Lecture 7 – Detectors - I

Early Techniques

Collider Detectors

Solenoidal Field

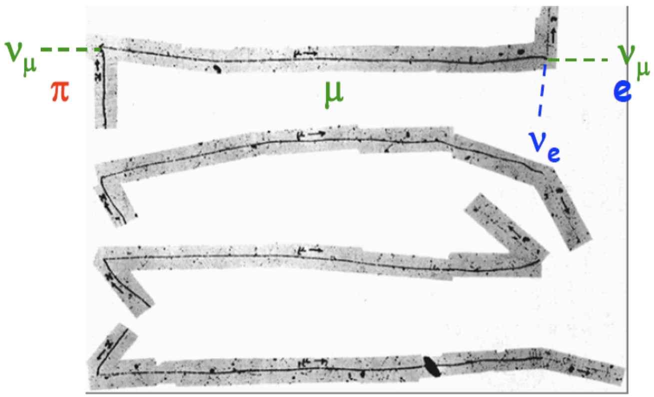
Tracking

Drift Chamber

Silicon Detector

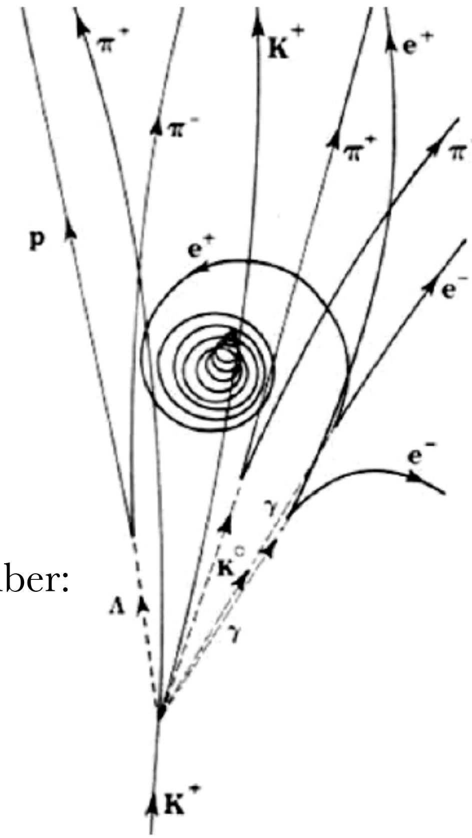
Introduction to Particle Physics - Max Klein – Lecture 7 - Liverpool University 17.3.14

Early Techniques

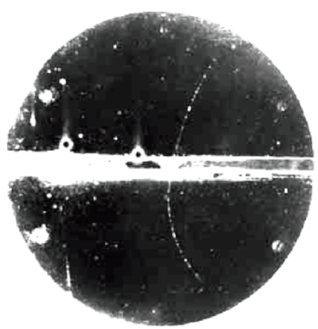


Emulsion: silver halide crystals in gelatine ($\pi^\pm$,$K^\pm$, ..)

The Study of Elementary Particles by the Photographic Method
C.Powell, P.Fowler, D.Perkins, Pergamon, London 1959



Bubble chamber:
ionisation in superheated liquid (Σ^0,Ξ^0..)



Cloud chamber: ionisation in cloud (e^+, $\mu^\pm$, K^0,..)

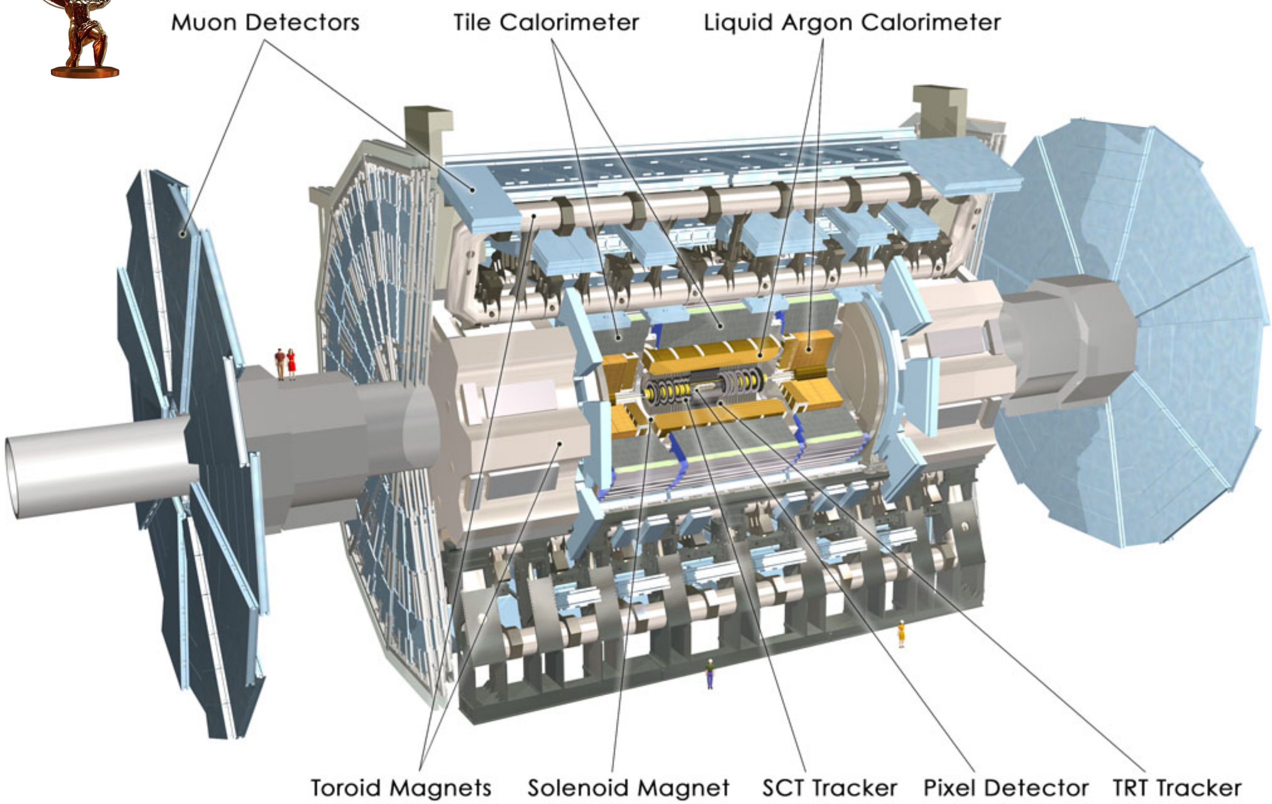
photographic techniques
not triggerable
small active volumes
→small event rates

