

The Z and Higgs bosons: let's discover them with the ATLAS detector!

Dott. Michele Pinamonti, Dott. Giancarlo Panizzo
Mohammed Faraj, Jacopo Magro

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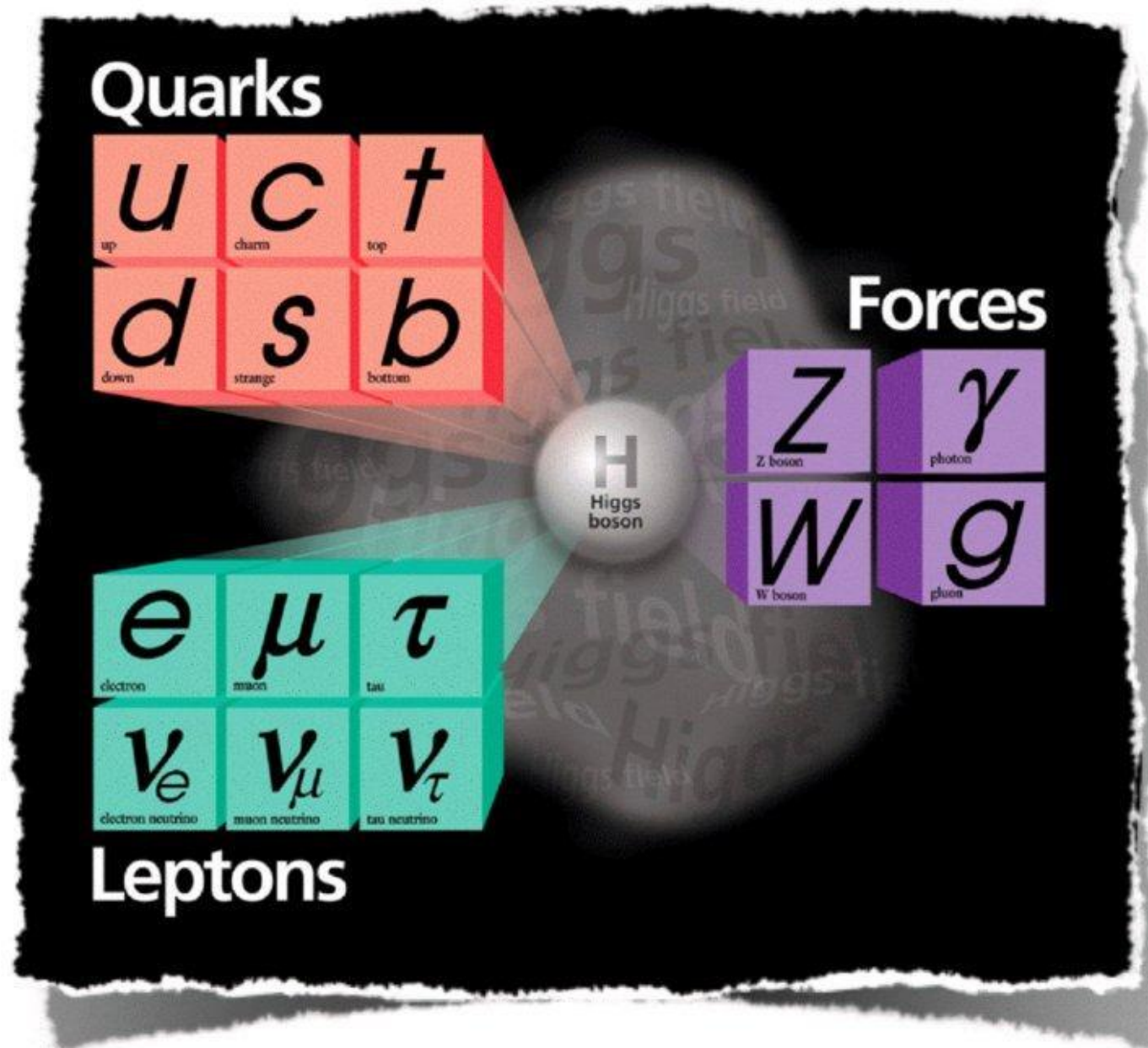
Particle Physics Summer School 2018, University of Udine
23/07/2018



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THE SM PARTICLES





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THE SM PARTICLES

QUARKS



UP QUARK

A teeny little point inside the proton and neutron, it is friends forever with the down quark.



CHARM QUARK

A second generation quark, it is charmed, indeed.



TOP QUARK

This heavyweight champion doesn't live long enough to make friends with anyone.

DOWN QUARK

A tiny little point inside the proton and neutron, it is friends forever with the up quark.



STRANGE QUARK

Why is this second generation quark so strange?



BOTTOM QUARK

This third generation quark is puttin' on the pounds.



LEPTONS

ELECTRON-NEUTRINO

These miniscule bandits like to steal away energy and escape detection.



MUON-NEUTRINO

A slightly heavier bandit than its sibling to the left.



TAU-NEUTRINO

Wily and sneaky, this bandit is the newest particle to arrive at the Zoo.



ELECTRON

A familiar friend, this negatively charged, busy fella likes to bond.



MUON

A "heavy electron" who lives fast and dies young.



TAU

A "heavy muon" who could stand to lose a little weight.

FORCE CARRIERS



PHOTON

The "light" waveicle we know and love.



GLUON

The "glue" of the strong nuclear force.



W BOSON

Z BOSON



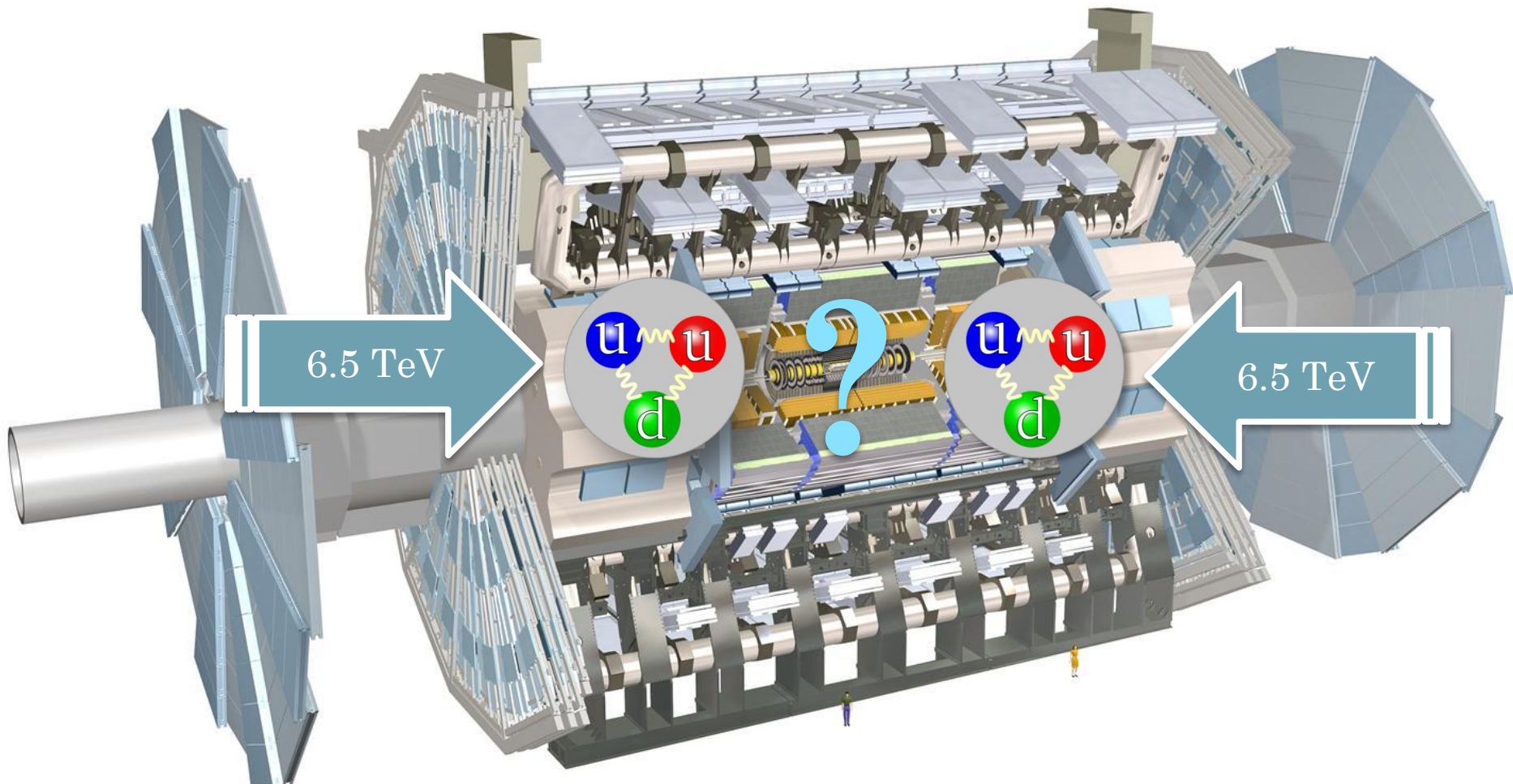
As the carrier particles of the weak nuclear force, they're downright bossy.



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WHAT HAPPENS IN P-P COLLISIONS?



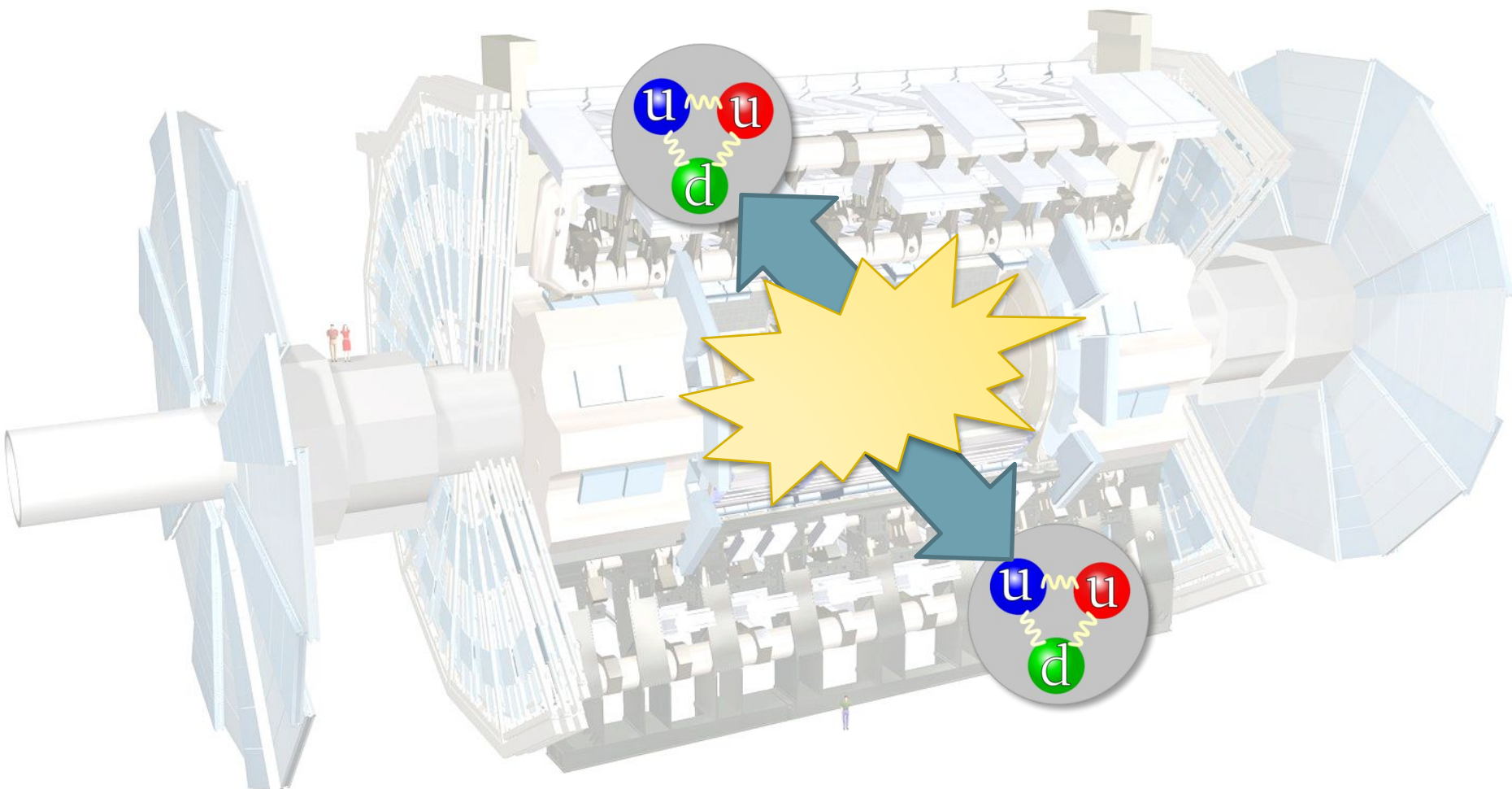


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WHAT HAPPENS IN P-P COLLISIONS?

- Elastic scattering





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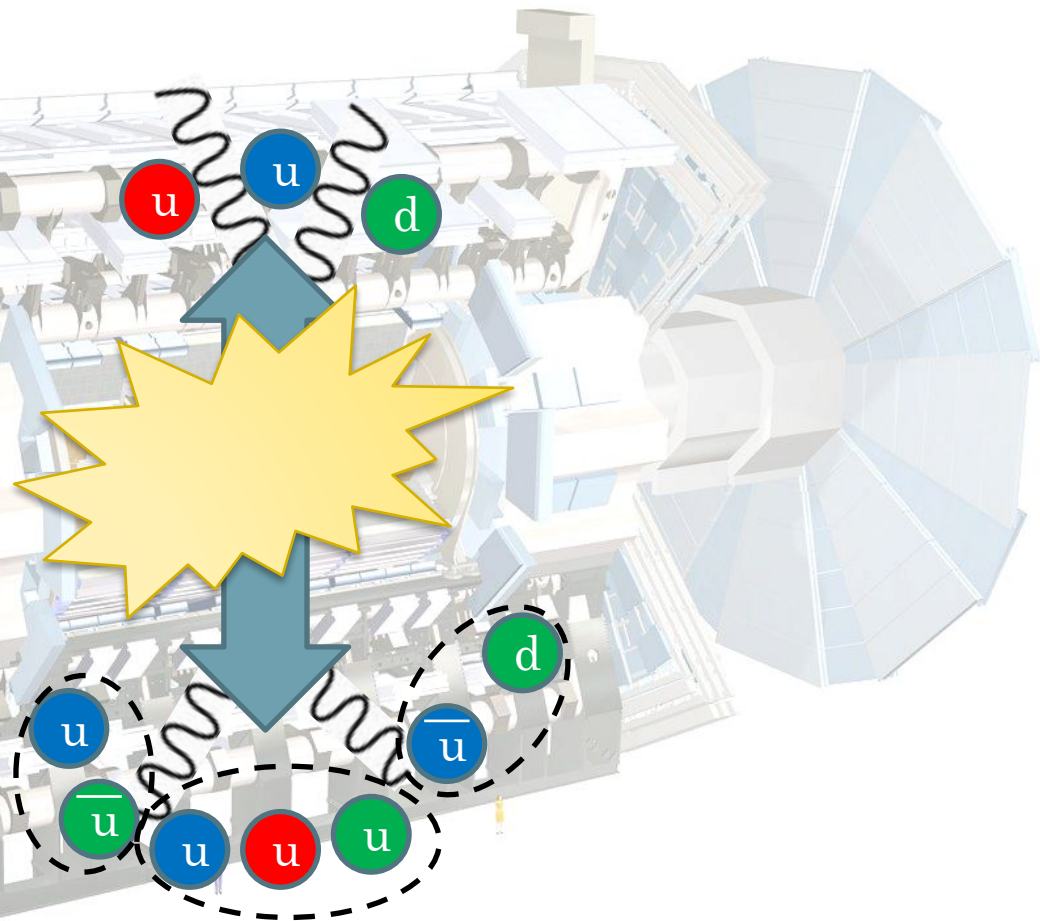
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WHAT HAPPENS IN P-P COLLISIONS?

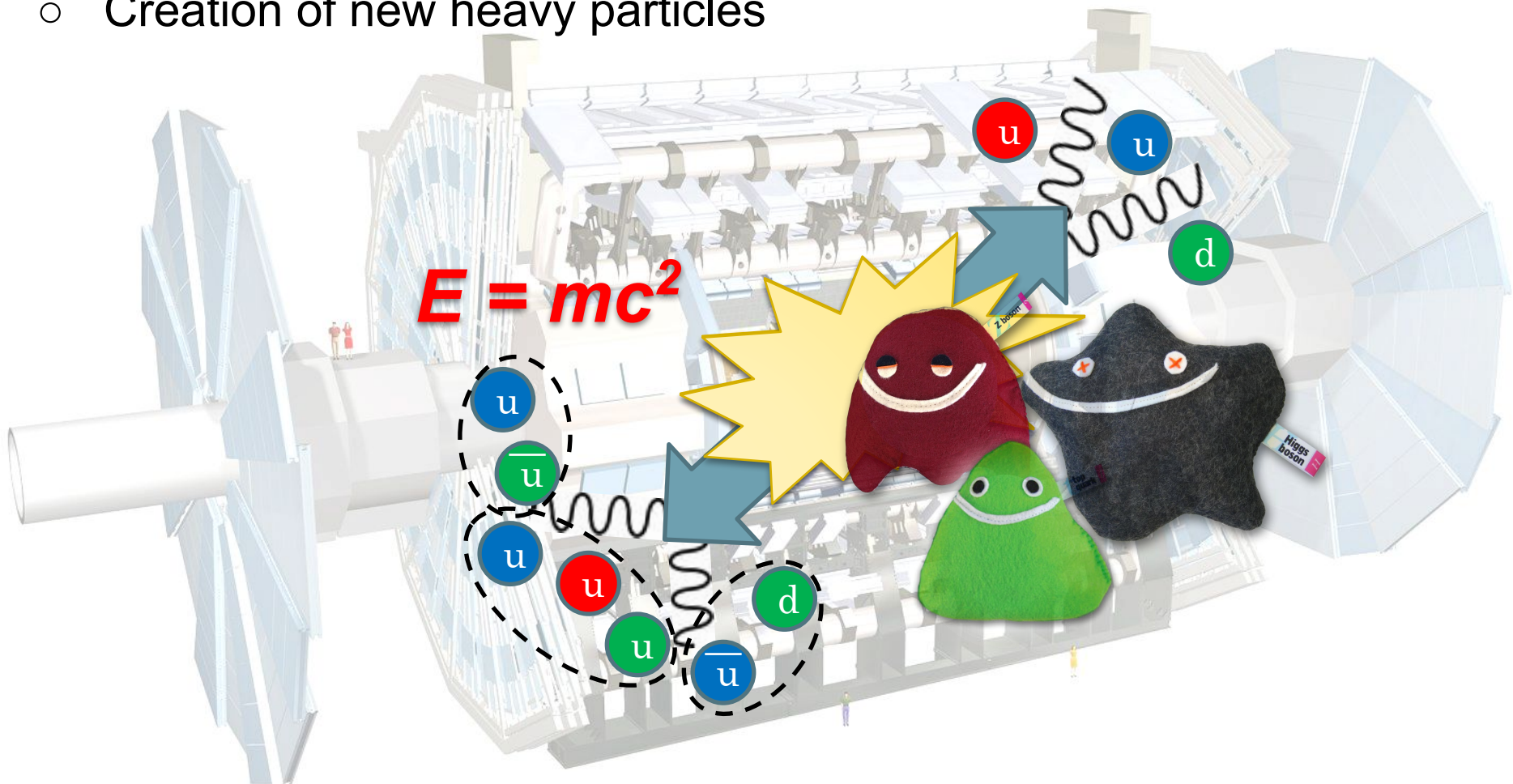
- Elastic scattering
- Inelastic scattering

Jets:

- the force between quarks is so strong that it materializes into new quarks
- quarks form bound states \rightarrow hadrons ($p, n, \pi \dots$)



- Elastic scattering
- Inelastic scattering
- **Creation of new heavy particles**





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HOW CAN WE SEE PARTICLES?

