The CMS Tracker

<u>Outline</u>

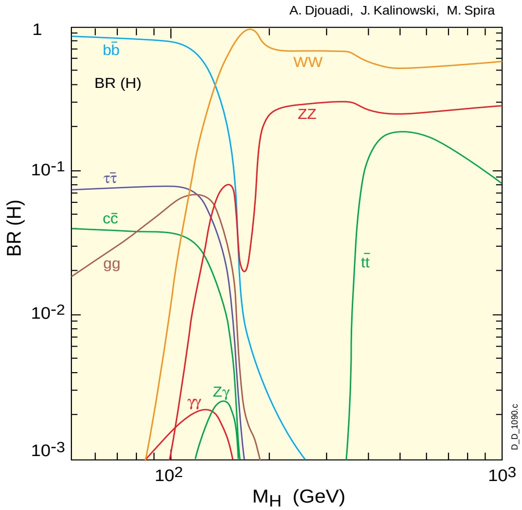
- Physics Requirements & Environment
- Pixel Detector
- Silicon Strip Detector
  - Layout
  - Mechanics & Modules
  - Production Status & Problems
  - Performance

Ariane Frey, CERN

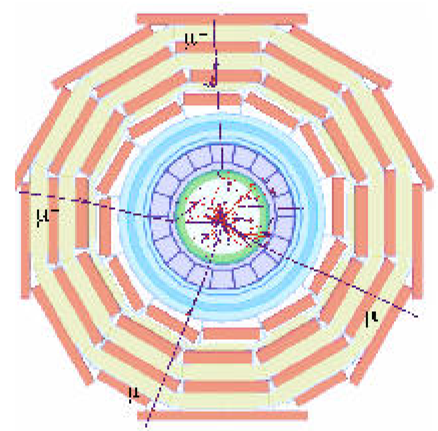
LHC Days in Split, October 2004

LHC Physics Goals and Tracker Requirements

Search for the Standard Model Higgs



Higgs Mass	Decays
80-140 GeV	$H \rightarrow \gamma\gamma$
140-700 GeV	$H \rightarrow ZZ^{(*)} \rightarrow 4\,l$
500-1000 GeV	$H \rightarrow ZZ \rightarrow ll\nu\nu$ $H \rightarrow ZZ \rightarrow lljj$ $H \rightarrow WW \rightarrow l\nu jj$



$M_{Higgs} = 150$ GeV

Search for SUSY: Higgses and sparticles (τ, b final states)

b Physics: CP violation, oscillations…

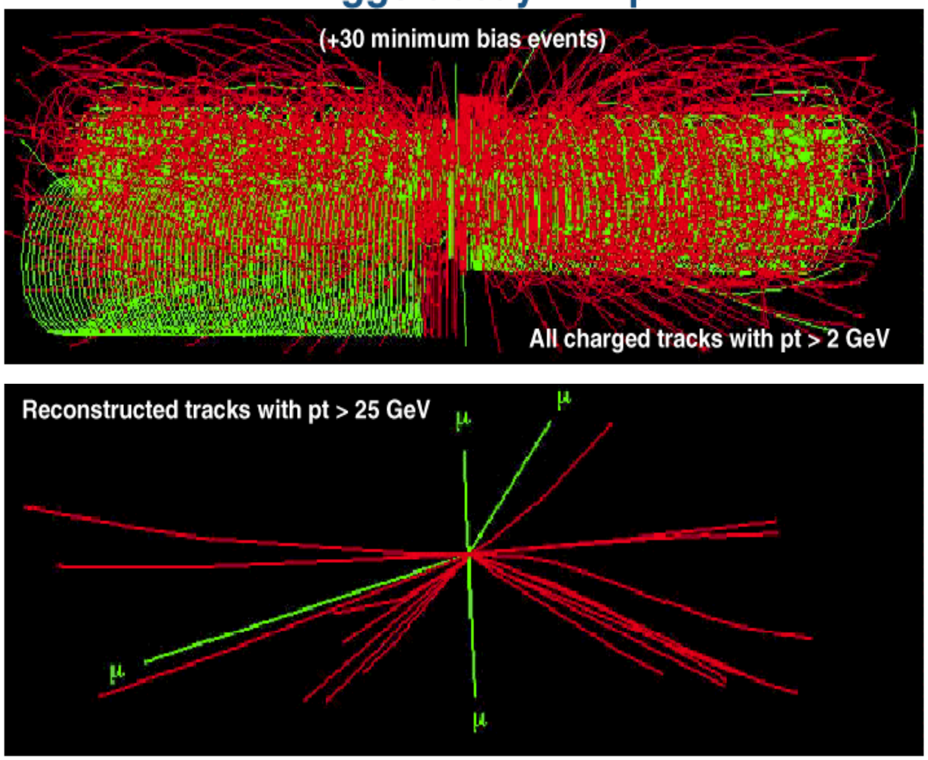
- Good photon/electron ID
- high momentum tracks (muons, electrons) and jets
- excellent geometrial and kinematical acceptance
- good impact parameter resolution
- secondary vertices (b, τ)

$$\frac{\sigma(p_T)}{p_T^2} \approx 10\,\%\,@\,1\,\mathrm{TeV}$$

$$\sigma_d \approx 20\ \mu\mathrm{m}$$

The LHC environment

Higgs decay in 4 μ



- Bunch crossing rate 40 MHz
- on average ~1000 charged tracks/BX

Need

fast read-out
bunch crossing identification

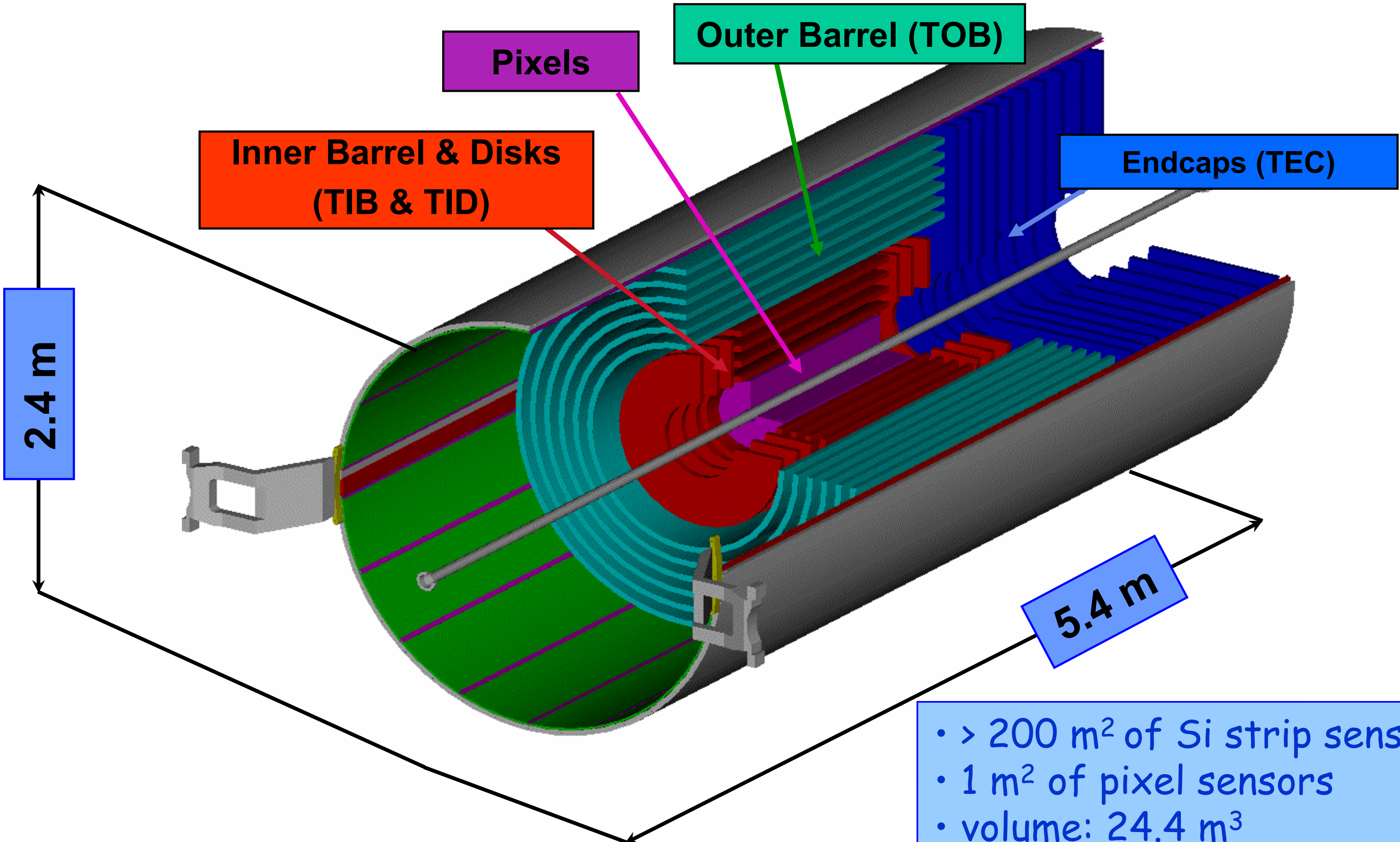
high granularity
small cell occupancy

radiation resistant devices

@ Pixel:
2.5×10^{15} hadrons/cm^2
1 MGray (Joule/kg)

