Operation and Performance of the CMS Silicon Tracker

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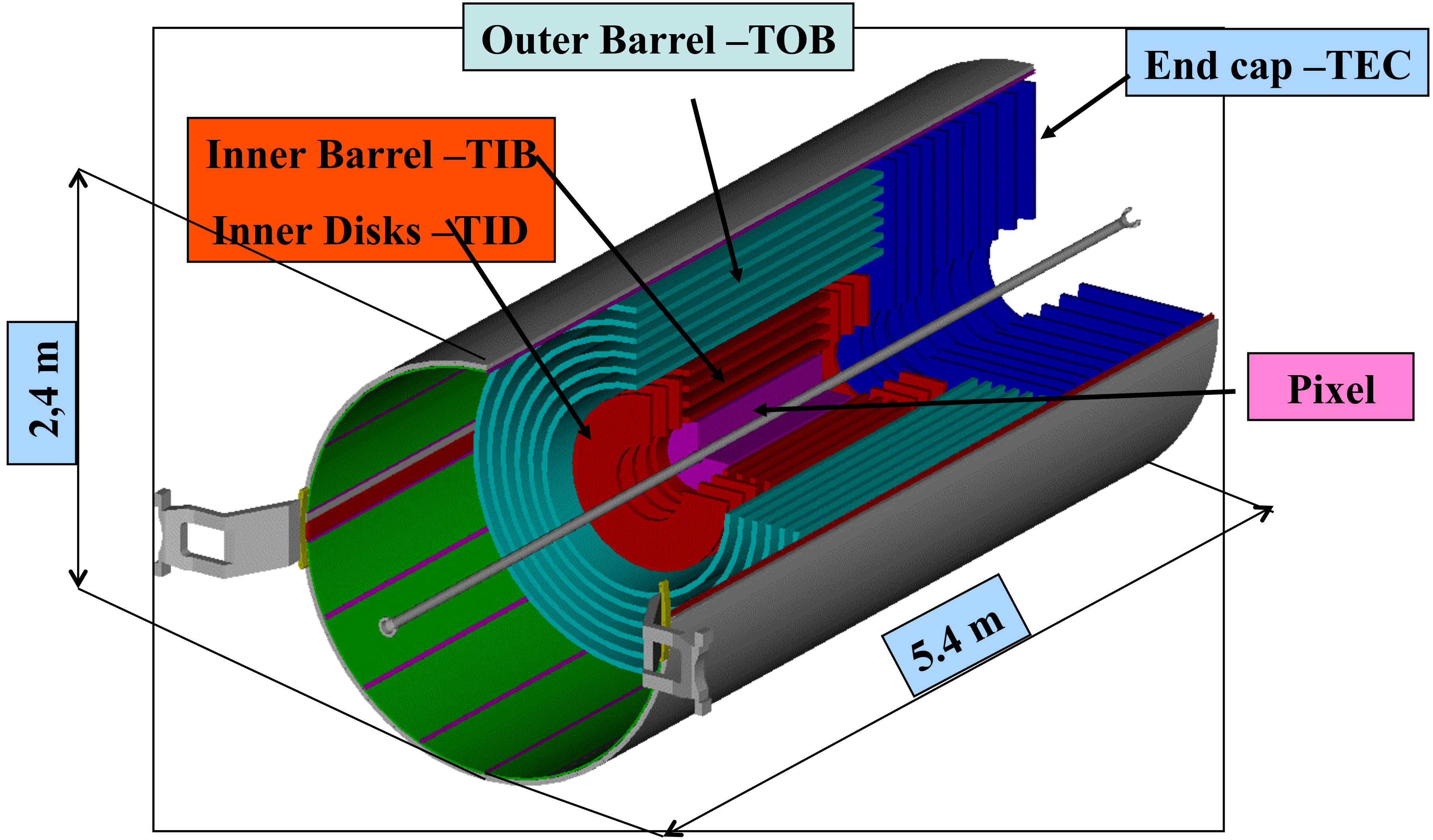
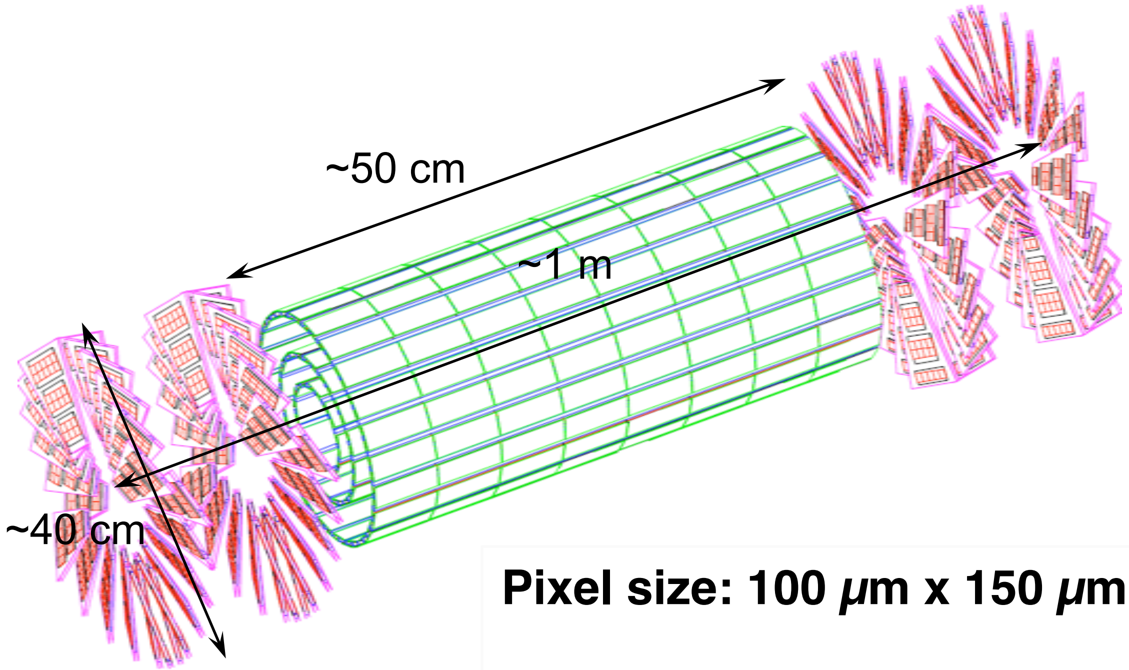
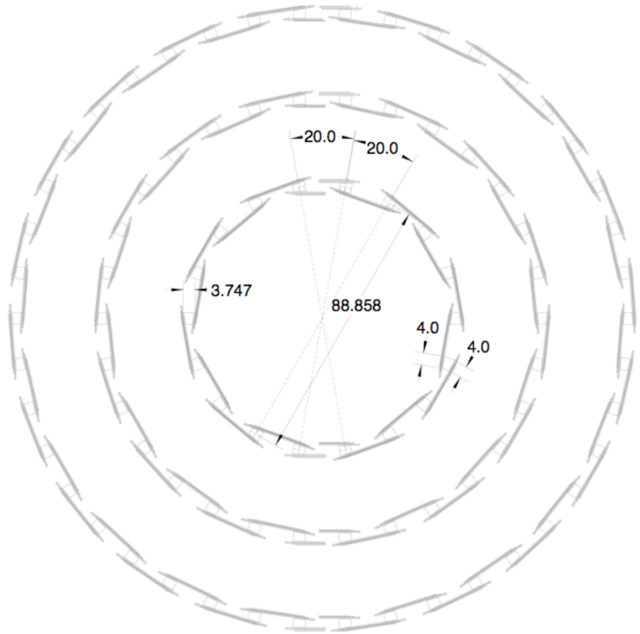
Outline

