Experiments @ LHC

Jim Bensinger
Brandeis University
New England Particle Physics Student Retreat
August 26, 2004

Outline of Presentation

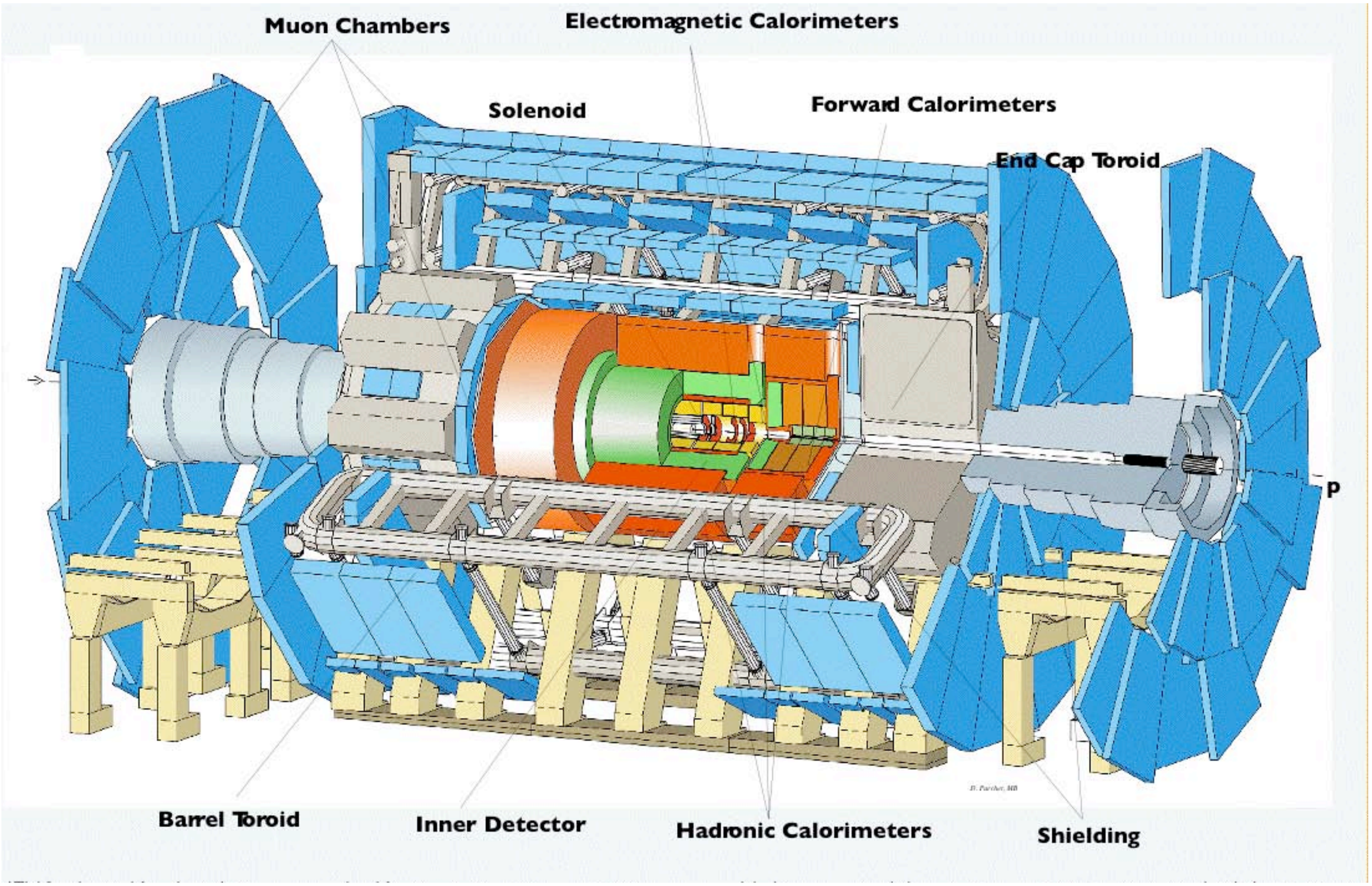
Existing Spectrometers – A Certain Sameness

