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

FCCee Physics Performance meeting

19th April 2021

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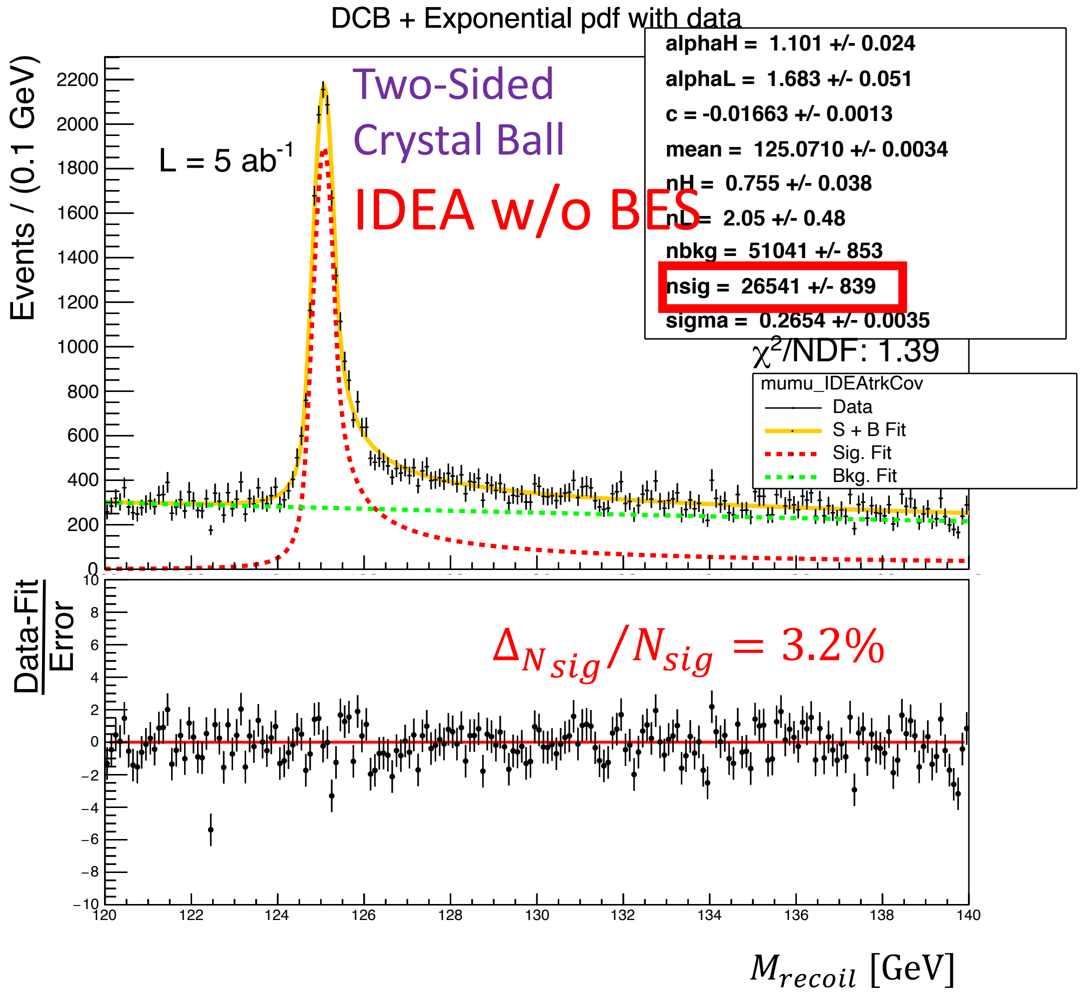
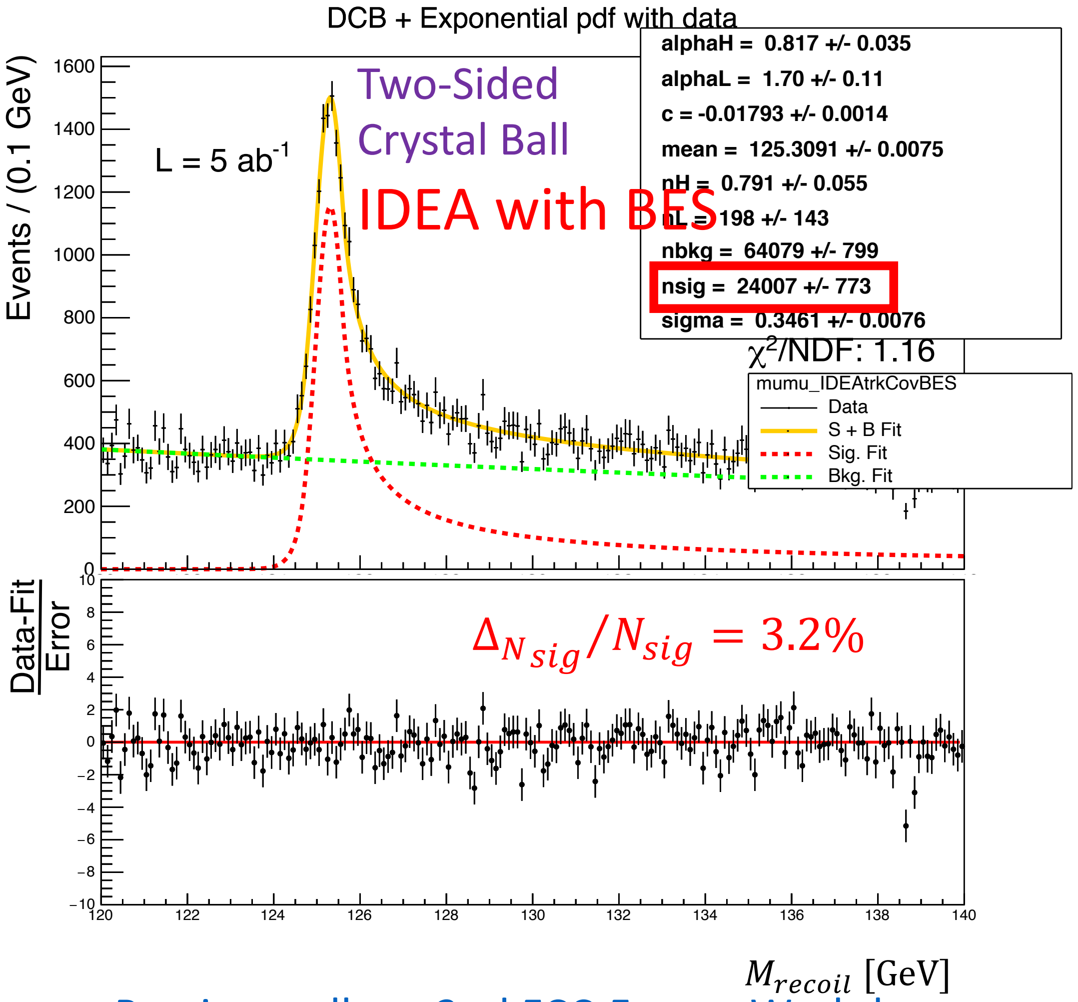
Plans

- **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





[Previous talk on 2nd FCC-France Workshop]

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:**
  $L = 5\ ab^{-1}$

- **Variables:**

$$M_{recoil}^2 = \left(\sqrt{s} - E_{f\bar{f}}\right)^2 - p_{f\bar{f}}^2$$
$$= s - 2E_{f\bar{f}}\sqrt{s} + m_{f\bar{f}}^2$$

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		
			Total efficiency	:ut efficiency %		Total efficiency	: efficiency %		Total efficiency	ut efficiency '	S/B	(S/Sqrt(S+B))
	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%

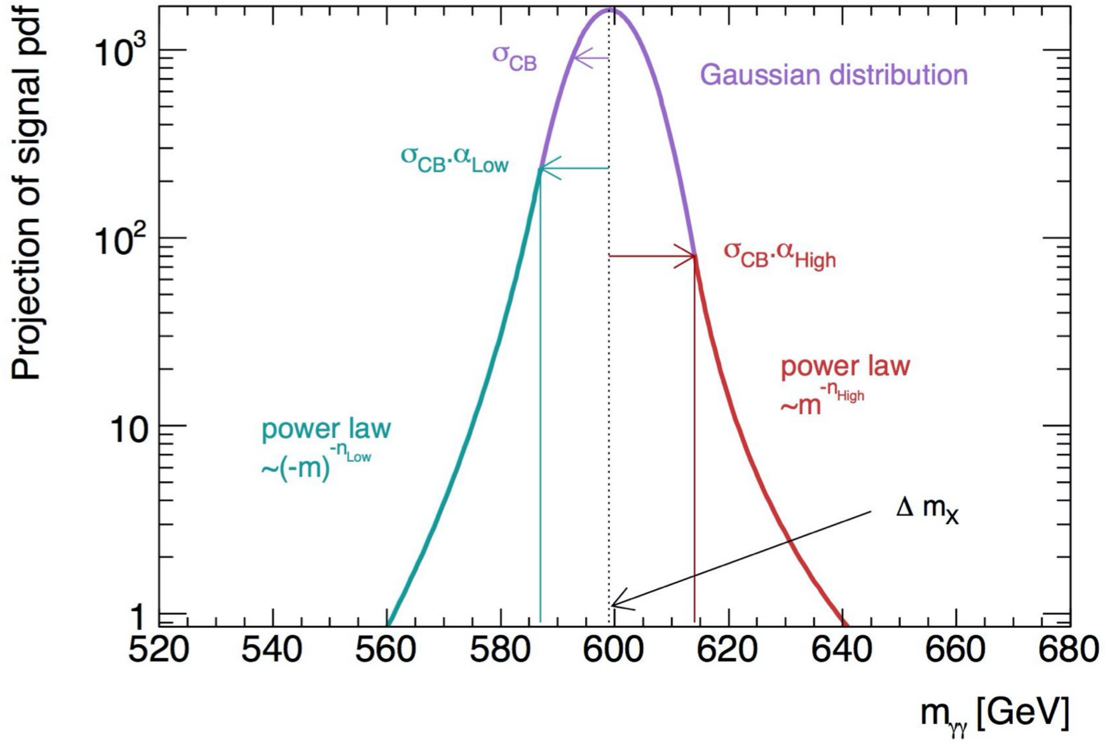
- $m_Z \in [86, 96]$GeV removes about 50% of WW comparing to $m_Z \in [80, 100]$GeV

Fit model and parameter settings

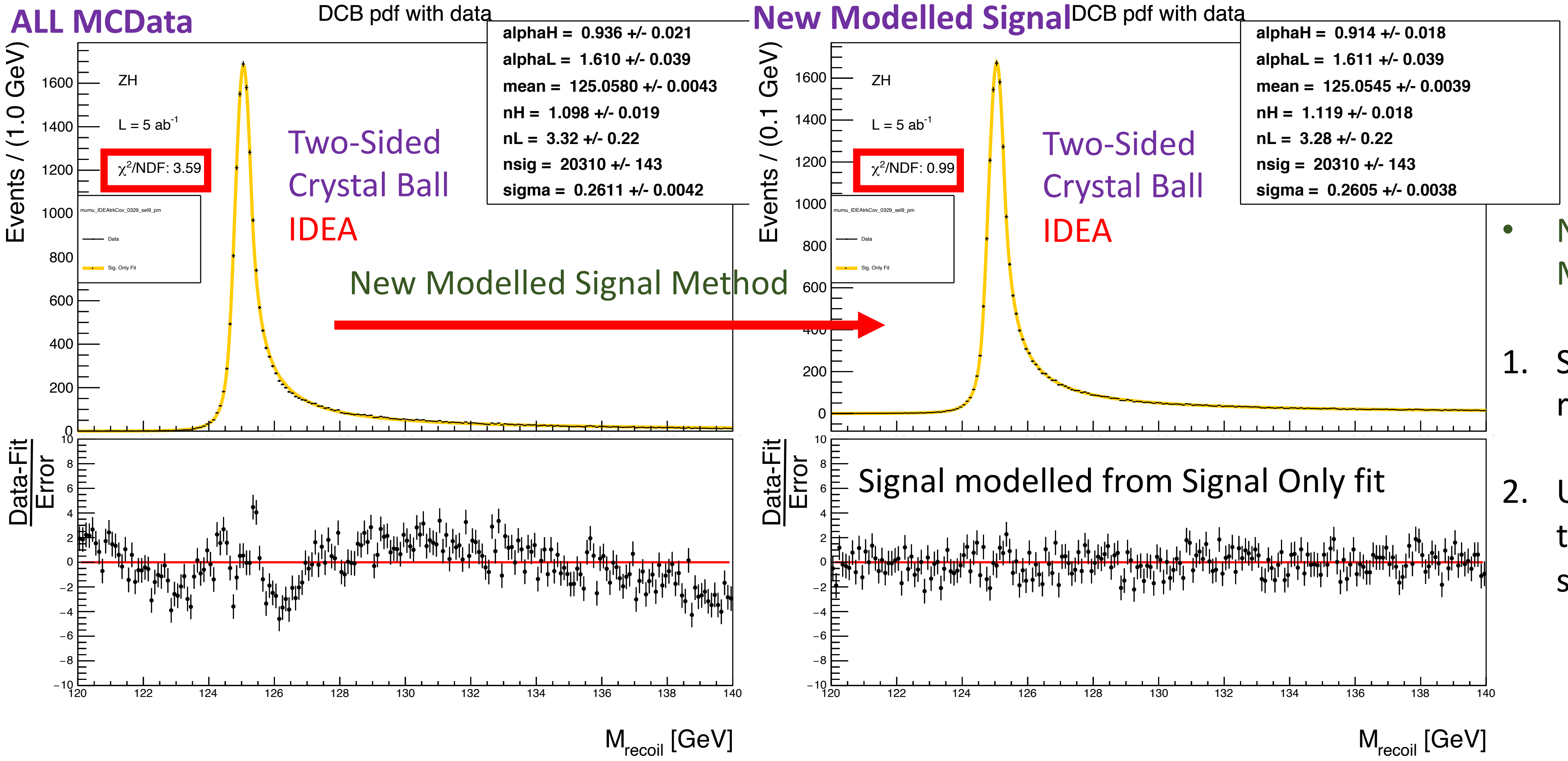
- **Signal:**
  - ZH
- **Background:**
  - ZZ, WW
- **Fitting functions**
  - Signal: Two-Sided Crystal Ball
  - Background: Second Order Polynomial
  - S + B = nsig*signal + nbkg*background

Two-Sided Crystal Ball function:

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



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



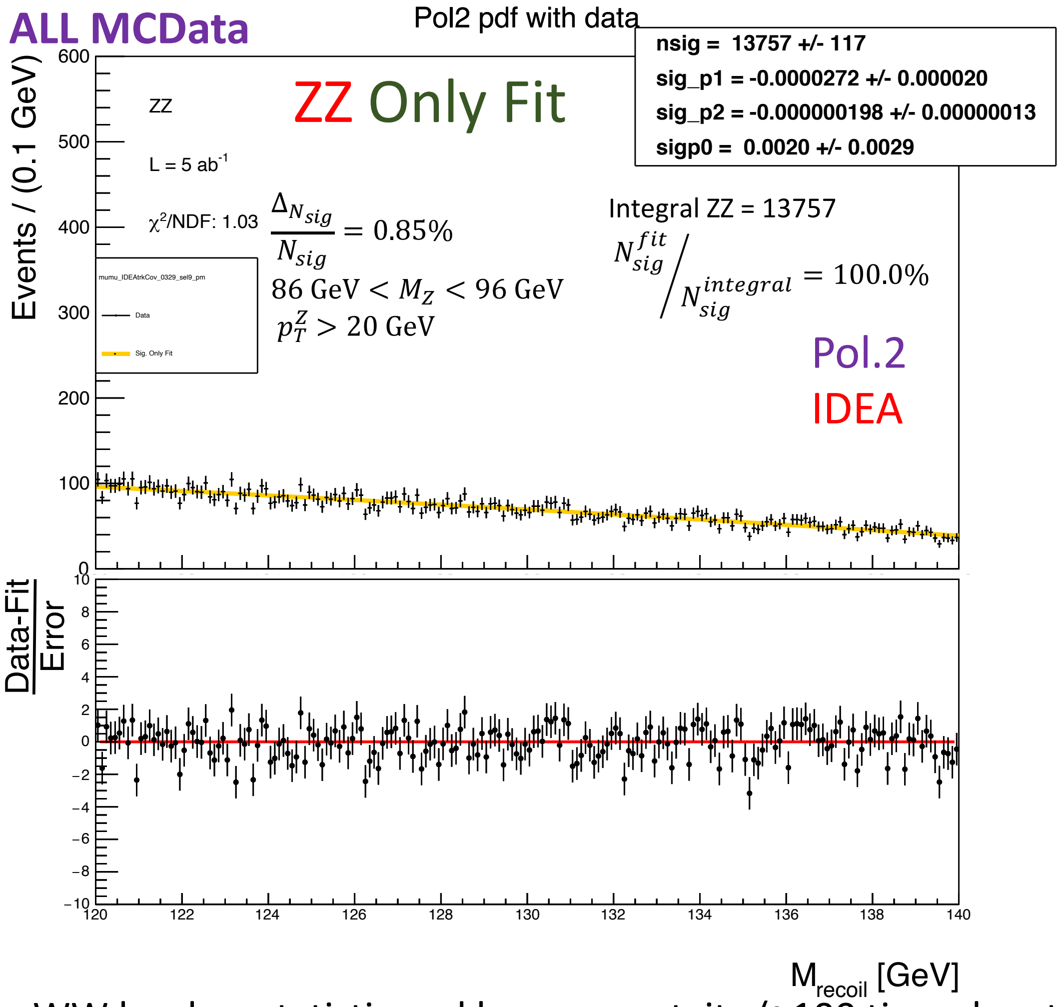
- New Modelled Signal Method

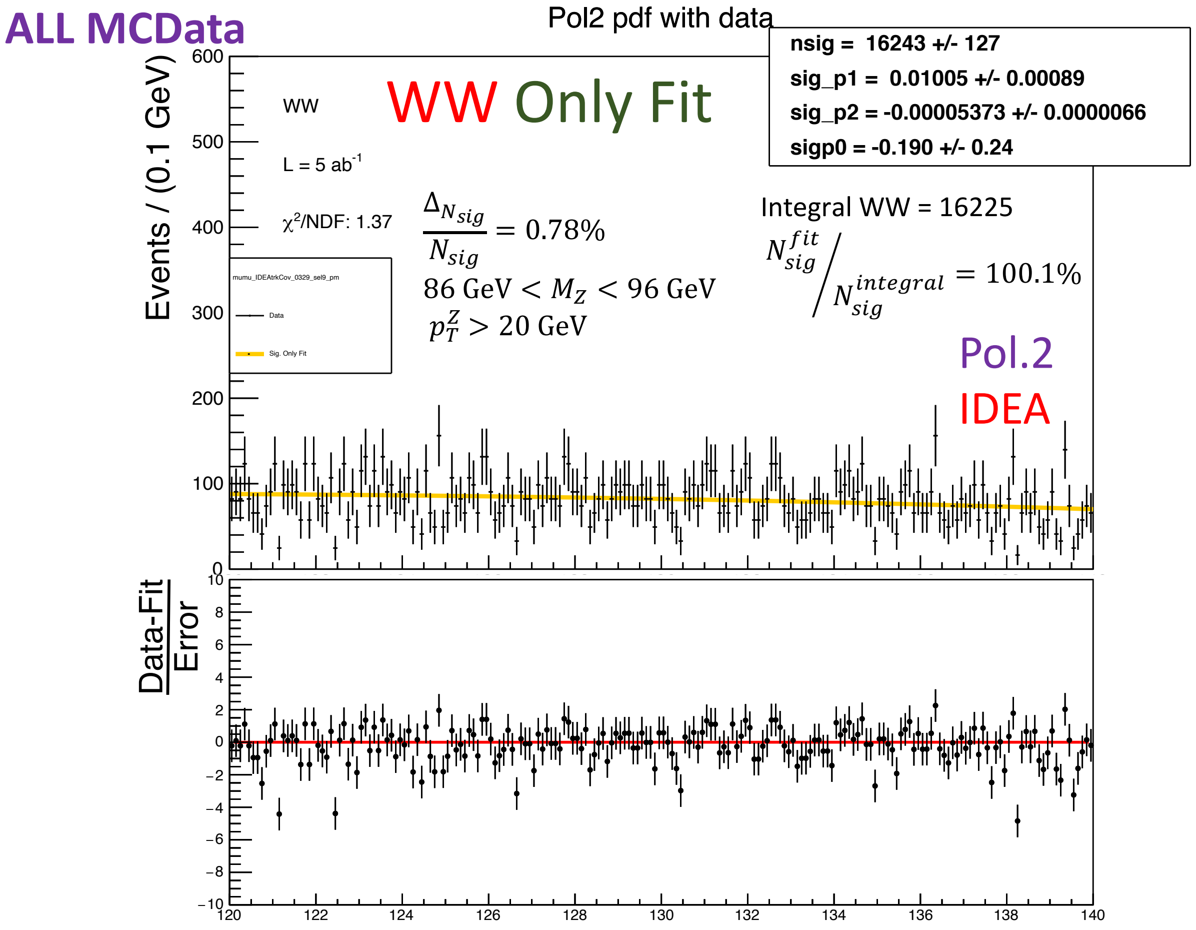
1. Signal Only Fit and receive parameters
2. Use these parameters to generate DSCB shape signal

- $\chi^2/_{NDF}$ 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)