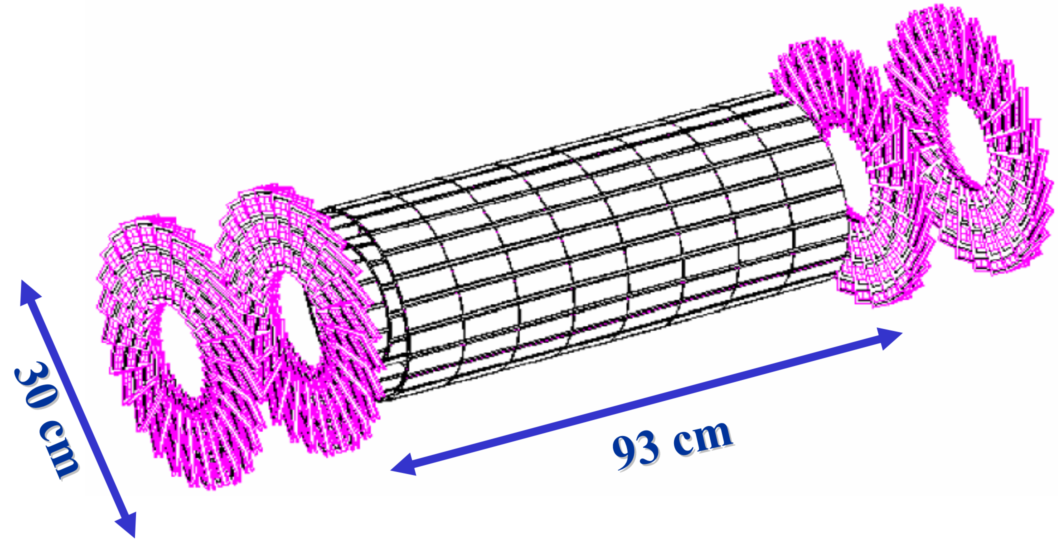
@ Strips:
2×10^{14} hadrons/cm^2
100 kGy

The CMS Tracker



- > 200 m^2 of Si strip sensors
- 1 m^2 of pixel sensors
- volume: 24.4 m^3
- running temperature: –10^0 C
- dry atmosphere for years

Pixel Vertex Detector



- 3 barrel layers (r = 4, 7, 11 cm)
- 2 forward disks (staged)
- Pixel size 100 μm × 150 μm

$4\ 10^7$ pixels

$IP_{trans.}$ resolution ~ 20 μm for tracks with P_t ~ 10GeV

Highest radiation environment:

- Specific program of sensor R&D
- n^+-on-n technology

Lorentzangle 28^0 at 4 T

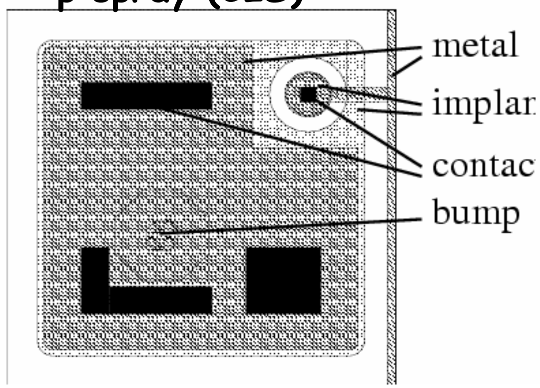
With this cell size occupancy is ~ 10^{-4} this makes Pixel seeding the fastest starting point for track reconstruction despite the extremely high track density

Pixel Vertex Detector Status

Preproduction of barrel and forward sensors submitted

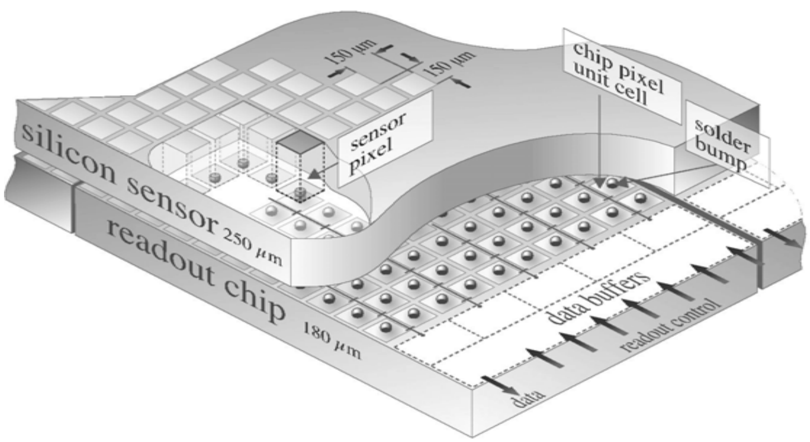
- **P-spray on oxygenated Silicon (CIS) for barrel**
- **SINTEF will produce sensors for forward**

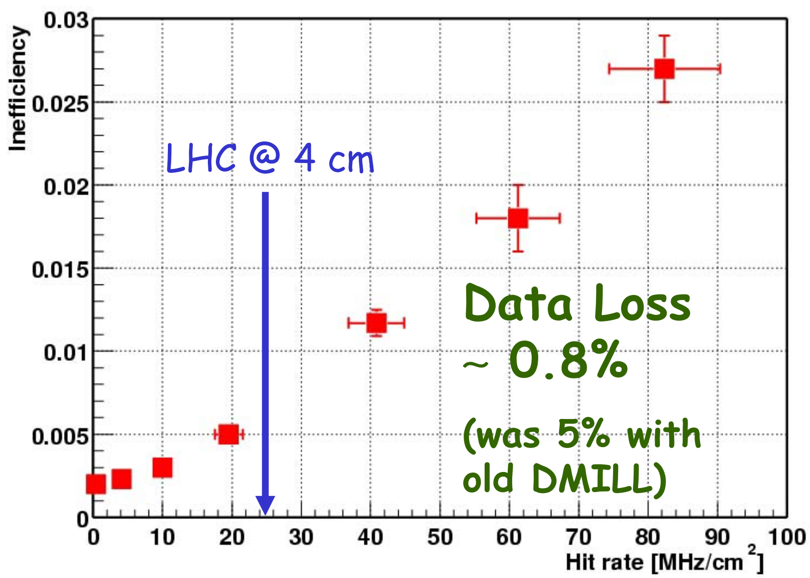
p spray (CIS)



2003 : Readout chip translated to deep submicron (IBM 0.25 μm process)

⇒Very successful, 2nd (probably last) iteration submitted on Aug 23rd

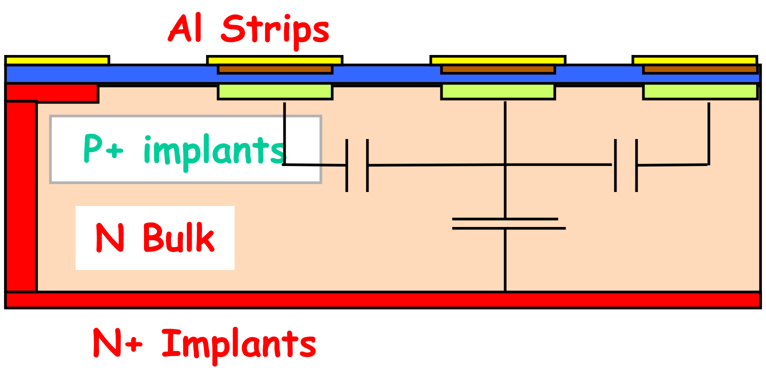


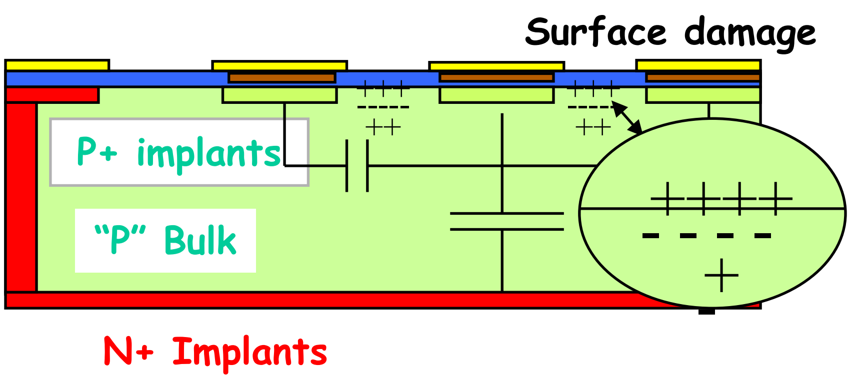


Radiation hard Silicon Strip sensors

ATLAS, CMS, ROSE …

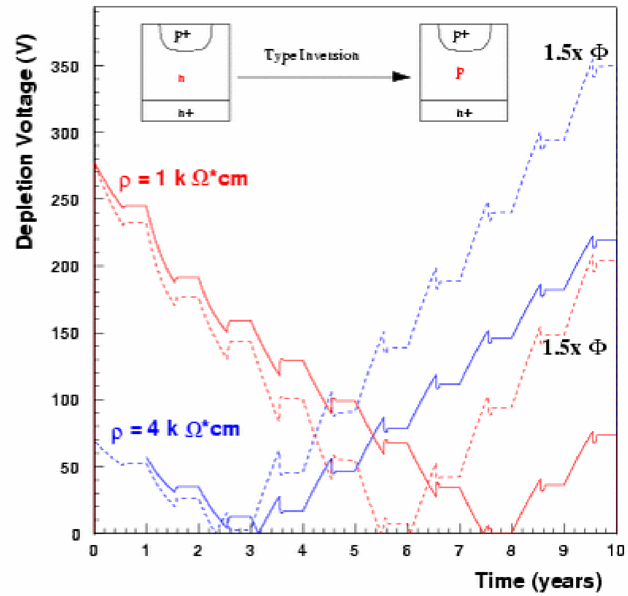
Single-Sided Lithographic Processing
(AC, Poly-Si biasing)





Radiation hardness "recipes"

P-on-N sensors work after bulk type inversion,
Provided they are biased well above depletion



