UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

CREATIONS
Developing an Engaging Science Classroom

Particle Physics Master-class

Analysing data from CERN

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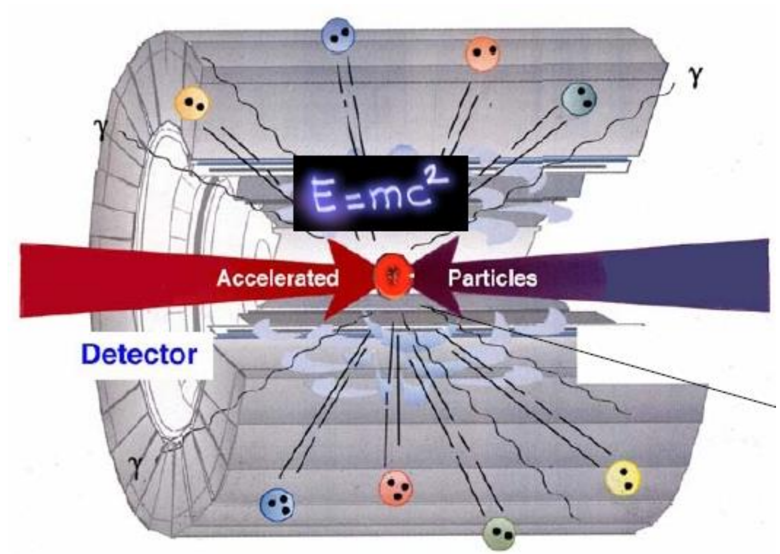
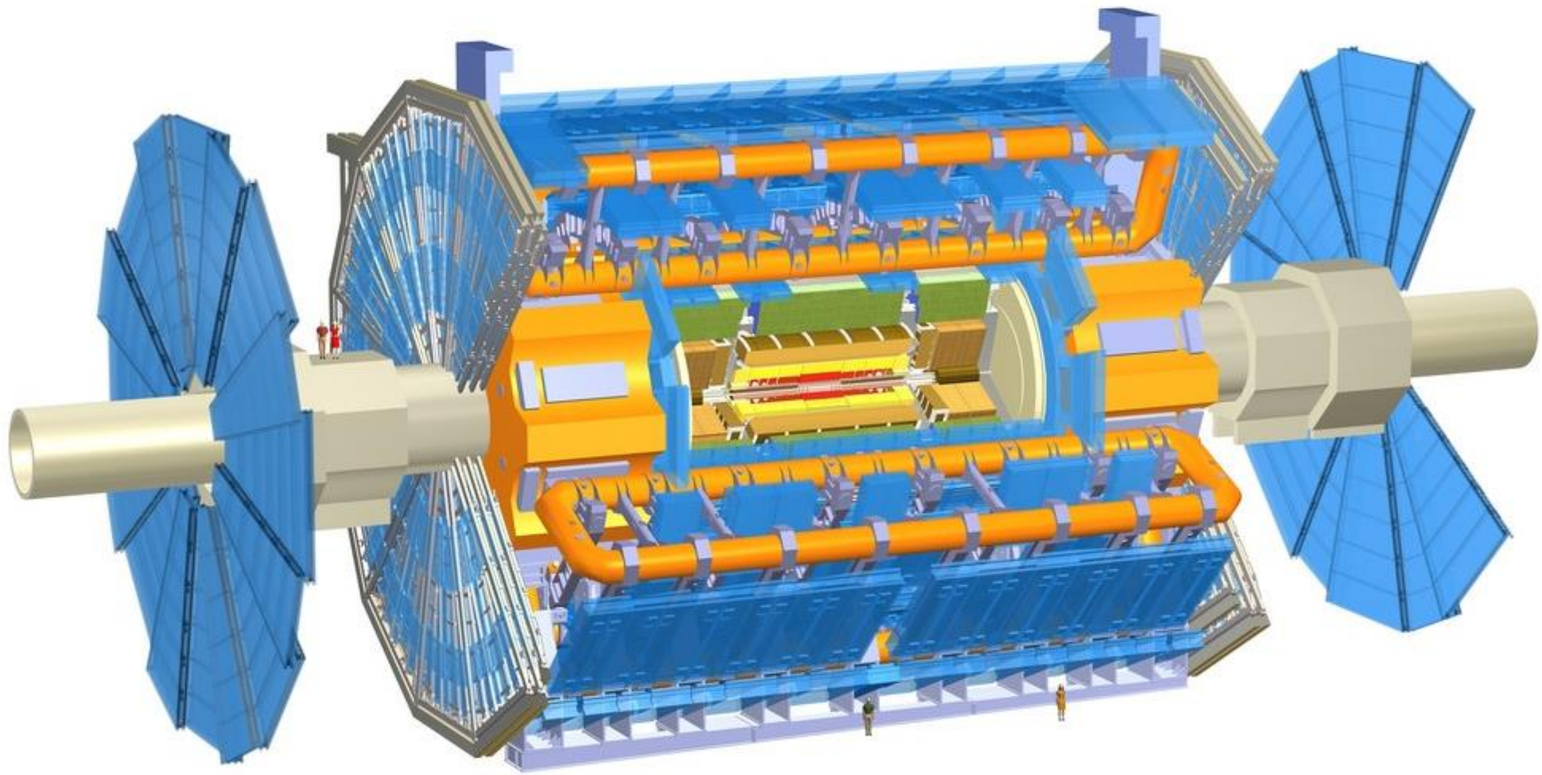
Principle of collider experiment

