Tuning Pythia8 for future e^+e^- colliders

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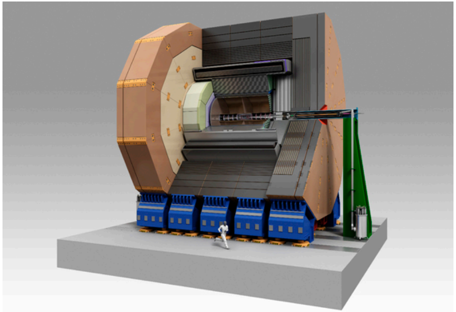
Overview

- Introduction
- Average Hadron Multiplicities
- ILD Simulation and Jet Energy Resolution (JER)
- Summary

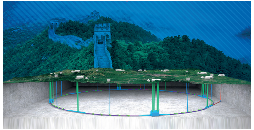


International Large Detector (ILD)

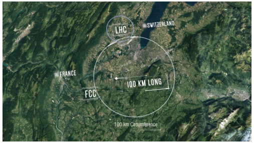
Introduction: Higgs Factories

Proposed future colliders:

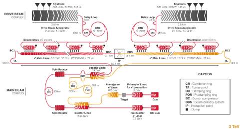
ILC



CEPC



FCC-ee



CLIC

- All of them are e^+e^- colliders.
- They are designed as Higgs factories for high precision physics.
- Features of lepton beams: initial state radiation (ISR), polarization, Beam-strahlung...

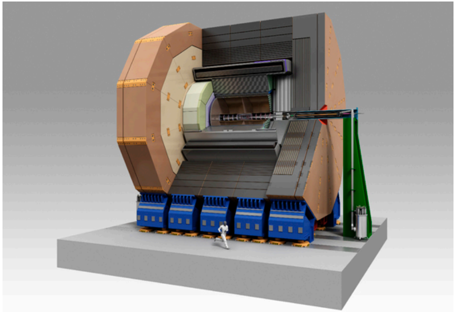
$\rightarrow$ Monte-Carlo events generator Whizard [W. Kilian *et al.*, 2007]

Introduction: Detector Concept for Higgs Factories

What is ILD?

- It is designed for e^+e^- collisions between 90 GeV and 1 TeV.
- It is optimized for particle flow algorithm (PFA).
- PFA aims at reconstructing every individual particle created in the event, i.e.:
  - Charged particles
  - Photons
  - Neutral hadrons (has large energy resolution)

$\rightarrow$ Depends on the tuning of parameters in the MC simulation chain.



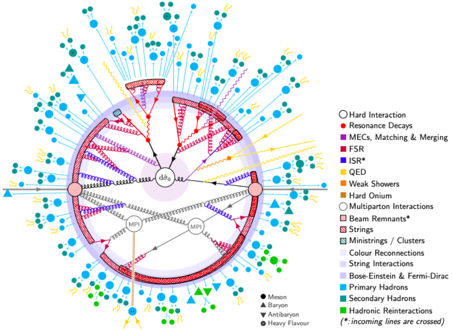
International Large Detector (ILD)

Introduction: Generator Tuning

Some physics aspects cannot be derived from first principles, especially in the area of soft QCD. Pythia contains many parameters that represent a true uncertainty in our understanding of nature. Tuning these parameters is important to describe data.

A good tune should have:

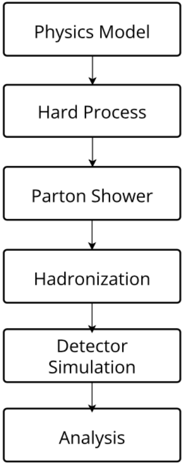
- Physically sensible parameter values, with good universality.
- Good agreement with data. (LEP1 in this talk)
- Reliable uncertainties.
- Best fit for our observables.



A $pp \to t\bar{t}$ events, modelled by Pythia [C. Bierlich *et al.*, 2022]

Goals

- Present events for analysis of e^+e^- colliders:
  - Leading order matrix elements are calculated by Whizard 1.95.
  - Parton shower and hadronization are performed by Pythia6.
  - OPAL tune for LEP is used.
- Our goals:
  - Upgrade the simulation chain to Whizard3+Pythia8.
  - Get agreement with LEP data, especially the neutral hadrons.
  - Include NLO matching because of the requirement of high precision.



Average Hadron Multiplicities

Hadronisation rates are crucial for studying particle flow performance. To study it, we use the following generator setup (LEP1 condition):

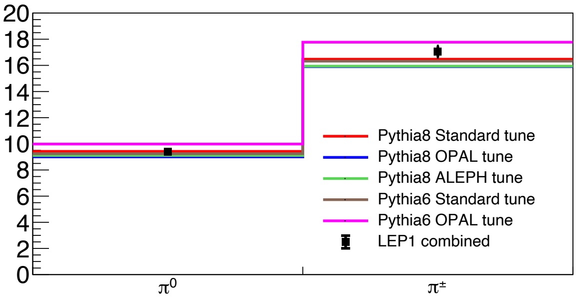
- Process: $e^+e^- \to q\bar{q}$ $(q = u, d, s, c, b)$.
- The center of mass energy is $E_{cm} = 91.19$ GeV.
- Beams are un-polarized.
- Beam-strahlung is not considered.
- ISR is switched on.

