The CMS Silicon Strip Tracker

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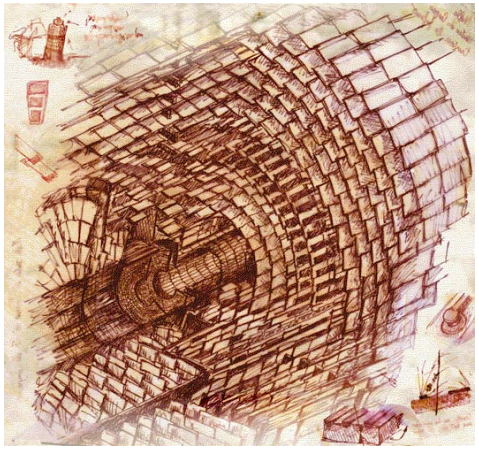
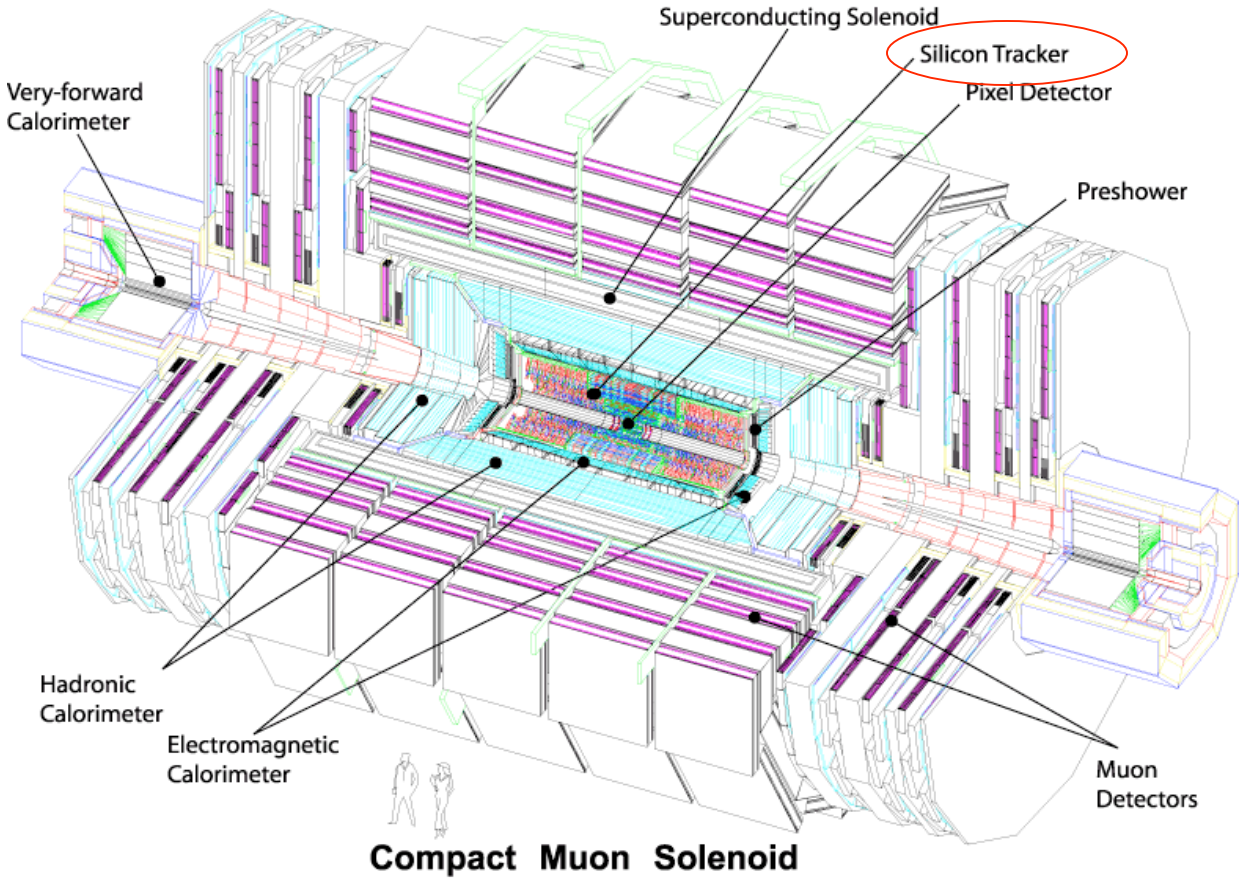


PANIC05
Santa Fe, 23-28 October, 2005

The CMS detector

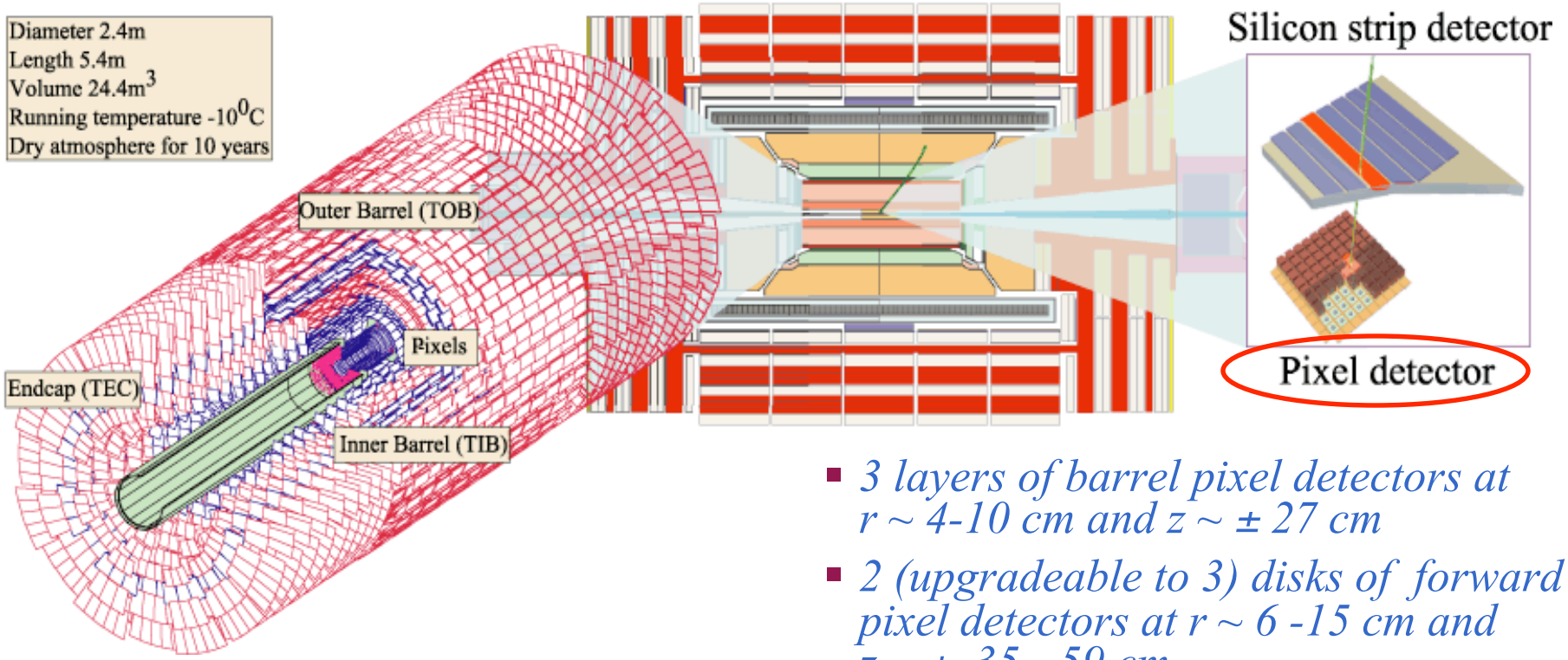
LHC at CERN: pp collisions at s=14 TeV from 2007
design luminosity: 10^{34} $cm^{-2}s^{-1}$, bunch crossing: 40 MHz

