Plans for Higgs recoil mass study

9/26/2014

Jacqueline Yan (Univ. of Tokyo)

Talk was given at **JPS conference** (9/19) *: Thank you everyone for the advice*

Comments / questions received:

Q: how do we know that GPET is the appropriate fitting function ?

what explains the long tail to the high energy side ?

A: long tail due to both ISR and beamstrahlung

need to investigate better fitting functions than GPET

Q: How are the results for Zee (vs Zmumu)

A: (quoted Watanuki-san's study for 250 GeV)

Zee : xsec error about 4%

(Watanuki-san's Zmumu results comparable to mine for 250 GeV)

Q: did you study case of no polarization also ?

A: I have looked at (−0.8, 0) (0,0) , etc … in past…. Results were as expected

(−0.8,+0.3) and (+0.8, − 0.3) are the most interesting for ILC physics group in discussing run scenario

Comment :

The difference in xsec error between 250 GeV and 350 GeV is dominated by statistics

xsec is larger for 250 GeV (simply scaled with statistics)

About participation in LCWS14

- Not planning to make the trip this time
- Higgs session already very busy

- No new updates since JPS meeting

- So no talk this time

- if necessary for discussion
  I can provide a few slides for others if necessary
  or please feel free to quote my results

Plan for Higgs study from next January (after D thesis finish)

(1) About the **recoil mass bias** 125.6 +/− 0.1 GeV (vs the 125.0 GeV in meta file)

• possible reasons are:

- ISR, beamstrahlung
- FSR --> identify photons , ejected very close to muons, and return their energy back to the muons
- imperfection of fitting by the function GPET (maybe correlated with radiation)
- the fitted "mean" should not be defined as the "higgs mass", but as "the higgs mass carrying bias".

option : see how much bias from the "only signal histogram fitting" , about 0.7 GeV,

subtract this bias from final histogram of "sig + BG", I would get Mh = 124.9 +/− 0.1 GeV.

First need to study the case deeper.

(2) **sudden decrease in signal efficiency** after the last cut of 120 GeV < M_recoil < 140 GeV:

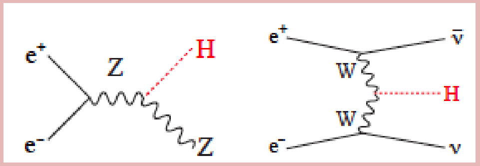
- still a lot of signal events beyond 140 GeV.
- However, widening the cut range, makes the xsec precision worse significantly due to lots of BG.
- I can reduce some residual WW-sl BG (2nd largest) by implementing the muon isolation cut

However ZZ-sl most dominant, and irreducible, so expect little improvement on signal effciency.

(3) study **other polarization scenarios** :: very easy

- LHC でのHiggs 粒子の発見 ➔ Higgsを詳細を研究出来るILCの物理の意義が非常に強くなった
- ILC建設の機運が高まっている

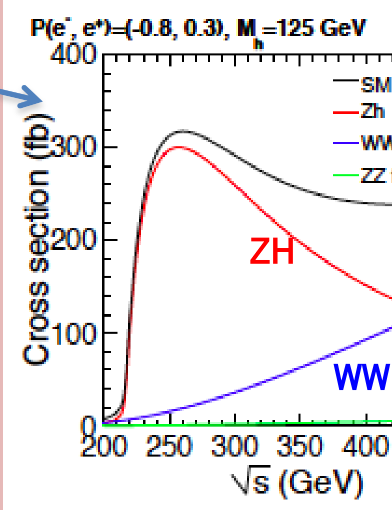
➔ 加速器増強・運転計画を考慮した現実的な性能評価の緊急性が増大



Higgs 結合定数の精度を評価する上。。。。

- ➢ ECM = 250 GeV : ZH随伴生成が最大
- ➢ ECM = 500 GeV : WW融合過程が十分強くなる

で評価が行われてきた



TDRより

- 中間の**ECM = 350 GeV** では多くの物理が重要となる(e.g. top物理)
- ILCでは、LINAC を拡張すれば、エネルギーを調整できる

今、350 GeVでのHiggs 測定の性能評価が重要視されている！

- 本研究ではその根幹となる、**ECM = 350 GeV** で

Higgs Recoil Measurement (反跳質量測定)を行う　*TDR パラメータを基にした初のstudy*

- ILC の強みの1つを活かす: **Higgs Property のモデル非依存的な測定:**

具体的なGoal:

- **Higgs 断面積** (σ_H) と recoil mass (M_H) の精密測定
- 異なる ECM と偏極の間で期待性能を比較

➔ **ILC run scenarioの検討、加速器と測定器の最適化　に貢献する**

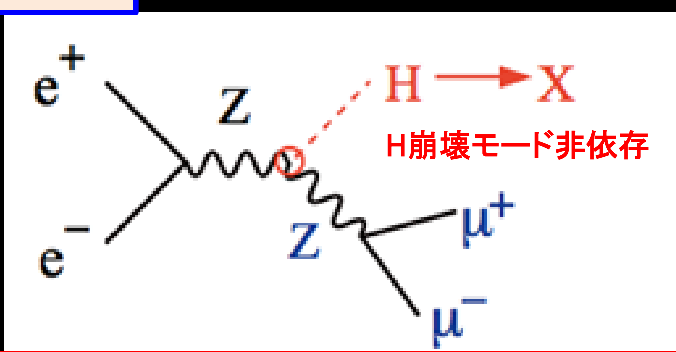
本講演の　LAYOUT

- 解析に用いるイベント選別手法の最適化
- Toy MC study　を通して評価した測定性能
- ECM = 350 GeV　vs　ECM = 250 GeV　の間の比較
- 異なる　ビーム偏極の間の比較
- Summary & Plans

物理解析に用いるILCサンプル	mh	ECM	L	Spin　polarization	Detector simulation
e+e→Zh->μμh	125 GeV	350 GeV (250 GeV)	333 fb-1 (250 fb-1)	P(e-,e+) = (-0.8,+0.3) (+0.8,-0.3)	Full ILD (ILD_01_v05 DBD ver.)

signal　Pe2e2h_.eL.pR　/　Pe2e2h._eR.pL

ILCはlepton collider なので、初期状態の4元運動量が分かる

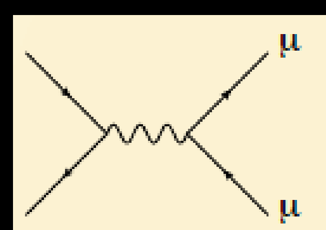


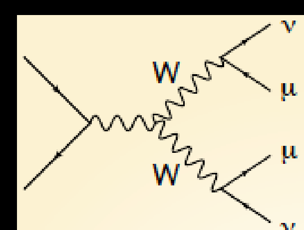
$$M_X^2 = \left(p_{CM} - (p_{\mu^+} + p_{\mu^-})\right)^2$$