M, p, Q from ionisation and curvature in magnetic field

A.Bettini, Introduction to Elementary Particle Physics, Cambridge, 2008

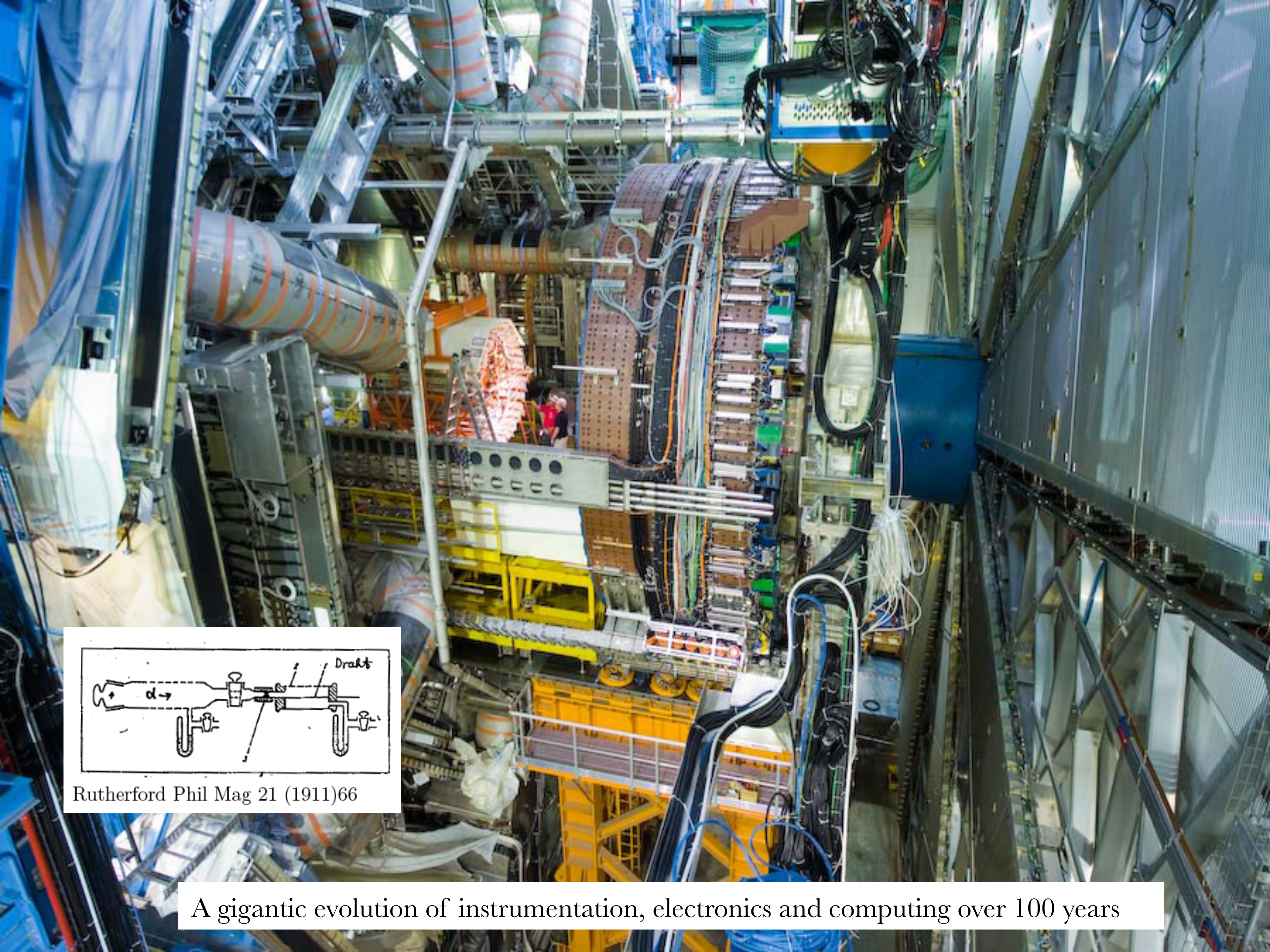
A now famous detector: ATLAS

Design 92-97
R&D 94-02
Construction 99-08
Operation 08-33(?)



High energies are nowadays achieved with colliders.
Full (4π) acceptance is crucial for searches for new particles.
This determines the by now classic detector structure,
at LEP, HERA, Tevatron, now the LHC as for future colliders.

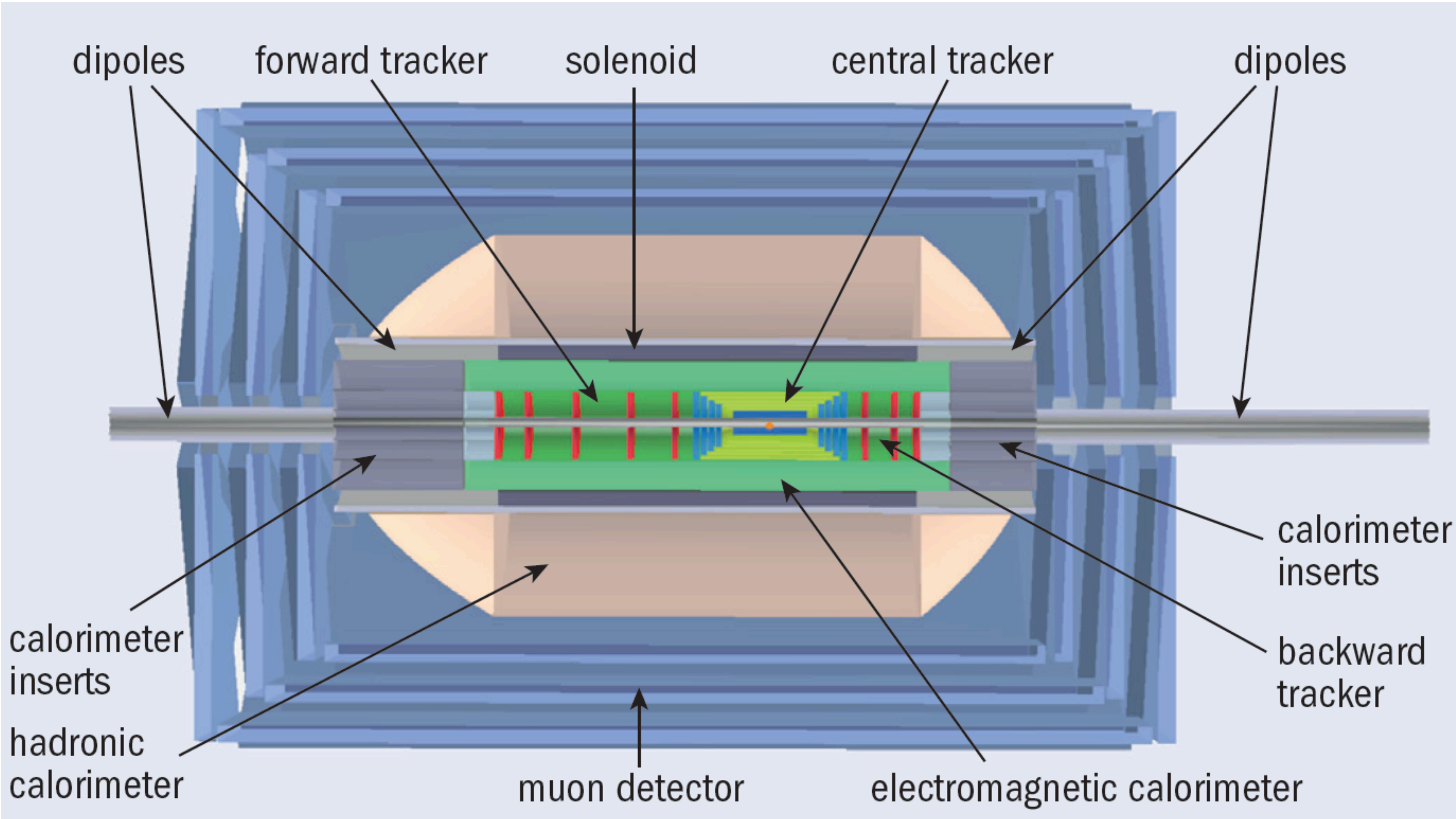
ATLAS: global collaboration of ~ 200 institutes and ~3300 physicists and engineers to explore the physics at the accelerator energy frontier.
Detector: housed 100m underground in cavern 25m x 45m D x Z, 7000t, 10^8 channels, 3000 cables



Rutherford Phil Mag 21 (1911)66

A gigantic evolution of instrumentation, electronics and computing over 100 years

