“Hedgehog” events revisited

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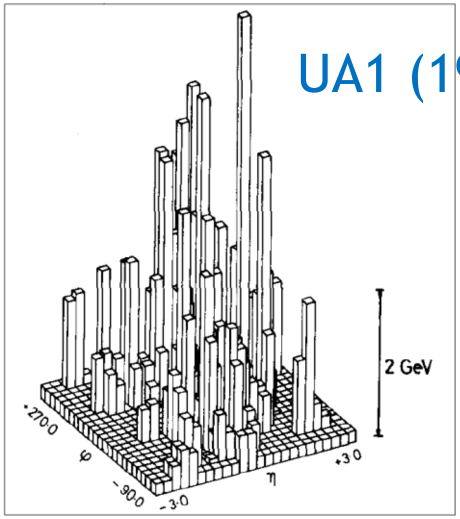
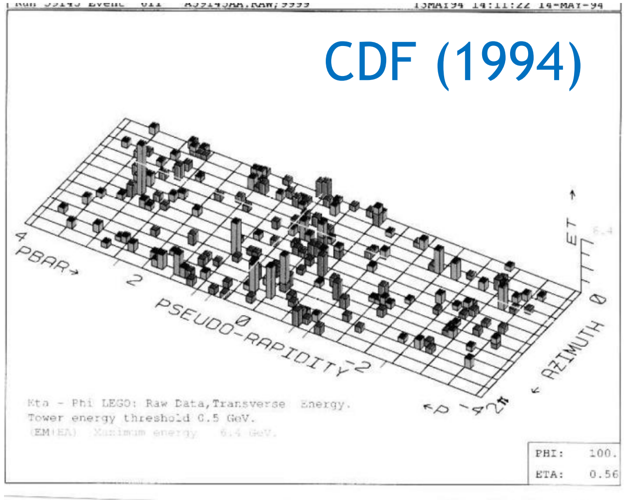
Introduction to "hedgehog" events

- The UA1 and CDF collaborations have reported the presence of events with a very extended structure of low momentum tracks filling in a uniform way the pseudorapidity-azimuth (η-φ) phase space.
- First dedicated analysis of highest E_T events seen in the UA1 detector at $\sqrt{s}$ = 630 GeV (with isotropic events with E_T ~ 210 GeV) – no evidence for non-QCD mechanism for these events.
- Unusual events observed in ppbar collisions at $\sqrt{s}$ = 1.8 TeV by CDF's Run 1 detector with more than 60 charged particles and ~320 GeV of transverse energy (E_T) – called "**hedgehog**" 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)

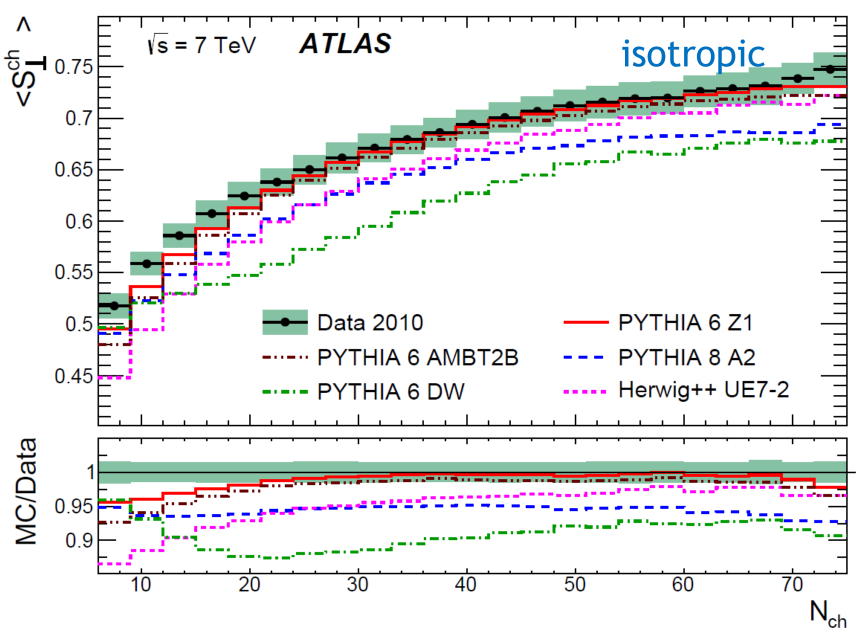
Characterisation of high-multiplicity events

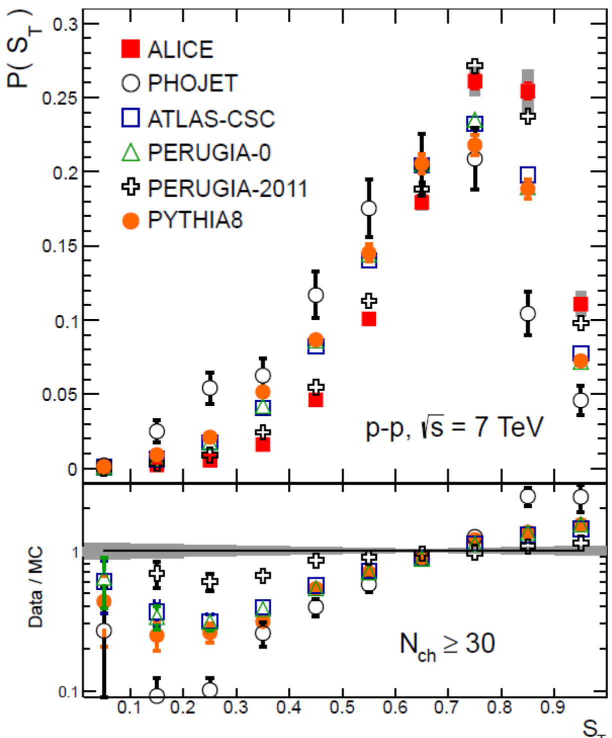
- Attempts to characterise these high-multiplicity events: use of event shapes, i.e. using transverse sphericity:

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

- 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)





pencil-like isotropic

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

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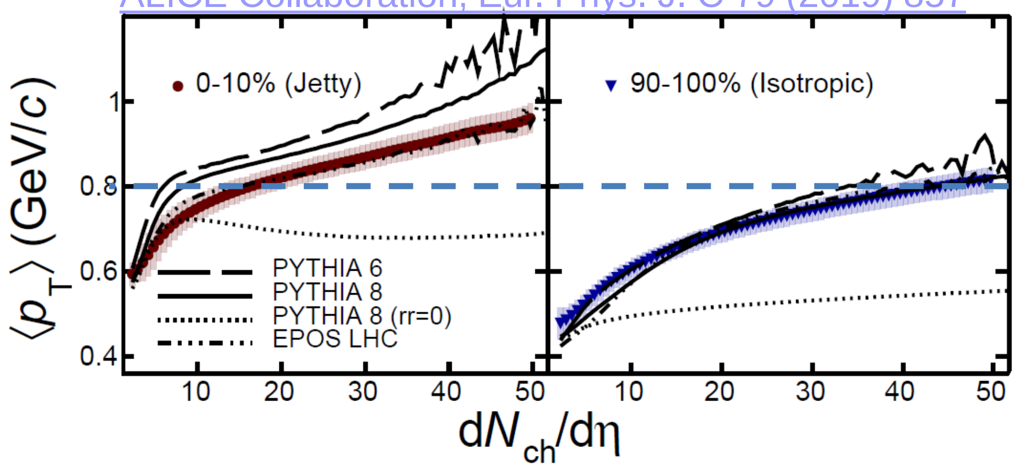
- ALICE measurement shows that $\langle p_T \rangle$ as a function of N_{ch} in isotropic events was found to be **smaller** than that measured in jet-like events, and that for jet-like events, the $\langle p_T \rangle$ is **over-estimated** by PYTHIA 6 and 8 models.

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



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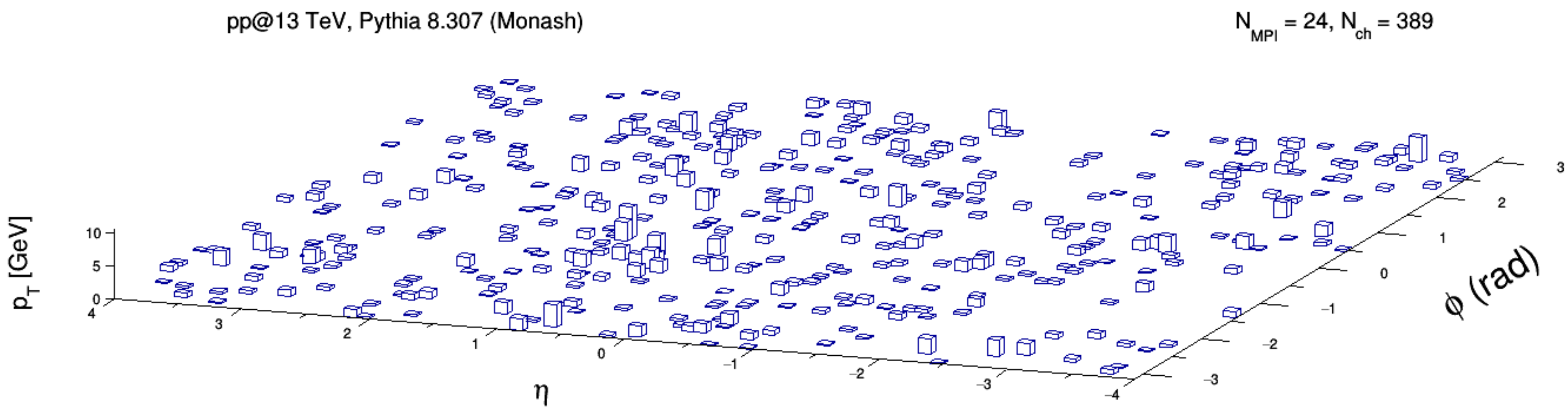
- Recently, a new event shape parameter, **flattenicity**, was proposed [A. Ortiz, G. Paic, Rev. Mex. Fis. Suppl. 3 (2022) 4, 040911] that allows one to identify and characterise high-multiplicity events with a quasi-isotropic distribution in a wide pseudorapidity range in proton-proton collisions.

- 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.