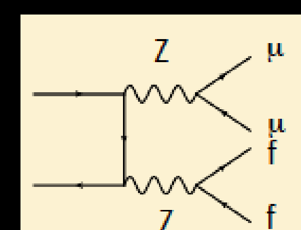
Higgs が　di-lepton（μμ）系に対して反跳する

BG :
全ての　2f,　4f, 6f　過程をsimulationに入れている

データ選別後の主な残留BG:
μμ、　μμνν、　μμff







Muon Selection

イベント選別手法

- reject neutrals
- P_total ＞ 5 GeV
- E_cluster / P_total ＜ 0.5
- cos(track angle) < 0.98 & |D0/δD0| < 5

Best muon pair candidate Selection

- ➢ **opposite charge**
- ➢ **invariant mass closest to Z mass**

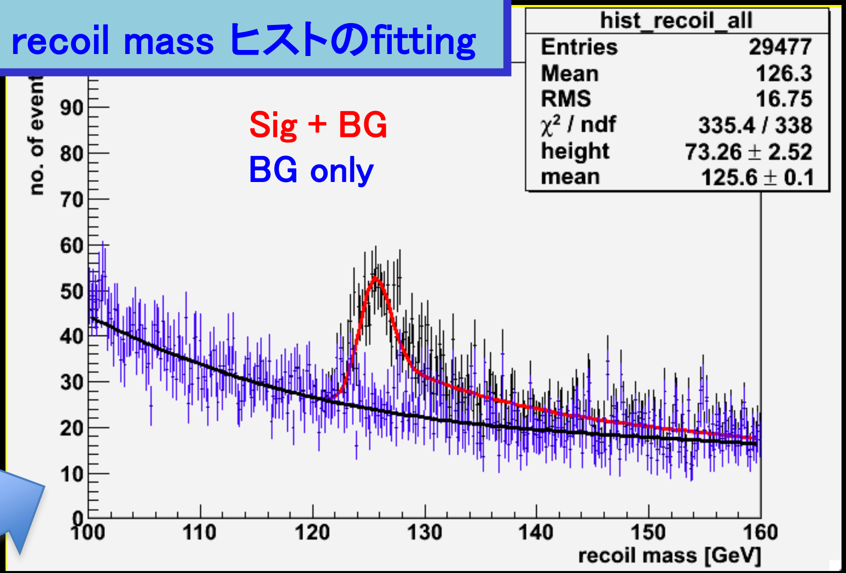
Final Selection

- •84 GeV < M_inv < 98 GeV
- 10 GeV < pT_mumu < 140 GeV
- dptbal = |pT_mumu – pTγ_max| > 10 GeV
- coplanarity < 3
- |cos(θ_Zpro)| < 0.91

120 GeV < Mrecoil < 140 GeV

シグナル効率とΔσ/σ を最適化するようにカット閾値を最適化した

recoil mass ヒストのfitting



- **Signal : GPET**
- **BG: 3rd order polynomial**

定義

- M_inv : invariant mass of 2 muons
- pT_mumu : pT of reconstructed muons
- pTγ_max : pT of most energetic photon
- θ_Zpro = Z production angle

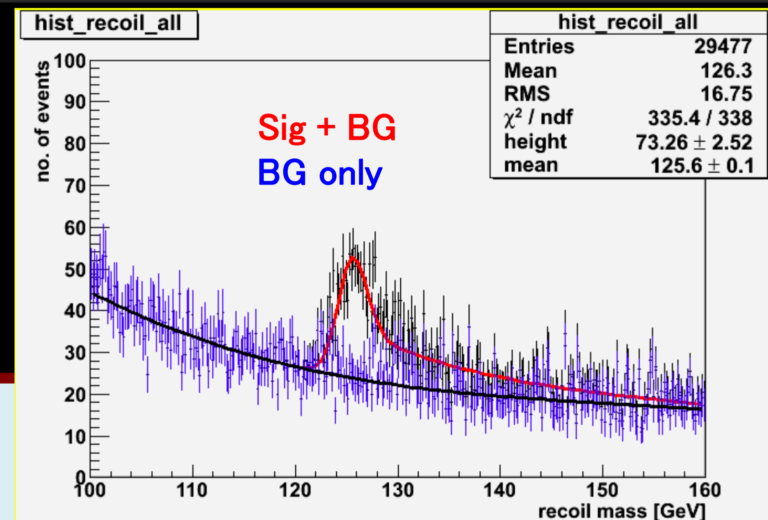
最終結果 ECM =350 GeV

- **シグナル効率 = 47.6 +/- 0.5%**
- S/B = 0.40, significance = 17.2
- シグナルイベント数= 1092+/−55

recoil mass ヒストのfitting 手法の詳細

Fit 範囲を広くしたらxsec精度が 0.2% 程度改善した

OLD: 115–150 GeV ➔ New: 100–160 GeV



1st step:

•SignalのみGPETでfit: Par 5つ全てfloat

•BGのみfit: 3rd order polynomial

2nd step :

Sig + BG をfit : Height と meanのみfloat

BG 関数と他のGPET Par はstep 1 の結果を固定

◆ SIGNAL: GPET: 5 parameters :

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

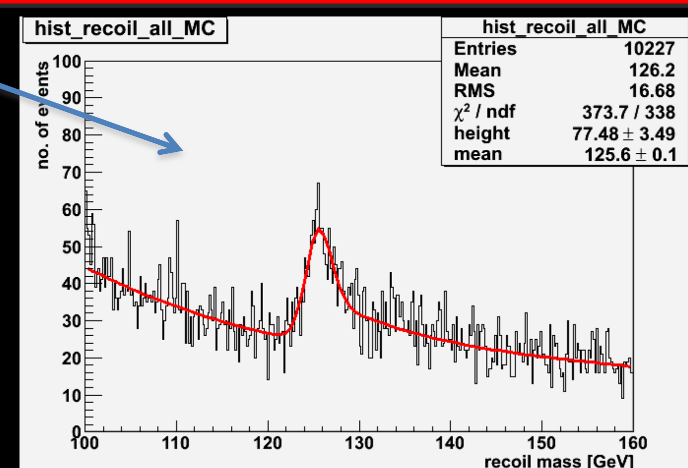
Gaus (left-side) ,

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

Gaus + expo (right side)

