Higgs Recoil Mass and Cross Section Measurements

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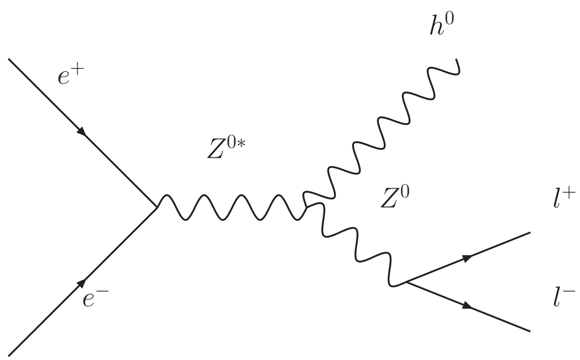
OUTLINE

- Motivation
- Software Chain
- General Remarks
- ZH->μμX Results - M. Ruan
- ZH->eeX Current Status - H. Li
- Summary

Motivation

- Higgs-Strahlung Process:



- Higgs Recoil Mass:

$$m_{h^0}^2 = s + m_{Z^0}^2 - 2E_{Z^0}\sqrt{s}$$

- Cross Section and Coupling Strength Measurement:

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

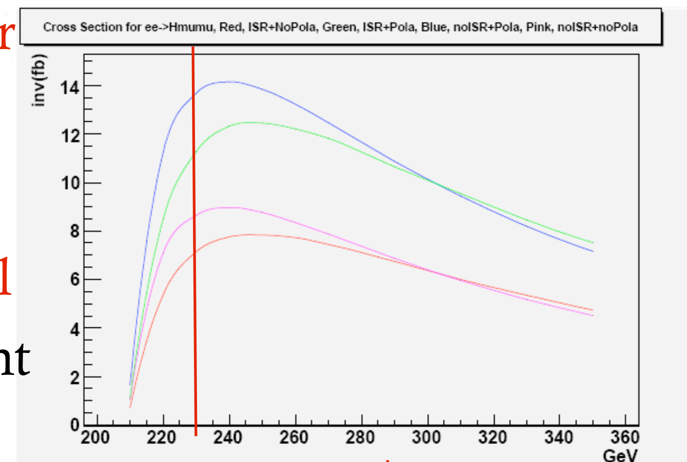
- Using only information of final state leptons

Although the Cross Section is not at the peak for Ecm = 230 GeV, but if we consider the resolution of the recoil mass and the cross section, we will find 230GeV is optimal

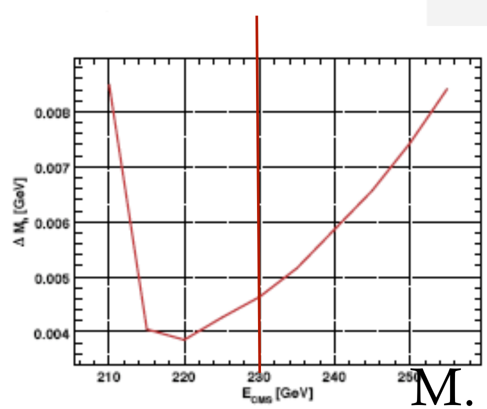
F. Richard

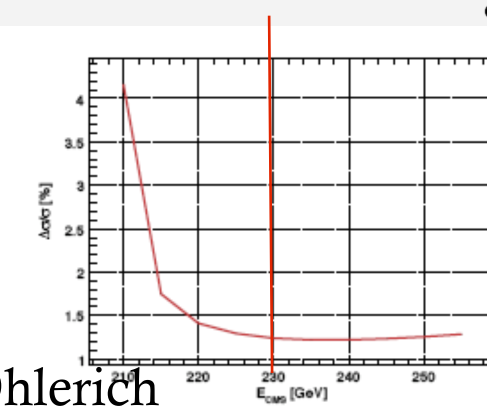
$$E_{CM} = 230\ GeV$$

$$M_{Higgs} = 120\ GeV$$



Precise Measurement





M. Ohlerich

General Remarks

Different Nature of muon channel and electron channel

Muon Channel

Golden Channel

Advantages:

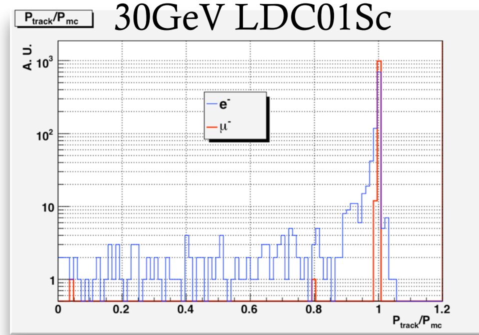
- less detector material dependence
- Perfect Tracking Resolutions
- no need to worry too much about the bremsstrahlung

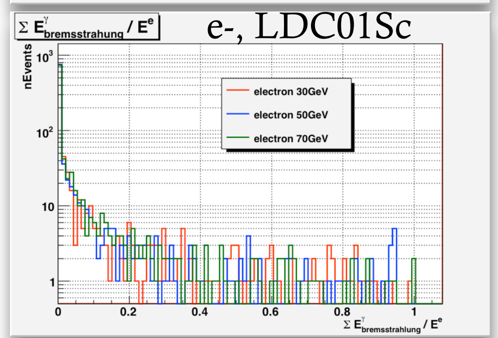
Efforts Before Analysis:

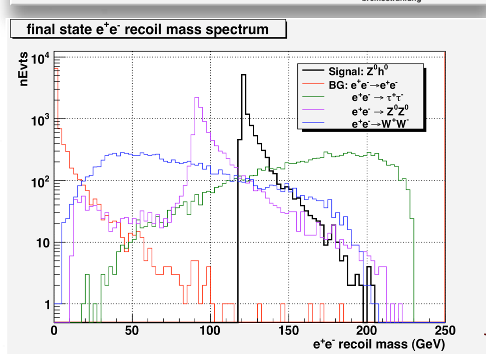
- not much

Efforts of Analysis:

- Pre-cuts are safe
- Signal Selection: increase S/N ratio







Electron Channel

Disadvantages:

- sensitive detector material dependence
- Bad Tracking resolutions
  - can NEVER as good as muons!
- Painful nature of bremsstrahlung

Efforts Before Analysis:

- Tracking of electrons: a big story

Efforts of Analysis:

- Pre-cuts affect the results: not safe
- Only full simulation can comparable with data: more efforts
- Signal Selection: increase S/N ratio

No Analysis Results Yet!

Software Chain

- Event Generation:
  - Beam Simulation: GUINEA-PIG
  - Signal :
    - ZH->μμX: WHIZARD
    - ZH->eeX: PYTHIA
  - Backgrounds: PYTHIA
- Simulation:
  - Full simulation: GEANT4 (Mokka)
  - Detector model:
    - Muon Channel: LDC01Sc
    - Electron Channel: LDC01Sc/ LDCPrime_02Sc
- Reconstruction:
  - Muon Channel:
    - FullLDCTracking (A. Raspereza)
    - Wolf (A. Raspereza)
  - Electron Channel:
    - FullLDCTracking (A. Raspereza)
    - PandoraPFA (M. Thomson)
- Analysis:
  - ROOT, RooFit

Muon Channel

Signal and Backgrounds Considered

Process	Cross Section* (fb)	Preselected** (%)
hZ	6.62	90.6
ZZ	1 340	2.6
WW	15 860	1.0
qq	57 600	0.12
$\gamma/Z\text{->}\mu\mu(\gamma)$	5 380	0.86

- *The cross section numbers are given for unpolarized beams
- **To generate efficiently 500 fb^{-1} MC samples, apply preselection cuts:
  - $E_{1,2} > 15$GeV (particles 1 and 2 have opposite charge)
  - $M_{12} > 70$ GeV
  - $\phi_{12} < 177.6^{o}$
  - $2E_1+E_2 < 180$ GeV & $2E_1+3E_2 > 200$ GeV