- Layout
- Operation 2010/2011
- Performance
- Future Upgrades

Layout of the CMS Inner Tracker







Pixel size: 100 μm x 150 μm

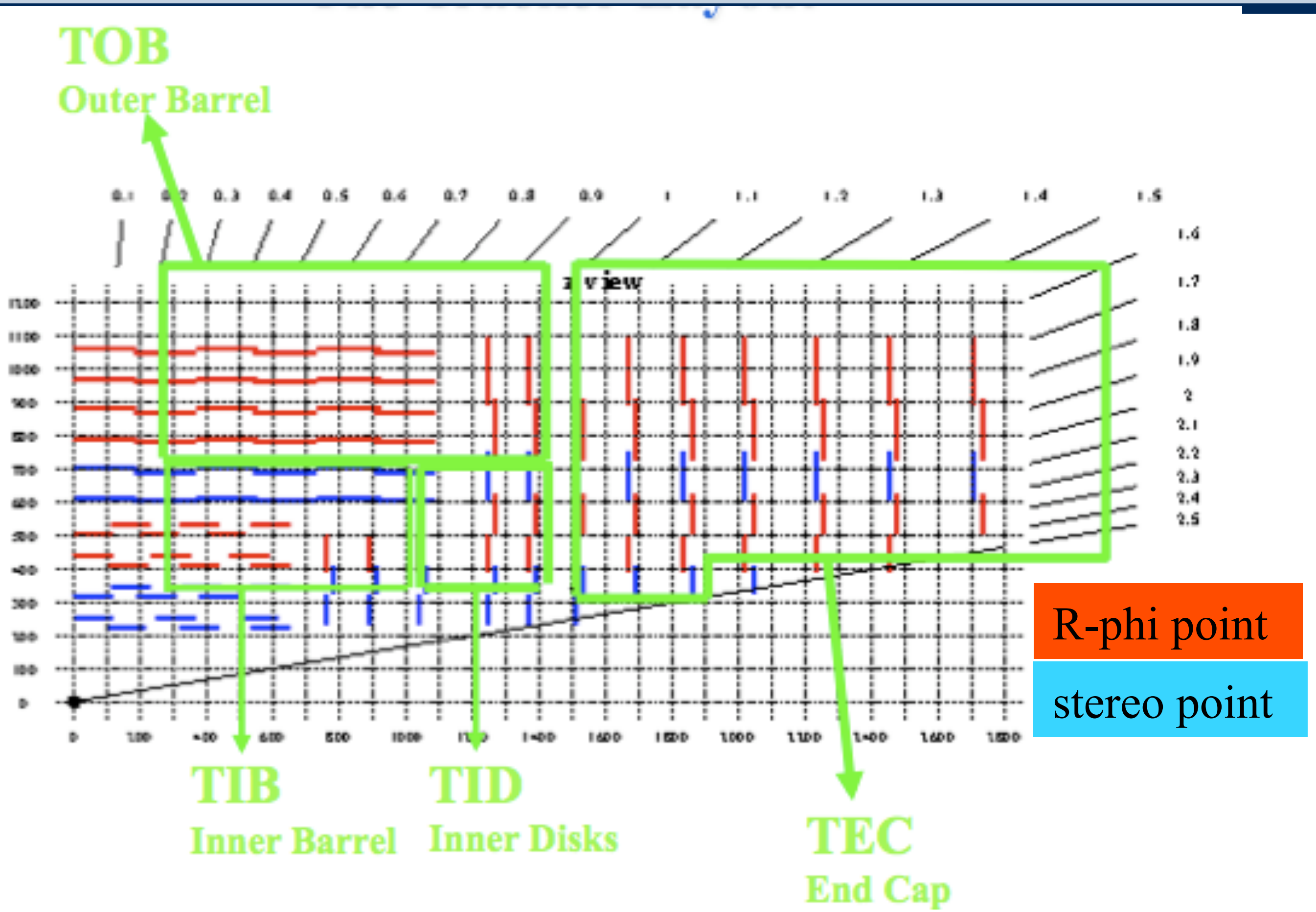
Barrel Pixel:

3 barrel layers at *r* of 4.3, 7.3, 10.4 cm
11520 chips (48 million pixels)

Forward Pixel:

4 disks at *z* of ±35.5 and ±46.5 cm
4320 chips (18 million pixels)
Modules tilted by 20^o for better charge sharing

The Strip Tracker Layout



Strip pitches:
80 μm to 205 μm
from in- to outside

Silicon thickness:
320 μm inner sensors
500 μm outer sensors
different resistivities

In blue stereo modules: two modules mounted back to back rotated by 100 mrad (5,7 grad)

The CMS Inner Tracker

Some numbers:

Pixel detector

1 m^2 detector area

1440 pixel modules

66 million pixels

Strip detector

~200 m^2 of silicon sensors

24,244 single silicon sensors

15,148 modules

9,600,000 strips ≡ electronics channels

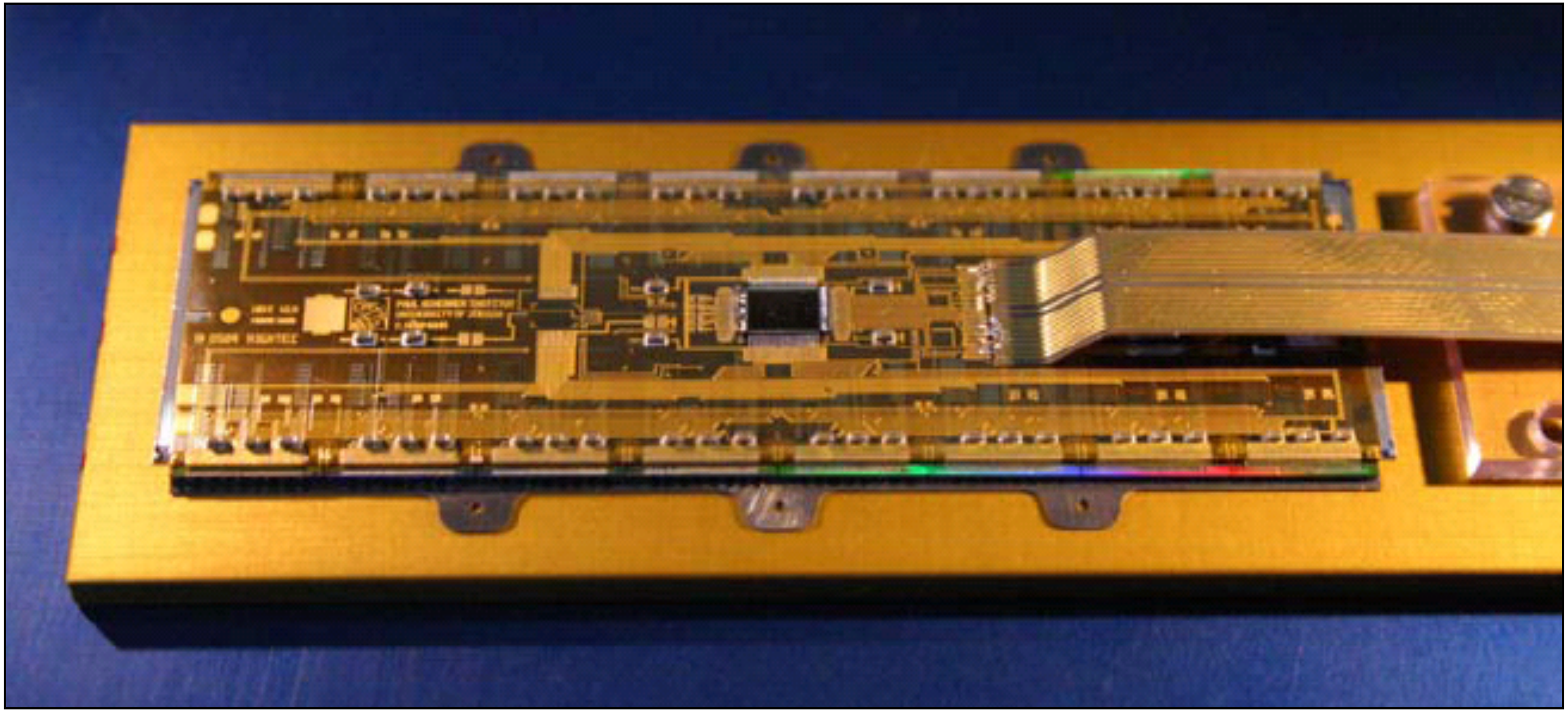
75,000 read out chips (APV25)

25,000,000 Wire bonds

Industrial type of production in many laboratories worldwide.

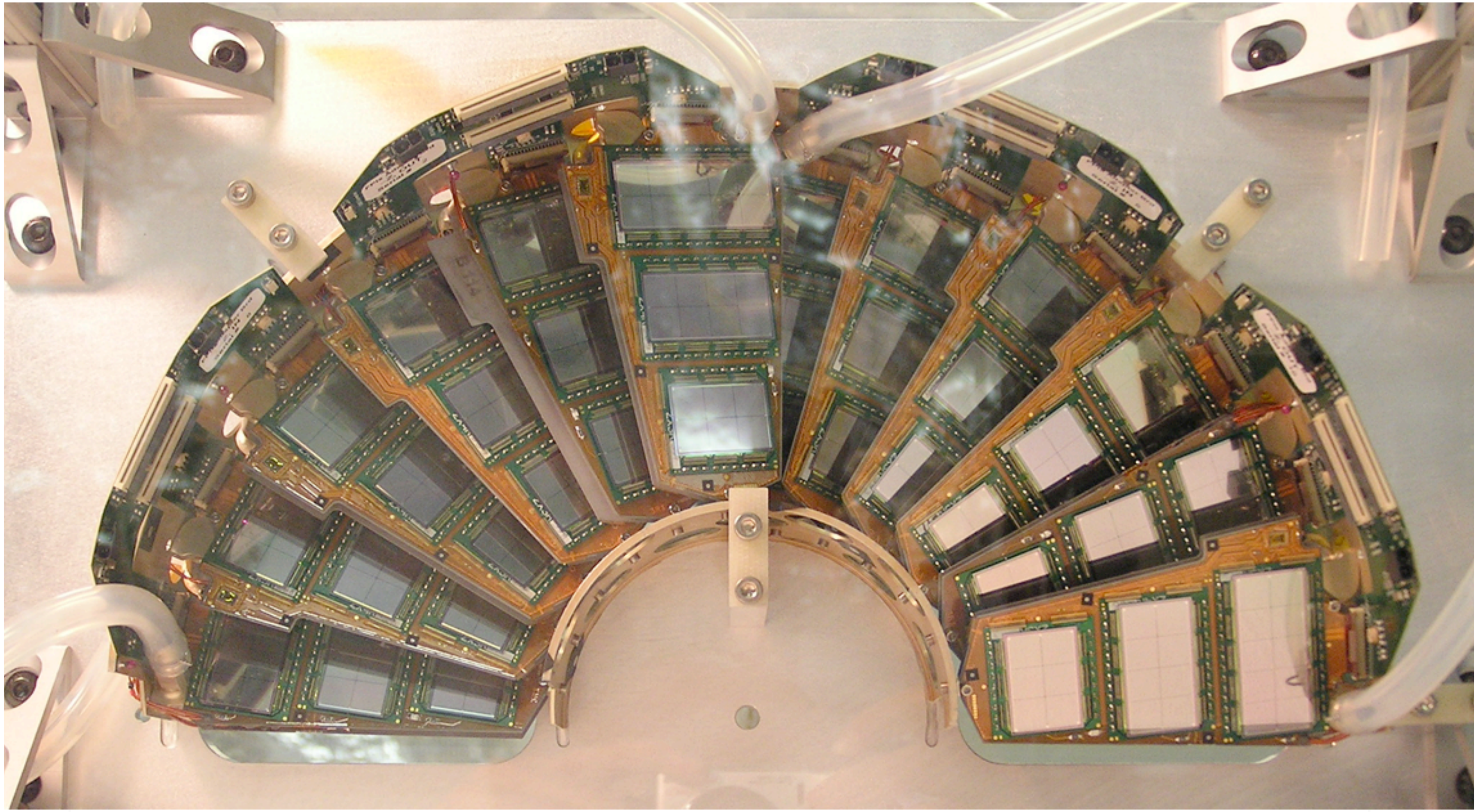
Largest Silicon detector built so far !

