

$e^+ e^- \rightarrow ZH$: Studies on the Higgs recoil mass

FCCee Physics Performance meeting
19th April 2021

Ang Li, Gregorio Bernardi

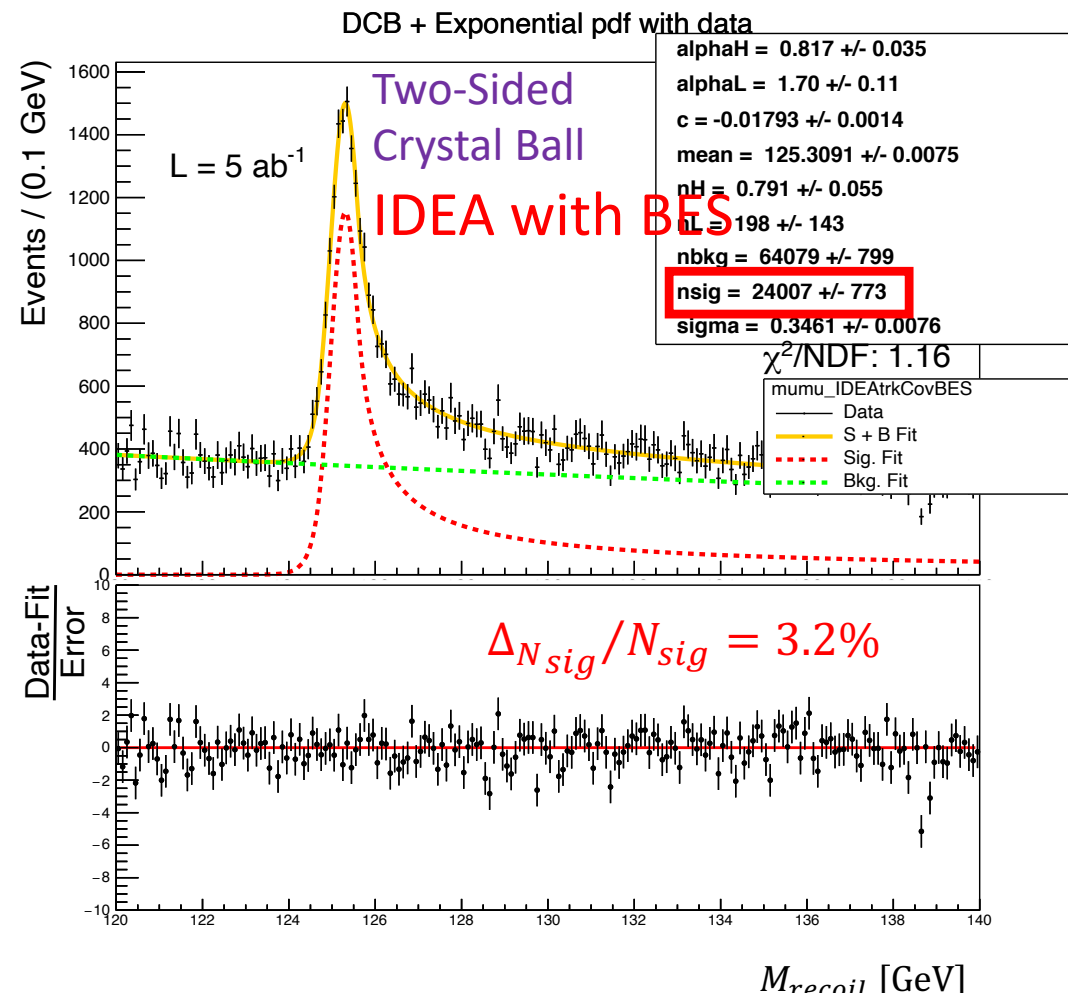
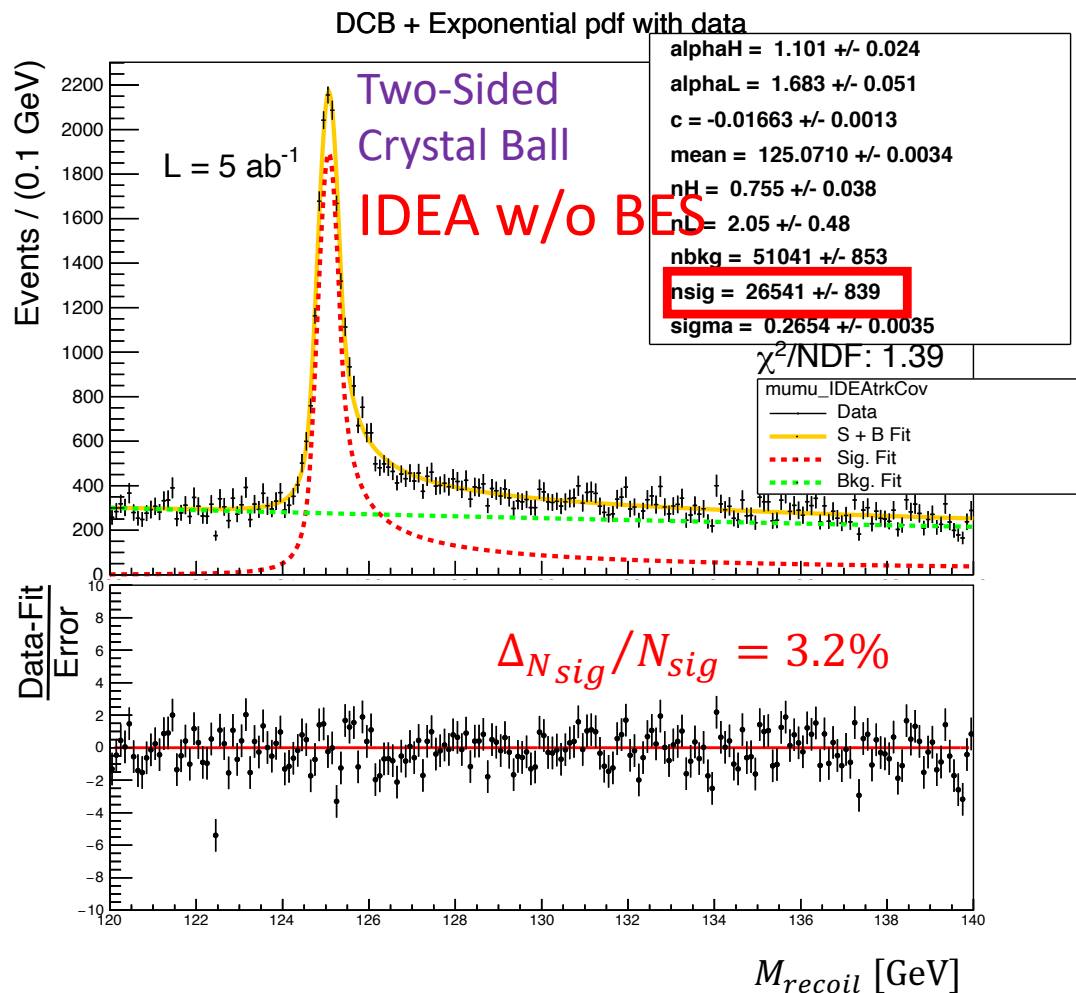


Plans

- **Simulation and Event selections**
- **Signal Only fit and New Modelled signal method**
- **Background fit**
- **ZH+ZZ+WW and ZH+ZZ fit**
- **Parameters fixing with Background sideband fit**
- **Beam Energy Spread and CLD**

Recap

- Large uncertainty of N_{sig}
- Need to investigate the large uncertainty



Simulations and Event Selection

- **Simulation configurations:**

- **Generator:**

- Pythia 8 (DelphesPythia8_EDM4HEP)

- **Detector card:**

- **IDEA:** \$DELPHES_DIR/cards/IDEAtrkCov.tcl

- **CLD:**

- /afs/cern.ch/user/s/selvaggi/public/4Emilia/delphes_card_CLDtrkCov_Tagging.tcl

- CLD tracker, the other parts are still IDEA

- **Channel: ZH, ZZ and WW decay leptonically,**

- 10^7 events for each channel

- Focus on $\mu^+ \mu^-$ pair final state ($e^+ e^-$ final state reconstruction has some issues)

- $\sqrt{s} = 240$ GeV

- **ISR and FSR on**

- **Selection:**

1. At least one μ^+ one μ^-
2. Z from pair of $\mu^+ \mu^-$
3. At least One Z boson,
4. $m_Z \in [86, 96]$ GeV
5. $p_T^Z \in [20, +\infty]$ GeV

- **Luminosity:**

$$L = 5 \text{ ab}^{-1}$$

- **Variables:**

$$\begin{aligned} M_{recoil}^2 &= (\sqrt{s} - E_{f\bar{f}})^2 - p_{f\bar{f}}^2 \\ &= s - 2E_{f\bar{f}}\sqrt{s} + m_{f\bar{f}}^2 \end{aligned}$$

CutFlow Table and From $m_Z \in [80, 100]$ GeV to $m_Z \in [86, 96]$ GeV

Lumi = 5 / ab		ZH	ZH	ZH	ZZ	ZZ	ZZ	WW	WW	WW	S/B	(S/Sqrt(S+B))
		Total efficiency: cut efficiency %			Total efficiency: cut efficiency %			Total efficiency: cut efficiency %				
	Xsec (pb)	0.201037			1.35899			16.4385				
	(XSec*Lumi)	1005185			6794950			82192500				
	cumulative											
	Total number of events	1005185			6794950			82192500				
sel0	# of mu+mu-	34511	100.00	3.43	529294	100.00	7.79	1200594	100.00	1.46	0.02	25.98
sel1	# of events with at least one Z inside 73-120 GeV	27765	80.45	80.45	352312	66.56	66.56	323238	26.92	26.92	0.04	33.11
sel2	# of events with at least one Z inside 80-110 GeV	26829	77.74	96.63	334807	63.26	95.03	204372	17.02	63.23	0.05	35.66
sel3	# of events with at least one Z inside 80-100 GeV	26080	75.57	97.21	321483	60.74	96.02	133185	11.09	65.17	0.06	37.61
sel4	# of events with at least one Z inside 84-98 GeV	24628	71.36	94.43	303079	57.26	94.28	93897	7.82	70.50	0.06	37.93
sel5	# of events with at least one Z inside 86-96 GeV	23008	66.67	93.42	282474	53.37	93.20	67357	5.61	71.73	0.07	37.68
sel6	# of events with pt-of-lepton-sum > 20 GeV	20818	60.32	90.48	250081	47.25	88.53	56968	4.74	84.58	0.07	36.36
sel7	# of events with Mrecoil between 116-140 GeV	20339	58.93	97.70	18254	3.45	7.30	19422	1.62	34.09	0.54	84.44
sel8	# of events with Mrecoil between 120-140 GeV	20310	58.85	99.86	13757	2.60	75.36	16225	1.35	83.54	0.68	90.57

	ZH	ZZ	WW
# of events with at least one Z inside 80-100 GeV	26080	321483	133185
# of events with at least one Z inside 86-96 GeV	23008	282474	67357
Cut efficiency	88.2%	87.9%	50.6%

- $m_Z \in [86, 96]$ GeV removes about 50% of WW comparing to $m_Z \in [80, 100]$ GeV

Fit model and parameter settings

- **Signal:**

- ZH

Two-Sided Crystal Ball function:

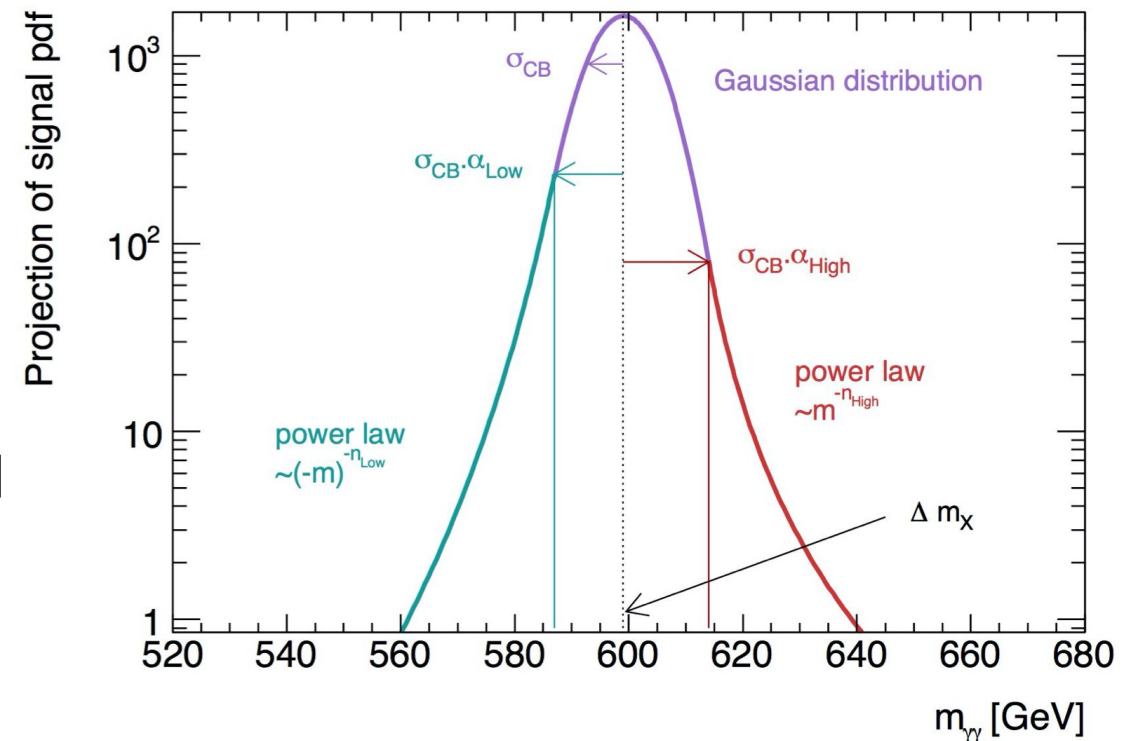
$$f_S(x; \vec{\theta}) = \begin{cases} \left(\frac{n_L}{|\alpha_L|}\right)^{n_L} \exp\left(-\frac{|\alpha_L|^2}{2}\right) \left(\frac{n_L}{|\alpha_L|} - |\alpha_L| - \frac{x-\mu}{\sigma}\right)^{-n_L}, & \text{for } \frac{x-\mu}{\sigma} \leq -\alpha_L \\ \exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right), & \text{for } -\alpha_L < \frac{x-\mu}{\sigma} < \alpha_R \\ \left(\frac{n_R}{|\alpha_R|}\right)^{n_R} \exp\left(-\frac{|\alpha_R|^2}{2}\right) \left(\frac{n_R}{|\alpha_R|} - |\alpha_R| + \frac{x-\mu}{\sigma}\right)^{-n_R}, & \text{for } \frac{x-\mu}{\sigma} \geq \alpha_R, \end{cases}$$

- **Background:**

- ZZ, WW

- **Fitting functions**

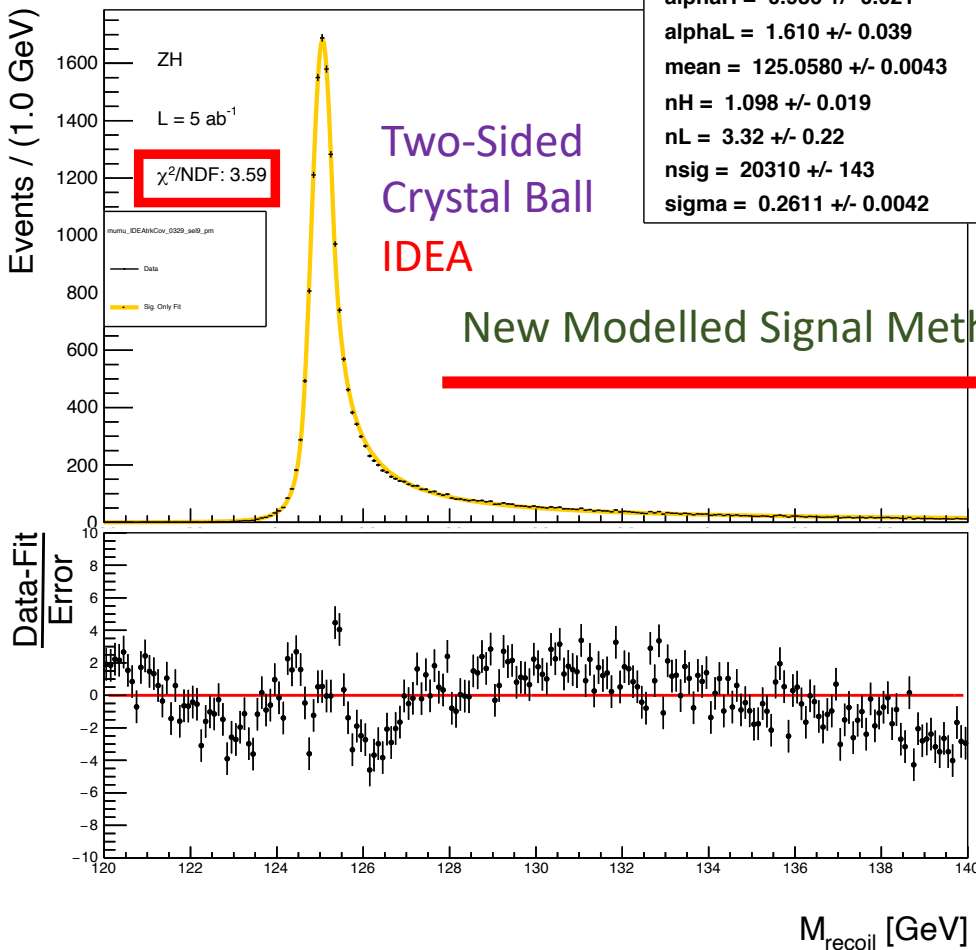
- Signal: Two-Sided Crystal Ball
- Background: Second Order Polynomial
- S + B = $n_{sig} * \text{signal} + n_{bkg} * \text{background}$



New Modelled Signal method in the Higgs region (120-140 GeV)

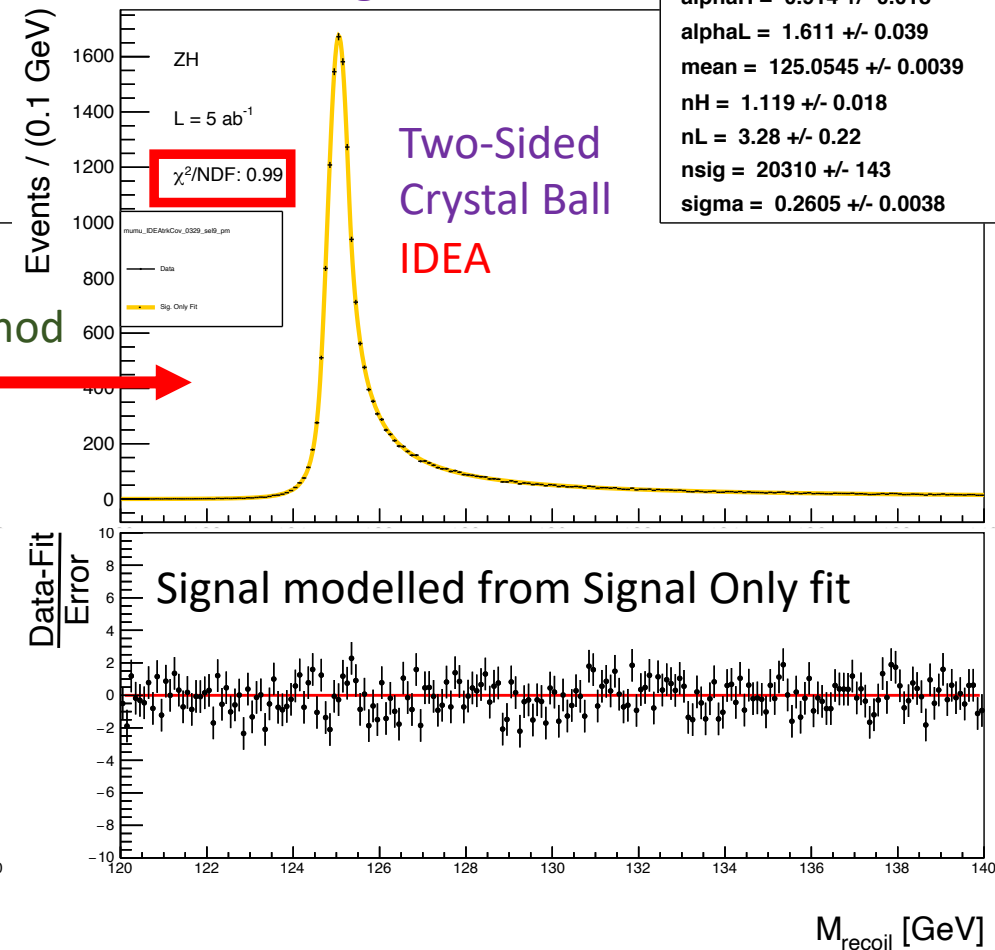
ALL MCData

DCB pdf with data



New Modelled Signal

DCB pdf with data



- New Modelled Signal Method
- Signal Only Fit and receive parameters
 - Use these parameters to generate DSCB shape signal

- χ^2/NDF is far from 1, Double-Sided Crystal Ball (DSCB) does not describe the signal well
- Need to improve the signal modeling function
- Modelled the signal with the signal only fit result to have a well described fit

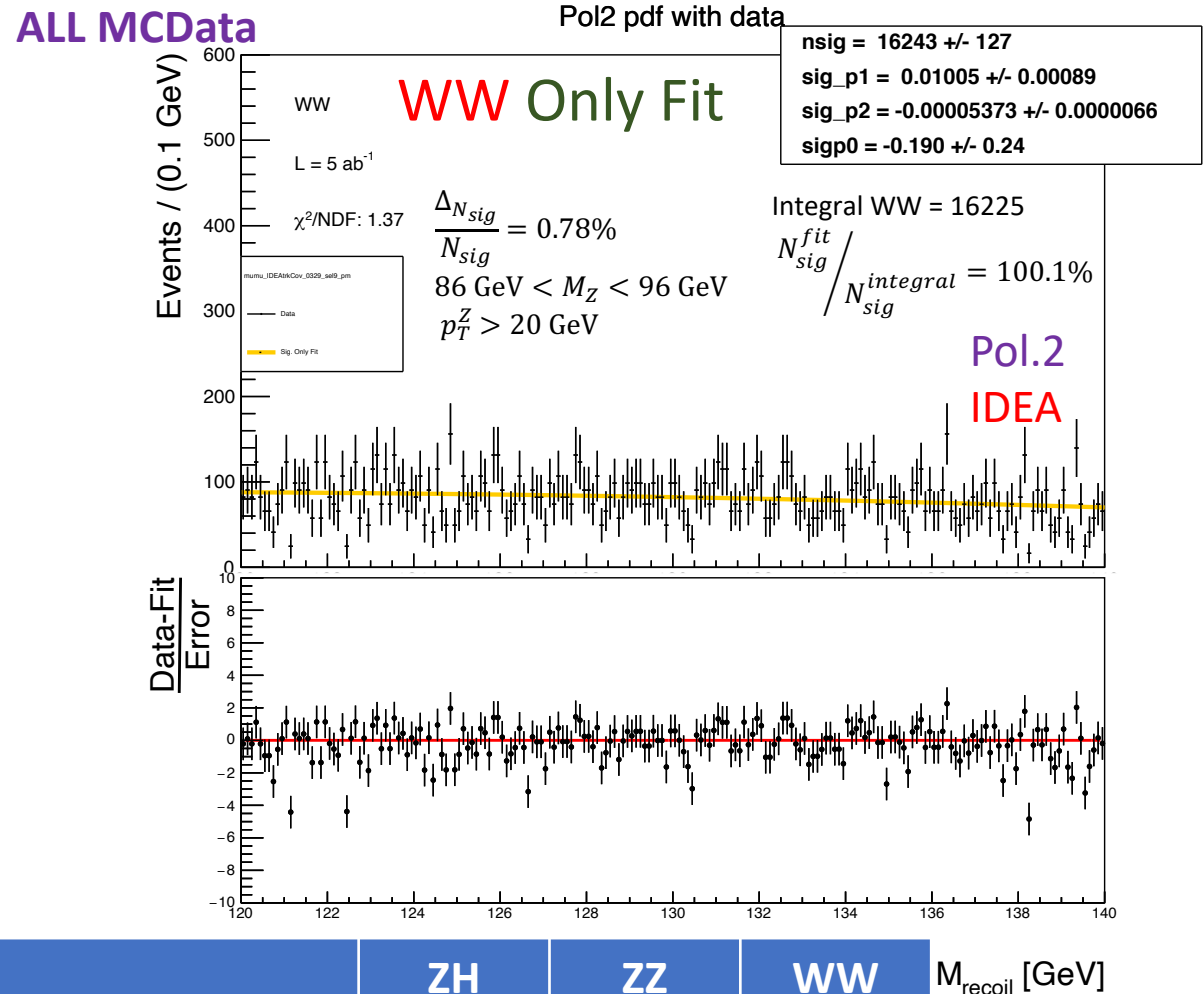
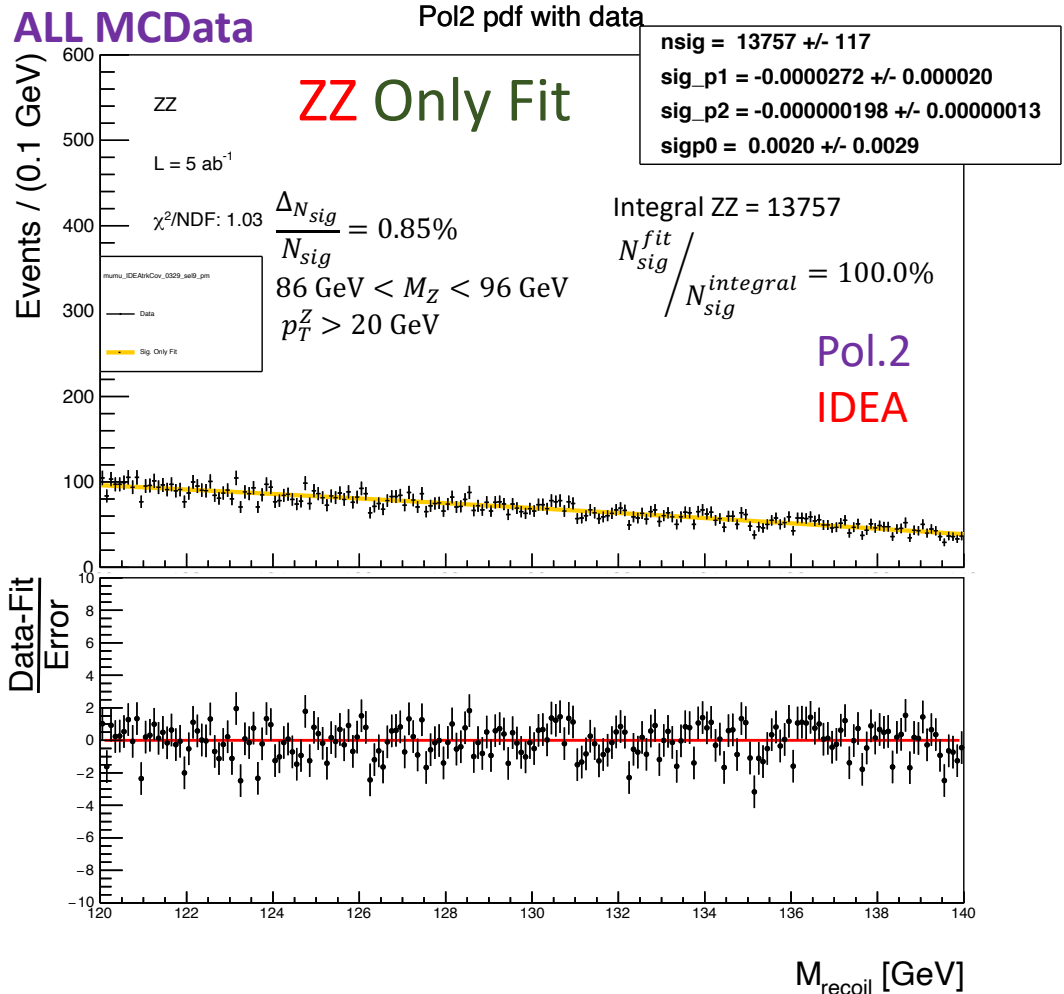
ALL MCData:

All data come from the MC simulation

New Modelled Signal:

ZH signal is modelled to perfect shape

Background fit of M_{recoil} with 2nd order Polynomial in the Higgs region (120-140 GeV)



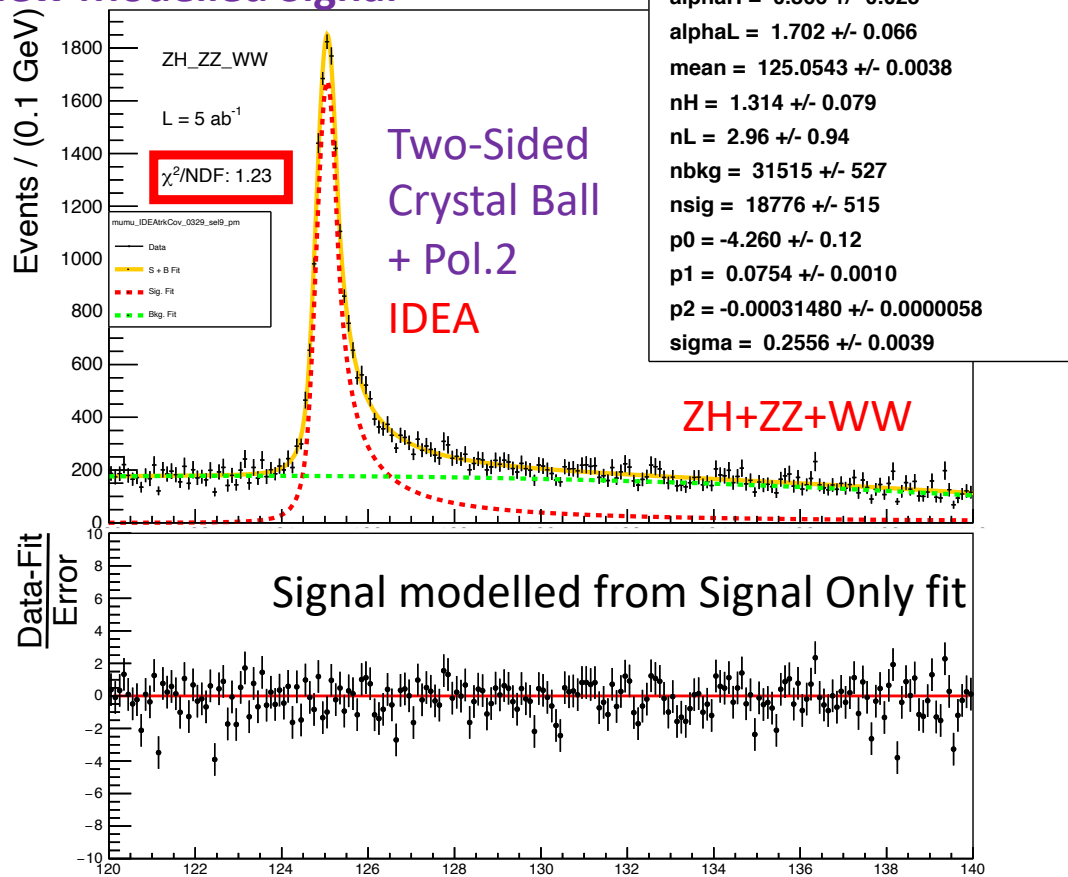
- WW has low statistic and large uncertainty (~100 times less than ZH)
- WW entries / # of events is ~ 10 times less than ZZ
- Need to generate more events
- Will focus on ZZ only background to see how precise we can be when we have enough statistics in the background

	ZH	ZZ	WW	M_{recoil} [GeV]
# of Events	20310	13757	16225	
Entries	202053	20246	1974	
Entries/# of Events	9.95	1.47	0.12	

Comparison of New Modelled Signal fit

New Modelled Signal

DCB_Pol2 pdf with data

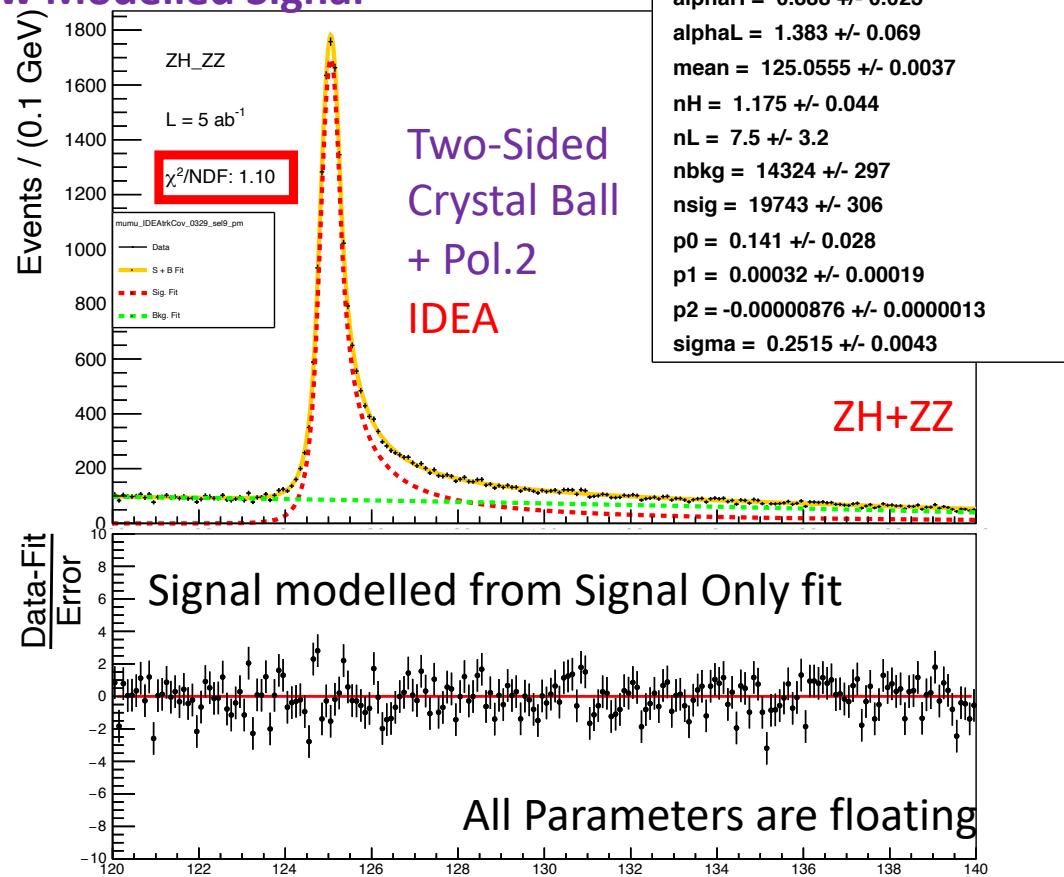


Integral ZH = 20310 M_{recoil} [GeV]

$\Delta_{N_{sig}}/N_{sig} = 2.74\%$ $N_{sig}^{fit}/N_{sig}^{integral} = 92.4\%$

New Modelled Signal

DCB_Pol2 pdf with data



Integral ZH = 20310 M_{recoil} [GeV]

$\Delta_{N_{sig}}/N_{sig} = 1.55\%$ $N_{sig}^{fit}/N_{sig}^{integral} = 97.2\%$

$\Delta_{N_{bkg}}/N_{bkg} = 2.07\%$

Integral ZZ = 13757

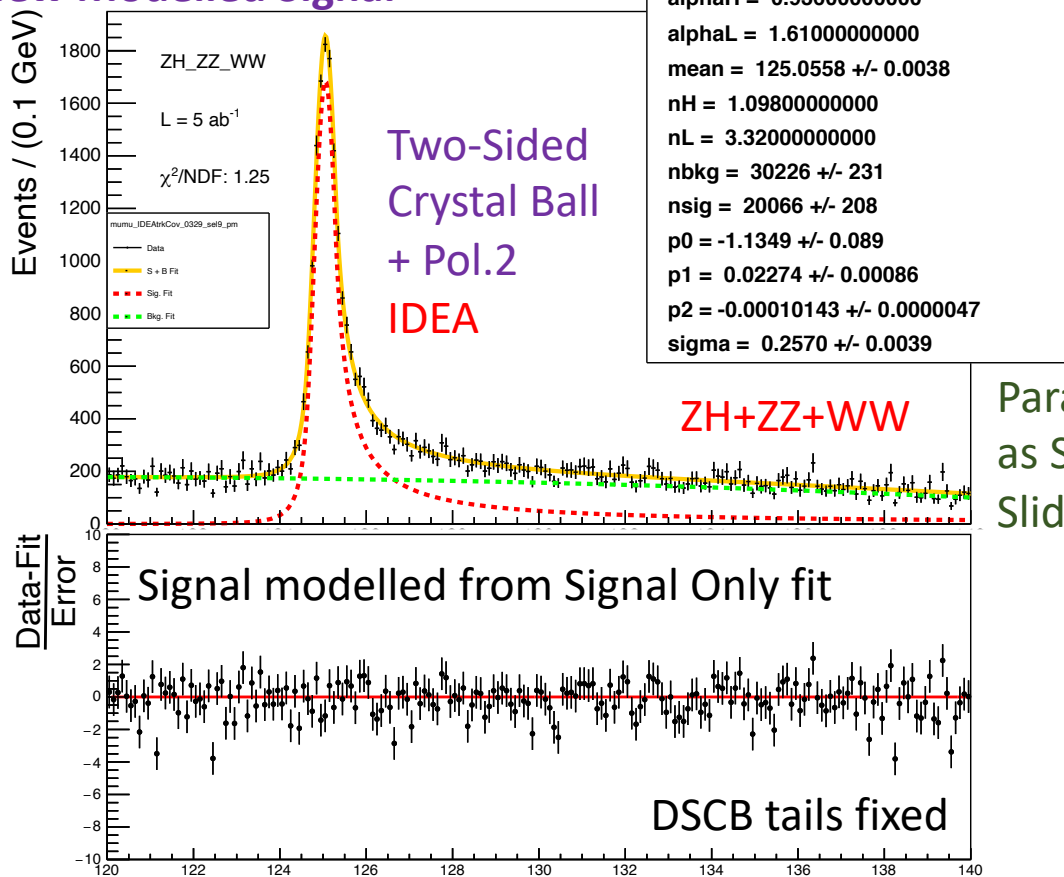
$N_{bkg}^{fit}/N_{bkg}^{integral} = 104.1\%$

- Removing WW background improves the $\Delta_{N_{sig}}/N_{sig}$ from 2.7% to 1.6%
- It improves also the χ^2/NDF (1.23 to 1.10) and the $N_{sig}^{fit}/N_{sig}^{integral}$ (92.4% to 97.2%)
- WW has important contribution to N_{sig} uncertainty $\Delta_{N_{sig}}/N_{sig}$

Two-Sided Crystal Ball + Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

New Modelled Signal

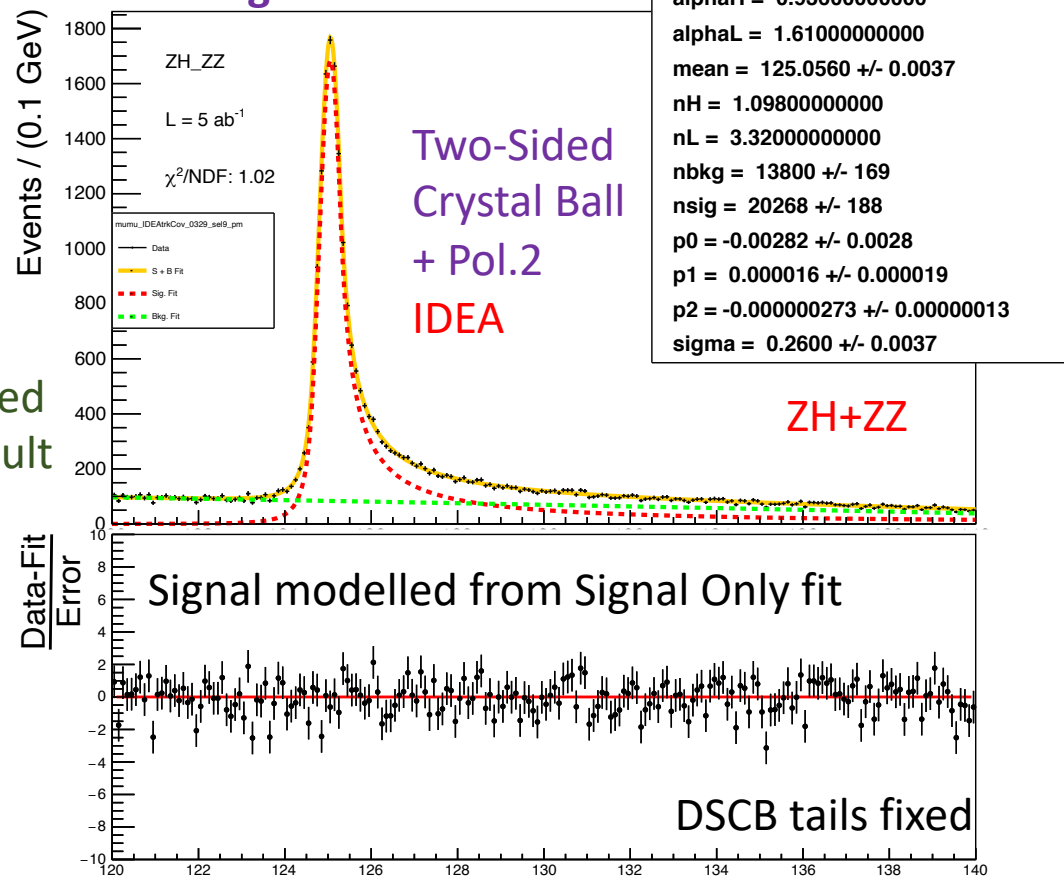
DCB_Pol2 pdf with data



$\alpha_H = 0.93600000000$
 $\alpha_L = 1.61000000000$
 $mean = 125.0558 \pm 0.0038$
 $n_H = 1.09800000000$
 $n_L = 3.32000000000$
 $nbkg = 30226 \pm 231$
 $nsig = 20066 \pm 208$
 $p_0 = -1.1349 \pm 0.089$
 $p_1 = 0.02274 \pm 0.00086$
 $p_2 = -0.00010143 \pm 0.0000047$
 $sigma = 0.2570 \pm 0.0039$

New Modelled Signal

DCB_Pol2 pdf with data



$\alpha_H = 0.93600000000$
 $\alpha_L = 1.61000000000$
 $mean = 125.0560 \pm 0.0037$
 $n_H = 1.09800000000$
 $n_L = 3.32000000000$
 $nbkg = 13800 \pm 169$
 $nsig = 20268 \pm 188$
 $p_0 = -0.00282 \pm 0.0028$
 $p_1 = 0.000016 \pm 0.000019$
 $p_2 = -0.000000273 \pm 0.00000013$
 $sigma = 0.2600 \pm 0.0037$

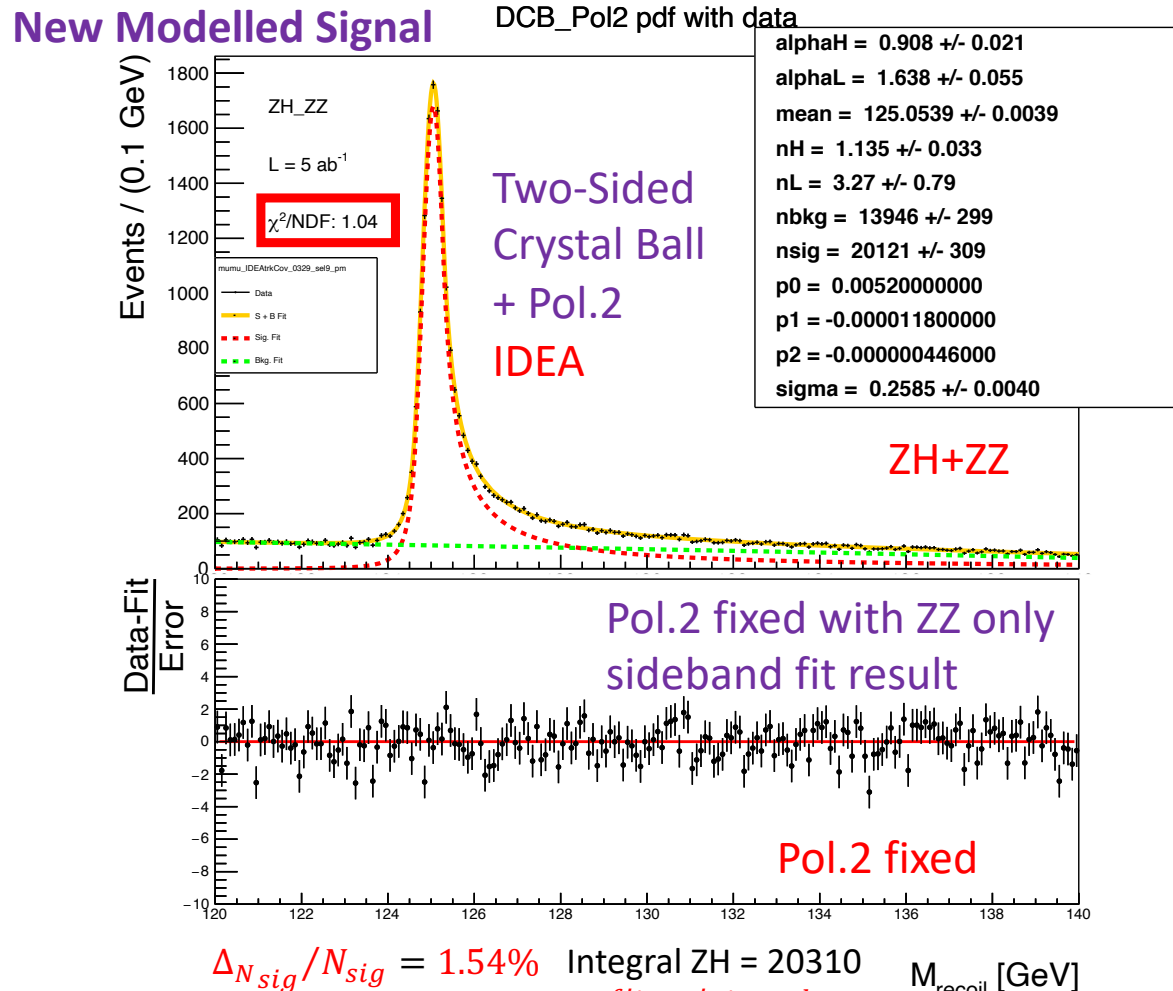
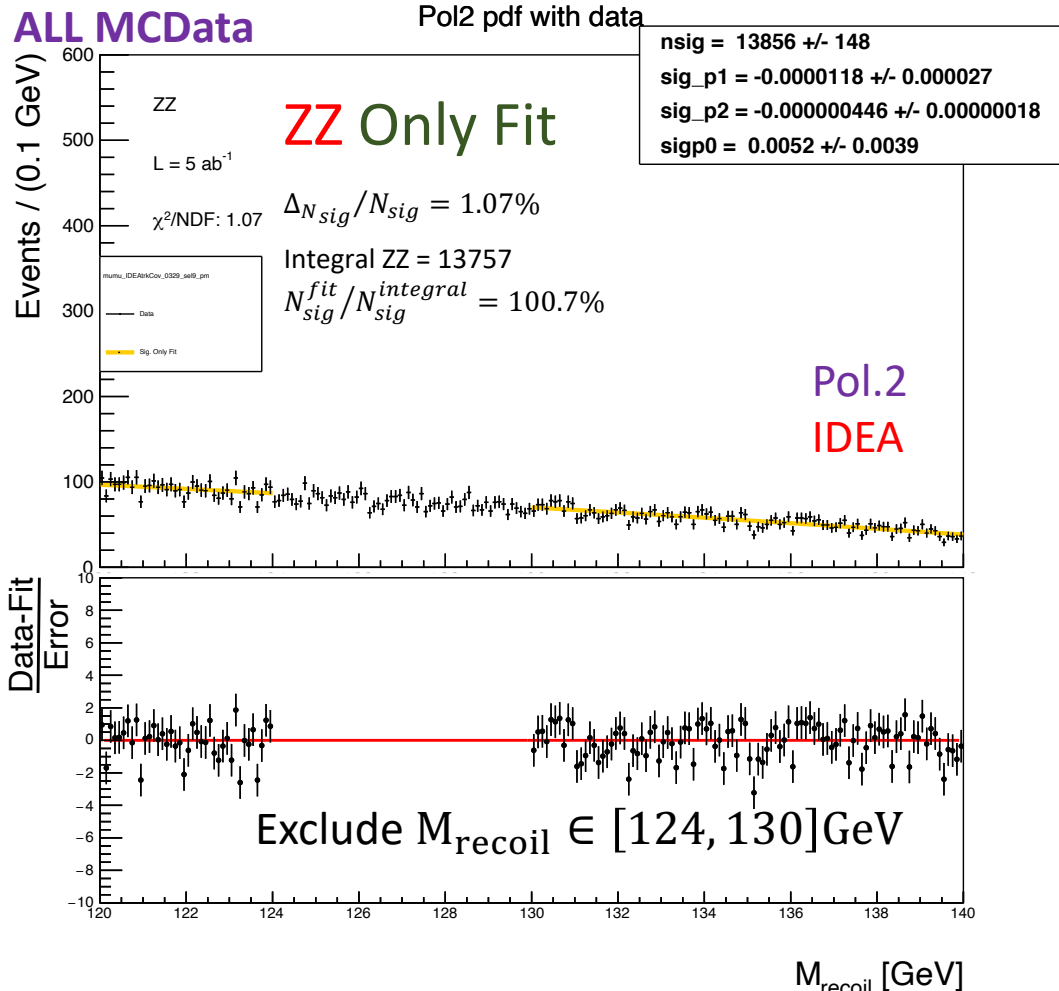
$\Delta N_{sig} / N_{sig} = 1.04\%$ Integral ZH = 20310 M_{recoil} [GeV]
 $N_{sig}^{fit} / N_{sig}^{integral} = 98.8\%$

