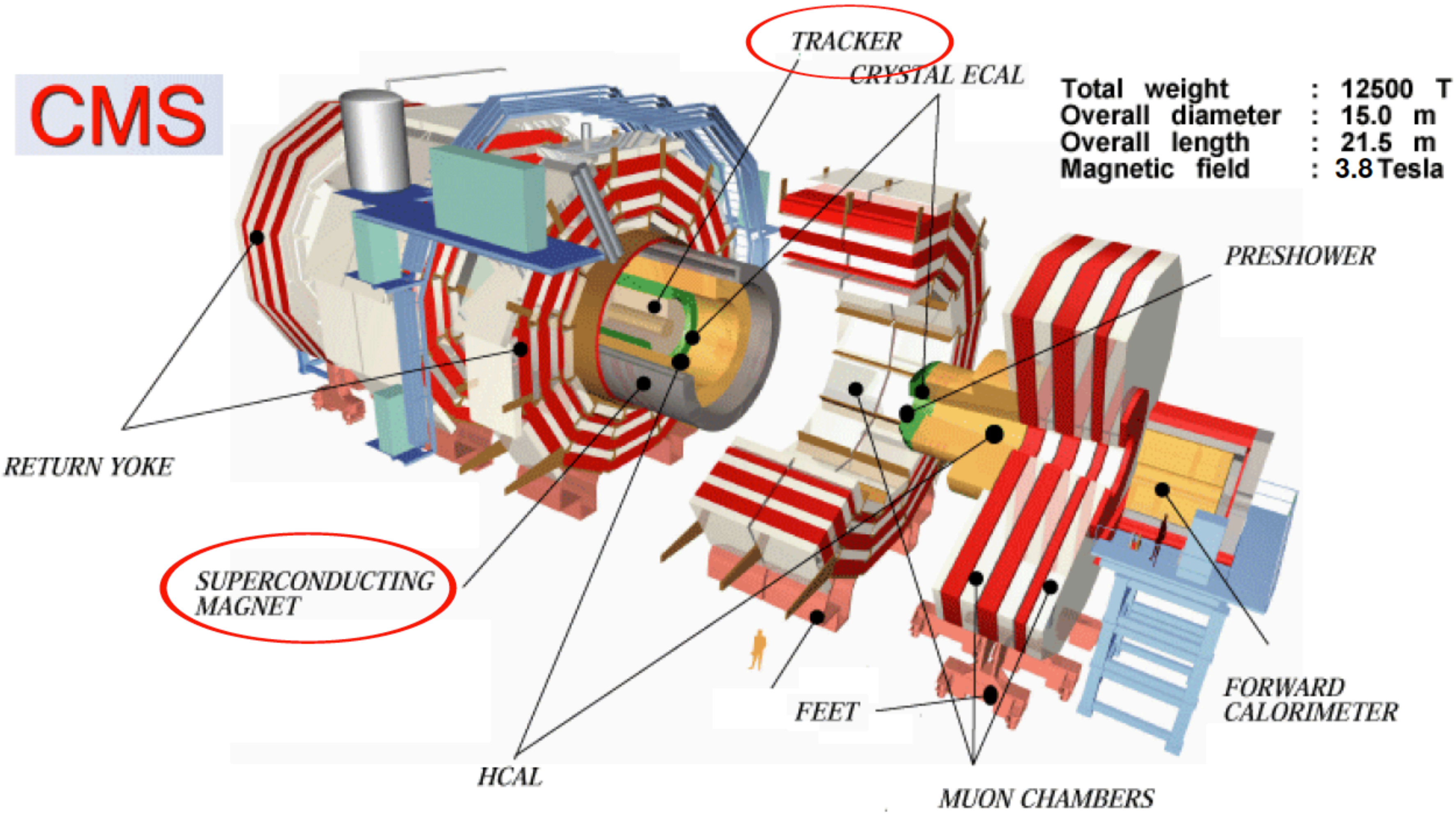
Experience with the CMS Tracker

L.Demaria - INFN Torino

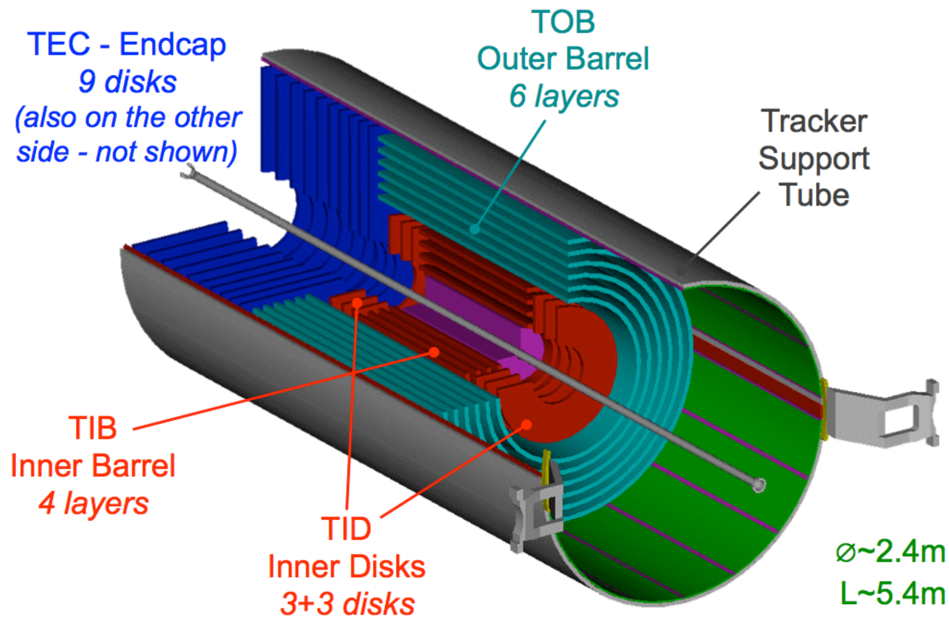
Outline

- Detector description
- Construction
- Commissioning
- Performance

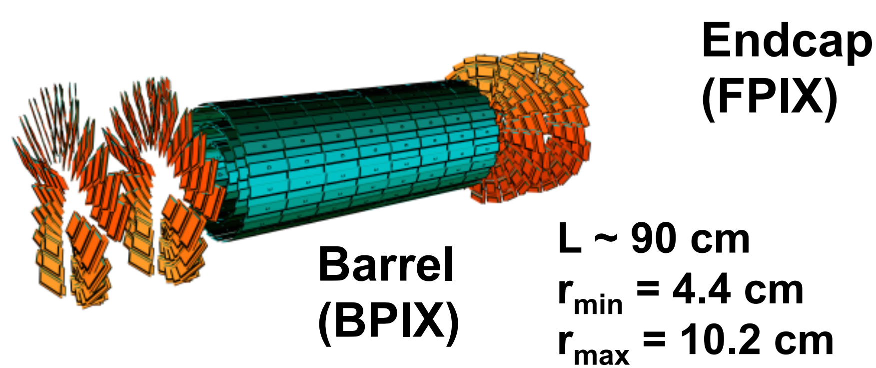

CMS
TRACKER
CRYSTAL ECAL
Total weight : 12500 T
Overall diameter : 15.0 m
Overall length : 21.5 m
Magnetic field : 3.8 Tesla
PRESHOWER
RETURN YOKE
SUPERCONDUCTING MAGNET
FEET
FORWARD CALORIMETER
HCAL
MUON CHAMBERS

CMS Silicon Tracker

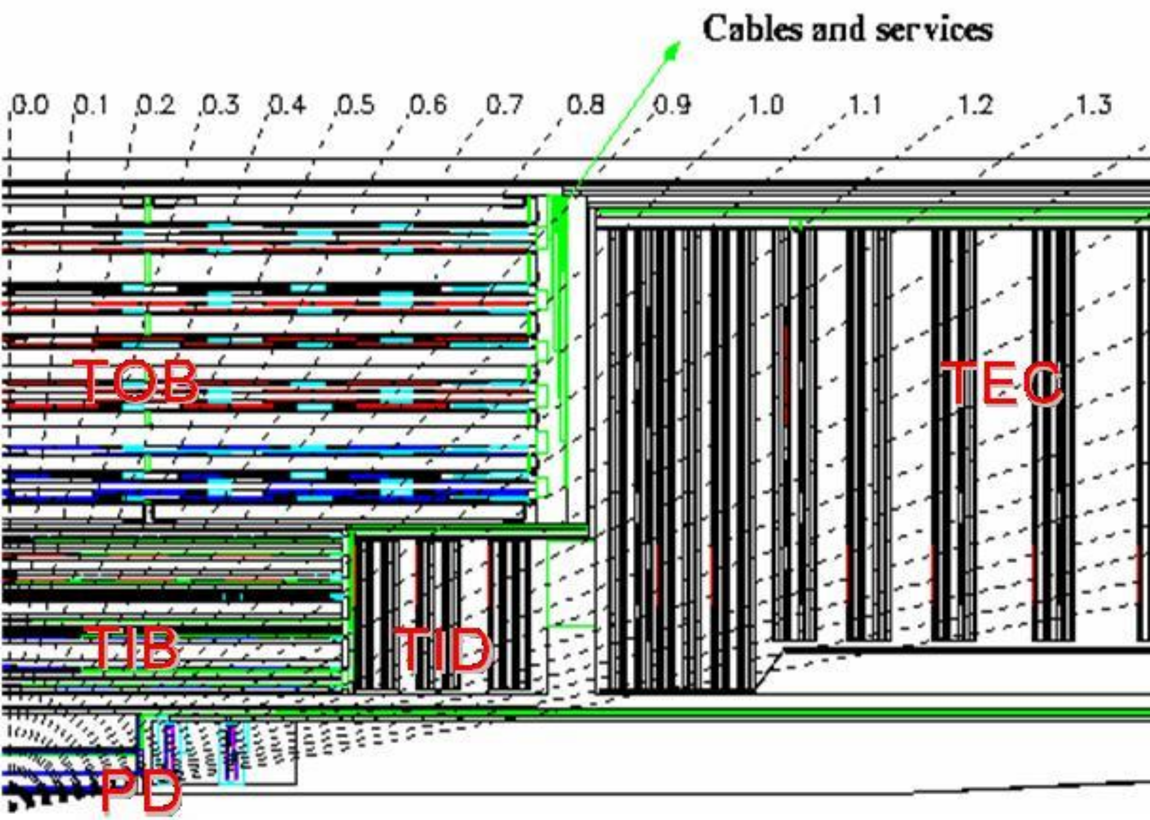
- Silicon pixel + Silicon strip detectors
- **Strips**
  - 9.6M channels ($198 m^2$)
  - pitches: 80-180 μm
  - 10-12 layers
    - about 4 stereo measurements
- **Pixel**
  - 66M channels
  - $100 \times 150\ \mu m^2$ pixels
  - 3 layers + 2 disks at each end
- Basic Performance:
  - $\sigma(p_t)/p_t \sim$ 1-2% ($p_t \sim$100 GeV)
  - IP resolution: ~10-20μm (p_t = 100-10 GeV)



2.4m diameter, 5.4m length



Silicon Strip Tracker



Modules:

- 3112 + 3024 Thin modules (ss +ds)
- 5496 + 3600 Thick modules (ss +ds)

Silicon:

- 6,136 Thin sensors = $48m^2$
- 18,192 Thick sensors = $162m^2$

198 m^2 of silicon microstrip sensors
(~420 m^2 of silicon wafers)

FE Electronics:

75,376 APV chips

9,648,128 strips ≡ electr. Channels

Tracker Inner Barrel (TIB): 4 layers: 2 Rϕ (2D), 2 Rϕ-Stereo (3D)

Tracker Outer Barrel (TOB): 6 layers, : 4 Rϕ (2D), 2 Rϕ-Stereo (3D)

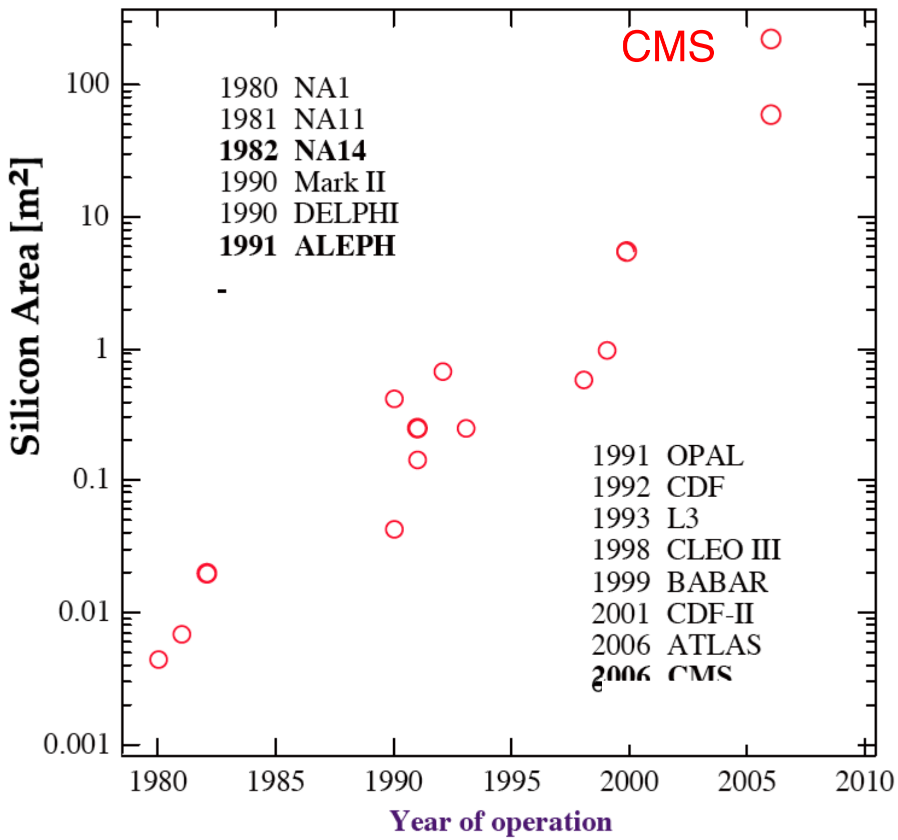
Tracker Inner Disks (TID): 3*2 disks, : 1 Rz (2D), 2 Rz-Stereo(3D)

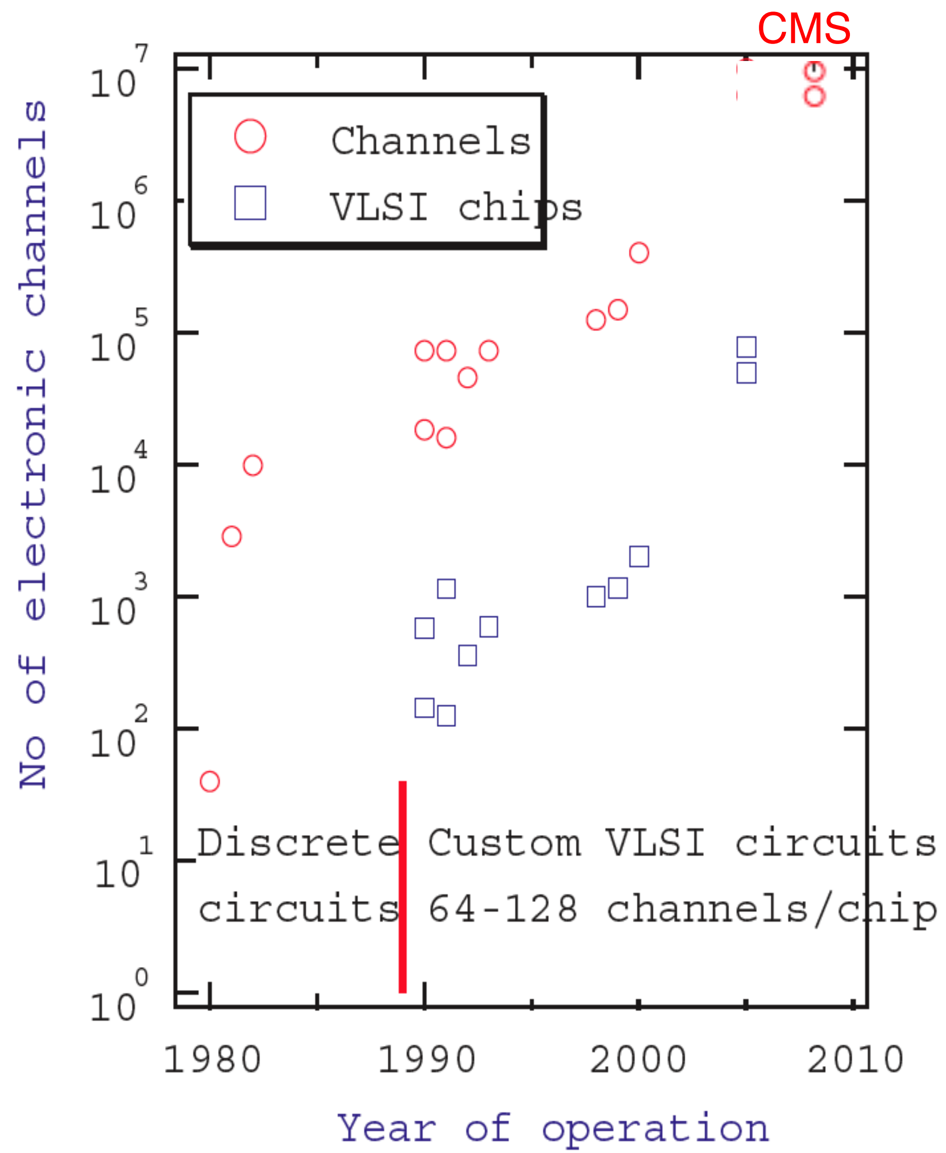
Tracker EndCap (TEC): 9*2 disks, : 4 Rz (2D), 3 Rz-Stereo(3D)

Each Track has at least
10 high precision measurements
for Pt and 4 in Θ

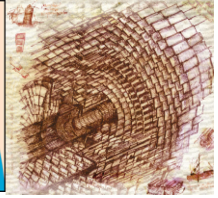
Coverage: | η | < 2.5

Evolution in Silicon & Electronics in High Energy Physics





CMS SST is the largest Silicon Tracker ever built !



Modules and Sensors

Silicon Microstrip Detector

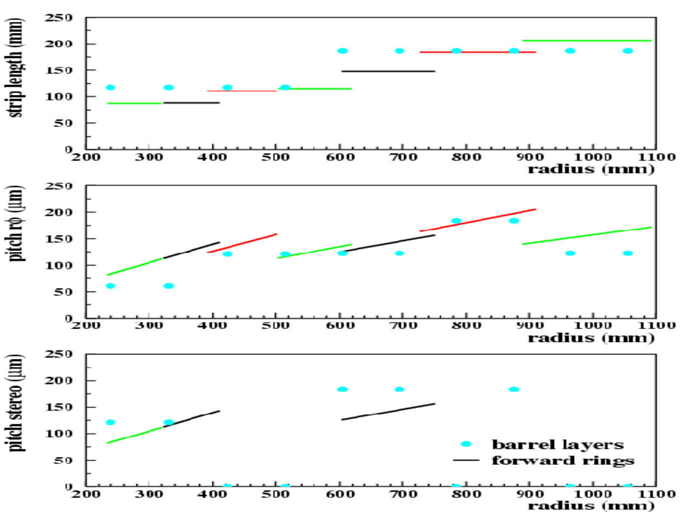
- p+ n detectors,
- 6” technology, <100> orientation
- AC coupled, R-poly biased,
- w/p=0.25, 4-8 μm metal overhang,
- V_{break} >500V

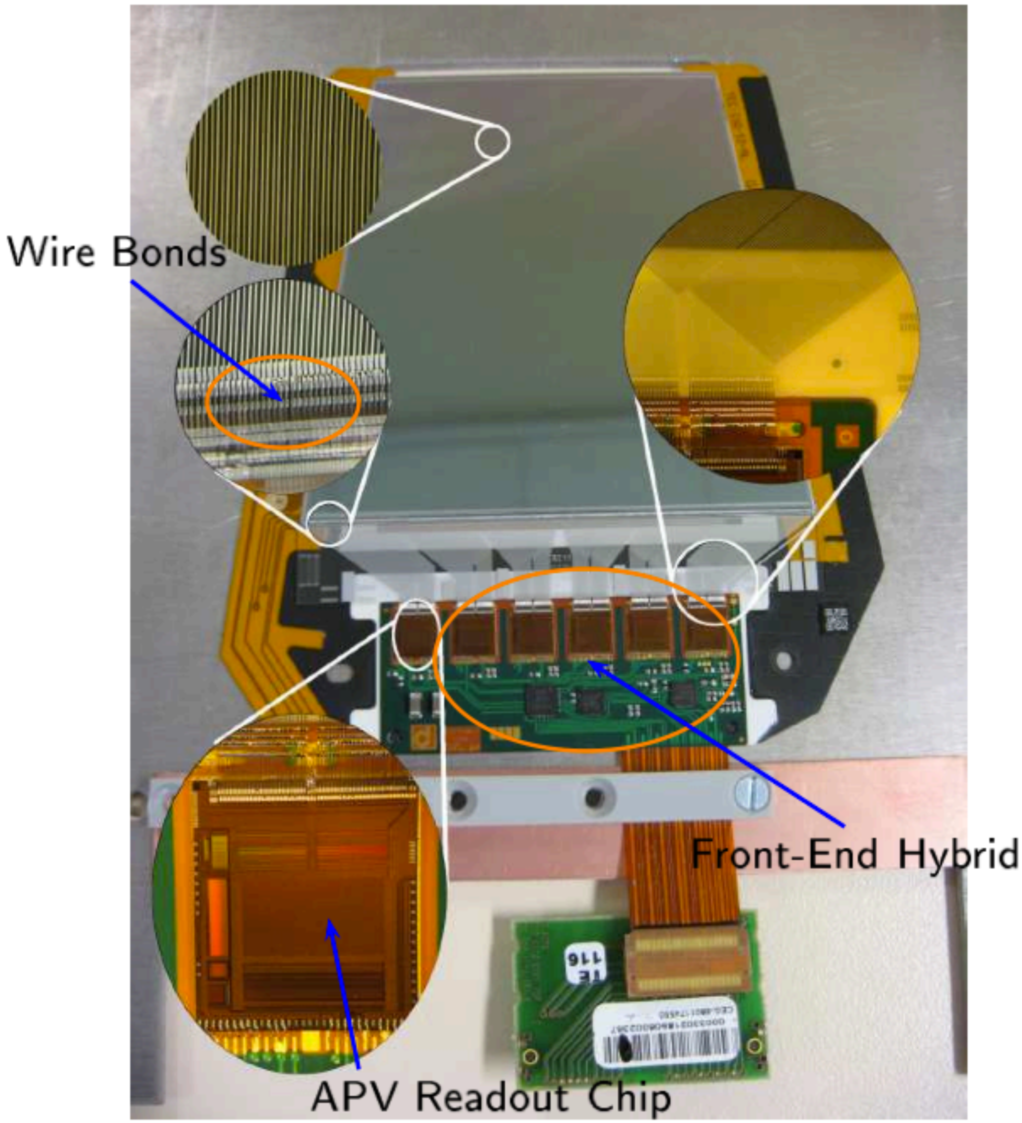
Thin sensors:300 μm, ρ = 1.5-3 kΩcm

Thick sensors:500 μm, ρ = 3.5-7 kΩcm

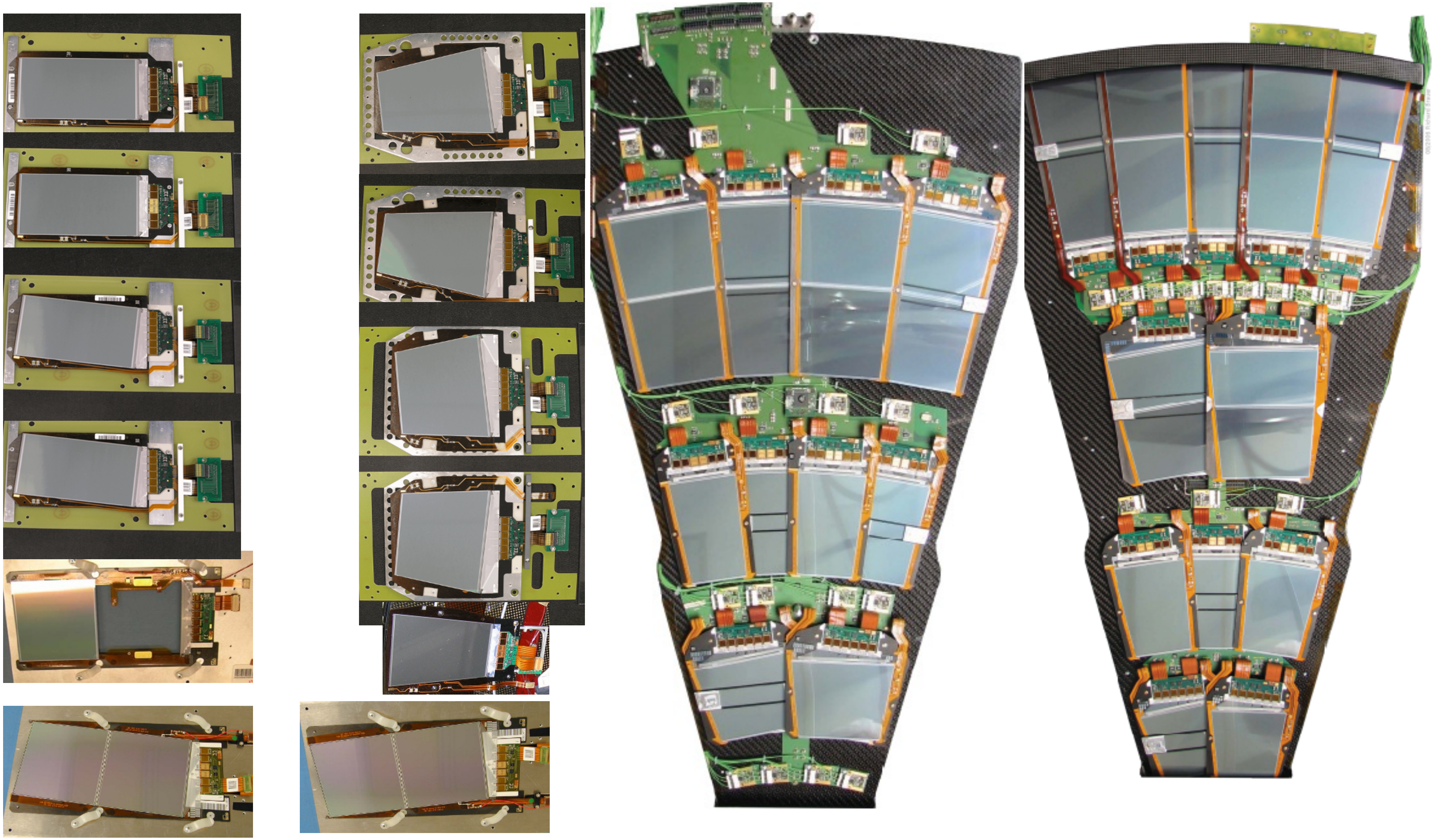
Different geometries and strip length.