Compact
Muon
Solenoid
detector



Magnetic field: 4 T
Weight: 12500 t
Length: 21.6 m
Diameter: 15 m

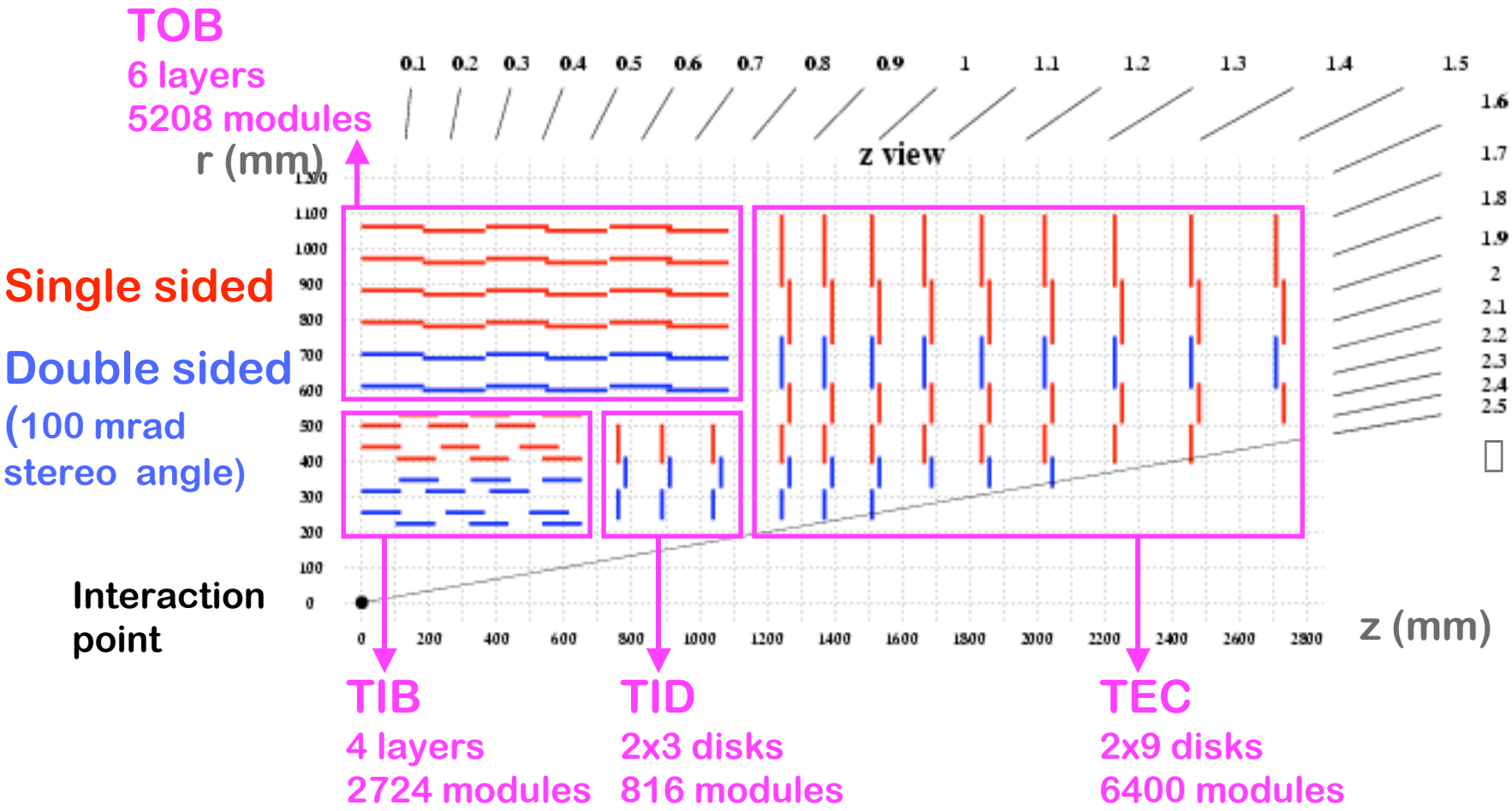
The Silicon Tracker



fluence ~1.6 10^{14} n(1 MeV equiv..)/cm^2 in 10 years at the innermost TIB layer

- *3 layers of barrel pixel detectors at r ~ 4-10 cm and z ~ ± 27 cm*
- *2 (upgradeable to 3) disks of forward pixel detectors at r ~ 6 -15 cm and z ~ ± 35 - 59 cm*
- *300 μm thick silicon sensors with 100·150 μm pixel size*
- *See talk of Ping Tan in this session*

The Silicon Strip Tracker layout



Barrel: strips parallel to beam
End cap: strips in radial direction

The size of the project

15 148 modules
24 244 silicon sensors
75 000 readout chips
9 600 000 readout channels
(=silicon strips)
25 000 000 wire bonds
210 m^2 active silicon area
29 module types
16 sensor design
12 hybrid types

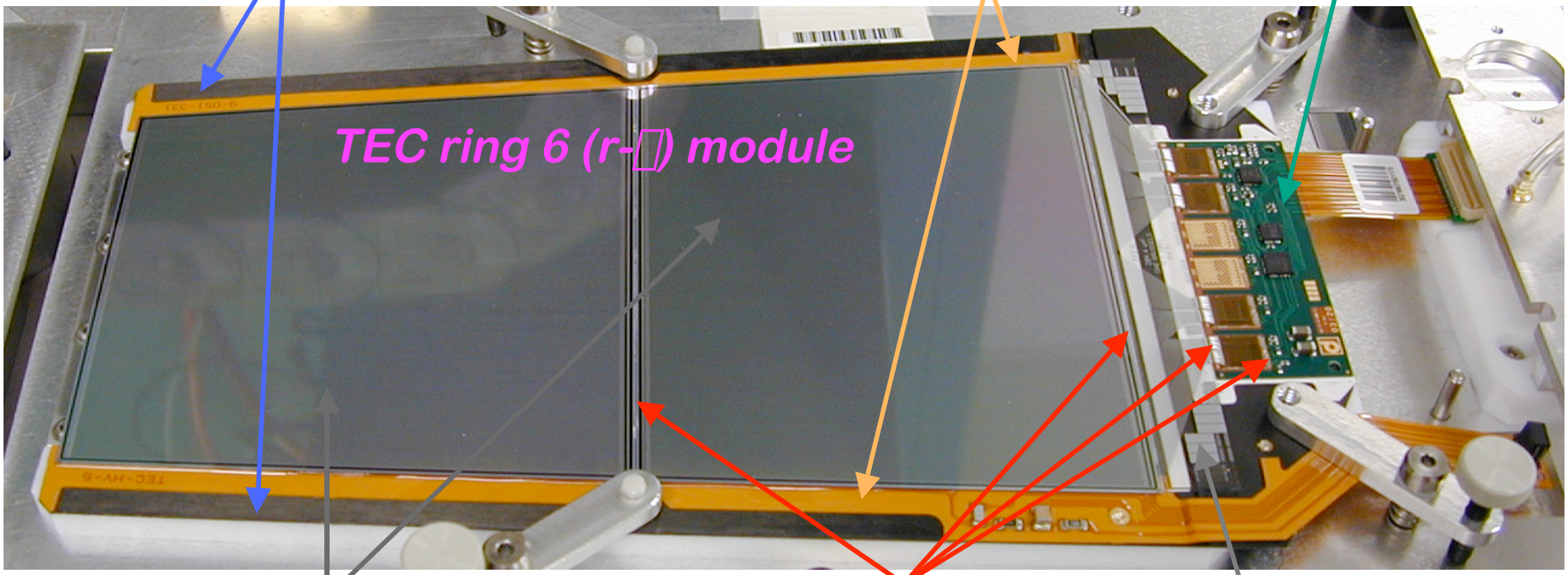
Complex logistics
involving ~ 25 institutes
and many industrial partners

The basic element: the module

Support frame
(graphite and carbon fiber)