Muon Channel

Model Independent Analysis/Results

Process	$N_{preselected}$	$N_{selected}$*
hZ	3.0k	2.1k
ZZ	17.7k	7.8k
WW	81.9k	4.3k
qq	34.6k	--
$\mu\mu(\gamma)$	23.1k	5.2k

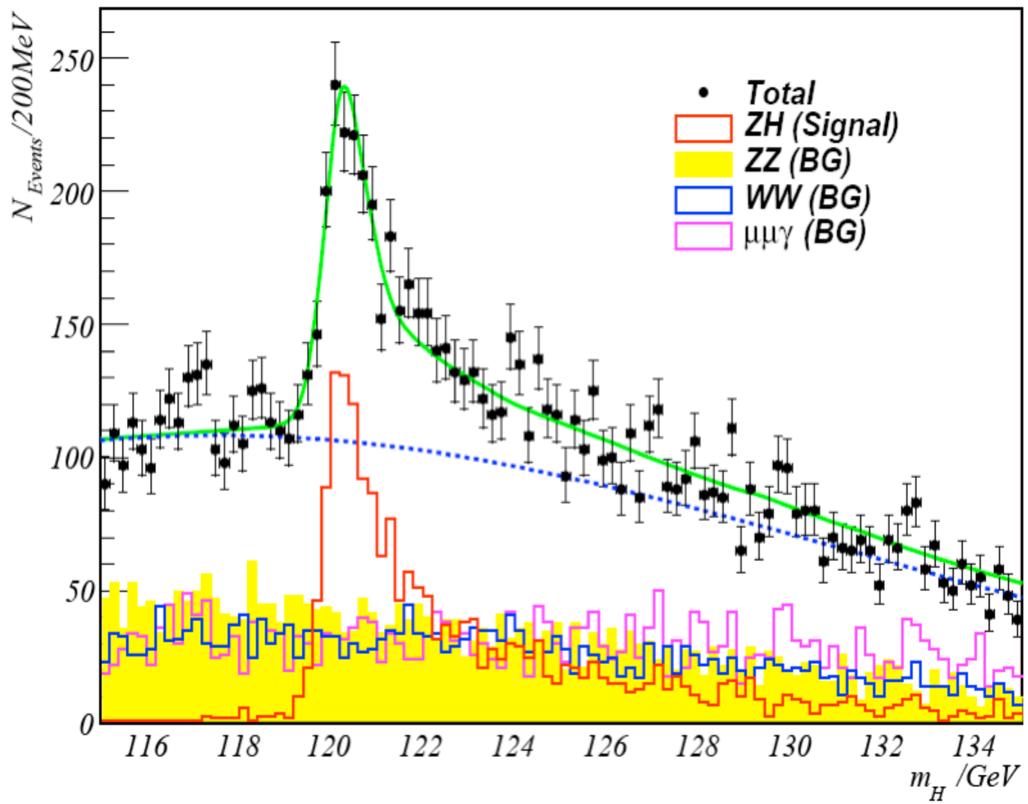
-> Eff.=63%

$m_H = 119.992 \pm 0.038$ GeV

$\sigma = 6.53\text{fb} \pm 0.35$ fb

* Final selection cuts:

- Muon ID
- $83 < M_{12} < 98$ GeV
  - $\phi_{12} < 175^o$
- $-0.99 < \cos\theta_{12} < -0.3$
- $P_T > 15$ GeV
- ……

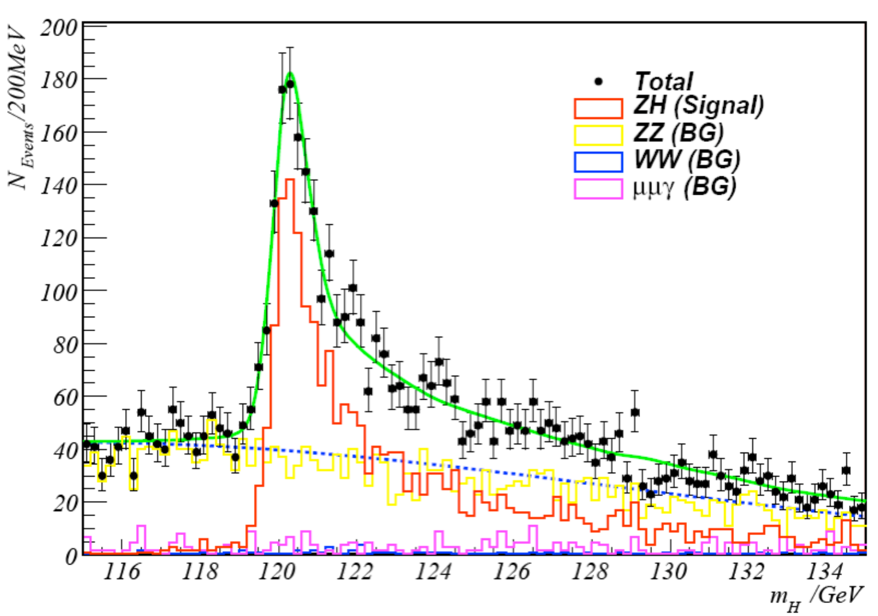


Muon Channel

Further (Model Dependent) Analysis

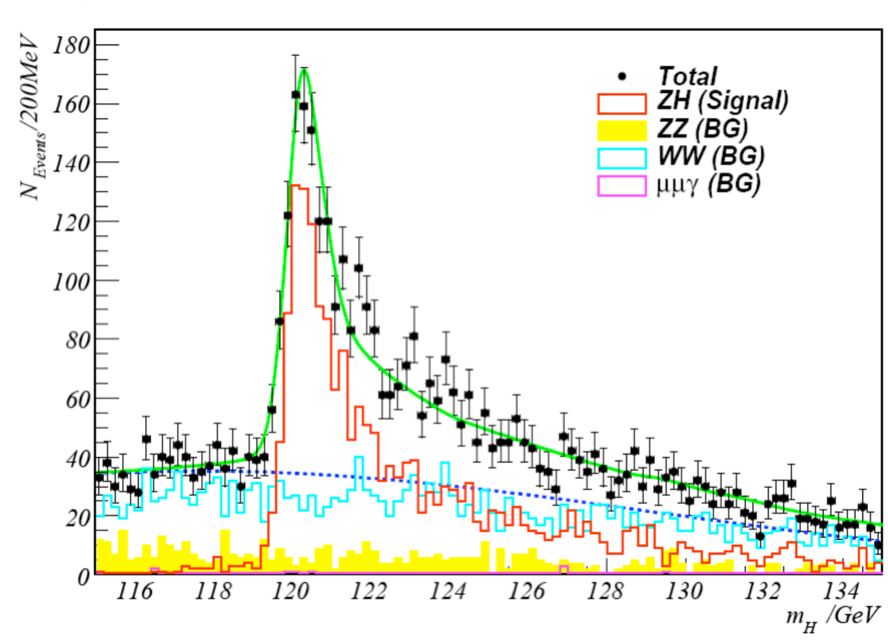
Using Higgs decay final state to improve the background rejection
Two possibilities studied:

1) SM-like Higgs boson
- $N_{track} > 2$



mH = 119.986 ± 0.029 GeV
σ =6.65fb ± 0.24 fb

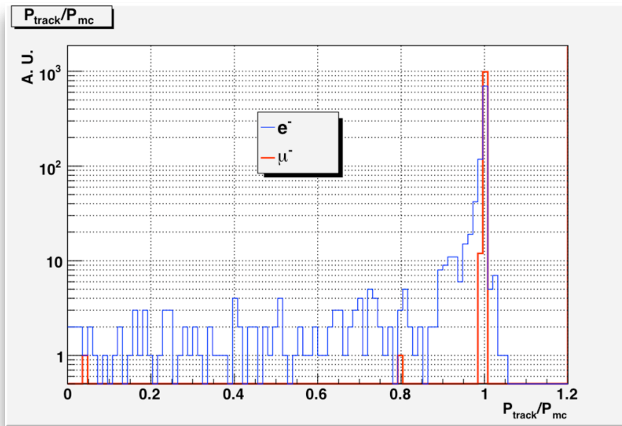
2) Dominant invisible decay mode
- $N_{track} < 4$

