Current Research Status and Future Plans

ILC group meeting

May 8, 2015

Jacqueline Yan

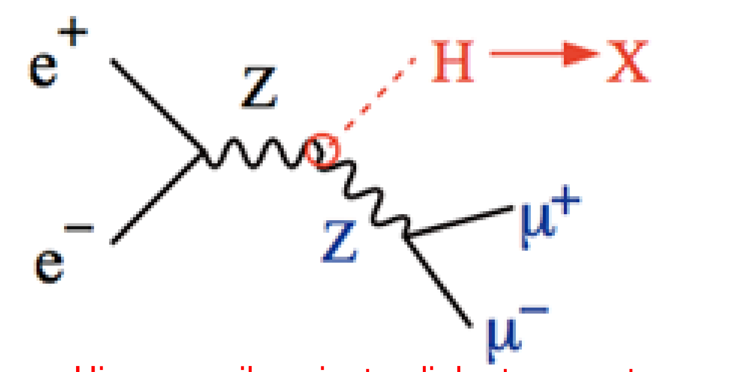
Research Plan

(ongoing and in near future)

◆ **recoil mass study using leptonic channels**

e+e- → ZH → μ+μ-H (e+e-H)

at alternative center of mass energies (ECM) and beam polarization



Higgs recoil against di-lepton system

$$M_X^2 = (p_{CM} - (p_{\mu^+} + p_{\mu^-}))^2$$

Goal:

precise model-independent measurement of absolute Higgs cross section

a "must-have" for measurement of total Higgs width and Higgs couplings

- **study impact of ECM and polarization on precision of σ_{ZH} and m_h**

  ➔ contribute to decision for ILC run scenario

Current Status

- analysis done for **Z→mumu channel at ECM = 250 GeV, 350 GeV**
  → see results presented at AWLC2014
- **recently also for ECM = 500 GeV**

  comparisons made between ECM and polarizations (e-, e+) = (-0.8, + 0.3) and (+0.8, -0.3)

- restructuring of analysis methods

Detailed Plans (including further future)

- **analysis for Z→ee channel at ECM = 250 GeV, 350 GeV, 500 GeV**
  combine both leptonic channels for a reliable estimate of statistical errors at each ECM
- also do analysis for **ZZ fusion process**

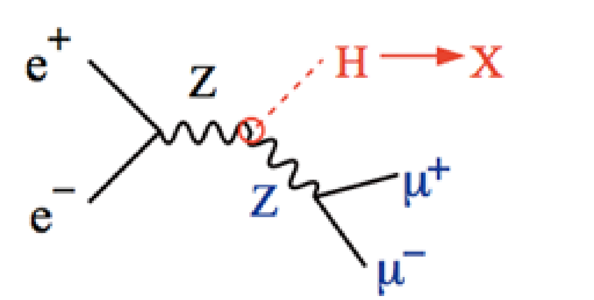
- **study systematic errors**
  e.g. effect on Higgs recoil mass measurement

Luminosity Spectrum (distribution of luminosity w.r.t. actual collision energy)
due to beam related factors
e.g. Beamstrahlung, beam energy spread, accelerator and beam related issues

Data Selection Method

Signal signature

a pair of isolated energetic muons with di-lepton invariant mass ($M_{\mu+\mu-}$) close to Z mass



$$M_X^2 = \left(p_{CM} - (p_{\mu^+} + p_{\mu^-})\right)^2$$

Recoil mass

Dominant backgrounds

- e+ e- → Z Z → μ+ μ- X : forward Z production angle
- e+ e- → γ Z → γ μ+ μ- : energetic γ , pt balanced with di-lepton
- e+ e- → W W → μ+ μ- ν ν : broad $M_{\mu+\mu-}$ distr.

recoil mass effective for cutting BG

Muon Candidate Selection

opposite +/− 1 charge

- E_cluster / P_total < 0.5
- isolation (small cone energy)
  → removes nearly all 4f_WW_sl BG
- Minv closest to Z mass
- cos(track angle) < 0.98 & |D0/δD0| < 5

Data selections done in a way to guarantee Higgs decay mode independence

Optimized in terms of signal significance and xsec measurement precision

definition

- M_inv : invariant mass of 2 muons
- pt_mumu : pt of reconstructed muons
- pt,γ : pt of most energetic photon
- θ_Zpro = Z production angle

Final Selection

- **73 < GeV < M_inv < 120 GeV**
- **10 GeV < pt_mumu < 140 GeV**
- $\left|\overrightarrow{P_{t,sum}}\right| \circ \left|\overrightarrow{P_{t,g}} + \overrightarrow{P_{t,dl}}\right|$ **> 10 GeV**
- **|cos(θ_Zpro)| < 0.9**
- **120 GeV < Mrecoil < 140 GeV**
- **Likelihood cut**

ECM=350 GeV, (-0.8,+0.3)

- **Use info of cone energy around most energetic gamma**

→ cut 2f_Z BG using info on pt_γ while prevent bias on signal

In red box: key improvement points w.r.t. previous studies

similar methods for other ECM and polarizations

	Nsig	Nbg	S/B ratio	significance	sig eff (before Mrec)
Ecm=350 GeV					
(−0.8,+0.3)	1172	2068	0.57	20.6	51% (83%)
(+0.8,−0.3)	776	774	1.00	19.7	49% (83%)
Ecm=250 GeV					
(−0.8,+0.3)	1579	2831	0.56	23.8	61% (72%)
(+0.8,−0.3)	1182	1182	1.00	24.3	68% (72%)

Performance of data selection

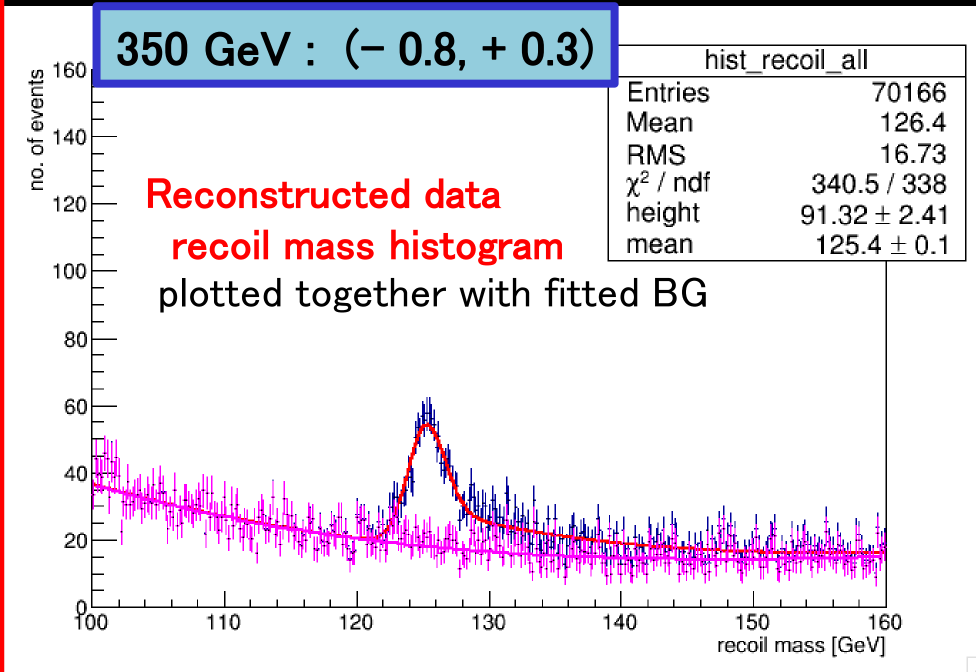
dominant BG after final selection

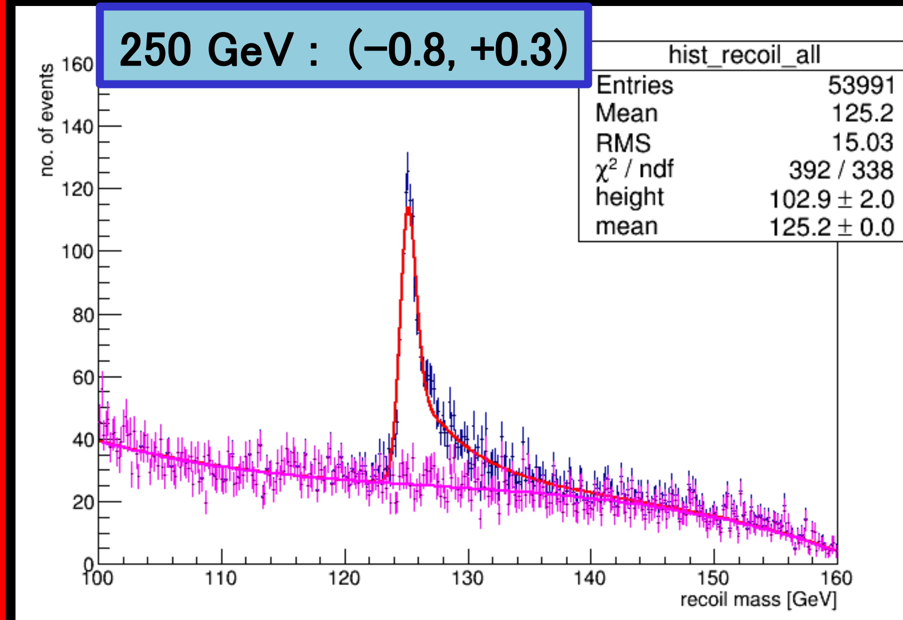
(Mrec 120−140 GeV + Likelihood cut)

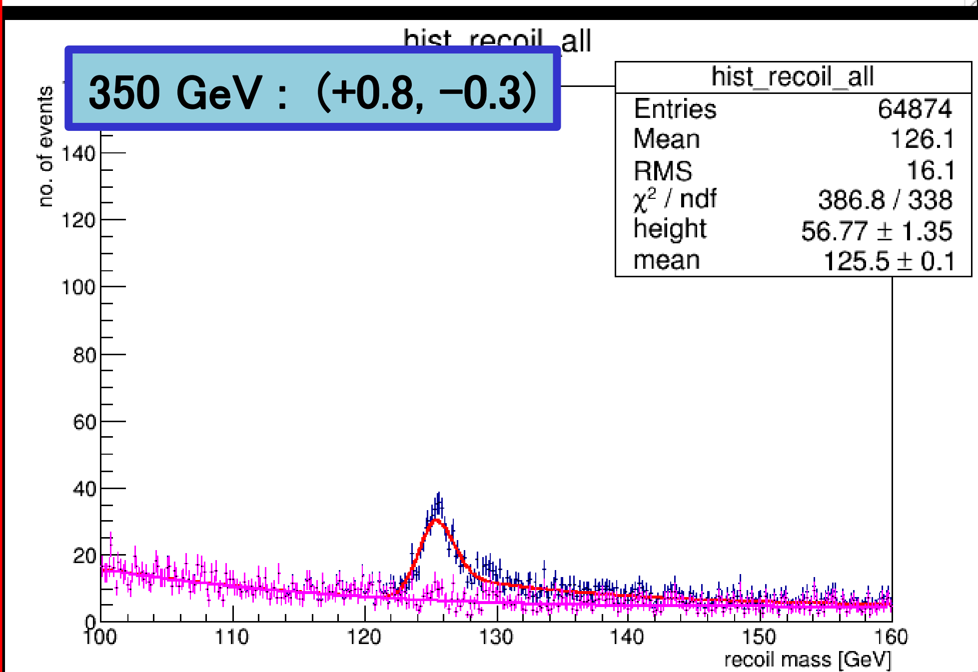
Balanced pt of γ and di−lepton

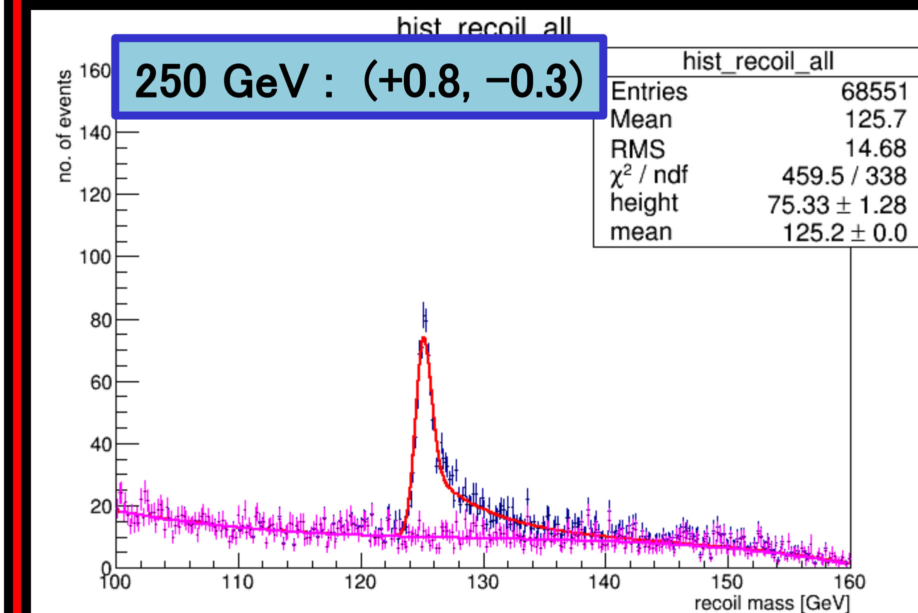
Isolated lepton finder

pol: (−0.8,+0.3)	original	after inv. mass pt_dl cut	after Pt,sum cut	final
signal	2288	2004	2003	1172
4f_ZZ_sl	188125	16962	16924	989
4f_ZZWWMix_l	541187	19295	19225	325
2f_Z_l	2227000	85335	21246	269
4f_WW_sl	2732980	17	17	0

