pandora:

an object-oriented event generator for linear collider physics

M. E. Peskin
October, 2000

pandora

is an event generator for e^+e^- linear collider physics processes,

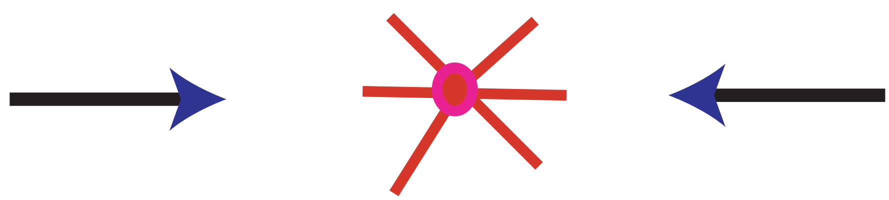
intended to handle:

- beam polarization
- beamstrahlung and ISR
- spin correlations and spin asymmetries
- inclusion of arbitrary hard processes

a general $e^+ e^-$ cross section has the form:

$$\sigma = \int d\vec{x}\, d\vec{y}\, d\vec{z} \cdot \frac{dP(h_1)}{d\vec{x}} \frac{d\sigma(h_1, h_2)}{d\vec{y}} \frac{dP(h_2)}{d\vec{z}}$$

beam process beam



assemble the integrand from beam and process functions

select weight-1 events from the full, correlated distribution

modular design $\rightarrow$ C++

- functionality of pandora
- process construction
- current status

pandora is a class with constructor

```
pandora P( beam1, beam2, process)
```

and methods

P.prepare(Nevents)
P.integral() → returns σ
P.getEvent() → returns a weight-1 event

pandora returns parton-level events in the LEvent data structure, which includes for each parton

- 4-vector
- particle ID
- final?
- color chain
- shower level *

* thanks to K. Fujii

Illustration: $e^+e^- \rightarrow t\,\bar{t} \rightarrow W^+ b\, W^- \bar{b}$

$\rightarrow u\,\bar{d}\;b\;\tau^-\,\bar{\nu}\;\bar{b}$

parton	ID	parent	final?	chain	sh.level
1	6	0	0	-1	1
2	5	1	1	-1	3
3	24	1	0	0	3
4	-1	3	1	5	4
5	2	3	1	-1	4
6	-6	0	0	1	1
7	-5	6	1	2	2
8	-24	6	0	0	2
9	15	8	1	-11	0
10	-16	8	1	0	0

these partonic events can be hadronized by PYTHIA using an interface

pandora_pythia by Masako Iwasaki

this program

- inserts the pandora generator into PYTHIA as an external subprocess
- requests QCD showers, level by level
- requests hadronization according to the color connection
- decays polarized τ s using TAUOLA
- writes final events to an external file in StdHEP format

```
int main(int argc, char* argv[]){

char* outfile = argv[1];
int nEvent = atoi(argv[2]);

double Eb = 250.0;
double Pol_e  = 0.8;
ebeam b1(Eb,Pol_e,electron,electron);
ebeam b2(Eb,0.0,positron, positron);
b1.setup(NLC500);
b2.setup(NLC500);

eetottbar prtt;
pandora P(b1,b2,prtt);

pandorarun PR(P,epluseminus,ECM,NEvent)
PR.initialize(outfile);
PR.getevents();
PR.terminate();

}
```

Examples of pandora parton-level output:

