

CERN ve Paraık Fiziđi

Kaya Tatar
CERN

Türkiye @ CERN – Halka Açık Toplantı
1 Ekim 2022

CERN

Conseil Européen pour la Recherche Nucléaire : Avrupa Nükleer Araştırma Merkezi

1945-1950 : Avrupa'ya ait üst seviye fizik araştırma merkezi
Bilimde önderlik ve birleşme

Bugün :
15000+ insan, 110+ ulus, 70+ ülke



1954

Kaynak : CERN



Amaç

Doğanın yapıtaşlarını ve işleyişini anlamak

Bu bağlamda

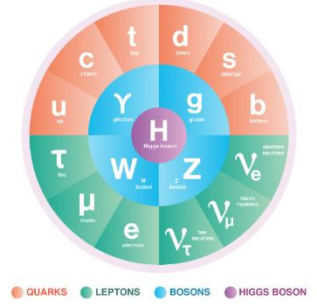
- Parçacıkları ve etkileşimlerini inceleyen kuramlar ve deneyler
- Parçacık hızlandırıcı tesisleri geliştirmek
- Dünya'nın her yerinden insanları bir araya getirmek

Ve ötesinde

- Teknolojik buluşlar ve sanayiye bilgi aktarımı
- Geleceğin bilim insanı ve mühendislerini yetiştirmek
- İnsanları bilim hakkında bilinçlendirmek

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + i\bar{\psi}\not{D}\psi + h.c. + \chi_i Y_{ij} \chi_j \phi + h.c. + |D_\mu \phi|^2 - V(\phi)$$

Kaynak : CERN



Kaynak : US DOE

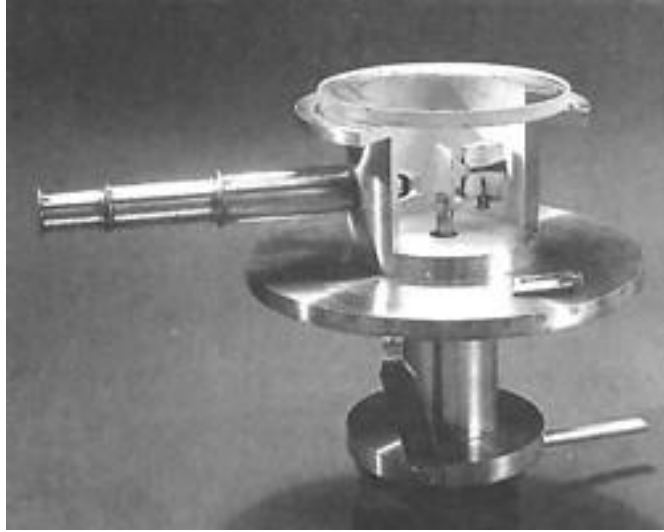


Kaynak : CERN

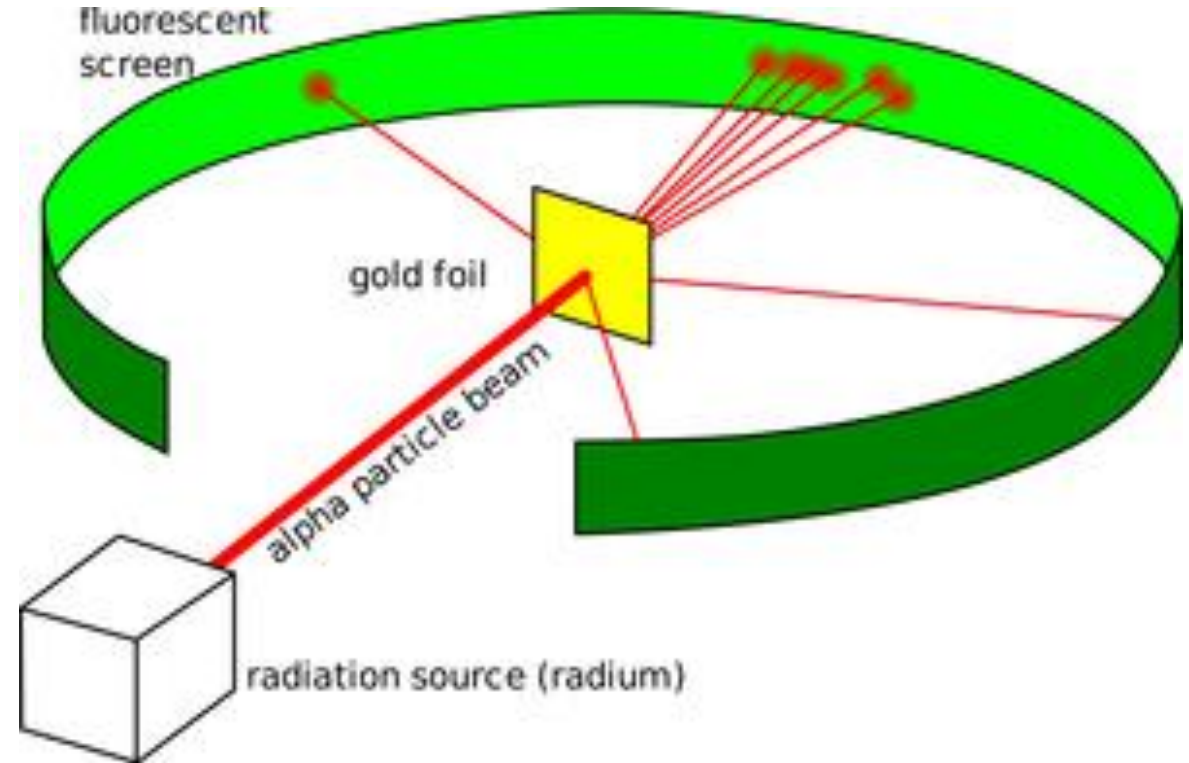
Geçmişte maddenin yapısı

- 19. yy : Atomlar (ör : hidrojen, karbon, oksijen, bakır, demir)
- 1897 : Elektron keşfediliyor. Atom artık temel parçacık değil.
- 19.yy sonu : Elektron ve karışık yüklü parçacık(lar) atomu oluşturuyor.

Atomun yapısı nedir ?

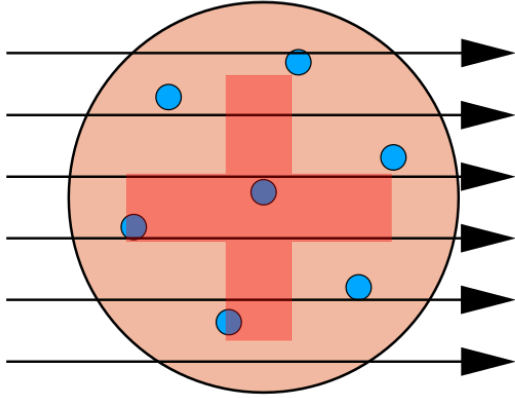


Geiger-Marsden deneyleri, 1908-13

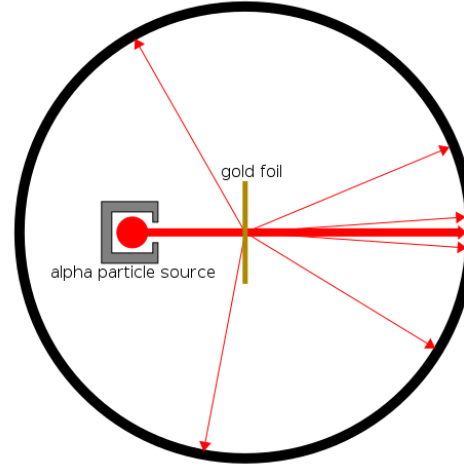
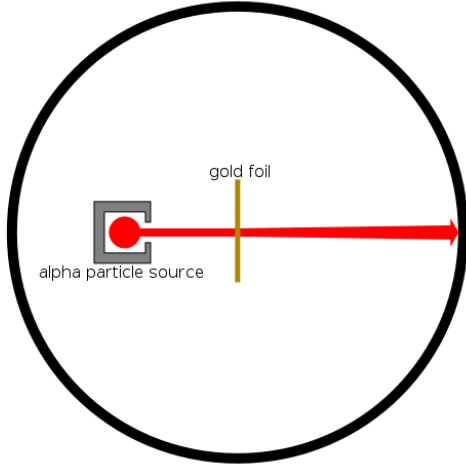
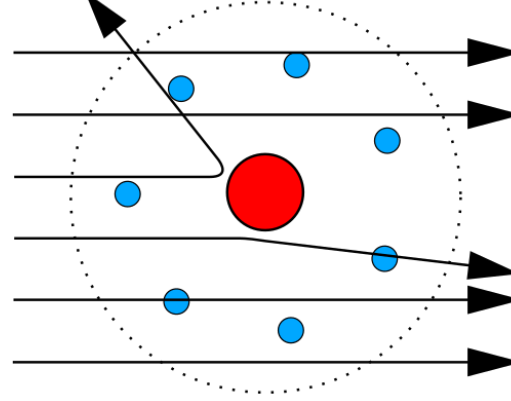


