Transverse sphericity of primary charged particles in minimum bias proton-proton collisions at $\sqrt{s}$ = 0.9, 2.76 and 7 TeV

Measurements of the sphericity of primary charged particles in minimum bias proton–proton collisions at√s= 0. 9, 2. 76 and 7 TeV with the ALICE detector at the LHC are presented. The observable is linearized to be collinear safe and is measured in the plane perpendicular to the beam direction using primary charged tracks with pT ≥ 0. 5 GeV/c in |η| ≤ 0. 8. The mean sphericity as a function of the charged particle multiplicity at mid-rapidity (Nch) is reported for events with different pT scales (“soft” and “hard”) defined by the transverse momentum of the leading particle. In addition, the mean charged particle transverse momentum versus multiplicity is presented for the different event classes, and the sphericity distributions in bins of multiplicity are presented. The data are compared with calculations of standard Monte Carlo event generators. The transverse sphericity is found to grow with multiplicity at all collision energies, with a steeper rise at low Nch , whereas the event generators show the opposite tendency. The combined study of the sphericity and the mean pT with multiplicity indicates that most of the tested event generators produce events with higher multiplicity by generating more back-to-back jets resulting in decreased sphericity (and isotropy). The PYTHIA6 generator with tune PERUGIA-2011 exhibits a noticeable improvement in describing the data, compared to the other tested generators.

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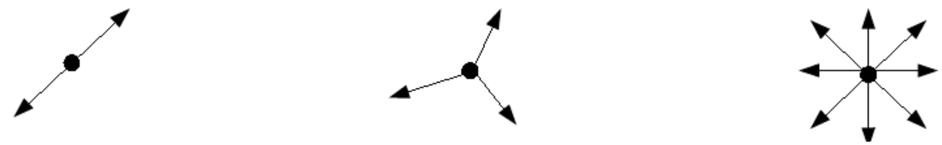
ALICE Collaboration

DEFINITIONS AT HADRON COLLIDERS:

– **Thrust** is defined $T \equiv \underbrace{max}_{\vec{n}_t} \frac{\sum_i |\vec{p}_{t,i} \cdot \vec{n}_t|}{\sum_i |\vec{p}_{t,i}|}$, and we can catch different configurations like:

$\tau \equiv 1 - T$



T = 1 T = 2/3 **T=2/π**

✓**Transverse Sphericity** is defined in terms of the eigen-values of the transverse momentum tensor:

$$\mathbf{S_{xy}} = \sum_i \begin{pmatrix} {p_x^{(i)}}^2 & p_x^{(i)} p_y^{(i)} \\ p_x^{(i)} p_y^{(i)} & {p_y^{(i)}}^2 \end{pmatrix}$$

$$S_\perp \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}$$

- =0, “pencil-like” events.
- =1, isotropic events.

ALICE-INT-2009-015 (A. Ortiz, G. Paic)
ALICE-INT-2010-013 & arXiv:1001.0613 (E. Cuautle, A. Ortiz, G. Paic)

<1-T> vs Multiplicity

Strategy:

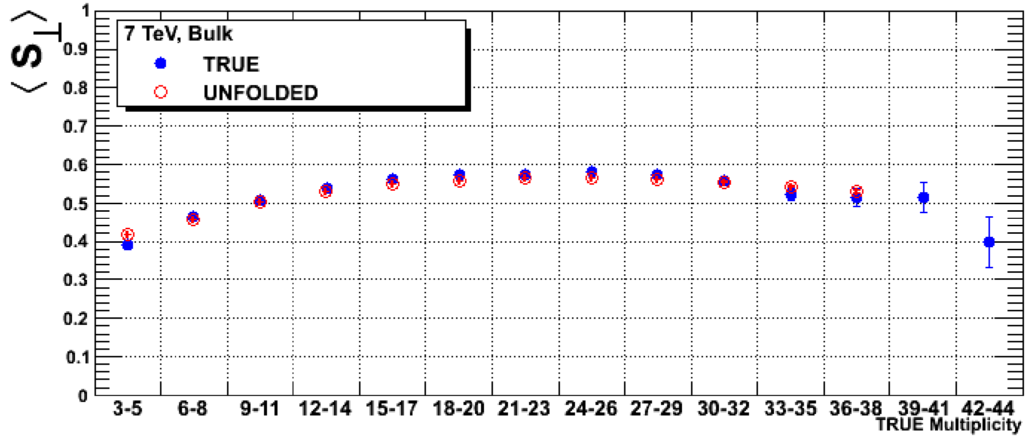
- Evaluate the Chi2-minimization method in multiplicity bins. We have observed that the resolution improves at high multiplicity!
- Extract the <1-T> as a function of Nm (measured multiplicity using tracks passed by the selection criteria described in 1) by Chi2-minimization. The bin size in this analysis is 2.
- Compute the response matrix for the multiplicity case: R(Nt,Nm). (PYTHIA).
- Extraction of <1-T> (Nt) using :