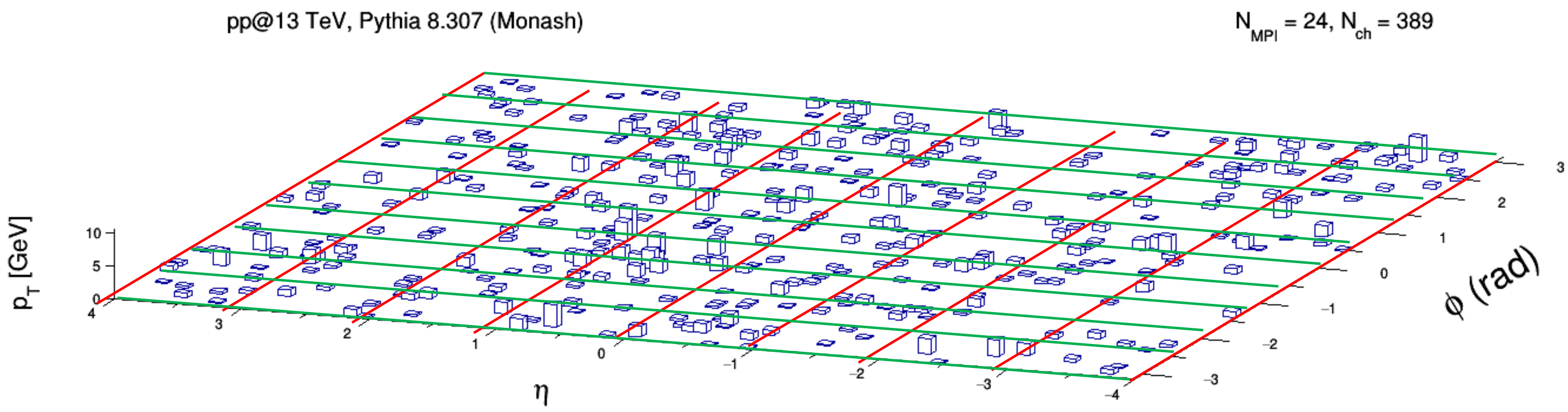
Calculating flattenicity

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



Calculating flattenicity

- Build **8** x **10** grid in (η-φ) space:



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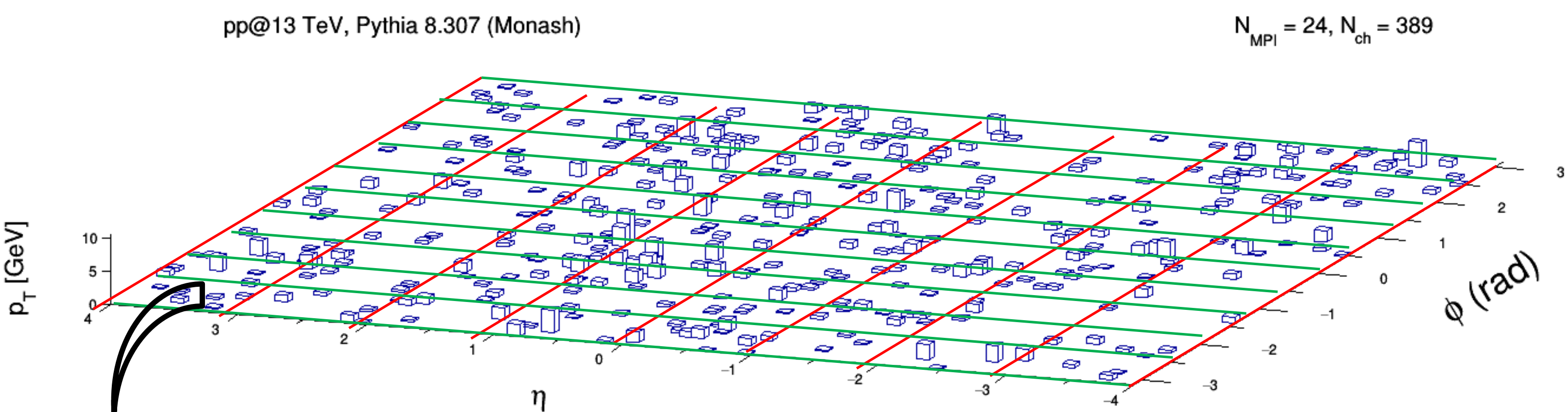
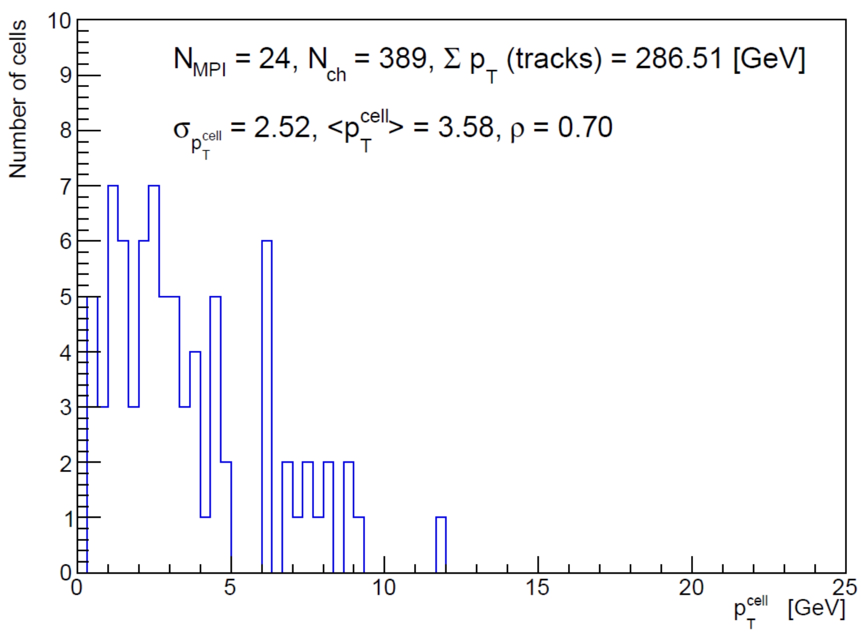


In each cell, the average transverse momentum is calculated: $p_{\mathrm{T}}^{\mathrm{cell}}$



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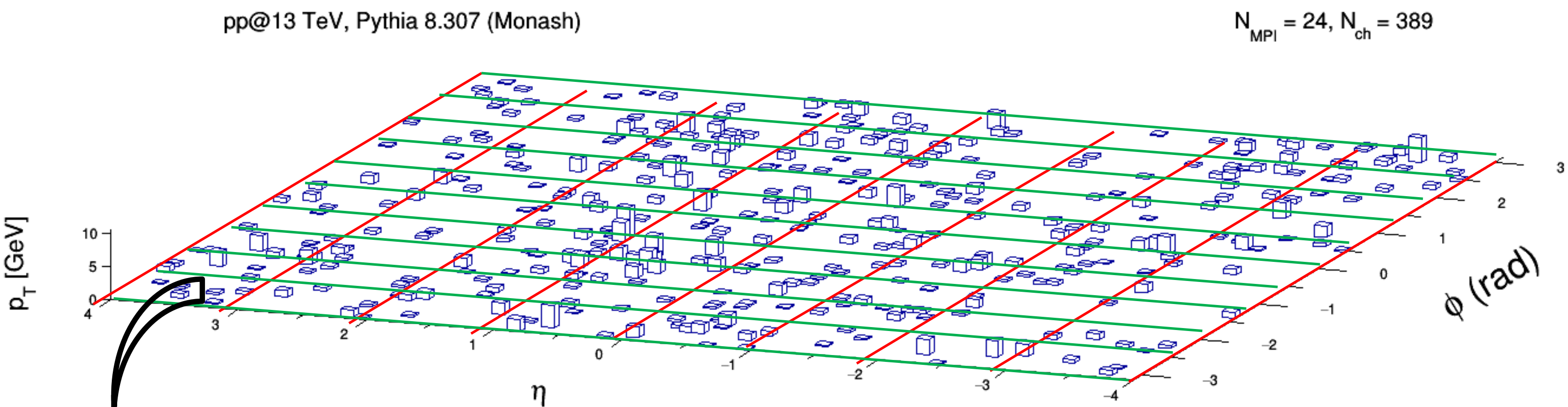
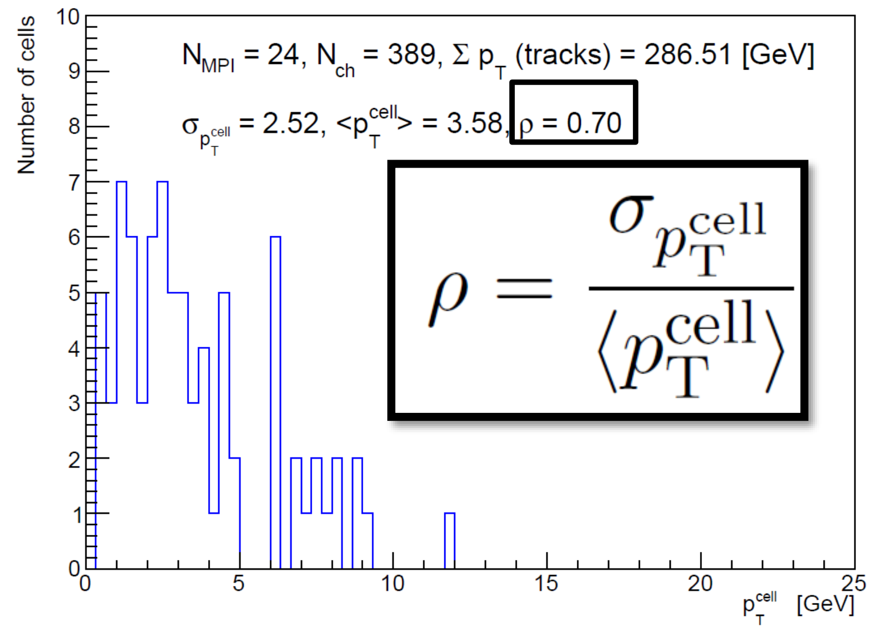


In each cell, the average transverse momentum is calculated: $p_{\mathrm{T}}^{\mathrm{cell}}$

- Event-by-event, the relative standard deviation of the $p_{\mathrm{T}}^{\mathrm{cell}}$ distribution is obtained – flattenicity.