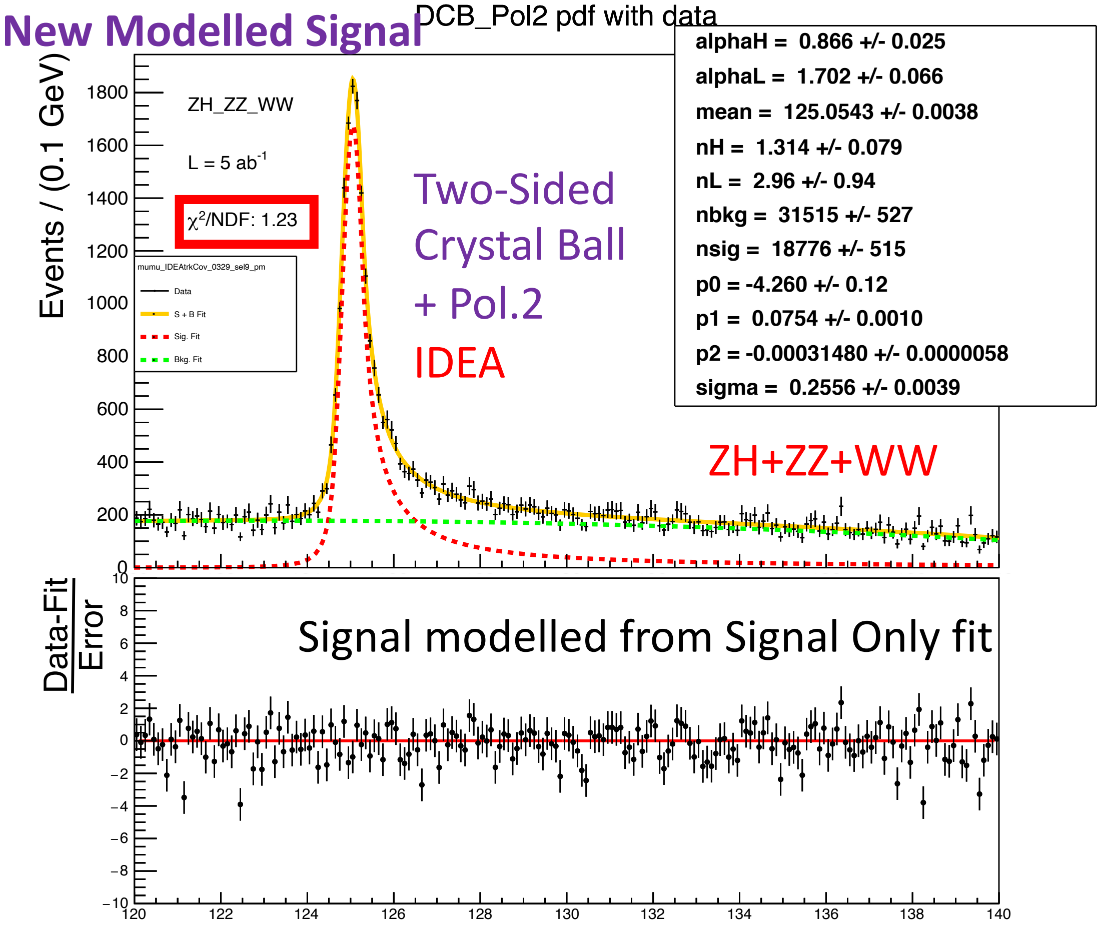




- WW has low statistic and large uncertaity (~100 times less than ZH)
- WW entries / # of events is ~ 10 times less than ZZ
- Need to generate more events
- Will focus on ZZ only background to see how precise we can be when we have enough statistics in the background

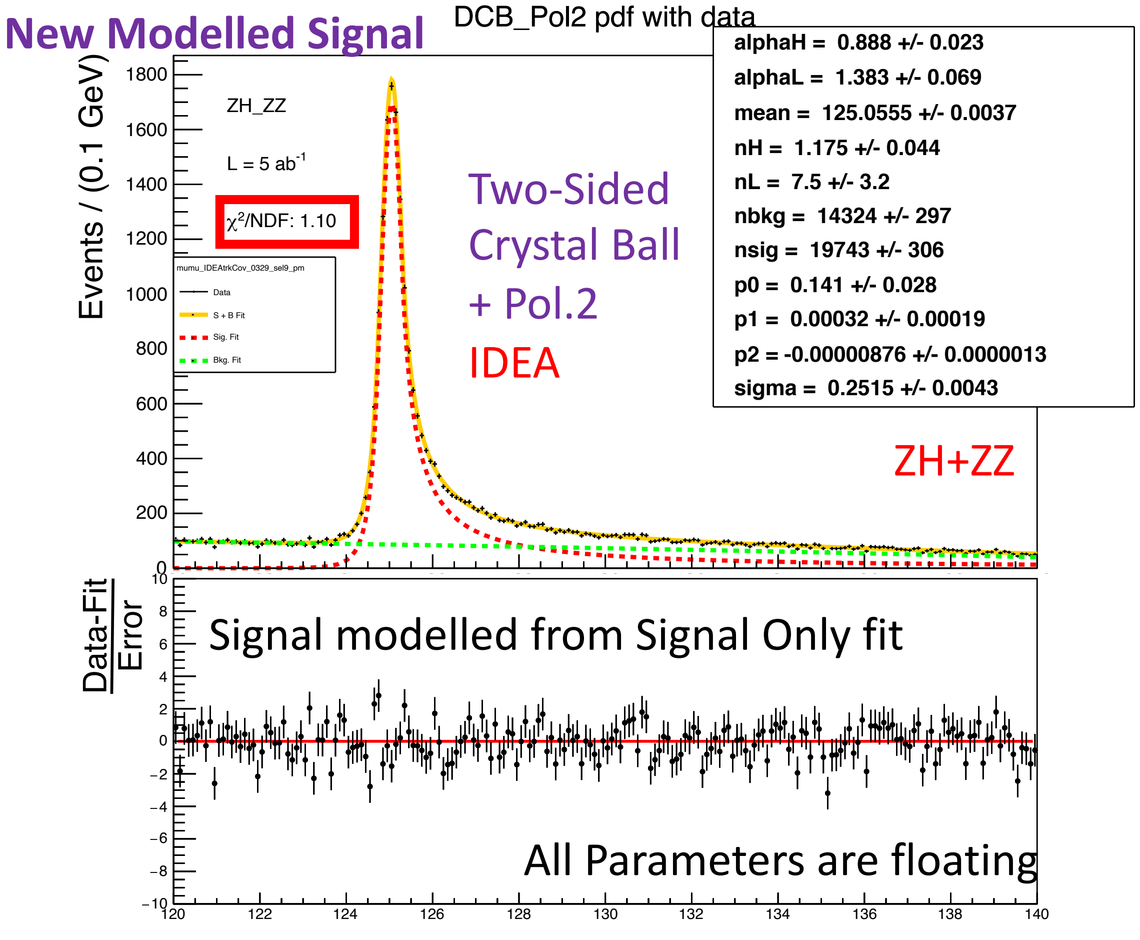
	ZH	ZZ	WW
# of Events	20310	13757	16225
Entries	202053	20246	1974
Entries/# of Events	9.95	1.47	0.12

Comparison of New Modelled Signal fit



Integral ZH = 20310

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



$\Delta_{N_{sig}}/N_{sig} = 1.55\%$

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

Integral ZH = 20310

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

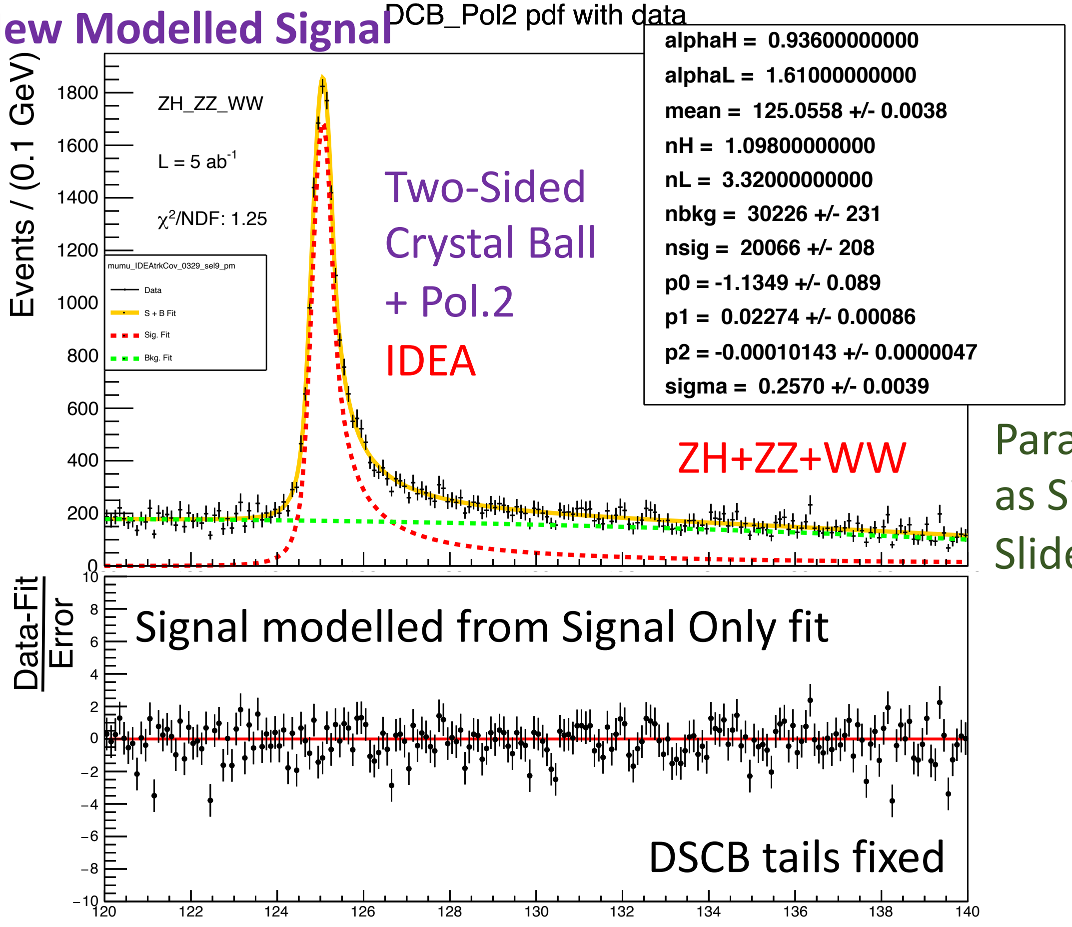
Integral ZZ = 13757

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

- 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 $\Delta_{N_{sig}}/N_{sig}$

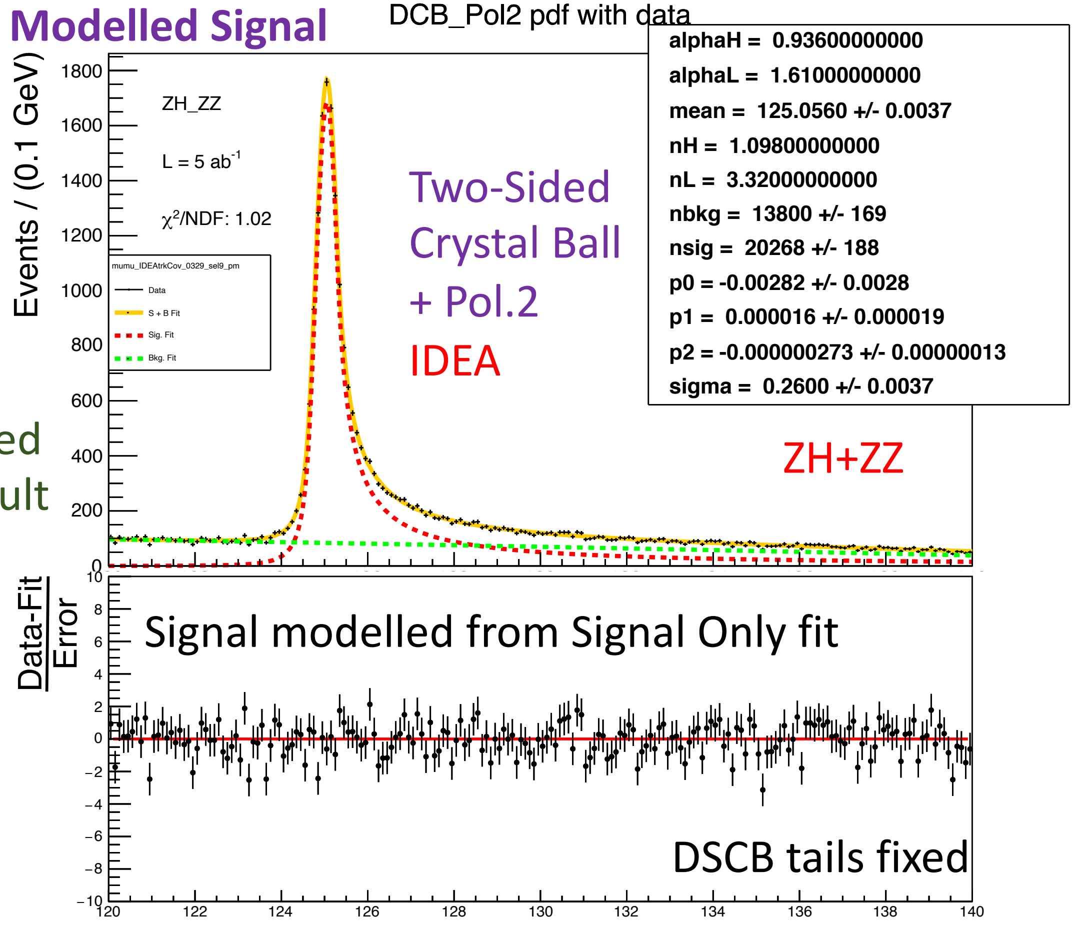
Two-Sided Crystal Ball + Pol2 fit of M_{recoil} in the Higgs region (120-140 GeV)

New Modelled Signal



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

New Modelled Signal



$\Delta_{N\,sig}/N_{sig} = 1.04\%$ Integral ZH = 20310

$N^{fit}_{sig}/N^{integral}_{sig} = 98.8\%$

$\Delta_{N\,sig}/N_{sig} = 0.93\%$ Integral ZH = 20310

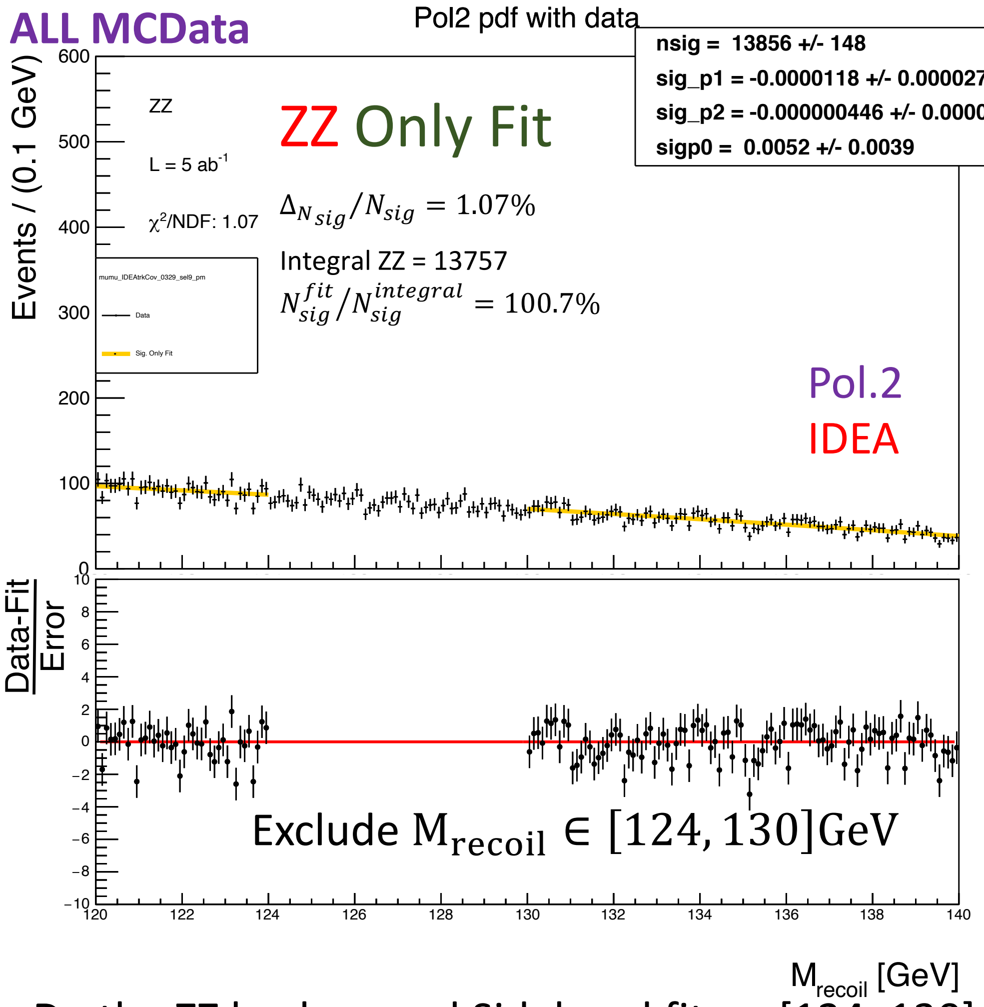
$\Delta_{N\,bkg}/N_{bkg} = 1.22\%$ $N^{fit}_{sig}/N^{integral}_{sig} = 99.8\%$

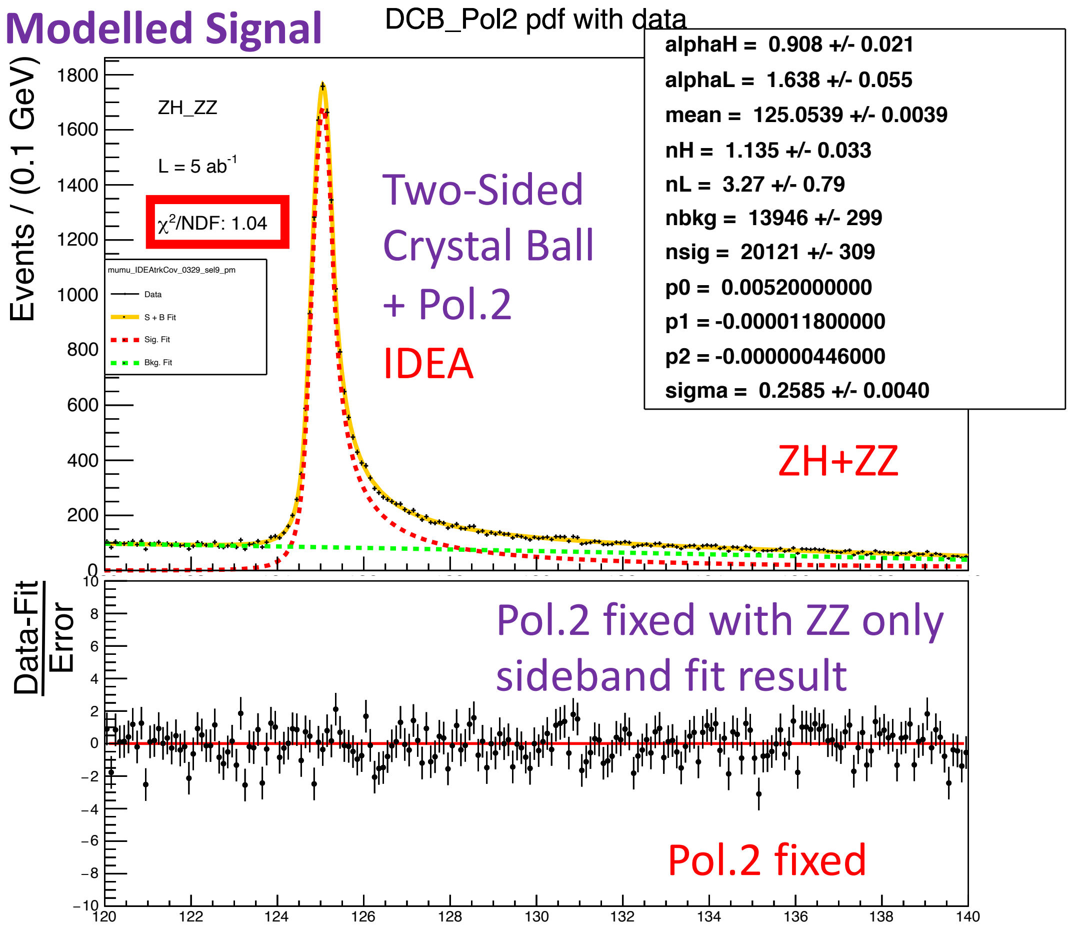
Integral ZZ = 13757

$N^{fit}_{bkg}/N^{integral}_{bkg} = 100.3\%$

- 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%

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





$\Delta_{N_{sig}}/N_{sig} = 1.54\%$ Integral ZH = 20310

$\Delta_{N_{bkg}}/N_{bkg} = 2.14\%$ $N_{sig}^{fit}/N_{sig}^{integral} = 99.1\%$

Integral ZZ = 13757

$N_{bkg}^{fit}/N_{bkg}^{integral} = 101.4\%$

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 ~ 1.5%
- The χ^2/NDF is ~ 1 and the $N_{sig}^{fit}/N_{sig}^{integral}$ is ~ 100%

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

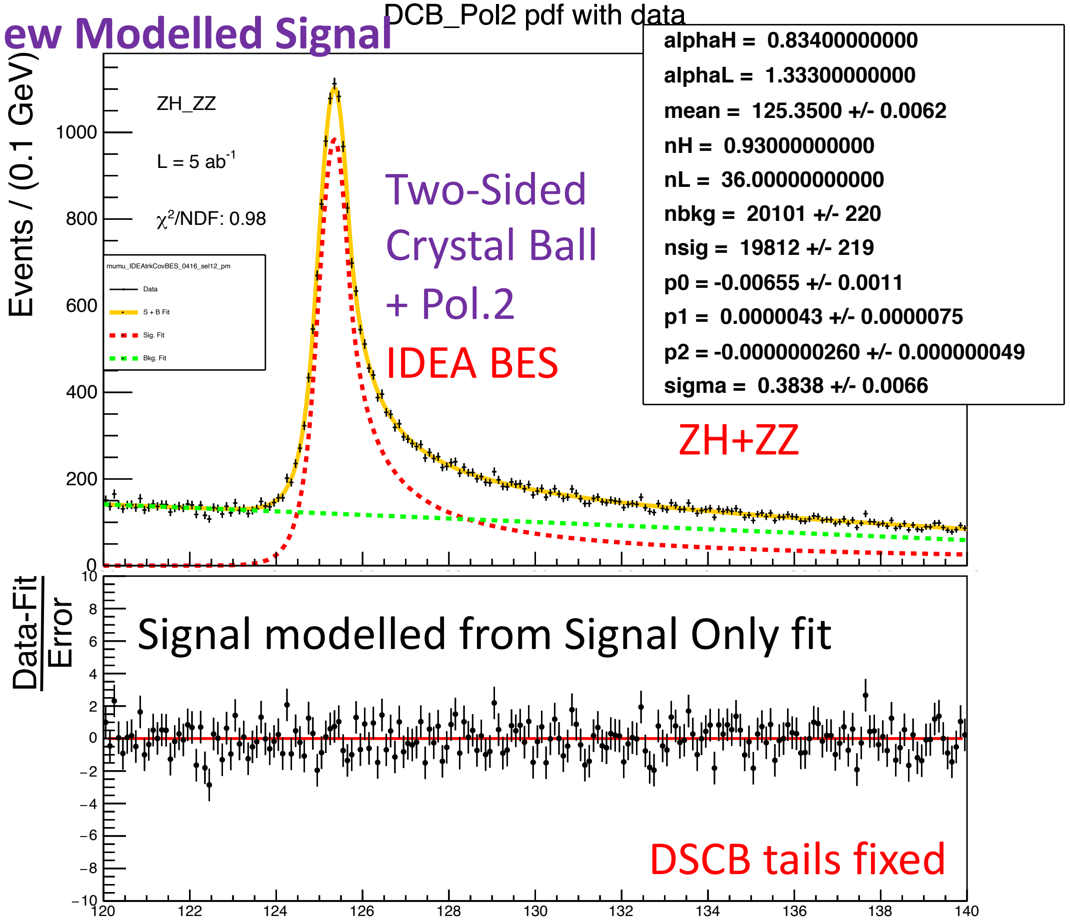
Two-Sided Crystal Ball + Pol.2 fit ZH+ZZ+WW	σ_H (GeV) Higgs Width	Δ_{σ_H} (GeV)	M_H (GeV) Higgs Mass	Δ_{M_H} (GeV)	$\Delta_{N_{sig}}/N_{sig}$
New Modelled Signal	0.2556	0.0039	125.0543	0.0038	2.742%
New Modelled Signal, tails fixed	0.2570	0.0039	125.0558	0.0038	1.037%