$\Delta N_{sig} / N_{sig} = 0.93\%$ Integral ZH = 20310 M_{recoil} [GeV]
 $\Delta N_{bkg} / N_{bkg} = 1.22\%$ $N_{sig}^{fit} / N_{sig}^{integral} = 99.8\%$

- For ZH+ZZ+WW, after fixing the tails, the uncertainty of N_{sig} decreases to **1.04%**
- For ZH+ZZ, after fixing the tails, the uncertainty of N_{sig} decreases to **0.93%**

Integral ZZ = 13757
 $N_{bkg}^{fit} / N_{bkg}^{integral} = 100.3\%$

Sideband fit of Bkg. with Pol.2 fit of M_{recoil} in the Higgs region (120-140 GeV)



1. Do the ZZ background Sideband fit on [124, 130] GeV exclusive
2. Use the fit result to fix the background parameters

- After fixing the background with the sideband fit, the uncertainty of N_{sig} becomes $\sim 1.5\%$

- The χ^2/NDF is ~ 1 and the $N_{sig}^{fit}/N_{sig}^{integral}$ is $\sim 100\%$

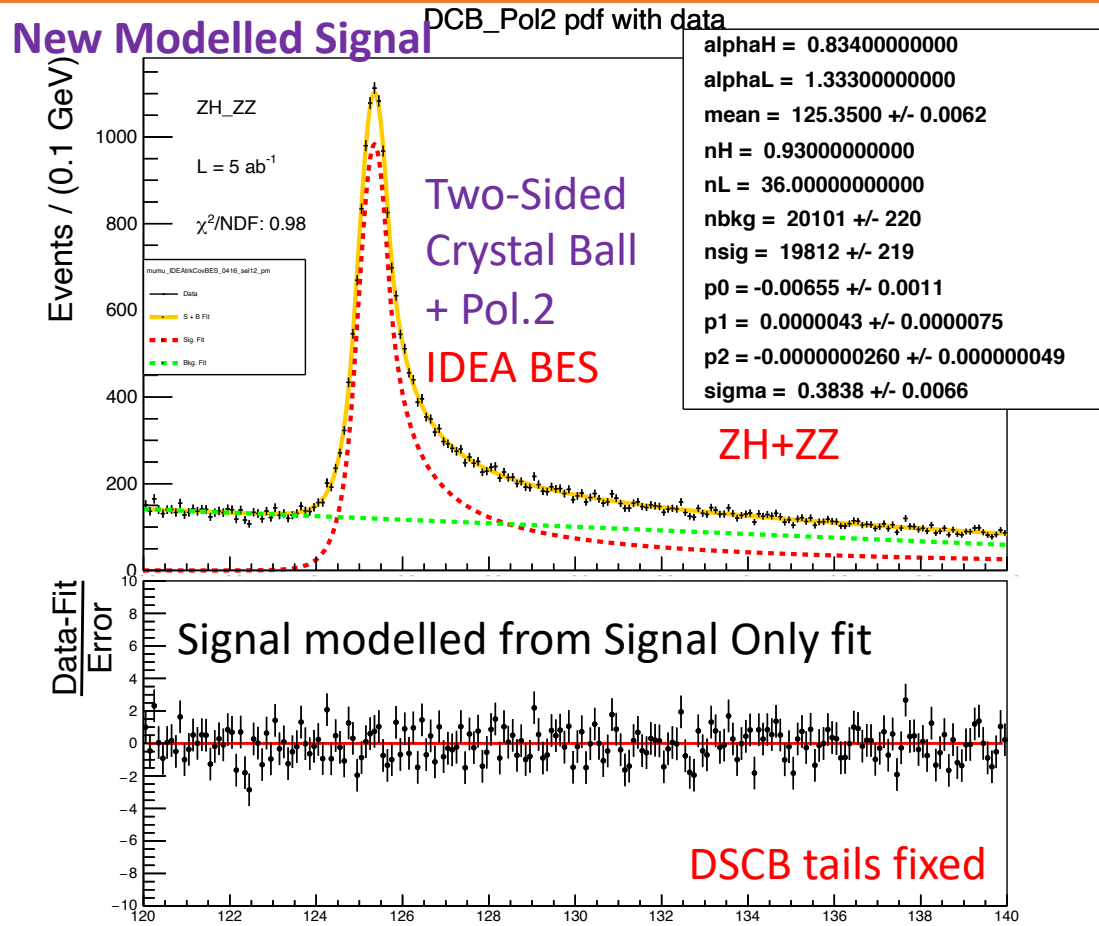
Fitted Width, mass, Nsig in the Higgs mass region (120-140 GeV)

Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ+WW	σ_H (GeV) Higgs Width	Δ_{σ_H} (GeV)	M_H (GeV) Higgs Mass	Δ_{M_H} (GeV)	$\Delta_{N_{sig}} / N_{sig}$
New Modelled Signal	0.2556	0.0039	125.0543	0.0038	2.742%
New Modelled Signal, tails fixed	0.2570	0.0039	125.0558	0.0038	1.037%

Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ	σ_H (GeV) Higgs Width	Δ_{σ_H} (GeV)	M_H (GeV) Higgs Mass	Δ_{M_H} (GeV)	$\Delta_{N_{sig}} / N_{sig}$
New Modelled Signal	0.2515	0.0043	125.0555	0.0037	1.550%
New Modelled Signal tails fixed	0.2600	0.0037	125.0560	0.0037	0.928%
New Modelled Signal Pol.2 fixed	0.2585	0.0040	125.0539	0.0039	1.536%

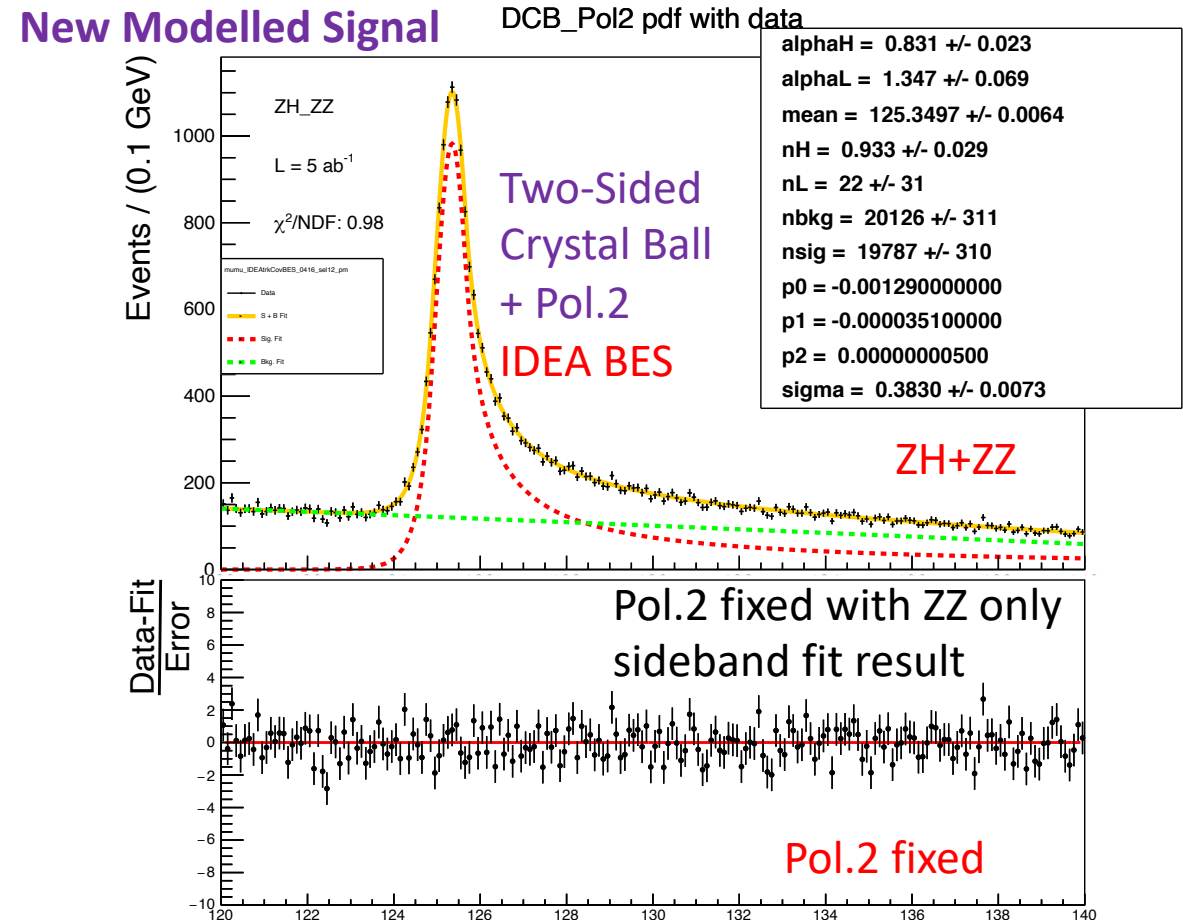
- For all the cases, the $\sigma_H = 0.256 \pm 0.004 \text{ GeV}$, $M_H = 125.056 \pm 0.004 \text{ GeV}$
- After fixing the tails, $\Delta_{N_{sig}} / N_{sig} \sim 1.0\%$.
- After fixing the background with the sideband fit, the uncertainty of N_{sig} becomes $\sim 1.5\%$

IDEA with Beam Energy Spread



$\Delta N_{sig}/N_{sig} = 1.11\%$ Integral ZH = 19684 M_{recoil} [GeV]
 $N_{sig}^{fit}/N_{sig}^{integral} = 100.7\%$

- Fixing the **tails**, the uncertainty of N_{sig} become $\sim 1.1\%$
- Fixing the **background** with the sideband fit, the uncertainty of N_{sig} becomes $\sim 1.6\%$



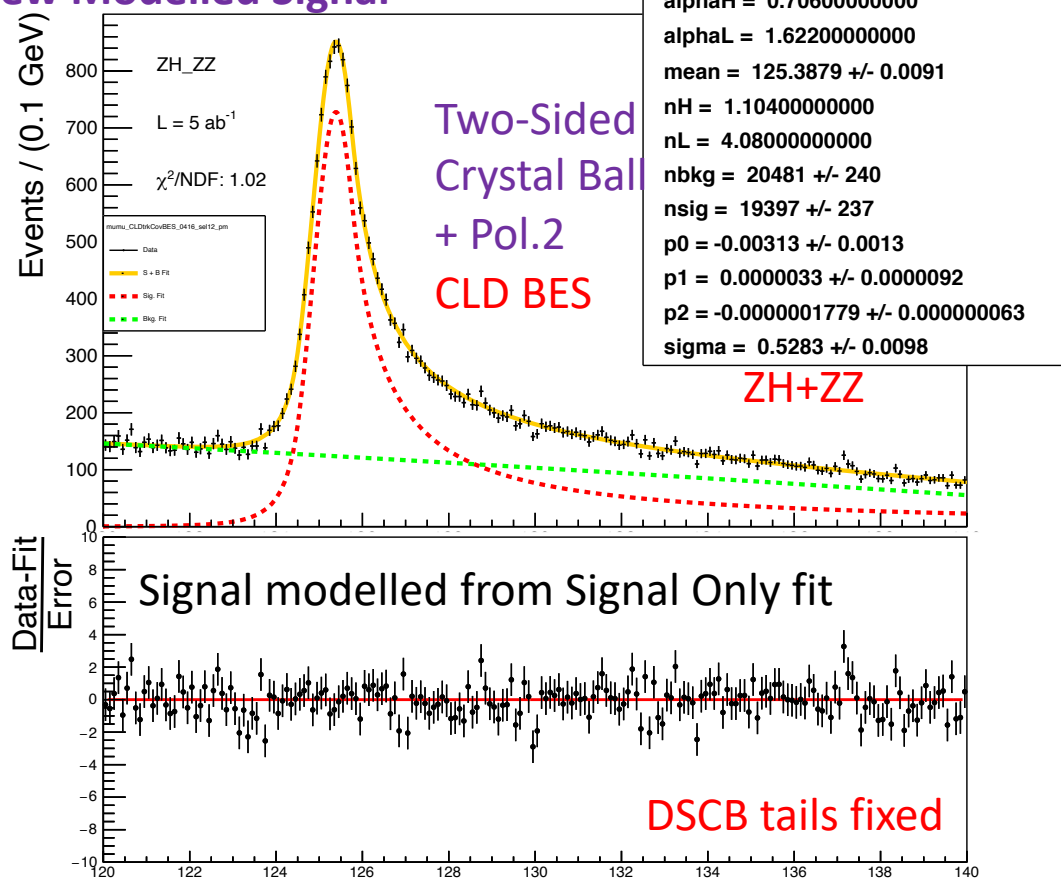
$\Delta N_{sig}/N_{sig} = 1.57\%$ Integral ZH = 19684 M_{recoil} [GeV]
 $\Delta N_{bkg}/N_{bkg} = 1.55\%$ $N_{sig}^{fit}/N_{sig}^{integral} = 100.5\%$
 Integral ZZ = 20228
 $N_{sig}^{fit}/N_{sig}^{integral} = 99.5\%$

Beam Energy Spread: Beams:allowMomentumSpread = on
 Beams:sigmaPzA = 0.198 (GeV)
 Beams:sigmaPzB = 0.198 (GeV)

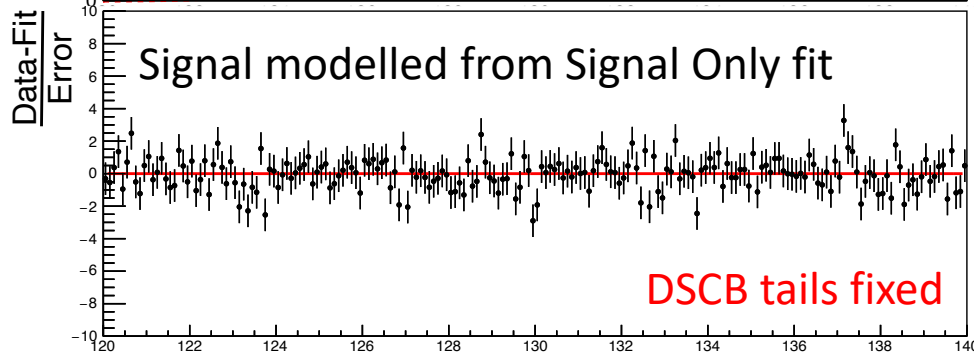
CLD with Beam Energy Spread

New Modelled Signal

DCB_Pol2 pdf with data



alphaH = 0.7060000000
 alphaL = 1.6220000000
 mean = 125.3879 +/- 0.0091
 nH = 1.1040000000
 nL = 4.0800000000
 nbkg = 20481 +/- 240
 nsig = 19397 +/- 237
 p0 = -0.00313 +/- 0.0013
 p1 = 0.0000033 +/- 0.0000092
 p2 = -0.000001779 +/- 0.00000063
 sigma = 0.5283 +/- 0.0098

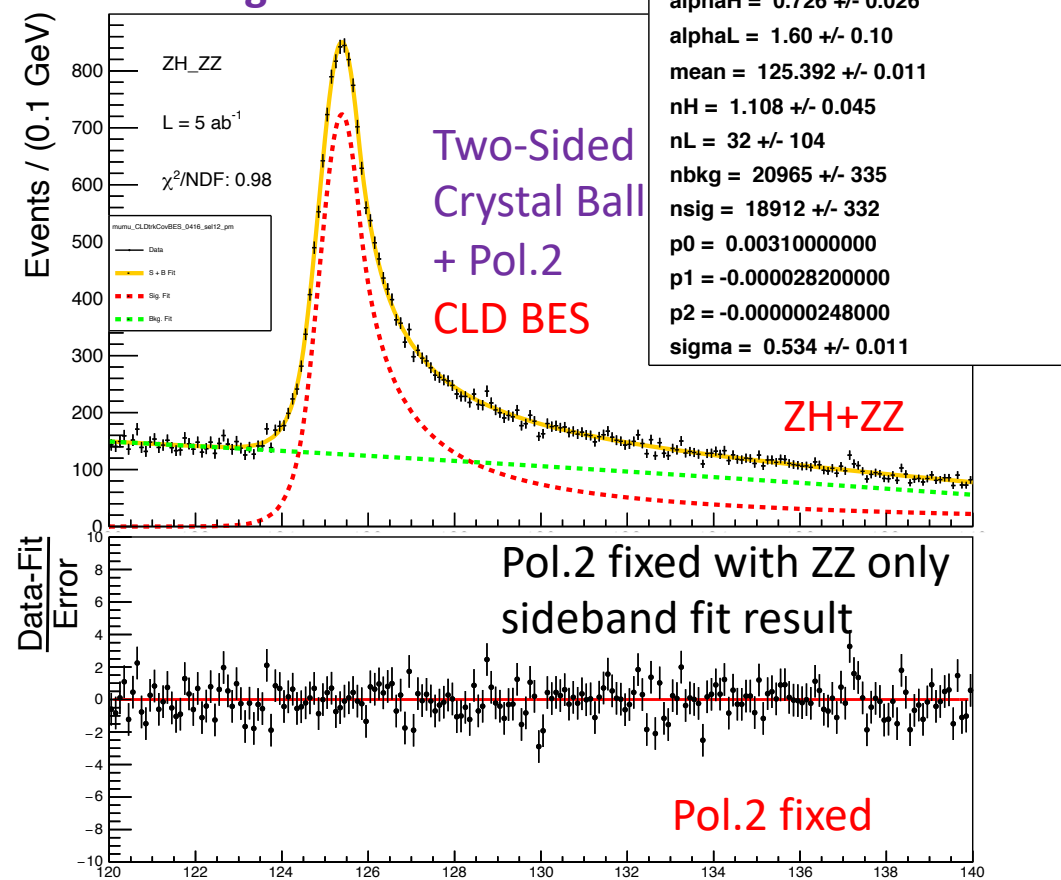


$\frac{\Delta N_{sig}}{N_{sig}} = 1.22\%$ Integral ZH = 19662 $M_{recoil} [GeV]$
 $N_{sig}^{fit} / N_{sig}^{integral} = 98.7\%$

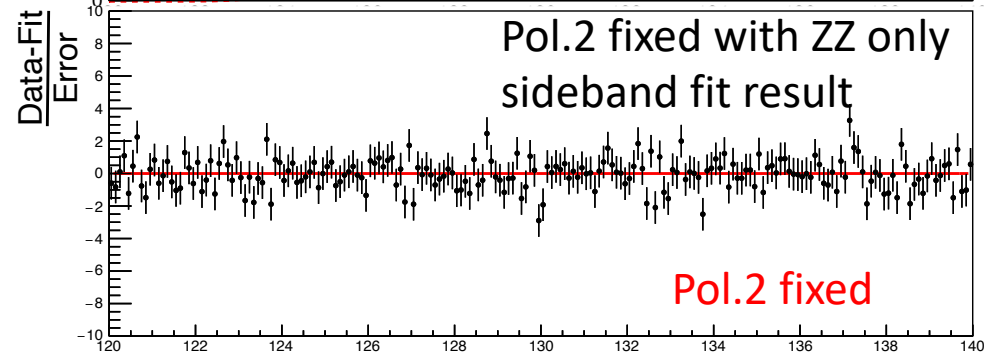
- Fixing the **tails**, the uncertainty of N_{sig} become $\sim 1.2\%$
- Fixing the **background** with the sideband fit, the uncertainty of N_{sig} becomes $\sim 1.8\%$

New Modelled Signal

DCB_Pol2 pdf with data



alphaH = 0.726 +/- 0.026
 alphaL = 1.60 +/- 0.10
 mean = 125.392 +/- 0.011
 nH = 1.108 +/- 0.045
 nL = 32 +/- 104
 nbkg = 20965 +/- 335
 nsig = 18912 +/- 332
 p0 = 0.0031000000
 p1 = -0.00002820000
 p2 = -0.000000248000
 sigma = 0.534 +/- 0.011



$\frac{\Delta N_{sig}}{N_{sig}} = 1.76\%$ Integral ZH = 19662 $M_{recoil} [GeV]$
 $N_{sig}^{fit} / N_{sig}^{integral} = 96.2\%$
 $\frac{\Delta N_{bkg}}{N_{bkg}} = 1.60\%$ Integral ZZ = 20216
 $N_{bkg}^{fit} / N_{bkg}^{integral} = 103.7\%$

Fitted Width, mass and N_{sig} precision

Two-Sided Crystal Ball + Pol.2 fit New Modelled Signal ZH+ZZ	σ_H (GeV) Width	Δ_{σ_H} (GeV)	M_H (GeV) Mass	Δ_{M_H} (GeV)	$\Delta_{N_{sig}}/N_{sig}$
IDEA DSCB tails Fixed	0.2600	0.0037	125.0560	0.0037	0.928%
IDEA Pol.2 Fixed	0.2585	0.0040	125.0539	0.0039	1.536%
IDEA with BES DSCB tails Fixed	0.3838	0.0066	125.3500	0.0062	1.105%
IDEA with BES Pol.2 Fixed	0.3830	0.0073	125.3497	0.0064	1.567%
CLD DSCB tails Fixed	0.4702	0.0066	125.1130	0.0060	0.995%
CLD Pol.2 Fixed	0.4698	0.0074	125.1156	0.0065	2.266%
CLD with BES DSCB tails Fixed	0.5283	0.0098	125.3879	0.0091	1.222%
CLD with BES Pol.2 Fixed	0.5340	0.0110	125.3920	0.0110	1.755%

- For IDEA, Beam Energy Spread effect increases the fitted width by ~ 0.12 GeV and shifts the fitted mass by ~ 0.3 GeV
- For CLD, Beam Energy Spread effect increases the fitted width by ~ 0.06 GeV and shifts the fitted mass by ~ 0.3 GeV
- CLD has larger fitted width ~ 80 %
- Fixing the tails, $\Delta_{N_{sig}}/N_{sig}$ is ~ 1.0 %
- Fixing Pol.2 can also decrease the $\Delta_{N_{sig}}/N_{sig}$ to 1.5% - 2.3%

Conclusions

IDEA:

- For all the cases, the $\sigma_H = 0.256 \pm 0.004 \text{ GeV}$, $M_H = 125.056 \pm 0.004 \text{ GeV}$
- After fixing the tails, $\Delta_{N_{sig}}/N_{sig} \sim 1.0\%$.
- After fixing the background with the sideband fit, the uncertainty of N_{sig} becomes $\sim 1.5\%$

Beam Energy Spread Effect and CLD:

- For IDEA, Beam Energy Spread effect increases the fitted width by $\sim 0.12 \text{ GeV}$ and shifts the fitted mass by $\sim 0.3 \text{ GeV}$
- For CLD, Beam Energy Spread effect increases the fitted width by $\sim 0.06 \text{ GeV}$ and shifts the fitted mass by $\sim 0.3 \text{ GeV}$
- CLD has larger fitted width $\sim 80 \%$

Next-Step

- Improve the Signal Modelling function
- Generate more WW events
- M_{recoil} fit on [116, 140] GeV to constraint the background and tails
- Reconstructed Z mass m_Z fit
- Reconstruct using generator-level muon instead of recorded muon
- Magnetic field :2T->3T

