Photon Identification at other experiments

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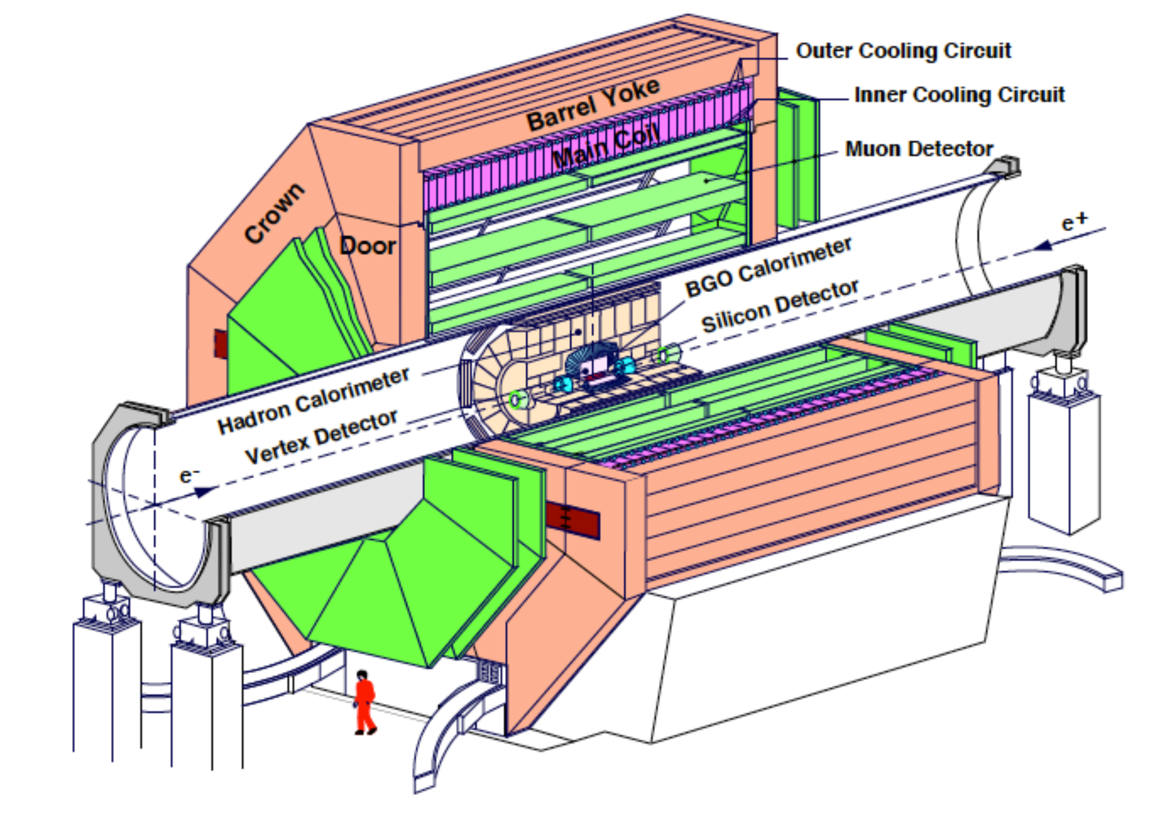
WHY LOOK ELSEWHERE?

- Naturally, we all think CMS is the best experiment, after all, we all chose to work on it.
- I do think it is useful not just to study what we do at CMS, but also to have a look at what other experiments have chosen to do for their own photon identification.
  - Good ideas are worth stealing after all.
  - This also informs experimental design: other experiments have different capabilities than ours, useful to see how that aids/ detracts.

EXAMPLES

- I want to look at a few experiments:
  - L3, for example which also had an electromagnetic calorimeter, though it was an experiment on LEP (WAY different environment)
  - D0, which is the only other experiment that I have full experience with.
  - ATLAS, because it's always worth knowing what the distinguished competition is doing.
- While I can't go into the same level of detail as I have with CMS, we can at least look at some of the contrasts.

L3



- Here's an overview picture. Note that the scale of this is different than you are used to.

L3

- If you were so inclined, you could view the L3 BGO (bismuth germanate) calorimeter as a forerunner to our own ECAL for a few reasons.
  - Not the least of which being because we inherited a number of L3 people as well.
  - The crystal dimensions for the barrel were 2x2x24 cm (hauntingly familiar, yes?)
- A few numbers:
  - In 1997, L3 had the world's largest electromagnet. In the tracking region, it had a field of around 0.5 T. This selfsame magnet is now used in ALICE.
  - The tracker itself only had a lever arm of about 31 cm.
  - Silicon vertex detector surrounded by drift chambers. Means they were dealing with less material than we do (not hard).

