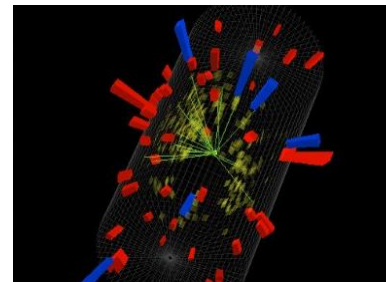
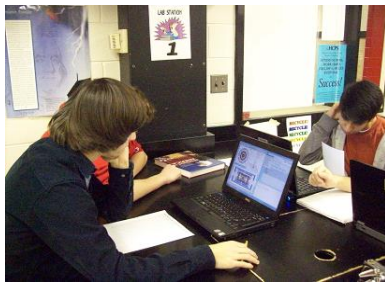
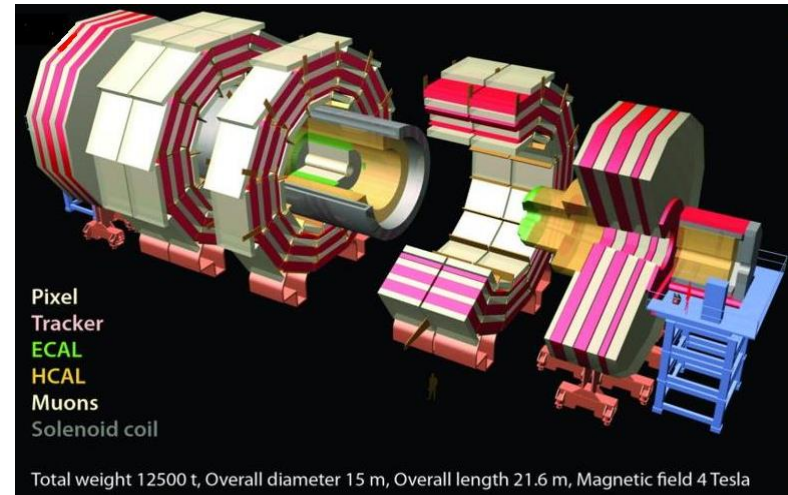
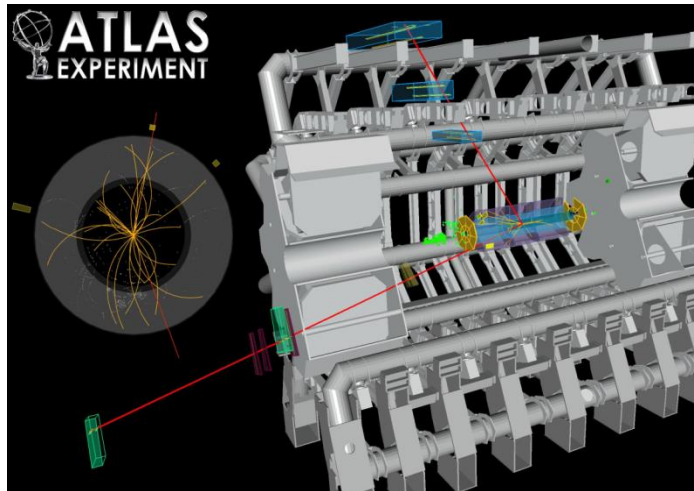




Compact W and Z Masterclass 2015



U.S. DEPARTMENT OF
ENERGY

Office of
Science



QuarkNet





The LHC and New Physics

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

At CERN, the LHC and its experiments are underway.



*The ATLAS and CMS detectors have been taking data. The first job was to confirm how the data corresponds to our understanding we call the **Standard Model**.*



Detectors

Generic Detector Design

Cylinders wrapped around the beam pipe

From inner to outer . . .