A detector under design



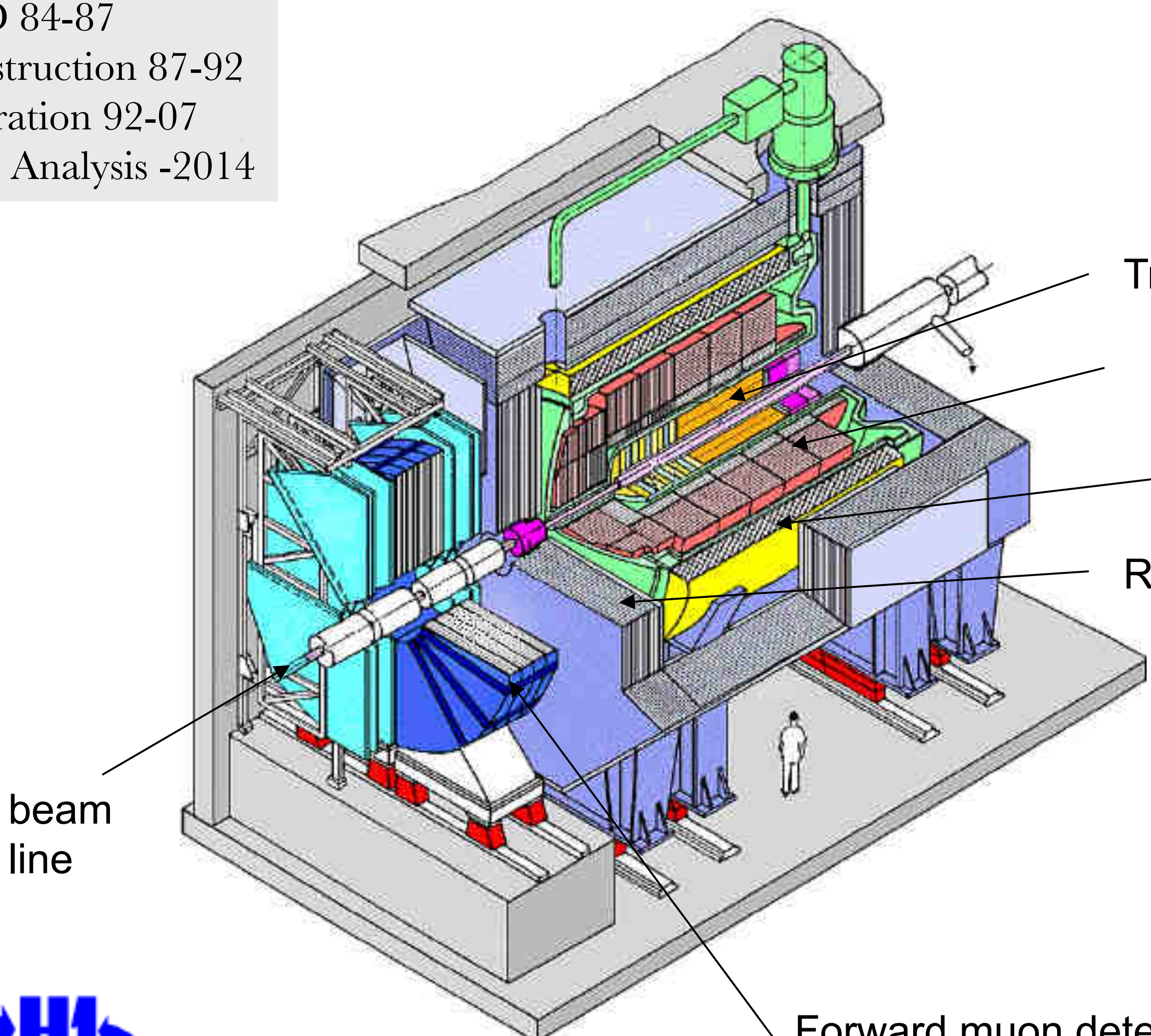
Muon detector: ID with few detector planes, no momentum measurement – unlike ATLAS

Detector dimensions: 9m diameter,12m length

H1 Detector at HERA

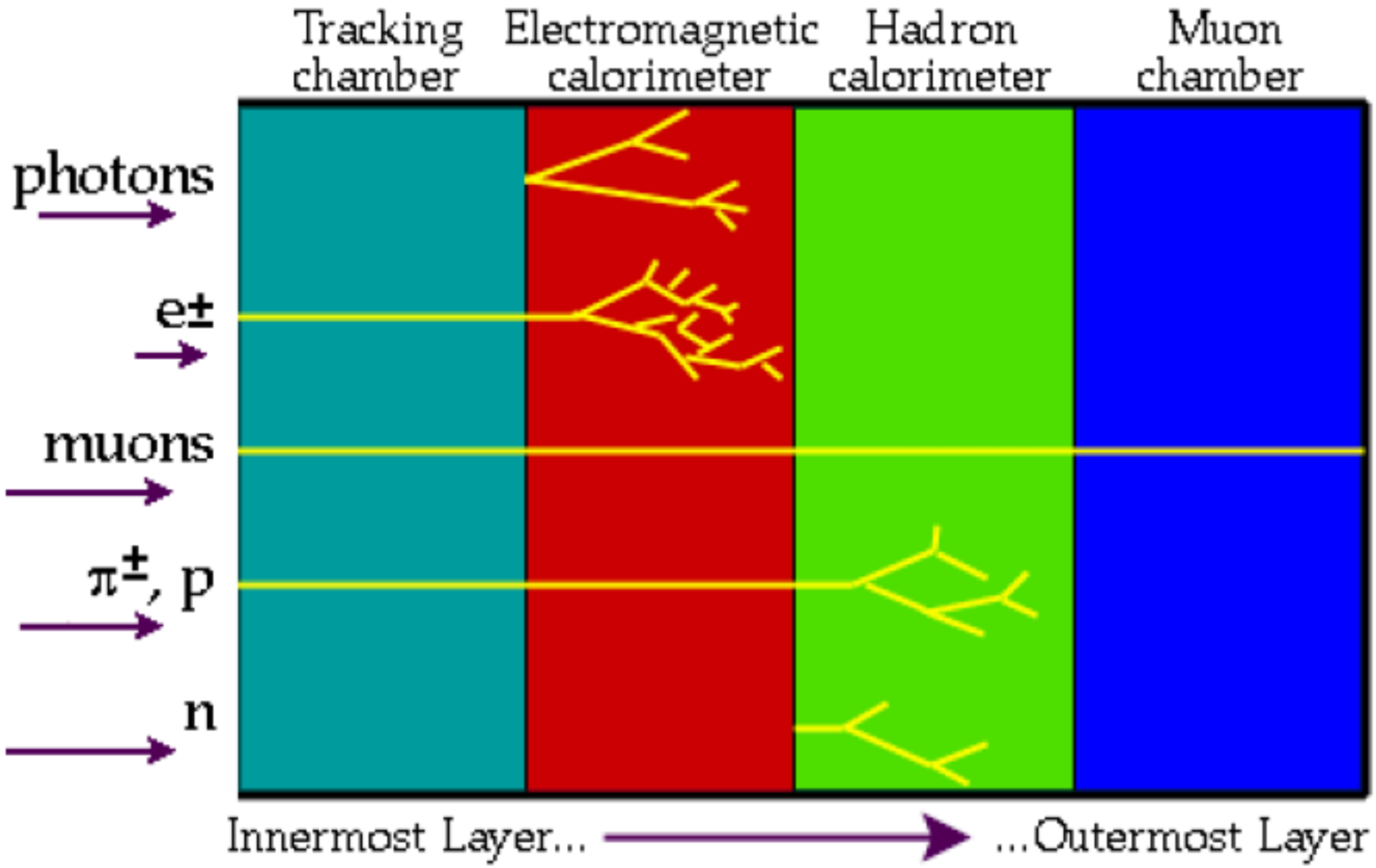
Design 83-85
R&D 84-87
Construction 87-92
Operation 92-07
Data Analysis -2014

