Results from Correlations in ALICE

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for the ALICE collaboration

Quark Matter 2011, Annecy
Correlations

- Pb-Pb collisions at LHC produce very hot and dense matter \((\text{min}(R_{AA}) \sim 0.14)\)
- Study the medium further by correlations of two or more particles
- Lower \(p_T\)
  - Assess the bulk of the correlations
  - Dominated by hydrodynamics and flow
  - Ridge
- Higher \(p_T\)
  - Dominated by jets
  - Quenching/suppression, broadening
- How do these phenomena at LHC compare to RHIC?
A Large Ion Collider Experiment

- EMCAL: $\gamma$, $\pi^0$, jets
- TRD: Electron ID (TR)
- PMD: $\gamma$ multiplicity
- TPC: Tracking, PID (dE/dx)
- PHOS: $\gamma$, $\pi^0$, jets
- T0/V0 Trigger
- L3 Magnet
- ACORDE Cosmic trigger
- HMPID: PID (RICH) @ high $p_T$
- TOF PID
- Dipole
- MUON $\mu$-pairs
- ITS: Low $p_T$ tracking PID + Vertexing
- Not shown: ZDC (at $\pm114m$)
Analysis

- Up to 19M Pb+Pb MB collisions used
- Centrality determination with V0 (forward scintillators)
- Tracking with Time Projection Chamber and Inner Tracking System in |η| < 0.9
  - Flat φ acceptance → No mixed events needed for acceptance correction (in Δφ projection)
  - Tracking efficiency ~ 85%
- Efficiency and contamination
  - Weakly centrality dependent
  - Two-track effects small but considered

Results from Correlations in ALICE - Jan Fiete Grosse-Oetringhaus

ALICE performance 10 Feb 2011

ALICE performance 14.03.11
MC Pb+Pb 2.76 TeV
TPC tracks

- p T (GeV/c) Tracking efficiency
  - 0-20%
  - 20-40%
  - 40-90%
Decomposition of Long-Range Correlations
Triggered Correlations

- Choose a particle from one \( p_T \) region ("trigger particle") and correlate with particles from another \( p_T \) region ("associated particles") where \( p_{T,\text{assoc}} < p_{T,\text{trig}} \) in bins of \( p_{T,\text{trig}} \) and \( p_{T,\text{assoc}} \)

\[
N_{\text{mixed}} \left( \frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{assoc}}}{d \Delta \varphi d \Delta \eta} \right)_{\text{same}} \bigg/ N_{\text{same}} \left( \frac{1}{N_{\text{trig}}} \frac{d^2 N_{\text{assoc}}}{d \Delta \varphi d \Delta \eta} \right)_{\text{mixed}}
\]

- Study long-range correlation structure in \( 0.8 < |\Delta \eta| < 1.8 \)
  - Very central events (0-2%) show mach cone type structure (without any flow subtraction)
  - Fourier decomposition

A Adare, Tu 15:00
Fourier Decomposition

- Fourier components are calculated
  \[ V_{n\Delta} = \langle \cos n\Delta \varphi \rangle = \frac{\int d\Delta \varphi C(\Delta \varphi) \cos n\Delta \varphi}{\int d\Delta \varphi C(\Delta \varphi)} \]

- 5 components describe correlation completely
  - Strong near-side ridge + double-peaked structure (in very central events) on away side at low \( p_T \)
  - Away-side peak dominated at high \( p_T \)
Fourier Components

- Coefficients increase with increasing $p_T$
- Odd terms become negative at large $p_T$ (influence of away-side jet)
- From central to peripheral, $v_{2\Delta}$ rises most
Flow vs Non-Flow Correlations

- Flow-related effects imply correlation of two particles through a plane of symmetry $\psi_n$
  - $V_{n\Delta}$ factorizes: $V_{n\Delta} = V_{n}^{\text{trig}} V_{n}^{\text{assoc}}$

- Jets cause correlations of a few energetic particles by fragmentation
  - There can be indirect correlations: length-dependent quenching
  - Would be largest w.r.t. $\psi_2$ since it reflects the collision geometry

