Overview of silicon strip detectors in current (ZEUS - ep) and future (CMS - pp) experiments

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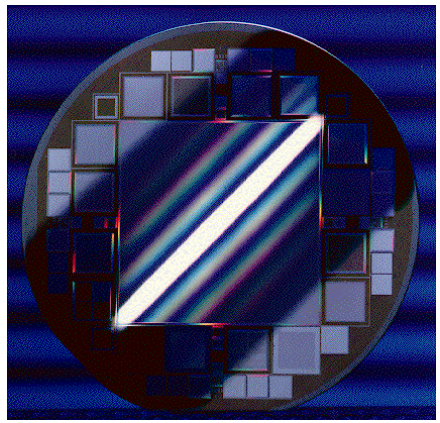
BNL

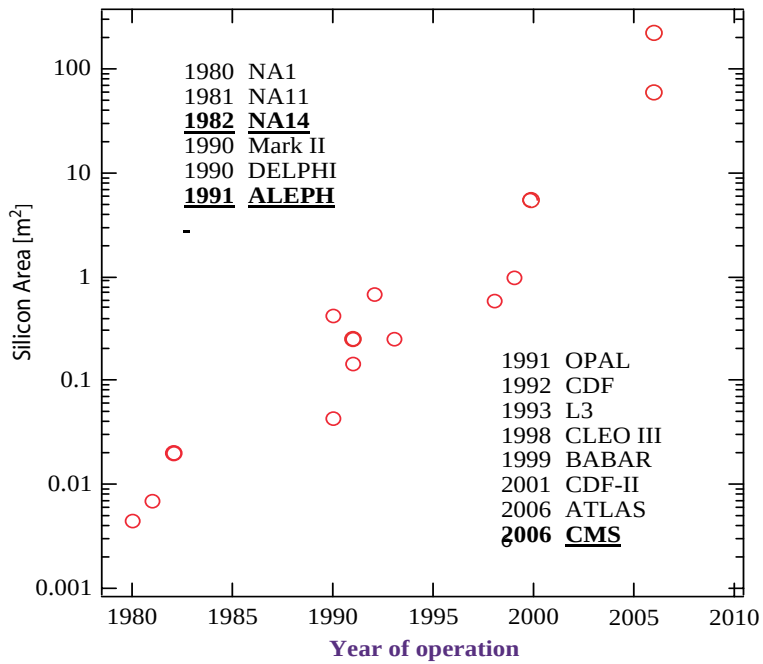
Introduction

- General comment on silicon strip detectors



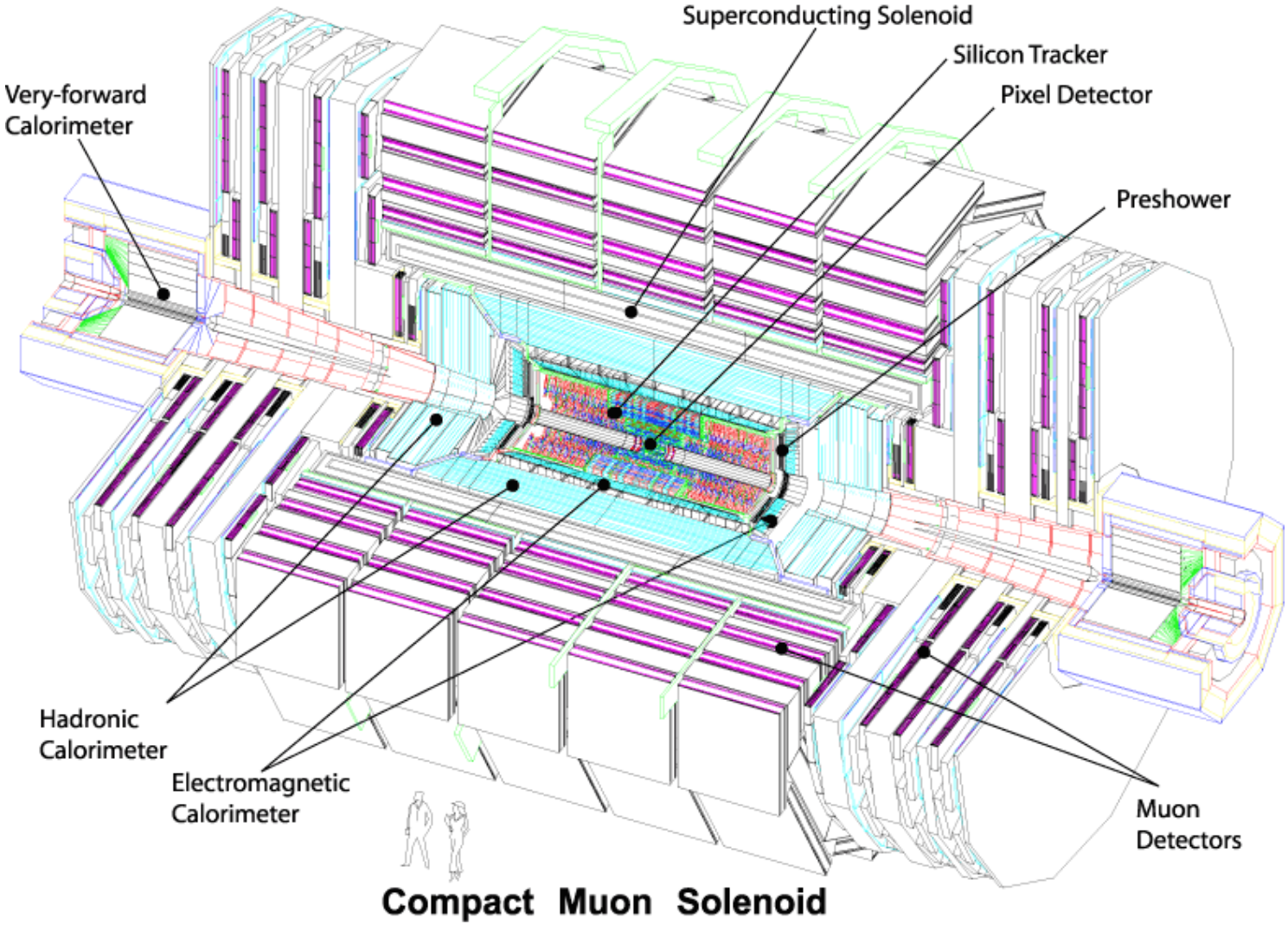
- Application of silicon strip detectors in particle and nuclear physics: ~25 years!
- By now, routinely used for:
  - ⇨ Precise tracking information
  - ⇨ Reconstruction of secondary vertices (Heavy flavor physics!)
- Fast readout (ns scale)
- Low material budget (Typical thickness: 300ms)

experiment	nb. of detectors	nb. of channels	silicon area [m^2]
CMS	15.95 k	10×10^6	223
ATLAS	16.0/2 k	6.15×10^6	60
AMS 2	2.3 k	196 k	6.5
DO 2		793 k	4.7
CDF SVX II	720	405 k	1.9
Babar		140 k	0.95
Aleph	144	95 k	0.49
L3	96	86 k	0.23



CMS

- Overview



CMS

Requirements on tracking system

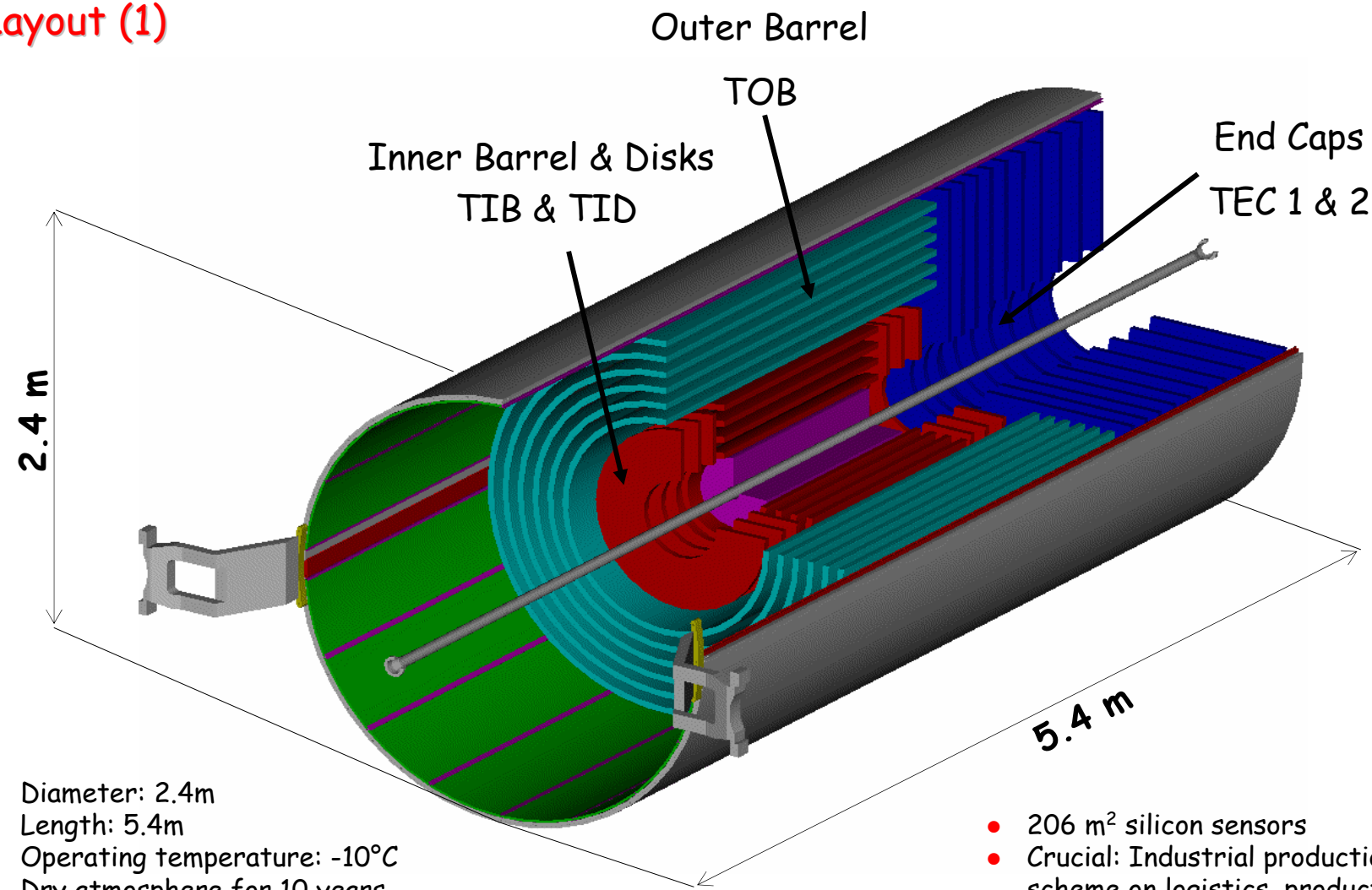
- Characterization of events involving heavy gauge bosons (W, Z) in particular through their leptonic decay
- Acceptance for $|\eta| < 2.5$
- Momentum resolution for isolated leptons in the central rapidity region:

$$\frac{\Delta p_T}{p_T} = 0.1 \times p_T$$

- Ability both to tag and to reconstruct in detail b-jets and B-hadrons within jets
- Reconstruction efficiency:
  - ⇨ > 95% for isolated high p_T tracks and
  - ⇨ > 90% for high p_T tracks with jets
- Resistance to high radiation dose
- Fast detector response (< 25ns) to reduce pile-up effects
- Minimal amount of material in front of the calorimeter
- Integration into the CMS trigger system

CMS

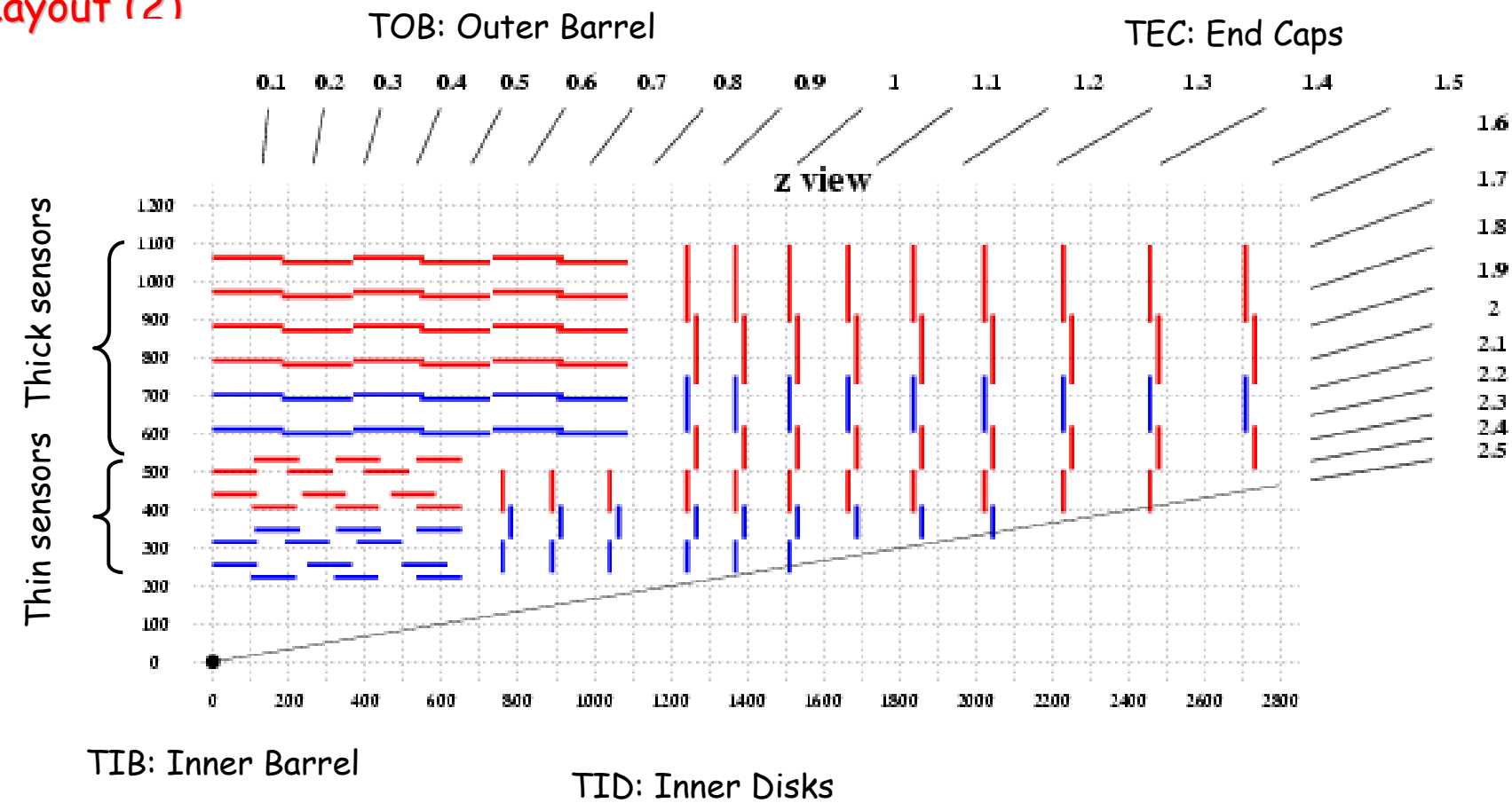
Layout (1)



- Diameter: 2.4m
- Length: 5.4m
- Operating temperature: -10°C
- Dry atmosphere for 10 years
- Expected rad. levels: 1.6 10^{14} MeV eq. neutrons / cm^2

- 206 m^2 silicon sensors
- Crucial: Industrial production scheme on logistics, production and quality assurance

Layout (2)



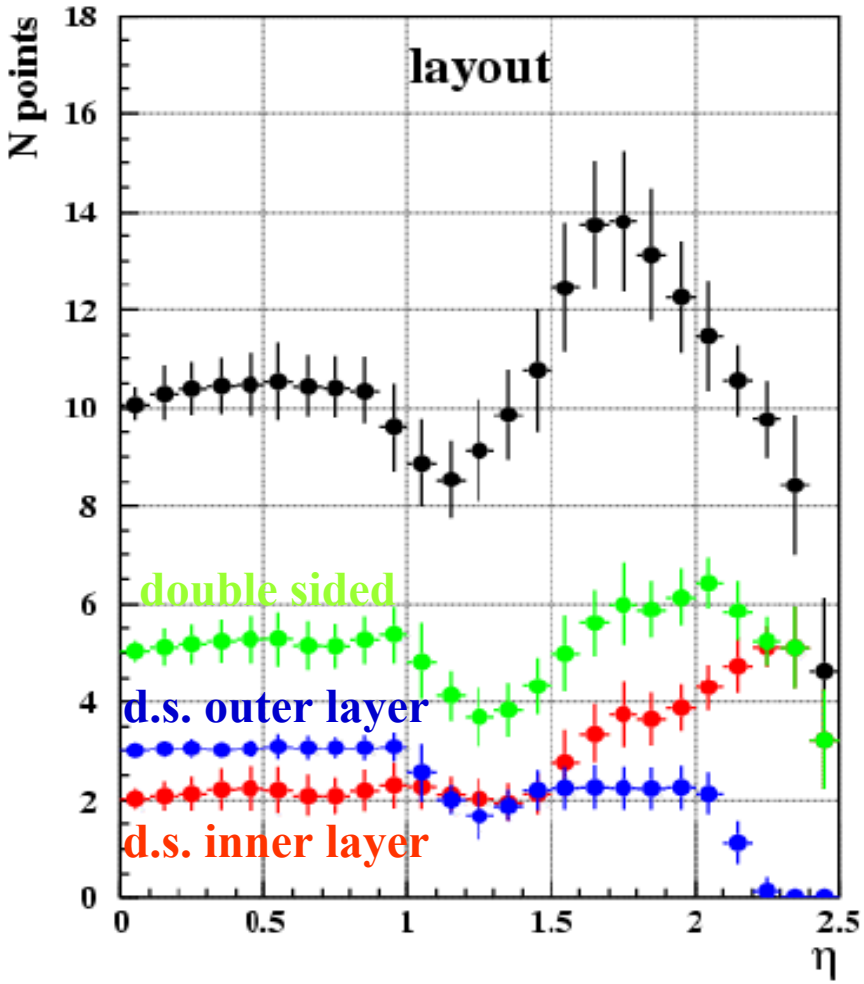
- Total modules: 8,608 single-sided modules and 3,312 double-sided detector modules