Capacitance at preamplifier ~ 1.2 pf/cm



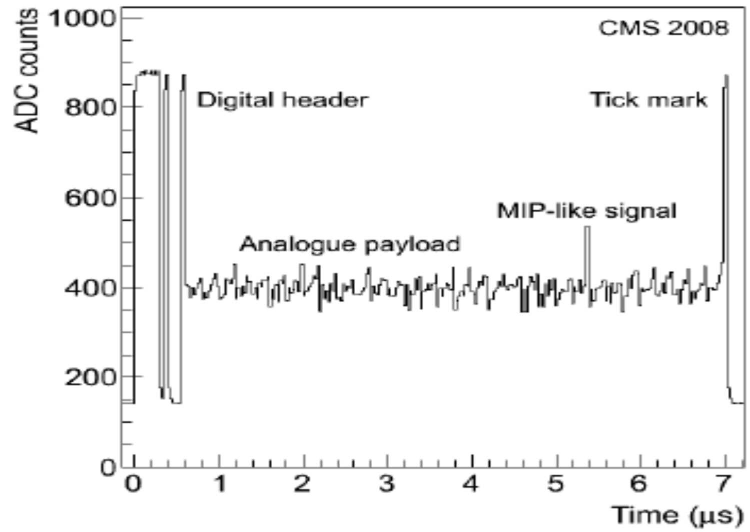


Different Module Geometries

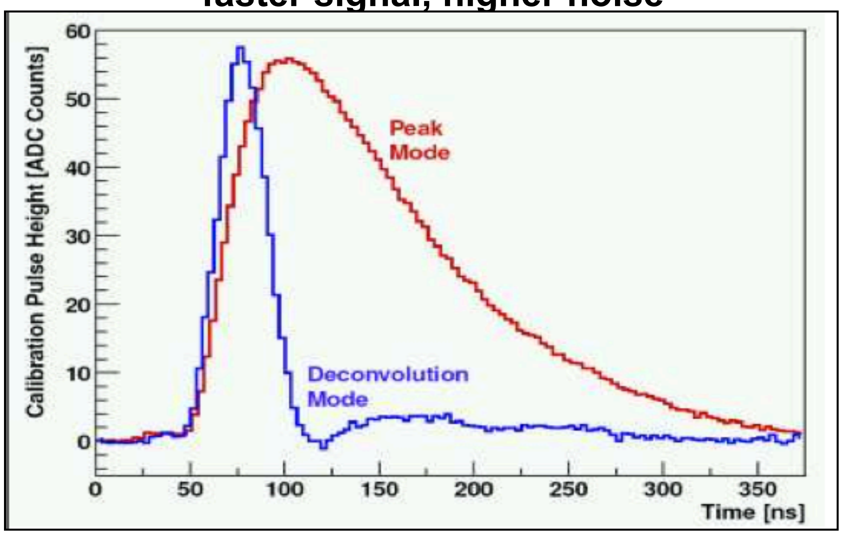


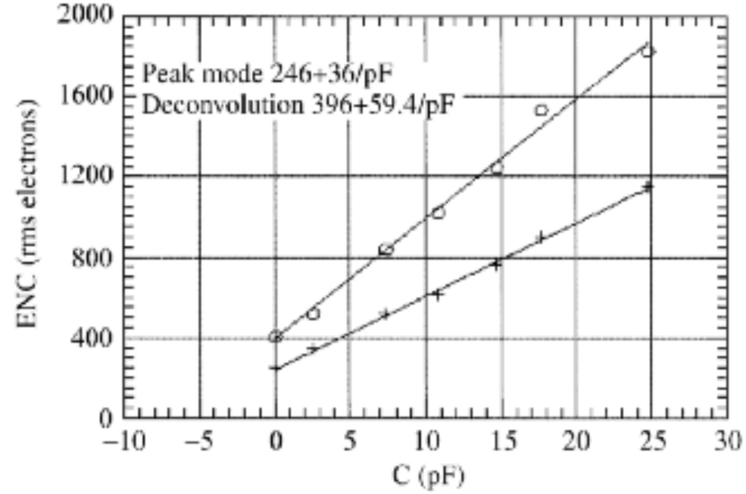
APV25 chip

Front end chip preamplifier:
- **0.25 μm technology , rad-hard tested**
- **128 channels, mux at 20 MHz**
- **50 ns shaping time, 192 analog cell pipe line**



Can run in two modes:
- **PEAK mode: normal CR-RC (50ns)**
  - **slow, lower noise**
- **DECONVOLUTION: takes 3 consecutive sampling and applying deconvolution algorithm**
  - **faster signal, higher noise**





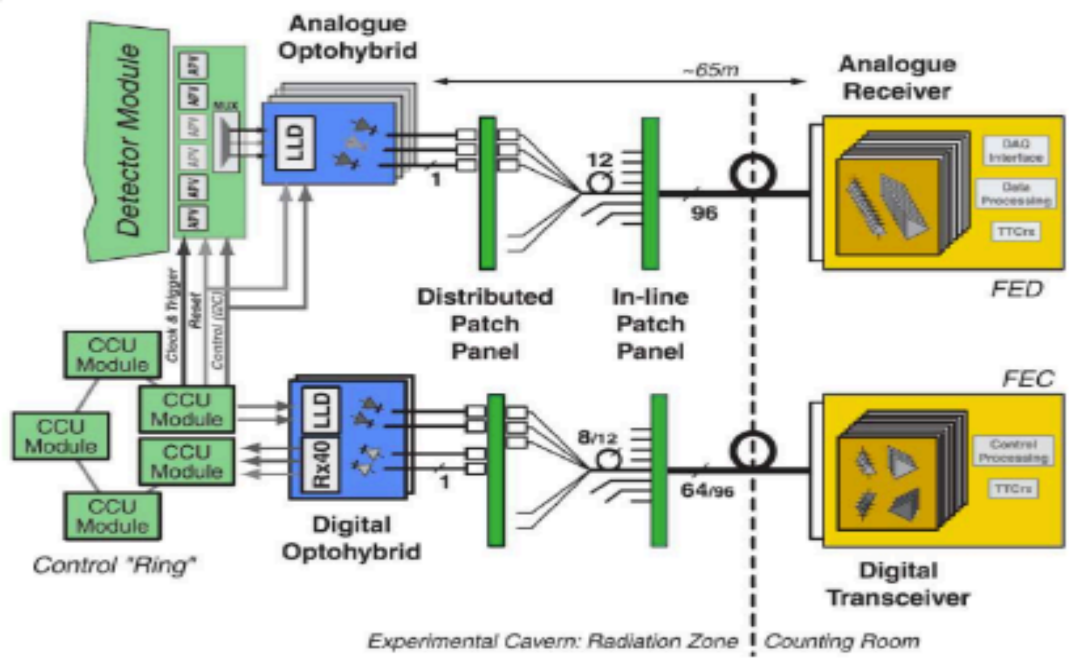
Readout and Control chain

Signal Path (upper half)

- Module: silicon ⇒ APV ⇒ MUX
- AOH (electric → light)
- Fibre
- FED

Control Rings (lower half)

- FEC
- Fibre
- DOH (electric ↔ light)
- CCU
  - ⇒ clock/trigger ring
  - ⇒ I²C communication
- Module (APV, DCU)



440 FEDs

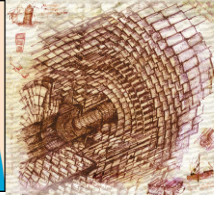
- Non-zero suppressed data from fibre.
- Digitisation, common mode noise subtraction, zero suppression.

⇒ Rely on pedestal and noise values.

Brief SST History

- 1992
  - **CMS Letter of Intent**
- 1994-1999
  - **1997: Tracker TDR**
  - R&D
- 2000-2002
  - **ALL SILICON Tracker: Addendum to TDR**
  - Additional **R&D** on 6” silicon
  - Pre-production of components
  - 2002: Started sensor production
- 2004-2006
  - Pre-series,
  - **module/mechanics constructions**, sub-assembly, back-end / services construction, general QA
  - Test of 2% of Tracker in the CMS Magnet Test Cosmic Challenge(MTCC)
- 2007
  - **Assembly at CERN**
  - commissioning and test with cosmic ray of 12.5% before insertion at T=15C, 10C, 0C, -10C
  - **insertion in CMS**
- 2008
  - Placement of services and connections at P5
  - Commissioning at T=18C
  - **CMS cosmics data taking ; SST** @ T=18C
- 2009
  - Commissioning at 4C
  - CMS cosmics data taking at T=4C
  - **First collisions data,** E=0.9, 2.2 TeV
- 2010
  - Commissioning in deconvolution mode
  - **Collisions in deconvolution, E=7 TeV**
- 2011
  - Collisions @ **L~10^{33}cm^{-2}Hz**
  - Lint ~ 7 fb-1, E=7 TeV
- 2012
  - Collisions @ **L ~ 6-7 10^{33}cm^{-2}Hz**
  - Lint ~ 23 fb-1, **E=8 TeV**

Construction of SST



SST Collaboration

TEC

Vienna

Brussels_UVB
Brussels_ULB
Antwerpen
Louvain Mons

Lyon
Mulhouse
Strasbourg

Aachen_I
Aachen _III
Karlsruhe
Hamburg

ETH

TIB/TID

Bari,
Catania,
Firenze,
Padova,
Perugia,
Pisa,
Torino

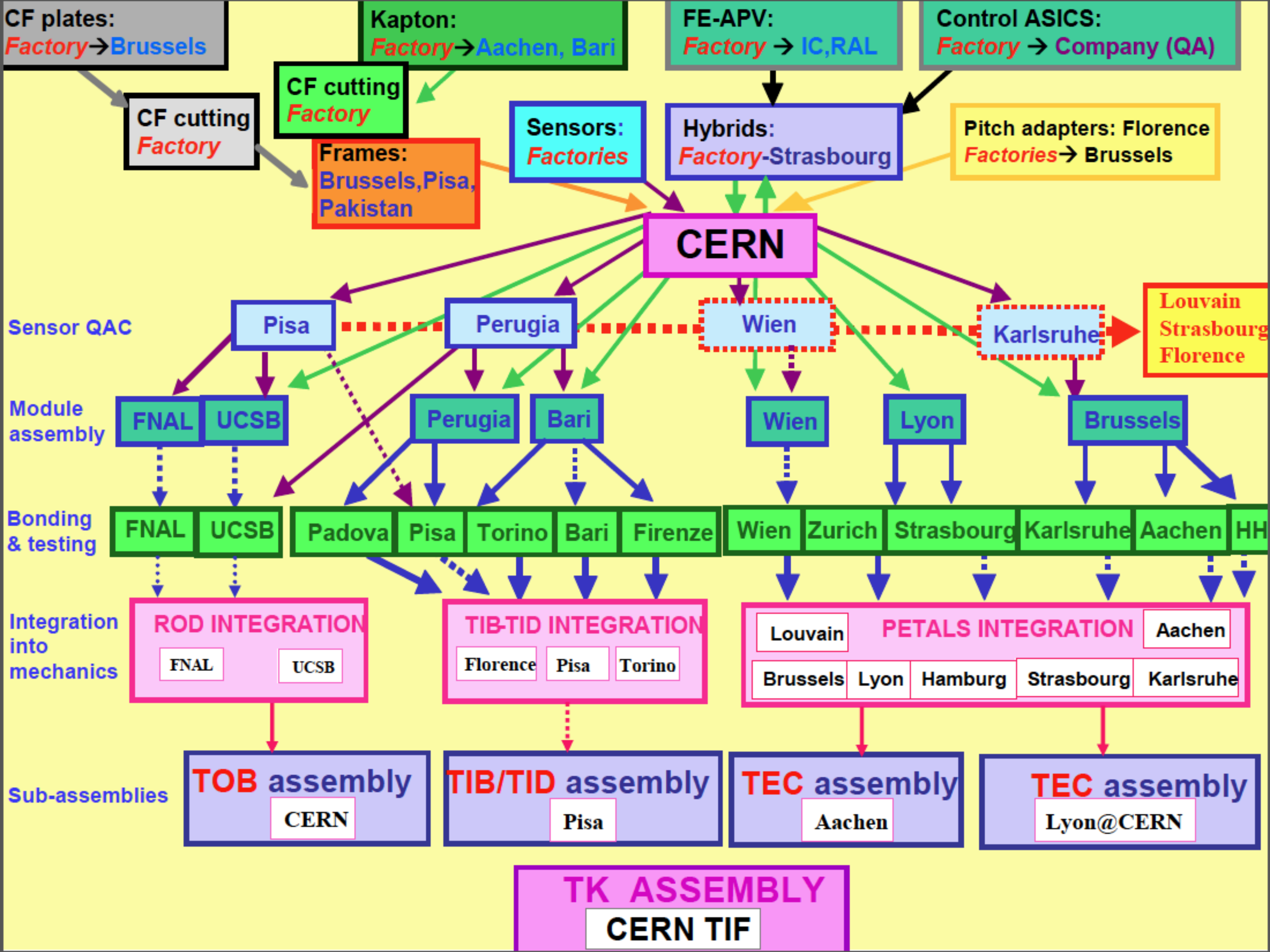
TOB

Helsinki
Oulu

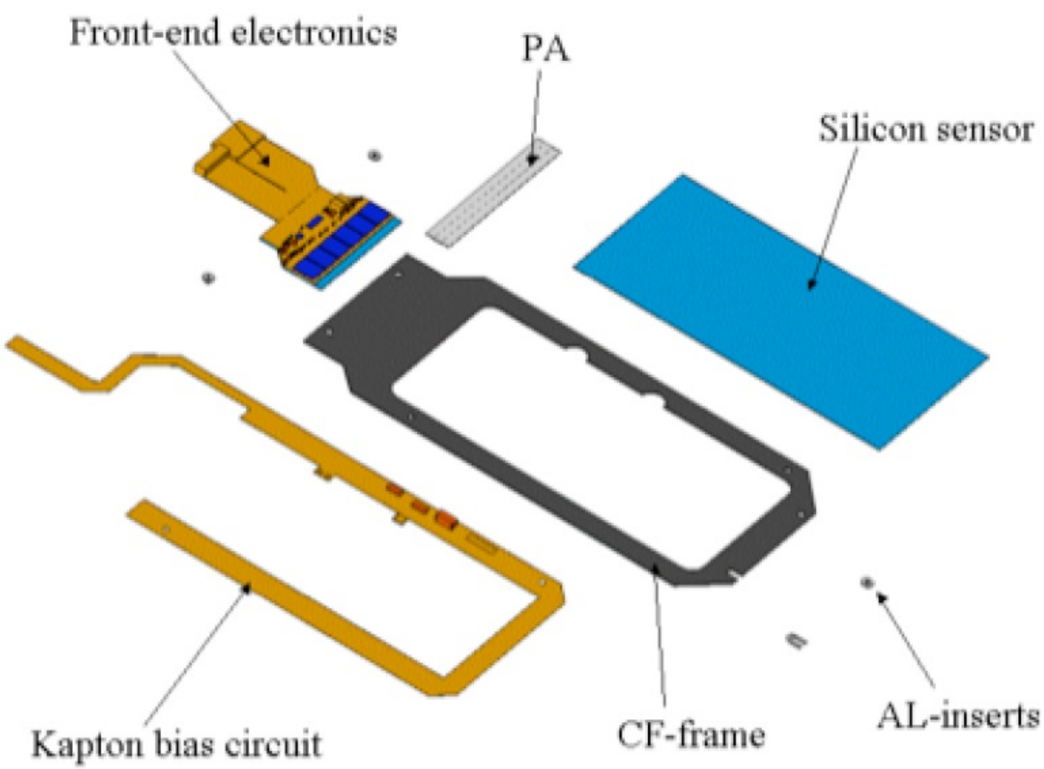
Fermilab
Illinois
Kansas
Kansas State
Purdue,
Rochester
Northwestern
St Barbara

ELECTRONICS

Imperial College
Rutherford
Brunel

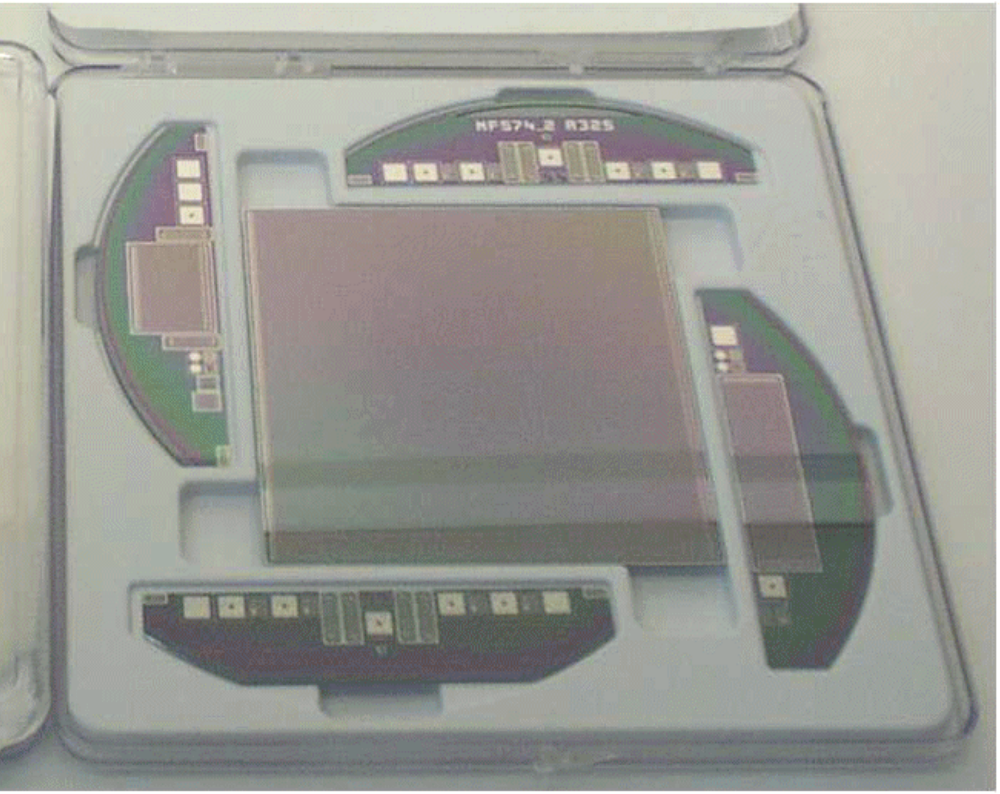

CF plates:
Factory→Brussels
Kapton:
Factory→Aachen, Bari
FE-APV:
Factory → IC,RAL
Control ASICS:
Factory → Company (QA)
CF cutting
Factory
CF cutting
Factory
Frames:
Brussels,Pisa,
Pakistan
Sensors:
Factories
Hybrids:
Factory-Strasbourg
Pitch adapters: Florence
Factories→ Brussels
CERN
Sensor QAC
Pisa
Perugia
Wien
Karlsruhe
Louvain
Strasbourg
Florence
Module assembly
FNAL
UCSB
Perugia
Bari
Wien
Lyon
Brussels
Bonding & testing
FNAL
UCSB
Padova
Pisa
Torino
Bari
Firenze
Wien
Zurich
Strasbourg
Karlsruhe
Aachen
HH
Integration into mechanics
ROD INTEGRATION
FNAL
UCSB
TIB-TID INTEGRATION
Florence
Pisa
Torino
PETALS INTEGRATION
Louvain
Aachen
Brussels
Lyon
Hamburg
Strasbourg
Karlsruhe
Sub-assemblies
TOB assembly
CERN
TIB/TID assembly
Pisa
TEC assembly
Aachen
TEC assembly
Lyon@CERN
TK ASSEMBLY
CERN TIF

Module Components



- 26 types of modules
- 15 types of sensor masks
- 24 types of pitch adapters
- 12 types of hybrids
- 19 types of frames

Sensors

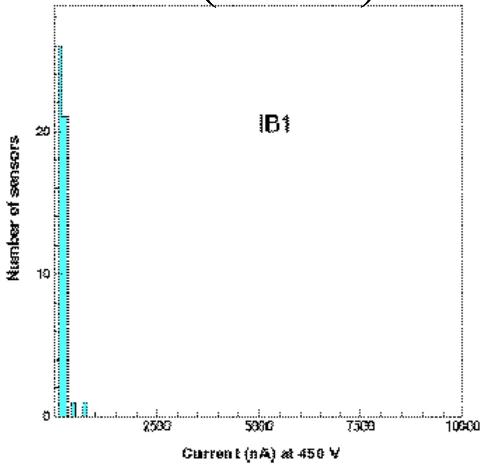


- IV : Itot < 100nA/cm 2 at Vbias = 500V, **Vbreak >500V**
- CV: **100 V < Vdep < 250 V**
- Pinhole measurement Current through AC pad: Idiel < 1nA
- Poly Resistance = 1.5±0.5M
- Strip Leakage Current: Ileak < 500nA
- Coupling Capacitance: 1.2–1.3 pF/cm per µm of impl. strip width
- **Total Defective strips <1%**

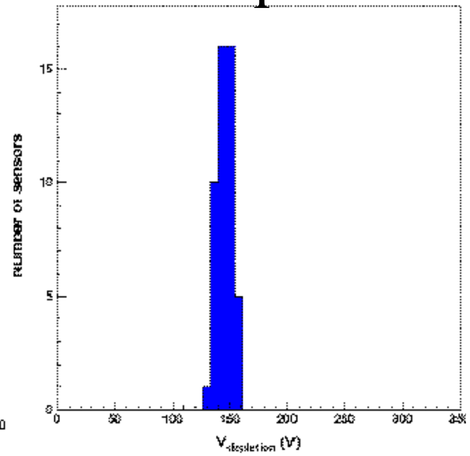
Thick sensors: 500 µm, high resistivity
Thin sensors : 300 µm, low resistivity

HPK sensors

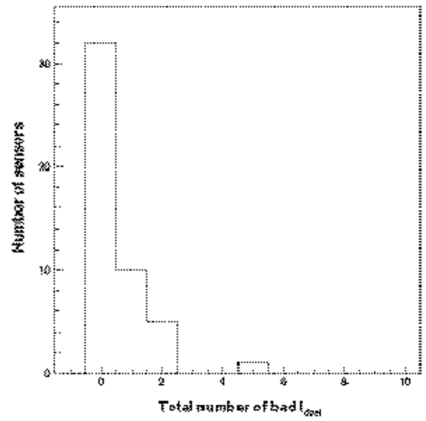
I(500V)



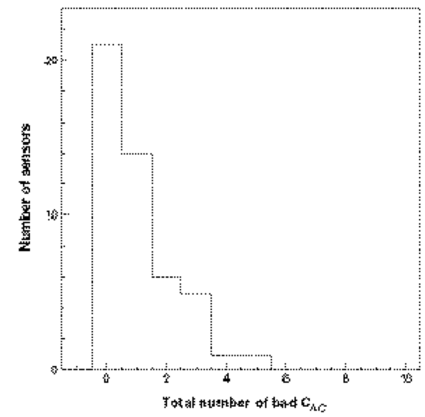
Vdep



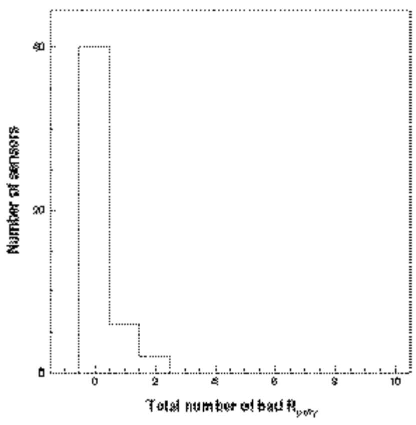
I_{diel}



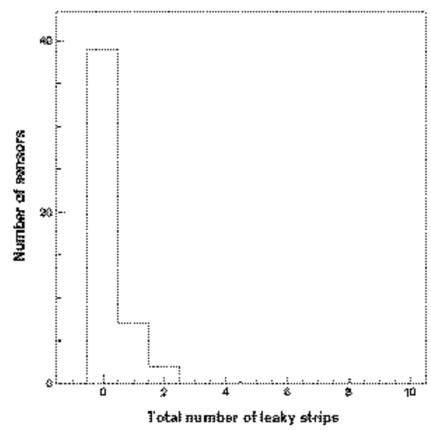
C_{ac}

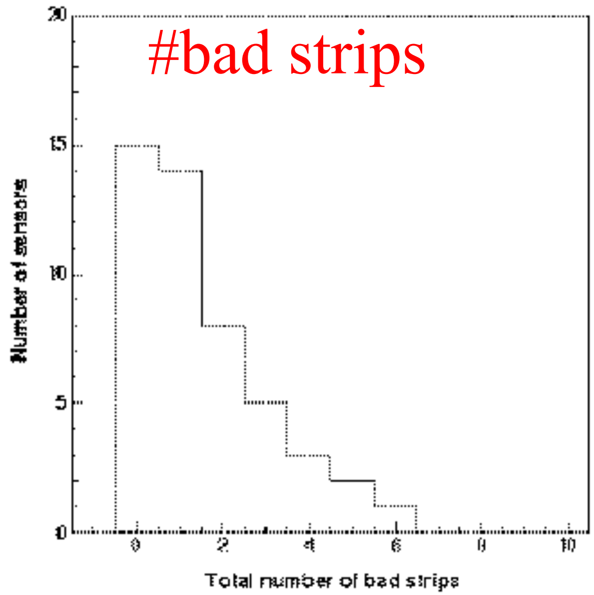


R_{poly}

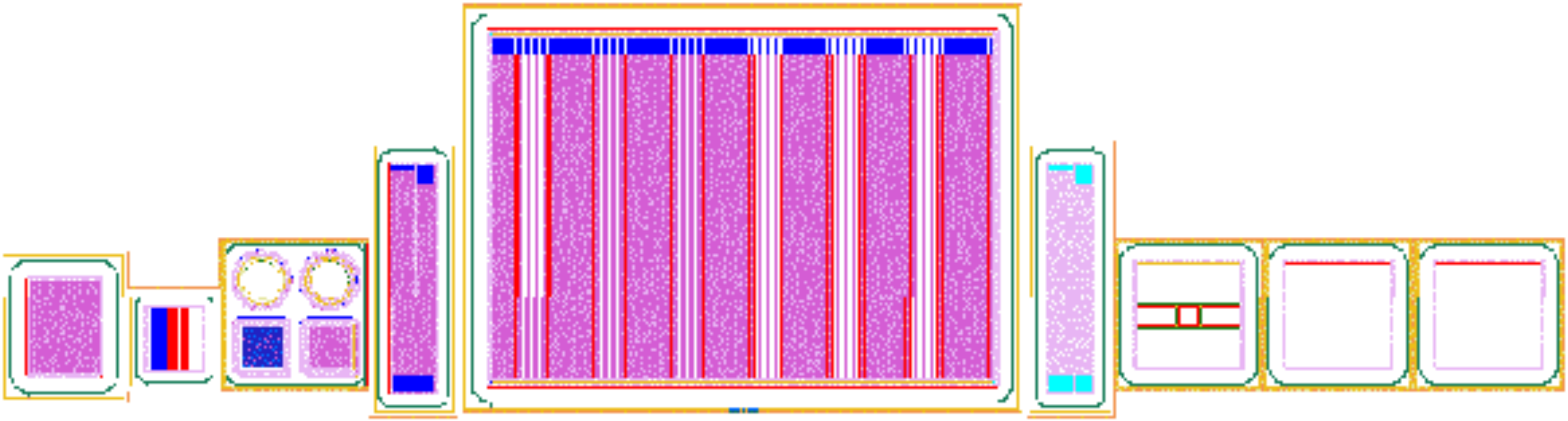


I_{strip}





Test Structures

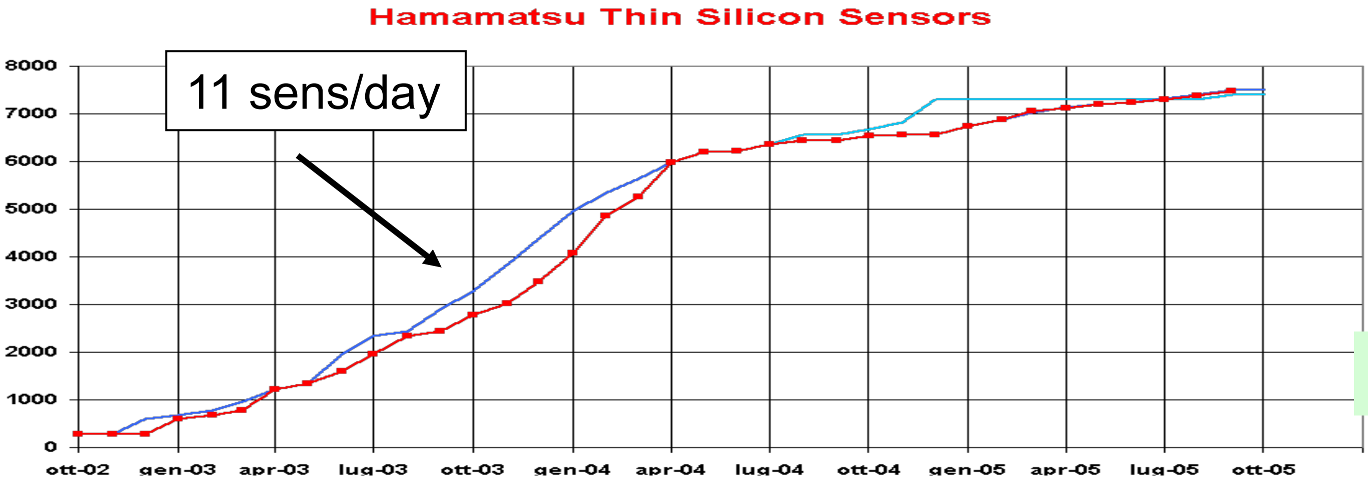


Used for process quality control and irradiation checks:

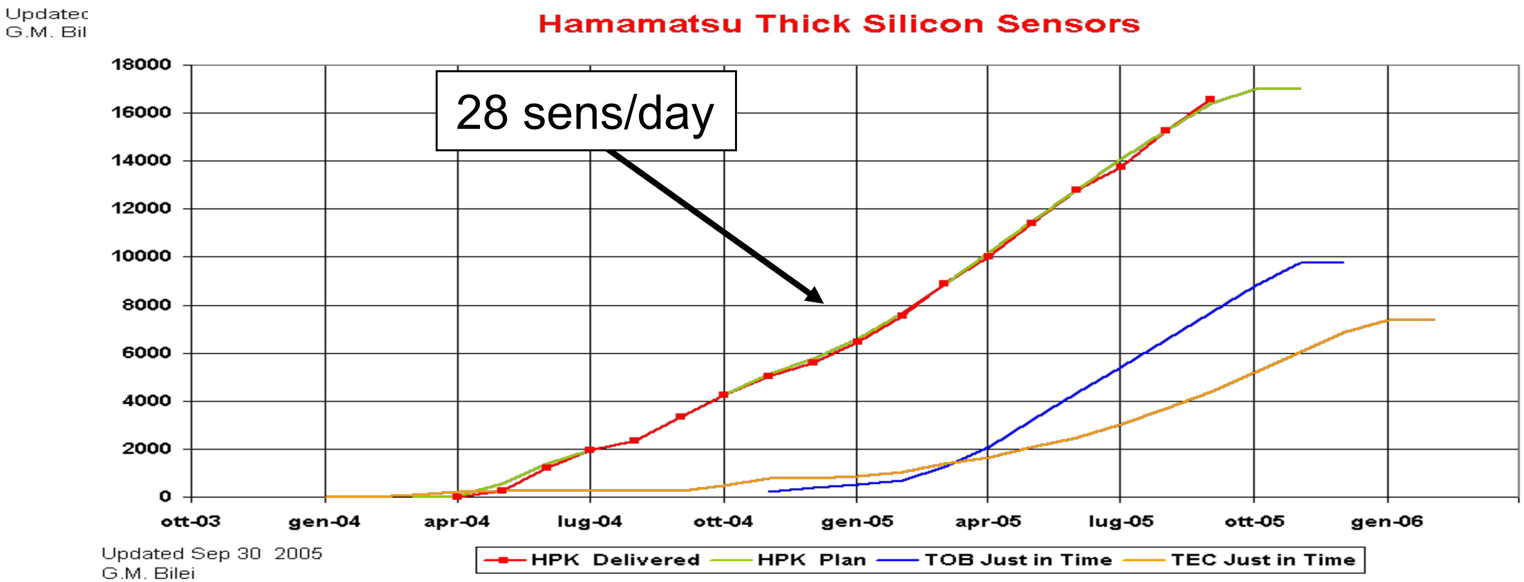
Tests	Acceptance criteria
CV	$100\ V < V_{dep} < 250\ V$ depends on resistivity
IV	Breakdown voltage > 500 V, Total leakage current < 100 nA/cm^2 @ 500 V at 21°C
C_{int}	C_{int} in 10% from the parametrization
R_{int}	$R_{int} > 1\ G\Omega$
R_{poly} R_{p+} R_{al}	$R_{poly} = 1.5 \pm 0.5\ M\Omega$; less than 1% may be outside the range $R_{p+} < 200\ k\Omega/cm$ $R_{al} < 18\ m\Omega/square$
C_{ac} V_{break} of C_{ac} I_{Die}	$C_{ac} > 1.2$ pF/cm per μm of implanted strip width. $V_{break(ac)} > 120V$ $I_{Die} < 1$ nA at 120 V

	Test	Acceptance criteria
Structures	CV on diodes	$V_{dep} < 250$ V
	C_{int}	$C_{tot} < 1.2$ pF/cm
	R_{int}	$> 20\ M\Omega$
	R_{poly}	$1.5 \pm 0.5 M\Omega$
Sensors	IV	$\alpha \sim 3.5\text{-}4.5 \times 10^{-17}$ A/cm $V_{break} > 500$ V
	CV	V_{dep}<300; C_{back} < as before irradiation + 10%
	C_{int}	$C_{tot} < 1.2$ pF/cm

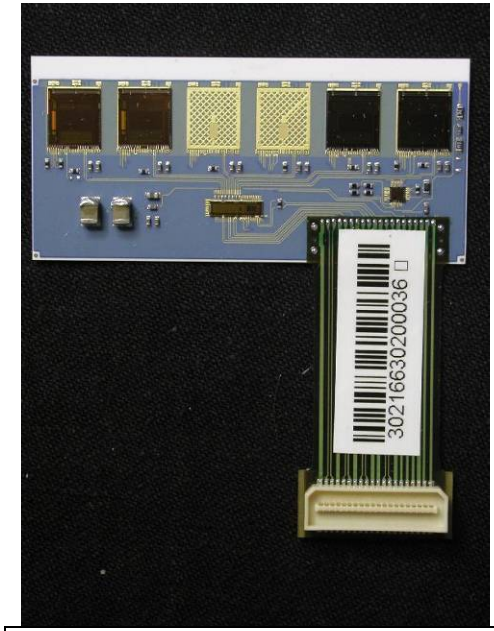
Sensor delivery



~3 years



Hybrid choice

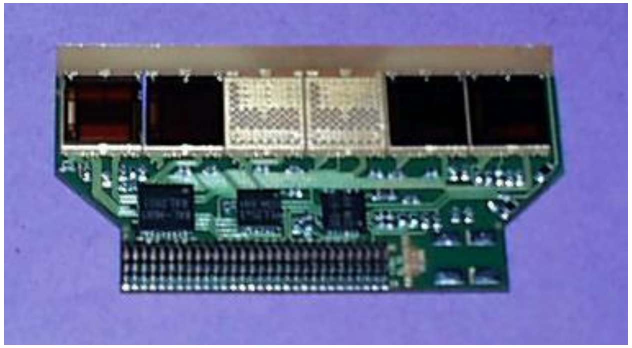


CERAMIC HYBRID

180 ceramic hybrids were produced

Main Difficulties:

- **Small feature size not suitable for mass production**
- **Soldering of kapton cable**
- expensive



Full FR4 HYBRID

Advanced" FR4 printed circuit board technology

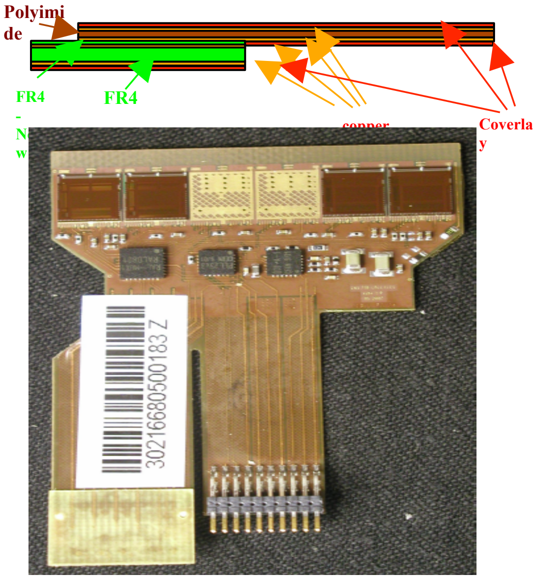
Could be very cheap in large quantities

But ….

Great difficulties to solder cable

Only a few working proto-types

➢ Go to Rigid-Flex hybrid



Flex-Rigid(FR4) Hybrid:

Different companies with different technologies and quality

Tolerances in thickness up to 100 micron

Non-Flatness in the order of 100 micron before SMD montage, and we have seen more

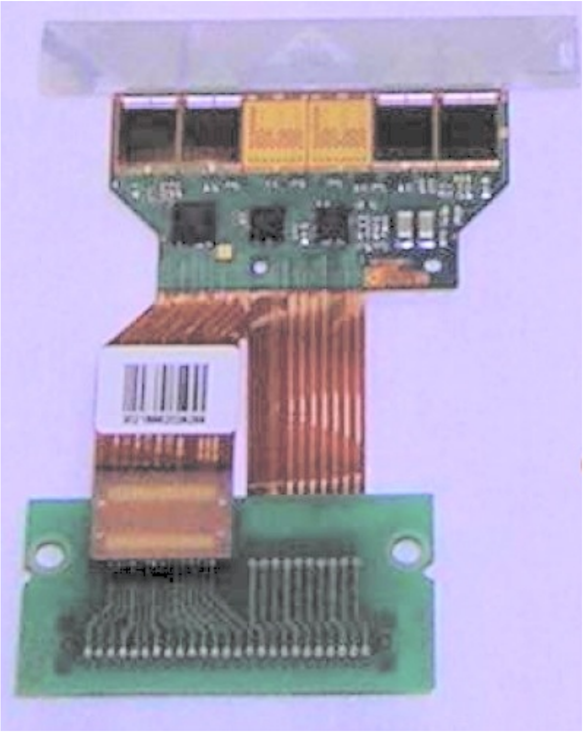
➔ Difficult to pick up

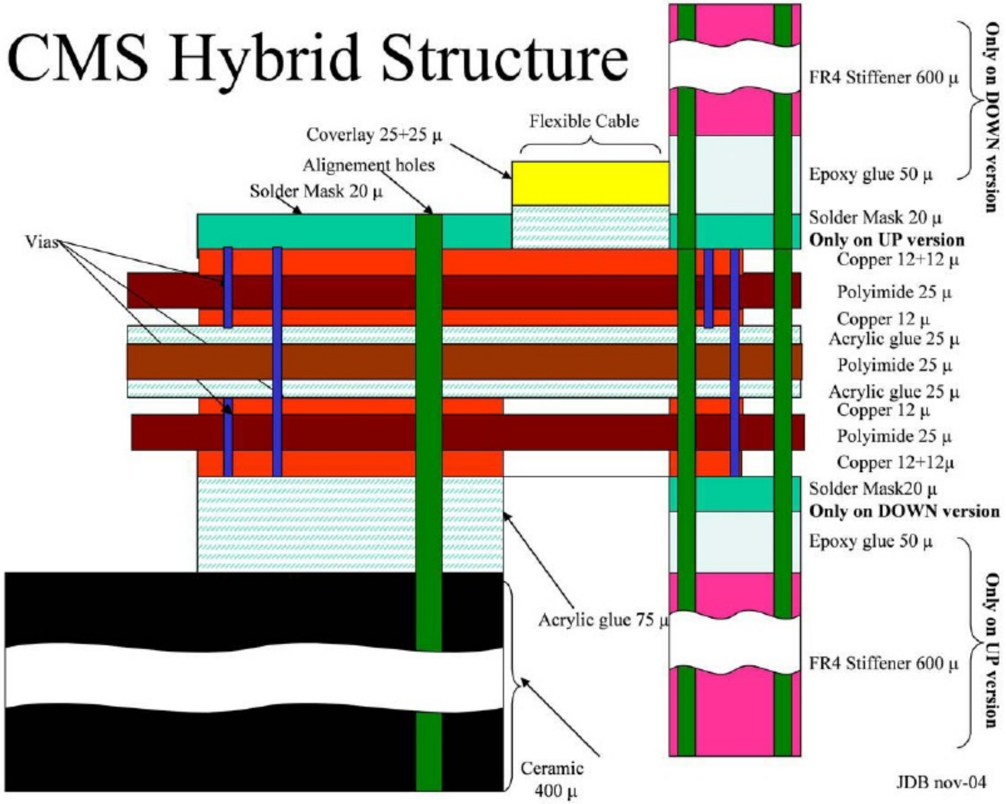
Extend FR4 part under PA

FR4 thickness is limited by diameter/length ratio for blind via

- Flex-Flex (all Kapton) laminated on Ceramic substrate (Al_2O_3)

Factory: Cicorel SA, (CH)





Robust solution for hybrid production

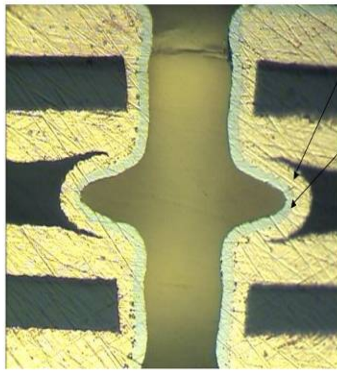
inaly deposited

deposited in the Via

Some via (100 μm diameter) results to be fragile specially to termal cycles.

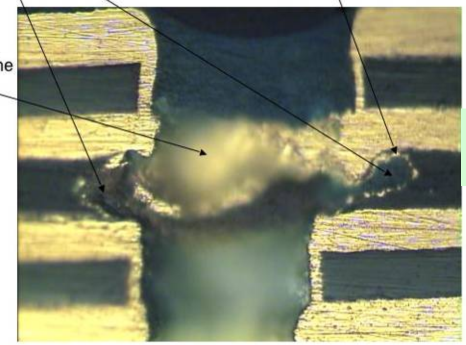
CS

Ni

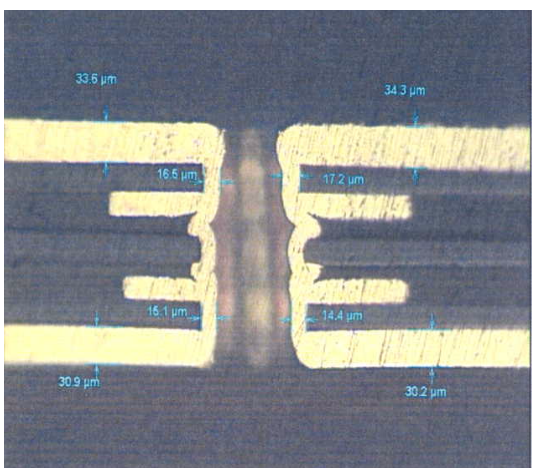


Normal via

This is due to the Picture.



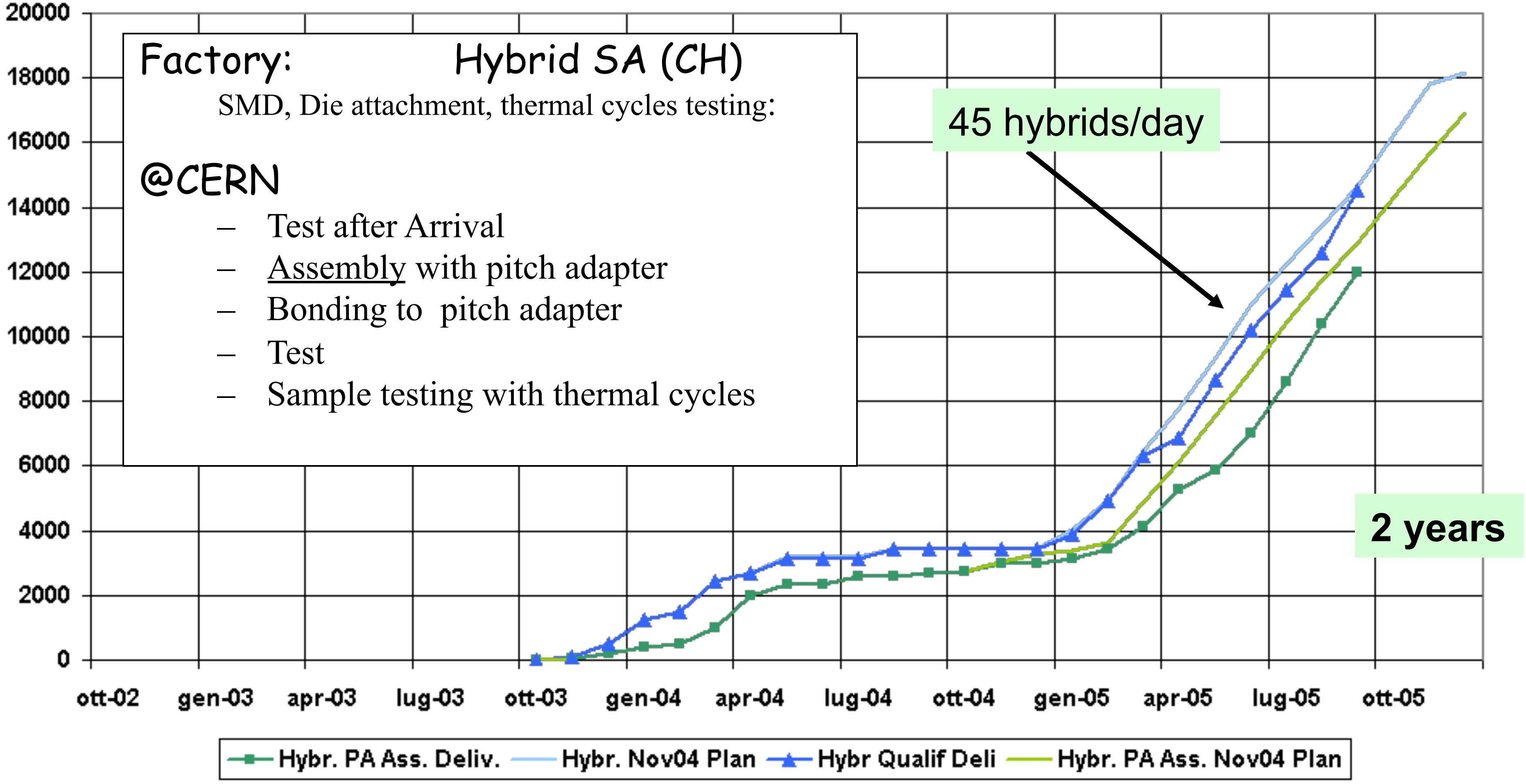
Broken via



1. Improved Hybrid design
2. Review of Process at Cicorel
   - Metallization, Etching, Laser Characterization, Glue Layer, Yield
   - test structure with 200 mm diameter VIA daisy chained
3. Stronger layer between kapton layers:
   - Glue – Poliamide – Glue (G-P-G with 25 μm layer each)

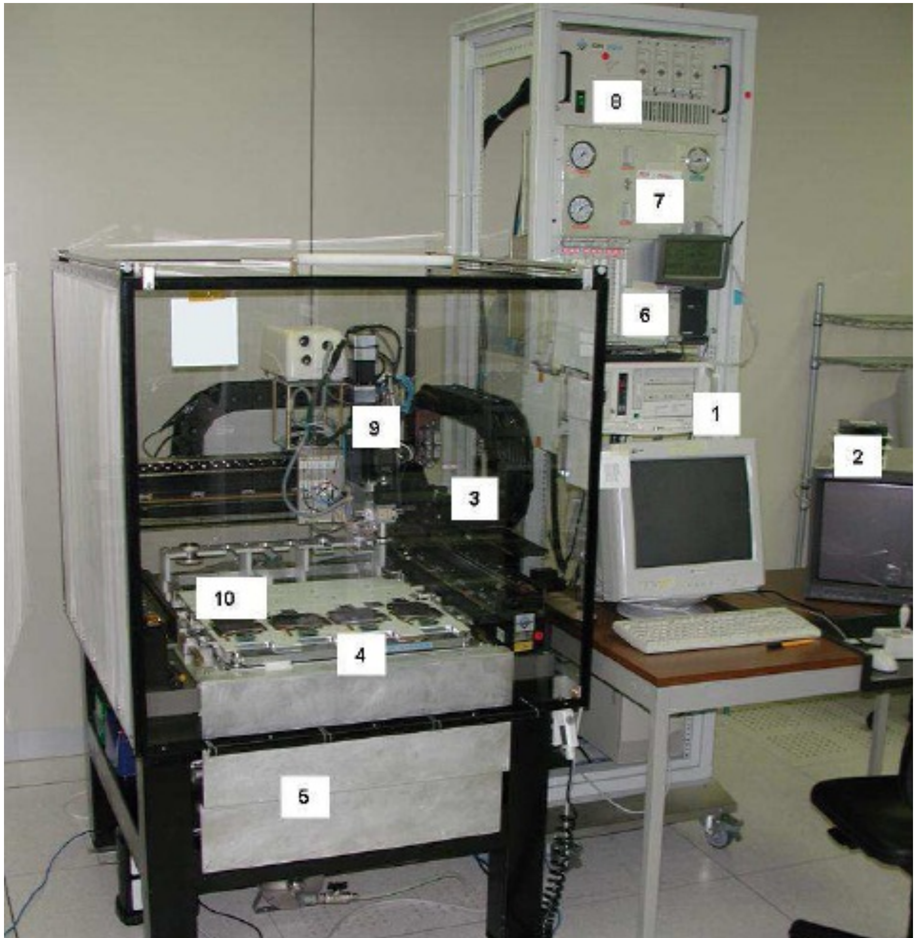
Production was back to full speed after 6 months !

Tracker Front End Hybrids



updated Sept 30 2005
G.M. Bilei

Module Assembly



1)PC, 2) camera monitor, 3)AGS 10000 Aerotech, 4)Assembly platform, 5)Vacuum system, 6) Digita I/O interface, 7) Air pressure system, 8)DR500 drive chassis, 9)CCD Camera 10)Tool rack

<u>Aerotech AGS 1000 Gantry</u>

50cm*50cm working area

X,Y.Z,ϕ rotation

CCD camera

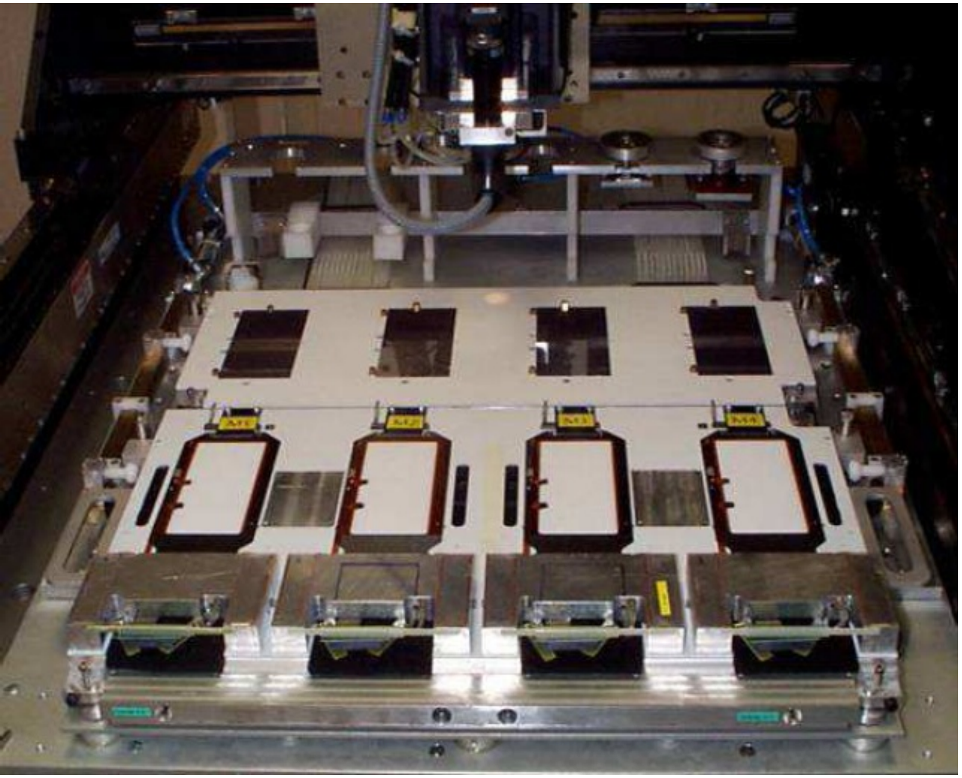
PC controlled

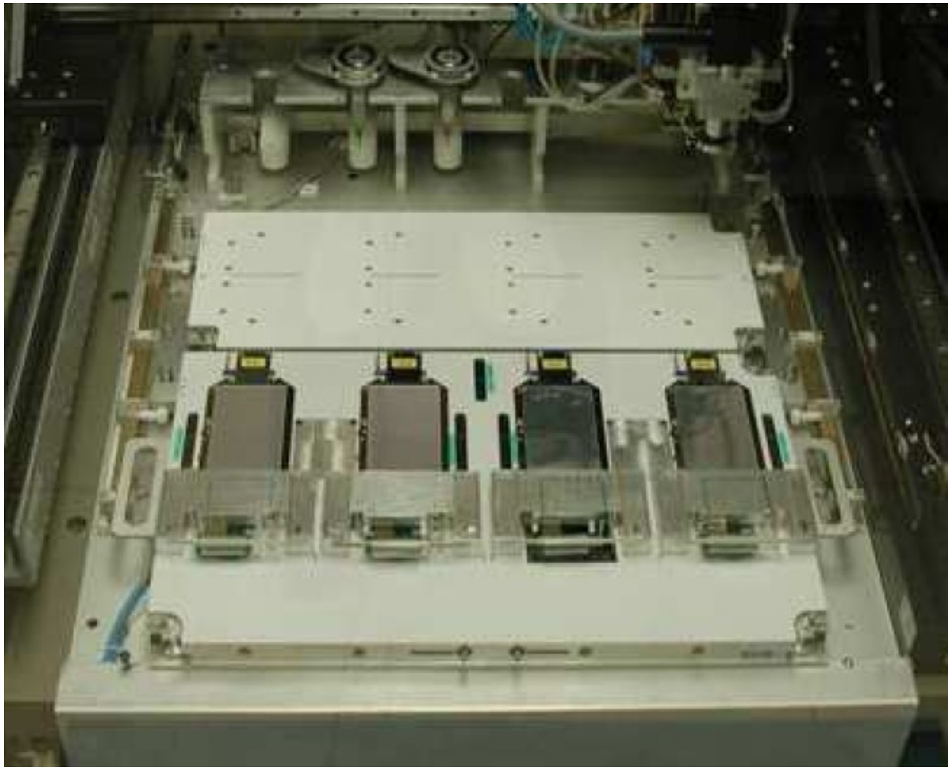
Sensor suppy platform

Assembly platform

Pick-up tools

Glue dispenser system

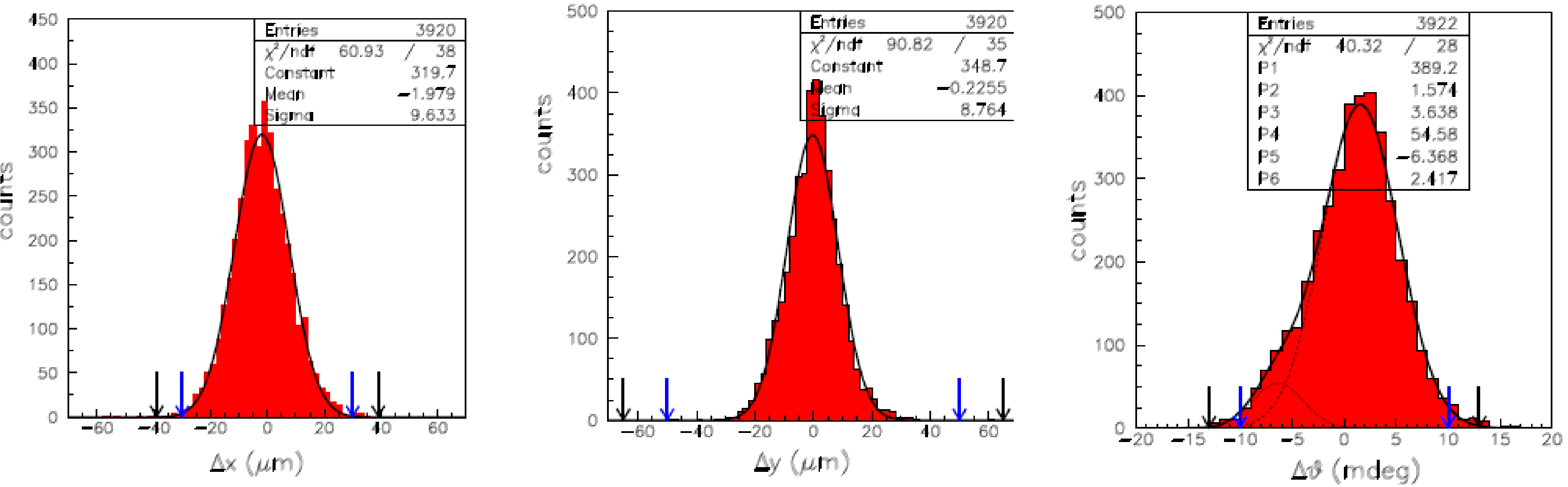




Components on plate

Components assembled and hold by vacuum. Plate can be placed to storage area for glue curing

Precision measured with Gantry after glue curing

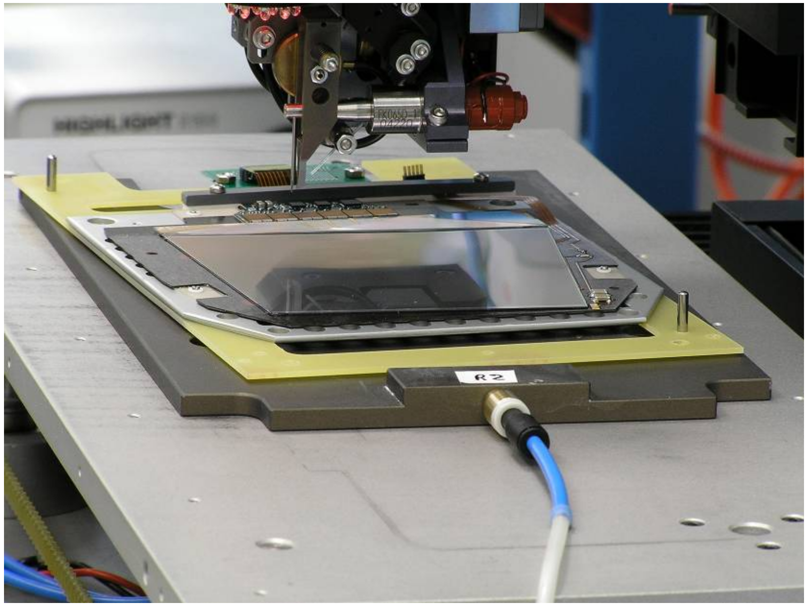


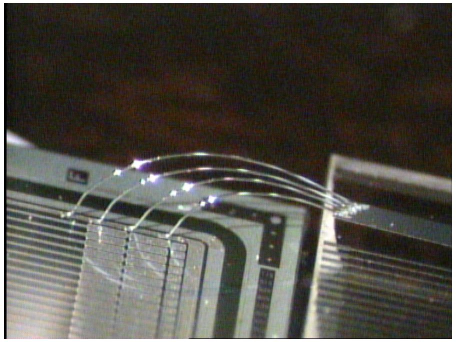
$< \Delta x >$ = - 2.0 μm, and $\sigma_{\Delta x}$ = 9.6 μm
$< \Delta y >$ = - 0.2 μm, and $\sigma_{\Delta y}$ = 8.8 μm

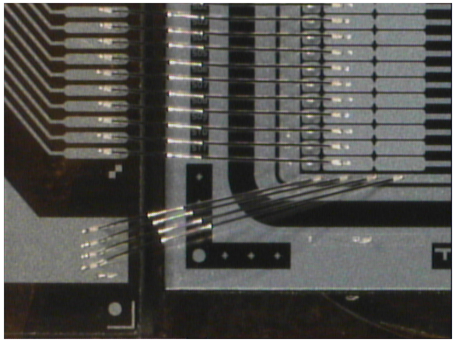
$< \Delta\theta >^1$ = 1.6 mdeg, and $\sigma_{\Delta\theta}{}^1$ = 3.7 mdeg
$< \Delta\theta >^2$ = - 6.4 mdeg, and $\sigma_{\Delta\theta}{}^2$ = 2.4 mdeg

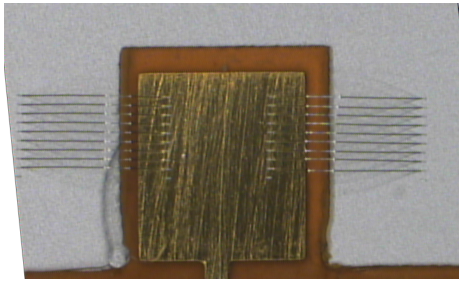
Precision checked with Mitutoyo (3 μm precision): differences < 10 μm.