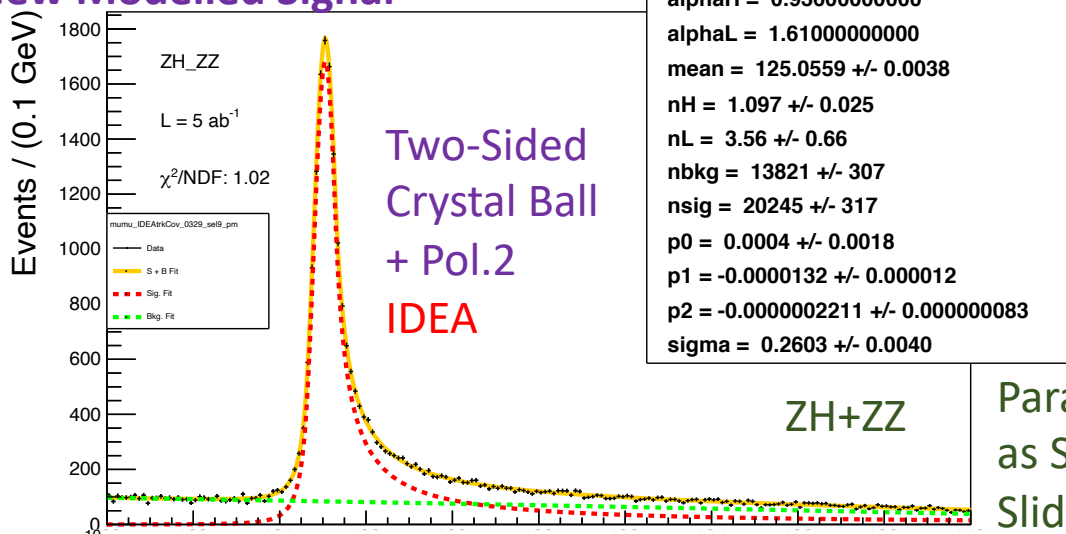
BackUp

IDEAtrkCov

Two-Sided Crystal Ball + Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

New Modelled Signal

DCB_Pol2 pdf with data

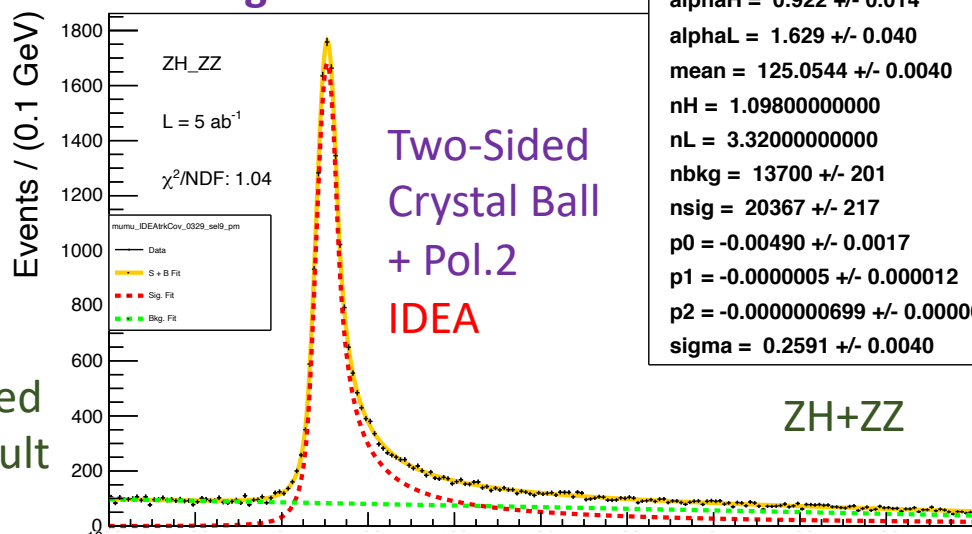


$\alpha_H = 0.93600000000$
 $\alpha_L = 1.61000000000$
 $mean = 125.0559 \pm 0.0038$
 $n_H = 1.097 \pm 0.025$
 $n_L = 3.56 \pm 0.66$
 $nbkg = 13821 \pm 307$
 $nsig = 20245 \pm 317$
 $p_0 = 0.0004 \pm 0.0018$
 $p_1 = -0.0000132 \pm 0.000012$
 $p_2 = -0.0000002211 \pm 0.000000083$
 $sigma = 0.2603 \pm 0.0040$

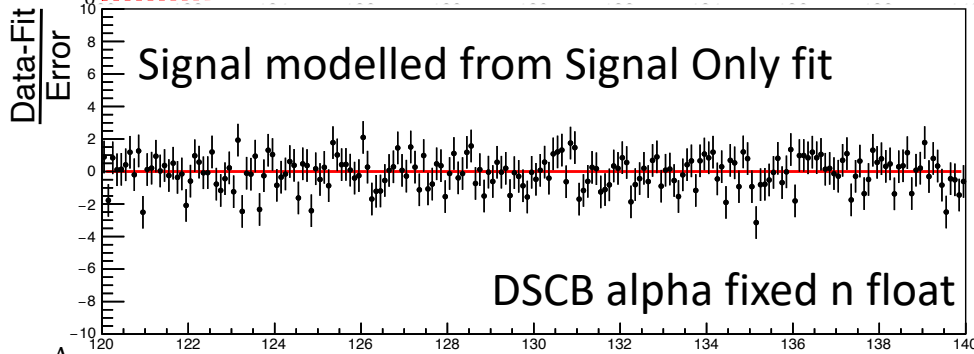
Parameters were fixed as Signal Only fit result Slide 6 left plot

New Modelled Signal

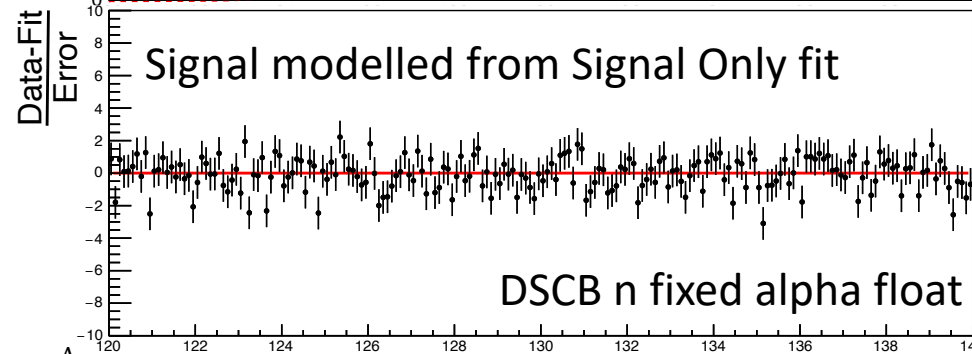
DCB_Pol2 pdf with data



$\alpha_H = 0.922 \pm 0.014$
 $\alpha_L = 1.629 \pm 0.040$
 $mean = 125.0544 \pm 0.0040$
 $n_H = 1.09800000000$
 $n_L = 3.32000000000$
 $nbkg = 13700 \pm 201$
 $nsig = 20367 \pm 217$
 $p_0 = -0.00490 \pm 0.0017$
 $p_1 = -0.0000005 \pm 0.000012$
 $p_2 = -0.000000699 \pm 0.000000079$
 $sigma = 0.2591 \pm 0.0040$



$\frac{\Delta N_{sig}}{N_{sig}} = 1.60\%$
 $\frac{\Delta N_{bkg}}{N_{bkg}} = 2.22\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$
 Integral ZH = 20310
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 99.7\%$
 $M_{recoil} [\text{GeV}]$
 Integral ZZ = 13757
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.5\%$

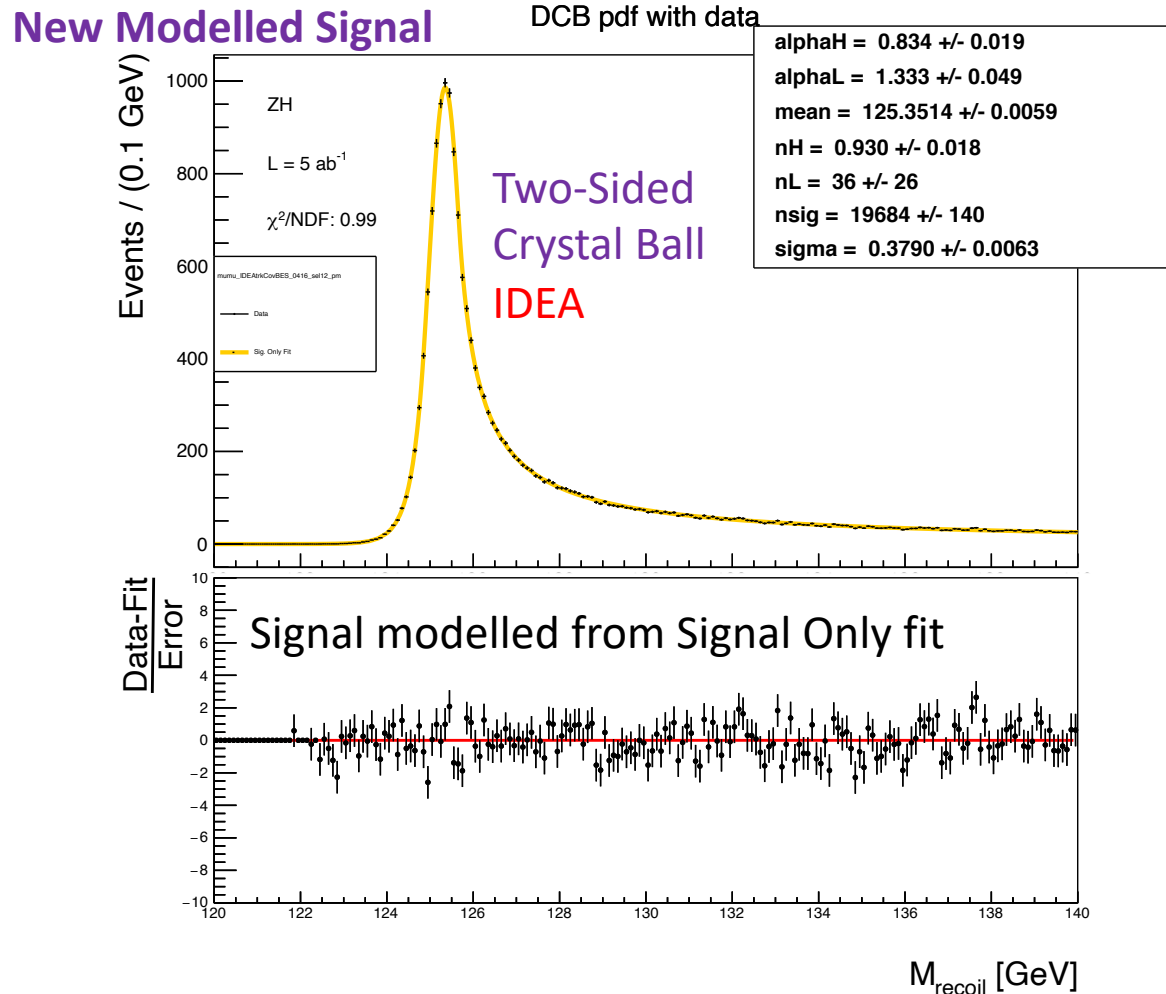
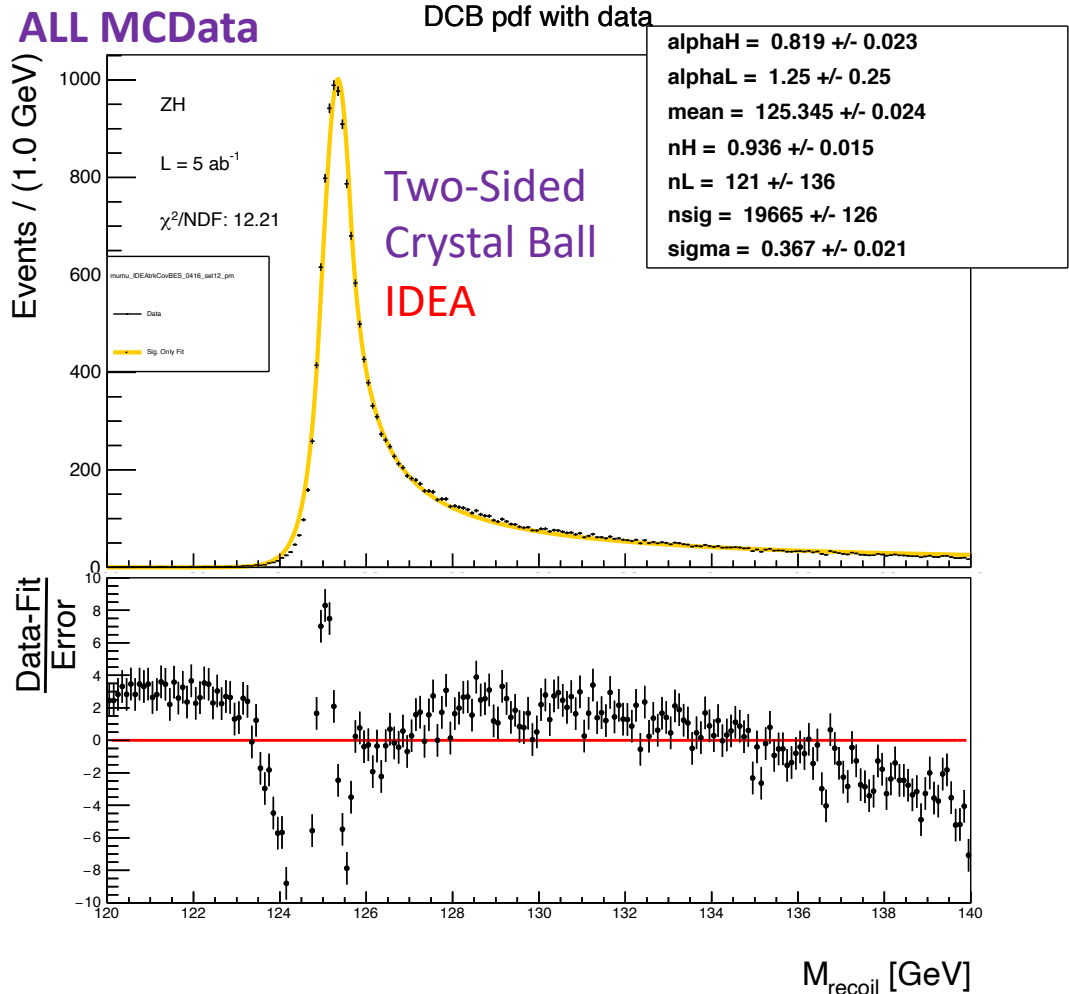


$\frac{\Delta N_{sig}}{N_{sig}} = 1.07\%$
 $\frac{\Delta N_{bkg}}{N_{bkg}} = 1.47\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$
 Integral ZH = 20310
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.3\%$
 $M_{recoil} [\text{GeV}]$
 Integral ZZ = 13757
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 99.6\%$

- After floating alphas, $\chi^2 / NDF \sim 1.0$

IDEAtrkCovBES

Two-Sided Crystal Ball fit of M_{recoil} in the Higgs region (120-140 GeV)



ALL MCData:
All data come from the MC simulation

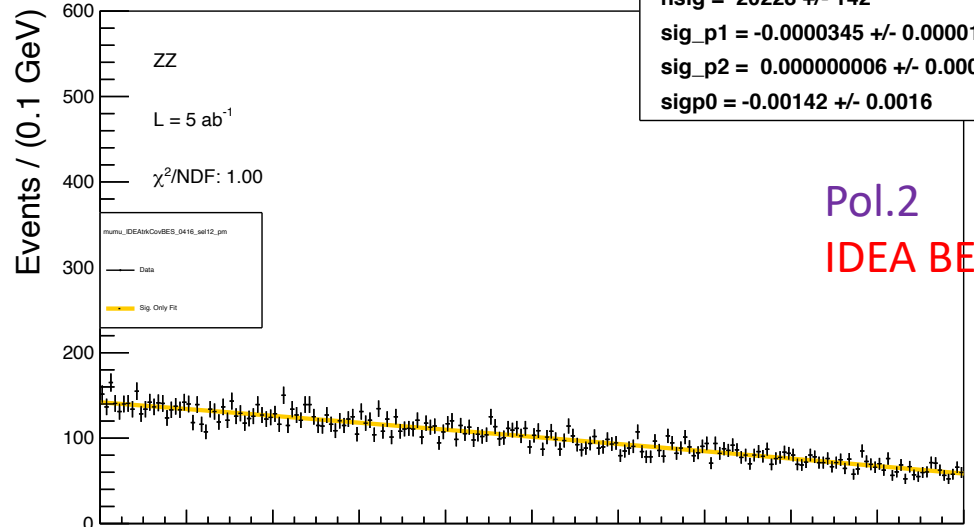
New Modelled Signal:
ZH signal is modelled to perfect shape

Bkg. Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

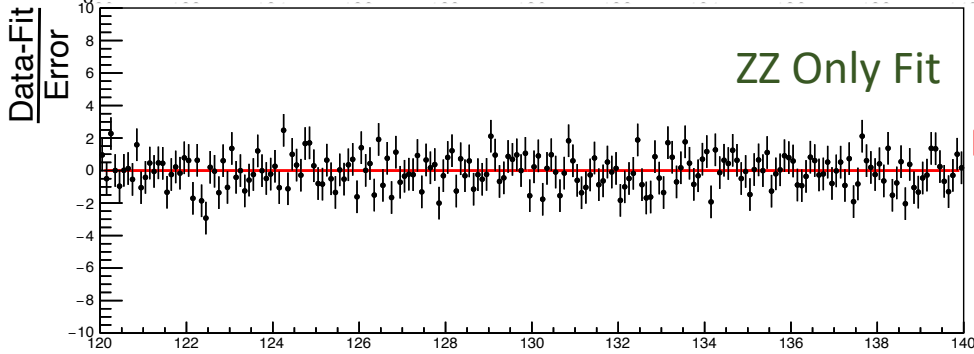
ALL MCDData

Pol2 pdf with data

$nsig = 20228 \pm 142$
 $sig_p1 = -0.0000345 \pm 0.000011$
 $sig_p2 = 0.000000006 \pm 0.000000072$
 $sigp0 = -0.00142 \pm 0.0016$



Pol.2
IDEA BES



Entries:

ZH: 196114
 ZZ: 39246
 WW: 2551

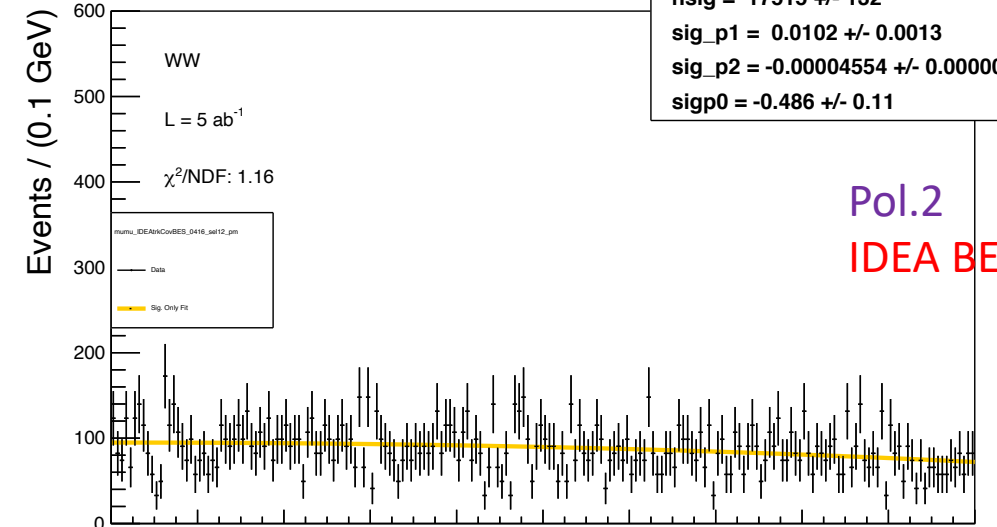
$\frac{\Delta N_{sig}}{N_{sig}} = 0.70\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$

Integral ZZ = 20228
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.0\%$
 $M_{recoil} [\text{GeV}]$

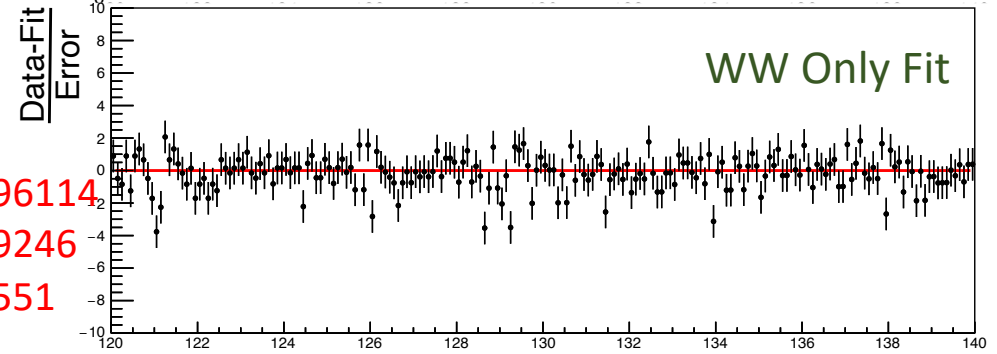
ALL MCDData

Pol2 pdf with data

$nsig = 17515 \pm 132$
 $sig_p1 = 0.0102 \pm 0.0013$
 $sig_p2 = -0.00004554 \pm 0.0000066$
 $sigp0 = -0.486 \pm 0.11$



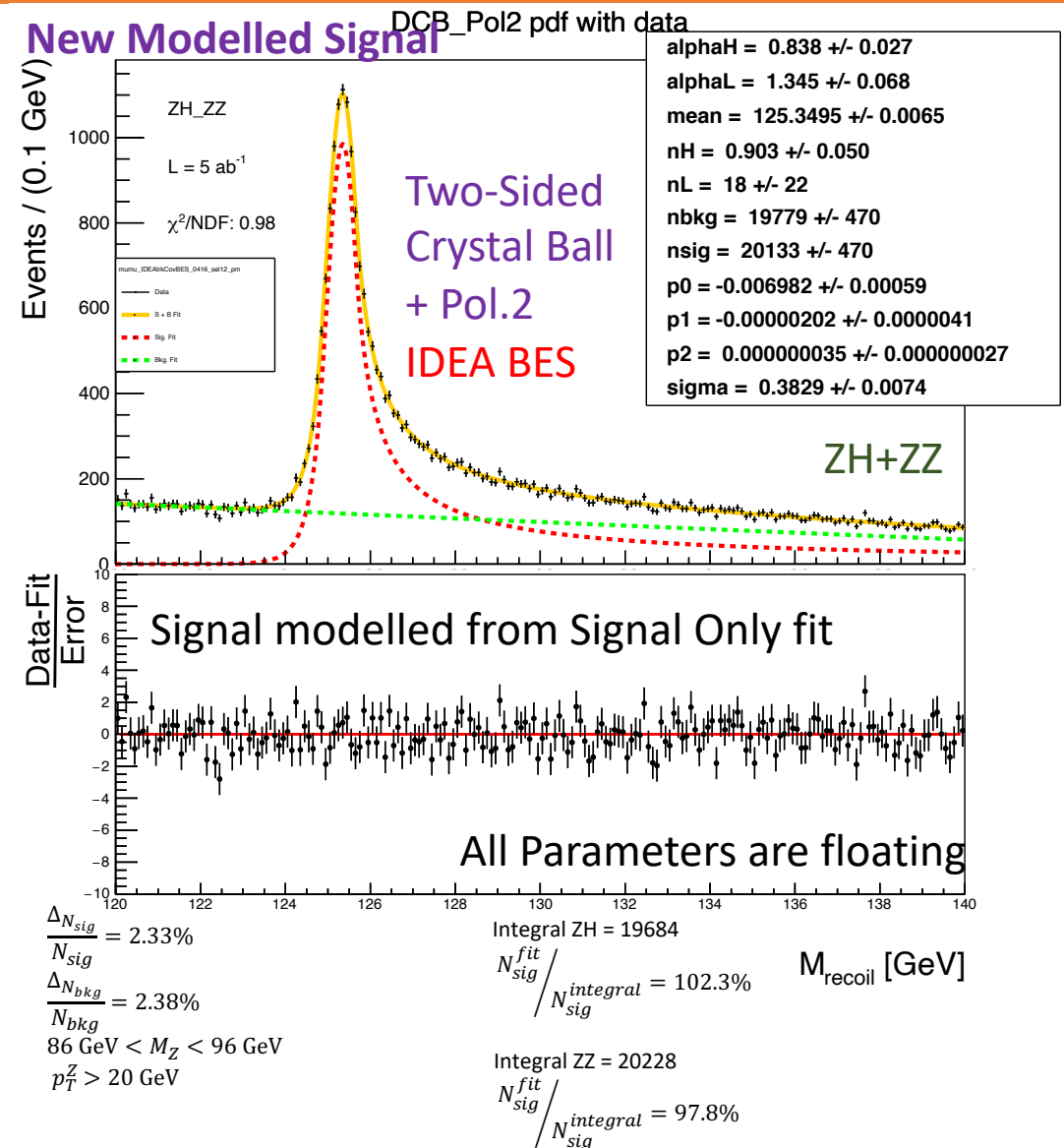
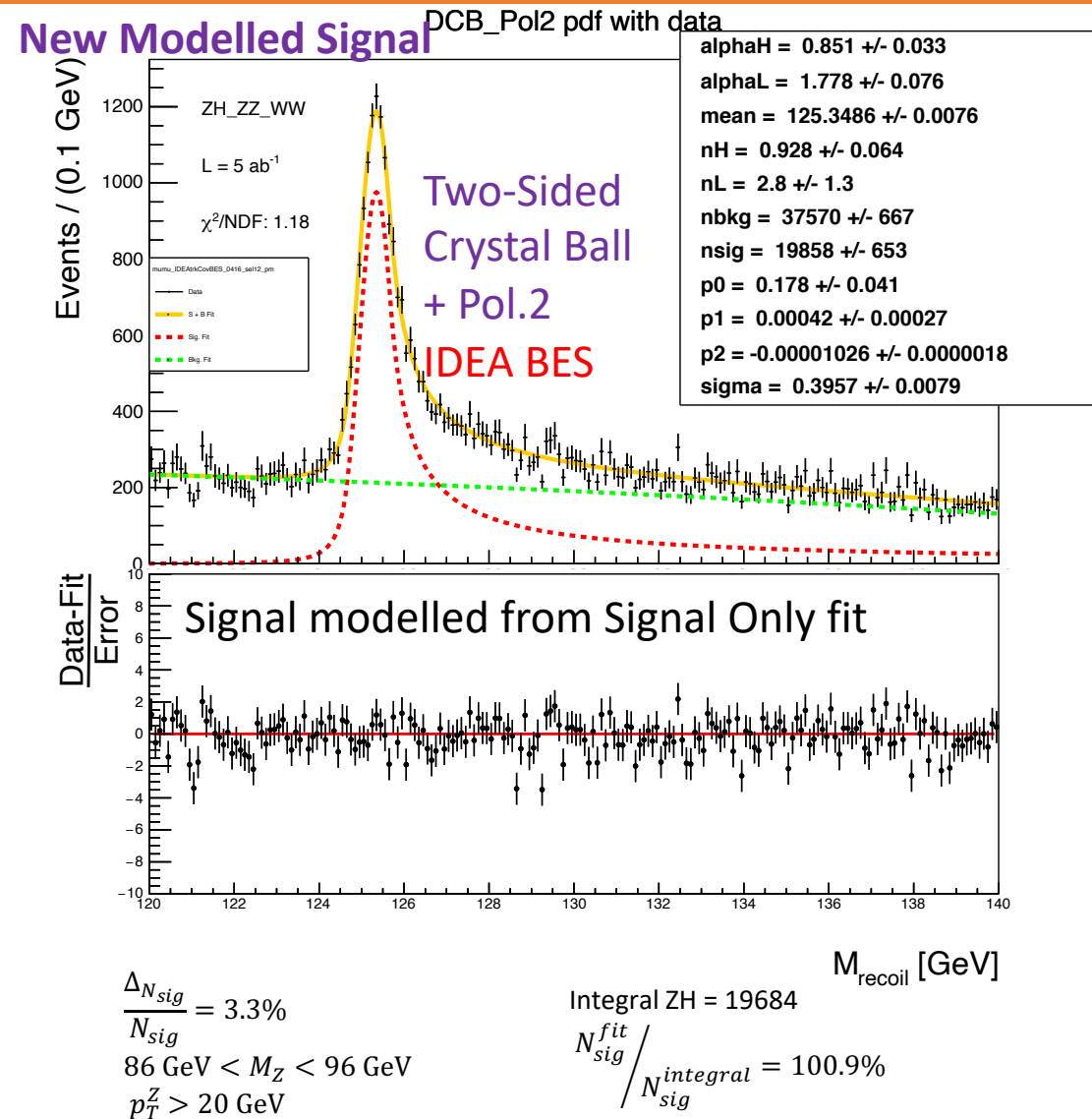
Pol.2
IDEA BES