electronic techniques
triggerable
large active volumes
→huge event rates



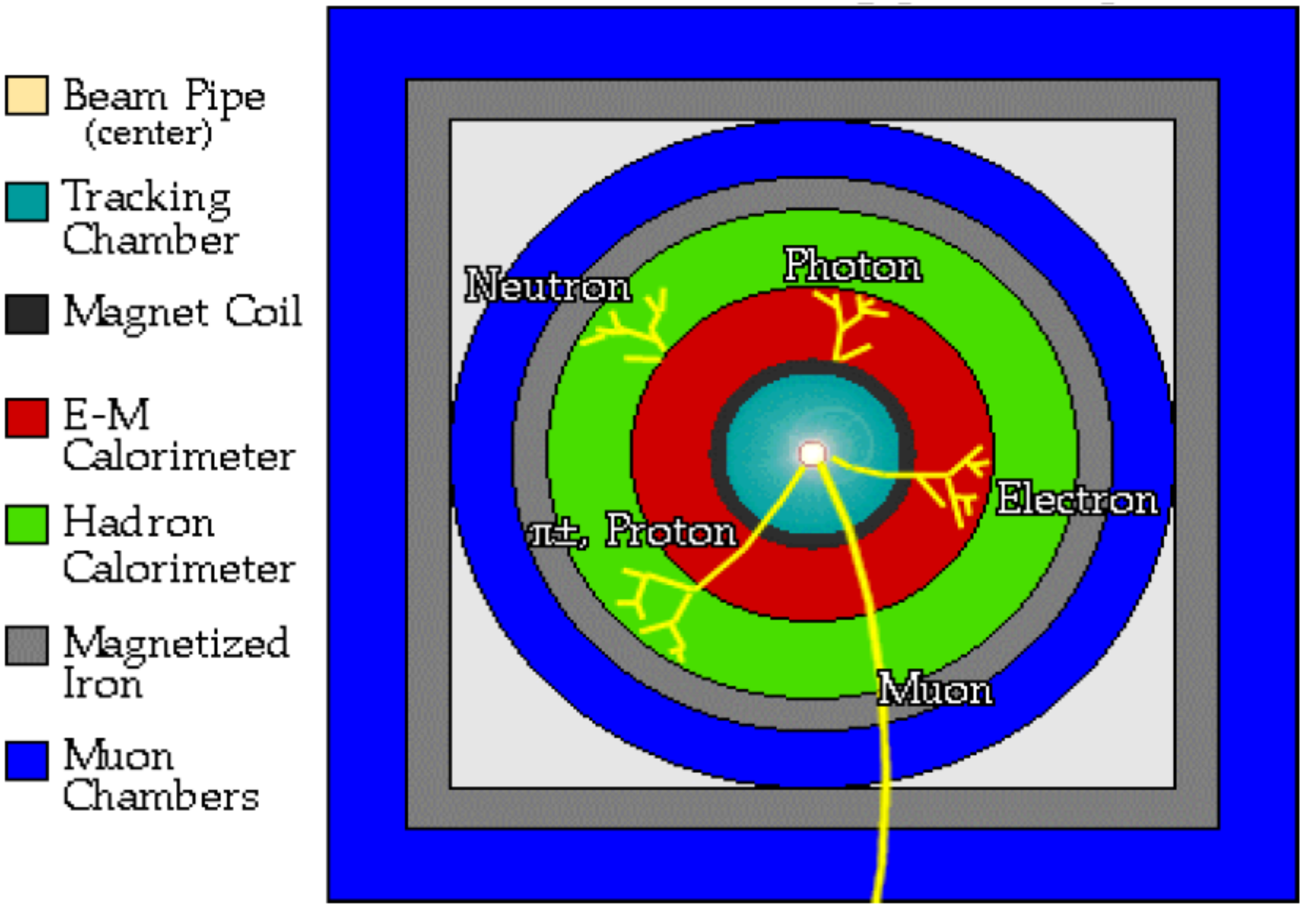
350 Physicists
100 PhD students/year
100 Engineers
40 Institutes
130 Publications

Particle Identification



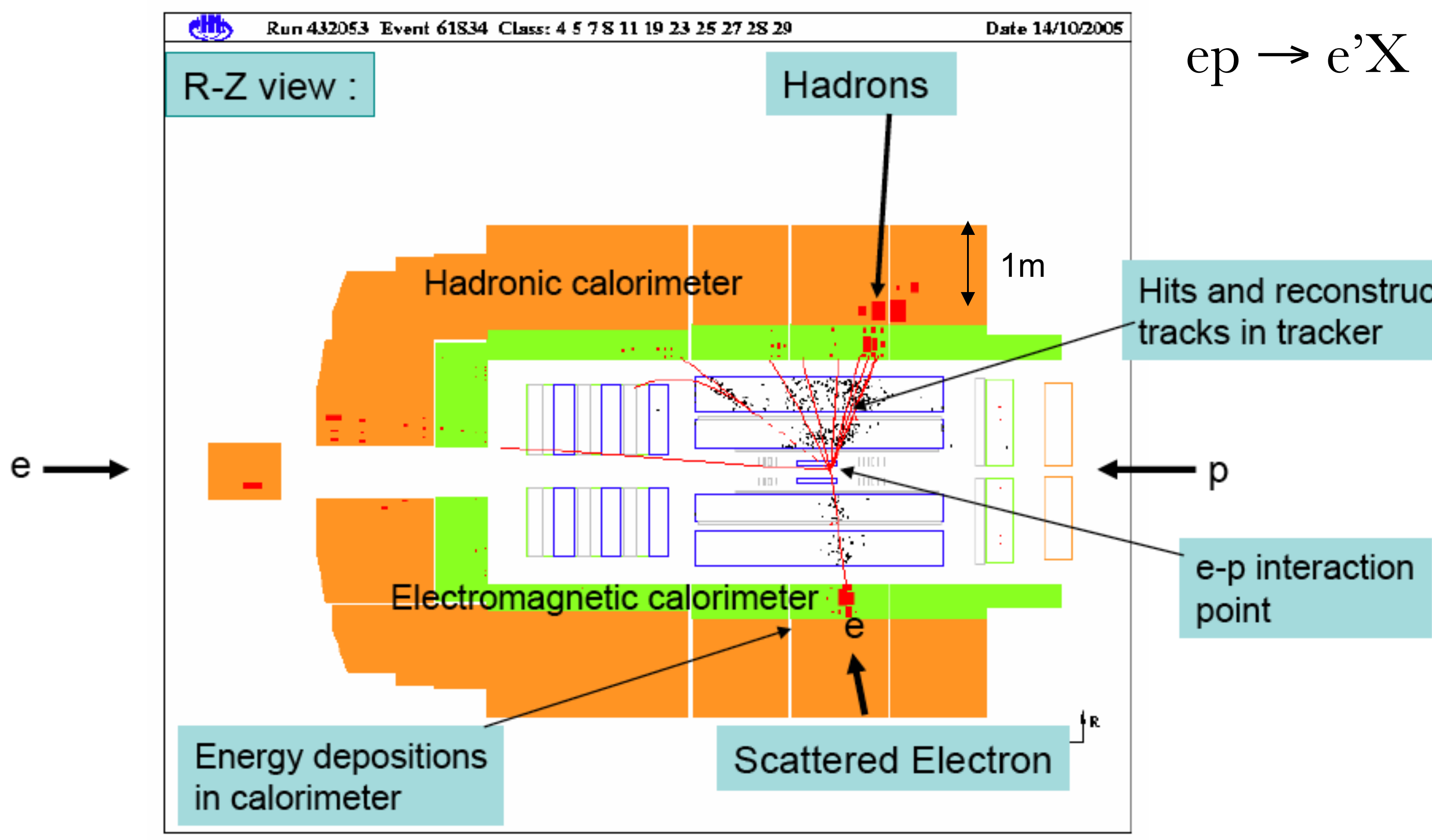
ν neutrino carries energy away ("missing E") **-- Hermetic Detector!**

