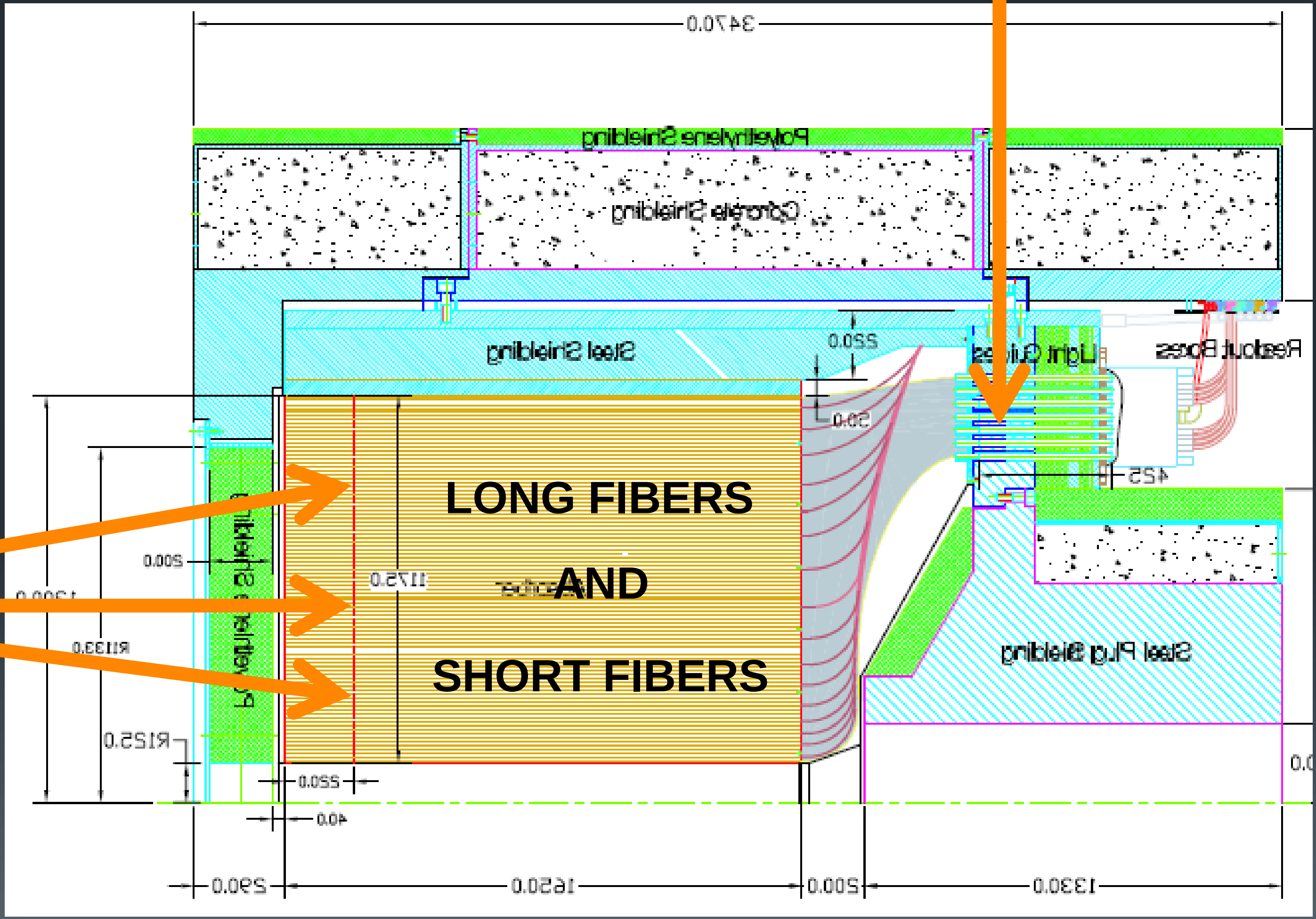
Rahmat

HF Calorimeter

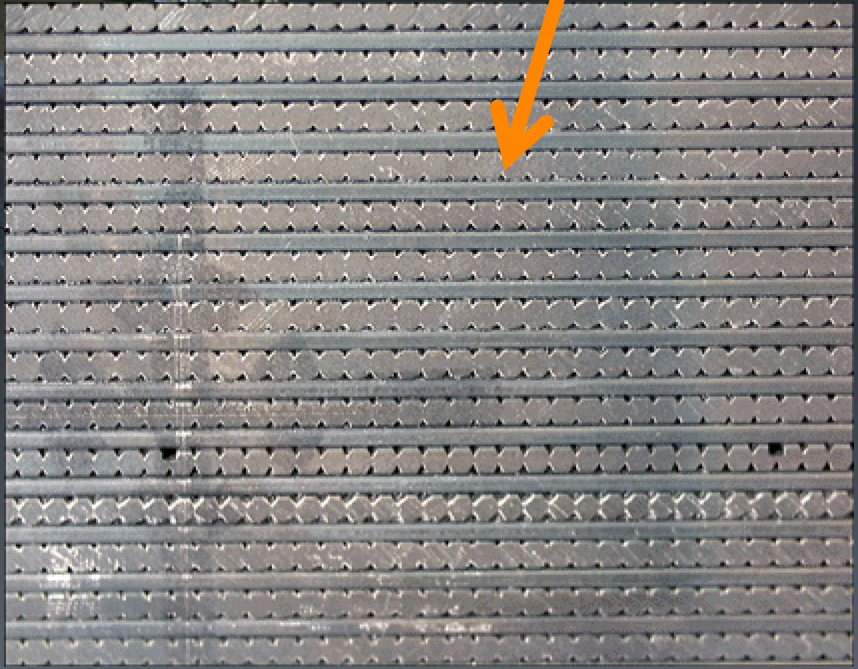
Light signal converted to electrical signal in Photo Multiplier Tubes (PMT)

Beam Collision

