Event-shape studies in pp collisions with ALICE

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How can we select “hard processes”? 

Many ways .. event-shape is one.

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Jet-like events
- Initially a hard process (that can be modeled!)
- particle production dominated by jet hadronization
- large jet collimation contribution to particle correlations

Spherical events
- multiple soft processes, non-perturbative QCD production (harder to describe!)
- no particle correlations due to collimation
Transverse sphericity - $S_T$

Scalar observable, sensitive to collimation
- Easy way to pick up on jet-like shapes!

\[ S^L_{xy} = \sum_i \frac{1}{p_{Ti}} \sum_i \left( \begin{array}{cc} p^2_{xi} & p_{xi}p_{yi} \\ p_{yi}p_{xi} & p^2_{yi} \end{array} \right) \]

\[ S_T = \frac{2\lambda_2}{\lambda_1 + \lambda_2} \Rightarrow S_T = \begin{cases} \approx 0 & \text{Jet-like} \\ \approx 1 & \text{Spherical} \end{cases} \]

Transverse spherocity - $S_0$

\[ S_0 = \frac{\pi^2}{4} \min_{\hat{n}} \left( \frac{\sum_i \vec{p}_{T,i} \times \hat{n}}{\sum_i p_{T,i}} \right)^2 \]

- High spherocity ($\approx 1$) contain jet-like cones
- High spherocity ($\approx 1$) contain jet-like cones
- => hard QCD process, single interaction!
- Low spherocity ($\approx 0$) selects soft-particle production events without jet structures

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- PYTHIA doesn’t describe exactly the $<p_T>$
- EPOS better at higher $N_{ch}$
- both MC generators struggle to describe the low $N_{ch}$ range of the distribution

- MC generators better describe lower spherocity spectra
- As in the case of jet-like events, low $N_{ch}$ events are not well described by MC
- Crossing point moving with mass and appears at higher $p_T$ for heavier particles
- Spherocity selection intuitively consistent among different particle species
How to apply event-shape selection in particle correlations analyses?

Two-particle correlations, femtoscopy
Bread and butter of femtoscopy

Using quantum statistics we can determine emission source size by measuring relative momenta of identical particles (π, K, p, ..)

Important information extracted from radii dependence on

\[ k_T = \frac{1}{2} |p_{T1} + p_{T2}| \]

Non-femtoscopic background from jet-collimation significantly limits the accessible range of \( k_T \)

What does femtoscopy look like with $S_T$ selection?
Correlation functions

- $S_T$ event selection, selecting for hardness, allows visualization of the dominating contributions to two-particle correlations.
- Spherical events do not show signs of background correlations while jet-like event correlation functions are dominated by them.
- Due to statistical separability the event-shape induced correlations are removable from measured CFs.

\[ \langle dN_{ch}/d\eta \rangle = 13.9 \pm 2.2 \]
\[ S_T < 0.3 \]
\[ \pi^+\pi^+ + \pi^-\pi^- \]

\[ \langle dN_{ch}/d\eta \rangle = 14.9 \pm 2.3 \]
\[ S_T > 0.7 \]
- observation of an ordering effect in pp
- previously reported by CMS and ALICE
  - Phys.Rev.Lett.105:032001,
  - Phys. Rev. C 89 024911
- signs of Lorentz-like source shape
- open question of CF shape interpretation
Final results

- Multiplicity scales with the volume
- Spherical events show a diminished dependence to $k_T$
- Jet-like events slope similar to min. bias events
- A new field of investigation opened in correlation studies!
Understanding event selection, going beyond min. bias, is a needed step in our field.

Event-shape techniques provide a reasonable way to select hard processes.

Spherical events have softer spectra and their radii are independent of pair $k_T$.

Jet-like events have higher $p_T$ and the radii show similar dependence to $k_T$ as min.bias.

Overlap with theory will significantly boost the reach of the method.
“There are more things in proton and proton, Than are dreamt of in our papers.”

Summa summarum
Back up
MonteCarlo background

- MonteCarlo generated correlations agree with measurement in a wide range of $Q_{inv}$
- Jet-like events are dominated by particle collimation contributions to correlation
- Non-femtoscopic background has a structure, which can not be described by a simple Gaussian form

Arxiv: 1901.05518