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

IDEA with Beam Energy Spread

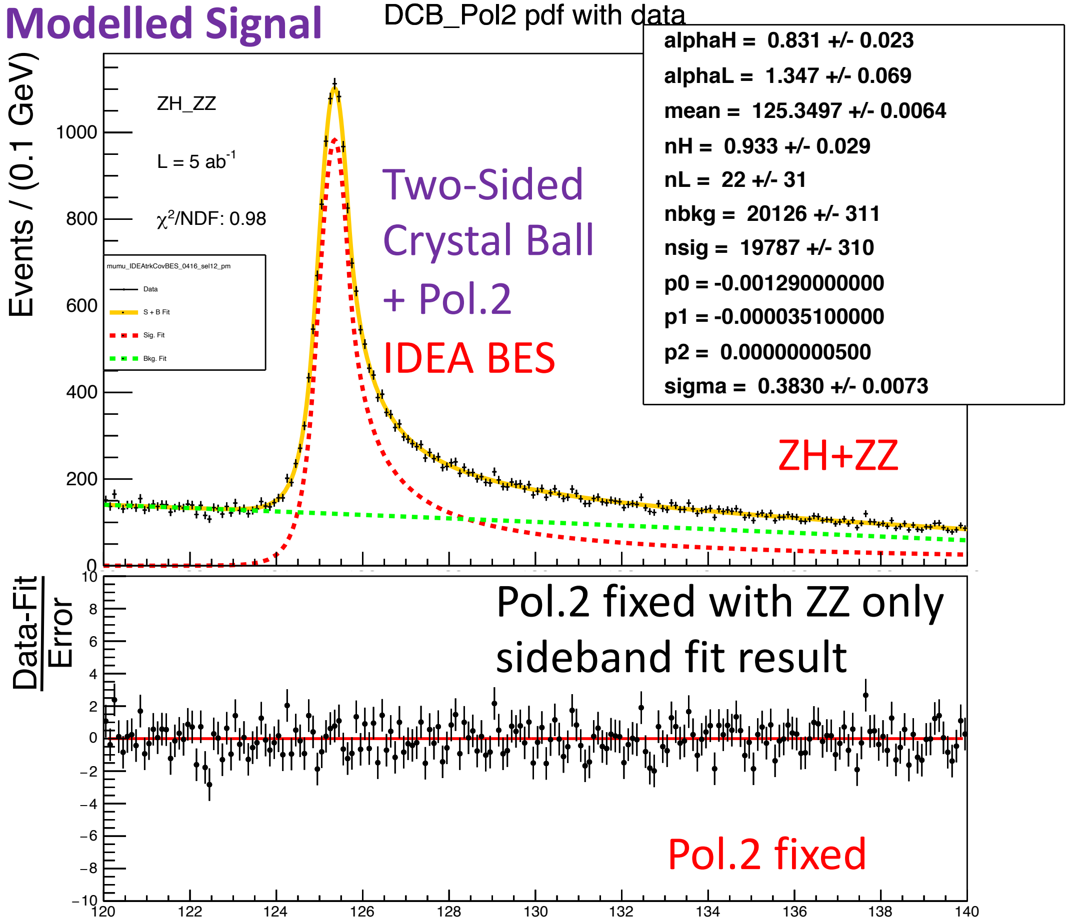
New Modelled Signal



$\Delta_{N_{sig}}/N_{sig} = 1.11\%$ Integral ZH = 19684

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

New Modelled Signal



$\Delta_{N_{sig}}/N_{sig} = 1.57\%$ Integral ZH = 19684

$\Delta_{N_{bkg}}/N_{bkg} = 1.55\%$ $N_{sig}^{fit}/N_{sig}^{integral} = 100.5\%$

Integral ZZ = 20228

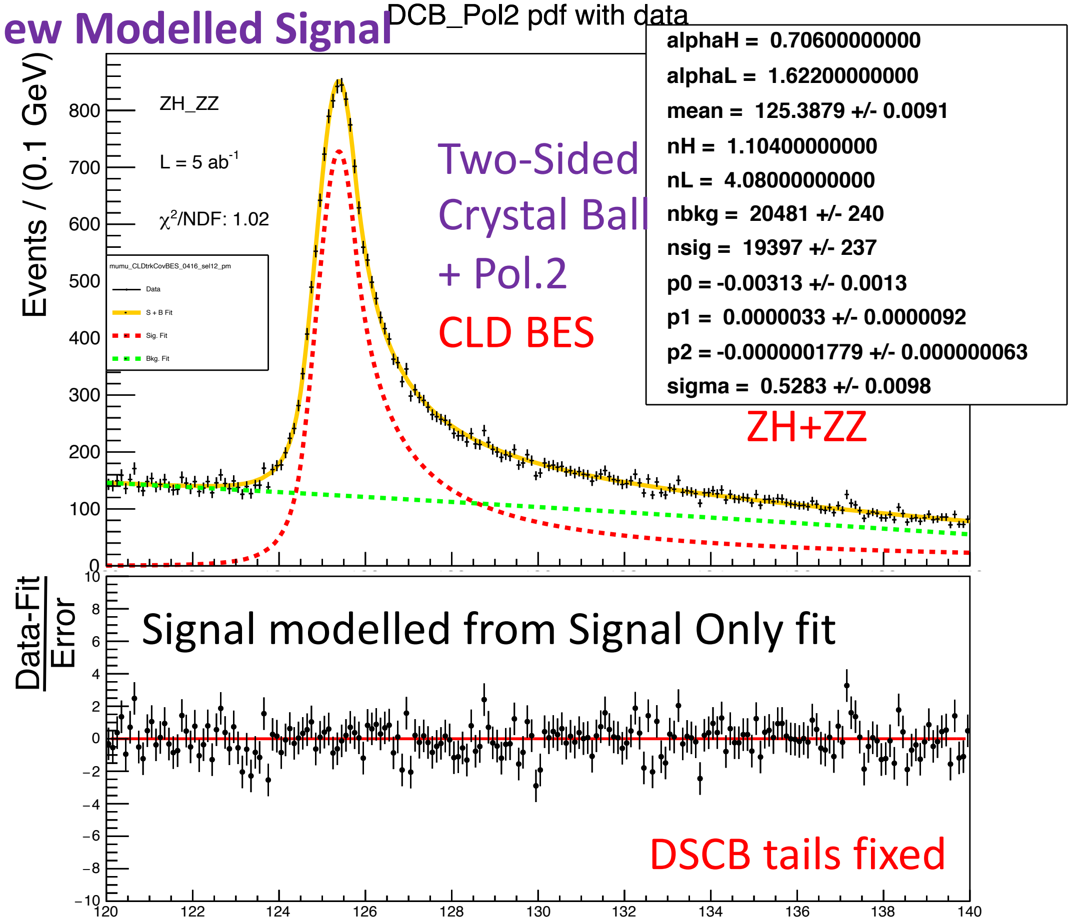
$N_{sig}^{fit}/N_{sig}^{integral} = 99.5\%$

- Fixing the tails, the uncertainty of N_{sig} becomse ~ 1.1%
- Fixing the background with the sideband fit, the uncertainty of N_{sig} becomes ~ 1.6%

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

CLD with Beam Energy Spread

New Modelled Signal



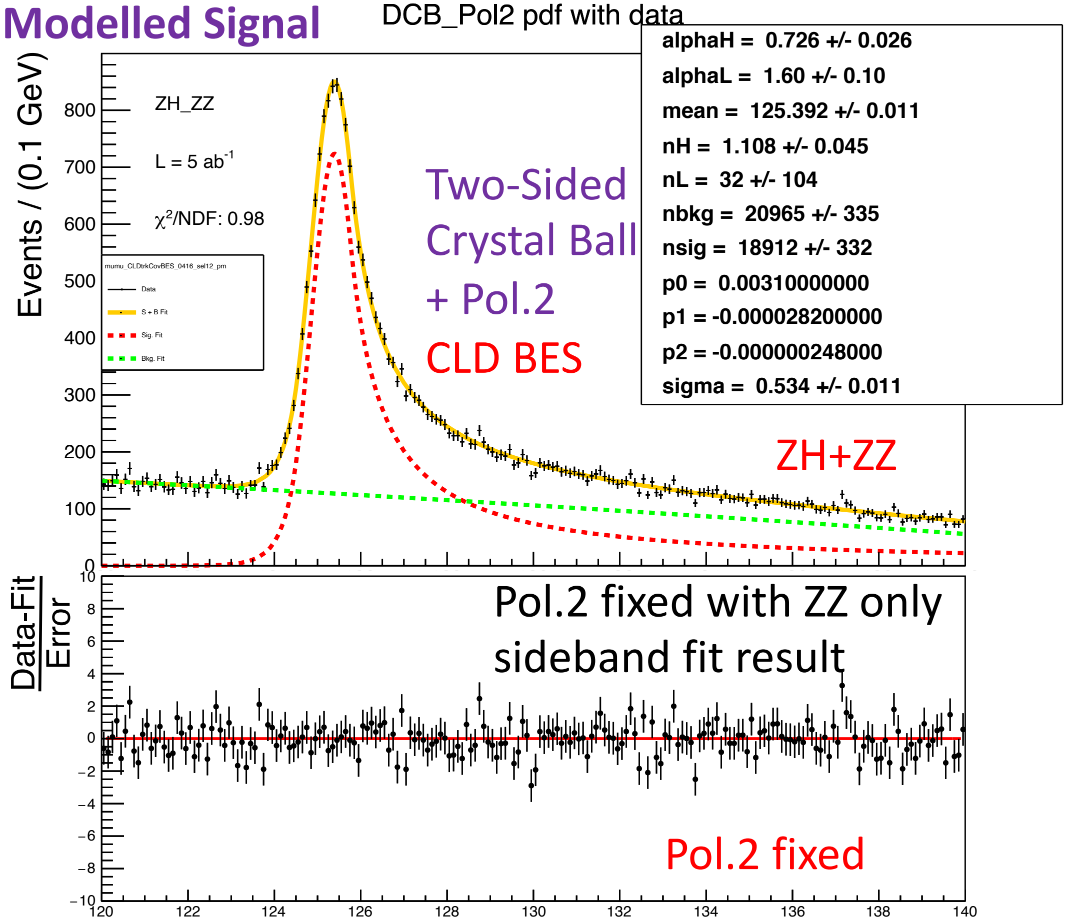
$$\frac{\Delta_{N_{sig}}}{N_{sig}} = 1.22\%$$

Integral ZH = 19662

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

M_{recoil} [GeV]

New Modelled Signal



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

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

Integral ZH = 19662

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

Integral ZZ = 20216

$$N_{bkg}^{fit}/N_{bkg}^{integral} = 103.7\%$$

M_{recoil} [GeV]

- Fixing the tails, the uncertainty of N_{sig} becomse ~ 1.2%
- Fixing the background with the sideband fit, the uncertainty of N_{sig} becomes ~ 1.8%

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

Beam Energy Spread Effect and CLD:

- 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 %

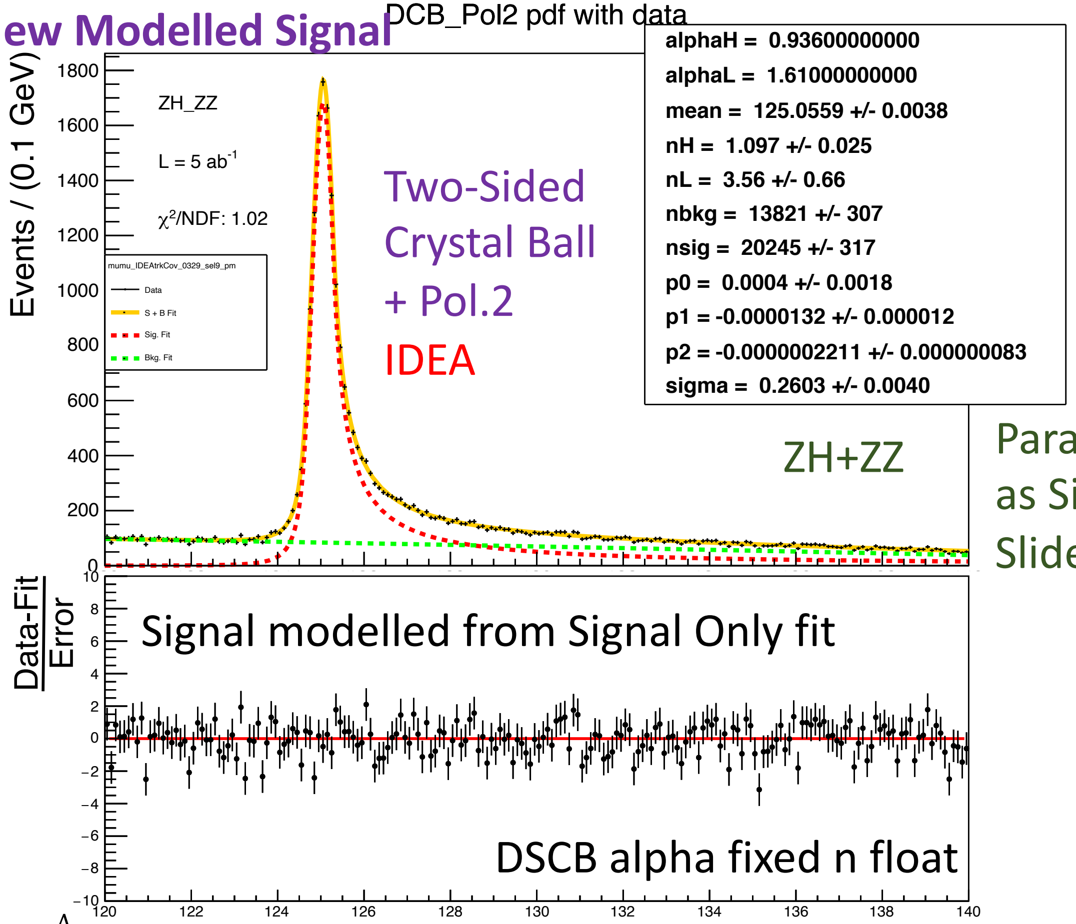
Next-Step

- 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)



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 1.60\%$

$\frac{\Delta_{N_{bkg}}}{N_{bkg}} = 2.22\%$

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

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

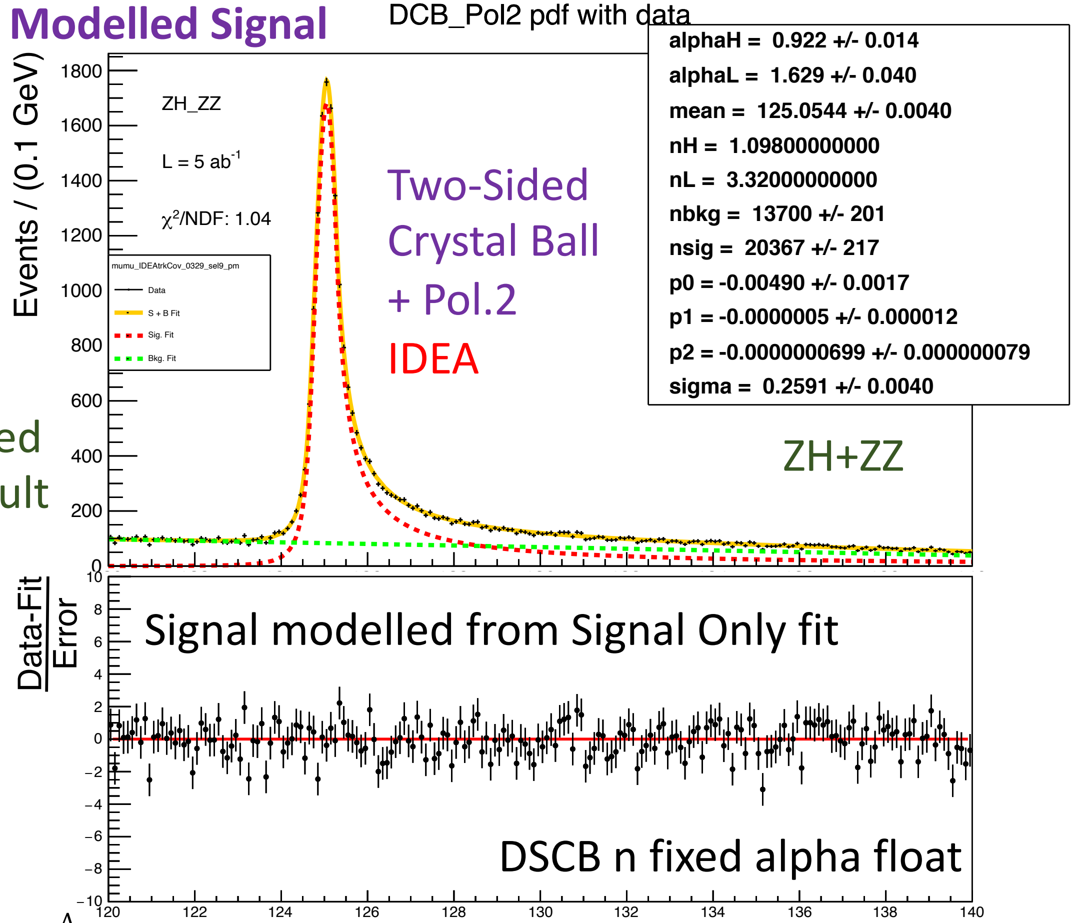
Integral ZH = 20310

$N_{sig}^{fit} / N_{sig}^{integral} = 99.7\%$

Integral ZZ = 13757

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

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



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

$\frac{\Delta_{N_{bkg}}}{N_{bkg}} = 1.47\%$

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

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

Integral ZH = 20310

$N_{sig}^{fit} / N_{sig}^{integral} = 100.3\%$

Integral ZZ = 13757

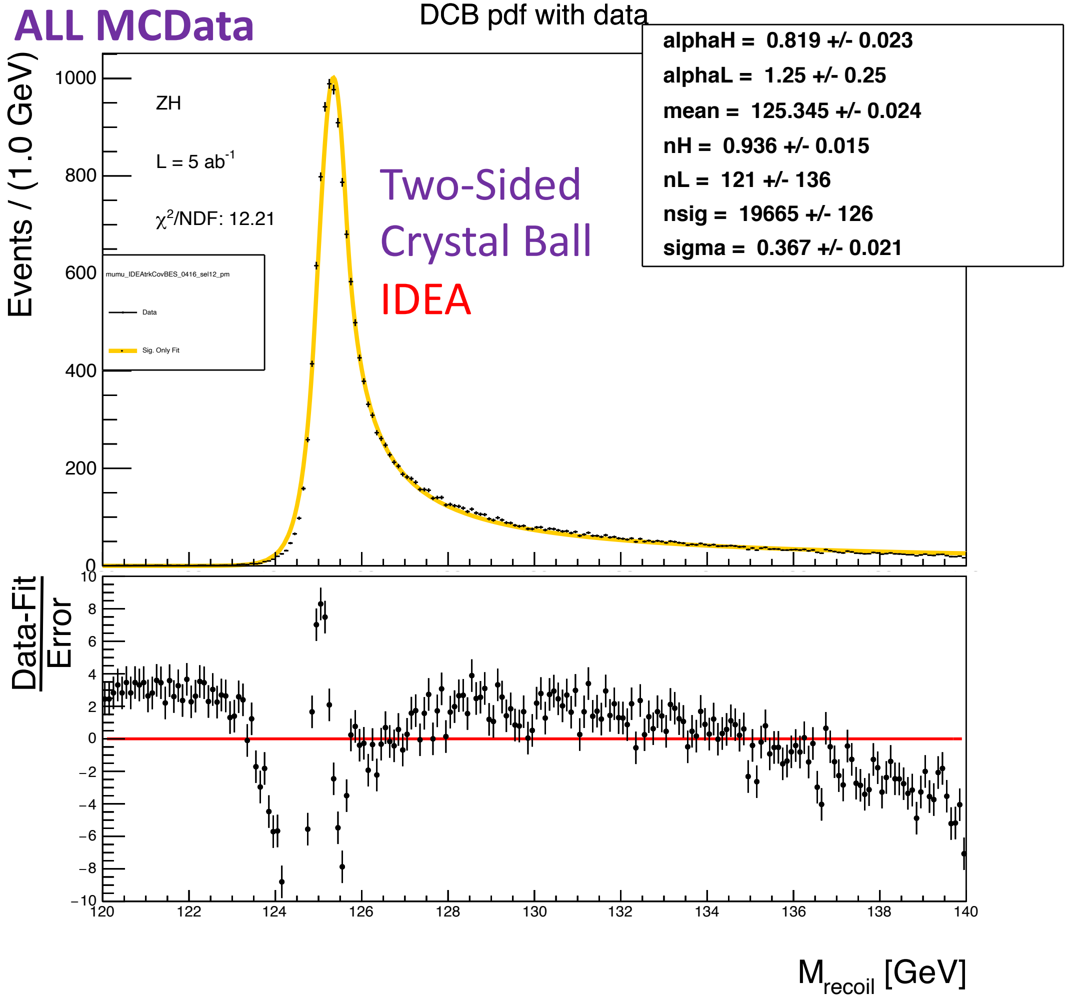
$N_{sig}^{fit} / N_{sig}^{integral} = 99.6\%$

