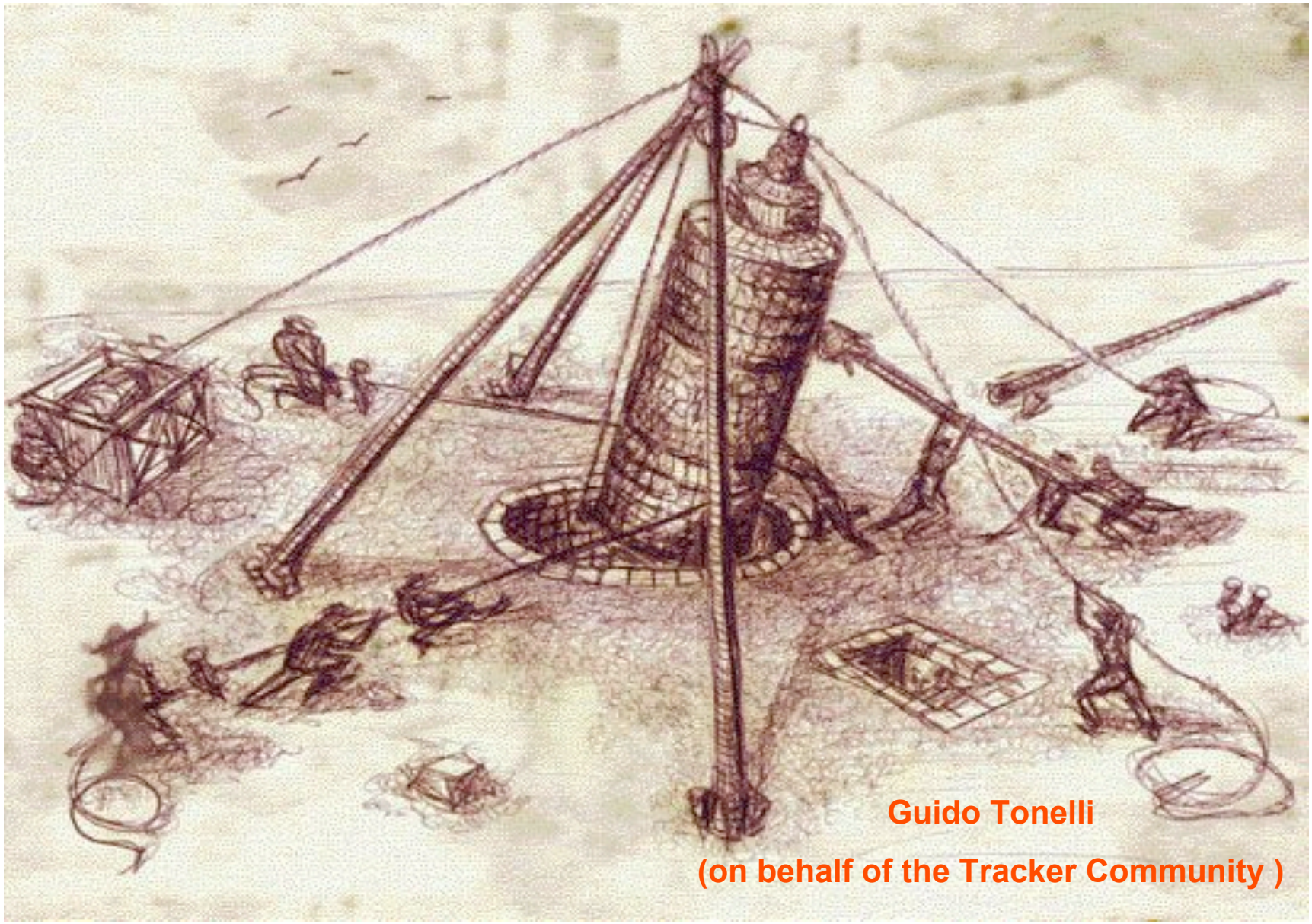
Status of the CMS Tracker

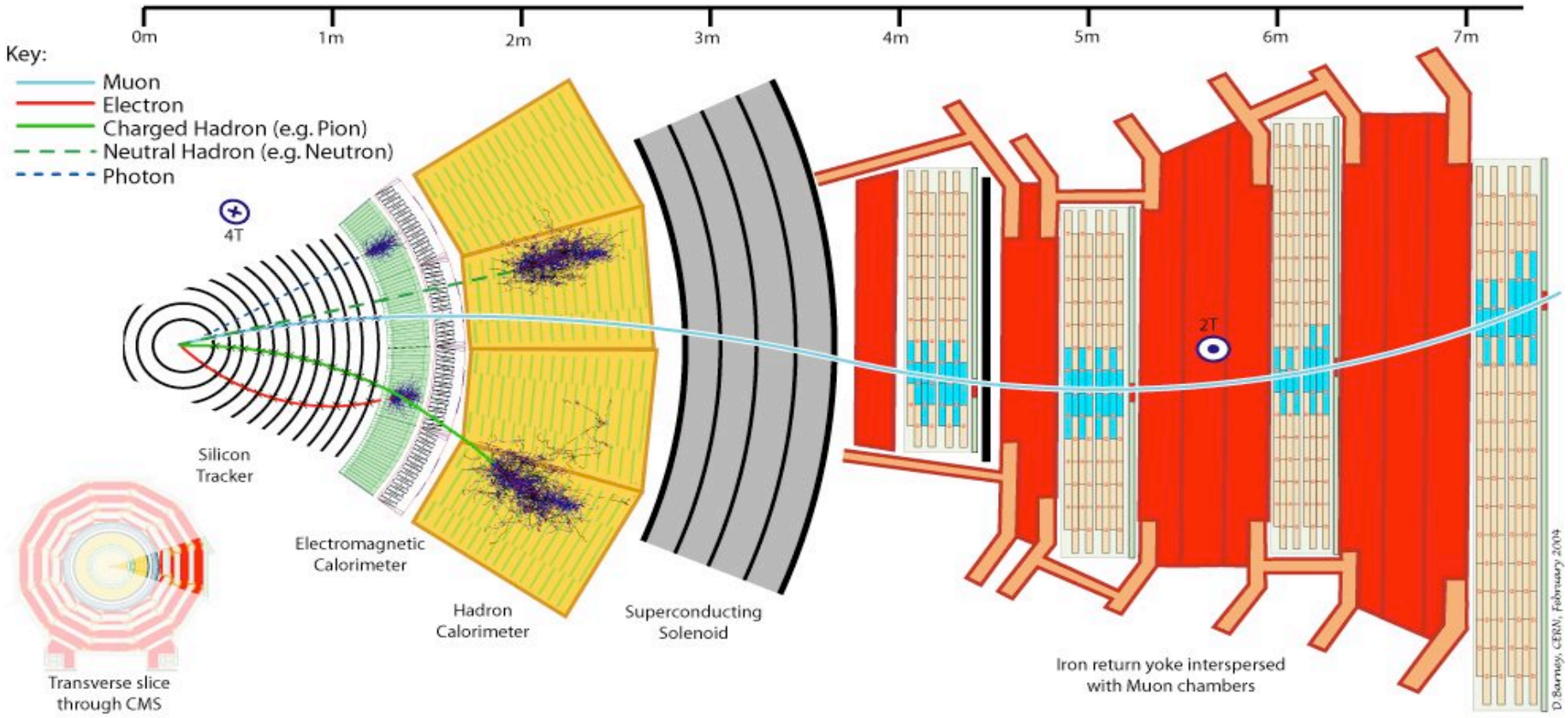


Guido Tonelli

(on behalf of the Tracker Community)

Tracking in CMS.

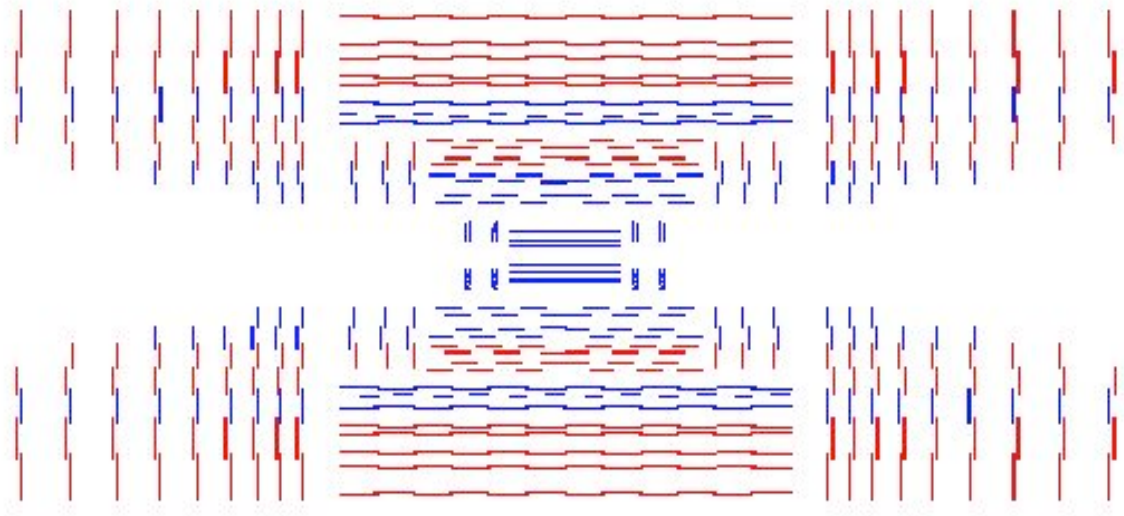
Tracking in CMS: >13 precision measuring points per track + 4T solenoidal field



CMS adopted a very aggressive approach for tracking @ LHC

- Optimal momentum resolution (Higgs→4μ; better cuts on the Z mass and use of invariant mass in general to reduce the irreducible backgrounds).
- **$\Delta p_t/p_t \leq 0.2 p_t$ (TeV/c)**
- High efficiency in reconstruction of tracks both isolated (muons and electrons) and within high transverse energy jets; (muon trigger validation, isolation cuts for single photons (H→γγ) and tracks in general).
- **$\varepsilon > 95\%$ for $p_t \geq 2$GeV/c**
- **THE FULL SILICON TRACKER:**
- very good point resolution, large lever arm (≥1m) and 4T field
- high granularity and extreme segmentation in z to cope with pattern recognition issues

Conceptual design of the CMS tracker



II radial region: 25cm<r<110cm :$10^{13}cm^{-2}<\Phi<10^{14}cm^{-2}$

Radiation resistance silicon microstrip detectors

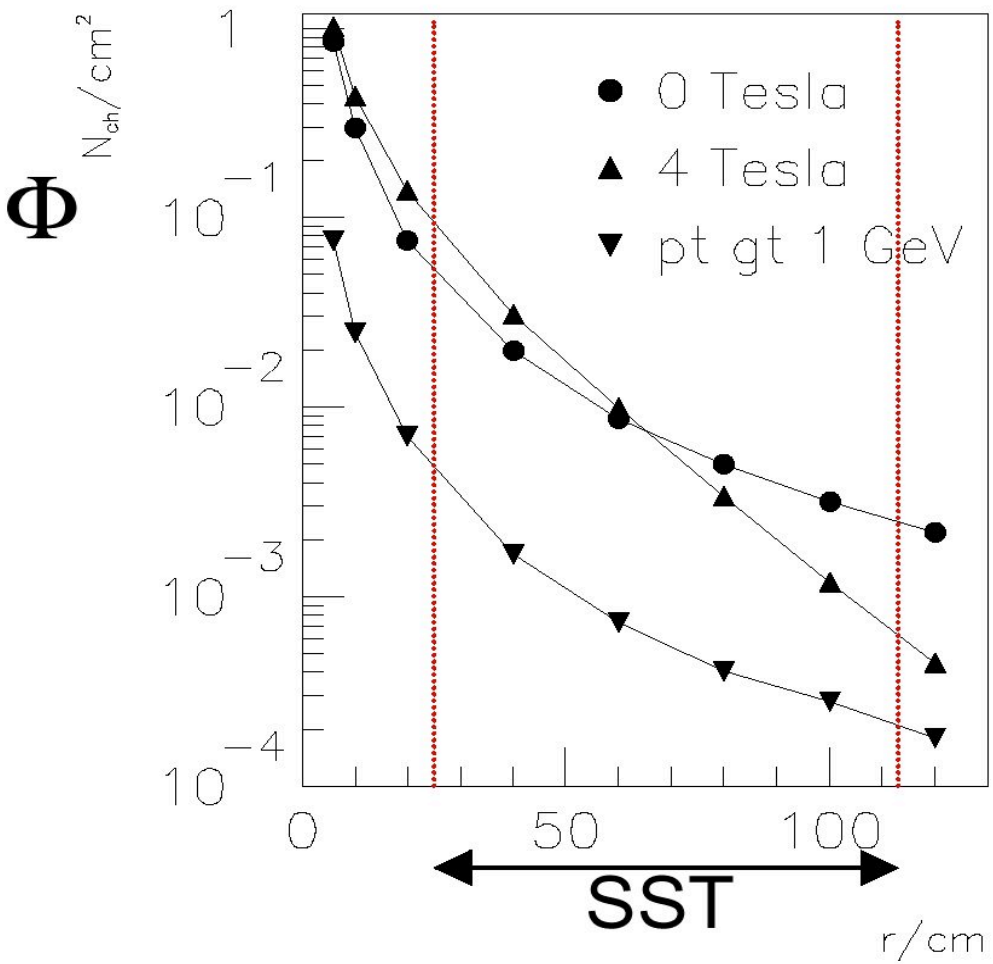
- Large scale, low cost production of rad-hard detectors ($2x10^{14}n/cm^2$)

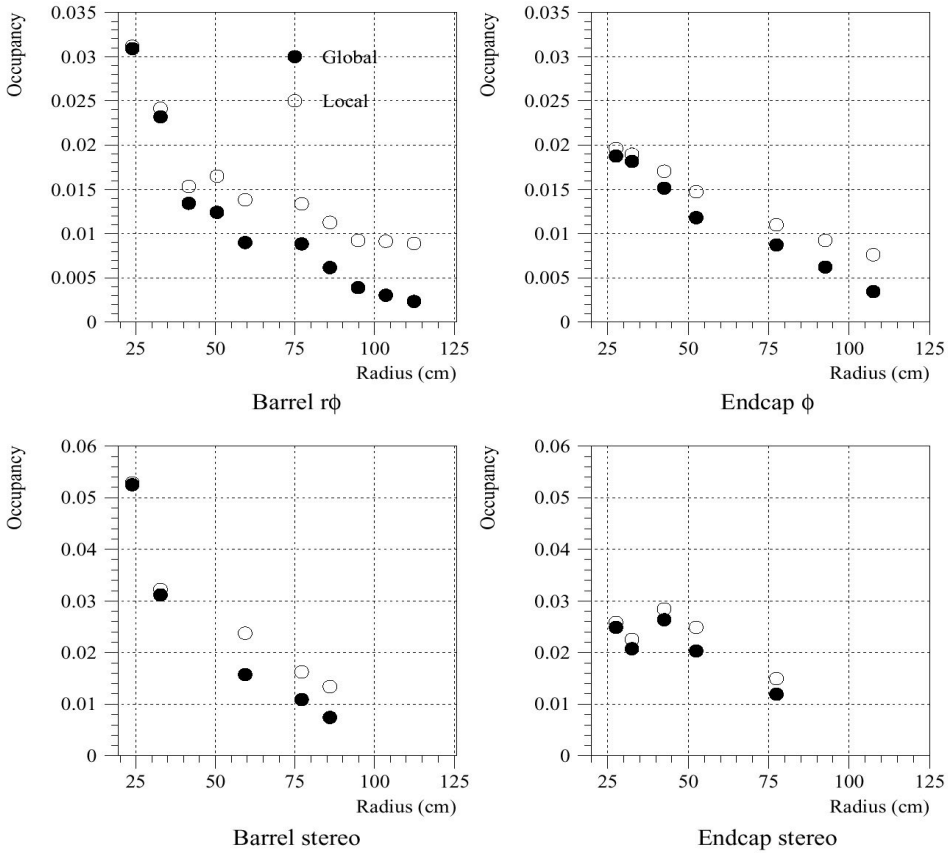
I radial region: 5cm<r<20cm :$10^{14}cm^{-2}<\Phi<10^{15}cm^{-2}$

