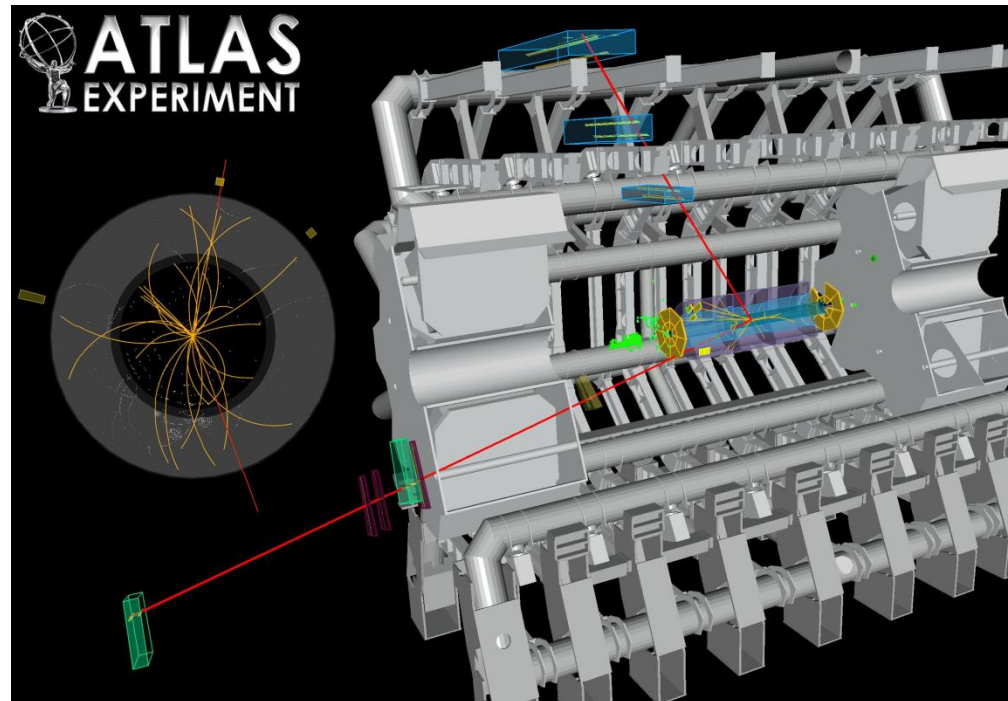
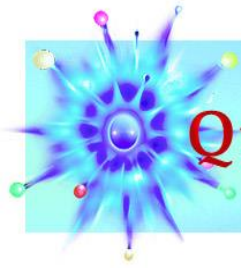


# ATLAS Z-Path Masterclass 2018





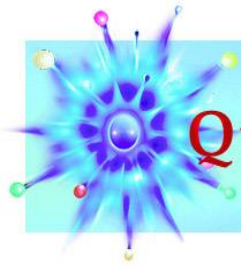
QuarkNet

## The LHC and New Physics

*It's a time of exciting new discoveries in particle physics!*

*At CERN, the LHC successfully completed Run I at 8 TeV of collision energy, confirming that the measurements correspond well to the **Standard Model** and then finding the Higgs boson. The LHC is now into Run II at an amazing 13 TeV and the task is to look for new phenomena...and we are off to a great start.*



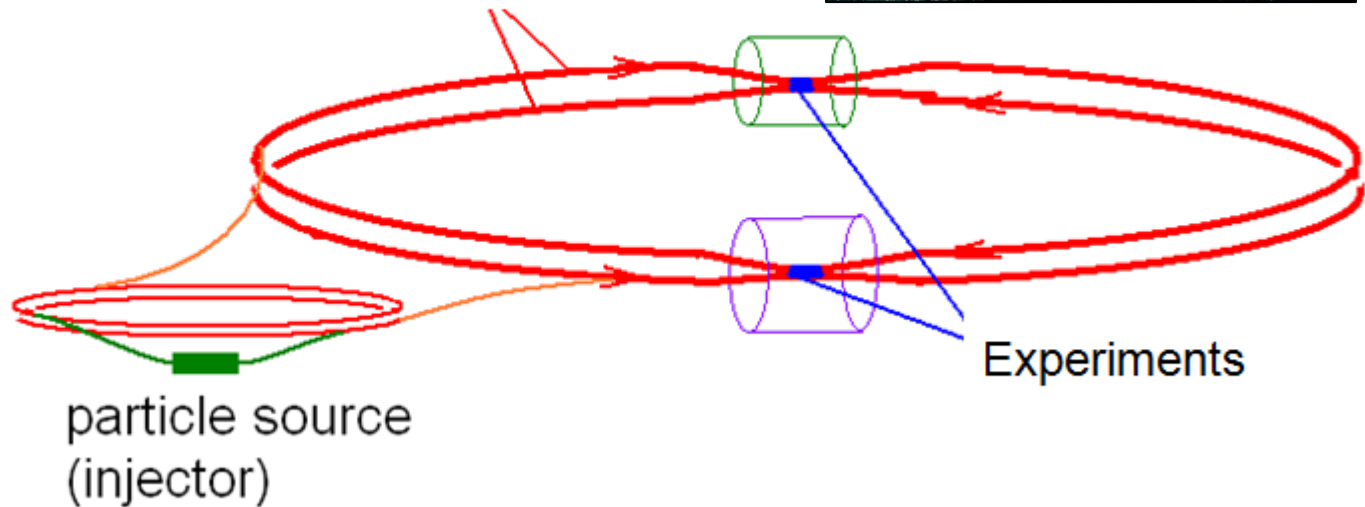


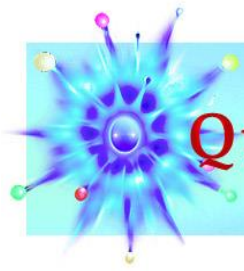
**QuarkNet**

# The LHC and New Physics

The LHC is buried ~100 m below the surface near the Swiss-French border.