- Events with isotropic distribution of particles (“**hedgehogs**”) are expected to have **a small value of flattenicity** (ρ < 1).



$$\rho = \frac{\sigma_{p_{\mathrm{T}}^{\mathrm{cell}}}}{\langle p_{\mathrm{T}}^{\mathrm{cell}} \rangle}$$

Calculating flattenicity

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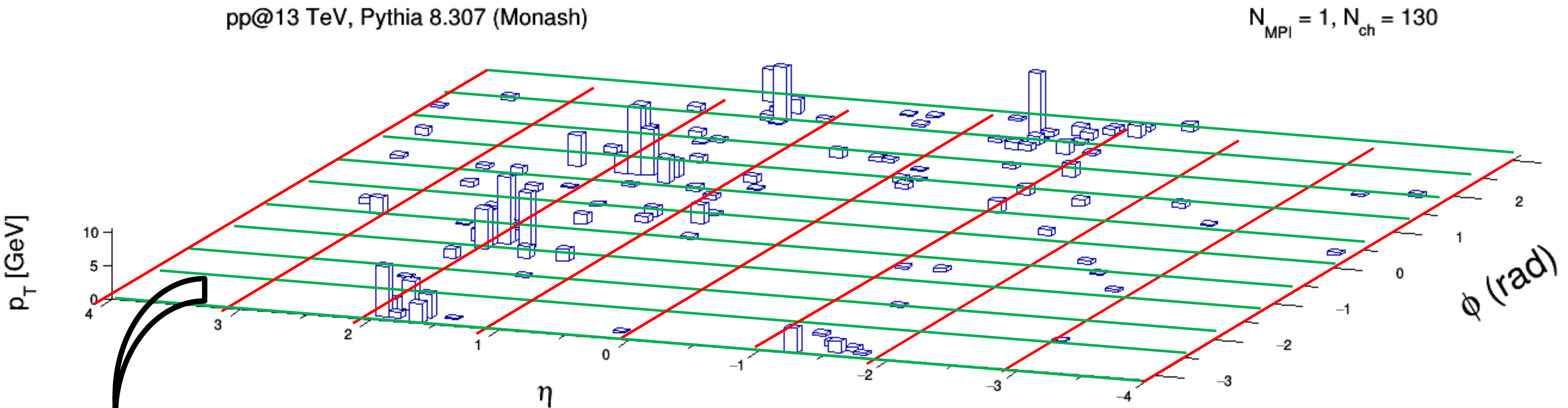
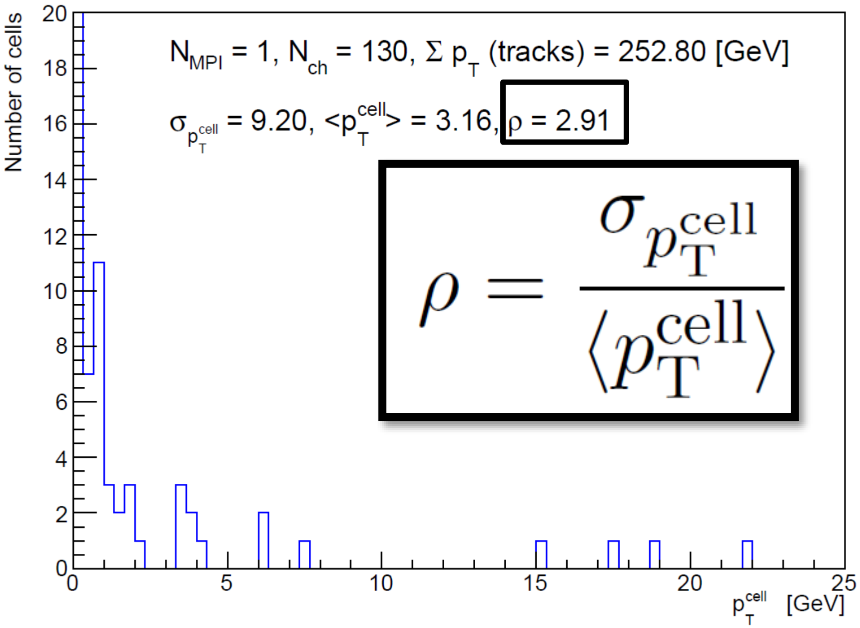


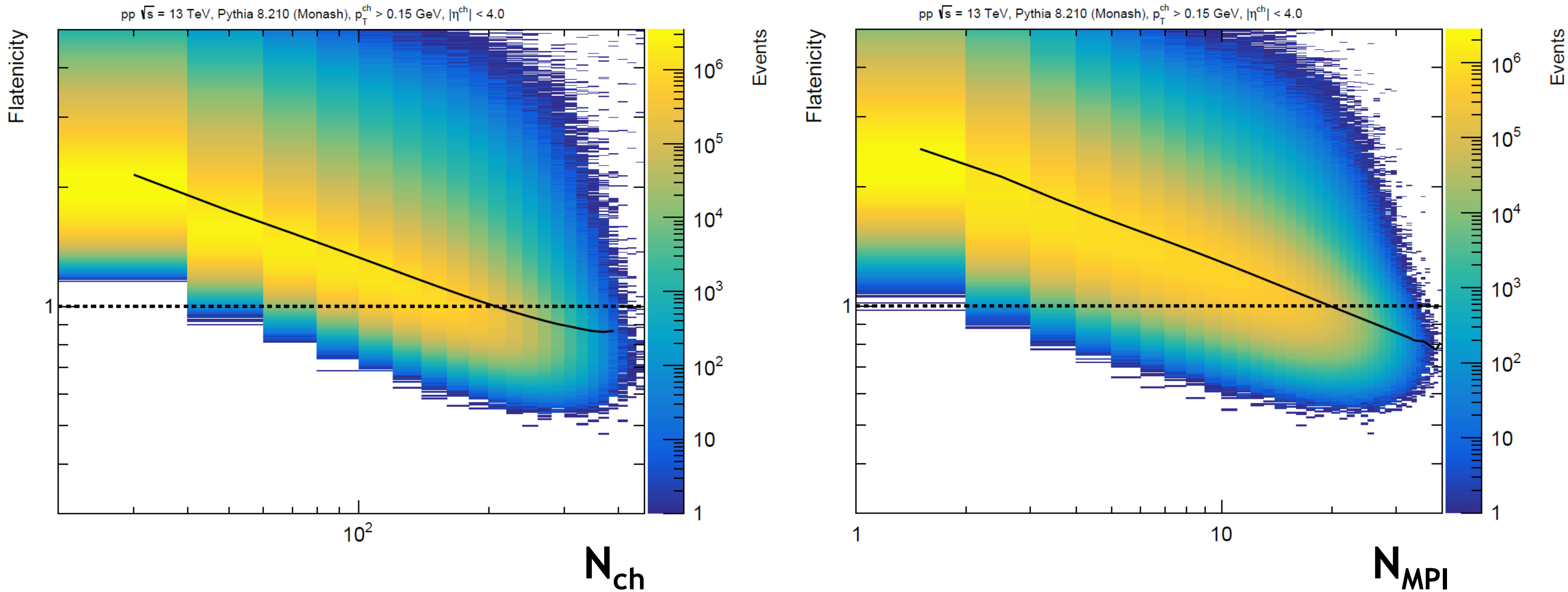
In each cell, the average transverse momentum is calculated: $p_{\mathrm{T}}^{\mathrm{cell}}$

- Event-by-event, the relative standard deviation of the $p_{\mathrm{T}}^{\mathrm{cell}}$ distribution is obtained – flattenicity.
- Events with **jet-like** structures are expected to have **larger values** of ρ.



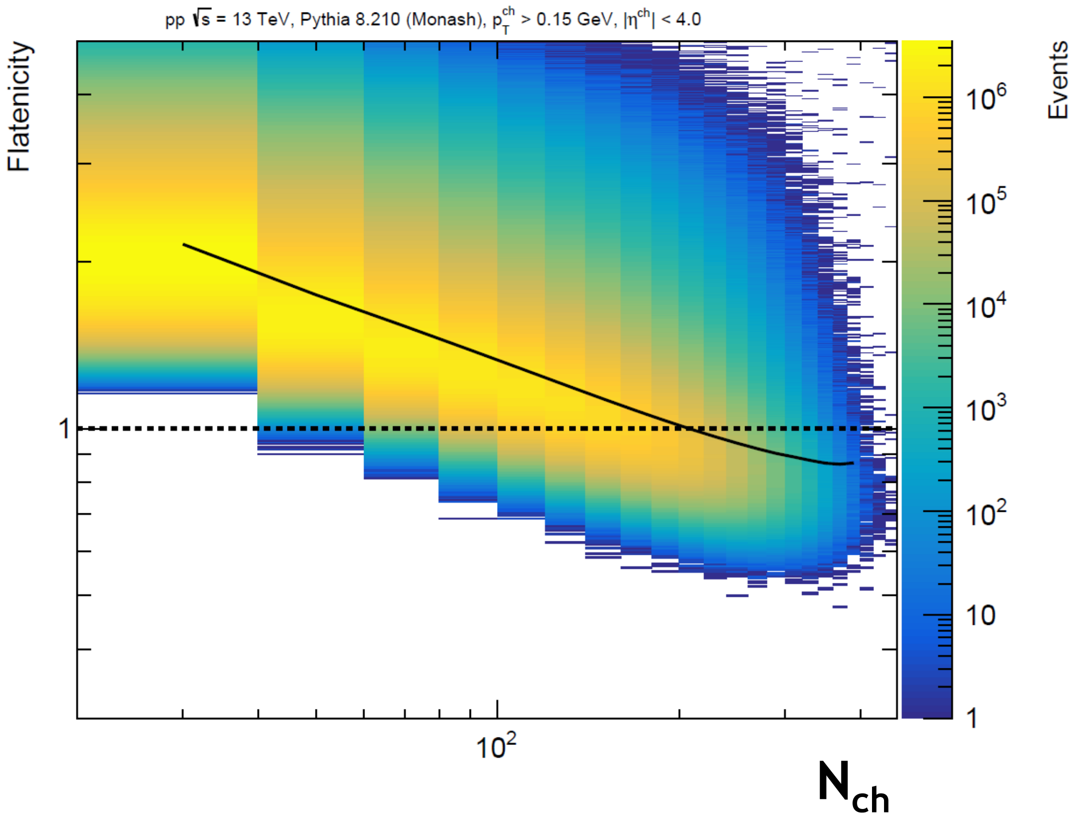
$$\rho = \frac{\sigma_{p_{\mathrm{T}}^{\mathrm{cell}}}}{\langle p_{\mathrm{T}}^{\mathrm{cell}} \rangle}$$

