Study of $WW \rightarrow qql\nu$ at ILC500

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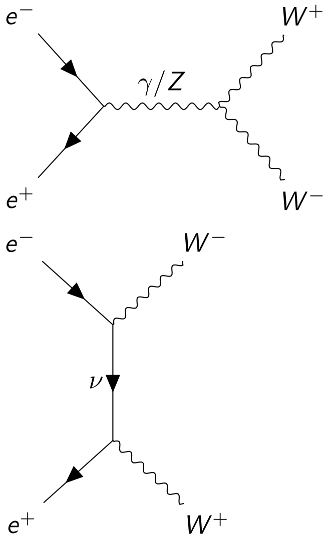
Introduction / Motivation



WW is a standard process with a large cross-section

- 15 pb in semileptonic channel at 500 GeV

Three central physics issues addressable by this channel are

- Dynamics of the charged triple gauge couplings
- Measurement of W boson mass, width, cross-section, and BR
- Beam polarization measurement

500 GeV Samples

$\sqrt{s} = 500$ GeV

Total luminosity : 4000 fb^{-1}

Polarizations:

Pol.	(-0.8,+0.3)	(+0.8,-0.3)	(-0.8,-0.3)	(+0.8,+0.3)
Lum. [fb^{-1}]	1600	1600	400	400

Reco/Sim: `ILCSoftv02-00-02` `ILD_l5_o1_v02`

MC Background Samples (DBD)–

– 2-fermion
  - Z-bhabhag/hadronic/leptonic

– 4-fermion
  - singleW-leptonic
  - Zee/vv-leptonic/semileptonic
  - singleZsingleWMix-leptonic
  - WW-hadronic/leptonic
  - ZZ-hadronic/leptonic/semileptonic
  - ZZWWMix-hadronic/leptonic

– 6-fermion
  - eeWW, llWW, vvWW, xxWW
  - ttbar
  - xxxxZ, yyyyZ

– SM Higgs
  - eeH, qqH, $\mu\mu$H, $\tau\tau$H, $\nu\nu$H

Note: signal events are split into WW-like and not WW-like events
events that contain an off shell W ($\pm 10 GeV$ to nominal mass) are considered to be not WW-like

Analysis Approach

Step 1-

Treat all lepton flavors universally

Start by identifiying signal tau candidates with TauFinder

Optimize TauFinder to efficiently find taus (based on decay products) and also reject tau fakes from hadronic jets

Separate into 7 categories:

prompt μ
prompt e
Inclusive τ
$\tau \rightarrow \mu\nu\nu$
$\tau \rightarrow e\nu\nu$
$\tau \rightarrow$ hadronic 1-prong
$\tau \rightarrow$ hadronic 3-prong

Step 2-

With a selected lepton, treat the remaining system as hadronic components of $W \rightarrow qq$

Use y-cut and kinematic cuts on mini-jets to mitigate pileup ($\gamma\gamma$)

Step 3- Perform basic event selection for multiple polarization scenarios

(1) TauFinder

TauFinder basic operation

Processor starts by seeding tau candidates with tracks ordered by $|P|$

–Particles that fall within a search cone around the seed track are added to the candidate

–Particles are sequentially added until there are no more in the search cone or until acceptance conditions are violated

Operating criteria

- Search Cone Angle - The opening angle of the search cone for the tau jet [rad]
- Isolation Cone Angle - Outer isolation cone anound the search cone of the tau jet [rad]
- Isolation Energy - The total energy allowed within the isolation cone region [GeV]
- Invariant Mass - The upper limit on tau candidate mass [GeV]

(1) TauFinder Optimization

Optimization of 3 parameters:

– searchCone $\in$ $[0, 0.15]$ rad with 0.01 rad steps

– isolationCone $\in$ $[0, 0.15]$ rad with 0.01 rad steps

– isolationEnergy $\in$ $[0, 5.5]$ GeV with 0.5 GeV steps

For simplicity, fix invariant mass cut at 3 GeV

Define optimization metrics:

Efficiency using $WW \to qqlnu$ for true leptons:

$\varepsilon_s = N_{matched}/N_{Stotal}$

– a tau candidate is considered matched within 100 mrads of the gen lepton

– if the gen lepton is a tau, the jet is matched to the gen visible components – excluding FSR