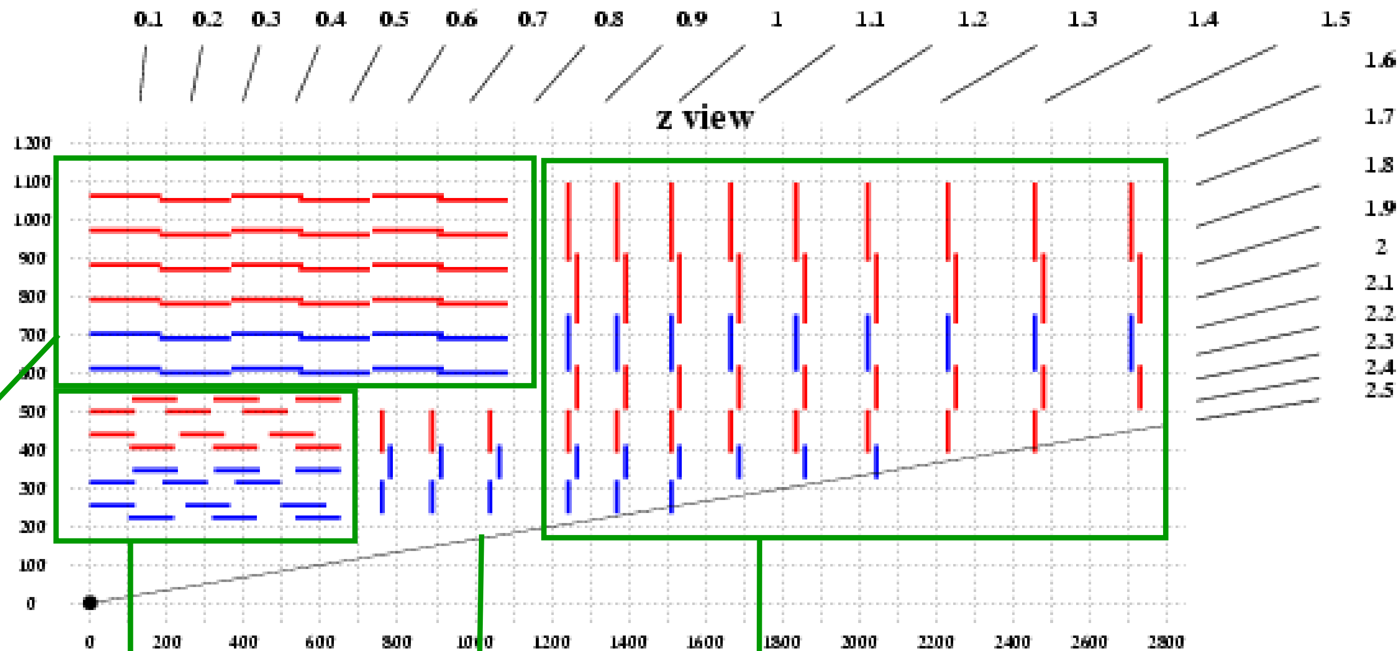
Match sensor resistivity & thickness to fluence
To optimize S/N over the full life-time

Use <100> crystal lattice orientation
instead of <111>
(no increase in strip capacitance & noise)

Tracker Layout

Outer Barrel

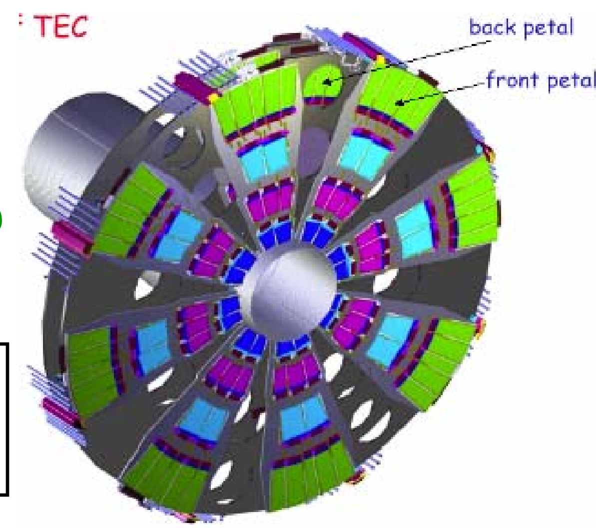
(picture out of date)



Inner Disks

Endcap

Inner Barrel



red: single sided detectors

blue: double sided detectors

Mechanical Structures

Lightweight Carbon fiber structures that carry the electronics boards and cooling circuitry

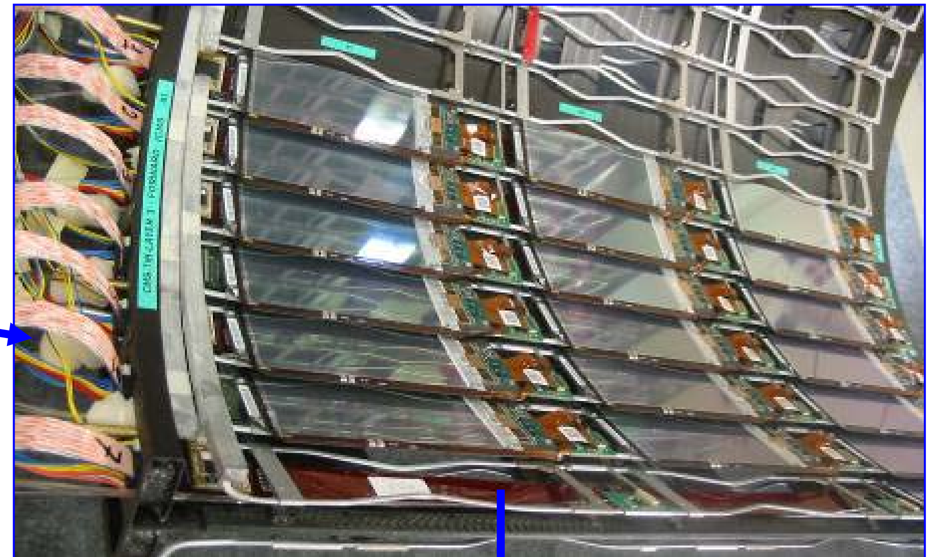




Almost all in hand !

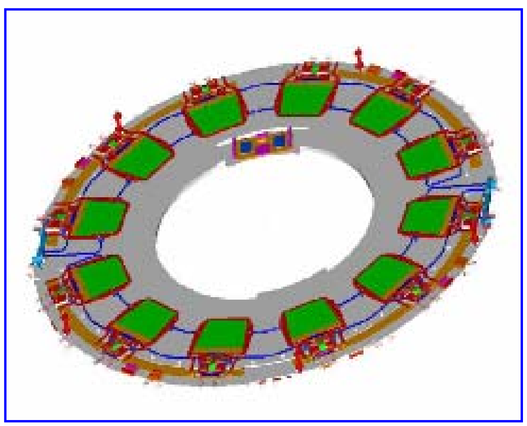
Inner Barrel

3800 modules (1 sensor)