Barrel Pixel Module



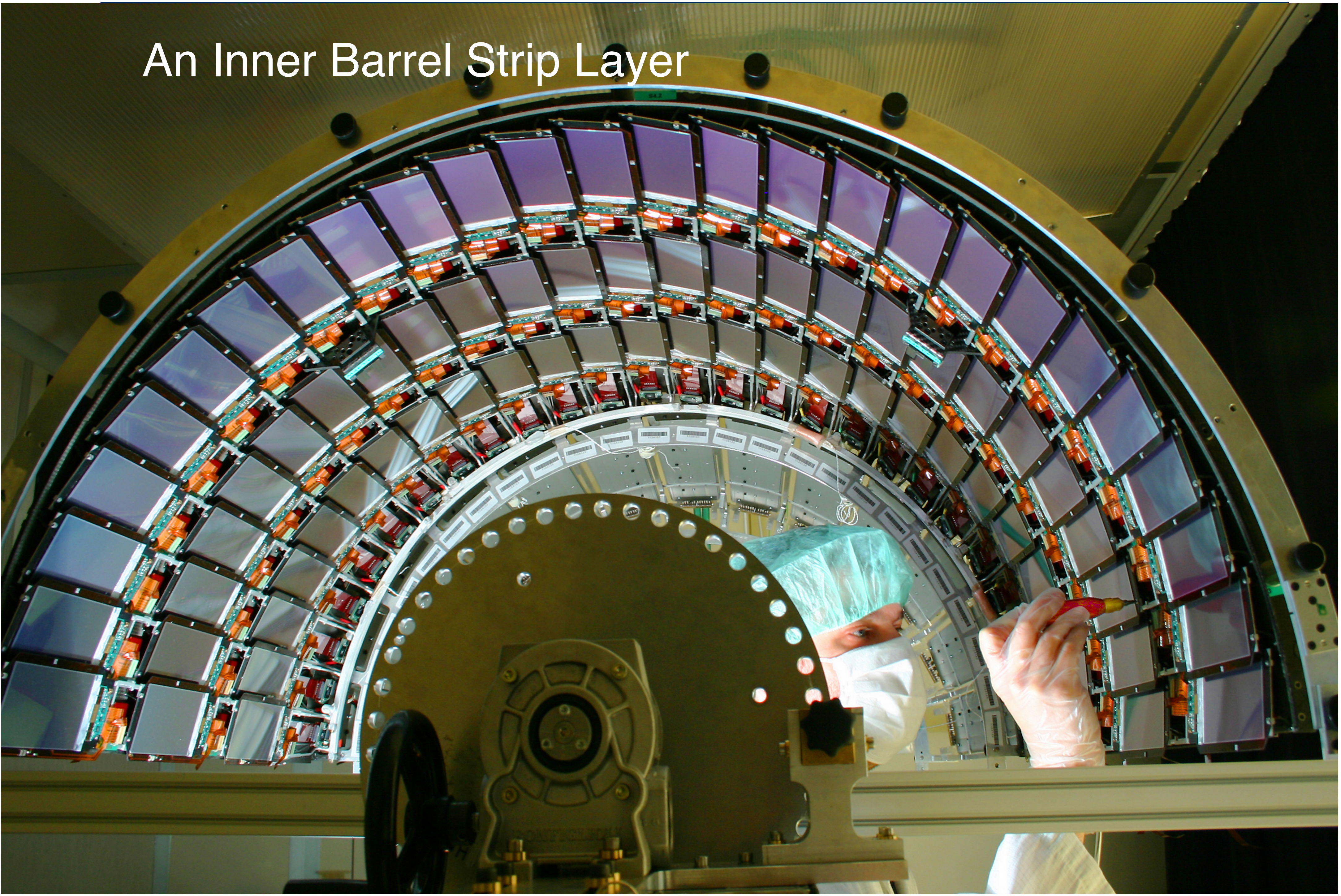
The barrel pixel consists of 768 modules (96 are half modules).

