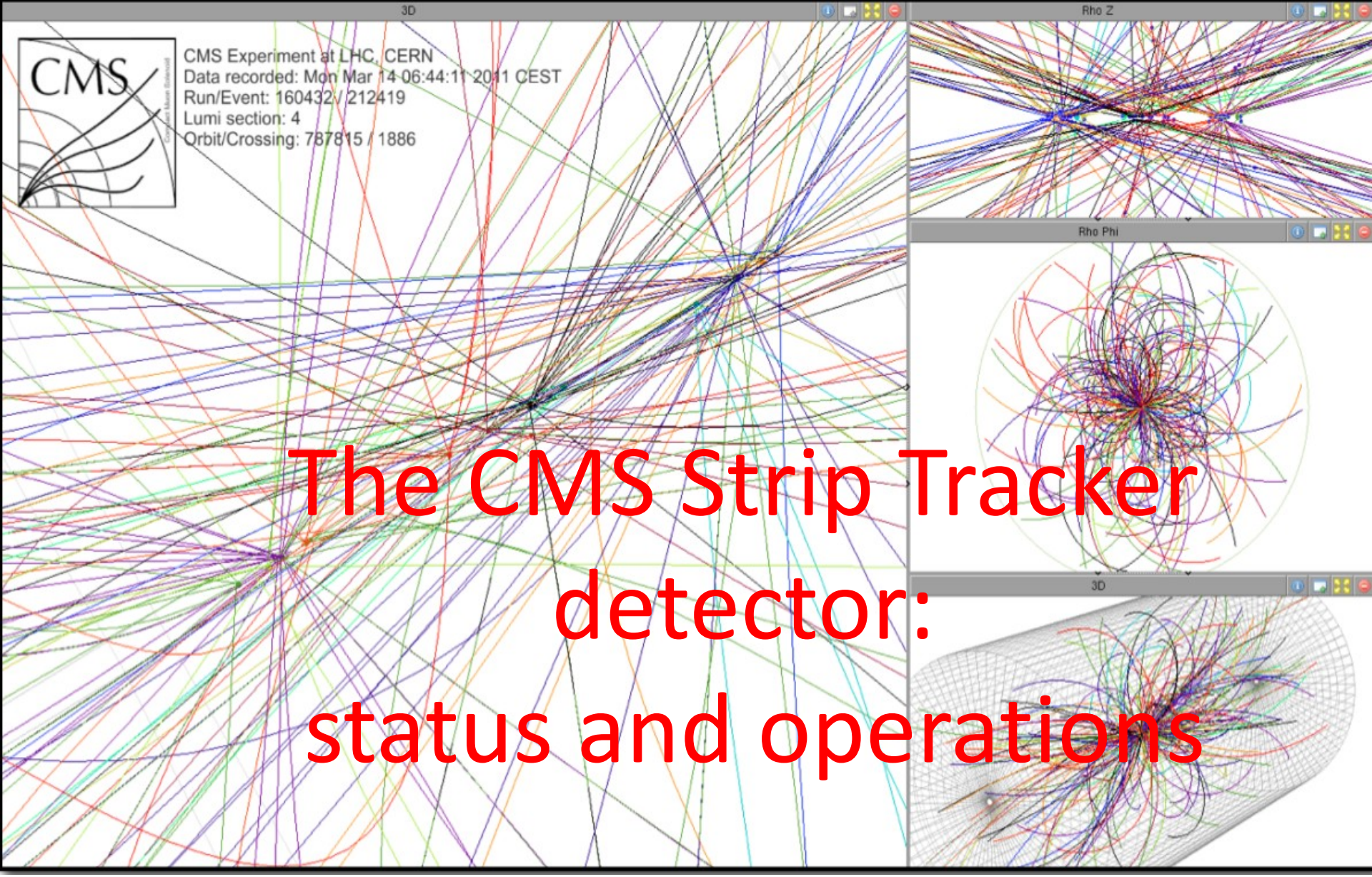


The CMS Strip Tracker detector: status and operations

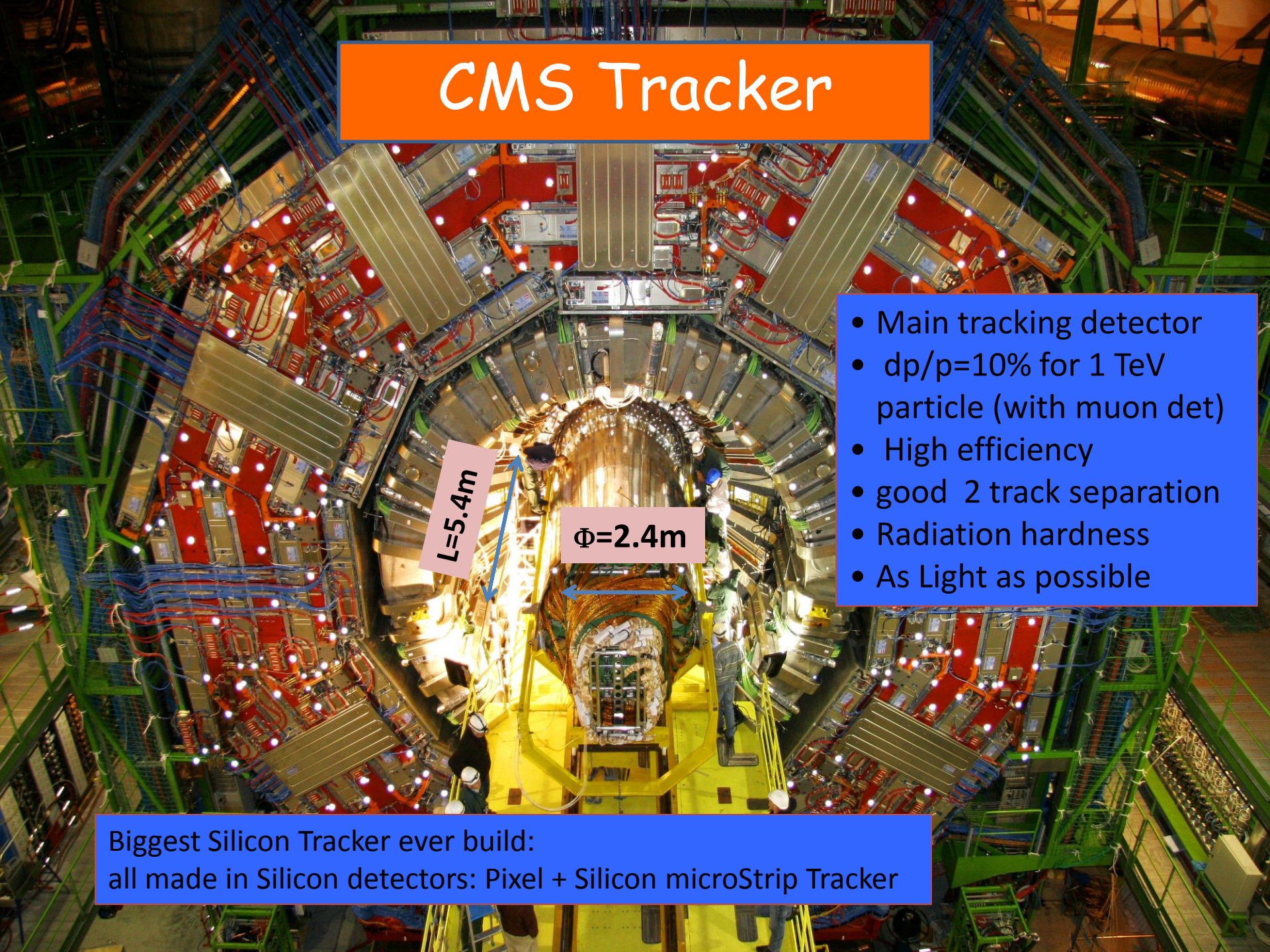
Lino Demaria -Torino INFN

VERTEX2011 workshop 19-24/06/2011

Outline of the talk

- CMS and the S(ilicon) S(trip) T(racker)
- Services
- Status of the detector
- Commissioning of SST
- Performances studies

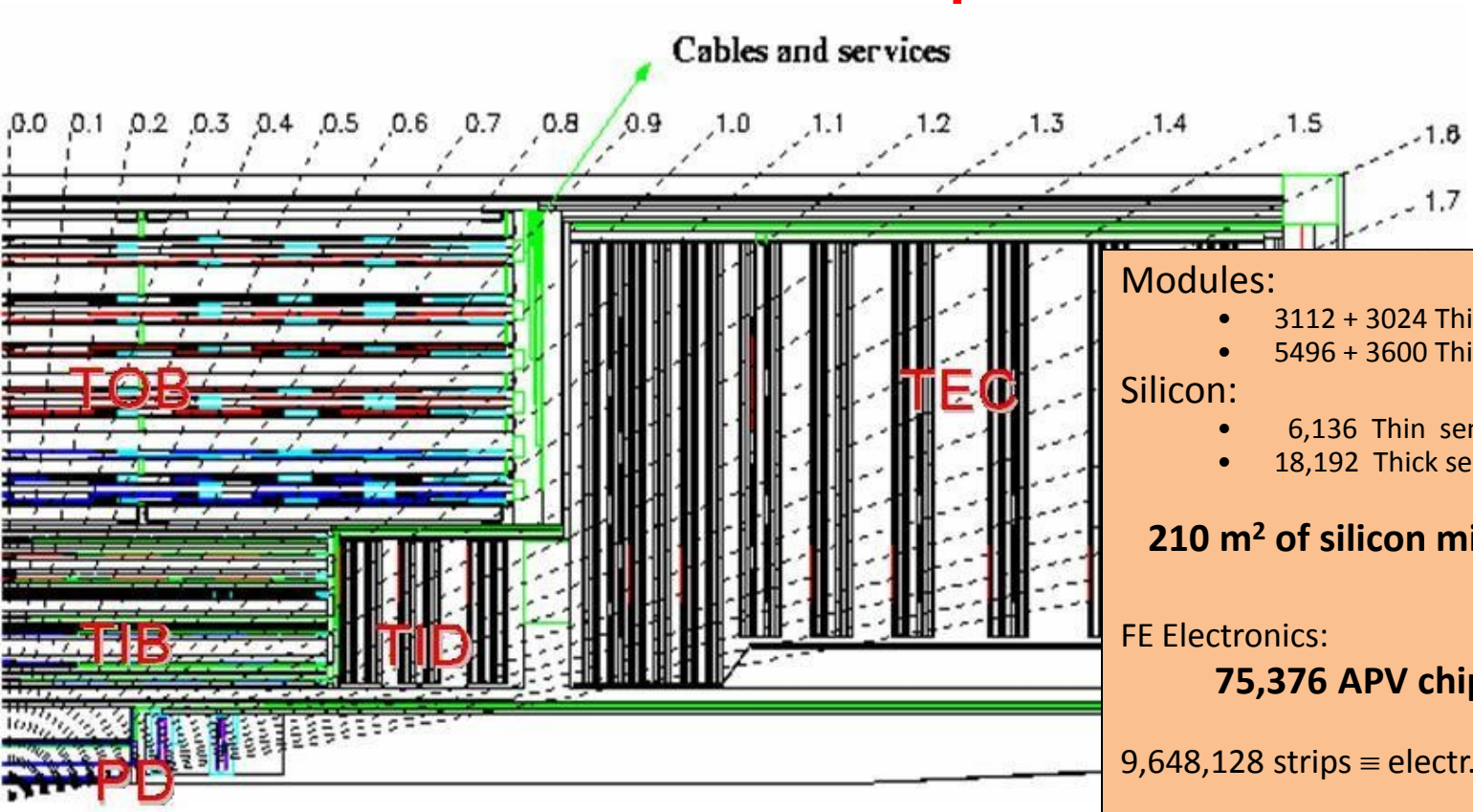
CMS Tracker



- 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

Biggest Silicon Tracker ever build:
all made in Silicon detectors: Pixel + Silicon microStrip Tracker

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

210 m^2 of silicon microstrip sensors

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

Modules and Sensors

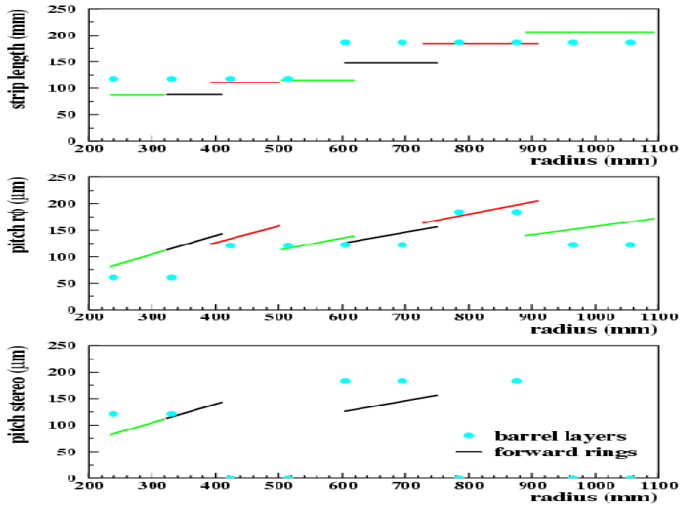
Silicon Microstrip Detector

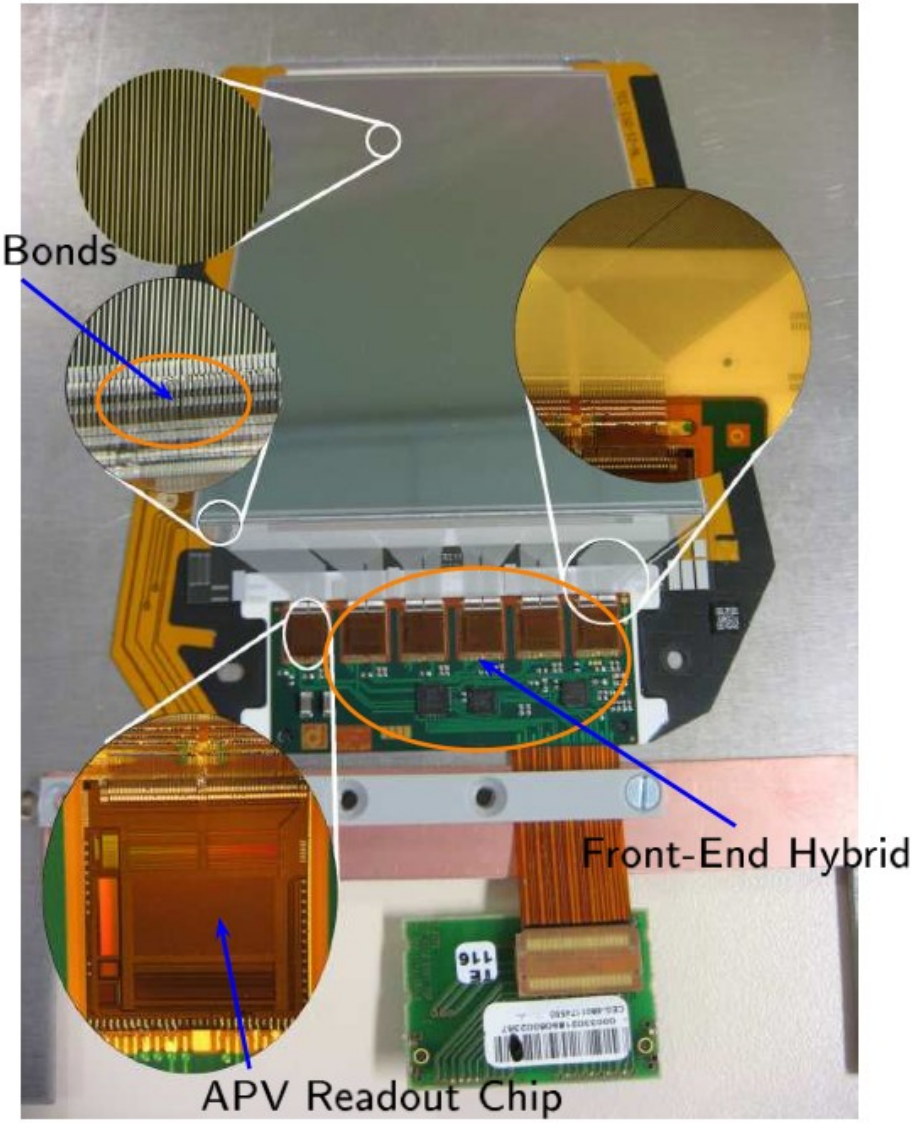
- p+ n detectors,
- 6” technology, <100> orientation
- AC coupled, R-poly biased,
- w/p=0.25, 4-8 μm metal overhang,
- Vbreak >500V

