Higgs mass measurement through μ channel of Higgs strahlungs process

($e^+e^- \rightarrow HZ \rightarrow \mu\mu H$)

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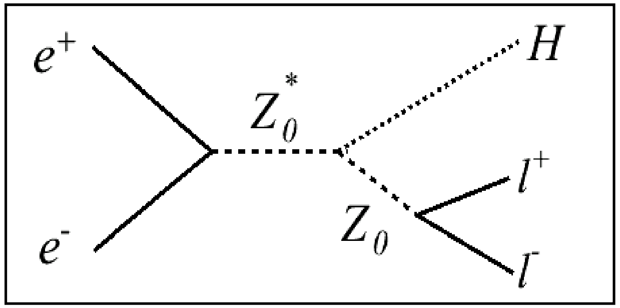
Outline

- Motivation & Software introduction
- Higgs Mass & cross section determination
  - Model independent Measurement
  - Model dependent event selection: treat Higgs SM/invisible decay separately
    - Result for SM Higgs
    - Result if Higgs can decay invisibly
- Test of Higgs mass measurement with different beam parameters
- Summary

Motivation: Higgs strahlung @ sqrt(s) = 230GeV



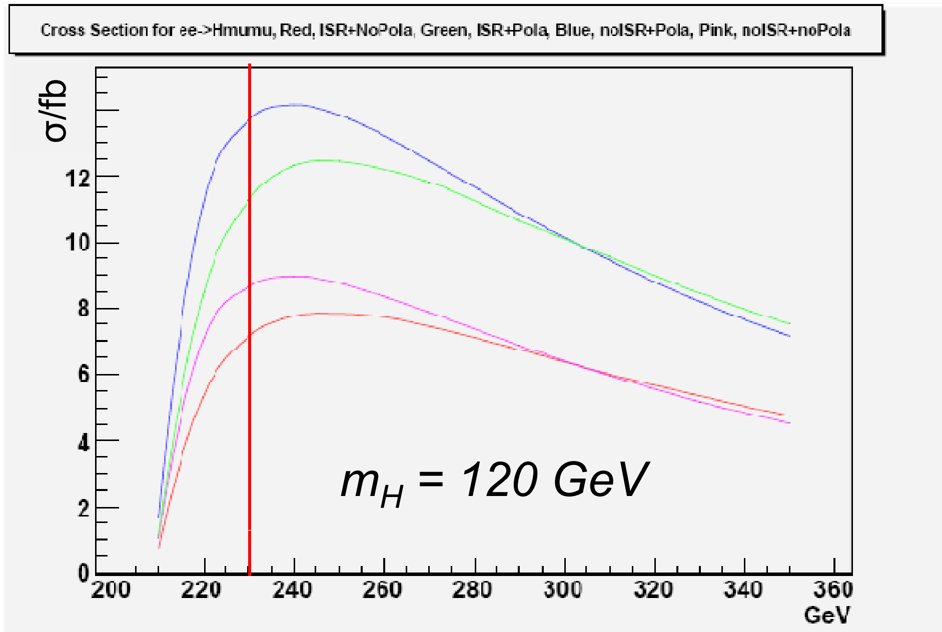
Golden Channel for measure Higgs Mass & Cross Section

$$m_h^2 = s + m_Z^2 - 2E_Z\sqrt{s}$$

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

Only muon momentum information is needed

A ***model independent*** analysis can be applied. We will avoid using any model dependent cuts (like separation angle, etc)



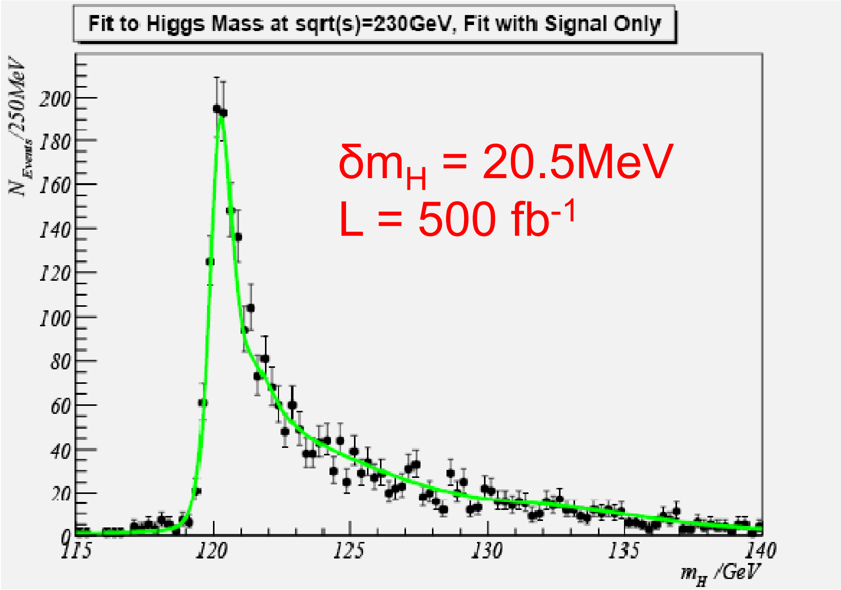
$\delta m_h^2 \sim p^2$;

Small sqrt(s) means better Higgs mass resolution!

Beam polarization will increase the signal cross section by 58%. (electron 80%, positron, 40%) ISR effect will reduce the cross section with sqrt(s)<300GeV (threshold effect) while increase it a little at higher energy

Software chain

- Generator: whizard-1.50 (for Signal), pythia 6.4.13 (for backgrounds) (with Guinea-Pig to simulate BS effect);
- Full Simulation: Mokka-v06-04. with LDC01_sc detector conception (184 TPC layer), *the accuracy of tracking system to 5e-5 at δ(1/P) on average*
- Reconstruction & Analysis: MarlinReco/Marlin, ROOT;
- Fit: Using likelihood method provides by RooFit: δm_H = 20.5MeV for pure signal



X section of 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)

- *Huge SM Background: Pre Cuts is needed!*
  - *Energetic pion/muon (E1>15GeV) (pions are included here for the PID has a chance ~1% to misidentify the a pion as a muon)*
  - *Exist another pion/muon (with energy E2), together with the most energetic pion/muon to form an invariant mass > 70 GeV*
  - Φ_{mumu}*<177.6Degree*
  - *Kinetic cut: 2E1+E2<180&&2E1+3E2>200*

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

Precut Chain at Generator level

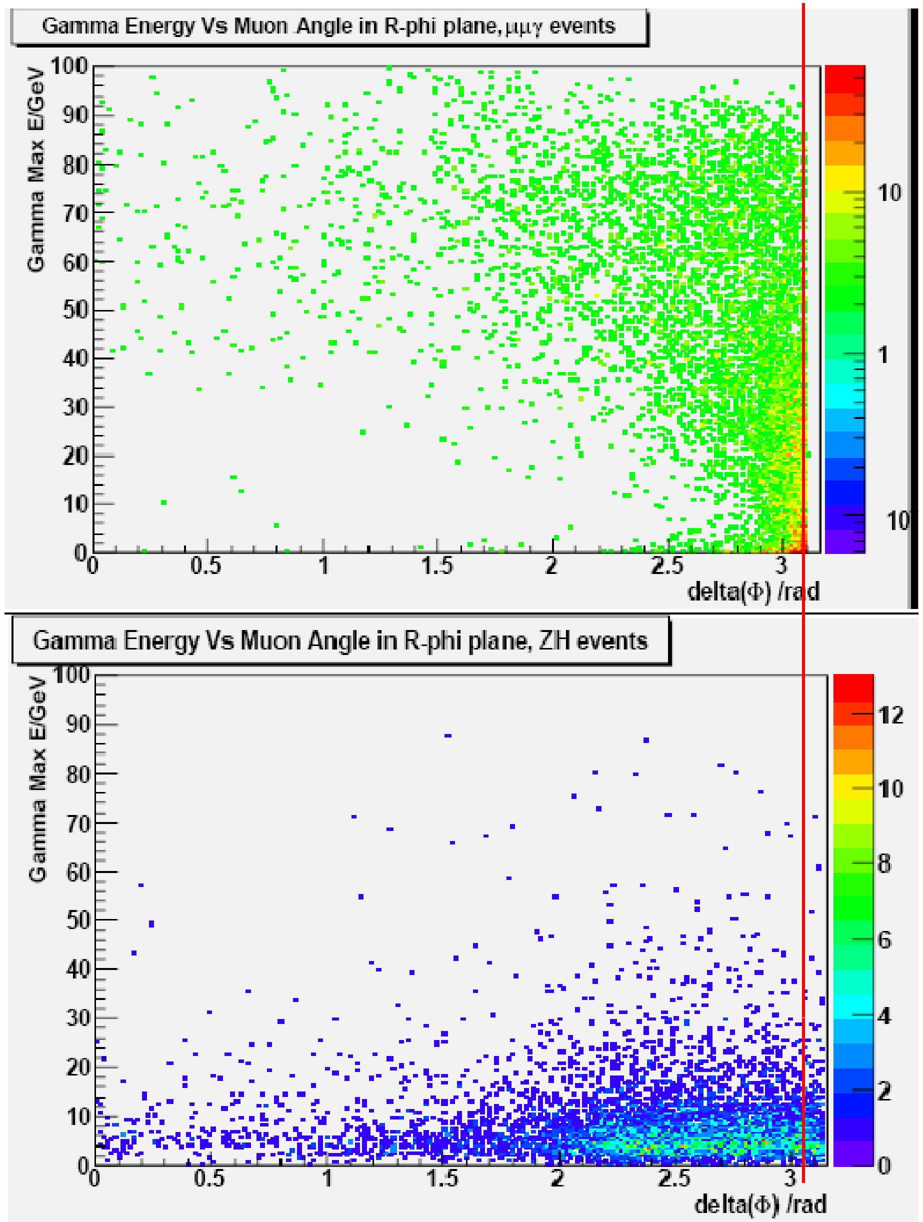
	ZH	ZZ	WW	QQ	μμγ
No Precut	3310	672k	7.93M	28.8M	2.69M
E1>15	3310	347k	5.22M	15.8M	2.69M
mZ>70	3147	43.7k	310k	169k	920k
Δφ < 3.10 (177.6°)	3042	42.1k	299k	62.6k	242k
Kinetic	3000	17.7k	81.9k	33.8k	23.1k
	90.6%	**2.6%**	**1.0%**	**0.12%**	**0.86%**

