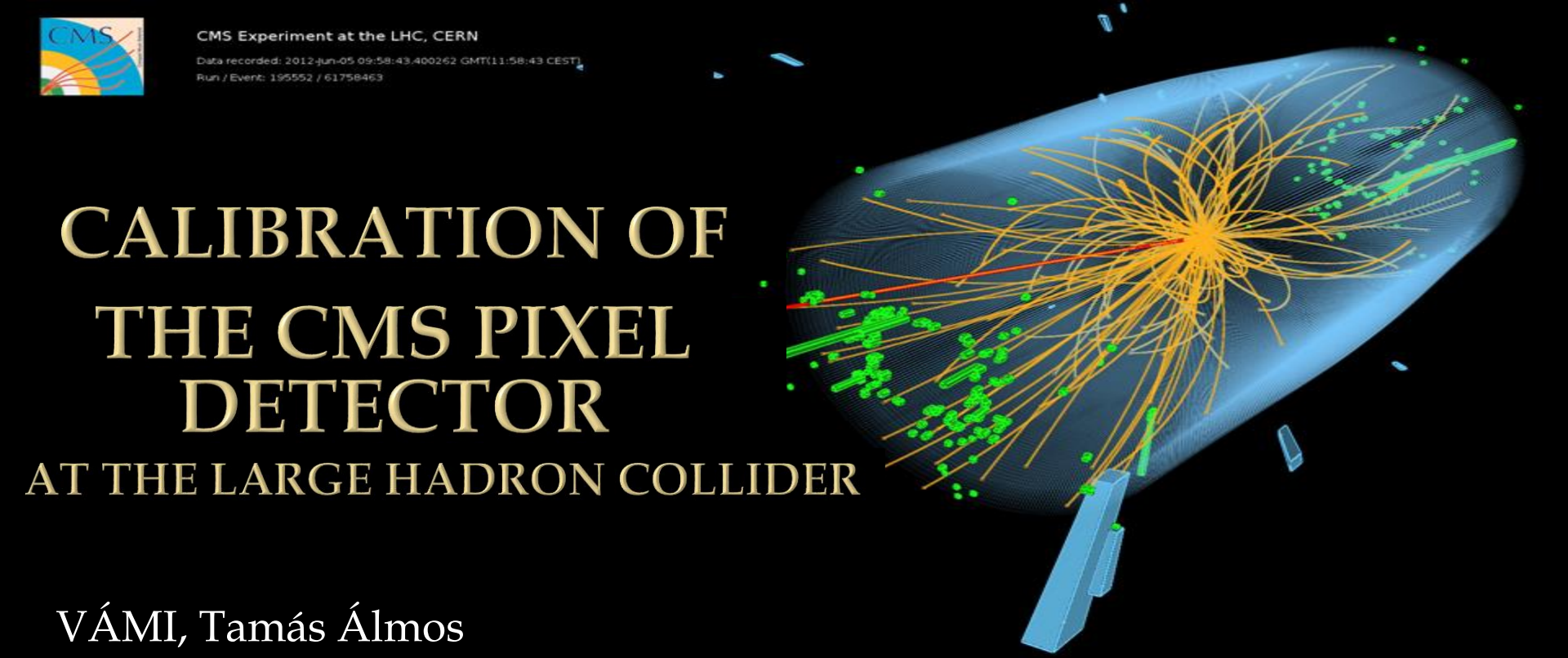


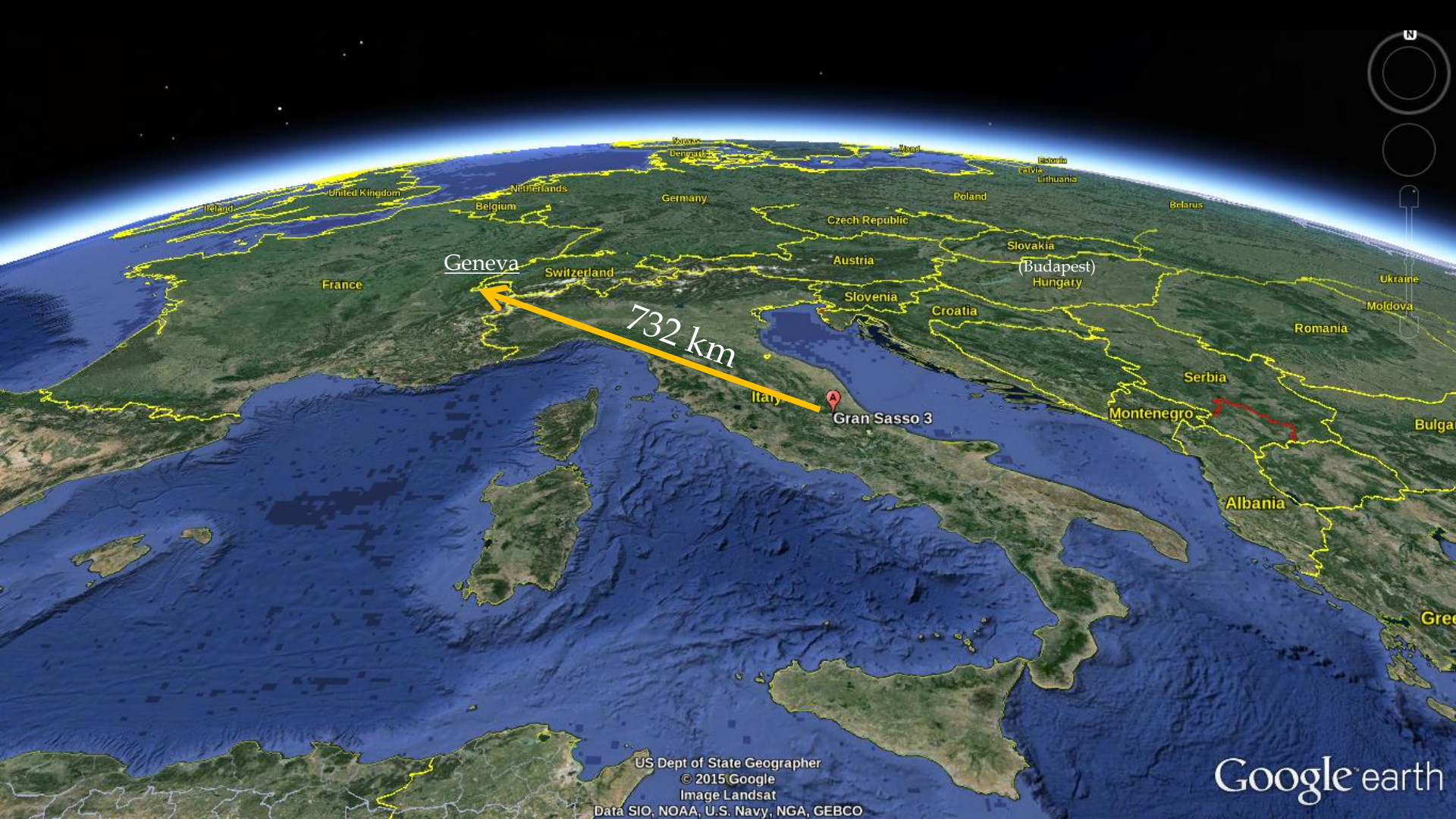

# CALIBRATION OF THE CMS PIXEL DETECTOR AT THE LARGE HADRON COLLIDER

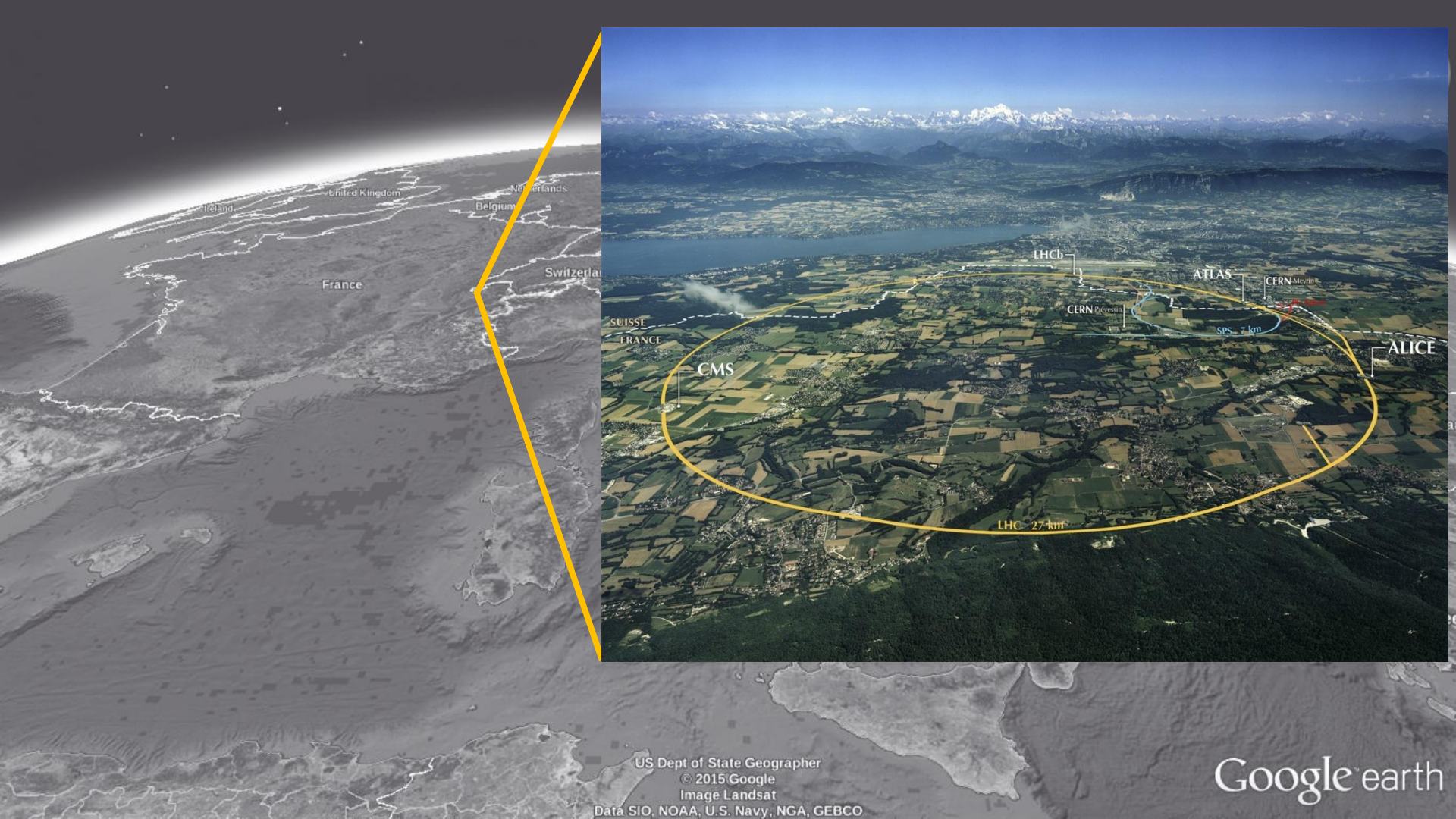
VÁMI, Tamás Álmos

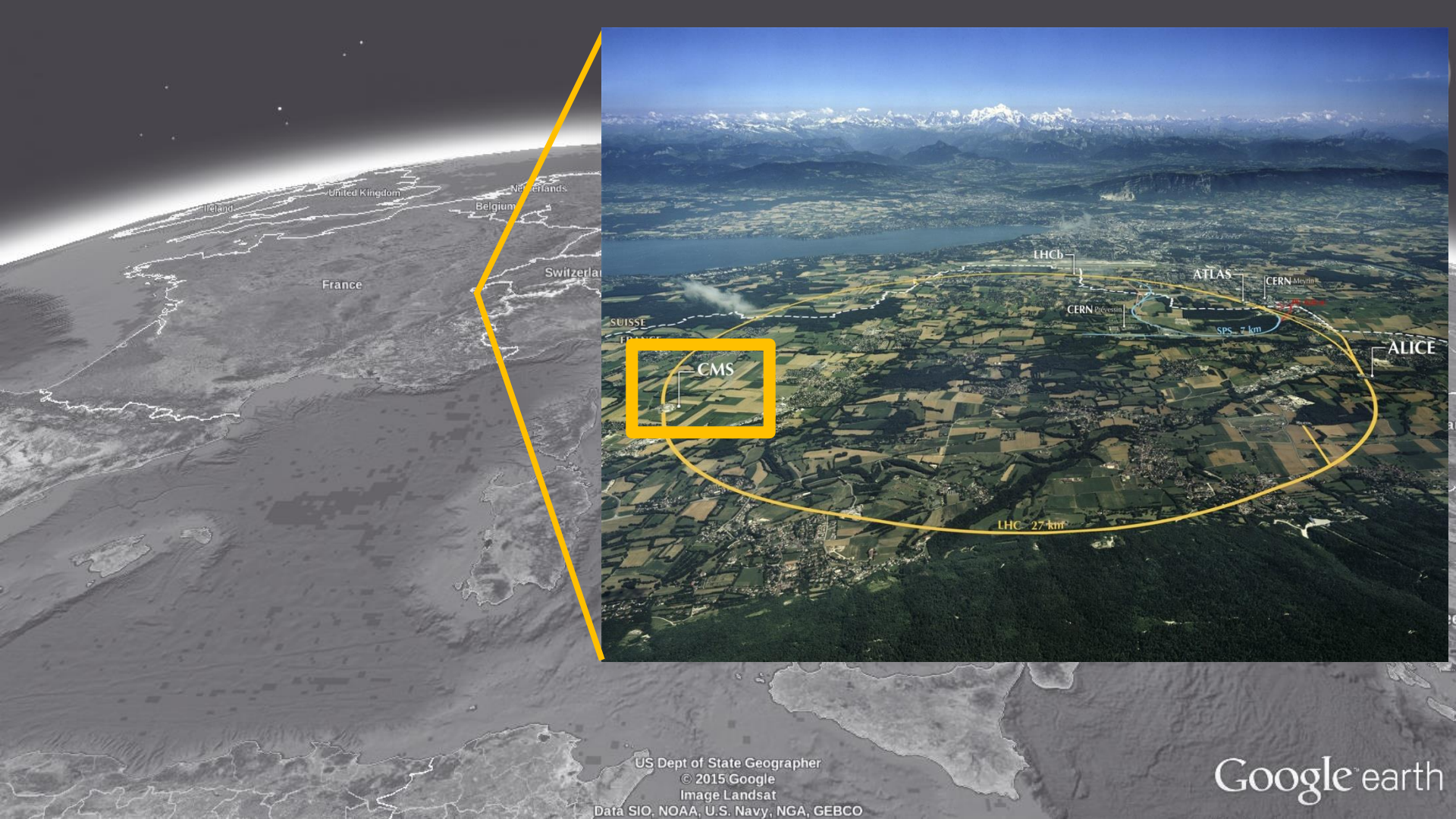
Wigner Research Centre for Physics,
Budapest, Hungary

This work was developed within the CMS Tracker and Pixel Offline Group. This work was supported by the Hungarian Scientific Research Fund No. K 109703


Tuscany
Marche
Umbria
Italy
Ascoli Piceno
IAPS@
Teramo
Gran Sasso 3
Terni
Pescara
Rieti
Viterbo
Abruzzo
L'Aquila
© 2015 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth


Geneva
732 km
Gran Sasso 3
(Budapest)
Ireland
United Kingdom
Netherlands
Belgium
Germany
Denmark
Poland
Belarus
Czech Republic
Slovakia
Austria
Switzerland
France
Hungary
Slovenia
Croatia
Ukraine
Moldova
Romania
Serbia
Montenegro
Albania
Italy