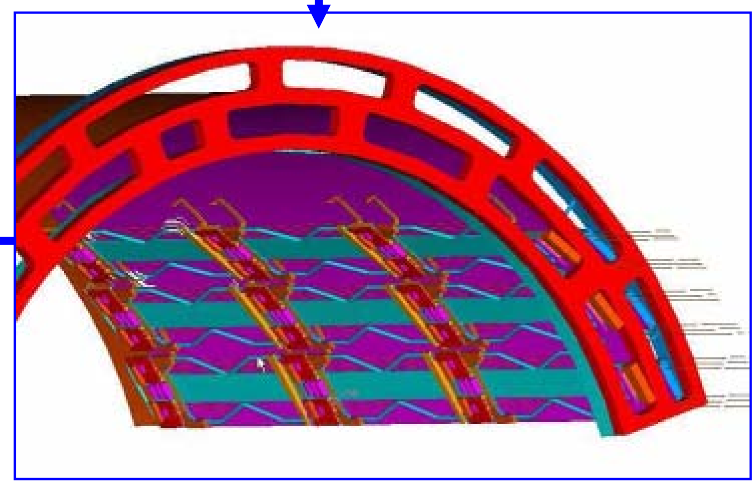


16 shells

6 inner disks

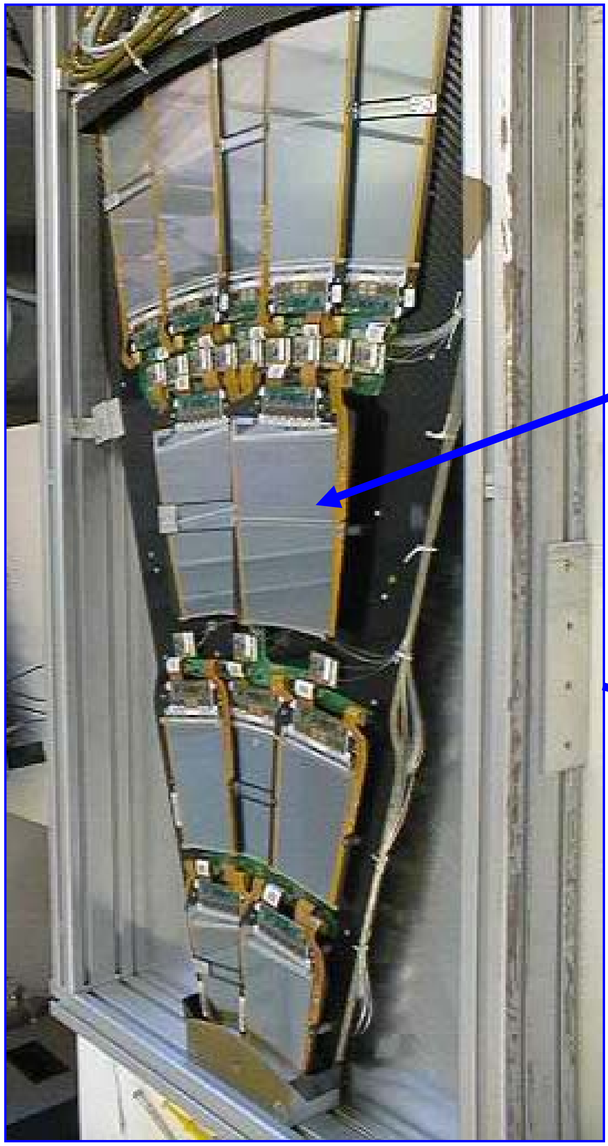


2 units

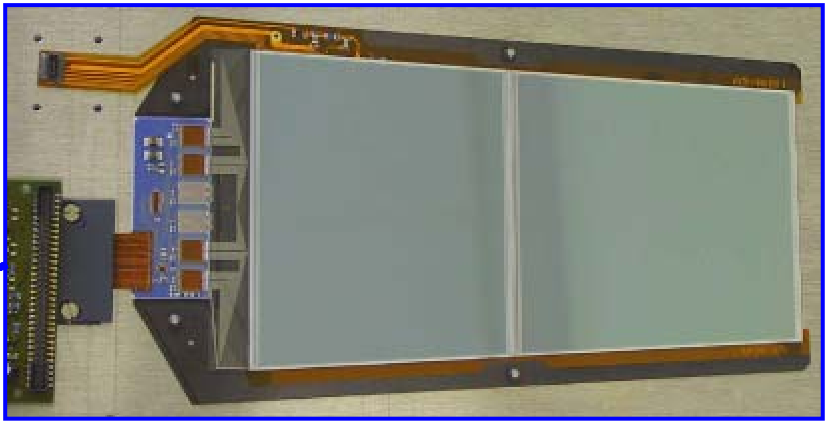


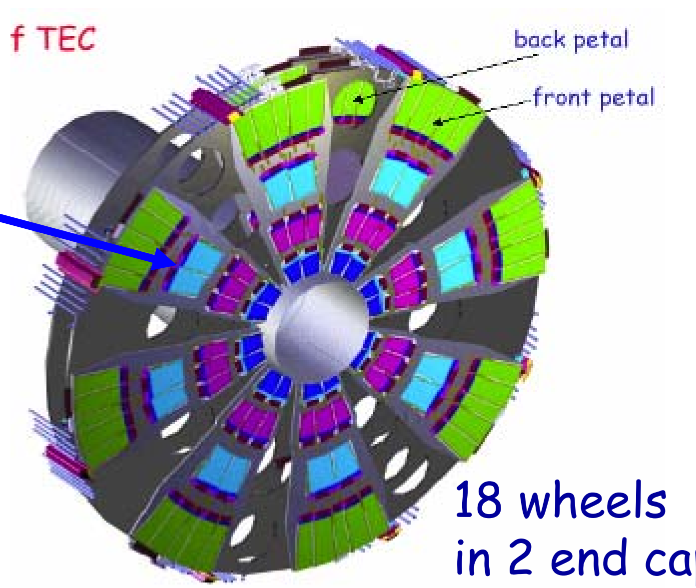
Endcaps

288
TEC petals



3800 TEC modules (1/2 sensors)

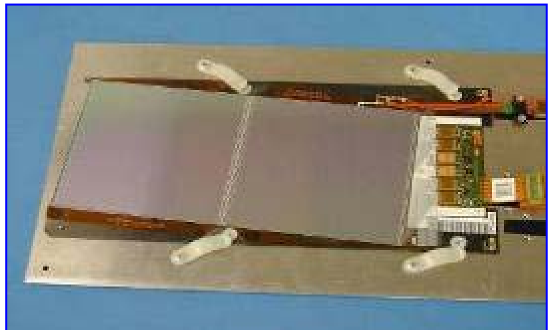


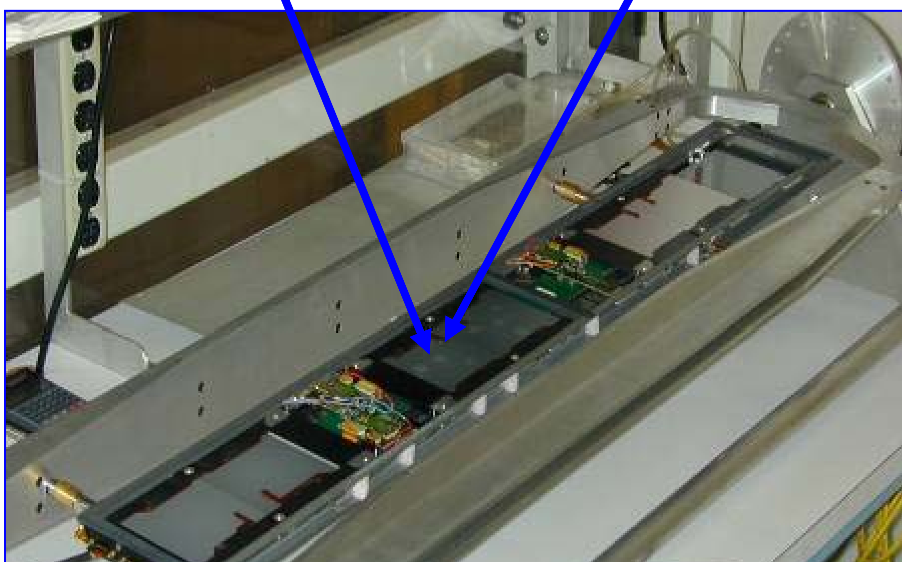


18 wheels
in 2 end caps

Outer Barrel

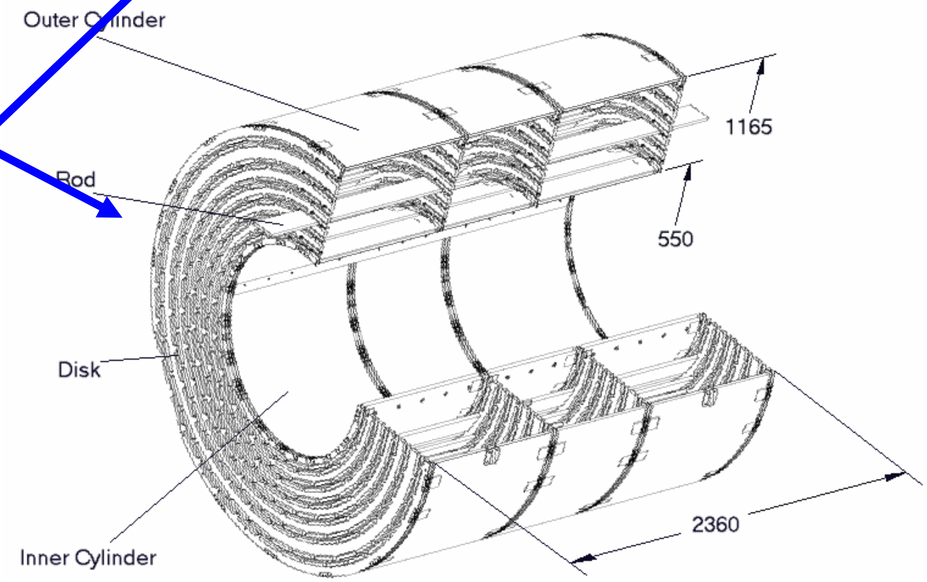
5200 TOB modules



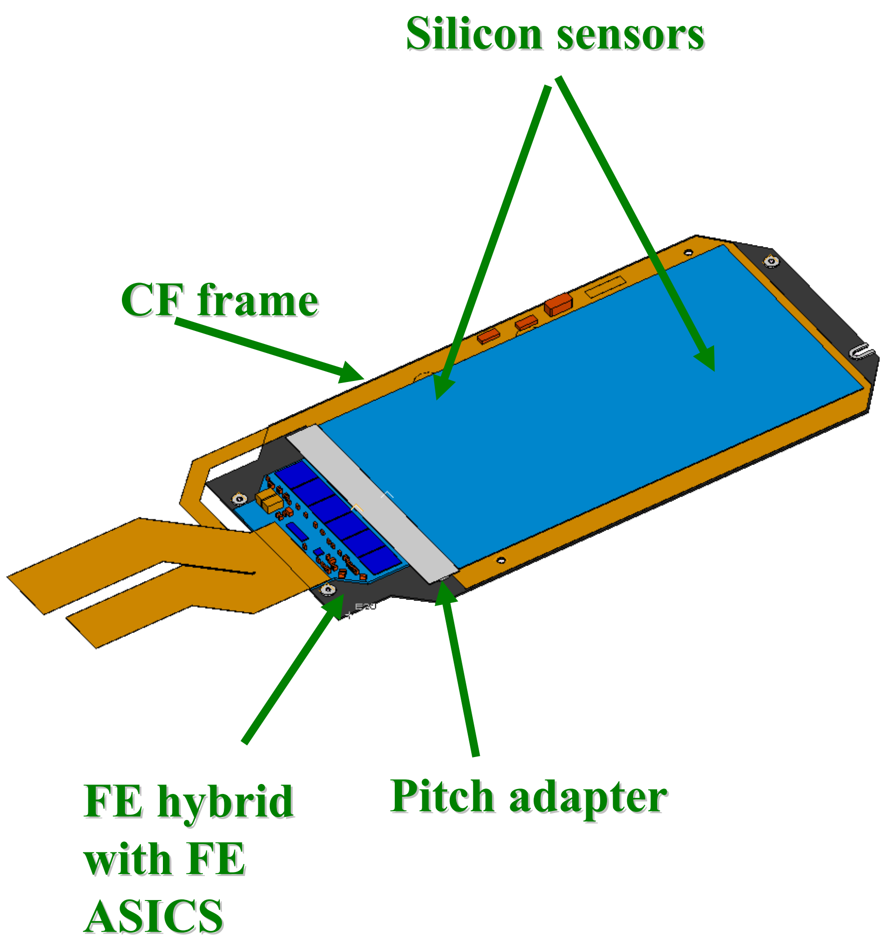


688 TOB rods w. 6/12 modules

TOB barrel wheel



Module Components



6,136 Thin sensors
18,192 Thick sensors

6,136 Thin detectors (1 sensor)
9,096 Thick detectors (2 sensors) } 15,232

3112 + 1512 Thin modules (ss +ds)
5496 + 1800 Thick modules (ss +ds)

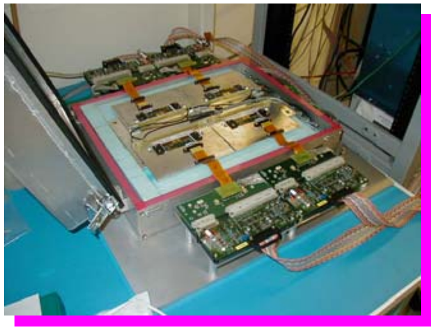
9,648,128 strips ≡ electronics channels

75,376 APV chips

25,000,000 Bonds

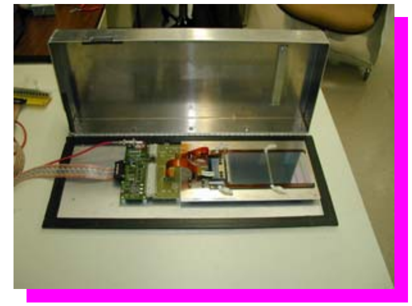
445 m^2 of silicon wafers
210 m^2 of silicon sensors ($162m^2 + 48m^2$)