Analysing flattenicity vs N_{ch} and vs N_{MPI}



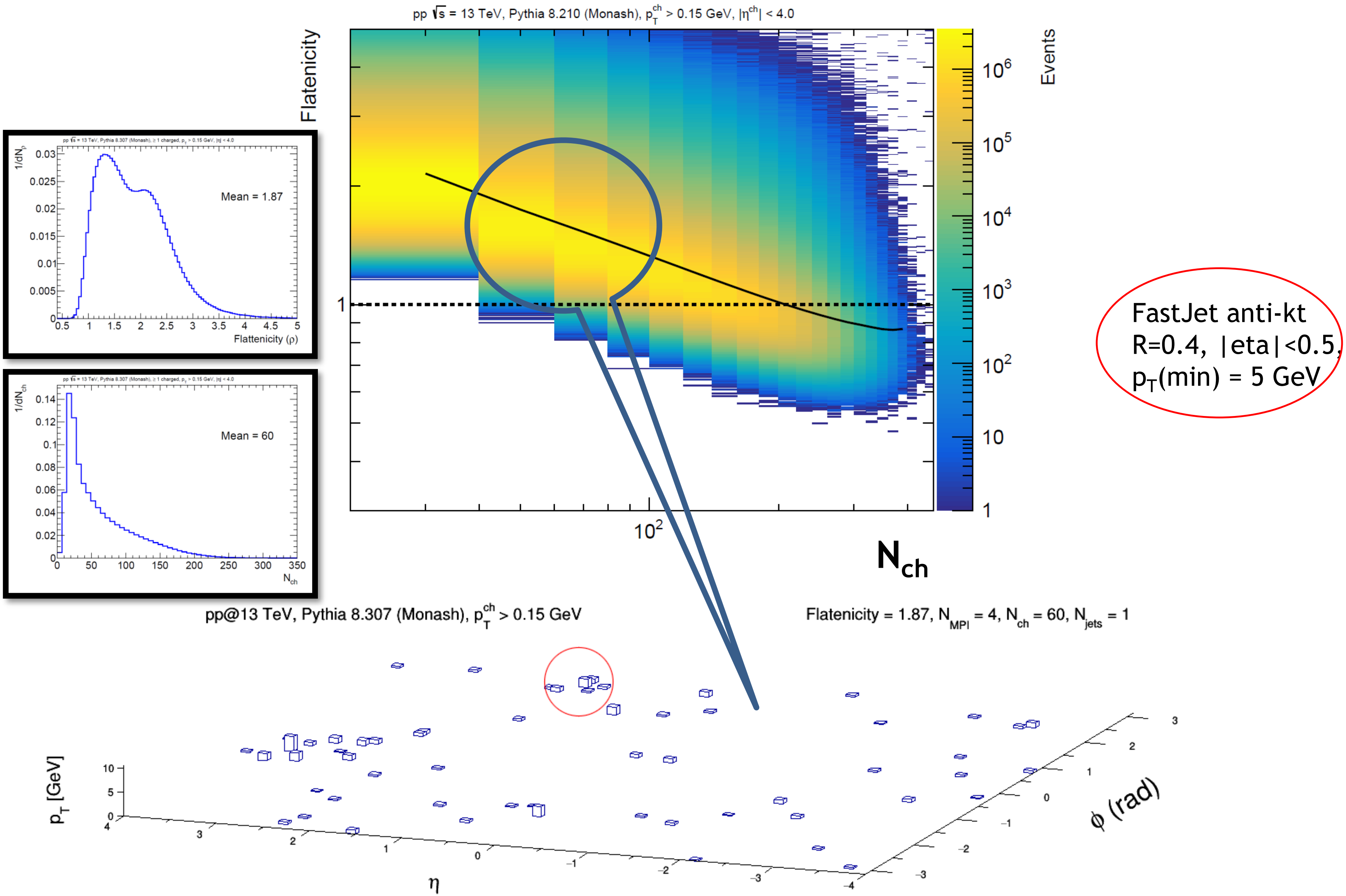
- Pythia 8.3 pp@13 TeV events with minimum-bias (SoftQCD:nonDiffractive) settings, Monash 2013 tune, with $|\eta| < 4$ and min p_T (chgd. particles) of 0.15 GeV.
- At low N_{ch} the flattenicity distribution is very wide, $\langle\rho\rangle$ is signicantly above unity.
- $\langle\rho\rangle$ goes below unity with $N_{ch} > 200$, and for very high values of N_{ch}, flattenicity approches 0.5 as the particles get to be quite uniformly distributed in the η-φ space.
- Similar correlation between flatenicity and the number of multiparton interactions.

Analysing flattenicity vs N_{ch}



- Almost all of the results rely on "means" and "averages" of the distributions, yet the interesting (and by definition rare) effects lie on the "outliers"!
- Flattenicity opens a new way to study pp collisions and analyse those outliers: looking for **hedgehog events**!

Analysing flattenicity vs N_{ch}



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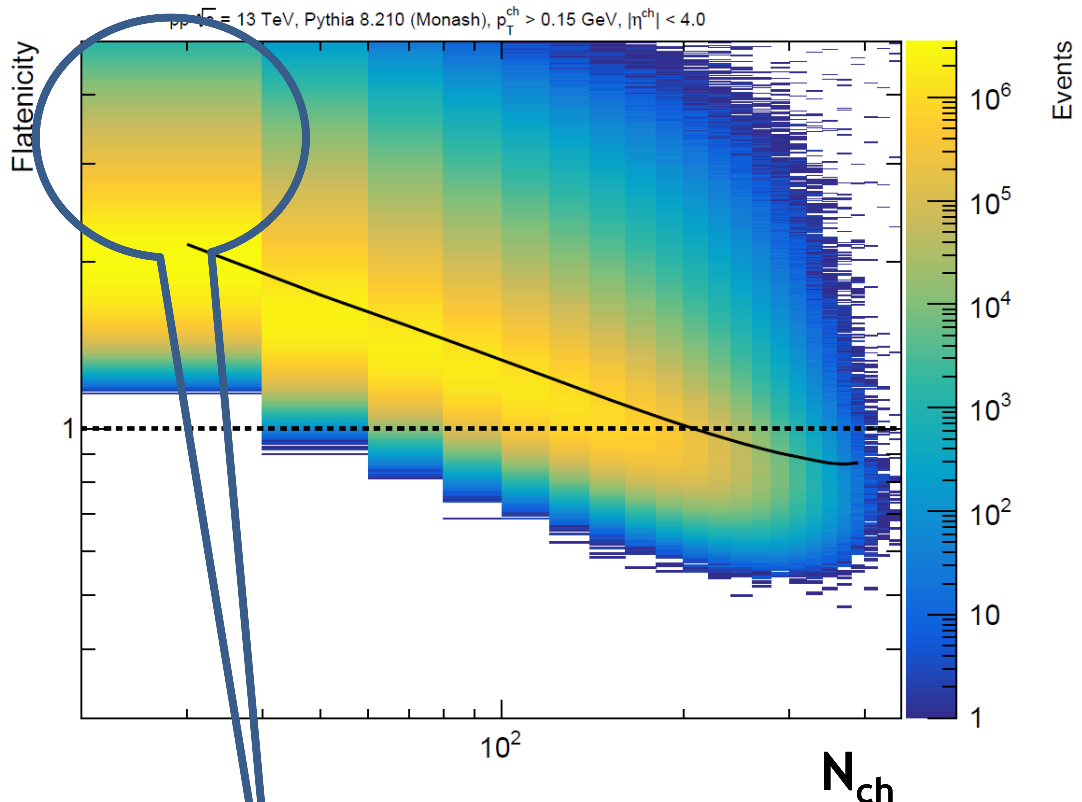
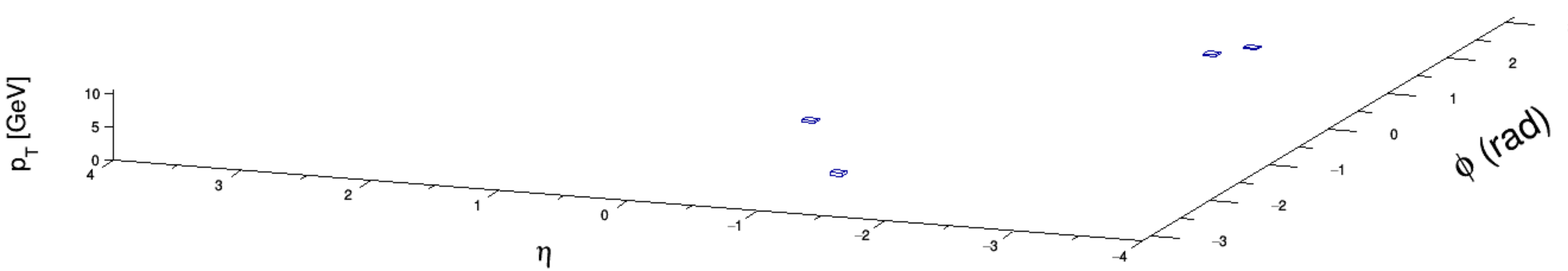