US Dept of State Geographer
© 2015 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth


United Kingdom
Ireland
Belgium
France
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
SUISSE
FRANCE
CMS
ALICE
LHC 27 km
US Dept of State Geographer
© 2015 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth


Ireland
United Kingdom
Belgium
France
SUISSE
LHCb
ATLAS
CERN Meyrin
CERN Prévessin
SPS 7 km
ALICE
CMS
LHC 27 km
US Dept of State Geographer
© 2015 Google
Image Landsat
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google earth

# Compact Muon Solenoid

Total weight : 14,000 tonnes
Overall diameter : 15.0 m
Overall length : 28.7 m
Magnetic field : 3.8 T

STEEL RETURN YOKE
12,500 tonnes

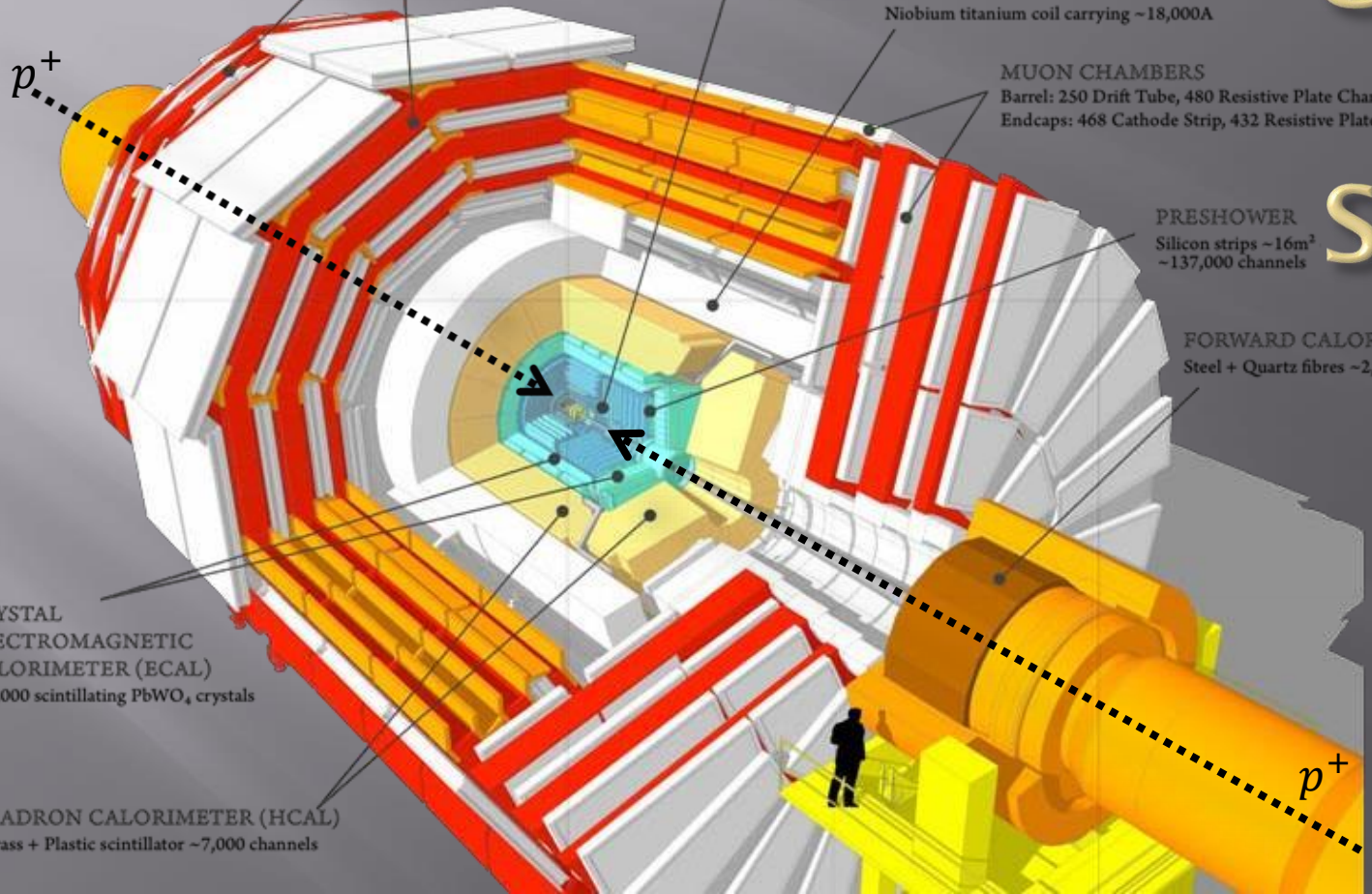
SILICON TRACKERS
Pixel (100x150 μm) ~16m² ~66M channels
Microstrips (80x180 μm) ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