20. yy başı : Atomun yapısı

THOMSON MODEL



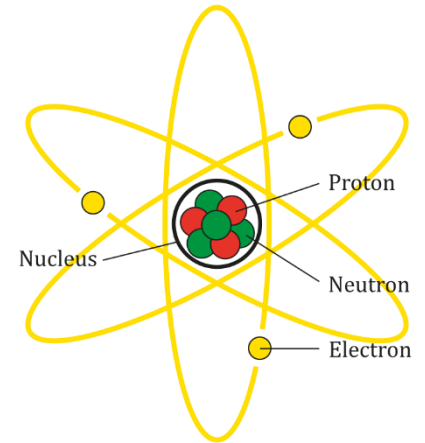
RUTHERFORD MODEL



“Üzümlü kek” modeli
Gözlenmedi

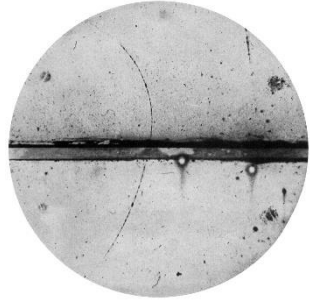


observed result
Atomun çekirdekli yapısı
Gözlenen

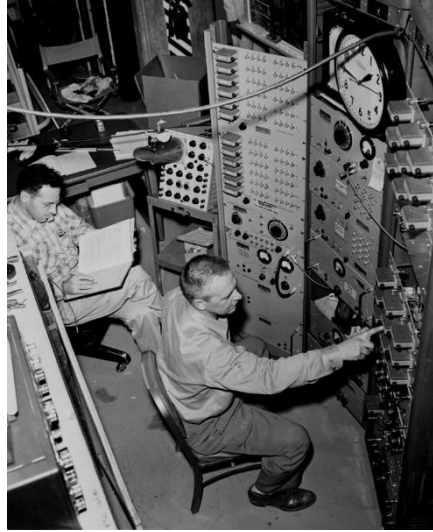


20. yy boyunca

Çok sayıda teknolojik atılım, kuramsal gelişmeler, ve deneysel keşifler



Pozitron keşfi, 1932



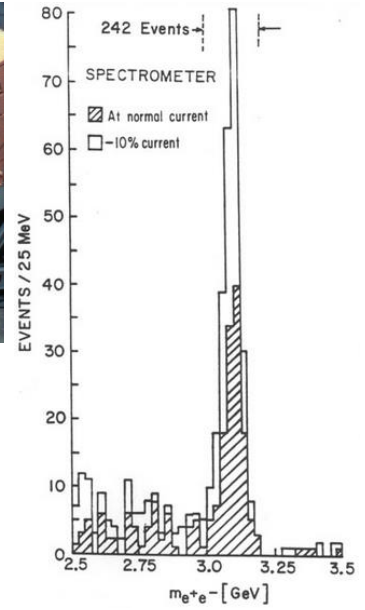
Cowan-Reines nötrino deneyi, 1956



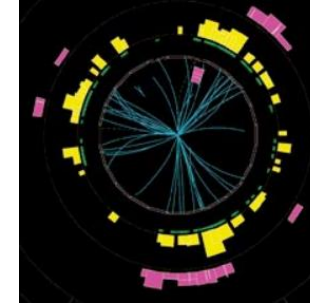
Big European Bubble Chamber, CERN



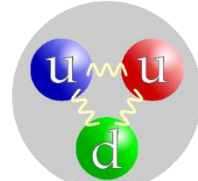
Derin inelastik saçılım deneyleri, SLAC, 1968



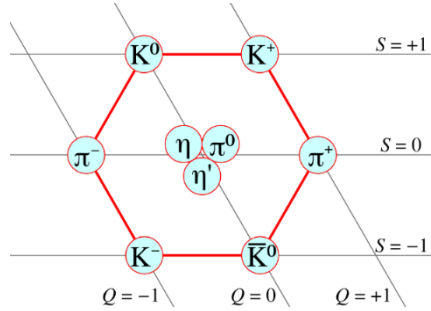
Tılsım (charm) kuark keşfi, 1974



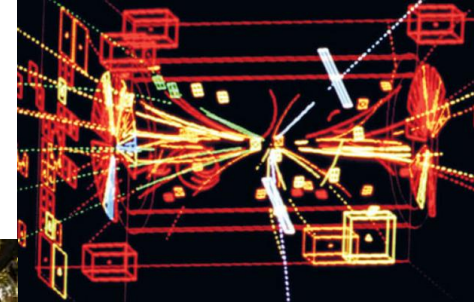
Doğrudan gluon gözlemi



Kuantum renk dinamiği, 1973



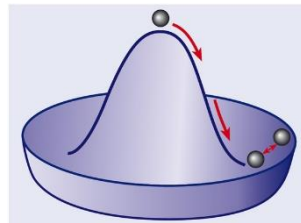
Kuark Modeli, 1964



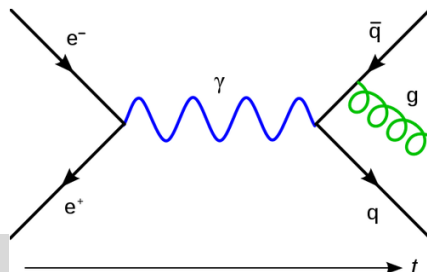
Z boson keşfi, CERN, UA1, 1983



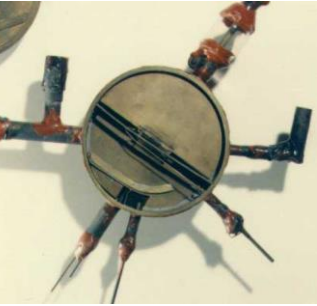
Super-Kamiokande deneyi



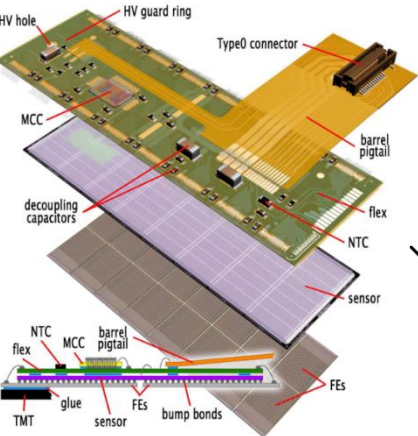
Higgs mekanizması



Kuantum alan teorisi



Küçük siklotron



Silikon detector modülü, CERN, ATLAS

2000'ler : Standart Model

Temel parçacıklar

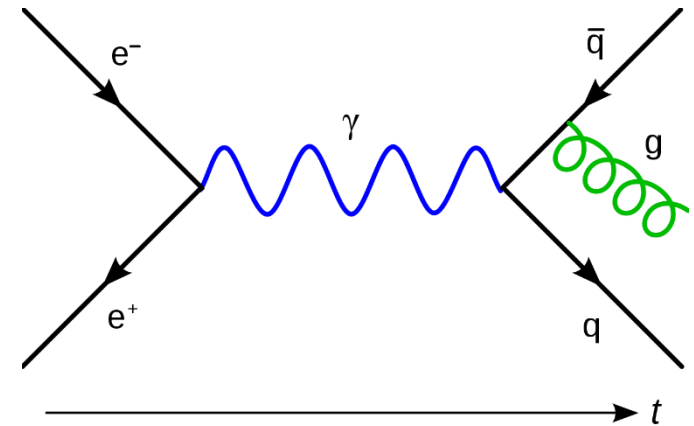
Standard Model of Elementary Particles

three generations of matter (fermions)			interactions / force carriers (bosons)	
I	II	III		
mass $\approx 2.2 \text{ MeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ u up	mass $\approx 1.28 \text{ GeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ c charm	mass $\approx 173.1 \text{ GeV}/c^2$ charge $\frac{2}{3}$ spin $\frac{1}{2}$ t top	0 0 1 g gluon	mass $\approx 124.97 \text{ GeV}/c^2$ 0 0 H higgs
mass $\approx 4.7 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ d down	mass $\approx 96 \text{ MeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ s strange	mass $\approx 4.18 \text{ GeV}/c^2$ charge $-\frac{1}{3}$ spin $\frac{1}{2}$ b bottom	0 0 1 γ photon	
mass $\approx 0.511 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$ e electron	mass $\approx 105.66 \text{ MeV}/c^2$ charge -1 spin $\frac{1}{2}$ μ muon	mass $\approx 1.7768 \text{ GeV}/c^2$ charge -1 spin $\frac{1}{2}$ τ tau	mass $\approx 91.19 \text{ GeV}/c^2$ 0 0 1 Z Z boson	
mass $< 1.0 \text{ eV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_e electron neutrino	mass $< 0.17 \text{ MeV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_μ muon neutrino	mass $< 18.2 \text{ MeV}/c^2$ charge 0 spin $\frac{1}{2}$ ν_τ tau neutrino	mass $\approx 80.39 \text{ GeV}/c^2$ ± 1 1 W W boson	

QUARKS
LEPTONS
GAUGE BOSONS VECTOR BOSONS
SCALAR BOSONS

ve etkileşimleri

$$\begin{aligned}
 \mathcal{L} = & -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} \\
 & + i\bar{\Psi}\not{D}\psi \\
 & + D_\mu\Phi^\dagger D^\mu\Phi - V(\Phi) \\
 & + \bar{\Psi}_L\hat{Y}\Phi\Psi_R + h.c.
 \end{aligned}$$



Higgs bozonu

Diğer parçacıkları ile etkileşimi onlara kütlelerini veriyor
 Modelin teyit edilen **son** parçası (2012)

Deney aletleri : 1. Hızlandırıcı

Hızlandırıcı → “İlginç” olaylar **yüksek** enerjilerde ve **çok nadiren** gerçekleşiyor

Ör : **Large Hadron Collider (LHC)** (*Büyük Hadron Çarpıştırıcısı*)



LHC

1 demet $\sim 10^{11}$ proton
Proton enerjisi ~ 5 TeV
Demet kesişimi ~ 40 MHz

27 km uzunluk
Yerin ~ 100 m altında



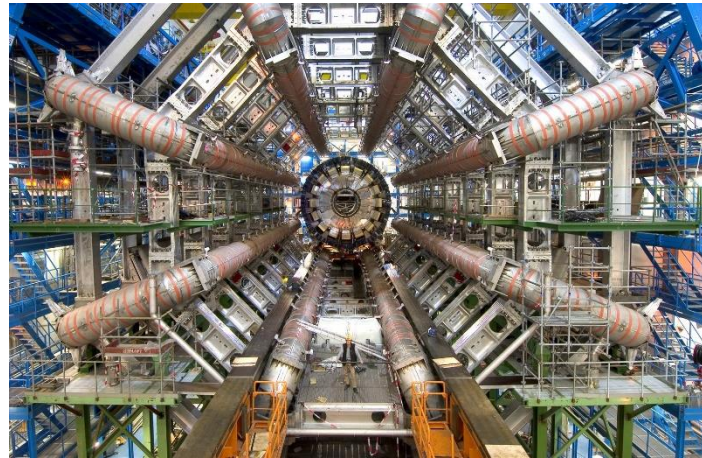
LHC tüneli

Deney aletleri : 2. Algıç

“İlginç” etkileşimlerin **izlerini** tespit eden ve onları incelemekte kullanılan aletler