Replace pre cuts with more strict cuts after reconstruction:

$E_1>15$	→	$E_{mu}>20$
$2E_1+E_2<180 \&\& 2E_1+3E_2>200$		$2E_1+E_2<178 \&\& 2E_1+3E_2>202$
$\Delta\varphi < 177.6^o$		$\Delta\varphi < 176.4^o$
$m_Z>70$		$76.2 < m_Z<100$

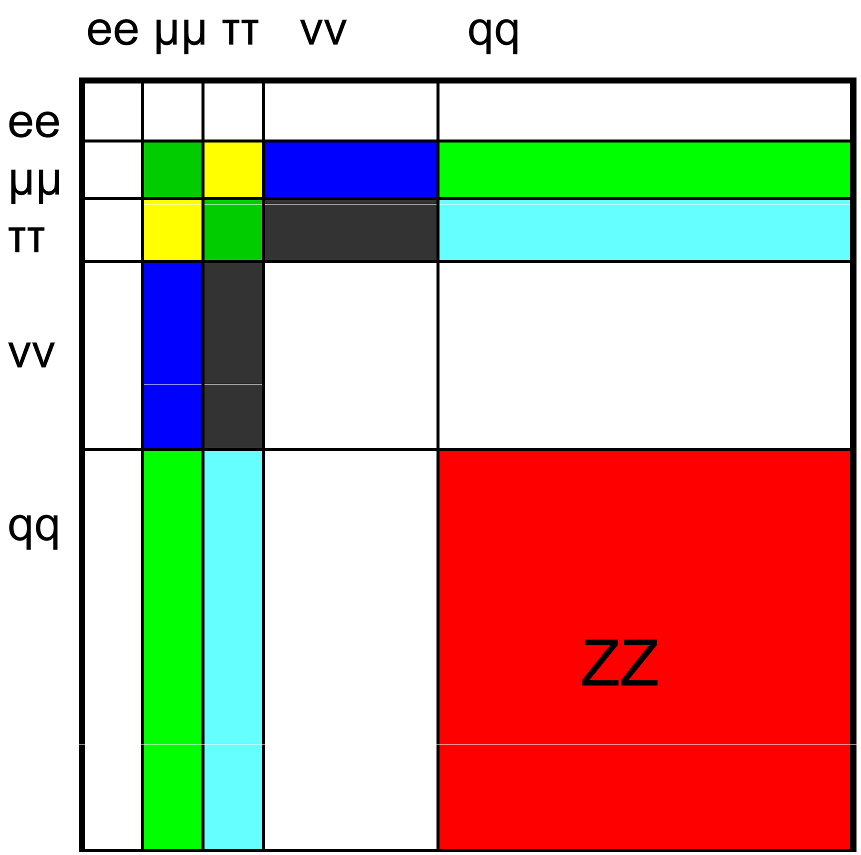
qq & μμγ BG

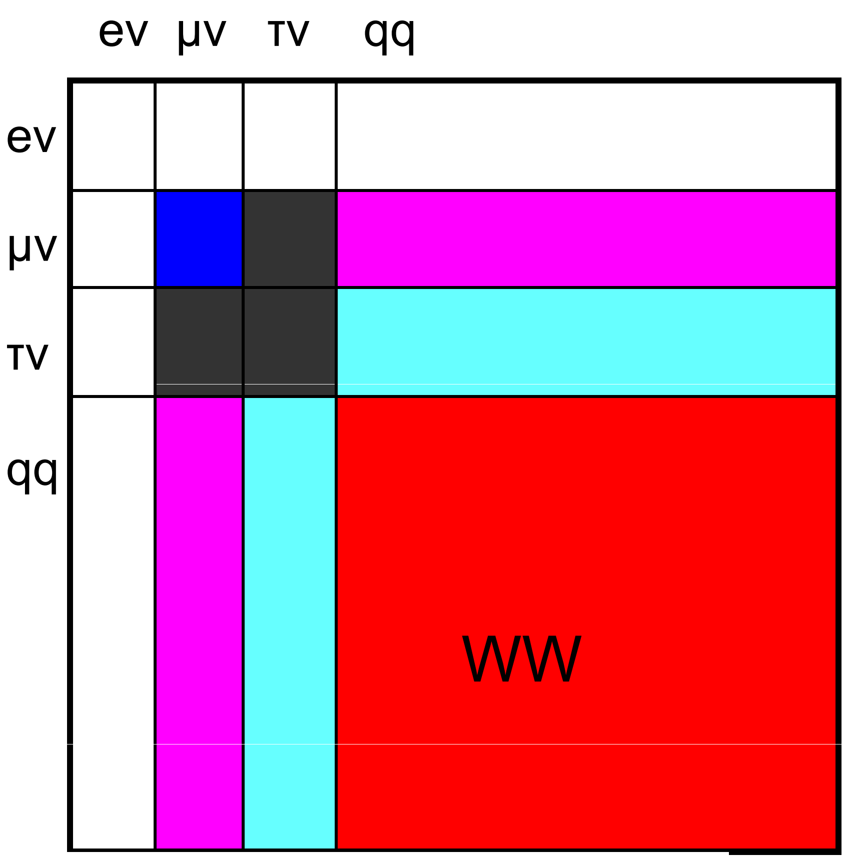
- QQ background vanishes after pre cut selection + μ id (*the majority of QQ BG passed the precut have pion, not muons*)
- **μμγ** BG: Veto events with no miss P_T ($\Delta\varphi \sim \pi$) or have reconstructed energetic photon;



ZZ & WW background

Z decay ratio: ~3% to lepton pairs (each),
~20% to neutrino pairs, ~70% to qq
W decay ratio: ~10% to lepton pairs (each), ~70% to qq