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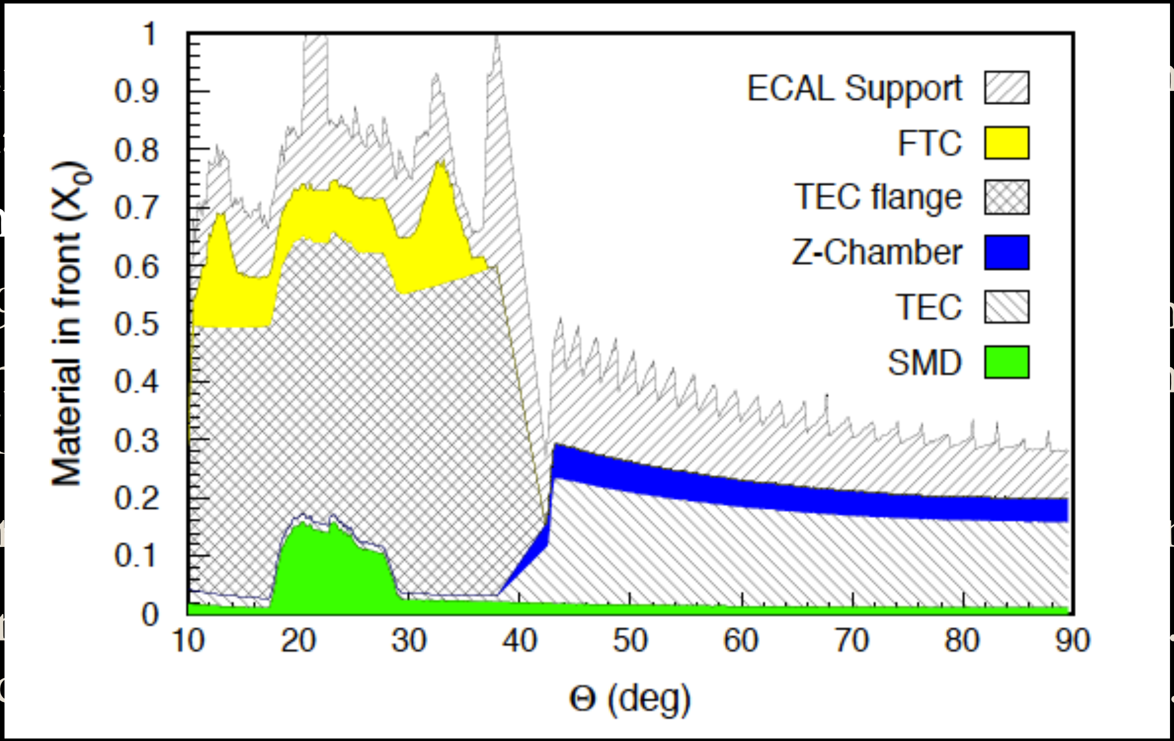
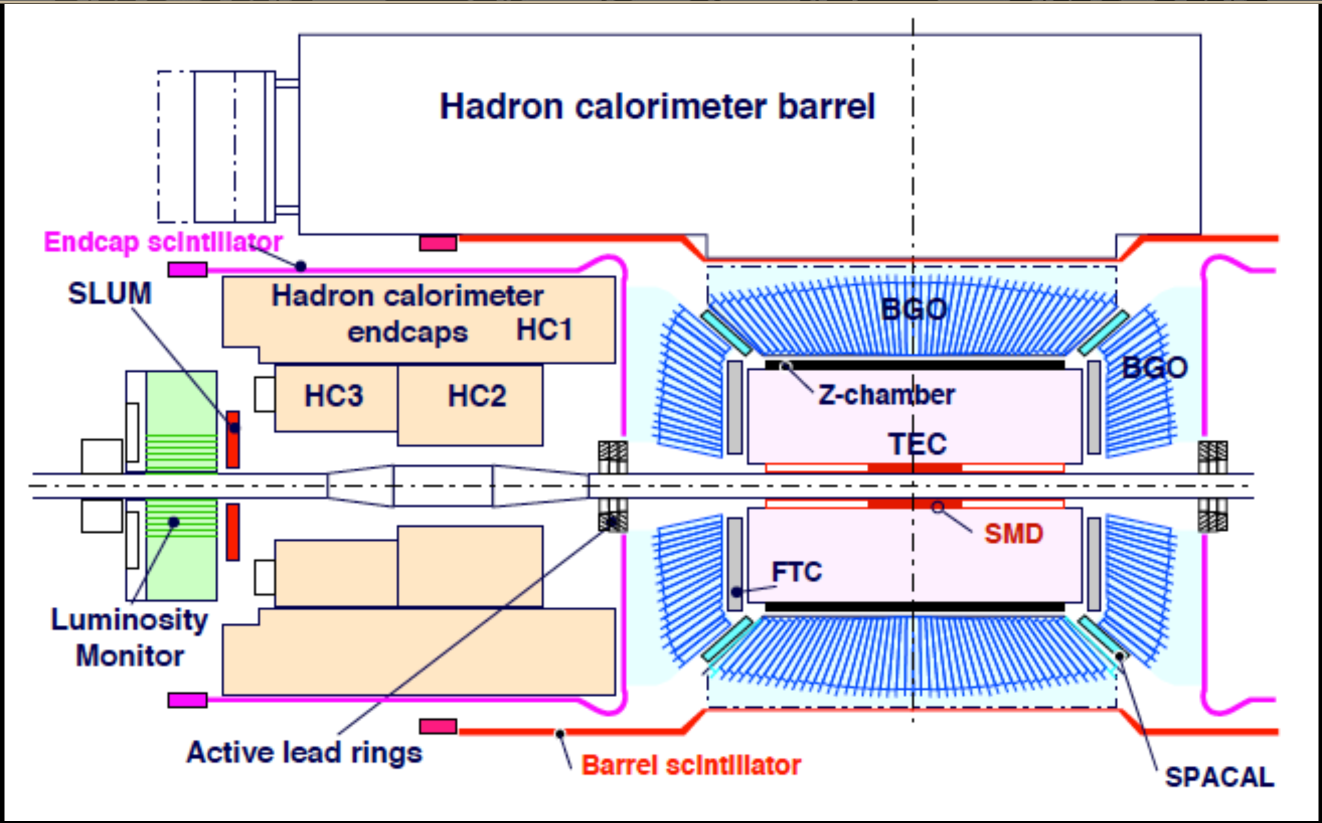