- LHC uses proton-proton collisions
- All detectors are build symmetrically around the collision point
- Each layer of the detector identifies a different particle type
- The collision energy converts into new particles
- We deduce the presence of the short-lived decayed particles (such as W and Z bosons) by looking at the end products of the collision



ATLAS: A Toroidal LHC ApparatuS



Looking at ATLAS in more detail

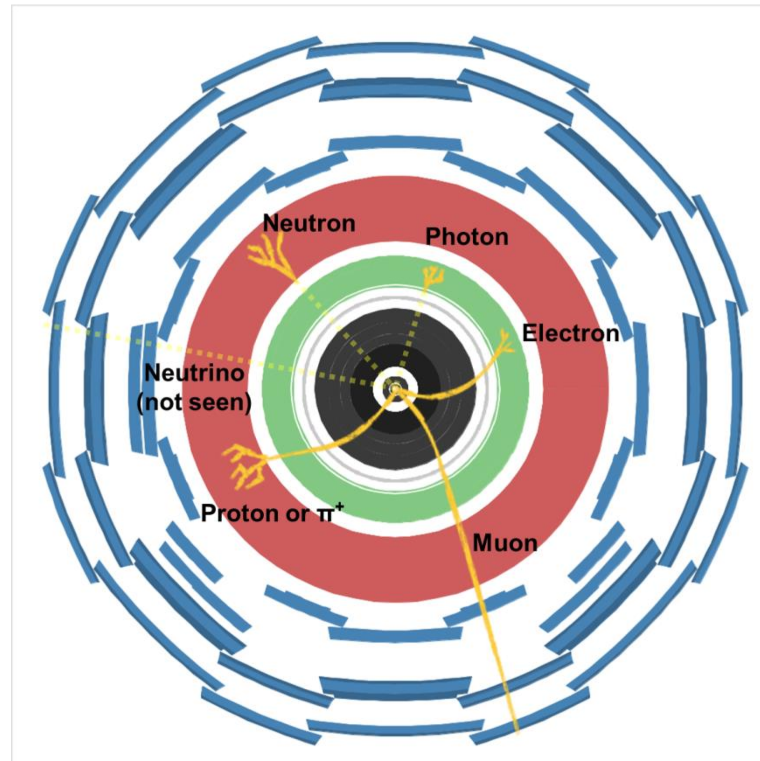
Identifying Particles

Inner Detector: measures charge and momentum of charged particles (neutral particles don't leave tracks)

