$B^0 \rightarrow D^\star l \nu_l$ analysis

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Analysis meeting
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Analysis strategy

- Test the core of the analysis strategy to determine the form-factors (on MC).

Generate events according to the differential decay rate

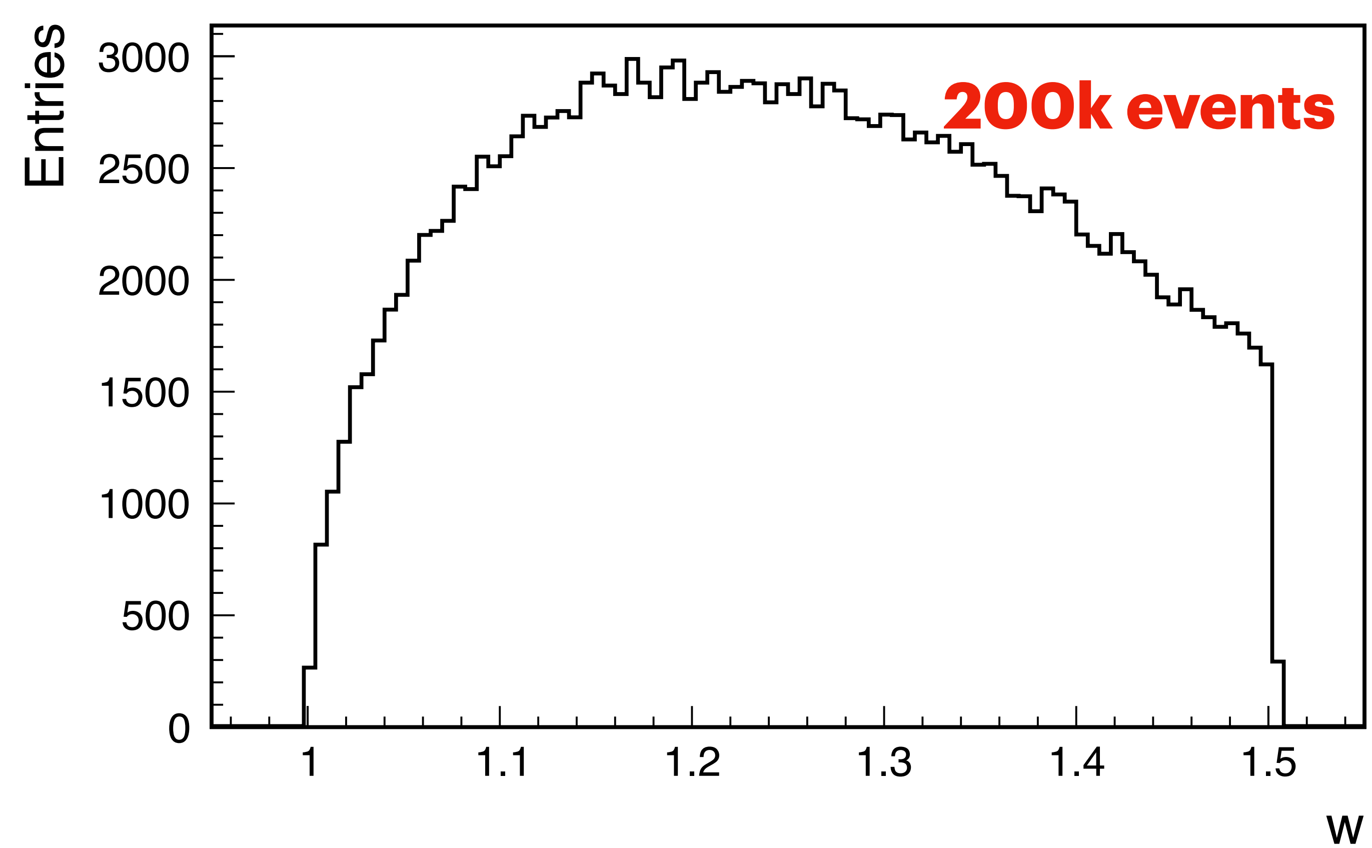
↓

Bin the w distribution and fit in each bin with the decay rate to extract the helicity amplitudes (these are functions of form factors)

↓

Compare the helicity amplitudes obtained from the fit with the values used during the generation

$$\begin{aligned}\frac{d^4\Gamma}{dw\,d\cos\theta_v\,d\cos\theta_\ell\,d\chi} = {} & \frac{3}{16\pi}\Gamma_0(w)|V_{cb}|^2\Big\{H_+^2(w)\,\sin^2\theta_v\,(1-\cos\theta_\ell)^2 \\ & + H_-^2(w)\,\sin^2\theta_v\,(1+\cos\theta_\ell)^2 + 4\,H_0^2(w)\,\cos^2\theta_v\,\sin^2\theta_\ell \\ & - 2\,H_-(w)H_+(w)\,\sin^2\theta_v\,\sin^2\theta_\ell\,\cos2\chi \\ & - 2\,H_+(w)H_0(w)\,\sin2\theta_v\,\sin\theta_\ell\,(1-\cos\theta_\ell)\,\cos\chi \\ & + 2\,H_-(w)H_0(w)\,\sin2\theta_v\,\sin\theta_\ell\,(1+\cos\theta_\ell)\,\cos\chi\Big\}\end{aligned}$$



Fitter

- Take fitter from Benigno and Riccardo.

- Modify some small elements in their scripts and add my fit function:

$$
\begin{aligned}
\frac{d^4\Gamma}{dw\,d\cos\theta_v\,d\cos\theta_\ell\,d\chi} = & \frac{3}{16\pi}\Gamma_0(w)|V_{cb}|^2\Big\{H_+^2(w)\ \sin^2\theta_v\ (1-\cos\theta_\ell)^2 \\
& + H_-^2(w)\ \sin^2\theta_v\ (1+\cos\theta_\ell)^2 + 4\ H_0^2(w)\ \cos^2\theta_v\ \sin^2\theta_\ell \\
& - 2\ H_-(w)H_+(w)\ \sin^2\theta_v\ \sin^2\theta_\ell\ \cos 2\chi \\
& - 2\ H_+(w)H_0(w)\ \sin 2\theta_v\ \sin\theta_\ell\ (1-\cos\theta_\ell)\ \cos\chi \\
& + 2\ H_-(w)H_0(w)\ \sin 2\theta_v\ \sin\theta_\ell\ (1+\cos\theta_\ell)\ \cos\chi\Big\}
\end{aligned}
$$

- Bin the w distribution in 7 bins. Divide with almost the same # of events for each bin.

