Ridge correlation structure in high multiplicity pp collisions with CMS

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for the CMS Collaboration
Results from High Multiplicity pp

CMS Experiment at the LHC, CERN

Data recorded: 2010-Jul-09 02:25:58.8398311 GMT (04:25:58 CEST)
Run / Event: 139779 / 4994190
Trigger on High Multiplicity pp

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 ($N>110$)

$R(\Delta\eta, \Delta\phi)$
Correlations in High Multiplicity pp

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

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

High multiplicity pp (N>110)

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

(not observed before in hadron collisions or MC models)
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)
Ridge in high multiplicity pp

Interpretations:
Multi-jet correlations
Jet-Jet color connections
Jet-proton remnant color connections

Color Glass Condensate

Glasma tube

Hydrodynamic flow

Quark Gluon Plasma

EPOS model: pp

CMS pp 7 TeV, N ≥ 110

59 citations (link to SPIRES)

CMS PbPb 2.76 TeV, 0-5%


K. Werner, WWND2011

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New Results

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

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

CMS Preliminary

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

$1 \frac{d^2 N_{\text{pair}}}{N_{\text{trig}} \, d\Delta \eta \, d\Delta \phi}$

$1.40$ $1.35$ $1.30$ $4$ $4$

$\phi$ $\eta$
New Results

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

Ridge goes away at high $p_T$
$|\Delta \eta|$ dependence of the ridge

Zero-Yield-At-Minimum (ZYAM)

CMS Preliminary

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

$2 < p_T^{\text{trig}} < 3$ GeV/c

$1 < p_T^{\text{assoc}} < 2$ GeV/c

Ridge is mostly flat in $|\Delta \eta|$
$\Delta \phi$ projections in various $p_T$ ranges

**CMS pp 7 TeV, N ≥ 110**

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

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Ridge in pp and PbPb

CMS pp 7 TeV, N ≥ 110

CMS PbPb 2.76 TeV, 0-5%

Ridge Region

CMS Preliminary

pp √s = 7 TeV, N ≥ 110

|Δη| dependence

L = 3.1 μb⁻¹

Ridge Region

CMS Preliminary

1 < p_{assoc} < 2 GeV/c

x10

Associated Yield

p_{T}^{trig}(GeV/c)

2 < p_{T}^{assoc} < 4 GeV/c

Associated Yield

p_{T}^{trig}(GeV/c)
Near-side yield vs $p_T$

Ridge first increases with $p_T$, and then drops at high $p_T$
Near-side yield vs $p_T$

MinBias-like

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

Ridge first increases with $p_T$, and then drops at high $p_T$
Near-side yield vs Multiplicity

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

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

Ridge in pp turns on around $N \sim 50-60$ (4x MinBias) smoothly

($\langle N \rangle \sim 15$ in MinBias pp events)
Near-side yield vs Multiplicity

Ridge starts to turn on around $N \sim 50-60$ (4x MinBias) smoothly

$<N> \sim 15$ in MinBias pp events

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

Ridge in pp turns on around $N \sim 50-60$ (4x MinBias) smoothly.
Summary

- Surprising new effect in pp
- $p_T$, $|\Delta \eta|$, multiplicity dependence
- New testing ground for high density QCD physics

Outlook
- $p_T$ distribution, global properties, PID correlations…
- Check more HI observables (jet quenching, dijet asymmetry, low $p_T$ PID spectra…)
Backups
Understanding the Correlation Structure

What was used in PHOBOS, ISR, UA5

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

CMS 7TeV pp minimum bias
“Away-side” ($\Delta \phi \sim \pi$) jet correlations:
Correlation of particles between back-to-back jets

Momentum conservation:
$\sim -\cos(\Delta \phi)$

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

CMS 7TeV pp minimum bias
Bose-Einstein correlations:
$(\Delta \phi , \Delta \eta) \sim (0,0)$

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

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Cross Check: Event Pileup

Compare different run periods

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

Change in pileup fraction by factor 4-5 has almost no effect on ridge signal
Correlate tracks from high multiplicity vertex with tracks from different collision (vertex) in same bunch crossing

\[ N > 110 \]
\[ 1.0 \text{GeV/c} < p_T < 3.0 \text{GeV/c} \]

No background or noise effects seen in cross-collision correlations
Cross Check: Analysis Code

Ridge is seen with three independent analysis codes

Independent code
Same definition of $R$
Same input file (skim)

Control analysis I
Control analysis II

Independent code
Different definition of $R$
Different input file (skim)
Min-bias trigger vs high mult trigger

Ridge is seen using min bias trigger + offline selection

HLT 70 vs HLT 85 for N > 110

No trigger bias seen from comparison of trigger paths
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
• Similar particle densities in these pp collisions as were seen in CuCu at RHIC
Tracker (Pixels and Strips)

Large coverage ($|\Delta \eta|<5.0$)

50 $\mu$m vertex resolution

EM Calorimeter (ECAL)

Hadron Calorimeter (HCAL)

Beam Scintillator Counters (BSC)

Forward Calorimeter (HF)

Muon system
**Trigger on High Multiplicity pp**

- **Level-1:** \( \sum E_T > 60 \text{ GeV} \) in calorimeters

- **High-Level trigger:** number of tracks with \( p_T > 0.4 \text{ GeV/c}, |\eta| < 2 \) from a **single** vertex

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**CMS trigger and DAQ**

- LV1
- Digitizers
- Front end pipelines
- Readout buffers
- Switching networks
- Processor farms

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