Kapton circuit
- bias voltage
- backplane isolation
- temperature sensor

Front-end hybrid
with flex tail



Silicon sensors
- 1 or 2 per module

micro-bonds

Pitch adapter (glass)
- fan-out from readout chip to sensor

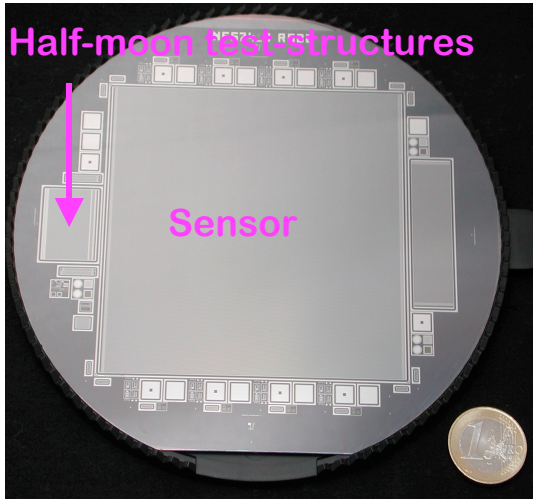
Double sided modules are constructed from two independent single sided modules mounted back to back with a stereo angle of 100 mrad

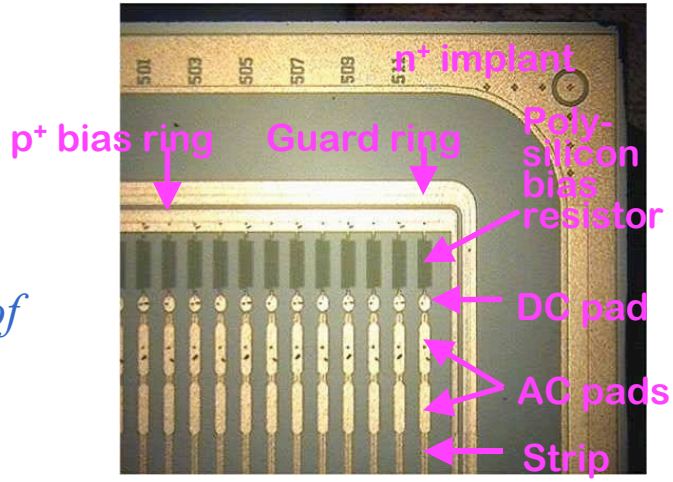
Silicon strip sensors

Simple and robust design
compatible with mass production

- *Single sided*
- *n-type bulk, not oxygenated,<100> lattice orientation*
- *Inner region: low resistivity 1.5-3.5 k□cm, thin 320 □m*
- *Outer region:high resistivity 3.5-7.5 k□cm, thick 500 □m*
- *512 or 768 p^+ strip implants with pitch = 80-205 □m, width/pitch = 0.25*
- *Al readout strips, AC coupled, metal overhang 4-8 □m*
- *p^+ guard ring floating, metal field planes extend beyond implantation of guard ring*
- *Distance between the implant region and edge: 2·thickness+110 □m*

- *16 different sensor designs*
- *Rectangular or wedge-shaped sensors with typical size of 10x10 cm made on 6" wafer*
- *Identical test-structures on every wafer type*

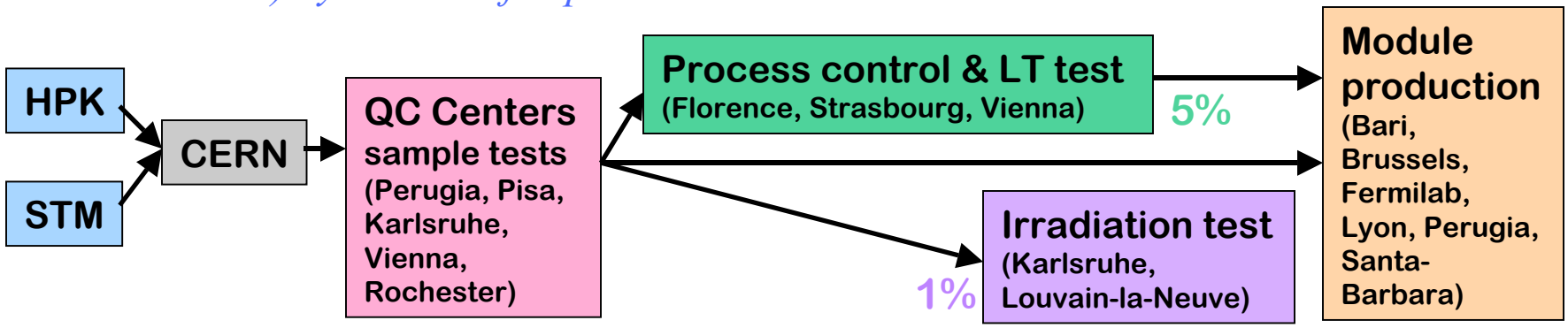




Sensor production

- *Total order (including prototypes and spares): 28600 sensors*
- *Thin sensors: Hamamatsu Photonics (HPK)*
- *Problems with thick sensors from SGS Thomson Microelectronics (STM) during mass production (low yield, unstable leakage current, high common mode, oxidation...)*
  ⇒ bulk of thick sensor production shifted to HPK
- *Thick sensors: 85% HPK, 15% STM*

- *All STM sensors delivered and qualified*
- *All HPK thin and 93% of thick sensors delivered, production will be completed in November 2005, excellent quality*
- *25555 sensors have been qualified and accepted for CMS*
- *An unprecedented extensive study of delivered wafers:*
  16 electrical parameters measured on about 13000 structures (8673 sensors and 4144 test-structures) by the end of September 2005

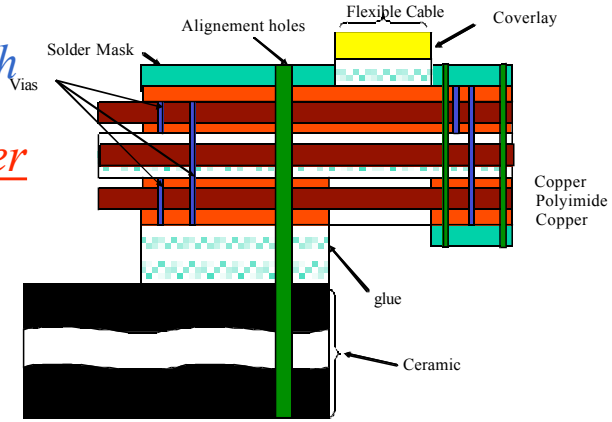


The front-end hybrid

- *Diverse functionality - strict constraints: mechanical and electrical interface to pre-defined elements, low mass, high reliability, inexpensive*

4-layer kapton substrate (flex) laminated to a ceramic carrier

- *12 different designs based on 3 layouts*
- *120 μm minimum feature size*



4 or 6 APV25 readout chips

- *Radiation hard 0.25 μm CMOS technology*
- *128 channels multiplexed to 1 analog output*
- *Charge sensitive amplifier with τ=50 ns, CR-RC shaper, 192 cell pipeline (4.8 μs) per channel*
- *Peak mode: 1 sample, τ=50 ns*
- *Deconvolution mode (for high luminosity): weighted sum of 3 samples, τ=25 ns*

MUX (Multiplexer)

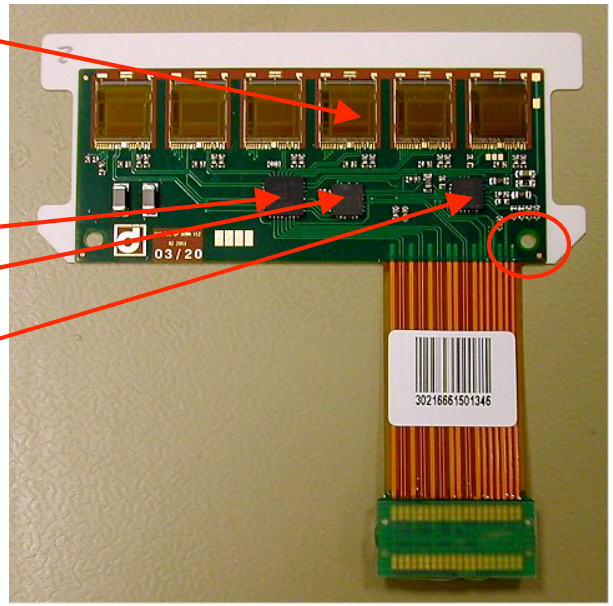
- *2 APV outputs multiplexed to 1 data line*