ATLAS

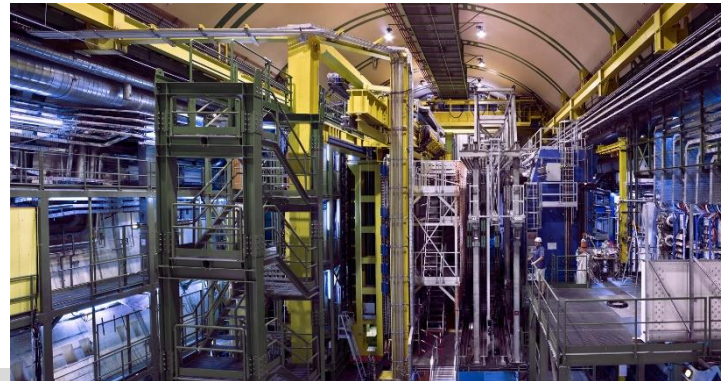
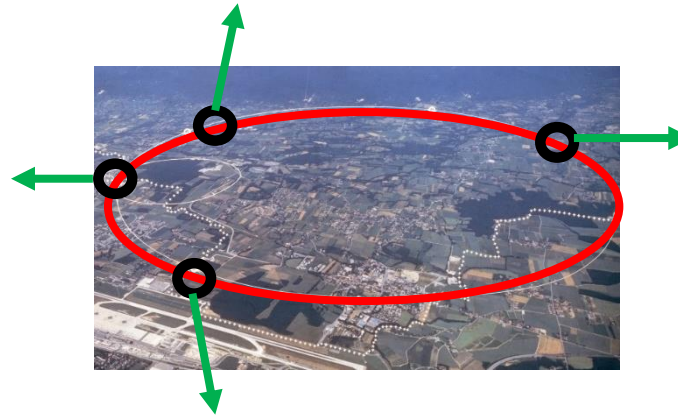
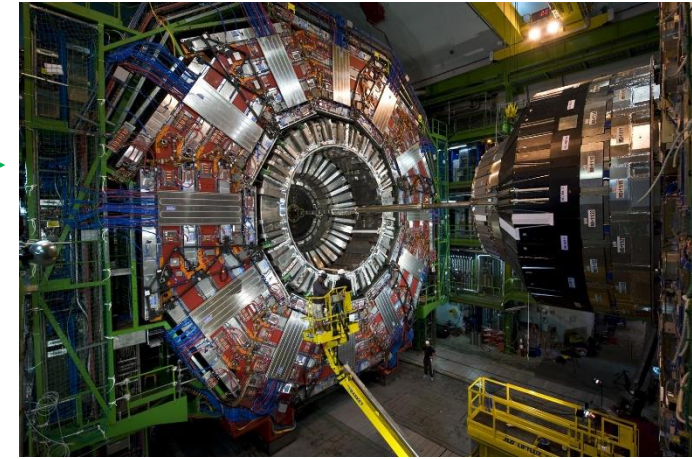
(A Toroidal LHC Apparatus)



ALICE
(A Large Ion Collider
Experiment)

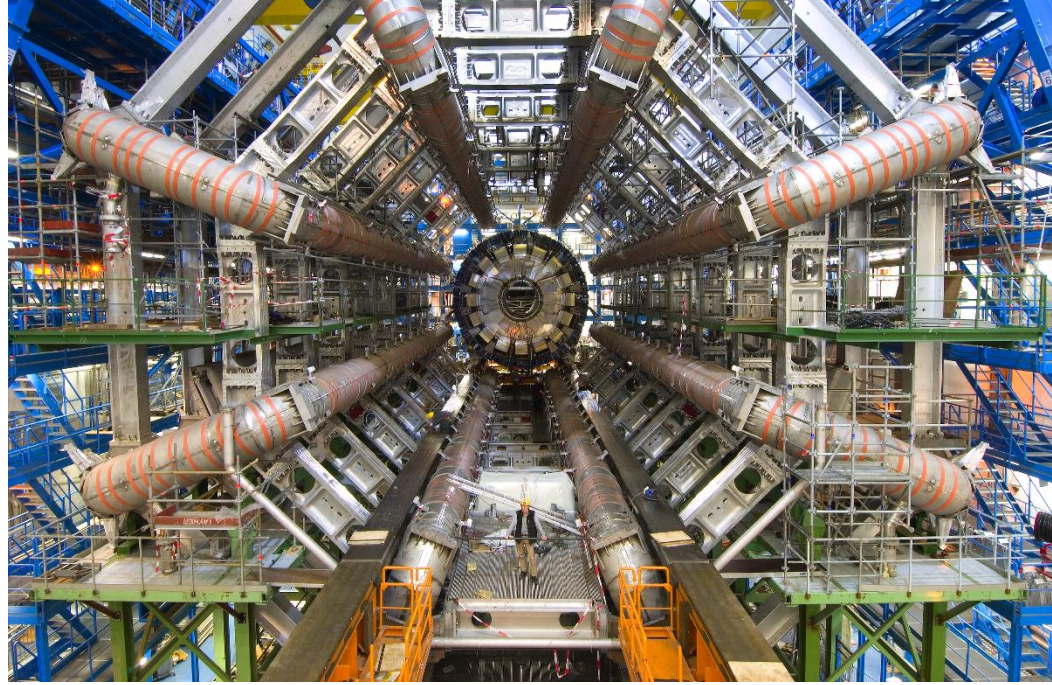
CMS

(Compact Muon Solenoid)



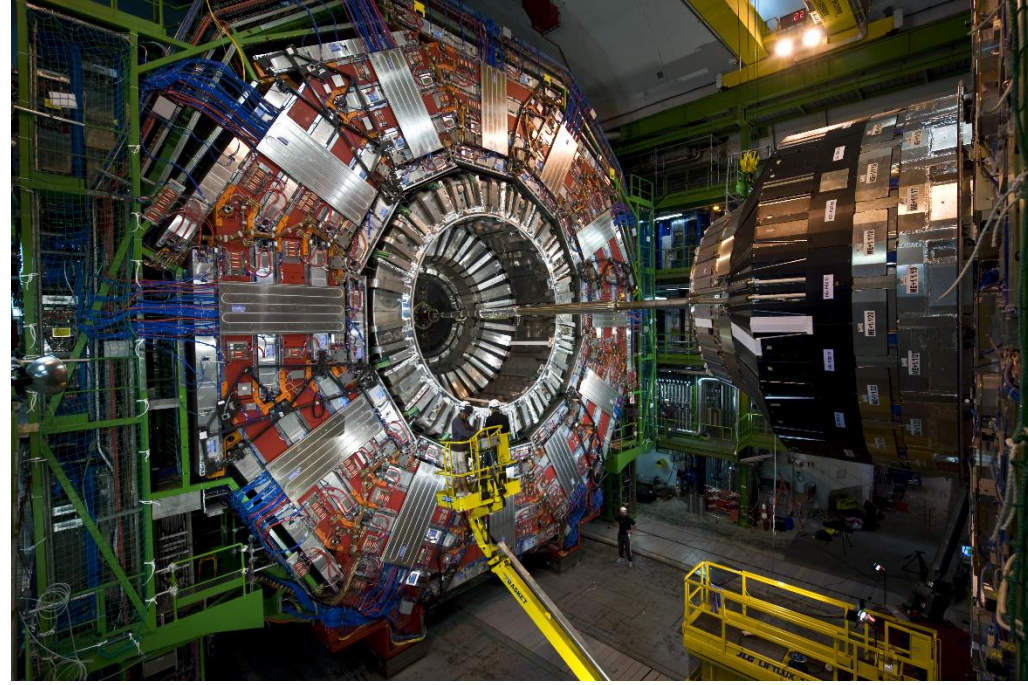
LHCb
(Large Hadron
Collider beauty)

LHC algıçları devasa aletler



ATLAS

46m x 25m x 25m boyut, 7000 ton
5500+ insan (245 kurum)



CMS

21m x 15m x 15m boyut, 14000 ton
5500 insan (241 kurum)

Parçacıkların algıçtaki izleri çok kısa süreli ($\sim 1 \mu\text{s}$ -ms)

Algıçlar çok amaçlı (2800 bilimsel makale [1])

Veriyi **aktaracak** ve **saklayacak** kaynaklar kısıtlı

→ Olaylar (çarpışmalar) **çabucak ayıklanmalı** ve incelenmek üzere **kayıt edilmeli**.

→ Sonuçta : saniyede ~ 100 olayın verisi → Günde ~ 1 Petabyte veri

[1] : CERN Courier, Ocak 2021 itibariyle

Veri analizi I : Parçacık izleri

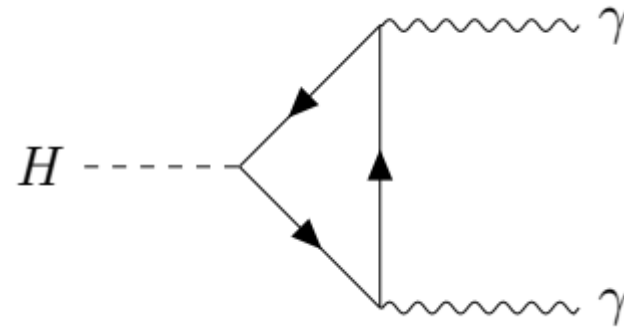
Standard Model of Elementary Particles

three generations of matter (fermions)			interactions / force carriers (bosons)		
	I	II	III		
mass	$\approx 2.2 \text{ MeV}/c^2$	$\approx 1.28 \text{ GeV}/c^2$	$\approx 173.1 \text{ GeV}/c^2$	0	$\approx 124.97 \text{ GeV}/c^2$
charge	$\frac{2}{3}$	$\frac{2}{3}$	$\frac{2}{3}$	0	0
spin	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0
	u up	c charm	t top	g gluon	H higgs
	d down	s strange	b bottom	γ photon	
	e electron	μ muon	τ tau	Z Z boson	
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	

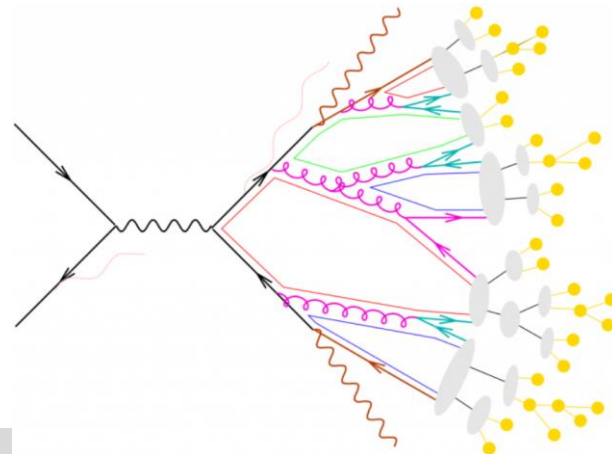
QUARKS (left side of fermion table)
LEPTONS (left side of fermion table)
GAUGE BOSONS (left side of boson table)
VECTOR BOSONS (left side of boson table)
SCALAR BOSONS (right side of boson table)

Temel parçacıkların büyük kısmı “kararsız”dır

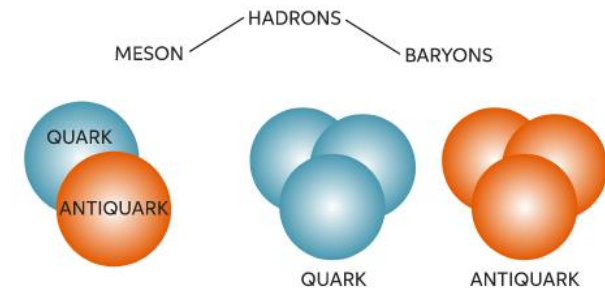
1) Başka parçacıklara dönüşürler.
Algıca Higgs bozonu değil, bozunma ürünleri ulaşır.



