Higgs Recoil Mass Study for ILD LOI and Beyond

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Outline

(A) Full Simulation Study: Ecm=250GeV, RDR250 Beam Parameters

- Production
- Background Suppression
- Fit to Extract the Results
- Bremsstrahlung Recovery (for the e-channel)
- Discussions

Results for ILD LOI

(B) Fast Simulation Study: SB2009 Beam parameters

- Fast Simulation
- Results
- Discussions

Dedicated Study for SB2009 Discussion,

- the impact on the Higgs recoil mass measurement

(C) Summary

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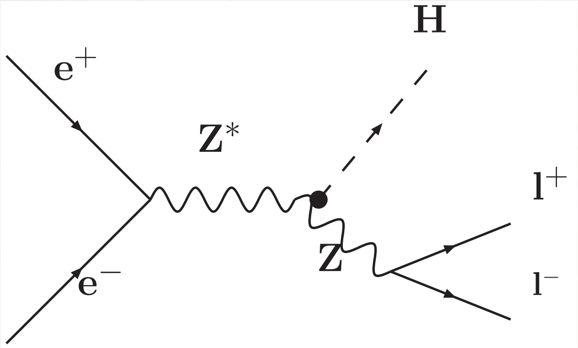
MC Production

- Higgs-Strahlung Process:



- Higgs Recoil Mass:

$$M_H^2 = M_{recoil}^2 = s + M_Z^2 - 2E_Z\sqrt{s}$$

- Cross Section and Coupling Strength Measurement:

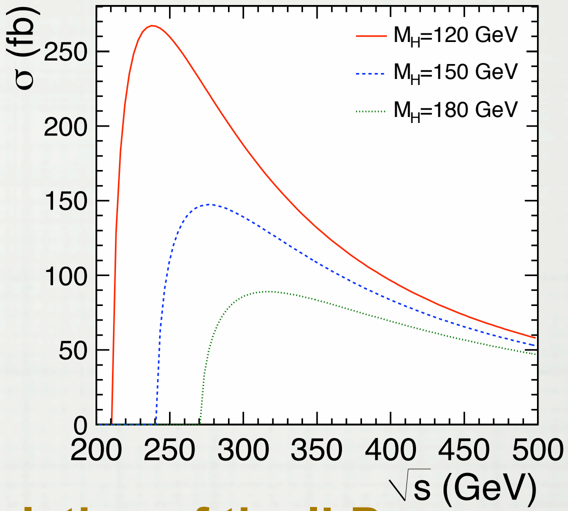
$$g^2 \propto \sigma = N/\mathcal{L}\epsilon$$

Advantages at Linear Collider:

- Using only the Z and Ecm

- Independent of the Higgs decay

Cross-Section



- Full Simulation of the ILD

- M_H = 120 GeV

- Ecm = 250 GeV **just above mass threshold**

- Beam Parameters: RDR250

- Luminosity: 250 fb^{-1}

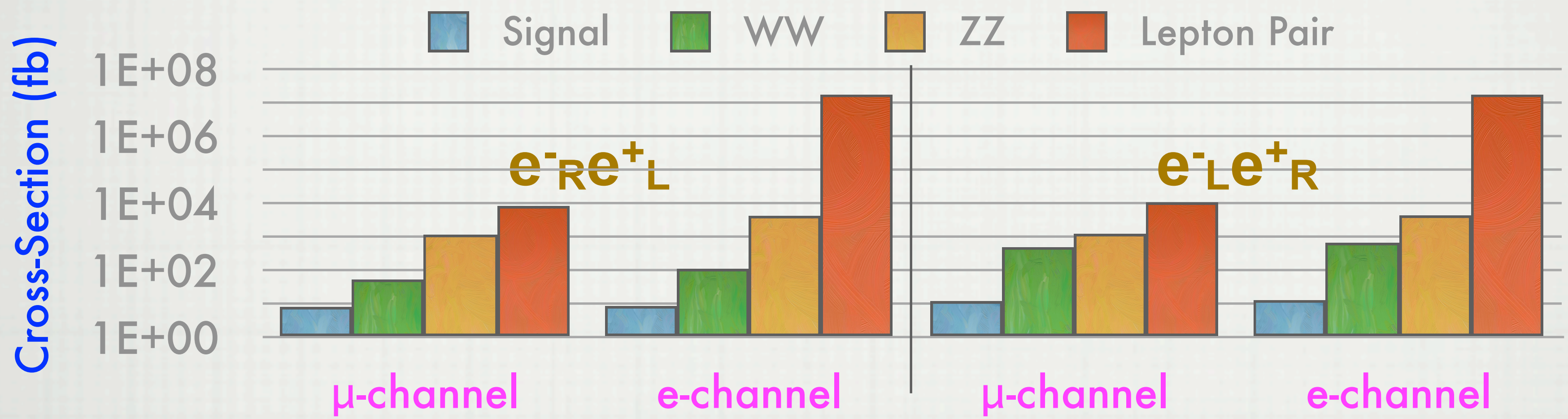
- Polarization:

$e^-_R e^+_L$: (e^-: +80%, e^+: -30%)

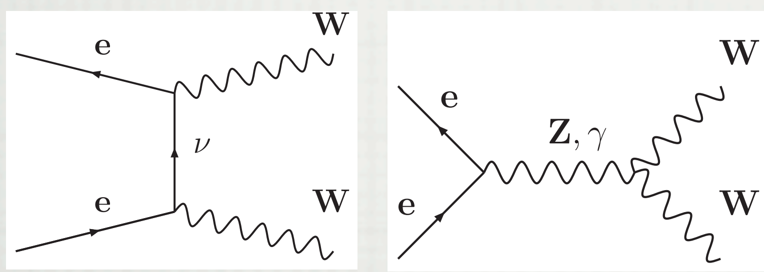
$e^-_L e^+_R$: (e^-: -80%, e^+: +30%)

MC Production

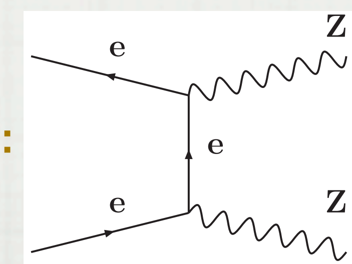
Backgrounds Reactions:



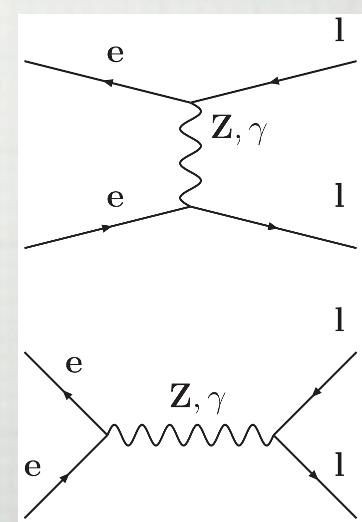
WW:



ZZ:



Lepton Pair:



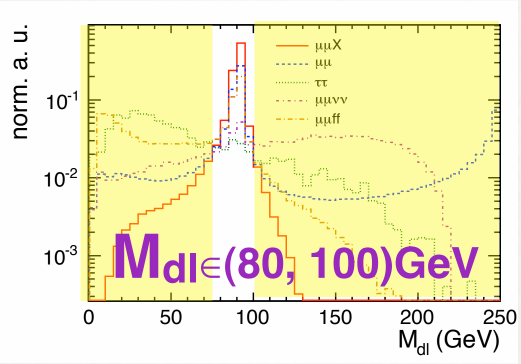
Production Statistics:

1) Signal: 10 ab^{-1} each
2) Background: mostly larger than 250 fb^{-1}

Background Rejection

Background Suppression in 2 Steps: (Model Independent)

Step One, by cuts: remaining major bkg: ZZ and WW



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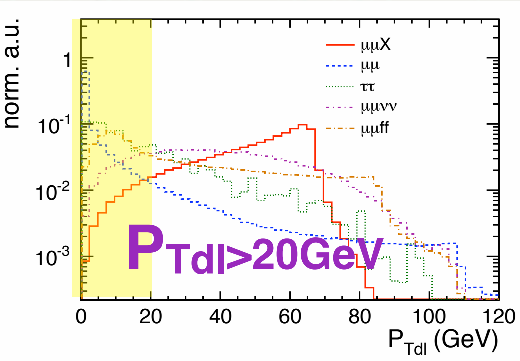

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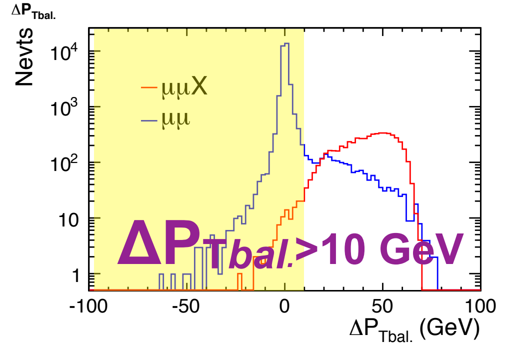
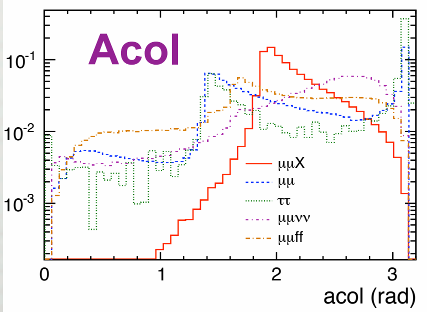
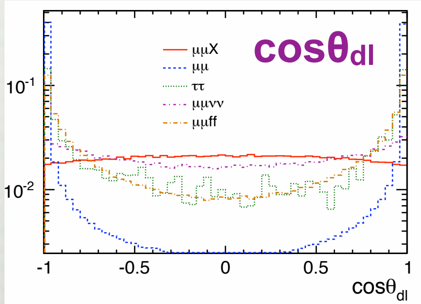


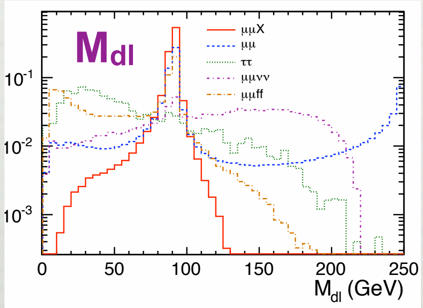
, etc....

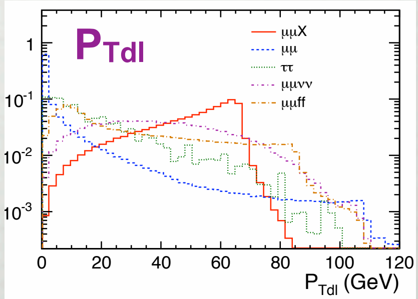
Step Two, by Likelihood: remaining major bkg: ZZ