The parton shower and hadronization are performed by Pythia8.
Three tunes are considered:

- The standard tune, using default parameters set of Pythia8.
- The OPAL tune.
- The ALEPH tune.

Average Hadron Multiplicities

The dominant hadrons are pions. The average numbers of pions in events are

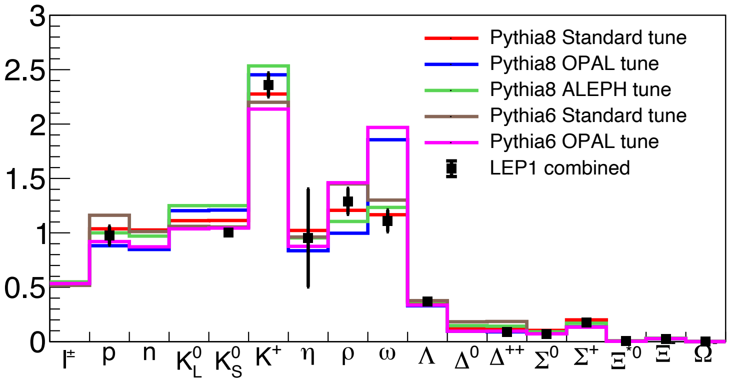


Tunes	n_{π^0}	$n_{\pi^\pm}$
P8 standard	9.42	16.47
P8 OPAL	9.00	15.90
P8 ALEPH	9.10	15.94
P6 standard	9.25	16.32
P6 OPAL	9.98	17.77
LEP1 combined	9.38 $\pm$0.19	17.05 $\pm$0.43

> LEP1 data are taken from [A. Boehrer, 1997] and [R. Barete *et al.*, 1998]

Average Hadron Multiplicities

We also compare other hadrons



> The Pythia8 standard tune is closest to data.

ILD Simulation and JER

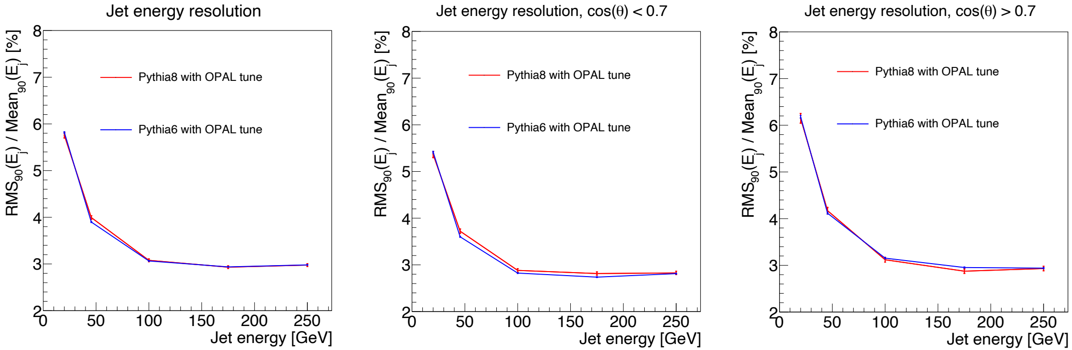
Full Geant4-based MC simulations are crucial to optimize a well performed dectector concept. We take ILD as an example. In this context, an important parameter is the JER of ILD.

To study it, we use the following generator setup:

- $e^+e^- \to q\bar{q}\ (q = u, d, s)$
- ISR is switched off.
- $E_{cm} = 40, 91, 200, 350, 500$ GeV.
- Full simulation is performed with ILD-L model.

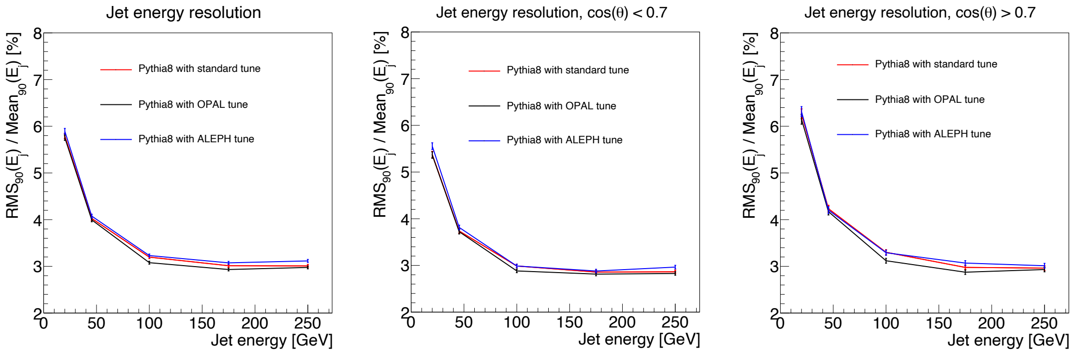
JER Results

- Compare with previous events that were used in ILD IDR [arXiv:2003.01116].



