Identifying Electromagnetic Showers in the Forward Hadron Calorimeter

CMS · LHC · CERN

Christopher Frye, University of Central Florida

Advisor: Jeremiah Mans
University of Minnesota
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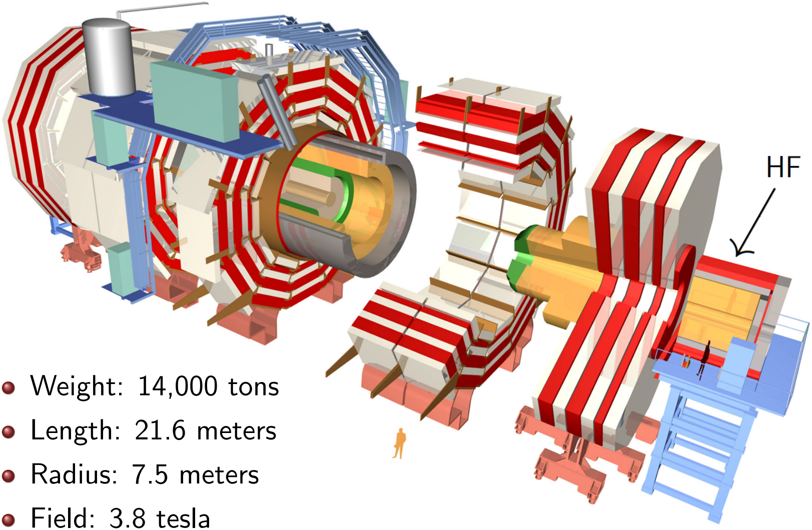
The Compact Muon Solenoid (CMS)

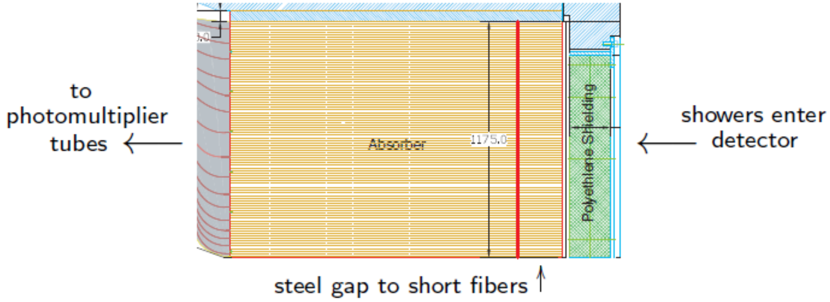


- Weight: 14,000 tons
- Length: 21.6 meters
- Radius: 7.5 meters
- Field: 3.8 tesla

The Forward Hadron Calorimeter (HF)

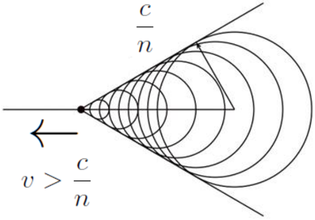
- Steel absorber plates and quartz fibers run parallel to the beam-line.
- HF detects Cherenkov radiation produced in these fibers.
- PMTs detect energy absorbed by long and short fibers separately.
- The quartz fibers are of two different lengths —

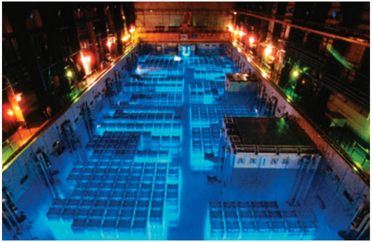
  Long: begin at inner face of detector, extend 1.65 m.
  Short: begin 0.22 m from inner face, extend 1.43 m.



What is Cherenkov Light?

- When a high-energy charged particle enters the detector, it moves at speed $v > c/n$, the speed of light in that material.
- Creates a light cone which is sent into the PMTs.
- Produces bluish glow.

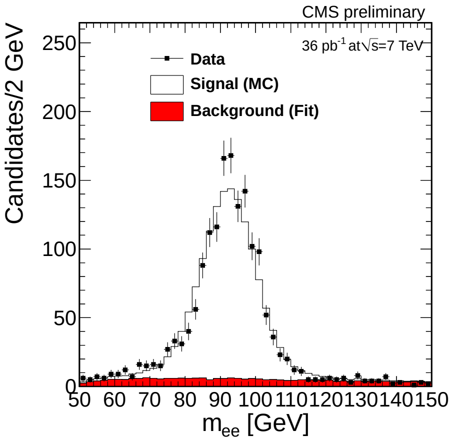


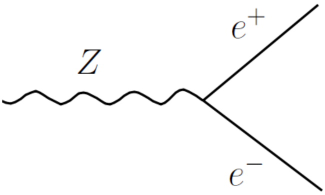


2011 $Z \longrightarrow e^+e^-$ LHC Data

Signal: Double e events with invariant mass in the Z range, $70\ \mathrm{GeV}/c^2 \leq m \leq 120\ \mathrm{GeV}/c^2$.