L3

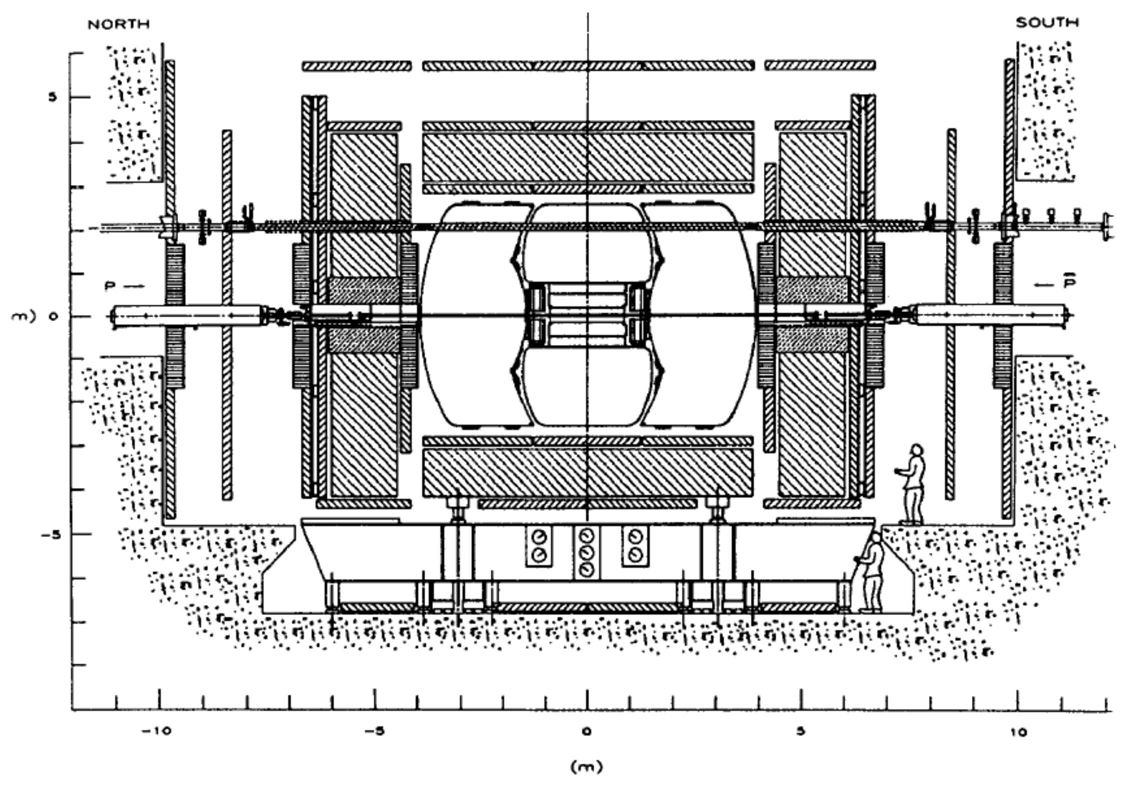


- Close up on the area that we're interested in.

L3 PHOTONS

- As much as I like this experiment, there's not a lot that's hugely different than what we do. I think, actually, those bits where we rely on matrices of crystals (R9, E_{5x5} windows) are inherited from L3.
  - Plus they had less material, in addition to lower occupancy, and a lower magnetic field, and a sample of pretty pure photons from Bhabba scattering…let's face it, life was a lot easier at LEP.
- Common quantities used were H/E, E_{3x3}/E_{5x5}, and one thing that we also implemented "Shower Roundness".
  - Form the matrix of 5x5 about your shower max, and find the corresponding eigenvalues for that matrix $F^{\mu\nu}=E_i x_i^\mu x_i^\nu$, where Ei is the energy of the ith crystal, and x_i^μ, x_i^ν are the local cartesian coordinates of the crystal.
  - The roundness is the ratio of the eigenvalues, if they are very similar, then the deposition is very round (as opposed to elliptical).
  - Not many people have actually used this at CMS, though we still could. Especially in an era where we have some real photons to work with.