beams accelerated in large rings  
(27 km circumference at CERN)

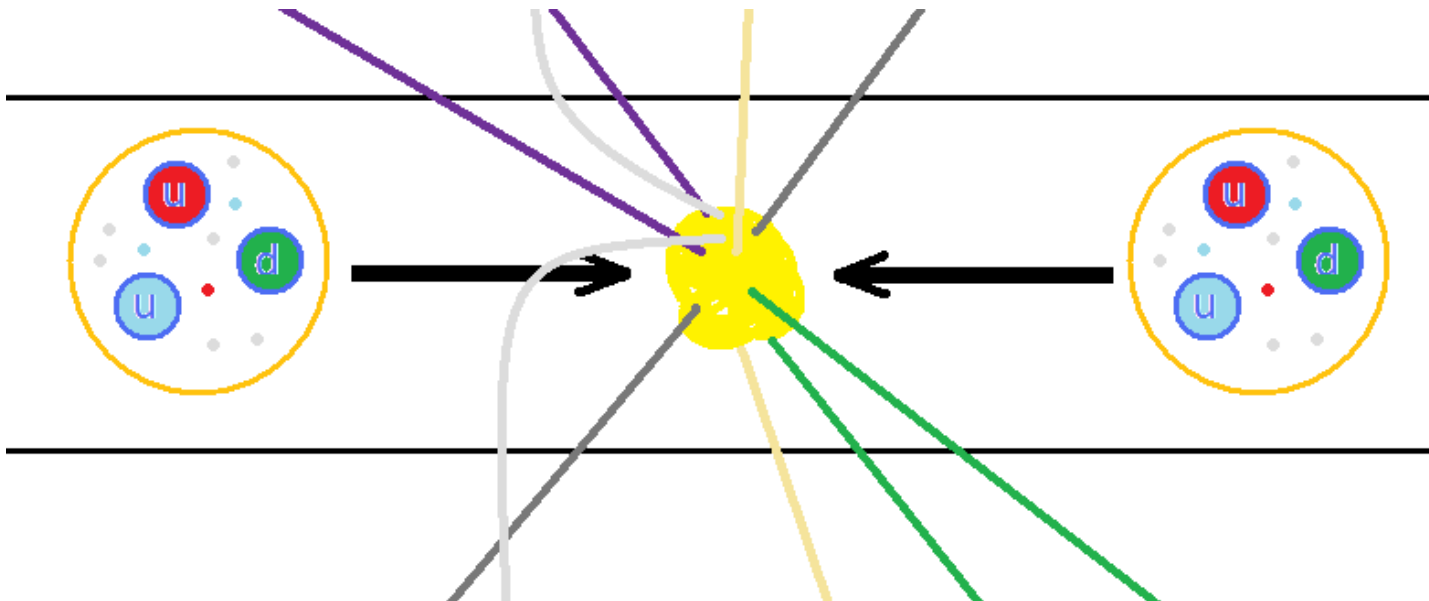


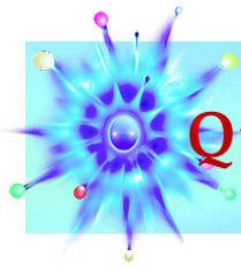


We will look at Run I, in which proton energy is 4 TeV\*.

- The total collision energy is  $2 \times 4 \text{ TeV} = 8 \text{ TeV}$ .
- But each particle inside a proton shares only a portion.
- So a newly created particle's mass ***must be*** smaller than the total energy.

*\*In Run II, this was increased to 6.5 GeV!*



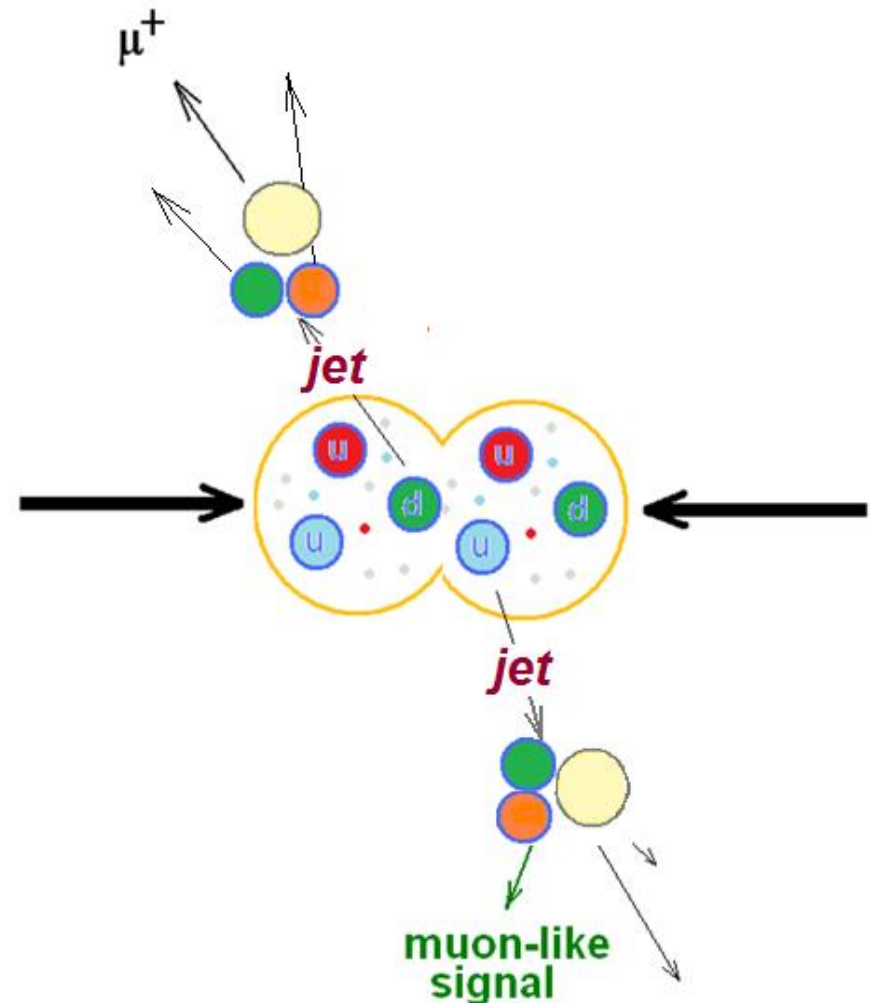
**QuarkNet**

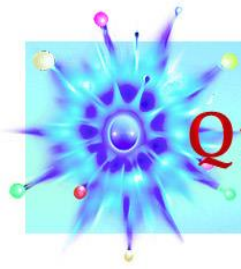
# Particle Decays

Often, quarks are scattered in collisions.

