Snowmass Energy Frontier

ILC Analysis Walkthrough

Daniel Jeans / KEK
Chris Potter / U. Oregon

on behalf of ILC physics & software groups

2020-October-14


beautiful views
&
fresh perspectives
our goal


storm clouds ?
our goal
vertical cliffs?
hidden gullies ?
bears?
snakes ?

hints on how to survive a 2 hour tutorial

1. stay hydrated

2. ask questions at any time

? ? ?

Introduction

http://ilcsnowmass.org/

MC/Simulation Framework Tutorial: ILC

August 28, 2020
US/Eastern timezone

https://indico.fnal.gov/event/45031/

MC/Simulation Framework Tutorial: Whizard for e+e-

September 29, 2020
Asia/Tokyo timezone

https://indico.fnal.gov/event/45413/

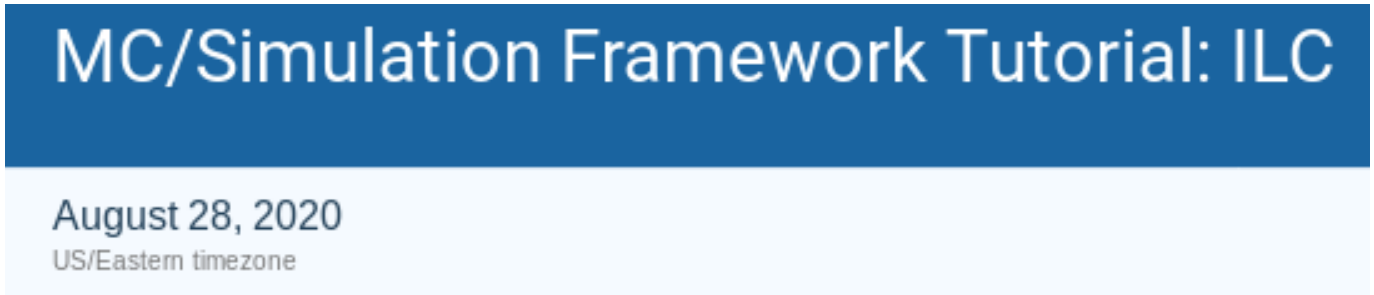
MC/Simulation Framework Tutorial: ILC Analysis Walkthrough

October 14, 2020
US/Eastern timezone

https://indico.fnal.gov/event/45721/

quiz to help us understand you, our audience:

Q. raise your hand if you attended



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Q. raise your hand if you are a post-doc

Q. raise your hand if you are staff / professor

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quiz to help us understand you, our audience:

Q. raise your hand if you have an account on
login.snowmass21.io

there will be some practical examples,
can run from login.snowmass21.io or
your own machine (preferably centos7 + cvmfs)

if you are using your own machine, can you see
/cvmfs/ilc.desy.de/sw/x86_64_gcc82_centos7/v02-02/init_ilcsoft.sh ?
→ if not, do you have lcio and ROOT installed?

quiz to help us understand you, our audience:

write us a zoom message with your physics interest
(whether at ILC or other)

today we'll build on the past tutorials

but we'll try to be self-contained,
so don't worry if you've forgotten some things

→ review how to generate a BSM signal@ILC using WHIZARD [Daniel]

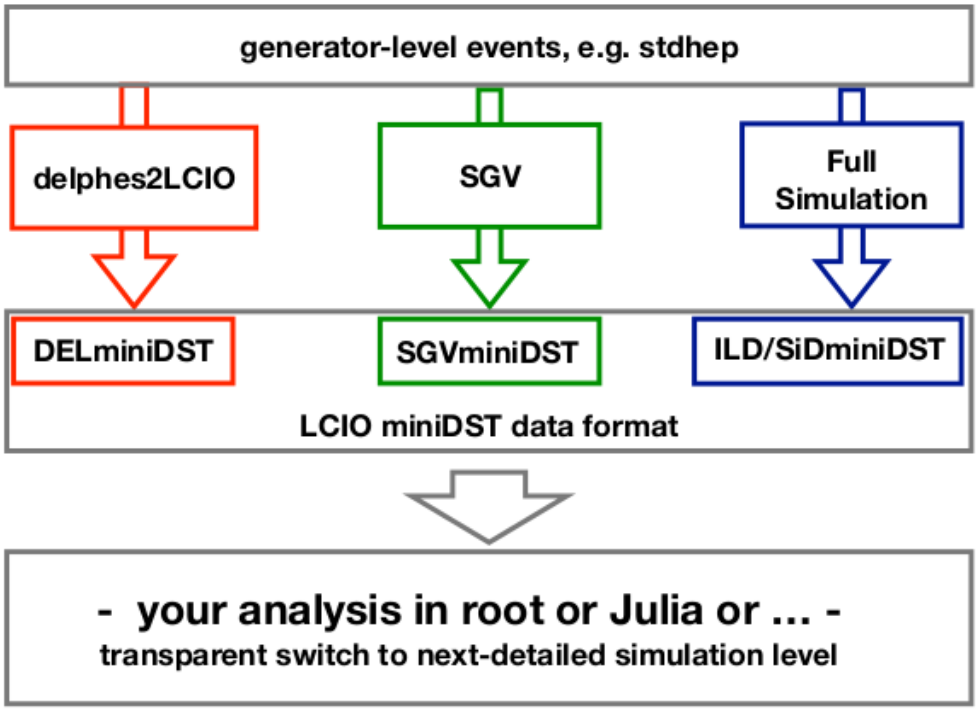
→ how to apply DELPHES ILC detector simulation [Chris]

→ how to analyse those data in ROOT, [Daniel]
get the event information you need
deal with beam polarization and luminosity
estimate SM background

future directions: analysis techniques,
more sophisticated detector simulation, ...

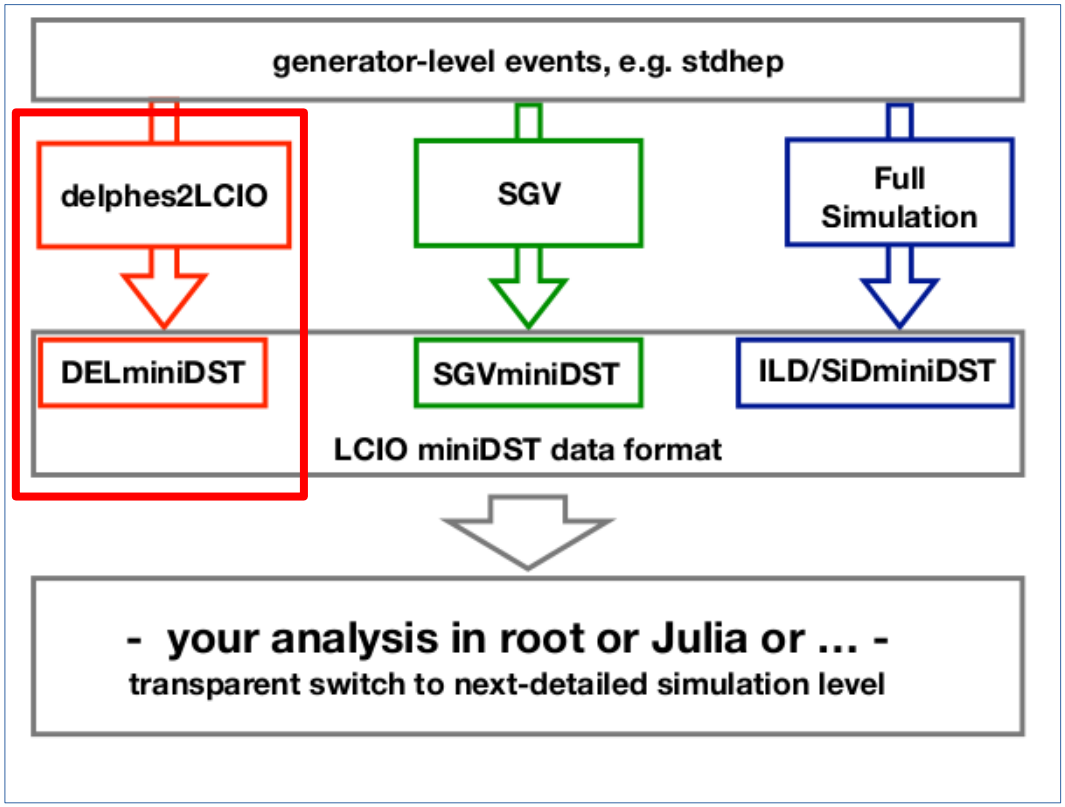
Parametrised, fast and full (=geant4-based) simulations

- **delphes2lcio**: an lcio application which makes Delphes (parametrised detector simulation) write out LCIO (https://github.com/iLCSoft/LCIO/tree/master/examples/cpp/delphes2lcio)
- **SGV**: **S**imulation a **G**rande **V**itesse (https://www.desy.de/~berggren/sgv_ug/sgv_ug.html) - detailed fast simulation from "first principles" (nearly no parametrisations!)
- **iLCSoft** (https://github.com/iLCSoft): software suite for full simulation and reconstruction of ILC & CLIC detectors