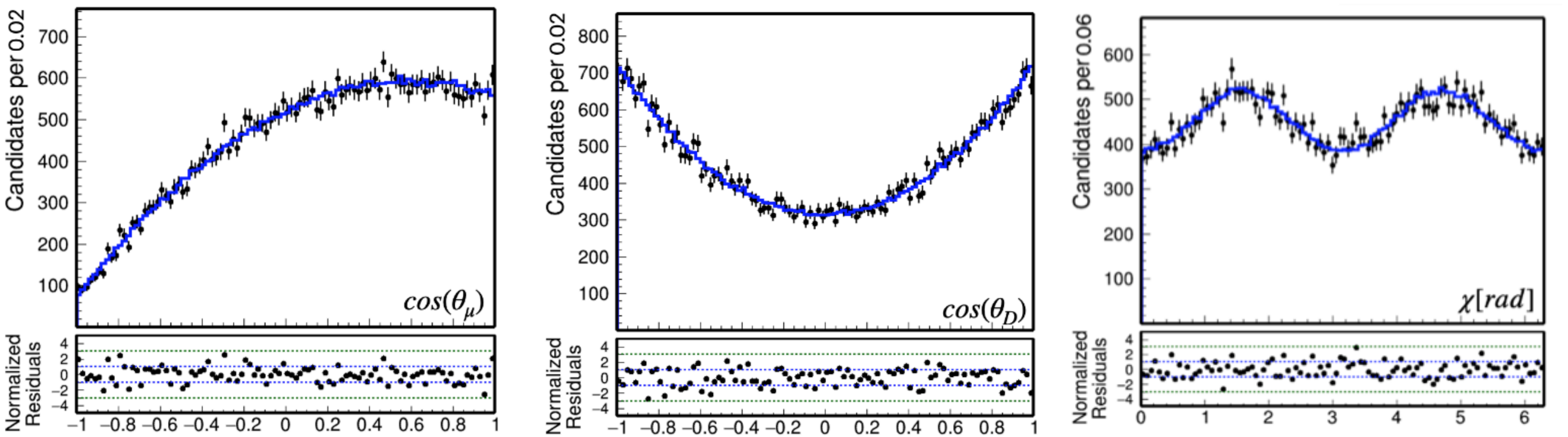
- Fit the $cos(\theta_D)$, $cos(\theta_\mu)$ and χ distributions in each bin.

- Extract, from the fit, H_+,H_- and H_0 in each bin.

Fit results

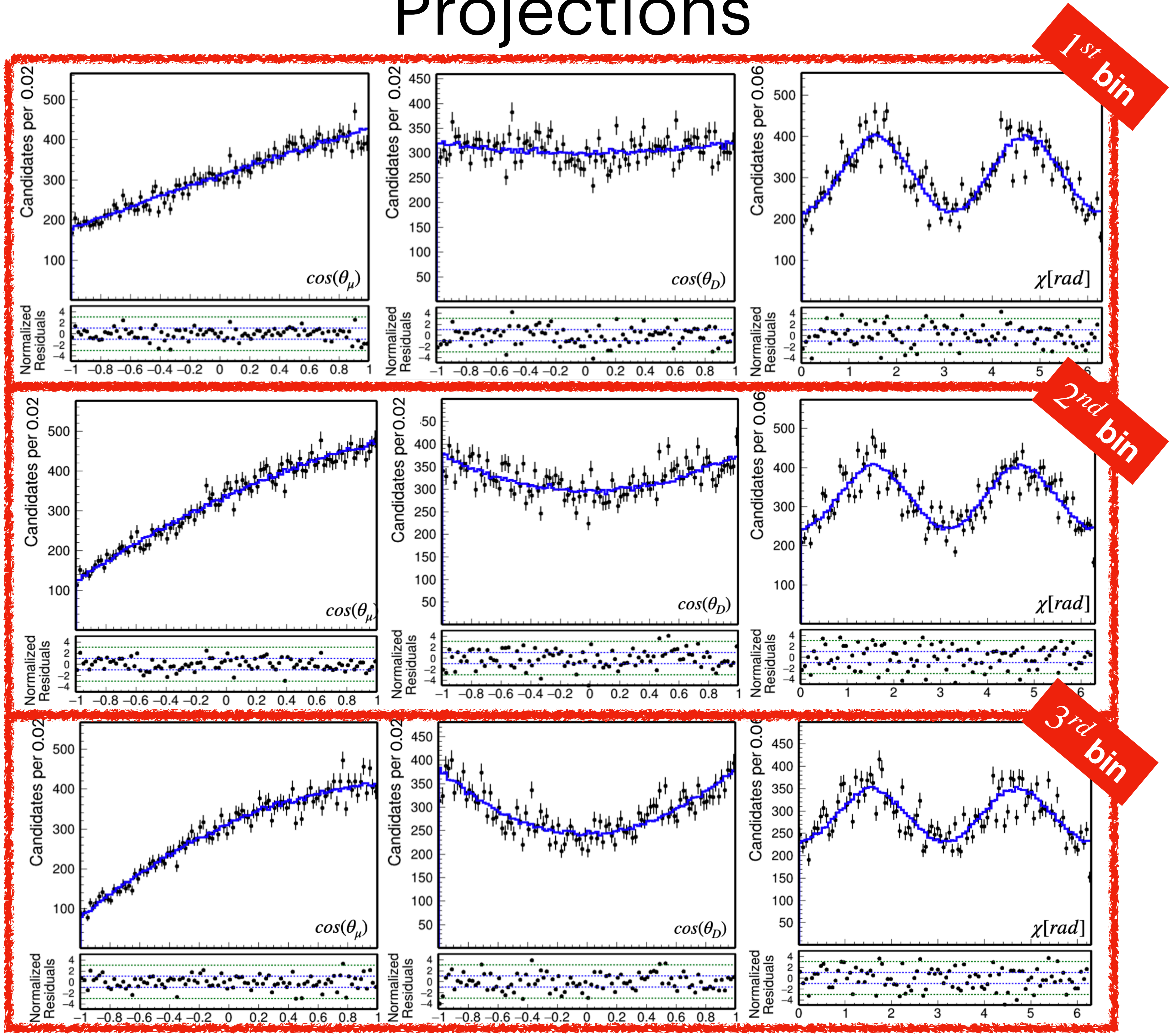
- Non extended ML fit.

Projections of $cos(\theta_D)$, $cos(\theta_\mu)$ and χ for a particular bin of w [1.25,1 .35].

