Investigation of QCD Antenna inspired Variables

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Motivation

- Understanding of QCD is crucial in a hadron collider environment
- QCD is the most important background for new-physics searches in all-hadronic channel, for example for SUSY searches
- We tried to construct new variables inspired by theoretical knowledge about QCD matrix elements, in order to describe especially multijet QCD processes
- The hope is that these variables are uncorrelated to other kinematic variables

Spinor helicity formalism

- Introduce Weyl Spinors

right-handed: $(\lambda_i)_\alpha = u_+(k_i)$
$h = +1/2$

left-handed: $(\tilde{\lambda}_i)_{\dot\alpha} = u_-(k_i)$
$h = -1/2$

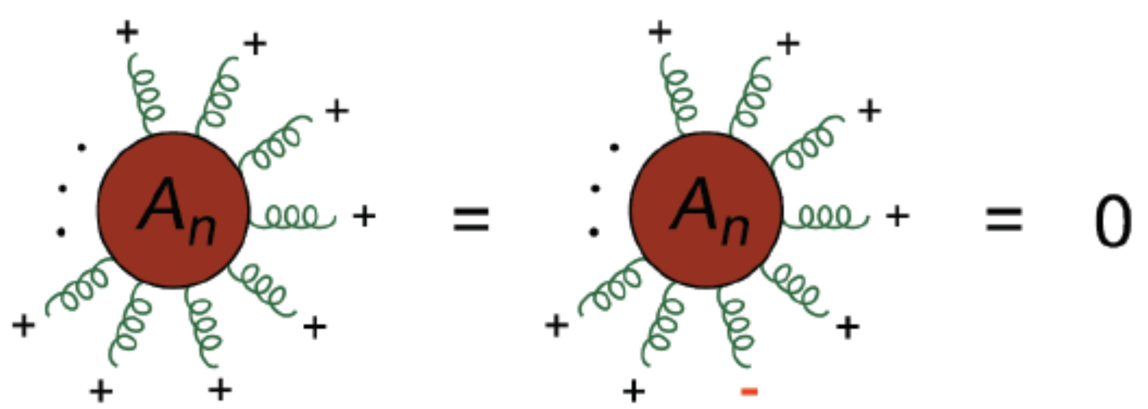
$$\varepsilon^{\alpha\beta}(\lambda_i)_\alpha(\lambda_j)_\beta = \langle i\, j\rangle$$
$$\varepsilon^{\dot\alpha\dot\beta}(\tilde\lambda_i)_{\dot\alpha}(\tilde\lambda_j)_{\dot\beta} = [i\, j]$$

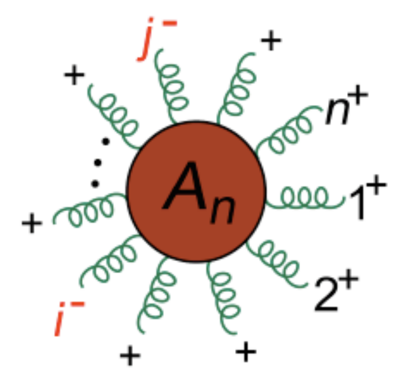
Always obey
$$\langle i\, j\rangle\, [j\, i] = s_{ij}$$

$$s_{ij} = 2(k_i \cdot k_j) = (k_i + k_j)^2$$ lightlike vectors

- Compute Helicity Amplitudes

Treat all particles as outgoing





$$= \frac{\langle i\, j\rangle^4}{\langle 1\,2\rangle\langle 2\,3\rangle\cdots\langle n\,1\rangle}$$

Notation:
$k_i \equiv i$

Parke-Taylor; Mangano, Parke, Xu; Berends, Giele (1986-1987)

Special Helicity Amplitudes

L. Dixon, *Unveiling Amplitudes*, Strings08

Approximation of tree-level QCD matrix elements

Assumptions of SPHEL

- Special helicity configurations are typical for all possible configurations. Only these amplitudes are calculated. All other non zero amplitudes are accounted for by introduction of a combinatorial factor
- Non leading order colour contribution is neglected

SPHEL in case of pure gluon scattering :

$$|\bar{\mathcal{M}}|^2 \propto \sum_{1\leq i\leq j\leq k} (i \cdot j)^4 \sum_{P(2\ldots k)} \frac{1}{(1\cdot 2)(2\cdot 3)\ldots(k\cdot 1)}$$

Notation:
$k_i \equiv i$

Full SPHEL approximation includes also terms for diagrams with up to 2 quark pairs

Pure gluon scattering:

$$|\bar{\mathcal{M}}|^2 \propto \sum_{1\leq i\leq j\leq k} (i\cdot j)^4 \sum_{P(2\ldots k)} \frac{1}{(1\cdot 2)(2\cdot 3)\ldots(k\cdot 1)}$$

All possible choices of two gluons with negative helicity

Permutations to get all terms, which contribute to different colour structures

incoming momenta

QCD Antenna Pattern

SPHEL overestimates the cross-section with respect to the exact result :
factor of 1.4 for 5 jets at $\sqrt{s}$ of 1.8 TeV (pure gluonic part)
However it reproduces correctly the shapes of the distributions

This approximation is meaningless in e.g. SUSY case : cascade decay of heavy particles !

