Exploring isotropic events in pp collisions using the flattenicity event shape variable

or

searching for hedgehogs at the LHC

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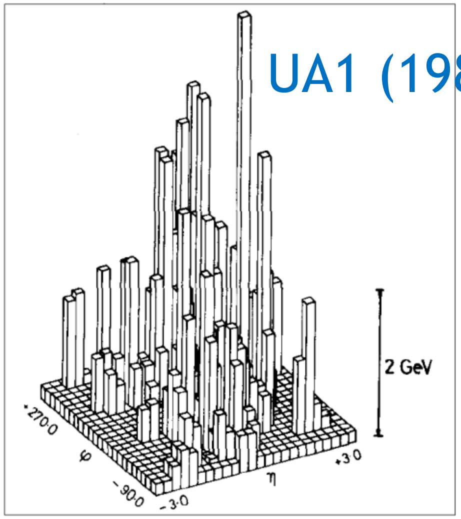
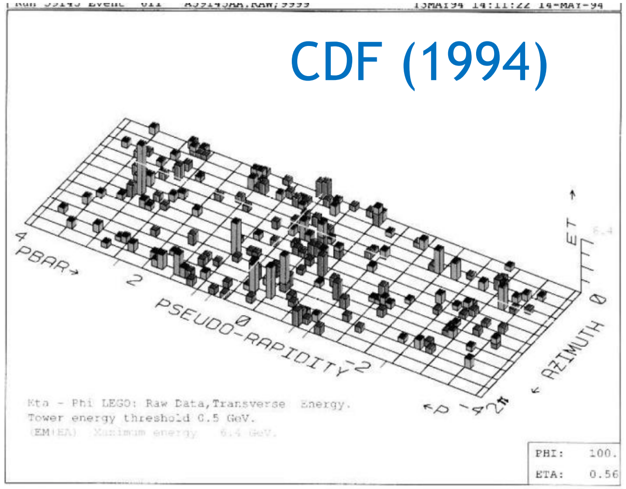
Hedgehogs (erizos) at the LHC?

Introduction to "hedgehog-like" events

- Looking for the presence of events with a very **extended structure** of low momentum tracks filling in a **uniform way the pseudorapidity-azimuth** (η-φ) space.
- First dedicated analysis of highest transverse energy (E_T) events seen in the UA1 detector at the SppS collider at CERN in proton-antiproton collisions at $\sqrt{s}$ = 630 GeV
- Several isotropic events with E_T ~210 GeV in UA1 observed (even tested for top quark production), no evidence for non-QCD mechanism for these events.
- Similar unusual events observed in p-pbar collisions at $\sqrt{s}$ = 1.8 TeV by CDF's Run 1 detector with more than 60 charged particles and E_T ~320 GeV
- Called "**hedgehog-like**" events by C. Quigg
- Taken for granted that in these events with high E_T perturbative aspects of QCD dominate the event properties: multi-jet events.



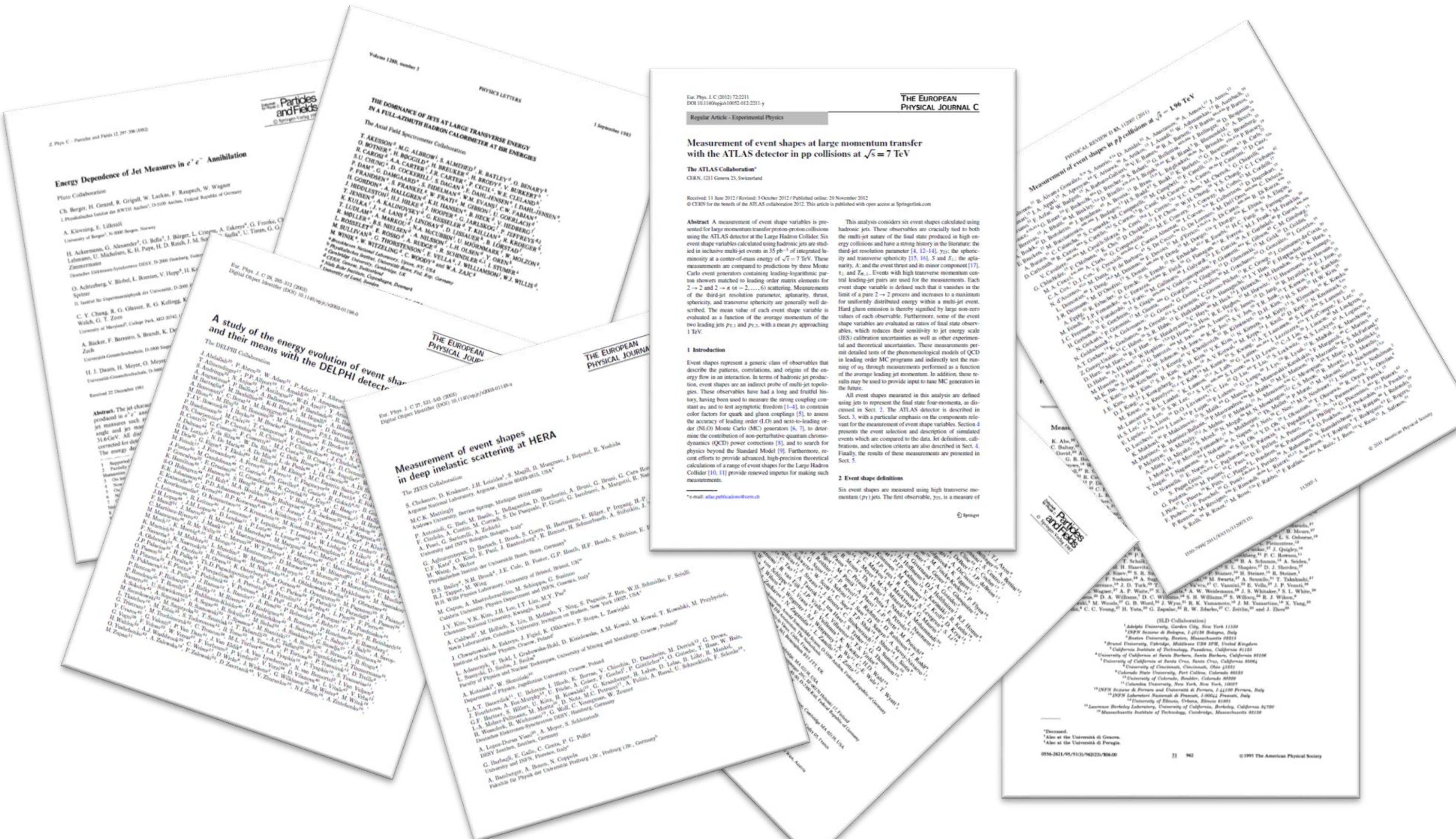
[UA1 Collaboration, Zeit. für Phys. C, V. 36, p. 33 (1987)]



