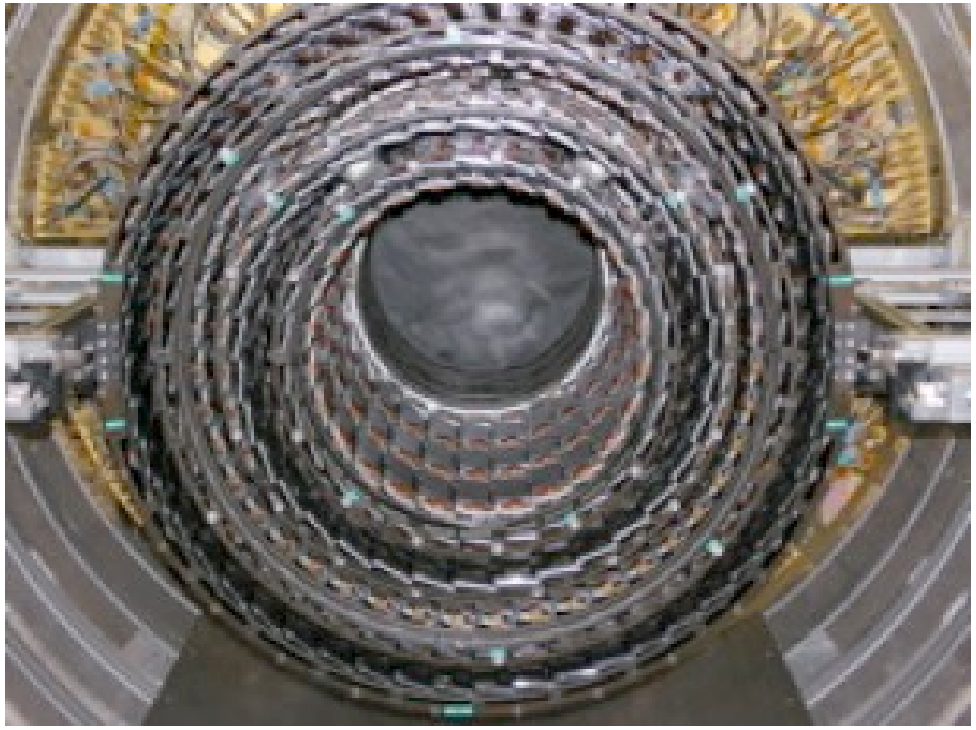
CMS Tracker



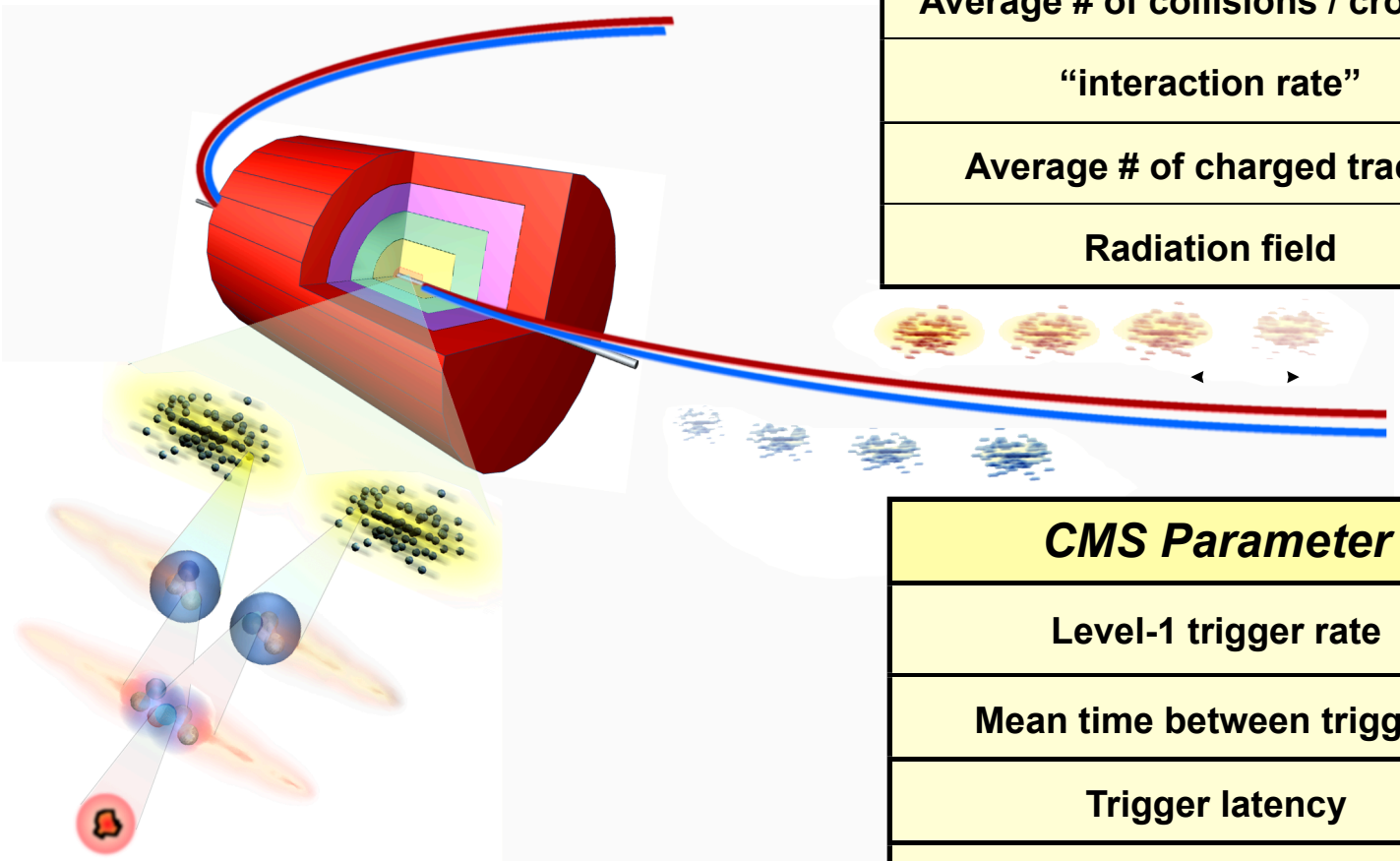
Kevin Burkett (Fermilab)
(Thanks to L. Spiegel and A. Satipathy for borrowed material)

Outline

- Tracker Design Philosophy and Goals
- Overview of CMS Tracker
- Description of Tracker Sub-Detectors
- Tracker Assembly and Testing
- Summary

LHC Environment

7 TeV ProtonProton
colliding beams



Parameter	*Value*
Bunch-crossing frequency	40 MHz
Average # of collisions / crossing	20
“interaction rate”	~10^9
Average # of charged tracks	1000
Radiation field	severe

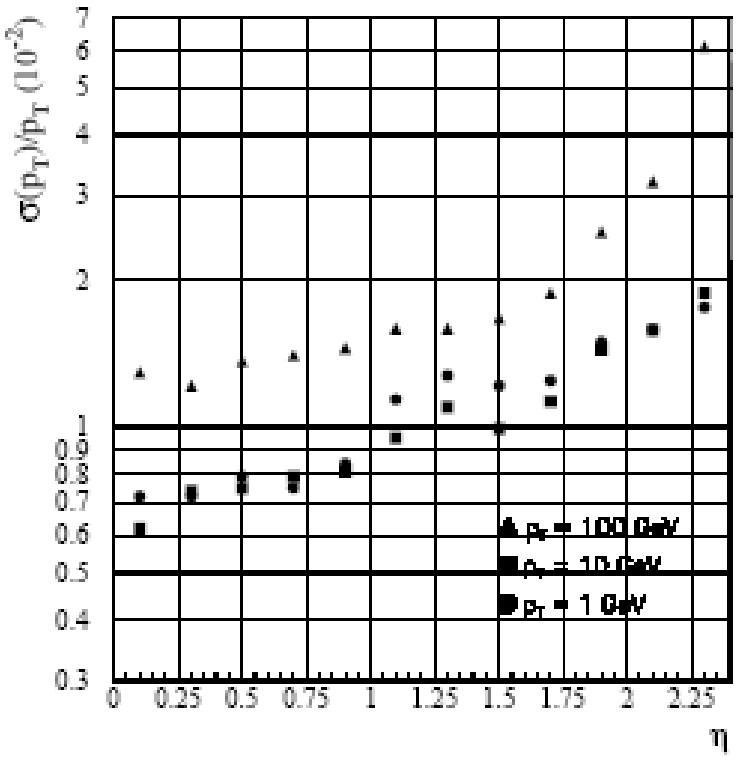
CMS Parameter	*Value*
Level-1 trigger rate	100 kHz
Mean time between triggers	10 μsec
Trigger latency	3.2 μsec
Solenoid field	4 T

Tracker Design Philosophy

- Higgs physics, SUSY, W', Z' etc place constraints on the Tracker design
  - Good momentum resolution for leptons from W, Z (W', Z') decays
  - Minimizing material for electrons (bremsstrahlung, isolation cuts).
  - Lepton isolation to suppress tt and Zbb bkgd for $H \rightarrow ZZ^{(*)} \rightarrow 4l^{\pm}$ modes
  - Use isolation criteria to suppress γ-π^0(jet) from $H \rightarrow \gamma\gamma$ decays
    - Minimize material to limit γ conversions
  - The ability to tag b-jets
    - Top quark decays
    - Signatures for new physics
  - Identifying τ leptons through isolation and displaced vertices.
  - Rare states will require very high luminosity
    - 10^{34} cm^{-2}s^{-1} design $L \Rightarrow$ 20-30 superimposed minimum bias events.
    - 25 ns time resolution
    - Resistance to radiation damage

Design Goals

From Tracker TDR



Tracker (only) transverse momentum resolution for muons.

High p_T isolated tracks

- $\delta p_T/p_T \approx (15 p_T \oplus 0.5)\%$ p_T in TeV for $|\eta| \leq 1.6$

  Gradually degrading to $\delta p_T/p_T \approx (60 p_T \oplus 0.5)\%$ for $\eta = 2.5$

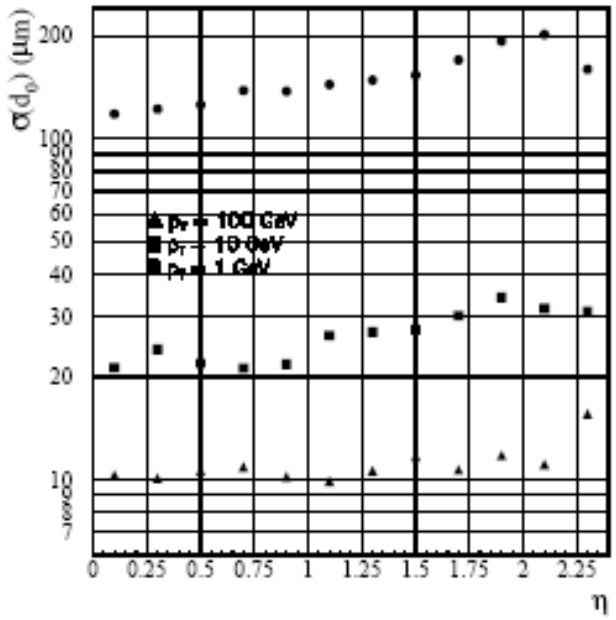
Well suited to the reconstruction of narrow states decaying into charged particles.

In combination with the outer muon system

- $\delta p_T/p_T \approx (4.5\sqrt{p_T})\%$ (p_T in TeV and for $p_T > .1$ TeV and η extending up to 2 units)

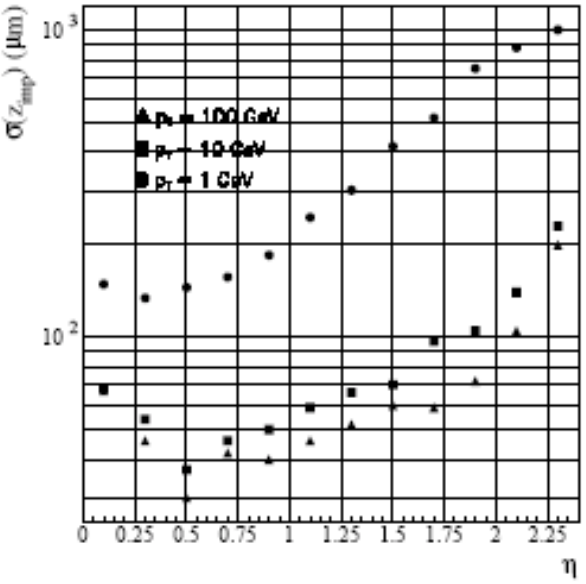
  Combined system momentum resolution better than in stand alone Tracker.

Design Philosophy



From Tracker TDR

Assumes perfect alignment



Transverse plane impact parameter resolution

- Better than 35 μm over the full $|\eta| \leq 2.5$ range (for $p_T > 10$ GeV)

Longitudinal impact parameter resolution

- Better than 75 μm up to $\eta = 1.6$

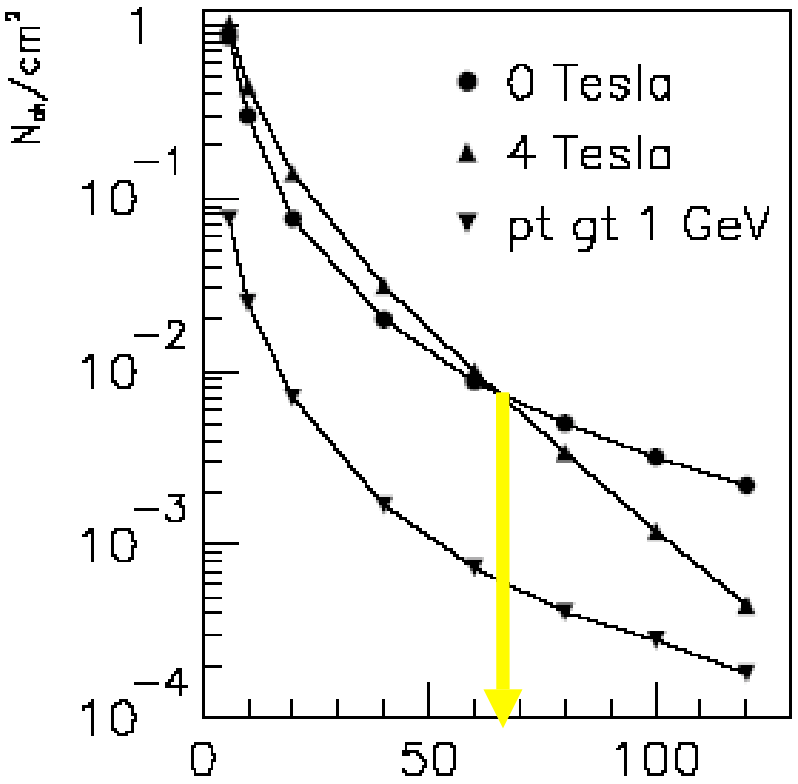
For cases in which there is a pixel barrel at r=41-45mm (low luminosity) the impact resolution is improved further.

