Event shapes in MB proton-proton collisions

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Outline

- What are the event shapes (es)?
- Definitions.
- Results from LHC.
- Sphericity vs Spherocity in MC simulations.
- Conclusions.

Why study event shapes

- People use to look for kind of collectivity in high multiplicity pp events (argument: multiplicity measured in pp at 7 TeV is comparable to Cu-Cu collisions at RHIC)

K. Werner at al. Phys.Rev.C83:044915,2011
k. Werner at al. J.Phys.Conf.Ser.316:012012,2011

- However, high multiplicity events may have different event structures associated with the hardness of the event.

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

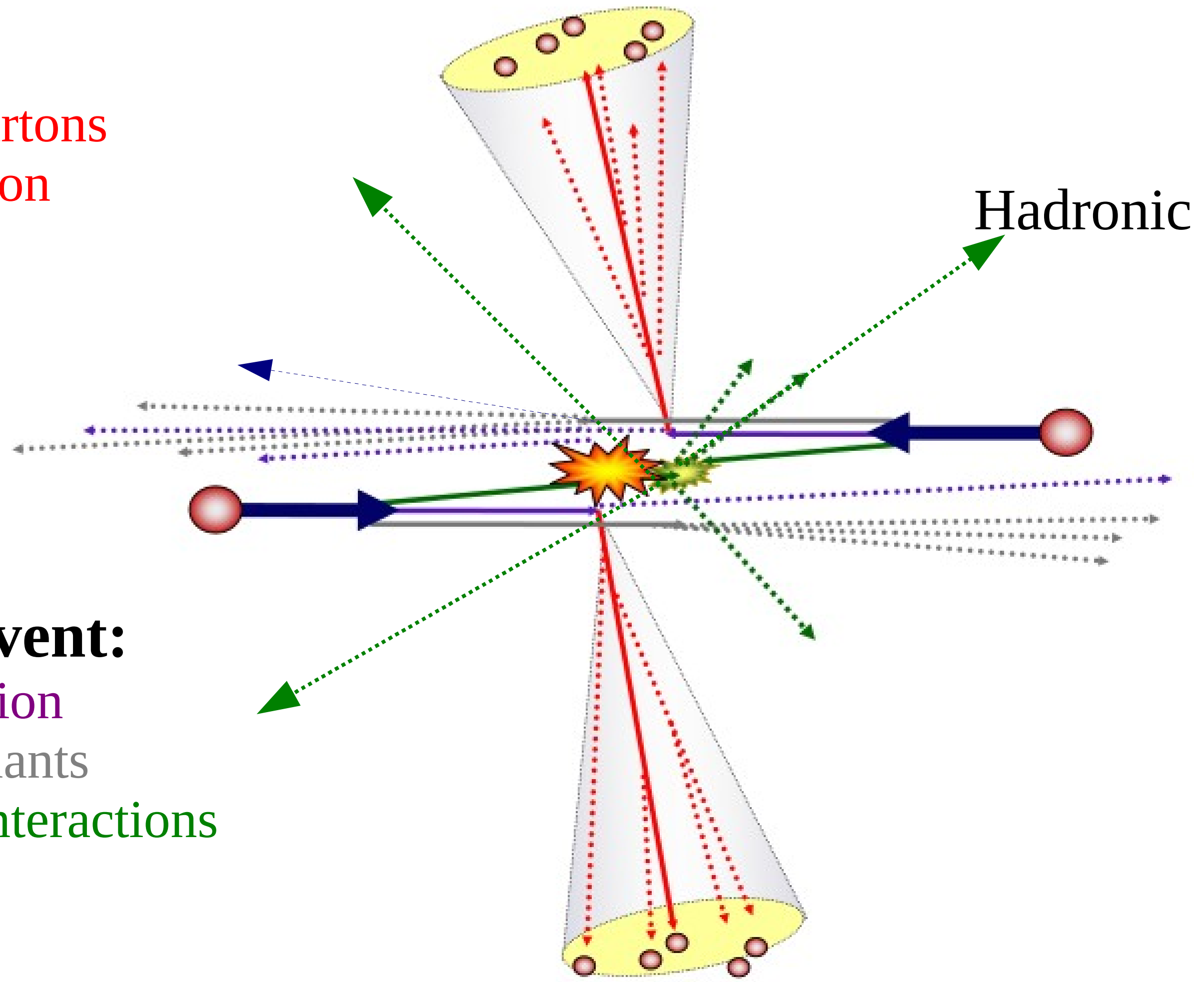
How to isolate high multiplicity events, with isotropic distribution of transverse momentum and with a small contribution from multi-jet topologies?

Goal: Understand effects which are observed in Pb-Pb collisions and may be present in pp collisions.

What are the event shapes?

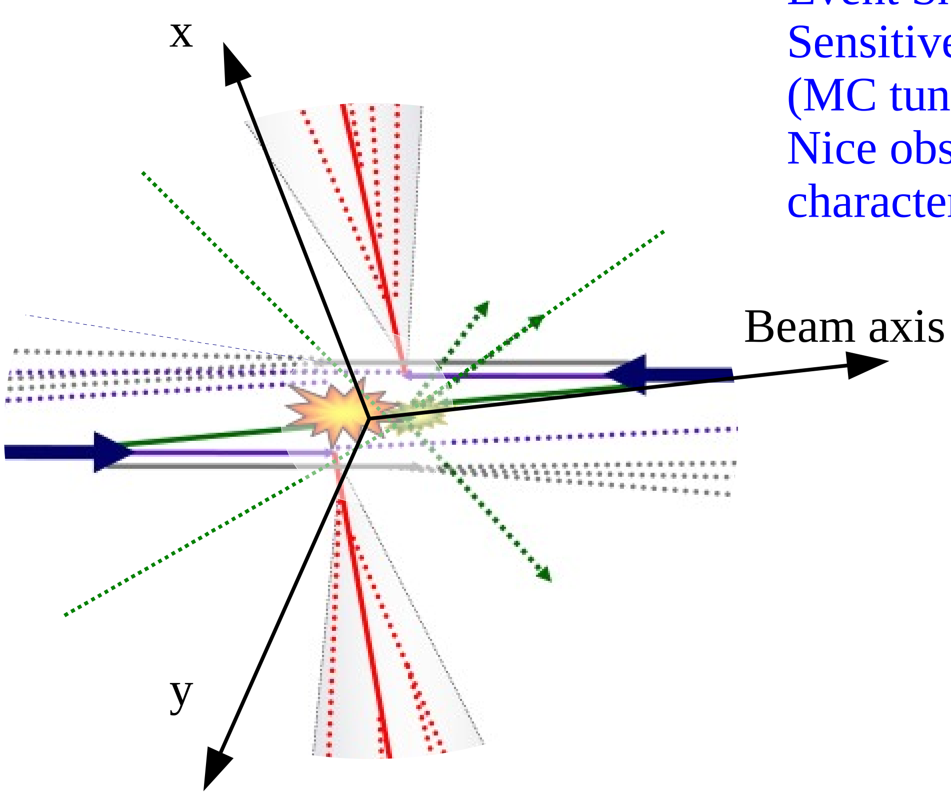
Jets:
Hard scattered partons
Final state radiation

Hadronic interactions



Underlying Event:
Initial state radiation
Beam-beam remnants
Multiple parton interactions

What are the event shapes?



Event Shapes in MB:
Sensitive to UE event (MC tune)
Nice observable to characteriza HM events

Event Shapes characterize the distribution of the outgoing particle energy from a high energy collision. In hadron-hadron collisions they are restricted to the transverse component w.r.t. beam axis (avoid the bias from the boost).

Examples

- Sphericity.

The following matrix is diagonalized:

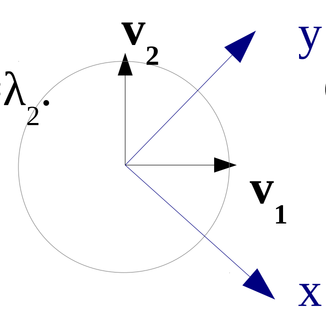
$$\mathbf{S}^{\mathbf{L}}_{\mathbf{xy}} = \frac{1}{\sum_i p_{\mathrm{T}i}} \sum_i \frac{1}{p_{\mathrm{T}i}} \begin{pmatrix} p_{\mathrm{x}i}^2 & p_{\mathrm{x}i}\, p_{\mathrm{y}i} \\ p_{\mathrm{y}i}\, p_{\mathrm{x}i} & p_{\mathrm{y}i}^2 \end{pmatrix}$$

Transverse sphericity is defined as follows:

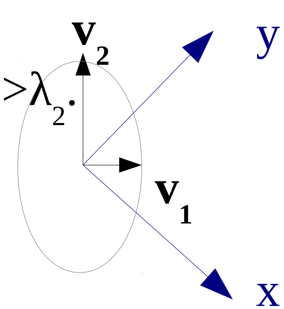
$$S_{\mathrm{T}} \equiv \frac{2\lambda_2}{\lambda_2 + \lambda_1}.$$

Where $\lambda_1 >= \lambda_2$.

Case $\lambda_1 = \lambda_2$.



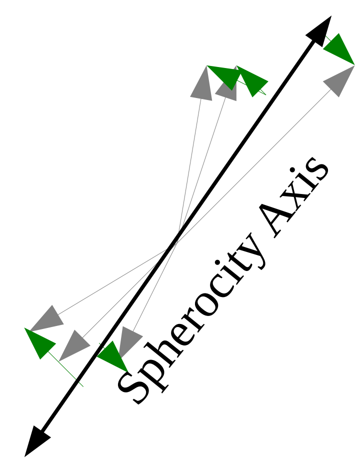
Case $\lambda_1 > \lambda_2$.



- Spherocity

Transverse spherocity is defined as follows:

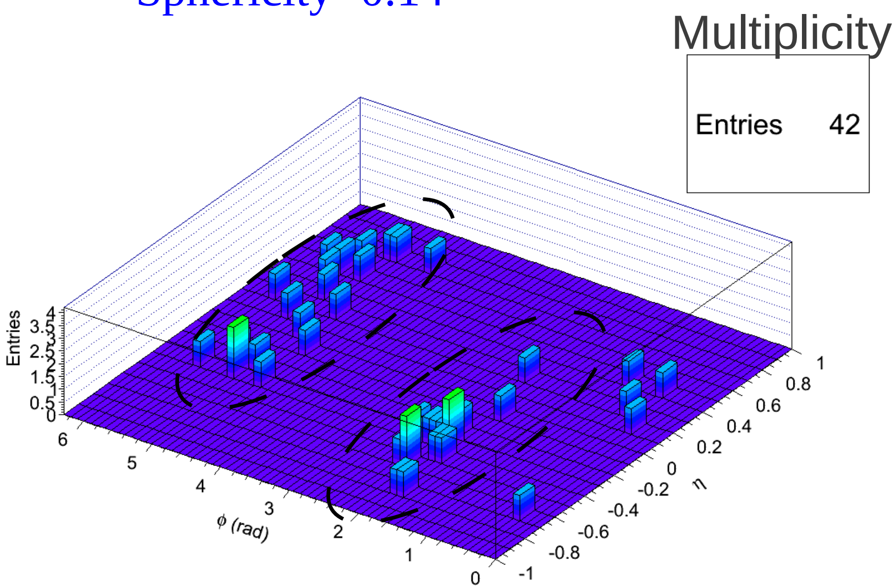
$$S_T^{pherocity} = \frac{\pi^2}{4} \min_{\vec{n}=(n_x,n_y,0)} \left(\frac{\sum |\vec{p}_{T_i} \times \vec{n}|}{\sum p_{T_i}} \right)^2$$



Andrea Banfi et al., “Phenomenology of the event shapes at hadron colliders”, arXiv:1001.4082