Toy MC study

Toy MC 10000 seeds



目的: Fitting手法の妥当性を検討

M_h、 xsec などの精度を評価

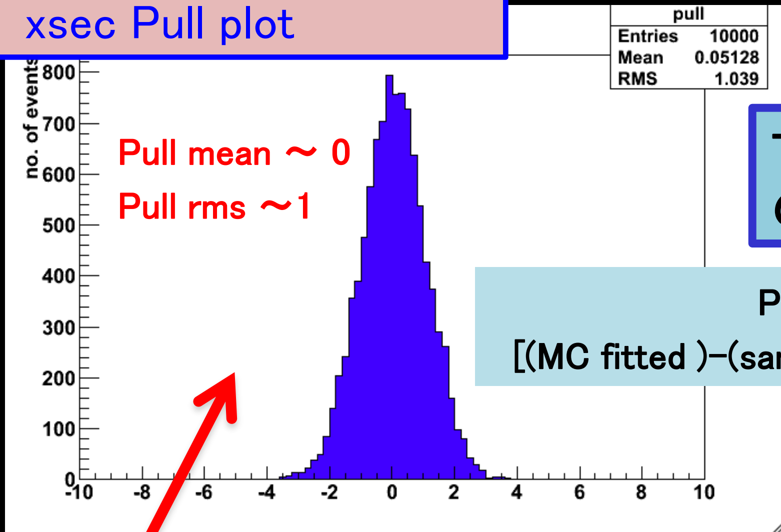
手法: 実サンプルに対するfitted関数に従ってMCを生成

（イベント数∝ Poisson 分布）

MCヒストを同じGPETを積分 → xsec を計算

Toy MC study の結果

xsec Pull plot

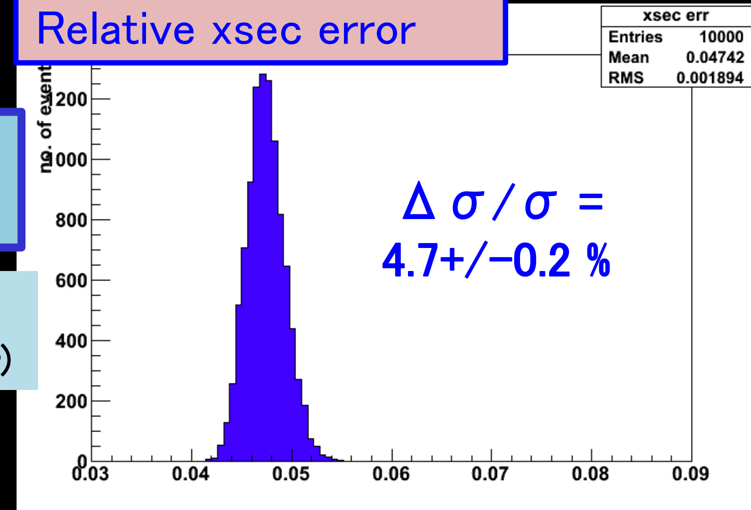


Pull mean ～ 0

Pull rms ～1

Pull =
[(MC fitted)−(sample)]/ (fitting error)

Relative xsec error



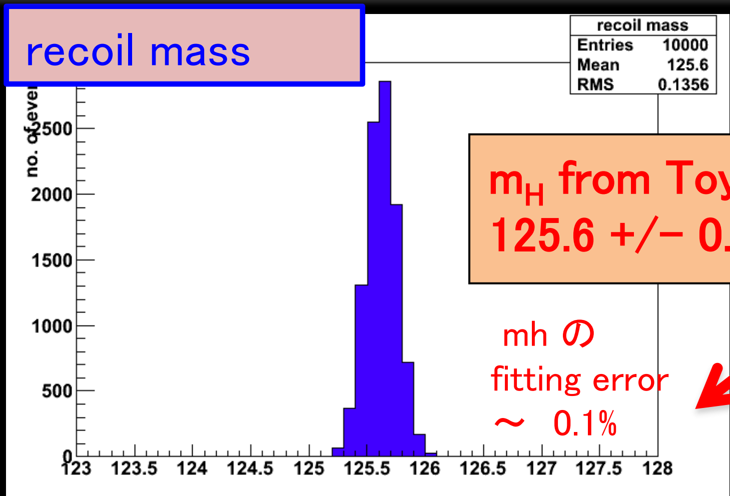
$\Delta\sigma/\sigma$ = 4.7+/−0.2 %

- Fitting手法は妥当　Nsig と xsec は実サンプルと一致　（不確定性範囲内で）

350 GeVの最新結果

ε	Δσ/σ	xsec[fb]	Nsig	S/B
47.6+/−0.5%	4.7+/−0.2%	6.9+/−0.3	1092+/−53	0.4

recoil mass



m_H from Toy MC: 125.6 +/− 0.1 GeV

mh の fitting error ～ 0.1%

問題点

- fitted m_h は 本当の125 GeV (in meta-file) から 4.8 sigma すれている

想定要因: *調査中*

Initial state radiation, Final state radiation, Beamstrahlung、 fitting関数の不完全性 etc…

断面積測定の精度の評価 ： 異なるECMとビーム偏極の比較

ECM	Pol	ε	Δσ/σ	xsec [fb]	Nsig	significance
350 GeV	(−0.8,+0.3)	47.6+/−0.5%	4.9+/−0.2%	6.71+/−0.34	1092+/−55	17.7
	(+0.8,−0.3)	47.8+/−0.5%	5.0+/−0.2%	4.53+/−0.26	720+/−41	17.8
250 GeV	(−0.8,+0.3)	66.4+/−0.5%	3.6+/−0.1%	10.52+/−0.38	1747+/−64	21.7
	(+0.8,−0.3)	64.4+/−0.5%	3.3+/−0.1%	8.68+/−0.30	1398+/−48	22.7

注） この表の fitting範囲は115−150 GeV （AWLC14 @ Fermilabより）
現在350 GeV のみ範囲を広げて、 Δσ/σが 4.7 +/− 0.2 % へ改善した

比較#1: ECM =350 GeV ←→ ECM = 250 GeV :

ECM= 250 GeVの方がΔσ/σ と Mh 精度 が良い *μの運動量測定の分解能は低いPTほど良い*

比較#2: Pol: （−0.8,+0.3）←→（+0.8, −0.3）:

- 異なる偏極の間でΔσ/σに大きな差がなさそう
- （+0.8, −0.3）: 統計が少ないが、S/B がずっと高い : WW BGが顕著に抑制

注意） 先行studyとの色んな違い:

- assumed L (350, 250 GeV) = (333 , 250 fb-1) vs RDR: (300 fb-1, 188 fb-1)
- このstudy : ALL 2f, 4f, 6f BGs (whizard generator) vs only WW, ZZ (pythia generator ?)