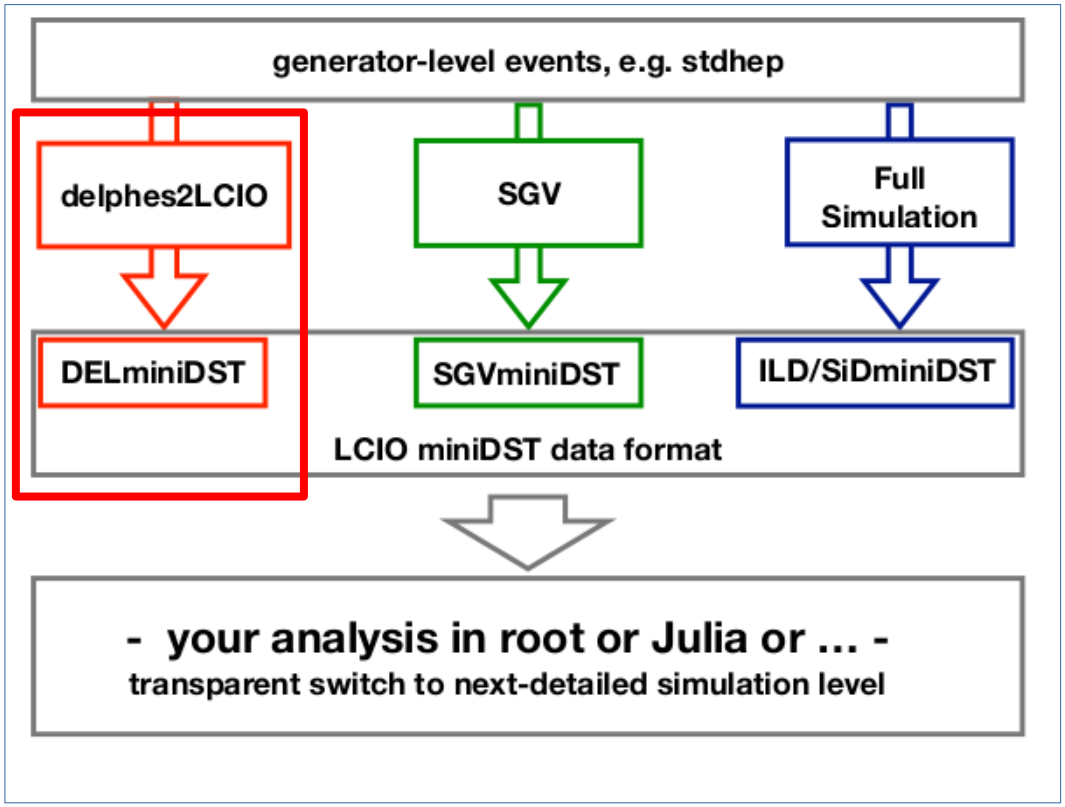
J.List

part 1: WHIZARD



part 1: WHIZARD

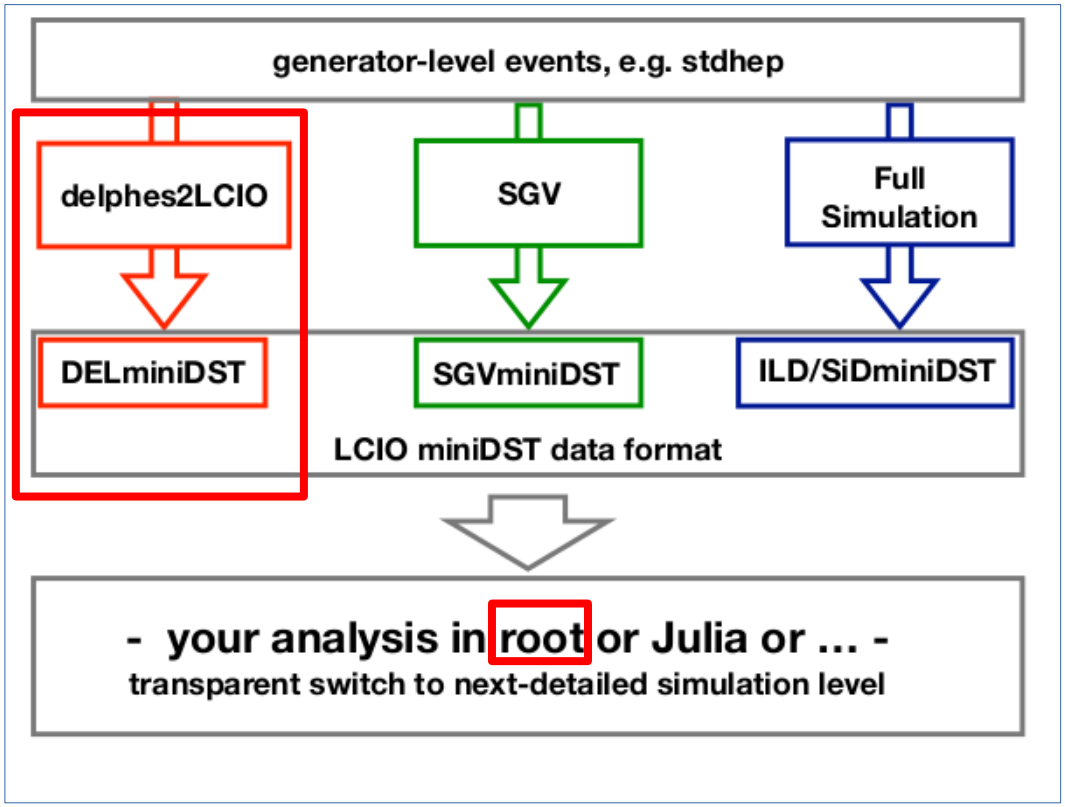
part2: delphes2LCIO



part 1: WHIZARD

part2: delphes2LCIO

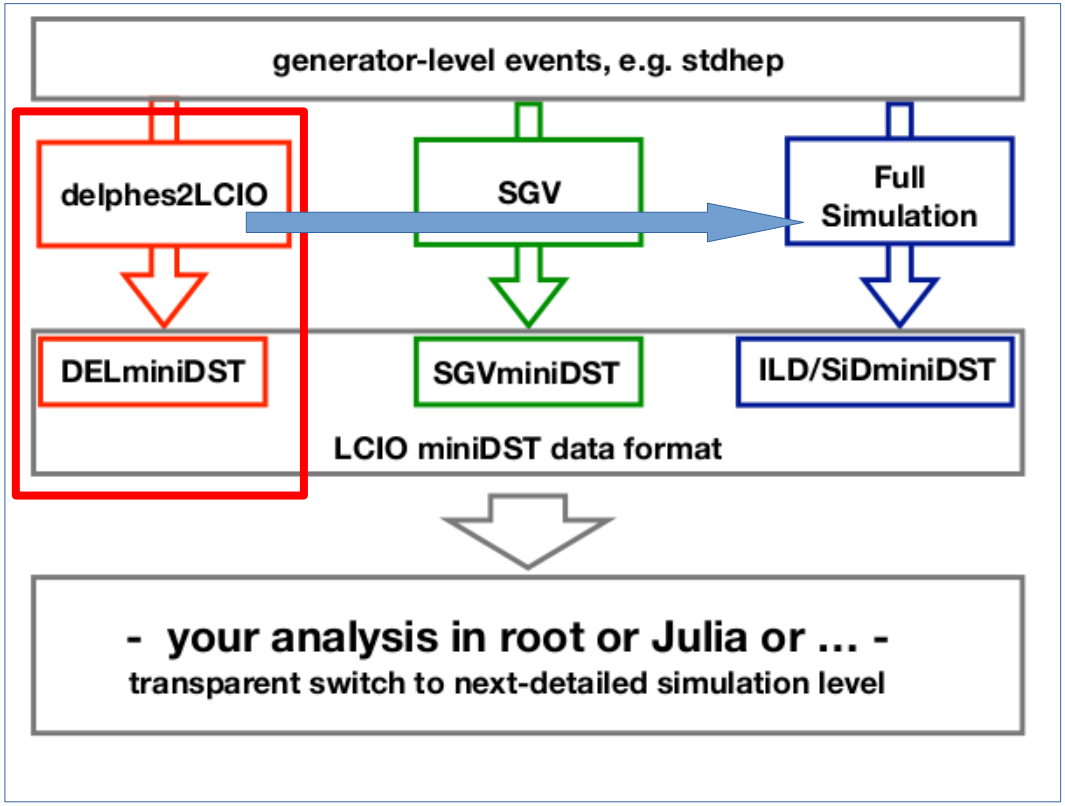
part3: analysis



part 1: WHIZARD

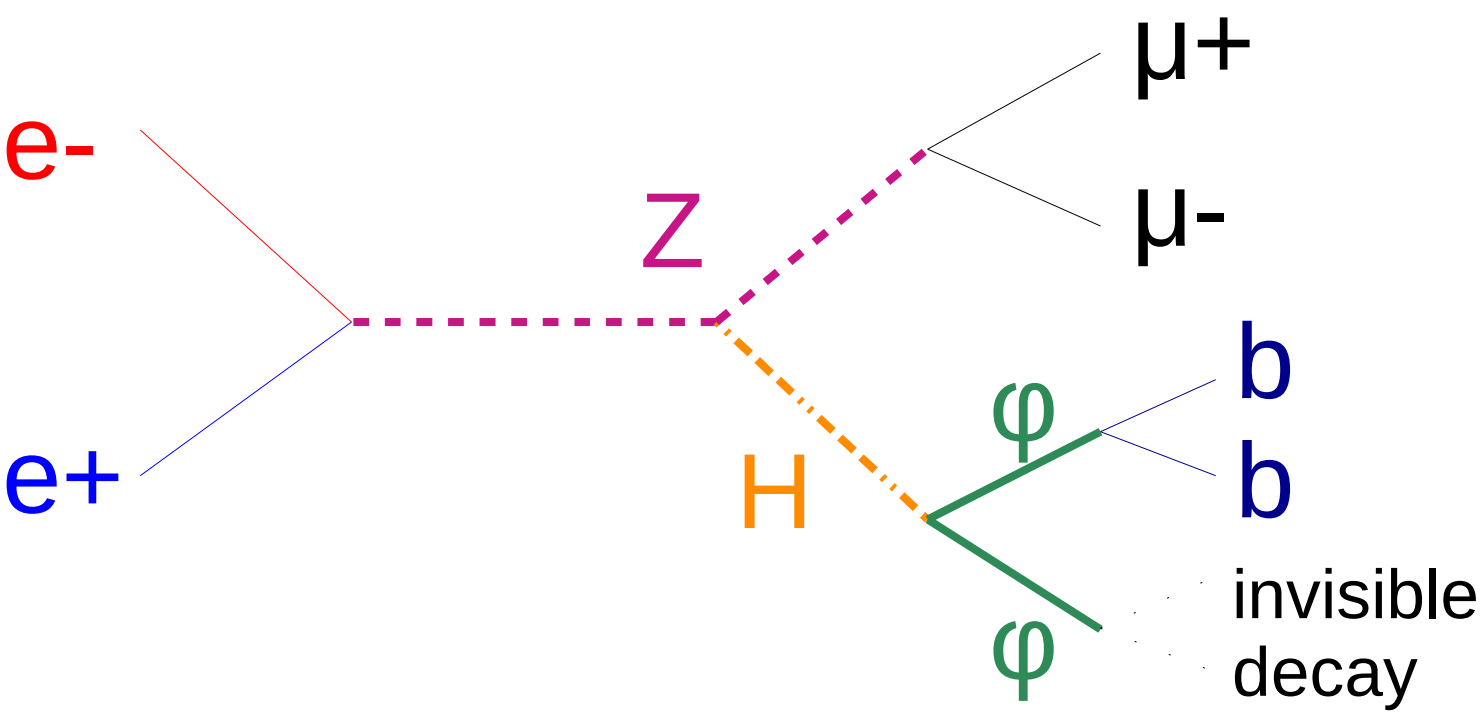
part2: delphes2LCIO

part3: analysis



+ increased realism

today we'll investigate sensitivity to this exotic H decay at ILC-250



φ → some new scalar

part 1: generate the signal

(we'll skip doing this in real time for time reasons)

WHIZARD@e+e- tutorial

https://indico.fnal.gov/event/45413/

https://whizard.hepforge.org/

the WHIZARD steering file (in sindarin)

```
model = "2HDM" (ufo)

!! Show particle content and couplings of '2HDM'
show (model)

mh1 = 125 GeV
mh2 = 40 GeV
mh3 = 40 GeV

process eemumuhh = "e-" , "e+" => "mu+", "mu-", "h2" , "h3" { $restrictions = "3+4~Z && 5+6~h1" }
process h2dec = h2 => "vm" , "vm~", "vt", "vt~"
process h3dec = h3 => "b" , "b~"

unstable h2(h2dec)
unstable h3(h3dec)

?ps_fsr_active = true
?hadronization_active = true
$shower_method = "PYTHIA6"
$ps_PYTHIA_PYGIVE = "MSTJ(28)=2;PMAS(25,1)=2000.0;PMAS(25,2)=10.0;MSTJ(41)=2; MSTU(22)=20; PARJ(21)=0.40000; PARJ(41)=0.11000;
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PARJ(17)=0.17000; MSTP(3)=1; MSTP(125)=2; MWID(25)=2"

beams = "e-", "e+" => circe2 => isr

$circe2_file = "ilc250.circe"
$circe2_design = "ILC"
?circe2_polarized = false

beams_pol_density = @(-1), @(+1)
beams_pol_fraction = 100%, 100%

!! Set α(0) for ISR splitting
isr_mass = 0.5109989500E-03 GeV
isr_alpha = 1/137.035999084

sqrts = 250 GeV

integrate (eemumuhh)

n_events = 10000
$sample = "eeZH_m10_LR"
sample_format = stdhep, lcio

!! Generate events with exclusive ISR photons.
?isr_handler = true
$isr_handler_mode = "recoil"

?keep_remnants = true
?keep_beams = true
?hadronization_active = true

simulate (eemumuhh)
```

```
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show (model)
```

We generate this final state using an existing 2DHM implementation:

https://feynrules.irmp.ucl.ac.be/wiki/2HDM

Whizard can interface to UFO model description:

https://feynrules.irmp.ucl.ac.be/raw-attachment/wiki/2HDM/2HDM_UFO.tar.gz

```
mh1 = 125 GeV
mh2
mh3

proc
proc
proc

unst
unst

?ps_
?had
$sho
$ps_
PARJ(42)=0.52000; PARJ(81)=0.25000;PARJ(82)=1.90000; MSTJ(11)=3; PARJ(54)=-0.03100; PARJ(55)=-0.00200;PARJ(1)=0.08500; PARJ(3)=0.45000;
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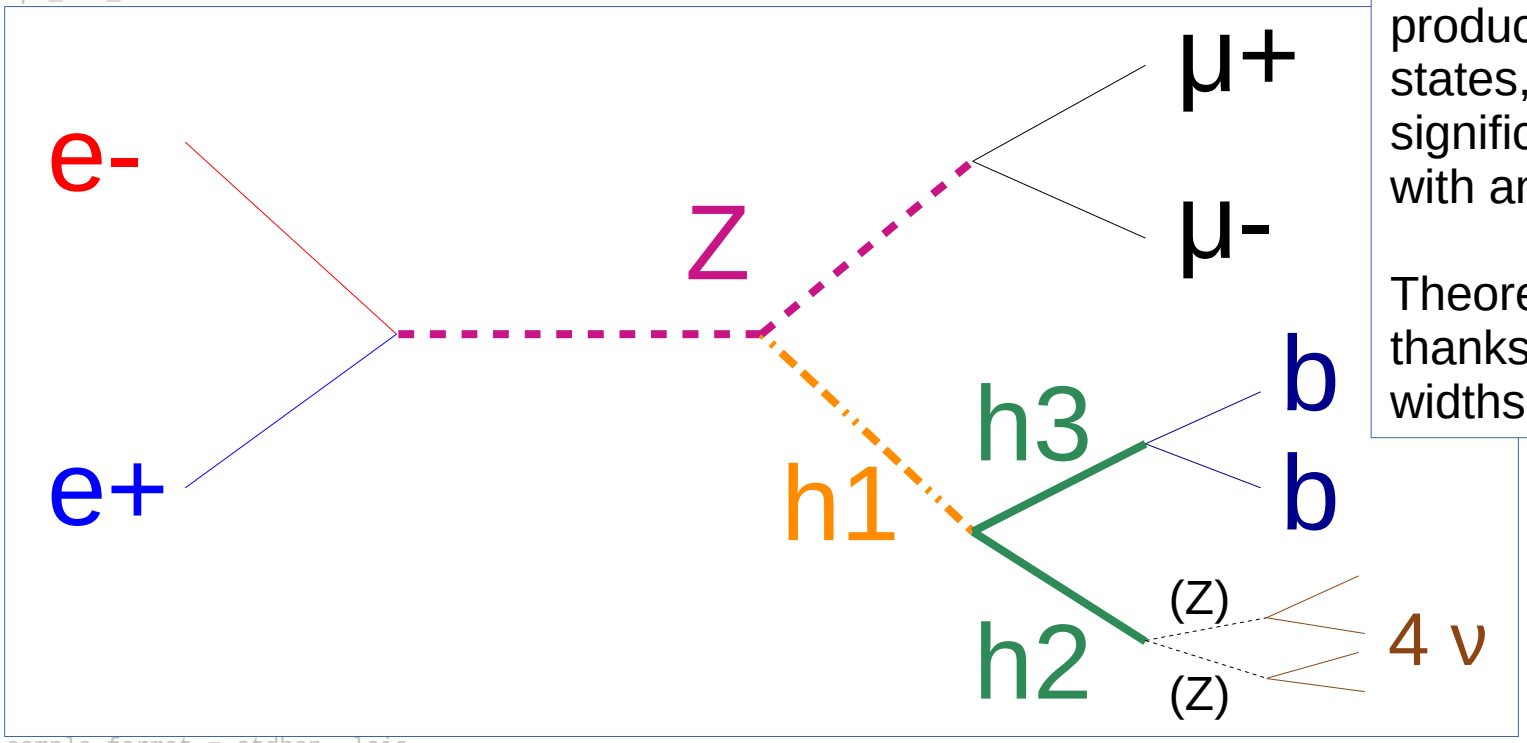
unstable h2(h2dec)
unstable h3(h3dec)

?ps_fsr_active = true
```

1 2 3 4 5 6



Hack # 1:
WHIZARD can directly produce full 8-fermion final states, but here it's significantly faster to split up with an intermediate stage.