[C. Quigg, Il Nuovo Cimento, V. 33C, N. 5 p. 327 (2010)]

Geometry of the final state: event shapes

- Event shape variables: instrumental in classifying the **geometrical and topological configurations** of the final-state particles produced in high-energy collisions at PETRA, ISR, SppS, SLD, LEP, HERA, Tevatron and the LHC.



Commonly used event shape variables

- Study the isotropy of the final-state energy distribution by defining the **linearized sphericity tensor of the event**, where the Greek indices denote the x, y, and z components of the momentum of the charged particle *i*. The eigenvalues must satisfy the normalization condition: $\lambda_1 \geq \lambda_2 \geq \lambda_3$ and $\lambda_1 + \lambda_2 + \lambda_3 = 1$.

$$S^{\alpha\beta} = \frac{\sum_i p_i^{\alpha} p_i^{\beta}}{\sum_i |\vec{p}_i|^2},$$

$$A = \frac{3}{2}\lambda_3; \quad S = \frac{3}{2}(\lambda_2 + \lambda_3).$$

- **Aplanarity (A)** serves as a measure of how planar an event is. A balanced pencil-like event corresponds to A = 0, and an isotropic event corresponds to A = 1/2.

- **Sphericity (S)** quanties the isotropy of an event, representing the degree to which energy and momentum are evenly distributed in all directions. S= 0 denotes a balanced dijet event, and S = 1 for an isotropic event.

Commonly used event shape variables

- **Centrality**: a measure of how much of the event is contained within the central part of the detector; ranges between 0 and 1, where a pencil-like has C = 0 and a centrally contained event corresponds to C = 1.

$$C = \frac{\sum_i p_{T,i}}{\sum_i E_i},$$

$$T = 1 - \max_{\hat{n}} \frac{\sum_i |\vec{p}_{\mathrm{T},i} \cdot \hat{n}|}{\sum_i |\vec{p}_{\mathrm{T},i}|},$$

- **Transverse thrust**: a widely used event shape ranging from 0 for a pencil-like topology to 1/3 for a circularly symmetric distribution of particles in the transverse plane.

- **Transverse spherocity**: infrared and colliner safe event shape that ranges from $S_0 = 0$ for events with back-to-back multijet final states to $S_0 = 1$ for isotropic event topologies.

$$S_0 = \frac{\pi^2}{4} \min_{\hat{n}_s} \left(\frac{\sum_i |\vec{p}_{T,i} \times \hat{n}_s|}{\sum_i p_{\mathrm{T_i}}} \right)^2 .$$

Characterisation of high-multiplicity events

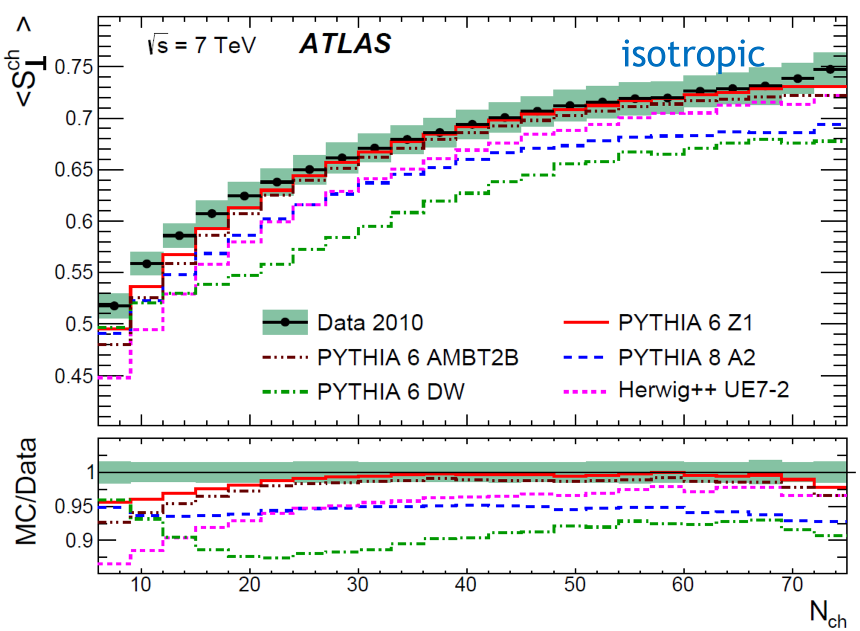
- Attempts to characterise these high-multiplicity events: use of event shapes, i.e. using **transverse sphericity**:

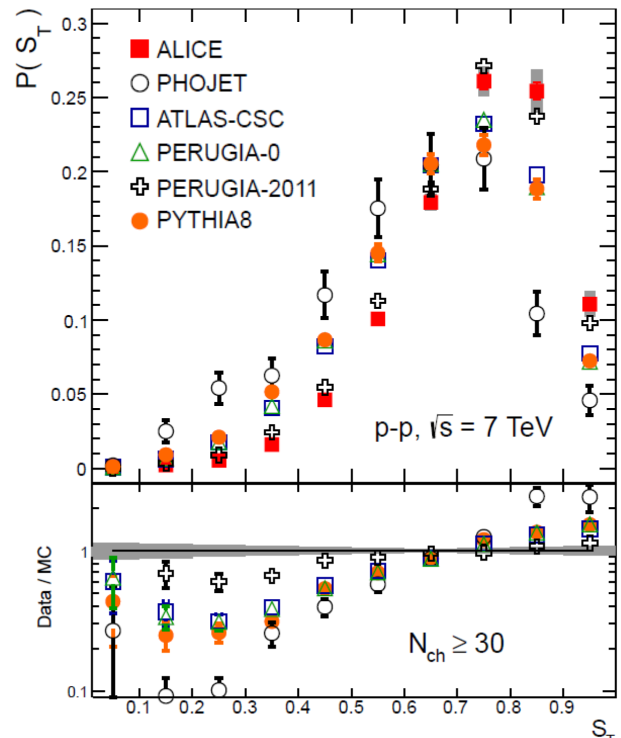
$$S_{\perp} = \frac{2\lambda_2^{xy}}{\lambda_1^{xy} + \lambda_2^{xy}}, \quad S^{xy} = \sum_i \frac{1}{|\vec{p}_{\mathrm{T},i}|^2} \begin{bmatrix} p_{x,i}^2 & p_{x,i}\, p_{y,i} \\ p_{x,i}\, p_{y,i} & p_{y,i}^2 \end{bmatrix}$$

- Both ALICE and ATLAS observed an **under-estimation of isotropic events by MC generators at high charged multiplicity** ($N_{ch} \geq 30$)

  ✓ Suggest that a very active underlying event (UE) is needed by the MC event generators in order to explain these high-multiplicity events

ATLAS Collaboration, Phys. Rev. D 88, 032004 (2013)





ALICE Collaboration, Eur. Phys. J. C 72 (2012) 2124

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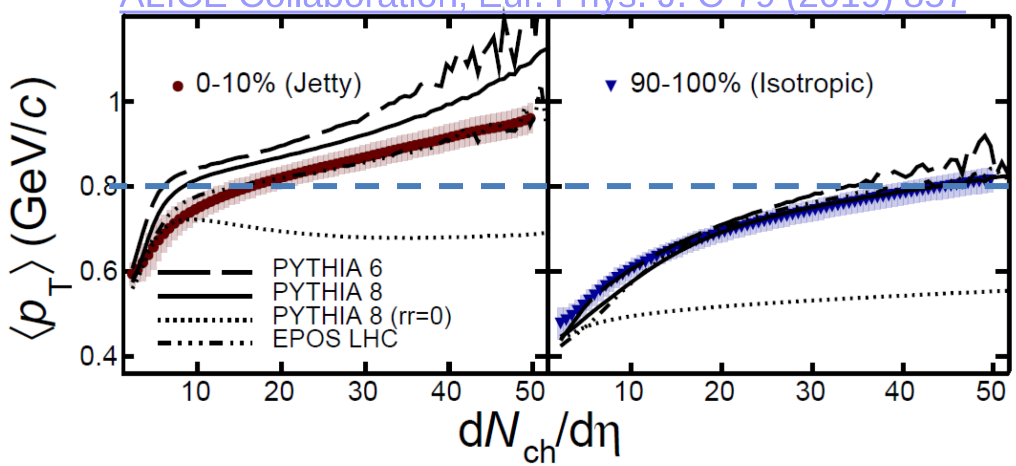
ALICE Collaboration, Eur. Phys. J. C 79 (2019) 857