Particles Enter



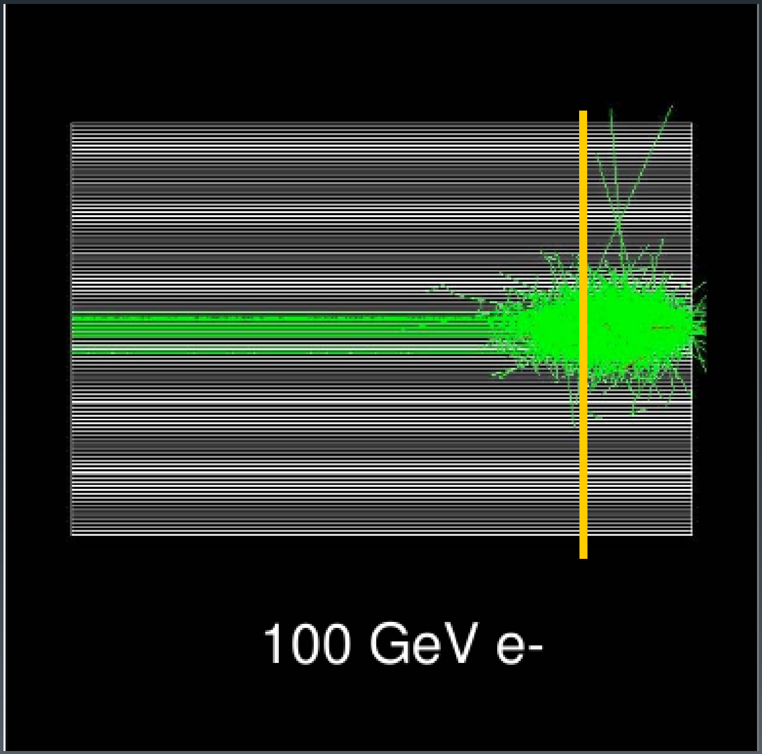
- Alternating steel and fiber structure in each wedge.

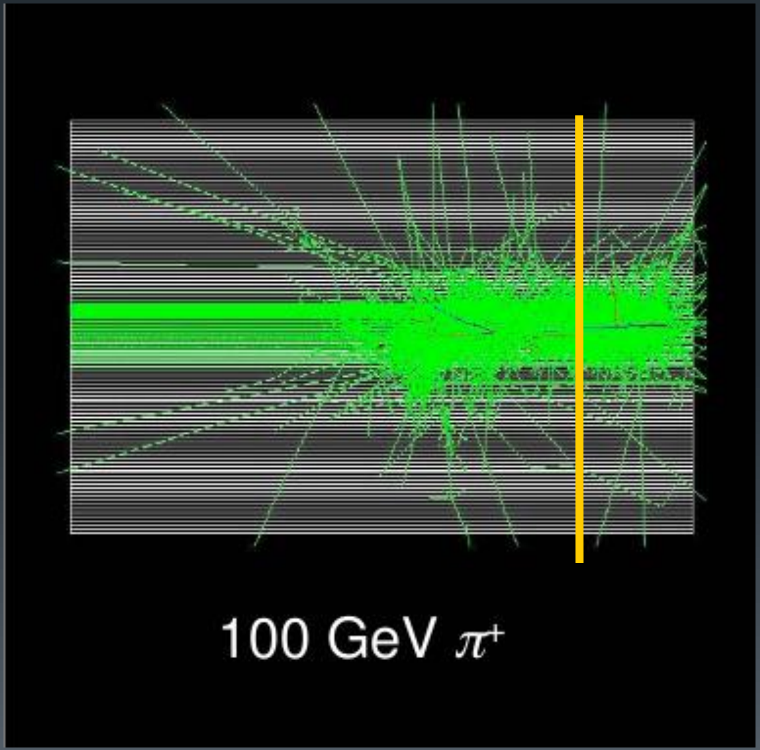


- Long fibers (165cm)
- Short fibers (143cm)

