Event shapes and jets in e^+e^- and pp collisions

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M. Sas, J. Schoppink, Nuclear Physics A vol. 1011, July 2021.
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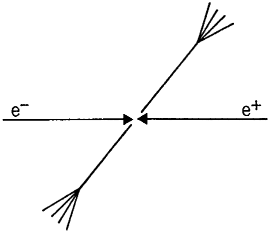
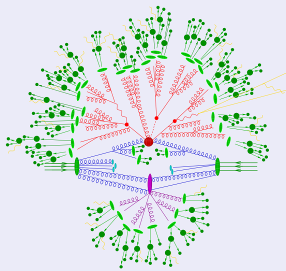
Properties of the collision systems



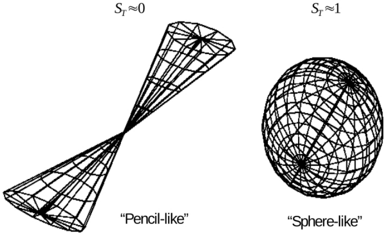


- Annihilation process: all of the center of mass energy is used
- Dominated by di-jet production

- Hard processes from partons with some momentum fraction of the proton
- Underlying event from multi-parton interactions (MPI)

Main question: What does the shape of the event tell us about the physics of the collision?
e^+e^- **collisions:** Can it discriminate between different jet topologies?
pp collisions: Can it discriminate between jet-like events and events that are dominated by soft production from the underlying event?

Transverse sphericity as the event shape observable



The transverse sphericity is calculated using

$$S_{\rm T} = \frac{2\lambda_2}{\lambda_2 + \lambda_1}, \quad (1)$$

where λ_1 and λ_2, with $\lambda_1 > \lambda_2$, are the two eigenvalues of the transverse momentum matrix.

Analysis steps:

- Generate simulation data
- Calculate the sphericity distributions
- Simultaneously run a jet-finder algorithm
- Investigate S_T as function of $N_{\rm jets}$
- Calculate the difference in the jet populations when selecting spherical vs pencil-like events

Jet finder settings (FastJet package):

- anti-k_T with $R = 0.4$ and $E_{\rm min} = 10$ GeV

System	$\sqrt{s}$	**PYTHIA8.1 settings**
e^+e^-	91 GeV	Z decay to quarks
pp	200 GeV	Monash tune, MPI-ON
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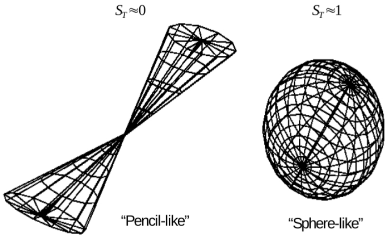

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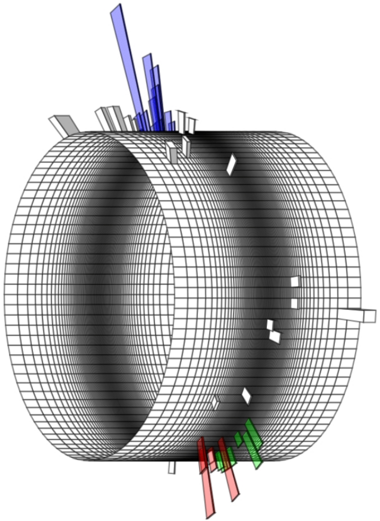
Example of a pencil-like pp event at 13 TeV



Transverse sphericity distributions

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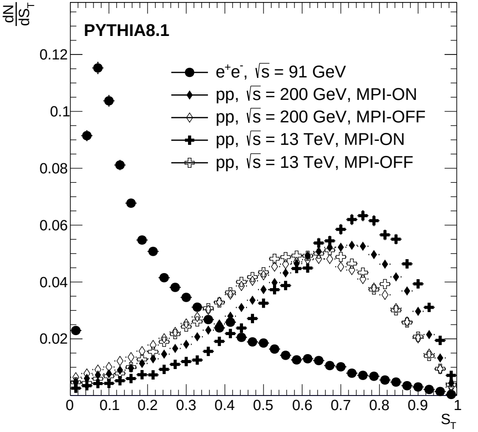

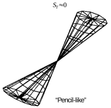

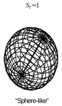

Observations:

- e^+e^- collisions much more pencil-like compared to pp collisions
- No large beam energy dependence in pp
- MPI increases $< S_T >$