- Most of the particles are unstable
- Very heavy particles (like the Z and Higgs bosons) decay immediately (after $3 \times 10^{-25} = 0.0000000000000000000000000000003$ sec)
- The decay conserves:
 - the electric charge
 - the energy

Z boson:

- electric charge = 0
- mass = $91 \text{ GeV}/c^2$





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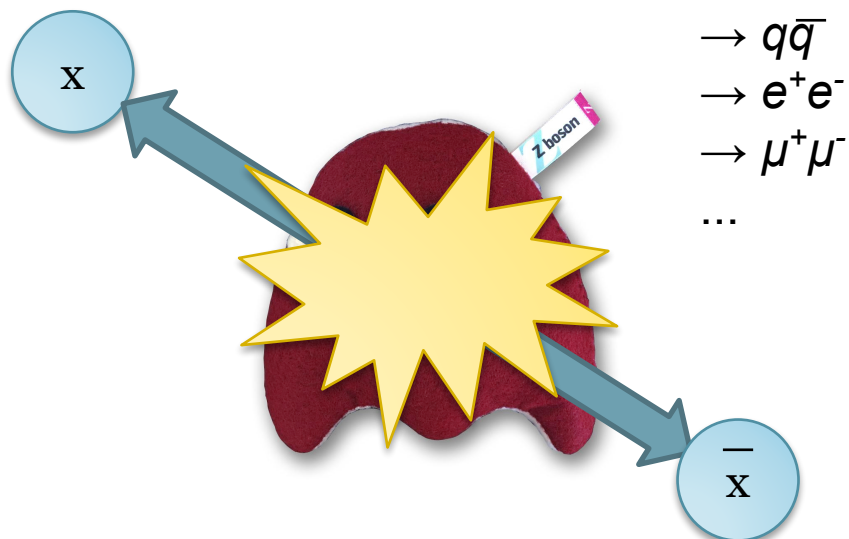
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HOW CAN WE SEE PARTICLES?

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 - ➔ the energy

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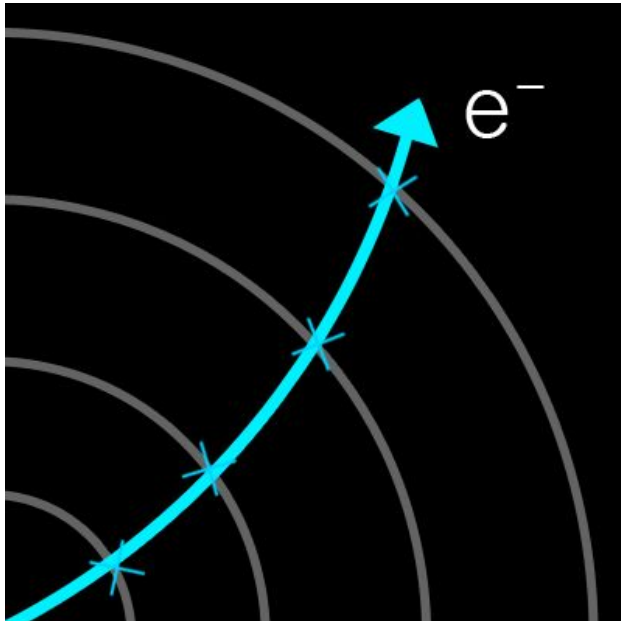
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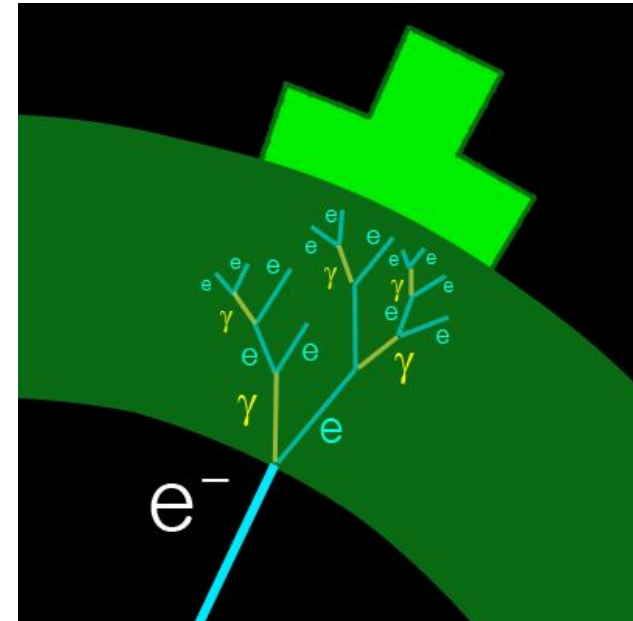
HOW CAN WE SEE PARTICLES?

- To see and measure stable particles we use **particle detectors**
 - ➔ many different types and technologies, that can:
 - see different types of particles, of different energies
 - measure different properties (energy, direction, charge...)
- Two main types of detectors:

“Trackers”



“Calorimeters”





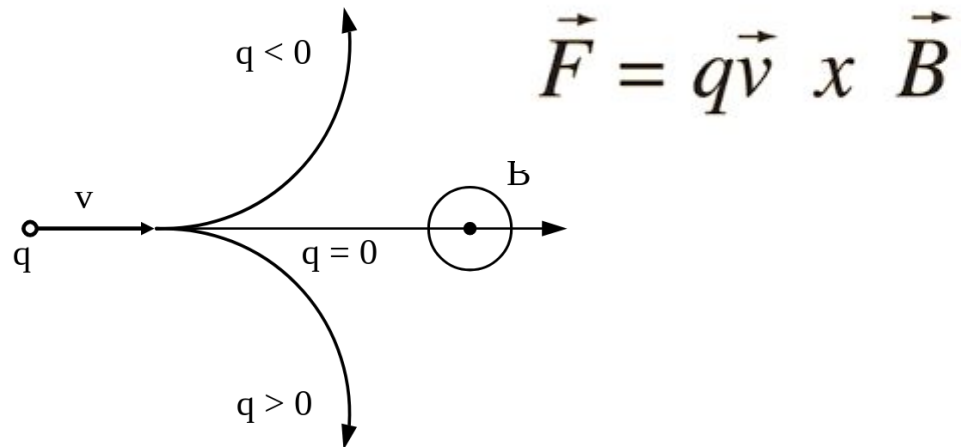
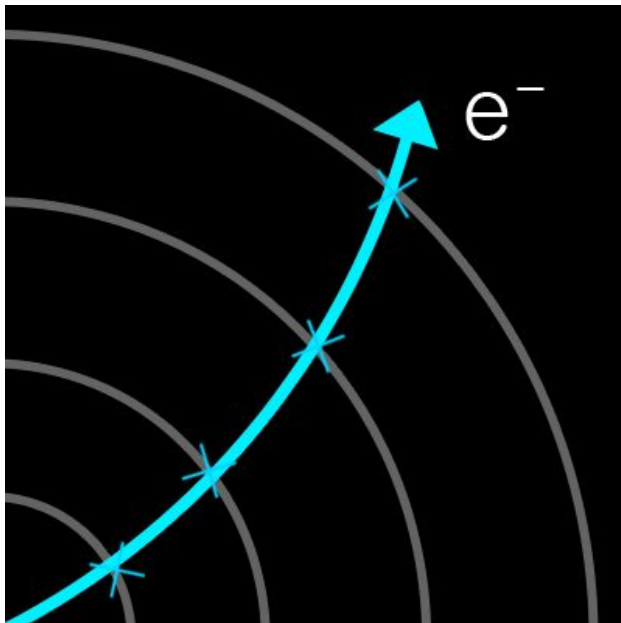
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HOW CAN WE SEE PARTICLES?

- thin layers \Rightarrow small perturbation of particle motion
- precise **trajectory** determination
- immerse in **magnetic fields** \Rightarrow measure **momentum**
 - direction of curvature \Rightarrow sign of electric **charge**

“Trackers”



Technology:

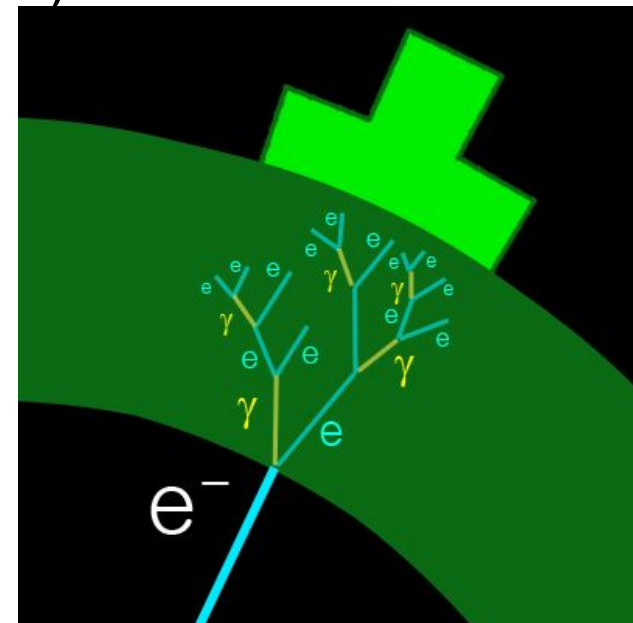
- silicon detectors (e.g. pixel)
- proportional chambers (gas detectors)



HOW CAN WE SEE PARTICLES?

- heavy and thick \Rightarrow **stop** particles
- particles interact with material and dissipate their entire kinetic energy \rightarrow collected and measured
- often built to stop and measure:
 - either electrons and photons (EM-Cal)
 - or hadronic particles (Had-Cal)

“Calorimeters”



Technology:

- heavy materials as “absorbers” (metals)
- active materials often scintillators

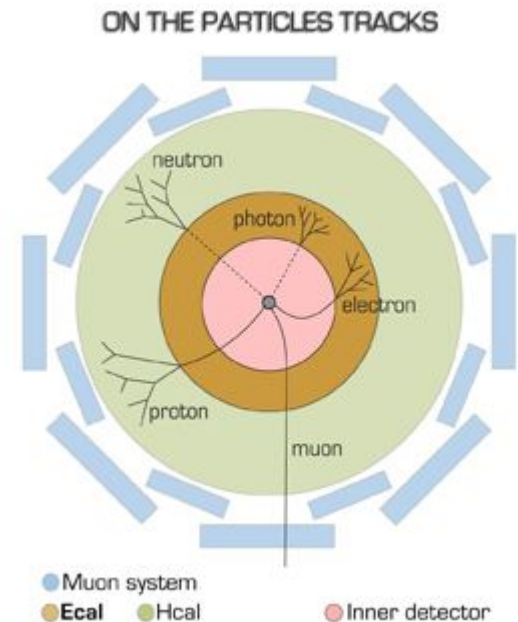
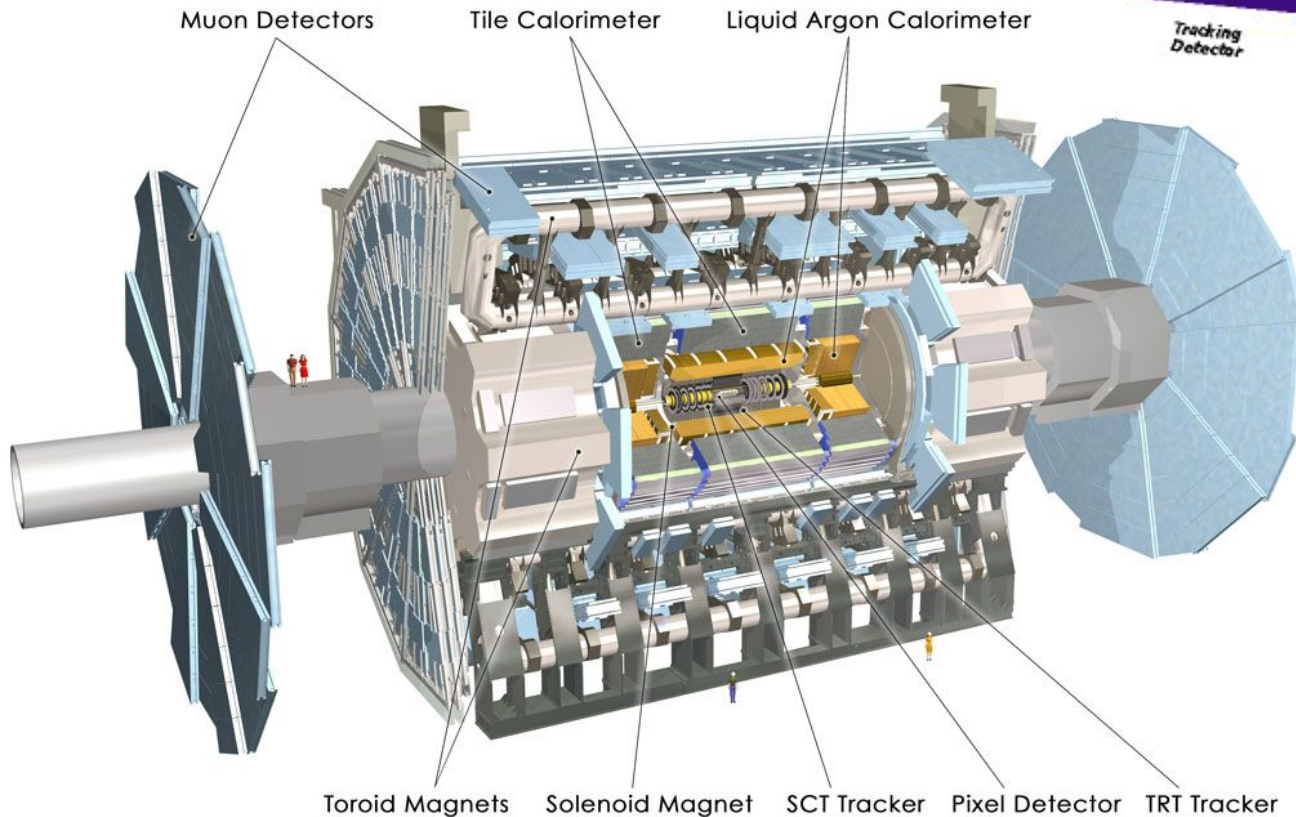
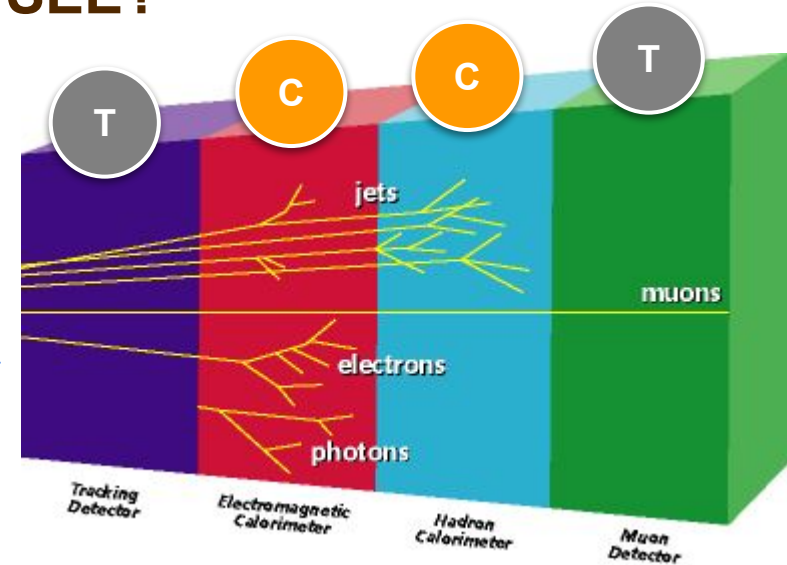


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WHAT CAN ATLAS SEE?

- ATLAS is built with several layers of different detectors
- can see and measure almost all stable particles





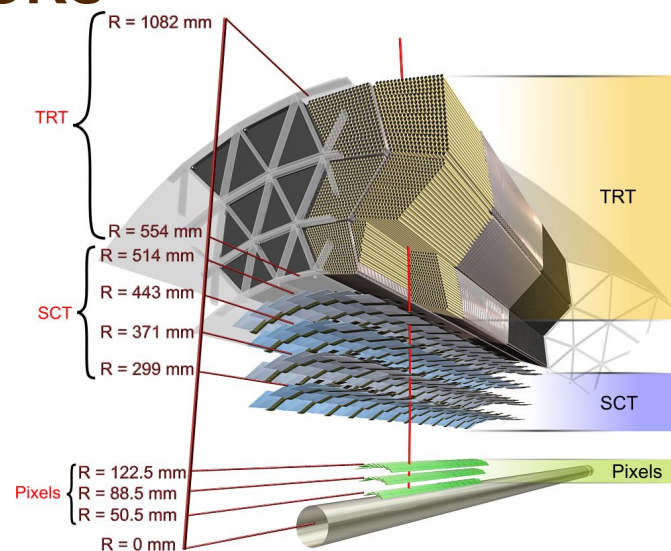
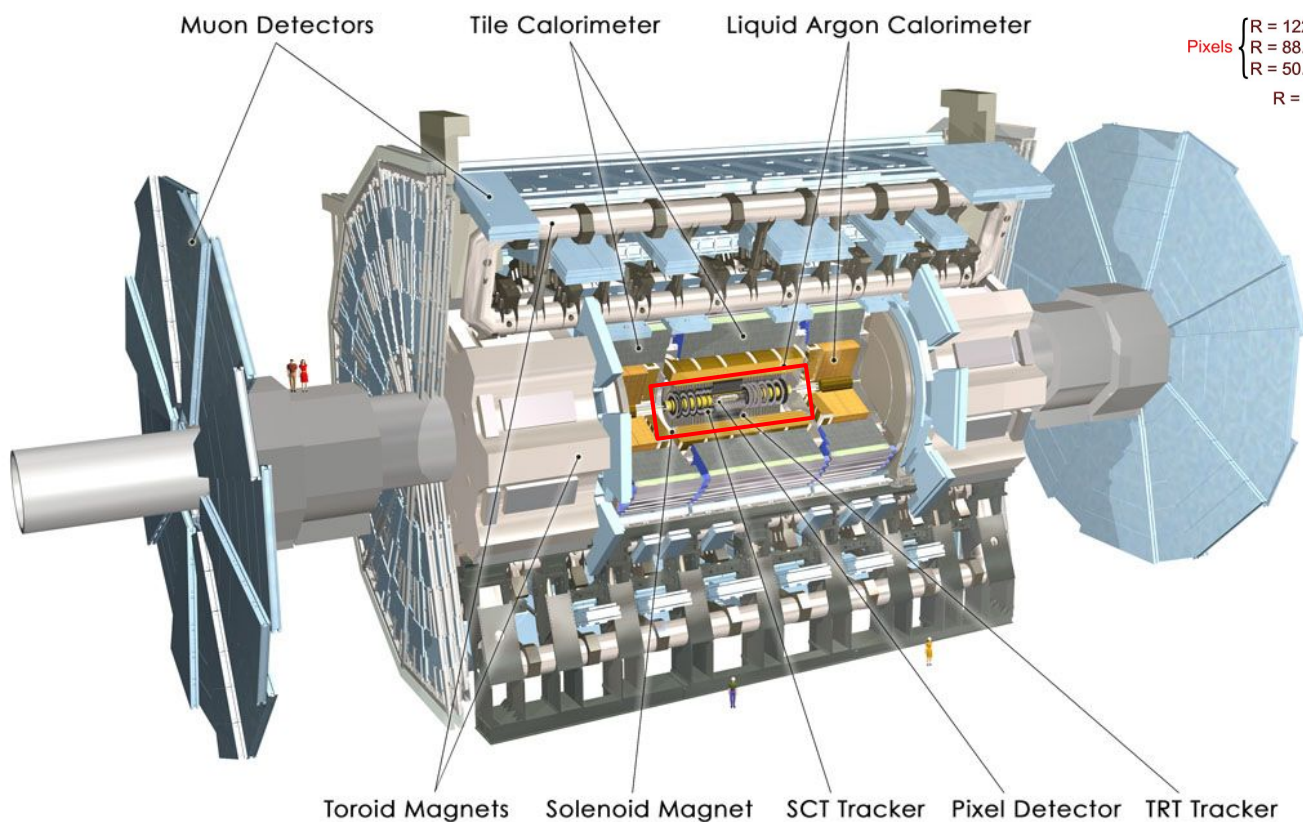
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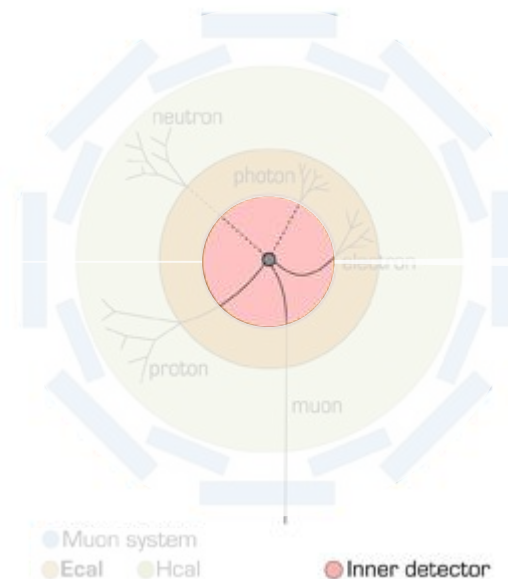
ATLAS SUB-DETECTORS