– N_{Stotal} is the Number of events with 3 visible gen fermions $|cos\theta| < 0.99$

fake leptons: Use $WW \to qqqq$

– $\varepsilon_b = N_b/N_{Btotal}$

N_b is any event with at least one reconstructed tau jet

4 quarks give 4 chances to create a tau jet ε_b

–Use a better tuning parameter P_{fake} which is the probability of reconstructing a tau jet from a single quark jet

$$P_{fake} = 1 - (1 - \varepsilon_b)^{\frac{1}{4}}$$

$$\sigma_{P_{fake}} = \frac{1}{4}\sqrt{\frac{\varepsilon_b}{N_{Btotal}\sqrt{1-\varepsilon_b}}}$$

The optimal working point is chosen from the two tuning parameters $\max[(1 - P_{fake})\varepsilon_s]$

(1) TauFinder Optimization Results

Channel	ε_s	$1 - P_{fake}$	% Matched	search-Cone [rad]	isoCone [rad]	isoE [GeV]
Prompt μ	0.905	0.974	0.992	0.03	0.15	3.0
Inclusive τ	0.736	0.943	0.958	0.07	0.15	4.5
$\tau \to \nu\nu\mu$	0.802	0.974	0.984	0.03	0.15	3.0
$\tau \to \nu\nu e$	0.781	0.963	0.981	0.05	0.15	3.5
τ Had-1p	0.707	0.943	0.951	0.07	0.15	4.5
τ Had-3p	0.709	0.930	0.937	0.07	0.15	5.5
Prompt e	0.839	0.961	0.97	0.04	0.15	4.0

(2) Hadronic System

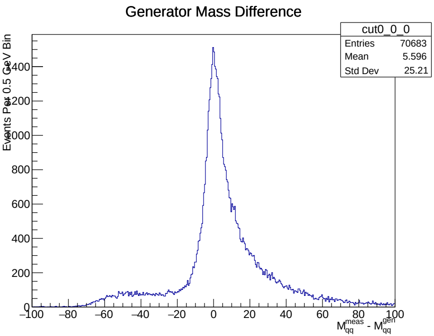
If a lepton(s) have been found by TauFinder,

- select highest energy candidate as signal lepton
- shuffle remaining fakes back into the hadronic system.

At least one quark tends to be very forward, so pileup tends to mix into the jets
These beam particles cannot be cleanly removed by standard methods e.g. kT algorithm tuned R values

My approach: "Jet Fragmentation"

- tune y-cut($\propto M_{jet}^2$) values on the durham algorthim (eekt)
- apply simple cuts to the resulting "mini-jets"



(2) Optimized W Mass

Find best W jet parameters over the ranges:
Use only signal events with gen. prompt muons

- yCut:$[1 \times 10^{-3}, 5 \times 10^{-6}]$
- pT:$[0, 5]$ bins of 0.5 GeV
- $|cos\theta|$:$[0.9, 1]$ 0.01 bins

Use 2 optimization parameters from the $M_{qq}^{meas} - M_{qq}^{gen}$ dist.:

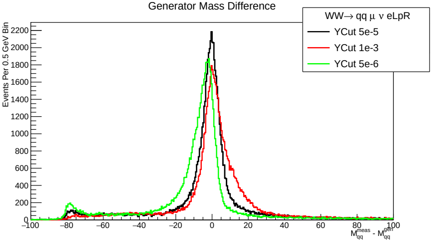
- Full Width Half Maximum (FWHM)
- Number of bin Entries in the Mode

The Mode Entries is the number of entries in the Maximum bin + the number of Entries of the nearest left/right neighbor bins
The Mode is the weighted mean of the center of the 3 Mode bins

The Maximum for the FWHM is the "Mode Average" or the average number of entries from the 3 mode bins

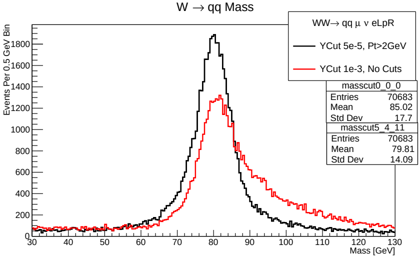
The edges of the Width for FWHM are the weighted average between the 2 bins around the half maximum (1 bin above 1 bin below)

(2) Hadronic System Results



Comparison of 3 YCuts with the same kinematic cuts Pt>2 GeV AND $|cos\theta| < 1$ (optimized for 5e-05)

Small peak around -80 GeV is where the W has been incorrectly thrown out



Significant Improvement !