Transverse sphericity distributions for different N_{jets}

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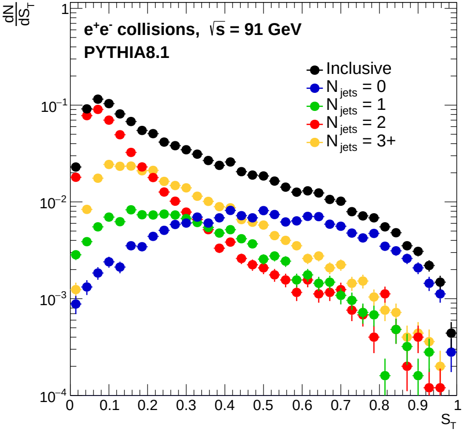

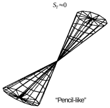

Observations in e^+e^- collisions:

- Low S_T dominated by di-jet production (in red)
- Possible to select certain jet topologies by selecting on S_T!

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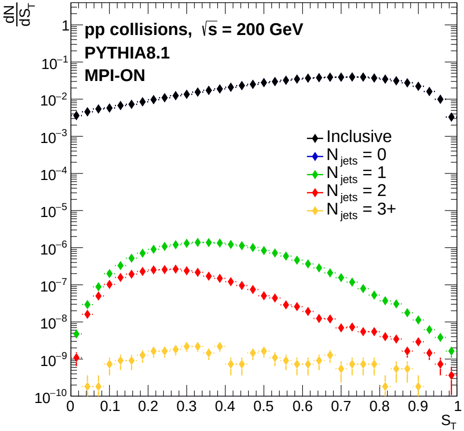
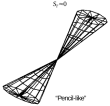
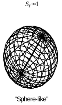
Observations in pp collisions:

- Inclusive distribution $\approx$ ($N_{\text{jets}} = 0$)
- In general many less jets per event
- Impossible to meaningfully enhance the jet population by selecting on S_T!
- Similar picture for the MPI-OFF case; $< S_T >$ reduced
- Same for higher beam energies; higher multiplicities increases S_T







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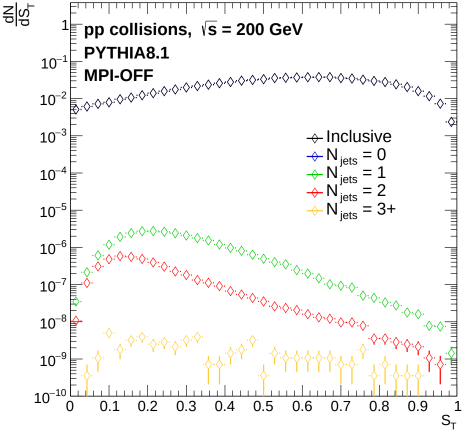

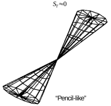

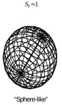

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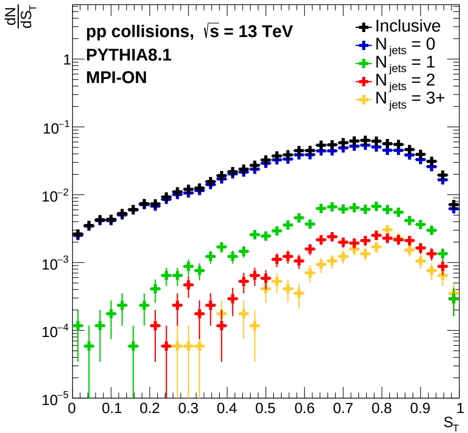

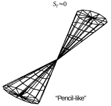

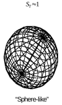

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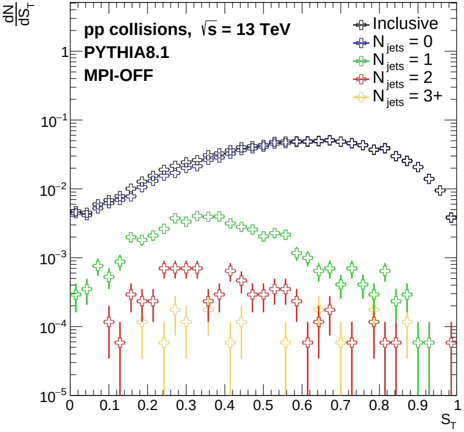

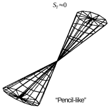

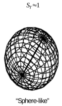

Transverse momentum of the leading parton

So what physics are we actually selecting when considering pencil- and spherical-like events?

What about the p_T of the leading parton..