Pixel detector in hybrid technology

- Development of a pixel detector capable to withstand $10^{15}n/cm^2$

Track occupancy

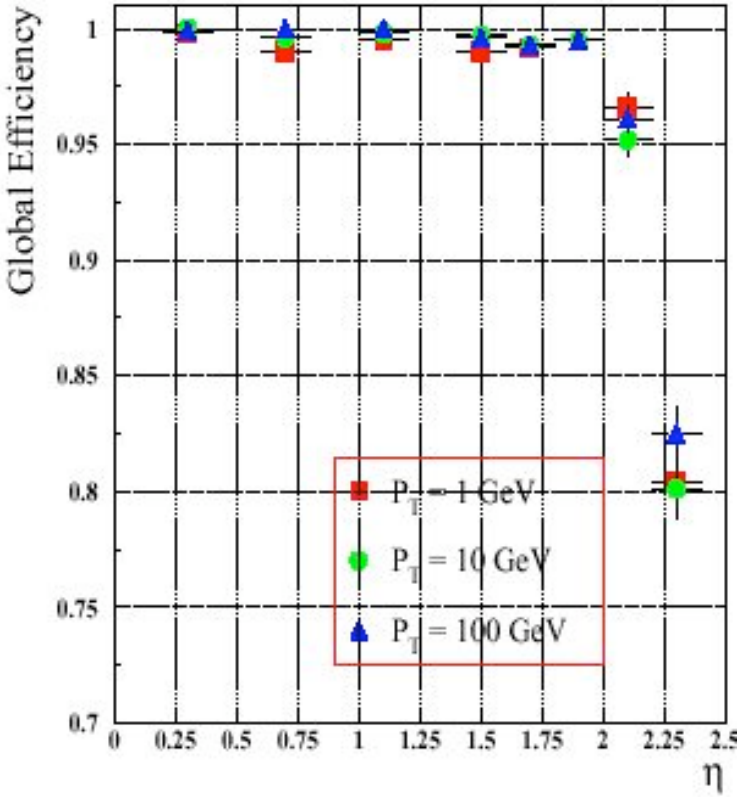


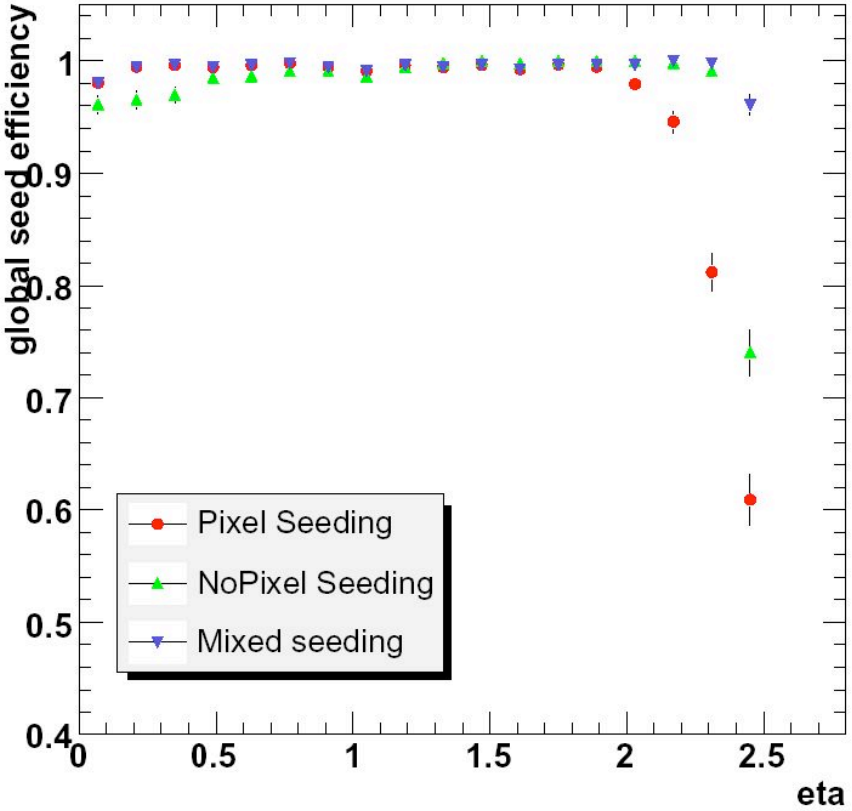


Primary charged particle densities integrating 20 minimum bias events

Tracking performance: isolated tracks

- Tracking efficiency (Kalman filter) for isolated muons
- > 99% for η<2.4

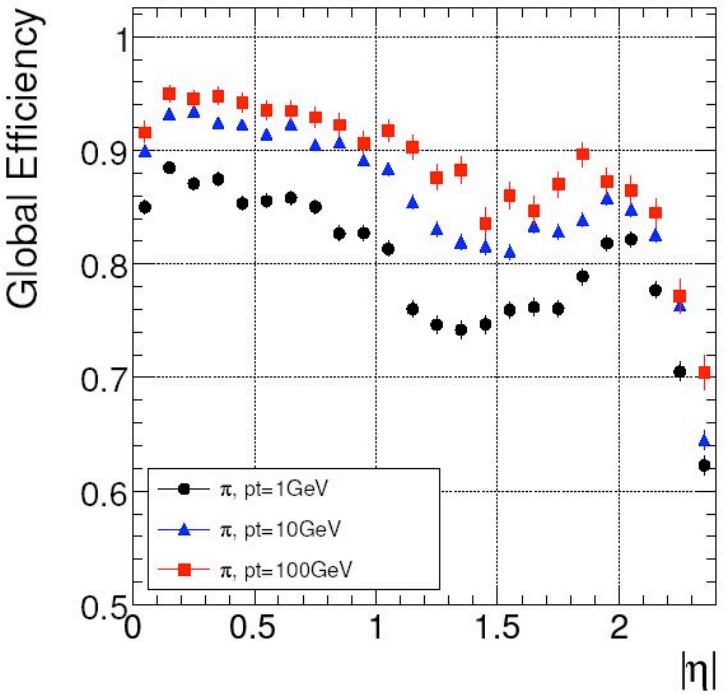




Track reconstruction in high pt jets

Track finding efficiency in 200 GeV E_T Jets; $p_T > 0.9$ GeV

		$\lvert\eta\rvert < 0.7$	$1.2 < \lvert\eta\rvert < 1.6$
≥ 6 hits	(eff.)	93.7 ± 0.6	91.6 ± 0.6
	(ghosts)	0.26 ± 0.09	0.10 ± 0.07
≥ 8 hits	(eff.)	88.3 ± 0.9	86.8 ± 0.8
	(ghosts)	0.10 ± 0.07	0.10 ± 0.07



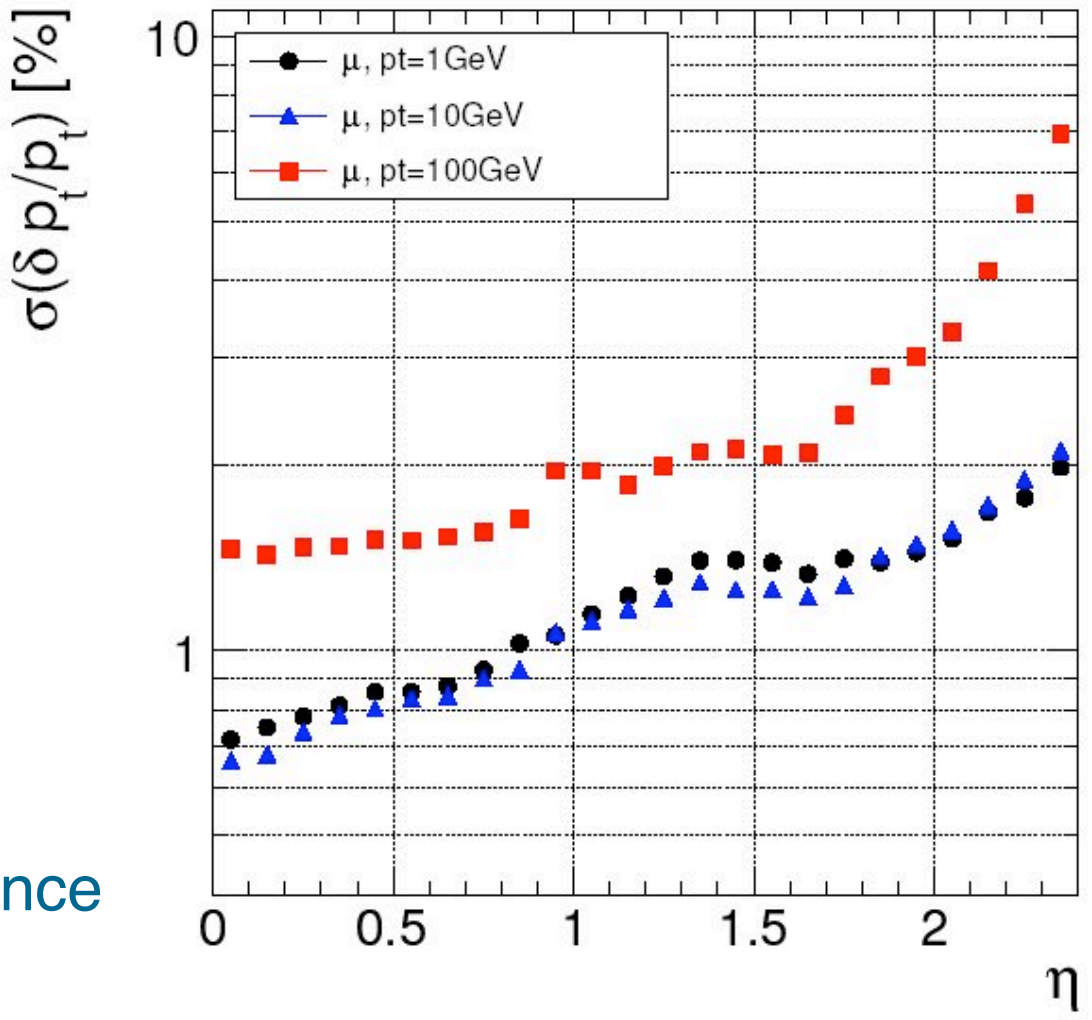
Reconstruction efficiency for low momentum pions

Momentum resolution

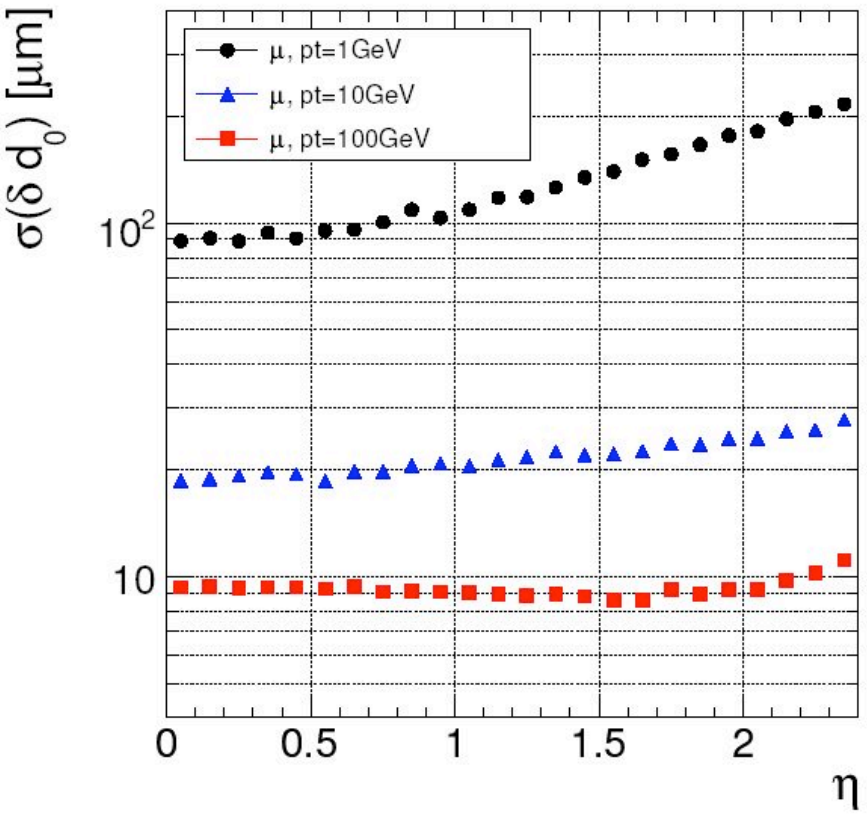
$\Delta p_t/p_t = 0.15\ p_t$ (TeV)
for high pt tracks

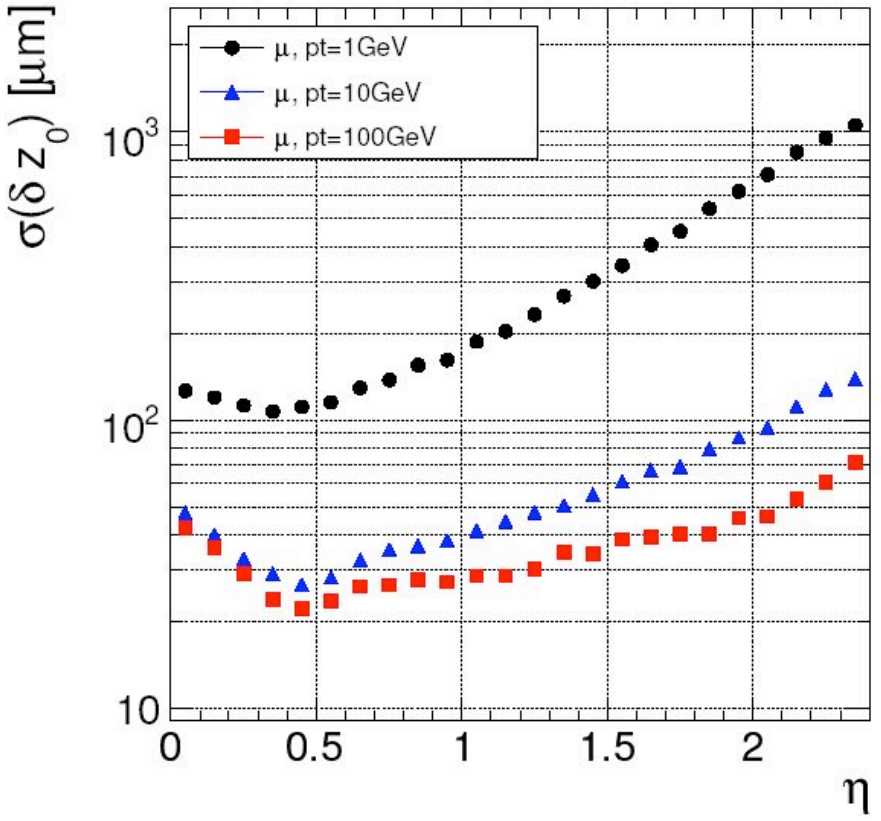
$\Delta p_t/p_t = 1.5\%$ for $p_t = 100$GeV
$\Delta p_t/p_t = 7.5\%$ for $p_t = 500$GeV