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

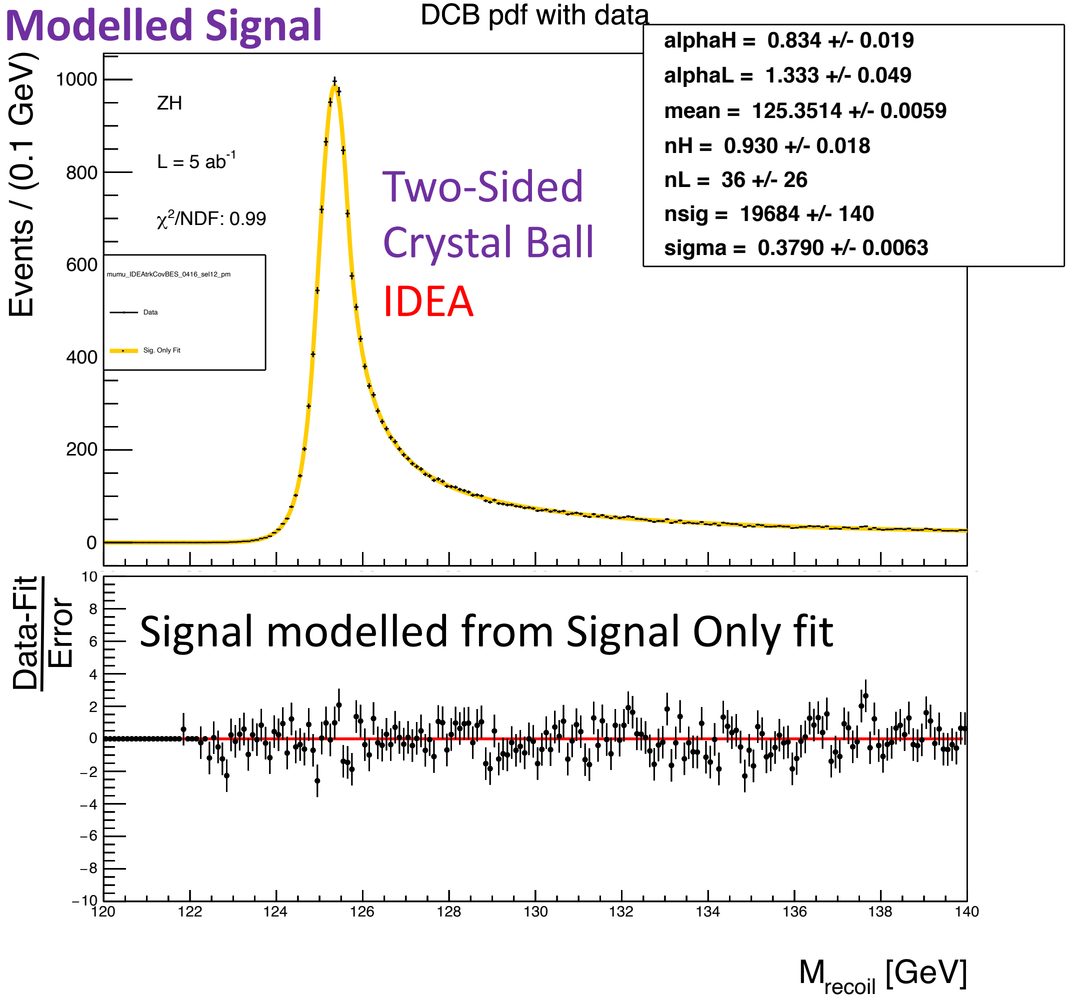
IDEAtrkCovBES

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

ALL MCData



New Modelled Signal



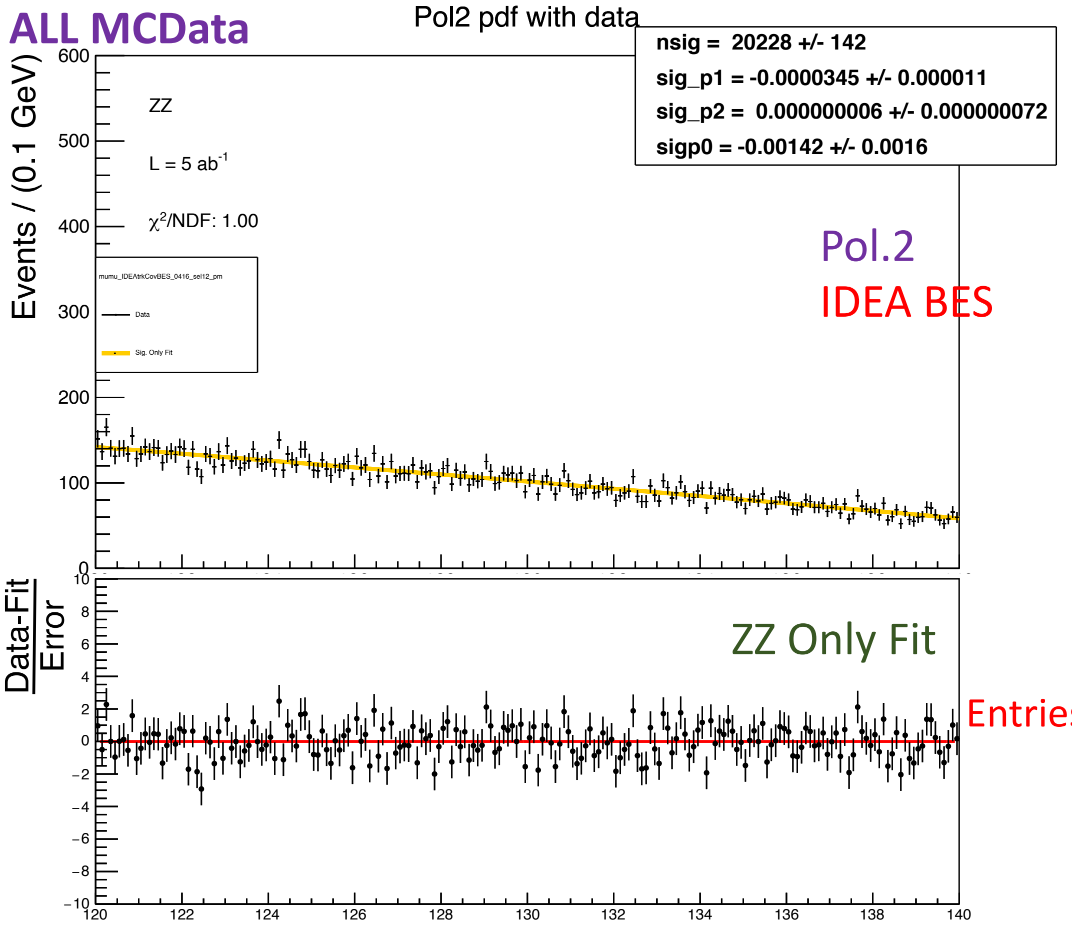
ALL MCData:

All data come from the MC simulation

New Modelled Signal:

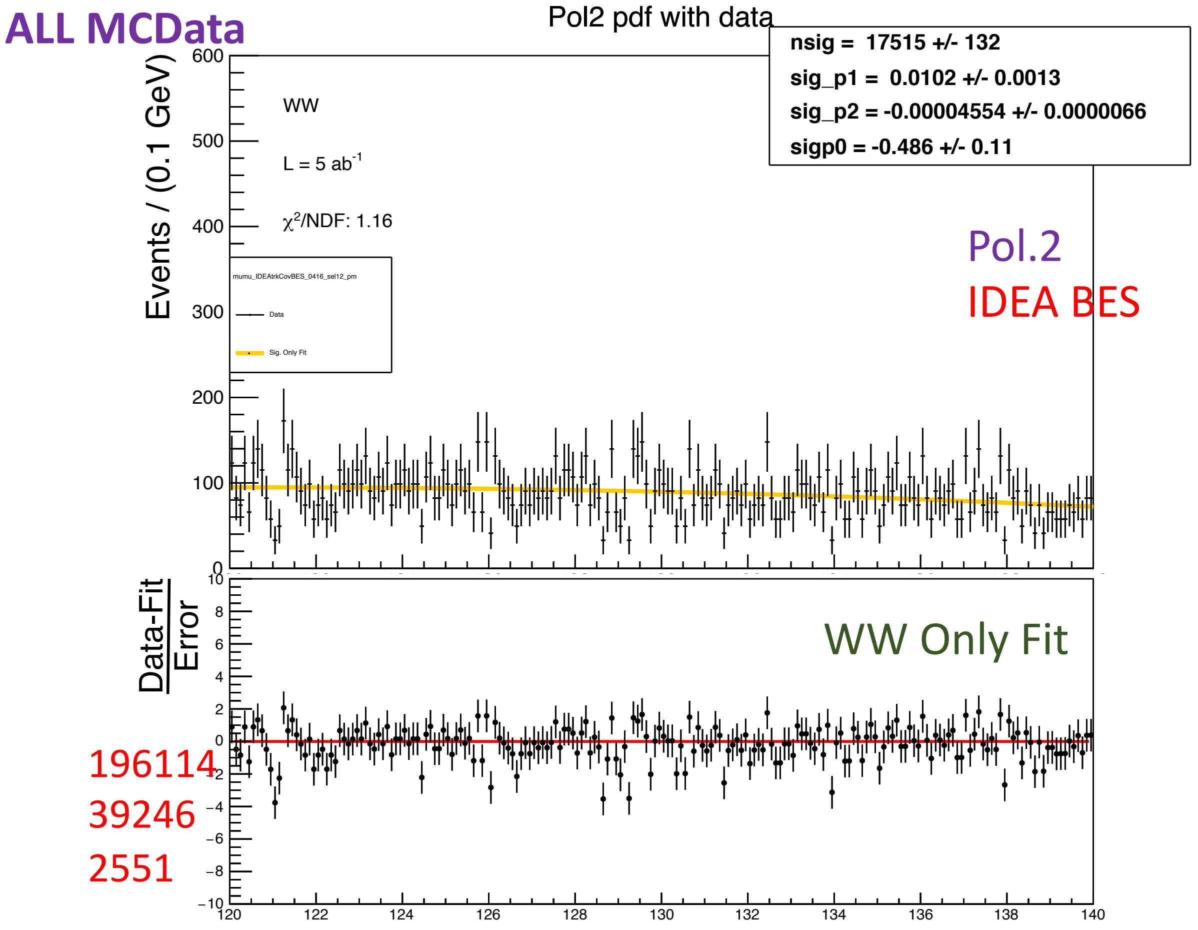
ZH signal is modelled to perfect shape

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



Entries:

ZH: 196114
ZZ: 39246
WW: 2551



ZZ:

$\frac{\Delta_{N_{sig}}}{N_{sig}} = 0.70\%$

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

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

Integral ZZ = 20228

$N_{sig}^{fit} / N_{sig}^{integral} = 100.0\%$

WW:

$\frac{\Delta_{N_{sig}}}{N_{sig}} = 0.75\%$

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

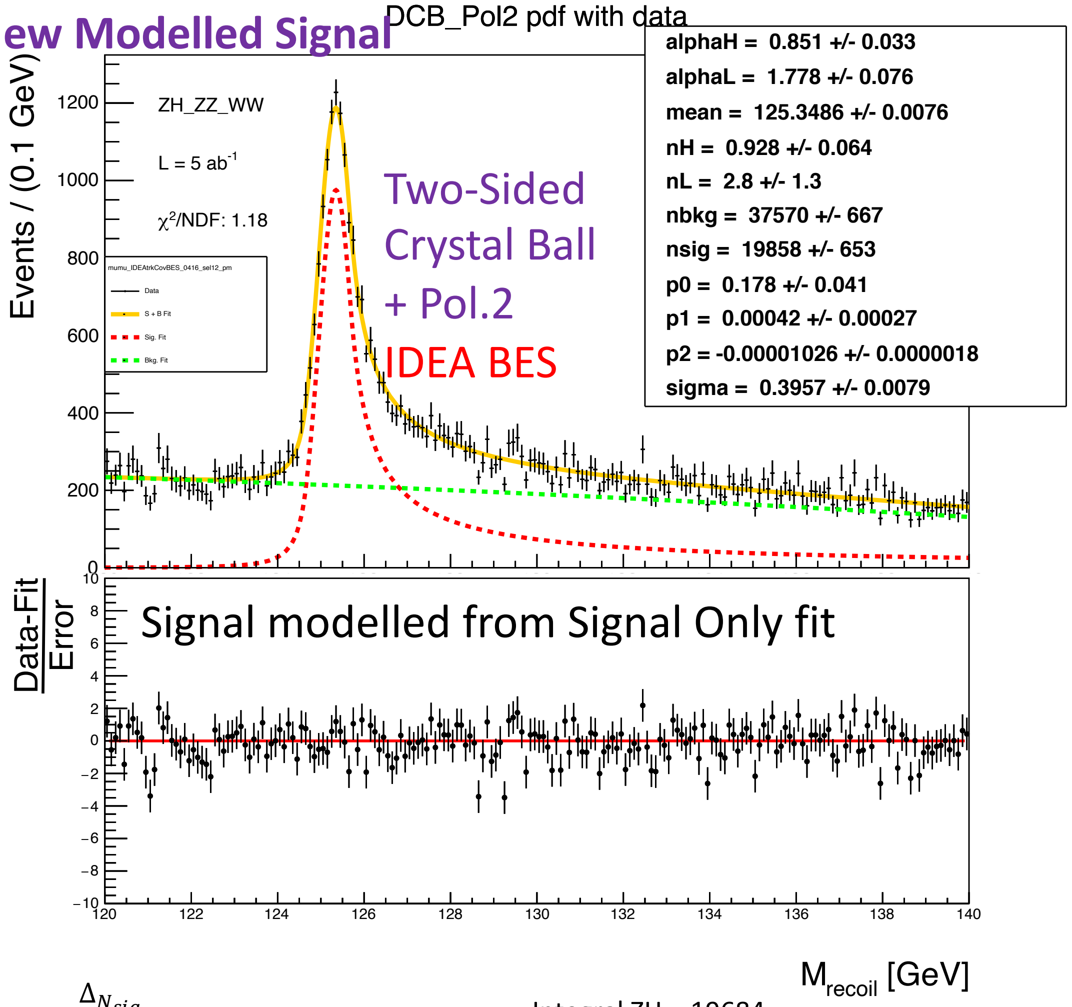
$p_T^Z > 20 \text{ GeV}$

Integral WW = 17515

$N_{sig}^{fit} / N_{sig}^{integral} = 100.1\%$

Comparison of ALL MCData fit and New Modelled Signal fit

New Modelled Signal



$$\frac{\Delta N_{sig}}{N_{sig}} = 3.3\%$$

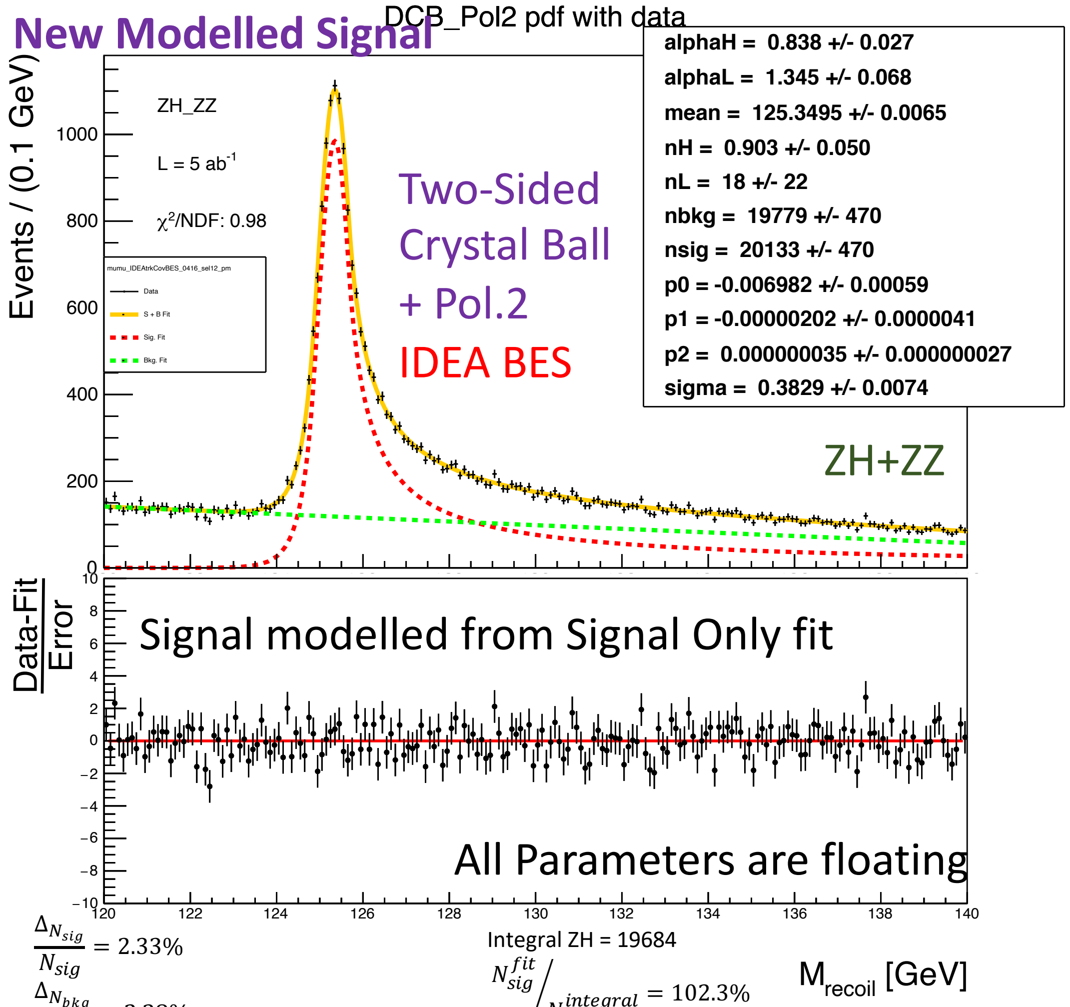
$86\ \text{GeV} < M_Z < 96\ \text{GeV}$

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

Integral ZH = 19684

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

New Modelled Signal



$$\frac{\Delta N_{sig}}{N_{sig}} = 2.33\%$$

$$\frac{\Delta N_{bkg}}{N_{bkg}} = 2.38\%$$

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

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

Integral ZH = 19684

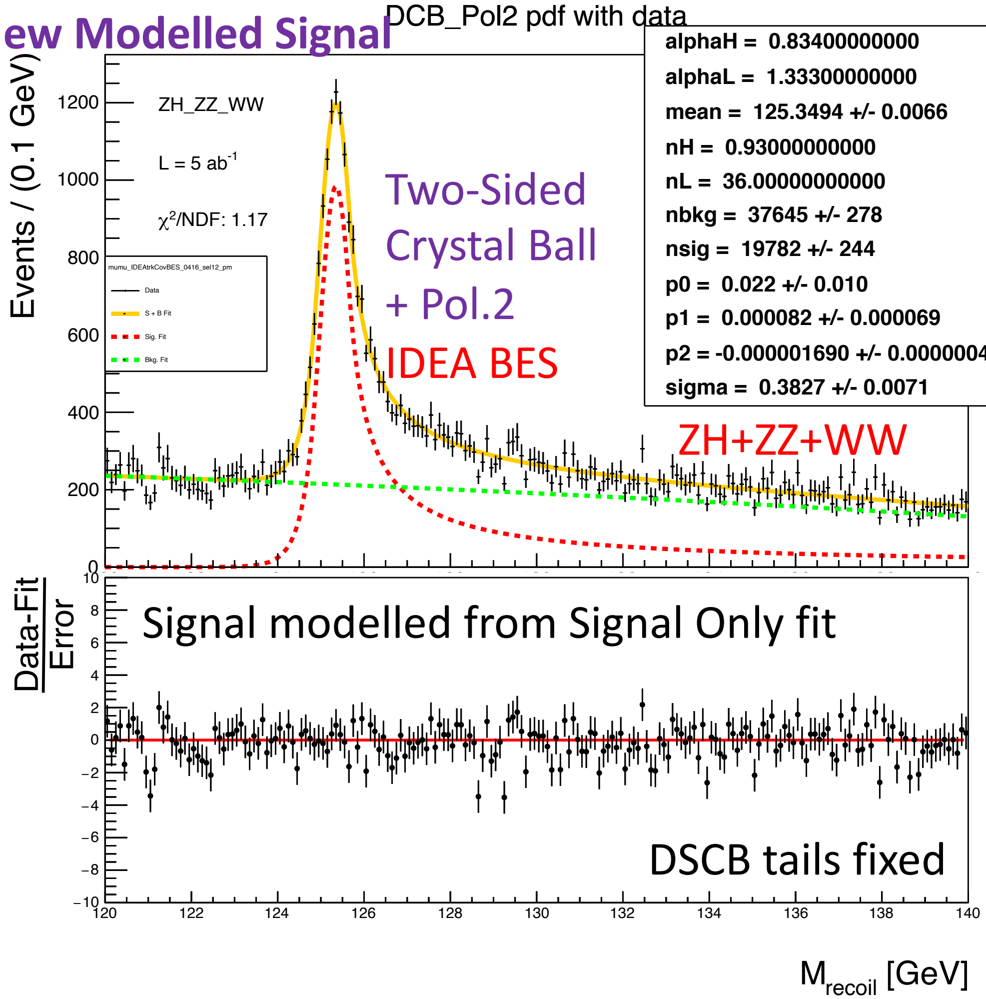
$$N_{sig}^{fit} \Big/ N_{sig}^{integral} = 102.3\%$$

