Intro to Detectors in Particle Physics

Jens Dopke, CERN

Prologue

- Don’t bother asking questions in between
- This is the first time I’m doing this and I am a little jet-lagged, hence ...

Outline

- Detection concepts
- Breaking it down using an LHC detector
  - Requirements
  - Strategy
  - Example
- Others...

Scintillation

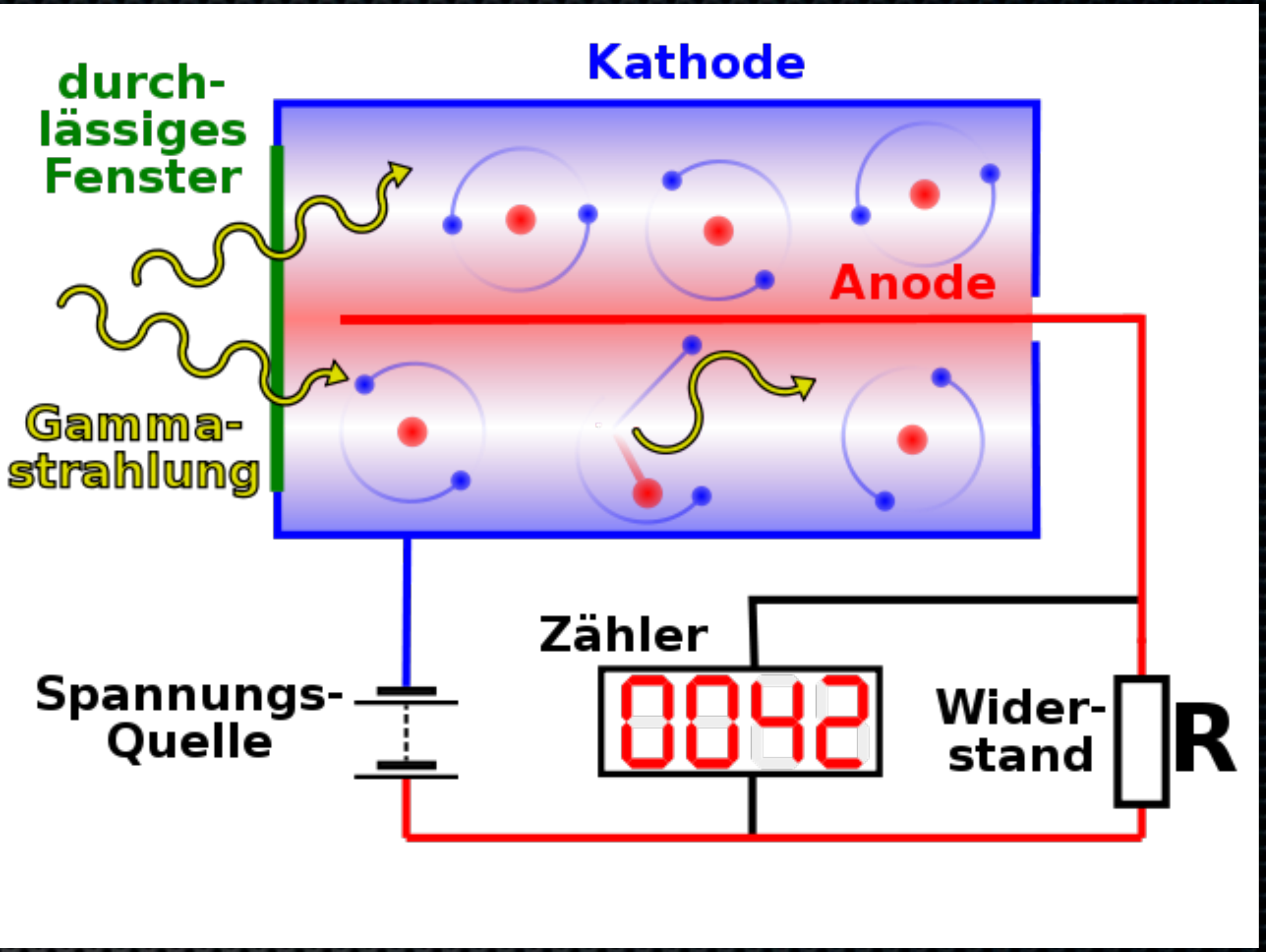
- Wikipedia:
  The process of scintillation is one of luminescence whereby light of a characteristic spectrum is emitted following the absorption of radiation.
- Classic Scintillators like *NaI* allow to make radiation visible in dark environments
- Strong amplification given by Photomultipliers allows photon detection down to single photons

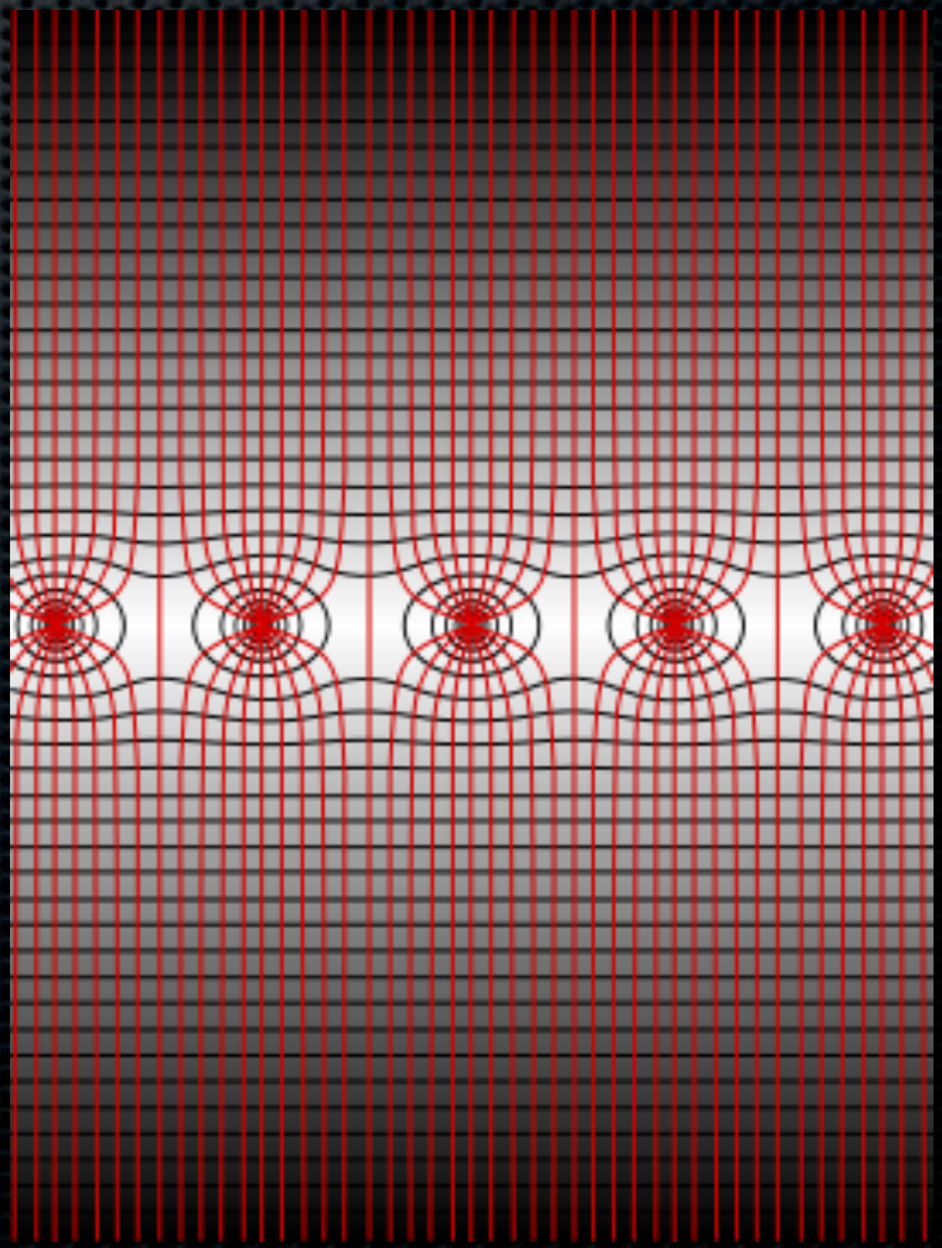
Clouds and Bubbles

- Radiation detection through traces of ionisation
- Cloud chambers work on basis of a saturated vapour
  - Given an initial seed in form of ionisation, a cloud can form
  - Under irradiation, clouds will form along ionisation tracks
- Concept also works within liquids, delivering a bubble chamber
  - Here the liquid is kept at pressure, up until a detection is wanted - Pressure is suddenly dropped and evaporation will first happen in places where energy is deposited

Ionisation

- Incoming radiation kicks out electrons which are then available to run a current through the tube
- Depending on the Bias voltage, the tube allows for either a baseline response, a linear response or an avalanche amplification
- Multiwire chambers the natural continuation, delivering more channels per unit space
- Concept is pretty much the same in semiconductors...