FastJet anti-kt
R=0.4, |eta|<0.5,
p_T(min) = 5 GeV



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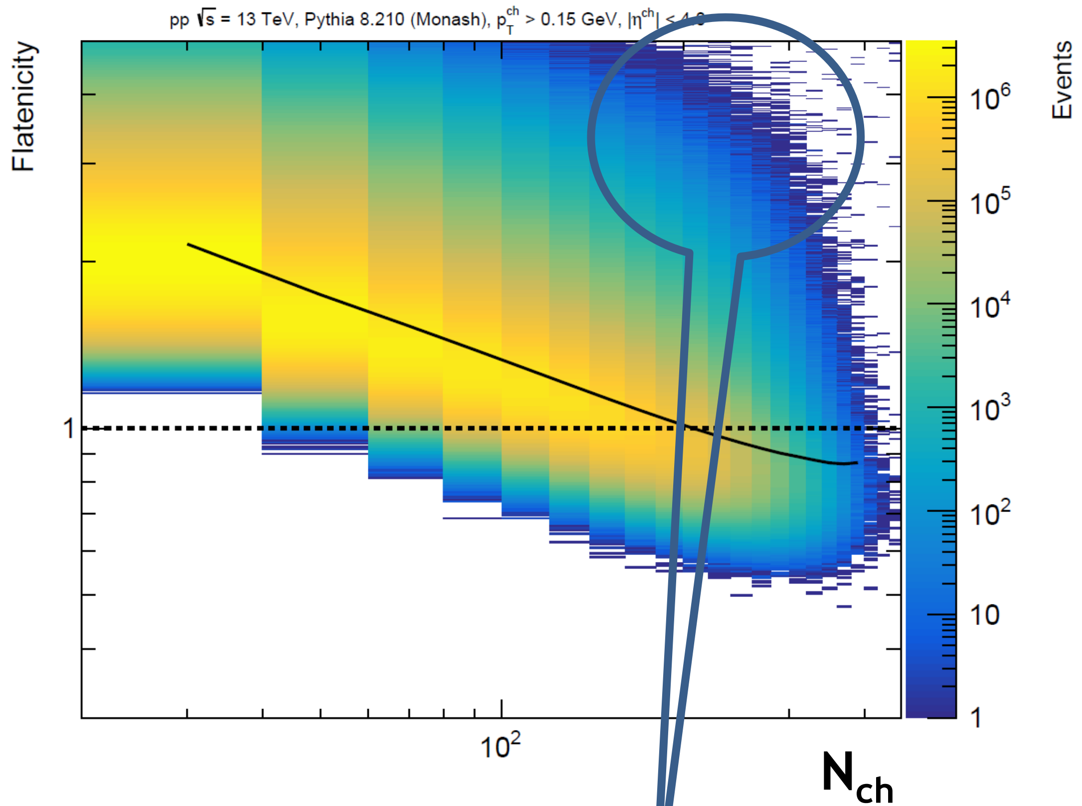

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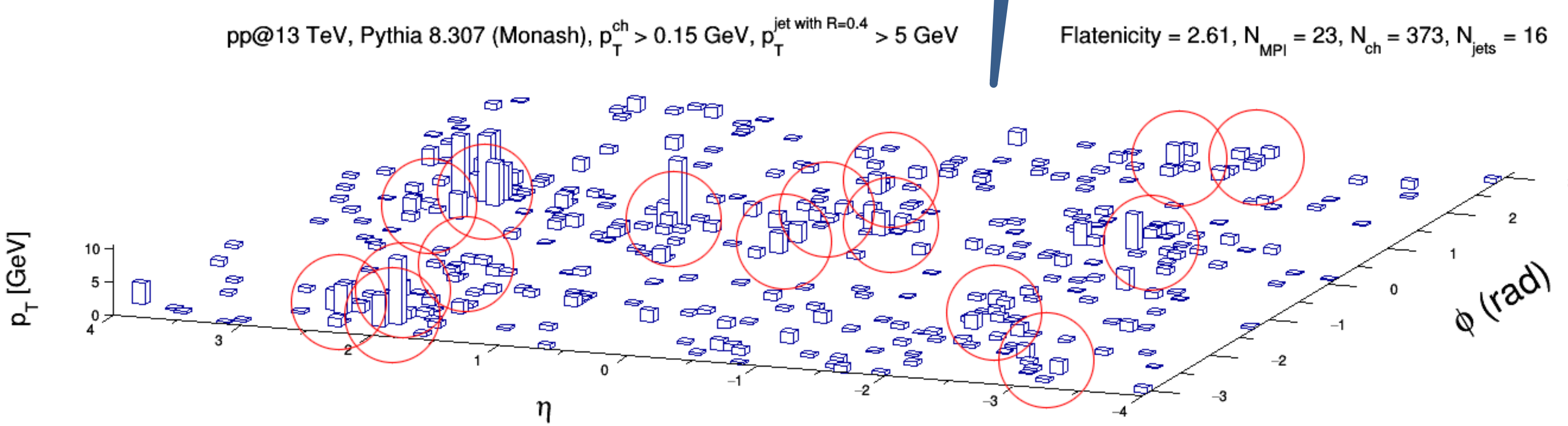

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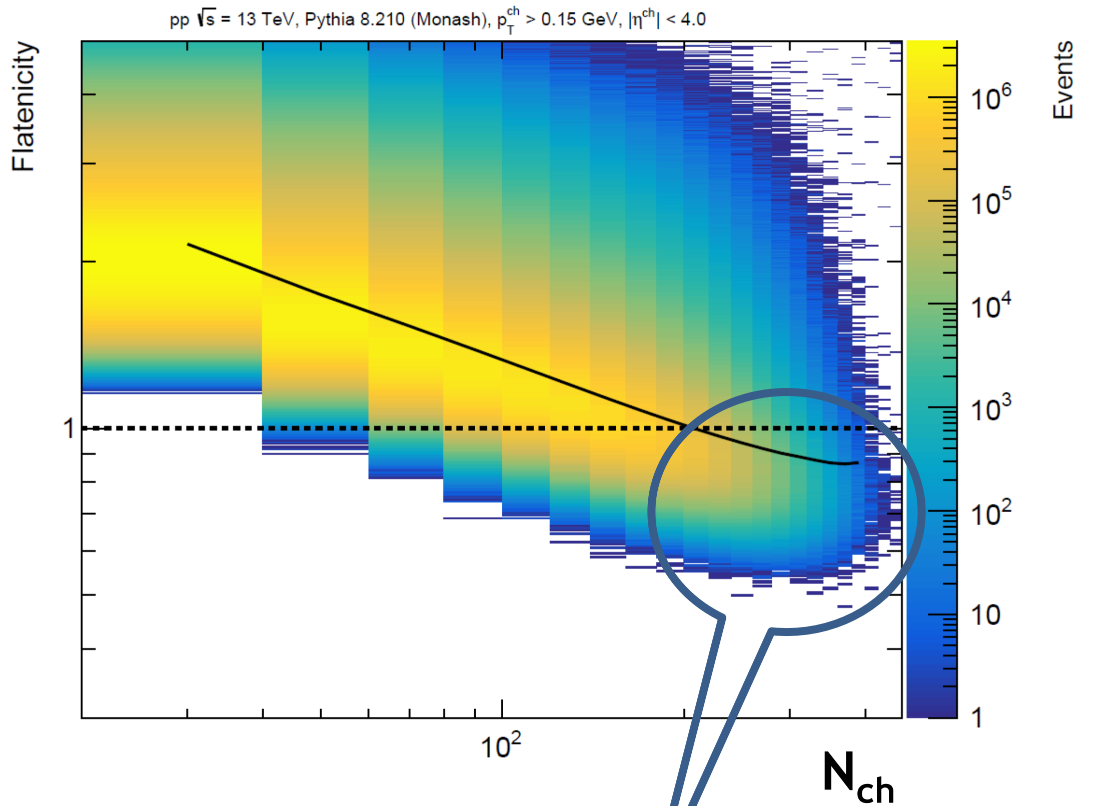

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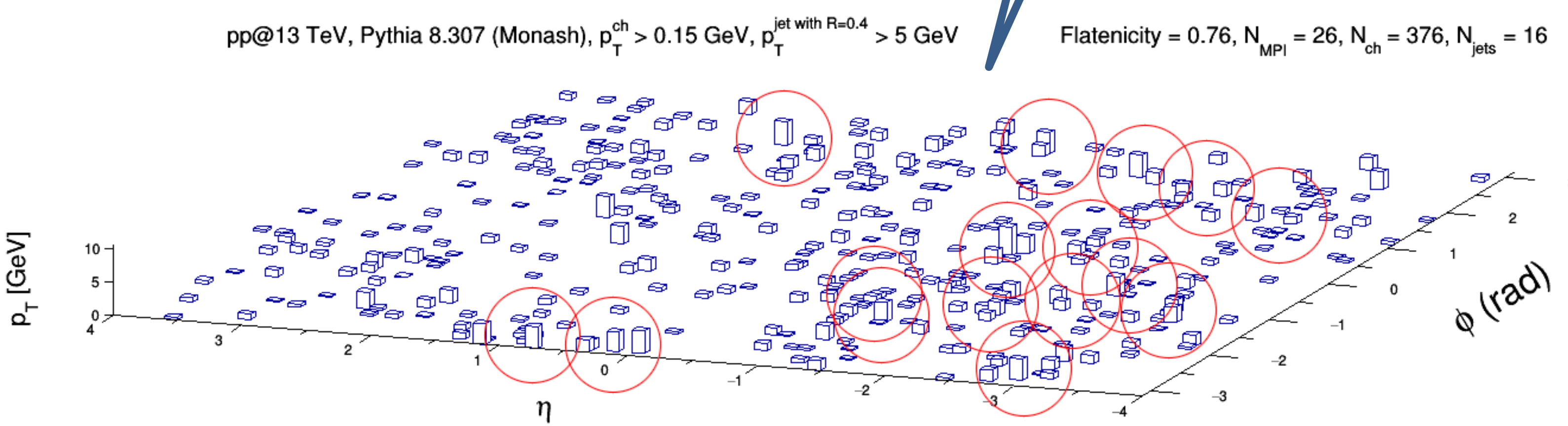