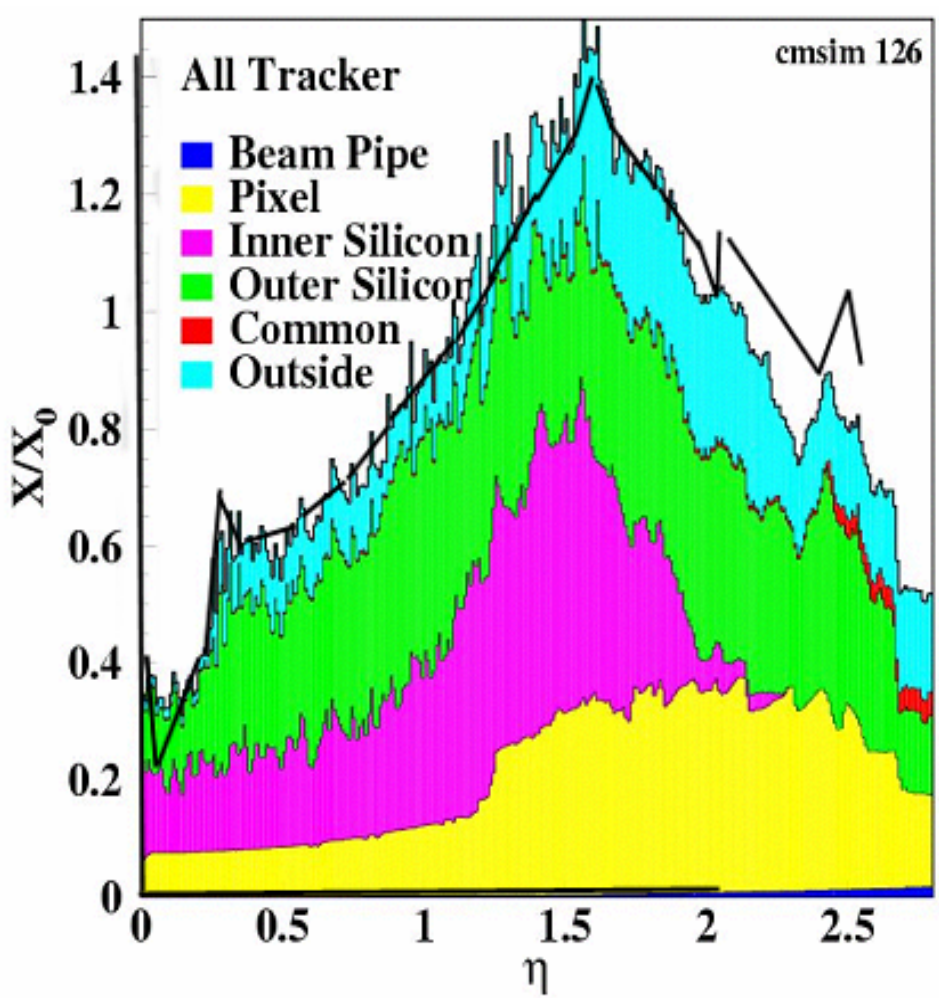
⇨ 15,232 single-sided equivalent modules!

- Strip length / Thickness:
  - ⇨ For r ≤ 55cm: 11.9cm / 300 μm
  - ⇨ For r > 55cm: 18.9cm / 500 μm

CMS

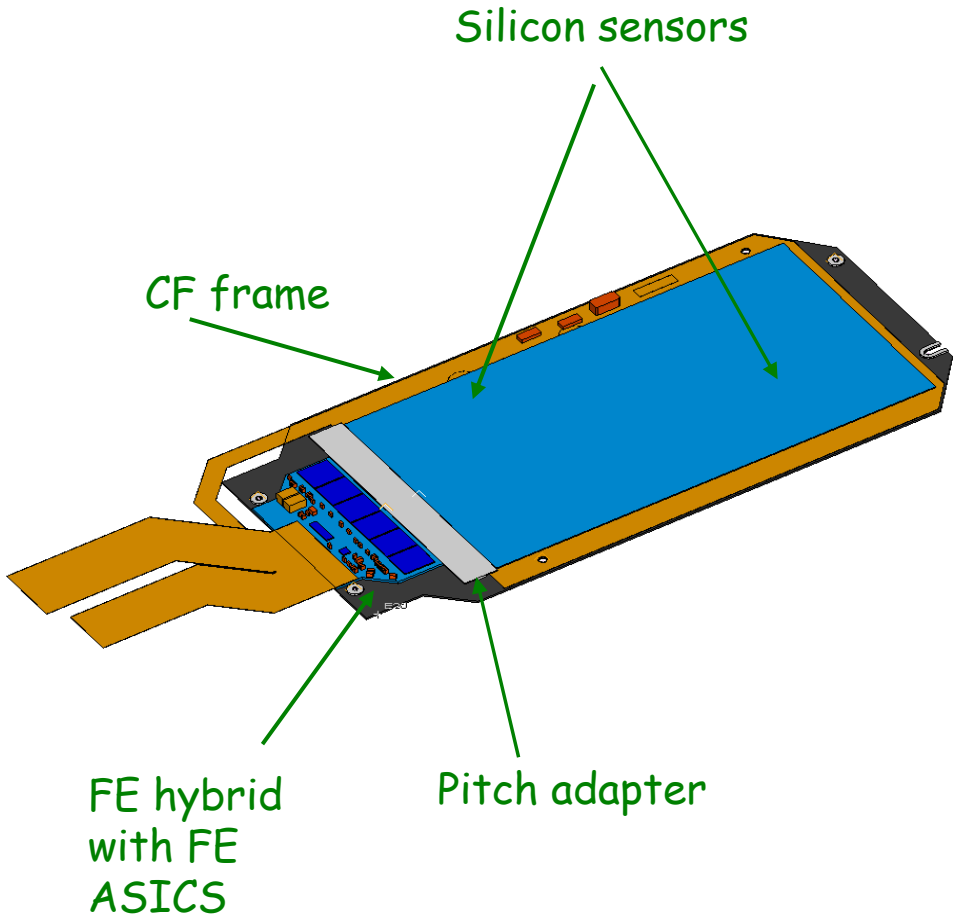
- Layout (3) (Number of hit points and dead material budget)





CMS

- Module components and accounting:



- 6,136 Thin sensors
- 18,192 Thick sensors

- 6,136 Thin detectors (1 sensor)
- 9,096 Thick detectors (2 sensors)

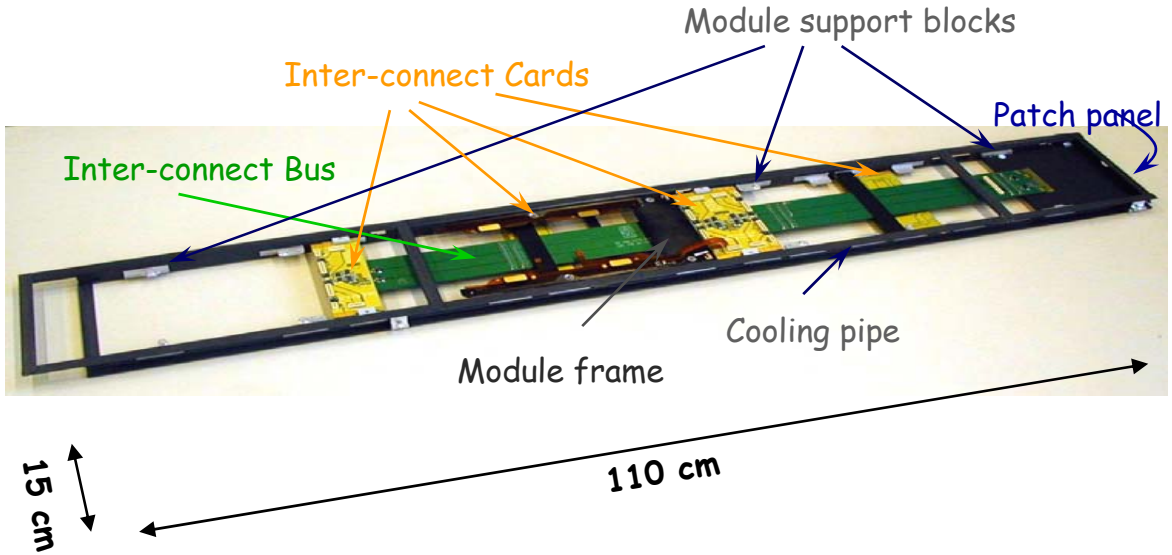
- 3112 + 1512 Thin modules (ss +ds)
- 5496 + 1800 Thick modules (ss +ds)