As they separate, the binding energy between them converts to sprays of new particles called jets. Also, lower energy electrons and muons can emerge.

They are not what we are looking for.



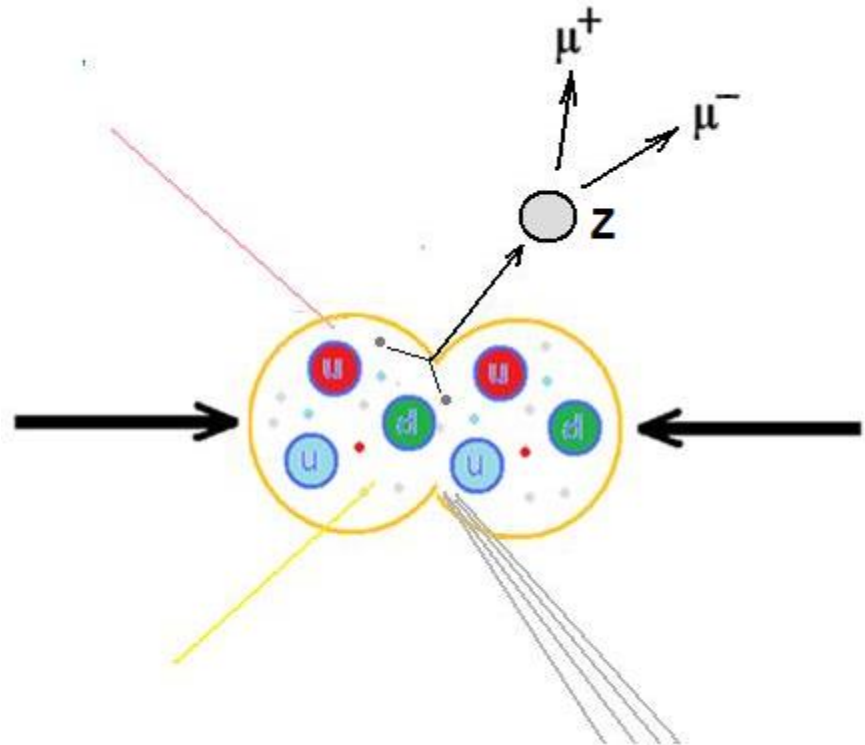


QuarkNet

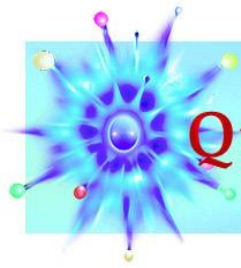
## Particle Decays

We are looking for the Z boson, a particle with no charge that decays into two muons or two electrons.\*

What do we know about the charges of the muons or electrons? What is the charge of the Z?



*\*The Z has other decays . . . but these are not what we are looking for.*

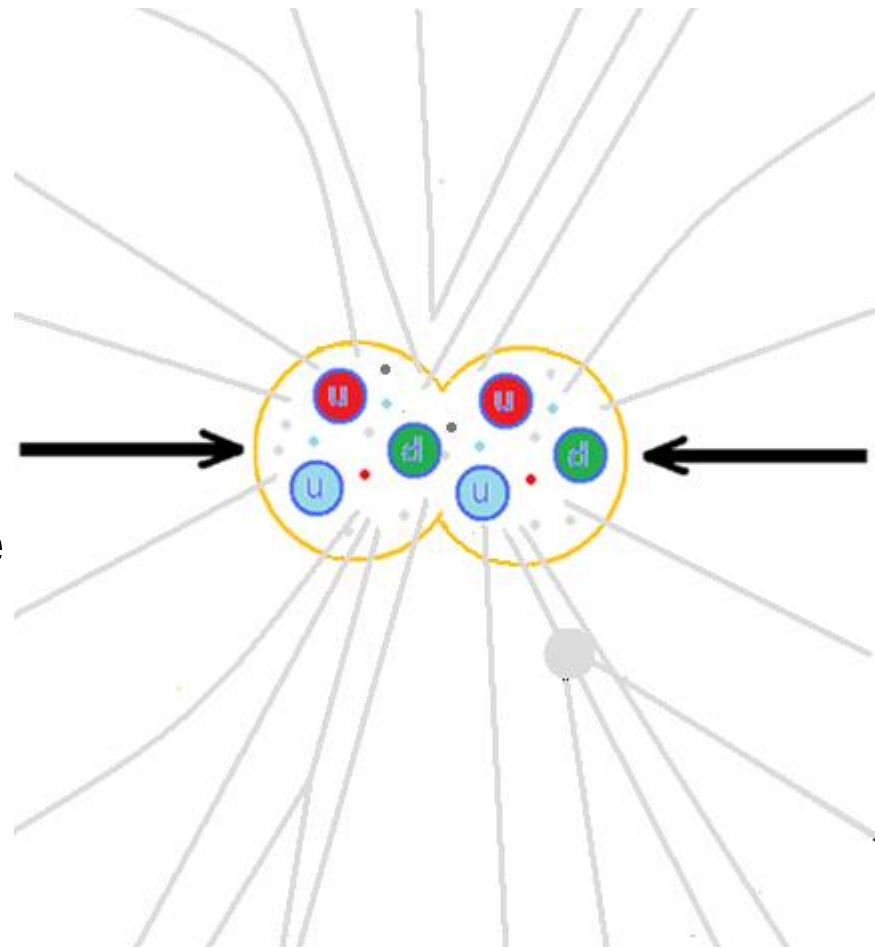


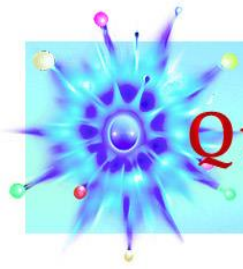
QuarkNet

## Particle Decays

A “dimuon” or “dielectron” event *might* be a decay of the particle that we are interested in.