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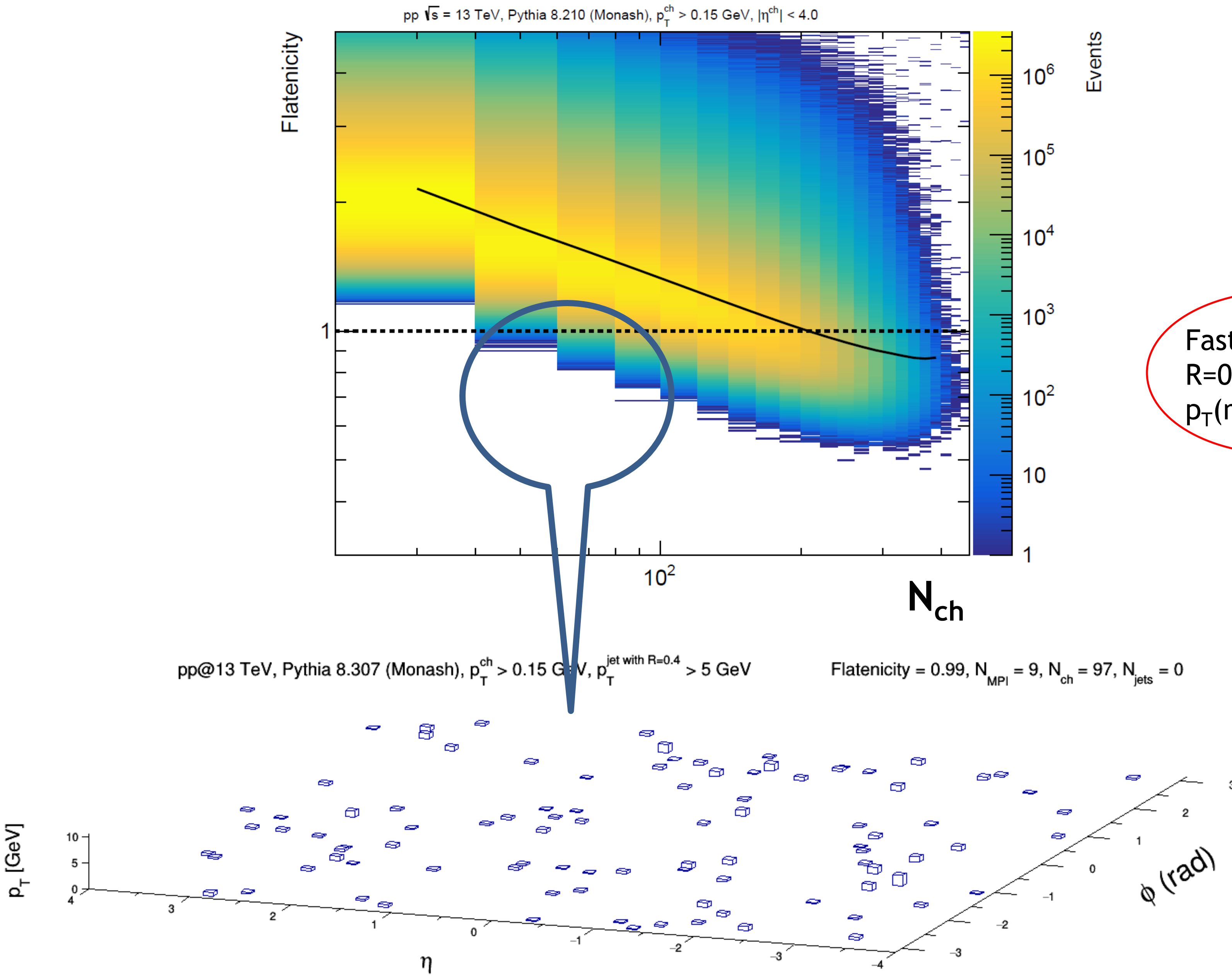

FastJet anti-kt
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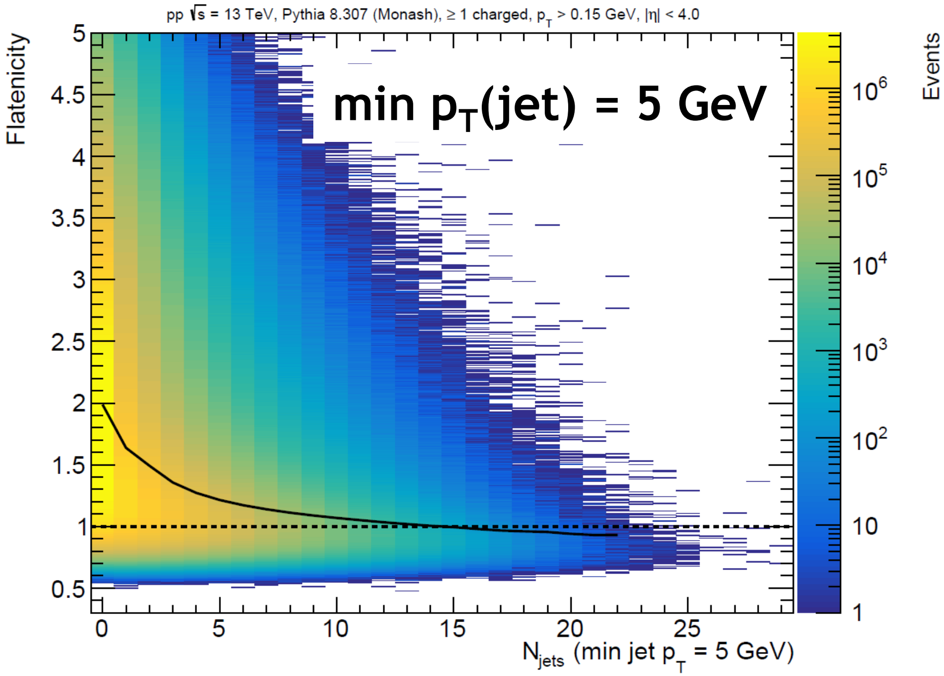
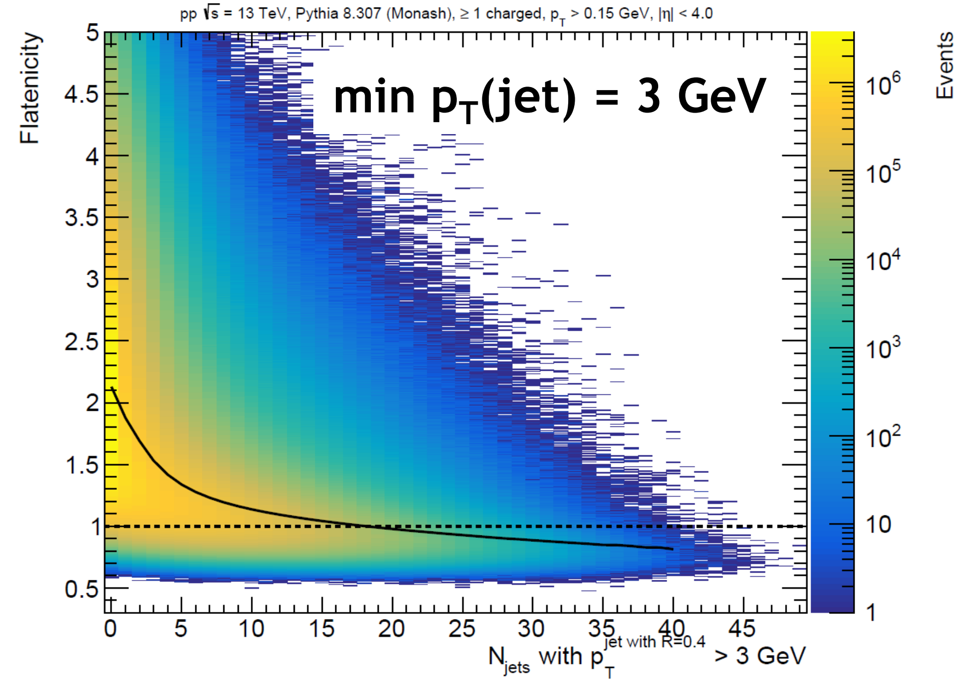
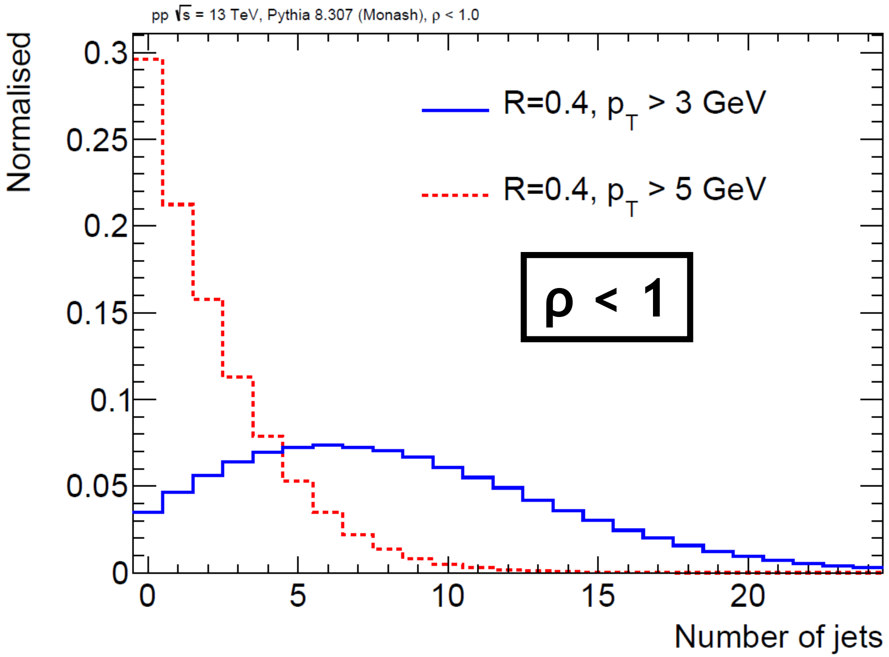
Analysing flattenicity vs N_{jets}

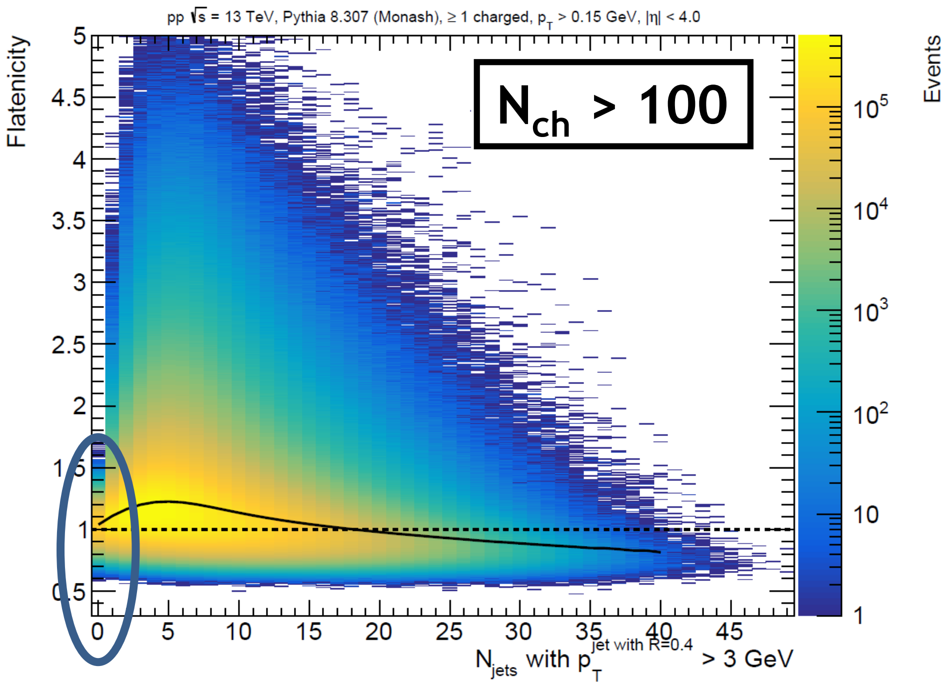




- As the jet energy decreases, the interpretation of the event topology becomes more difficult and the definition of a "jet" becomes arbitrary.
- Considering that events with high p_T are consistent with having a substantial component of QCD jets, the 3 GeV cut represents the lowest reasonable limit below which any attempt to separe experimentally soft production fluctuations from hard scattering would be unreliable.