Electromagnetic Calorimeter: measures energy of electrons, positrons and photons

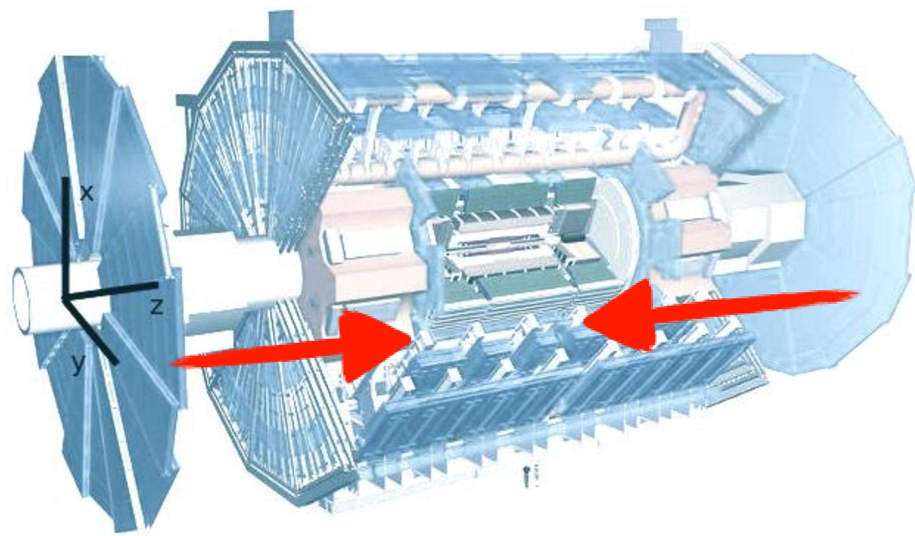
Hadronic Calorimeter: measures energy of particles containing quarks, (e.g. protons, pions, neutrons)

Muon Spectrometer: measures charge and momentum of muons



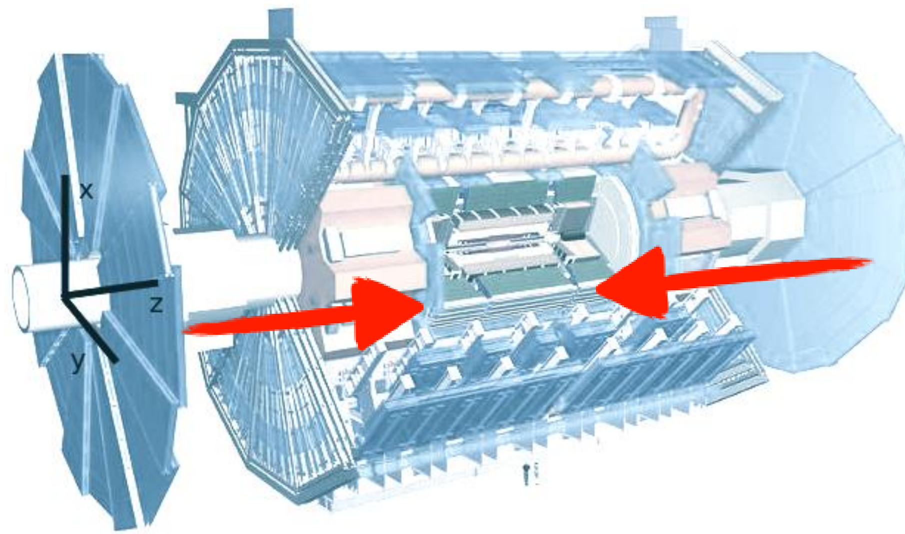
Importance of Transverse Momentum

- protons move in the z-direction only
- In x-y, directions momentum is zero; this must be conserved after the collision
- the particle's **transverse** momentum (in x-y plane) can be measured
- Interesting collisions contain particles with big transverse momentum



Missing Energy and neutrinos

- ATLAS does not detect neutrinos
- If neutrinos are present after the collision there will be some missing momentum in the data



