Consideration of Photon Radiation in Kinematic Fits for Future e^+e^- Colliders

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DESY - FLC

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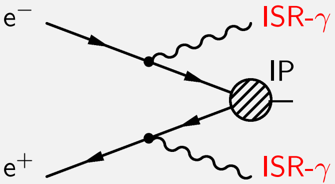
Introduction

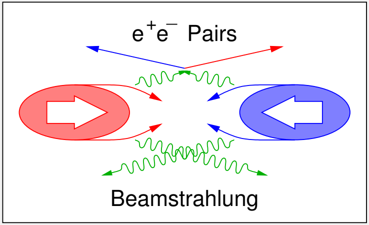
Kinematic fitting

- Energies & momenta of reconstructed particles measured with errors (due to limited detector resolution etc.)
- Event bound to *constraints*, e.g. energy conservation
- Use redundant information for correction: kinematic fit
  $\Rightarrow$ Better detector resolution, e.g. for W mass @ LEP

Introduction
Photon radiation

Initial state radiation (ISR) and beamstrahlung

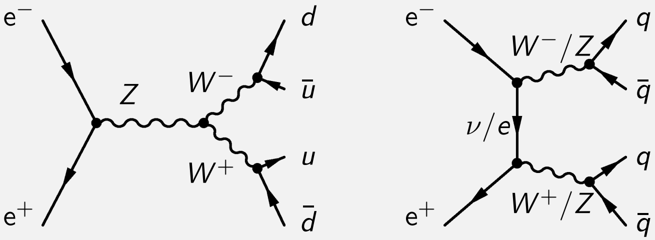




- Emitted mostly parallel to beam
- Missing energy and momentum
- Constraints incomplete ⇒ fit goes wrong

Introduction
Test sample

- Test sample to exemplify problem:
  $e^+e^- \rightarrow WW/ZZ(\sim 2\%) \rightarrow u\bar{d}d\bar{u}$ (4 hadron jets)



- Generated by WHIZARD, ILD_00 mass production
- $\sqrt{s} = 500$ GeV, 100 fb^{-1}
- Jet quality cuts and "no γ seen in detector" ($\theta_\gamma < 0.29°$)
- Aim: separation of WW/ZZ by invariant di-jet masses

Introduction

Photon radiation: What's new?

- LEP: Fit goes wrong, but deviations are small
  ($\Delta m \sim 100$ MeV, missing energy blows up masses)
  $\rightarrow$ Simulate deviations with MC for correction afterwards

Photon radiation: What‘s new?

- LEP: Fit goes wrong, but deviations are small ($\Delta m \sim 100$ MeV, missing energy blows up masses)
  $\rightarrow$ Simulate deviations with MC for correction afterwards
- ILC aims for higher CM energy and luminosity
  - more photon radiation
  - lose events ($\sim 20\%$) due to not-converged fits
  - requires consideration of photon in the fit (new)

Modelling a photon in a kinematic fit

Parametrization

- Parametrization via momentum: $p_x, p_y, p_z, (m = 0)$
- Only photons parallel to beam (are covered in this talk)
  $\Rightarrow p_x, p_y$ negligible $\Rightarrow$ set fix to 0

Modelling a photon in a kinematic fit
Parametrization

- Parametrization via momentum: $p_x, p_y, p_z, (m = 0)$
- Only photons parallel to beam (are covered in this talk)
  $\Rightarrow p_x, p_y$ negligible $\Rightarrow$ set fix to 0
- Pseudo-measured fit object:
  - assume photon measured to $\vec{p} = 0$
  - error reflecting the momentum distribution
    $\Rightarrow$ must feed photon momentum spectrum into fit
  - detail: parametrize $p_z^\gamma(p_g)$ such that p_g is approximately Gaussian-distributed for physical ISR spectrum

Modelling a photon in a kinematic fit

Energy spectrum

- ISR energy spectrum given by power function:

$$N_\gamma \propto E_{\mathrm{ISR}}^{(b(s)-1)}$$

$$b = 0.1235 \text{ for } \sqrt{s} = 500 \text{ GeV}$$

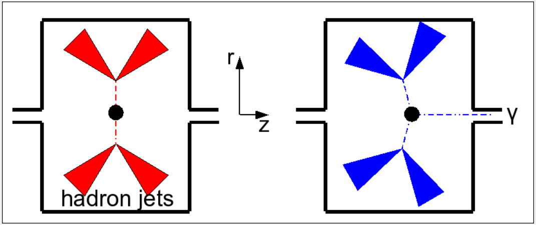
- Addition of beamstrahlung modifies ISR spectrum mostly at small energies ($\lesssim$ 5 GeV)
  (will be considered later)