Particle Identification



Deep inelastic scattering event in H1

$ep \rightarrow e'X$



The same event in xy view

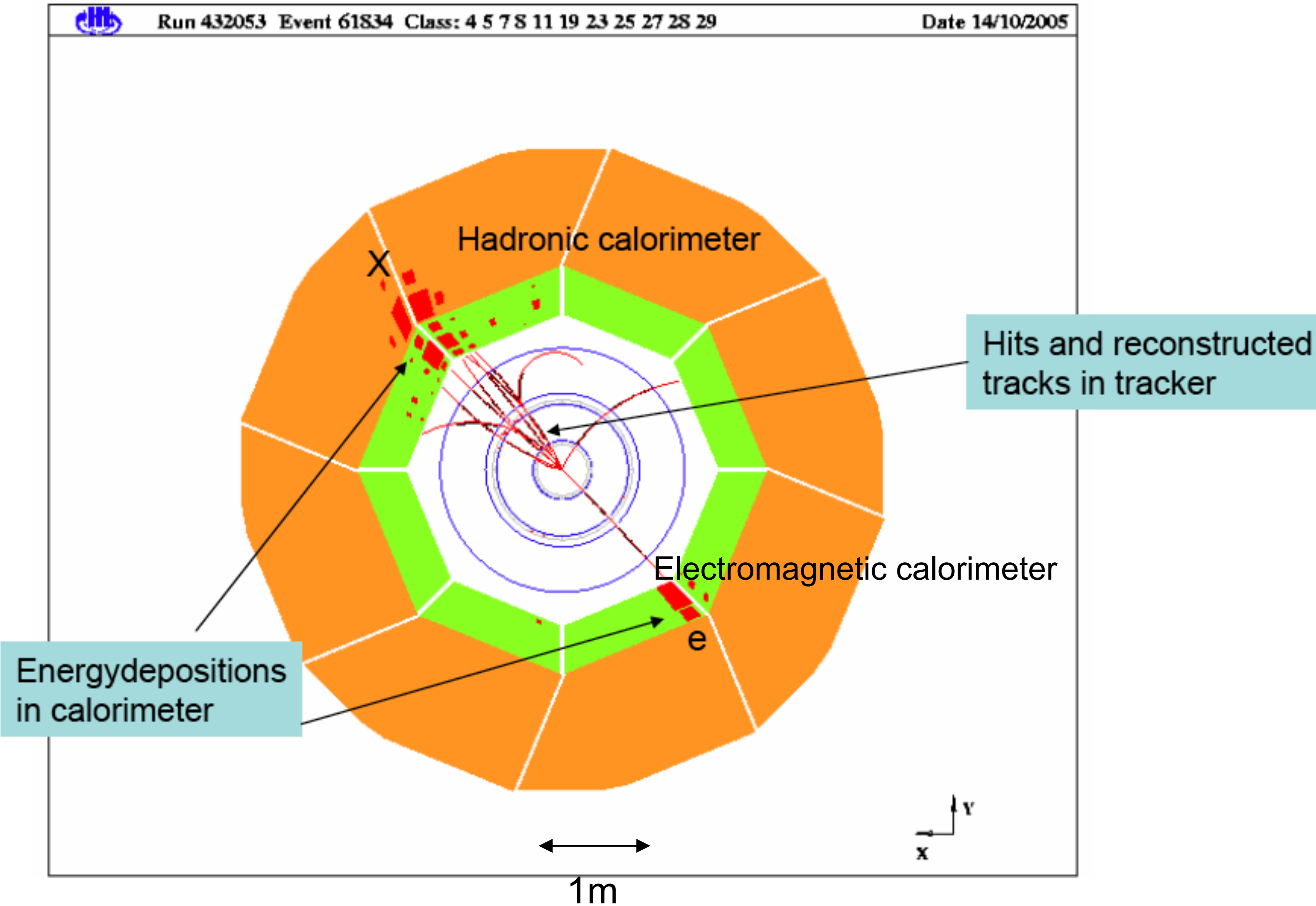
$$ep \rightarrow e^{'}X$$

soleniodal magnetic field bends charged particle tracks.

transverse momentum conservation: e-h back to back

Electron deposits full energy in elem. Calorimeter

hadrons deposite all energy in elem and subsequent hadronic calorimeter [cf detectors – II]



Momentum Measurement

Lorentz force

$$\vec{F} = q \cdot \vec{v} \times \vec{B}$$

$$F = qvB\sin(\vec{v},\vec{B})$$

In solenoidal field:
transverse motion
perpendicular to B:

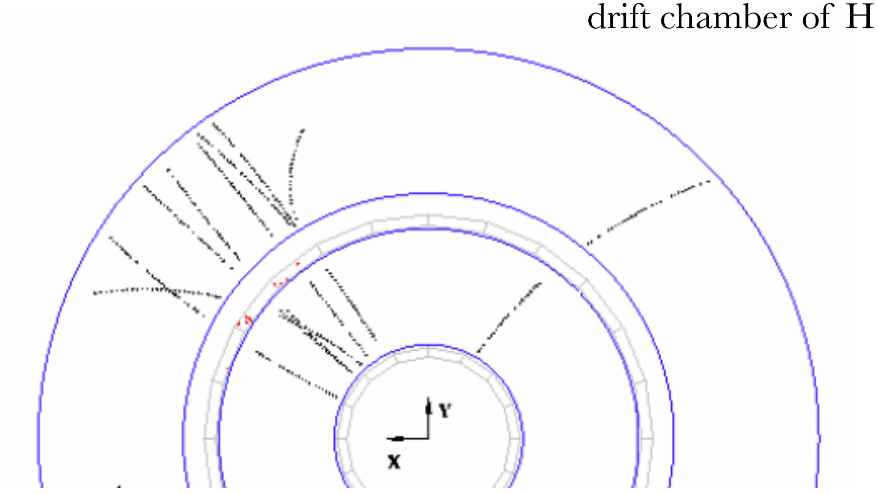
$$F = qvB = \frac{mv^2}{r}$$ centrifugal force

$$mv = p_T$$

$$p_T = 0.3 \cdot B \cdot r$$

[GeV] [T] [m]

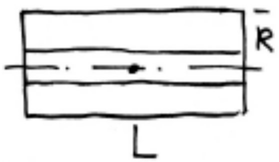
Tracks in the central drift chamber of H1



Charged particles ionize gas of a tracking chamber: the ionisation is detected on wires and the track is reconstructed using the drift time information. Hits are found to be on a curved track - in the plane transverse to the beam, i.e. the solenoidal field. The curvature is the larger the smaller the transverse momentum, p_t , of the track is.

Solenoid - Magnet

Magnetic field parallel to the beam axis



$$B(0,0) = \frac{\mu_0 \cdot W \cdot I}{\sqrt{L^2 + 4R^2}} \approx \mu_0 \cdot w \cdot I$$

Stored energy

$$E = \frac{1}{2\mu_0} \cdot \int B^2 dV$$

$$E \cong \frac{1}{2\mu_0} \cdot \pi R^2 \cdot L \cdot B^2$$

Keep dimensions small to keep cost down.