Aims for today's exercises

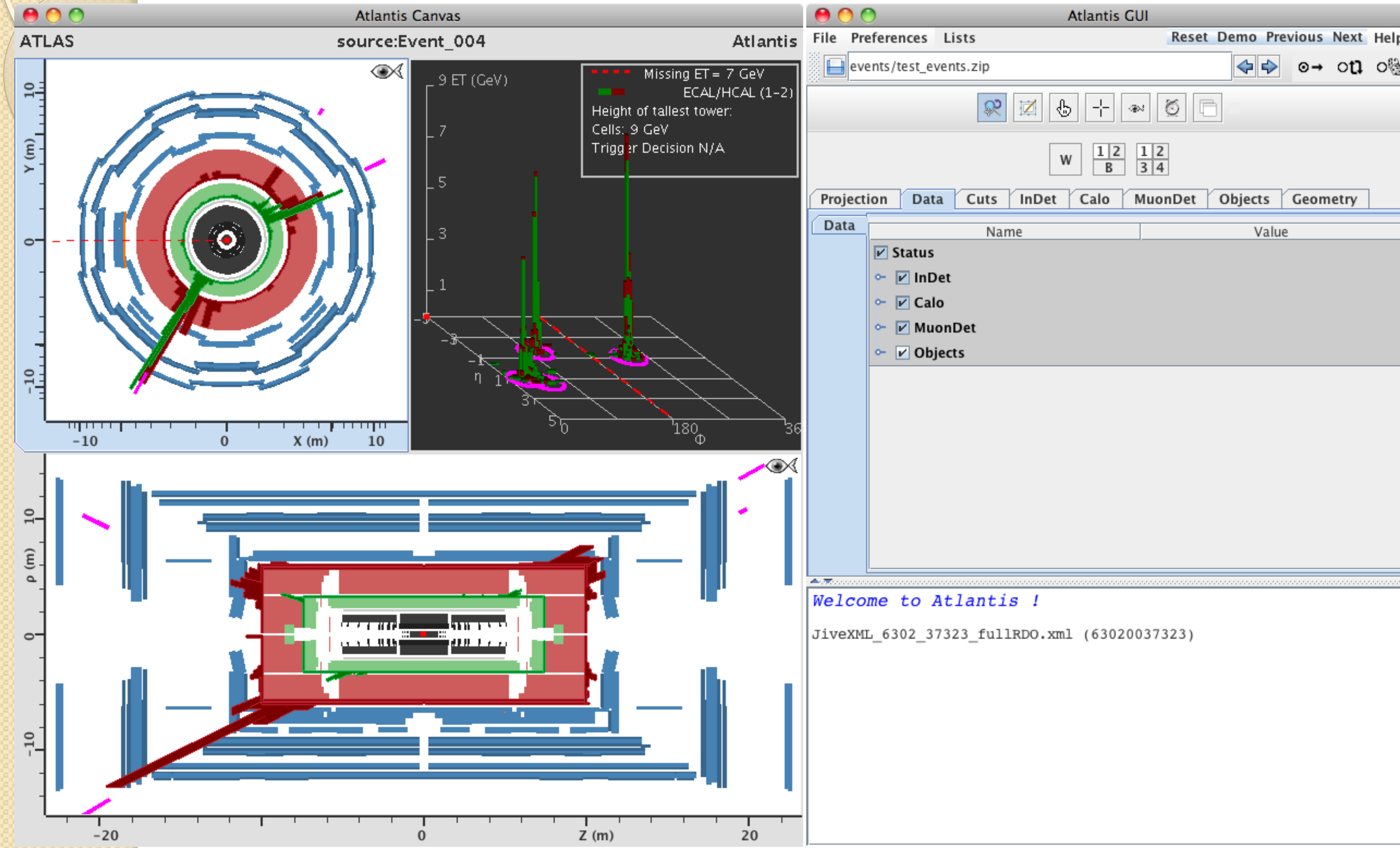
1. Identify the particles detected by ATLAS with the Atlantis Event Display

2. Determine the types of events you are looking at:

   i. W → electron + neutrino
   ii. W → muon + neutrino
   iii. Z → electron + positron
   iv. Z → muon + anti-muon
   v. Background
   vi. H → 4 leptons (leptons: electrons, muons)