Thin sensors:300 μm, ρ = 1.5-3 kΩcm

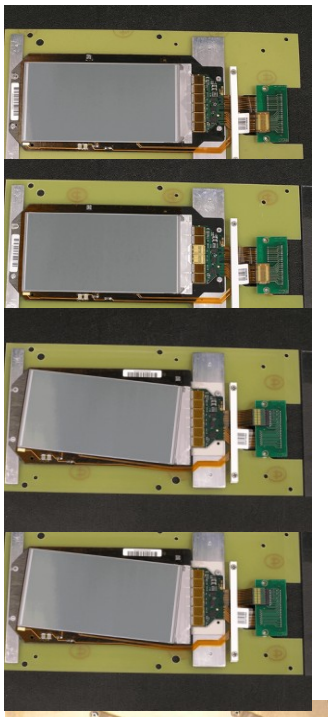
Thick sensors:500 μm, ρ = 3.5-7 kΩcm

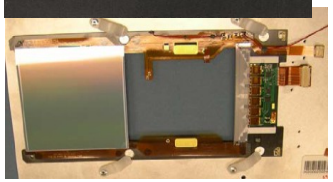
Different geometries and strip length.

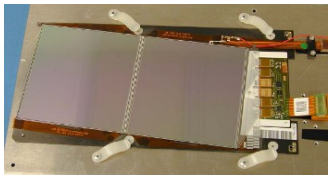


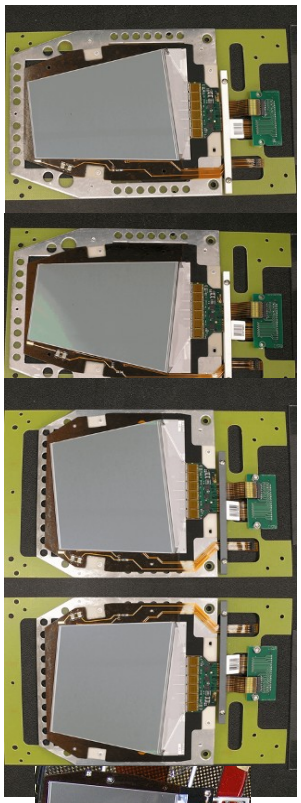


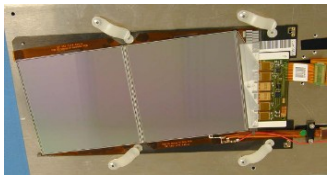
Different Module Geometries





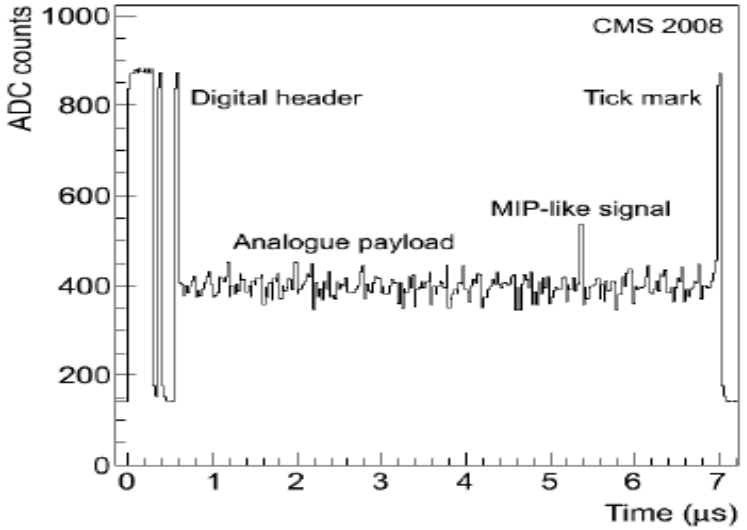




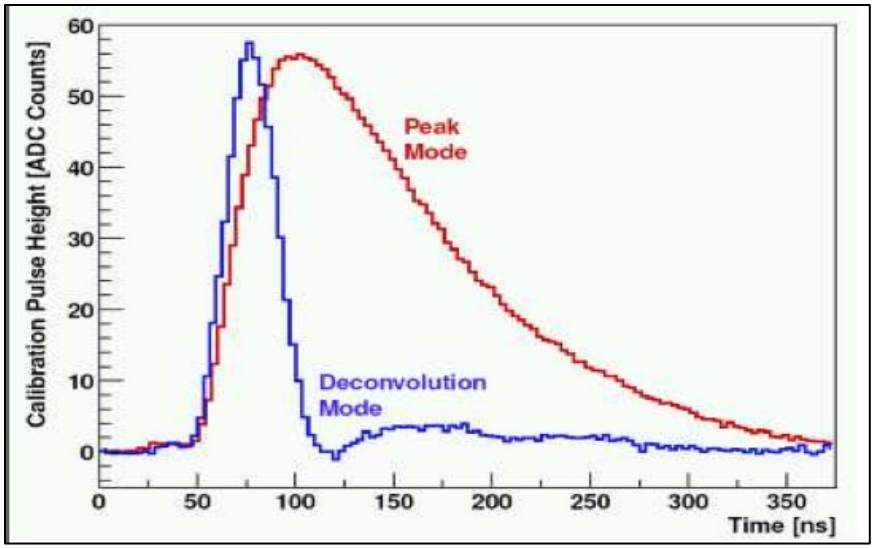


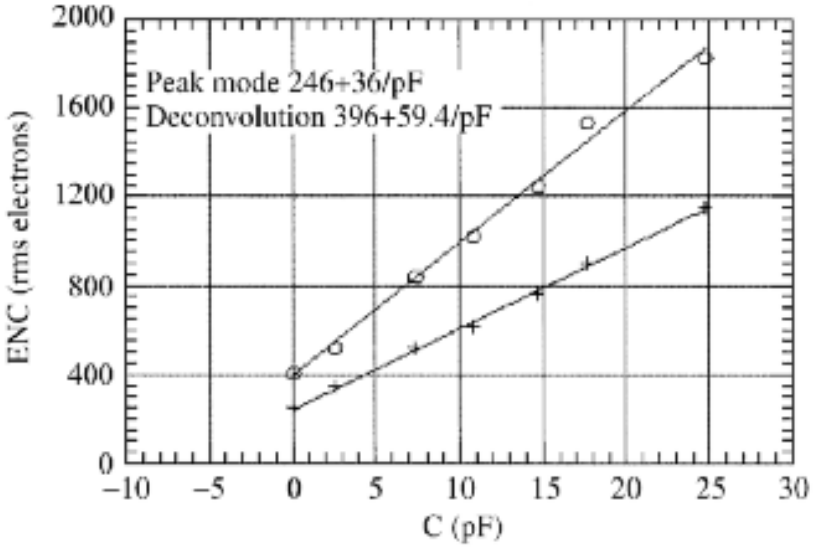
APV25 chip

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





Electronics chain

Signal route (analog):

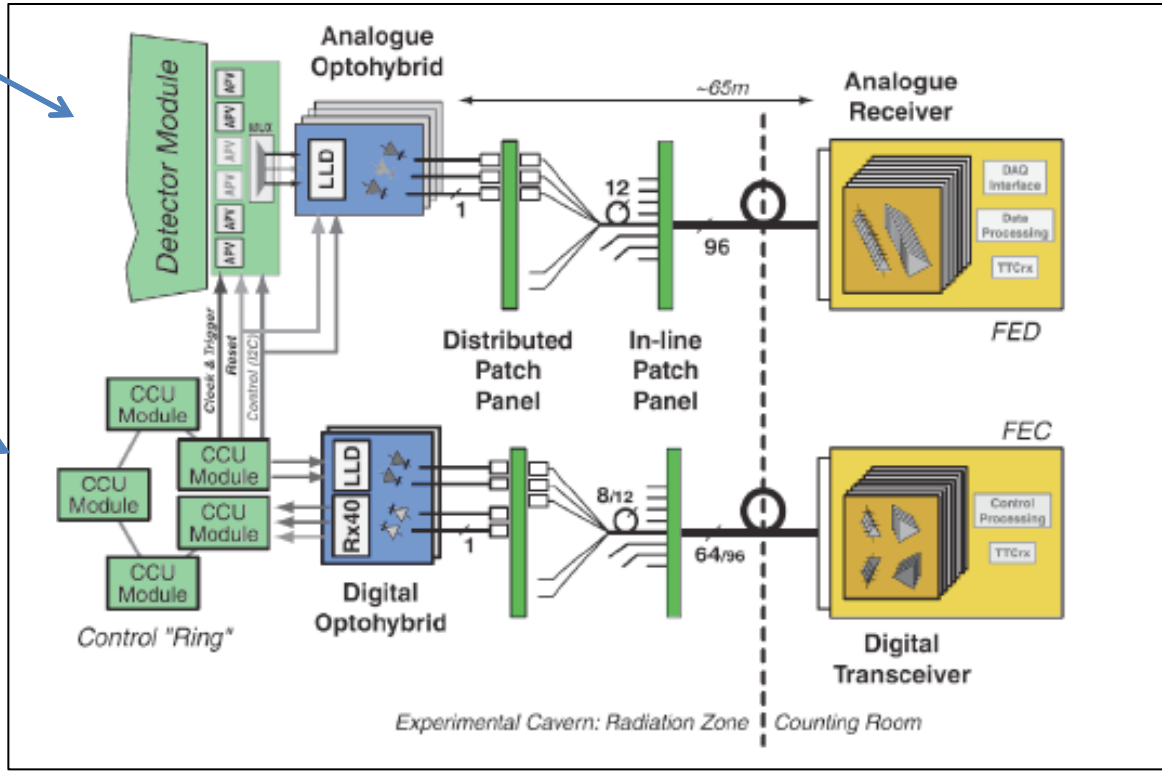
- Module
  - Silicon
  - APV
  - MUX
- AOH (electric to light)
- fiber (length =O(50m))
- .
- FED channel

Clock/Trigger/I2C (Control Rings)

- FEC
- Fiber
- .
- DOH ->CCU rings
- CCU
  - Clock/Triggert:
    - » PLL
    - » APV
  - I2C to:
    - » APV
    - » PLL
    - » MUX
    - » DCU

FED digitize, apply CM rejection, makes Zero Suppression. Relies on the upload of good Pedestal and noise values