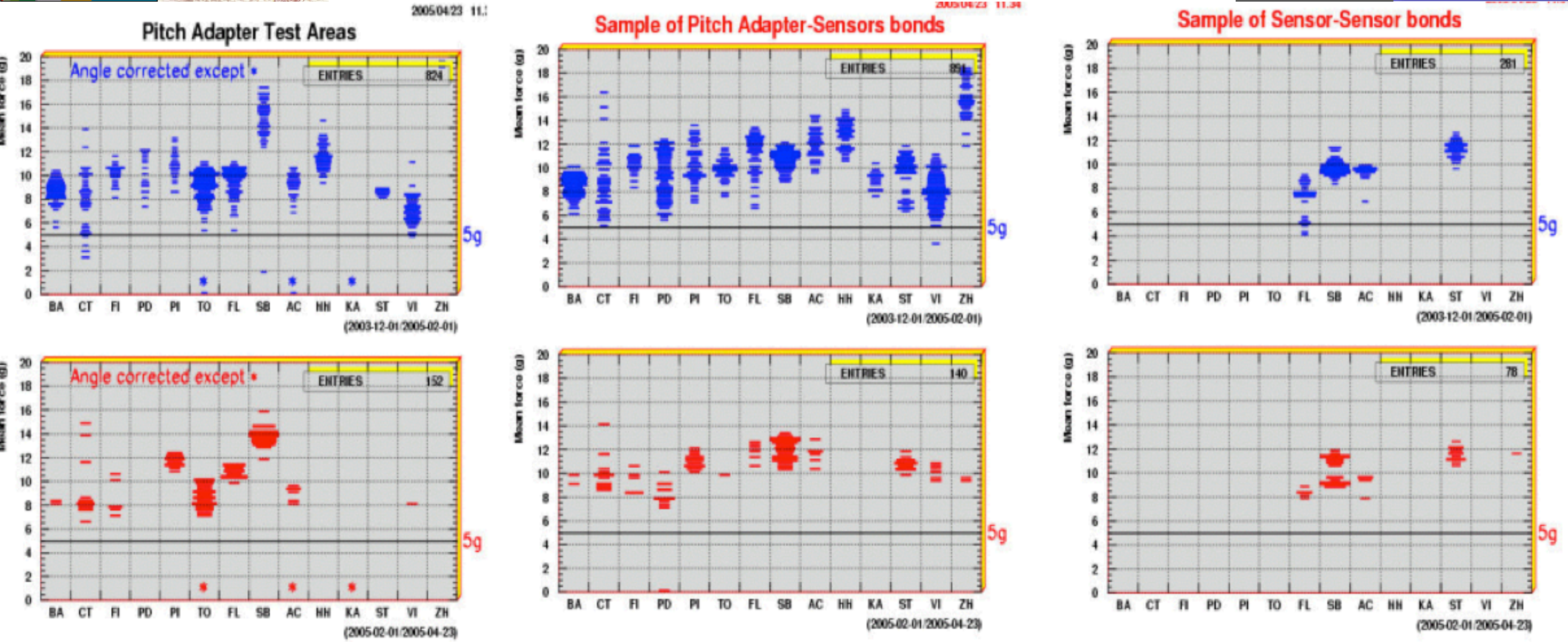
Wire Bonding











Bonding pull force monitored regularly for all centers. Within specs

Bonding

10 Million bonds on hybrid:

all done in CERN: 3 Delvotec, all testing equip.

25 Million bonds on modules made in 13 centers :

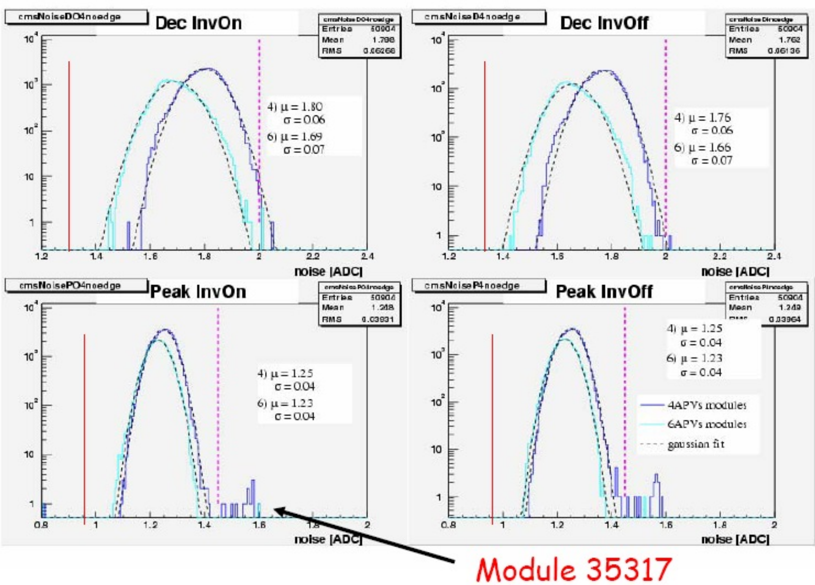
test / repairs made in labs ➔ time intensive

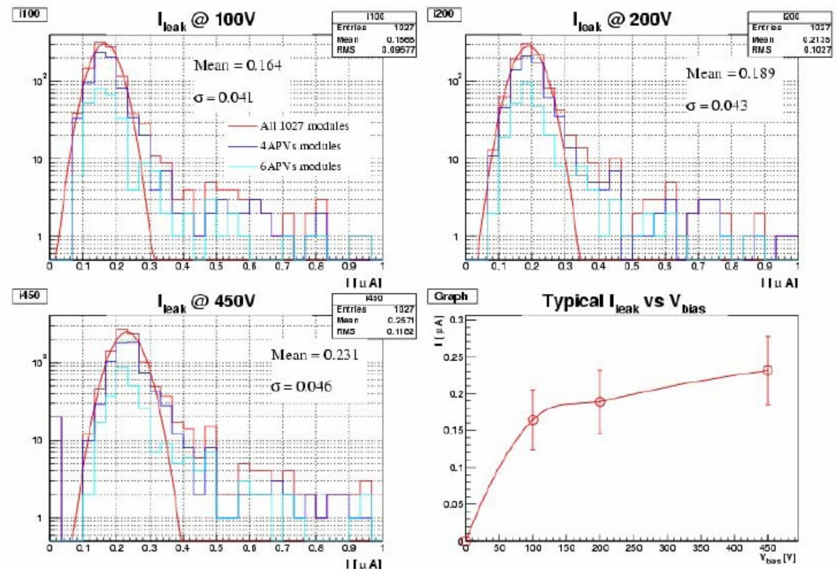
take in mind bad sensors channel need rework / unbonding

frequency : ~1 Hz even if faster speed achievable

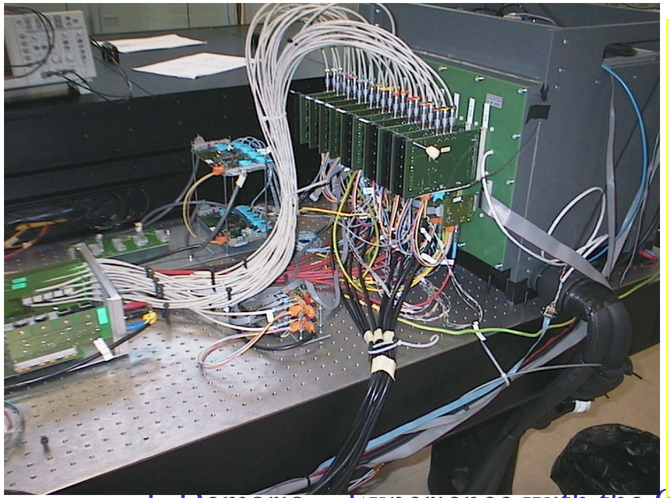
768 ch = 13 minutes (+align./controls etc…)

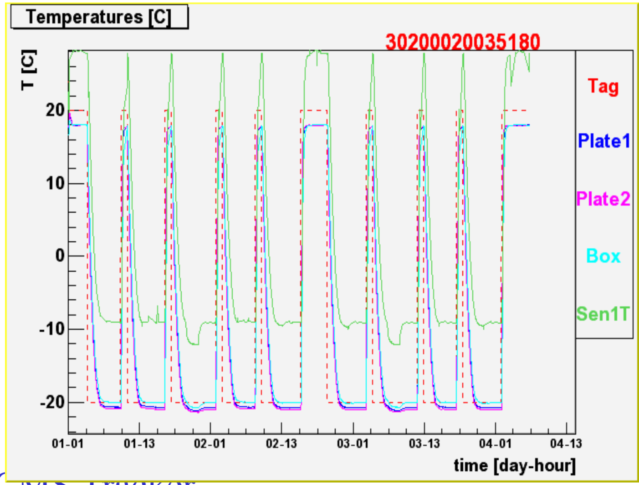
Module Testing



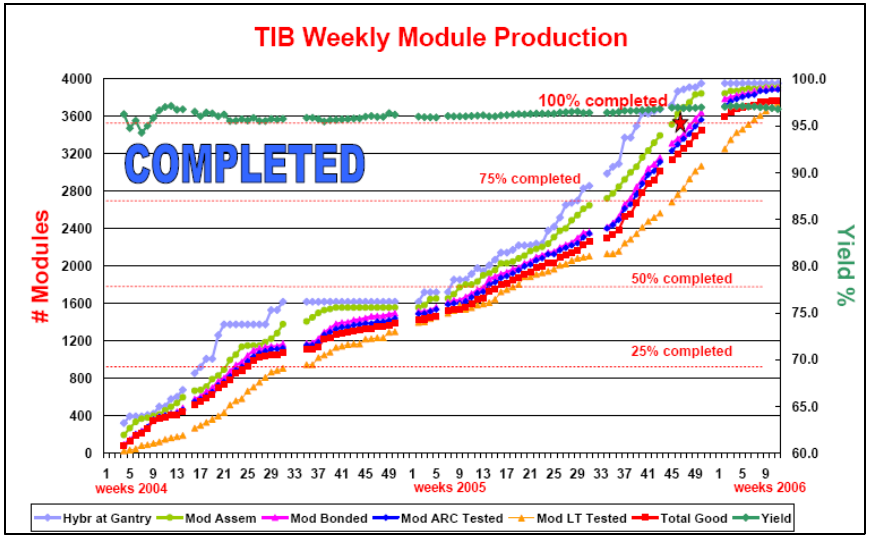


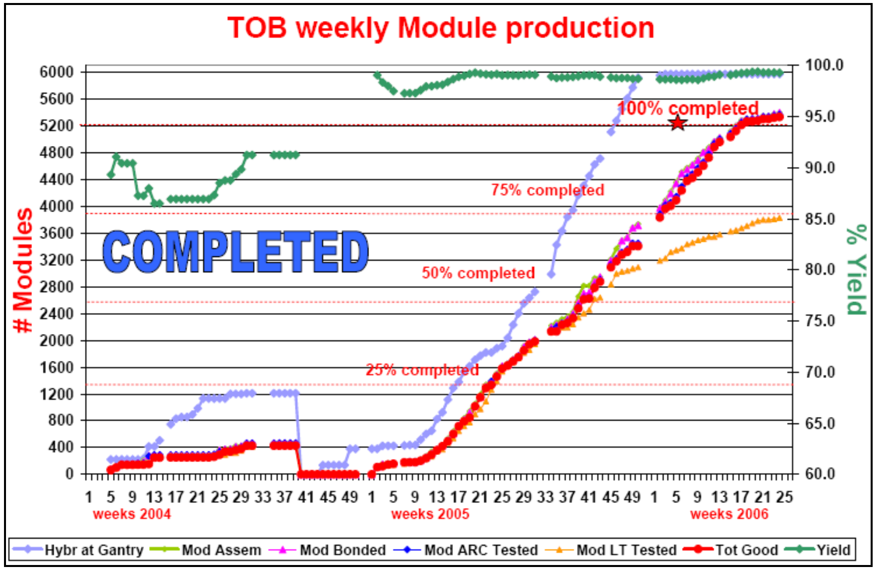
- reception test
- test after HV bonding (first 100 modules)
- test after full bonding
- Long term test
  - 2-3 days cycling from 20C to -20C

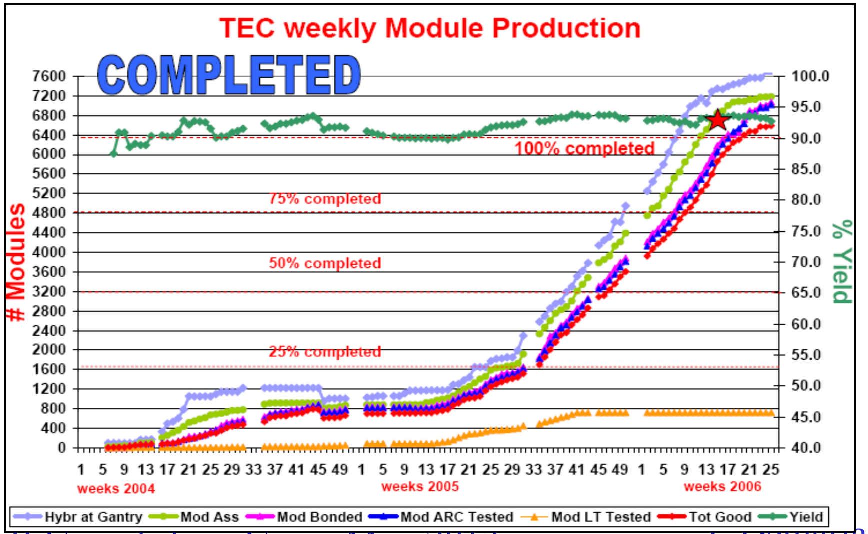




Module hystory







Up to 10 module/day in TIB
Up to 14 modules/day in TOB
Up to 18 modules/day in TEC

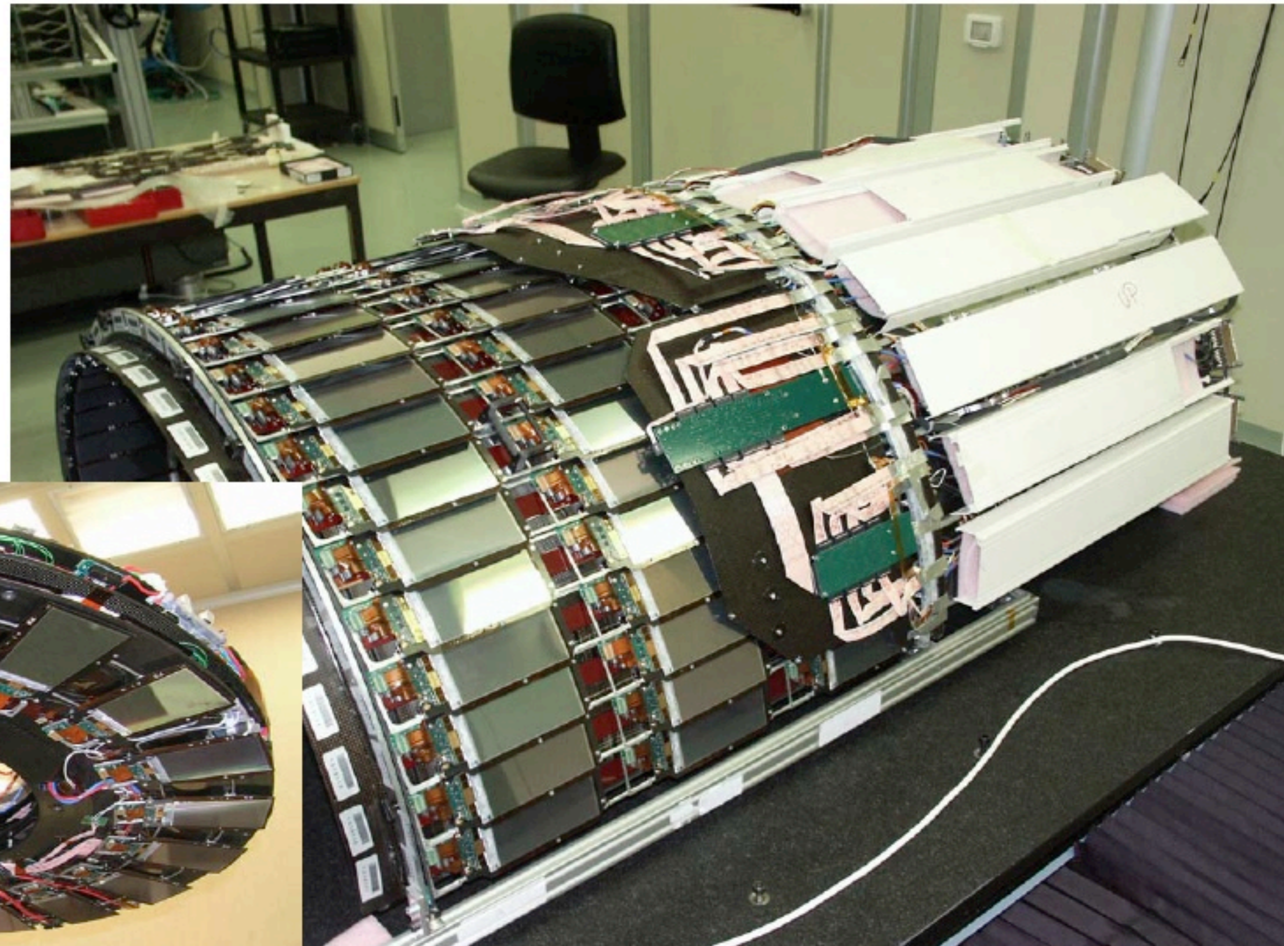
2.5 years

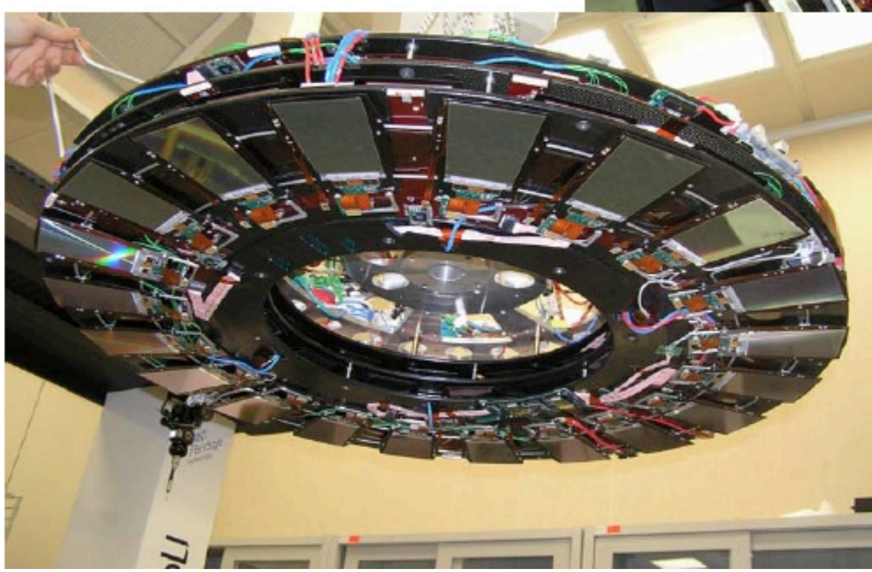
10% spare (roughlty) was achieved a level of 0.1% level defect in good modules (97% of total)

Sub-Detectors Integration in Laboratories and Final Assembly and First Commissioning at CERN

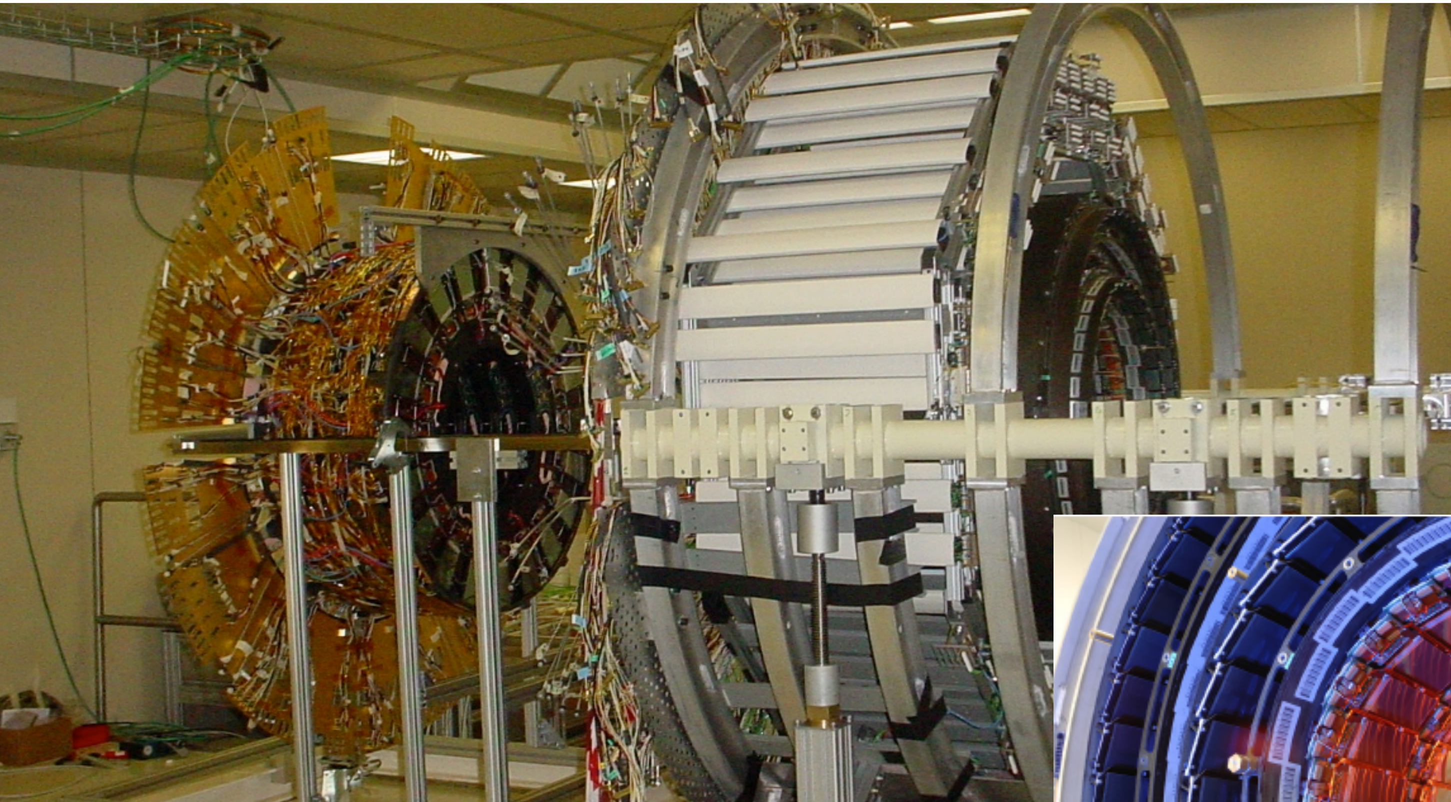
Integrated TIB half-shell and one Disk

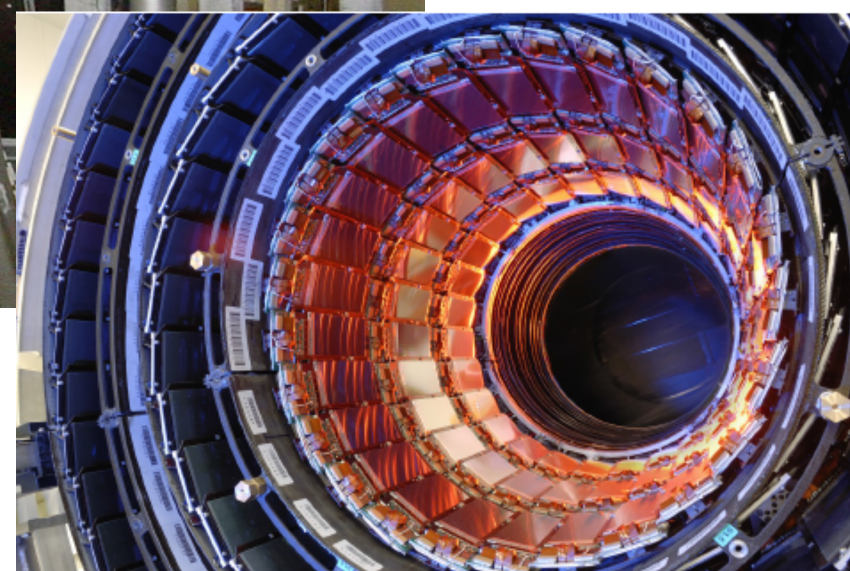
- The one shown was in Florence. It was then brought to Pisa where it was coupled with another half-shell
- The disks were integrated in Torino and then sent to Pisa.