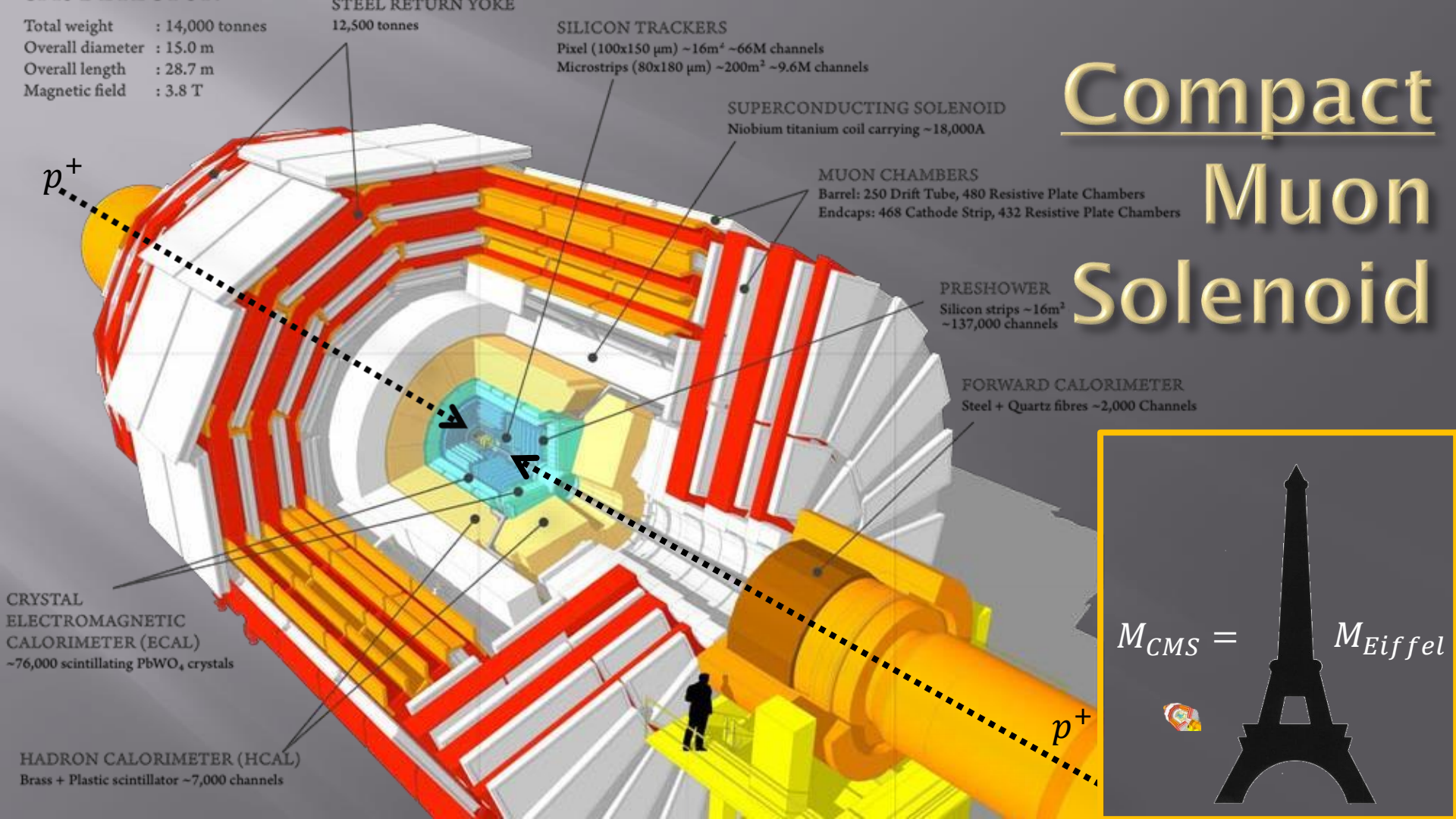
PRESHOWER
Silicon strips ~16m²
~137,000 channels

FORWARD CALORIMETER
Steel + Quartz fibres ~2,000 Channels




CRYSTAL ELECTROMAGNETIC CALORIMETER (ECAL)
~76,000 scintillating $PbWO_4$ crystals

HADRON CALORIMETER (HCAL)
Brass + Plastic scintillator ~7,000 channels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$p^+$
$p^+$
Compact Muon Solenoid
$M_{CMS} =$
$M_{Eiffel}$

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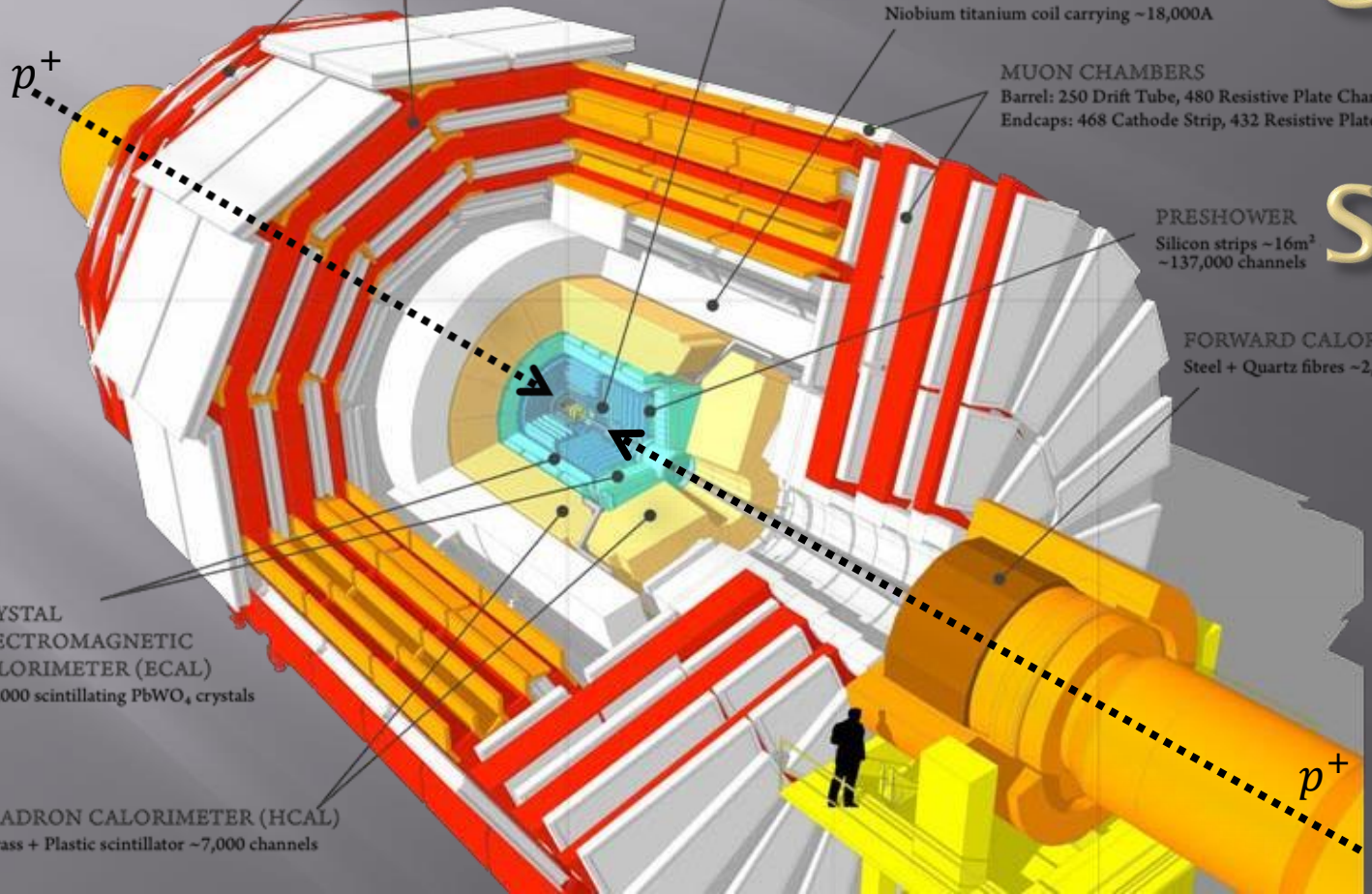


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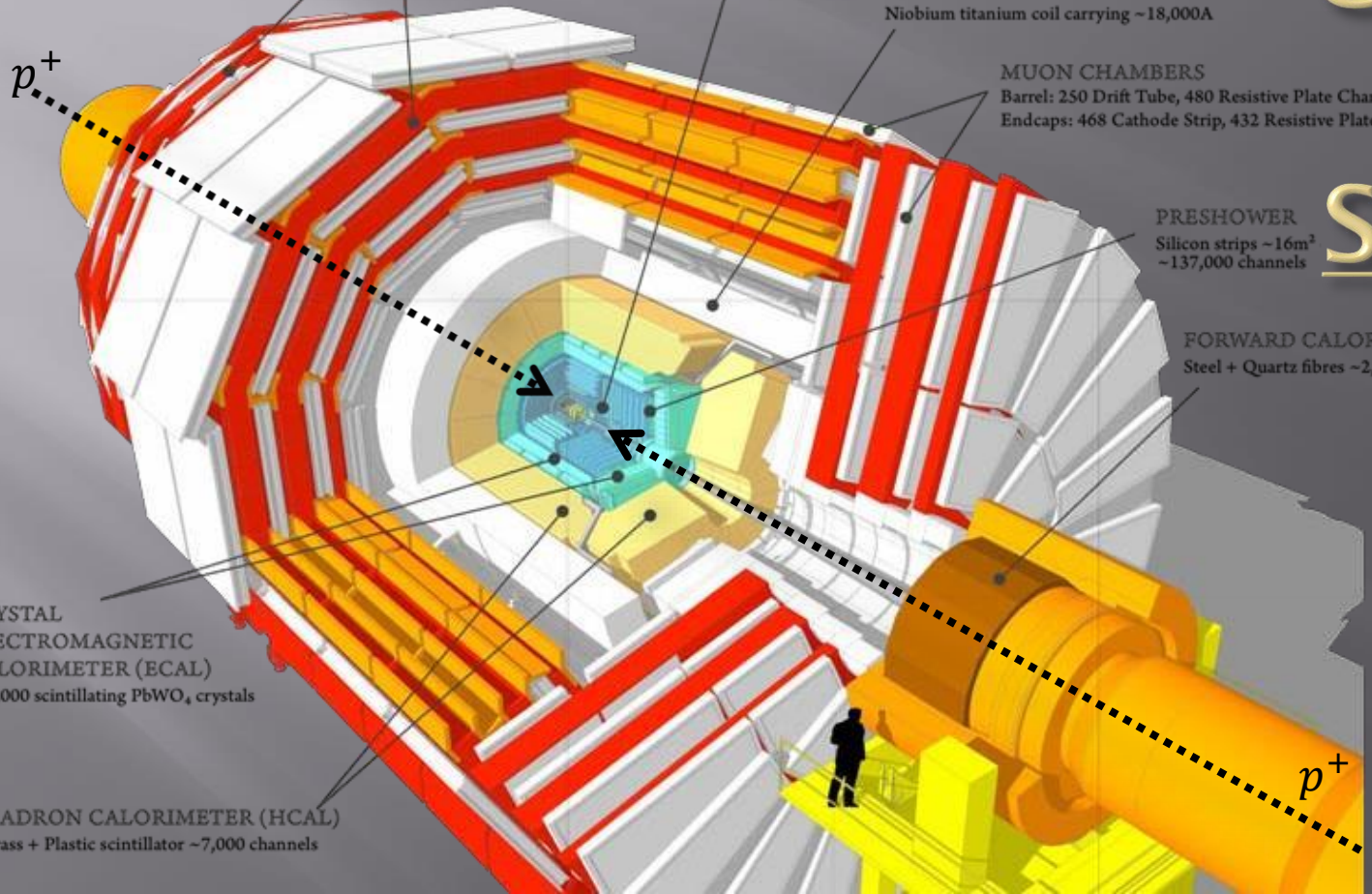