- In e^+e^-, low S_T selects di-jets, peaking for $p_T \approx \sqrt{s}/2$
- In pp collisions (MPI-ON), $p_{T,\mathrm{leading\ parton}}$ **increases** for spherical events

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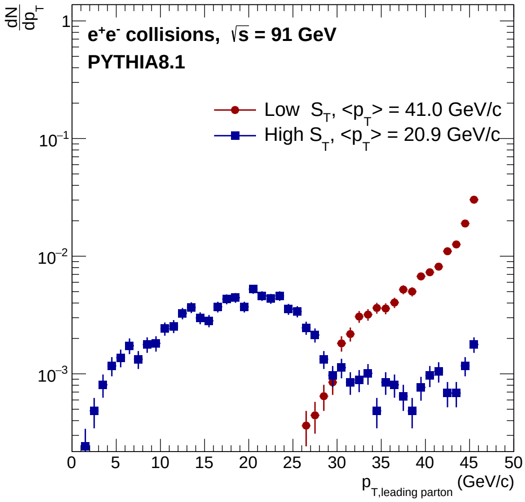

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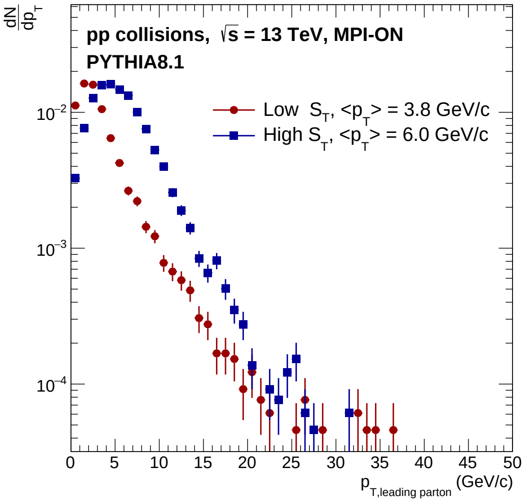

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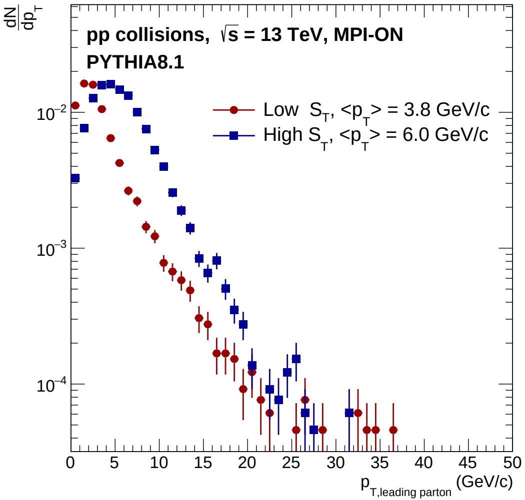
Should we consider spherical pp collisions as being more jetty than pencil-like events?

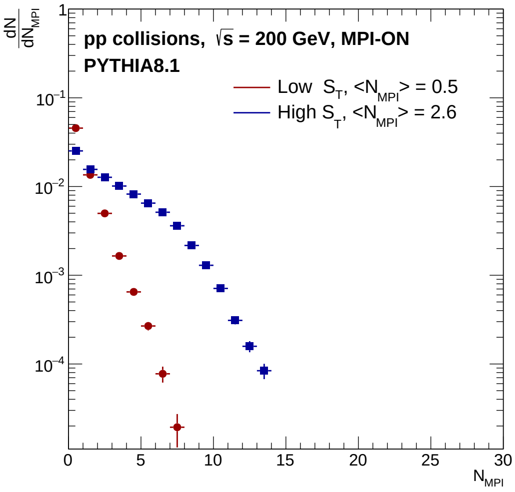


Multi-parton interactions

So what physics are we actually selecting when considering pencil- and spherical-like events?

What about the number of multi parton interactions (N_{MPI})**..**

- N_{MPI} peaks at $N_{\mathrm{MPI}} = 0$ for both sphericity selections
- Large increase in N_{MPI} for spherical collisions
- Selecting events with low and high particle multiplicity has even higher discriminating power in N_{MPI}