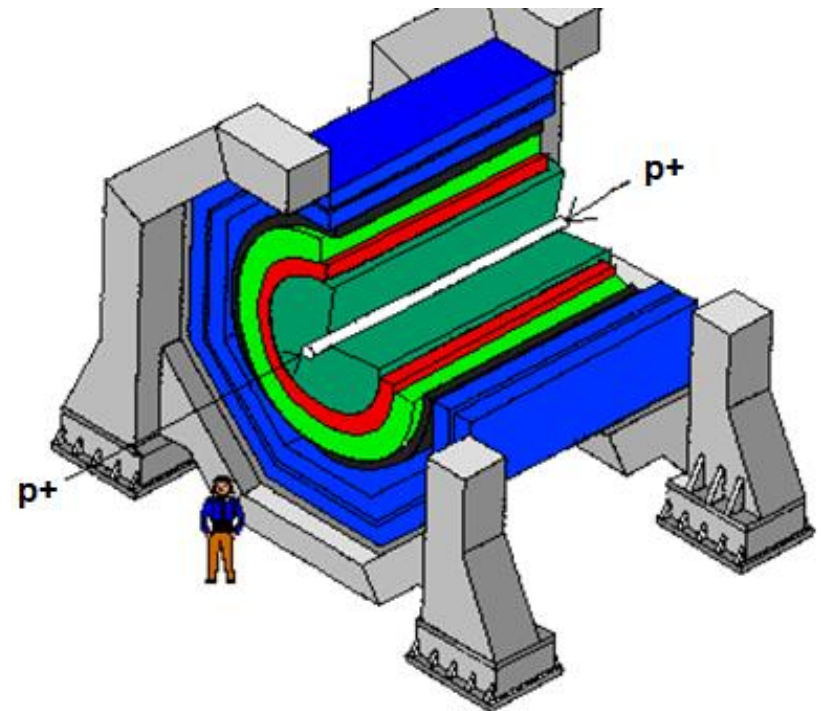
Tracking

Electromagnetic calorimeter

Hadronic calorimeter

Magnet*

Muon chamber



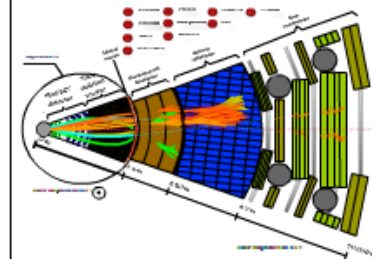
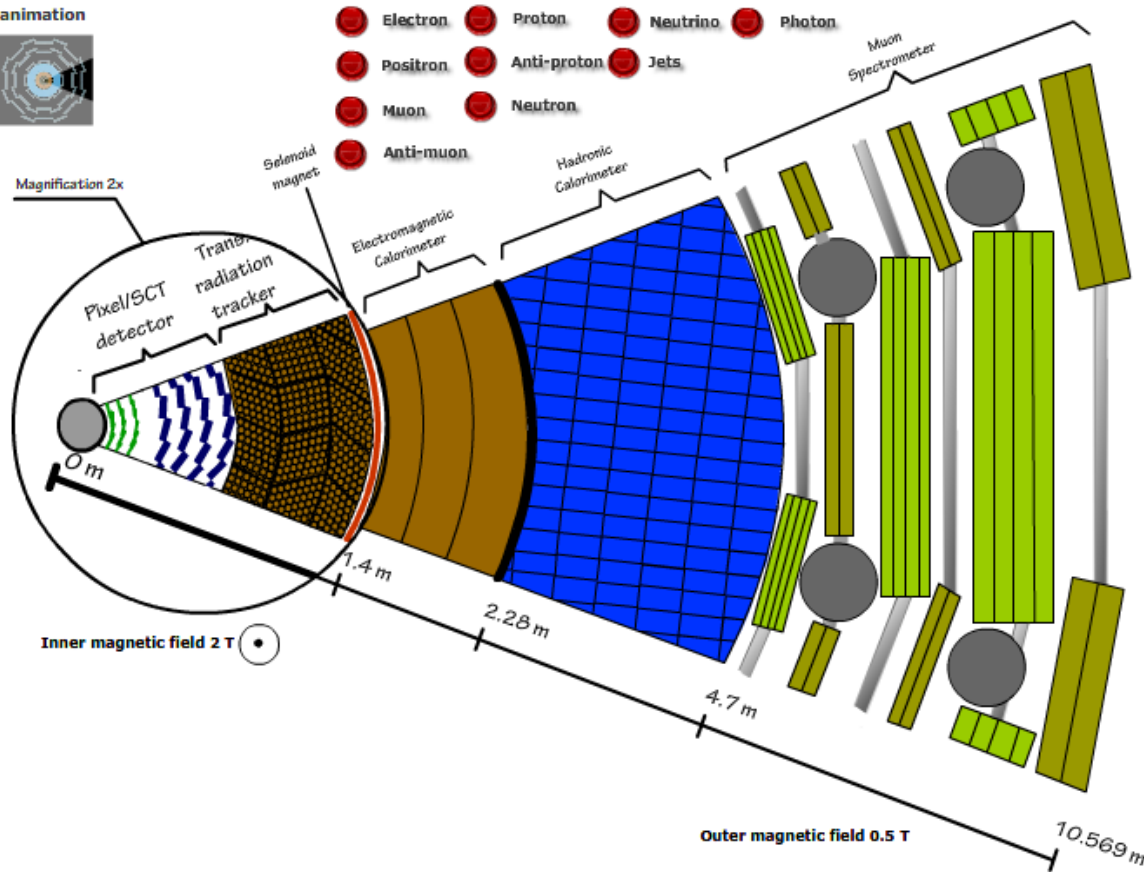
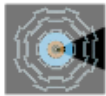
* *Location of magnet depends on specific detector design.*



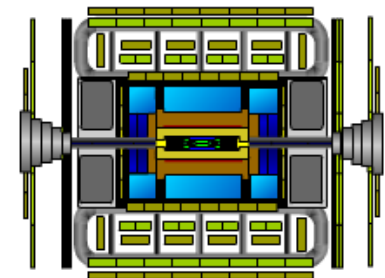
ATLAS Detector

ATLAS

animation



End view



Side view

Created by Jeřábek, Jende 2010

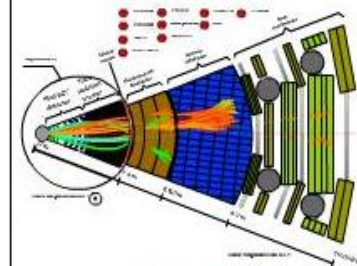
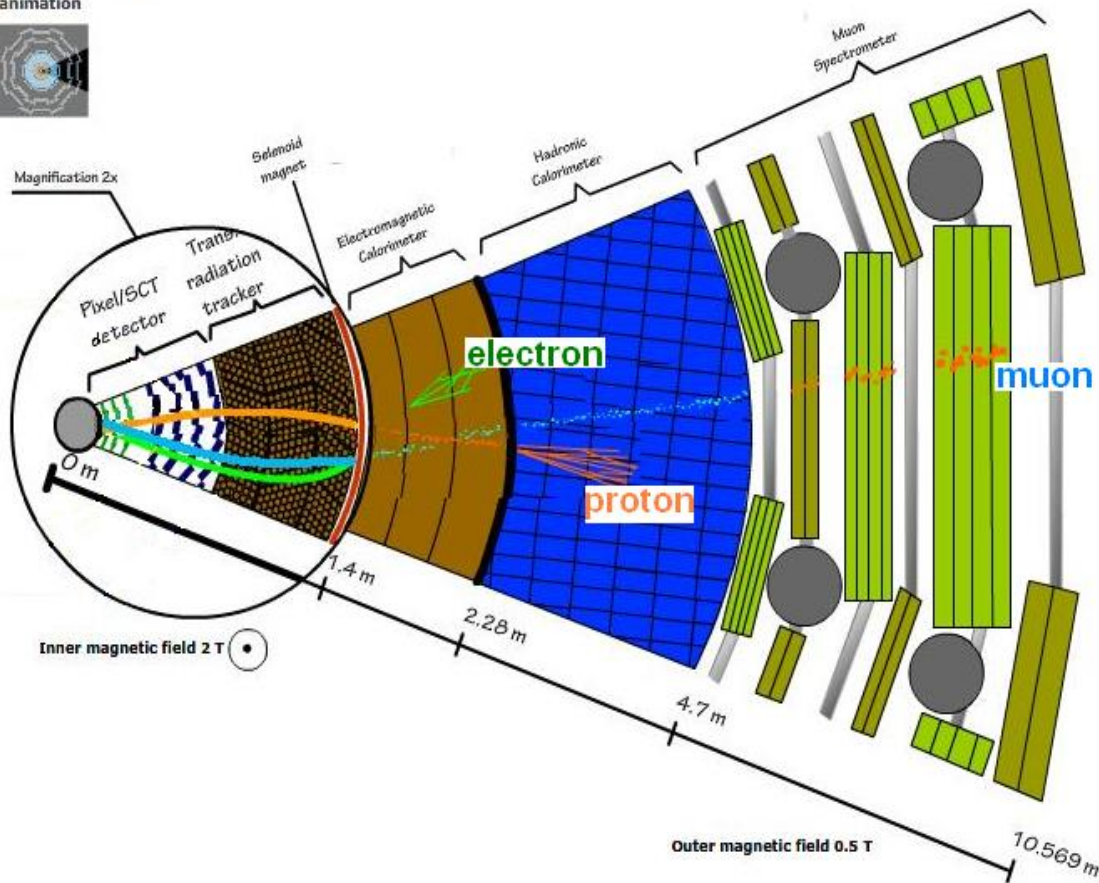
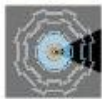
[Play with ATLAS online!](#)