3. Measure the rest mass of the Z boson from selected Z candidates

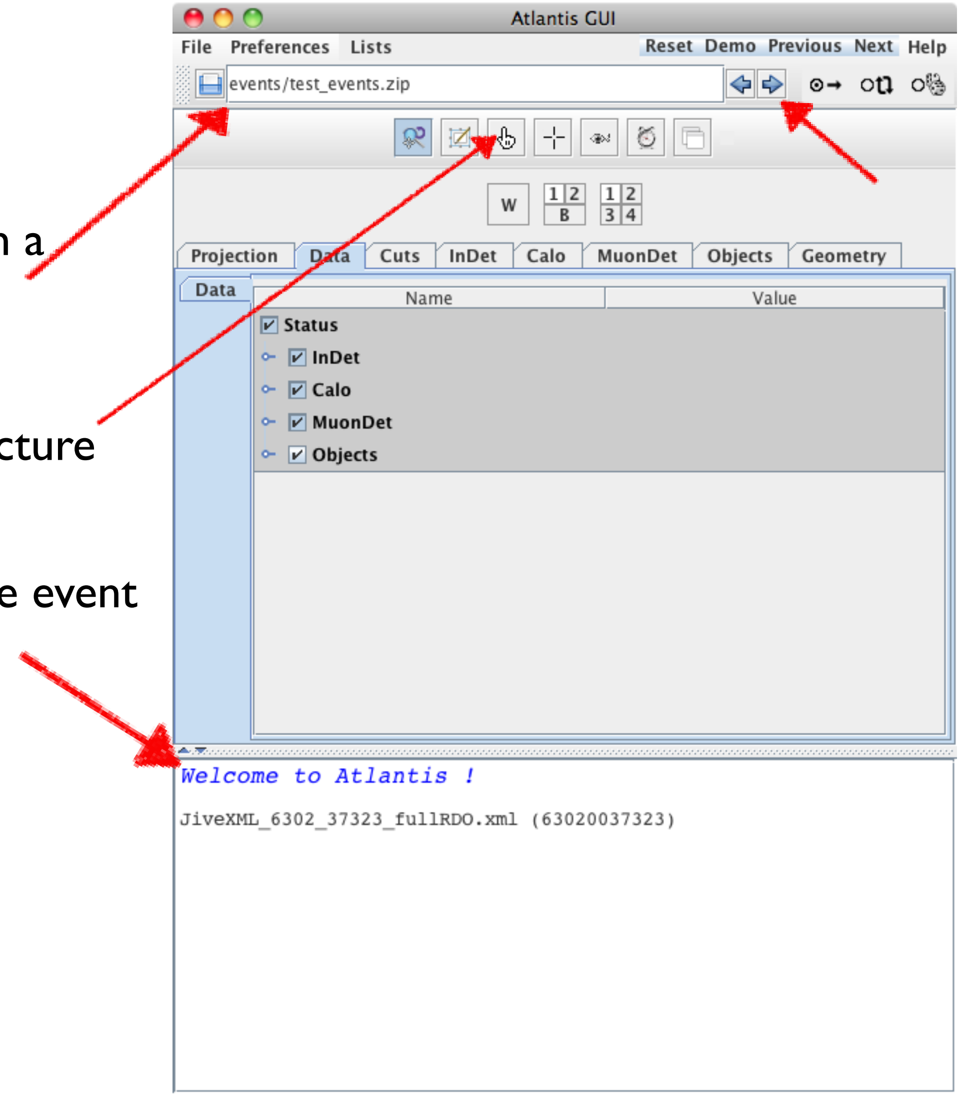
Atlantis


Atlantis Canvas
ATLAS
source:Event_004
Atlantis
Y (m)
X (m)
ρ (m)
Z (m)
Missing ET = 7 GeV
ECAL/HCAL (1-2)
Height of tallest tower:
Cells: 9 GeV
Trigger Decision N/A
ET (GeV)
η
Φ
Atlantis GUI
File
Preferences
Lists
Reset
Demo
Previous
Next
Help
events/test_events.zip
Projection
Data
Cuts
InDet
Calo
MuonDet
Objects
Geometry
Name
Value
Status
InDet
Calo
MuonDet
Objects
Welcome to Atlantis !
JiveXML_6302_37323_fullRDO.xml (63020037323)