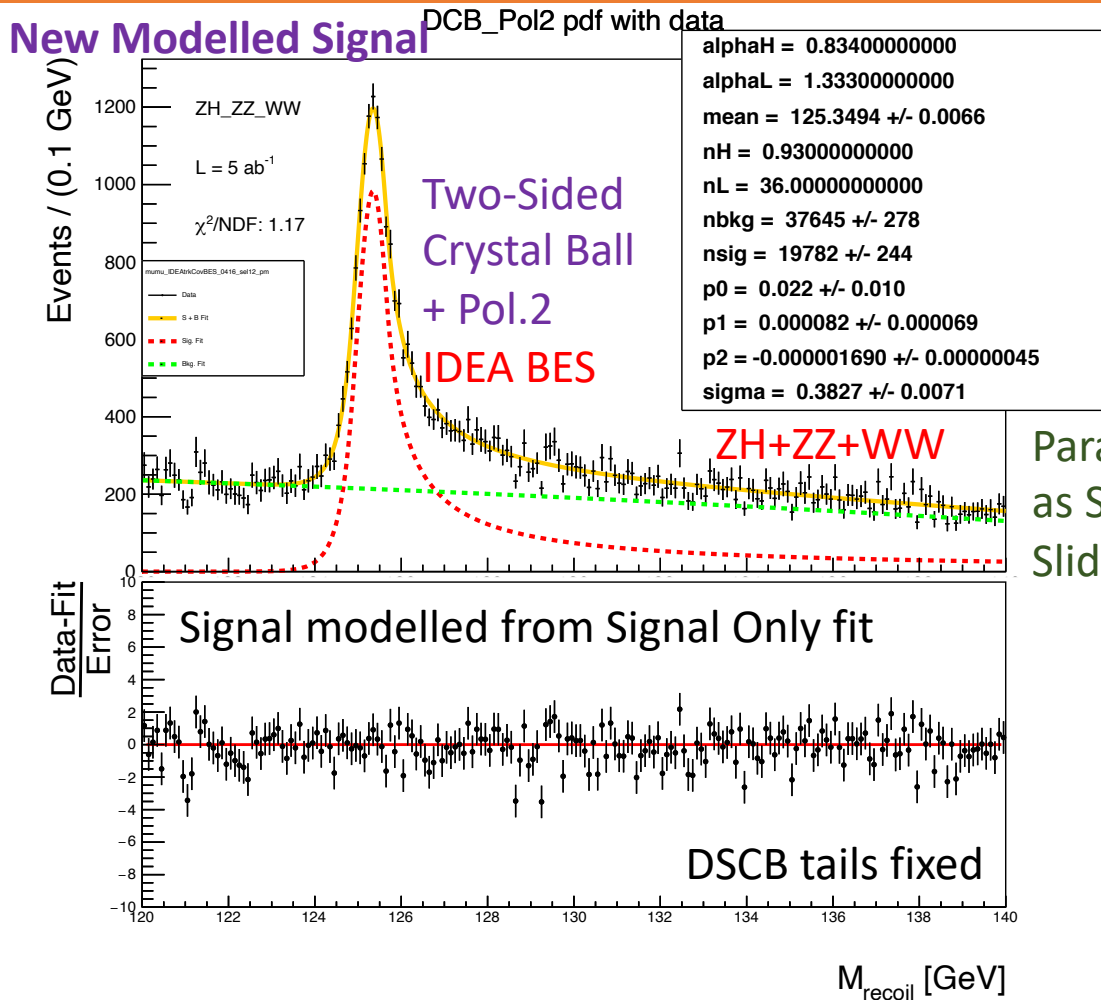
$\frac{\Delta N_{sig}}{N_{sig}} = 0.75\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$

Integral WW = 17515
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.1\%$
 $M_{recoil} [\text{GeV}]$

Comparison of ALL MCDData fit and New Modelled Signal fit



Two-Sided Crystal Ball + Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)



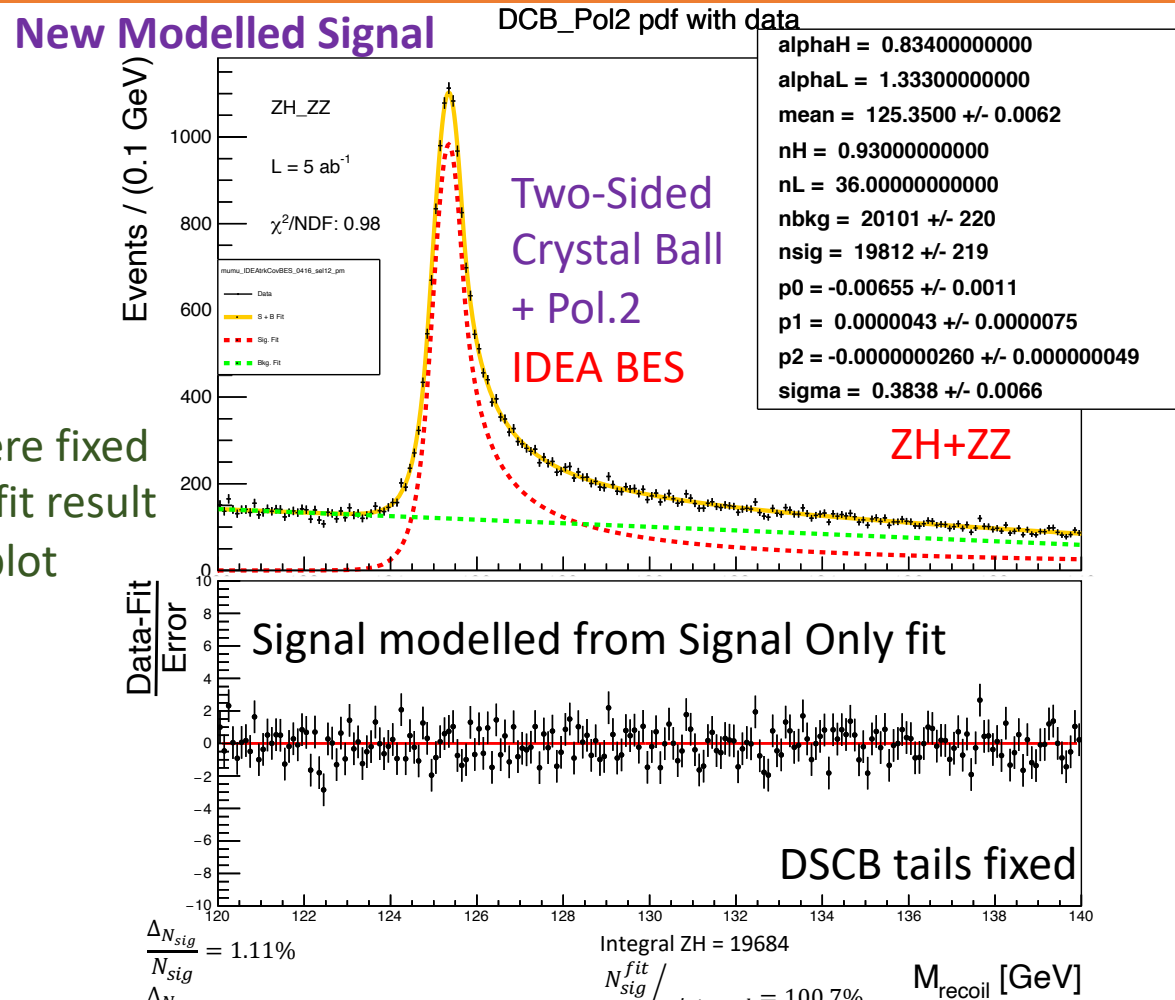
$$\frac{\Delta N_{sig}}{N_{sig}} = 1.23\%$$

$$86 \text{ GeV} < M_Z < 96 \text{ GeV}$$

$$p_T^Z > 20 \text{ GeV}$$

Integral ZH = 19684

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.5\%$$



$$\frac{\Delta N_{sig}}{N_{sig}} = 1.11\%$$

$$\frac{\Delta N_{bkg}}{N_{bkg}} = 1.09\%$$

$$86 \text{ GeV} < M_Z < 96 \text{ GeV}$$

$$p_T^Z > 20 \text{ GeV}$$

Integral ZH = 19684

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.7\%$$

Integral ZZ = 20228

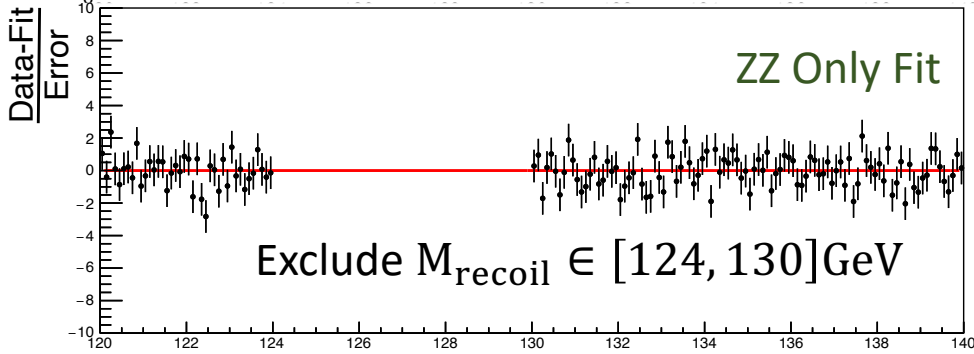
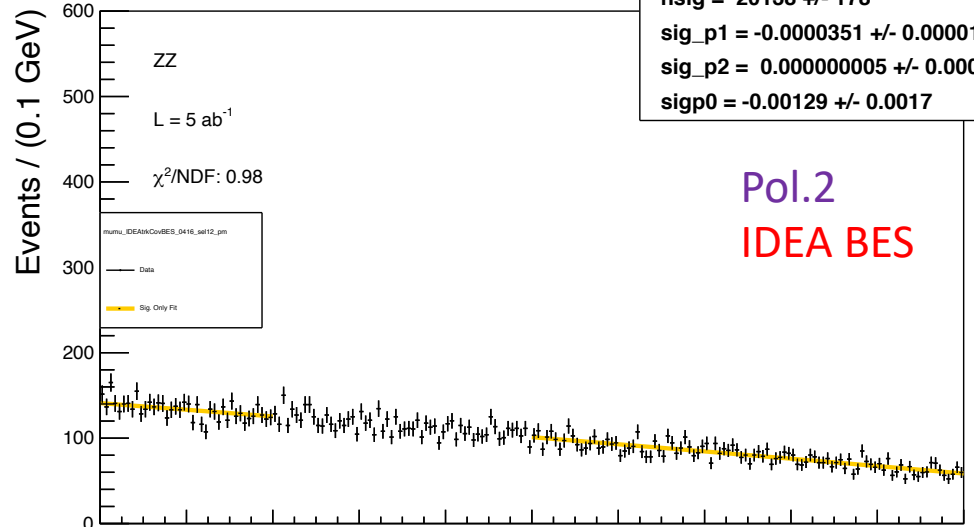
$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 99.4\%$$

Bkg. Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

ALL MCDData

Pol2 pdf with data

$n_{sig} = 20138 \pm 178$
 $sig_p1 = -0.0000351 \pm 0.000012$
 $sig_p2 = 0.000000005 \pm 0.000000079$
 $sigp0 = -0.00129 \pm 0.0017$



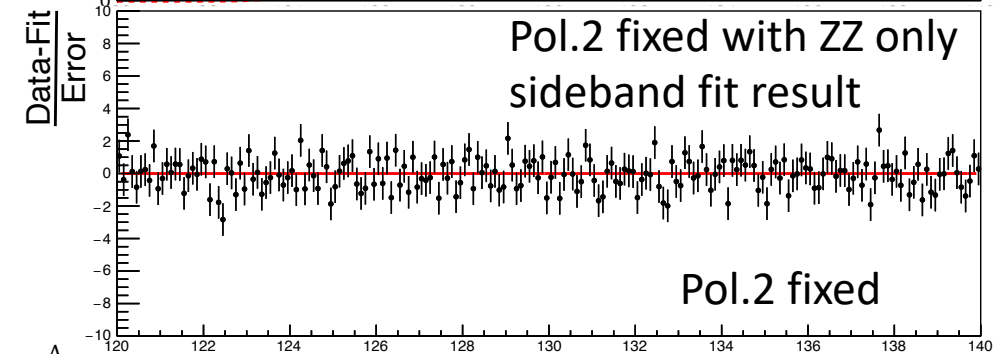
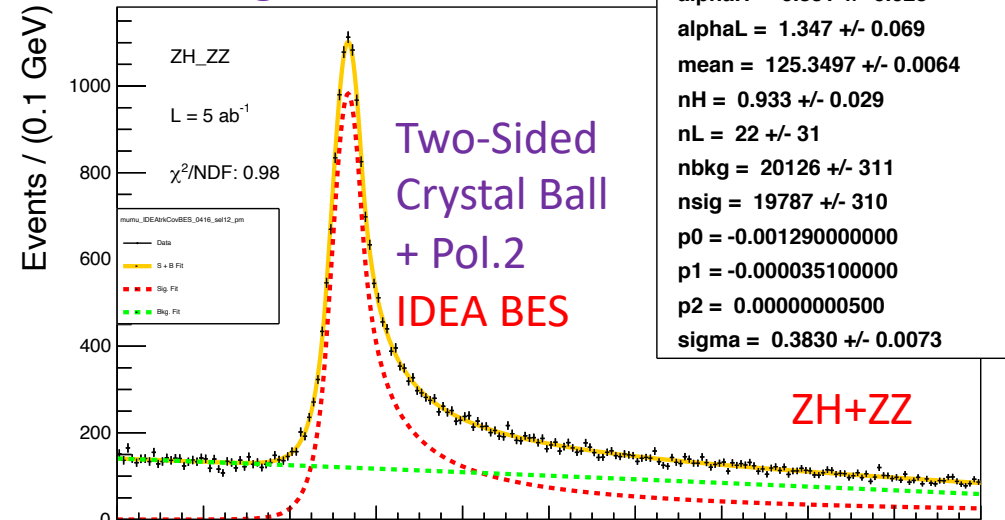
$\frac{\Delta N_{sig}}{N_{sig}} = 0.88\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$

Integral ZZ = 20228
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 99.6\%$
 $M_{recoil} \text{ [GeV]}$

New Modelled Signal

DCB_Pol2 pdf with data

$alphaH = 0.831 \pm 0.023$
 $alphaL = 1.347 \pm 0.069$
 $mean = 125.3497 \pm 0.0064$
 $nH = 0.933 \pm 0.029$
 $nL = 22 \pm 31$
 $nbkg = 20126 \pm 311$
 $n_{sig} = 19787 \pm 310$
 $p0 = -0.001290000000$
 $p1 = -0.000035100000$
 $p2 = 0.000000005000$
 $sigma = 0.3830 \pm 0.0073$



$\frac{\Delta N_{sig}}{N_{sig}} = 1.57\%$
 $\frac{\Delta N_{bkg}}{N_{bkg}} = 1.55\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$

Integral ZH = 19684
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.5\%$
 $M_{recoil} \text{ [GeV]}$
 Integral ZZ = 20228
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 99.5\%$

Fitted Width, mass, Nsig in the Higgs mass region (120-140 GeV)

Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ+WW	σ_H (GeV)	Δ_{σ_H} (GeV)	M_H (GeV)	Δ_{M_H} (GeV)	$\Delta_{N_{sig}} / N_{sig}$
New Modelled Signal	0.3957	0.0079	125.3486	0.0076	3.3%
New Modelled Signal, tails fixed	0.3827	0.0071	125.3494	0.0066	1.2%

Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ	σ_H (GeV)	Δ_{σ_H} (GeV)	M_H (GeV)	Δ_{M_H} (GeV)	$\Delta_{N_{sig}} / N_{sig}$
New Modelled Signal	0.3829	0.0074	125.3495	0.0065	2.3%
New Modelled Signal tails fixed	0.3838	0.0066	125.3500	0.0062	1.1%
New Modelled Signal Pol.2 fixed	0.3830	0.0073	125.3497	0.0064	1.6%

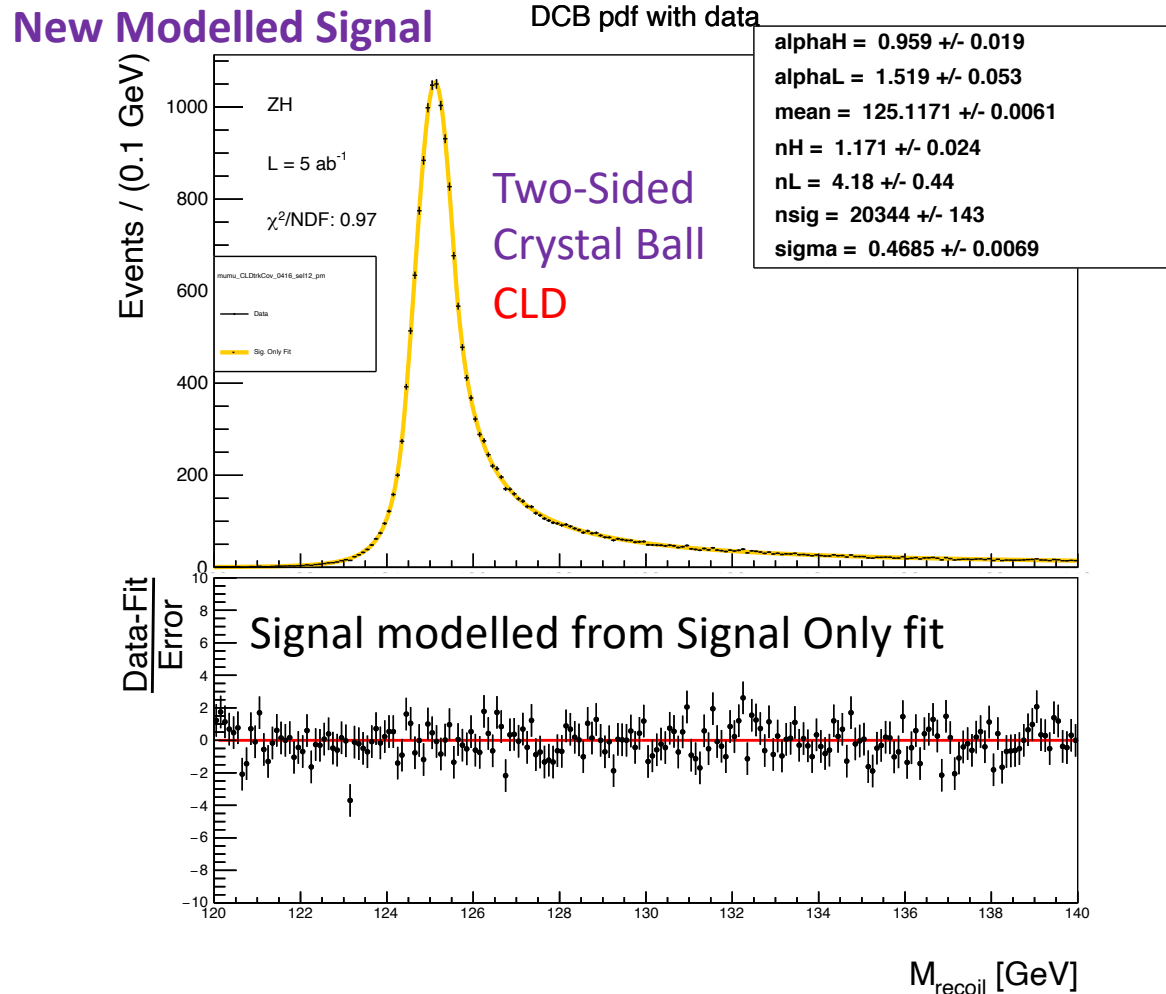
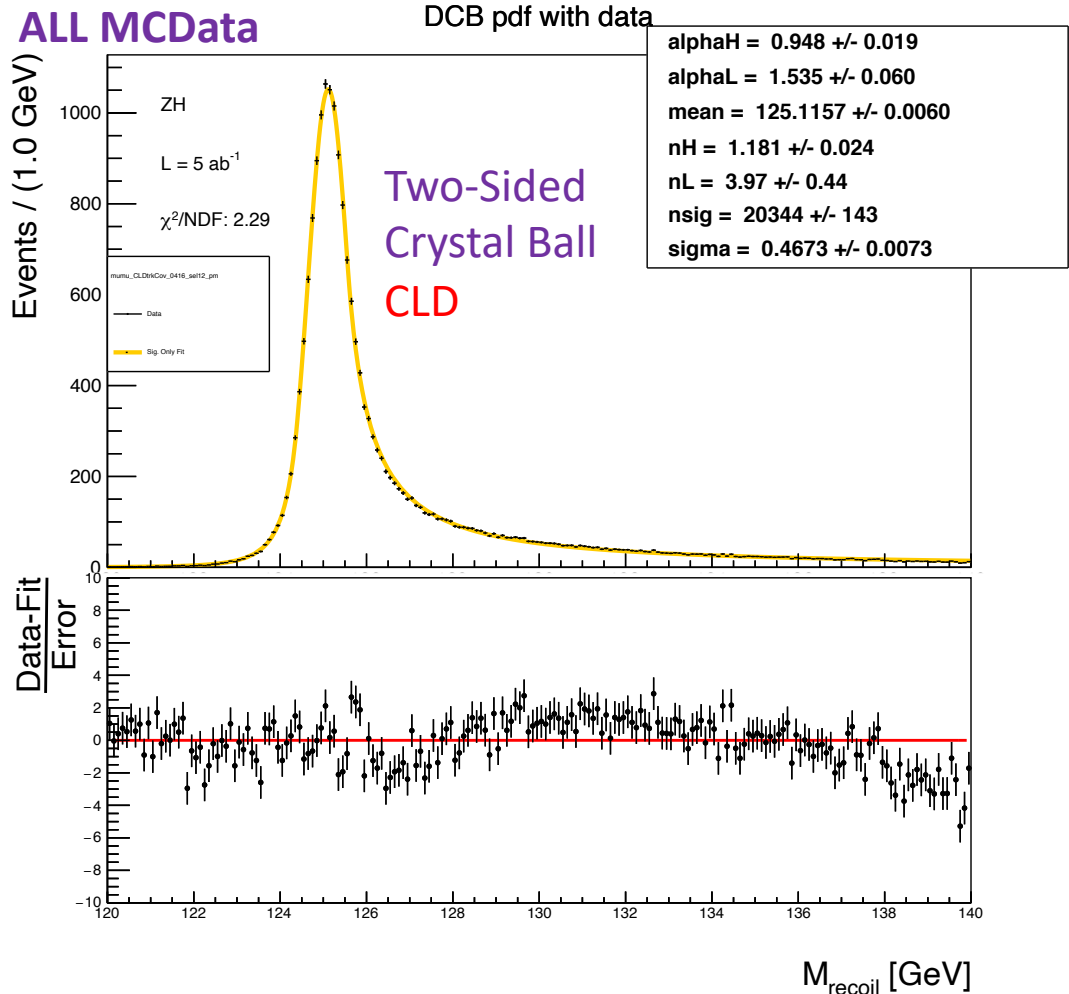
For New Modelled signal, the $\sigma_H \sim 0.39$ GeV, $\Delta_{\sigma_H} \sim 8$ MeV, $M_H \sim 125.3$ GeV, $\Delta_{M_H} \sim 7$ MeV

After fixing the tails, $\Delta_{N_{sig}} / N_{sig} \sim 1.0\%$.