Other Design Goals

- In jet environments charged hadrons with $p_T > 10$ GeV are reconstructed with an efficiency of 95%
  - 85% for 1 GeV charged tracks
  - Better than 98% for muons over full η range
    - p_T as low as 1 GeV
  - Above 90% for high energy electrons
- Tagging efficiencies of 50% or better for central rapidity *b* jets between 50 GeV and 200 GeV E_T
  - Mis-tagging probability 1-2%
  - 40% in forward rapidity region (for same mis-tagging rate)
- Neither photon converts within the Tracker in close to 50% of Higgs to $\gamma\gamma$ channel
  - Somewhat degraded since original TDR

CMS Solenoid

Figure taken from TDR.



Primary charged particle density at η=0 for 20 minimum bias events (in %)

4 T magnetic field provided by super-conducting solenoidal magnet.

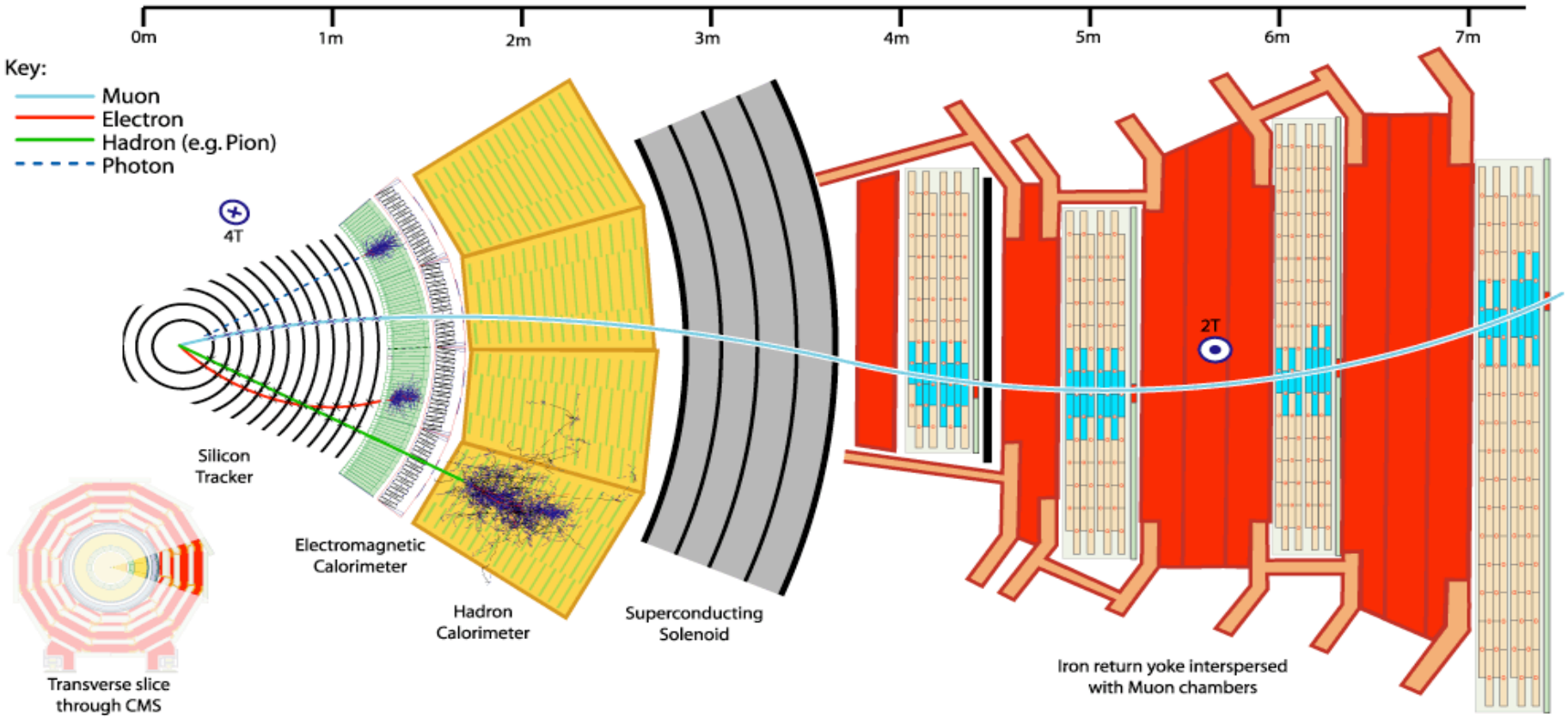
- Full analyzing power up to $|\eta| \leq 1.6$
- A charged particle with p_T = 1TeV will have a sagitta of 195 μm.

The high magnetic field affects event topologies (see plot)

- Low momentum tracks confined to small radius helical trajectories.
- Below r=65cm the charged track density falls more slowly with the field on; above 65cm the density falls more rapidly.

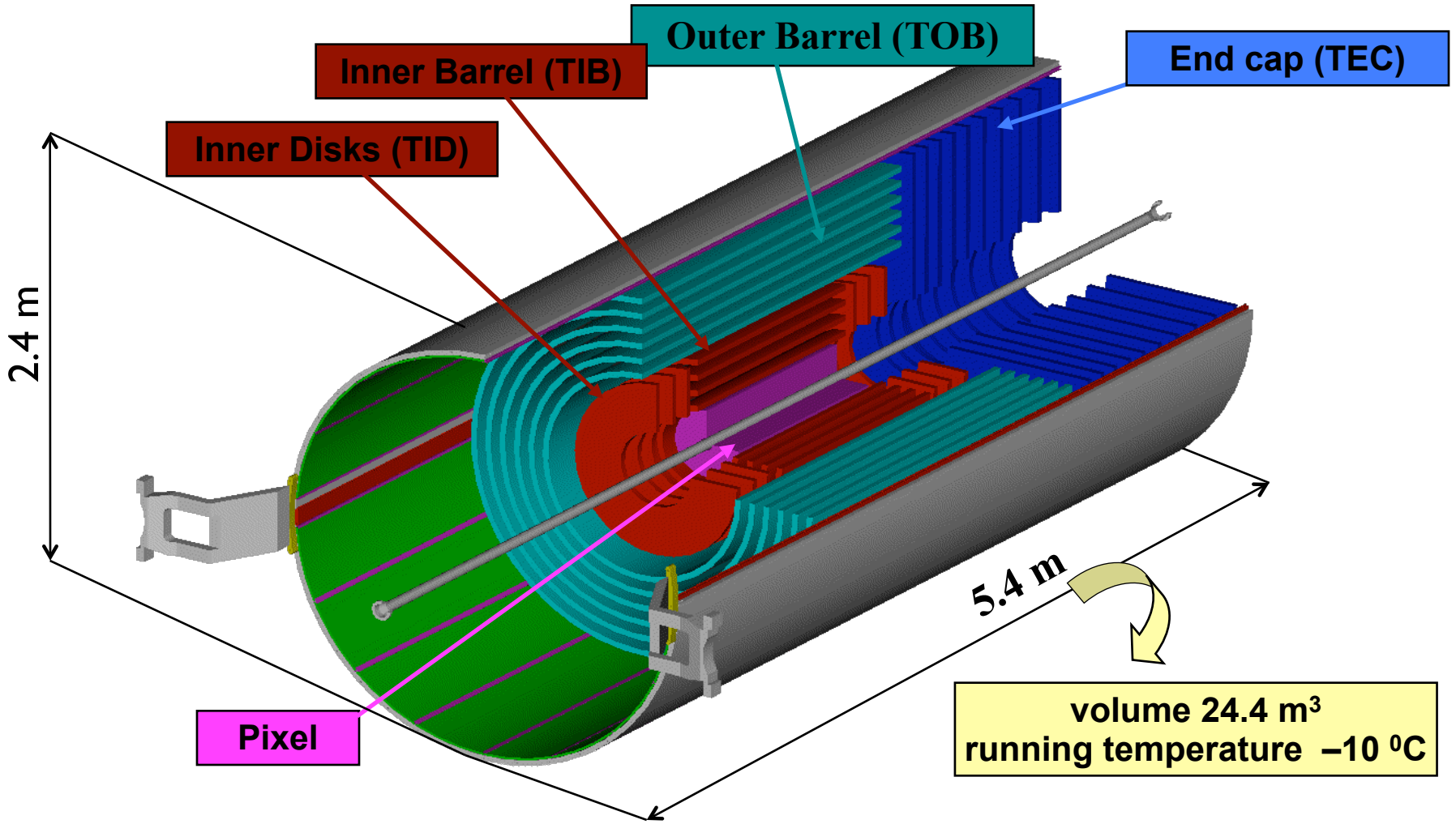
0 T $\Leftrightarrow$ $1/r^2$

CMS Detector Slice



Muon chambers could be considered to be part of the Tracking System (for muons). For high p_T muons the combined system has a better momentum resolution. However, they are not the topic of this talk.