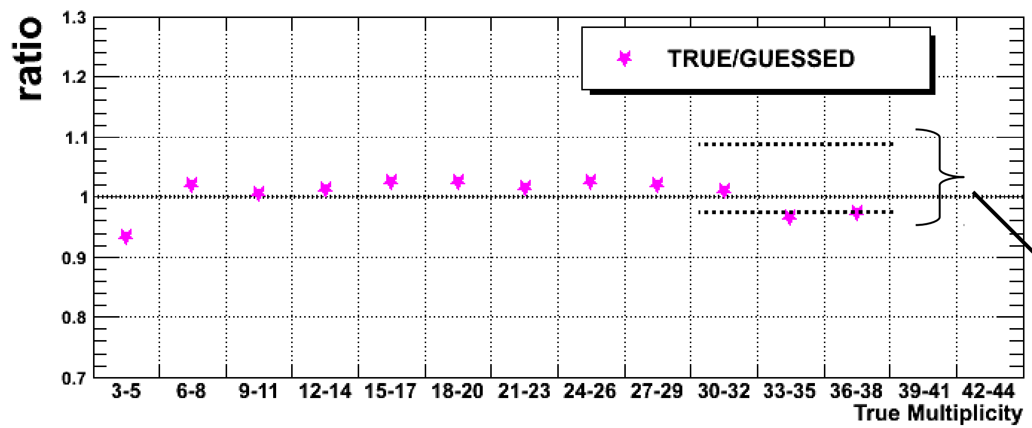
$$\langle 1-T\rangle(N_t) = \sum_m \langle 1-T\rangle^u (N_m)\,\mathbf{R}(N_t, N_m)$$

Procedure to measure $<S_\perp>$ vs Multiplicity.

$$\langle 1 - T \rangle (N_t) = \sum_m \langle 1 - T \rangle^u (N_m) \mathbf{R}(N_t, N_m)$$

From unfolding procedure. Multiplicity-Response-Matrix





Response Matrix from PYTHIA; tune ATLAS-CSC.

Evaluation using PYTHIA simulations: tune PERUGIA-0 (flat multiplicity) to reach high multiplicities.

Differences < 5 %

Unfolding the Thrust Spectrum

The Chi2-minimization method as an approach to unfold the thrust spectrum...

Measured spectrum

$$\hat{\chi}^2(U) = \sum_m \left(\frac{M_m - \sum_t R_{mt} U_t}{e_m} \right)^2$$

Response Matrix.

$$\chi^2(U) = \hat{\chi}^2(U) + \beta P(U)$$

Regularization term.

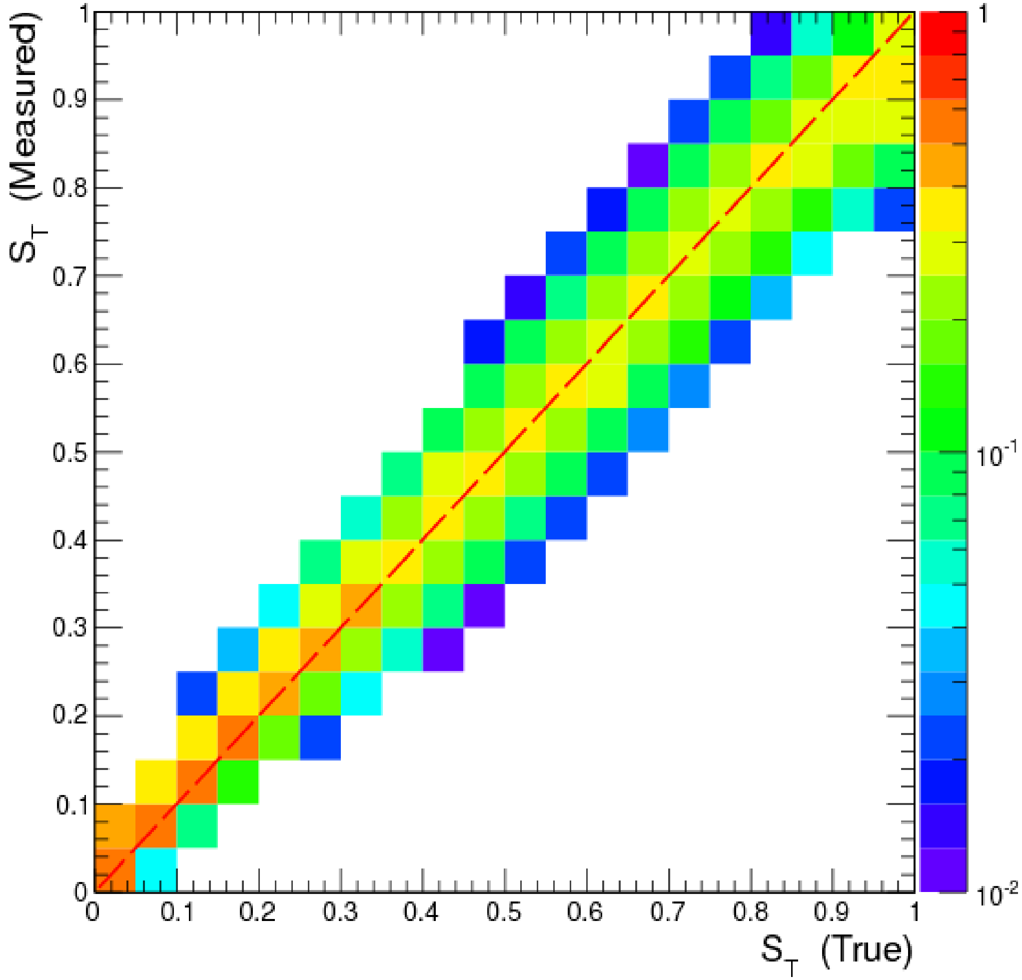


Fig. 2: Example of the sphericity response matrix for a measured multiplicity of 25 charged particles at midrapidity.
The events are generated using the PYTHIA6 tune ATLAS-CSC (pp collisions at $\sqrt{s}$ = 7 TeV) and then
transported through the detector. Particles and tracks with $|\eta| \leq 0.8$ and $pT \geq 0.5$ GeV/c are used.