vars employed=>

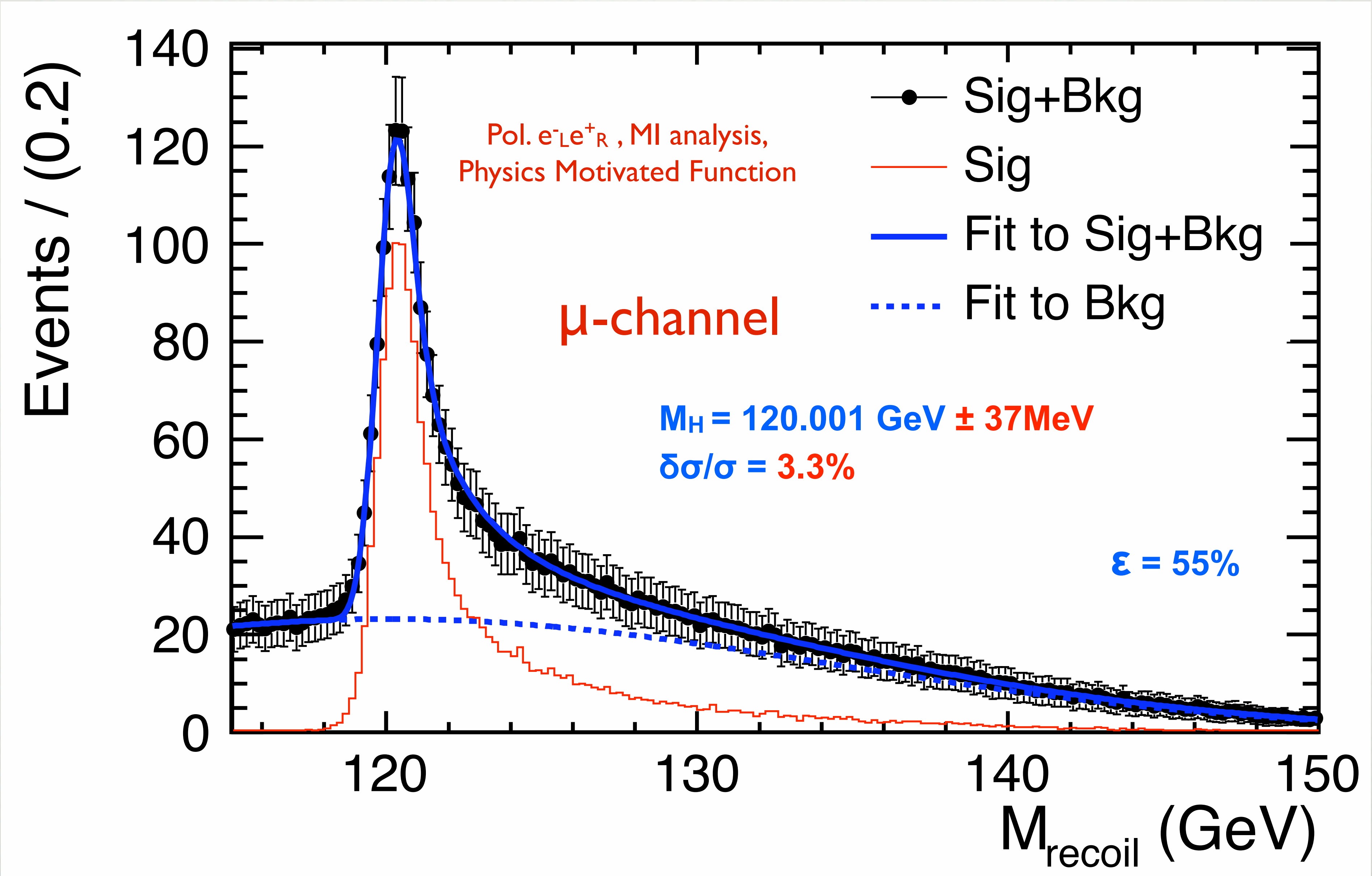




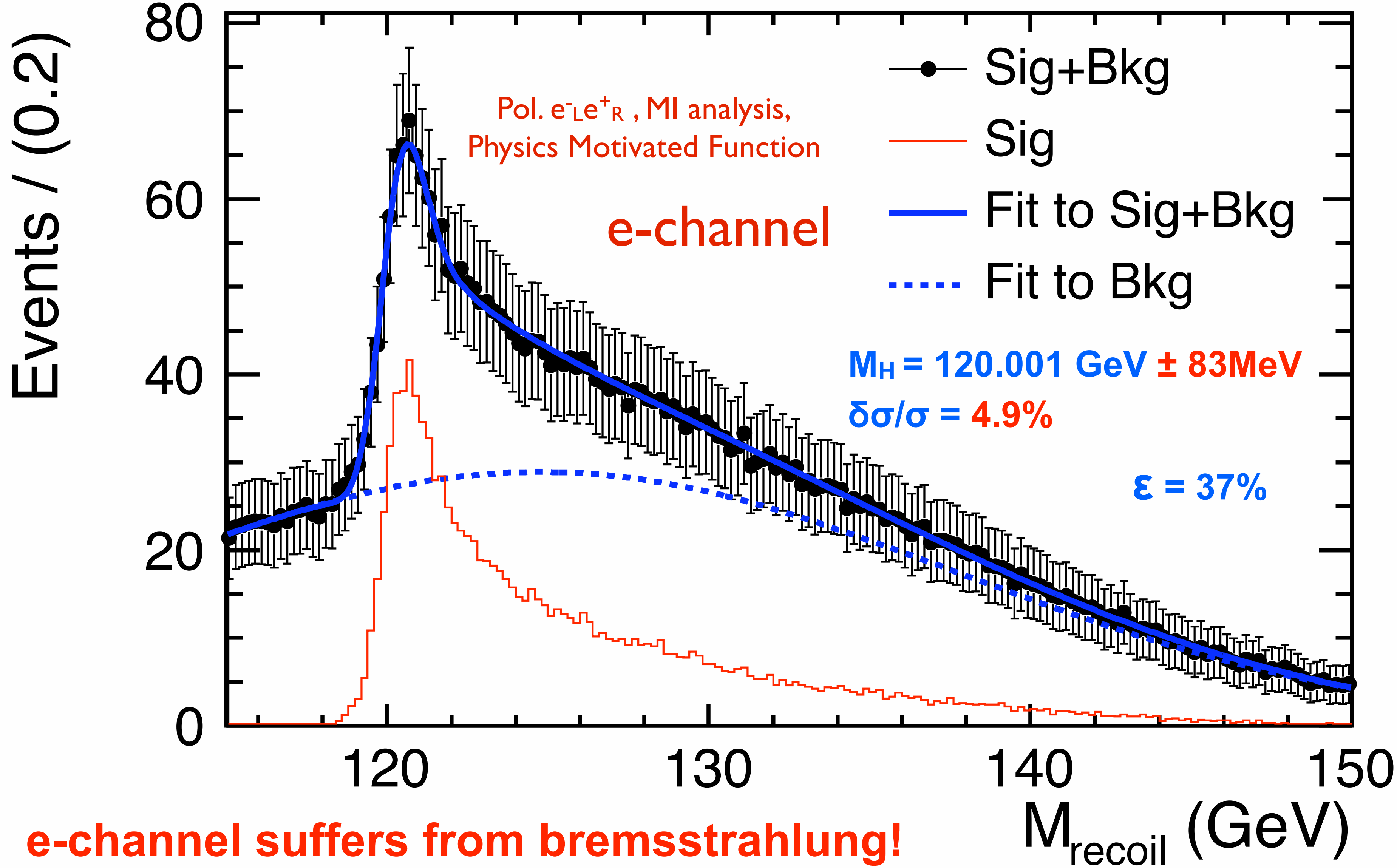




Fit: μ-channel, MI Analysis



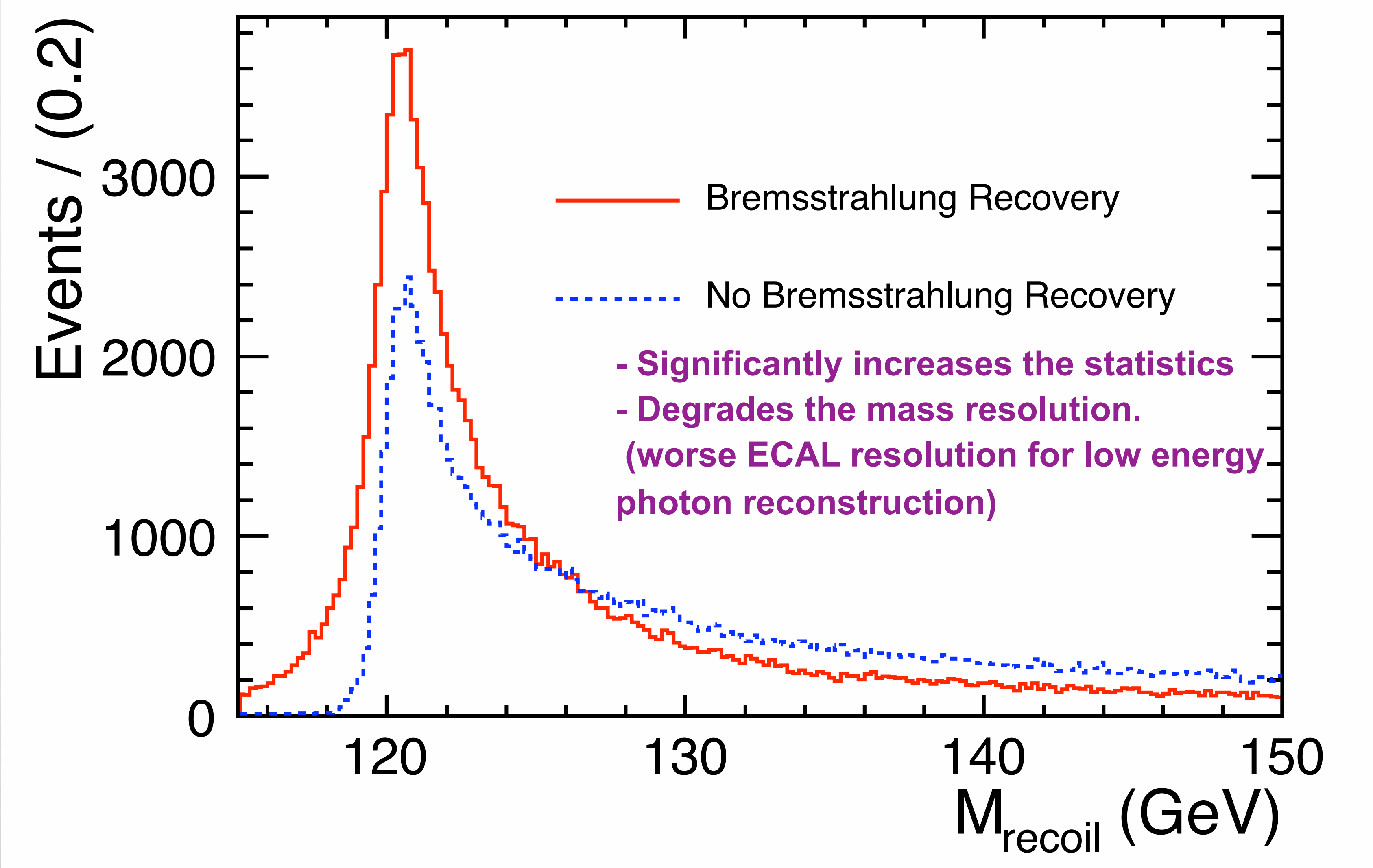
Fit: e-channel, MI Analysis



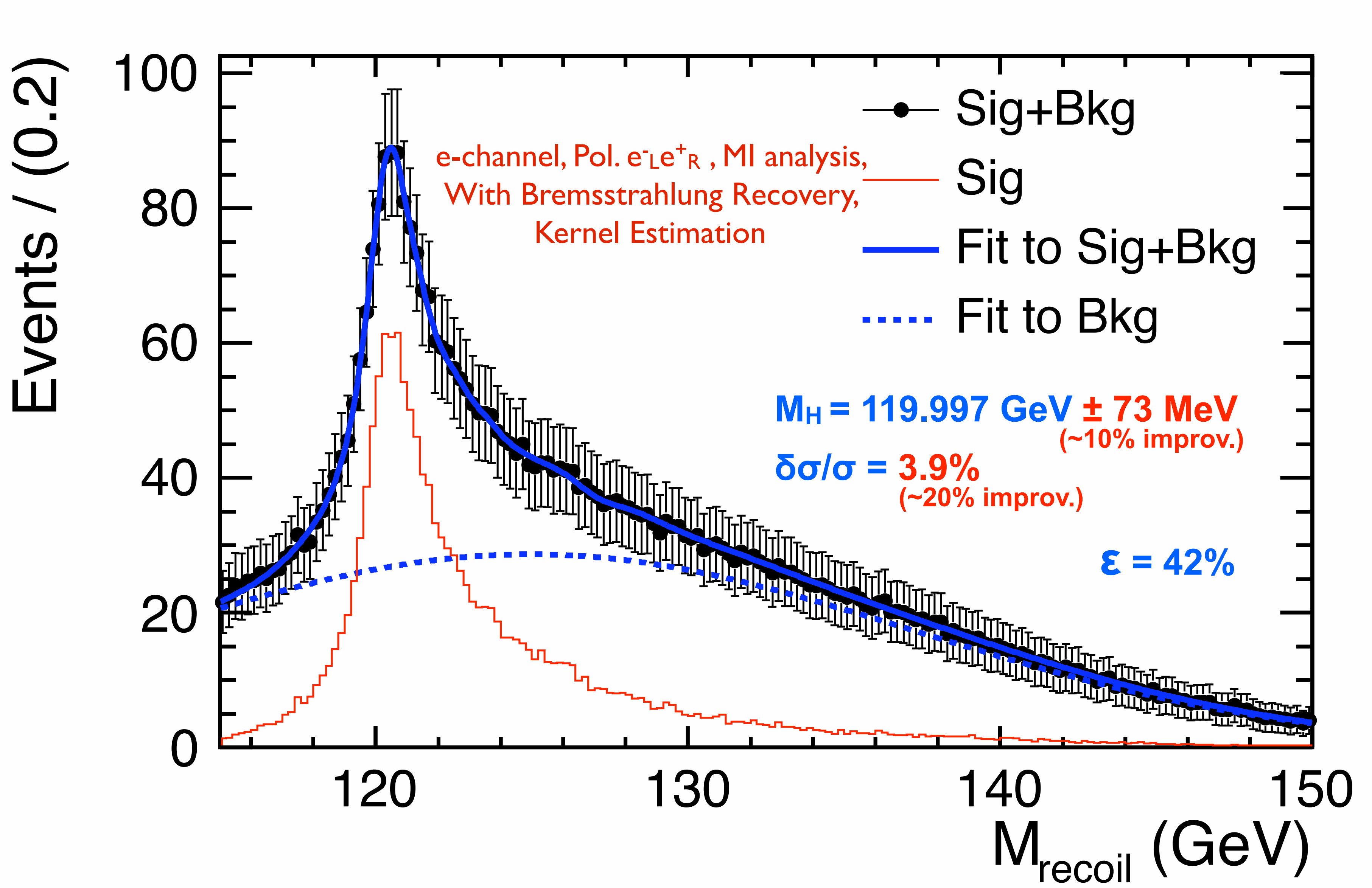
e-channel suffers from bremsstrahlung!