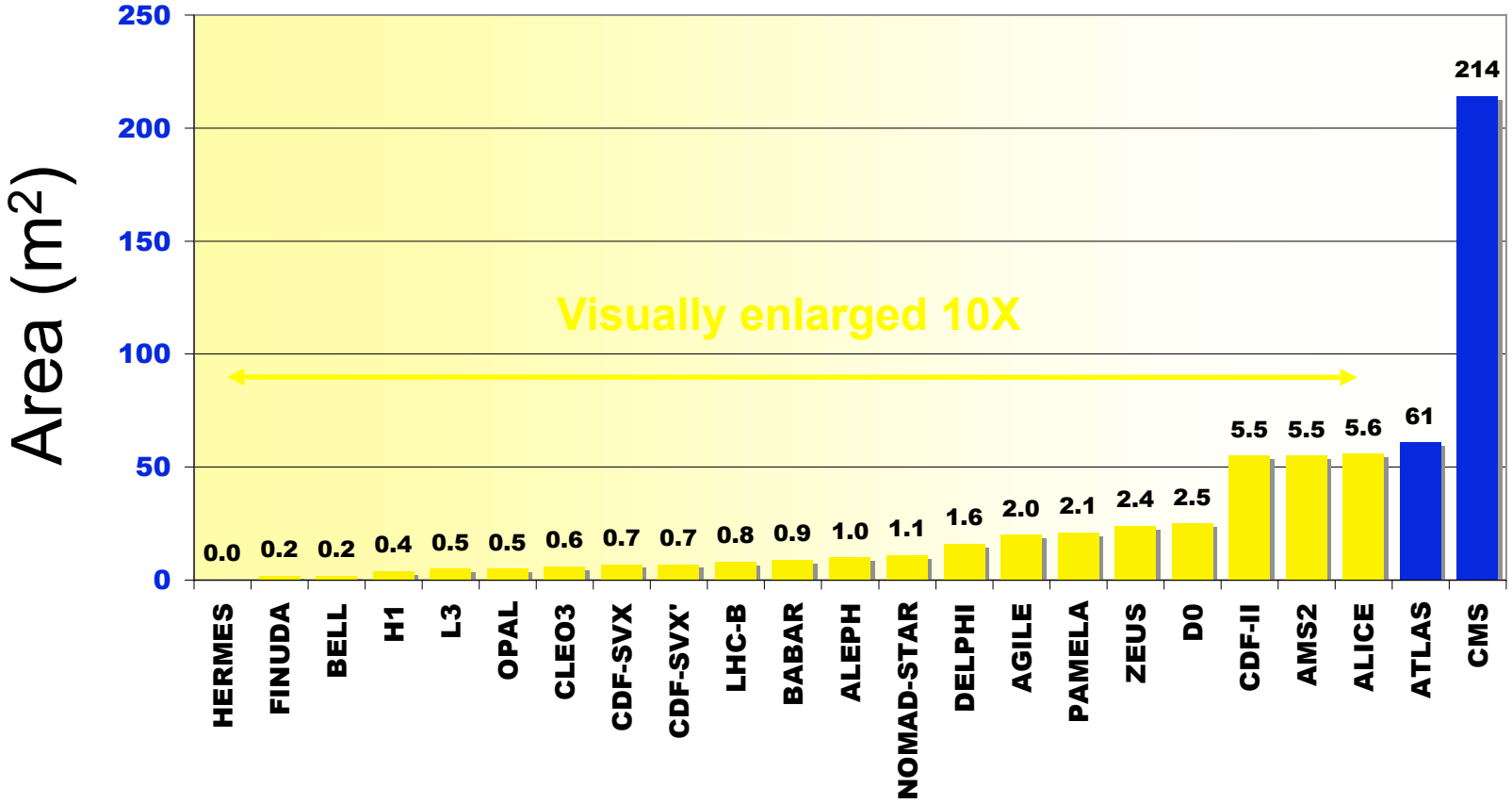
Tracking Volume



volume 24.4 m^3
running temperature –10 ^{0}C

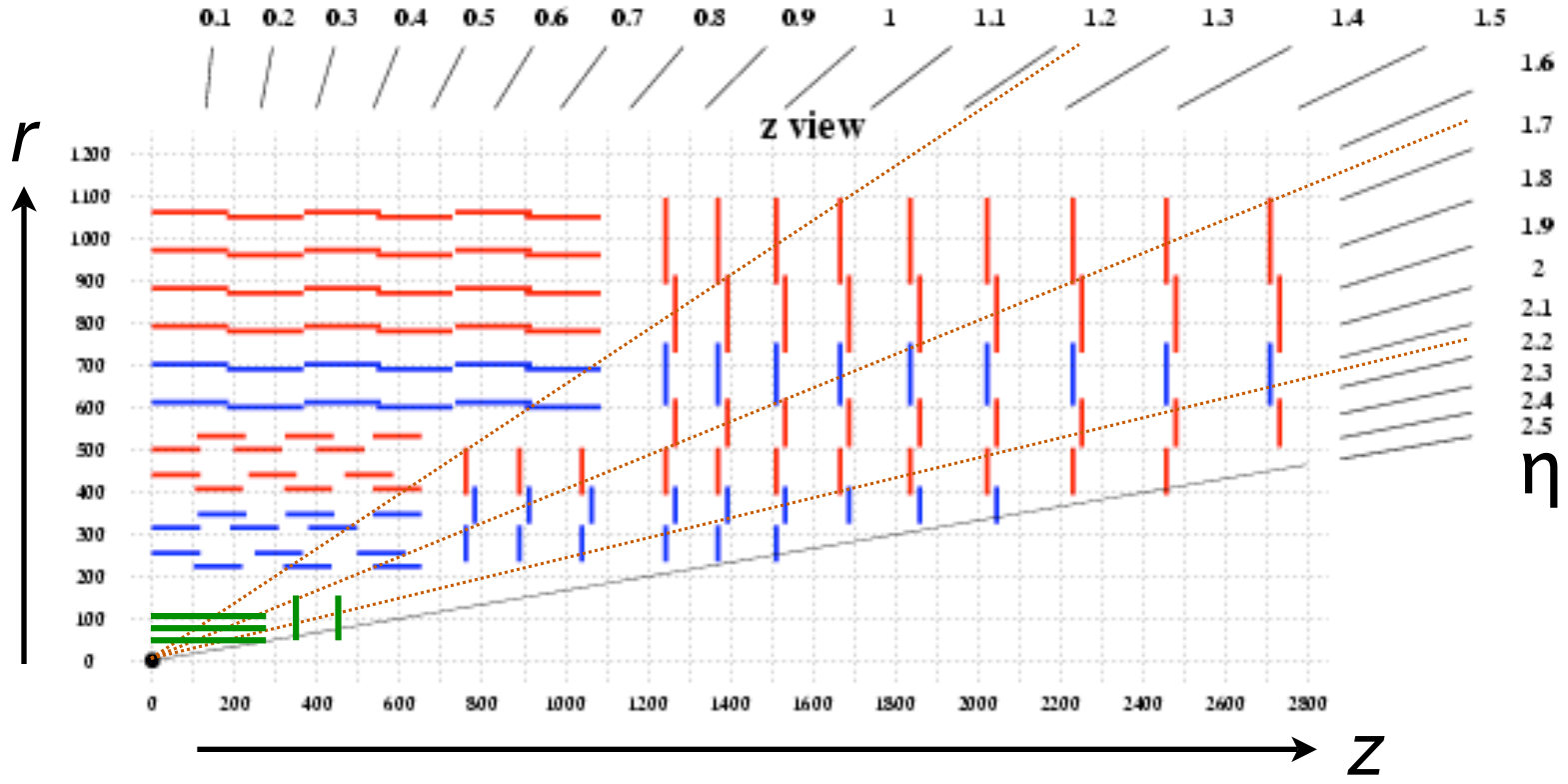
11.4 million silicon strips
65.9 million pixels in final configuration

Comparison with other Si Systems



Original slide and data provide by Marcel Demarteau (FNAL)

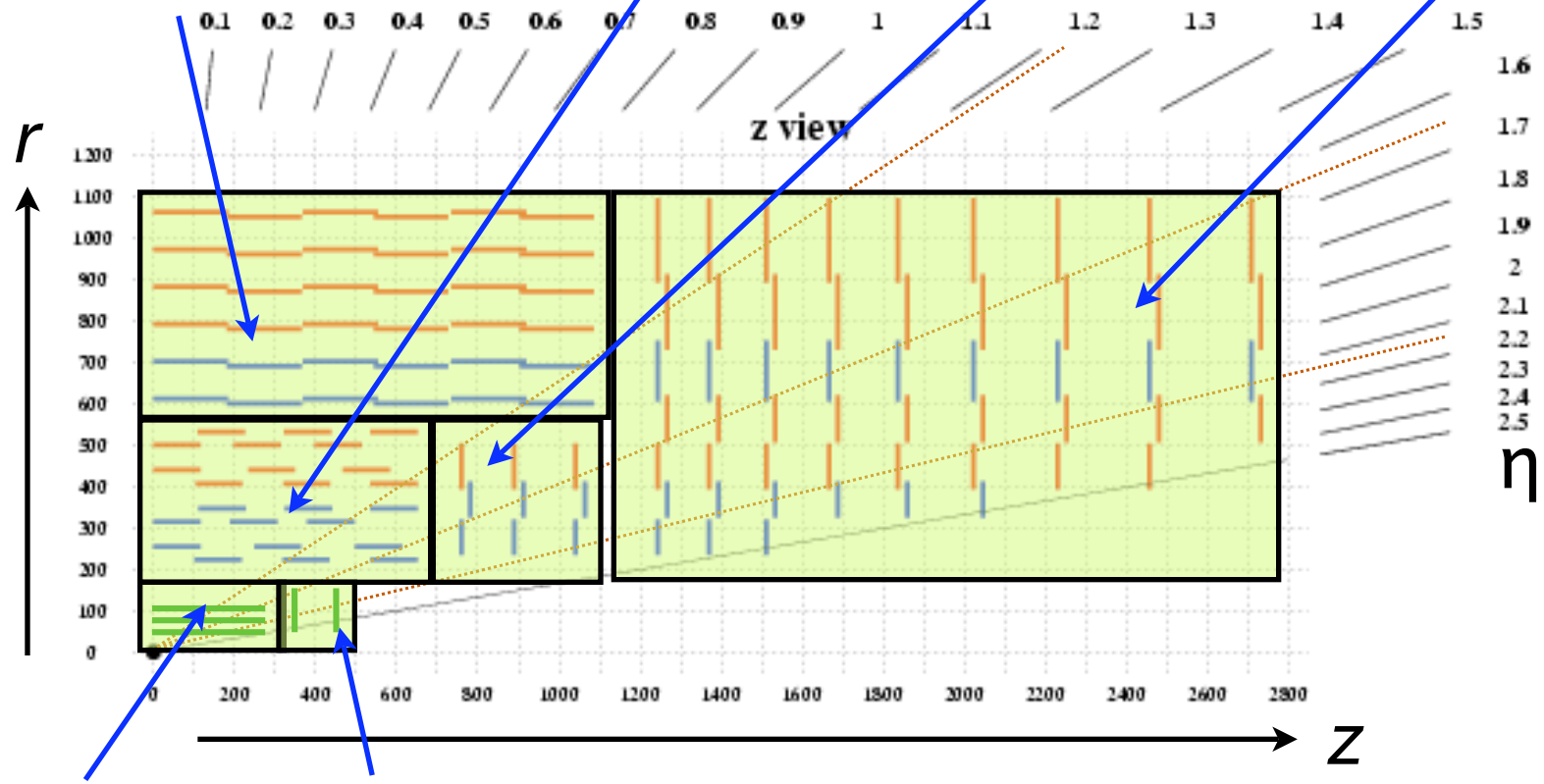
Summary of Tracking System



Red=Single Blue=Double

Double modules are made up from two single sided modules glued back-to-back

Summary of Tracking System



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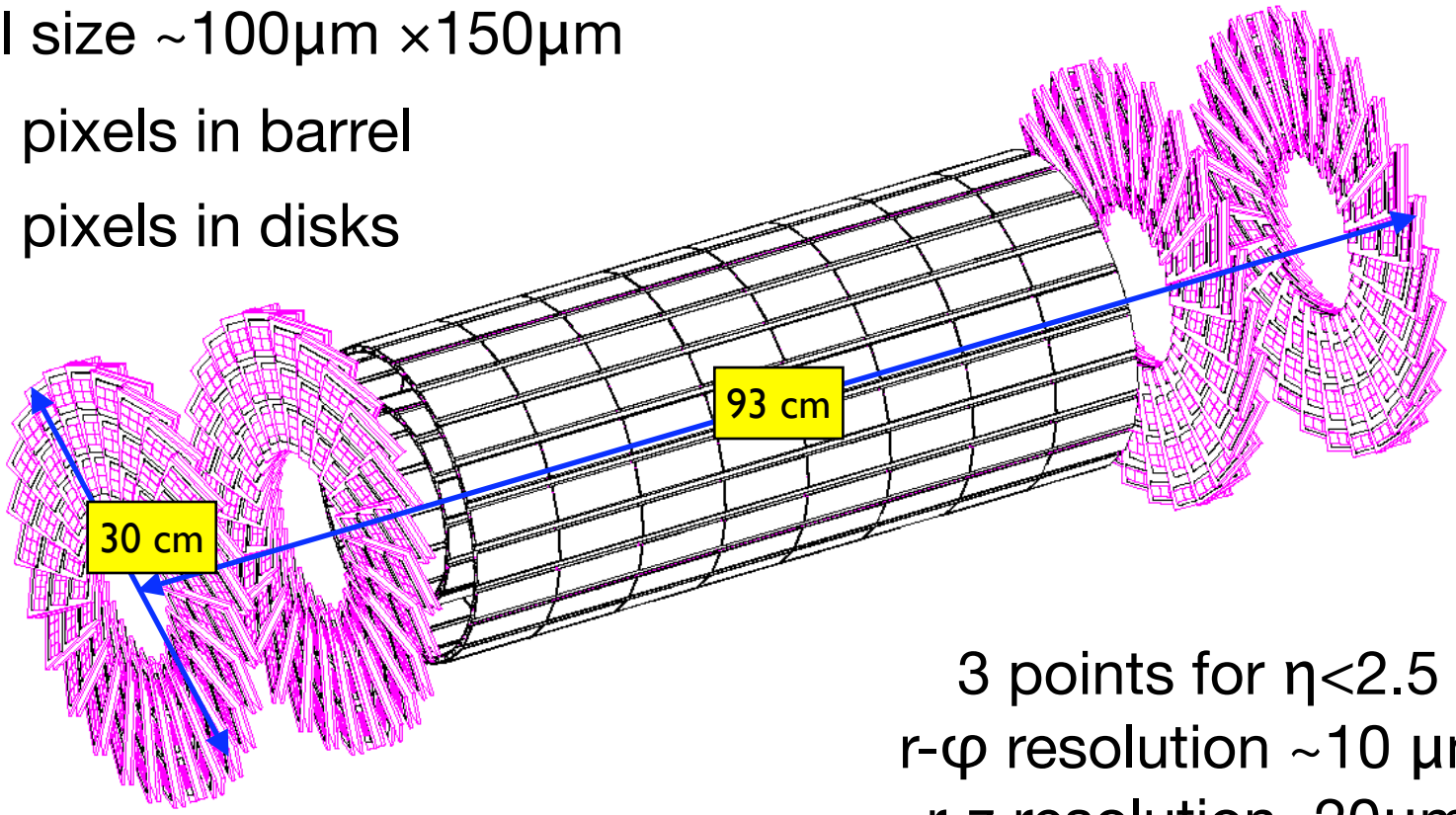
Pixel Tracker

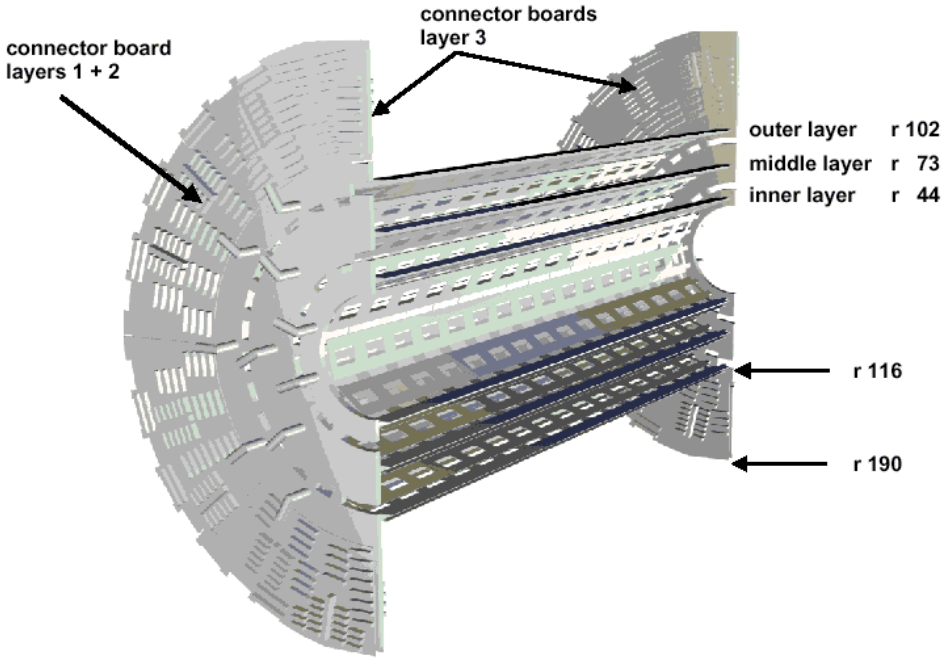
- Barrel layers at r=4, 7, 11 cm
- Two disks at each end, z=34, 46 cm
- Pixel size ~100μm ×150μm
- 48M pixels in barrel
- 18M pixels in disks