Half Disc of the Forward Pixel Detector

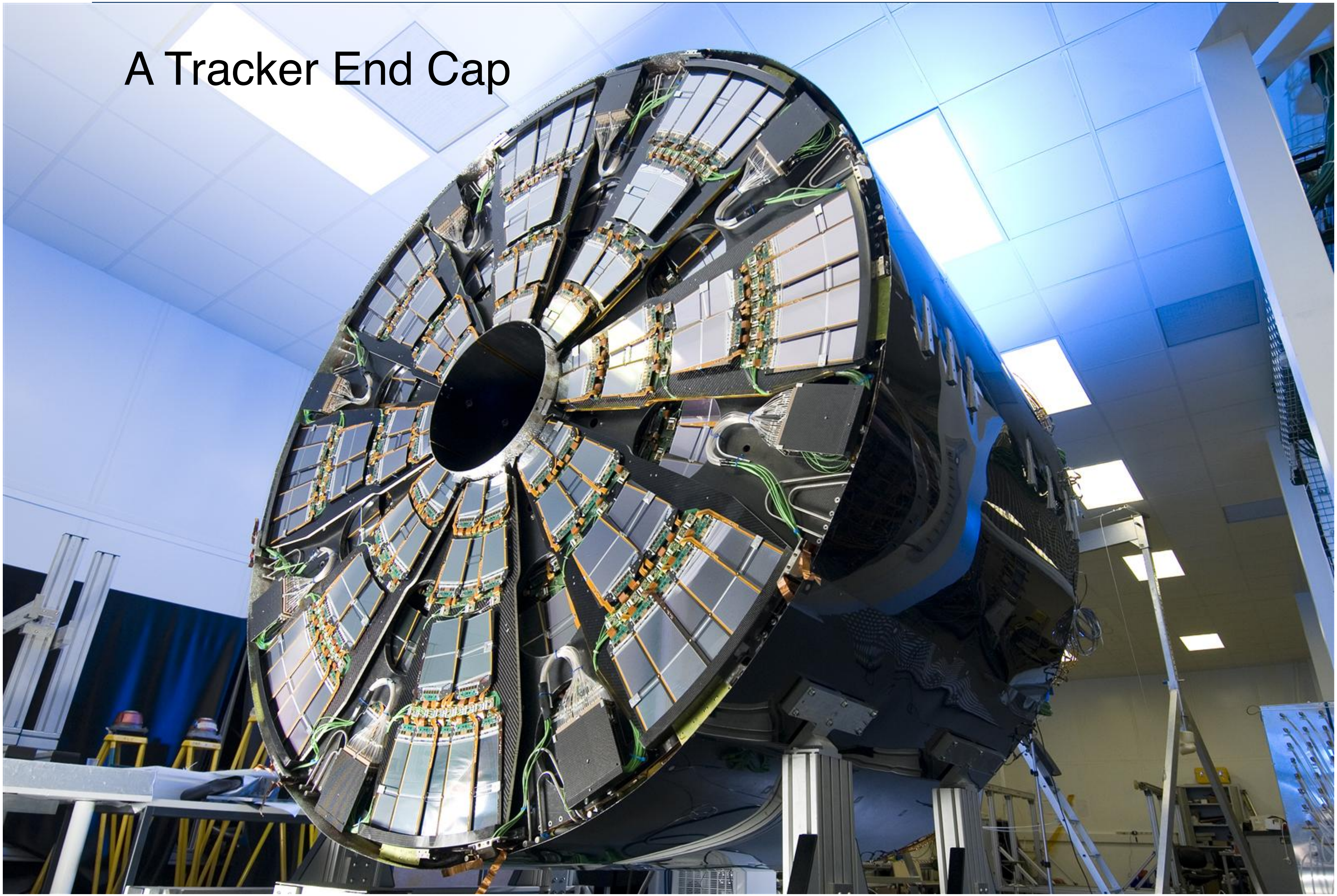


Forward Pixel: consists of 672 plaquettes

An Inner Barrel Strip Layer



A Tracker End Cap

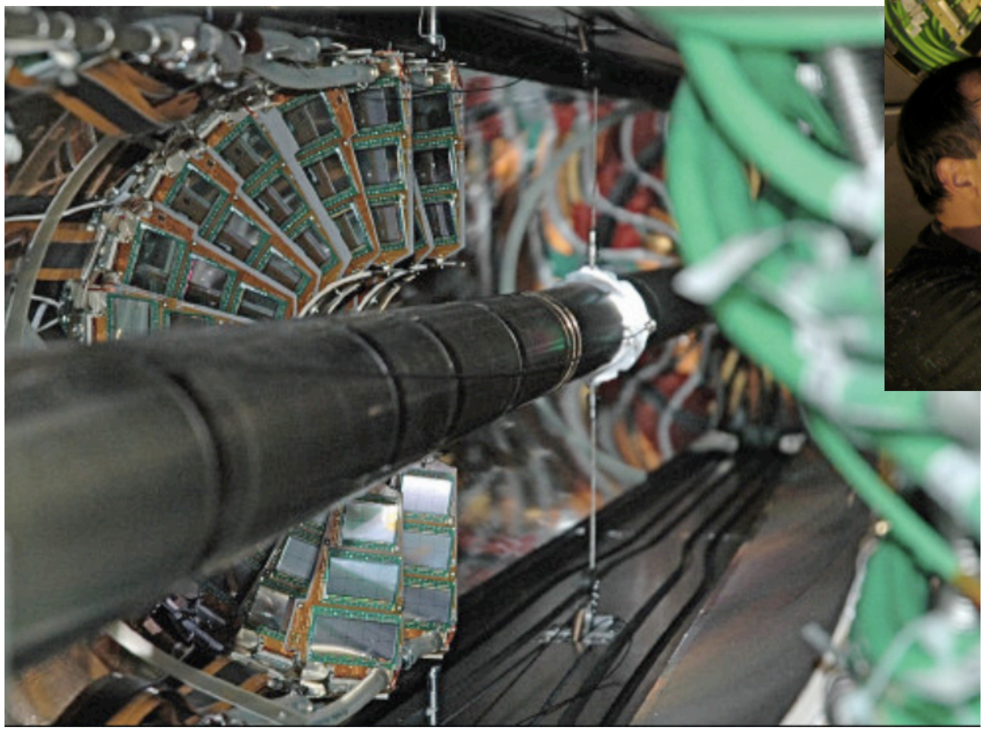


Insertion of the Strip Tracker

Insertion of the Pixel Detector

Barrel Pixel

Installation independent from
strip tracker!



Forward Pixel

Pixel Operation 2010/2011

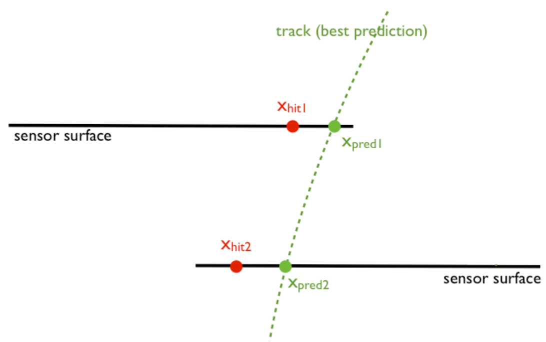
- **Cooling:** operated at +7,4ºC → no problems
  In 2012 plan to got to -10ºC, need to solve humidity problem within confined space during winter technical stop
- **Electronic and power supplies** → stable
  Lost only one sense wire
- **Firmware:** several updates implemented to cope with high multiplicity events from beam background, heavy ion events (larger event size), internal noise, etc.
- **Efficiency:** CMS efficient 92% (pp since restart March 2011)
  Pixel contributes with 6% to total inefficiency
- **Pixel status:** 96.9% functional ROCs (15324 from a total of 15840)

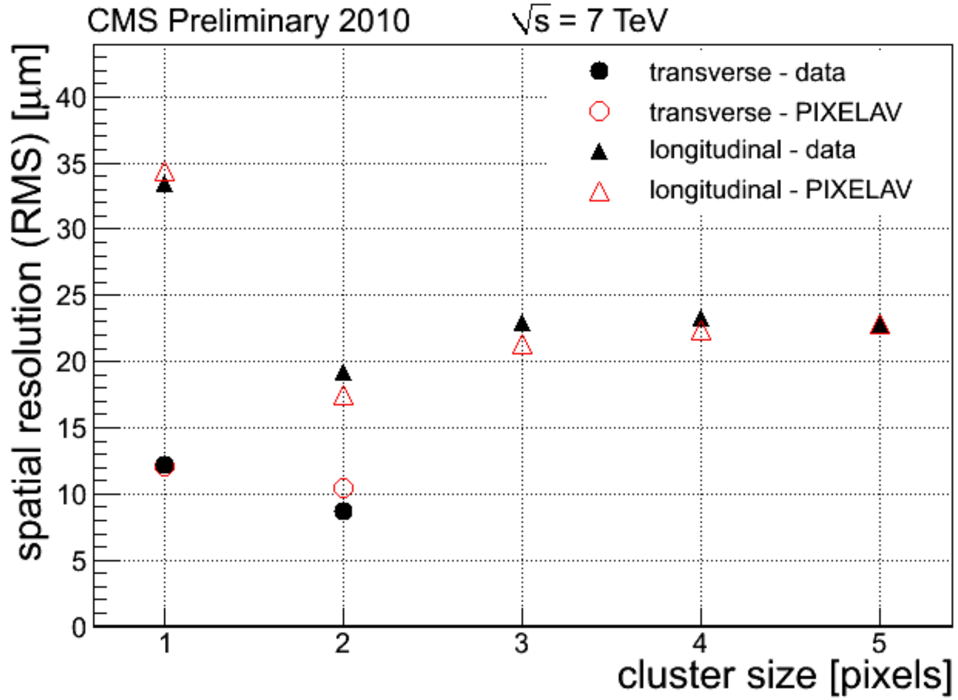
Pixel Performance - Resolution

Barrel Pixel

Transverse and longitudinal hit resolution as a function of the cluster size and compared with simulation (PIXELAV).