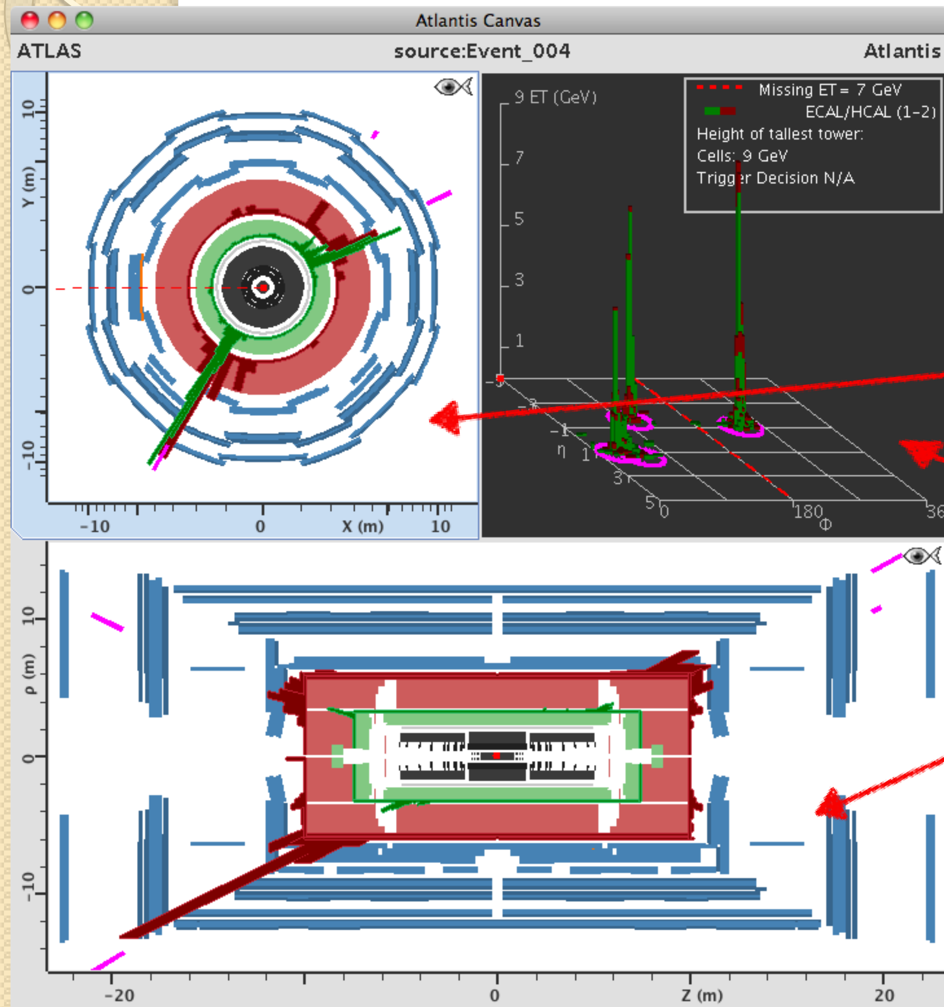
The Graphical User Interface (GUI)

From the GUI you can:

- Load and navigate through a collection of events
- Interact with the event picture
- View output data from the event



The Canvas



The Canvas shows:

- The end-on view of the detector
- Energy shown in 'rolled out' calorimeters
- The side view of the detector

Event sheet to complete

W/Z Ratio in the ATLAS Expt. at the LHC

Event Number	$W \rightarrow e\,\nu$	$W \rightarrow \mu\,\nu$	$Z \rightarrow e\,e$	$Z \rightarrow \mu\,\mu$	$H \rightarrow 4l$ ($l = e, \mu$)	Background
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
TOTALS						

Event sheet answers

ATLAS Expt. at the LHC

Teacher's sheet for recognising the 20 events in Minerva (after 5 tutorial events)