Summary

Higgs recoil study using **e+e- → Zh → μ+μ-h** @ **ECM =350 GeV**, L = 333 fb^{-1}

- **イベント選別手法の最適化**
- **Toy MC を用いた解析手法の検証 ＋ Higgs 断面積の精度の評価**

＜ 最新結果＞ **ECM = 350 GeV**

(-0.8, +0.3) **Δσ / σ = 4.7 +/-0.2 %** **(+0.8, -0.3)** **Δσ / σ = 4.9 +/-0.2 %**

ε_sig = 47.6 +/- 0.5 %,

異なる重心系エネルギー(ECM) やビーム偏極の間で物理の期待精度を比べることによりILC run scenario、加速器と測定器の性能の最適化を検討することが重要

- **ECM = 250 GeV,** L = 250 fb^{-1} **との比較**
  ECM =250 GeVの方がΔσ/σ と Mh 精度 が良い

- **異なる偏向状態の比較** ： **(-0.8, 0.3)** **vs (+ 0.8, -0.3)**
  Δσ/σに大きな差がなさそう
  (+0.8, −0.3) : 統計が少ないが、S/B (significance) がずっと高い： WW BGが顕著に抑制

Plans

- **データ選別手法の更なる改善**：
  残留WW BG に対して muon isolation cut
- fitted recoil mass M_H のバイアスを検討
  FSR γ を同定してエネルギーを補正

ご清聴ありがとうございました

BACKUP

Cut Efficiency

BACKUPに詳細あり

	2f_Z_l	eff	4f_WW_sl	eff	4f_ZZ_sl	eff	signal	eff	BG	eff
raw events	2226362	100.00%	2732834	100.00%	188087	100.00%	2288	**100.00%**	31657512	**100.00%**
best mu pair	946129	42.50%	236802	8.67%	42345	22.51%	2254	**98.51%**	2373876	**7.50%**
D0	925330	41.56%	152599	5.58%	39825	21.17%	2241	**97.95%**	1813049	**5.73%**
track angle	843738	37.90%	136568	5.00%	36073	19.18%	2205	**96.37%**	1618485	**5.11%**
84 <M_inv <98	269446	12.10%	5702	0.21%	16365	8.70%	1826	**79.81%**	313998	**0.99%**
10 <P_Tdl<140	71877	3.23%	5659	0.21%	14934	7.94%	1819	**79.50%**	111823	**0.35%**
dpTbal>10 GeV	10674	0.48%	5505	0.20%	14108	7.50%	1798	**78.58%**	48694	**0.15%**
copl < 3	9612	0.43%	4578	0.17%	13347	7.10%	1773	**77.49%**	44735	**0.14%**
cos(θ Z)<0.91	5709	0.26%	2940	0.11%	9147	4.86%	1698	**74.21%**	30428	**0.10%**
120 GeV <M_rec <140 GeV	276	0.01%	405	0.01%	1123	0.60%	1088	**47.55%**	2700	**0.01%**

全カット後の支配的なBG：

sqrt(s) = 350 GeV : #1) 4f_ZZ_sl #2) 4f_WW_sl #3) 2f_Z_l *ttbar BG 残らず*

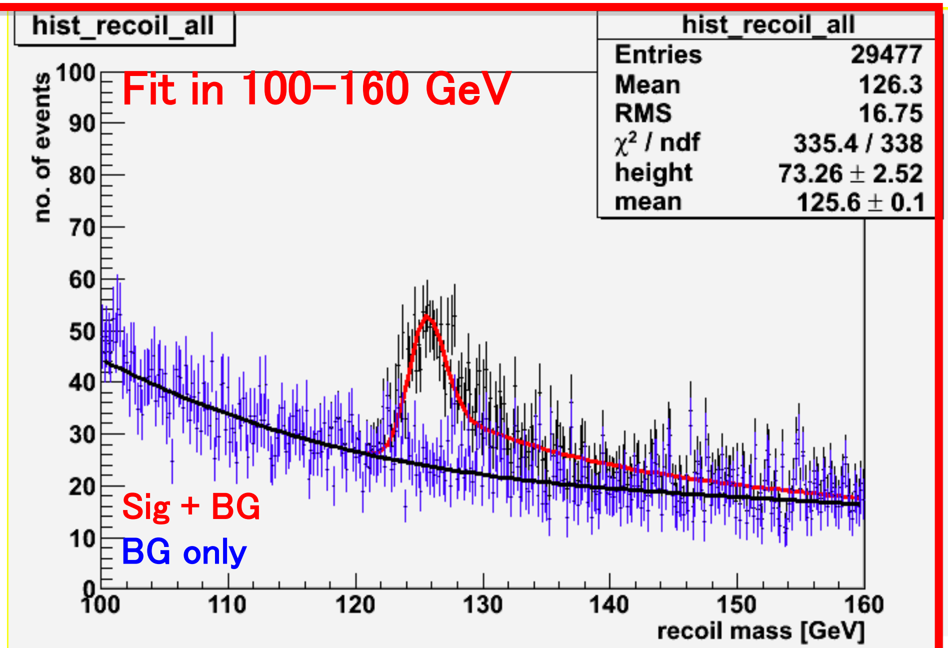
sqrt(s) = 250 GeV : #1) 4f_ZZWWMix_l #2) 4f_ZZ_sl #3) 2f_Z_l

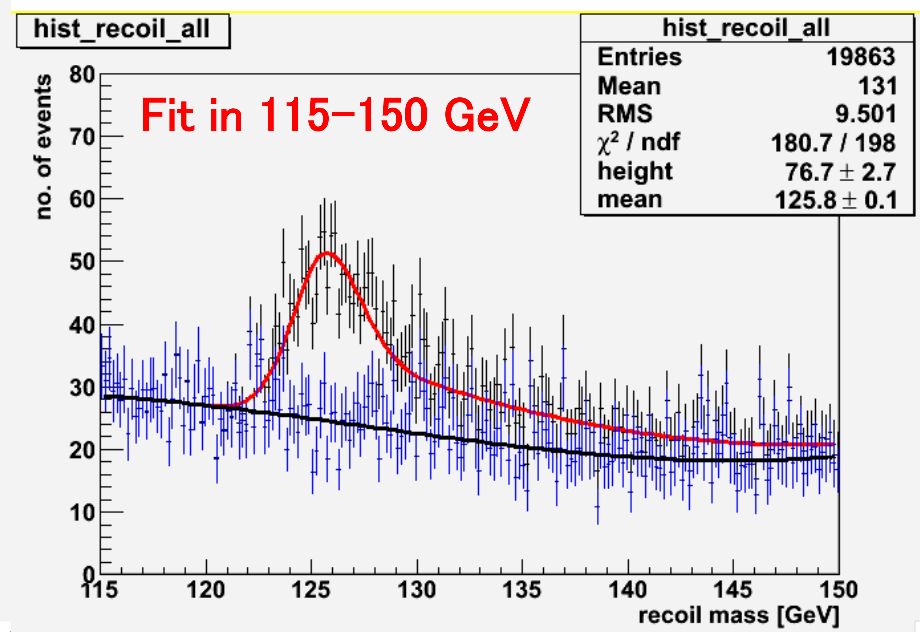
MC study の結果 : sqrt(s) =350 GeV , L = 333 fb-1