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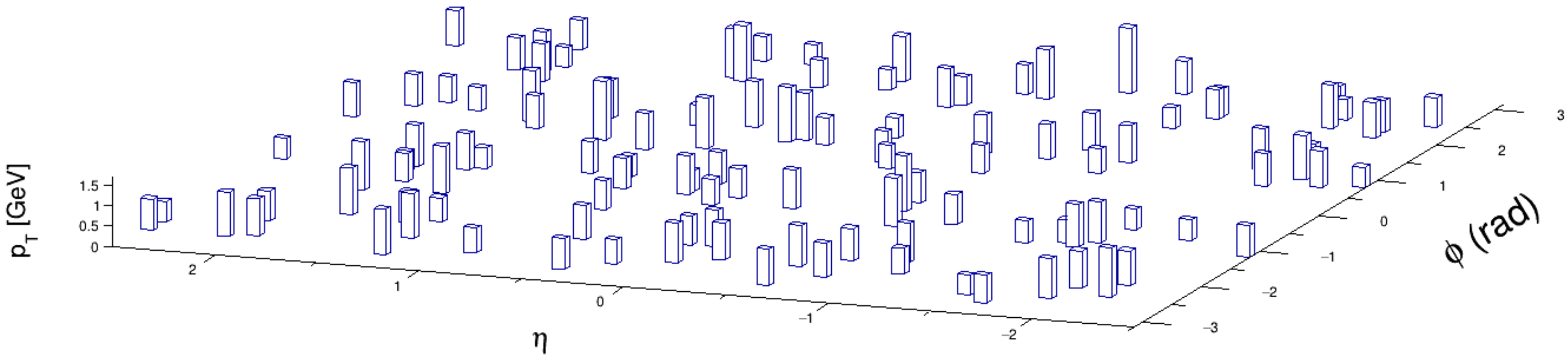
- Recently, **a new event shape parameter, flattenicity**, was proposed [A. Ortiz, G. Paic, Rev. Mex. Fis. Suppl. 3 (2022) 4, 040911] that allows one to identify and characterise high-multiplicity events with a quasi-isotropic distribution in a wide pseudorapidity range in proton-proton collisions.

- MC event generators are able to model "hedgehog" events, which opens the possibility to study their properties and find a potential way to experimentally trigger these events.

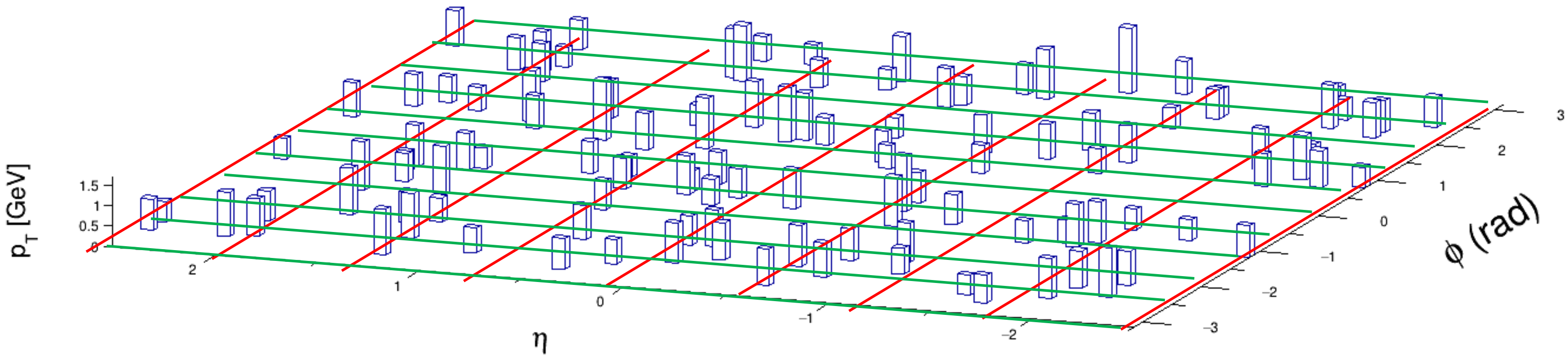
Calculating flattenicity

- The idea: find out how uniform the p_T of tracks is distributed in a given event!



Calculating flattenicity

- Build 10 x 12 grid in (η-φ) space:



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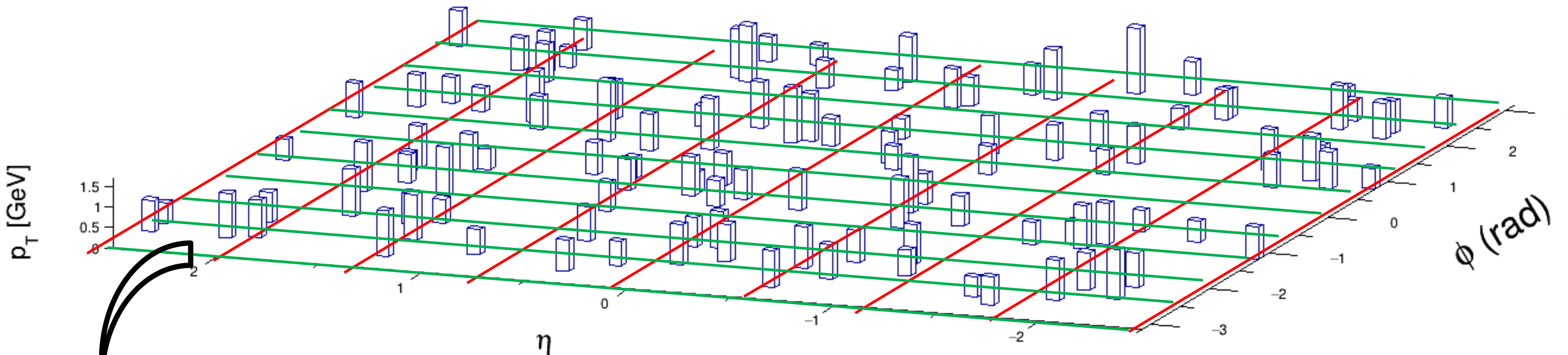