Integral ZZ = 20228

$$N_{sig}^{fit} \Big/ N_{sig}^{integral} = 97.8\%$$

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

New Modelled Signal

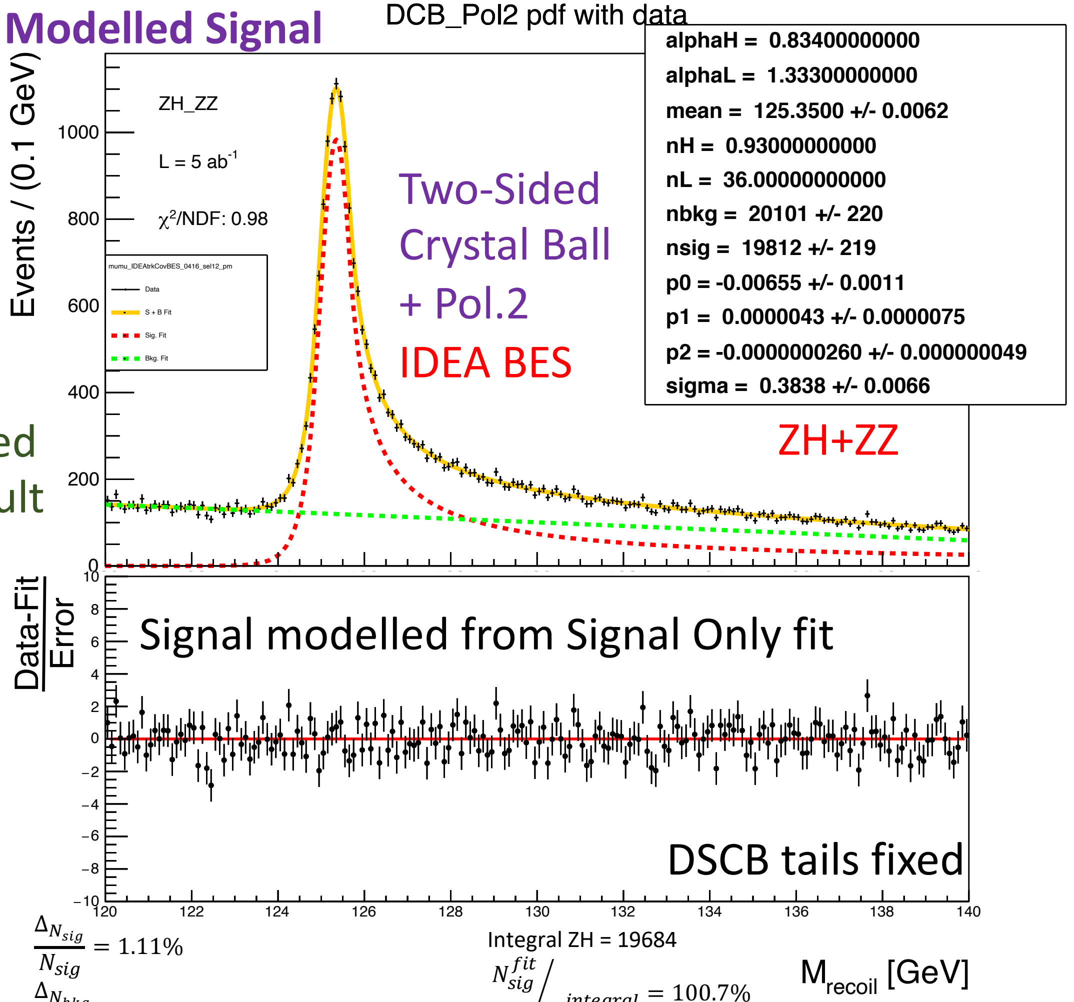


$\frac{\Delta_{N_{sig}}}{N_{sig}} = 1.23\%$
$86 \text{ GeV} < M_Z < 96 \text{ GeV}$
$p_T^Z > 20 \text{ GeV}$

Integral ZH = 19684
$N_{sig}^{fit} / N_{sig}^{integral} = 100.5\%$

Parameters were fixed as Signal Only fit result Slide 14 right plot

New Modelled Signal



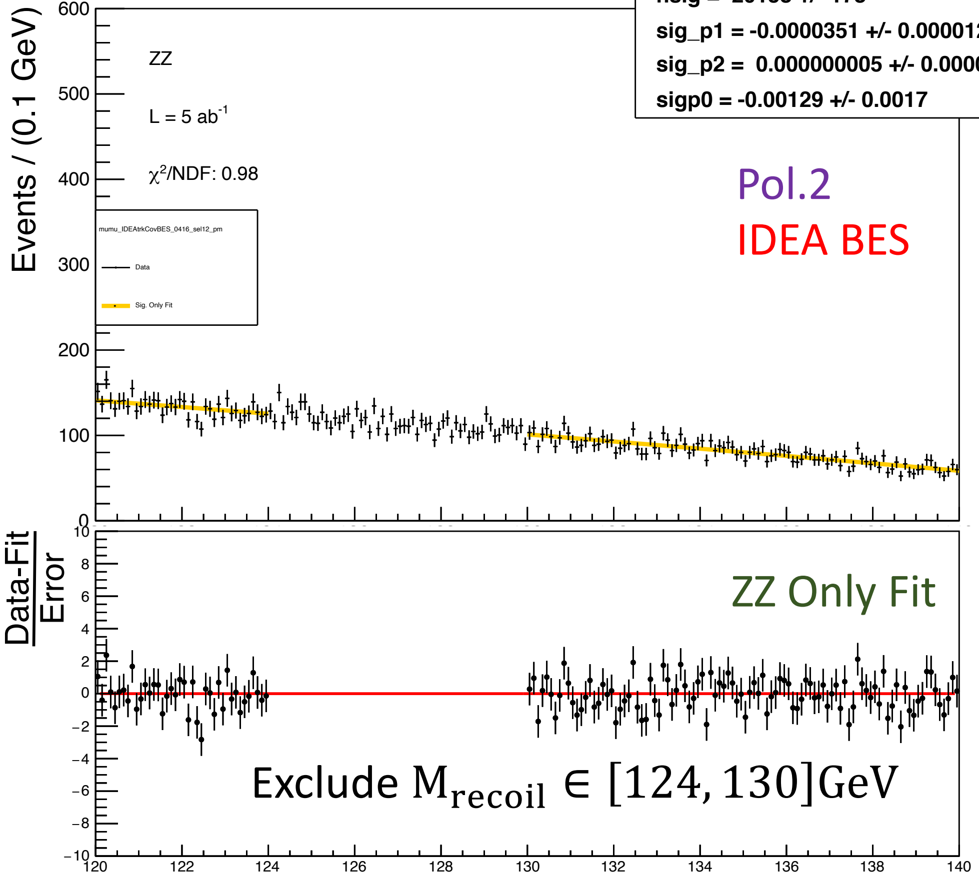
$\frac{\Delta_{N_{sig}}}{N_{sig}} = 1.11\%$
$\frac{\Delta_{N_{bkg}}}{N_{bkg}} = 1.09\%$
$86 \text{ GeV} < M_Z < 96 \text{ GeV}$
$p_T^Z > 20 \text{ GeV}$

Integral ZH = 19684
$N_{sig}^{fit} / N_{sig}^{integral} = 100.7\%$

Integral ZZ = 20228
$N_{sig}^{fit} / N_{sig}^{integral} = 99.4\%$

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

ALL MCData



M_recoil [GeV]

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

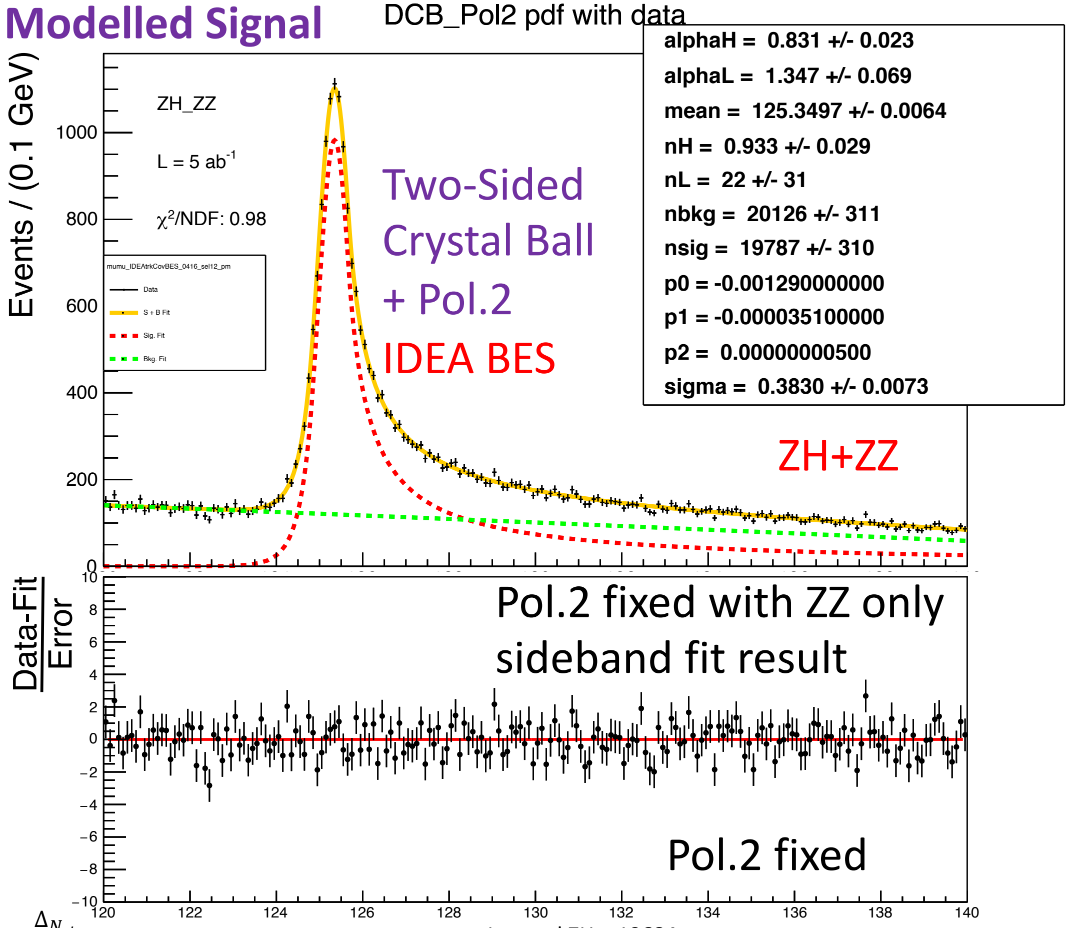
$86 \text{ GeV} < M_Z < 96 \text{ GeV}$

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

Integral ZZ = 20228

$N_{sig}^{fit} / N_{sig}^{integral} = 99.6\%$

New Modelled Signal



M_recoil [GeV]

$\frac{\Delta_{N_{sig}}}{N_{sig}} = 1.57\%$

$\frac{\Delta_{N_{bkg}}}{N_{bkg}} = 1.55\%$

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

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

Integral ZH = 19684

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

Integral ZZ = 20228

$N_{sig}^{fit} / N_{sig}^{integral} = 99.5\%$

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 $\boldsymbol{\sigma_H}$ ~0.39 GeV, $\boldsymbol{\Delta_{\sigma_H}}$ ~ 8 MeV, M_H ~ 125.3 GeV, $\boldsymbol{\Delta_{M_H}}$ ~ 7 MeV

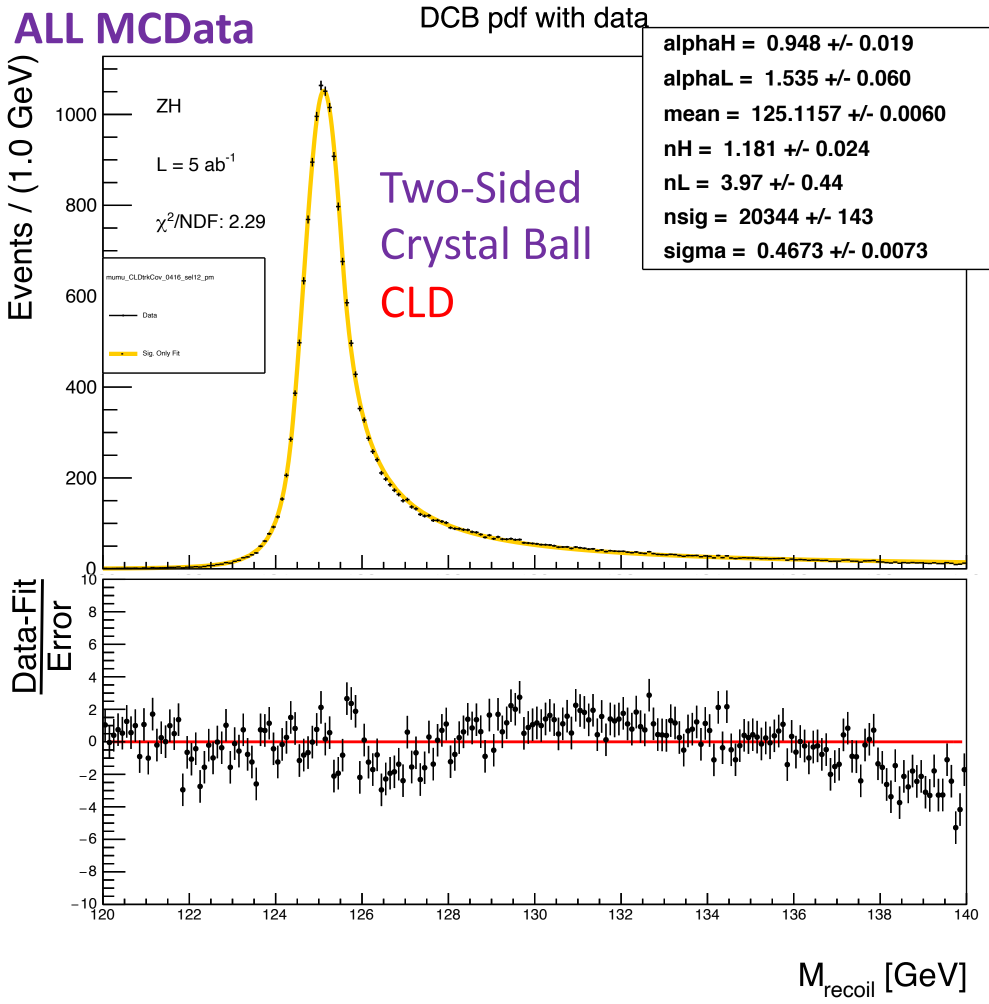
After fixing the tails, $\Delta_{N_{sig}}/N_{sig}$ ~ 1.0%.

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

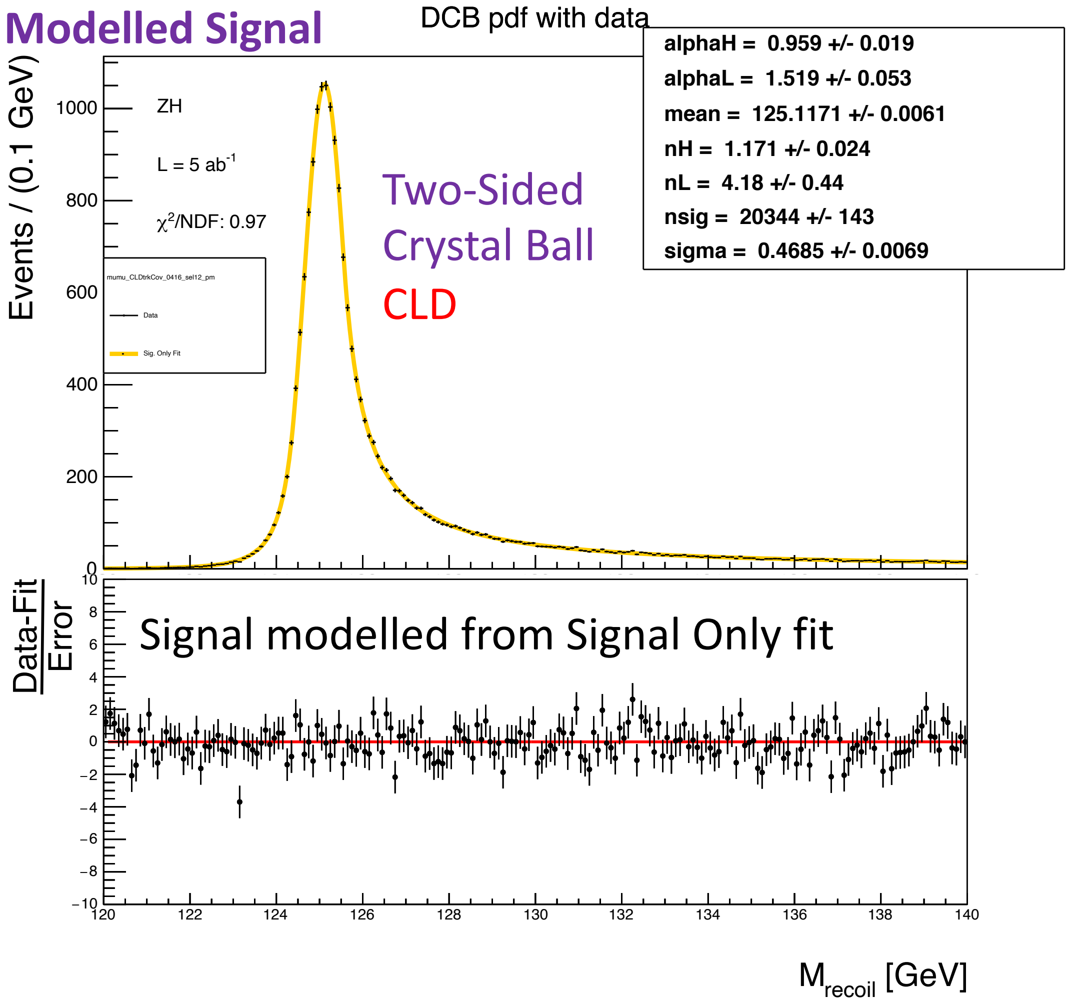
CLDtrkCov

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

ALL MCData

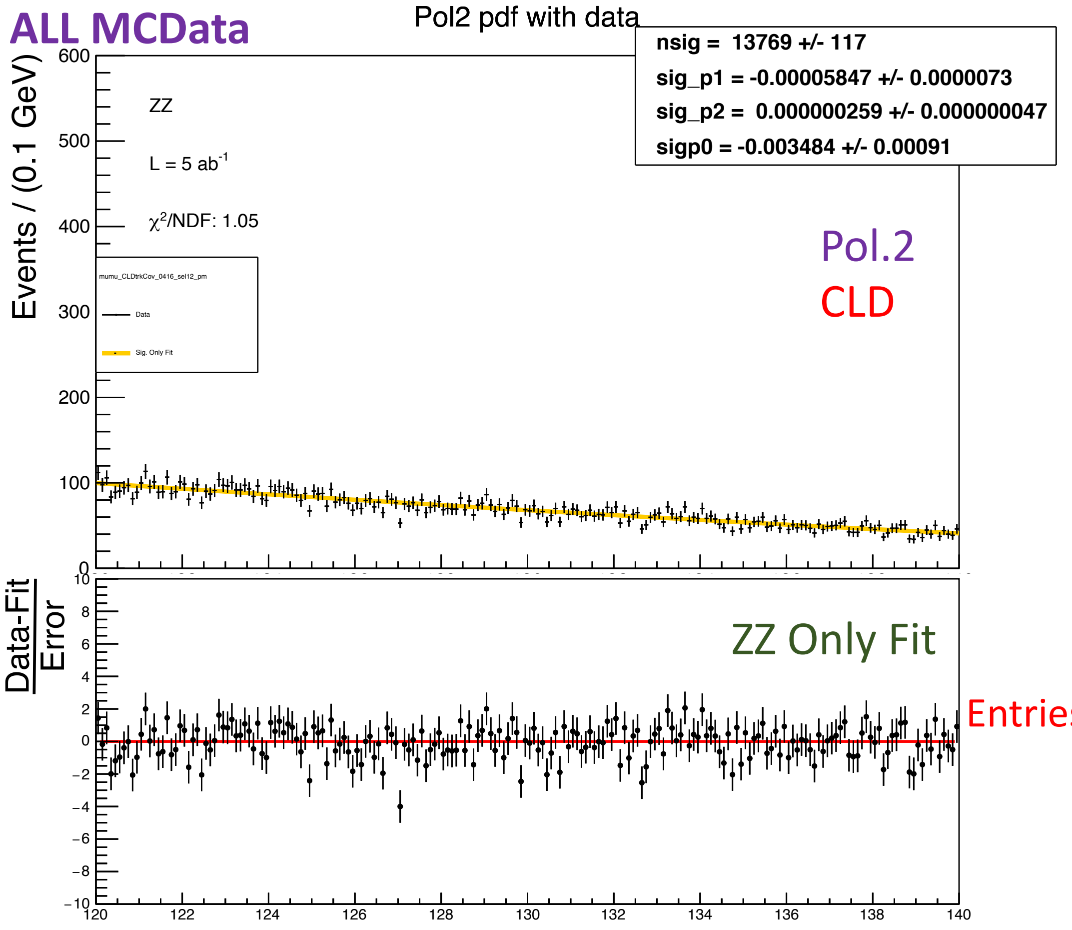


New Modelled Signal



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)



