Higgs mass measurement through μ channel of Higgs strahlungs process

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

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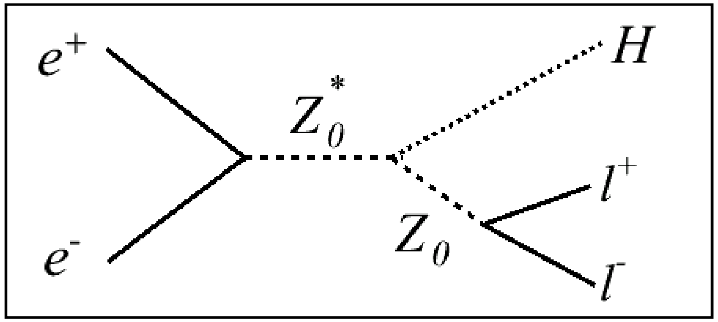
Outline

- Motivation & Software introduction
- Higgs Mass & Xsection 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 strahlungs process:

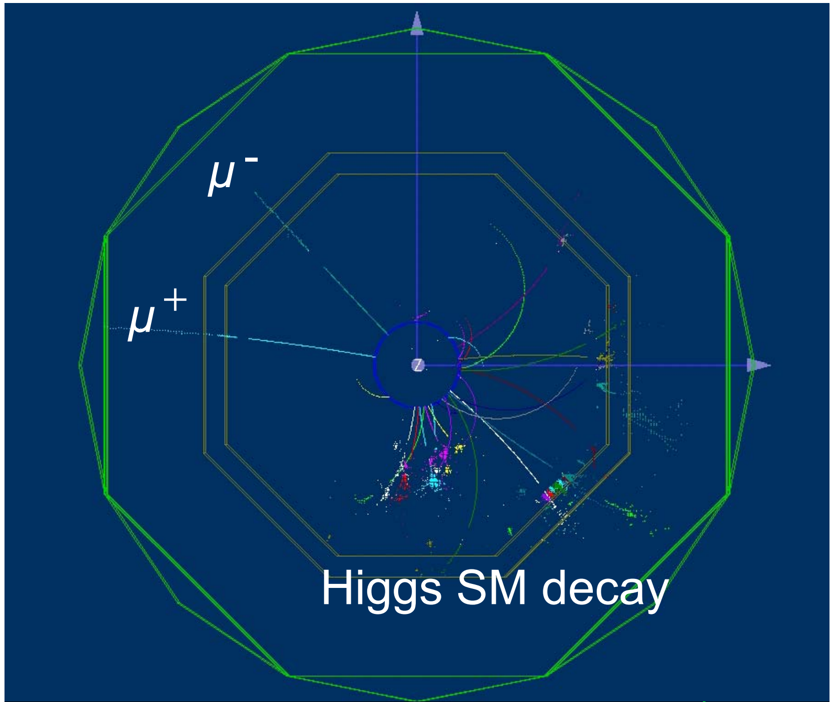


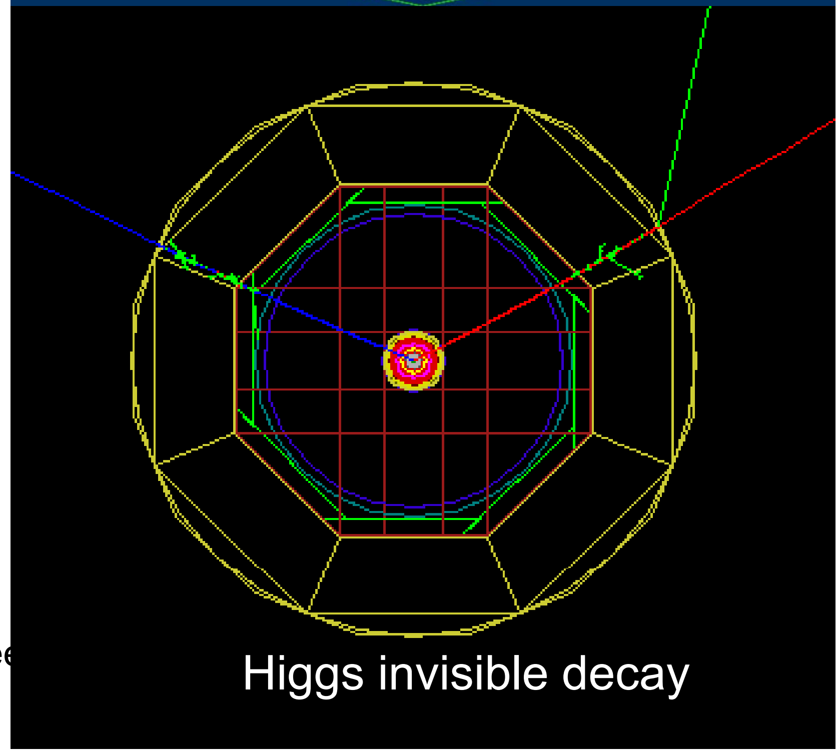
- Higgs Recoil Mass

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

- X section measurement: coupling strength

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





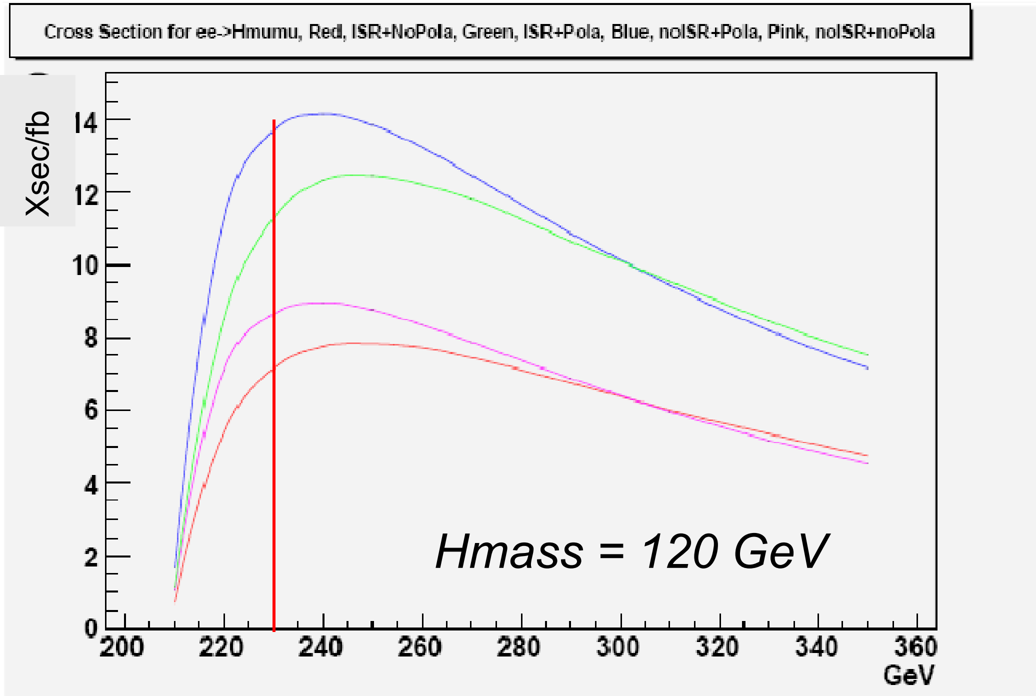
Motivation:

Why Higgs strahlung:

Only muon momentum information is needed in Higgs strahlung channel analysis

A ***model independent*** (without any assumption on Higgs decay) analysis can be applied

Any potentially model dependent cut will not be used here



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

Sqrt(s) = 230GeV:

Recall the analytic form of error on Higgs mass:

$\delta m_h^2 = \mathrm{sqrt}\{((4Ep_1-m_Z^2)p_1k(p_1))^2 + ((4Ep^2-m_Z^2)p_2k(p_2))^2\} \sim p^2$;

Small sqrt(s) means better Higgs mass resolution!

Software chain

- Generator: whizard-1.50 (for Signal), pythia 6.4.13 (for background) (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: RooFit package

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 (8M)	15.61k (7.81M)	1.155k (5.77M)
ee→qq (fb)	57.6k (28.8M)	52.2k (26.1M)	22.63k (11.3M)

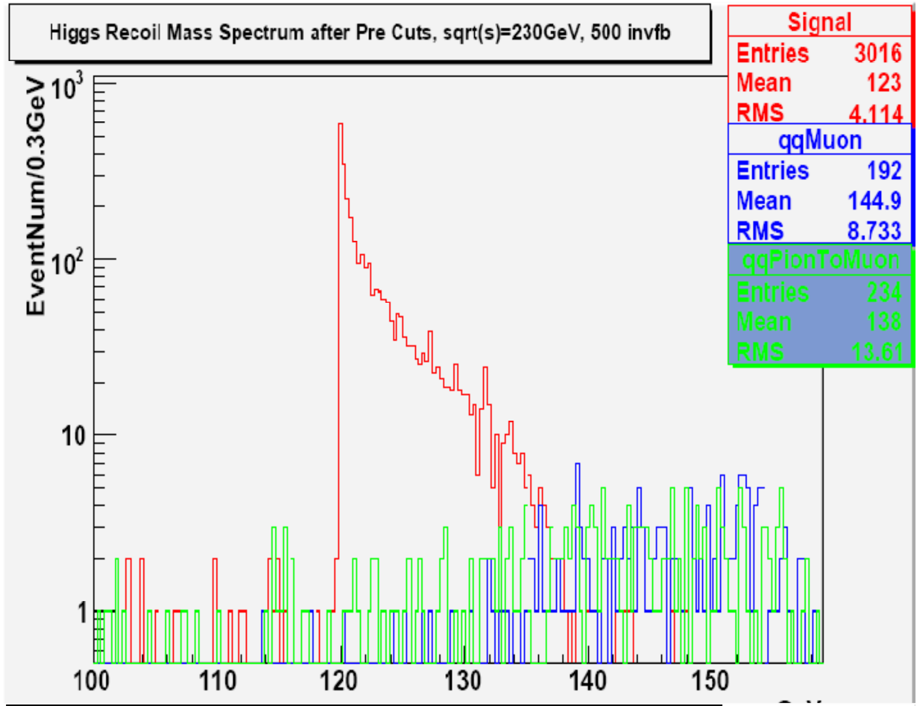
- *Huge SM Background: Pre Cuts is needed!*
  - *Energetic pion/muon (E1>15GeV) (pions are included here for the PID have a chance ~1% to misidentify the a pion as a muon)*
  - *Exist another pion/muon (with energy E2), together with the most energetic pion/muon to form a invariant mass > 70 GeV*
  - *Kinetic cut: 2E1+E2<180&&2E1+3E2>200*
  - $\cos(\theta_{mumu})>-0.95$

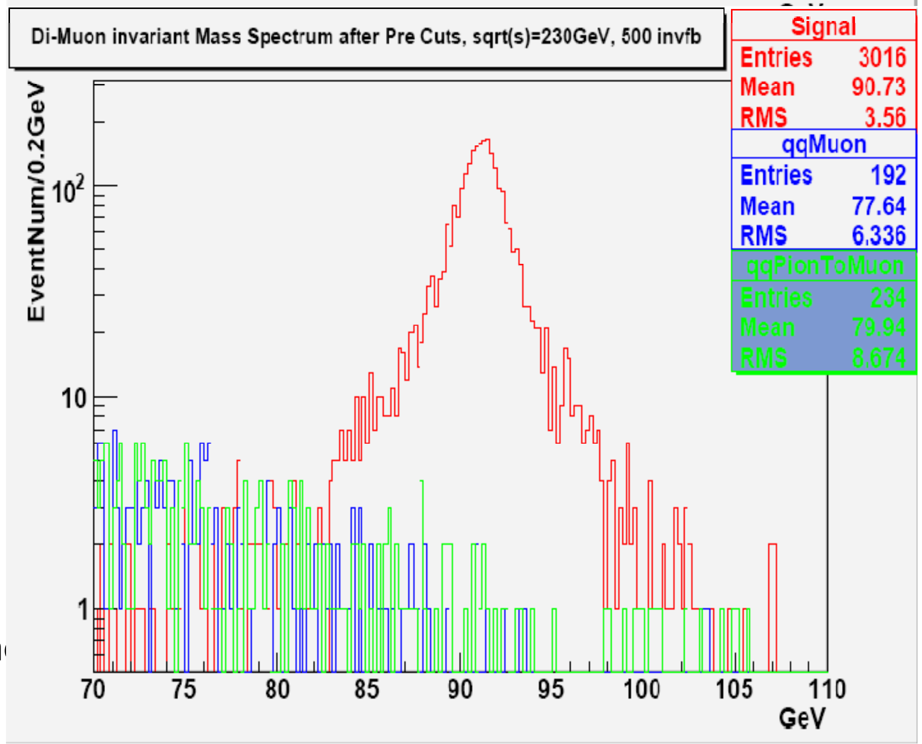
Non-Polarized beam at 500 fb^{-1}; ISR, BS actived. **no FSR yet**

qq background

- 3 Pre cuts to reduce the qq back ground
  - Energetic muons > 15GeV
  - Invariant mass of Muons > 70 GeV
  - $\cos(\theta_{mumu})$> -0.95

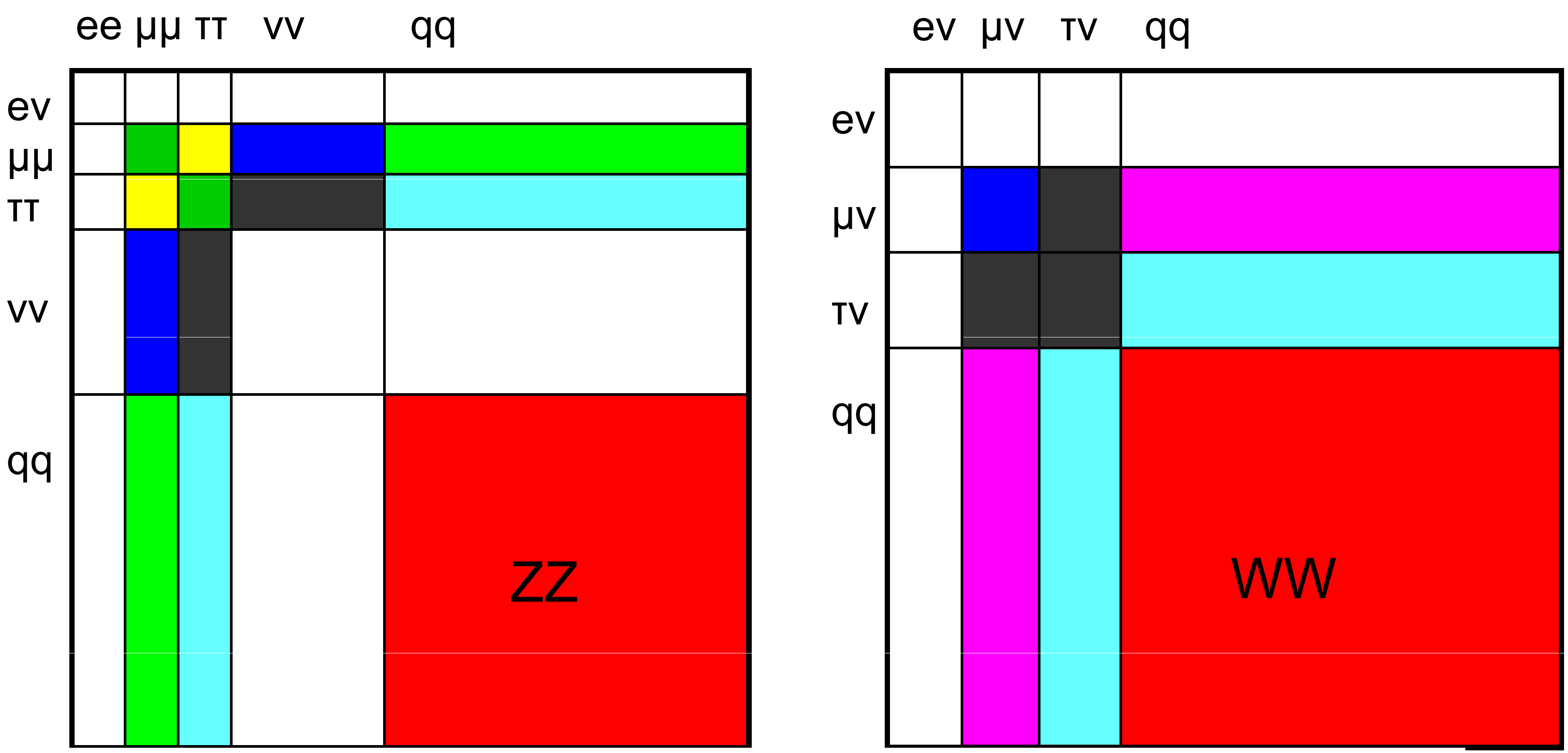
- A few hundreds qq Events survive, far from signal region (115 -140GeV): qq back ground vanishes after pre cut selection