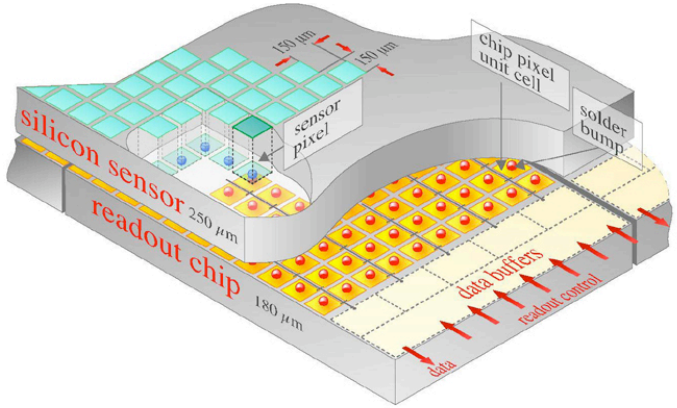


3 points for η<2.5
r-φ resolution ~10 μm
r-z resolution~20μm

Barrel Pixel Geometry

	barrel 1	barrel 2	barrel 3
radius in mm	41.05 - 46.46	70.16-75.55	98.88-104.26
faces in phi	18	30	42
detector modules/half (1)	128/32	224/32	320/32
readout chips	2304	3840	5376
pixels (100*150)	9.6M	16M	22.4M
readout links	288	480	352





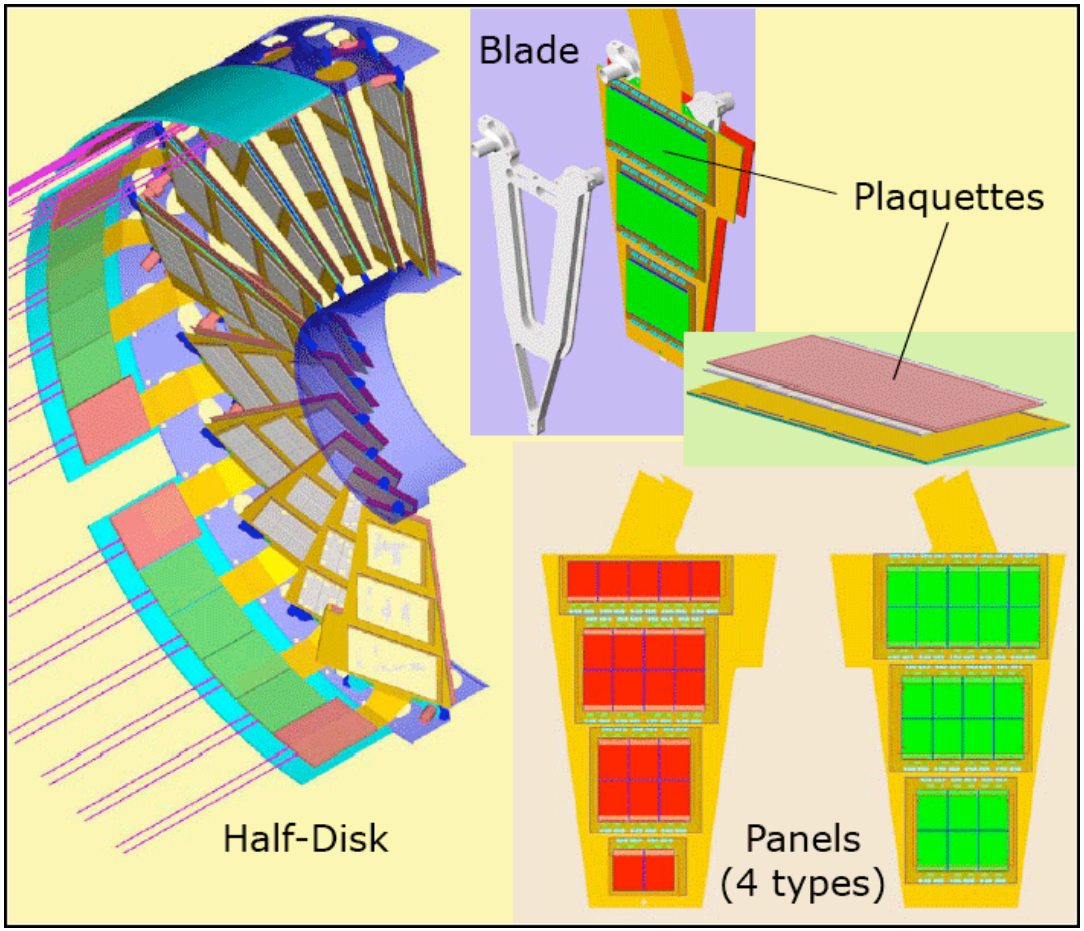
1 barrel ladder = 8 detector modules

2.2 mm gaps in Z

Left and right shells

Forward Pixels

- 24 blades in each disk
- Blades rotated by 20^{o} for charge sharing (Lorentz angle, track inclination)
- 7 detector modules per blade (4 on front and 3 on back of the blade)
- 45 read out chips/blade
- Room for another disk @ z=58.5 cm if needed



Microstrip Detectors

- Single-sided detectors cut from 6” wafers
  - ‘Double-sided’ achieved by back-to-back stereo and axial modules.
  - Longest strip length: ~2x10 cm
  - Disk modules have trapezoidal shapes
- Front-end electronics, optical hybrids, fiber optics, FEC, FED, etc common to all 3 sub-systems
- Shell, disk, barrel, and sector mechanics
- Beyond the front-end electronics many elements of the readout chain are similar or identical with those in the pixel systems.

TIB/TID (Inner Barrel / Inner Disk)

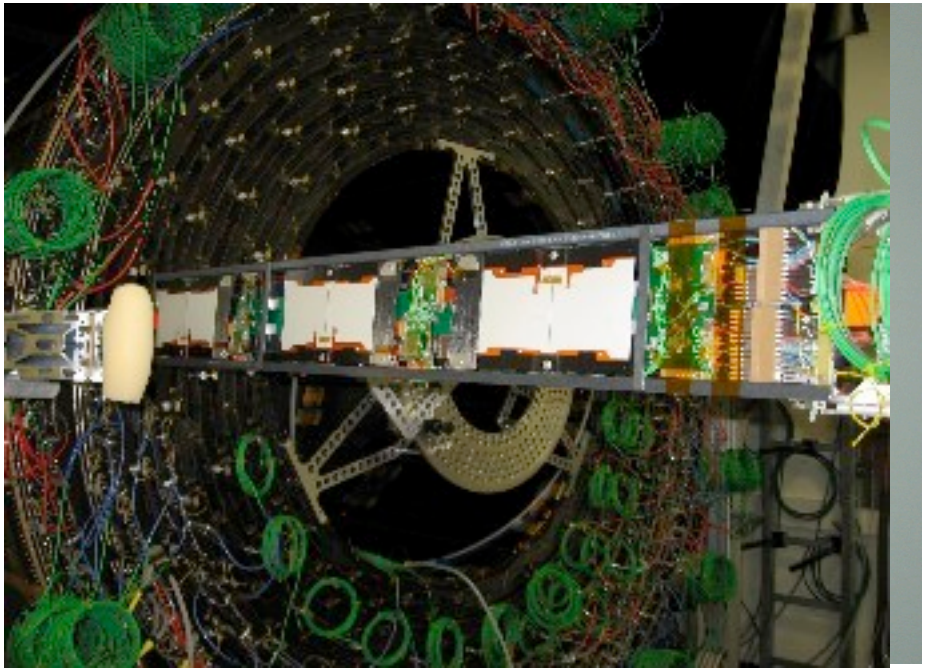
Layer #	Avg. radius	Modules in phi	Total # of modules	APV / det	Pitch phi	Pitch stereo	Total # of APVs
TIB1	255	26-30	336	6 + 6	80	80	4032
TIB2	340	34-38	432	6 + 6	80	80	5184
TIB3	430	44-46	540	4	120	-	2160
TIB4	520	52-56	648	4	120	-	2592

Ring #	Modules in phi	N of rings in z	Total # of modules	APV / det	P1/P2 phi	P1/P2 stereo	Total # of APVs
TID1	24	6	144	6 + 6	81/112	81/112	1728
TID2	24	6	144	6 + 6	113/143	113/143	1728
TID3	40	6	240	4	123/158	-	960

- Inner barrel has four layers
  - 9° tilt to compensate for Lorentz effect
- TIB1 and TIB2 contain double-sided modules.
- Support structure in the form of shells with separation at z=0
  - Each half contains 6 detectors in z.
- TID disks have 3 rings that are identical to inner 3 rings of TEC disks
  - 240 single modules and 288 double modules

TOB (Outer Barrel)

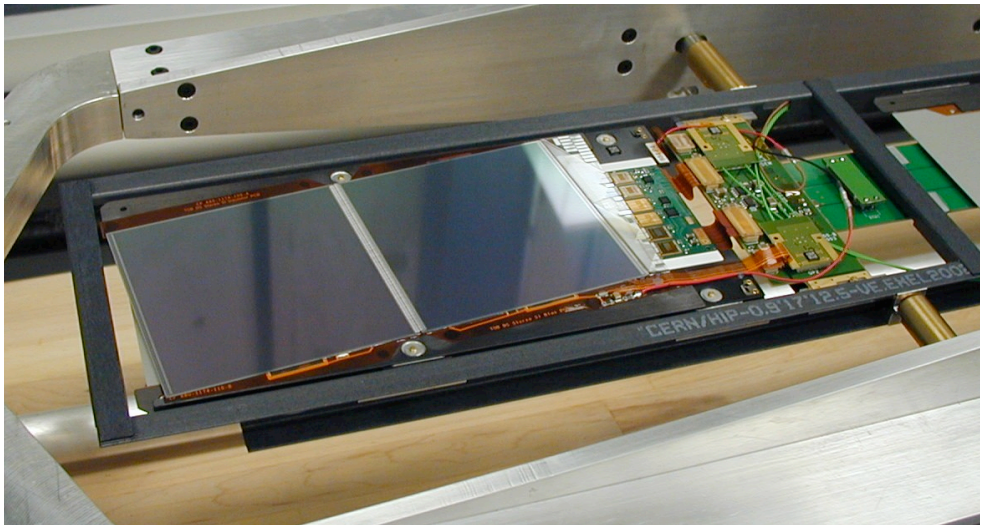
Layer #	Avg. radius	Modules in phi	Total # of modules	APV / det	Pitch phi	Pitch stereo	Total # of APVs
TOB1	608	42	504	4 + 4	183	183	4032
TOB2	692	48	576	4 + 4	183	183	4608
TOB3	780	54	648	4	183	-	2592
TOB4	868	60	720	4	183	-	2880
TOB5	965	66	792	6	122	-	4752
TOB6	1080	74	888	6	122	-	5328



5208 Modules, organized into 688 rods which go into 6 layers on the +/-Z sides of TOB “wheel”

- Layers 1, 2 Stereo
- Overlap in phi, Z
- No tilting for Lorentz effect
- Rods notched at ends to provide overlap at Z=0

TOB Modules



- Tracker Outer Barrel consists of 5208 modules

Two sensors per module

- ~10 cm x 10 cm sensors, 500μ thick
- Stereo = 100 mrad tilt angle
- Small non-overlap region

Layers 1,2 are double-sided -- contain back-to-back axial+stereo modules

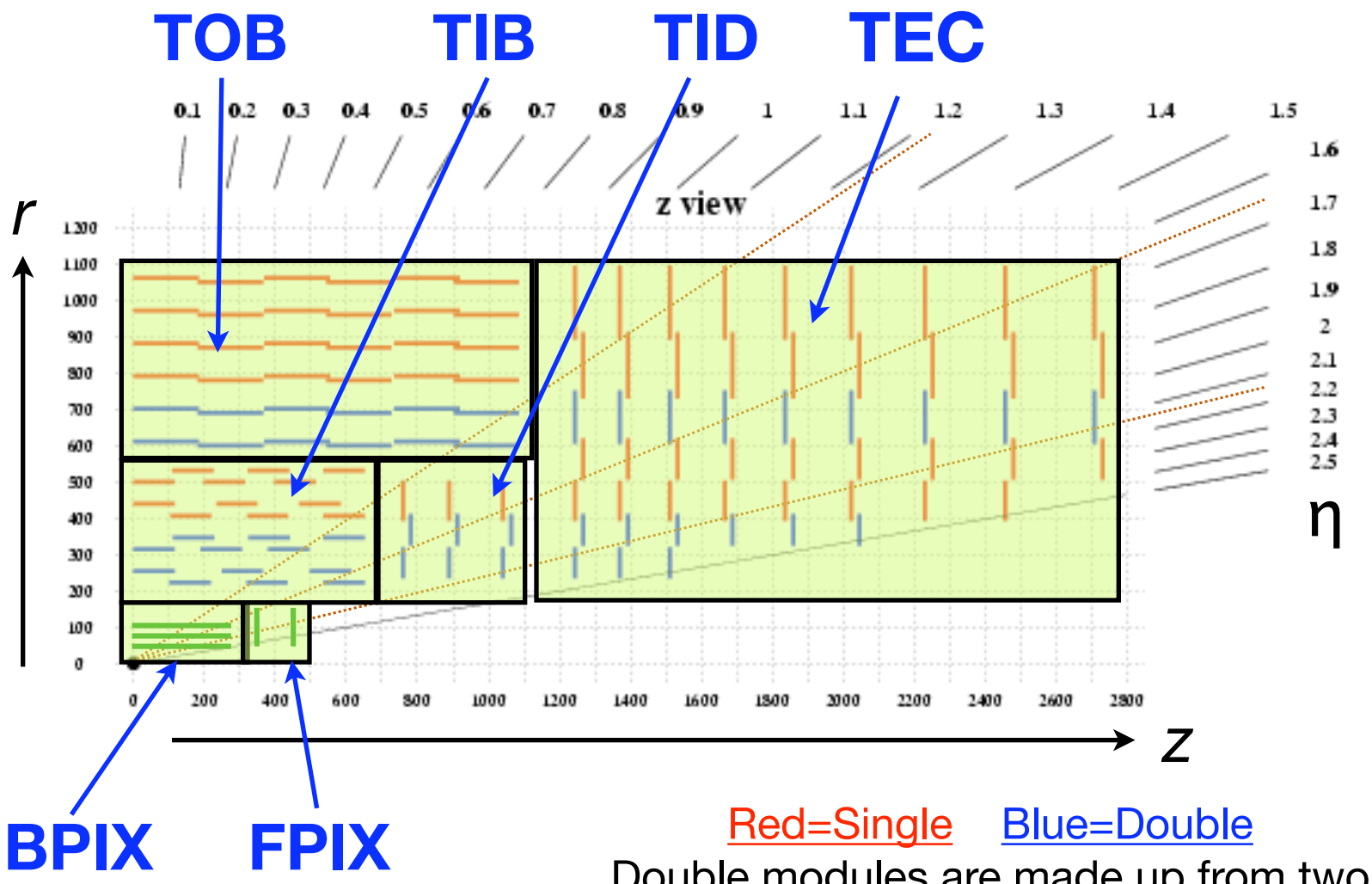
- “Double”, “twin”, “back-to-back”,“glued”
- 12 modules per DS rod; 6 for SS rods