Assembly & Testing



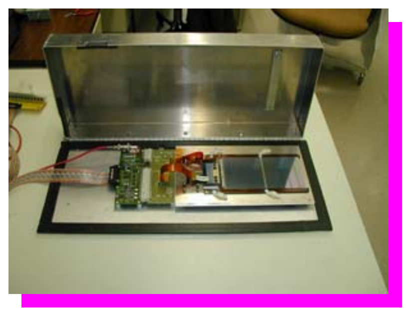
Thermal/quick test hybrid

Gantry makes modules



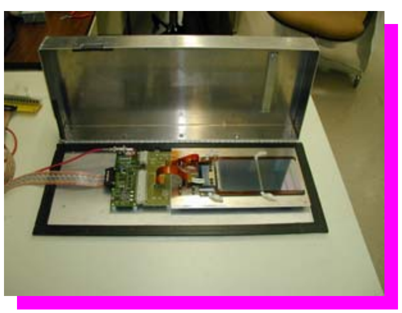
Quick test unbonded module

Wirebond

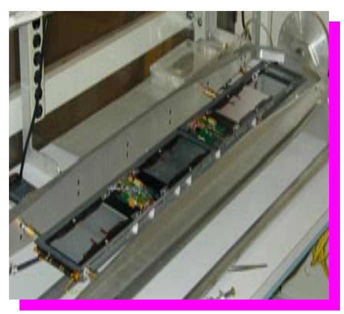


Bonded module test

Thermal cycle module



Final pinhole test

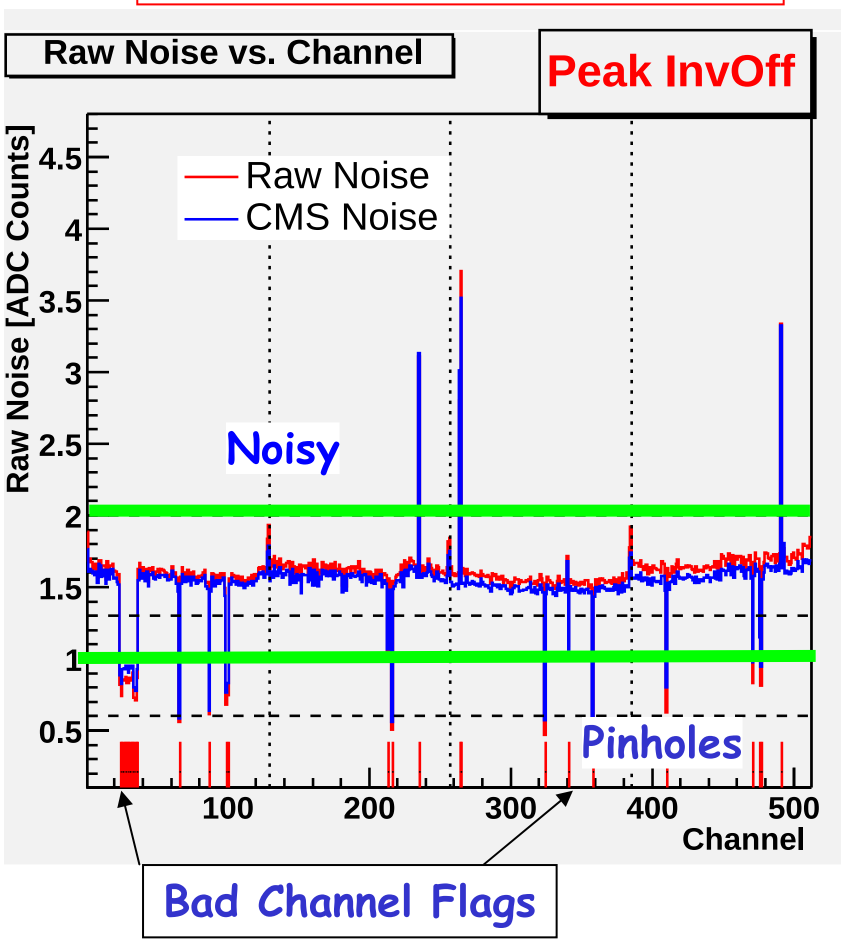


Assemble/test petals/rods

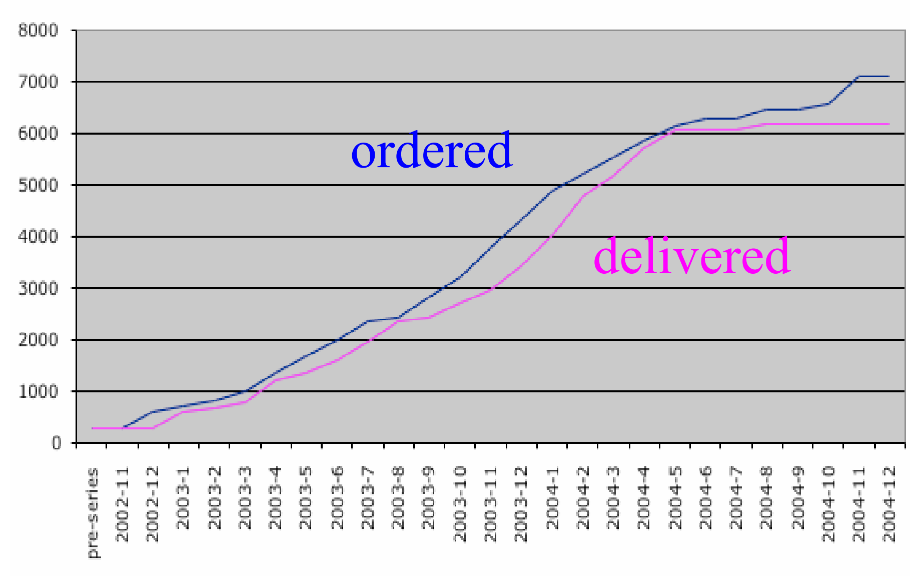
Petal/rod burn-in

Module Tests & Sensor Procurement

Noise Measurement



Ordered ≈ 700 thin sensors from Hamamatsu



Delivery almost complete.

Quality is excellent !

Thick sensor procurement

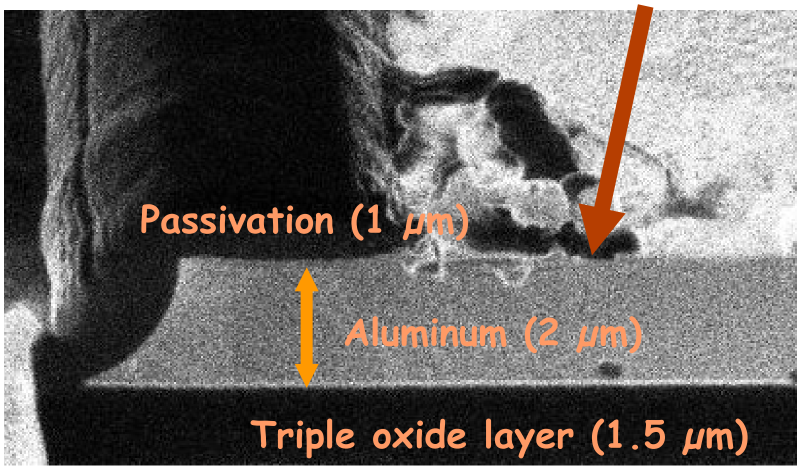
Originally, contract for all ≈ 18,000 thick sensors awarded to STM.

However, continuous problems were detected:

High leakage currents, scratches, CMN on modules, aluminum corrosion,…

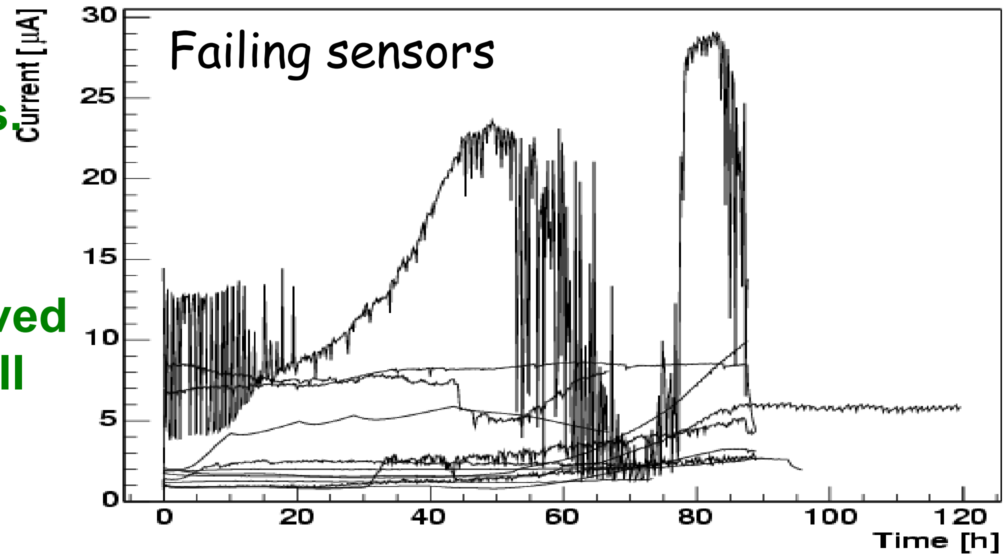
"Dots and Stains"

Aluminum corrosion



Thick sensor procurement (II)

Leakage current Longterm test

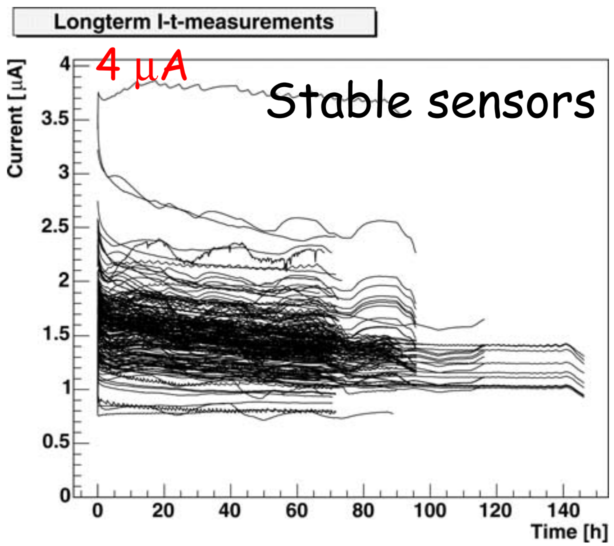


Feb '04: Agreement on new qualification batch of 1000 sensors. Reduction of contract (ordered 7000 sensors from HPK)

New batch has significantly improved quality, however, longterm test still shows high rate of failure ⇒ batch not qualified

(>72 h test, 233 sensors, 12 failures ⇒ 5 %)