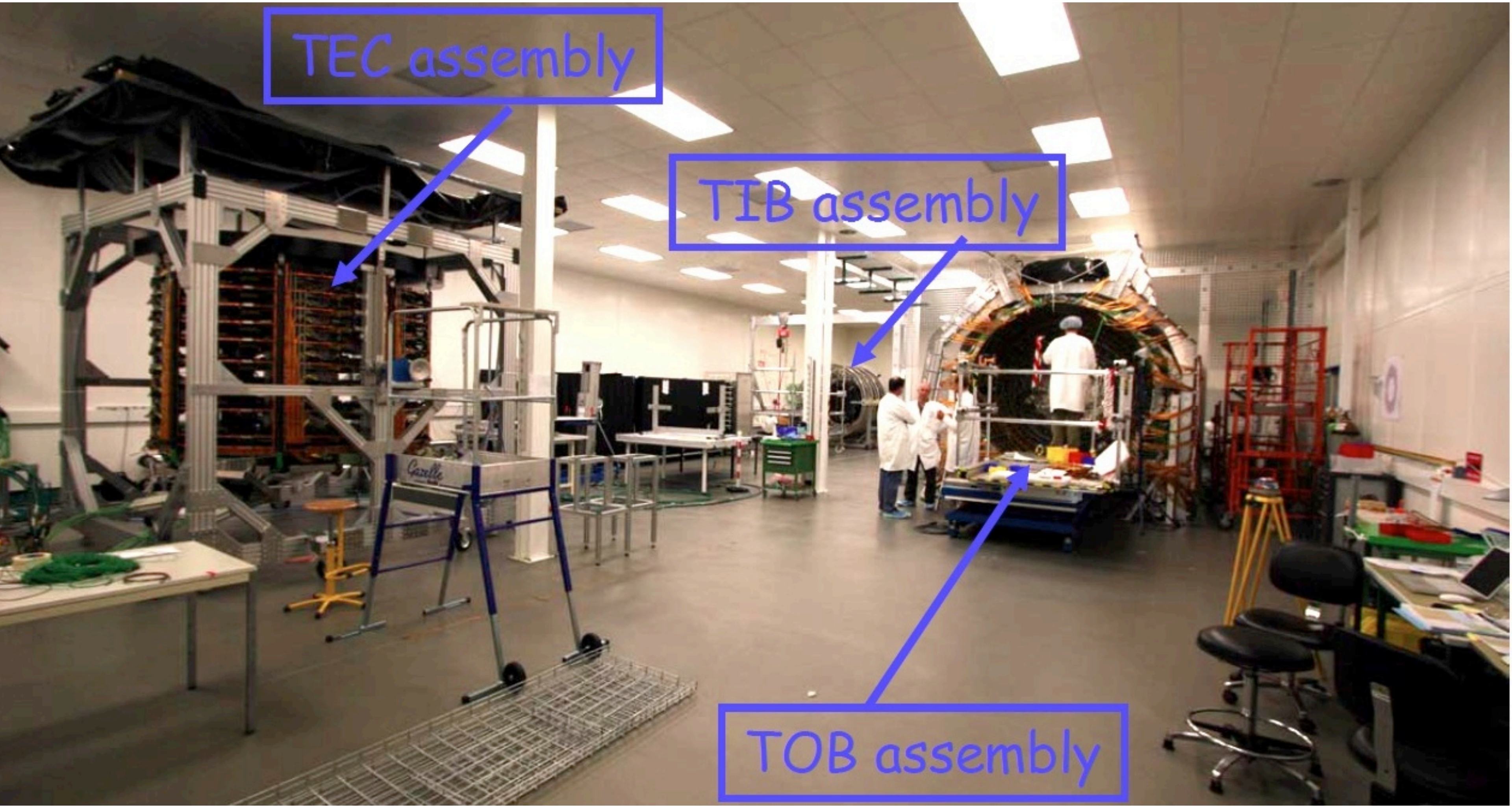


TIB-TID assembly



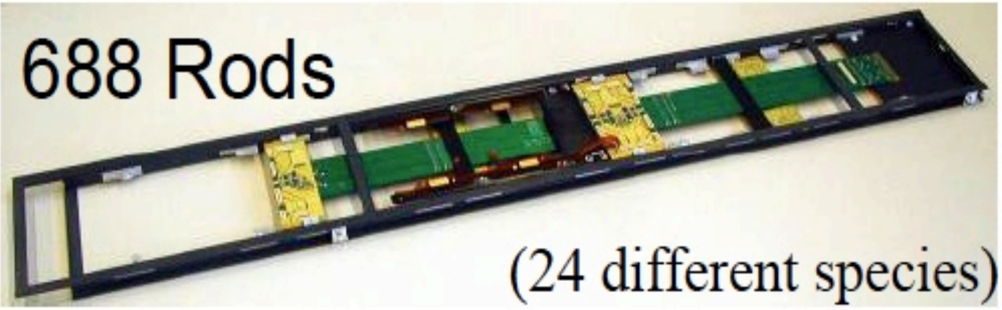


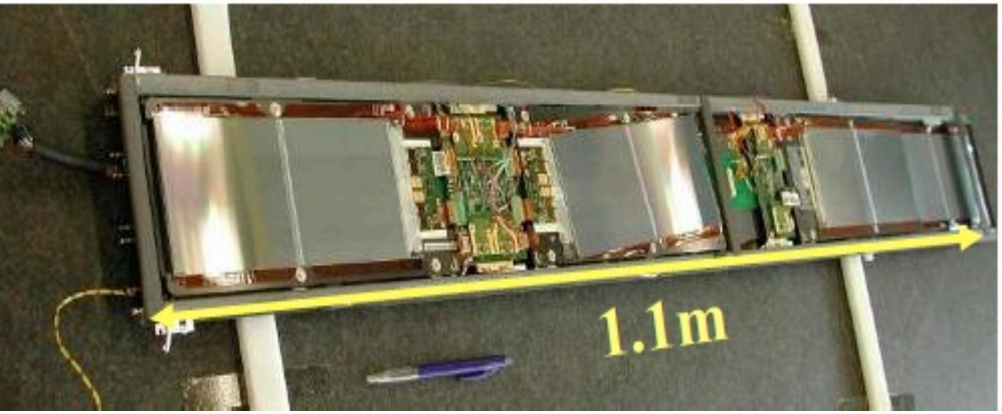
Tracker Integration Facility at CERN



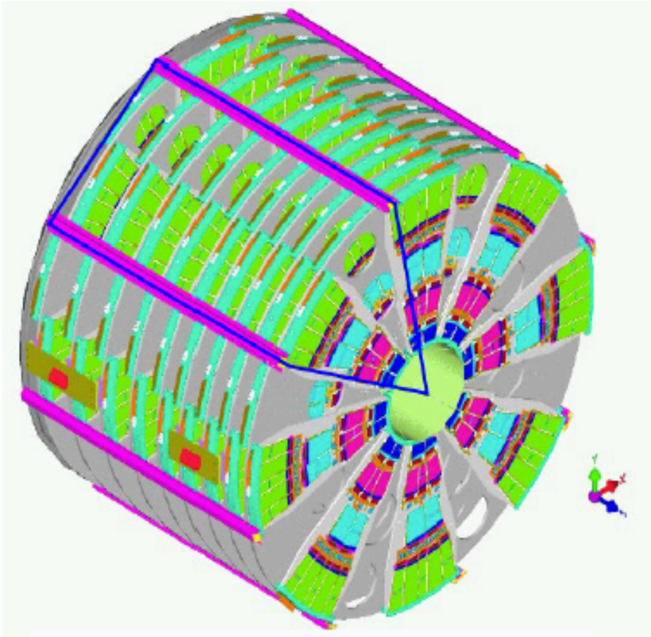
+ cooling plant, power supplies, readout back-end electronics for 12.5% of SST

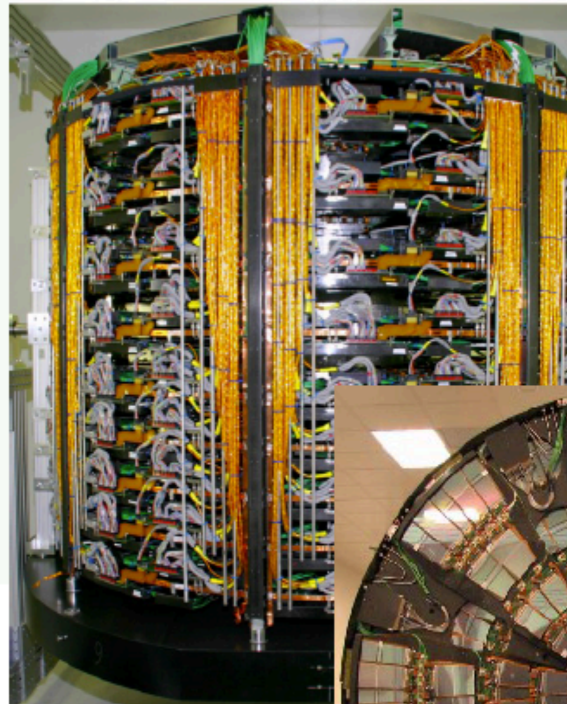
TOB

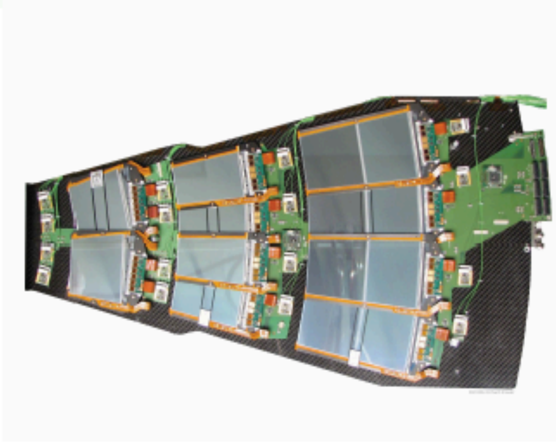


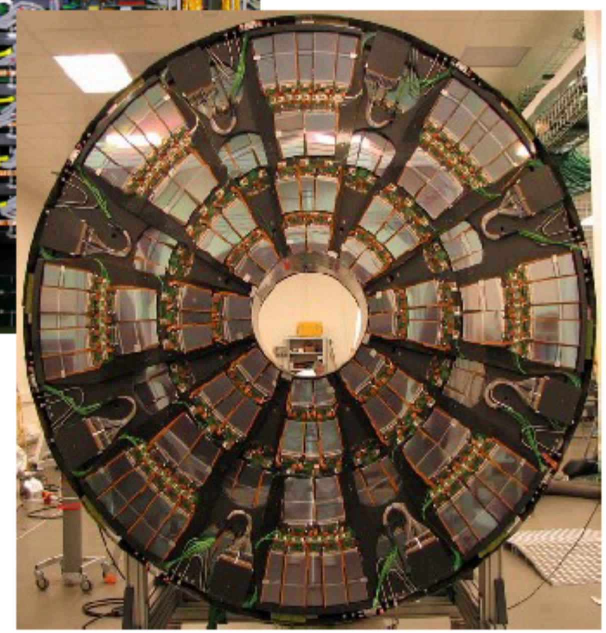


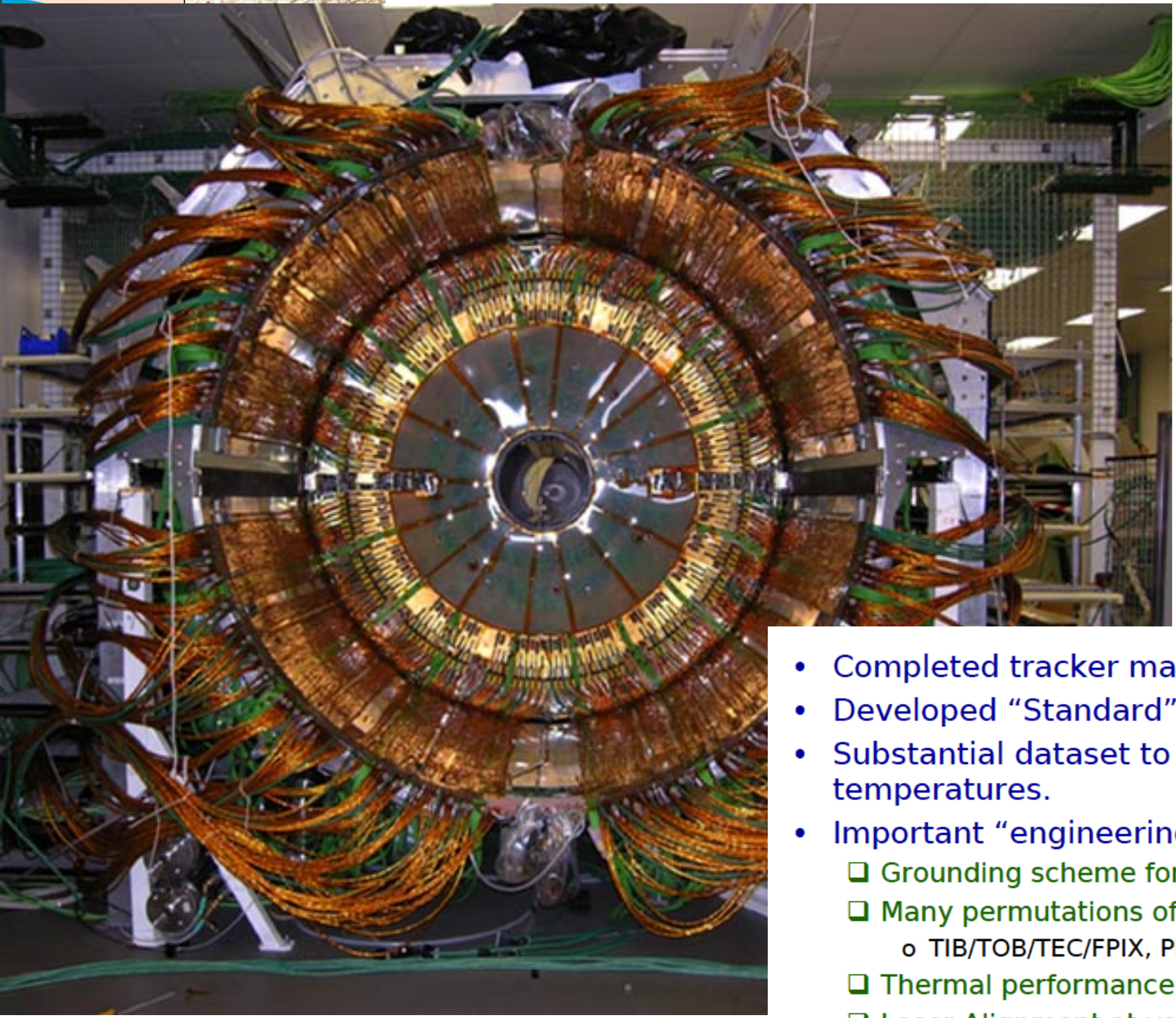
TEC











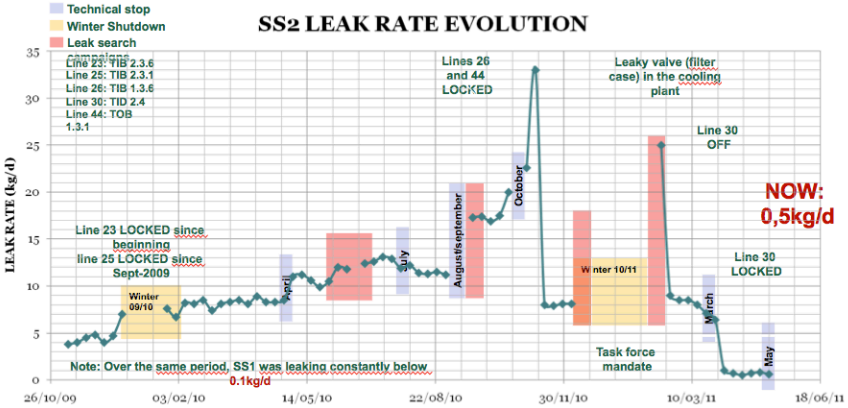
- Completed tracker maintaining high quality of production.
- Developed "Standard" DAQ/Detector Control /Data Quality tools.
- Substantial dataset to evaluate TK performance at various temperatures.
- Important "engineering" tests
  - ❑ Grounding scheme for all subdetectors
  - ❑ Many permutations of interference (noise) tests
    - o TIB/TOB/TEC/FPIX, Plus versus Minus,...
  - ❑ Thermal performance at various temperatures
  - ❑ Laser Alignment at various temperatures
  - ❑ Zero Suppression vs Virgin Raw data
  - ❑ Stability of Noise, Gain, etc over time
- Cosmic Data Taking
  - ❑ 5,025,043 events taken
  - ❑ Are used for tracking and alignment studies

2007

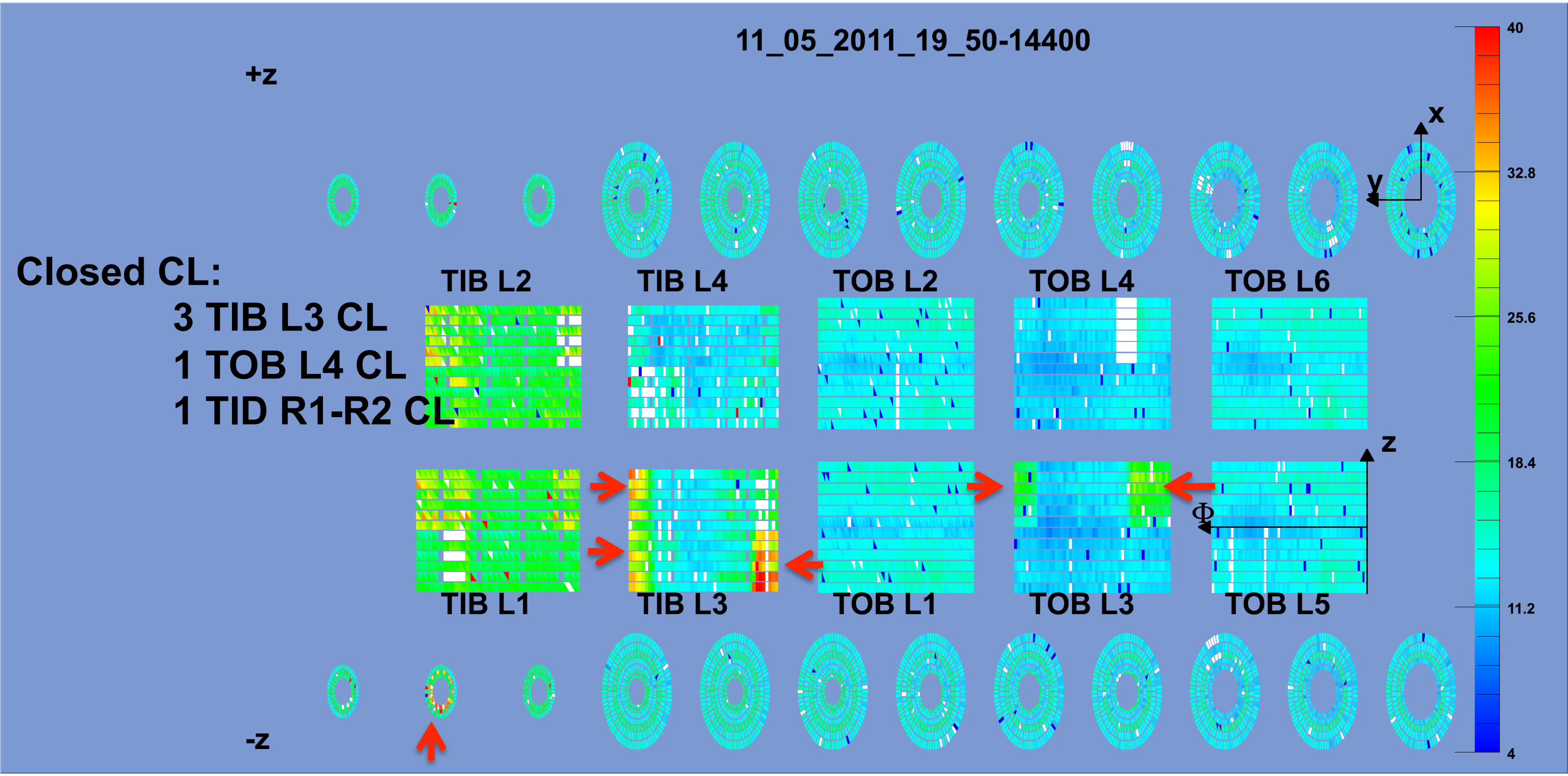
CMS Tracker inside CMS

Cooling

- It is a double stage cooling: main chiller is serving several cooling plants of which the two biggest ones are serving the Strip Tracker
  - Main chiller was originally a Brine circuit, on 2007 was changed to C_6F_{14}
- Has to take 60 kW power from the Tracker. Liquid: C_6F_{14}, very volatile and neutral to electronics
  - 2 independent system, each with 90 lines each
  - **Liquid at 4C temperature**
- System running stably: stable **Low Leak rate** achieved: SS1~0; SS2~0.5 kg/d (5 lines closed, out of 90)
- Improvement in 2011:
  - **pressure to the detector reduced** for unchanged module's temperature (0.6-0.8 Bar reduction)
  - **CP pressure reduced** from 9 to 7Bar and safety pressure switches were installed
  - Pump running with Variable Frequency Driver: longer lifetime, **smoother operation**, no pressure glitches, vibrations (pump were replaced due to overheat)
  - Bigger bypass valve installation to allow a **smoother operation**



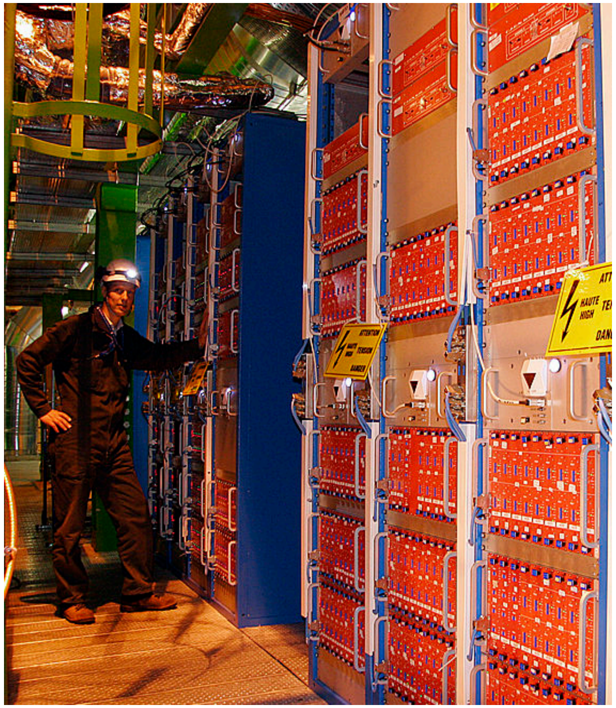
Silicon Detector temperatures



Power Supply system

- Floating Power supplies.
- Located inside experimental cavern, in crates
- powered via AC/DC converter.
- Rad.Hard and B-field resistant
- Power to modules
  - 1000 power supply modules (PSM).
  - each PSM hosts 2 units (PSU) each connected via a 30-50m cable to a part of the SST and providing
  - 1 PSU = 1 LV (1.25V, 2.5V) and 2 HV lines for detector modules. 1944 PSU used.
- Power to Control Rings:
  - 356 control power supply 2.5V

Mainframe at Service Cavern



Racks @ Exp. Cavern

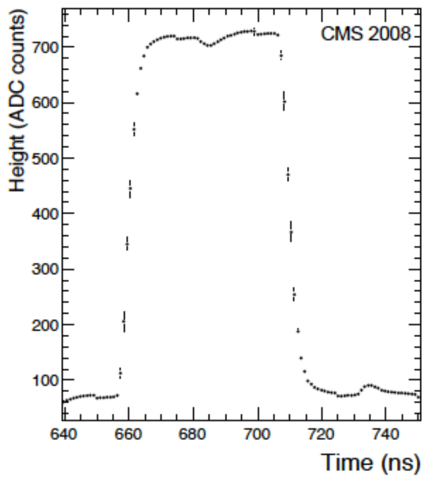
Reached a Failure rate of 1% per year (2PSU/month) during 2010. During 2011 system is even more stable, below 1%

All failures have a negligible impact on hit efficiency and no effect on tracking efficiency. Only Power groups failed (there are 2000 of them)

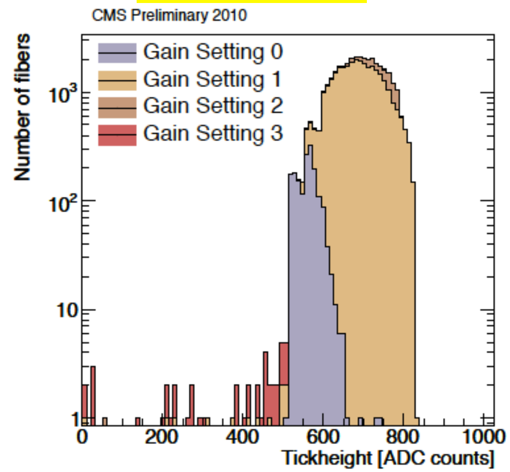
Commissioning Steps

- Internal synchronizat
- Gain calibration
- Base line adjustment
- Pulse shape adjustme
- Pedestal and noise measurement
- Synchronization with particles

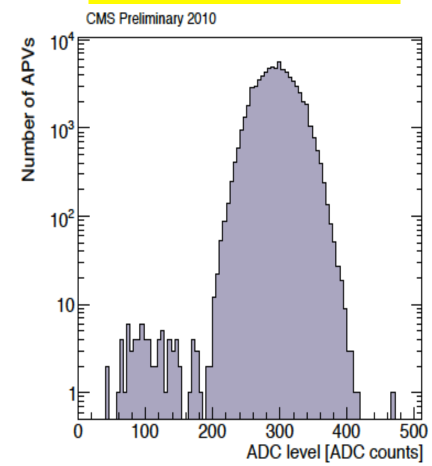
Internal synch



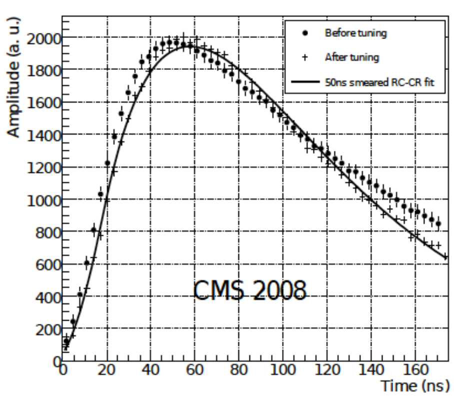
Gain Calibr



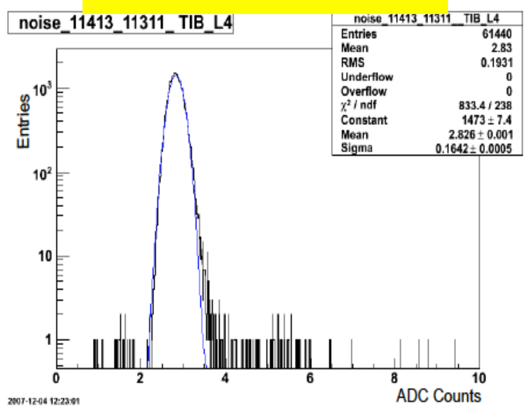
Base line adjust



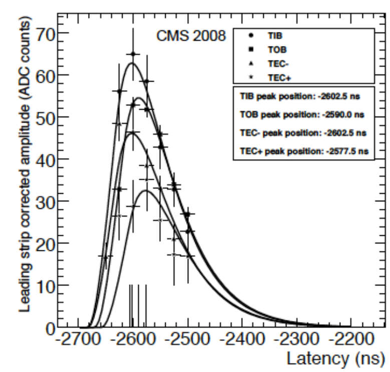
Pulse shape tuning



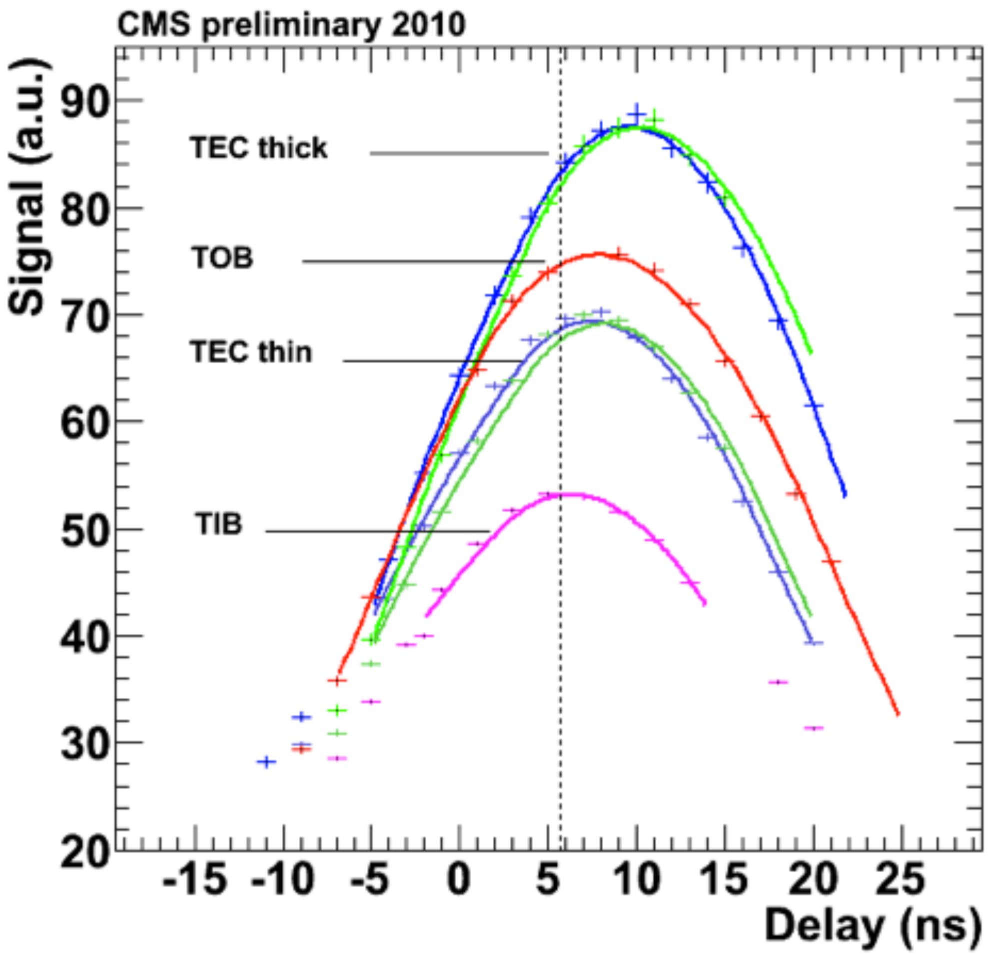
Pedestal and noise



Latency scan (peak)



Time synchronization with collisions



Deconvolution readout

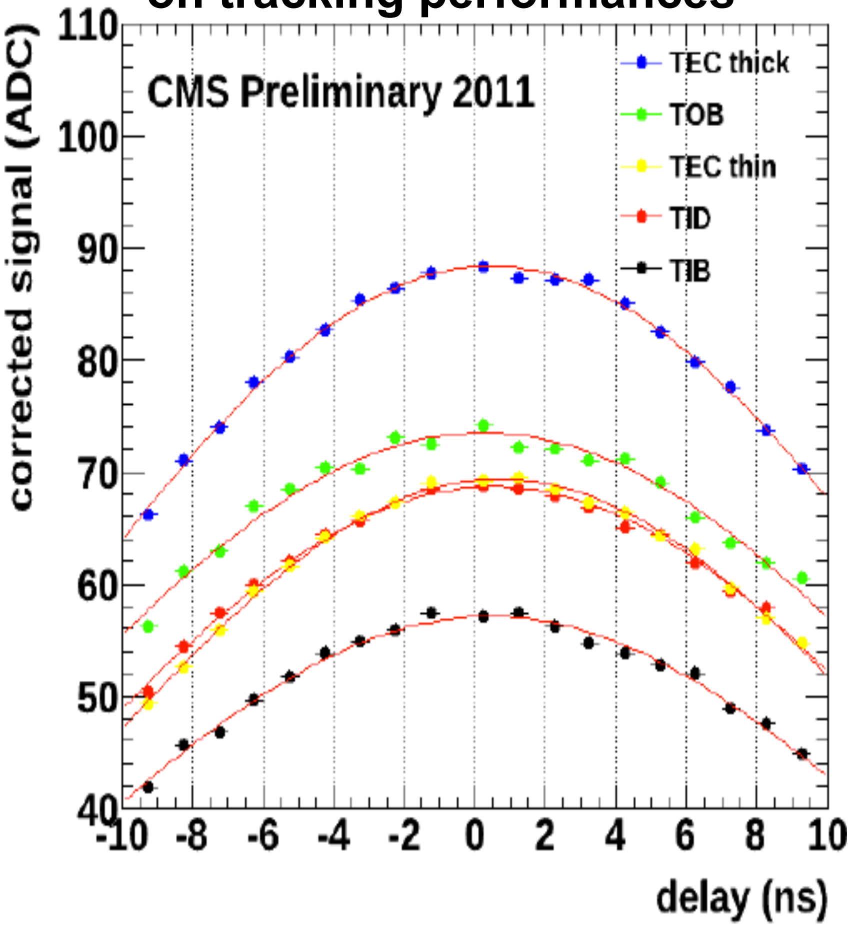
All layers but that under measurement are in peak mode and act as telescope for the layer under measurement

The layer under measurement is put in deconvolution mode and the charge of the hit associated to the track is searched. The timing of this layer is scanned in steps of 2ns from -25 ns to 25 ns

One layer per sub-detector. The delay setting are then uploaded correcting for the time of flight according to the module position.