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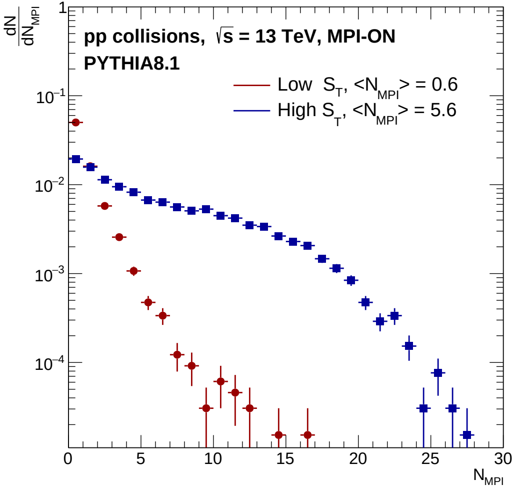

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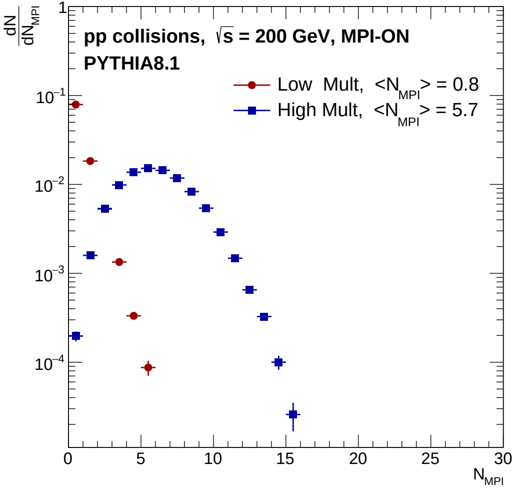

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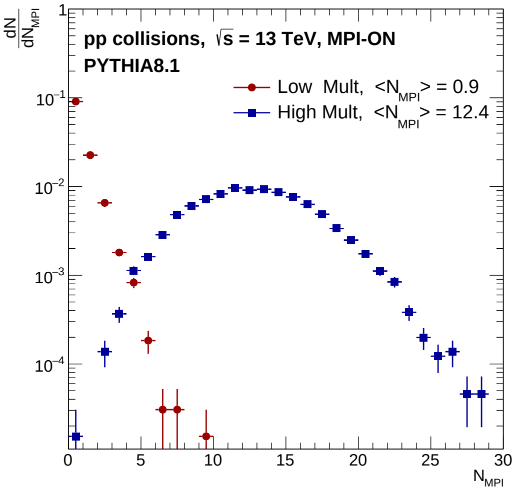

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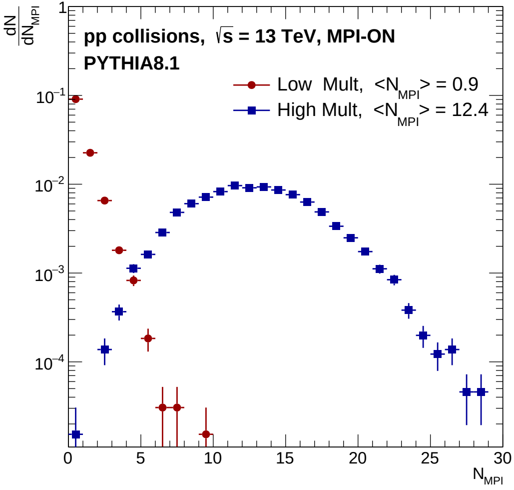
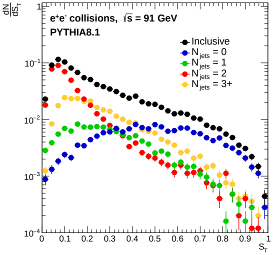
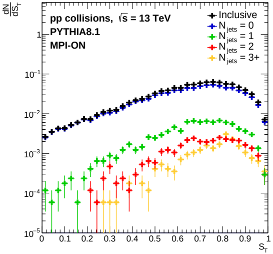


Putting this all together..

In this talk it was shown that S_T:

- Behaves as expected in e^+e^- collisions; it is able to discriminate between different final state topologies
- Is unable to meaningfully enhance jet-like topologies in pp collisions at both RHIC and LHC energies, contrary to what is usually stated in papers
- Spherical pp collisions, on average, contain higher momentum parton fragmentations
- High correlation in pp collisions with N_{MPI}, multiplicity correlates even better





Summary

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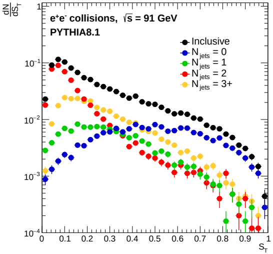
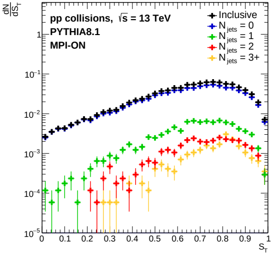


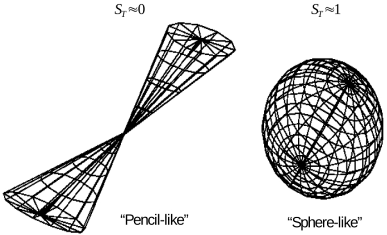


Thanks for your attention!

