

The Signal and Background: LLP

You will go through event displays containing:

- **Signal** from LLP as:
 - Displaced Vertex + Invisible particles : **DV + MET**
 - Displaced Vertex + Muon: **DV + μ**
- **Background:** “misreconstructed” tracks or jets, beam/gas collision, cosmic rays etc.

Invariant mass: a tool for discovery

From **Special Relativity**, the energy of a relativistic particle of mass m and momentum p is:

$$E = \sqrt{(pc)^2 + (mc^2)^2}$$

If we use a system where $c = 1$:

$$E^2 = p^2 + m^2 \rightarrow m^2 = E^2 - p^2$$

The quantity m can be calculated for one particle but also for a system of particles. **This quantity is conserved in relativistic interactions.**

So, consider e.g. a Z^0 decaying in two leptons: $Z \rightarrow l_1 l_2$. The mass of the particles should be the same on the left and on the right:

$$m(Z) = m(l_1 l_2) = \sqrt{E(l_1 l_2)^2 - p(l_1 l_2)^2} \rightarrow m_Z = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$

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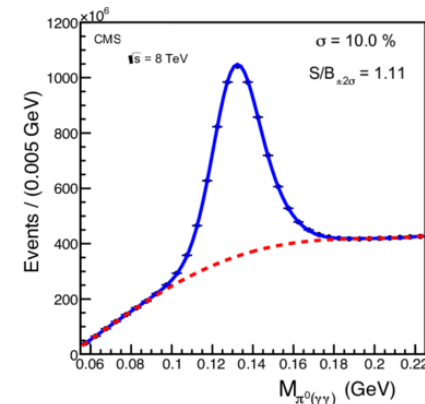
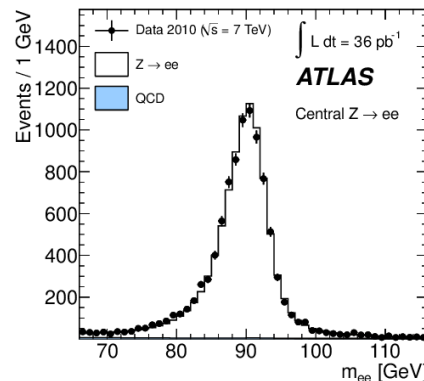
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As a consequence, we can **measure the mass of a “parent” particle** by reconstructing the energy and momentum of “daughter”



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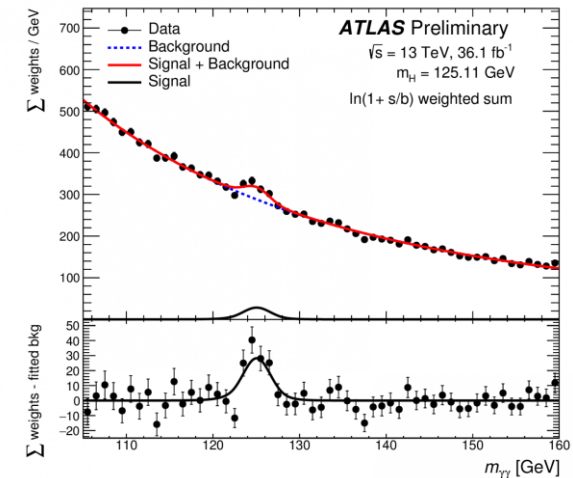
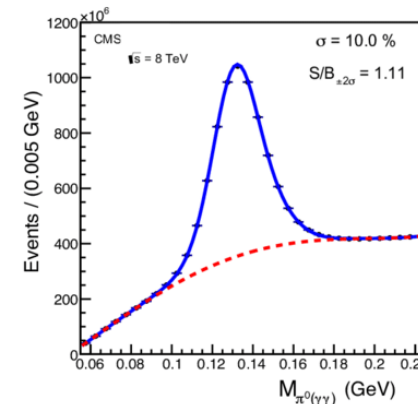
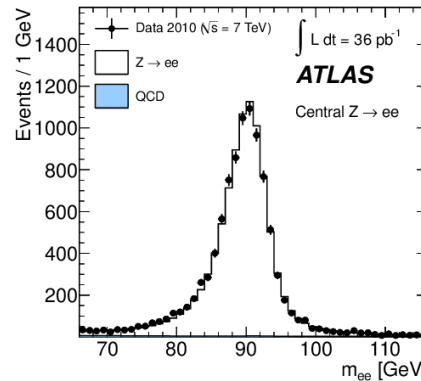
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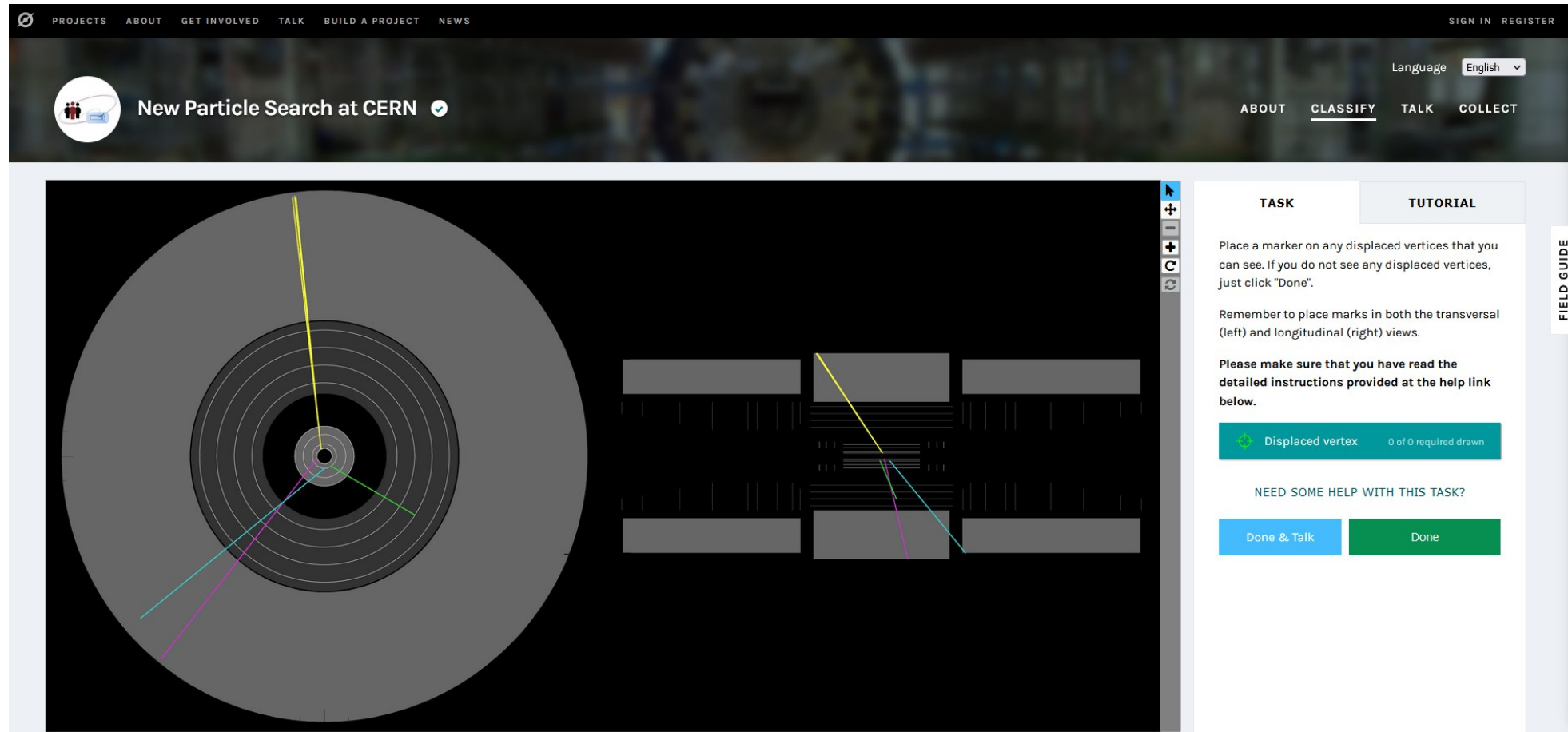
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Stage 1: Displaced vertices

