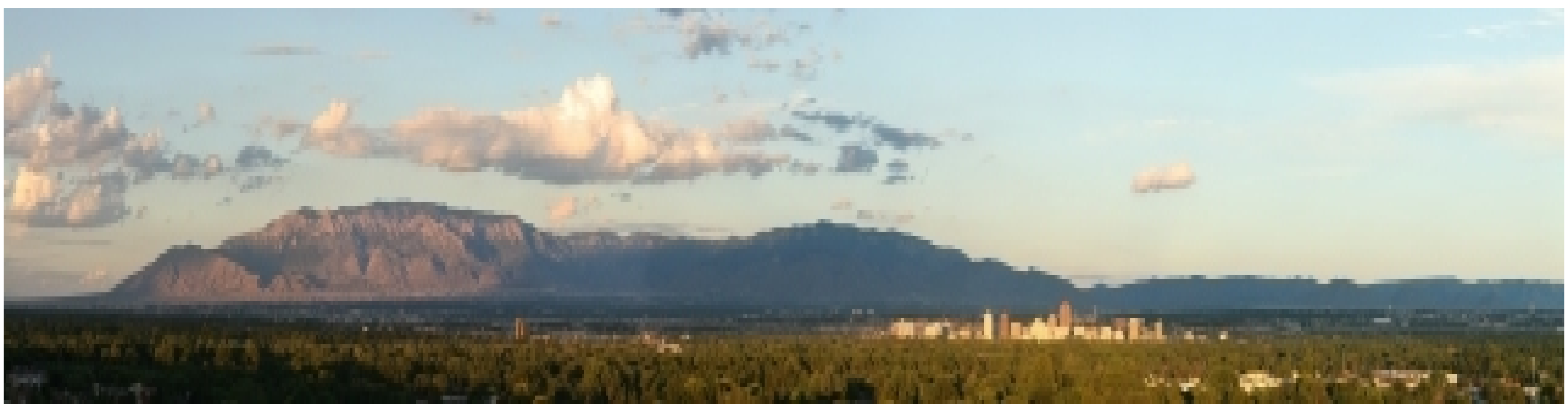
Benchmark Reactions for the LOIs

- Study of Higgs Recoil Reaction ee → HZ → l^+l^- -

Roman Pöschl
LAL Orsay

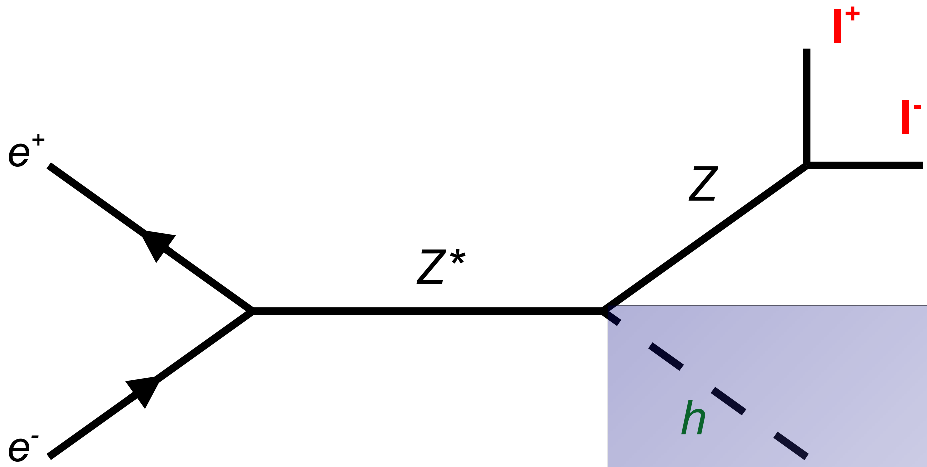


Linear Collider Workshop LCWA09 Albuquerque NM Sept./Oct. 2009

Thanks to T. Barklow, H. Li and G. Tassielli for helping to prepare the talk

References: LOIs by SiD, ILD and 4th Concept + IDAG answer documents
PREL-LC-PHSIM-2009-003

Higgs-strahlung Process



Decay leptons from Z
μ Pairs, e pairs

Higgs Mass and ZZH coupling
by **Model Independent**
measurement

Higgs Recoil Mass: $M_h^2 = M_{recoil}^2 = s + M_Z^2 - 2E_Z\sqrt{s}$

Benchmark Parameters:

√s = 250 GeV – fairly close to HZ threshold
Luminosity 500 fb^{-1} shared equally between different Beam Polarisation modes:

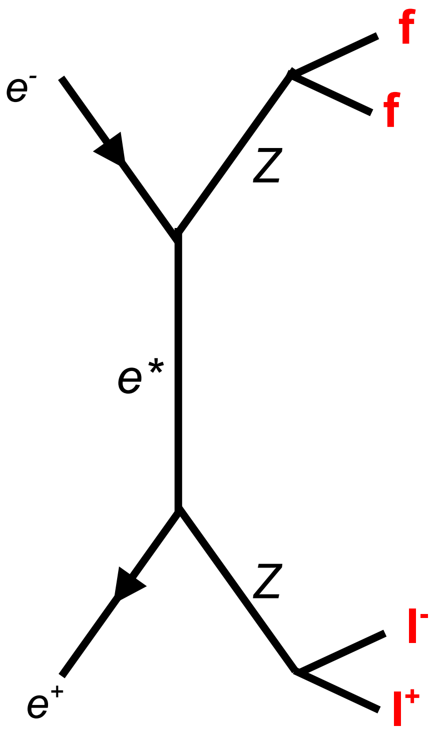
$e_L^- e_R^+: \; P_{e^-} = -80\% \;\; P_{e^+} = +30\%$ $\qquad$ $e_R^- e_L^+: \; P_{e^-} = +80\% \;\; P_{e^+} = -30\%$

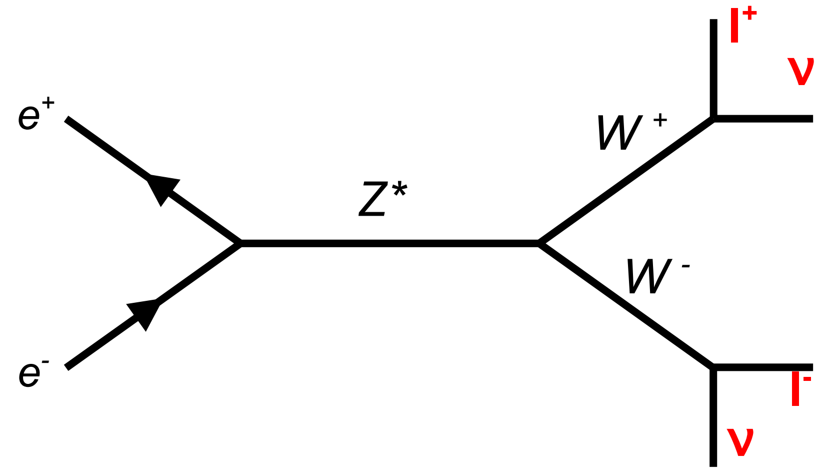
Realistic Beam Conditions (2007 – ILC Reference Design Report)
Incoming Beam by GUINEA PIG
Beam Energy Spread 0.18% for e^+ and 0.28% for e^-
Beam Strahlung in agreement with Yokoya-Chen formula

Results will be given w/o crossing angle of 14mrad!!!