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

Cuts Chain for model independent analysis

	ZH	ZZ	WW
Total event num at 500 fb^{-1}	3310	672k	8M
Expected event num after preCuts	3.0k	17.3k	96.6k
Reconstructed event num after recover precut	2365	8132	4335
$\|cos(\theta)\|<0.99$	2363	8123	4329
Event num in signal region (115-140GeV)	2351	2176	2583

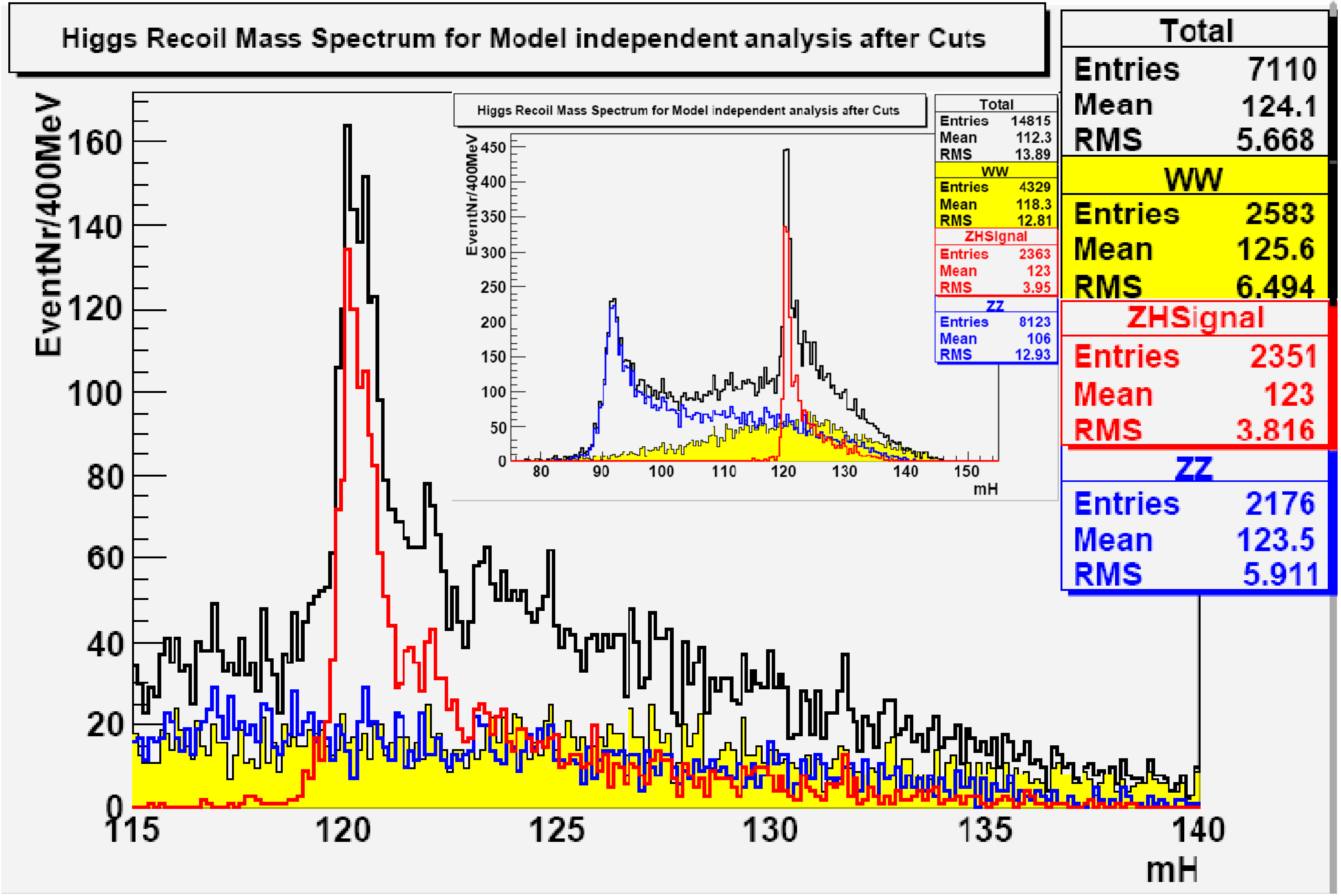
Recover pre cuts with more strict cuts:

$E_1>15$
$2E_1+E_2<180 \&\& 2E_1+3E_2>200$
$cos(\theta_{mumu})>-0.95$
$m_Z>70$

→

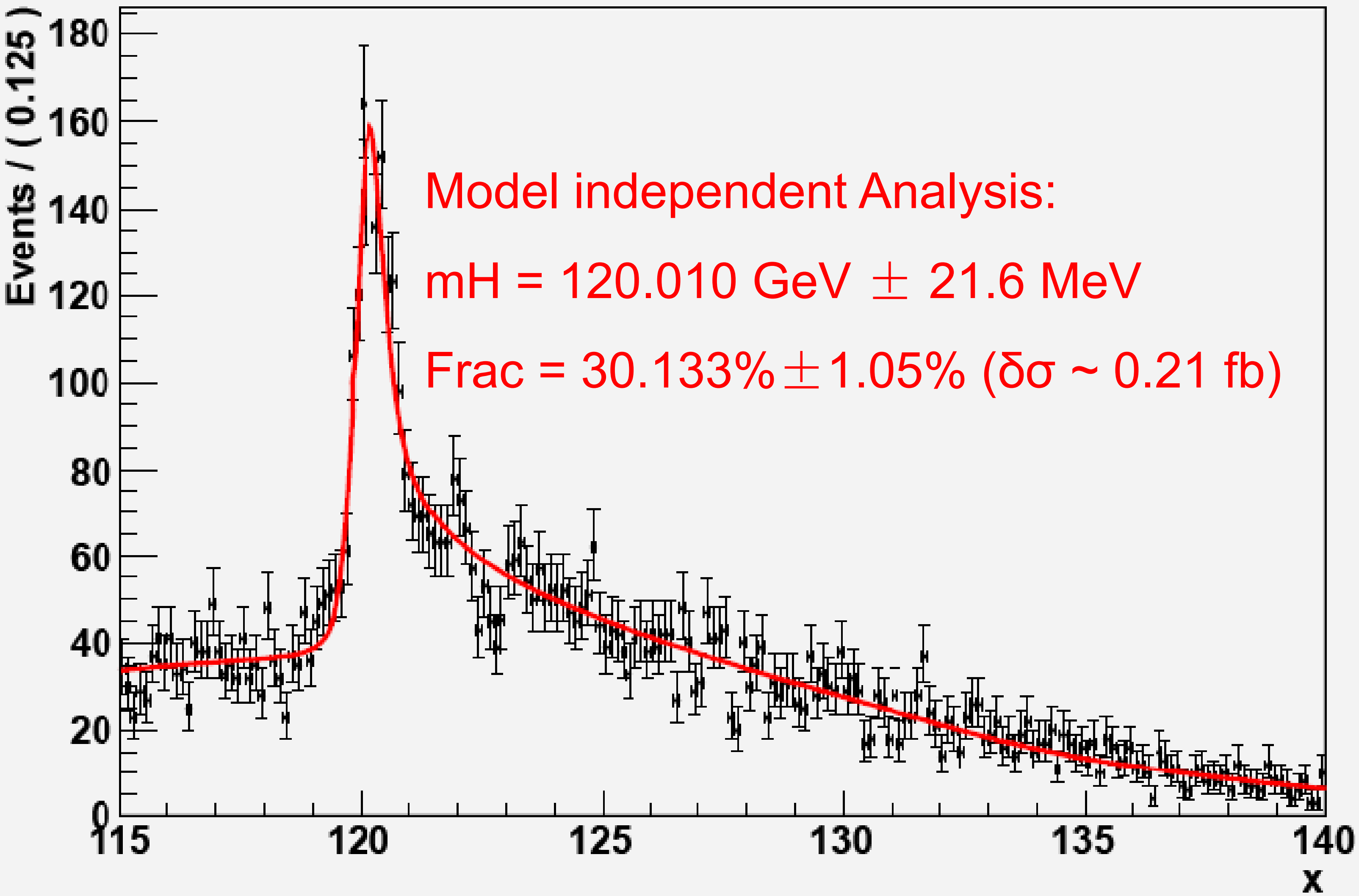
$E_{mu}>20$
$2E_1+E_2<178 \&\& 2E_1+3E_2>202$
$cos(\theta_{mumu})>-0.95$
$|m_Z-m_{lepton}|<10$

S+B locate at signal region & Gaussian BK



Fit 2 parameters with likelihood method : mH & Fraction

Likelihood fit of Fraction & Higgs Mass for Model independent analysis



Separate Higgs invisible/SM decay

- By a simple judgment on multiplicity, 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*

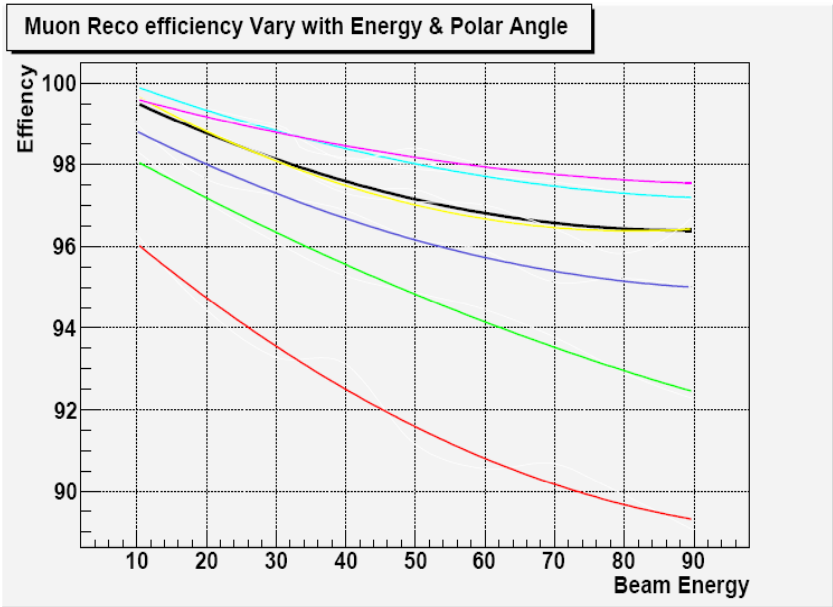
- If N_track < 4, (Higgs invisible decay), no pre cut

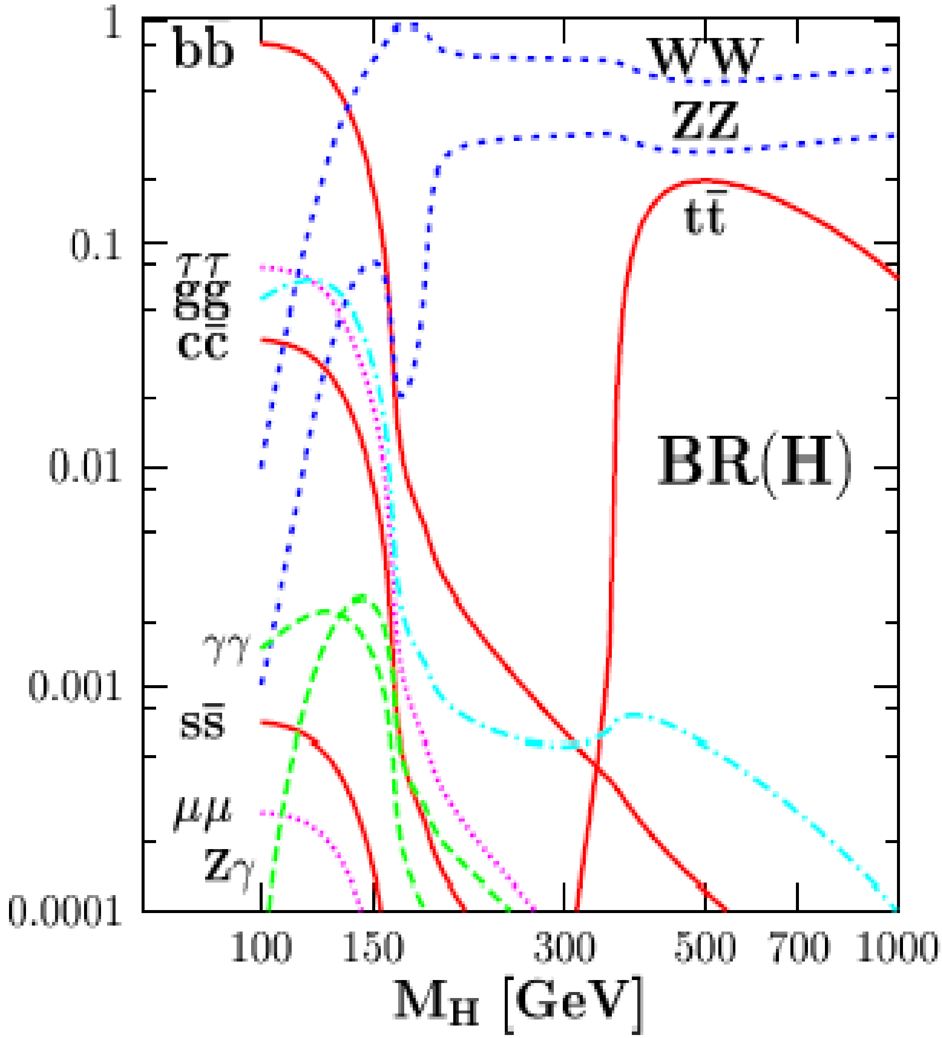
- If N_track > 3, (SM Higgs decay), apply the previous pre cuts & cut chain

- Combine the result from SM/invisible Higgs assumption together

Higgs SM decay

Current muon id efficiency ~ 93.6%
purity ~ 99% (O.Martin, RDR)





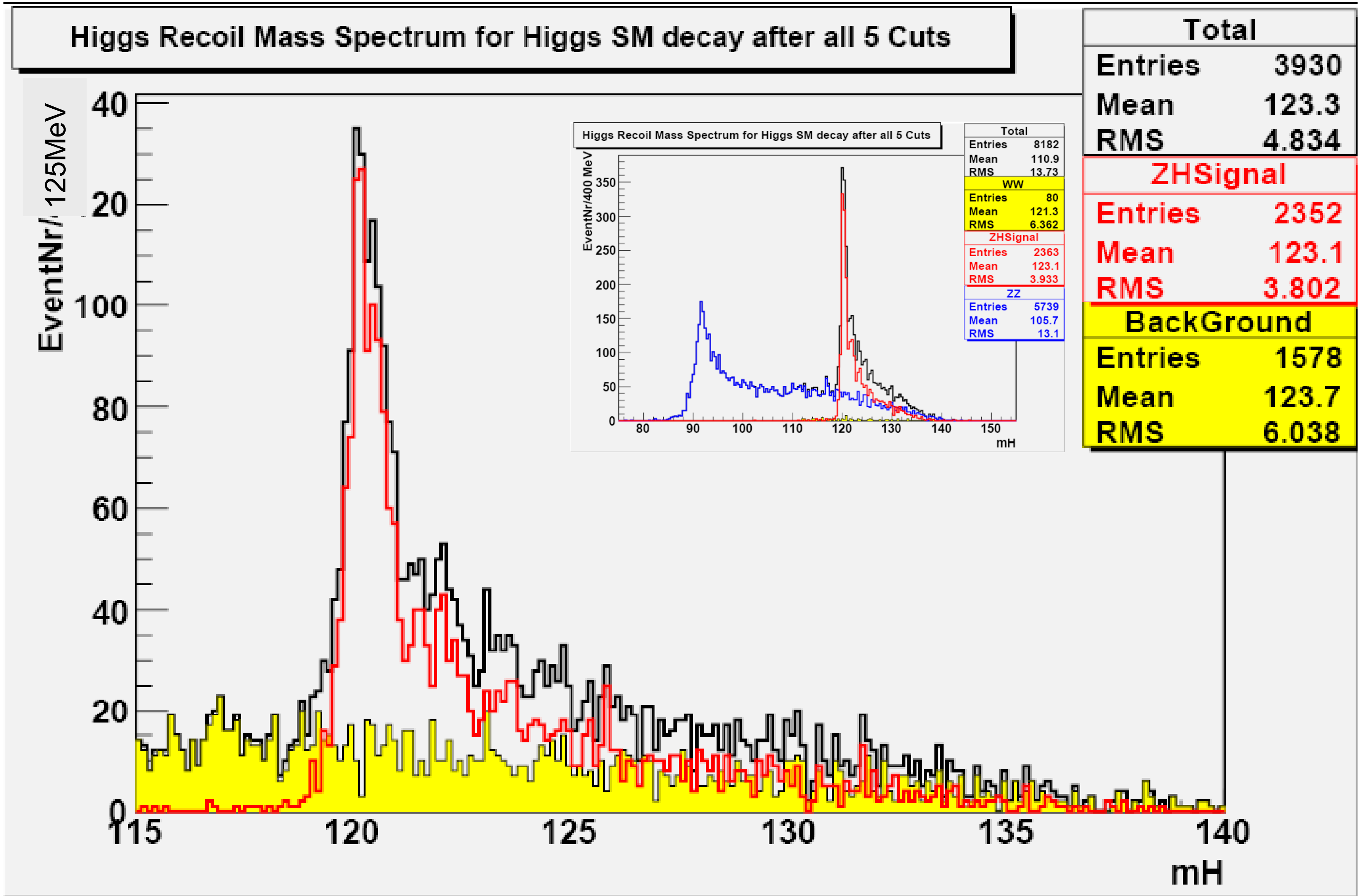
Cuts Chain in Higgs SM decay

	ZH	ZZ	WW
Total EventNum at 500 fb^{-1}	3310	672k	8M
Precut & Both muon identified	2714	8638	400
$\lvert\cos(\theta)\rvert<0.99$	2710	8621	400
$E_{mu}>20$	2693	8531	318
$2E_1+E_2<178 \&\& 2E_1+3E_2>202$	2672	7218	289
$\cos(\theta_{mumu})>-0.95$	2462	7022	259
$\lvert m_Z-m_{lepton}\rvert<10$	2363 (71.4%)	5739	80