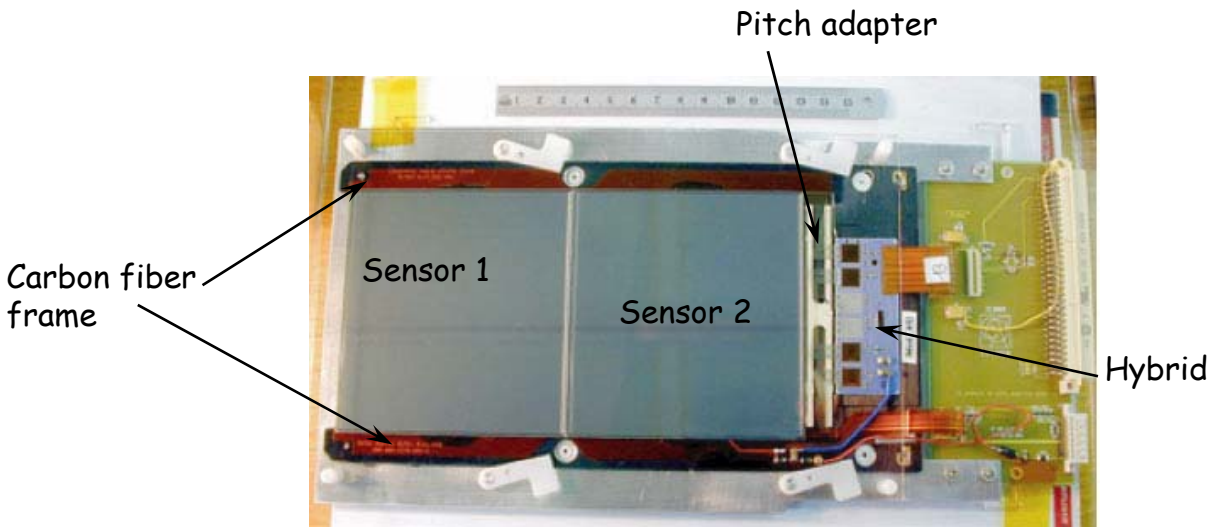
- 9,648,128 strips ≡ electronics channels

- 75,376 APV chips
-
- 25,000,000 Bonds

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

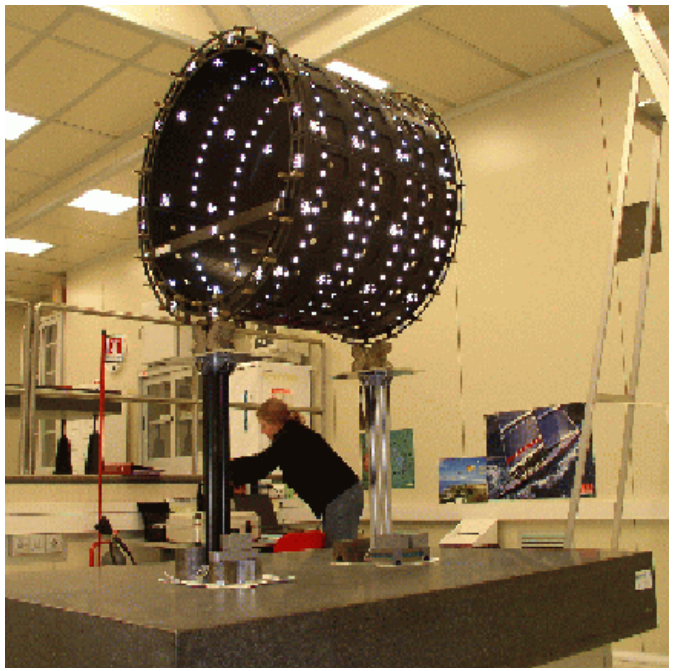
- Tracker Outer Barrel: TOB

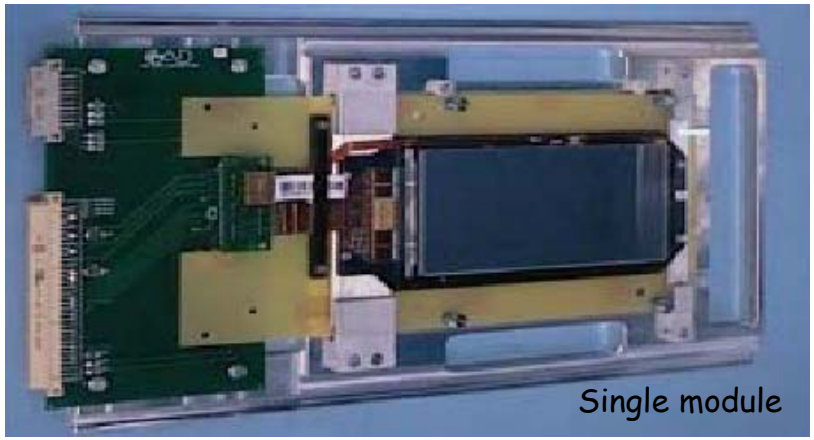


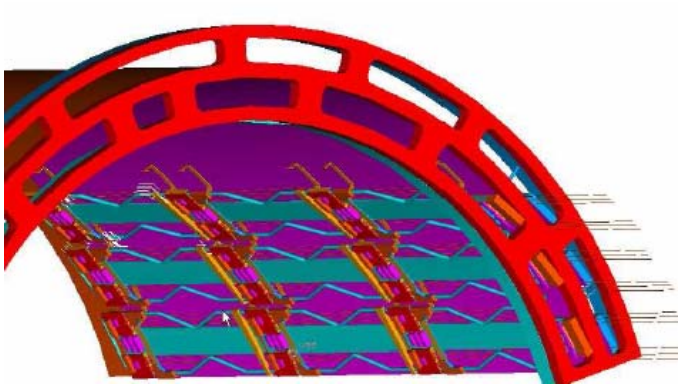


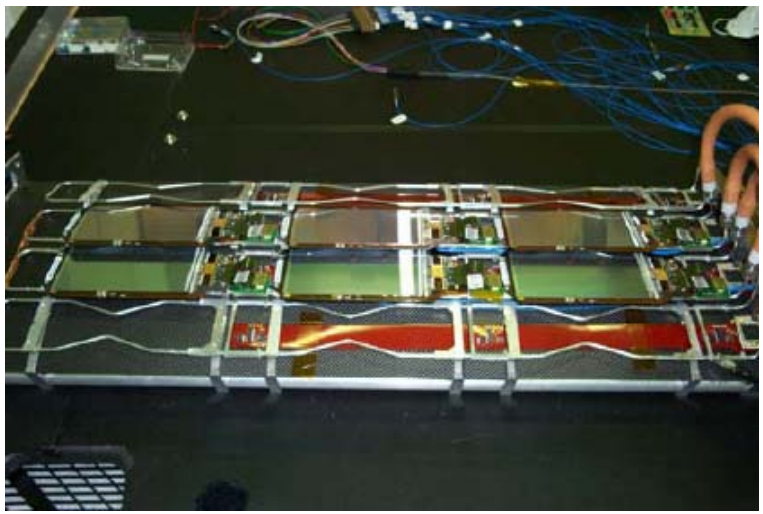
CMS

- Tracker Inner Barrel and Disk: TIB and TID





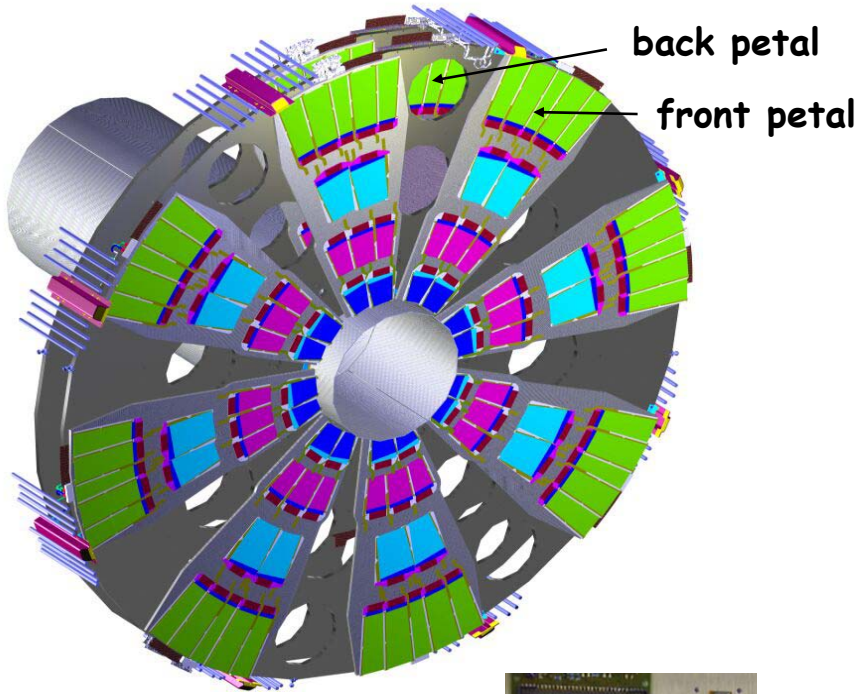




CMS

Tracker End-Cap: TEC

- Two end-caps with 9 wheels each
- On each wheel: 8 front and 8 back petals
- Wedge shaped modules mounted on petals
- Petals can be extracted and inserted individually