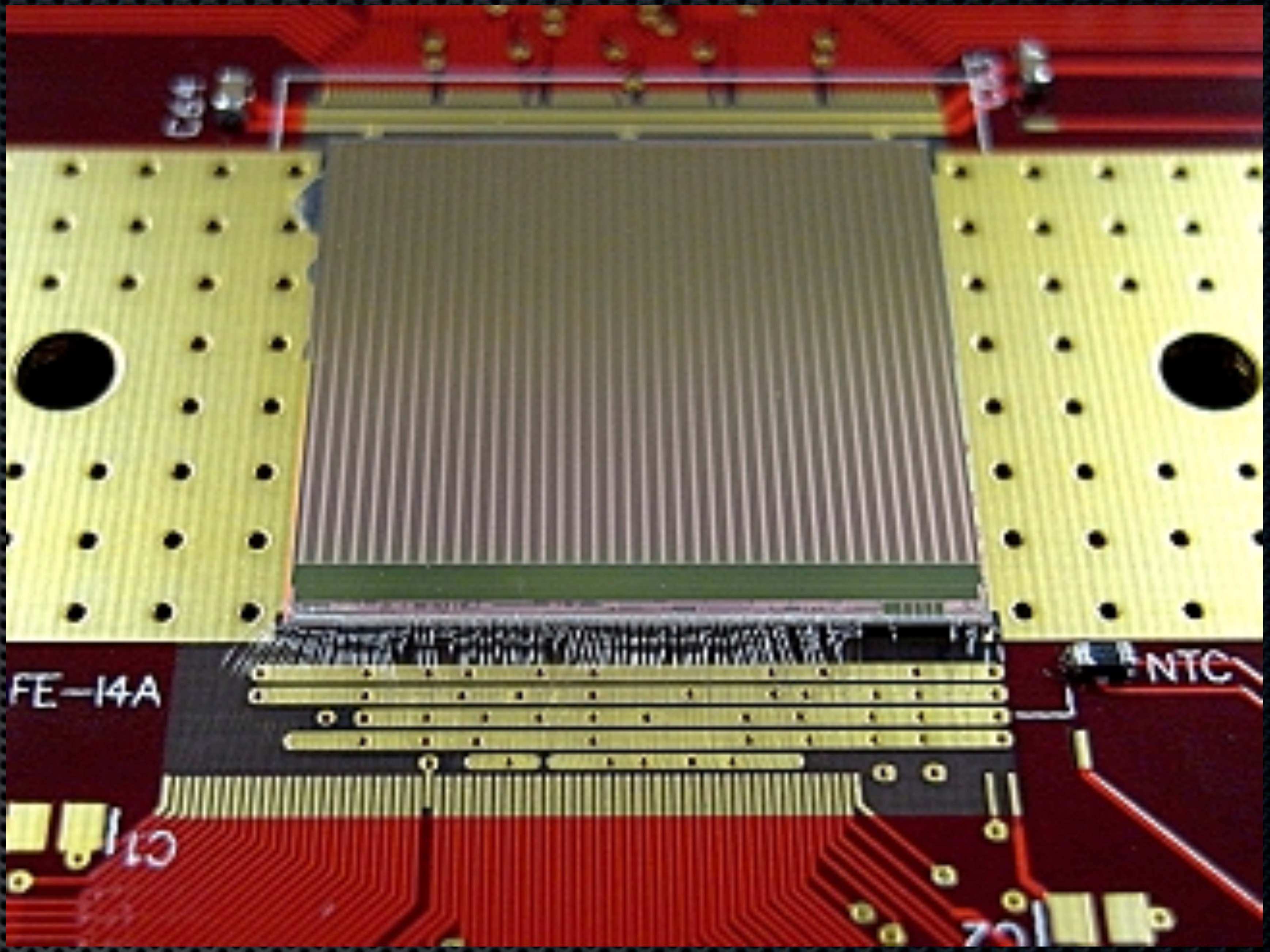




Semiconductors

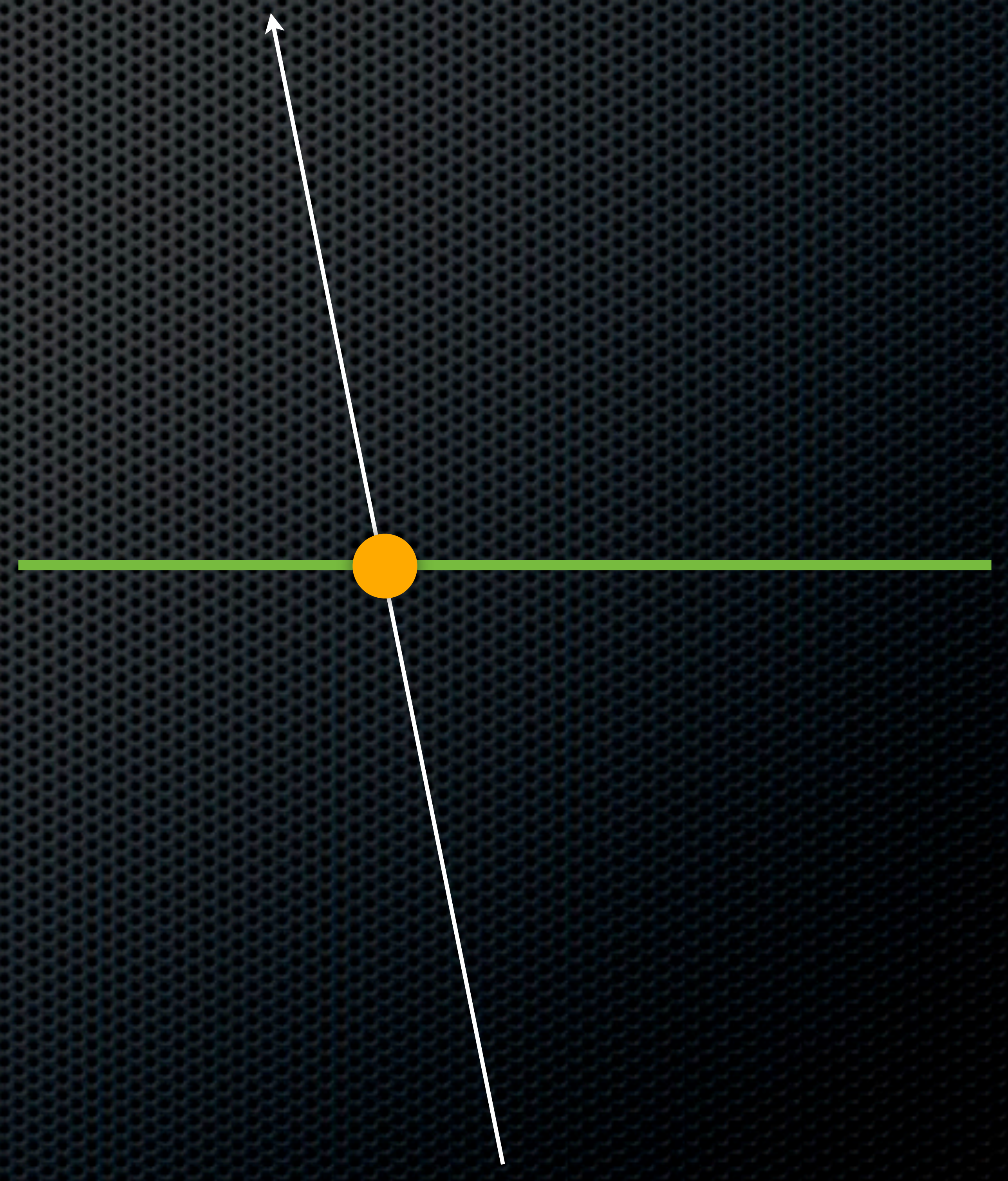
- Besides the classical methods, more recently semiconductors have started playing a major role in particle physics:
- Semiconductor diode with reverse Bias has almost no current flowing
- Traversing particles can deposit energy, freeing electrons which then allow for a current to flow
- Structures can be made extremely small

Examples



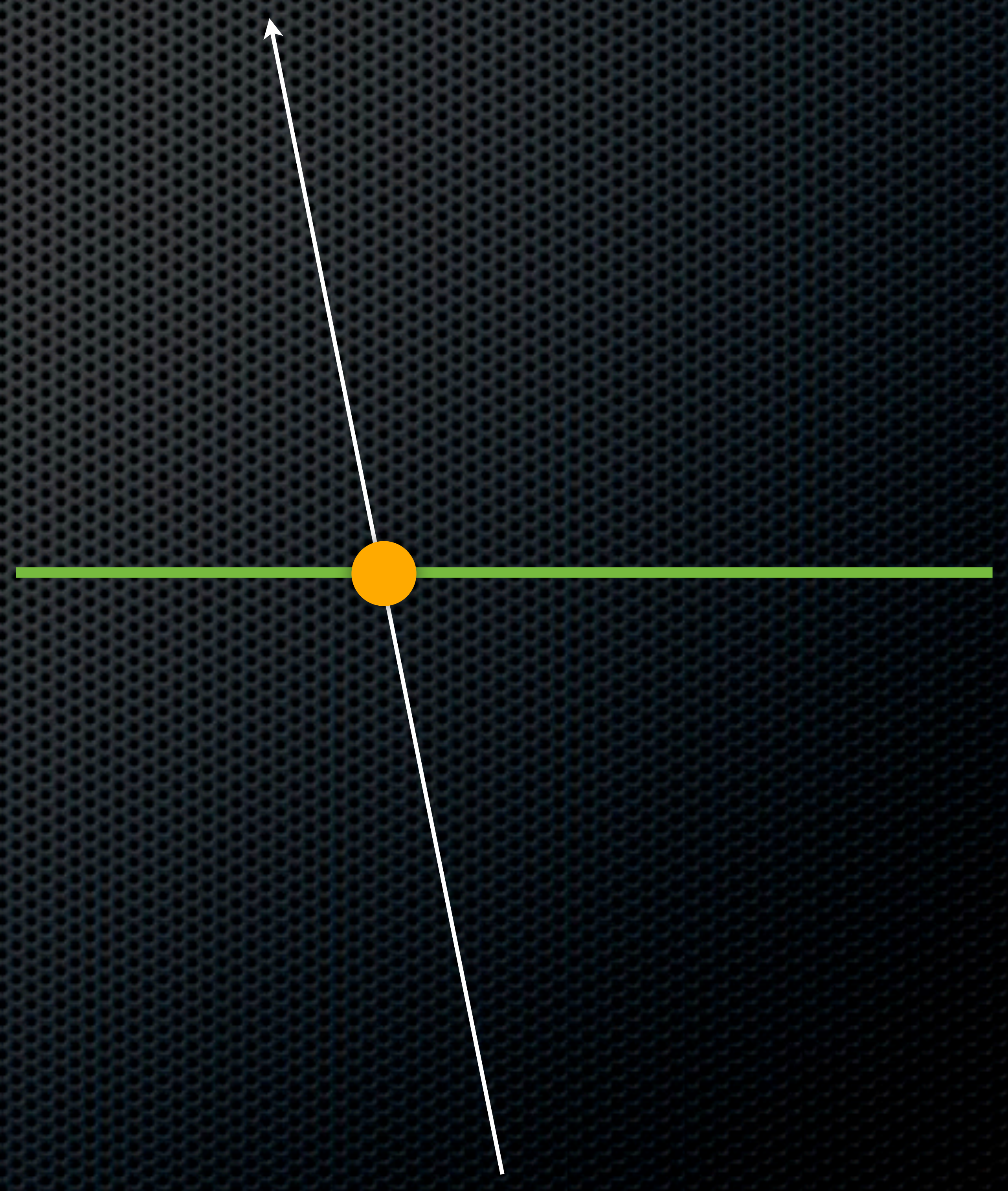
- $50x250\ um^2$ per pixel
- ~27 thousand Pixels in 2x2cm
- Works like a digital camera with a relatively bad resolution but: 40 million zero suppressed “images” can be recorded per second here, in a rather harsh radiation environment

Measuring Momentum



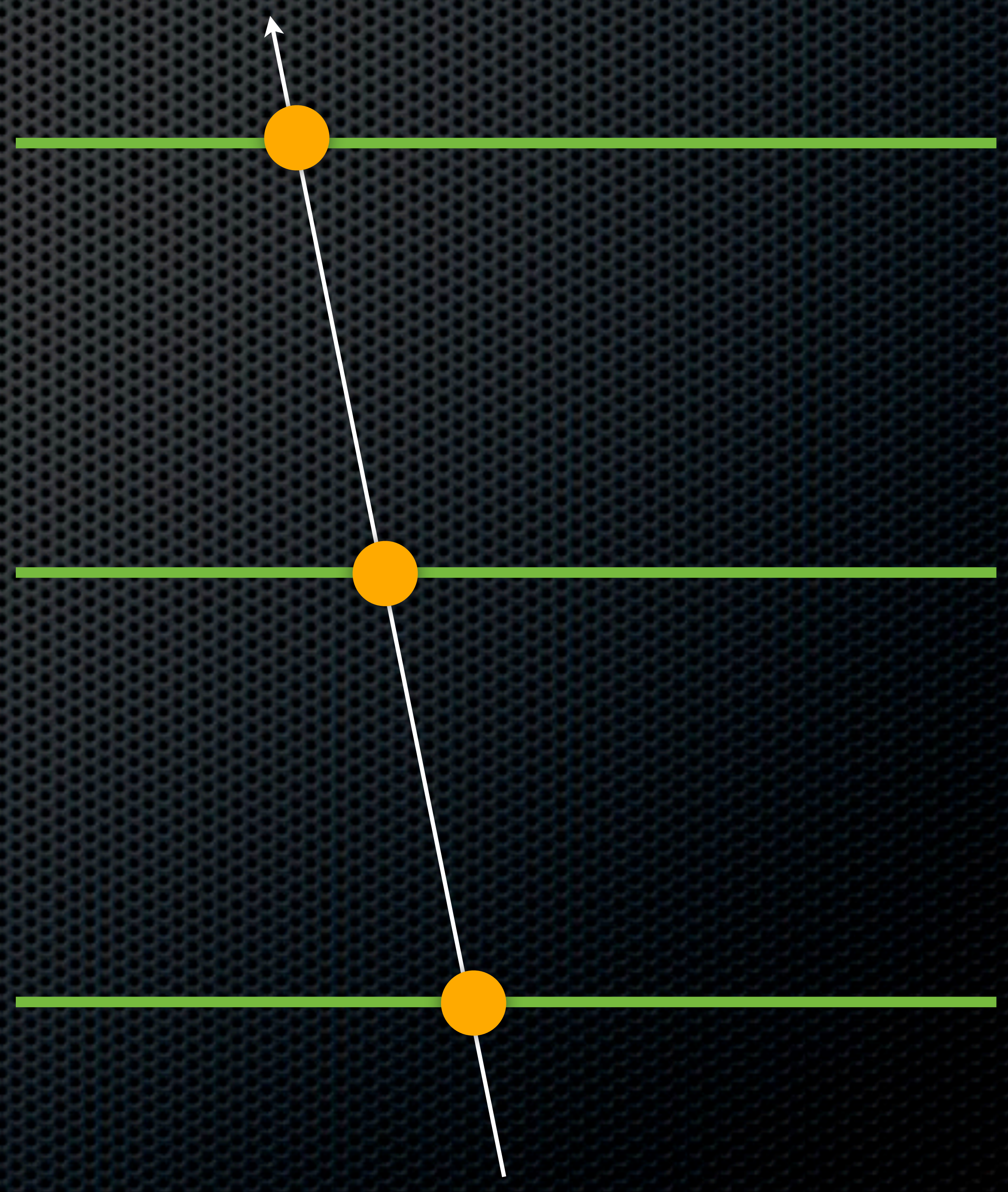
Measuring Momentum

- So far we have ways to measure whether or not a particle is passing through a place - not very helpful