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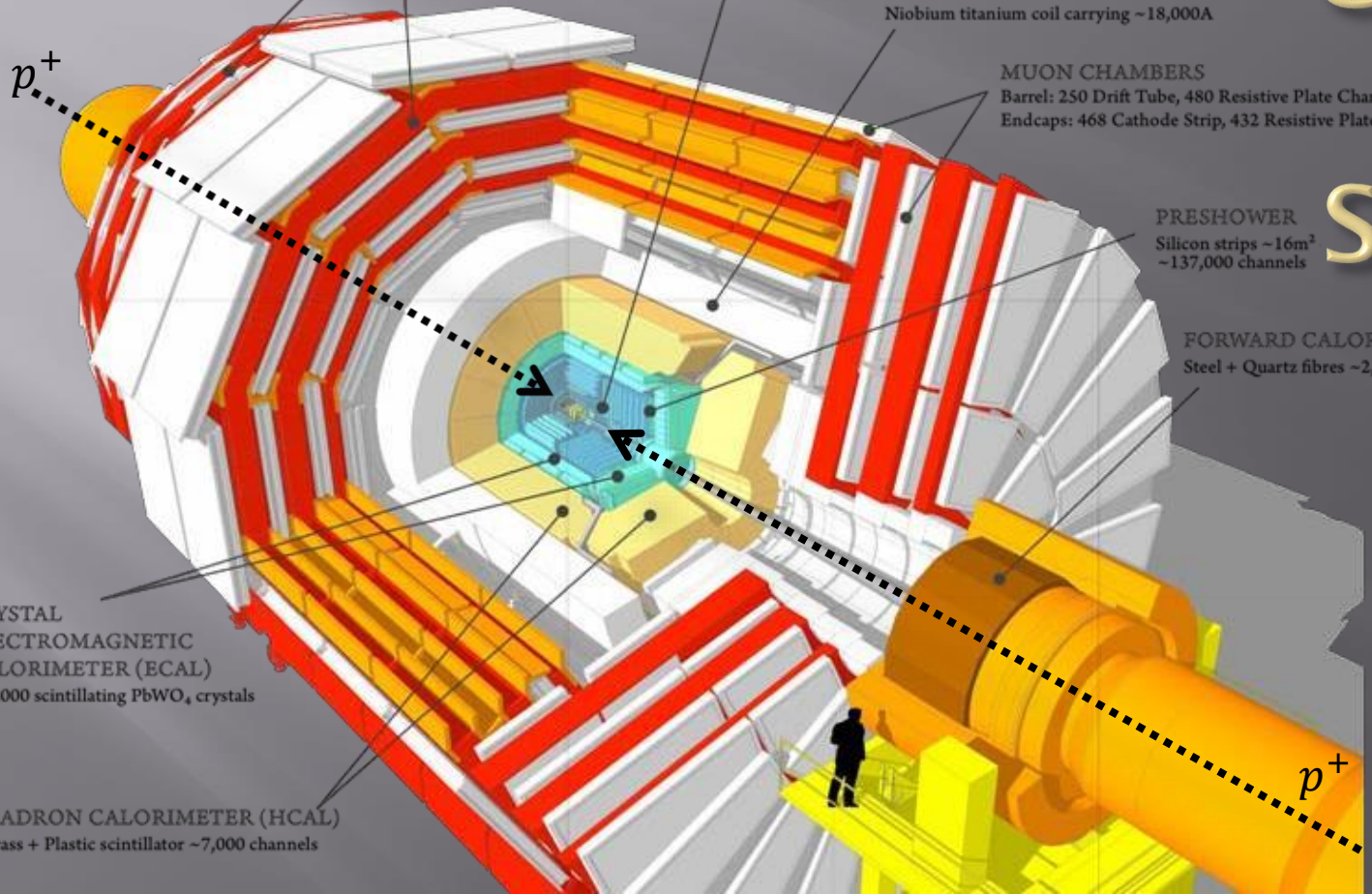


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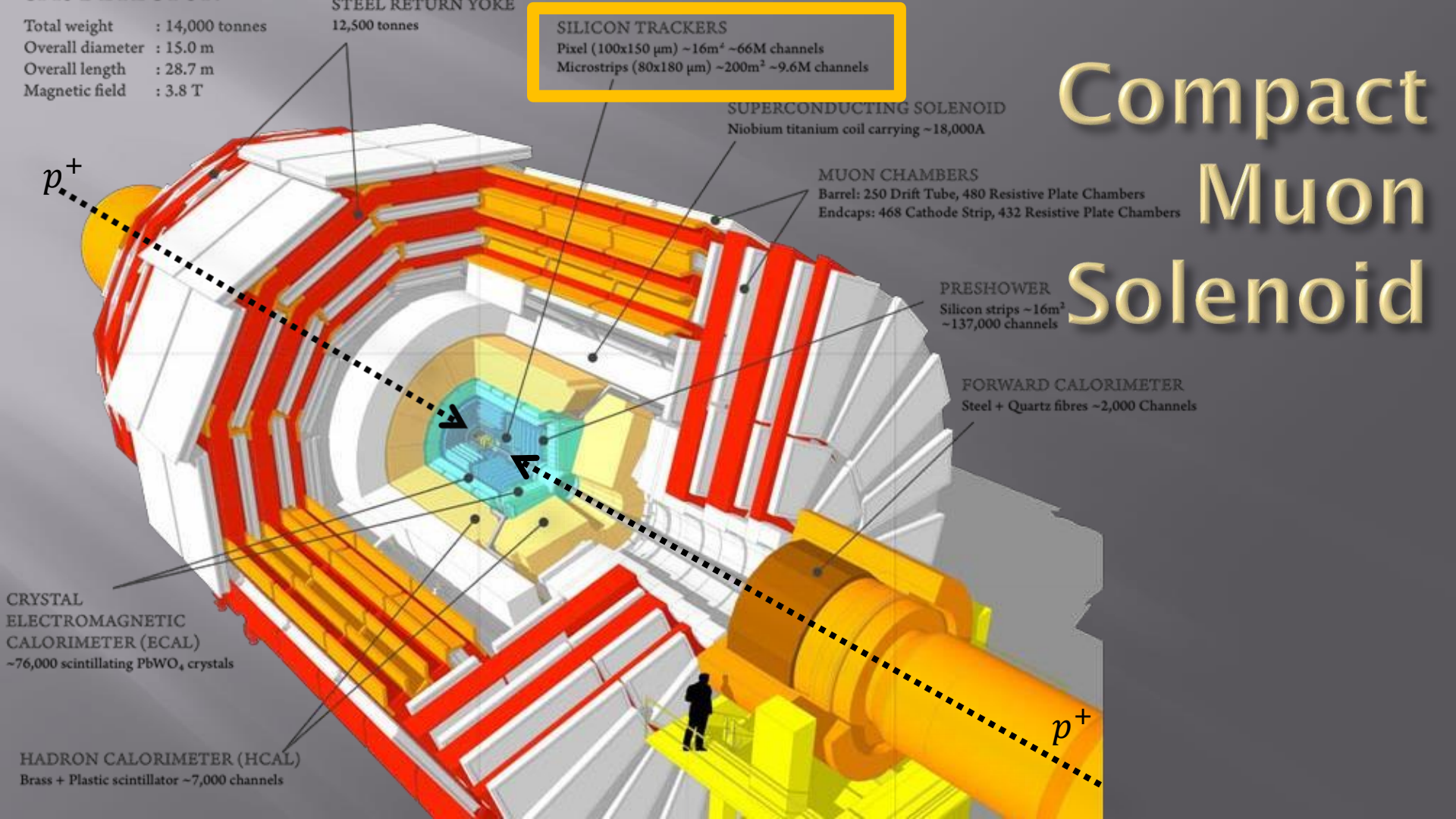
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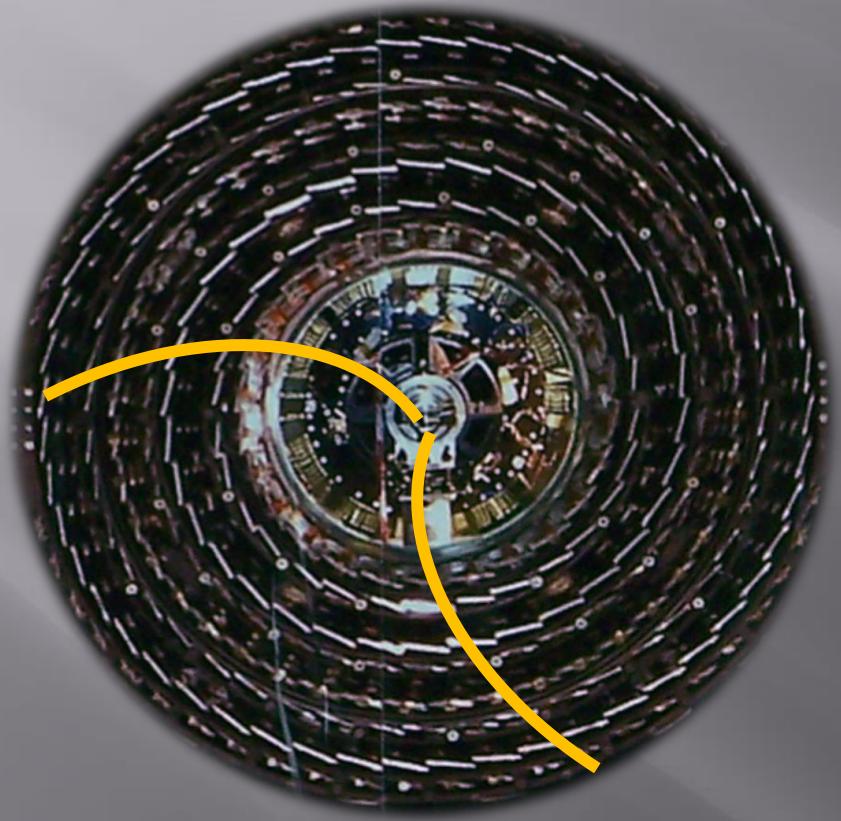
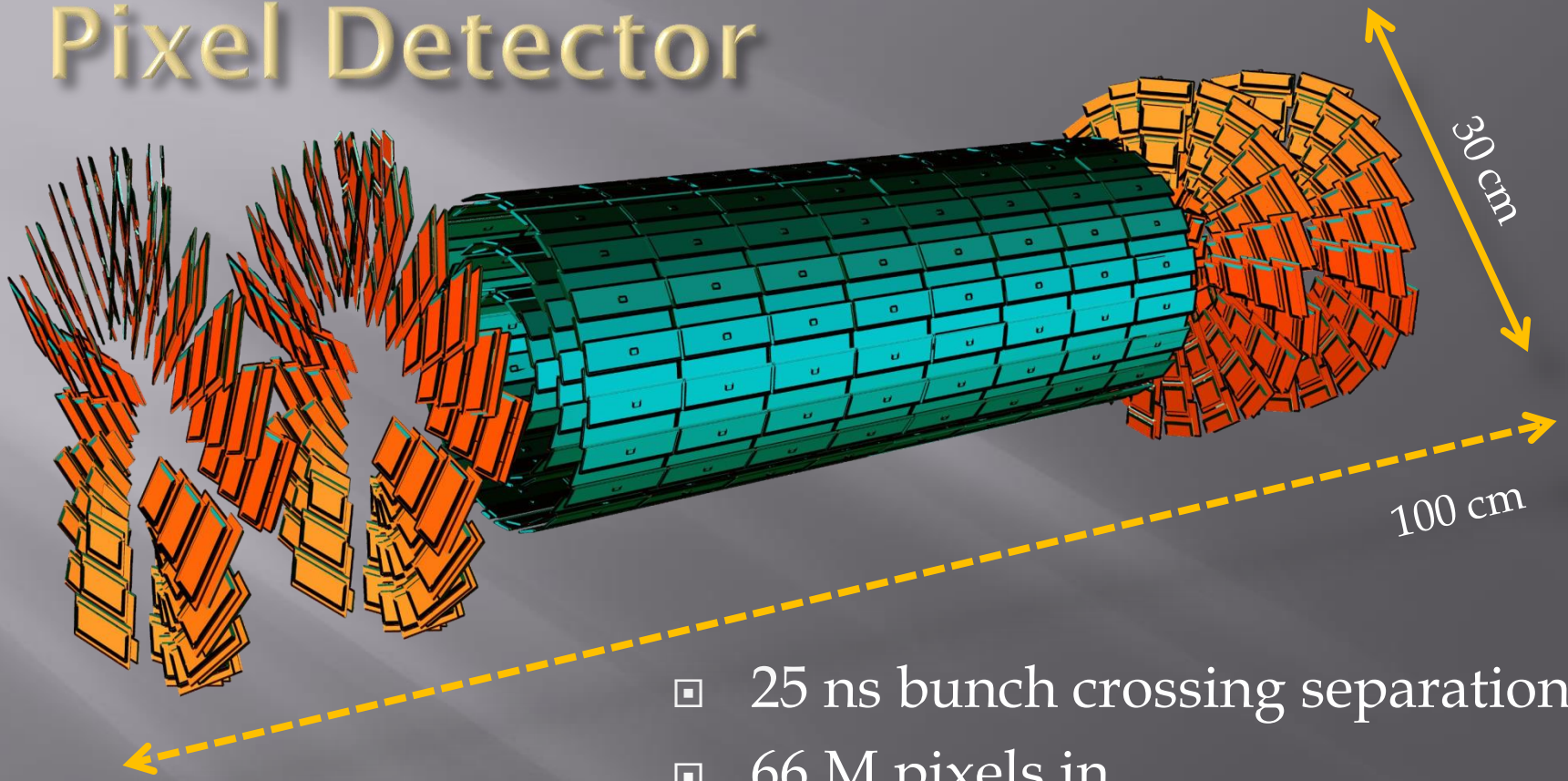
$p^+$
$p^+$
Compact Muon Solenoid