Kuijf, *Multiparton Production at Hadron Colliders,* PhD Thesis, 1991

Construction of experimental observables out of measured Jets

Approximation:

- Ignore differences between pure gluon, and gluon-quark events
- Use measured momenta of Jets, reconstructed with a specific Jet algorithm
- Approximate momenta of incoming partons

$$1^m \equiv k_1 = \frac{\sqrt{s}}{2}(x_1, 0, 0, x_1)$$

$$2^m \equiv k_2 = \frac{\sqrt{s}}{2}(x_2, 0, 0, -x_2)$$

$$x_1 = \frac{1}{\sqrt{s}} \sum_i m_i^T (e^{y_i})$$

$$x_2 = \frac{1}{\sqrt{s}} \sum_i m_i^T (e^{-y_i})$$

$$m_i^T = \sqrt{m_i^2 + p_i^{T2}}$$

Hope: QCD sensitivity of these variables due to different event structures of QCD and e.g. SUSY

Antenna variables

- Straightforward example: Antenna nJet* Variable
  - Examine events with exactly n Jets (defined with the Kt algorithm (R=0.4))
  - Use all these jets to compute Antenna variable

$$A_{n*} \quad \propto \quad \log_{10}\left(\sum_{1\le i\le j\le (n+2)} (i^m \cdot j^m)^4 \sum_{P(2\ldots n)} \frac{1}{(1^m \cdot 2^m)(2^m \cdot 3^m)\ldots((n+2)^m \cdot 1^m)} \times GeV^{2*(n-2)}\right)$$

Complicacy: Not enough statistics in each nJet bin

- Simplest example: Antenna 3jet Variable
  - Examine all events with at least 3 jets
  - Use 3 leading jets to compute Antenna variable

$$A_3 \propto \log_{10}\left(\sum_{1\le i\le j\le 5} (i^m \cdot j^m)^4 \sum_{P(2\ldots 5)} \frac{1}{(1^m \cdot 2^m)(2^m \cdot 3^m)\ldots(5^m \cdot 1^m)} \times GeV^2\right)$$

3 jets may do not describe properly QCD multijet structure

Antenna variables

- **Antenna 3plus Variable**
  - Examine all events with at least 3 jets
  - Use 2 leading jets and a vector sum of all additional jets to compute Antenna variable

$$A_{3plus} \propto \log_{10}\left(\sum_{1\leq i\leq j\leq 5}(i^m\cdot j^m)^4 \sum_{P(2\ldots 5)} \frac{1}{(1^m\cdot 2^m)(2^m\cdot 3^m)\ldots(5^m\cdot 1^m)} \times GeV^2\right)$$