It may be hard to find the tracks we want unless we make a “cut” on low- energy tracks.



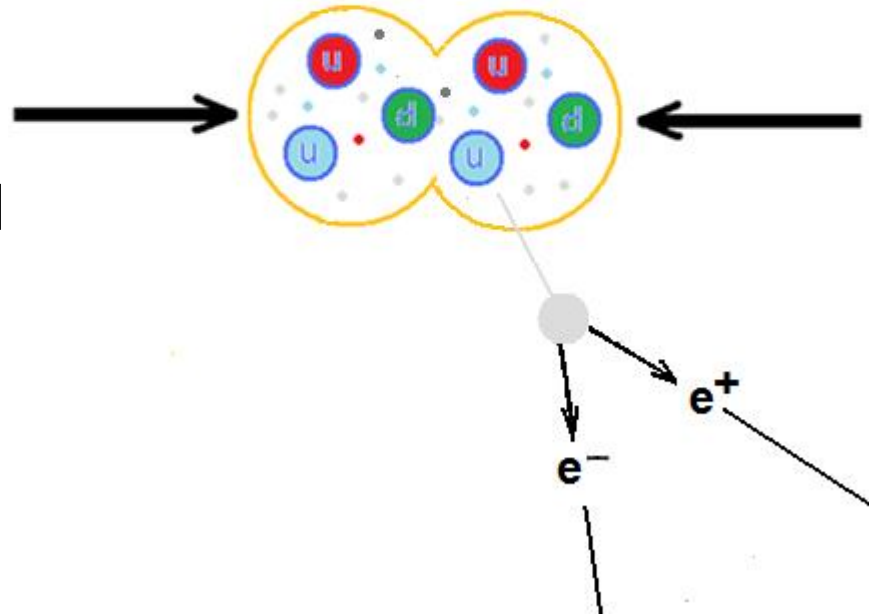


QuarkNet

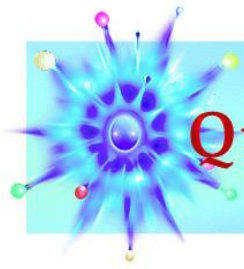
## Particle Decays

If we cut out all tracks below, say, 5 GeV momentum, the picture is clearer.

Today, we will filter many events to find  $Z \rightarrow e^- e^+$  and  $Z \rightarrow \mu^- \mu^+$  signals and use momentum information from these to find the mass of the Z boson.





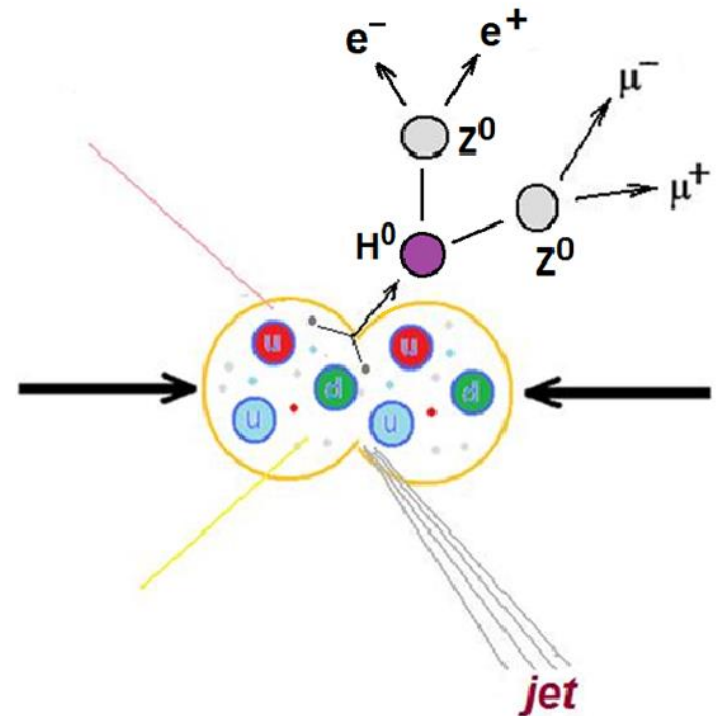


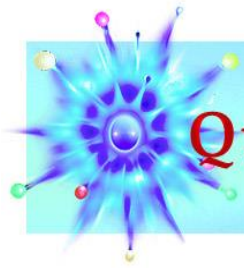
QuarkNet

# Particle Decays

The Higgs boson was discovered by CMS and ATLAS and announced on July 4, 2012.

This long-sought particle is part of the “Higgs mechanism” that accounts for other particle having mass.





# QuarkNet

## Helping Develop America's Technological Workforce

# HYPATIA Event Display

Hybrid pupils' analysis tool for interactions in ATLAS - version 6.0 - Invariant Mass Window

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	$\phi$	$\eta$	M(Z <sub>ij</sub> ) [GeV]	M(4l) [GeV]	e/ $\mu$
00036_JiveXML_166964_987982.xml	19.626	Tracks 3	112.6	+	49.4	1.441	-1.464	95.325		$\mu$
		Tracks 69	96.8	-	45.9	-1.720	-1.378			$\mu$

Canvas Window - File: 00036\_JiveXML\_166964\_987982.xml Run: 166964 Event: ...