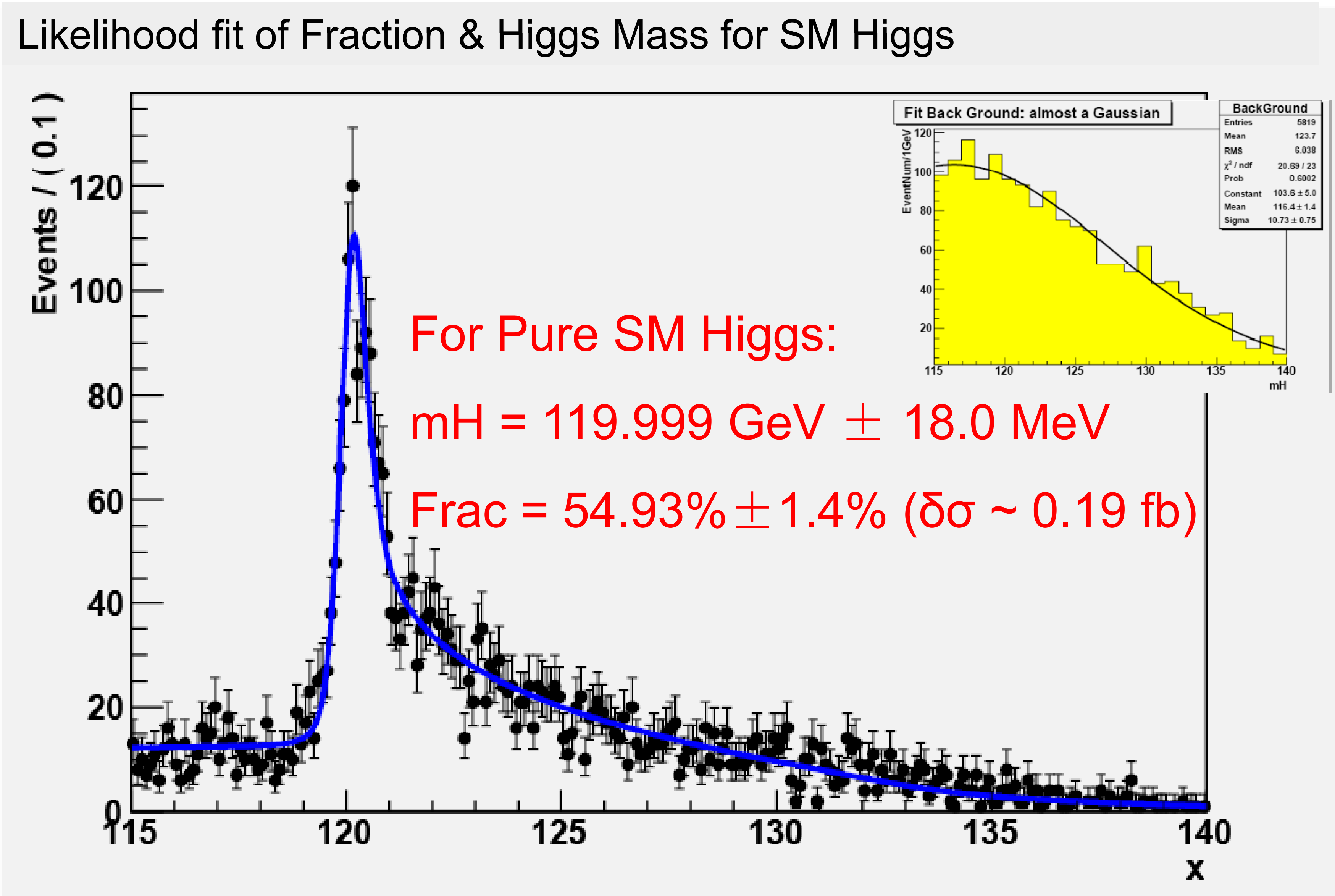
Require both muon be identified will reduce our efficiency by ~17%, but also reduce greatly the back ground → a muon is more easily to be misidentified in forward region

Cut applied on the reconstructed data is more strict than the pre cut at MC truth level

S+B after cuts & Gaussian like background



Fit 2 parameters with likelihood method : mH & Fraction



Higgs Invisible decay

Exotic Model beyond SM:

SUSY ?

Extra dimension ?

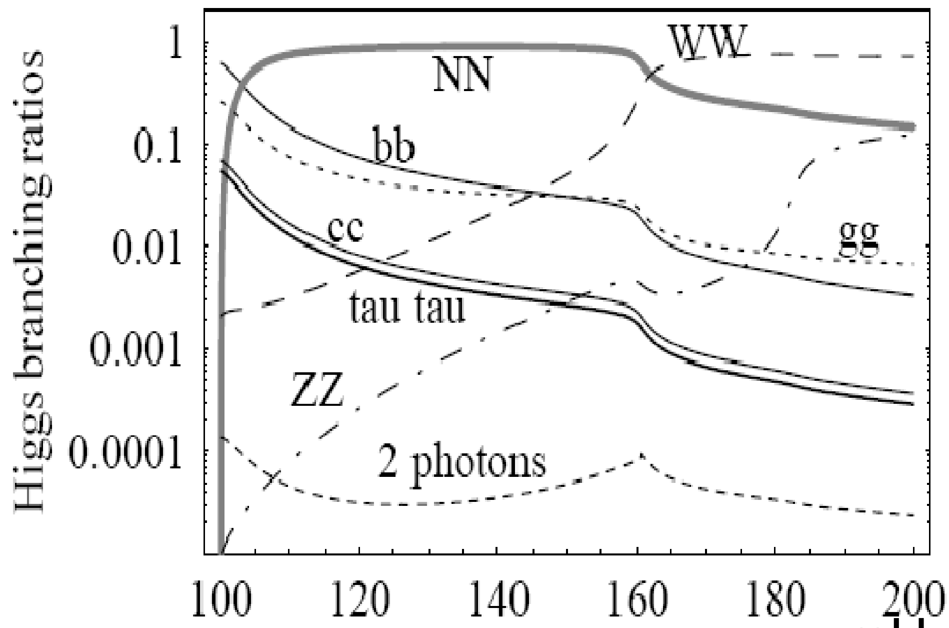
Heavy neutrino ?

...

Main background

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

not require both muon identified to save statistic



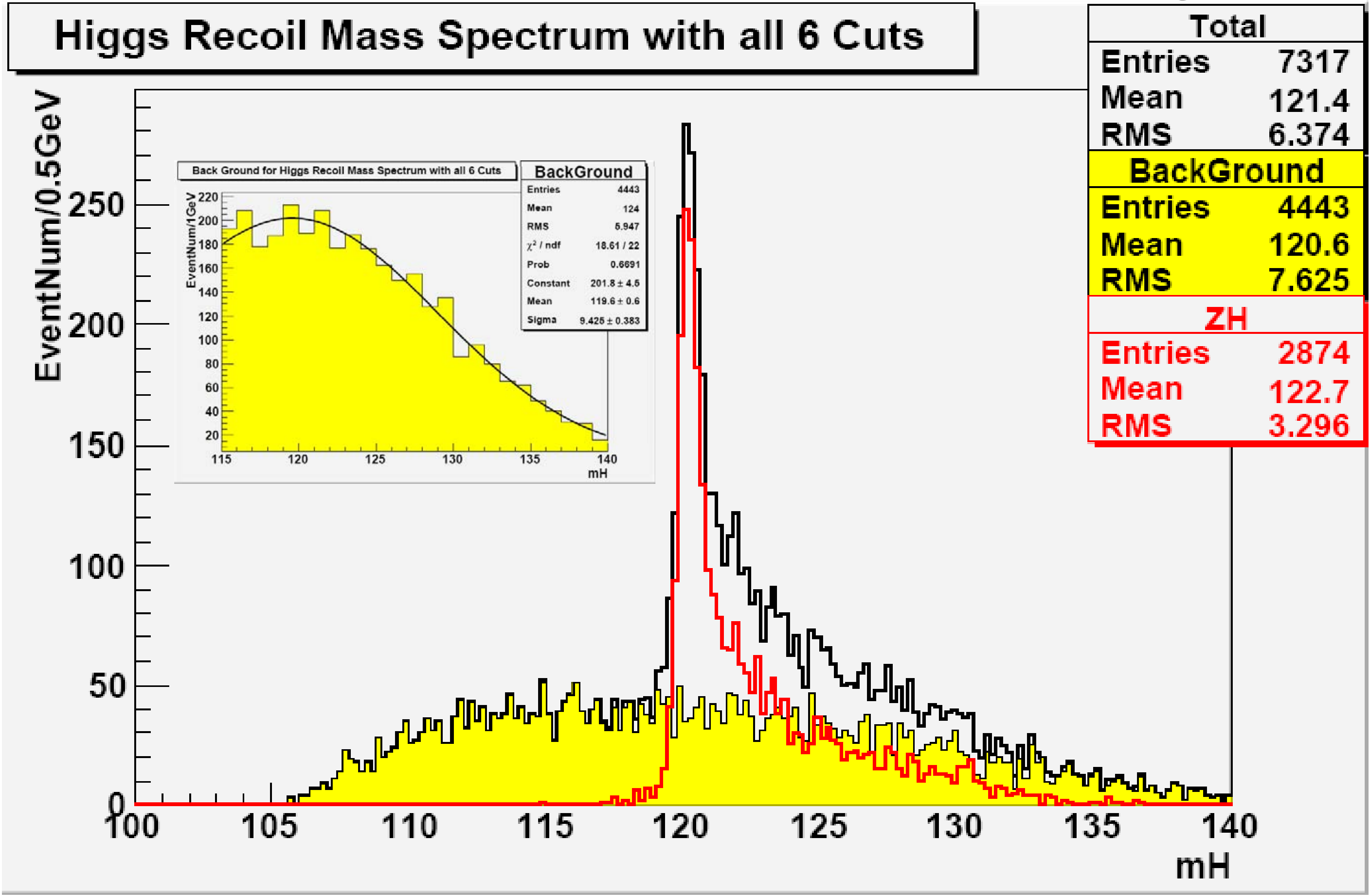
Higgs Decay Br with a forth neutrino with mass = 50 GeV

K.Belotsky hep-ph/0210153 (2002)

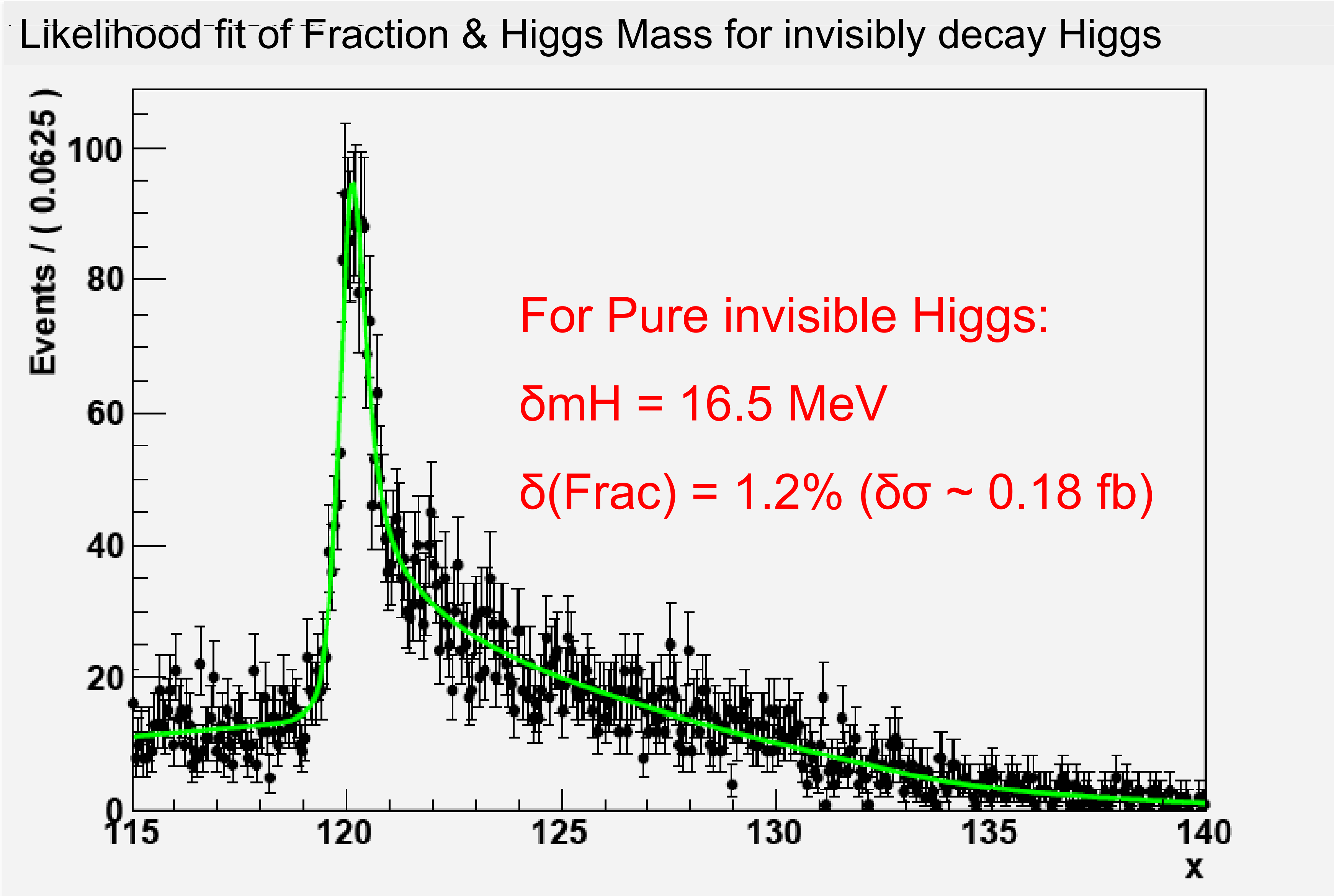
Cuts Chain in Higgs invisible decay

	ZH	ZZ	WW
X Section (fb)	6.62	15.42	207.96
Total EventNum at 500 fb^{-1}	3310	7710	103980
Reconstructed event num & efficiency (with mH resolved)	3260 (98.5%)	7614 (98.8%)	96661 (93.0%)
$\|\cos(\theta)\|<0.99$	3230 (97.6%)	7566 (98.1%)	96157 (92.5%)
$\|m_Z-m_{lepton}\|<10$	3091 (93.4%)	7134 (92.5%)	11570 (11.1%)
$E_{mu}>20$	3091 (93.4%)	7129 (92.5%)	11570 (11.1%)
$\cos(\theta_{mumu})<-0.4$	3091 (93.4%)	4765 (61.8%)	6868 (6.61%)
Total energy<110	3086 (93.2%)	1762 (22.9%)	4827 (4.64%)
Cut on W mass resolve: (2<Ratio<4)	2874 (86.8%)	1165 (15.1%)	3278 (3.15%)