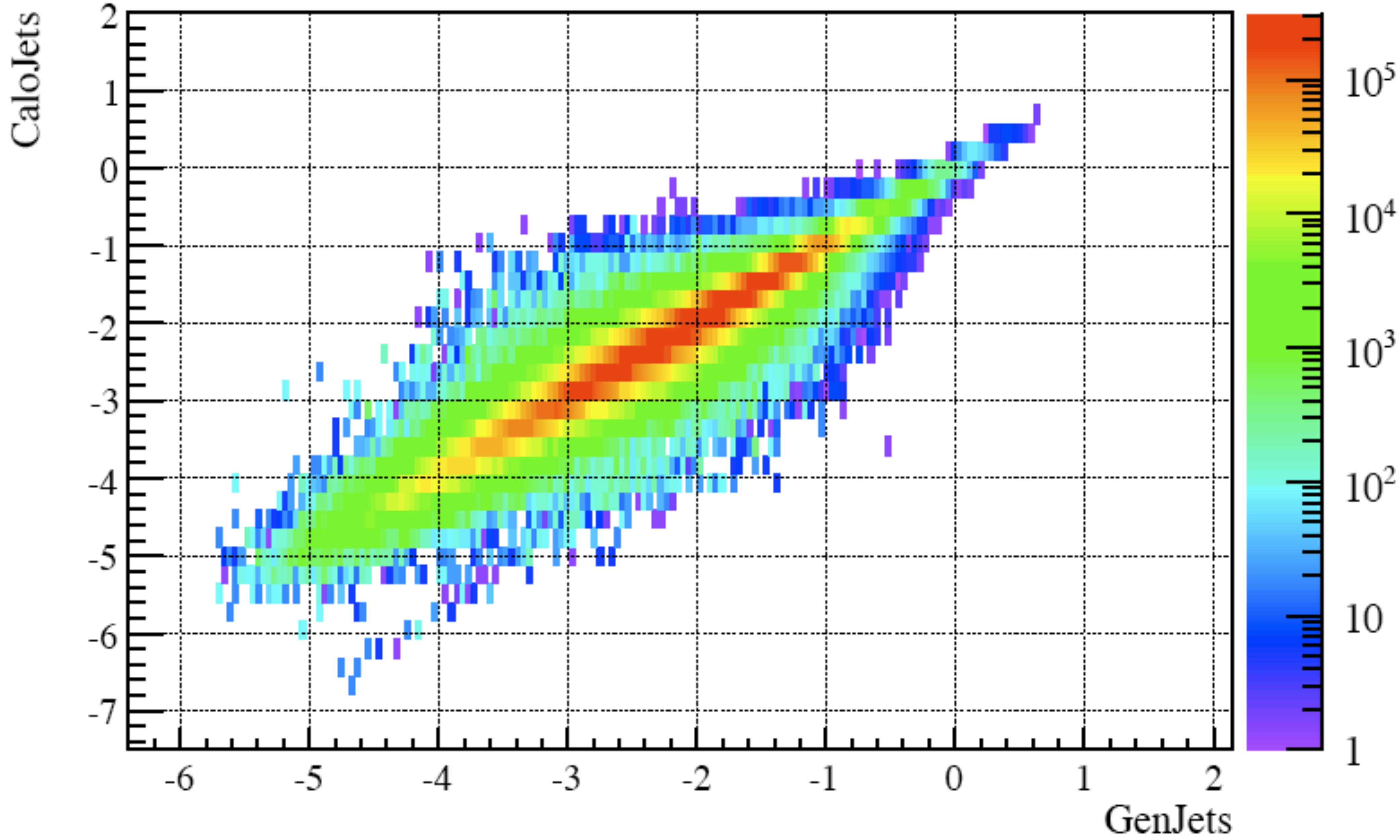
$$3^m = \sum_{k_i=3}^{n} k_i, \quad \text{n - total number of jets}$$

- **Antenna 6jet Variable**
  - Examine all events with at least 6 jets
  - Use 6 leading jets to compute Antenna variable

$$A_6 \propto \log_{10}\left(\sum_{1\leq i\leq j\leq 8}(i^m\cdot j^m)^4 \sum_{P(2\ldots n)} \frac{1}{(1^m\cdot 2^m)(2^m\cdot 3^m)\ldots(8^m\cdot 1^m)} \times GeV^8\right)$$

