Reconstruction and Identification of Particles at the LHC
V Uniandes Particle Detector School

Andrés Flórez

December 13, 2021

Overview

Introduction.

1. The Standard Model and its problems
2. The Large Hadron Collider

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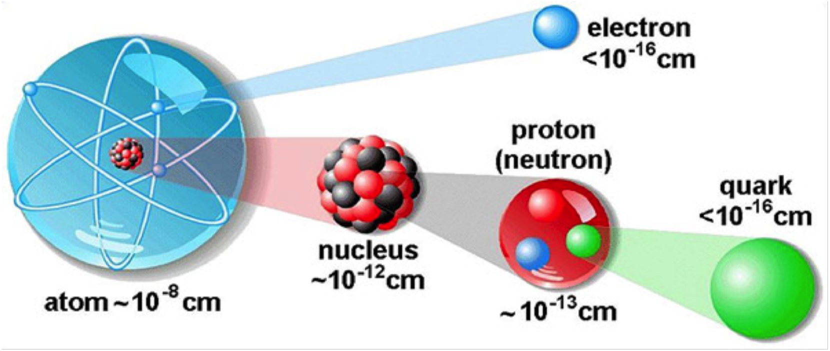
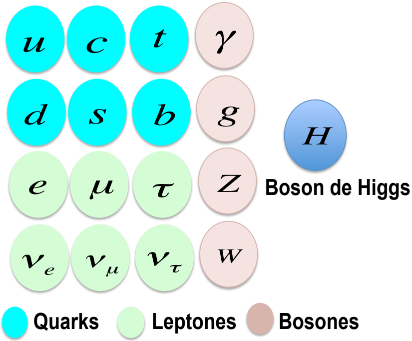
What have we learned about matter?

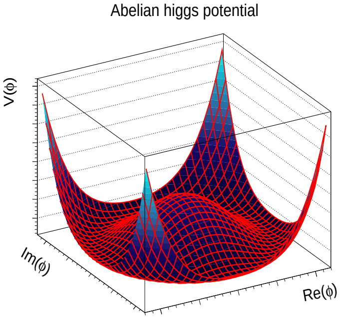


Fundamental particles and their interactions:

$$\mathbf{SU(3)_C} \otimes \mathbf{SU(2)_L} \otimes \mathbf{U(1)_Y}, \qquad (1)$$



$$V(\phi) = -\mu^2\phi^\dagger(\phi) + \lambda(\phi^\dagger\phi)^2 \qquad (2)$$



$$|\langle 0|\phi|0\rangle|^2 = \frac{\nu^2}{2}, \text{with } \nu^2 = -\frac{\mu^2}{\lambda} \qquad (3)$$

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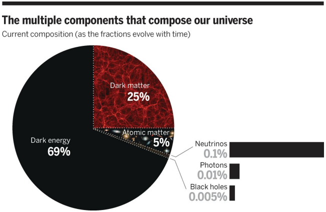

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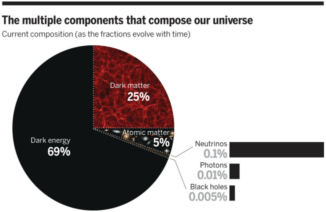


The Large Hadron Collider (LHC)

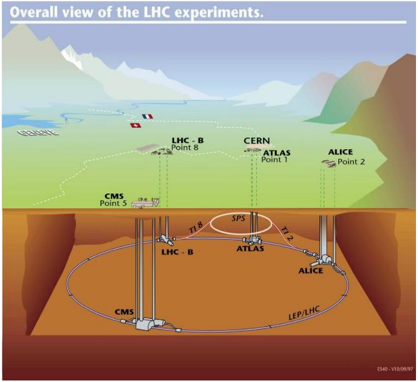


Figure: Sketch of the LHC. The main experiments are: CMS, ATLAS, ALICE and LHCb

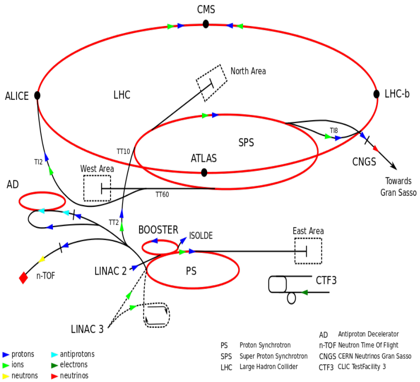
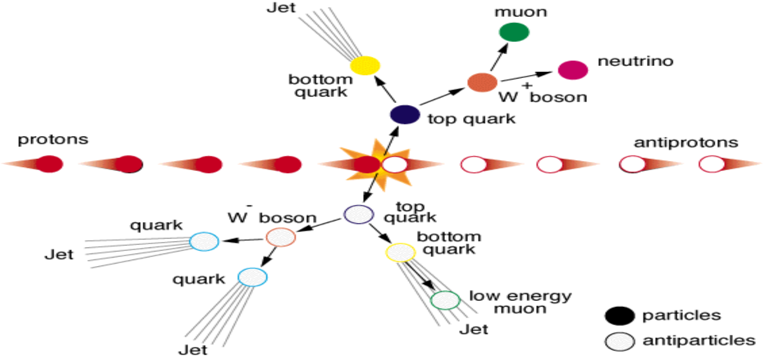