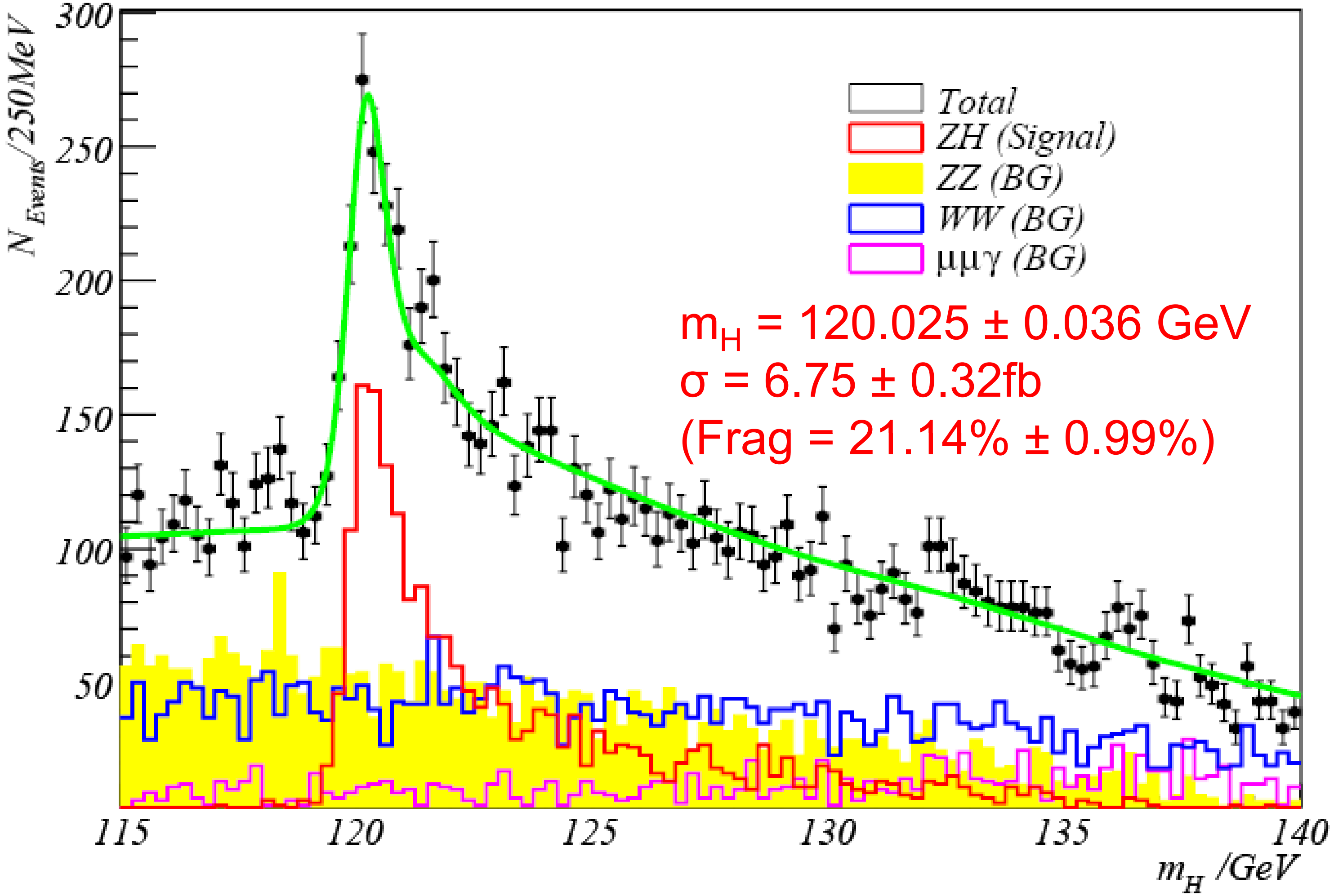


Blue: background for Higgs invisible decay
Gray: background for Higgs invisible decay through tau leptonic decay
Light green: background for Higgs SM decay
Red, pink and light blue: possible background for Higgs SM decay (pion be misidentified as muon & muon from bb, cc)
Yellow and Dark Green: background for Higgs SM decay: H → ττ

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
recover 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
μμγ events veto	2210	5.4k	4.8k	1401
115GeV < Hmass < 140GeV	2192	3531	3745	1138

Model independent measurement: δ(mH) = 36.3MeV



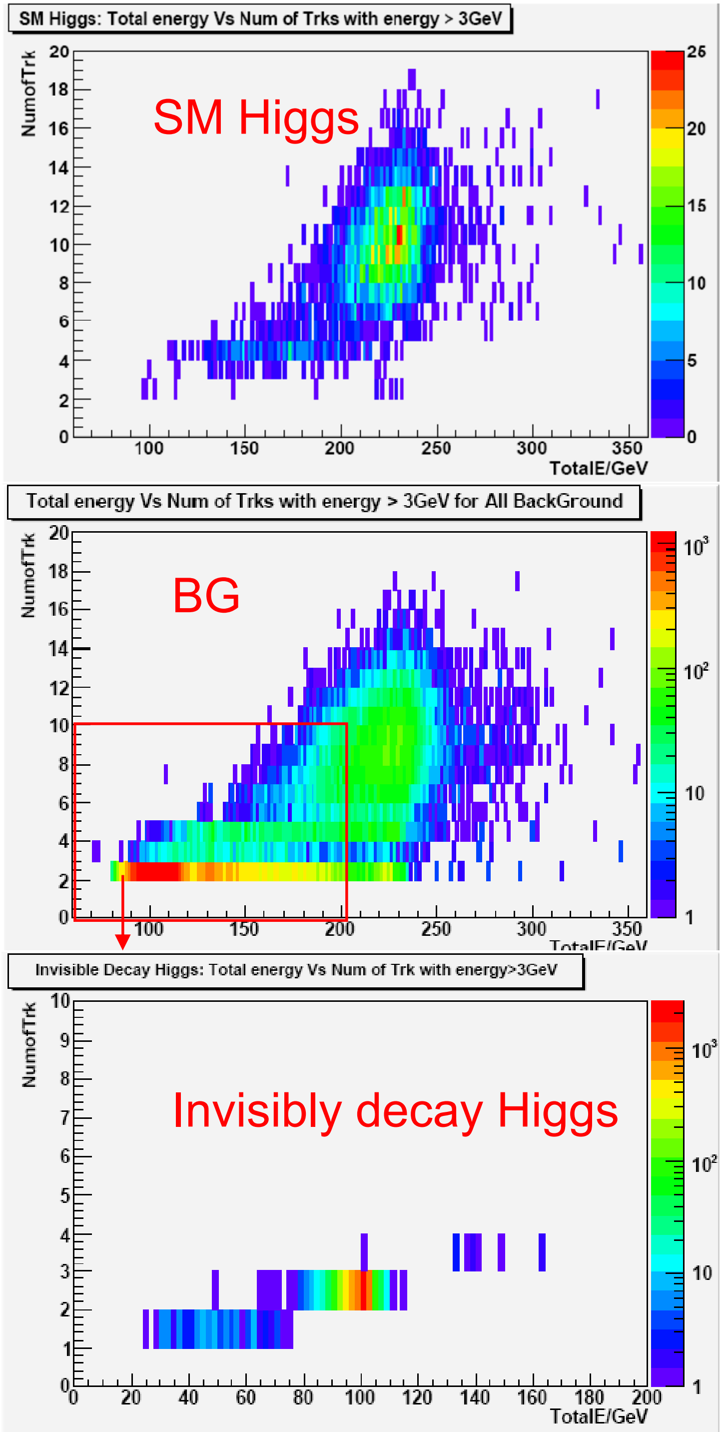
Further (model dependent) analysis using information on H decay final states

- We can separate the Higgs SM/invisible decay events with 2 obvious benefits
  - *Larger S/N ratio and thus better measurement*
  - *Freedom to tune cuts for different decay models*

- Use the variable: Num of tracks with energy>3GeV & Total measured energy

- Count the If N_track < 4 && Total energy<110GeV, Higgs invisible decay

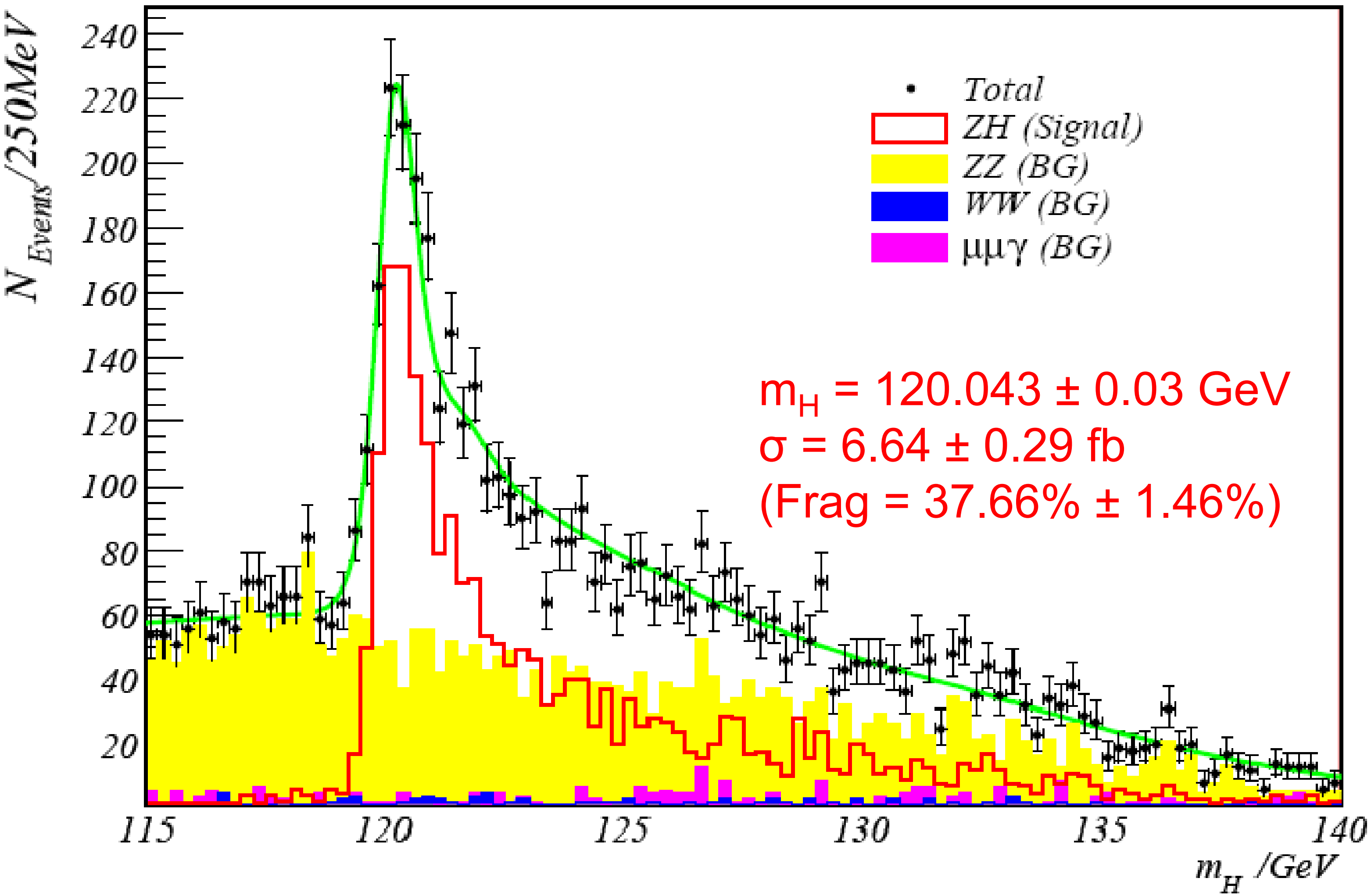
- If N_track > 2 && Total energy > 150GeV, SM Higgs decay events



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
Loose Veto on γ Energy (30GeV)	2280 68.9%	3.4k	124	269

SM measurement: δ(mH) = 29.95MeV



Higgs Invisible decay

Exotic Model beyond SM:

SUSY ?