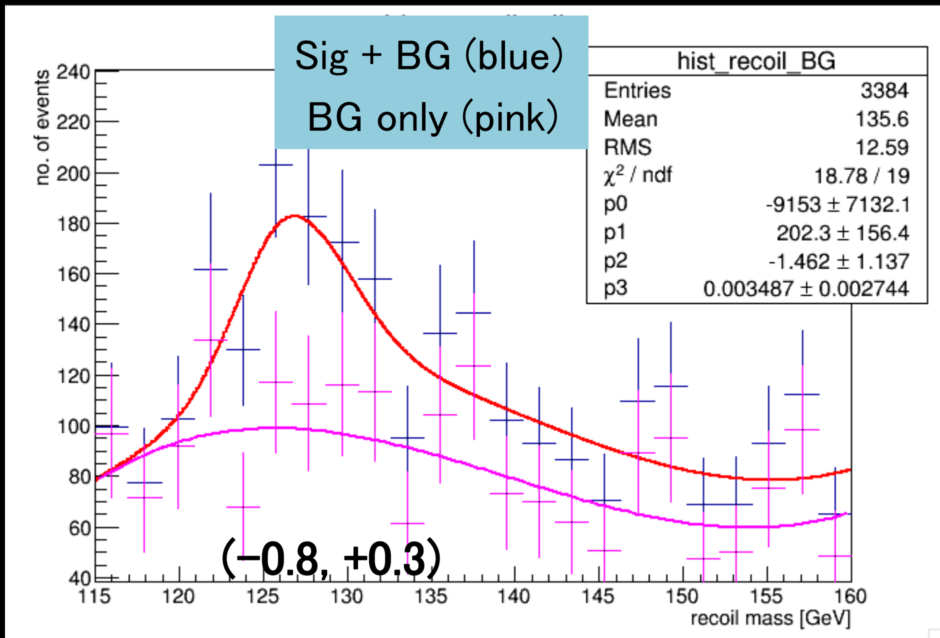

350 GeV : (− 0.8, + 0.3)
Reconstructed data
recoil mass histogram
plotted together with fitted BG
hist_recoil_all
Entries 70166
Mean 126.4
RMS 16.73
χ2 / ndf 340.5 / 338
height 91.32 ± 2.41
mean 125.4 ± 0.1
no. of events
recoil mass [GeV]

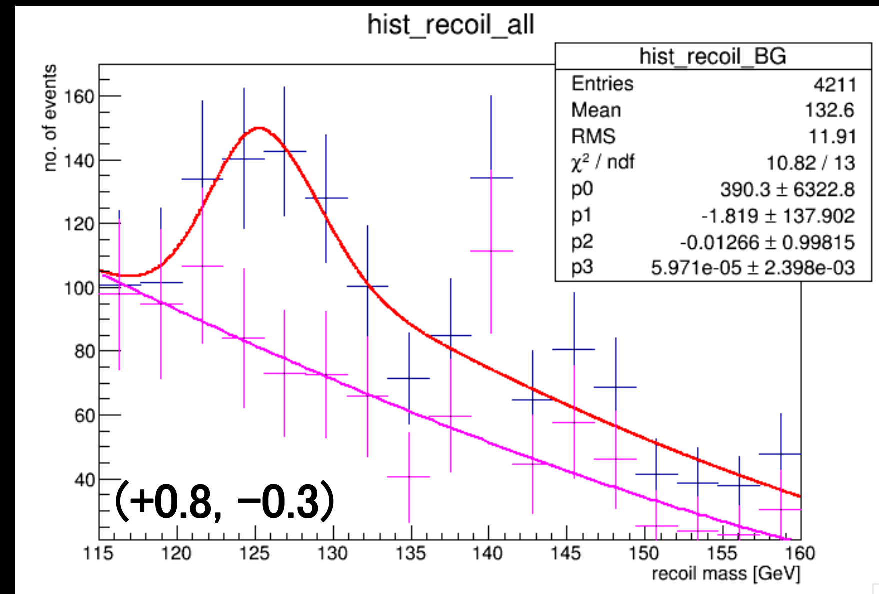

250 GeV : (−0.8, +0.3)
hist_recoil_all
Entries 53991
Mean 125.2
RMS 15.03
χ2 / ndf 392 / 338
height 102.9 ± 2.0
mean 125.2 ± 0.0
no. of events
recoil mass [GeV]


hist_recoil_all
350 GeV : (+0.8, −0.3)
hist_recoil_all
Entries 64874
Mean 126.1
RMS 16.1
χ2 / ndf 386.8 / 338
height 56.77 ± 1.35
mean 125.5 ± 0.1
no. of events
recoil mass [GeV]


hist_recoil_all
250 GeV : (+0.8, −0.3)
hist_recoil_all
Entries 68551
Mean 125.7
RMS 14.68
χ2 / ndf 459.5 / 338
height 75.33 ± 1.28
mean 125.2 ± 0.0
no. of events
recoil mass [GeV]

Recently I have analyzed 500 GeV results as well





Fitting over a wider range 115 – 225 GeV

Many challenges

- lower signal cross section
- signal peak buried in BG
- Difficulties in fitting

From Toy MC study,

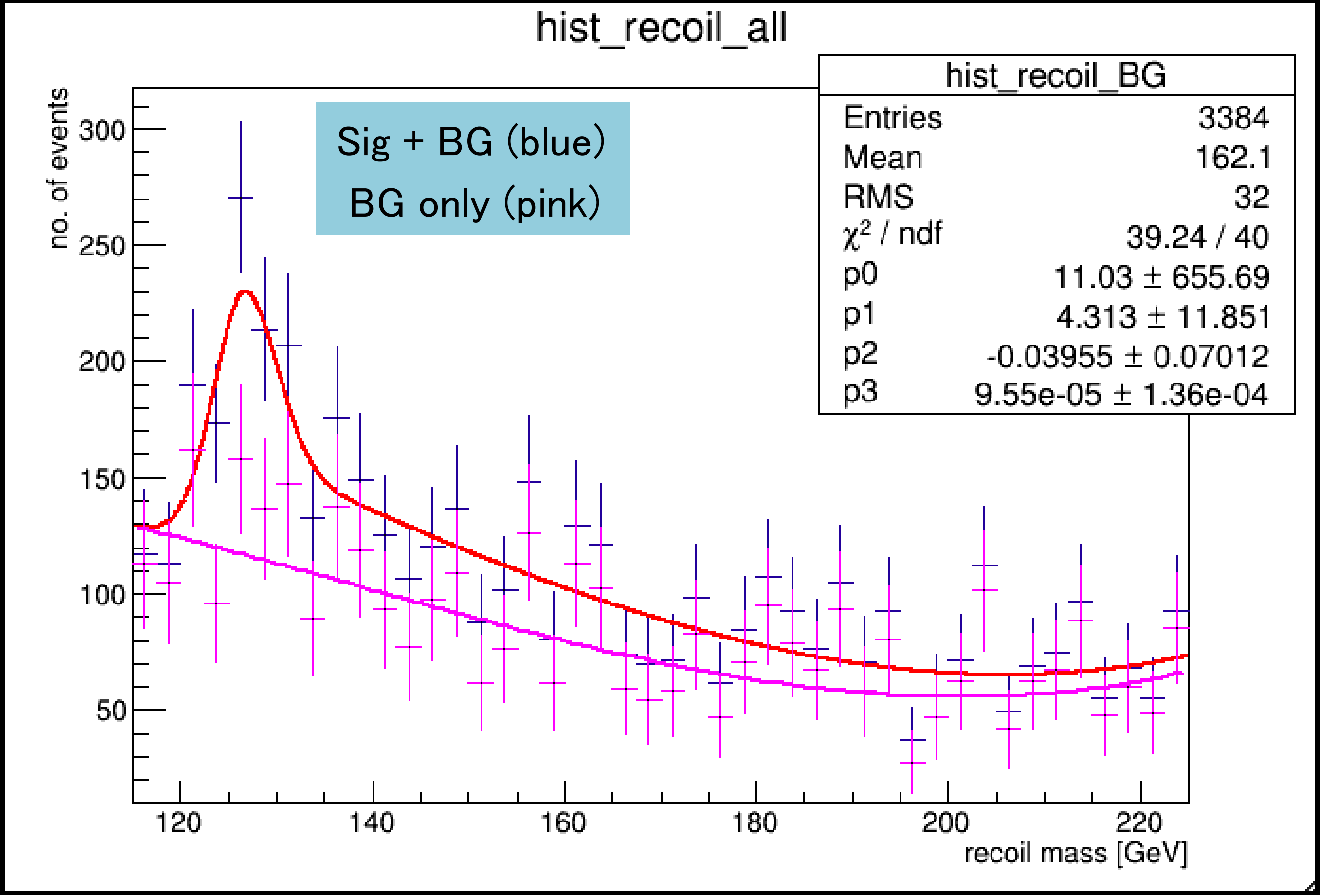
500 GeV xsec error 6– 8%

Zmumu signal xsec

- 250 GeV : 17.14 fb
- 350 GeV: 11.31 fb
- 500 GeV: 5.679 fb

(～ 1/2 of 350 GeV, 1/3 of 250 GeV)

If we ignore issue of H*→WW peak beyond 160 GeV threshold and fit in a wider range for 500 GeV



Fitting over a wider range 115 – 225 GeV

Better xsec error in this case ～ 5 %

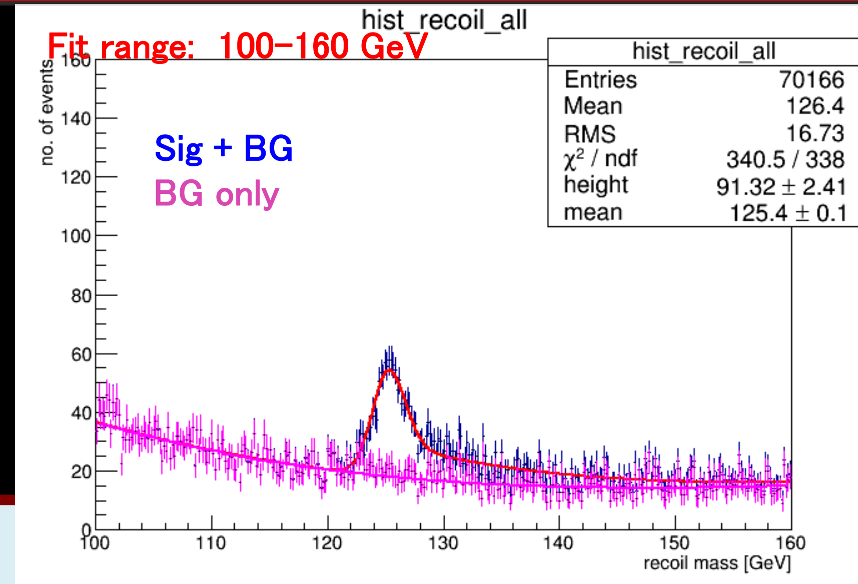
we can still achieve this if we use the appropriate fitting function (?)

recoil mass fitting method

- Fit signal with **GPET**

  Gaussian Peak with Exponential Tail

- Fit BG with 3^{rd} order polynomial



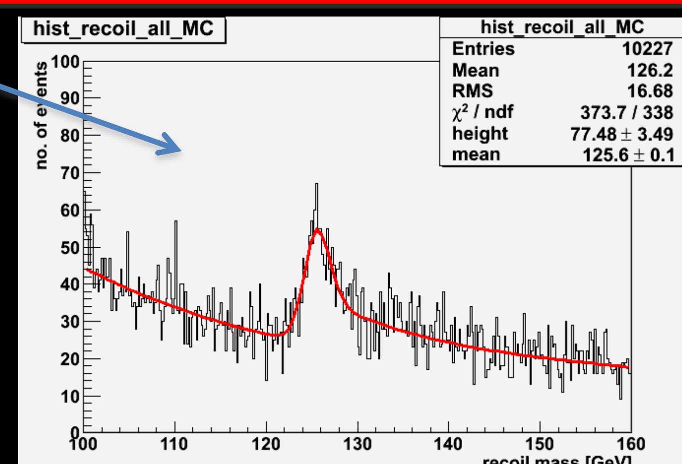
◆ SIGNAL: GPET: 5 parameters :

$$\frac{N}{\sqrt{2\pi}\sigma}\exp\left\{-\frac{1}{2}\left(\frac{x-x_{mean}}{\sigma}\right)^2\right\} \qquad \left(\frac{x-x_{mean}}{\sigma}\le k\right)$$ Gaus (left-side) ,

$$\frac{N}{\sqrt{2\pi}\sigma}\left[b\cdot\exp\left\{-\frac{1}{2}\left(\frac{x-x_{mean}}{\sigma}\right)^2\right\}+(1-b)\exp\left\{-k\left(\frac{x-x_{mean}}{\sigma}\right)\right\}\exp\left(k^2/2\right)\right] \qquad \left(\frac{x-x_{mean}}{\sigma}\ge k\right)$$ Gaus + expo (right side)