Spectacular invariant mass distributions.
Precision measurements
and positive effects on significance of elusive channels



Impact parameter resolution





Excellent results both in the transverse plane (10-20μm) and the r-z plane (20-40μm) (several tagging techniques available)

Very good idea…. but

• 10 Millions read-out channels; 25.000 silicon detectors; 15.000 detector modules

→ costs, complexity, logistics of procurements and construction

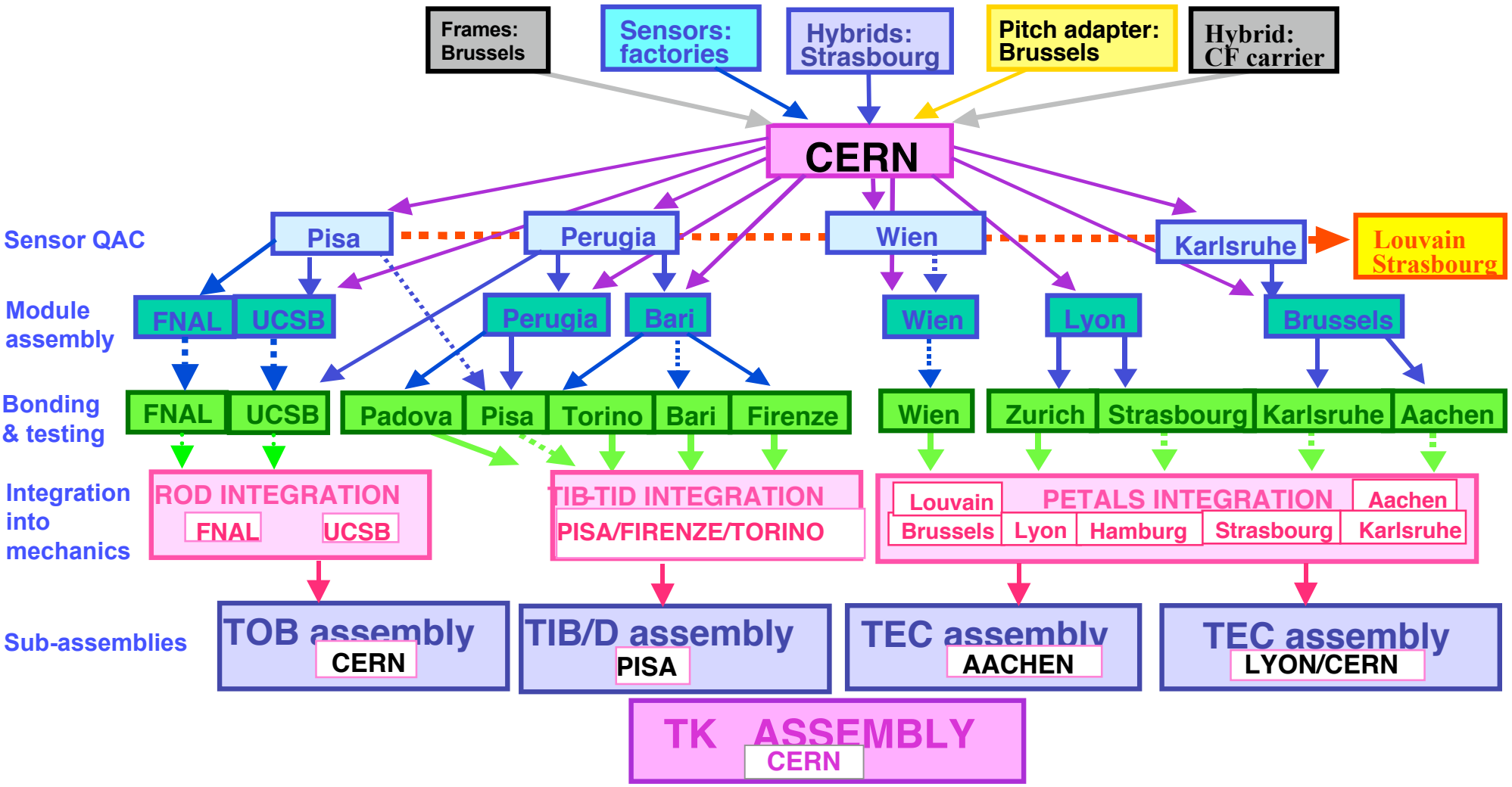
Several years spent to overcome QC/QA issues related to large scale production of sensors, hybrids, read-out chip and electrical and optical components in general.

•The silicon is solid and must be precisely held in place; each channel implies power and cooling

•→material budget

Paranoidal care in trying to minimize the material and in keeping track of all components.

The silicon tracker construction



The CMS Full Silicon Tracker

Pixel Detector

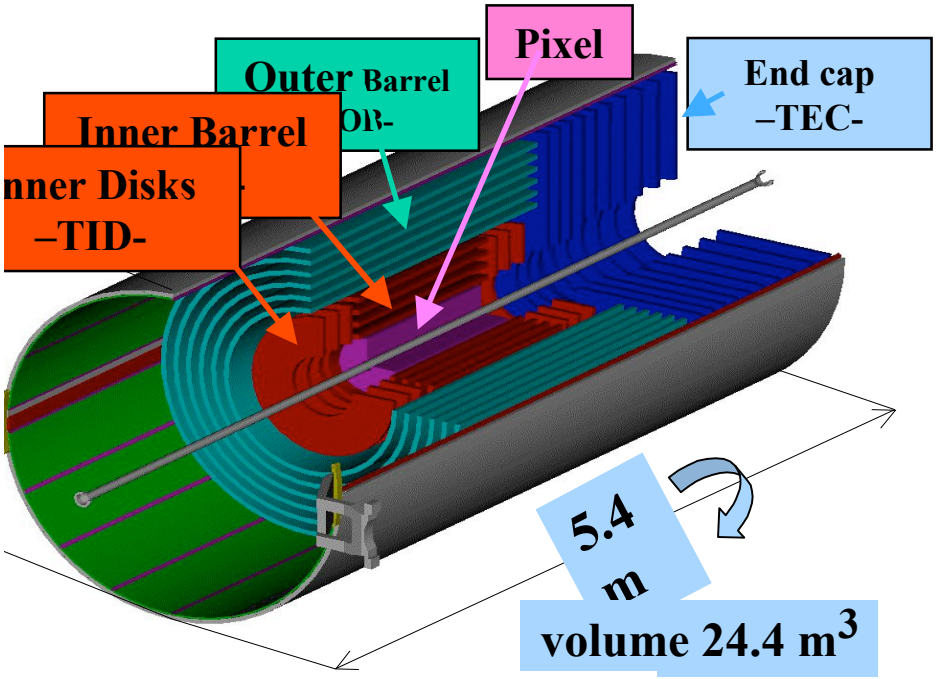
- 3 barrels, 4 disks: 60×10^6 pixels
- barrel radii: 4.1-10 cm
- pixel size 100×150 μm
- $\sigma_{r\phi}=10\mu m$ $\sigma_z=10\mu m$

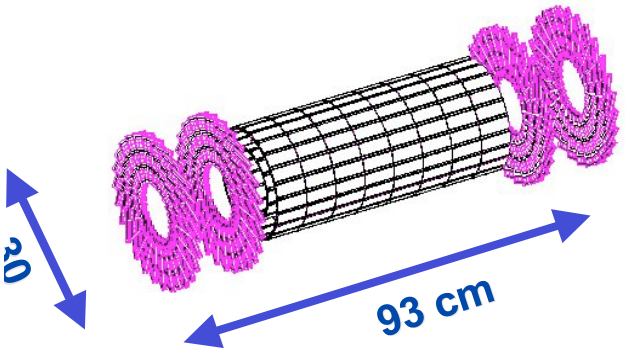
Internal Silicon Strip Tracker

- 4 barrels, 6 disks: 2×10^6 strips
- barrel radii: 22-50cm
- strip pitch 80,120μm
- $\sigma_{r\phi}=25\mu m$ $\sigma_z=250\mu m$

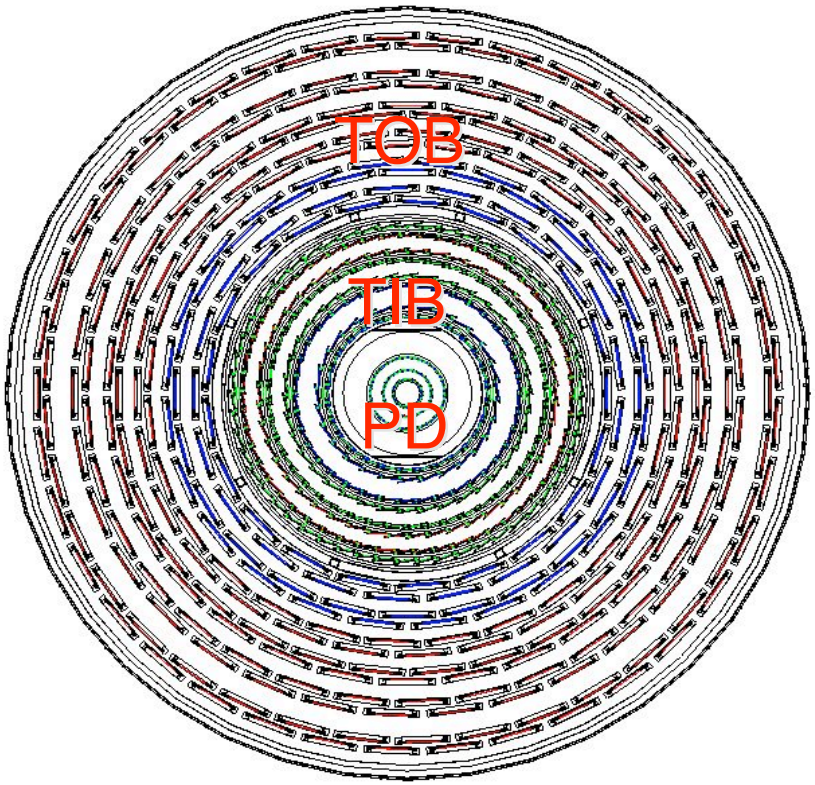
External Silicon Strip Tracker

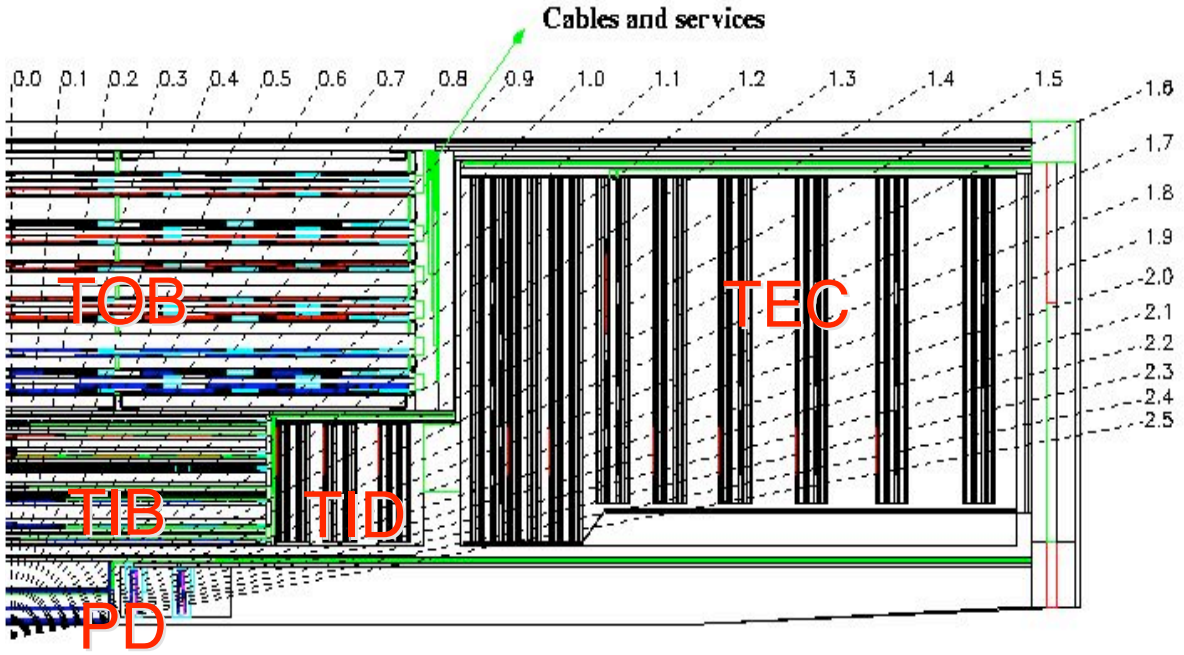
- 6 barrels, 18 disks: 8×10^6 strips
- barrel radii: 60-110 cm
- strip pitch 120-240μm
- $\sigma_{r\phi}= 30\mu m$ $\sigma_z = 300\mu m$





The CMS Full Silicon Tracker





- 207m^2 of microstrip silicon detectors 15.232 modules
- 6136 thin sensors, 320μm (HPK) and19292, thick sensors 500μm (HPK + STM) all produced on 6" wafers.
- 60M channels pixel detector.