Extra dimension ?

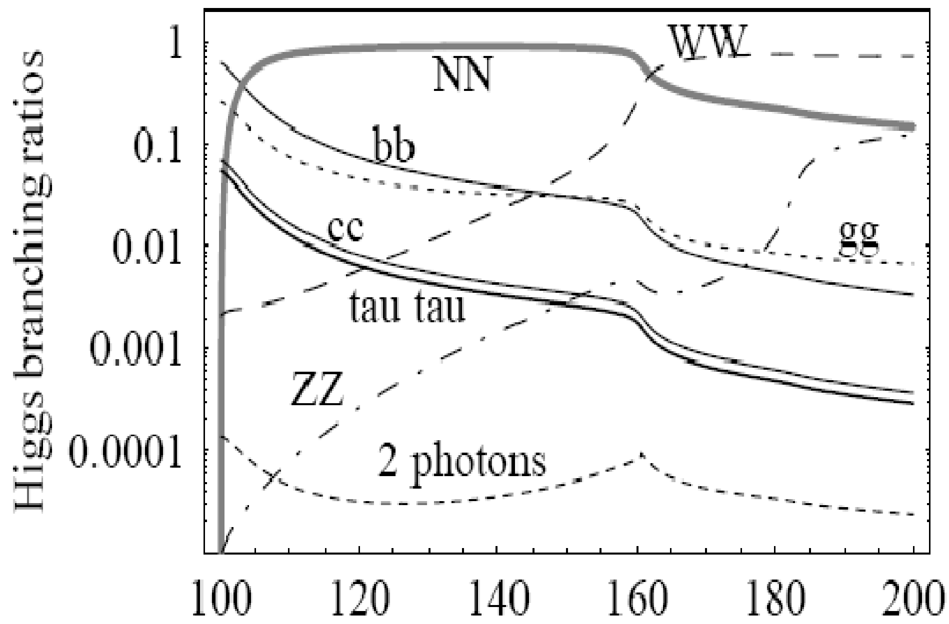
Heavy neutrino ?

...

Main background

$e^+e^- \rightarrow WW, ZZ \rightarrow \mu\mu\nu\nu$

$e^+e^- \rightarrow \mu\mu(\gamma)$



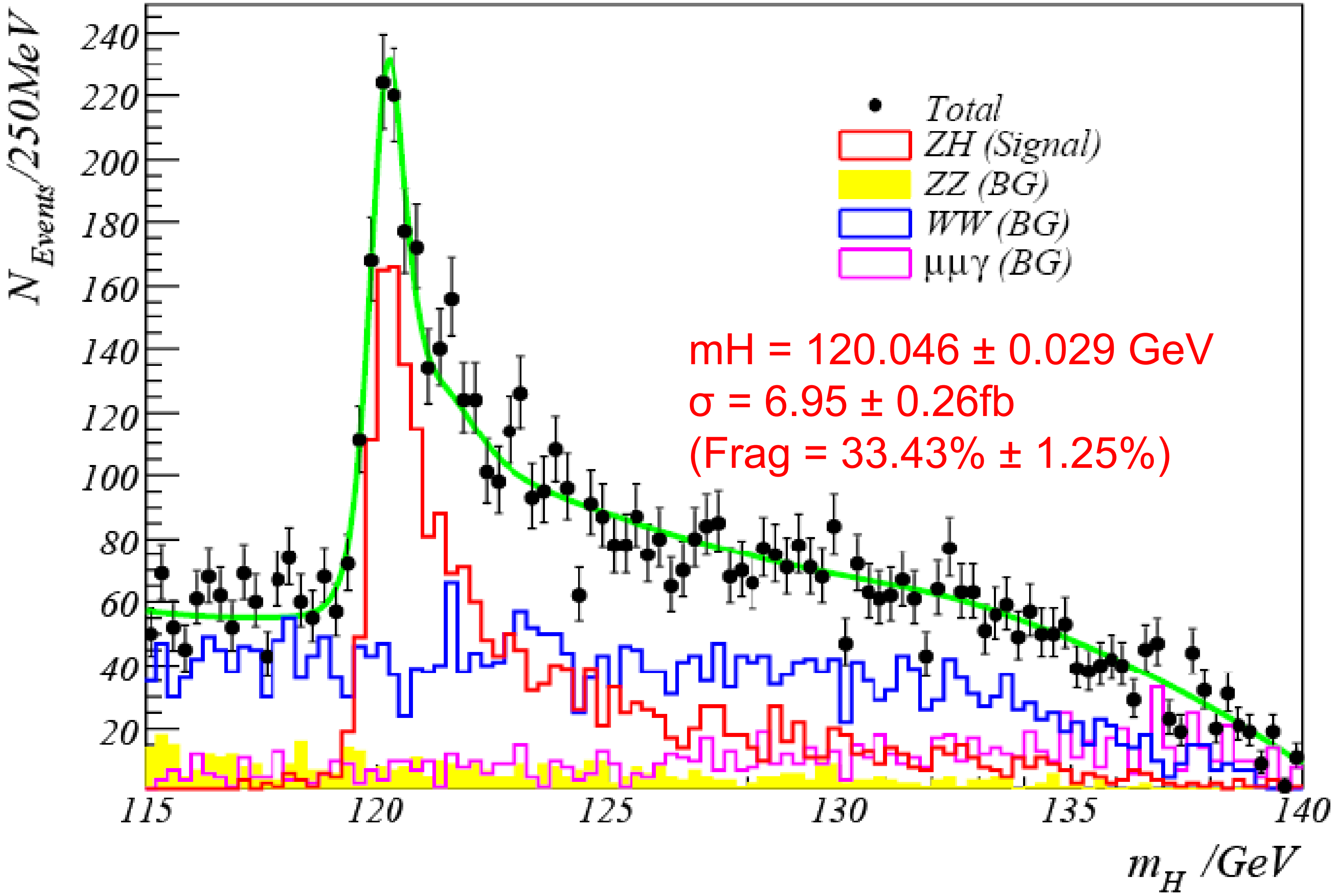
Higgs Decay Br with a forth neutrino with mass = 50 GeV m_H

K.Belotsky hep-ph/0210153 (2002)

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
μμγ *events veto*	2285	863	4.1k	1164
115GeV < Hmass < 140GeV	2267	554	3316	1016

Invisible Higgs measurement: δ(mH) = 29.2MeV



Changing beam parameters

- For Linear collider, we can
  - Change beam parameters (eg, changing σ_z β_x β_y as ~ E_{cm}) to maintain the same luminosity (and also same Beamstrahlung), which is the current strategy we applied on our Full simulation analysis. *But this is technologically hard to achieve*
  - Keep beam parameter constant, we have L ~ E_{cm}; BS ~ E^2_{cm}; while for small E_{cm}, we suffer more from the weak field reduction, and thus have less than 230 fb^{-1} the integration luminosity if scale the machine time to achieve 500 fb^{-1} luminosity for 500GeV nominal beam, but also much smaller Beamstrahlung.
  - Some strategy in between above 2
- Use toy MC (*Generator + hand made fast simulation*) to test accuracy of Higgs mass measurement for signal only with different tentative beam parameter provided by BDS group

Points on beam parameter space yet scanned

Sqrt(s) /GeV	230	230	250	250	350	350	350	350
L* /m	3.5	4.5	3.5	4.5	3.5	4.5	3.5	4.5
β_x /nm	22.7	29.2	20.9	26.9	15.0	19.2	20.3	20.5
ColliX	6	6	6	6	6	6	7.0	6.2
η_L /percent	80.7	77.0	83.0	79.5	90.1	87.8	90.1	87.8
L /$10^{37}m^{-2}s^{-1}$	6.70	5.55	7.93	6.54	14.7	12.4	12.4	12.1
L /fb^{-1}	181	150	214	177	397	335	335	327
σ /fb	7.03	7.06	7.81	7.83	4.80	4.80	4.78	4.80
Exp event num	1272	1059	1671	1386	1906	1608	1601	1570
δ(mH) /MeV	22.4	24.7	32.8	31.9	107.2	109.1	115.2	117.5