HF Calorimeter

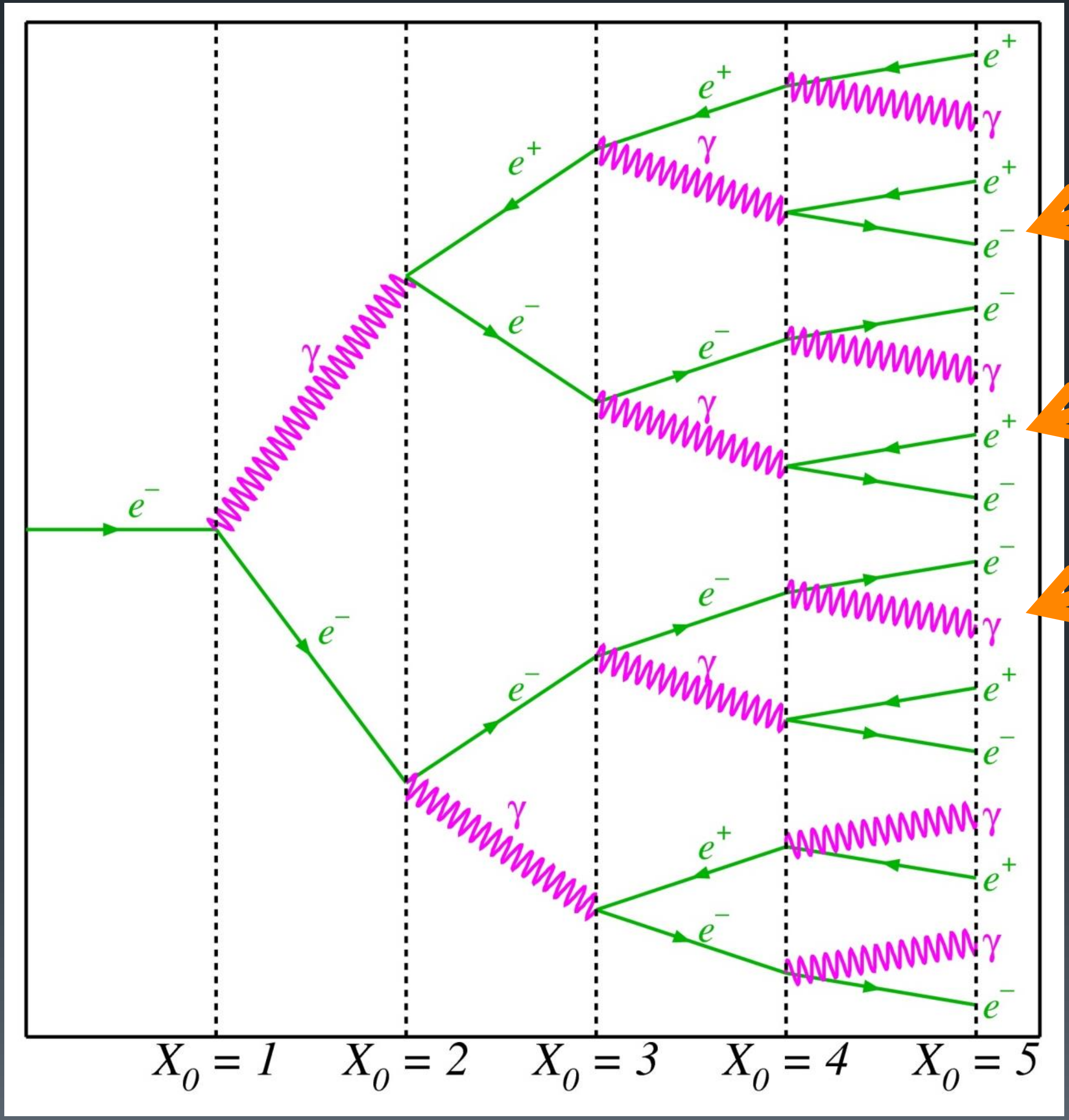
- Use LONG and SHORT Fibers to differentiate shower from electromagnetic (e^-) and hadronic particles (π^+).