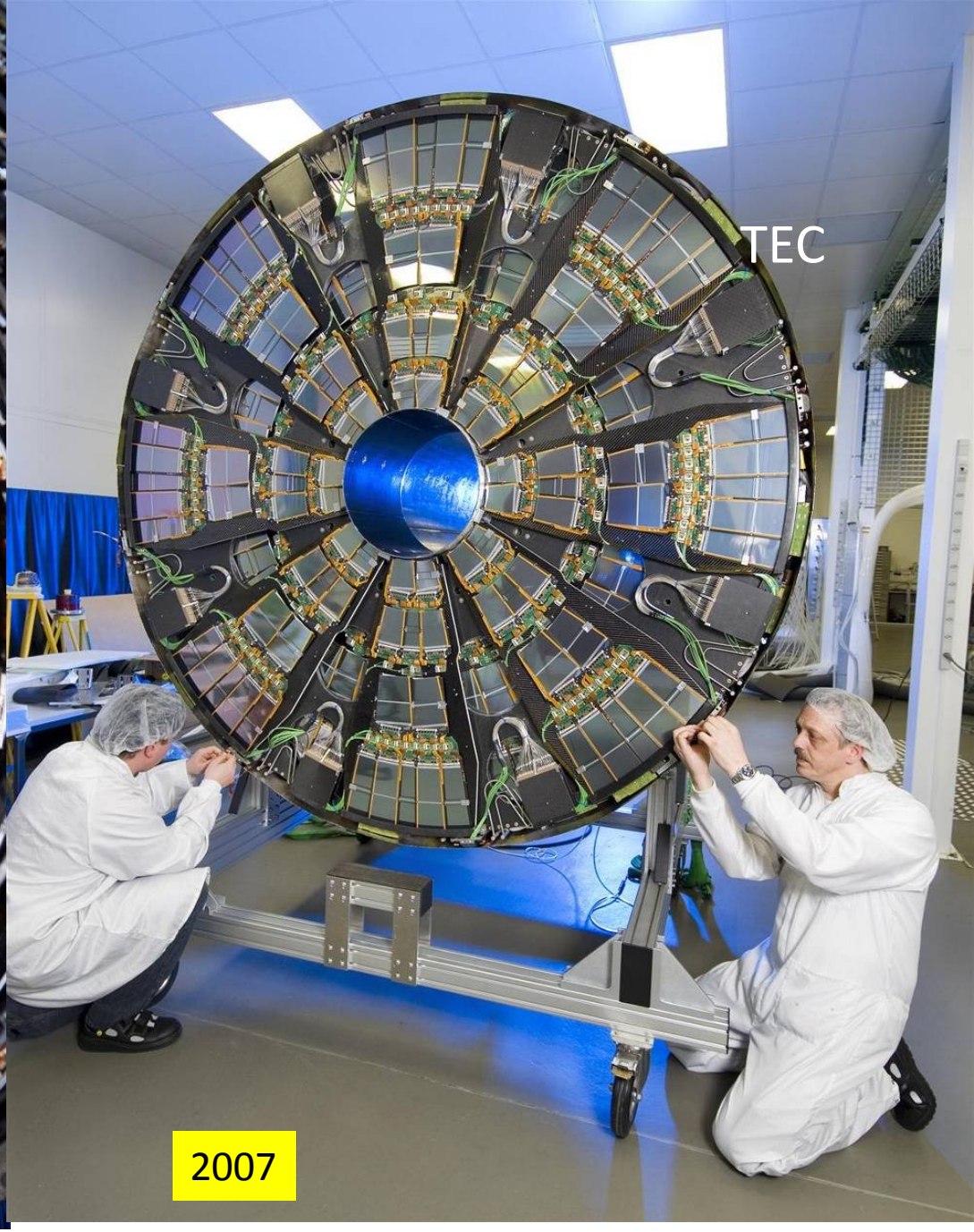
440 FEDs

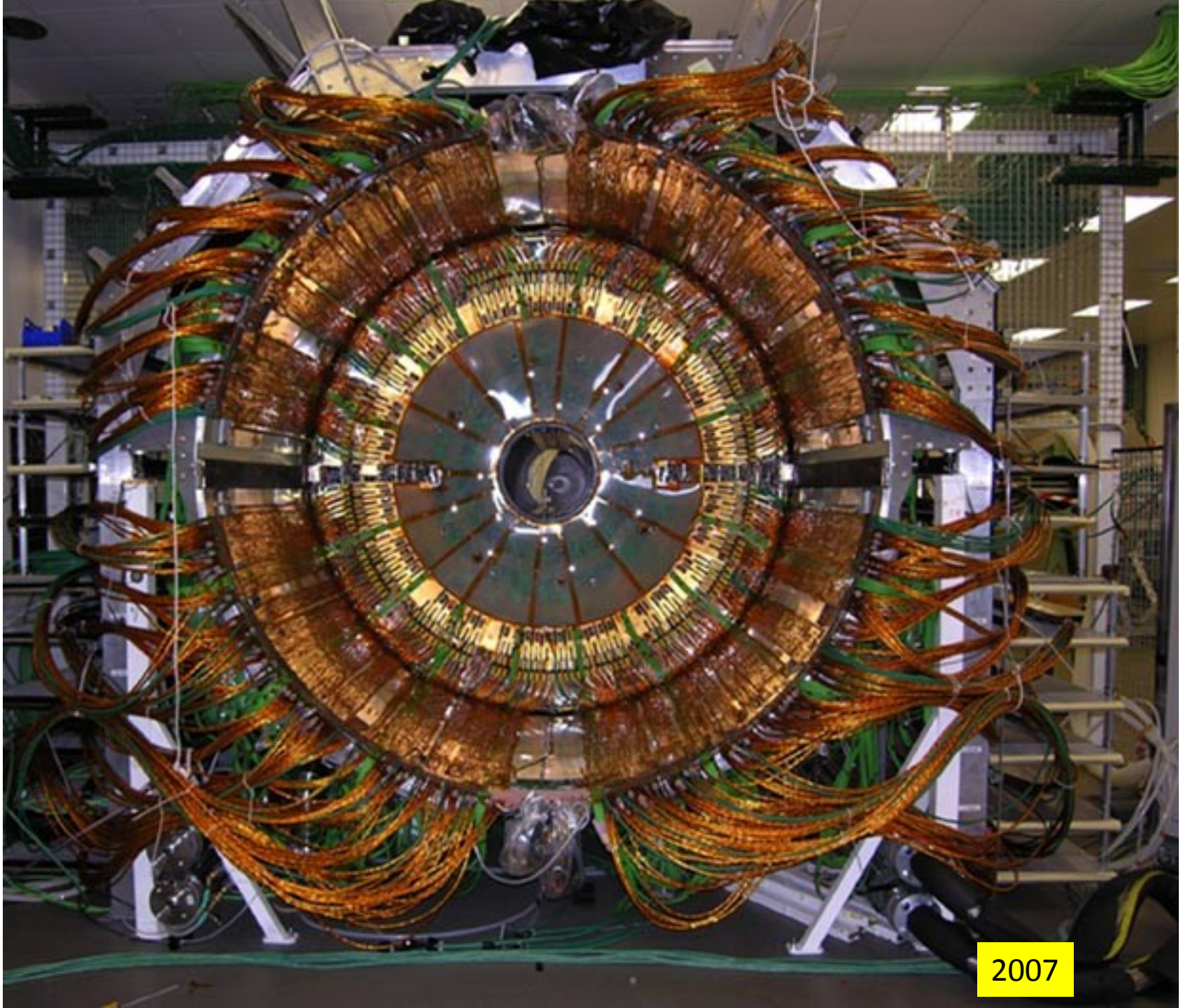


Brief SST History

- 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 25% 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 at T=18C
- 2009
  - Commissioning at 4C
  - CMS cosmics data taking at T=4C
  - First collisions data (most in peak mode, 50 ns integration time)
- 2010
  - Commissioning in deconvolution mode
  - Collisions in deconvolution
- 2011
  - Collisions @ $L \sim 10^{33} cm^{-2} Hz$


TIB
2007

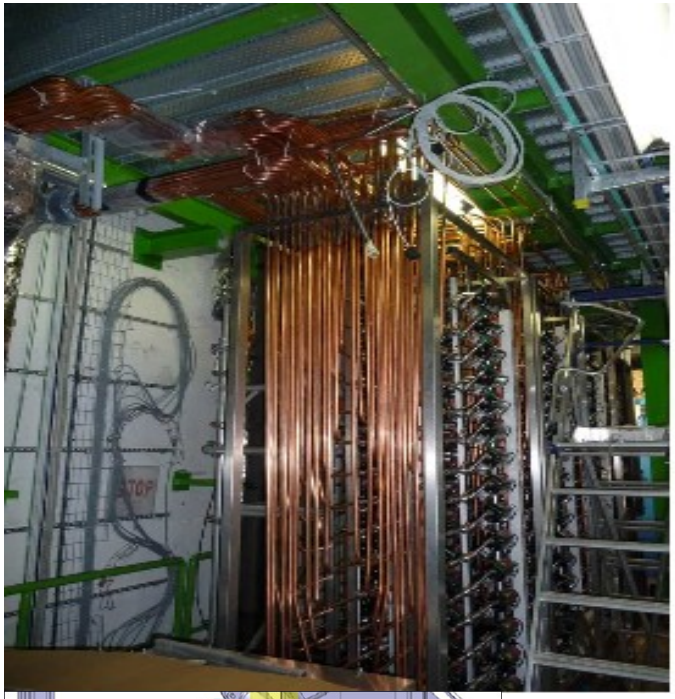

TEC
2007

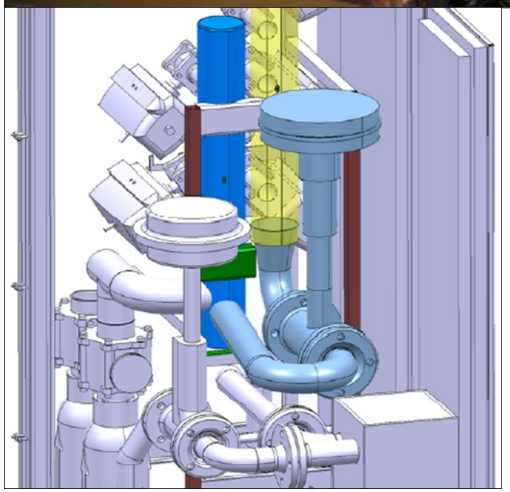

2007

Services

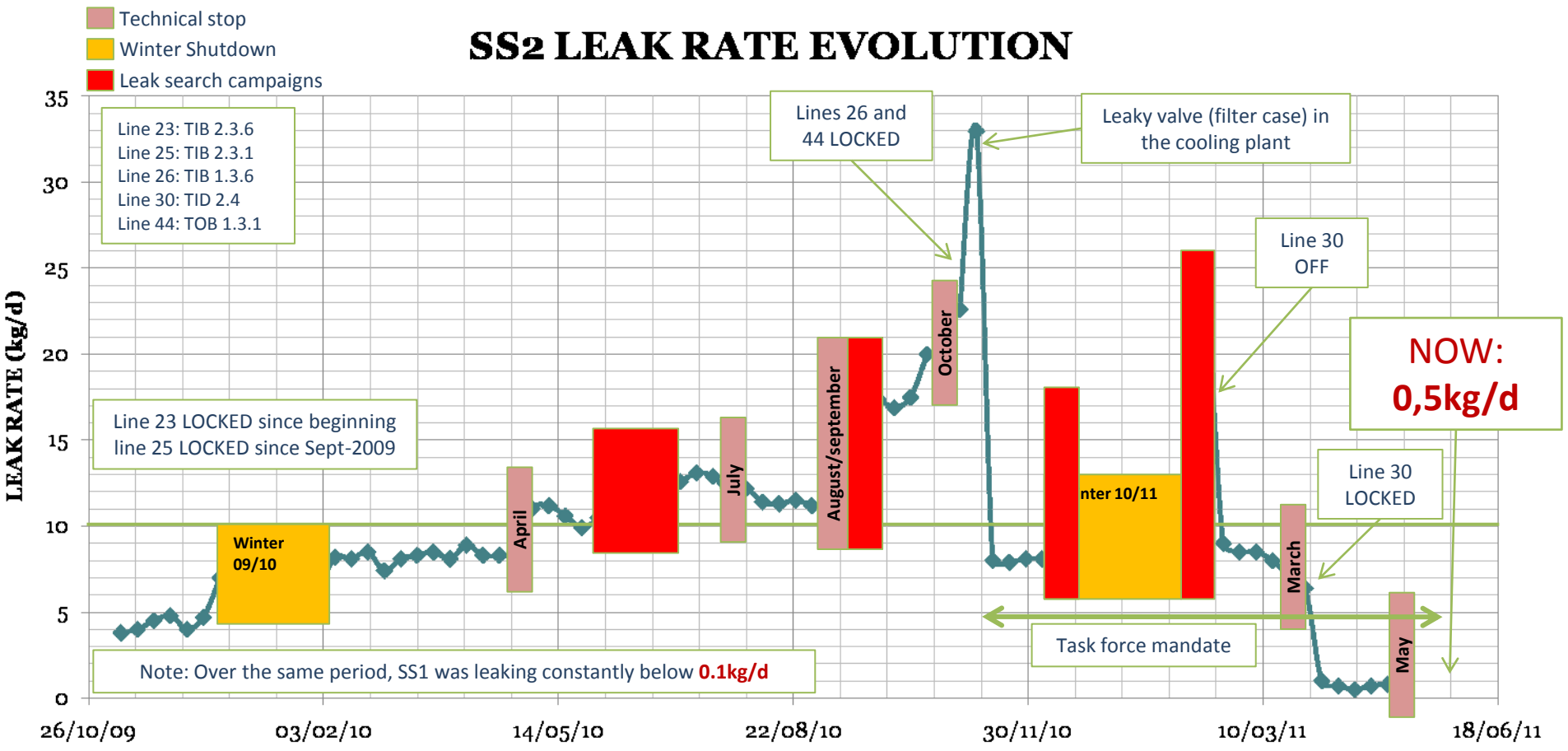
Cooling

- 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**





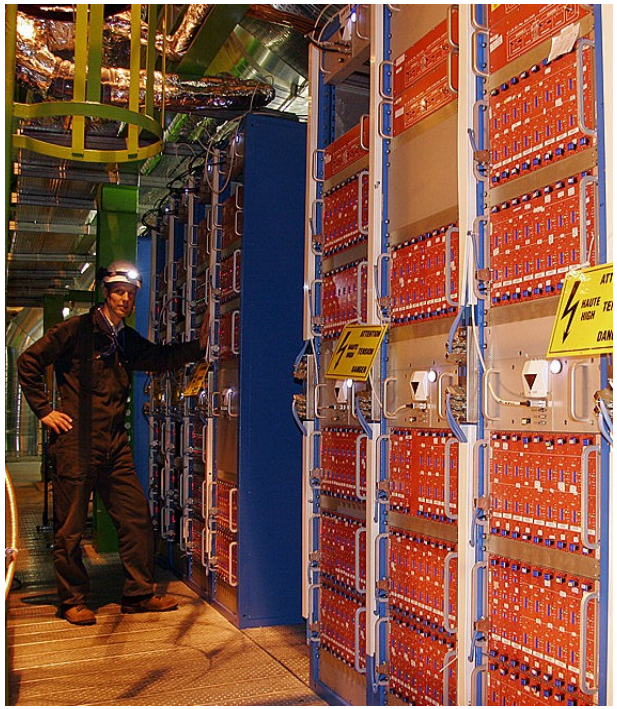
Struggling with Leak Rate



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)

DAQ

The Strip Tracker is by far the largest fraction of CMS to be readout, it consist of 440 FED, to be compared with less than 200 for the rest of CMS.

System is very stable

Down-time are caused in general to single FEDs stopping the DAQ. Several sources have been found and being addressed.