Theoretically sort of OK here, thanks to narrow higgs boson widths

Hack # 2:
to force the two new scalars to decay in different ways, we pretend they are different particles

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```

use PYTHIA6 for
Final State Radiation and
hadronisation

The parameters are the so-called
"OPAL-tune" of hadronization parameters,
determined from LEP data

```
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```

not all collisions will be at exactly 250 GeV

```
beams = "e-", "e+" => circe2 => isr
```

beam energy spectrum (by CIRCE2)
+ Initial State Radiation

```
$circe2_file = "ilc250.circe"
$circe2_design = "ILC"
?circe2_polarized = false
```

ILC250 beam energy spectrum

```
beams_pol_density = @(-1), @(+1)
beams_pol_fraction = 100%, 100%
```

beam polarisation
100% left-handed electron
100% right-handed positron

```
!! Set α(0) for ISR splitting
isr_mass = 0.5109989500E-03 GeV
isr_alpha = 1/137.035999084
```

details for ISR

```
sqrts = 250 GeV
```

nominal center-of-mass energy

```
integrate (eemumuhh)

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```

simulate ISR with p_T

```
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simulate (eemumuhh)
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?keep_remnants = true
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?hadronization_active = true

simulate (eemumuhh)
```

# of events

output filename

output format(s)

do it!

detailed instructions to (re-)create signal samples [for offline reference]

```
mkdir runWhizard
cd runWhizard

# set up environment for whizard (here on login.snowmass21.io)
source /local-scratch/software/ee_gen/bin/ee_gen_setenv.sh

# get the UFO model for 2HDM model that we'll use
wget https://feynrules.irmp.ucl.ac.be/raw-attachment/wiki/2HDM/2HDM_UFO.tar.gz
tar fvxz ./2HDM_UFO.tar.gz

# run whizard
#  (look at the sindarin steering file we've just gone through,
#    adjust parameters such as masses, beam polarization, ...)
whizard my_steering_file.sin

# we've asked events to be output in 2 formats:
#   eeZH_m10_LR.slcio (slcio) & eeZH_m10_LR.hep (stdhep)
# check event #3 from lcio file
dumpevent eeZH_m10_LR.slcio 3
```


all in `/local-scratch/software/ilc_walkthrough/runWhizard`

part 2. [Chris]

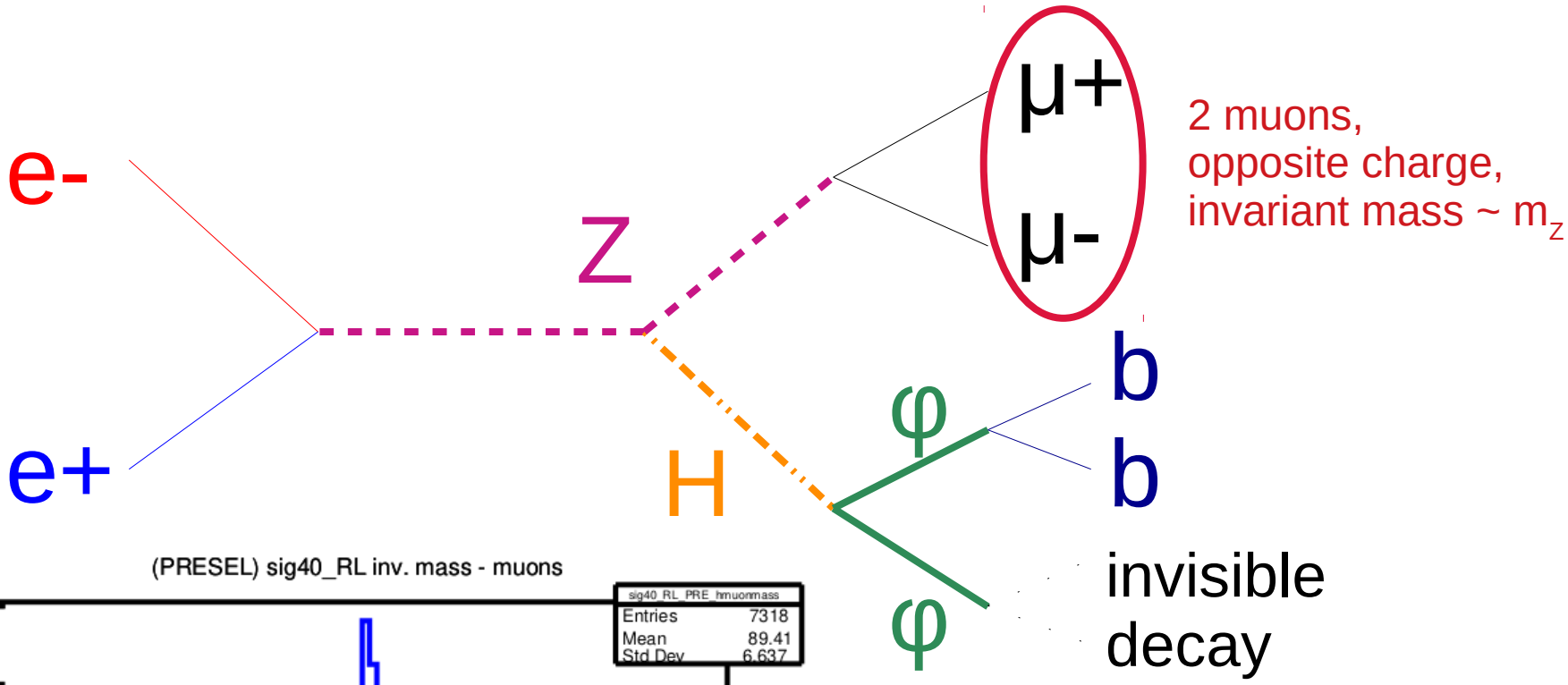
detector simulation using DELPHES

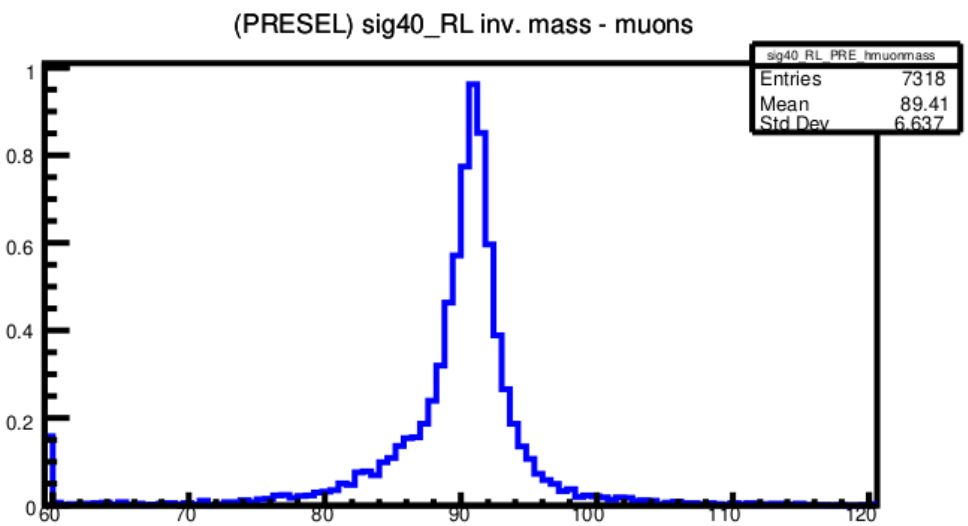
→ miniDST lcio files

part 3.

a simple analysis to look for this signal

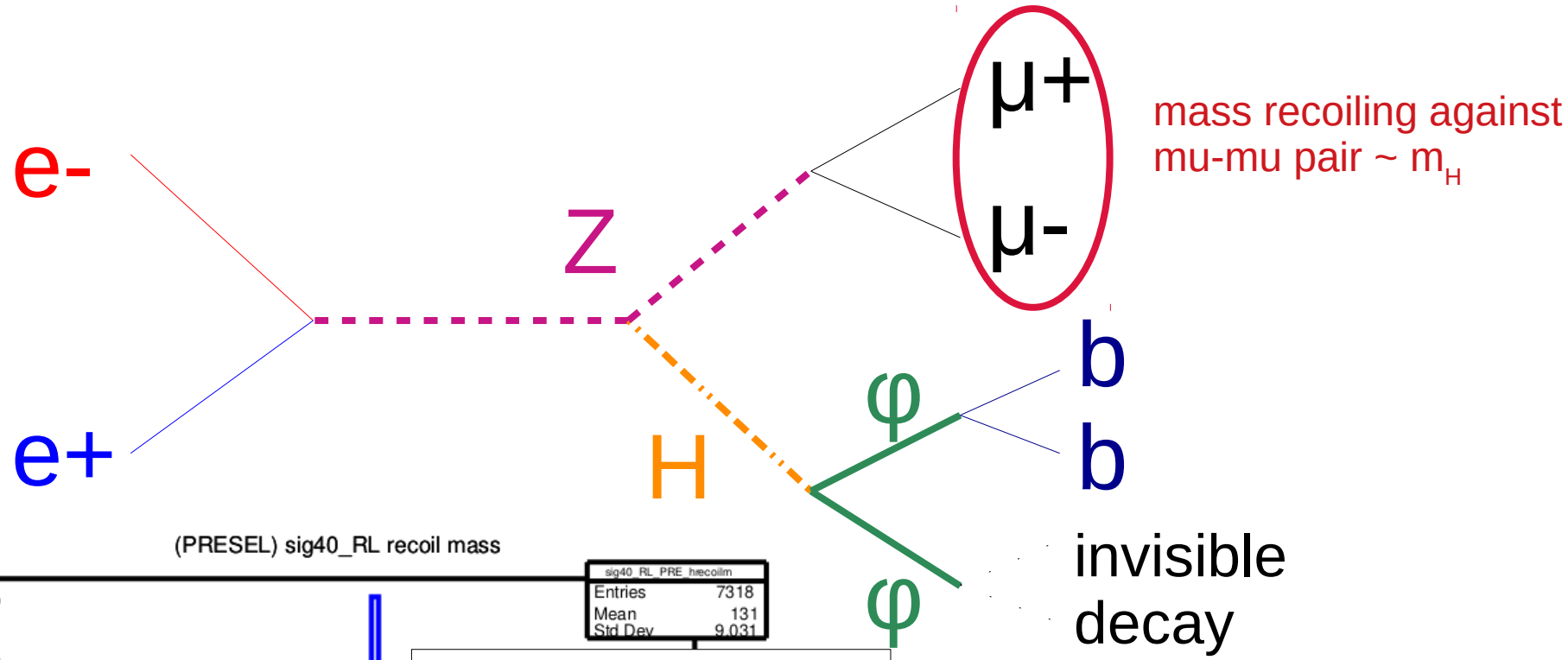
signal properties

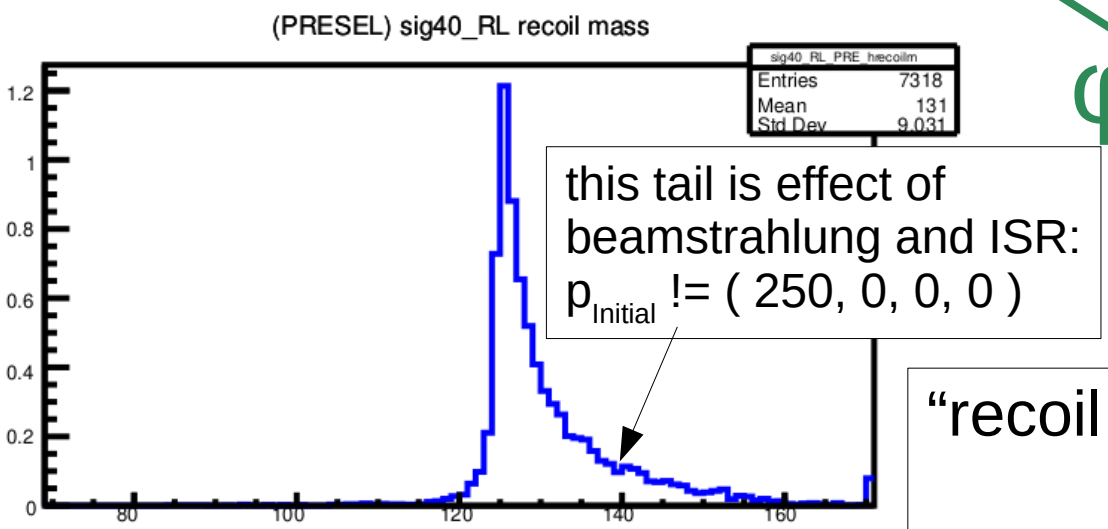




mu+ – mu- invariant mass

signal properties





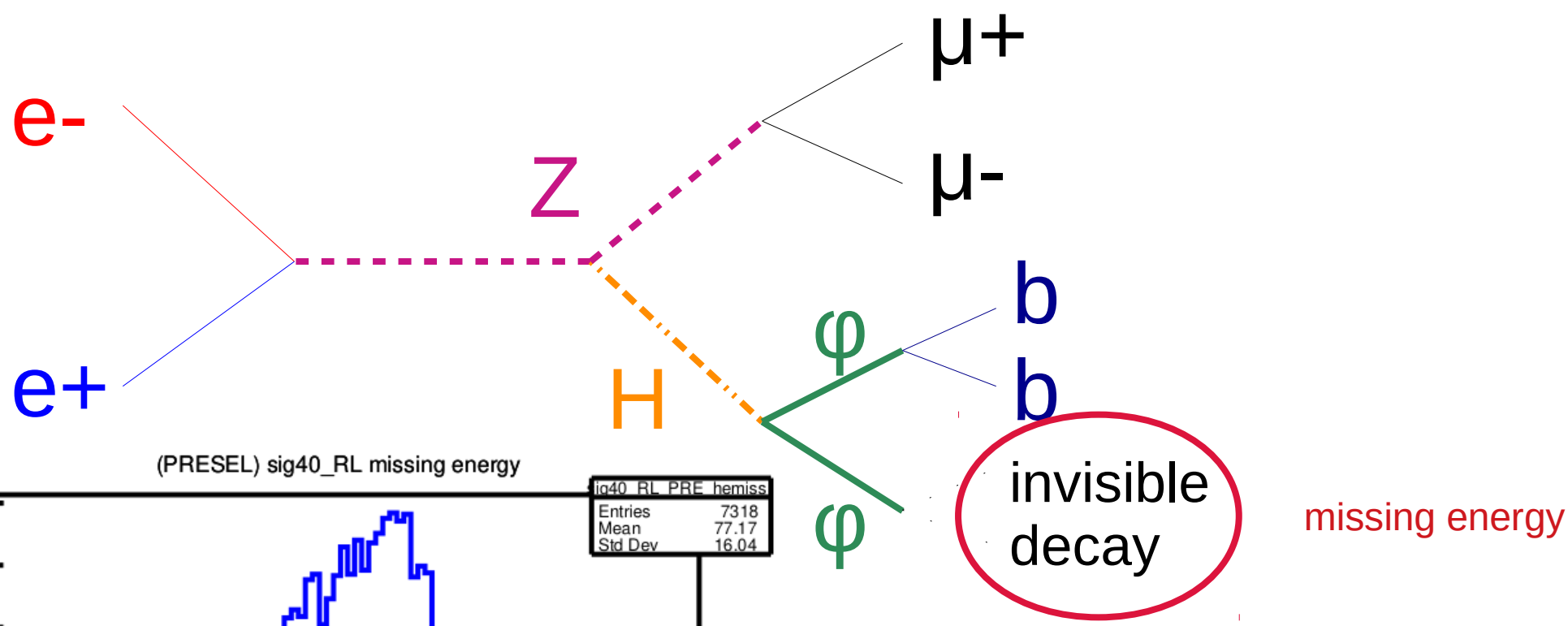
this tail is effect of beamstrahlung and ISR: $p_{Initial}$!= (250, 0, 0, 0)