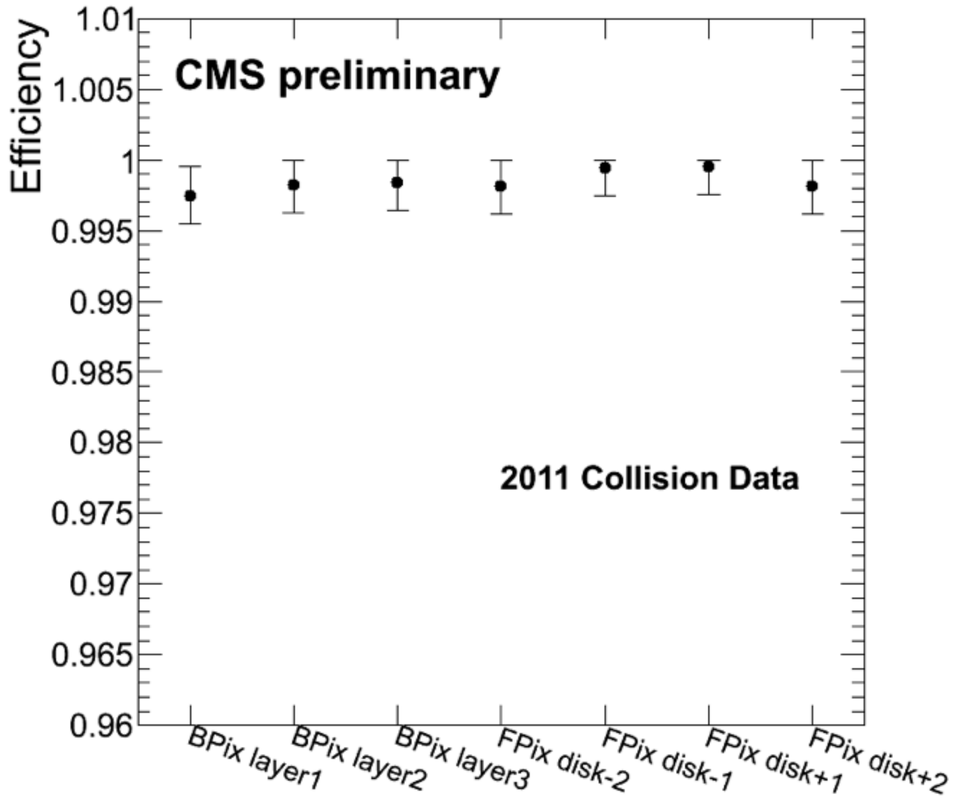
Measured using pixel overlaps





Pixel Performance - Hit Efficiency

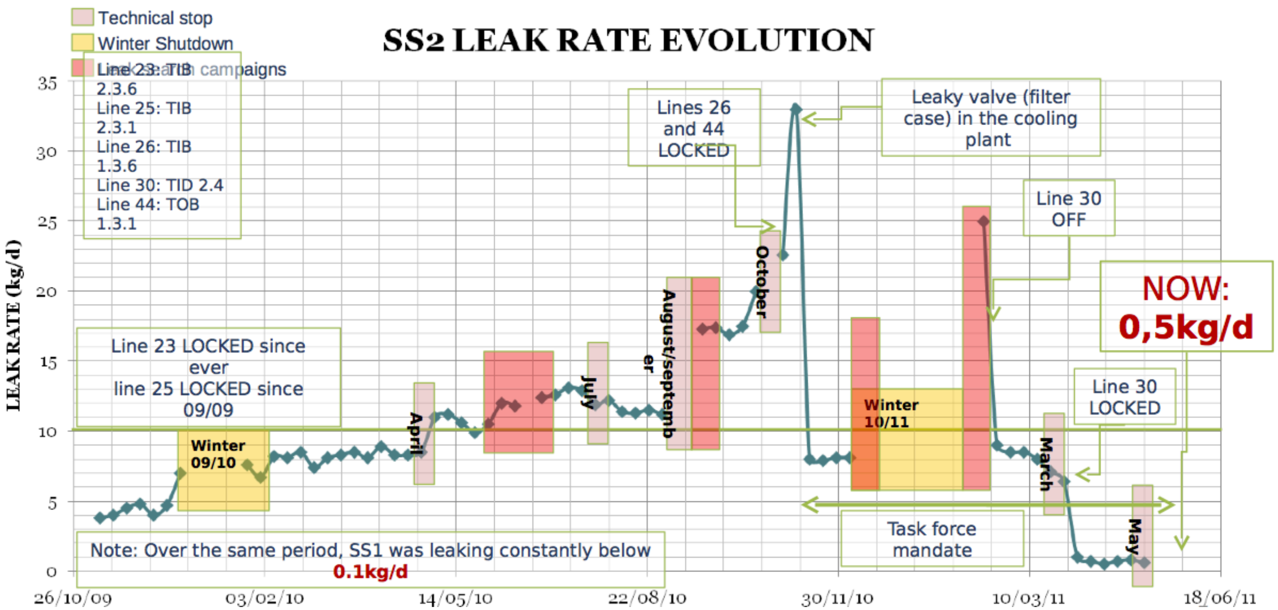
Pixel efficiency versus layer:



Strip Detector Operation

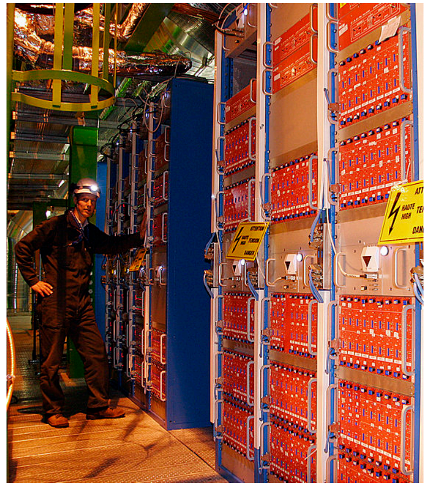
• **Cooling:** Double stage cooling system using C_6F_{14} (main chiller originally using brine). Temperature 4ºC (until end of 2012).
Next long shutdown will be used for improvements (humidity in confined regions) to be able to operate at lower temperature.

Struggle to reduce leak rate.
Now with 5 lines closed (out of 90) low leak rate of about 0,5 kg/day achieved.

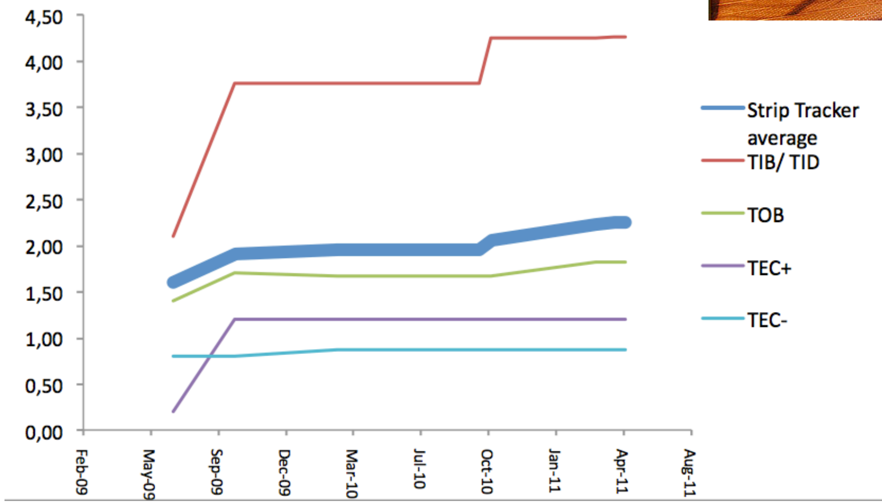


Strip Detector Operation cont‘

- **Power Supplies**: ~2000 power supply units located in experimental cavern. Failure rate at present 2 PSU/month → negligible impact on detector performance
- **DAQ:** up time 98,6% in 2011 (98,8% in 2010)

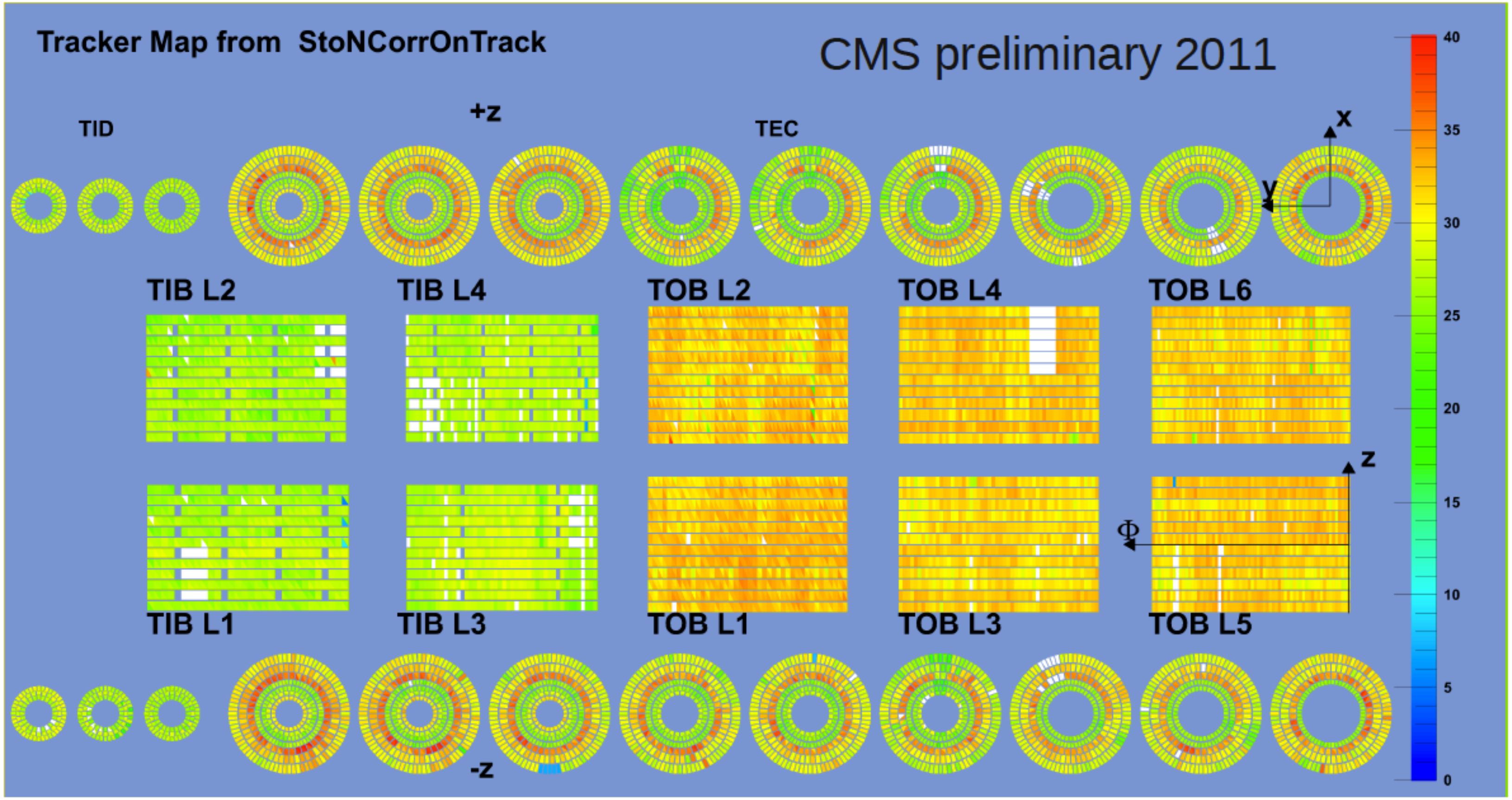


- **Strip Detector Status:** Dead channels in SST 2,2%



L. Demaria, VERTEX2011

Strip Performance - Signal to Noise

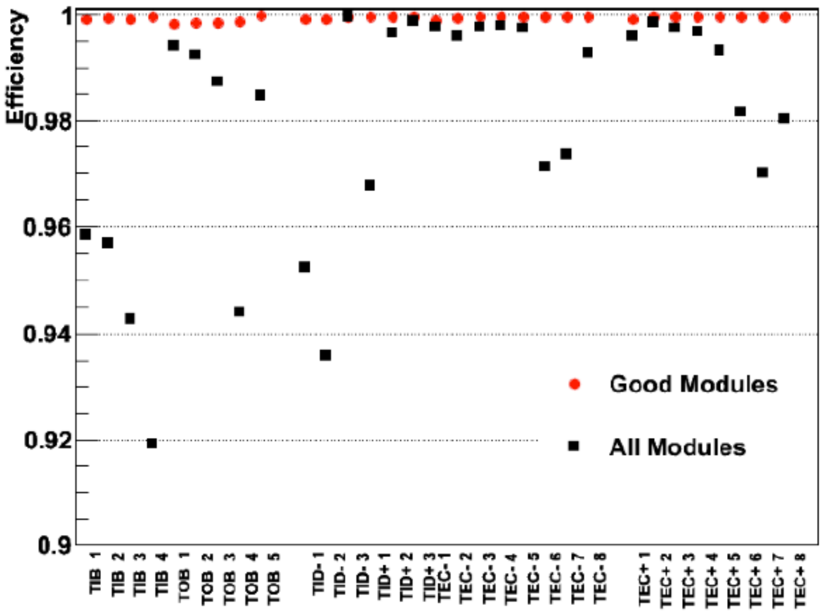


S/N ~ 20 for inner layers (300 μm thick Si)
S/N ~ 30 for outer layers (500 μm thick Si, 2 sensor modules)