Bremsstrahlung Recovery

A dedicated algorithm for inclusion of Bremsstrahlung photons. (Thanks to M. Thomson)

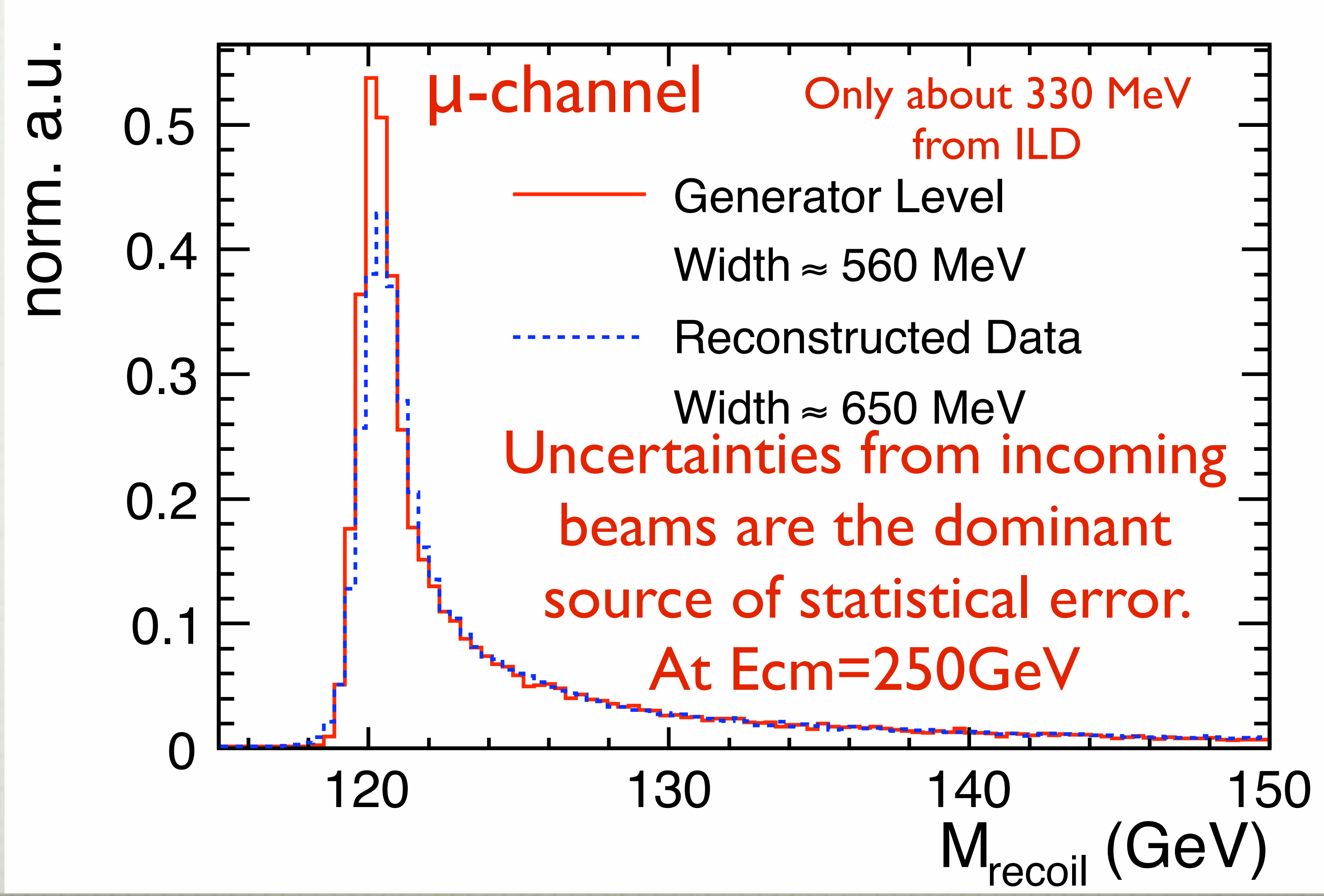


Bremsstrahlung Recovery



Discussion I: Accelerator Impact

- The Higgs Recoil Mass measurement is very sensitive to accelerator effects:
  - **Beam Energy Spread:** Increases the width of recoil mass peak, thus reduces the accuracy of the measurement.
  - **Beamstrahlung:** Largely reduces the effective statistics on the recoil mass peak



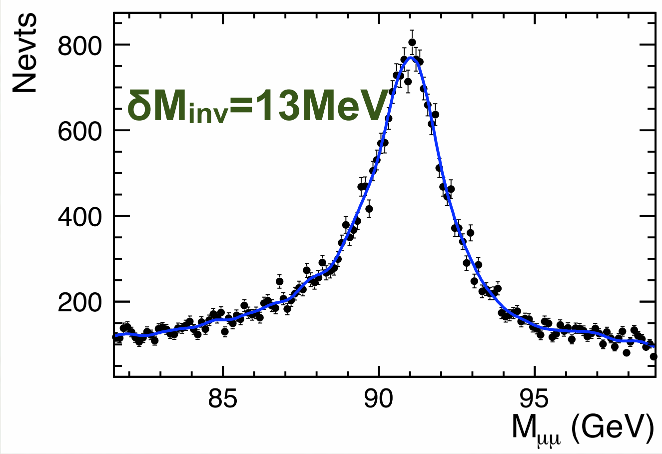
Discussion II: Systematic Errors

- On the Higgs recoil mass measurement

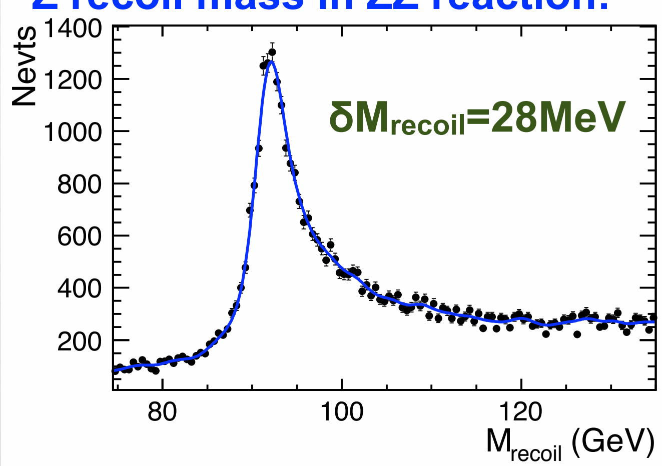
$$M_H^2 = M_{recoil}^2 = s + M_Z^2 - 2E_Z\sqrt{s}$$

  - Reference reaction ZZ can be used
  - Z invariant mass: control the tracking momentum
  - Z recoil mass: control the center of mass energy and radiative effects

Z invariant mass in ZZ reaction:



Z recoil mass in ZZ reaction:



- On the cross-section measurement

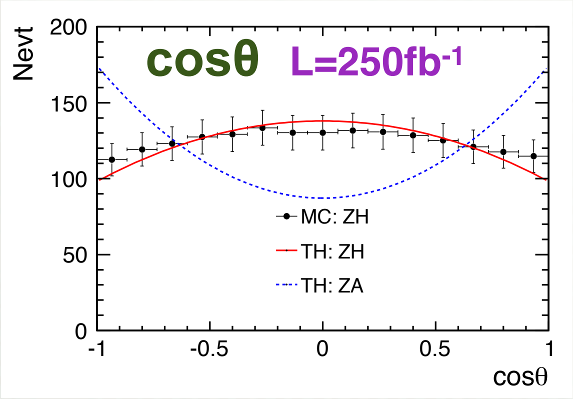
$$g^2 \propto \sigma = N/\mathcal{L}\epsilon$$

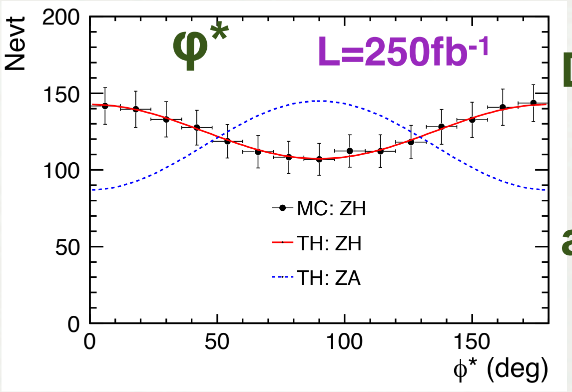
  - Efficiency is the main source, uncertainty due to background suppression
  - By simplifying the background suppression, i.e. only several common cuts:
  - $\delta\sigma_{stat.}$ increases by ~10%, But, largely reduces the uncertainty of efficiency.

Discussion III: Angular Analysis

We can determine the Higgs Spin Parity from angular analysis:

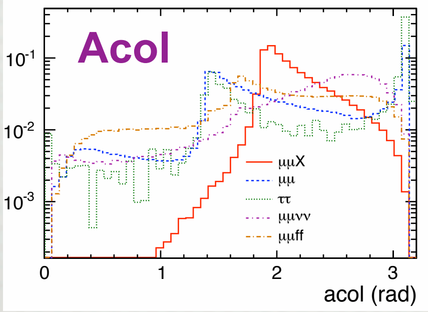
H: $J^{PC}=0^{++}$
A: $J^{PC}=0^{+-}$





Definition:
θ : ZH production angle
φ*: Z decay azimuthal angle in the Z rest frame

But, in the background suppression we employed many angular cuts!
e.g.



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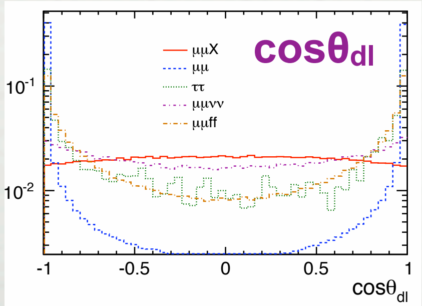

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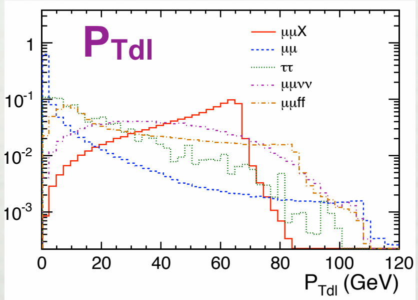

, etc....

This means we have to re-design our background suppression in order to perform this analysis: working in progress...

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(I will present the details in the morning of Mar. 28 on "GDE :Beam Delivery System")

Dedicated Study for SB2009 Discussion,

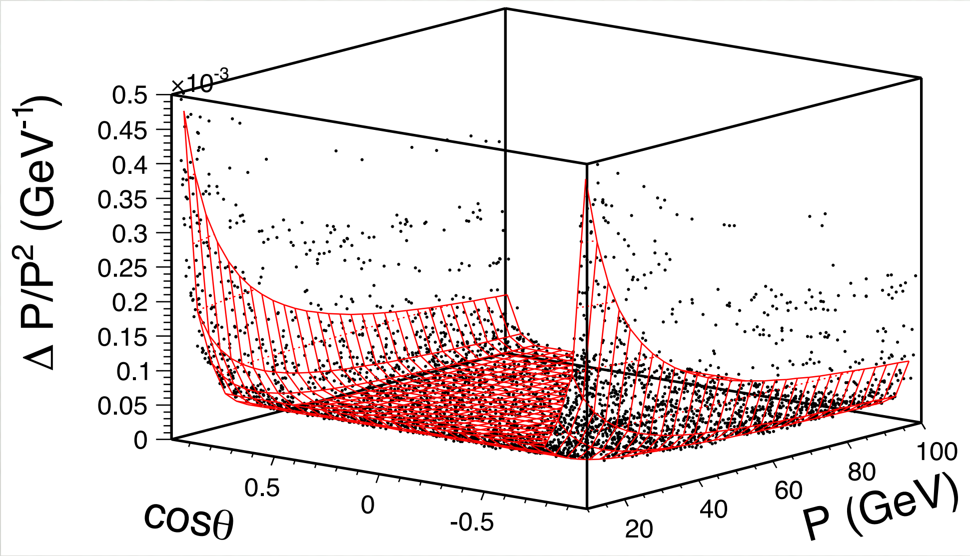
- the impact on the Higgs recoil mass measurement

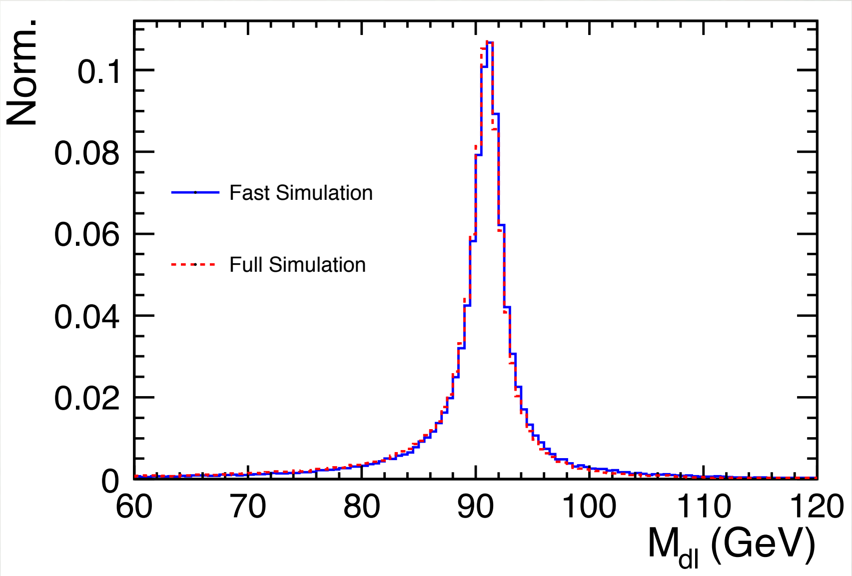
(C) Summary

Fast Simulation

- A dedicated Fast Simulation Algorithm is developed for the ILD concept
- Parameterize the Momentum Resolution as a function of P and cosθ
- The MC true momentum of a given muon is smeared according to this parameterization.

$$\frac{\Delta P}{P^2} = \begin{cases} a_1 \oplus b_1/P & : \ |\cos\theta| < 0.78 \\ (a_2 \oplus b_2/P) \Big/ \sin(1 - |\cos\theta|) & : \ |\cos\theta| > 0.78 \end{cases}$$