The Basic Interaction

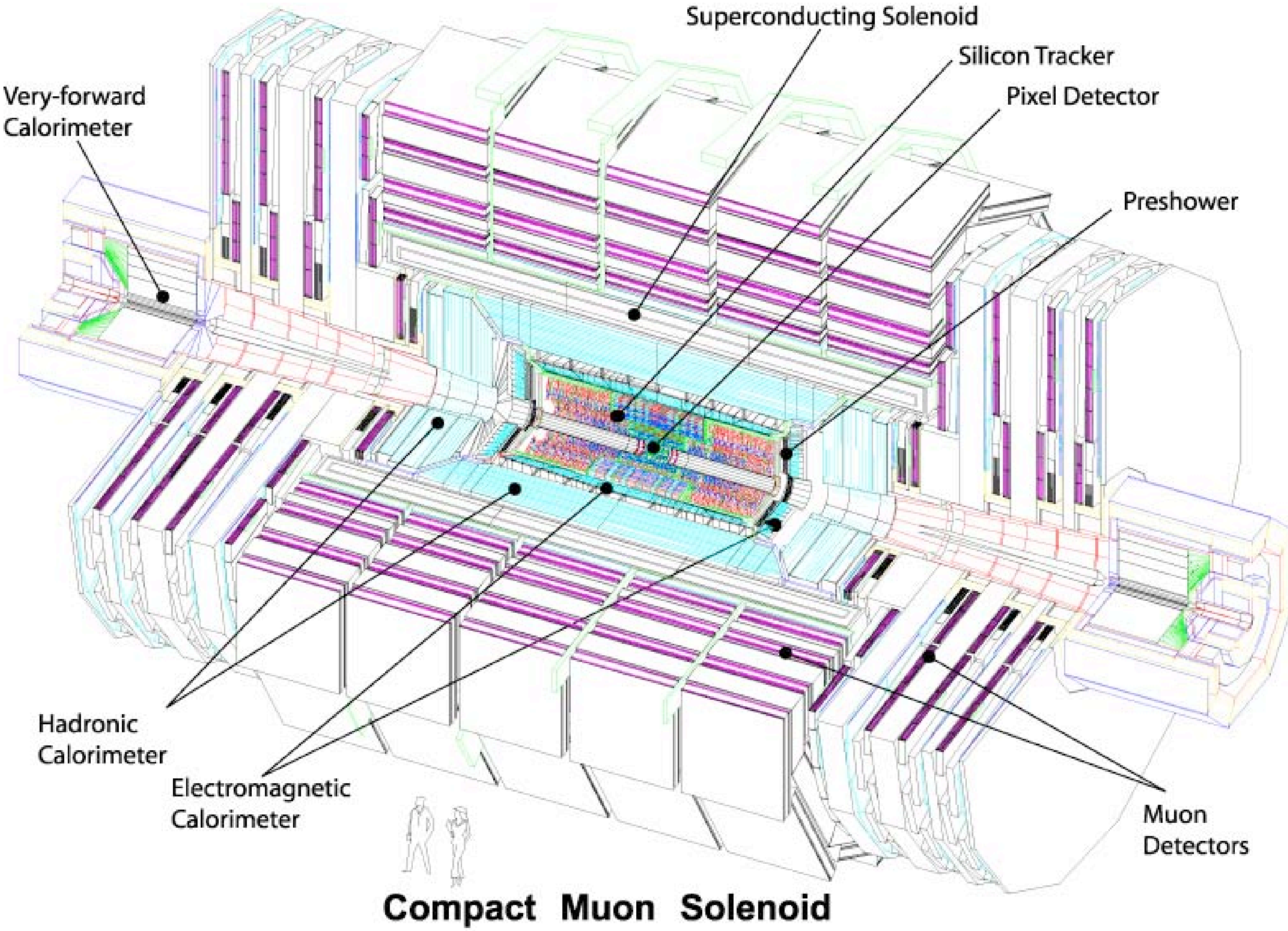
The Primitives

Spectrometer Design

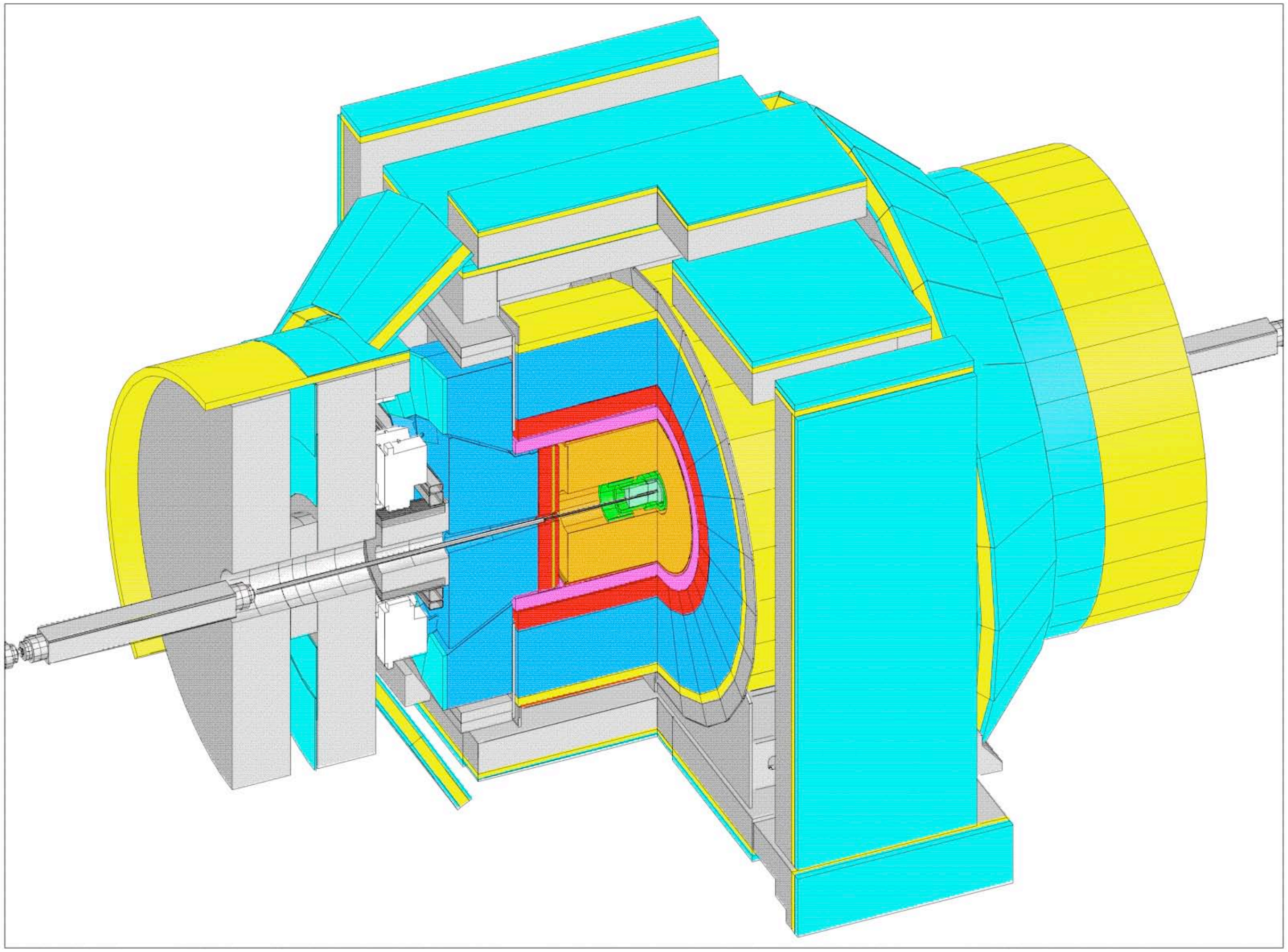
A Certain Sameness - ATLAS



A Certain Sameness – CMS



