SMEAR version 3.02, A Detector Simulation Program for e^+e^- Linear Collider Studies[1]

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Abstract: We describe a program for smearing of momentum 4-vectors which serves as a detector simulation program for e^+e^- linear collider studies.

Program Summary

Program name:	SMEAR
Version number:	3.02
Date of last modification:	October 16, 1996
Program language:	FORTRAN-77
Number of program lines:	735 lines
Other programs used:	None
Used libraries:	The CERN library MATHLIB (for the random number generator `RNDM`).

[1]The program can be obtained from `http://www.desy.de/~hspiesb/smear.html`.

[2]Supported by Bundesministerium für Bildung, Wissenschaft, Forschung und Technologie, Bonn, Germany, Contract 05 7BI92P (9).

1 Introduction

SMEAR is a subroutine to smear four-momenta of final state charged or neutral particles. The present version was developed from a former version written by S. Manly for NLC physics studies [1]. The program SMEAR implements a simplified model of a detector with electromagnetic and hadronic calorimetry and a tracking device as detector components.

The main application of the detector simulation we have in mind is the physics at future e^+e^- linear colliders with center-of-mass energies of several 100 GeV. Many physics issues will have to deal with high energy leptons and photons. Therefore it is assumed that these particles are measured in the electromagnetic calorimeter and for simplicity the information from the tracking device is completely ignored for electrons. The momenta of charged hadrons, usually having smaller energies, are measured in the tracker. In this case no additional information from the hadronic calorimeter is taken into account. The tracker is also responsible for the measurement of muons. The hadronic calorimeter is, of course, the only possibility to measure the momenta of neutral hadrons.

The model for the electromagnetic calorimeter determines the energy E of photons and electrons. For these particles, E is smeared as a Gaussian with half-width, $\sigma_{EM}(E)$, given by the following expression:

$$\frac{\sigma_{EM}(E)}{E} = \frac{\mathtt{AEM}}{\sqrt{E}} + \mathtt{BEM}. \tag{1}$$

The direction of photons and electrons is smeared in a cone about the original direction with the half-angle of the cone Gaussian-distributed with half-width SIG_EMDIR=0.57 (corresponding to 10 mrad). For electrons, the magnitude of the output momentum is determined from the smeared calorimeter energy assuming the mass of the particle is that of an electron.

Similarly, the model for hadronic calorimetry is responsible for the measurement of neutral particles interacting hadronically: their energy is smeared as a Gaussian with half-width, $\sigma_{HAD}(E)$, given by the following expression:

$$\frac{\sigma_{HAD}(E)}{E} = \frac{\mathtt{AHAD}}{\sqrt{E}} + \mathtt{BHAD}. \tag{2}$$

Neutral hadronic particle's total momentum is determined from the smeared energy assuming the particle is a π^0. The direction is smeared in a cone about the original direction with the half-angle of the cone Gaussian-distributed with half-width SIG_HDIR=0.86 (corresponding to 15 mrad).

The tracking device for the measurement of 4-momenta of charged particles other than electrons is modelled in the following way:

1. The transverse momentum p_T and azimuth ϕ are smeared together, taking into account their correlation (see Ref. [2]). The components of the covariance matrix VCOV(i,j) are parametrized as follows:

$$\sigma^2\left(\frac{1}{p_T}\right) = \mathtt{VCOV(1,1)} = \mathtt{PRES}^2 + \left(\frac{\mathtt{PMSPTS}}{p_T\sqrt{\sin(\mathtt{ANG})}}\right)^2, \tag{3}$$

$$\sigma^2(\phi) = \mathtt{VCOV(2,2)} = \mathtt{PRES}^2 + \left(\frac{\mathtt{PMSPHS}}{p_T\sqrt{\sin(\mathtt{ANG})}}\right)^2, \tag{4}$$

$$\text{correlation :} \qquad \mathtt{VCOV(1,2)} = -\left(\frac{\mathtt{PMSPCS}}{p_T\sqrt{\sin(\mathtt{ANG})}}\right)^2, \tag{5}$$

i.e., $1/p_T$ and ϕ are Gaussians of half-widths given by $\sqrt{\mathtt{VCOV(1,1)}}$, $\sqrt{\mathtt{VCOV(2,2)}}$, resp. and correlation `VCOV(1,2)`. `PRES` and `PMSPxS` (`x` = `T`, `H`, `C`) are given as a function of θ (one value given for each 5° increment in the detector). `ANG` is the angle θ.

2. The z-component is smeared by projecting the transverse momentum, i.e. according to a Gaussian in $1/p_z$ with half-width

$$\sigma\left(\frac{1}{p_z}\right) = \frac{\mathtt{PMSPTS}}{p_z\sqrt{\sin(\mathtt{ANG})}}, \tag{6}$$

assuming perfect knowledge of θ.

3. The energy of the particle is then determined from the smeared momentum assuming the particle is either a $\pi^\pm$ or a μ. Perfect μ-identification is assumed in the present version of `SMEAR`.

Smearing is performed as a function of the scattering angle θ, i.e. the coefficients in the above expressions are θ-dependent. The angular dependence is taken into account in steps of 5 degrees in this version. Note that this makes a more correct treatment of measurement errors on θ in the expressions for the momentum resolution, Eq. (3 - 6), inessential. Symmetry with respect to the detector midplane is assumed. The array `ANGLE` is used for angular dependence bookkeeping.

The acceptance hole around the beampipe is determined by the value of `LOWANG`. Tracks with an angle with respect to the beampipe less than `LOWANG` are removed from the event.

Efficiencies for charged (`CHGEFF`) and neutral particles (`NEUEFF`) can be given as a function of angle (in 5 degree increments) with respect to the beampipe. In the present version, for both efficiencies the angular-independent value 0.98 is used.