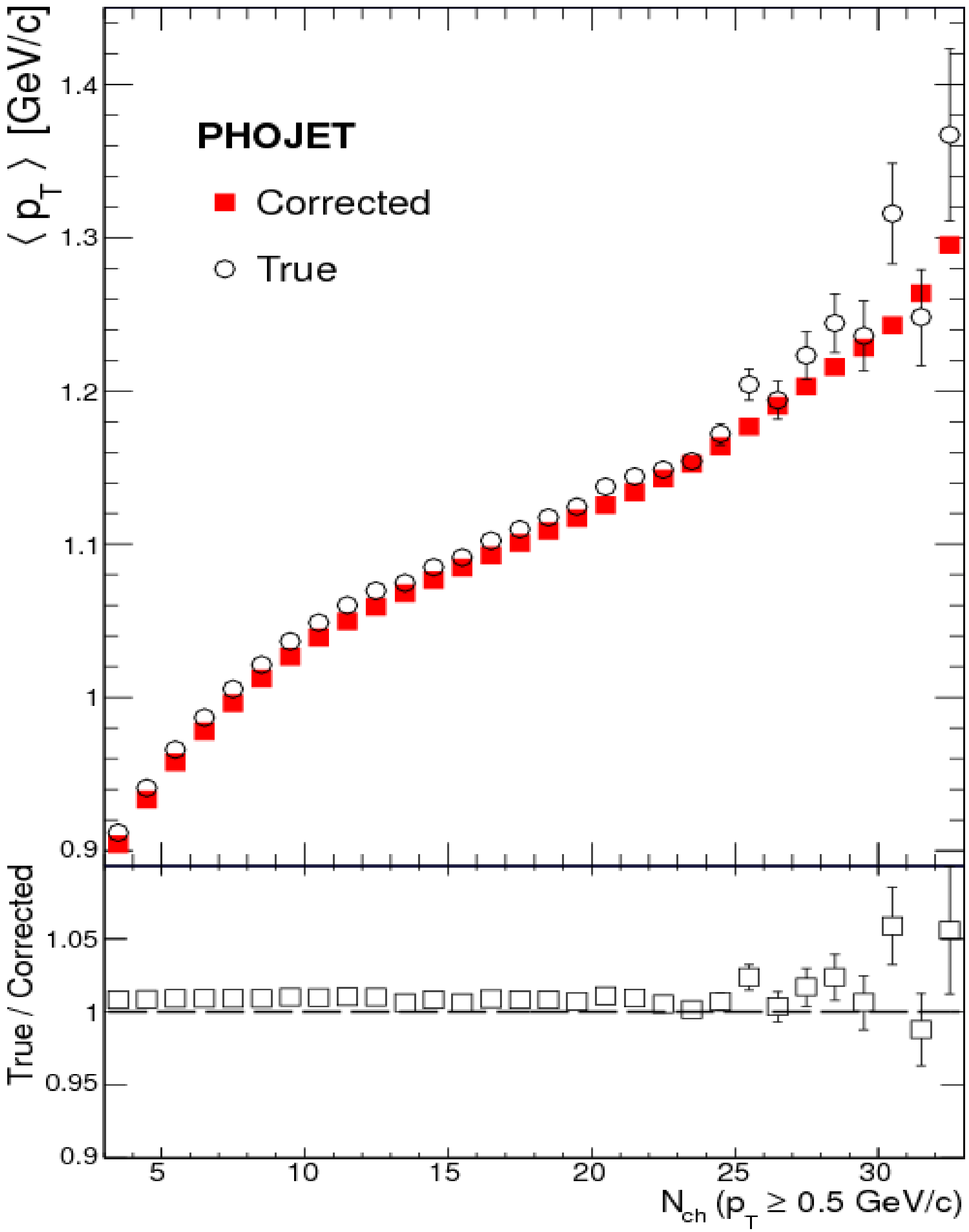


Fig. 4: Performance of the procedure to correct the reconstructed mean pT as a function of multiplicity for "all" events. The method is tested using PHOJET as input and applying corrections derived from PYTHIA. The MC true (PHOJET result at generation level) is compared with the corrected result after simulation and reconstruction.