Results

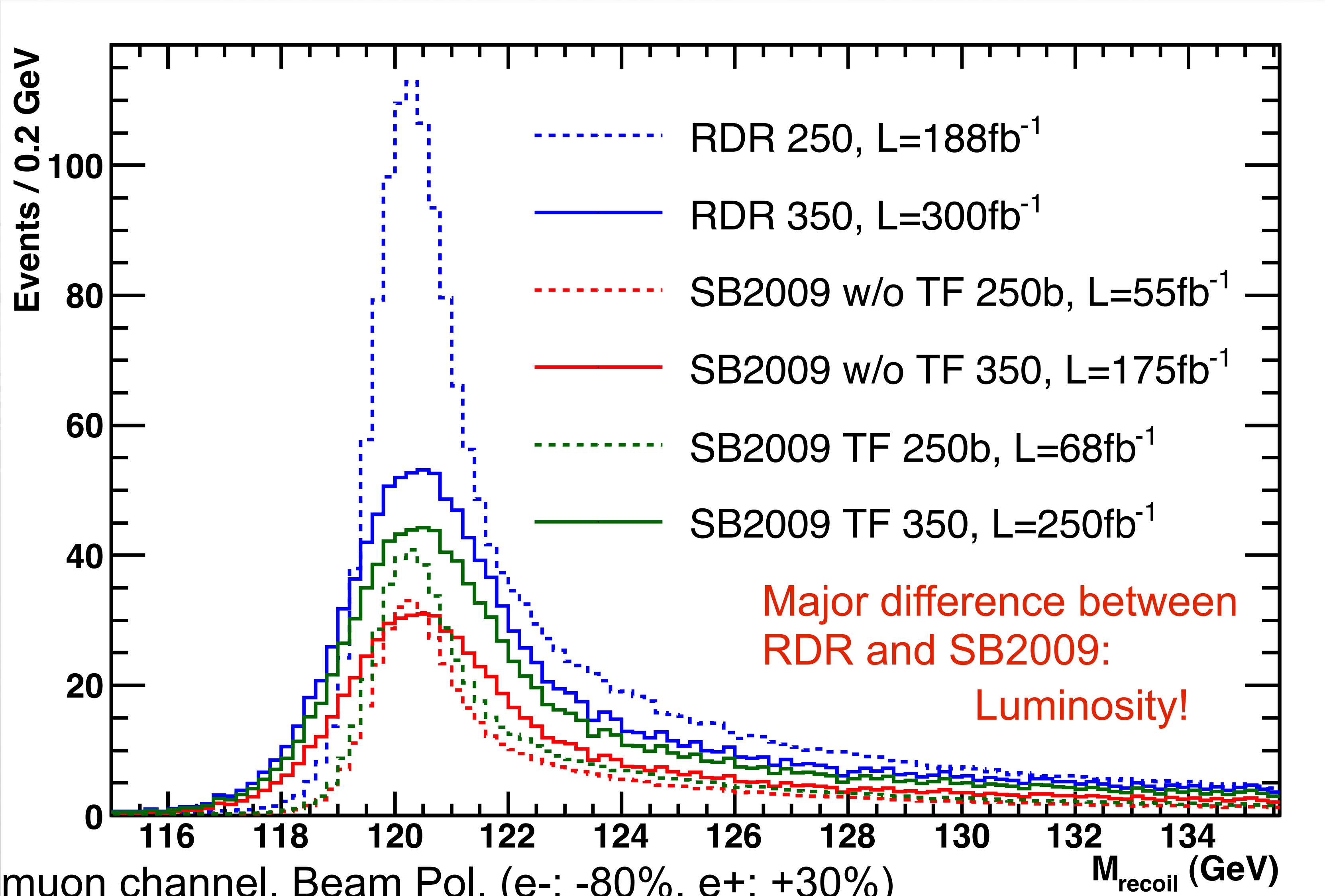
Only muon-channel, Beam Pol. (e-: -80%, e+: +30%)

Beam Par	$\mathcal{L}_{\text{int}}$ (fb^{-1})	ϵ	S/B	M_H (GeV)	σ (fb) ($\delta\sigma/\sigma$)
RDR 250	188	55%	62%	120.001 ± 0.043	11.63 ± 0.45 (3.9%)
RDR 350	300	51%	92%	120.010 ± 0.084	7.13 ± 0.28 (4.0%)
SB2009 w/o TF 250b	55	55%	62%	120.001 ± 0.079	11.63 ± 0.83 (7.2%)
SB2009 w/o TF 350	175	51%	92%	120.010 ± 0.110	7.13 ± 0.37 (5.2%)
SB2009 TF 250b	68	55%	62%	120.001 ± 0.071	11.63 ± 0.75 (6.4%)
SB2009 TF 350	250	51%	92%	120.010 ± 0.092	7.13 ± 0.31 (4.3%)

- Discussions:
  - Luminosity of SB2009 is worse than RDR: Given Ecm, SB2009 gives worse results than RDR
  - TF (Travel Focus) indeed gives better results than w/o TF, due to higher luminosity.
  - S/B higher at 350 GeV than 250GeV: due to better bkg suppression
  - At 350 GeV, detector effect is dominant, while at 250 GeV accelerator effects are dominant

Discussions

Comparison of Higgs Recoil Mass distributions with different beam parameters:



muon channel, Beam Pol. (e-: -80%, e+: +30%)

Discussions

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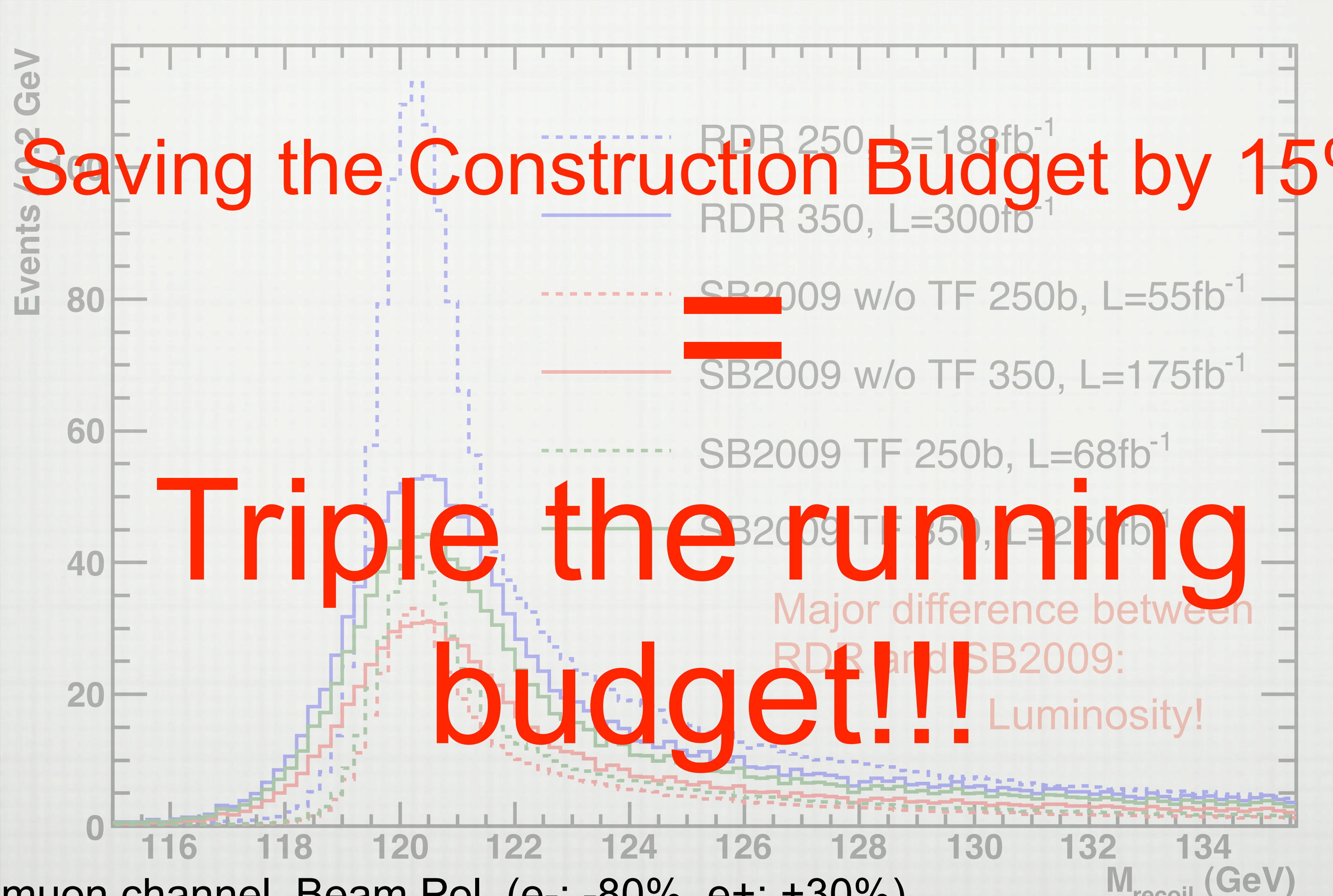


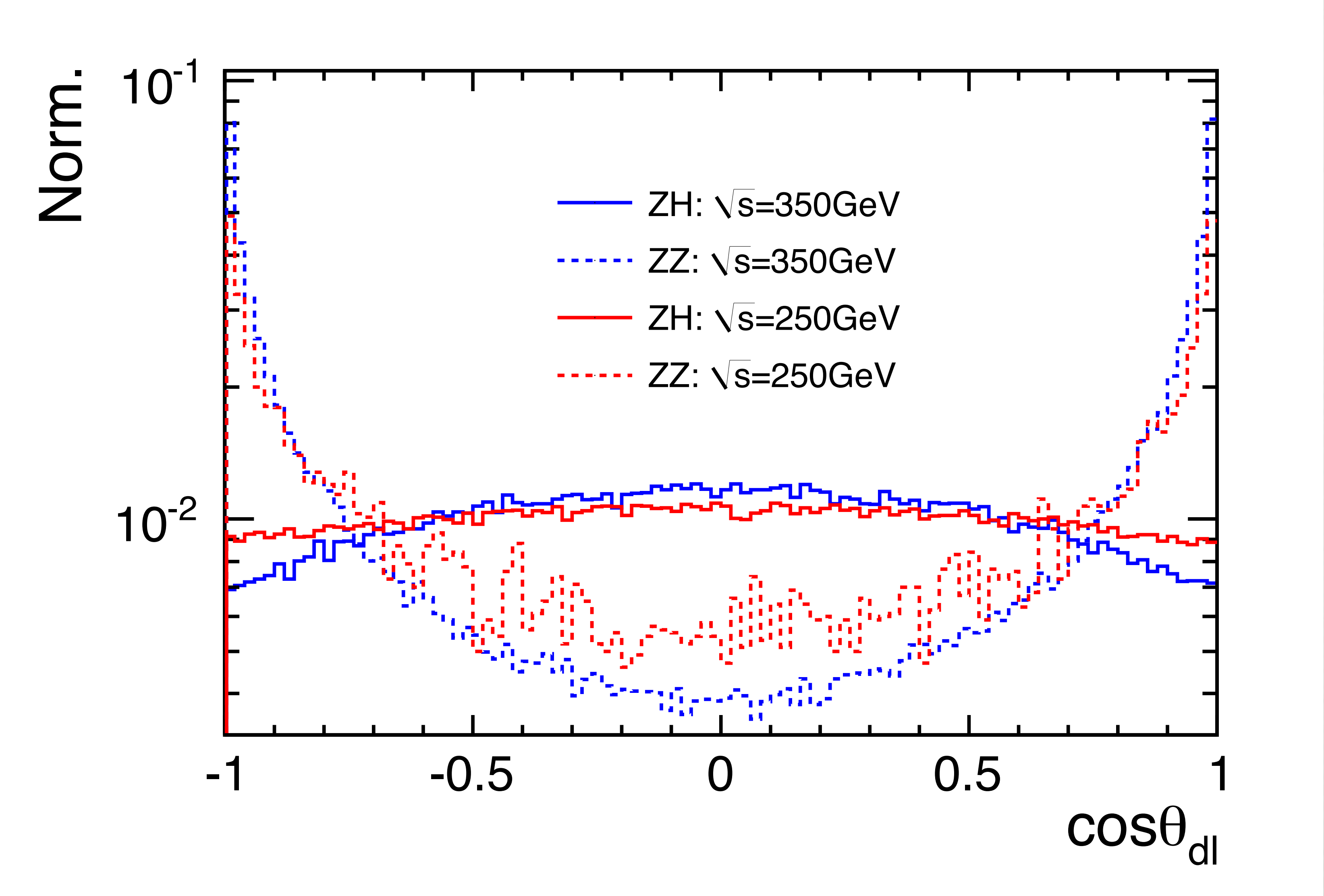
Saving the Construction Budget by 15%

=

Triple the running budget!!!

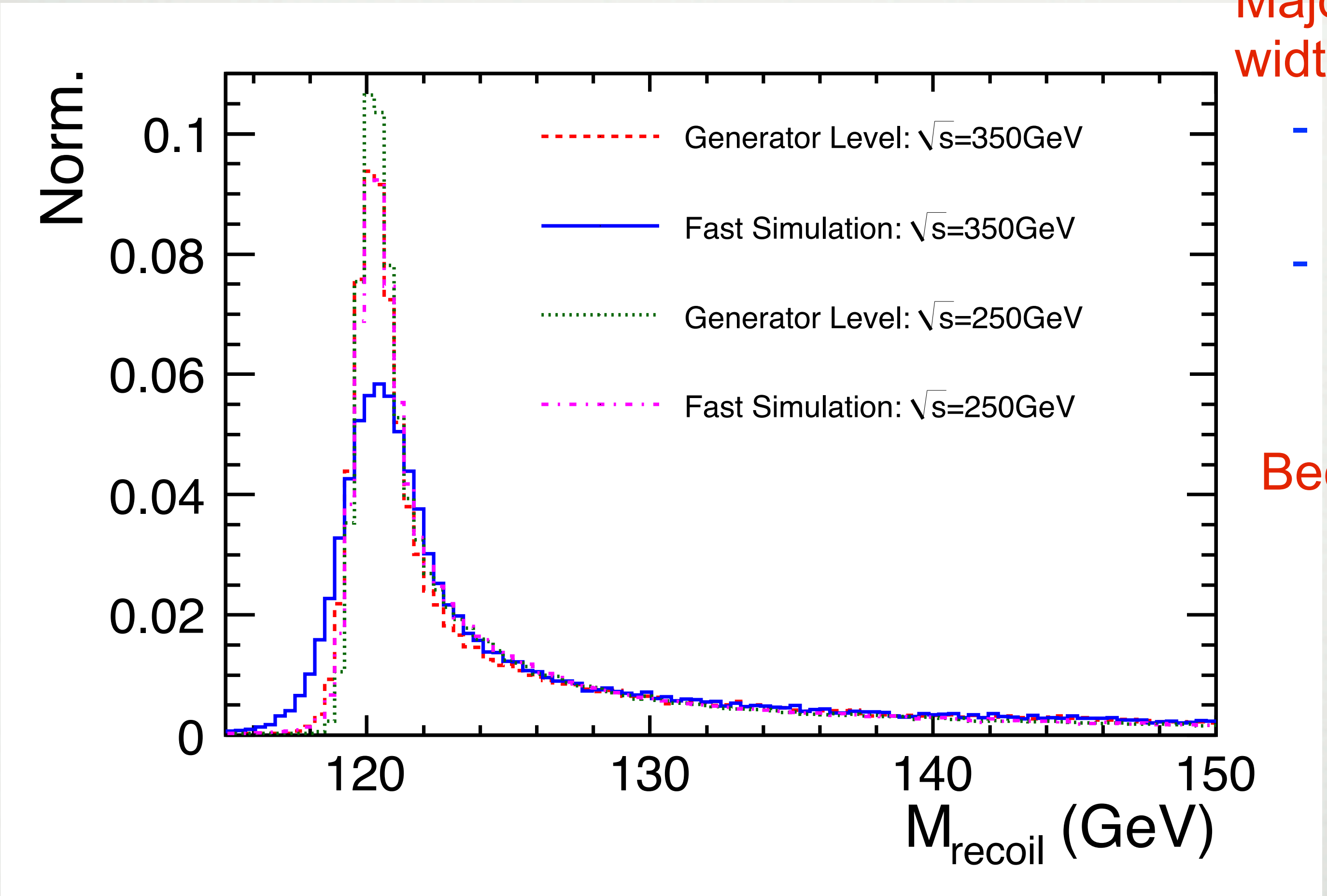
muon channel, Beam Pol. (e-: -80%, e+: +30%)

Why Better BKG suppression at 350GeV?