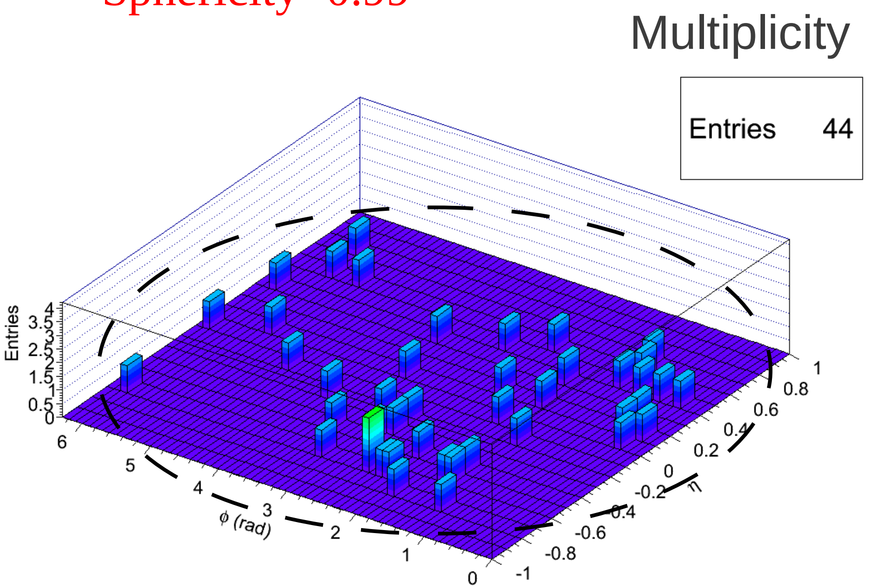
Event Structure

Spherocity=0.09
Sphericity=0.14



Pythia6, tune Perugia 2011

Spherocity=0.96
Sphericity=0.99



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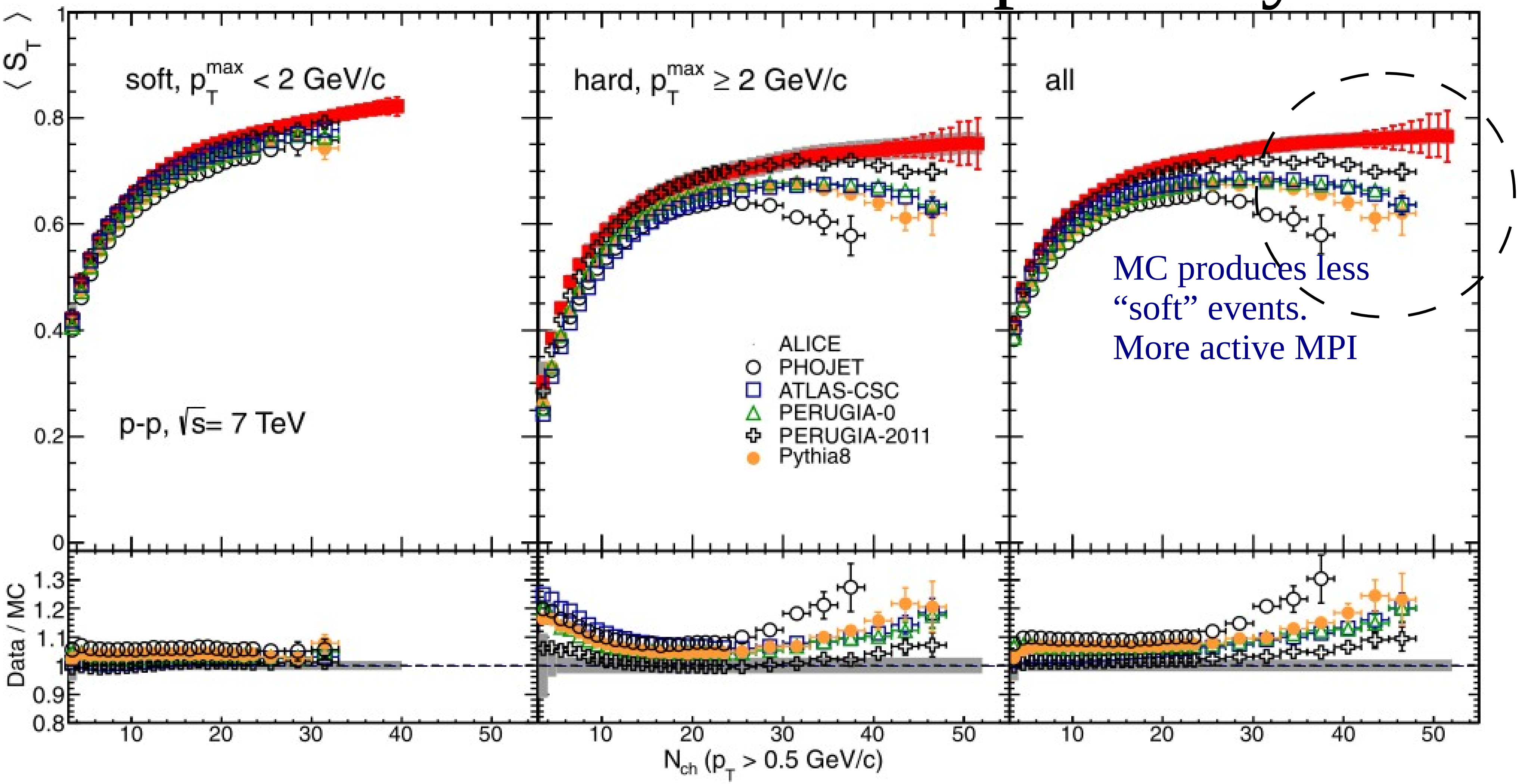
Results for transverse sphericity



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

High multiplicity events seems more isotropic than MC.

Results for transverse sphericity

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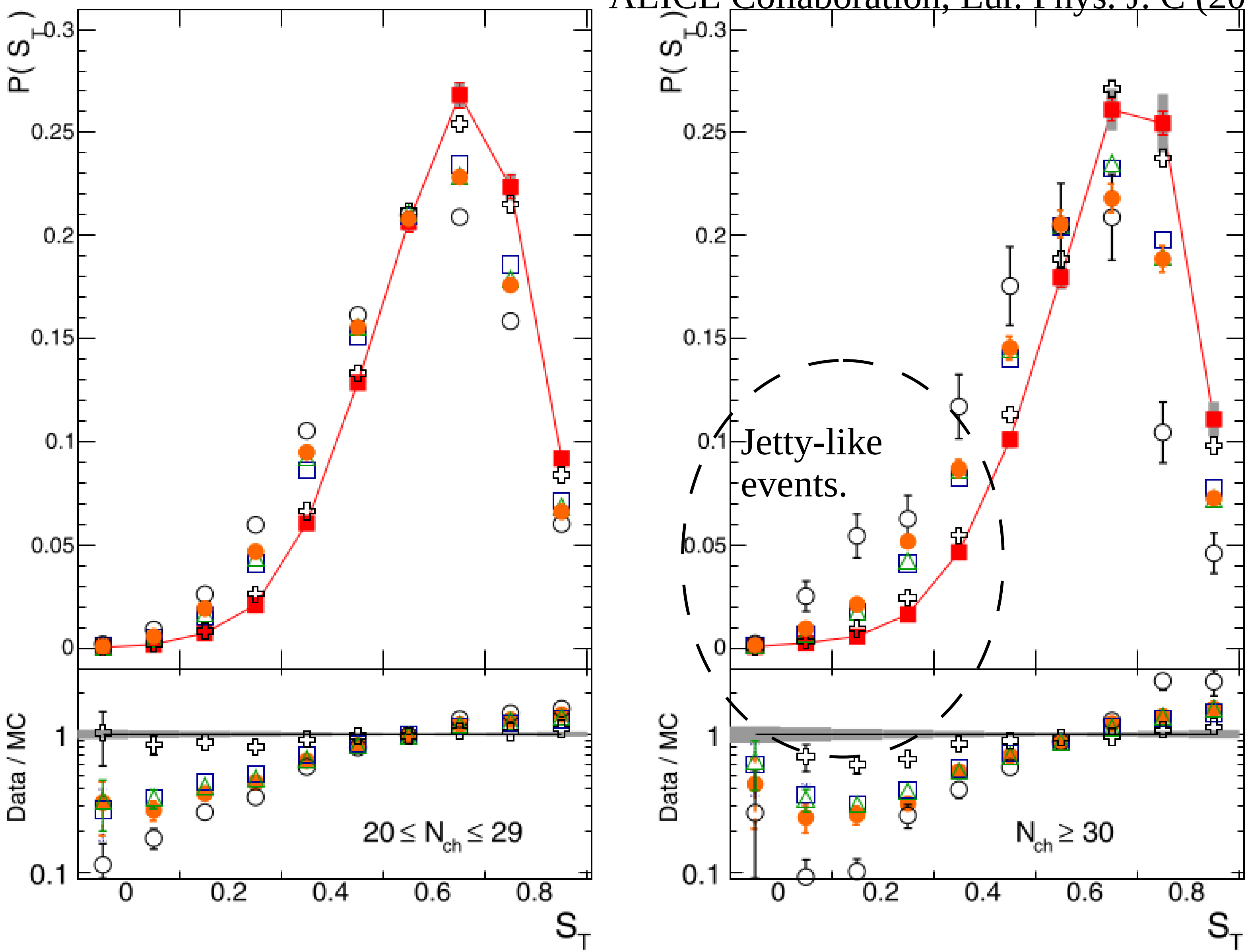
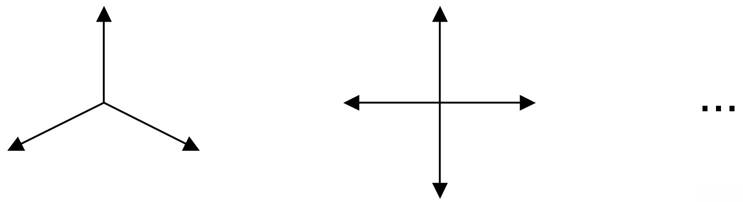


What else can we learn from event shapes?

Simulations:
Pythia6, tune Perugia 2011.
Pythia8, v 8.17, Tune 4 C.

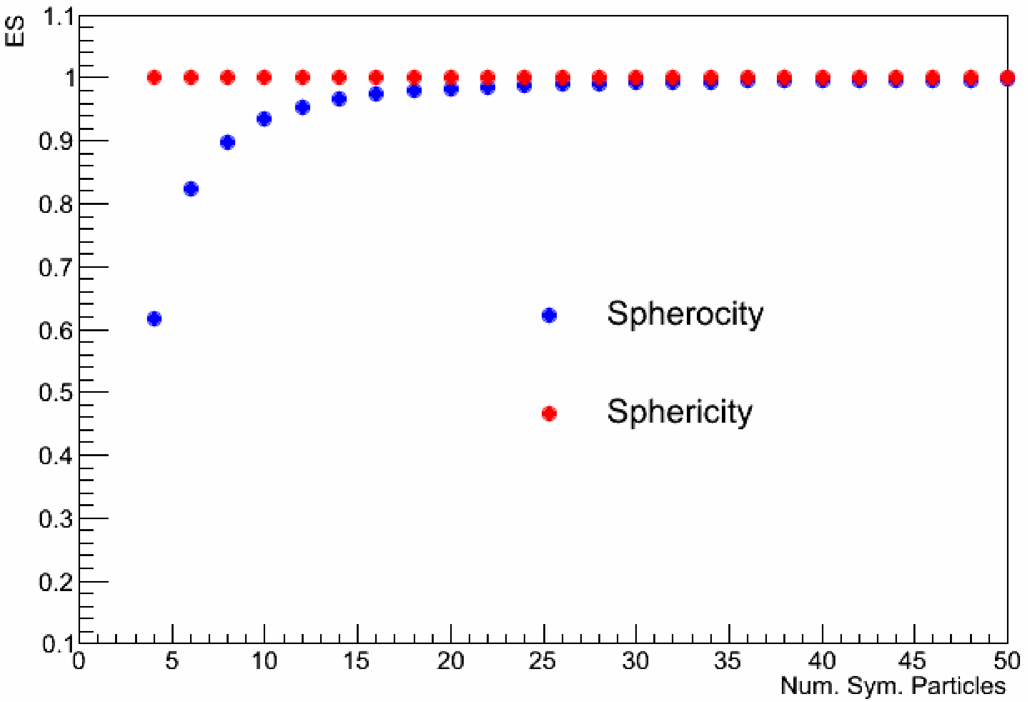
What is the “best” observable that can distinguishing truly spherical events from simpler multi-jet topologies, (like symmetric transverse-planar events)?

Exercise: generate symmetrical configurations with N “particles” (same p_T).



Vspherical: limit value of the observable.
V(N): value of the observable for N particles.

SPHEROCITY seems a good option.



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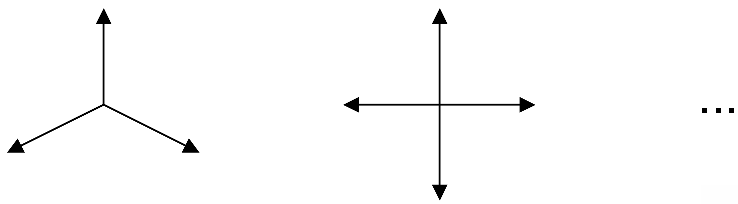
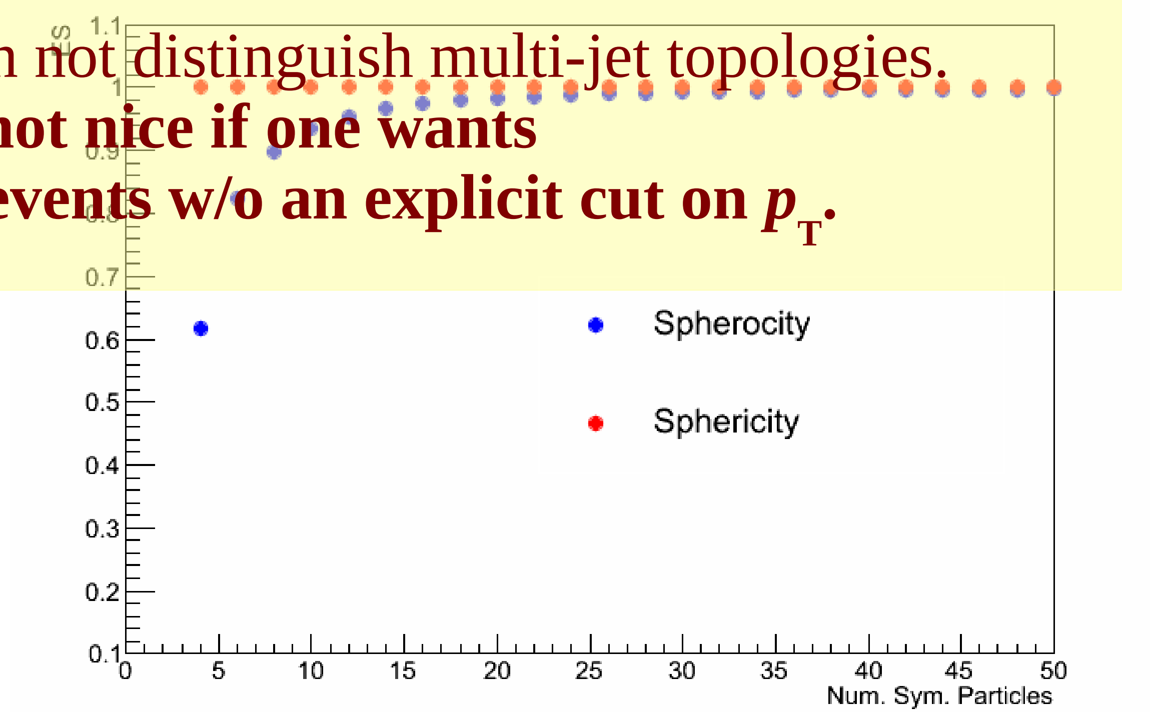


Vspherical: limit value of the observable.
V(N): value of the observable for N particles.

