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:

$$m(Z) = m(l_1 l_2) = \sqrt{E(l_1 l_2)^2 - p(l_1 l_2)^2} \rightarrow m_Z = \sqrt{(E_1 + E_2)^2 - (\overrightarrow{p_1} + \overrightarrow{p_2})^2}$$

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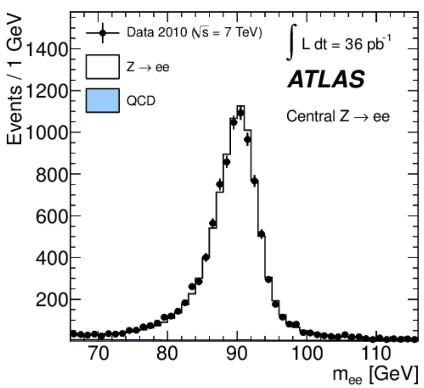
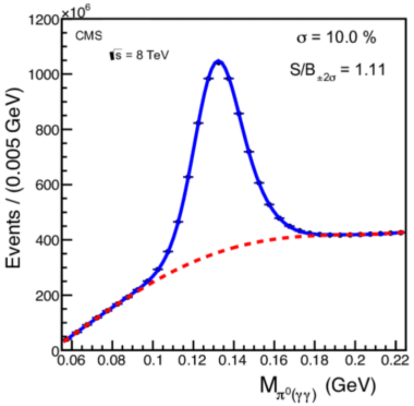
As a consequence, we can **measure the mass of a "parent" particle** by reconstructing the energy and momentum of "daughter"





Invariant mass: a tool for discovery

Brussels III

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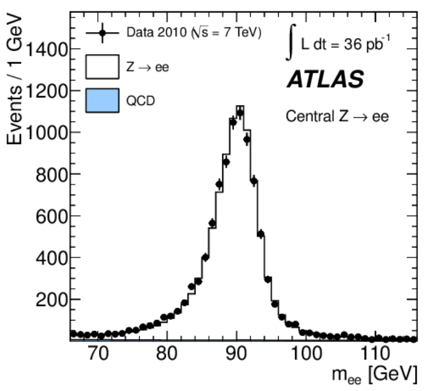
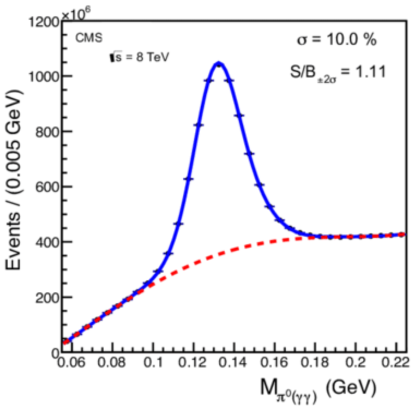
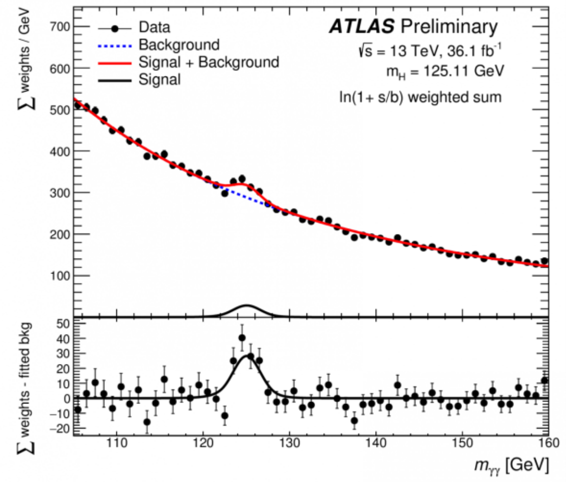
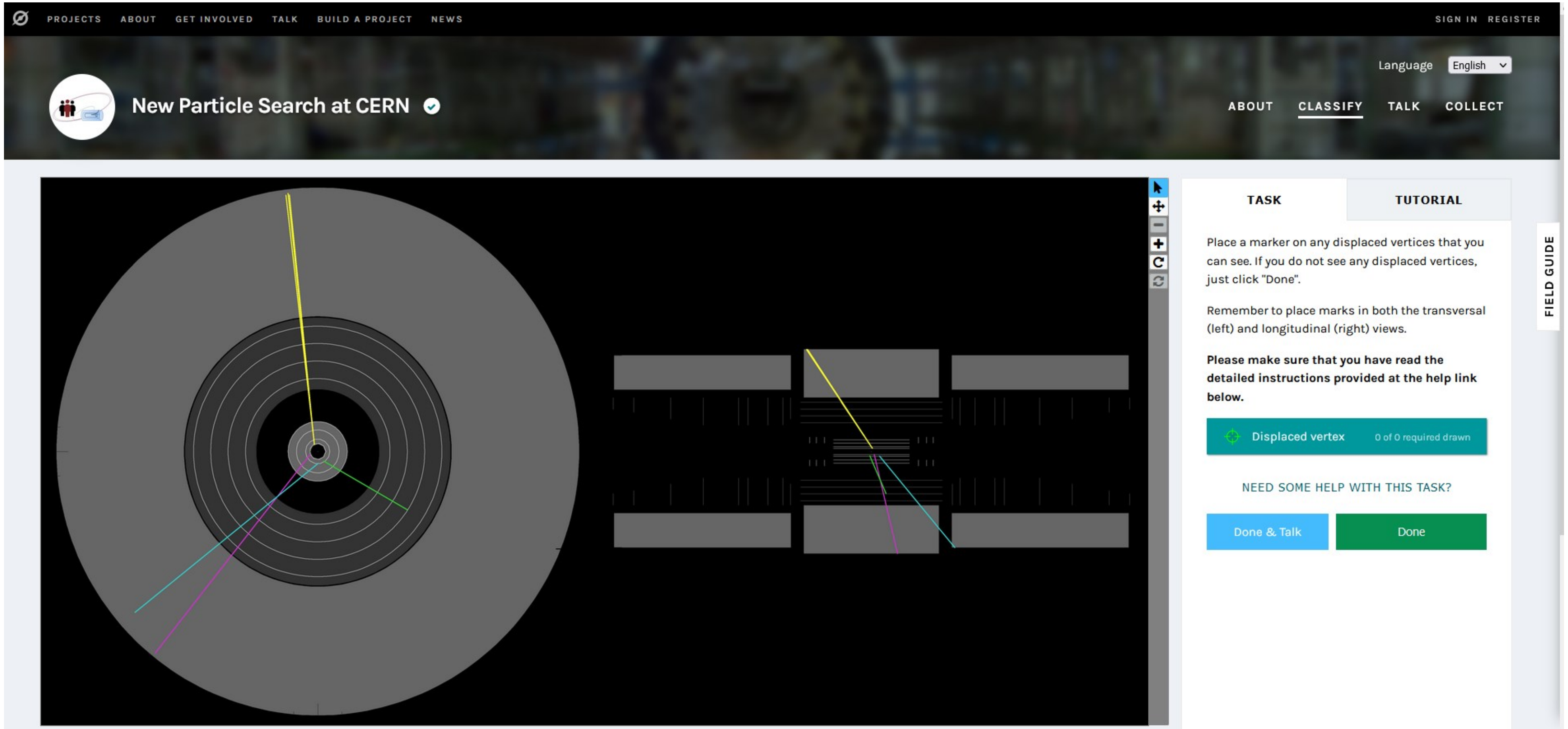