Webpage : <https://www.zooniverse.org/projects/reinforce/new-particle-search-at-cern/classify>
(no need to Register)



PROJECTS ABOUT GET INVOLVED TALK BUILD A PROJECT NEWS SIGN IN REGISTER

Language English

New Particle Search at CERN

ABOUT CLASSIFY TALK COLLECT

TASK **TUTORIAL**

Place a marker on any displaced vertices that you can see. If you do not see any displaced vertices, just click "Done".

Remember to place marks in both the transversal (left) and longitudinal (right) views.

Please make sure that you have read the detailed instructions provided at the help link below.

Displaced vertex 0 of 0 required drawn

NEED SOME HELP WITH THIS TASK?

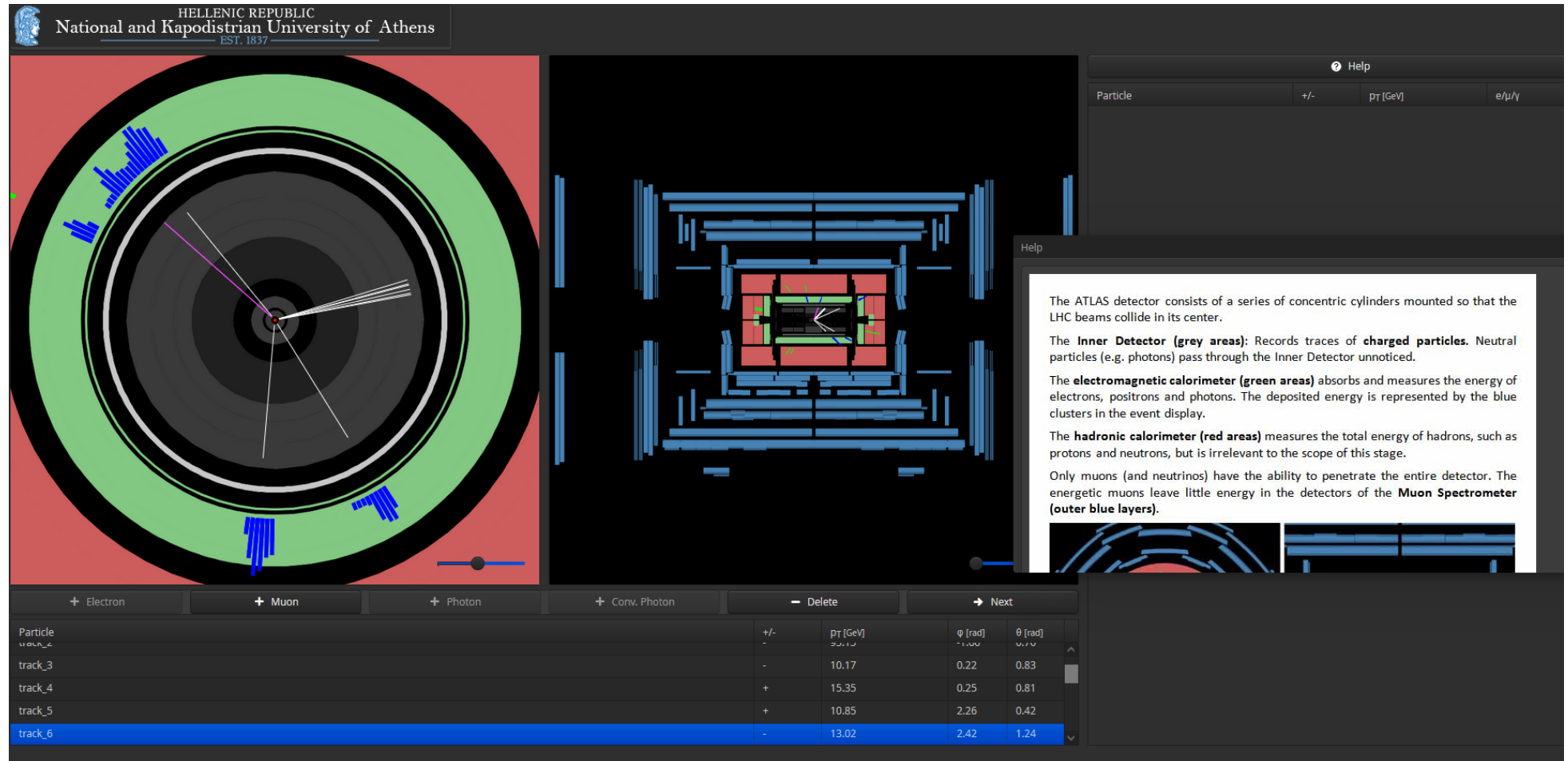
Done & Talk Done

FIELD GUIDE

Stage 2: Particle Identification

This stage uses a web event display called [HYPATHIA](#)

HELLENIC REPUBLIC
National and Kapodistrian University of Athens
EST. 1837



Help

Particle	+/-	p_T [GeV]	$e/\mu/\gamma$
track_3	-	10.17	
track_4	+	15.35	
track_5	+	10.85	
track_6	-	13.02	

Help

The ATLAS detector consists of a series of concentric cylinders mounted so that the LHC beams collide in its center.