Status of the tracker: LHCC milestones

Milestones for the Microstrip Tracker

	Milestone date	
Completion of TIB / TID+ Integration in Italy	May-06	ok
Completion of TOB Modules	May-06	ok
Magnet Test System at P5 commissioned	May-06	ok
Completion of TEC Modules	Jun-06	ok
Completion of TIB / TID- Integration in Italy	Aug-06	ok
Completion of TOB RODs	Aug-06	ok
Completion of the Integration of TOB+	Aug-06	ok
Completion of TEC Petals	Sep-06	ok
Completion of the Integration of TEC+ in Aachen	Sep-06	ok
Completion of the Integration of TOB-	Oct-06	
Completion of the Integration of TEC- at CERN	Nov-06	
TRACKER READY FOR TRANSPORT TO P5	Jan-07	

Milestones for the Forward Pixels

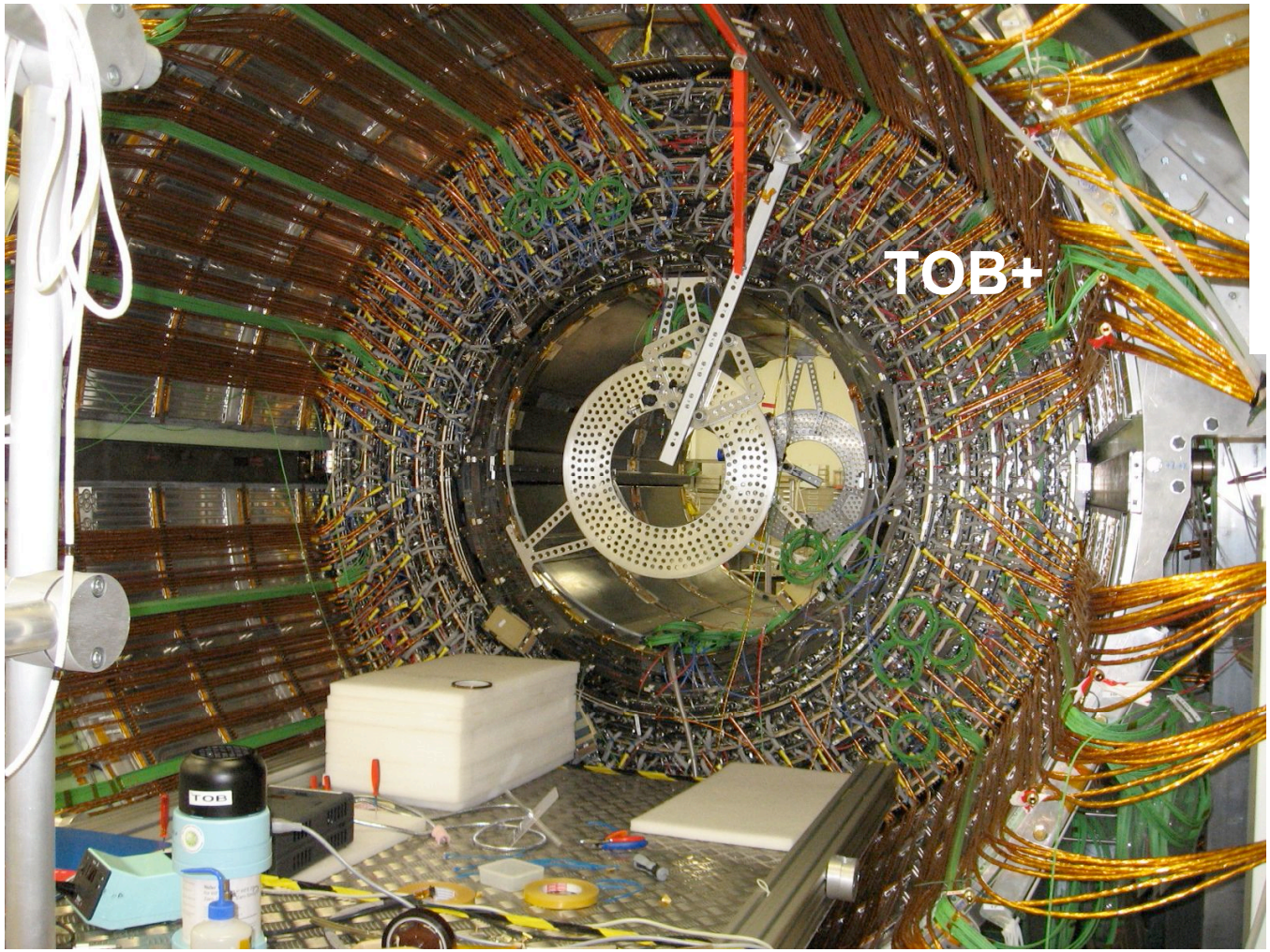
Completion of a full production blade	Jul-06	ok
Completion of the first production half ring	Dec-06	
Completion of full FPIX readout chain system test	Dec-06	

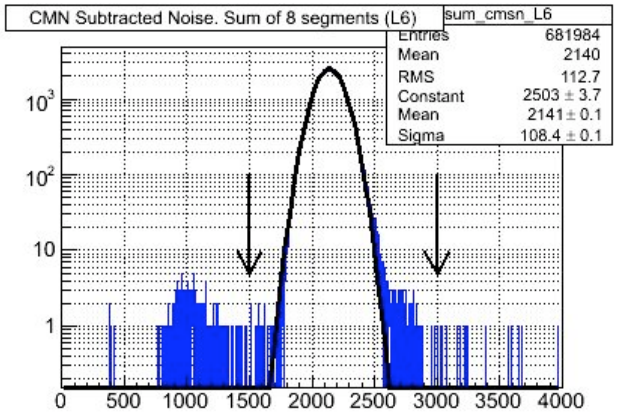
Milestones for the Barrel Pixels

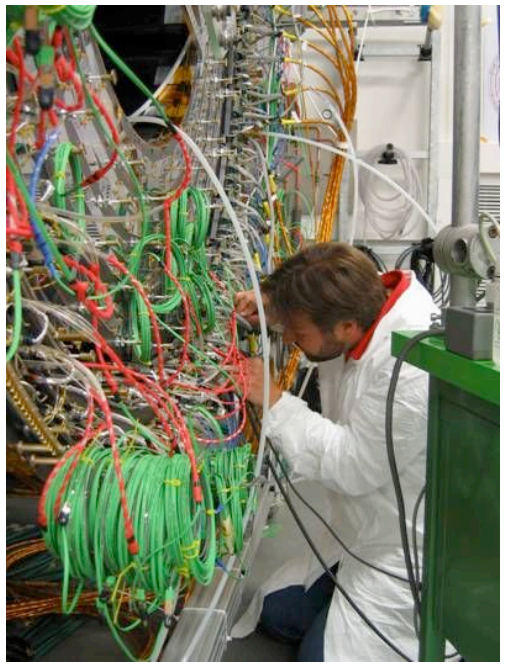
System test of complete BPIX module group with supply tube and final powering	Jul-06	ok
1/3 of modules for layer 1 & 2 fabricated & tested	Sep-06	
2/3 of modules for layer 1 & 2 fabricated & tested	Nov-06	
Supply tubes & mechanics for commissioning system delivered to PSI	Dec-06	

Tracker Outer Barrel (USA and CERN)>74% completed

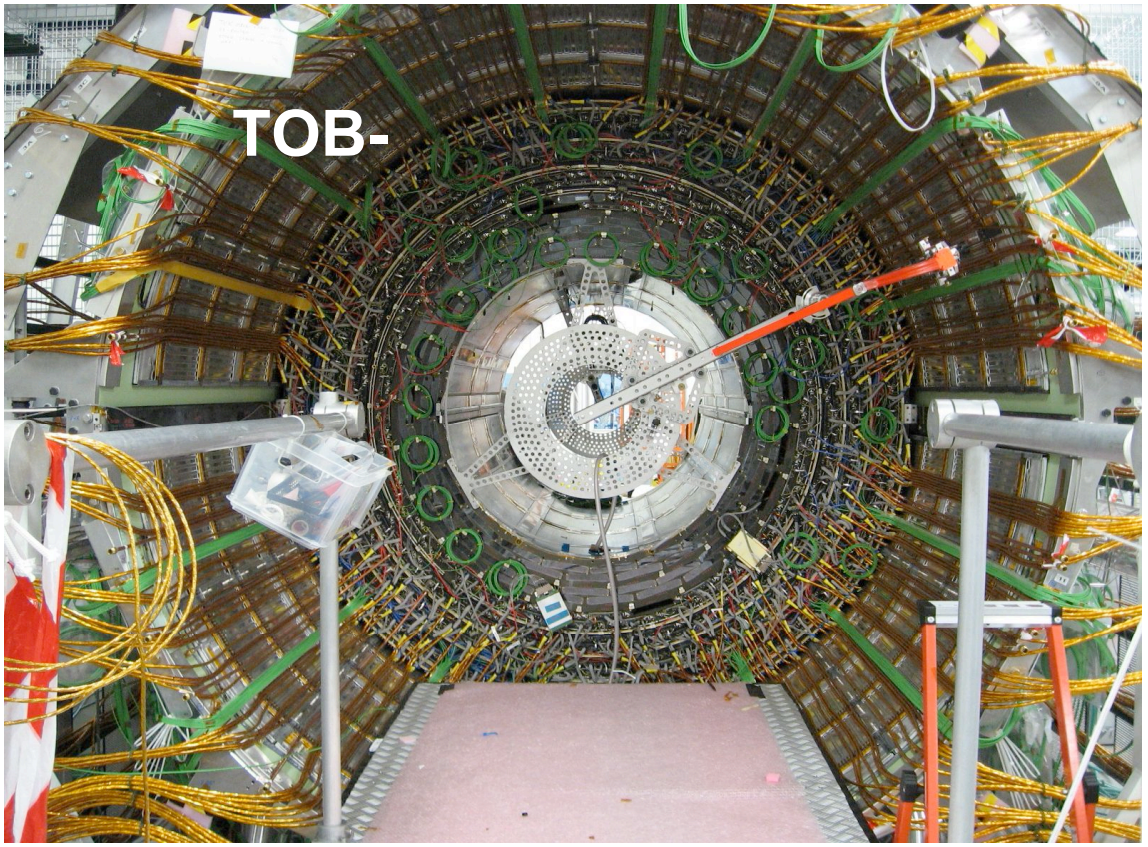
688/688 rods produced 100%.
597 rods inserted 87% and 508 tested and validated 74%.
Excellent quality. Bad or noisy channels <0.5%.





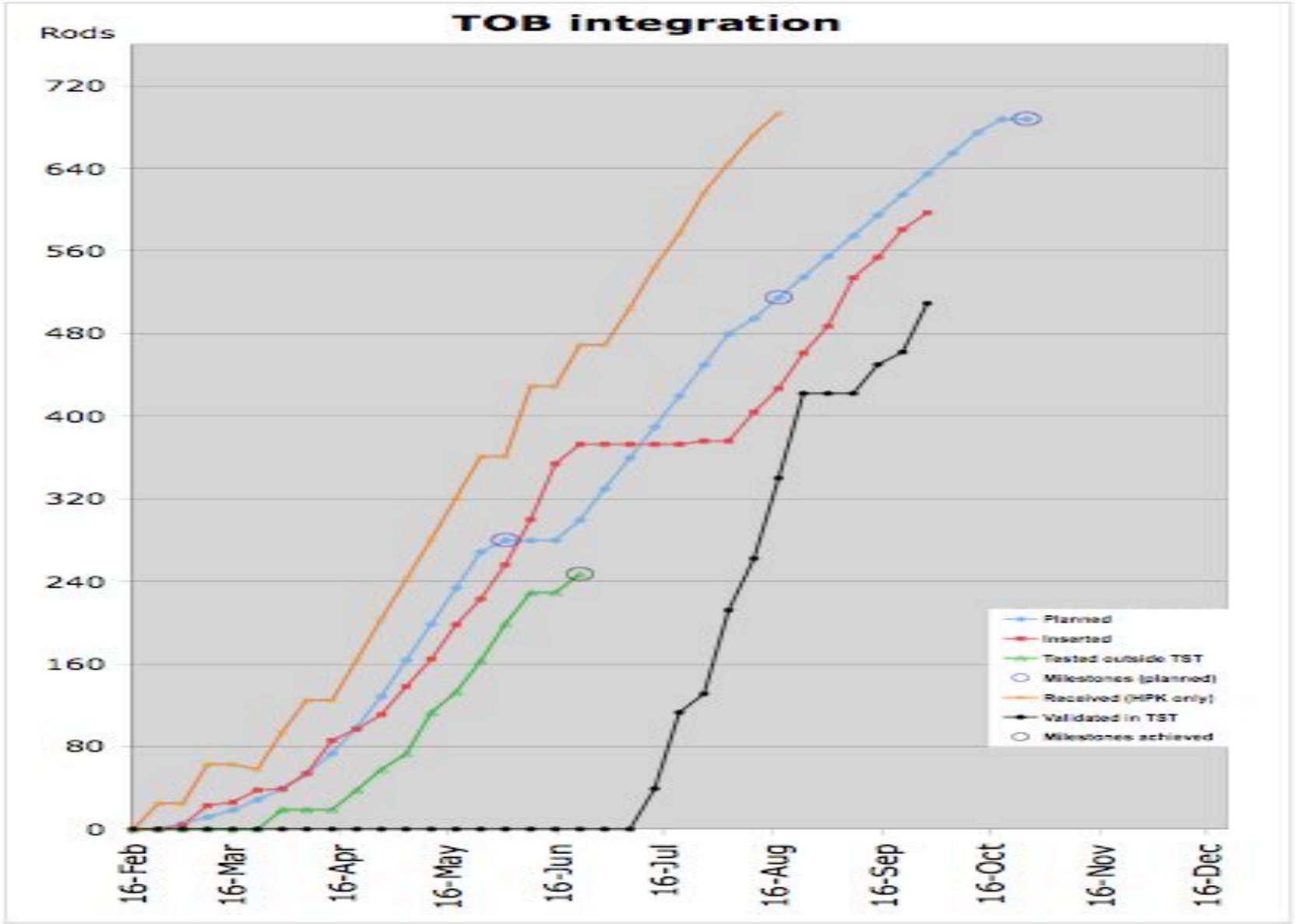


Current status of TOB integration



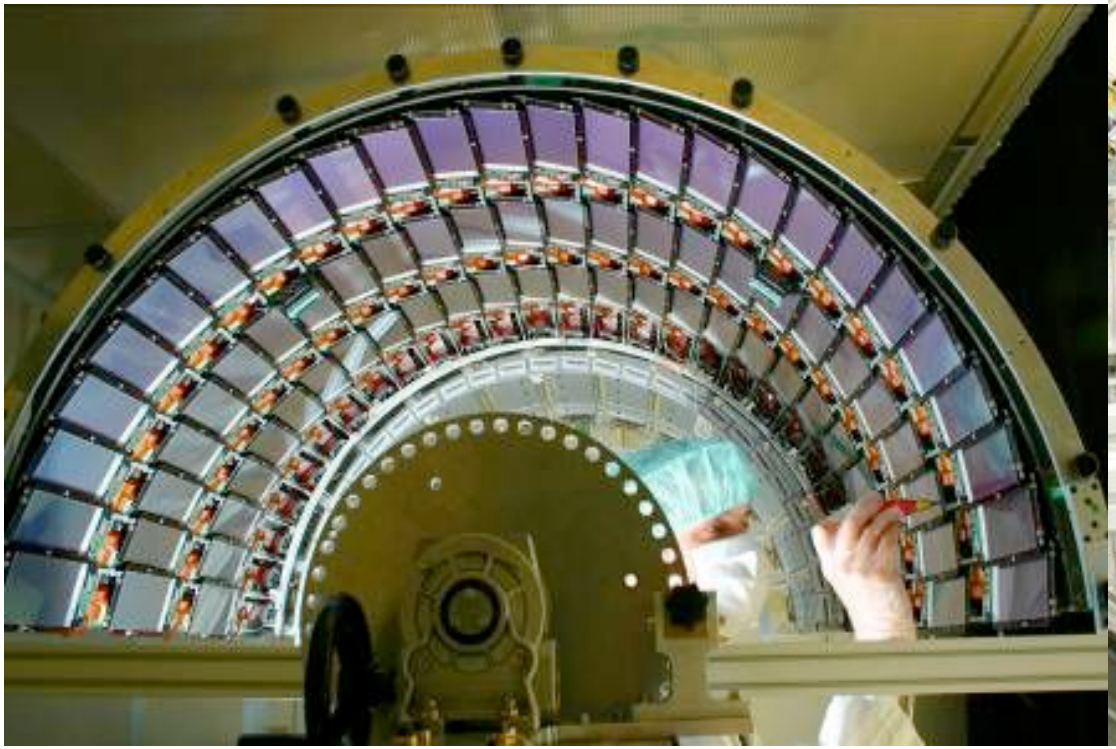
Layers 6+, 5+, 4+, 3+, 2+, 1+100% integrated and validated
Layers 6-, 5-, 4-, 3- 100% integrated and validated
Priority for TOB+ to follow the planned assembly sequence (TOB+, TIB/TID+, TEC+ then TOB-, TIB/TID-, TEC-).
TOB+ ready for insertion of TIB/TID+ second half of October.