Discussion: Accelerator Impact

- For a given luminosity, Comparison Before and After Detector Simulation.



Major contribution to the width of peak:

- Ecm=250GeV
  Accelerator effects
- Ecm=350GeV
  Detector effects

Because:

- beam energy spread : same at 250 and 350 GeV
- lepton momentum is higher at 350GeV, and $\Delta P \sim P^2$

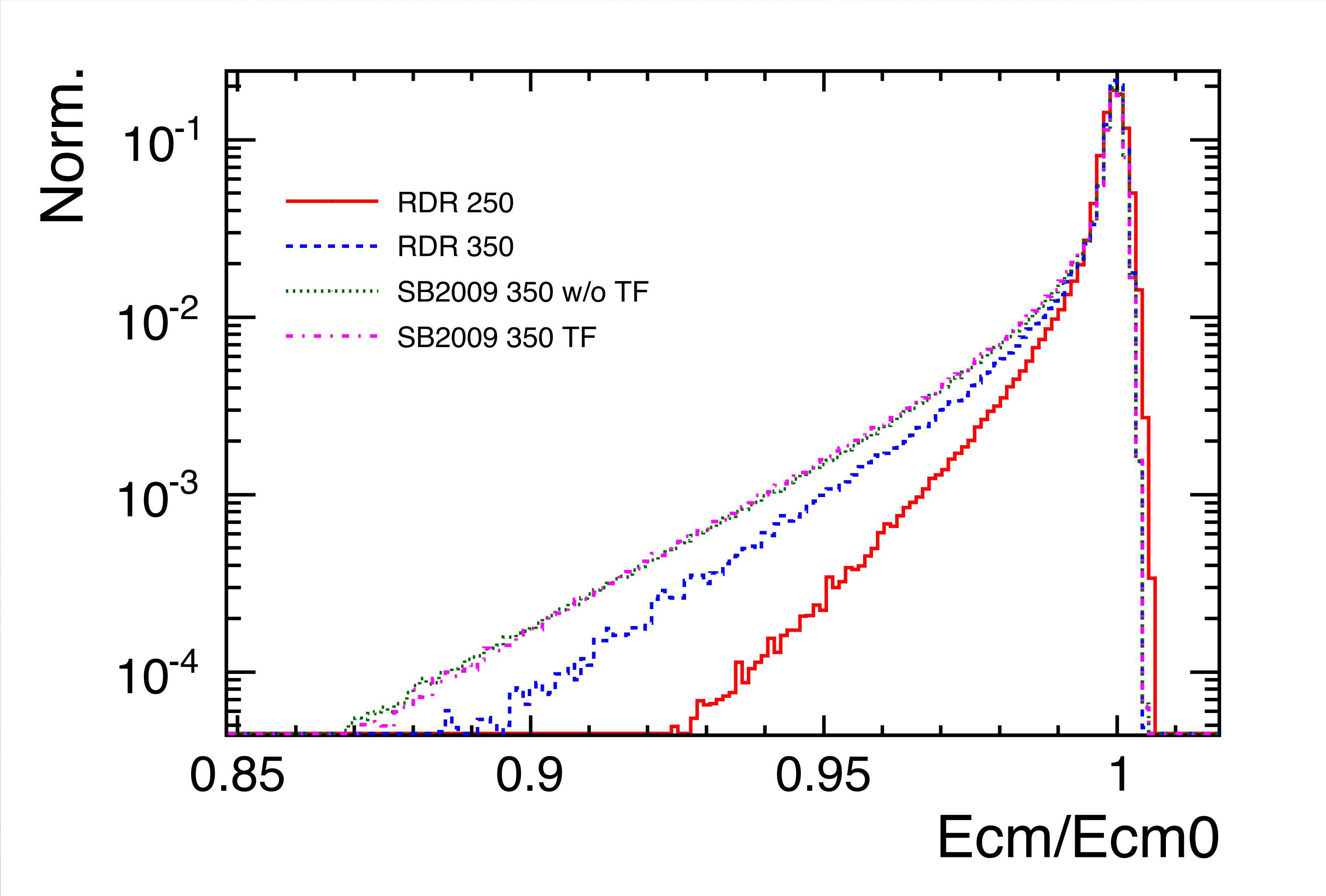
Summary

- Full Simulation Study for ILD LOI:
  - Background rejection: near total suppression of WW and lepton pair
  - Combined Results (e and mu channel) Achieved:
    - δM_H=33MeV, $\delta\sigma/\sigma$=2.5%
  - Accelerator Effects are dominant at Ecm=250GeV
  - Systematic Error is waiting for study
  - Higgs spin parity should be able to be measured by angular analysis
- Fast Simulation Study for SB2009:
  - Worse results from SB2009 due to smaller luminosity
  - TF gives better results than w/o TF
  - at Ecm=350GeV, background suppression can be more efficient
  - at Ecm=350GeV, given the luminosity, detector effect is dominant

Thanks to All of You!

Beam Simulation

- Using GUINEA-PIG with SB2009 Beam parameters given by Brian Foster's talk on SB2009 Meeting at DESY 2009



Estimation of the Integrated Luminosity

- Estimate the Integrated Luminosity for various sets of beam parameters according to Peak Luminosities: taken RDR 500 as reference

$$\mathcal{L}_{\text{int}} = \frac{\mathcal{L}_{\text{peak}}}{\mathcal{L}_{\text{peak,RDR500}}} \cdot \mathcal{L}_{\text{int,RDR500}}$$

- Resulting numbers:

	RDR			SB2009 w/o TF				SB2009 w/ TF			
$\sqrt{s}$ (GeV)	250	350	500	250.a	250.b	350	500	250.a	250.b	350	500
Peak L ($10^{34}\text{cm}^{-2}\text{s}^{-1}$)	0.75	1.2	2.0	0.2	0.22	0.7	1.5	0.25	0.27	1.0	2.0
Integrated L (fb^{-1})	188	300	500	50	55	175	375	63	68	250	500

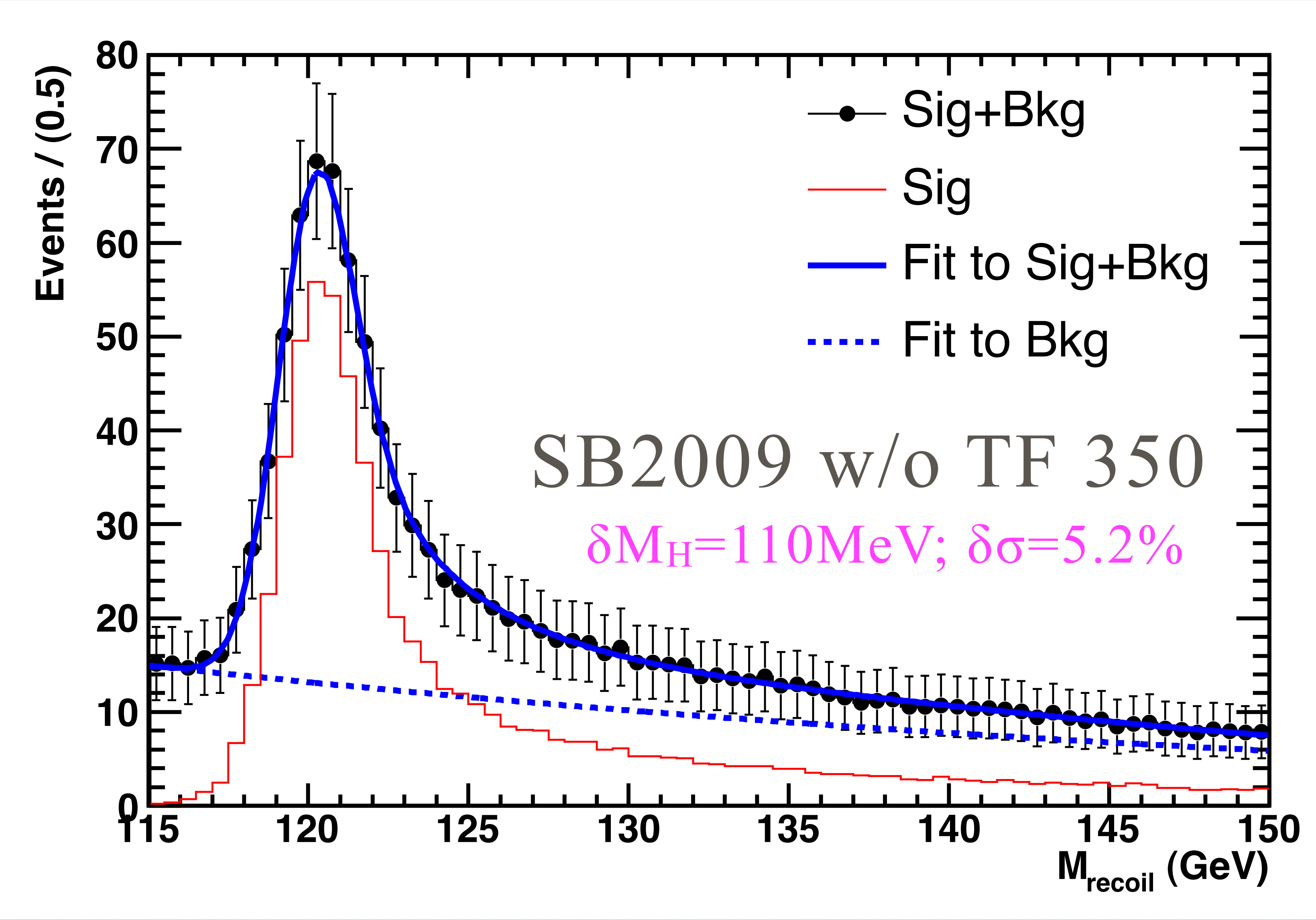
The major difference between RDR and SB2009 is the Luminosity!

Analysis

- Event generation using PYTHIA:
  - Beam Pol. (e-: -80%, e+: +30%) at Ecm=350GeV
  - taken only muon-channel, and bkg only ZZ and WW
- Same analysis procedure as for the LOI.
- Numbers of signal and bkgs: Ecm=350GeV, SB2009 w/o TF 350

Reactions	$ZH \to \mu\mu X$	ZZ	WW
$N_{initial}$	1248	29k	61k
$N_{selected}$	633	658	30

Analysis



Events / (0.5)
0
10
20
30
40
50
60
70
80
115
120
125
130
135
140
145
150
M recoil (GeV)
Sig+Bkg
Sig
Fit to Sig+Bkg
Fit to Bkg
SB2009 w/o TF 350
δM H=110MeV; δσ=5.2%