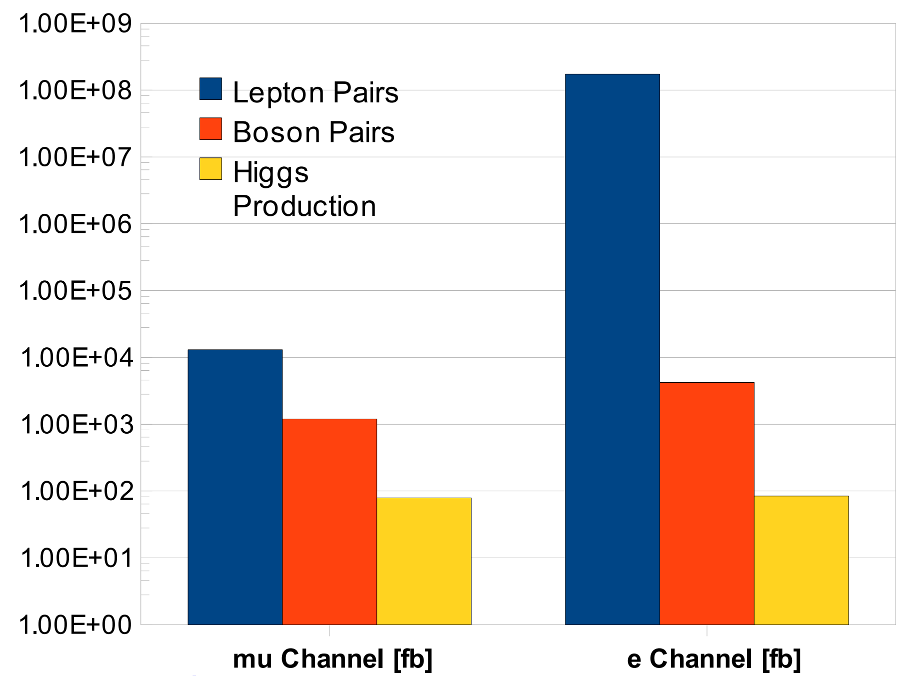
(Main) Background Processes

Boson Pair Production

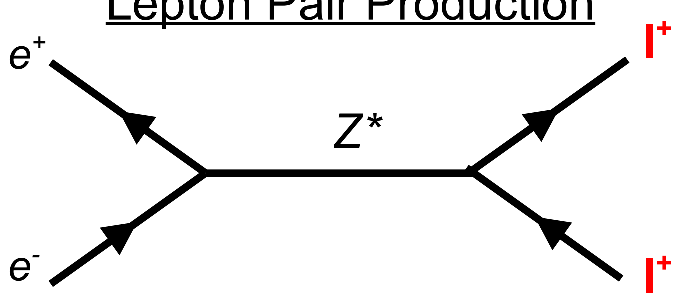




Example for $e^-_R e^+_L$ Polarisation Mode



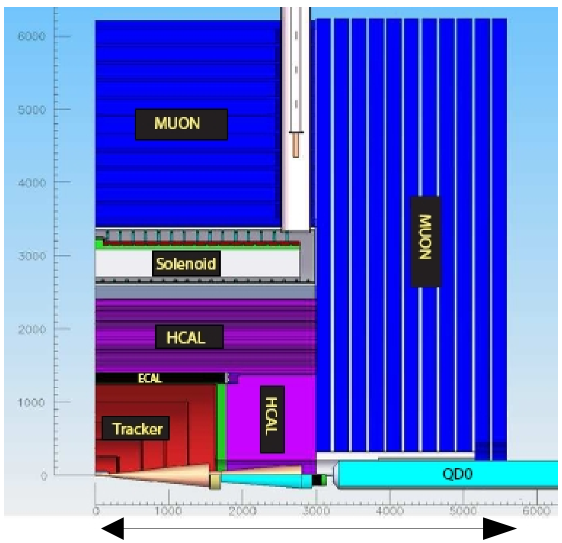
Lepton Pair Production



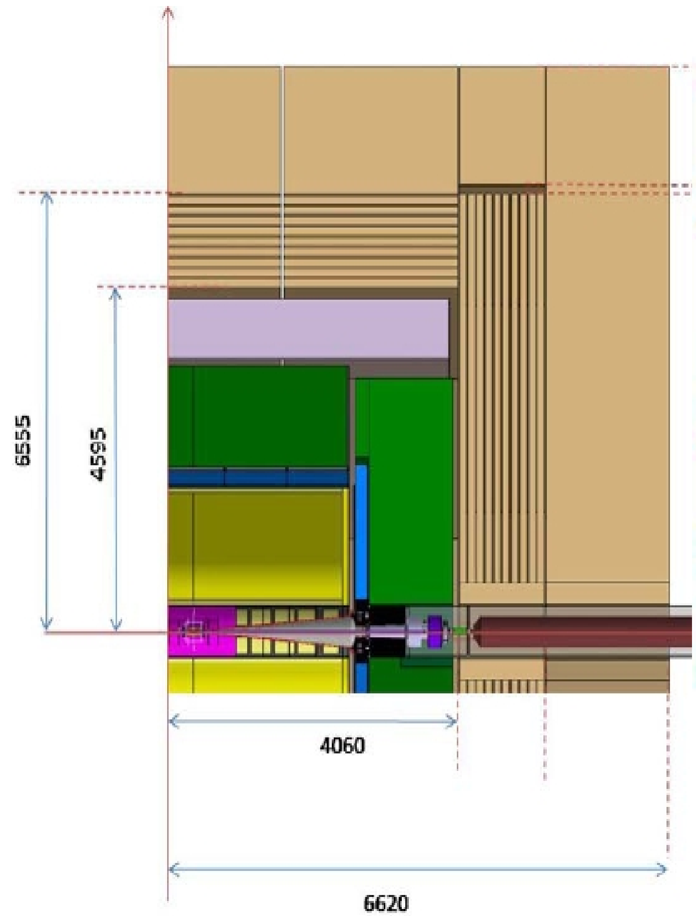
Enourmous Background $\sigma_{signal}/\sigma_{bkgr.}$ ~0

Proposed Detector Concepts

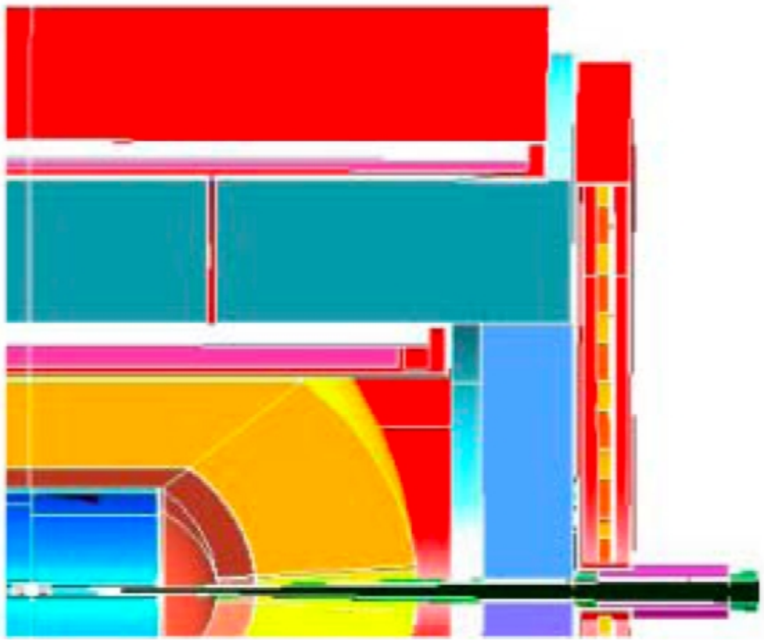
SID



ILD



4^{th}



Compact Detector with Silicon (Central) Tracking

Larger Volume with Gaseous Tracking (TPC)

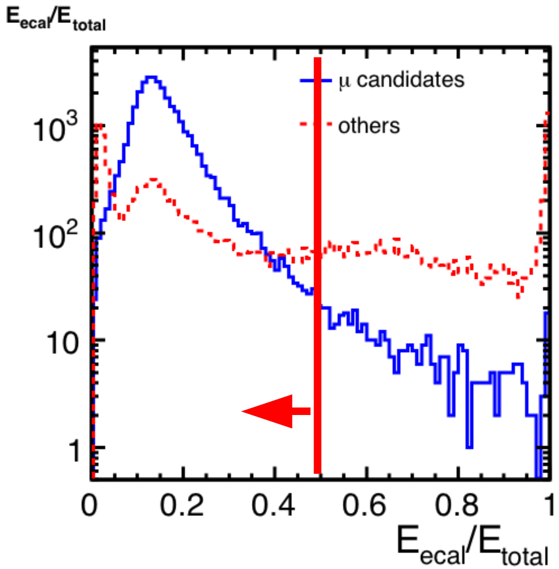
Tracking with small cell He Drift Chamber