Figure: Sketch of the acceleration chain at the LHC



A Top Antitop Quark Event from the
D-Zero Detector at Fermilab

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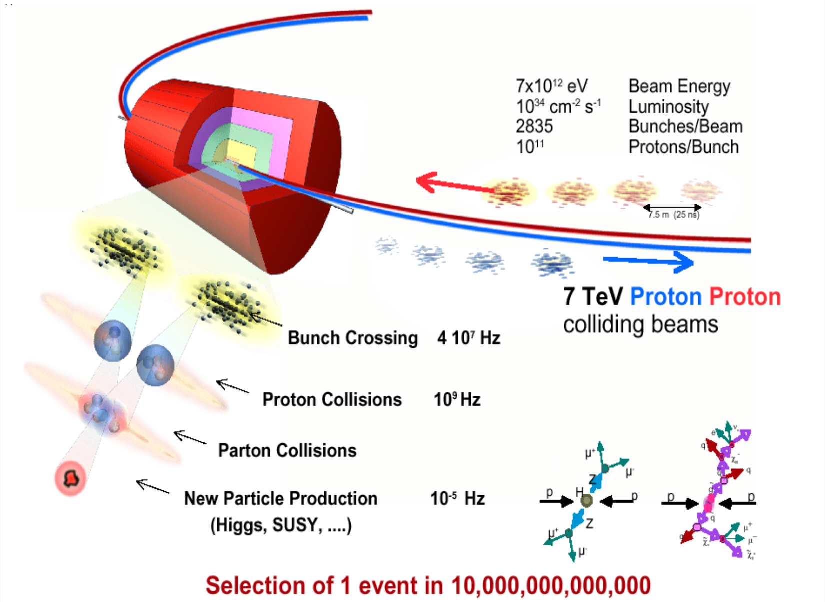
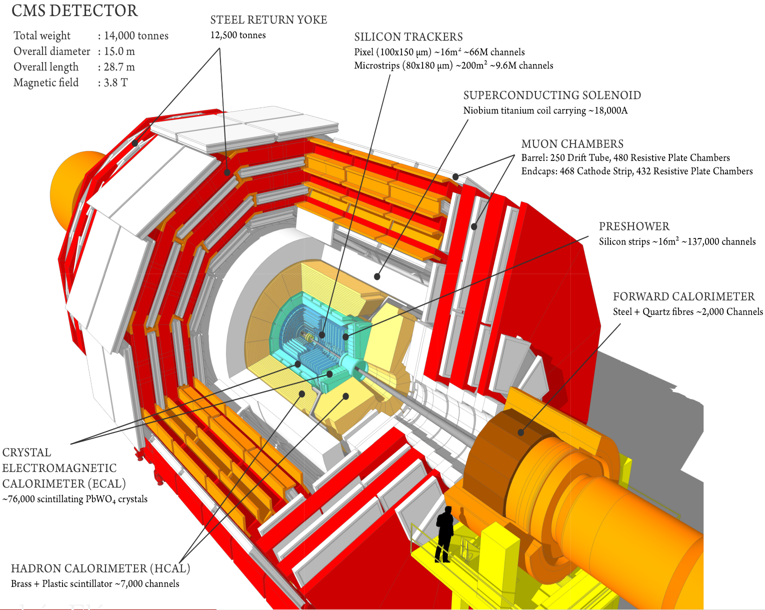


The CMS Detector



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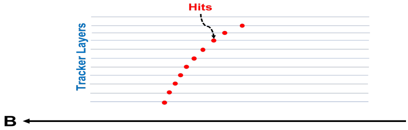

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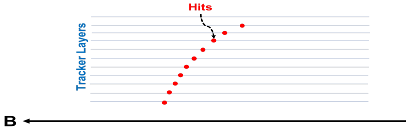

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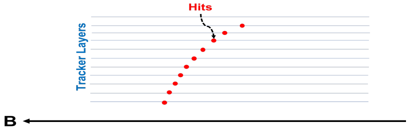

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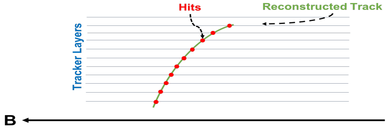

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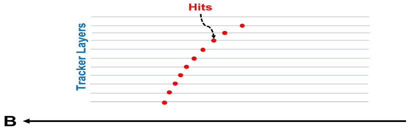

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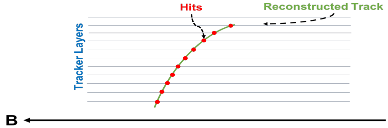
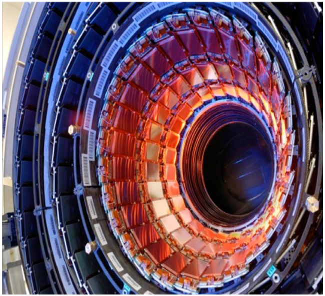
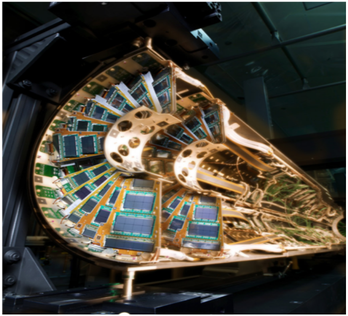
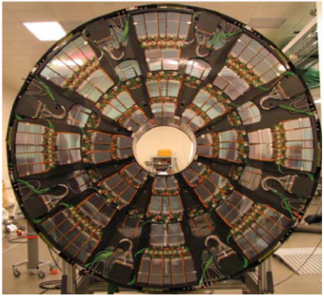


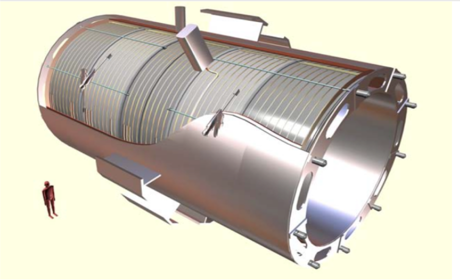
- The CMS tracking system is composed of a silicon-based pixel detector y a silicon-based strip detector (tracker).
- The pixel detector is used to reconstructed primary and secondary vertices.
- The tracker detector is used to reconstruct the trajectory of particles with electric charge.