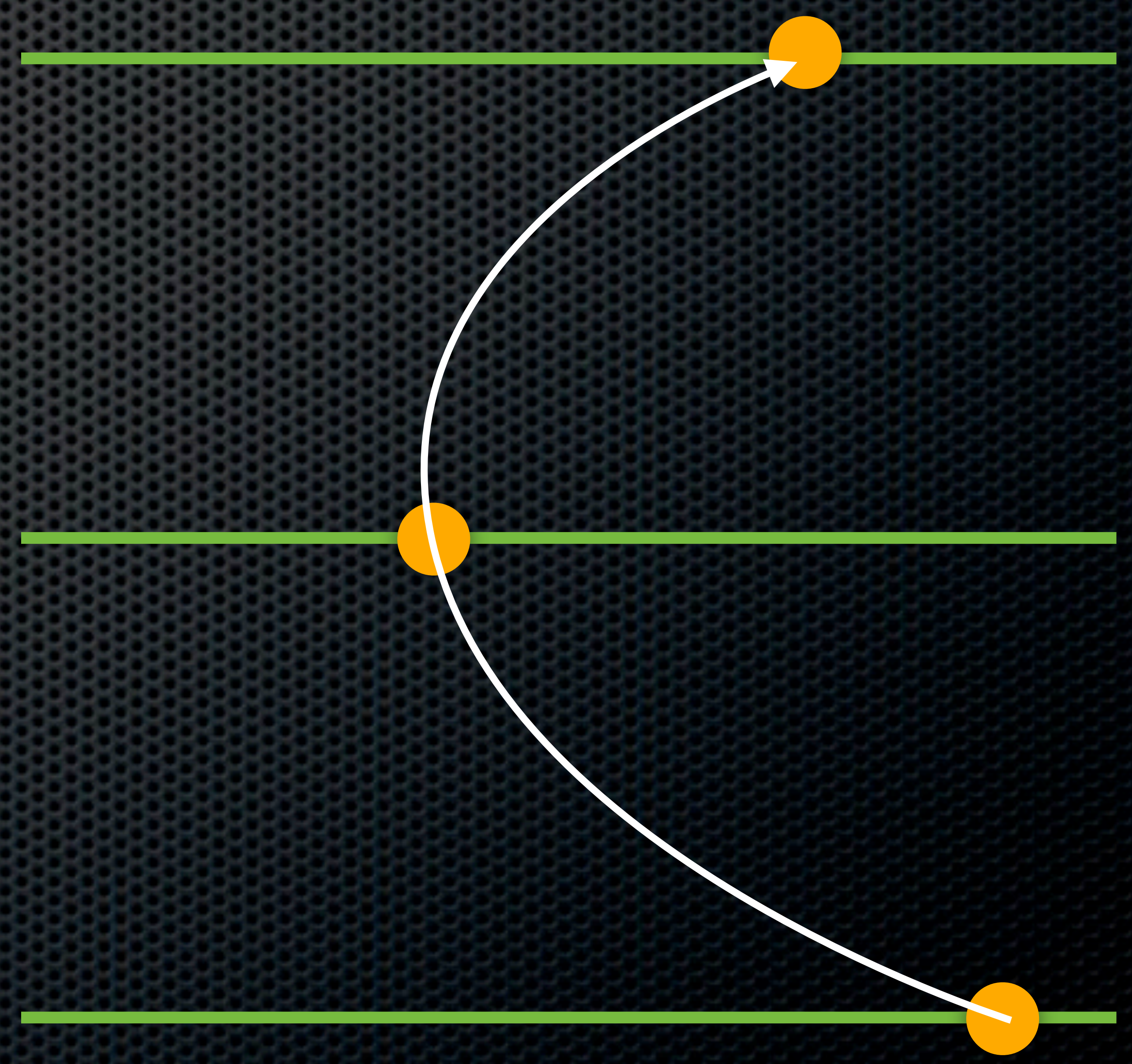
Measuring Momentum

- So far we have ways to measure whether or not a particle is passing through a place - not very helpful
- Placing multiple layers of sensitive material in an expected penetration direction allows to “track” the particles path - more

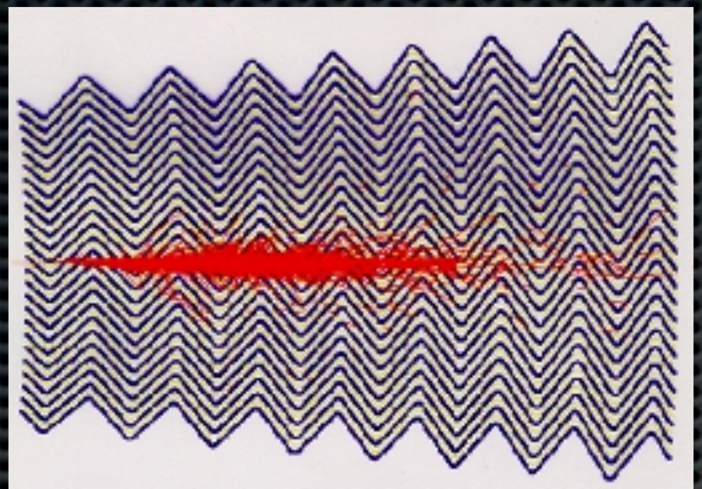


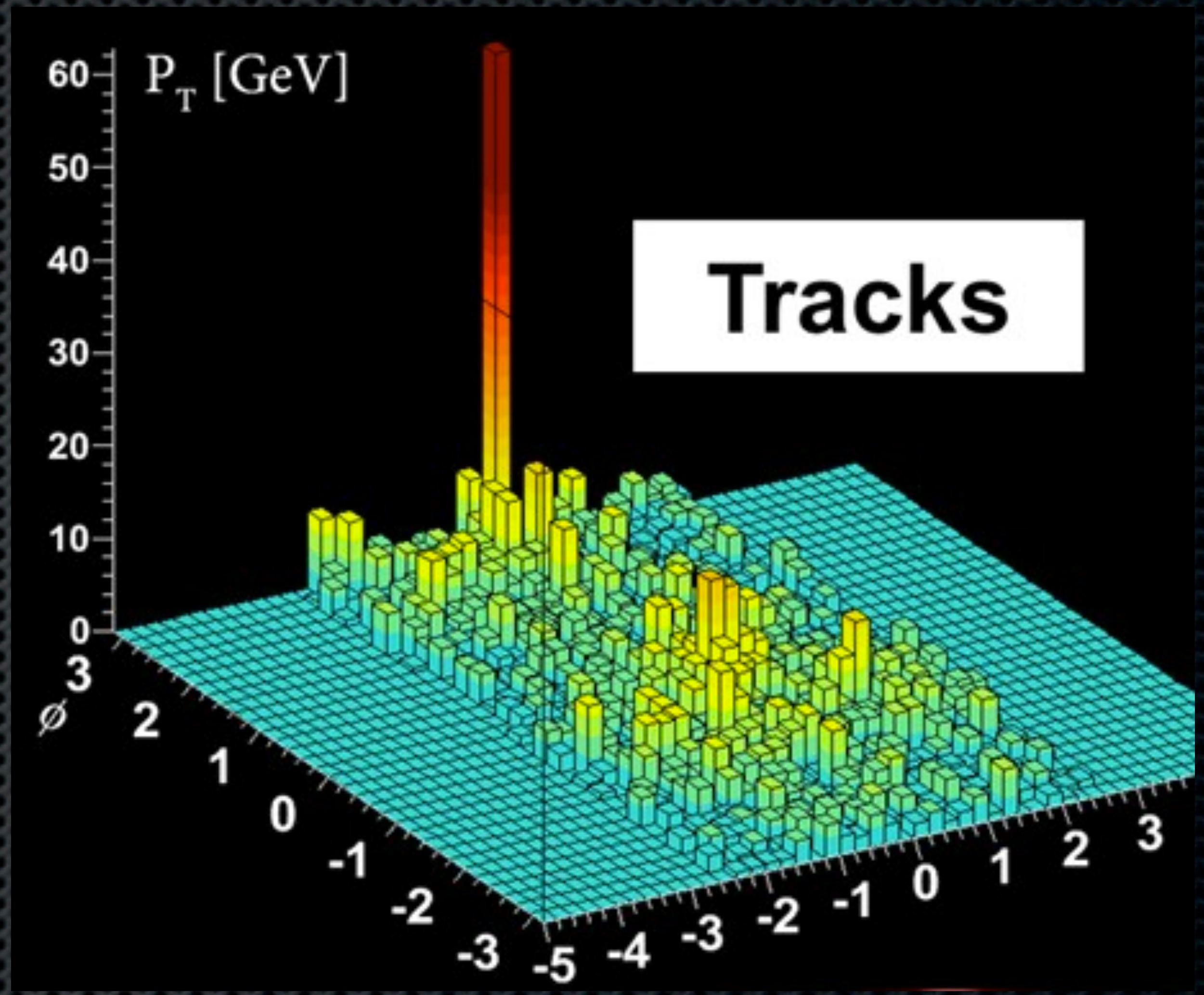
Measuring Momentum

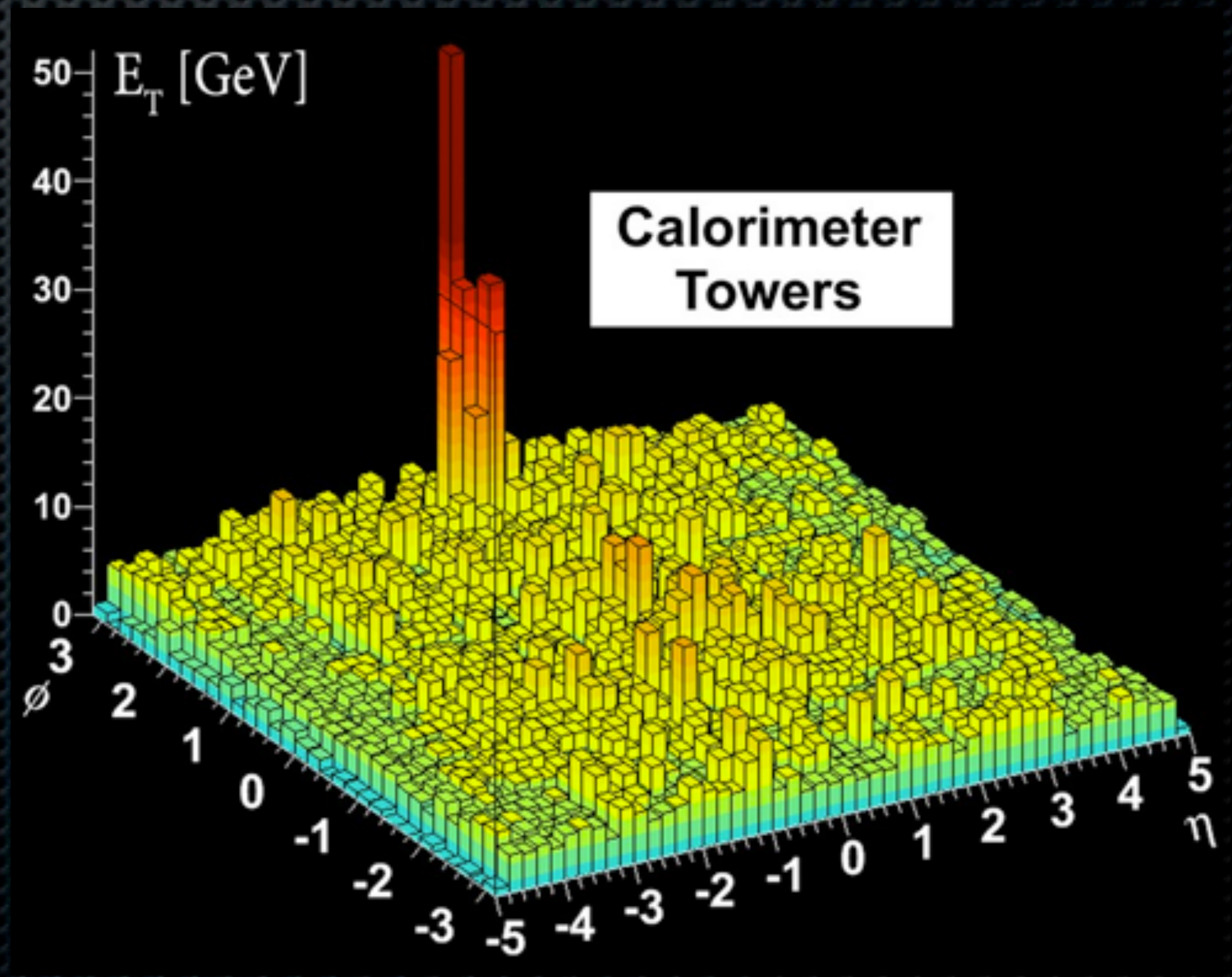
- So far we have ways to measure whether or not a particle is passing through a place - not very helpful
- Placing multiple layers of sensitive material in an expected penetration direction allows to “track” the particles path - more
- Adding a magnetic field, charged particles form a curved trajectory, that allows to measure their momentum - A Tracker!