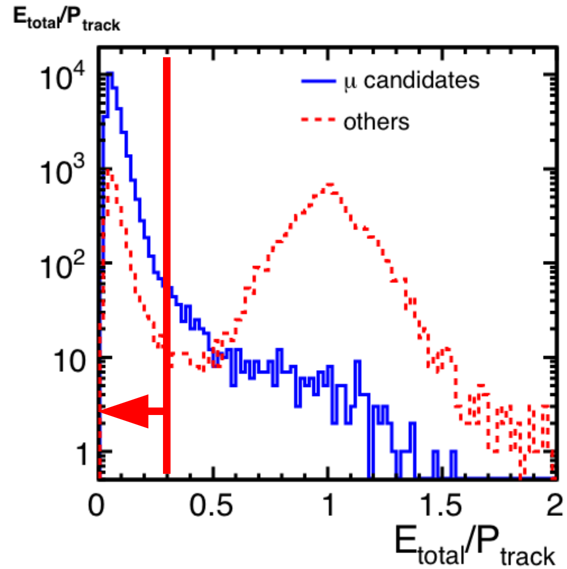
Xtal Calorimeter Dual Readout

Calorimeter optimised for Particle Flow

*All units are in cm

Signal Selection in ILD – Using Calorimetric Information

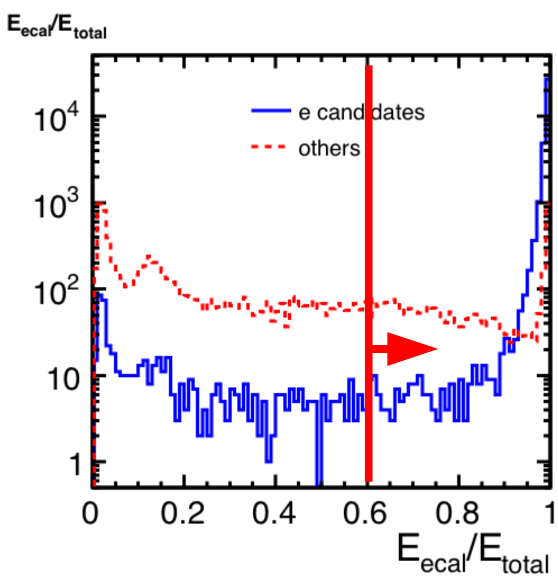


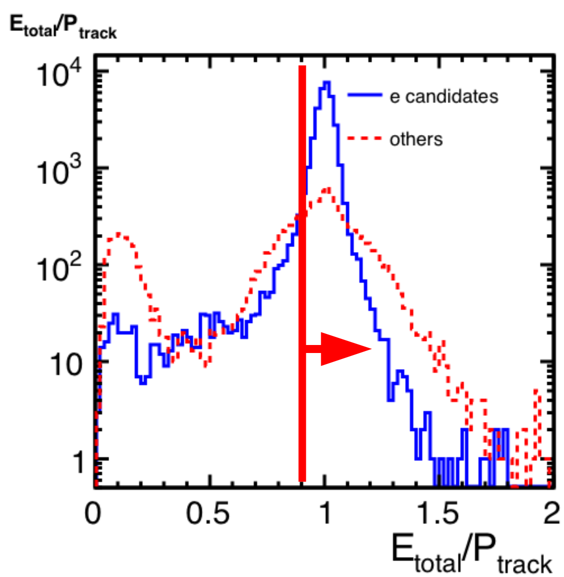


Muon Channel

$$E=\frac{N_{true\cap iden}}{N_{true}}=0.976$$

$$P=\frac{N_{true\cap iden}}{N_{iden}}=0.914$$





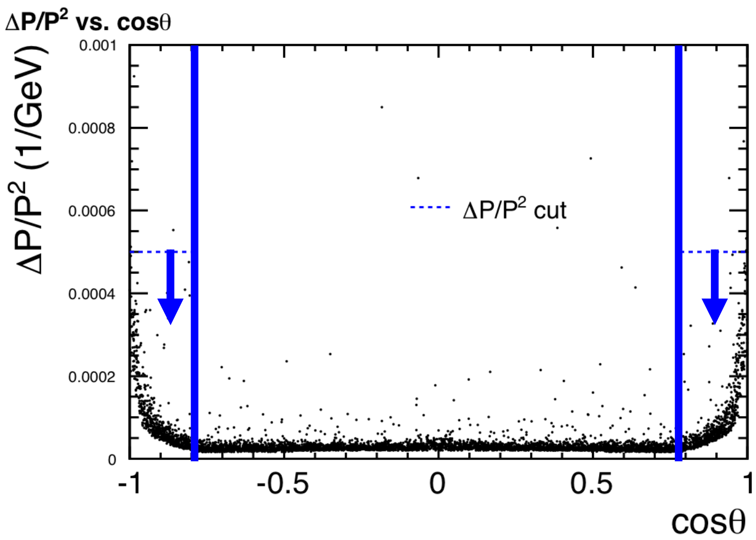
Electron Channel

$$E=\frac{N_{true\cap iden}}{N_{true}}=0.963$$

$$P=\frac{N_{true\cap iden}}{N_{iden}}=0.961$$

Signal Selection in ILD - Track Selection

Signal consists of two oppositely Charged Tracks

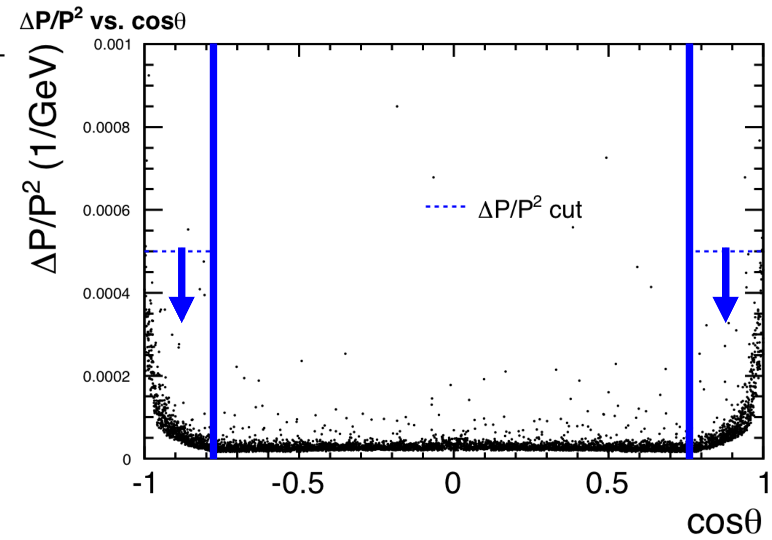


Electron Channel

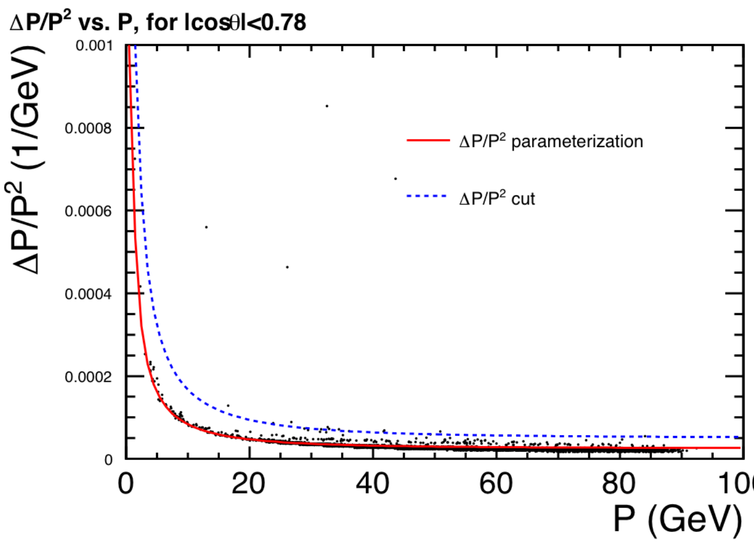
End Caps |cosθ|>0.78

Track Rejected if:

$$\frac{\Delta P}{P^2} > 5\times 10^{-4}$$



μ Channel



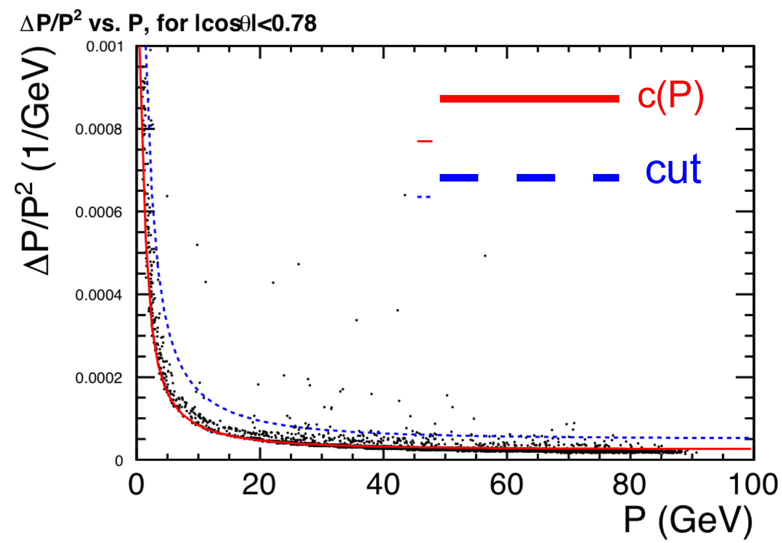
Barrel Region

Track Resolution:

$$c(P) = \frac{\Delta P}{P^2} = 2.5\times 10^{-5} \oplus \frac{8\times 10^{-4}}{P}$$

Track Rejected if:

$$\frac{\Delta P}{P^2} > 2\cdot c(P)$$



Background Rejection

SiD

$87 < M_{dl} < 95$ GeV
$|\cos\theta_{l+}|, |\cos\theta_{l-}| < 0.99$
$|\cos\theta_{dl}| < 0.85$
$|\cos\theta_{miss.}| < 0.99$

- Very tight constraint on Z-Mass for dilepton system

ILD

$P_{T,dl} > 20$ GeV
$80 < M_{dl-} < 100$ GeV
$0.2 < acop < 3.0$
$\Delta P_{Tbal.} > 10$ GeV
$|\cos\theta_{miss.}| < 0.99$
$115 < M_{recoil} < 150$ GeV
Dedicated cuts for radiative events
Multivariate Analysis

- Relaxed constraint on dilepton Mass
- Cuts more closely 'tailored' to background