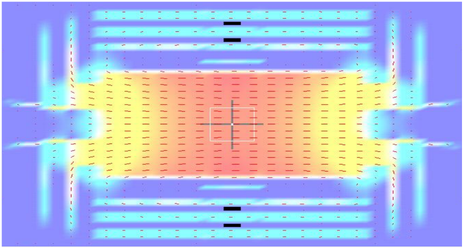




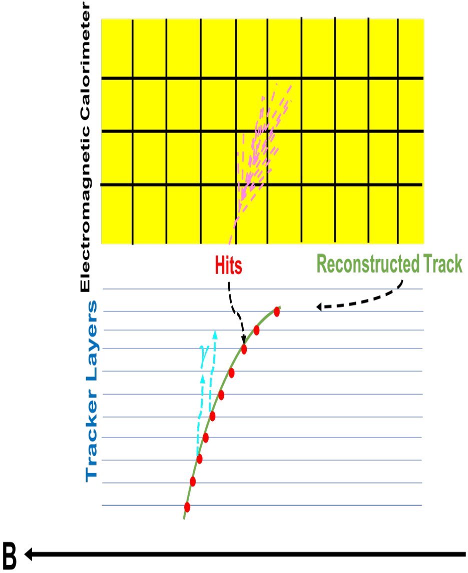


- **CMS has a superconducting solenoid, around the tracking system, which provides a 3.8 T magnetic field.**
- The solenoid is made of stabilised reinforced Niobium-Titanium (NbTi).

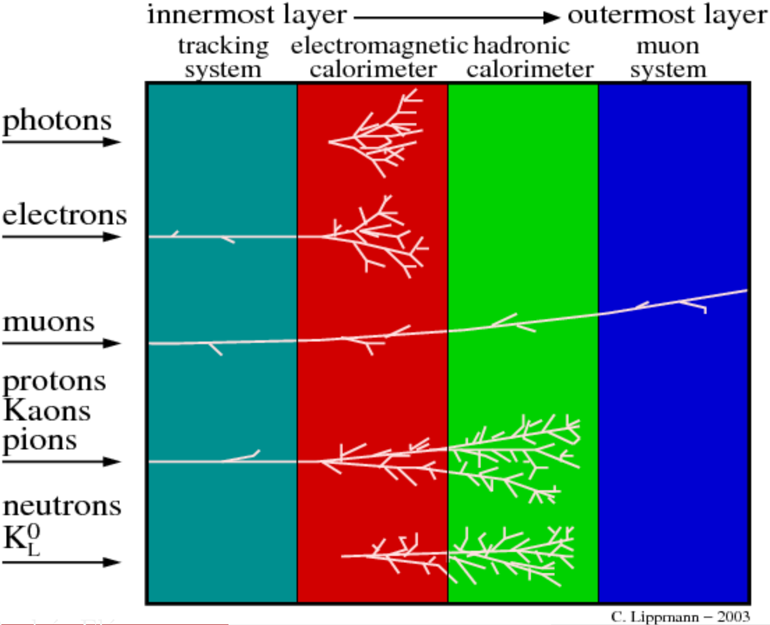




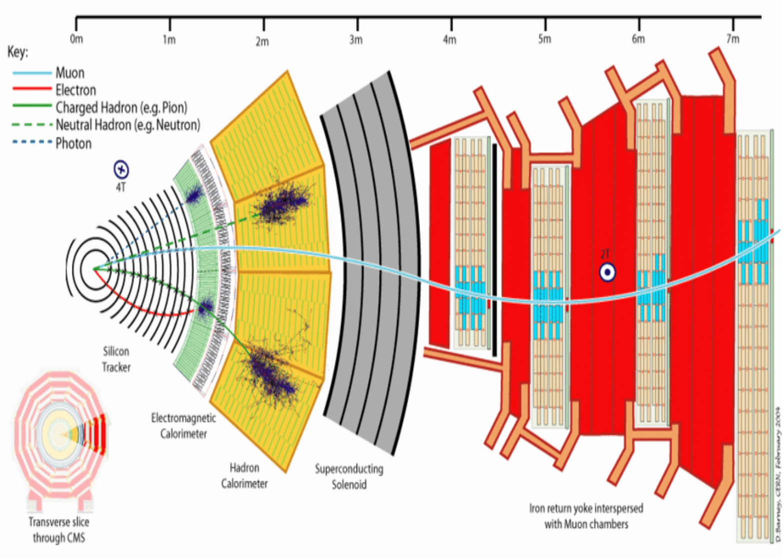
- The electromagnetic calorimeter is a detector used to measure the energy of particles which primarily have electromagnetic interactions.
- When the trajectory of a charged particle bends due to a magnetic and/or electric field, photons are emitted due to the change in its acceleration. This effect is commonly referred to as Bremsstrahlung radiation.