Background: Jets that survive loose e cuts in Z mass window.

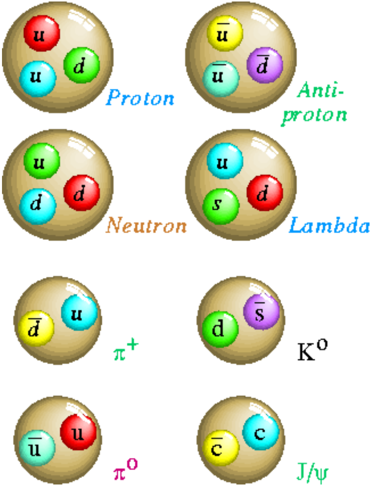




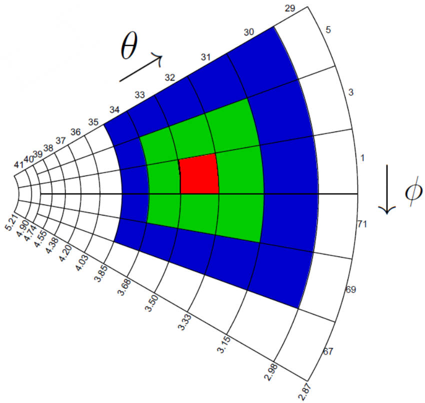
One electron received in HF, second received in barrel.

What are Jets?

- Collisions produce quarks, which carry color charge.
- Quarks must combine to form hadrons.
- Jets, groups of hadronized quarks, spray our detector.
- Hadrons in jets are much heavier than the e^-, e^+ we detect.



How Do We Identify Detected Particles?



- Inner face of HF detector is divided into cells.
- Seeds: cells that absorb $E_\mathrm{T} > 5$ GeV in the long fibers.
- Form clusters around seeds,

  Seed : red

  3×3 : red + green

  5×5 : red + green + blue

  Core : red + highest E neighbor

- For each cell in a cluster, store

  (1) Long-fiber energy,

  (2) Short-fiber energy.

Measuring Transverse Shower Shape

Lateral Containment

$$E_{9/25} = \frac{\sum_{3\times 3} \text{total energy}}{\sum_{5\times 5} \text{total energy}}$$

Heavy particles spread out in collisions while light particles remain laterally dense $\Rightarrow$

EM: $E_{9/25} \to 1$,

Jets: $E_{9/25}$ is lower.

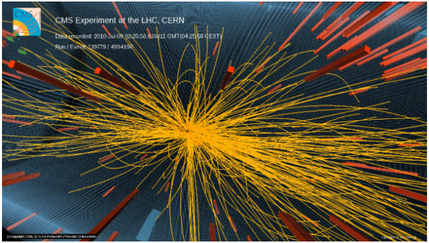
Transverse Shape

$$E_{C/9} = \frac{\sum_{\text{core}} \text{long-fiber energy}}{\sum_{3\times 3} \text{long-fiber energy}}$$

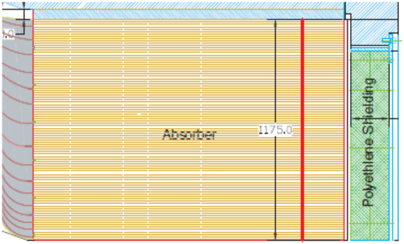
Using the same reasoning,

EM: $E_{C/9} \to 1$,

Jets: $E_{C/9}$ is lower.



Measuring Longitudinal Shower Shape



steel gap to short fibers ↑

Longitudinal Shape

$$E_{S/L} = \frac{\sum_{3\times 3}\text{short-fiber energy}}{\sum_{3\times 3}\text{long-fiber energy}}$$

The 0.22 m steel gap between the inner face of HF and the short fibers is

- EM: 12.5 radiation lengths $\Rightarrow$ $E_{S/L}$ is small,
- Jets: 1.3 interaction lengths $\Rightarrow$ $E_{S/L} \approx 1/2$.

Inadequacy of Current Methods

Signal Isolation in the Present-day LHC: $\mathcal{L} \approx 2 \times 10^{33}$ cm^{-2}s^{-1}

Lateral Containment: $E_{9/25} \geq 0.94,$

Two-dimensional Shape: $E_{C/9} - 1.125 \cdot E_{S/L} \geq 0.2,$

- Increase in beam luminosity $\mathcal{L}$ will create more frequent events and more pileup (uninteresting secondary interactions).
- Creates need for tighter cuts.
- Tighter cuts expose faults in the current method of signal isolation —

  (1) Energy-dependent efficiency,
  (2) Failure of longitudinal shower-shape cuts.