Event Number	$W \to e\nu$	$W \to \mu\nu$	$Z \to e\,e$	$Z \to \mu\,\mu$	$H \to 4l$ ($l=e,\mu$)	Background
1	X					
2		X				
3						X
4						X
5	X					
6						X
7		X				
8			X			
9						X
10		X				
11		X				
12	X					
13						X
14	X					
15						X
16					X	
17						X
18	X					
19		X				
20						X
TOTALS	5	5	1		1	8

Observed patterns: W and Z decays

- $\frac{W \rightarrow e\ v}{W \rightarrow \mu\ v} = 1$
- $\frac{Z \rightarrow e\ e}{Z \rightarrow \mu\ \mu} = 1$
- $\frac{W}{Z} = 10.2$

Some reasons for this difference:

How often W and Z decay into leptons:

1. $\frac{Z \rightarrow l\ l}{Z \rightarrow all} = 3.4\%$
2. $\frac{W \rightarrow l\ v}{W \rightarrow all} = 10.8\%$

In addition:

$W \sim 13\%$ lighter than Z

Calculating the rest mass of Z

- In general, for any particle, using the usual SI units

$$E^2=p^2c^2+m^2c^4$$

where m is the rest mass of the particle, E its total energy, p its momentum and c the speed of light in vacuum.

- If a Z boson decays into e^- and e^+ then energy and momentum must be conserved:

$E_{e+} + E_{e-} = E_Z$ and $p_{e+} + p_{e-} = p_z$

- Then m_z can be calculated as

$$m_z^2 = (E_z^2 - p_z^2c^2)/c^4$$

Units for particle physicists

- Particle physicists work with less familiar units that simplify the above equation to

$$E^2=p^2+m^2$$

where

E is measured in GeV

m is measured in GeV/c^2

p is measured in GeV/c

- So in these units

$$m^2= E^2 - p^2$$

- For electrons and muons $m<<p$, so we can approximate this with the equation

$$E=p$$

Example of spreadsheet calculation

$$\sqrt{(P_x{}^2 + P_y{}^2 + P_z{}^2)}$$

$$\sqrt{(P_{x[e]}{}^2 + P_{y[e]}{}^2 + P_{z[e]}{}^2)}$$

$$E_e + E_p$$

$$\sqrt{E^2 - p^2}$$

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	EVENT	ELECTRON (OR MUON)			POSITRON (OR ANTIMUON)			total	total	total	momentum of	Ee	Ep	energy of	rest mass of
2	NUMBER	Px[e]	Py[e]	Pz[e]	Px[p]	Py[p]	Pz[p]	Px	Py	Pz	Z boson			Z boson	Z boson
3	Z1							0	0	0	0	0	0	0	0
4	Z2							0	0	0	0	0	0	0	0
5	Z3							0	0	0	0	0	0	0	0
6	Z4							0	0	0	0	0	0	0	0
7	Z5							0	0	0	0	0	0	0	0
8	Z6							0	0	0	0	0	0	0	0
9	Z7							0	0	0	0	0	0	0	0
10	Z8							0	0	0	0	0	0	0	0
11	Z9							0	0	0	0	0	0	0	0
12	Z10							0	0	0	0	0	0	0	0
13	Z11							0	0	0	0	0	0	0	0
14	Z12							0	0	0	0	0	0	0	0
15	Z13							0	0	0	0	0	0	0	0
16	Z14							0	0	0	0	0	0	0	0
17	Z15							0	0	0	0	0	0	0	0
18	Z16							0	0	0	0	0	0	0	0
19	Z17							0	0	0	0	0	0	0	0
20	Z18							0	0	0	0	0	0	0	0
21	Z19							0	0	0	0	0	0	0	0
22	Z20							0	0	0	0	0	0	0	0