CMS

Choice of silicon sensors and readout

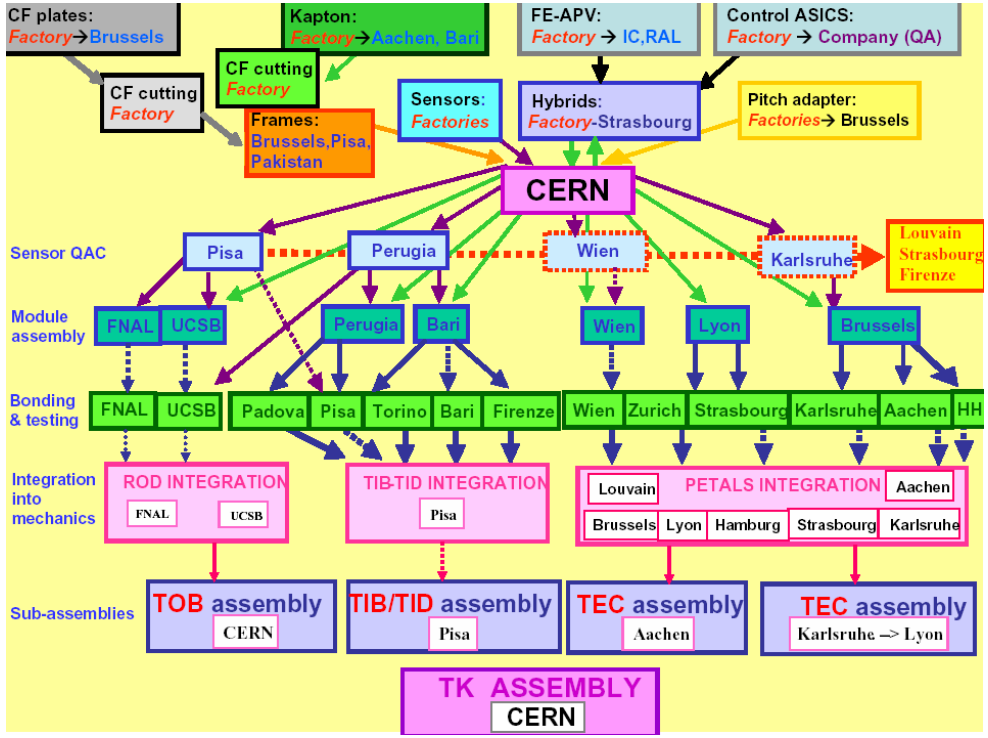
- Sensors:
  - Single-sided silicon strip detectors: p+ on n, AC coupled with polysilicon bias resistors of 1.5MΩ
  - Different geometry (rectangular and wedge shaped) with varying strip pitch (80 – 200 μm) and strip length (9 – 20 cm) moving from smaller to larger radii
  - Compensation for higher capacitance by longer strip sensors by thicker substrate: 300μm for r ≤ 50cm and 500μm for r > 50cm
  - Resistivity: 1.3-3.0kΩcm for thin and 3.5-70kΩcm for thick sensors
  - 14 different sensor designs
  - Two manufactures: Hamamatsu (thin sensors) and STMicroelectronics (thick sensors)
  - Quality: Better acceptance rate in case of Hamamatsu

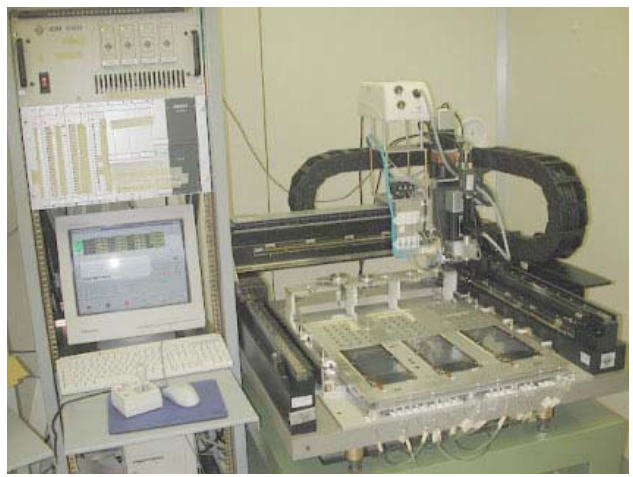
Extensive R&D programs have been carried out to investigate sensor type, geometry and substrate by means of simulations, irradiations, electrical characterization and beam tests!

- Readout: Analog readout based on APV chips
  - Charge sensitive amplifier and shaper with 50ns shaping time
  - Analog pipeline: 40MHz sample frequency and storing of samples in pipeline memory for a time equal to the L1 trigger latency (3.2μs)

Production

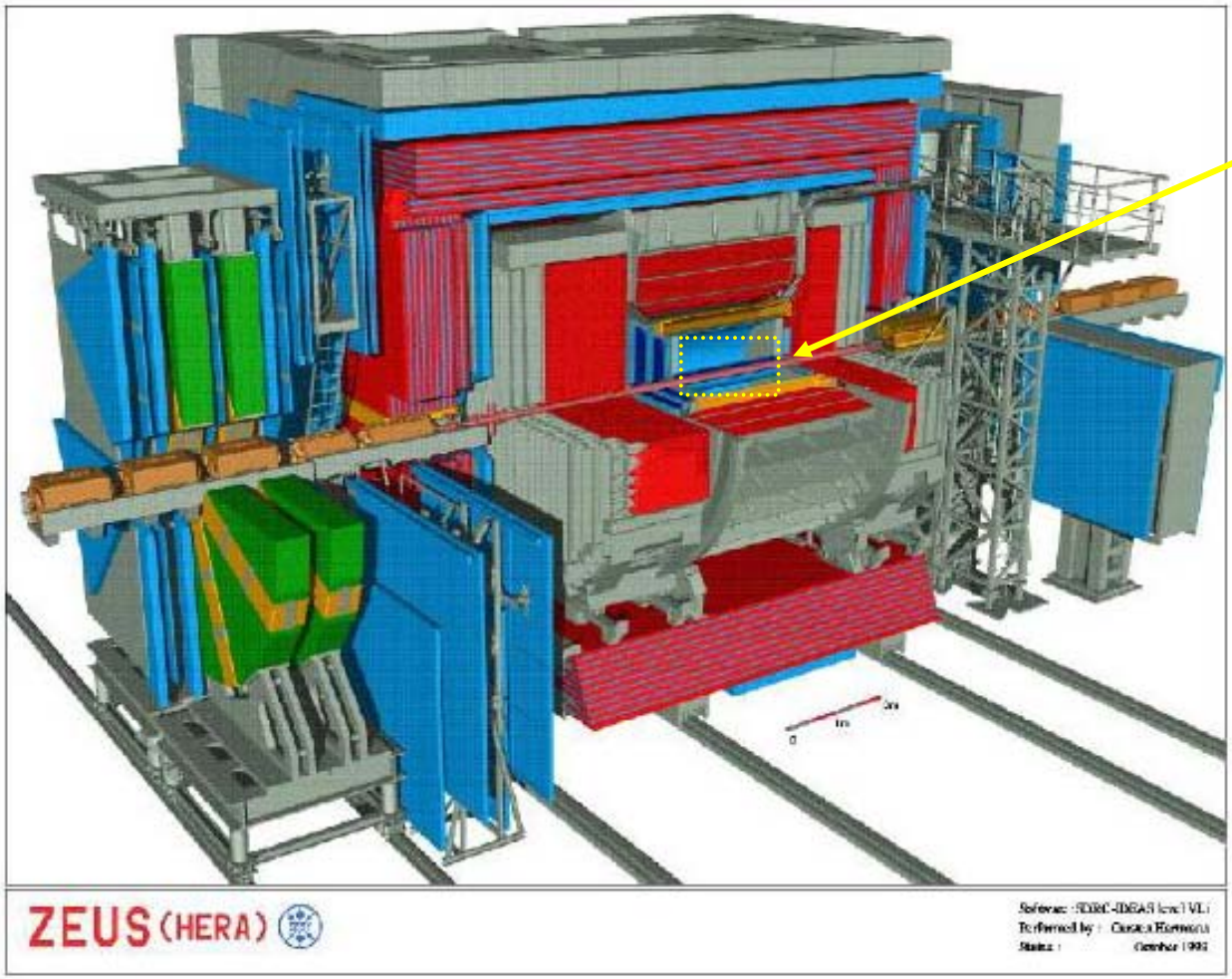
- Quality assurance, assembly and bonding will be realized under quasi-industrial conditions with high multiplicity:
  - 4 centers are testing the overall sensor quality using fully automatic probe stations
  - 3 centers are monitoring the process quality
  - 2 centers are checking the radiation hardness.
- Assembly robots in 7 centers, plus industrial bonding machines in 12 places ensure high quality and reliability over the long construction period
- All parameters and logistics are monitored using a global database
- Assembly: 50 modules/day
- Micro-bonding: 16 modules/day
- CMS module production: 2.5years