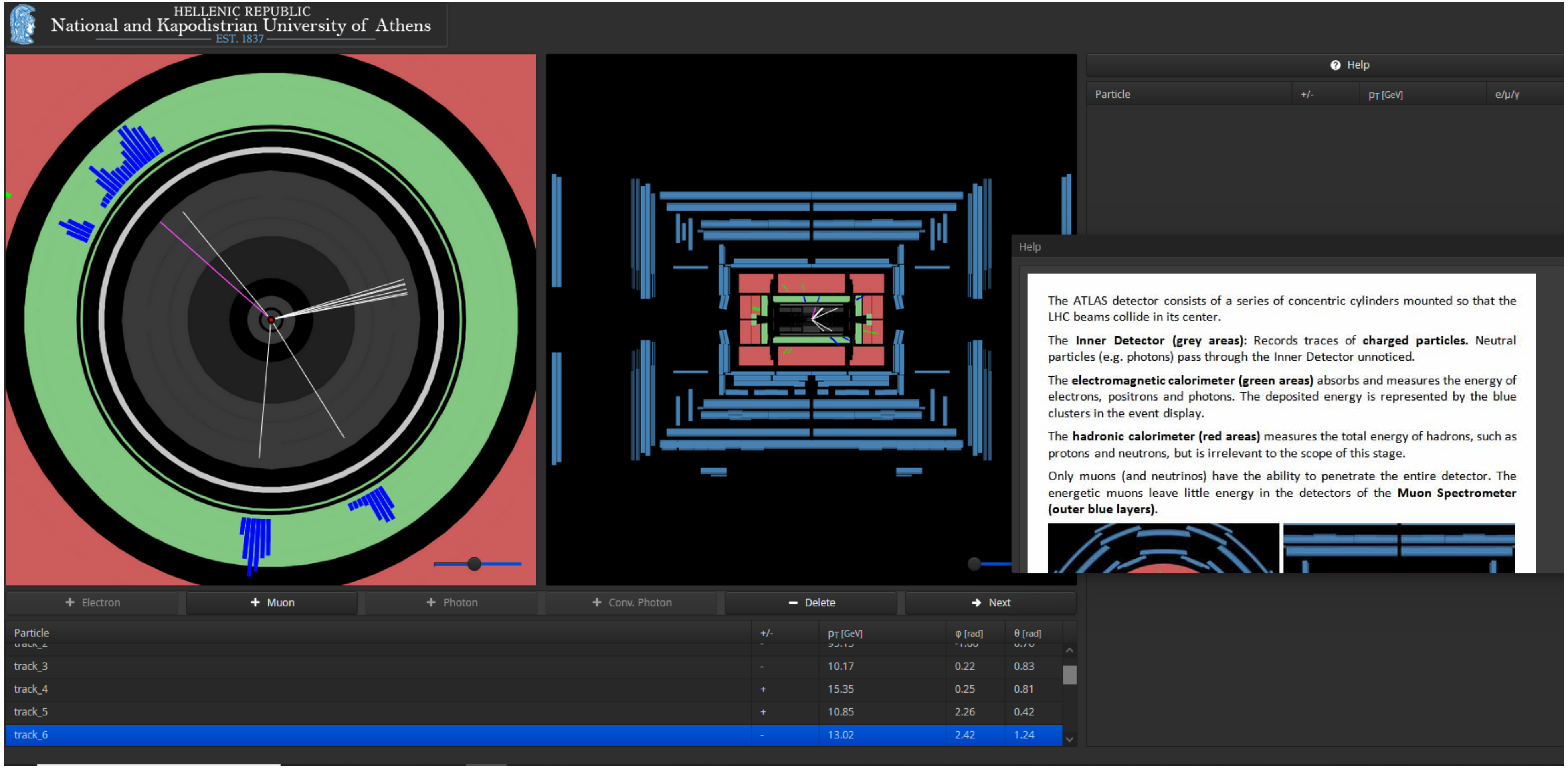
Stage 1: Displaced vertices

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



Stage 2: Particle Identification

This stage uses a web event display called [HYPATHIA]