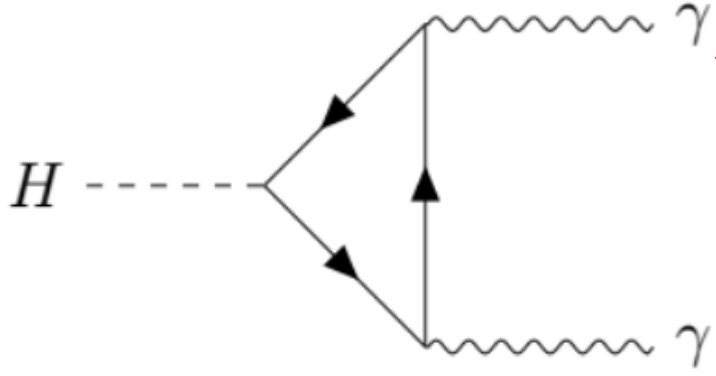
2) Veya başka parçacıklar birleşmek isterler, yeni parçacık üretimi tetiklenir
Kuark renk hapsi, ve hadron enkazı



- hard scattering
- (QED) initial/final state radiation
- partonic decays, e.g. $t \rightarrow bW$
- parton shower evolution
- nonperturbative gluon splitting
- colour singlets
- colourless clusters
- cluster fission
- cluster \rightarrow hadrons
- hadronic decays

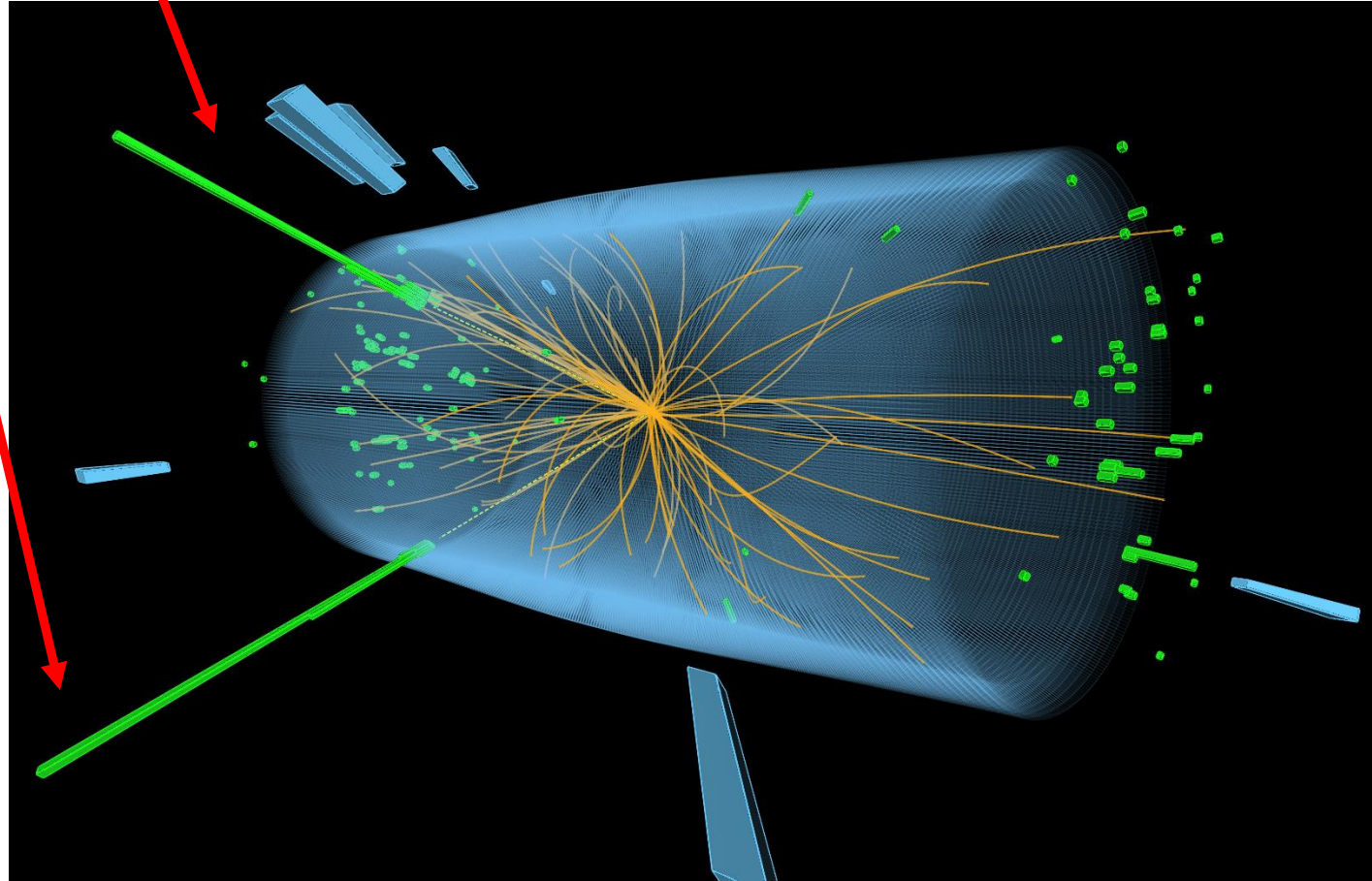


Verideki izler - I

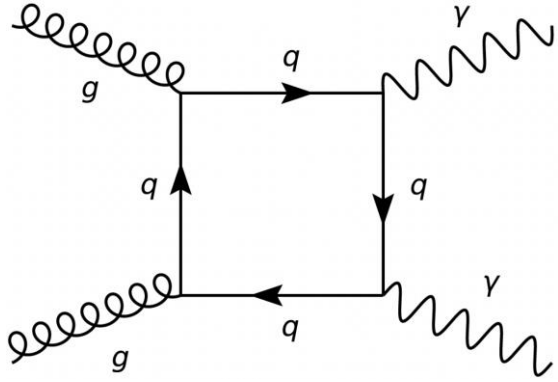


Algıç iki tane yüksek enerjili photon “adayı” buldu.
Bu bir Higgs bozonu olayı mı ?

Sinyal (İlginç olan) ?

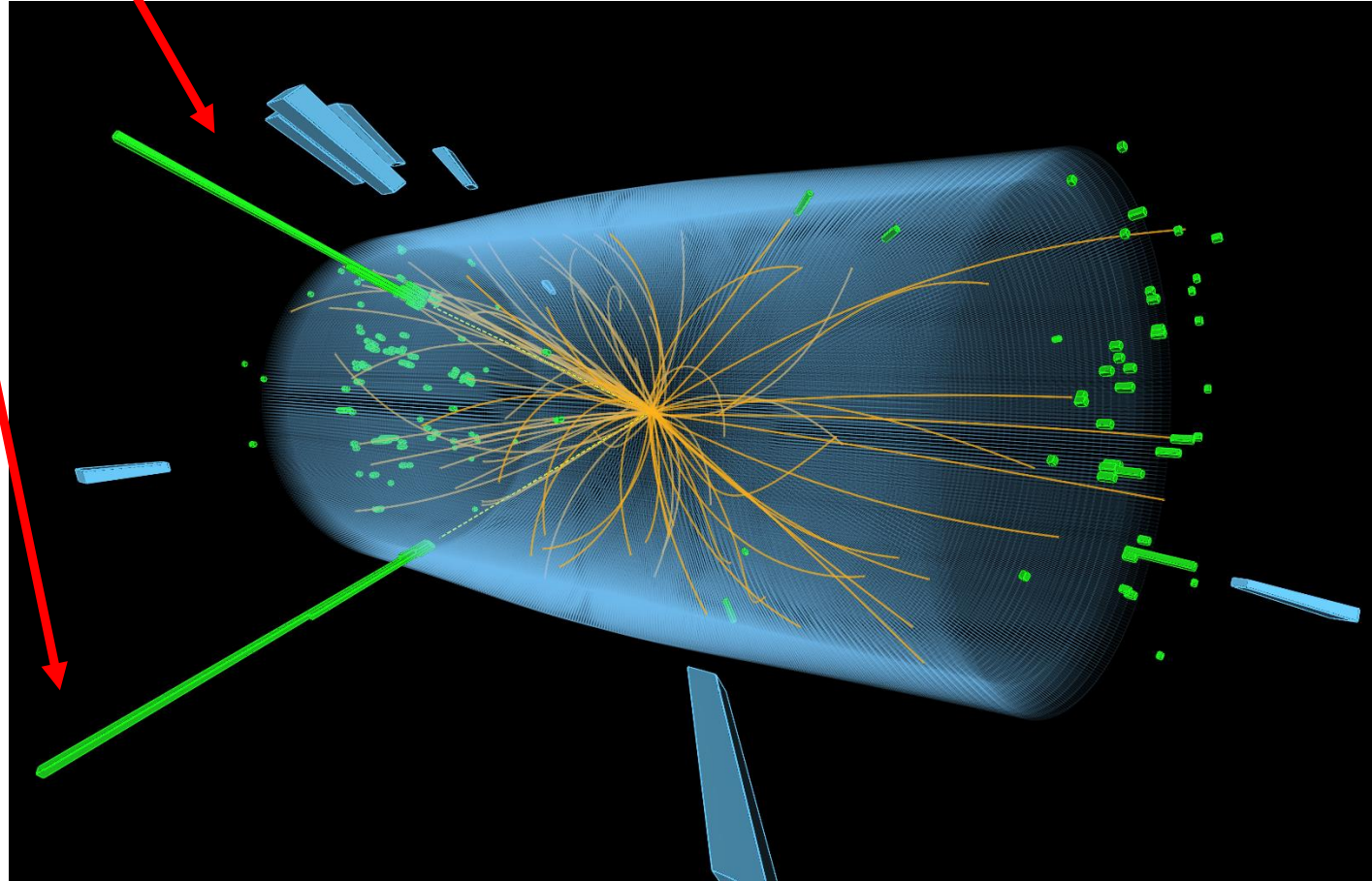


Verideki izler - II



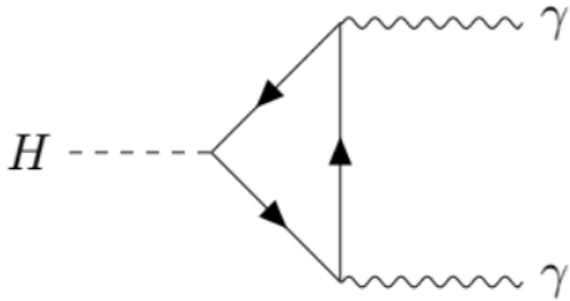
Ama aynı izle sonuçlanan farklı olaylar da olabilir.
Yoksa sıradan bir olay mı ?