Fixing Pol.2 can also decrease the $\Delta_{N_{sig}} / N_{sig}$ from $\sim 2.3\%$ to 1.6% .

CLDtrkCov

Two-Sided Crystal Ball fit of M_{recoil} in the Higgs region (120-140 GeV)



ALL MCData:
All data come from the MC simulation

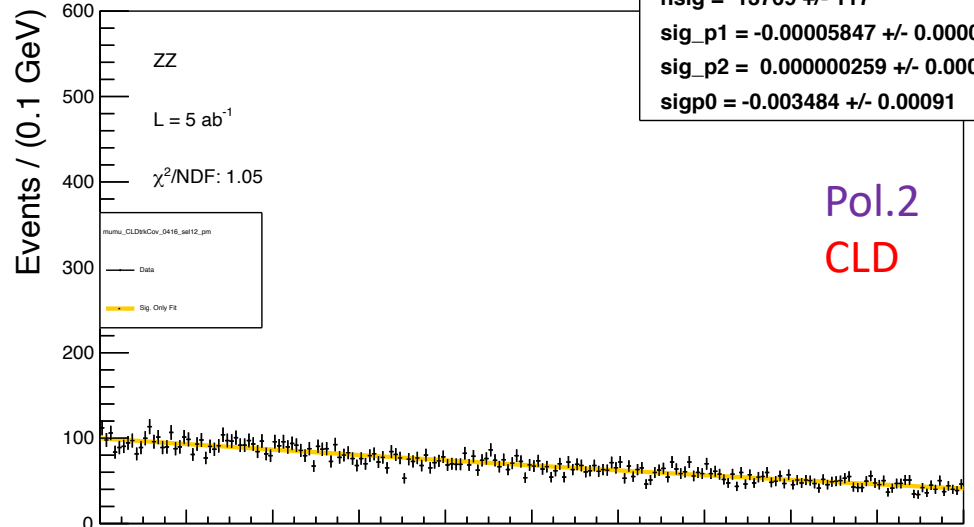
New Modelled Signal:
ZH signal is modelled to perfect shape

Bkg. Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

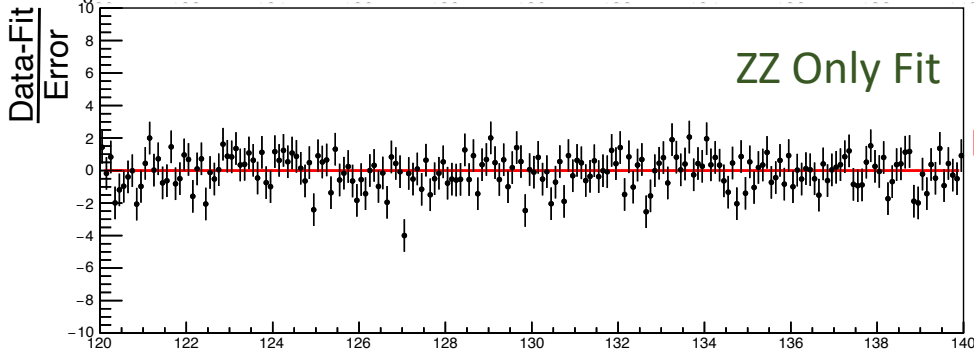
ALL MCDData

Pol2 pdf with data

$n_{sig} = 13769 \pm 117$
 $sig_p1 = -0.00005847 \pm 0.0000073$
 $sig_p2 = 0.000000259 \pm 0.000000047$
 $sigp0 = -0.003484 \pm 0.00091$



Pol.2
CLD



Entries:

ZH: 202693
 ZZ: 26842
 WW: 2416

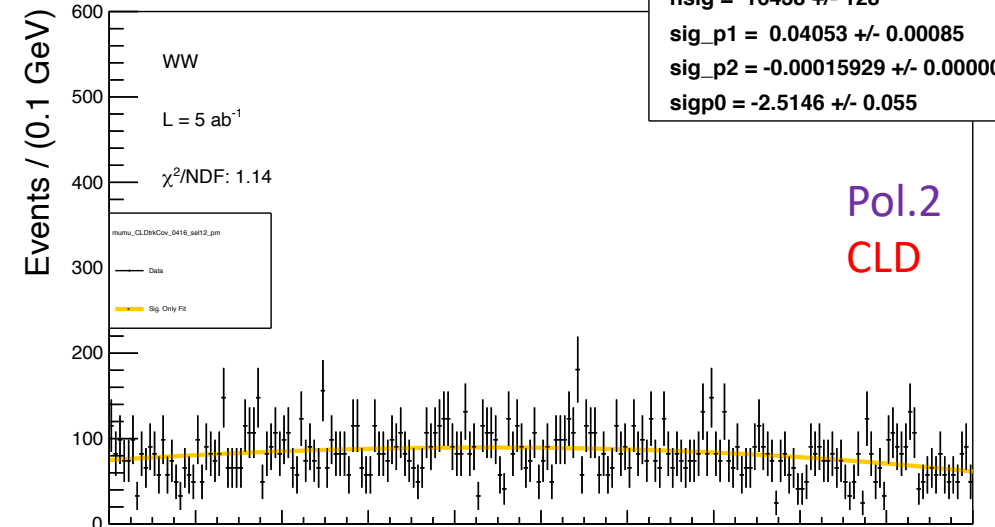
$\frac{\Delta N_{sig}}{N_{sig}} = 0.85\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$

Integral ZZ = 13769 $M_{recoil} [\text{GeV}]$
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.0\%$

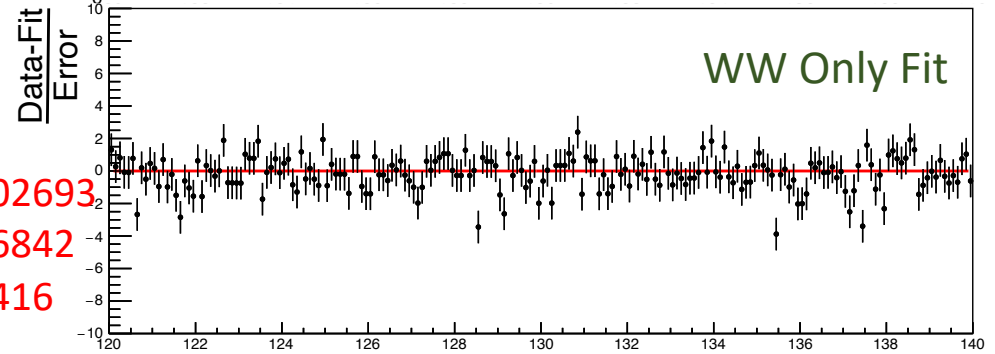
ALL MCDData

Pol2 pdf with data

$n_{sig} = 16438 \pm 128$
 $sig_p1 = 0.04053 \pm 0.00085$
 $sig_p2 = -0.00015929 \pm 0.0000034$
 $sigp0 = -2.5146 \pm 0.055$



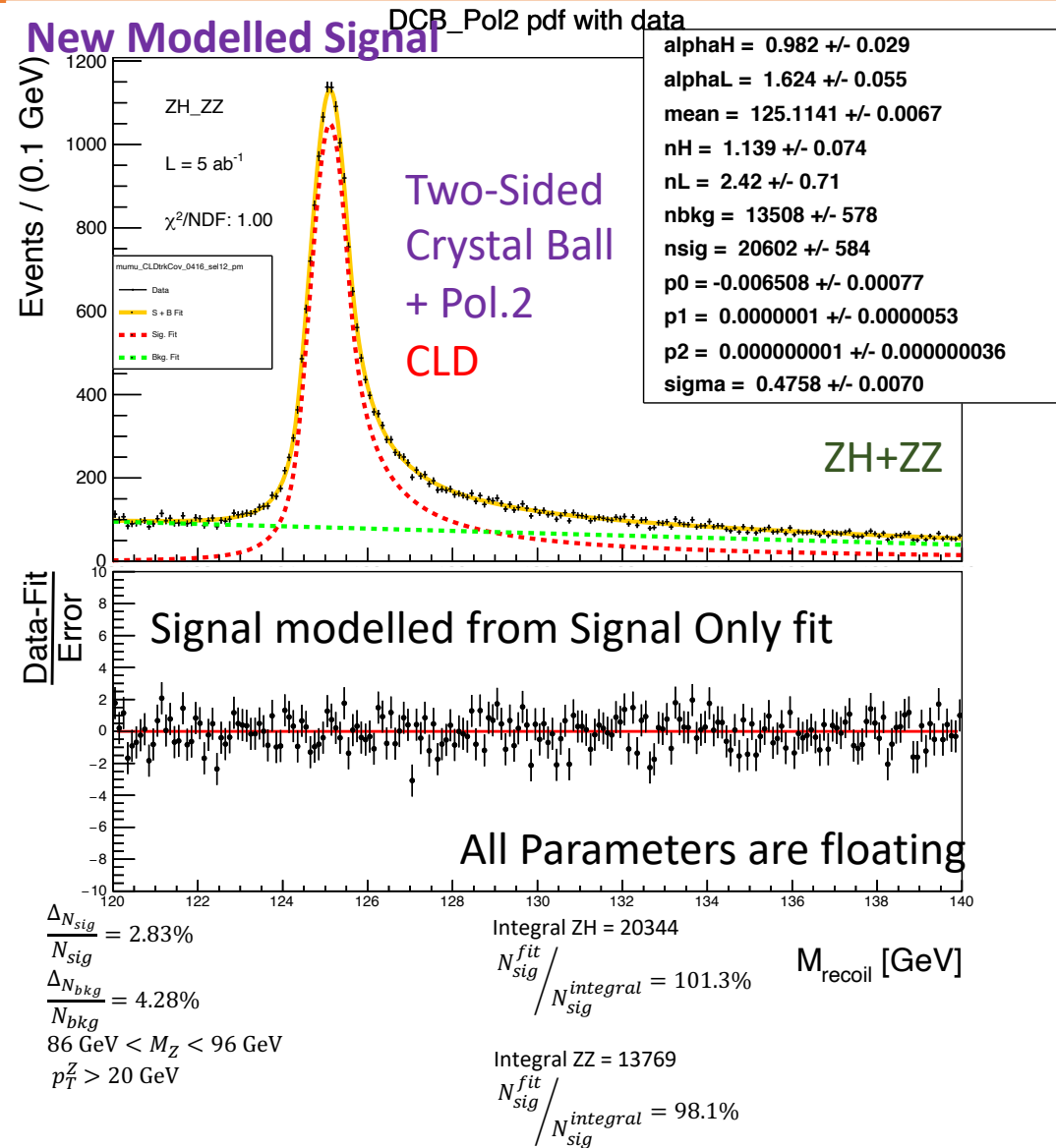
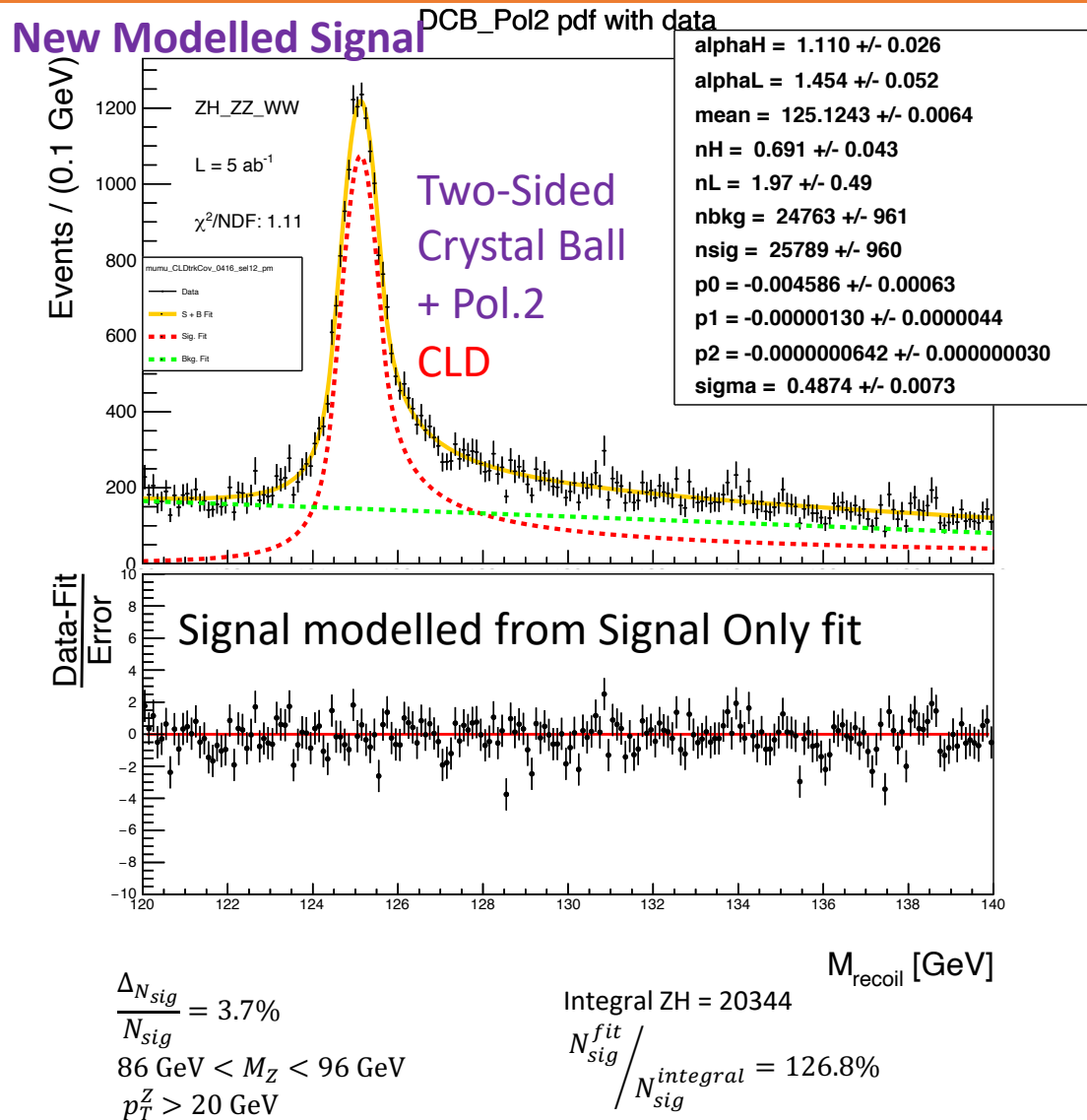
Pol.2
CLD



$\frac{\Delta N_{sig}}{N_{sig}} = 0.78\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$

Integral WW = 16439 $M_{recoil} [\text{GeV}]$
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.0\%$

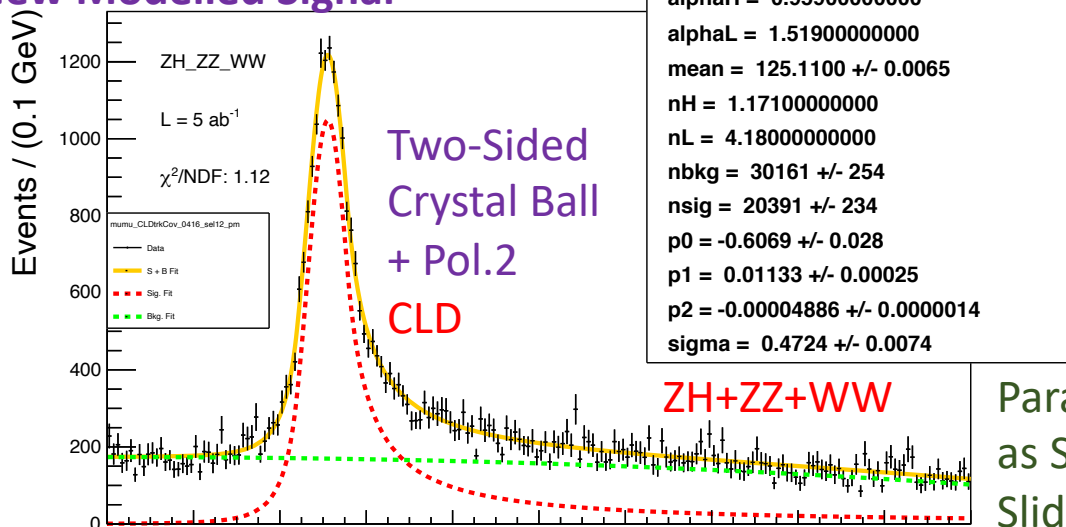
Comparison of ALL MCDData fit and New Modelled Signal fit



Two-Sided Crystal Ball + Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

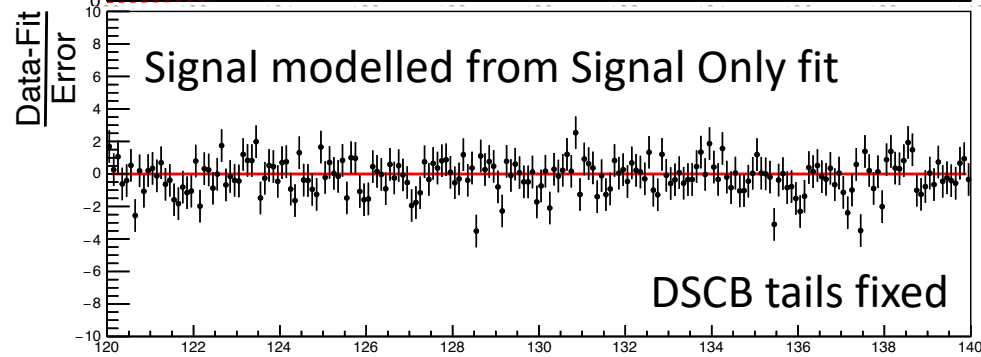
New Modelled Signal

DCB_Pol2 pdf with data



$\alpha_H = 0.95900000000$
 $\alpha_L = 1.51900000000$
 $mean = 125.1100 \pm 0.0065$
 $n_H = 1.17100000000$
 $n_L = 4.18000000000$
 $nbkg = 30161 \pm 254$
 $nsig = 20391 \pm 234$
 $p_0 = -0.6069 \pm 0.028$
 $p_1 = 0.01133 \pm 0.00025$
 $p_2 = -0.00004886 \pm 0.0000014$
 $sigma = 0.4724 \pm 0.0074$

Parameters were fixed as Signal Only fit result Slide 33 right plot

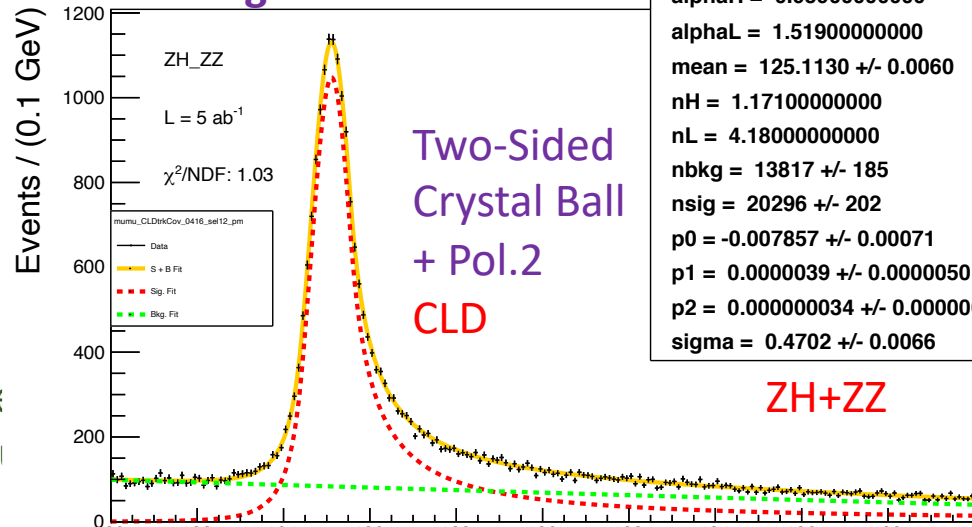


$\frac{\Delta N_{sig}}{N_{sig}} = 1.15\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$

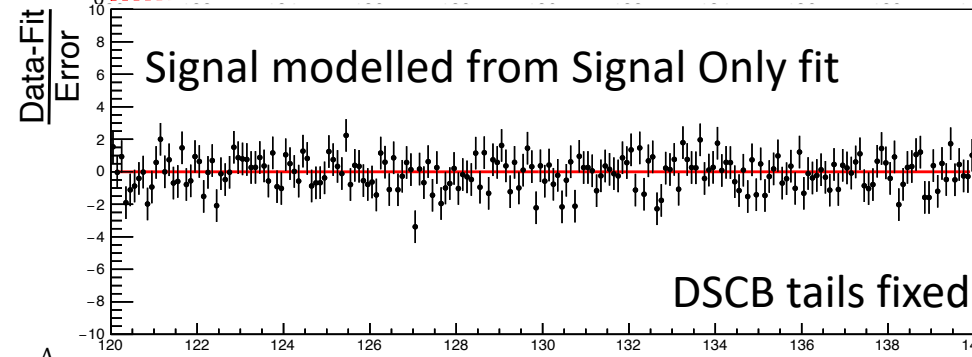
$Integral \text{ ZH} = 20344$
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.2\%$

New Modelled Signal

DCB_Pol2 pdf with data



$\alpha_H = 0.95900000000$
 $\alpha_L = 1.51900000000$
 $mean = 125.1130 \pm 0.0060$
 $n_H = 1.17100000000$
 $n_L = 4.18000000000$
 $nbkg = 13817 \pm 185$
 $nsig = 20296 \pm 202$
 $p_0 = -0.007857 \pm 0.00071$
 $p_1 = 0.0000039 \pm 0.0000050$
 $p_2 = 0.00000034 \pm 0.000000030$
 $sigma = 0.4702 \pm 0.0066$



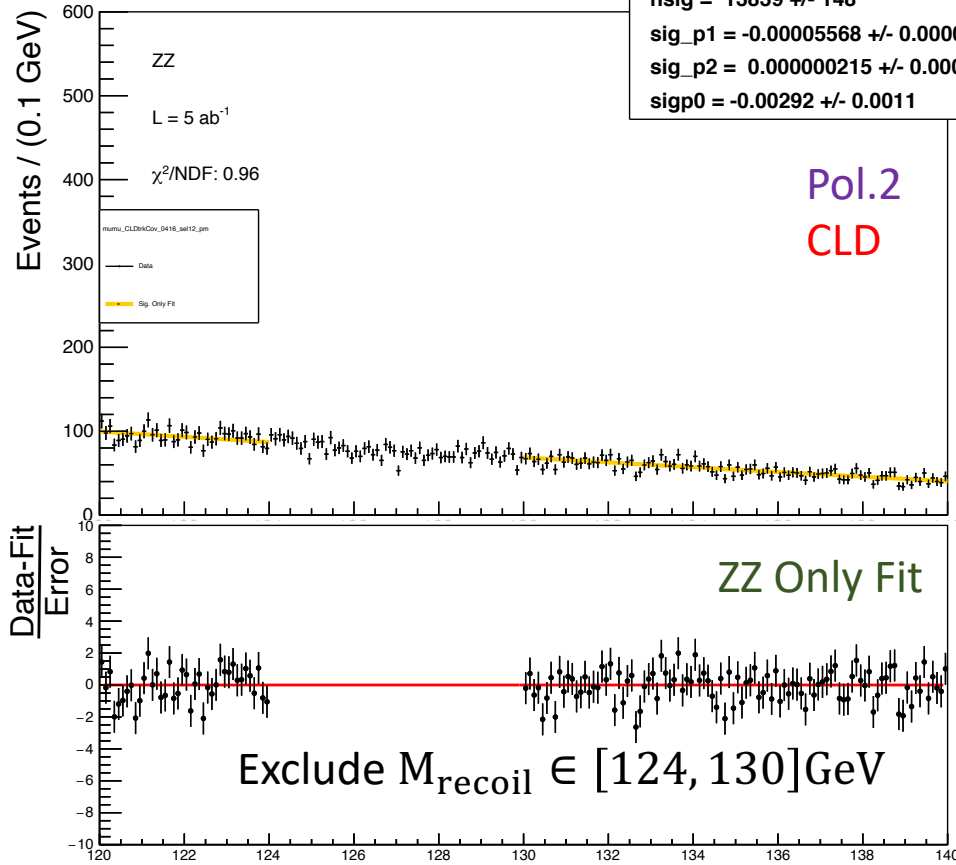
$\frac{\Delta N_{sig}}{N_{sig}} = 1.00\%$
 $\frac{\Delta N_{bkg}}{N_{bkg}} = 1.34\%$
 $86 \text{ GeV} < M_Z < 96 \text{ GeV}$
 $p_T^Z > 20 \text{ GeV}$