A Certain Sameness – CDF



A Certain Sameness - DØ

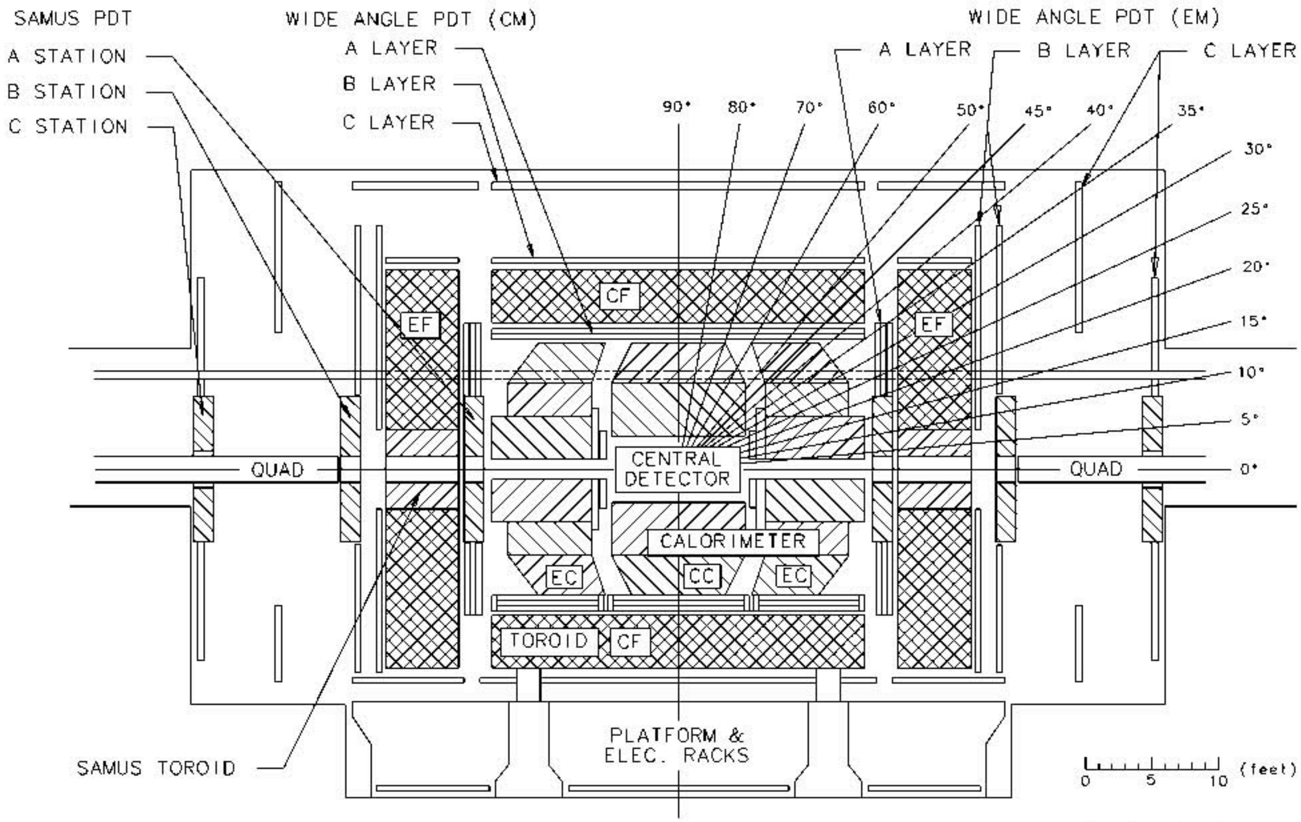
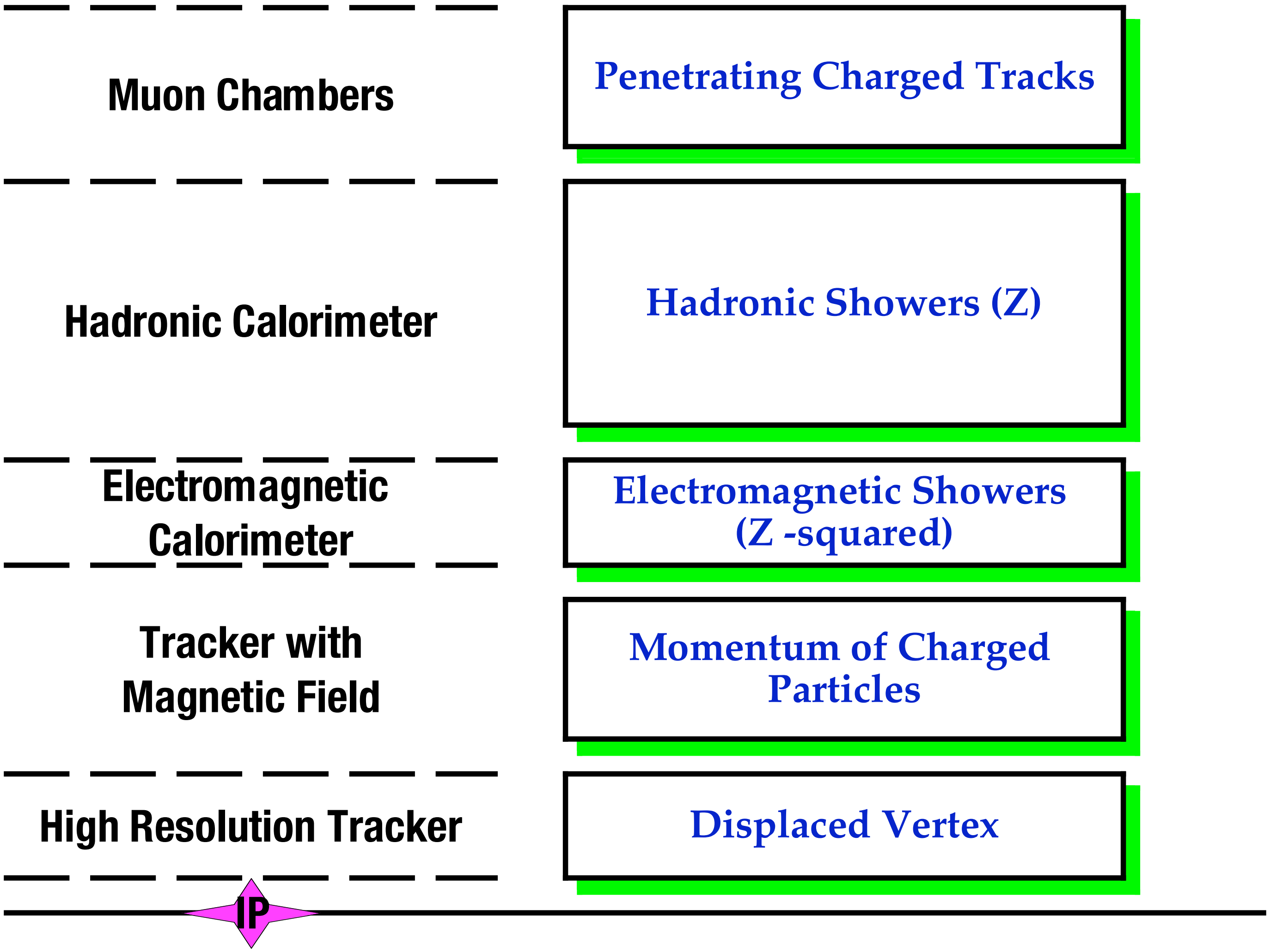
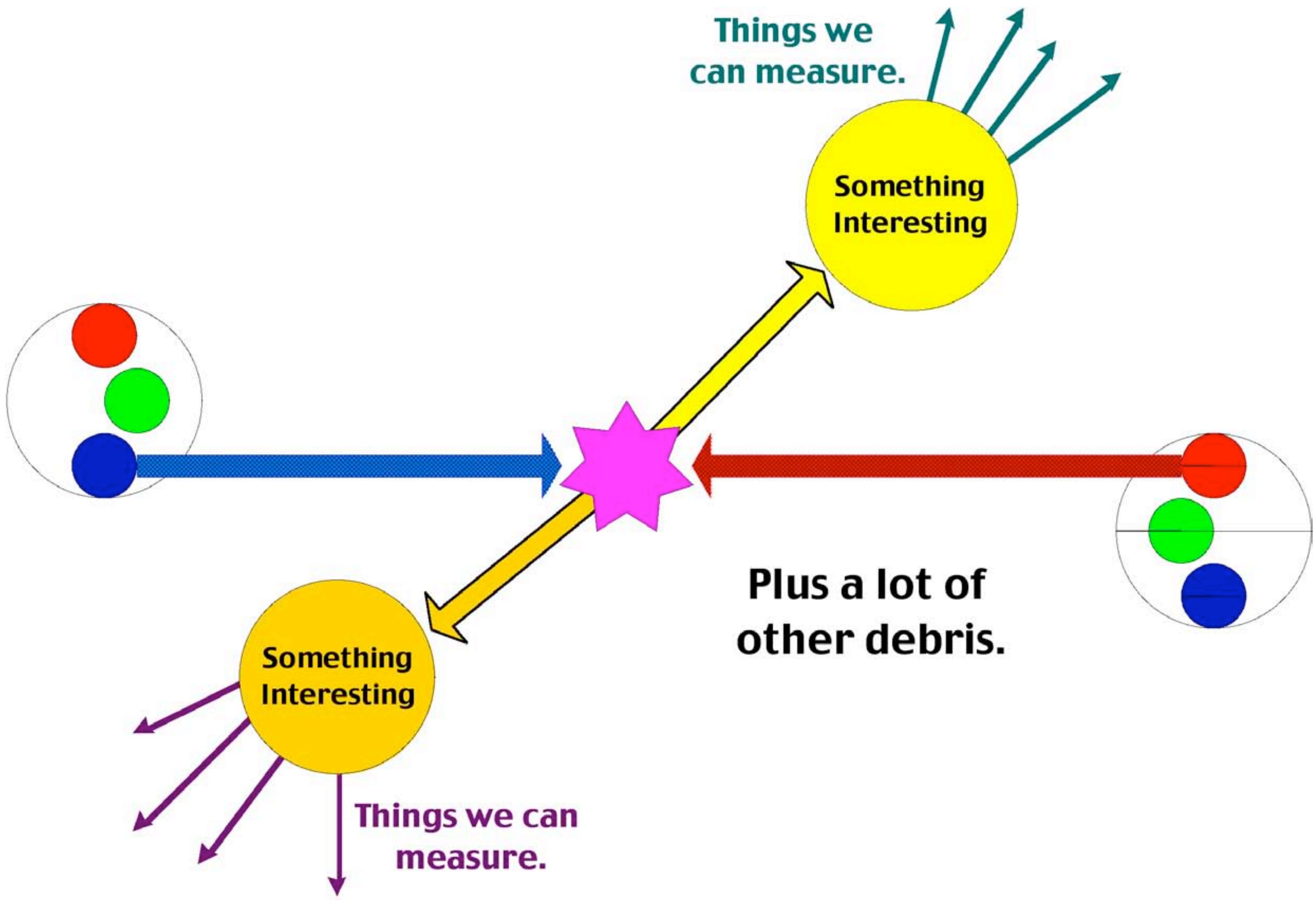