PLL (Phase-locked loop)

- *Decodes clock & trigger signals*

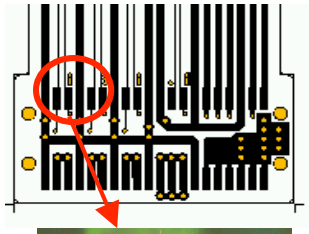
DCU (Detector Control Unit)

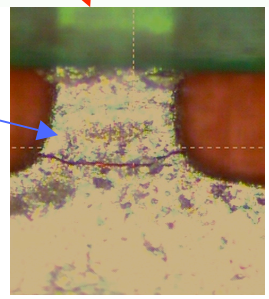
- *12-bit ADC for 8 channels: hybrid and sensor temperatures, leakage current, low voltages*

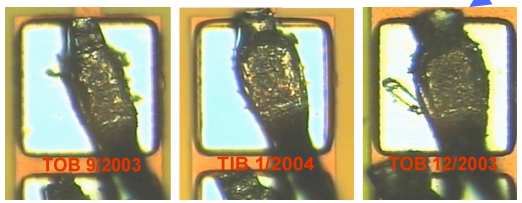


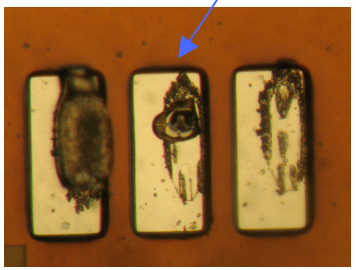
Front-end hybrid production

- *Flex circuits produced by Cicorel, assembly done by Hybrid SA*
- *Provided supplier with a test setup (Front-end Hybrid Industrial Tester)*
  - *Connectivity, electrical and functional tests in ~ 1 minute per hybrid*
- *Several problems at start-up and during mass production*
  - *Lamination on ceramic*
  - *Cracked lines near connector – fragile Ni/Au pads on kapton*
  - *Bonding quality and long-term reliability (over-deformation, cratering)*
  - *Broken via's*









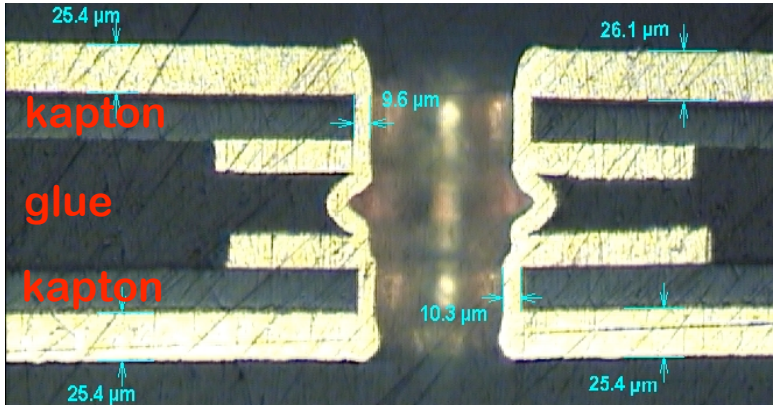
- *Response to problems*
  - *Strengthen QA/QC at producer and within CMS*
  - *Establish a backup hybrid line (flex circuits from GS Präzision, assembly at AmTech)*
- *Production stabilized, rate increased from ~300 to 400 hybrids / week*
  - *TIB: order completed*
  - *TOB: 90%*
  - *TEC: 64%*
  - *In total 82% completed*
  - *Production expected to end in December*

Problems during production

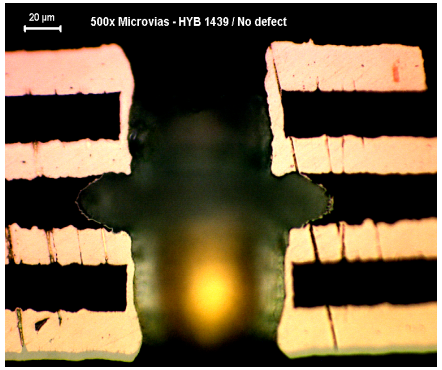
Unreliable via's

- *100 μm vias with broken contact (2004 April) found in module long-term test (anomalous pedestal behavior in a 10-20 minute period)*
- *hidden defect, not picked up by fast FHIT test (~1 minute)*
- *all vias tested at Cicorel, these must have broke during further processing*
- *serious concern with hybrid reliability: ~2180 hybrids rejected and ~320 modules affected*
- *solution: increase via diameter to 120 μm and add additional kapton layer*