For more information:
M. Sas, J. Schoppink, Nuclear Physics A, July 2021.
`https://arxiv.org/abs/2101.12367`

Backup

Transverse sphericity as the event shape observable



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where λ_1 and λ_2, with $\lambda_1 > \lambda_2$, are the two eigenvalues of the transverse momentum matrix S_{xy}^L, which is given by

$$S_{xy}^L = \frac{1}{\sum_i p_{T,i}} \sum_i \frac{1}{p_{T,i}} \begin{bmatrix} p_{x,i}^2 & p_{x,i}p_{y,i} \\ p_{y,i}p_{x,i} & p_{y,i}^2 \end{bmatrix}, \tag{3}$$

where $p_{T,i}$, $p_{x,i}$, and $p_{y,i}$, are the components of the momentum vectors of particle i in transverse, x, and y direction, respectively.

Analysis steps:

- Generate simulation data
- Calculate the sphericity distributions in various datasets
- Simultaneously run a jet-finder algorithm
- Investigate how S_T behaves as function of N_{jets}
- Calculate how the jet populations change by selecting spherical and pencil-like events

Jet finder settings (FastJet package):

- anti-k_t with $R = 0.4$ and $E_{\mathrm{min}} = 10$ GeV

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Data Set	energy	MPI	$N_{\rm jets}$(%), All 0	1	2	3+	$N_{\rm jets}$(%), pencil-like 0	1	2	3+	$N_{\rm jets}$(%), sphere-like 0	1	2	3+
e^+e^-	91 GeV	—	16.1	11.8	44.9	27.2	1.9	5.9	83.8	8.4	58.8	11.0	10.4	19.8
pp	200 GeV	ON	$>$ 99.9	$<$ 0.01	$<$ 0.01	$<$ 0.01	$>$ 99.9	$<$ 0.01	$<$ 0.01	$<$ 0.01	$>$ 99.9	$<$ 0.01	$<$ 0.01	$<$ 0.01
pp	200 GeV	OFF	$>$ 99.9	$<$ 0.01	$<$ 0.01	$<$ 0.01	$>$ 99.9	0.02	$<$ 0.01	$<$ 0.01	$>$ 99.9	$<$ 0.01	$<$ 0.01	$<$ 0.01
pp	13 TeV	ON	85.5	9.2	3.2	2.1	93.1	5.5	1.3	0.2	83.9	8.7	4.4	3.0
pp	13 TeV	OFF	93.9	5.2	0.8	0.1	83.6	13.9	2.2	0.3	99.2	0.6	0.1	0.1

Reduced table:

Data Set	energy	MPI	$N_{\rm jets}$(%), All 0	1	2	3+	$N_{\rm jets}$(%), pencil-like 0	1	2	3+	$N_{\rm jets}$(%), sphere-like 0	1	2	3+
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pp	13 TeV	ON	85.5	9.2	3.2	2.1	93.1	5.5	1.3	0.2	83.9	8.7	4.4	3.0

Backup

The cross section of $\sigma_{h_1 h_2 \to a}$ represents the likelihood of colliding hadrons h_1 and h_2, and producing a particle a. Assuming that the scattering processes are independent from the fragmentation of the produced partons, the cross section is factorisable and can be calculated as:

$$\sigma_{h_1 h_2 \to a} = f_i^{h_1}(x_1, Q^2) f_j^{h_2}(x_2, Q^2) \otimes \sigma^{ij \to k}(x_1 p_1, x_2 p_2, Q^2) \otimes D_{k \to a}(z, Q^2), \quad (4)$$

where $f_i^{h_1}$ and $f_i^{h_2}$ are the parton distribution functions (PDFs) of the colliding particles, $\sigma^{ij \to k}$ the partonic cross sections., i.e. the chance that parton i and j produce the parton k, and $D_{k \to a}$ is the fragmentation function describing the production of particle a from parton k. The PDFs for protons and the PDFs for nuclei (nPDFs) give the average quark and gluon content of the nucleon (either free or bound in a nucleus), as function of the longitudinal momentum fraction x and momentum transfer Q^2.