2011		2012		2014		2020
$\mathcal{L}$	$\longrightarrow$	$5\mathcal{L}$	$\longrightarrow$	$10\mathcal{L}$	$\longrightarrow$	$20\mathcal{L}$

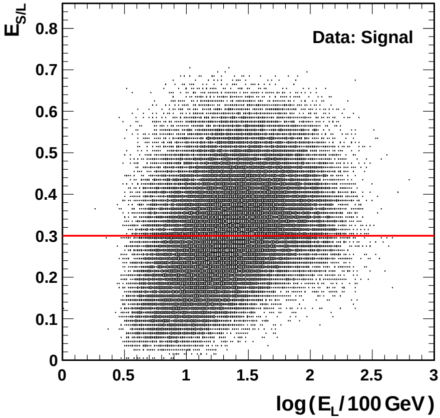
A Problem with the Longitudinal Cut

- Penetration depth depends on total shower energy.
- Using the variable

$$E_L = \sum_{3\times 3} \text{long-fiber energy},$$

proportional to total shower energy, we can study this effect graphically.

- An $E_{S/L}$ cut removes mainly high-energy EM events — their penetration depth disguises them as jets.

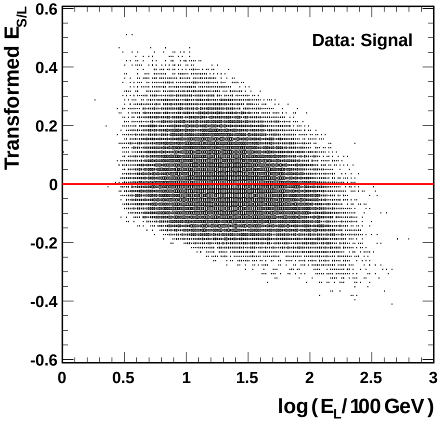


Transforming $E_{S/L}$

- To eliminate this dependency, we send $E_{S/L} \longmapsto E^{\text{cor}}_{S/L}$ as follows.

  1. Fit the points in the plot of $E_{S/L}$ v. $\log(E_L\,/\,100\,\text{GeV})$ to a line, $y = mx + b$.
  2. Rotate the data clockwise by $\tan^{-1}(m)$ so that the fit line becomes the x-axis.
  3. Call the new y-value of each entry $E^{\text{cor}}_{S/L}$.

- $E^{\text{cor}}_{S/L}$ measures deviation of penetration depth from that of a typical electron with similar E.



Optimizing the Longitudinal Cut

- In comparing the effectiveness of different cuts, we use

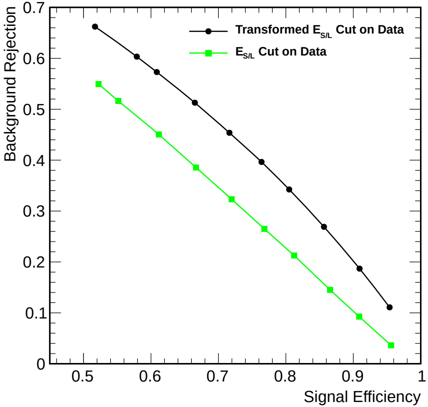
Signal Efficiency

$$\frac{\#\text{ of signal events surviving cut}}{\text{total }\#\text{ of signal events}}$$

Background Rejection

$$\frac{\#\text{ of background events failing cut}}{\text{total }\#\text{ of background events}}$$

- For all values of signal efficiency, the $E_{S/L}^{\text{cor}}$ cut performs better than the $E_{S/L}$ cut.

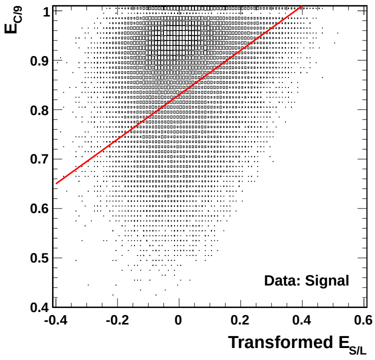


Optimizing the Two-dimensional Cut

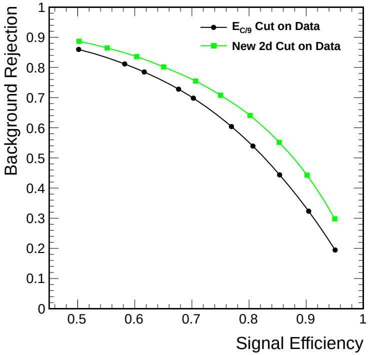
New 2D Cut

$$E_{C/9} - m \cdot E_{S/L}^{\text{cor}} > C_{2d}.$$

- An algorithm optimizes the choices of m, C_{2d}, choosing a diagonal cut-line:



- For all values of signal efficiency, the new 2D cut performs better than the $E_{C/9}$ cut.



Conclusion

1. Improved the effectiveness of the longitudinal shower-shape cut by removing the energy dependency from the $E_{S/L}$ variable.

$$E_{S/L} \longmapsto E_{S/L}^{\text{cor}}$$

2. Introduced a new 2D shower-shape cut that out-performs the $E_{C/9}$ cut, which was previously most effective for tight cuts.

$$E_{C/9} - m \cdot E_{S/L}^{\text{cor}} > C_{2d}$$

Questions?