Answers: spreadsheet calculations

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	EVENT	ELECTRON (OR MUON)			POSITRON (OR ANTIMUON)			total	total	total	momentum of	Ee	Ep	energy of	rest mass of
2	NUMBER	Px[e]	Py[e]	Pz[e]	Px[p]	Py[p]	Pz[p]	Px	Py	Pz	Z boson			Z boson	Z boson
3	Z1	-45.9	13.423	-18.66	44.32	-13.769	-15.965	-1.615	-0.346	-34.6	34.66437027	51.37	49.082	100.45132	94.28069279
4	Z2	-28.2	32.58	-87.12	24.49	-33.343	-40.244	-3.69	-0.763	-127	127.4177276	97.19	57.717	154.90448	88.09154499
5	Z3	-29.3	31.729	31.304	28.19	-28.407	-14.387	-1.08	3.322	16.92	17.27388124	53.32	42.527	95.849011	94.27961537
6	Z4	-49.6	39.475	-105.6	18.58	-25.839	-74.658	-30.98	13.636	-180	183.4149897	123.2	81.157	204.31163	90.0121262
7	Z5	-1.86	13.022	81.957	5.24	-12.27	-29.895	3.377	0.752	52.06	52.17682893	83.01	32.737	115.74314	103.3153091
8	Z6	7.957	36.855	-33.67	-10.5	-48.394	-132.507	-2.502	-11.54	-166	166.5989223	50.55	141.45	192.00657	95.453236
9	Z7	-13.2	39.756	5.343	10.45	-46.144	-0.308	-2.777	-6.388	5.035	8.594736645	42.24	47.314	89.55353	89.14014386
10	Z8	31.03	23.514	34.044	-30.7	-32.907	11.469	0.362	-9.393	45.51	46.4735695	51.72	46.423	98.143169	86.44240246
11	Z9	39.05	34.091	-137.2	2.991	-47.48	-216.711	42.04	-13.39	-354	356.6484587	146.7	221.87	368.53516	92.84416254
12	Z10	6.061	1.558	-21.88	-29.7	-34.245	-52.274	-23.6	-32.69	-74.2	84.40015695	22.75	69.172	91.925543	36.4268994
13	Z11	-44	8.566	20.185	40.21	-6.342	4.944	-3.839	2.224	25.13	25.51765542	49.2	41.001	90.201747	86.51707549
14	Z12	45.21	-47.719	430.66	-17.7	-2.312	10.688	27.55	-50.03	441.3	445.0275253	435.6	20.766	456.41212	101.3040996
15	Z13	-18.8	44	-22.35	7.267	-33.229	10.048	-11.5	10.771	-12.3	19.99008867	52.8	35.467	88.266312	85.97289237
16	Z14	3.037	39.857	20.878	-0.12	-36.359	7.605	2.917	3.498	28.48	28.84486405	45.1	37.146	82.242531	77.01822993
17	Z15	-39.7	26.059	-5.03	36.46	-17.801	-16.667	-3.251	8.258	-21.7	23.4419149	47.76	43.86	91.620062	88.57038058
18	Z16	-23.5	14.864	-6.878	40.45	-43.479	-14.086	16.98	-28.62	-21	39.32891782	28.62	61.032	89.648037	80.56057846
19	Z17	39.01	8.976	14.788	-42.8	-8.871	38.829	-3.837	0.105	53.62	53.75422107	42.67	58.501	101.17523	85.71412079
20	Z18	29.65	16.426	3.183	-28.4	-43.193	40.528	1.222	-26.77	43.71	51.2700409	34.04	65.697	99.738459	85.55199108
21	Z19	4.652	-18.777	-44.76	-13.4	26.781	29.895	-8.75	8.004	-14.9	19.01486292	48.76	42.315	91.075336	89.06824233
22	Z20	-47.6	7.044	9.733	46.68	0.949	10.577	-0.879	7.993	20.31	21.84391883	49.06	47.876	96.93165	94.4382765
23															

Answer: Rest mass of Z boson

- Use the histogram to calculate the rest mass of the Z boson with an appropriate uncertainty from the spread

- Compare your value to the current value of

$$91.1876 \pm 0.0021\ GeV/c^2$$

Art Exhibition on Particle Collisions

Artists get inspiration from the world around them!

http://artcms.web.cern.ch/