Fig. 1 ELEVATION OF DO/ DETECTOR

A Certain Sameness



Basic Interaction



Things We Can Measure

Neutrino (ν) - Missing momentum and energy, ν's leave no evidence in the detector.

Photon (γ) – No track, an electromagnetic shower with no hadronic shower.

Electron (e) – Track in the inner trackers, electromagnetic shower with no hadronic shower.

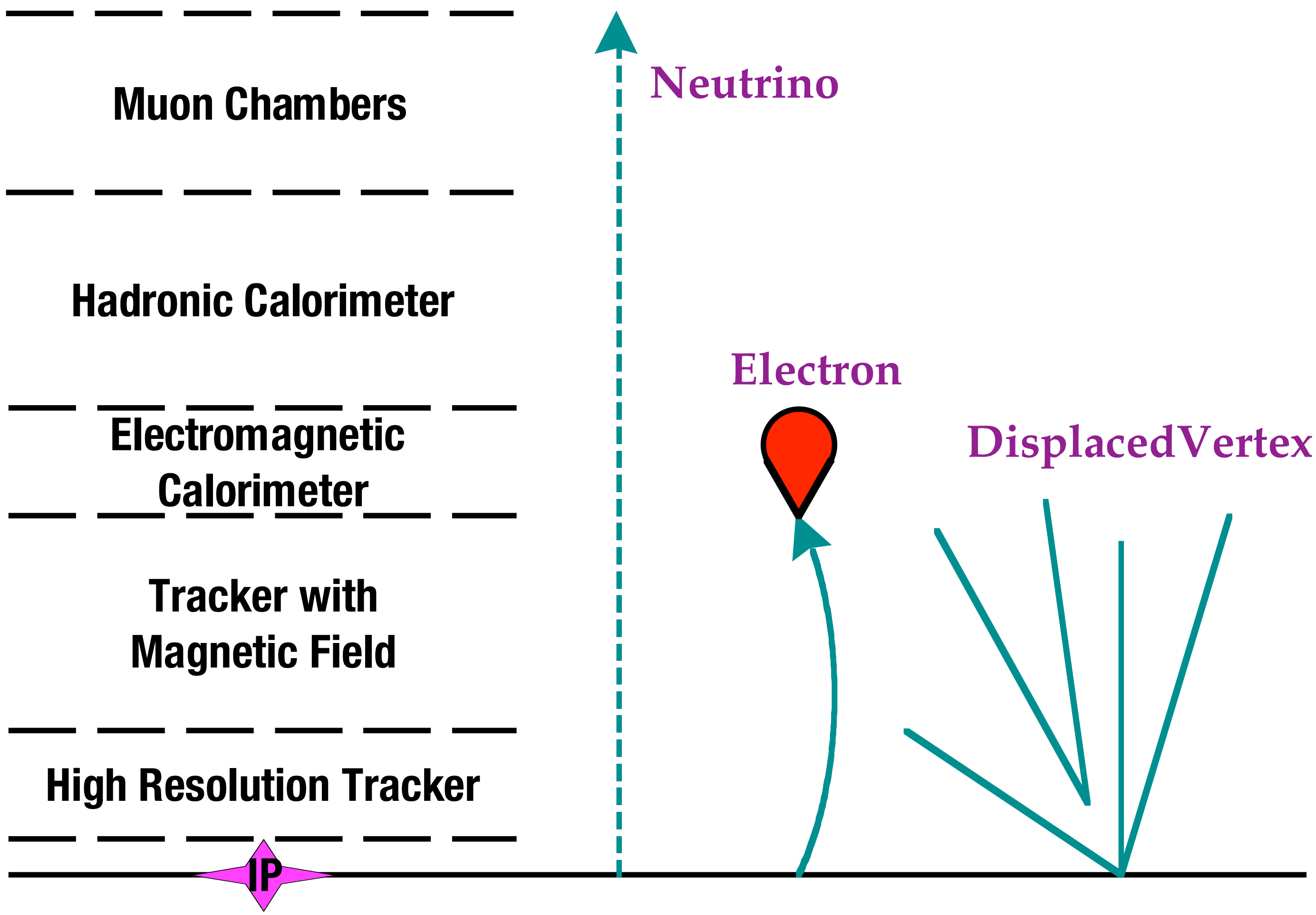
Muon (μ) – Track in the inner trackers, minimum energy in the electromagnetic and hadronic calorimeters, and a track in the muon chambers.

Long Lived Particles (π, proton, Λ and K) – Charged tracks.

Light Quark (q) – [Jet] - Collimated spray of particles in the inner tracker, and energy in the calorimeters.