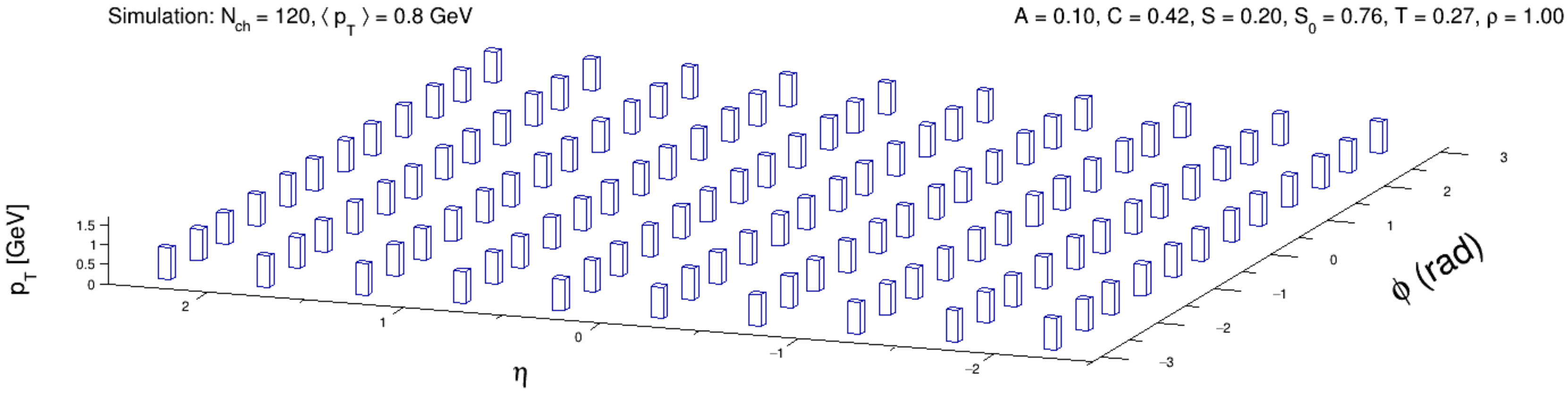
In each cell, the average transverse momentum is calculated: $p_{\mathrm{T}}^{\mathrm{cell}}$

- Event-by-event, the relative standard deviation of the $p_{\mathrm{T}}^{\mathrm{cell}}$ distribution is obtained.
- Events with isotropic distribution of particles ("**hedgehogs**") are expected to have $\rho = 1$.

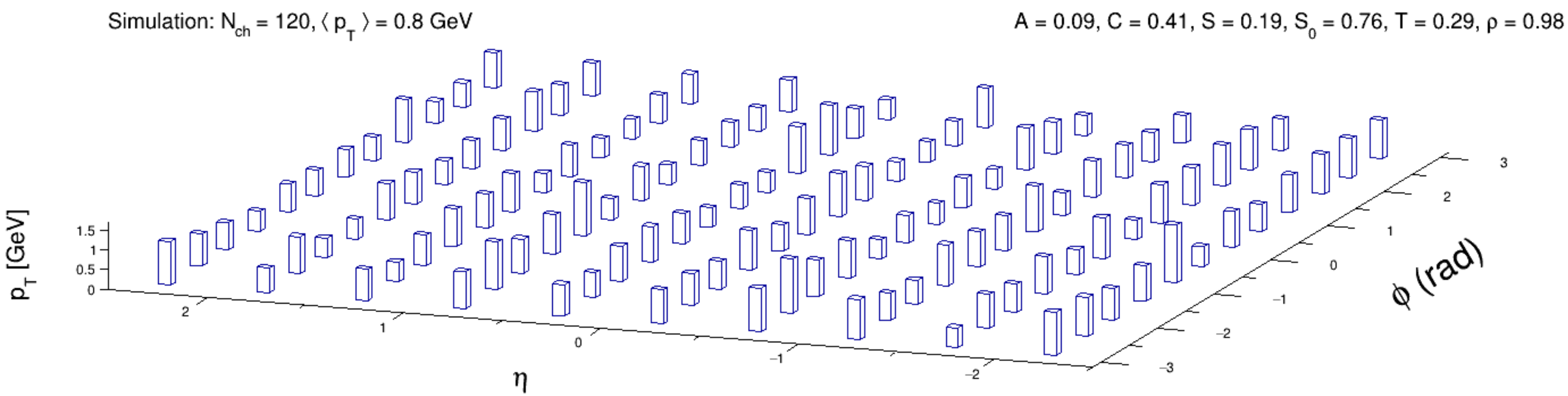
$$\rho = 1 - \frac{\sqrt{\sum_{i=1}^{i=120} \left(p_{\mathrm{T}}^{\mathrm{cell},i} - \langle p_{\mathrm{T}}^{\mathrm{cells}} \rangle\right)^2 / \mathrm{N}_{\mathrm{cell}}^2}}{\langle p_{\mathrm{T}}^{\mathrm{cells}} \rangle},$$