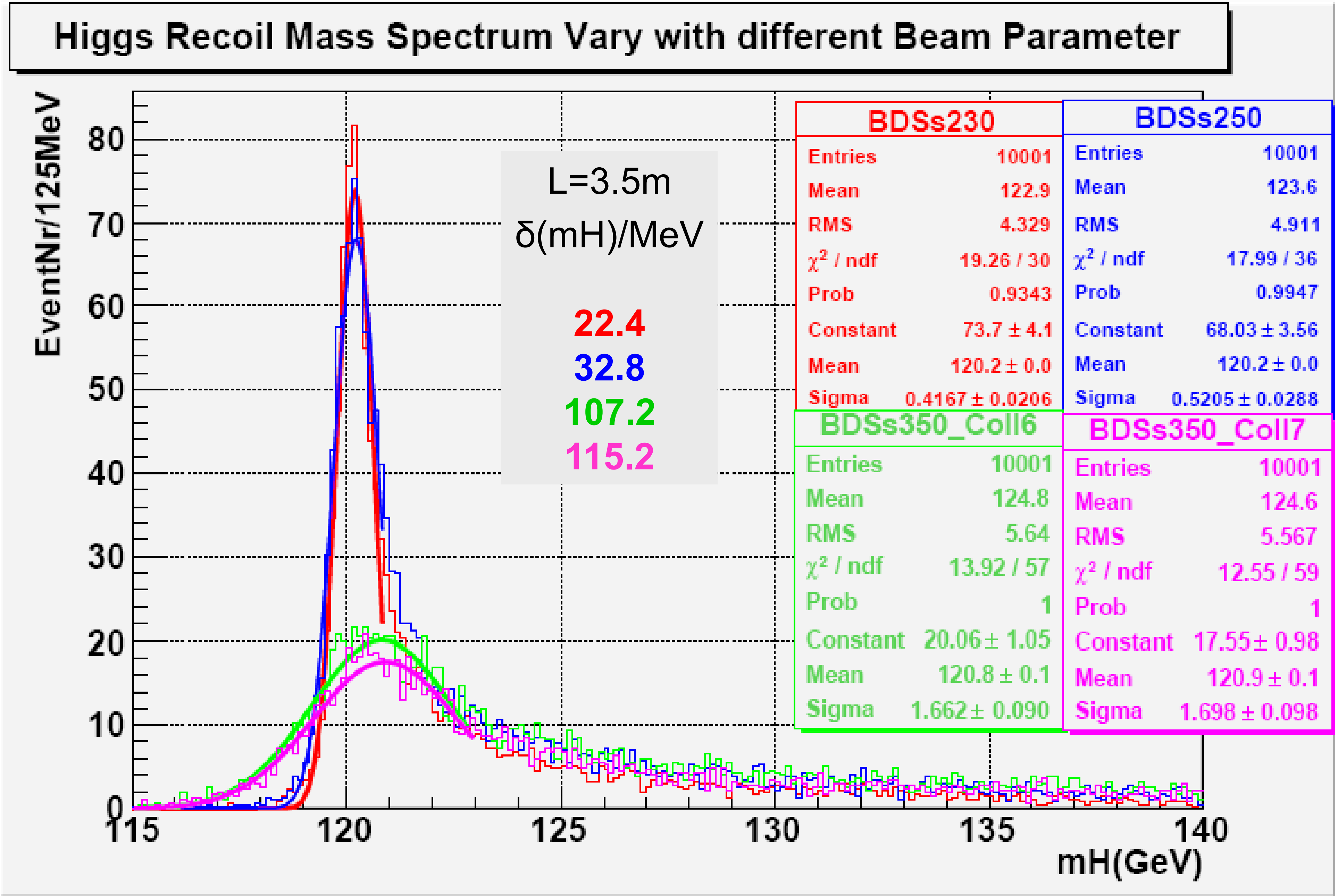
Machine time had been set to make Nominal beam (500GeV) reach an integrated Luminosity be 500 fb^{-1}

η_L: weak field reduce factor on Luminosity. $L_{true} = L_{geo} * H_D * \eta_L$

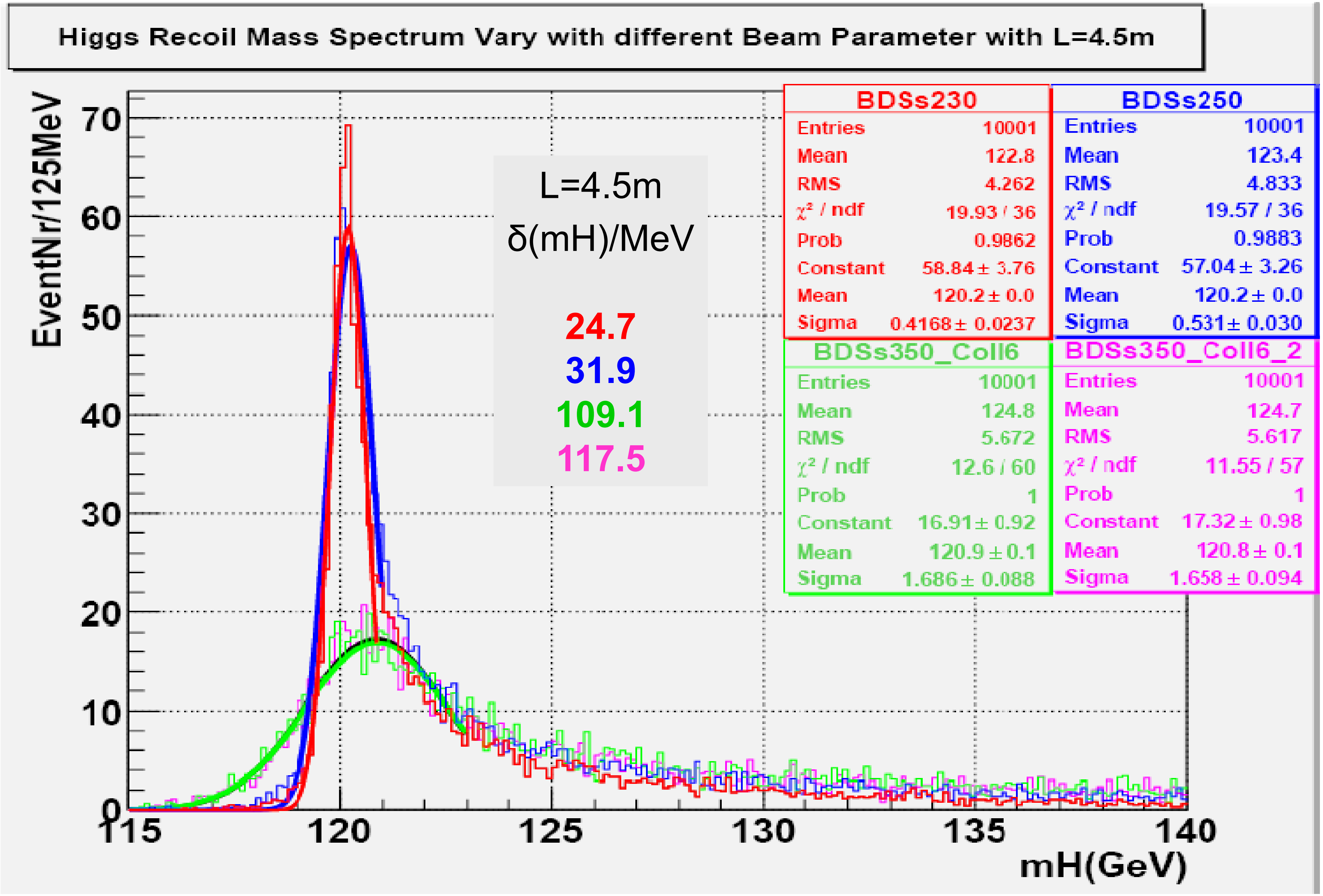
ColliX: Collimator depth X, always bigger than 6

TENTATIVE !

Sample Gaussian fit to the core; L* = 3.5m



Sample Gaussian fit to the core; L* = 4.5m



Summary

- Accuracy of Higgs mass and cross section measurement through ee→HZ→Hμμ with Higgs SM decay and Higgs invisible decay assumption have been studied.

- Condition: 120GeV Higgs. Non polarized beam (with ISR, FSR & BS) with an integration luminosity of 500 fb^{-1}

- Two strategies had been applied:
  - Model independent Higgs mass measurement: δ(mH) = 36MeV
  - Treat SM/Invisible decay Higgs separately: δ(mH) could be measured better than 30MeV.
  - Cross section can be measured to an accuracy of 0.3 fb

- It is foreseen to improve a lot with beam polarization for it will not only reduce the WW background but also increase ~58% the cross section of Higgs strahlung channel (electron, 80%, positron, 40%).

- To do: likelihood methods for events identification; for SM Higgs, use jet energy information to reduce the ZZ Background

- With beam parameter suggested by BDS group, best higgs mass measurement achieved at sqrt(s) = 230GeV


Thank you!