With sphericity we can not distinguish multi-jet topologies.

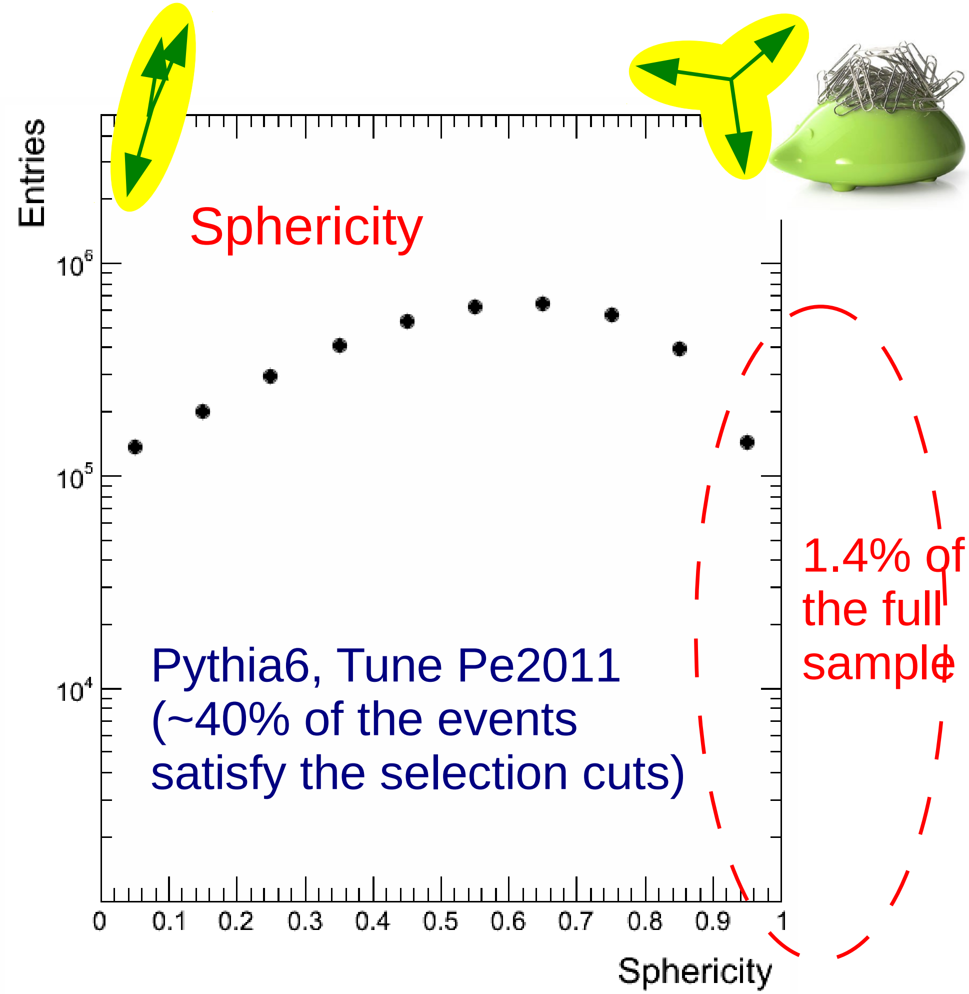
It is not nice if one wants to isolate “soft” events w/o an explicit cut on p_T.



SPHEROCITY seems a good option.

Distribution of the event shapes

- Event Shapes (ES) are defined using primary charged particles at $|\eta|<0.8$
- Experimentally, the resolution of the observables is better for events with more than 3 particles (p_T>0.5 GeV/c).



Amount of high sphericity events is of the same order than low sphericity events.

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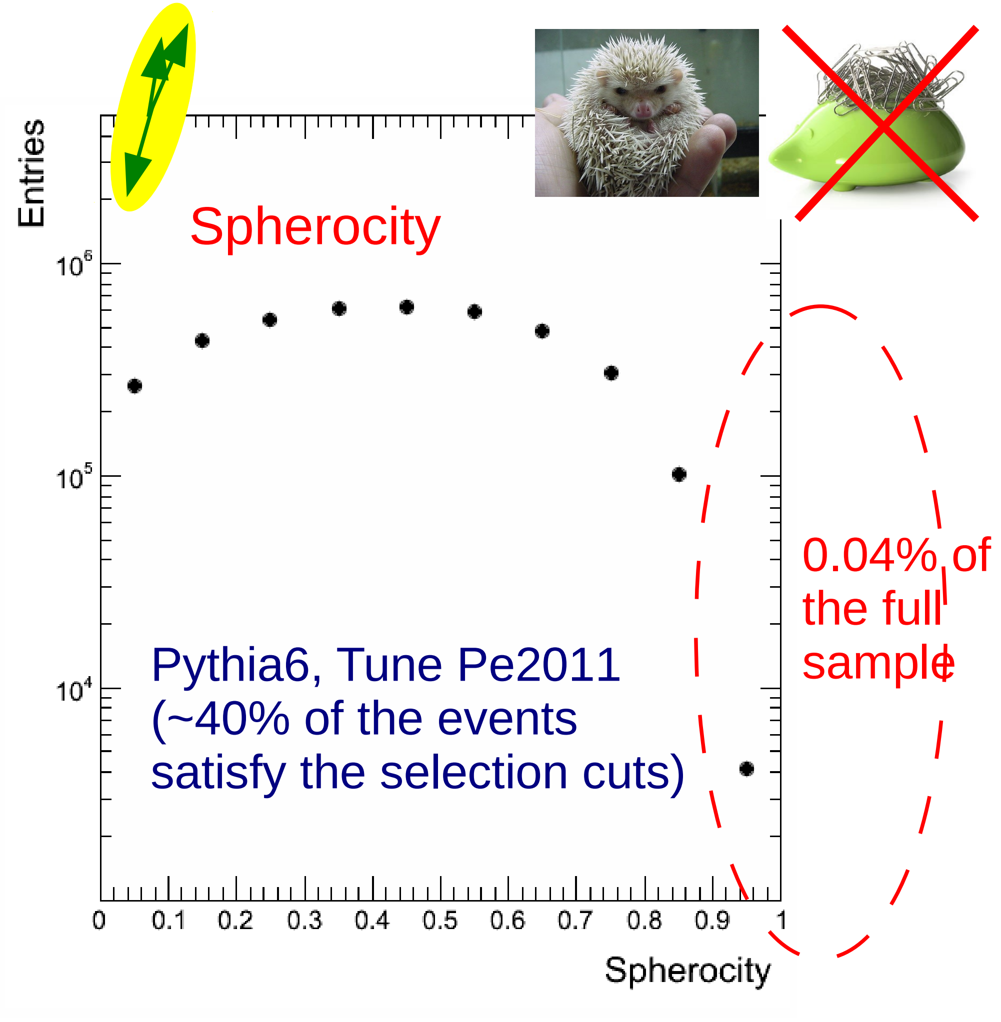
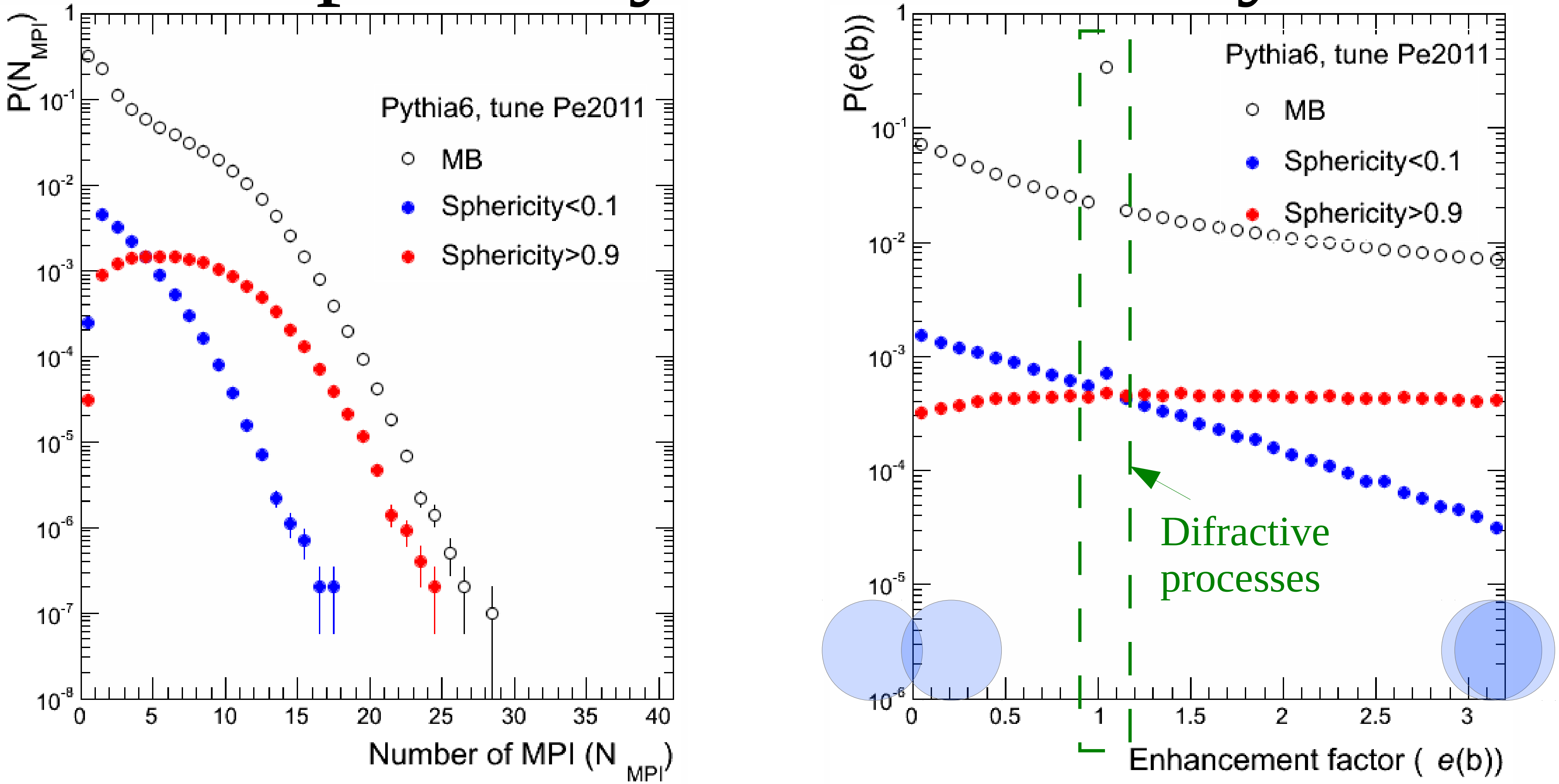