Calorimetry







- Trying to measure the full energy of a particle
- Approach is to stop the particle, capturing all energy within sensitive area:
  - Either build a large scintillator block, in which the particle is stopped and thus deposits its momentum as well as rest energy in case it ain’t stable - Large!
  - Alternating tiles of absorber and sensitive material deliver good energy absorbtion whilst allowing to measure

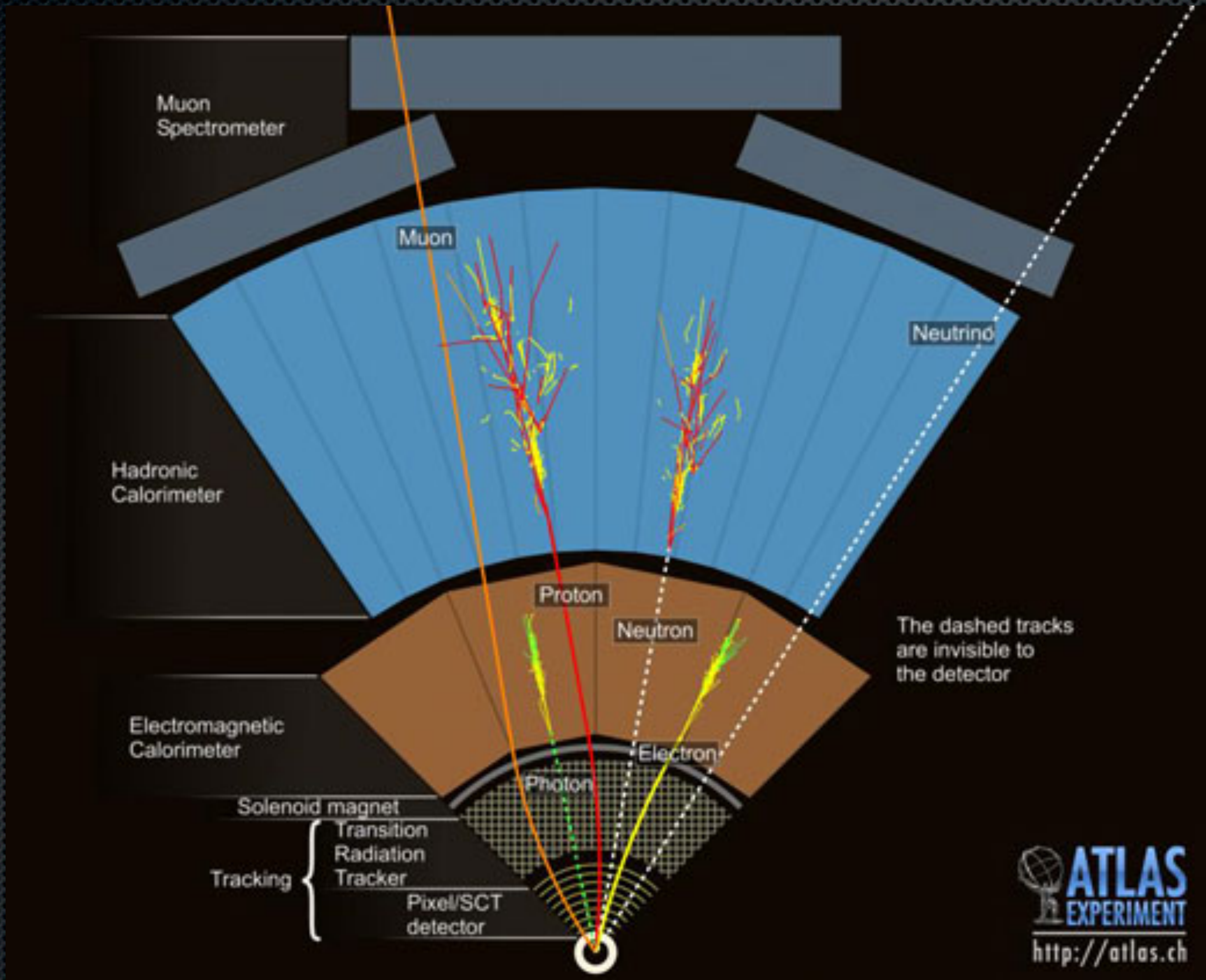
An example: ATLAS

- Sorry for not being very random here
- ATLAS: 46m x 22m (length x diameter), 7000t
  [Numbers varying depending on who is asked]
  - Largest complex machine ever built in particle physics (well...)
- Typical Onion Structure:
  - Tracking (Momentum), Calorimetry (Energy), Muons
  - Transition Radiation allows for better particle IDs