ZEUS

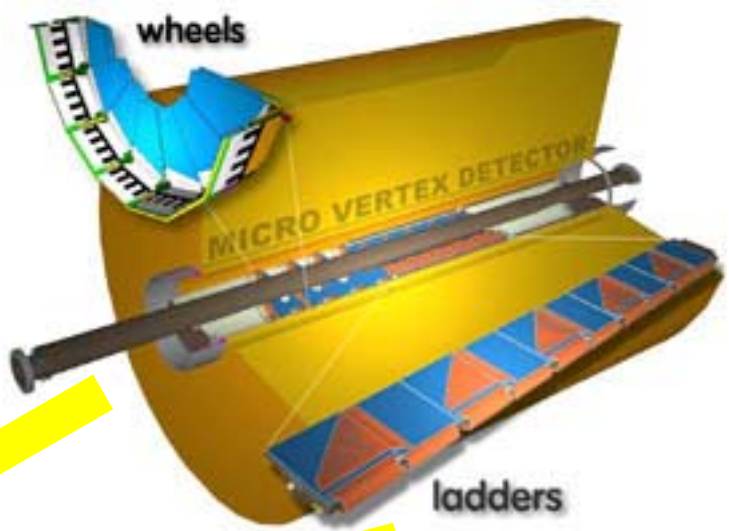
- The ZEUS Micro-Vertex Detector (MVD)



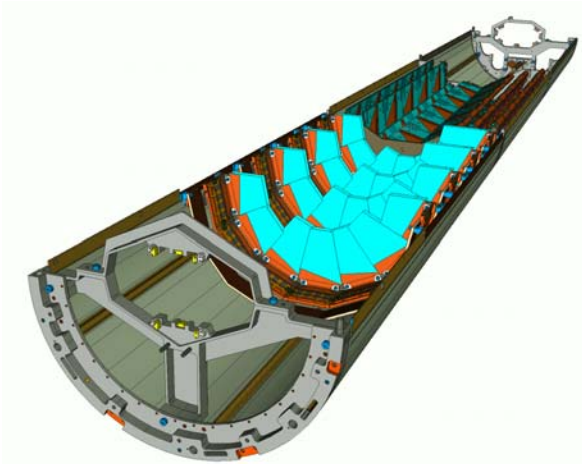
ZEUS

- MVD design

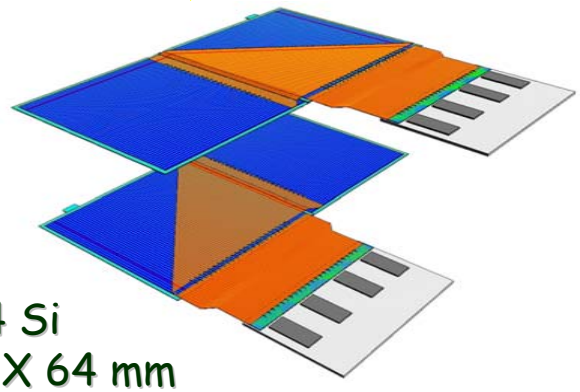
The detector consists of a 65cm long Barrel with 3 layers of Si detectors parallel to the beam. These layers are constructed of several carbon-fiber supports each with 5 Si module (Ladders)



In the forward region there are 4 layers of Si detectors, perpendicular to the beam. 14 modules are mounted on a carbon-fiber support (Wheel)



Half MVD contained in a carbon-fiber sandwich support tube

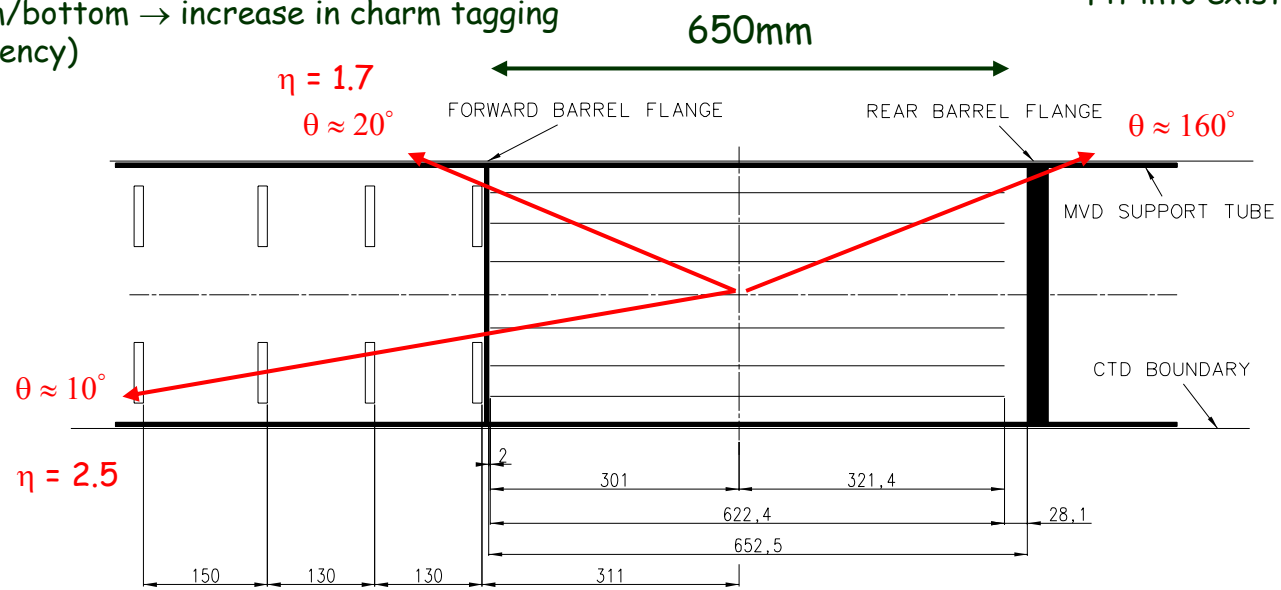


Module with 4 Si detectors 64 X 64 mm

MVD design

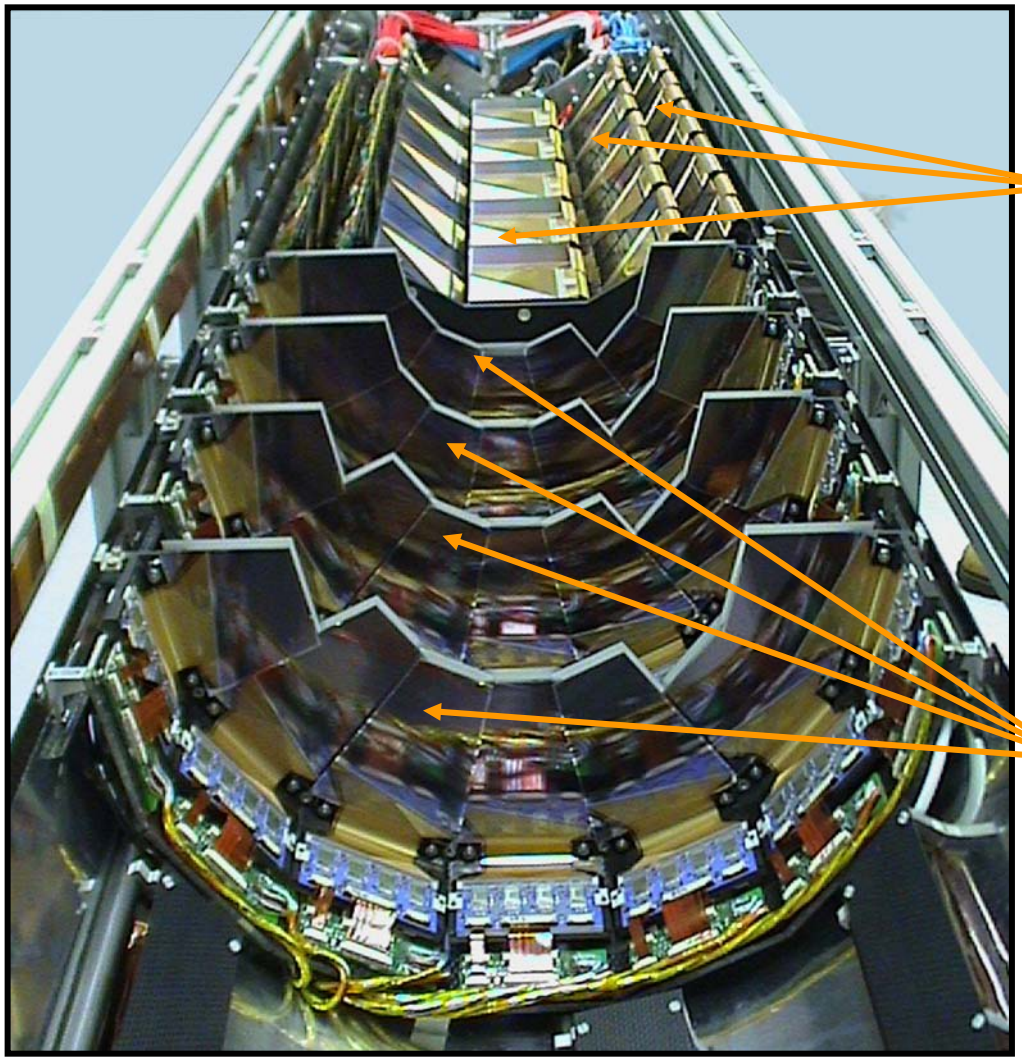
- Motivation:
  - Increase of angular acceptance in the forward direction (high Q^2 events)
  - Improvement in the overall precision of the tracking system (momentum and impact parameter resolutions)
  - Tagging events with displaced secondary vertices (long-lived particles e.g. weak decays of hadrons containing charm/bottom → increase in charm tagging efficiency)