Old design

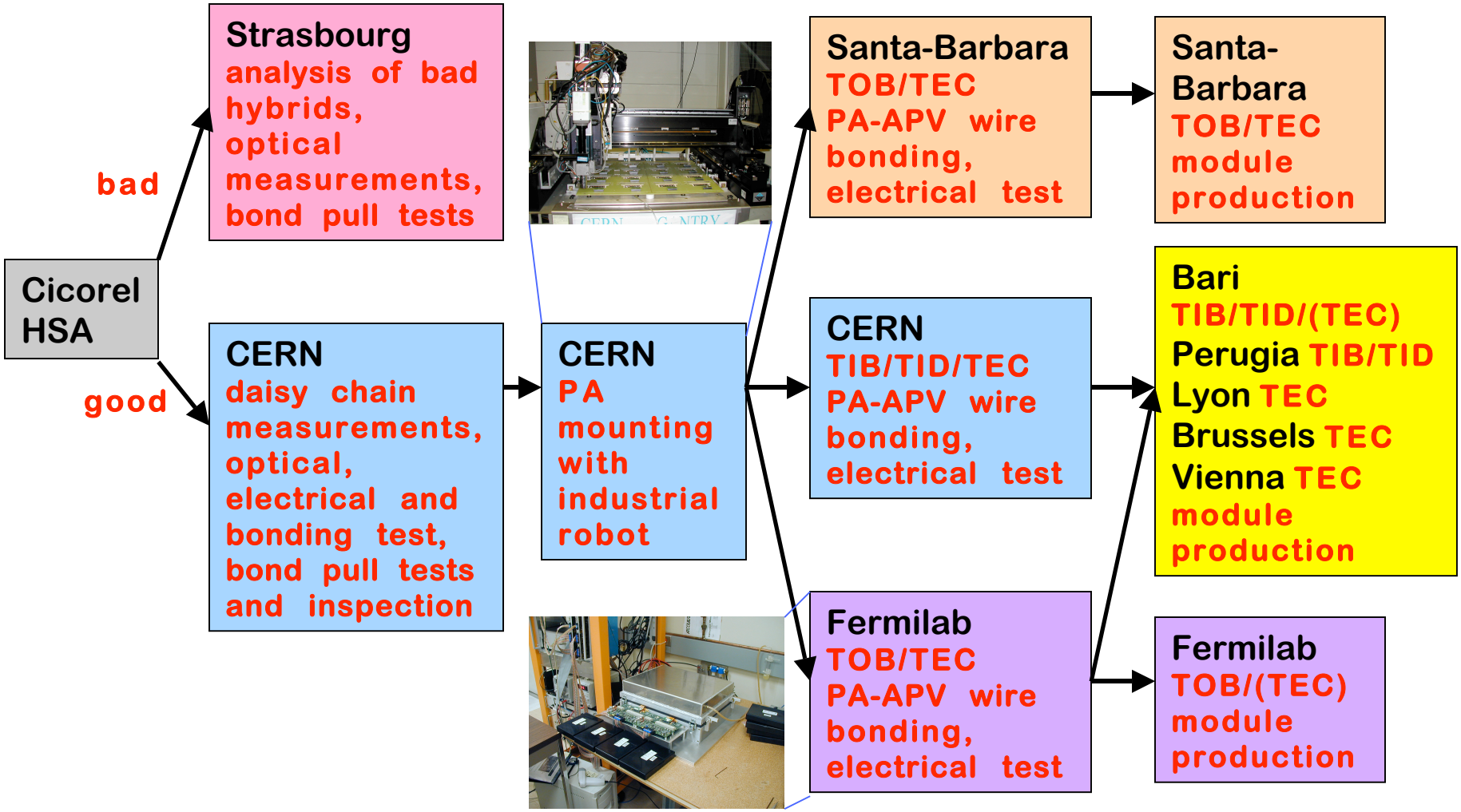


Bad via



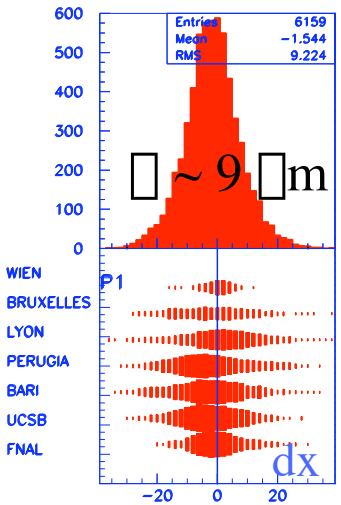
New design

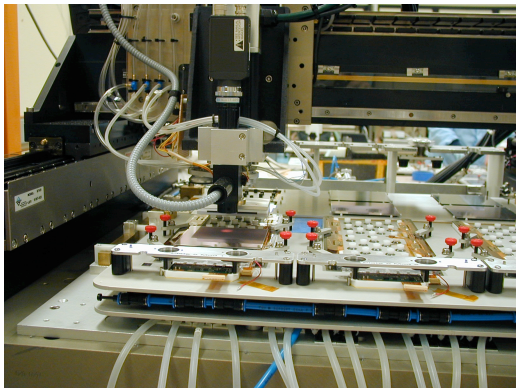
Front-end hybrid flow

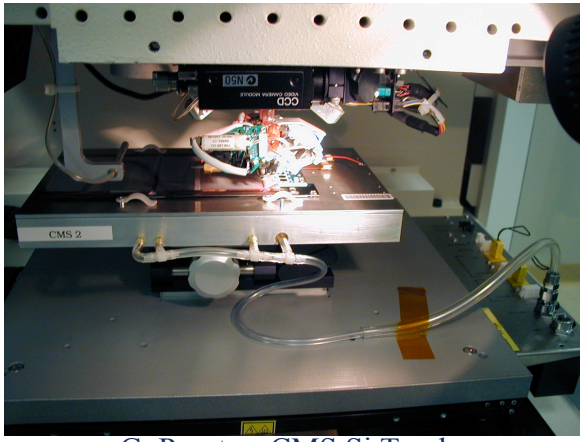


Module production and test

- *Robotic assembly of modules at 6 gantry centers: gluing the sensors and the FE hybrid to the frame with high precision (e.g. x strips < 39 m)*
  99% within specifications
- *Wire bonding between pitch adapter and sensor(s) using 23 automatic bonding machines*
- *Single module test with ARC (APV Readout Controller) and long-term test using a CMS like DAQ system including several thermal cycles:*
  - *Noise measurements*
  - *Pulse-shape verification*
  - *Bad strip identification (disconnected or shorted strips, pinholes, noisy channels)*
  - *IV curve*
  - *Pipeline errors*

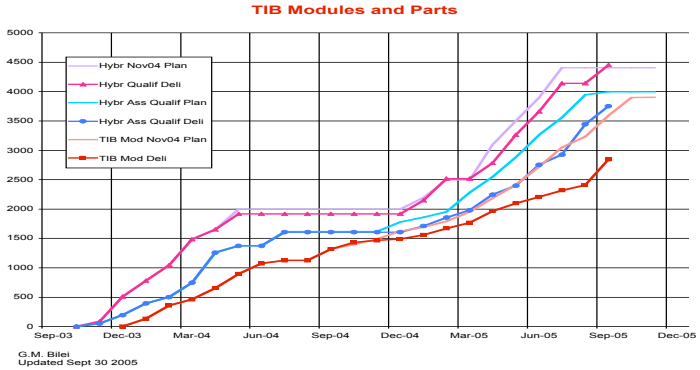


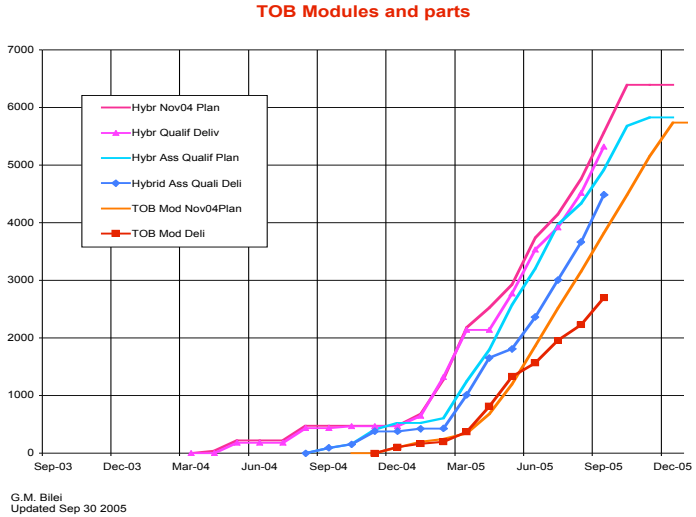


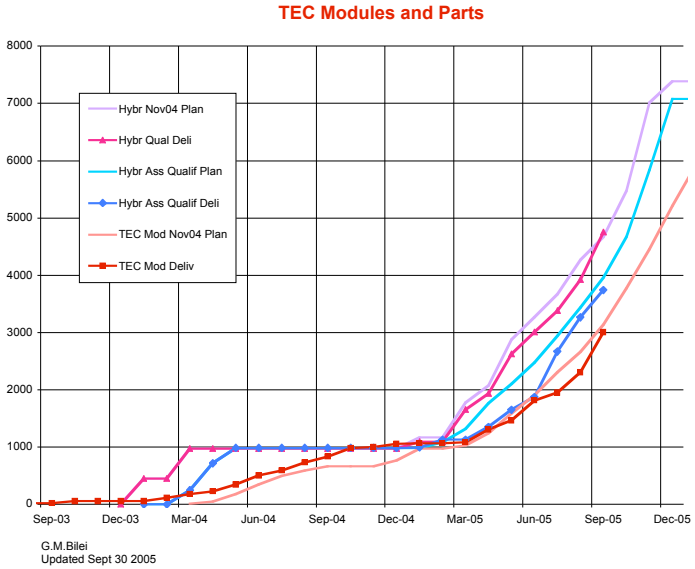


Module production status

- *Completed, not including spares:*
  - *TIB/TID: 80 %*
  - *TOB: 52 %*
  - *TEC: 42%*
- *Typically 0.1-0.3% of bad strips per module*
- *Module production yield (including mechanical and electrical problems): 94-99%*
- *Production rate, efficiency improves*
- *Expected end of production: February 2006*