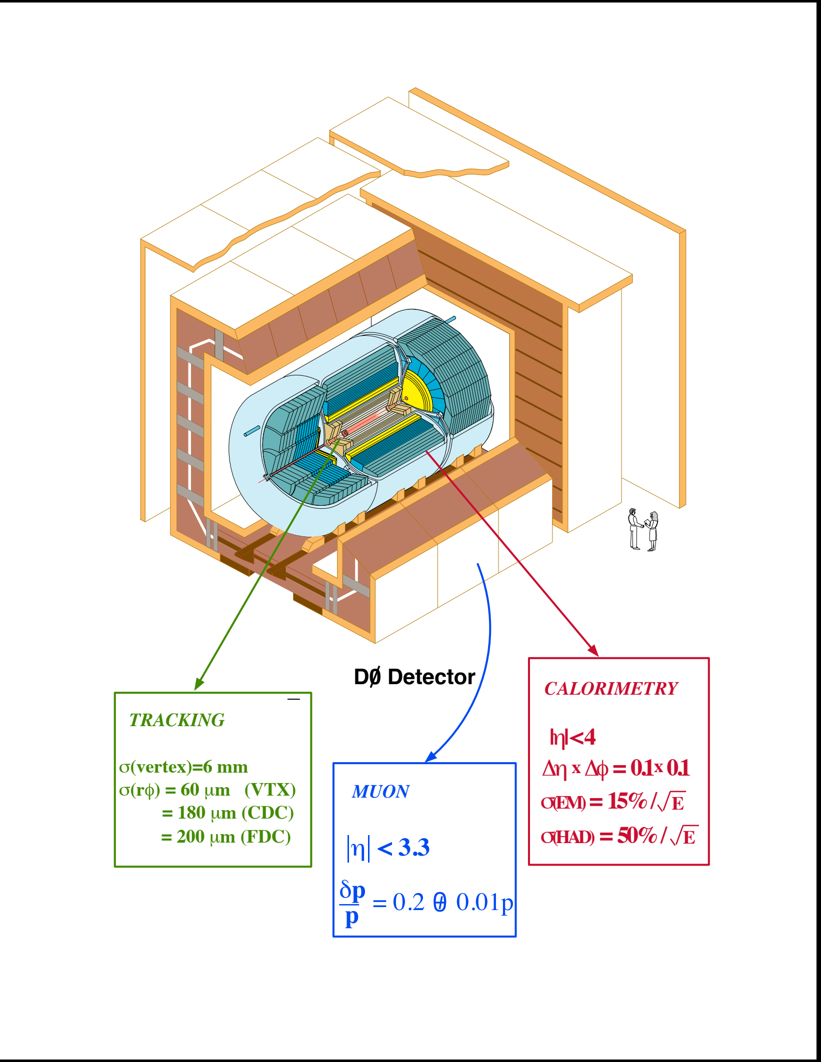
D0 RUN I



- So above, find a diagram of the original D0 detector. I show this because it highly influenced the upgraded one, and because it is NOT "normal" for a general purpose detector.

D0 RUN I

- This picture includes a lot more of the underlying performance numbers of the original detector.



D0

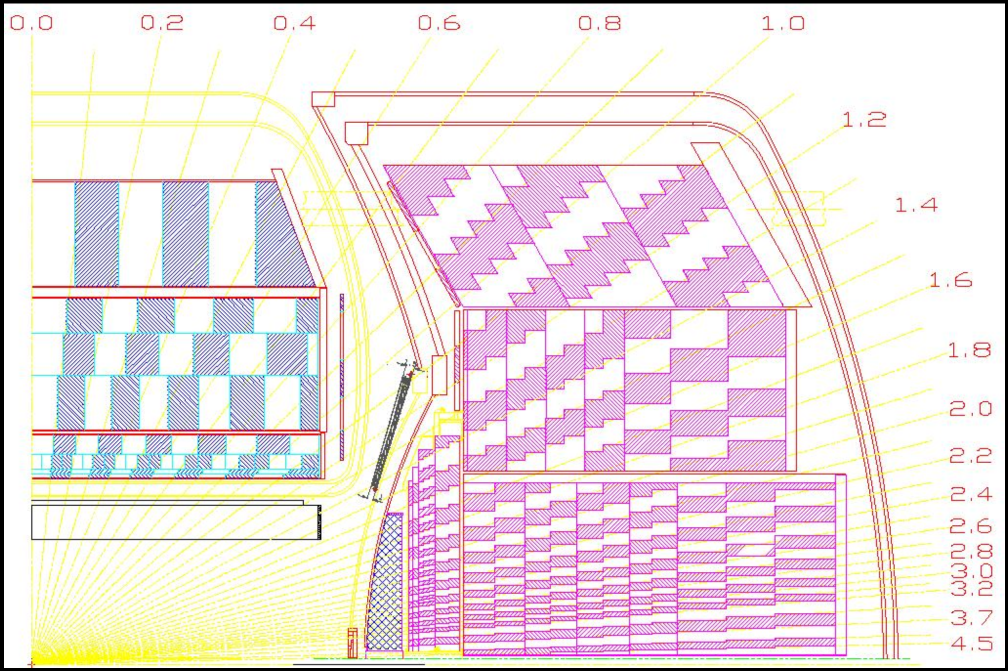
- Original, OG detector had no central magnetic tracking. It "tracked" (in straight lines) using drift chambers.
  - Muon system had a separate toroidal field, but resolution was very limited.
- For photon identification and reconstruction, very heavily calorimetric based, all there was for electron/photon discrimination was hits on a road between the vertex position and the calorimeter position.
  - Most of the actual info came from the shower profile in each of four EM layers of the calorimeter, both transverse and longitudinal.
- Run I mainly had pretty low instantaneous luminosity, crossing was only 3 μs or so.
- From my point of view, the interest of looking at D0 Run I is to provide a direct contrast with the Run II detector.

SAMPLING CALORIMETER

- So L3 and CMS both use total absorption electromagnetic calorimeters.
- D0 (and ATLAS as well) use sampling calorimeters.
  - I probably don't need to say this, but the main difference is that instead of having a big uniform piece of active material, instead you "sample" the developing electromagnetic shower as it develops. You then have to "weight" each layer and sum them up to get your final energy estimate.
  - Typically these different "layers" of calorimeter have different granularities, the best (or smallest) is reserved for the position where you think the shower max will occur.

D0 CALORIMETER

- This is a quarter of the D0 detector, meant to show off the geometry.
- Each projective tower is 0.1 x 0.1 in $\Delta\eta \times \Delta\phi$.
- The third layer of the EM calorimeter is 0.05 x 0.05.
- Liquid argon active media, with uranium as the absorber.