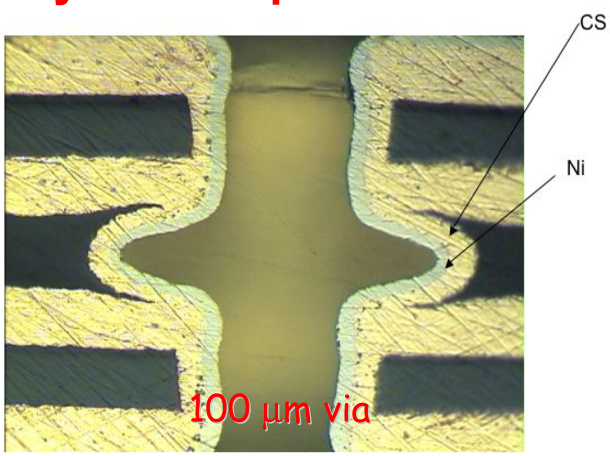
1000 h test ⇒ 3 out of 26 fail (>10%)

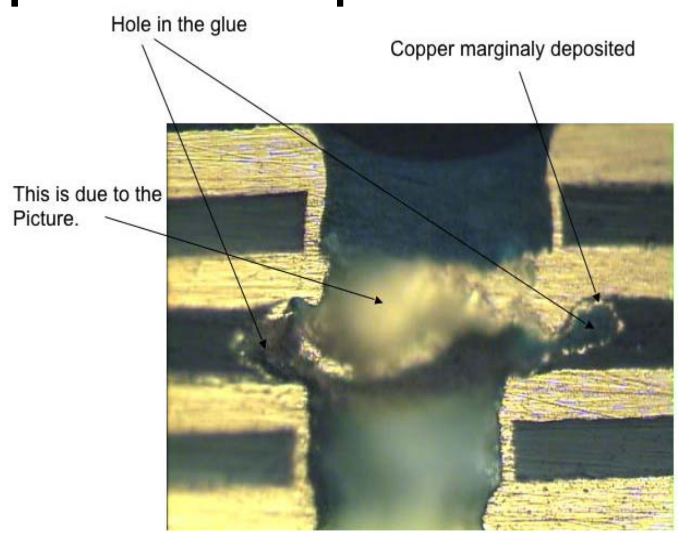


Initial delivery of thick sensors by Hamamatsu delayed, but started in May 04
-> Quality is excellent

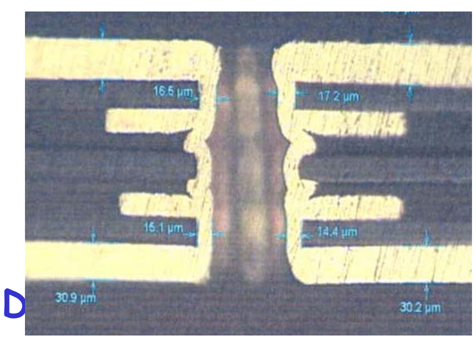
Front-End Hybrid

- Flex Kapton circuit laminated onto ceramic (Cicorel/Hybrid SA)
- Production started in Spring '03
- Since then, 3 different problems encountered and solved
  - ✓ Flex cable stability ⇒ additional stiffener introduced
  - ✓ Wire bonding weakness ⇒ optimization of parameters
  - ✓ Hybrid Via problem ⇓





Problem solved now (increased vias to 250 µm, additional Kapton layer), but lost about 6 months !



Production Status & Schedule

Production completely driven by delivery of FE hybrids (& thick sensors)

All other parts (mechanics, on- and off-detector electronics) well on path.

Status on Module production today:

4.000 Hybrids delivered to the Gantries

2.850 Modules assembled (670 ST and 2180 HPK)

2.350 Modules bonded

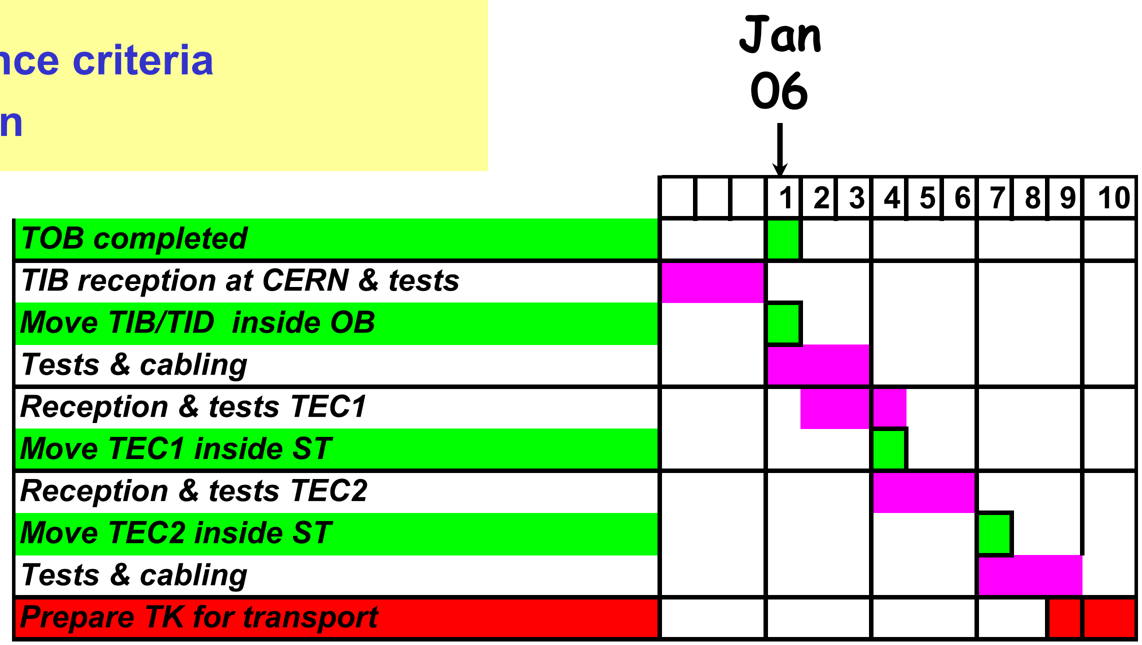
2.300 Modules tested

2.150 Modules met our acceptance criteria

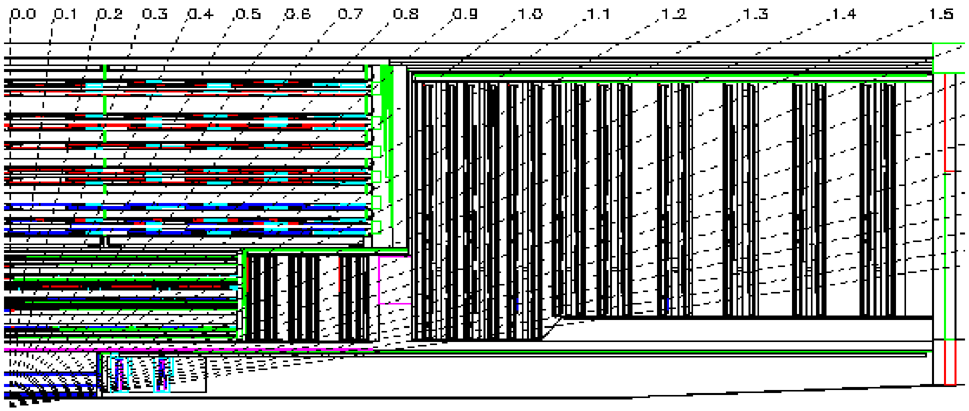
~ 94 % global yield of production

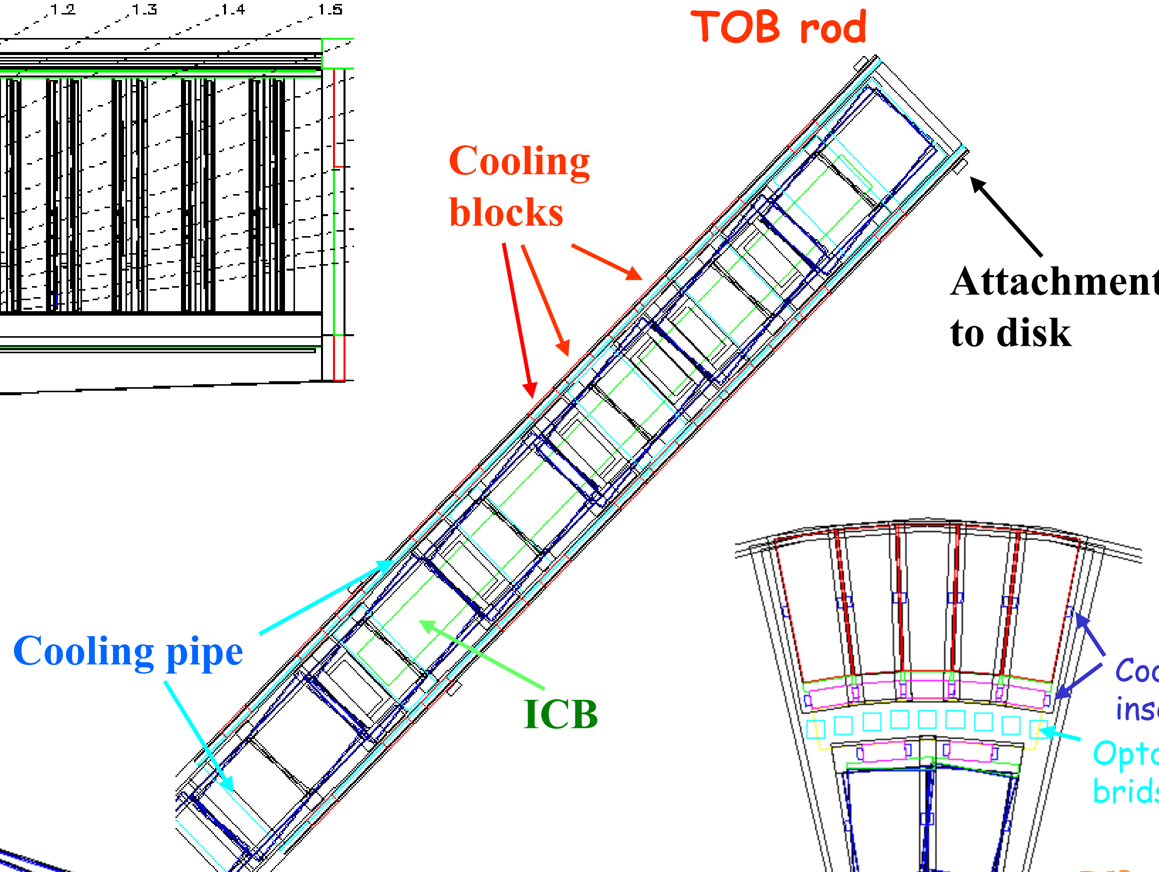
Schedule:
restart module production at full speed in Jan '05