No attempt is made in this version to take into account energy cluster overlaps for closely spaced particles (i.e., those in narrow jets).

The detector parameters have been chosen in accord with results of the work done during the 'Joint ECFA/DESY Study on Physics and Detectors for a Linear Collider' (February to November 1996) [3]. The corresponding values, appropriate for a 1TeV detector, are stored on the common block `SMRCOM` and initialized by a block data subroutine. They can be reset to values describing the performance of a typical LEP/SLD-type of detector (subroutine `SMBDD2`) or to any other values as desired by the user.

A detailed discussion of the properties of the detector model inplemented in the present version of `SMEAR` and comparisons with both a full detector simulation for ALEPH as well as another detector simulation program [6] will be given elsewhere.

Original author:	Steve Manly, Yale University, written for NLC physics studies, summer 1995
Modifications by:	S. Manly, R. Dubois, B. Barakat
Version 3.0x by:	R. Settles, H. Spiesberger and W. Wiedenmann, September 13, 1996, e-mail: `hspiesb@mppmu.mpg.de`.

2 Technical Description of the Program

2.1 Subroutines

`SMRINT` (S):	Interface to external calling programs. The input four-momenta are expected on the standard JETSET event record `LUJETS`.
`SMEAR` (S):	Performs 4-momentum smearing, called from `SMRINT`.
`SMEARD` (S):	Performs directional smearing for neutral hadronic particles and electrons, called from `SMEAR`.
`SMANGL` (S):	Calculates polar and azimuthal angles from Cartesian coordinates.
`SMGAUS` (F):	Generates a Gaussian distribution with given mean and half-width from two input random numbers [4].
`SMGAU2` (S):	Generates a two-dimensional Gaussian with given means, half-widths and correlation from four input random numbers [5].
`SMROTA` (S):	Calculates the components of a vector in a rotated coordinate system.
`SMBDDA` (B):	Block data subroutine to initialize detector parameters for a typical 1TeV detector.
`SMBDD2` (S):	Resets detector parameters for a LEP/SLD detector.
`RAN` (F):	Interface to the CERNLIB random number generator `RNDM`.

2.2 Input/Output for subroutine `SMEAR`

Input:

`CHARGE:` Charge of particle:
$= 0$: particle is neutral,
$= 1$: particle is charged;

`EM:` Particle interacts electromagnetically or hadronically:
$= 0$: smearing done using hadronic calorimetry,
$= 1$: smearing done using electromagnetic calorimetry;

`IV(4):` 4-momentum vector of generator-level final state particle (unsmeared).

Output:

V(4): 4-momentum vector of final state particle after detector smearing;

EFF: Flag showing whether particle passed efficiency cuts:
=0 : particle did not pass efficiency cut and should be removed from the event record,
=1 : particle passed efficiency cut;
=2 : particle passed efficiency cut, but has an angle with respect to the beampipe of less than LOWANG and should be removed from the event record;

ERR: Error flag:
=0 : no error occured during execution,
=1 : error occured during execution.

2.3 Common block SMRCOM

```
REAL AEM,BEM,AHAD,BHAD,PRES,PMSPTS,PMSPHS,PMSPCS,LOWANG,ANGLE
REAL SIG_HDIR,SIG_EMDIR,CHGEFF,NEUEFF
INTEGER SEED
COMMON/SMRCOM/AEM,BEM,AHAD,BHAD,PRES(18),PMSPTS(18),PMSPHS(18),
$             PMSPCS(18),LOWANG,
$             ANGLE(19),CHGEFF(18),NEUEFF(18),SIG_HDIR(18),
$             SIG_EMDIR(18),SEED
```

Content: Parameters describing the performance of various detector components.

AEM: (D=0.10) Parameter for the energy-dependent term of energy smearing for electromagentic calorimetry;

BEM: (D=0.01) Parameter for the constant term of energy smearing for electromagnetic calorimetry;

AHAD: (D=0.50) Parameter for the energy-dependent term of energy smearing for hadronic calorimetry;

BHAD: (D=0.04) Parameter for the constant term of energy smearing for hadronic calorimetry;

PRES: Momentum resolution of the tracker. PRES is given as function of θ in 5°-degree increments, the default value at 90° is 0.0002;

PMSPTS: (D=0.0015) Multiple scattering contribution to the p_T measurement;

PMSPHS: (D=0.00044) Multiple scattering contribution to the measurement of the azimuth ϕ;

PMSPCS: (D=0.0030) (p_T, ϕ)-correlation coefficient due to multiple scattering;

LOWANG: (D=8.1) Opening angle of the beamhole;

ANGLE: Array to set grid on polar angle in steps of 5°. Symmetry with respect to the detector midplane is assumed;

SIG_HDIR: (D=0.86) Half-angle of Gaussian directional smearing for hadronic neutral particles;

SIG_EMDIR: (D=0.57) Half-angle of Gaussian directional smearing for photons and electrons;
CHGEFF: (D=0.98) Efficiency for charged particles;
NEUEFF: (D=0.98) Efficiency for neutral particles;
SEED: Seed for random number generator.

References

[1] S. Manly, SMEAR.FOR v.2.0, http://nlc.physics.upenn.edu/nlc/nlc.html

[2] R. L. Gluckstern, Nucl. Inst. Meth. 24 (1963) 381.

[3] http://www.info.desy.de/conferences/ecfa-desy-lc96.html.

[4] The Particle Data Group, *Review of Particle Physics*, Phys. Rev. D54 (1996) 169.

[5] F. James, Rept. on Progr. in Phys. 43 (1980) 1145.

[6] J. Schreiber, SIMDET, program for detector smearing, private communication.