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 0.85\%$

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

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

Integral ZZ = 13769

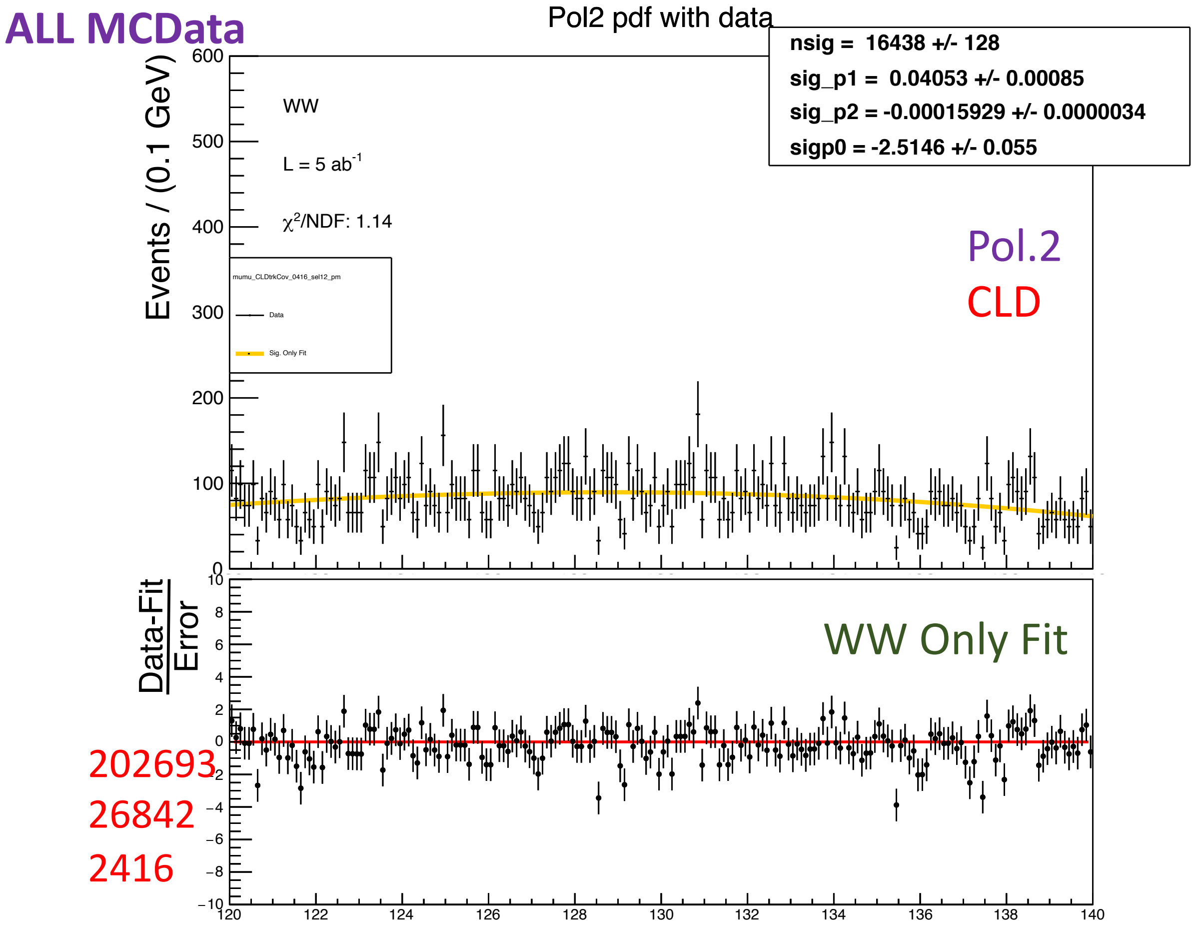
$N_{sig}^{fit} / N_{sig}^{integral} = 100.0\%$

Entries:

ZH: 202693

ZZ: 26842

WW: 2416



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 0.78\%$

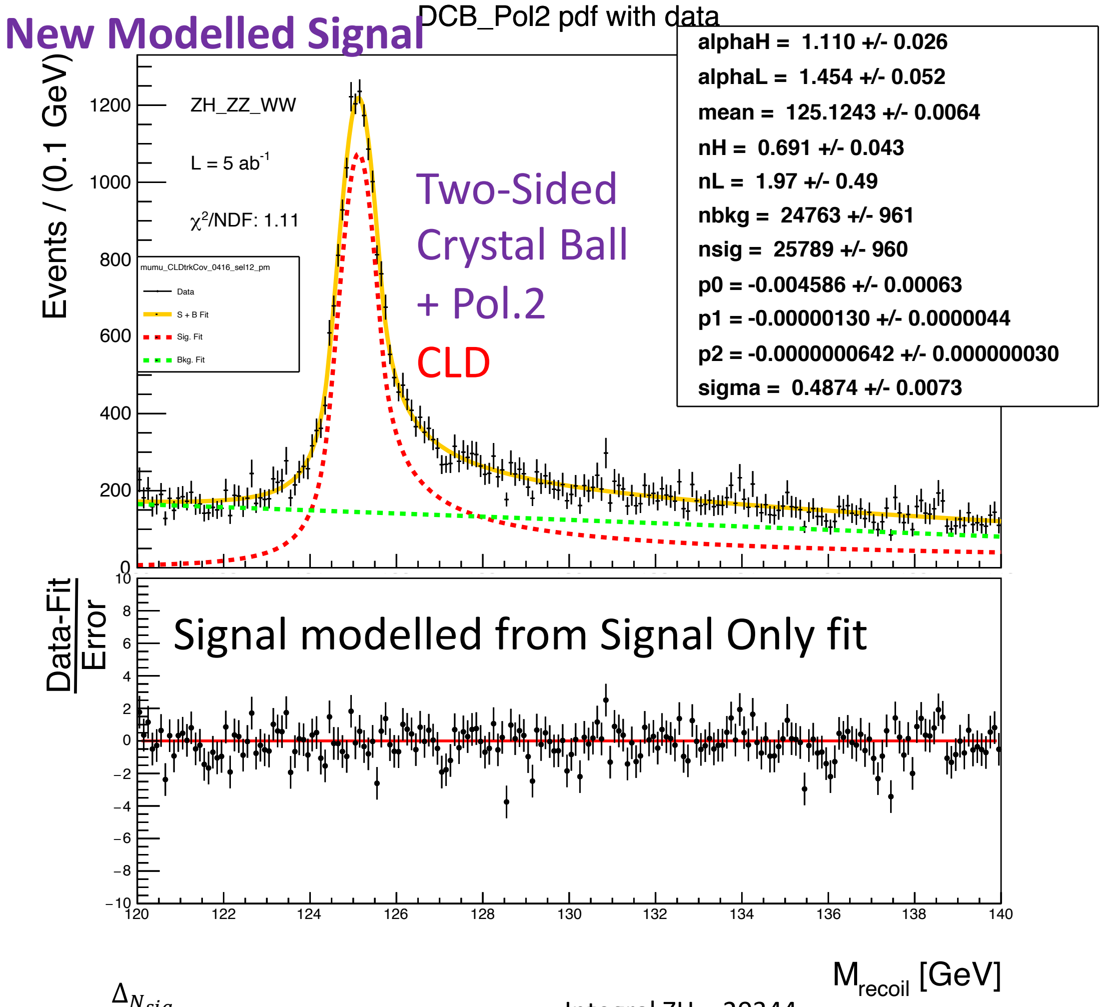
$86\ \text{GeV} < M_Z < 96\ \text{GeV}$

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

Integral WW = 16439

$N_{sig}^{fit} / N_{sig}^{integral} = 100.0\%$

Comparison of ALL MCData fit and New Modelled Signal fit



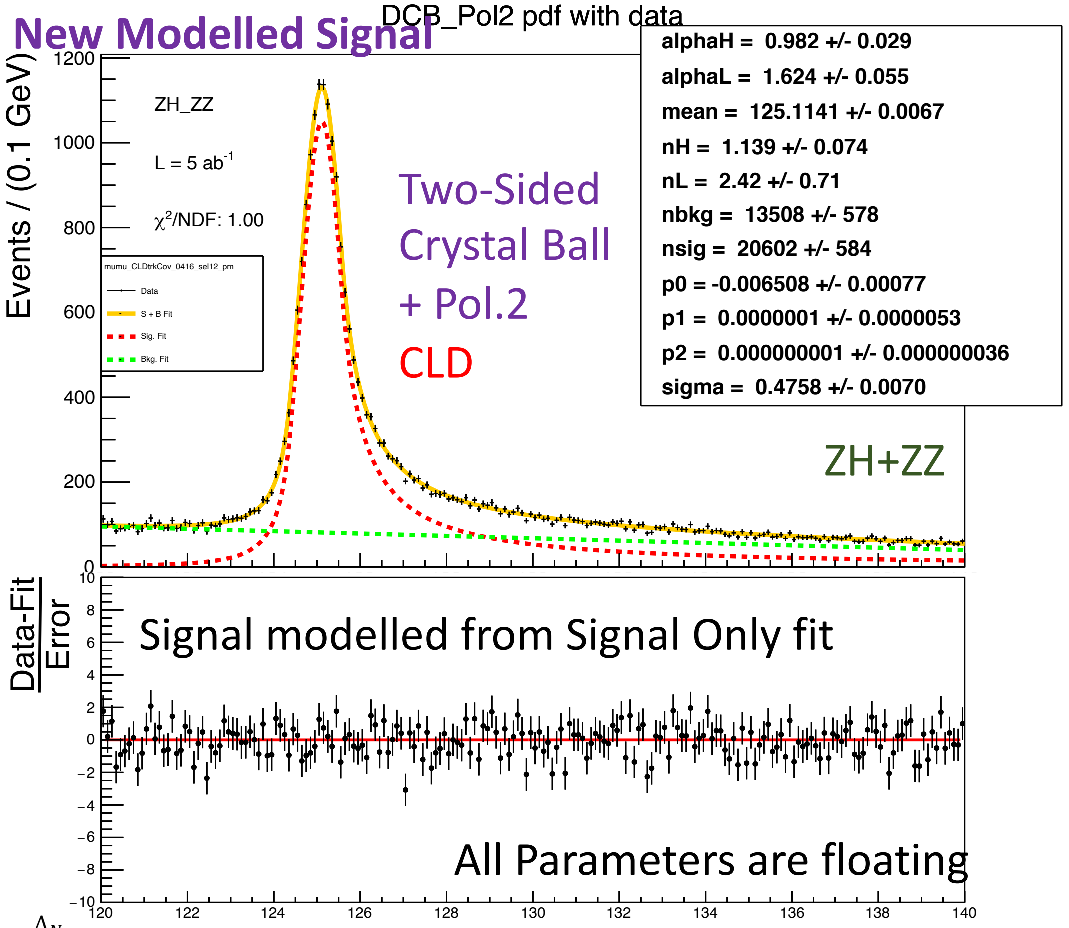
$\frac{\Delta_{N_{sig}}}{N_{sig}} = 3.7\%$

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

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

Integral ZH = 20344

$N_{sig}^{fit} \big/ N_{sig}^{integral} = 126.8\%$



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 2.83\%$

$\frac{\Delta_{N_{bkg}}}{N_{bkg}} = 4.28\%$

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

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

Integral ZH = 20344

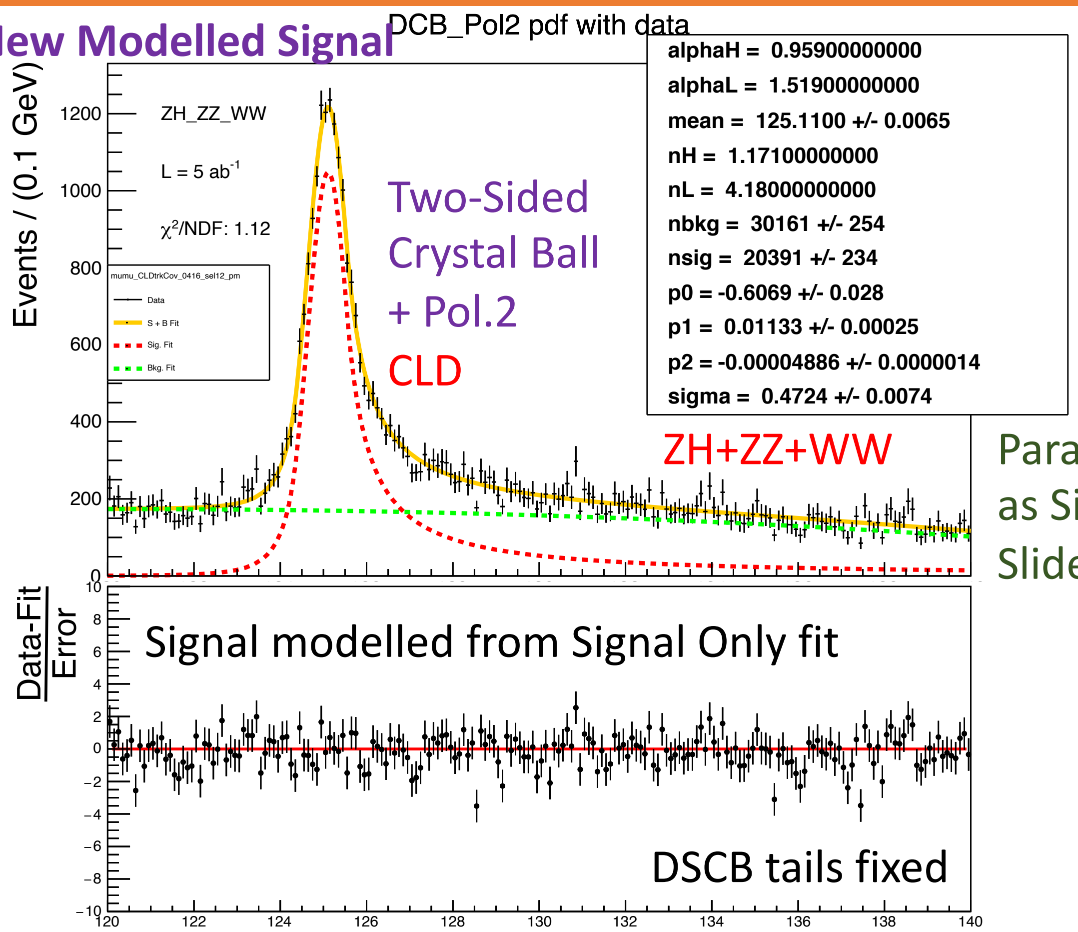
$N_{sig}^{fit} \big/ N_{sig}^{integral} = 101.3\%$

Integral ZZ = 13769

$N_{sig}^{fit} \big/ N_{sig}^{integral} = 98.1\%$

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

New Modelled Signal



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 1.15\%$

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

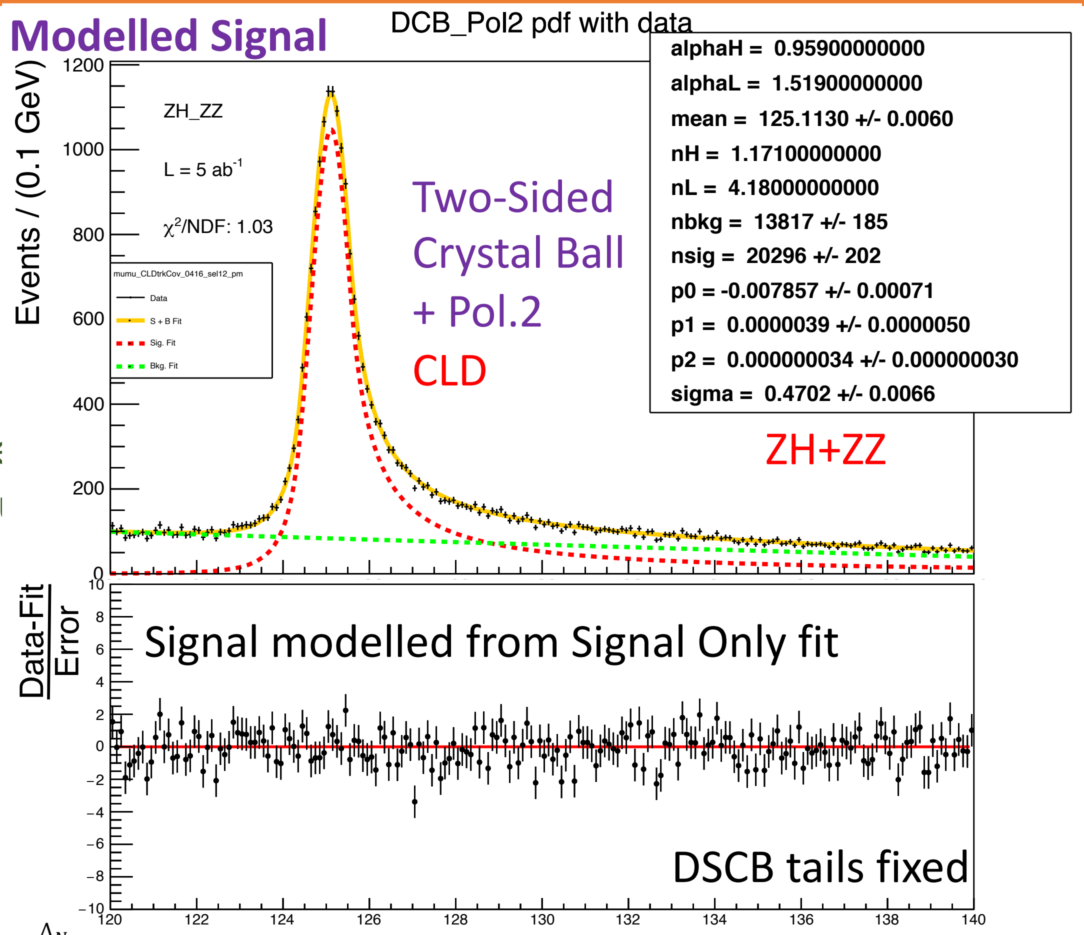
$p_T^Z > 20 \text{ GeV}$

Integral ZH = 20344

$N_{sig}^{fit} / N_{sig}^{integral} = 100.2\%$

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

New Modelled Signal



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 1.00\%$

$\frac{\Delta_{N_{bkg}}}{N_{bkg}} = 1.34\%$

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

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

Integral ZH = 20344

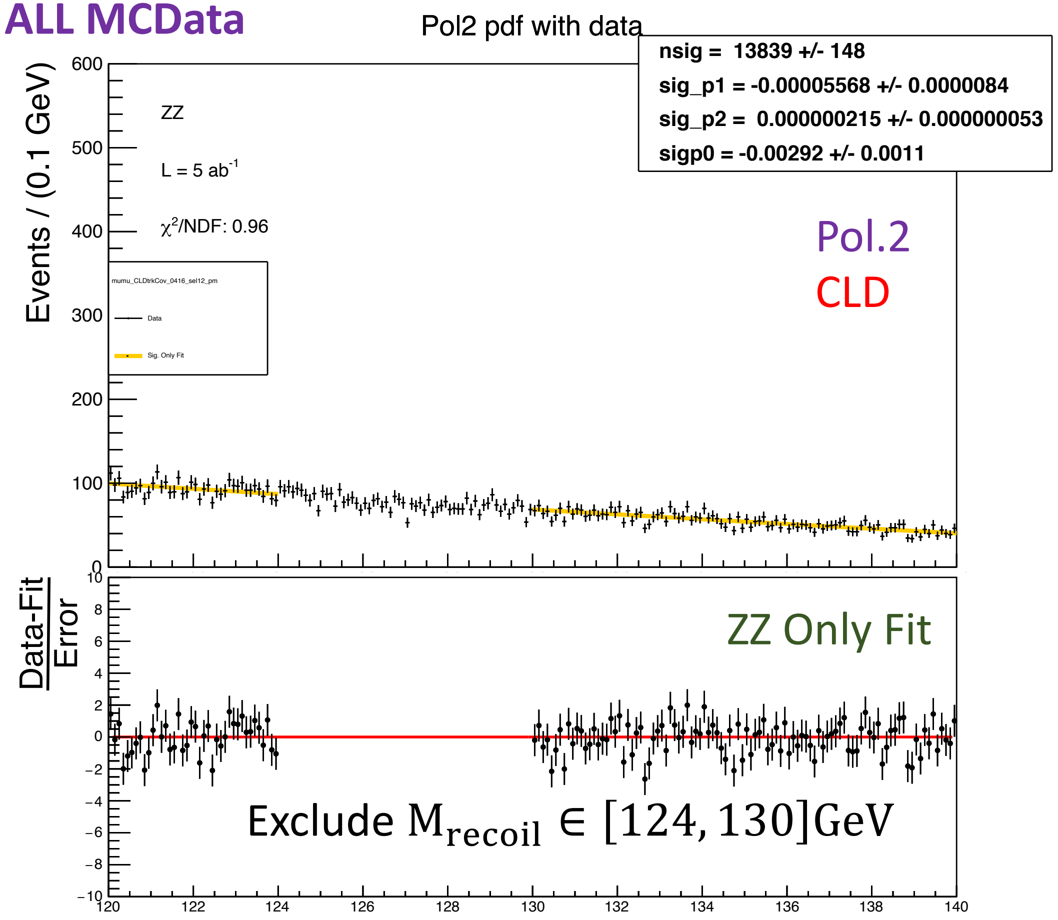
$N_{sig}^{fit} / N_{sig}^{integral} = 99.8\%$