T

The Inner Detector



ON THE PARTICLES TRACKS





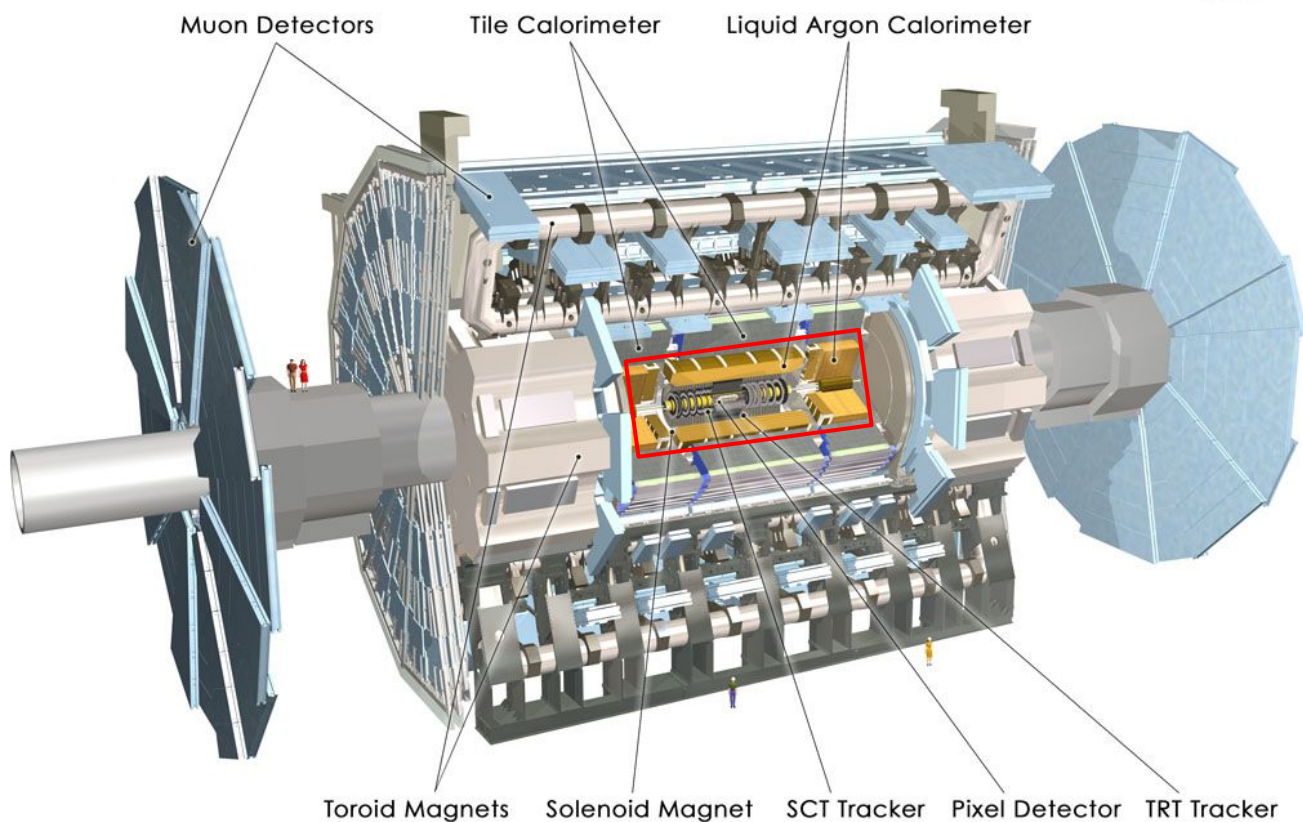
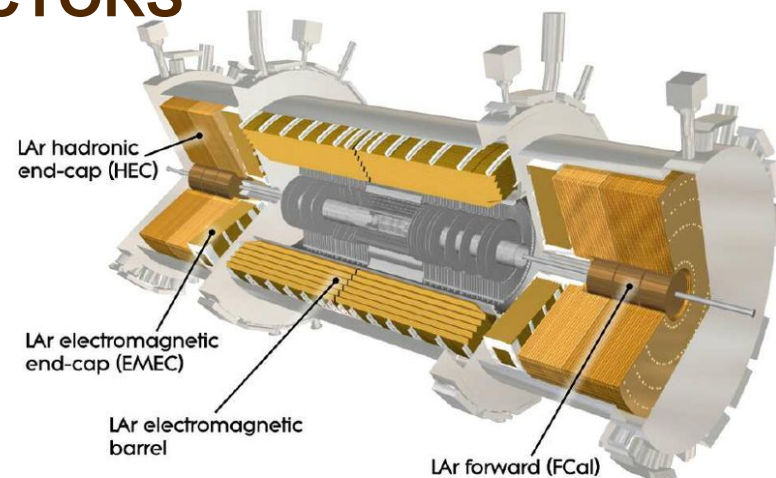
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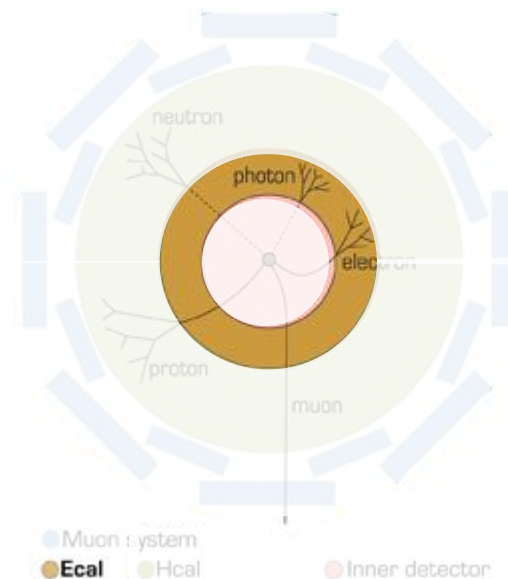
ATLAS SUB-DETECTORS

c

The EM-Calorimeter



ON THE PARTICLES TRACKS





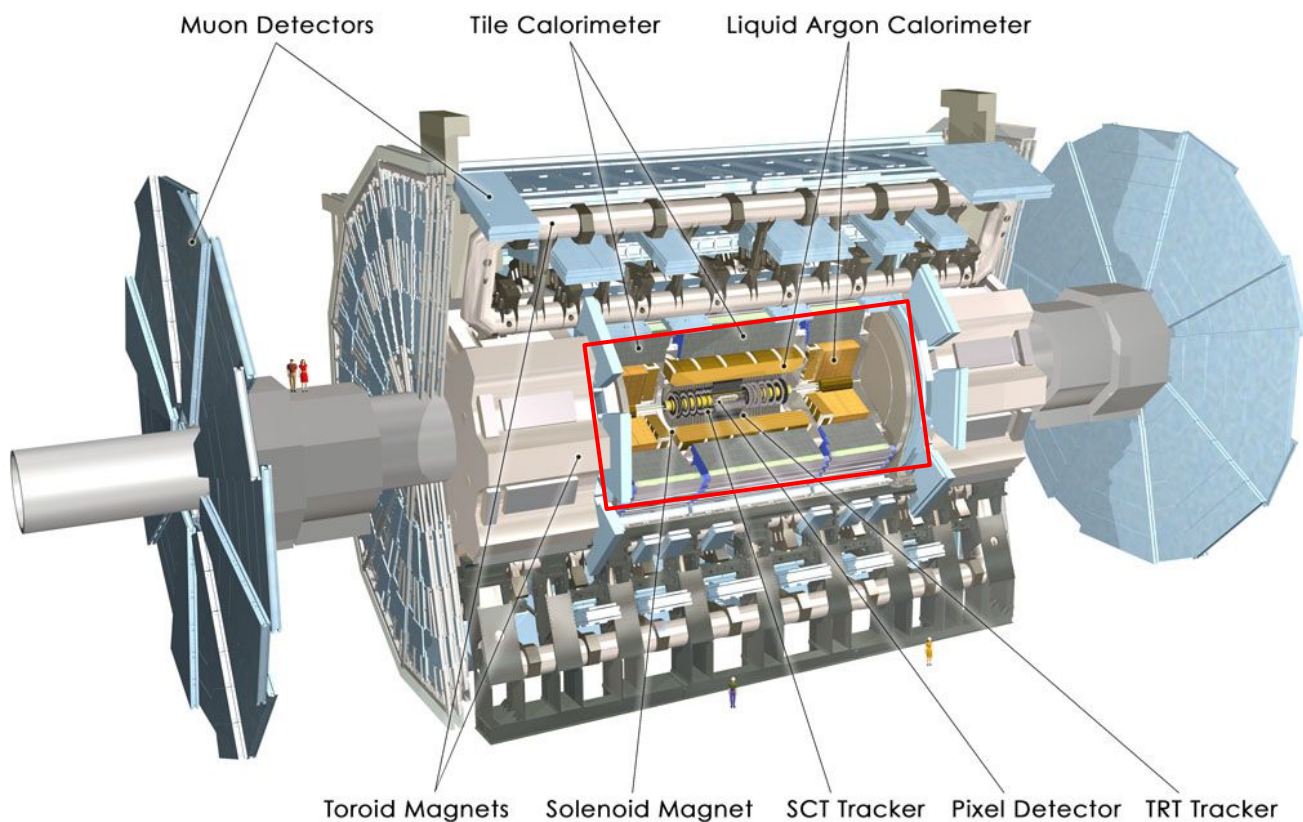
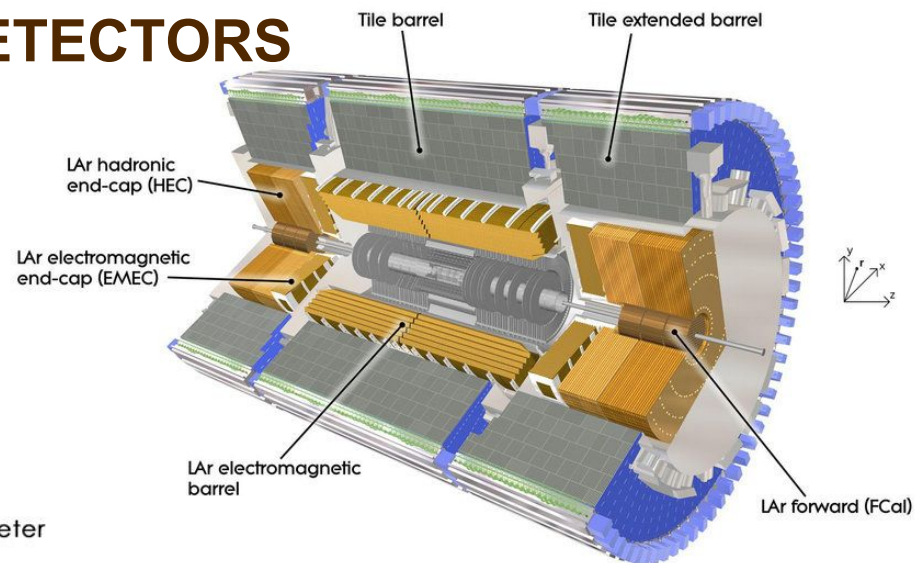
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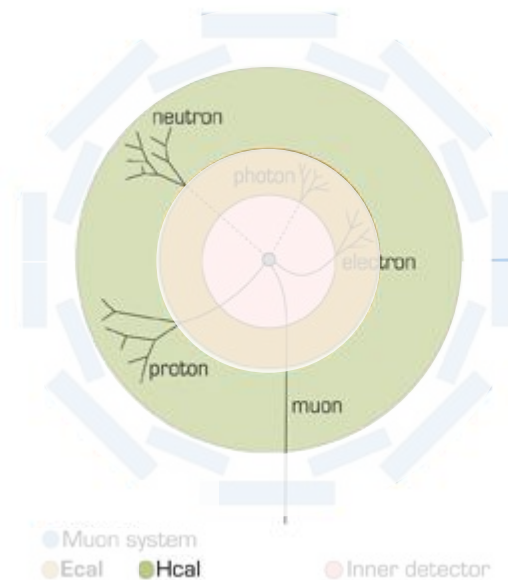
ATLAS SUB-DETECTORS

c

The Hadronic-Calorimeter



ON THE PARTICLES TRACKS



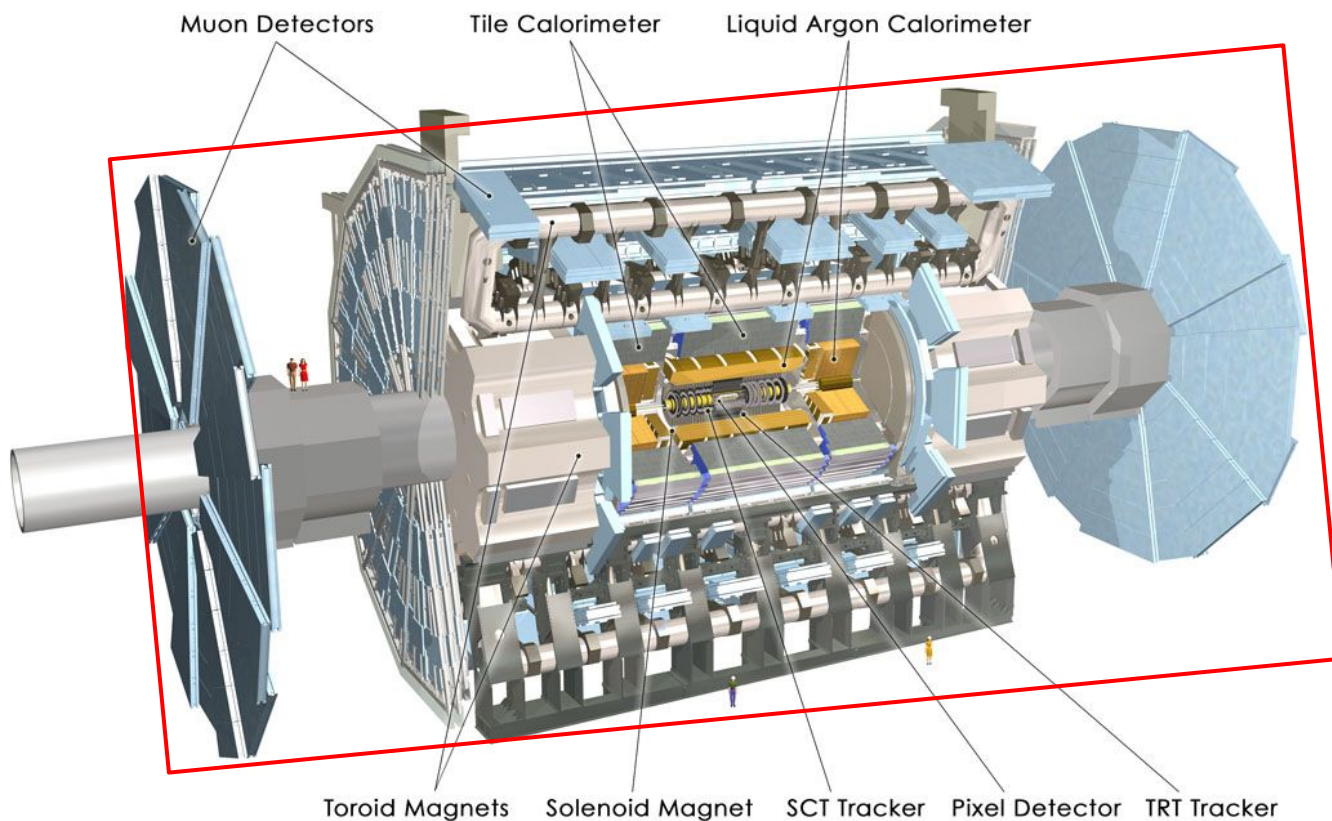
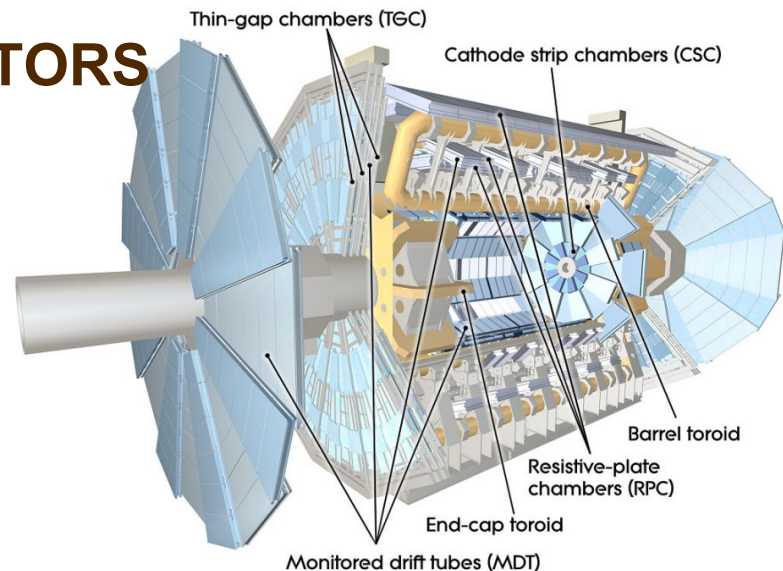


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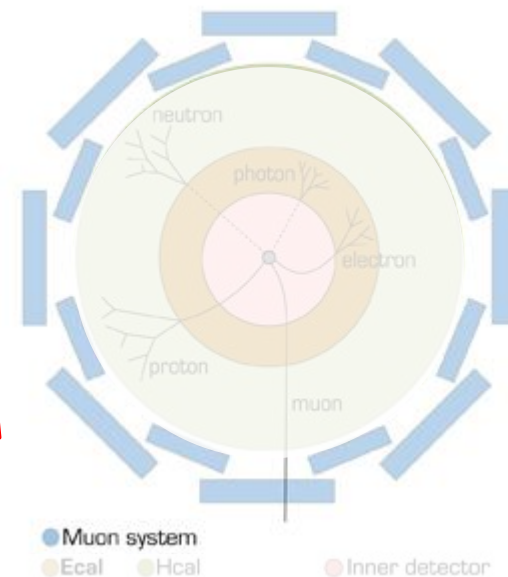
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ATLAS SUB-DETECTORS

The Muon Spectrometer



ON THE PARTICLES TRACKS



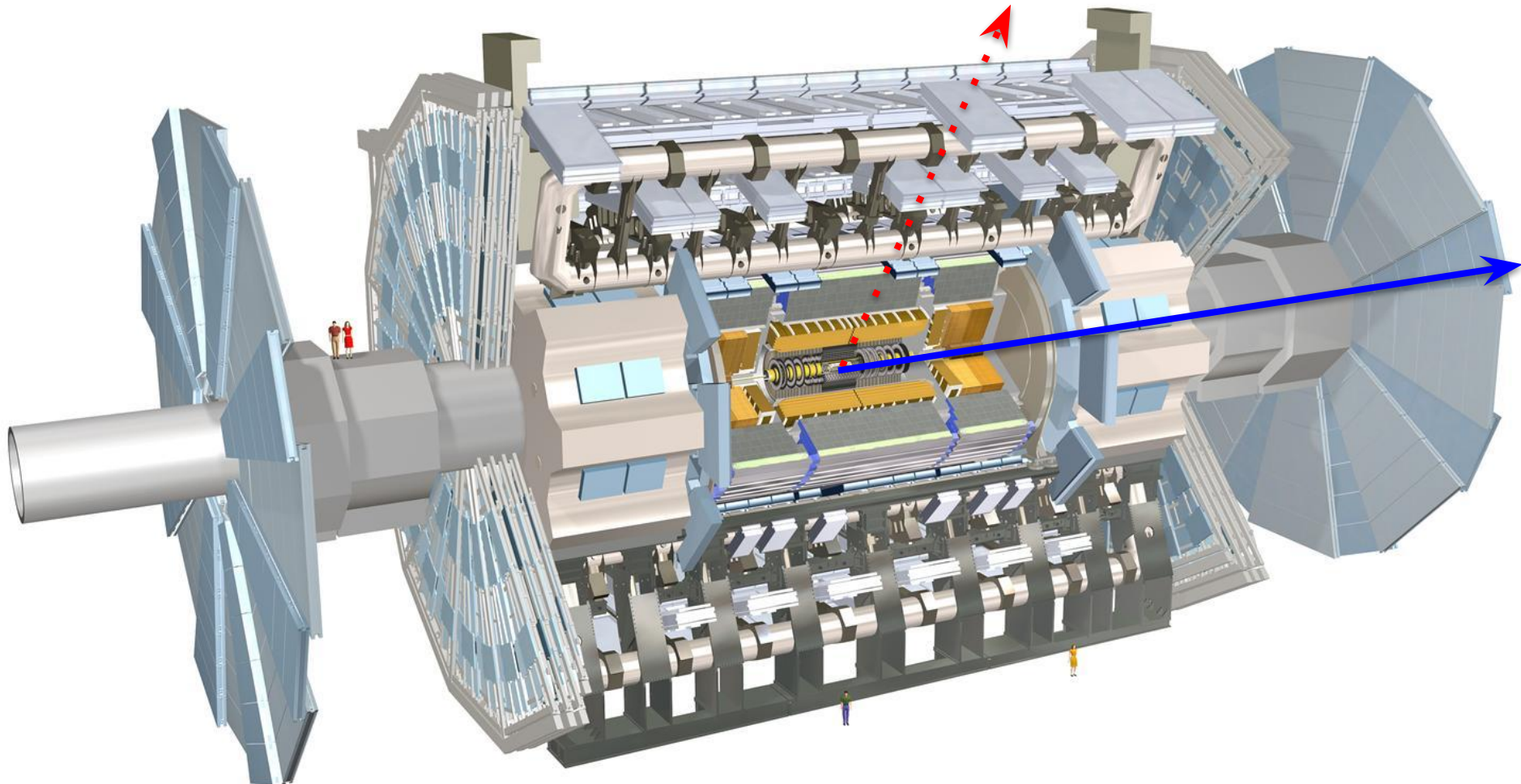


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WHAT ATLAS CANNOT SEE

- Neutrinos (or new particles that interact only via weak interaction)
- Particles that are too forward / too close to the beam directions