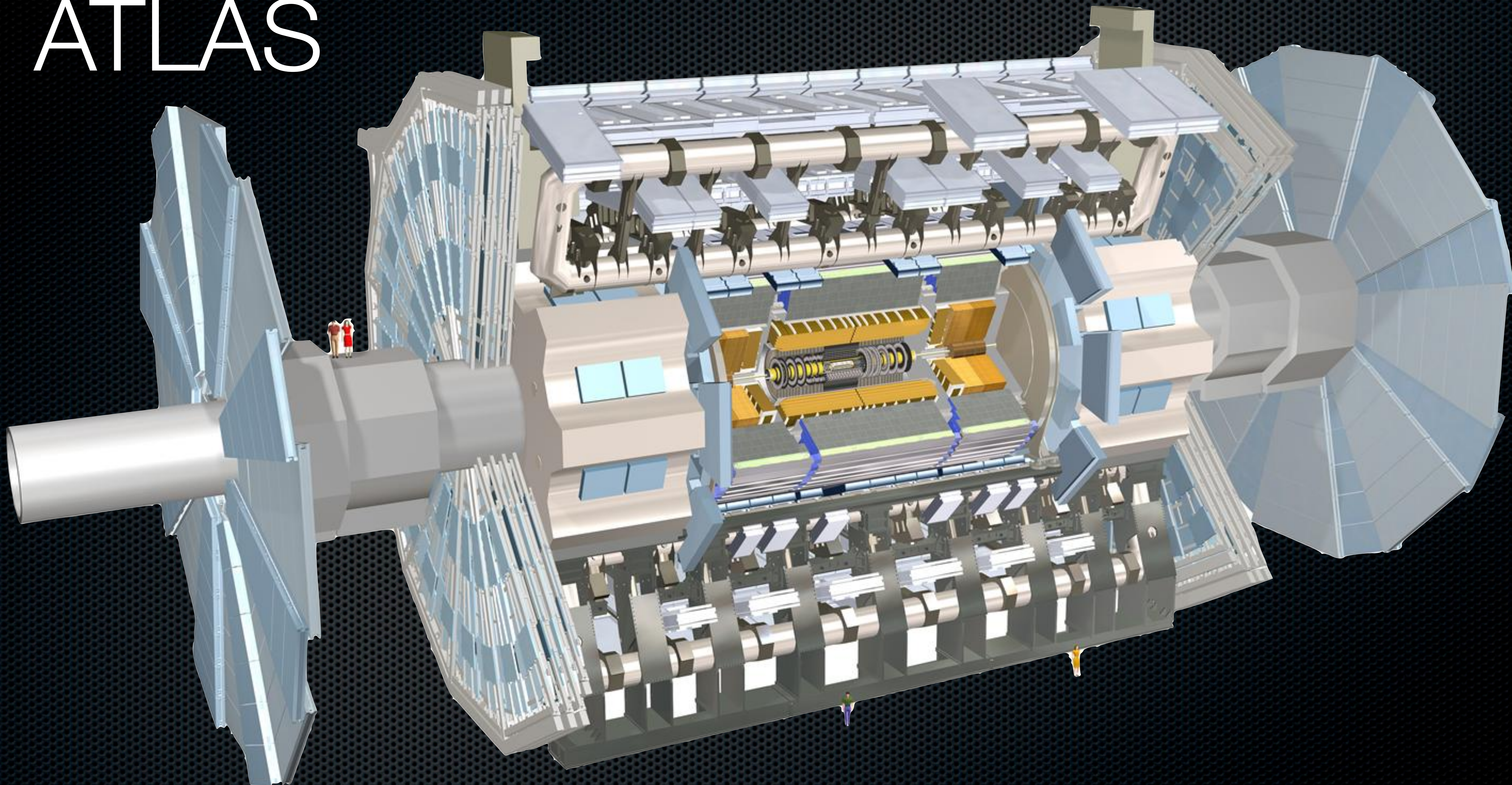
Deliverables

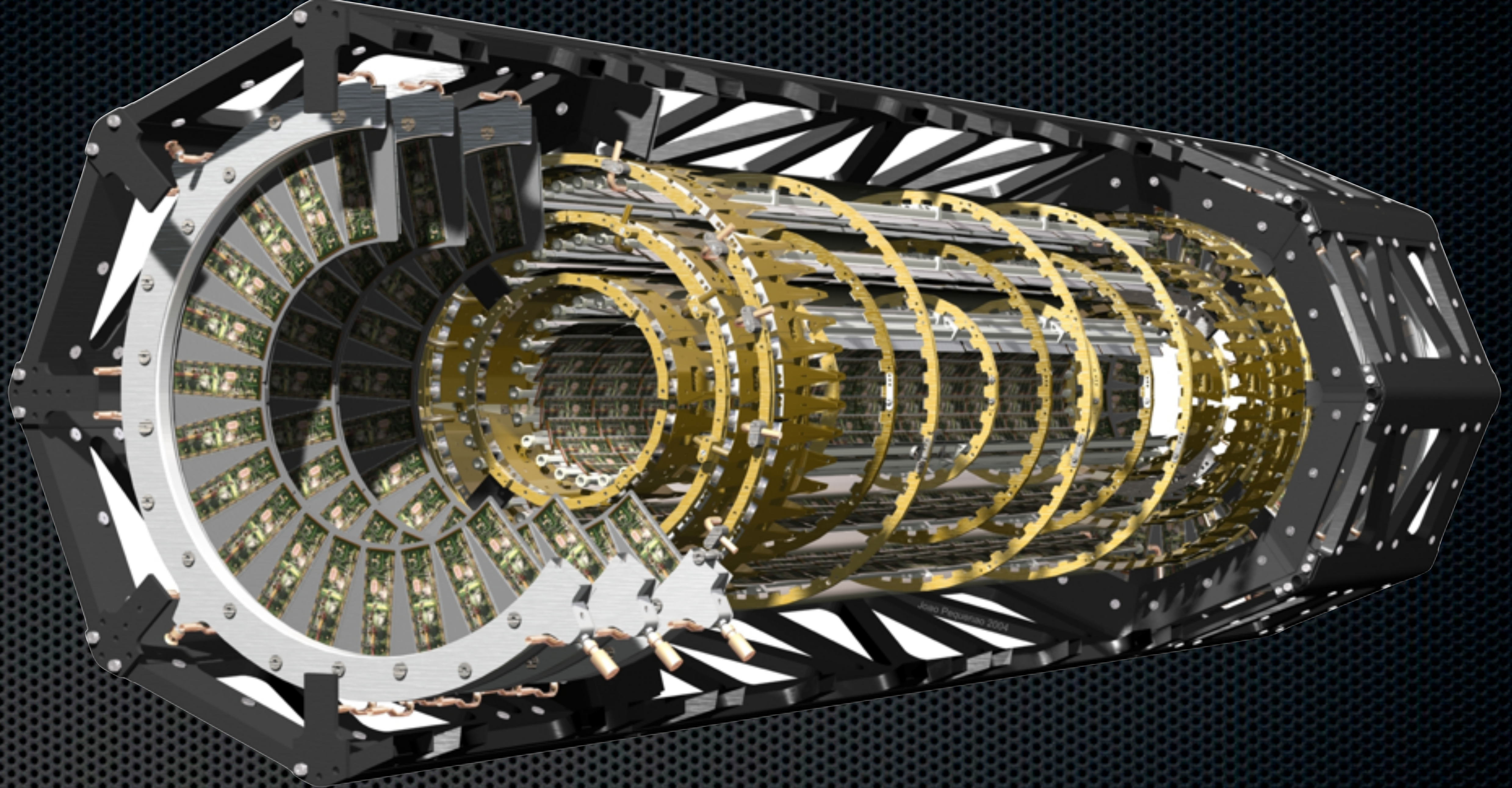
- We’re heading for TeV physics here, Objects are generally considered to be in the high GeV scale
  - Excellent P_t and E_t resolution is needed
- On average, 25 collisions are supposed to occur within a single crossing of bunches inside the experiment
  - Eventually even z-resolution (along the beam axis) is important, to help resolving multiple interactions

Onion Structures...



ATLAS



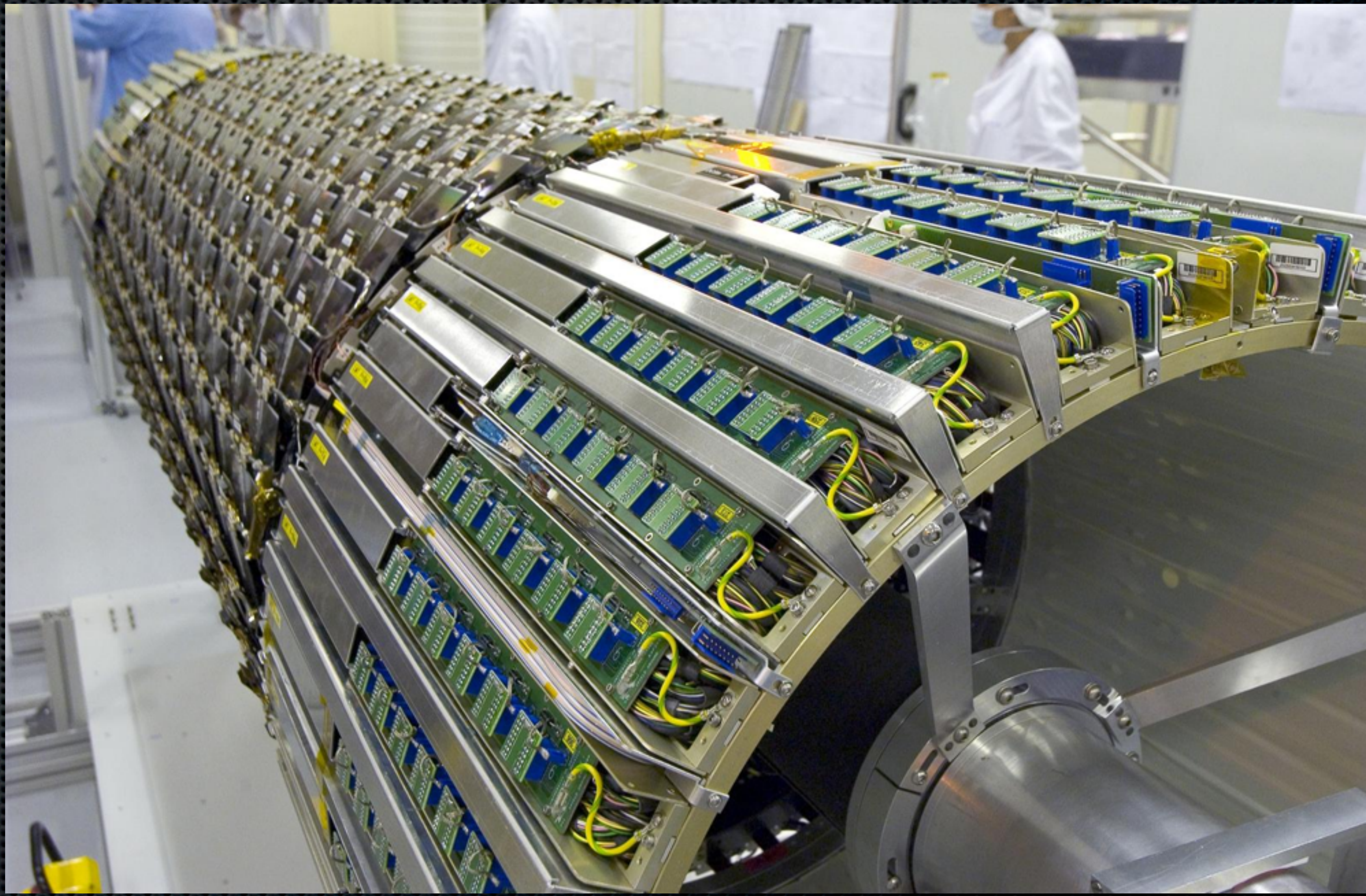


Pixel

- ~80M sensor units delivered in 1744 modules
- 40MHz real sampling rate, with 8bit charge resolution
  - Zero suppressed module produces O(10 Gbit/s)
- Carbon fibre support and cooling structure
  - Lightweight detector to not cause energy loss/multiple scattering
- Delivers 3 hits per track within |Eta| < 2.5

Semiconductor Tracker (SCT)

- ~6M channels in ~ 4k Modules
- Zero suppressed binary readout (above/ below threshold)
- At least 8 (4x2) strip hits per track