Mean transverse sphericity vs p_t^{max}

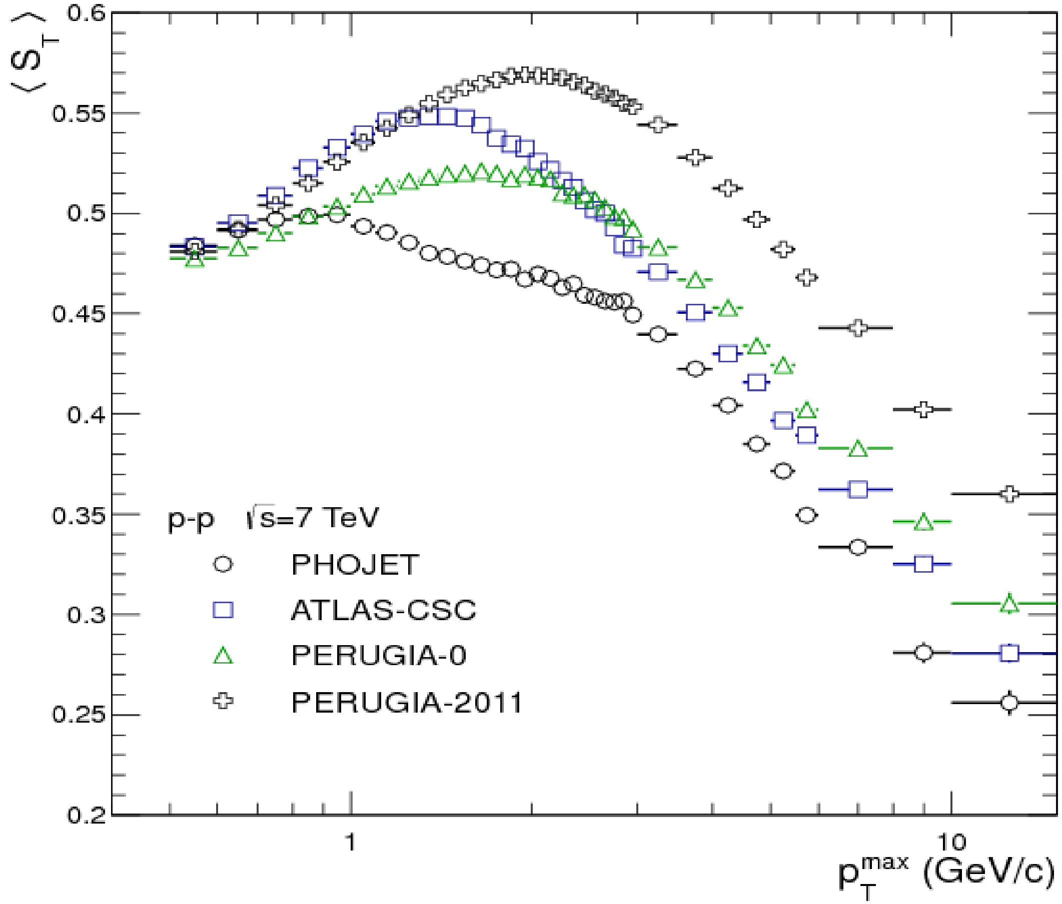
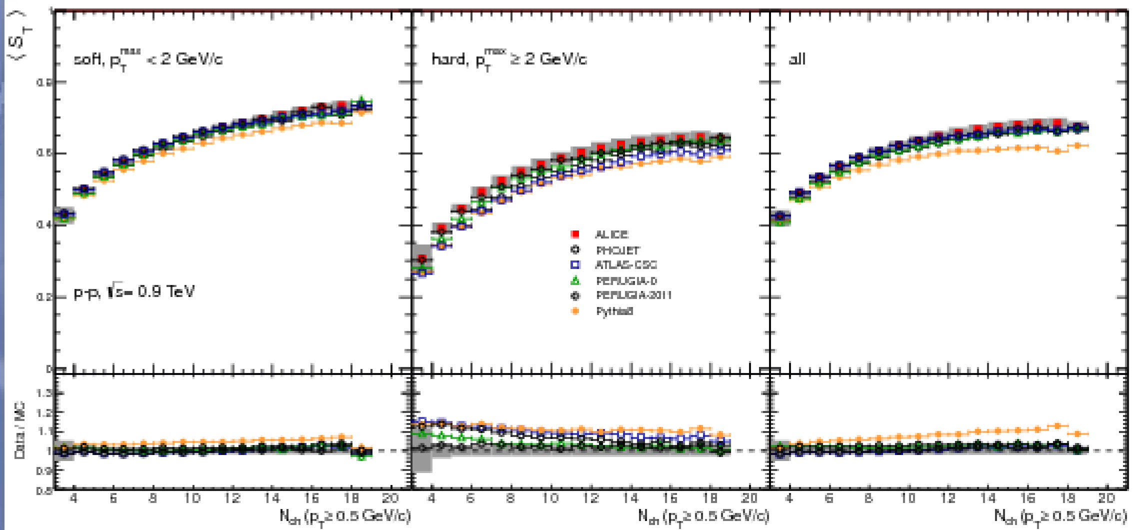