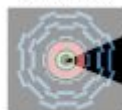
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HOW PARTICLES LOOK LIKE IN ATLAS

ATLAS

animation



☐ display instantly



Electron



Proton



Neutrino



Photon



Positron



Anti-proton



Jets



Muon

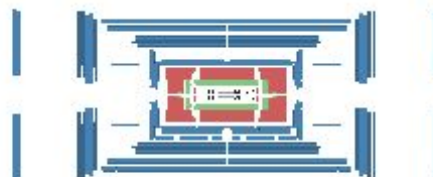
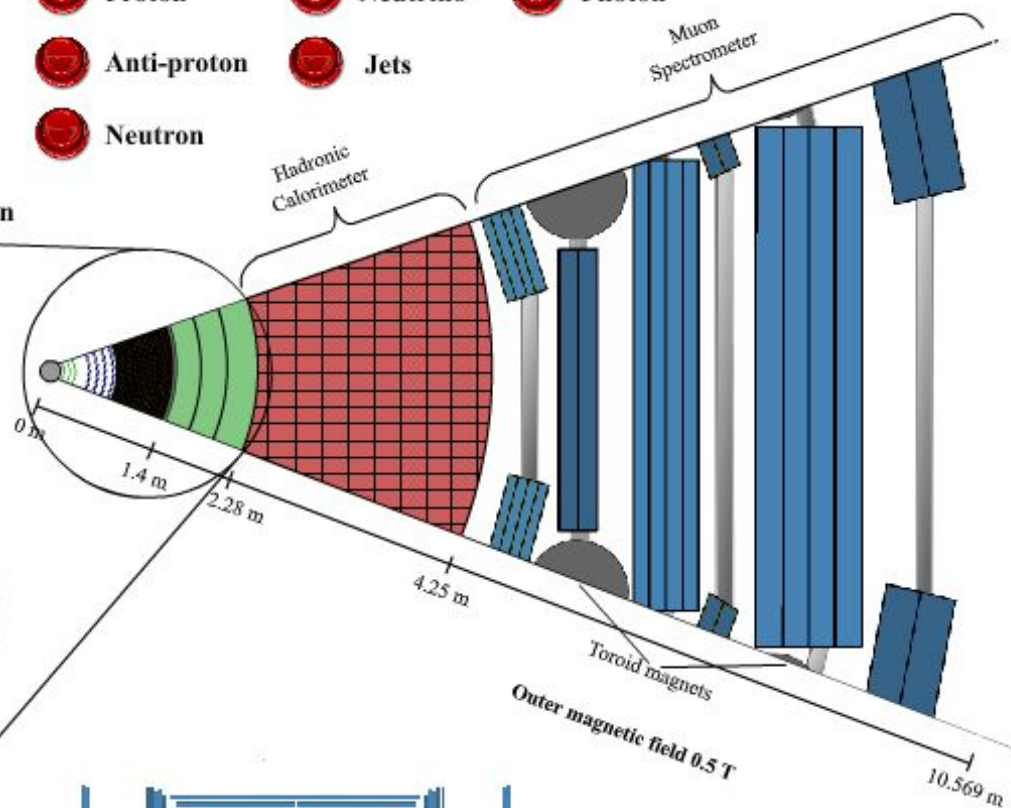
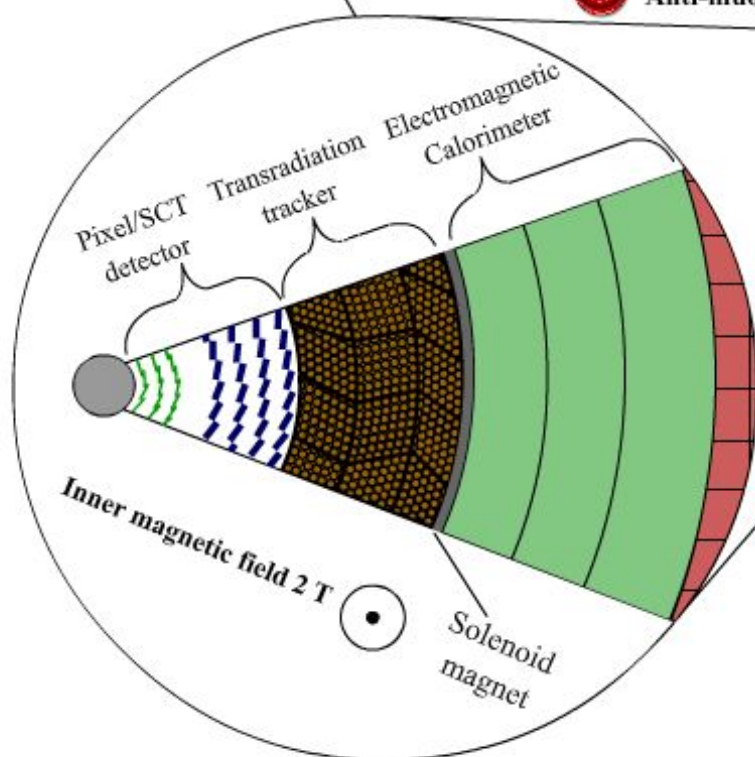


Neutron



Anti-muon

Magnification 3x

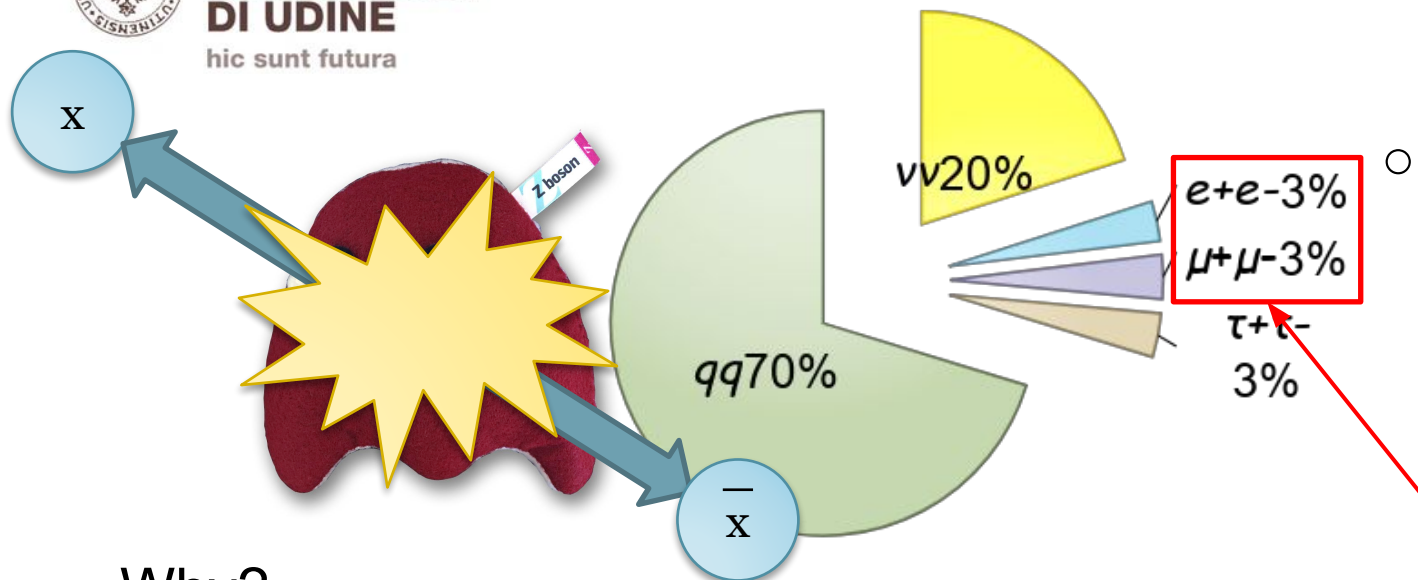




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HOW CAN WE RECONSTRUCT THE Z BOSON?



- Out of the possible decays of the Z boson, we choose **these ones**

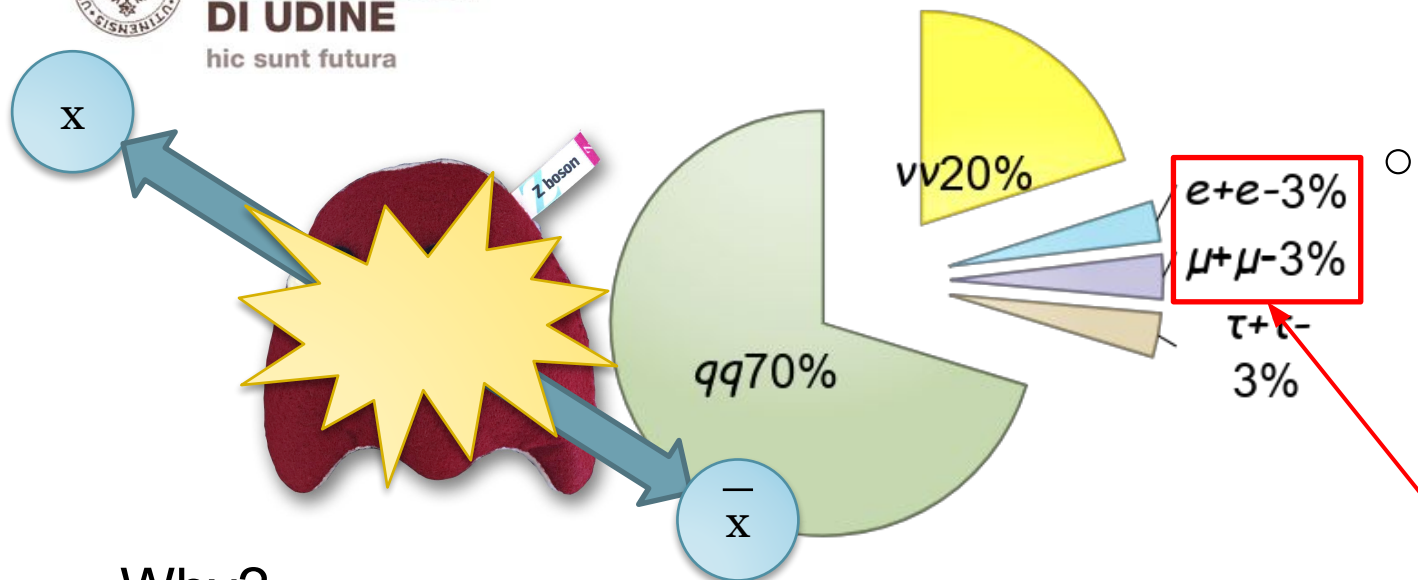
- Why?



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HOW CAN WE RECONSTRUCT THE Z BOSON?



○ Out of the possible decays of the Z boson, we choose **these ones**

● Why?

- ATLAS can measure electrons and muons with high precision
- can distinguish $Z \rightarrow ee / \mu\mu$ events from “background” events with production of just jets

● Invariant mass reconstruction:

- use conservation of energy and momentum
- can determine mass of parent particle from 4-momenta of its decay products

$$m_0^{(Z)} = \sqrt{\left(\frac{(E_{e^-} + E_{e^+})}{c^2}\right)^2 - \left(\frac{\vec{p}_{e^-} + \vec{p}_{e^+}}{c}\right)^2}$$

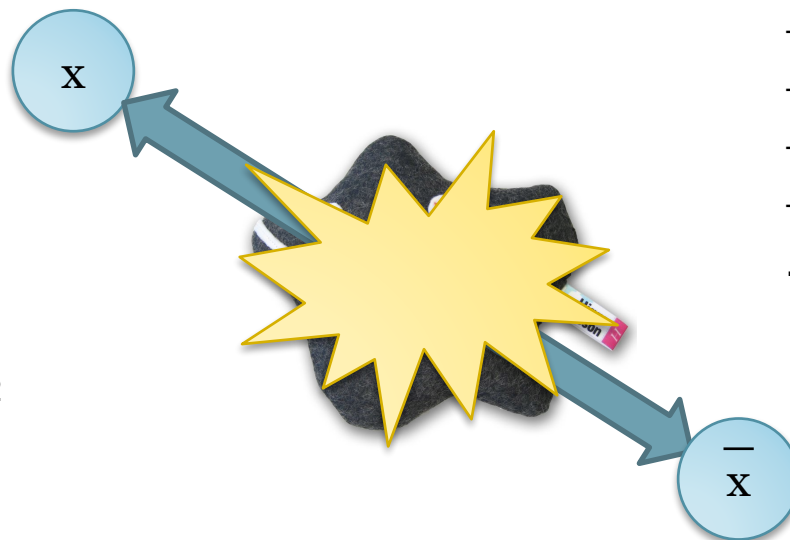


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AND WHAT ABOUT THE HIGGS BOSON?

- The Higgs boson is special:
→ he prefers to decay into heavy particles



$\rightarrow b\bar{b}$
 $\rightarrow \tau^+\tau^-$
 $\rightarrow W^+W^-$
 $\rightarrow ZZ$
 $\rightarrow \gamma\gamma$
 ...

Higgs boson:

- electric charge = 0
- mass = 125 GeV/c²

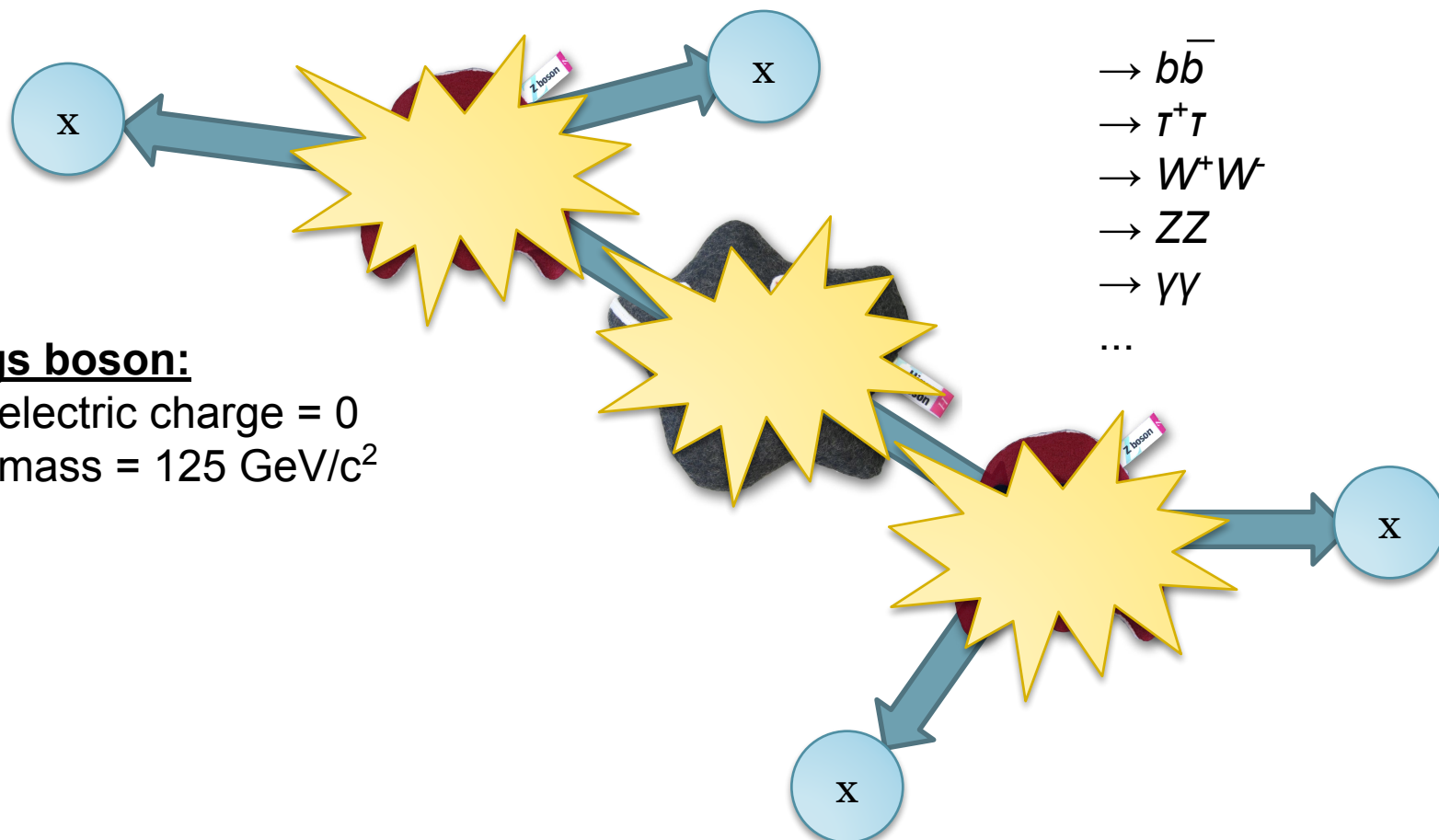


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AND WHAT ABOUT THE HIGGS BOSON?

- The Higgs boson is special:
 - ➔ he prefers to decay into heavy particles
 - ➔ some of these heavy particles can also be unstable and decay



Higgs boson:

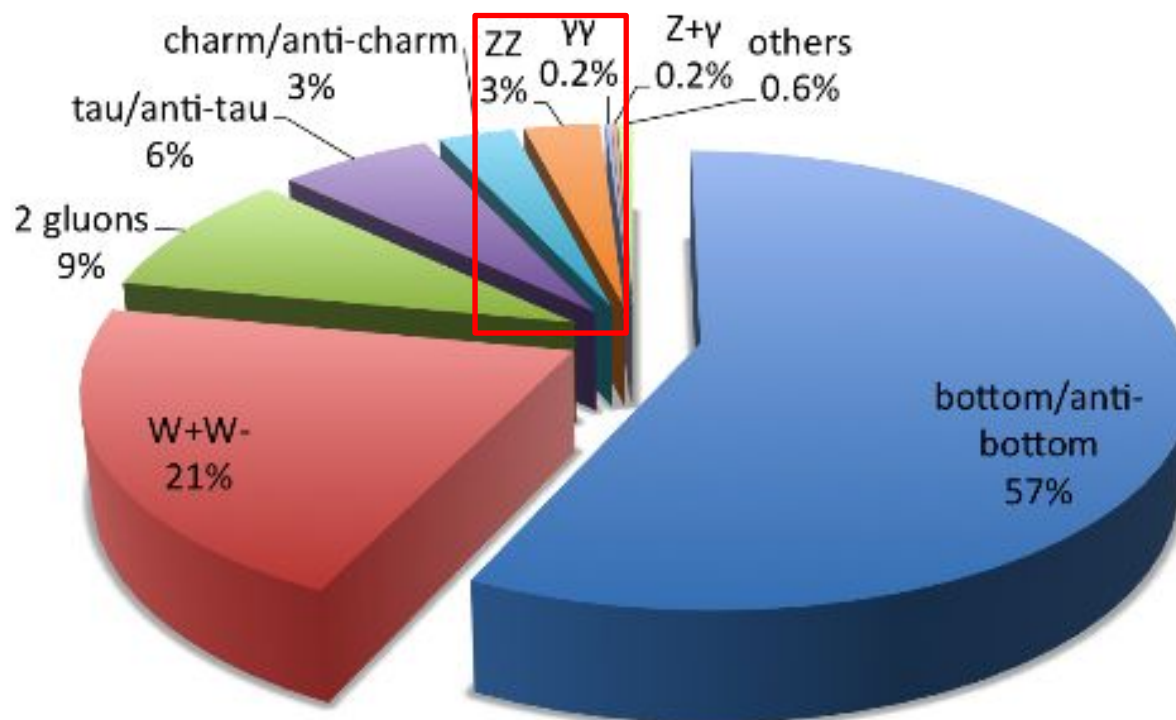
- electric charge = 0
- mass = $125 \text{ GeV}/c^2$



AND WHAT ABOUT THE HIGGS BOSON?