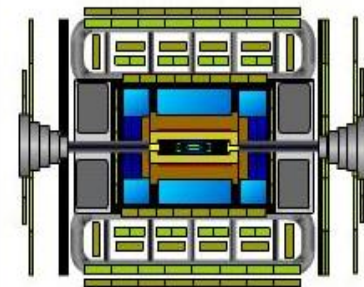
ATLAS Detector

ATLAS

animation



End view



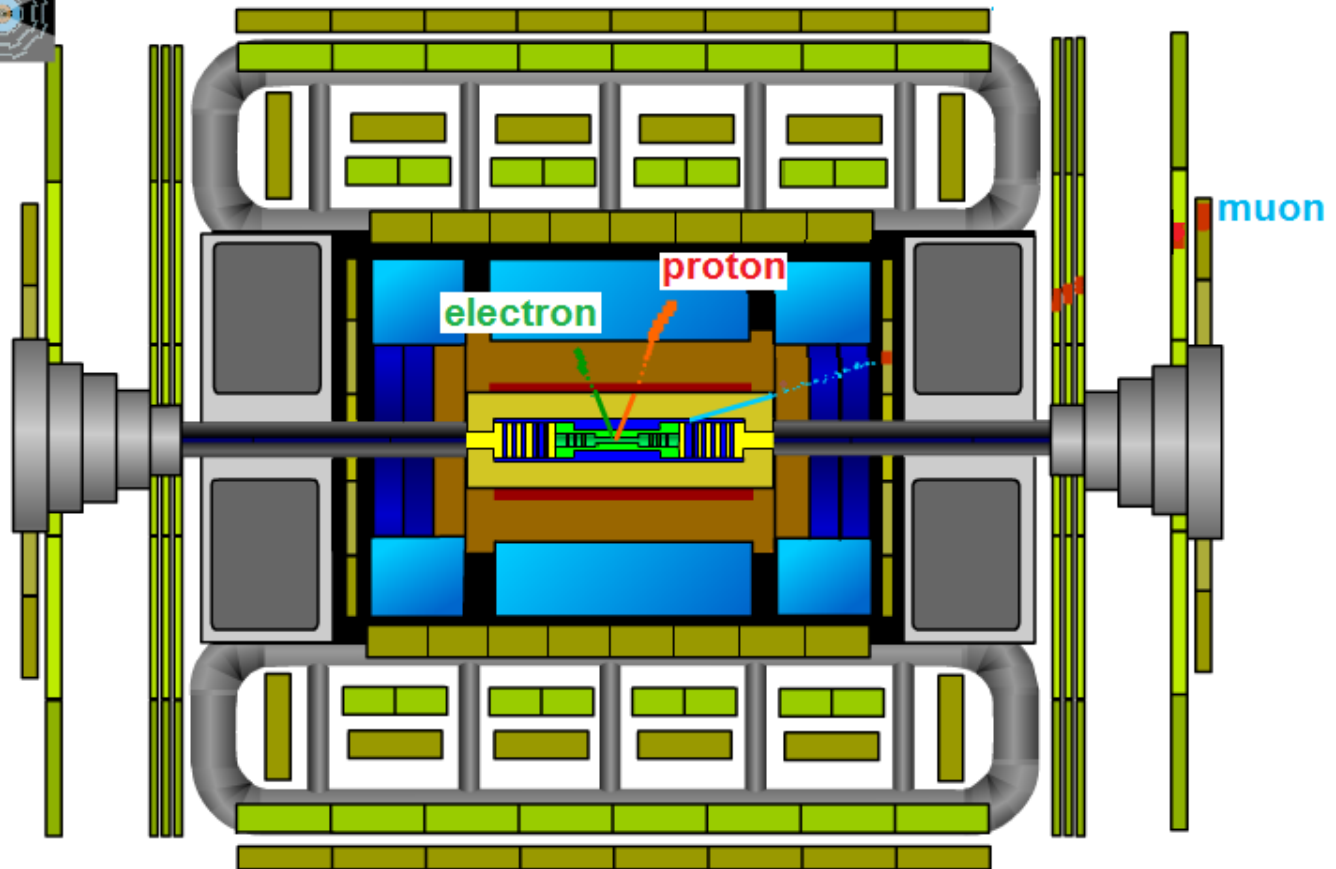
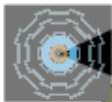
Side view



ATLAS Detector

ATLAS

animation

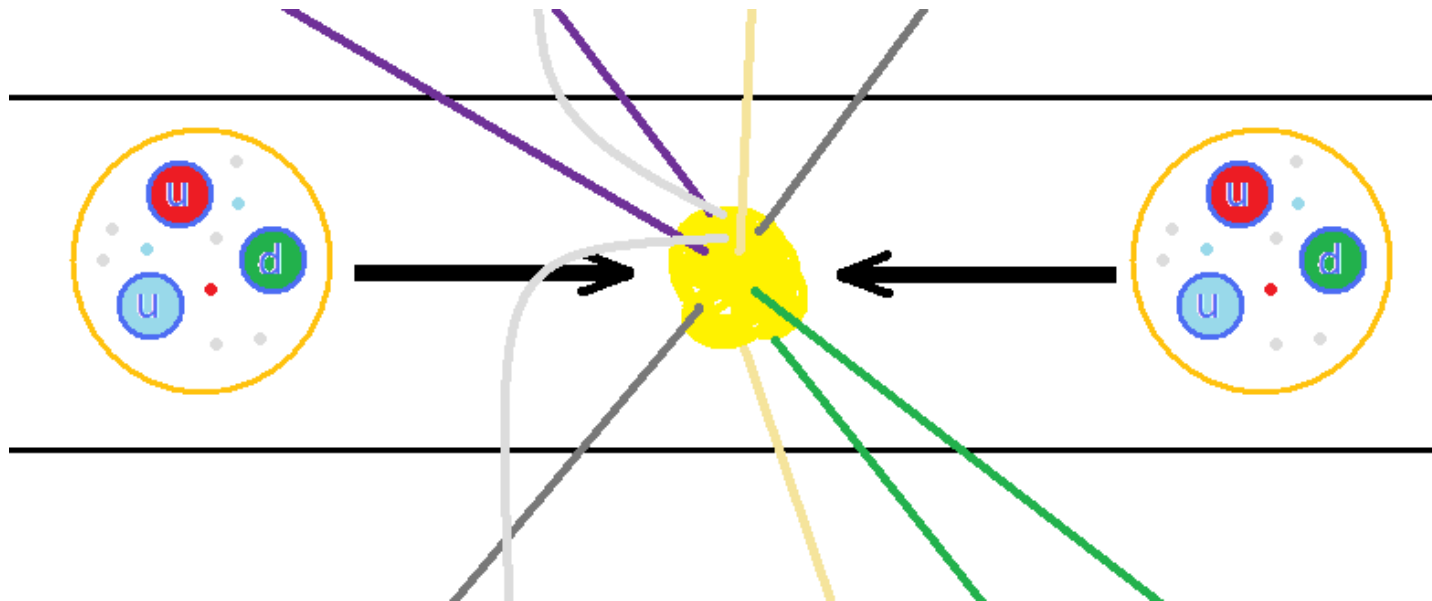




Proton Interactions

If each beam proton has energy 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.