Background Rejection I: By Cuts

Cut-Chain: Model Independent

(1) $P_{Tdl} > 20$ GeV

(2) $M_{dl} \in (80, 100)$ GeV

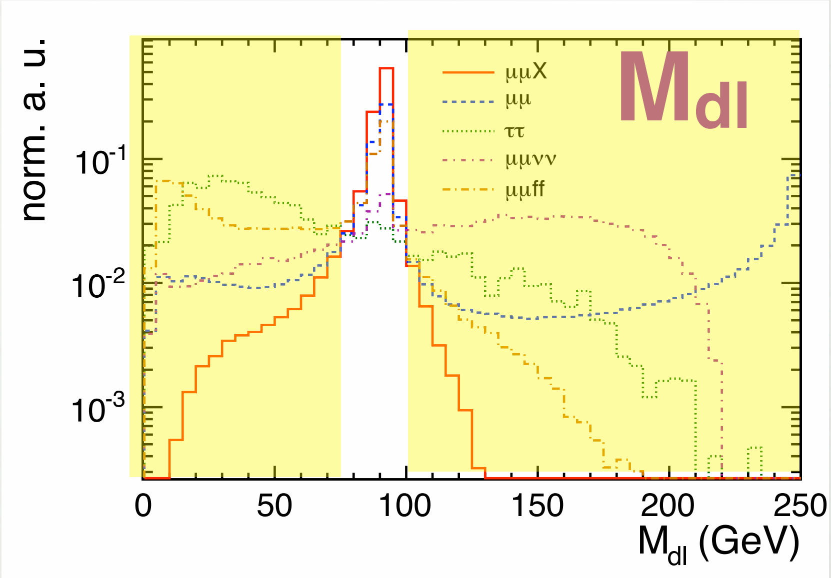
(3) acop $\in (0.2, 3.0)$

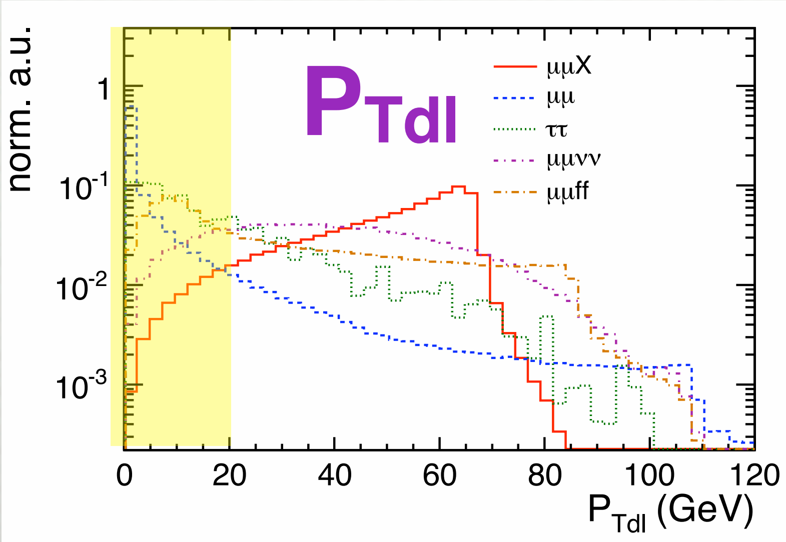
(4) $\Delta P_{Tbal.} > 10$ GeV

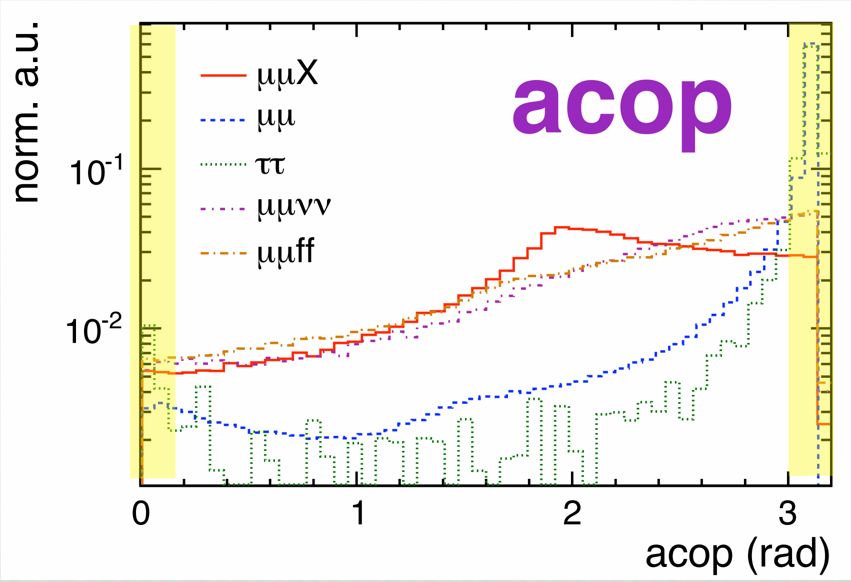
(5) $|\Delta\theta_{2tk}| > 0.01$

(6) $|\cos\theta_{missing}| < 0.99$

(7) $M_{recoil} \in (115, 150)$ GeV







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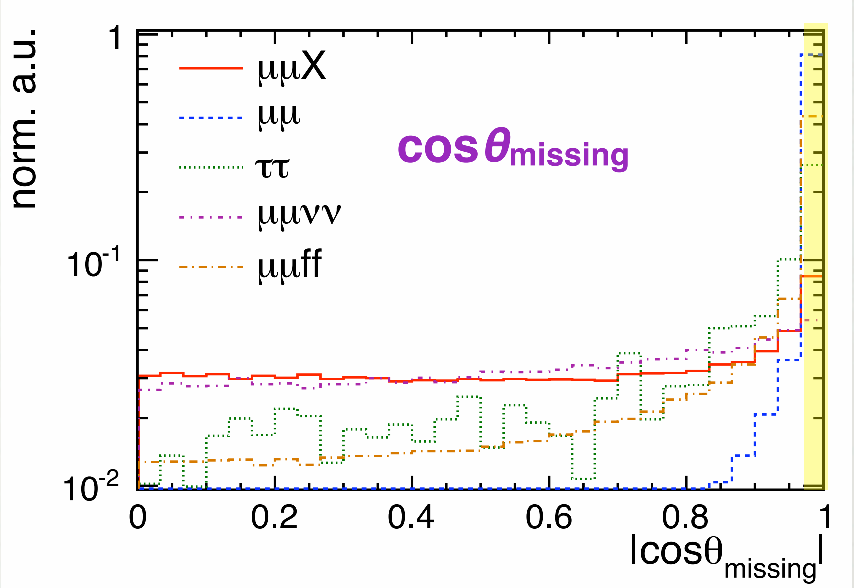
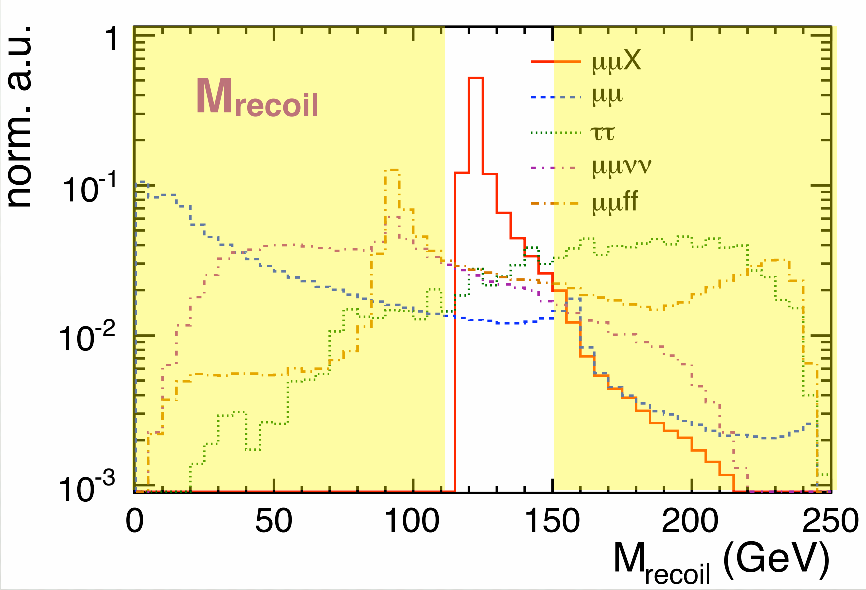


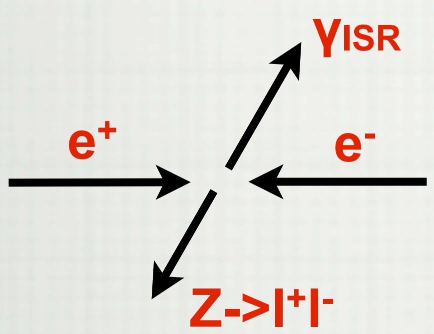


Background Rejection I: By Cuts

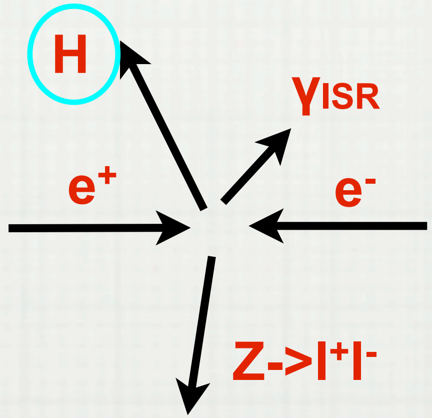
$\Delta P_{Tbal.}$ to reject lepton pair background:

①

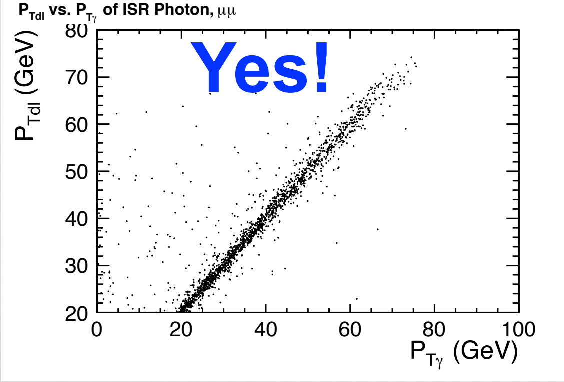
Lepton Pair Background

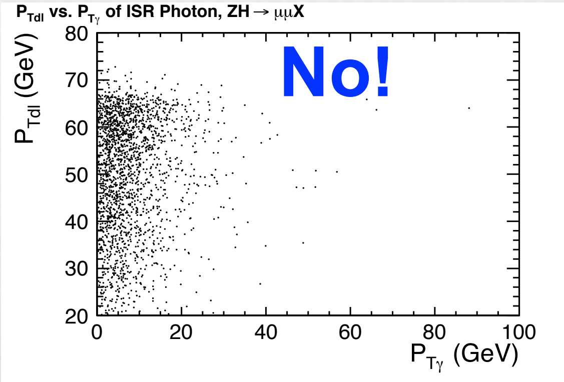


ZH Signal



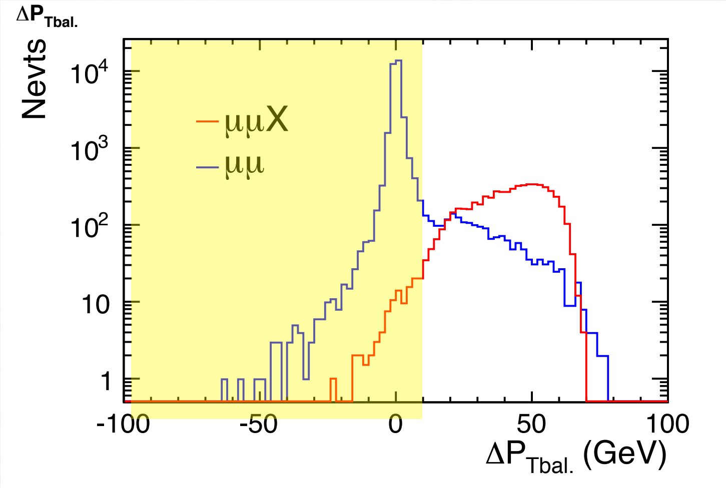
P_{Tdl} balance $P_{T\gamma}$?





②

Define $\Delta P_{Tbal.} = P_{Tdl} - P_{T\gamma}$



$\Delta P_{Tbal.} > 10$ GeV

- **Reduces lepton pair background almost totally.**
- **Signal loss: ~1%**

Background Rejection II: By Likelihood

After cuts rejection, major background remained is the ZZ/WW production,
Further rejection using Likelihood Method is applied

Likelihood:

① $$L = \prod_i P_i$$

Probability (P_i)

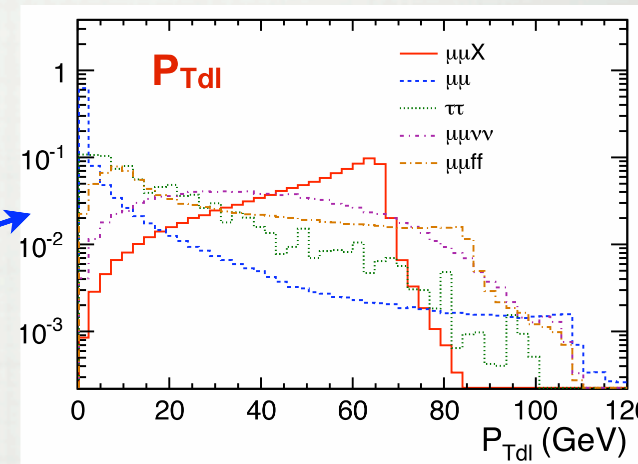
i th Variable (i)

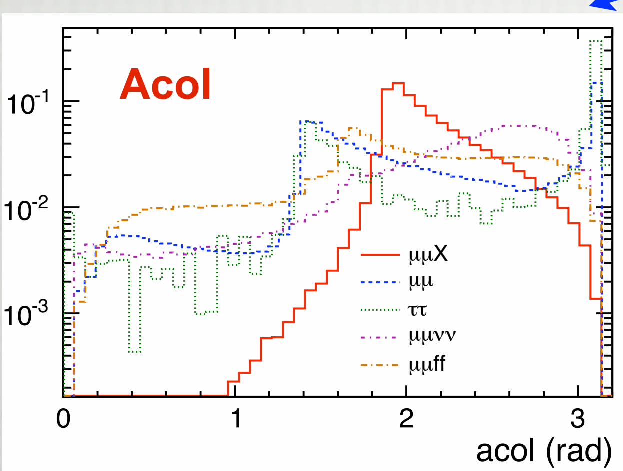
Likelihood Fraction:

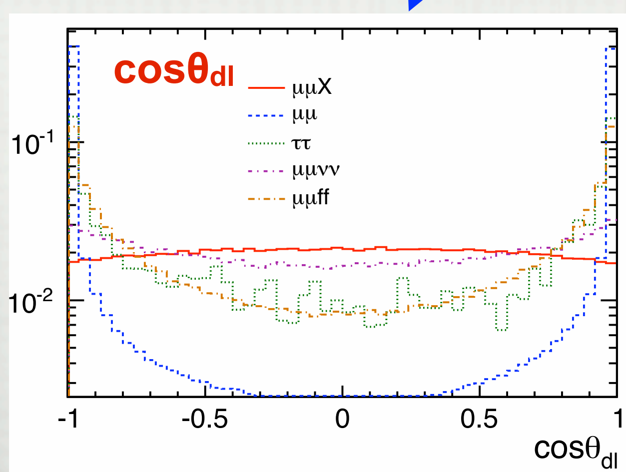
$$f_L = L_S/(L_S + L_B)$$

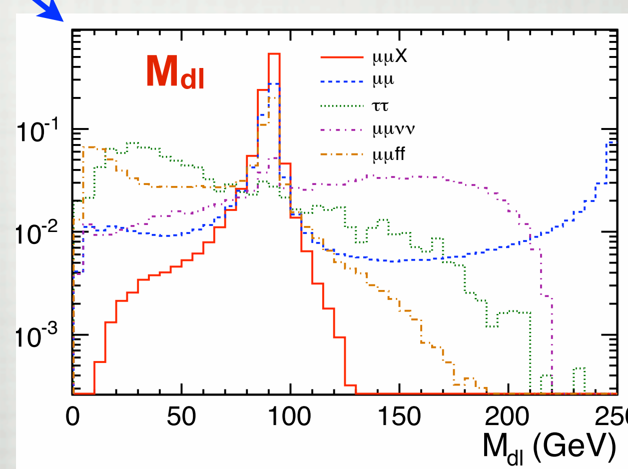
within (0, 1)