S+B after cuts & Gaussian like background



Fit 2 parameters with likelihood method : mH & Fraction



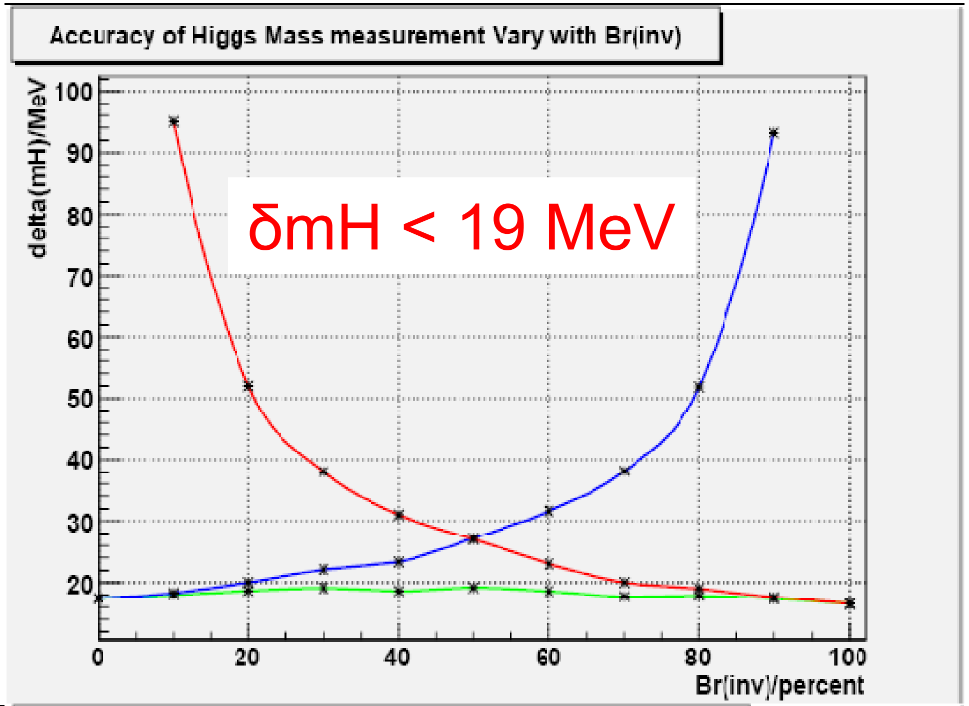
For arbitrary Br(inv)

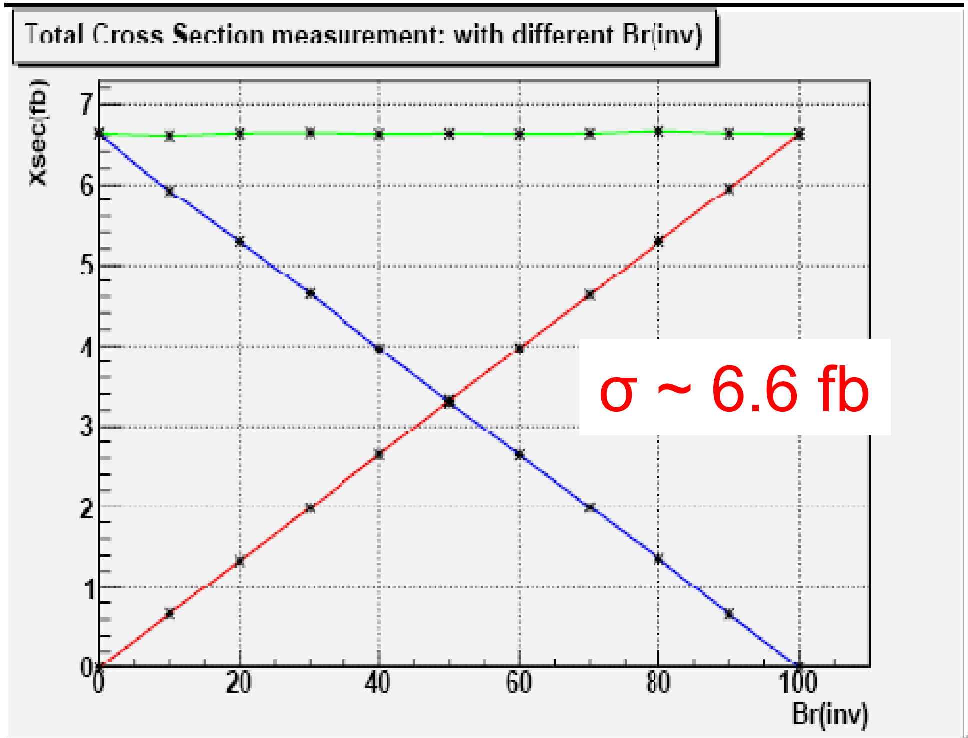
Combination the result from Higgs invisible and visible decay (Br(inv) + Br(visible) =100%)

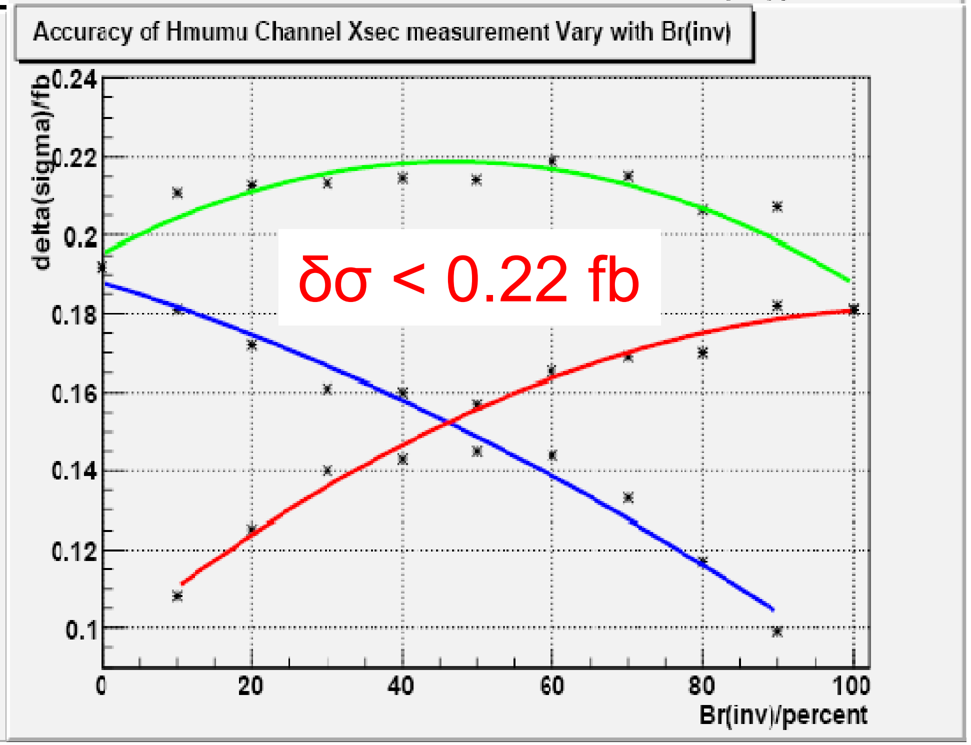
Red, invisible part contribution

Blue, visible part contribution

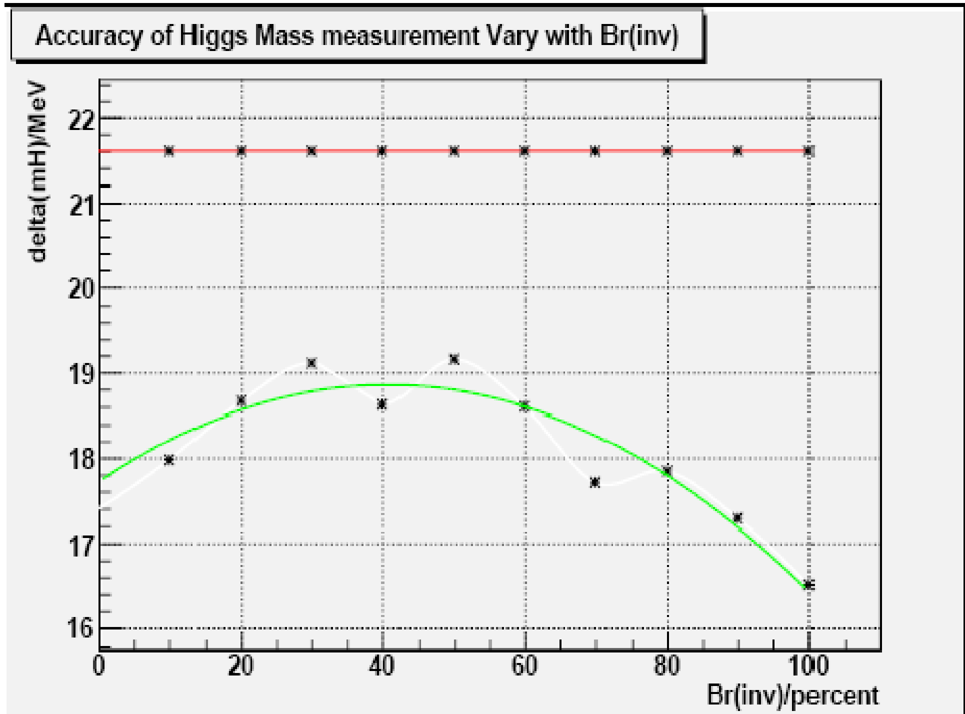
Green, overall result

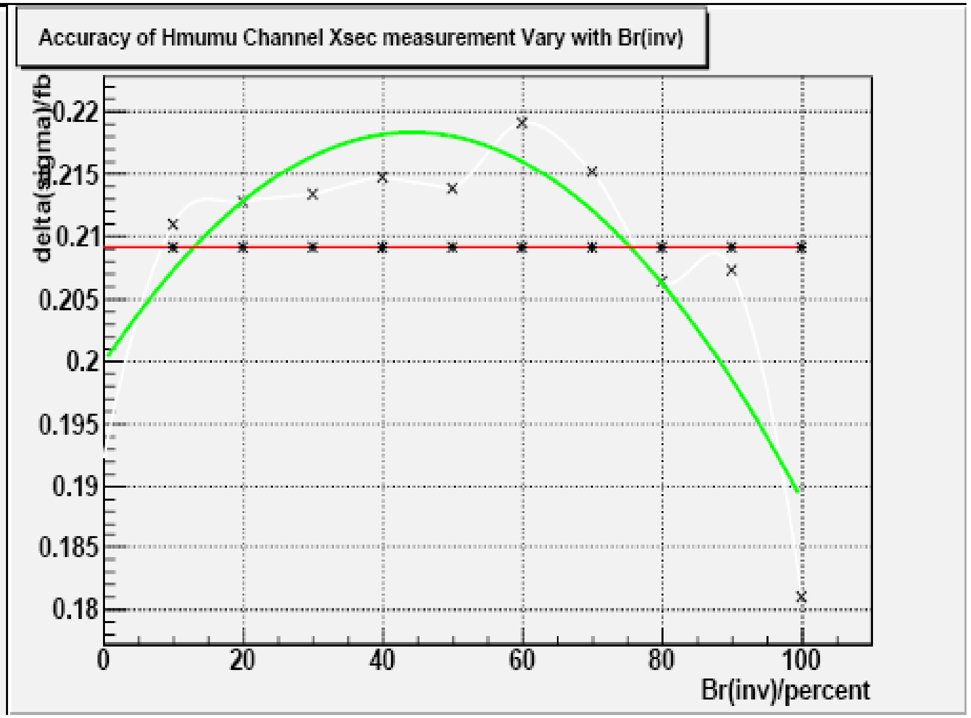






Comparison on effect of different analysis strategy





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)

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 with 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
B_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

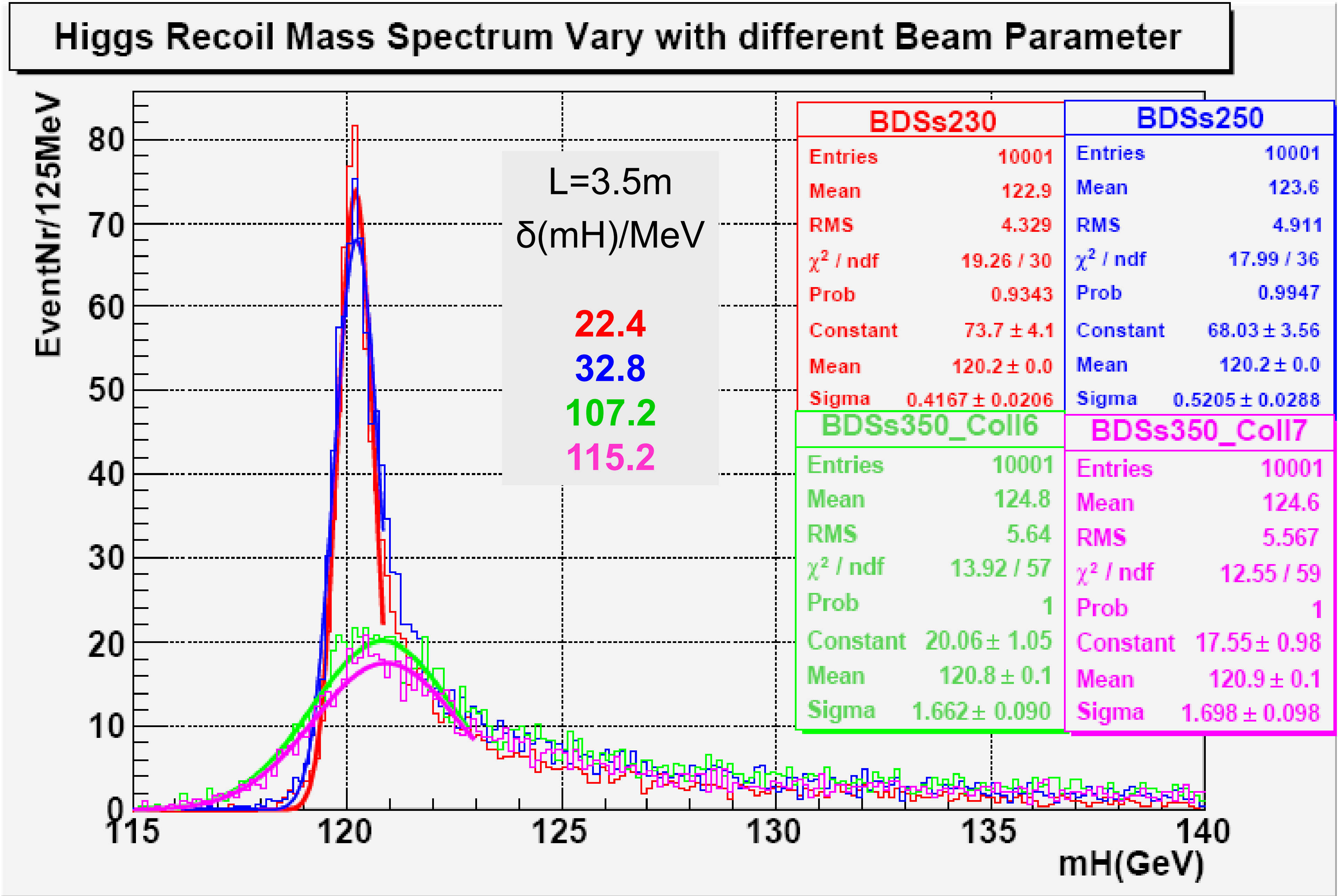
Machine time had been set to make Nominal beam (500GeV) reach an integrated Luminosity be 500 fb^{-1}