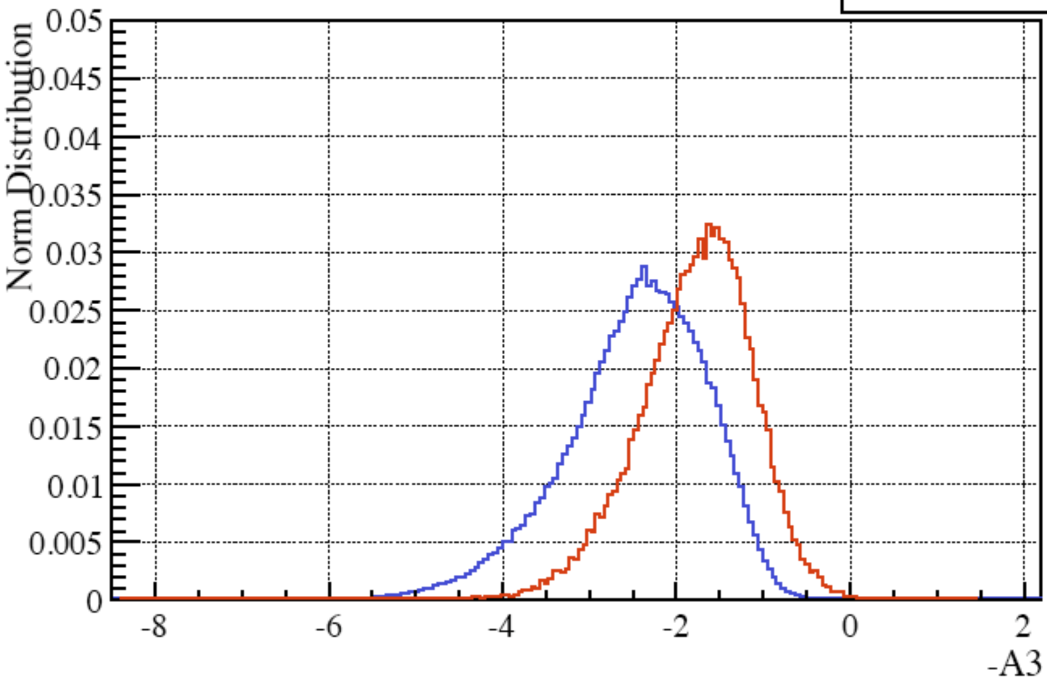
Example: Antenna 3jet

Transition from Generator to Detector jets

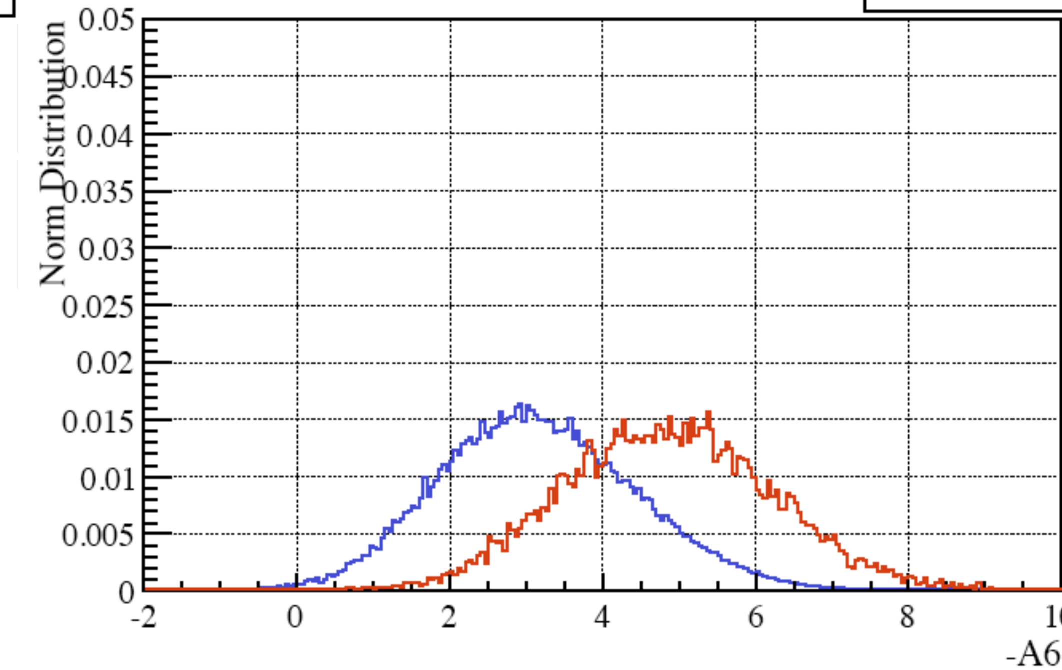


Antenna variables in QCD and SUSY(LM1) case

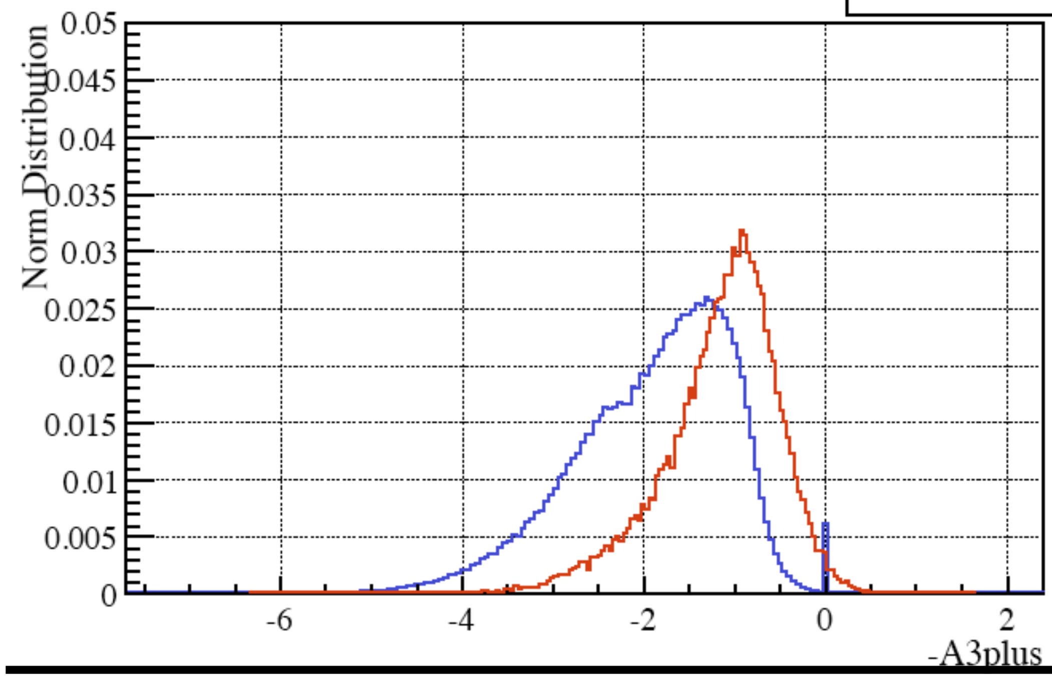
Antenna 3jet



Antenna 6jet



Antenna 3plus



Cuts:

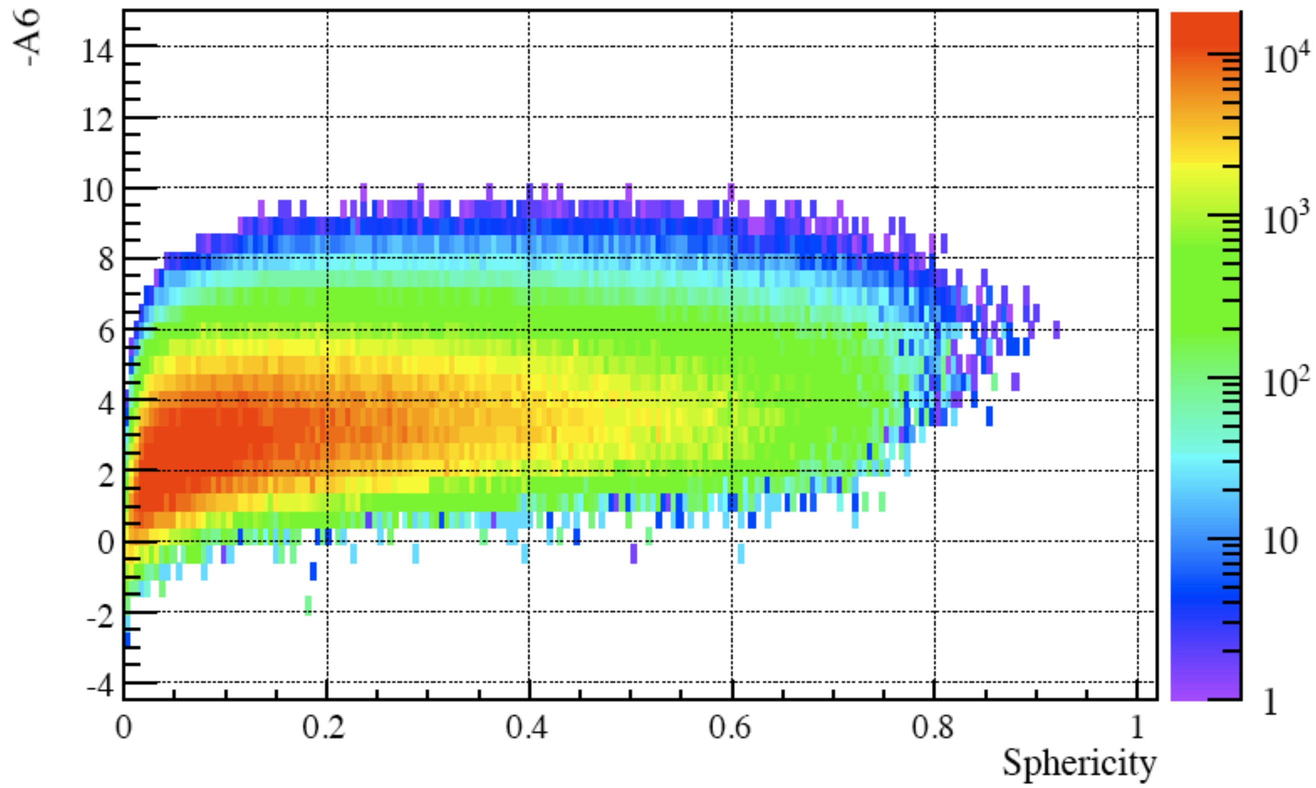
- Lepton veto
- At least 3 or 6 jets respectively
- 1st jet: Et > 200 GeV, |η| < 1.5
  2nd jet: Et > 150 GeV, |η| < 3.0
  3rd jet: Et > 20 GeV, |η| < 3.0
  ...
  (6. jet: Et > 20 GeV, |η| < 3.0)

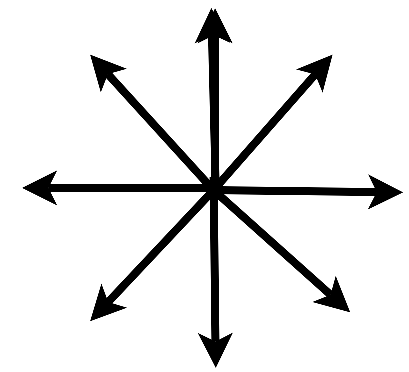
Antenna variables in QCD and SUSY(LM1) case

Variables deliver a guess for the matrix element of a given measured event, assuming this event was pure QCD.

True QCD events lie in different range of this variables in comparison with events having other structure (e.g. decay of heavy particles).