Mass Difference Statistics:
ycut: 0.001 ptcut: 2 costcut: 1 FWHM: 11.769 RMS: 24.1855 Mode: -0.24211 mean: 0.782898 modeEnt: 5199
ycut: 5e-05 ptcut: 2 costcut: 1 FWHM: 9.7087 RMS: 25.2774 Mode: -0.25127 mean: -3.09776 modeEnt: 6326
ycut: 5e-06 ptcut: 2 costcut: 1 FWHM: 11.567 RMS: 25.7475 Mode: -1.75521 mean: -9.57673 modeEnt: 5475

Best Performance is reached with:
ycut= 5e-05 and removal of mini-jets with pT $<$ 2 GeV

(3) Event Selection Overview

Perform event selection with two mutually exclusive groups:

1st group will use μ cone (optimized for prompt muons)

- "tight" selection will yield some efficiency ϵ_0 and purity p_0
- tight cuts will be targeted towards prompt signal leptons μ/e

2nd group will use the τ cone (optimized for inclusive τ decays)

- "loose" selection will yield some efficiency ϵ_1 and purity p_1
- "loose" cuts should address τs not reconstructed by muon cone
- orthognalize selection require 0 tight leptons in loose selection

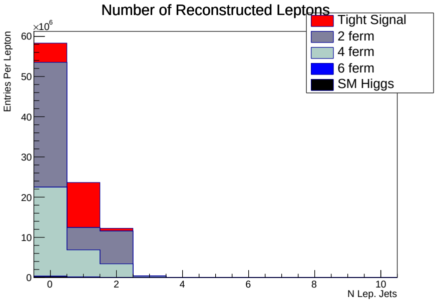
Optimize selection for some overall efficiency $\epsilon = \epsilon_0 + \epsilon_1$ times purity $p = (N_0 + N_1)/(B_0 + B_1 + N_0 + N_1)$

Description of current cuts:(currently tight/loose are mostly the same)
adapted from ref. `I.MarchesiniDESY-THESIS2011`
–Note reconstucted particles are boosted against crossing angle boost– (3.5 GeV in x)

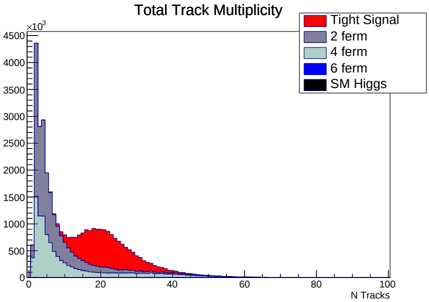
- Lepton - Require at least 1 reconstructed lepton
- Track Multiplicity > 10 - at least 10 tracks in the event (targeting rejection of 2f Bkg.)
- Pt > 5 GeV - reject events with no genuine missing Pt
- $E_{vis} < 500$ GeV Sum of the total visible energy in the event
- $E_{com} > 100$ GeV - target rejection of 2f and leptonic eeZ,
  $E_{com} = E_{vis} + |P_{miss}|$ $\quad P^{\mu}_{miss} = (|P_{miss}|, -\sum \vec{p}_{vis})$
- $40 < M_{qq} < 120$ - constrains jet system to be W-like
- $-qcos\theta_W$ - require the W^- to scatter forward

(3) Event Selection (Tight)

Tight Signal $\Rightarrow$ muon cone for μ, e, τ signal events
All plots include an N Lepton $>$ 0 cut (except N Lepton plot)
Polarization: (-0.8,+0.3)   Luminosity: 1600 fb^{-1}



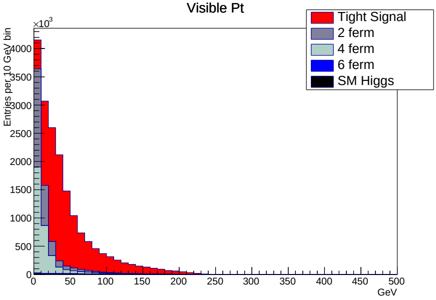
N Leptons $>$ 0



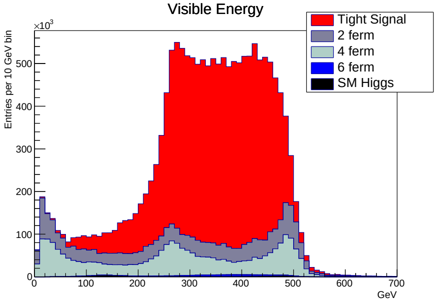
N Tracks $>$ 10

(3) Event Selection (Tight)

Tight Signal $\Rightarrow$ muon cone for μ, e, τ signal events
All plots include an N Lepton > 0 cut
Polarization: (-0.8,+0.3) Luminosity: 1600 fb^{-1}