JER Results

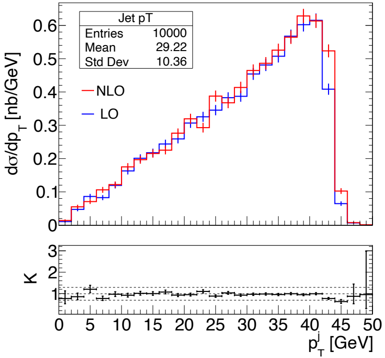
Comparison with three tunes:



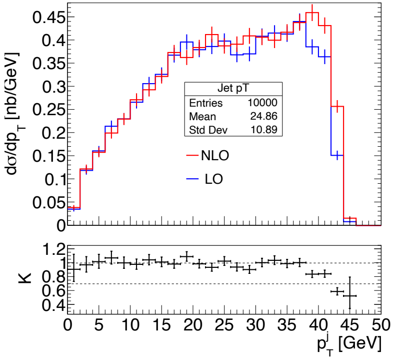
> OPAL tune shows the best resolution in this context.

First glance to the NLO events

- NLO QCD corrections can be calculated by interfacing Whizard with OpenLoops. [F. Bucchioni *et al.*, 2019]
- Whizard supports POWHEG matching. [P. Nason, 2004]



Leading jet



Sub-leading jet

Summary

- The MC simulation chain is necessary to upgrade to Whizard3+Pythia8.
- We compare three tunes: the standard Pythia8 tune, the OPAL tune and the ALEPH tune.
- The standard tune can give hadron multiplicities close to LEP1 data, and the best JER is obtained by OPAL tune.
- Work in progress: testing the NLO mode of Whizard and generating events by POWHEG matching.

Thank You

Backup slides

Pythia8 Parameters

Parameter	name in PYTHIA8	standard	OPAL	ALEPH
$P(qq)/P(q)$	StringFlav:probQQtoQ	0.081	0.085	0.105
$P(s)/P(u)$	StringFlav:probStoUD	0.217	0.310	0.283
$(P(su)/P(du))/(P(s)/P(u))$	StringFlav:probSQtoQQ	0.915	0.45	0.710
$\frac{1}{3}(P(ud_1)/P(ud_0))$	StringFlav:probQQ1toQQ0	0.0275	0.025	0.05
$(S=1)$ d,u	StringFlav:mesonUDvector	0.50	0.60	0.54
$(S=1)$ s	StringFlav:mesonSvector	0.55	0.40	0.46
$(S=1)$ c,b	StringFlav:mesonCvector	0.88	0.72	0.65
	StringFlav:mesonBvector	2.20	0.72	0.65
$S=1, s=0$ prob.	StringFlav:mesonUDL1S0J1	0.0	0.43	0.12
$S=0, s=1$ prob.	StringFlav:mesonUDL1S1J0	0.0	0.08	0.04
$S=1, s=1$ prob.	StringFlav:mesonUDL1S1J1	0.0	0.08	0.12
tensor mesons (L=1)	StringFlav:mesonUDL1S1J2	0.0	0.17	0.20
leading baryon suppr.	StringFlav:suppressLeadingB	off	on	on
	StringFlav:lightLeadingBSup	0.5	1.0	0.58
	StringFlav:heavyLeadingBSup	0.9	1.0	0.58
σ (GeV)	StringPT:sigma	0.335	0.4000	0.362
η' suppression	StringFlav:etaPrimeSup	0.12	0.40	0.27
a of LSFF	StringZ:aLund	0.68	0.11	0.40
b of LSFF	StringZ:aLund	0.98	0.52	0.824
Δa for s quark	StringZ:aExtraSQuark	0.0	0.0	0.0
Δa for Di-quark	StringZ:aExtraDiquark	0.97	0.5	0.5
ϵ_c	StringZ:usePetersonC	off	on	on
	StringZ:epsilonC	0.05	-0.031	0.04
ϵ_b	StringZ:usePetersonB	off	on	on
	StringZ:epsilonB	0.005	-0.002	0.0018
PS QCD cut-off (GeV)	TimeShower:pTmin	0.5	0.95	0.735
PS cut-off for QED adiation off quarks (GeV)	TimeShower:pTminChgQ	0.5	0.95	0.735