Toy MC study

Toy MC 10000 seeds



<u>goal:</u> test quality of fitting method

evaluate xsec precision

<u>method</u>:

generate MC events according to fitted "real" data (Poisson distr.)

fit MC hist with same function as "data" → get Nsig,

Compare of results between alternative ECM and polarizations

Ecm=250 GeV		Ecm=350 GeV		Ecm=500 GeV	
(−0.8,+0.3)	3.5%	(−0.8,+0.3)	4.1%	(−0.8,+0.3)	6.1%
(+0.8,−0.3)	3.6%	(+0.8,−0.3)	4.5%	(+0.8,−0.3)	7.2%

Current (April, 2015)

xsec precision is improved by 17%

from AWLC 2014 (@Fermilab)

for ECM=350 GeV Pol (−0.8, + 0.3)

- **ECM= 250 GeV has 17 % better xsec precision** (w.r.t. 350 GeV)

  higher statistics, better momentum resolution → sharper recoil mass peak

- **Pol (+0.8, −0.3) has 10% worse xsec precision**

  although WW BGs significantly suppressed (higher S/B ratio), statistics is lower

Toy MC study results
Fitted Higgs mass

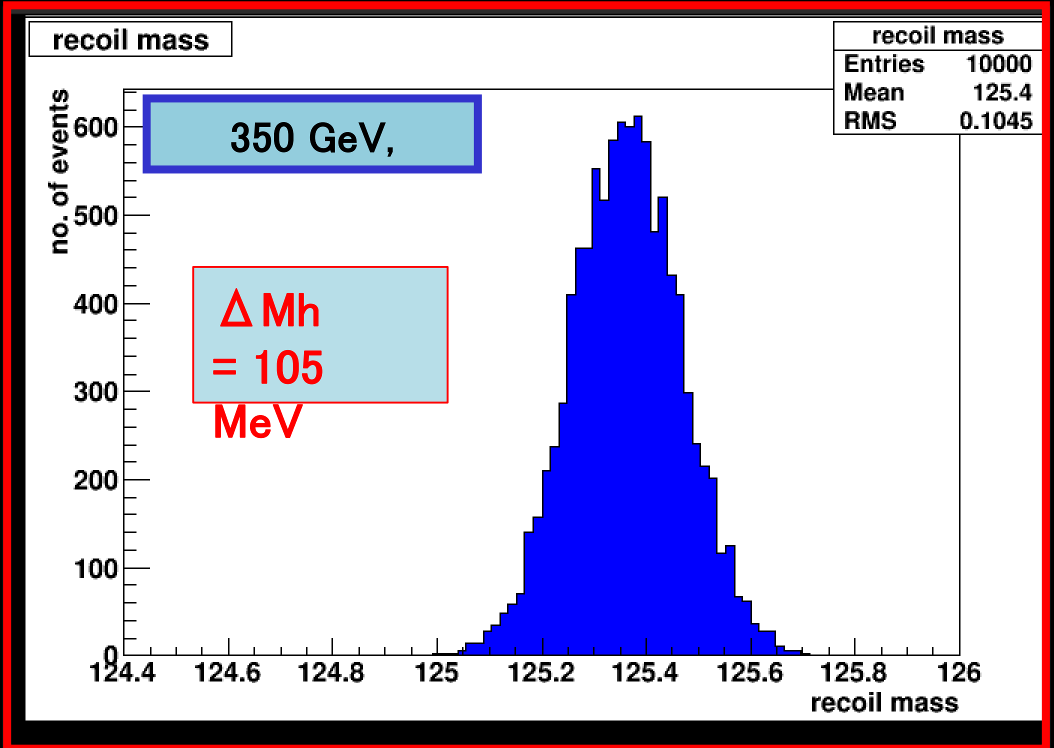
Statistical error (RMS) is :

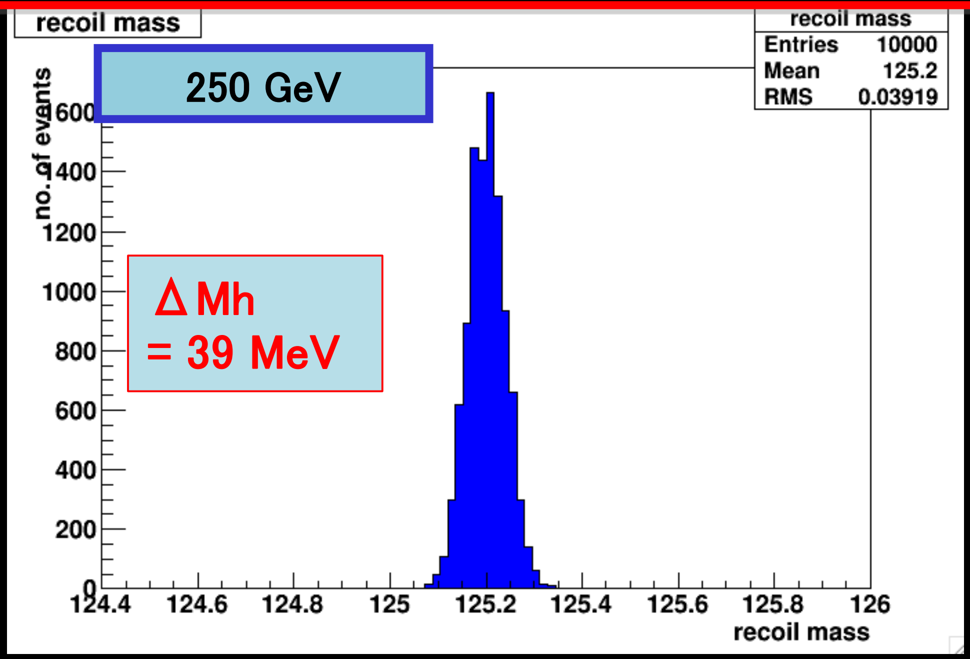
105 MeV (0.08%) for ECM=350 GeV

and

39 MeV (0.03%) for ECM=250 GeV

systematic bias of fitted mass still need to be studied





Study Plans in the Future :
Evaluation of Luminosity Spectrum

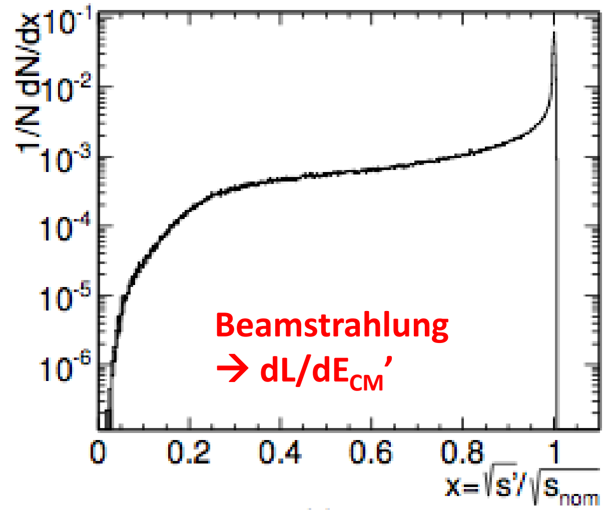
Due to beam–beam effects,

collision occur below nominal ECM

i.e. ECM' < ECM ➔ **luminosity spectrum** (dL/dE_{CM}')

precision measurements require knowledge of σ

e.g. Top mass , Higgs recoil mass , etc…….

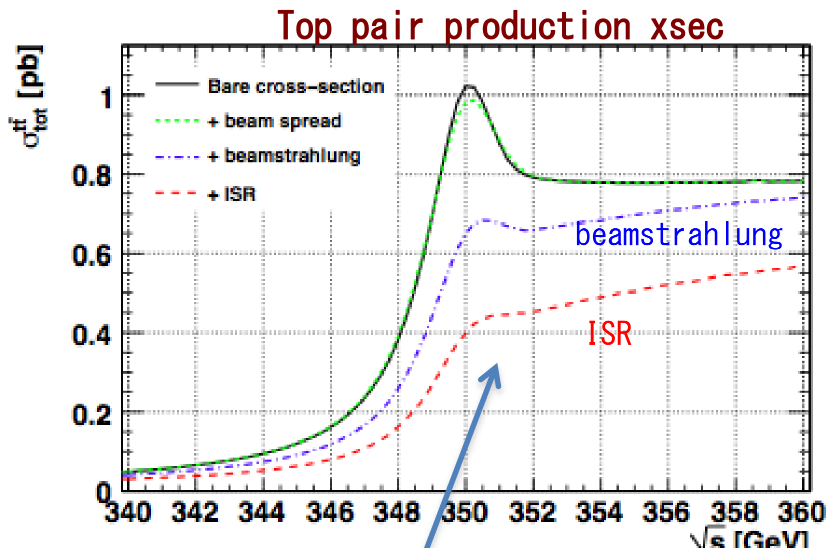


accelerator and beam–beam factors affect ECM

•ISR, beamstrahlung, beam energy spread

depend on geometry and energy correlation of colliding bunches

difficult to simulate/ calculate



ref) Filimon Gournaris, Doctoral Thesis

Goal of study *a rough vision*

- **precisely evaluate Luminosity spectrum and study its effects on physics**
- systematic errors from beam & detector factors, physics BG
- hope to apply some past accelerator experiences

top mass and top-Yukawa coupling measurement by threshold scan

beam effects smear / shift resonant peak

Evaluate effective cross section

→ correct for beam beam effects

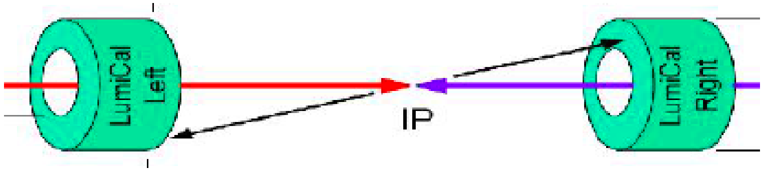
$$\sigma_{eff} = \int_0^{x_{max}} dx \cdot L(x) \sigma\left(x\sqrt{s}\right)$$

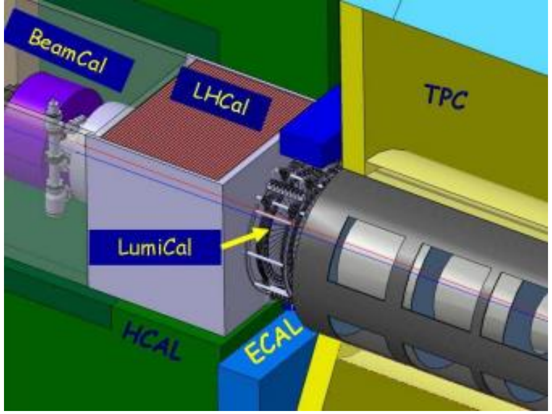
Luminosity Measurement

precision monitor to measure L : **LumiCal**

•2.5 m from IP 、30-80 mrad

•2 calorimeters: W absorber, Si sensor pads sandwiched





Use **Bhabha scattering** to measure Luminosity

well known properties and sufficient statistics :

Measures **angle (θ) and E of scattered e+e-**

$$L = N_B/\sigma_B$$

goal precision : $\Delta L/L < 2 \times 10^{-3}$

reconstruction of luminosity Spectrum dL/dE_{CM}'

1. **make a model for energy spectrum dL/dE_{CM}'**
2. **generate bunch-by-bunch Bhabha scattering events , smear with beam-beam effects**
3. test reconstruction of **dL/dE_{CM}'**
   observe dependence of model precision on beamstrahlung, assumptions, ect…

Strategy: (1) reconstruct L spec as a function of x' = ECM' / ECM

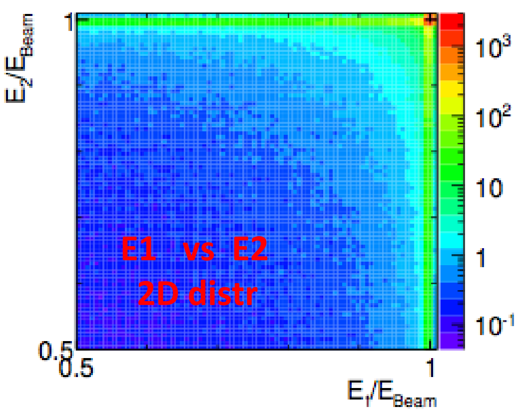
x' measured using acollinearity of outgoing particles

