# Status

Low mass Zprime :

- 2nd EB today
- Unblinding approval next week.
- Update the new signal modelling with different couplings
- Update the theoretic unc.
- Update the final results with different couplings.

Quirk track:

- Prepare for submitting. (In April or May)
- Finish new scan with more dataset/epochs.

Shifts:

- GIT merge request review, Level 1
- 5 shifts now. 2 or 3 one week in the next two months.

Hardware:

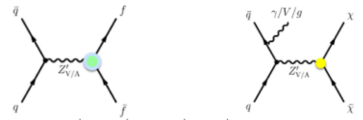
- Build a framework for monitoring and recording data.

# Signal Modelling

s-channel for spin-1 mediators:

$$\mathcal{L}_V \supset \frac{1}{2} m_{Z'} V_\mu V^\mu - g_q^{ij} V_\mu \bar{q}_i \gamma^\mu q_j - g_l^{ij} V_\mu \bar{l}_i \gamma^\mu l_j - g_\chi^{ij} V_\mu \bar{\chi} \gamma^\mu \chi$$

$$\mathcal{L}_A \supset \frac{1}{2} m_{Z'} V_\mu V^\mu - g_q^{ij} V_\mu \bar{q}_i \gamma^\mu \gamma_5 q_j - g_l^{ij} V_\mu \bar{l}_i \gamma^\mu \gamma_5 l_j - g_\chi^{ij} V_\mu \bar{\chi} \gamma^\mu \gamma_5 \chi$$




| | $g_q$ | $g_l$ | $g_\chi$ |
|---|---|---|---|
| Vector | 0.1 | 0.01 | 0 |
| Axial-vector | 0.1 | 0.1 | 0 |

## Narrow width Signal MC sample:

- 8 mass points has been studied: 35,40,45,50,55,60,65,70 GeV.

Two DM coupling are proposed:

- $g_l = 0.01, g_q = 0.1$
- $g_l = 0.1, g_q = 0.1$
- (The intrinsic width is smaller enough than the resolution of these benchmarking models)

## New Signal MC sample:

- 2 mass points with different DM couplings: (45GeV, 65GeV)
  - $g_l = g_q = 0.1, 0.15, 0.2, 0.25, 0.3$

## A convolution of BW and DSCB function for signals:

- Mass shape of benchmarking signals can be well modelled by the convolution:
- Breit-Wigner: $\Gamma$ is fixed to intrinsic width.

$$f(x) \propto \frac{1}{(x-\mu)^2 + \left(\frac{1}{2}\Gamma\right)^2}$$

- DSCB:

$$DSCB\,(x;\sigma,\alpha_L,n_L,\alpha_R,n_R) = \begin{cases} A_L \cdot \left(B_L - \frac{x}{\sigma}\right)^{-n_L}, & \text{for } \frac{x}{\sigma} < -\alpha_L \\ \exp\left(-\frac{x^2}{2\sigma^2}\right), & -\alpha_L \leqslant \text{ for } \frac{x}{\sigma} \leqslant \alpha_R \\ A_R \cdot \left(B_R + \frac{x}{\sigma}\right)^{-n_R}, & \text{for } \frac{x}{\sigma} > \alpha_R \end{cases}$$

$$A_i = \left(\frac{n_i}{|\alpha_i|}\right)^{n_i} \cdot \exp\left(-\frac{|\alpha_i|^2}{2}\right)$$

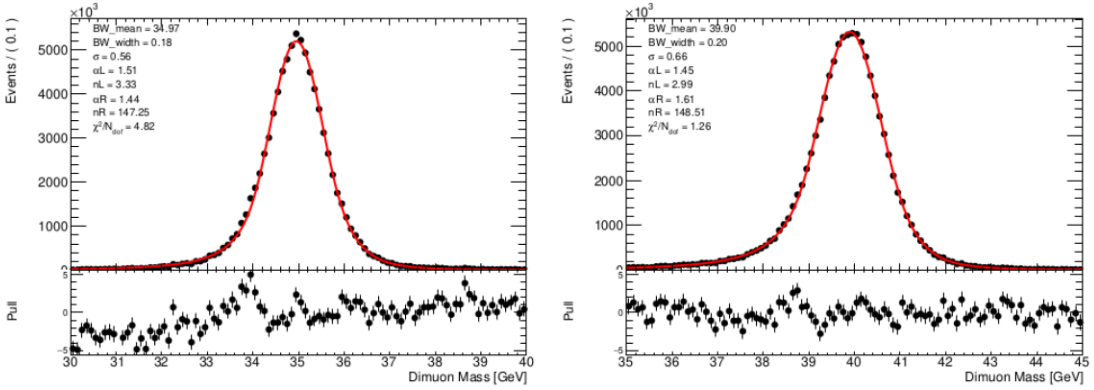
$$B_i = \frac{n_i}{|\alpha_i|} - |\alpha_i|$$