Results

Fit hypotheses

- 2 fit hypotheses:

  4 jets (5C) 4 jets plus photon (5C+γ)



- 5 Constraints:

  #1 $E_{CM} = 500$ GeV (energy conservation)
  #2-4 $\sum p_{x,y,z} = 0$ (momentum conservation)
  #5 equal invariant 2-jet masses
  (pairing found by best fit convergence)

Results
Photon reproduction (ISR only)

- One photon *per beam* is simulated:
  If $E_{\gamma 1} \sim E_{\gamma 2}$, diverging energy and momentum constraints force 'compromise'
- Define
  $|Q| = 0.5 * (\sum E + |\sum p_z|)$
- Q corresponds to p_z of higher-energetic photon

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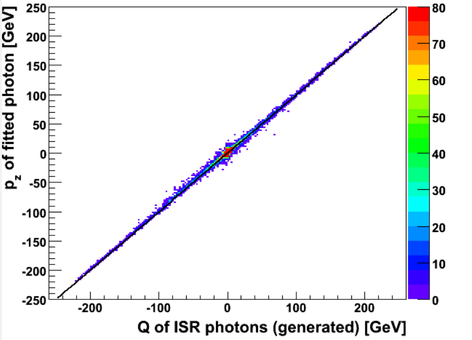
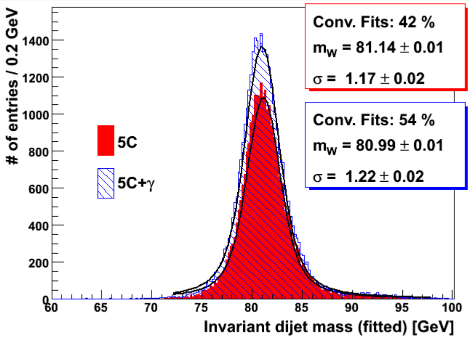


W/Z peaks smeared out with

- decay width (Breit-Wigner)
- detector etc. (Gaussian)

Fit function: sum of 2 Voigt functions
(Breit-Wigner folded with Gauss)



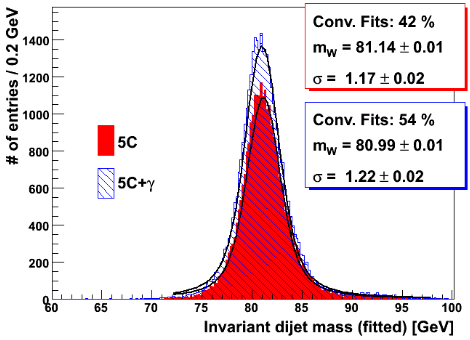
Results
Fit performance (ISR only)

W/Z peaks smeared out with

- decay width (Breit-Wigner)
- detector etc. (Gaussian)

Fit function: sum of 2 Voigt functions
(Breit-Wigner folded with Gauss)

% of converged fits (wanted large)
σ: Gaussian width (wanted small)
m_W: W mass (wanted unchanged)
missing energy blows up masses



Results

Fit performance (ISR only)

Fit	conv. [%]	$m_W - m_{\mathrm{W,Lit}}$ [GeV]	σ [GeV]
5C	42	0.74	1.17
5C+γ	54	0.59	1.22
3C	55	0.88	2.02

- 3C: 4 jets, without E, p_z constraints
- Bad overall convergence due to equal-mass constraint and hadronization
- 5C loses $\approx 20\%$ of events in comparison to 3C
- 5C+γ converges as good as 3C,
- but with the same resolution as 5C

Results

Fit performance (ISR only)

Fit	$\sum E_\gamma$ [GeV]	conv. [%]	$m_W - m_{W,Lit}$ [GeV]	σ [GeV]
5C		42	0.74	1.17
5C+γ		54	0.59	1.22
3C		55	0.88	2.02
5C	> 30	0	$\div$	$\div$
5C+γ	> 30	47	0.69	1.20

$\sum E_\gamma > 30$ GeV:

- 5C fails (too much energy missing)
- 5C+γ loses few events, but no resolution

Results

Fit performance (ISR only)