- Again, we like rare (but clean!) processes, so we look for:
 - $H \rightarrow$ two photons
 - $H \rightarrow ZZ \rightarrow$ four leptons (electrons or muons)

Decays of a 125 GeV Standard-Model Higgs boson



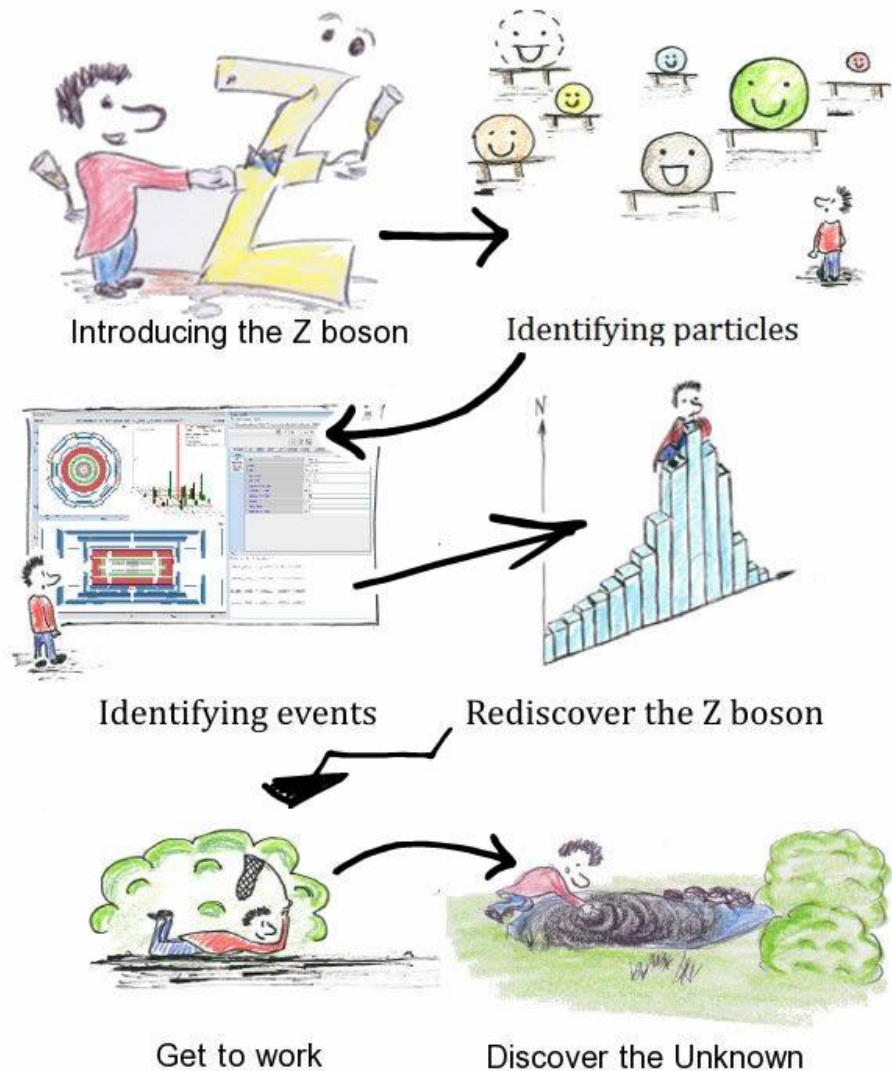


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HANDS ON

- We will use the software Hypatia
→ an “event viewer”
- For each collision event
(even real ATLAS data!)
it shows as an interactive picture,
with which we can:
 - see revealed particle trajectories
 - distinguish different types of particles
 - combine pairs of particles to see hypothetical parent particle (Z or Higgs bosons?)

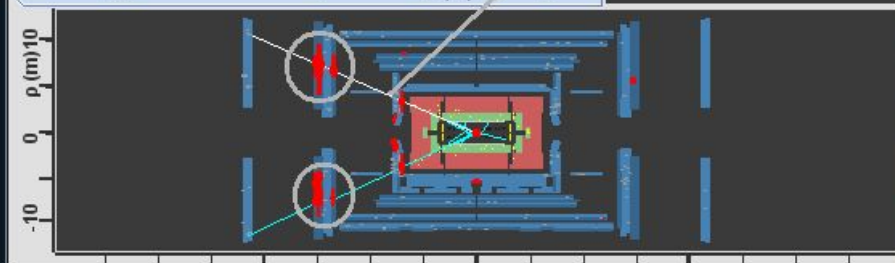
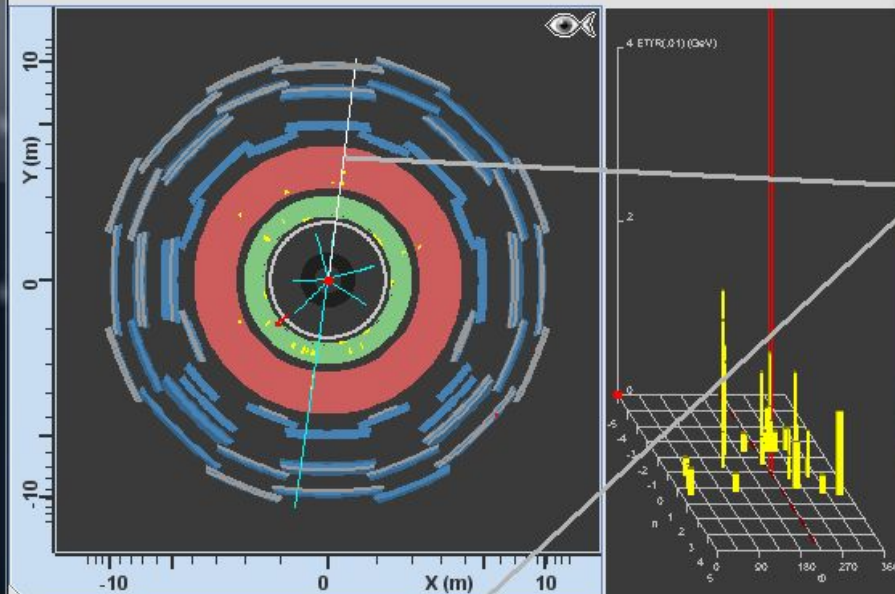


Hybrid pupils' analysis tool for interactions in ATLAS - version 6.0 - Invariant Mass Window

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	ϕ	η	M(2l) [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 ey:987982 HYPATIA



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\groupA\00036_JiveXML_166964_987982.xml

Reconstructed Tracks

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

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



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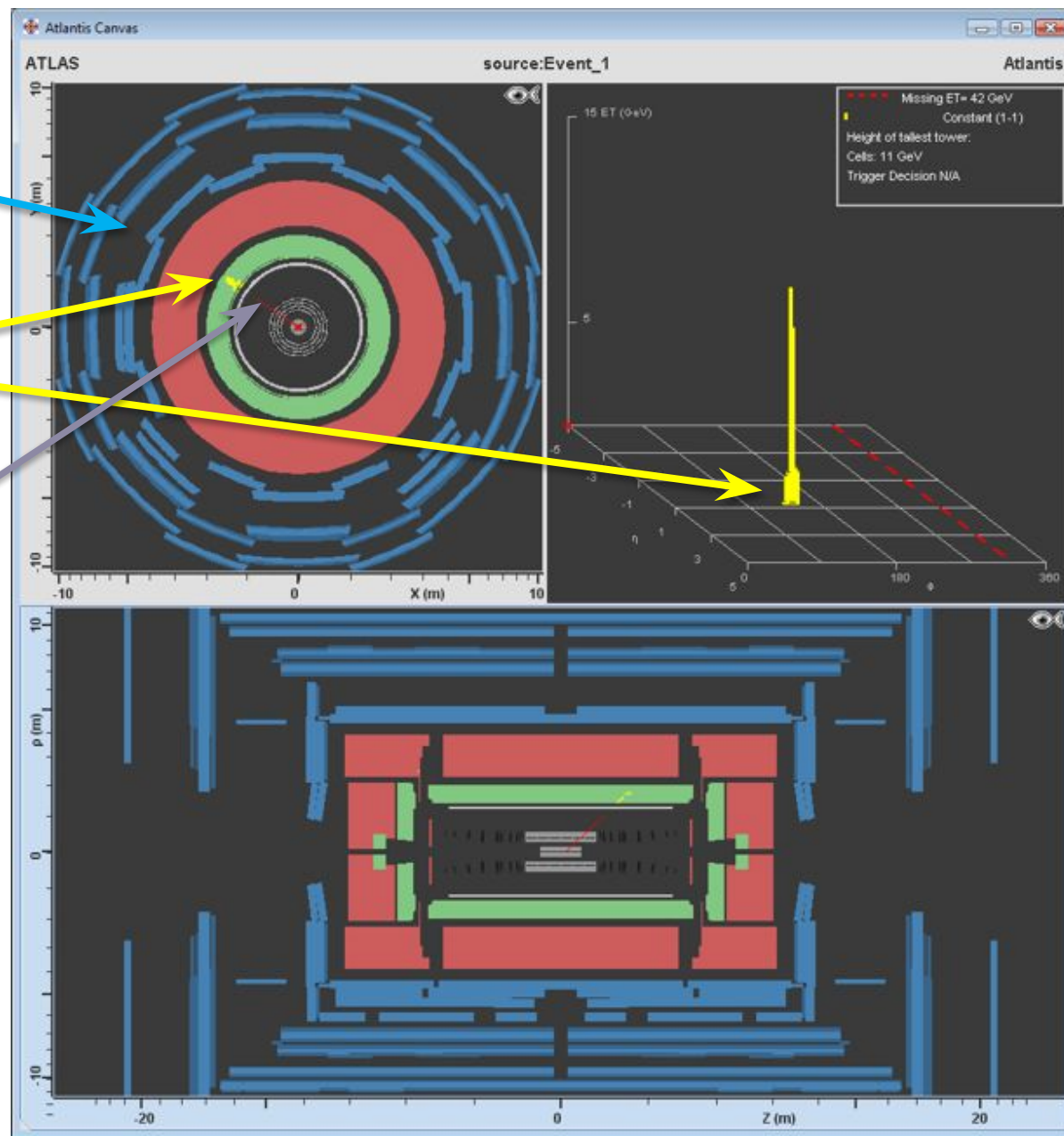
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ELECTRON

no energy in the
Had-Cal

energy in the
EM-Cal

isolated track



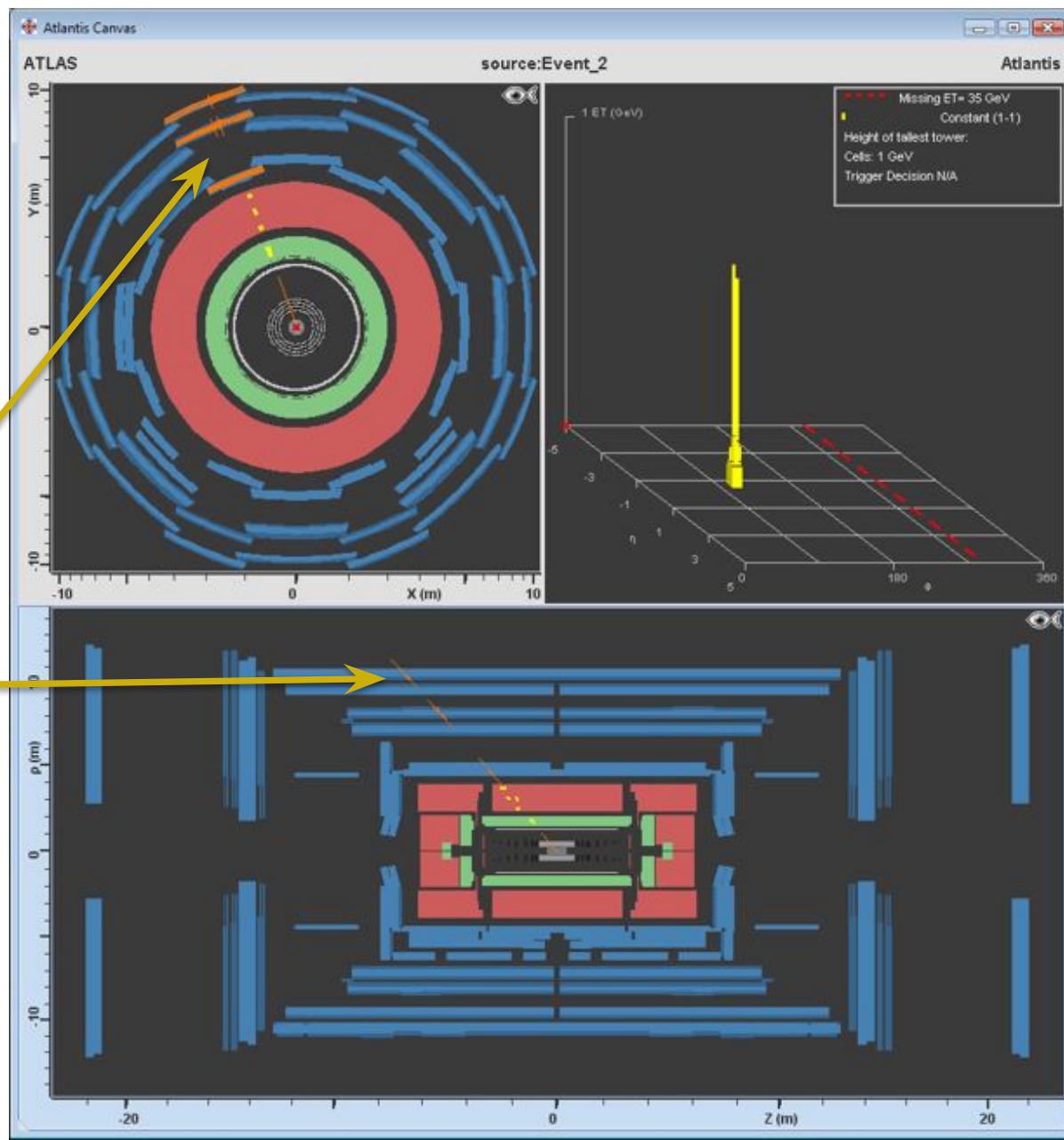


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MUON



isolated track in
the muon
spectrometer



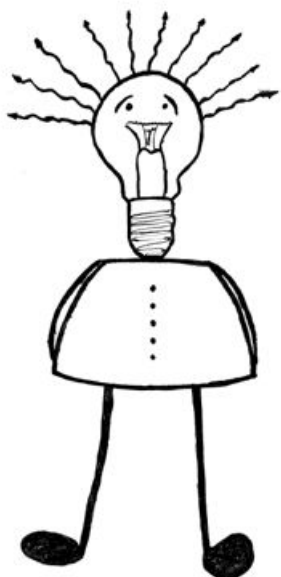


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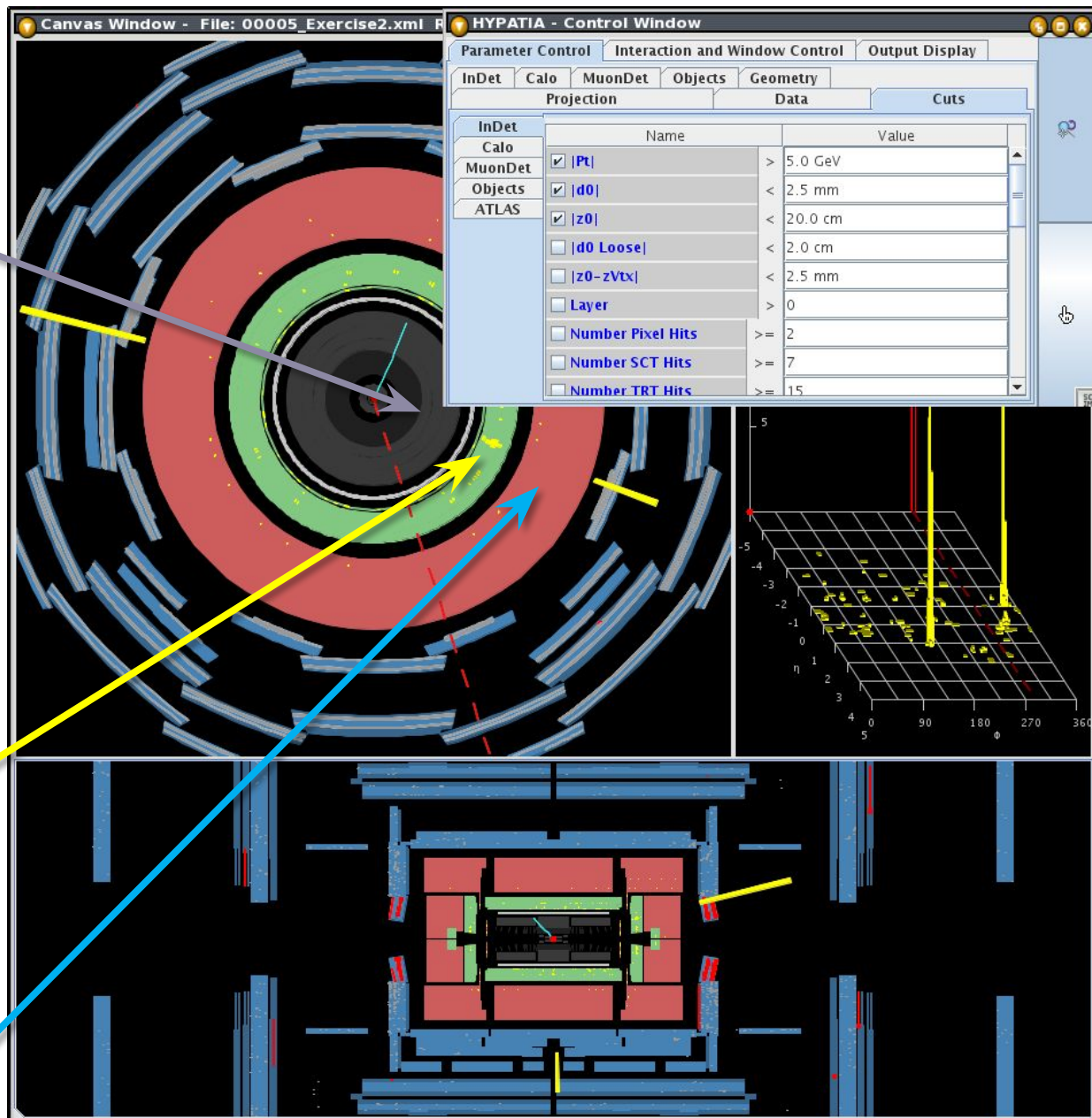
PHOTON

no energetic
track
associated



energy in the
EM-Cal

no energy in the
Had-Cal





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NEUTRINO

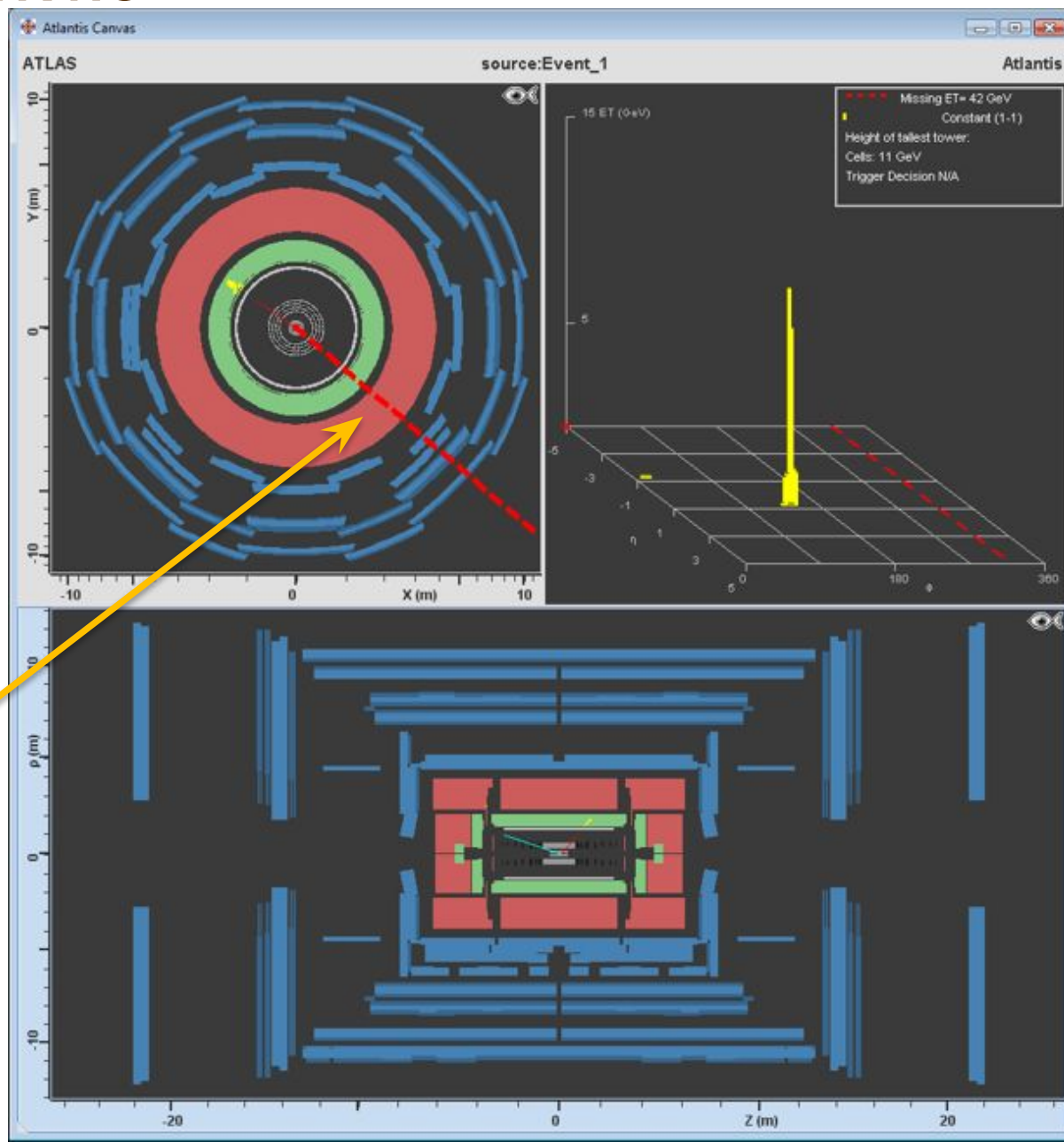
- Neutrinos are not revealed by ATLAS
→ but can be seen / reconstructed as missing energy or momentum (in the transverse plane)



Neutrino

look at the value of the
EtMiss!