Fit 範囲を広くしたらxsec精度が改善

- OLD: 115-150 GeV
- New: 100-160 GeV

350 GeV	ε	Δσ/σ	xsec	Nsig	S/N	significance
(-0.8,+0.3)	47.6+/-0.5%	4.7+/-0.2%	6.9+/-0.3	1092+/-53	0.4	17.7
(-0.8,+0.3)	47.6+/-0.5%	4.9+/-0.2%	6.7+/-0.3	1092+/-55	0.4	17.7

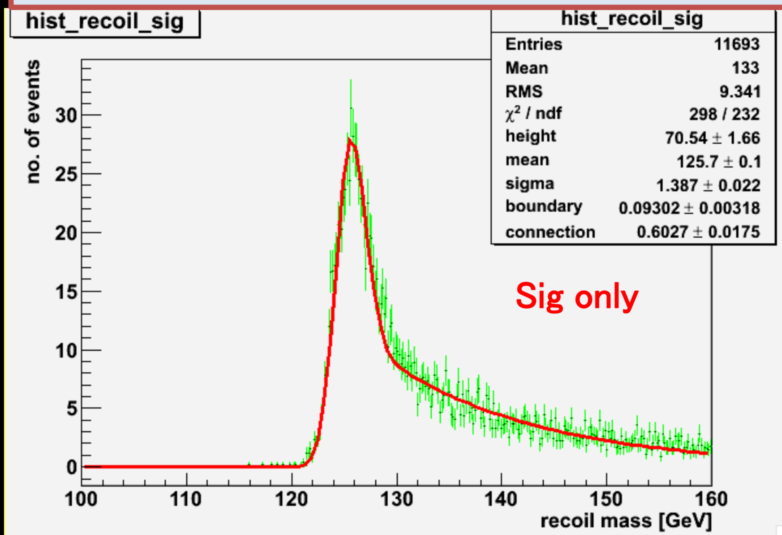




fitting for recoil mass histogram

1^{st} time fitting:

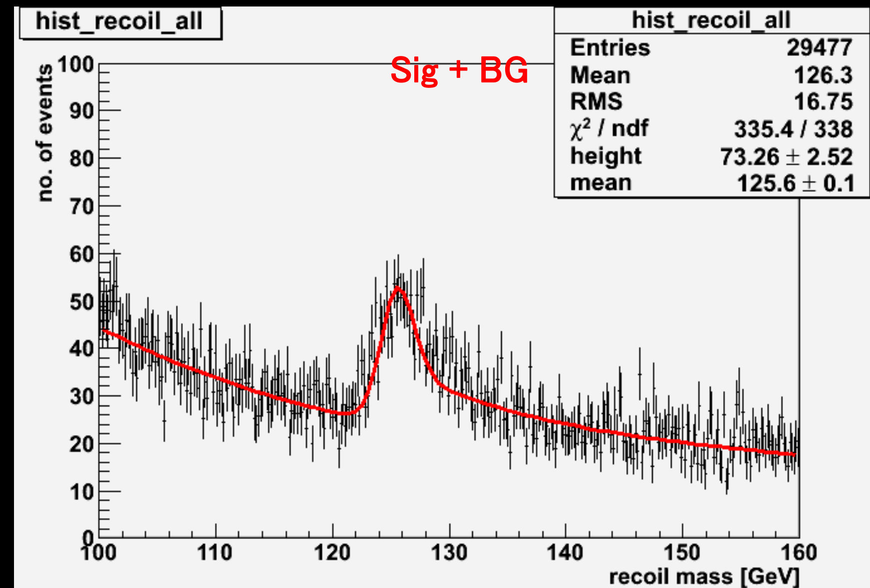
- fit only signal : float all 5 GPET pars
- fit BG only 3^{rd} order polynomial



Final fitting:

float only height and mean,

Fix BG function and remaining GPET pars from 1^{st} time fitting

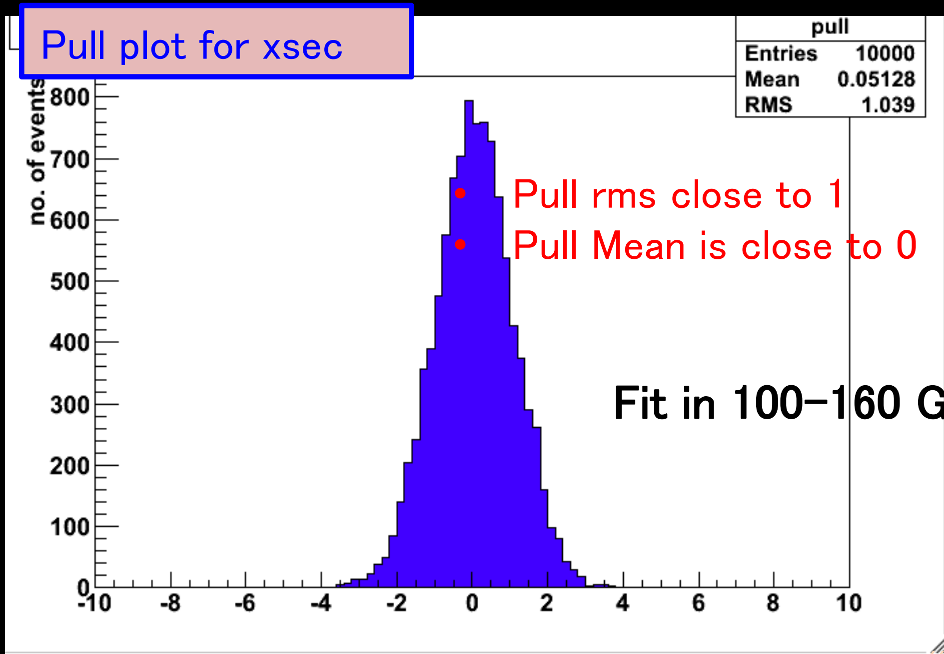


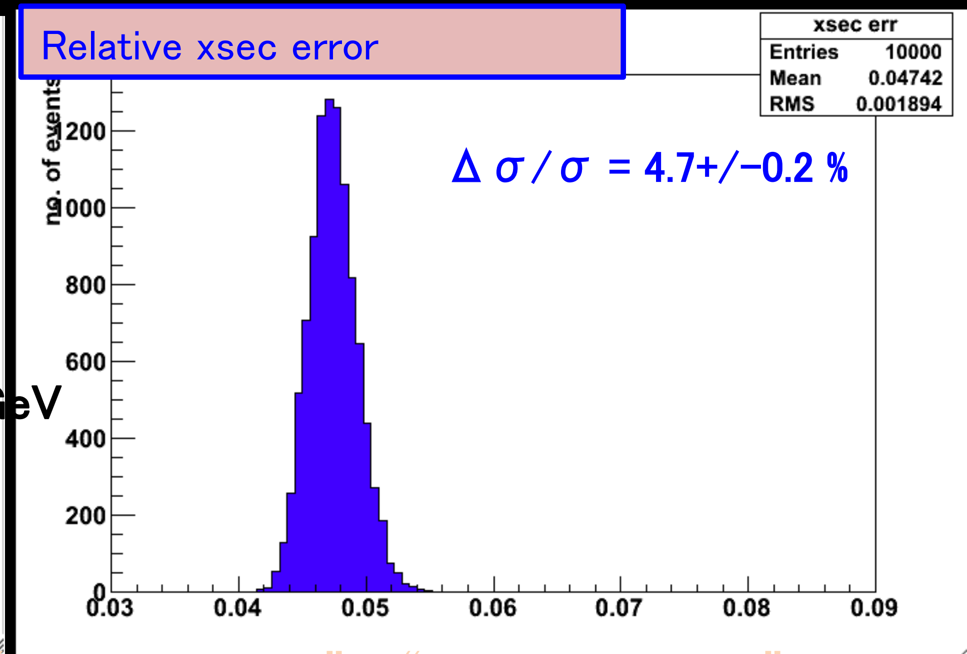
◆ **SIGNAL: GPET:** 5 parameters :

Gaus (left-side) , Gaus + expo (right side)

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

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



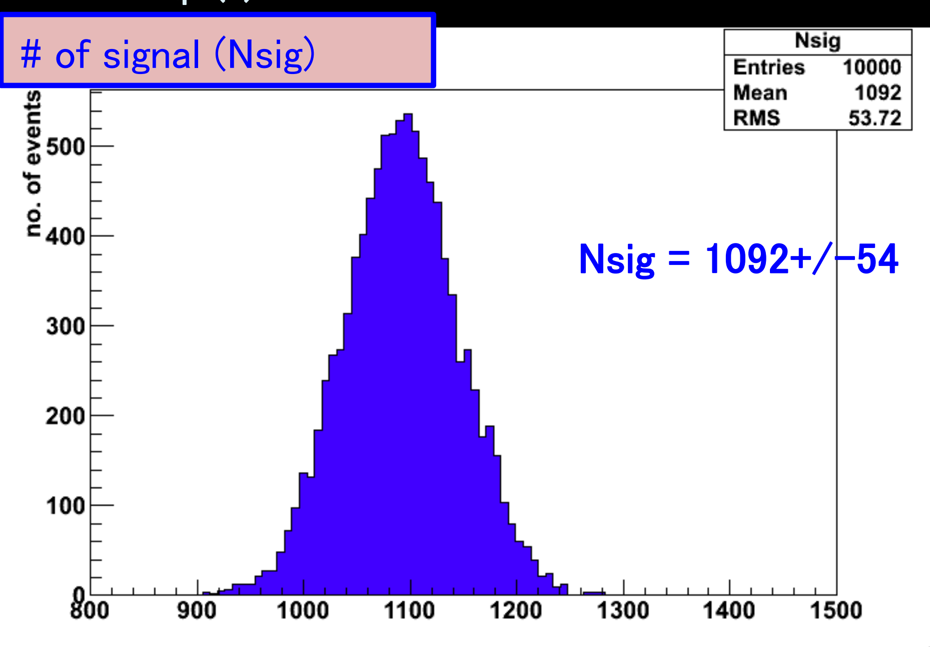


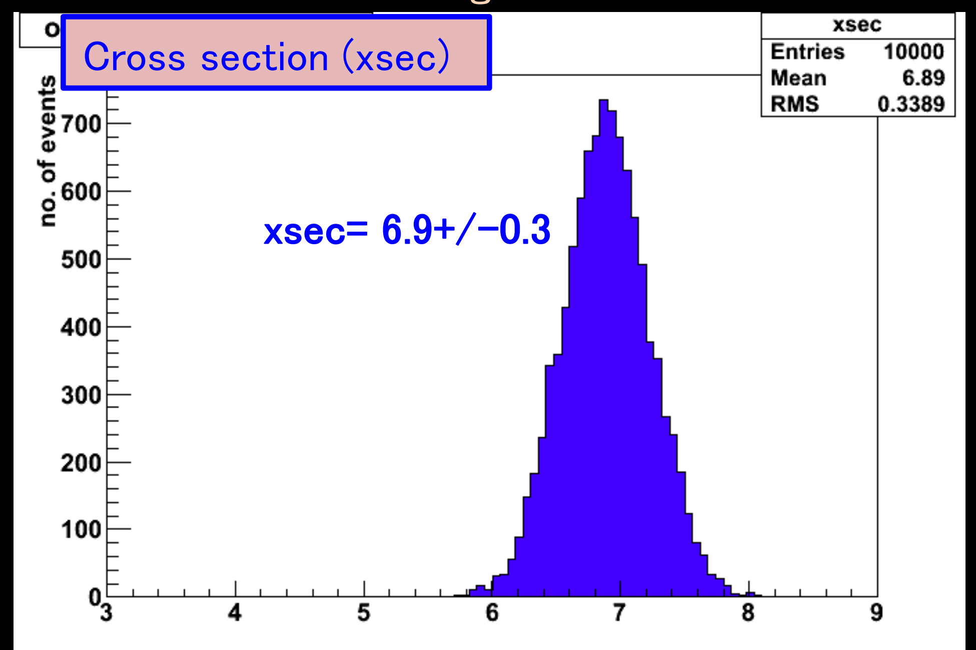
Result of Toy MC 10000 seeds

sqrt(s)=350 GeV

- “real xsec = 6.87” , “ real Nsig = 1089”