TEC (End Cap) System

Ring #	Modules in phi	N of rings in z	Total # of modules	APV / det	P1/P2 phi	P1/P2 stereo	Total # of APVs
TEC1	24	6	144	6 + 6	81/112	81/112	1728
TEC2	24	12	288	6 + 6	113/143	113/143	3456
TEC3	40	16	640	4	123/158	-	2560
TEC4	56	18	1008	4	113/139	-	4032
TEC5	40	18	720	6 + 6	126/156	126/156	8640
TEC6	56	18	1008	4	163/205	-	4032
TEC7	80	18	1440	4	140/172	-	5760

- Contains 7 rings
  - Rings 1-3 identical with TID rings
  - Rings 1, 2, and 5 double-sided
  - Number of rings per disk decreases with increasing |z|

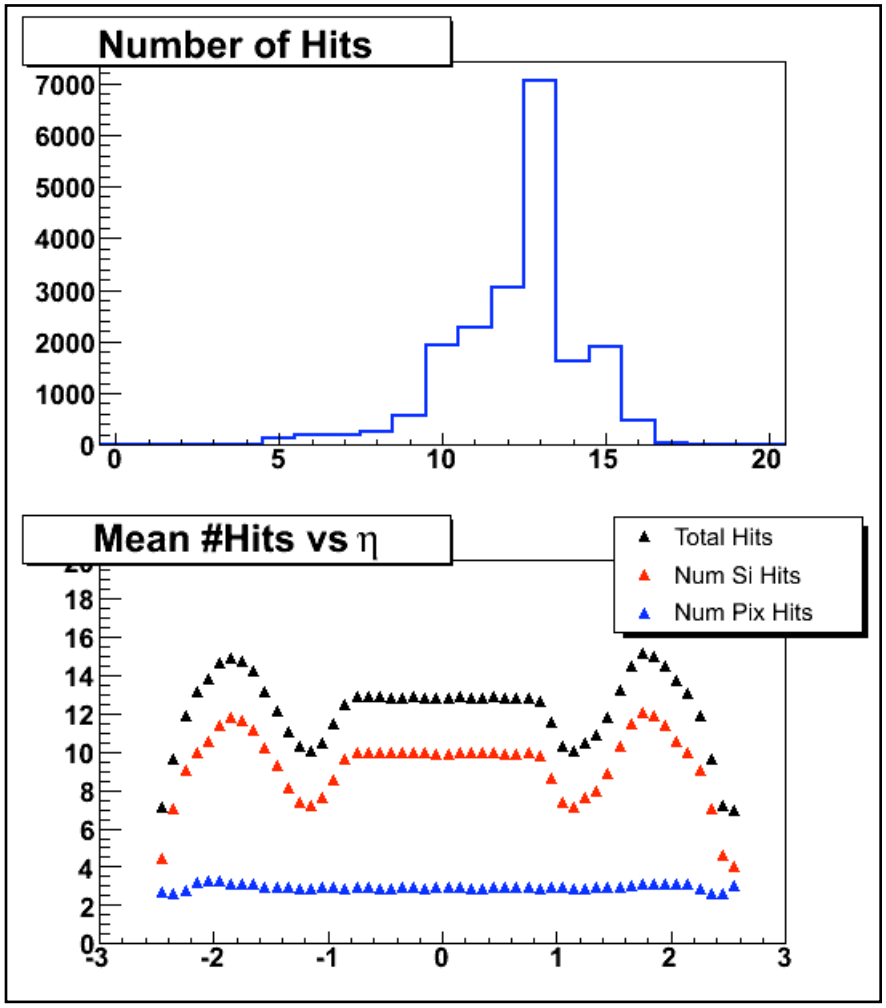
Summary of Tracking System



Red=Single Blue=Double

Double modules are made up from two single sided modules glued back-to-back

Number of Points



Sub-Detector	*Channels*
Pixels	**66 x 10^6**
Silicon microstrips	**11.4 x 10^6**
ECAL crystals	**0.076 x 10^6**
Preshower strips	**0.137 x 10^6**
HCAL	**0.01 x 10^6**
Muon chambers	**0.576 x 10^6**
TOTAL	**78.2 x 10^6**

Tracker Occupancy: 1-3%

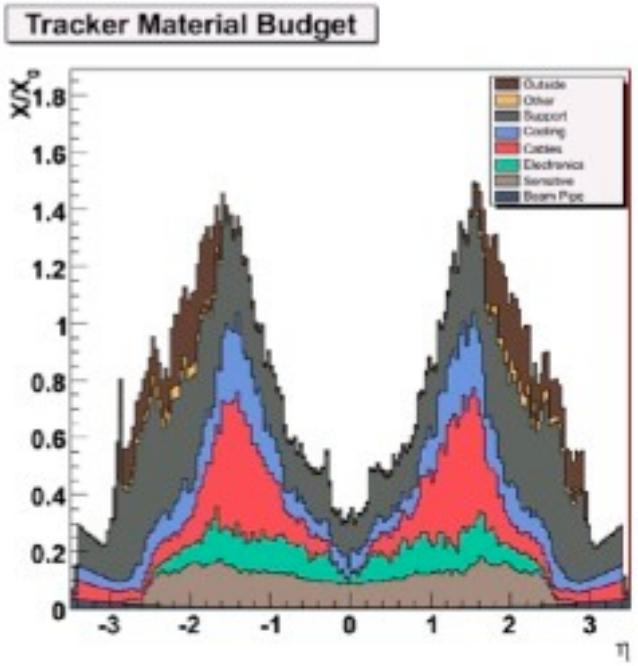
Few hits on a track, but they are very precise

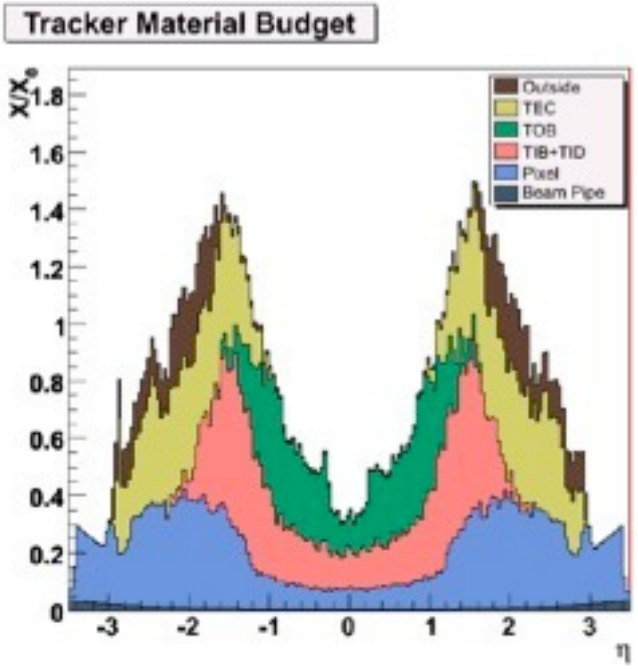
Comparison of ATLAS/CMS

	ATLAS	CMS
Tracker Radius	110 cm	115 cm
Tracker Length	7 m	5.4 m
Solenoid Field	2T	4T
Pixels		
# Barrel Layers	3	3
Barrel Radii	5.05, 9.85, 12.25	4.4, 7.5, 10.2
#Fwd Disks	3	2(3)
Disk Positions	49.5, 56.0, 65.0 cm	35.5, 48.5, 61.5 cm
Microstrips		
#Barrel Layers	4	10
# Disk Layers	9	9
Radial Span	25-50 cm	20-110 cm
Measurement points in central region	7 precision + 36 TRT	13 precision

ATLAS tracker includes straw layers

Material Budget

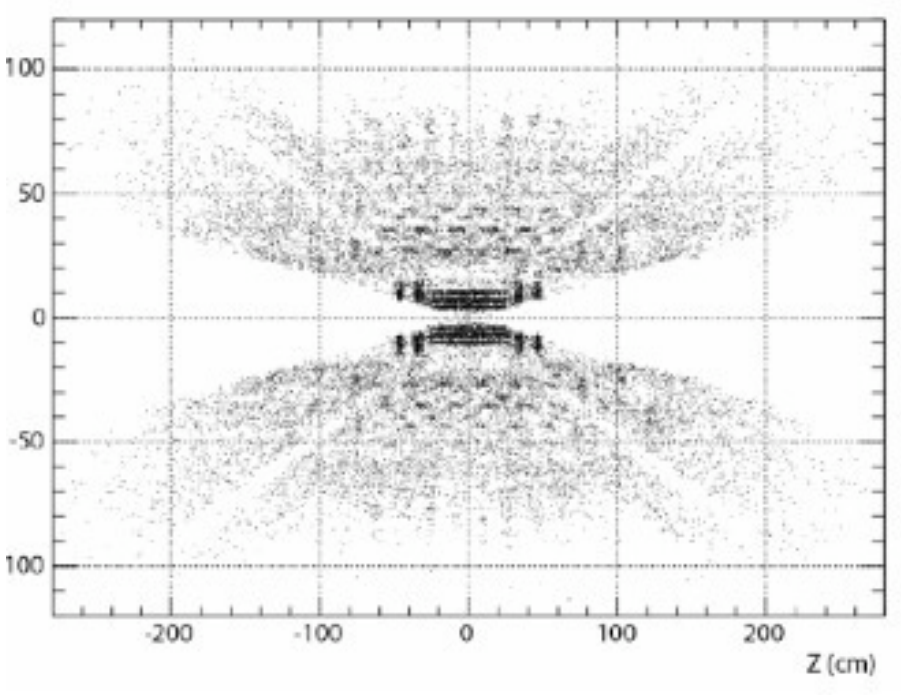




- There is a significant amount of material in the Tracker
  - More pronounced at higher η
  - Major elements include the sensitive elements, electronics, support mechanics, cables, and cooling
    - Driven in part by radiation considerations: -10 °C, pixel replacement
    - Also, large number of readout elements (control cables), choice of cooling pipe material

Photon Conversions

- Simulation of conversions in Tracking System material
  - Partly inspired by similar CDF study
  - Physics interest was H→γγ mode
  - Pixel elements are clearly visible and to some extent TIB
  - TOB blurred due to inefficiencies in reconstructing short tracks without any DS detectors
  - Can be used as a cross-check of detailed material budget study.



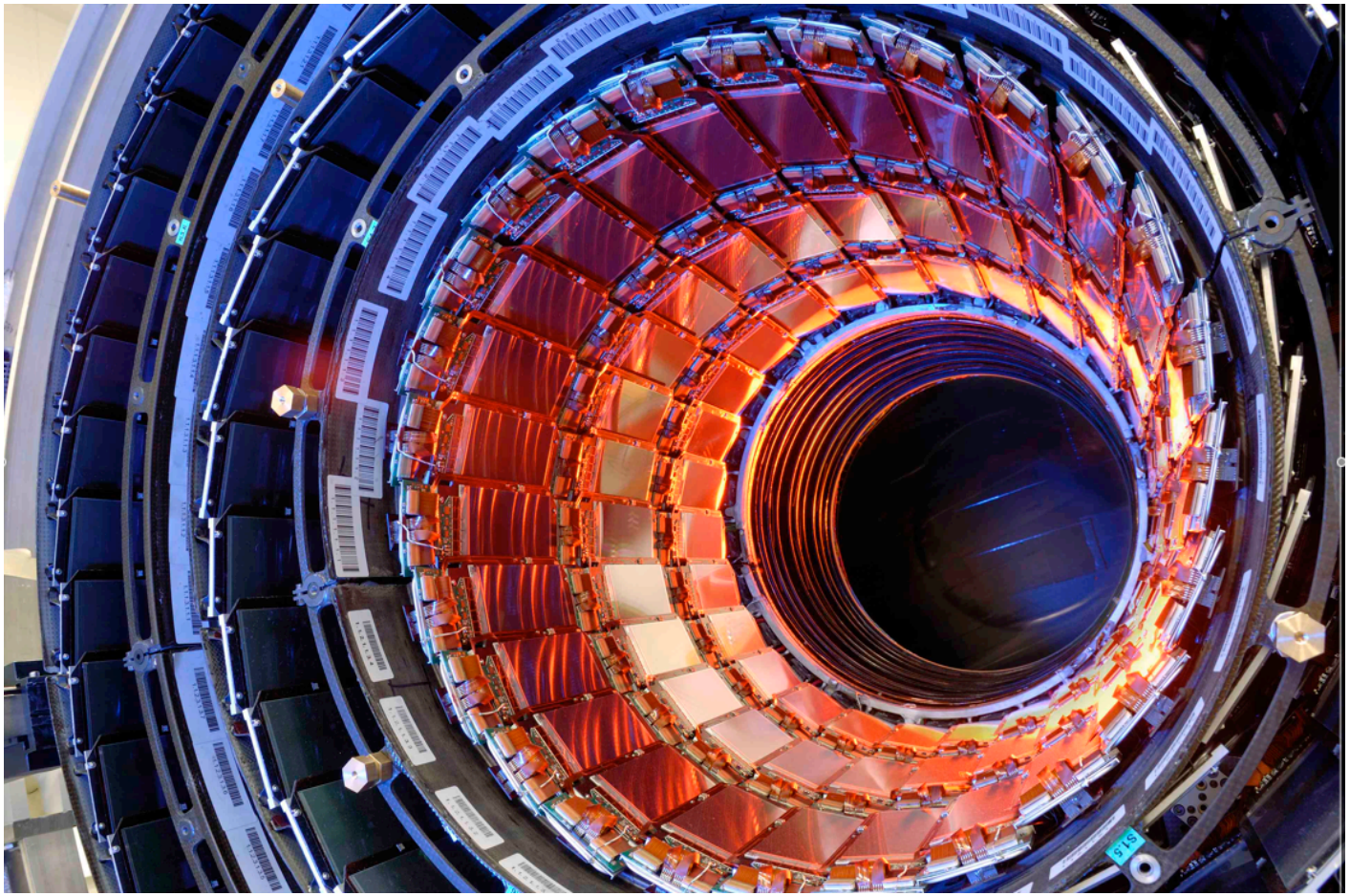
Reconstructed γ conversions
Study by Nancy Marinelli