Analysing flattenicity vs N_{jets}





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- In the **low flattenicity regime**, we are able to select hedgehog events with **high multiplicity** and with **no jet production** (**~0.1% of all events**).

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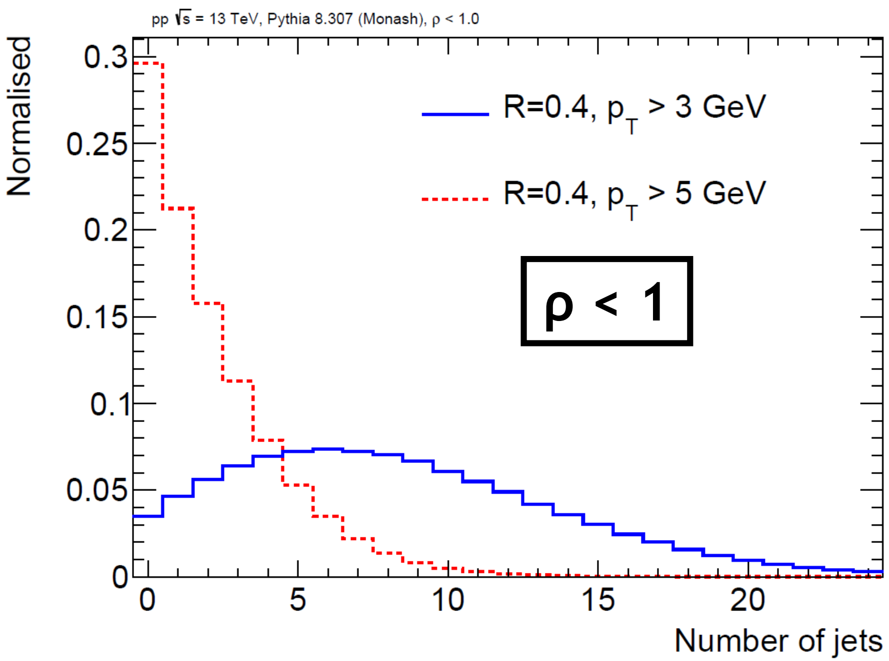
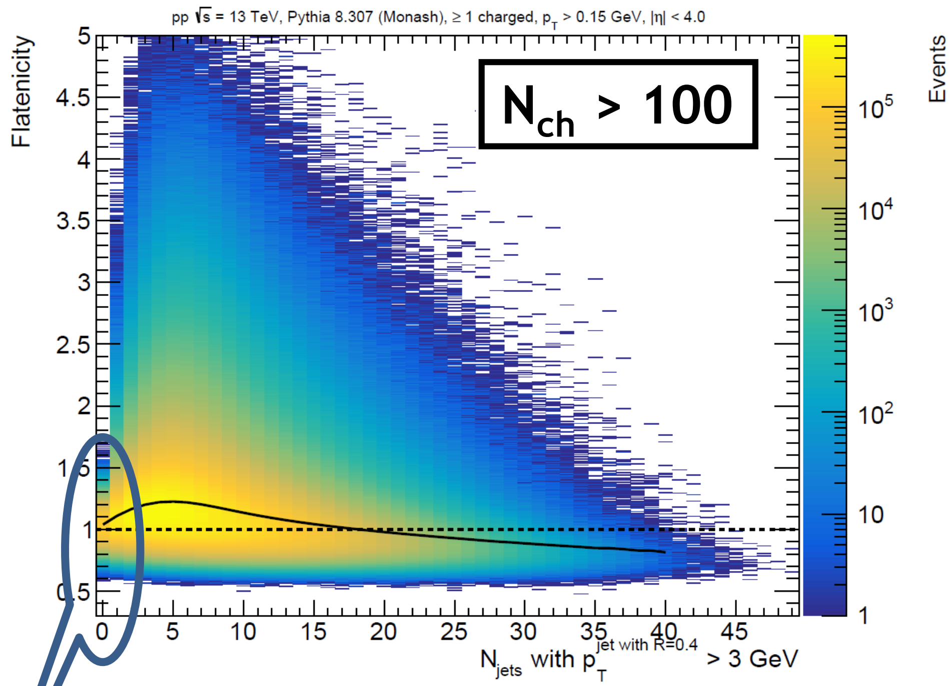
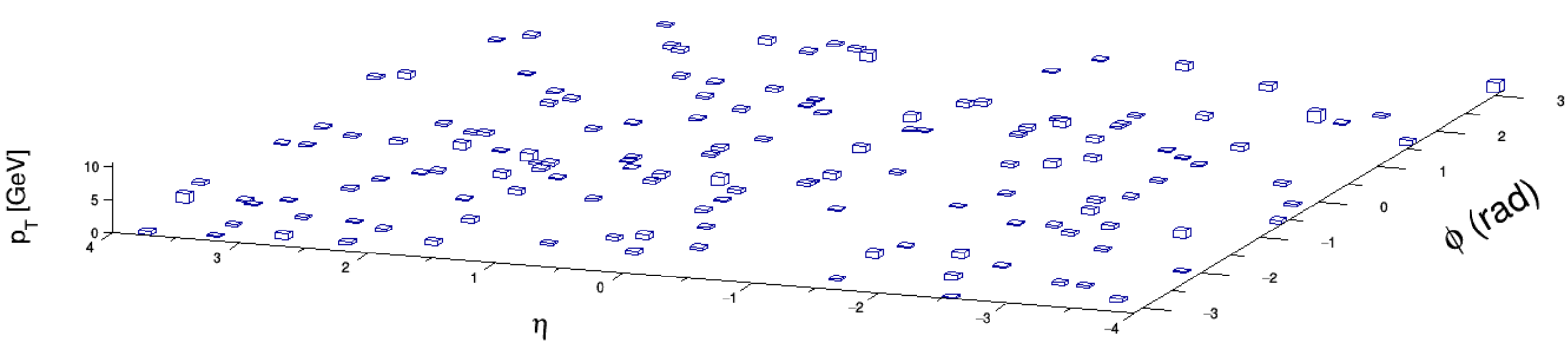
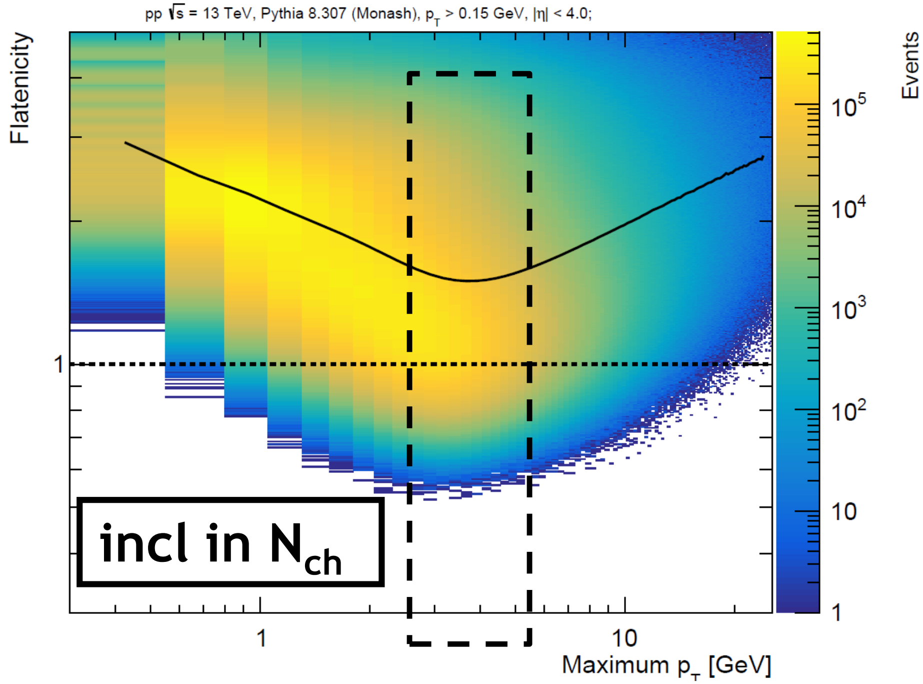