Particles Enter

HF Calorimeter



Electron

Positron

Photon

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- Goal was to improve the speed and accuracy of the GFlash computer simulation using data from CMS, Test Beam, and Shower Library.
- Daily work included changing variables to test accuracy and speed of the HF Calorimeter simulation.
    - *Energy of the Electron and Pion (GeV)*
    - *Eta = pseudorapidity (η)*
    - *Φ = an angular measurement*

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- Increase the speed of the simulations by removing particles such as soft neutrons (low energy).
- These particles have low interaction rates.
- Cut any interactions below 1.0-1.5 GeV to achieve this.
- Any particle below this threshold is "killed" and we don't collect further data on it

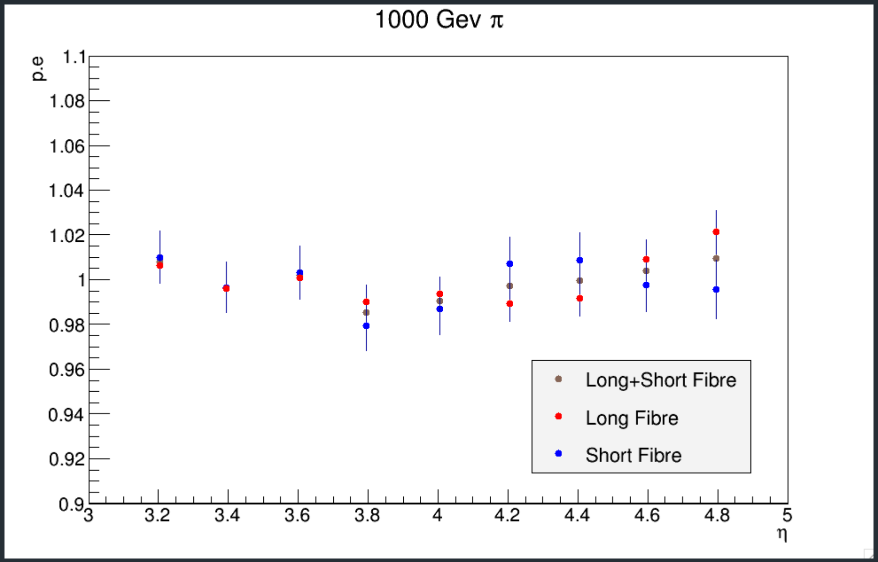
SOFT NEUTRON THRESHOLD RESULTS

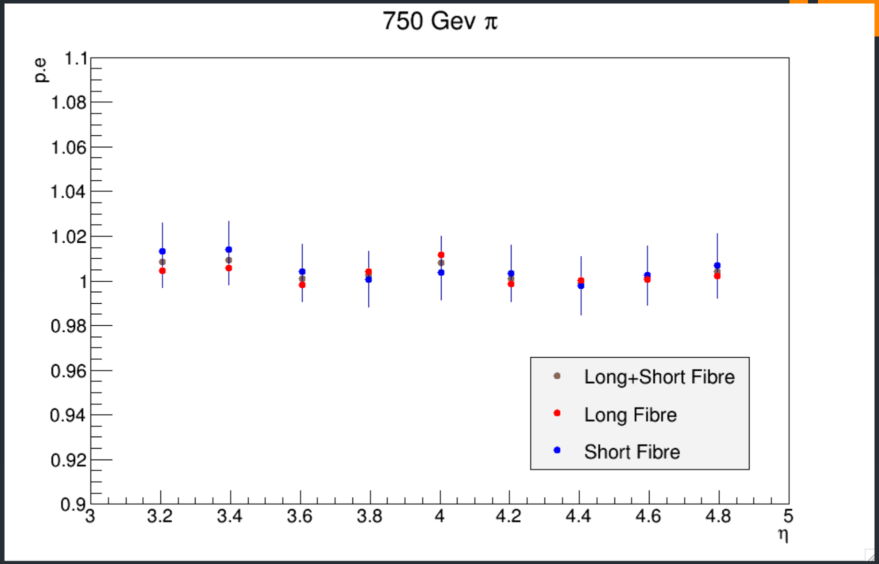
Universidad Nacional Autónoma de México

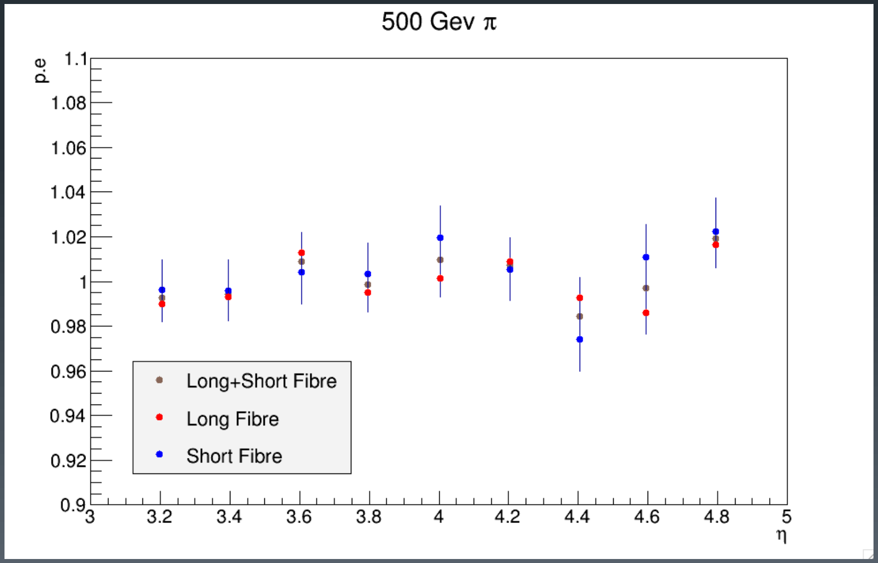
Cut	1.0	1.1	1.2	1.3	1.4	1.5
% Faster	30	45	76	81	84	86
Mean Ratio	1.000	1.003	0.999	0.997	1.002	0.997
Mean Relative Error %	1.15	1.04	1.24	1.36	1.34	1.32
Std. Dev. MRE	0.59	0.49	0.32	0.42	0.80	0.87