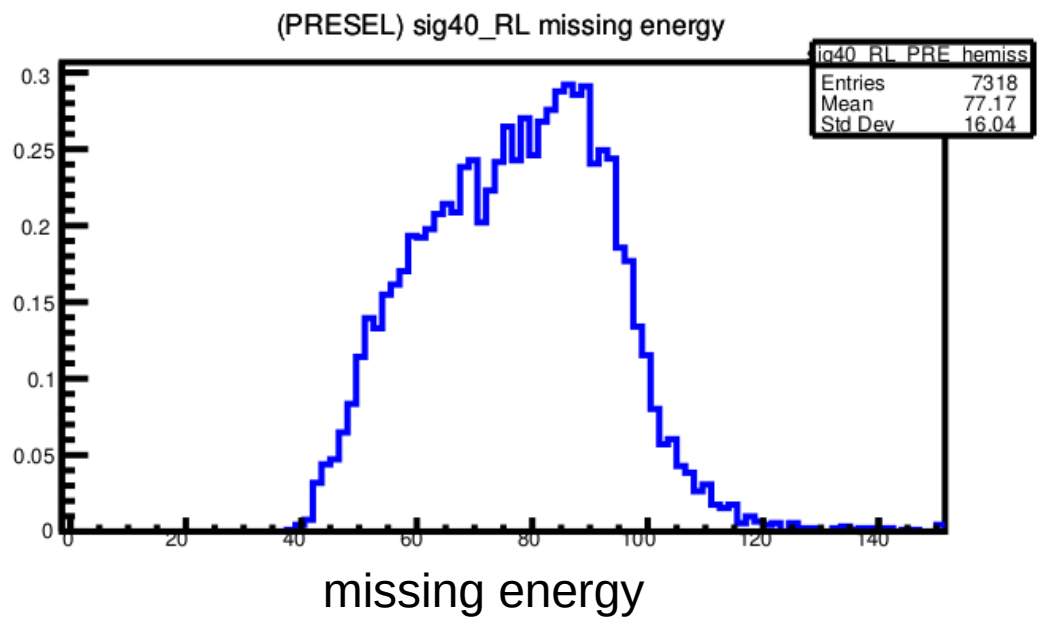
mass recoiling against mu-mu

"recoil mass" = ($p_{Initial}$ – p_Z).Mass()

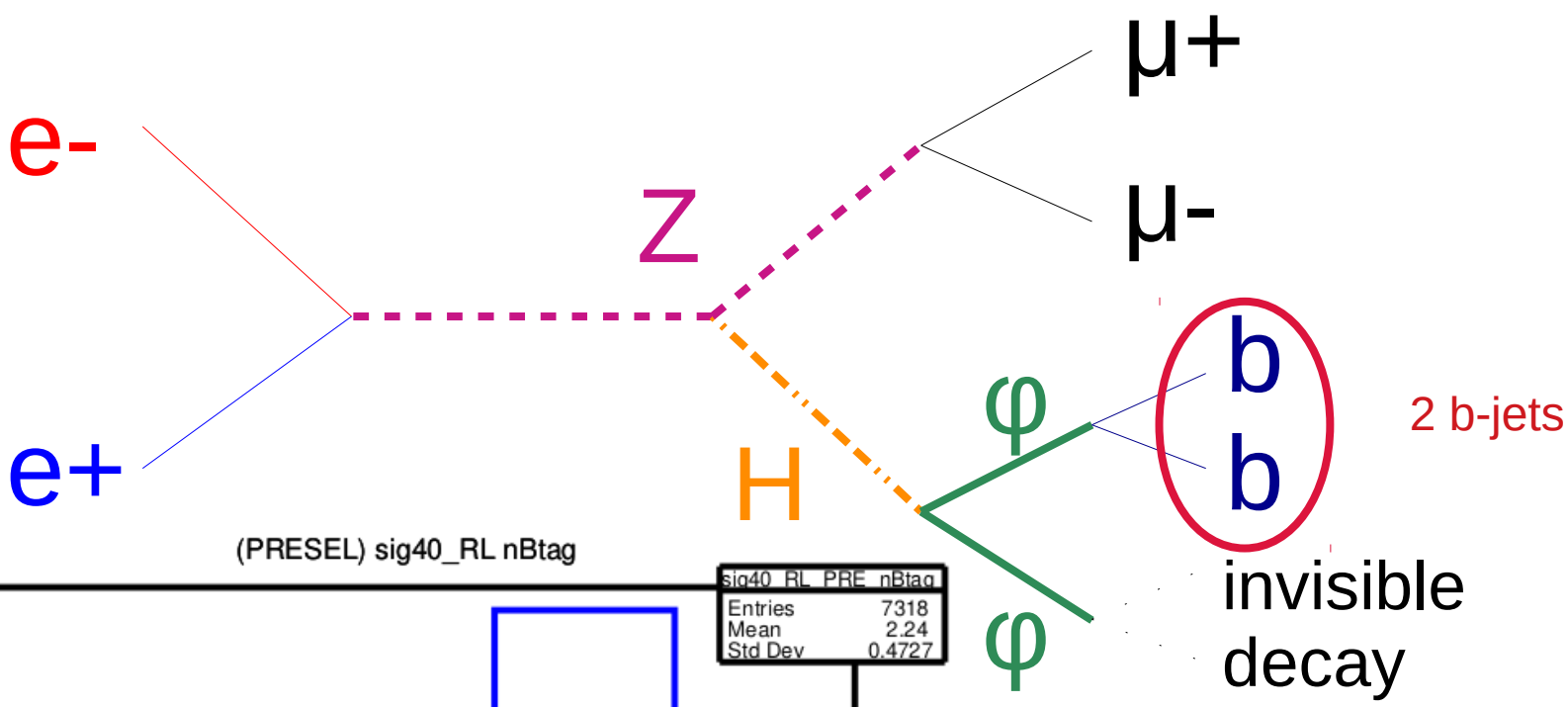
$p_{Initial}$ = (250, 0, 0, 0)