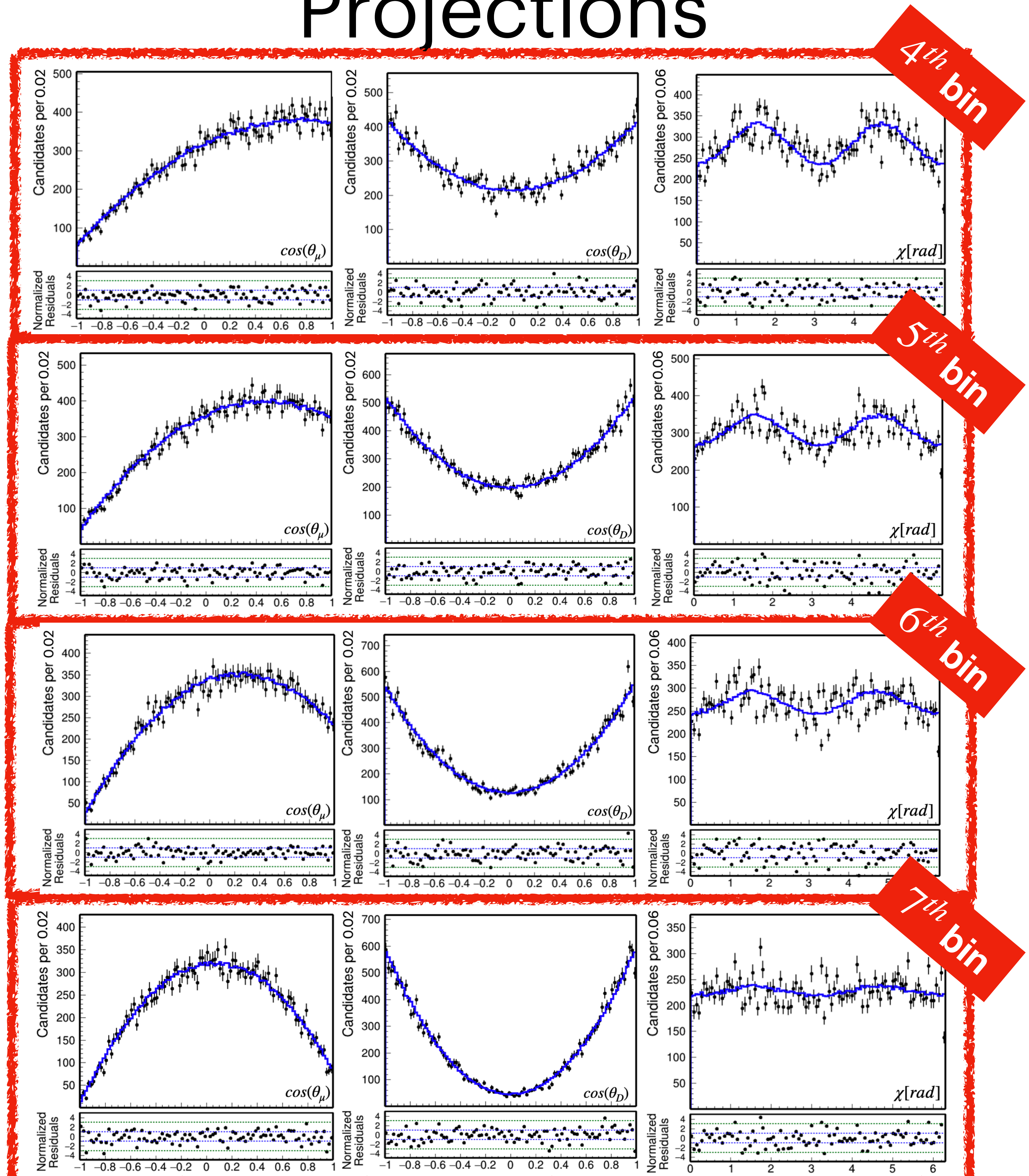


Looks good

Projections



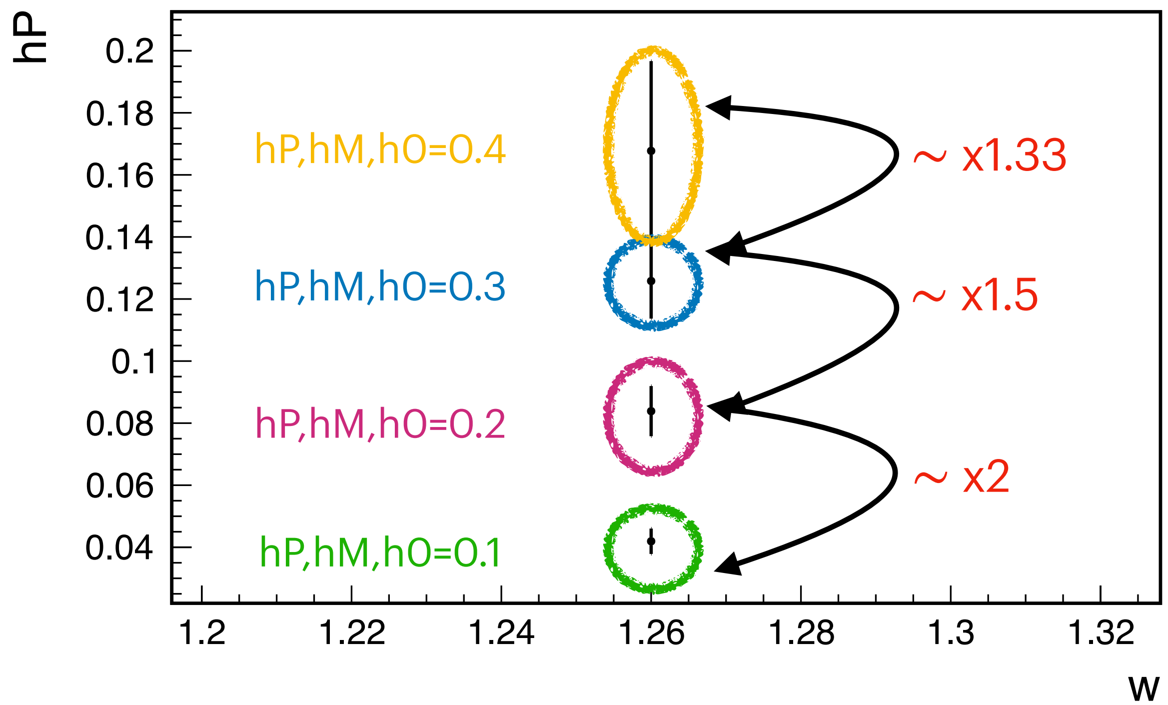
Projections

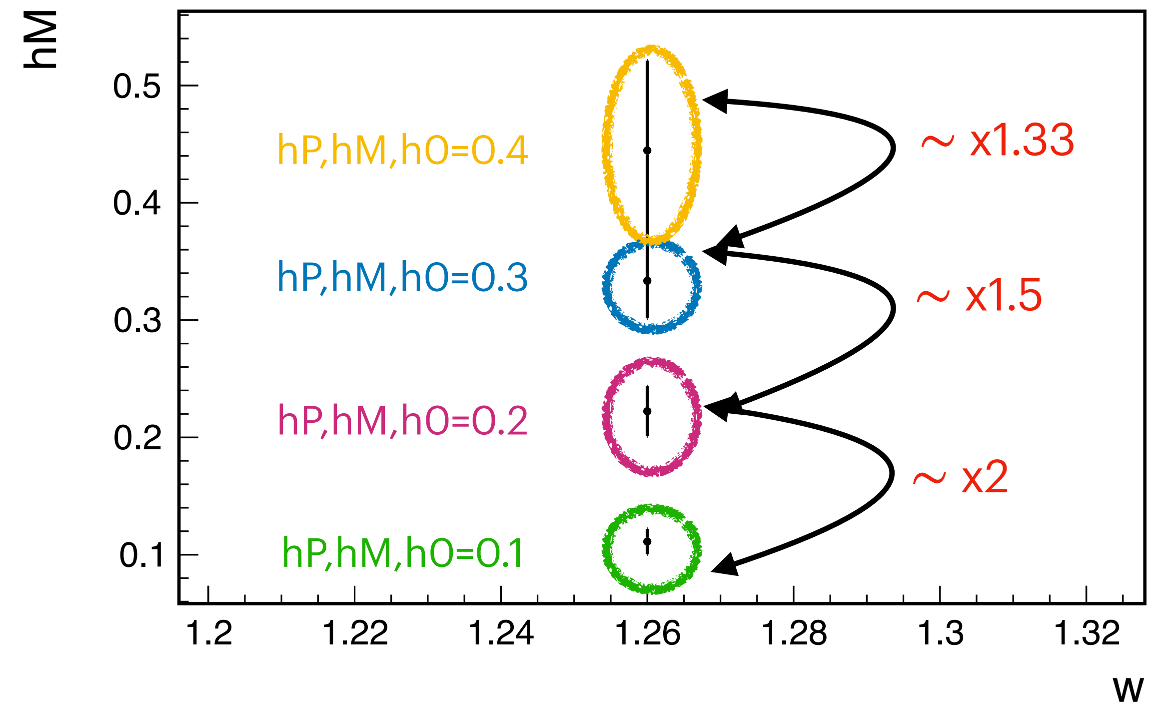


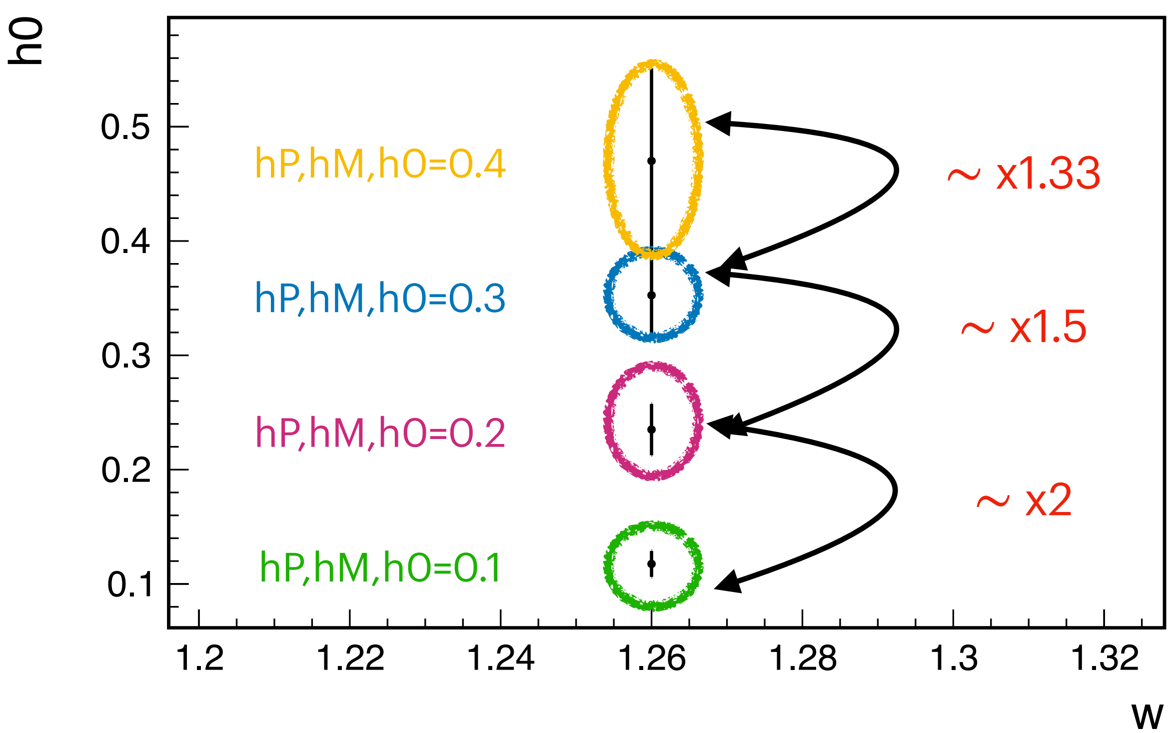
H_+, H_- and H_0

- Fit H_+, H_- and H_0 values in one w bin giving different initial values of parameters.