Heavy Quark (Q) – Displaced vertex, one or more jets, and leptons (electrons or muons).

Examples of Measurements



Electron Identification

Not only do you have to measure the electron, you have to measure a lot of things that look like electron - but are not.

- **Asymmetric pair production from early conversion**
- **Overlap of a charged particle with a photon**
- **Pions that showers early and mostly electromagnetically**

Typically you want to reject non-electron tracks by a factor of 10^3 or 10^4. This requires more than one identifier.

- **Silicon detector can detect double ionizations of tracks near a conversion vertex**
- **TRTs (Xenon filled wire chambers) can measure the few kV X-rays produced when electron cross transition radiators**
- **Shower-Max detectors determine if shower centroid aligns with track.**
- **Measure shower profile – longitudinal and/or transverse**
- **No leakage into hadronic calorimeter**

A New Collider ?

The thing to remember about accelerators is that they are very expensive.

There are 4 basic decisions on any major project – Economic and Political first then Scientific and Engineering second.

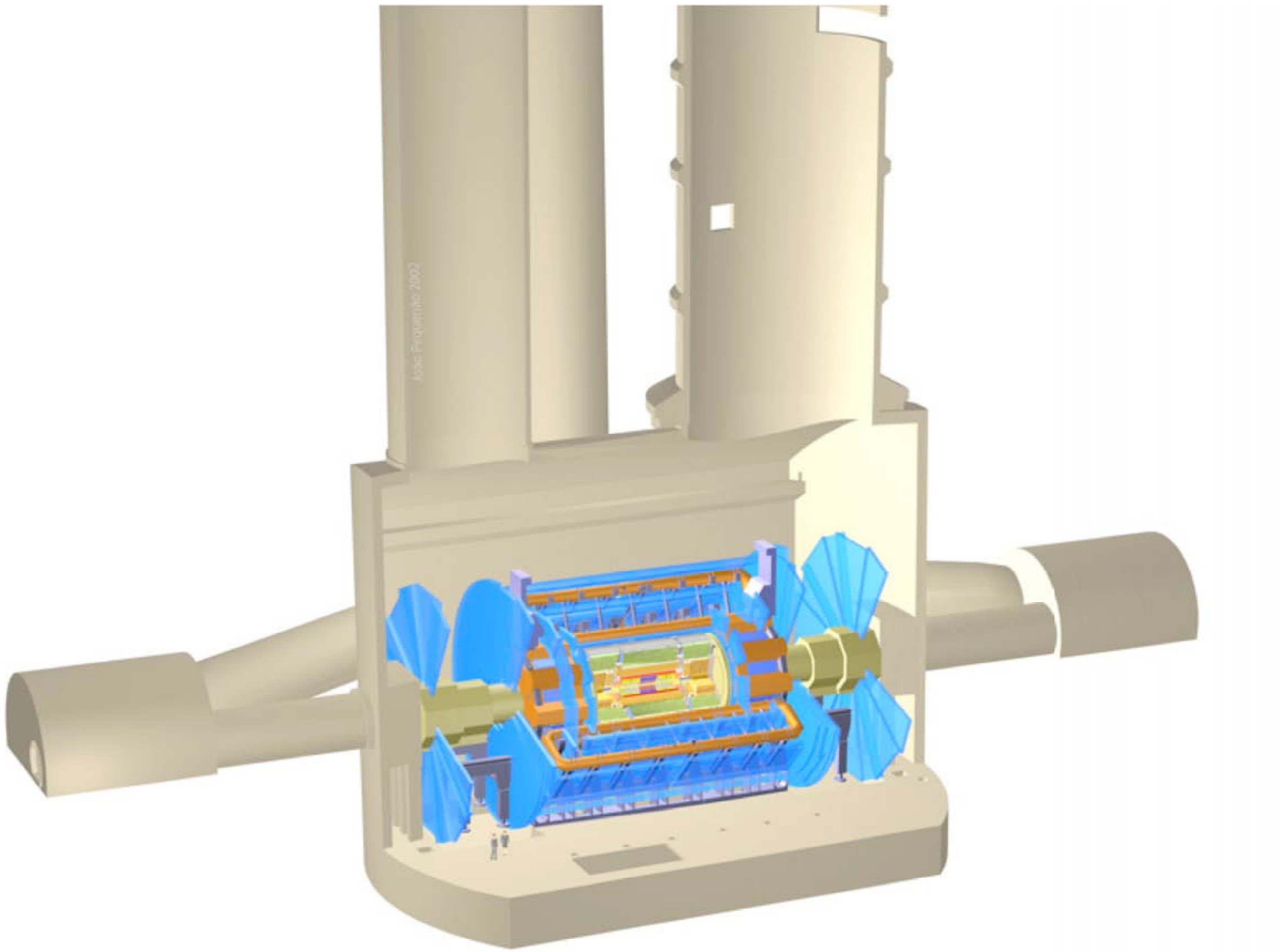
There has to be a sound and widely supported scientific justification for the project.

The money is a public trust, not an entitlement. This means that we do what we say we are going to do at the cost we advertise.