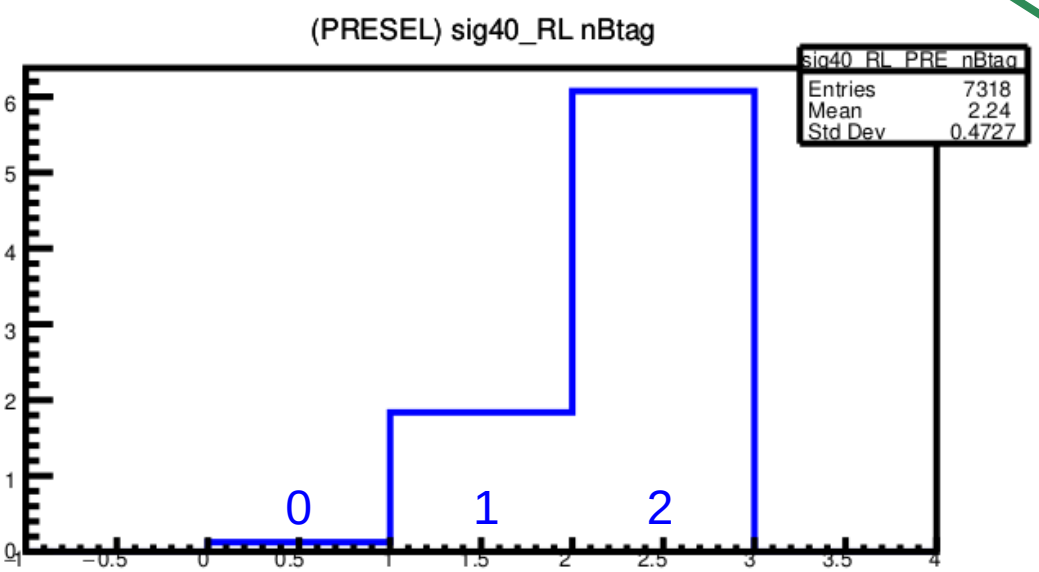
signal properties





signal properties

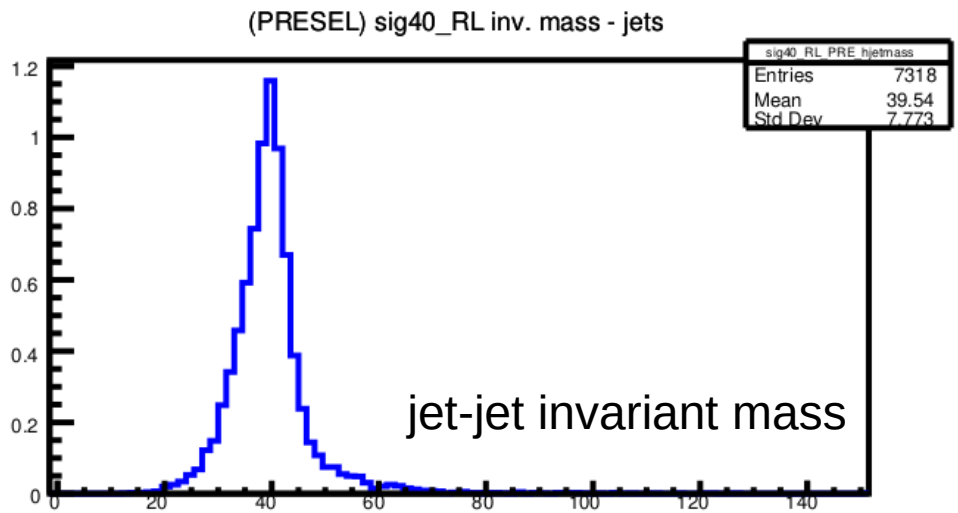


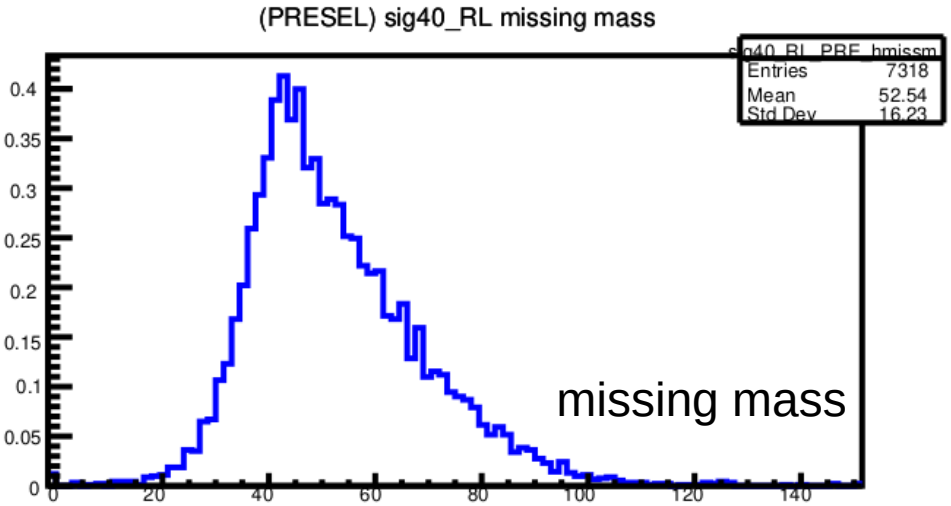


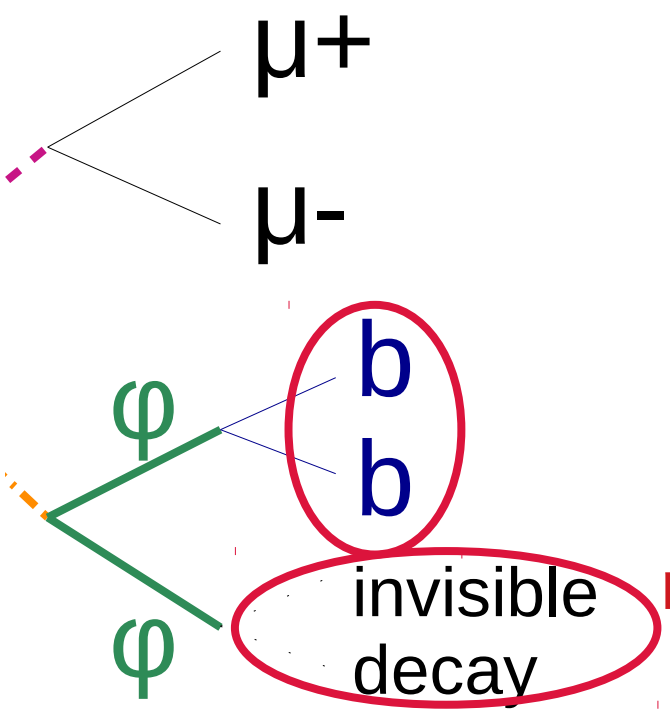
number of b-tagged jets

signal properties

$$\text{“missing mass”} = (p_{Initial} - p_Z - p_{bb}).\text{Mass}()$$

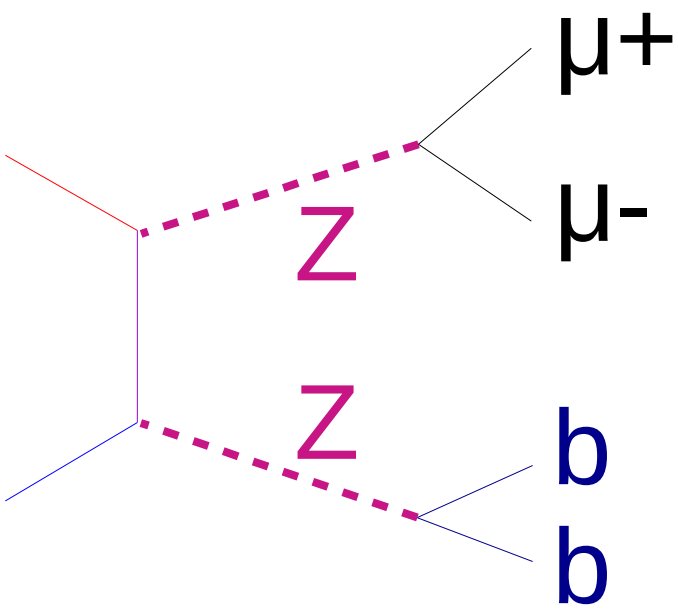


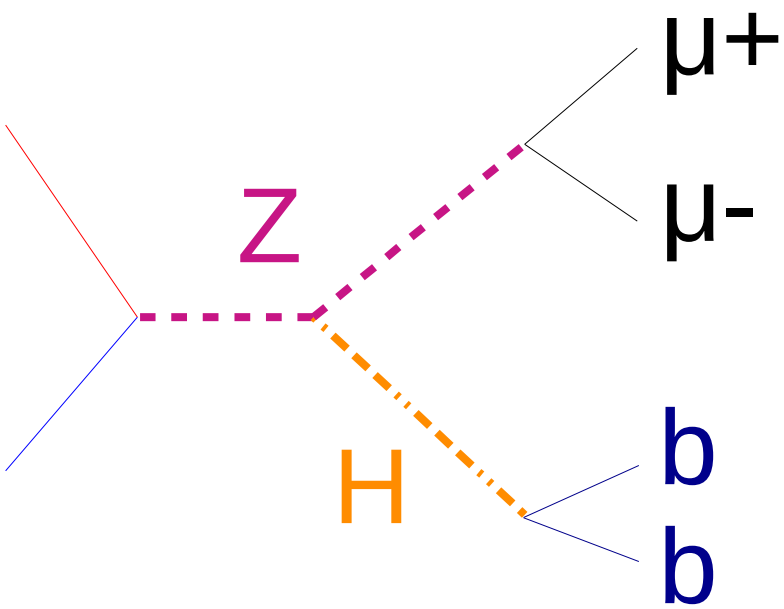




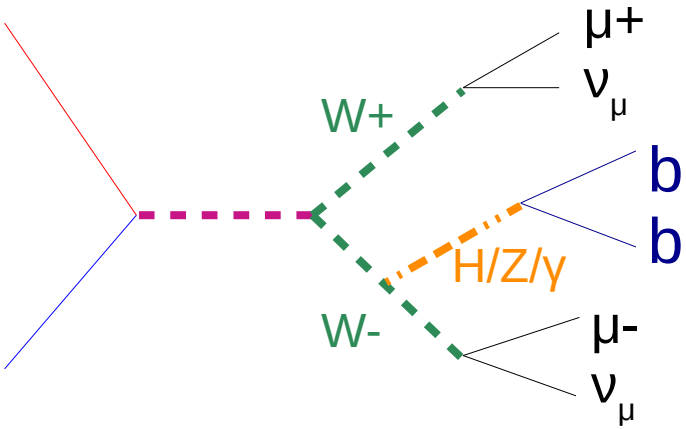
b-b mass
~
missing mass

major SM backgrounds





SM 6-f backgrounds have small x-sec at ILC-250: ignore for this exercise



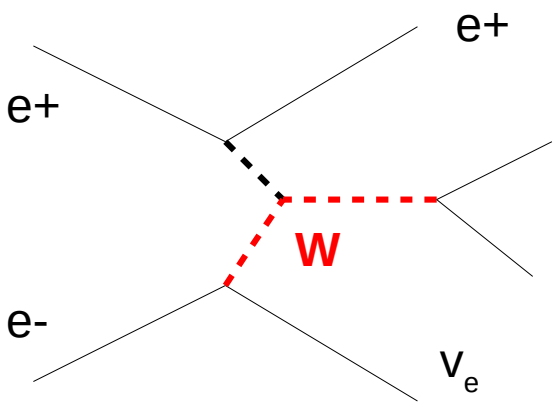
grouping & naming of SM 4-f processes

- all tree-level diagrams contributing to a particular final state are considered
  [except Higgs → these are in dedicated samples]
- similar final state combinations are grouped together

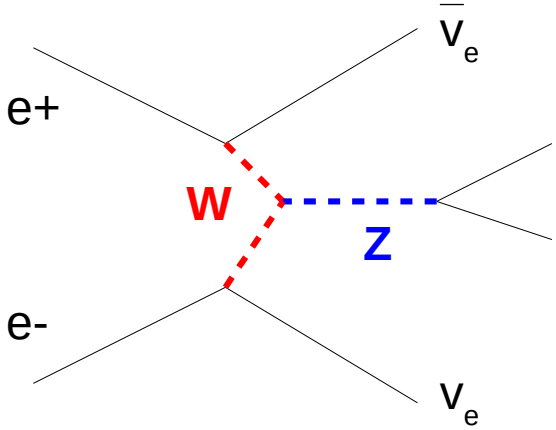
in order of priority:

name	final state which **could** be produced by	**example**
szeorsw	single-W **or** single-Z	e+ ν_e e- $\bar{\nu}_e$
sze	single-Z (with e)	e+ e- μ+ μ-
sznu	single-Z (with ν_e)	μ+ ν_e μ- $\bar{\nu}_e$
sw	single-W	e+ ν_e μ- $\bar{\nu}_\mu$
zzorww	ZZ **or** WW	μ- $\bar{\nu}_\mu$ μ+ ν_μ
zz	ZZ	μ- μ+ $\bar{\nu}_{tau}$ ν_{tau}
ww	WW	μ- $\bar{\nu}_\mu$ τ+ ν_{tau}

h = fully hadronic = 4 quarks
l = fully leptonic = 4 leptons
sl = semi-leptonic = 2 quarks, 2 leptons



example of "single-W" diagram



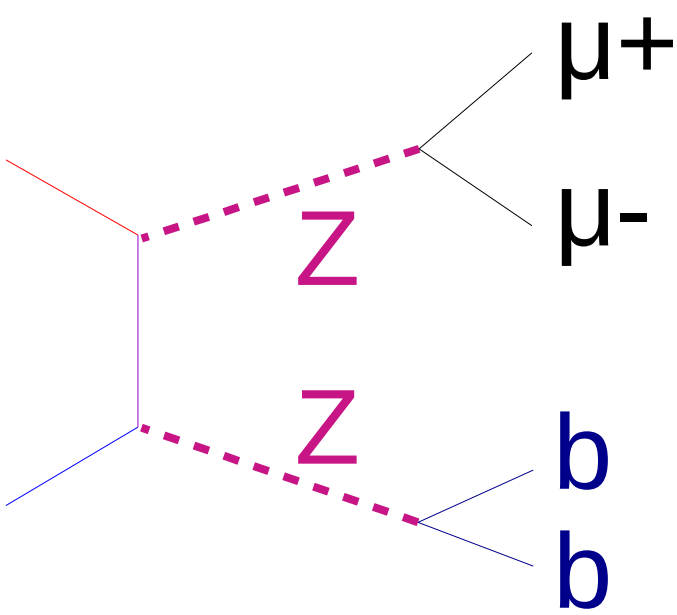
example of "single-Z" diagram

grouping & naming of SM 4-f processes

- all tree-level diagrams contributing to a particular final state
  [except Higgs → these are in dedicated samples]
- similar final state combinations are grouped together

name	final state which **could** be produced by	**example**
szeorsw	single-W **or** single-Z	$e+\ \nu_e\ e-\ \bar{\nu}_e$
sze	single-Z (with e)	$e+\ e-\ \mu+\ \mu-$
sznu	single-Z (with ν_e)	$\mu+\ \nu_e\ \mu-\ \bar{\nu}_e$
sw	single-W	$e+\ \nu_e\ \mu-\ \bar{\nu}_\mu$
zzorww	ZZ **or** WW	$\mu-\ \bar{\nu}_\mu\ \mu+\ \nu_\mu$
zz	ZZ	$\mu-\ \mu+\ \bar{\nu}_{tau}\ \nu_{tau}$
ww	WW	$\mu-\ \bar{\nu}_\mu\ \tau+\ \nu_{tau}$

_h = fully hadronic = 4 quarks
_l = fully leptonic = 4 leptons
_sl = semi-leptonic = 2 quarks, 2 leptons



our major background has 4 fermions (2-leptons, 2-hadrons) in “ZZ”-like combination

→ **zz_sl**

location of SM data (DELPHES miniDST)

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/

E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eR.pL.I106576.???.stdhep.delphes_card_ILCgen.tcl.slcio
E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eL.pR.I106575.???.stdhep.delphes_card_ILCgen.tcl.slcio

CM energy
beam parameters

process name

beam
polarisation

delphes model

also have SM higgs background

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/higgs

E250-TDR_ws.Pe2e2h.Gwhizard-1_95.eL.pR.I106479.001.stdhep.delphes_card_ILCgen.tcl.slcio
E250-TDR_ws.Pe2e2h.Gwhizard-1_95.eR.pL.I106480.001.stdhep.delphes_card_ILCgen.tcl.slcio

"e2e2h" = μ- μ+ h

n.b. many, but not all, samples have zero x-sec for eL.pL and eR.pR

let’s get the data

SM background files

on login.snowmass21.io they are already at
/collab/project/snowmass21/data/ilc/analysis-walkthrough/backgrounds/

if you are **not** on login.snowmass21.io , download these to a dedicated directory (e.g. ~/snow_walk_data)

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eL.pR.I106575.001.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eL.pR.I106575.002.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eL.pR.I106575.003.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eL.pR.I106575.004.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eL.pR.I106575.004.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eR.pL.I106576.001.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eR.pL.I106576.002.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eR.pL.I106576.003.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eR.pL.I106576.004.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/4f/E250-TDR_ws.P4f_zz_sl.Gwhizard-1_95.eR.pL.I106576.005.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/higgs/E250-TDR_ws.Pe2e2h.Gwhizard-1_95.eL.pR.I106479.001.stdhep.delphes_card_ILCgen.tcl.slcio

http://osggridftp02.slac.stanford.edu:8080/sdf/group/lcddata/ilc/user/c/cpotter/mc-dbd/delphes/miniDST/250-TDR_ws/higgs/E250-TDR_ws.Pe2e2h.Gwhizard-1_95.eR.pL.I106480.001.stdhep.delphes_card_ILCgen.tcl.slcio

BSM signal files

on login.snowmass21.io they are at

/collab/project/snowmass21/data/ilc/analysis-walkthrough/signal/miniDST-delphes

otherwise, download from https://research.kek.jp/people/jeans/snowmassSignal/

https://research.kek.jp/people/jeans/snowmassSignal/eeZH_m10_LR.delphes.slcio https://research.kek.jp/people/jeans/snowmassSignal/eeZH_m10_RL.delphes.slcio	m_φ = 10 GeV
https://research.kek.jp/people/jeans/snowmassSignal/eeZH_m20_LR.delphes.slcio https://research.kek.jp/people/jeans/snowmassSignal/eeZH_m20_RL.delphes.slcio	m_φ = 20 GeV
https://research.kek.jp/people/jeans/snowmassSignal/eeZH_m30_LR.delphes.slcio https://research.kek.jp/people/jeans/snowmassSignal/eeZH_m30_RL.delphes.slcio	m_φ = 30 GeV
https://research.kek.jp/people/jeans/snowmassSignal/eeZH_m40_LR.delphes.slcio https://research.kek.jp/people/jeans/snowmassSignal/eeZH_m40_RL.delphes.slcio	m_φ = 40 GeV

let’s look in one of the signal miniDST files

```
anajob eeZH_m30_RL.delphes.slcio | head -40
```

https://github.com/iLCSoft/ILCDelphes/blob/master/doc/Data.md

```
$ anajob eeZH_m30_RL.delphes.slcio | head -40

.
.
.
//////////////////////////////////
EVENT: 1
RUN: 0
DETECTOR: unknown
COLLECTIONS: (see below)
//////////////////////////////////

-------------------------------------------------------------------------
COLLECTION NAME                COLLECTION TYPE          NUMBER OF ELEMENTS
=========================================================================
Durham2Jets                    ReconstructedParticle            2
Durham3Jets                    ReconstructedParticle            3
Durham4Jets                    ReconstructedParticle            4
Durham5Jets                    ReconstructedParticle            5
Durham6Jets                    ReconstructedParticle            6
IsolatedElectrons              ReconstructedParticle            0
IsolatedMuons                  ReconstructedParticle            2
IsolatedPhotons                ReconstructedParticle            1
Jets                           ReconstructedParticle            1
MCParticles                    MCParticle                      95
MCTruthRecoLink                LCRelation                      32
PFOs                           ReconstructedParticle           32
RecoMCTruthLink                LCRelation                      32
-------------------------------------------------------------------------
```