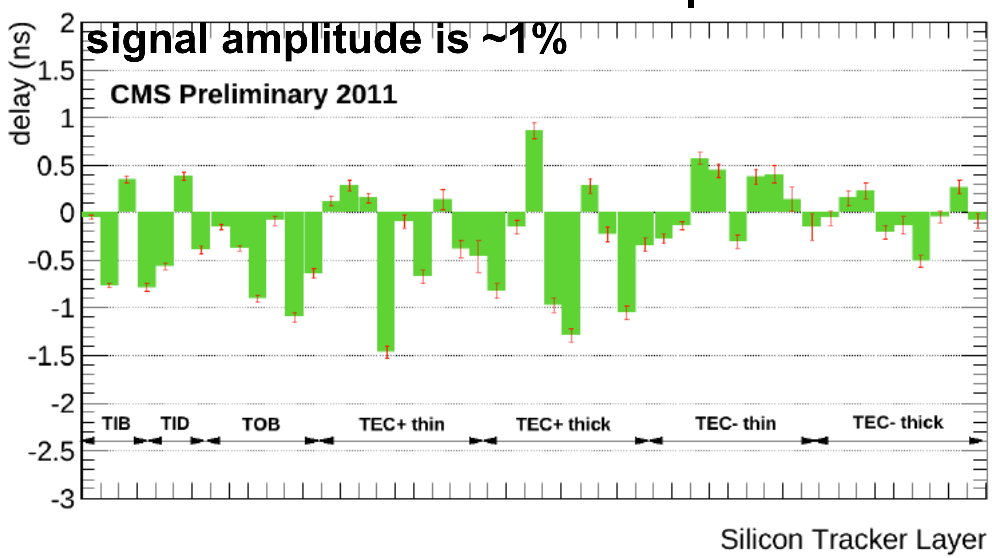
Signal time profile

Time profile of the signal in different parts of the silicon strip tracker. Obtained in dedicated short run with randomized timing. Profile show the expected width of 12ns. This measurement can be performed without impact on tracking performances

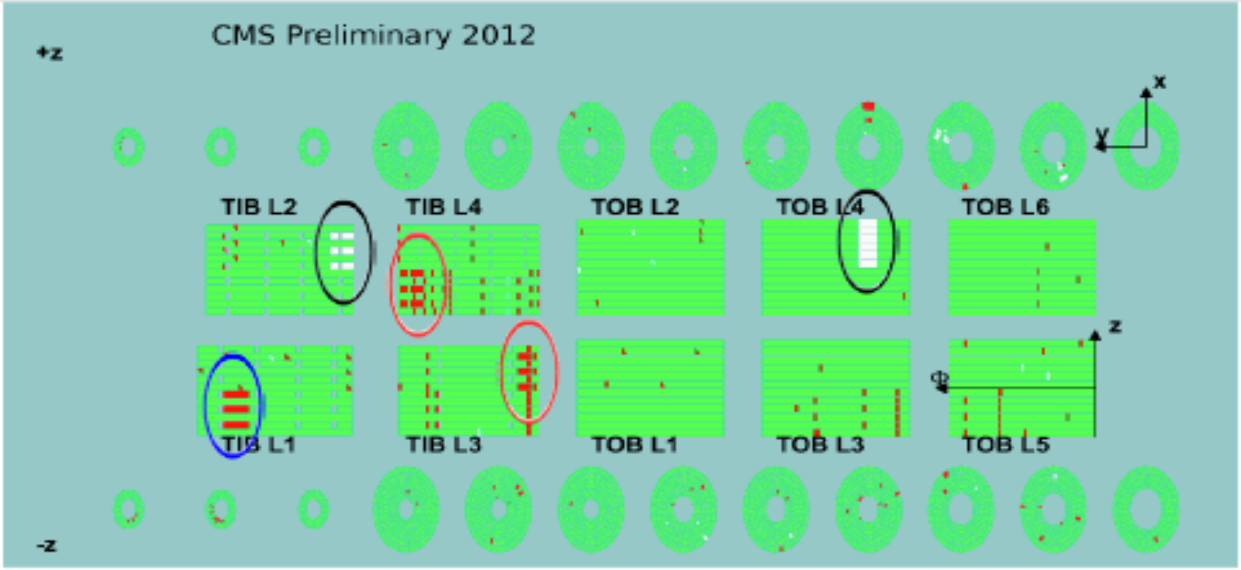


- **Measured position of signal maximum wrt the nominal sampling point**

- **Deviation in within ~1ns. Impact on signal amplitude is ~1%**



Active channels



Active, Masked, Not Commissioned

Reasons for Masking

- Control ring **shorts**
- Control rings **missing**
- HV line **shorts**
- HV lines open
- fibres/CCU/...

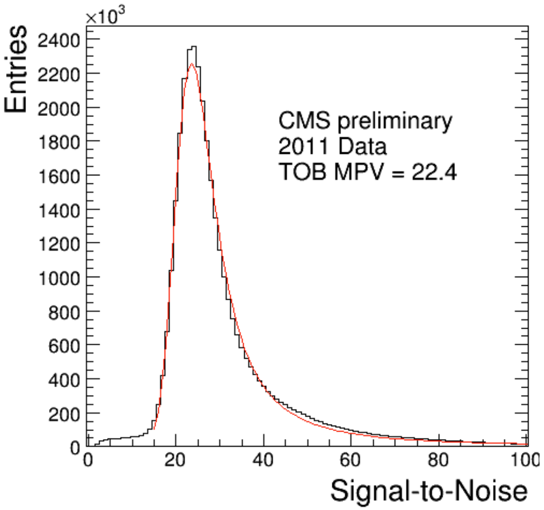
Active by Partition

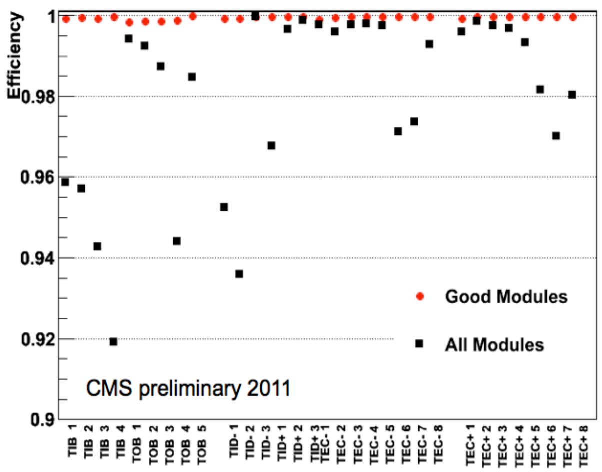
TIB/TID	94.63 %
TOB	98.19 %
TEC+	98.81 %
TEC-	99.13 %
Tracker	97.61 %

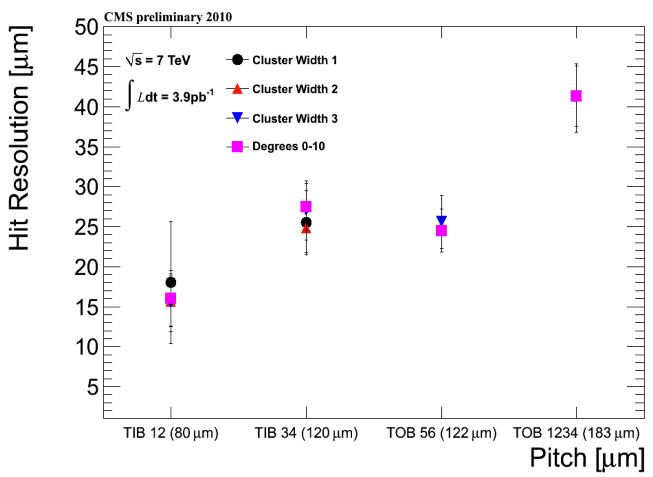
Almost stable:

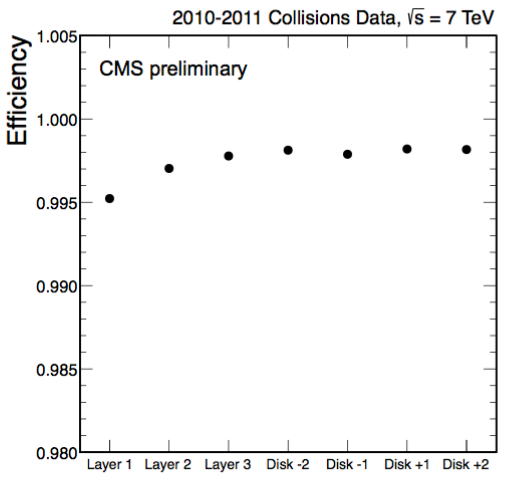
- 2008: 98.5%
- 2011: 97.75 %
- Potentially recoverable in 2013/14 shutdown: 2-3 control rings (0.7-1.0%).

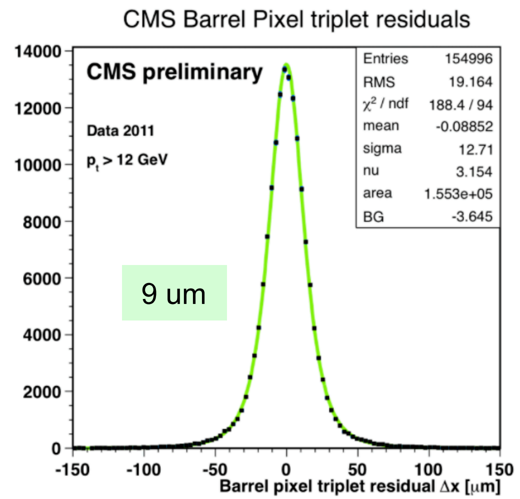
Basic Performance

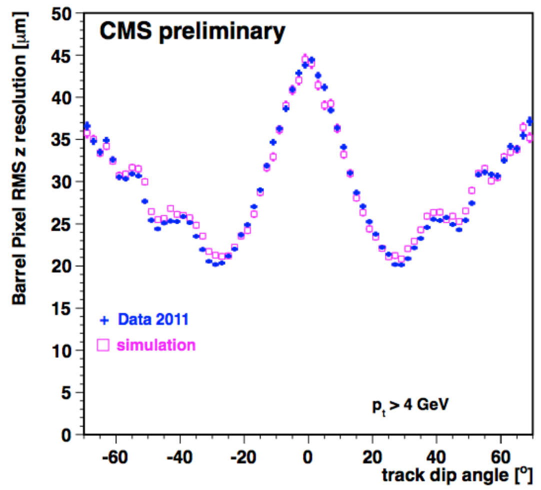






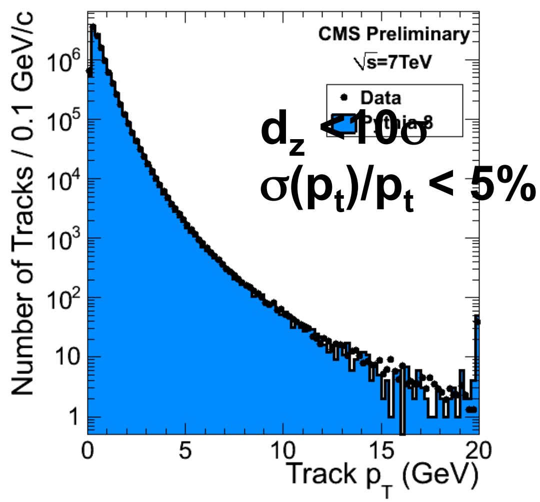


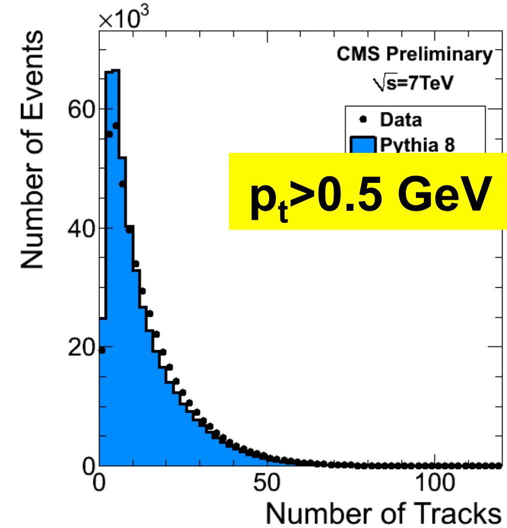


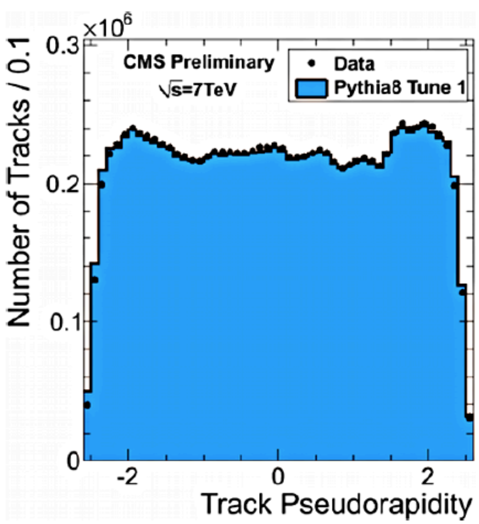


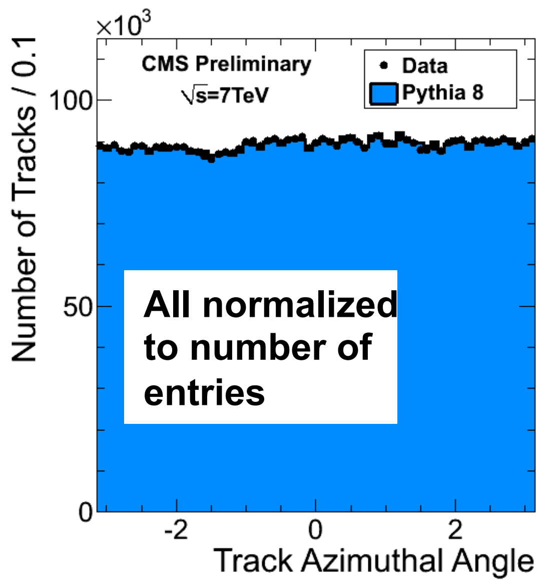
Track Reconstruction

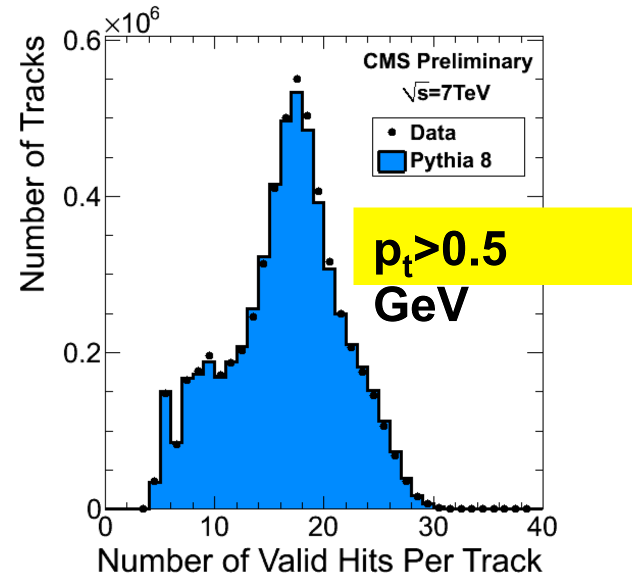
- No need for fixes in reconstruction algorithm with first collisions
- First results already useful for MC model tuning
- Detailed simulation of detector defects in MC





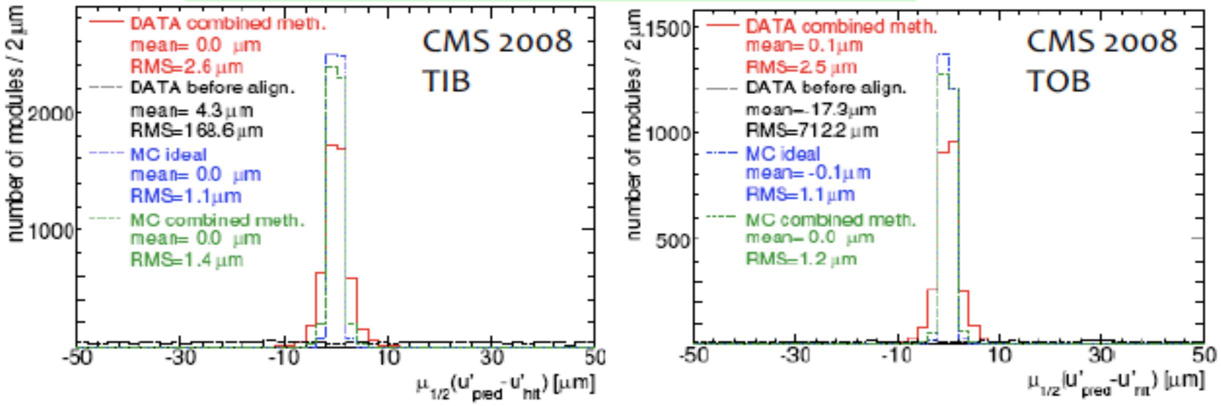




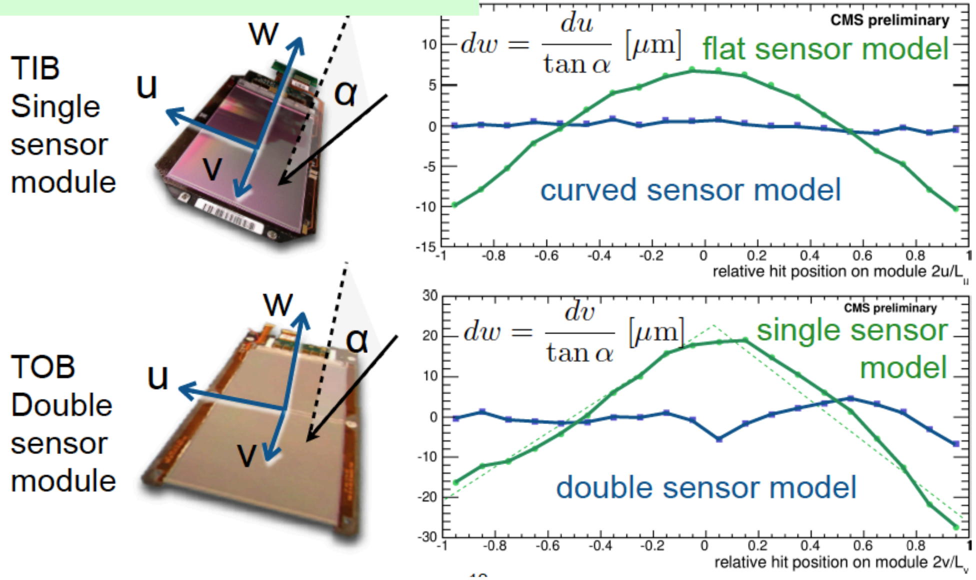


Alignment

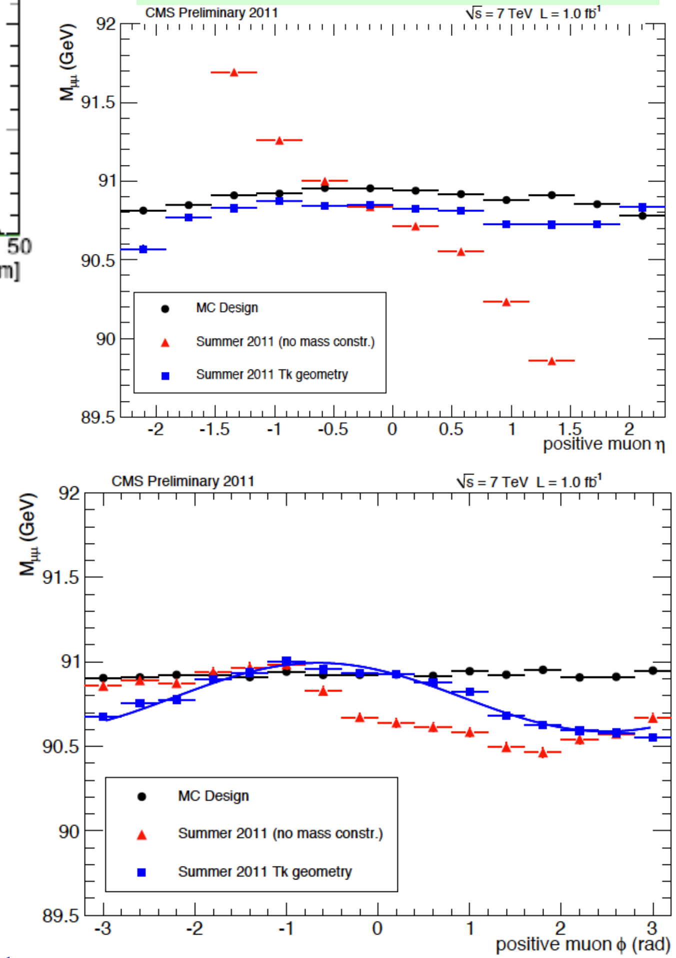
All modules aligned with few um



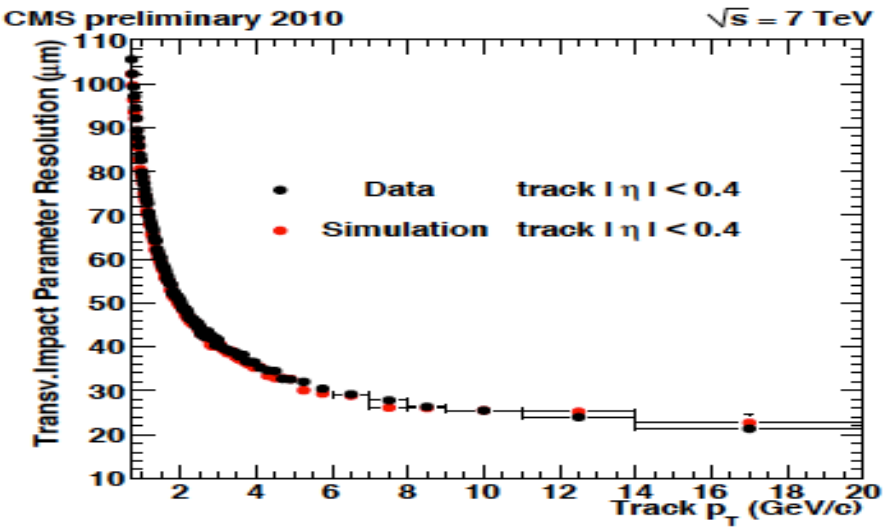
Bow and tilt of detector

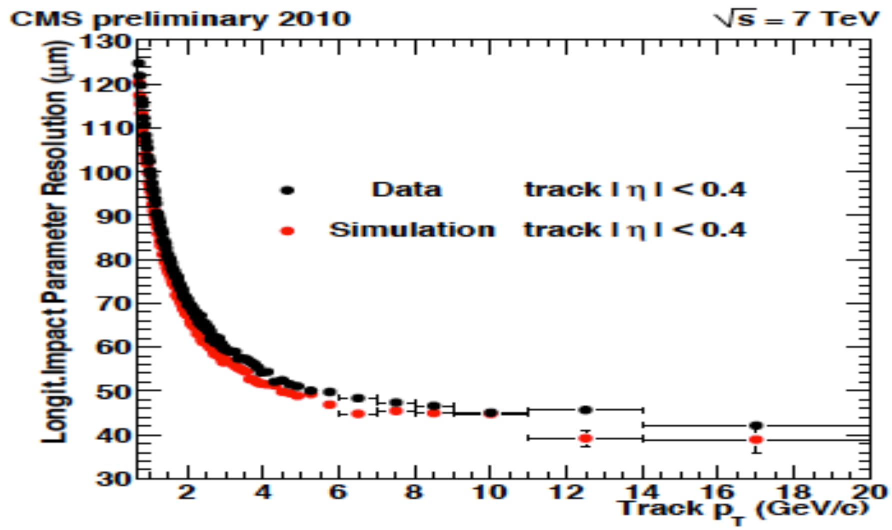


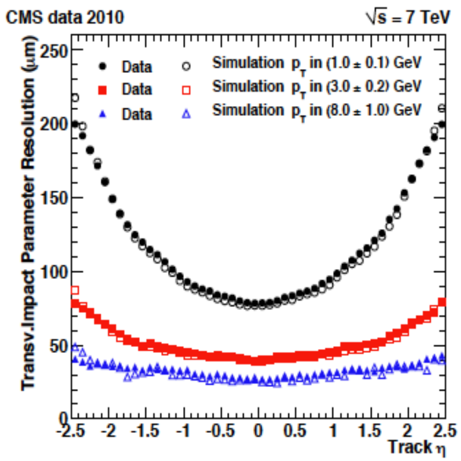
Weak mode correction

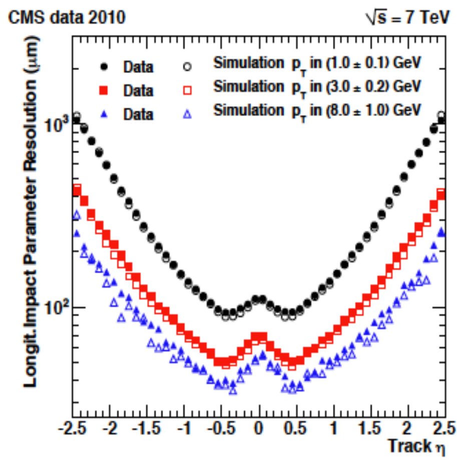


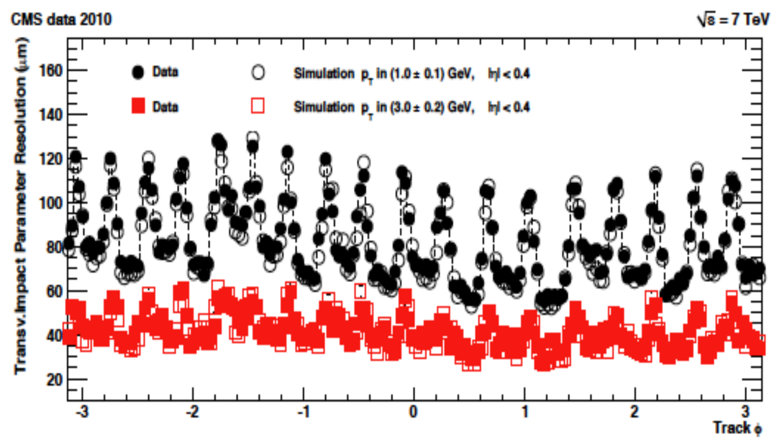
Impact Parameter







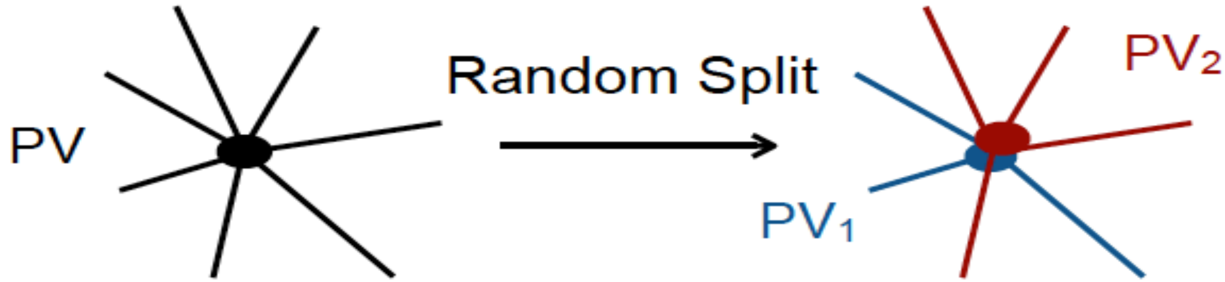


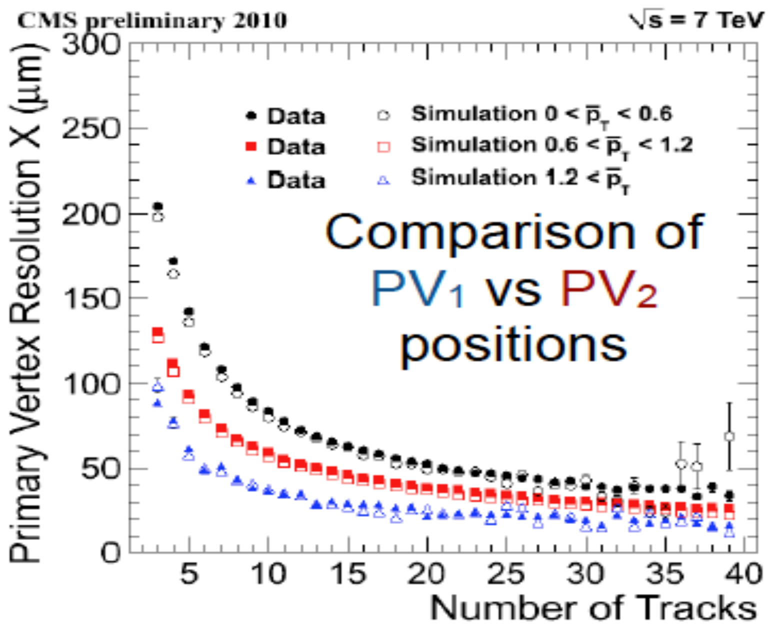


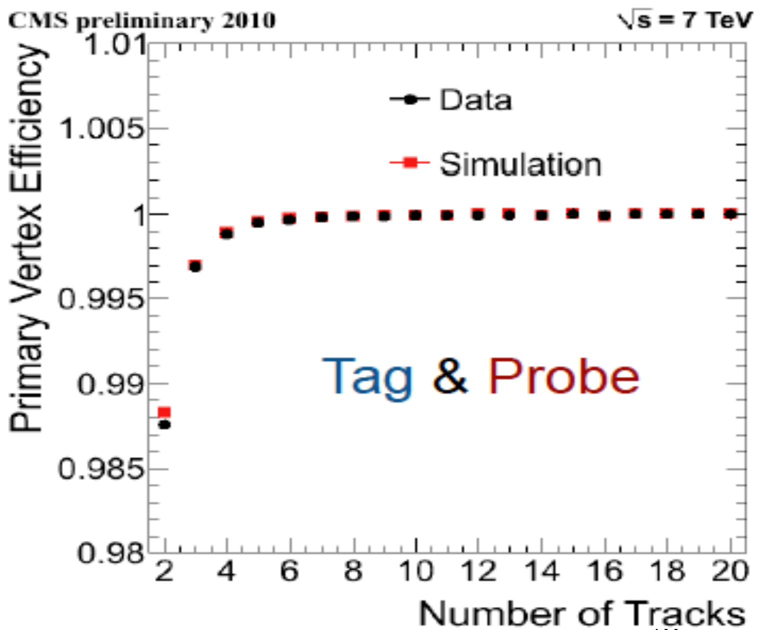
Primary vertex reconstruction

Event-by-event reconstruction of primary vertices is important: beam spot measurement, pile-up, b-tagging. PV algorithm is an Adaptive Kalman Filter.