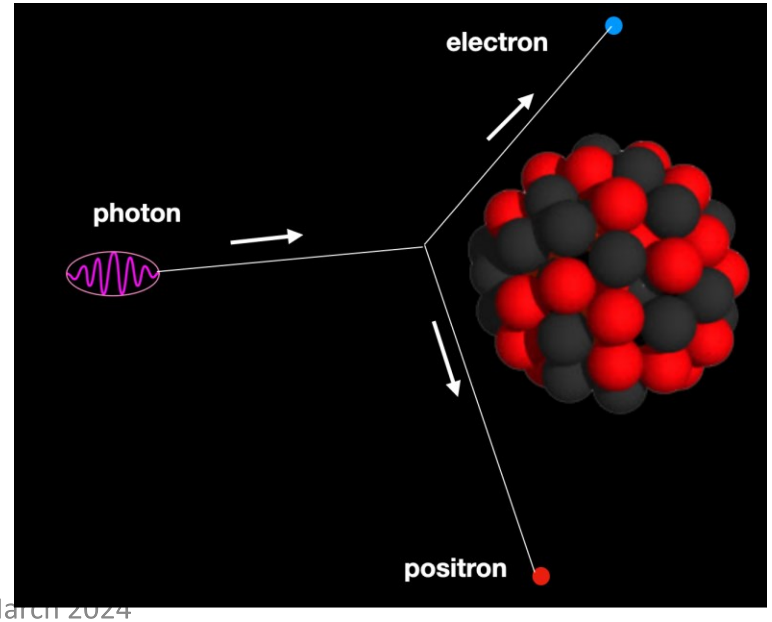


Stage 2: Particle Identification

This stage uses a web event display called [HYPATHIA]

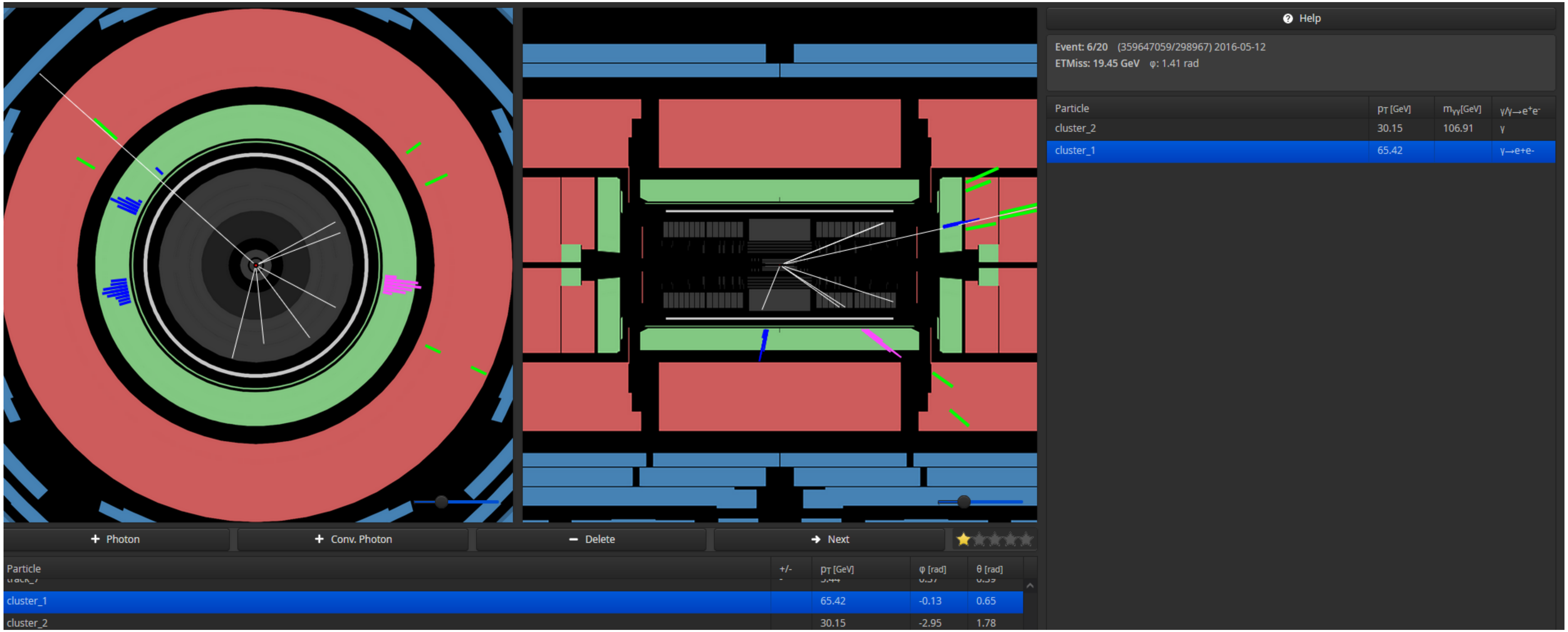
This will help you to get familiar with:

- 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)

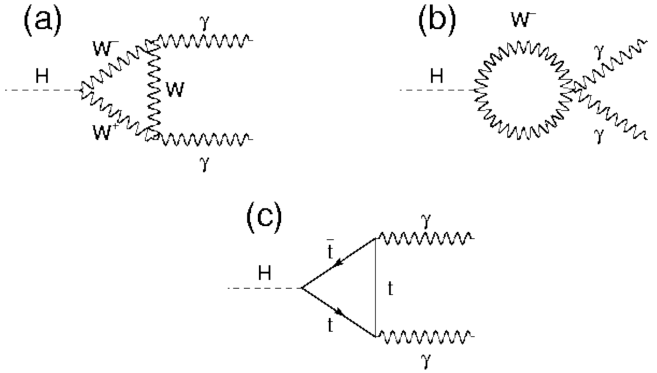


Stage 3a: Higgs Identification

This uses a different link from HYPATHIA



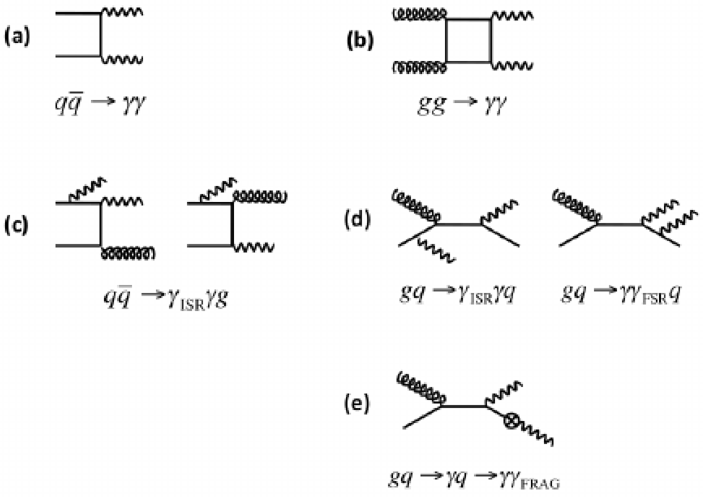
The Signal and Background: Higgs



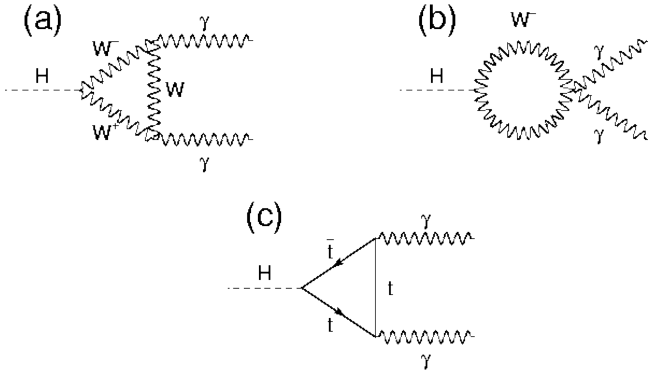
You will go through event displays containing:

- **Signal** from Higgs decay as:
  - **H → γγ** : two photons with m(γγ) ~ m_H
  - **H → γγ∗** : one photon and one converted with m(γγ∗) ~ m_H

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

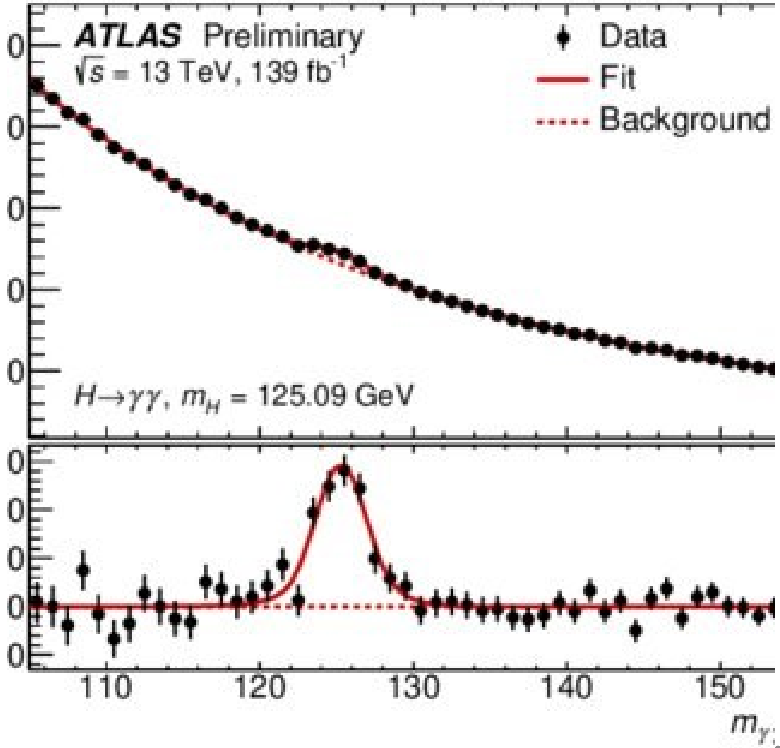


The Signal and Background: Higgs



You will go through event displays containing:

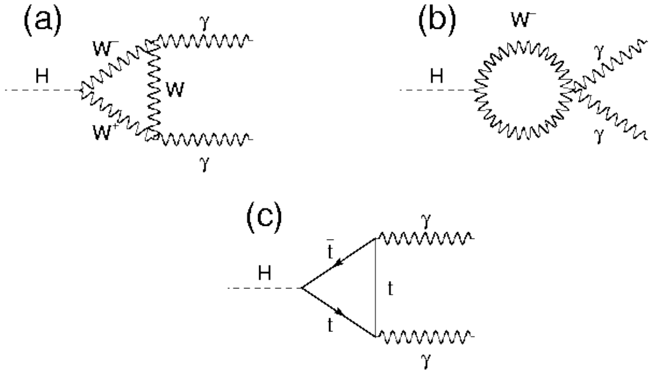
- **Signal** from Higgs decay as:
  - **H → γγ** : two photons with $m(\gamma\gamma) \sim m_H$
  - **H → γγ*** : one photon and one converted with $m(\gamma\gamma*) \sim m_H$
- **Background:** "misreconstructed" electrons/photons and production from other Standard Model processes



To be more likely to come from a Higgs:

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

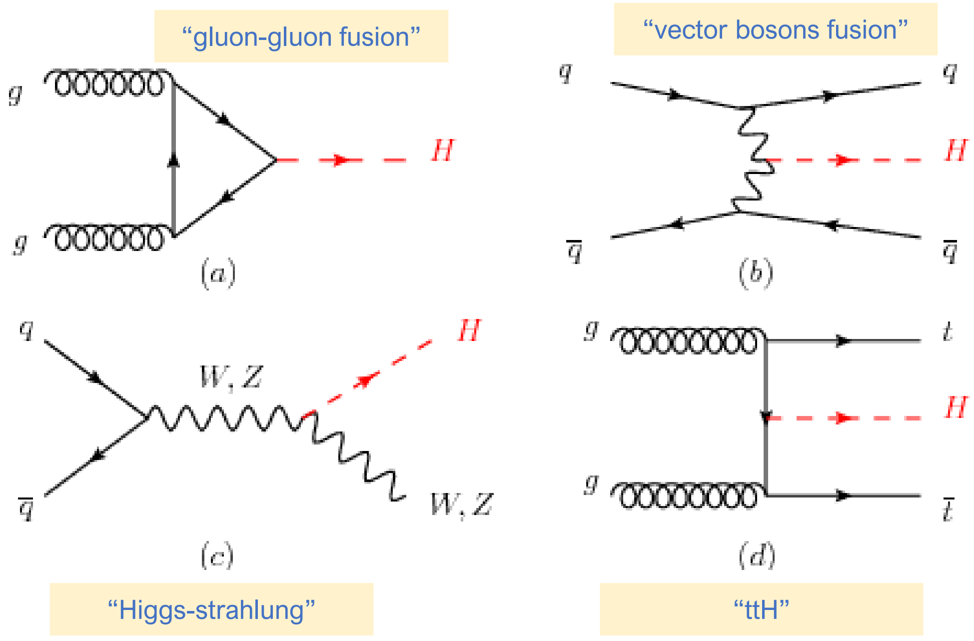
The Signal and Background: Higgs



You will go through event displays containing:

- **Signal** from Higgs decay as:
  - **H → γγ** : two photons with m(γγ) ~ m_H
  - **H → γγ*** : one photon and one converted with m(γγ*) ~ m_H

- **Background:** "misreconstructed" electrons/photons and production from other Standard Model processes



- In some Higgs production mechanisms there are no other processes than γγ production

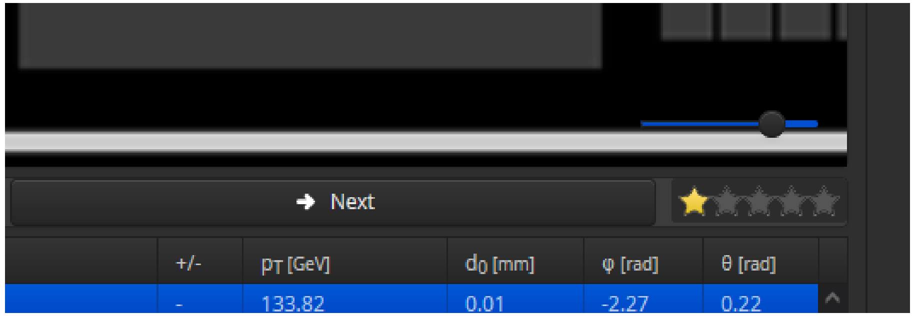
- In some other ones, additional jet and tracks can be present

Your own Higgs Identification

Brussels III

To maximize the outcome of possible H→ $\gamma\gamma$ 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($\gamma\gamma$)
pT > 45 GeV	120<m<130 GeV