Arkapan (Sıradan) ?

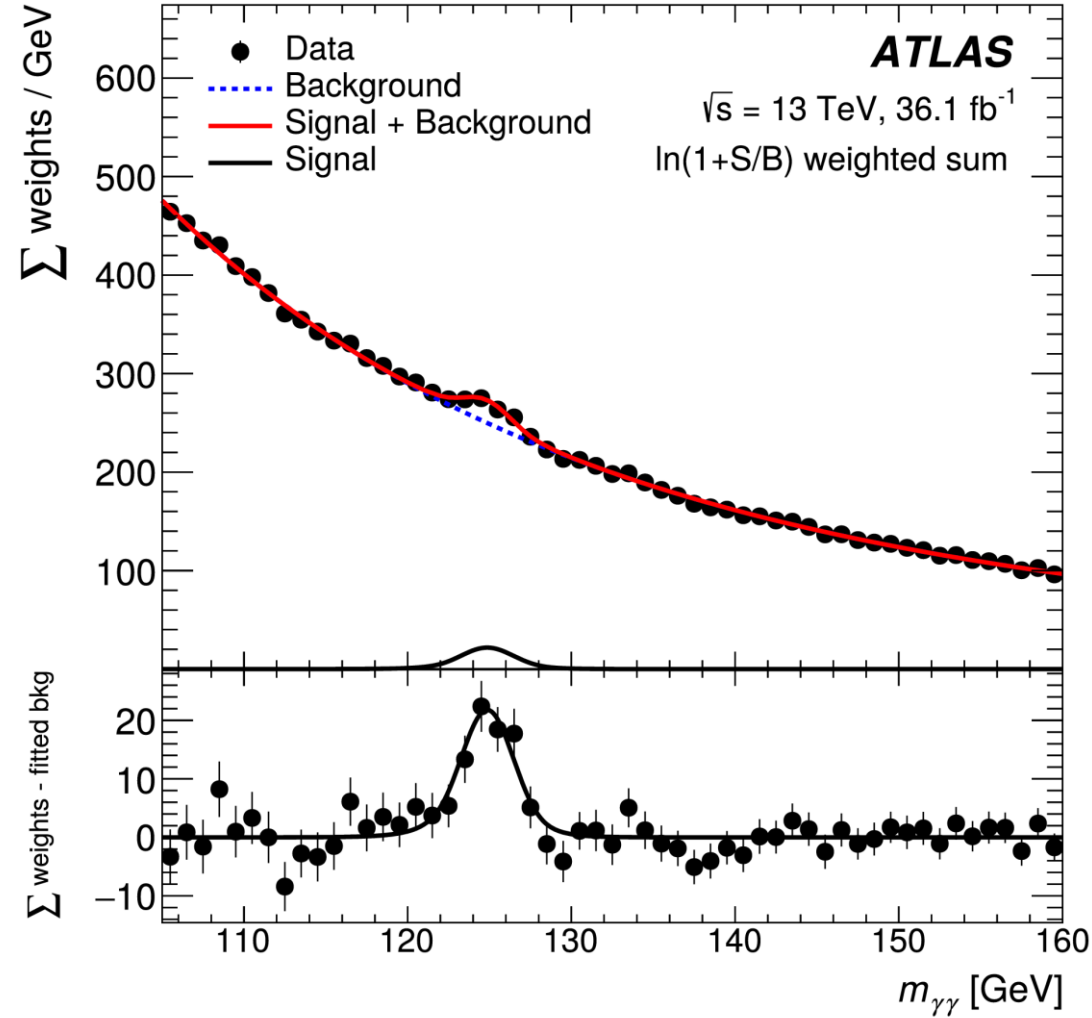
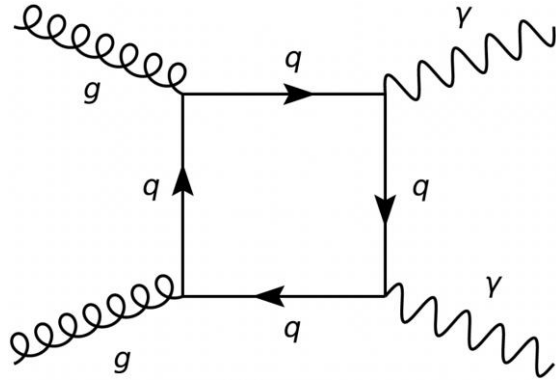


Higgs bozonu gözlemi

Sinyal (İlginç)



Arkaplan (Sıradan)



PLB 784 (2018) 345

Sinyali ortaya çıkarmak için hassas bir ölçüm gerekli.

Samanlıkta iğne aramak, birbirine benzeyen samanları saymak !!

Standart Modelin son parçası



Kaynak : CERN

Temmuz 2012'de
ATLAS vs CMS deneyleri
yeni bir bozon (Higgs) gözlemini duyurdular.



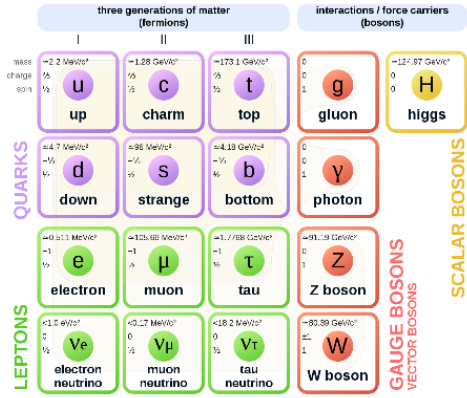
François Englert ve Peter Higgs
CERN, 4 Temmuz 2012



2013 Nobel Fizik Ödülü
François Englert ve Peter Higgs
*"Parçacıkların kütlelerini edinmesini
açıklayan ve deneylerle teyit edilen
kuram için"*

Kapatırken

Standard Model of Elementary Particles



Neden bunları yapıyoruz ?

Merak

Doğayı anlamak

Bir şeyleri çözme ve yanıt bulma isteği

$$\mathcal{L} = -\frac{1}{4}F_{\mu\nu}F^{\mu\nu} + i\bar{\Psi}\not{D}\psi + D_{\mu}\Phi^{\dagger}D^{\mu}\Phi - V(\Phi) + \bar{\Psi}_L\hat{Y}\Phi\Psi_R + h.c.$$

Neden parçacık fiziği ve CERN ?

En temel seviyeye inmek



Yararı nedir ?

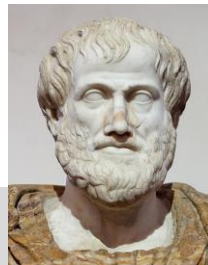
Doğanın parçasıyız, onu anlamak bizim faydamıza

Geleceğin ve günümüzün teknolojisi

Yan/Beklenmedik uygulamalar (iletişim, tıp, tarih, enerji vs)