$e^+e^- \rightarrow W^+W^-$ $\sqrt{s}$ = 500 GeV

W mass

W, l , ν energies

$e^+e^- \rightarrow t\,\bar{t}$

W, t masses

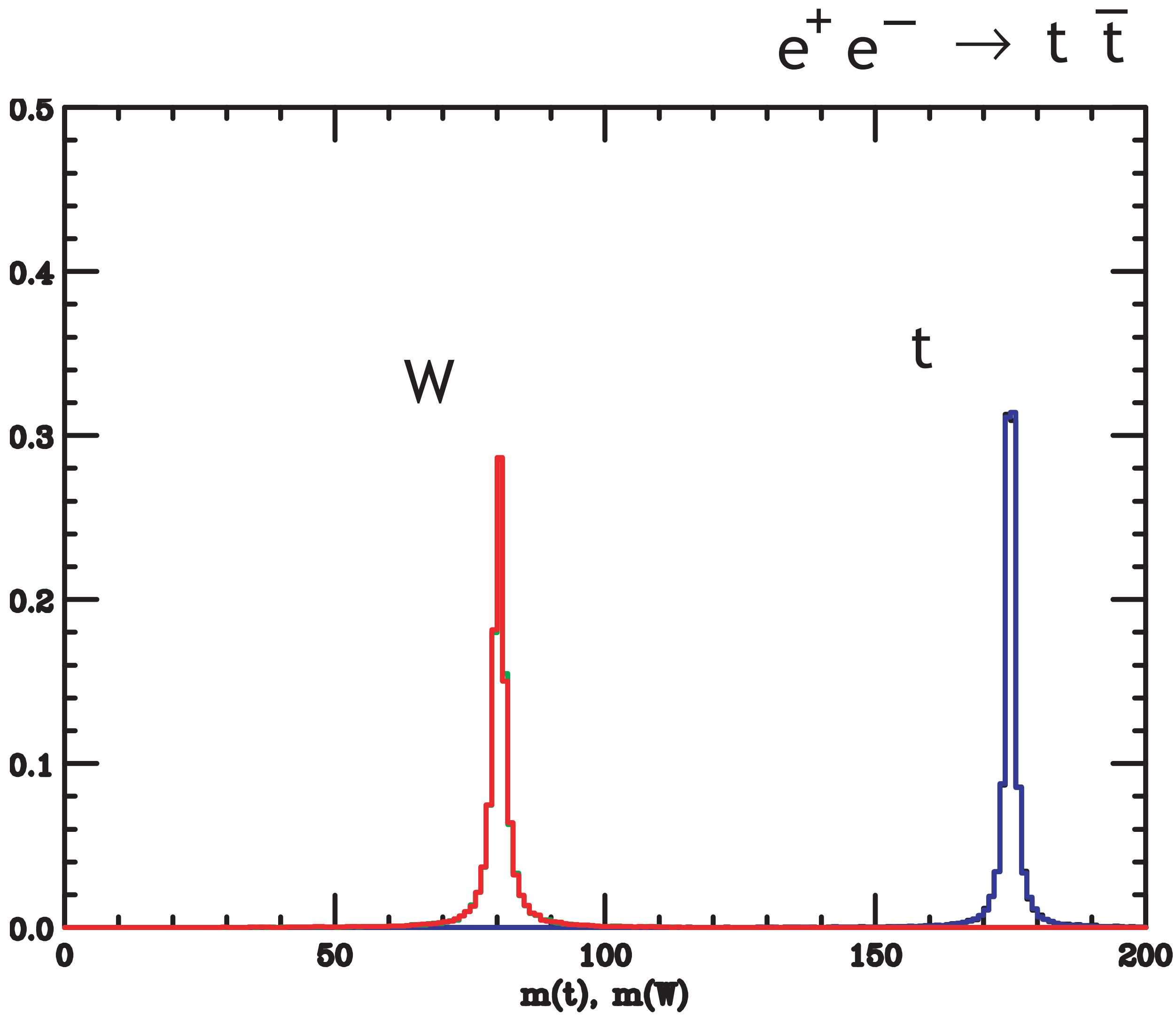