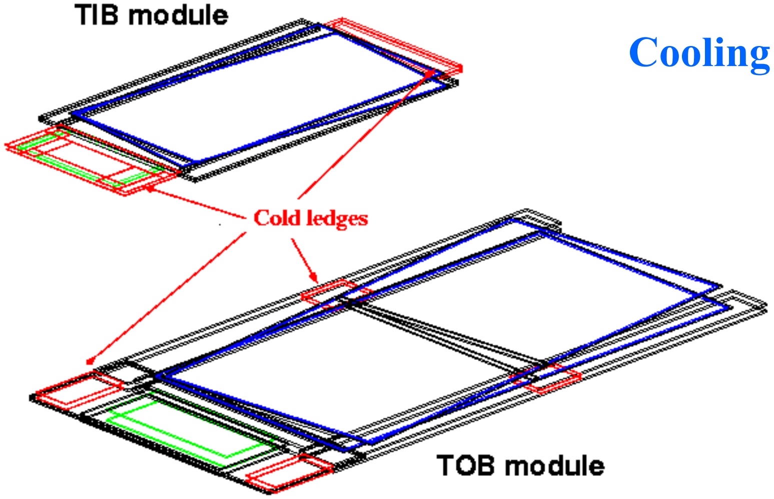
Tracker ready for installation in Pt. 5 November 2006

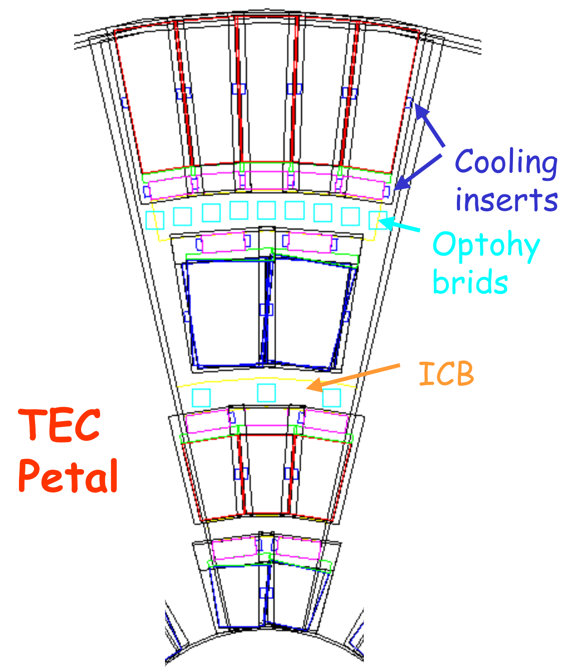


Simulation and Modeling of SST







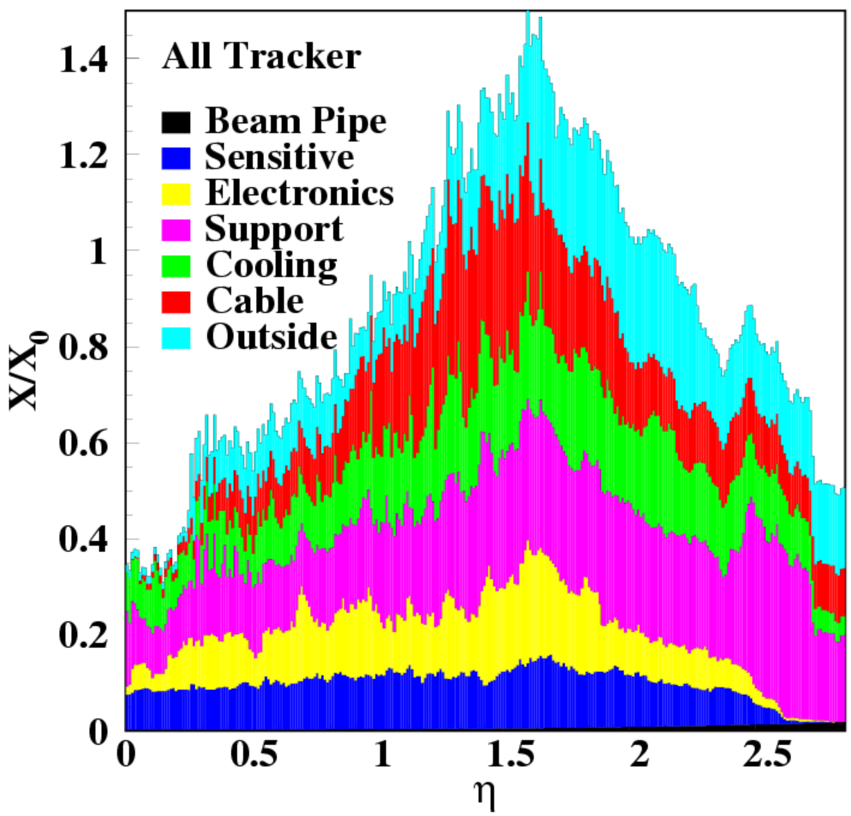


Ariane Frey, CERN

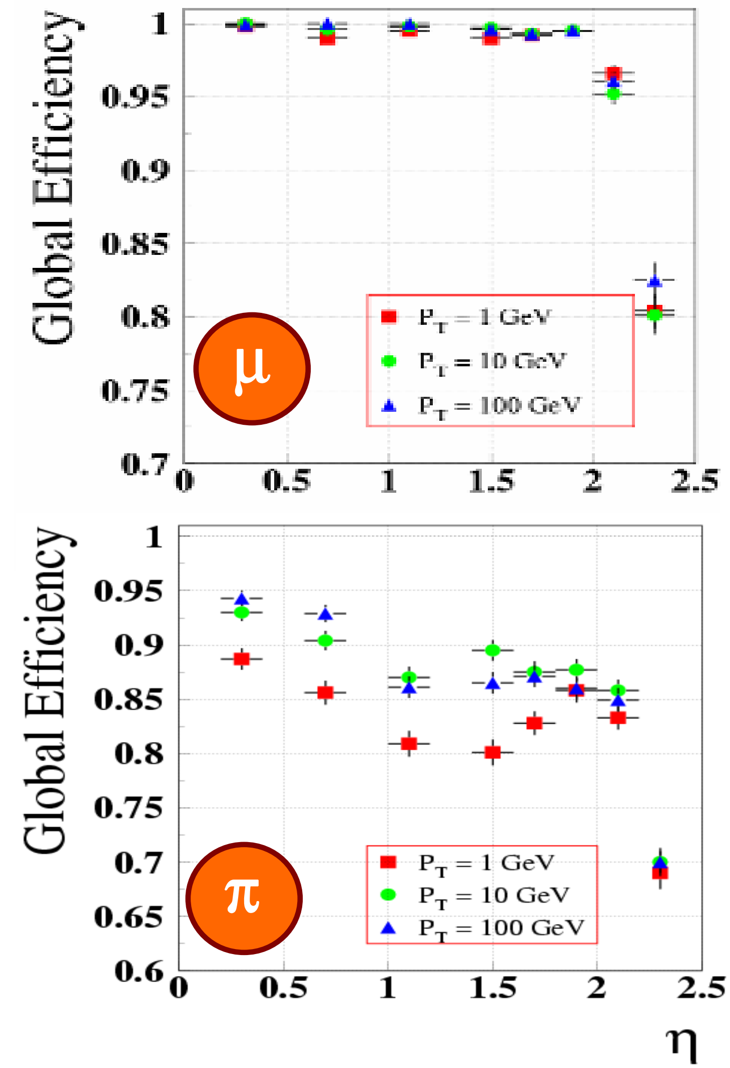
Performance

Silicon is a solid state material, and the strong cooling and mechanical requirements cost a price….

Tracker material budget



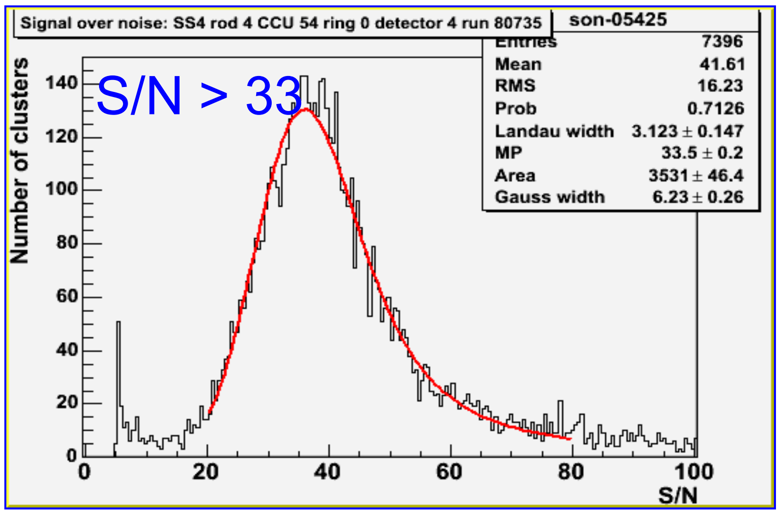
Track finding efficiency

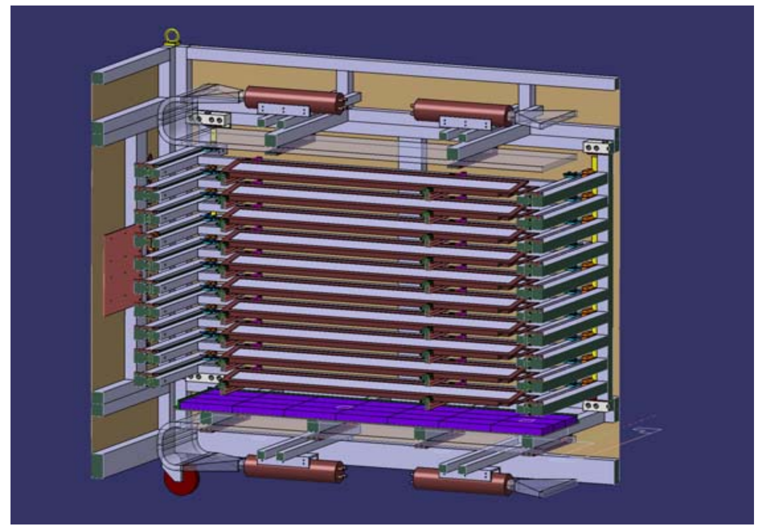


Testbeam

May & October 2004 test beam @ CERN with 25 ns bunched muon/pion beam

Multiple TOB rods & 2 TEC petals (number of channels > # channels ALEPH TPC)