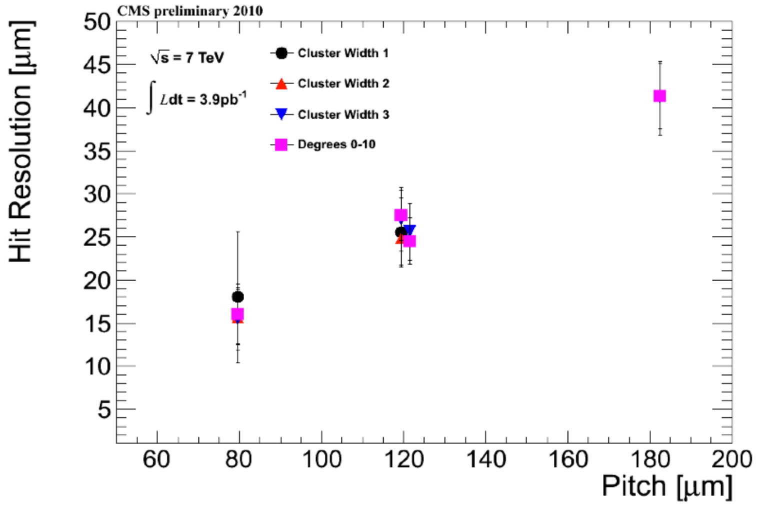
Strip Performance - Signal Hit Efficiency, Hit Resolution

Strip efficiency versus layer:

CMS preliminary 2011 – run 166010



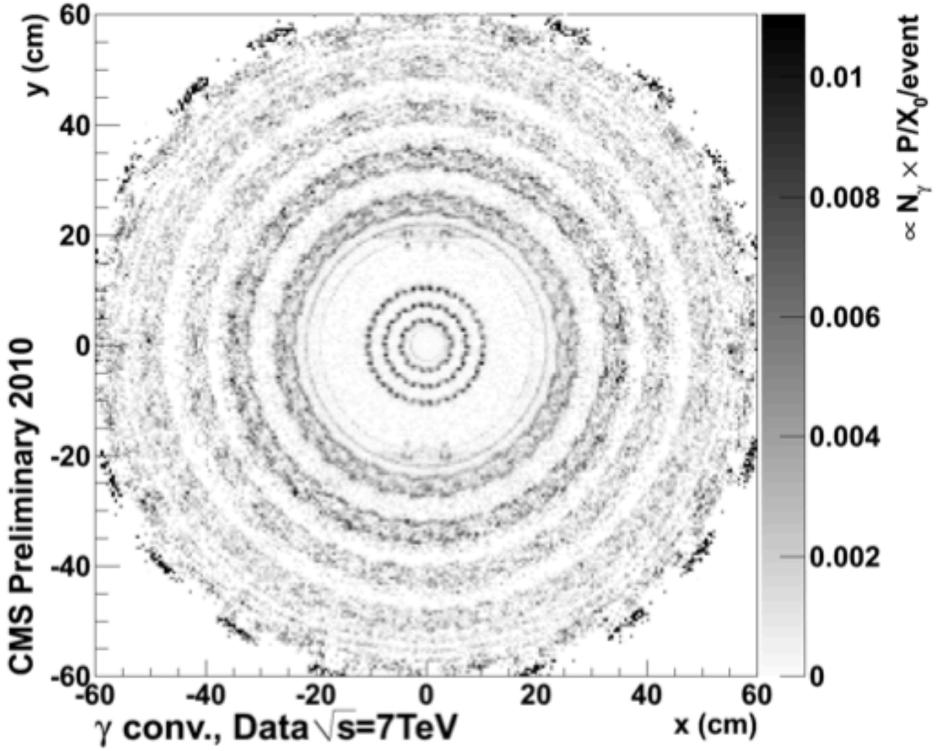
Hit resolution (for TIB and TOB detectors):

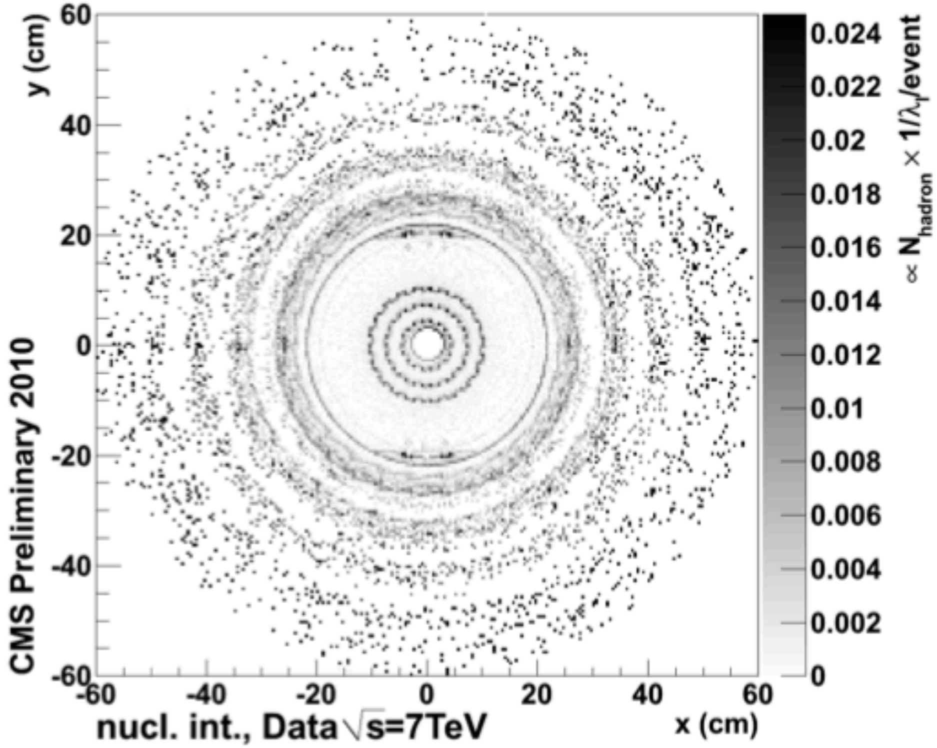


Sensor pitch	Resolution
80 μm	~ 17 μm
120-122 μm	~ 26 μm
183 μm	~ 41 μm

Probing Detector Description

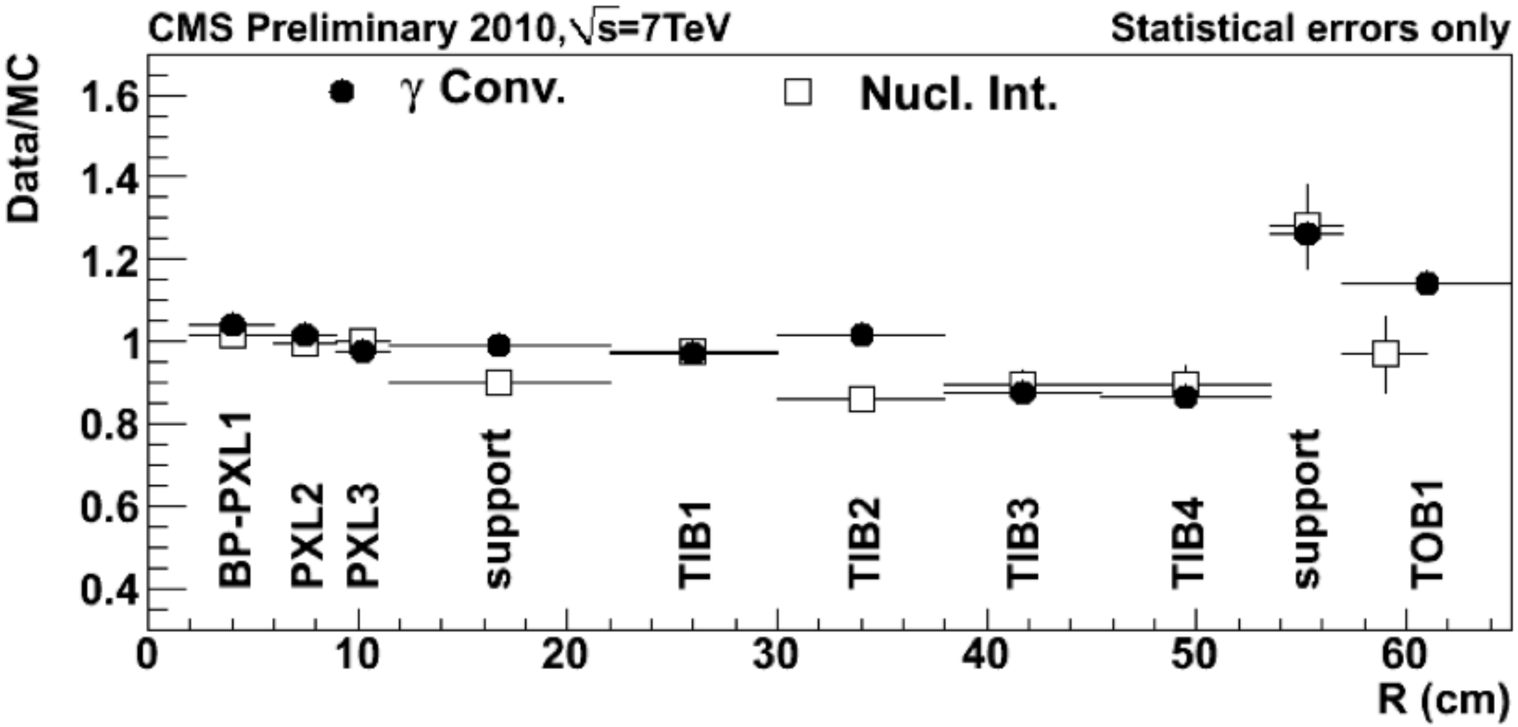
Knowlege of material distribution of the tracker is crucial for physics analysis.
Use counting of photon conversions and nuclear interactions to probe material.