W, b, l, ν energies

$e^+e^- \rightarrow Z^0\,h^0$

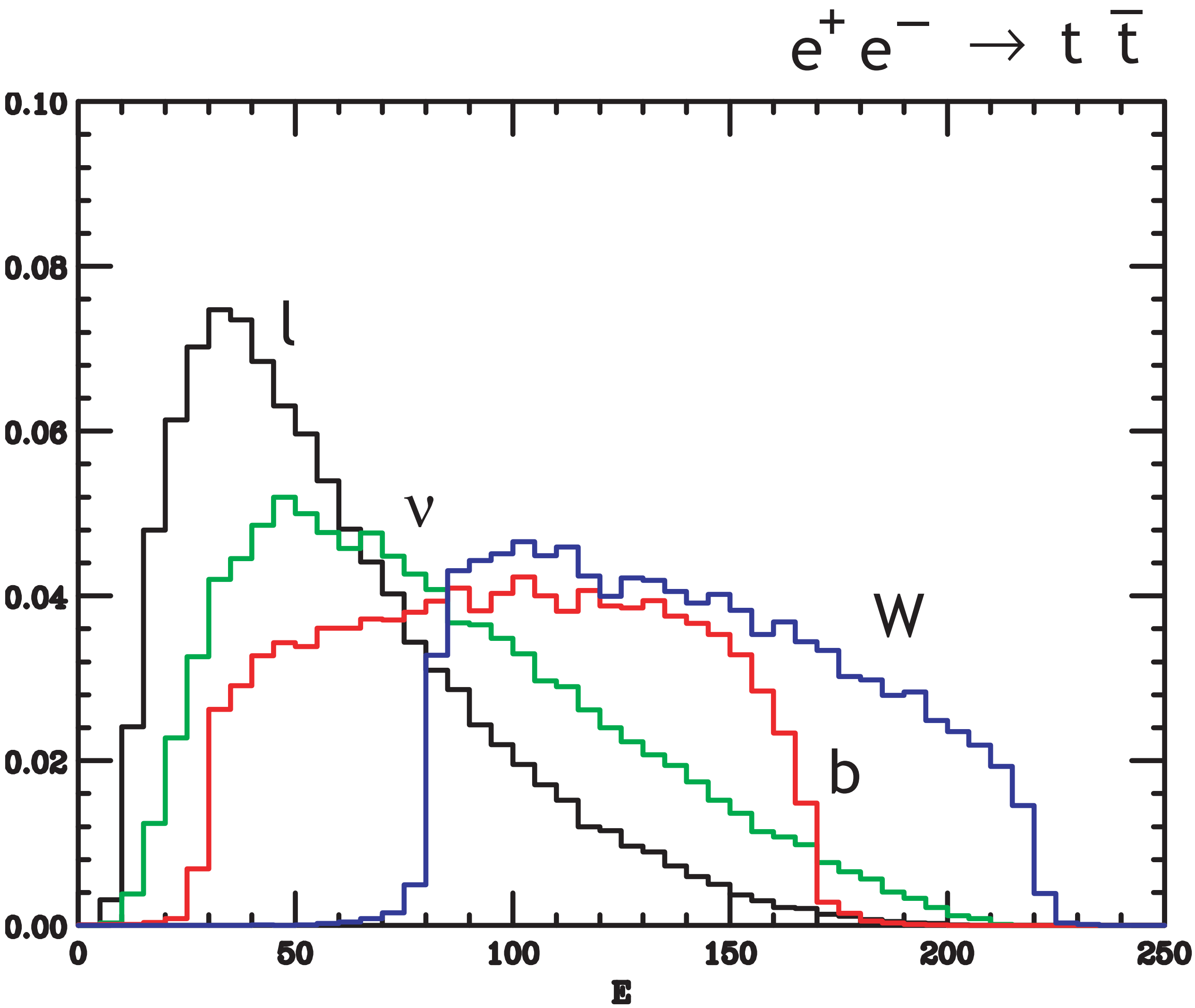
h, Z energies

W, Z masses in h decay to WW*, ZZ*