Antenna 6jet vs. EventShape variables (QCD)



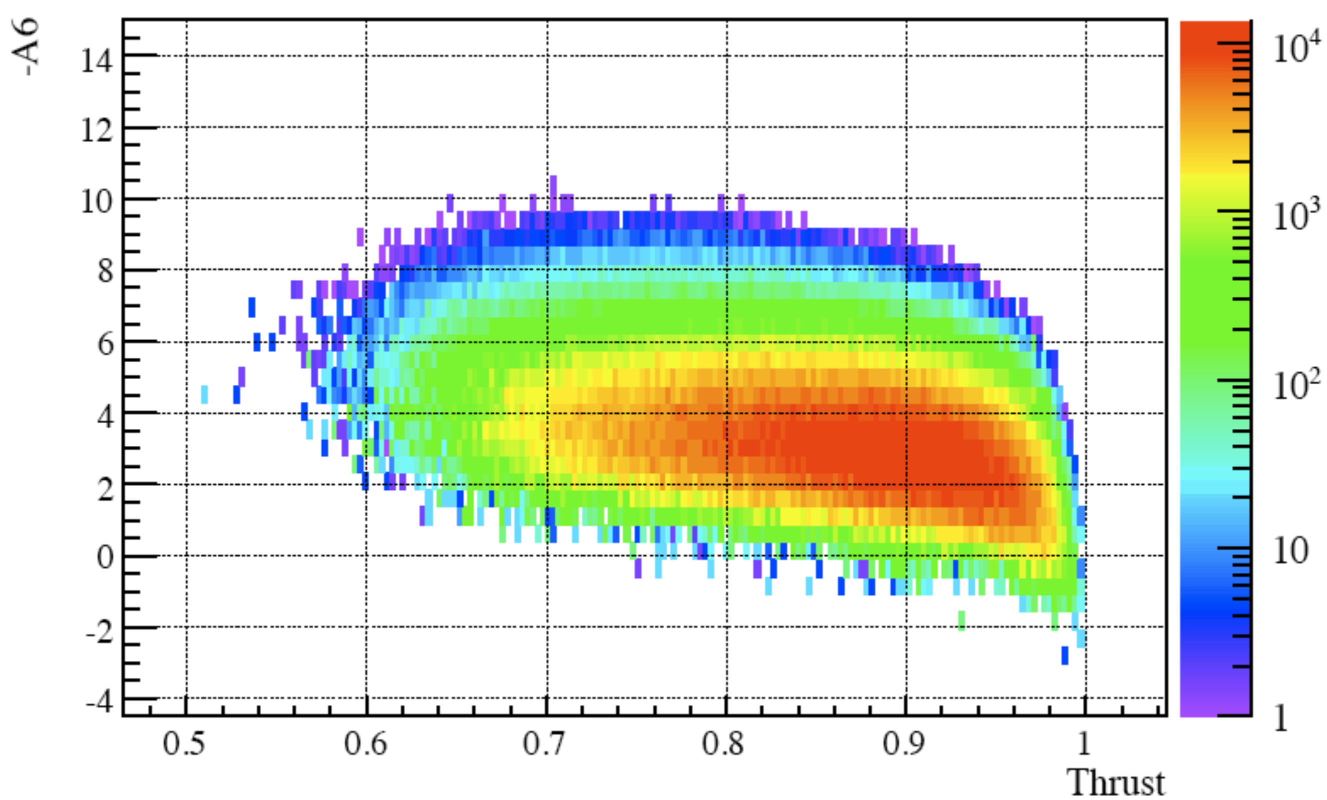


Spherical Event

S = 1
T = 1/2

Pencil-like event

S = 0
T = 1



The variables are sensitive to the shapes of the events, which are in general different in pure QCD and e.g. SUSY case

Antenna variables are uncorrelated with Thrust and Sphericity over wide range of the spectrum -
new EventShape variables

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Application: QCD background reduction

Signal : SUSY (LM1)

Cuts:

- Lepton veto
- At least 3 or 6 jets respectively
- 1st jet: Et > 200 GeV, |η| < 1.7
  2nd jet: Et > 150 GeV, |η| < 3.0
  3rd jet: Et > 20 GeV, |η| < 3.0
  ...
  (6. jet: Et > 20 GeV, |η| < 3.0)
- HT > 800 GeV