Zihinsel gelişim

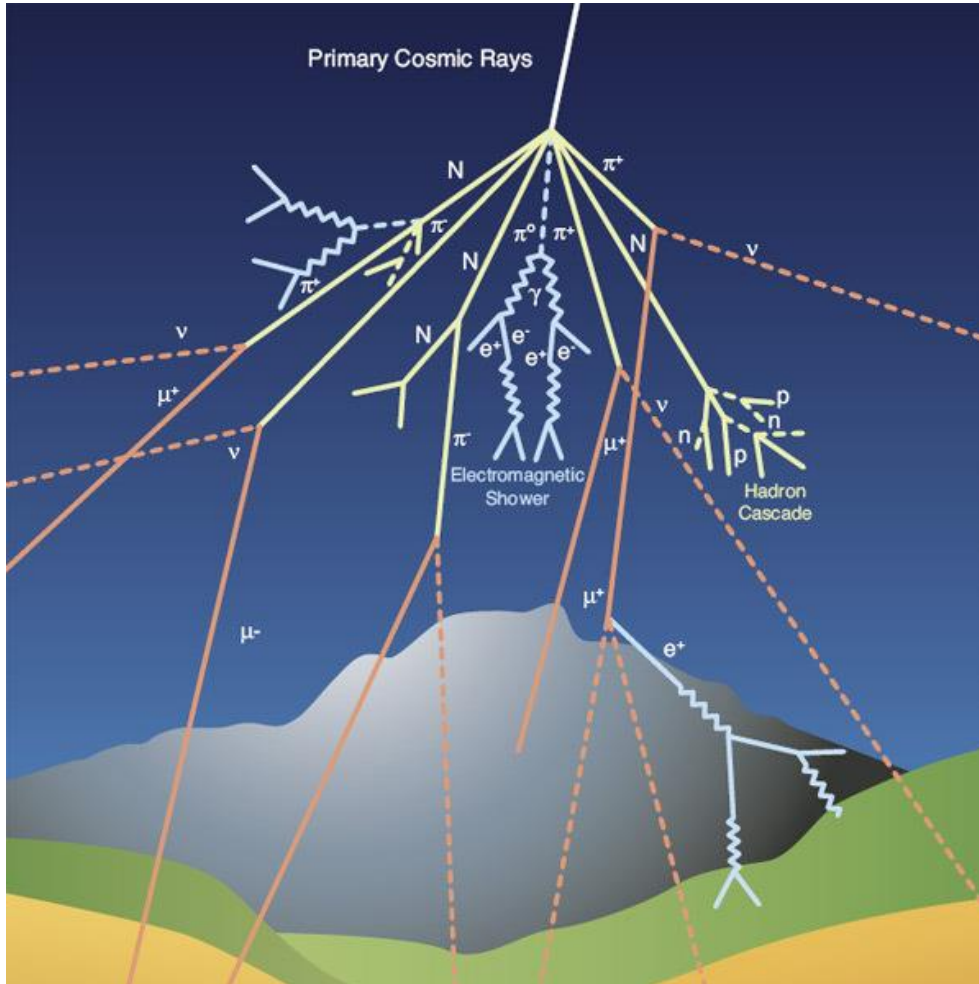


YEDEKLER

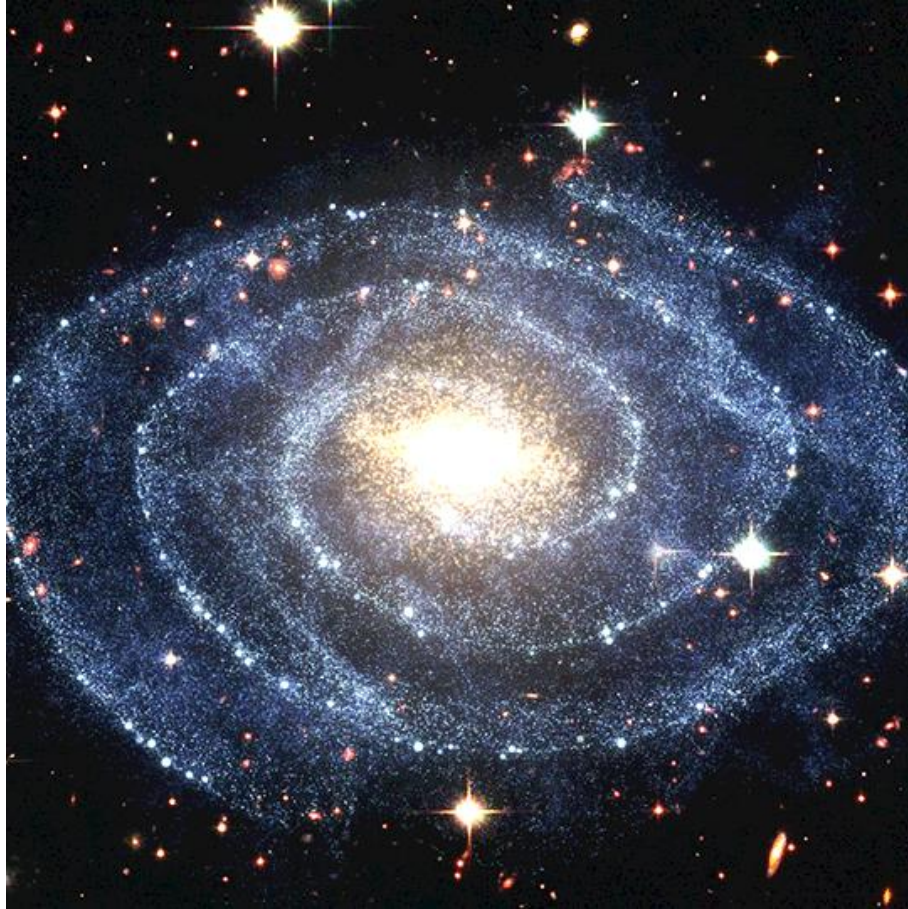
Parçacıklar bozunur

proton $> 10^{34}$ yıl, elektron $> 10^{28}$ yıl,
nötron ~ 15 dk, yüklü pion $\sim 10^{-8}$ s,
Z boson $\sim 10^{-25}$ s

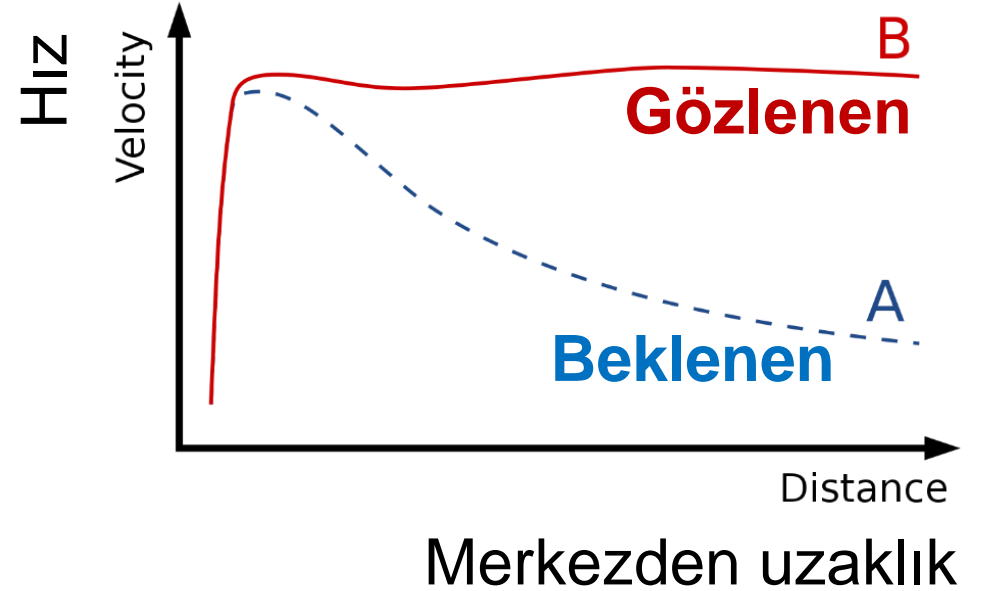
Deteköre ulaşamaz.
Nasıl tespit edeceğiz ?



Kara madde



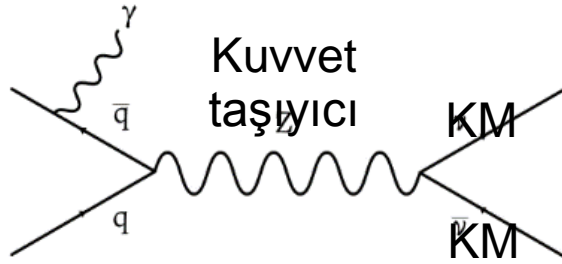
Vera Rubin, Kent Ford, Ken Freeman,
1960-1970



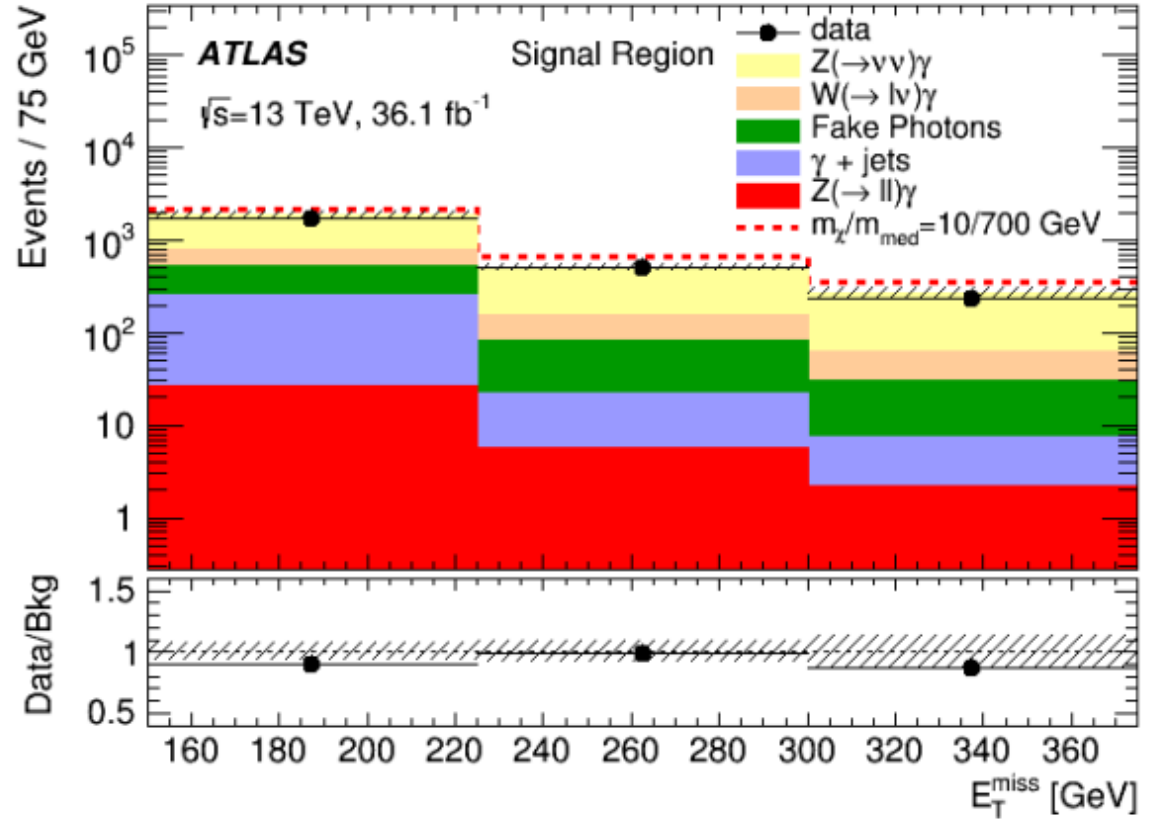
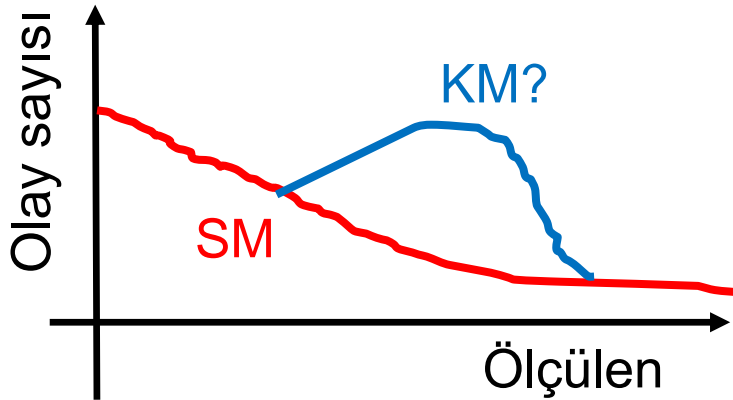
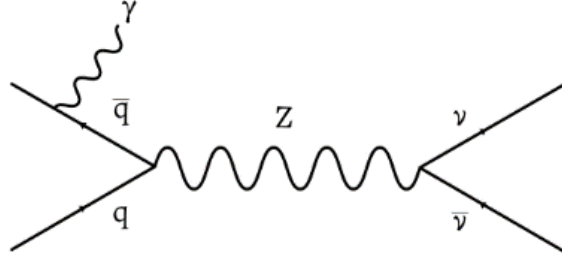
Tespit edilen, ama görülemeyen bir kütle
Karanlık madde