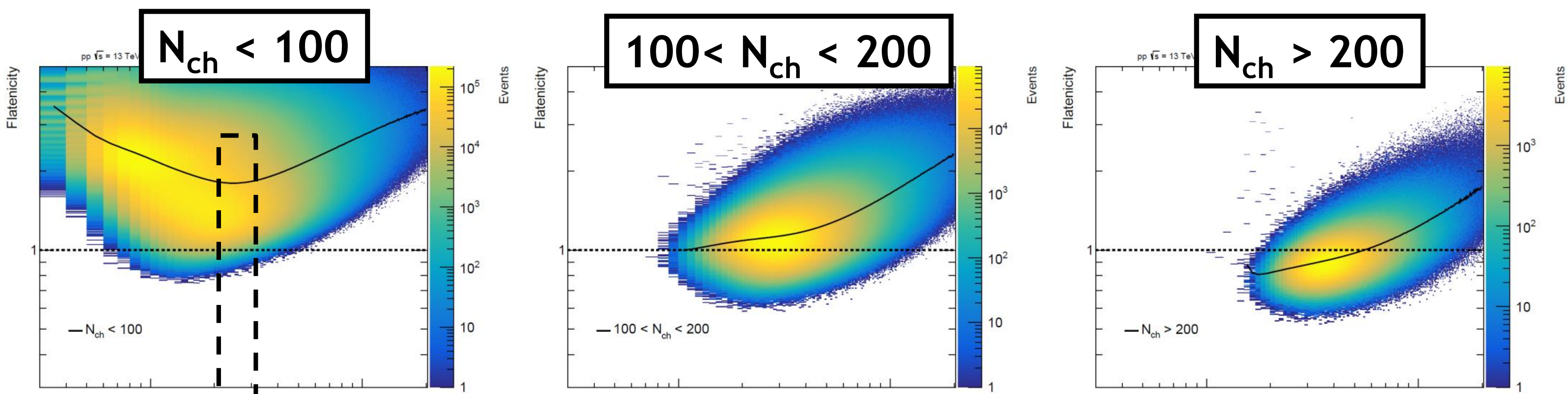




Analysing flattenicity vs leading chgd. particle p_T



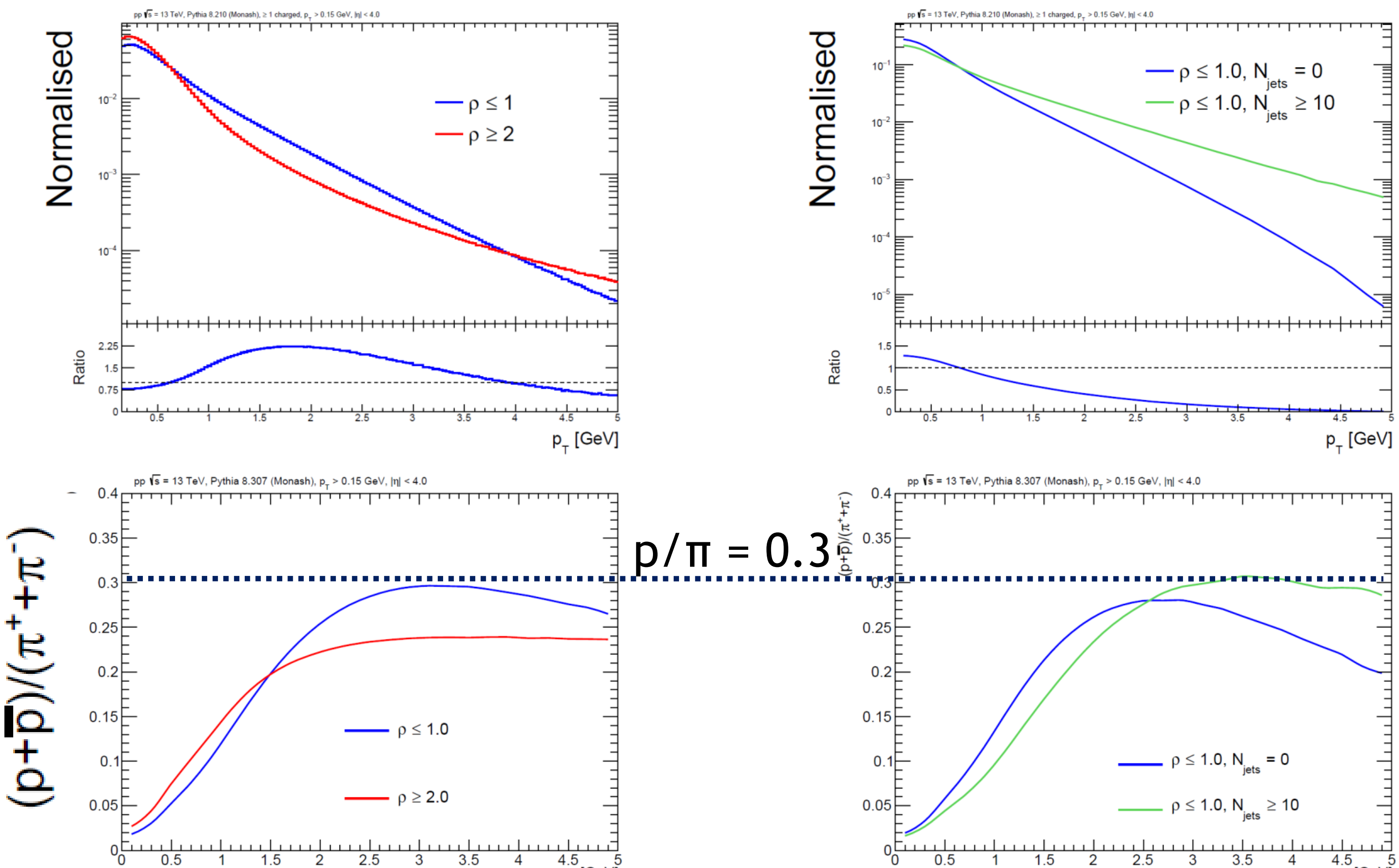
- Leading charged particle p_T shows a prominent feature: <ρ> has a dip around 3-5 GeV, while events with lower multiplicity show a dip at lower values (~ 2-3 GeV)
- At higher N_{ch}, <ρ> shows a trend towards higher p_T values
- A step towards studying the underlying event by using the leading particle p_T



Leading p_T (chgd. particle) [GeV]

Analysing flattenicity vs chgd. particle p_T and p/π ratio

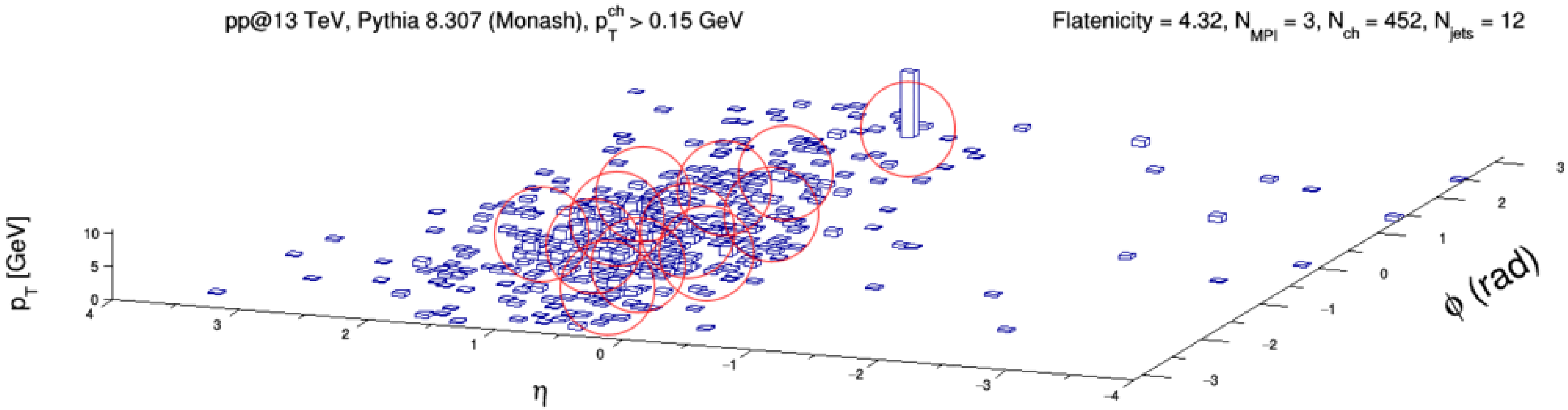
- We study the p_T (particle) as well as the proton-to-pion ratio in 0.15 to 5 GeV interval by selecting events with $\rho < 1$ and $\rho > 2$. For events with $\rho < 1$, we also select jetty events (≥10 jets with min p_T(jet) = 5 GeV) and events with no jets at all.



p_T (chgd. particle) [GeV]

Analysing very atypical events

- Flattenicity allows one to find quite atypical (and rare 1/100M) events:
    - i.e. high chgd. multiplicities (>300) and low number of hard-scatterings (MPI=3)



- In some events we see one very high p_T charged particle (around which a jet is usually build, and particle p_T divided by jet p_T approaches unity!) .
- Recoil jets are usually produced opposite in φ, and fragment into several particles.
- Nor the partonic hard-scattering p_T , nor the additional multiparton interactions p_T are high enough nor match the reconstructed energy for these events.
- Are we looking at the limit of fragmentation and/or ISR/FSR emissions?
- We are identifying an experimental way to find these events, and it would be a perfect place to study data and tune our generators!

Conclusions

- Hedgehog events have never been seriously studied in pp collisions at the LHC. These events are "rare" – but as rare as a Z-boson production!

Selection	Probability
$\rho < 1$	4×10^{-2}
$\rho < 0.75$, $N_{ch} > 100$, $N_{jets}=0$	2×10^{-6}
$\rho < 0.75$, $N_{ch} > 400$	6×10^{-8}

- Flattenicity - the new event structure parameter - allows one to identify the hedgehog events and is more detailed than sphericity/spherocity/RT, as one can observe the evolution of events from jetty to hedgehog type.

- We are able to identify different classes of hedgehog events: those with high jet multiplicity (jetty) and with no jet production.

- Events with low flattenicity show an enhancement in the proton-to-pion ratio compared to those with high flattenicity.

- Studying these events may shed light to the search for the "energy re-distribution" effect in pp collisions.

- Next step: look for hedgehog events in data!

BACK-UP

Transverse sphericity

A. Ortiz, arXiv:1110.2278 [hep-ex]

sphericity is measured in the acceptance $|\eta| \leq 0.8$, for events with more than two tracks ($p_T \geq 0.5$ GeV/c). The observable is defined as follows:

$$S_T \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1} \tag{1}$$

where: $\lambda_1 > \lambda_2$ are the eigenvalues of the transverse momentum matrix:

$$\mathbf{S}^{\mathbf{L}}_{\mathbf{xy}} = \frac{1}{\sum_i p_{Ti}} \sum_i \frac{1}{p_{Ti}} \begin{pmatrix} {p_{xi}}^2 & p_{xi}p_{yi} \\ p_{xi}p_{yi} & {p_{yi}}^2 \end{pmatrix}$$

By construction, the limits of the variable are related to specific configurations in the transverse plane

$$S_{\mathrm{T}} = \left(\begin{cases} = 0 & \text{“pencil-like” limit} \\ = 1 & \text{“isotropic” limit} \end{cases} \right.$$.