Signal/Background > 30%

4th

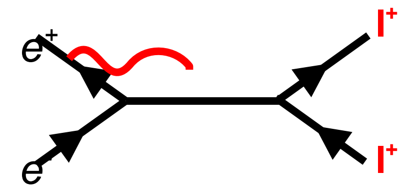
$72 < M_{dl} < 110$ GeV
$102 < M_{recoil} < 168$ GeV
$|\cos\theta_{l+}|, |\cos\theta_{l-}| < 0.98$
$P_{T,max} > 20$ GeV
$|\cos\theta_{miss.}| < 0.99$
DCA for e,μ < 6mm

Particle ID by muon spectrometer and exploitation of mult r/o of Calorimeter

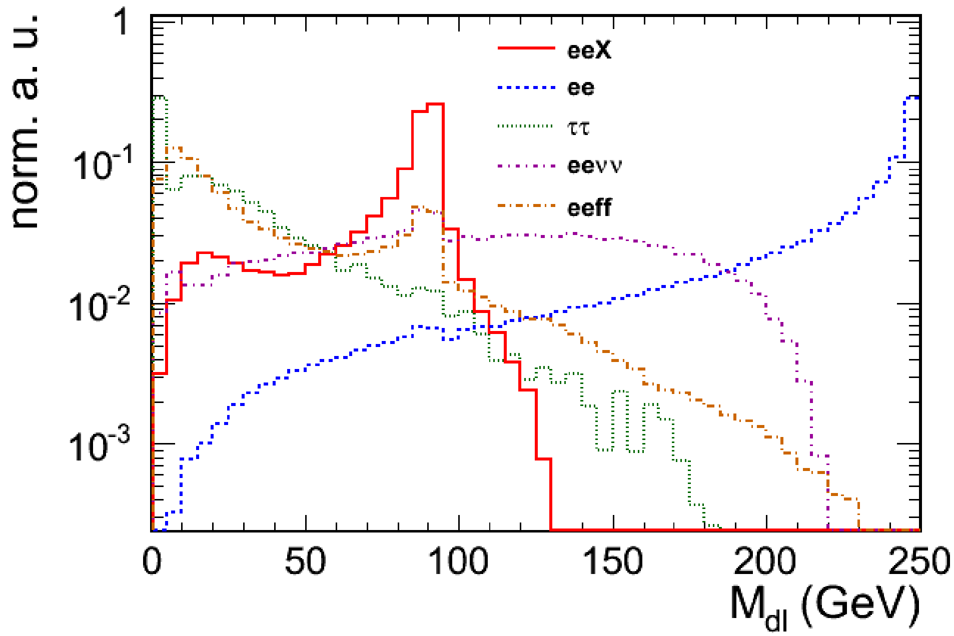
Additional Tracks in Default Analysis!!!

Remaining background: Boson Pair Production
Bhabha Background

Signal and Background – Examples



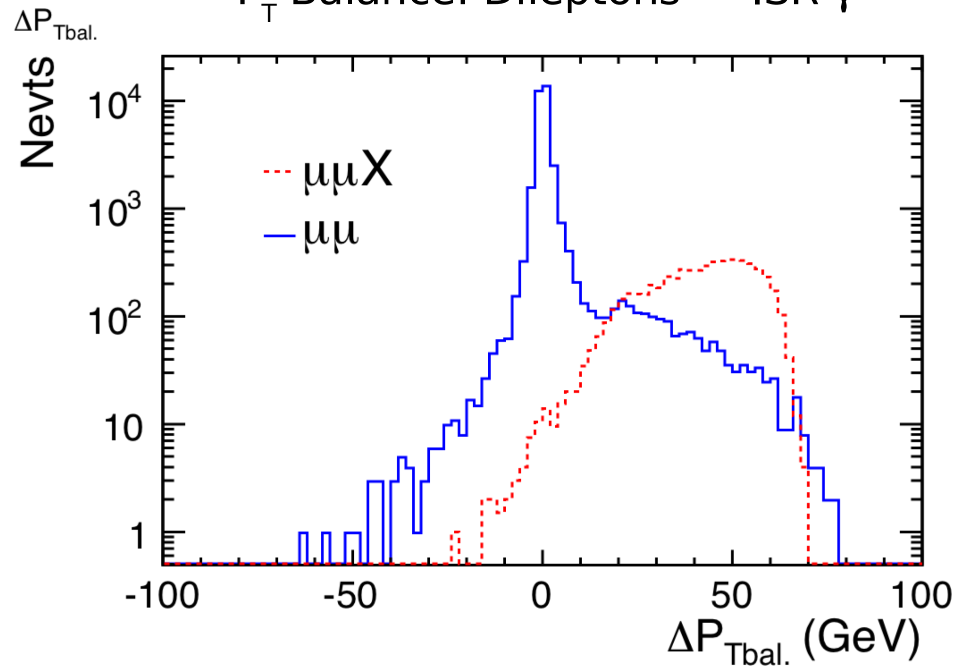
Dilepton Mass in e-Channel



Radiative effects lead to widening of peak

→ Effort to keep these events → later

P_T Balance: Dileptons ↔ ISR γ



Efficient cut to suppress lepton pair events

Background reduction by factor 10

Extraction of Results

Results extracted without assumption on shape of spectrum

SiD

Linear Least χ^2 fit to bin contents:

$$\hat{N}_i = \hat{N}_{ibkg} + \hat{N}_{i,signal} + \frac{\hat{N}_i}{M_h}(M_h - 120\ GeV)$$

$$\chi^2(M_h) = \sum \frac{(N_i - \hat{N}_i(M_h))^2}{s_i^2}, \quad s_i = \sqrt{\hat{N}_{ibkg} + N_{isignal}}$$

$\frac{\hat{N}_i}{M_h}$ Calculated using training samples around M_h=120 GeV

ILD

(Simplified) Kernel Estimation for signal

$$F_S(x) = \frac{1}{N}\sum_{j=1}^{m} n_j G(x; t_j; h_j)$$

$$h_j = \left(\frac{4}{3}\right)^{1/5} N^{-1/5} \Delta x \sqrt{\frac{N}{n_j}}$$

$$x \rightarrow x' = x - M_h$$

Background approximated by second order polynomial

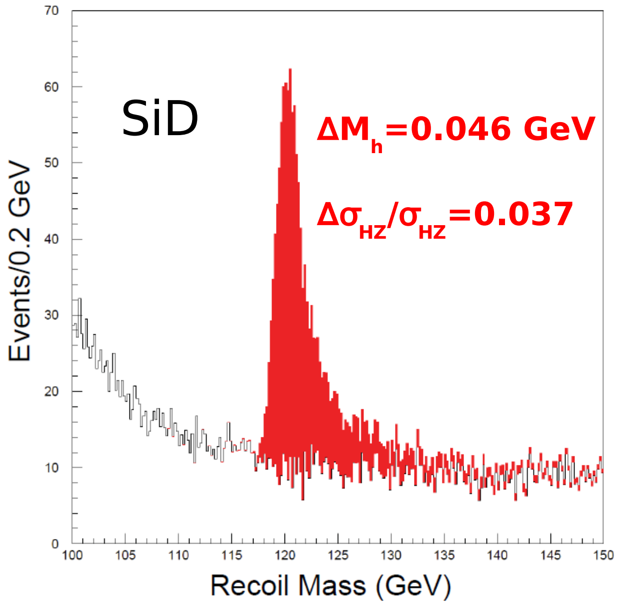
4th

Convolution of Gaussian and Second Order Polynomial

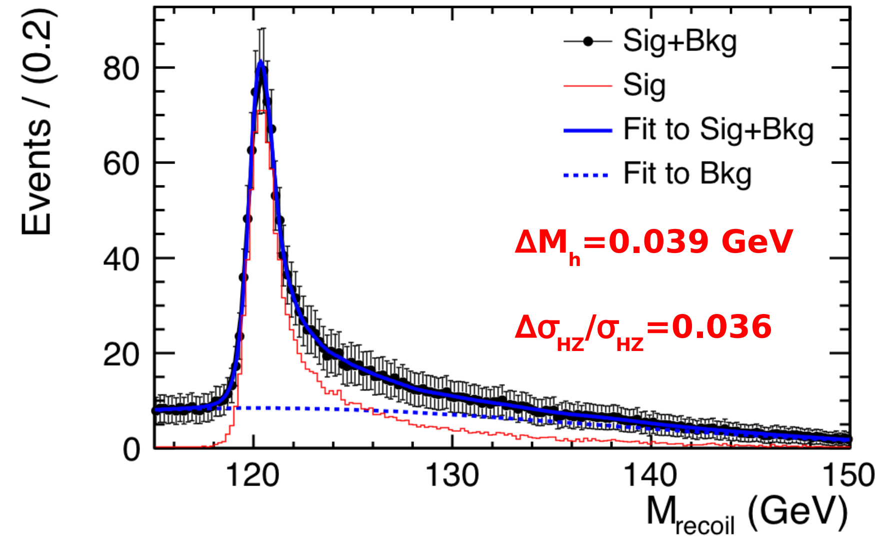
Different/Complementary methods to extract Results