Comparison variables

$$S^* = \frac{S}{\sqrt{B}}; \quad A = \frac{S}{B}$$

$$S^*_a = S^*_{ant.cut}; \quad A_a = A_{ant.cut}$$

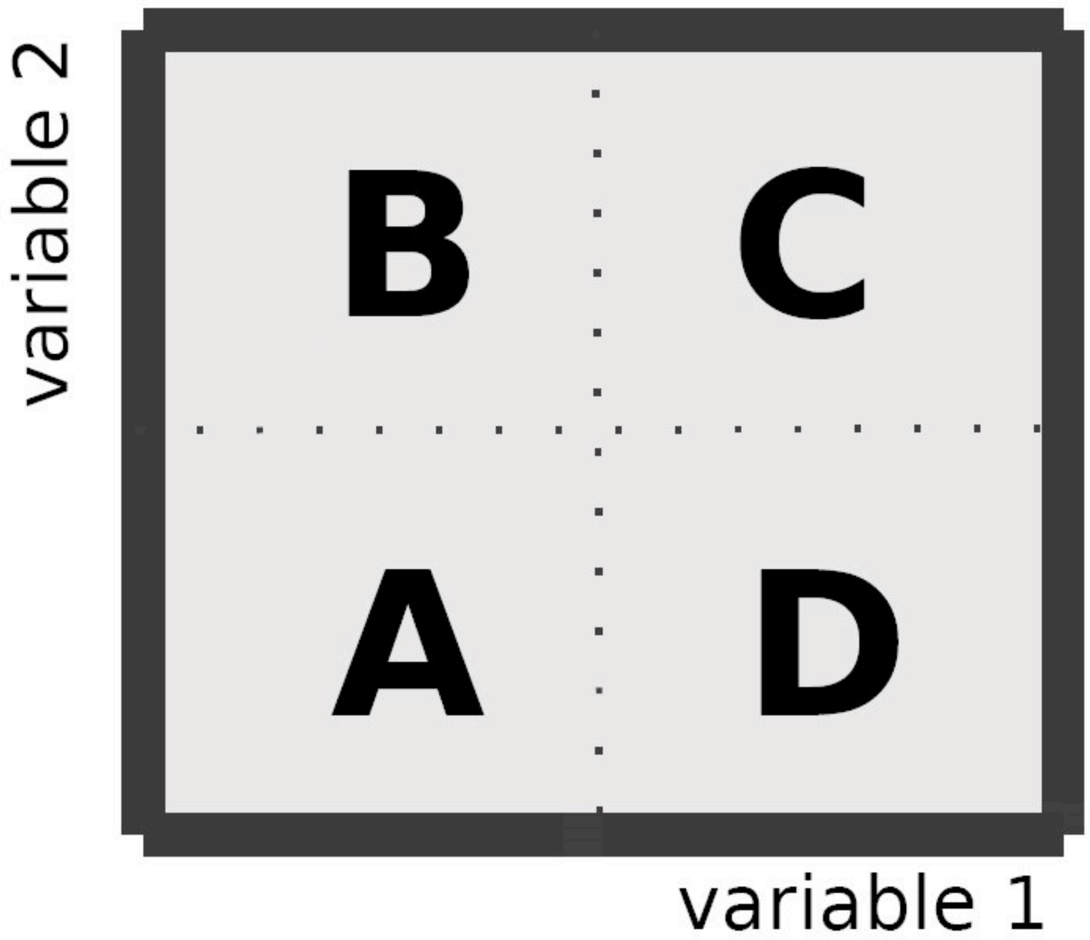
$$Q = \frac{S^*_a}{S^*}; \quad R = \frac{A_a}{A}$$