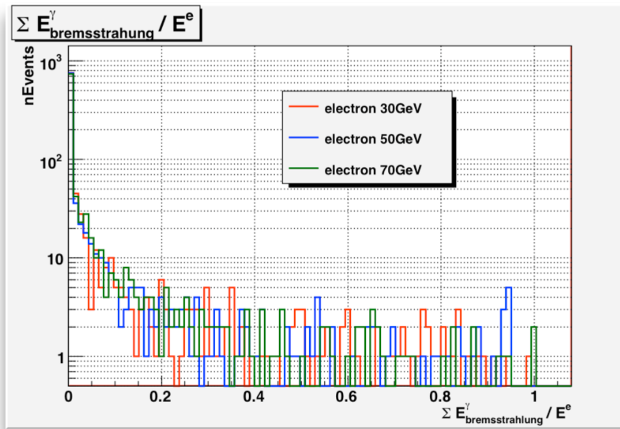


mH = 119.996 ± 0.029 GeV
σ =6.80fb ± 0.25 fb

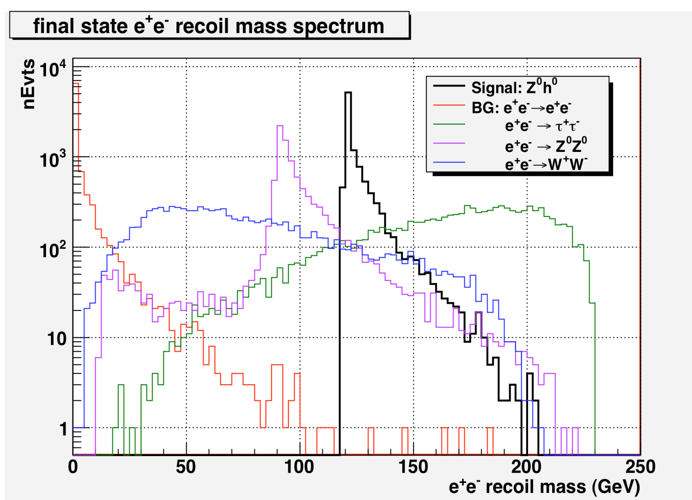
Remarks on Electrons

- The painful nature of electrons: Bremsstrahlung!!





- Pre-cuts applied on muon channel are not safe for electrons!
  - e.g. recoil mass of ee->ee (red), will shift into the signal window (black).
- Solution:
  - Step 1: Event Weights
  - Step 2: Evaluated which pre-cuts are safe



Electron Channel

Cross Section Evaluation

	Process	σ [fb](N_{EVT})		
		PYTHIA	WHIZARD	BHWIDE
Signal	$e^+e^- \to Z^0h^0 \to e^+e^-X$	6.31(3155)	6.34(3170)	
Background	$e^+e^- \to e^+e^-\gamma_s$ [1]	2531[pb] (1.266×10^9)		2408[pb] (1.204×10^9)
	$e^+e^- \to \tau^+\tau^- \to e^+\nu_e\bar{\nu}_\tau e^-\bar{\nu}_e\nu_\tau$	4753.5 (2.376×10^6)		
	$e^+e^- \to W^+W^- \to e^+\nu_e e^-\bar{\nu}_e$	189.7(94850)		
	$e^+e^- \to Z^0Z^0 \to e^+e^-f\bar{f}$ [2]	120.72(60360)		
	$e^+e^- \to Z^0Z^0 \to e^+e^-e^+e^-$ [3]	2.836(1418)		

- Results considered beamstrahlung, ISR and FSR, for E_{cm}=230GeV
- Backgrounds, angular acceptance of $|\cos\theta|<0.996$ is considered in the cross section evaluation: ONLY!
- Signal, the fraction of final state two electrons within angular acceptance is 0.989
- Expected N_{EVT} is for an integrated luminosity of 500 fb^{-1}

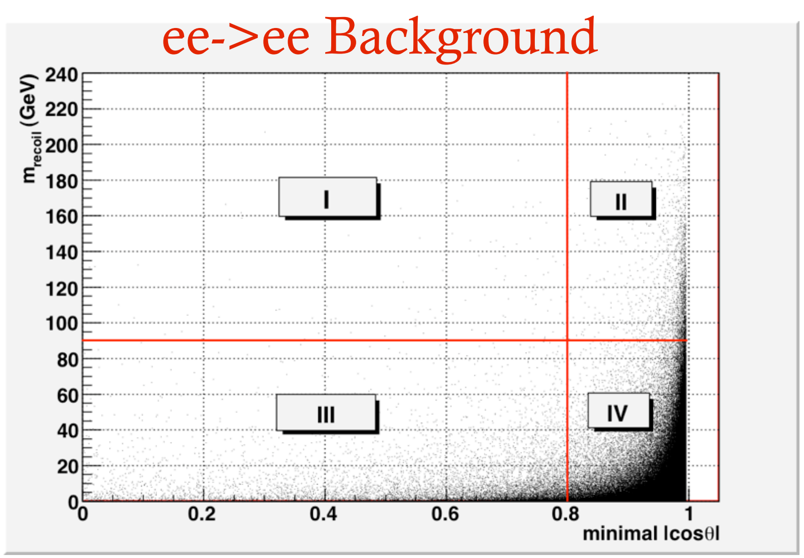
[1] Including both γ^* and Z^0 neutral currents, where, PYTHIA considers only t-channel exchange, while BHWIDE considers both t-channel and s-channel exchanges.
[2] $f\bar{f}$ here excludes $Z^0 \to e^+e^-$.
[3] At least one pair of the final state e^+e^- within the angular acceptance range.

Electron Channel

Event Weight: Safely Reduce the Simulation Amount

- Since the pre-cuts in generator level is not safe, Event Weight can be one way to reduce the simulation amount safely.
- e.g. Divide the ee->ee background into four parts:

  I: m_{recoil}>90GeV and min|cosθ|<0.8
  II: m_{recoil}>90GeV and min|cosθ|>0.8
  III: m_{recoil}<90GeV and min|cosθ|<0.8
  IV: m_{recoil}<90GeV and min|cosθ|>0.8



- Simulate 100k events for each division
- Apply Event Weights: (in the form)
- Then, statistics are enough

Backgrounds		*Divisions*			
		I	II	III	IV
$e^+e^-(\gamma_s)$	fraction	9.22×10^{-5}	1.9505×10^{-3}	1.60028×10^{-2}	0.9821253
	weight	1.167	24.693	202.595	12433.706