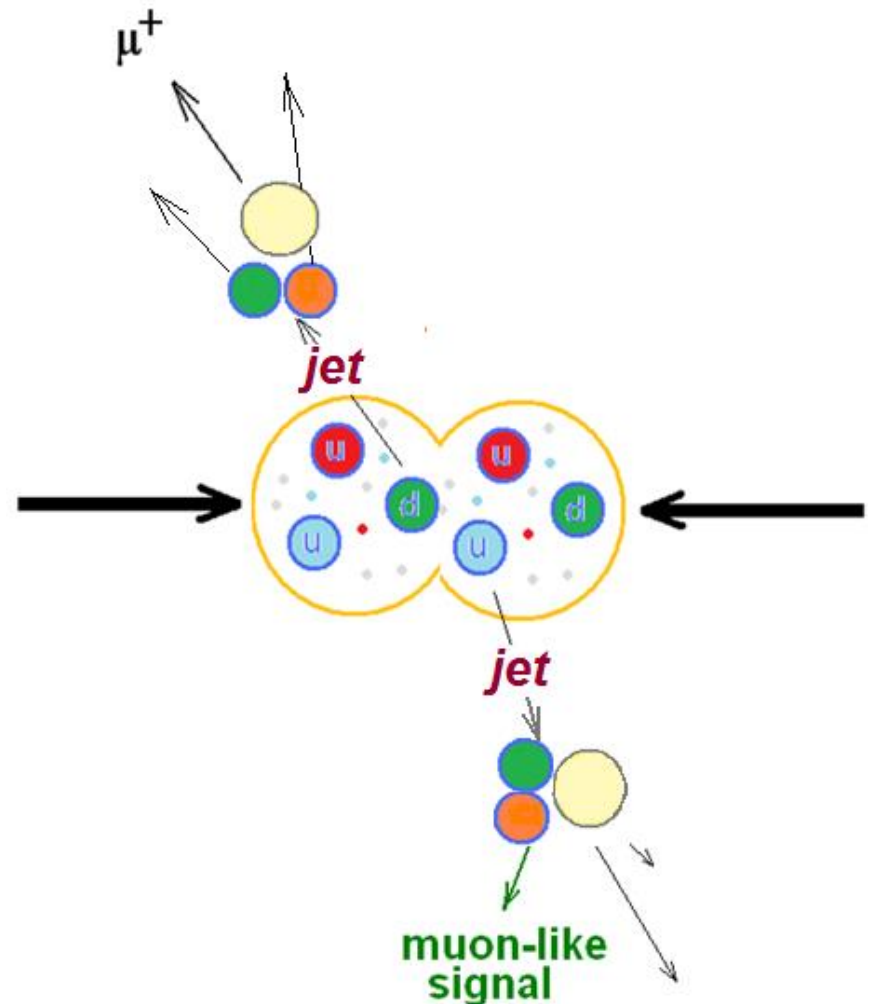


Particle Decays

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.



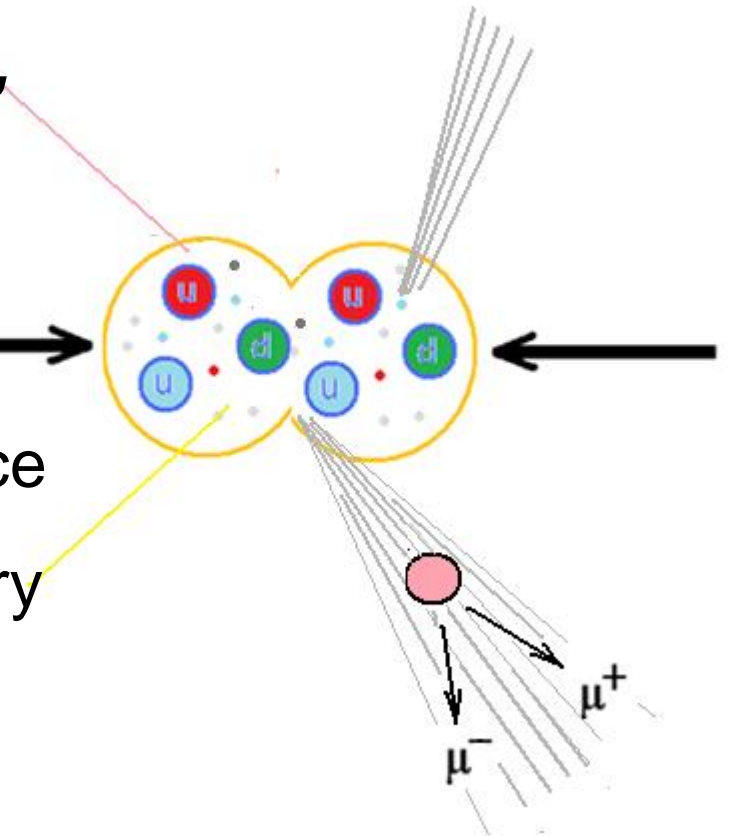


W and Z Particles

We are looking for the mediators of the **weak interaction**:

- electrically charged **W^+ boson**,
- the negative **W^- boson**,
- the neutral **Z boson**.

Unlike electromagnetic forces carried over long distances by massless photons, the weak force is carried by massive particles which restricts interactions to very tiny distances.



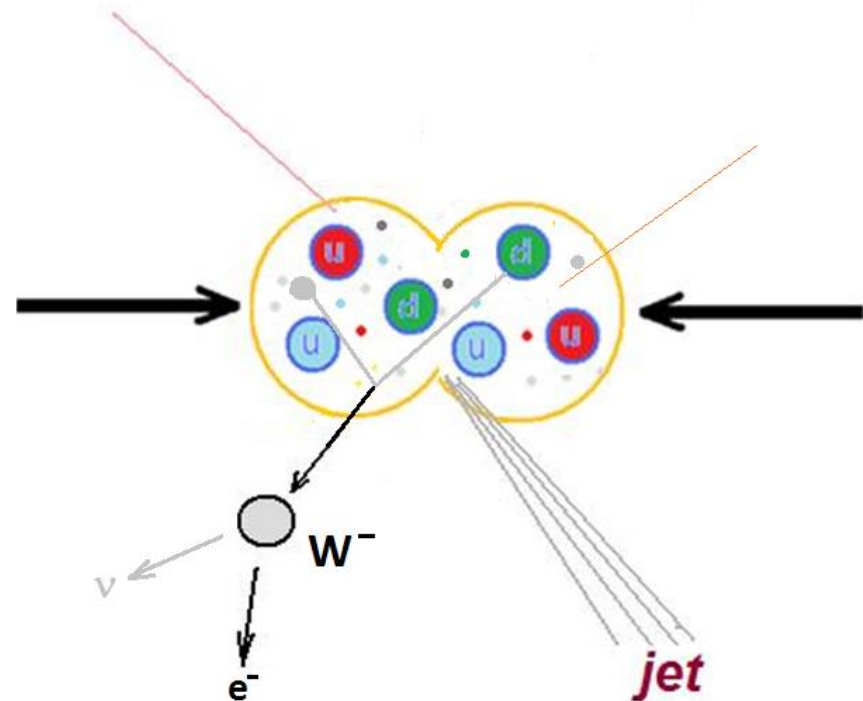


W and Z Particles

The W bosons are responsible for radioactivity by transforming a proton into a neutron, or the reverse.

Z bosons are similarly exchanged but do not change electric charge.

Collisions of sufficient energy can create W and Z or other particles.