However, if we aim for higher precision, it is not so easy

need to boost of initial system, energy correlation between 2 particles

(2) reconstruct L spec using a template fit using info of both E and θ

E1 vs E2



currently working on Higgs recoil study using **e+e- → ZH → μ+μ-**H
@ ECM = 250 GeV, 350 GeV (and recently 500 GeV)

Summary

- studied impact of ECM and polarization on model – independent measurement of ZH xsec
- contributes to deciding ILC run scenario and detector design optimization

< Preliminary results >

350 GeV: **(-0.8, +0.3)** **Δσ / σ = 4.1 %**
(+0.8, -0.3) **Δσ / σ = 4.5 %**

250 GeV: **(-0.8, +0.3)** **Δσ / σ = 3.5 %**
(+0.8, -0.3) **Δσ / σ = 3.6 %**

- **ECM= 250 GeV has better Δσ/σ by 17%** w.r.t. 350 GeV
- **(+0.8, -0.3) has 10% worse Δσ/ σ**
  better S/B , but lower statistics
- Higgs mass precision is worse at ECM=350 GeV by a factor of 3

- **xsec precision improved significantly (by ~ 17 %) from AWLC 2014** (350 GeV, (-0.8, + 0.3)
- **efforts made to minimize signal bias i.e. prevent Higgs decay mode dependence**

Preliminary results for the challenging ECM = 500 GeV:

- Δσ / σ > 5% (optimistic scenario), Δσ / σ > 10% (pessimistic scenario)

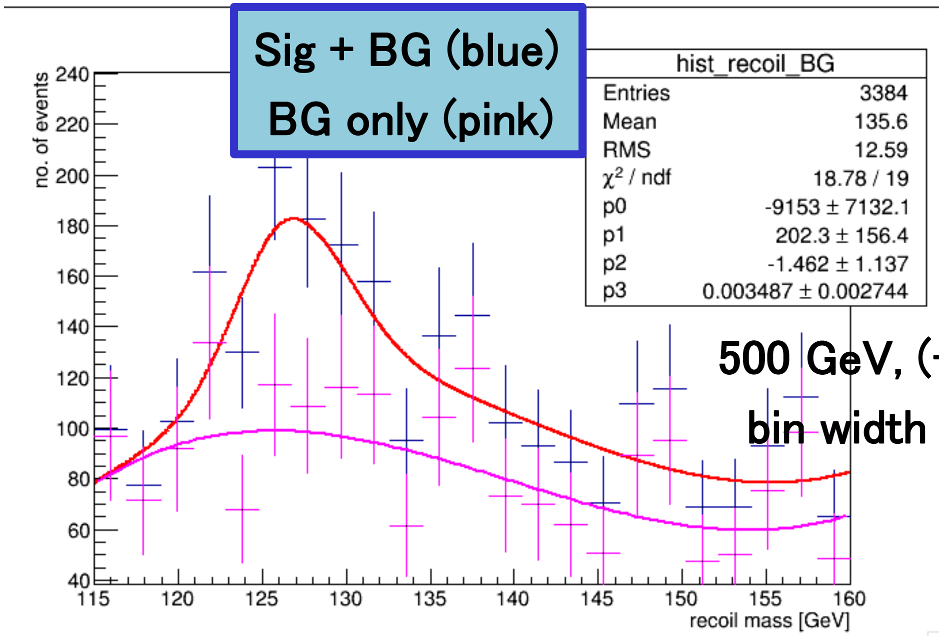
Future Plans

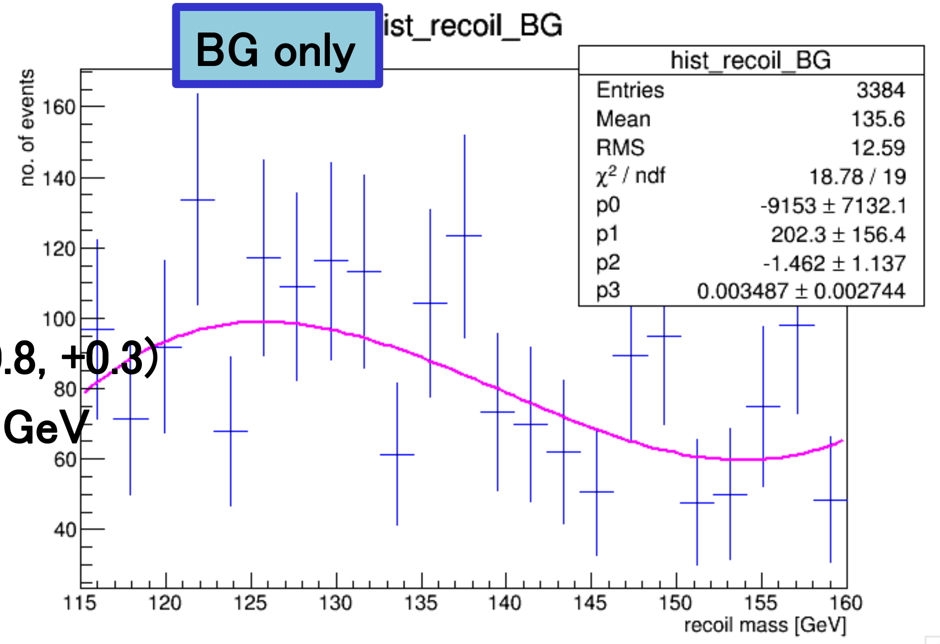
- **analysis for Zee channel , and ZZ fusion process**

→ full evaluation of statistic errors for all ECM and polarization by combining both leptonic channels

- **study systematic errors, including Luminosity spectrum**

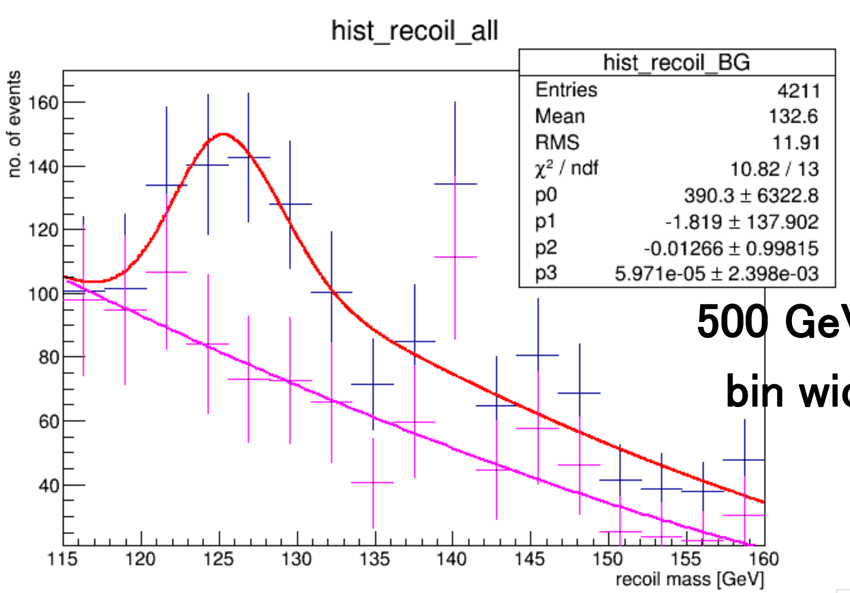
BACKUP

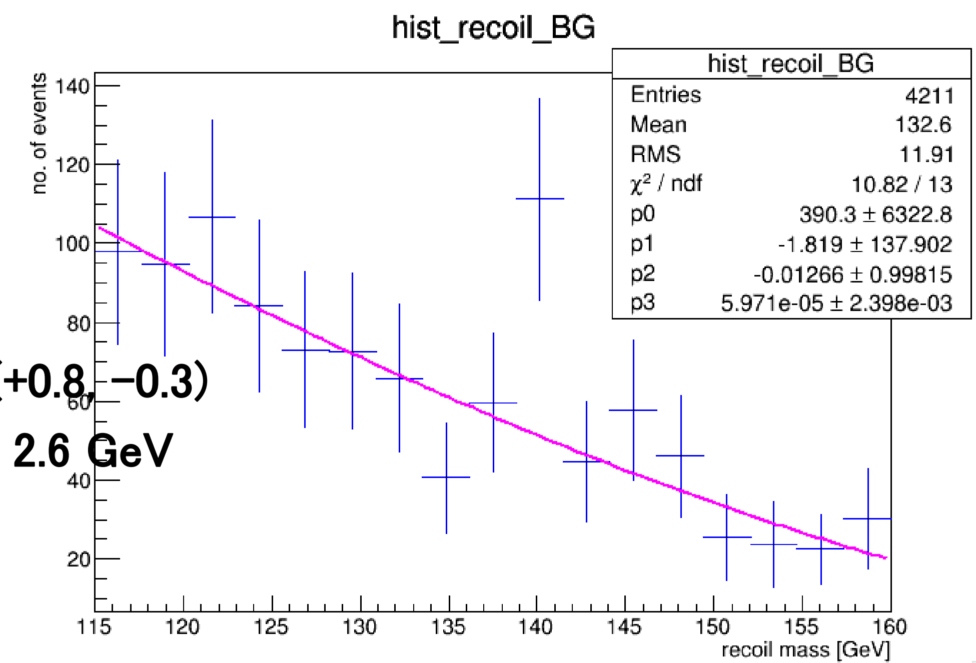




500 GeV, (−0.8, +0.3)

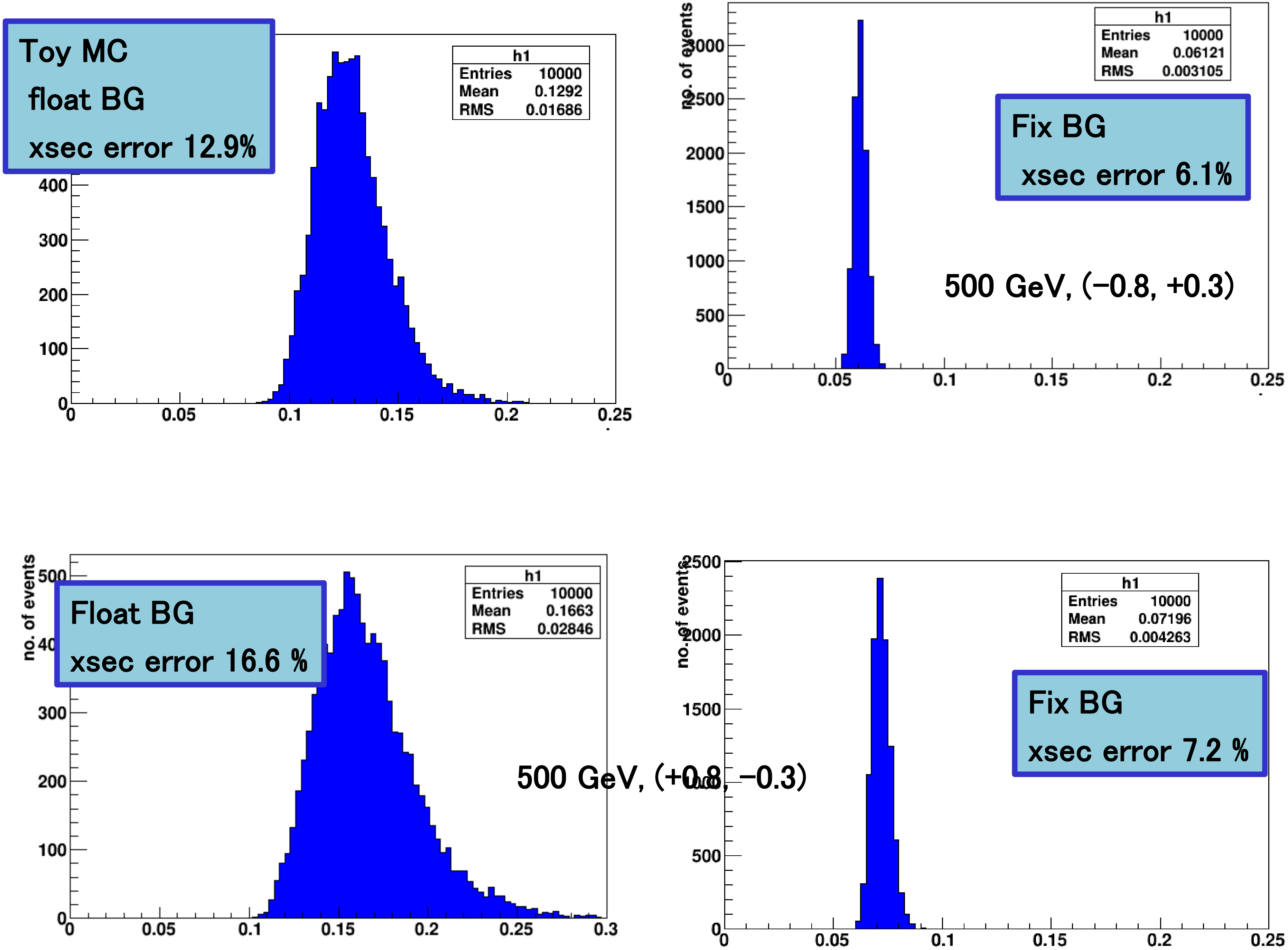
bin width 2 GeV





500 GeV, (+0.8, −0.3)

bin width 2.6 GeV


Toy MC
float BG
xsec error 12.9%
h1
Entries 10000
Mean 0.1292
RMS 0.01686
no. of events
h1
Entries 10000
Mean 0.06121
RMS 0.003105
Fix BG
xsec error 6.1%
500 GeV, (−0.8, +0.3)
no. of events
Float BG
xsec error 16.6 %
h1
Entries 10000
Mean 0.1663
RMS 0.02846
500 GeV, (+0.8, −0.3)
no. of events
h1
Entries 10000
Mean 0.07196
RMS 0.004263
Fix BG
xsec error 7.2 %

