Track reconstruction with first collision data in CMS

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On behalf of CMS collaboration

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7-10 June 2010
LHC started at CERN in November-December 2009

Trigger inclusive configuration to accept Minimum Bias events (Beam Scintillator Counter)

Luminosity recorded
~ 10 µb^{-1} @ 900 GeV
~ 0.4 µb^{-1} @ 2.36 TeV
~ 85% efficiency recording data

From end of March until end of May
~ 17.1 nb^{-1} @ 7 TeV
~ 91% efficiency recording data
CMS DETECTOR

SUPERCONDUCTING COIL

Total weight: 12,500 t
Overall diameter: 15 m
Overall length: 21.6 m
Magnetic field: 4 Tesla

CALORIMETERS
ECAL Scintillating PbWO₄ HCAL Plastic scintillator Crystals
brass sandwich

IRON YOKE

TRACKERS

Silicon Microstrips Pixels

MUON BARREL

Drift Tube Chambers (DT)
Resistive Plate Chambers (RPC)

Cathode Strip Chambers (CSC)
Resistive Plate Chambers (RPC)

MUON ENDCAPS

strip
CMS TRACKER

• Pixel:
  ~ 1 m² sensitive Si Pixel
  66 M #ch read-out, 1440 modules
  R= 4, 7, 11 cm L= 53 cm
• Strip:
  ~ 200 m² sensitive Si microstrip
  10 M #ch read-out, 15148 modules
  10 barrel layers (4 double sided)
  9 endcap wheels

• Inserted in 4 Tesla field
• -10 °C to limit radiation damage
• Coverage up to |η|<2.4
  (≥3 pixel hits, ≥10 strip hits)
• Efficiency&Resolution from MC:
  efficiency ~ 99% for muons
  efficiency ~ 90% for hadrons
  resolution Δpt/pt ~ 1-2% (|η|<1.6)
98.4% operational channels with loss mainly due to faulty read-out firmware

Synchronization of charge collection with bunch crossings & time scanning

Charge distribution corrected with the impact track angle

Data/MC agreement excellent after optimization
STRIP DETECTOR RESPONSE 2009 RUNS

- Detector Calibration performed
  - Check of the channel status
  - Electronic gain calibration
  - Lorentz angle measurement
  - Hit reconstruction efficiency (>99.9%)
  - Synchronization with the LHC clock phase
- Time delay scan to determine maximum charge collection
- Charge distribution corrected with the impact track angle
- Cluster Signal/Noise ratios in agreement with expectation

<table>
<thead>
<tr>
<th>Sub-Detector</th>
<th>S/N</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIB</td>
<td>26</td>
</tr>
<tr>
<td>TID</td>
<td>26</td>
</tr>
<tr>
<td>TOB</td>
<td>32.6</td>
</tr>
<tr>
<td>TEC</td>
<td>29.9/36</td>
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</tbody>
</table>
Charged tracks reconstructed with Kalman filter technique in a high track density environment

- Seeding -> Pattern recognition -> Track fitting
- Seeding by pixel hit triplets or pixel/strip hit pairs with constraint from the beam spot
- Iterative tracking (6 iterations)
- At each iteration remove track-assigned hits and relax seed cuts

Event/track selection:
- one PV (>3 tracks)
- $|dxy| < 2\text{cm}$, $|dz| < 15\text{ cm}$
- rejection of beam-induced backgrounds

Data and MonteCarlo (MC) agree in the shape of the reconstructed variables

- MC data include realistic description of magnetic field, detector conditions, calibrations, alignment

Effect of inactive modules in the $\varphi \sim -1.2$ region well reproduced in data and MC
Tracker Alignment Parameters measured with:

- 3.2M cosmic muon tracks in B field 3.8T (2008-2009) connect different parts of the detector
- low statistics in the endcaps & in the pixels
- LHC collisions huge statistics in the endcaps

Final strategy using both cosmics and collisions (using primary vertex constraint for collisions)
Alignment at few μm and approaches ideal geometry in MC

Median of the track residuals in the tracker subdetectors:

<table>
<thead>
<tr>
<th>r.m.s of DMR (μm)</th>
<th>DATA</th>
<th>MC NoMisal.</th>
<th>MC STARTUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>PXB (u)</td>
<td>2</td>
<td>1</td>
<td>3</td>
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<tr>
<td>PXB (v)</td>
<td>6</td>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>PXE (u)</td>
<td>6</td>
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<td>11</td>
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<tr>
<td>PXE (v)</td>
<td>7</td>
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<td>TEC</td>
<td>10</td>
<td>3</td>
<td>22</td>
</tr>
</tbody>
</table>
Reconstruct primary vertex from all compatible tracks

Beam width estimated with a gaussian fit

X Y Z
0.22/0.25/39 mm

Data-Driven Primary Vertex resolution as function of number of tracks and track momentum:
- separating tracks in two independent sets
- Very good agreement with MC
**V° RECONSTRUCTION**

Long-lived $K^0_s \to \pi^+\pi^- (c\tau=2.7 \text{ cm})$ and
$\Lambda^0 \to \pi^- p (c\tau=7.9 \text{ cm})$ (+c.c.)

