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IFIC (CSIC/UVEG) - Valencia, Spain
M. Boronat, J. Fuster, I. García,
E. Ros, M. Vos
(Ignacio.Garcia@ific.uv.es)

A new jet reconstruction algorithm for e^+e^- colliders

In experiments at future lepton colliders at the energy frontier (ILC, CLIC, TLEP) high-performance reconstruction of jets is crucial to the precision measurements of the Higgs boson and top quark physics. In full-simulation studies of the ILC and CLIC detector concepts, the non-negligible level of $\gamma\gamma \rightarrow hadrons$ background has been found to degrade the performance of classical e^+e^- algorithms. We present a sequential recombination algorithm and show that its performance in several benchmark channels is much more robust under the expected background levels at the ILC and CLIC. The algorithm achieves similar or better performance than the longitudinally invariant k_t algorithm, while maintaining the natural distance criterion for lepton colliders.

A brief history of sequential recombination algorithms

JADE 1980s	Durham or e^+e^- k_t algorithm (LEP and SLC)	Cambridge-Aachen (n=0) Long. invariant k_t (n=1) Anti-k_t (LHC default) (n=-1)	Generalised e^+e^- k_t algorithm
$y_{ij} = \frac{E_i^2, E_j^2}{Q^2}(1-\cos\theta_{ij})$	$d_{ij} = 2min(E_i^2, E_j^2)(1-\cos\theta_{ij})$	$d_{ij} = min(p_{Ti}^{2n}, p_{Tj}^{2n})\Delta R_{ij}^{2n}/R^{2n}$ $d_{iB} = p_{Ti}^{2n}$	$d_{ij} = min(E_i^2, E_j^2)\frac{(1-\cos\theta_{ij})}{(1-\cos R)}$ $d_{iB} = E_i^2$
First jet algorithm	e^+e^- data at Z-pole	Hadron colliders	e^+e^- algorithms

Boost invariance and background levels at lepton colliders

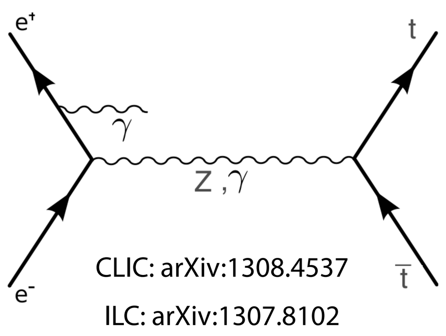
Initial State Radiation (ISR) can carry away significant fractions of the nominal c-o.m energy

However at future lepton colliders **ISR** leads to **a minor boost**

The basis [E,θ] is the most natural choice

LEP or **SLC presented effectively negligible background**

At **CLIC and ILC,** the $\gamma\gamma \rightarrow hadrons$ has **strong** impact on jet reconstruction performance



CLIC: arXiv:1308.4537
ILC: arXiv:1307.8102

The Valencia jet algorithm

Valencia jet algorithm combines the good features of lepton collider algorithms
Durham-like distance criterion

$$d_{ij} = min(E_i^{2\beta}, E_j^{2\beta})(1-\cos\theta_{ij})/R^2$$

with the **robustness against background of** the longitudinally invariant k_t **algorithm**

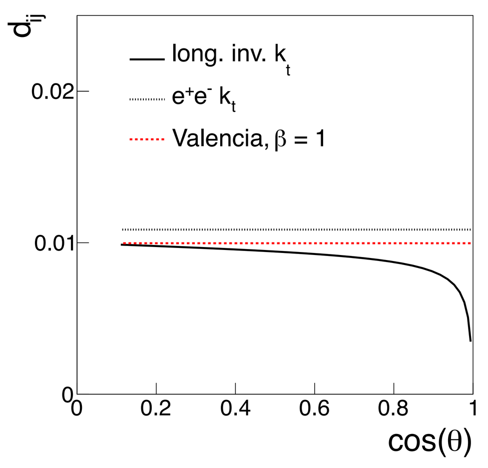
$$d_{iB} = p_T^{2\beta}$$

β allows to ***tune* the background rejection** level

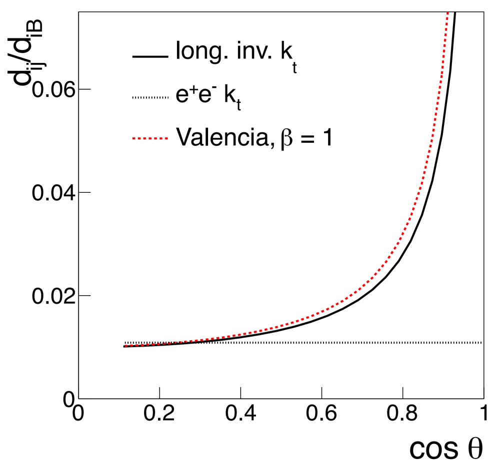
The algorithm has been implemented as a **plugin for the *FastJet*** package