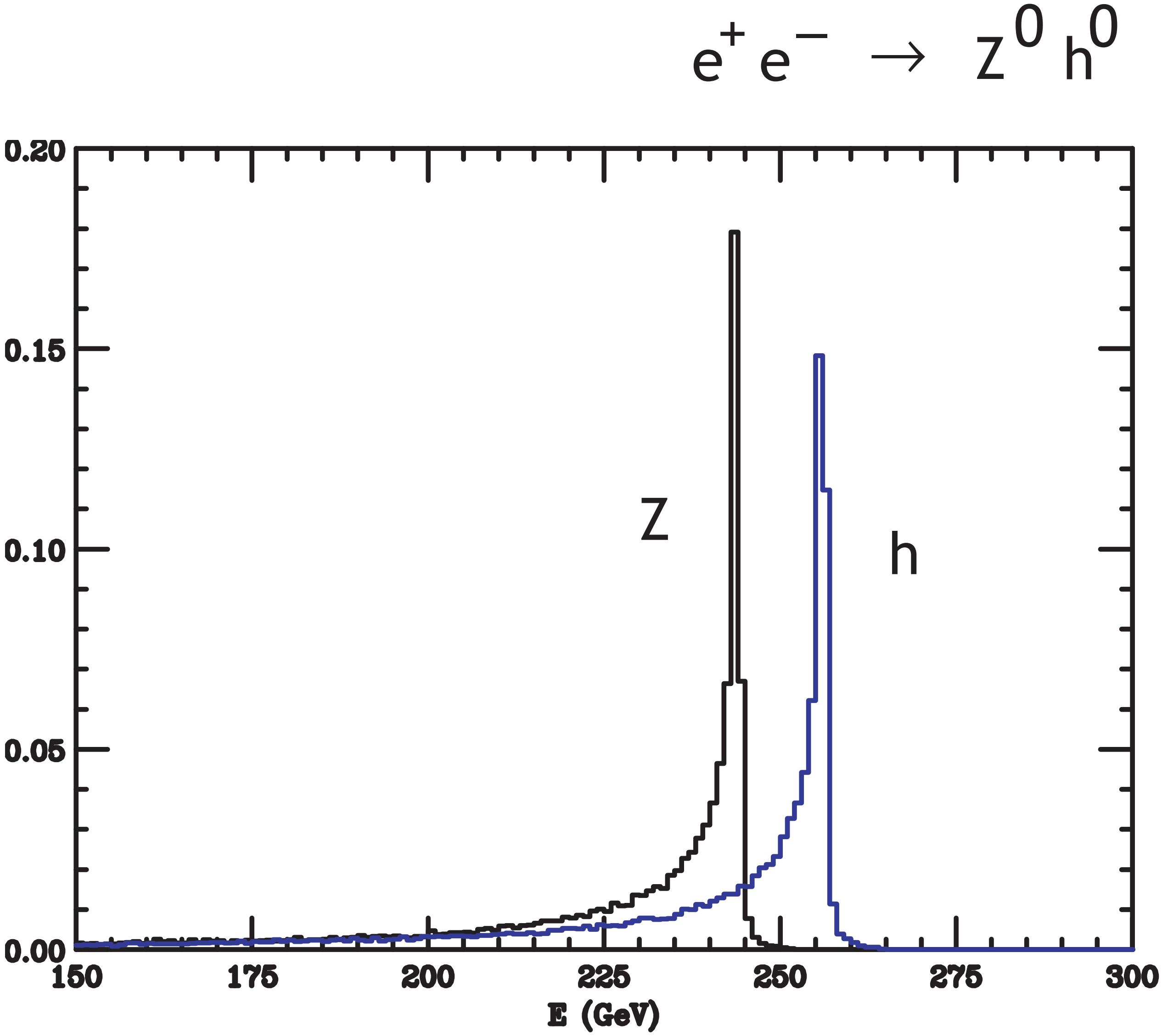
h BR's



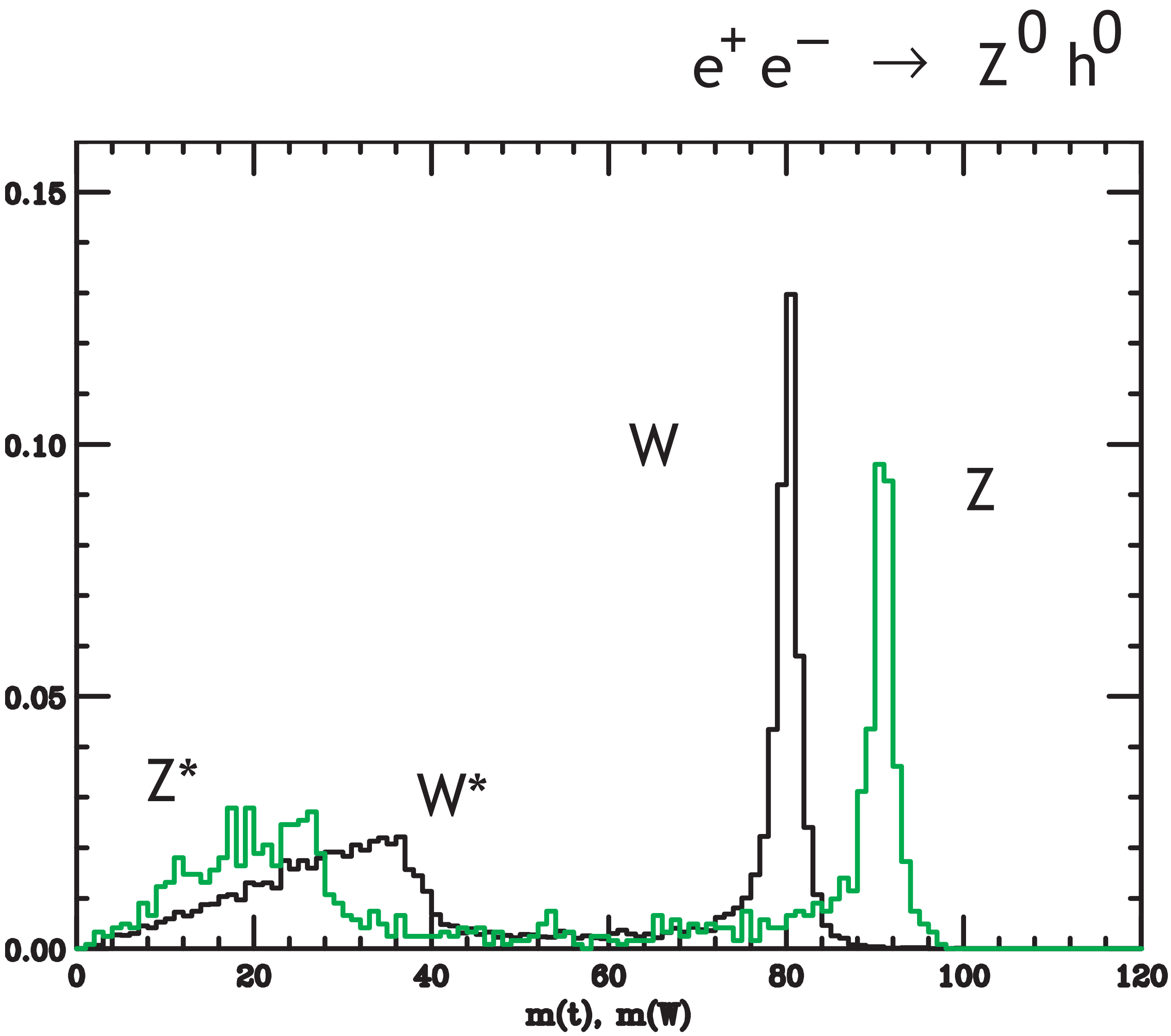
$e^+ e^- \rightarrow t\ \bar{t}$
W
t
0.5
0.4
0.3
0.2
0.1
0.0
0
50