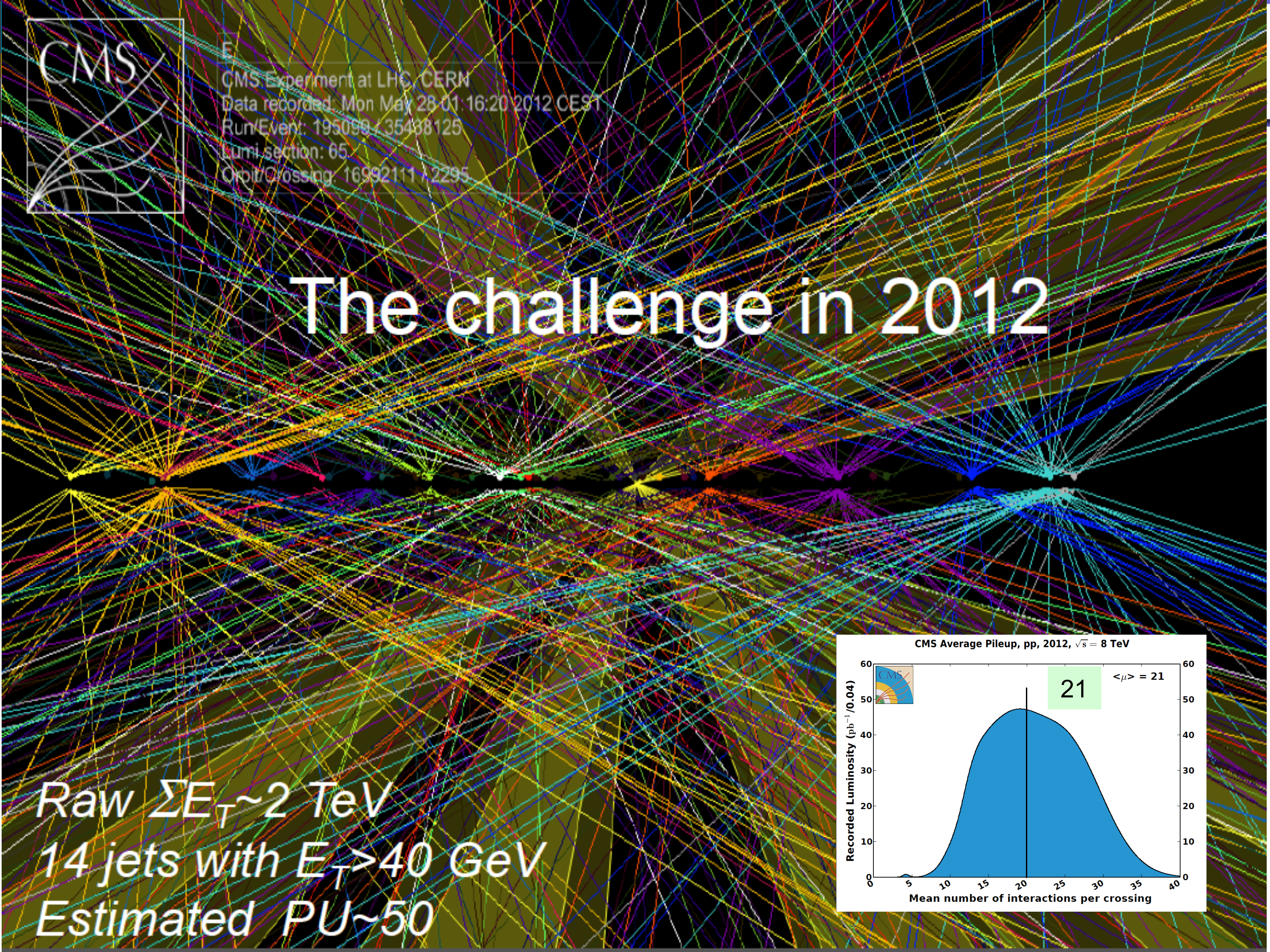
Data-driven method to measure efficiency and position resolutions







The challenge in 2012



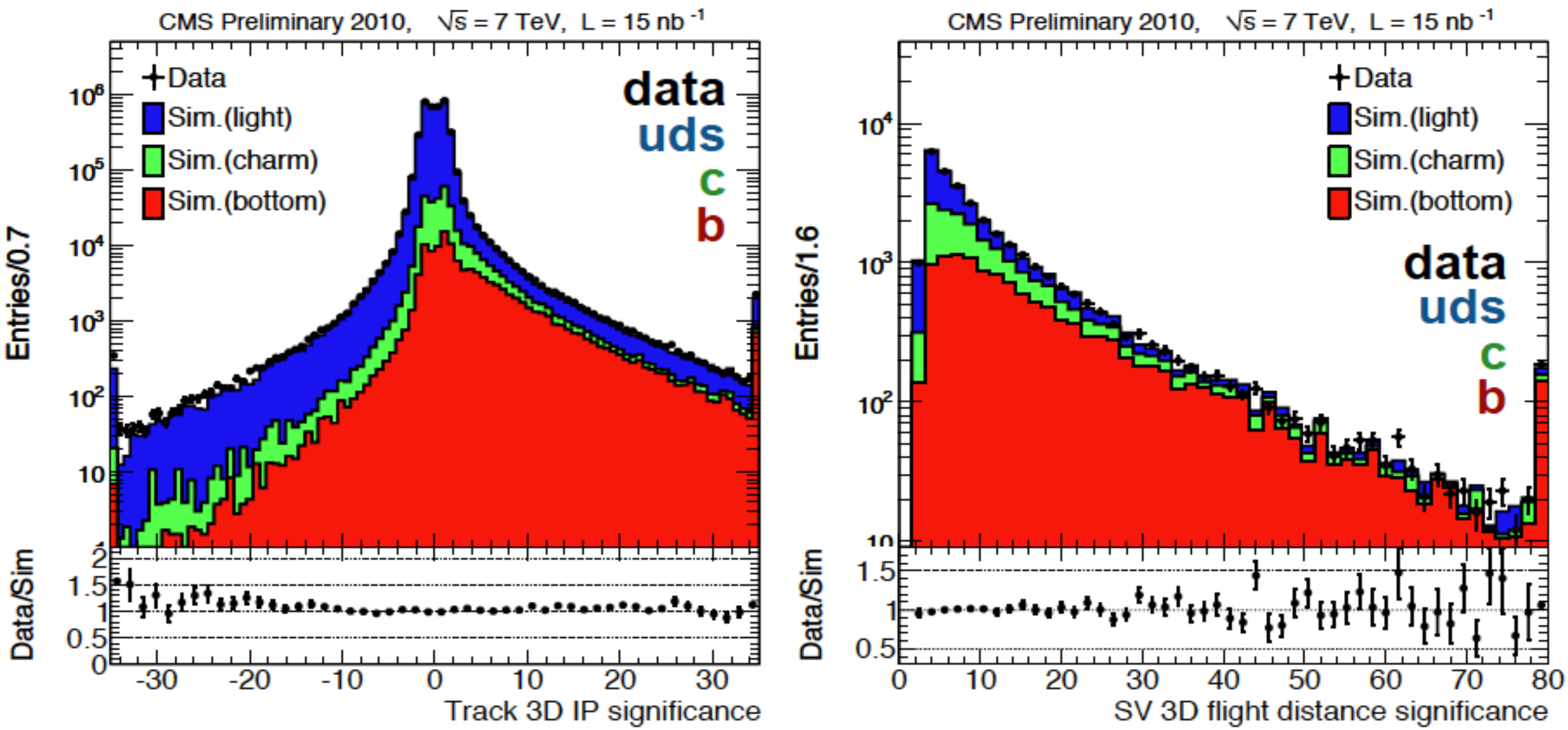
Raw ΣE_T~2 TeV

14 jets with E_T>40 GeV

Estimated PU~50

B-tagging primitives

b-quark jets tagging based on tracking, pixel detector is crucial

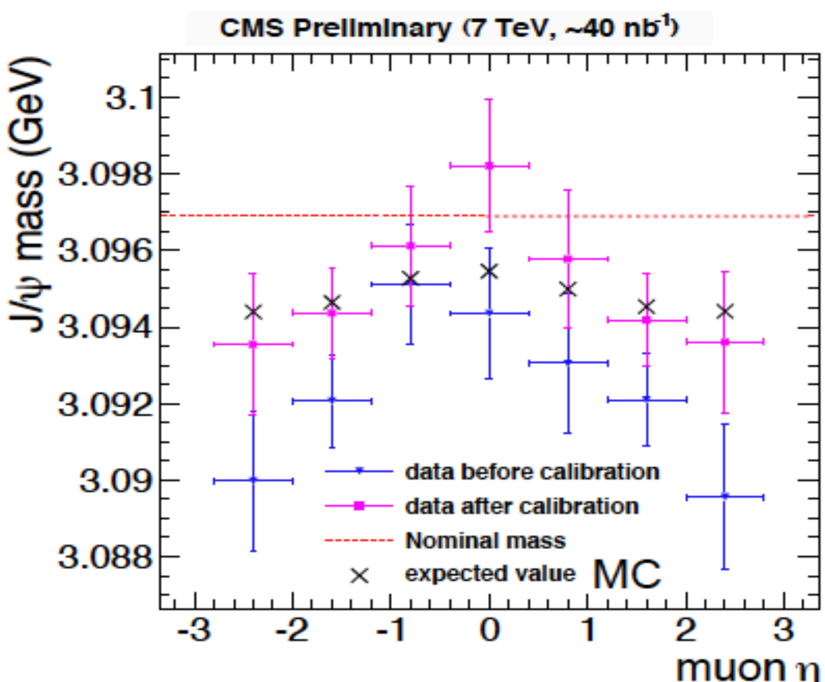


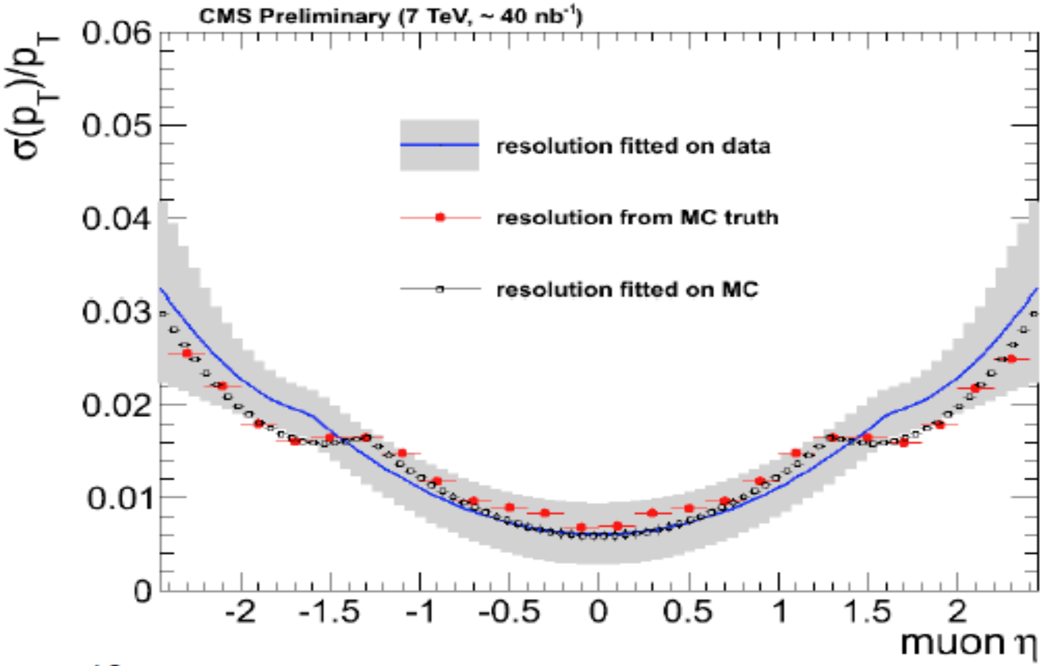
3D IP significance | SV 3D flight distance significance

J/ψ→μμ : momentum scale and resolution

Measured J/ψ line-shape (mass and width) depends on absolute momentum scale and on momentum resolution ⇒ scale calibration and measure of momentum resolution

J/ψ mass vs. η | Momentum resolution





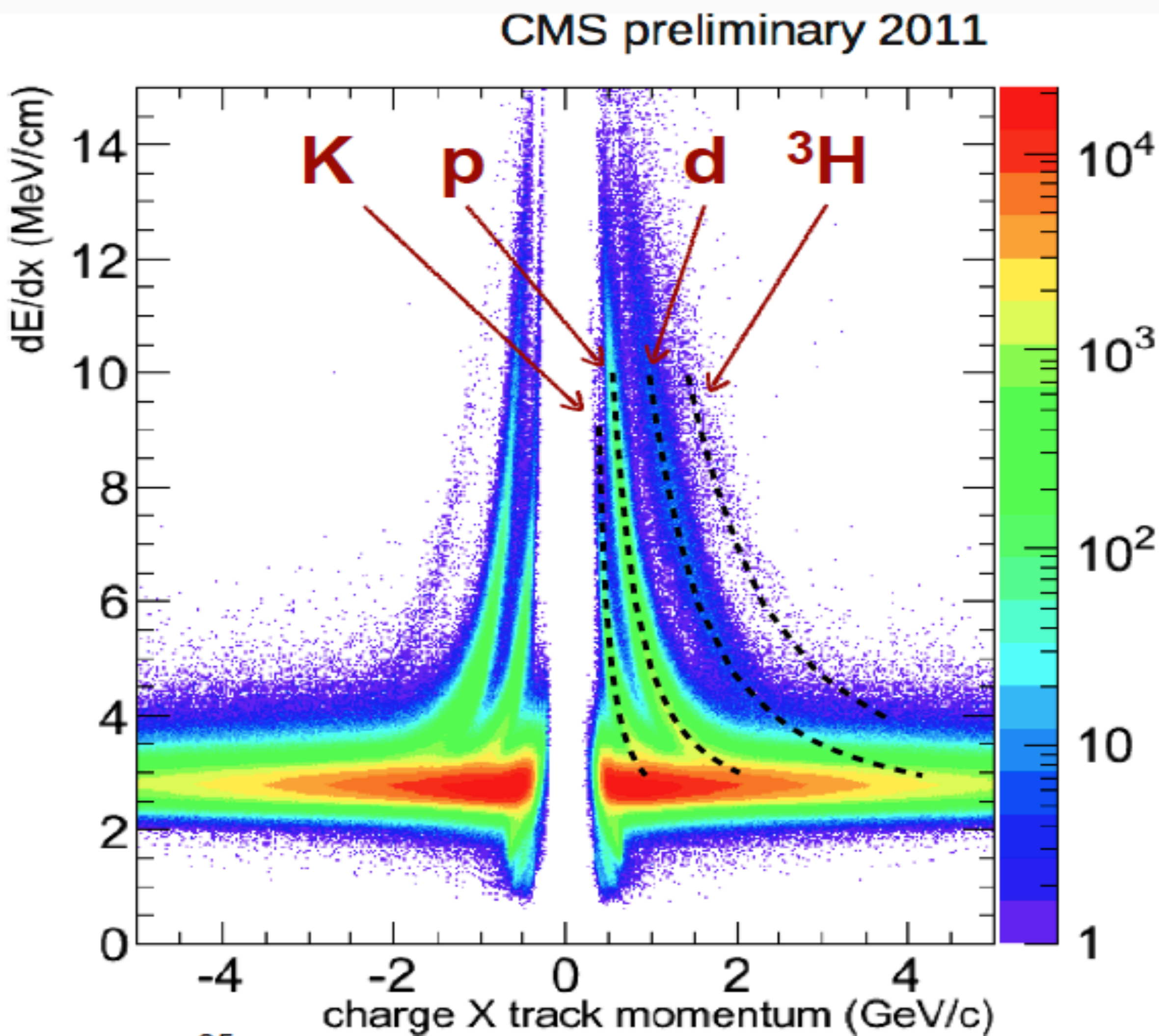
dE/dx

Analog readout; many independent measurements (in total more than ½cm of silicon)

Charge asymmetry is appreciable when plotting dE/dx vs. q×p.

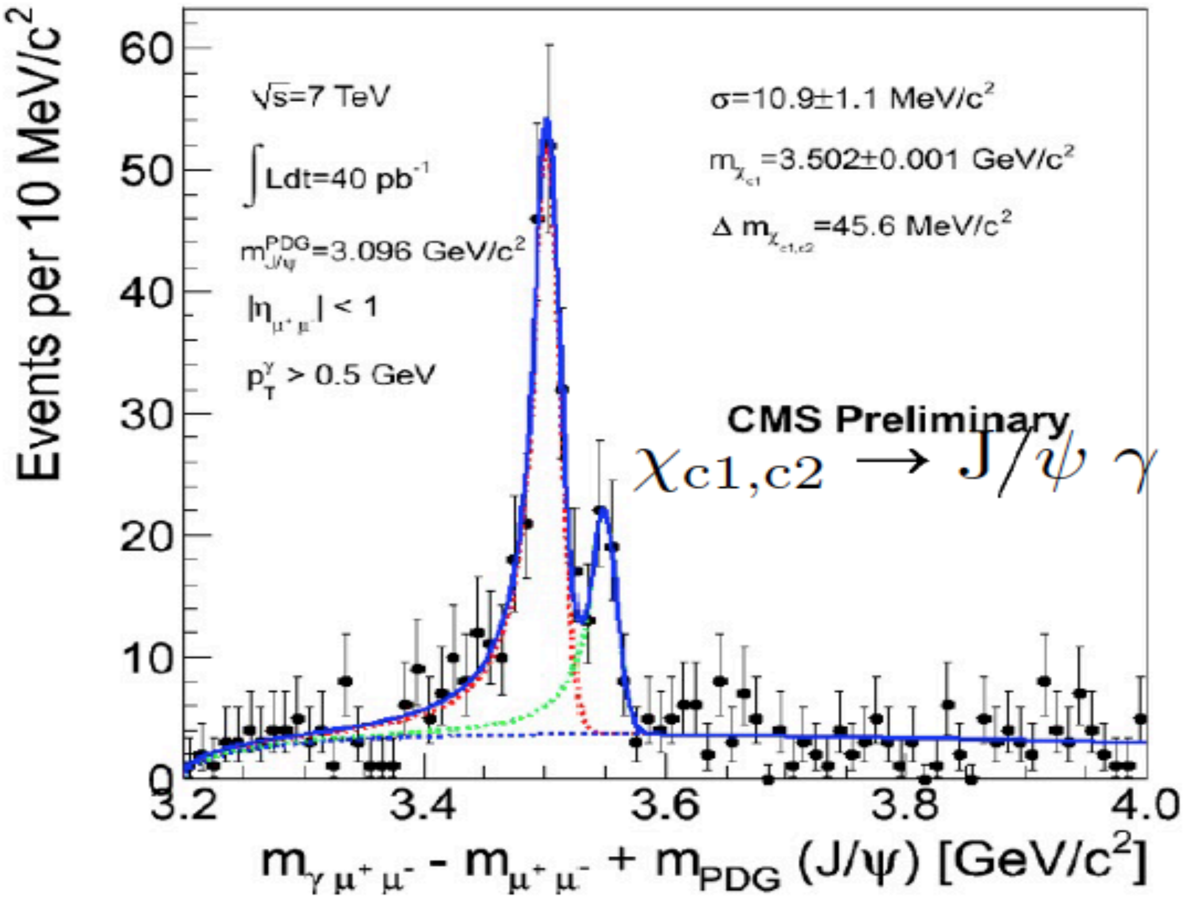
$$\frac{dE}{dx} = K\frac{m^2}{p^2} + C$$

(Lines drawn by hand to guide the eye!)



Photon Conversions

Observation of the χ_C radiative decay into J/ψ



The mass peaks of χ_{C1} and χ_{C2} ($\Delta m \sim 46$MeV) are separated thanks to the conversion based reconstruction of the soft radiative photon.

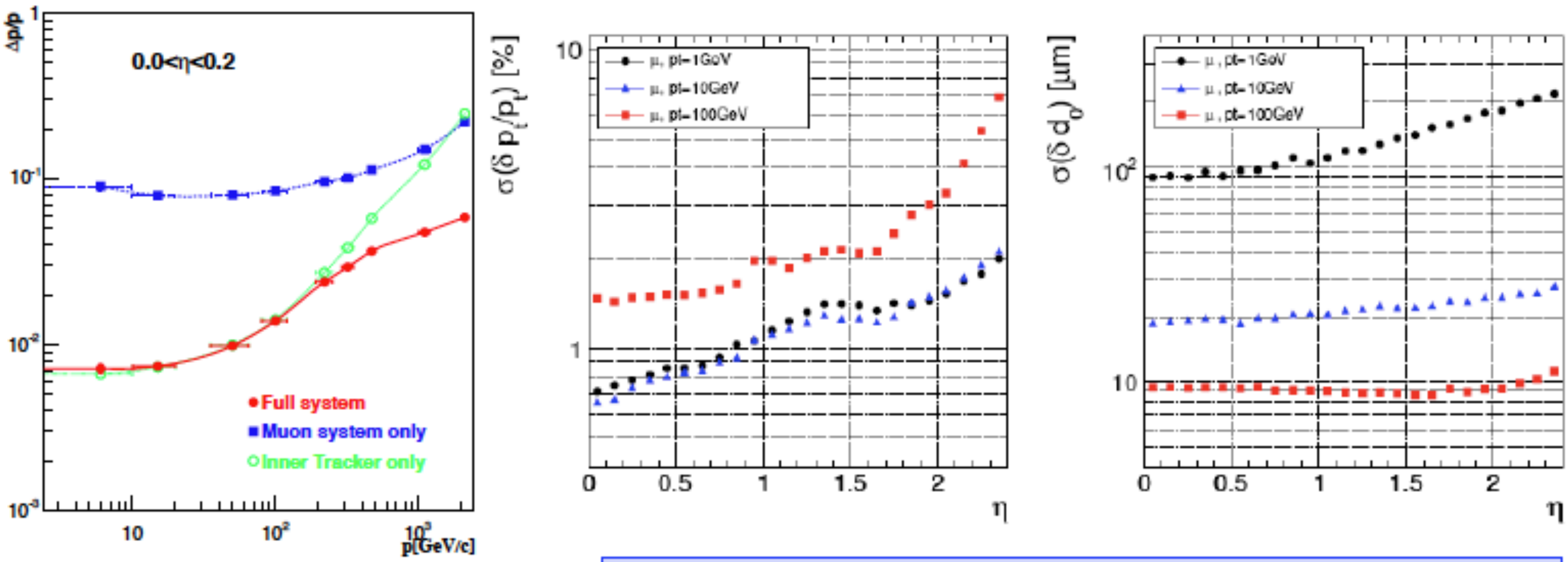
Concluding Summary

- CMS has adopted for the first time an ALL Silicon Tracker detector solution. This was a success thanks to:
  - Reliable 6” sensor production (<1% defect)
  - Reliable components obtained thanks to prototypes, pre-series
  - High QA along all production chain, qualified in all the several production centers
  - Early commissioning of sub-detectors and of Tracker well before insertion
- Detector is very stable and reliable. Most problems came from cooling system: deep intervention along few years have been needed to fix it. Lesson learned !
- Performance are excellent and data matches very well simulation predictions, even if pile-up is 50% higher than nominal
- Detector temperature will run with coolant at -20C (-10C at silicon detector) starting on 2015, to be more radiation resistant
- Studies on SST detector longevity show that is not a problem to reach 500 fb^{-1} with full tracking efficiency. This allows to reach with ample margin the end of LHC, i.e. before HL_LHC era begin.
- Pixel detector will be replaced on 2016/17 with a new detector with 4 barrel layers, 3+3 disks, less material and new digital front end electronics to cope with Phase 1 luminosity and radiation hardness