Try to arrange the magnet to contain the calorimeter

$L = 5.7m$

$W = 1683$

$R = 0.96m$

$I = 10kA$

$\mu_0 = 4\pi \cdot 10^{-7} N \cdot A^{-2}$

$B = 3.5T, [T = \frac{N}{Am}]$

$E(LHeC) \approx 80 MJ, [J = Nm]$

$prize \sim \frac{1}{2}(E / MJ)^{0.66}$

$\sim 9 Mio US\$$

LHeC

H1: L=5.7m, R=3m, I=6kA,W=1238, B=1.13T, E=100MJ

Tracking

$$s = r_2 - (\frac{r_3 + r_1}{2}), \delta r = \Delta$$

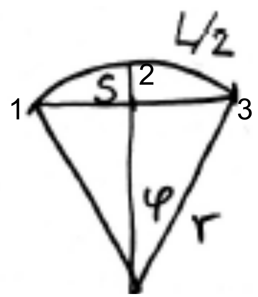
$$\delta s = \Delta \sqrt{\frac{3}{2}}$$ "triple sagitta"

$$\frac{\delta p_T}{p_T} = \frac{\delta s}{s} \approx \frac{p_T}{0.3BL^2} \Delta \cdot 8 \sqrt{\frac{3}{2}}$$

$$f = \sqrt{\frac{720}{N+4}}$$

R.Glueckstern, NIM 24(1963)381

s = sagitta



$$s = r - r\cos\frac{\varphi}{2} = r \cdot 2\sin^2\frac{\varphi}{4}$$

$$s = \frac{r}{8}\varphi^2 = \frac{L \cdot \varphi}{8}$$

$$\varphi = \frac{L}{r} = \frac{0.3 \cdot B \cdot L}{p_T}$$

$$s = \frac{0.3 \cdot B \cdot L^2}{8 p_T}$$

$$\frac{\delta p_T}{p_T^2} = \frac{\Delta}{0.3BL^2} \cdot f$$

→ small Δ, high field B, large L (+ 'no' material)

$$CST : \frac{\delta p_T}{p_T^2} := 5 \cdot 10^{-4} GeV^{-1}$$

$$B = 3.5T, \Delta \approx 10\mu m, N = 9, L = 0.4m$$

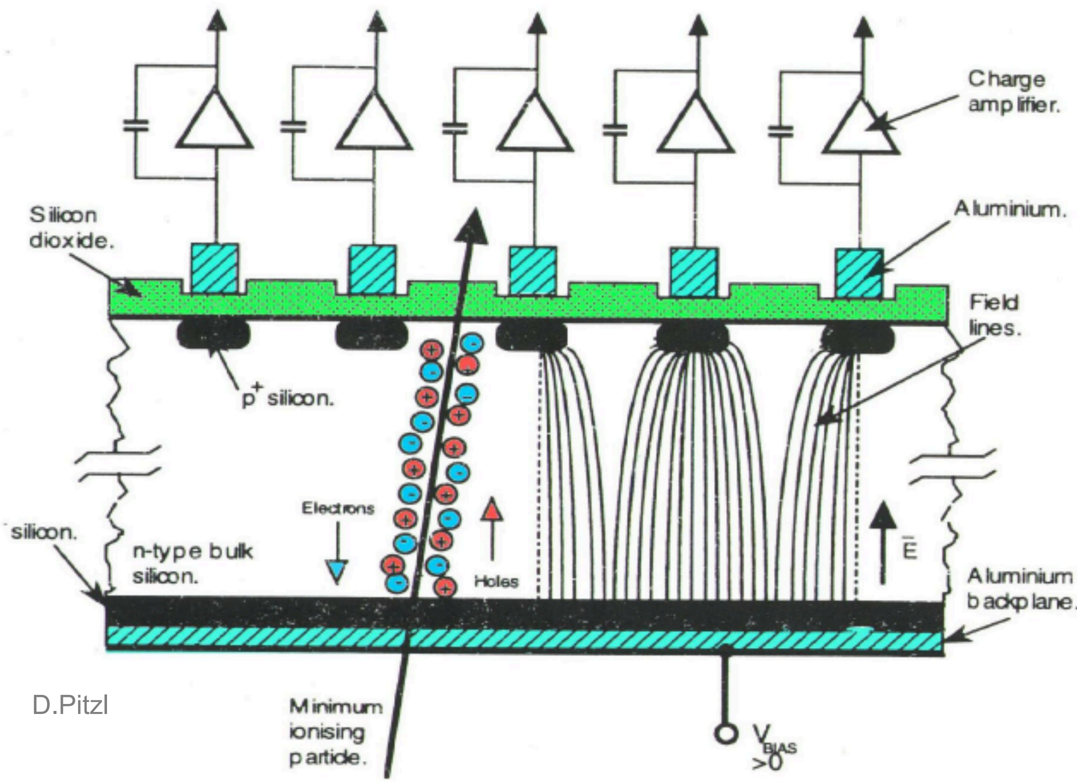
LHeC

Given the desired momentum resolution, the field, the point resolution and the number of layers, the radial extension of the tracker is fixed to be ~0.5m

[note clash in notation: r is the radius of curvature, L is the track length, which in a solenoidal field determined the radial extension of the tracking detector ..]

Silicon Detectors

“p in n”



Planar sensor from pure Si wafer segmented with implants (pn)

Strip pitch p~50μm,δ≈p/√12
Resolution worsens with inclination

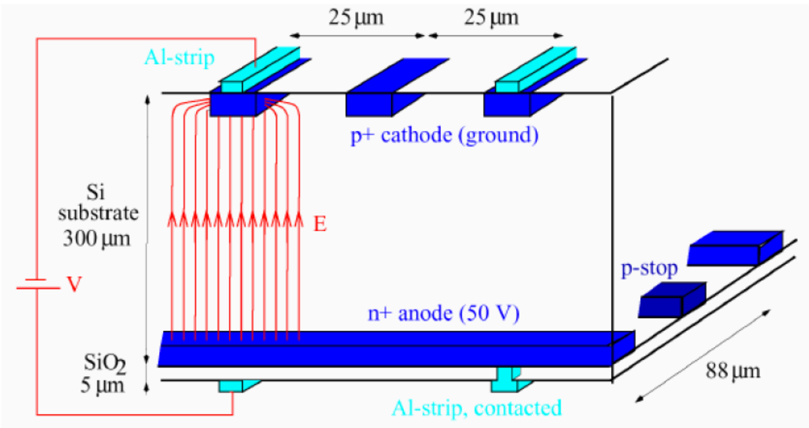
Bulk Si ‘depleted’ by reverse bias V
Ionisation creates e-h pairs
e (h) drift time 10 (25) ns

Charge amplified for strip
Pedestal defined by random noise
…
Visit ground floor at “Oliver Lodge”

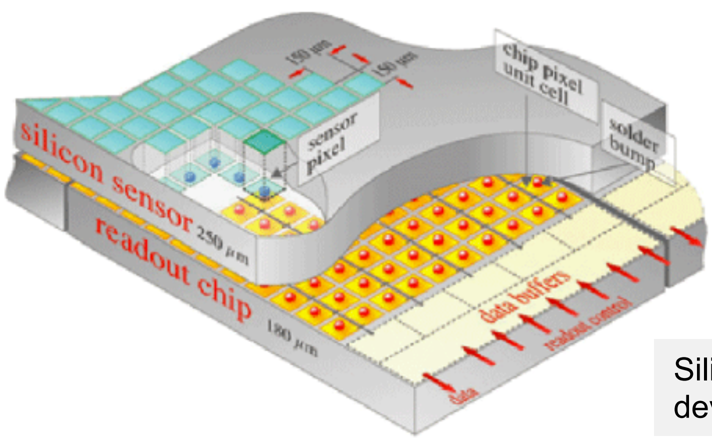
Modern semiconductor detectors use charge deposited by minimum ionising particle for high precision measurement of charged particle tracks to ~10μm hit reconstruction precision.
Signal: ~20ke in 250μm Si, Noise: interstrip C~ 1k, leakage current 0.1k, bias resistors 0.2k [BST H1]