ATLAS 2010-10-18 04:39:34 CEST run:166964 ev:987982 HYPATIA

HYPATIA - Track Momenta Window

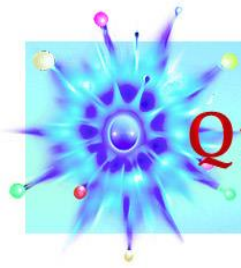
Track	+/-	P [GeV]	Pt [GeV]	$\phi$	$\theta$
Tracks 3	+	112.57	49.42	1.441	2.687
Tracks 69	-	96.83	45.88	-1.720	2.648
Tracks 127	-	37.93	30.81	1.803	0.948
Tracks 128	+	25.73	12.70	0.303	2.625
Tracks 134	+	121.30	89.22	-0.597	2.315
Tracks 136	-	34.18	8.63	-3.123	0.255
Tracks 154	+	14.19	8.35	-2.346	2.513
Tracks 176	-	13.53	12.74	0.259	1.915

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

Projection Data Cuts InDet Calo MuonDet Objects Geometry

InDet	Name	Value
Calo	<input checked="" type="checkbox"/>  Pt	> 5.0 GeV
MuonDet	<input type="checkbox"/>  d0	< 2.5 mm
Objects	<input type="checkbox"/>  z0	< 20.0 cm
ATLAS	<input type="checkbox"/>  d0 Loose	< 2.0 cm
	<input type="checkbox"/>  z0-zvtx	< 2.5 mm



## Generic Design

Cylinders wrapped around the beam pipe

From inner to outer . . .

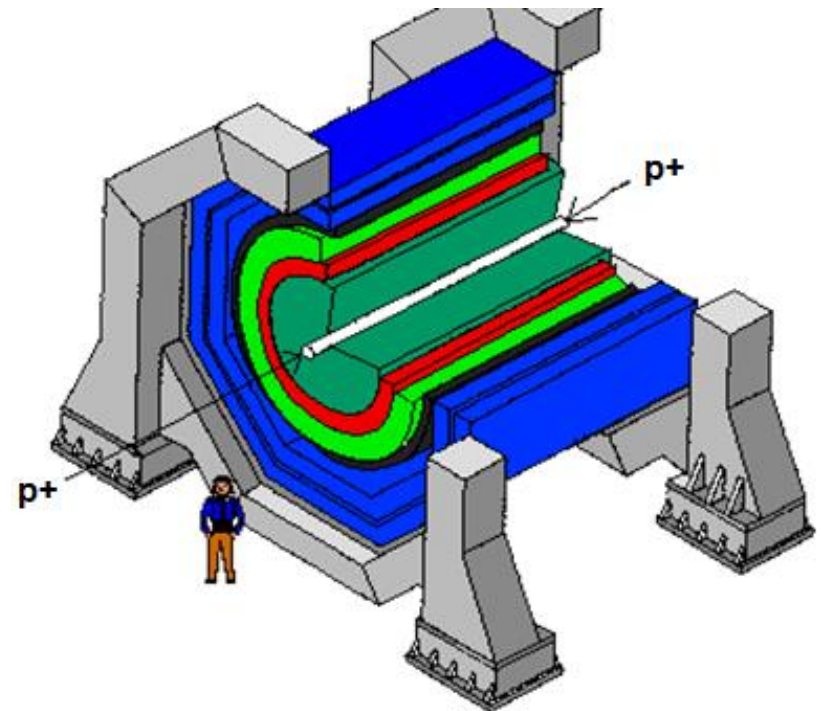
Tracking

Electromagnetic calorimeter

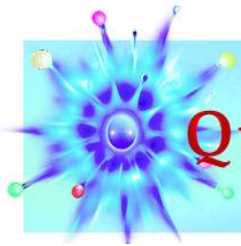
Hadronic calorimeter

Magnet\*

Muon chamber



*\* Location of magnet depends on specific detector design.*

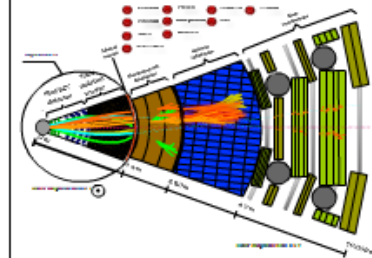
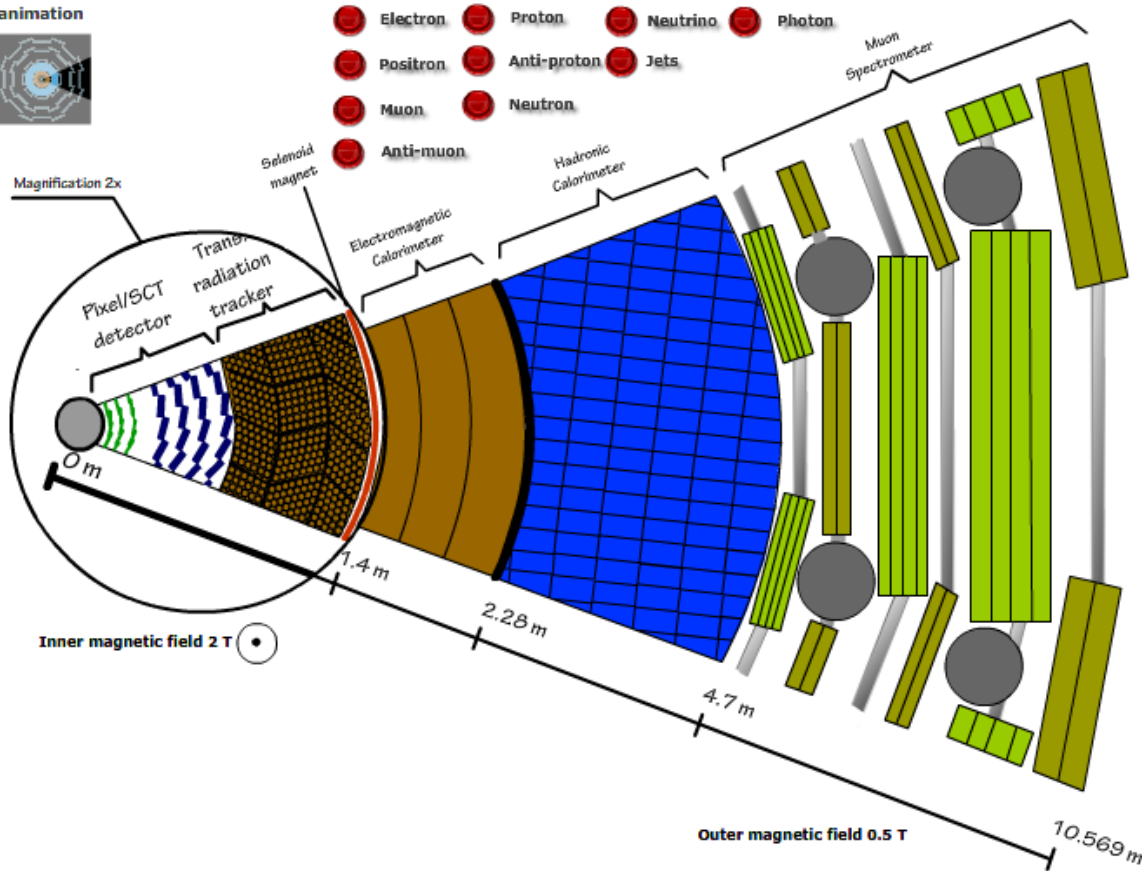
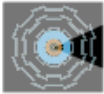