# Tracker



- Tracks of electrically charged particles
- Measure the curvature of a particle's trajectory
- Determine the particle's momentum

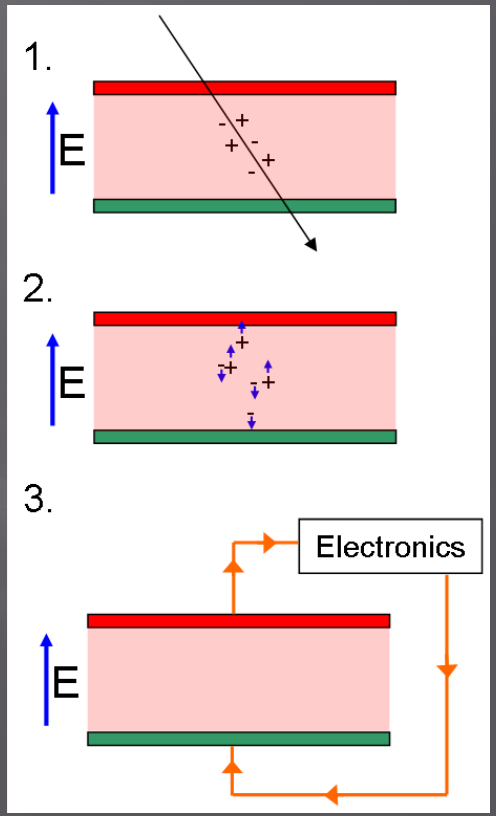
# Pixel Detector




- 25 ns bunch crossing separation
- 66 M pixels in
  - 3 barrel layers (BPIX) & 2x2 disks (FPIX)

# Functioning Principal of the Pixels

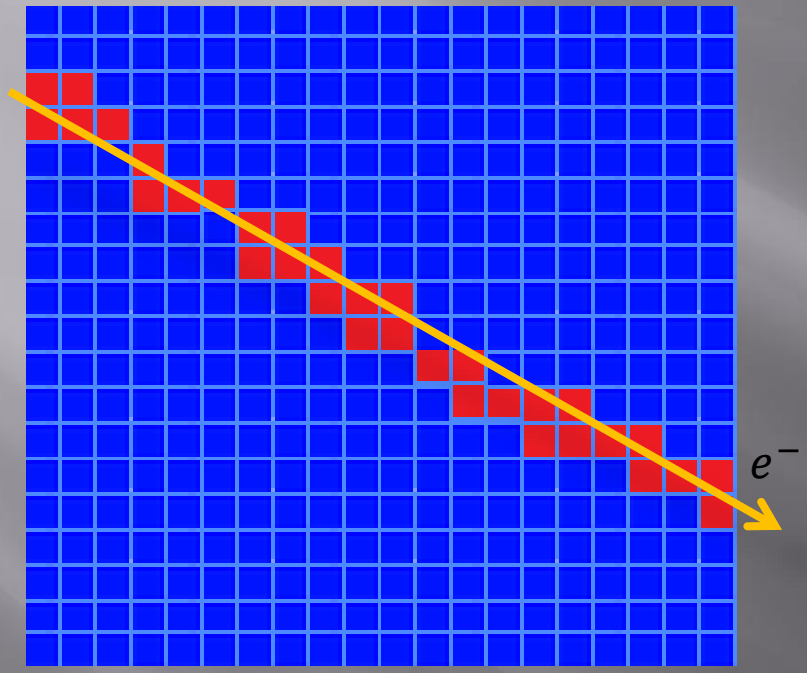
- Electron-hole pairs are created by traversing particle
- Bias voltage induced electric field pulls out charges
- Analog value of charge is read out by Read Out Chip electronics and digitized to an ADC value



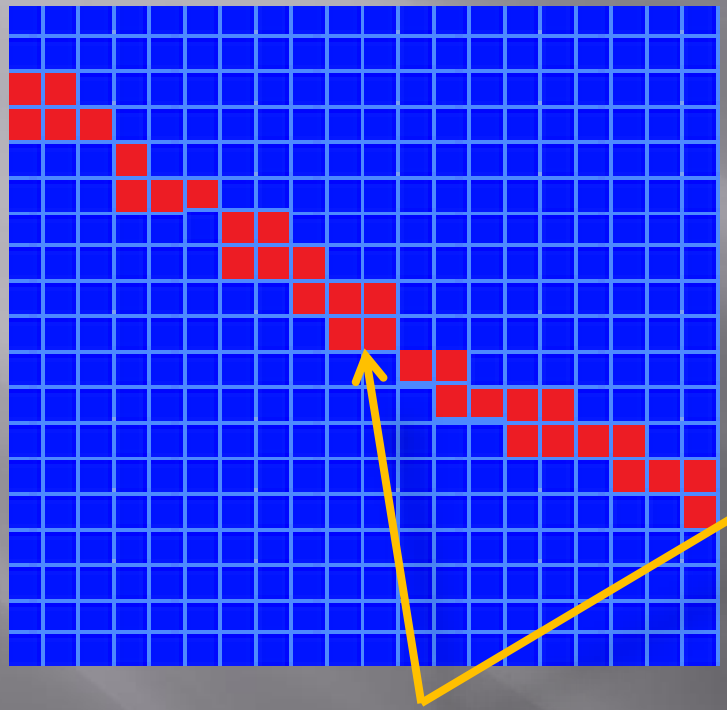
# Local Reconstruction

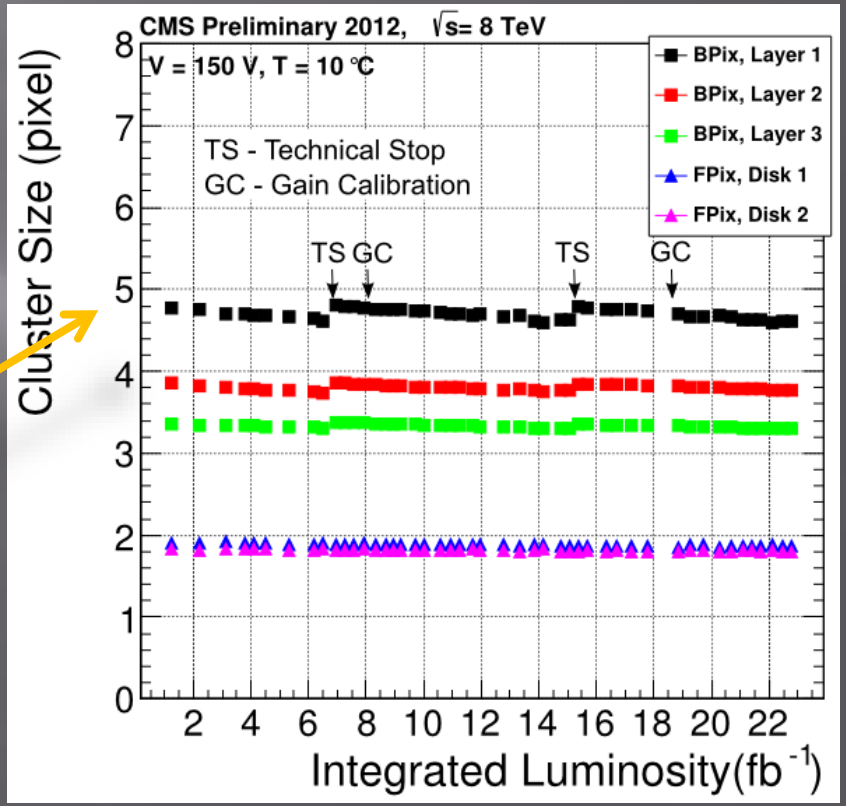
- Hits and pixel charges are determined from *„digis"* using the ADC values
- *digi* = pixel with deposited charge above threshold
- Adjacent digis are combined into clusters