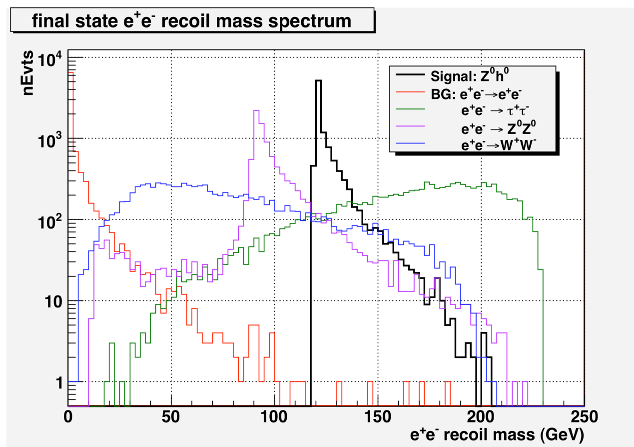
Electron Channel

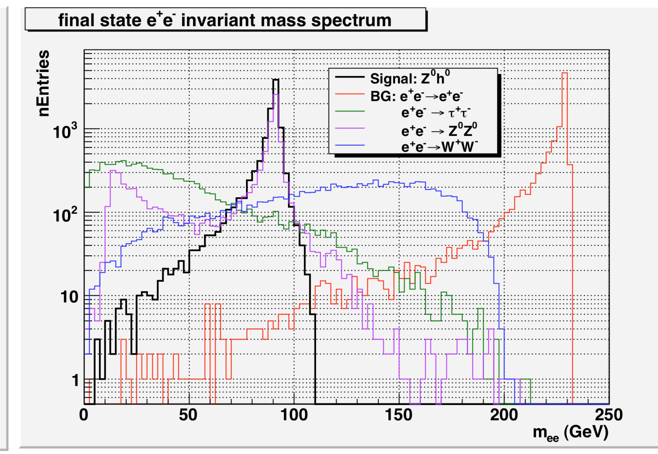
Variables For Signal Selection

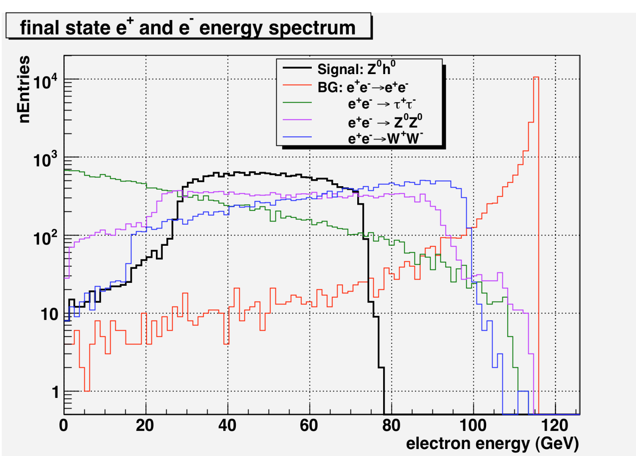
Signal Selection Variables:
- Kinematic
- Angular

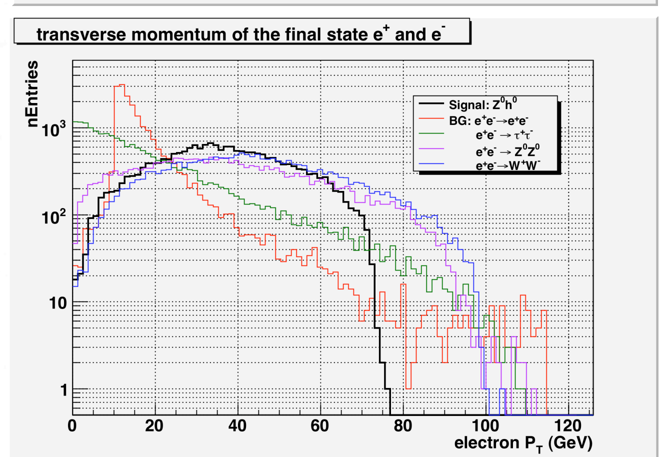
10k events for each type of reactions
All the plots are in log view.

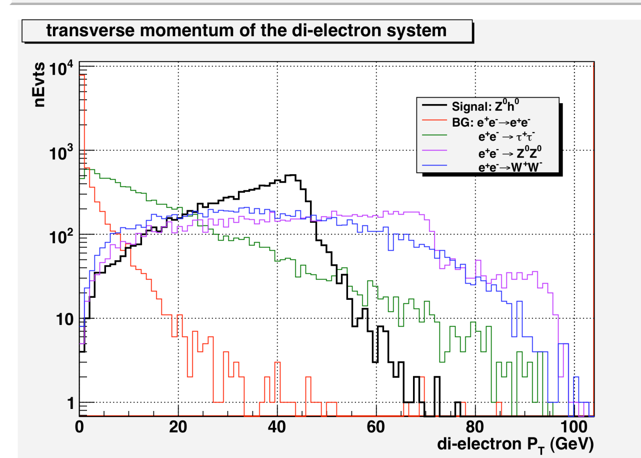
Kinematic Variables:







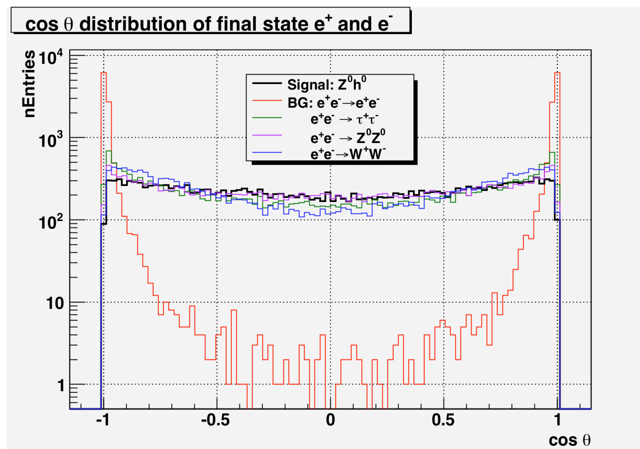


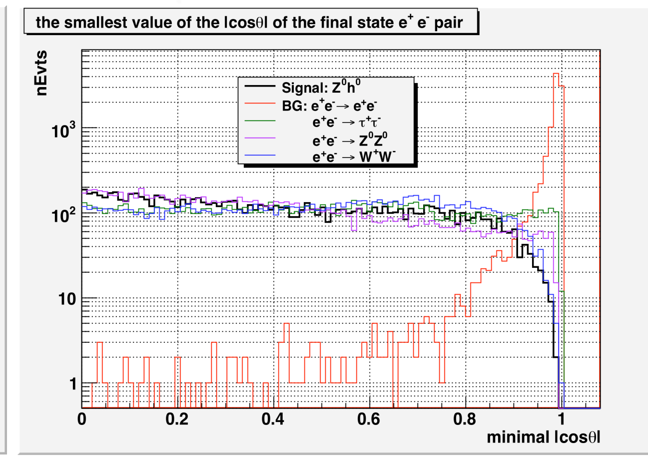


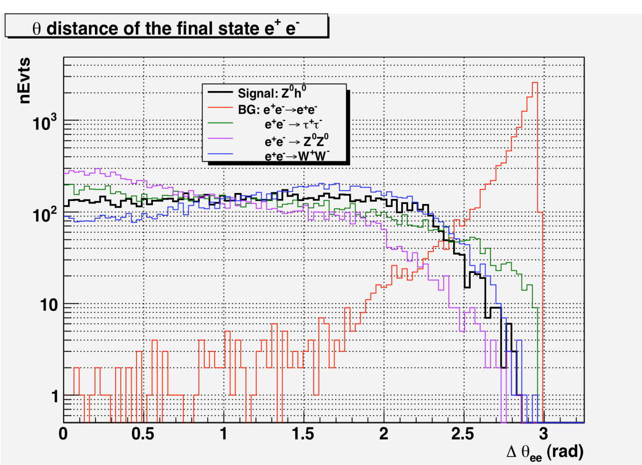
Variables For Signal Selection

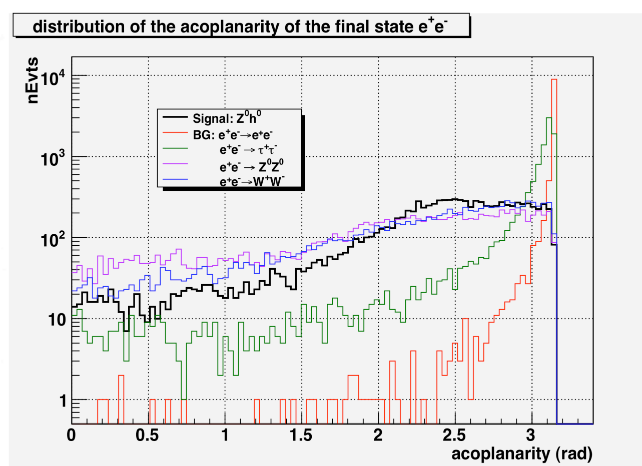
All these Kinematic and Angular Variables can be used later on for signal selection : 1) Cuts ; 2) Likelihood