QuarkNet

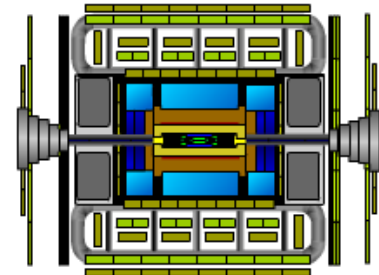
# ATLAS Detector

## ATLAS

animation



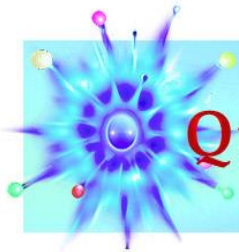
End view



Side view

Created by Jeřábek, Jende 2010

[Play with ATLAS online!](#)

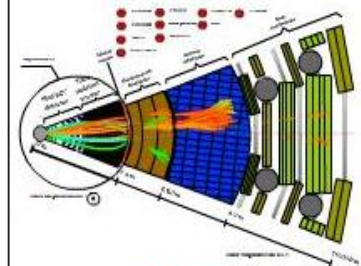
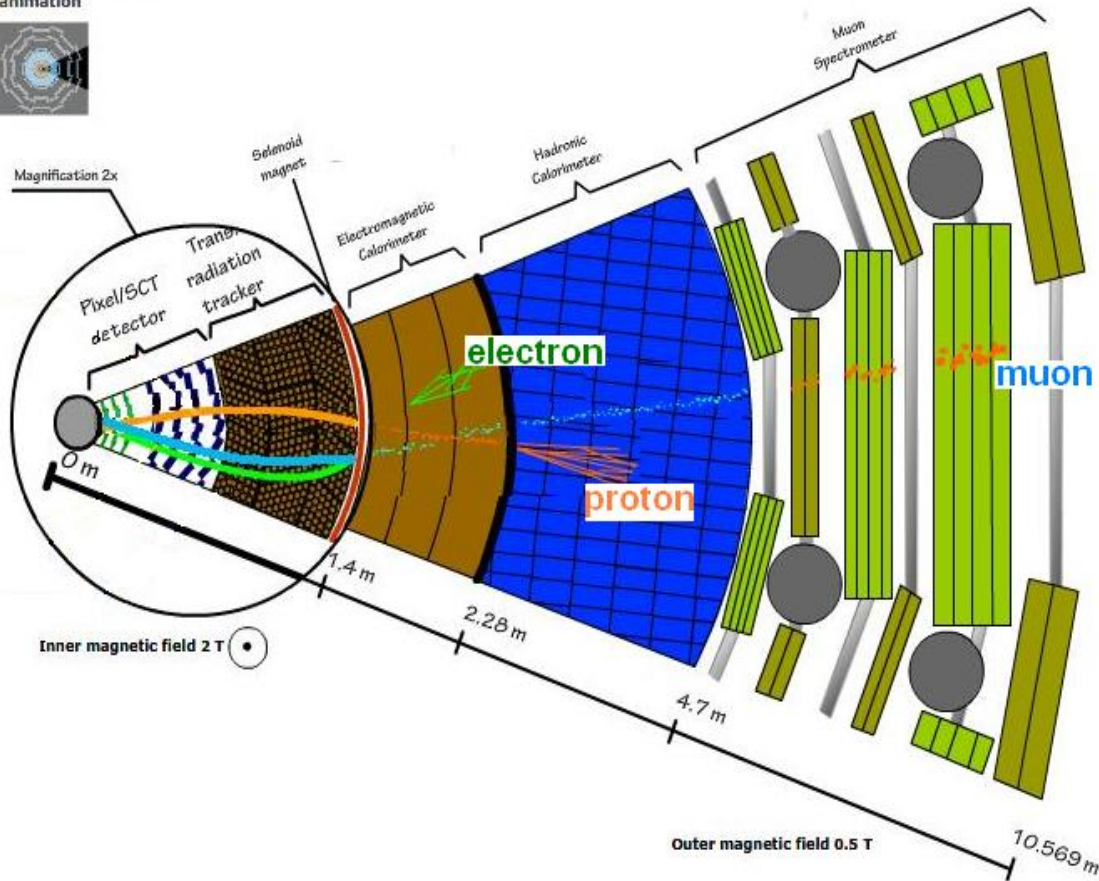