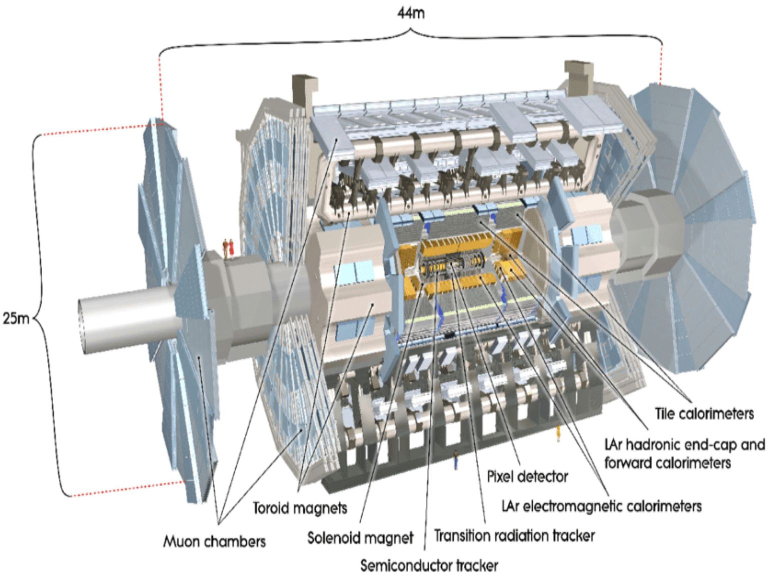
Detection of Particles



The CMS Detector



The ATLAS Detector

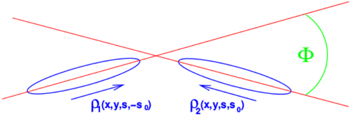


1. Cross Section
2. Luminosity

In particle physics, a cross section (σ) represents the *probability of production* of a specific process. This quantity is related with the level of the interaction between the beam and the target, or between two beams, and it depends on the energy of collisions.

Some important concepts

1. Cross Section
2. Luminosity
3. Coordinate systems

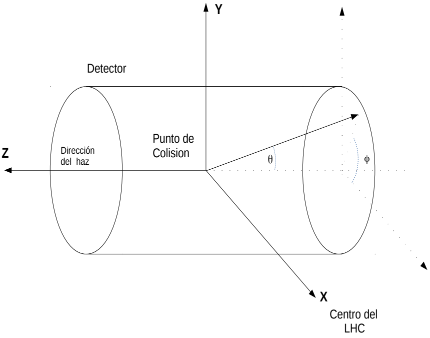


$$\mathcal{L} \sim \frac{N_A \times N_B \times f \times F}{4\pi(\sigma_A \times \sigma_B)} \tag{5}$$

$$L = \int \mathcal{L} dt \tag{6}$$

$$N_i = \sigma_i \times L \tag{7}$$

1. Cross Section
2. Luminosity
3. Coordinate systems
4. Pseudorapidity



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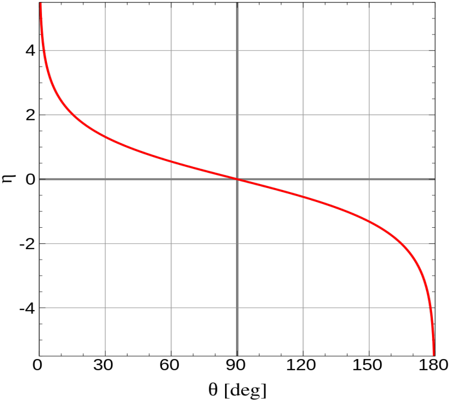
5. η-gaps.

$$\eta \equiv -ln\left[tan\left(\frac{\theta}{2}\right)\right].$$



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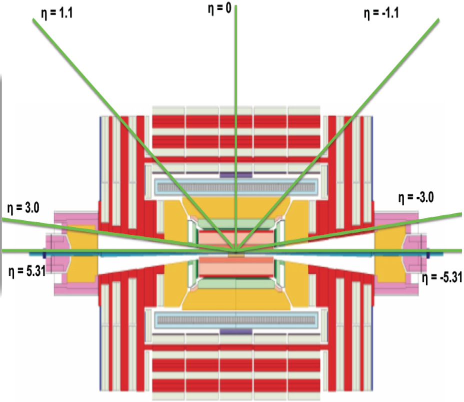

$$\sum_i \vec{p}_i^T = 0,$$

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6. Missing transverse momentum $\not{p}_T$

$$= \sum_j \vec{p}_j^T(visible) + \sum_k \vec{p}_k^T(invisible)$$

$$\sum_k \vec{p}_k^T(invisible) = -\sum_j \vec{p}_j^T(visible)$$

$$\not{p}_T = -\sum_j \vec{p}_j^T(visible) \tag{5}$$

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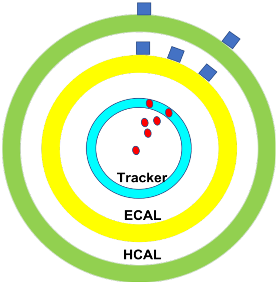