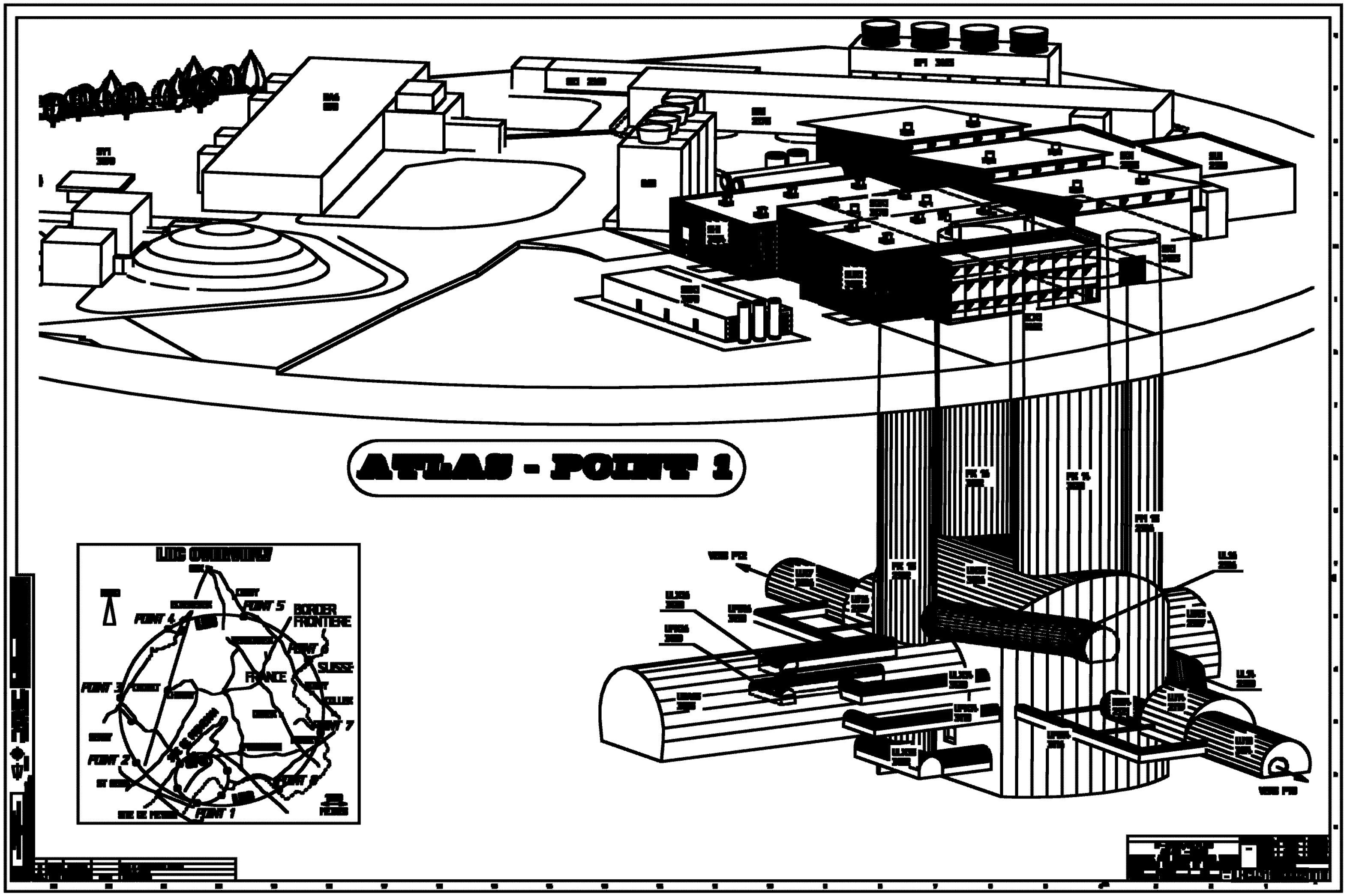
Time scales are long – 10 years to get approval and 10 years to build.

Choosing a site – geologically stable and friendly natives.

The Cavern (ATLAS)



The Cavern


ATLAS - POINT 1
LHC OVERVIEW
POINT 5
BORDER
FRONTIERE
POINT 4
FRANCE
SUISSE
POINT 3
POINT 7
POINT 2
POINT 1

Some Sociology

Axiom: Money is always less than needed and many things follow from that.

Evolution of detector proposals – when a new collider is proposed there will be a number of proposals for detectors that have a variety of approaches to whatever problems the collider addresses. Through a series of workshops, meetings, reviews and other assessments organized by the lab sponsoring the collider these will be reduced to "n".

As many groups will want to stay with the project and the proposal are short of people (i.e. expertise) and money. The consequence is that groups with different will have to work together. This has several positive and negative consequences.

Sociology (cont.)

Organization of collaborations:

- Hierarchical: This organization tends to work well for people who want their own "piece of the action" but don't care for the problems associated with getting funding, decision making, etc.
- "Democratic": Appeals to those with more comprehensive interests. These groups tend to have more conflicts.

The consequence of this and that there is a lot of unknowns when organizing an experiment mean that there are a lot of technical problems with more than one proposed solution. How to solve the technical problems?

- Be clear about what the problem is and make sure the requirements are clear to all.
- Don't solve the problem until at least one of the solutions has been shown to work.

Sociology (cont.)

When all else fails, you end up with a "shoot out" – a head-to-head test of the technologies. If you are lucky one will come out a clear winner. More probably each one will have strengths and weaknesses but they will all work. In some cases it may be possible to "split the difference" each one will do their thing in a different place. If a decision has to be made capability, economic and political decision will have to be made – that can be very painful. Some accommodations has to be made for the second place team – we really need talented people in the field.

How do you keep creative people creative in these big organizations? People need to have an area where they exercise full control and an area where they most conform to whatever standards are set.

Sociology (cont.)

Good enough is good enough. Have a clear understanding of what is needed. When you have achieved that STOP. Doing more than is needed is a waste of time, money and manpower. It also means that something that something else you have to do isn't being done.

Something new. When do you propose a new idea? You will probably get one of the following answers.

- We have this group who has been working on the subject for years. What do we do with them?
- We have spent all the money.
- It's too early.
- It's too late.
- There was only a millisecond between them and you missed it.

General Design Considerations

Measurements should be balanced. They should complement each other. It is possible to take a given detector and improve every single piece and end up with a worse detector. For example making a calorimeter thicker for more containment can reduce the ability to measure low energy muons and reduce the b physics capabilities.

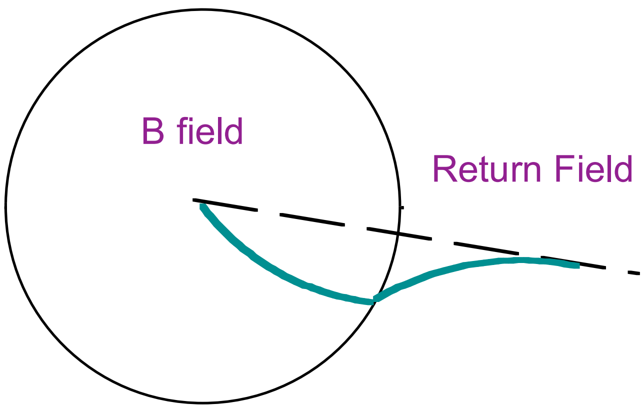
One person's physics is another person's background. Each piece of the detector will have to do many different measurements. Many of these would prefer a different optimization.

Proofing a detector – test against a long list of physics possibilities. If it can do enough of them well enough means you are probably OK for what ever comes along.

Don't over do. It could lead to bad decisions at the end. ($)

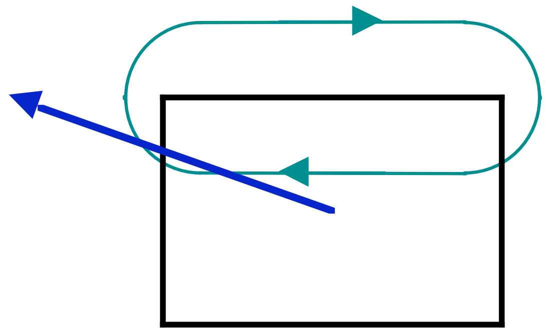
Choice of Magnet

We don't want the magnet to have any effect on the beam and we want a symmetric field. Use either a solenoidal or toroidal magnet. Solenoid for the central detector as a toroid would require material near the beam pipe.



In a solenoidal field, conservation of momentum says that the track far away will point away from the vertex. Then measurements inside (when the momentum is sufficiently high enough so the error is not dominated by multiple scattering) and outside can be combined to improve the momentum resolution.

Magnet (cont.)



The disadvantage of a solenoid is that the field decreases in the forward direction and the tracks run parallel to the field lines. There is a loss of measurement capability in that direction.