$Integral \text{ ZH} = 20344$
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 99.8\%$
 $Integral \text{ ZZ} = 13769$
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.3\%$

Bkg. Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

ALL MCData

Pol2 pdf with data



$$\frac{\Delta N_{sig}}{N_{sig}} = 1.07\%$$

$$86 \text{ GeV} < M_Z < 96 \text{ GeV}$$

$$p_T^Z > 20 \text{ GeV}$$

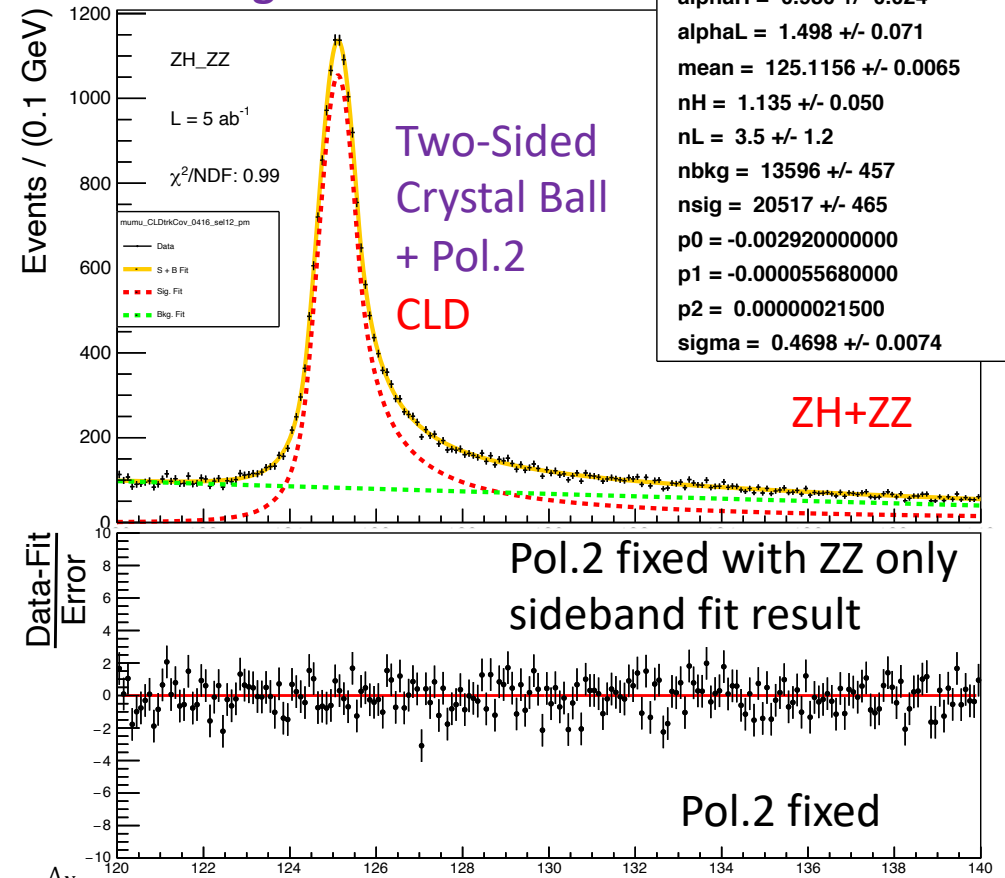
Integral ZZ = 13769

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.5\%$$

M_{recoil} [GeV]

New Modelled Signal

DCB_Pol2 pdf with data



$$\frac{\Delta N_{sig}}{N_{sig}} = 2.27\%$$

$$\frac{\Delta N_{bkg}}{N_{bkg}} = 3.36\%$$

$$86 \text{ GeV} < M_Z < 96 \text{ GeV}$$

$$p_T^Z > 20 \text{ GeV}$$

Integral ZH = 20344

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.9\%$$

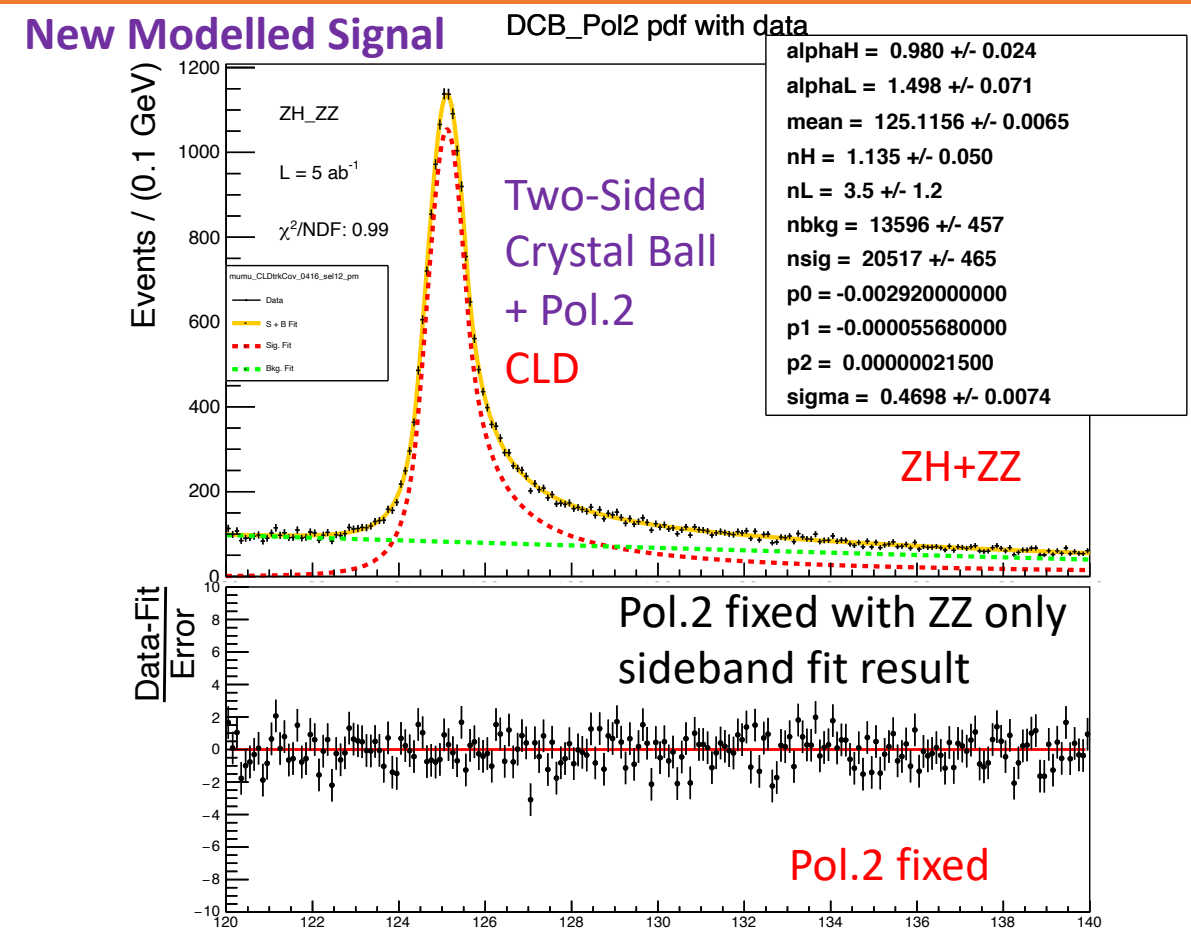
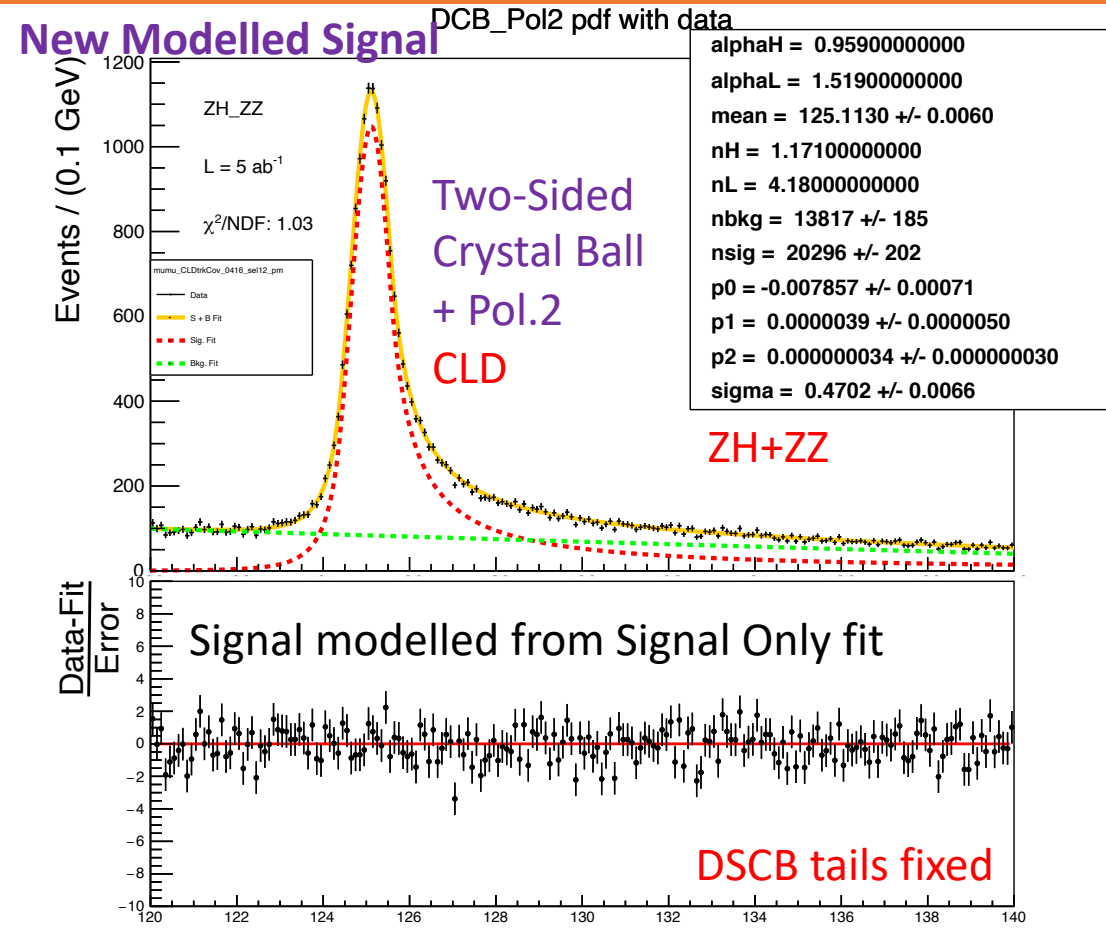
M_{recoil} [GeV]

Integral ZZ = 13769

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 98.7\%$$

nsig = 13839 +/- 148
sig_p1 = -0.00005568 +/- 0.0000084
sig_p2 = 0.000000215 +/- 0.000000053
sigp0 = -0.00292 +/- 0.0011

alphaH = 0.980 +/- 0.024
alphaL = 1.498 +/- 0.071
mean = 125.1156 +/- 0.0065
nH = 1.135 +/- 0.050
nL = 3.5 +/- 1.2
nbkg = 13596 +/- 457
nsig = 20517 +/- 465
p0 = -0.002920000000
p1 = -0.000055680000
p2 = 0.00000021500
sigma = 0.4698 +/- 0.0074



$\Delta N_{sig}/N_{sig} = 1.00\%$ Integral ZH = 20344 M_{recoil} [GeV]
 $N_{sig}^{fit}/N_{sig}^{integral} = 100.2\%$

$\Delta N_{sig}/N_{sig} = 2.27\%$ Integral ZH = 20344 M_{recoil} [GeV]
 $\Delta N_{bkg}/N_{bkg} = 3.36\%$ $N_{sig}^{fit}/N_{sig}^{integral} = 100.9\%$

Integral ZZ = 13769
 $N_{bkg}^{fit}/N_{bkg}^{integral} = 98.7\%$

- Fixing the **tails**, the uncertainty of N_{sig} is $\sim 1.2\%$
- Fixing the **background**, the uncertainty of N_{sig} is $\sim 2.3\%$

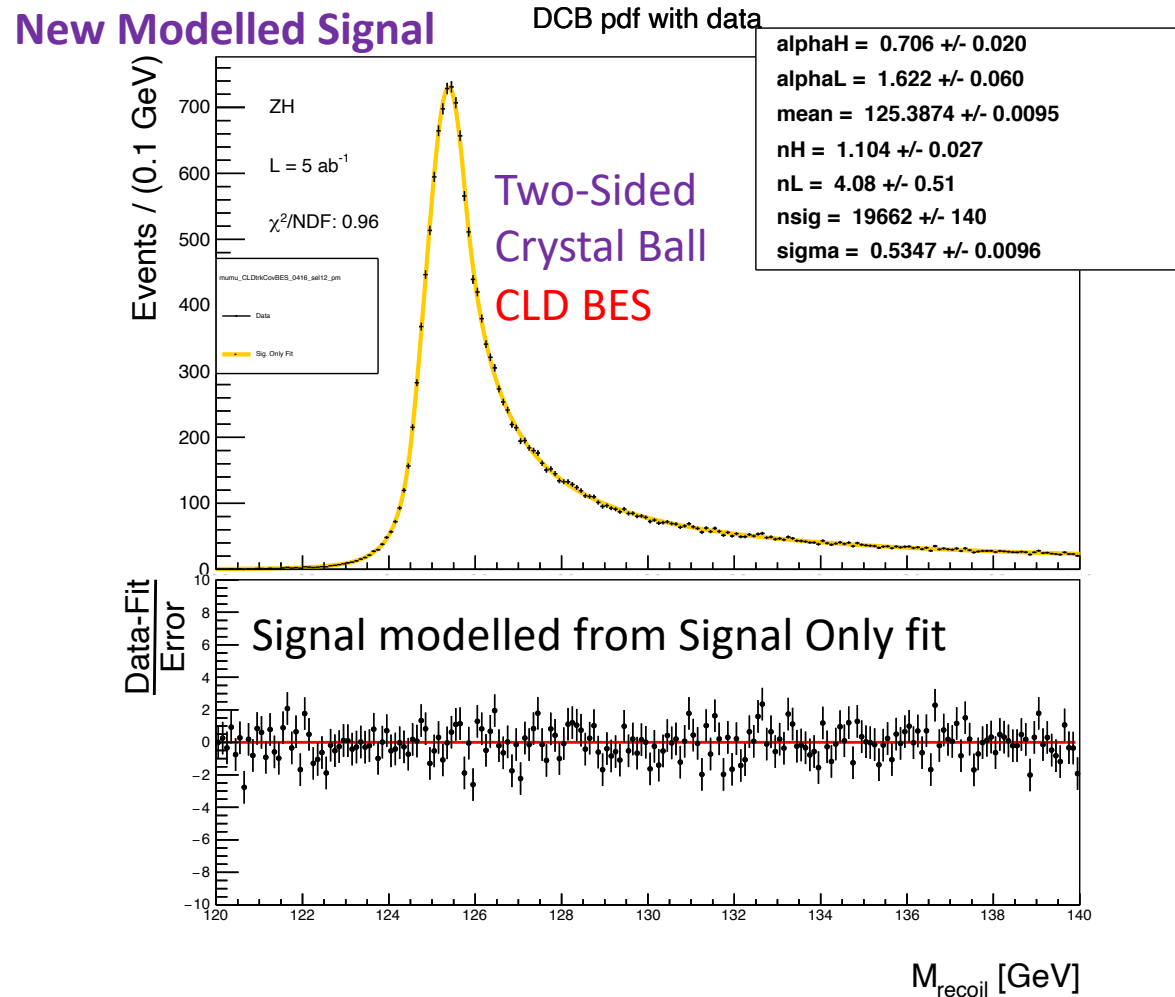
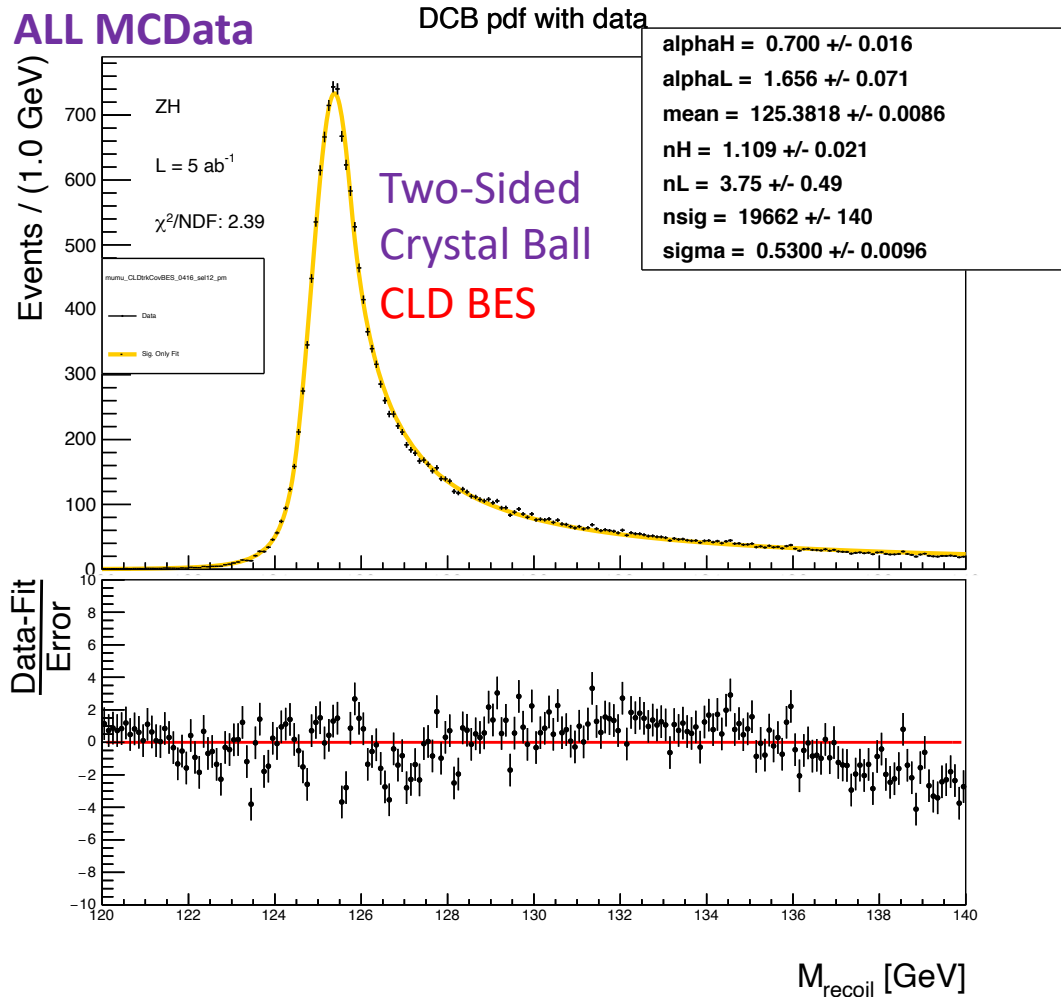
Fitted Width, mass, Nsig in the Higgs mass region (120-140 GeV)

Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ+WW	σ_H (GeV)	Δ_{σ_H} (GeV)	M_H (GeV)	Δ_{M_H} (GeV)	$\Delta_{N_{sig}} / N_{sig}$
New Modelled Signal	0.4874	0.0073	125.1243	0.0064	3.7%
New Modelled Signal, tails fixed	0.4724	0.0074	125.1100	0.0065	1.2%

Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ	σ_H (GeV)	Δ_{σ_H} (GeV)	M_H (GeV)	Δ_{M_H} (GeV)	$\Delta_{N_{sig}} / N_{sig}$
New Modelled Signal	0.4758	0.0070	125.1141	0.0067	2.8%
New Modelled Signal tails fixed	0.4702	0.0066	125.1130	0.0060	1.0%
New Modelled Signal Pol.2 fixed	0.4698	0.0074	125.1156	0.0065	2.3%

CLDtrkCovBES

Two-Sided Crystal Ball fit of M_{recoil} in the Higgs region (120-140 GeV)



ALL MCData:

All data come from the MC simulation

New Modelled Signal:

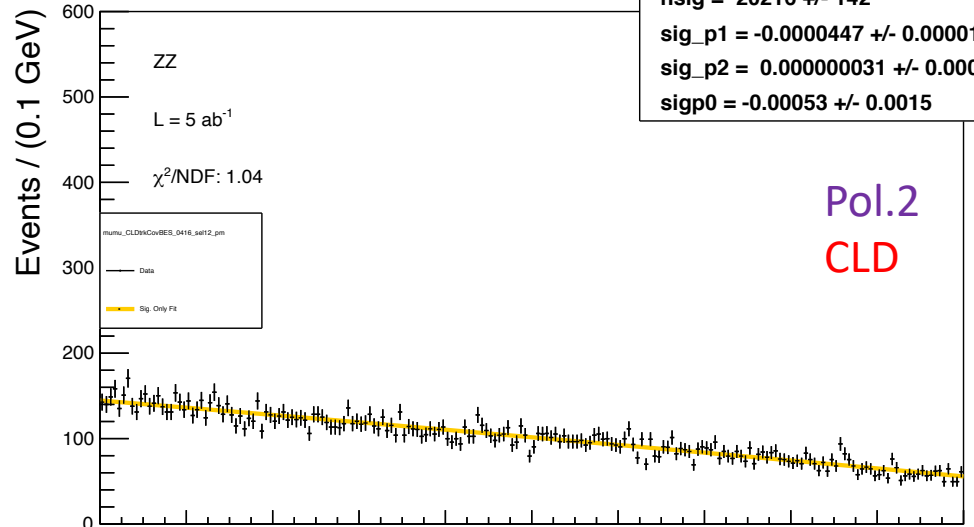
ZH signal is modelled to perfect shape

Bkg. Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

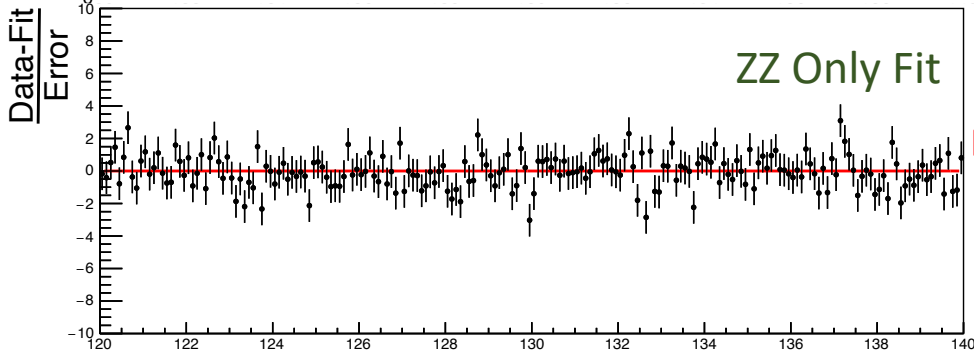
ALL MCDData

Pol2 pdf with data

nsig = 20216 +/- 142
 sig_p1 = -0.0000447 +/- 0.000010
 sig_p2 = 0.000000031 +/- 0.000000068
 sigp0 = -0.00053 +/- 0.0015



Pol.2
CLD



Entries:

ZH: 195883
 ZZ: 39273
 WW: 2550

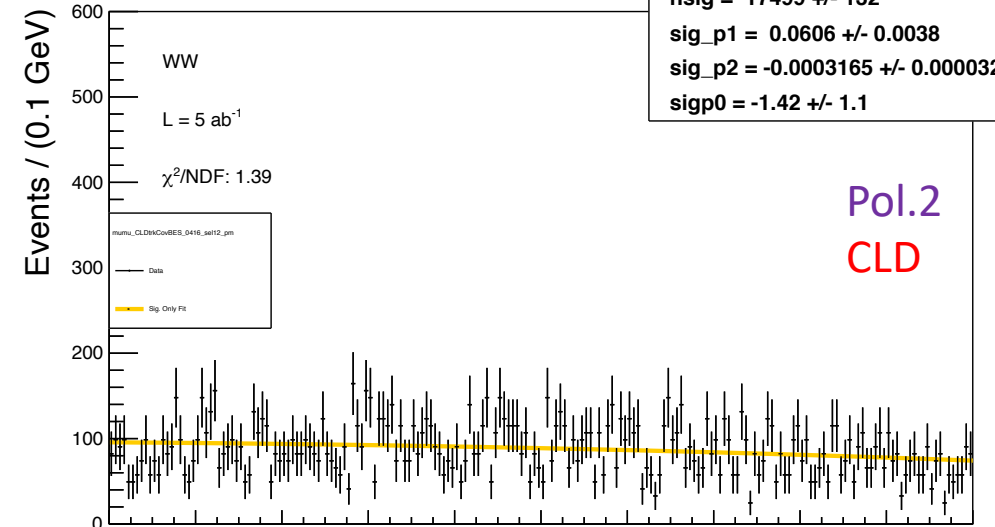
$\frac{\Delta N_{sig}}{N_{sig}} = 0.70\%$
 86 GeV < M_Z < 96 GeV
 $p_T^Z > 20$ GeV

Integral ZZ = 20216
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.0\%$
 M_{recoil} [GeV]

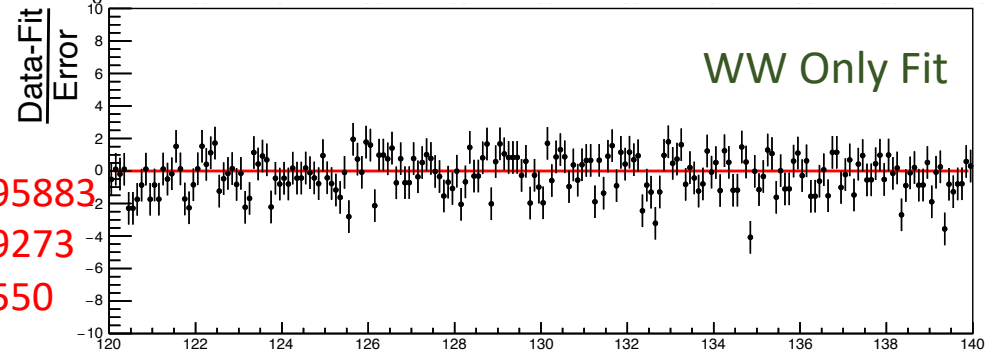
ALL MCDData

Pol2 pdf with data

nsig = 17499 +/- 132
 sig_p1 = 0.0606 +/- 0.0038
 sig_p2 = -0.0003165 +/- 0.000032
 sigp0 = -1.42 +/- 1.1



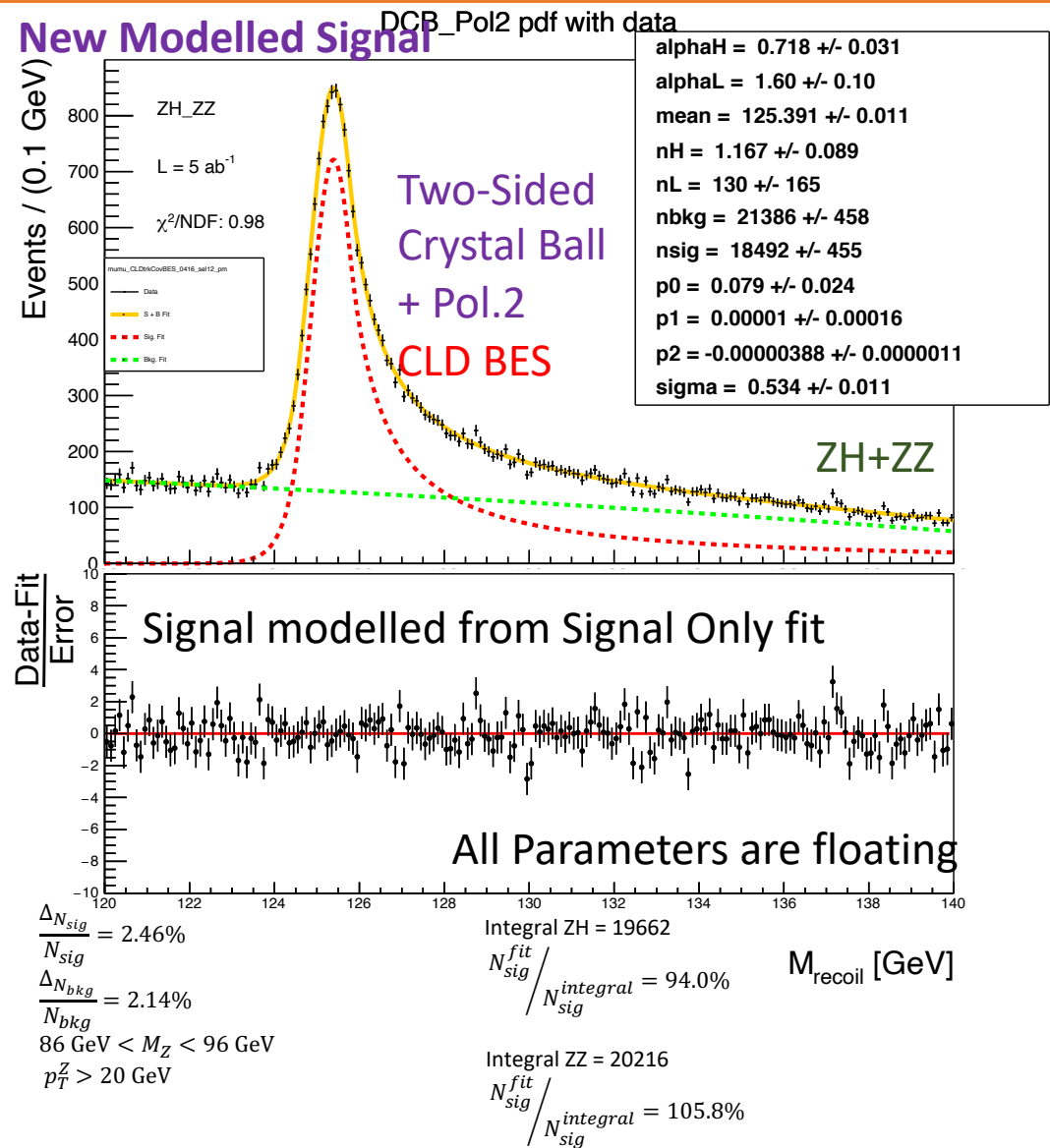
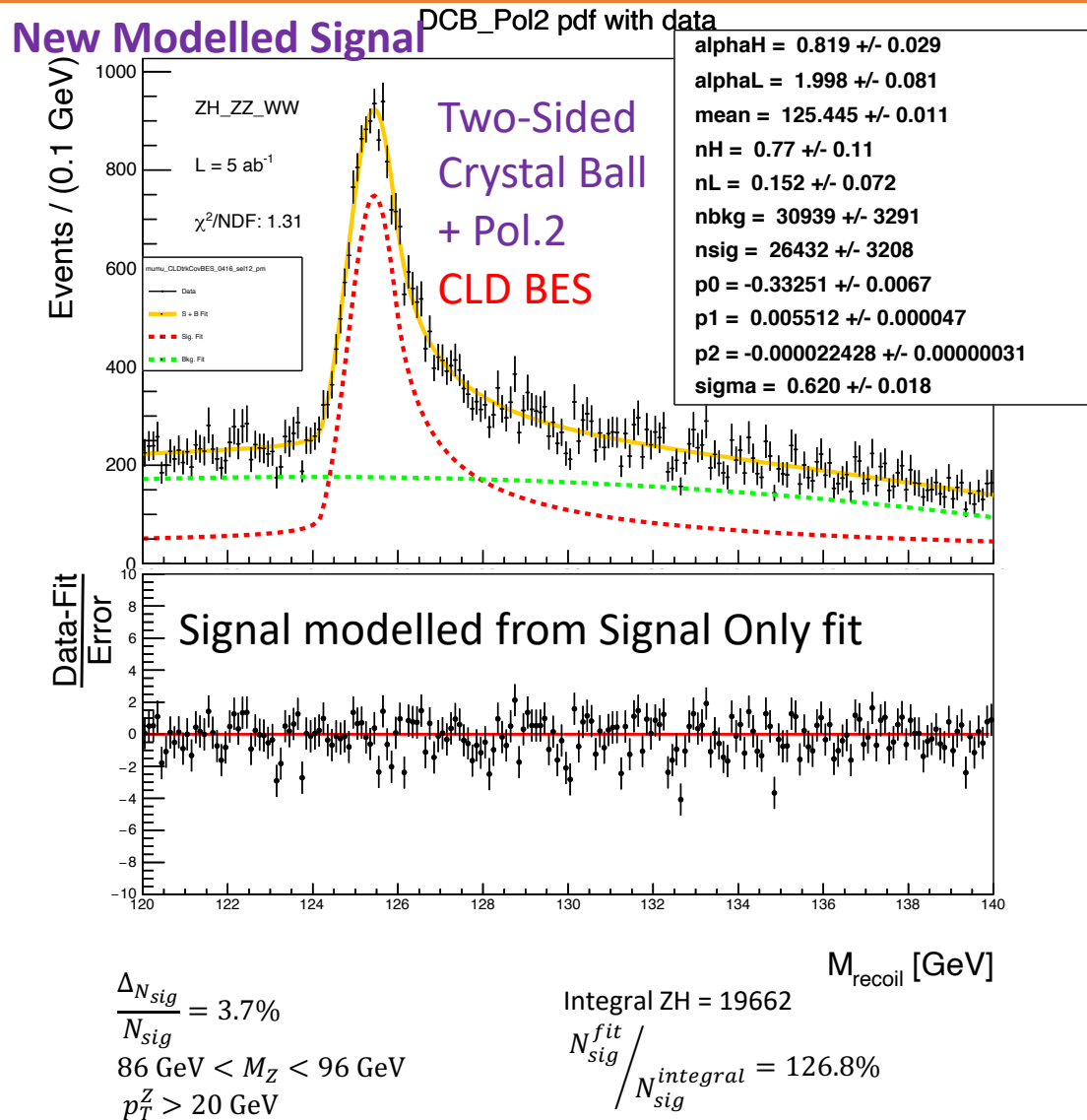
Pol.2
CLD



$\frac{\Delta N_{sig}}{N_{sig}} = 0.75\%$
 86 GeV < M_Z < 96 GeV
 $p_T^Z > 20$ GeV

Integral WW = 17499
 $\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 100.0\%$
 M_{recoil} [GeV]

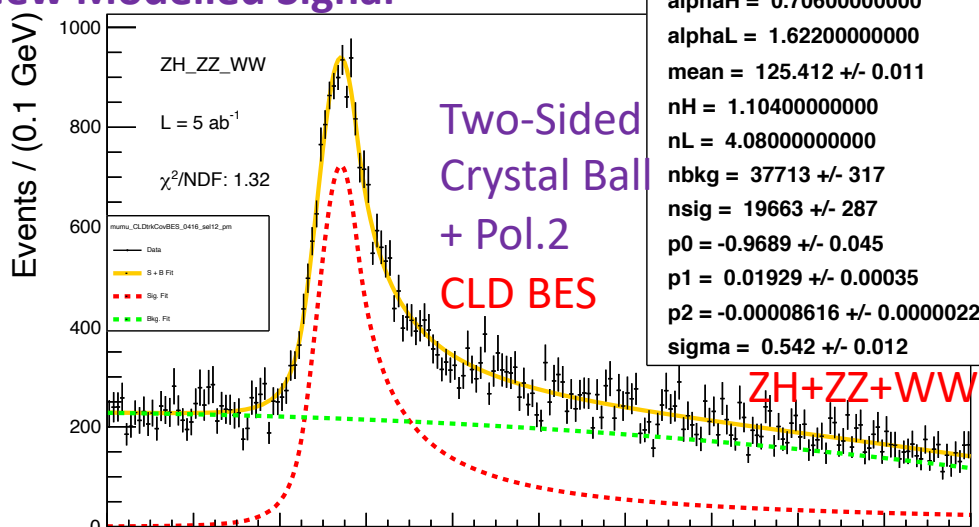
Comparison of ALL MCDData fit and New Modelled Signal fit



Two-Sided Crystal Ball + Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

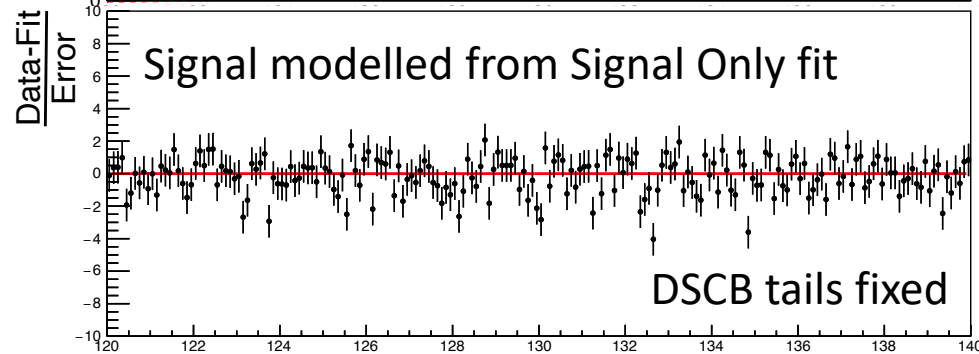
New Modelled Signal

DCB_Pol2 pdf with data



alphaH = 0.7060000000
alphaL = 1.6220000000
mean = 125.412 +/- 0.011
nH = 1.1040000000
nL = 4.0800000000
nbkg = 37713 +/- 317
nsig = 19663 +/- 287
p0 = -0.9689 +/- 0.045
p1 = 0.01929 +/- 0.00035
p2 = -0.00008616 +/- 0.0000022
sigma = 0.542 +/- 0.012

Parameters were fixed as Signal Only fit result Slide 33 right plot



$$\frac{\Delta N_{sig}}{N_{sig}} = 1.44\%$$

$$86 \text{ GeV} < M_Z < 96 \text{ GeV}$$

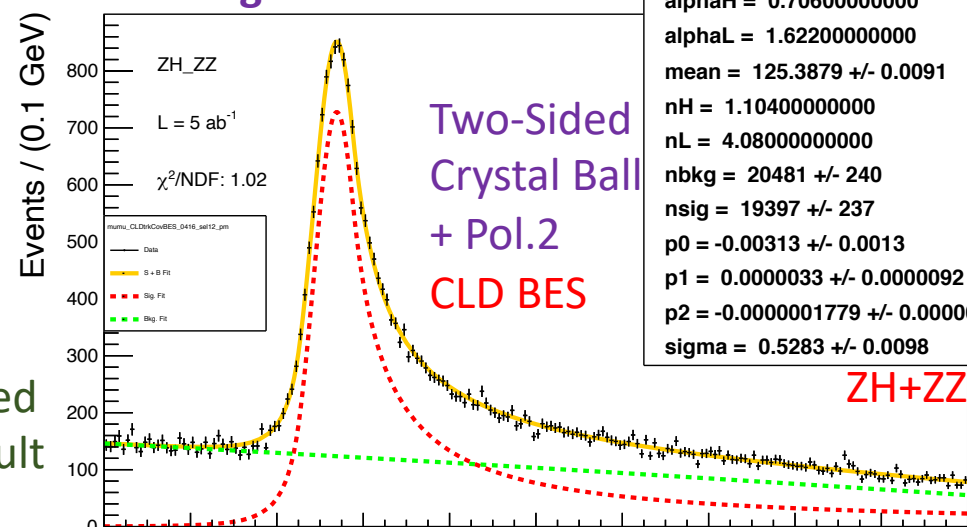
$$p_T^Z > 20 \text{ GeV}$$

Integral ZH = 19662

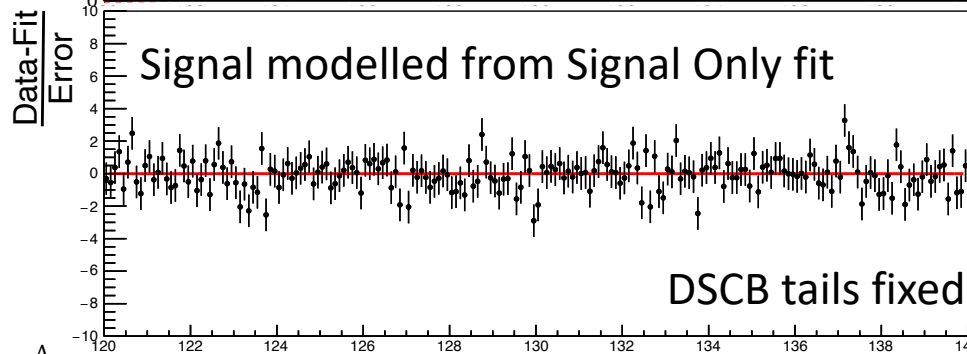
$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 101.4\%$$

New Modelled Signal

DCB_Pol2 pdf with data



alphaH = 0.7060000000
alphaL = 1.6220000000
mean = 125.3879 +/- 0.0091
nH = 1.1040000000
nL = 4.0800000000
nbkg = 20481 +/- 240
nsig = 19397 +/- 237
p0 = -0.00313 +/- 0.0013
p1 = 0.0000033 +/- 0.0000092
p2 = -0.000001779 +/- 0.00000063
sigma = 0.5283 +/- 0.0098



$$\frac{\Delta N_{sig}}{N_{sig}} = 1.22\%$$

$$\frac{\Delta N_{bkg}}{N_{bkg}} = 1.17\%$$

$$86 \text{ GeV} < M_Z < 96 \text{ GeV}$$

$$p_T^Z > 20 \text{ GeV}$$

Integral ZH = 19662

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 98.7\%$$

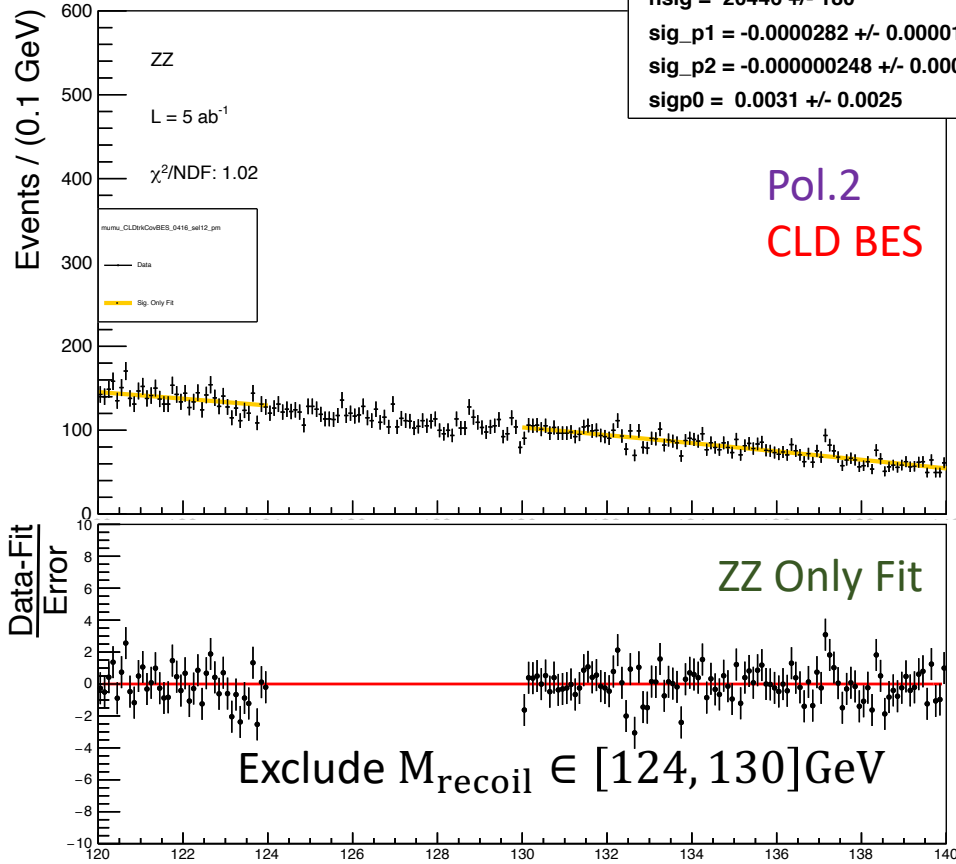
Integral ZZ = 20216

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 101.3\%$$

Bkg. Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

ALL MCData

Pol2 pdf with data



$$\frac{\Delta N_{sig}}{N_{sig}} = 0.88\%$$

$$86 \text{ GeV} < M_Z < 96 \text{ GeV}$$

$$p_T^Z > 20 \text{ GeV}$$

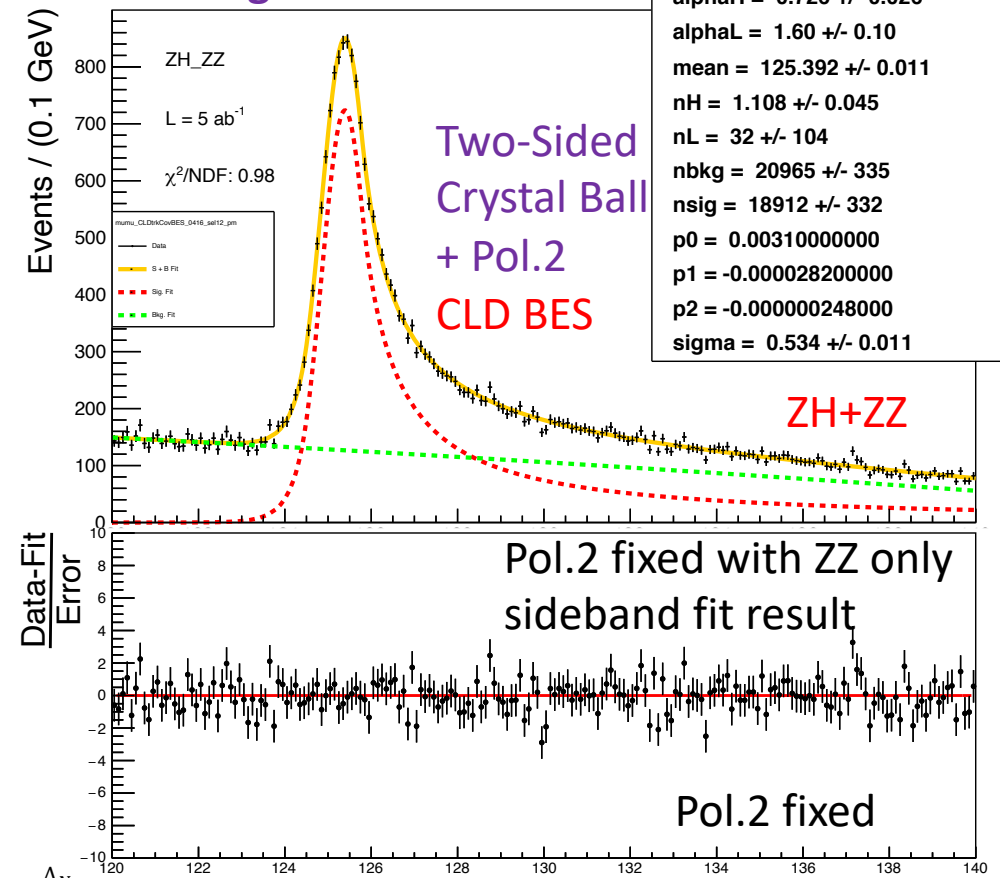
Integral ZZ = 20216

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 101.1\%$$

M_{recoil} [GeV]

New Modelled Signal

DCB_Pol2 pdf with data



$$\frac{\Delta N_{sig}}{N_{sig}} = 1.76\%$$

$$\frac{\Delta N_{bkg}}{N_{bkg}} = 1.60\%$$

$$86 \text{ GeV} < M_Z < 96 \text{ GeV}$$

$$p_T^Z > 20 \text{ GeV}$$

Integral ZH = 19662

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 96.2\%$$

M_{recoil} [GeV]

Integral ZZ = 20216

$$\frac{N_{sig}^{fit}}{N_{sig}^{integral}} = 103.7\%$$

Fitted Width, mass, Nsig in the Higgs mass region (120-140 GeV)

Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ+WW	σ_H (GeV)	Δ_{σ_H} (GeV)	M_H (GeV)	Δ_{M_H} (GeV)	$\Delta_{N_{sig}} / N_{sig}$
New Modelled Signal	0.620	0.018	125.445	0.011	3.7%
New Modelled Signal, tails fixed	0.542	0.012	125.412	0.011	1.5%

Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ	σ_H (GeV)	Δ_{σ_H} (GeV)	M_H (GeV)	Δ_{M_H} (GeV)	$\Delta_{N_{sig}} / N_{sig}$
New Modelled Signal	0.534	0.011	125.391	0.011	2.5%
New Modelled Signal tails fixed	0.5283	0.0098	125.3879	0.0091	1.2%
New Modelled Signal Pol.2 fixed	0.534	0.011	125.392	0.011	1.8%