# Clusters



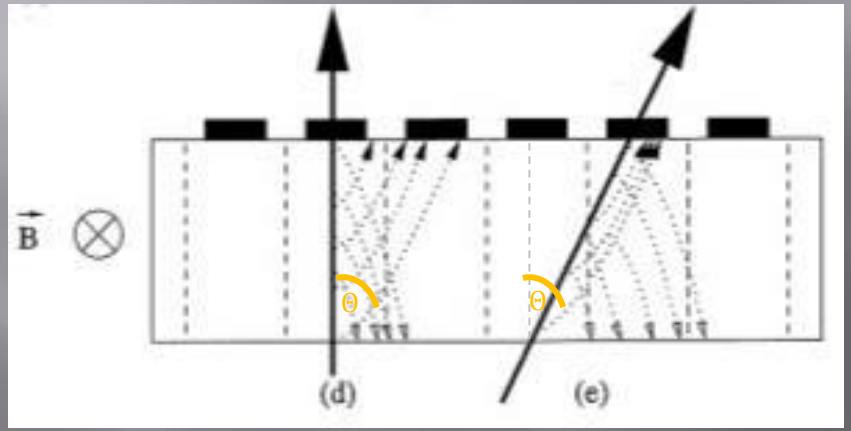
# Clusters






- Approximately 5 pixels in Layer 1

# Cluster Calibration: Lorentz Angle

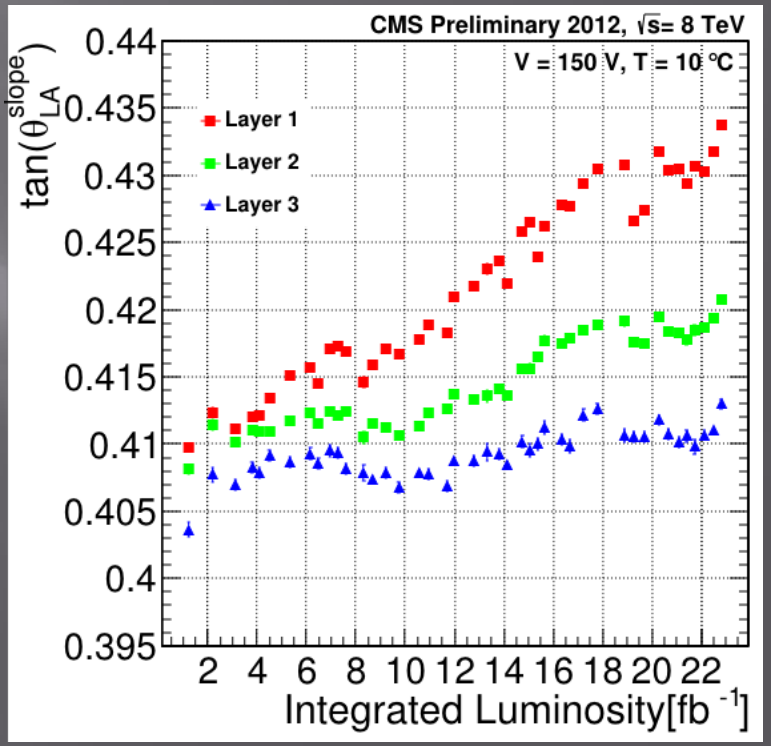



Ref.: Rossi, Fischer, Rohe and Wermes, "Pixel Detectors: From Fundamentals to Applications", Springer (2005)

- The charge carriers are deflected by the Lorentz force due to the 3.8 T magnetic field
- This deflection is characterized by its angle, which is called the Lorentz Angle ($\Theta_{LA}$)

# Cluster Calibration: Lorentz Angle

- Lorentz Angle as a function of luminosity



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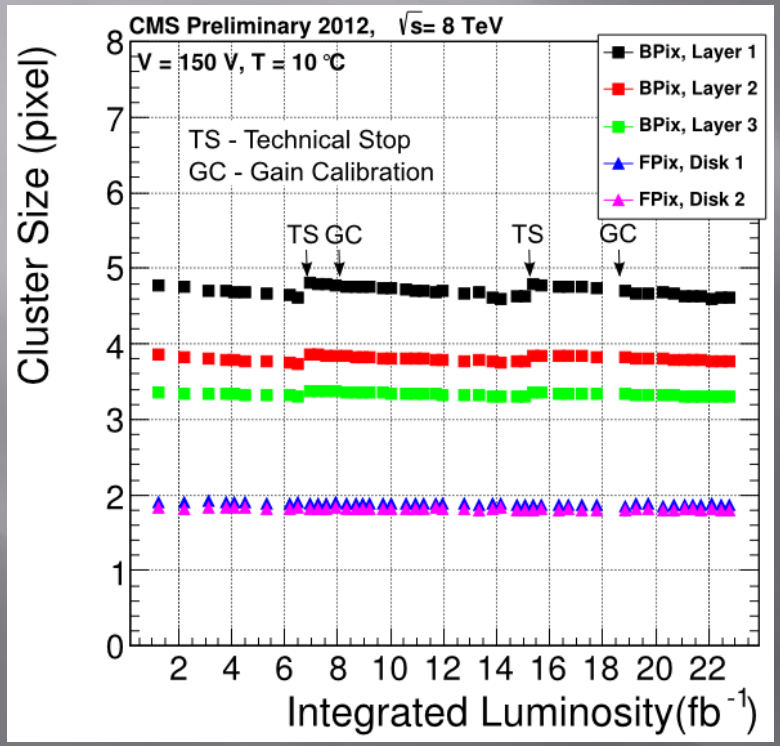
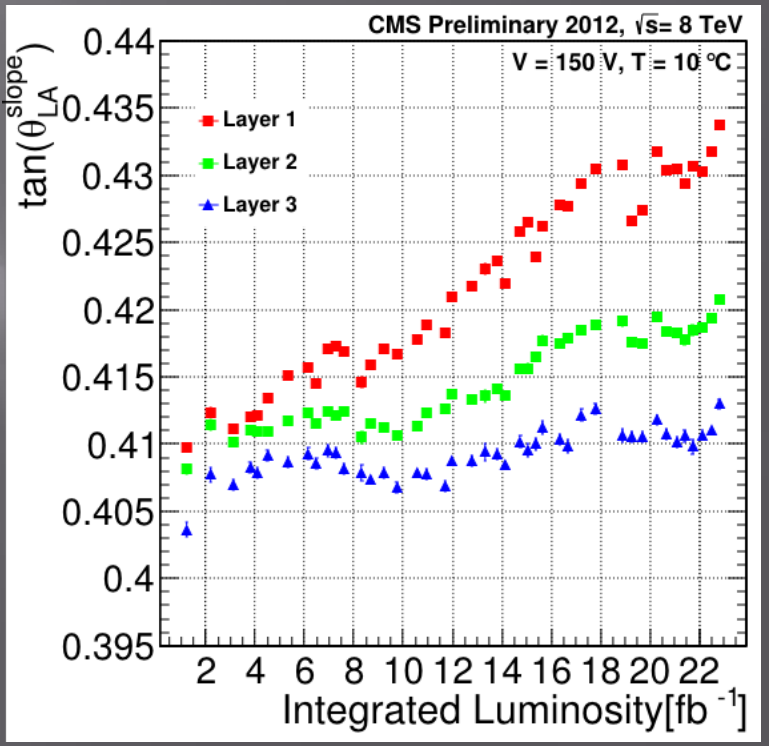
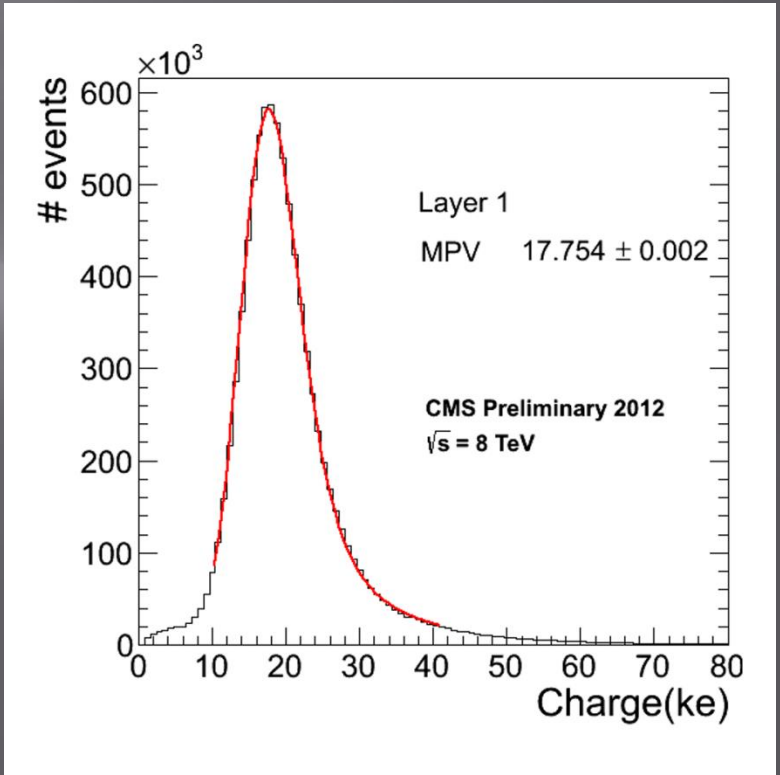