- Our Z and Higgs event shouldn't have EtMiss...





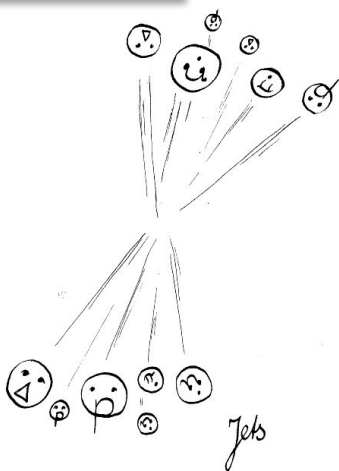
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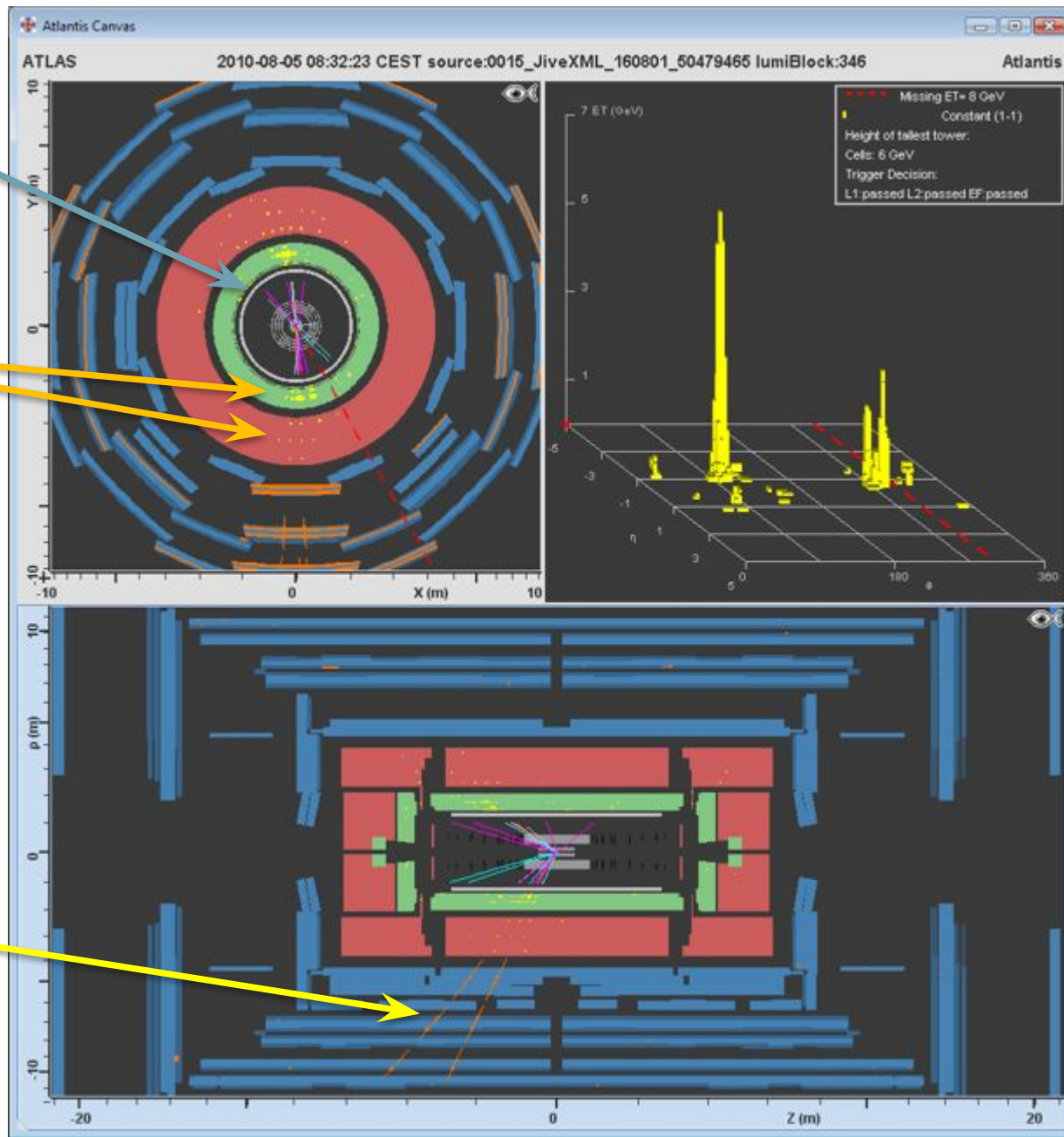
JET

many nearby
tracks

energy in
both EM and
Had-Cal



- Muons can be found inside jets:
→ we don't want to take them as real muons!





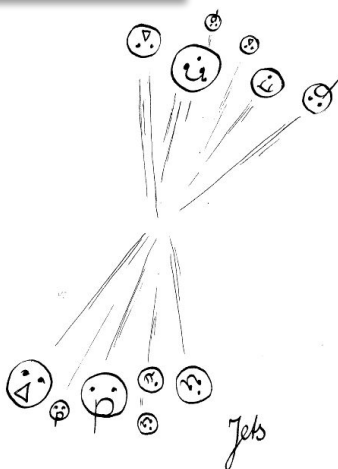
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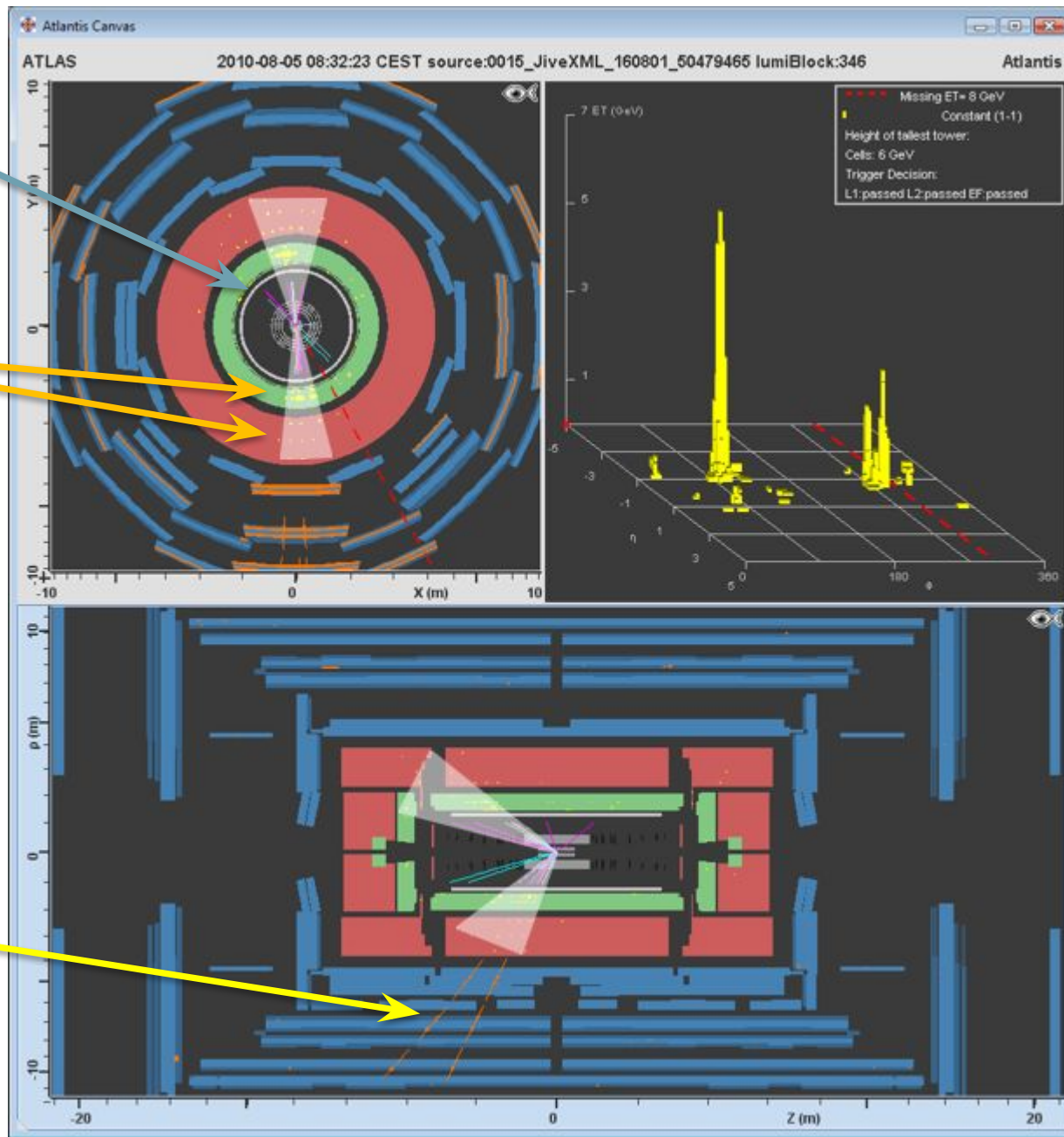
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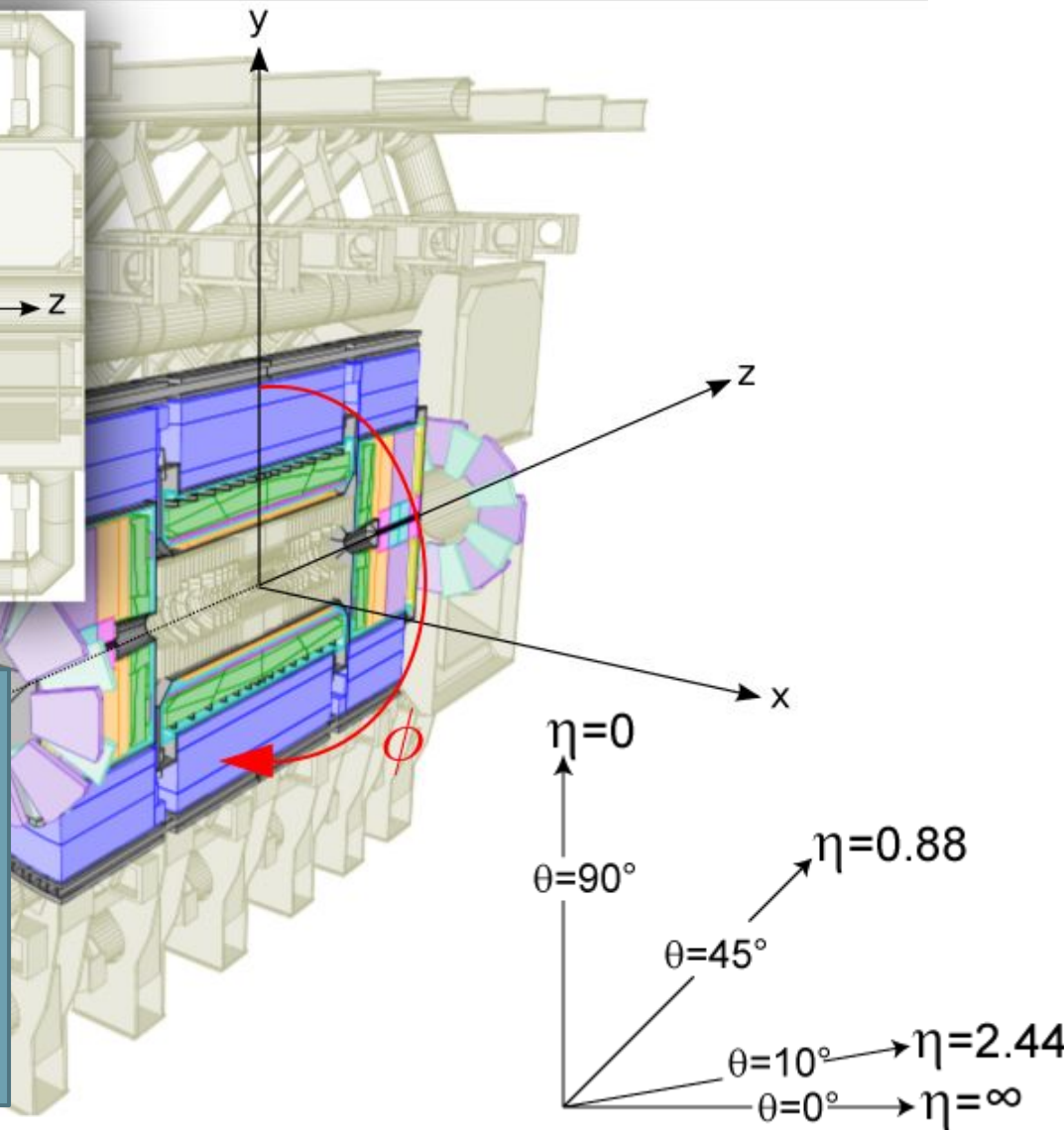
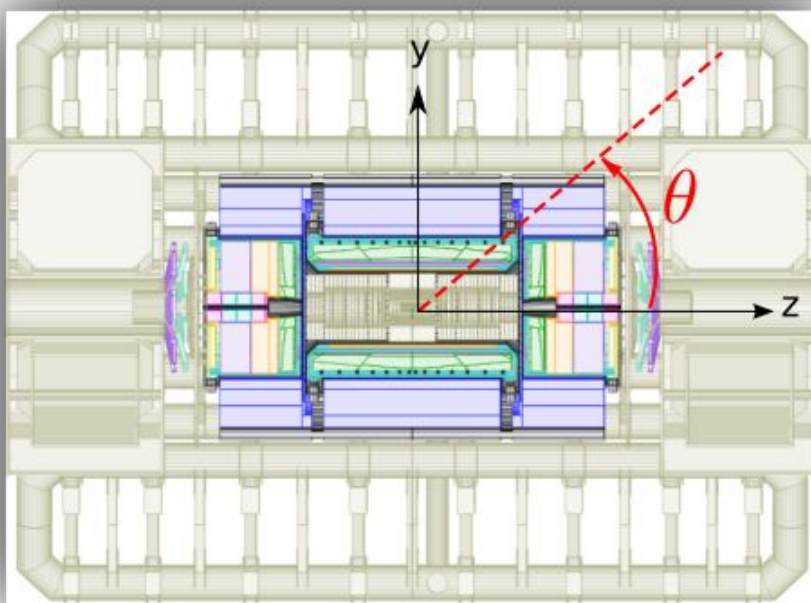




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COORDINATES IN ATLAS



We will use:

- Momentum: p
- Transverse momentum: p_T

$$p_T = \sqrt{p_x^2 + p_y^2}$$
- Angle in the transverse plane: ϕ
- Angle with respect to z: θ

$$\eta = -\ln(\tan(\theta/2))$$

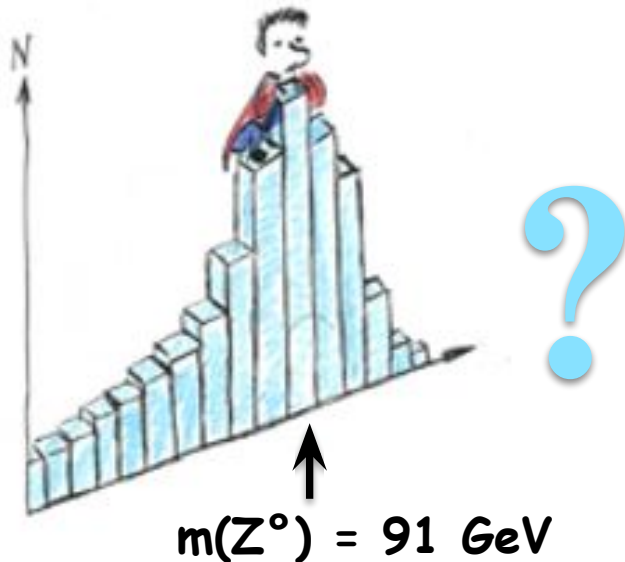
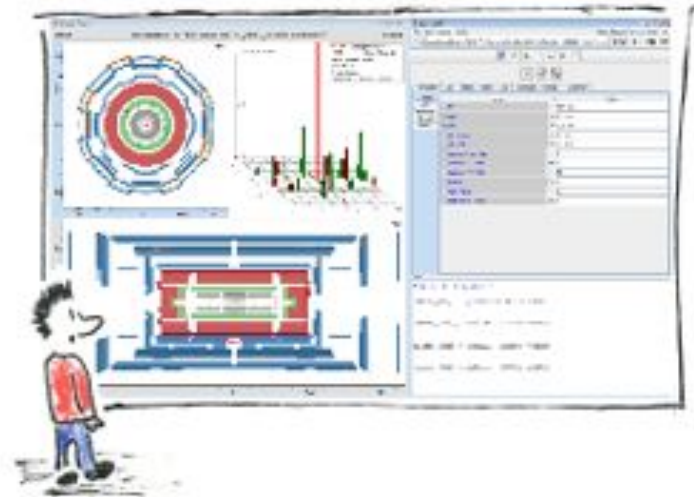


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RE-DISCOVER THE Z BOSON

- Our exercise will consist in:
 - select “good” events
 - select electron, muon, photon pairs
 - fill histograms with invariant mass values



- if we do things correctly we should see a “peak” around the Z-boson mass
- but we might see something else or something more!



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... AND THE HIGGS BOSON

- Higgs-boson-production events are very rare
→ you will see few of them
- To obtain the Higgs boson discovery it took time!