QuarkNet

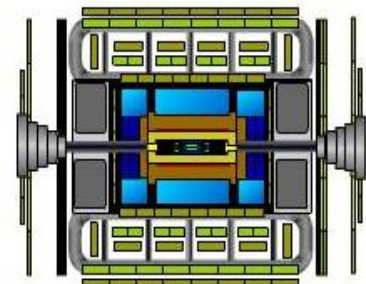
# ATLAS Detector

## ATLAS

animation



End view



Side view

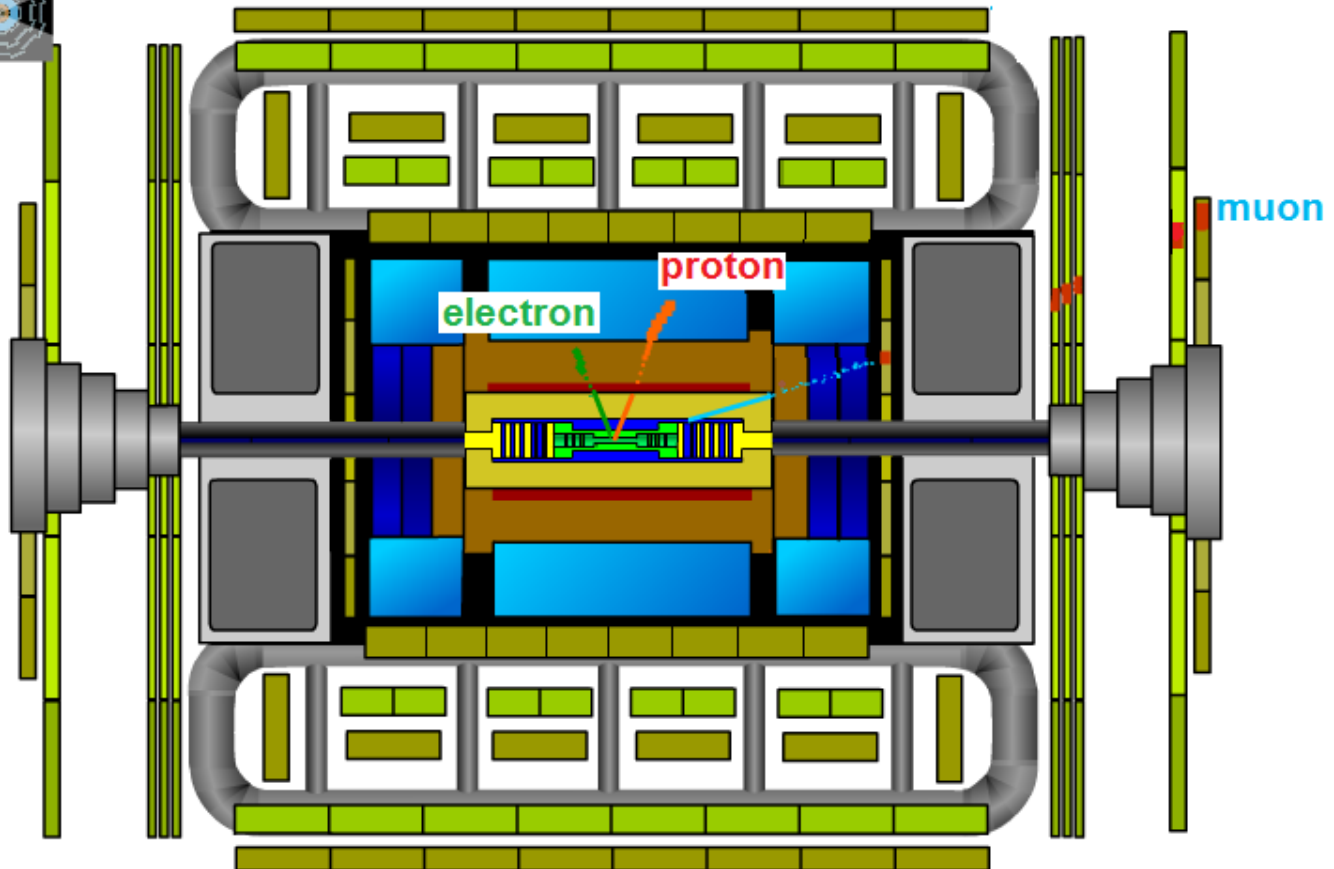
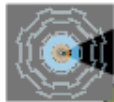