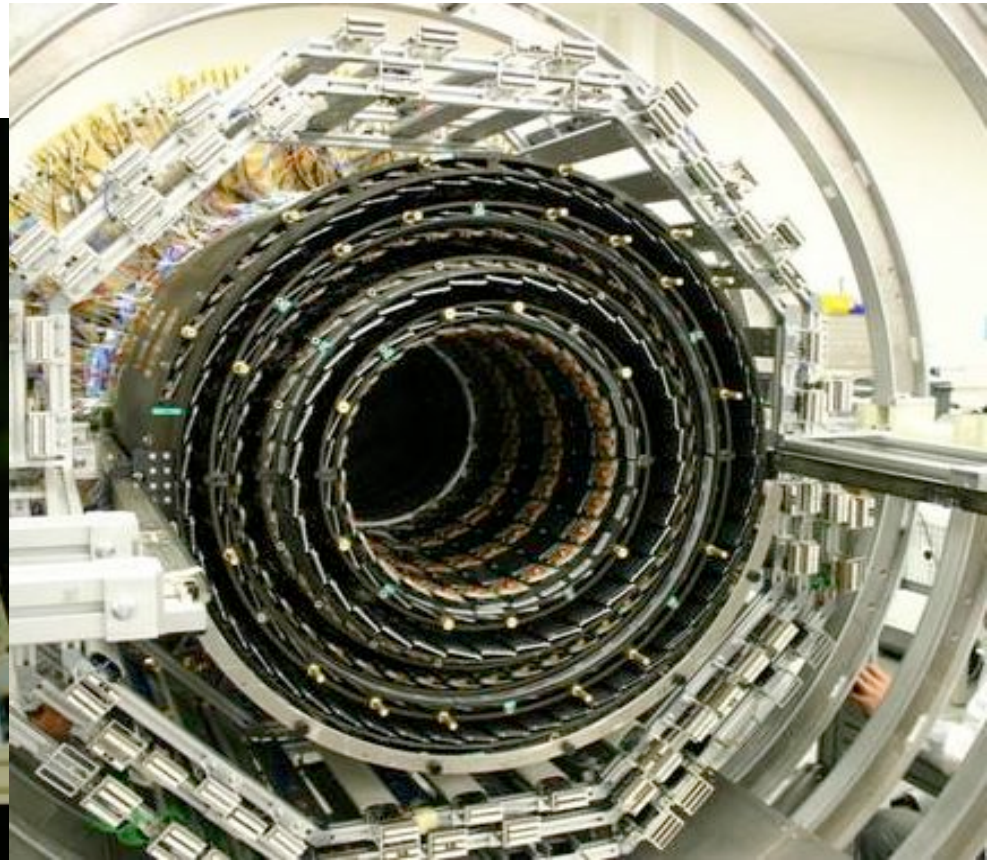
Plan for the TOB integration



Tracker Inner Barrel and Disks (Italy): 100% completed

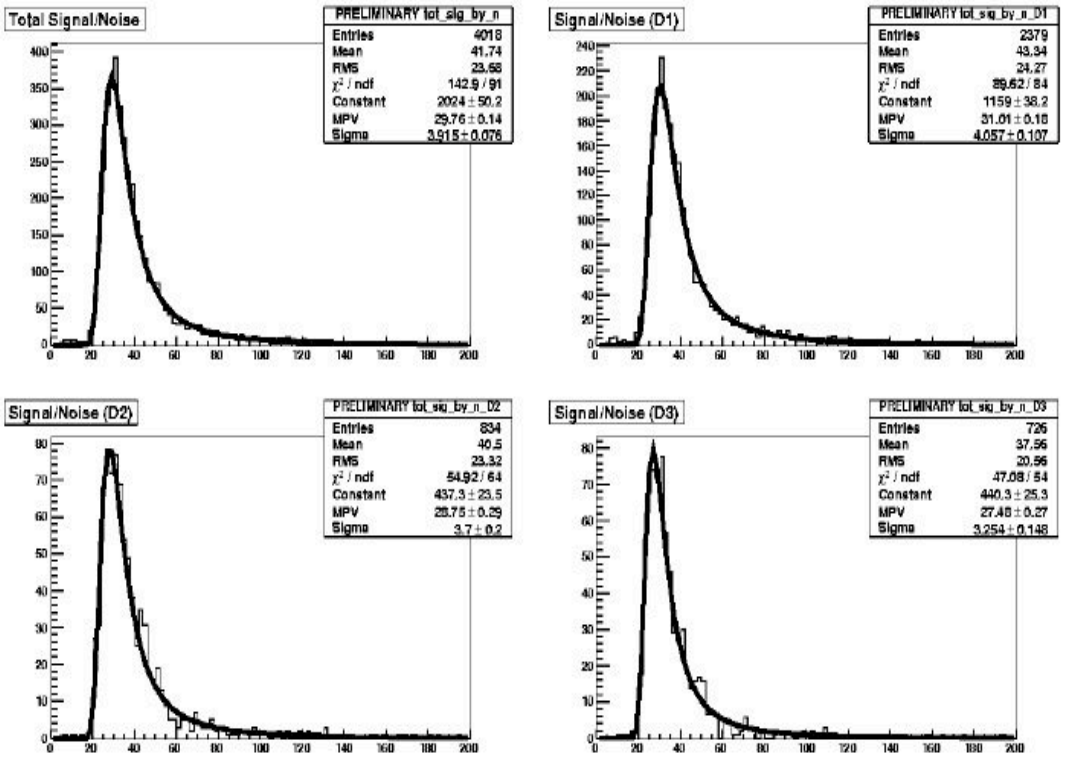
3540 modules integrated in 22 sub-structures (shells and disks).
TIB/TID+ delivered to CERN in June.
TIB/TID- in final sub-assembly in Pisa (delivery to CERN this month).
Excellent quality. Dead or noisy channels <0.2%.
All sub-structures (shells and disks) long-term tested in operating conditions (-10°C)
Very reliable cooling performance.
Excellent S/N ratio >25:1 in peak mode.

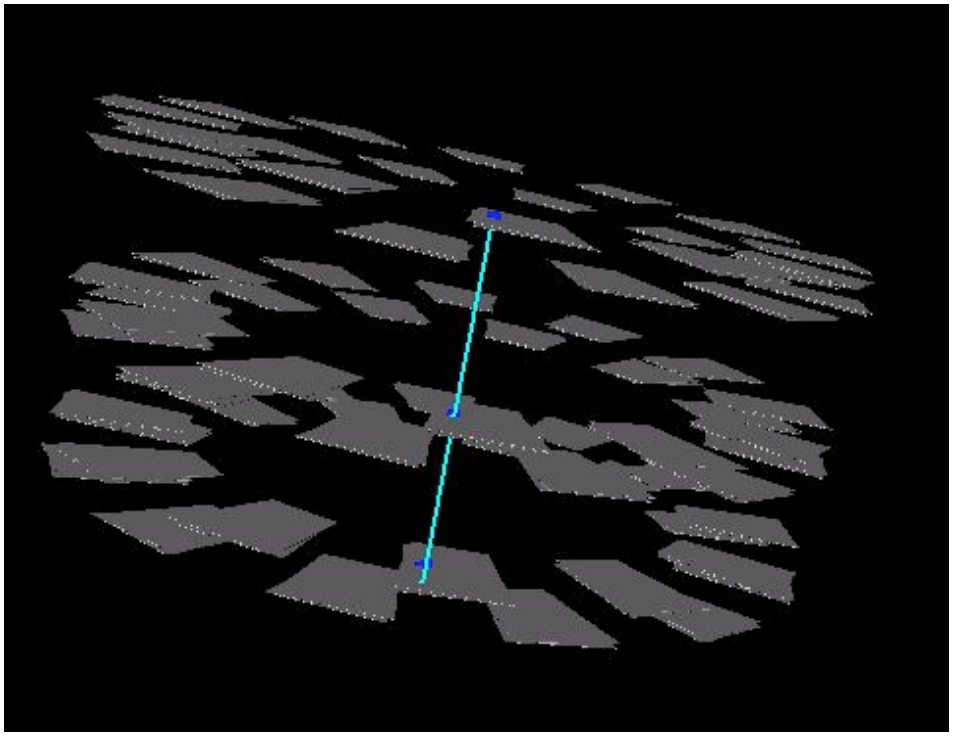




Cosmic data taking during integration

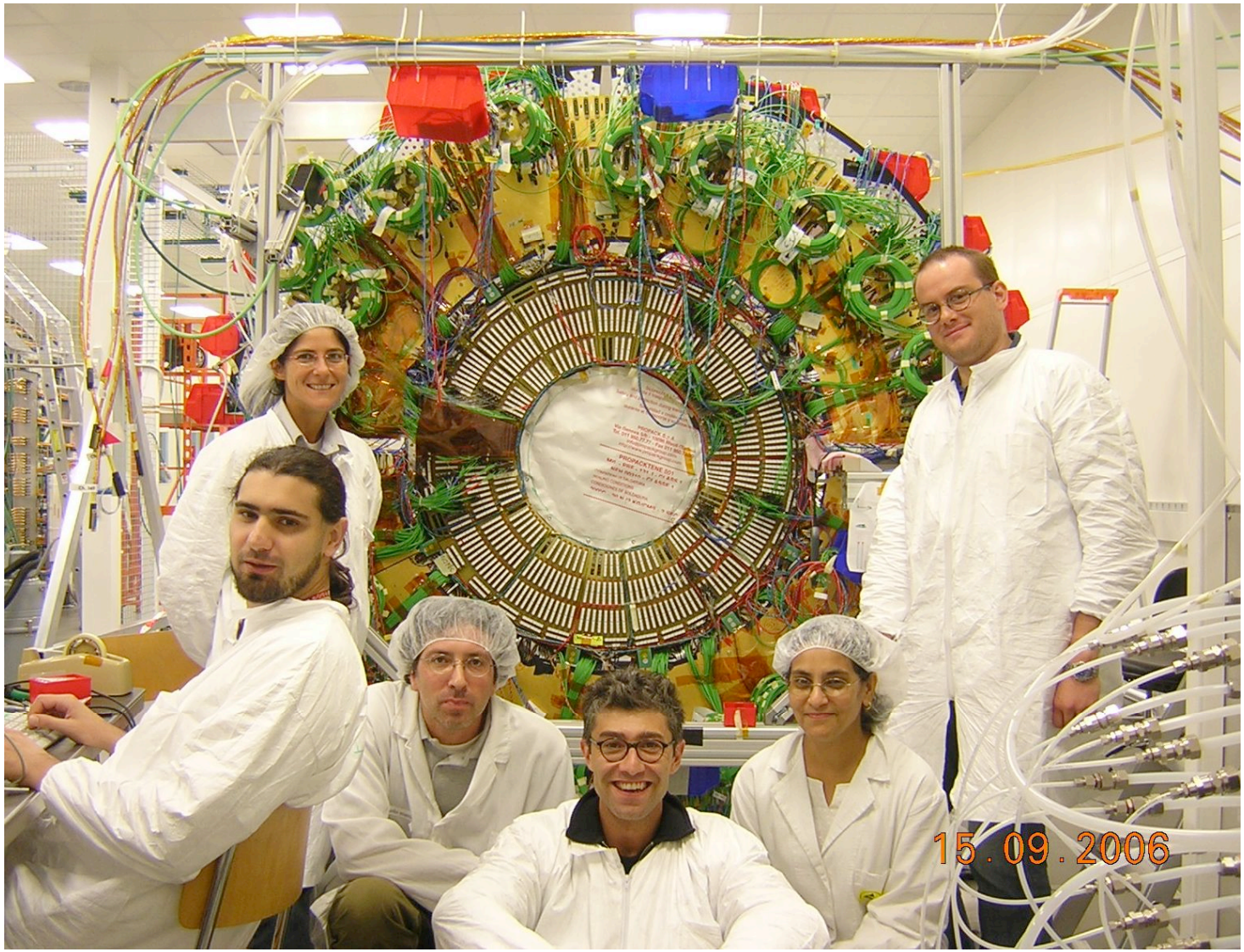
runs taken in peak mode (3000 ev/run); ~8 Hz (~ 8 FED readout rate with SBS+VME and no zero suppression); **Signal to noise ratio >25 in peak mode.**



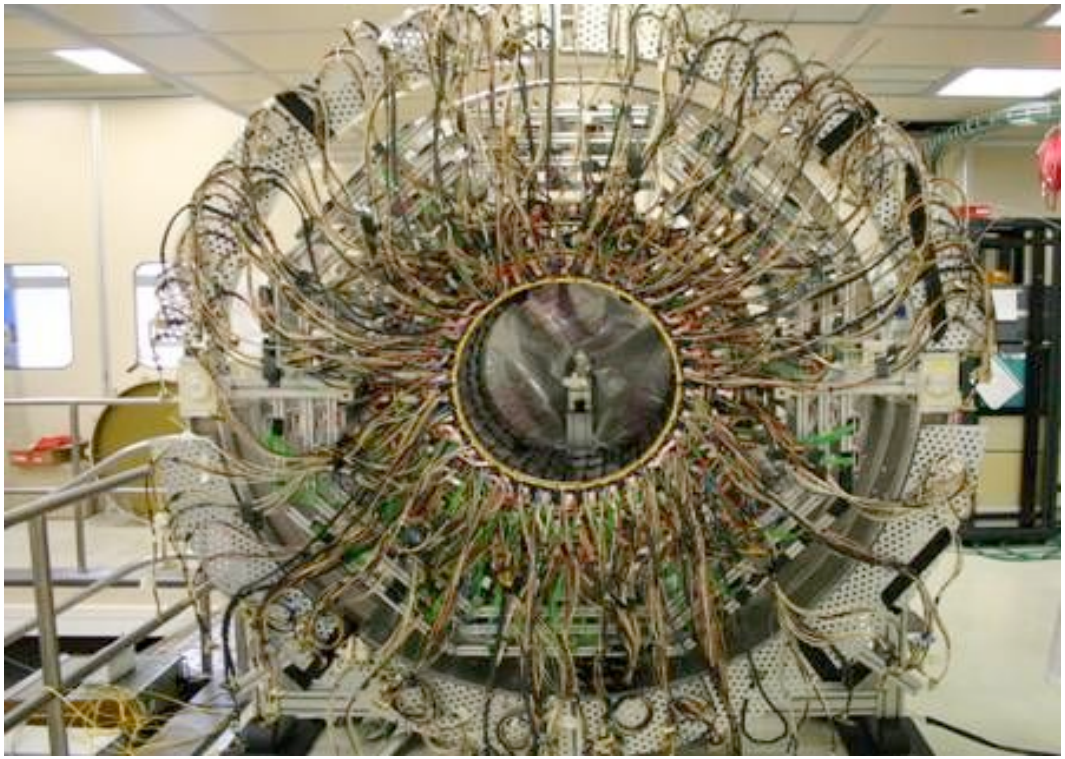


New software used for track reconstruction and iguana display.