Compare of results between alternative ECM and polarizations

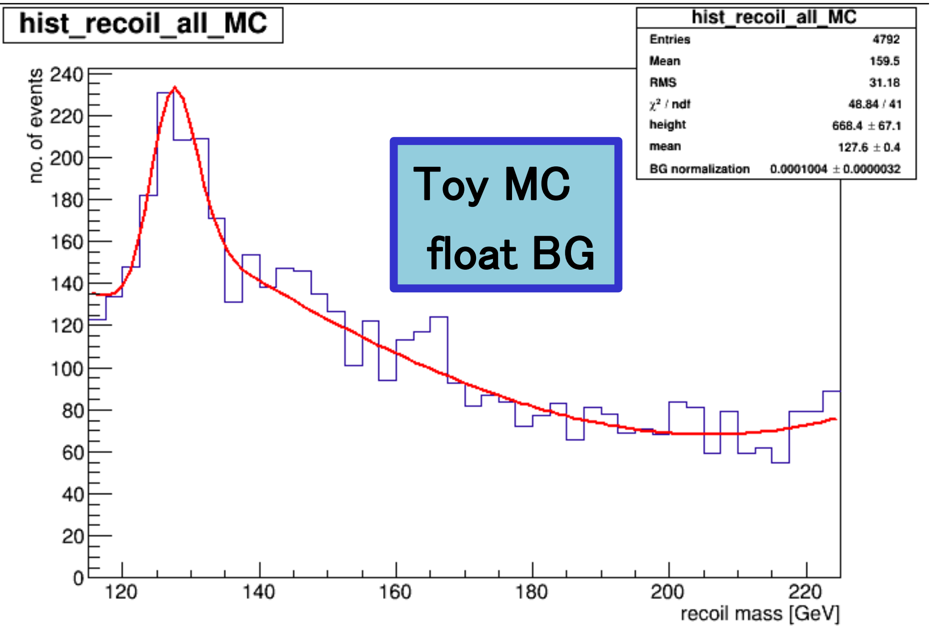
Ecm=250 GeV		Ecm=350 GeV		Ecm=500 GeV	
(−0.8,+0.3)	3.5%	(−0.8,+0.3)	4.1%	(−0.8,+0.3)	5.3% (10%)
(+0.8,−0.3)	3.6%	(+0.8,−0.3)	4.5%	(+0.8,−0.3)	5% (13%)

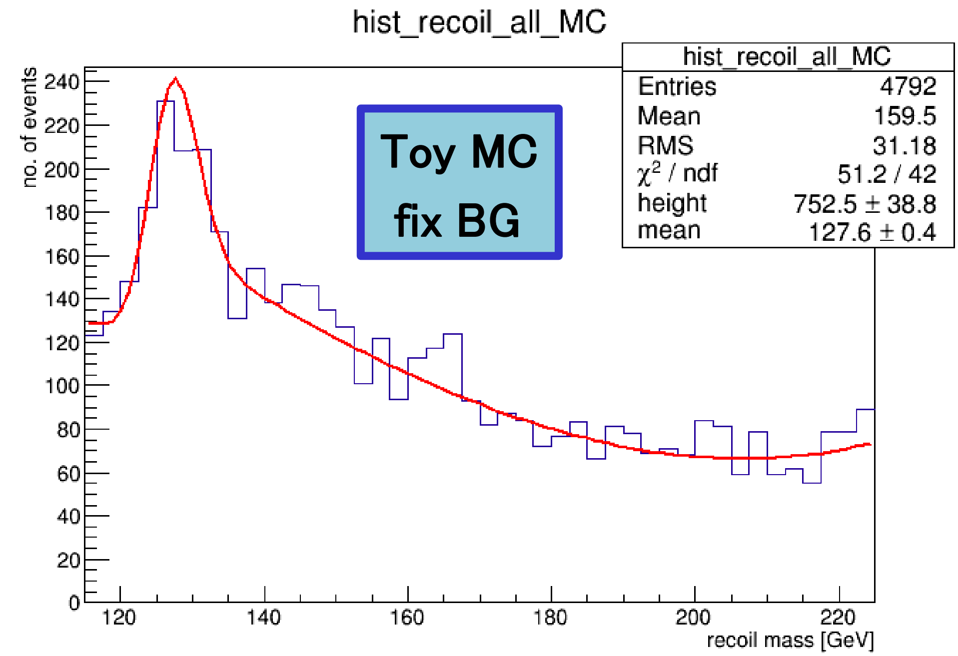
inside ( ) :
float BG normalization for Toy MC
Due to lack of statistics, may not be able to reliably estimate Bg levels at 500 GeV (?)

Current (April, 2015)
xsec precision is improved by 17%
from AWLC 2014 (@Fermilab)
for ECM=350 GeV Pol (−0.8, + 0.3)

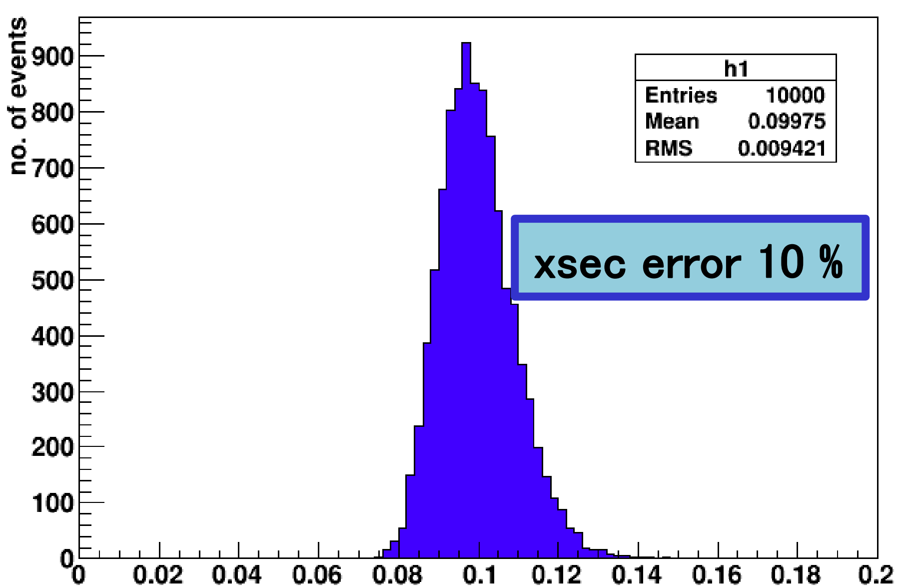
- **ECM= 250 GeV has 17 % better xsec precision** (w.r.t. 350 GeV)
  higher statistics, better momentum resolution → sharper recoil mass peak

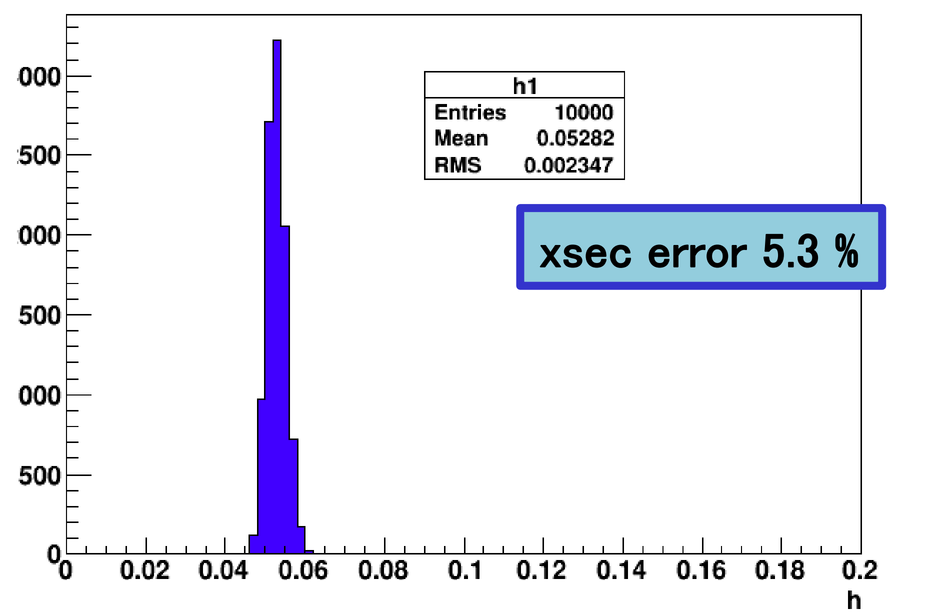
- **Pol (+0.8, −0.3) has 10% worse xsec precision**
  although WW BGs significantly suppressed (higher S/B ratio), statistics is lower

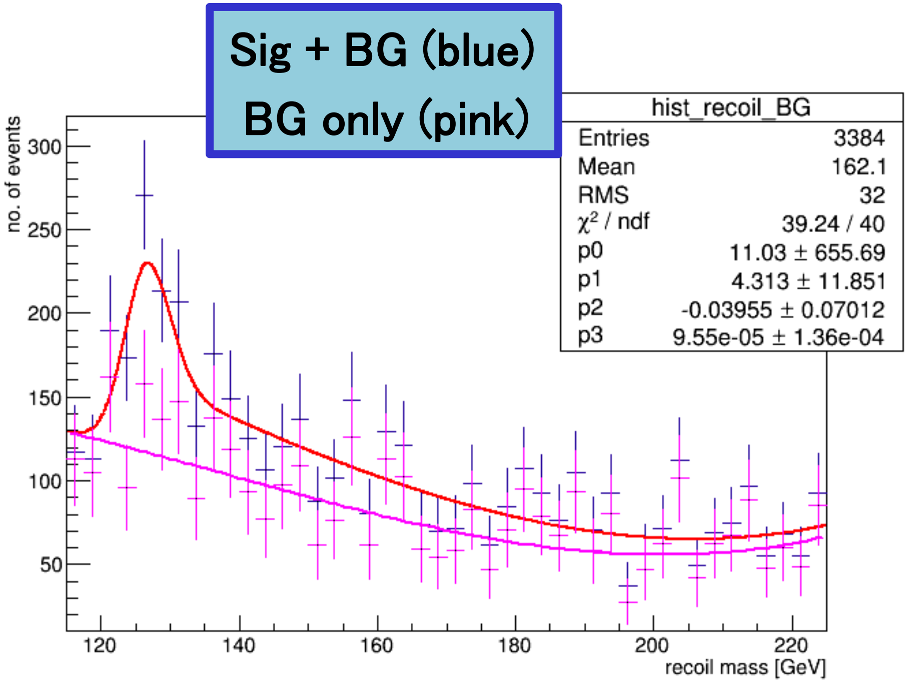

hist_recoil_all_MC
Toy MC
float BG
hist_recoil_all_MC
Entries 4792
Mean 159.5
RMS 31.18
χ² / ndf 48.84 / 41
height 668.4 ± 67.1
mean 127.6 ± 0.4
BG normalization 0.0001004 ± 0.0000032
no. of events
recoil mass [GeV]

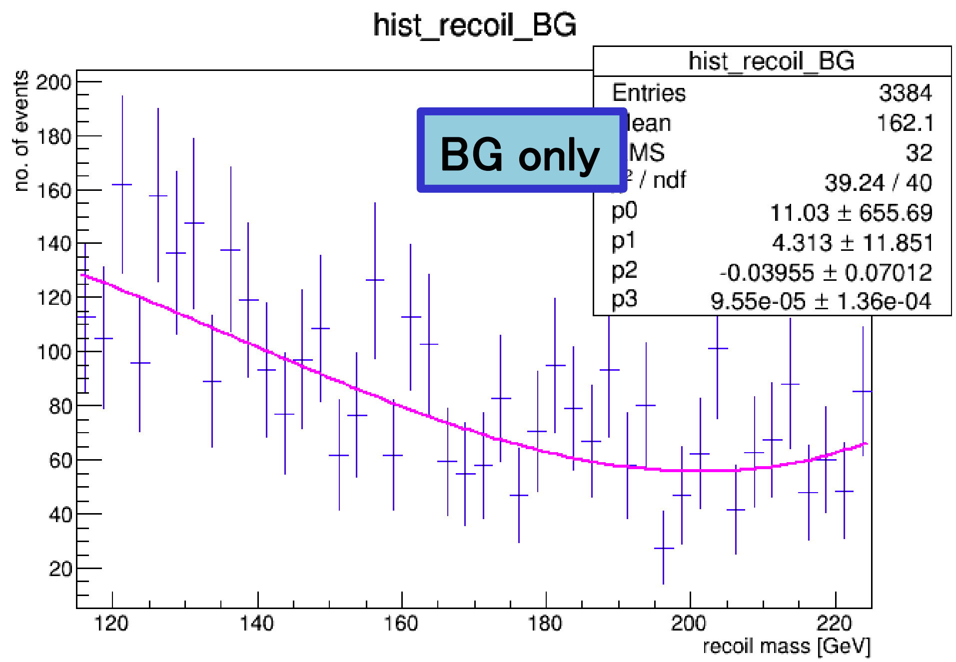

hist_recoil_all_MC
Toy MC
fix BG
hist_recoil_all_MC
Entries 4792
Mean 159.5
RMS 31.18
χ² / ndf 51.2 / 42
height 752.5 ± 38.8
mean 127.6 ± 0.4
no. of events
recoil mass [GeV]

