CMS Tracking Performance in 2009 Collision Runs

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INTRODUCTION

• First LHC collisions: Nov. 23rd
• First Stable beams $\sqrt{s} = 900$ GeV: Dec 6th
• First Collisions at $\sqrt{s} = 2.36$ TeV: Dec 14th

• Luminosity recorded by CMS with the full detector ON
  • $\sim 10 \, \mu b^{-1} \, @ \, \sqrt{s} = 900$ GeV
  • $\sim 0.4 \, \mu b^{-1} \, @ \, \sqrt{s} = 2.36$ TeV
    • Normalized to MC $\sigma_{\text{minbias}} = 52$ mb
  • High data taking efficiency
    • $\sim 85\%$ delivered luminosity under any beam condition
• Trigger
  • Inclusive configuration to accept Minimum Bias events (Beam Scintillator Counter)

• Outline
  • Tracker Detector Performance
  • Tracking Performance
    • Basic tracking / vertexing
    • Resonances: $K^0\text{s}$, $\Lambda$, $\Xi^\pm$, $K^{*\pm}$, $\Phi$
    • $b$-tagging related variables
  • Conclusions
The CMS detector layout

- Total Weight: 12,000 t
- Overall Diameter: 15 m
- Overall Length: 21.6 m
- Superconducting Coil Temp. 4K

- Lead tungstate E/M Calorimeter (ECAL)
- Hermetic (|η|<5.2) Hadron Calorimeter (HCAL) [scintillators & brass]
- All Silicon Tracker (Pixels and Microstrips)
- Redundant Muon System (RPCs, Drift Tubes, Cathode Strip Chambers)

3.8T Superconducting Solenoid
The CMS Tracker System

Silicon Pixel detector surrounded by Silicon Strip detectors

- **Pixels:**
  - \( \sim 1 \text{ m}^2 \) of Si sensors, 66 M channels, 1440 modules
  - \( r = 4, 7, 11 \text{ cm} \); \( L = 53 \text{ cm} \)

- **Strips**
  - \( \sim 198 \text{ m}^2 \) of Si sensors, \( \sim 9.6 \text{ M} \) channels, 15148 modules
  - 10 barrel layers, 9 End-Cap Wheels per side

From simulation studies

- Tracking efficiency: \( \varepsilon > 99\% (\mu), \sim 90\% \) hadrons
- Resolution: \( \Delta p_t/p_t \sim 1-2\% \) (@ 100 GeV, \( \eta < 1.6 \))

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Tracker Detector Operation in 2009 collision Runs

- Full Tracker detector active after the declaration of stable beams
- Large fraction of operational channels
  - Pixel Detector: 98.4%  Strip Detector: 97.2%
- Data analysis confirmed excellent performance of the detector
  - Reconstructed Hit Signal distributions match with expectation (previous cosmic ray runs and MC)
- Detector Calibration performed (in some cases within few hours from the data acquisition)
  - Check of the channel status,
  - electronic gain calibration,
  - lorentz angle measurement,
  - hit reconstruction efficiency (>99.9%)
  - synchronization with the LHC clock phase
The Tracker Alignment

- Tracker Alignment Parameters measured with 3.2M cosmic muon tracks in B field 3.8T (collected during summer ‘09)

- Modules aligned at the level of 3-4 $\mu$m in barrel and 3-14 $\mu$m in endcaps

- Data-driven alignment validation: cosmic track splitting and comparison of the two track legs
  - $\sim$ 1% resolution on $p_T$
  - Good agreement with ideal geometry

!! Data before alignment!!
CMS Track Reconstruction based on three steps

- 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

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

- MC data include realistic description of detector conditions, calibrations, alignment
  - Effect of inactive modules in the $\phi \sim -1.2$ region well reproduced in data and MC
    - Affecting ONLY reconstruction of low $p_T$ tracks
Primary Vertex Reconstruction

- Primary Vertex distribution for a single run
  - beam width estimated from a gaussian fit

- Data-Driven Primary Vertex resolution:
  - separating tracks in two independent sets and comparing the fit
  - Very good agreement with MC
    - -> accuracy of the alignment well modeled in MC
**$V^0$ Reconstruction**

- Long-lived $K^0_s(\rightarrow \pi^+\pi^-)$ and $\Lambda^0(\rightarrow \pi p)$ (+c.c.)
  - $c\tau_{K_S} = 2.7$ cm, $c\tau_{\Lambda} = 7.9$ cm

- Reconstruction strategy for secondary vertexes
  - Two high quality tracks with opposite charge, missing the PV

- Vertex requirement
  - $V^0$ vertex separated from primary vertex: $>15\sigma$ in radial direction.
  - No daughter track hits $>4\sigma$ inside of vertex.
**$K^0_s$ and $\Lambda^0$ Mass and Lifetime**