Final test and service preparation TIB/TID+



Final assembly TIB/TID-

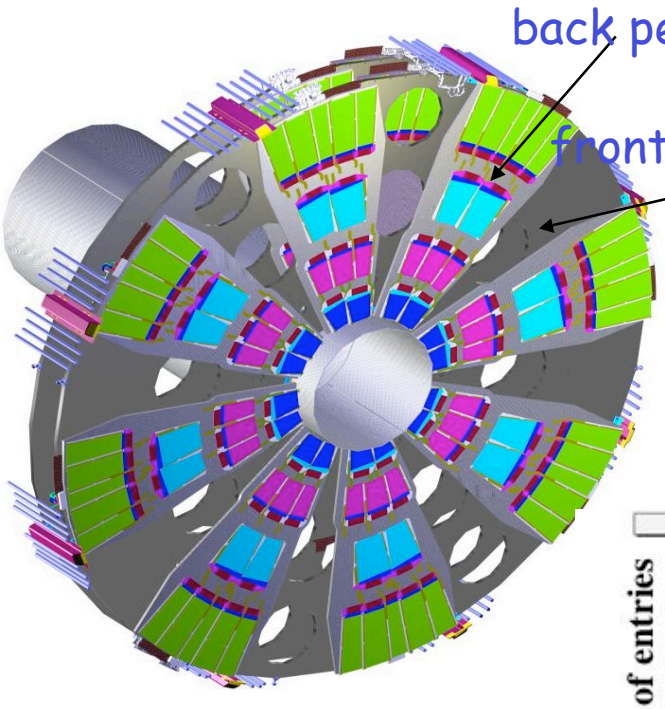


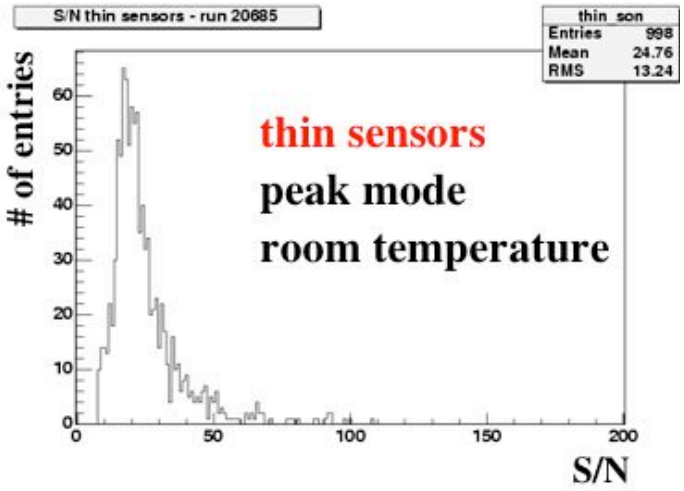
Coupling of TIB/TID- planned for this week
Organization of the services next two weeks

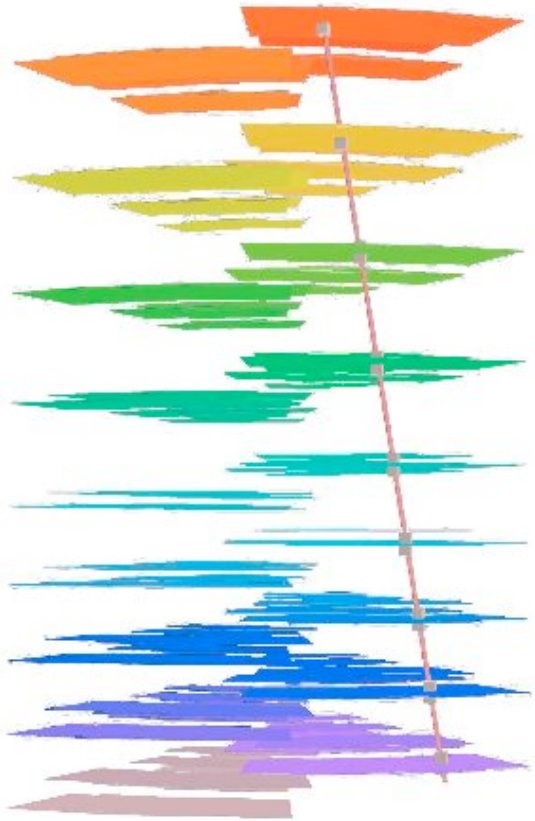
Transport to CERN on October 23-rd..

Tracker End-Cap (D, F, CH, A, B)>62% completed

288/288 petals produced 100%; 252 inserted, 87%; 180 validated 62%.
TEC+ completed in Aachen on September 1-st
Excellent quality: total number of dead or noisy channels <0.5%.



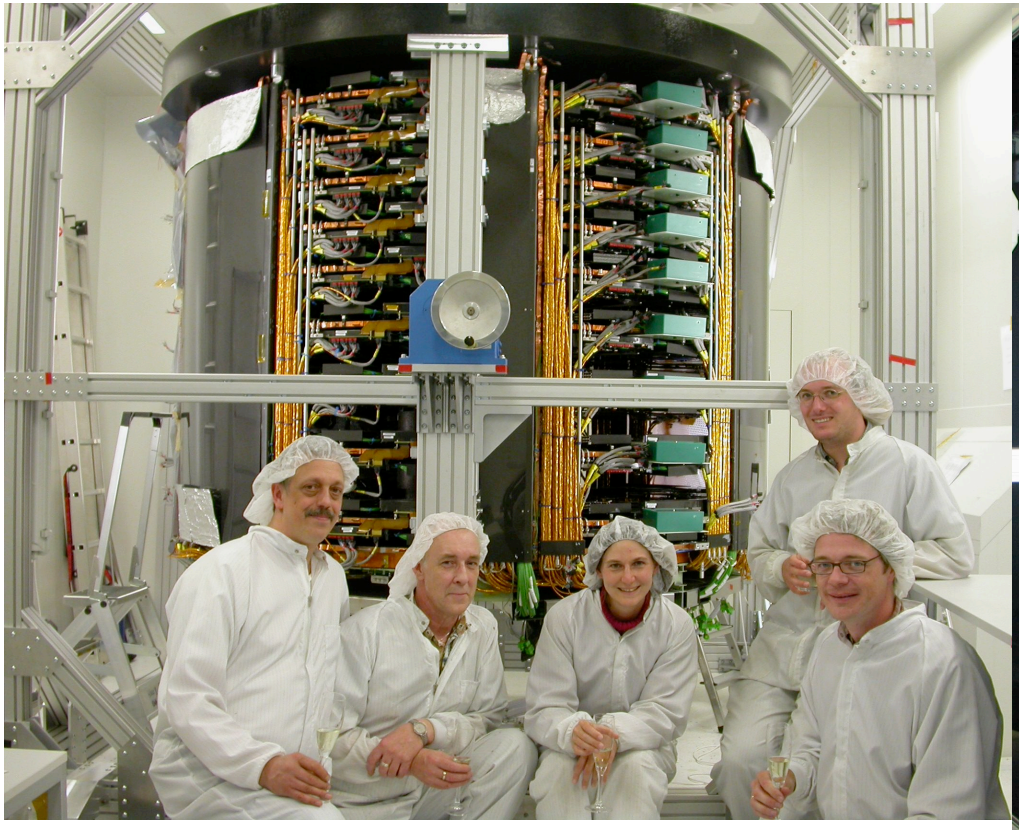


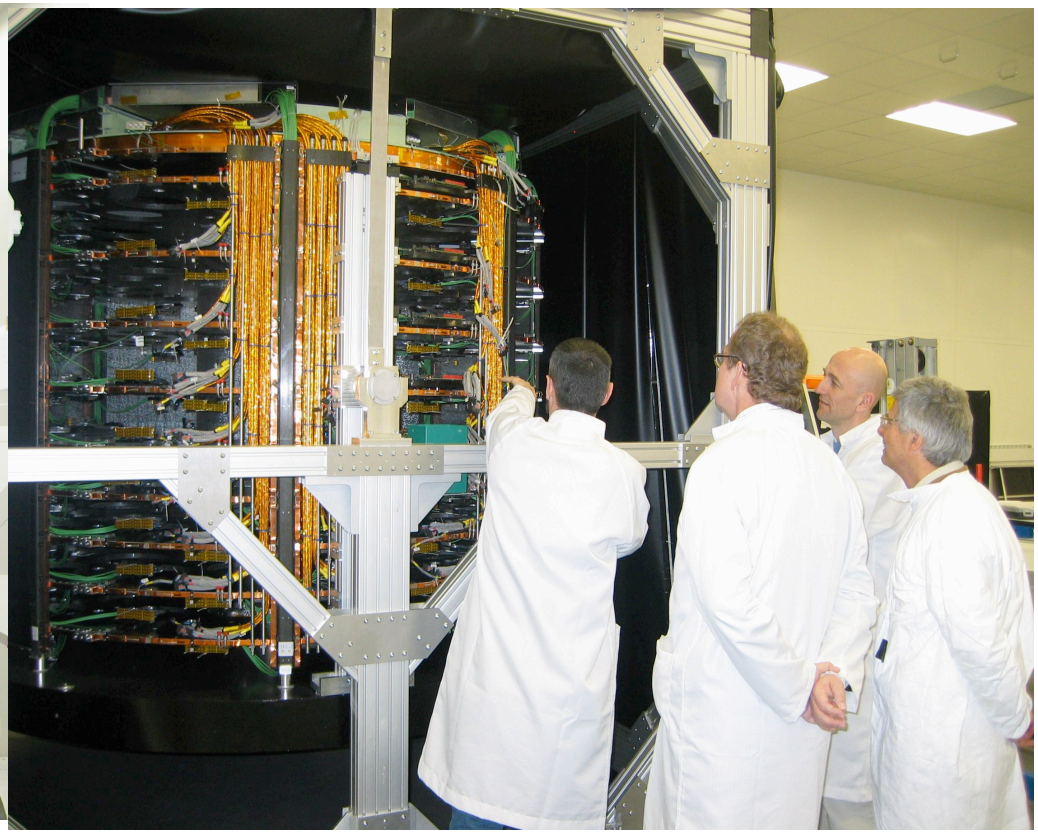


TEC+ (Aachen) and TEC- (Lyon/Cern)

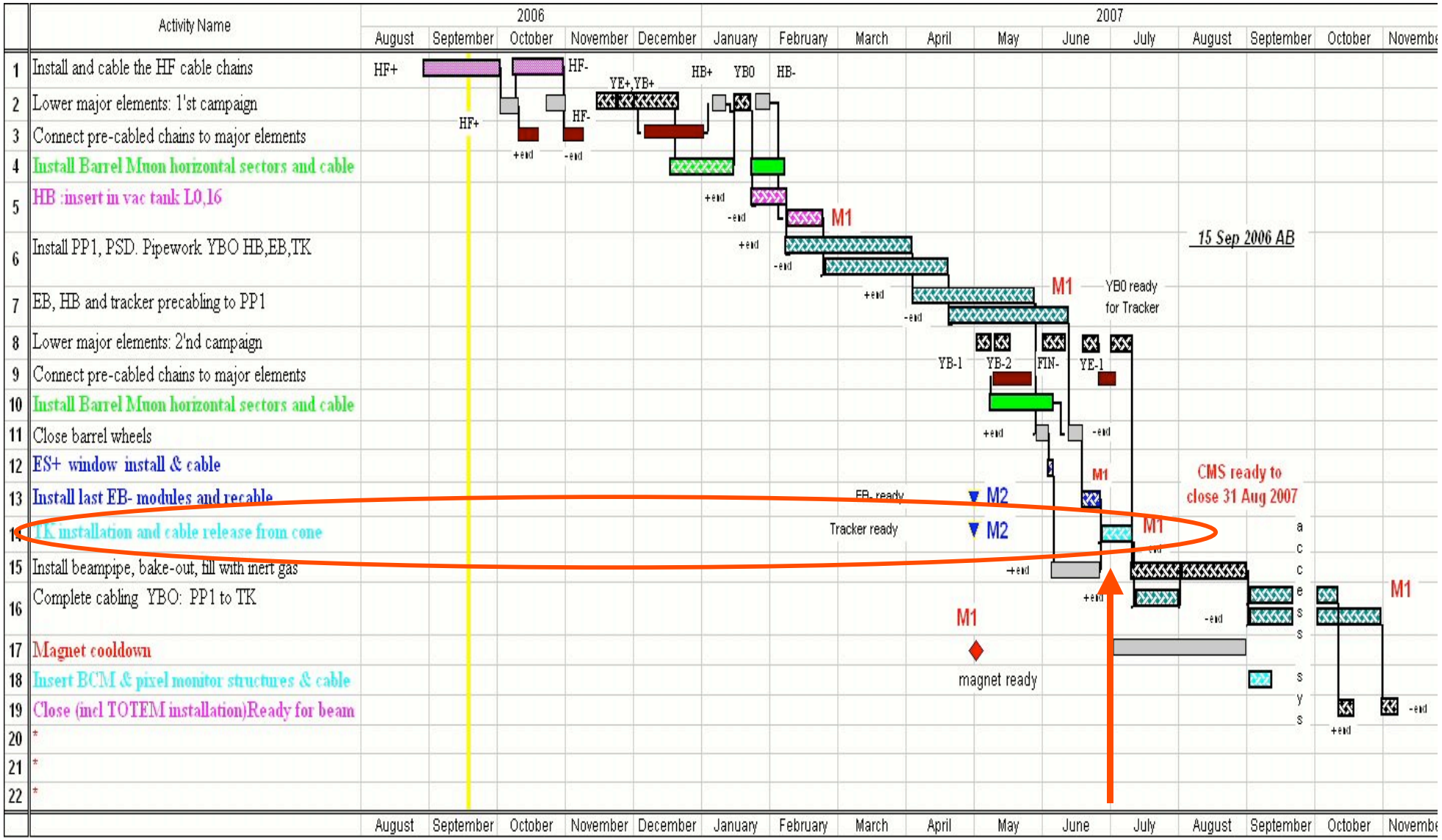
TEC+ will be at CERN by the end of October; cold test and integration into the Tracker Cylinder are foreseen in November.