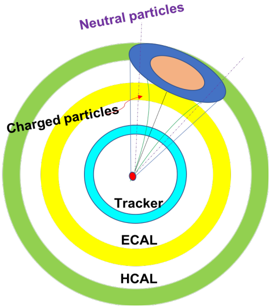

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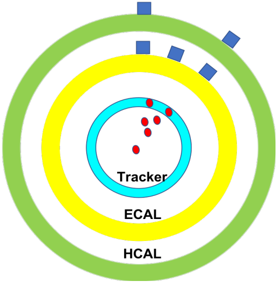
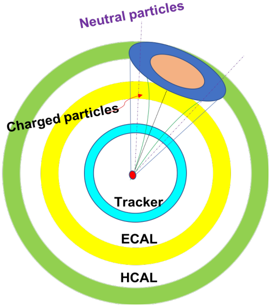
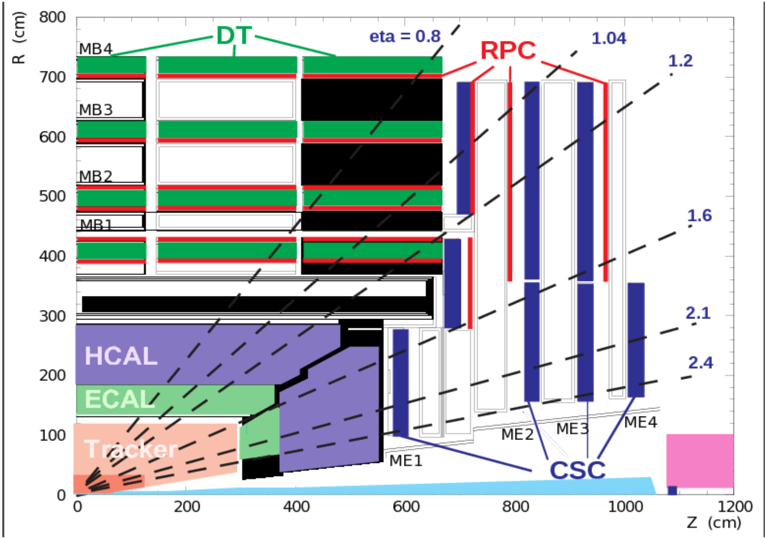
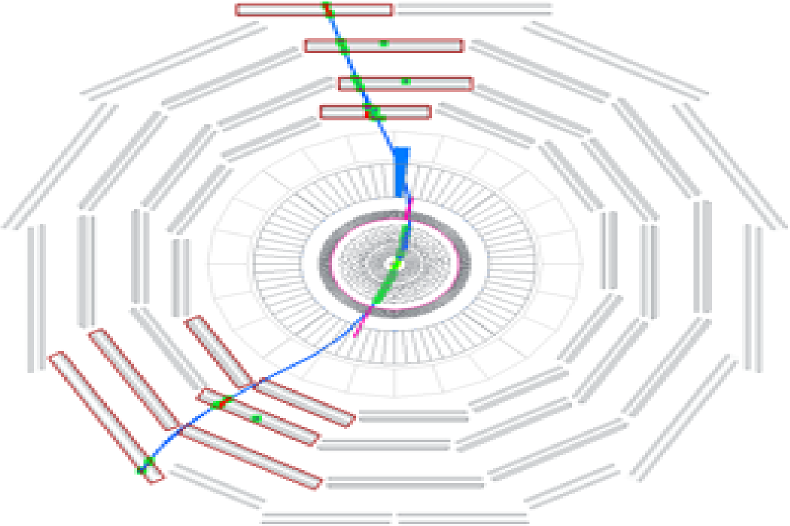




Reconstruction of Muons





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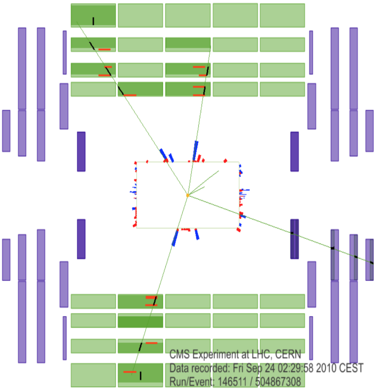

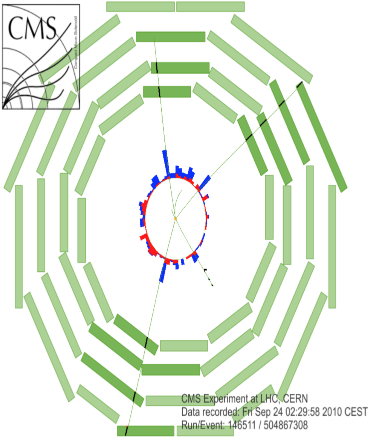

Some important concepts

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    3. Detector

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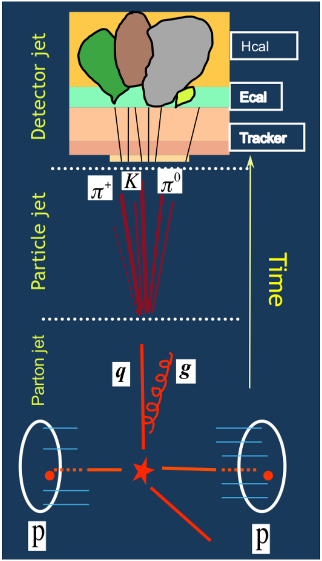

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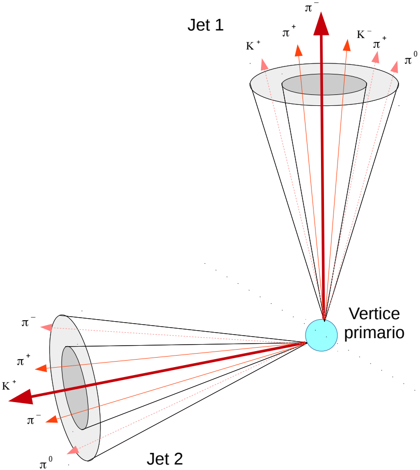

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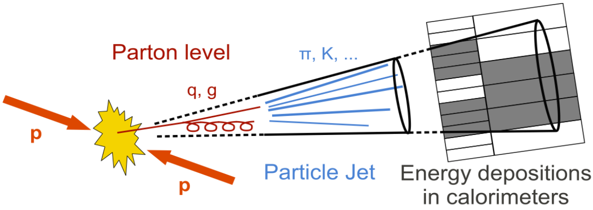

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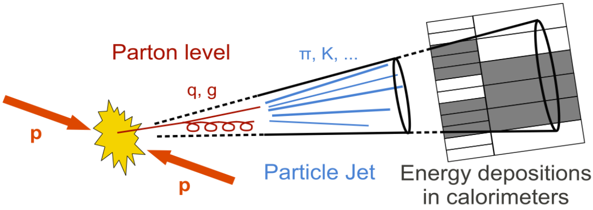

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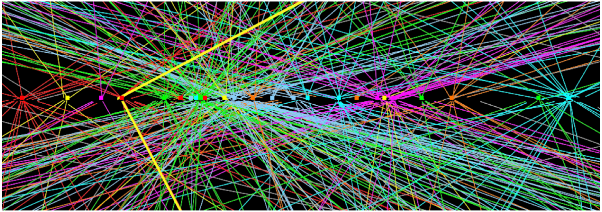