If you put a toroidal filed around the solenoid, the field increases as 1/r big improvement in the forward direction but you are dealing with things that look like ->

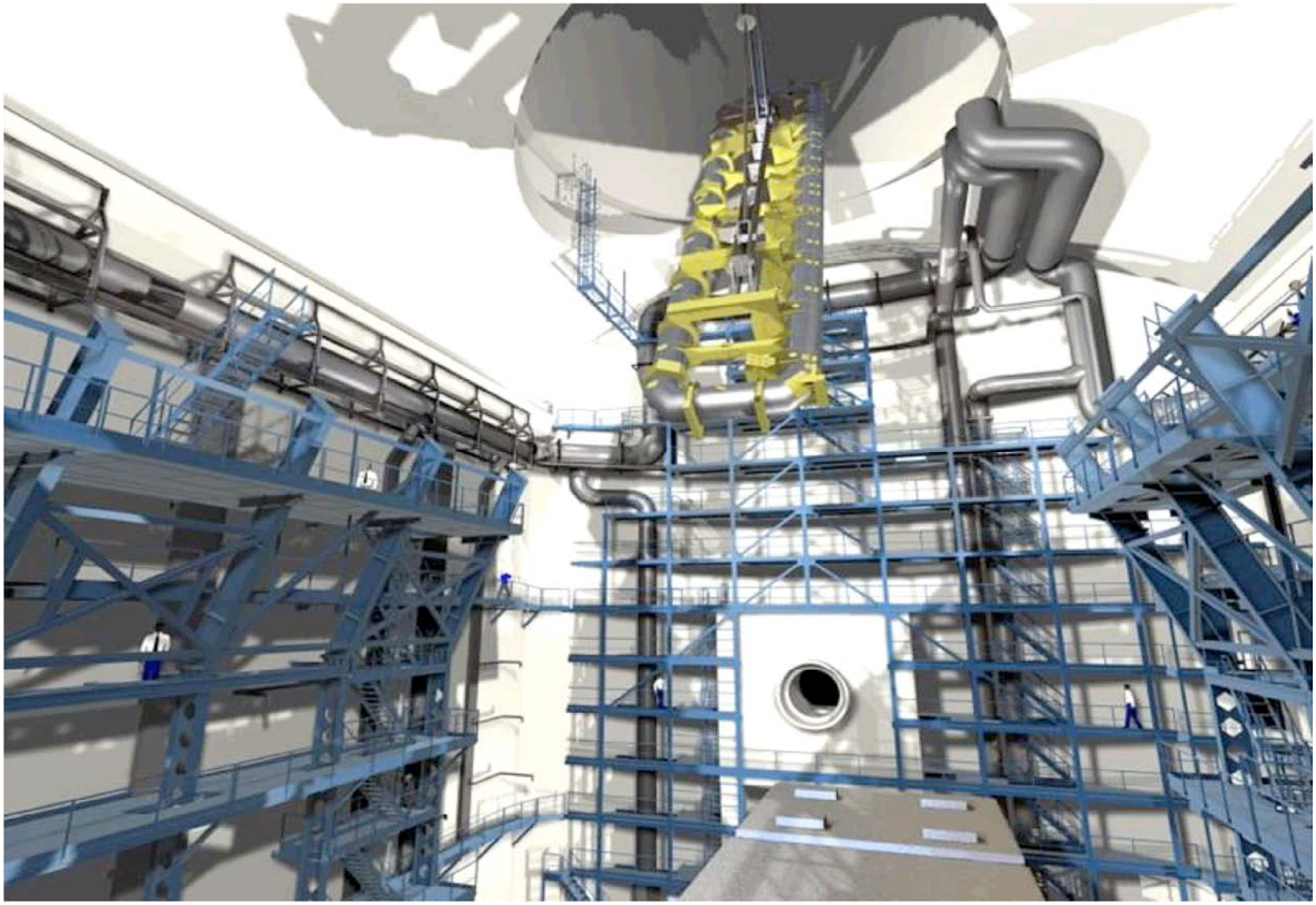
Air core superconducting magnets sound like they have no material but the cryostat and structural material add up to a lot.

Magnet (cont.)

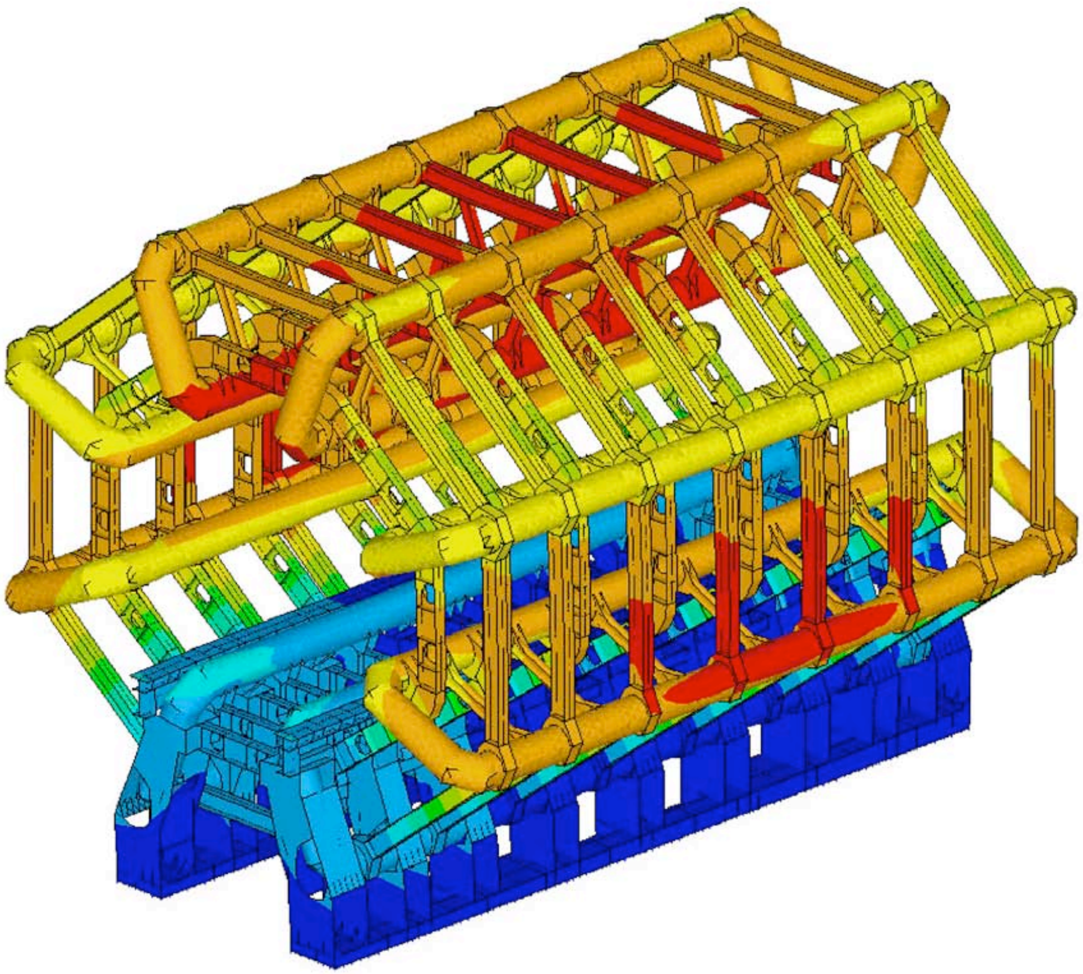
Magnet (cont.)