TEC- already at CERN, 6/8 sectors integrated; expected to be completed in November and ready to be inserted in December, early January.

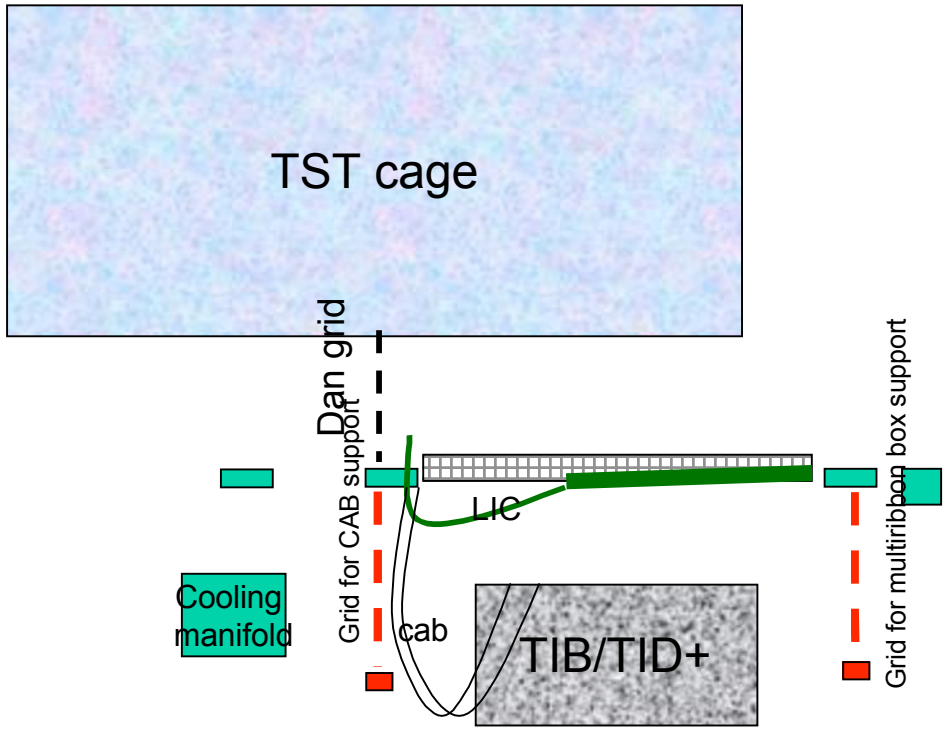




Installation schedule v35.1



Test of 25% of the Tracker (October06-May07)



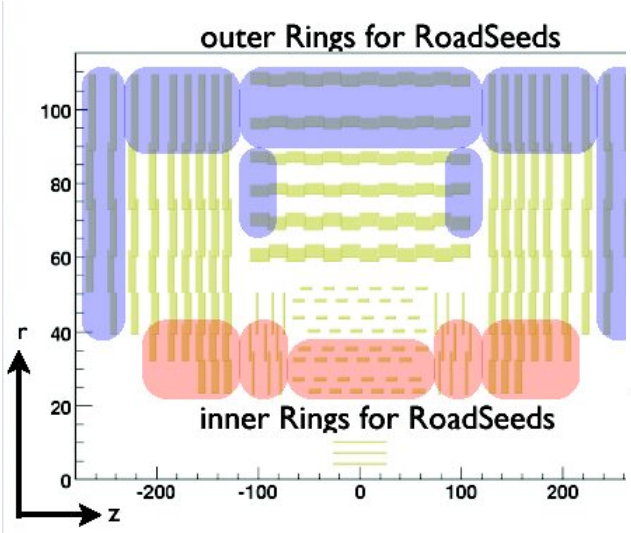
- Typical read-out test at the level of sub-structures= 200kchannels
- Next week we start by reading out 600K channels of the TIB/TID+.
- Expansion to 1.2M channels (TIB/TOB test) in November after the TIB insertion.
- Expansion to 2.5Mchannels in December.Test TIB/TOB/TEC.
- Run in cold and data taking with cosmics after February 07.

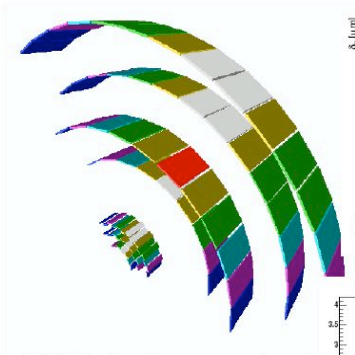
Commissioning of the electronics and power system

FED 463/500 delivered; 362/500 S-Link Transition Cards; FEC 50/50 produced; VME controllers 18/44; VME crates 44/44.
PSM 1000/1000 ; Easy Crates 104/130; Branch Controllers 22/22 and SY1527 mainframes (2/2); Backboards (720/1000)delivered.
System tests operational since months. Tracker partition fully validated.

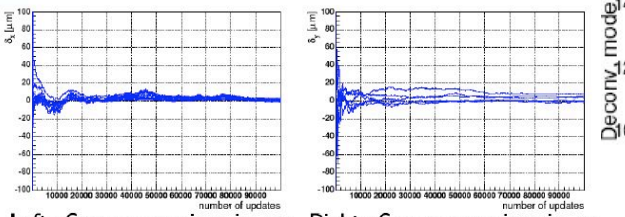
Commissioning of the software

- Well advanced on geometry, simulation, material description.
- Many tools fully validated for DCS,DSS,DAQ control, sincronization, calibration and data handling.
- DQM and visualization tools available.
- Three algorithms working for track reconstruction (with and without pixel).
- Different alignment algorithms under evaluation.
- Higher level software (vertexing, b-tagging, tau-tagging available)

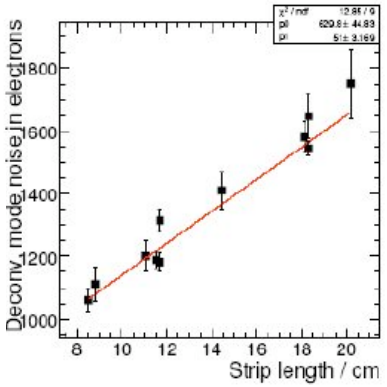


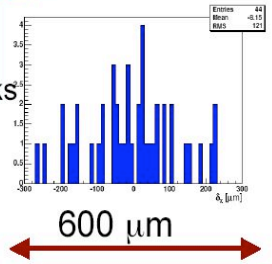


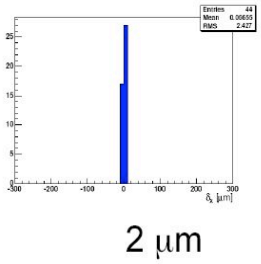
After 100K single muon tracks



Left: Convergence in x in μm, Right: Convergence in y in μm







Pixel detector (Switzerland, USA, Italy)

B-PIX status: in production

so far 104/672 modules produced; 71% yield for grade A modules. Work on-going to reduce defect rate for chips, HDI, bump-bonding and assembly.

F-PIX status: completed pre-production

The first 26/900 plaquettes have been produced and are currently being qualified.

Production of barrel modules

Pixel Barrel Module

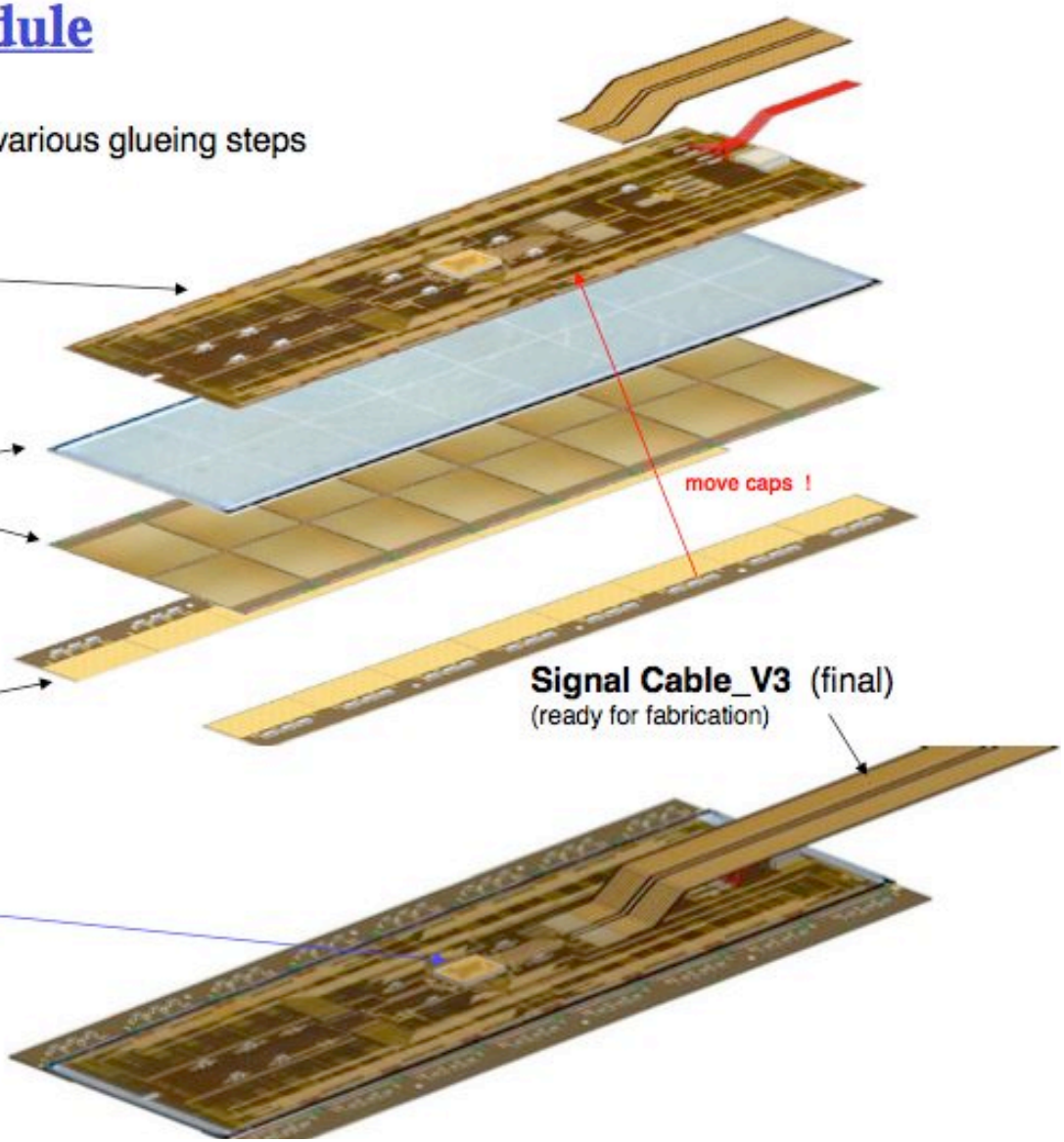
Fabrication of modules with various glueing steps

HDI_V3.1 (final)

Bump bonding
at PSI, capacity now
4-6 modules /day

Si_3N_4 baseplate
move **caps** to HDI
simpler fabrication

TBM_V5 (final)
Ready.



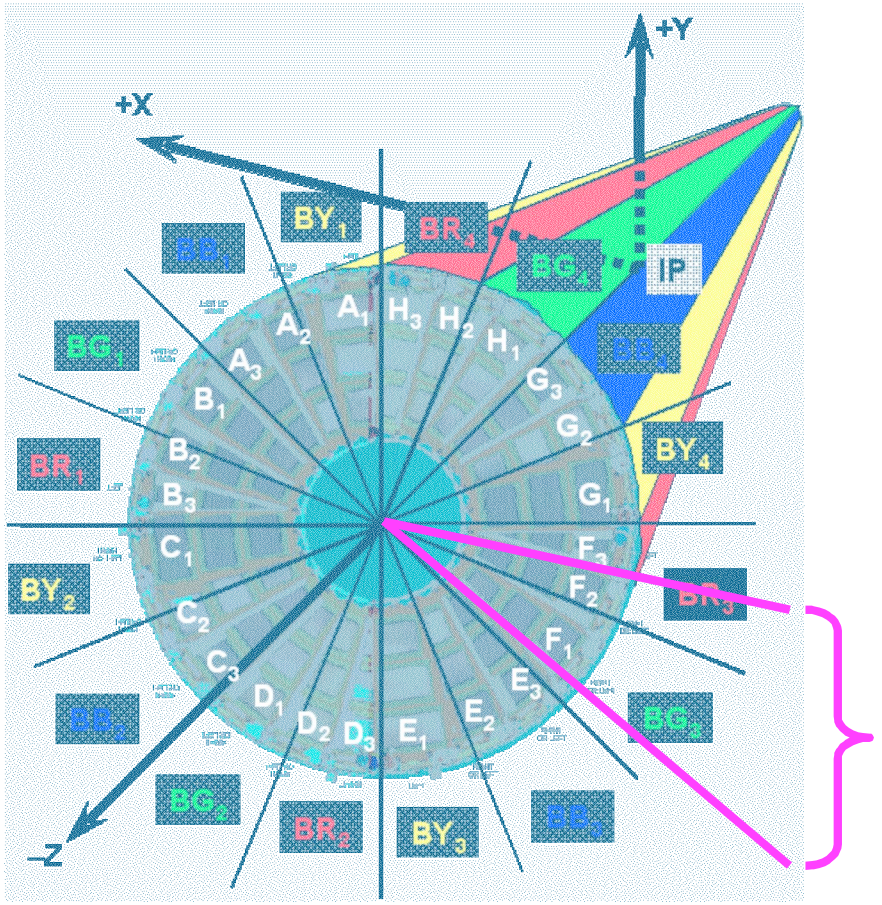
The pixel detector in the pilot run (2007).

A wedge of the barrel (three layers) and the corresponding two sectors of the forward (F1 ed F2).

Learn how to assemble, commission and install the system. Gain experience in integrating the pixel in the read-out.