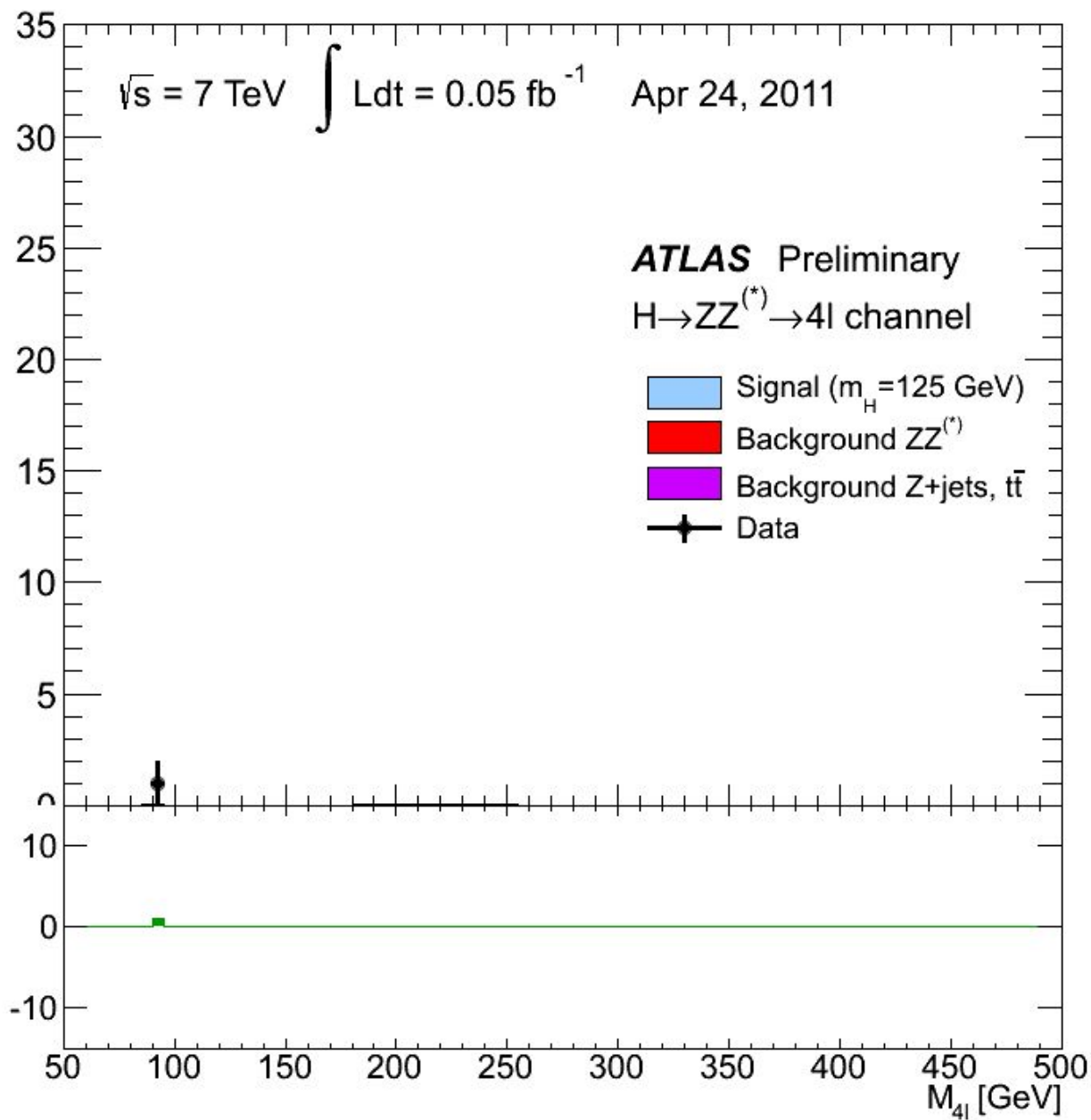


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hic sunt futura

Events / 5 GeV

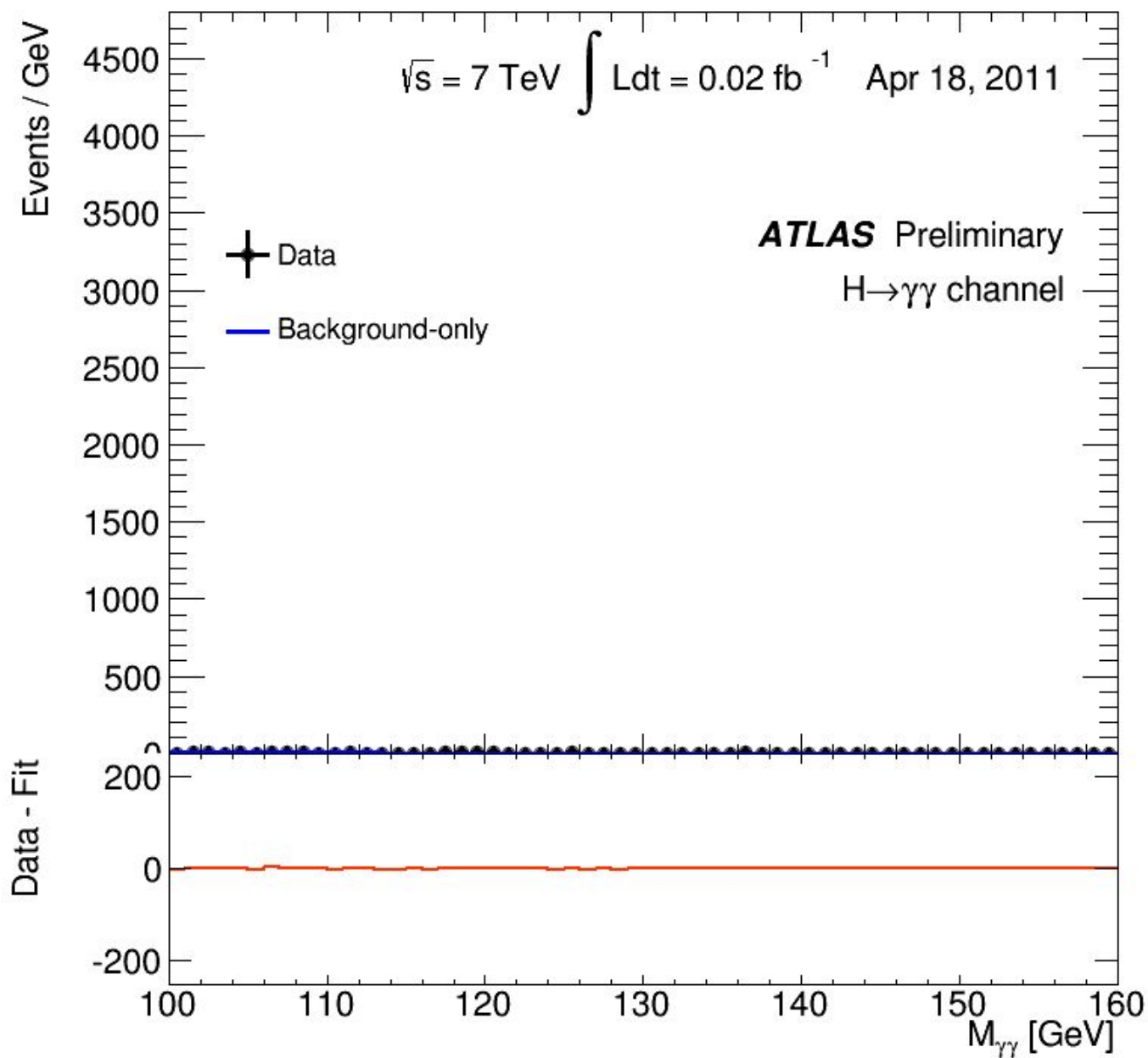
Data - Background





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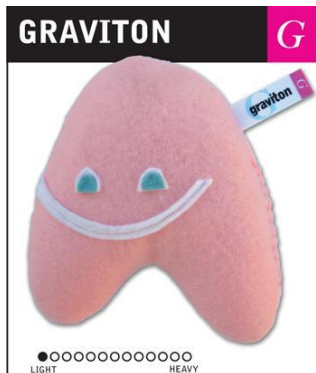


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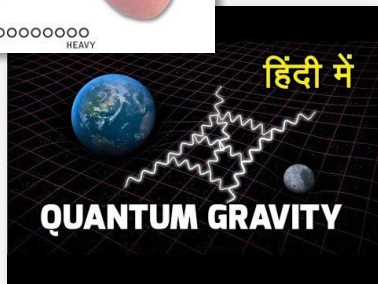
hic sunt futura

DISCOVERING NEW PHYSICS

- Many new theories predict new particles...
 - ➔ ... even heavier than the Z and the Higgs!
- The Z' boson:
 - ➔ heavy brother of the Z boson (how heavy?)
 - ➔ same decays of the Z boson
 - how to distinguish the two?



- The graviton:
 - ➔ excited states of the graviton might have large masses and be produced at the LHC
 - ... and decay in a similar way as the Higgs boson!





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TO WORK!

- And keep in mind:
 - work together
 - it takes time to practise
 - let's think critically
 - don't be shy: ask questions and ask for suggestions!



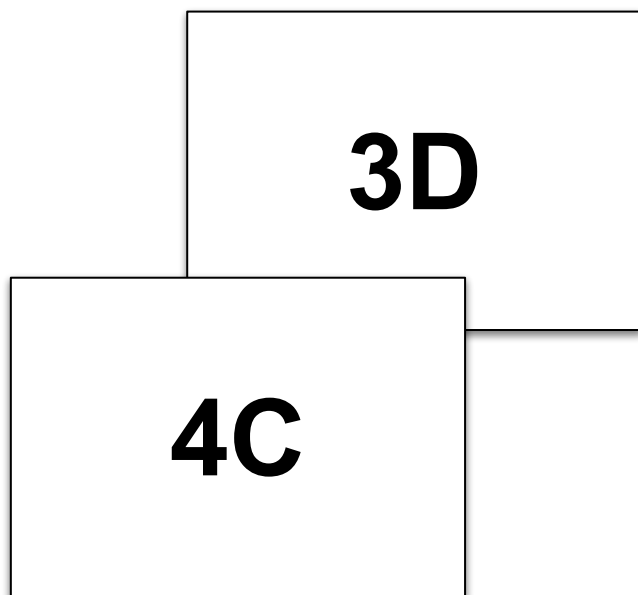


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WELCOME

- Work in groups of two people
 - ➔ every group has:
 - one PC
 - two pieces of paper with a letter and a number
(these are the identifiers for the data you will analyse!)





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ACCESS CREDENTIALS

- PC accounts:
 - ➔ username = masterclass
 - ➔ password = Uniud2018

- For Masterclass web-site (when requested):
 - ➔ username = ippog
 - ➔ password = imc



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CREATE YOUR WORKSPACE

- Create a new directory (on your Desktop) with an identifier of your group (i.e. one of the two letter+numbers you have)
- Every time you copy something or create a new file, do it inside there!

7D



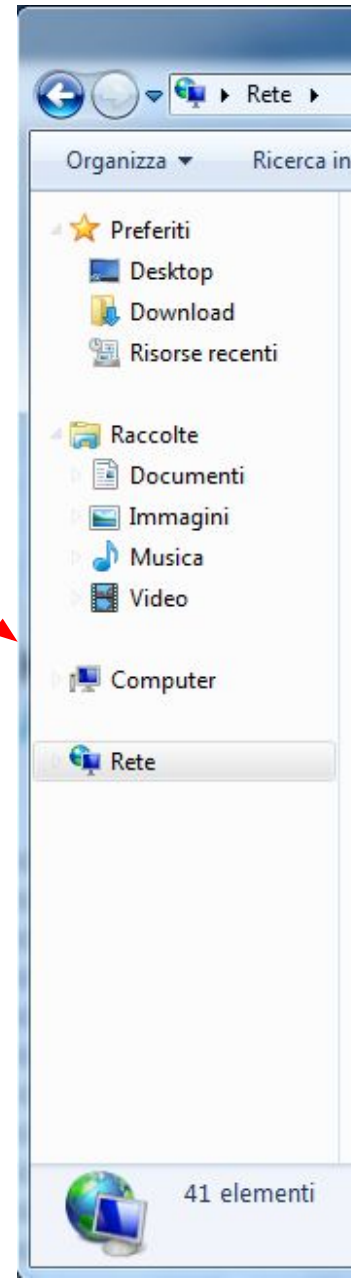


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ACCESS THE SHARED DIRECTORY

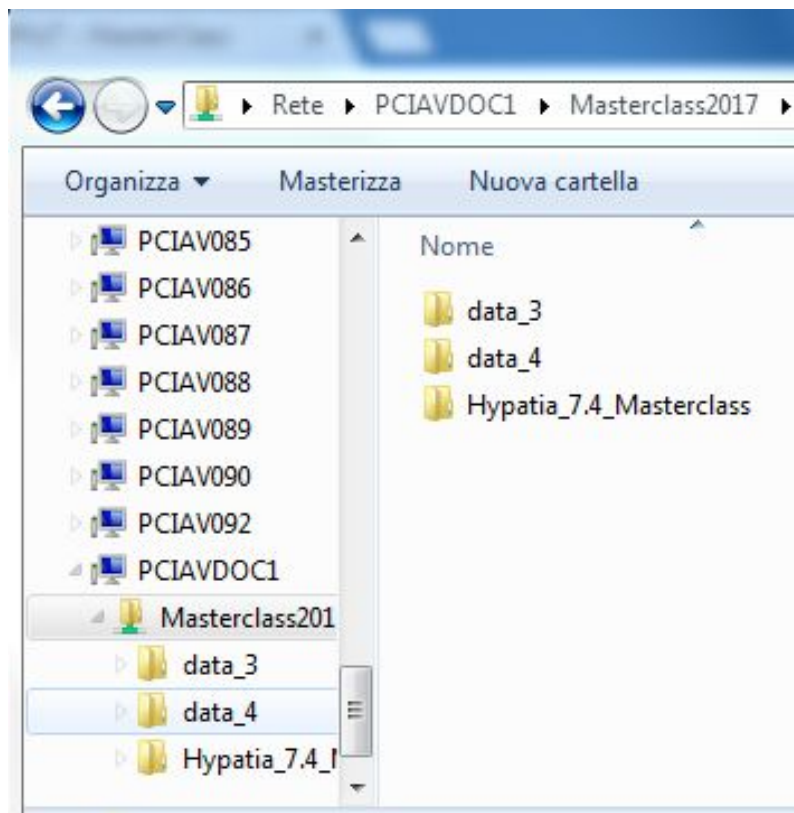
- Open the file manager and look for the shared directory “masterclass” under “Computer”
- Go to the sub-directory “SummerSchool2018”:
 - ➔ inside there you have:
 - the Hypatia software
 - the data to analyze (including a common test data-set)
 - a text file with two web links





COPY NEEDED FILES

- Copy the following things to your directory:
 - ➔ The Hypatia directory “Hypatia_7.4_Masterclass”
 - ➔ The “Test” directory
 - ➔ The data-set directories corresponding to the letter/numbers you are assigned
 - under “Set 9”
 - or “Set 10”
 - ➔ the text file “link”





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THE MASTERCLASS WEBSITE

- Open a web browser (better Internet Explorer)
- Go to this address:
→ <http://physicsmasterclasses.org/>



Home

Participate!

Schedule

My Country

Physics

ALICE

ATLAS

CMS



Hands on Particle Physics Masterclasses
ATLAS

ELISA:

- ATLAS measurement - czech
- ATLAS measurement - danish
- ATLAS measurement - english
- ATLAS measurement - french
- ATLAS measurement - german
- ATLAS measurement - greek

- Let's navigate to:
 - Physics
 - ATLAS
 - ATLAS measurement - english
 - choose "Z-path" (at the top)



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THE MASTERCLASS WEBSITE

- Now let's spend some time going through the material on the website



Z-Path

Welcome to the Z-path! Here you will learn about some particles, such as the Z boson and the Higgs boson, and their importance to our understanding of Nature. In this quest you will use real ATLAS data from the Large Hadron Collider (LHC) at CERN.

Before taking on this task, we will lead you through a journey into the tiniest structures known to man: the elementary particles. You will see how these can be produced in proton-proton collisions at the LHC, and you will learn how to identify elementary particles in the ATLAS detector. Finally, you will do a real physics measurement on fresh data from the ATLAS detector: identify the Z boson

Z-Path

Introducing the Z boson
Introducing the Higgs boson
New Physics
Identifying particles
Identifying Events
Search and discover with mass
Get to work!

- Stop at “Visualization with Hypatia”



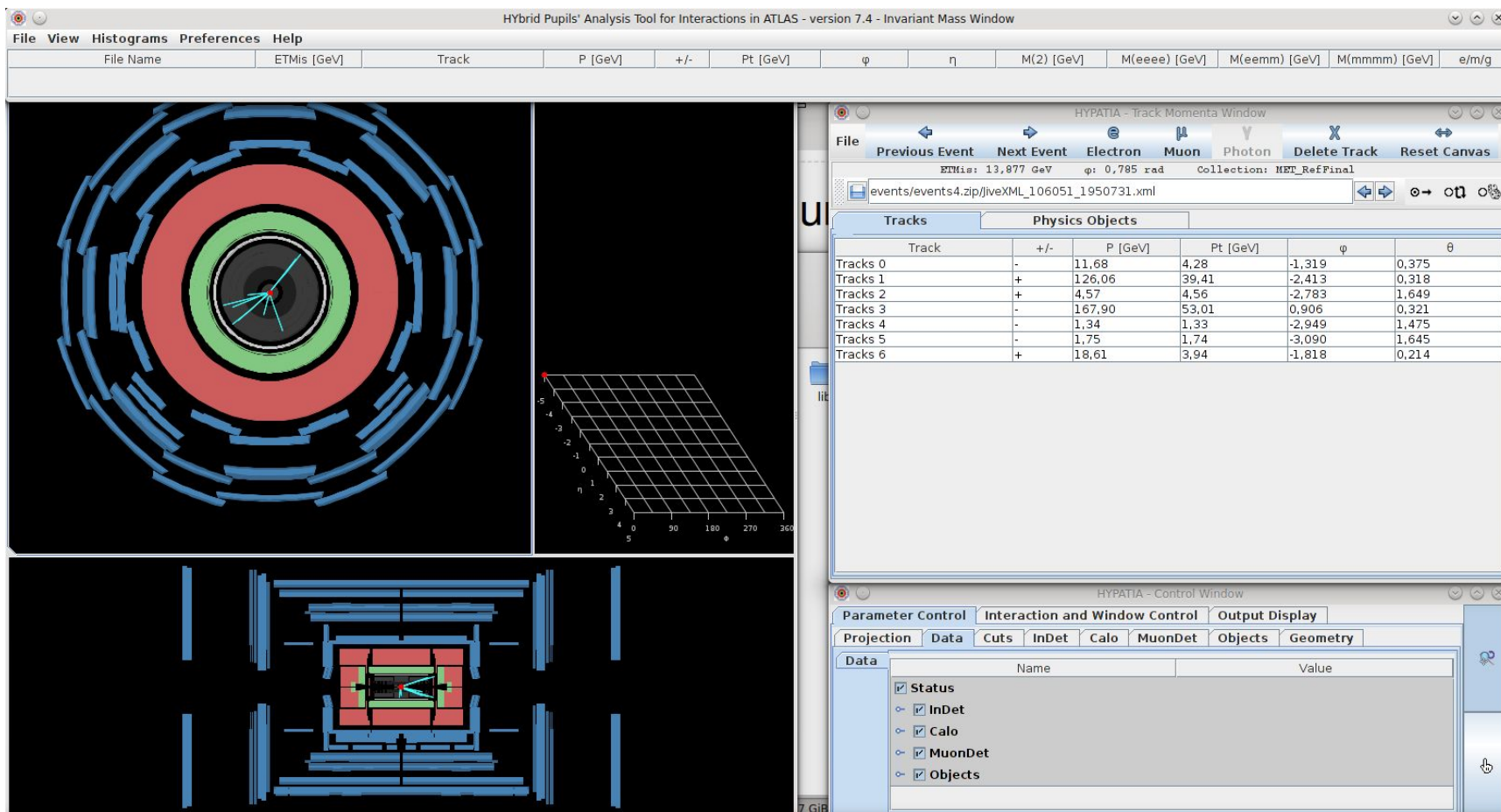


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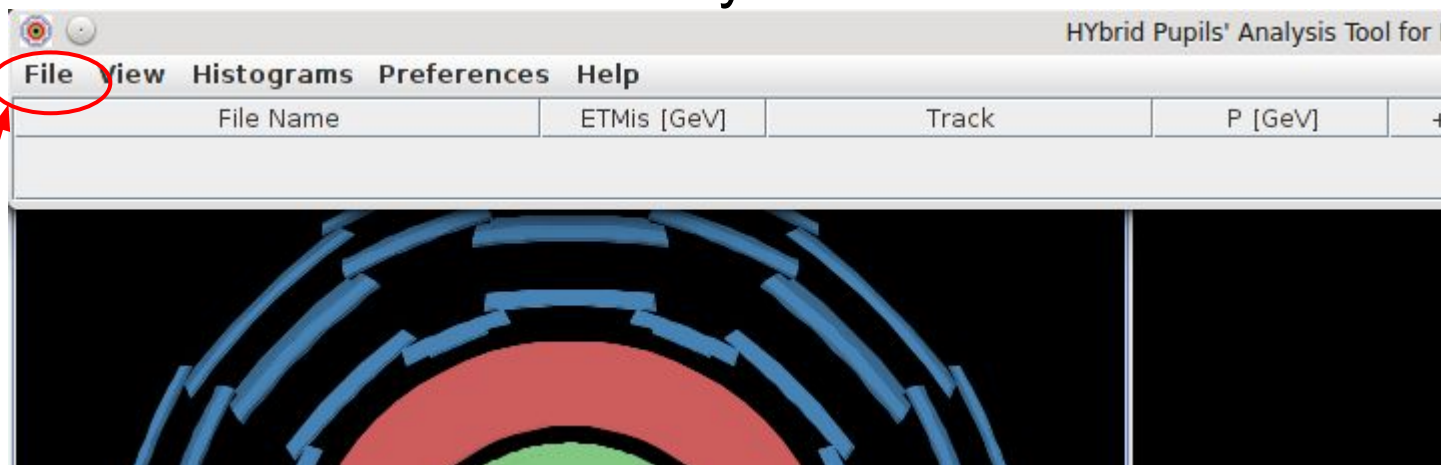
HYPATIA

- To start Hypatia:
 - ➔ go to the Hypatia directory you copied into your directory
 - ➔ double-click on Hypatia_7.4_Masterclass\Hypatia_7.4_Masterclass.jar





- Not consider the events that are there by default!