I noticed that my fit results change if I assign different initial parameters values.







The problem is due to the fact that my pdf is normalised to 1, so it doesn't predict the number of events in each bin.
I can't determine uniquely the 3 parameters.

a' and b'

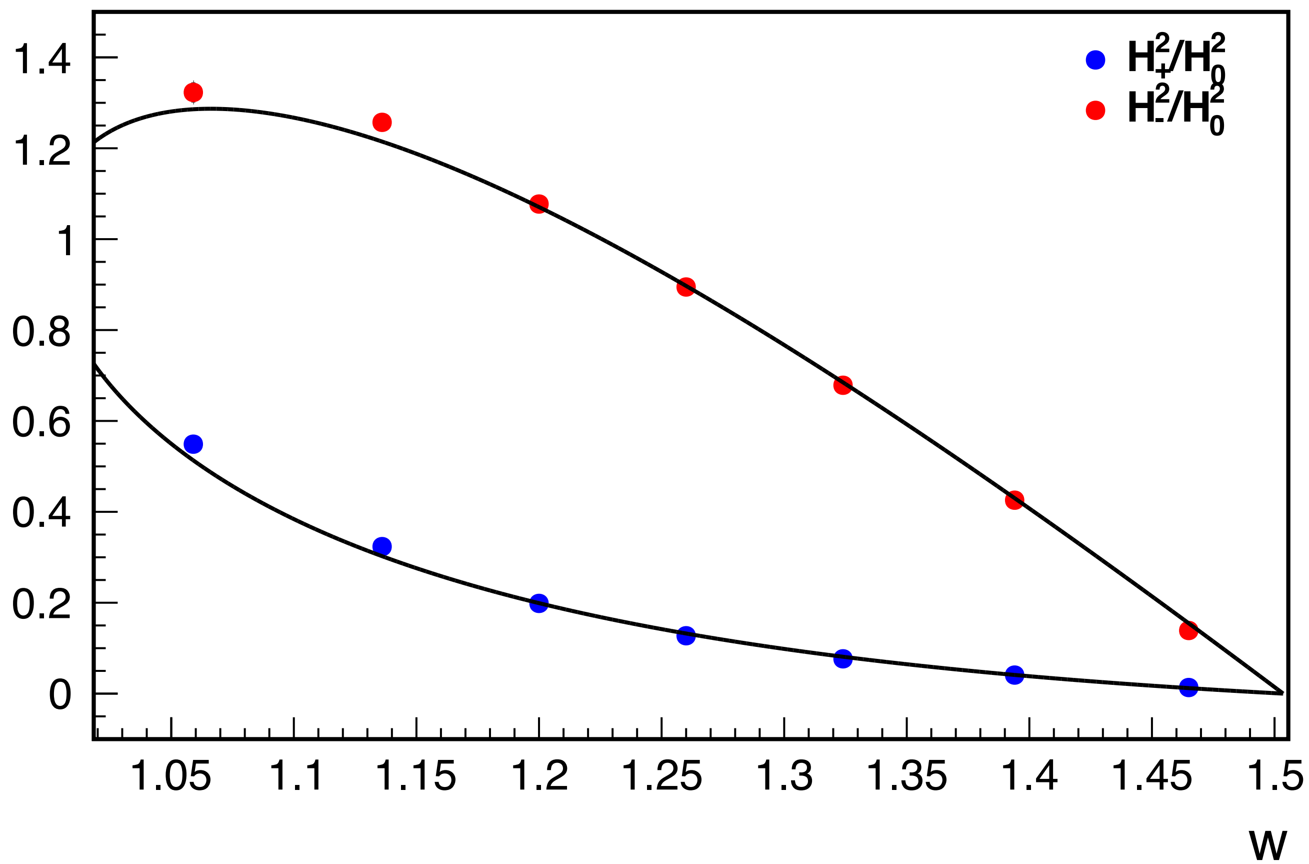
Rewrite my pdf with only two parameters $a' = \frac{H_+^2}{H_0^2}$ and $b' = \frac{H_-^2}{H_0^2}$.

