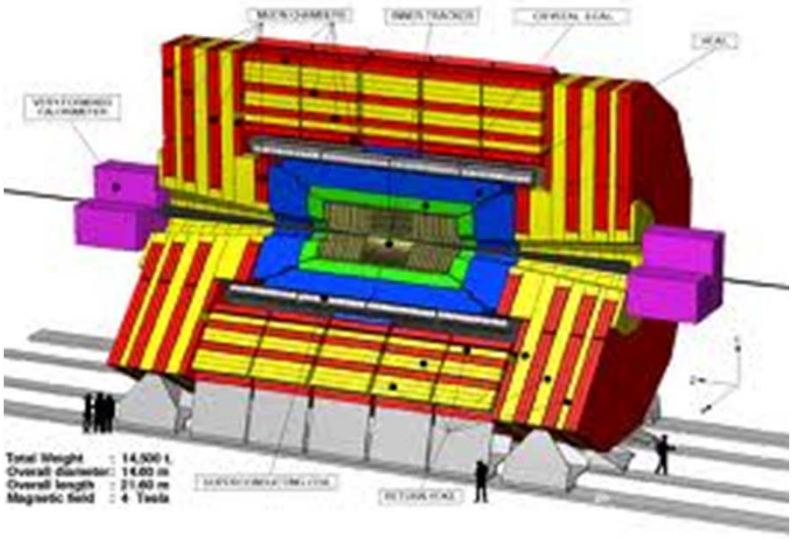
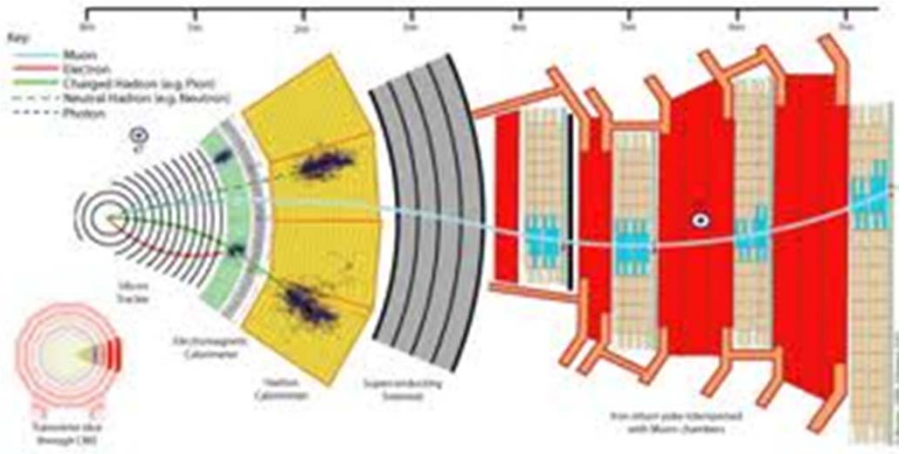
Detecting & observing particles

How does one go from “producing them” to claiming you see them?

Experimenters toolbox - detectors

- General Purpose Detectors
  - Mainly looking to directly detect high mass particles
- Key features (GPDs)
  - ✓ Hermetic
  - ✓ Excellent reconstruction of high energy electrons, muons, photons and “jets”
  - ✓ Identify b-quark jets
  - ✓ Missing E_T
- Specialized expts (LHCb)
  - Hadron ID (π, K, p)
  - Precision vertexing
  - + …





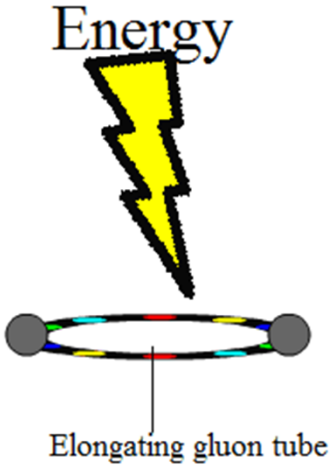
Jets

- In high energy (proton) collisions, highly energetic quarks (or gluons) emerge from the collision

  … Then what?

  – In a very short time (~10^{-23} sec) after, they get bound up into hadrons (baryons or mesons).

  – The process is called "**hadronization**" (process of making hadrons)

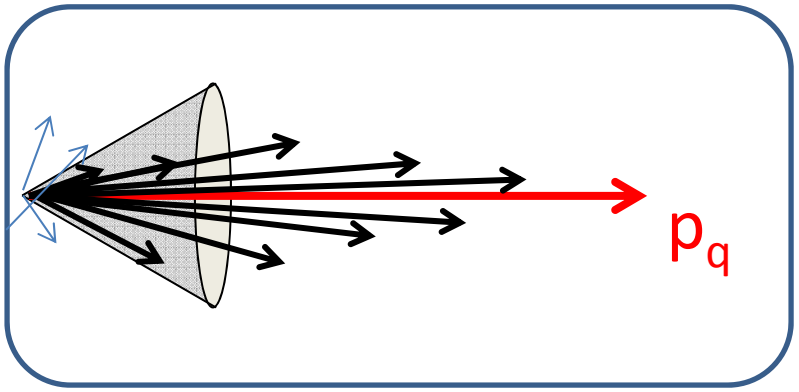


  – In this way, many $q\bar{q}$ pairs are created in violent collisions during the hadronization process

  – The resulting "spray" of particles are called "jets".