The **Inner Detector (grey areas)**: Records traces of **charged particles**. Neutral particles (e.g. photons) pass through the Inner Detector unnoticed.

The **electromagnetic calorimeter (green areas)** absorbs and measures the energy of electrons, positrons and photons. The deposited energy is represented by the blue clusters in the event display.

The **hadronic calorimeter (red areas)** measures the total energy of hadrons, such as protons and neutrons, but is irrelevant to the scope of this stage.

Only muons (and neutrinos) have the ability to penetrate the entire detector. The energetic muons leave little energy in the detectors of the **Muon Spectrometer (outer blue layers)**.

+ Electron + Muon + Photon + Conv. Photon - Delete → Next

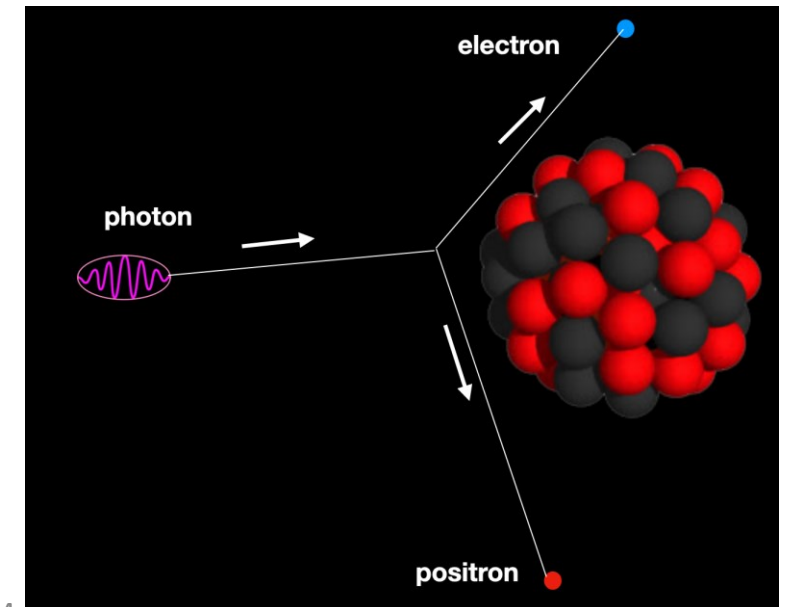
Particle	+/-	p_T [GeV]	ϕ [rad]	θ [rad]
track_3	-	10.17	0.22	0.83
track_4	+	15.35	0.25	0.81
track_5	+	10.85	2.26	0.42
track_6	-	13.02	2.42	1.24

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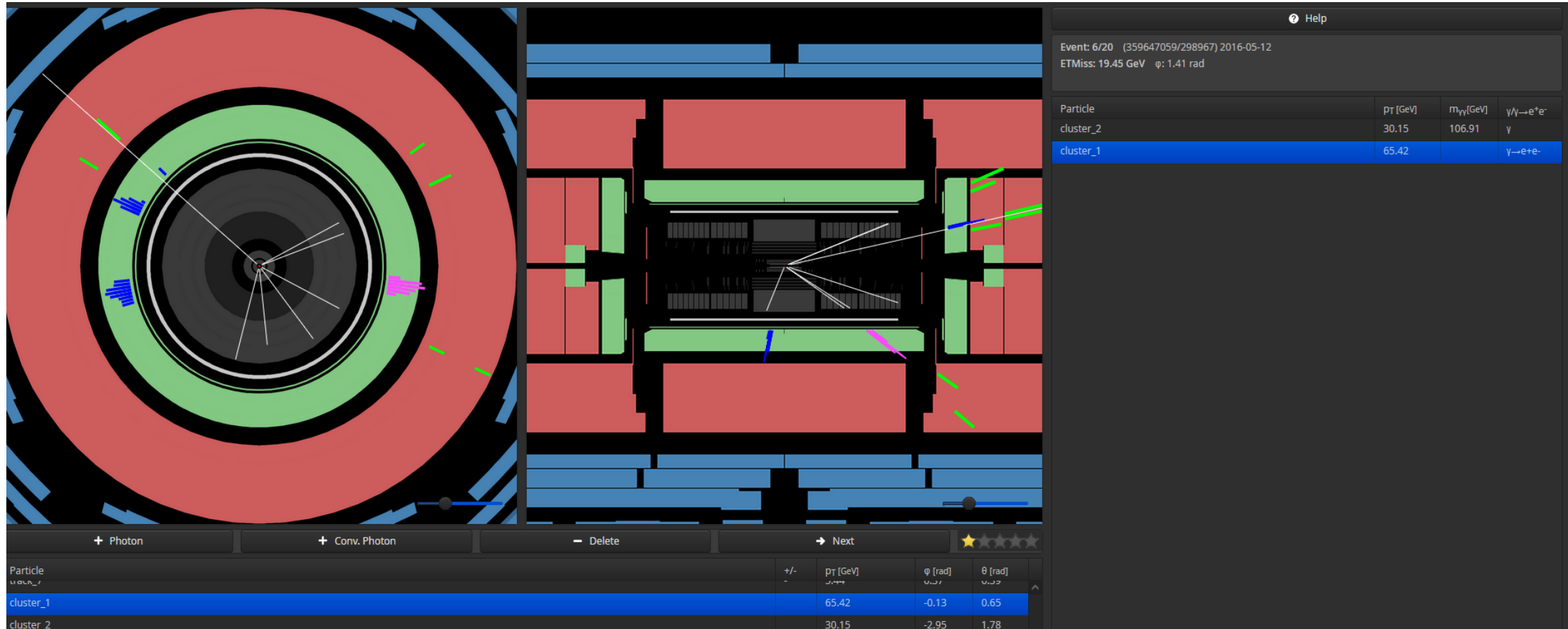
This will help you to get familiar with:

- ATLAS event displays and measures of charge and pT
- How to explore details in the r-phi and r-z view
- How to identify μ / e / γ / converted γ
 - When interacting with matter, a high energy photon **can transform in a e^+e^- pair** (photo-conversion)



Stage 3a: Higgs Identification

This uses a different link from [HYPATHIA](#)



The screenshot displays a particle physics analysis interface. On the left, there are two detector views: a top-down view of the ATLAS detector and a longitudinal cross-section view. The interface includes a control bar with buttons for '+ Photon', '+ Conv. Photon', '- Delete', and '+ Next'. A table at the bottom left shows particle details for 'cluster_1' and 'cluster_2'. On the right, a panel shows event information and a table with columns for 'Particle', 'p_T [GeV]', 'm_{γγ} [GeV]', and 'γγ → e⁺e⁻'.

Particle	p _T [GeV]	m _{γγ} [GeV]	γγ → e ⁺ e ⁻
cluster_2	30.15	106.91	γ
cluster_1	65.42		γγ → e ⁺ e ⁻

Particle	+/-	p _T [GeV]	φ [rad]	θ [rad]
cluster_1	-	65.42	-0.13	0.65
cluster_2	-	30.15	-2.95	1.78

The Signal and Background: Higgs

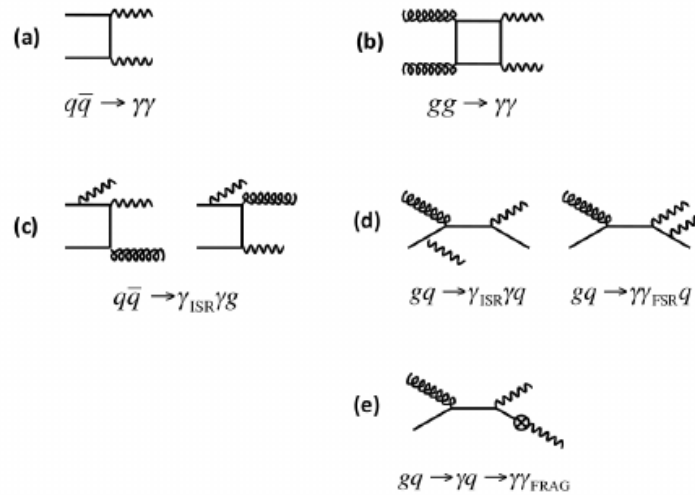
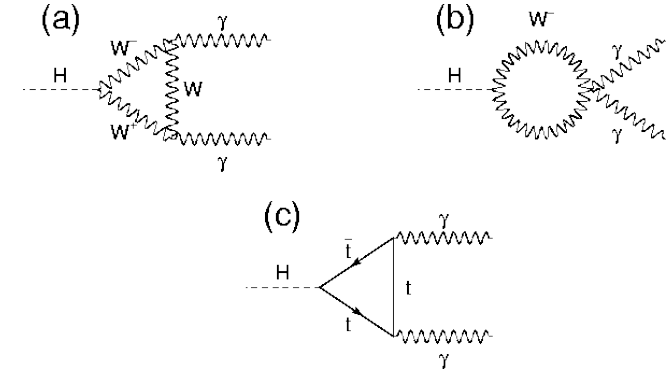
You will go through event displays containing:

➤ **Signal** from Higgs decay as:

➤ $H \rightarrow \gamma\gamma$: two photons with $m(\gamma\gamma) \sim m_H$

➤ $H \rightarrow \gamma\gamma^*$: one photon and one converted with $m(\gamma\gamma^*) \sim m_H$

➤ **Background:** “misreconstructed” electrons/photons and production from other Standard Model processes



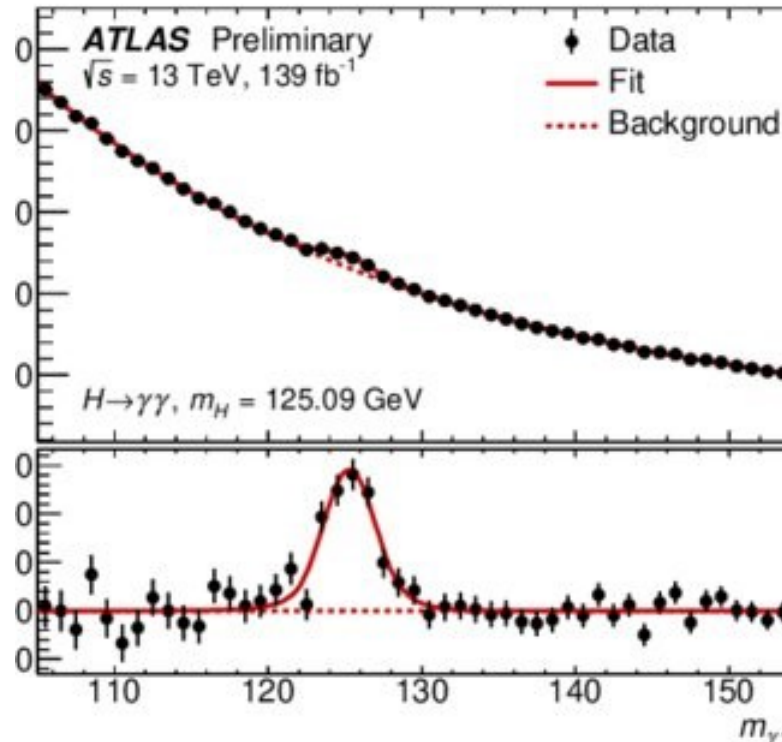
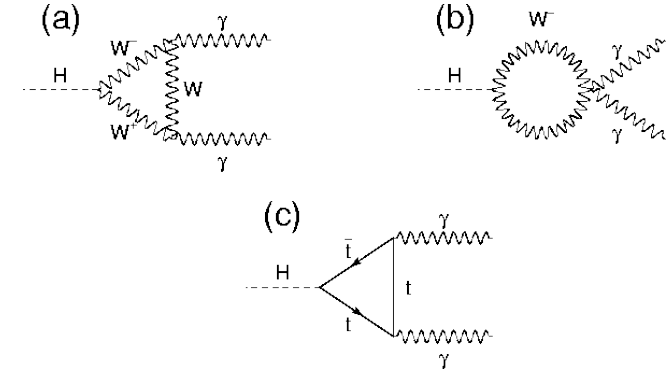
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To be more likely to come from a Higgs:

- Photons have to be quite energetic: $p_T(\gamma) > 50 \text{ GeV}$
- Reconstructed invariant mass should fit a window: $120 < m(\gamma\gamma) < 130 \text{ GeV}$

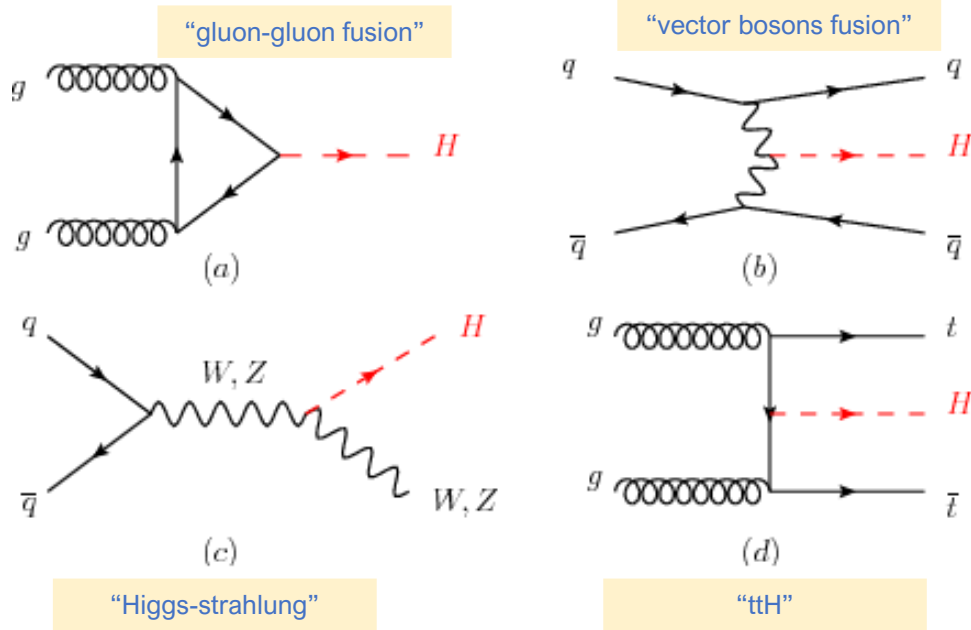
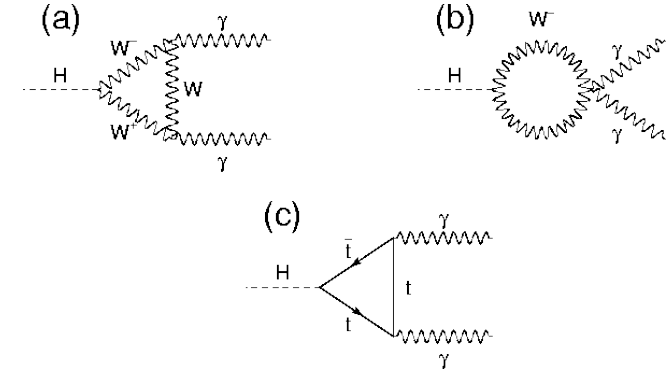
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➤ **Background:** “misreconstructed” electrons/photons and production from other Standard Model processes



- In some Higgs production mechanisms there are no other processes than $\gamma\gamma$ production
- In some other ones, additional jet and tracks can be present

Your own Higgs Identification

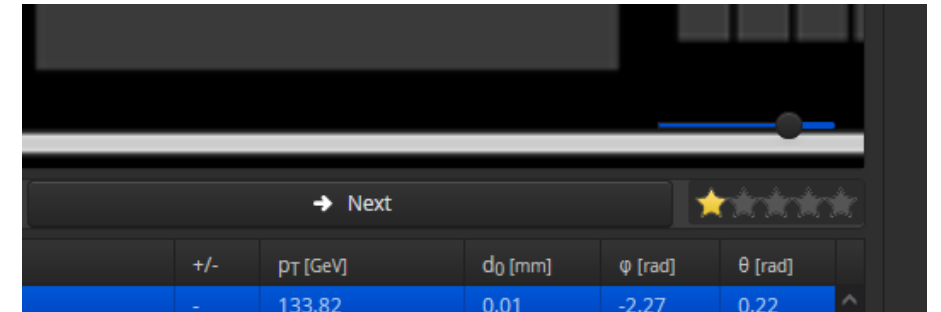
To maximize the outcome of possible $H \rightarrow \gamma\gamma$ candidates, ATLAS uses a **Machine-Learning algorithm** :

- It goes through many (really many!) events and **gives a rating** to the most signal-like ones
- It can be much more effective than a “traditional” selection based on simple cuts
- ...but only if it is **trained**: it should learn what a signal has to look like