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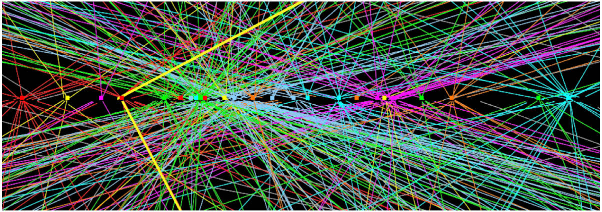

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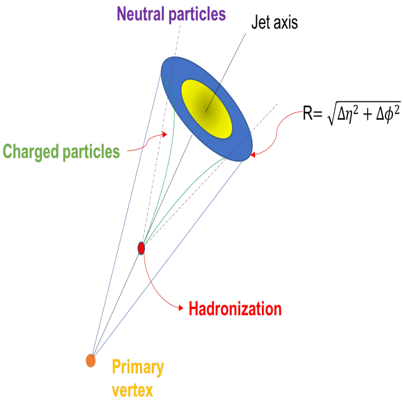

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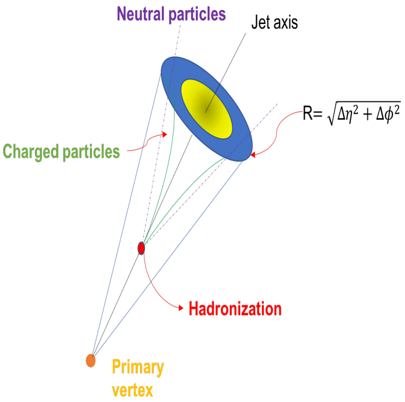

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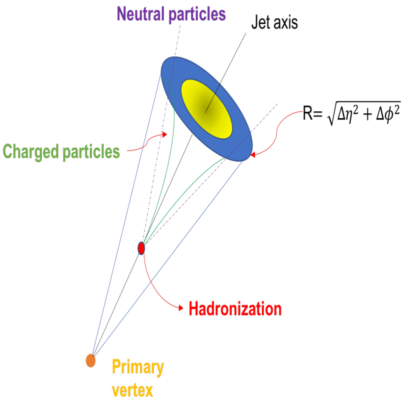

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- For the Cambridge/Aachen scenario, the $a = 0$.

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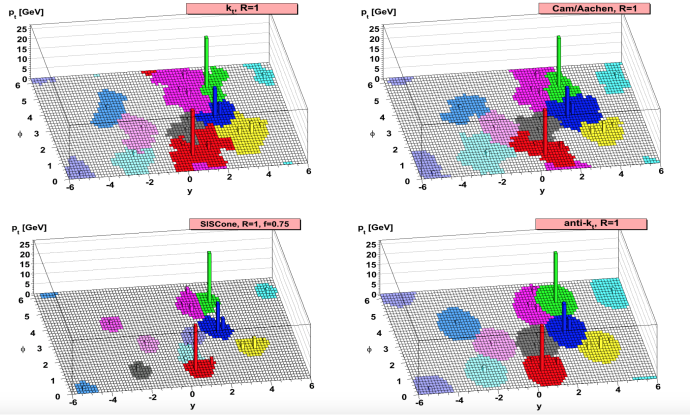
- **The distance variables are independent of the momentum, therefore this algorithm is something is between the K_t and Anti$-K_t$ algorithms.**



Jets reconstruction - CMS

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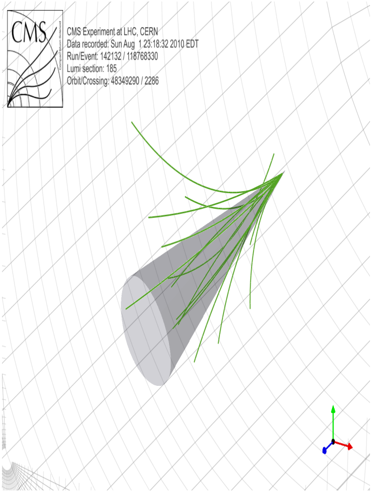

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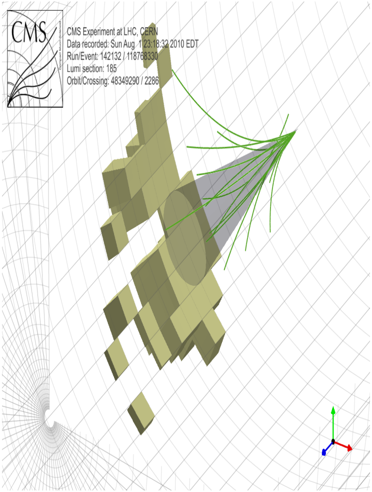

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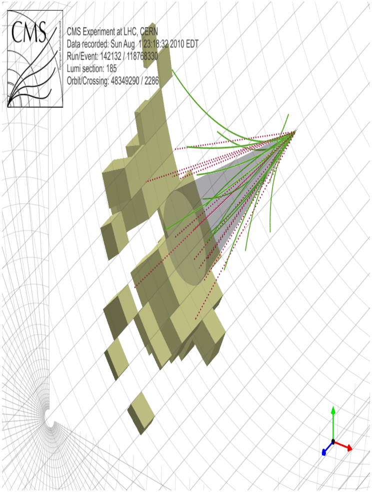

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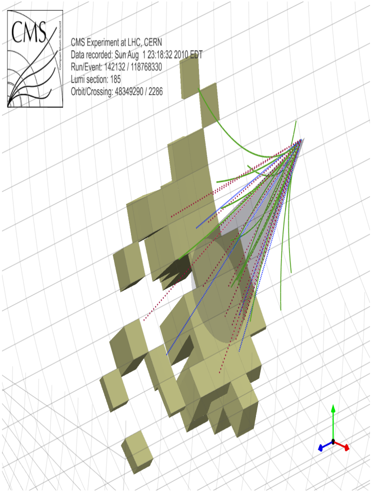