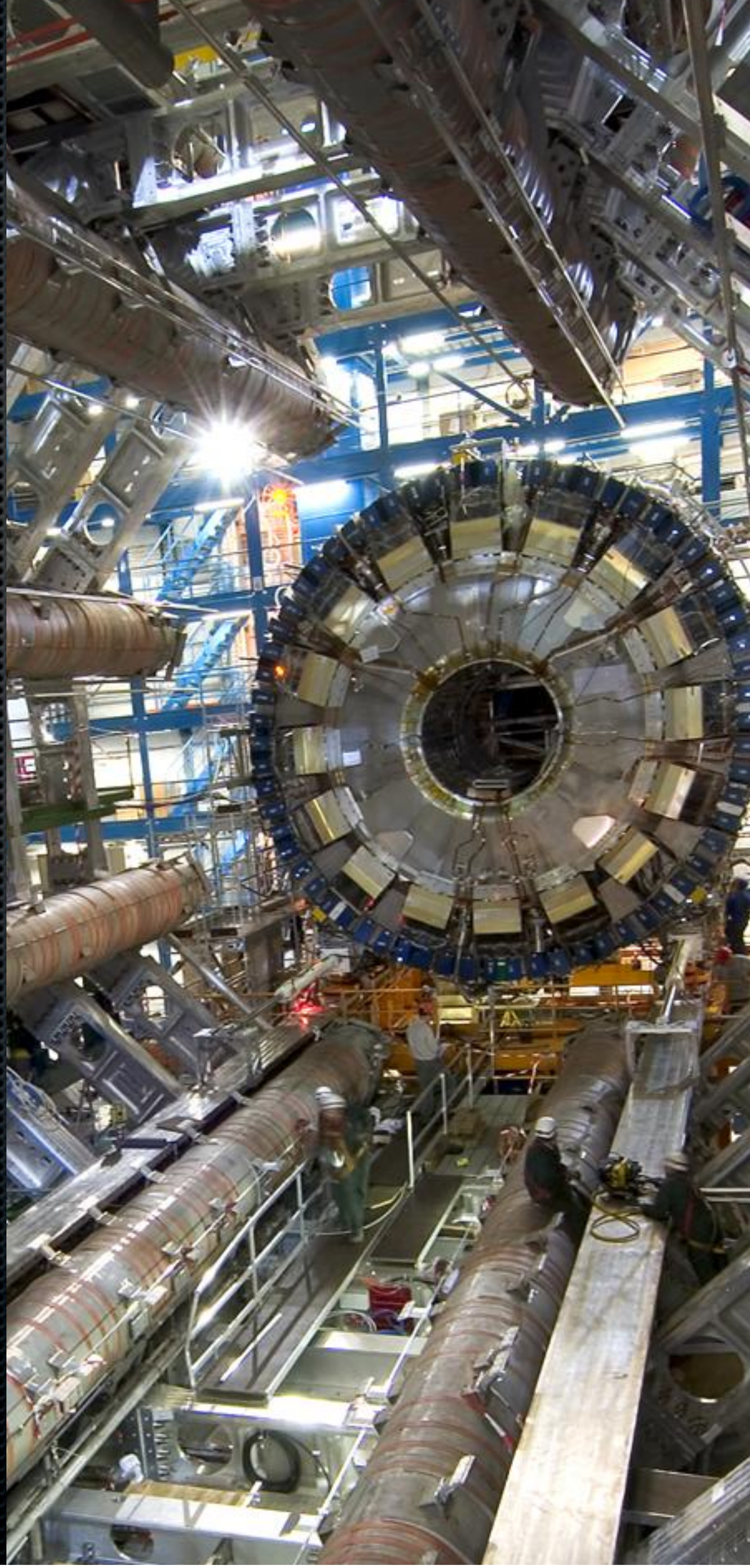


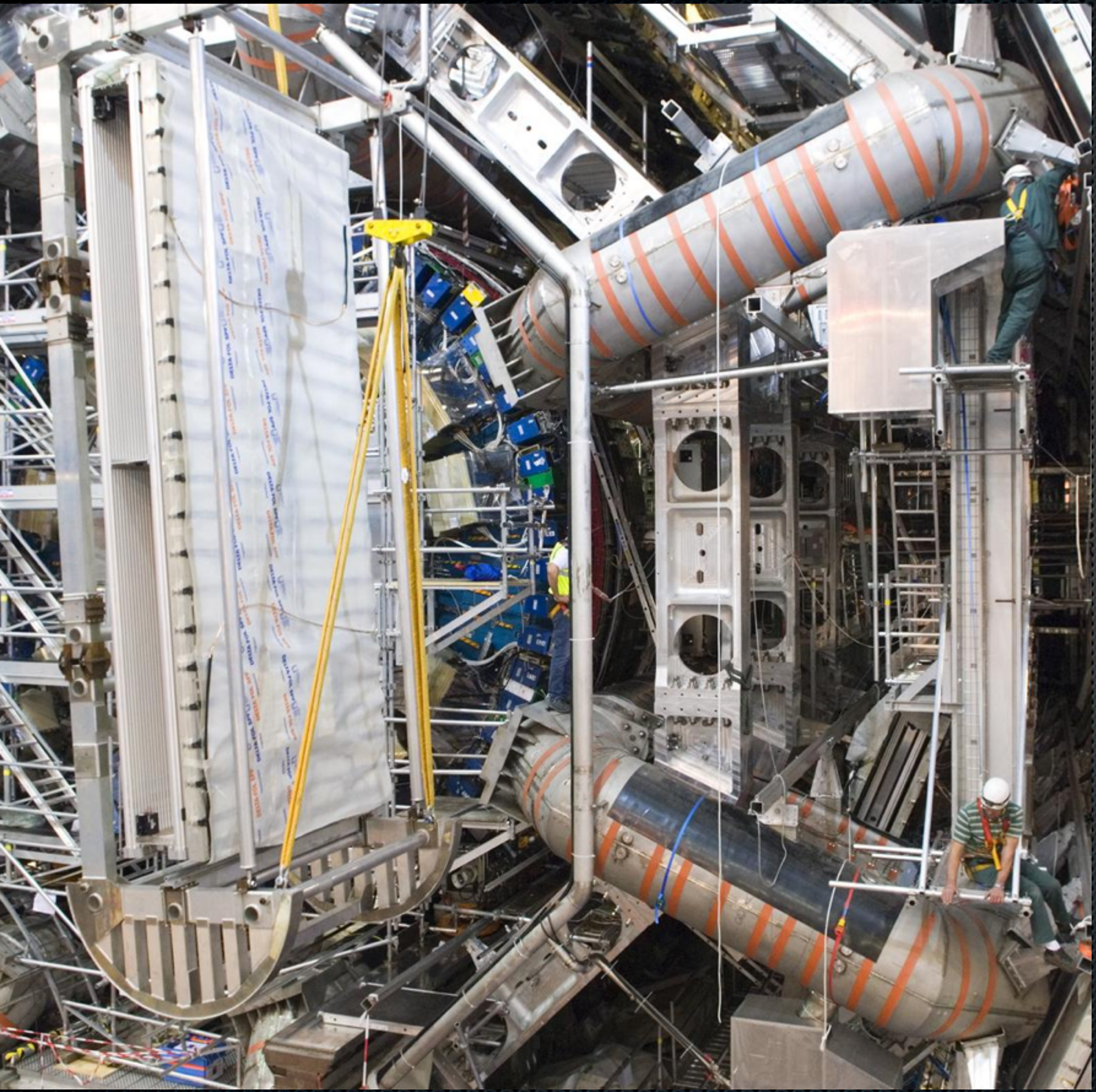
Transition Radiation Tracker (TRT)

- Straw tube extension of the tracker
- >36 (!) tubes hit per track
- Plastic foil to create additional transition radiation
  - Allows for separation of heavy over light charged particles
- Cheap....

Calorimetry

- Liquid Argon Calorimeter system for Electromagnetic calorimeter, as well as hadronic endcaps and forward calorimeter (FCAL)
- Different absorber materials, depending on calorimeter type and location
- Hadronic Barrel based on Steel Absorbers with interleaved scintillators
- Both systems with fast and slow readout structures (channel number O(10k)) to generate fast ***trigger*** as well as slow precision information



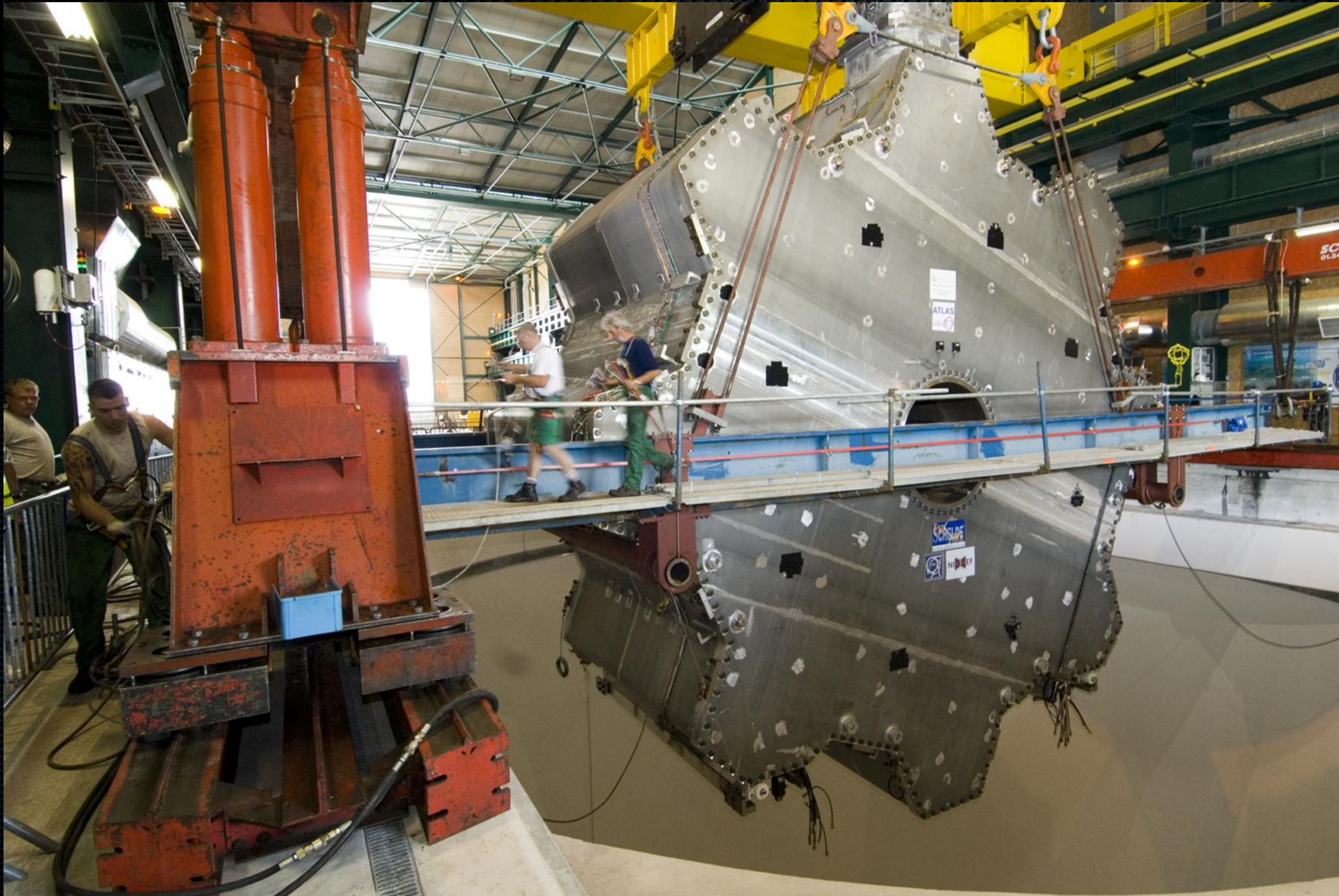


Muons

- Muon Spektrometer based on a total of 4 different types of muon chambers:
  - Monitored Drift Tubes - Precision measurement in Barrel and Endcap
  - Thin gap chambers + Resistive Plate Chambers for fast trigger Information
  - Cathode Strip Chambers for far forward signals (high occupancy)
- Precision up to O(TeV) muons
- Internal laser aligment system

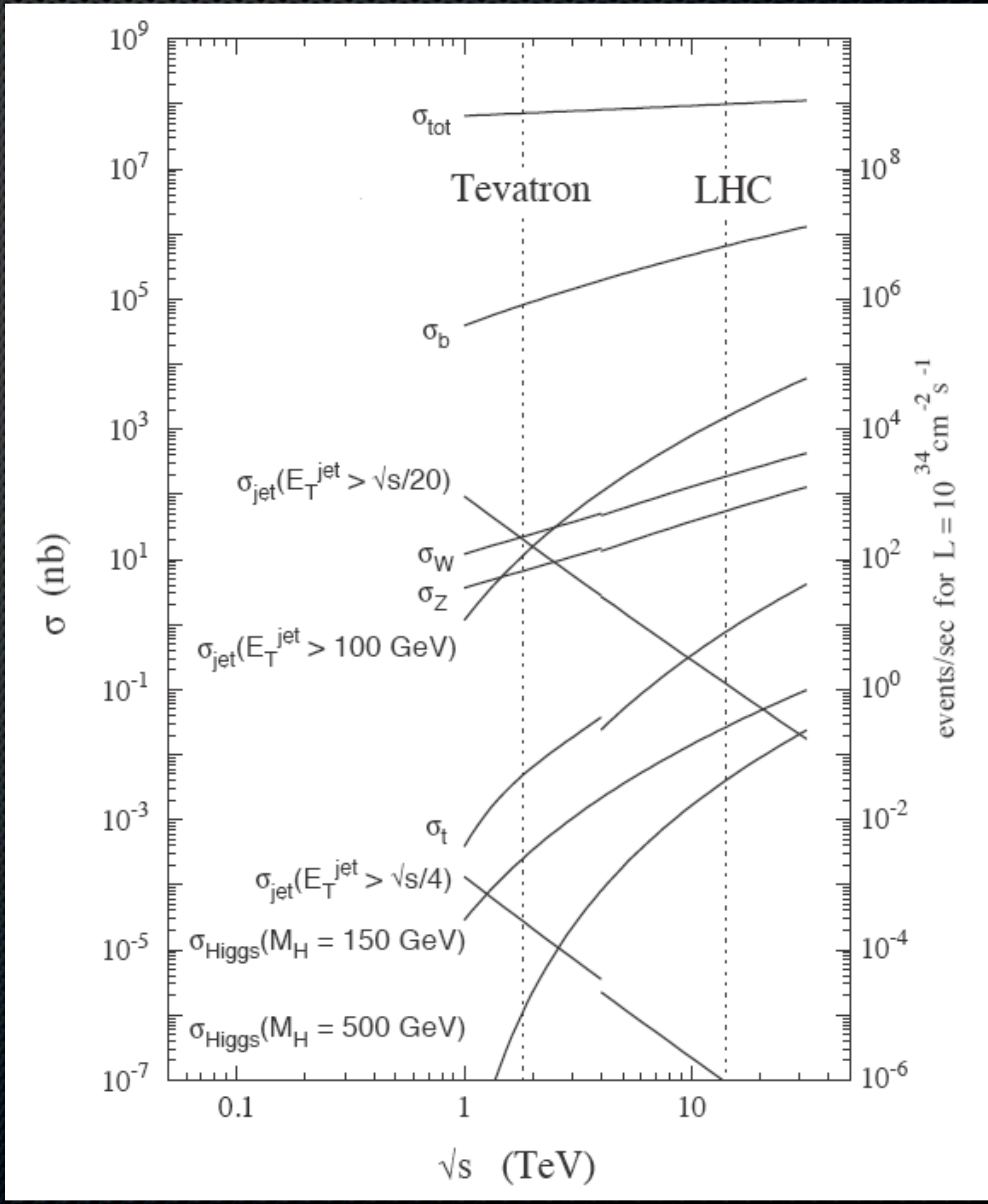
Magnets

- Solenoidal Magnet delivers 2T magnetic field along the full inner detector (7m long, 2m diameter)
- Torroidal magnet system allows for muon measurements, independent of the inner detector
  - Seperate measurements can be matched into “combined muons”
- Transition region has lower fields, hence the calorimetry system experiences less jet blowup