# Signal Modelling

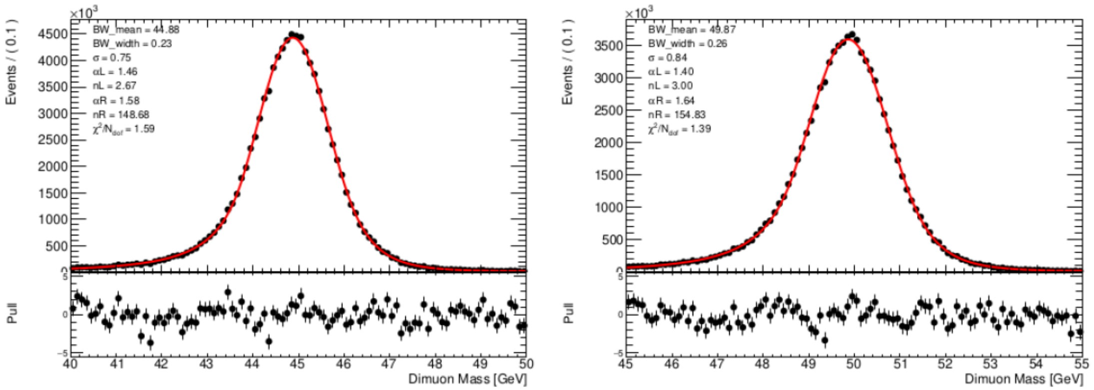
A convolution of BW and DSCB function for signals:

- Mass shape of benchmarking signals can be well modelled by the convolution:

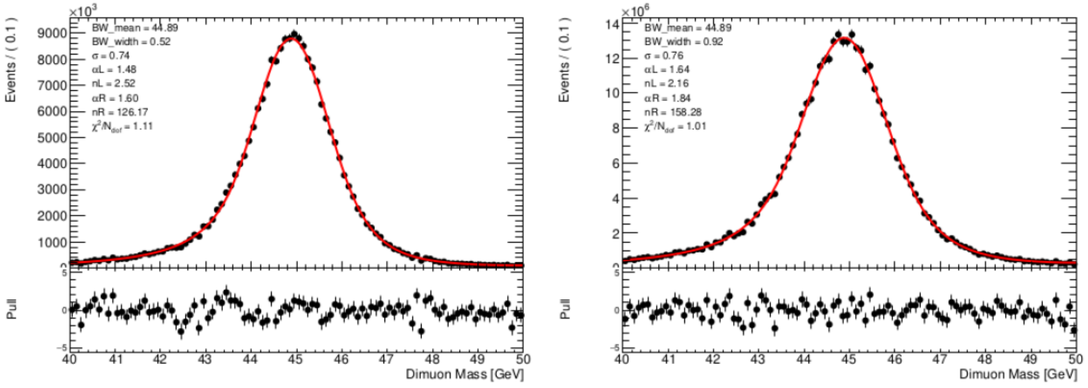
Different mass with same couplings:



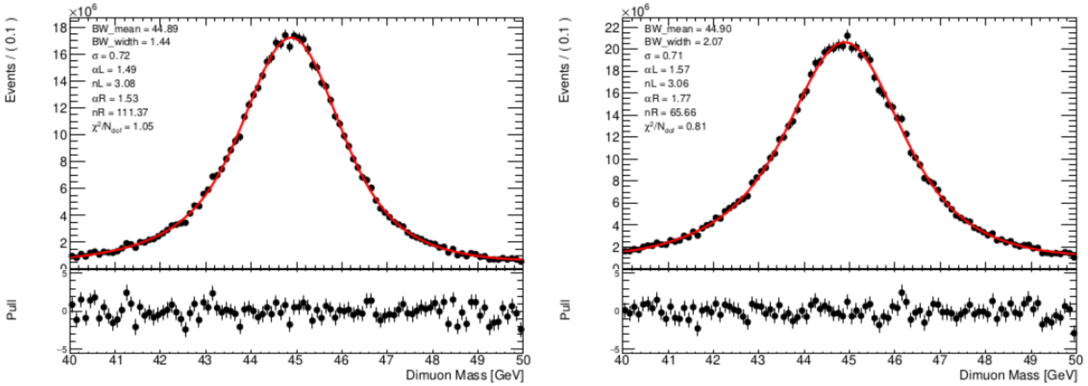

(a) (b)




Same mass with different couplings:




(a) (b)

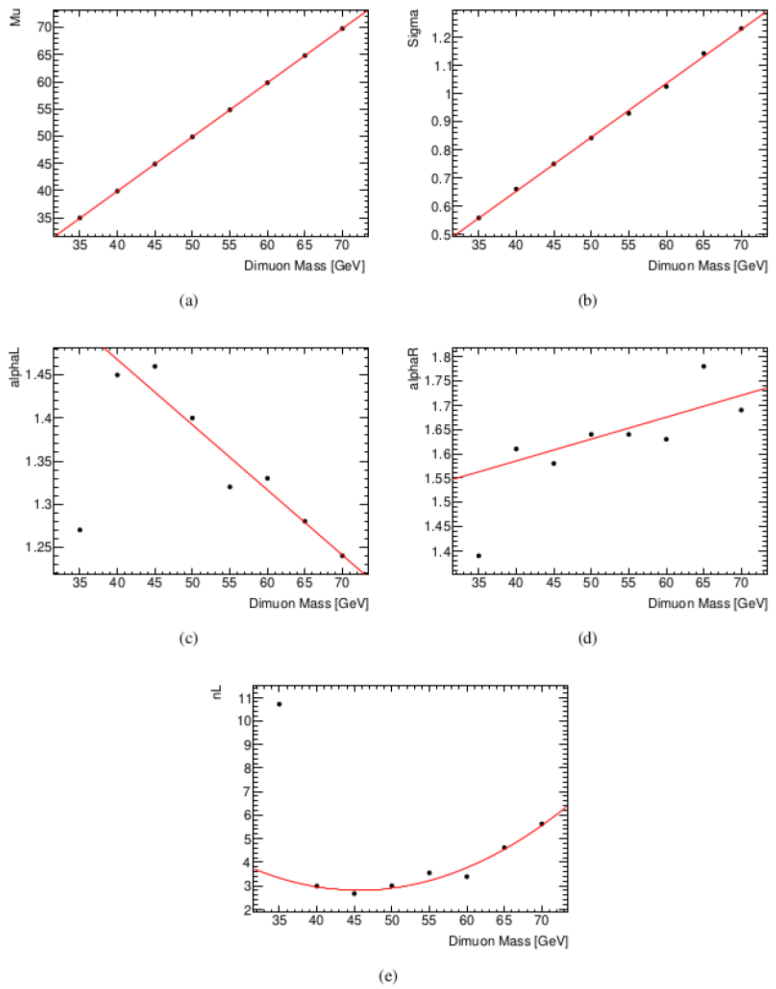


# Signal Modelling

Continuous signal modelling for narrow width assumption:

- Interpolation by polynomial functions for various signal masses $M_X$.
- $\Gamma$ is fix to intrinsic width.
- The parameterization of the DSCB functions is following:

- $\mu(M_X) = 0.99629 \times M_X + 0.04976$ [GeV]
- $\sigma(M_X) = 0.01906 \times M_X - 0.10887$ [GeV]
- $\alpha_L(M_X) = -0.00757 \times M_X + 1.77064$
- $\alpha_R(M_X) = 0.0045 \times M_X + 1.40536$
- $n_L(M_X) = 0.00463 \times M_X^2 - 0.42245 \times M_X + 12.44857$
- $n_R(M_X) = 150$




➢ It was noted that the extrapolation to the 35 GeV signal points is suboptimal in the plots.