Fit extended.

Fit parameters: N, a' and b'

$$\frac{d^4\Gamma}{dw d\cos\theta_v d\cos\theta_\ell d\chi} = \frac{3}{16\pi}\Gamma_0(w)|V_{cb}|^2\Big\{H_+^2(w)\ \sin^2\theta_v\ (1-\cos\theta_\ell)^2$$
$$+\ H_-^2(w)\ \sin^2\theta_v\ (1+\cos\theta_\ell)^2 + 4\ H_0^2(w)\ \cos^2\theta_v\ \sin^2\theta_\ell$$
$$-\ 2\ H_-(w)H_+(w)\ \sin^2\theta_v\ \sin^2\theta_\ell\ \cos 2\chi$$
$$-\ 2\ H_+(w)H_0(w)\ \sin 2\theta_v\ \sin\theta_\ell\ (1-\cos\theta_\ell)\ \cos\chi$$
$$+\ 2\ H_-(w)H_0(w)\ \sin 2\theta_v\ \sin\theta_\ell\ (1+\cos\theta_\ell)\ \cos\chi\Big\}$$

Fit converged and provide the same parameters values for different initial values.
Fit in each bin and compare the a' and b' values with those used during the generation.



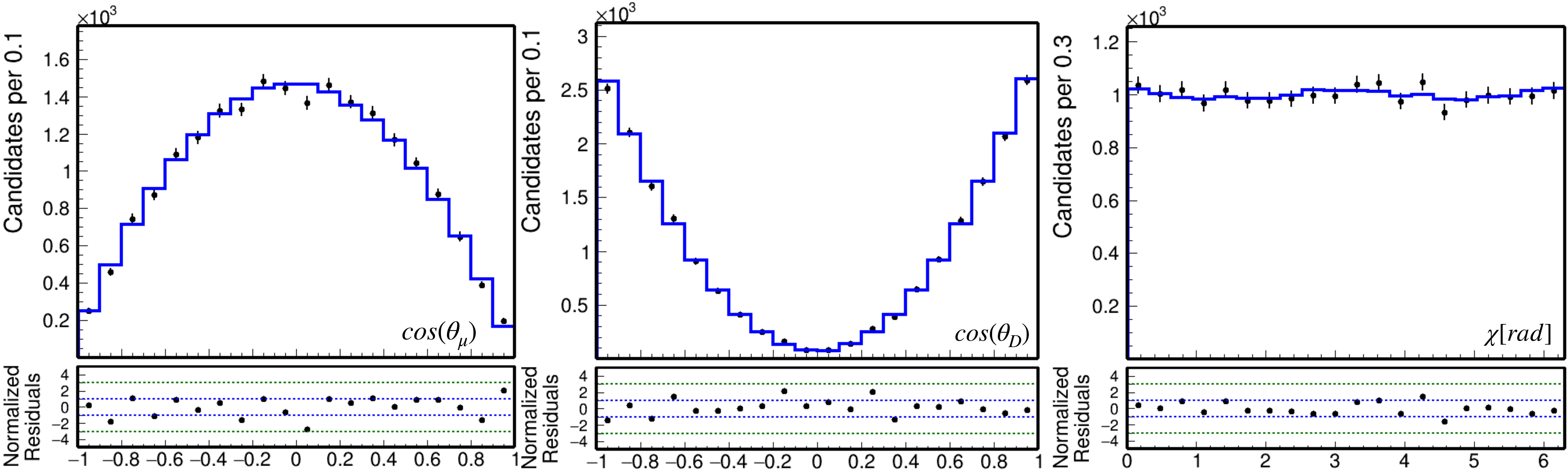
I'm able to reproduce, with a good precision, the a' e b' values used during the generation.
But this is not a good parametrisation to extract, easily, the information of $H_{\pm,0}$ -> find a new way to write my pdf to have directly access to $H_{\pm,0}$.

Toy

- To validate my fit I also generated one sample after setting $a'_{in} = 0.2$ and $b'_{in} = -0.1$.

- Fit the generated sample.

- I found $a'_{fit} = 0.2013 \pm 0.0051$ and $b'_{fit} = -0.0953 \pm 0.0051$ that are compatible with those given in generation.



Next steps

- Write in different way my pdf to fit the $H_{\pm,0}$ (Hint: N, $a^{'}, b^{'} \rightarrow H^{+}_{eff}, H^{-}_{eff}, H^{0}_{eff}$);

- Generalise the code to fit simultaneously n bins of w;

- 2^{nd} priority: find a final solution for the resolution study.