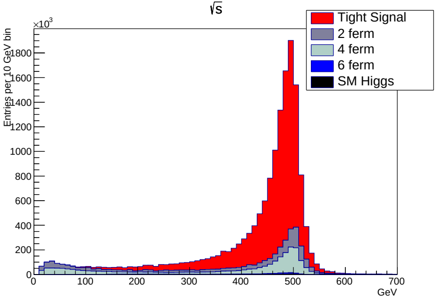
Visible Pt > 5 GeV



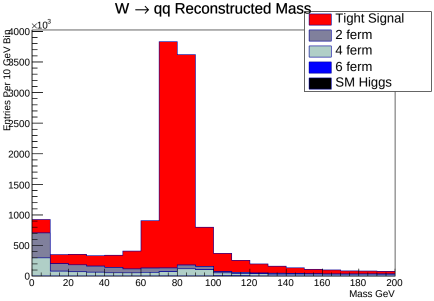
Visible Energy < 500 GeV

(3) Event Selection (Tight)

Tight Signal $\Rightarrow$ muon cone for μ, e, τ signal events
All plots include an N Lepton > 0 cut
Polarization: (-0.8,+0.3) Luminosity: 1600 fb^{-1}



$E_{com} > 100$ GeV

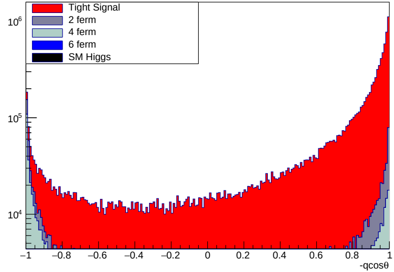


$40 < M_{qq} < 120$

(3) Event Selection (Tight)

Tight Signal $\Rightarrow$ muon cone for μ, e, τ signal events
All plots include an N Lepton > 0 cut
Polarization: (-0.8,+0.3) Luminosity: 1600 fb^{-1}

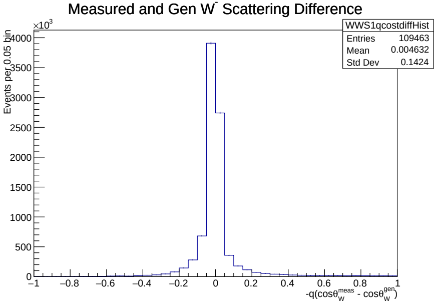
W Scattering angle

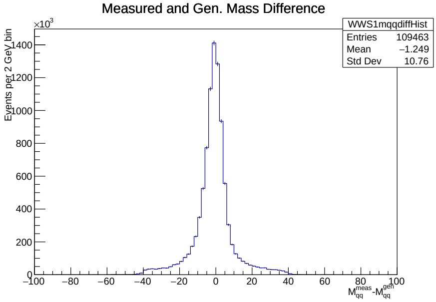


$-qcos\theta_W > -0.95$

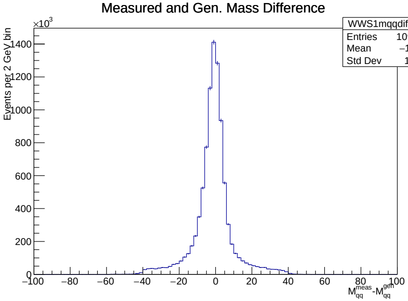
(3) Event Selection (Tight)

Performance of hadronic mass and W^- scattering angle
Polarization: (-0.8,+0.3) Luminosity: 1600 fb^{-1}
All cuts applied, tight selection only with μ, e, τ

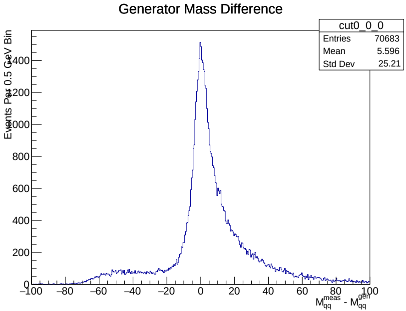




Comparison of Generator mass differences
with pileup rejection and selection cuts vs. no pileup rejection or selection cuts