Jets reconstruction - CMS

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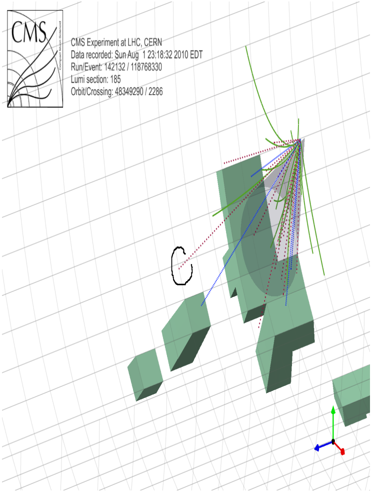

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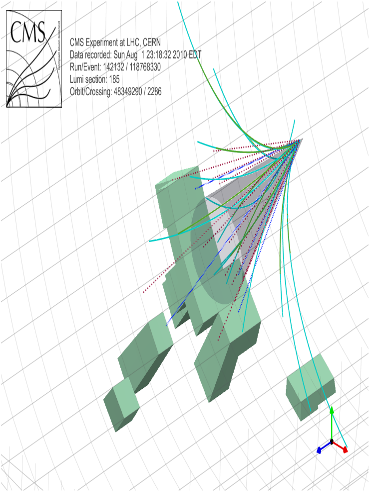

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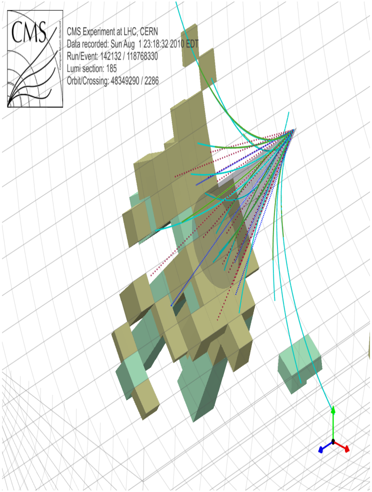

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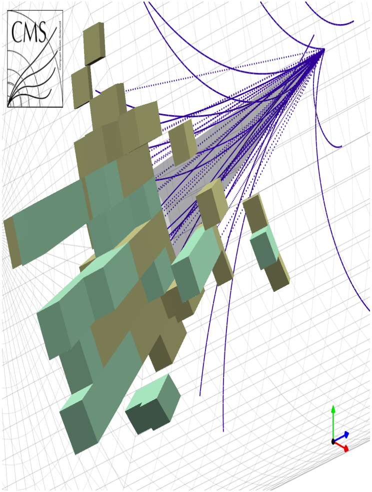

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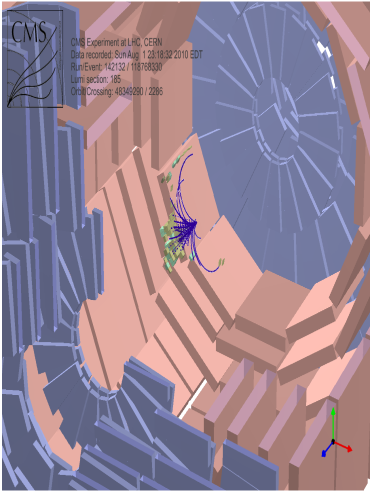
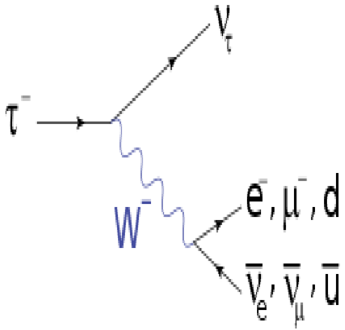


- Taus (τ) are the heaviest known leptons: Mass 1.777 GeV.
- Because of their large mass, taus can decay both leptonically and hadronically.



Decay mode	Meson resonance	$\mathcal{B}$ [%]
$\tau^- \to e^- \bar{\nu}_e \nu_\tau$		17.8
$\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau$		17.4
$\tau^- \to h^- \nu_\tau$		11.5
$\tau^- \to h^- \pi^0 \nu_\tau$	$\rho(770)$	26.0
$\tau^- \to h^- \pi^0 \pi^0 \nu_\tau$	$a_1(1260)$	9.5
$\tau^- \to h^- h^+ h^- \nu_\tau$	$a_1(1260)$	9.8
$\tau^- \to h^- h^+ h^- \pi^0 \nu_\tau$		4.8
Other modes with hadrons		3.2
All modes containing hadrons		64.8

- The table shows the decay branching fraction for taus.
- Note that hadronic final states are the dominant decay modes : 64.8%.

- The ATLAS experiment uses a multivariate analysis technique, Boosted Decision Tree , based upon the shape of the hadronic shower and information from the tracker system.
- ATLAS uses a version of the PF method for the reconstruction of hadronic taus τ_h.
- The CMS experiment uses also Particle Flow combined with discriminators based on Deep-Learning algorithms for the τ_h reconstruction.
- I explain the main concepts behind τ_h reconstruction using the CMS algorithm as a example.
- CMS uses the Hadron Plus Strips (HPS) algorithm for reconstruction and identification of $\tau_h' s$:
  1. Reconstruction: PF charged and neutral particle candidates, compatible with the expected signature of a τ_h, are combined to form a τ_h candidate.
  2. Identification: A set of discriminators are used to separate the τ_h candidate from possible misidentified objets from jets, electrons and muons.
- The HPS algorithm uses a seeds jets with $p_T > 14$ GeV and $|\eta| < 2.5$, reconstructed with the Anti$-K_t$ algorithm.