https://fastjet.hepforge.org/trac/browser/contrib/contribs/ValenciaJetAlgorithm

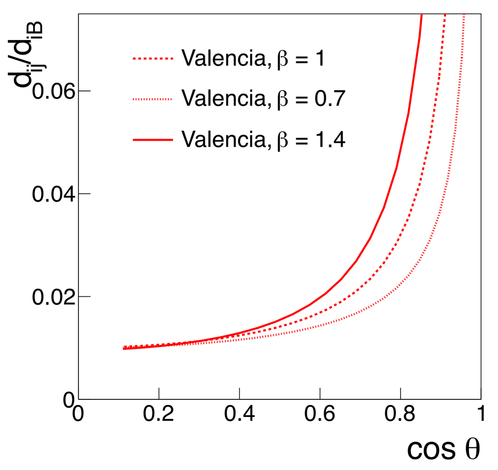
Comparison of the distance criteria



Inter-particle distance of popular jet algorithms versus polar angle of a two-particle system with constant energy and opening angle

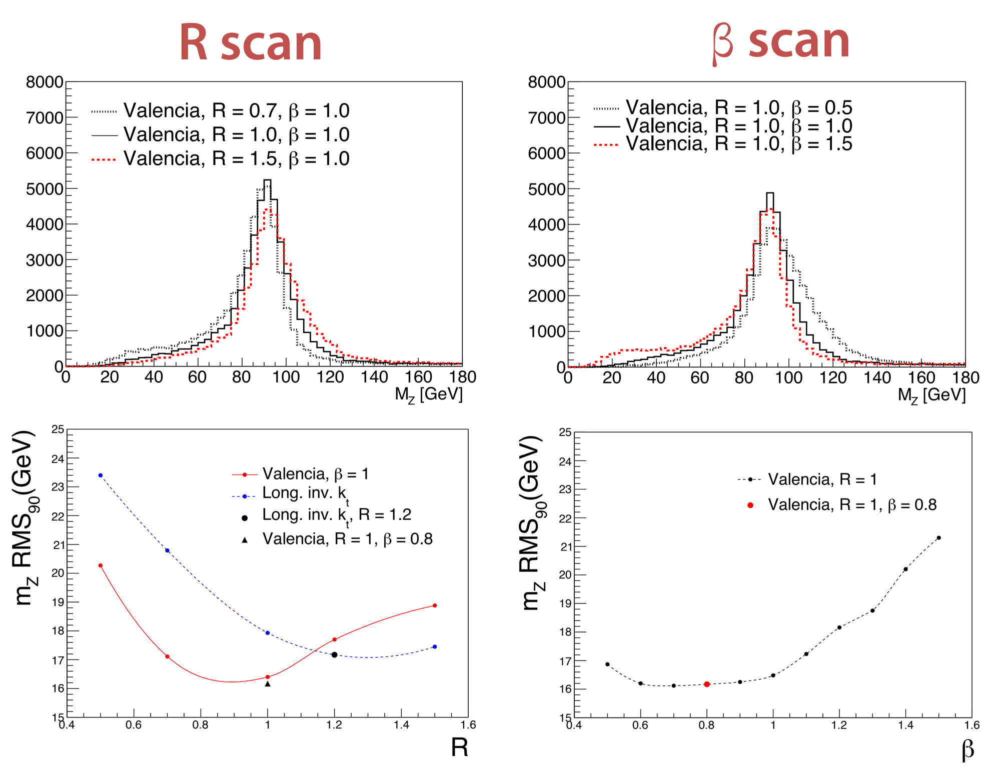


The ratio of the inter-particle distance and the beam distance (d_{ij}/d_{iB})



The extra parameter β in the Valencia algorithm controls the background rejection in the forward region

Algorithm parameters optimisation: R & β scan



The choice of parameters corresponds to the optimal setting determined in a scan over a broad range of parameters.

Criterion of selection is based on the RMS$_{90}$ and the mean value of M_Z distribution

Jet reconstruction performance

$e^+e^- \rightarrow t\bar{t}$ ILC @ 500 GeV

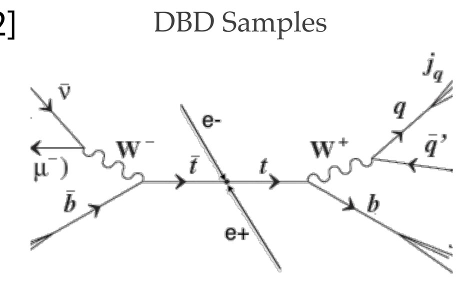
IFIC/LAL study of ILC lepton+jets $t\bar{t}$ @ 500 GeV, [arXiv:1307.8102]

Event Generation *Whizard 1.95*

Reconstruct Particle Flow objects using PANDORA

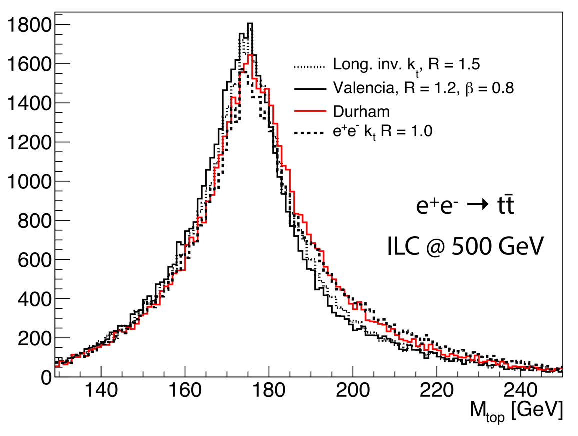
Reconstruct jets (exclusive, n=4)