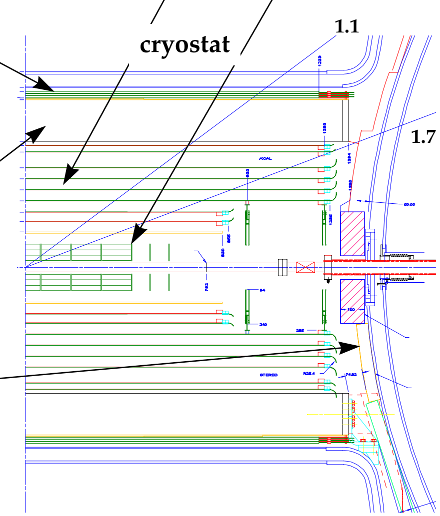


D0 UPGRADE:

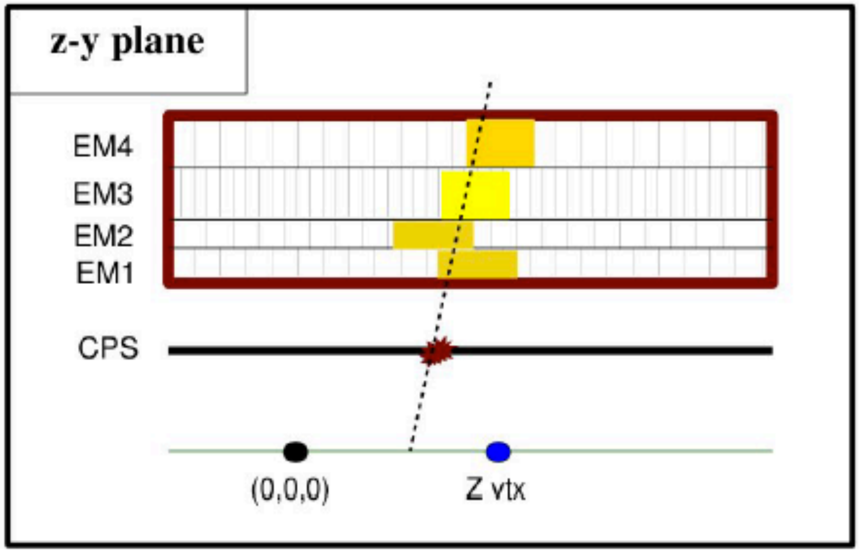
- Almost EVERYTHING on this slide directly contributes to better e/γ reconstruction (in my opinion at least).
  - Magnetic tracking is really HUGE. Not only can you truly track particles, you get their momenta for isolation purposes.
  - Preshowers add additional granularity, and at the same time use a separate technology from the calorimeter (no noise correlations)

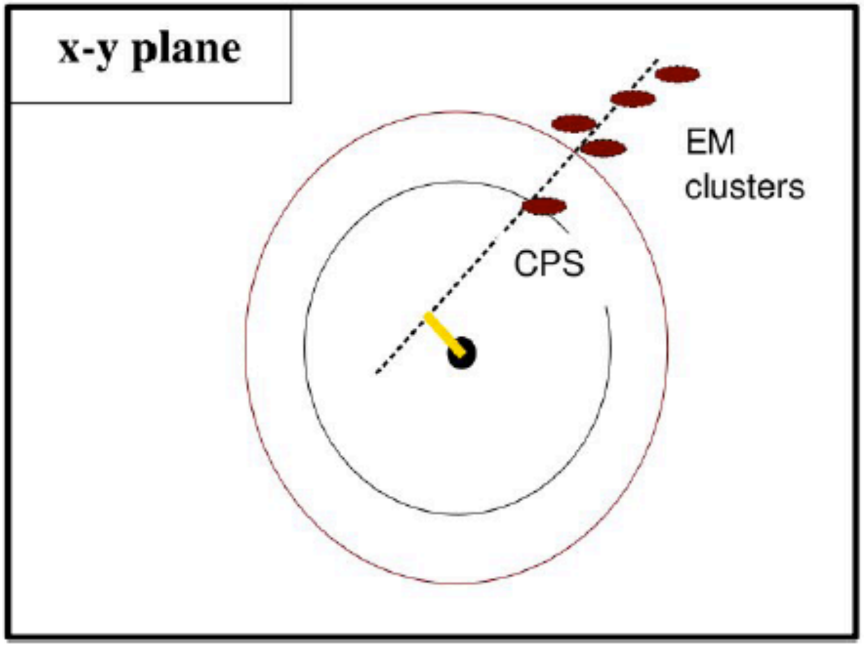
The D0 Upgrade - Tracking

- Silicon Tracker
  - Four layer barrels (double/single sided)
  - Interspersed double sided disks
  - 840,00 channels
- Fiber Tracker
  - Eight layers sci-fi ribbon doublets (z-u-v, or z)
  - 74,000 830um fibers w/ VLPC readout
- Central Preshower
  - Scintillator strips, WLS fiber readout
  - 6,000 channels
- Solenoid
  - 2T superconducting
- Forward Preshower
  - Scintillator strips, stereo, WLS readout
  - 16,000 channels



D0 UPGRADE:

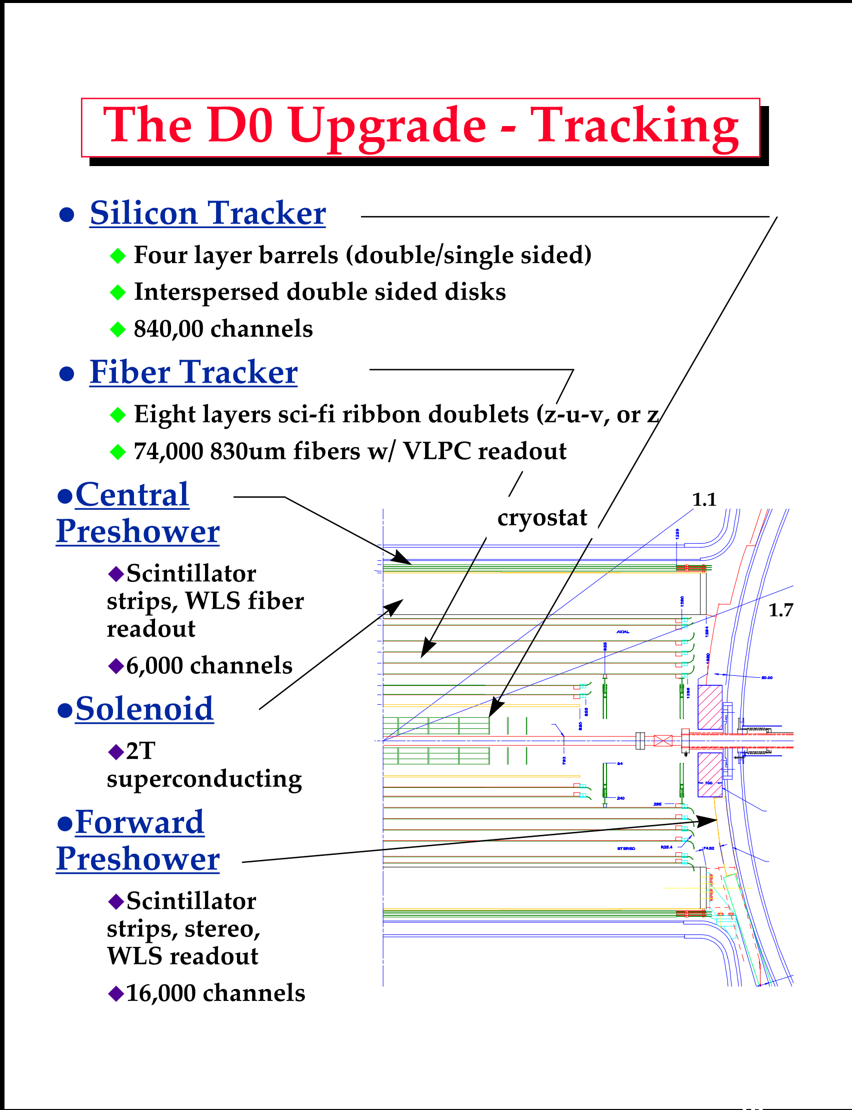




- The CC photons specifically could use the positions in the four ECAL layers plus the central preshower (CPS) to “point” in Z and DCA back to the primary vertex to about 1 cm.
- The CPS also gave a measurement of the transverse width of the shower almost as good as from the shower max layer.

D0 UPGRADE:

- Not all roses however:
  - That's a LOT of silicon, a comparatively light outer tracker, a freaking solenoid and additional layer of lead extra material. Major change in the layer weights needed.
  - It's also worth noting that even though this is a nice tracker, it has a lever arm of about 50 cm, and a field of 2 T, and comparatively few hits. Track momentum resolution for electrons wasn't brilliant.
  - Bremsstrahlung wasn't really much of a problem though. Most of the energy from the brem photons still ended up in the same final clusters.

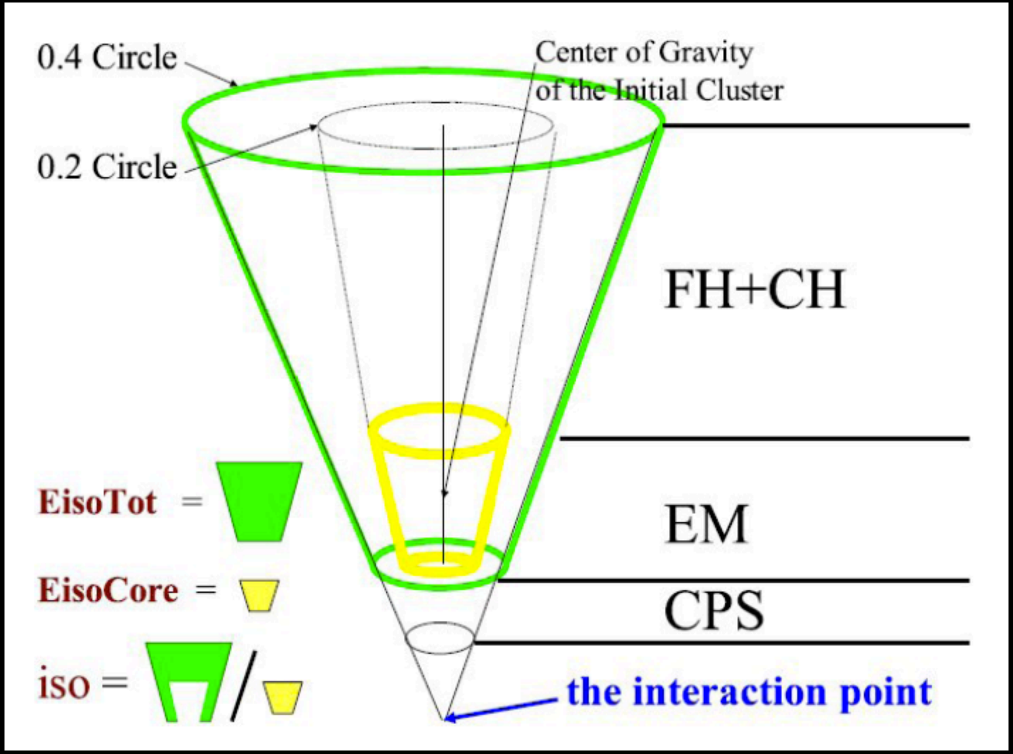


D0 PHOTON ID

- There are some things at the Tevatron that were similar to the LHC, and there are a lot of differences.
- Run II crossing frequency was 396 ns, and the spread of the luminous region had a sigma of about 23 cm. It was also one of the first real experiences with significant pileup.
  - Most efficiencies ended up being parametrized in a couple of kinematic quantities, and then instantaneous luminosity.
  - Environment certainly more like LHC than LEP, and one of the central problems was that there was not a pure sample of photons to directly make comparisons with.