	A3	A3plus	A6
Cut value	-1	-0.5	5
R	2.79	3.86	3.07
Q	0.65	0.86	1.28

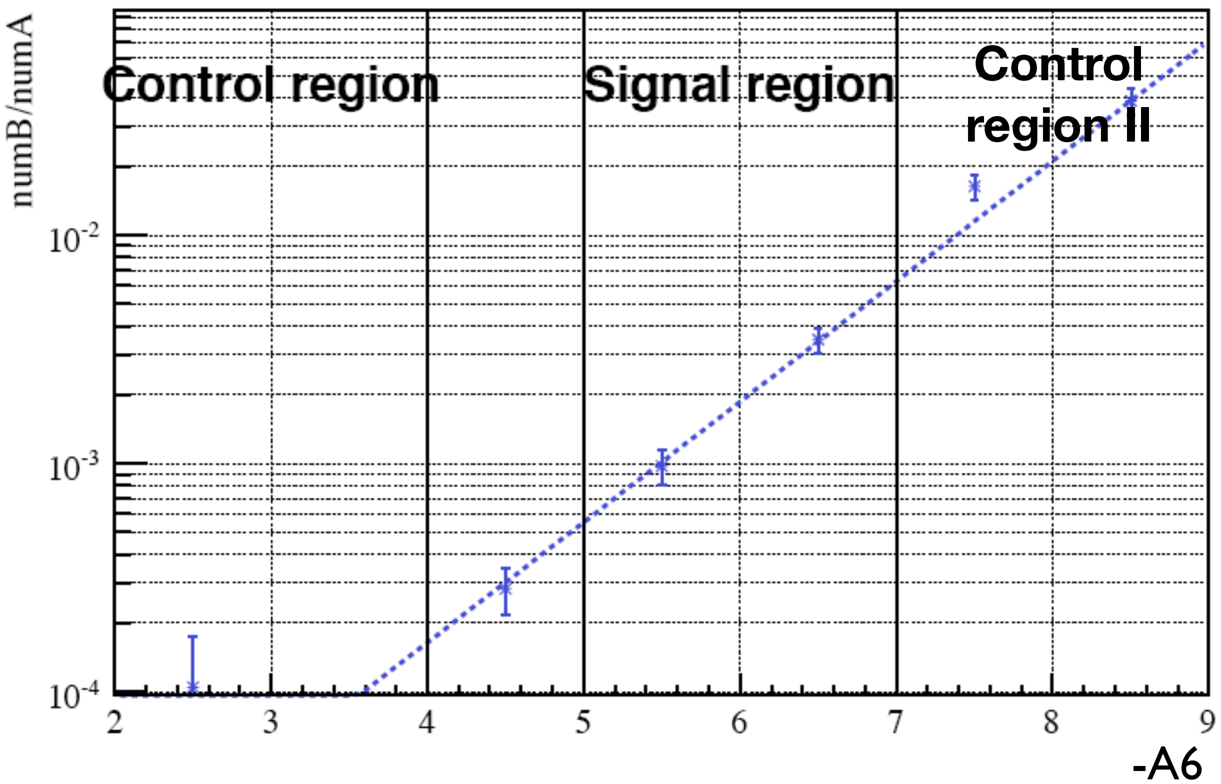
ABCD Method

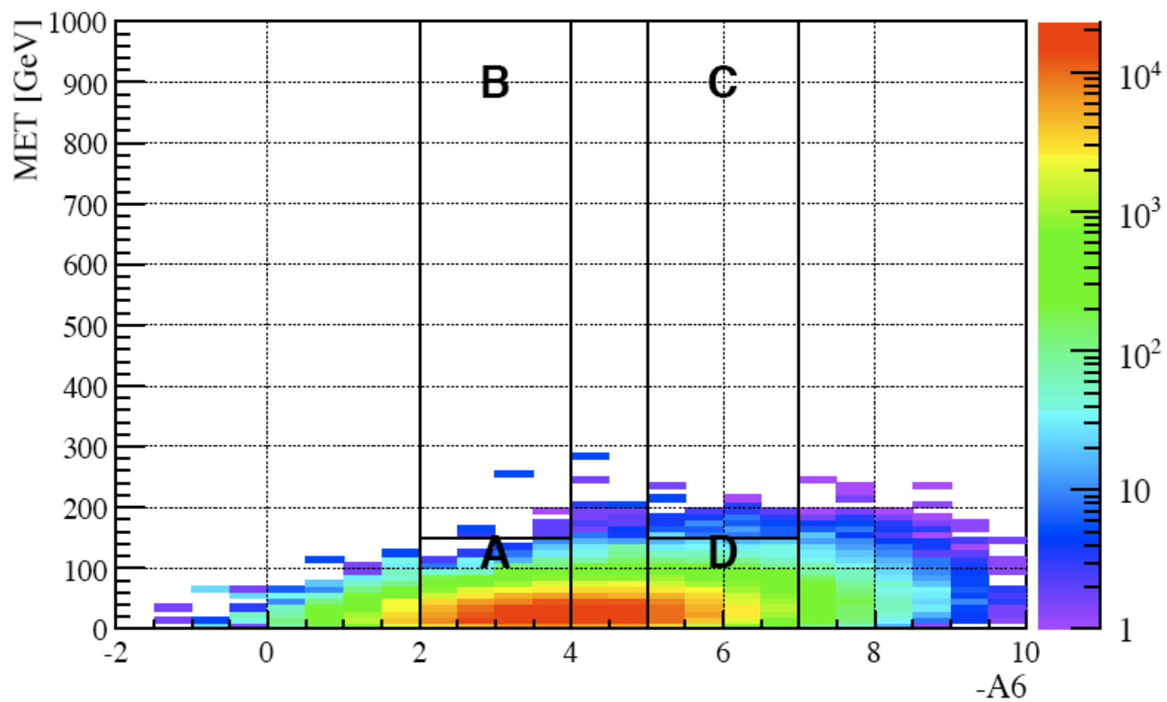
- ABCD uses two uncorrelated variables with separation power to define background (A, B, D) and signal (C) regions.

- We can estimate the number of QCD events in the signal region with: $\boxed{\frac{N_B}{N_A} = \frac{N_C}{N_D}}$



Application: QCD background estimation





Variables:

- A6
- Missing transverse Energy (MET)

Correlation with MET

Correlation is expected, since there is a correlation between jet energy and MET as well as between Antenna variables and jet energy

SOLUTION:

Advanced Background Estimation method, which interpolates a fit function from two control regions into the signal region

True QCD	Estimated QCD	Deviation
152	147	-4%

Conclusions

- In this approach we tried to construct new variables by exploiting our knowledge about QCD processes
- It is possible to construct such variables, and they show different behaviour for pure multijet QCD and other processes as desired
- These variables are interconnected with shapes of the events
- Detailed investigations on the dependence of this variables on different Monte Carlo schemes and on correlations with other kinematic variables are ongoing
- Data-driven QCD background estimation can make use of this new variables, that allow interpolation

Acknowledgements

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