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

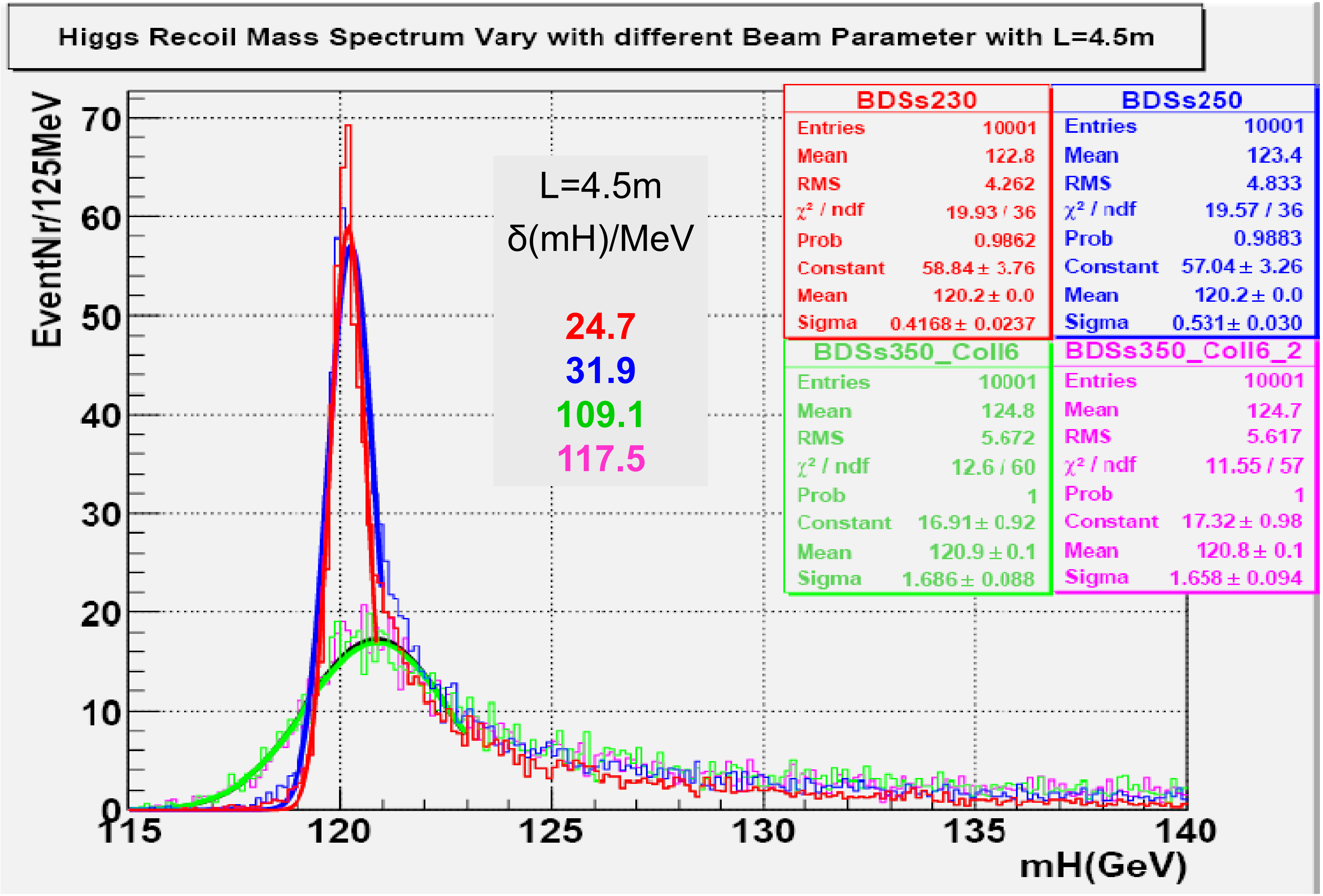
ColliX: Collimator depth X, always bigger than 6

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 & BS) with an integration luminosity of 500 fb^{-1}

- Two strategies had been applied:
  - Model independent Higgs mass measurement: δ(mH) = 22MeV
  - Treat SM/Invisible decay Higgs separately: δ(mH) could be measured better than 19MeV.
  - Cross section measure to 3% level for both strategies
  - Overall reconstruction efficiency is 71.4% for SM Higgs decay case (same for model independent analysis), and 86.8% for Higgs invisible decay

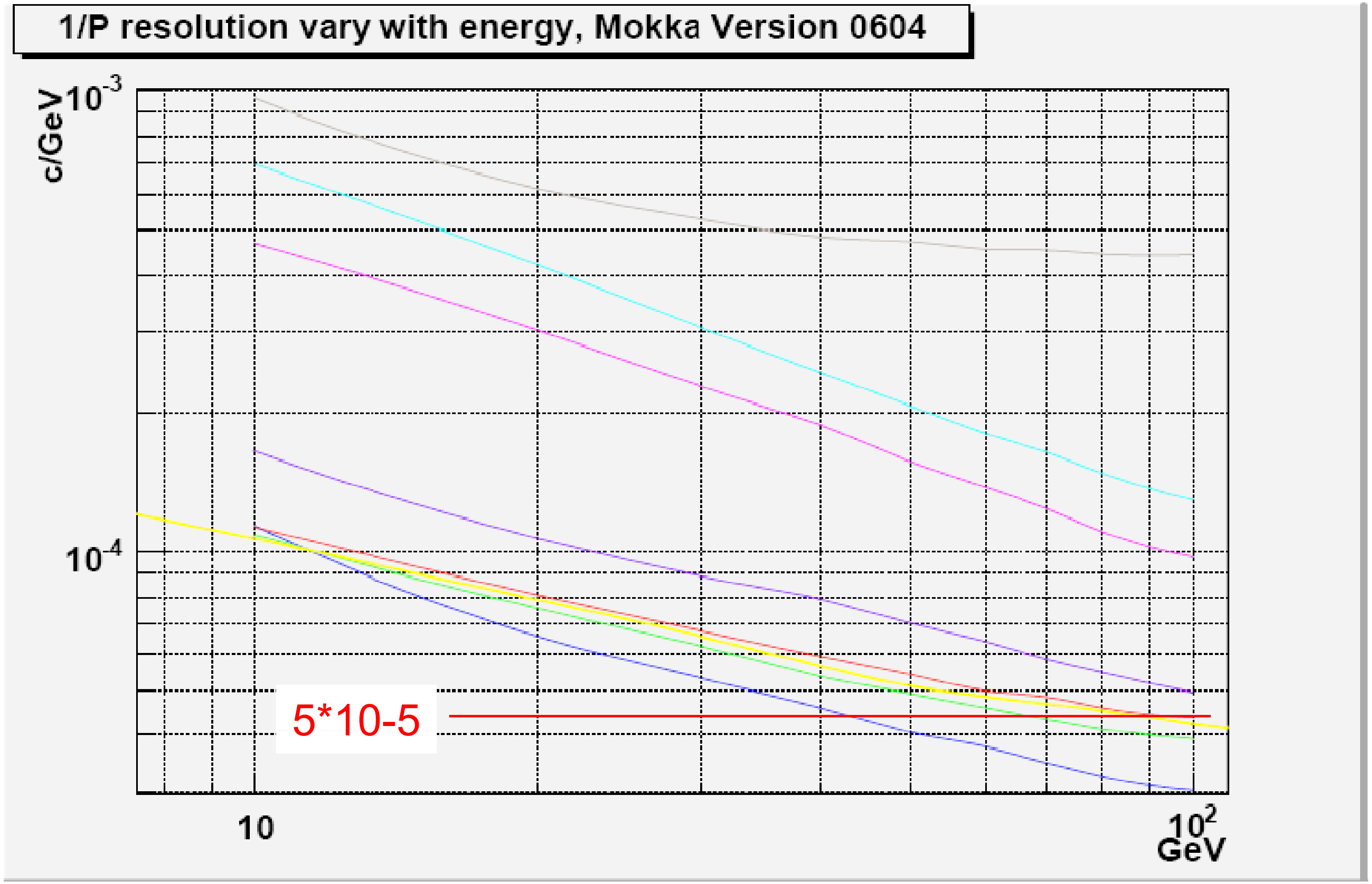
- It is foreseen to improve a lot with beam polarization for it will not only reduce the WW background but also increase ~58% the cross section of Higgs strahlung channel (electron, 80%, positron, 40%).

- To do: adding the FSR effect, background from ZH events (with H→bb→mumuX, etc.) & further optimization for the Cuts

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

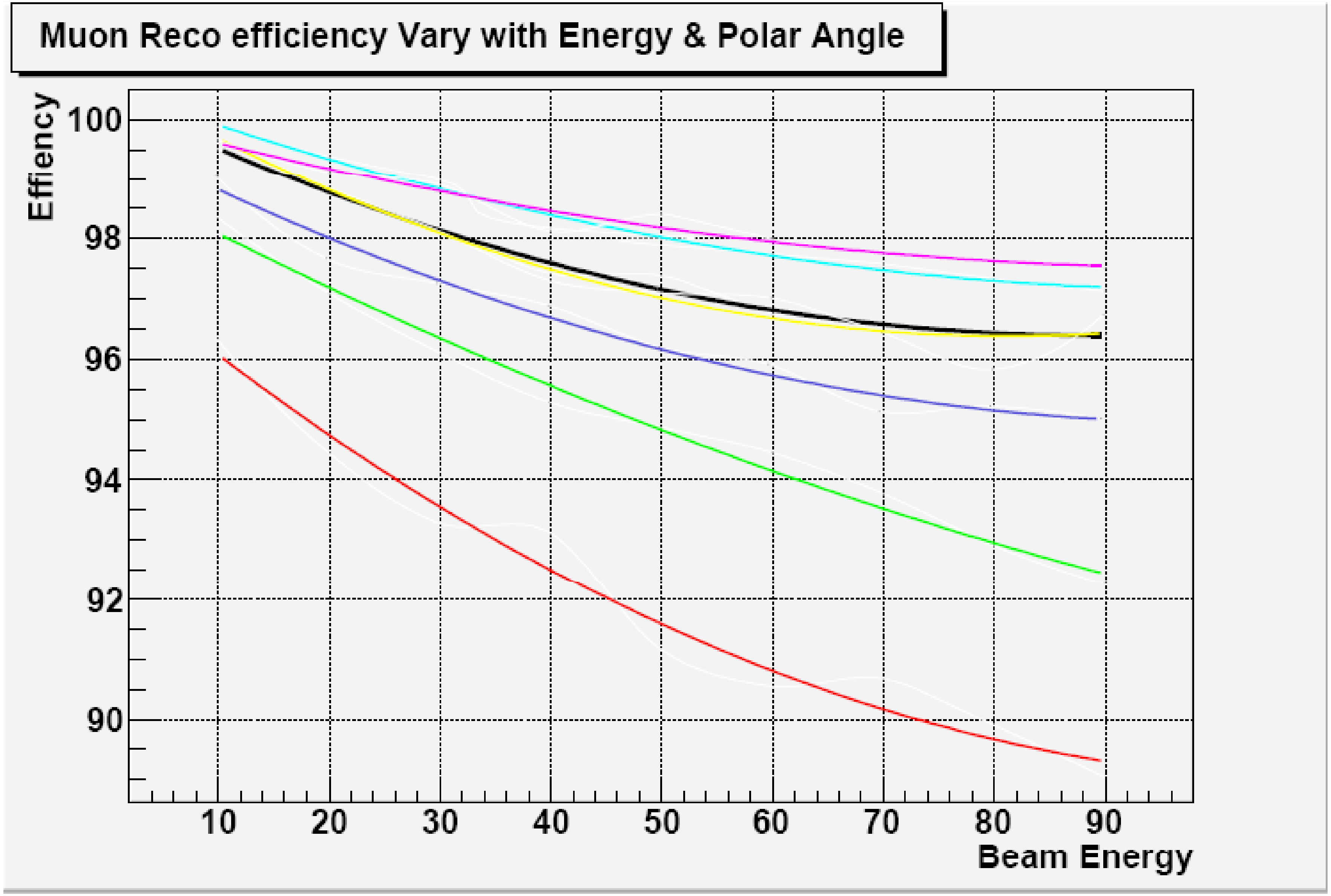
Back up

Momentum resolution vary with energy: 10°, 15°, 20°, 30° ,40°, 60°, 80° polar angle: yellow curve is the Fast simulation result from M.Berggren

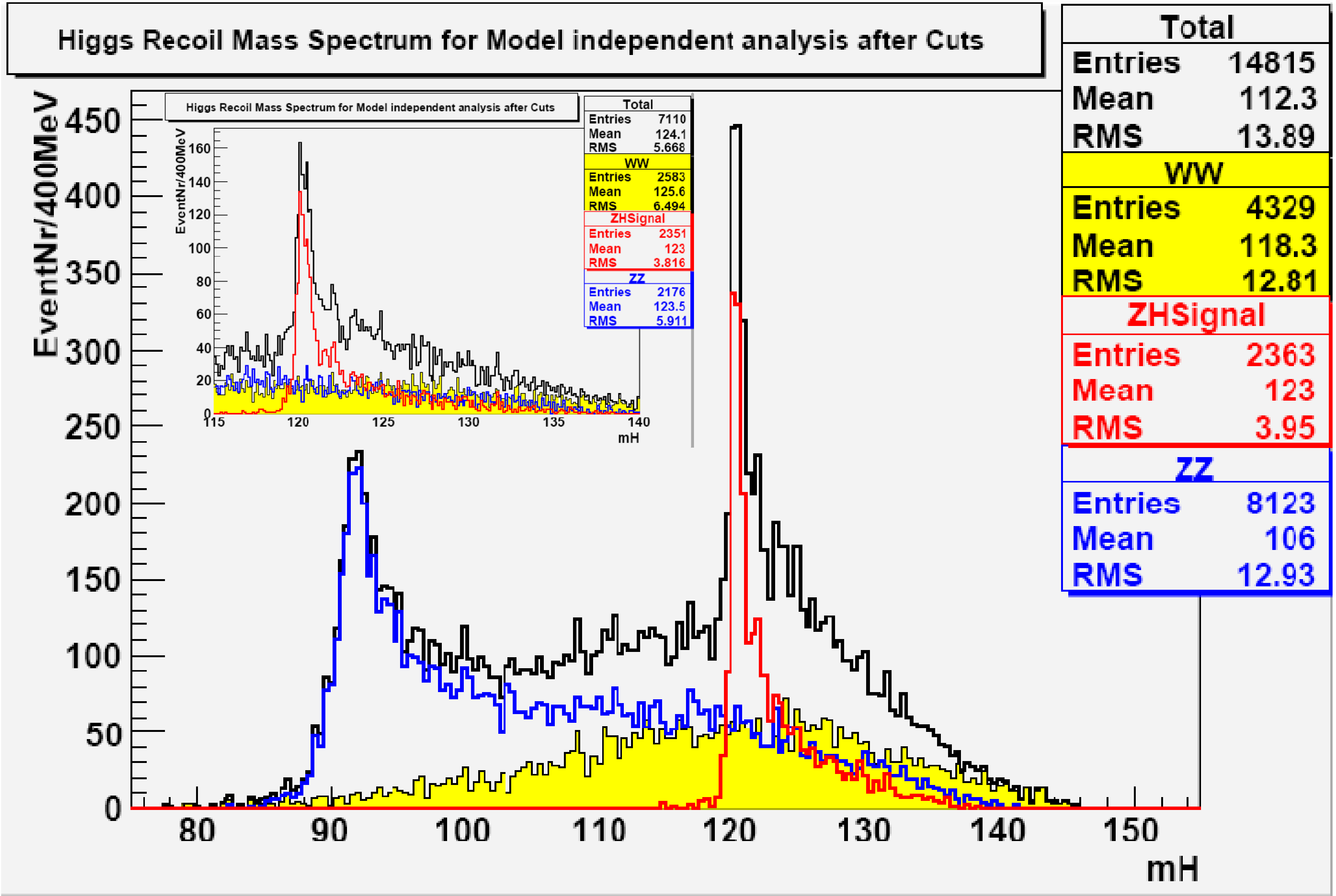


- Thanks to hengne's work on the SIT radiation length, we have gain a factor of 5% improvement in the mu momentum resolution ☺