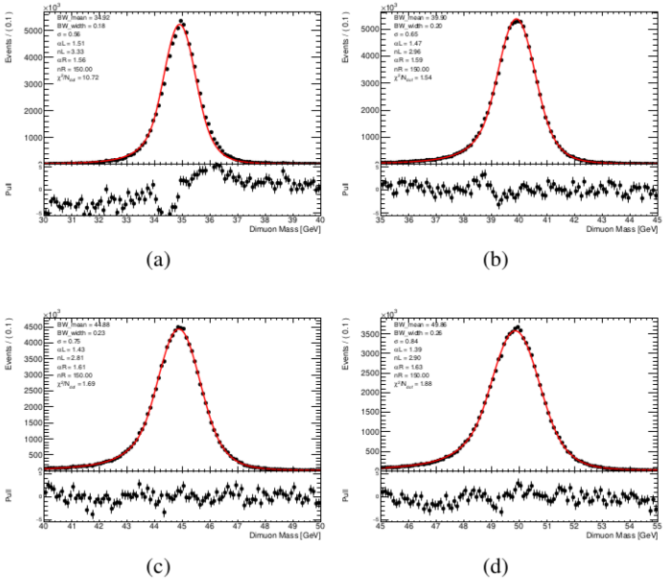
➢ For $n_R(M_X)$, it is hard to be parametrize and has little impact to the fit performance, so we fix this parameter to the 150.

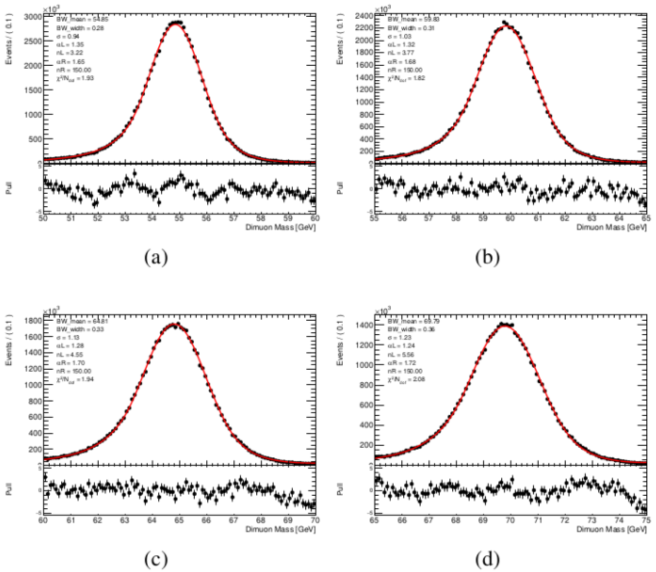
➢ We checked that the signal mass shape modelling is still valid even with these suboptimal parameters and no impact in the signal extractions in the linearity study and spurious signal test.

# Signal Modelling

After applying continuous signal modelling:

- Only the performance of 35GeV not good enough, others are well fitted:
- And we check this deviation from the continuous signal modelling at 35GeV has no impact on the results





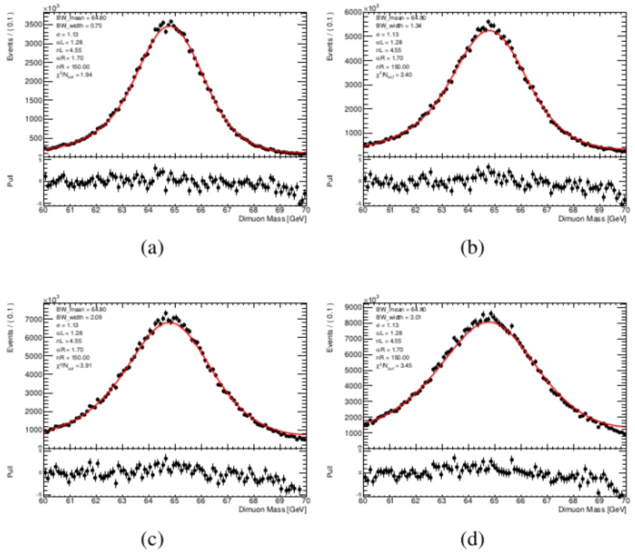


Figure 23: The distribution at 65 GeV $Z'$ mass with different couplings: (a) $g_\ell = g_q = 0.15$; (b) $g_\ell = g_q = 0.20$ ; (c) $g_\ell = g_q = 0.25$; (d) $g_\ell = g_q = 0.30$. Using the fixed parameters come from the extrapolation.