Fit	$\sum E_\gamma$ [GeV]	conv. [%]	$m_W - m_{\mathrm{W,Lit}}$ [GeV]	σ [GeV]
5C		42	0.74	1.17
5C+γ		54	0.59	1.22
3C		55	0.88	2.02
5C	$\in [5, 30]$	15	1.69	1.25
5C+γ	$\in [5, 30]$	53	0.76	1.24

5 GeV $< \sum E_\gamma <$ 30 GeV:

- 5C loses many events
- Bias towards higher W masses

Results

Fit performance (ISR only)

Fit	$\sum E_\gamma$ [GeV]	conv. [%]	$m_W - m_{\mathrm{W,Lit}}$ [GeV]	σ [GeV]
5C		42	0.74	1.17
5C+γ		54	0.59	1.22
3C		55	0.88	2.02
5C	< 5	53	0.70	1.15
5C+γ	< 5	55	0.55	1.21

$\sum E_\gamma < 5$ GeV:
5C and 5C+γ perform equally well.

Results
Fit performance

	Fit	conv. [%]	$m_W - m_{\mathrm{W,Lit}}$ [GeV]	σ [GeV]
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Results
Fit performance

	Fit	conv. [%]	$m_W - m_{\mathrm{W,Lit}}$ [GeV]	σ [GeV]
ISR only	5C	42	0.74	1.17
	5C+γ	54	0.59	1.22
	3C	55	0.88	2.02
ISR + beamstrahlung	5C	31	0.99	1.25
	5C+γ	52	0.81	1.32
	3C	55	0.88	2.02

Inclusion of beamstrahlung:

- 5C loses more events (more energy missing)
- 5C+γ is affected only little

Application to *your* analysis

- Kinematic fitting software `MarlinKinFit` included in ILCSoft MarlinReco
- MarlinReco contains *PhotonFitObjectPxyg* class for approximation by power function (beta version)
- For other approximations: cooking recipe exists
- Documentation (publication, LCnote) in preparation

Summary and outlook

- Consideration of photon radiation yields
  - as many events as a fit without E, p_z constraints
  - without loss in resolution
  - without mass bias
- Ready for use

Summary and outlook

- Consideration of photon radiation yields
  - as many events as a fit without E, p_z constraints
  - without loss in resolution
  - without mass bias
- Ready for use
- Left for the future:
  - test with semi-leptonic decays
  - treat events with two high-energy photons
  - extend parametrization to beamstrahlung

Many thanks for your attention!

- Fit needs underlying *hypothesis*:
  which *objects* are to be fitted?
  - $e^+e^- \to WW \to q\bar{q}q\bar{q}$: 4 jets
  - $e^+e^- \to WW \to q\bar{q}l\bar{\nu}$: 2 jets + lepton + ν
- Object represented by *parameters*

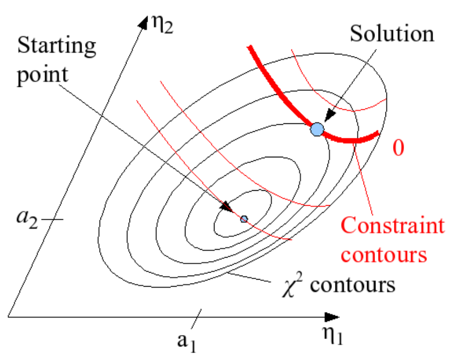
examples:

object	measured?	free parameters	fixed
hadron jet	measured	$E, \theta, \phi, \Delta E, \Delta\theta, \Delta\phi$	m
neutrino	unmeasured	p_x, p_y, p_z	m

Backup slides

Kinematic fitting: general concept

- Vary free parameters slightly to fulfill constraints
- $\chi^2 \geq 0$: quantifies variation of parameters by measurement errors
- Task: Minimize χ^2 under constraints (smallest variation)

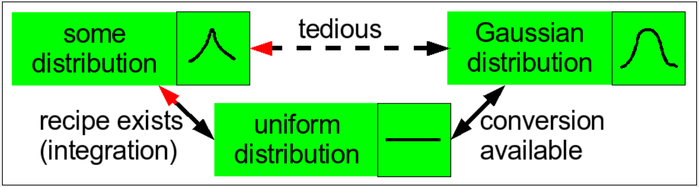


Backup slides

Modelling a photon in a kinematic fit

- Fitting algorithm designed for Gaussian error distribution

  Idea: Replace p_z by parameter p_g such that photon momentum spectrum becomes Gaussian-shaped!



- Technical issue: Fitting algorithm needs derivatives of E, p_i w.r.t. parameters

  $\Rightarrow$ corresponding requirements to spectrum description