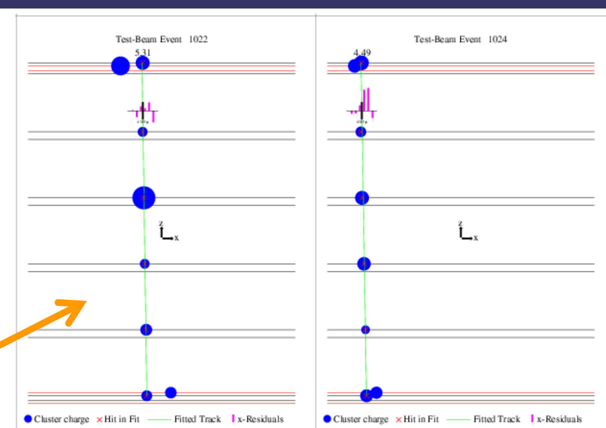


TOB Cosmic Rack :

Holds up to 20 TOB rods

Test structure for integration tests

Tracking with standard CMS software



Summary

- Tracking at the LHC is a very challenging task:
  - harsh radiation environment, extremely high rates
- Tracker is essential ingredient of CMS
  - world largest Si strip tracker
  - all silicon: pixels + strips
- Tracker production delayed, but major obstacles overcome. Will be ready for installation end of 2006.
- Test beam results agree with expectations.

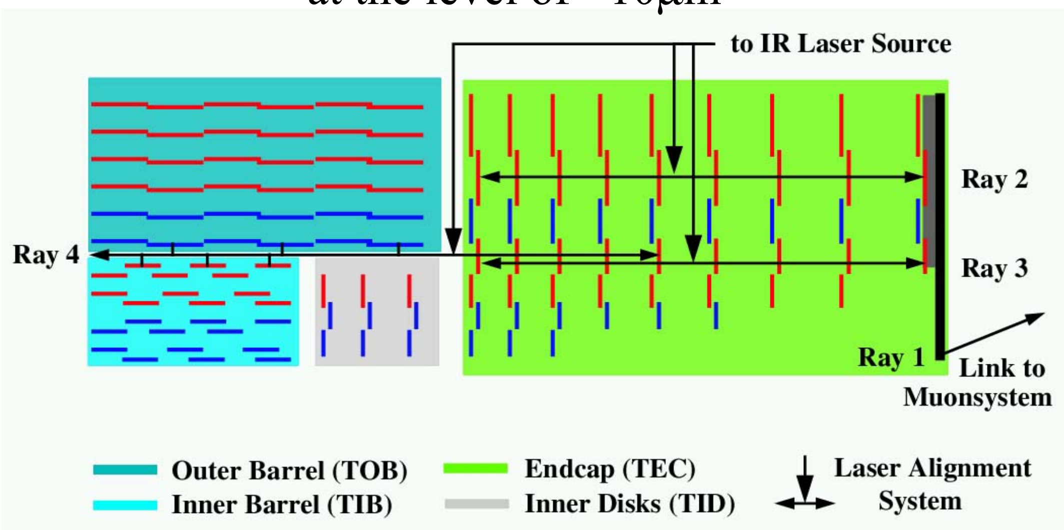
We are eager to see the first tracks from collisions

Back up slides

Tracker Alignment

Challenge: Alignment uncertainties should not degrade intrinsic tracker resolution: ≈20µm

LAS: Aligns global support structures and will monitor relative movements at the level of ≈10µm



Mechanical Constraints:
Sensors on Modules: ≈10µm
Large Structures: 0.1-0.5 mm

First Data Taking:

Laser Alignment

⊗

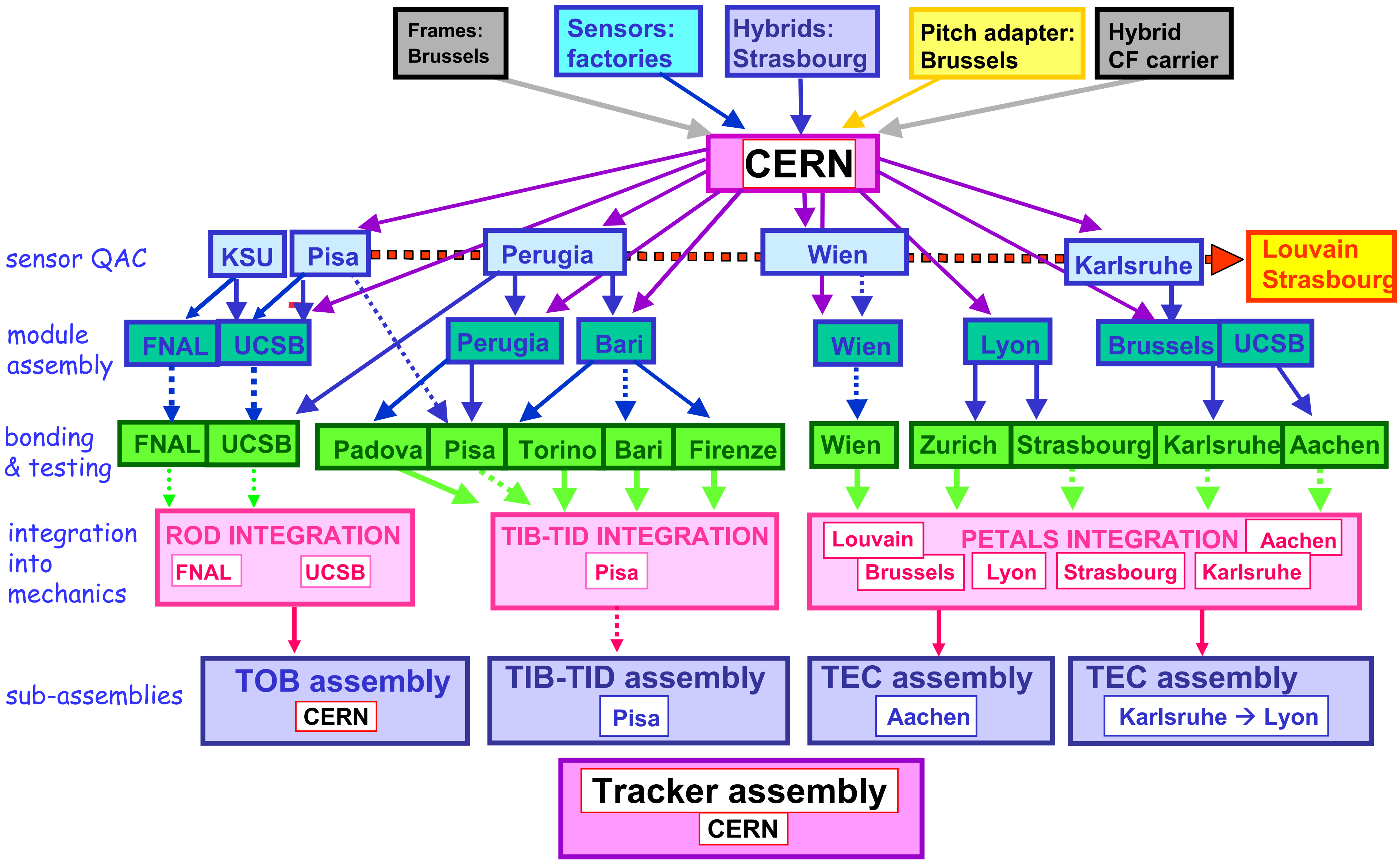
Mechanical Constraints

⇒≈100µm alignment uncertainties

Sufficient for a first efficient pattern recognition.

Final Alignment: Use Tracks in order to achieve the desired level of alignment uncertainties of ≈10µm. A combination of track based alignment and laser alignment will insure an accurate monitoring of time dependent alignment effects.

Production Flow



Distributed Module Production

4 Si sensors quality assurance centers
2 Si sensors irradiation facilities
2 centers for FE hybrid assembly/bonding (40/day)
7 module assembly centers (Gantry) (>90/day)
13 bonding centers and QA&C (>130000/day)

43 major working points

10 centers where module are installed into mechanical supporting structures
4 centers where sub-detectors are assembled
1 Tracker assembly center

Momentum resolution

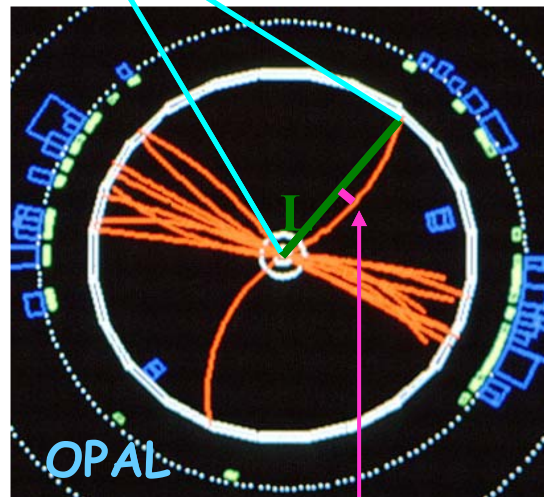
$$\sigma\left(\frac{1}{p_T}\right) \propto \frac{\sigma_{spacial}}{\sqrt{N_{sample}}} \cdot \frac{1}{B \cdot L^2}$$

Most previous collider experiments have used large drift chambers (TPC, jet chamber, …)
→ many samples, point resolution >> 100 μm

but large drift times (O(μs))

Need detectors with smaller structures

(I.e. fast charge collection times)



sagitta s

This momentum resolution allows to reconstruct

$Z \rightarrow \mu^+\mu^-$ with $\Delta m_z < 2$ GeV up to $p_t \sim 500$ GeV

Goal:

$$\frac{\sigma(p_T)}{p_T^2} \approx 10\,\%\,@\,1\,\text{TeV}$$

→

for B = 4 T , L = 1.1 m (CMS)

sagitta s = 200 μm σ(s) ≈ 20 μm

Thickness of a human hair: 40 μm