BHÇ'de Karanlık Madde Arayışı

Varsayımsal Karanlık Madde (KM) etkileşimleri



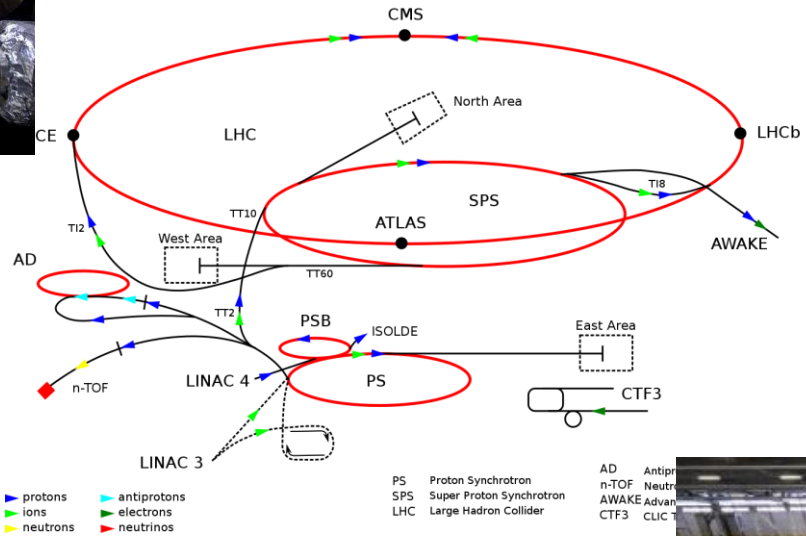
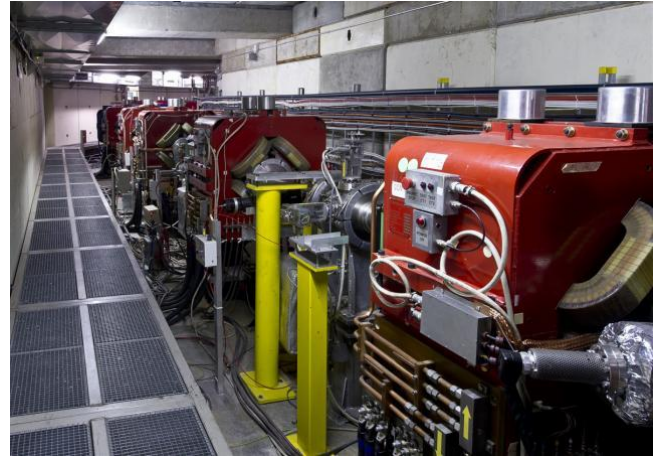
Benzer son ürünlü Standard Model (SM)



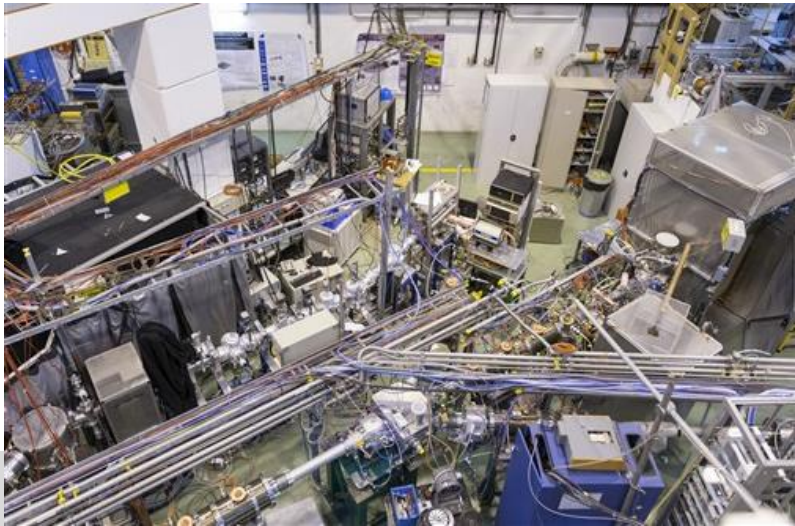
Sonuçlar SM beklentisi ile uyumlu
Bu veri hassasiyeti "SM dışında bir şey buldum" diyemiyor

LHC dışındaki deneyler

Antiproton Decelerator
Antimadde özellikleri
Kütleçekimi



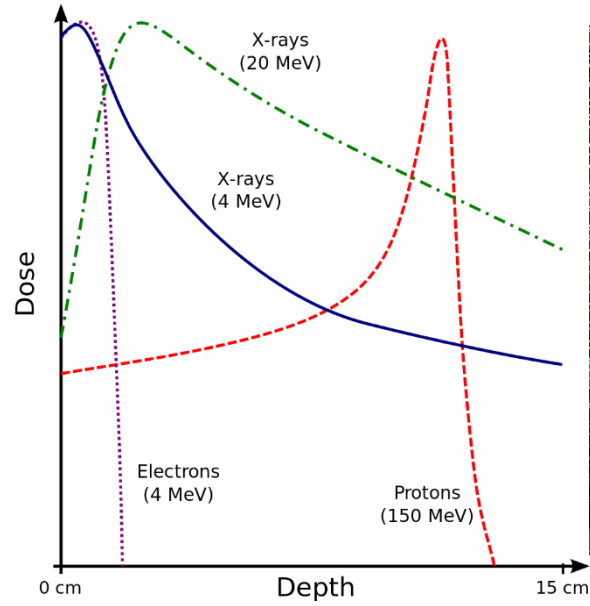
CLOUD
Bulut oluşumu



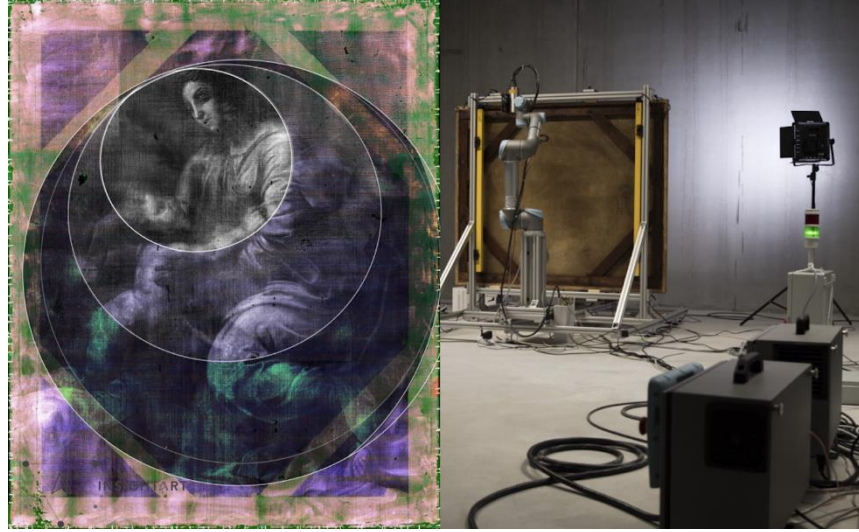
ISOLDE
Nükleer
spektroskopi

Teknoloji

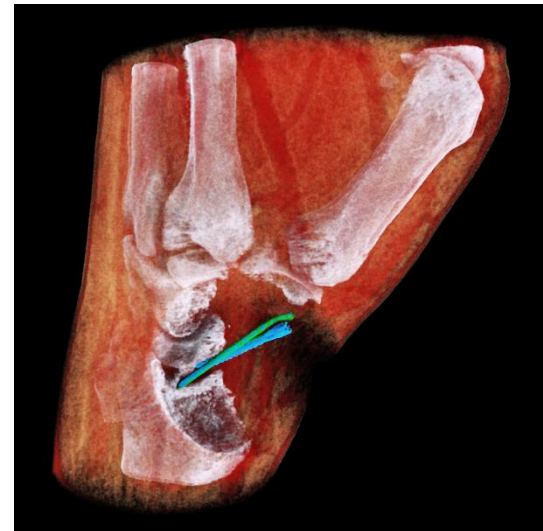
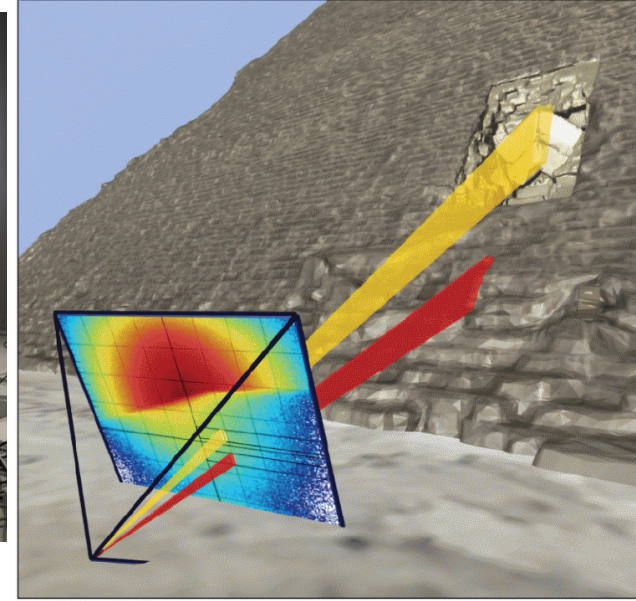
Hadron terapi