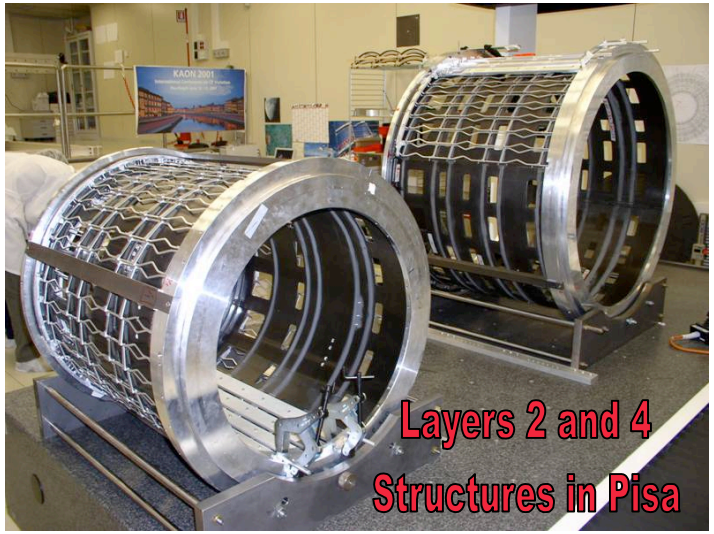






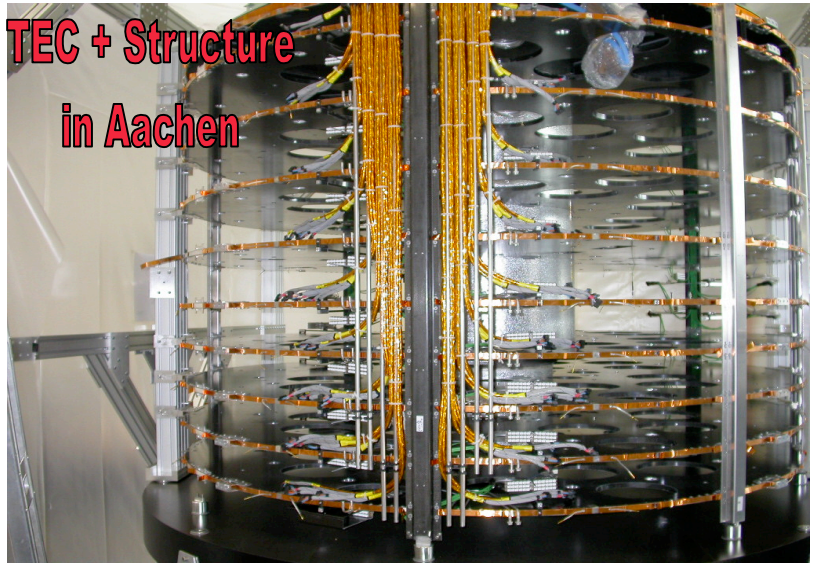
TIB structure

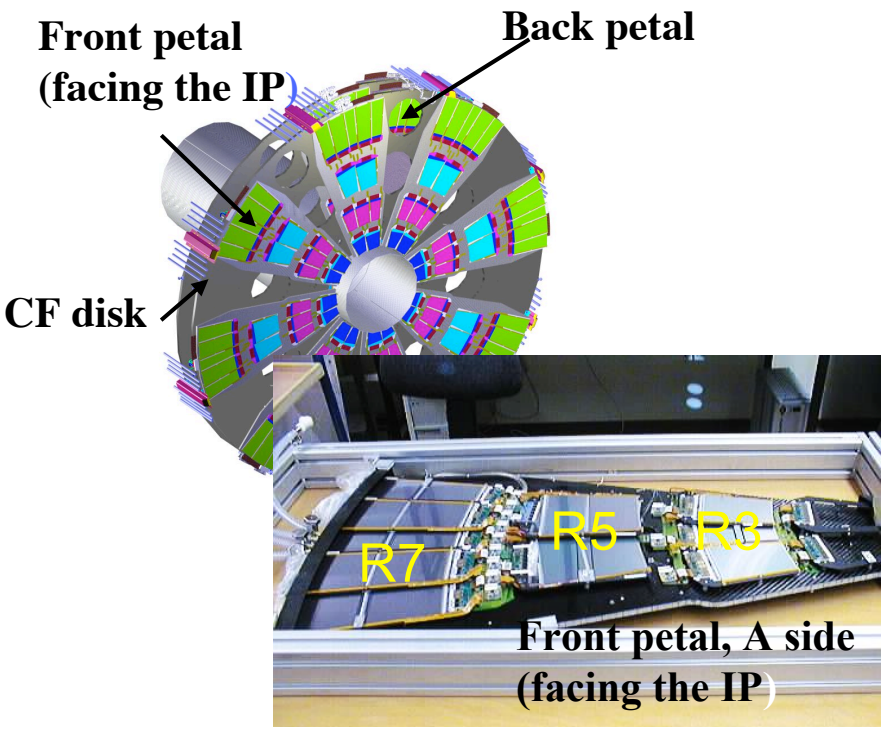
- *4 cylindrical layers each made of 4 carbon-fiber half-shells*
- *strings of 3 thin modules are mounted inside and outside the half-shells*
- *Layers 3+ and 4+ are completed*
- *Tests during installation and burn-in show excellent performance (e.g. noise compatible with expectations from single module tests)*



TEC structure

- *2x9 CF disks*
- *basic substructure - petal: wedge shaped CF support plate carrying up to 28 wedge shaped modules arranged in 7 radial rings*
- *Front and back petals have different geometry and have different number of modules*





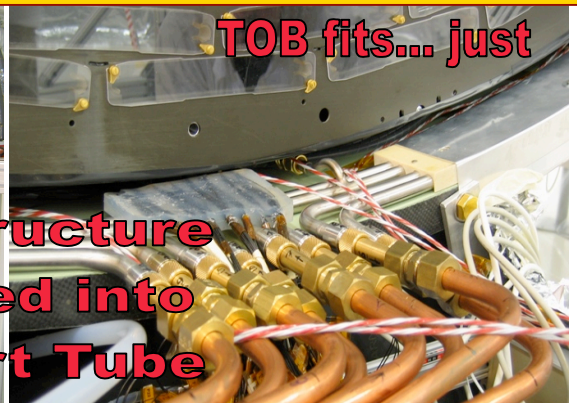
TEC+: more advanced

- *mechanically assembled*
- *rotation exercised*
- *photometry performed*
- *first experience to insert petals into structure*
- *first production petals modified for clearance*
- *cosmic trigger to be used during assembly tested*
- *wait for missing services (till November)*

TEC-: prepare for transport to CERN
for insertion test and integration

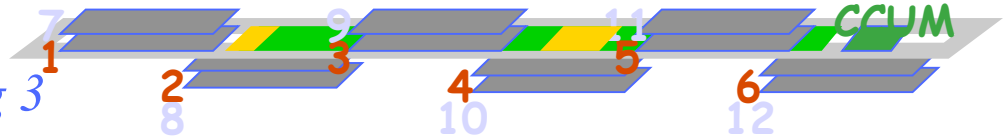
TOB support structure: wheel

Integration test, July 2005



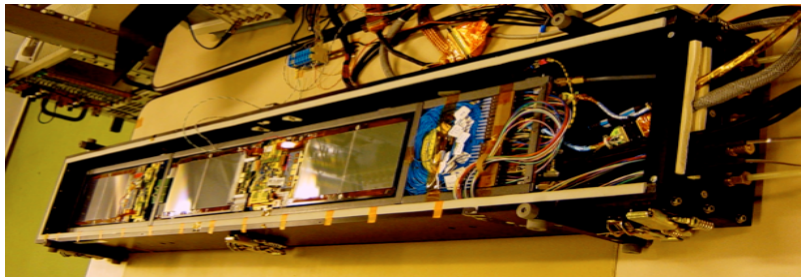
TOB sub-structure: rod

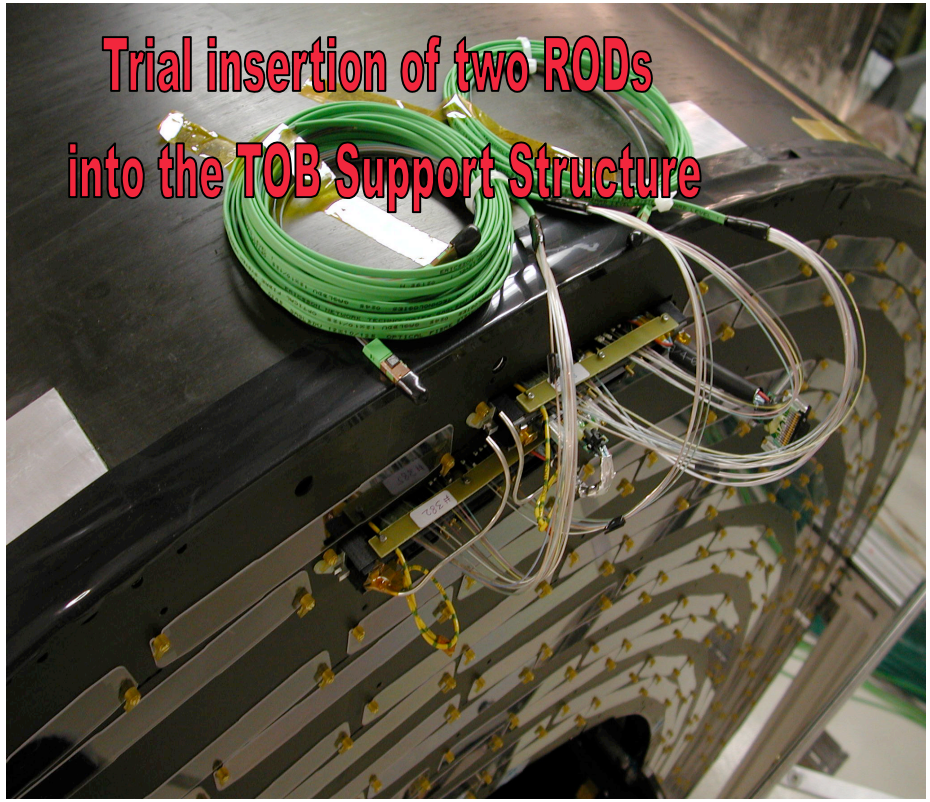
- *6 cylindrical layers*
- *basic substructure - rod: carbon fiber support frame carrying 3 single or 3 double sided thick modules on each side*