DBD Samples



The signal is reconstructed by choosing the combination of *b* quark jet and W boson that minimises the following equation

$$d^2 = \left(\frac{m_{cand.} - m_t}{\sigma_{m_t}}\right)^2 + \left(\frac{E_{cand.} - E_{beam}}{\sigma_{E_{cand.}}}\right)^2 + \left(\frac{p_b^* - 68}{\sigma_{p_b^*}}\right)^2 + \left(\frac{cos\theta_{bW} - 0.23}{\sigma_{cos\theta_{bW}}}\right)^2$$



RMS$_{90}$ [GeV]	E_{4j}	E_W	m_W	E_t	m_t
Durham	23.2	19.6	20.3	19.5	21.4
e^+e^- k_t	25.6	20.8	21.6	20.5	22.8
long. inv. k_t	21.7	18.4	18.9	18.4	20.1
Valencia	21.4	18.0	18.8	18.2	20.0

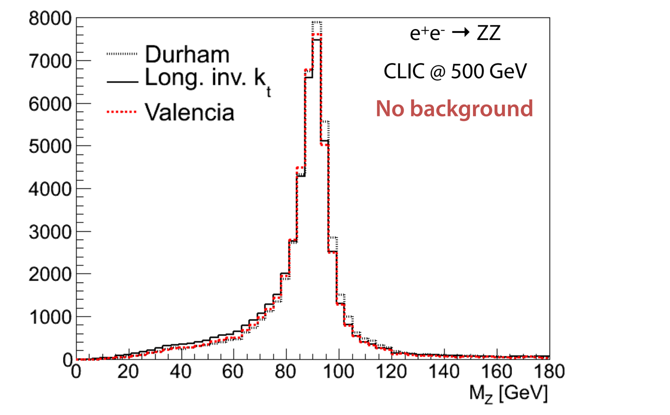
Durham is affected by $\gamma\gamma \rightarrow hadrons$, longitudinally invariant k_t and Valencia OK

$e^+e^- \rightarrow ZZ$ CLIC @ 500 GeV

CLIC di-boson (ZZ) production @ 500 GeV — + 300 BX of $\gamma\gamma \rightarrow$ hadrons

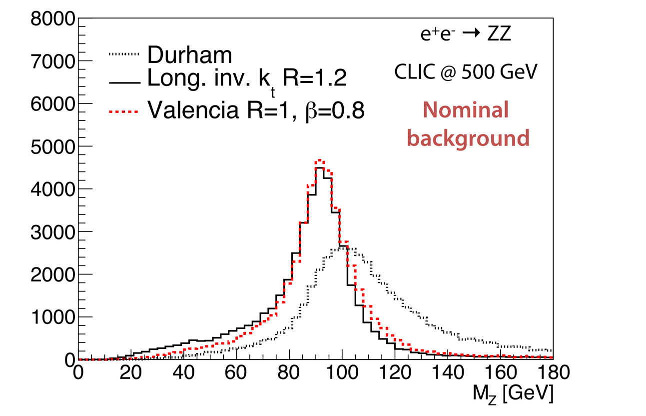
Reconstruct Particle Flow objects using PANDORA — + quality and timing cuts

Reconstruct jets (exclusive, n=4) and form Z boson candidates, selecting best jet pairs



$\sqrt{s}$ = 500 GeV, no background overlay			
[GeV]	m_Z	σ_Z	RMS$_{90}$
Durham	90.6	5.4	13.8
long. inv. k_t	90.4	5.3	14.3
Valencia	90.3	5.2	12.5

If no background is included, all algorithms have similar performance



$\sqrt{s}$ = 500 GeV, 0.3 $\gamma\gamma \rightarrow hadrons$ events/BX			
[GeV]	m_Z	σ_Z	RMS$_{90}$
Durham	101.1	13.6	28.8
long. inv. k_t	92.0	9.0	17.2
Valencia	92.5	9.2	16.2

Durham is severely affected, longitudinally invariant k_t and Valencia are robust

Conclusions

Reconstructed jets with classical **e^+e^- algorithms** are severally **degraded** by the $\gamma\gamma \rightarrow hadrons$ **background. A new sequential recombination algorithm - the Valencia algorithm** - offers **robust performance** in the presence of the $\gamma\gamma \rightarrow hadrons$ background levels expected at lepton colliders

The ***β*** parameter allows **tuning the background rejection** and **R defines the jet size.** So the Valencia jet algorithm can work in several benchmark analyses (Higgs, top quark, ZZ …) in the different lepton colliders (ILC, CLIC)

A new jet reconstruction algorithm for lepton colliders, *Boronat, Garcia, Vos*, arXiv:1404.4294