- Assess flow vs. non-flow by testing the collectivity relation $V_{n\Delta} = V_{n}^{\text{trig}} V_{n}^{\text{assoc}}$
  - Instead of calculating $V_{n\Delta}$ in each $p_{T,\text{assoc}} \times p_{T,\text{trig}}$ bin ($N(N-1)/2=55$ bins), allow only one $V_{n\Delta}$ per $p_T$ bin (11 parameters)
Flow vs Non-Flow Correlations

- Compare single calculated values with global fit
- To some extent, a good fit suggests flow-type correlations, while a poor fit implies non-flow effects
  - $v_{2\Delta}$ to $v_{5\Delta}$ factorize until $p_T \sim 3-4$ GeV/c, then jet-like correlations dominate
  - $v_{1\Delta}$ factorization problematic (influence of away-side jet)
Soft Near-Side Decomposition
Untriggered Correlations

- Map out the centrality dependence of the bulk of the correlation
- Correlate all charged particles ($p_T > 0.15$ GeV/c)

\[
\frac{\Delta \rho}{\sqrt{\rho_{ref}}} = \frac{dN_{ch}}{d \eta} \left( \frac{\rho_{same}}{\rho_{ref}} - 1 \right)
\]

- Evolution of the correlation function
  - Sharp peak from HBT, conversions
  - Elliptic flow ($v_2$) dominates in mid central collisions
  - Stronger correlation structures towards central collisions
  - Near-side long-range correlation structure "ridge" builds up towards central collisions
Decomposition

- Quantify the near-side correlation by decomposing it with a fit

\[ \frac{\Delta \rho}{\rho_{ref}} = A + B \text{Gauss}\ (\Delta \phi, \Delta \eta) + \sum_{n} C_n \cos n\Delta \phi \]

- Gauss around near-side with independent width in \( \Delta \phi \) and \( \Delta \eta \)
- Only \( v_1 \) and \( v_2 \) as well as \( v_1 \) … \( v_4 \)
- cos-terms only \( \Delta \phi \) dependent
- 0, 0 peak excluded from fit

- Fit with and without \( v_3 \) and \( v_4 \) describes correlation structures well
  - Long-range correlation "ridge" fully described by \( v_n \)-components
  - Remaining Gaussian on near-side
Decomposition (2)

- Growth of amplitude and $\Delta \eta$-width significantly smaller when $v_3$ and $v_4$ are included ($\Delta \phi$-width independent)
- Structure has width of $\Delta \eta \sim 0.6 - 1.0$, $\Delta \phi \sim 0.6 - 0.7$
Gaussian "Volume"

- Gaussian volume = \(2\pi B\)
  \[\sigma_{\Delta\phi} \sigma_{\Delta\eta}\]
  - Measure of total number of pairs in near-side Gaussian
  - Magnitude of rise dictated by the inclusion of \(v_3\) and \(v_4\)

- Within our systematics binary scaling \(<N_{\text{bin}}>\) scaling (number of pairs scales with \(<N_{\text{bin}}>\), calibrated in the most peripheral bin) is not excluded
Charge Dependence

- Nearside 2D Gaussian shows strong charge dependence
- Large fraction of the structure stems from unlike sign pairs
- Like-sign near side structure wider

Near-side projection:

- 60-70% Unlike sign
- 10-20% Like sign
Modification of the Jet Particle Yield $I_{AA}$ and $I_{CP}$
Modification of Jet Particle Yield

- Extract near and away-side jet yields from per-trigger yields
  - Compare central and peripheral collisions $\rightarrow I_{CP}$
  - Compare Pb+Pb and pp $\rightarrow I_{AA}$
- Non-jet component (baseline) needs to be removed
  - No known assumption-free methods…
  - Determine pedestal by a fit around $\pi/2$ (ZYAM)
  - Estimate elliptic flow ($v_2$) contribution using ALICE flow measurement
- Measure in a region where the signal dominates over pedestal and $v_2$ modulation
  (8 GeV/c $< p_{T,\text{trig}}$ $< 15$ GeV/c)
- Aim: constrain energy-loss mechanisms together with $R_{AA}$
Near-side of central events slightly enhanced $I_{AA} \sim 1.2$ ... unexpected and interesting
Away side of central events suppressed: $I_{AA} \sim 0.6$ ... expected from in-medium energy loss

Peripheral events consistent with unity
$v_2$ contribution small except in lowest bin, there $v_3$ of same order
$I_{AA}(0-5\%)$ consistent with $I_{CP}$ with respect to near-side enhancement and away-side suppression
Comparison with RHIC

