Recent Results from CMS

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On behalf of the CMS Collaboration

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ISVHECRI: The XVI International Symposium on Very High Energy Cosmic Ray Interactions
28th June 2010
Compact Muon Solenoid

SUPERCONDUCTING COIL

CALORIMETERS
- ECAL: Scintillating PbWO4 crystals
- HCAL: Plastic scintillator/brass sandwich

η<3
η<5

IRON YOKE

TRACKER
- Silicon Microstrips
- Pixels

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

MUON BARREL
- Drift Tube Chambers (DT)
- Resisitive Plate Chambers (RPC)

MUON ENDCAPS
- Cathode Strip Chambers (CSC)
- Resistive Plate Chambers (RPC)
CMS timeline and energies

- **0.9 TeV**
  - 23rd of November 2009, FIRST COLLISIONS!
  - 6th of December, First physics fills

- **2.36 TeV**
  - 14th of December 2009, FIRST COLLISIONS!
  - About 20000 events collected

- **7 TeV**
  - 30th of March 2010, FIRST COLLISIONS!
Multi-jet event @7TeV!

CMS Experiment at the LHC, CERN

Run: 132440
Event: 3087931
Lumi section: 138
Orbit: 35985009
Crossing: 1
Integrated Luminosity

\[ \sim 21 \text{nb}^{-1} \] delivered by LHC and \[ \sim 19 \text{nb}^{-1} \] collected by CMS

- 91% overall data taking efficiency
- 90% after quality flags and data certification for physics
Performances
Primary Vertex, Pixel Clusters and Strip Trackers identification

Primary Vertex

Pixel Clusters

Strip Tracker

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6/28/2010
Secondary Vertices, b-tagging

- Signed 3D impact parameter wrt primary vertex for all tracks selected for b-tagging in jets with $p_T > 40$ GeV and $|\eta| < 1.5$
- Pretty good agreement with MC expectation for key tagging ingredients
Double b-Tag in Data
Tracking - Inclusive $D^0$ production

- Selection criteria
  - *good* runs: 132440 - 133038
  - transverse momentum cuts
    \( P_T(K) > 1.25 \text{ GeV}, P_T(\pi) > 1.0 \text{ GeV}, P_T(D^0) > 3.0 \text{ GeV} \)
  - Vertexing cuts

- MC expectations:
  - Peak: $1.863 \pm 0.002 \text{ GeV}$
  - Width: $0.014 \pm 0.002 \text{ GeV}$
Tracking - $D^*$ production

- Data: 37M events in good runs
- Reconstruct $D^* \rightarrow D^0 \pi_S$, $D^0 \rightarrow K \pi$
  - kinematical selection
  - Track quality
  - Mass windows
- Unbinned extended ML fit (RooFit)
Tracking - Strange Resonances

Reconstructed channels

- $K^*(892)^+ \rightarrow K_S^0 + \pi^+$
- $\Sigma(1385)^+ \rightarrow \Lambda + \pi^+$
- $\Sigma(1385)^- \rightarrow \Lambda + \pi^-$
- $\Xi(1530)^0 \rightarrow \Xi + \pi^+$

Signatures:

- Studied states are strong resonances with very short lifetime decay instantly at the production point → decay products originate from primary vertex
- Decay chains contain neutral hadrons ($K_S^0$, $\Lambda$) → neutral vertices
$K^*$ and $\Sigma(1385)$ Mass Distributions

$\sqrt{s} = 7$ TeV

$K^*(892)^+ \rightarrow K_S^0\pi^+$
- Yield: $96021 \pm 1038$
- Mean: $890.36 \pm 0.37$ MeV/$c^2$
- $\Gamma$ (fixed): $50.8$ MeV/$c^2$
- $\sigma$: $2.55 \pm 0.13$ MeV/$c^2$

$\sqrt{s} = 7$ TeV

$K^*(892)^- \rightarrow K_S^0\pi^-$
- Yield: $95500 \pm 1039$
- Mean: $890.43 \pm 0.38$ MeV/$c^2$
- $\Gamma$ (fixed): $50.8$ MeV/$c^2$
- $\sigma$: $2.46 \pm 0.12$ MeV/$c^2$