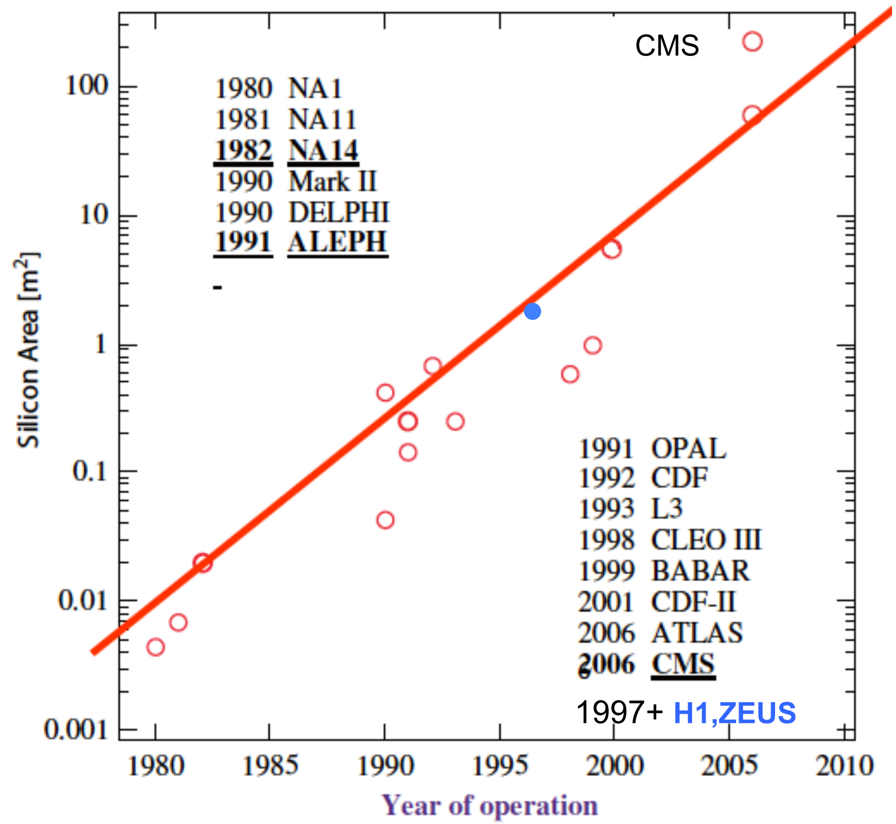
Segmentation and History

Two dimensional strip readout
(often preferred back-to-back single sided r/o)



CMS pixel detector

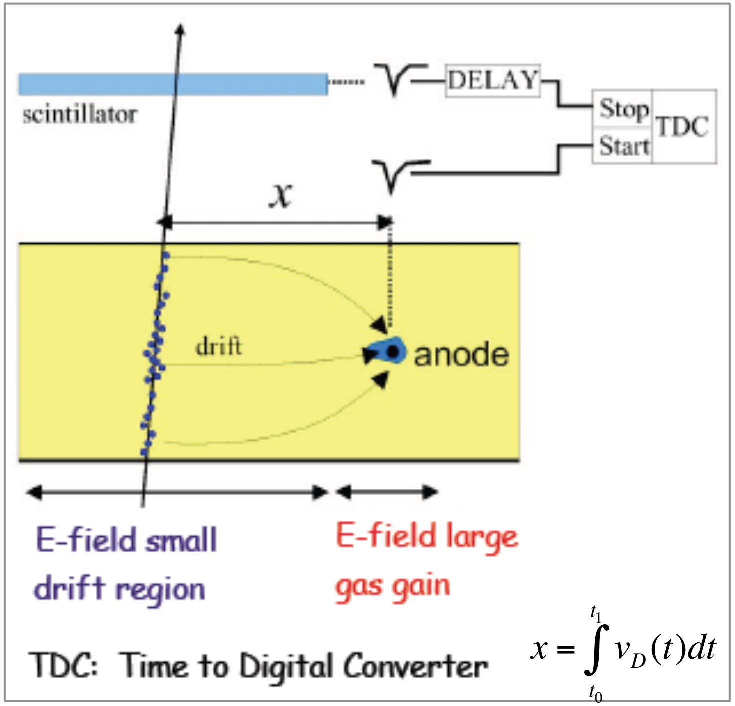




Silicon detectors have dominated tracking detectors and major efforts are devoted to high resolution, radiation hardness, fast and integrated readout..

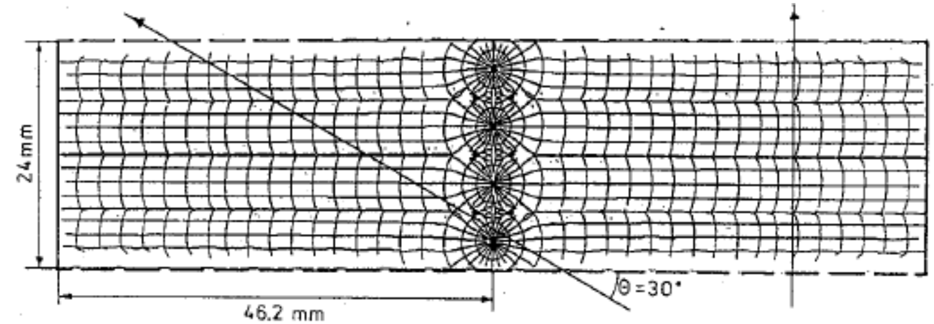
Drift Chambers

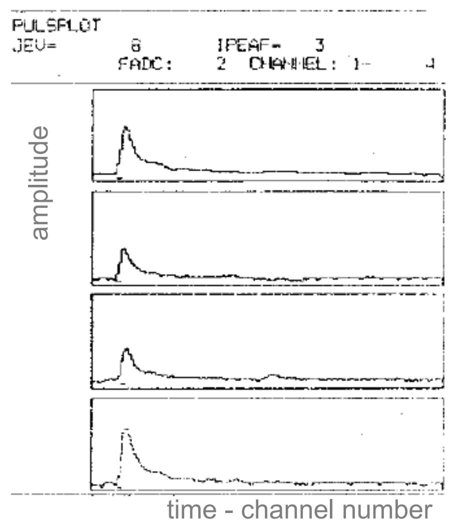
Example: COZ of H1 (PHE 88-02, Zeuthen)



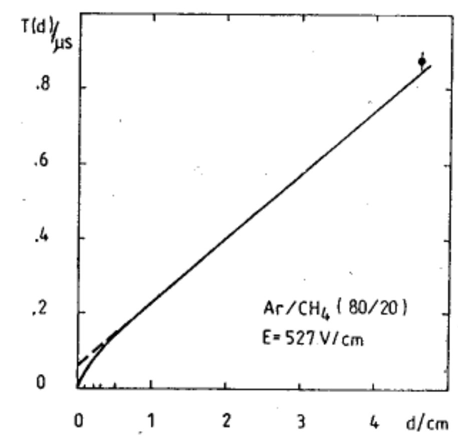
C.Niebuhr

Electric field lines and drift time isochrones in a drift cell





Calculation of time-distance relation and measurement of maximum drift time to determine the drift velocity v_D=56μm/ns



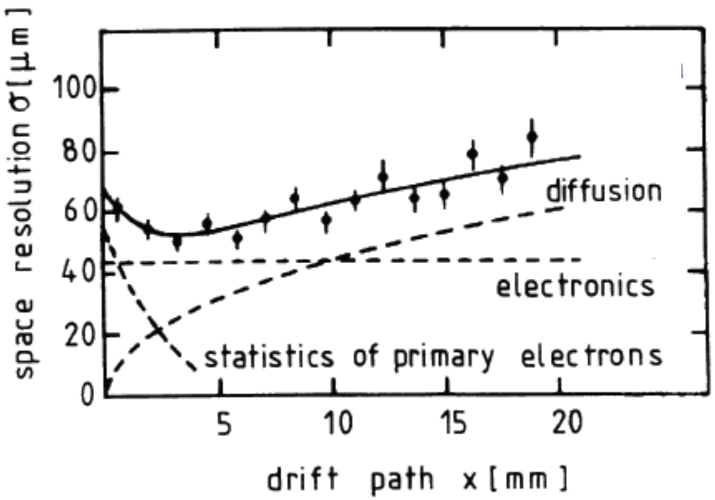
Large sensitive volume
Point resolution of order 200μm
Typical: 1m radius, 10^4 wires positioned to 20μm precision, strung parallel to beam or circular around ("z chambers").