BACK-UP

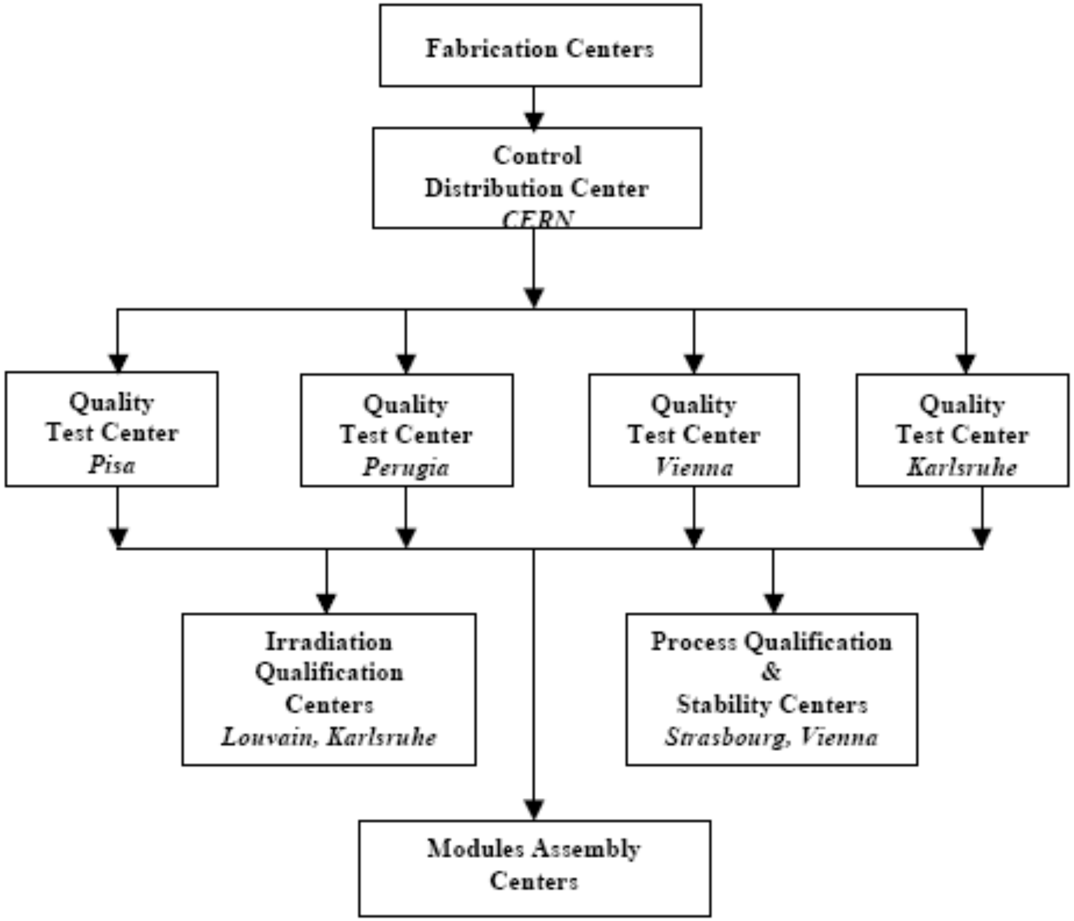
Expected performances

- In the central region performance fully dominated by Tracker (up to p=100 GeV)
- Challenging demand for momentum and transverse impact parameter resolution

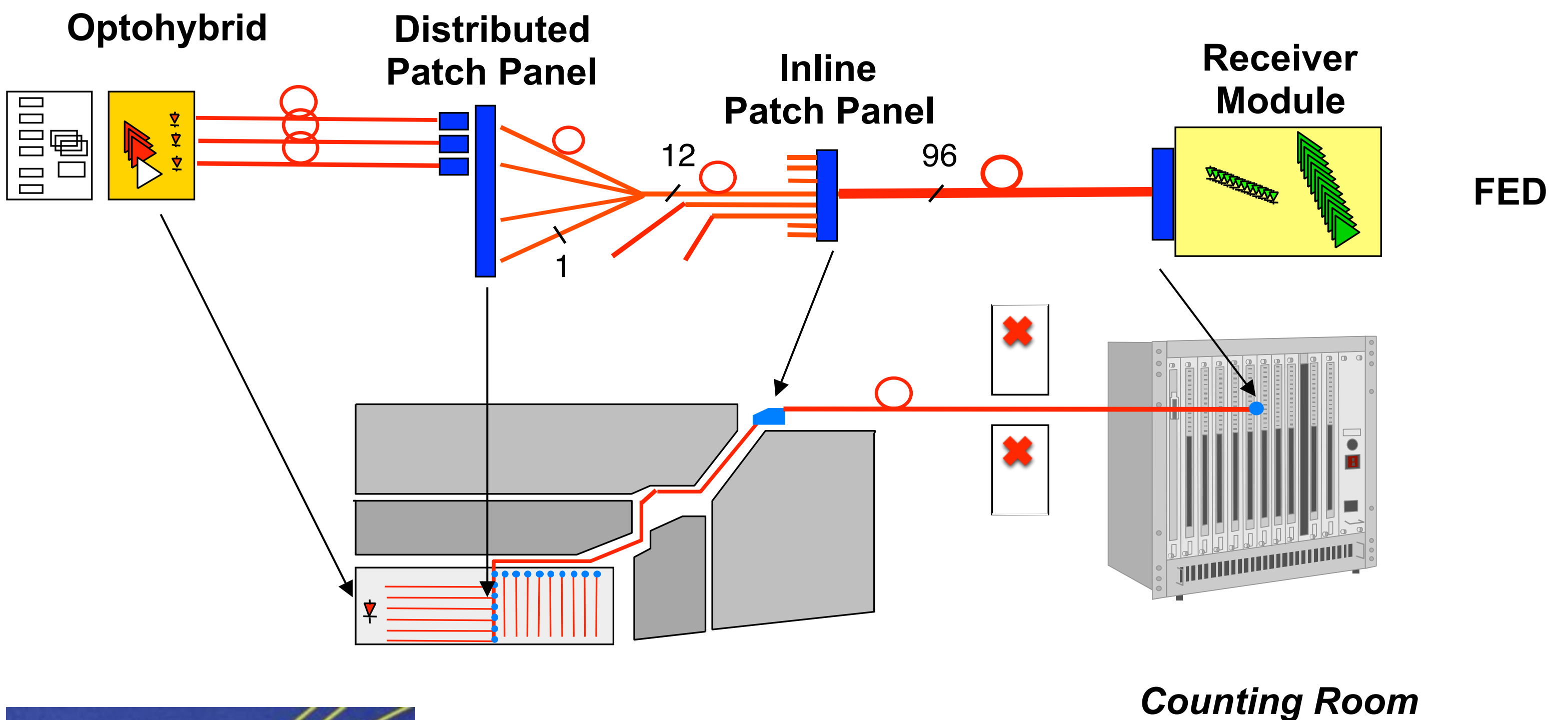


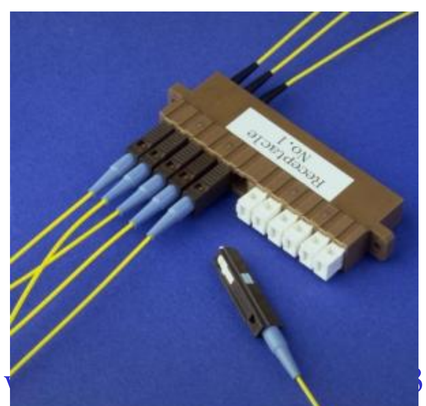
p_T resolution < 1% for low momentum muons in the central region and d_0 resolution up to 10 μm for high pT muons

Sensor testing centers



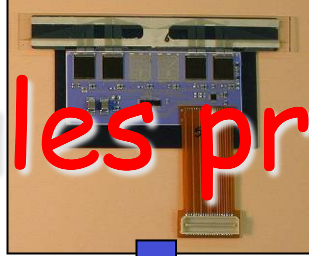
Analog Optical link

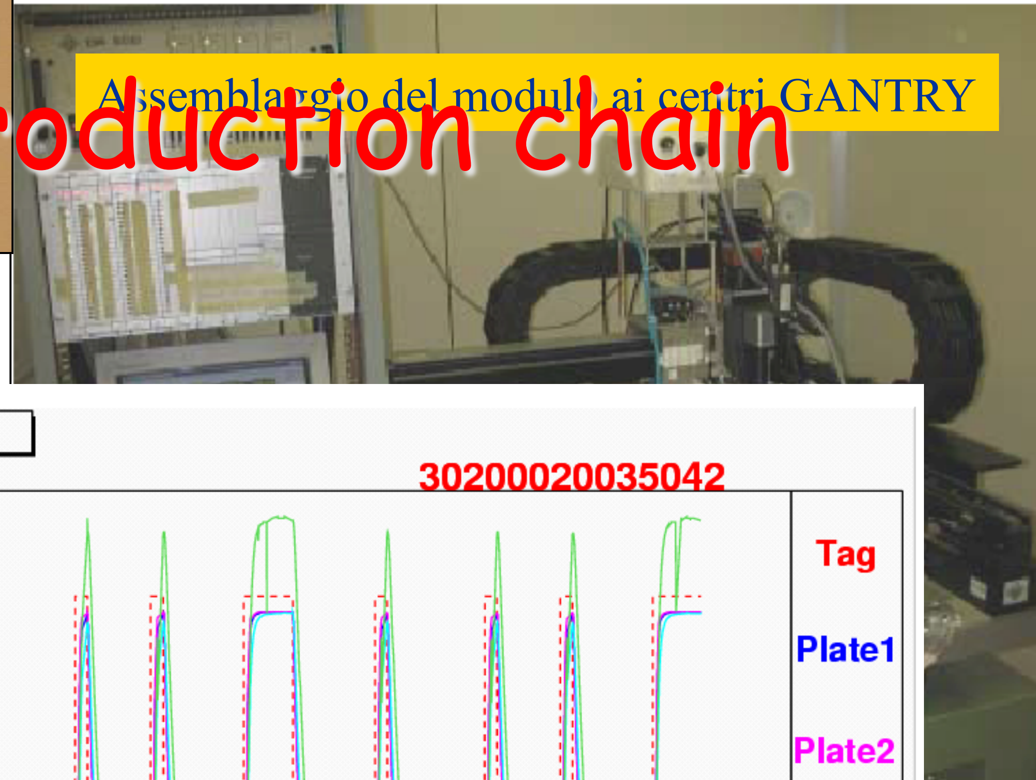


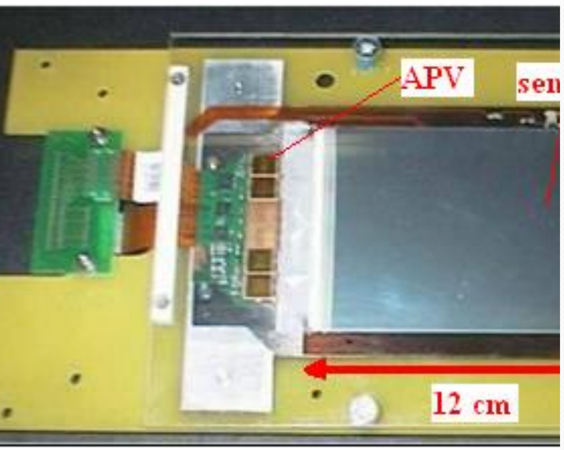


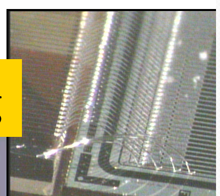
8 ribbon fiber cable

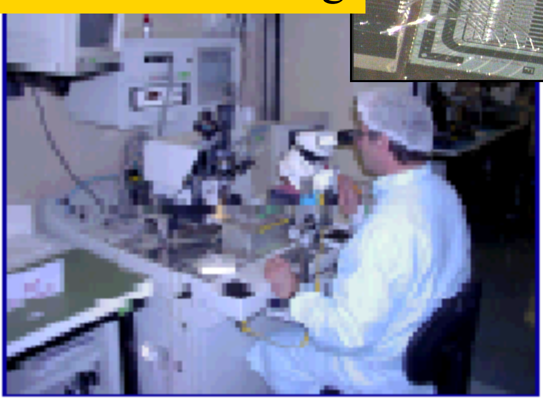
Modules production chain

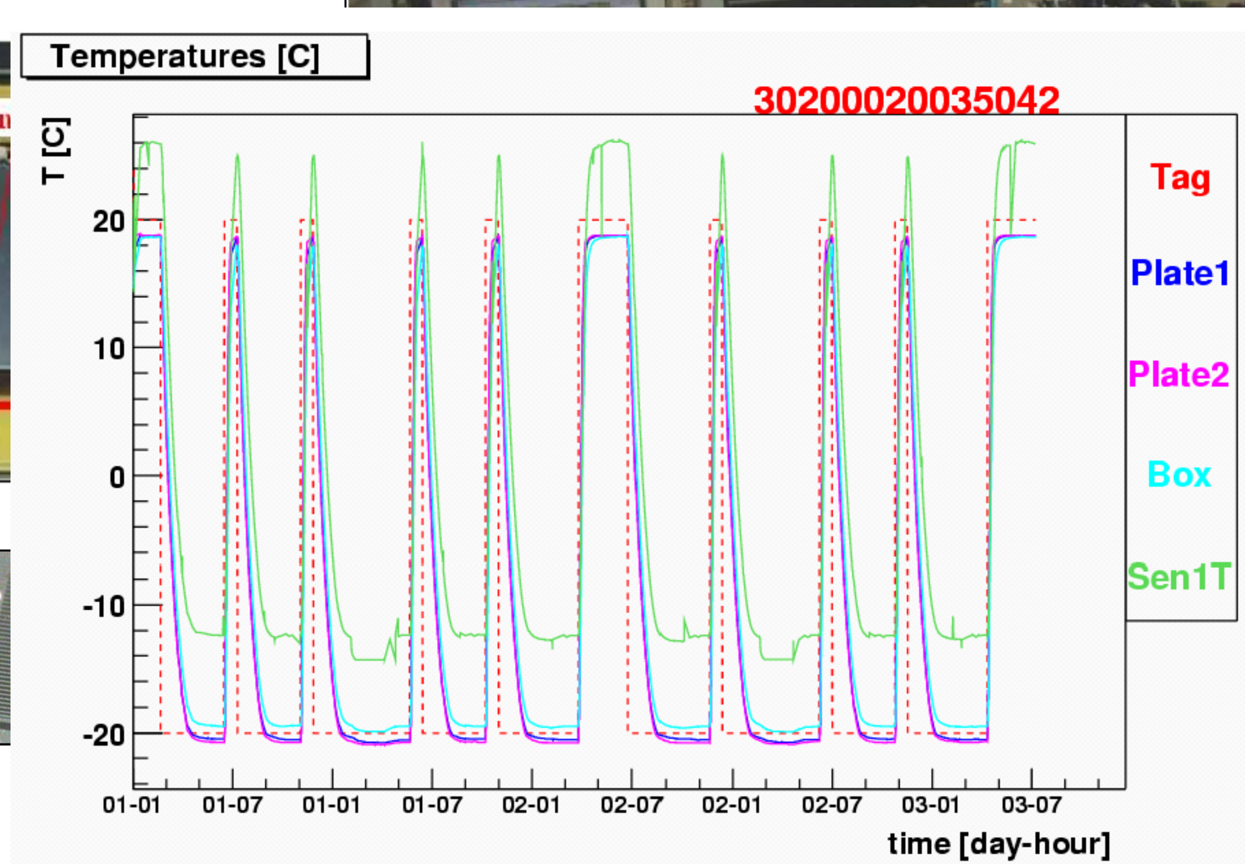


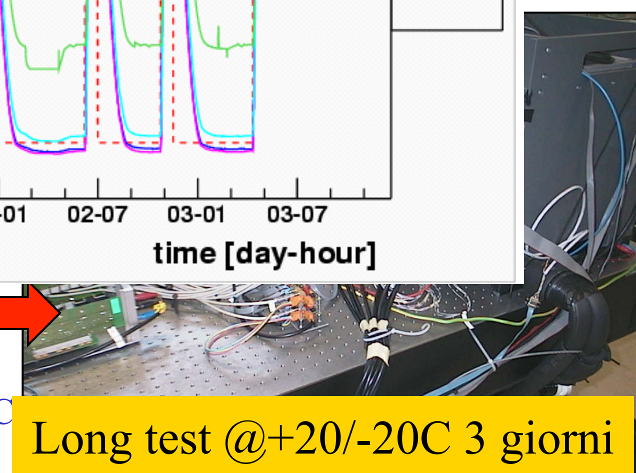




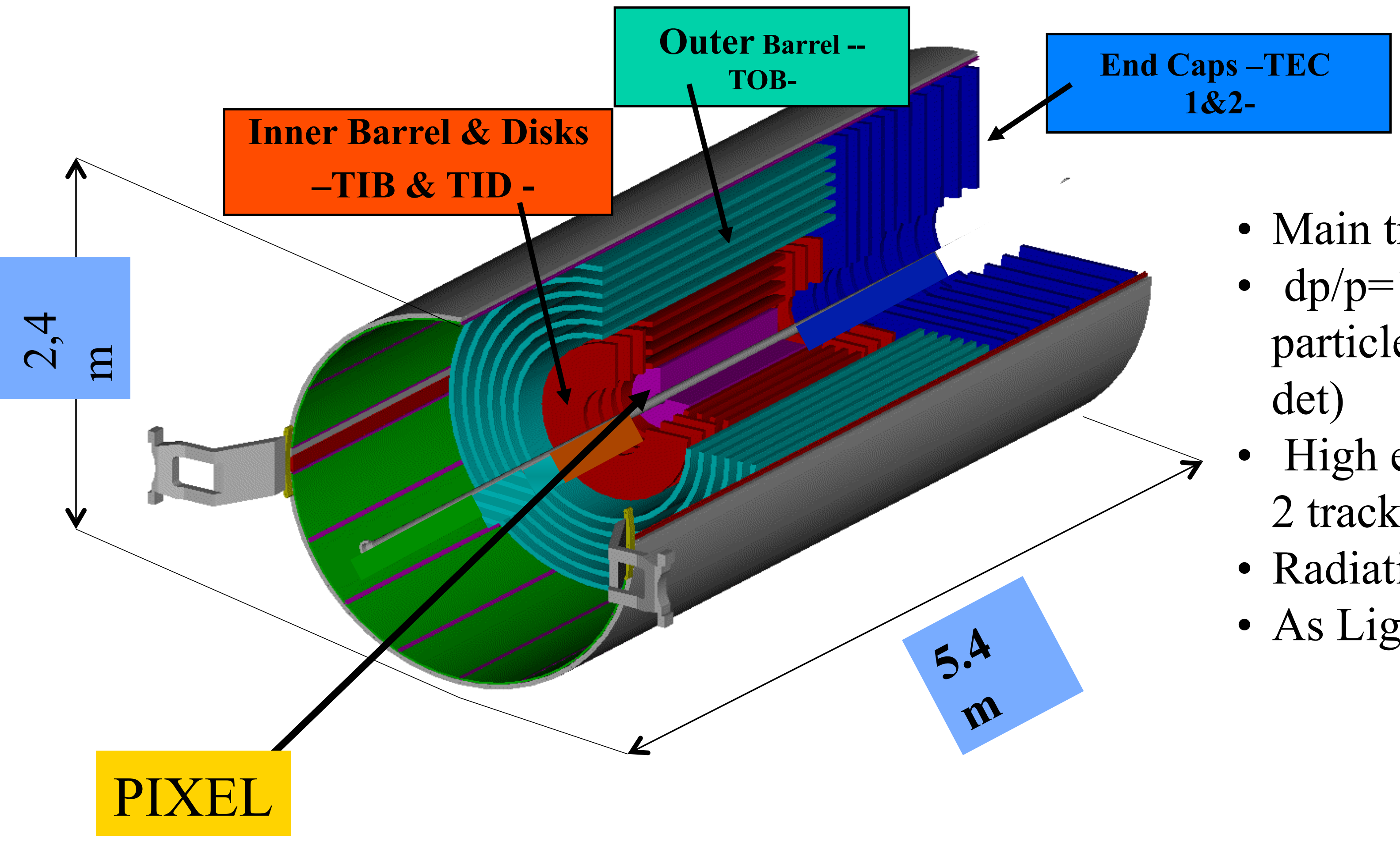








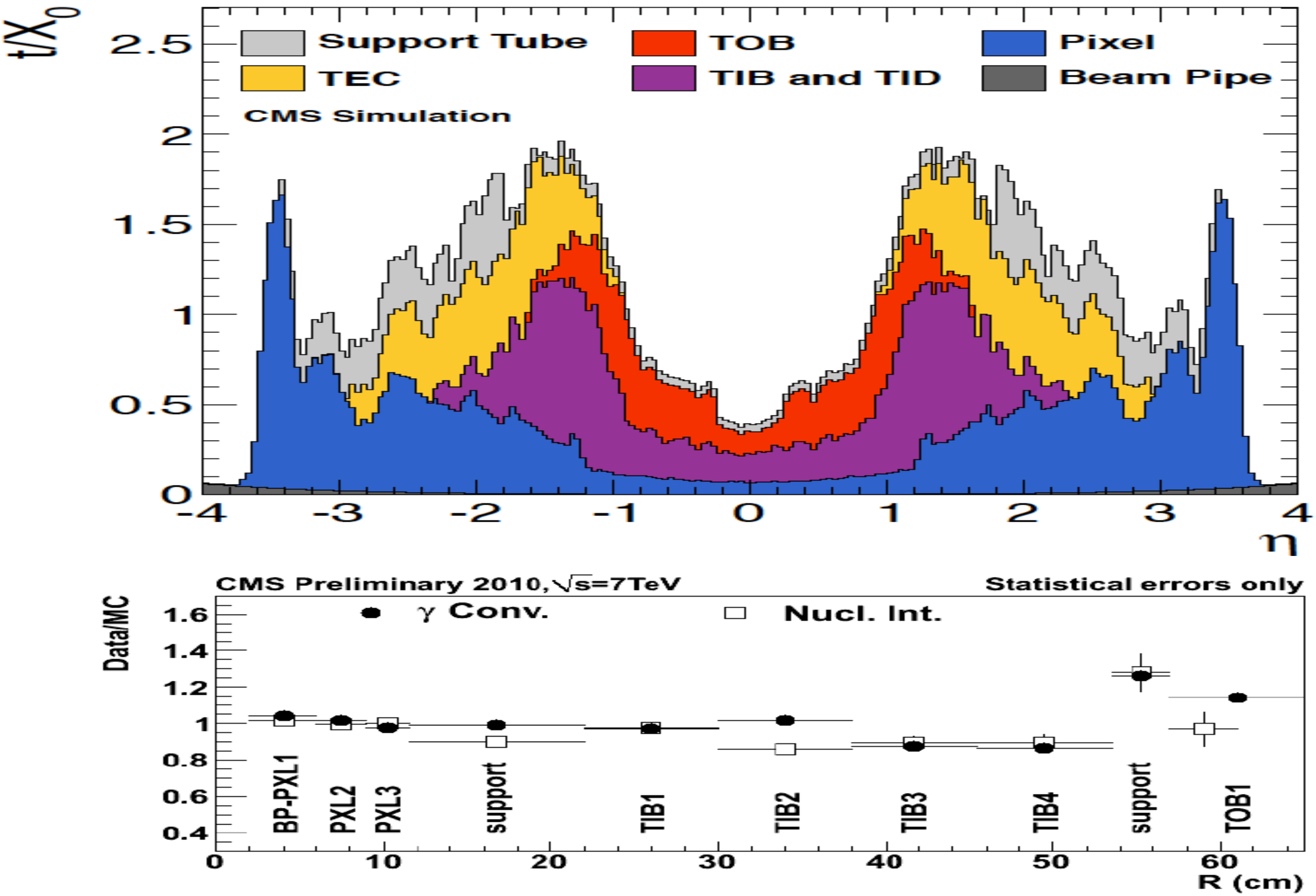
CMS TK



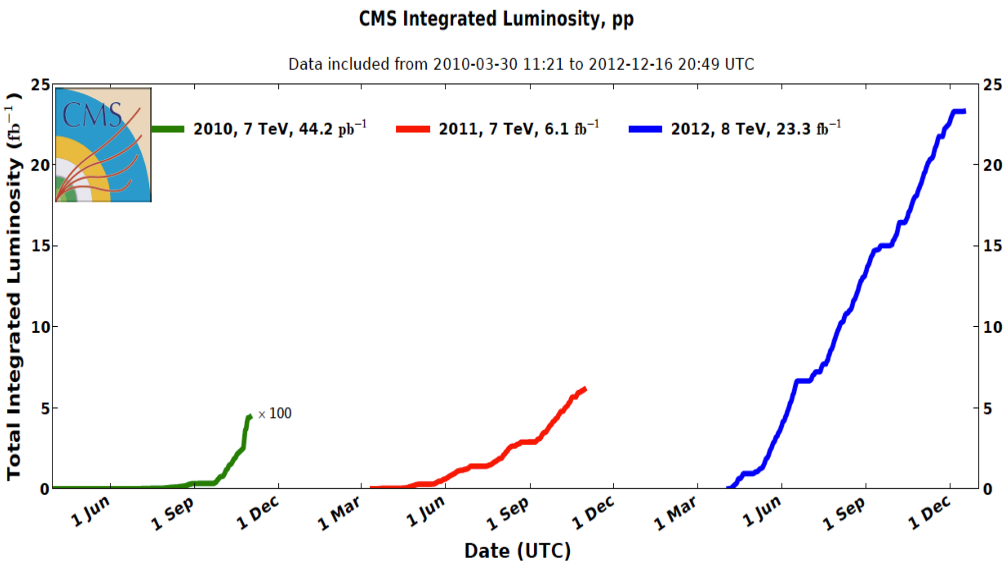
- Main tracking detector
- dp/p=10% for 1 TeV particle (with muon det)
- High efficiency,good 2 track separation
- Radiation hardness
- As Light as possible

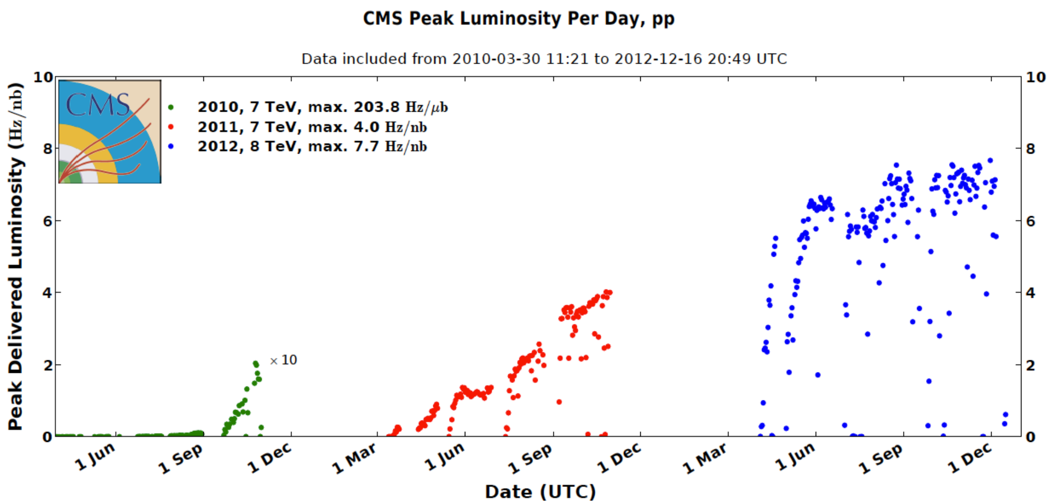
All made in Silicon detectors: Pixel + Silicon microStrip Tracker

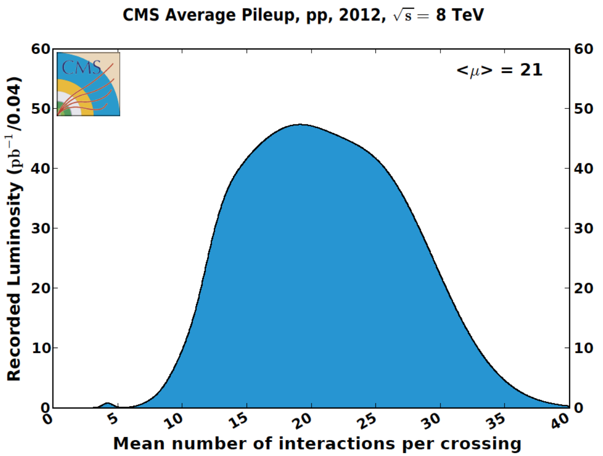
Tracker Material



LHC performance







Summary on Module Production

Structure	Channels	Dead/noisy strips	Defects	Total bad strips	Dead/noisy strips	Defects	Total bad strips
		TEC+			TEC-		
Sector 1	241664	278	1 module with I^2C problem	1046 (0.43%)	512	-	512 (0.21%)
Sector 2	241664	284	-	284 (0.12%)	591	-	591 (0.24%)
Sector 3	241664	234	2 bad APVs	490 (0.20%)	680	1 dead fiber	936 (0.39%)
Sector 4	241664	305	1 dead fiber	561 (0.23%)	304	1 bad APV 1 dead fiber	688 (0.28%)
Sector 5	241664	276	1 module with I^2C problem 2 modules without HV	1812 (0.75%)	725	-	725 (0.30%)
Sector 6	241664	373	1 bad APV	501 (0.21%)	604	-	604 (0.25%)
Sector 7	241664	391	1 dead fiber 1 bad APV	775 (0.32%)	345	-	345 (0.14%)
Sector 8	241664	296	-	296 (0.12%)	360	2 dead fibers	872 (0.36%)
All sectors	1933312	2437		5765 (0.30%)	4121		5273 (0.27%)
		TIB/TID+			TIB/TID-		
All layers	893952	1123	1 module with PLL problem 1 module with bad tick 2 modules with I^2C problem 1 dead fiber	3939 (0.44%)	471	4 disconnected modules 3 dead fibers	3287 (0.37%)
All disks	282624	657	2 dead fibers	1169 (0.41%)	408	1 dead fiber	664 (0.23%)
TIB/TID	1176576	1780		5108 (0.43%)	879		3951 (0.34%)
		TOB+			TOB-		
Layer 1	258048		-			-	
Layer 2	294912		-			-	
Layer 3	165888		-			1 dead fiber	
Layer 4	184320		-			-	
Layer 5	304128		-			1 module without HV	
Layer 6	340992		-			1 module with HV short	
All layers	1548288	921		921 (0.06%)	1096		2888 (0.19%)