**Selection**
- Two high quality tracks with opposite charge
- Two daughter tracks missing the primary vertex
- Good vertex $V^0$ separated from the primary more than 15 $\sigma$ in the transverse plane
- No tracks hits inside of the vertex
• V0 masses in good agreement with PDG values
• Momentum scale under control
• Resolution of the mass fit:
  \( K^0_s : 7.99 \pm 0.14 \) MeV
  \( \Lambda^0 : 3.01 \pm 0.08 \) MeV
• Agreement Data/MC
  \( K^0_s : 7.62 \pm 0.03 \) MeV
  \( \Lambda^0 : 2.99 \pm 0.04 \) MeV
• Measured lifetime in agreement with PDG:
  \( K^0_s \) PDG: \( \tau = 89.53 \pm 0.05 \) ps
  \( K^0_s \) CMS: \( \tau = 90 \pm 2.1 \) ps
  \( \Lambda^0 \) PDG: \( \tau = 263 \pm 3 \) ps
  \( \Lambda^0 \) CMS: \( \tau = 271 \pm 20 \) ps

Correct for the acceptance bin-by-bin with MC:
MC corrections, nice exponential dependence!
Apply vertex fit with Vº candidate plus charged track
Require all three tracks miss the primary vertex

\[ \Xi^- \rightarrow \Lambda^0 \pi^- (+cc) \], c\tau = 4.9 \text{ cm} :

- tracks displaced from primary vertex (d3D>3\sigma)
- constrain \( \Lambda \) mass to PDG value

\[ K^*(892) \rightarrow K^0_s \pi^- \] :

- strong resonance with extremely short lifetime
- \( K^0_s \) and \( \pi^- \) tracks compatible with primary vertex

Masses in agreement with PDG values

\[ \Xi^- \rightarrow \Lambda^0 \pi^- (+cc) \]
D^+_+ \rightarrow D^0(K\pi\pi) (and c.c.):
- combine oppositely charged tracks with pT > 0.5GeV and perform a vertex constrained kinematic fit
- |M(K\pi) - M(D^0_{PDG})| < 200 MeV
- combine D0 candidate with a soft pion with M(K\pi\pi)-M(K\pi) < 0.18GeV

D^+ \rightarrow K\pi+\pi+ (and c.c.):
- secondary vertices formed by 3 good quality reconstructed tracks with total charge +/-1.
- reconstructed D^+ momentum has to point back to the primary vertex within 5*Sigma_XY in the transverse plane X-Y
- L/S cut (detachment between the primary and secondary vertices divided by its error).
dE/dX: particle ID

CMS Silicon Tracker analog read-out allows particle identification using energy loss information. At least 10 measurements along the track.

Robust estimator (k=-2):

\[ \frac{dE}{dx} = \left( \frac{1}{N} \sum_{i} \left( \frac{\Delta E}{\Delta x} \right)^{k} \right)^{1/k} \]

dE/dX selection validated with \( \Lambda^0 \rightarrow p\pi \) decays reconstructed by CMS, where the lower momentum particle is always the pion.
Φ (1020) → K^+K^-

- High quality tracks compatible with Primary Vertex
- Particle ID: select low p tracks (< 1 GeV) with dE/dx compatible with K hypothesis
- Meas. Mass in 200 MeV around the K mass

Anti K hypothesis

CMS preliminary \(\sqrt{s} = 900\) GeV

CMS preliminary \(\sqrt{s} = 7\) TeV
166564 ± 1220 \(\Phi\) candidates
Mass = (1.01959 ± 0.00003) GeV/c^2
Sigma = (1.56 ± 0.04) MeV/c^2
Width fixed to PDG value
INTERACTIONS IN THE TRACKER

Photon Conversions:
First CMS Tracker radiography
Two tracks with track-fit $\chi^2$ prob $> 10^{-6}$,
parallel in both $\perp$ and $//$ planes, positive decay length
Visible offset between beam pipe and pixel detector
Estimation of material budget

Nuclear interactions:
Clustering and refitting tracks from a common displaced vertex
Dependence of # nucl interactions vs radius
Reasonable description of material in BPIX and tracker endcaps
Smearing of the beam pipe in data (shift relative to BPIX not simulated)
The first collision data collected by CMS were used to evaluate the performance of the tracker detector

- Both the pixel and strip subdetectors performed well
- Track reconstruction algorithm is robust

Excellent match of reconstructed and PDG mass and V0 lifetime is proof of the very understanding of the detector (calibrations, alignment, magnetic field and material budget)

Matching with Monte Carlo Simulation is impressive
- The detector simulation is accurate, thanks to years of fine tuning with data from test beams and cosmic ray runs