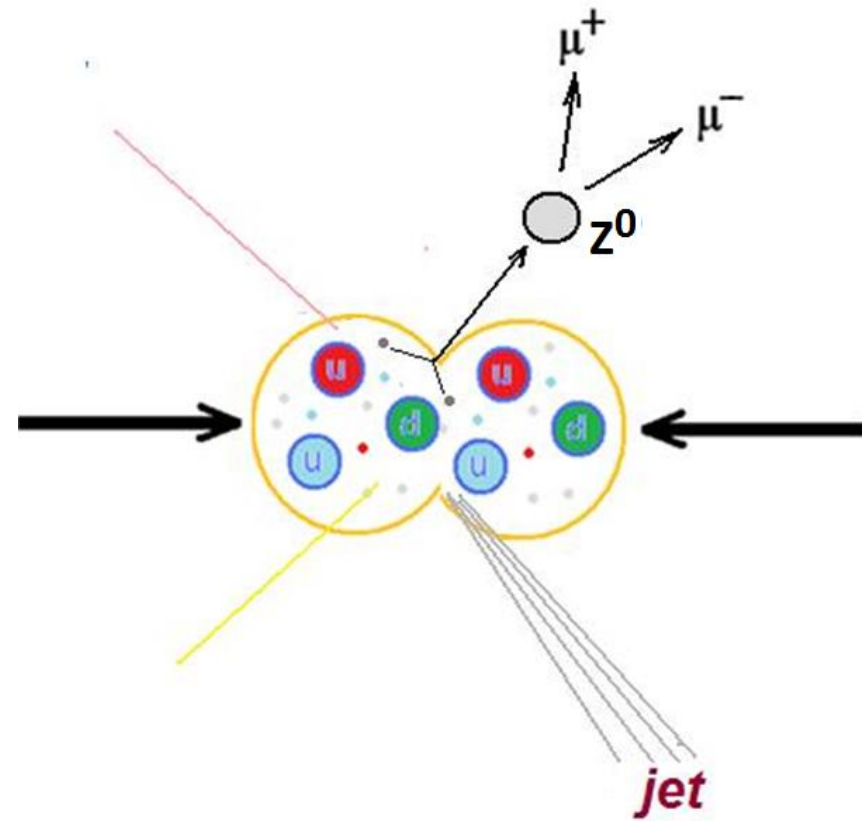


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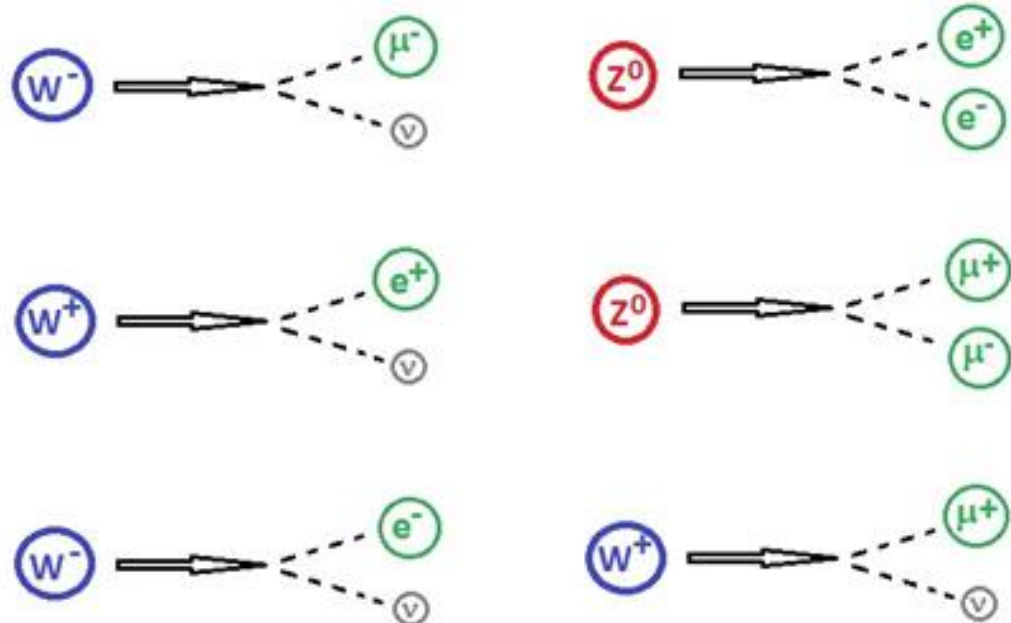


W and Z Decays

Because bosons only travel a tiny distance before decaying, ATLAS and CMS do not “see” them directly.

We can detect :

- electrons
- muons
- photons



We can infer:

- neutrinos from “missing energy”



ATLAS 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]	ϕ	η	M(Zij) [GeV]	M(4l) [GeV]	e/ μ
00036_JiveXML_166964_987982.xml	19.626	Tracks 3	112.6	+	49.4	1.441	-1.464	95.325		μ
		Tracks 69	96.8	-	45.9	-1.720	-1.378			μ

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

File Previous Event Next Event Insert Electron Insert Muon Delete Track Reset Canvas

ETMis: 20.808 GeV ϕ : -2.415 rad Collection: MET_RefFinal

C:\installers\HYPATIA\groupAI\00036_JiveXML_166964_987982.xml

Track	+/-	P [GeV]	Pt [GeV]	ϕ	θ
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

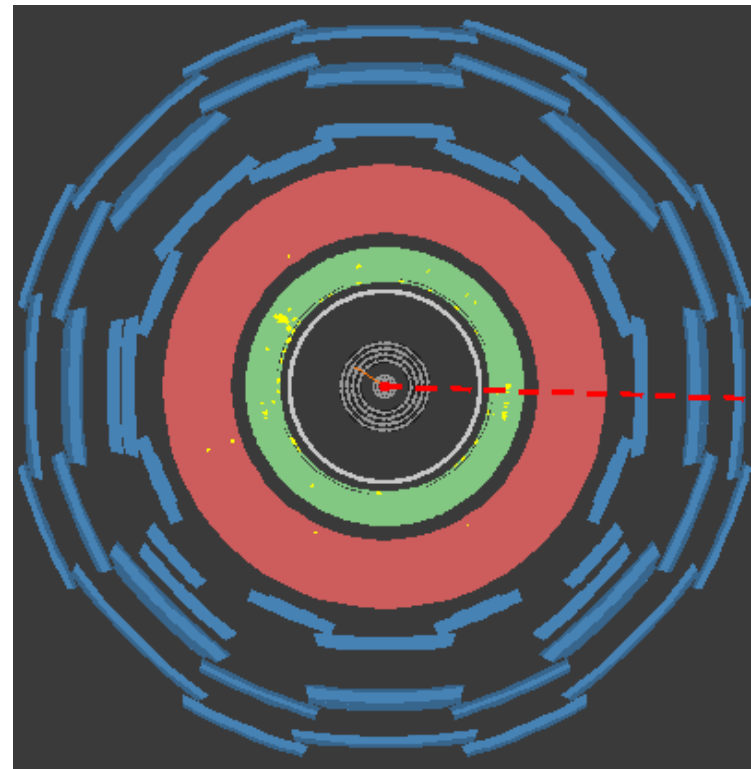
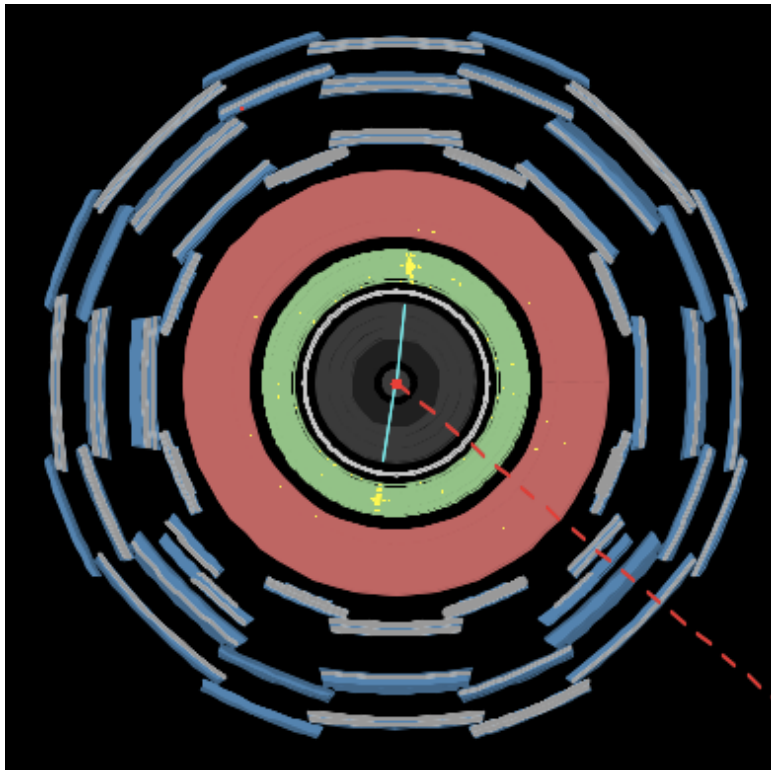
Parameter Control Interaction and Window Control Output Display