Benchmark hedgehog-like structures

ρ = 1

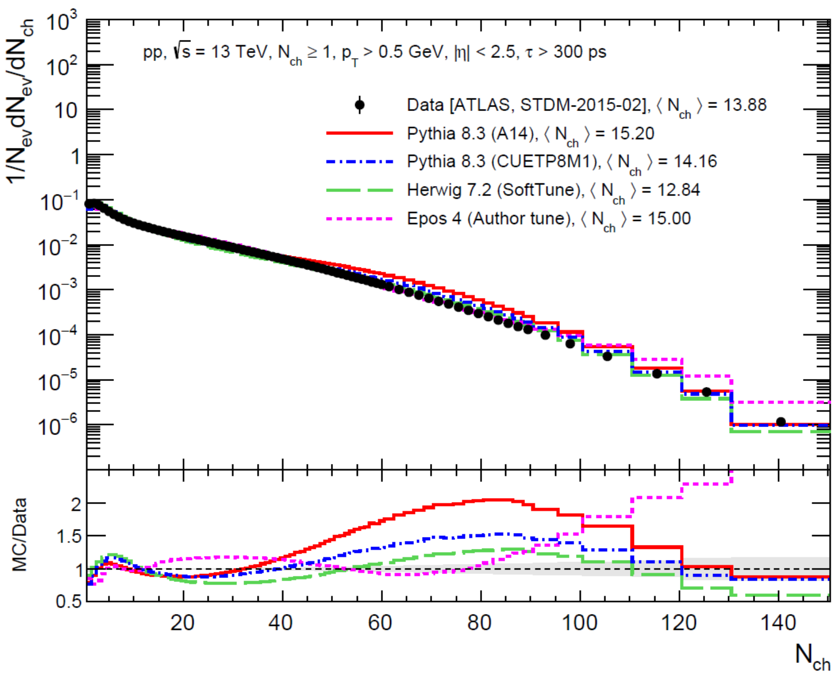


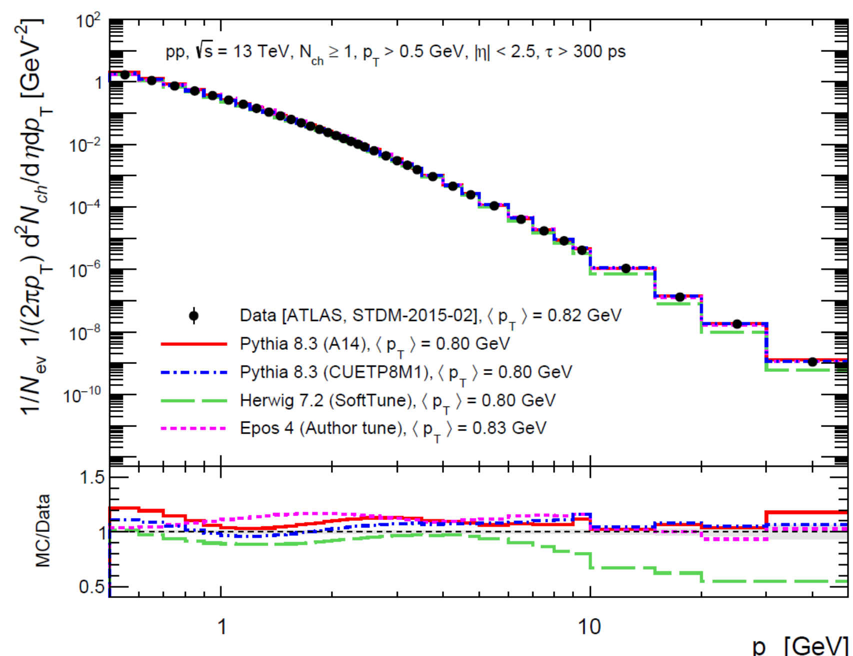
ρ = 0.98



Flattenicity using different MC generators

- Two sets of inelastic events, including non-diffractive and diffractive components, were simulated using **Pythia 8.309**: ATLAS A14 tune and CMS CUETP8M1 tune.
- **Herwig 7.2.0** with SoftTune based on the MMHT2014 LO PDF
- Recently released **EPOS 4.0.0** framework using authors tune
- First, **revise the performance** of these MC models in reproducing the 13 TeV pp collision data.





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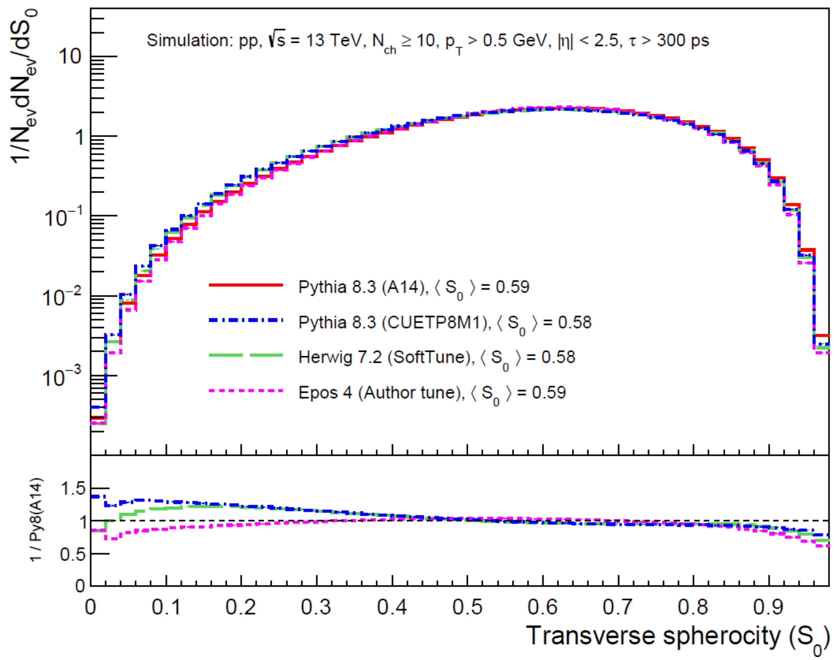
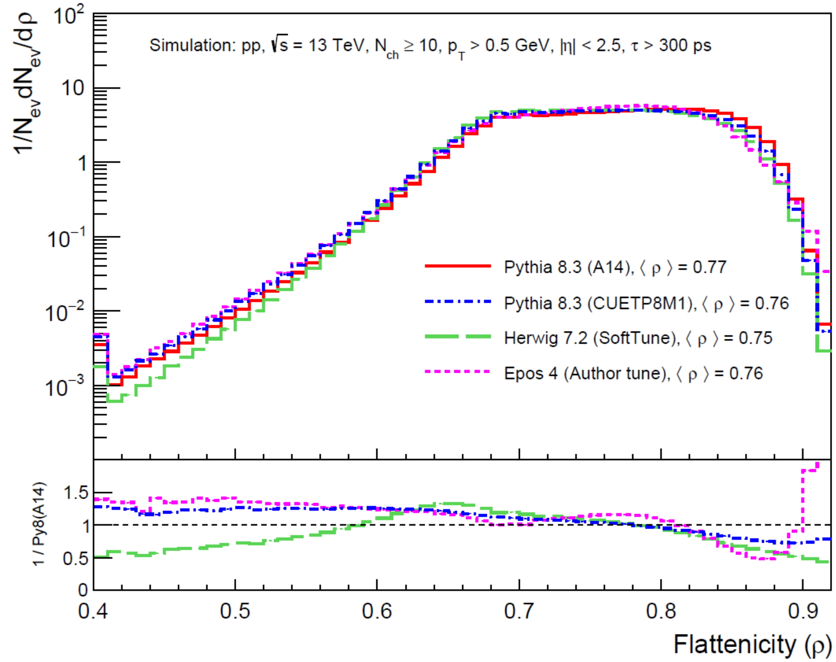
- Then, **compare transverse spherocity and flattenicity** for the 4 MC settings