- Occasionally spurious data are seen at the input of single FED and generate fake extra events, spoiling the synchronization with other DAQ. A FED firmware was implemented: it signal a state of Out-of-Sync at which DAQ reply with a resync command: FED cleans up the bad data and data taking can restart quickly;
- Level of CRC error is small and negligible (was fixed during 2010)

Slow control data are readout via DCU → CCU → DOH → FEC. At module level they provide monitoring of: low voltages levels, silicon leakage current, hybrid and sensor temperatures. These are important ingredients to understand detector instabilities, working conditions, radiation damage:

- the readout efficiency of DCU full chain has been greatly improved this year
- some rings of CCU stop to work after some time: a recovery procedure is underdevelopment with a on-the-flight reset of the DCU

Status of detector and operation

Tk status – run 163817

Alive channels: **97.75%**

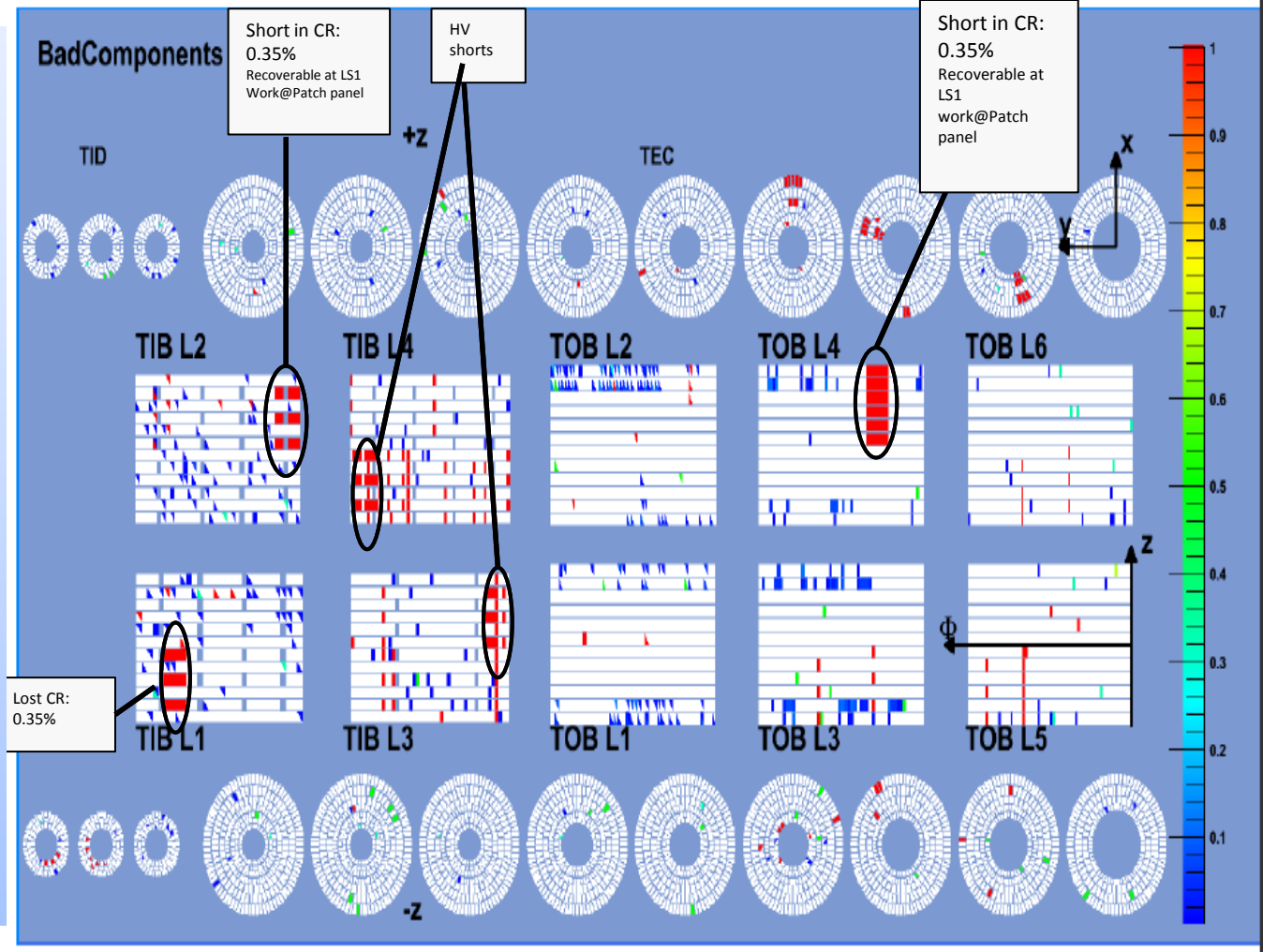
- TIB 94.3%
- TID 98.1%
- TOB 98.2%
- TEC 98.9%

Details:

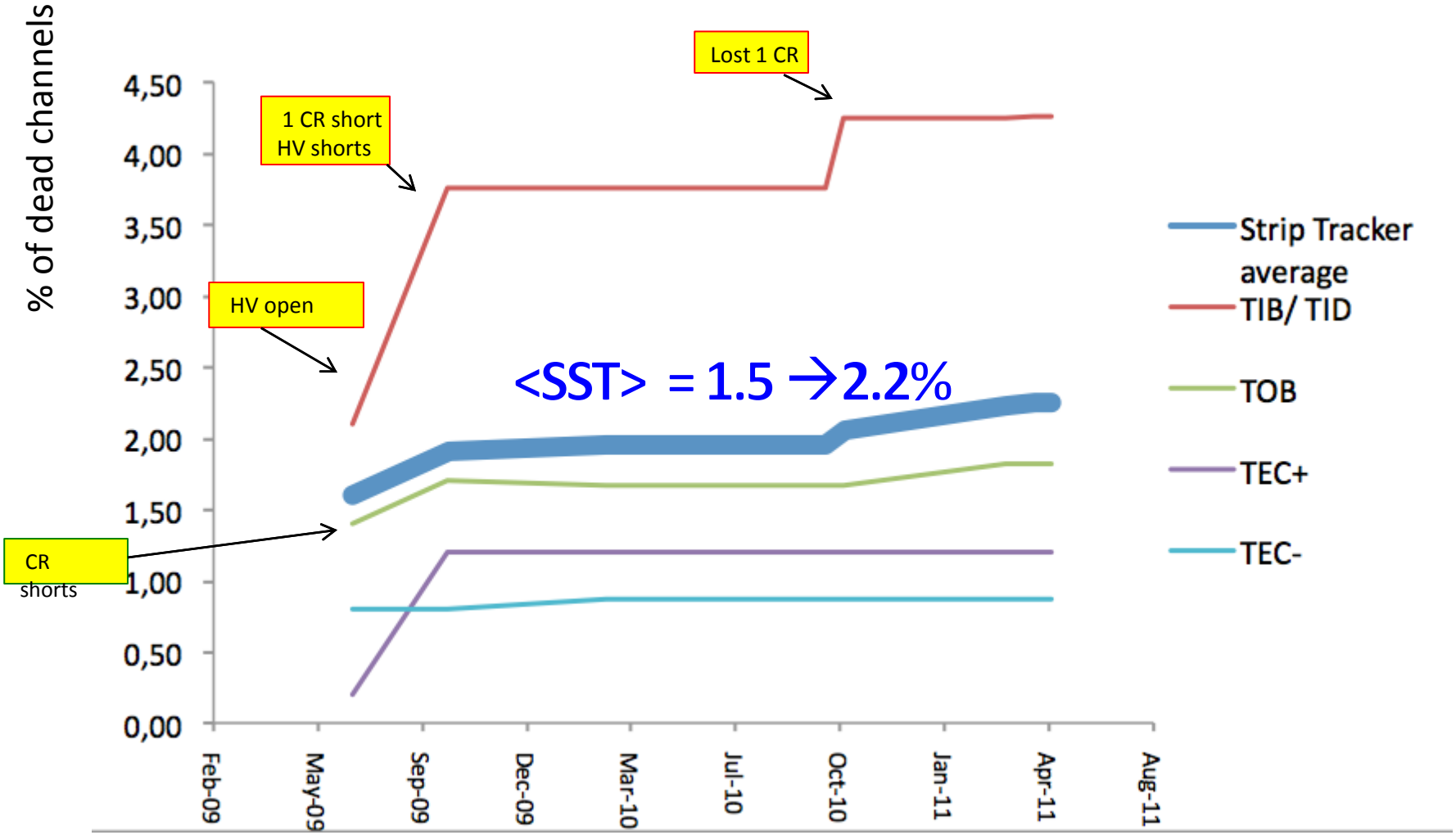
- 2 CR in short (~0.7%)
- 1 CR missing (0.35%)
- HV lines missing(0.1%)
- HV lines shorts (0.7%)
- fibers/CCU /others (0.4%)

Recoverable at LS1:

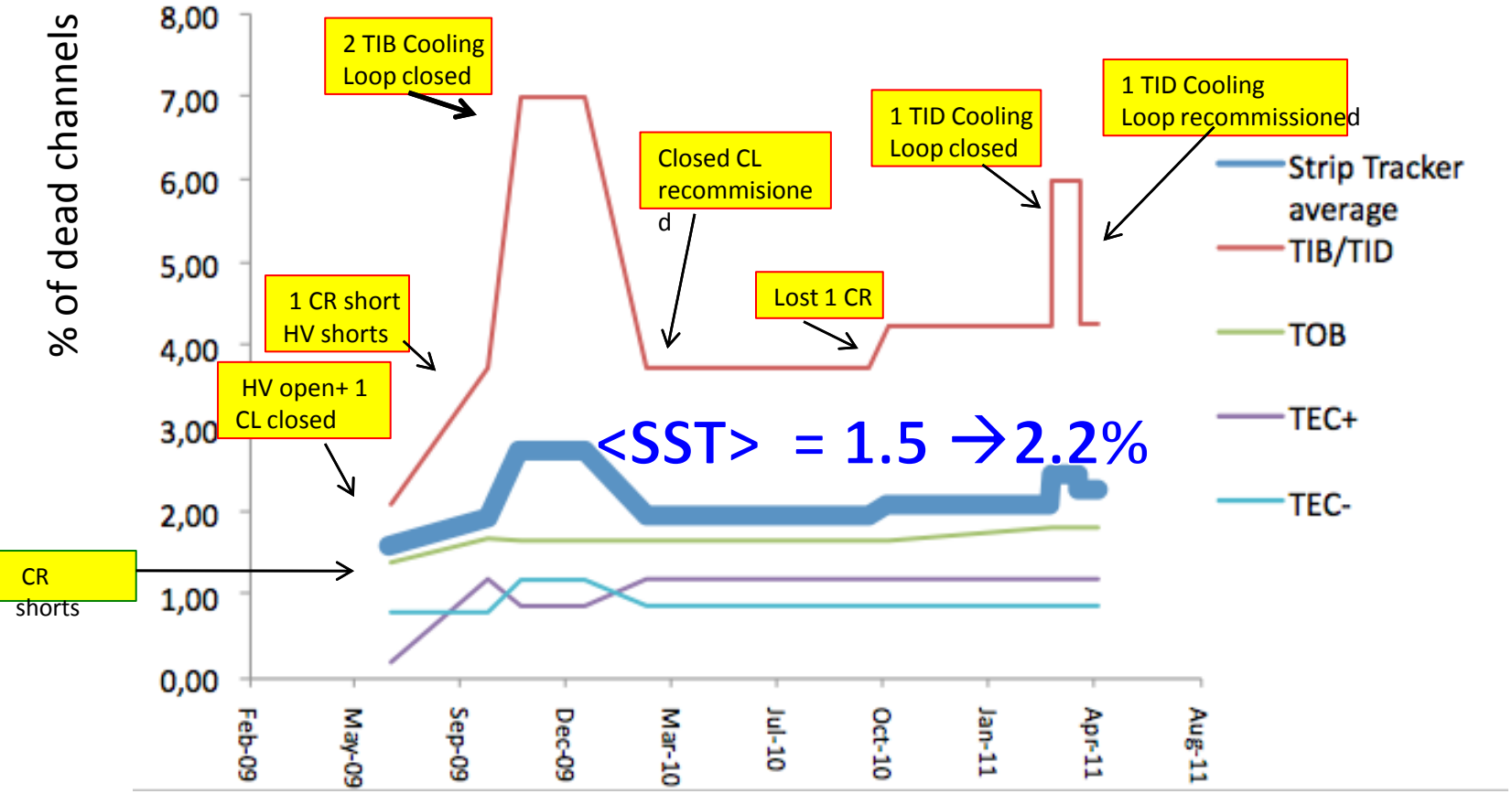
2-3 CR corresponding to 0.7-1%



Dead channels evolution:
<SST> =1.5 → 2.2%



Channels excluded from DAQ: time evolution
<SST> =1.5 → 2.2%



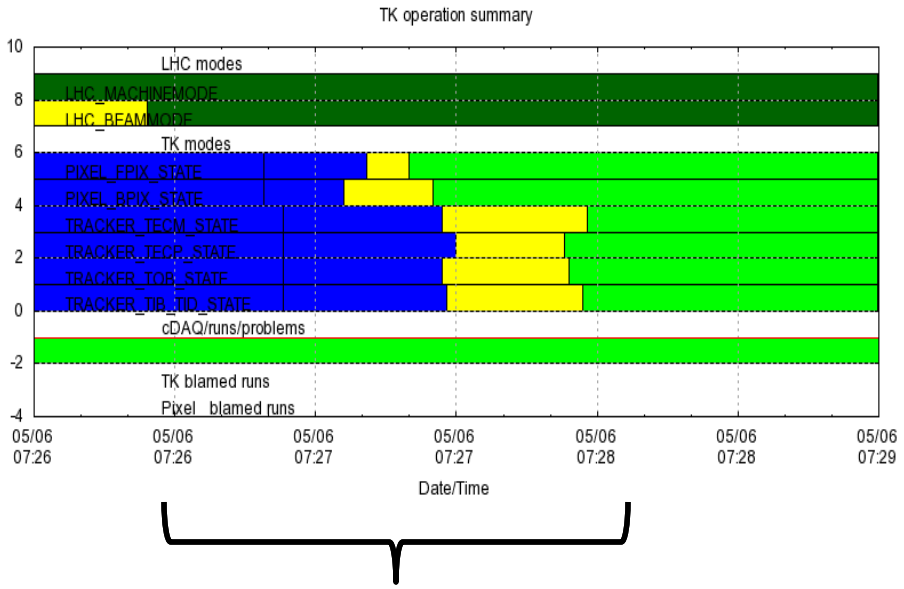
We were able to promptly recover modules associated with closed cooling loops
They were recovered before physics data taking, both during 2010 and 2011

- Always ready for collisions:
  - 2011 Up-time : 98.6% (98.8% on 2010)
  - Live time ~ 99.9%

  - SST HV-on >99% when regular fill of collision time:

    - HV turned on@stable beam with validation of good beam background
      - Turn on take 70 sec
    - HV turned off@handshake for Beam Dump (or adjust). Now HV turned down with with 3' delay (LHC dump 5' after handshake)
    - Work on-going to further increase the % of HV on

	STANDBY	ON	HVMIXED
TRACKER_TIB_TID_STATE	156.7sec **0.28%**	55898.4sec **99.62%**	58.3sec **0.1%**
TRACKER_TOB_STATE	156.2sec **0.28%**	55904.1sec **99.63%**	53.1sec **0.09%**
TRACKER_TECP_STATE	160.8sec **0.29%**	55906.1sec **99.63%**	46.4sec **0.08%**
TRACKER_TECM_STATE	156.2sec **0.28%**	55895.3sec **99.61%**	61.9sec **0.11%**