Probing Detector Description cont‘

Compare data with simulation (ratio of counts data/MC):



CMS PAS TRK-10-003

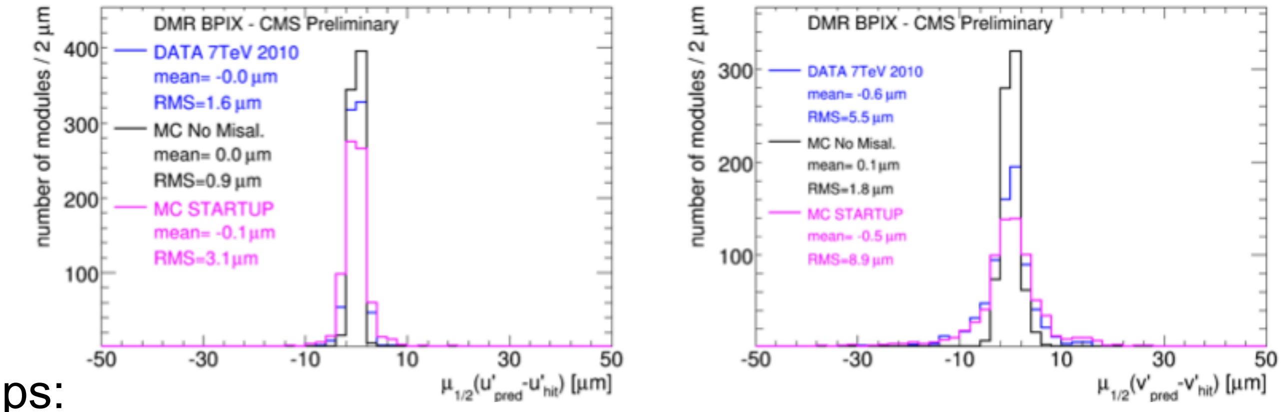
Only central region accessible with this method.

Good agreement within 10%!

Alignment – Comparison Data MC

Distribution of Median of Residuals

Example Barrel Pixel:



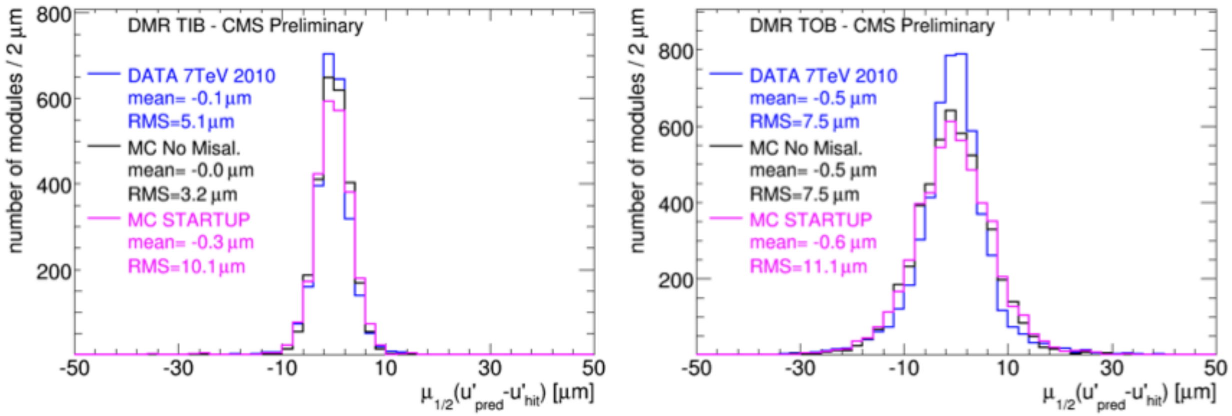
Example TIB and TOB strips:

p>3 GeV/c

p_T>0.65GeV/c

Only modules with >200 hits

STARTUP scenario based on alignment with cosmics '08

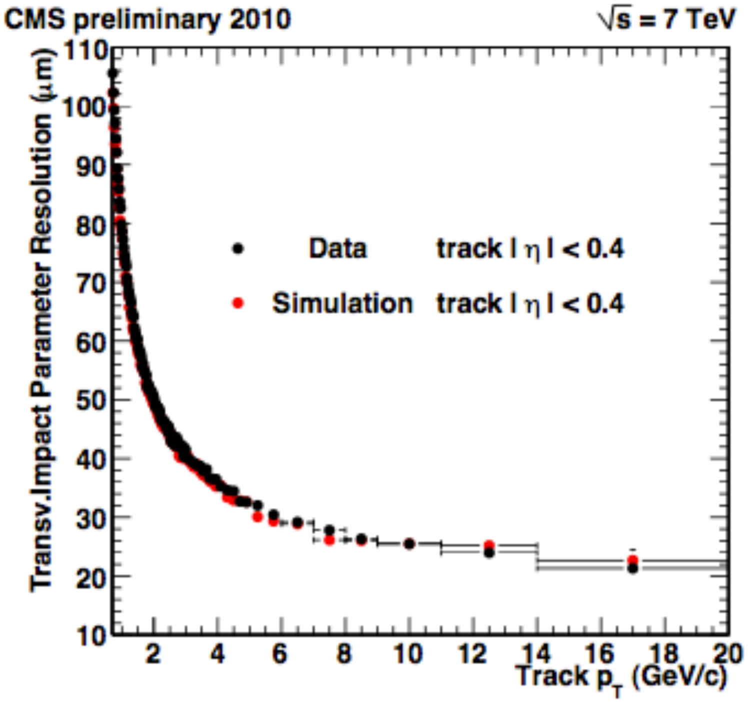


Comparison with MC ideal close within a few µm.

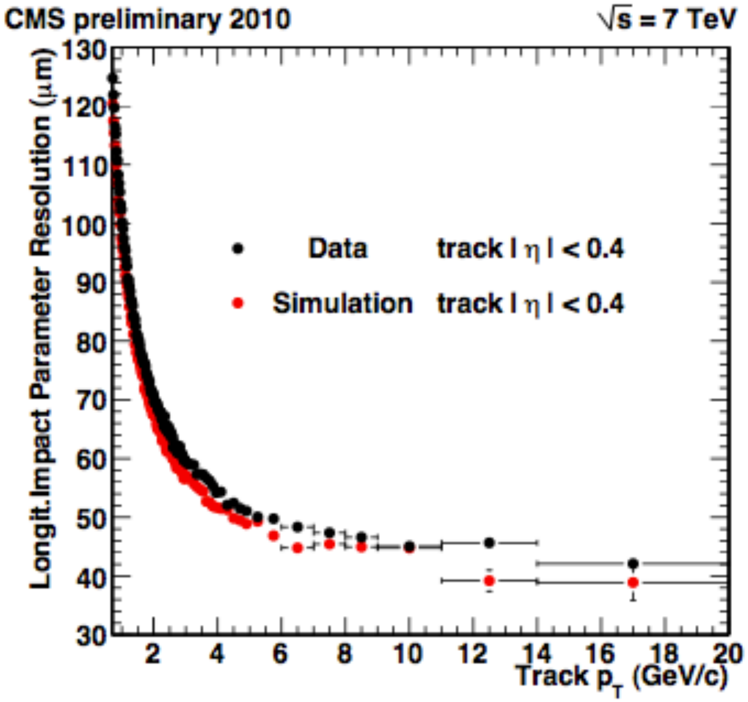
Impact Parameter Resolution

Track impact parameter resolution as function of the track p_T

Transversal:



Longitudinal:

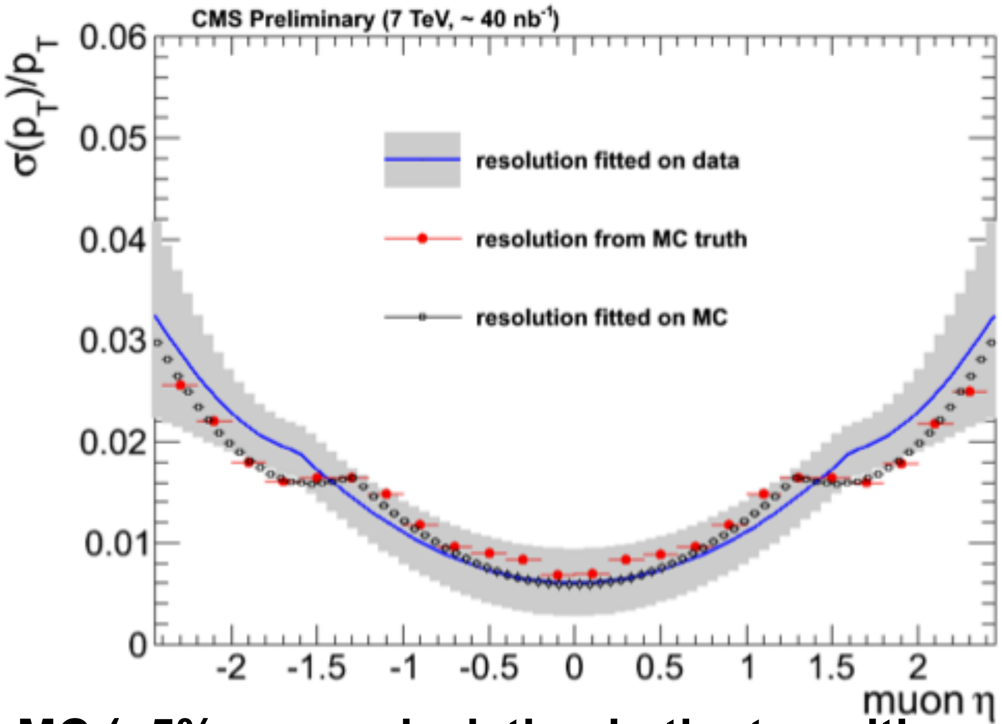


CMS PAS TRK-10-005

Momentum Resolution

Resolution on transverse momentum measured using J/ψ mass line-shape. Tracks from J/ψ have on average a momentum of a few GeV. At this momenta the inner tracker dominates the momentum measurement.

Sensitive to:
- Knowledge of the tracker material
- Alignment
- B field
- Reconstruction algorithms



CMS PAS TRK-10-004

In general good agreement with MC (~5%, some deviation in the transition region of barrel to end cap).

CMS Tracker Upgrade

- **Upgrade Phase 1** (mid of present decade)
  - Exchange present pixel detector
  - 4 barrel layers, 3 end cap discs
  - Subtantially reduced material
  - CO_2 cooling, DC-DC converter, etc.

- **Upgrade Phase 2** (beginning of next decade)
  - Exchange Full Tracker
  - New tracker to provide input for level 1 trigger
  - Includes also new 3rd generation pixel detector

CMS Tracker Upgrade Phase 2

Requirements:

- Cope with instantaneous luminosity of up to $5x10^{34}$
  - → 200 - 250 collisions per bunch crossing
  - → keep occupancy of sensor elements below a few %
- Withstand a total integrated luminosity of > 3000 fb^{-1}
  - → huge radiation fluence → intense sensor R&D
- At high luminosity the CMS level 1 trigger (present scheme even with upgrades) will not be able to keep rates of e, μ and jets below ~100 kHz level (raising simply the trigger thresholds would decrease physics performance)

→ New tracker has to provide input for trigger level 1.

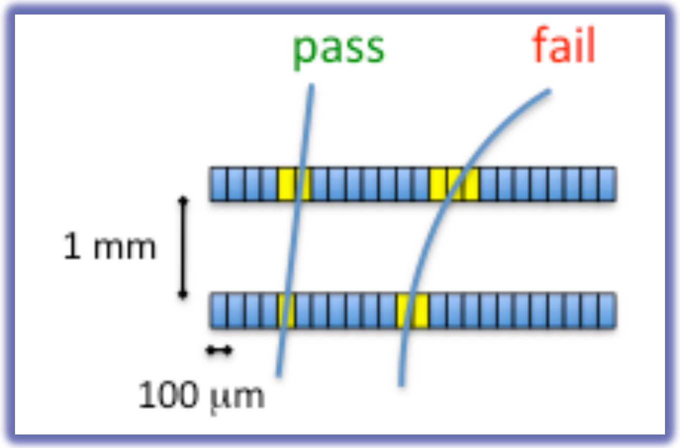
Constraints:

- New tracker has to re-use installed services such as cables, cooling pipes.
- Tracker material should be reduced despite additional requirements.

Modules for p_T Discrimination

Need for data reduction and track trigger requires local inteligence at the module level:

Two sensor elements (strips-strips or strips-pixels) spaced by ~1 mm.
Strong CMS magnetic field displaces tracks significantly depending on p_T.

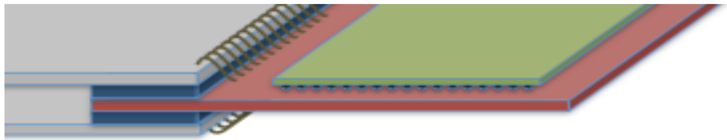


Call such objects „stubs“

Applying p_T cut of ~1 GeV reduces data rate by 1 order of magnitude.

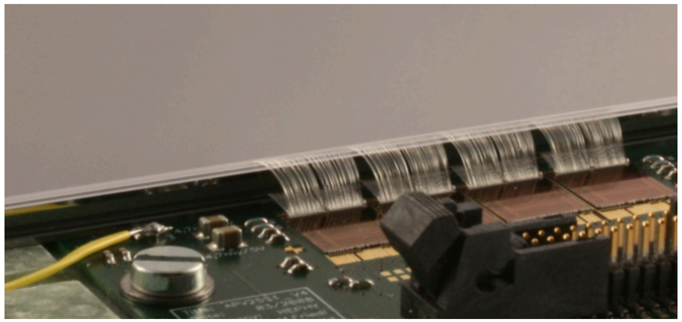
Two Approaches for p_T Modules

Simple sensors plus wire bonds:

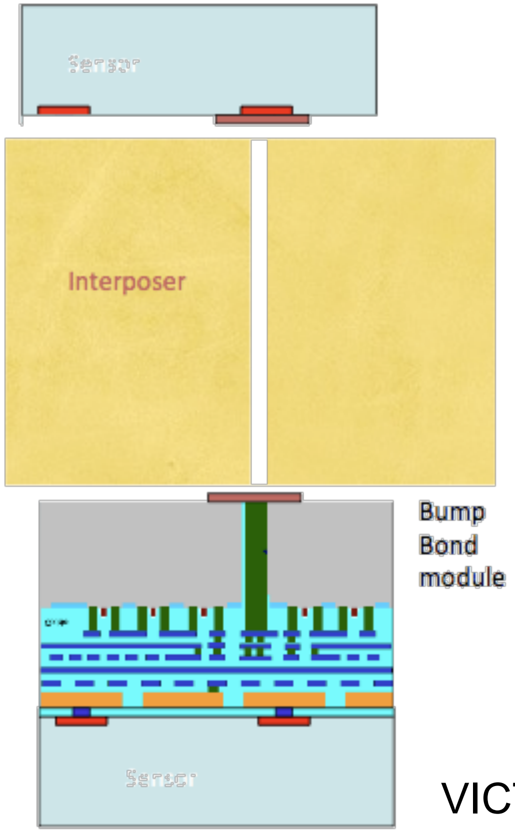


Connect strips from both sensors using wire bonds to one hybrid.

Only rφ measurement. Ok for outer modules.
In case of strip – pixel modules slightly more complicated.



Vertically interconnected sensors:



Technologically challenging!

Might be limited in surface

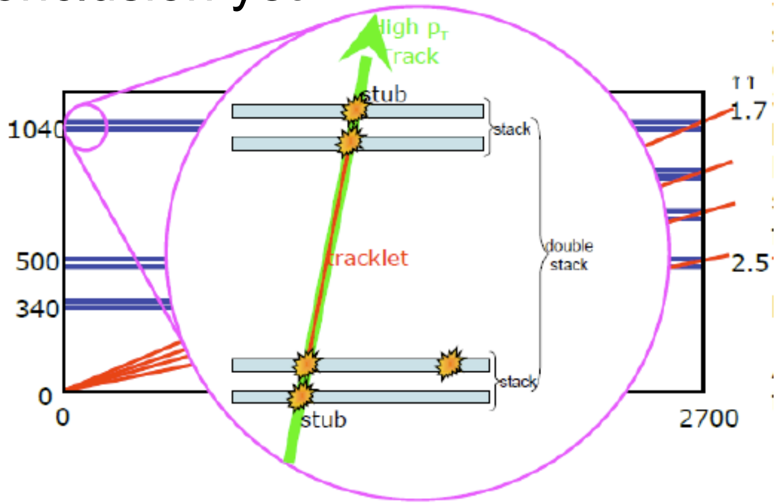
Yield and cost issue

VICTR project at FNAL

From “Stubs” to “Tracklets” to Tracks

Several tracker layouts under study – no conclusion yet

Track finding for level 1 trigger:
+ Combine pairs of stubs from double layers (seperated order few cm) → „tracklets“
+ Processing using FPGAs



In the layout studies a compromise is sought between trigger requirements (number of trigger layers) and physics performance of the final tracker and **material budget**.

→ use of dedicated software package to study different layouts

→ study feasibility of track trigger concept and implementation in CMS combined triggers

Summary

- Largest Silicon detector commissioned
- Only minor problems during operations
  (biggest issue strip tracker cooling)
- Excellent agreement of detector description with real object
- Physics performance spectacular

- Two phase upgrade foreseen
  Large R&D effort ongoing to define layout,
  sensor materials and other components for full
  tracker replacement mid 2020.