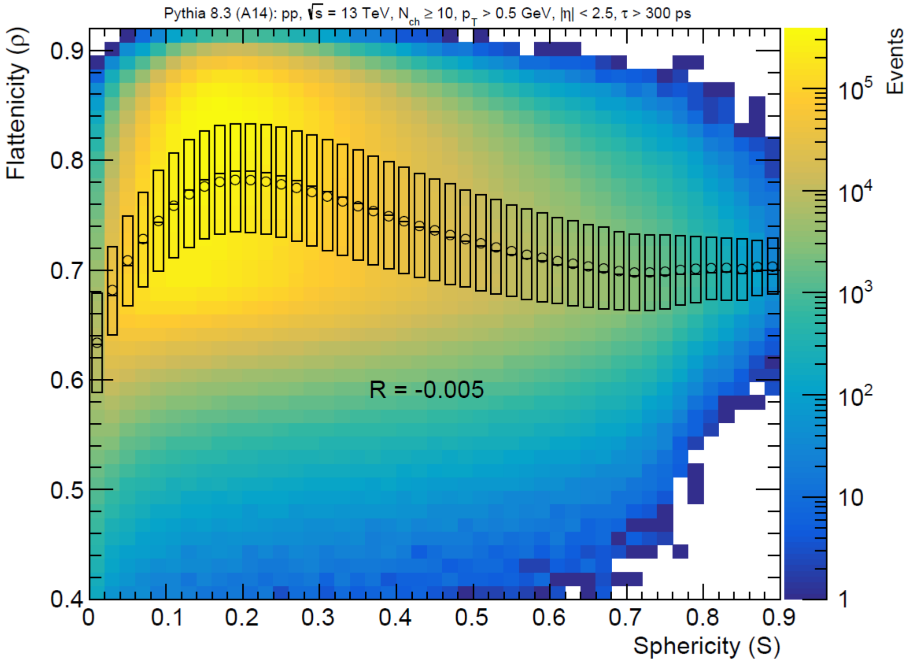


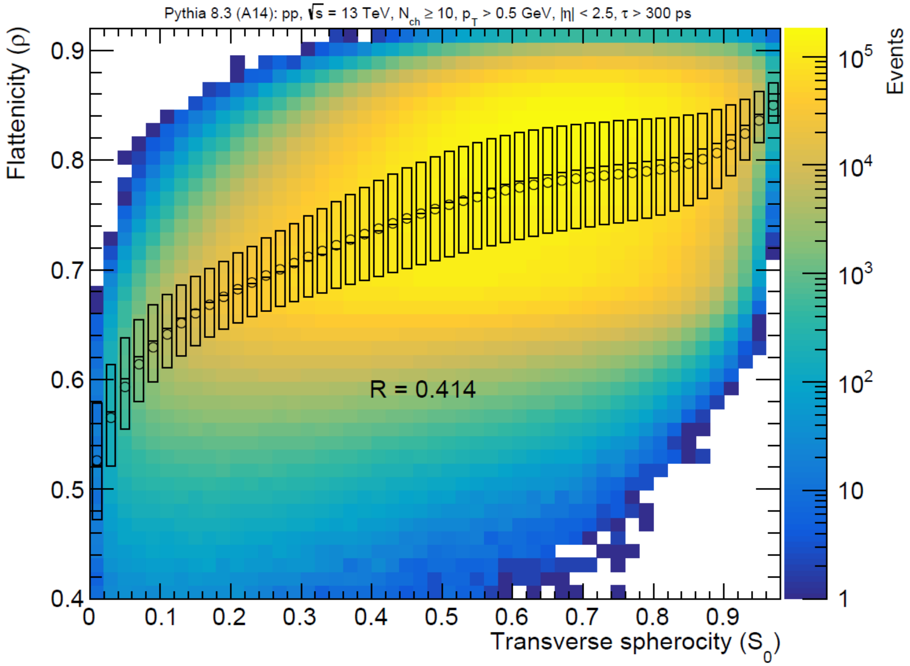


Flattenicity correlations

- To demonstrate flattenicity's value in identifying isotropic events and its complementary information about the global shape of an event, we study its correlation with other event shape variables.