Magnet (cont.)

Magnet (cont.)

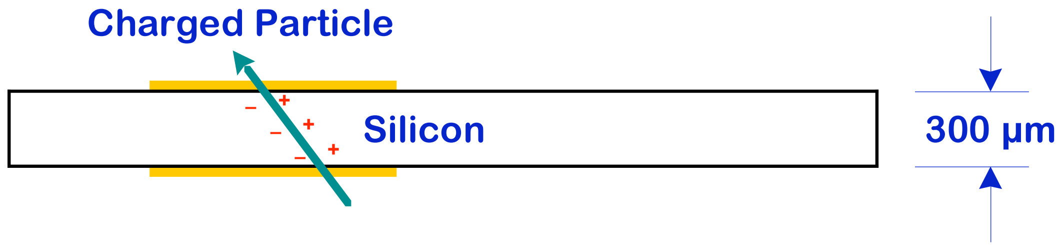


Magnet (cont.)



Silicon Trackers – Secondary Vertices

A charged particle going through 100 μm of Silicon will produce about 20,000 electron/hole pairs that drift to the electrodes on the surface to be readout.



Uses:

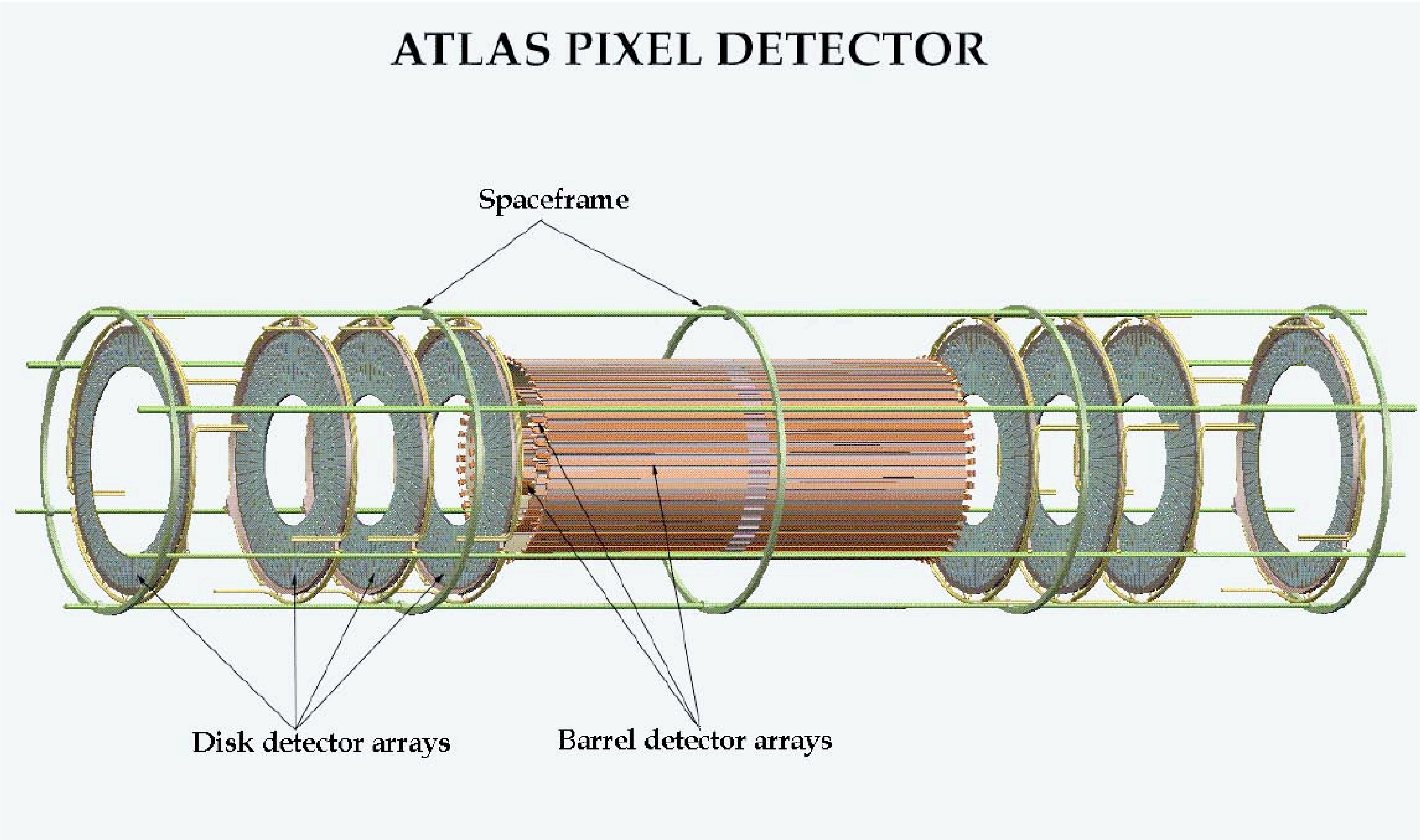
- **Vertexing – identifying t or b particles**
- **dE/dx – Identification of magnitude of charge**
- **Helps with momentum resolution**
- **Sort out high multiplicity events**
- **Assign particle to the correct primary vertex**

Silicon Tracker (cont.)

Considerations:

- Coverage vs. Cost. How many layers? Making this bigger not only cost more for Silicon but pushes everything else out and drives up that cost.
- Radiation Hardness (it's near the beam pipe – 300kGy & 5x1014 neutrons). The closer to the beam pipe the better resolution but more problems with radiation.
- Mechanical Support (precision and stability ~ 5-10 μm). Must also have almost no mass. There are as many photons as charged tracks, so even a few % of a radiation length is a problem.
- Large Number of Amplifiers (a lot of heat –> cooling). Even at 1 mW/ch it's a lot of heat in a confined space.
- Getting the signals out – cabling is always a problem.

Silicon Tracker (cont.)



Hadronic Calorimeter

Sampling calorimeters create a hadronic shower in a dense material and then measure a portion of that energy in some active medium. While electromagnetic showers are reasonably well behaved, hadronic interactions are subject to large fluctuations. If they happen in the early stages of shower development they can have a large effect on the energy measurement.

- **Neutrinos and muons produced in the shower remove energy from the system.**
- **The fraction of the shower that is electromagnetic can vary greatly. Making a calorimeter respond equally (e/h ratio) can be difficult and expensive.**
- **Showers have a natural transverse spread.**

Errors go as $1/\sqrt{E}$. In the forward direction, you measure E but are interested in ET so almost anything you do is good enough.