Rod production status:

- *all frames produced, ~ 60% cabled*
- *assembly started... 25/344 rods assembled and LT tested in the US*
- *reception tested at CERN with a Ruthenium source on an X-Y table: no rejected rods, 0.07% bad channels, S/N~23*
- *... but rod production paused to solve a problem with the I^2C system until November*





Substructure performance in testbeam

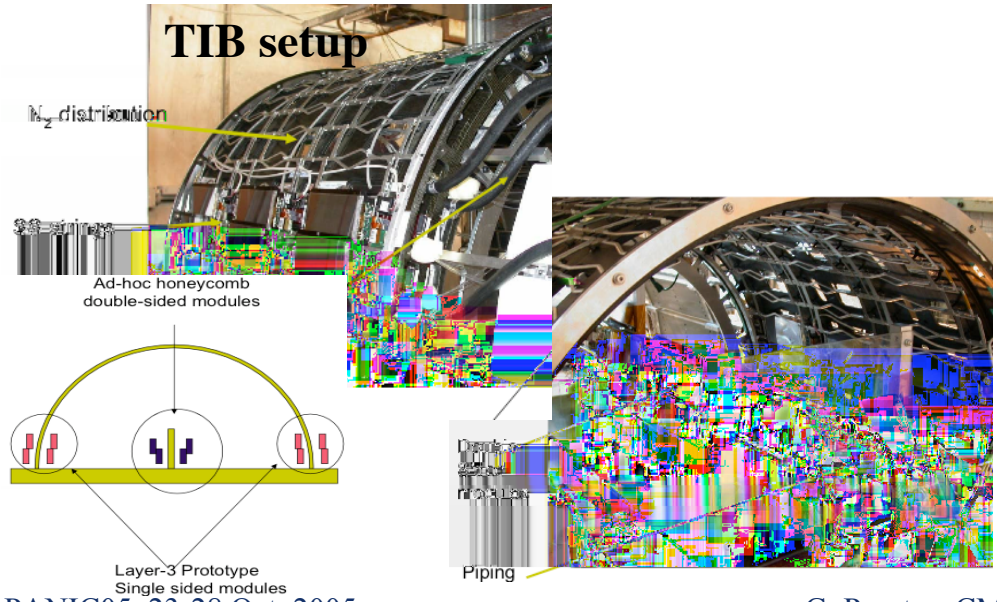
Beam: 120 GeV pions or 70-120 GeV muons at CERN X5 in 2004

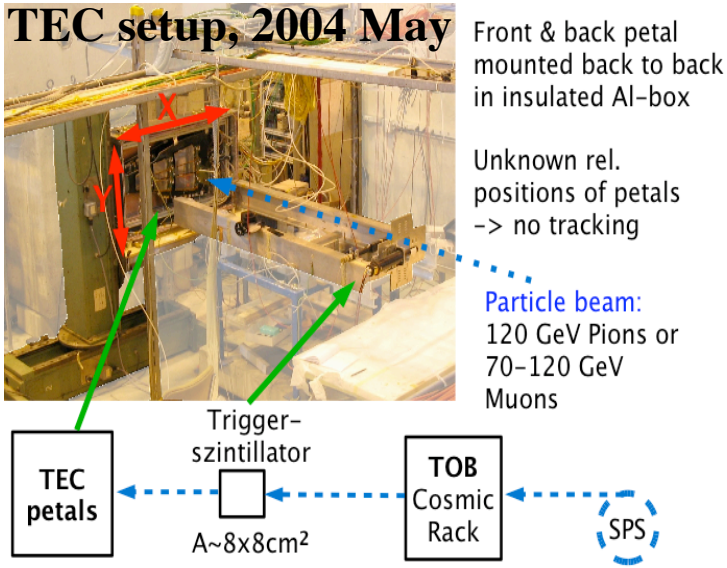
Including:

- *2 TEC petals (1 complete control ring with 51 modules, 1% of TEC)*
- *6 TOB rods in Cosmic Rack (precision support structure with integrated cooling) operated at CMS temperature (~-10 C)*
- *TIB Layer 3 prototype plus some double sided strings on an ad-hoc structure*

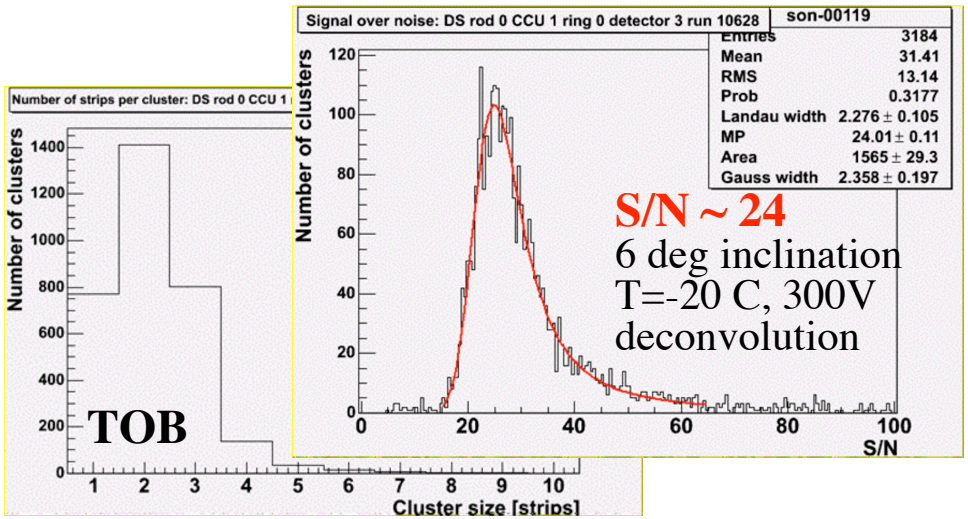
Excellent system behavior:

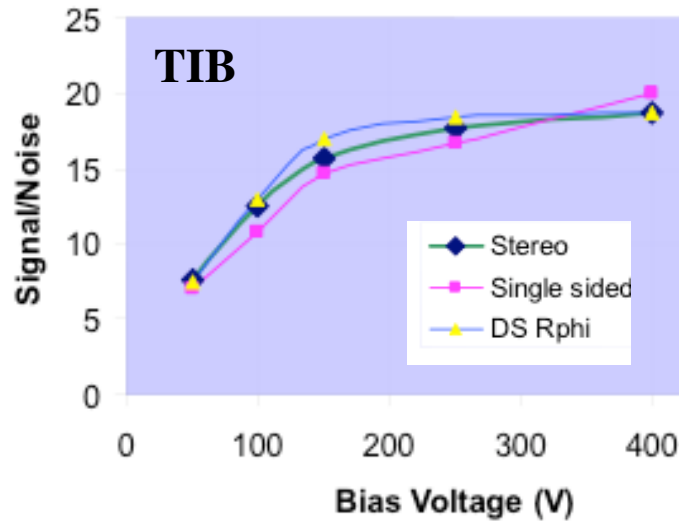
- *Stable communication and readout at all temperatures*
- *Uniform noise distribution, small common mode*
- *Signal/noise ~ 20*
- *Equivalent noise charge consistent with expectation from measurements on single APVs*