Jets

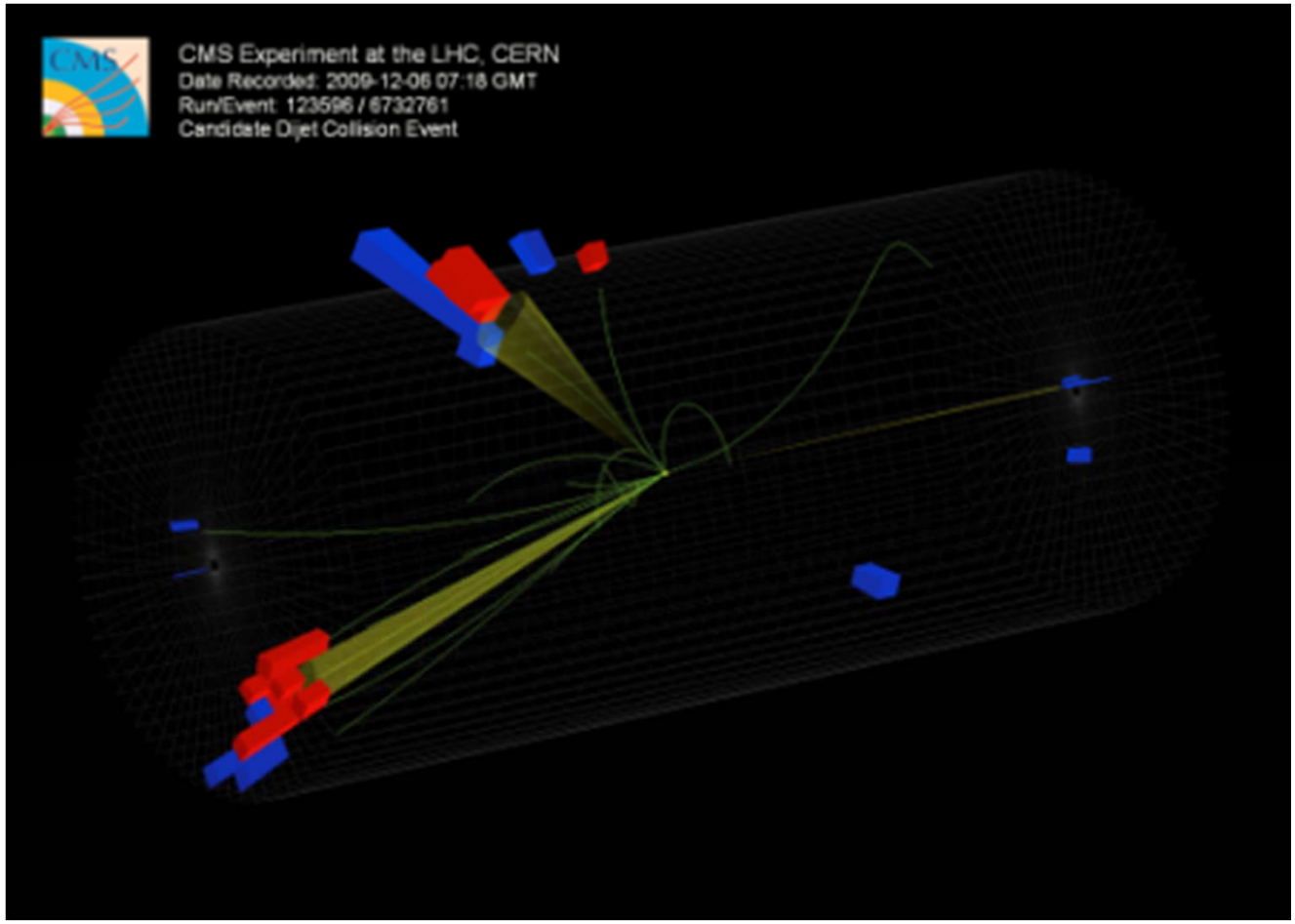
- The spray of particles created is called a JET.



Particles are collimated in a cone around the initial quark direction

- The total (p,E) of the jet should reflect the (p,E) of the quark.
- Buuuuuttttt …. some particles inevitably not accounted for; also usually use calorimeters, which have worse energy resolution, than tracking. Energy resolution ~10-20% typical.
- Compare to single particles, momentum resolution ~ 0.5% (p = qBR) !

