Ridge correlation structure in high multiplicity pp collisions with CMS

Dragos Velicanu

for the CMS Collaboration
Results from High Multiplicity pp

CMS Experiment at the LHC, CERN

Data recorded: 2010-Jul-09 02:25:58.839811 GMT (04:25:58 CEST)
Run / Event: 139779 / 4994190
CMS Experiment

EM Calorimeter (ECAL)

Hadron Calorimeter (HCAL)

Beam Scintillator Counters (BSC)

Forward Calorimeter (HF)

Tracker
(Pixels and Strips)
Large coverage (|\Delta \eta|<5.0)
50 \mu m vertex resolution

Muon system
Trigger on High Multiplicity pp

CMS trigger and DAQ

High-Level trigger:
number of tracks with $p_T > 0.4$ GeV/c, $|\eta| < 2$
from a **single** vertex
Total integrated luminosity: 980nb⁻¹

Two HLT thresholds:
- \(N^{\text{online}} > 70\)
- \(N^{\text{online}} > 85\)

\(N^{\text{online}} > 85\) trigger un-prescaled for full 980nb⁻¹ data set

\(~350K\) top multiplicity events (\(N > 110\)) out of 50 billion collisions
Angular Correlation Technique

Signal distribution:
\[ S(\Delta \eta, \Delta \phi) = \frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{same}}}{d \Delta \eta d \Delta \phi} \]

Background distribution:
\[ B(\Delta \eta, \Delta \phi) = \frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{mix}}}{d \Delta \eta d \Delta \phi} \]

\[ \Delta \eta = \eta^{\text{assoc}} - \eta^{\text{trig}} \]
\[ \Delta \phi = \phi^{\text{assoc}} - \phi^{\text{trig}} \]

\[ \frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{pair}}}{d \Delta \eta d \Delta \phi} = B(0,0) \times \frac{S_N(\Delta \eta, \Delta \phi)}{B_N(\Delta \eta, \Delta \phi)} \]

Divide signal by background
Correlations in High Multiplicity pp

Intermediate $p_T$: 1-3 GeV/c

High multiplicity pp ($N > 110$)
High multiplicity pp (N>110)

Intermediate $p_T$: 1-3 GeV/c

“Away-side” ($\Delta\phi \sim \pi$)
back-to-back jet correlations

“Near-side” ($\Delta\phi, \Delta\eta \sim 0$)
correlations from single jets
Correlations in High Multiplicity pp

Intermediate $p_T$: 1-3 GeV/c

Striking “ridge-like” structure extending over $\Delta \eta$ at $\Delta \phi \sim 0$
Correlations in High Multiplicity pp

Intermediate $p_T$: 1-3 GeV/c

Striking “ridge-like” structure extending over $\Delta \eta$ at $\Delta \phi \sim 0$

(not observed before in hadron collisions or MC models)

High multiplicity pp ($N>110$)

High multiplicity MC

Minbias pp

(b) MinBias, $1.0\text{GeV}/c<p_t<3.0\text{GeV}/c$
Correlations in High Multiplicity pp

Intermediate $p_T$: 1-3 GeV/c

Striking “ridge-like” structure extending over $\Delta \eta$
at $\Delta \phi \sim 0$

High multiplicity pp ($N>110$)
Correlations in High Multiplicity pp

**Intermediate $p_T$: 1-3 GeV/c**

Striking “ridge-like” structure extending over $\Delta \eta$ at $\Delta \phi \sim 0$

(Similarity to Heavy Ion)

---

High multiplicity pp (N>110)

---

CMS PbPb 2.76 TeV

arXiv:1105.2438
Interpretations of the Ridge

CMS pp 7 TeV, N ≥ 110

CMS PbPb 2.76 TeV, 0-5%

Dragos Velicanu (MIT)
New Results

- 2x as much data
  - $|\Delta \eta|$ dependence
  - $p_T$ dependence
  - Multiplicity dependence

$\sqrt{s} = 7$ TeV, $N \geq 110$

$2 < p_T^{\text{trig}} < 3$ GeV/c
$1 < p_T^{\text{assoc}} < 2$ GeV/c
New Results

- 2x as much data
  - $|\Delta \eta|$ dependence
  - $p_T$ dependence
  - Multiplicity dependence

Ridge goes away at high $p_T$
|Δη| dependence of the ridge

Zero-Yield-At-Minimum (ZYAM)

Ridge is mostly flat in |Δη|

pp √s = 7 TeV, N ≥ 110

2 < p_{trig} < 3 GeV/c
1 < p_{asso} < 2 GeV/c

Associated Yield

Dragos Velicanu (MIT) pp Ridge for Quark Matter 2011
CMS Preliminary

CMS pp 7 TeV, N ≥ 110

Dragos Velicanu (MIT)  pp Ridge for Quark Matter 2011
$\Delta \phi$ projections in bins of $p_T$