$\sqrt{s} = 7$ TeV

$\Sigma(1385)^+ \rightarrow \Lambda\pi^+ + \text{c.c}$
- Yield: $22545 \pm 490$
- Mean: $1381.56 \pm 0.6$ MeV/$c^2$
- $\Gamma$ (fixed): $35.8$ MeV/$c^2$
- $\sigma$: $4.47 \pm 0.15$ MeV/$c^2$

$\sqrt{s} = 7$ TeV

$\Sigma(1385)^- \rightarrow \Lambda\pi^- + \text{c.c}$
- Yield: $23712 \pm 512$
- Mean: $1384.6 \pm 0.66$ MeV/$c^2$
- $\Gamma$ (fixed): $39.4$ MeV/$c^2$
- $\sigma$: $5.29 \pm 0.15$ MeV/$c^2$
All mass distributions show a perfect agreement with the PDG values!
Neutral pions decaying to $\gamma \gamma$ 

- first $\pi^0$ peak shown already the 27th November
- good agreement with MC for peak position and S/B
- uncorrected energies are shown here
Dijets candidate event at $\sqrt{s} = 7$ TeV

CMS Experiment at LHC, CERN
Run 133450  Event 16358963
Lumi section:  285
Sat Apr 17 2010, 12:25:05 CEST

Jet1 $p_T$: 253 GeV
Jet2 $p_T$: 244 GeV
Dijet Mass: 764 GeV
Di-jets Mass

Di-jet selection: Jets $P_T > 25$ GeV, $|\eta| < 3$ and $\Delta \phi > 2.1$
Missing Transverse Energy

Three methods for the calculation of the missing $E_T$:

- Calorimeter
- Calorimeter + Tracks
- Particle Flow
Muons At Last!

The CMS Detector Performance Results

Conclusions

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Muons, data-MC comparisons for a few kinematical distributions

Consider two types of muon candidates:
- Tracker muons (tracker tracks matched to at least one segment in the muon system)
- Global muons (combined fit of all tracker and muon hits)

On all plots, MC is normalized to the number of muons in data.

**Global Muons**

**Tracker Muons**
Global Muons

Tracker Muons

P and $P_T$ spectra
Impact Parameter w.r.t. primary vertex

Global Muons

Tracker Muons
\( J/\Psi \rightarrow \mu^+ \mu^- \)

- pixel layers with hit > 1
- pixel+strip hits > 11
- \( |d_0| < 5 \text{ cm}, \ |z_0| < 20 \text{ cm} \)
- Tracker only
- Tracker+Muon system
- vertex probability > 0.1%

Crucial for the tracker and muon-system calibration and alignment!
$W \rightarrow e\nu$ Candidates

CMS Experiment at LHC, CERN
Run 133874, Event 21466935
Lumi section: 301
Sat Apr 24 2010, 05:19:21 CEST

Electron $p_T = 35.6$ GeV/c
$M_E = 36.9$ GeV
$M_T = 71.1$ GeV/c$^2$
W → µν Candidates

CMS Experiment at LHC, CERN
Run 133875, Event 1228182
Lumi section: 16
Sat Apr 24 2010, 09:08:46 CEST

Muon $p_T = 38.7$ GeV/c
$M_E = 37.9$ GeV
$M_T = 75.3$ GeV/c²
Z → e^+ e^- Candidates

CMS Experiment at LHC, CERN
Run 133877, Event 28405693
Lumi section: 387
Sat Apr 24 2010, 14:00:54 CEST

Electrons $p_T = 34.0$, 31.9 GeV/c
Inv. mass $= 91.2$ GeV/c$^2$
Z → \mu^+\mu^- Candidates

CMS Experiment at LHC, CERN
Run 135149, Event 125426133
Lumi section: 1345
Sun May 09 2010, 05:24:09 CEST

Muon p_T = 67.3, 50.6 GeV/c
Inv. mass = 93.2 GeV/c^2
Physics Results
Transverse-momentum and pseudorapidity
distributions of charged hadrons in pp collisions at
$\sqrt{s} = 0.9$ and 2.36 TeV