100
150
200
m(t), m(W)



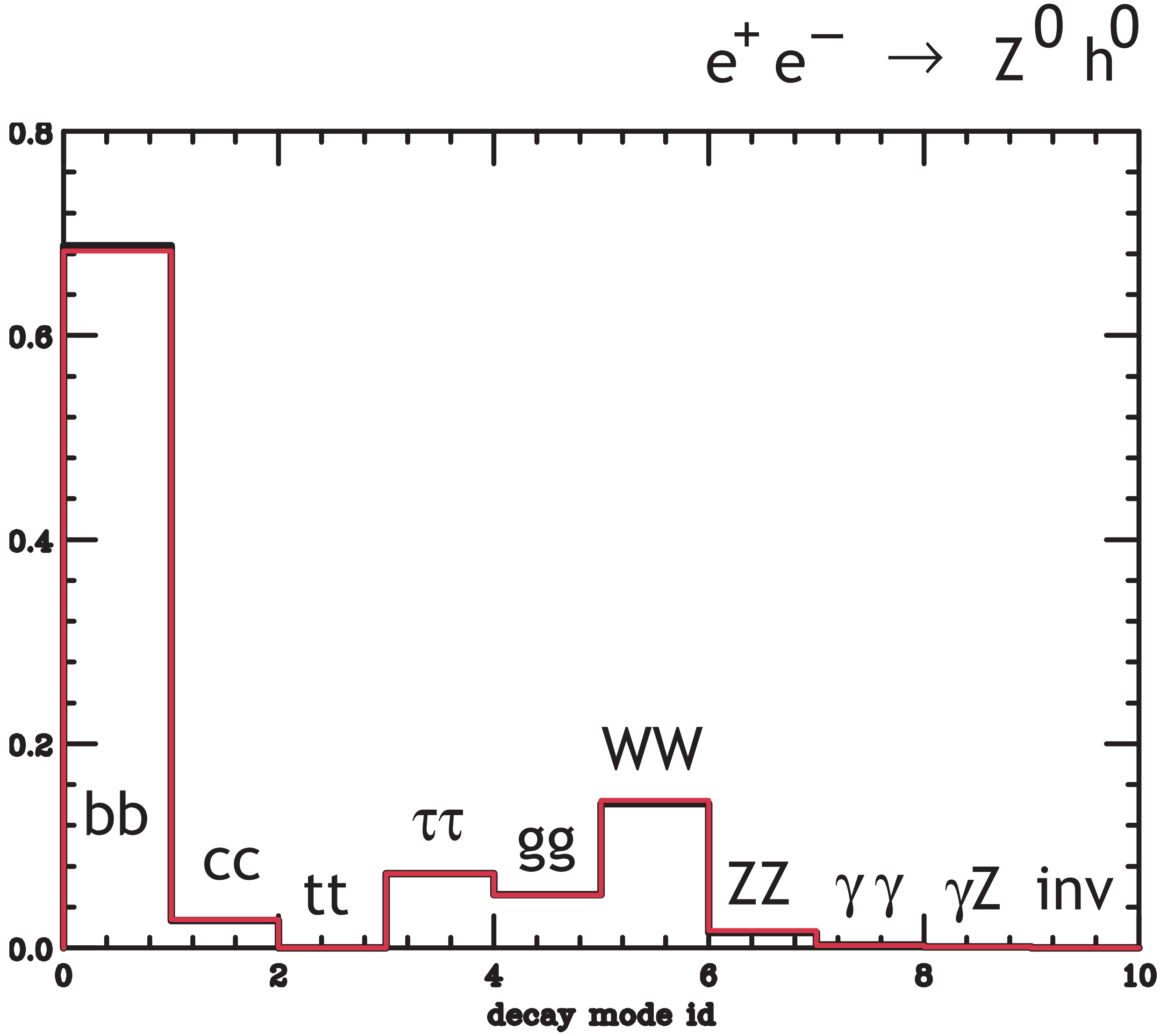
$e^+ e^- \to t \bar{t}$
0.10
0.08
0.06
0.04
0.02
0.00
0
50
100
150
200
250
E
l
ν
W
b