after cuts



before cuts

Note: right distribution is not weighted and 100% LR

(3) Event Selection – "WW-like" Signal

Polarization: (-0.8,+0.3) Luminosity: 1600 fb^{-1}

Tight Selection with muon cone

	Prompt μ	Prompt e	τ	Tot. Sig.	2f	4f	6f	Higgs
Base Evts.	3.87×10^6	3.89×10^6	3.90×10^6	1.17×10^7	4.22×10^7	3.22×10^7	2.14×10^5	4.12×10^5
Lepton	3.31×10^6	3.20×10^6	2.28×10^6	8.78×10^6	1.15×10^7	1.18×10^7	1.63×10^5	1.15×10^5
N Tracks	3.22×10^6	3.11×10^6	2.21×10^6	8.54×10^6	2.84×10^6	2.83×10^6	1.50×10^5	9.36×10^4
Pt visible	3.18×10^6	3.07×10^6	2.18×10^6	8.44×10^6	1.81×10^6	2.08×10^6	1.47×10^5	8.40×10^4
E visible	3.16×10^6	3.00×10^6	2.18×10^6	8.33×10^6	1.66×10^6	1.96×10^6	1.46×10^5	8.11×10^4
E_{com}	3.15×10^6	2.99×10^6	2.16×10^6	8.31×10^6	1.37×10^6	1.63×10^6	1.45×10^5	7.96×10^4
M_{qq}	2.70×10^6	2.56×10^6	1.82×10^6	7.08×10^6	4.02×10^5	2.67×10^5	2.08×10^4	3.06×10^4
$-qcos\theta_W$	2.69×10^6	2.55×10^6	1.81×10^6	7.05×10^6	3.21×10^5	2.37×10^5	2.01×10^4	2.94×10^4
ϵ	0.6951 ± 0.0018	0.6551 ± 0.0019	0.4644 ± 0.002	0.6047 ± 0.0011	$0.007589 \pm 1.3e-05$	$0.007363 \pm 1.5e-05$	0.09395 ± 0.00063	0.0714 ± 0.0004

Loose selection with tau cone

	Prompt μ	Prompt e	τ	Tot. Sig.	2f	4f	6f	Higgs
Base Evts.	3.87×10^6	3.89×10^6	3.90×10^6	1.17×10^7	4.22×10^7	3.22×10^7	2.14×10^5	4.12×10^5
Lepton	3.36×10^6	3.30×10^6	2.82×10^6	9.48×10^6	1.30×10^7	1.36×10^7	1.77×10^5	1.38×10^5
Veto Tight Lep.	7.72×10^4	1.28×10^5	5.70×10^5	7.76×10^5	1.93×10^6	2.15×10^6	1.61×10^4	3.12×10^4
N Tracks	7.45×10^4	1.23×10^5	5.55×10^5	7.52×10^5	1.61×10^6	1.85×10^6	1.58×10^4	2.81×10^4
Pt visible	7.34×10^4	1.22×10^5	5.48×10^5	7.43×10^5	9.22×10^5	1.12×10^6	1.36×10^4	2.52×10^4
E visible	7.27×10^4	1.19×10^5	5.48×10^5	7.40×10^5	8.75×10^5	1.02×10^6	1.32×10^4	2.46×10^4
E_{com}	7.04×10^4	1.18×10^5	5.41×10^5	7.29×10^5	7.33×10^5	9.83×10^5	1.32×10^4	2.43×10^4
M_{qq}	4.54×10^4	8.08×10^4	4.22×10^5	5.48×10^5	1.85×10^5	1.18×10^5	1.15×10^3	1.28×10^4
$-qcos\theta_W$	4.00×10^4	7.74×10^4	4.12×10^5	5.29×10^5	1.17×10^5	1.01×10^5	1.11×10^3	1.23×10^4
ϵ	0.01032 ± 0.0004	0.01991 ± 0.0005	0.1057 ± 0.0012	0.0454 ± 0.0005	$0.002775 \pm 8.1e-06$	$0.003146 \pm 9.9e-06$	0.005167 ± 0.00015	0.0299 ± 0.00027

(3) Event Selection – Not “WW-like” Signal

Polarization: (-0.8,+0.3) Luminosity: 1600 fb^{-1}
Signal events containing off-shell W
Signal events with at least 1 off off shell(O.S.) W are separated into a new category of not “WW-like” signal events

Tight Selection with muon cone

	Prompt μ O.S.	Prompt e O.S.	Tau O.S.
nocut	5.78×10^5	3.88×10^6	5.70×10^5
lepton	5.11×10^5	2.27×10^6	3.42×10^5
ntracks	4.99×10^5	2.21×10^6	3.36×10^5
ptcut	4.93×10^5	2.19×10^6	3.31×10^5
esum	4.89×10^5	2.18×10^6	3.30×10^5
roots	4.89×10^5	2.17×10^6	3.29×10^5
mwhad	3.41×10^5	1.88×10^6	2.37×10^5
qcostw	3.40×10^5	1.80×10^6	2.36×10^5
ϵ	0.5885 ± 0.0052	0.463 ± 0.002	0.4138 ± 0.0052