Tracker Assembly Status

- Strip tracker sub-detectors completed last year
  - Quality of detectors is extremely high
    - Dead or noisy strips < 3/1000
    - Signal-to-noise better than 25:1
  - Complete detector has been assembled at the Tracker Integration Facility (TIF) at CERN

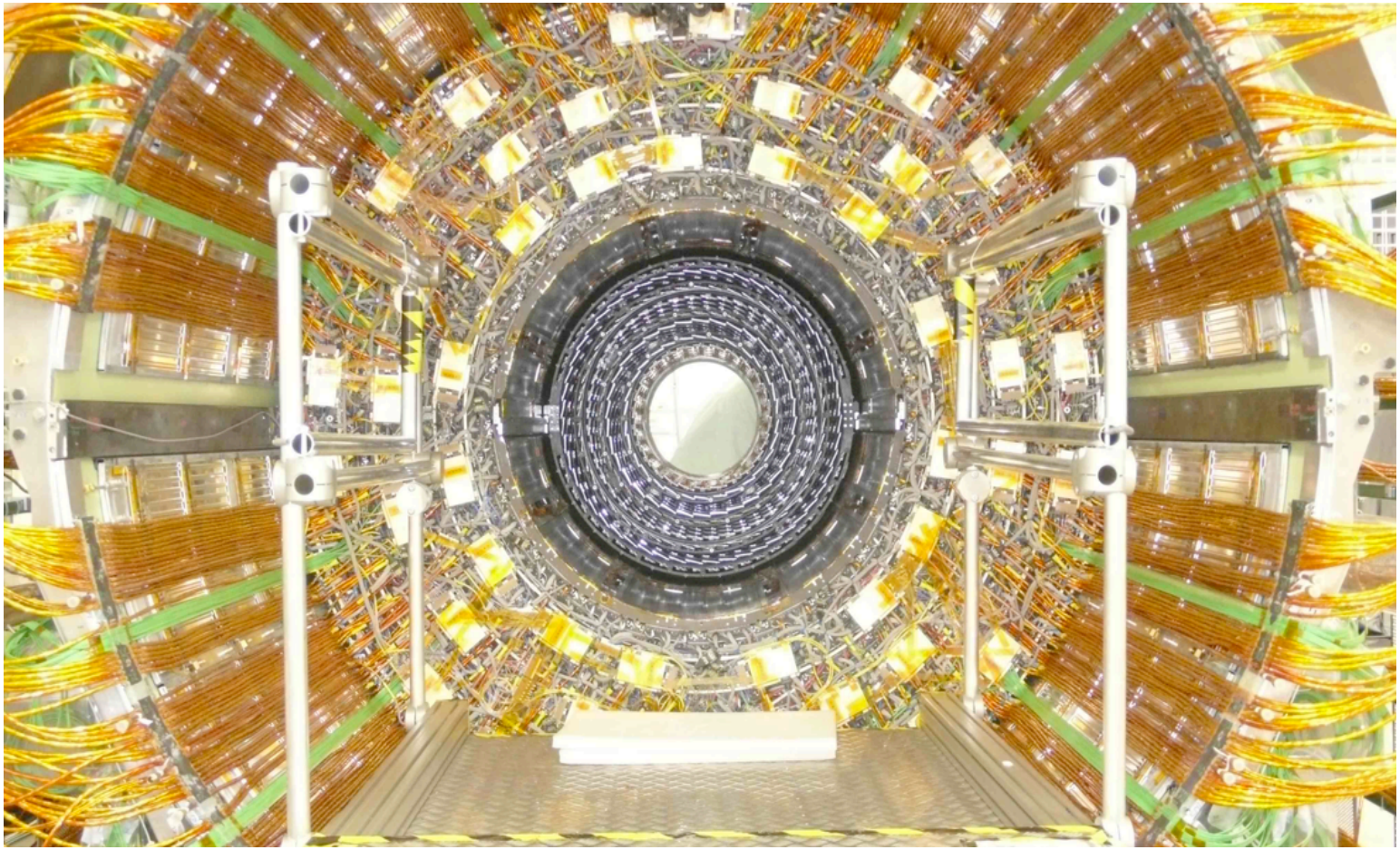
- Barrel and Forward Pixels still completing production
  - With recent cancellation of pilot run at end of 2007, the pixels should now be ready for the start of initial data-taking

Assembly of the Tracker at TIF



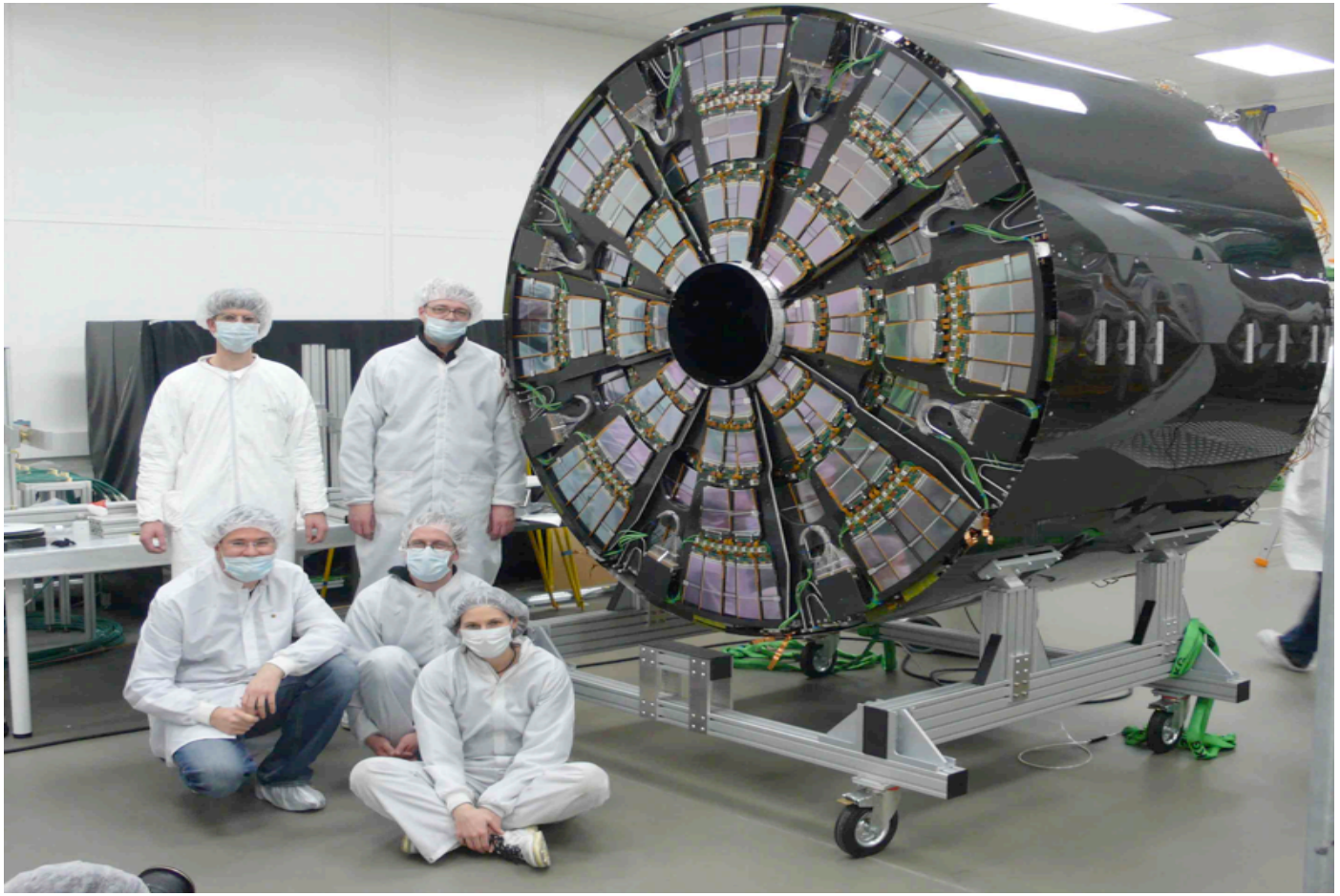
TIB / TID + at the TIF

Assembly of the Tracker at TIF



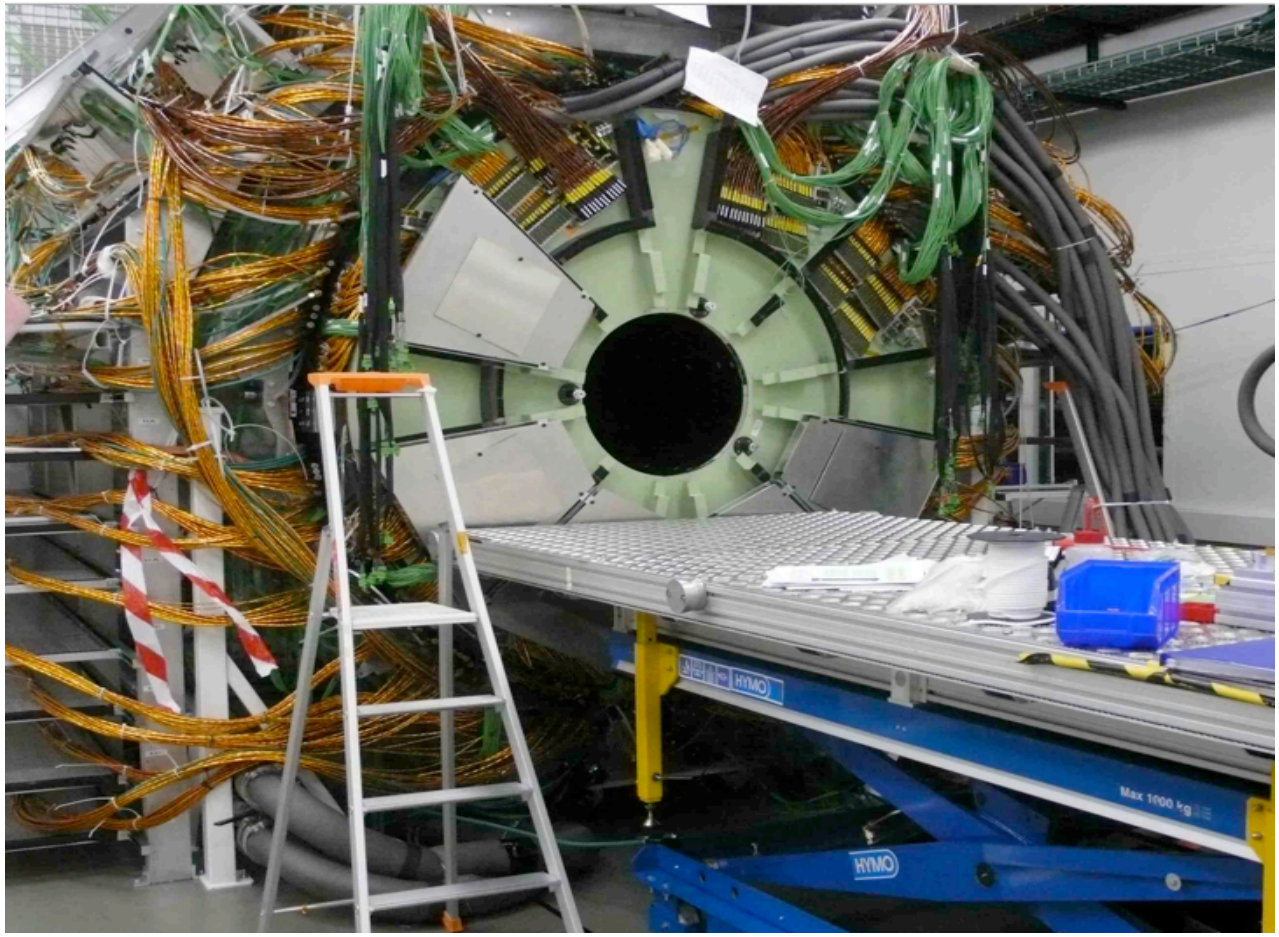
TIB + Integrated into TOB + late December 2006