- Overall, there is clear indication that while flattenicity is related to other event shape variables, it **provides distinct and complementary** info of the isotropy of events

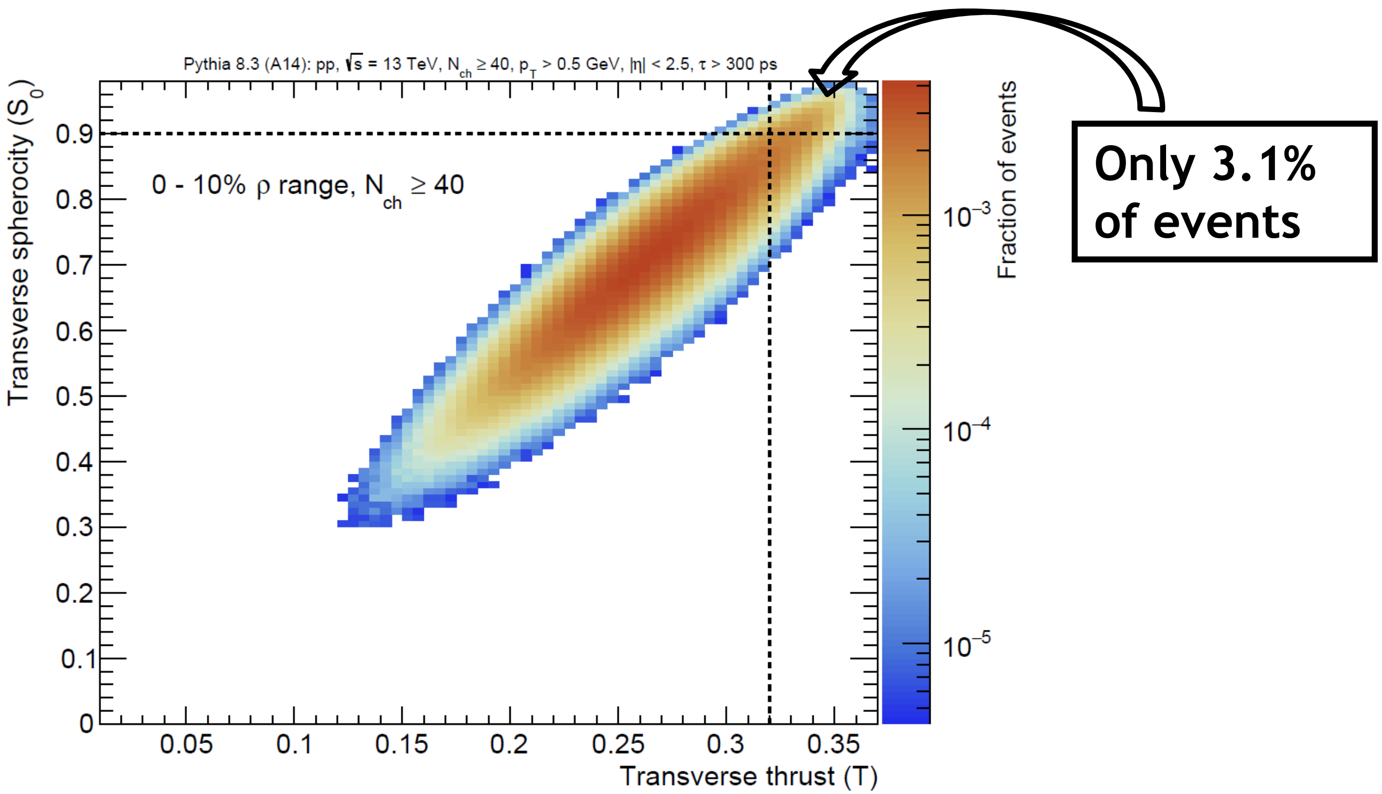




Flattenicity correlations

- Classify the **top 10%** of events in the distributions of flattenicity, transverse spherocity, and transverse thrust for each multiplicity class as **isotropic events.**

- Our observation is that for the highest charged-particle multiplicity class, only 3.1% of events meet all the three criteria: clearly indicates that **flattenicity selects a different subset** of events as compared to widely used S_0 and T.



Conclusions

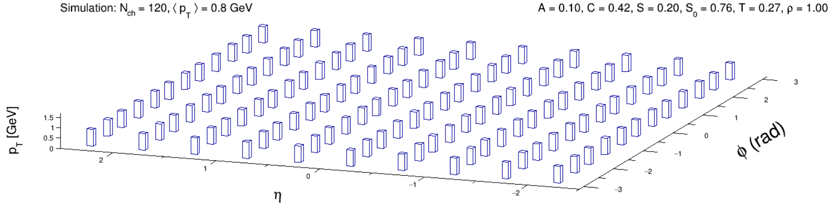
- Hedgehog events **have never been seriously studied** in pp collisions at the LHC. These events are “rare” – but as rare as a top-quark–pair production!

- Flattenicity - the new event structure parameter - allows one to identify the hedgehog events and observe the evolution of events from jetty to hedgehog type.

- When compared to other event shape variables widely used in the literature, such as transverse spherocity, we found that flattenicity is able to **identify** a subset of isotropic events with **hedgehog-like structures**.

- Our results will be submitted to a journal asap, while experimental measurements using flattenicity are on their way!

- Next steps: analyze hedgehog events in data, so stay tuned!



Muchas gracias por su atención!