Consistent within error ranges

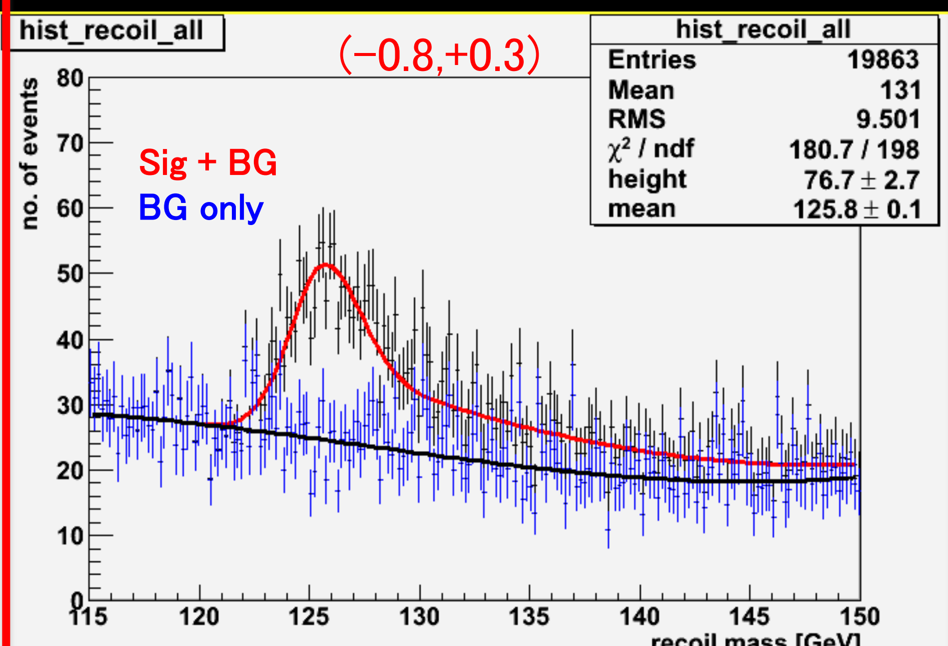


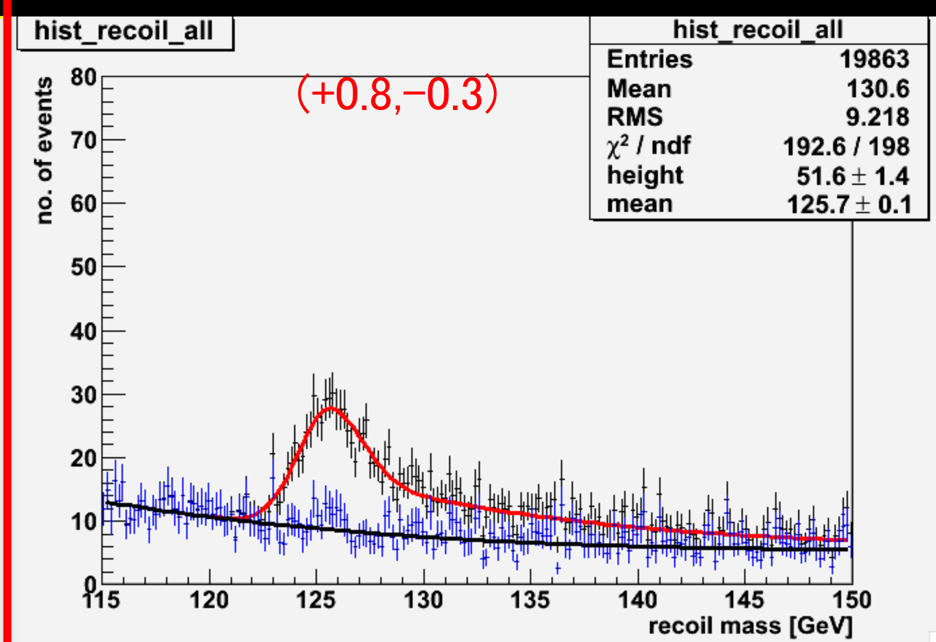


results for sqrt(s) =350 GeV , L = 333 fb-1

evaluated using Toy MC generated from fitted function shapes

350 GeV	ε	Δσ/σ	xsec	Nsig	S/N	significance
(−0.8,+0.3)	47.6+/−0.5%	4.9+/−0.2%	6.71+/−0.34	1092+/−55	0.4	17.7
(+0.8,−0.3)	47.8+/−0.5%	5.0+/−0.2%	4.53+/−0.26	720+/−41	0.75	17.8