Assembly of the Tracker at TIF



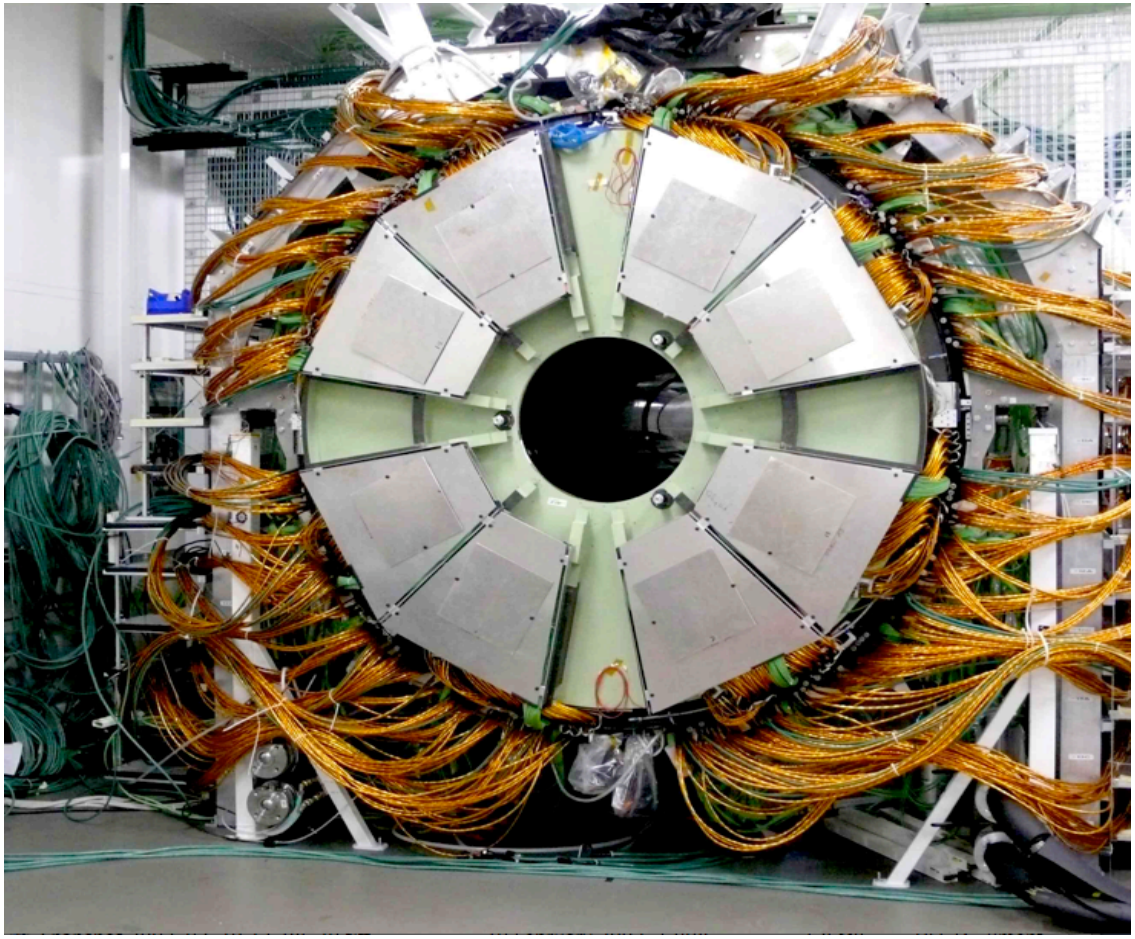
TEC + Arrives at TIF from Aachen

Assembly of the Tracker at TIF



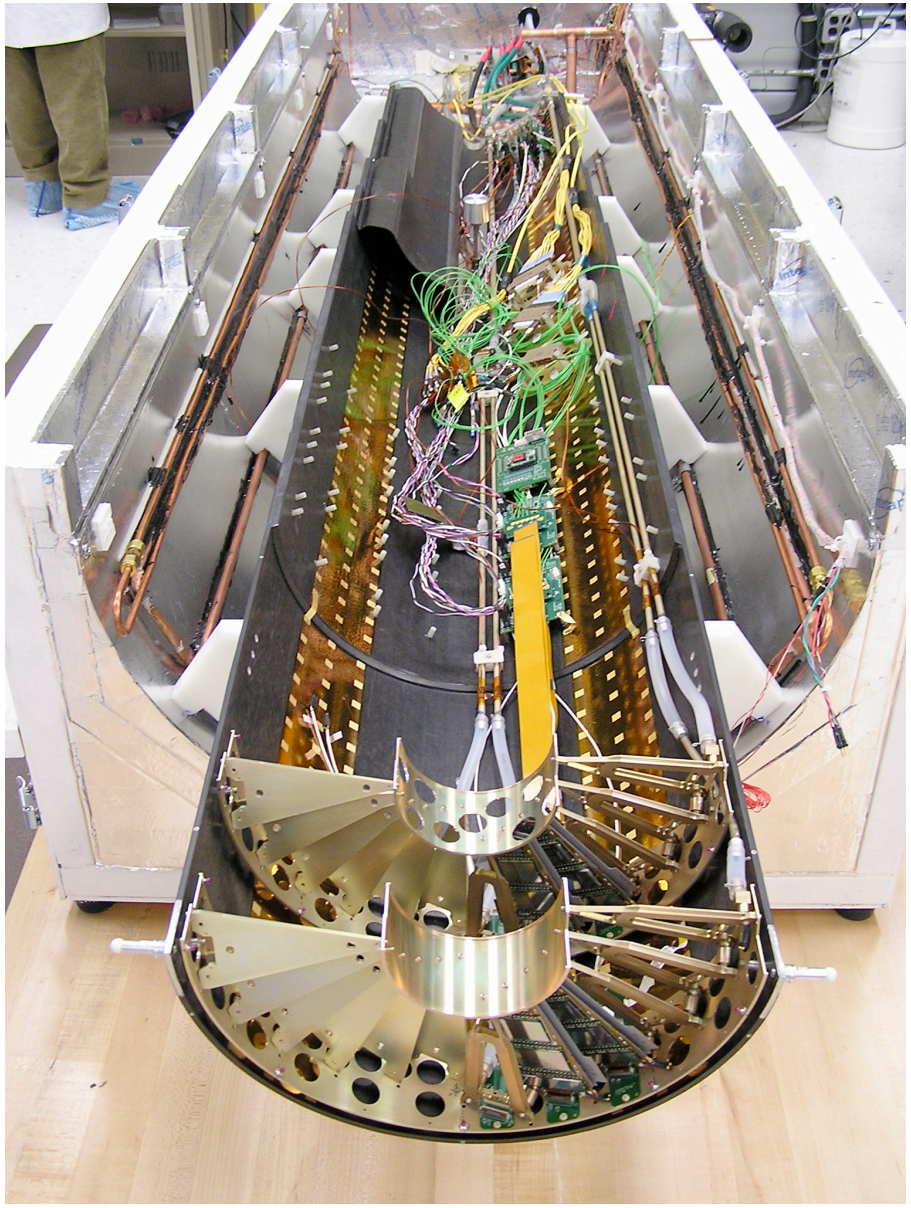
TEC+ Integrated into Tracker Support Tube

Assembly of the Tracker at TIF



TEC+ Integrated into Tracker Support Tube

Forward Pixel Detectors for Pilot Run

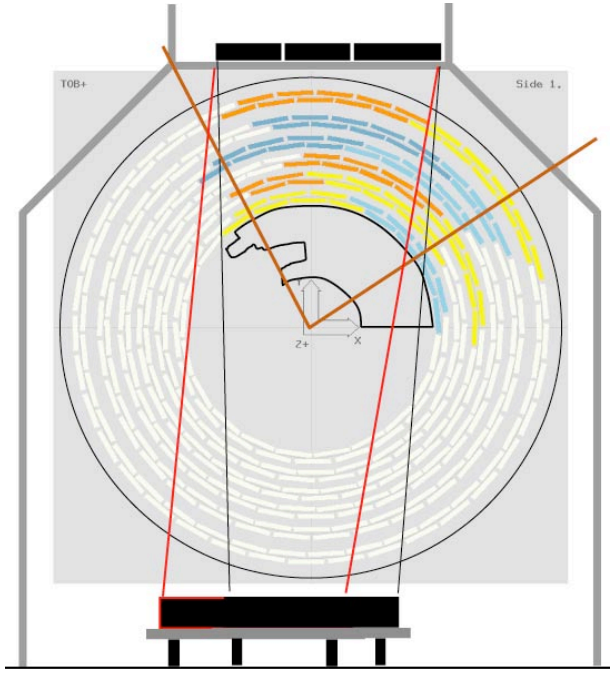


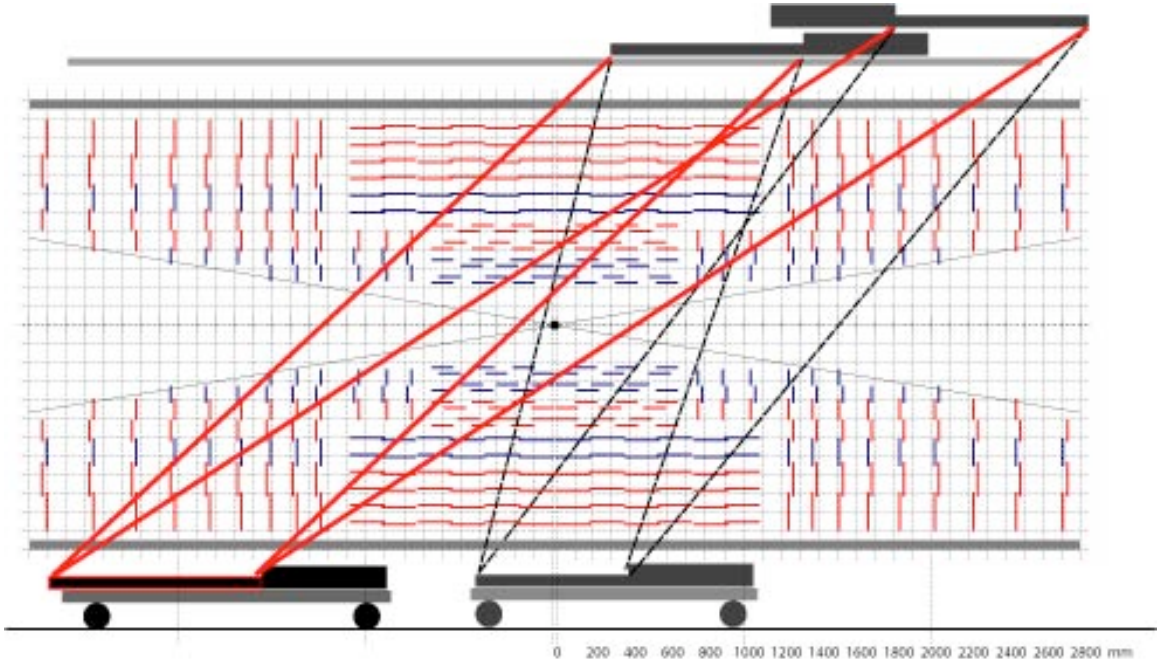
Tracker Commissioning at TIF

- Complete strip tracker assembled at TIF
- From January-July 2007 about 25% of the detector was integrated to collect tracks from cosmic rays to test system performance
  - Significant effort to setup DAQ, power, control, etc. for such a large system
  - Testing online control software, safety systems, data quality monitoring (DQM)
  - Test track reconstruction and detector performance
  - Test alignment algorithms

Tracker Commissioning at TIF

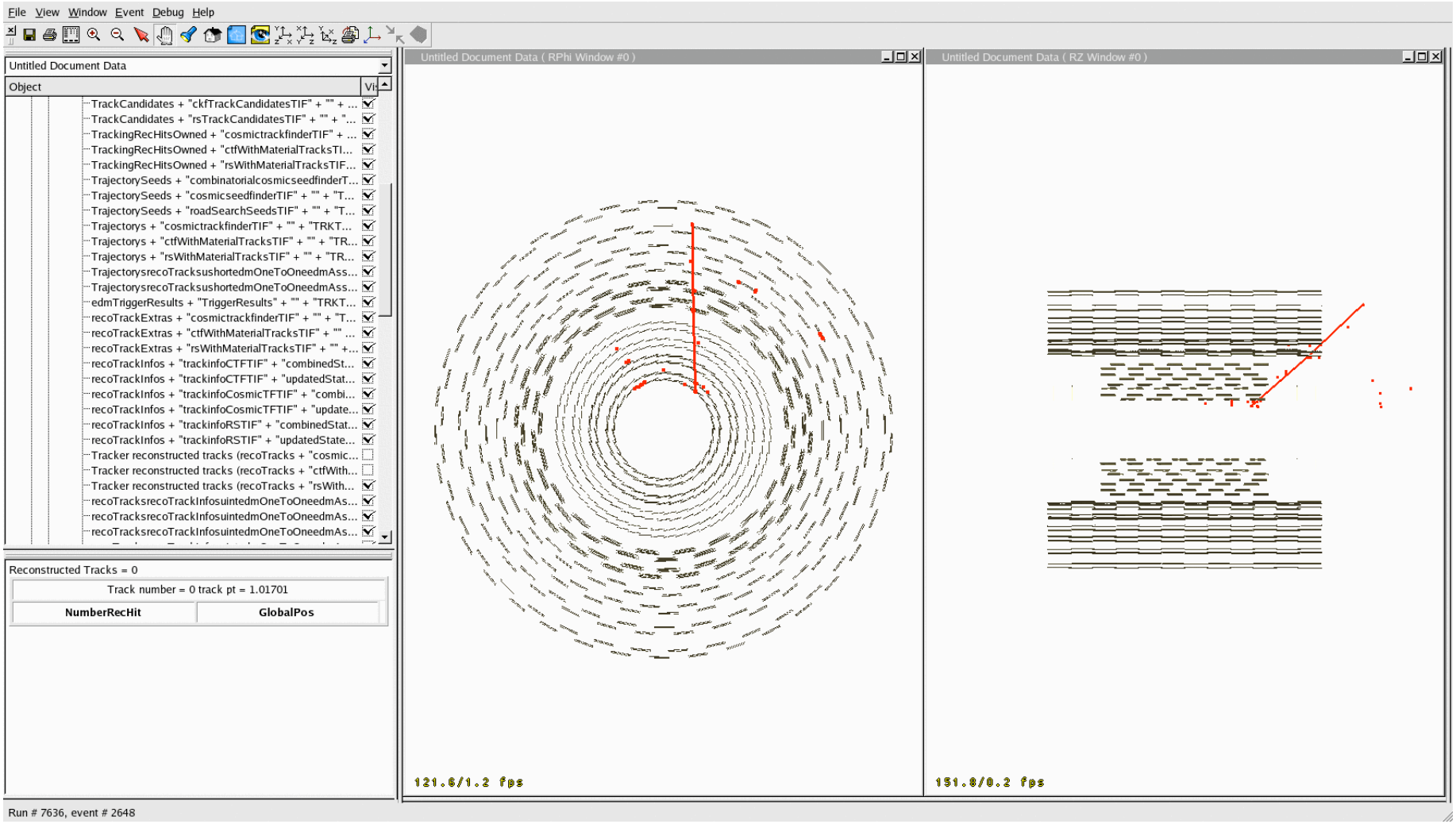
- Multiple trigger configurations to record tracks passing through different parts of the detector
  - Test all sub-detectors
  - Input for tracker alignment