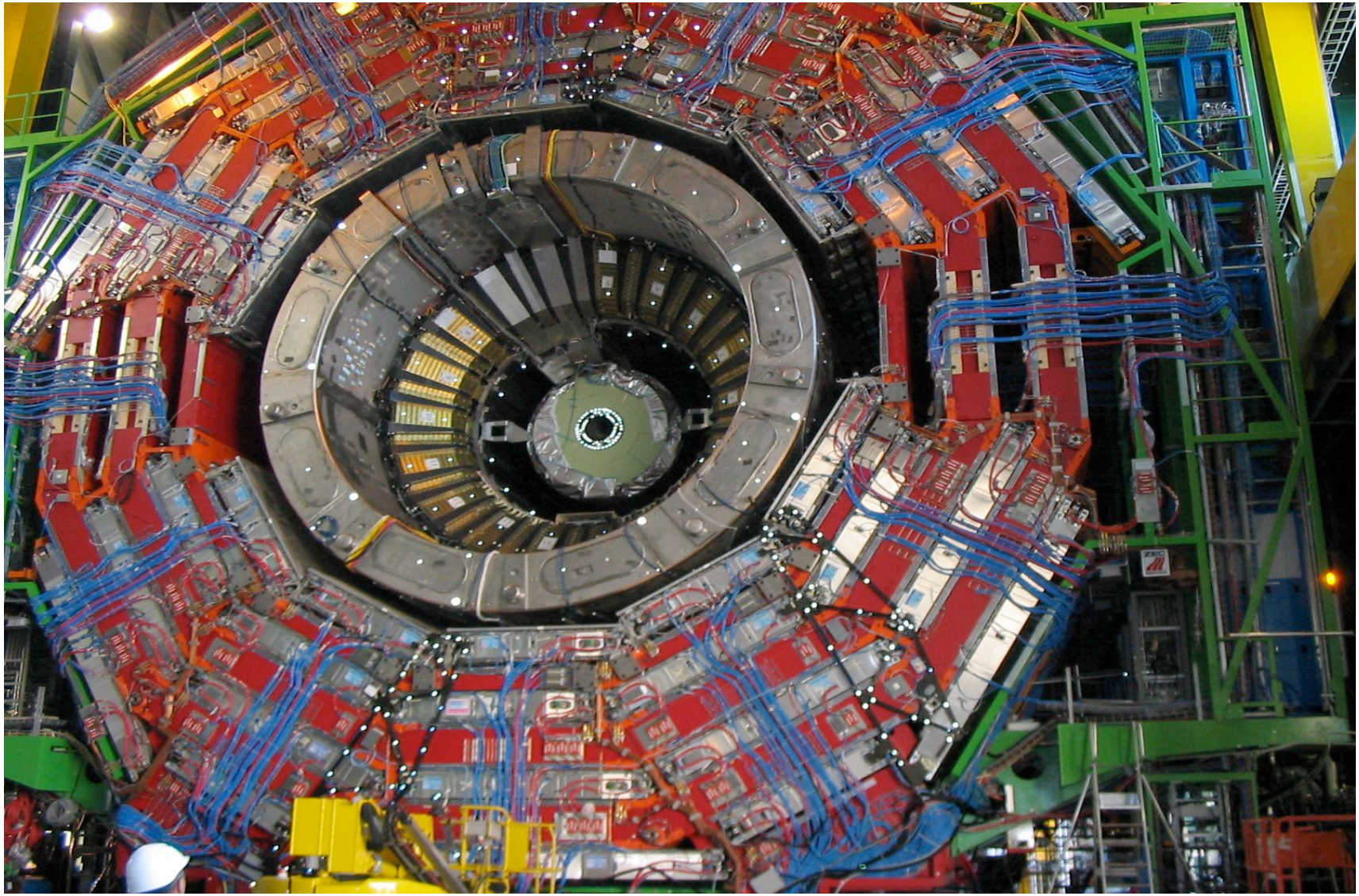
Cross check any possible interference, ground scheme, pick-up etc.

Reconstruct tracks with pixel seeds, tune the alignment tools, first experience in HLT.



The installation of the full pixel detector is planned for the first physics run (spring 2008).

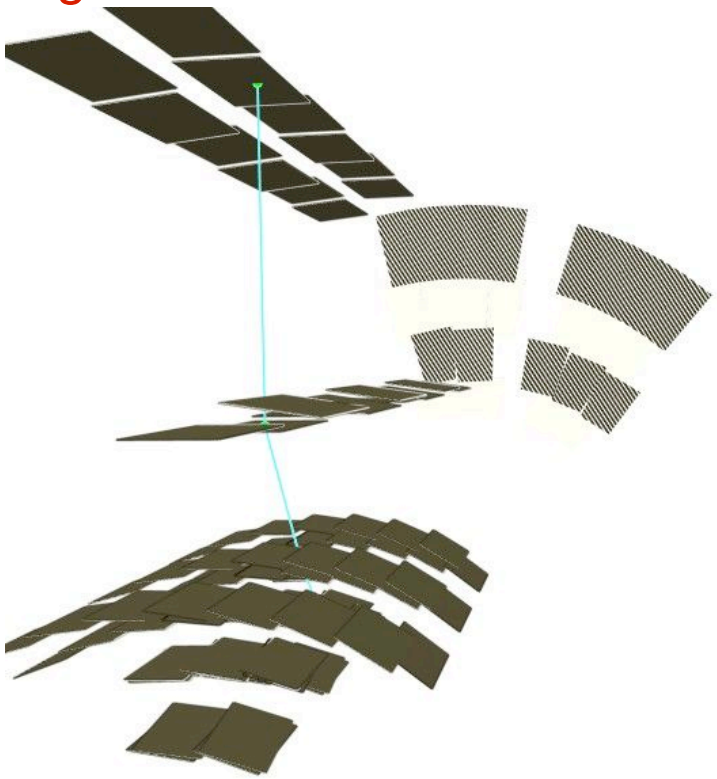
MTCC (July-August_06)

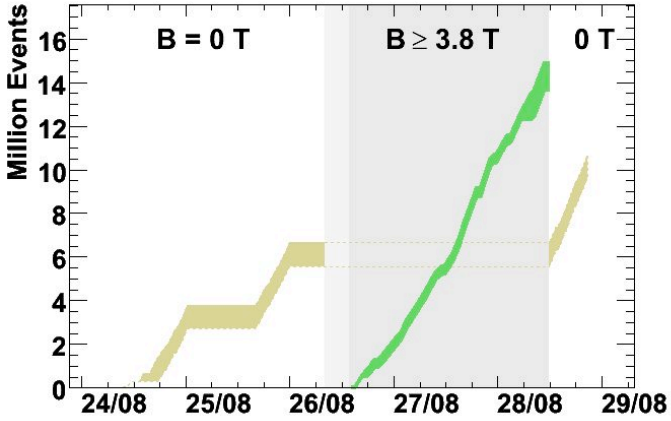


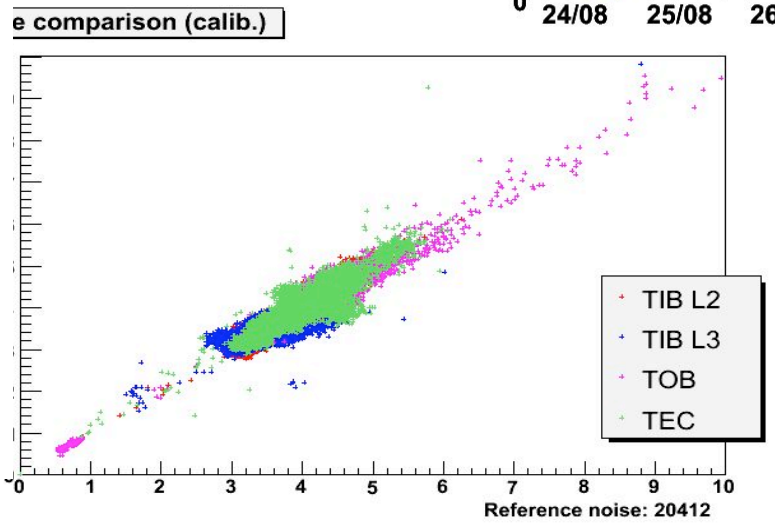
How to install and cable the tracker.

MTCC data taking

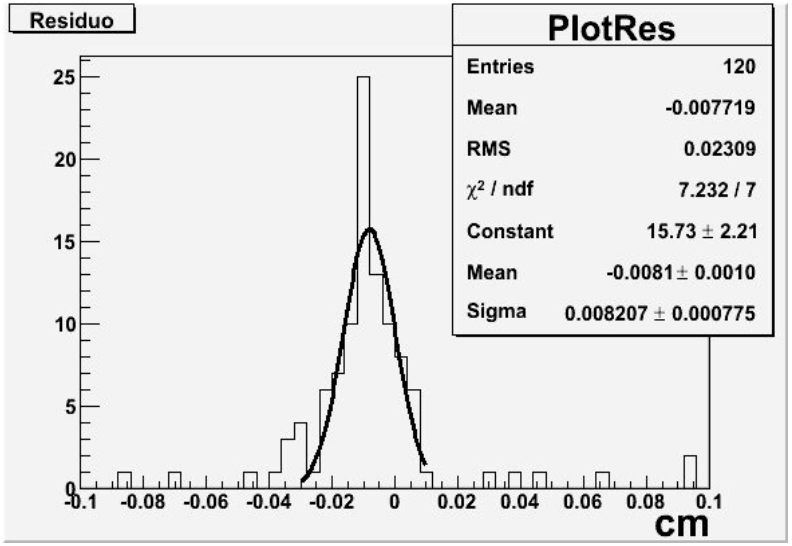
Barrel DT+RPC provided >25M triggers in 5 days (magnet on and off).
Stable DAQ , efficiency ≥90%.
Tracker DAQ fully integrated in the general CMS DAQ.
Validation of detectors, power system and services for 4T operations.
New software tools fully validated: DQM, event display, track reconstruction, alignment.



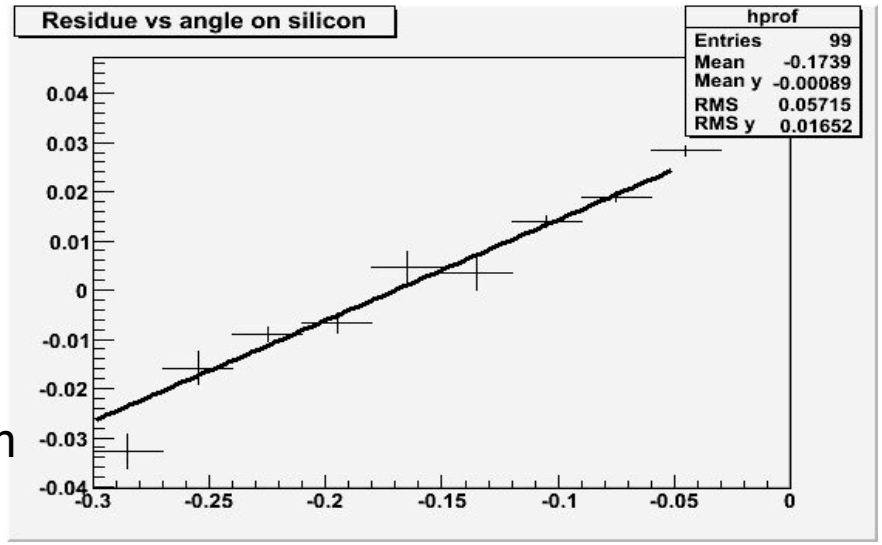




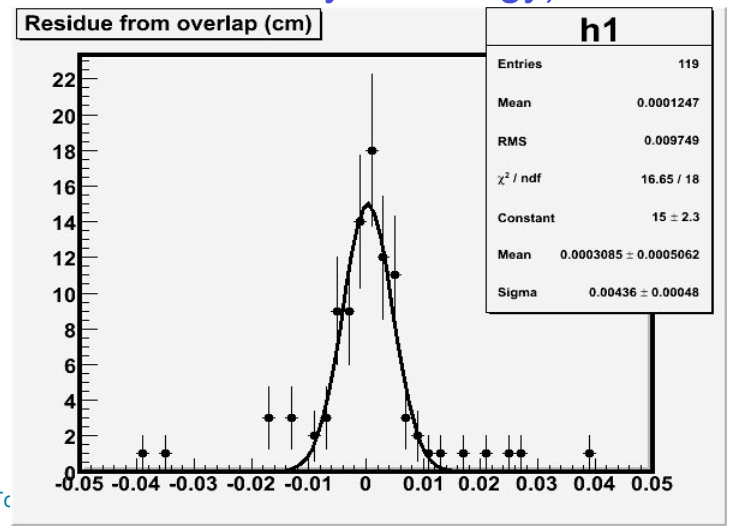
Preliminary alignment: tracker



<x> ~ -81 μm
σ ~ 82 μm



Found large dependence from track angle: due to vertical displacement of Layer 2 (about 2mm, confirmed by metrology)



$\sigma_{residue}$ ~ 44 μm

σ_{point} ~ 35 μm

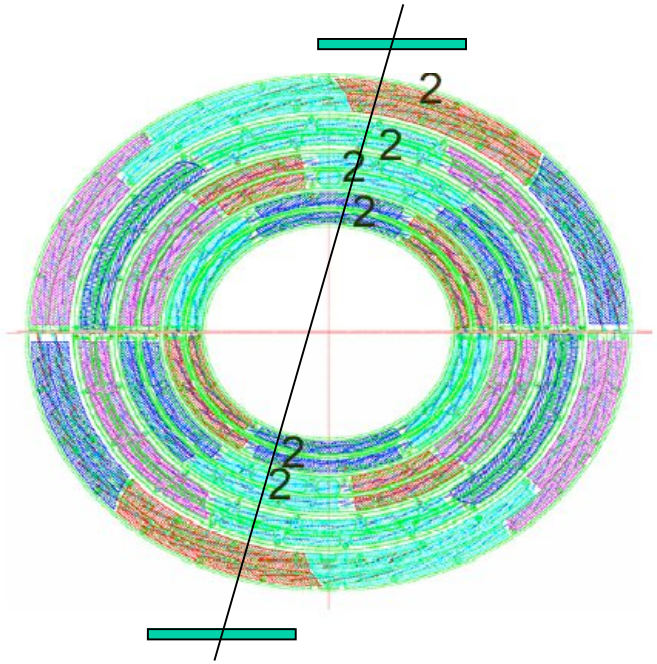
First ideas for the pilot run 900GeV (11/07)

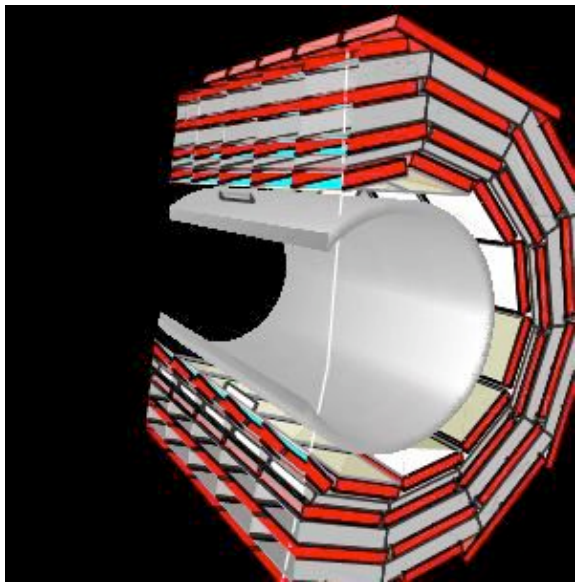
Pre-align with cosmics

Test 25% at the Tracker Integration Facilities (no B)

Cosmic run (in cold and with B)

Rate for muons> 10GeV reaching the tracker : 60Hz





The goal is to reach a pre-aligned tracker (better than 100μm) prior to collisions (May07). Using minimum bias events from the first collisions (700k tracks>2GeV) we plan to align in the range of ~20μm in ≤3months.

Conclusion

The CMS tracker is close to completion.

The quality and performance of the sub-components are excellent.

The installation of the silicon strip tracker in CMS is planned for late spring 2007, in time to record the first collisions of the LHC engineering run.

The complete tracker, including the entire pixel detector, is planned to be operational for the first LHC physics run (spring 2008).