Results for: $e^{-}_{R}e^{+}_{L}$: $P_{e^-}=+80\%$ $P_{e^+}-30\%$

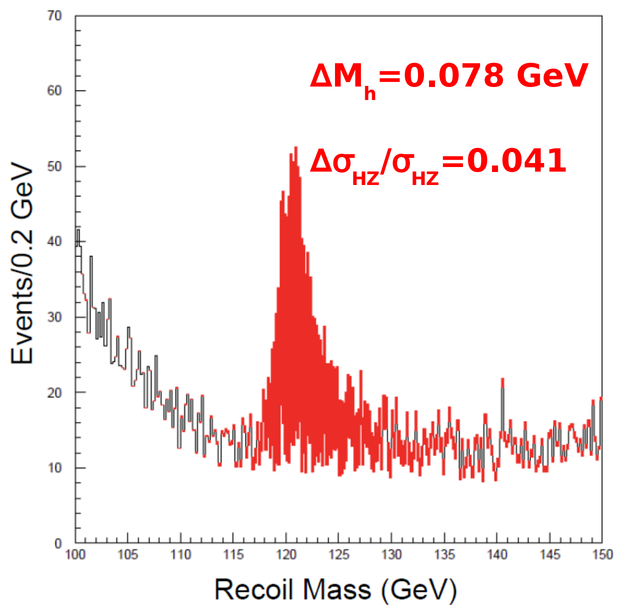
Muon Channel



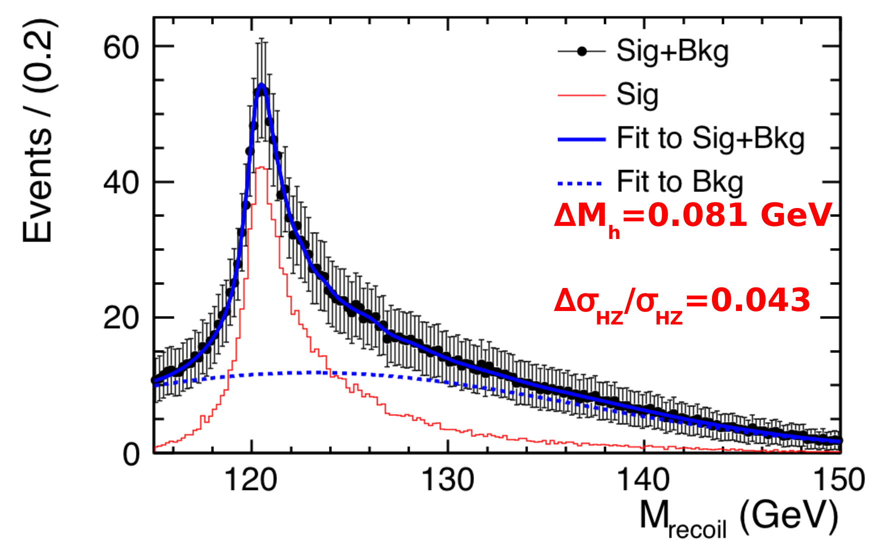
Very Precise Measurement



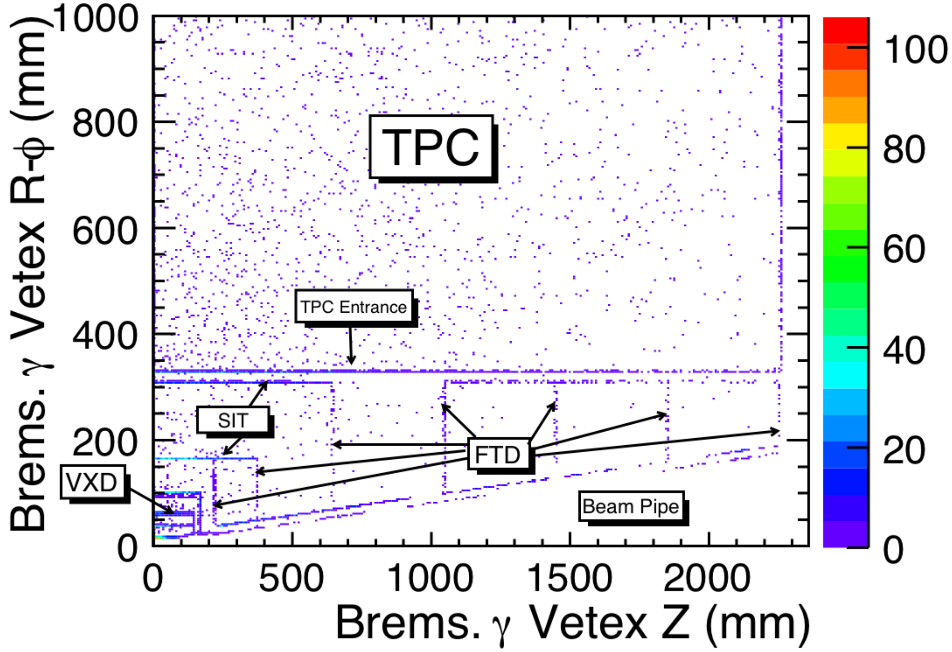
Electron Channel



Less Precise Measurement

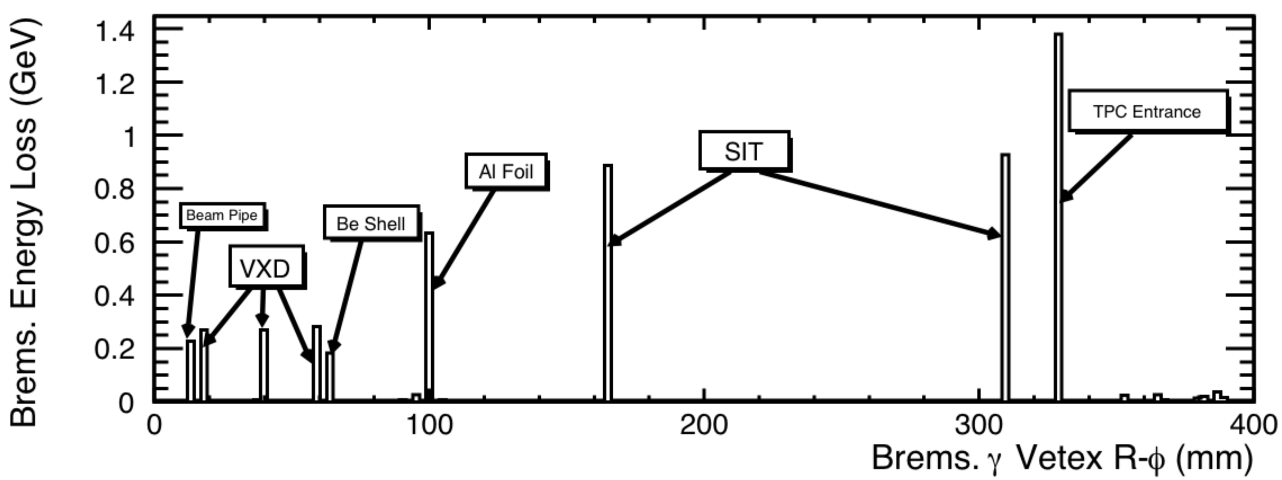


Sources of Bremsstrahlung



Landscape of ILD Detector by Bremsstrahlung

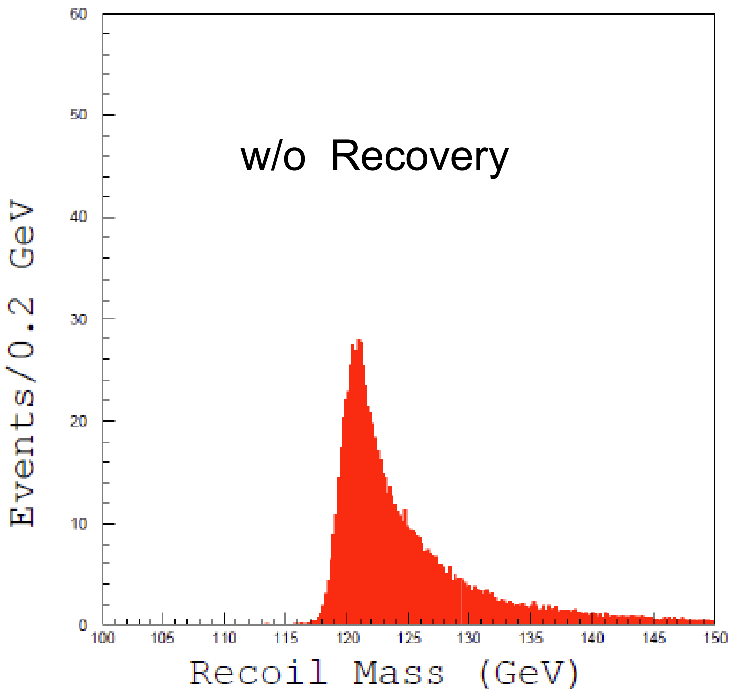
Energy loss by Passive Material

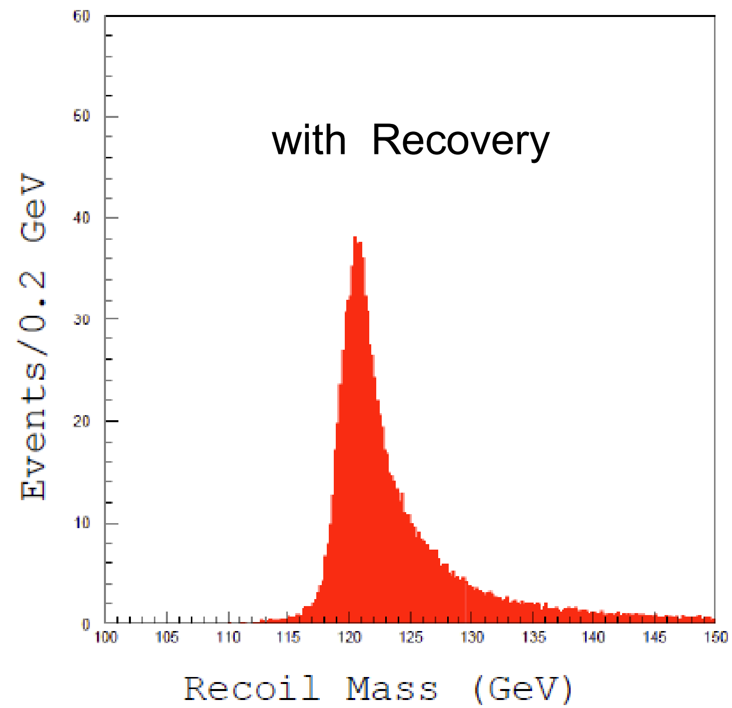


Figures from PhD Thesis: H. Li (LAL)

Bremsstrahlung Recovery

Collecting Bremsstrahlung Photons in elm. Calorimeter
Gain: Higher Statistics in Signal Region