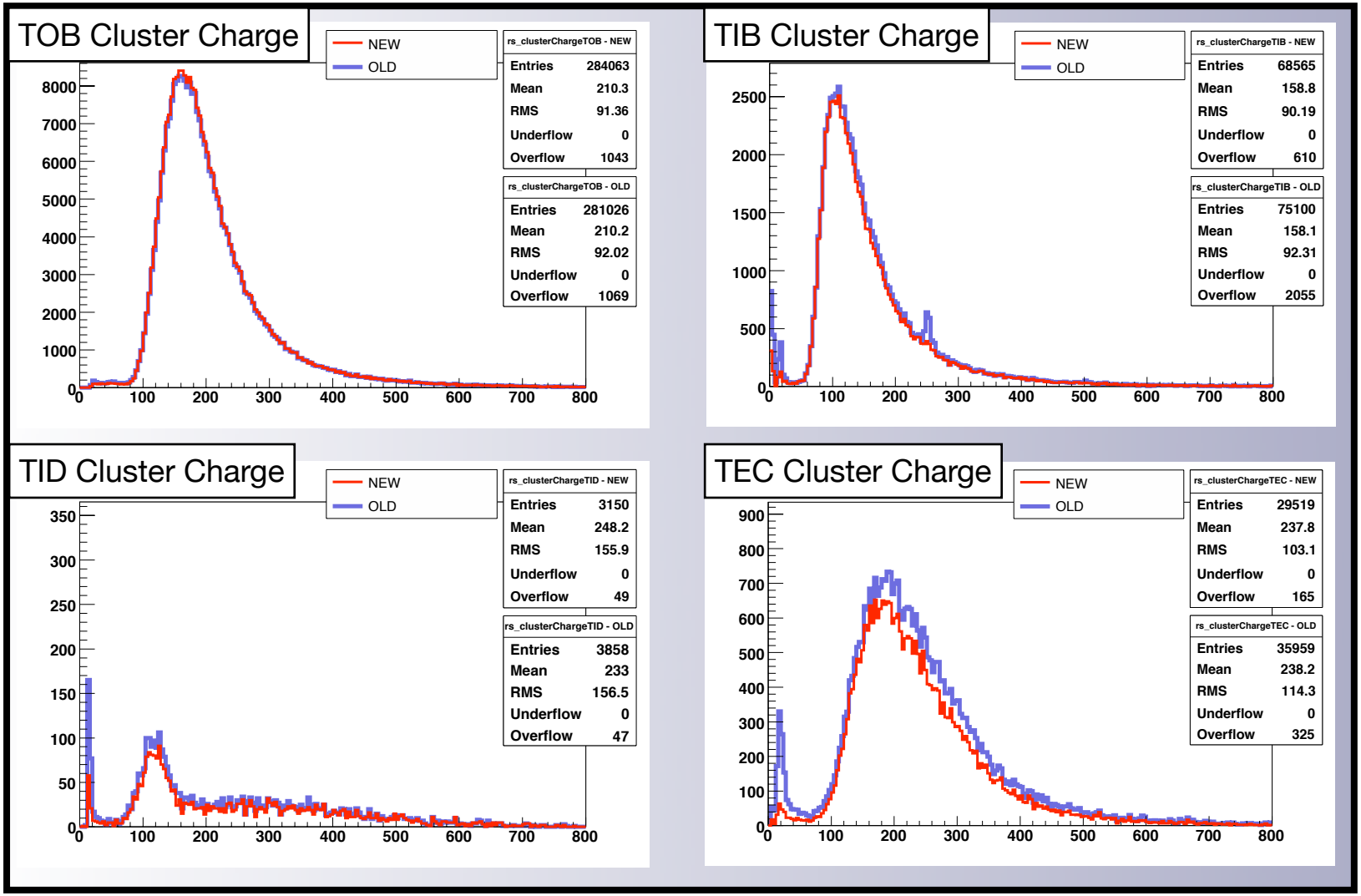
Tracker Commissioning at TIF

Reconstruction of a typical event

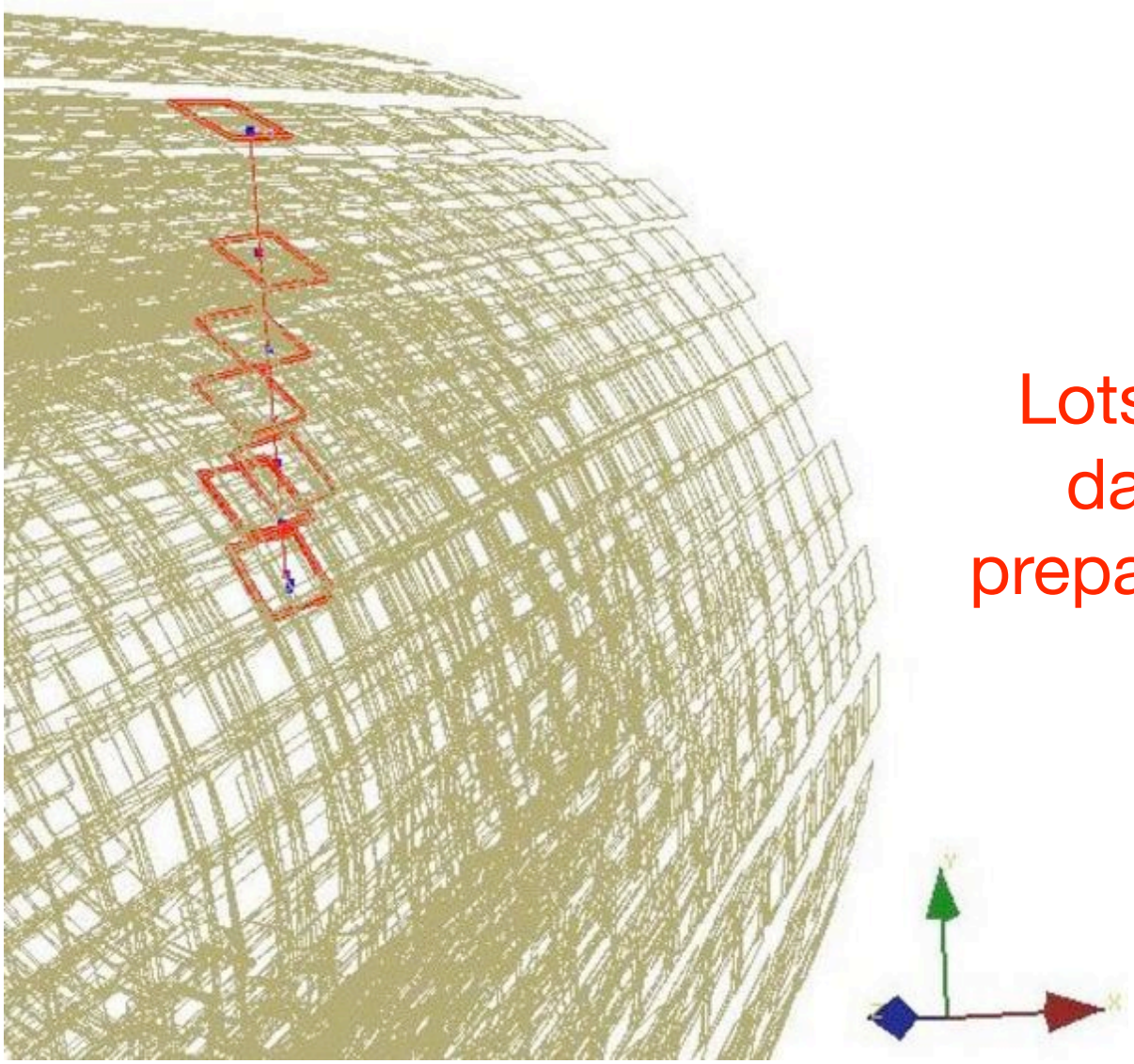


Tracker Commissioning at TIF

Cluster charge for hits on tracks -- low noise

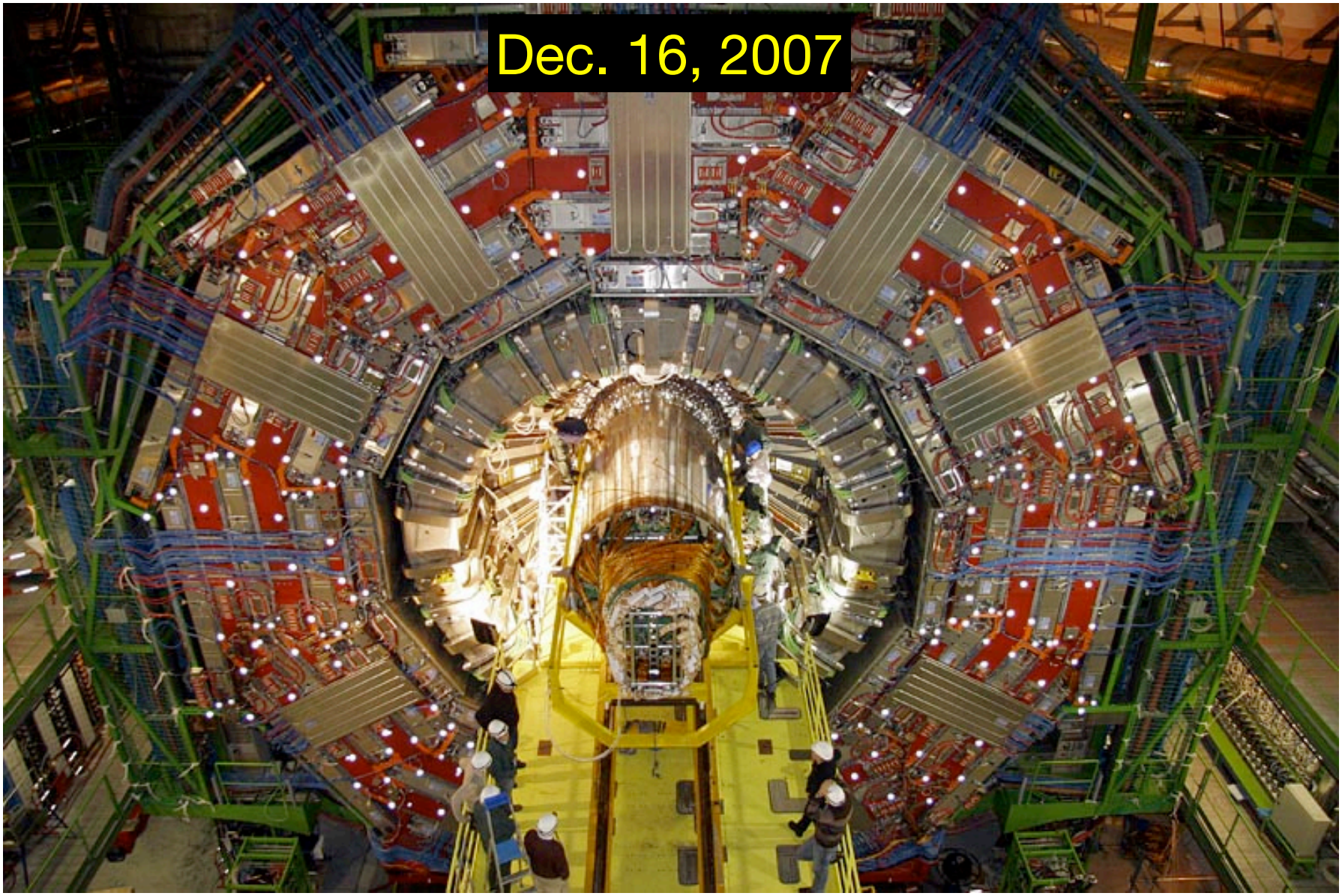


Tracker Commissioning at TIF



Lots of interesting data studied in preparation for beam

Tracker Installation at P5



Tracker Installation at P5

- Strip tracker was moved to P5 in December last year
  - Immediately installed inside CMS
  - Since then, extensive work connecting cables, cooling, etc.
  - Checkout ongoing, but should be completed within a few weeks
  - Then we will take cosmics with the full detector, with the magnetic field both off and on, to further commission the tracker as done at the TIF
- Pixel detector commissioning nearly complete
  - Pixel detectors should be installed prior to closing the detector, and will then be present for first collisions

Summary

- CMS strip tracker assembled, tested at TIF, installed at P5
  - Detector quality high
  - Performance excellent so far
- Barrel and Forward Pixels nearing completion
  - Should be ready for the start of initial data-taking
- Operation of Tracker at P5 will begin within weeks to record tracks from cosmics, in preparation for collisions coming soon after

- For more information:
  - http://cmsdoc.cern.ch/Tracker/Tracker2005/