$e^+ e^- \rightarrow Z^0 h^0$
0.20
0.15
0.10
0.05
0.00
150
175
200
225
250
275
300
E (GeV)
Z
h



e+ e− → Z0 h0
0.15
0.10
0.05
0.00
0
20
40
60
80
100
120
m(t), m(W)
W
Z
Z*
W*



e+ e− → Z0 h0
0.0
0.2
0.4
0.6
0.8
0
2
4
6
8
10
decay mode id
bb
cc
tt
ττ
gg
WW
ZZ
γ γ
γZ
inv

beam class:

e^+e^- beams have

ISR

using Fadin-Kuraev structure fcns.

beamstrahlung

using `consistent Yokoya-Chen'

to construct a beam, input using setup()

a standard design

NLC/JLC	500	1000	1500
TESLA	500	800	
CLIC	500	1000	3000

or basic machine parameters

N , β_i , σ_i

γ beams have

γ, e spectra from Compton backscattering

ISR for scattered electrons

there is also a beam class for $e^- e^-$.

All beam classes take full account of beam polarization.

the process class

is essentially an interface that implements the operations:

- tell if $\vec{x}$ is in the allowed phase space
- compute the differential cross section
- construct the partonic final state in the CM frame

more specifically, a process must implement four functions ...

```
class process{

int n;   /* number of integration
            variables for the process */
char * name    /* identifying string */
DMatrix cs;
 /* helicity-dependent cross section */

virtual int computeKinematics(
   double & J, DVector & X, double s,
                 double beta);
     /* returns 0 if X is invalid;
         J is the Jacobian of the
           transoformation from X
           to useful variables   */

virtual void crosssection();
virtual LVlist buildVectors();
virtual LEvent buildEvent();

};
```

to save time, allocate all vectors and matrices before starting the repetitive phase of event generator (speedup by a factor 20)

How does one construct a process class?