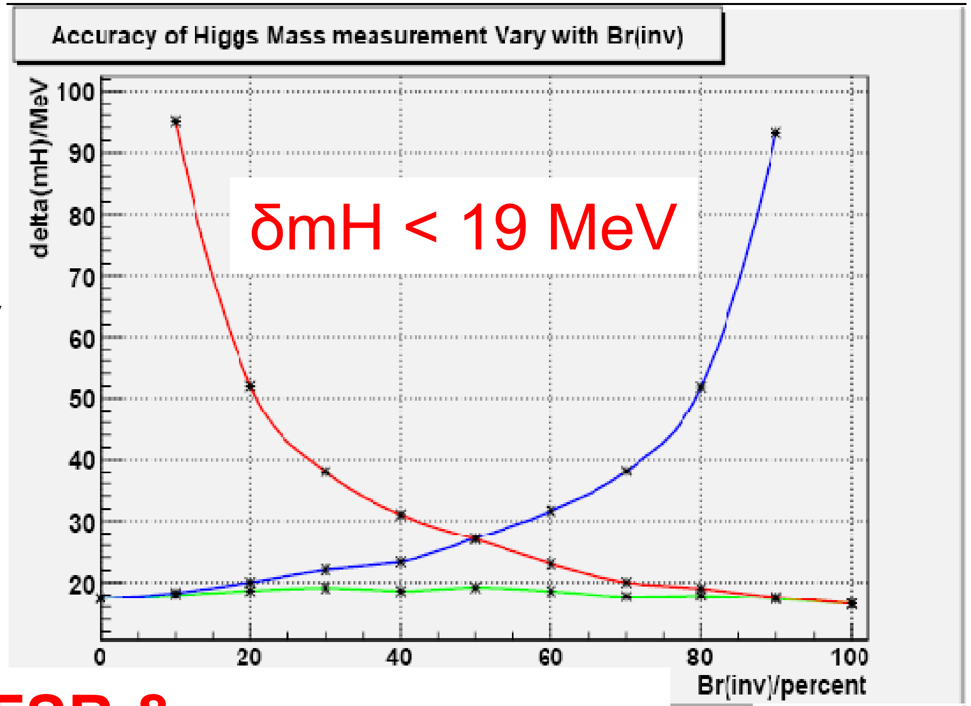
For arbitrary Br(inv)

Combination the result from Higgs invisible and visible decay (Br(inv) + Br(visible) =100%)