Your own Higgs Identification

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

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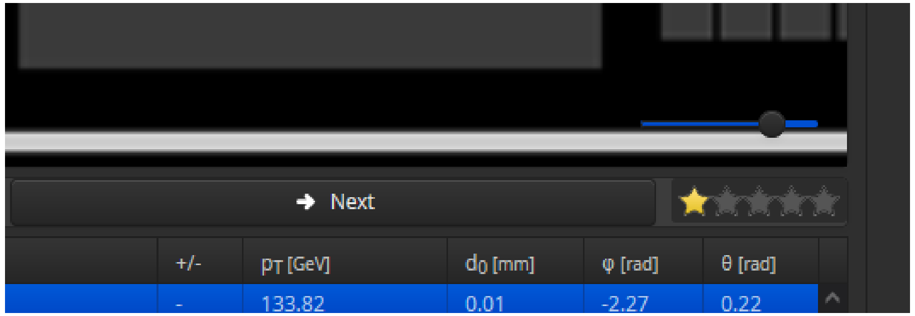


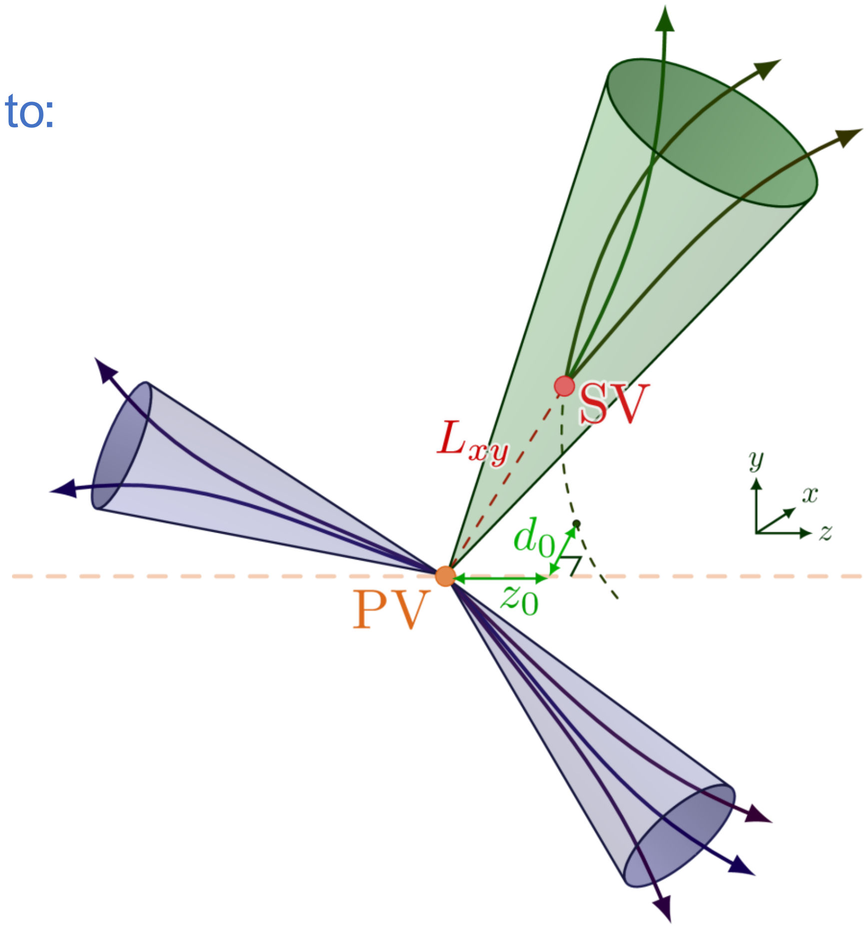
→ You fill tables like this one with m($\gamma\gamma$) from 100 events and produce the histogram **(invariant mass plot)**

→ You can declare the **mass of the Higgs candidate** as Mean ± σ/n

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

DV + μ

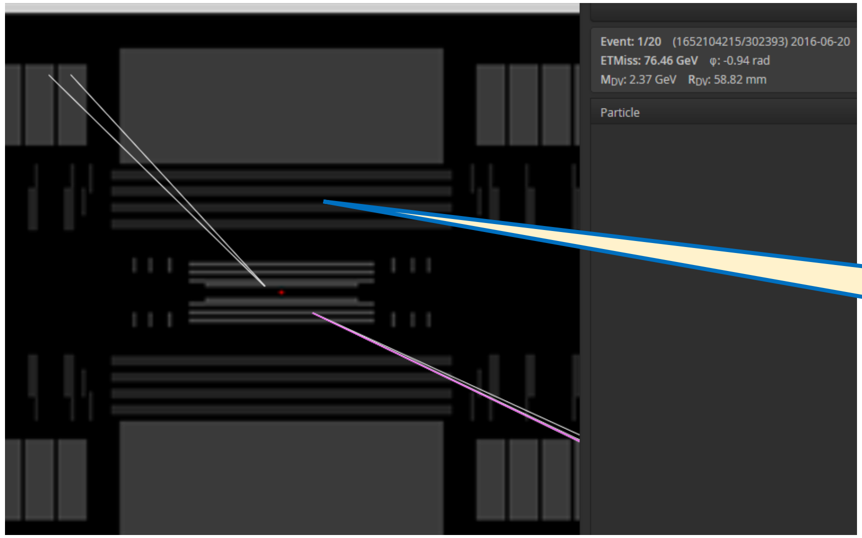
- **Muon selection.** To be more likely to come from the signal, it has to:
  - be quite energetic: pT > 45 GeV
  - “impact parameter” large enough: $|d_0|>2$ mm