- Caveat: same trigger \( p_T \) probes different parton \( p_T \) at different \( \sqrt{s_{NN}} \)
- STAR and PHENIX subtract \( v_2 \) \( \rightarrow \) compare with ALICE line
  - STAR \( I_{AA} \) w.r.t. to dAu reference
  - STAR has different centrality for peripheral events
  - Away side larger than at STAR
  - PHENIX has (slightly) different \( p_{T,trig} \) ranges
- Near side enhancement not incompatible with RHIC

\[
\begin{align*}
\text{Near side:} & \quad |\eta| < 1.0 \quad \text{ALICE preliminary} \\
8 \text{ GeV/c} < p_{T,trig} < 15 \text{ GeV/c} & \quad p_{T,assoc} < p_{T,trig} \\
\end{align*}
\]

\[
\begin{align*}
\text{Away side:} & \quad |\eta| < 1.0 \quad \text{ALICE preliminary} \\
8 \text{ GeV/c} < p_{T,trig} < 15 \text{ GeV/c} & \quad p_{T,assoc} < p_{T,trig} \\
\end{align*}
\]

STAR: stat. unc. only

\[
\begin{align*}
\text{Near side:} & \quad 0-20\% / pp \\
\text{ALICE:} 8 \text{ GeV/c} < p_{T,trig} < 15 \text{ GeV/c} & \quad \text{PHENIX:} 7 \text{ GeV/c} < p_{T,trig} < 9 \text{ GeV/c} \\
& \quad \text{PHENIX:} 9 \text{ GeV/c} < p_{T,trig} < 12 \text{ GeV/c} \\
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\end{align*}
\]

Explanations for Near-Side Enhancement

- Same trigger $p_T$ in Pb-Pb collisions probes a different parton spectrum than in pp collisions
  - A harder/flatter spectrum causes more associated particles $\Rightarrow I_{AA} > 1$
- Larger energy loss of gluons in the medium and harder fragmentation of quarks [T Renk, PRC 77, 044905 (2008)]
  - Study for LHC energies: "we observe that the yield per trigger is enhanced by 10–20% in Pb-Pb relative to p-p collisions"
- $I_{AA}$ increase affects near and away side

$8 < p_{T,\text{trig}} < 15$

Parton $p_T$ (GeV/c)

$5 < p_T < 50$

$5 < p_T + 2 < 50$

$P_{\text{P-P}}$
$P_{\text{Pb-Pb}}$

$\sqrt{s} = 50-70$ GeV/c
Theory Comparison

Near side enhancement:
- reproduced by AdS/CFT pQCD hybrid ($L^3$ path length dependence) and ASW ($L^2$ dependence)
- YaJEM(-D) too high

Away side suppression:
- reproduced by AdS/CFT, ASW, YaJEM-D
- YaJEM too high (L dependence)
- X N Wang slightly too low

AdS/CFT, ASW, YaJEM(-D) simulations from T Renk [private communication, to appear; talk Tu 16:40]
X N Wang [private communication, following calculation in PRL98:212301 (2007)]
Summary

• Hadron correlations probe the hot and dense medium produced in LHC HI collisions
• Long-range correlations at \(0.8 < |\Delta \eta| < 1.8\) are well-described by the first 5 Fourier coefficients
  – The flow factorization \(V_{n\Delta} = \langle v_{N,\text{trig}} \rangle \langle v_{N,\text{assoc}} \rangle\) holds at low to intermediate \(p_T\) (< 3-5 GeV/c)
  – Jet correlations break the factorization at higher \(p_T\)
  – Method quantifies the transition from flow to jet dominated correlations
• Long-range correlation structure (aka "the ridge") at \(\Delta \phi \sim 0\) fully described by \(v_1\) to \(v_4\) components
  – Remaining Gaussian near-side structure increases with centrality, compatible with binary scaling
    • A strong charge dependence is observed
• \(I_{AA}\) Measurement
  – Away-side suppression (~0.6) and near-side enhancement (~1.2) is measured
  – The effect of the medium on the near side is visible at LHC

Talk, A Adare, Triggered correlations, Tu 15:00
• Talk, A Timmins, Untriggered correlations, Tu 15:40
• Poster, J Ulery, 3-particle correlations