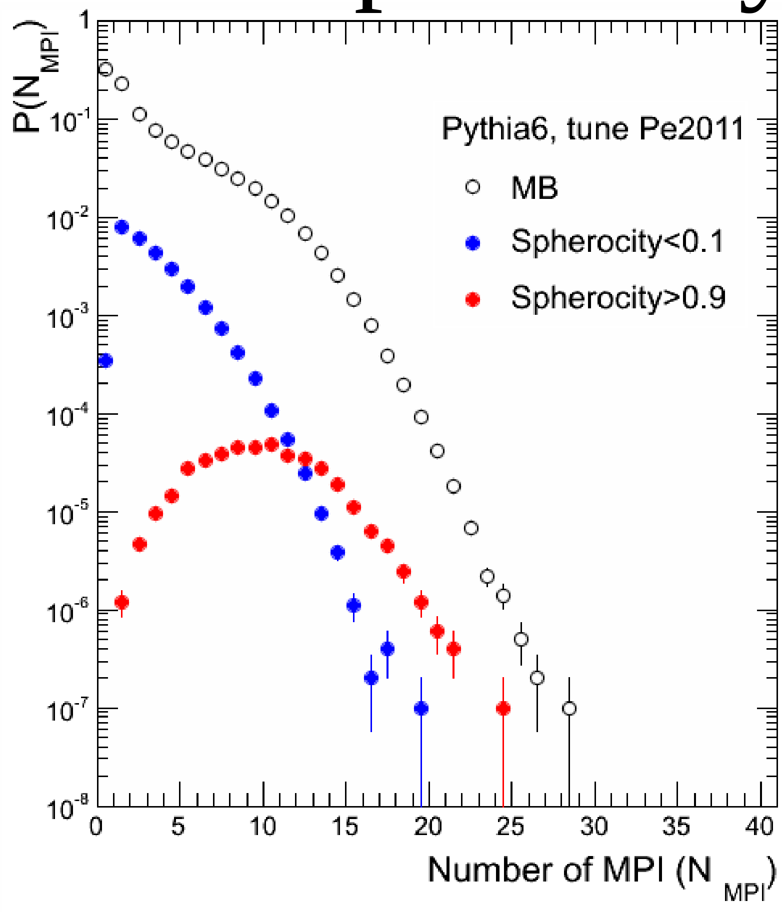
Sphericity and Centrality

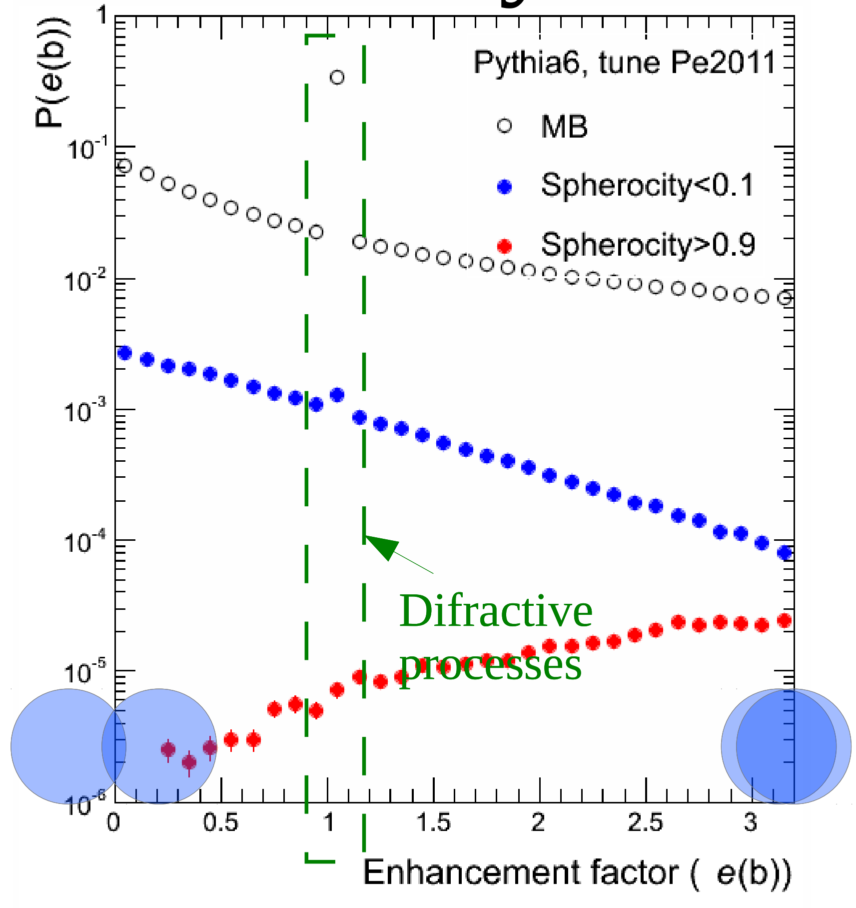


$$f(x_\perp, b) = e(b)\, f(x_\perp) = (\langle \tilde{n}(b)\rangle / \langle kO(b)\rangle)\ f(x_\perp).$$

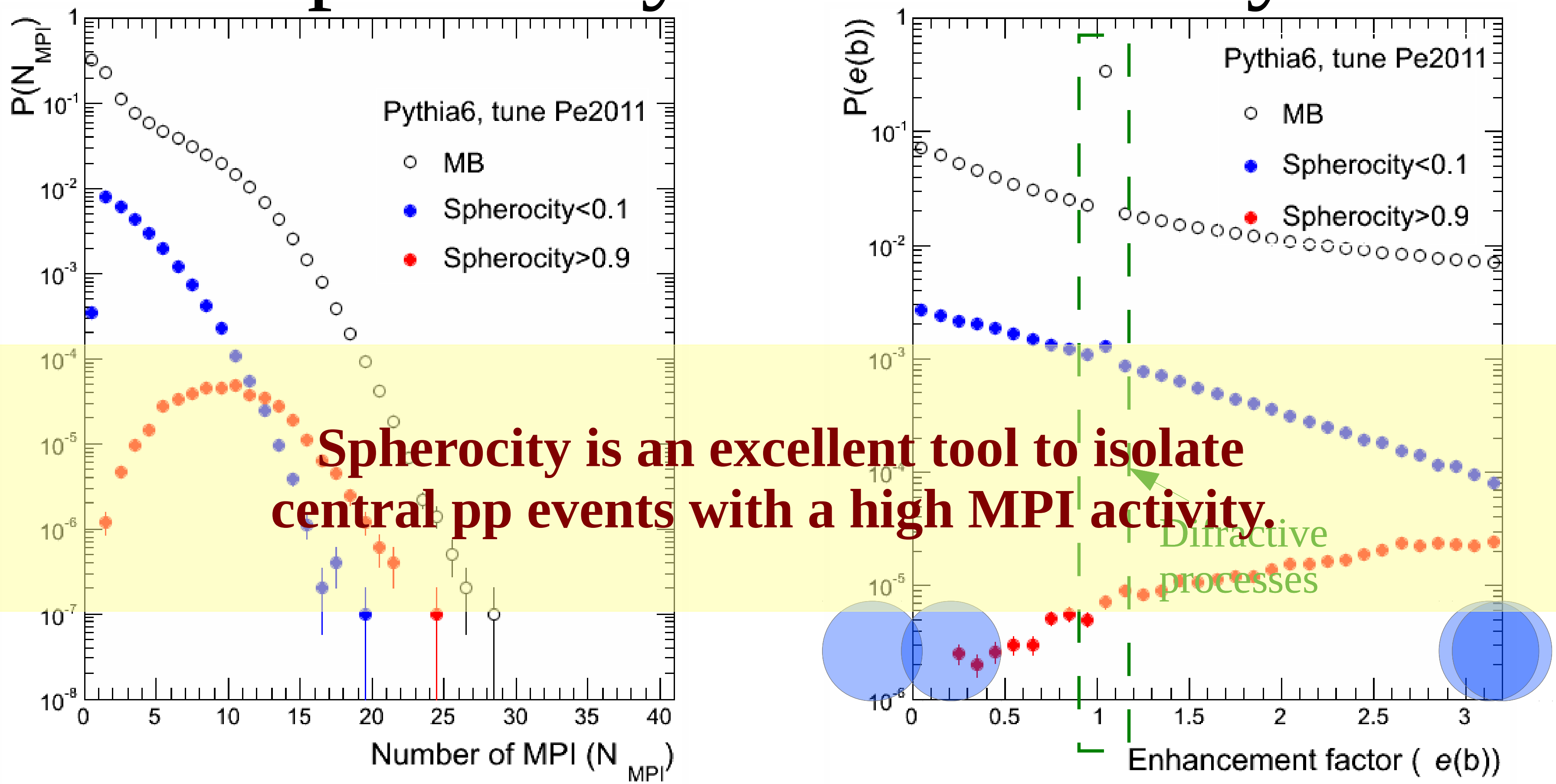
For a impact parameter *b*, $f(x_\perp)$ is the probability to have a parton–parton interaction at $x_\perp$ ($2p_T/\sqrt{s}$), given that the two hadrons undergo a non-diffractive, inelastic collision. *O(b)*: time-integrated overlap between the matter distribution of the colliding hadrons, ñ: counts the number of interactions when two hadrons pass each other.

Spherocity and Centrality



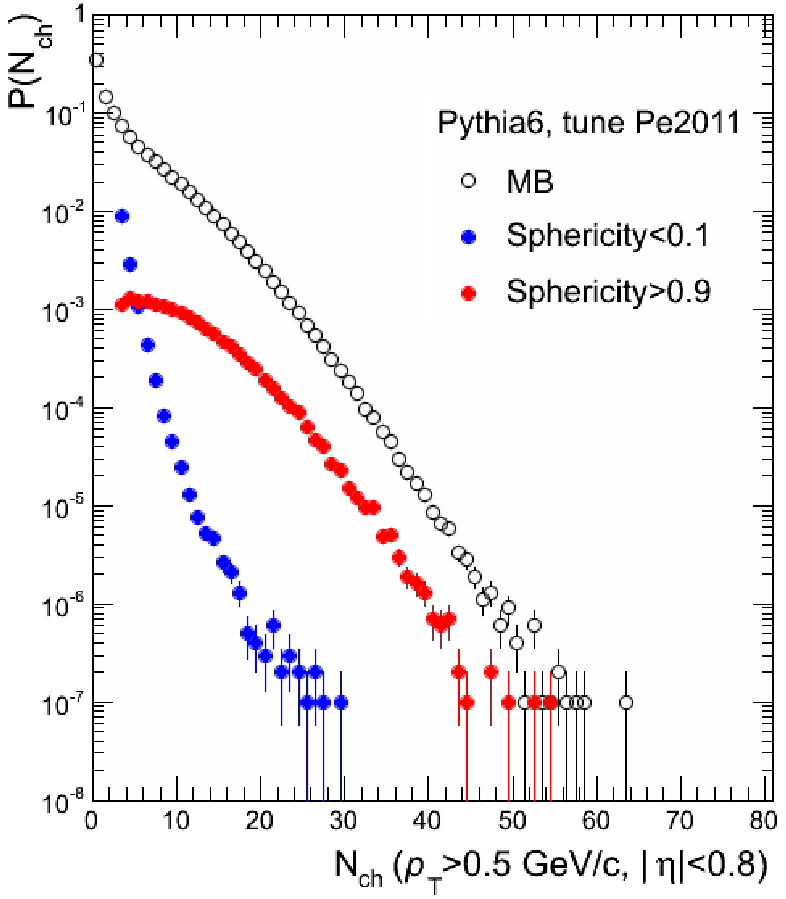


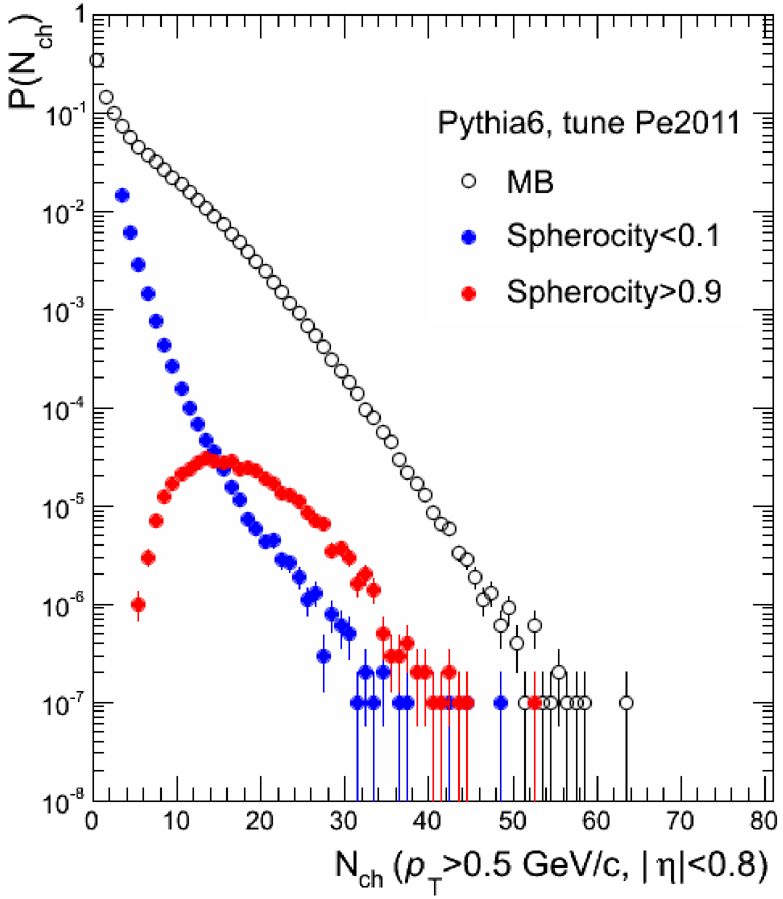
Spherocity and Centrality



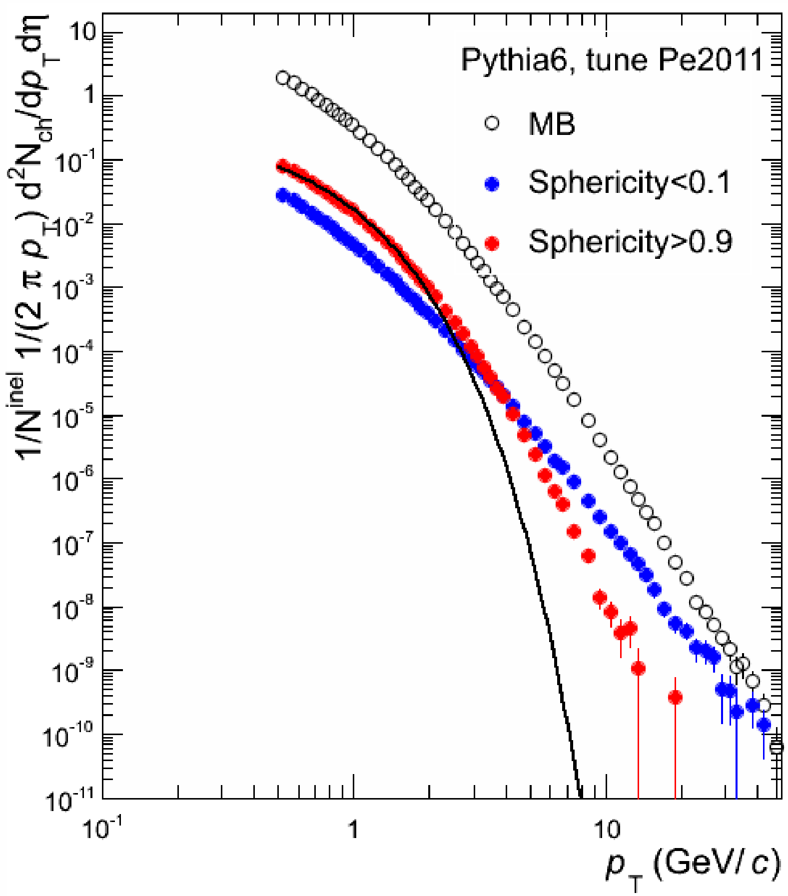
Spherocity is an excellent tool to isolate central pp events with a high MPI activity.