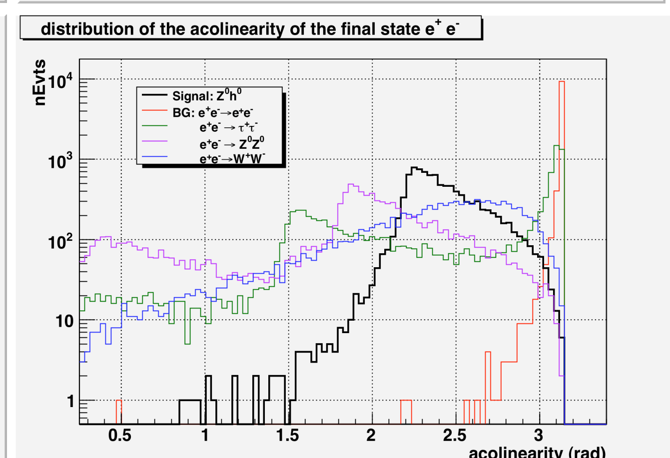
Angular Variables:











Summary

- Ecm=230GeV is a good choice
- ZH->μμX Analysis - M. Ruan
  - Wise and Sophisticated Cut Study gains good resolution of Recoil Mass and Cross Section measurements
    - Model Independent: $\delta(m_h)$~38MeV, $\delta(\sigma)$~0.35fb
    - SM Decay: $\delta(m_h)$~29MeV, $\delta(\sigma)$~0.24fb
    - Invisible Decay: $\delta(m_h)$~29MeV, $\delta(\sigma)$~0.25fb
- ZH->eeX Analysis - H. Li
  - Pre-cuts are not safe for electrons: Bremsstrahlung
  - Event weight method applied
  - Various variables for signal selection are studied in generator level
  - Large amount of simulations and reconstruction are running on the Grid ...

Backup Slides

X section of Signal and main BG

Sqrt(s)	230GeV	250GeV	350GeV
ZH(fb)	6.62 (3310 evt)	7.78 (3890)	4.87 (2435)
ee→ZZ (fb)	1.34k (672k)	1.27k (635k)	0.856k (428k)
ee→WW (fb)	15.86k (7.93M)	15.61k (7.81M)	1.155k (5.77M)
ee→qq (fb)	57.6k (28.8M)	52.2k (26.1M)	22.63k (11.3M)
ee→μμγ (fb)	5.38k (2.69M)	4.34k (2.17M)	2.20k (1.1M)

Non-Polarized beam at 500 fb^{-1}; ISR, FSR, BS activated

- *Huge SM Background: Pre Cuts is needed! In Generator Level:*

	ZH	ZZ	WW	QQ	μμγ
Before Precuts	3310	672k	7.93M	28.8M	2.69M
E1>15	3310	347k	5.22M	15.8M	2.69M
mZ>70	3147	43.7k	310k	169k	920k
Δφ < 3.10 (177.6°)	3042	42.1k	299k	62.6k	242k
2E1+E2<180 && 2E1+3E2>200	3000 **90.6%**	17.7k **2.6%**	81.9k **1.0%**	33.8k **0.12%**	23.1k **0.86%**

* E1 and E2 means the most energetic two muons

Model independent analysis

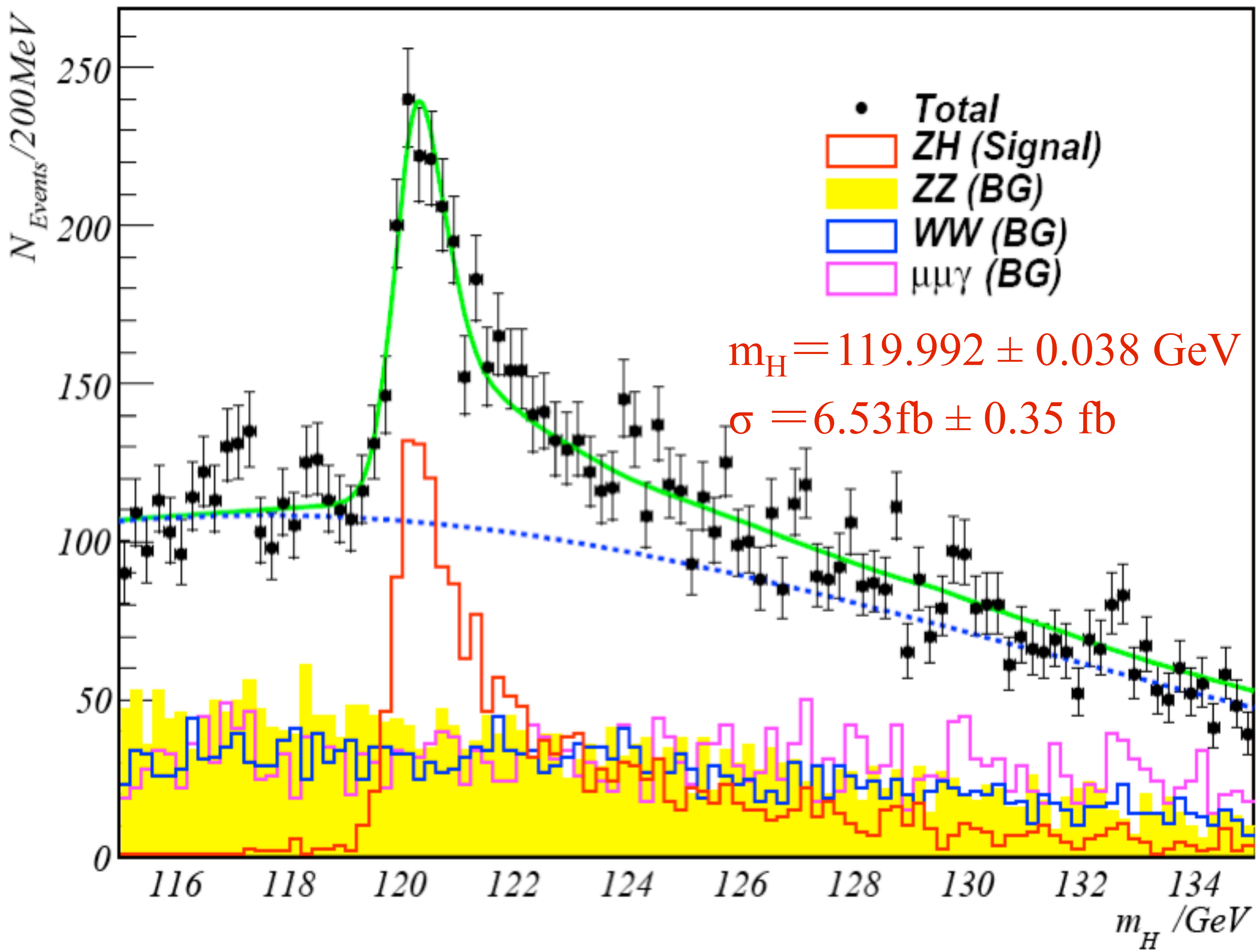
- *After Simulation and Reconstruction:*
  - *Restrict the cuts to:* ***E_{mu}>20***
    $2E_1+E_2<178 \&\& 2E_1+3E_2>202$
    $\Delta\varphi < 176.4^o$
    $76.2 < m_Z < 100$