# Spurious signal and linearity test

Spurious signal and linearity test for new signal modelling with different couplings:

For different couplings(gl in the range 0.01—0.2), the ss unc. And linearity unc. is similar, so we use the unc from gl=0.1=gq(baseline)

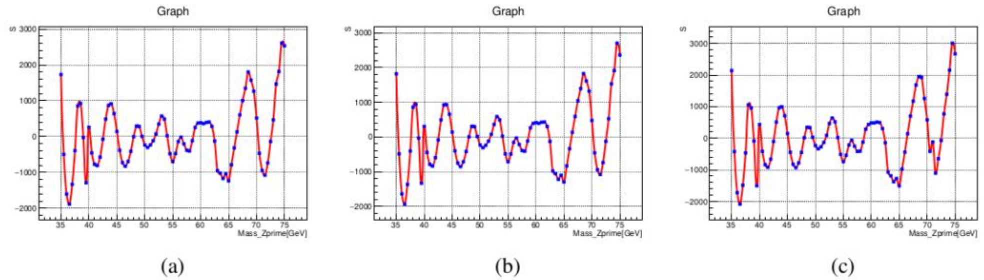


Figure 61: The spurious signal yield as a function of $Z'$ mass with different couplings($g_q$ fix to 0.10): (a) $g_\ell = 0.01$; (b) $g_\ell = 0.10$ ; (c) $g_\ell = 0.20$.

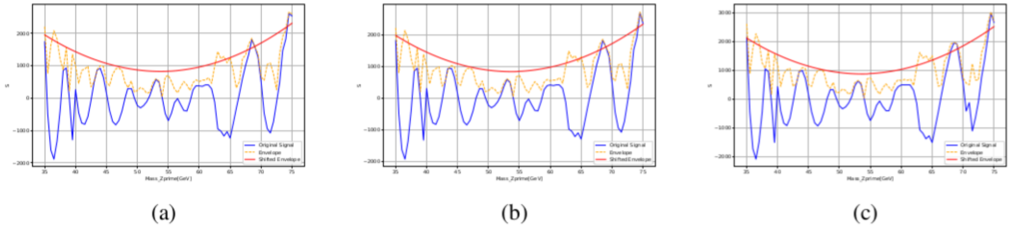


Figure 62: The compare plot of spurious signal yield as a function of $Z'$ mass with different couplings($g_q$ fix to 0.10) after envelope: (a) $g_\ell = 0.01$; (b) $g_\ell = 0.10$ ; (c) $g_\ell = 0.20$.

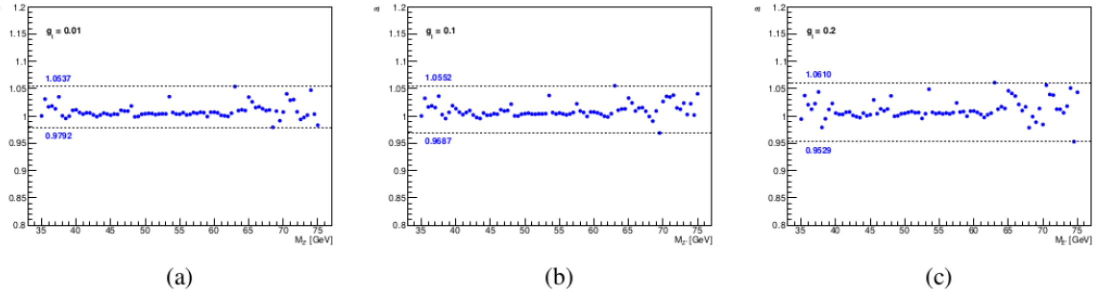
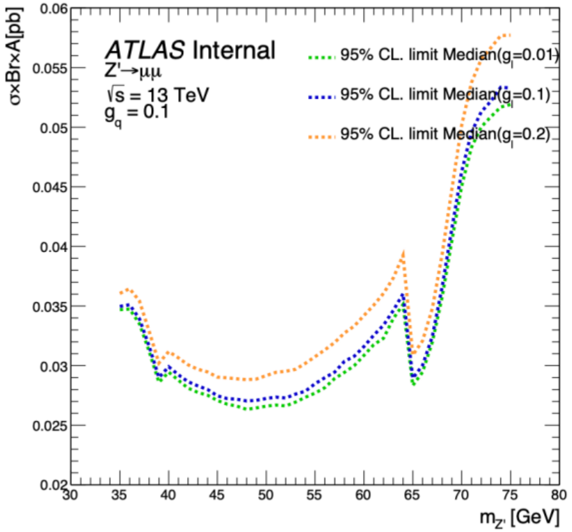