1. Compute helicity amplitudes for the process.

pandora's conventions:
view process in the event plane
(works for up to 3-body final states)

for a vector boson moving in the +3 direction:

$$\varepsilon_{+1} = \frac{1}{\sqrt{2}}(0, 1, i, 0) \qquad \varepsilon_{-1} = \frac{1}{\sqrt{2}}(0, 1, i, 0)$$

$$\varepsilon_0 = (k/m , 0 , 0, E/m)$$

use 2-component notation for all fermions!

for a massive fermion moving in the +3 direction

$$u_{+1/2} = \sqrt{E-p}\begin{pmatrix}1\\0\end{pmatrix} \qquad u_{-1/2} = \sqrt{E+p}\begin{pmatrix}0\\1\end{pmatrix}$$

$$v_{+1/2} = \sqrt{E+p}\begin{pmatrix}0\\1\end{pmatrix} \qquad v_{-1/2} = \sqrt{E-p}\begin{pmatrix}-1\\0\end{pmatrix}$$

rotate in the 3-1 plane to other orientations

2. Call standard decay amplitudes for massive and unstable partons

decay classes have been written for

W^+ W^- Z^0 t $\bar{t}$ h^0 (SM)

it is crucial to adhere to a common, boost-invariant, convention

```
class Wplusdecay: public decaytotwozz{

Wplusdecay();

CVector Camp;
   /* the helicity-dependent decay
                amplitude   */
void decayamp();  /* fill Camp  */

  /*  inherited from decaytotwozz:
int computeDecayKinematics(double & J,
     DVector & X, int i, double m);
LVlist buildDecayVectors(); */

void placeIDs(LEvent & LE, int i,
                       int parent);

};
```

3. Inherit from classes which compute the reaction kinematics

- these classes include finite width effects with the prescription:

  a Breit-Wigner about M gives masses m_1 m_2
  from these and $\sqrt{s}$, compute p (CM)
  from this, compute

$$E_{ia} = (p^2 + m_i^2)^{1/2} \qquad E = (p^2 + M^2)^{1/2}$$

  use E_{ia} to compute kinematics,
  E to compute production amplitudes

- these classes cut off kinematic singularities appropriately in their constructors

```
class twototwomzt:  public process {

/* cos theta = tanh((2 X[1]-1) * 10)
   m = sqrt(M*M + M*Gamma *
      * tan((PI-2Gamma/M)(X[2]-1/2))*/

twototwomzt(int N, double M, double G,
   double thetamin, double ptmin,
   double Emin);
twototwomzt(int N, double M, double G);
   /* implements default choices  */

int validEvent(DVector & X, double s,
                     double beta);

int computeKinematics(double & J,
  DVector & X, double s, double beta);

LVlist buildVectors();

};
```

4. Code the full quantum-mechanical amplitudes for production and decay, using the helicity bases.

5. Construct the final state parton momenta using boost and rotations of 4-vector lists provided by the decay classes.

6. Add ID's to the LEvent using functions from the decay classes.

```
LVlist eetottbar::buildVectors(){
    /* t decay products  */
 LVlist Lt = TD.buildDecayVectors();
 Lt.boost(p/E1a);
    /* tbar decay products  */
 LVlist Ltb = TBD.buildDecayVectors();
 Ltb.boost(p/E2a);
 Ltb.reverseinplane();
    /*  finish  */
 LVlist L = merge(Lt,Ltb);
 L.rotateinplane(cost);
 L.rotate(phi);
 return L;
}

LEvent eetottbar::buildEvent(){
 LEvent LE(buildVectors());
 TD.placeIDs(LE, 1, 0);
 TBD.placeIDs(LE, 6, 0);
 LE.connect(6,1);
 LE.connect(7,2);
 LE.addshower(1,6);
 return LE;
}
```

processes included in pandora 2.1

$e^+ e^-$ $e^- e^-$ $\gamma\,\gamma$ beam classes

$e^+ e^- \to l^+ l^-$ $q\,\bar{q}$ $t\,\bar{t}$ $W^+ W^-$
$Z^0 \gamma$ $Z^0 Z^0$ $Z^0 h^0$

$e^+ e^- \to t\,\bar{t}$ with general form factors

$\gamma\,\gamma \to l^+ l^-$ $q\,\bar{q}$ $t\,\bar{t}$ h^0 $W^+ W^-$

$e^- \gamma \to e^- \gamma$ $e^- Z^0$ $\nu\, W^-$

It would be good if pandora could also contain:

general $e^+ e^- \rightarrow$ 4 parton backgrounds

this requires: spinor product methods
multigrid event selection
(VAMP, FOAM, ...)

a general object-oriented formalism for supersymmetry processes

I am working on both of these projects.

the current distributions of

pandora and pandora_pythia

can be found from the links

www-sldnt.slac.stanford.edu/
nld/new/Docs/Generators/

GENERATORS.htm
PANDORA.htm
PANDORA_PYTHIA.htm