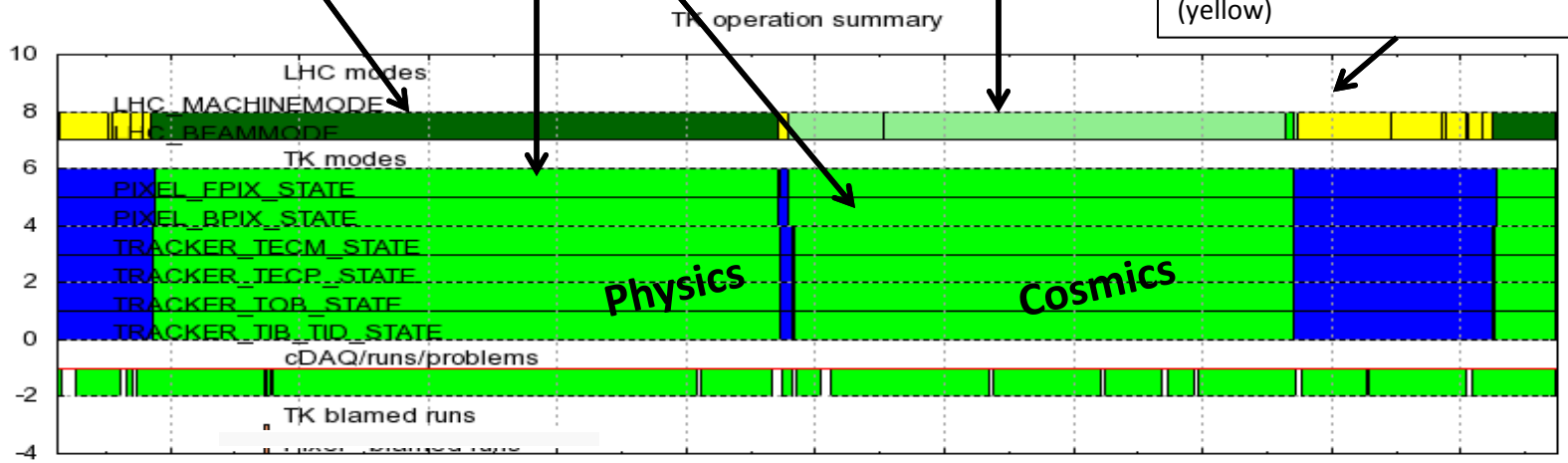
Validation and turn-on~3'

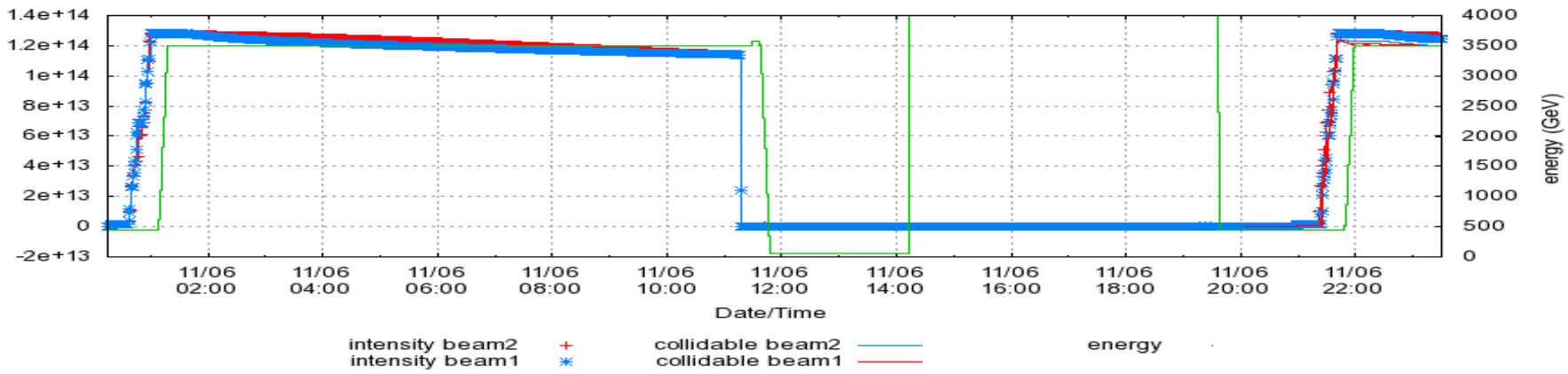
HV on

No beam in LHC:
ramp down, setup,nobeam
(light green)

Stable beam
(dark green)

Beam preparation:
injection, ramp-up,flat top,…),
(yellow)





Interfill periods are used to collect cosmics ray, important for weak modes in alignment

Operation in Heavy Ion

- Occupancy during Heavy Ion collisions is very high. The zero suppressed algorithm implemented on FEDs is optimized for pp collision and the baseline needs optimization for HI data: it was **decided to take data non-zero suppressed** (200 kBytes/evt → 23 Mbytes/evt)
  - ok for FED up to several kHz
  - Optimization from central DAQ was needed in order to process and digest the amount of data

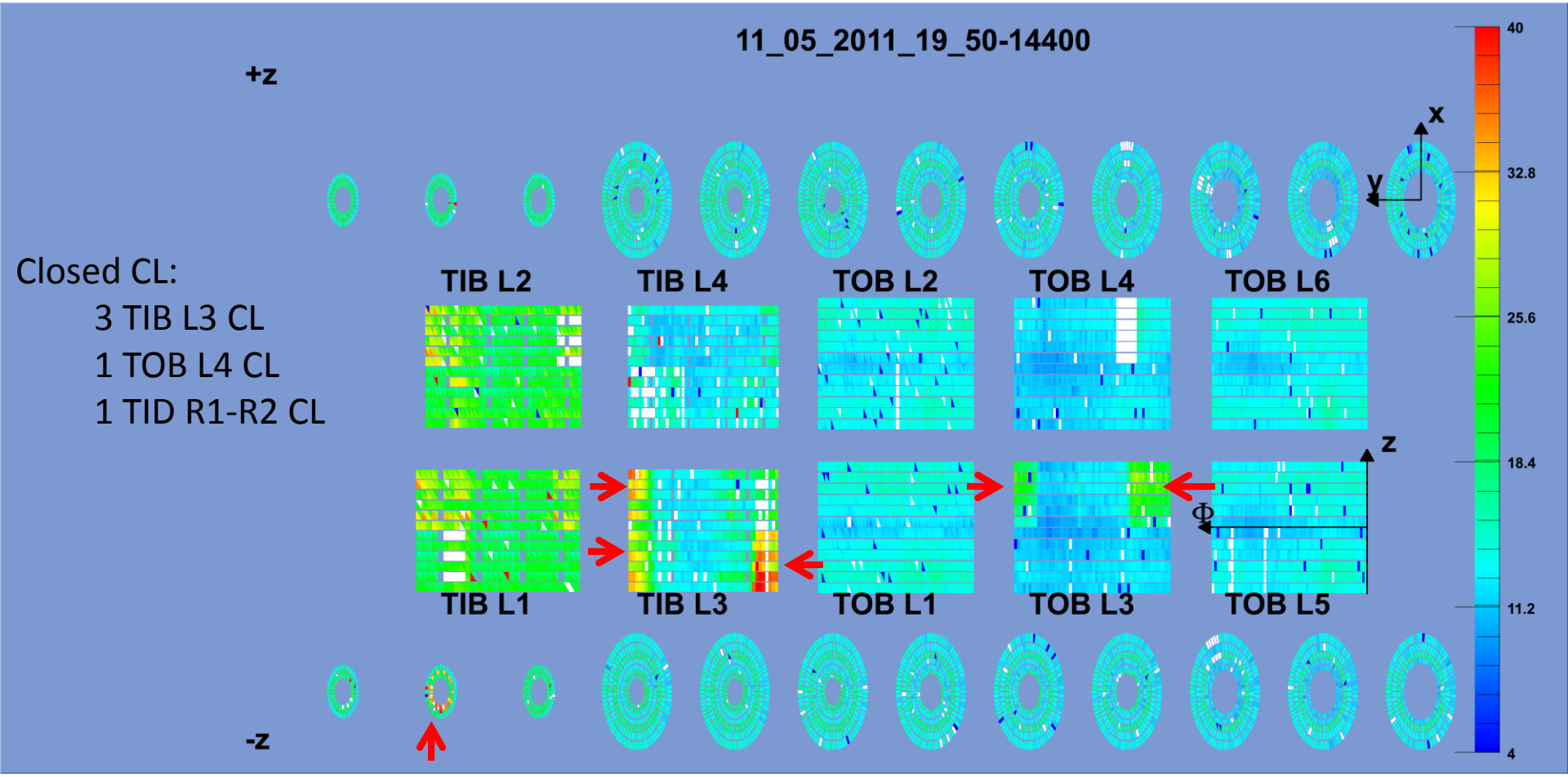
- **Detector up-time of 99.7%**
- The average tracker occupancy for the barrel was measured to be up to 8 % in minumum bias and up to 18 % for 0-10% central collisions.

- The comparison between the FED ZS and the new ZS schema showed a tracking efficiency increase of 2% for MB events.
  - Good input for a specialized FED firmware for Heavy Ion collisions

Operation temperature

- Present temperature of coolant is 4C, no need so far to go colder
  - Original requirement for cooling system was to be able to achieve coolant temperature of -30C
  - For high irradiation is important to stay below 0C on silicon sensors; at -10C towards the end of the high luminosity period (TDR).
- Strip Tracker baseline for 2011 and 2012 is to stay at coolant temperature of 4C
  - no problems foreseen wrt radiation damage
- The long shutdown (LS1) will be used to make all needed interventions to go to as cold as needed in the high luminosity phase
  - We might use bigger heat exchanger (chiller/cooling plant)
  - We need to lower the dew point in the region just outside the strip tracker volume with a better sealing there
- We are working now to define at best the intervention for LS1
  - Cold temperature test of cooling plant
  - Defining cooling efficiency for all strip tracker modules

Silicon Detector temperatures



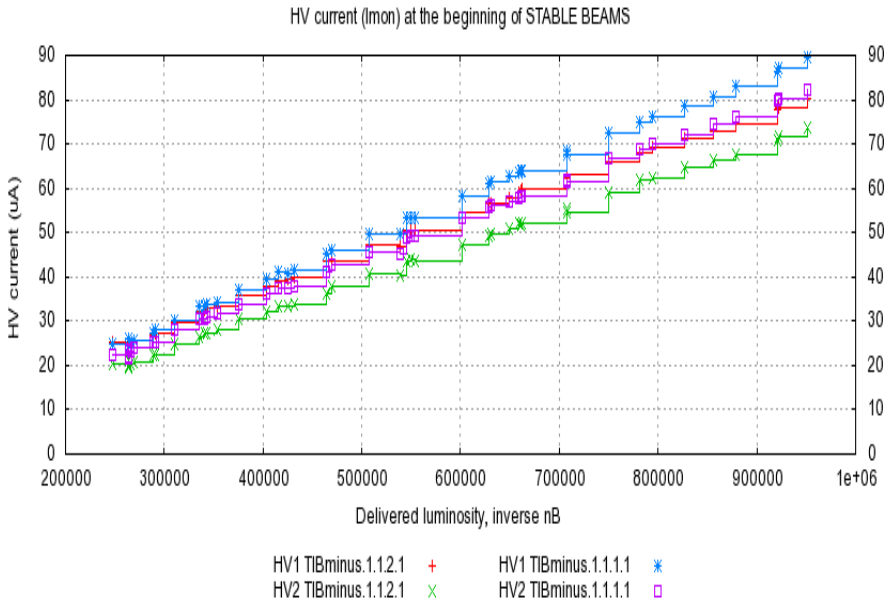
Closed CL:

- 3 TIB L3 CL
- 1 TOB L4 CL
- 1 TID R1-R2 CL

Effect of leakage current from irradiation

Radiation induced leakage current started to be visible on silicon sensors. Clear linear dependence is seen wrt integrated luminosity

Imon at the beginning of STABLE BEAMS vs delivered lumi



Measurements		
	Ileak	Temp
TIB L1	84	23
TIB L2	64	23
TIB L3		18
TIB L4	32	14
TOB L1	128	15
TOB L2	108	15
TOB L3	40	13
TOB L4	36	13

Table with Ileak of single HV lines in different Layer, at the present Temperature.

Ileak expressed in $\mu A/fb^{-1}$ (slope)

Normalization of current to the silicon volume and sensor temperature allows to determine the distribution of the radiation dose in the strip tracker: first preliminary analyses indicate that radial dependency and absolute values are compatible with simulation models expectations

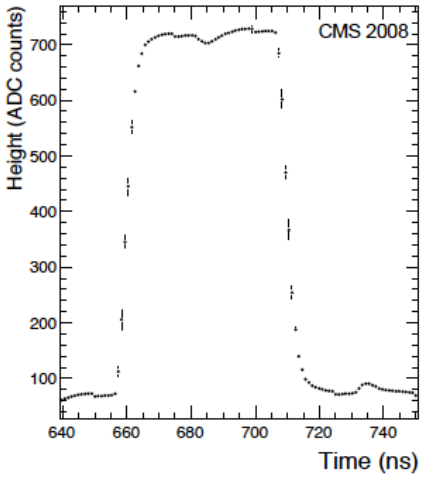
➔ More on F.Hartmann's talk at this conference