Penalty: Worse resolution by low energetic photons $\sigma/E \sim 17\%/\sqrt{E}$





SiD: ΔM_h=0.113 GeV, $\Delta\sigma_{HZ}/\sigma_{HZ}$=0.049 → ΔM_h=0.097 GeV, $\Delta\sigma_{HZ}/\sigma_{HZ}$=0.042

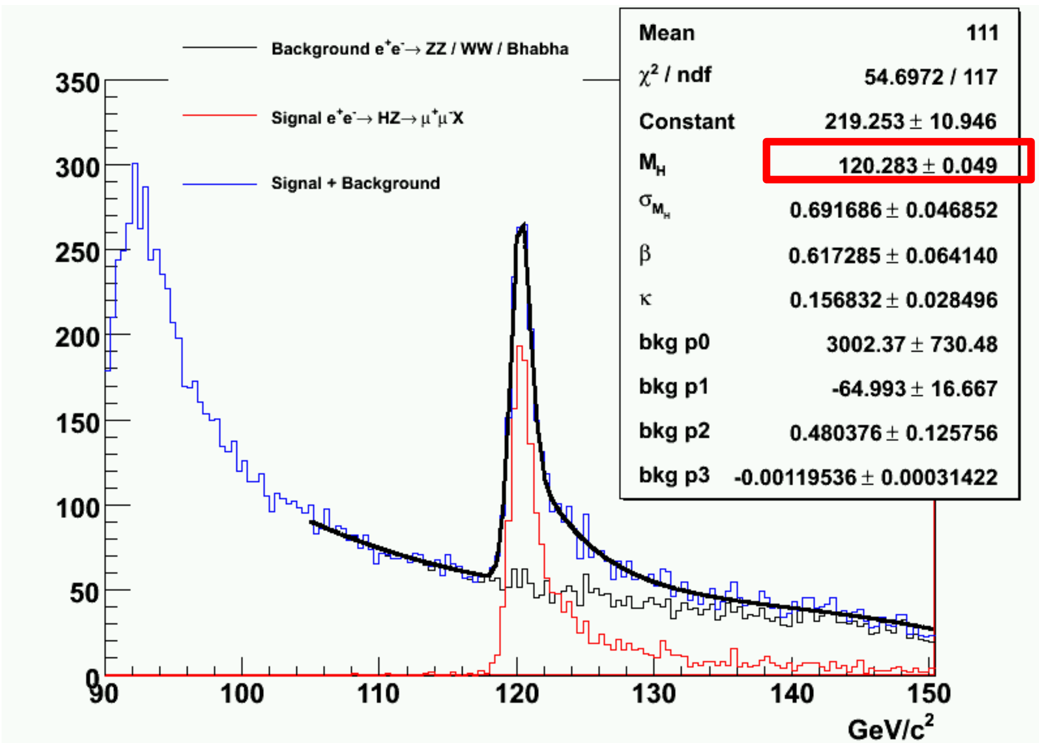
ILD: ΔM_h=0.092 GeV, $\Delta\sigma_{HZ}/\sigma_{HZ}$=0.051 → ΔM_h=0.081 GeV, $\Delta\sigma_{HZ}/\sigma_{HZ}$=0.043

Statistical Gain "beats" modest energy resolution

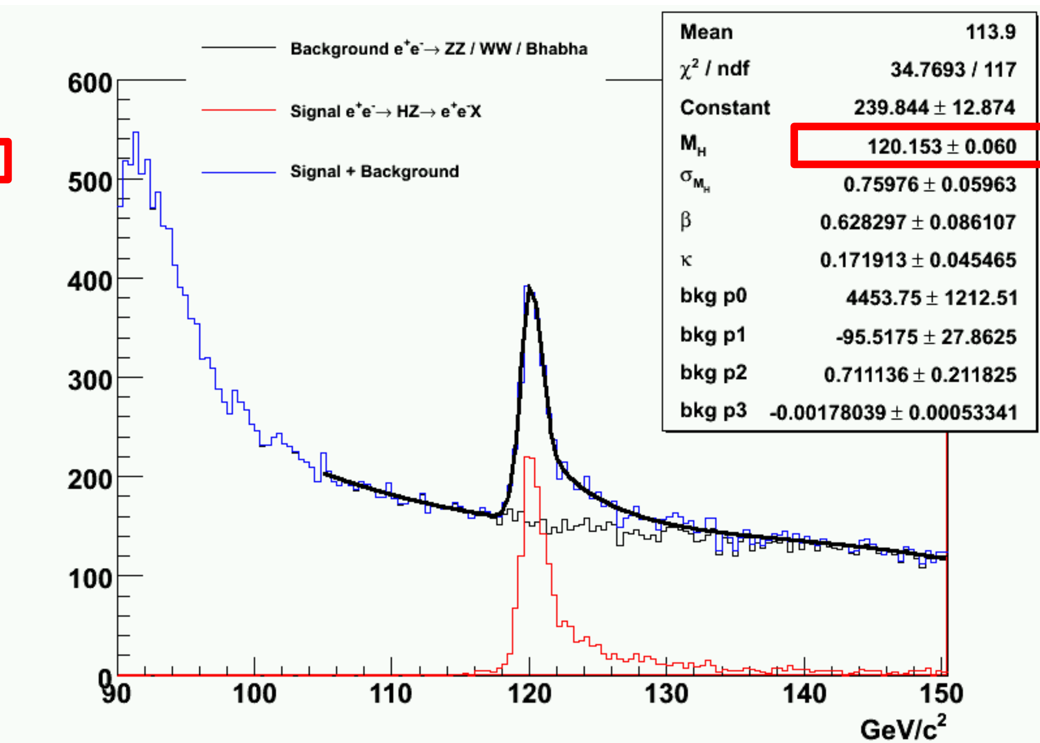
Bremsstrahlung Recovery in the 4th

Xtal calorimeter: superb elm. energy resolution σ/E~3%/√E

Muon Channel



Electron Channel



ΔM_h=0.05 GeV

ΔM_h=0.06 GeV

Comparable (statistical) Precision in Electron and Muon Channel!!!