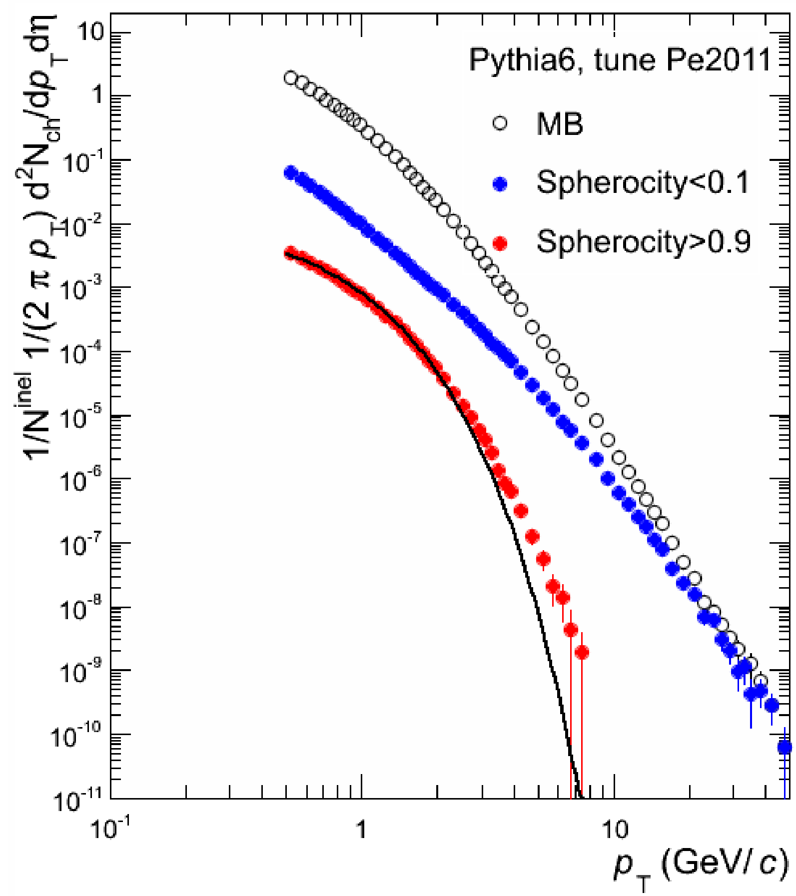
Multiplicity distribution





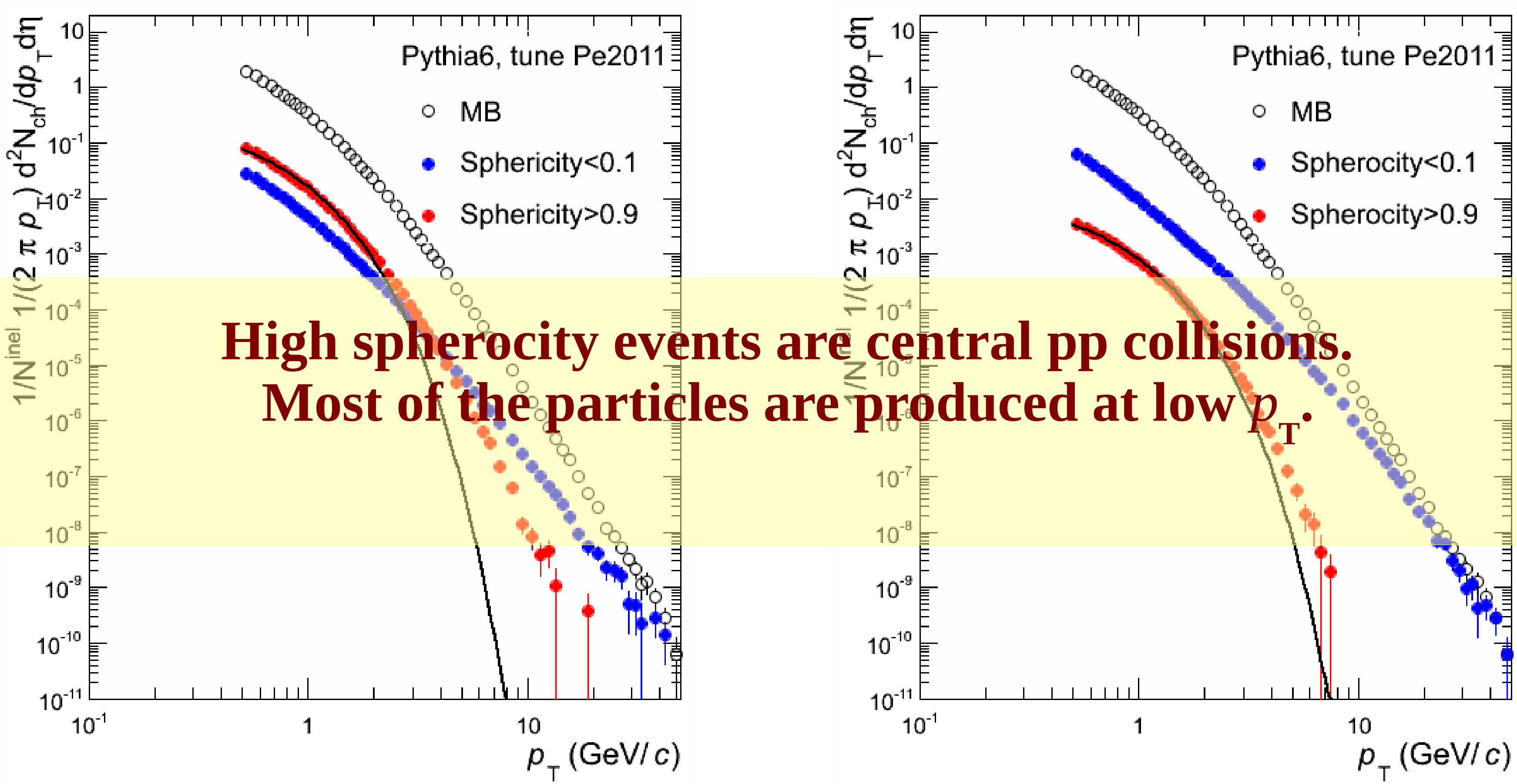
Transverse momentum spectrum





Low spherocity captures better the high p_T component. **High spherocity** p_T spectrum is more compatible with exponential shape. Power law component is more visible in **high sphericity** events (multi-jet origin?).

Transverse momentum spectrum

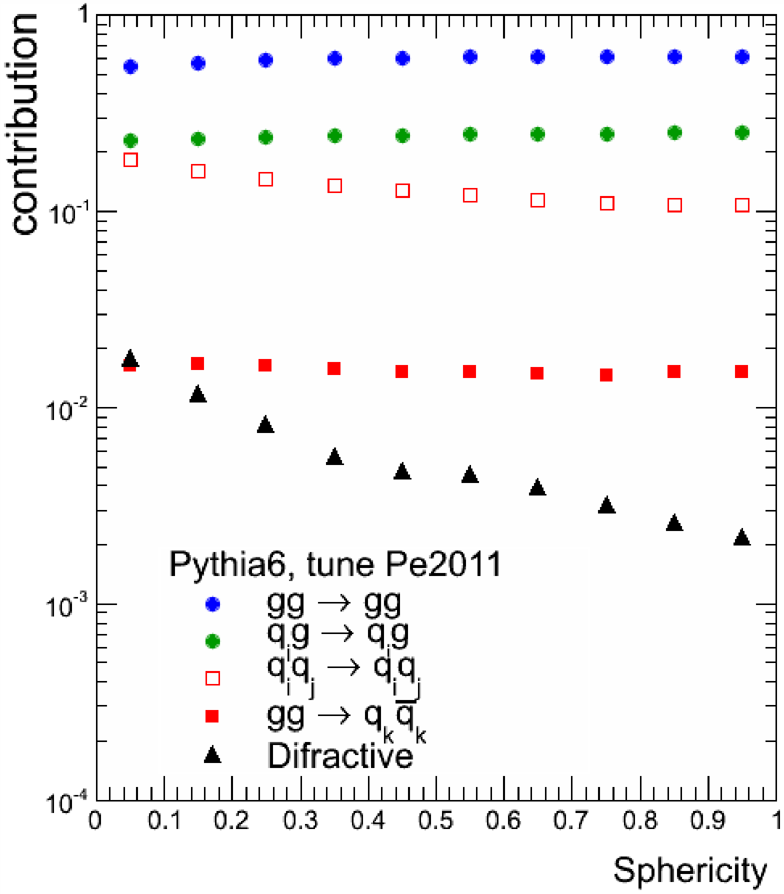


High spherocity events are central pp collisions.
Most of the particles are produced at low p_T.

Low spherocity captures better the high p_T component. **High spherocity** p_T spectrum is more compatible with exponential shape. Power law component is more visible in **high sphericity** events (multi-jet origin?).

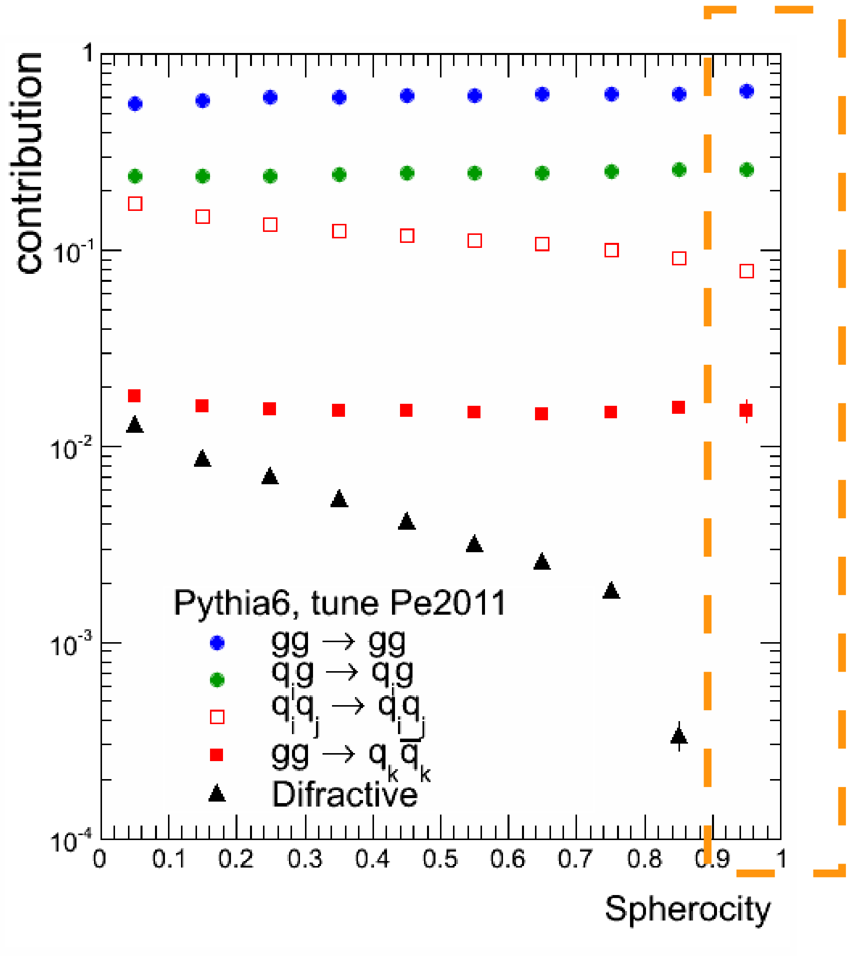
Decomposition of the MB sample as a function of **sphericity**

- Quark jets contribution seems more important in pencil-like events than in isotropic.