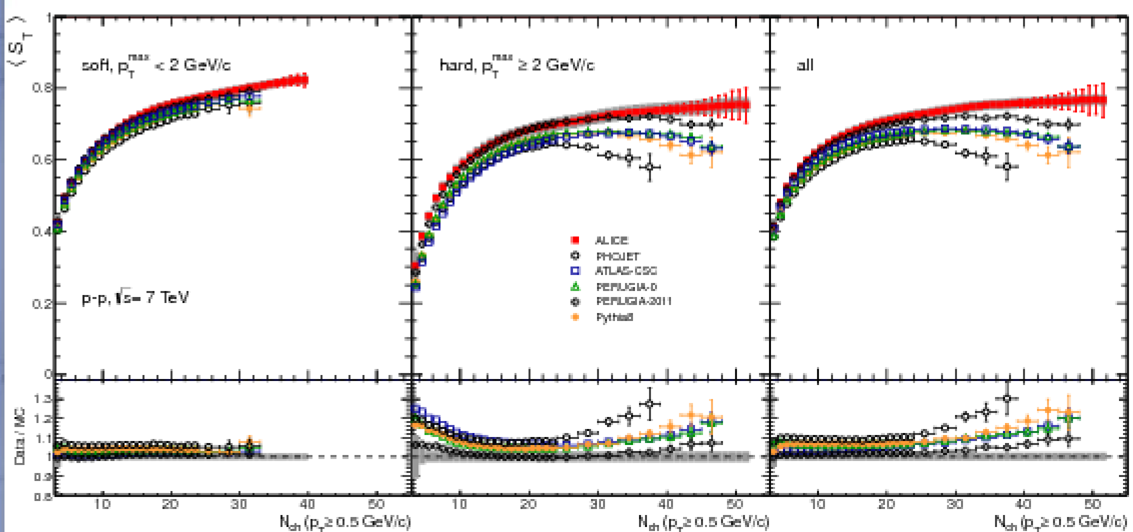
Fig. 1: Mean transverse sphericity versus p_T^{max} for MC simulations at $\sqrt{s}$ = 7 TeV. Results are shown for PHOJET and PYTHIA6 (tunes ATLAS-CSC, PERUGIA-0 and PERUGIA-2011) simulations. The events are required to have more than 2 primary charged particles in $|\eta| \leq 0.8$ and transverse momentum above 0.5 GeV/c.

Mean transverse sphericity vs multiplicity for 0.9 and 7 TeV's



0.9 TeV

Fig. 5: Mean transverse sphericity as a function of charged particle multiplicity. The ALICE data are compared
with five models: PHOJET, PYTHIA6 (tunes: ATLAS-CSC, PERUGIA-0 and PERUGIA-2011) and PYTHIA8.
Results at √s = 0.9 and 7 TeV are shown in the top and bottom rows, respectively. Different event classes are presented:



7 TeV

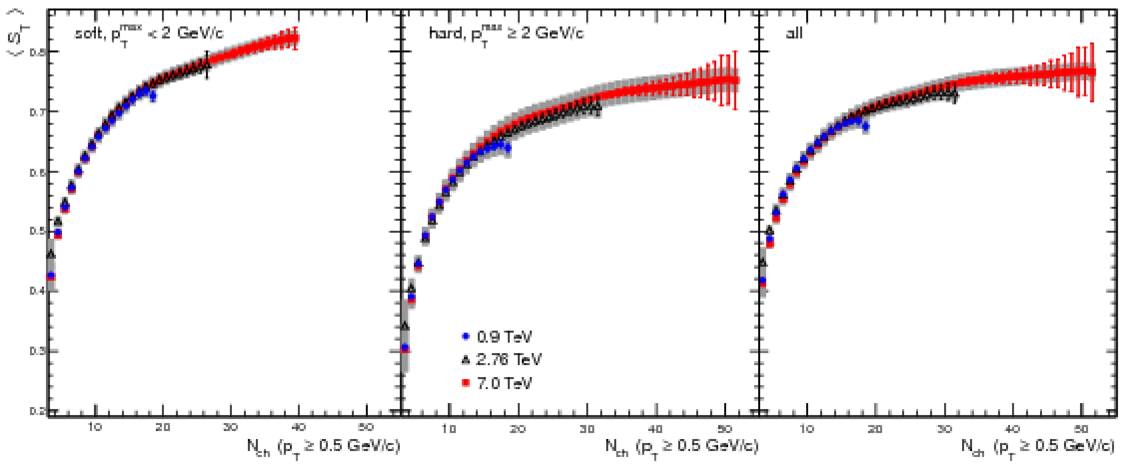


Fig. 6: Mean sphericity versus multiplicity for (left) "soft", (middle) "hard" and (right) "all" events for √s = 0.9, 2.76 and 7 TeV. The statistical errors are displayed as error bars and the systematic uncertainties as the shaded area.