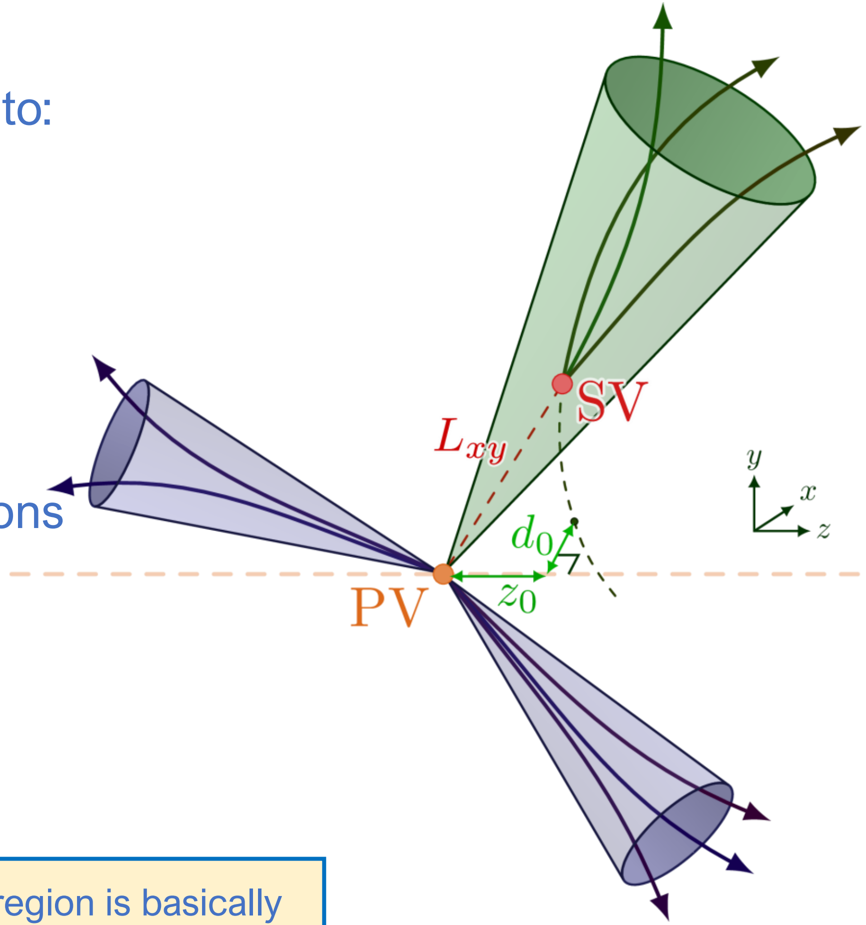
DV + μ

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

- **DV selection.** To be more likely to come from the signal, it has to:
  - Be quite fare 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



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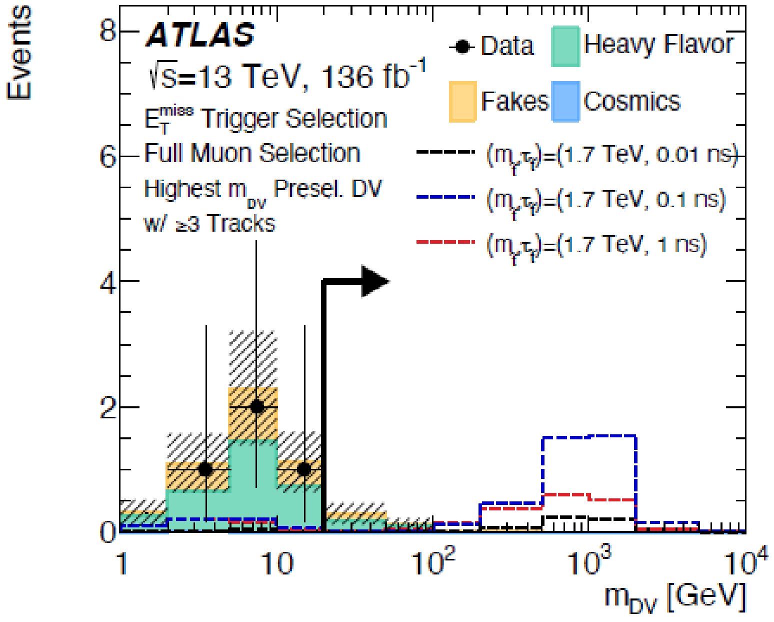
- **DV selection.** To be more likely to come from the signal, it has to:
  - Be quite fare from the primary vertex: r_{DV} > 140 mm
  - …but not too far not to be confused with cosmics or interactions with detector material: r_{DV} < 180 mm
  - m_{DV} is the "invariant mass" associated with the DV. 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