Backup

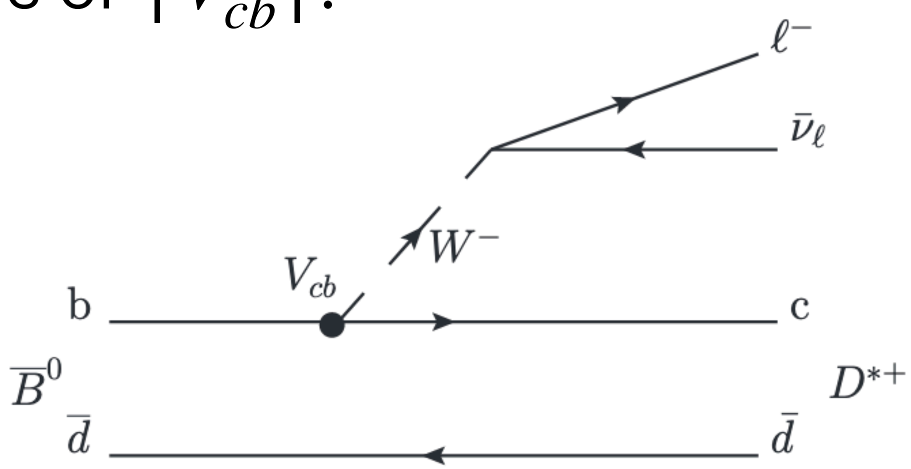
Motivation

$|\mathbf{V_{cb}}|$ is the magnitude of the weak-interaction coupling between *b* and *c* quarks.

$|V_{cb}|$ is an important SM benchmark parameter that impacts also BSM interpretations of suppressed B decays measurements.

Two different approaches lead to two different value of $|V_{cb}|$:

$|V_{cb}| = (42.2 \pm 0.8) \times 10^{-3}$ (using $B \to X_c l \nu$ decays)
(inclusive approach)
$|V_{cb}| = (39.5 \pm 0.9) \times 10^{-3}$ (using $B \to D^{(*)} l \nu$ decays)
(exclusive approach)



Calls for a deeper investigation of the two methods.

Focus on the exclusive approach: the determination of $|V_{cb}|$ from this method relies on the description of strong-interaction effects for the *b* and *c* quarks bound in mesons (modeled into effective quantities called "form factors").

Final goal: provide the first model-independent measurement of the form factors on $B^0 \to D^\star l \nu$ using the full Belle II data set collected so far (~ 430 fb^{-1}), to yield a better determination of $|V_{cb}|$.

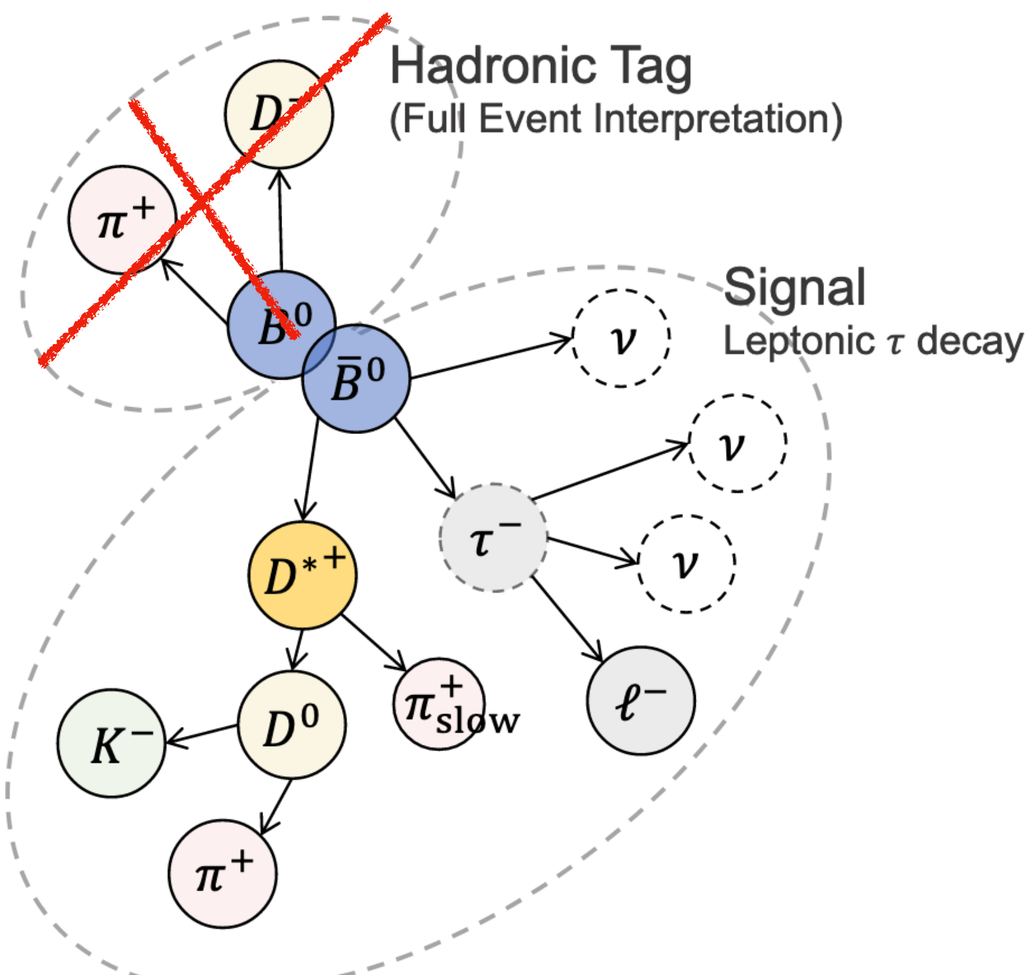
Untagged analysis

The form factors are functions of the recoil energy of the D^* meson in the B rest frame.

$$w = \frac{E_{D^*}}{m_{D^*}}$$

To measure w, we need to know the B momentum (to boost the D^* in the B rest frame).

Neutrino is not reconstructed → **kinematics is not closed** → cannot reconstruct the B momentum.



Two different approaches:

- Reconstruct the other B in the $e^+e^- \to \Upsilon(4s) \to B\bar{B}$ decay. From momentum conservation in the CM, the B signal momentum can be extracted: **low efficiency**, **high resolution**.
- Don't reconstruct the other B, approximate kinematics: **high efficiency**, **low resolution**.

I expect my precision to be limited by sample size → I use the second approach.