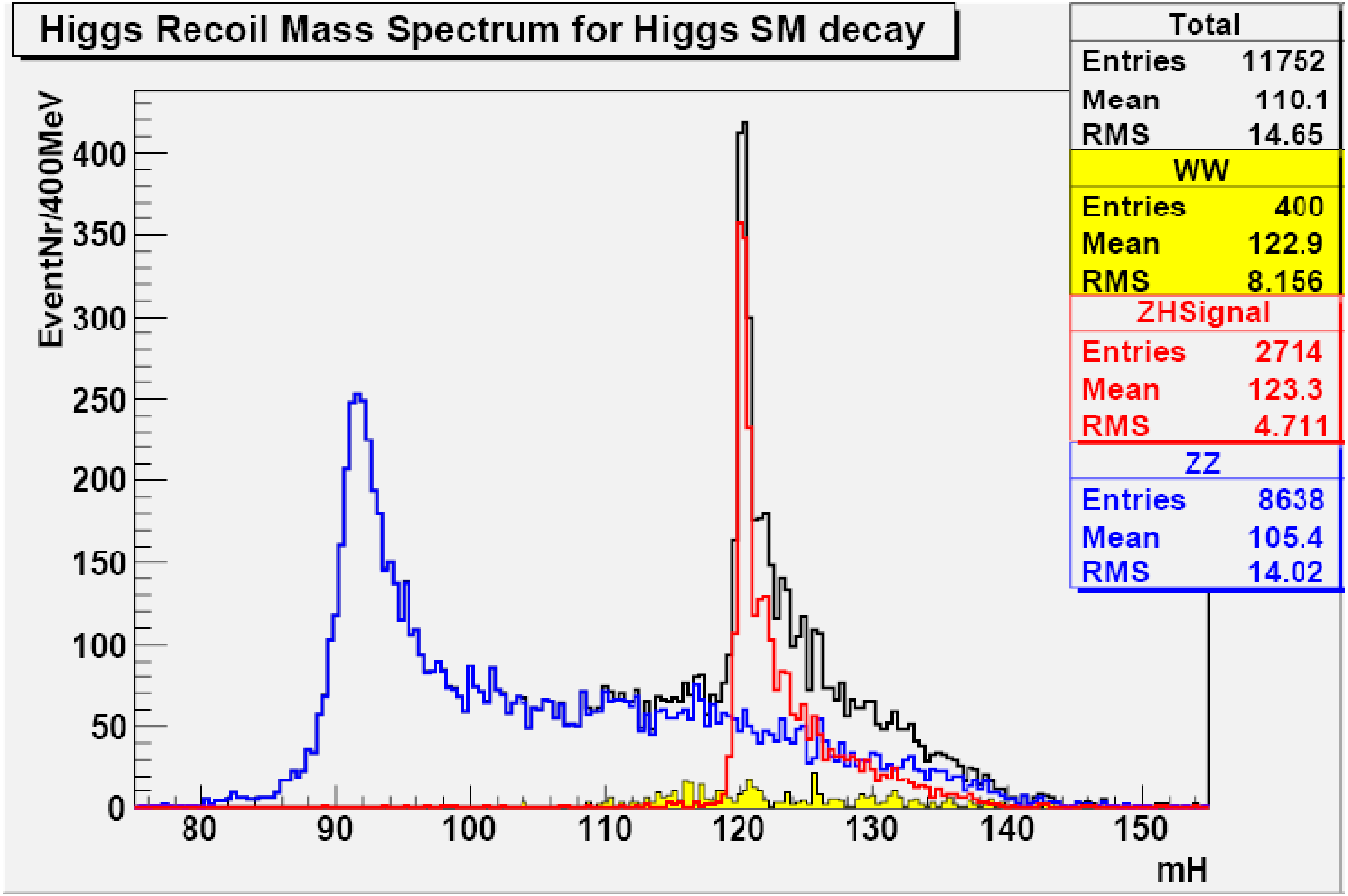
Efficiency vary with energy & Polar angle (10, 15, 20, 30, 40, 60, 80 Degree)



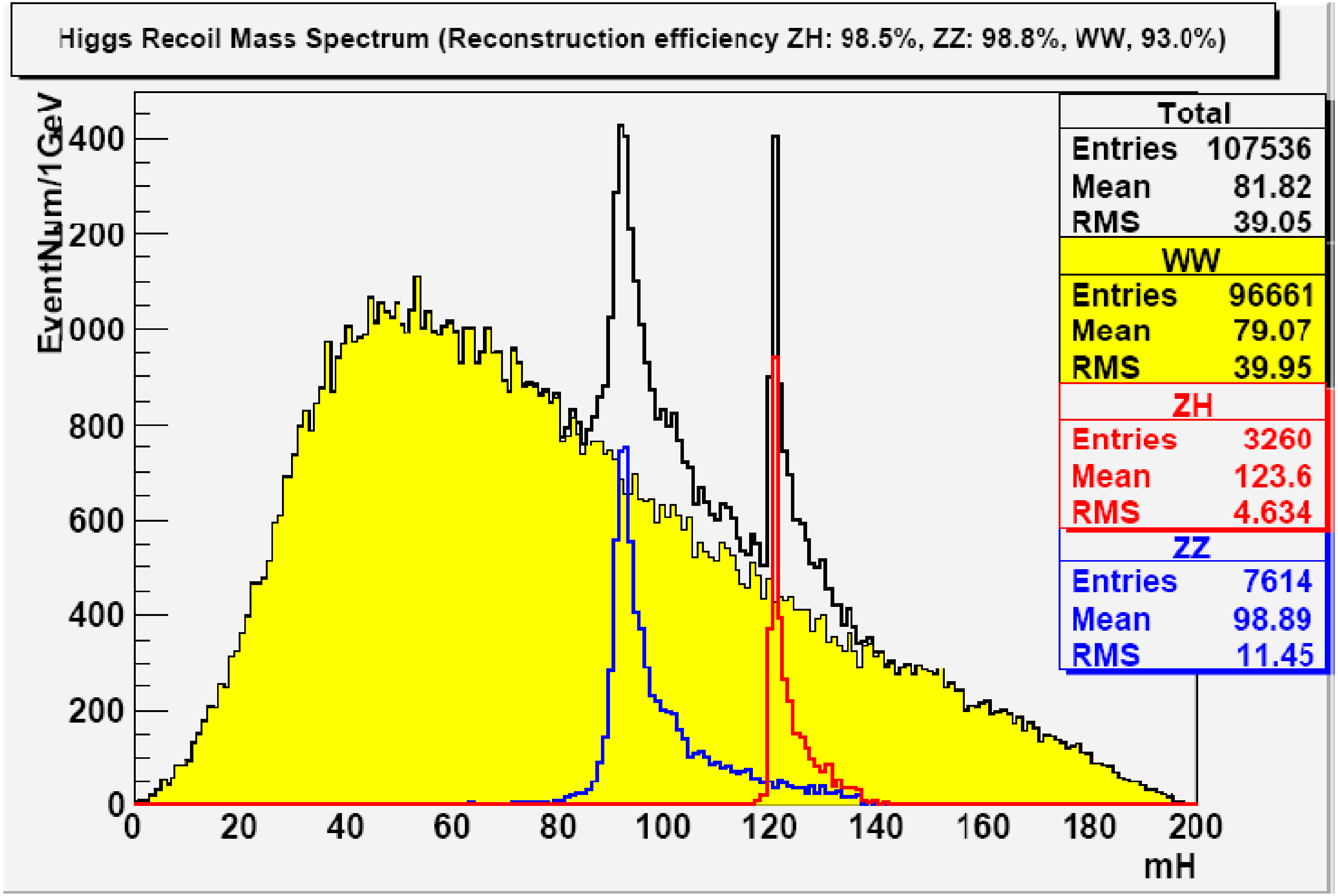
S+B for model independent analysis



S+B for Higgs SM decay. Br(SM)=100%



S+B for Higgs invisible decay. Br(inv)=100%



Fit Algorithm

- Generate 2 samples with mH=119GeV and mH=121 GeV assumption (currently 10k statistic each).

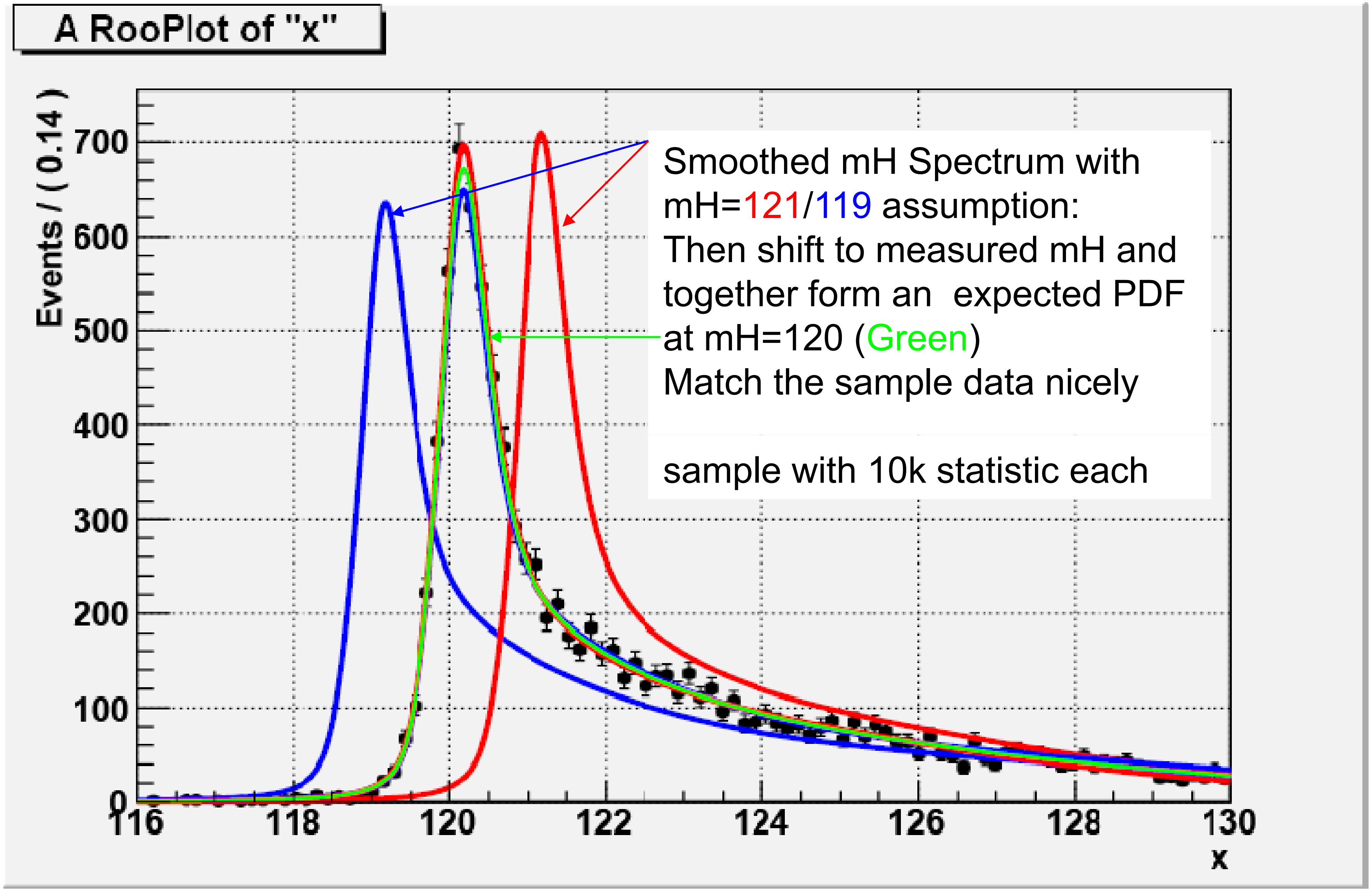
- Getting PDF f(119,m), f(121,m): smooth the Higgs recoil mass spectrum to a PDF function.

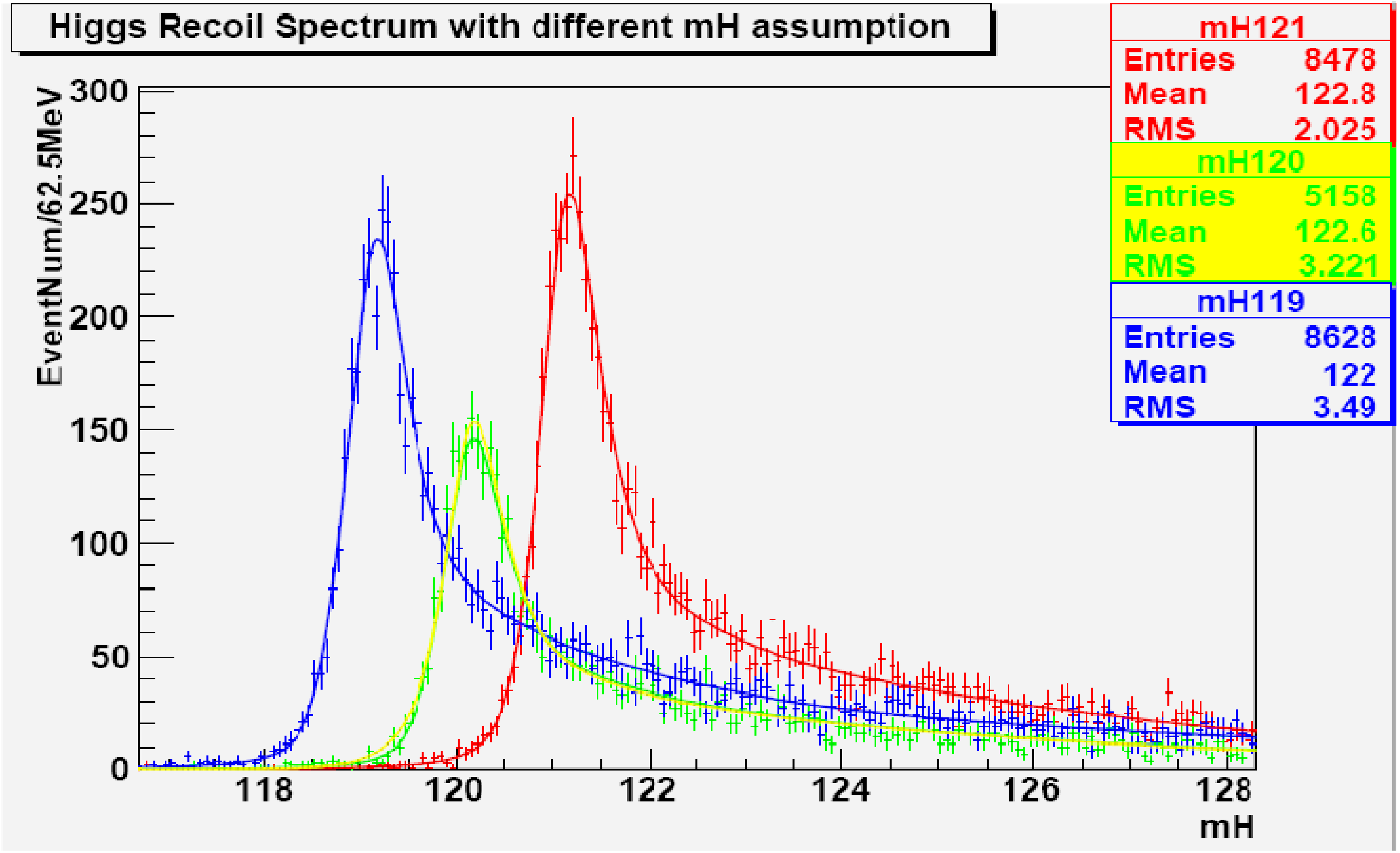
- Assume the higgs mass is m_a (119< m_a <121); then the expected PDF $f(m_a,m)$ will be a linear combination of $f(119,m-(m_a-119))$ and $f(121,m+(121-m_a))$: (Shift the PDF(119) & PDF(121) to expected position and make a linear combination)

$$f(m_a) = 0.5*((m_a -119)* f(121,m+(121-m_a)) + (121-m_a)* f(119,m-(m_a-119)))$$

- Use likelihood method to fit m_a

How the likelihood method works:





Red/Green/Blue: Smoothed mH Spectrum with mH=121/120/119 assumption and original Histogram (show in error bar);
Yellow: expected PDF at mH=120, calculated from f(119) and f(121) → match to the sample (Green) nicely.
10k statistic for mH=121 & mH=119 cases; 6k statistic for mH=120 case.