PDFs of the 4 variables employed





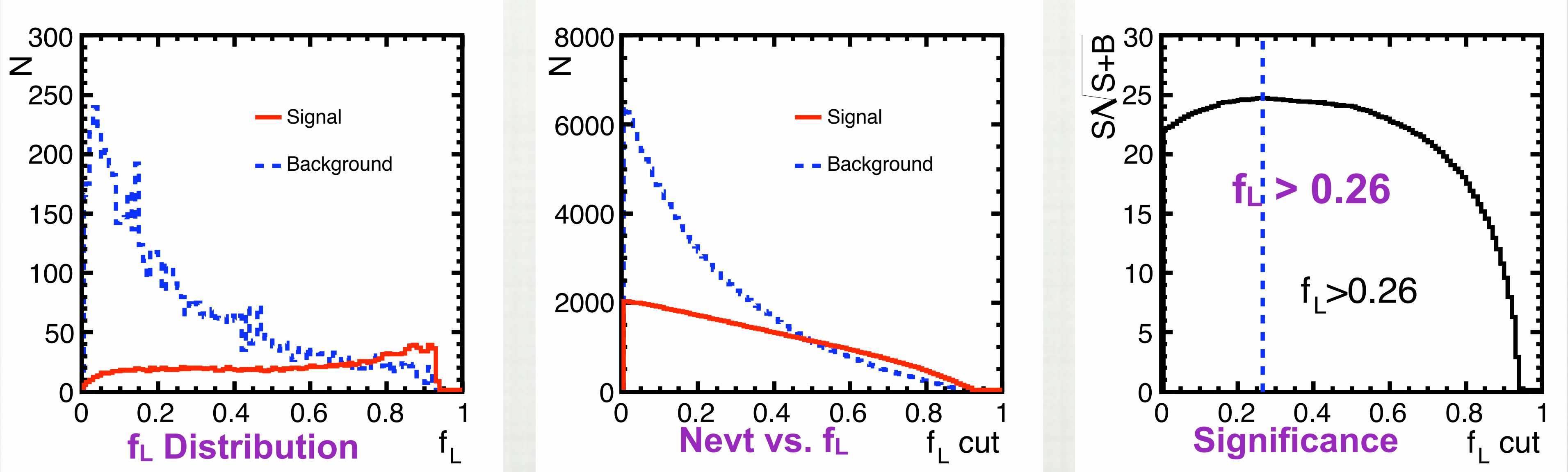




Background Rejection II: By Likelihood

② **Decide the f_L cut by the maximum significance for each particular analysis channel**

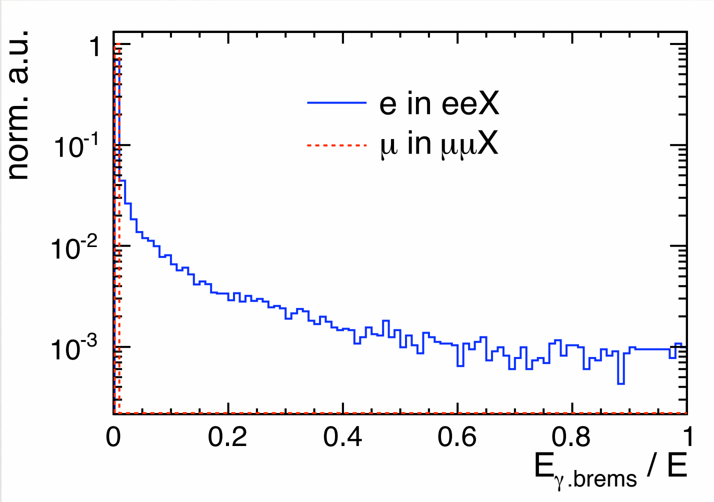
Pol. $e^-_L e^+_R$, μμX-channel, MI Analysis for illustration



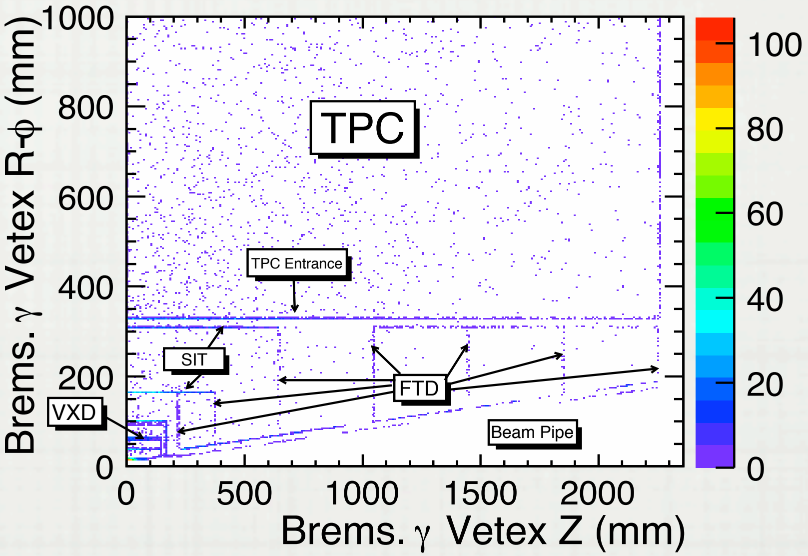
On average, Likelihood further rejection suppresses ZZ background by a factor of 2, and remove nearly all the WW background, with a loss of signal about 10%.

Sources of Bremsstrahlung

Fraction of Brem. Energy Loss

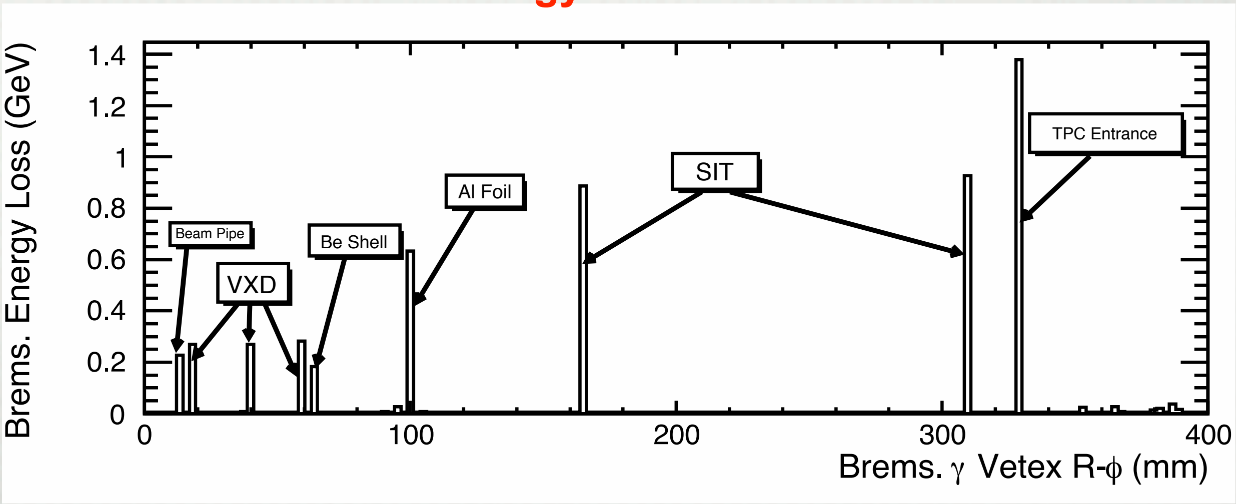


Brem. Vertex



using electrons from ZH->eeX

Brem. Mean Energy Loss vs. Brem. Vertex



~4% X_0 Material before TPC!

Lepton ID and Track Selection

1) Cuts for lepton ID:

	μ-Identification	e-Identification
E_{ecal}/E_{total}	< 0.5	> 0.6
E_{total}/P_{track}	< 0.3	> 0.9

Efficiency of lepton pair ID:
(pair selection according to Z Mass)

μ-channel (muon ID) : 95.4%
e-channel (electron ID) : 98.8%

2) ΔP/P² criterion on tracks in the selection of lepton candidates

- Parameterize ΔP/P² for central region

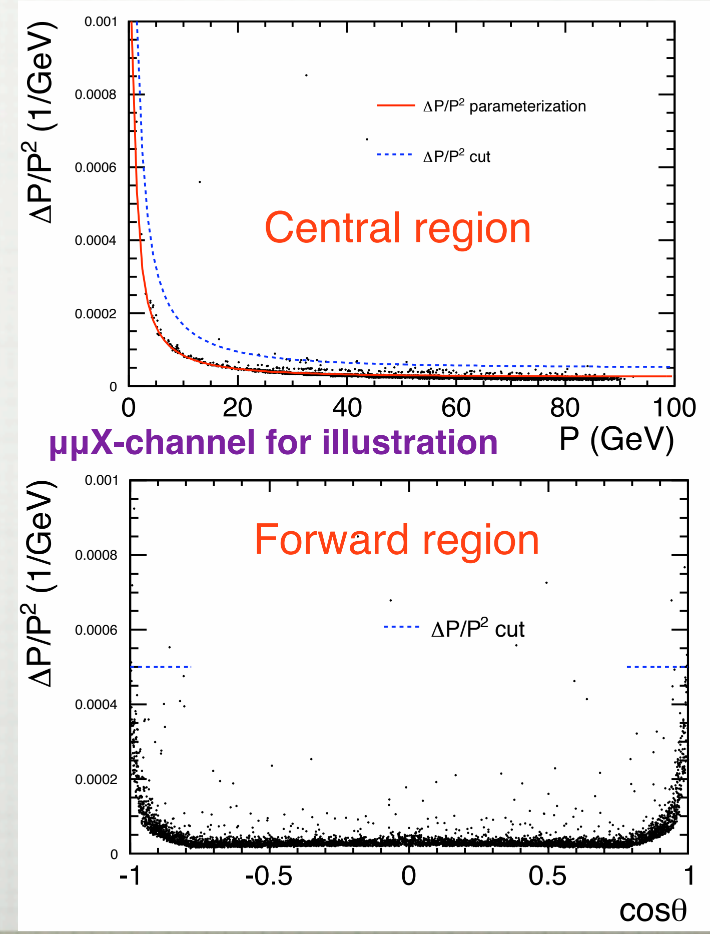
$$\Delta P/P^2 = a \oplus b/P;$$
$$where\ a = 2.5 \times 10^{-5};\ b = 8 \times 10^{-4}$$

- The criterion ΔP/P² applied

$$|cos\theta| < 0.78: \quad \Delta P/P^2 < 2 \times (2.5 \times 10^{-5} \oplus 8 \times 10^{-4}/P)$$
$$|cos\theta| > 0.78: \quad \Delta P/P^2 < 5 \times 10^{-4}$$

ΔP is propagated from tracking error matrix

Same cuts applied on both μ-channel and e-channel



A Model Dependent Analysis

An Additional Model Dependent Analysis is Performed:

Assume Higgs decay dominantly has two or more charged tracks.

MD Cut-Chain:

(1) $P_{Tdl} > 10$ GeV

(2) $M_{dl} \in (71, 111)$ GeV

(3) $N_{add.TK} > 1$

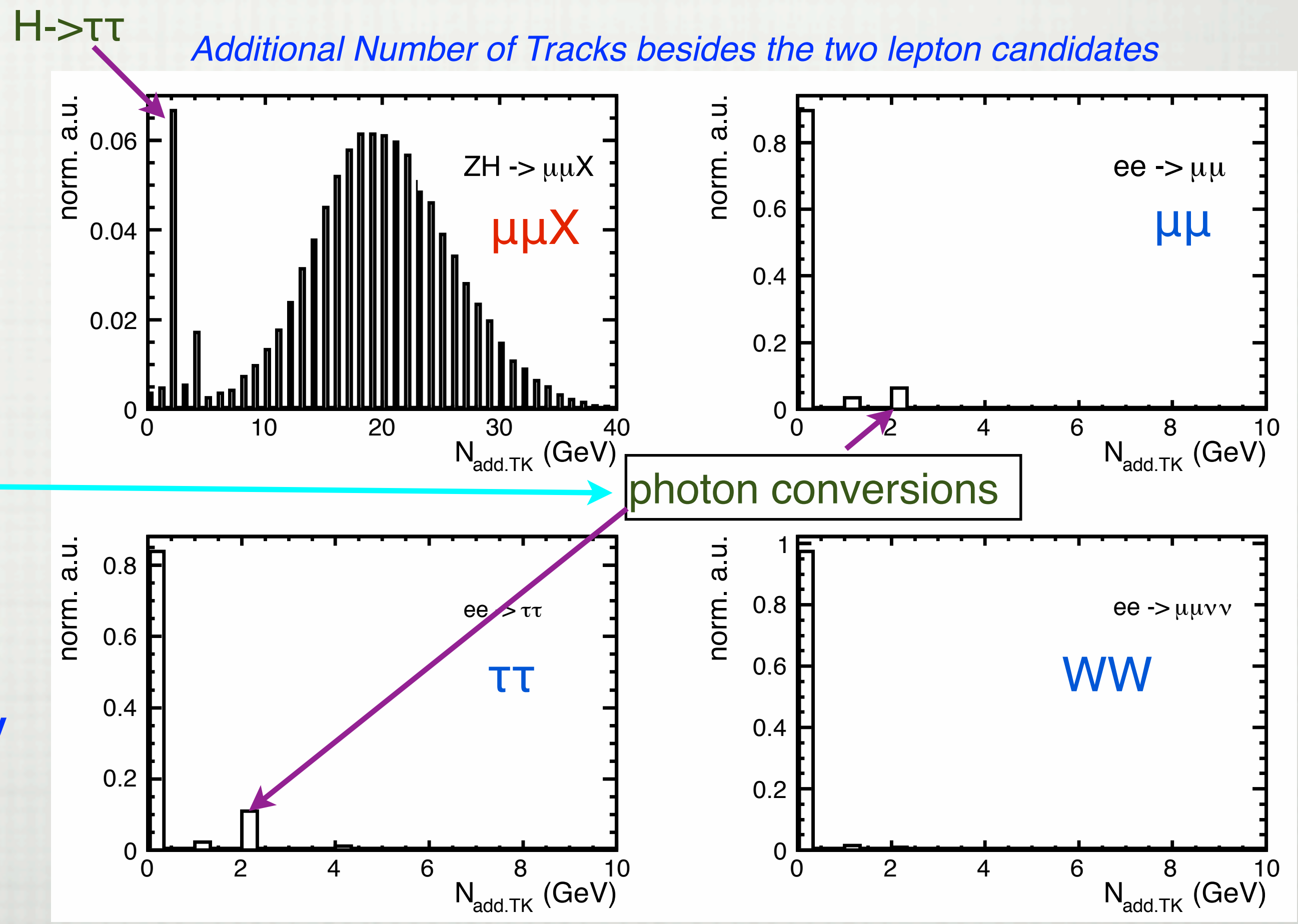
(4) $|\Delta\theta_{2tk}| > 0.01$

(5) $|\Delta\theta_{min}| > 0.01$

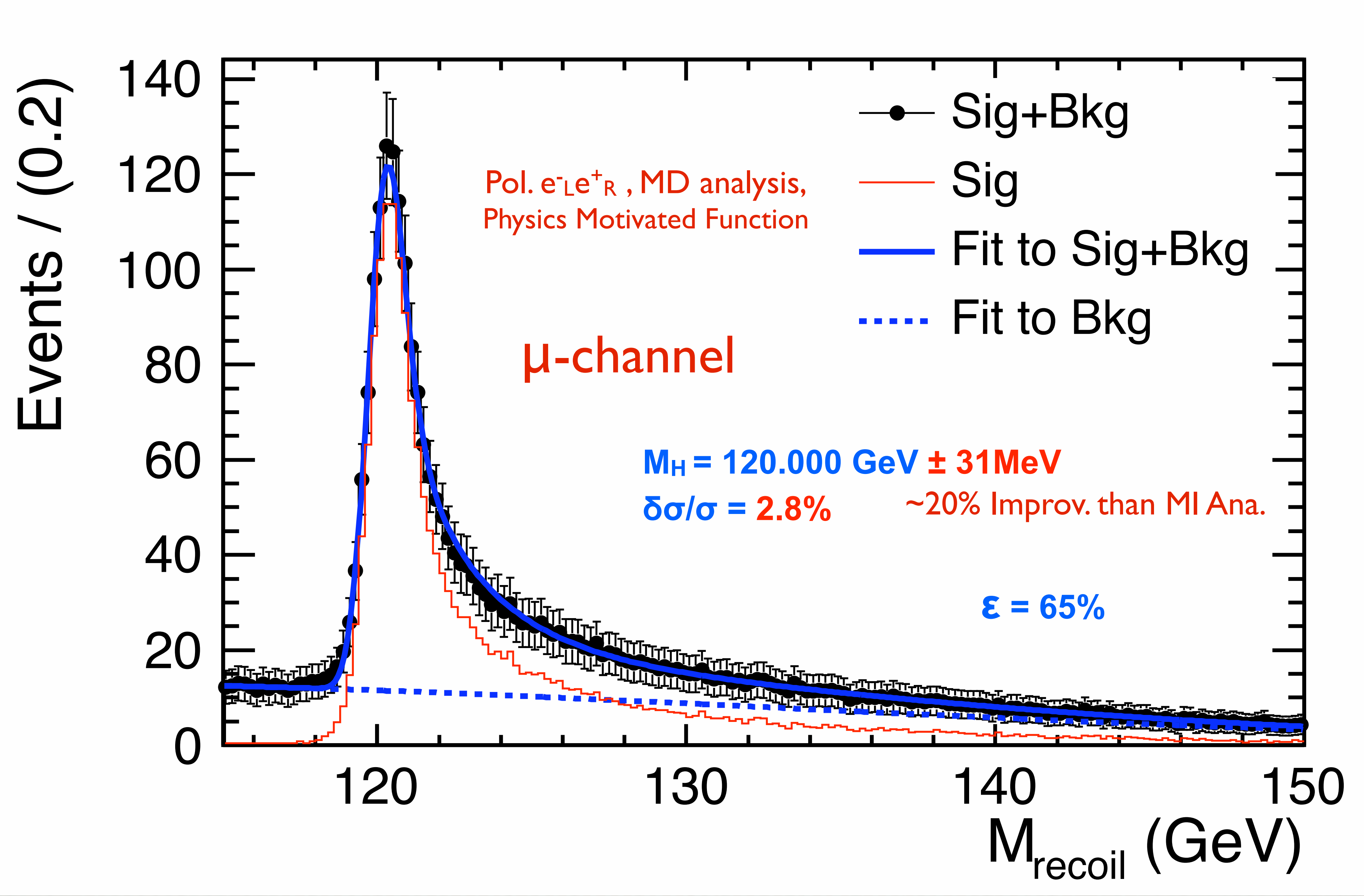
(6) acop $\in (0.2, 3.0)$

(7) $|\cos\theta_{missing}| < 0.99$

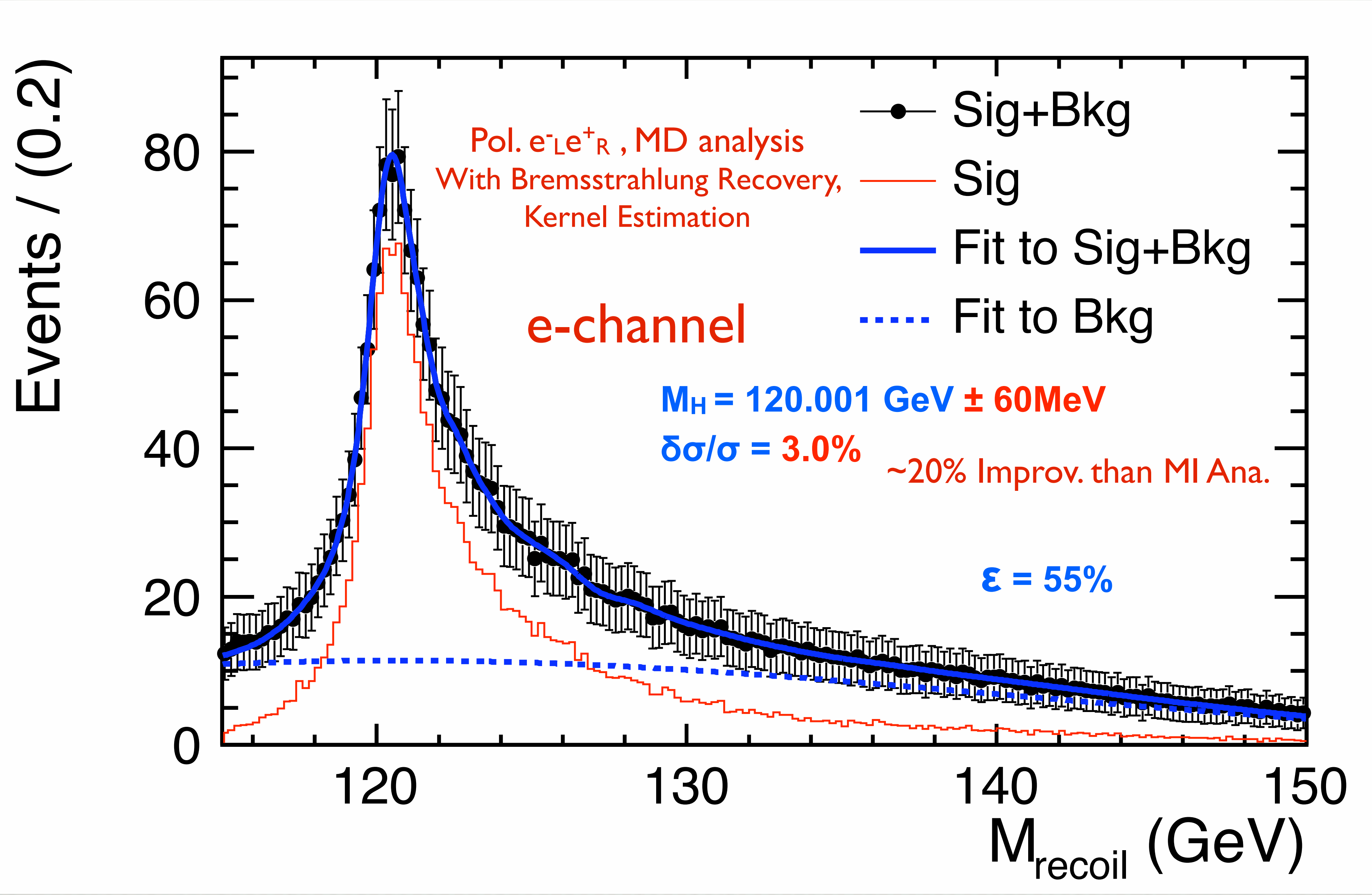
(8) $M_{recoil} \in (115, 150)$ GeV



Fit: μ-channel, MD Analysis



Fit: e-channel, MD Analysis



Fit Methods

Signal Functions: (three functions are studied, with identical results)

GPET Function: Gaussian core for the Peak with an Exponential complementing the tail, updated from previous contributions.

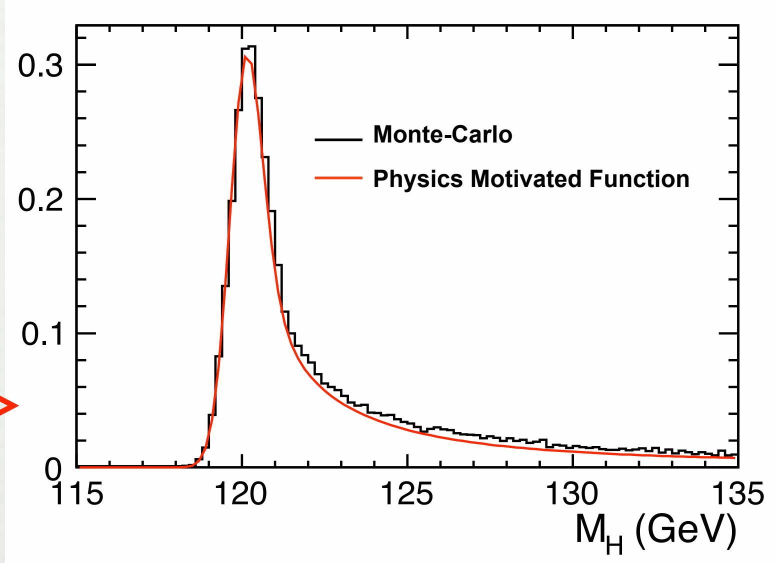
Kernel Estimation: An universal method for all kinds of distributions, Intensively used at LEP for Higgs searches,

Physics Motivated Function: New!

Beamstrahlung (Yokoya-Chen) $\otimes$ ISR $\otimes$ Gaussian $\Longrightarrow$ Higgs Recoil Mass

Analytical Numerical Propagate to

With beam parameters given in advance, Can predict the MC distribution



Background: Polynomial Function

Build Composite Model:

To be extracted!

$$F_M(x;\ \mathrm{M_H}, N_S) = N_S \cdot F_S(x;\ \mathrm{M_H}) + N_B \cdot F_B(x)$$

Kernel Estimation

- A sum of Kernels

$$f(x) = \frac{1}{N}\sum_{i=1}^{N}\frac{1}{h_i}K\left(\frac{x-t_i}{h_i}\right),$$

Physics Motivated Function

$$F_S(x) = f_2(y(x)) \cdot \left|\frac{dy}{dx}\right|$$

where,

$$y(x) = \frac{1}{2s^2} \cdot \Big[2s(x^2 - \mathrm{M_H}^2) + (s + x^2 - \mathrm{M_Z}^2)(s - x^2 + \mathrm{M_Z}^2) -$$

$$(s - x^2 + \mathrm{M_Z}^2) \cdot \sqrt{4s(\mathrm{M_H}^2 - \mathrm{M_Z}^2) + (s - x^2 + \mathrm{M_Z}^2)^2}\Big] \, ,$$

$$\frac{dy}{dx} = \frac{x}{s^2} \cdot \frac{\left[s - x^2 + \mathrm{M_Z}^2 + \sqrt{4s(\mathrm{M_H}^2 - \mathrm{M_Z}^2) + (s - M^2 + \mathrm{M_Z}^2)^2}\right]^2}{\sqrt{4s(\mathrm{M_H}^2 - \mathrm{M_Z}^2) + (s - x^2 + \mathrm{M_Z}^2)^2}} \; ;$$

and,

$$f_2(y) = \sum_{i=0}^{N} p(i) \cdot [g_1(y;i) \otimes G(y;0,\sigma)] \, ,$$

with

$$p(i) = \frac{2^i}{i!}\left(\frac{n_\gamma}{2}\right)^i e^{-n_\gamma} \, ,$$

$$g_1(y;i) = \kappa^{\frac{i}{3}} \cdot y^{(\frac{i}{3}+\beta-1)} \cdot \frac{\Gamma(1+\beta)}{\Gamma(\frac{i}{3}+\beta)} \cdot \; {}_1F_1(\frac{i}{3}, \frac{i}{3}+\beta, -\kappa y) \, .$$