Detector Commissioning

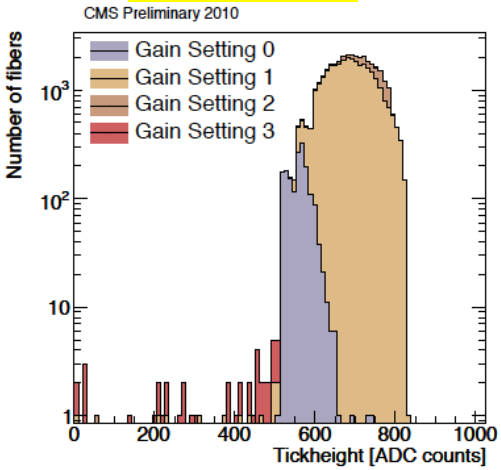
Commissioning Steps

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

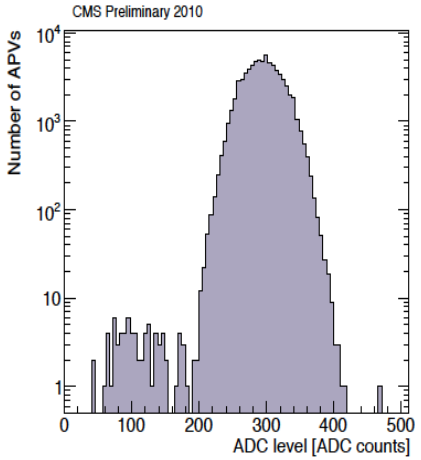
Internal synch



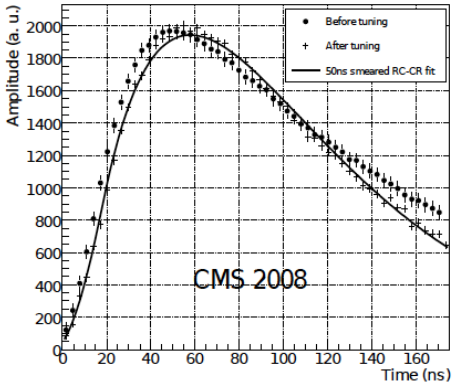
Gain Calibr



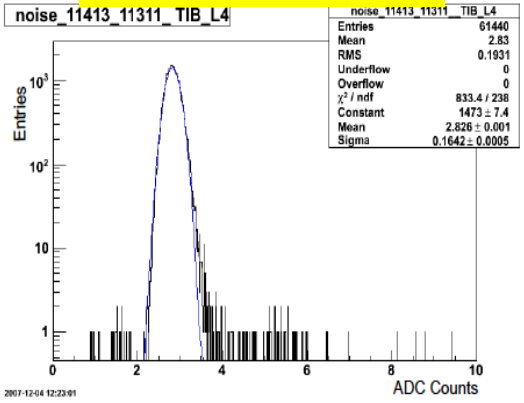
Base line adjust



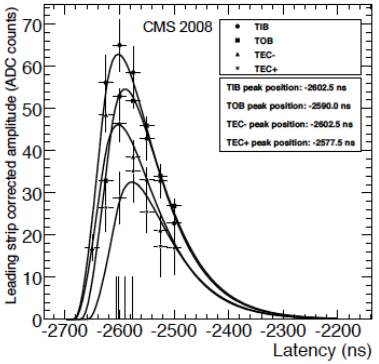
Pulse shape tuning



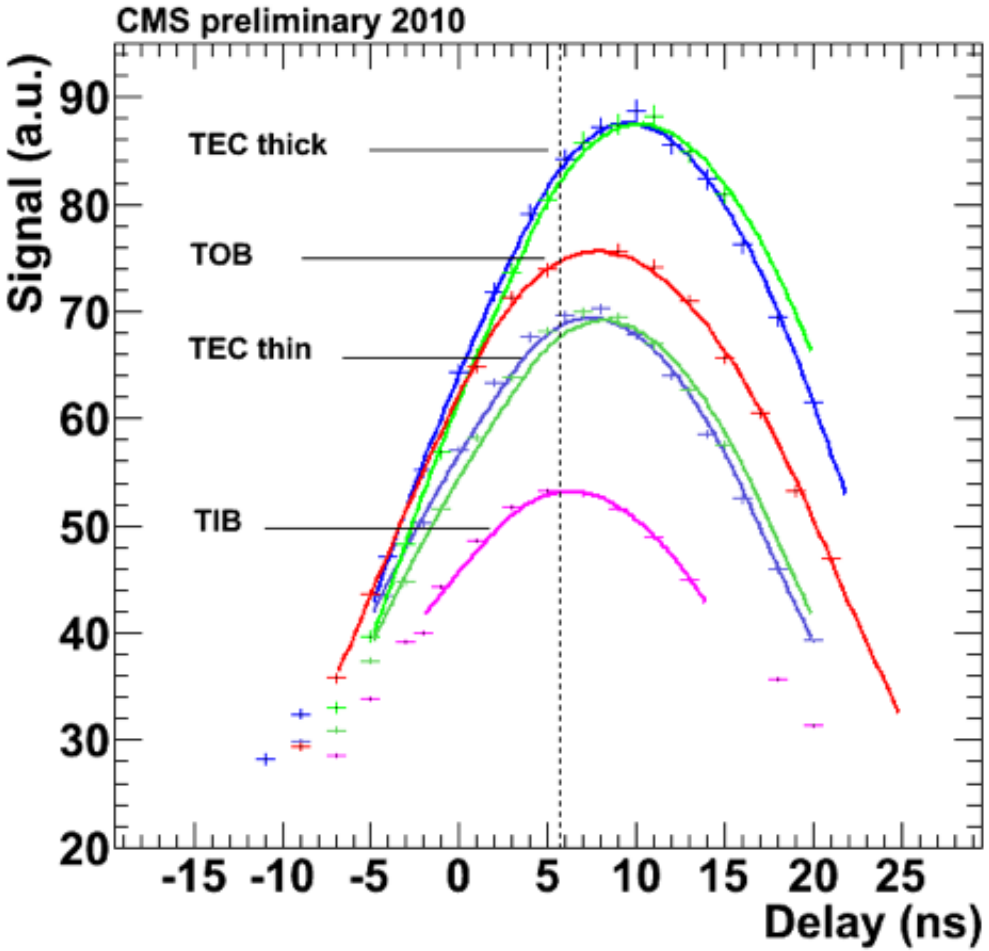
Pedestal and noise



Latency scan (peak)



Time synchronization with collisions



Deconvolution readout

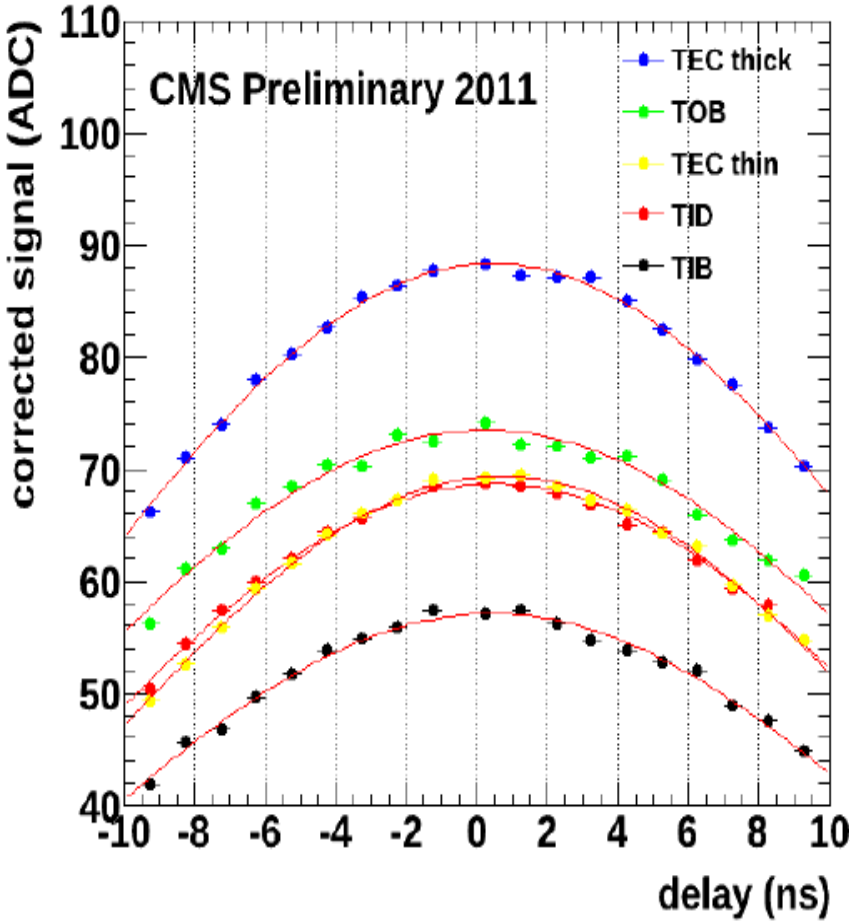
All layers but that under measurement are in peak mode and act as telescope for the layer under measurement

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.

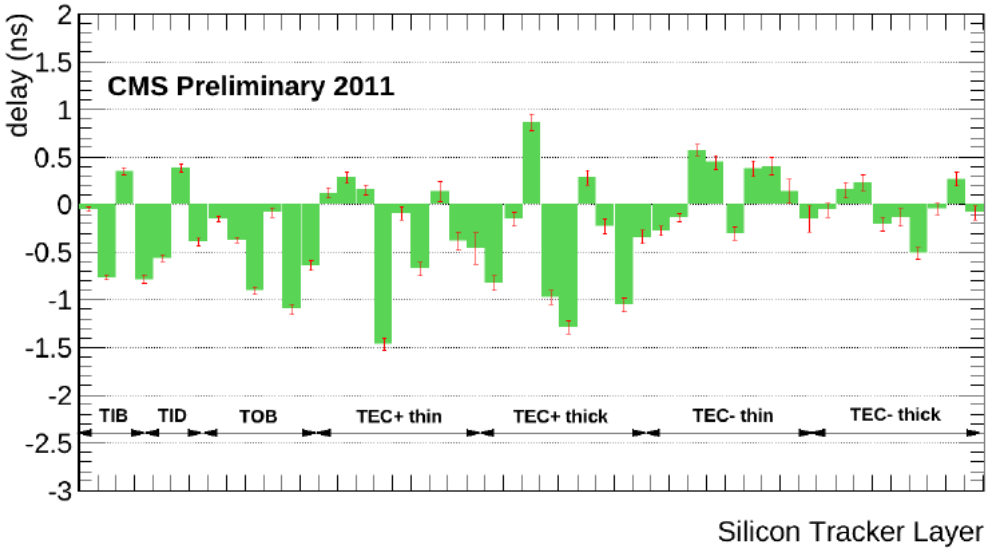
Signal time profile

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

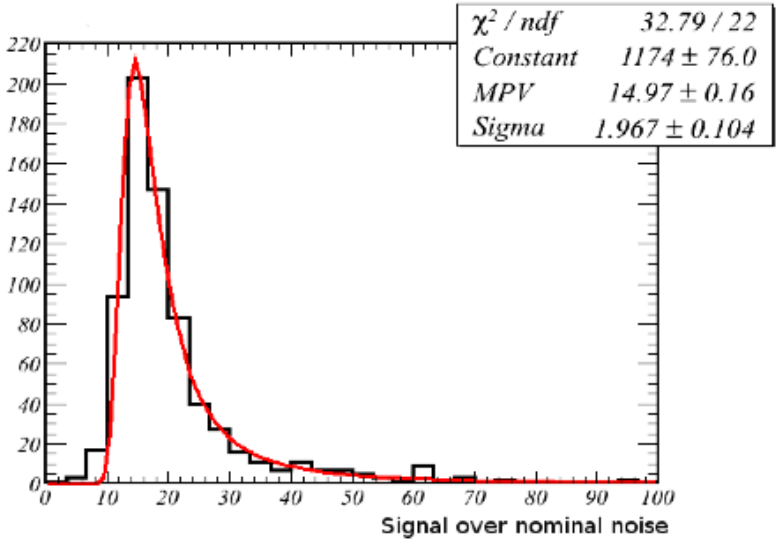
- Deviation in within ~1ns. Impact on signal amplitude is ~1%

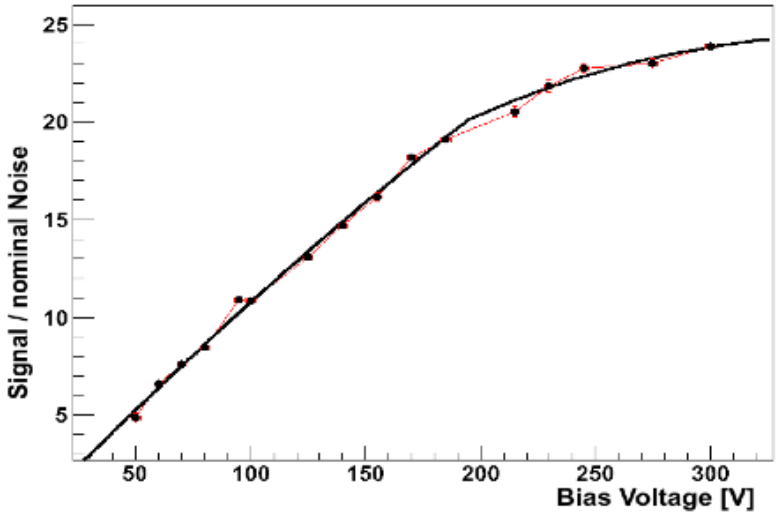


HV Scan

The HV of all the strip modules is scanned. Fitting the signal over the nominal noise the depletion voltage is measured. This measurement is done twice per year

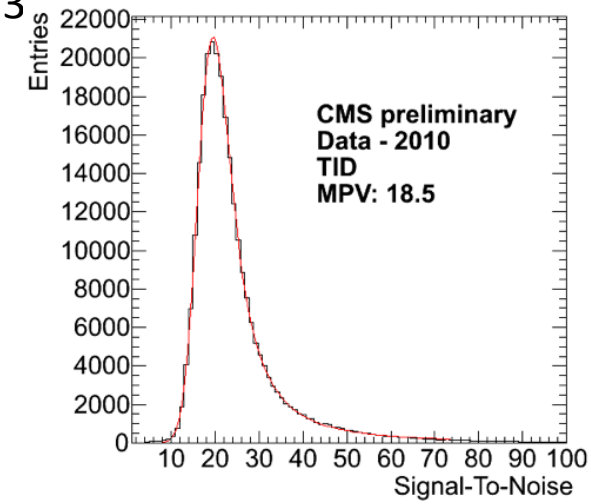
➔ More on Frank Hartman's talk during this conference