Loose Selection with tau cone

	Prompt μ O.S.	Prompt e O.S.	Tau O.S.
nocut	5.78×10^5	3.88×10^6	5.70×10^5
lepton	5.15×10^5	2.47×10^6	4.26×10^5
mucone	8.18×10^3	2.61×10^5	8.83×10^4
ntracks	7.87×10^3	2.48×10^5	8.63×10^4
ptcut	7.87×10^3	2.46×10^5	8.53×10^4
esum	7.57×10^3	2.46×10^5	8.53×10^4
roots	7.42×10^3	2.35×10^5	8.47×10^4
mwhad	3.94×10^3	1.28×10^5	4.91×10^4
qcostw	3.63×10^3	1.18×10^5	4.77×10^4
ϵ	0.0062 ± 0.0081	0.0303 ± 0.0007	0.083 ± 0.003

– selection is not that efficient for these types of events

Event Selection Summary (LR)

(-0.8, +0.3) 1600 fb^{-}1

	Tight Selection			Tight + Loose Sel.		
	Sel. Total	Efficiency	Purity	Sel. Total	Efficiency	Purity
Bkg.	6.07e+05			8.39e+05		
Signal	4.50e+06	0.579 ± 0.002	0.881	4.95e+06	0.638 ± 0.002	0.855
Sig.+O.S.	6.98e+06	0.545 ± 0.002	0.920	7.56e+06	0.590 ± 0.002	0.900

- Signal is only on-shell WW-like events
- Signal + O.S. includes both selections including the not WW-like signal events
- in LR we find ratio of S/B to be 1 order of magnitude
- Good efficiency and high purity for the signal case
- When adding O.S. events we only strengthen the purity, but efficiency drops because the events are not ideal for selection

Event Selection Summary (RL,LL,RR)

(+0.8, -0.3) 1600 fb^{-1}

	Tight Selection			Tight + Loose Sel.		
	Sel. Total	Efficiency	Purity	Sel. Total	Efficiency	Purity
Bkg.	3.09e+05			3.89e+05		
Signal	2.91e+05	0.585 ± 0.002	0.485	3.21e+05	0.645 ± 0.002	0.452
Sig.+O.S.	5.54e+05	0.447 ± 0.002	0.642	6.06e+05	0.489 ± 0.002	0.609

(-0.8, -0.3) 400 fb^{-1}

	Tight Selection			Tight + Loose Sel.		
	Sel. Total	Efficiency	Purity	Sel. Total	Efficiency	Purity
Bkg.	1e+05			1.33e+05		
Signal	6.06e+05	0.579 ± 0.002	0.858	6.67e+05	0.638 ± 0.002	0.834
Sig.+O.S.	9.7e+05	0.525 ± 0.002	0.906	1.05e+06	0.569 ± 0.002	0.888

(+0.8, +03) 400 fb^{-1}

	Tight Selection			Tight + Loose Sel.		
	Sel. Total	Efficiency	Purity	Sel. Total	Efficiency	Purity
Bkg.	6.61e+04			8.16e+04		
Signal	1.28e+05	0.581 ± 0.002	0.659	1.41e+05	0.640 ± 0.002	0.633
Sig.+O.S.	2.4e+05	0.450 ± 0.002	0.784	2.62e+05	0.492 ± 0.002	0.763

- semi-leptonic decays are suppressed in RL, so purity is reduced
- other polarizations (LL,RR) are comparable to LR but slightly worse
- Can potentially improve with more cuts :
  - Recoil mass
  - Leptonic W mass (fitted)
  - Other fit quantities

W.I.P– Kinematic fitting with E,P and equal mass constraints. Currently “working” but there appears to be a clash between neutrino fit object and isr photon fit objects in Marlin Kinfit

Summary

Completed Tasks:

- Performed a benchmarking analysis with $WW \rightarrow qql\nu$
- Treated the leptons universally with TauFinder
- Rejected $\gamma\gamma$ pileup by fragmenting jets and making a Pt cut on the resulting mini-jets
- Performed a basic event selection for all polarizations for a total of 4000 fb^{-}1 of data

TODO:

- fix constrained fitting
- improve event selection
- study efficiency as a function of $cos\theta$ of the lepton