Cut Chain for model independent analysis

Minimal Version	ZH	ZZ	WW	μμγ
Total event num at 500 fb^{-1}	3310	672k	7.93M	2.69M
Expected event num after preCuts	*3k*	17.7k	81.9k	23.1k
Both muon identified	2824	15.3k	13.9k	20.3k
restrict precuts +Geometry	2439	12.1k	8.6k	14.5k
E_2> 20 && E_2<53 && 2E1+E2<178 && 2E1+3E2>202 && 2E1+3E2<264	2437	7.3k	7.5k	11.9k
-0.995 < Cos(θμμ) < -0.3	2426	7.0k	7.1k	11.1k
$\Delta\varphi_{\mu\mu} < 176.4^o$ && Eγ<30	2210	5.4k	4.8k	1401
115GeV < Hmass < 140GeV	2192	3531	3745	1138

* qqbar disappeared after muon ID

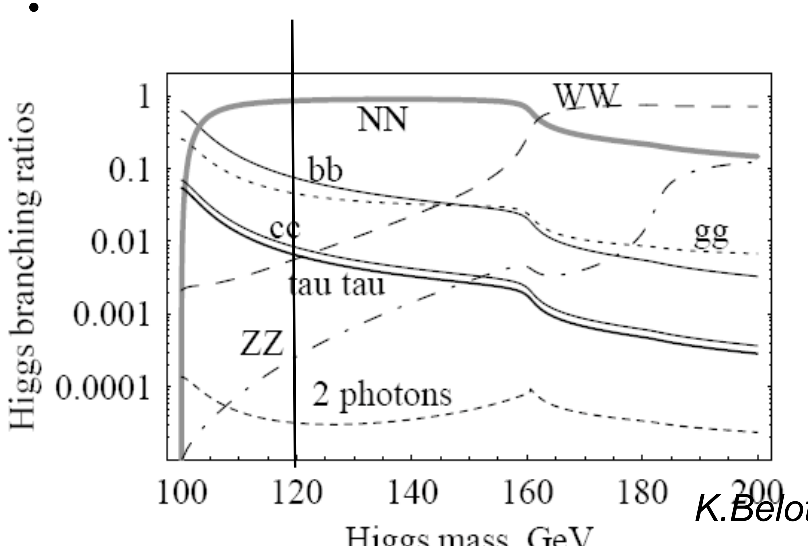
Model independent measurement: δ(mH) = 38MeV



Model dependent analysis

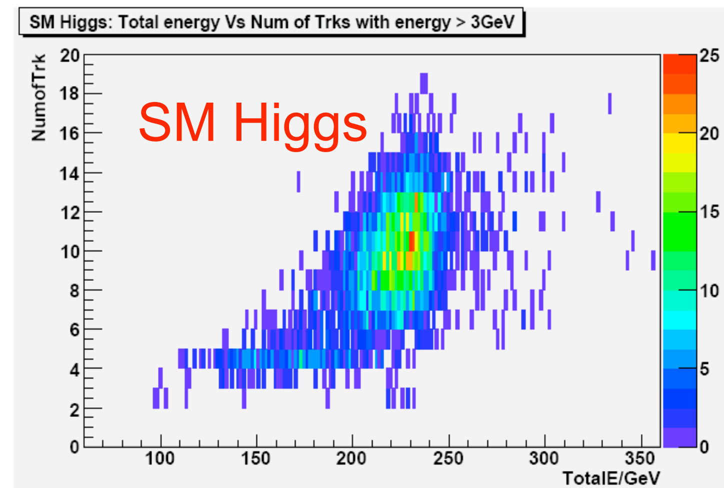
Higgs SM decay and Invisible Decay

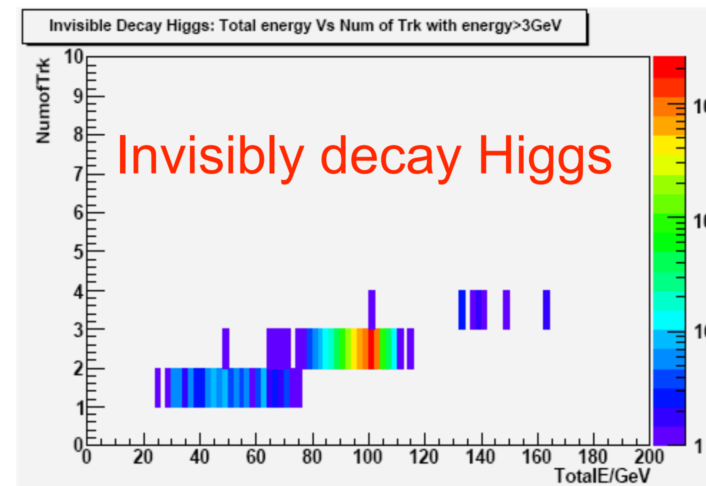
- SM Higgs decay events:
  - N_track > 2
  - Total energy > 150GeV
- Higgs invisible decay:
  - N_track < 4
  - Total energy<110GeV
- Two obvious benefits
  - Larger S/N ratio and thus better measurement
  - *Freedom to tune cuts for different decay models*
-

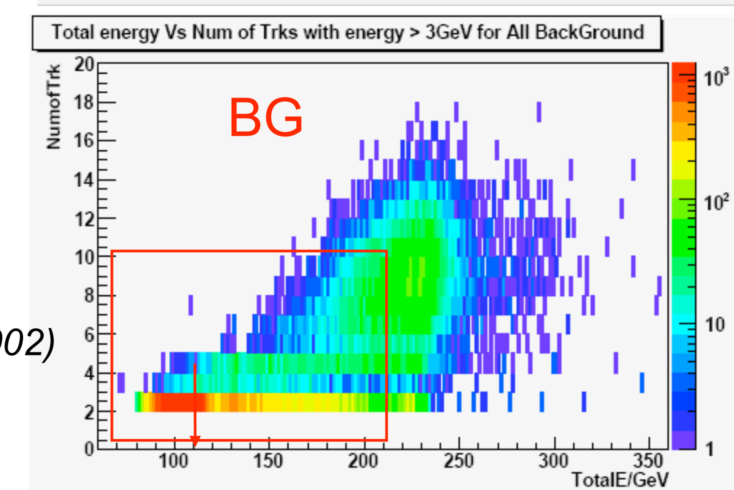


K.Belotsky hep-ph/0210153 (2002)

