Interpreting the CMS “ridge” in 7 TeV p-p collisions from the LHC

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STAR@RHIC
p-p at 0.2 TeV

CMS@LHC

p-p at 7 TeV

APS Meeting, Anaheim, CA – April 30-May 3, 2011
Relative angular correlations on $\eta, \phi$

- Fill histograms: $h_{\text{sibling}}(\eta_1-\eta_2, \phi_1-\phi_2)$
  $h_{\text{reference}}(\eta_1-\eta_2, \phi_1-\phi_2)$

- No “trigger” particle
- Include all charge particle pairs in the acceptance & $p_t$ cuts

CMS definition

$$R = \left( \langle N \rangle - 1 \right) \left[ \frac{h_{\text{sibling}}}{h_{\text{reference}}} - 1 \right]$$

$\langle N \rangle$ is mean multiplicity

Minimum-bias p-p at 0.2 TeV - STAR

- low $p_t$ pairs
- higher $p_t$ pairs

longitudinal fragmentation, quantum correlations (HBT)

Jet and dijet correlations

All pairs

MB p-p at 7 TeV


This was expected…
But then an unexpected “ridge” appeared

**p-p at 7 TeV, N > 110, 1 < p_t < 3 GeV/c**

All jets in acceptance

Inter-jet correlations - dijets

**What is this?**

CMS notes similarity to same-side ridge in A-A collisions at RHIC

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**At RHIC:**

Au-Au 200 GeV mid-central, all particles

p_t > 0.15 GeV/c

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Abelev (*STAR*), *Phys.Rev.C 80,064912(2009).*

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Alver (*PHOBOS*), *PRL 104,062301(2010).*
What is actually observed in Au-Au at RHIC?

Au-Au at 200 GeV from STAR – all pairs, no “trigger” particle

STAR Preliminary

64-74%  55-64%  46-55%  38-46%  28-38%

increasing collision centrality

- Jet correlations increase in amplitude and **η width** more than binary scaling; described by 2D Gaussian; not a “ridge”

- **Quadrupole** correlation: near-side and away-side ridges
Long $\eta$-range & Quadrupole correlations: Ideas

T. Sjostrand (Pythia): Talk given at CERN, 12 Oct 2010


**$\eta$ extended jet correlations**

EbyE energy density fluctuations + radial flow

- Color Glass Condensate flux tubes
  \(Dumitru\ et\ al.,\ Phys.Lett.B697,21(2011)\)
- Initial stage hot spots, \(Gavin\ PRL97,162302\)
- Beam-jet fragments, \(Shuryak,arXiv:1009.4635\)

\[
\begin{align*}
N(\phi) & \propto 1 + 2\nu_2 \cos(\phi - \psi_{RP}) \\
C(\phi_1 - \phi_2) & \propto 2\nu_2^2 \cos[2(\phi_1 - \phi_2)]
\end{align*}
\]

(quadrupole) Thought to be caused by hydrodynamic pressure - collective flow.

Anisotropic emission wrt reaction plane:

- Higher order 2\(\rightarrow\)3 or 2\(\rightarrow\)4 matrix elements.

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Rick Field – ISMD, ECT* 2010

[Diagram of proton-proton collision with extended jet correlations]

[Diagram of Color Glass Condensate (CGC) with hot spots and radial flow]

[Diagram of anisotropic emission with angular correlation functions]
Phenomenological fits based on these ideas:

**Jets, dijets, longitudinal fragmentation:**

- 2D peak
- For higher-order jet or color-flux tube fragmentation: extended $\eta$ width, non-Gaussian geometry (optional)

**Initial stage energy density fluctuations with pressure driven radial flow:**

- SS periodic Gaussian “ridge” (optional)

**Non-central collision overlap geometry:**

- Quadrupole (optional)

* [Plus: 2D exponential (HBT), $\eta$-modulations of AS Gaussian, SS Gaussian, and quadrupole]
Phenomenological fits to 7 TeV data:

- minbias, $p_t > 0.1$
- minbias, $1 < p_t < 3$
- $N > 110$, $p_t > 0.1$
- $N > 110$, $1 < p_t < 3$

Data

Model Fit

No SS Gaussian ridge or quadrupole

With quadrupole

Comparison of three trial models:

<table>
<thead>
<tr>
<th>( \chi^2 / \text{DoF} )</th>
<th>Jet+AS Gaussian No quad or SS-ridge</th>
<th>with SS-ridge, no quad.</th>
<th>with quad., no SS-ridge</th>
</tr>
</thead>
<tbody>
<tr>
<td>N&gt;110, pt&gt;0.1GeV/c</td>
<td>13.9</td>
<td>10.9</td>
<td>9.8</td>
</tr>
<tr>
<td>N&gt;110, 1&lt;pt&lt;3GeV/c</td>
<td>16.3</td>
<td>4.6</td>
<td>4.2</td>
</tr>
</tbody>
</table>

- Extended jet peak cannot reproduce the CMS data
- Minbias data are not improved with SS Gaussian or quadrupole
- Fits to the N>110 data cannot rule out SS Gaussian or quad
- Quadrupole fit obtains lowest \( \chi^2 \)
- Inferred \( \nu_2 \):

\[
A_{Quad} = 2[\langle N \rangle - 1] \nu^2_2; \quad \nu_2 = 0.046 \text{ (all } p_t\text{), } 0.053 \text{ (higher } p_t\text{); } [\pm 0.001 \text{ (stat), } \pm 0.01 \text{ (syst)}]
\]

similar magnitude to Au-Au at RHIC

Other fitting analyses:
Quadrupole in A-A at RHIC & p-p at LHC: Hydrodynamics or something else?

• Heavy ion hydrodynamic models require rapid, ~1 fm/c, kinetic equilibration to work.

• Can parton cascade achieve such rapid equilibration?
  Yes, if effective $\alpha_s$ is large enough
  No, via pQCD and non-perturbative instanton model.

• Also, semi-hard (mini)jet-like correlations persist in Au-Au at RHIC which is not expected in hydro-like (opaque) medium. [Ray, PoS(CERP2010)032; Trainor, Mod.Phys.Lett. A 23, 569 (2008); J.Phys G: 37, 085004 (2010).]

• Could other, QCD mechanisms generate the quadrupole?
  Trainor (Mod.Phys.Lett. above) suggests multipole gluon radiation from color current-current interactions in analogy to electrodynamics.
Conclusions

- The quadrupole, well known in heavy-ion correlation analysis, produces the best fits to the 7 TeV CMS p-p “ridge” data, in agreement with two previous studies.

- In conventional A-A collision phenomenology the quadrupole correlation (or $v_2$) is assumed to be caused by hydrodynamic pressure driven flow.

- It is not understood how the required rapid equilibration (~1 fm/c) can occur in heavy ion collisions, much less in p-p.

- If the CMS p-p “ridge” correlations are in fact a quadrupole structure, then further theoretical study of possible QCD mechanism(s) producing azimuth anisotropy is in order, e.g. color-dipole, gluon radiation.

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