- Go to:
 - ➔ File
 - ➔ Read event locally
- Navigate until you find the “test” dataset you copied to your directory
- Select the first .xml file there



THE HYPATIA WINDOWS

- Hint adjust the windows!

Hybrid Pupils' Analysis tool for interactions in ATLAS - version 7.4 - Invariant Mass Window

File View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	ϕ	η	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
jiveXML_106051_1950731.xml	13,877	Tracks 0	11,7	-	4,3	-1,319	1,661	13,699			110,863	e
		Tracks 1	126,1	+	39,4	-2,413	1,830					e
		Tracks 2	4,6	+	4,6	-2,783	-0,078	45,411				m
		Tracks 3	167,9	-	53,0	0,906	1,820					m

Canvas Window - File: jiveXML_106051_1950731.xml Run: 106051 Event: 19...

Main window:

- shows list of selected events
- for each event show selected "objects"
- use it to load events, export results, exit program...

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

Projection Data Cuts InDet Calo MuonDet Objects Geometry

Data

Name	Value
<input checked="" type="checkbox"/> Status	
<input checked="" type="checkbox"/> InDet	
<input checked="" type="checkbox"/> Calo	
<input checked="" type="checkbox"/> MuonDet	
<input checked="" type="checkbox"/> Objects	

800.00MHz 09:58



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THE HYPATIA WINDOWS

- Hint adjust the windows!

Hybrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

File View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	ϕ	η	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
jiveXML_106051_1950731.xml	13,877	Tracks 0	11,7	-	4,3	-1,319	1,661	13,699			110,863	e
		Tracks 1	126,1	+	39,4	-2,413	1,830					e
		Tracks 2	4,6	+	4,6	-2,783	-0,078	45,411				m
		Tracks 3	167,9	-	53,0	0,906	1,820					m

Canvas Window - File: jiveXML_106051_1950731.xml Run: 106051 Event: 19...

HYPATIA - Track Momenta Window

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

ETMis: 13,877 GeV ϕ : 0,785 rad Collection: MET_RefFinal

ML_106051_1950731.xml

Physics Objects

Track	+/-	P [GeV]	Pt [GeV]	ϕ	θ
Tracks 0	-	11,68	4,28	-1,319	0,375
Tracks 1	+	126,06	39,41	-2,413	0,318
Tracks 2	+	4,57	4,56	-2,783	1,649
Tracks 3	-	167,90	53,01	0,906	0,321
Tracks 4	-	1,34	1,33	-2,949	1,475
Tracks 5	-	1,75	1,74	-3,090	1,645
Tracks 6	+	18,61	3,94	-1,818	0,214

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

Projection Data Cuts InDet Calo MuonDet Objects Geometry

Data

Name	Value
<input checked="" type="checkbox"/> Status	
<input checked="" type="checkbox"/> InDet	
<input checked="" type="checkbox"/> Calo	
<input checked="" type="checkbox"/> MuonDet	
<input checked="" type="checkbox"/> Objects	

Graphical window

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THE HYPATIA WINDOWS

- Hint adjust the windows!

Hybrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

File View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	ϕ	η	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
jiveXML_106051_1950731.xml	13,877	Tracks 0	11,7	-	4,3	-1,319	1,661	13,699			110,863	e
		Tracks 1	126,1	+	39,4	-2,413	1,830					e
		Tracks 2	4,6	+	4,6	-2,783	-0,078	45,411				m
		Tracks 3	167,9	-	53,0	0,906	1,820					m

Canvas Window - File: jiveXML_106051_1950731.xml Run: 106051 Event: 19...

HYPATIA - Track Momenta Window

File Previous Event **Next Event** Electron Muon Photon Delete Track Reset Canvas

ETMis: 13,877 GeV ϕ : 0,785 rad Collection: MET_RefFinal

events/events4.zip#jiveXML_106051_1950731.xml

Tracks Physics Objects

Track	+/-	P [GeV]	Pt [GeV]	ϕ	θ
Tracks 0	-	11,68	4,28	-1,319	0,375
Tracks 1	+	126,06	39,41	-2,413	0,318
Tracks 2	+	4,57	4,56	-2,783	1,649
Tracks 3	-	167,90	53,01	0,906	0,321
Tracks 4	-	1,34	1,33	-2,949	1,475
Tracks 5	-	1,75	1,74	-3,090	1,645
Tracks 6	+	18,61	3,94	-1,818	0,214

List of tracks

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

Projection Data Cuts InDet Calo MuonDet Objects Geometry

Data

Name	Value
<input checked="" type="checkbox"/> Status	
<input checked="" type="checkbox"/> InDet	
<input checked="" type="checkbox"/> Calo	
<input checked="" type="checkbox"/> MuonDet	
<input checked="" type="checkbox"/> Objects	

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THE HYPATIA WINDOWS

- Hint adjust the windows!

Hybrid Pupils' Analysis Tool for Interactions in ATLAS - version 7.4 - Invariant Mass Window

File View Histograms Preferences Help

File Name	ETMis [GeV]	Track	P [GeV]	+/-	Pt [GeV]	ϕ	η	M(2) [GeV]	M(eeee) [GeV]	M(eemm) [GeV]	M(mmmm) [GeV]	e/m/g
jiveXML_106051_1950731.xml	13,877	Tracks 0	11,7	-	4,3	-1,319	1,661	13,699			110,863	e
		Tracks 1	126,1	+	39,4	-2,413	1,830					e
		Tracks 2	4,6	+	4,6	-2,783	-0,078	45,411				m
		Tracks 3	167,9	-	53,0	0,906	1,820					m

Canvas Window - File: jiveXML_106051_1950731.xml Run: 106051 Event: 19...

HYPATIA - Track Momenta Window

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

ETMis: 13,877 GeV ϕ : 0,785 rad Collection: MET_RefFinal

events/events4.zip/jiveXML_106051_1950731.xml

Track	+/-	P [GeV]	Pt [GeV]	ϕ	θ
Tracks 0	-	11,68	4,28	-1,319	0,375
Tracks 1	+	126,06	39,41	-2,413	0,318
Tracks 2	+	4,57	4,56	-2,783	1,649
Tracks 3	-	167,90	53,01	0,906	0,321
Tracks 4	-	1,34	1,33	-2,949	1,475
Tracks 5	-	1,75	1,74	-3,090	1,645
Tracks 6	+	18,61	3,94	-1,818	0,214

HYPATIA - Control Window

Parameter Control Interaction and Window Control Output Display

Projection Data Cuts InDet Calo MuonDet Objects Geometry

Data

Name	Value
<input checked="" type="checkbox"/> Status	
<input checked="" type="checkbox"/> InDet	
<input checked="" type="checkbox"/> Calo	
<input checked="" type="checkbox"/> MuonDet	
<input checked="" type="checkbox"/> Objects	

Tool window

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PRACTISE

- Go back to the web-site
- Spend some time to go over the preliminary exercises:



Z-Path

1.

Introducing the Z boson
Introducing the Higgs boson
New Physics
Identifying particles
ATLAS detector
Play!
Visualization with HYPATIA
Particle footprint visualization
Practice!



- Go back to the web-site
- Spend some time to go over the preliminary exercises:



Z-Path

1.

Introducing the Z boson
Introducing the Higgs boson
New Physics
Identifying particles
ATLAS detector
Play!
Visualization with HYPATIA
Particle footprint visualization
Practice!

2.

Identifying Events
When protons collide
Z events
Higgs events
Background events
Visualization
Practice!
Search and discover with mass
Get to work!

For this exercise
we need few more
slides....



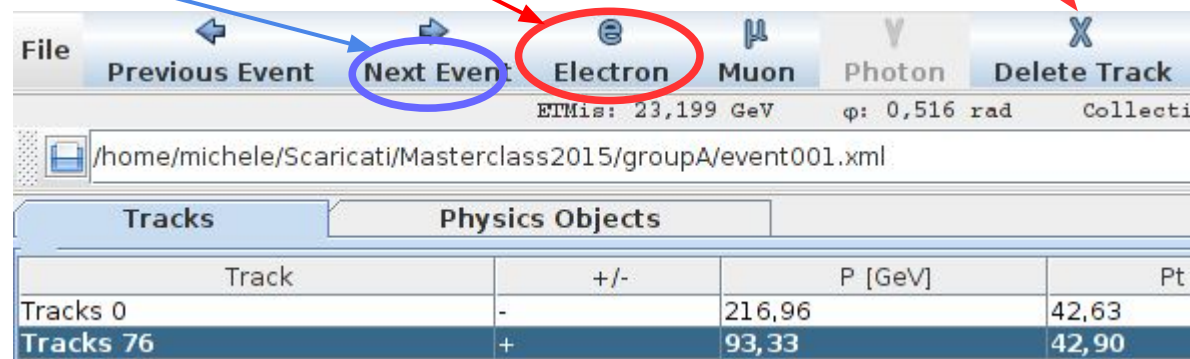
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HOW TO PROCEED

- For every event, you will have to:
 - ➔ look for electrons, muons or photons
 - ➔ decide if the event is one of the following:
 - type $Z \rightarrow e^+e^- / \mu^+\mu^-$
 - type $H \rightarrow ZZ \rightarrow 4\text{-leptons}$
 - type $H \rightarrow \gamma\gamma$
 - ➔ if yes (!!), **select** the proper objects
 - they will be saved in the upper window
 - ➔ if not, the event is “background”
 - pass to **next event**

to remove objects
wrongly inserted





FEW TRICKS

- Check pT of objects:
 - ➔ Z and Higgs boson decay products are typically high-pT
 - ➔ relatively high pT means $> 10 \text{ GeV}/c$
 - ➔ in case of doubt between different tracks to select, choose the higher pT one

- Check the electric charge:
 - ➔ pair of particles have to be oppositely-charged
 - ➔ in Higgs \rightarrow 4-lep events the order is important:
 - $+ - + - \rightarrow \text{yes}$
 - $+ - - + \rightarrow \text{yes}$
 - $+ + - - \rightarrow \text{no!}$

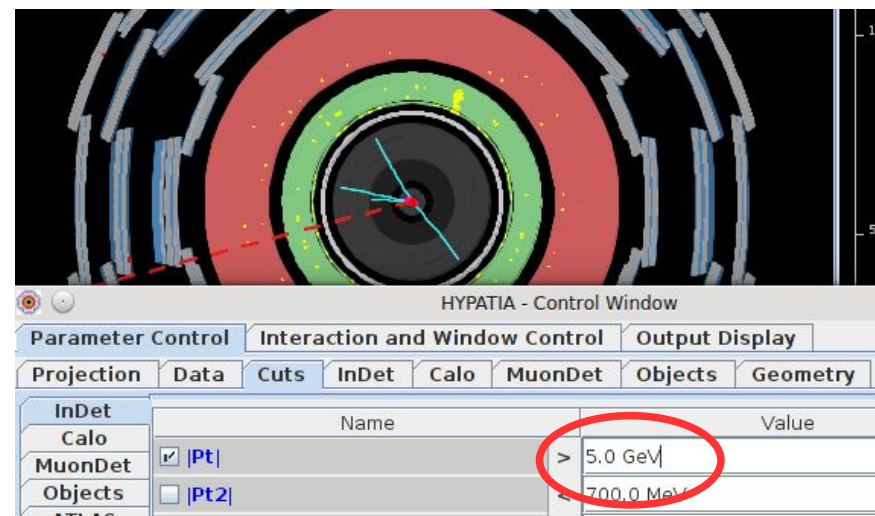
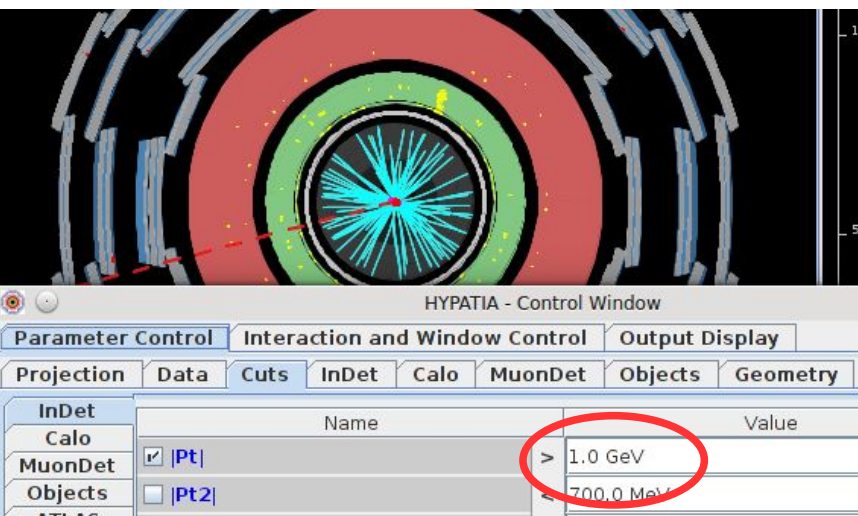


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FEW TRICKS

- Rise the pT cut on the tracks to clean-up the view!
➔ to do it, go to the tools window, “Parameter Control”, “Cuts”



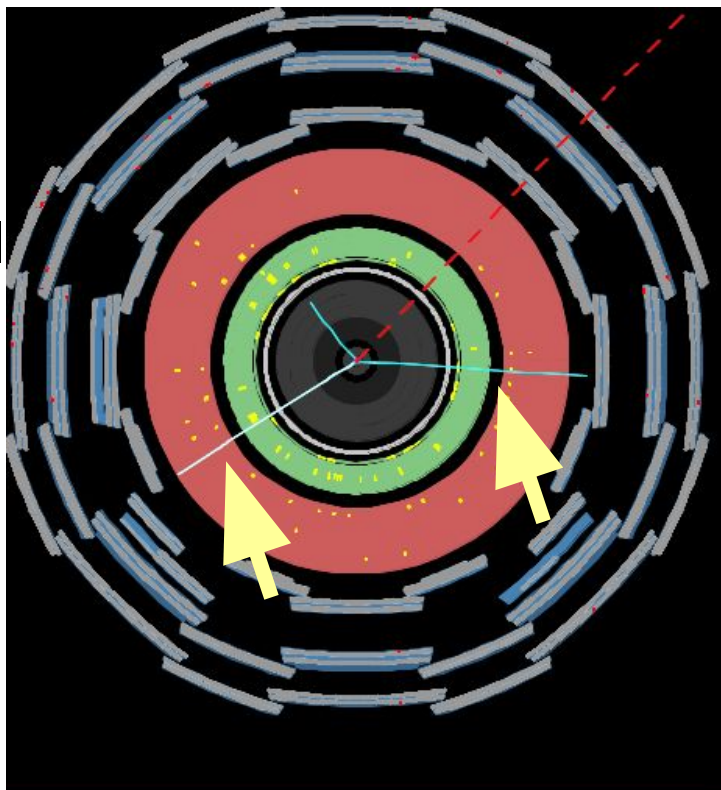


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FEW TRICKS

- Pay attention to non-central muons, electrons, photons...



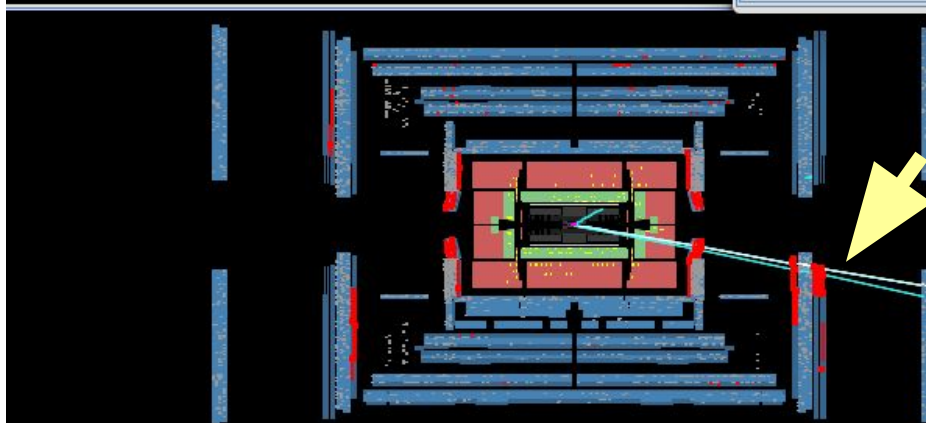
HYPATIA - Track Momenta Window

File Previous Event Next Event Electron Muon Photon

ETHis: 22,591 GeV ϕ : 0,814 rad Collection: M

/home/michele/Scaricati/Masterclass2015/groupA/event006.xml

Track	+/-	P [GeV]	Pt [GeV]
Tracks 3	+	238,68	42,22
Tracks 4	-	141,08	27,58
Tracks 173	+	9,84	5,05



Parameter Control

Projection Data

Data

<input checked="" type="checkbox"/> Status
<input checked="" type="checkbox"/> InDet
<input checked="" type="checkbox"/> Calo
<input checked="" type="checkbox"/> MuonDe
<input checked="" type="checkbox"/> Objects



FINAL INDICATIONS

- Don't look at the “invariant mass” values when collecting events!
 - ➔ select events regardless of the invariant mass values
 - ➔ e.g. keep events even if 4-lepton invariant mass is 10 GeV, or 1000 GeV!!

event004.xml	173,818	Tracks 0	605,3	-	582,0	2,195	-0,282	944,102				m
		Tracks 2	383,5	+	380,6	-0,908	-0,123					m
event005.xml	26,783	Tracks 3	58,2	-	37,7	0,707	-1,001	88,235		109,073		m
		Tracks 4	79,7	+	57,0	-1,794	-0,864					m
		Tracks 13	14,5	+	11,7	-2,513	-0,686	18,954				e
		Tracks 180	9,8	-	9,3	-0,295	-0,348					e

- ➔ we will look at the invariant mass later



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READY STEADY, GO!

- You have two sets of 50 events each group
- And 2 hours to analyse them
- have fun!



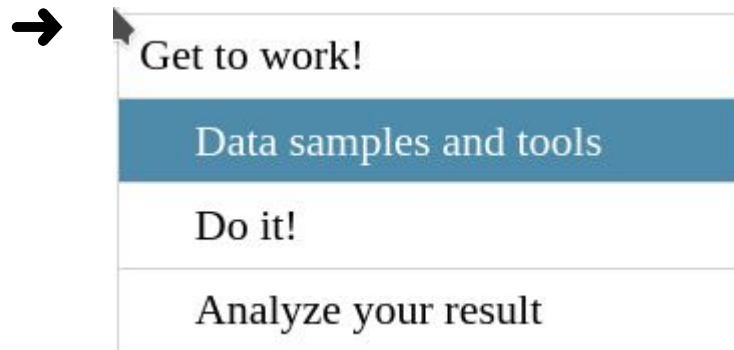
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EXPORT THE RESULTS

- “File” → “Export invariant masses”
→ save the file in your working directory

- Then, from the web-site:



- 3. Open the plot submission page from [here](#)
 - select “student” and upload your file(s)