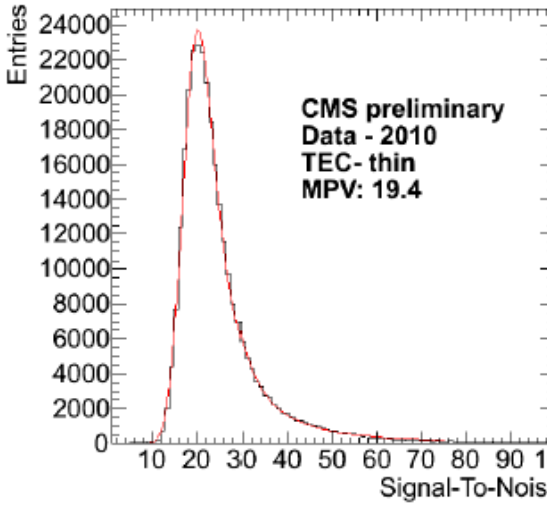


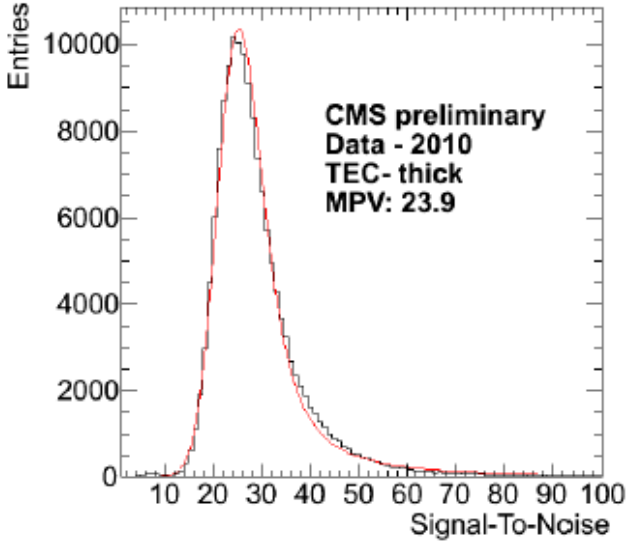


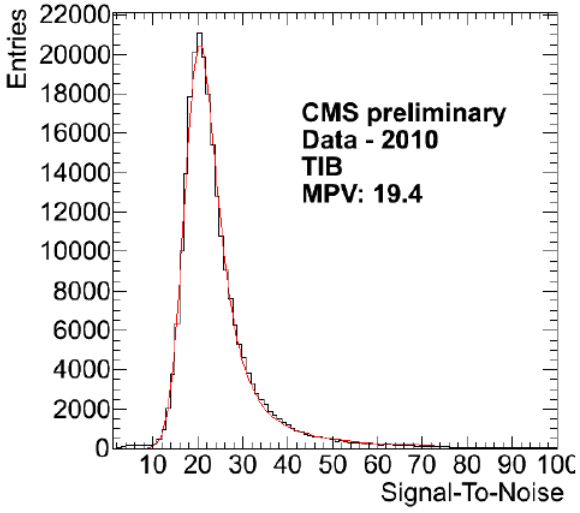
Detector Performance

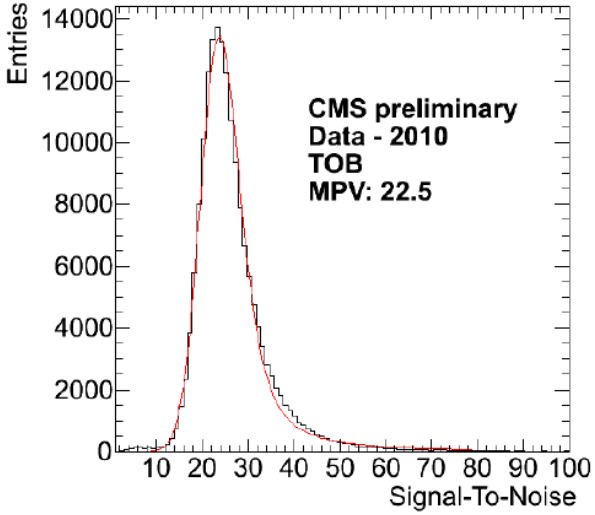
S/N performance: deconvolution





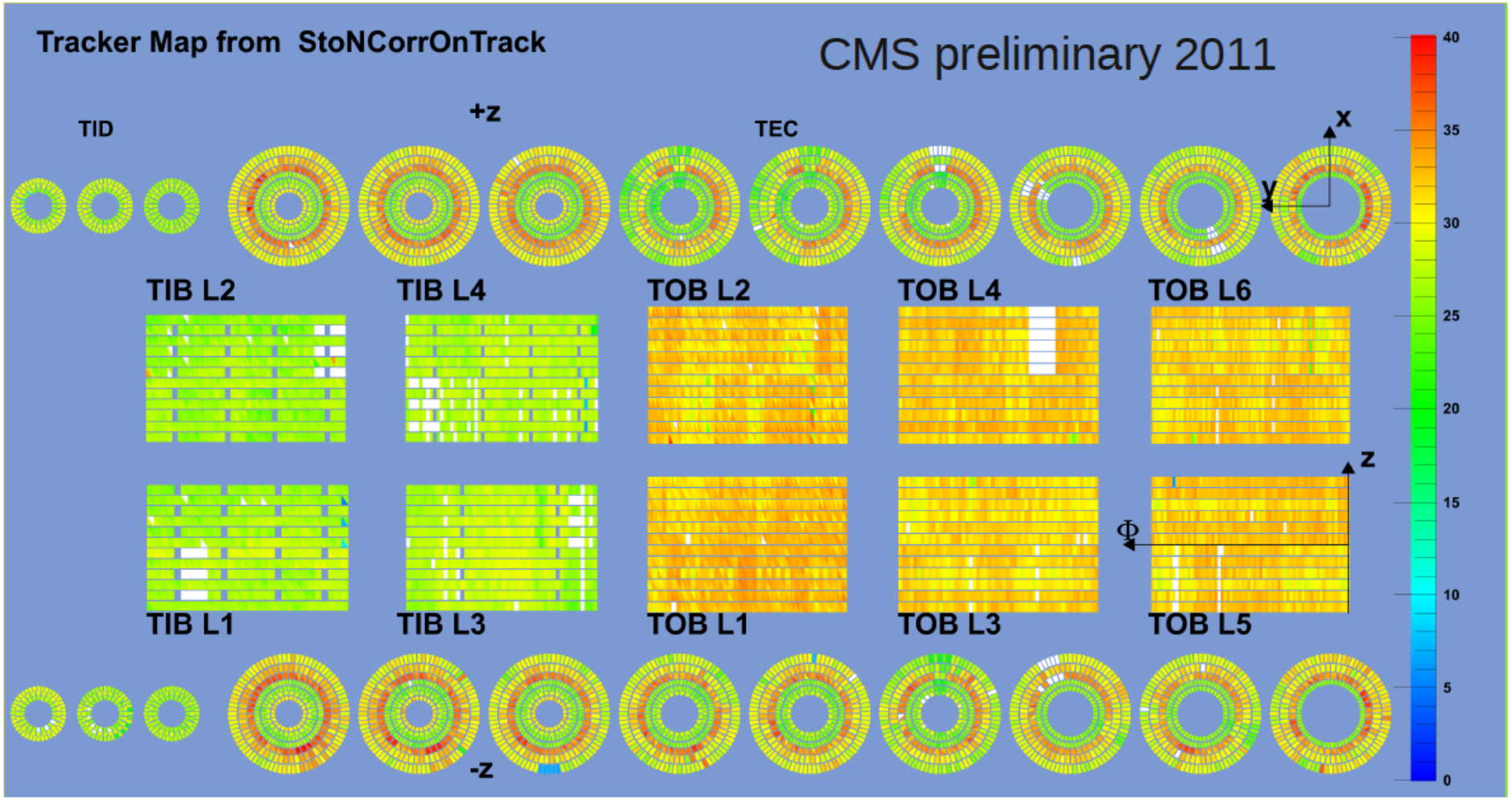






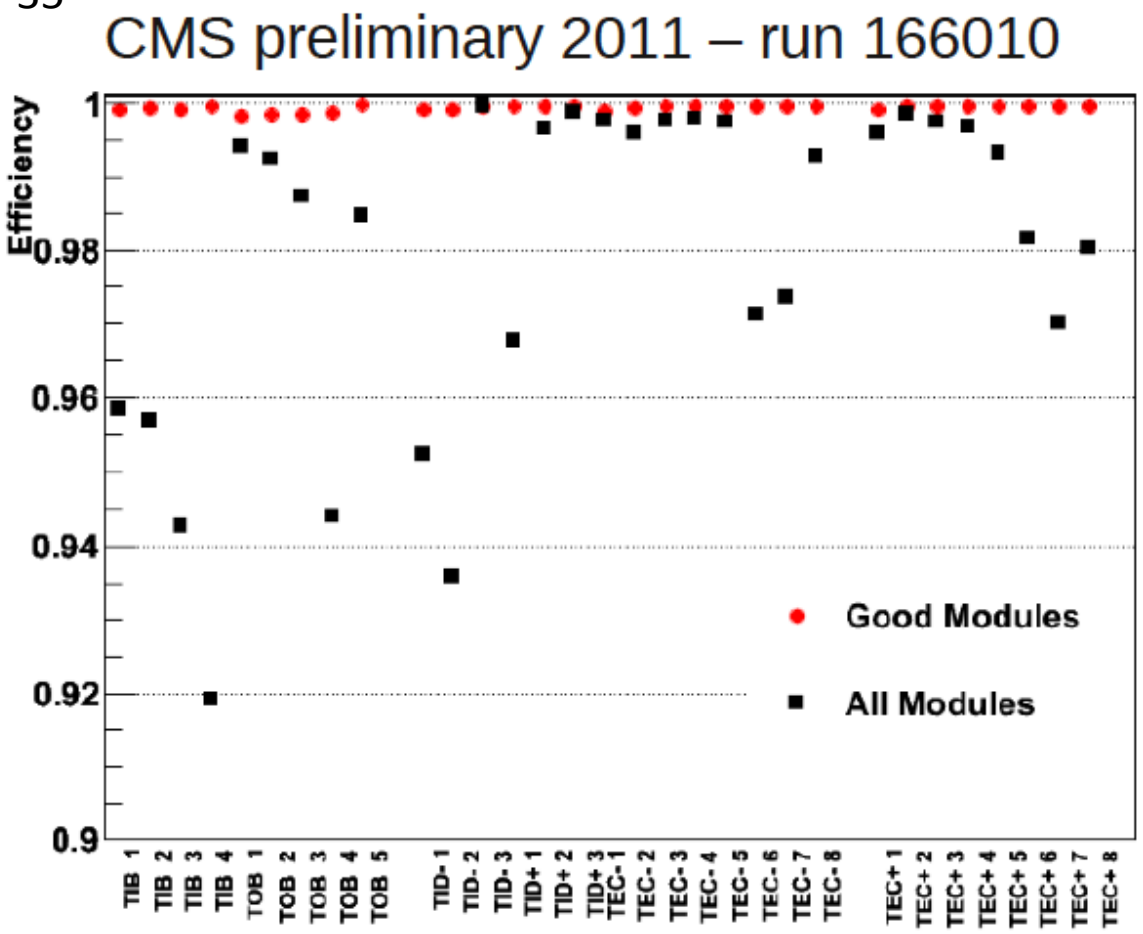
Deconvolution mode is the default for collisions.
Results agrees with expectations

S/N module per module



S/N~20 for thin silicon (300 μm); S/N~30 for thick silicon (500 μm)

Hit Efficiency



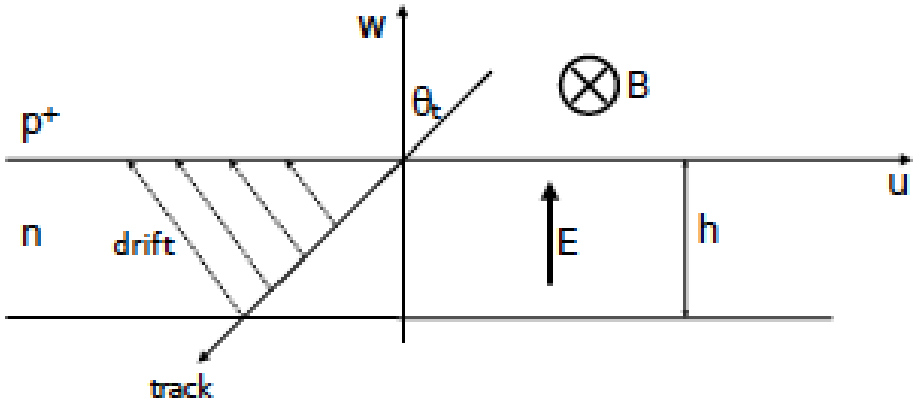
Given a good track crossing a layer the presence of a hit in that layer measures its hit efficiency.

Cuts are applied, avoiding tracks crossing a layer at the border of the acceptance region, given the extrapolation error of the track

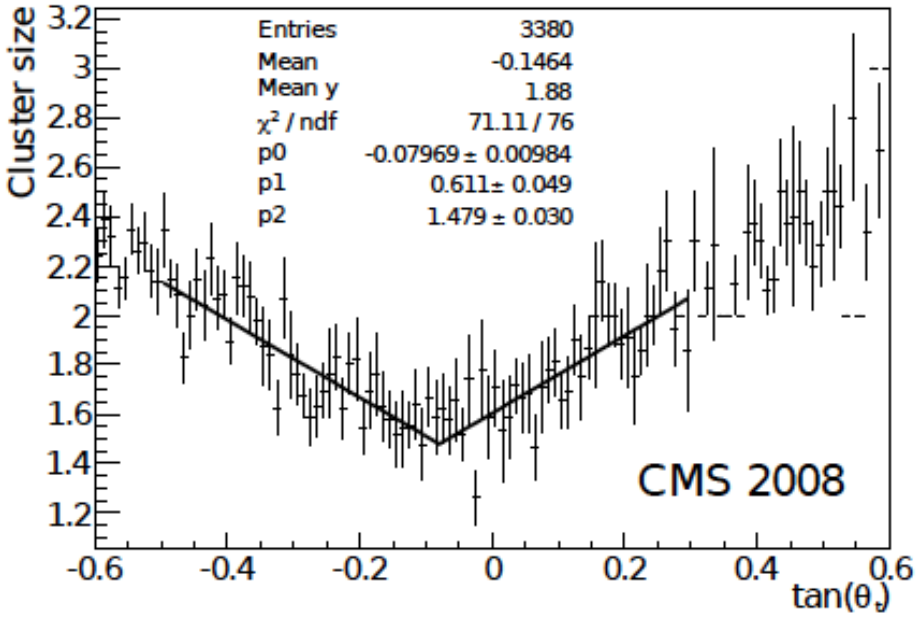
Results are shown included ANY module in the readout (black square) and selecting only modules known to be good.

Lorentz angle

The hole charge drifting to the strips is displaced by the magnetic field by (Lorentz force). The Lorentz angle is measured plotting cluster width vs. the tangent of the track angle: it is minimum identify the Lorentz angle

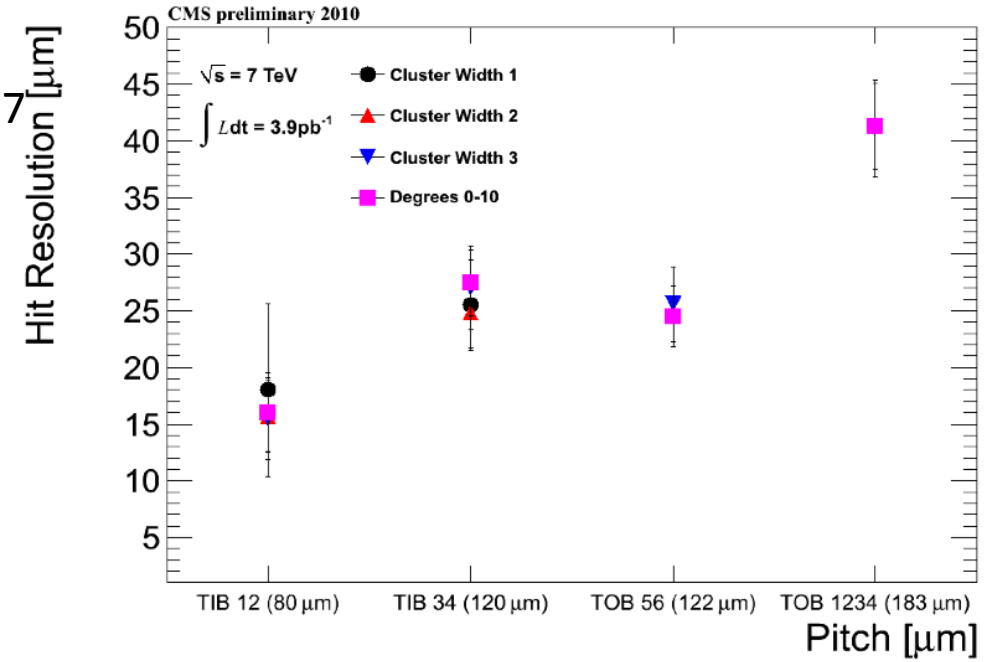


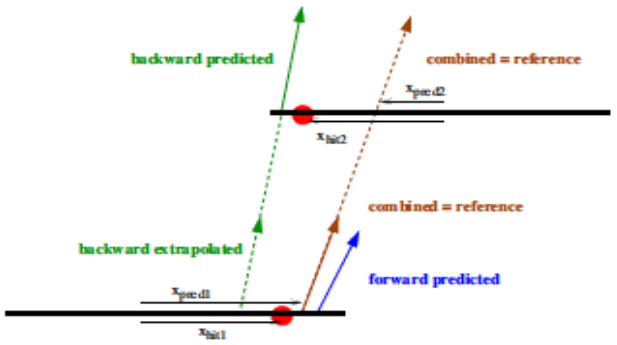
$$f(\theta_t) = \frac{h}{p} \cdot p_1 \cdot |\tan\theta_t - p_0| + p_2$$



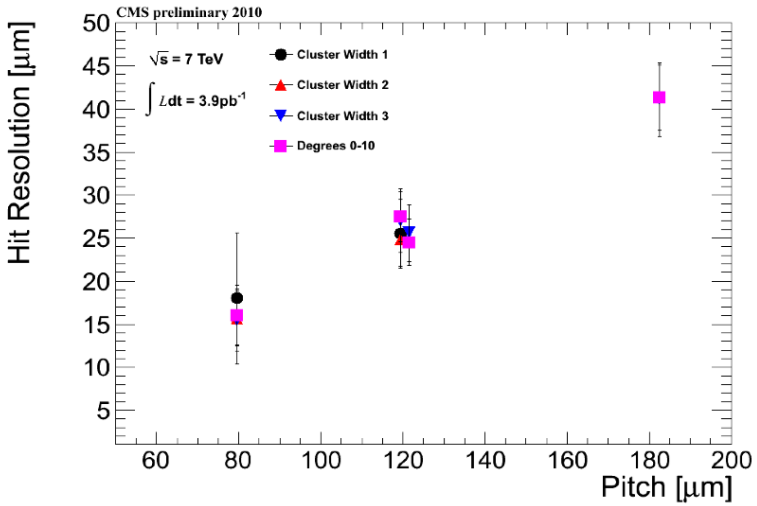
TIB : $\tan(\theta_L) = 0.07 \pm 0.02$
TOB: $\tan(\theta_L) = 0.09 \pm 0.01$

Hit Resolutions





Detector hit resolutions are measured using module overlaps. Results are shown here for track angles between 0 and 10 degrees



Resolutions are below the binary resolution.