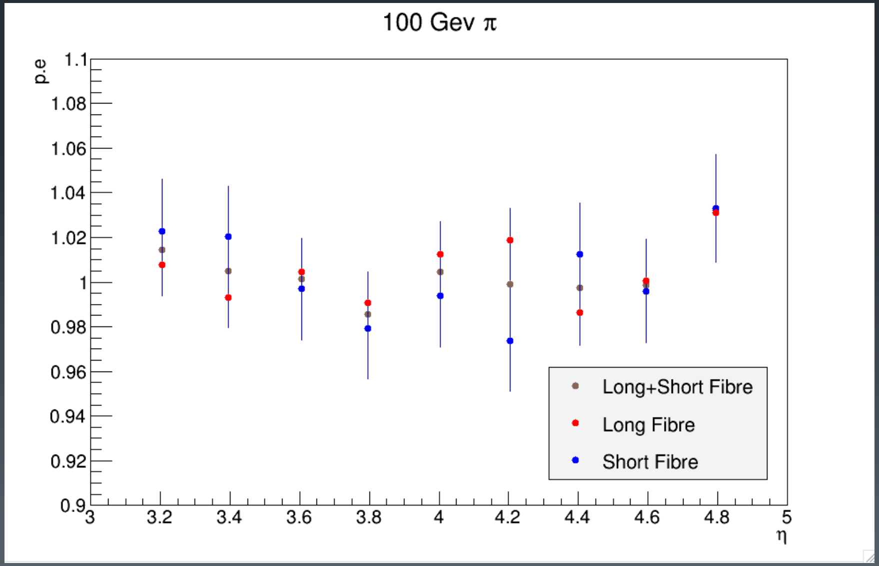
Table 1: Soft Neuton Threshold results

HF Calorimeter



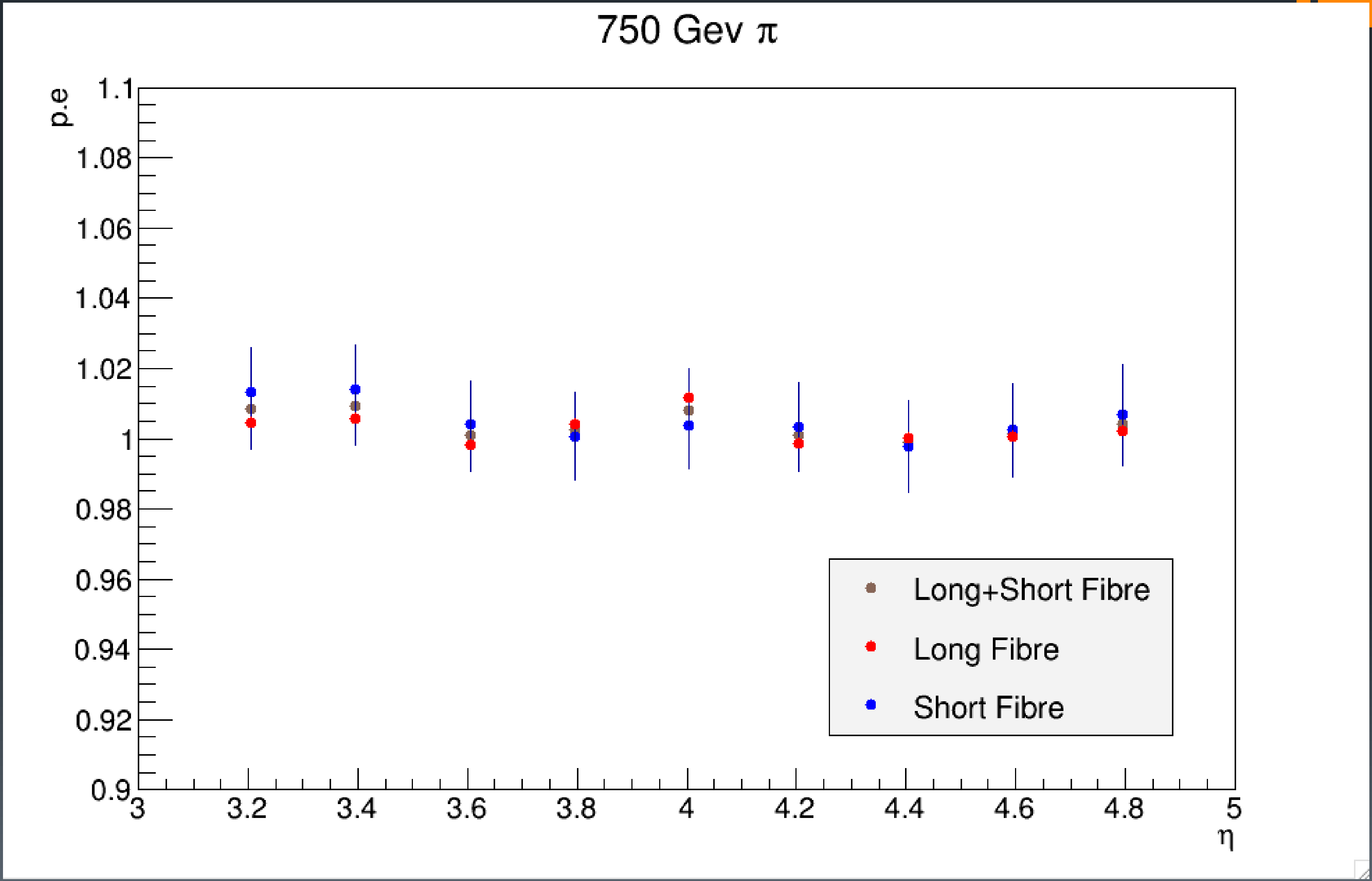






E. Ibarra

HF Calorimeter



E. Ibarra

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- Final step was to tune very precise parameters to reduce the discrepancy between test beam data and our simulation.
  - 10 parameters (variables) to change
  - 3^{10} possible combinations = 59,049*

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- We assigned each parameter a letter. We then altered the variables up or down in various combinations.

A.1.1 Average longitudinal profiles

A

$$T_{hom} = \ln y - 0.858$$

$$\alpha_{hom} = 0.21 + (0.492 + 2.38/Z)\ln y$$

B C D

A.1.2 Fluctuated longitudinal profiles

E

$$\langle \ln T_{hom} \rangle = \ln(\ln y - 0.812)$$

F

$$\sigma(\ln T_{hom}) = (-1.4 + 1.26\ln y)^{-1}$$

H

$$\langle \ln \alpha_{hom} \rangle = \ln(0.81 + (0.458 + 2.26/Z)\ln y)$$

G

$$\sigma(\ln \alpha_{hom}) = (-0.58 + 0.86\ln y)^{-1}$$