ATLAS

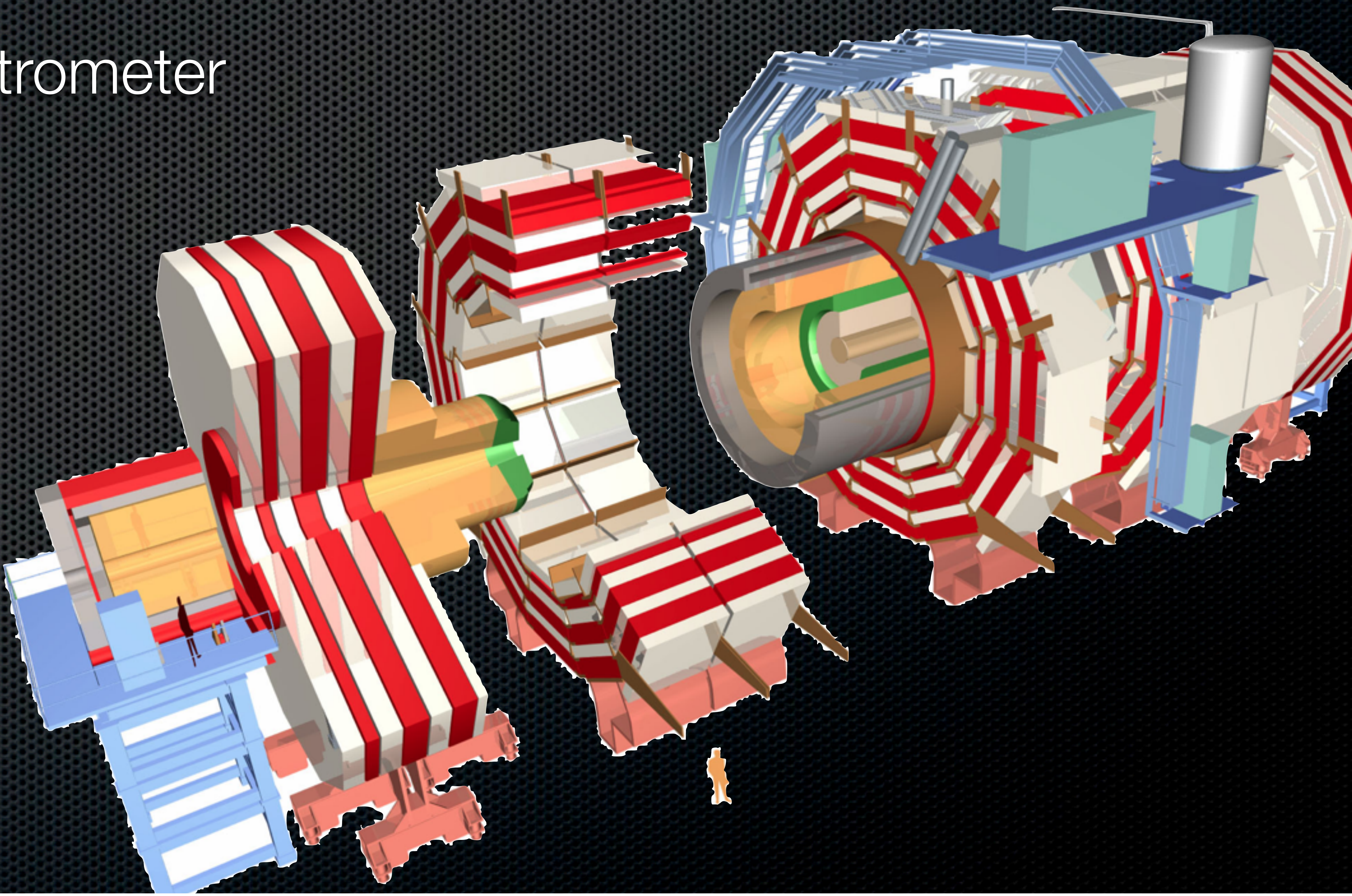
Triggering

- Sad, but true: We're not actually recording all data, ~31 MHz
- Fast/Coarse systems allow to quickly characterise all events and sort out interesting from uninteresting ones - Level 1, 75kHz
- Reading out all detector data, we analyse part of it around Level 1 Trigger objects (e.g. a fast muon) - Level 2, O(2kHz)
- Eventually all surviving events are fully analysed to search for interesting Objects - Level 3, O(100Hz)
- Data selected in the last stage is then written to disk ... tape actually



A word on our little brother

- Compact Muon Spectrometer
- Twice our weight
- ~Half our size, in all dimensions
- Functional Concepts equal in most matters

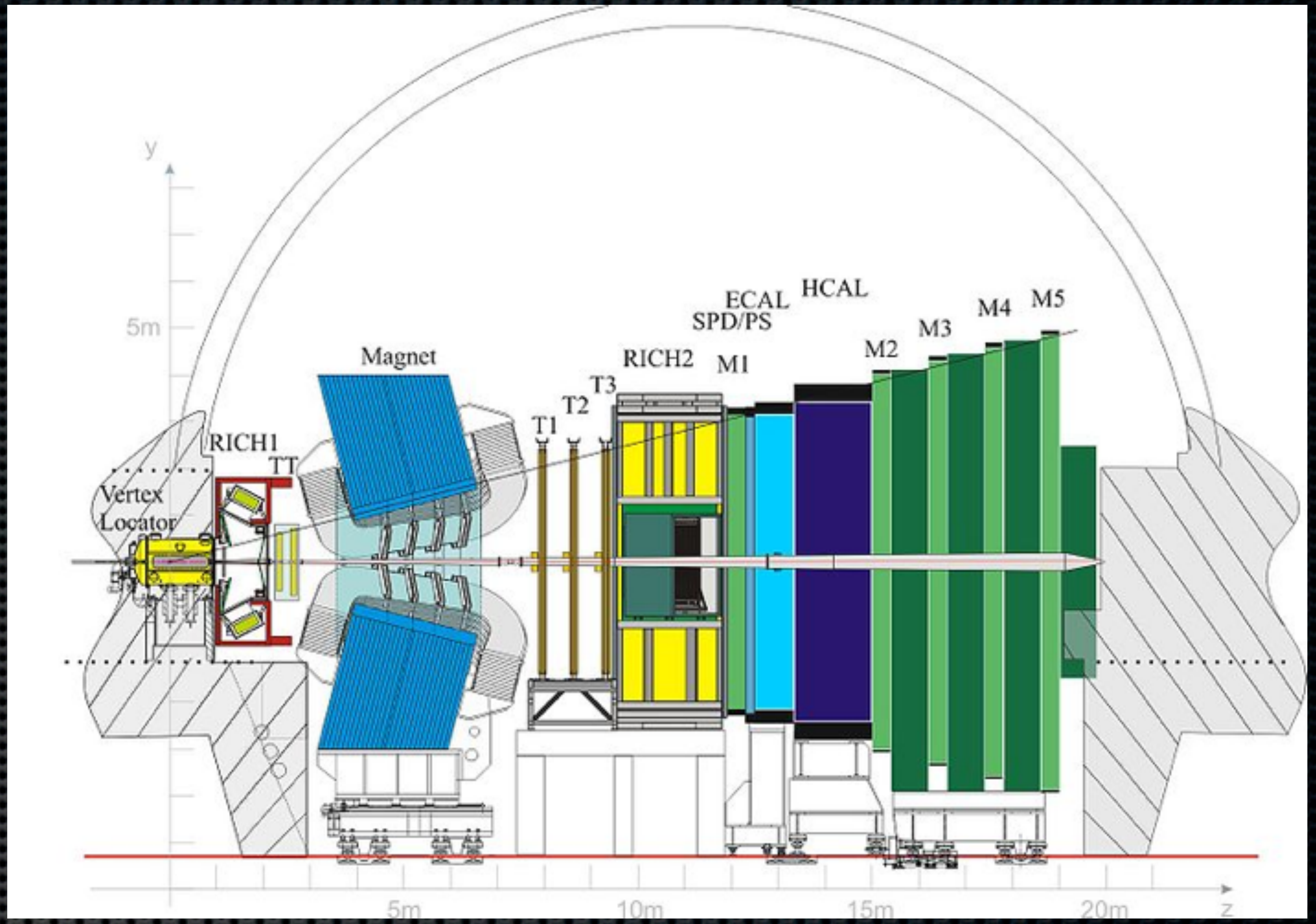


Conclusions?

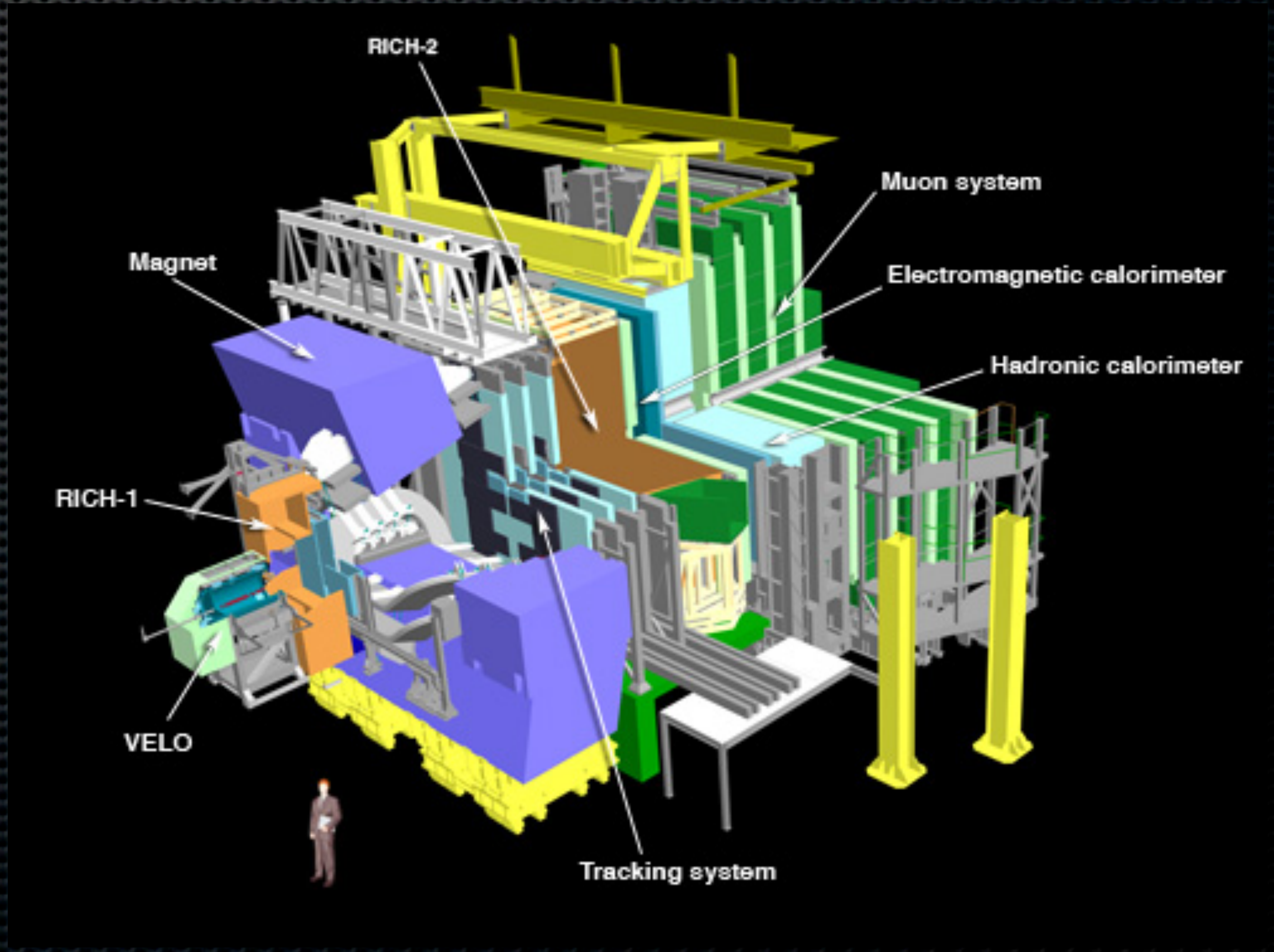
- Building Detectors to measure about 25 Proton-Proton Interactions with a rate of ~30 MHz is not easy
  - General Detector Structure is simple: tracker, calorimeter, muons - and it needs magnets
  - Not all data can be recorded, yet we don’t need it all. Different subsystems help sorting the known stuff out and seeing the unknown...
- Questions?