Event Display – 2 jet event from CMS



One small detail: In the interaction, you don't know what initial p_z is. So, the event can be "boosted" in one direction or the other

“Tagging” Jets initiated by a b-quark

- For jets that are initiated by gluons or light quarks, all the particles in the jet ought to point back to the pp interaction vertex (“Primary Vertex”)

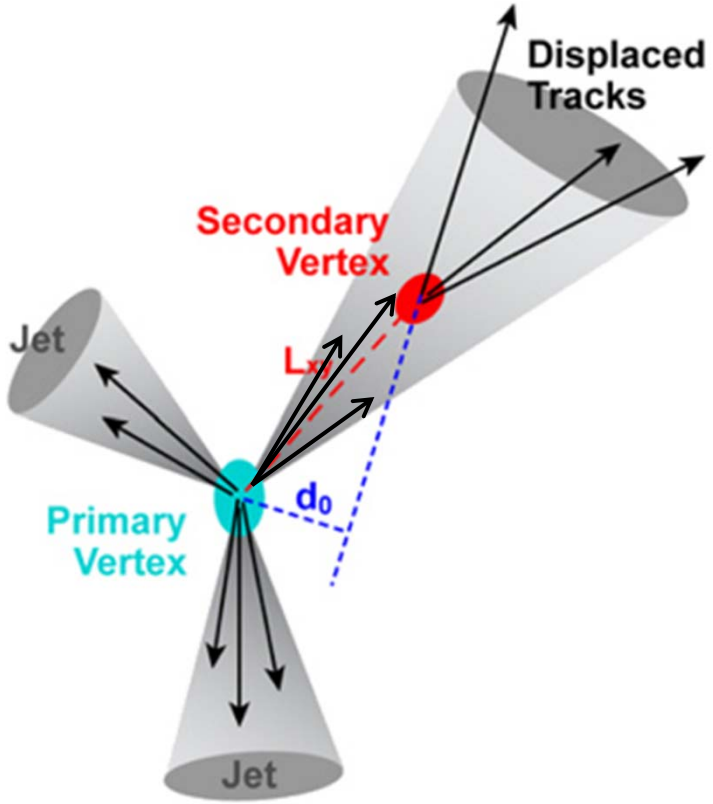
- BUT, jets initiated by a b-quark will produce a B hadron, which has a “long” lifetime.

- The B-hadron will travel ~ 1 cm before decaying to several particles.

- A jet that has 2 or more particles that form a “secondary vertex” is called “tagged” as a b-jet.

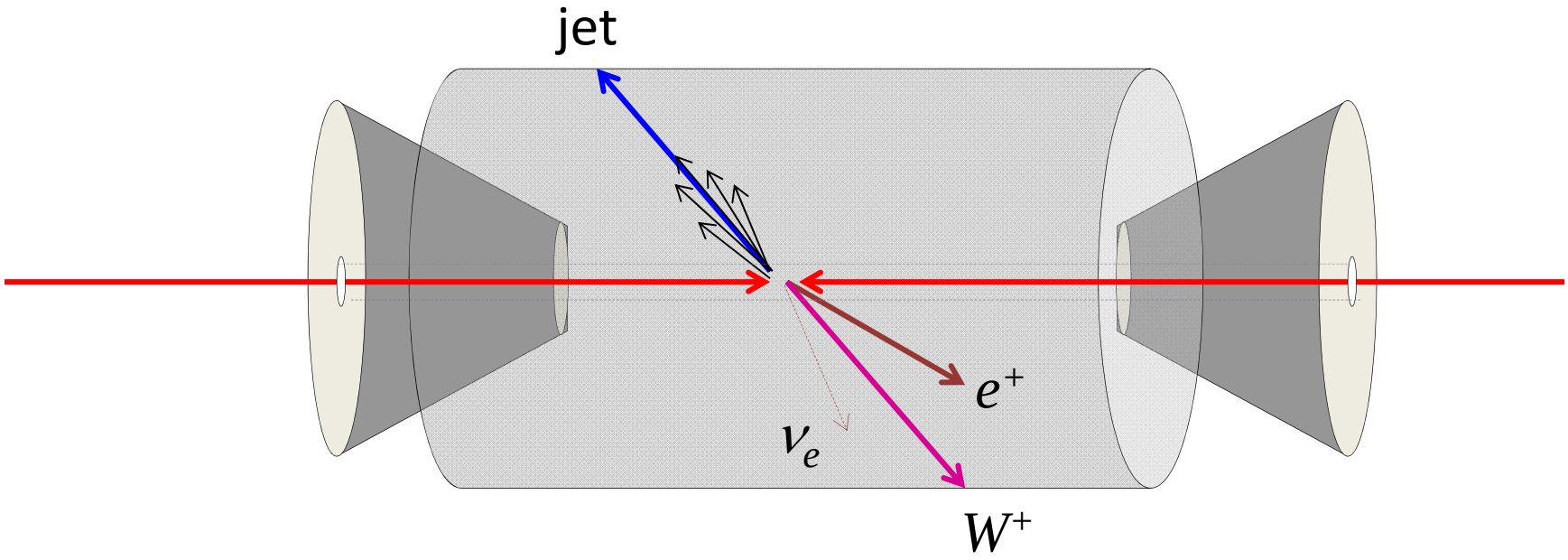
WHY DO THIS ?