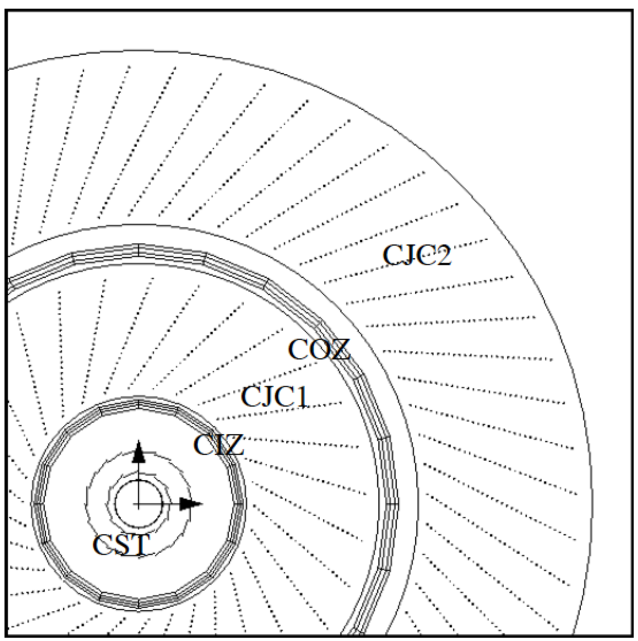
Sensitive to ageing, gas impurities, wire and wire-feedthrough mechanics..

Analog pulses to determine the spatial resolution using different pulse shape analyses.
Second coordinate from readout at both ends (charge division)

Drift Chambers

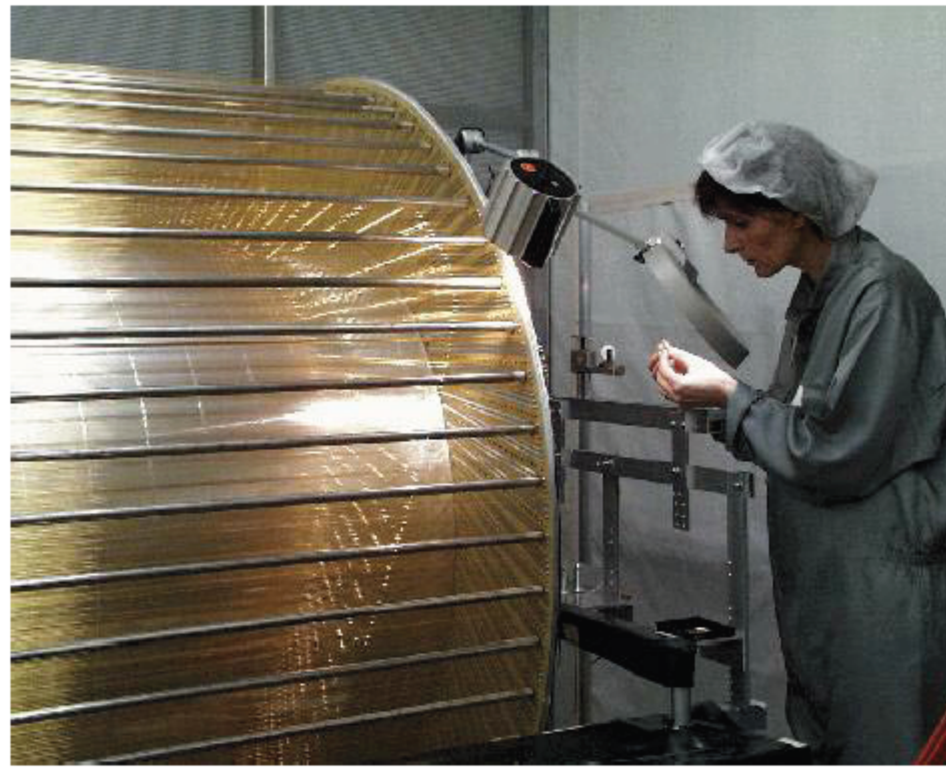
spatial resolution vs drift length



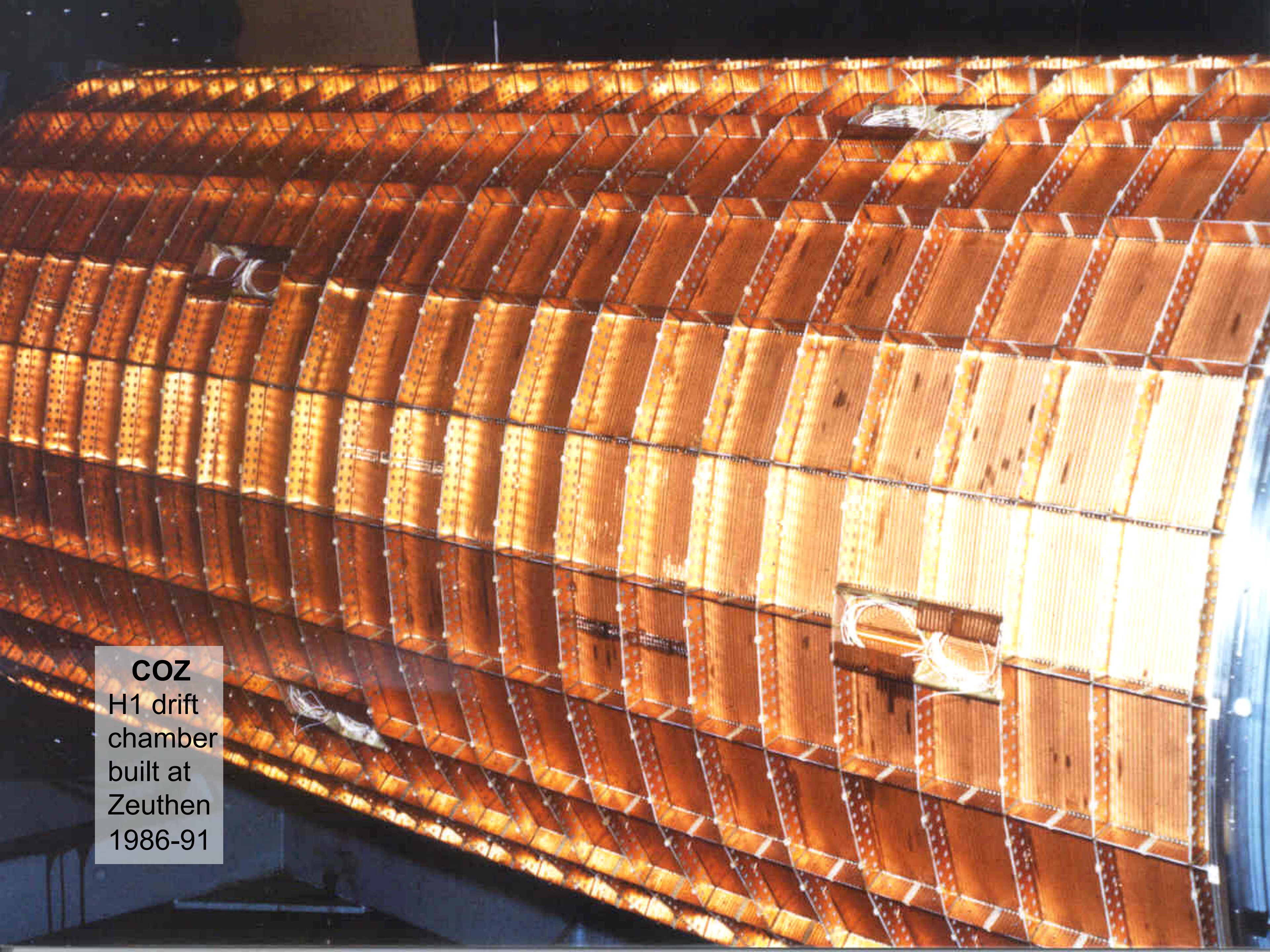


Radial view of H1 central tracker

Outer H1 central jet chamber (CJC2)



15 000 wires,, 6 tons on endflange, separating CJC from forward tracker


COZ
H1 drift
chamber
built at
Zeuthen
1986-91