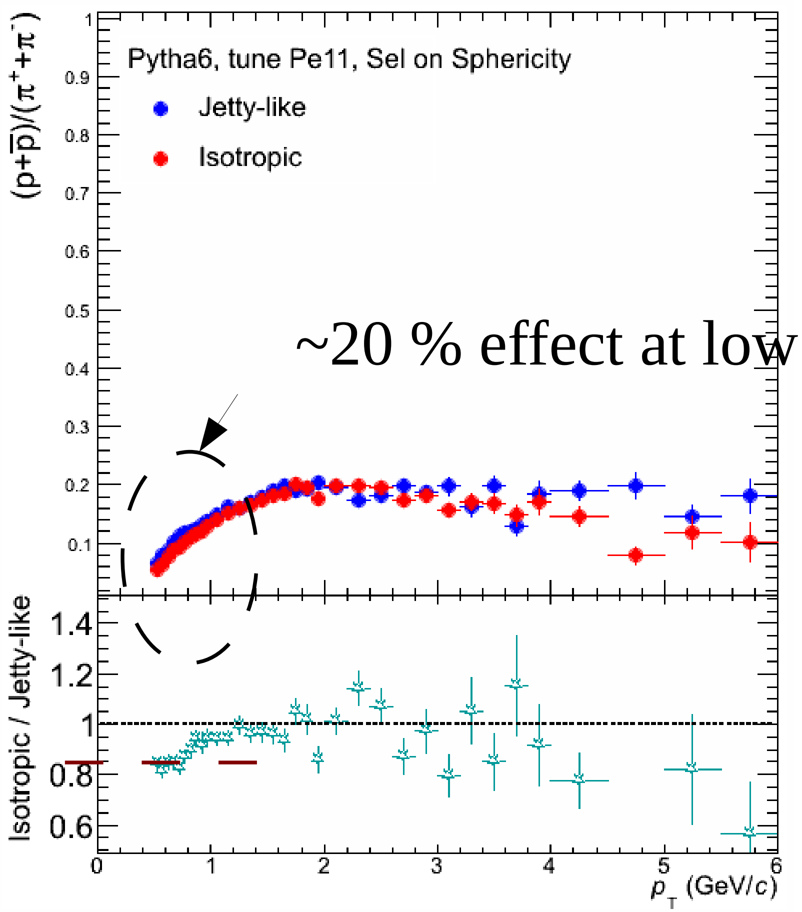


Decomposition of the MB sample as a function of **spherocity**

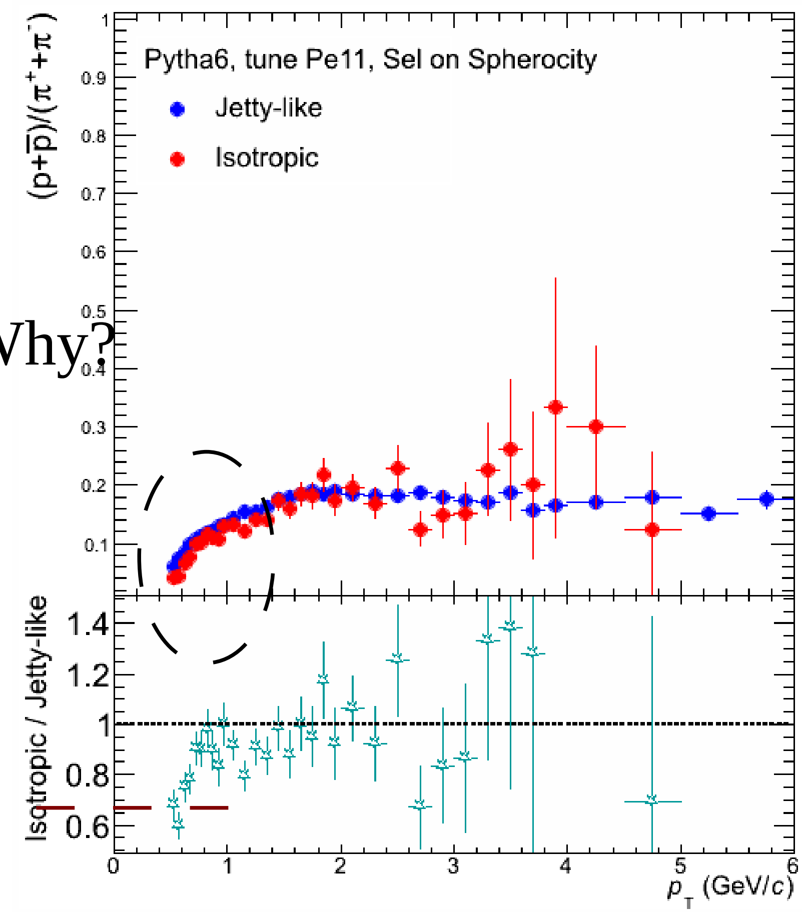
- Nice power to reject diffractive events in the isotropic limit.
- Contribution from quark-jest is significantly reduced in the isotropic limit (w.r.t. sphericity).



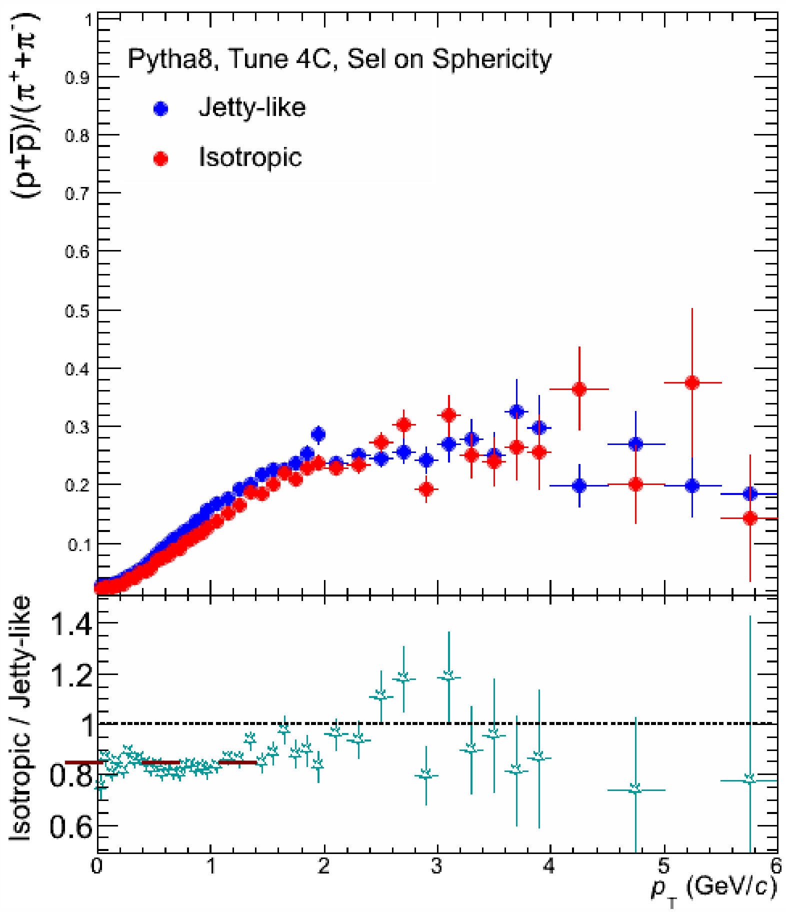
Selection on sphericity

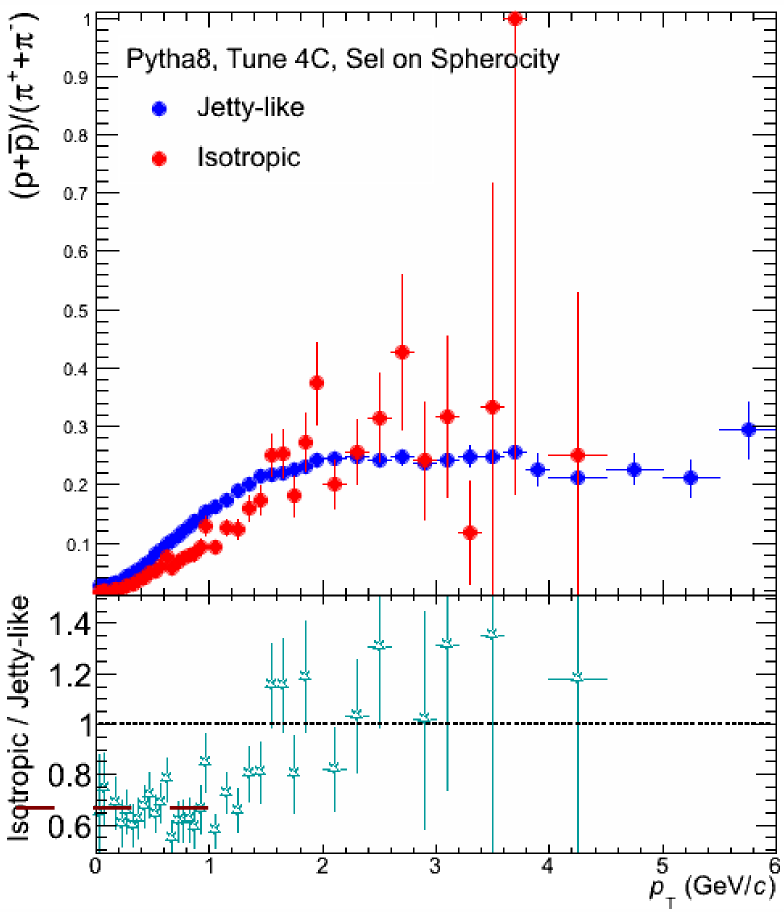


~20 % effect at low p_T. Why?



Same exercise with Pythia8 (HardQCD replaced by SoftQCD)

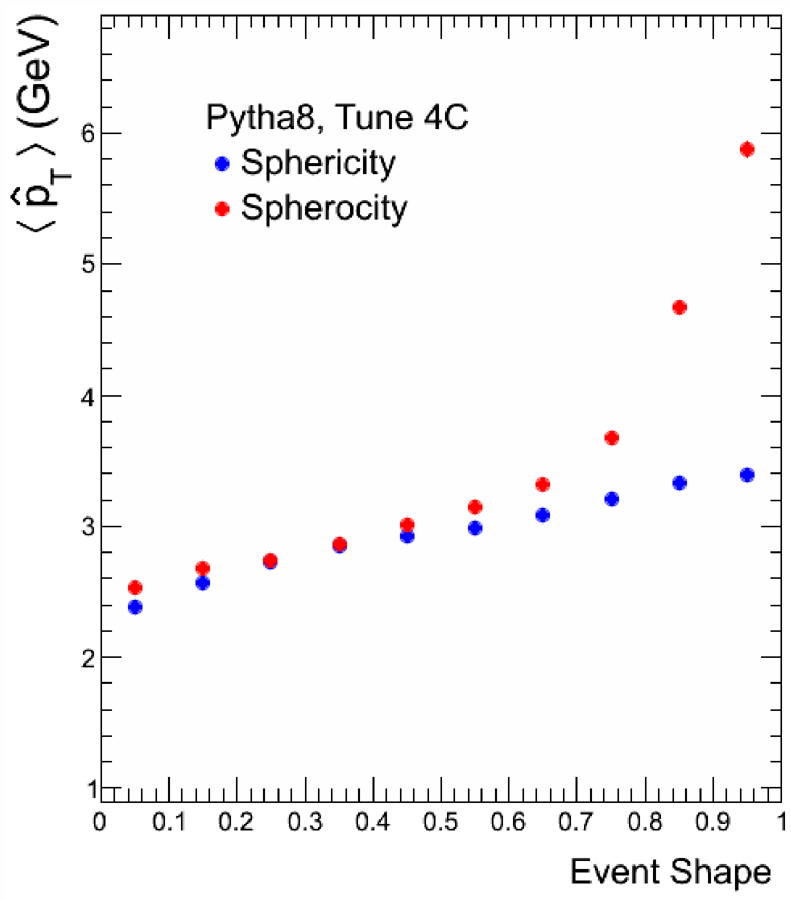


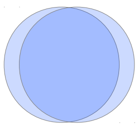


The effect is considerably increased, why? We only increased the jet energy by turning on HardQCD.

Hardness vs Event Shape

- Pythia generates high spherocity events through violent parton-parton scatterings.
- The majority are gg → gg (~70%), which produces high multiplicity events.
- Particles are mostly produced at low p_T.