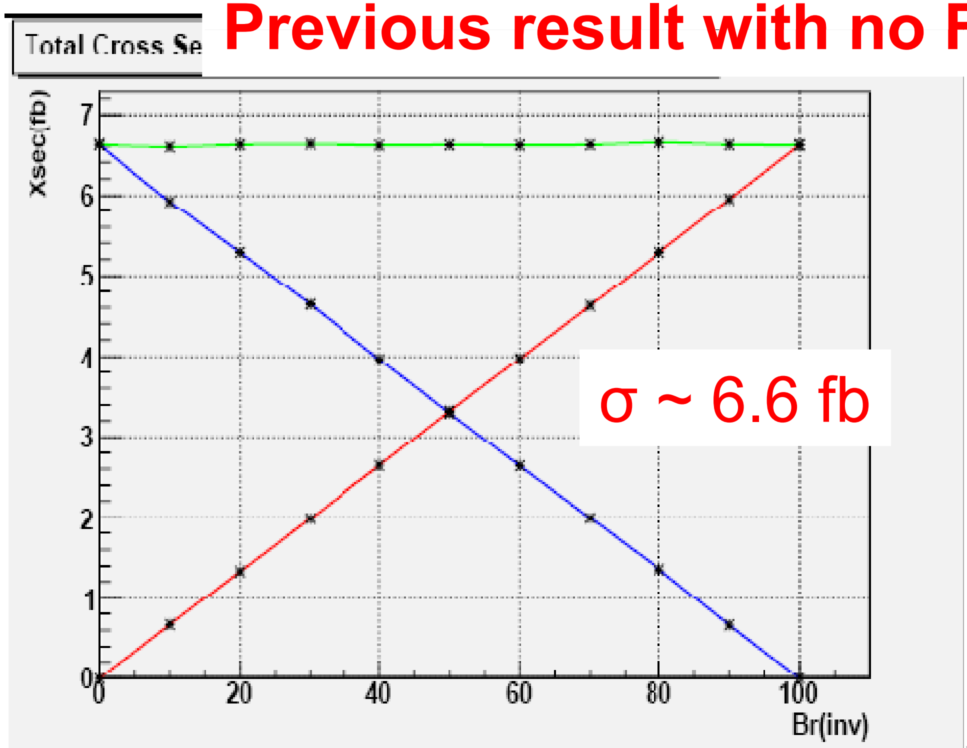
Red, invisible part contribution

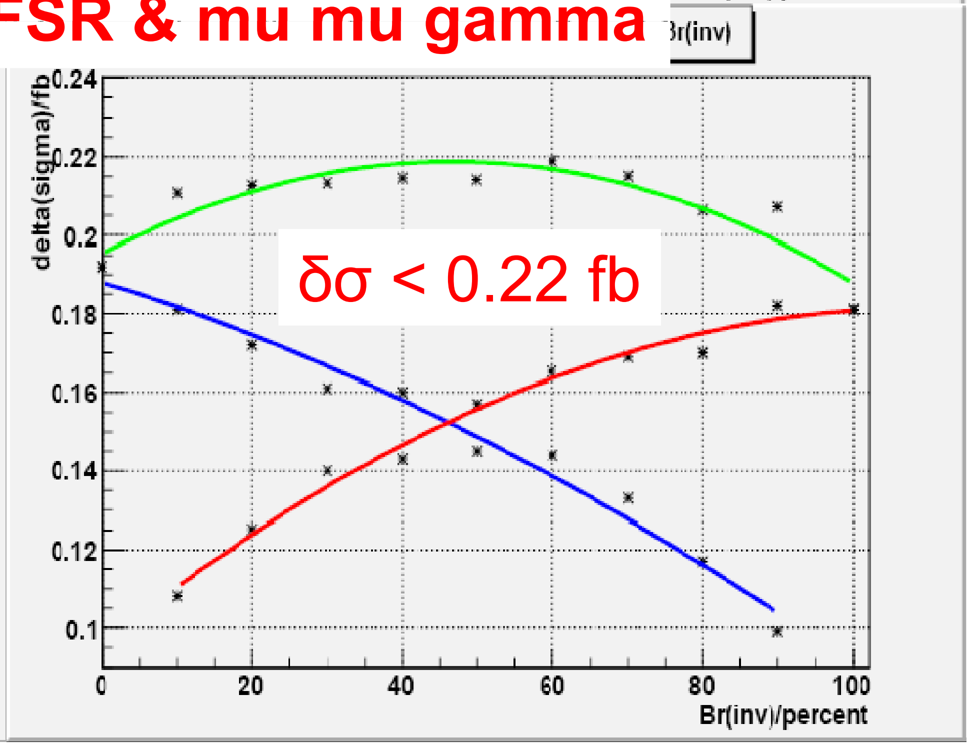
Blue, visible part contribution

Green, overall result

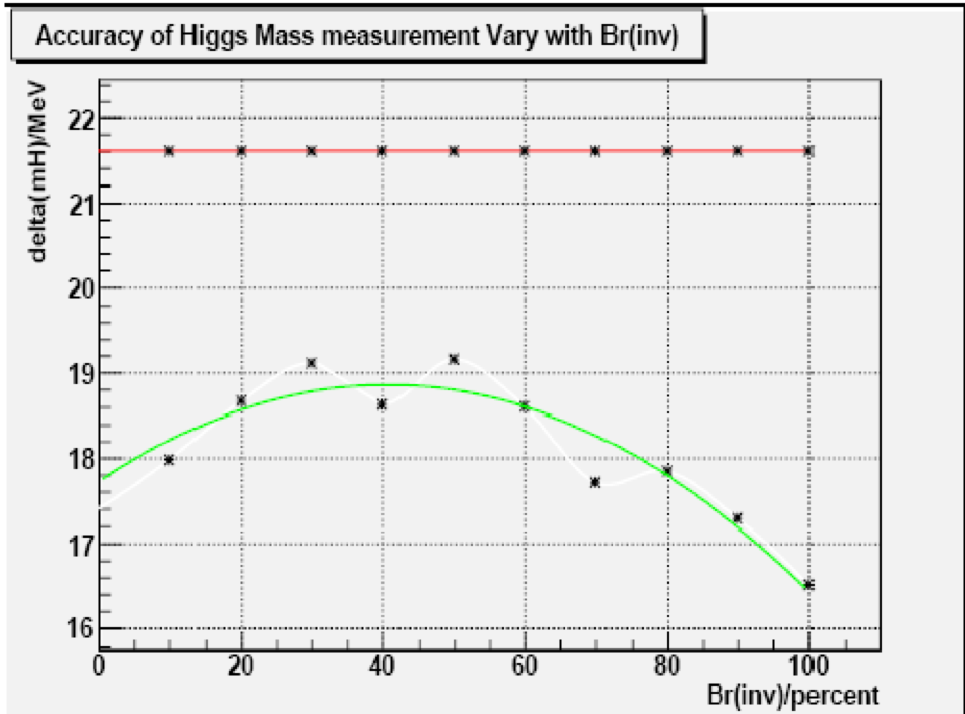


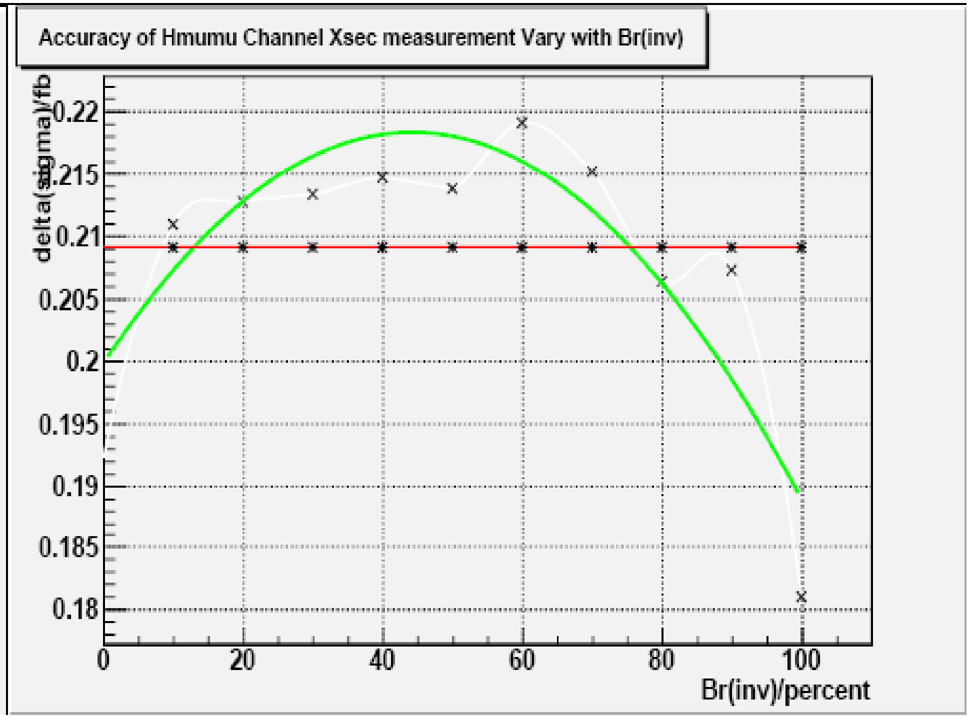
Previous result with no FSR & mu mu gamma





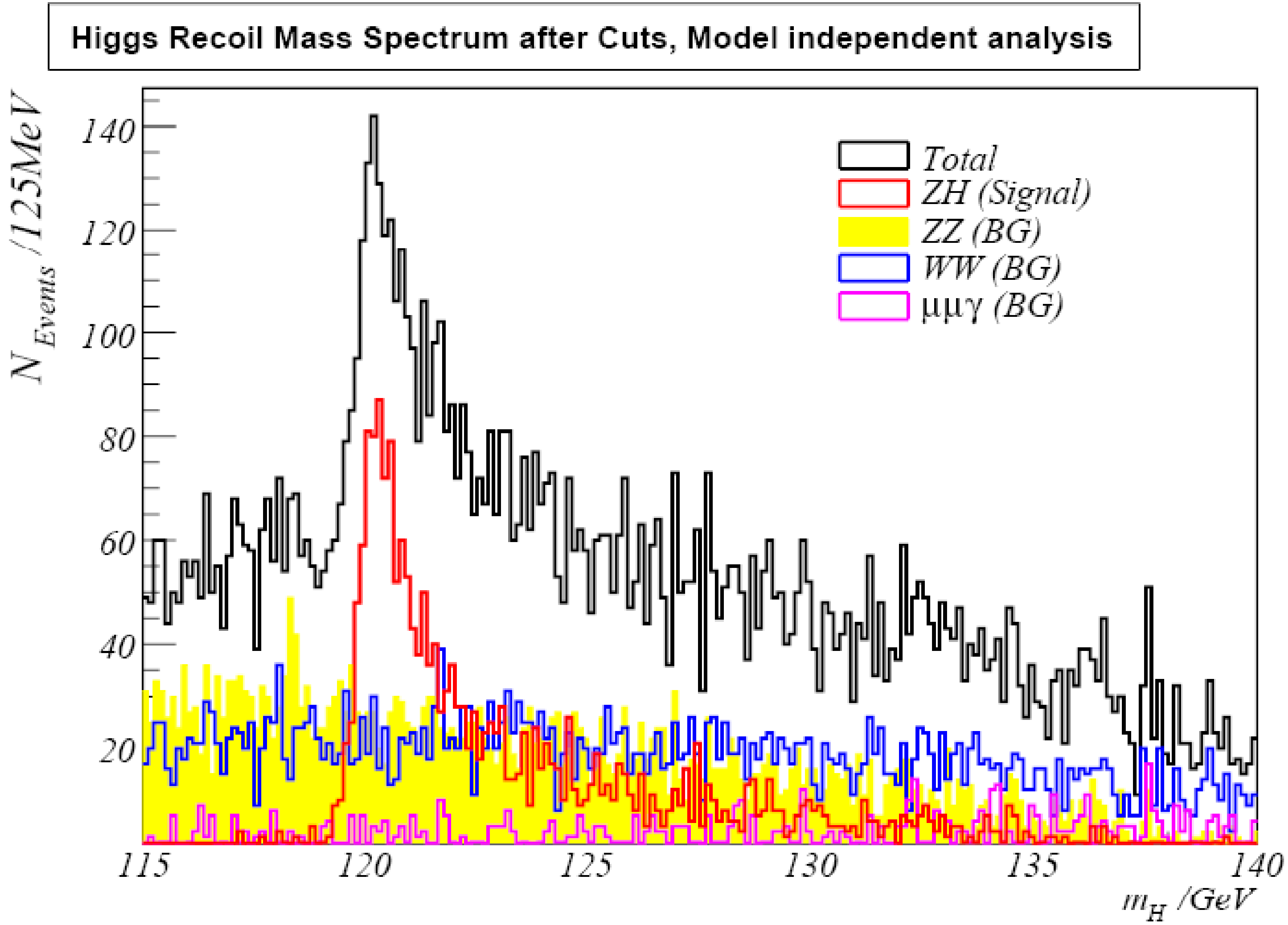
Comparison on effect of different analysis strategy