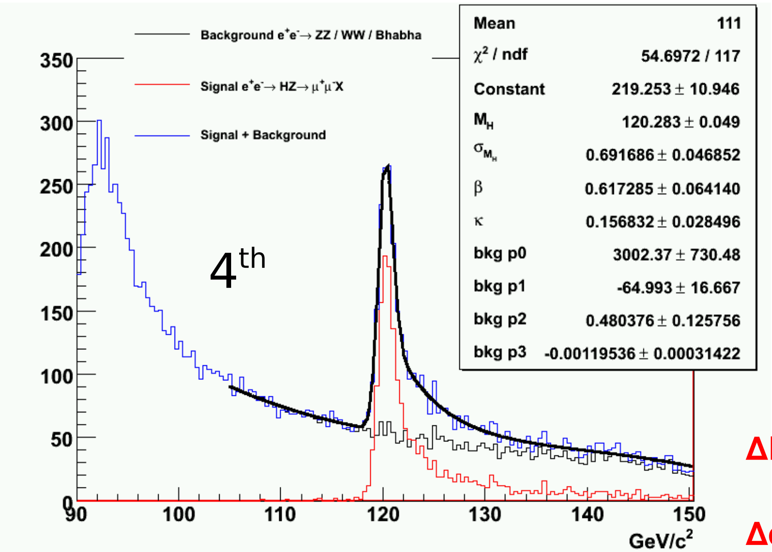
Result of emphasising the role of Calorimetry!!?

Note: Results here for Model Dependant Analysis (Requirement of add. Charged Tracks)

Results for: $e^-_L e^+_R$: $P_{e^-} = -80\%$ $P_{e^+} + 30\%$

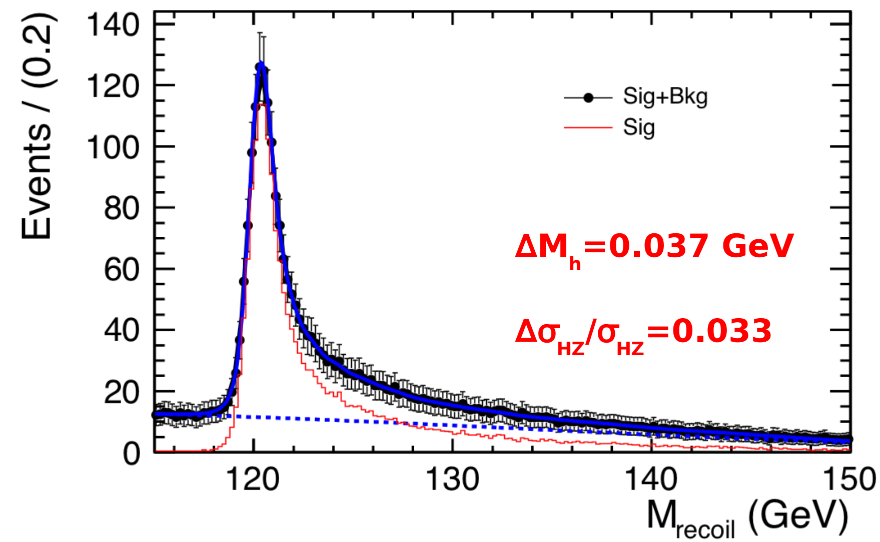
Model Dependant Analysis: Additional Tracks required