- Design considerations:
  - Polar angle coverage: 10° - 170°
  - 3 spatial measurements in 2 projections per track
  - Point resolution ≤ 20μm
  - Impact parameter resolution ~ 50μm
  - Hit efficiency > 97%
  - Two-track separation ~200 μm
  - Alignment accuracy ~20 μm
  - Fit into existing detector layout



ZEUS

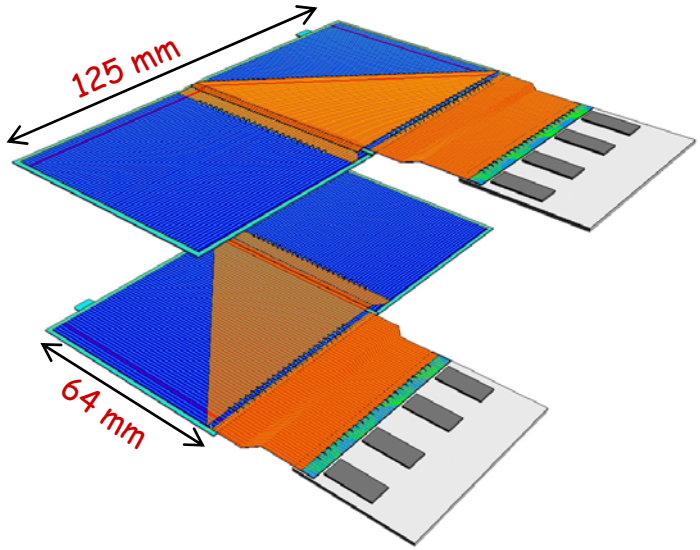
MVD design



- Barrel MVD:
  - 3 cylinders: 4, 10 and 16 ladders
  - 1 ladder: 5 modules
  - 1 module: 1 (r-z, r-ϕ) + 1 (r-ϕ) half-module
  - 1 half-module: 512 readout channels
- Forward MVD:
  - 4 wheels: 14 sectors
  - 1 sector: 2 trapezoidal sensors (r-ϕ)
  - 1 sensor: 480 readout channels

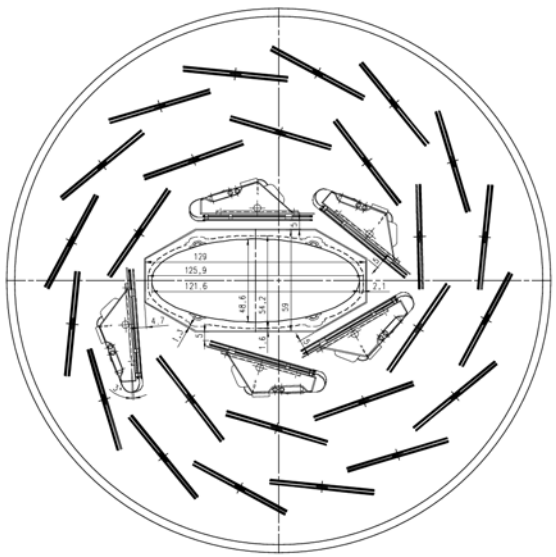
Barrel modules

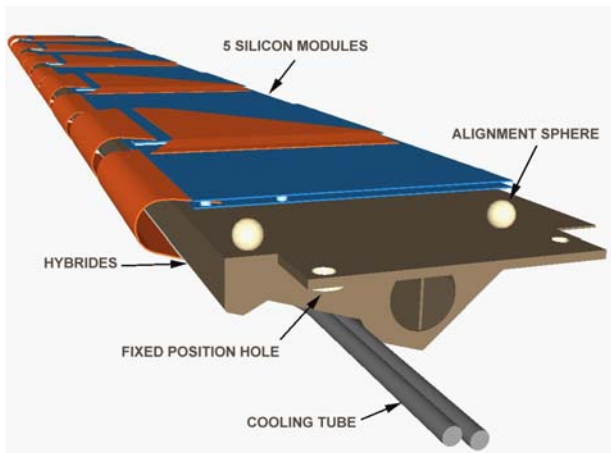
- Two single side sensors are glued and bonded to gold strips plated on Upilex flex foils, and finally to a FE hybrid
- Two planes are glued together to form a module with x-y readout



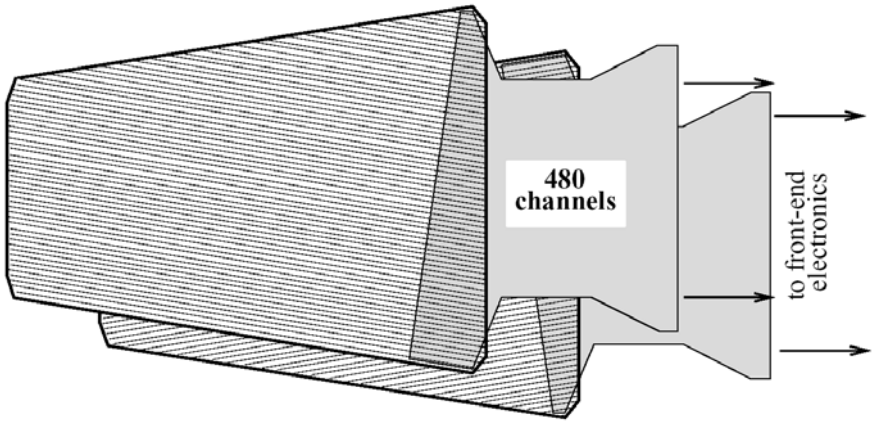
- Five modules are mounted on a carbon fiber support structure to form a ladder.
- The Si planes, Hybrids and Cabling are located on the 3 planes of the ladder

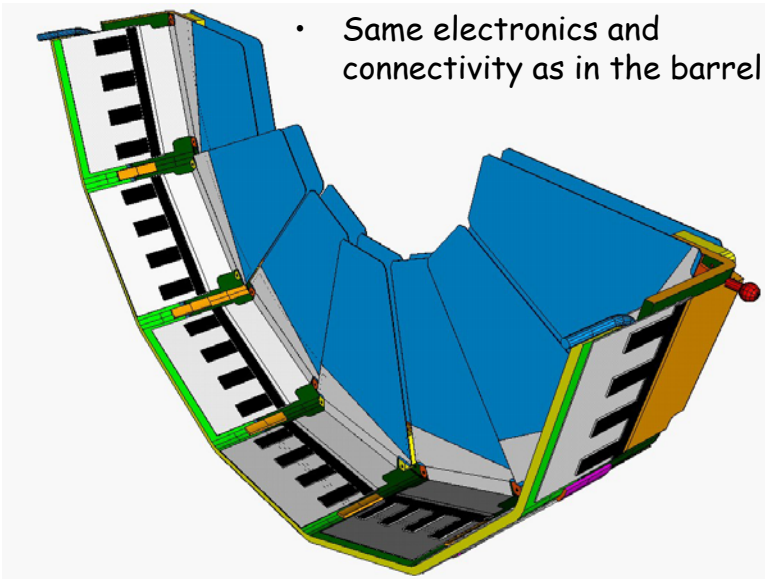
- 30 ladders, in 3 planes, are positioned around the elliptical beam pipe in the MVD barrel detector





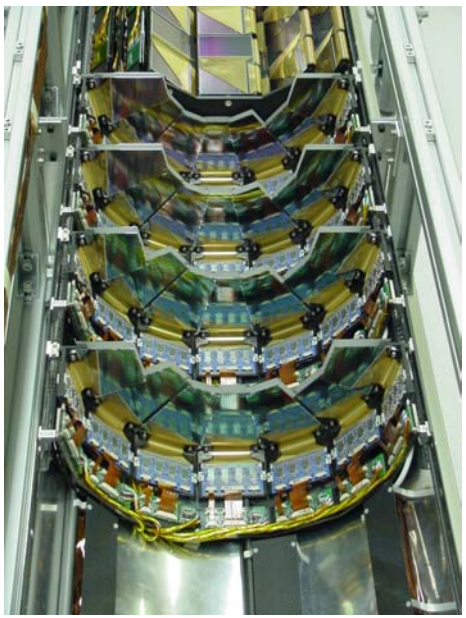
Forward wheel modules

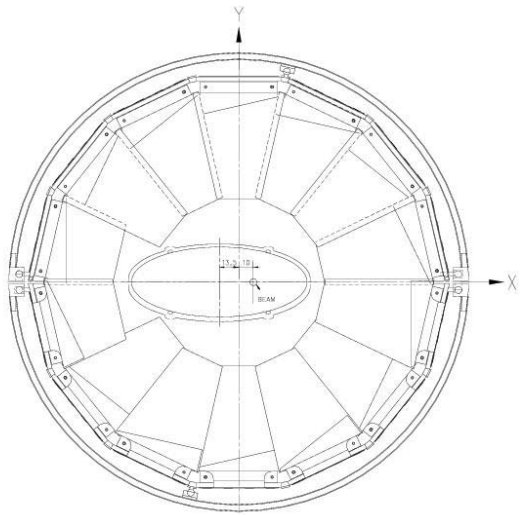




- Same electronics and connectivity as in the barrel

- The forward wheels have detector differently shaped (trapezoidal with two different sizes to accommodate the beam pipe)
- Two layers of single side Si detectors, same pitch and construction as in the barrel, strips cross at an angle of 26°