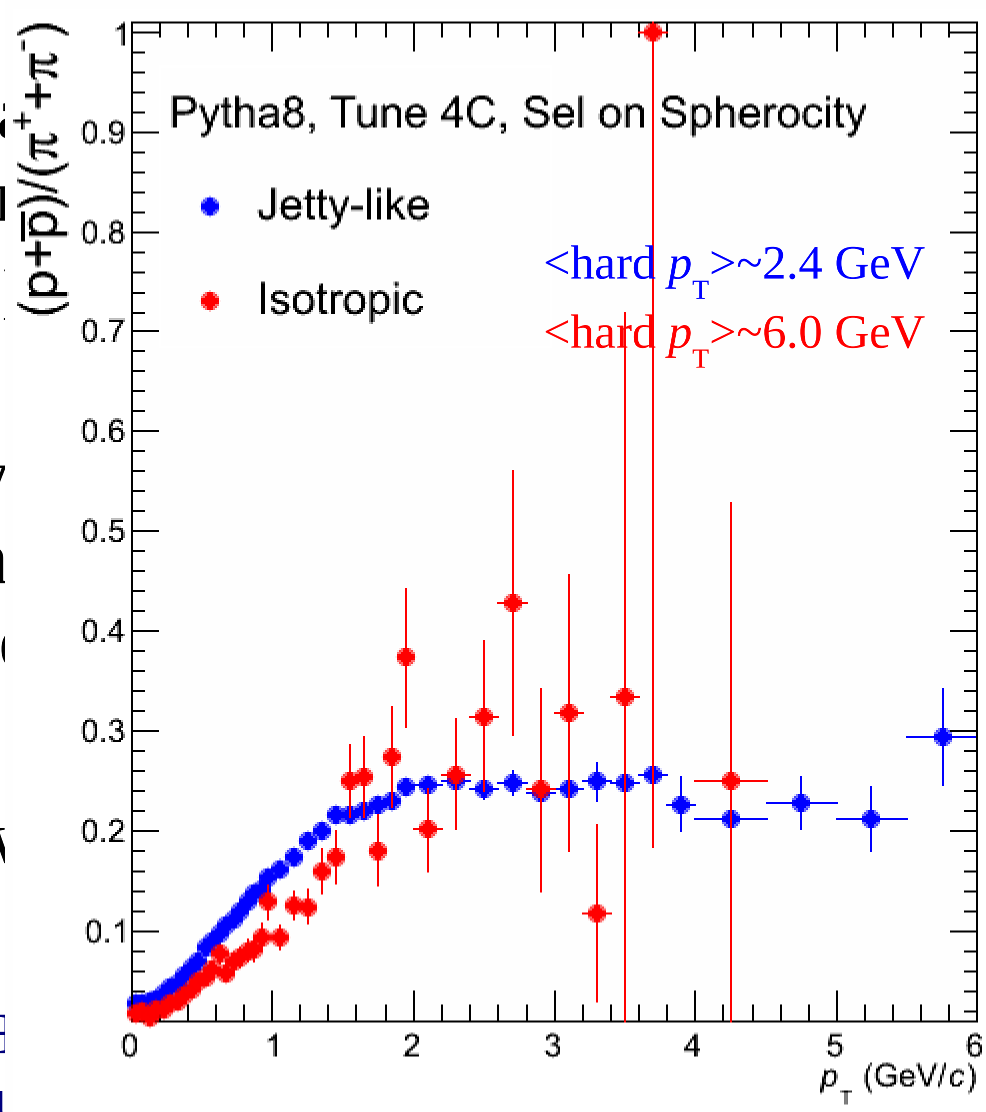


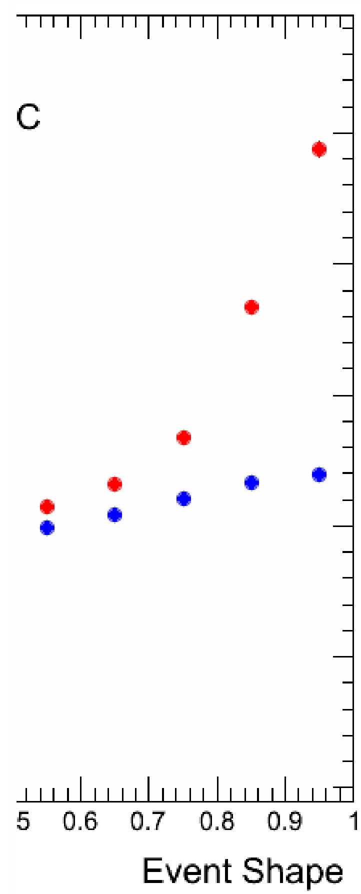


High Spherocity (Sphericity) represents **0.006%** (0.5%) of the full statistics.

Hardness vs Event Shape

- Pythia gener… spherocity eve… violent parton-… scatterings.
- The majority (~70%), which … multiplicity ev…
- Particles are produced at lo…





H… …**006%** (0.5%) of the
fu…

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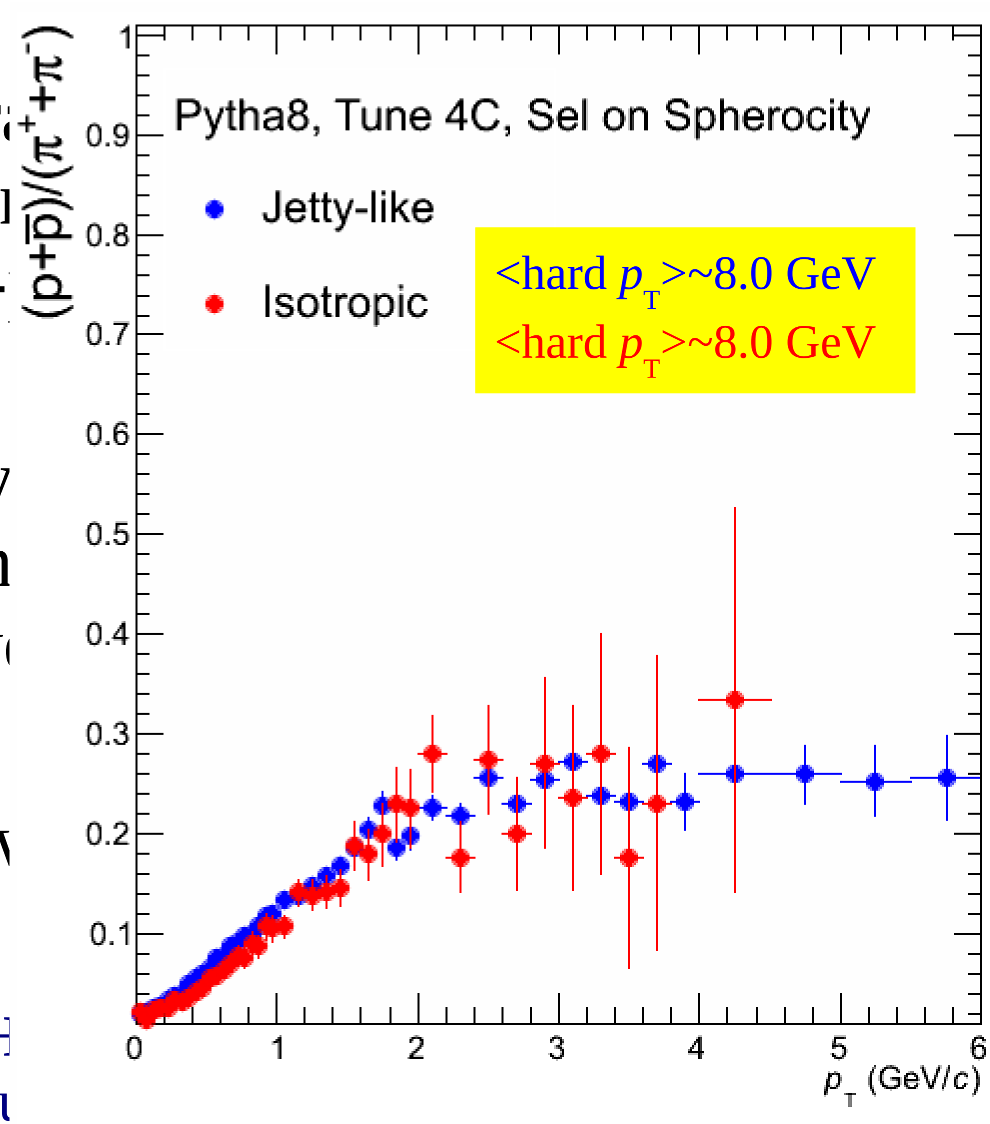

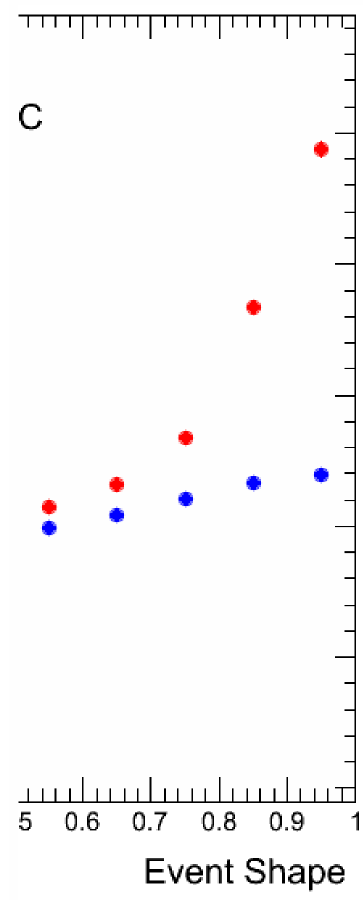

H **006%** (0.5%) of the
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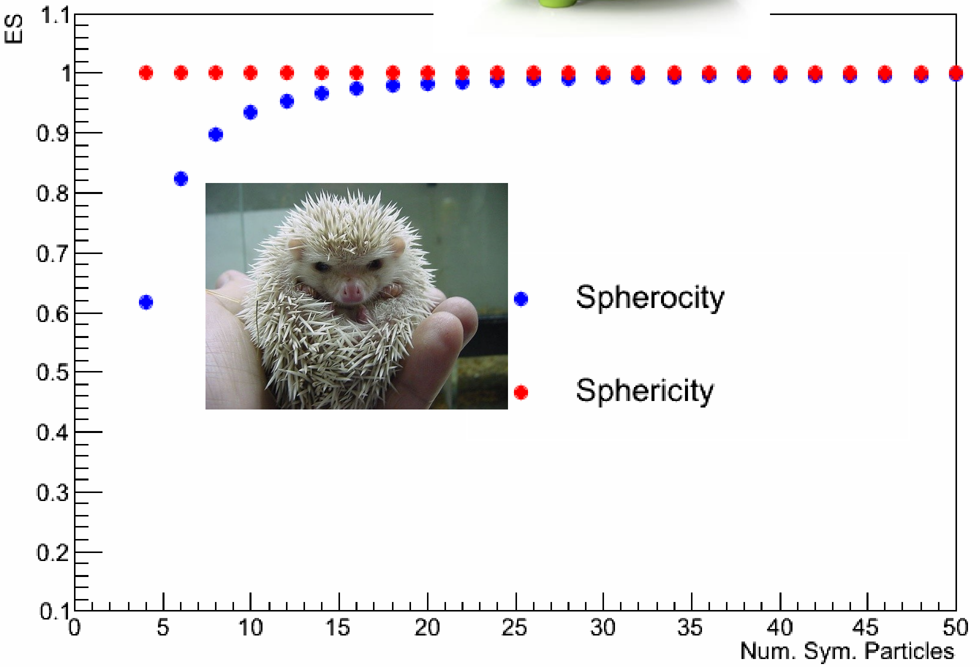
Conclusions

- Sphericity and spherocity exhibit different kind of sensitivities.