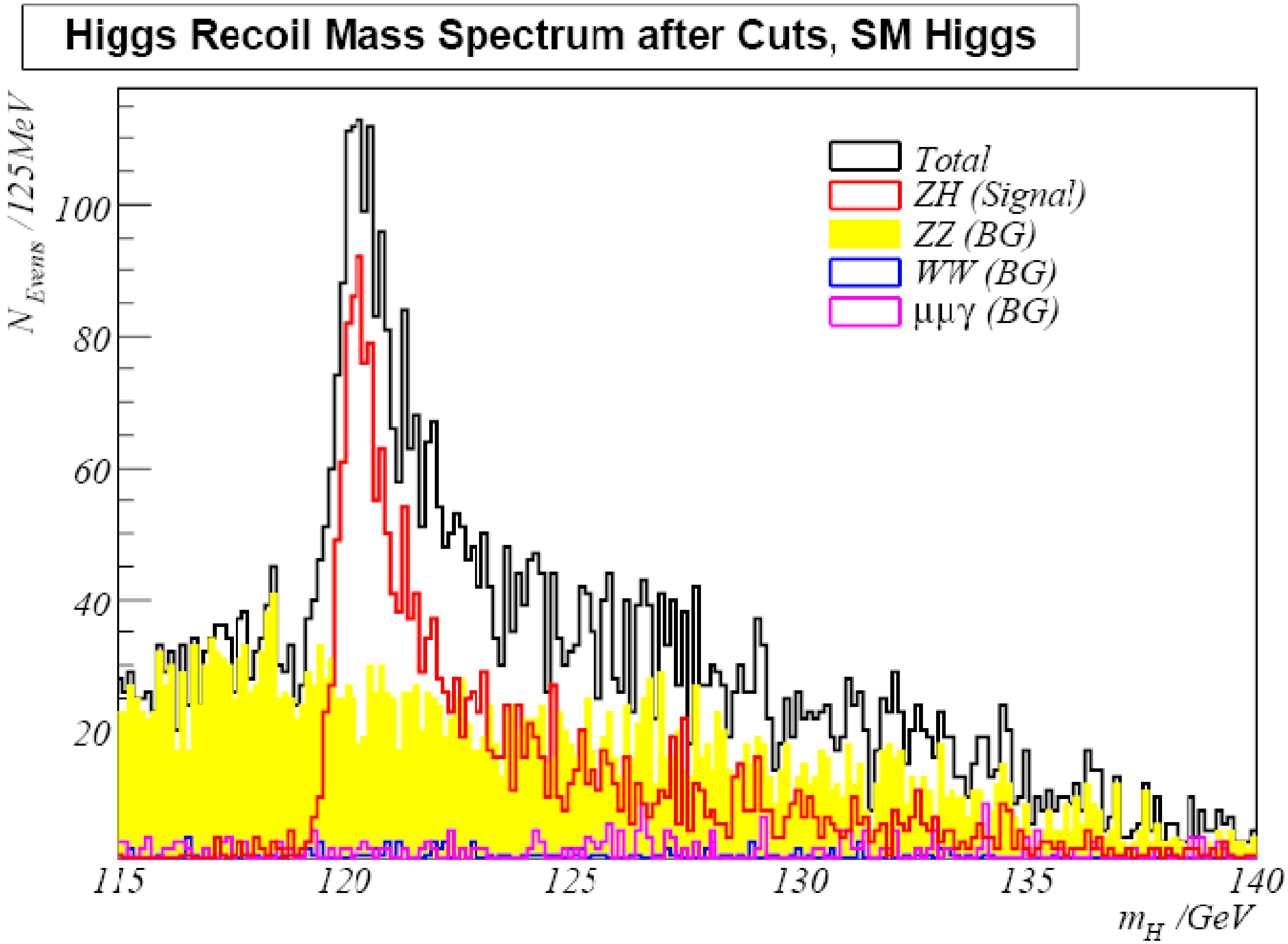


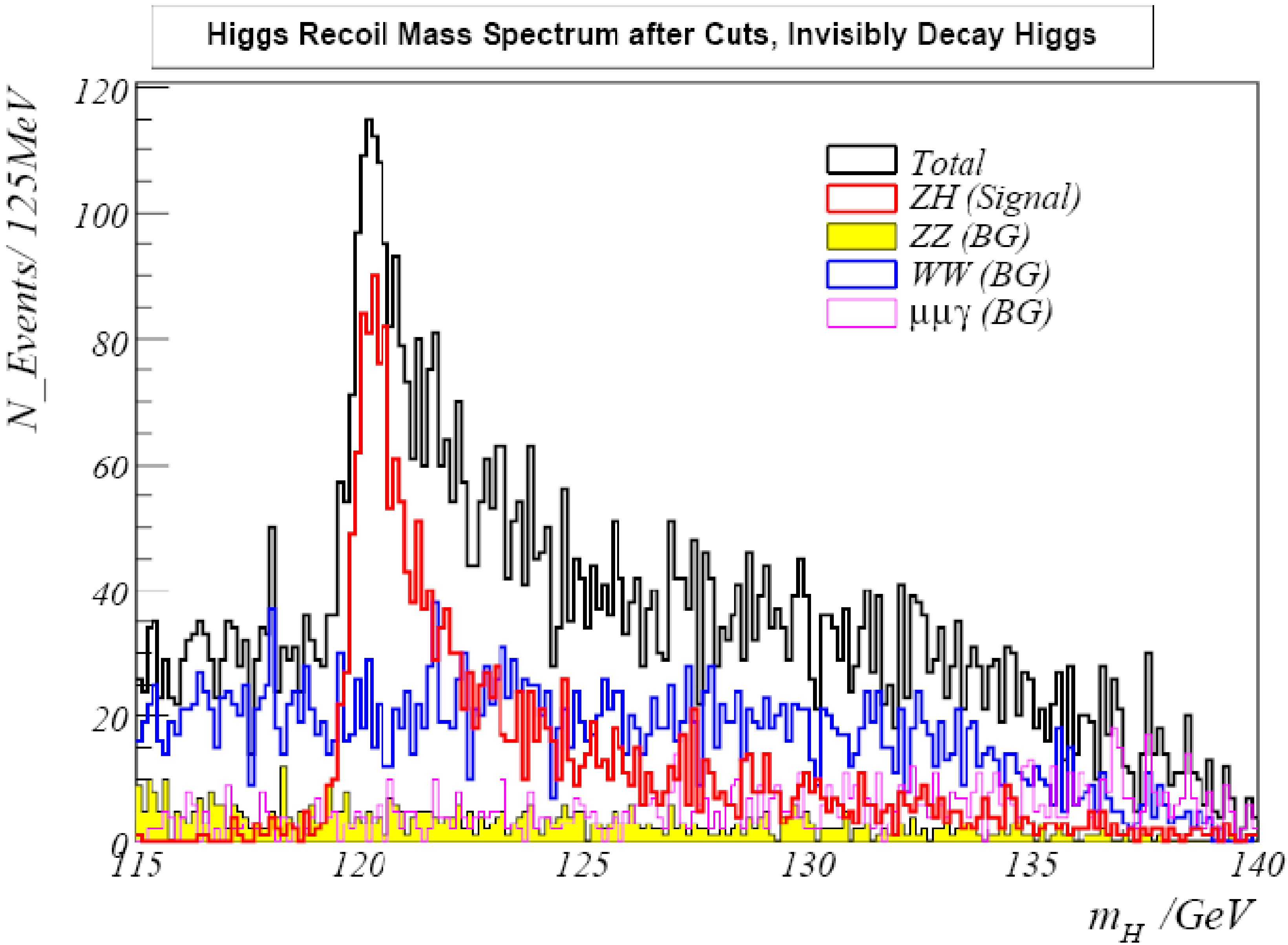


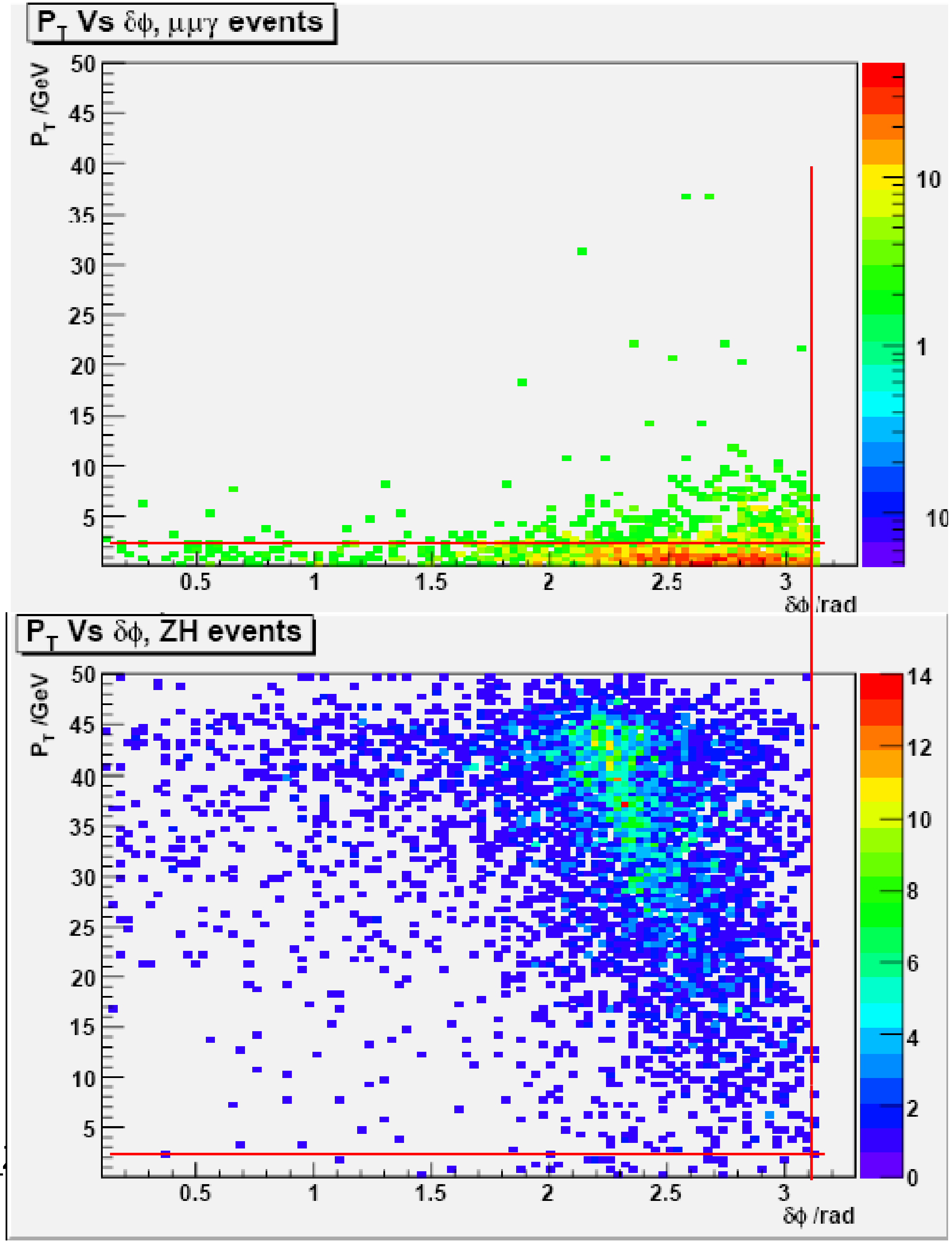
For Higgs Mass Measurement, the accuracy is improved by ~15% with using the Separate strategy; while for the cross section measurement, no obvious improve

The separate strategy achieves best resolution while 100% Higgs decay invisibly (High reconstruction efficiency)


Higgs Recoil Mass Spectrum after Cuts, Model independent analysis
N_{Events} /125MeV
140
120
100
80
60
40
20
Total
ZH (Signal)
ZZ (BG)
WW (BG)
μμγ (BG)
115
120
125
130
135
140
m_H /GeV


Higgs Recoil Mass Spectrum after Cuts, SM Higgs
N_Evens /125MeV
100
80
60
40
20
115
120
125
130
135
140
m_H /GeV
Total
ZH (Signal)
ZZ (BG)
WW (BG)
μμγ (BG)


Higgs Recoil Mass Spectrum after Cuts, Invisibly Decay Higgs
N_Events/ 125MeV
0
20
40
60
80
100
120
115
120
125
130
135
140
m_H /GeV
Total
ZH (Signal)
ZZ (BG)
WW (BG)
μμγ (BG)


P_T Vs δφ, μμγ events
P_T /GeV
δφ /rad
P_T Vs δφ, ZH events
P_T /GeV
δφ /rad