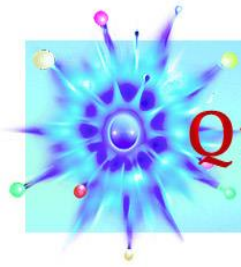
QuarkNet

# ATLAS Detector

**ATLAS**

animation

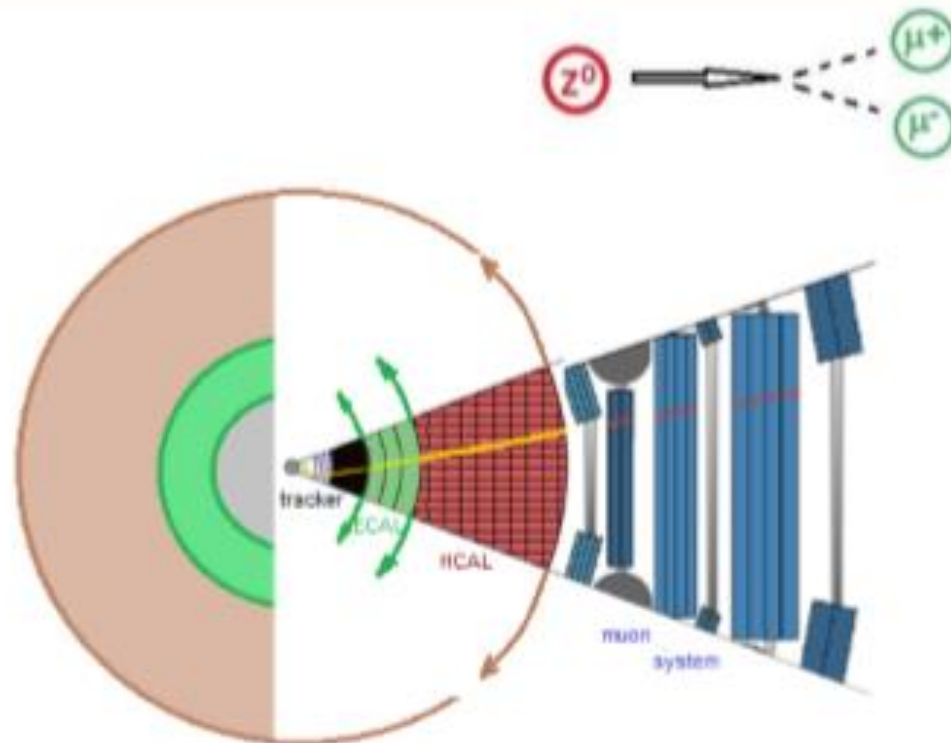




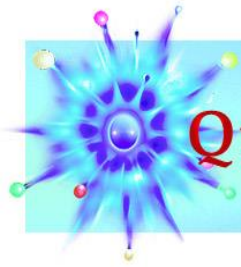
QuarkNet

Sketch the tracks in ATLAS

$$(Z^0) \rightarrow \mu^+ \mu^-$$



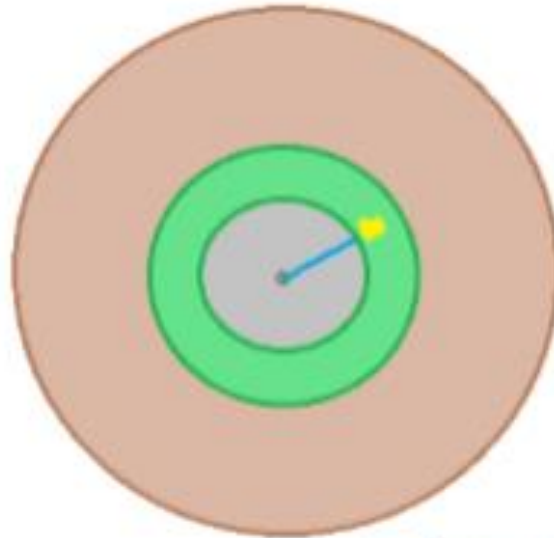
Complete the circles for ECAL and HCAL. One muon travels through the detector slice. Draw the other muon, roughly opposite from the vertex.



QuarkNet

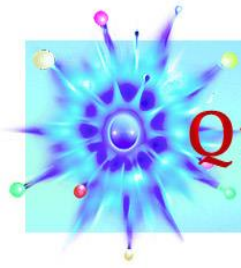
Sketch the tracks in ATLAS

$$(Z^0) \rightarrow e^+ e^-$$



One electron travels through the tracker and deposits in ECAL. Draw the other electron.

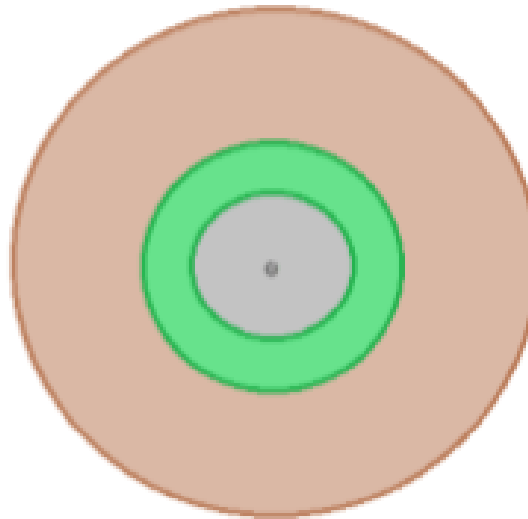




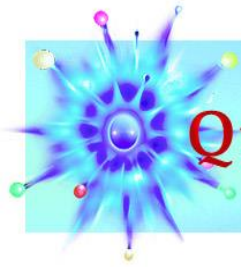
QuarkNet

Sketch the tracks in ATLAS

$(H^0) \rightarrow (Z^0 Z^0) \rightarrow 4 \text{ leptons}$



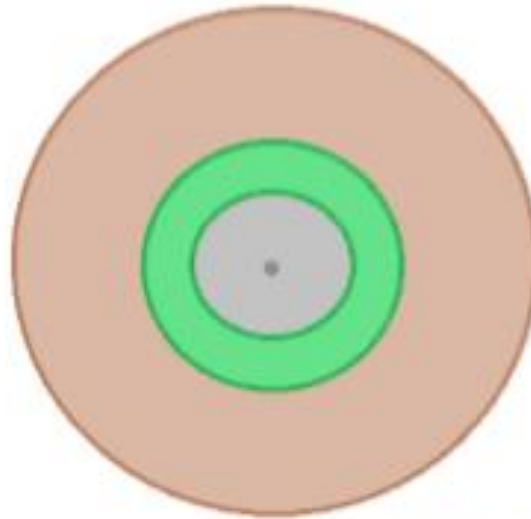
Each Z promptly decays into 2 muons or 2 electrons. Draw a combination of muons and/or electrons that results.



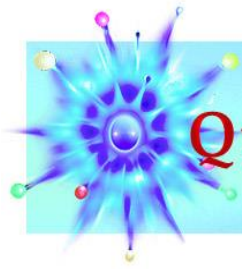
QuarkNet

Sketch the tracks in ATLAS

$(H^0) \rightarrow \gamma\gamma$



Each photon ( $\gamma$ ) is undetected by the tracker but leaves a deposit in ECAL. Draw them.



QuarkNet

## Let's Analyze Events!

Make teams of two.

Practice.

Talk with physicists.

Find good Z and H candidates...and more.

Which events will be included in the mass plot?

AND plot the mass!

Report! Rapport! Rejoice! Relax!