Backup... (More things)

Different Detectors

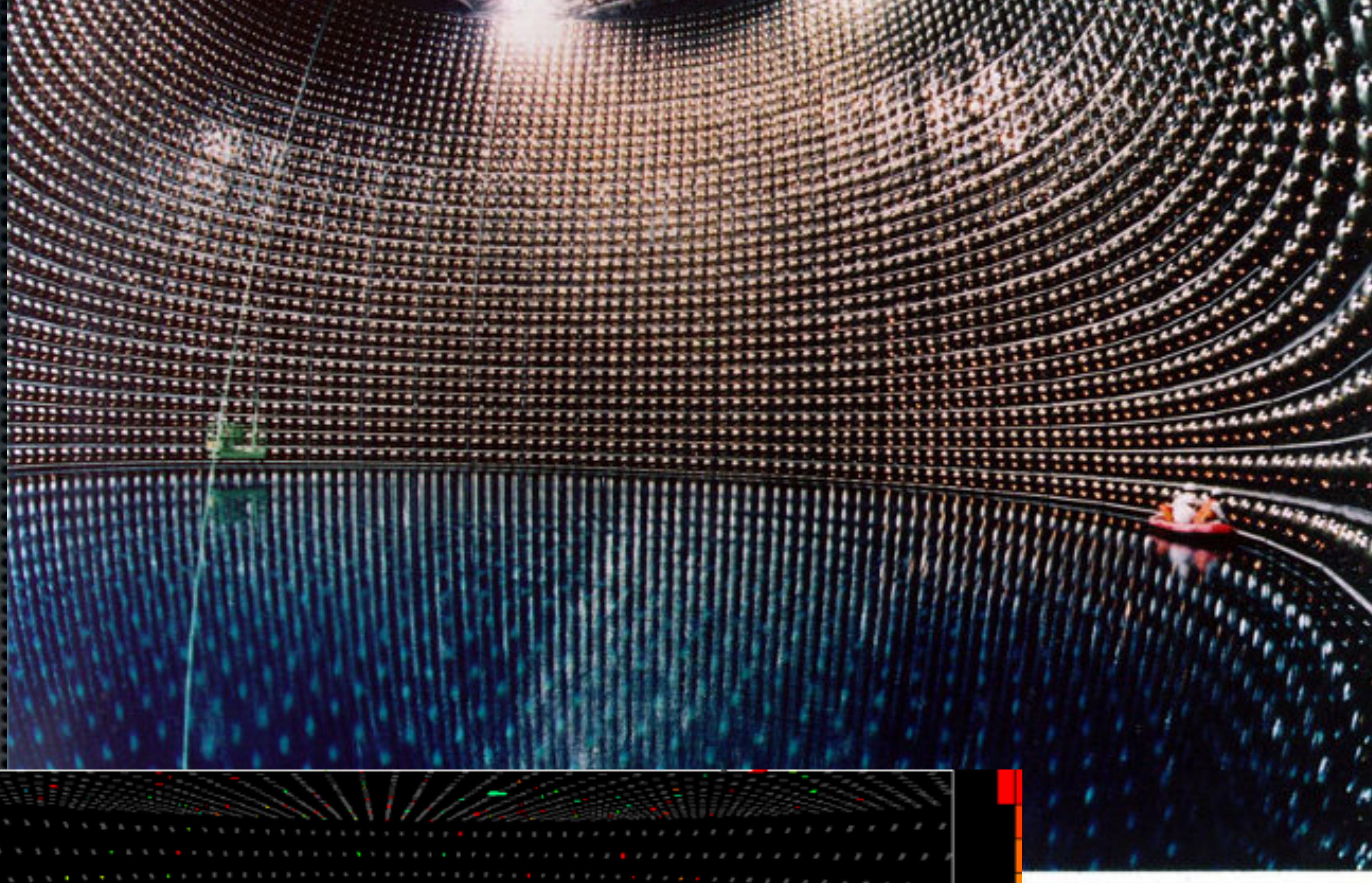


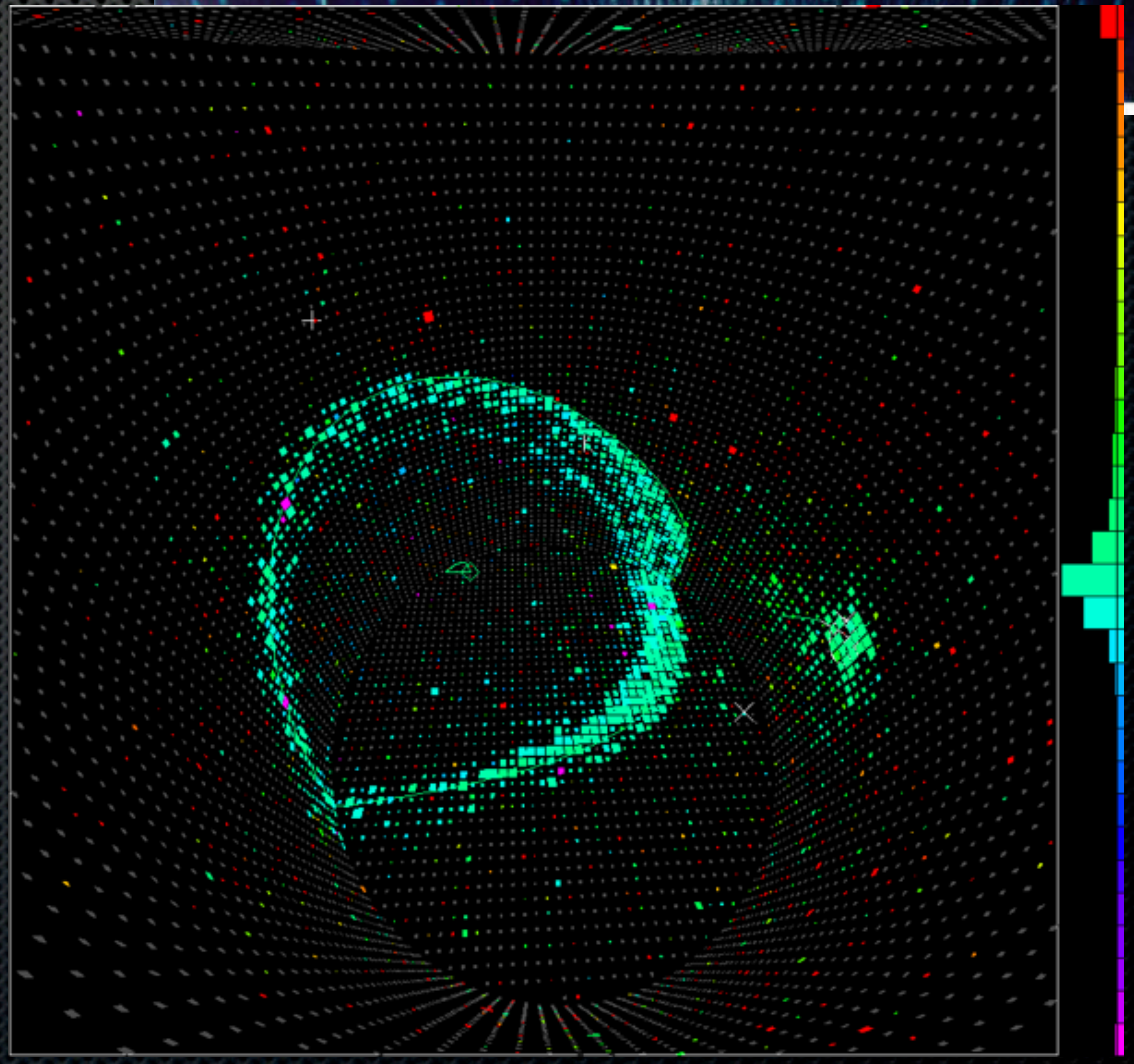
- Not all detectors are SM 4pi HEP detectors...
- LHCb works on forward physics, measuring matter/antimatter asymmetries



Different Detectors

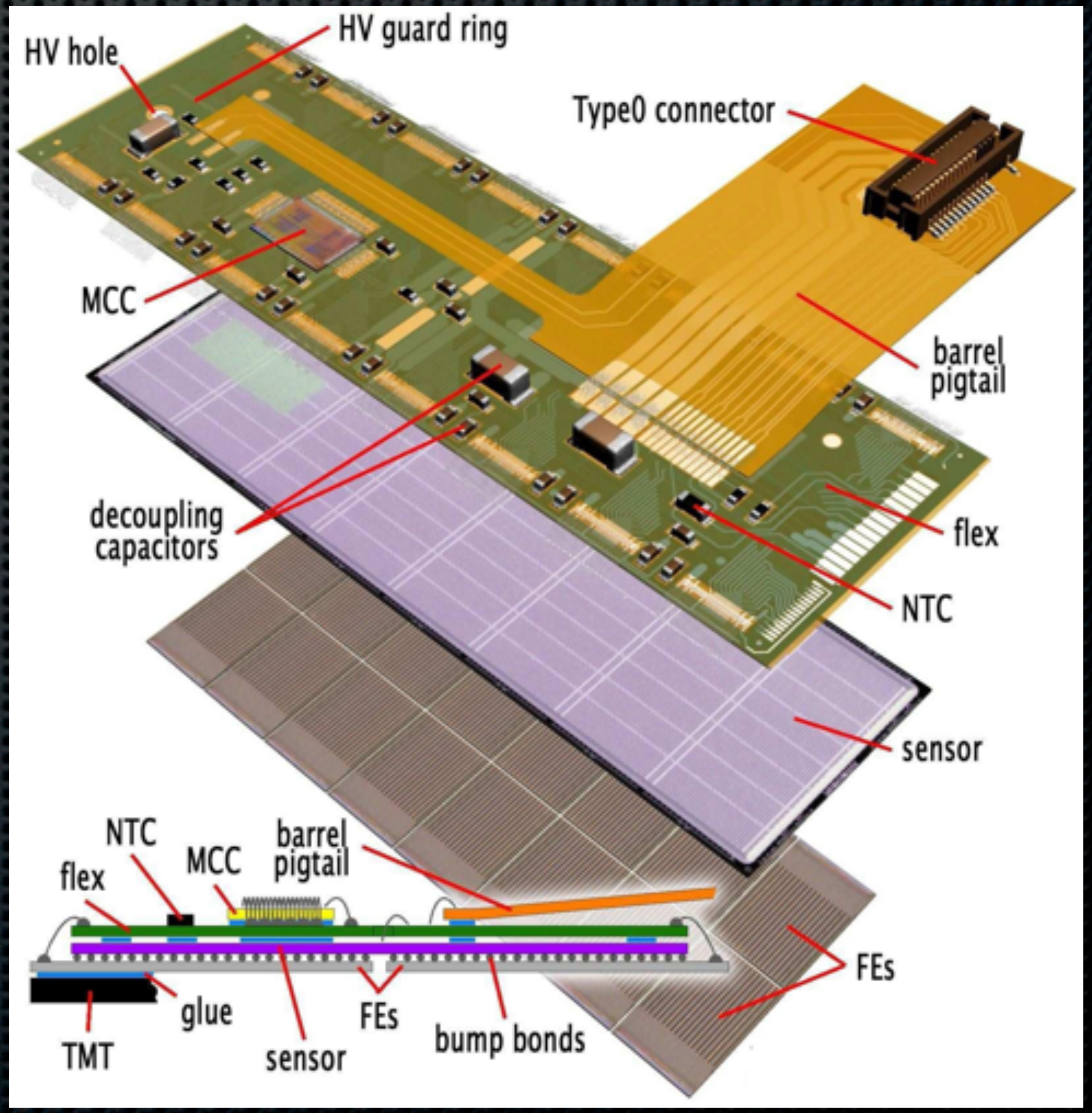
- Neutrino Detektors with higher volumes and masses than both ATLAS and CMS
- Detector structure as such is simple thus, as can be seen at right
- Be warned, understanding data is all but simple





ATLAS Pixel

- Each Module delivers 46k Pixels
- Slight overlap between Modules in all directions allows no escape of particles
- Pixel detector weight - 4.4kg
- Each module is supplied individually
- Total Detector bandwidth: ~132 Gbit/s



How to install

- Full system was built/finished in SR-1, just aside of ATLAS
- All modules have been fully tested and some flaws on the detector were corrected before installation
- The services available to test the detector are now integrated into a ~5% system test, which allows for developing software and analysing problems observed during operation
- Detector was tested for functionality during installation as well
- Full installation took from insertion summer 2007 to cosmic commissioning in summer 2008 (with a large break to allow the other detectors to install their cables)