500 GeV, (−0.8, +0.3)


h1
Entries 10000
Mean 0.09975
RMS 0.009421
xsec error 10 %
no. of events

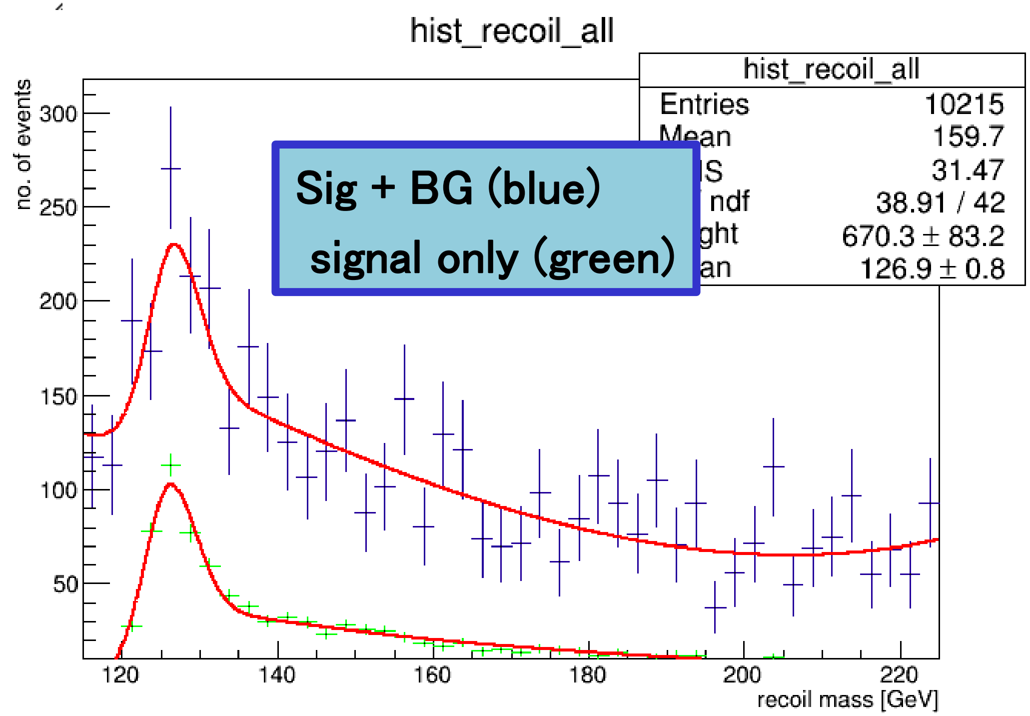

h1
Entries 10000
Mean 0.05282
RMS 0.002347
xsec error 5.3 %
h

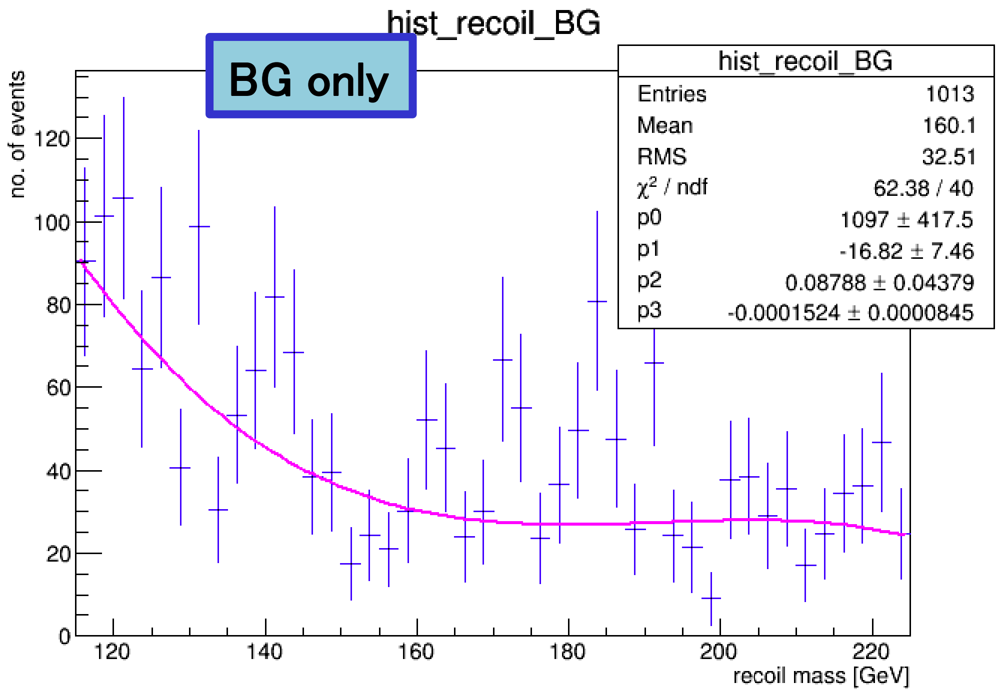




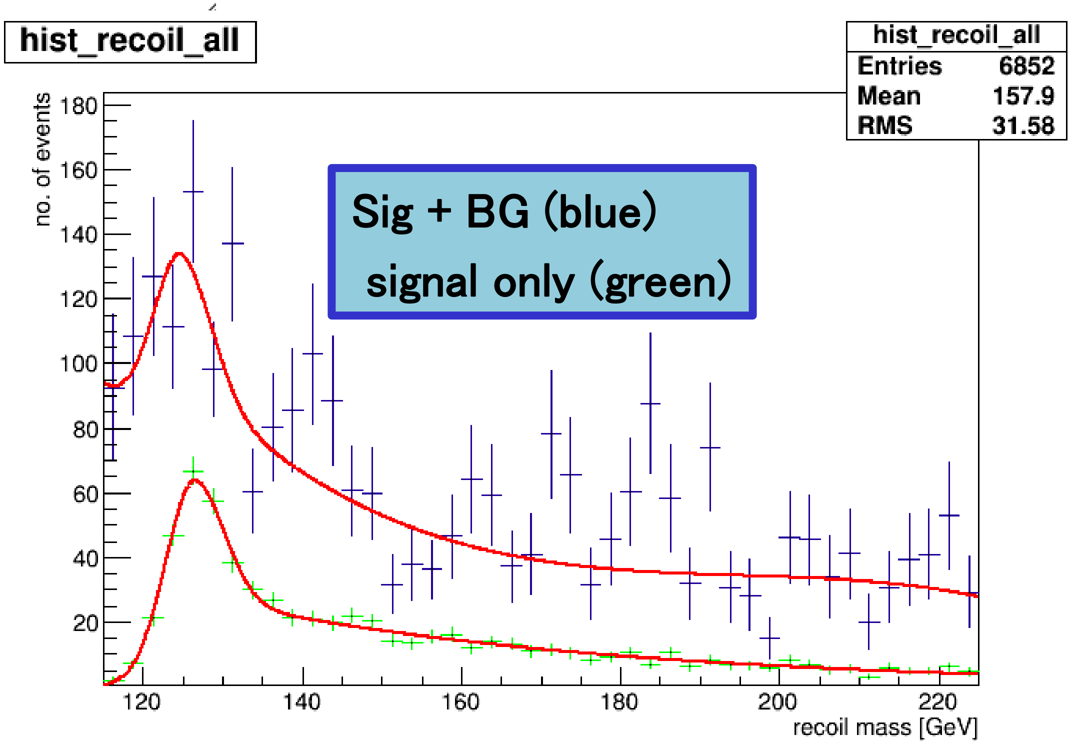
500 GeV, (−0.8, +0.3)

Bin width 2.5 GeV

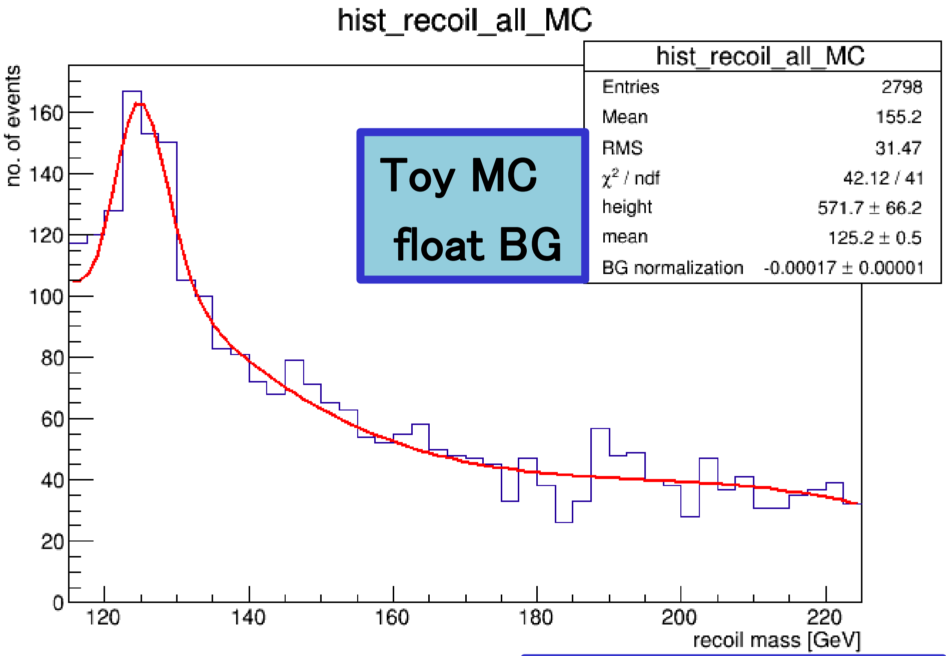



hist_recoil_BG
BG only
hist_recoil_BG
Entries 1013
Mean 160.1
RMS 32.51
χ² / ndf 62.38 / 40
p0 1097 ± 417.5
p1 -16.82 ± 7.46
p2 0.08788 ± 0.04379
p3 -0.0001524 ± 0.0000845
no. of events
recoil mass [GeV]

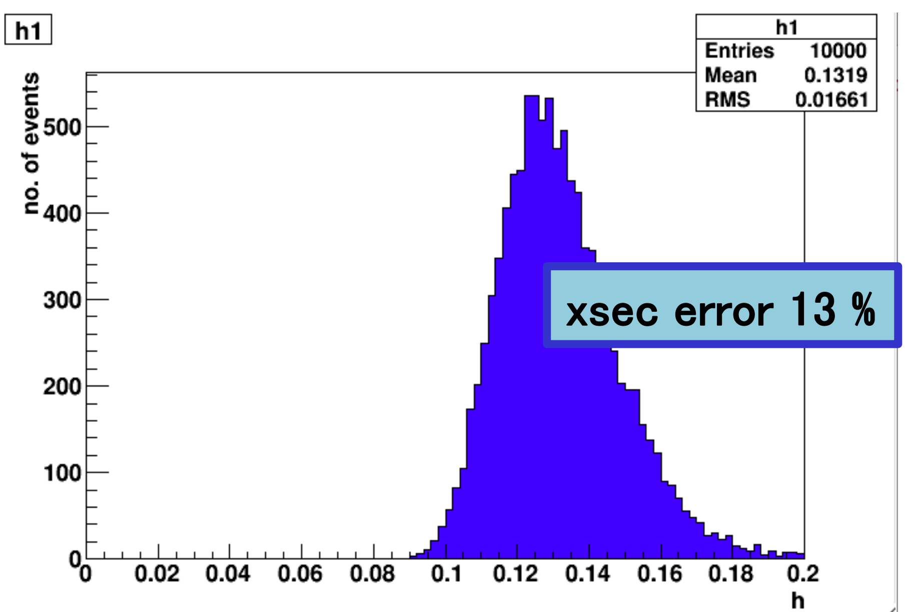
500 GeV, (+0.8, −0.3)