Integral ZZ = 13769

$N_{sig}^{fit} / N_{sig}^{integral} = 100.3\%$

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

ALL MCData



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

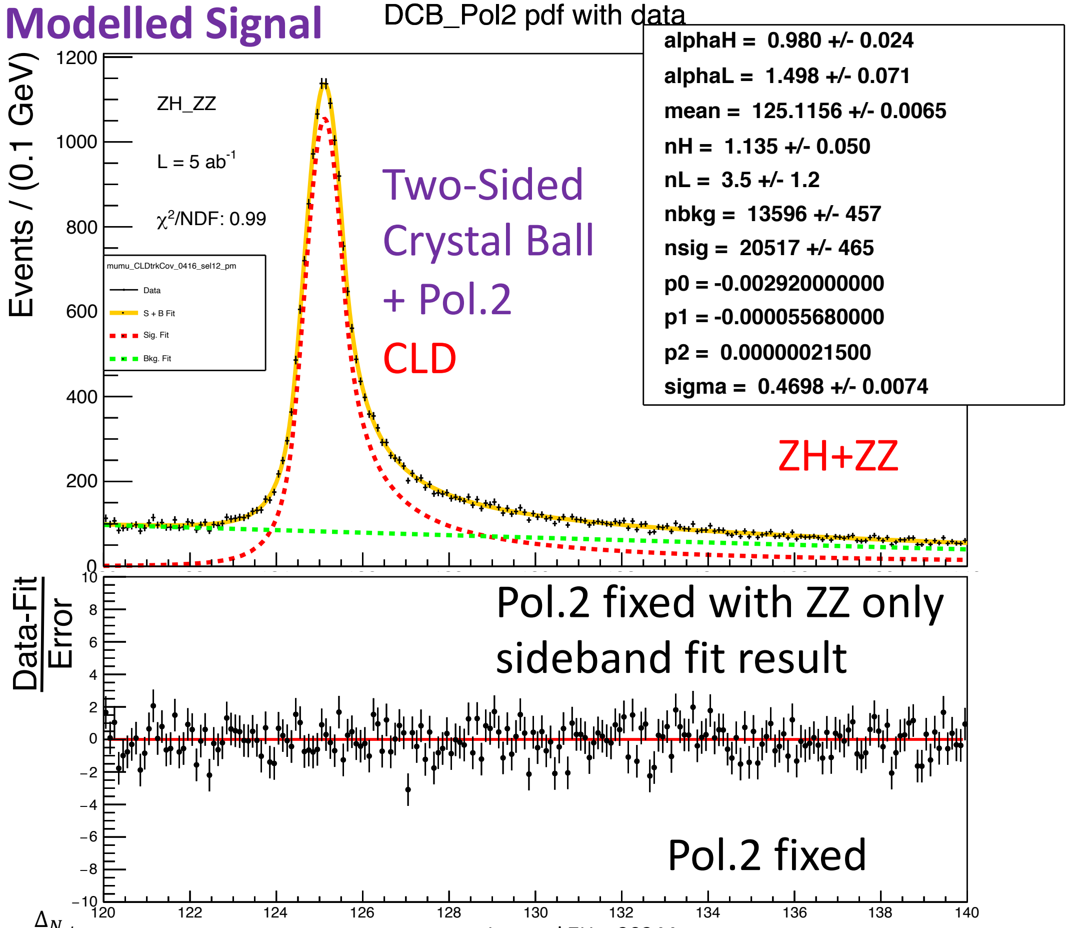
$86\text{ GeV} < M_Z < 96\text{ GeV}$

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

Integral ZZ = 13769

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

New Modelled Signal



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

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

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

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

Integral ZH = 20344

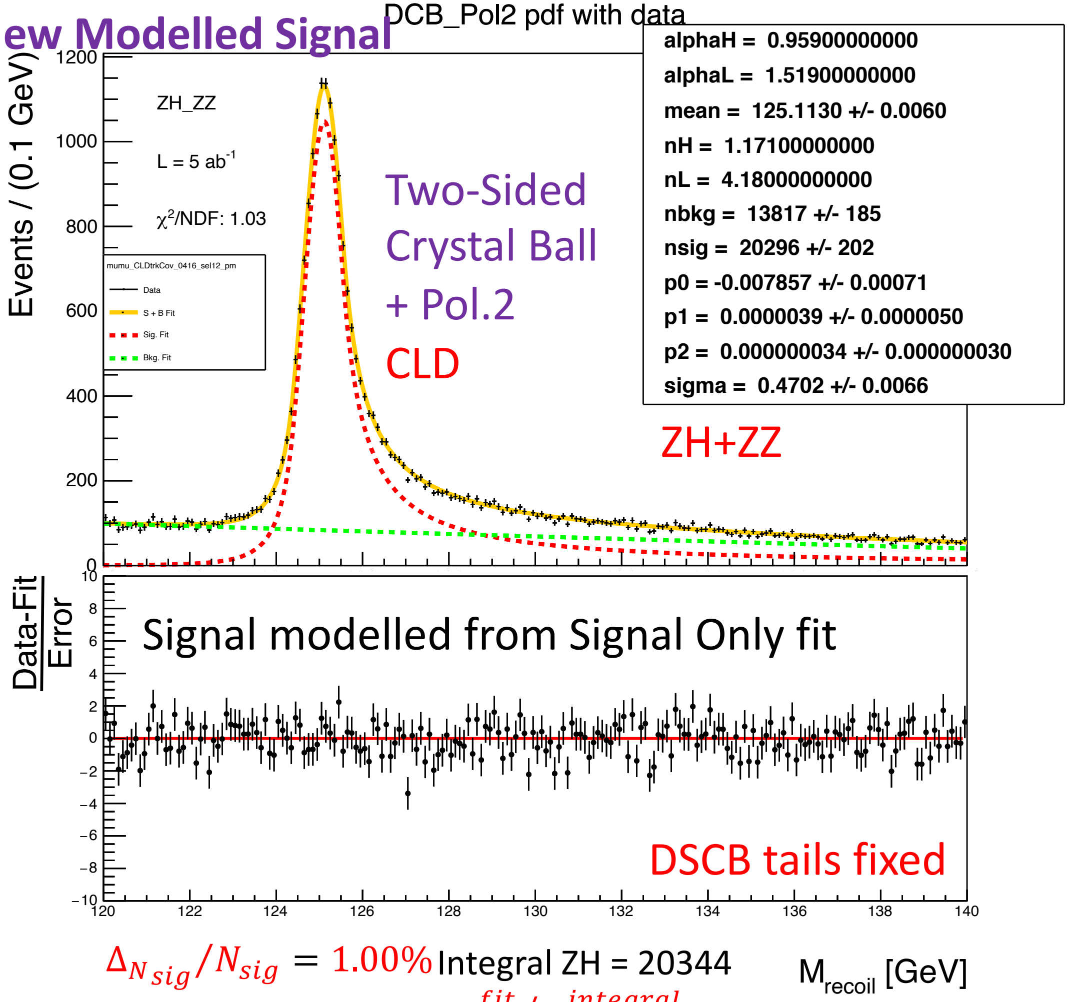
$N_{sig}^{fit} / N_{sig}^{integral} = 100.9\%$

Integral ZZ = 13769

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

CLD

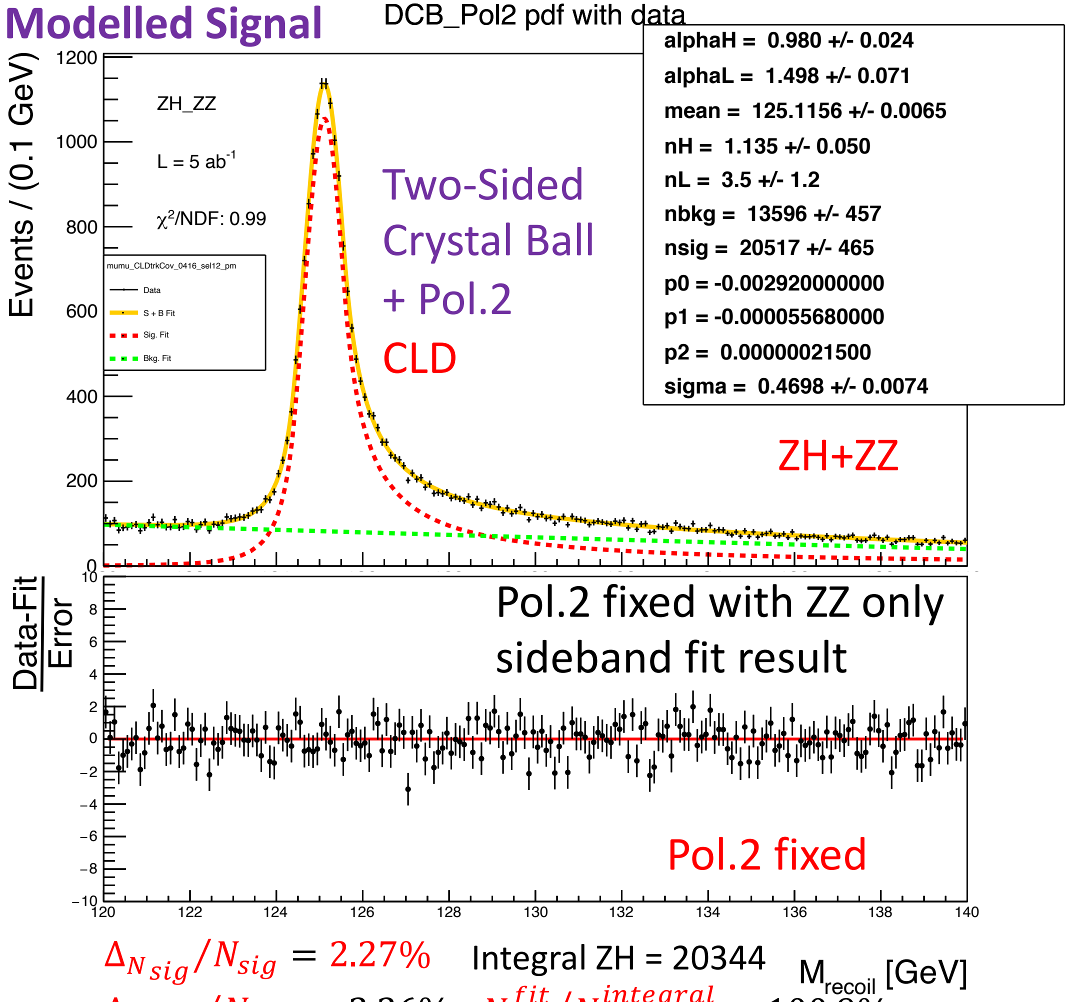
New Modelled Signal



$\Delta_{N_{sig}}/N_{sig} = 1.00\%$ Integral ZH = 20344

$N_{sig}^{fit}/N_{sig}^{integral} = 100.2\%$

New Modelled Signal



$\Delta_{N_{sig}}/N_{sig} = 2.27\%$ Integral ZH = 20344

$\Delta_{N_{bkg}}/N_{bkg} = 3.36\%$ $N_{sig}^{fit}/N_{sig}^{integral} = 100.9\%$

Integral ZZ = 13769

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

- Fixing the tails, the uncertainty of N_{sig} is ~ 1.2%
- Fixing the background, the uncertainty of N_{sig} is ~ 2.3%

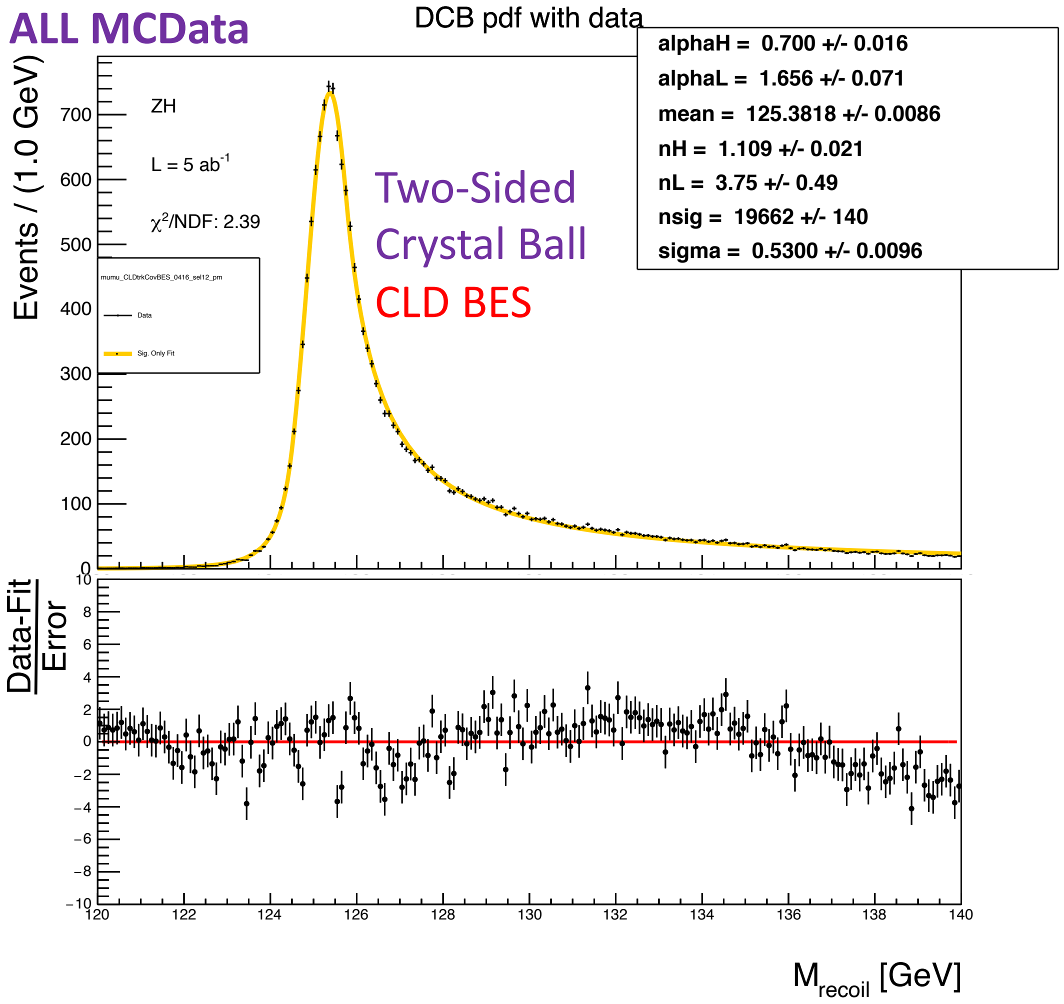
Fitted Width, mass, Nsig in the Higgs mass region (120-140 GeV)

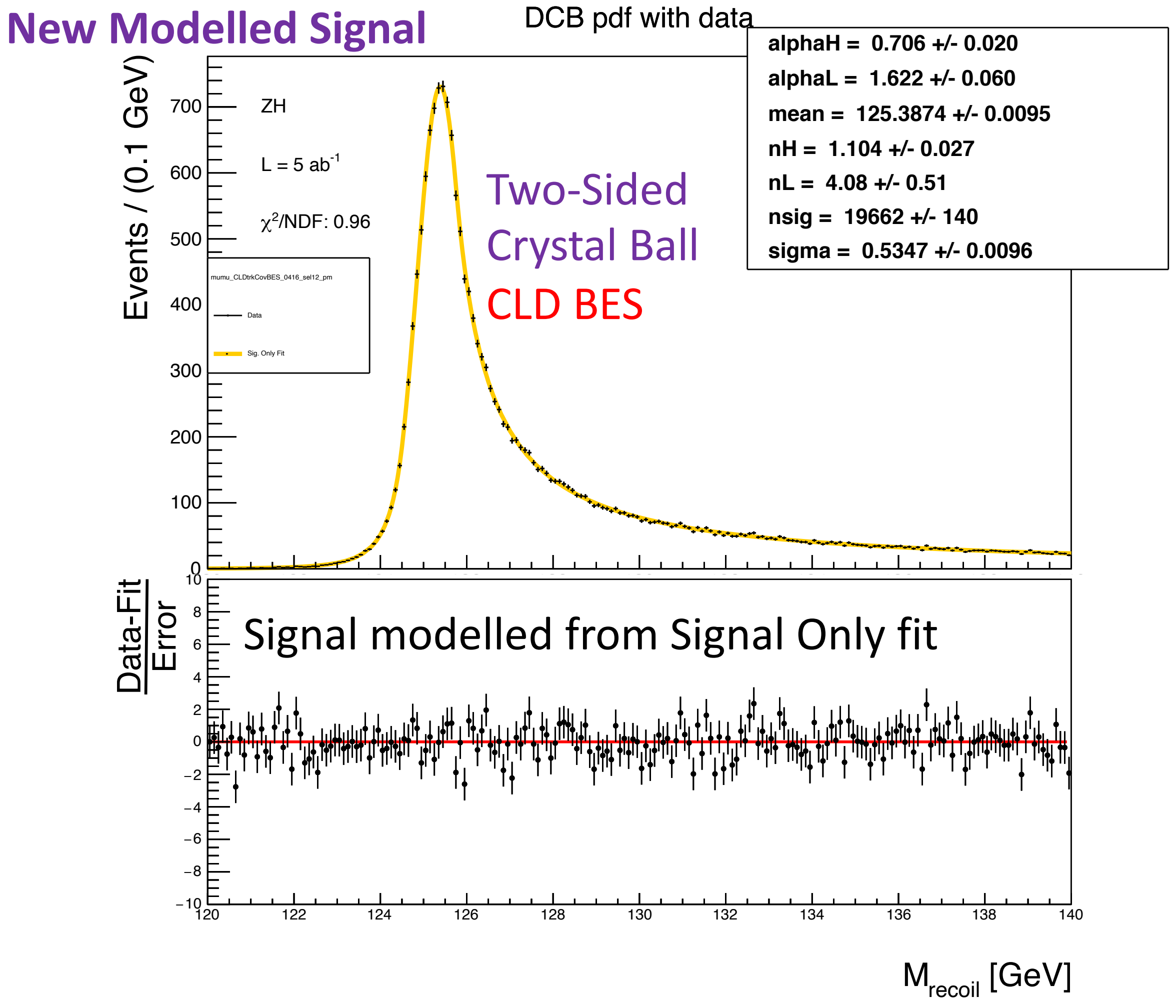
Two-Sided Crystal Ball + Pol.2 fit **ZH+ZZ+WW**	σ_H (GeV)	Δ_{σ_H} (GeV)	M_H (GeV)	Δ_{M_H} (GeV)	$\Delta_{N_{sig}}/N_{sig}$
New Modelled Signal	0.4874	0.0073	125.1243	0.0064	3.7%
New Modelled Signal, tails fixed	0.4724	0.0074	125.1100	0.0065	1.2%

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)





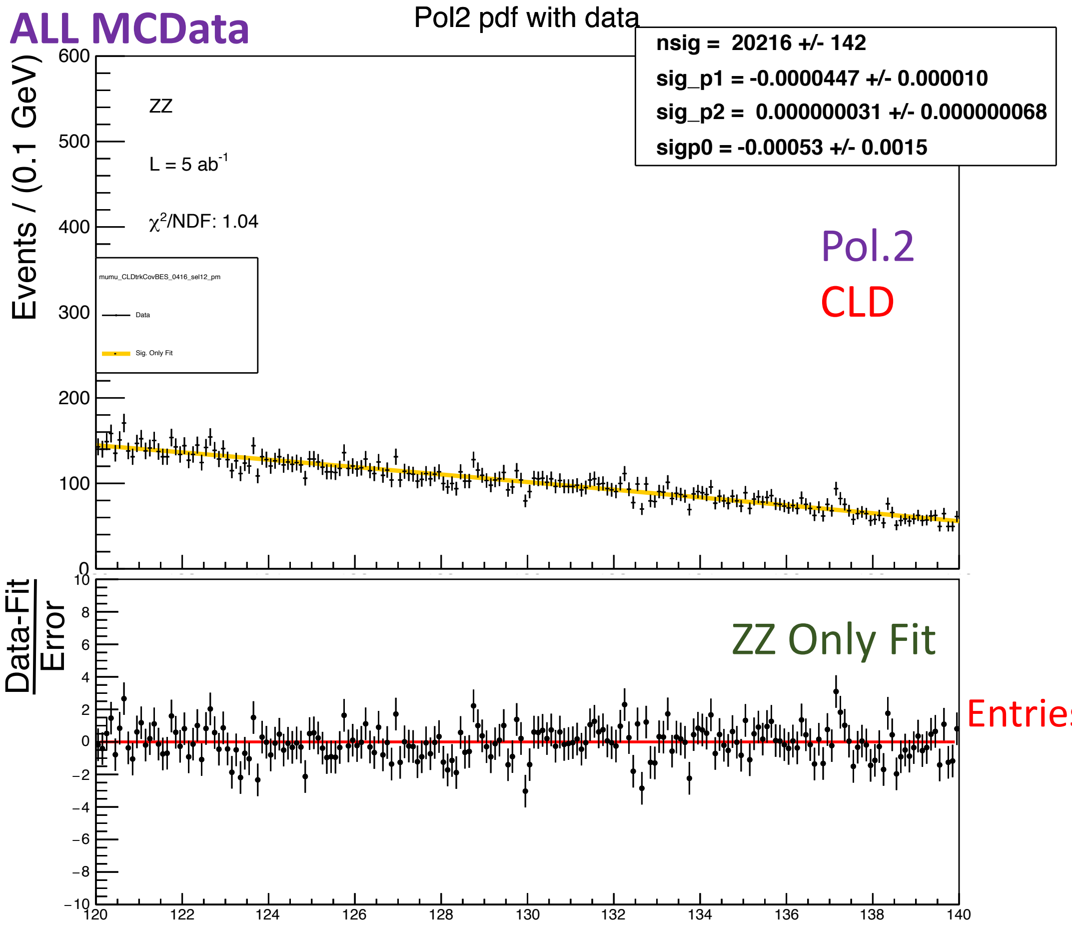
ALL MCData:

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)



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 0.70\%$

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

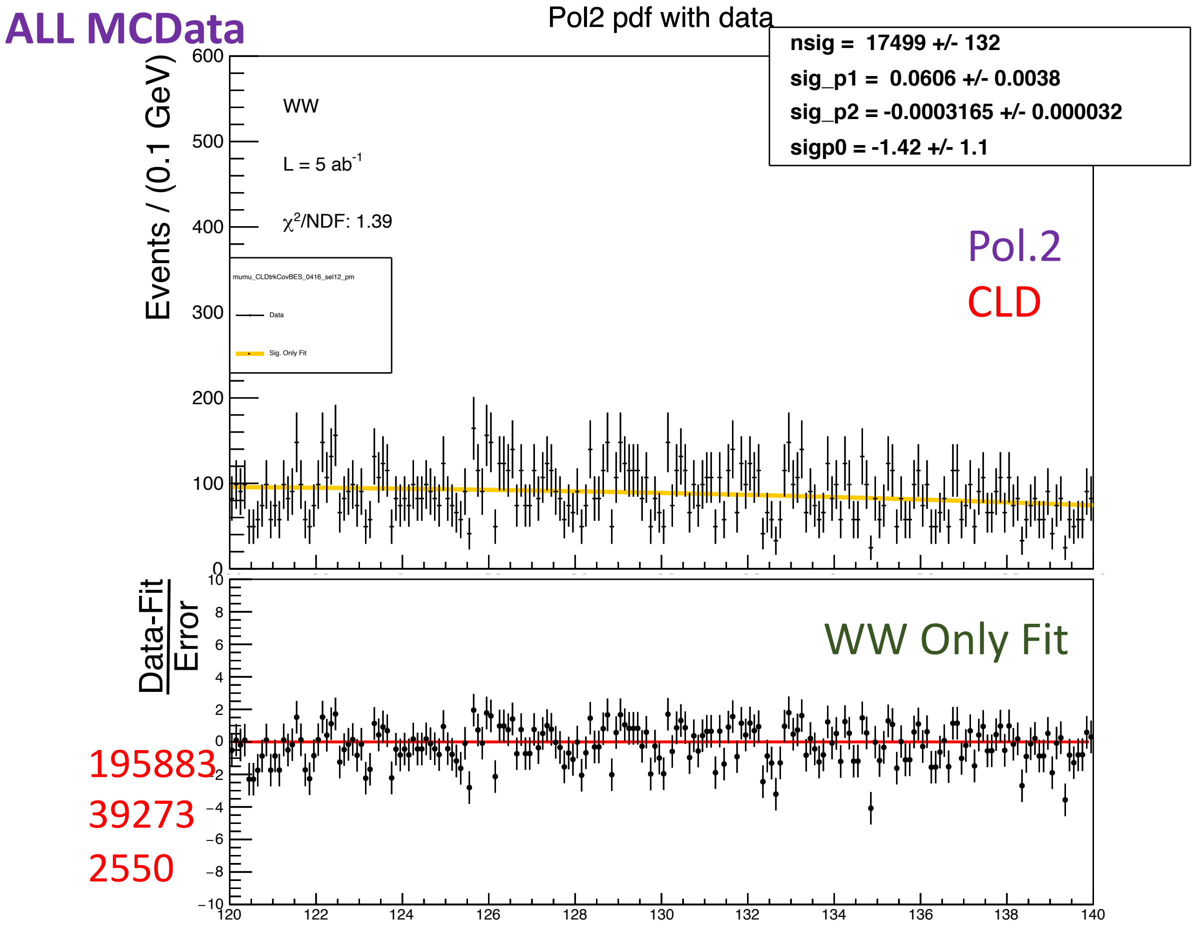
$p_T^Z > 20 \text{ GeV}$

Integral ZZ = 20216

$N_{sig}^{fit} / N_{sig}^{integral} = 100.0\%$

Entries:

ZH:	195883
ZZ:	39273
WW:	2550



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 0.75\%$

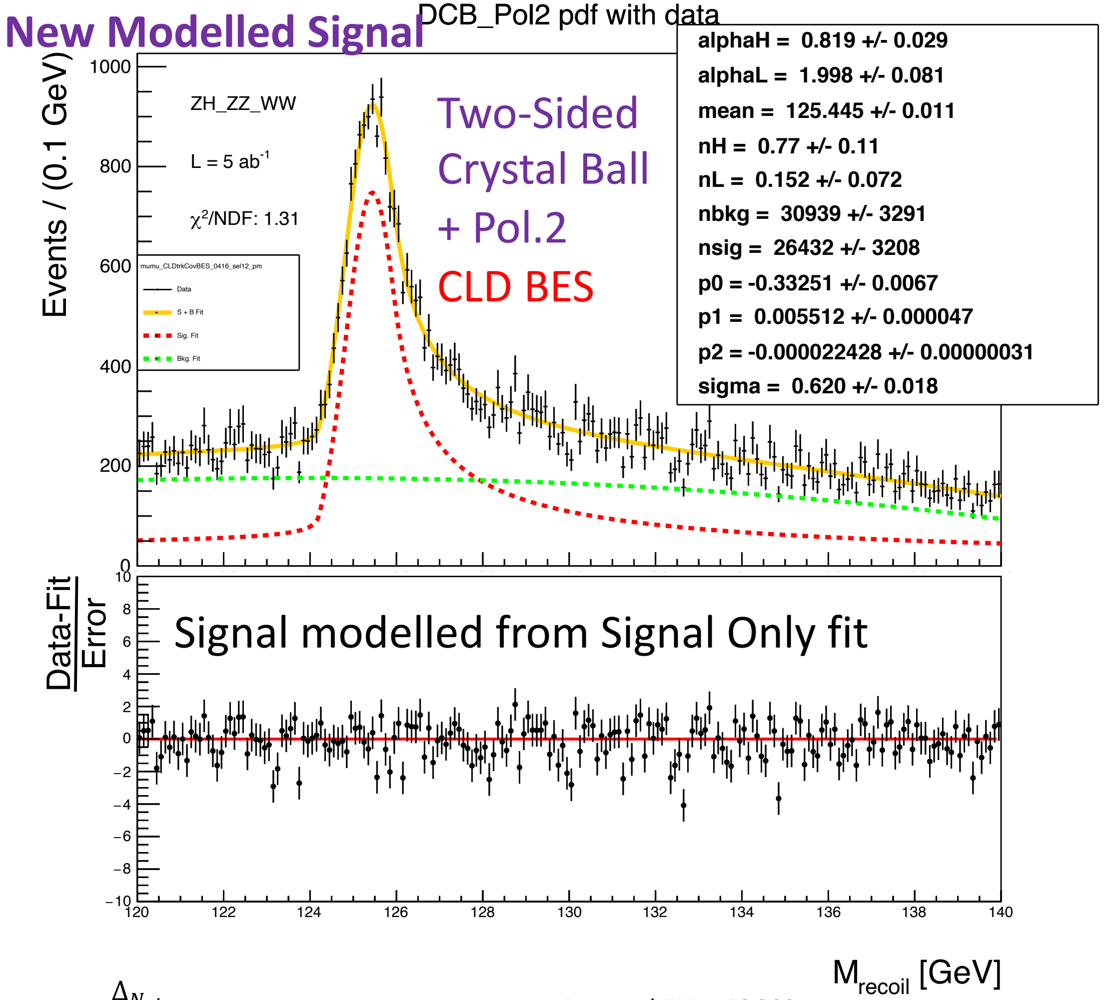
$86 \text{ GeV} < M_Z < 96 \text{ GeV}$

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

Integral WW = 17499

$N_{sig}^{fit} / N_{sig}^{integral} = 100.0\%$

Comparison of ALL MCData fit and New Modelled Signal fit



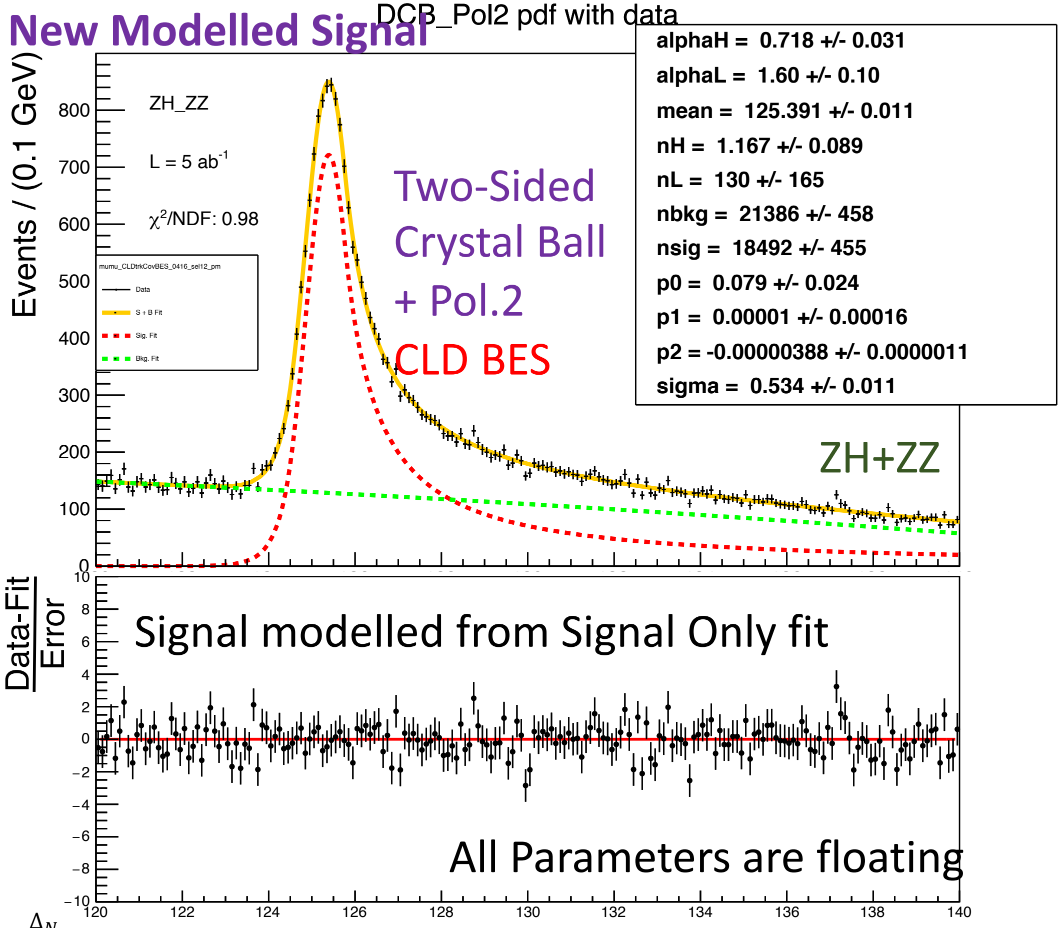
$\frac{\Delta_{N_{sig}}}{N_{sig}} = 3.7\%$

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

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

Integral ZH = 19662

$N_{sig}^{fit} / N_{sig}^{integral} = 126.8\%$



$\frac{\Delta_{N_{sig}}}{N_{sig}} = 2.46\%$

$\frac{\Delta_{N_{bkg}}}{N_{bkg}} = 2.14\%$

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

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

Integral ZH = 19662

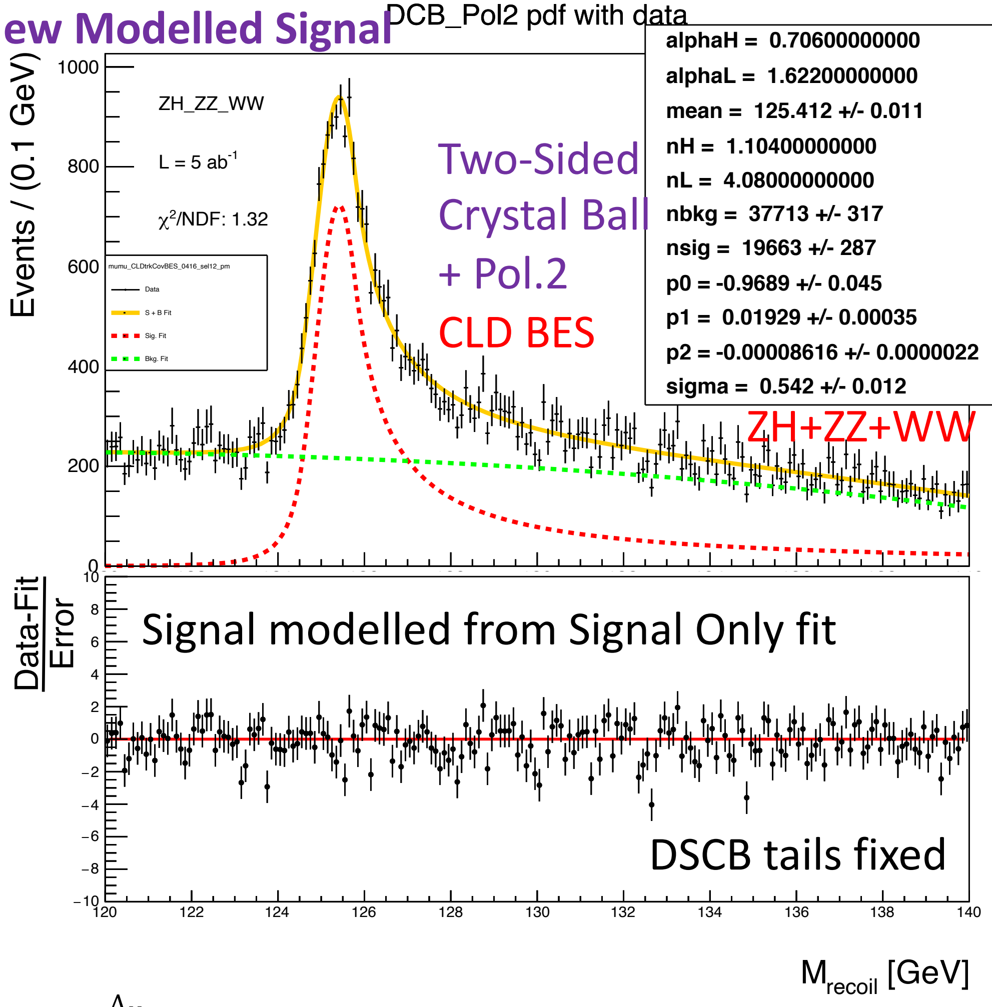
$N_{sig}^{fit} / N_{sig}^{integral} = 94.0\%$

Integral ZZ = 20216

$N_{sig}^{fit} / N_{sig}^{integral} = 105.8\%$

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

New Modelled Signal



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

86 GeV $< M_Z <$ 96 GeV

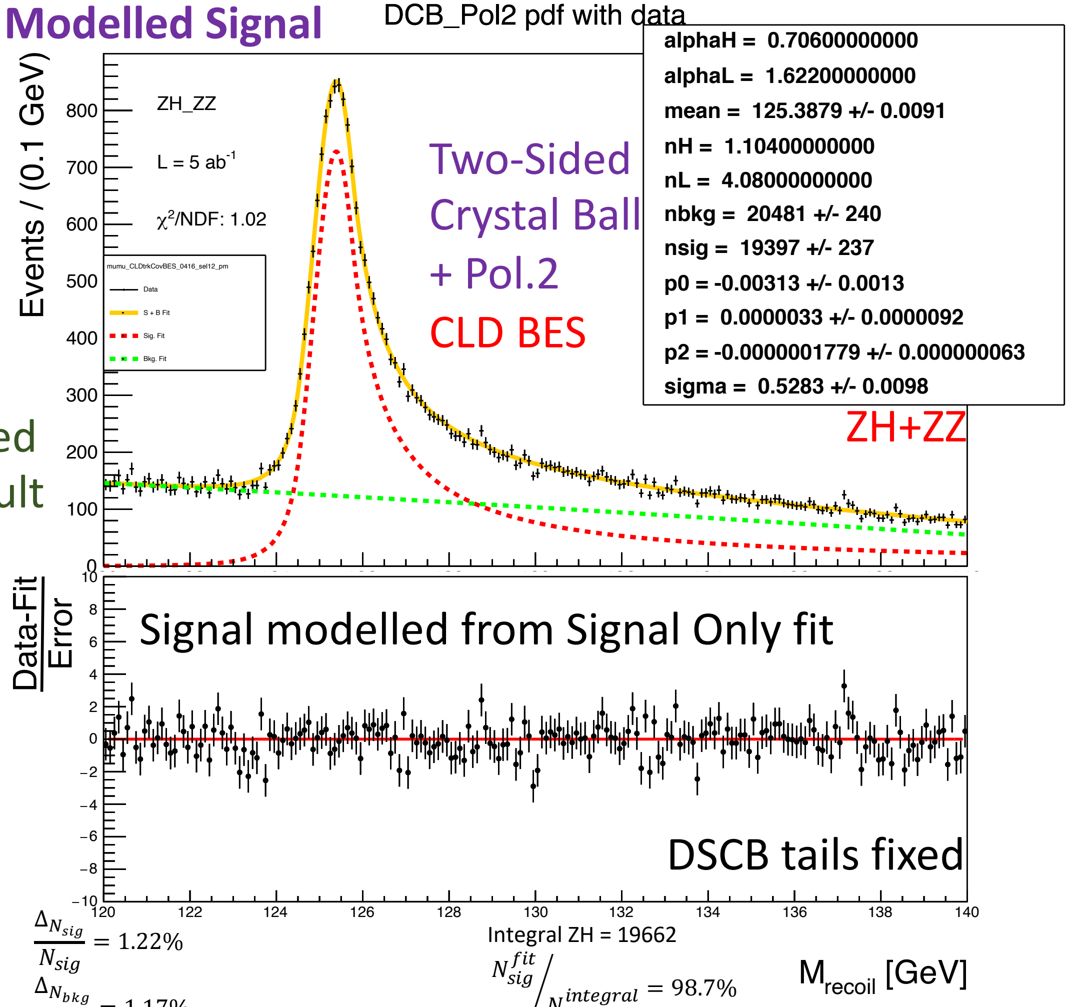
$p_T^Z > 20$ GeV

Integral ZH = 19662

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

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

New Modelled Signal



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

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

86 GeV $< M_Z <$ 96 GeV

$p_T^Z > 20$ GeV

Integral ZH = 19662

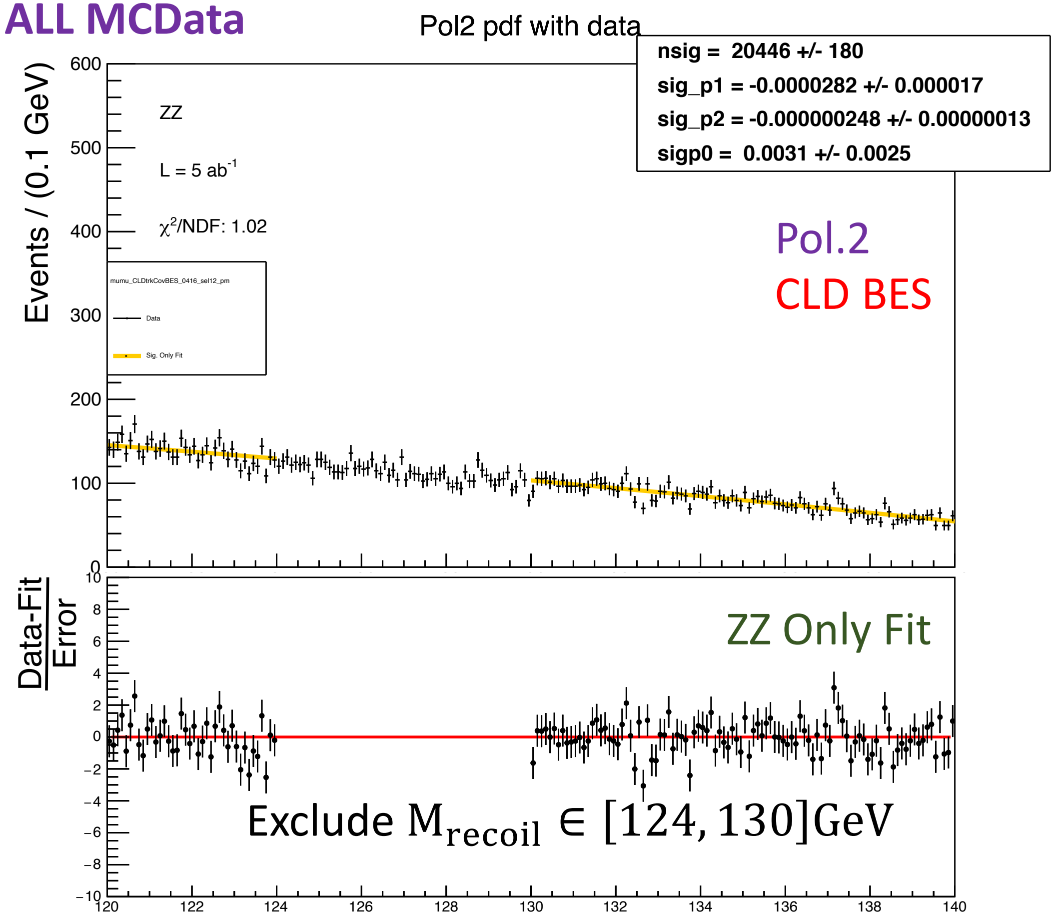
$N_{sig}^{fit} / N_{sig}^{integral} = 98.7\%$

Integral ZZ = 20216

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

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

ALL MCData



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

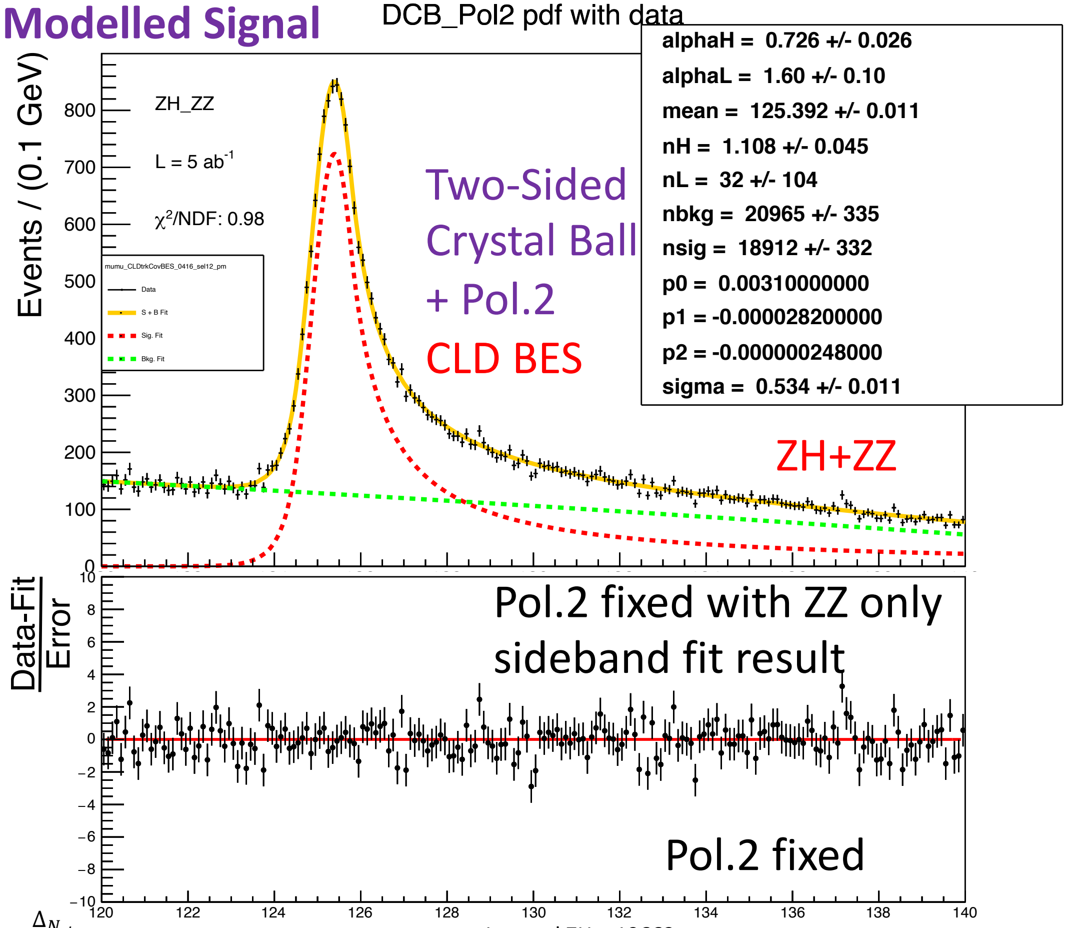
$86\ \text{GeV} < M_Z < 96\ \text{GeV}$

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

Integral ZZ = 20216

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

New Modelled Signal



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

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

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

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

Integral ZH = 19662

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

Integral ZZ = 20216

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

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%