$$\rho(\ln T_{hom}, \ln \alpha_{hom}) = 0.705 - 0.023\ln y$$

I J

G. Grindhammer and S. Peters

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- Check our simulation against the Test Beam data for each combination of fibers.

A (0.7157)
B (0.7996)
C (0.4581
D (2.0628)
E (-1.0)
F (1.495)
G (-0.18)
H (1.26)
I (0.505)
J (0.003)

Electron			
10,000 entries	L	S	L+S
30	8.711	1.77	10.481
50	14.34	3.434	17.774
100	28.88	8.445	37.325
150	43.23	14.11	57.34
Pion			
10,000 entries	L	S	L+S
30	5.494	3.889	9.383
50	9.442	7.221	16.663
100	19.92	16.04	35.96
150	30.7	25.66	56.36

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- Use formulas to calculate the uncertainty and error discrepancy from test beam data.

Gaussian Aprox							
Se/Le	Uncertainty	Lp/Le	Uncertainty	Sp/Le	Uncertainty	Sp/Lp	Uncertainty
0.2032	0.0012	0.6307	0.0014	0.4464	0.0013	0.7079	0.0022
0.2395	0.0007	0.6584	0.0008	0.5036	0.0008	0.7648	0.0013
0.2924	0.0004	0.6898	0.0004	0.5554	0.0004	0.8052	0.0006
0.3264	0.0002	0.7102	0.0003	0.5936	0.0003	0.8358	0.0004