- $V^0$ 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
  - Applied efficiency correction from MC
Other Reconstructed resonances

- Based on vertex reconstruction with the $V^0$ candidate plus charged track
  - $\Xi^- \rightarrow \Lambda^0 \pi^- (+cc)$
    - tracks displaced from primary vertex ($d_{3D}>3\sigma$)
    - Constrain $\Lambda$ mass to PDG value
- $K^*(892)^\pm \rightarrow K^0_s \pi^\pm$
  - Strong resonance with extremely short lifetime
  - $K^0_s$ and $\pi^\pm$ tracks compatible with primary vertex

$K^*(892)^\pm$ Mass Fit:
  - Relativistic Breit-Wigner for signal
  - Bkg: $1-\exp[(m_k+m_\pi - m)/B]$
**Particle ID using dE/dX**

- Specific energy loss in silicon strip sensors is a powerful observable for particle identification.
- CMS Silicon Tracker has analog readout
- At least 10 measurements per track
- Robust dE/dx estimator
- Discrimination of kaon and proton tracks

\[ p < 2 \text{ GeV} \quad \frac{dE}{dx} > 4.15 \text{ MeV/cm} \]

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

![Graphs and plots showing dE/dX distributions and mass spectra for different particles.](image-url)
$\Phi(1020) \rightarrow K^+K^-$ using $dE/dx$

- Selection criteria
  - 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 $\pm 200$ MeV around the $K$ mass

$$m/m_{\text{PDG}} = 1 + (1.2 \pm 2) \times 10^{-4}$$

- Resolution: $1.29 \pm 0.32$ MeV
• Very limited b-jets in first collisions
  - @ 900 GeV, many b-tag observables lose their sensitivity

• Study impact parameter and secondary vertex to compare bkg with MC
  - Relaxed cuts

• Data/MC matching implies that $udsg$-bkg and fakes are well described in MC
Conclusions

• The first collision data collected by CMS were used to evaluate the performance of the tracker detector

• The excellent match of reconstructed and PDG mass and $V^0$ lifetime are proof of the very good understanding of the detector
  • calibrations, alignment, magnetic field and material budget
  • tracking and vertexing algorithms

• 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

• Ready to explore a higher energy domain with the incoming data at $\sqrt{s} = 7$ TeV
• Backup
Track Distributions

- Normalized $\chi^2$ distribution.
- Number of valid hits per track.
- Track $dxy$ corrected by pvtx (cm).
- Track $dz$ corrected by pvtx (cm).
• Exploit the impact parameter \( (d_0) \) Vs \( \phi_0 \) correlation to fit the Beam Spot

Beam Spot fixed in (0,0) of the coordinate frame

Mean of primary vertex distribution and beam spot positions are consistent

Beamwidth measured in 900(2360)GeV
\[ \sigma_x \sim 200(120)\mu m, \quad \sigma_y \sim 250(120)\mu m \quad \text{and} \quad \sigma_z \sim 4(2.8)cm \]
Primary Vertex Vs Pt

CMS Preliminary, $\sqrt{s} = 900$ GeV

- Data
- Simulation

Primary Vertex Resolution X ($\mu$m)

Primary Vertex Resolution Z ($\mu$m)

Number of Tracks

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**$V^0$ Simulation**

CMS Simulation

PDG $K^0_S$ mass: $497.614 \pm 0.022$ MeV/c$^2$

Yield: $270829 \pm 592$
Mean: $498.11 \pm 0.01$ MeV/c$^2$
Core $\sigma$: $4.47 \pm 0.04$ MeV/c$^2$
Tail $\sigma$: $10.49 \pm 0.11$ MeV/c$^2$
Core fraction: $0.58 \pm 0.01$

CMS Simulation

Yield: $31034 \pm 211$
Mean: $1115.92 \pm 0.02$ MeV/c$^2$
$\sigma$: $2.62 \pm 0.02$ MeV/c$^2$

PDG $\Lambda^0$ mass: $1115.683 \pm 0.006$ MeV/c$^2$
Displaced Secondary Vertex Event

B-tagging algorithm found a secondary vertex made of 4 tracks

- 3D Decay length 2.6mm (significance 7.02), mass = 1.64 GeV
**Nuclear Interactions**

- Reconstruction of nuclear interactions based on tracks
  - Resolution of the vertex position ~ 500 µm
  - Regions with more interaction correspond to the highest density of matter

- Nuclear interactions in the barrel pixel $|z| < 26$ cm

- Beam pipe off-center can be seen very clearly
- Visible also the inner carbon fiber shielding of the Pixel detector