MC particles

```
$ anajob eeZH_m30_RL.delphes.slcio | head -40

.
.
.
//////////////////////////////////
EVENT: 1
RUN: 0
DETECTOR: unknown
COLLECTIONS: (see below)
//////////////////////////////////

-------------------------------------------------------------------------
COLLECTION NAME                COLLECTION TYPE          NUMBER OF ELEMENTS
=========================================================================
Durham2Jets                    ReconstructedParticle            2
Durham3Jets                    ReconstructedParticle            3
Durham4Jets                    ReconstructedParticle            4
Durham5Jets                    ReconstructedParticle            5
Durham6Jets                    ReconstructedParticle            6
IsolatedElectrons              ReconstructedParticle            0
IsolatedMuons                  ReconstructedParticle            2
IsolatedPhotons                ReconstructedParticle            1
Jets                           ReconstructedParticle            1
MCParticles                    MCParticle                      95
MCTruthRecoLink                LCRelation                      32
PFOs                           ReconstructedParticle           32
RecoMCTruthLink                LCRelation                      32
-------------------------------------------------------------------
```

reconstructed particles
= Particle Flow Objects
PFOs

```
$ anajob eeZH_m30_RL.delphes.slcio | head -40

.
.
.
//////////////////////////////////
EVENT: 1
RUN: 0
DETECTOR: unknown
COLLECTIONS: (see below)
//////////////////////////////////

-------------------------------------------------------------------------
COLLECTION NAME                COLLECTION TYPE          NUMBER OF ELEMENTS
=========================================================================
Durham2Jets                    ReconstructedParticle            2
Durham3Jets                    ReconstructedParticle            3
Durham4Jets                    ReconstructedParticle            4
Durham5Jets                    ReconstructedParticle            5
Durham6Jets                    ReconstructedParticle            6
IsolatedElectrons              ReconstructedParticle            0
IsolatedMuons                  ReconstructedParticle            2
IsolatedPhotons                ReconstructedParticle            1
Jets                           ReconstructedParticle            1
MCParticles                    MCParticle                      95
MCTruthRecoLink                LCRelation                      32
PFOs                           ReconstructedParticle           32
RecoMCTruthLink                LCRelation                      32
-------------------------------------------------------------------------
```

associations between MC and PFOs in both directions

```
$ anajob eeZH_m30_RL.delphes.slcio | head -40

.
.
.
//////////////////////////////////
EVENT: 1
RUN: 0
DETECTOR: unknown
COLLECTIONS: (see below)
//////////////////////////////////

-------------------------------------------------------------------------
COLLECTION NAME                COLLECTION TYPE          NUMBER OF ELEMENTS
=========================================================================
Durham2Jets                    ReconstructedParticle            2
Durham3Jets                    ReconstructedParticle            3
Durham4Jets                    ReconstructedParticle            4
Durham5Jets                    ReconstructedParticle            5
Durham6Jets                    ReconstructedParticle            6
IsolatedElectrons              ReconstructedParticle            0
IsolatedMuons                  ReconstructedParticle            2
IsolatedPhotons                ReconstructedParticle            1
Jets                           ReconstructedParticle            1
MCParticles                    MCParticle                      95
MCTruthRecoLink                LCRelation                      32
PFOs                           ReconstructedParticle           32
RecoMCTruthLink                LCRelation                      32
-------------------------------------------------------------------------
```

PFOs identified as isolated e, mu, gamma

```
$ anajob eeZH_m30_RL.delphes.slcio | head -40

.
.
.
//////////////////////////////////
EVENT: 1
RUN: 0
DETECTOR: unknown
COLLECTIONS: (see below)
//////////////////////////////////

-------------------------------------------------------------------------
COLLECTION NAME                COLLECTION TYPE          NUMBER OF ELEMENTS
=========================================================================
Durham2Jets                    ReconstructedParticle            2
Durham3Jets                    ReconstructedParticle            3
Durham4Jets                    ReconstructedParticle            4
Durham5Jets                    ReconstructedParticle            5
Durham6Jets                    ReconstructedParticle            6
IsolatedElectrons              ReconstructedParticle            0
IsolatedMuons                  ReconstructedParticle            2
IsolatedPhotons                ReconstructedParticle            1
Jets                           ReconstructedParticle            1
MCParticles                    MCParticle                      95
MCTruthRecoLink                LCRelation                      32
PFOs                           ReconstructedParticle           32
RecoMCTruthLink                LCRelation                      32
-------------------------------------------------------------------------
```

remaining PFOs clustered into 2 → 6 jets using Durham algorithm

remaining PFOs clustered by anti-k_T algorithm, R=1 and $p_T$min= 5 GeV

set up your environment

1. setup ilcsoft:

```
source /cvmfs/ilc.desy.de/sw/x86_64_gcc82_centos7/v02-02/init_ilcsoft.sh
```

(actually, only ROOT and LCIO are needed for this example)

2. change to a new directory

```
mkdir run_walk ; cd run_walk
```

[don't try to run before you can walk]

3. get the example analysis script:

on login.snowmass21.io :

```
cp /local-scratch/software/ilc_walkthrough/tutorial-code/walkthrough_ana.C .
```

otherwise

```
wget https://research.kek.jp/people/jeans/snowmassSignal/walkthrough_ana.C
```

4. create file

`rootlogon.C`

with this content:

```
{
  gInterpreter->AddIncludePath("$LCIO");
  gSystem->Load("${LCIO}/lib/liblcio.so");
  gSystem->Load("${LCIO}/lib/liblcioDict.so");
}
```

5. if not running on login.snowmass21.io
specify the data directory for signal files:
edit these lines in `walkthrough_ana.C`

```
TString inputDir_SIGNAL = "...";
TString inputDir_BACKGD = "...";
```

6. now let's compile and run the script

```
$ root -b
   ------------------------------------------------------------
  | Welcome to ROOT 6.18/04                  https://root.cern |
  |                                (c) 1995-2019, The ROOT Team |
  | Built for linuxx8664gcc on Sep 11 2019, 15:38:23           |
  | From tags/v6-18-04@v6-18-04                                |
  | Try '.help', '.demo', '.license', '.credits', '.quit'/'.q' |
   ------------------------------------------------------------

root [0] .L walkthrough_ana.C+
Info in <TUnixSystem::ACLiC>: creating shared library /././walkthrough_ana_C.so
root [1] runall(1000)
```

I won't help you if you don't compile your (non-trivial) root macros !

1000=max. events/process
(to speed things up)
default (0) is to use all events

→ creates * plots in walkthrough.pdf,
* histograms in walkthrough.root and
* selection efficiency tables to stdout

let’s look at the code in a bit more detail

```
std::vector <TH1F*> analyse_process( TString nickname, std::vector <TString> fnames, int minDstFlavour ) {
```

this runs over files / events of a given process,

- gets event information
- calculates kinematic variables (at MC and reconstructed level)
- defines and fills histograms
- applies simple cut-based event selection

```
void runall(int _maxevt=1000) {
```

specify files for signal and background processes
calls analyse_process for each
gives appropriate weights to samples (polarisation and integrated luminosity)
calculates & displays signal efficiencies and backgrounds after selection

accessing MC information

$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

```
$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less
```

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

the nominal beam electron & positron

```
$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less
```

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

the beam electron & positron **w/ beam energy spectrum**

```
$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less
```

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

beam electron & positron **after ISR**

$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

the ISR photons

```
$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less
```

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

the two muons

```
$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less
```

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

the neutrinos from the invisible new scalar decay

```
$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less
```

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

the b quarks from the other scalar decay

```
$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less
```

```
 collection name : MCParticles
 parameters:

--------------- print out of MCParticle collection ---------------

  flag:  0x0
  simulator status bits: [sbvtcls]  s: created in simulation b: backscatter v: vertex is not endpoint of parent t: decayed in
tracker c: decayed in calorimeter l: has left detector s: stopped o: ove\
rlay


[   id   ]index|      PDG |    px,     py,        pz    |...| energy  |gen|...|    mass |...| [parents] - [daughters]

[00000073]    0|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000074]    1|       -11| 0.00e+00, 0.00e+00,-1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [] - [2,3]
[00000075]    2|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [0,1] - [4,8]
[00000076]    3|       -11| 0.00e+00, 0.00e+00,-1.23e+02|...| 1.23e+02| 2 |...| 0.00e+00|...| [0,1] - [5,9]
[00000077]    4|        11| 0.00e+00, 0.00e+00, 1.25e+02|...| 1.25e+02| 2 |...| 0.00e+00|...| [2] - [6,7,10,11]
[00000078]    5|       -11| 0.00e+00, 0.00e+00,-1.00e+02|...| 1.00e+02| 2 |...| 0.00e+00|...| [3] - [6,7,10,11]
[00000079]    6|        35|-3.62e+01,-2.60e+01, 1.89e+01|...| 6.28e+01| 2 |...| 4.00e+01|...| [4,5] - [12,13,14,15,24]
[00000080]    7|        36| 2.06e+01, 3.00e+01,-3.41e+01|...| 6.39e+01| 2 |...| 4.00e+01|...| [4,5] - [16,17]
[00000081]    8|        22| 0.00e+00, 0.00e+00, 2.50e-12|...| 2.50e-12| 1 |...| 0.00e+00|...| [2] - []
[00000082]    9|        22| 0.00e+00, 0.00e+00,-2.27e+01|...| 2.27e+01| 1 |...| 0.00e+00|...| [3] - []
[00000083]   10|       -13| 5.13e+01, 8.37e+00, 2.27e+01|...| 5.68e+01| 2 |...| 0.00e+00|...| [4,5] - []
[00000084]   11|        13|-3.57e+01,-1.24e+01, 1.69e+01|...| 4.14e+01| 2 |...| 0.00e+00|...| [4,5] - [24]
[00000085]   12|        14| 6.80e-01,-3.13e+00, 1.02e+01|...| 1.07e+01| 2 |...| 0.00e+00|...| [6] - [18]
[00000086]   13|       -14|-1.02e+01,-9.85e+00, 2.65e+00|...| 1.44e+01| 2 |...| 0.00e+00|...| [6] - [19]
[00000087]   14|        16|-2.49e+01,-1.07e+01,-3.82e+00|...| 2.74e+01| 2 |...| 0.00e+00|...| [6] - [20]
[00000088]   15|       -16|-1.79e+00,-2.28e+00, 9.86e+00|...| 1.03e+01| 2 |...| 0.00e+00|...| [6] - [21]
[00000089]   16|         5| 2.54e+01, 3.64e+01,-2.90e+01|...| 5.33e+01| 2 |...| 4.70e+00|...| [7] - [22]
[00000090]   17|        -5|-4.83e+00,-6.47e+00,-5.11e+00|...| 1.07e+01| 2 |...| 4.70e+00|...| [7] - [23]
```

the detected particles

walkthrough_ana.C

```
    mcpColName="MCParticles";
. . . .
      //-------------------------------------------------------------
      // first look at some MC-level information
      //-------------------------------------------------------------
      LCIterator<MCParticle> mcps( evt, mcpColName ) ;

      // find the initial mu+- and b/b-bar in the event listing
      MCParticle* MCmuplus(0);
      MCParticle* MCmuminus(0);
      MCParticle* MCb(0);
      MCParticle* MCbbar(0);
      auto mcp = mcps.next();
      while ( mcp ) {
        switch ( mcp->getPDG() ) {
        case 13:
          if ( !MCmuminus ) MCmuminus=mcp;
          break;
        case -13:
          if ( !MCmuplus ) MCmuplus=mcp;
          break;
        case 5:
          if ( !MCb ) MCb=mcp;
          break;
        case -5:
          if ( !MCbbar ) MCbbar=mcp;
          break;
        default:
          break;
        }
        mcp = mcps.next();
      }
. . . .
     const auto& vMCmuminus = v4( MCmuminus );
```

reconstructed information

the muons

```
  std::string muoColName = "IsolatedMuons";

      LCIterator<ReconstructedParticle> muons( evt, muoColName ) ;

. . .

      if( jets.size() == 2 && muons.size() == 2 ) {

      auto mu1 = muons.next();
      auto mu2 = muons.next();

. . .

      // TLorentzVectors for the objects
      const auto& vm1 = v4(mu1) ;
      const auto& vm2 = v4(mu2) ;
```

beware: names of collections are often different in delphes/SGV/fullsim-miniDST

the jets

```
jetColName="Durham2Jets";

  LCIterator<ReconstructedParticle> jets( evt, jetColName ) ;



  if( jets.size() == 2 && muons.size() == 2 ) {

  auto j1 = jets.next();
  auto j2 = jets.next();

  const auto& vj1 = v4Jet(j1) ;
  const auto& vj2 = v4Jet(j2) ;

  int j1_nch(0);
  for ( size_t i=0; i<j1->getParticles().size(); i++) {
    if ( j1->getParticles()[i]->getCharge()!=0 ) j1_nch++;
  }
```

* there is a bug in the current delphes2LCIO,
  which can give rise to neutral hadrons with E < M (just been fixed, samples will be re-created)

`v4Jet()` contains an approximate work-around

b-tag information

```
    pidName="JetParameters";

      // particle ID handler for the jets (eg to get b-tag information)
      PIDHandler *pidh = new PIDHandler( evt->getCollection( jetColName ) );
      int ilcfi = pidh->getAlgorithmID( pidName );
      int ibtag = pidh->getParameterIndex(ilcfi, "BTag");

      // btag information for the two jets
      float flvtag1 = pidh->getParticleID(j1, ilcfi).getParameters()[ibtag];
      float flvtag2 = pidh->getParticleID(j2, ilcfi).getParameters()[ibtag];
      if ( minDstFlavour==0 ) { // delphes
        // this is how to get other b/c-tag info from the jets (DELPHES)
        // int btag1_90 = (flvtag1 & ( 1 << 0 )) >> 0; // btag hiEff  90% eff
        // int btag1_70 = (flvtag1 & ( 1 << 1 )) >> 1; // btag medEff 70% eff
        // int btag1_50 = (flvtag1 & ( 1 << 2 )) >> 2; // btag hiPur  50% eff
        // int ctag1_55 = (flvtag1 & ( 1 << 3 )) >> 3; // btag hiEff  55% eff
        // int ctag1_30 = (flvtag1 & ( 1 << 4 )) >> 4; // btag medEff 30% eff
        // int ctag1_20 = (flvtag1 & ( 1 << 5 )) >> 5; // btag hiPur  20% eff
        btag1 = ( int(flvtag1) & ( 1 << 0 )) >> 0;
        btag2 = ( int(flvtag2) & ( 1 << 0 )) >> 0;
      } else if ( minDstFlavour==1 ) { // SGV, cut on lcfi btag output
        btag1 = int(flvtag1>0.7); // user-defined cut on b-tag score
        btag2 = int(flvtag2>0.7);
      }
```

```
$ dumpevent SIGNAL_LOCATION/eeZH_m40_LR.delphes.slcio 4 | less

 collection name : Durham2Jets
 parameters:

--------------- print out of ReconstructedParticle collection ---------------

  flag:  0x0
 parameter PIDAlgorithmTypeID [int]: 0,
 parameter ExclYflip12_78 [float]: 0, 0.0026713, 0.000272677, 0.000215444, 0.000209659, 0, 0,
 parameter PIDAlgorithmTypeName [string]: JetParameters,
 parameter ParameterNames_JetParameters [string]: Flavor, FlavorAlgo, FlavorPhys, BTag, BTagAlgo,
BTagPhys, TauTag, Charge, EhadOverEem,
```

links between reconstructed and MC particles

→ which MC particle(s) produced the hits included in this reconstructed particle?
→ to which reconstructed particle(s) were the hits induced by this MC particle assigned ?