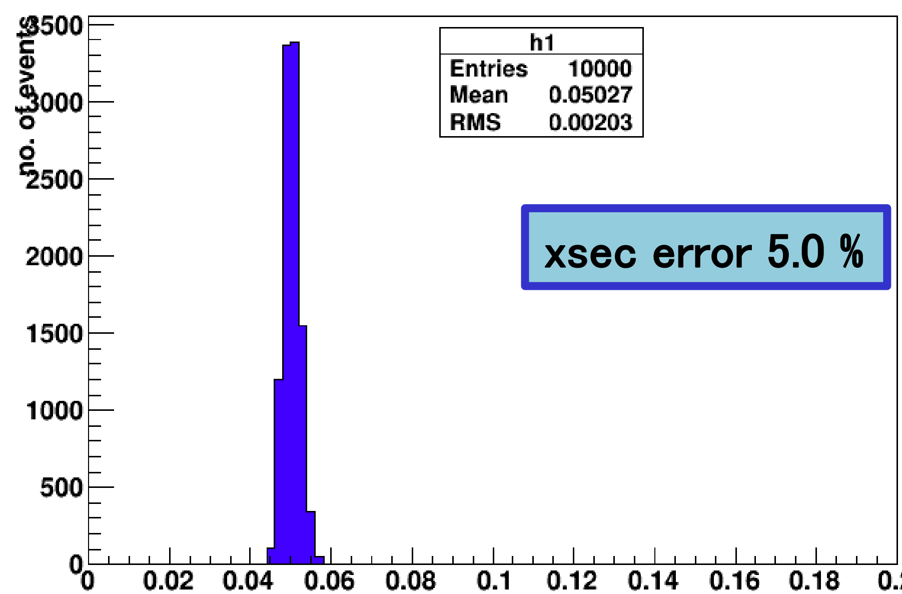

hist_recoil_all
hist_recoil_all
Entries 6852
Mean 157.9
RMS 31.58
Sig + BG (blue)
signal only (green)
no. of events
recoil mass [GeV]

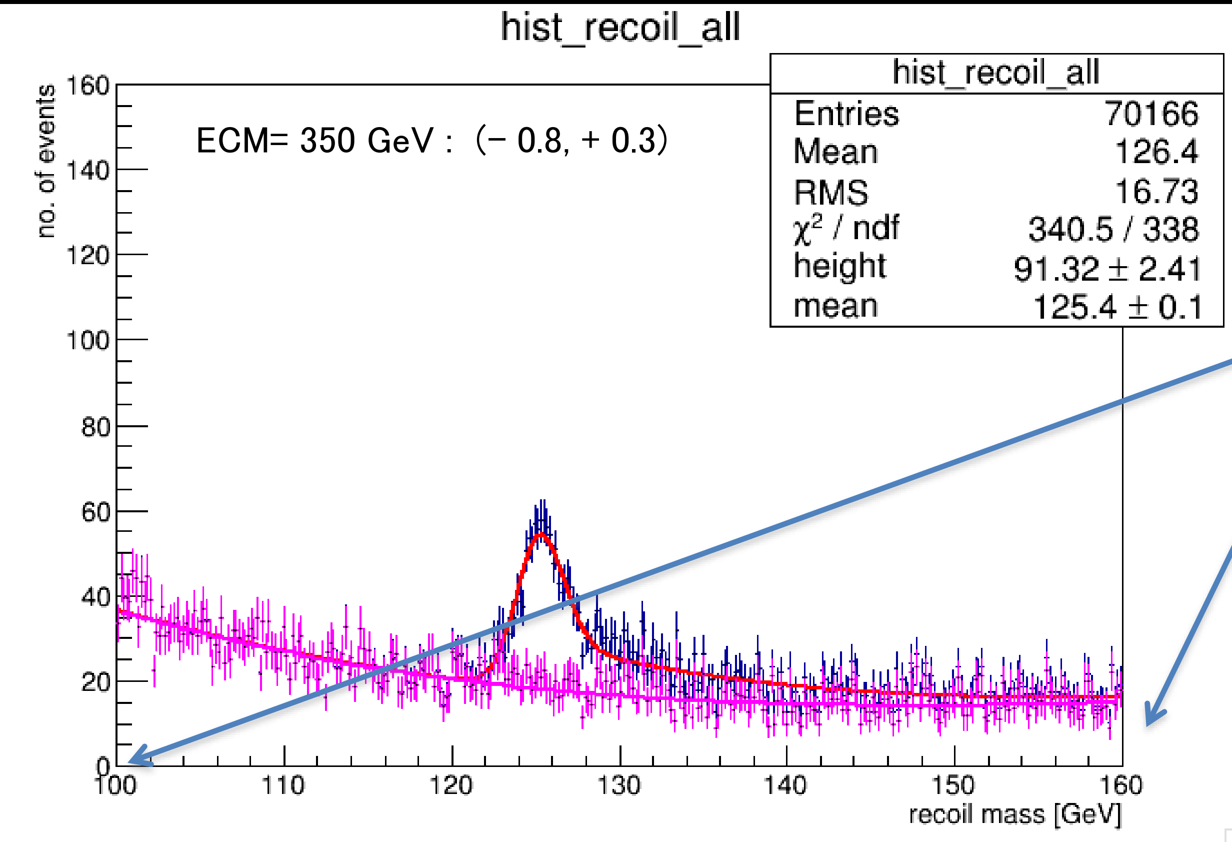
500 GeV, (+0.8, −0.3)



Bin width 2.5 GeV







BG level fluctuation is controlled by fitting recoil mass over a wide range (100 – 160 GeV)

This is an improvement from previous studies

- BG level is usually fixed for Toy MC (optimistic scenario)
- xsec error is about 10 % worse if we float BG (pessimistic scenario)
  not a big degradation since I fit recoil mass spectrum over a wide range
  GOOD

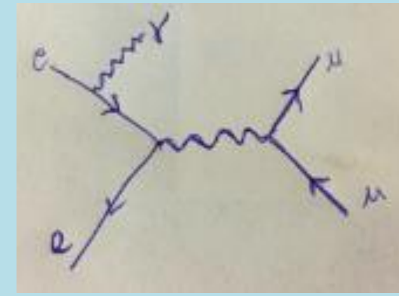
$\Delta\sigma/\sigma$ (fix BG) = 4.07 %	→	$\Delta\sigma/\sigma$ (float BG) = 4.46 %

Measures were taken to prevent signal bias i.e. Higgs decay mode dependence

- the “traditional” dptbal (= |Pt,dl | − |Pt, γ |) cut

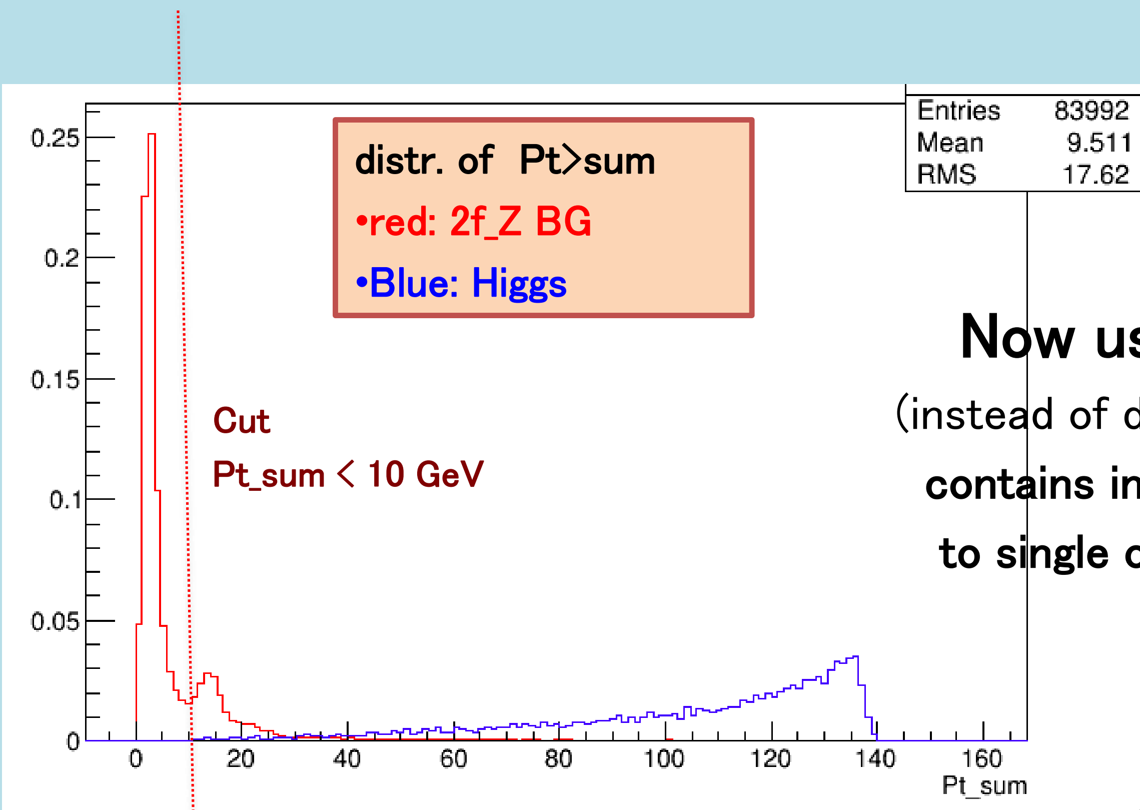
  for removing 2f BG (γ back–to back w.r.t. di–lepton)

  used to be a concern for signal bias (esp. H → $\tau\tau$, H→ $\gamma\gamma$)



- isolated photon finder: *NEW*

  confirms almost all γ we look at have small cone energy) i.e. not from Higgs decay



Now use $\left|\overrightarrow{P_{t,sum}}\right| \circ \left|\overrightarrow{P_{t,g}} + \overrightarrow{P_{t,dl}}\right|$ *NEW*

(instead of dptbal)

contains info on vector direction

to single out back to back events

Owing to the improved data selection methods, Higgs decay mode dependence is minimized

Shows effect of isolated γ finder

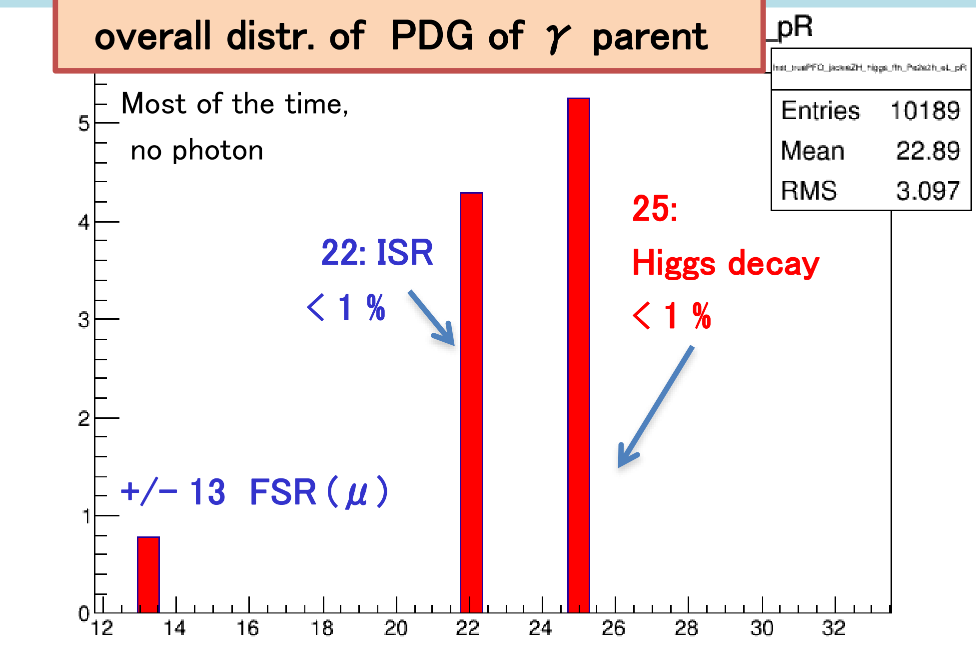
total signal loss due to Pt_sum < 10 events

out of this,

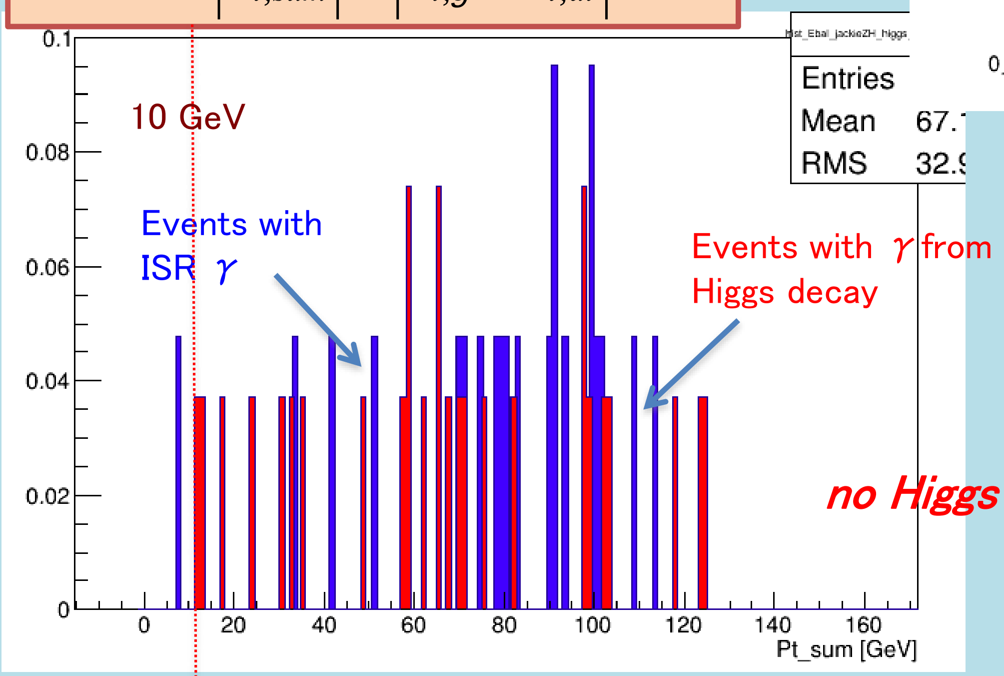
events with γ from Higgs decay < 1

for any ECM, polarization

overall distr. of PDG of γ parent



distr. of $\left|\overrightarrow{P_{t,sum}}\right| \circ \left|\overrightarrow{P_{t,g}}+\overrightarrow{P_{t,dl}}\right|$