➔ *You can help the training by rating the event display !*

➔ *You can give  to:*

Photon	$m(\gamma\gamma)$
$p_T > 45 \text{ GeV}$	$120 < m < 130 \text{ GeV}$



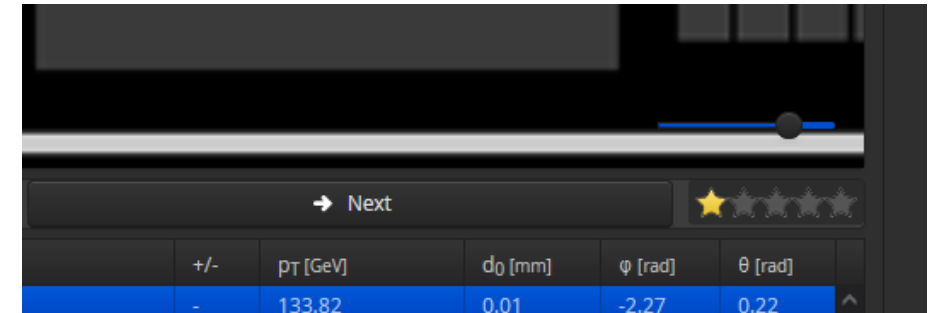
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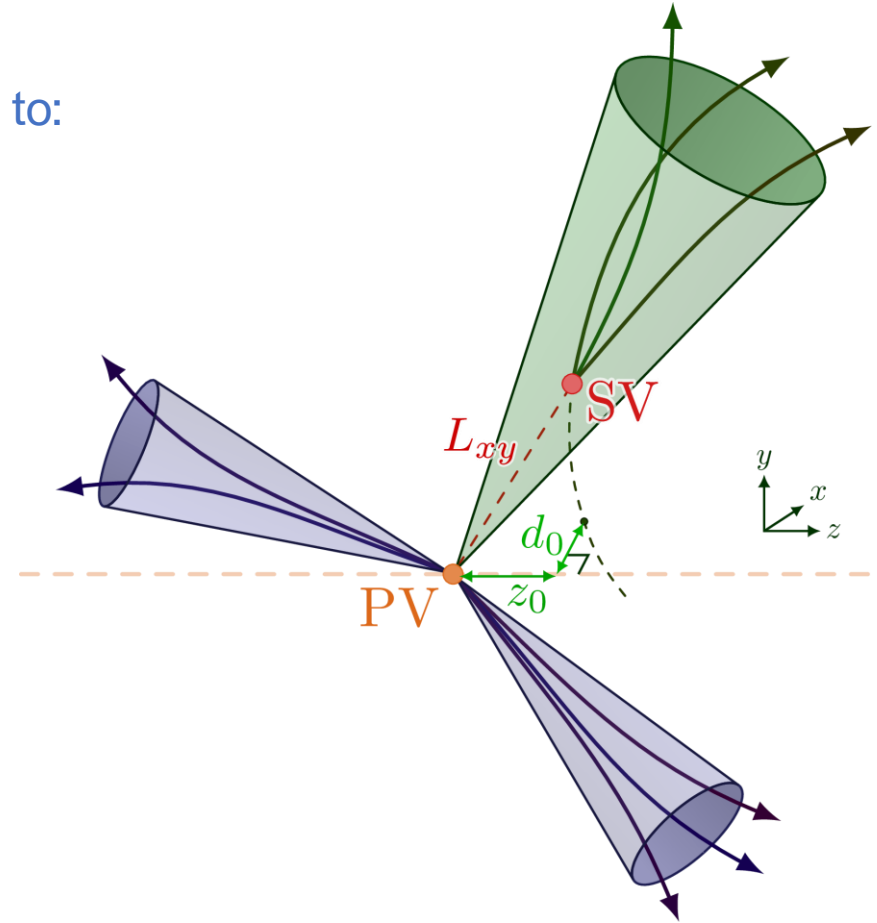
→ You fill tables like [this one](#) with $m(\gamma\gamma)$ from 100 events and produce the histogram (**invariant mass plot**)

→ You can declare the **mass of the Higgs candidate** as $\text{Mean} \pm \sigma/n$

→ You should be ready to show **examples of rating for each category**

DV + μ

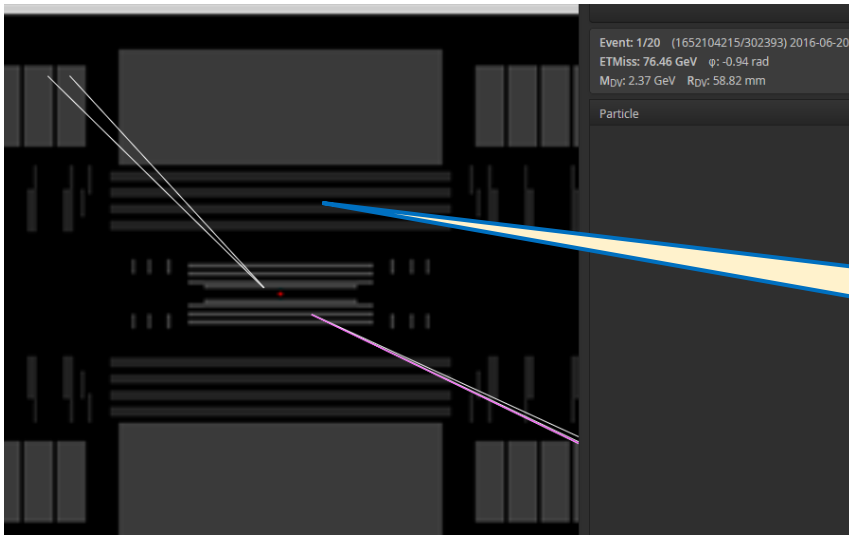
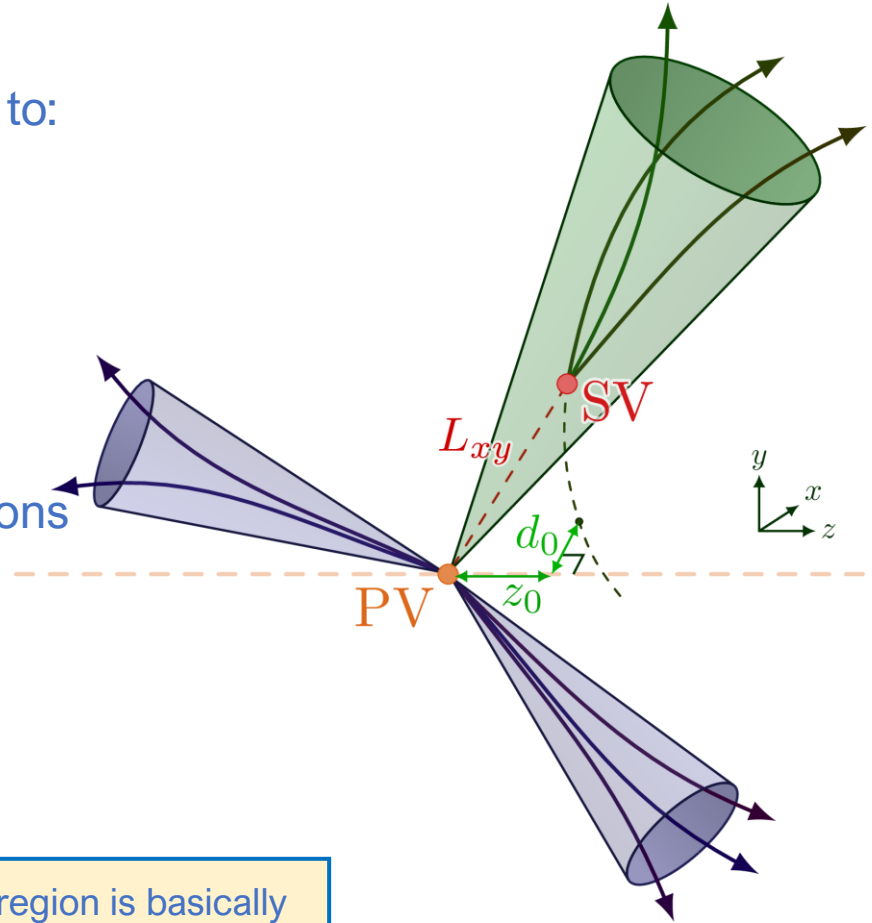
- **Muon selection.** To be more likely to come from the signal, it has to:
 - be quite energetic: $p_T > 45$ GeV
 - “impact parameter” large enough: $|d_0| > 2$ mm