RecoMCTruthLink	LCRelation
MCTruthRecoLink	LCRelation

```
// links from reco -> MC particles
LCCollection* linkcol = evt->getCollection( "RecoMCTruthLink" );
LCRelationNavigator reco_mc_Navi( linkcol );

cout << "number of MC particles linked to the isolated muon PFO = " <<
                                  reco_mc_Navi.getRelatedToObjects(mu1).size() << endl;

for (size_t k=0; k<reco_mc_Navi.getRelatedToObjects(mu1).size(); k++) {
  cout << k << " " << reco_mc_Navi.getRelatedToObjects(mu1)[k] << endl;
  if ( reco_mc_Navi.getRelatedToObjects(mu1)[k] ) {
    MCParticle* mcp = dynamic_cast <MCParticle*> (reco_mc_Navi.getRelatedToObjects(mu1)[k]);
    // weight of the connection; this is a combination of "track" and "cluster" weights
    float wgt = reco_mc_Navi.getRelatedToWeights(mu1)[k];
    // decomposed into track weight
    //  (what fraction of tracker hits in this PFO were created by this particle)
    float trackwgt = (int(wgt)%10000)/1000.;
    // similar, for calorimeter hit energies
    float clusterwgt = (int(wgt)/10000)/1000. ;
  }
}
```

[probably mostly useful for full-simulation studies,
in which reconstruction can get it wrong on a hit-level]

look at walkthrough.pdf file you created

look at walkthrough.pdf file you created

4 pages, one per polarisation combination -+, +-, ++, --

Interlude 2: Why these funny values?
- The ILC Strawman Running Scenario & Polarisation

all up-to-date numbers in ILC input document to the European strategy

- beam polarisation absolute values:
  - Electron beam: $|P(e^-)| \geq 80\%$
  - Positron beam: $|P(e^+)| = 30\%$,
    at 500 GeV upgradable to 60%
    at 1 TeV assume 20%
- **Notation: ($P(e^-)$, $P(e^+)$)**
- sharing of luminosity between polarisation signs:

$\sqrt{s}$	$\int \mathscr{L}\, dt$	-+	+-	++	- -
250 GeV	2 ab^{-1}	0.9 ab^{-1}	0.9 ab^{-1}	0.1 ab^{-1}	0.1 ab^{-1}
350 GeV	200 fb^{-1}	135 fb^{-1}	45 fb^{-1}	10 fb^{-1}	10 fb^{-1}
500 GeV	4 ab^{-1}	1.6 ab^{-1}	1.6 ab^{-1}	0.4 ab^{-1}	0.4 ab^{-1}
1 TeV	8 ab^{-1}	3.2 ab^{-1}	3.2 ab^{-1}	0.8 ab^{-1}	0.8 ab^{-1}
91 GeV	100 fb^{-1}	40 fb^{-1}	40 fb^{-1}	10 fb^{-1}	10 fb^{-1}
161 GeV	500 fb^{-1}	340 fb^{-1}	110 fb^{-1}	25 fb^{-1}	25 fb^{-1}

detailed reasoning c.f. arXiv:1506.07830

J. List

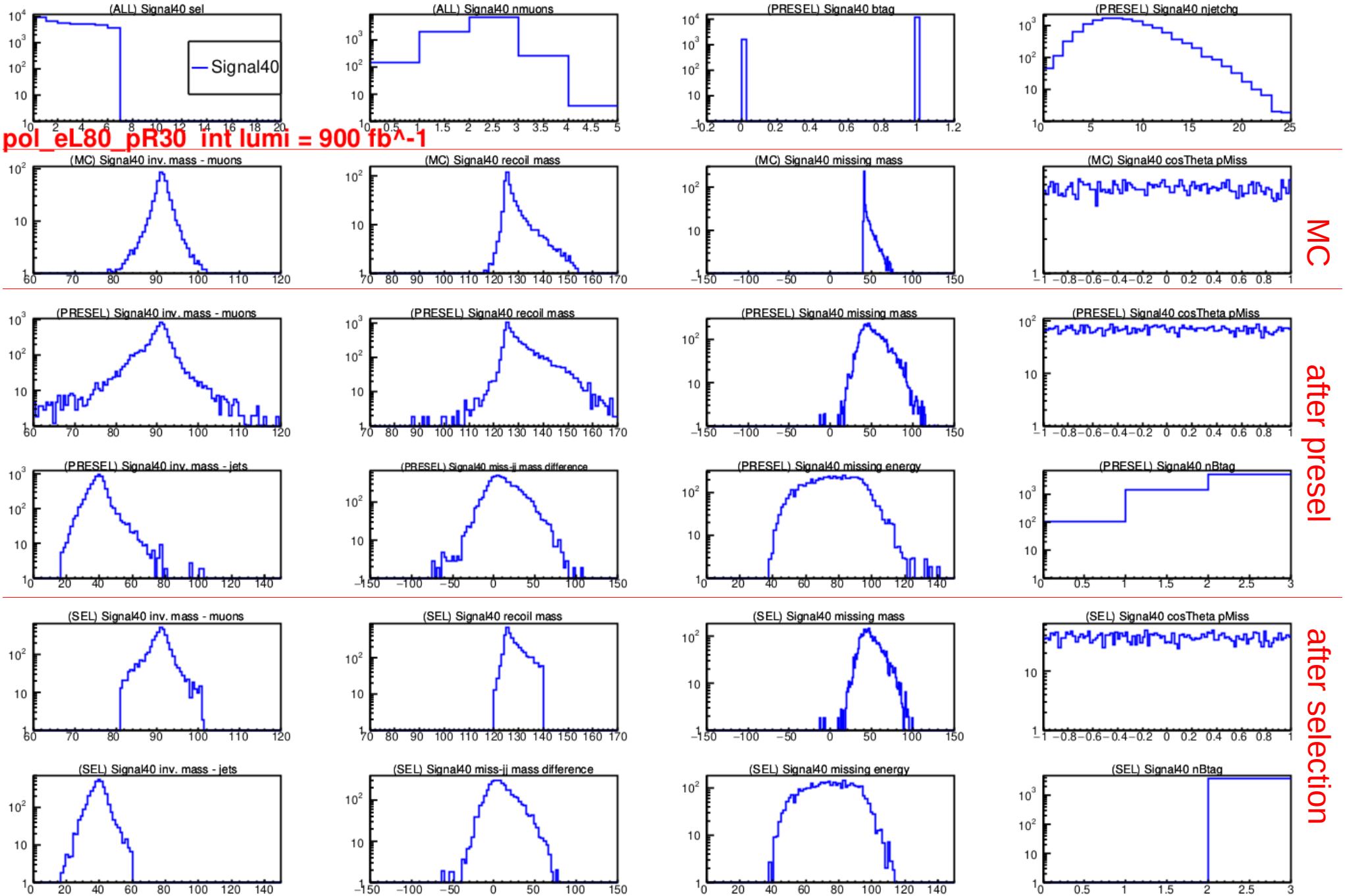
these are essentially 4 statistically independent experiments

collection of all the histograms we defined

BSM signal (m=40 GeV)

normalised assuming that $\sigma_{BSM} = \sigma_{SM}$

pol_eL80_pR30 int lumi = 900 fb^-1

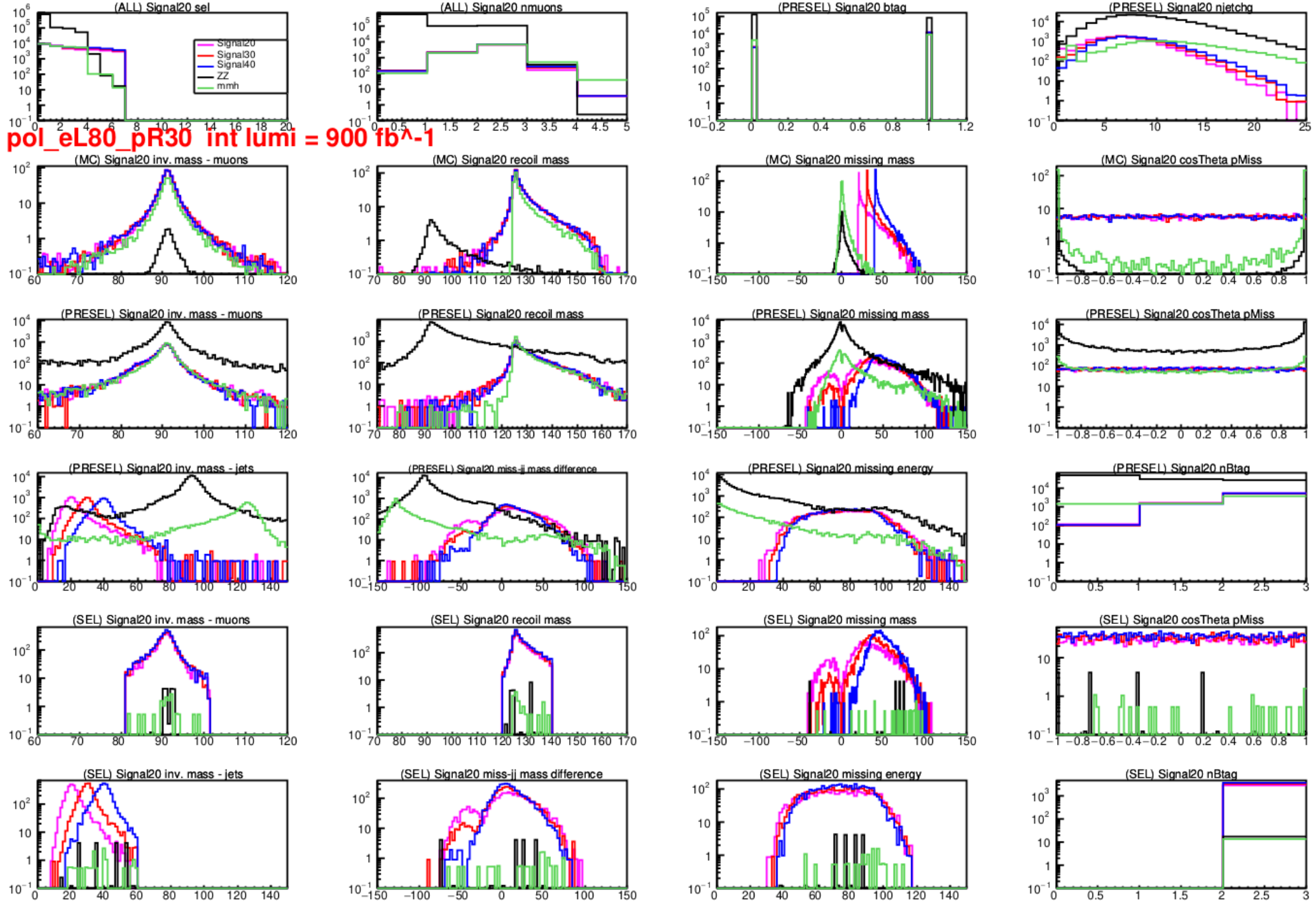


exercises to try now (or later):

add in the BSM signals with different φ masses
(un-comment the relevant lines)

add in the zz_sl and mu-mu-h backgrounds
(un-comment the relevant lines)

signal (m=20, 30, 40) ; ZZ background ; Higgs background

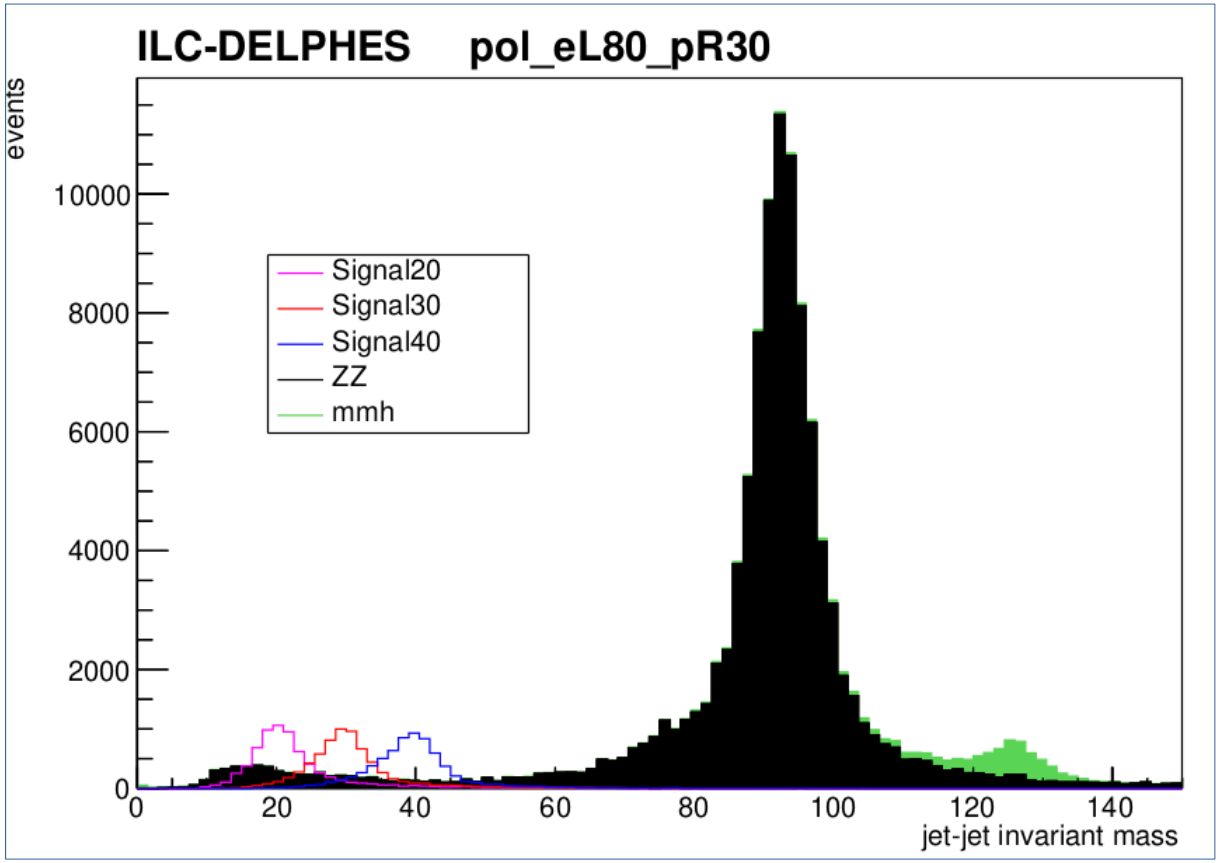


make a pretty plot for a note from histograms stored in the root file

`/local-scratch/software/ilc_walkthrough/tutorial-code/makePrettyPlot.C`

https://research-up.kek.jp/people/jeans/snowmassSignal/makePrettyPlot.C creates a pdf figure

```
$ root -b
root [0] .x makePrettyPlot.C("walkthrough.root", "pol_eL80_pR30", "_PRE_jetmass", "jet-jet invariant mass" )
```



normalised assuming that $\sigma_{BSM} = \sigma_{SM}$

exercises to try now (or later):

convert into an upper limits on the BR for this exotic decay
for each polarisation set
(using your favourite statistical approach)

simplistic limit extraction

```
 ---------------------------------------------------
EVENT cut table pol_eL80_pR30  int lumi = 900 fb^-1
 ---------------------------------------------------


 ---SELECTION SUMMARY----------------
...
CUT 7 ;  expected SM-BG events  30.7514 expected signal events (@ 100% BR) : Signal20  2918.49 ; Signal30  3332.84 ; Signal40  3688.61 ;
...
```