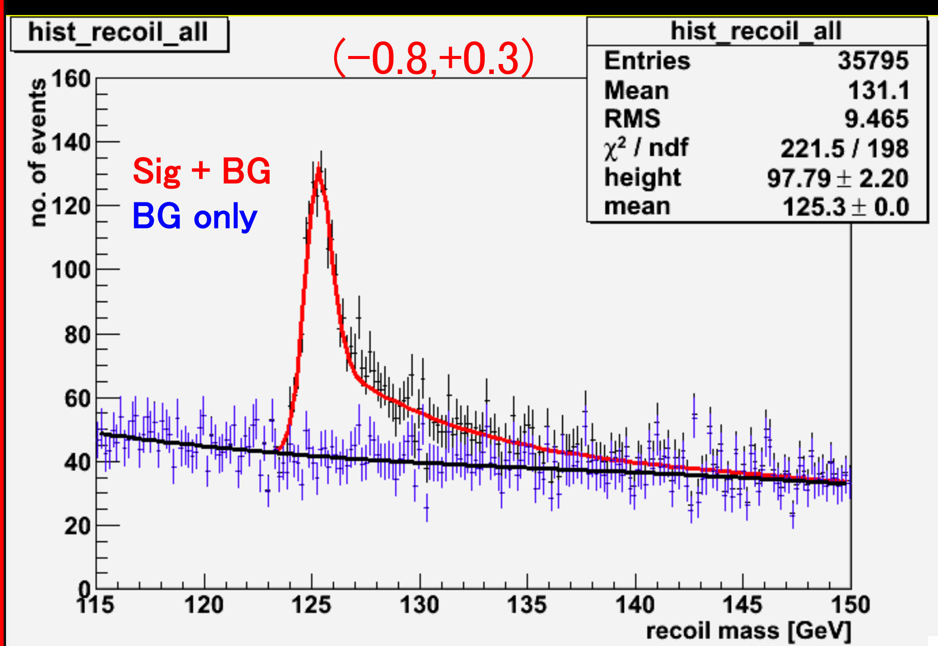


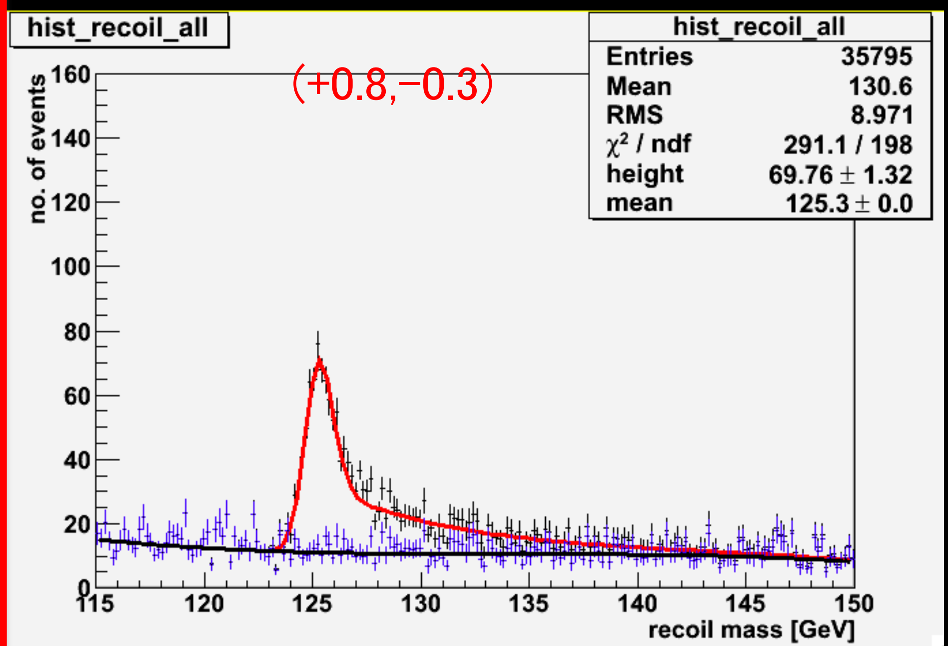


results for sqrt(s) =250 GeV , L = 250 fb−1

evaluated using Toy MC generated from fitted function shapes

250 GeV	ε	Δσ/σ	xsec	Nsig	S/N	significance
(−0.8,+0.3)	66.4+/−0.5%	3.6+/−0.1%	10.52+/−0.38	1747+/−64	0.37	21.7
(+0.8,−0.3)	64.4+/−0.5%	3.3+/−0.1%	8.68+/−0.30	1398+/−48	0.81	22.7





		2f_Z_l	eff	4f_WW_sl	eff	4f_ZZ_sl	eff	signal	eff	BG	eff
raw events	eLpR	2128619		2714856		182762		2204			
	eRpL	97743		17978		5325		84			
	total	2226362	100.00%	2732834	100.00%	188087	100.00%	2288	100.00%	31657512	100.00%
best mu pair	eLpR	906955		235263		41072		2171			
	eRpL	39174		1539		1273		83			
	total	946129	42.50%	236802	8.67%	42345	22.51%	2254	98.51%	2373876	7.50%
D0	eLpR	886948		151718		38624		2158			
	eRpL	38382		881		1201		83			
	total	925330	41.56%	152599	5.58%	39825	21.17%	2241	97.95%	1813049	5.73%
track angle	eLpR	808861		135726		35002		2124			
	eRpL	34877		842		1071		81			
	total	843738	37.90%	136568	5.00%	36073	19.18%	2205	96.37%	1618485	5.11%
84 <M_inv <98	eLpR	259828		5673		15959		1758			
	eRpL	9618		29		406		68			
	total	269446	12.10%	5702	0.21%	16365	8.70%	1826	79.81%	313998	0.99%
10 <P_Tdl<140	eLpR	69251		5630		14566		1752			
	eRpL	2626		29		368		67			
	total	71877	3.23%	5659	0.21%	14934	7.94%	1819	79.50%	111823	0.35%
dpTbal>10 GeV	eLpR	10272		5478		13761		1731			
	eRpL	402		27		347		67			
	total	10674	0.48%	5505	0.20%	14108	7.50%	1798	78.58%	48694	0.15%
copl < 3	eLpR	9252		4557		13019		1707			
	eRpL	360		21		328		66			
	total	9612	0.43%	4578	0.17%	13347	7.10%	1773	77.49%	44735	0.14%
cos(θ Z)<0.91	eLpR	5492		2921		8927		1635			
	eRpL	217		19		220		63			
	total	5709	0.26%	2940	0.11%	9147	4.86%	1698	74.21%	30428	0.10%
120 GeV <M_rec <140 GeV	eLpR	265		403		1098		1048			
	eRpL	11		2		25		40			
	total	276	0.01%	405	0.01%	1123	0.60%	1088	47.55%	2700	0.01%

		(+0.8,−0.3) 2f_Z_l	eff	4f_WW_sl	eff	4f_ZZ_sl	eff	signal	eff	BG	eff
raw events	eLpR	127353		162427		10934		132			
	eRpL	1633703		1076		89009		1411			
	total	1761057	100.00%	163503	100.00%	99943	100.00%	1543	100.00%	16166900	100.00%
best mu pair	eLpR	54262		14076		2457		130			
	eRpL	654769		92		21274		1389			
	total	709031	40.26%	14168	8.67%	23731	23.74%	1519	98.44%	1146571	7.09%
D0	eLpR	53065		9077		2311		129			
	eRpL	639852		53		20077		1383			
	total	692917	39.35%	9130	5.58%	22388	22.40%	1512	97.99%	938198	5.80%
track angle	eLpR	48393		8120		2094		127			
	eRpL	582938		50		17901		1356			
	total	631331	35.85%	8170	5.00%	19995	20.01%	1483	96.11%	827736	5.12%
84 <M_inv <98	eLpR	15545		339		955		105			
	eRpL	160766		2		6790		1130			
	total	176311	10.01%	341	0.21%	7745	7.75%	1235	80.04%	191148	1.18%
10 <P_Tdl<140	eLpR	4143		337		871		105			
	eRpL	43892		2		6145		1123			
	total	48035	2.73%	339	0.21%	7016	7.02%	1228	79.59%	60616	0.37%
dpTbal>10 GeV	eLpR	615		328		823		104			
	eRpL	6715		2		5806		1113			
	total	7330	0.42%	330	0.20%	6629	6.63%	1217	78.87%	19128	0.12%
copl < 3	eLpR	554		273		779		102			
	eRpL	6015		1		5478		1097			
	total	6569	0.37%	274	0.17%	6257	6.26%	1199	77.71%	17591	0.11%
cos(θ Z)<0.91	eLpR	329		175		534		98			
	eRpL	3624		1		3680		1052			
	total	3953	0.22%	176	0.11%	4214	4.22%	1150	74.53%	11306	0.07%
120 GeV <M_rec <140 GeV	eLpR	16		24		66		63			
	eRpL	191		0		419		675			
	total	207	0.01%	24	0.01%	485	0.49%	737	47.76%	977	0.01%

Signal sample:

Pe2e2h_.eL.pR & Pe2e2h._eR.pL

relevant BG process for Zmumu

- 4f_ZZ_leptonic
- 4f_ZZ_semileptonic
- 2f_Z_leptonic
- 4f_WW_leptonic
- 4f_WW_semileptonic
- 4fSingleZee_leptonic
- 4fSingleZnunu_leptonic
- 4f_ZZWWMix_leptonic
- 6f backgrounds (sqrt(s)=350 GeV)