RECONSTRUCTION

- Frankly, I've always found this to be kinda weird.
- The low level photon reconstruction at D0 looks a lot like a jet algorithm, crossed with something that looks like τ-id.
- You DON'T reconstruct anything that isn't "isolated" at some level.



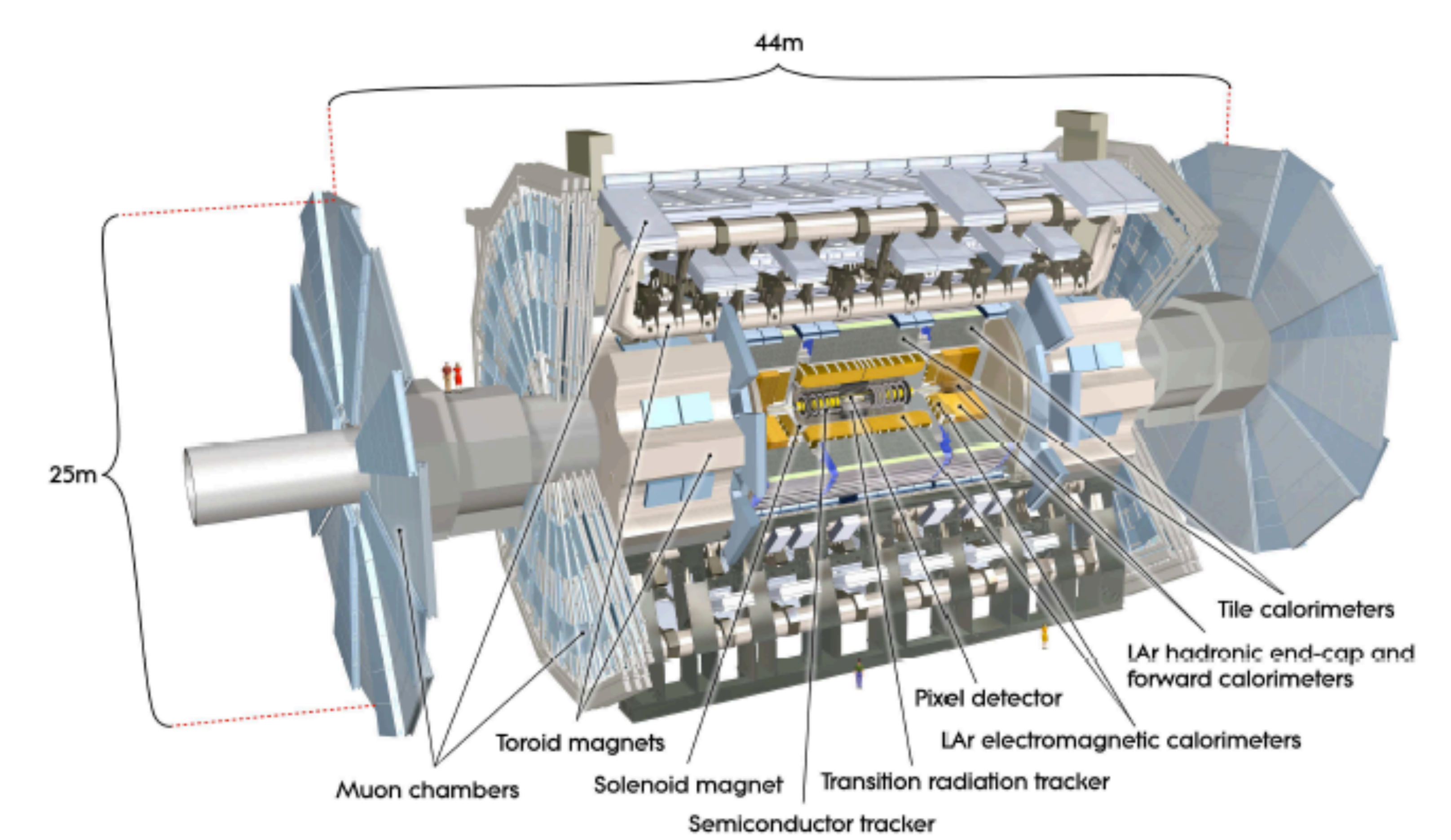
ON THE ONE HAND:

- On the one hand, D0's ID criteria for most of it's objects almost always used multivariate techniques. That's a real advantage.
- On the other, D0's simulation was NEVER fully trusted, or trusted at all really. Data/MC scale factors varied wildly, depending on what quantities were used.
- The result was that you ended up with multivariate techniques that used only quantities that were well modeled in the simulation by doing comparisons with electrons.
  - Systematics on e/γ discrimination were really bad until finally the use of Zγ became more commonplace.
  - Ultimately, you ended up combining information from track match, longitudinal shower profile, transverse shower profile to give you the best discrimination against hadronic activity.

WE USE THIS NOW!