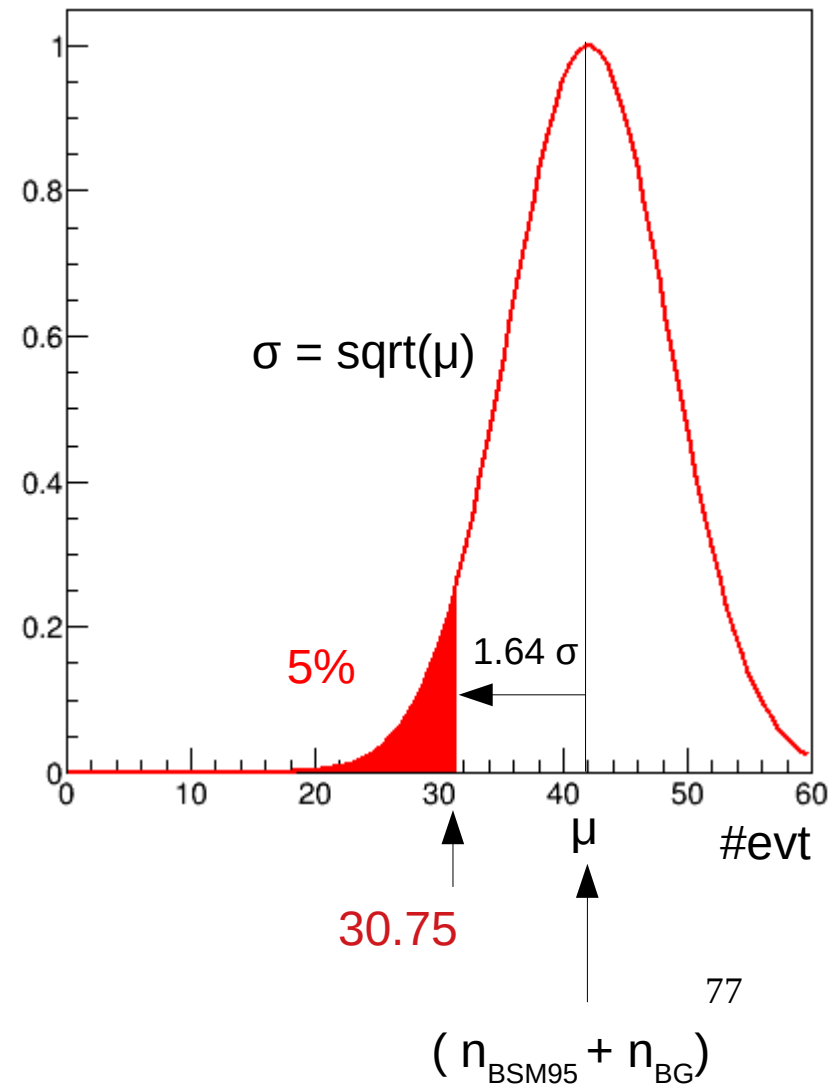
in eLpR polarisation part of ILC-250,
after selection expect

30.75 SM background events
3332.84 BSM signal events [$\sigma_{BSM} = \sigma_{SM}$, m_{φ} = 30 GeV]

estimate expected 95% upper limit on
number of BSM signal events:

for n~30, Poisson ~ Gaussian [mean μ, width sqrt(μ)]
→ 5% lies in range 0 < n < μ – 1.64*sqrt(μ)

want expected 95% upper limit on $n_{95} = n_{BSM95} + n_{BG}$
$n_{95} - 1.64\ \mathrm{sqrt}(n_{95}) = 30.75$
→ $n_{95} = 41.3$
→ $n_{BSM95} = 41.3 - 30.75 = 10.6$
→ 95% upper limit on
BR(H→(φ→ bb) (φ →invis))
$= \sigma_{BSM} / \sigma_{SM}$
= 10.6 / 3332. ~ 0.3%



exercises to try now (or later):

look at the plots; adjust the cut values, add new cuts
(there are some commented-out suggestions in the code)

only few MC background events are selected
we are using only a fraction of available ZZ files available
→ use them all to reduce effect of finite MC statistics
(there are additional files on login.snowmass21 in the same directory)

calculate limits separately in the 4 polarisation sets

combined them into a single limit for the whole ILC-250 program
→ nb each set will have different sensitivity,
so don't just add SIG & BG for each set !

additional ideas:

the least-well measured objects in these events are the **jet energies**

one could apply a constrained kinematic fit:

→ jet energies are free (or loosely constrained) parameters
→ allow for net p_z due to ISR photon(s)
→ impose 4-mom conservation
→ impose jet-jet invariant mass = “invisble” mass
→ impose higgs mass 125 GeV
…..

additional ideas:

this example used only Z→ mu+ mu- decays
the much larger Z→hadrons channel is in general more sensitive

~ 20x more data, fully exploitable at lepton colliders
no dominant QCD background
→ will be collected [no trigger], and is useful

again because of trigger-less operation,
"all" low momentum / displaced / appearing / disappearing
particles are recorded and can be used

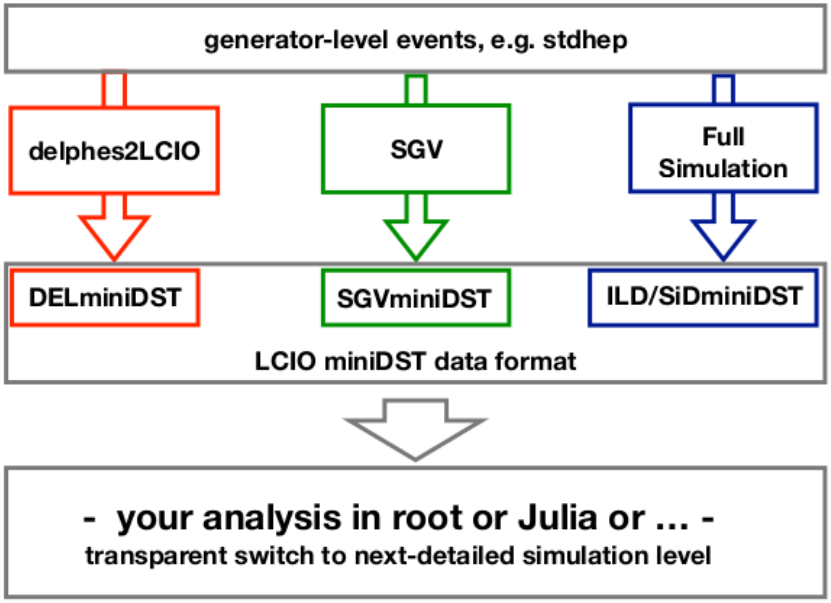
additional ideas:

DELPHES applies a (carefully) parameterised momentum smearing
describes the central part of distributions pretty well,
but less good at the non-Gaussian tails

SGV-based fast simulation should give more realistic description
→ signal samples at /collab/project/snowmass21/data/ilc/analysis-walkthrough/signal/miniDST-SGV
→ some changes required in the analysis code: they are documented there

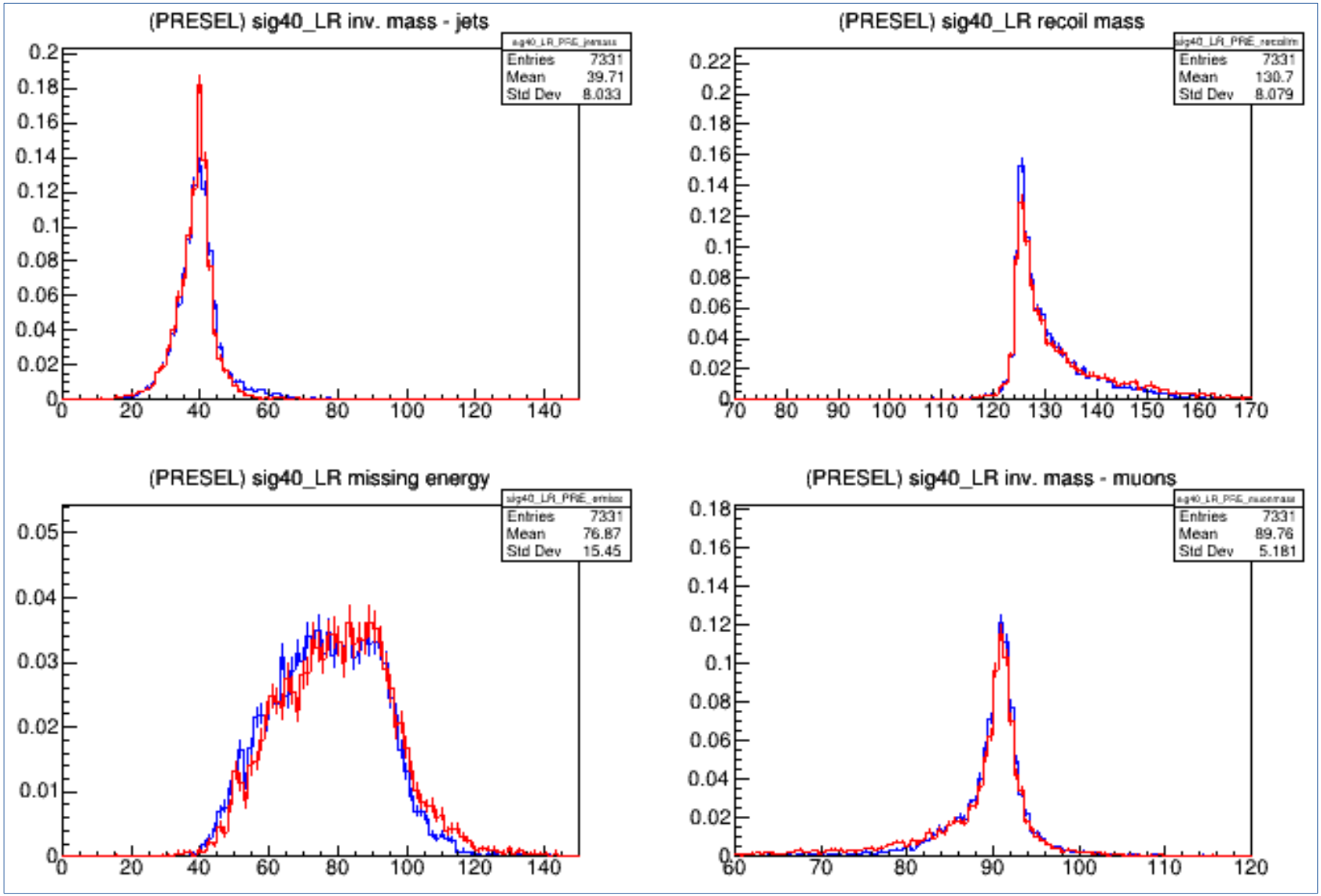
full Geant4 detector simulation of SiD / ILD concepts is most accurate

- **delphes2lcio**: an lcio application which makes Delphes (parametrised detector simulation) write out LCIO (https://github.com/iLCSoft/LCIO/tree/master/examples/cpp/delphes2lcio)
- **SGV**: **S**imulation a **G**rande **V**itesse (https://www.desy.de/~berggren/sgv_ug/sgv_ug.html) - detailed fast simulation from "first principles" (nearly no parametrisations!)
- **iLCSoft** (https://github.com/iLCSoft): software suite for full simulation and reconstruction of ILC & CLIC detectors



example: comparison of some observables in our signal sample (@40 GeV)

DELPHES vs. SGV



fully simulated MC data

there are very detailed Geant4 models of 2 detector concepts, SiD and ILD
these will give the most reliable estimates of ILC's potential

if you want to use such fully-simulated data,
we ask you to become
a "guest member" of
one of these concept groups

[you are welcome to join even
if you don't plan to use full-sim data]

To join the SiD group, please contact

- Spokespersons: Andrew White (awhite@uta.edu), Marcel Stanitzki (marcel.stanitzki@desy.de)
- Physics Coodinator: Tim Barklow (timb@slac.stanford.edu)

To join the ILD group, please contact

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- Physics Coodinators: Keisuke Fujii (keisuke.fujii@kek.jp), Jenny List (jenny.list@desy.de)
- Executive Team member from the US: Graham Wilson (gwwilson@ku.edu)

resources & help

http://ilcsnowmass.org/ (developing) details of available samples etc

https://arxiv.org/abs/2007.03650 links to current status reports &
lots of ideas for additional studies

#ilc-snowmass Slack channel

Contact information

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thanks for your attention!