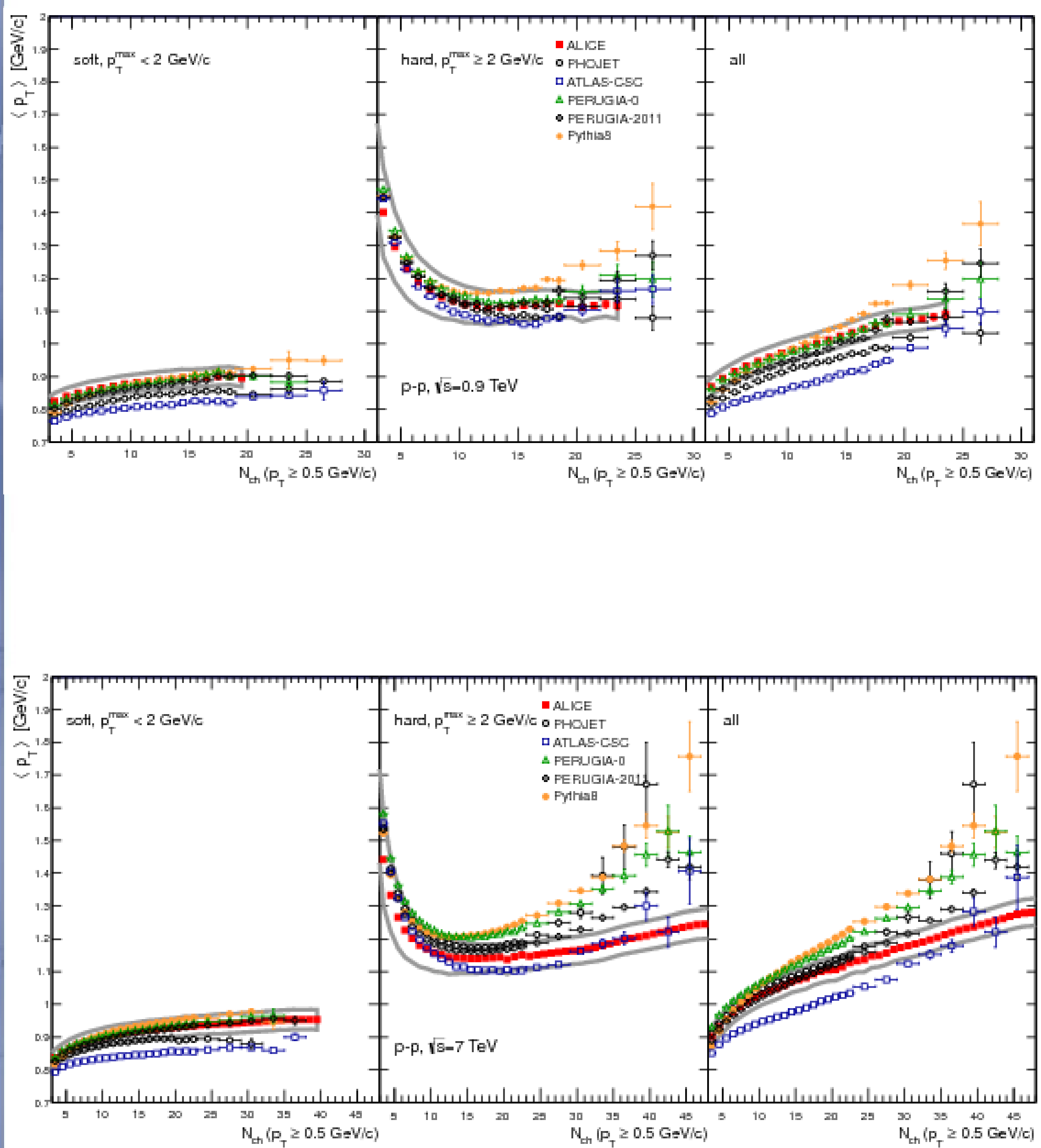


Fig. 7: Mean transverse momentum versus multiplicity. The ALICE data are compared with five models: PHOJET, PYTHIA6 (tunes: ATLAS-CSC, PERUGIA-0 and PERUGIA-2011) and PYTHIA8. Results at √s = 0.9 and 7 TeV are shown in the top and bottom rows, respectively. Different event classes are presented: (left) "soft", (middle) "hard" and (right) "all". The gray lines indicate the systematic uncertainty on data and the horizontal error bars indicate the bin widths.