Methods

We know the magnitude of B momentum in the CMS but not its direction. We can exploit these two informations:

A. B vector momentum should lie on a cone around the D^*l vector-momentum with a known opening angle (from E-p conservation assuming 1 missing neutrino) ;

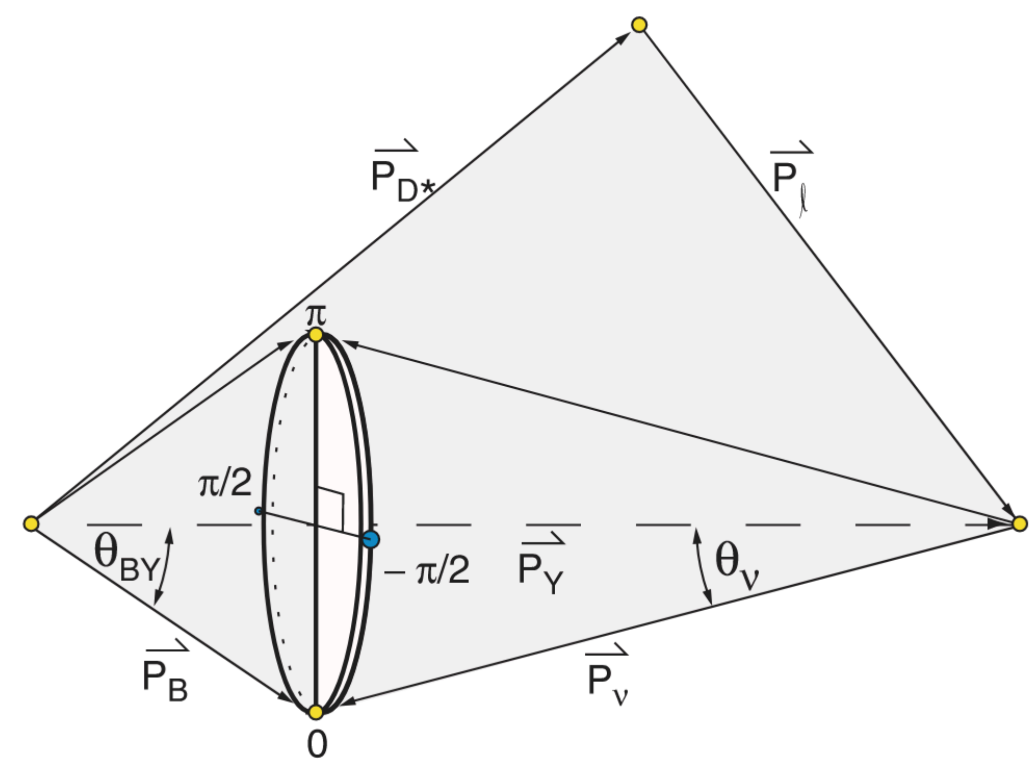
B. B meson is more likely to be perpendicular to the beams (from $Y(4S)$ polarisation).

Three methods to estimate the B's momentum direction:

1. Average a number of random directions by weighting them with B) probability;

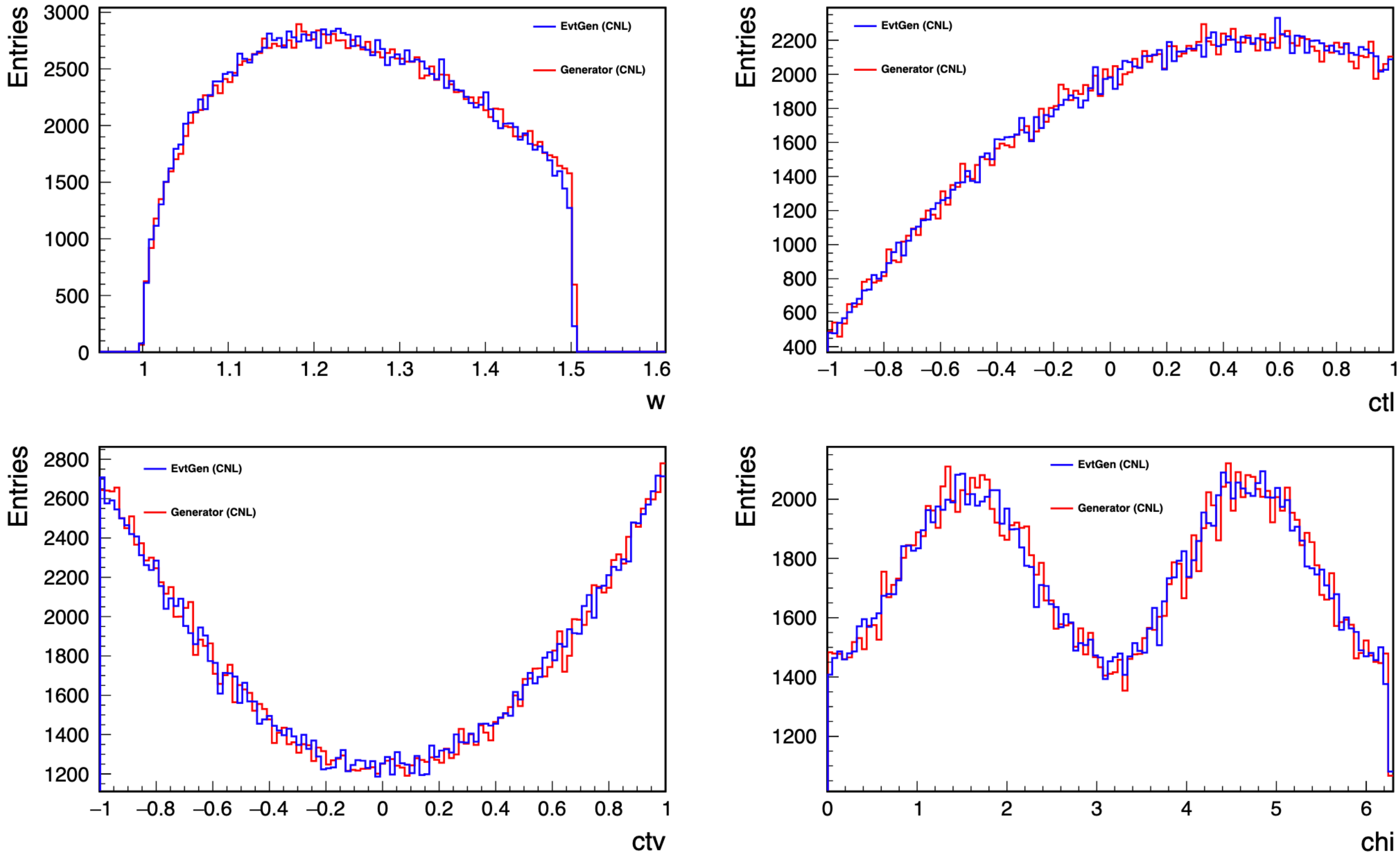
2. Reconstruct the other B inclusively and look for the direction on the cone closest to the opposite direction of the other B.