- It's interesting, some of the first uses of $Z\gamma \to ll\gamma$ (the radiative mode) were from D0 in order to work around the limitations of it's simulation. The problem was, you needed AT LEAST 1 fb^{-1} of data in order to have enough events to make a statement with a better uncertainty than you would have had from the simulation.
- This usage is really commonplace today, AND we have serious statistics to play with.

ATLAS



- Overview of ATLAS detector. Damn, it is BIG.

ATLAS

- Okay, so let's talk about ATLAS. Specifically it's electromagnetic calorimeter.
  - Like D0, it's a sampling calorimeter that uses liquid argon, though the absorber is lead.
  - If you're a fan of calorimetry, you're going to like this one.
- Four layers of sampling:
  - Layer 0 is a thin layer of active material (LAr), and is known as the presampler. (0.025 x 0.1 in η x ϕ), mainly for catching showers which already began in material.
  - Layer 1 is known as the "strip" layer with fine granularity in η (0.0031 x 0.1 in η x ϕ)
  - Layer 2 is the primary sampler, which contains the bulk of the shower energy (0.025 x 0.025 in η x ϕ)
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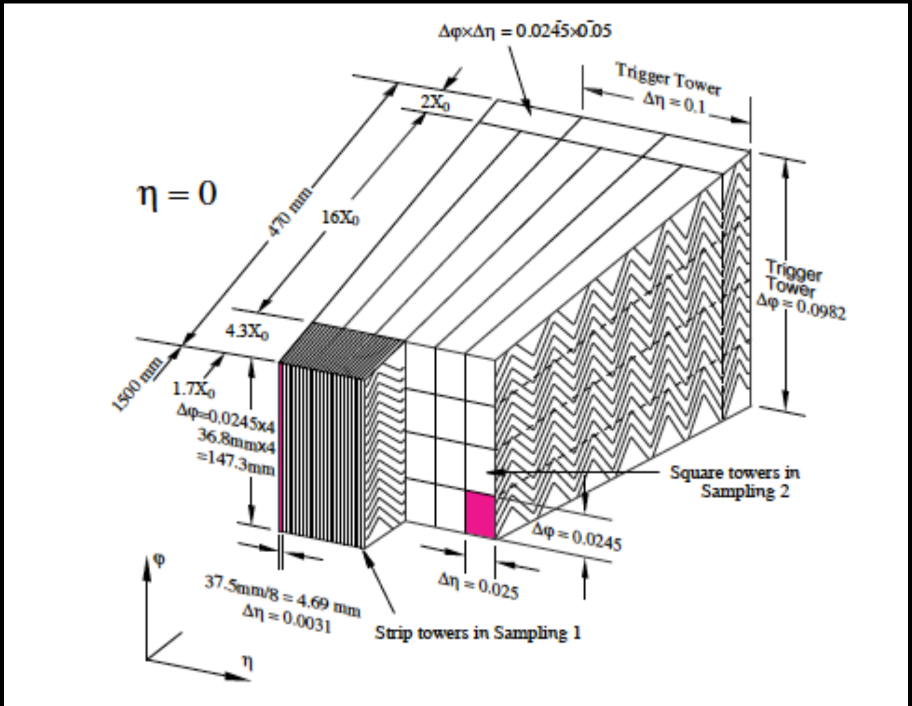

ATLAS CLUSTERING

- ATLAS uses a sliding window algorithm to cluster regions in its electromagnetic calorimeter.
  - First make towers in the ECAL (or EMB/EMC in ATLAS-speak)
  - Then find towers that are local maxima (in a 5x5 array), above threshold.
  - Compute the position within a 3x3 (this defines the seed)
  - Take a fixed array of cells about the seed position, first in the middle layer, and then use that position for the strips, presampler and then the back.
    - Key insight: width of window taken in f depends on the particle hypothesis. ATLAS does their tracking/conversion finding step first and then decides on the hypothesis before doing clustering.
- They also have a nearest-neighbor algorithm, which is used for things like τs.

ATLAS CLEANING

- I didn't get into huge detail about our cleaning, and I'm not going to get into a ton with ATLAS.
  - Especially since that would probably require more insider info than I'm privvy to.
- Just like at D0, it's very natural to make requirements that a cluster in the ATLAS ECAL not be due to a single channel in a single layer. That's pretty simple topological criteria, and one expects any loss is negligible.

ATLAS ID

- We had some pretense of calling a subset of cuts "Photon ID", as separate from isolation. Which was always pretty laughable.
- ATLAS genuinely has a suite of variables separate from the isolation that characterize the agreement with the expected shower shape, for converted and non-converted photons separately. I list a few on the next slide that are different than ours.

QUANTITIES:

- Middle layer: ratio of 3x3 to 3x7 in η and ϕ. Lateral width of middle layer.
- Strip layer: width of three strips about max, total lateral width, fractional energy outside core strips, difference between max and second max of cluster in strip layer, and ratio between the two.
- Ratio of energy in Ecal to first layer of Hcal in barrel, and total Hcal in endcap.
- There is an H-matrix style combination of these factors that attempts to exploit these correlations.

ISOLATION:

- ATLAS also uses a $\Delta R<0.3$ cone in the calorimeter, less the energy of the photon.
- Their tracking isolation is also $\Delta R<0.3$, with tracks within 0.1 required not to match up to a conversion track.
  - They also make explicit hit and p_T requirements of the tracks used in this isolation sum. If there's an equivalent for our charged hadron isolation, I don't know it.

SUMMARY

- There's no real punchline here, this is merely to introduce you to other experiments an the choices that they made.
- There's a real argument to be made that we might take a cue from some of these choices to improve our own efficiency.