Jet region ($|\Delta \eta| < 1$)

Ridge region ($2 < |\Delta \eta| < 4$)

CMS pp 7 TeV, $N \geq 110$
$p_T$ dependence of the ridge

Jet region ($|\Delta \eta|<1$)

Ridge region ($2<|\Delta \eta|<4$)
Near-side yield vs $p_T$

Jet region ($|\Delta \eta| < 1$)

Ridge region ($2 < |\Delta \eta| < 4$)

Ridge first increases with $p_T$, and then drops at high $p_T$
Ridge in pp turns on around $N \sim 50-60$ (4x MinBias) smoothly

$(\langle N \rangle \sim 15$ in MinBias pp events)
Summary

- Surprising new effect in pp
  - Never before seen in pp or pp MC
  - Similar to HI
- New results provide more detailed properties of ridge
  - $p_t$, $|\Delta\eta|$, multiplicity dependence
- New testing ground for high density QCD physics

Wei Li (Plenary session Thursday)

CMS pp 7 TeV, $N \geq 110$

Jeremy Callner (Parallel Tuesday)

CMS PbPb 2.76 TeV, 0-5%
Backups
Understanding the Correlation Structure

What was used in PHOBOS, ISR, UA5

\[ R(\Delta \eta, \Delta \varphi) = \left( N - 1 \right) \left( \frac{S_N(\Delta \eta, \Delta \varphi)}{B_N(\Delta \eta, \Delta \varphi)} - 1 \right) \]

CMS 7TeV pp minimum bias

\[ p_T \text{ inclusive} \]
Momentum conservation:
\[ \sim -\cos(\Delta \phi) \]

“Away-side” \((\Delta \phi \sim \pi)\) jet correlations:
Correlation of particles between back-to-back jets

CMS 7TeV pp minimum bias

Bose-Einstein correlations:
\((\Delta \phi, \Delta \eta) \sim (0,0)\)

“Near-side” \((\Delta \phi \sim 0)\) jet peak:
Correlation of particles within a single jet

Short-range correlations \((\Delta \eta < 2)\):
Resonances, string fragmentation, “clusters”
Comparing to various MC

(a) MinBias, $p_T > 0.1\text{GeV/c}$

(b) MinBias, $1.0\text{GeV/c} < p_T < 3.0\text{GeV/c}$

(c) $N > 110$, $p_T > 0.1\text{GeV/c}$

(d) $N > 110$, $1.0\text{GeV/c} < p_T < 3.0\text{GeV/c}$

PYTHIA8, v8.135
More MC models

PYTHIA D6T MinBias, N>70

PYTHIA D6T, Dijet 80-120GeV

HERWIG++, N>110

Madgraph, Dijet 100-250GeV, N>90
Cross Check: Event Pileup

Compare different run periods

$90 < N < 110, 2.0 < |\Delta \eta| < 4.8, 1.0 \text{GeV/c} < p_T < 2.0 \text{GeV/c}$

- Run 135000-138000
- Run 138000-139500
- Run 139500-140400

$R(\Delta \phi)$

$\Delta \phi$

Change in pileup fraction by factor 4-5 has almost no effect on ridge signal
Cross Check: Event Pileup

Correlate tracks from high multiplicity vertex with tracks from different collision (vertex) in same bunch crossing.

- $N > 110$
- $1.0 \text{GeV/c} < p_T < 3.0 \text{GeV/c}$
- $2.0 < |\Delta \eta| < 4.8$

No background or noise effects seen in cross-collision correlations.
Ridge is seen with three independent analysis codes
Cross Check: Trigger

Min-bias trigger vs high mult trigger

Ridge is seen using min bias trigger + offline selection

Min trigger

N>70, N>80, N>90, N>90, Trigger

1<p_T<2 GeV/c |
\Delta\eta|>2

HLT 70 vs HLT 85 for N > 110

No trigger bias seen from comparison of trigger paths

N>110 1<p_T<2 GeV/c |
\Delta\eta|>2
Cross Check: ECAL photons

Use ECAL “photon” signal
Mostly single photons from $\pi^0$s
No efficiency, and $p_T$, $\phi$ smearing corrections

Track-photon correlations

Note: photons reconstructed using “particle flow” event reconstruction technique
**Cross Check: ECAL photons**

Use ECAL "photon" signal
Mostly single photons from $\pi^0$'s
No efficiency, and $p_T$, $\phi$ smearing corrections

Photon-photon correlations
Qualitative confirmation

Independent detector, independent reconstruction
Particle density in high Mult pp

• Similar particle densities in these pp collisions as were seen in CuCu at RHIC

![Graphs showing particle density in CMS pp 7TeV, N>100 and PHOBOS CuCu 62.4GeV.](image-url)