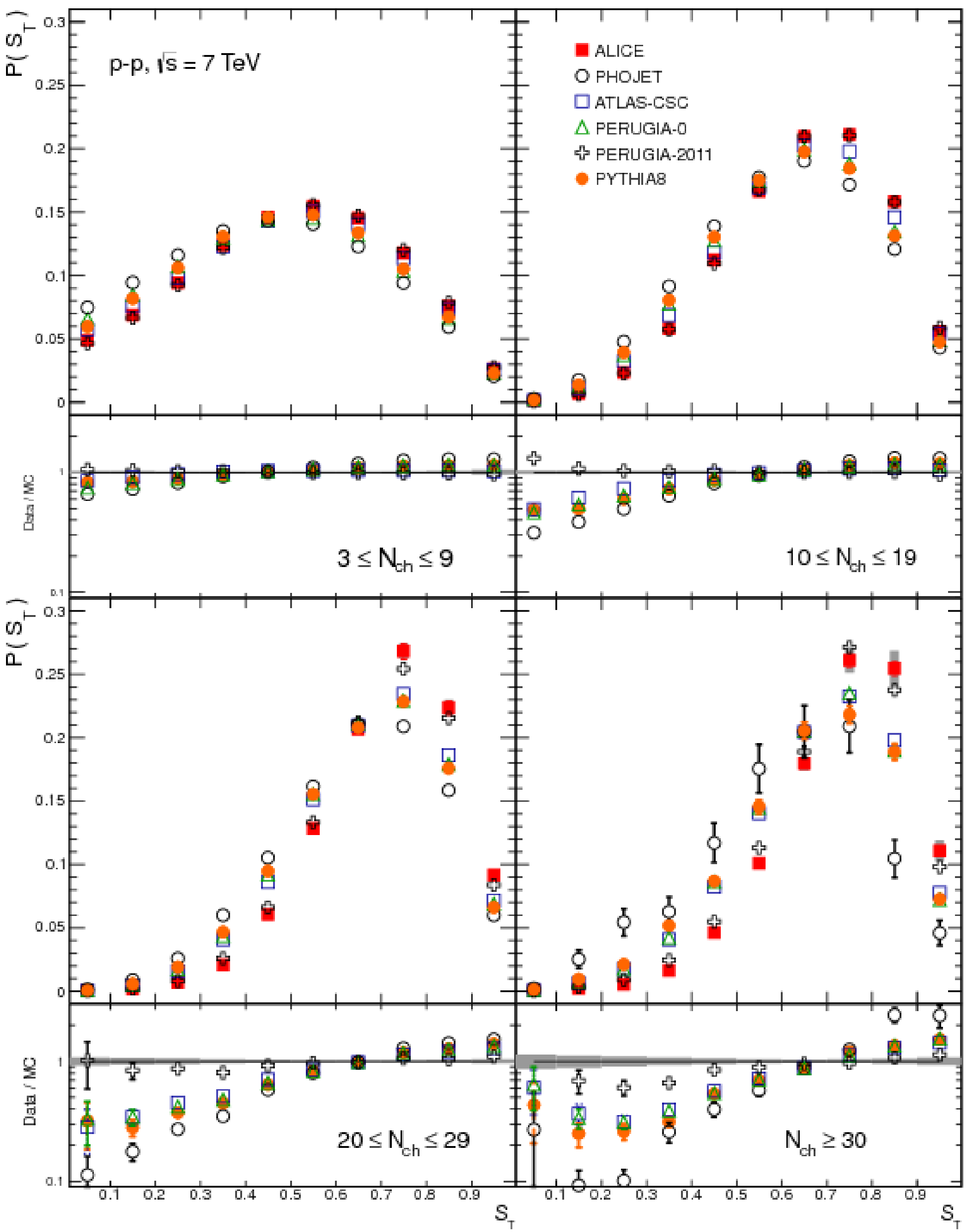


Fig. 8: Sphericity distributions in four bins of multiplicity: (upper-left) 3 ≤ Nch ≤ 9, (upper-right) 10 < Nch ≤ 19, (bottom-left) 20 < Nch ≤ 29 and (bottom-right) Nch ≥ 30 at √s = 7 TeV. The statistical errors are displayed as error bars and the systematic uncertainties as the shaded area.

Conclusions

- Systematic characterization of the event shape in minimum bias proton-proton collisions at Sqrt(s) = 0.9, 2.76, 7 TeVs.

- The transverse sphericity is used to provide insight into the production mechanism.

- MC generators exhibit a decrease of <S□> at high multiplicity with a simulataneos steep rise of <pt>, while ALICE data stays approximately constant or slightly rising of <S□>. and mild increase in <pt>

- The <S□> seems to primarily depend on the multiplicity and not on the collision energy.

- At high multiplicity (Nch>30) the generator underestimate the production of isotropic events and overestimate the production of pencil-like events.

- The study suggest that the tuning of generators should include the sphericity as and additional reference.