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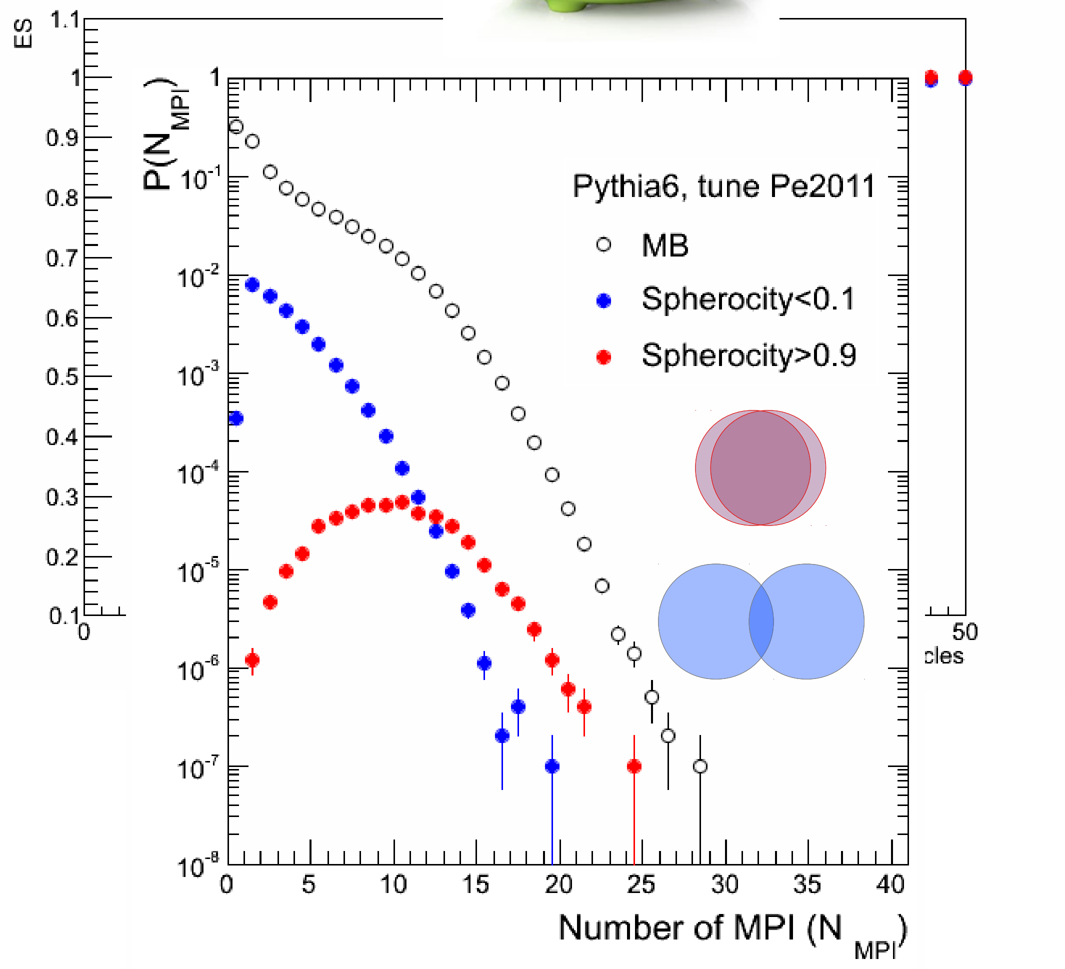
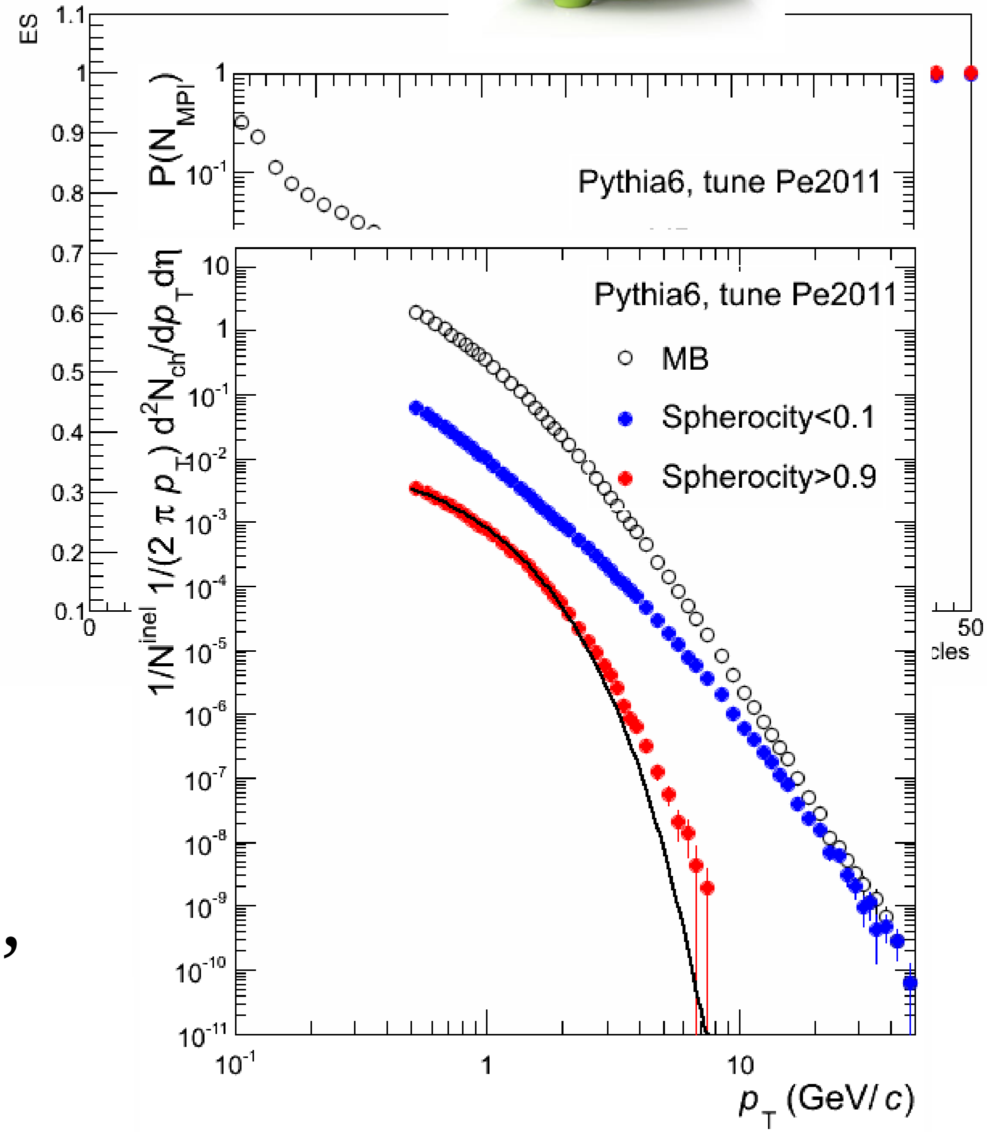


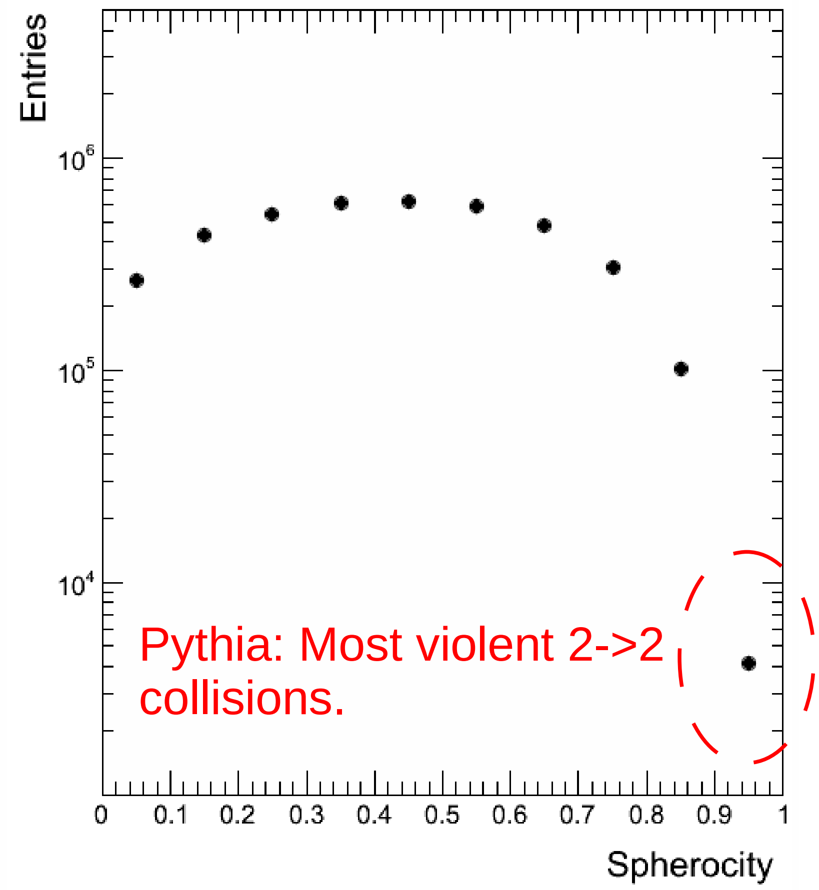
Conclusions

- Sphericity and spherocity exhibit different kind of sensitivities.
- In Pythia, high spherocity events have a very active MPI (central and high multiplicity events).
- Spherocity seems to be an excellent tool to split the sample in “soft” and “hard” (w/o an explicit cut on p_T).



Interesting studies which can be done in pp data

- What is the amount of events with high spherocity (MB ~0.04%, HardQCD ~0.006%).



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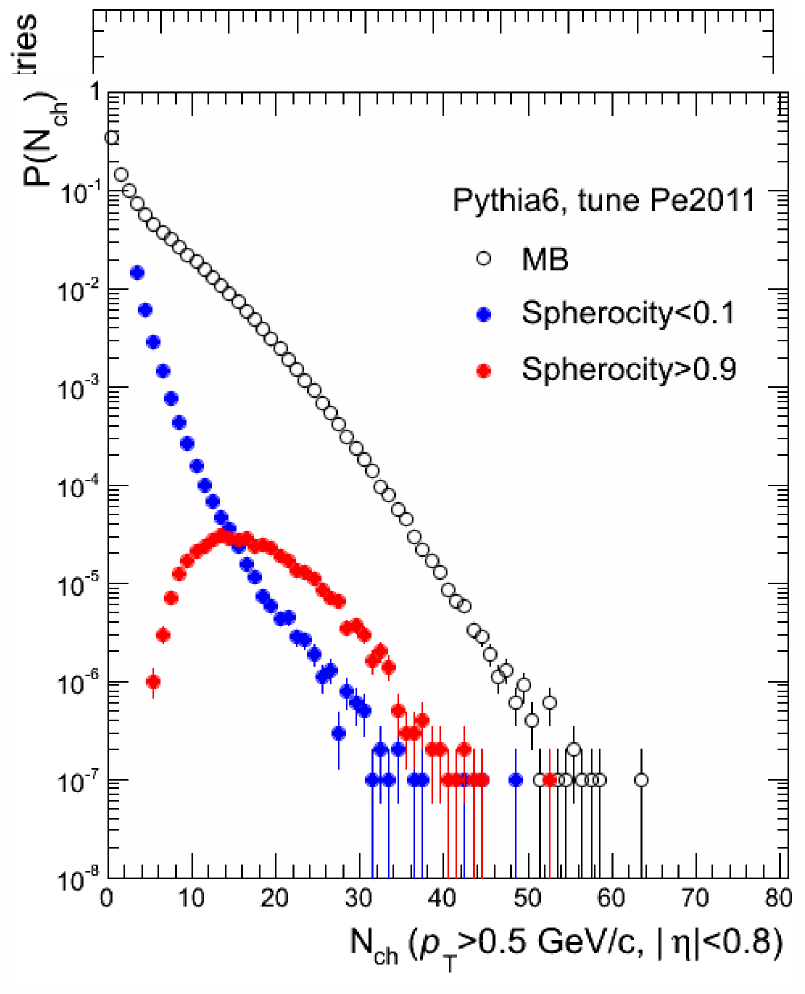
- Characterization of high spherocity events: transverse momentum distribution, multiplicity distribution, dependence with multiplicity.



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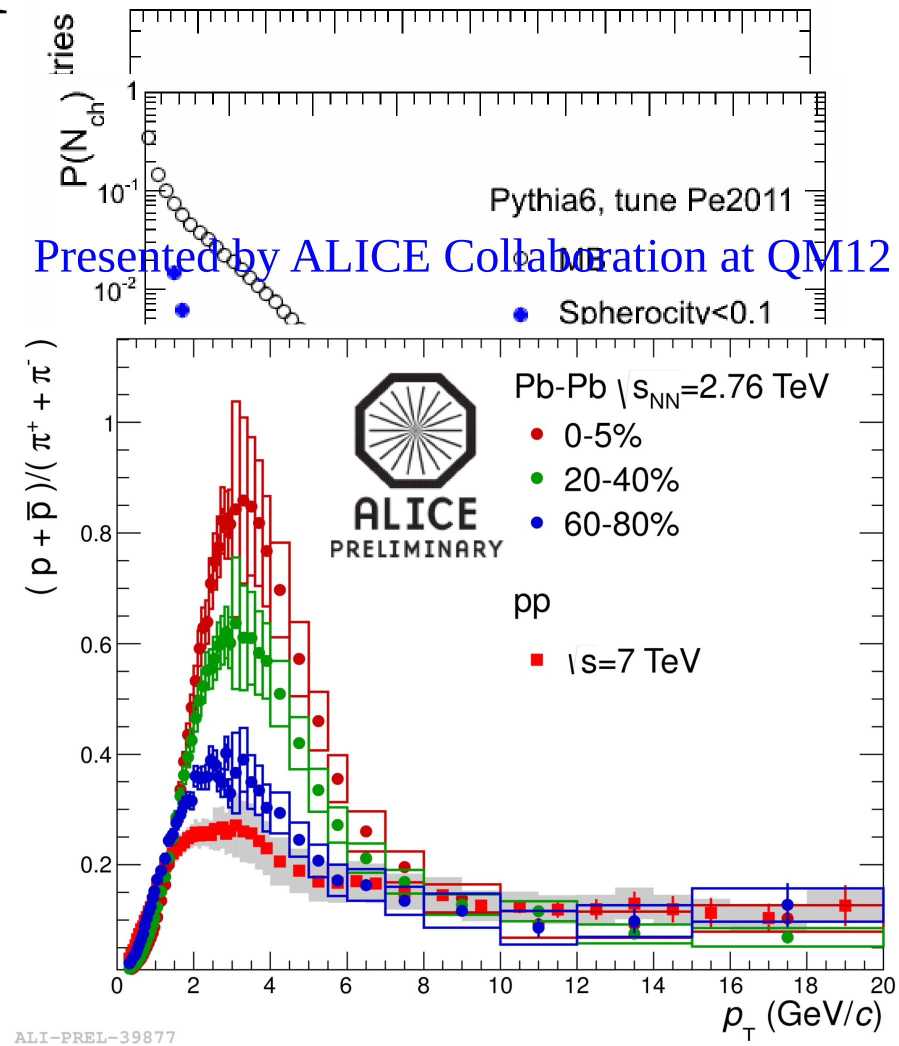
- What is the amount of events with high spherocity (MB ~0.04%, HardQCD ~0.006%).
- Characterization of high spherocity events: transverse momentum distribution, multiplicity distribution, dependence with multiplicity.
- Transverse momentum spectra for identified hadrons, particle ratios. From Pythia we know that high spherocity events contanin more pions than MB or jetty like. What do we expect in LHC data?
- ...



Presented by ALICE Collaboration at QM12