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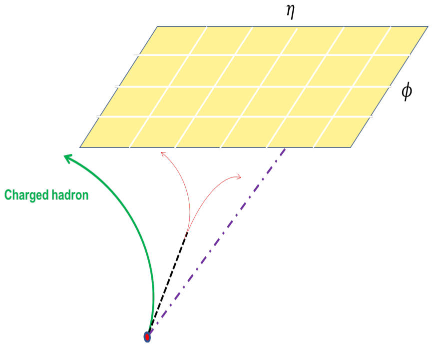

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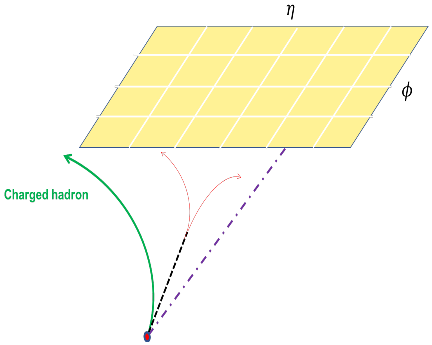

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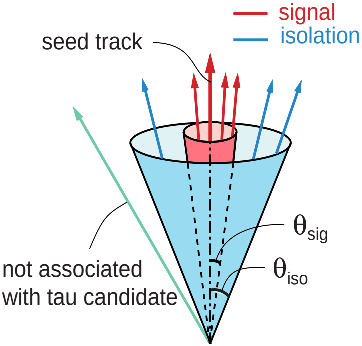
- Jets from QCD processes can often be misidentified as τ_h candidates. A key aspect to suppress the misidentification rate is isolation.



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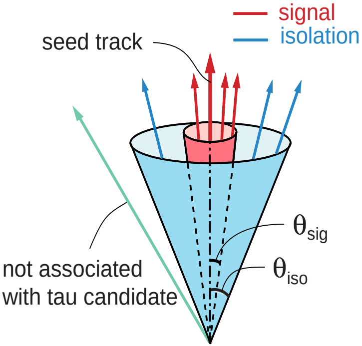

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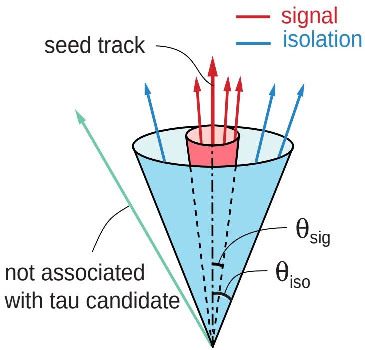

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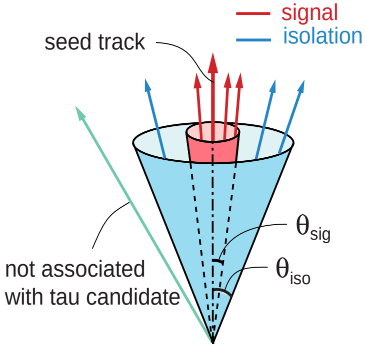

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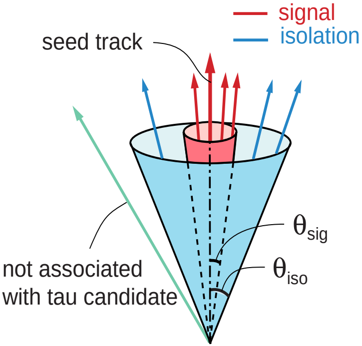
- Currently, CMS leans towards the MVA approach.



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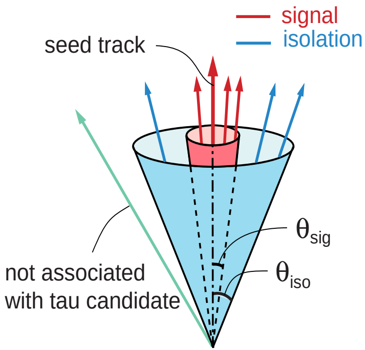

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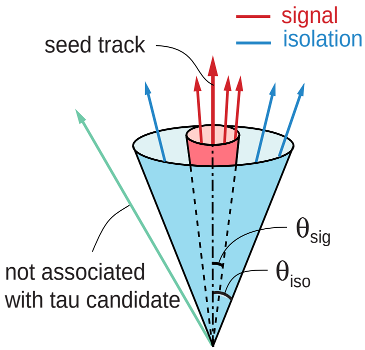

Electron Discriminator

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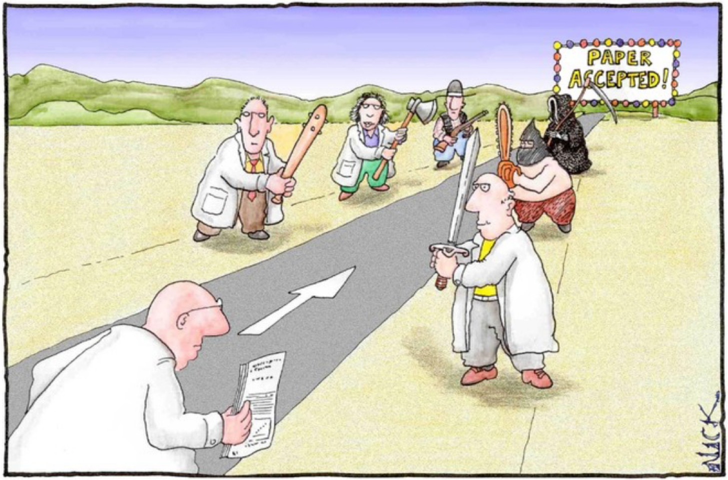
Questions?



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