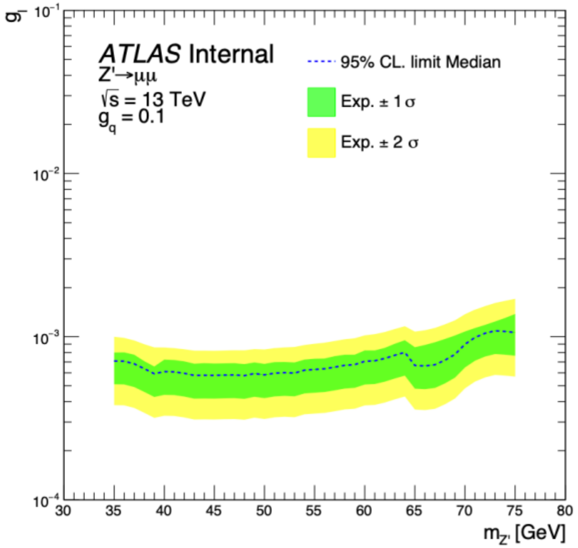

Figure 64: Fit response linearity in different $Z'$ mass with different couplings($g_q$ fix to 0.10): (a) $g_\ell = 0.01$; (b) $g_\ell = 0.10$ ; (c) $g_\ell = 0.20$.

# Theroy unc. And updated results

- Theory uncertainty
  - Theory uncertainty from QCD and PDF affects the final signal yields in two ways
    - Acceptance
    - Inclusive Cross section
      - We use k-factor from NLO to calculate the cross section.

| Effect | QCD Scale | PDF |
|---|---|---|
| Acceptance | 0.075 | 0.018 |
| Inclusive | 0.27 | 0.25 |




- Limit Setting with new samples which has widen width, scan gl in the range 0.01-0.2 , fix the gq=0.1.
- The limit on the coupling gl (Considering the XS corresponding to the gl)

# Quirk track

Different eff corresponding to the oscillation length d.

The number removed by red line will be updated soon.

TABLE I: Efficiency to reconstruct quirk tracks for various values of quirk mass ($m_Q$), confinement scale ($\Lambda$), and number of tracking layers. We also calculate the mean Lorentz factor of the quirks ($\bar{\gamma}$) and the standard deviation ($\sigma(\gamma)$) in each of the generated datasets to calculate oscillation length $d$ as calculated by 1 which can be useful for understanding reconstruction efficiencies. See text for details

| $m_Q$ (GeV) | $\Lambda$(eV) | $\bar{\gamma}$ | $\sigma(\gamma)$ | $d$ [cm] | Efficiency |
|---|---|---|---|---|---|
| 100 | 100 | 3.7 | 3.4 | 540 | 93.4% |
| | 500 | | | 22 | 85.1% |
| | 1000 | | | 5.4 | 80.8% |
| | 5000 | | | 0.2 | 0% |
| 500 | 100 | 1.8 | 0.6 | 800 | 85.4% |
| | 500 | | | 32 | 72.9% |
| | 1000 | | | 8 | 71.1% |
| | 5000 | | | 0.3 | 0% |
| 1000 | 100 | 1.4 | 0.3 | 800 | 93.7% |
| | 500 | | | 32 | ~~48.7%~~ |
| | 1000 | | | 8 | 77.9% |
| 5000 | 100 | 1.03 | 0.003 | 300 | 97.1% |
| | 500 | | | 12 | ~~73.7%~~ |
| | 1000 | | | 3 | ~~68.0%~~ |

$$d_{cm} \approx 2\ \text{cm}(\gamma - 1)\left(\frac{m_Q}{100\ \text{GeV}}\right)\left(\frac{\text{keV}}{\Lambda}\right)^2$$