mH measurement with no background

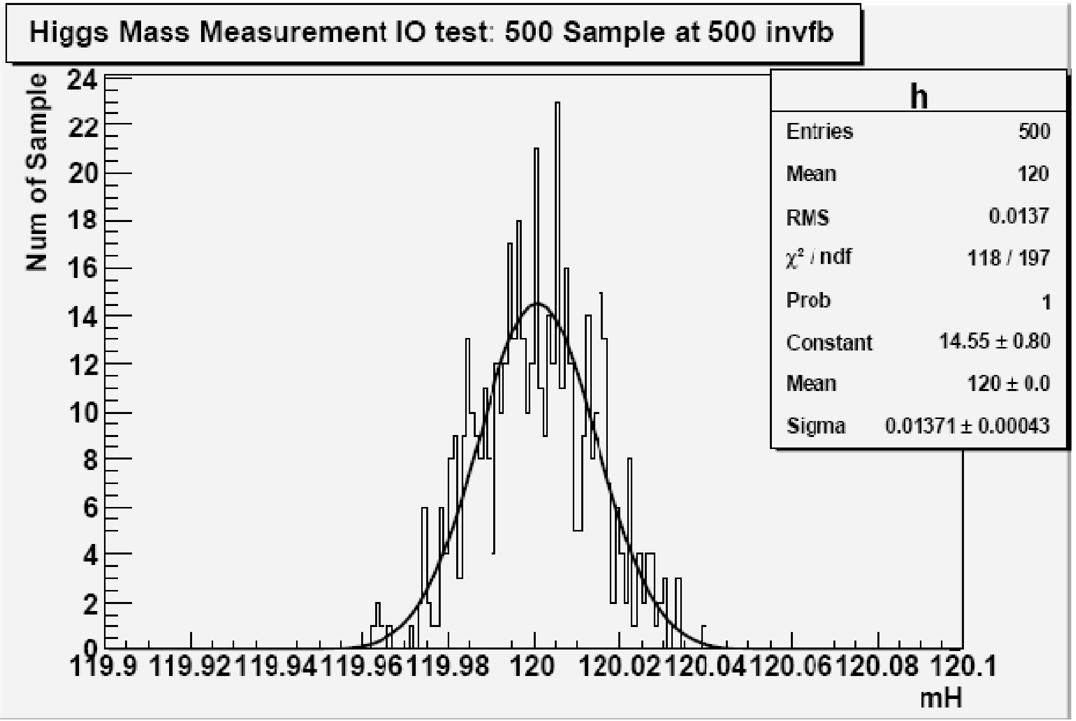
IO test at 500fb^{-1}

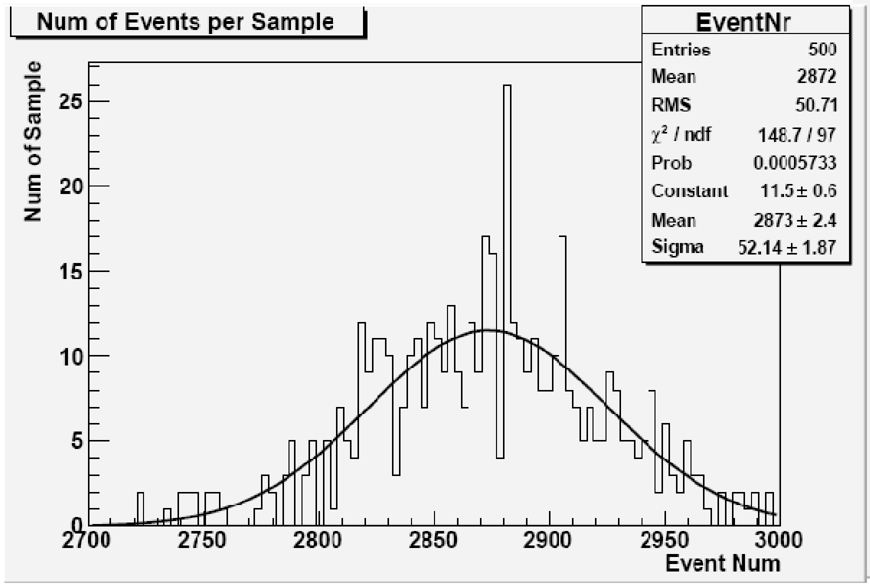
Use toy MC provide by RooFit:

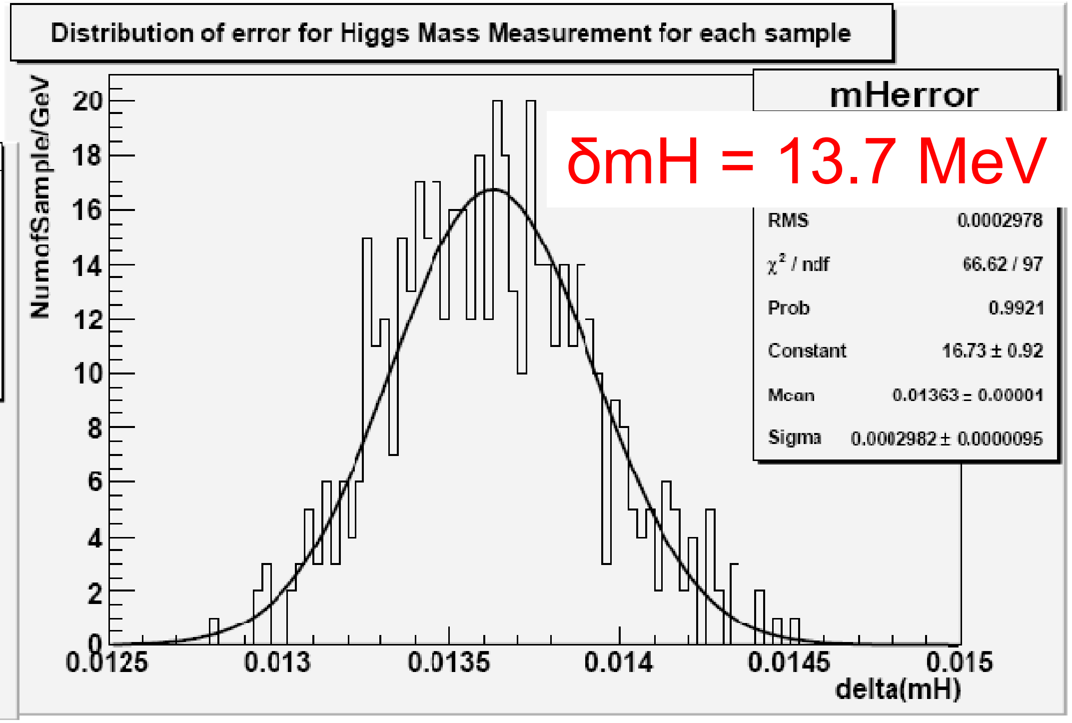
Num of events per run is determined
By a gaussian distribution
Gaus(N, sqrt(N)). Totally 500 run

Error on mH nicely agreed with
Error on sample means distribution:

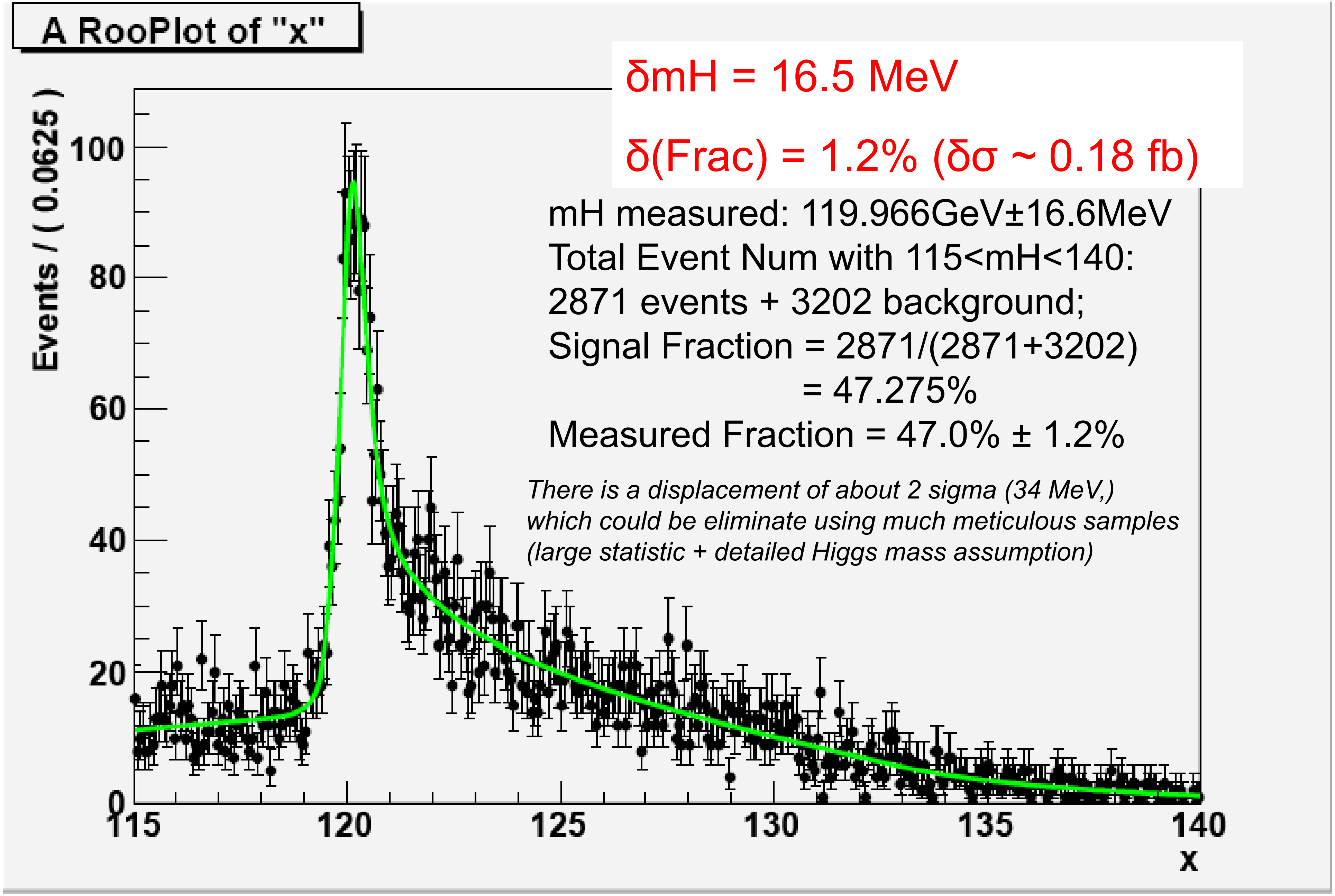
IO test fine







Fit 2 parameters with likelihood method : mH & Fraction



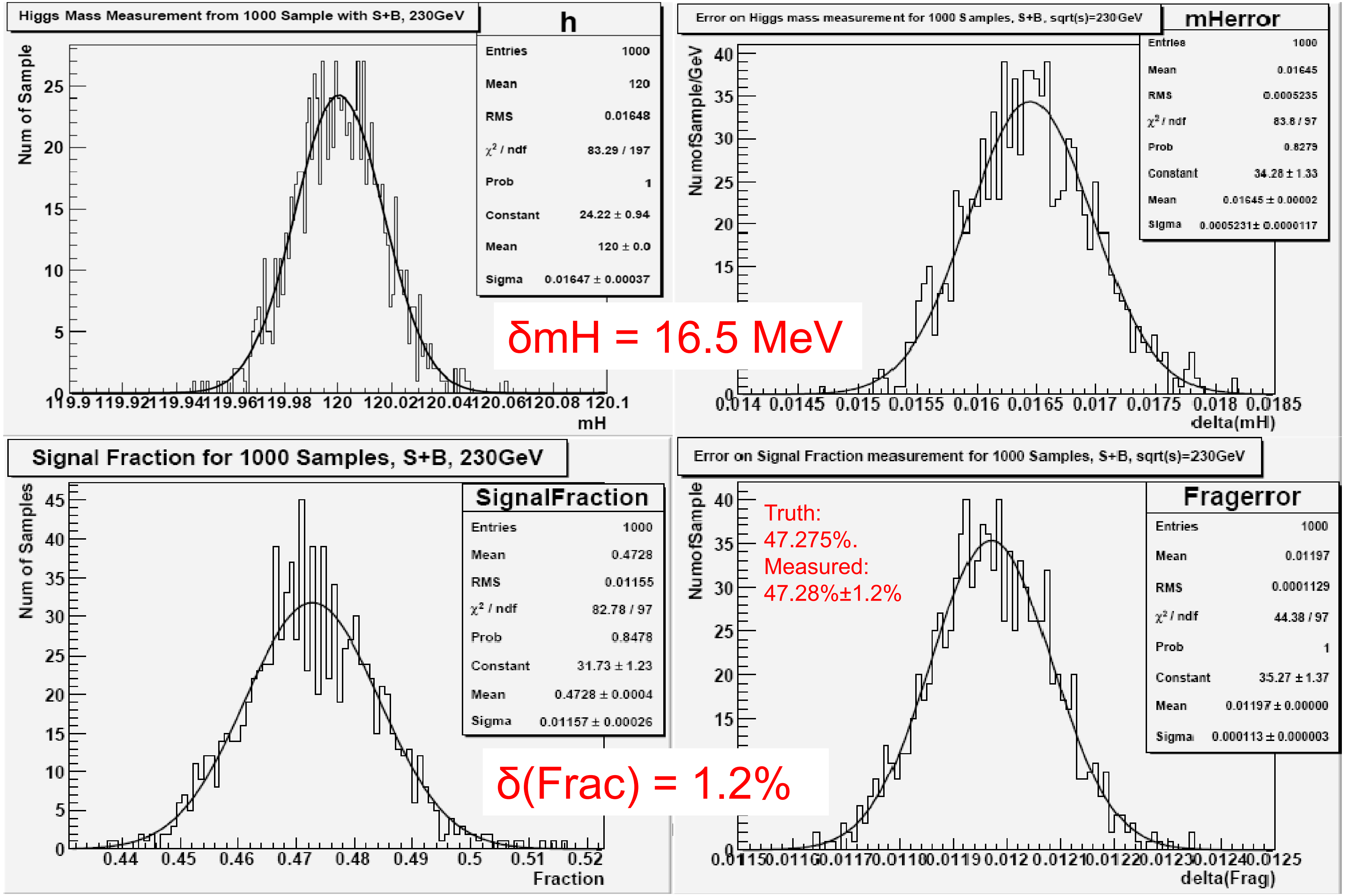
δmH = 16.5 MeV

δ(Frac) = 1.2% (δσ ~ 0.18 fb)

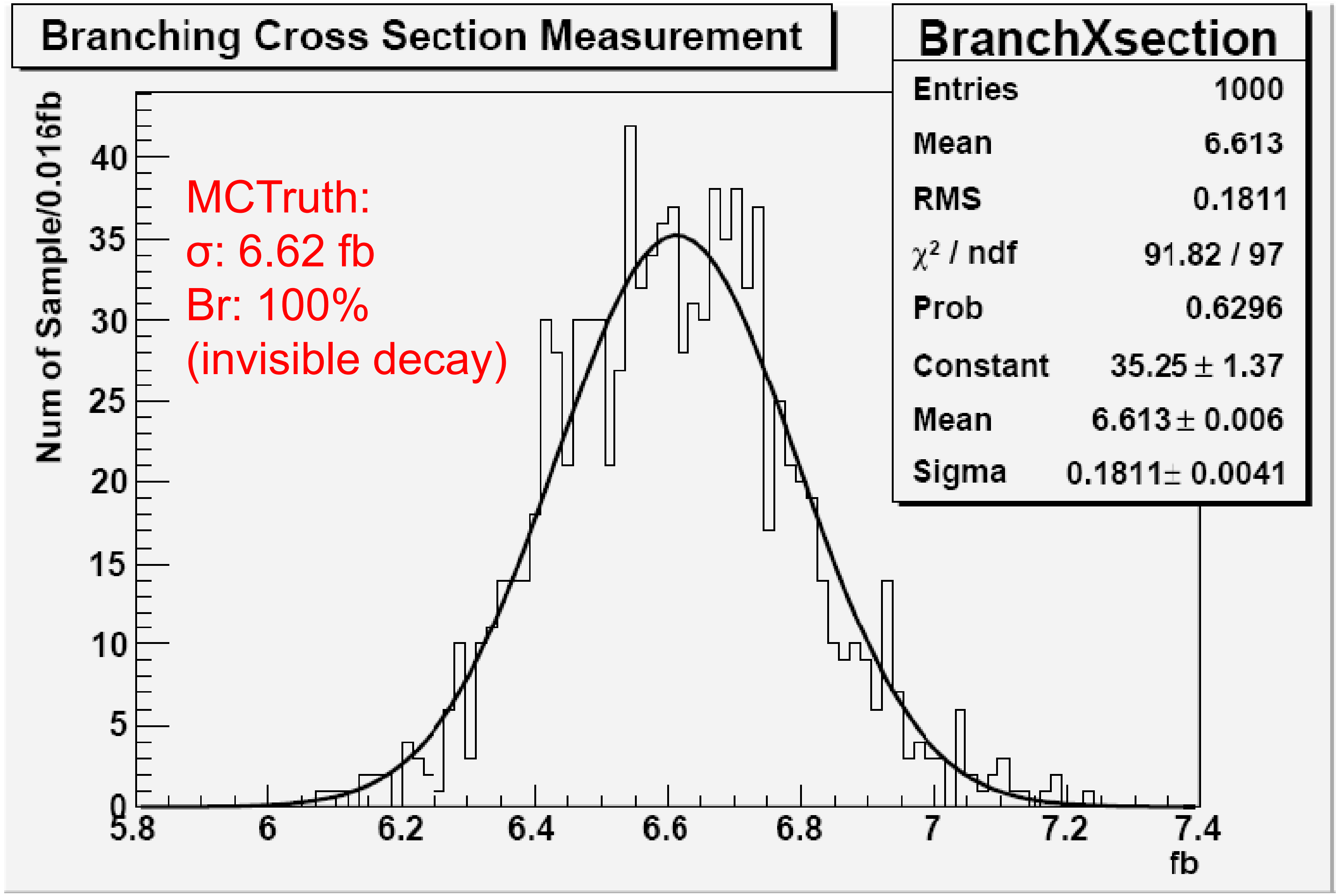
mH measured: 119.966GeV±16.6MeV
Total Event Num with 115<mH<140:
2871 events + 3202 background;
Signal Fraction = 2871/(2871+3202)
= 47.275%
Measured Fraction = 47.0% ± 1.2%