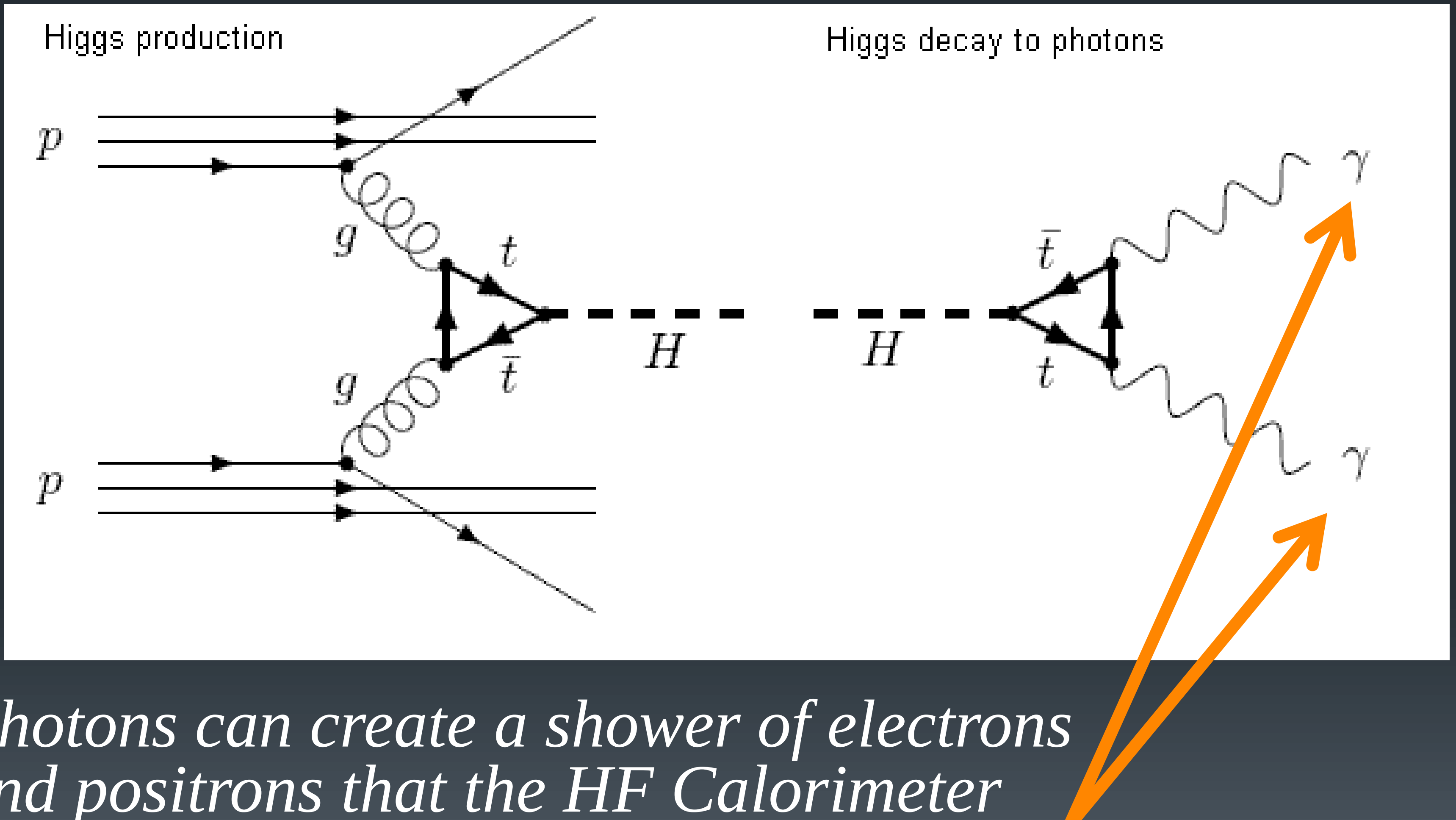
Test Beam Data							
Se/Le	Uncertainty	Lp/Le	Uncertainty	Sp/Le	Uncertainty	Sp/Lp	Uncertainty
0.2034	0.0048	0.6237	0.0052	0.4441	0.0050	0.7120	0.0086
0.2419	0.0029	0.6593	0.0031	0.5040	0.0046	0.7645	0.0072
0.3000	0.0000	0.7020	0.0020	0.5650	0.0030	0.8048	0.0056
0.3380	0.0025	0.7297	0.0026	0.5976	0.0025	0.8189	0.0045

% Discrepancy							
0.10	Yes	1.12	%	0.53	Yes	0.58	Yes
1.00	Yes	0.13	Yes	0.09	Yes	0.04	Yes
2.53	NO	1.74	NO	1.70	NO	0.05	Yes
3.43	NO	2.68	NO	0.67	%	2.07	NO