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



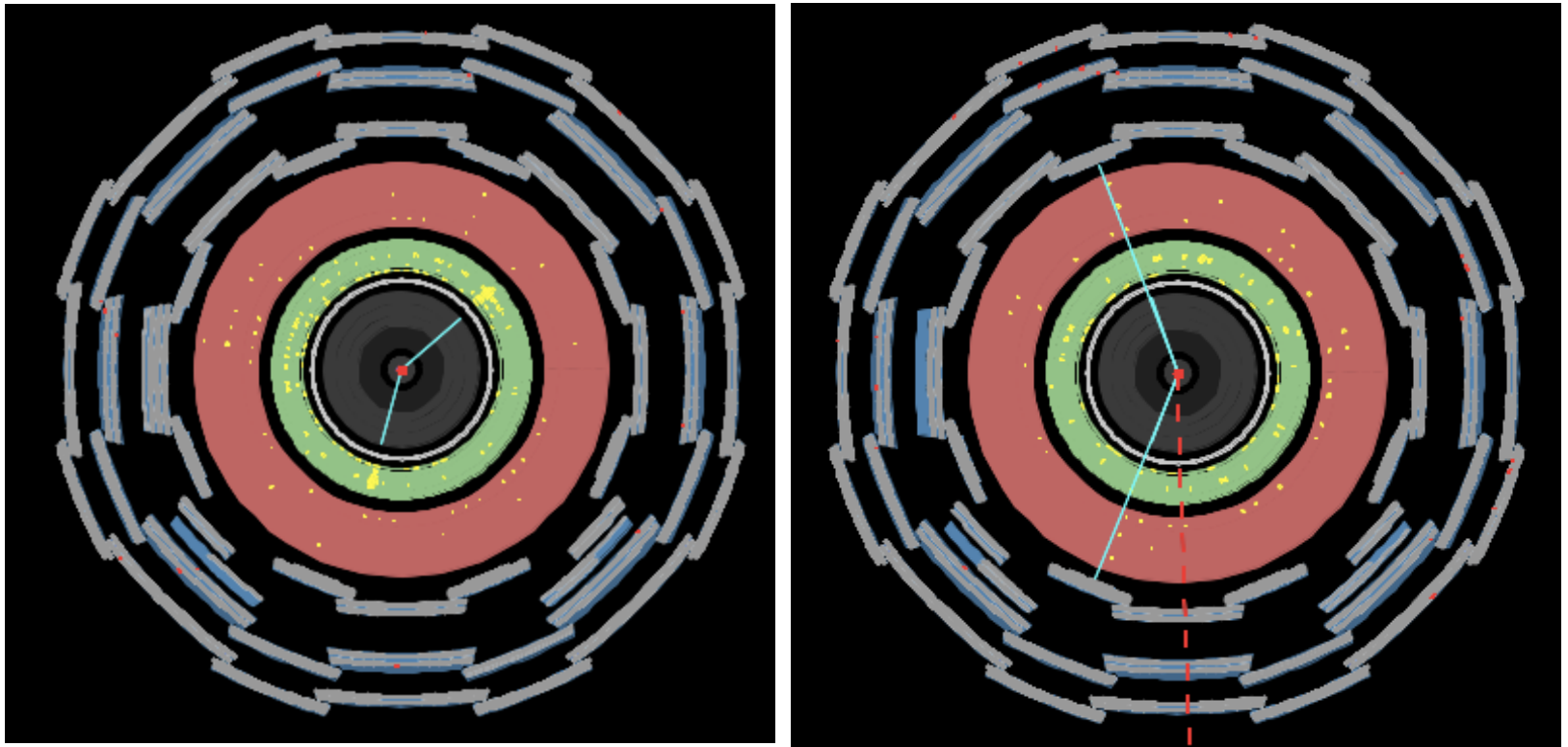
ATLAS Event Display



How are these events similar? Different? Why?



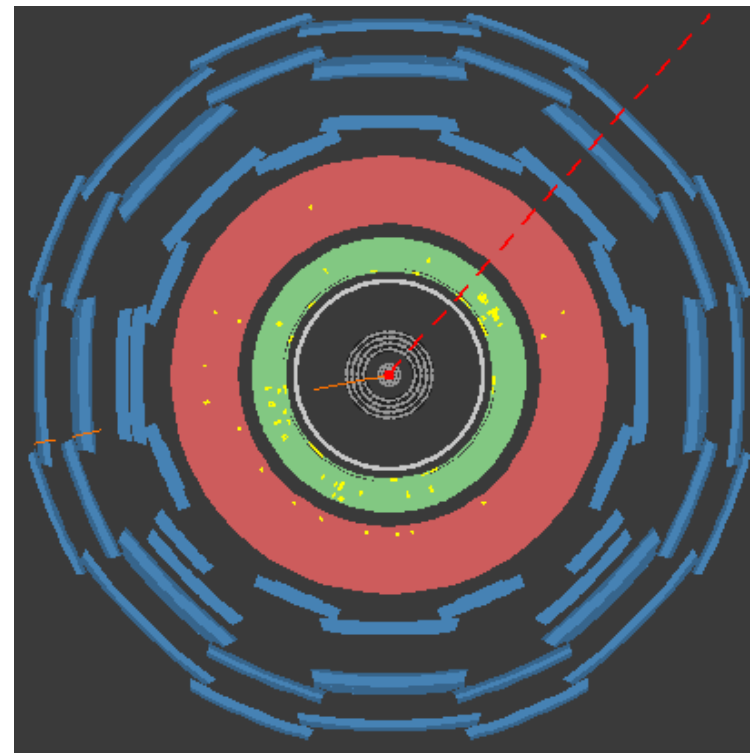
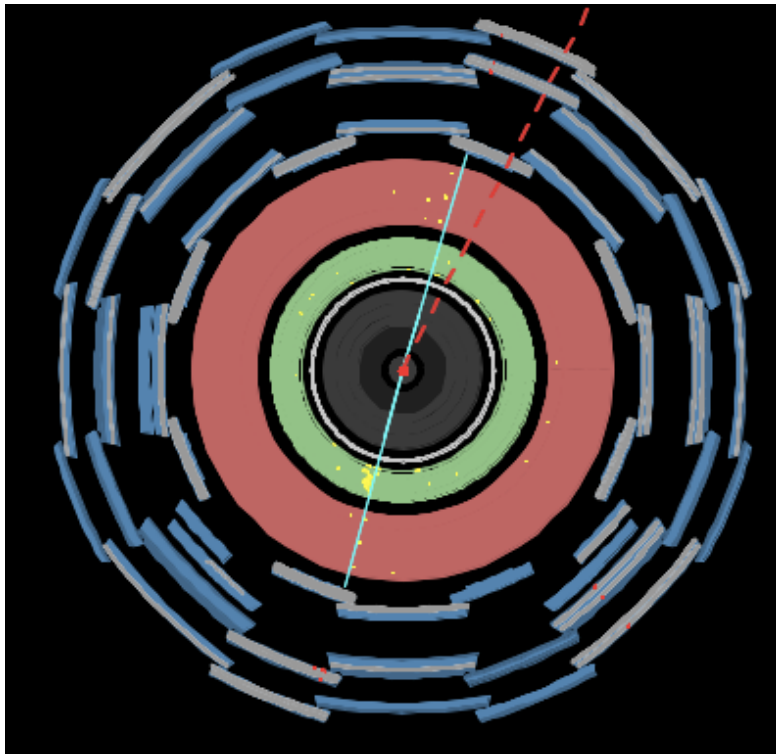
ATLAS Event Display



How are these events similar? Different? Why?