There is a displacement of about 2 sigma (34 MeV,) which could be eliminate using much meticulous samples (large statistic + detailed Higgs mass assumption)

IO test with toy MC at 500fb^{-1}. Br(invisible) = 100%. 1000 Samples



X Section measurement Br(inv)=100%

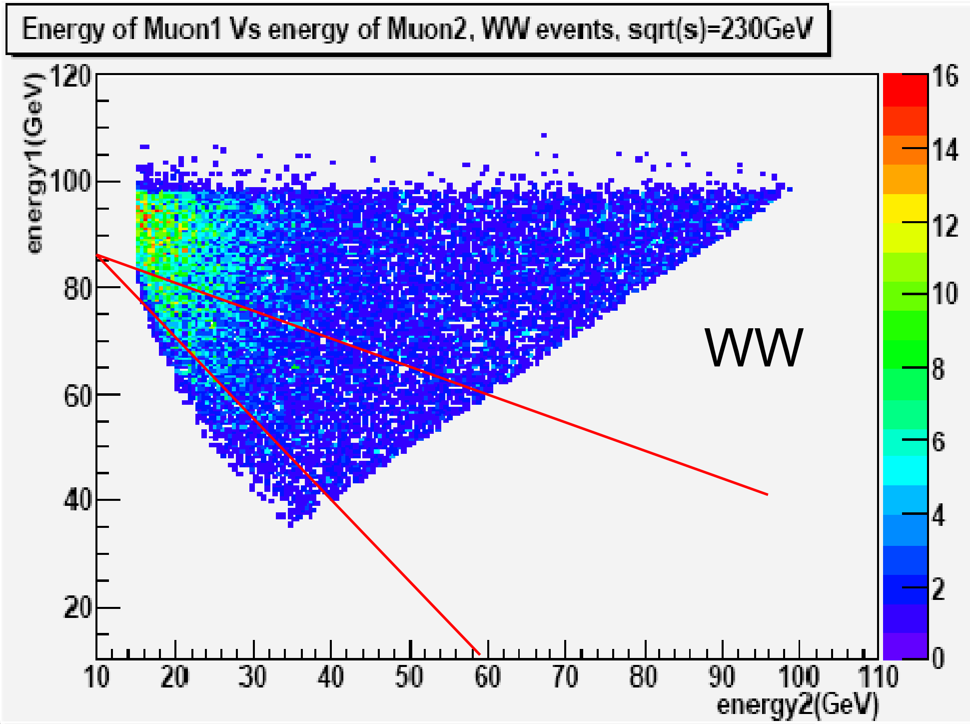


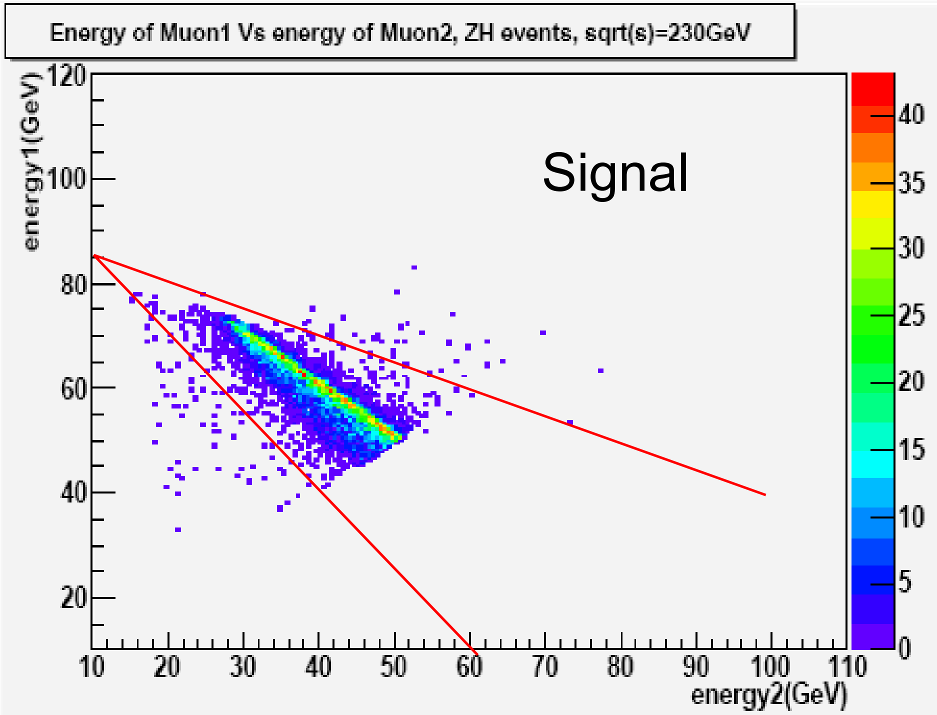
- TotalEventNr*fraction=BranchingRatio*efficiency*luminosity*Xsection
- Efficiency = 86.83%; luminosity = 500 fb^{-1}
- Result: 6.613±0.181 fb. Accuracy at 2.7% level

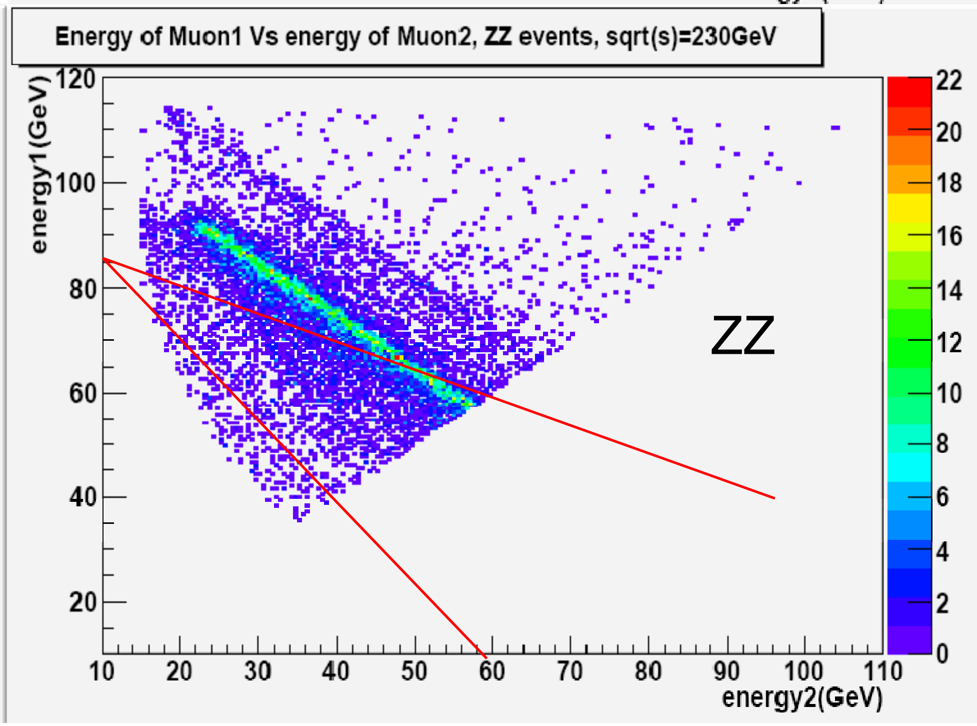
Dynamical Pre Cut
For SM Higgs decay

2*E1+E2<180 && 2*E1+3*E2>200

Effect:
Signal Channel: 98.8%
Back Ground WW: 25.4%
ZZ: 31.9%



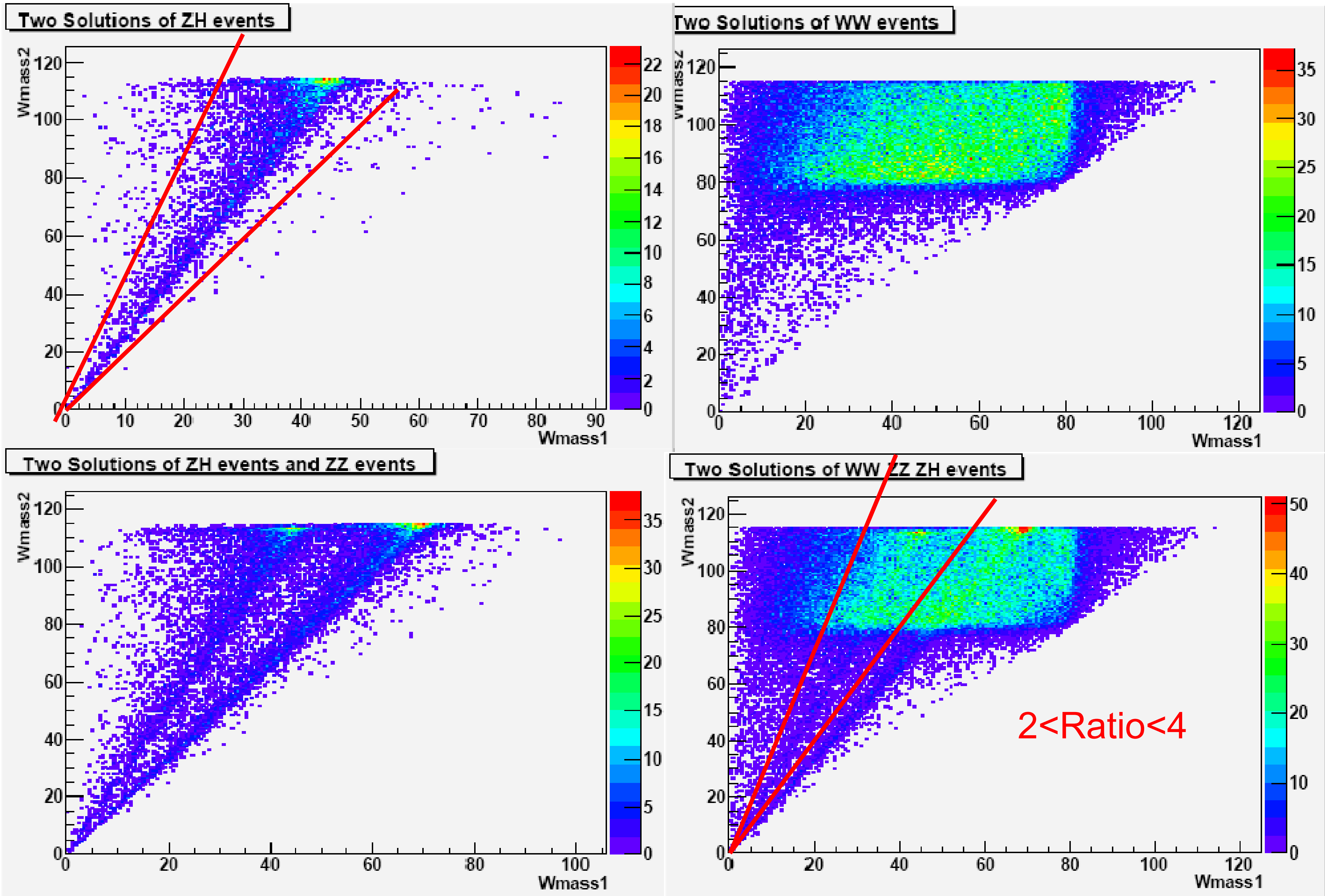


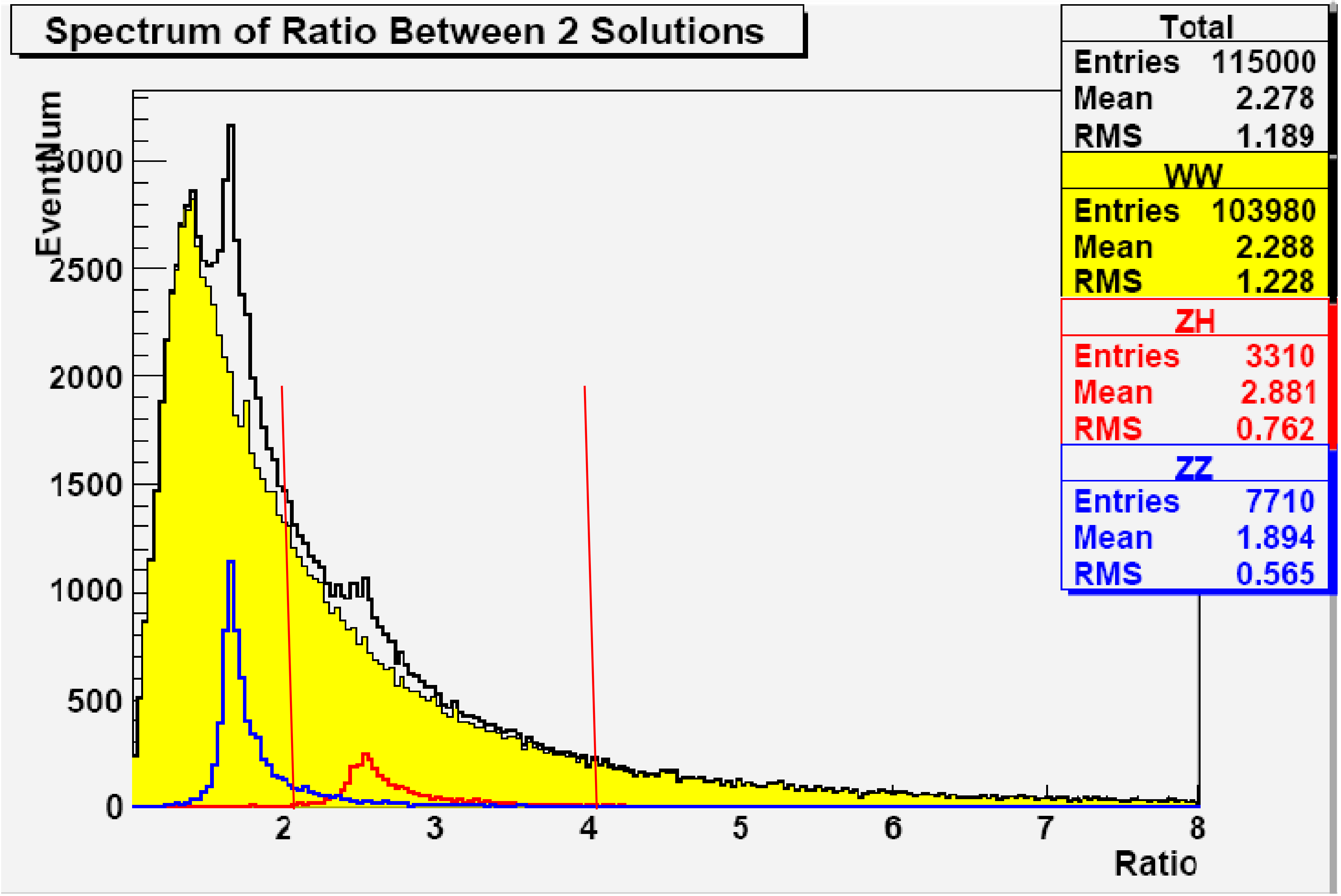


Effect of individual Cuts for Higgs invisible decay

	ZH	ZZ	WW
X Section (fb)	6.62	15.42	207.96
Total EventNum at 500 fb^{-1}	3310	7710	103980
Reconstructed event num & efficiency (with mH resolved)	3260 (98.5%)	7614 (98.8%)	96661 (93.0%)
$\lvert\cos(\theta)\rvert<0.99$	3229 (97.6%)	7566 (98.1%)	96157 (92.5%)
$\lvert m_Z-m_{lepton}\rvert<10$	3120 (94.3%)	7175 (93.1%)	11626 (11.2%)
$E_{mu}>20$	3248 (98.1%)	7584 (98.4%)	94128 (90.5%)
$\cos(\theta_{mumu})<-0.4$	3211 (97.0%)	5123 (66.4%)	74202 (71.4%)
Total energy<110	3253 (98.3%)	2056 (26.7%)	25107 (24.1%)
Cut on W mass resolve: (2<Ratio<4)	2956 (89.3%)	1407 (18.2%)	32444 (31.2%)

Cut on W mass resolve: (2<Ratio<4)





Spectrum of Ratio Between 2 Solutions
EventNum
3000
2500
2000
1500
1000
500
0
2
3
4
5
6
7
8
Ratio
Total
Entries 115000
Mean 2.278
RMS 1.189
WW
Entries 103980
Mean 2.288
RMS 1.228
ZH
Entries 3310
Mean 2.881
RMS 0.762
ZZ
Entries 7710
Mean 1.894
RMS 0.565

Higgs Recoil Mass Spectrum at sqrt(s)=230GeV, with different L*