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 - be quite energetic: $p_T > 45$ GeV
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- **DV selection.** To be more likely to come from the signal, it has to:
 - Be quite far from the primary vertex: $r_{DV} > 140$ mm
 - ...but not too far not to be confused with cosmics or interactions with detector material: $r_{DV} < 180$ mm

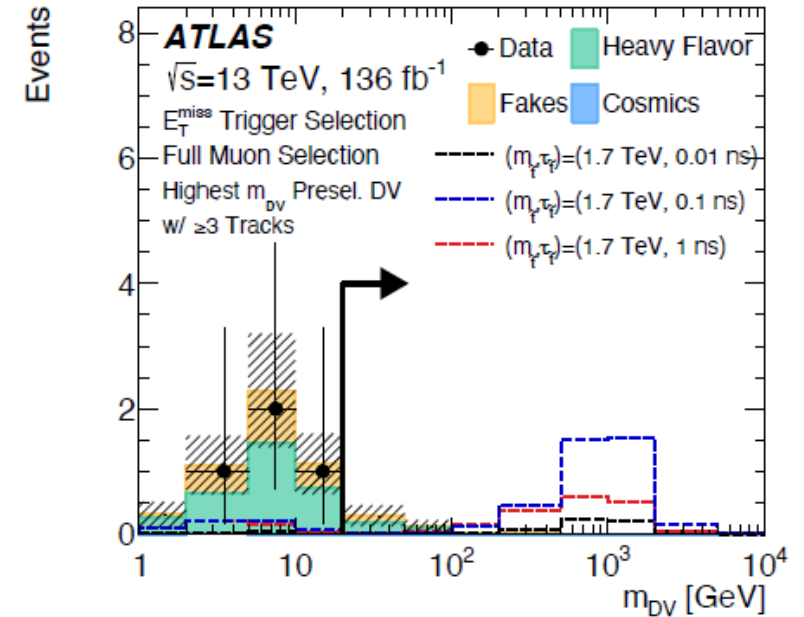


The $140 < r_{DV} < 180$ mm region is basically background-free

DV + μ

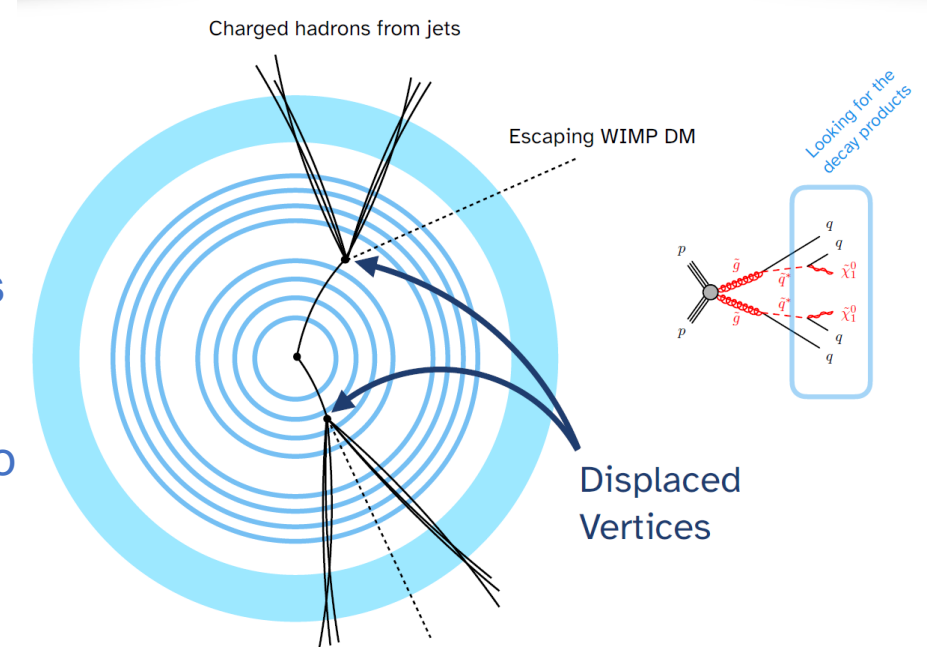
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 - m_{DV} is the “invariant mass” associated with the DV. It corresponds to the mass of a parent particle, which decayed into the particles associated with the DV. A large m_{DV} reduces the probability that the muon of the DV originates from interactions with detector material. Here $m_{DV} > 20$ GeV