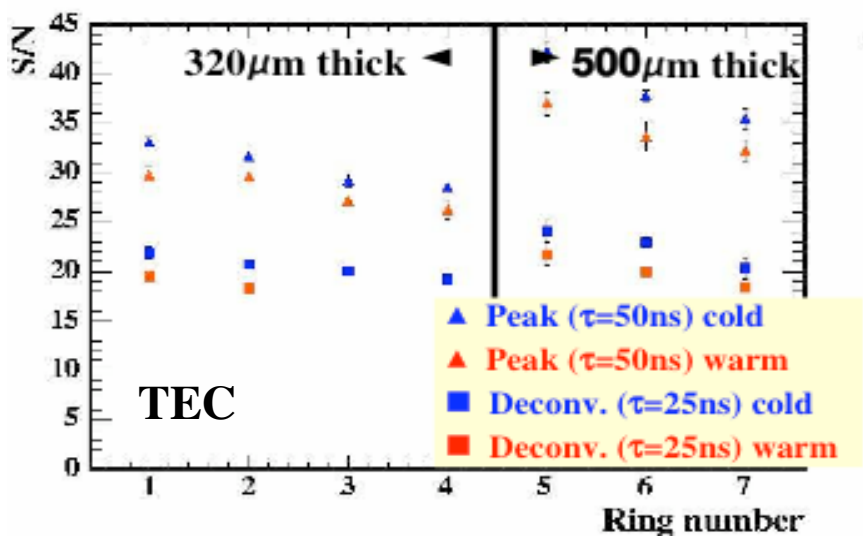


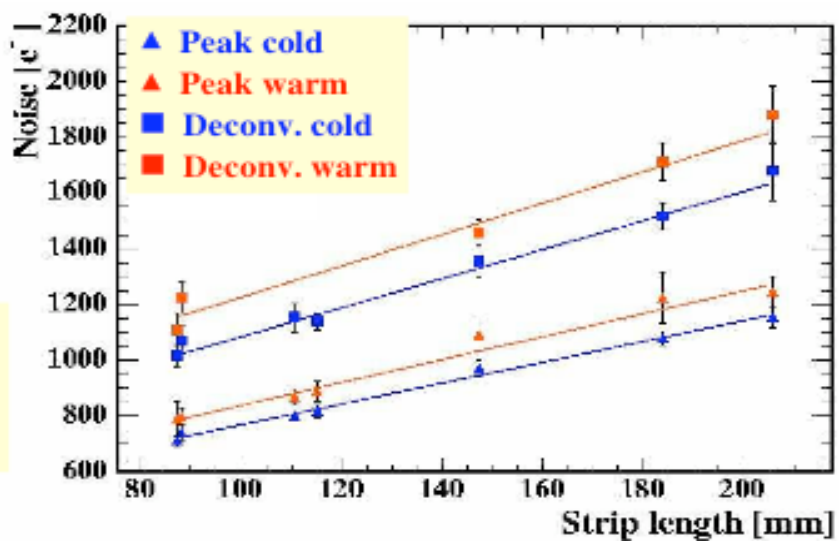


Signal / Noise performance





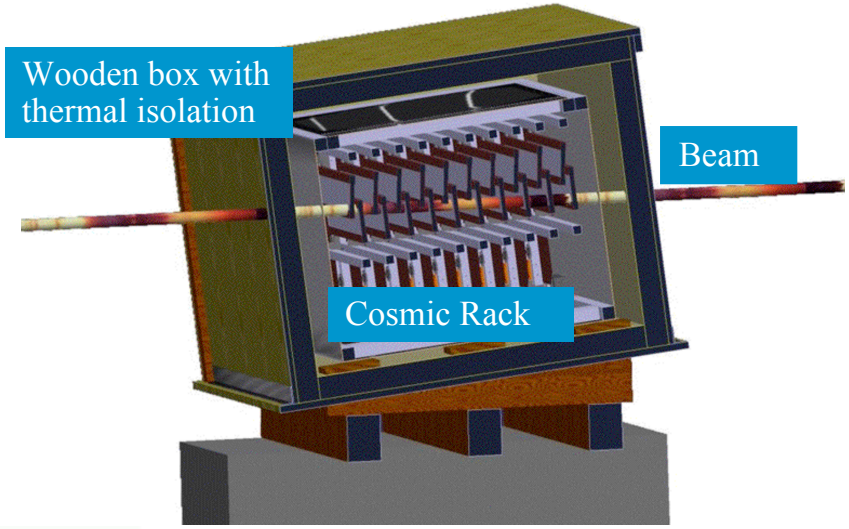


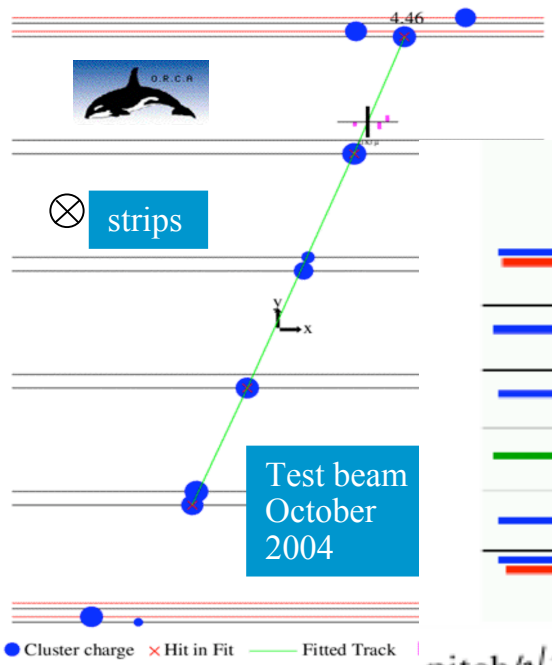


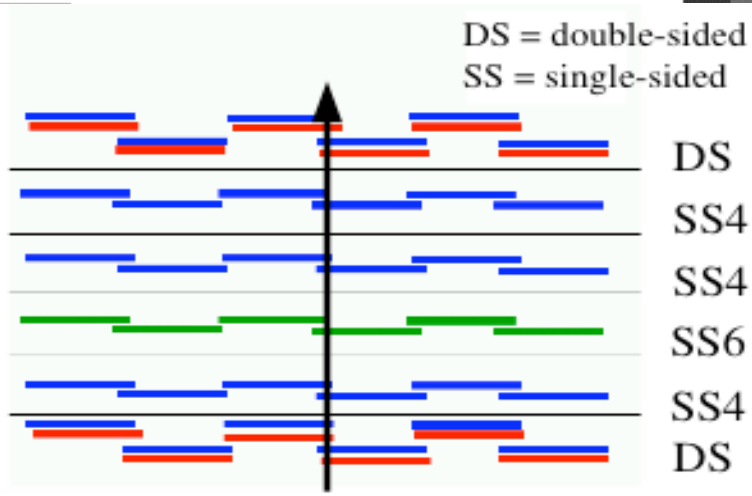
Tracking studies with Cosmic Rack

Successful tracking in Cosmic Rack using official CMS software (ORCA)

- *Spatial resolution agree with expectation*
- *Resolution improved for inclined tracks as in average 2 strips are hit*







σ_may (μm)	σ_sept (μm)
straight tracks	6° inclination
45	29
45	34
42	38
35	28
54	33
50	30

pitch/√12=35μm (SS6) and 53μm (DS, SS4)

Summary

- *Sensor production almost complete*
- *Hybrid production will be completed this year*
- *Module production progressing well*
- *Rod and petal production started and encountered problems were solved*
- *Quality of substructures (strings, rods and petals) is excellent*
- *Integration process has started*
- *L3+ and L4+ of TIB are complete and work ongoing on L2+*
- *Tracker Support Tube fully commissioned*
- *TOB support structure complete, trial integration successful*
- *TEC+ support structure almost complete, trial integration started*
  TEC – being prepared for transport to CERN
- *Beneficial occupancy of new Tracker Integration Facility expected for end of October*
- *Tracker Integration will start in November*
- *Commissioning by readout tests of 25% of the Tracker with final DAQ system will start in March 2006*
- *Tested Tracker to be delivered to LHC Point 5 by November 2006*