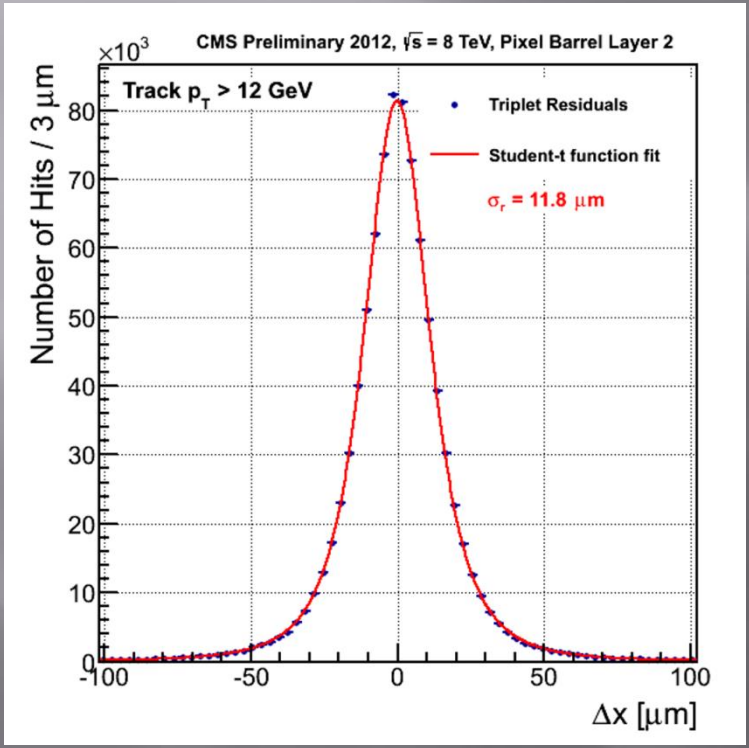



# Cluster Charge

- Charge & 2D position
- Hit position is determined by cluster charge template fitting
- Find the hits in the fraction of the sensor
- Extremely good resolution



# Resolution

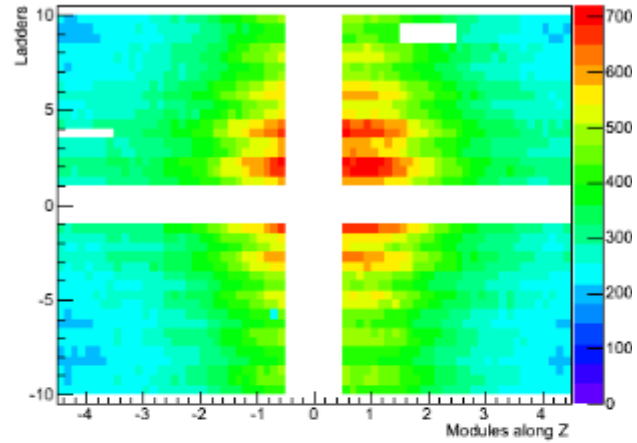



- Resolution determines the accuracy of the track reconstruction
- Hits can be reconstructed with 11.8 μm accuracy on Layer 2, merely a fraction of the 100-by-150 μm 2 pixel cell size

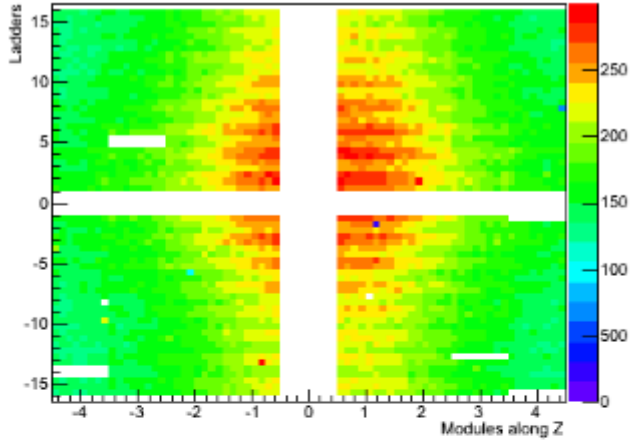
# Bad modules: SiPixelQuality

- Permanently bad modules are identified by measuring the occupancy of each module
- Using this method we create a map, where we identify the not working sensors
- This information (stored in the SiPixelQuality database) is used during tracking

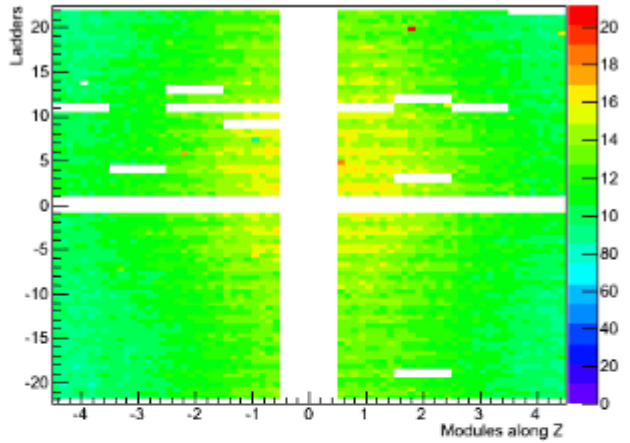
Layer 1



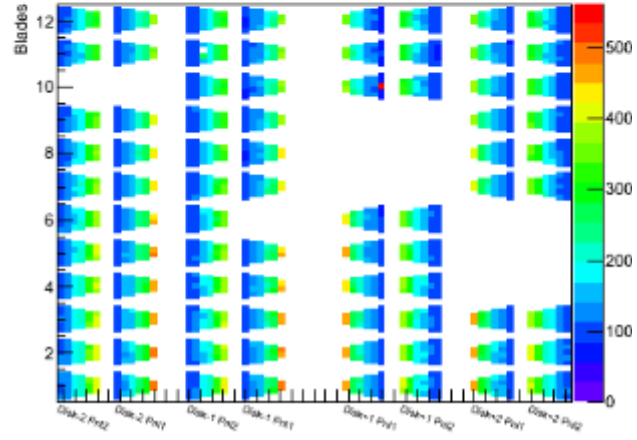

Layer 2



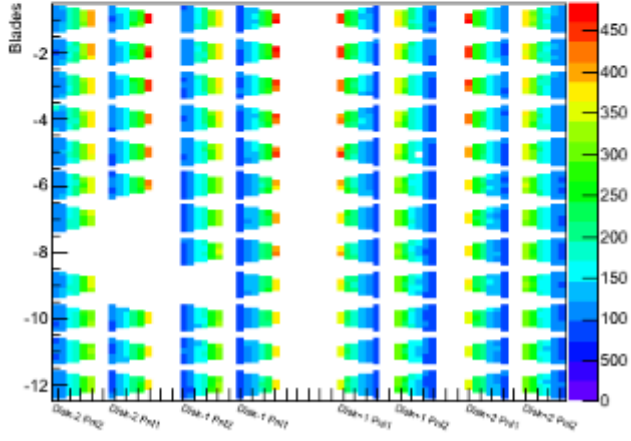

Layer 3




FPix Inner Shells (+x)




FPix Outer Shells (-X)