Muon Channel

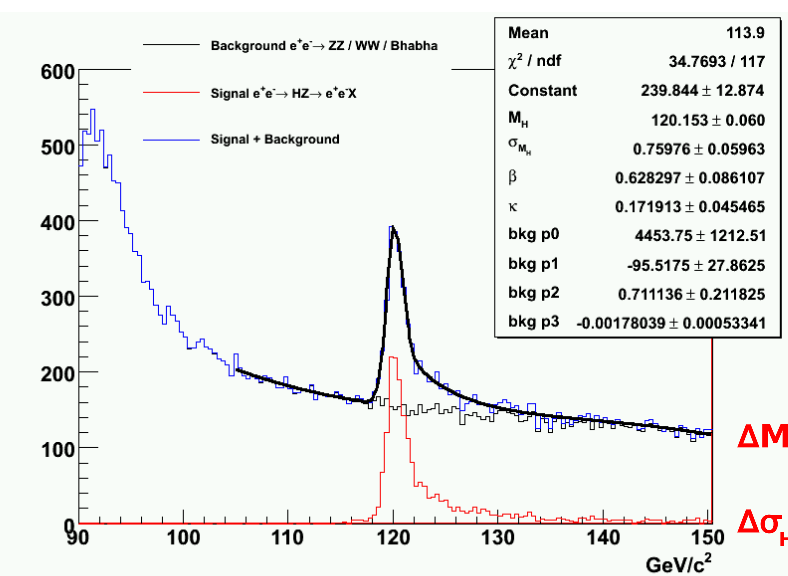


ΔM_h=0.049 GeV

$\Delta\sigma_{HZ}/\sigma_{HZ}$=0.1

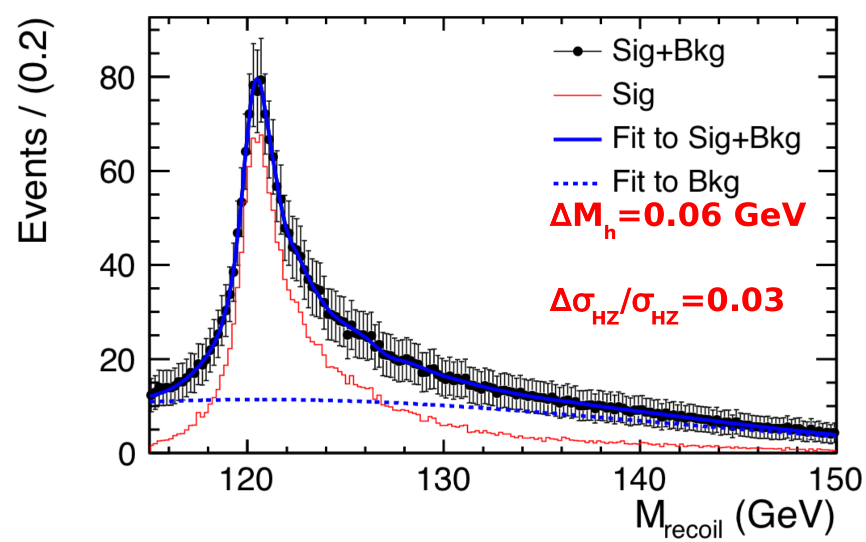


Electron Channel



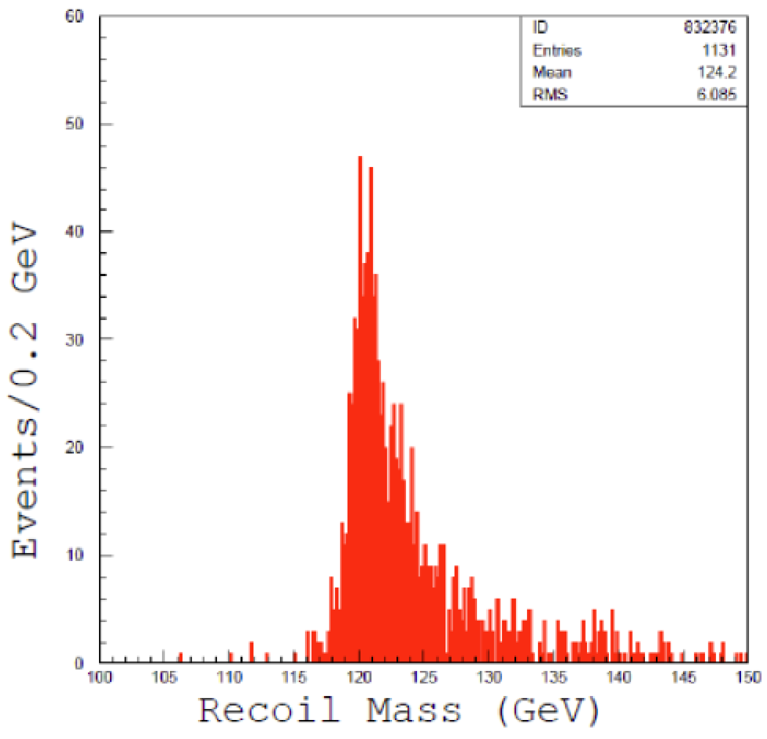
ΔM_h=0.060 GeV

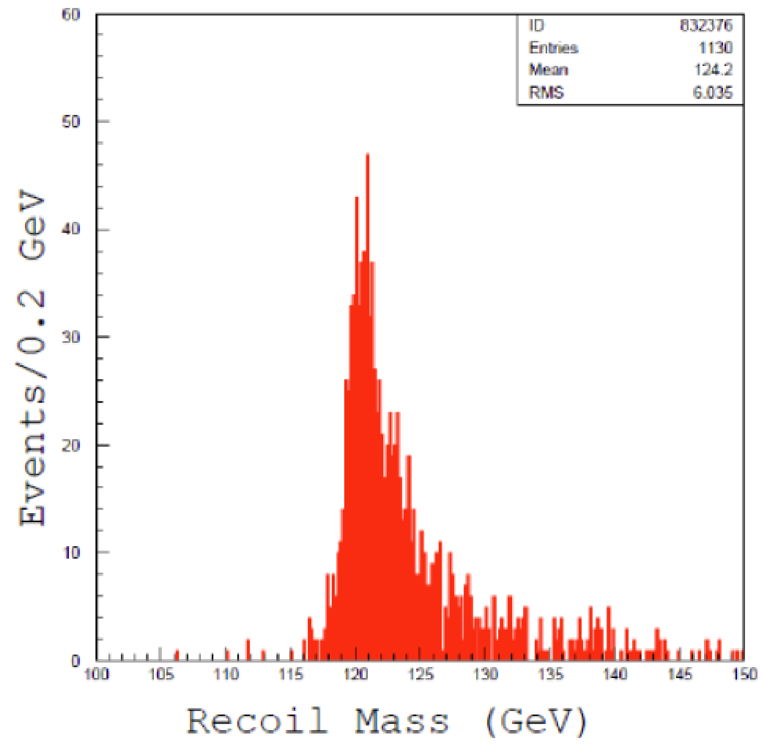
$\Delta\sigma_{HZ}/\sigma_{HZ}$=0.15



γγ - Background

Processes: γγ → e^+e^- γγ→ $\mu^+\mu^-$ γγ→ *hadrons*

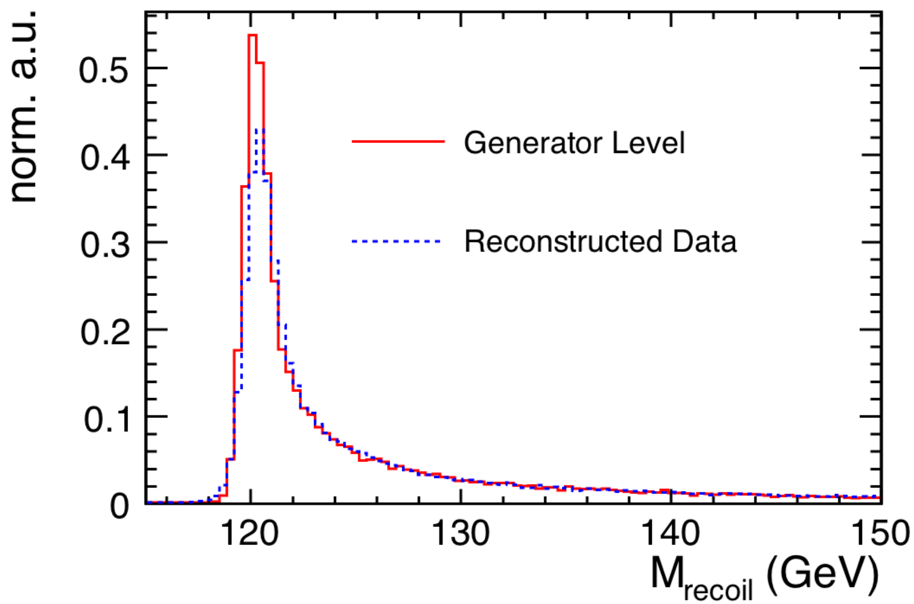




Beam Background has only little effect on recoil mass spectrum

Influence of Machine Parameters

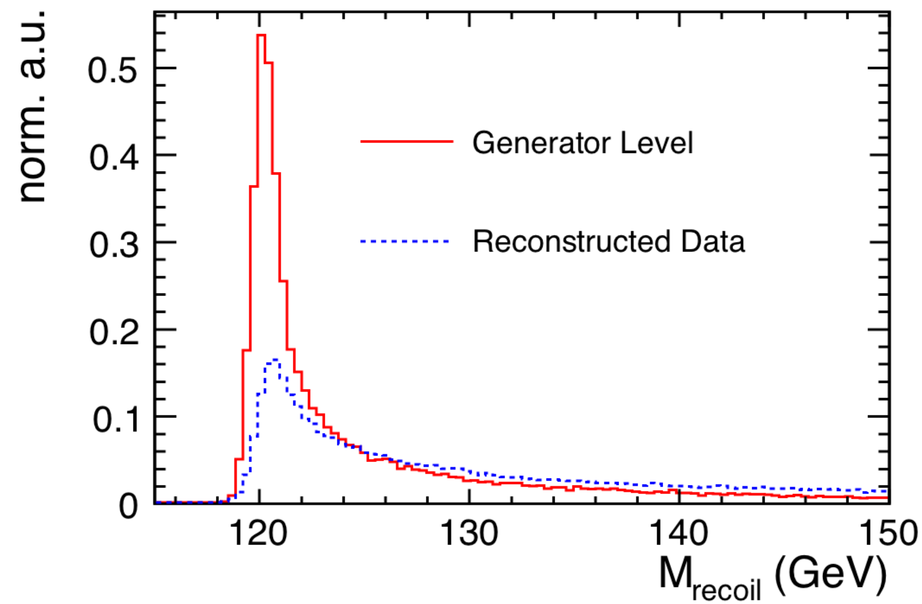
Muon Channel



ΔM_{tot} = 650 MeV

$\Delta M_{mach.}$ = 560 MeV $\Delta M_{det.}$ = 330 MeV

Electron Channel



ΔM_{tot} = 750 MeV

$\Delta M_{mach.}$ = 560 MeV $\Delta M_{det.}$ = 500 MeV

Uncertainties of incoming beams are dominant source
of Statistical Error

(even in Electron Channel)

Shopping List beyond LOI

- Do we want/need to compare the performance of Detector Concepts?

  Agreement on common set of cuts would be helpful!

- Study of systematic errors entirely missing (Lack of time, manpower)

  Need to identify major sources of systematic errors
  Knowledge of Detector R&D needs to go into Physics Studies
  e.g. Answers to IDAG contain parameters on tracking precision
  More guidance to Detector R&D by Physics Studies!?
  Disjunct groups !!?

- Conclusions for Detector R&D from LOIs?

  LOI should lead to directions for R&D, does it?

- Feedback to change of Machine Parameters

  Need ability to ponder timely the influence of Physics Performance

Conclusions and Outlook

- Detector Concepts promise precision measurement of Higgs-strahlungs Process

  ΔM_h: O(40 MeV)

  $\Delta\sigma_{HZ}$: < 5%

  Detector Layout allow for Efficient Background suppression
  → up to Six Orders of Magnitude!!!!

  LOIs witness enormous physics potential of ILC and its Detectors!!!

- Electron Channel “suffers” from Bremsstrahlung

  Material Budgets need to be watched closely!!
  First Algorithms for recovery successfully applied!!
  Excellent Calorimetry can help!?

- Higgs Recoil mass channel is very sensitive to Beam Parameters!!!

- Systematic Effects

  Algorithms developped for LOIs allow for study of systematic errors
  e.g. via ee → ZZ

- LOIs are not the end but the start

  Directions for R&D emerging from LOIs?

Tables with Quantitative Results

ILD - Model independent Analysis

Pol.	Ch.	M_H (GeV)	σ (fb)
$e^-_R e^+_L$ $\mathcal{L} = 250$ fb^{-1}	$\mu^+\mu^- X$	120.006 ±(0.039)	7.89 ± 0.28 (3.55 %)
	$e^+e^- X$	120.005 ±(0.092)	8.46 ± 0.43 (5.08 %)
	merged	120.006 ±(0.036)	8.06 ± 0.23 (2.91 %)
$e^-_L e^+_R$ $\mathcal{L} = 250$ fb^{-1}	$\mu^+\mu^- X$	120.008 ±(0.037)	11.70 ± 0.39 (3.33 %)
	$e^+e^- X$	119.998 ±(0.085)	12.61 ± 0.62 (4.92 %)
	merged	120.006 ±(0.034)	11.96 ± 0.33 (2.76 %)

Table 13: Resulting Higgs mass M_H and cross section σ of the *MI Analysis* using *Kernel Estimation.*

For details and further results using alternative fit methods and a Model Dependant Analysis, see PREL-LC-PHSIM-2009-003

SiD - Model independent Analysis

80eR lumi	80eL lumi	Mode	ΔM_H (GeV)	$\Delta\sigma_{ZH} / \sigma_{ZH}$
250 fb^{-1}	0 fb^{-1}	e^+e^-H	0.078	0.041
250 fb^{-1}	0 fb^{-1}	$\mu^+\mu^-H$	0.046	0.037
250 fb^{-1}	0 fb^{-1}	$e^+e^-H + \mu^+\mu^-H$	0.040	0.027
0 fb^{-1}	250 fb^{-1}	e^+e^-H	0.066	0.067
0 fb^{-1}	250 fb^{-1}	$\mu^+\mu^-H$	0.037	0.057
0 fb^{-1}	250 fb^{-1}	$e^+e^-H + \mu^+\mu^-H$	0.032	0.043

Source: Tim Barklow, e-mail of 28/9/09

W.r.t. LOI and LOI update for IDAG:
Correction for 14mrad crossing angle included

		Mass	StError	sigma	StError
	mumu	120.28	0.05	0.69	0.05
5 trk:	ee	120.47	0.10	0.83	0.09
	ee+Cal	120.15	0.06	0.76	0.06
	mumu	120.24	0.06	0.61	0.05
MI:	ee	120.51	0.41	0.81	0.39
	ee+Cal	120.16	0.24	0.73	0.25

Mail by Giovanni Tassielli 26/09/09