Altta yatanı ortaya çıkarma



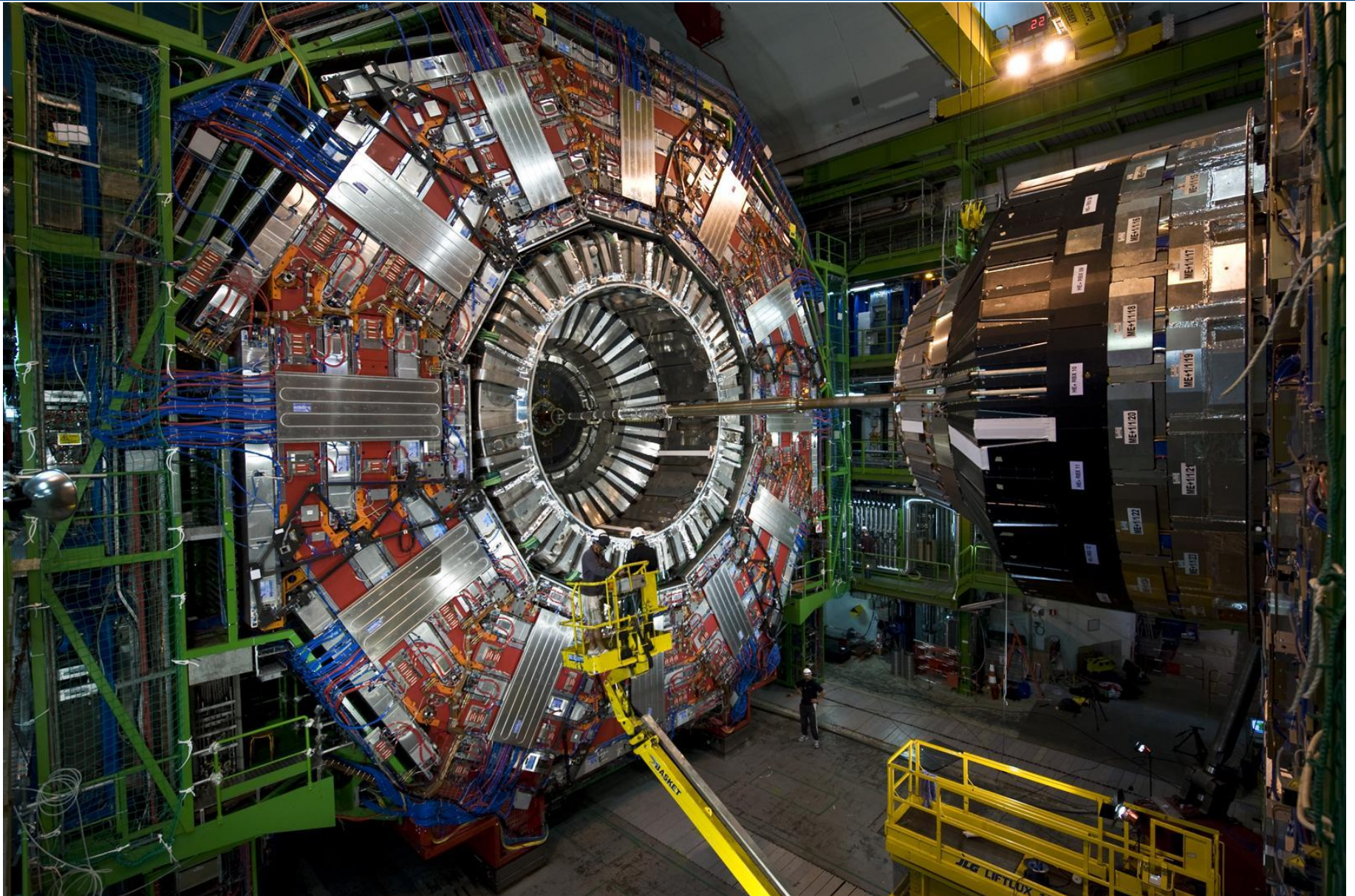
Arkeoloji ve muon detektörler



Medipix



Compact Muon Solenoid



Compact Muon Solenoid - II

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 ($100 \times 150 \mu\text{m}^2$) $\sim 1.9 \text{ m}^2$ $\sim 124\text{M}$ channels
Microstrips ($80\text{--}180 \mu\text{m}$) $\sim 200 \text{ m}^2$ $\sim 9.6\text{M}$ channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying $\sim 18,000 \text{ A}$

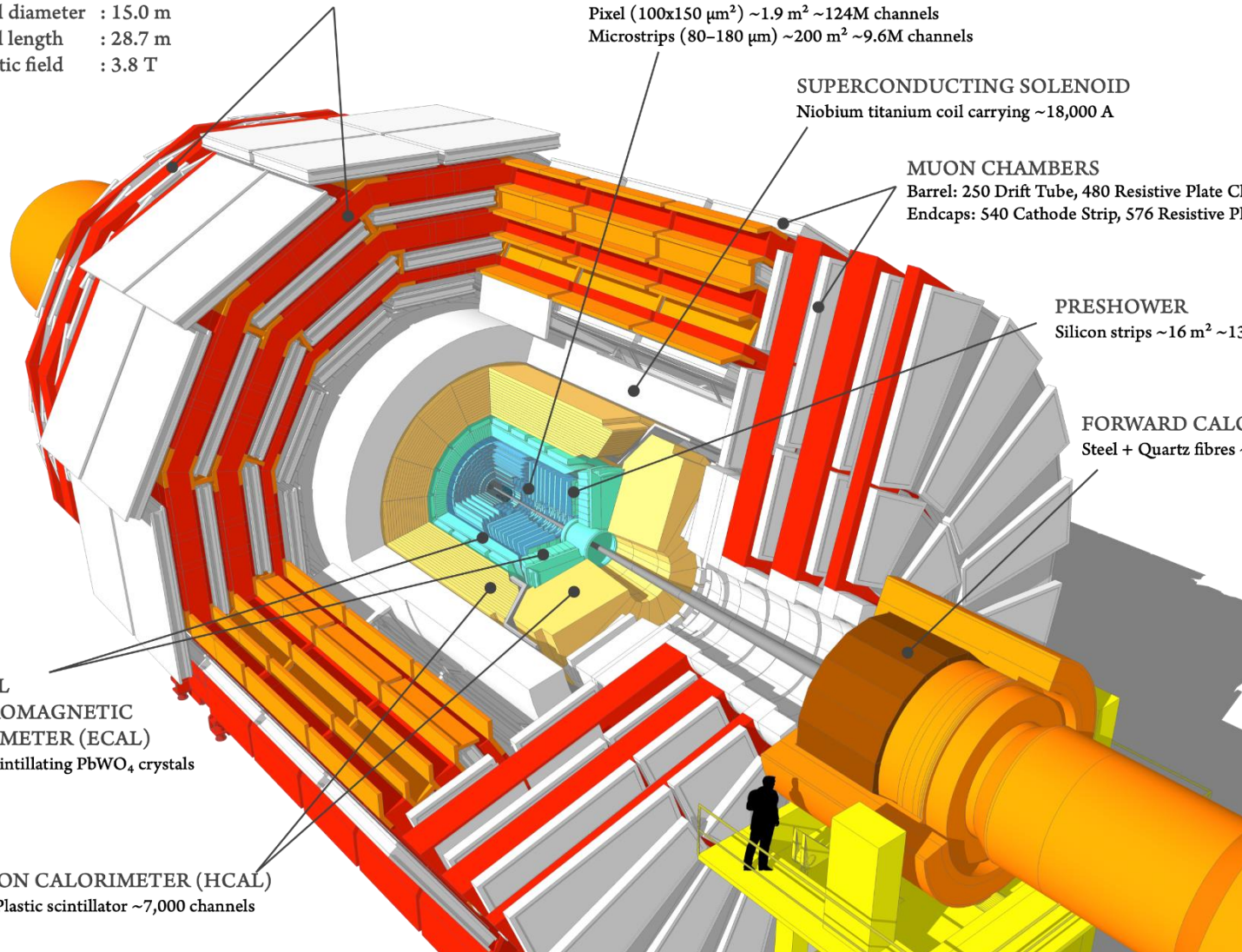
MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 540 Cathode Strip, 576 Resistive Plate Chambers

PRESHOWER
Silicon strips $\sim 16 \text{ m}^2$ $\sim 137,000$ channels

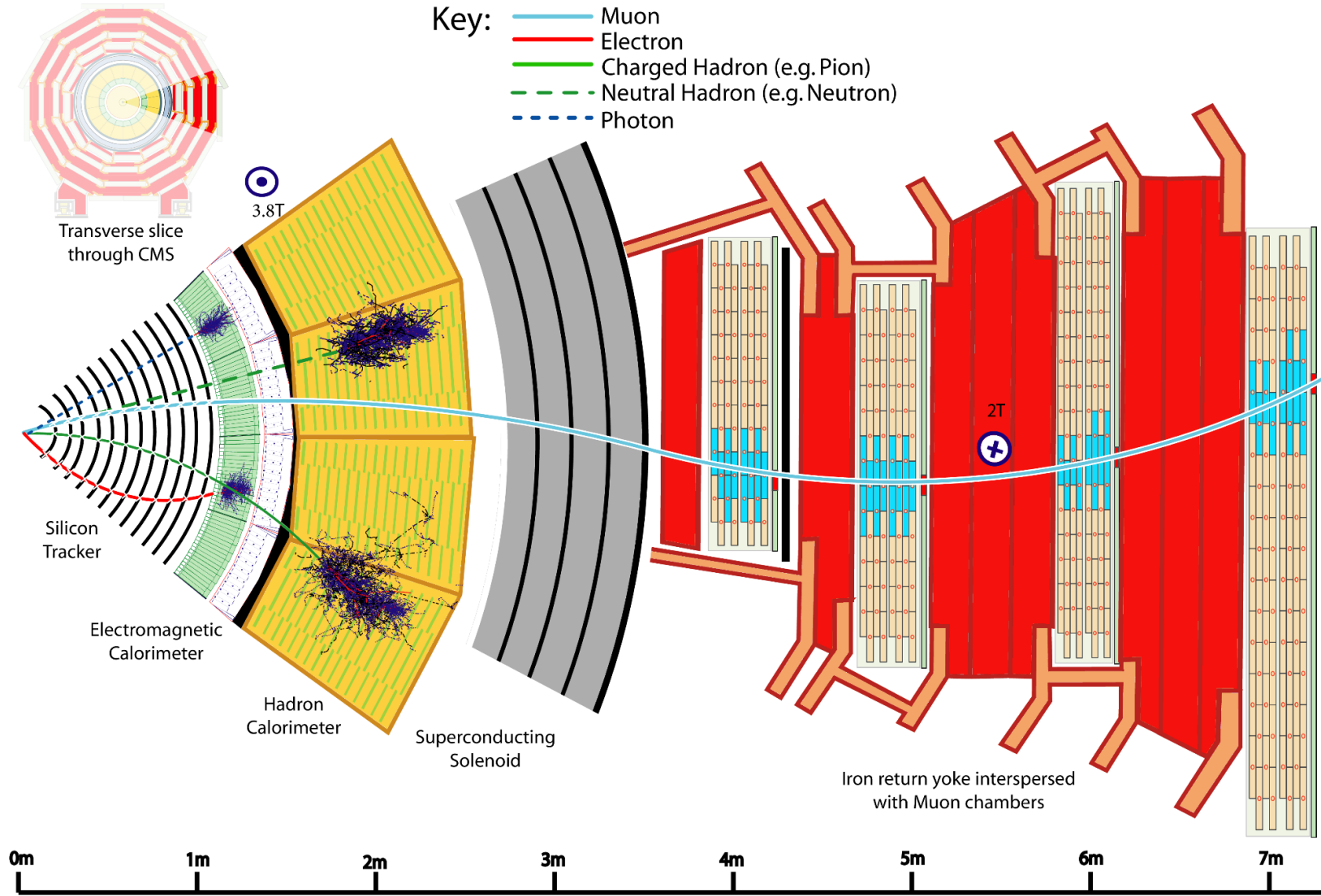
FORWARD CALORIMETER
Steel + Quartz fibres $\sim 2,000$ Channels

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

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator $\sim 7,000$ channels



Compact Muon Solenoid - III



Farklı parçacıklar detektörde farklı iz bırakırlar.

(Neutrino ve erken bozunanlar hariç)