Higgs Decay Br with a forth neutrino with mass = 50 GeV



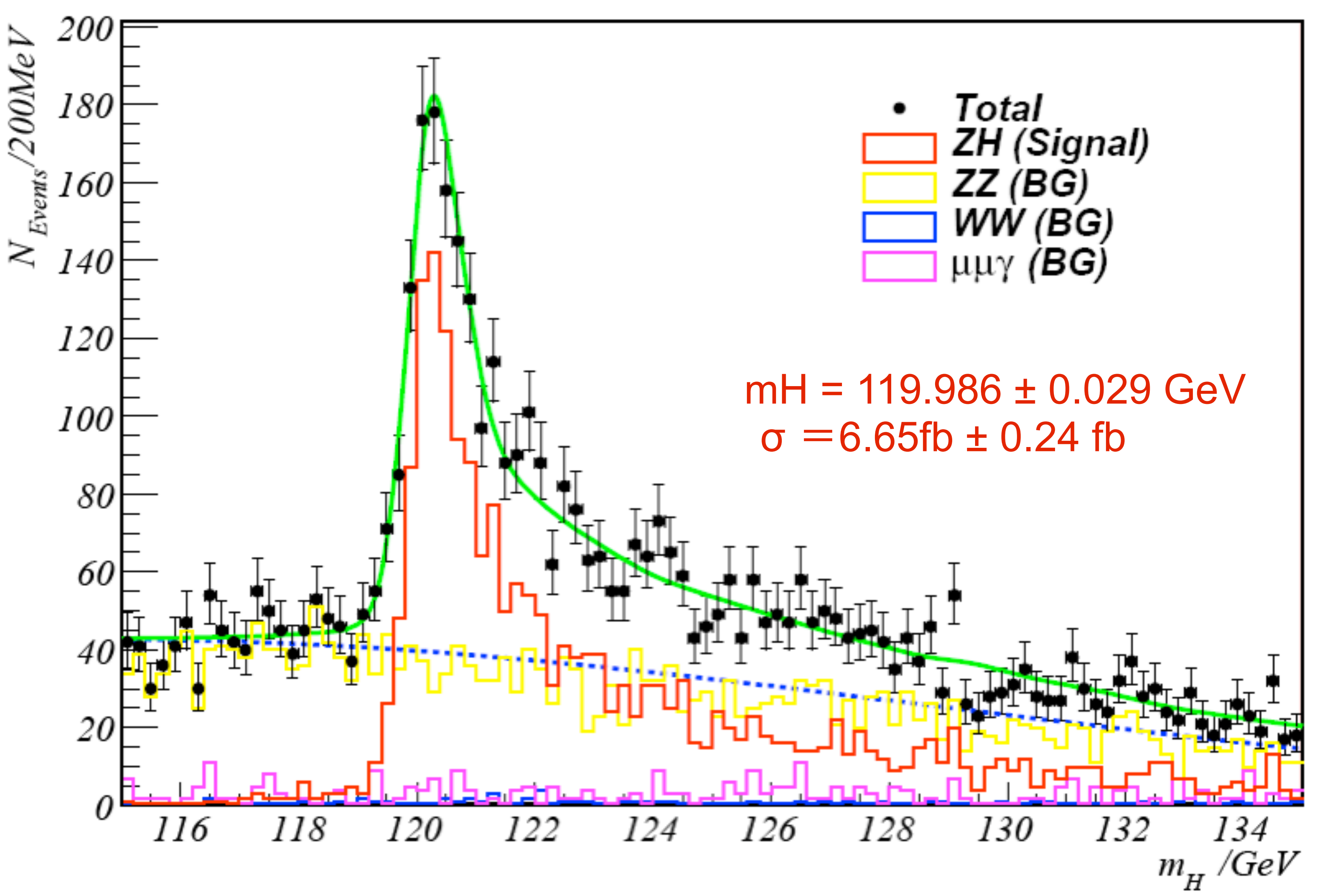




Cuts Chain for SM Higgs analysis

	ZH	ZZ	WW	μμγ
Total event num at 500 fb^{-1}	3310	672k	7.93M	2.69M
Expected event num after preCuts	*3k*	17.7k	81.9k	23.1k
Both muon identified	2824	15.3k	13.9k	20.3k
recover precuts +Geometry	2439	12.1k	8.6k	14.5k
Same Kinetic Cut as model independent analysis	2426	7.0k	7.1k	11.1k
TrkNum>2 && TotalEn>150	2338	5.4k	526	146
115GeV < Hmass < 140GeV	2319	3.5k	128	389
Eγ<30GeV	2280 68.9%	3.4k	124	269

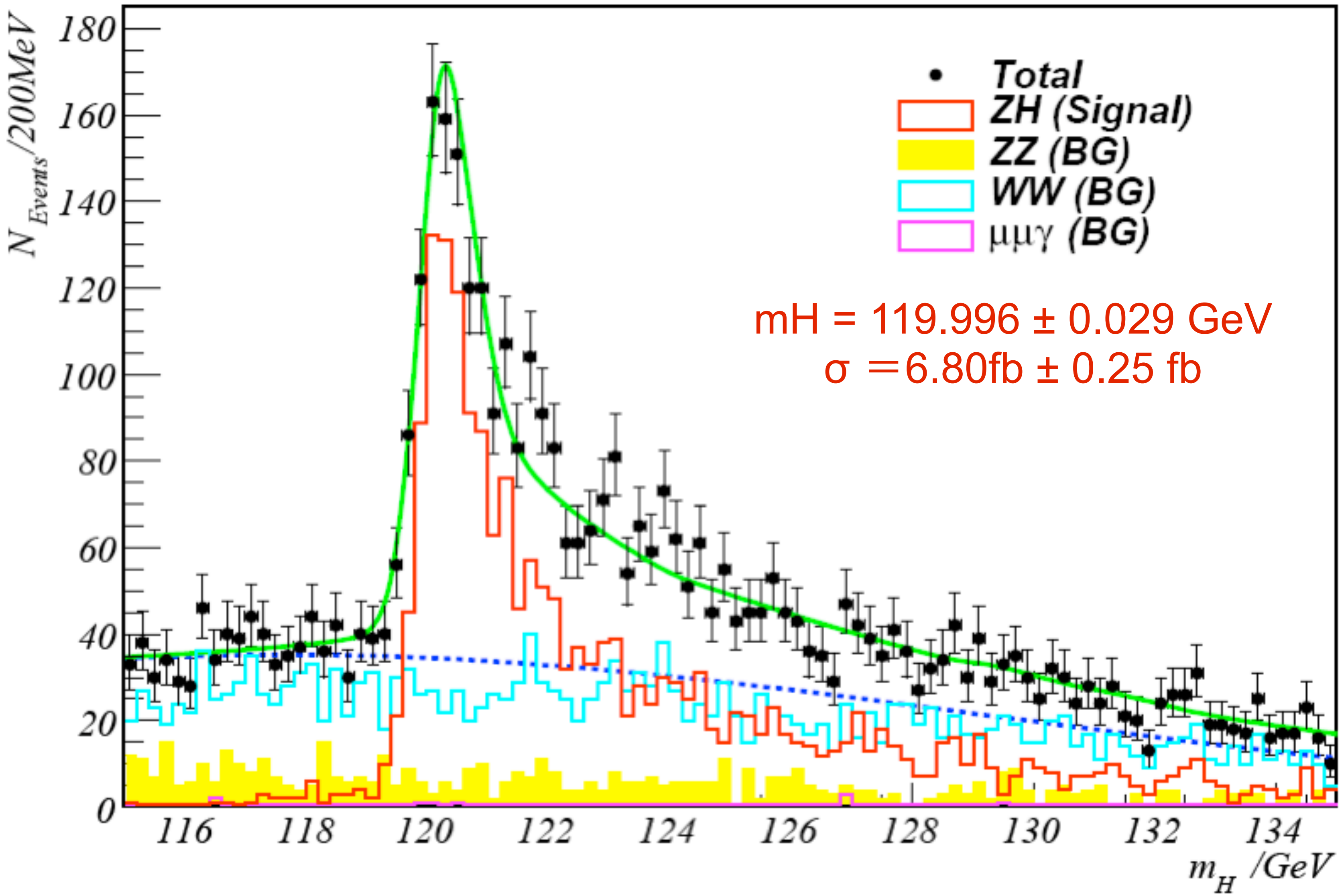
SM measurement: δ(mH) = 29MeV



Cuts Chain for Invisible Higgs analysis

	ZH	ZZ	WW	μμγ
Total event num at 500 fb^{-1}	3310	672k	7.93M	2.69M
Expected event num after preCuts	*3k*	17.7k	81.9k	23.1k
recover precuts +Geometry	2439	12.1k	8.6k	14.5k
Same Kinetic Cut as model independent analysis	2426	7.0k	7.1k	11.1k
TrkNum<4 && 90<TotalEn<110	2326	1.1k	5.2k	2090
Eγ<30	2285	863	4.1k	1164
115GeV < Hmass < 140GeV	2267	554	3316	1016

Invisible Higgs measurement: δ(mH) = 29MeV



ZH->μμX Analysis - M. Ruan

- \- Software Chain
- \- Model Independent Analysis
- \- Model Dependent Analysis
- - SM Higgs Decay
- - Invisible Decay