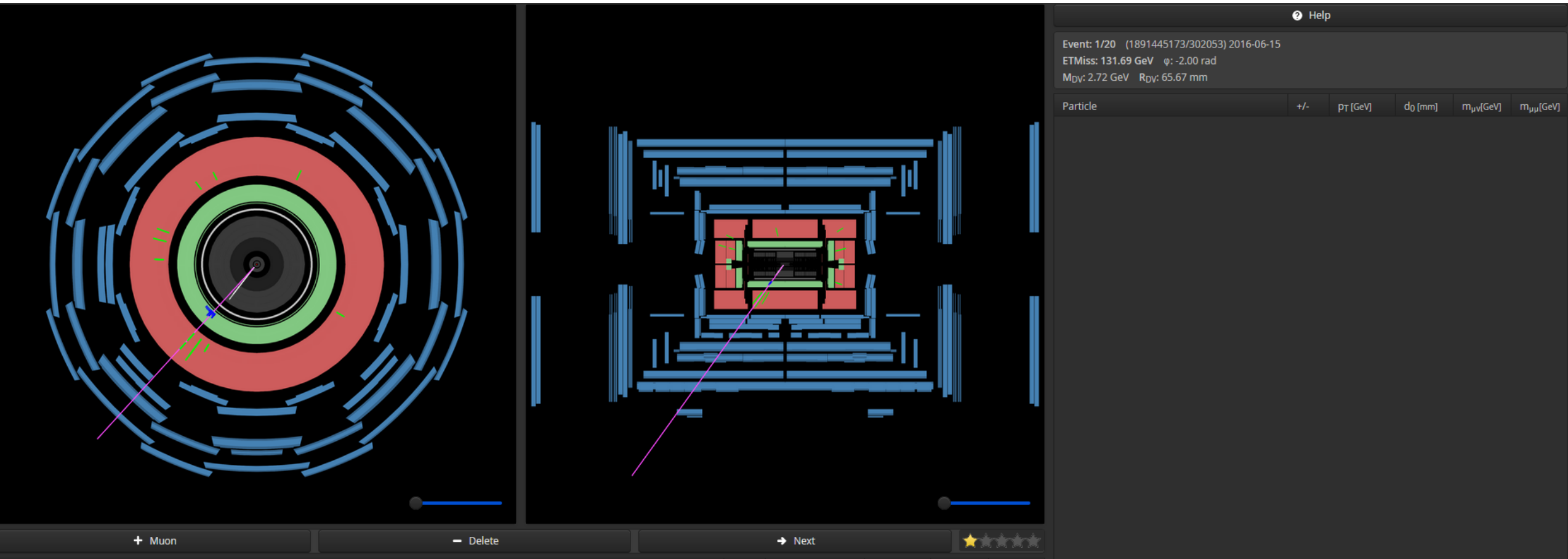
DV + MET

- **Missing energy selection.** To be more likely to come from the signal, it has to:
 - be quite energetic: $MET > 250 \text{ GeV}$
- **DV selection.** To be more likely to come from the signal, it has to:
 - Be quite far from the primary vertex: $r_{DV} > 140 \text{ mm}$
 - ...but not too far not to be confused with cosmics or interactions with detector material: $r_{DV} < 180 \text{ mm}$
 - m_{DV} is the “invariant mass” associated with the DV. It corresponds to the mass of a parent particle, which decayed into the particles associated with the DV. A large m_{DV} reduces the probability that the muon of the DV originates from interactions with detector material. Here $m_{DV} > 20 \text{ GeV}$



Stage 3b: LLP Identification

This uses a different link from [HYPATHIA](#)



The screenshot displays a software interface for particle physics analysis. On the left, there are two detector views: a top-down view of a circular detector with concentric rings (red, green, blue) and a side-view cross-section of the detector. A pink line indicates a particle trajectory in both views. On the right, a panel shows event information and a table for particle identification.

Event: 1/20 (1891445173/302053) 2016-06-15
ETMiss: 131.69 GeV ϕ : -2.00 rad
M_{DY}: 2.72 GeV R_{DY}: 65.67 mm

Particle	+/-	p _T [GeV]	d ₀ [mm]	m _{μν} [GeV]	m _{μμ} [GeV]

Bottom navigation: + Muon, - Delete, → Next, ★★★★★

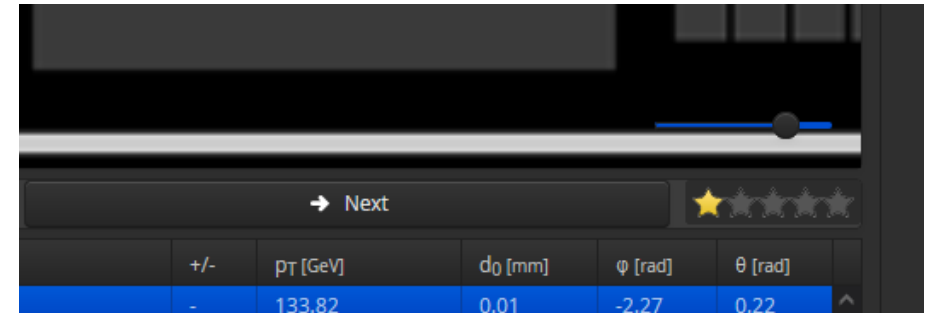
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Muon	DV
pT > 45 GeV	140 < rDV < 180 mm
d0 > 2 mm	mDV > 20 GeV

or

MET	DV
MET > 250 GeV	140 < rDV < 180 mm
	mDV > 20 GeV

→ *All the other ratings have to be justified by you*

...Enjoy!



LLP in real research

Brussels III

```

pos_base = [];
pos_top = [];
alpha_b = 2.5*deg2rad;
alpha_t = 10*deg2rad;
height = 2.0;
radius_b = 3.0;
radius_t = 1.0;

for i = 1:3,
% base points
angle_m_b = (2*pi/3)* (i-1) - alpha_b;
angle_p_b = (2*pi/3)* (i-1) + alpha_b;
pos_base(2*i-1,:) = radius_b* [cos(angle_m_b), sin(angle_m_b), 0.0];
pos_base(2*i,:) = radius_b* [cos(angle_p_b), sin(angle_p_b), 0.0];
% top points (with a 60 degree offset)
angle_m_t = (2*pi/3)* (i-1) - alpha_t + 2*pi/6;
angle_p_t = (2*pi/3)* (i-1) + alpha_t + 2*pi/6;
pos_top(2*i-1,:) = radius_t* [cos(angle_m_t), sin(angle_m_t), height];
pos_top(2*i,:) = radius_t* [cos(angle_p_t), sin(angle_p_t), height];

```