1) $H^0 \rightarrow b\bar{b}$ (produces two b-jets)
2) B-jets play a central role in many searches for New Physics



Missing E_T

- CMS and ATLAS (LHC detectors) cover nearly the full angular range.
- Only close to the beam pipe do they not have detectors
  → They see almost all of the energy produced in the collision!



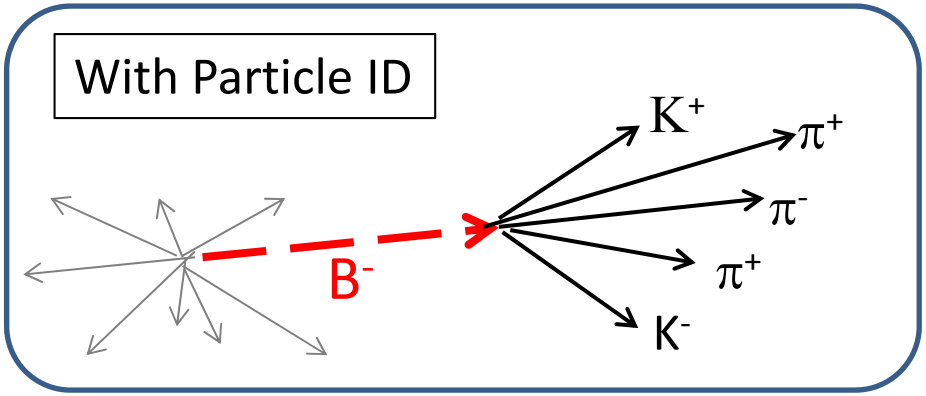
By momentum/energy conservation: $p_x^{jet} = p_x^W$ $p_y^{jet} = p_y^W$

Of course, we only see the high energy electron from the W

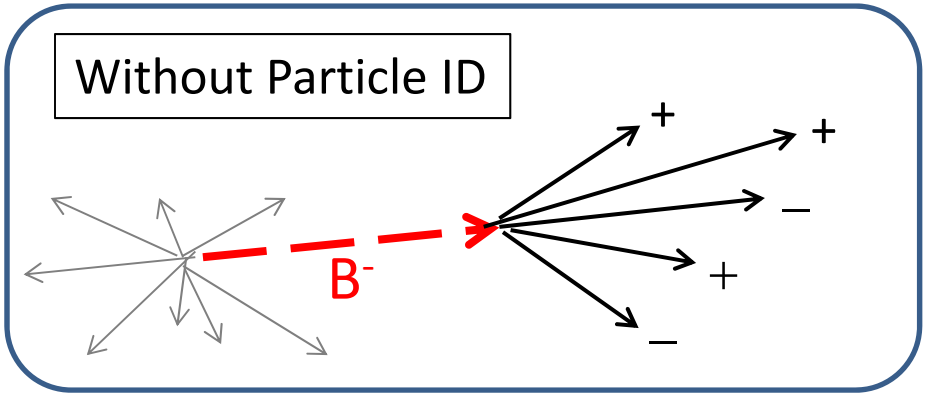
Using what we measure, we have an **imbalance of momentum perpendicular to the beam direction**. This imbalance is called **missing E_T.** When there is a W in the event, the missing E_T is very large, about ½ the W mass (~40 GeV)!

Particle ID (PID)

- In LHCb, we are looking to reconstruct B hadrons in many specific decay modes.
- The decays may involve any of the 5 stable particles - π, K, p, μ, e.
- Consider this decay : $B^+ \to K^+K^-\pi^+\pi^-\pi^+$



How many different ways can you form the above decay w/ PID?



How many different ways can you form the above decay w/o PID?

Moreover, how do you know the decay on the right is not:

$B^+ \to K^+\pi^-\pi^+\pi^-\pi^+, B^+ \to \pi^+\pi^-\pi^+\pi^-\pi^+,$

$B^+ \to K^+K^-K^+\pi^-\pi^+, B^+ \to K^+K^-K^+K^-\pi^+, \ldots$

You can see that the level of ambiguity "explodes", if you don't have PID. **PID critical for LHCb and many other specialized expts.**