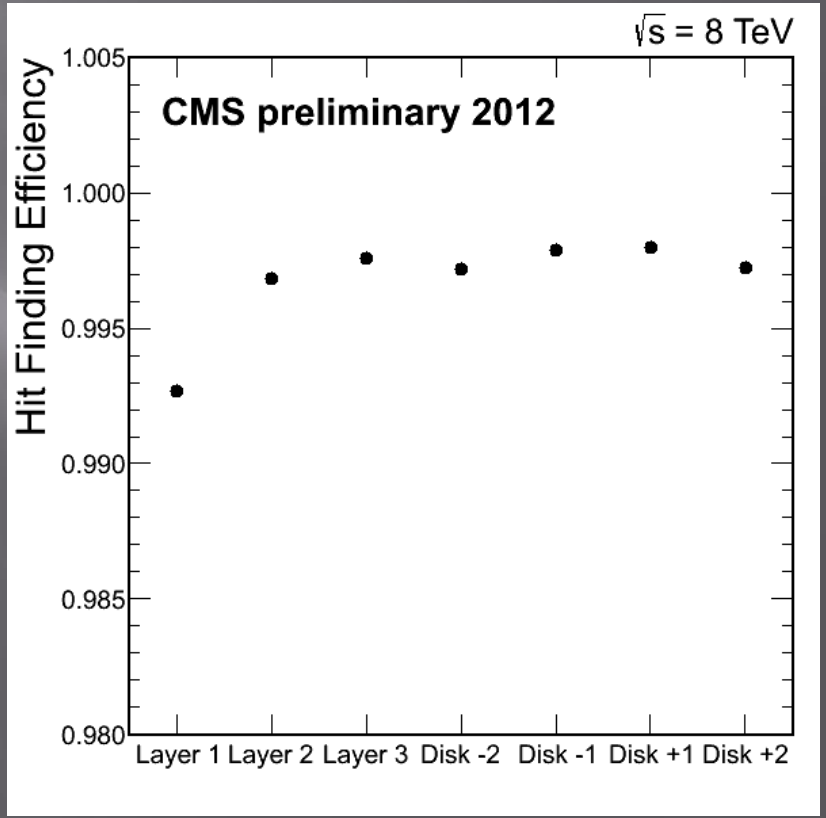


# Efficiency

- $Hit\ Efficiency :=$

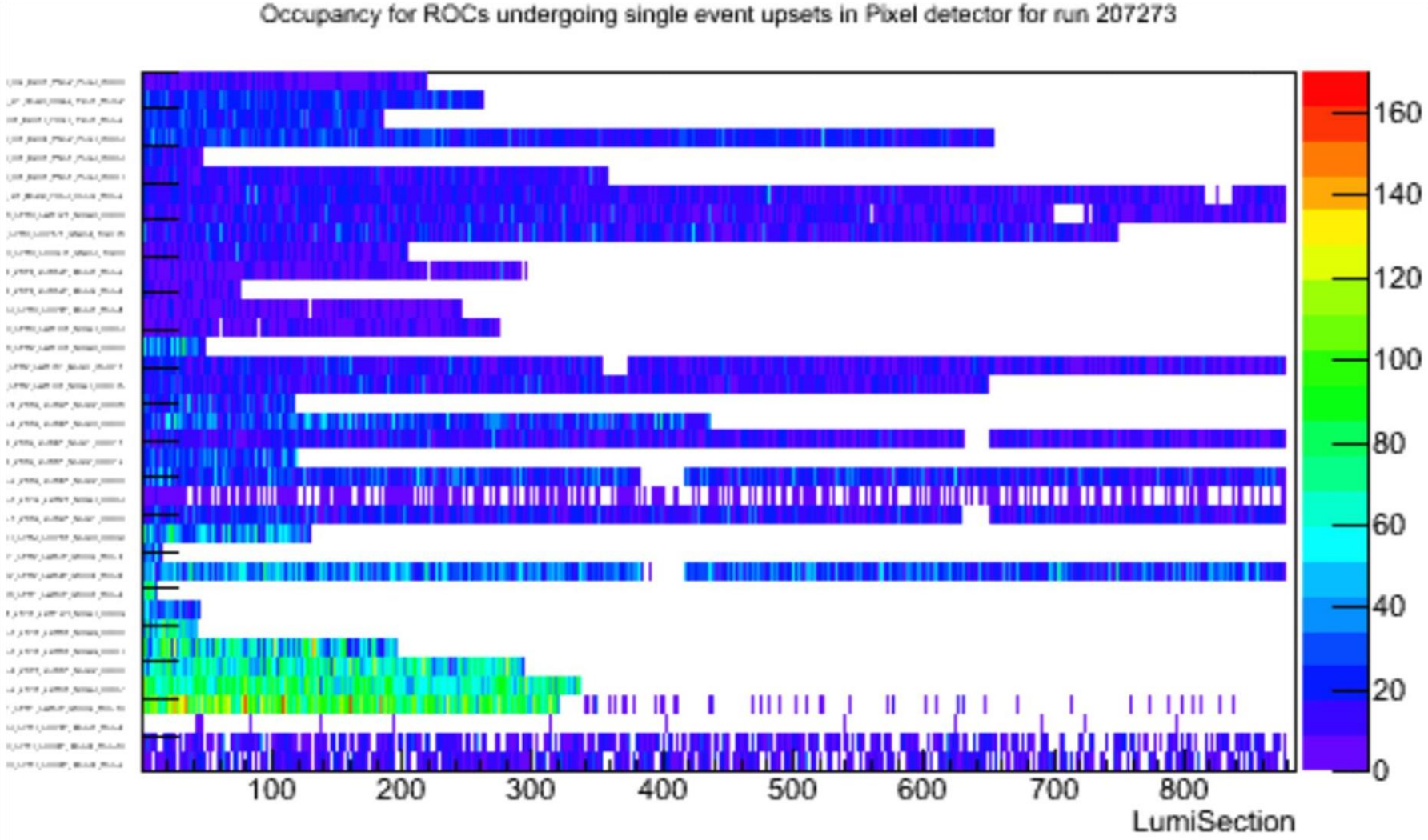
$$\frac{\#\text{found clusters}}{\#\text{expected clusters}}$$

- Approximately 99.7%, except the first layer
  - in fiducial region
  - excluding dead components
- Dynamic efficiency loss (here the buffer saturates)
- Single Event Upsets



# Single Event Upsets (SEUs)

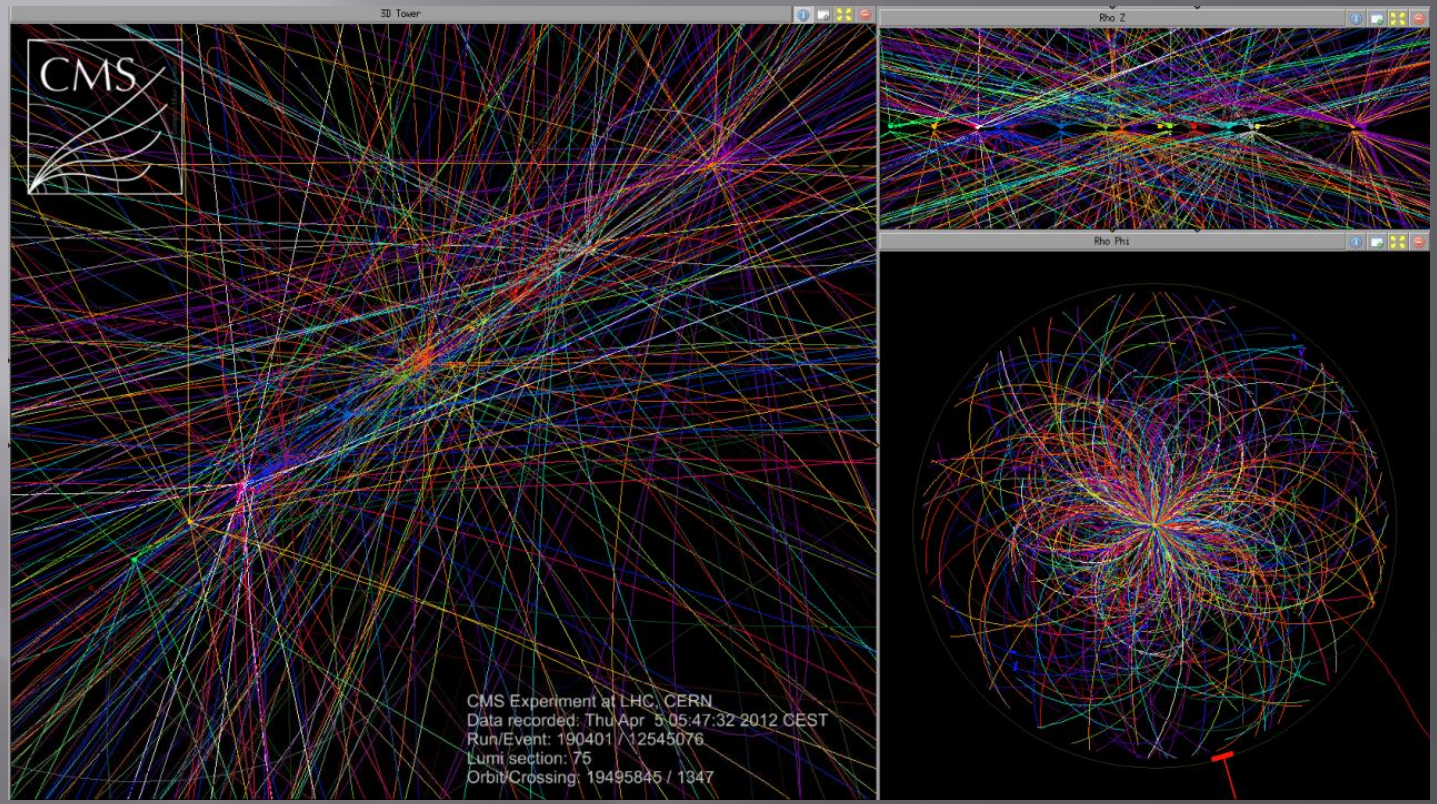
- Radiation may flip the memory state of the Read Out Chip (0↔1)
- This effect is fixed by reprogramming the Read Out Chips
- Using an automatic online monitoring and recovery system we could improve the efficiency (0.05% per hour)


Occupancy for ROCs undergoing single event upsets in Pixel detector for run 207273
160
140
120
100
80
60
40
20
0
100
200
300
400
500
600
700
800
LumiSection

# Conclusion

- Using these calibrations the Pixel Detector works with high accuracy
- Its resolution is in the order of 10 μm in the transverse plane
- Excellent results in detector reliability and tracking performance
- The efficiency of the detector was >99% in 2012
- We can monitor the malfunctions in order to improve the efficiency

# Importance


3D Tower
Rho Z
Rho Phi
CMS
CMS Experiment at LHC, CERN
Data recorded: Thu Apr 5 05:47:32 2012 CEST
Run/Event: 190401 / 12545076
Lumi section: 75
Orbit/Crossing: 19495845 / 1347

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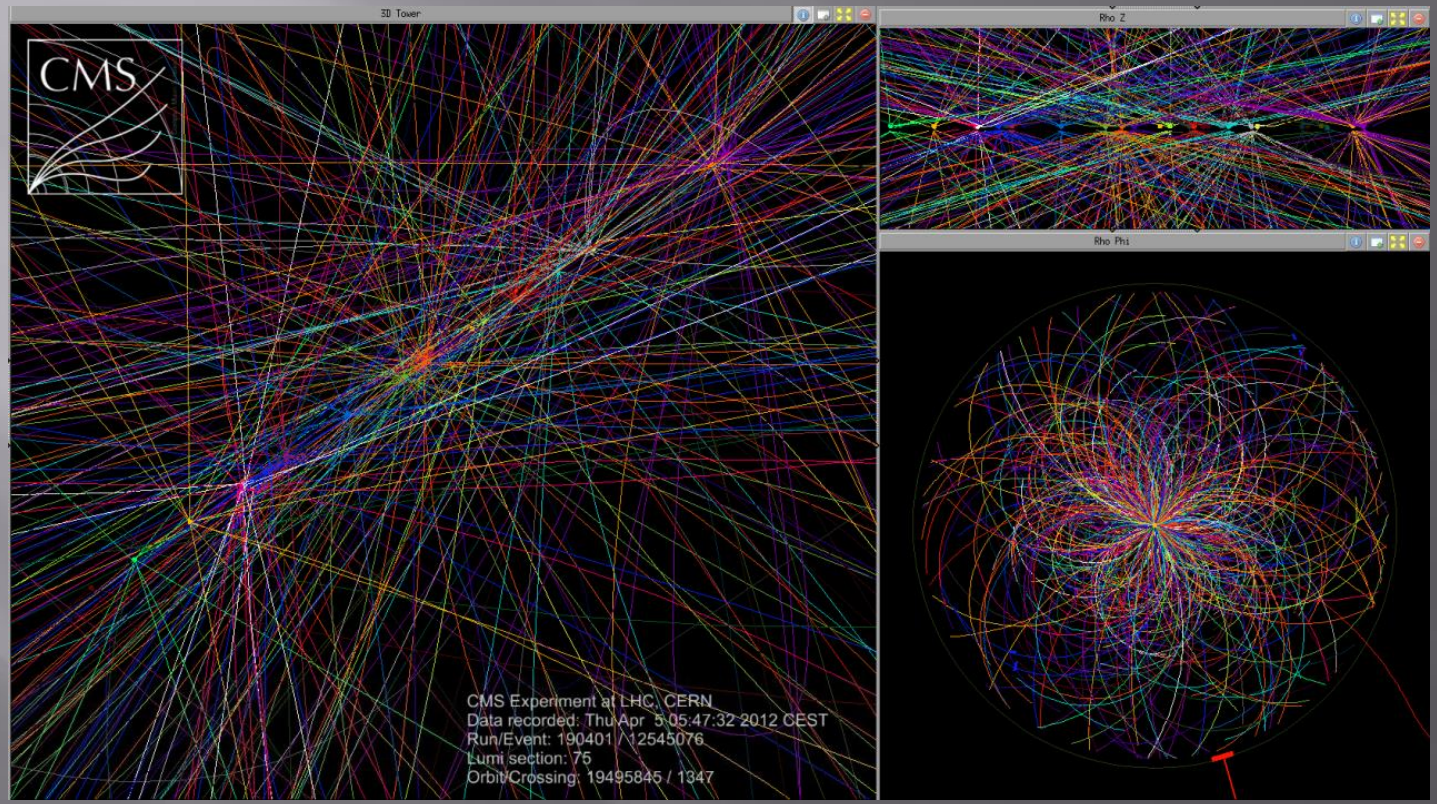


Thank you for listening!

E-mail: vami.tamas@wigner.mta.hu