Results

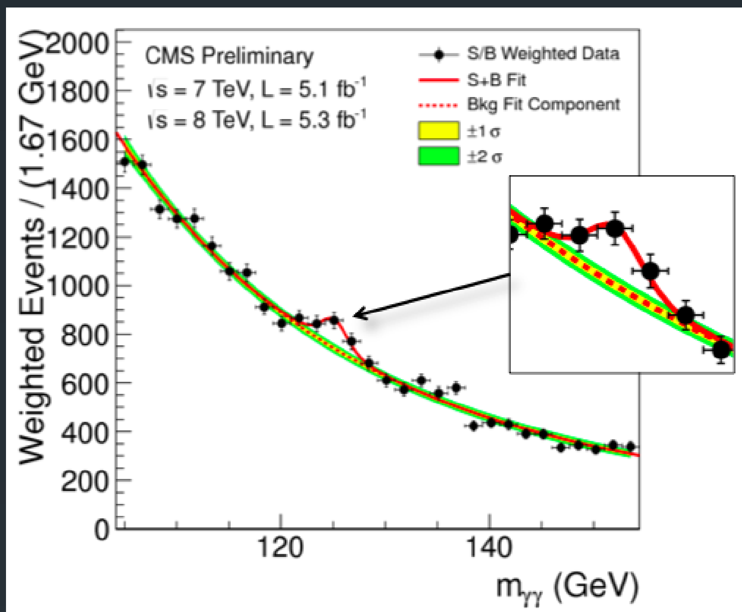
- We were able to tune HF GFlash simulations:
  - Reduced the error by 55%
  - Runs 76% faster
  - Achieved a 1.15% mean discrepancy when compared to Test Beam Data

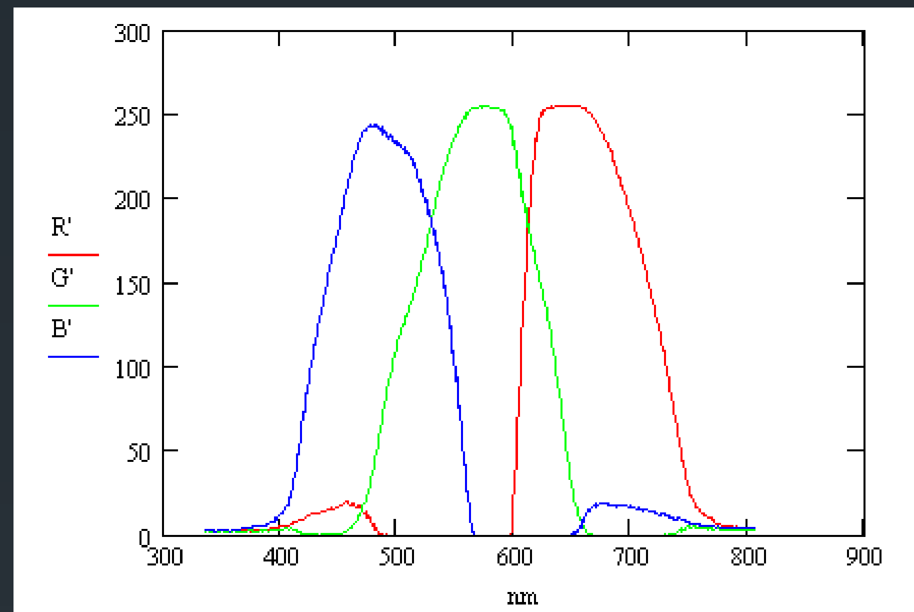
What lies ahead?

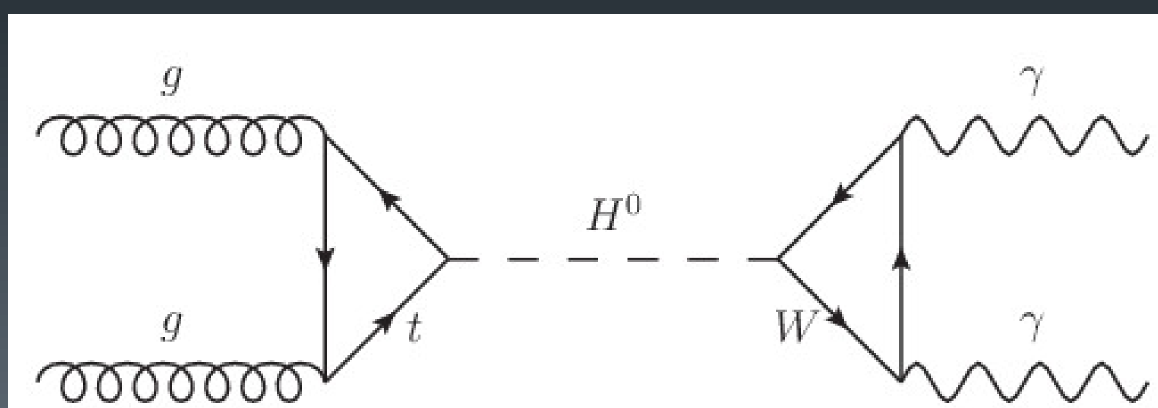


Photons can create a shower of electrons and positrons that the HF Calorimeter can measure. Could be a signature of Higgs production.

Looking for Non-Standard Model Higgs







What lies ahead?

- GFlash could be used in many other large scale data analysis scenarios.
  - *International Linear Collider*
  - *Muon Colliders*
  - *Other applications?*

References

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