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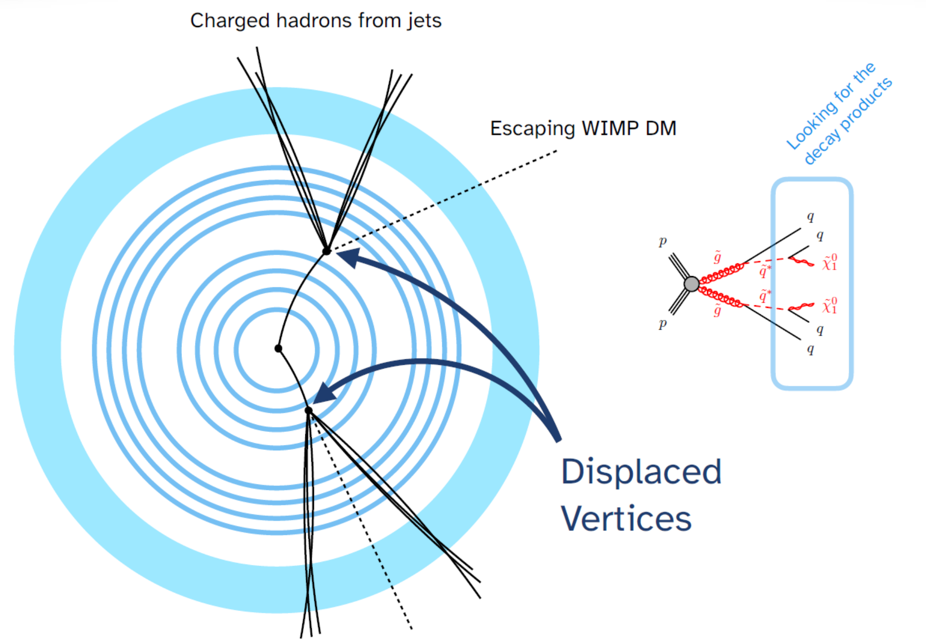
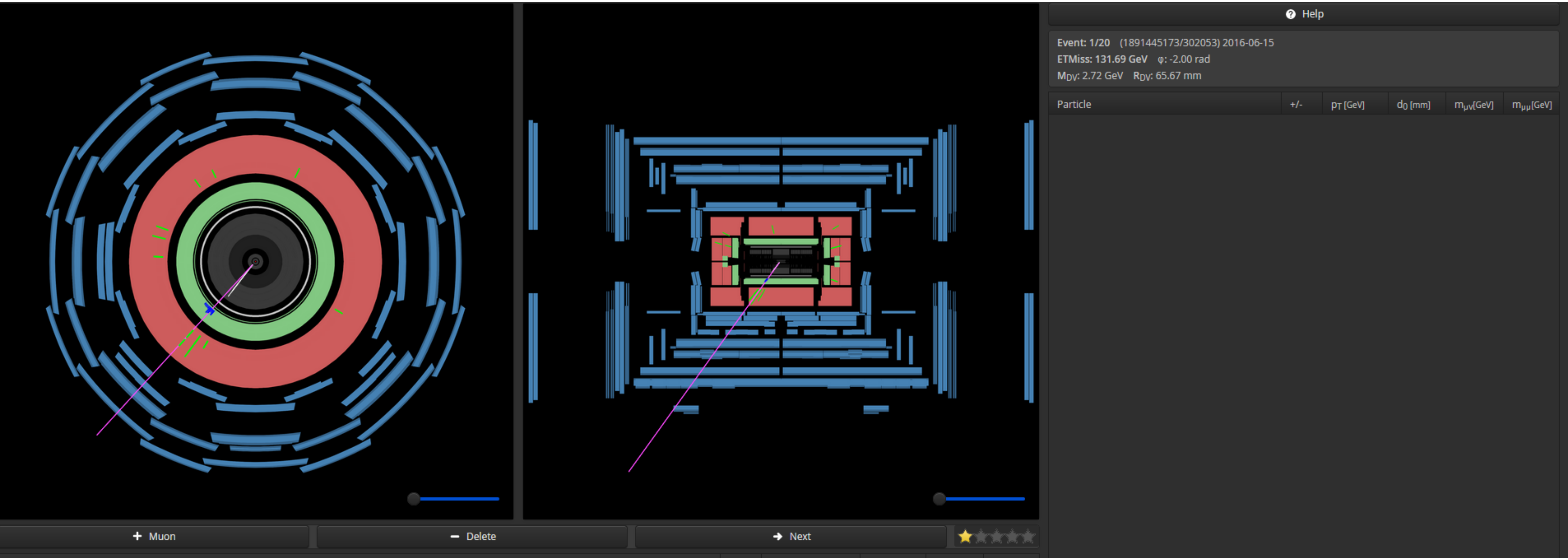
- **Missing energy selection**. To be more likely to come from the signal, it has to:
  - be quite energetic: MET > 250 GeV

- **DV selection**. To be more likely to come from the signal, it has to:
  - Be quite fare 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
  - 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



Stage 3b: LLP Identification

This uses a different link from HYPATHIA



Stage 3b: LLP Identification

To maximize the outcome of possible LLP candidates, ATLAS uses a **Machine-Learning algorithm** :

- It goes through many (really many!) events and **gives a rating** to the most signal-like ones
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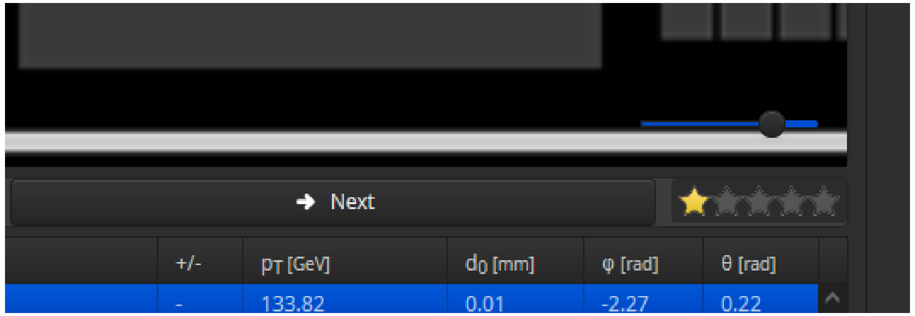
- …but only if it is **trained**: it should learn what a signal has to look like



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

→ ***You can give***  ***to:***

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];
```