CMS Collaboration

ABSTRACT: Measurements of inclusive charged-hadron transverse-momentum and pseudorapidity distributions are presented for proton-proton collisions at $\sqrt{s} = 0.9$ and 2.36 TeV. The data were collected with the CMS detector during the LHC commissioning in December 2009. For non-single-diffractive interactions, the average charged-hadron transverse momentum is measured to be $0.46 \pm 0.01$ (stat.) $\pm 0.01$ (syst.) GeV/c at 0.9 TeV and $0.50 \pm 0.01$ (stat.) $\pm 0.01$ (syst.) GeV/c at 2.36 TeV, for pseudorapidities between $-2.4$ and $+2.4$. At these energies, the measured pseudorapidity densities in the central region, $dN_{ch}/d\eta|_{|\eta|<0.5}$, are $3.48 \pm 0.02$ (stat.) $\pm 0.13$ (syst.) and $4.47 \pm 0.04$ (stat.) $\pm 0.16$ (syst.), respectively. The results at 0.9 TeV are in agreement with previous measurements and confirm the expectation of near equal hadron production in pp and pp collisions. The results at 2.36 TeV represent the highest-energy measurements at a particle collider to date.
Charged Hadron: 3 methods

- **Pixel hit counting (1 hit)**
  - Using the primary vertex;
  - Immune to detector mis-alignment;
  - $p_T > 30$ MeV/c, $|\eta| < 2$;

- **Tracklets (2 hits)**
  - From hit pairs;
  - Data-driven background subtraction;
  - $p_T > 50$ MeV/c, $|\eta| < 2$;

- **Tracks (pixel+strips)**
  - Use all pixel and strip hits;
  - Sensitive, most complex;
  - $p_T > 100$ MeV/c, $|\eta| < 2.4$;
Three different methods yielding consistent results down to $P_T > 100$ MeV

Measurement provide valuable feedback to theoretical predictions
Charged Hadron Multiplicity

- Steeper increase of multiplicity density with collision energy compared to current predictions
  - MC tuning after few days of data taking before LHC enters high luminosity era (tuning effort is still ongoing)
Underlying Event @ 900 GeV

- Hard scattering track jets with $P_T > 3$ GeV to study underlying event activity in transverse region
- Significant discrepancy in both shape and normalization wrt many existing Pythia tunes

Observation of Single Diffractive events

- Variable used: $\Sigma(E+p_z) = \Sigma E(1+\cos \theta)$
- The sum runs over the full calorimeter acceptance
- Events below 5 GeV are mainly SD type!

Uncorrected distributions (CMS PAS FWD-10-001)
Bose-Einstein Correlations

- Measure correlation between identical bosons with momenta $p_1$ and $p_2$

$$ R = \frac{P(p_1, p_2)}{P(p_1)P(p_2)} = \frac{(dN/dQ)}{(dN/dQ_{ref})} \quad Q = \sqrt{-(p_1 - p_2)^2} = \sqrt{m_{inv}^2 - 4m^2} $$

$$ R(\Omega) = C[1 + \lambda \Omega(Qr)] \cdot (1 + \delta Q) $$

- Several references samples for normalization
  - opposite charge pairs, rotated particles, opposite hemishpere, mixed events

![Graphs showing double ratio for CMS preliminary $\sqrt{s} = 0.9$ TeV and $2.36$ TeV with fit parameter $r = (1.59 \pm 0.05)$ fm and $\lambda = 0.62 \pm 0.02$ for $\sqrt{s} = 0.9$ TeV, and $r = (1.99 \pm 0.18)$ fm and $\lambda = 0.66 \pm 0.07$ for $\sqrt{s} = 2.36$ TeV.]}
Conclusions

- CMS is well advanced with the detector commissioning and calibration
- The understanding of the detector performance with the data continues to make progress
- CMS has published three papers on Minimum Bias data so far:
  - $dN/d\eta$ and $dN/dp_T$ at 0.9 and 2.36 TeV
  - $dN/d\eta$ and $dN/dp_T$ at 7 TeV
  - Bose-Einstein Correlations
- CMS has used its calorimeters to observe single-diffractive events
- Many other upcoming results/publications!