ATLAS Event Display



How are these events similar? Different? Why?



CMS Event Display

Detector Model ?

- Tracker
- ECAL Barrel
- ECAL Endcap
- ECAL Preshower
- HCAL Barrel
- HCAL Endcap
- HCAL Outer
- HCAL Forward
- Drift Tubes (muon)
- Cathode Strip Chambers (muon)
- Resistive Plate Chambers (muon)

Tracking ?

- Tracks (reco.)
- Clusters (Si Pixels)
- Clusters (Si Strips)
- Rec. Hits (Tracking)

ECAL ?

- Barrel Rec. Hits
- Endcap Rec. Hits
- Preshower Rec. Hits

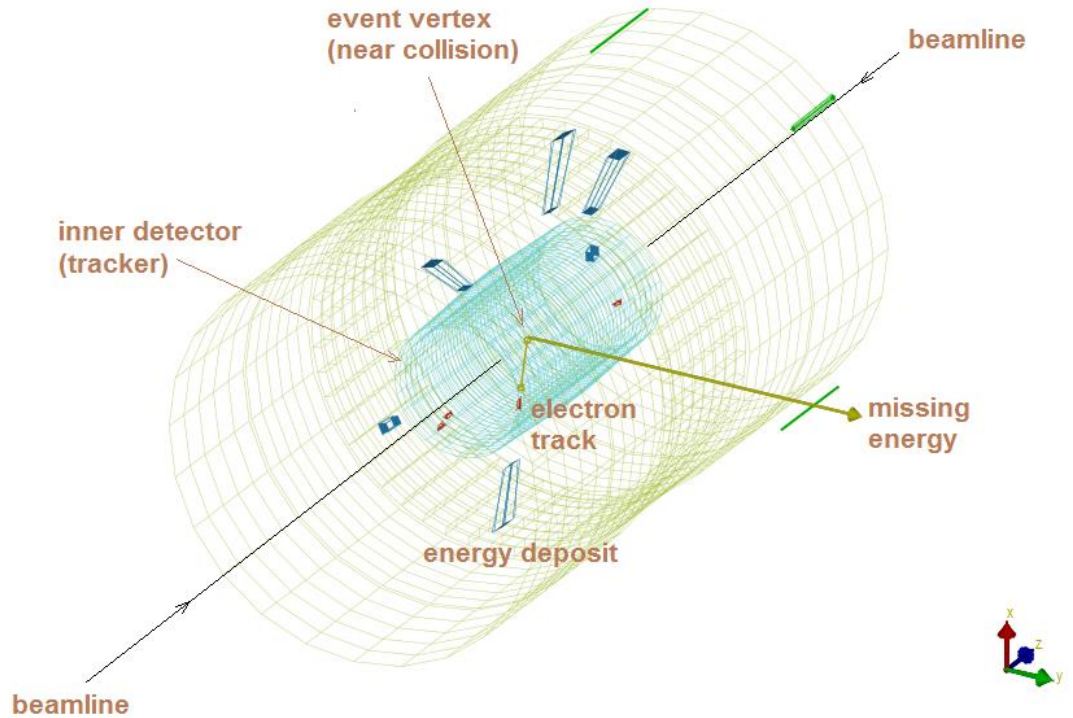
HCAL ?

- Barrel Rec. Hits
- Endcap Rec. Hits
- Forward Rec. Hits
- Outer Rec. Hits

Controls:

- rotate
- Ctrl** + → pan x / y
- Shift** + → pan z

event display controls

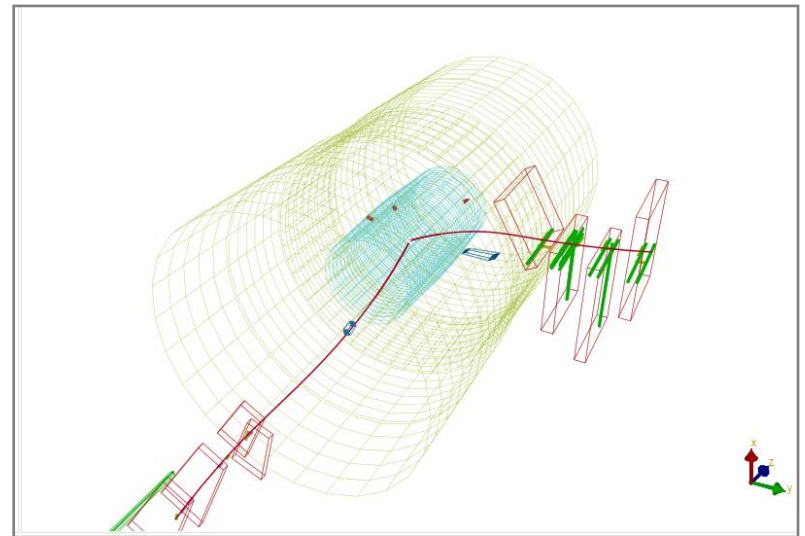
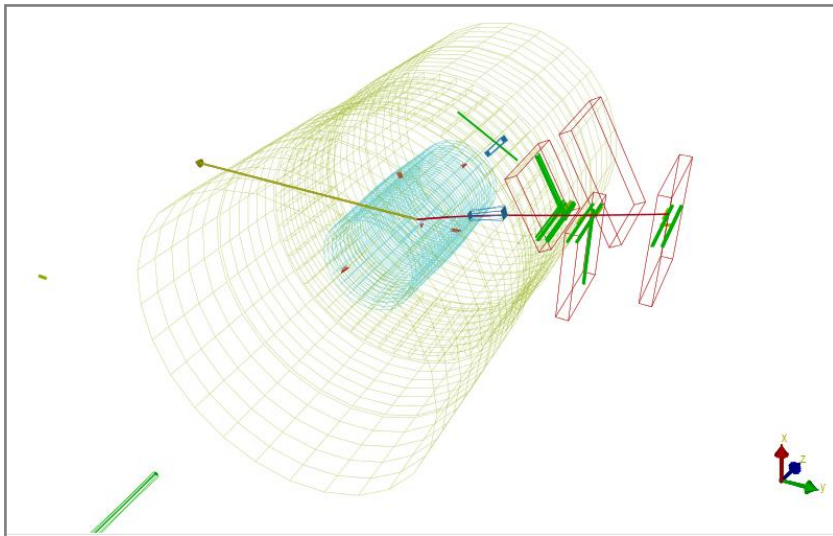




CMS Event Display

Use new data from the LHC in iSpy to test performance of CMS:

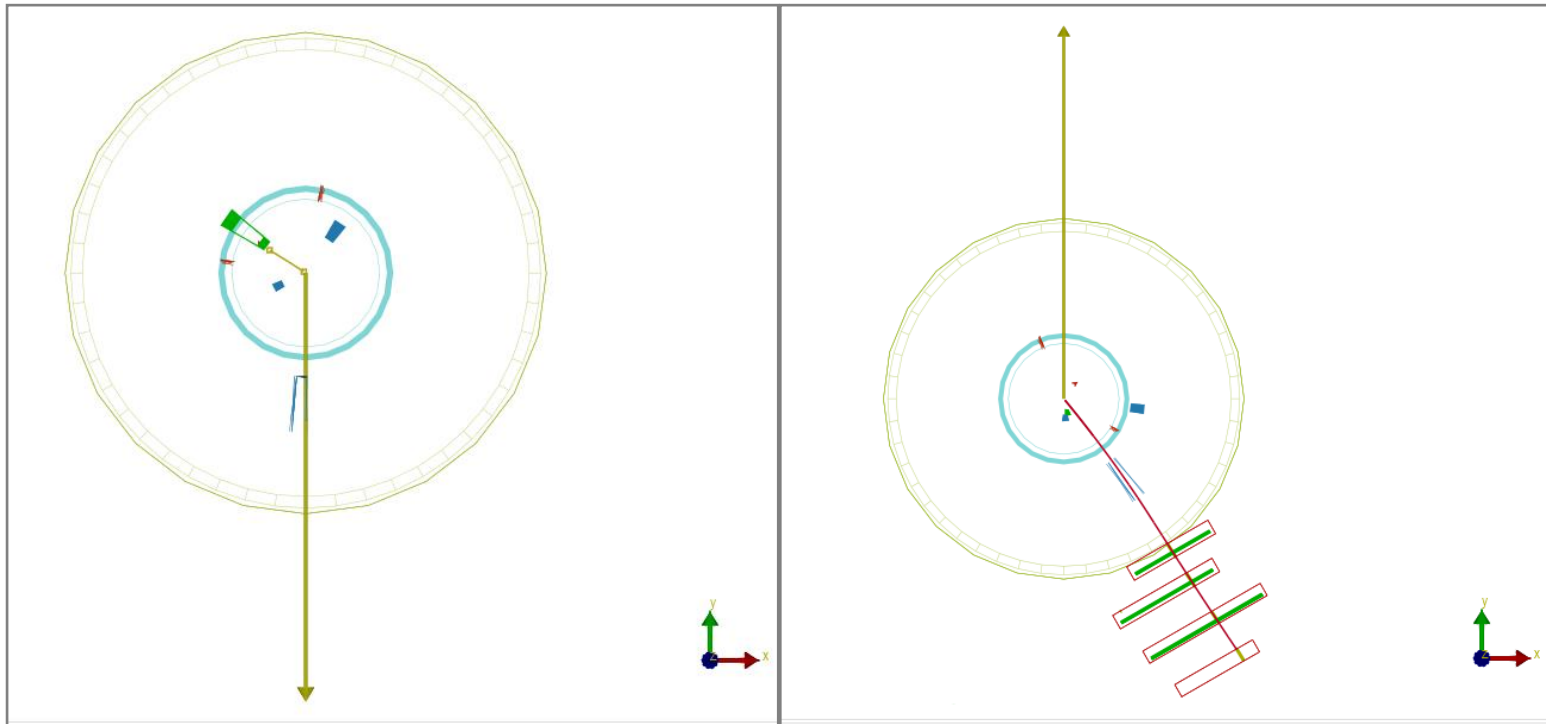
- Can we distinguish W from Z candidates?





CMS Event Display

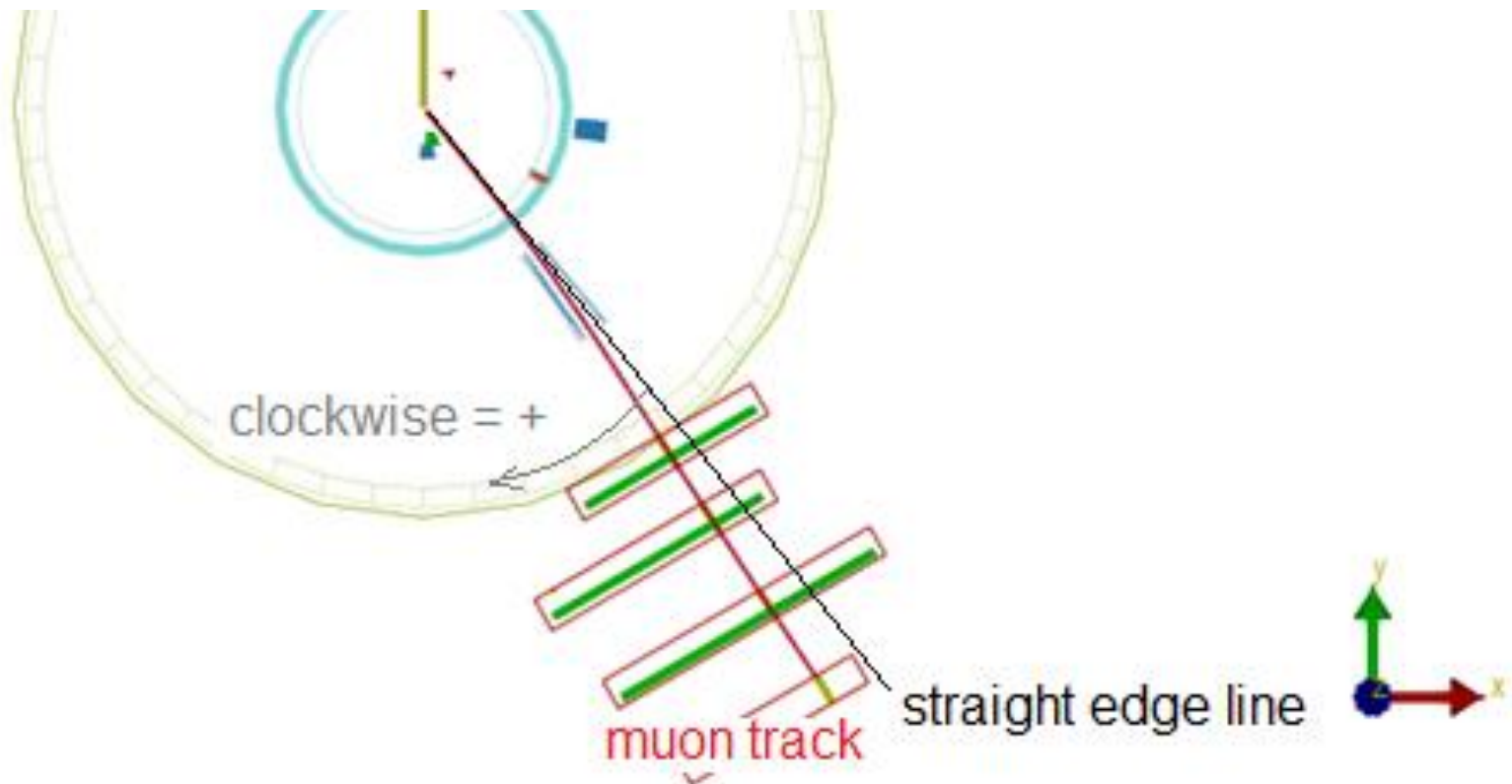
- Can we calculate the e/μ ratio?





CMS Event Display

- Can we calculate a W^+/W^- ratio for CMS?





Analyze Events!

Make an ATLAS team and a CMS team.

Practice events.

Find good Z and W candidates...and more.

Which events will be included in the mass plot? Which will give us W^+/W^- ?

Report! Rapport! Rejoice! Relax!