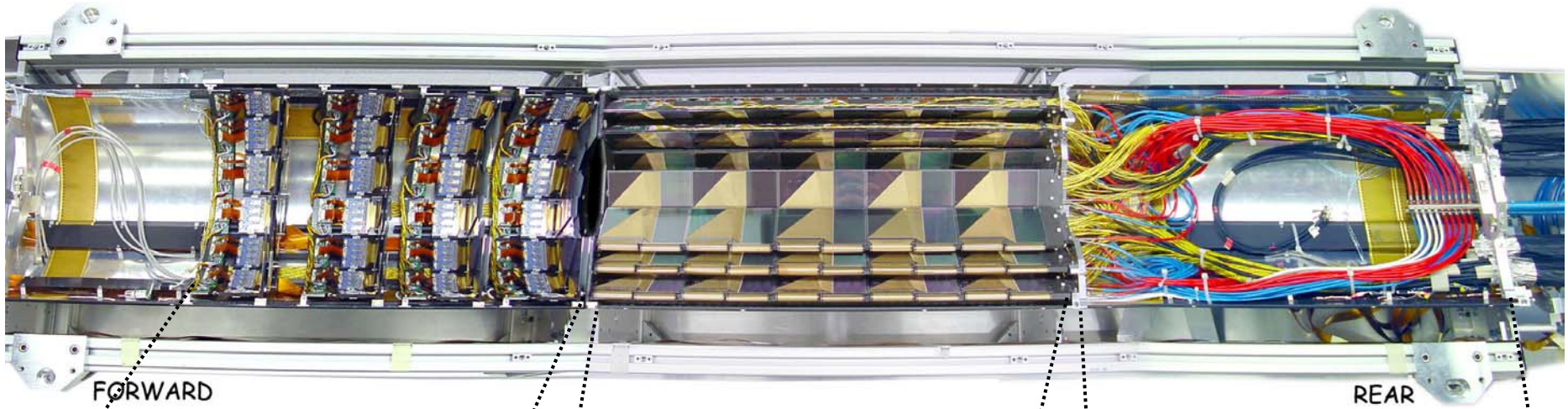




ZEUS

- Overall structure

One half of the entire MVD!

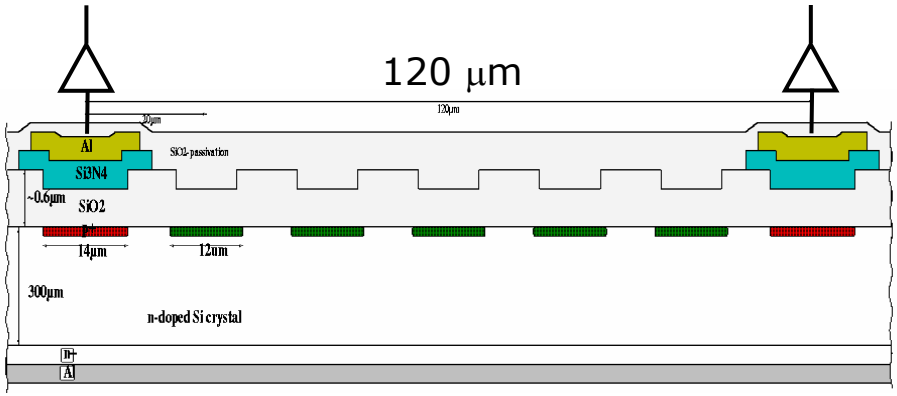


The forward section:
- 4 wheels
- each one composed by 2 layers of 14 Si detectors
- Total of 112 hybrids, >50k channels

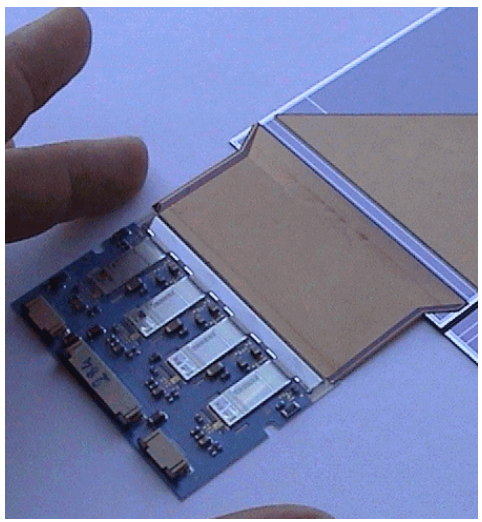
The barrel section:
- 30 ladders
- each one composed of 5 modules of 4 Si detectors
- Total of 300 hybrids, >150k channels

The read section:
- Cooling pipes and manifolds
- Distribution of FE, slow control and alignment cables

Sensors and readout

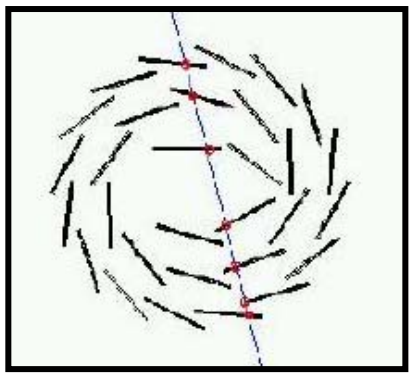


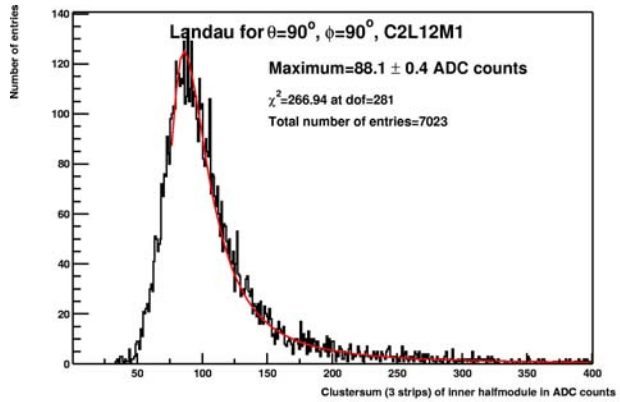
- n-doped silicon wafers (300 μm thickness) with p+ implantations (12 or 14 μ m wide), HAMAMATSU
- 512 readout AC coupled channels in the barrel, 480 in the wheels
- Using the capacitive *charge sharing*, the analogue readout of one strip every 6 allows a good resolution (<20 μ m) despite the readout pitch of 120 μ m

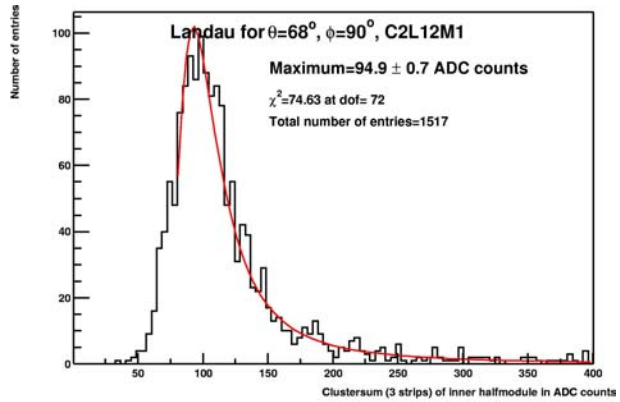


- Readout with analogue chip (HELIX3.0, Heidelberg+Nikhef) built with AMS 0.8 CMOS technology
- Only preamp, analog pipeline and drivers on chip
  - LVDS Clock and Control drivers 6m far on special patch boxes
  - ADCs 30m far on the MVD racks !
- Special care on cabling, signal handling, grounding, shielding!

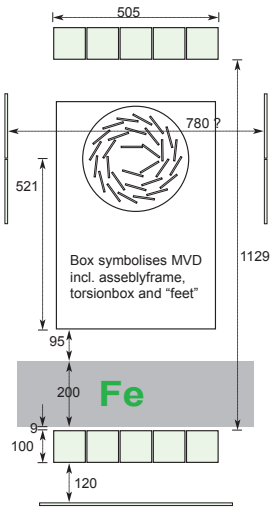
MVD performance (Cosmic ray test-stand)

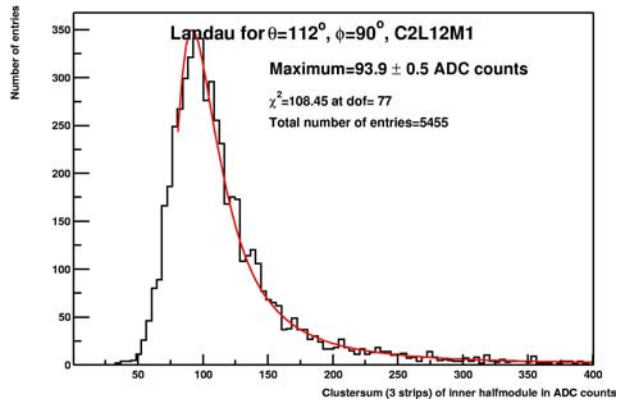






Cosmic ray events during the MVD cosmic ray test





- Landau distributions selecting different angles for one detector module
- The peak positions scale with the respective impact angle

ZEUS

- ZEUS MVD events display (High Q^2 DIS event)