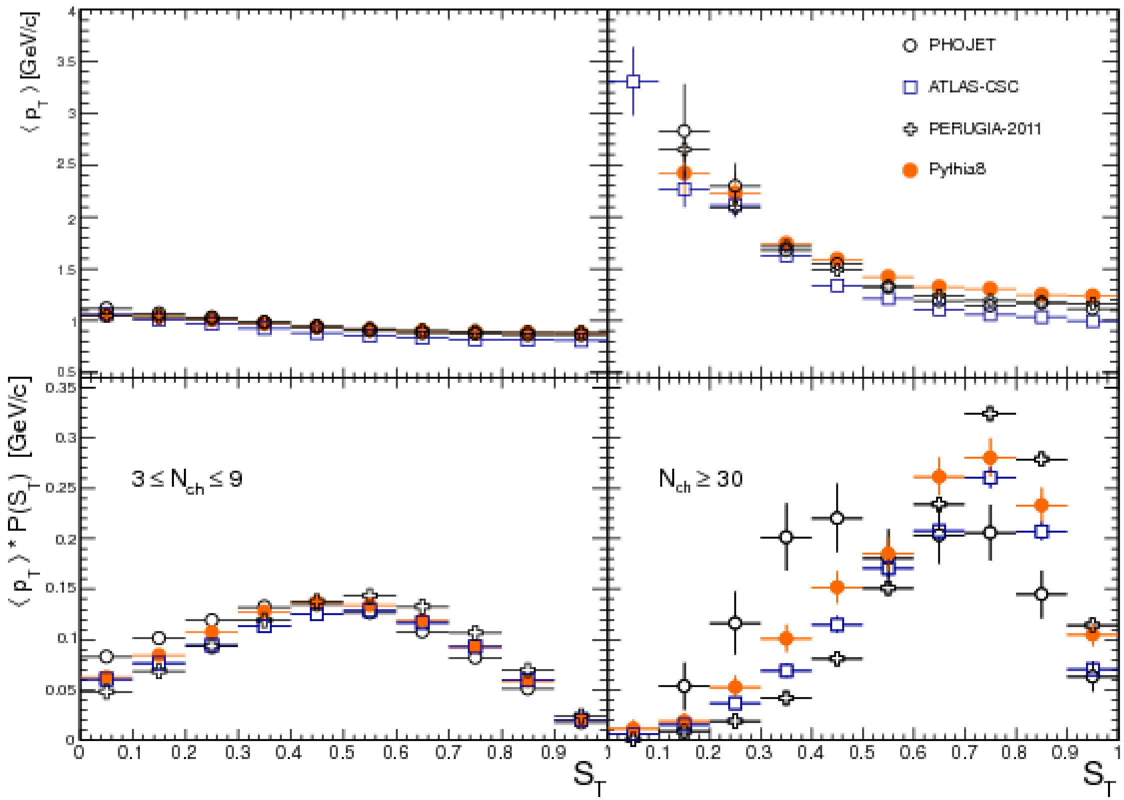
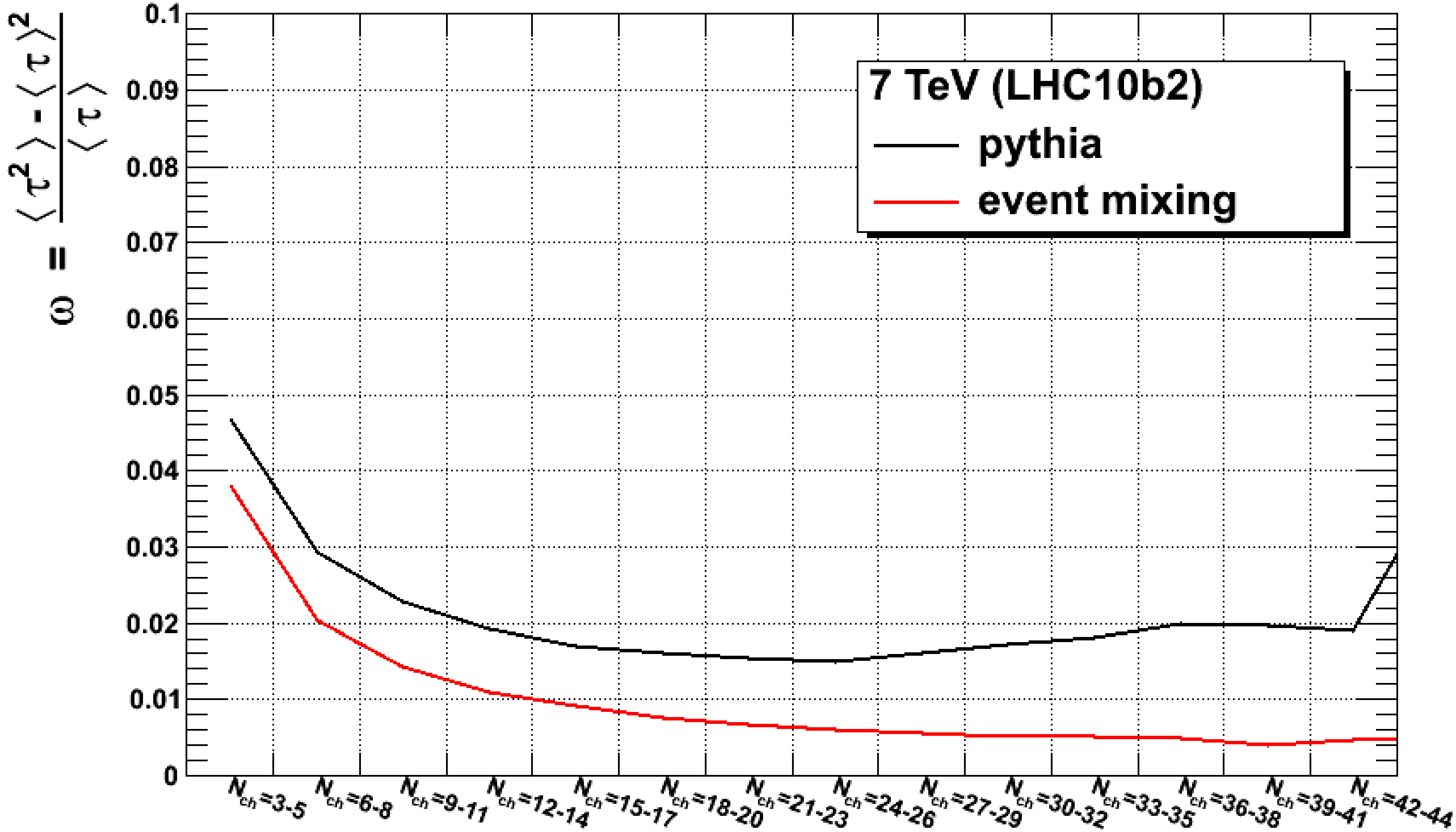


Fig. 9: Mean pT (top) as a function of sphericity for two multiplicity bins (left) 3 ≤ Nch ≤ 9 and (right) Nch ≥ 30 for minimum bias pp collisions at √s = 7 TeV simulated with four different MC generators: PHOJET, PYTHIA6 (tune ATLAS-CSC and PERUGIA-2011) and PYTHIA8. Also the contributions of the different event topologies to the averaged mean pT are presented (bottom).

<1-T> vs Multiplicity

Other view...



Unfolding the Thrust Spectrum

RESPONSE MATRIX, LHC10a8-10, PYTHIA-D6T, 1.5 Million of events