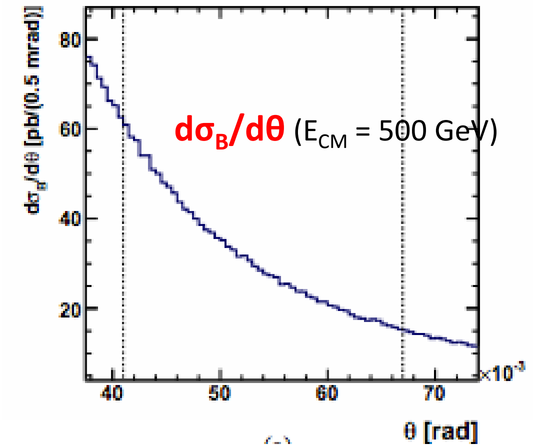
no Higgs decay mode bias caused by Pt_sum cut

Luminosity measurement: hardware

Bhabha scattering xsec strongly dependent on θ : **dσ / dθ∼θ^{-3}**

- **luminosity measurement especially sensitive to θmin :** ΔL/L∼2*Δθ/θ
  goal precision : Δθmin < 10^{-3} mrad, inner radius < O(μm), θ res. < 2.2x10^{-2} mrad

•Optimization of alignment and segmentation of LumiCal sensor pads
on-going by FCAL group



H. Abramowicz et al,
"Forward Instrumentation for ILC Detectors"

Luminosity measurement: Physics

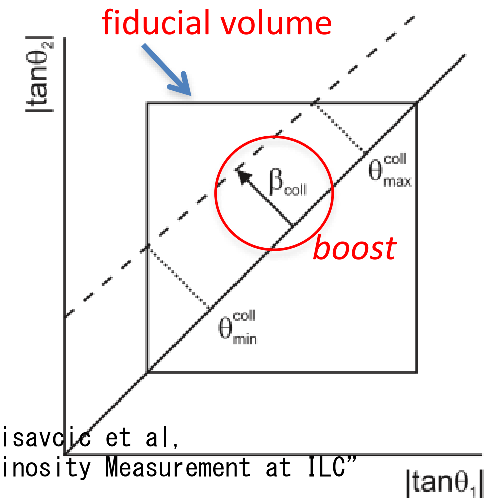
boost of collision frame due to beam-beam effects (acollinearity)
e.g. random, asymmetrical **beamstrahlung / ISR**

→θ acceptance loss → luminosity reduction

serious for nm beam size and high E_{CM}

❖ L measurement systematic error can be corrected
measure scattered angle → calculate boost → weigh event-by-event

$$\beta_{coll} = \frac{\sin\left(\theta_1^{lab} + \theta_2^{lab}\right)}{\sin\left(\theta_1^{lab}\right) + \sin\left(\theta_2^{lab}\right)} \quad \Rightarrow \quad w\left(\beta_{coll}\right) = \frac{\int_{\theta_{min}}^{\theta_{max}} d\theta \left(d\sigma / d\theta\right)}{\int_{\theta_{min}^{coll}}^{\theta_{max}^{coll}} d\theta \left(d\sigma / d\theta\right)}$$



B. Jelisavcic et al,
"Luminosity Measurement at ILC"

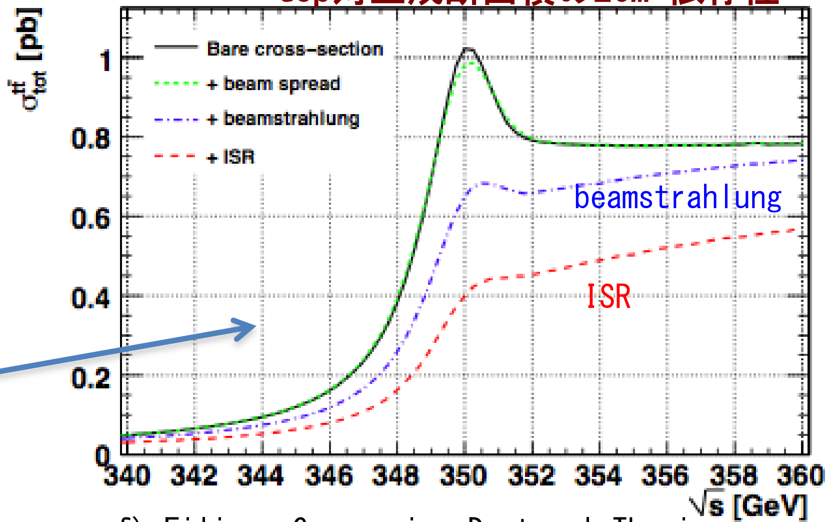
予定研究の重要部分は luminosity spectrum dL/dE_{CM}' の精密測定

dL/dE_{CM}'の正確な情報が重要なILC物理解析に大インパクトを与える

代表例：
threshold scan によるtop quark 質量の精密測定
- E_{CM}=350 GeV周辺でtop対生成断面積の急上昇現象を利用
- Top-yukawa 結合定数、崩壊幅、SUSY質量の測定にも有用
- **実験由来の系統誤差が約80MeVと大きい！！**
（c.f. 理論誤差～100MeV、統計誤差～30 MeV）

ビーム効果は共鳴ピーク位置をsmear・シフトさせる

top対生成断面積のECM 依存性



ref) Filimon Gournaris, Doctoral Thesis

ビーム効果に起因する E_{CM}の変化が物理量決定に与える系統誤差を評価・補正することが重要

例）理論計算（ビーム効果無視）に**dL/dE_{CM}'で畳み込み積分**する

$$\sigma_{eff} = \int_0^{x_{max}} dx \cdot L(x)\sigma\left(x\sqrt{s}\right)$$

Luminosity Spectrum dL/dE_{CM}' 測定の流れ

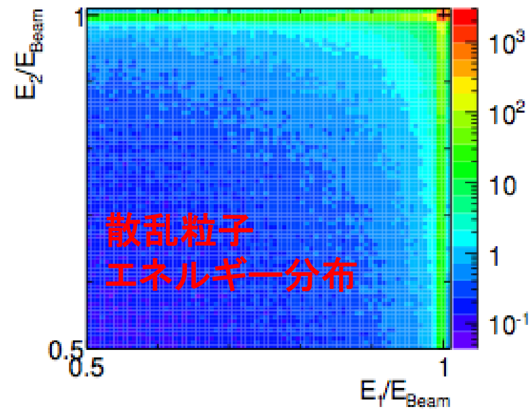
1. **dL/dE_{CM}' のモデル**を特定の実験パラメータを基に構築 =「既知」のエネルギースペクトラム
2. バンチ衝突シミュレーションで**「未知」のスペクトラムとBahbha事象を生成**
3. 1.と2. を比較 **(fitting) ➔** 生成データの **dL/dE_{CM}' を x = E_{CM}'/E_{CM}の関数として再構成**

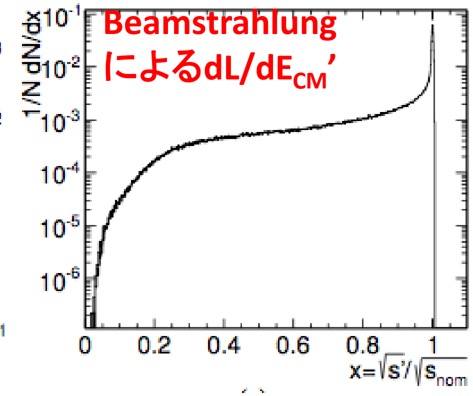
更に、 **dL/dE_{CM}' 再構成手法の性能試験を行う**
- モデルに使用される簡易化仮定からくる再構成の系統誤差
- 再構成精度のbeamstrahlungの酷さへの依存性

従来のsimulation tool:

- Beamstrahlungの生成： Guinea-Pig
- Bhabha 散乱、断面積の計算： BHWIDE (MC)

参照：Luminosity Spectrum Reconstruction at Linear Colliders, by Andre Sailer (CERN)





dL/dE$_{CM}$' 測定： 様々な課題

LumiCal hardware への要請

- 厳密なdL/dE$_{CM}$'再構成は 散乱後の θだけではなく、エネルギーも必要
  エネルギー分解能 ($\Delta E/E \sim 0.21 / \mathrm{sqrt}(E[GeV])$) と簡易化仮定をバランスさせた解析手法

先行研究を参考にしながら dL/dE$_{CM'}$ の測定手法を改善する

◆ **従来の簡易化仮定を発展させる：**

- 粒子**間のエネルギー相関**、非対称ビーム（交差角度）、OFF- axis ISR, 複数光子輻射

◆ **ビーム情報をより忠実にシミュレーションに反映**

- 加速器の中で**ビームパラメータが時間とともに変動** ←→ beamstrahlungとの相関
  バンチの形状、サイズ、電荷分布、位置オフセットはBeamCalやpair monitorのバンチ毎の測定を参照
- Beam energy spread、 ビーム偏極誤差、バンチ毎のエネルギーと位置のジッター、終状態 deflection

◆ **物理BG由来の系統誤差** を研究する ($\Delta L/L|BG \sim 2\times10^{-3}$ 、4 fermion 過程が支配的)

- 色々な複雑な要素を考慮して**データ選別手法を最適化する**：（角度、エネルギーのcut など）

一方で、simulation と ビーム情報の正確さへの依存性を軽減させる手法を開発すべき

	S/B ratio	significance	sig eff	Δ σ / σ (MC)	improvement
Ecm=350 GeV					
(−0.8,+0.3)	0.57	20.6	51%	4.1%	17%
(+0.8,−0.3)	1.00	19.7	49%	4.5%	11%
Ecm=250 GeV					
(−0.8,+0.3)	0.56	23.8	61%	3.5%	3%
(+0.8,−0.3)	1.00	24.3	68%	3.6%	−8%

Compare with results from AWLC2014 (Fermilab)

Current
April, 2015

AWLC14: May, 2014

	S/B ratio	significance	sig eff	Δ σ / σ (MC)
Ecm=350 GeV				
(−0.8,+0.3)	0.40	17.7	48%	4.9%
(+0.8,−0.3)	0.75	17.8	48%	5.0%
Ecm=250 GeV				
(−0.8,+0.3)	0.37	21.7	66%	3.6%
(+0.8,−0.3)	0.81	22.7	64%	3.3%

Compare of results between alternative ECM and polarizations

	Δσ/σ (Toy MC)
Ecm=350 GeV (−0.8,+0.3)	4.1%
(+0.8,−0.3)	4.5%
Ecm=250 GeV (−0.8,+0.3)	3.5%
(+0.8,−0.3)	3.6%

Current (April, 2015)

xsec precision is improved by 17%

from AWLC 2014 (@Fermilab)

for ECM=350 GeV Pol (−0.8, + 0.3)

- ◆ **ECM= 250 GeV has 17 % better xsec precision** (w.r.t. 350 GeV)

  higher statistics, better momentum resolution → sharper recoil mass peak

- ◆ **Pol (+0.8, −0.3) has 10% worse xsec precision**

  although WW BGs significantly suppressed (higher S/B ratio), statistics is lower

Relative results

ECM = 350 GeV vs 250 GeV

	xsec err		xsec err
Ecm=350 GeV (−0.8,+0.3)	1.17	Ecm=350 GeV (+0.8,−0.3)	1.25
Ecm=250 GeV (−0.8,+0.3)	1	Ecm=250 GeV (+0.8,−0.3)	1

- xsec error is 17% better for 250 GeV

Comparing polarization

	xsec err		xsec err
Ecm=350 GeV (−0.8,+0.3)	1	Ecm=250 GeV (−0.8,+0.3)	1
(+0.8,−0.3)	1.10	(+0.8,−0.3)	1.02

- xsec error is 10% better for left pol