Pitch=80 for TIB L1, L2
Pitch=122 for TIB L3,L4 TOB L5, L6
Pitch=183 for TOB L1, L2, L3, L4

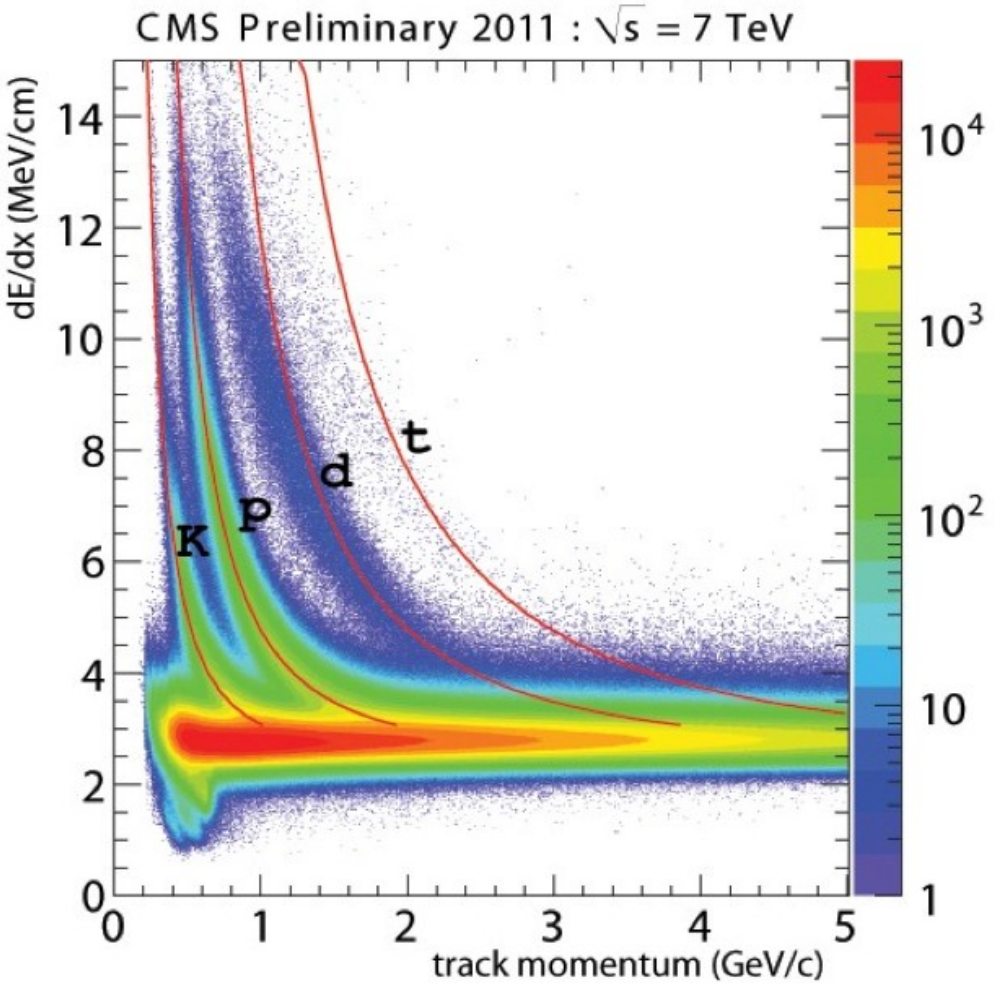
dE/dx vs. momentum

The dE/dx measurement of a track is obtained from all values of the hits (~10 points).

Kaons, protons, deuterons and tritium are visible.

• Red lines are Bethe-Bloch expectations extrapolated from a fit of the proton line.

• Small deviation at large dE/dx from saturation.



Conclusions (1)

- The Strip Tracker is the main tracking detector of CMS

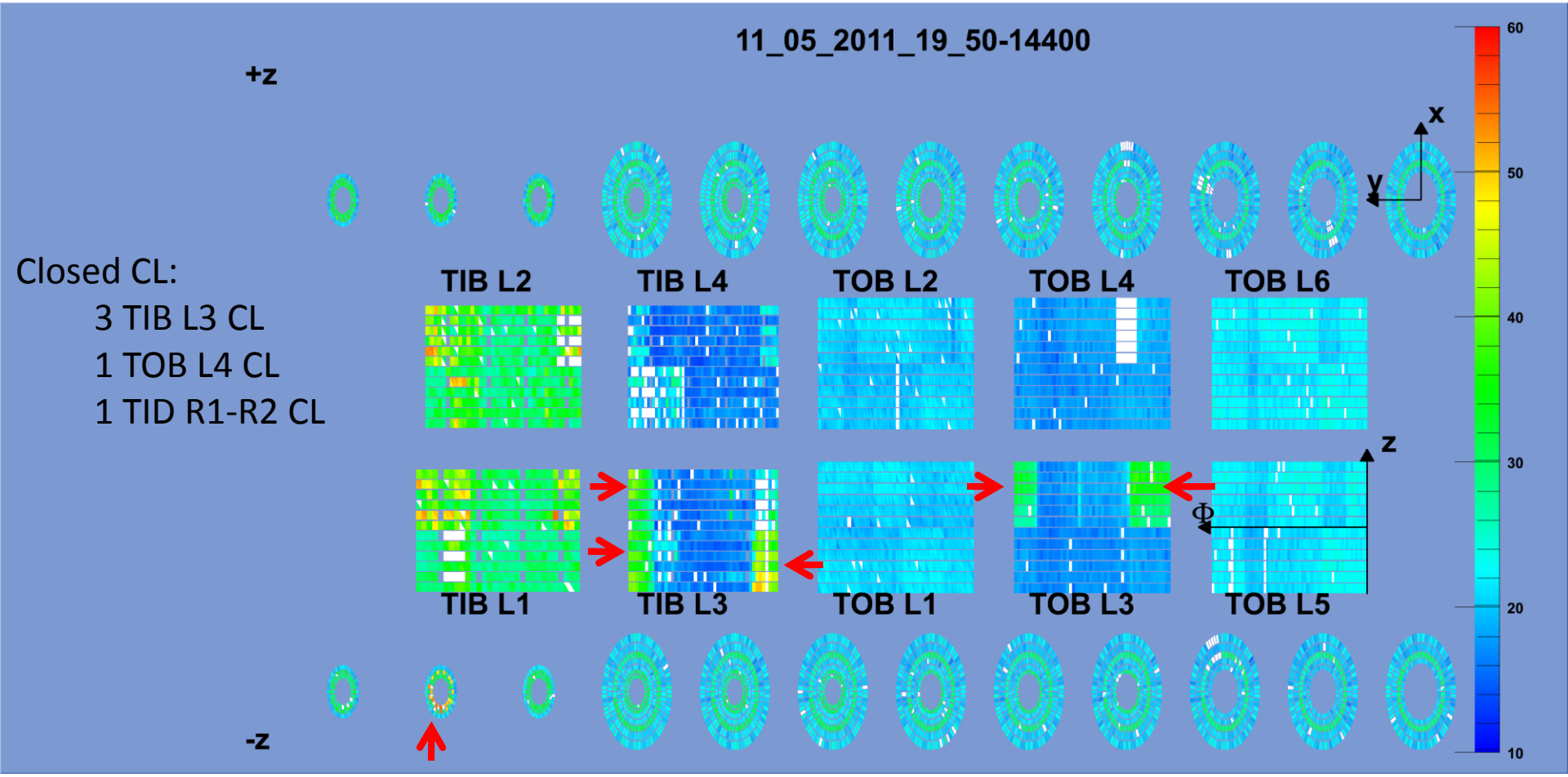
- Detector has maintained excellent operational performance during the 2011 data taking period. The increase of instantaneous luminosity up to 10^{33} $cm^{-2}s^{-1}$ did not introduced any new issues for the detector
  - high quality physics data were collected with an uptime above 98.5%.
  - Sources of downtime have been identified and problems were properly addressed
- Services and infrastructures are reliable and stable

Conclusions (2)

- Detector Performance is excellent:
  - S/N>18 in deconvolution (with BX identification)
  - >99.8% hit efficiency
  - Resolution of 20 micron for smaller pitches
  - dE/dx measurements show kaons, protons and deuterons
- First effects on radiation damage of silicon sensors give indication to follow expectations
- Detector is well in shape and ready to continue collecting excellent data for the whole 2011-2012 period

BACKUPS

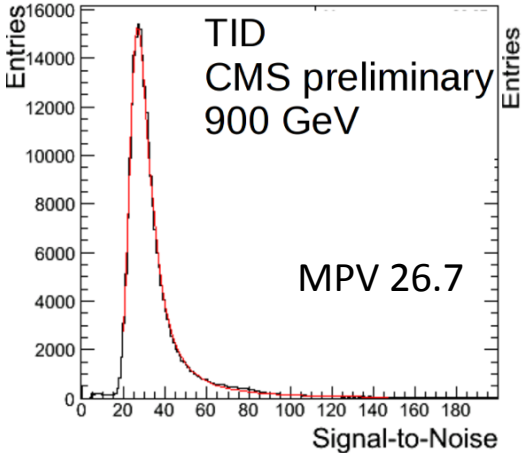
Hybrid temperatures

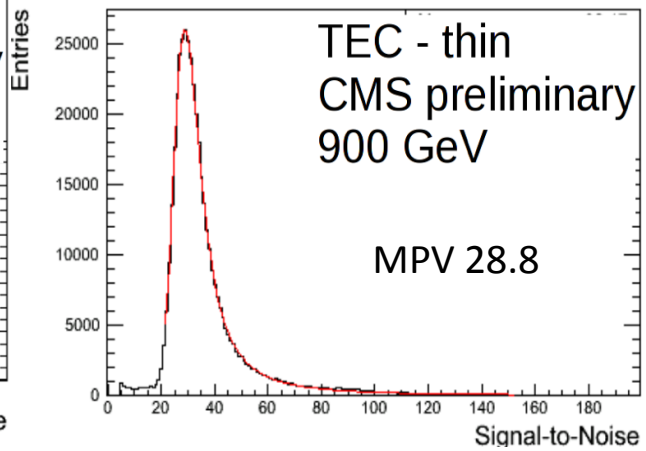


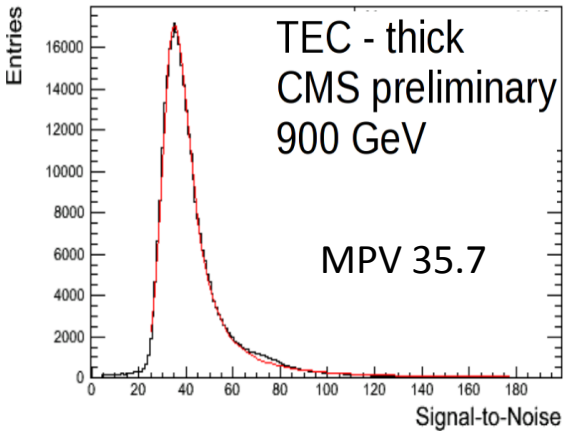
Closed CL:

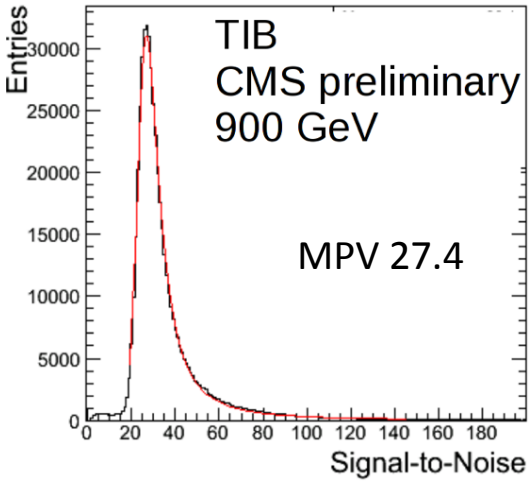
- 3 TIB L3 CL
- 1 TOB L4 CL
- 1 TID R1-R2 CL

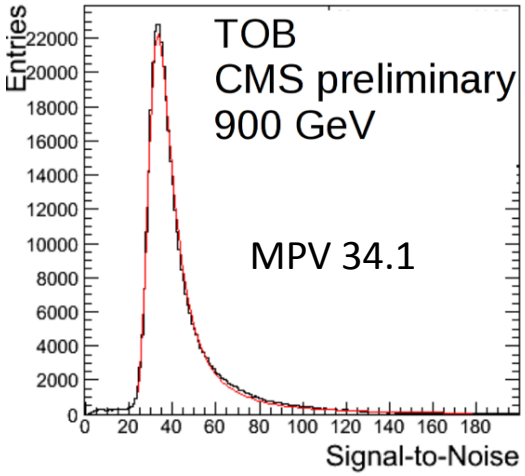
S/N performance: Peak











Peak mode used during cosmic ray
and in 2009 collisions.
Results agrees with expectations