ZH->eeX Analysis - H. Li

- General Remarks on Electrons
- Software Chain
- Beam Simulation: GUINEA-PIG
- Cross Section Evaluation
- Variables For Event Selection
- Event Weight

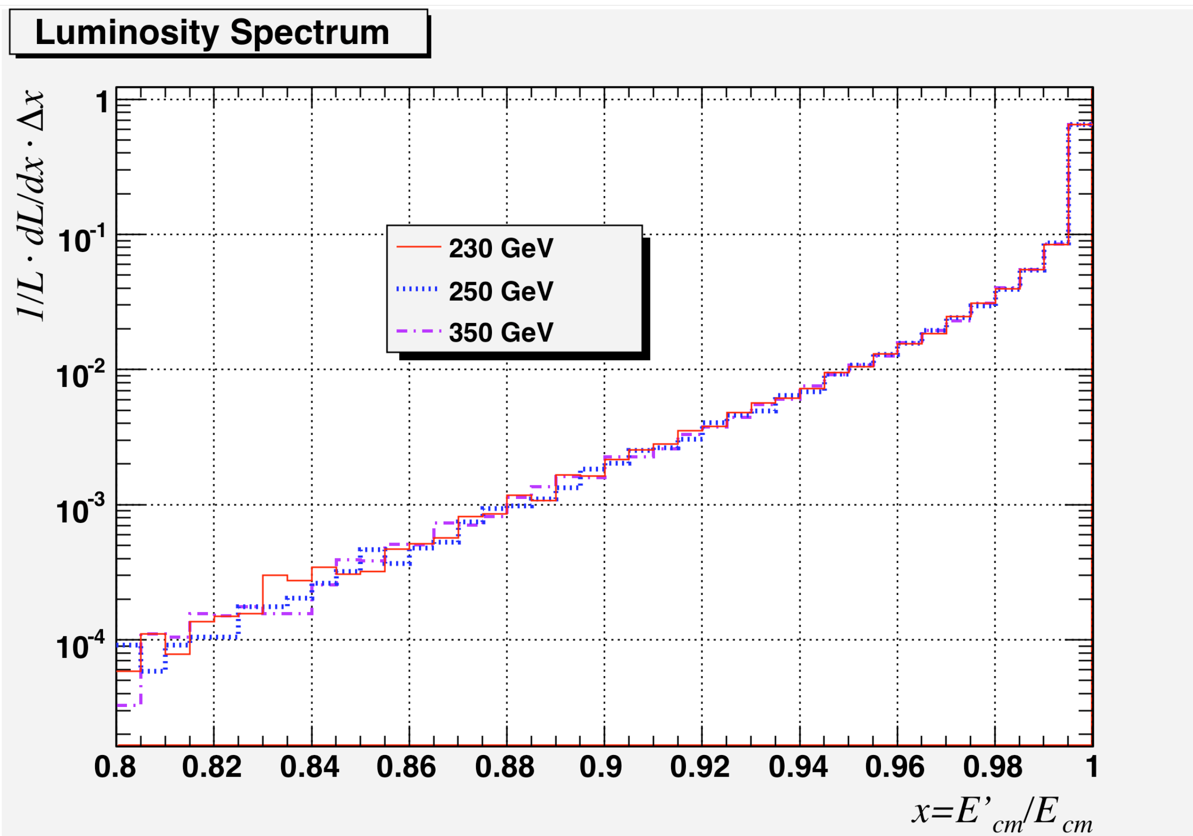
Software Chain

- Beam Simulation: GUINEA-PIG
- Event Generation (Signal and Backgrouds): PYTHIA
- Simulation: Mokka (LDC01Sc and LDCPrime)
- Reconstruction:
  - Tracking: FullLDCTracking (A. Raspiareza)
  - Clustering and PFA: PandoraPFA (M. Thomson)
  - Electron ID: CutBasedEID (H. Li)
- Analysis: ROOT, RooFit, etc.

Electron Channel

Beam Simulation: GUINEA-PIG

Luminosity Spectrum Resulting from Beamstrahlung



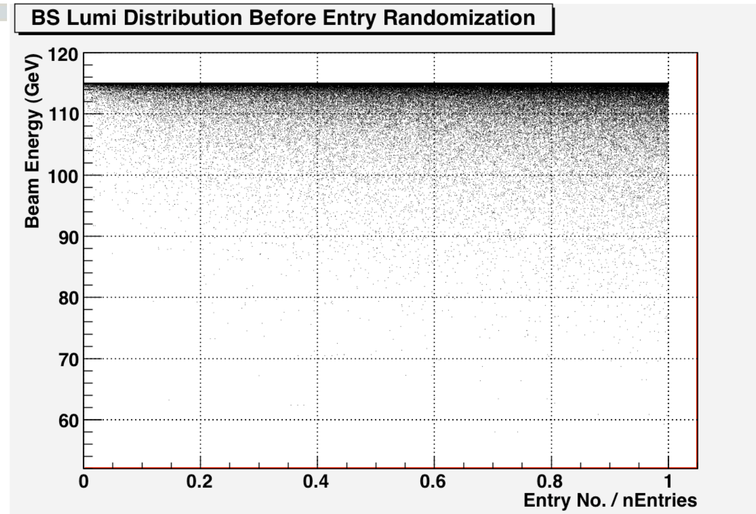
Beam Parameters *

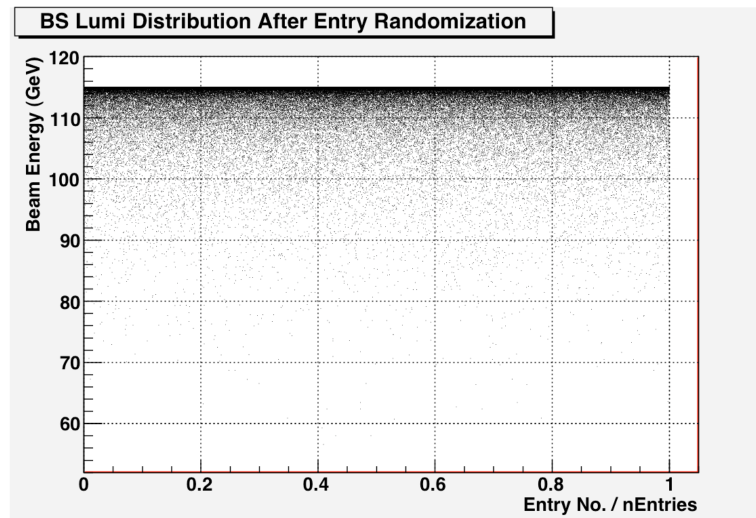
Ecm (GeV)	**230**	**250**	**350**
energy (GeV)	115	125	175
$sigma_x$ (mm)	639	639	639
$sigma_y$ (mm)	5.7	5.7	5.7
$sigma_z$ (μ m)	138	150	210
$Beta_x$ (mm)	9.2	10	14
$Emitt_y$ (10^{-6}m•rad)	0.04	0.04	0.04

*From M. Ruan, to keep persistence with his muon channel study.

GUINEA-PIG to PYTHIA Interface

- GUINEA-PIG lumi spectrum output is not randomly distributed
- Methods:
  - 1) Randomize lumi_file entries before passing it to the generators
    - BeamRand: (Hengne Li) to randomize the lumi_file
    - Beams: (Yuanning Gao), to read lumi_file in generators
  - 2) Randomly pick up the entries from the complete lumi_file
    - CALYPSO*: (Daniel Schulte), randomly read and pass lumi_file entries to generators, from the author of GUINEA-PIG





* Machine-Detector Interface at CLIC / Daniel Schulte, (CERN) : CERN-PS-2001-002-AE; CLIC-Note-469