3. Arithmetic average of 1. and 2. solutions.

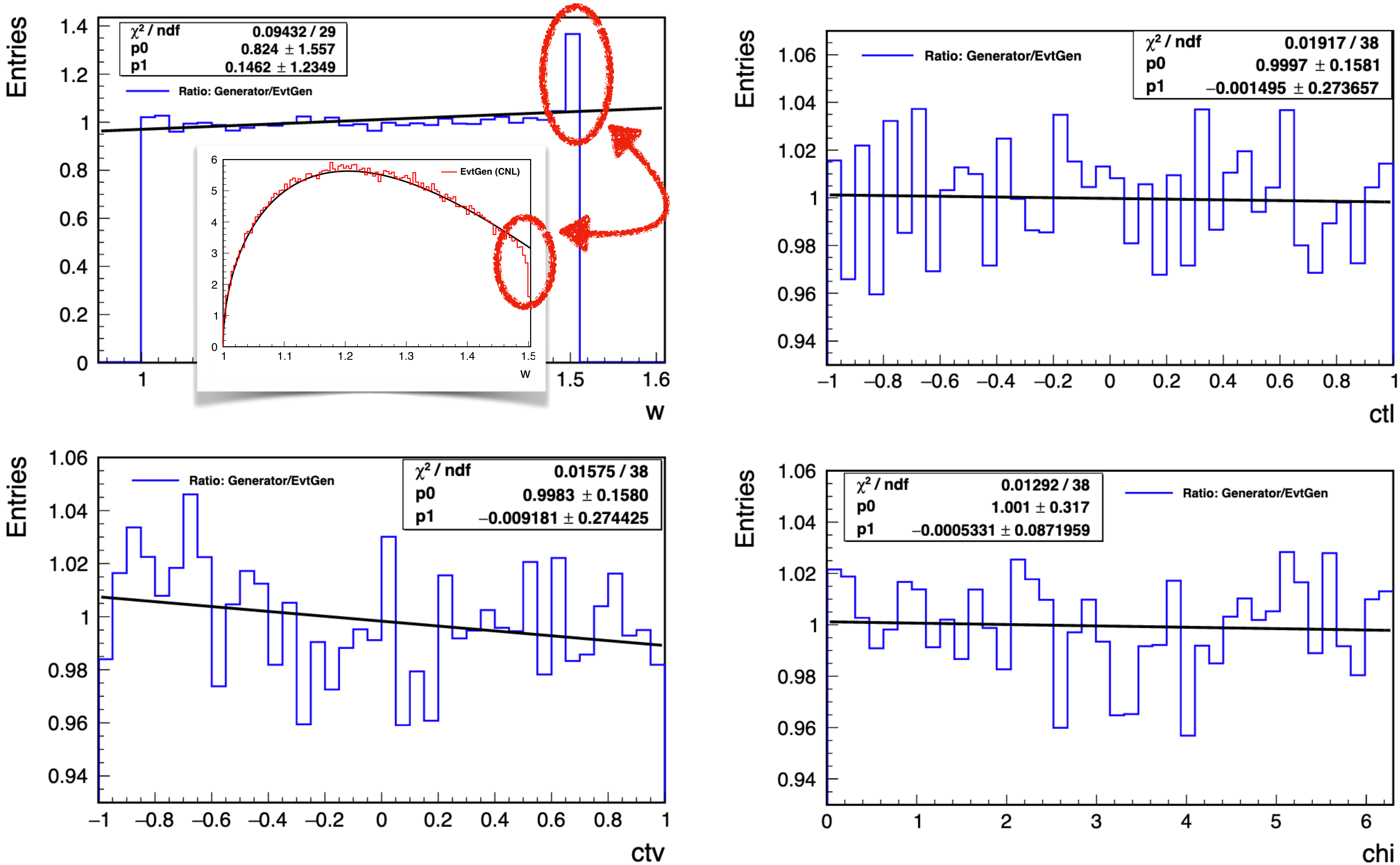


Generator vs EvtGen validation

Before starting the fit procedure, I tried to validate our generator (random values according to the decay rate). I compared the w, $cos(\theta_D)$, $cos(\theta_\mu)$ and χ distributions obtained from our generator with those of EvtGen.



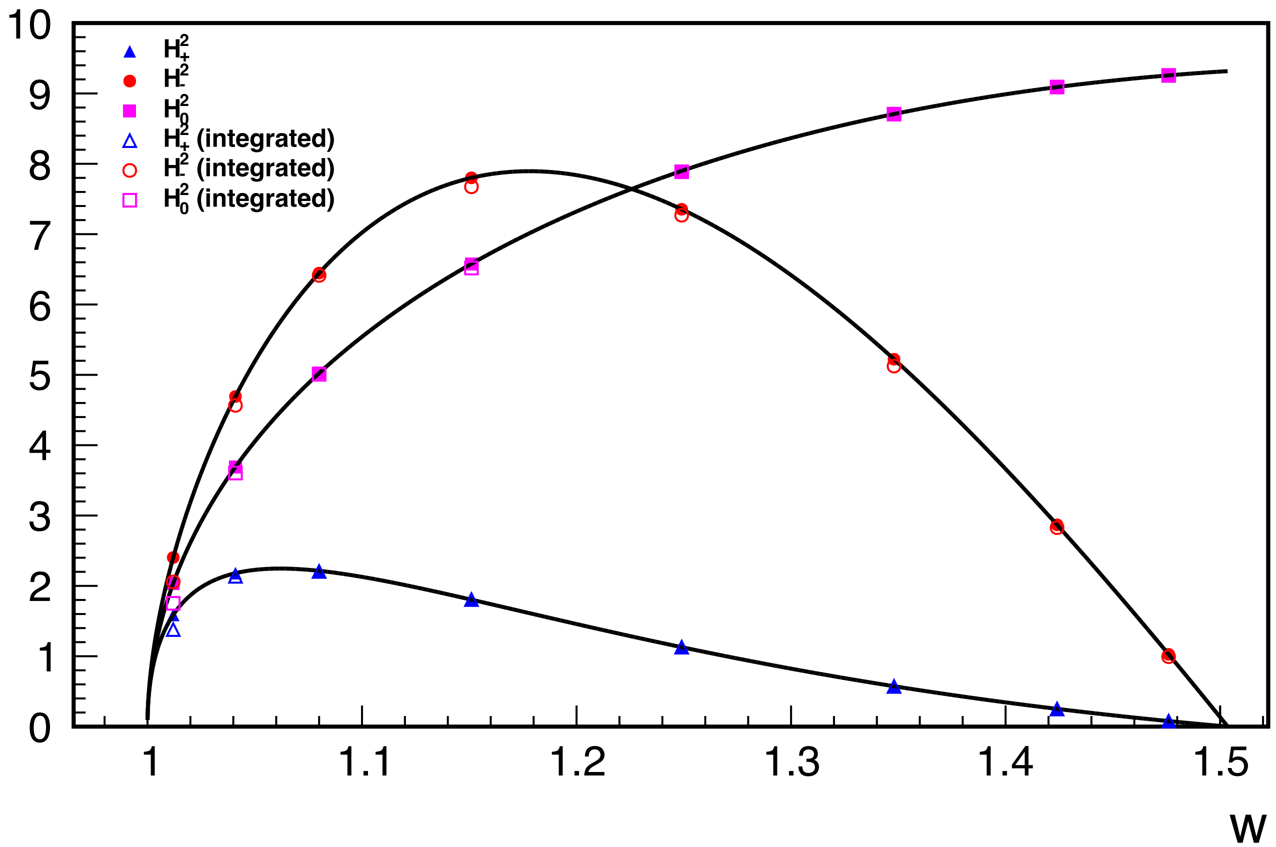
Generator vs EvtGen validation

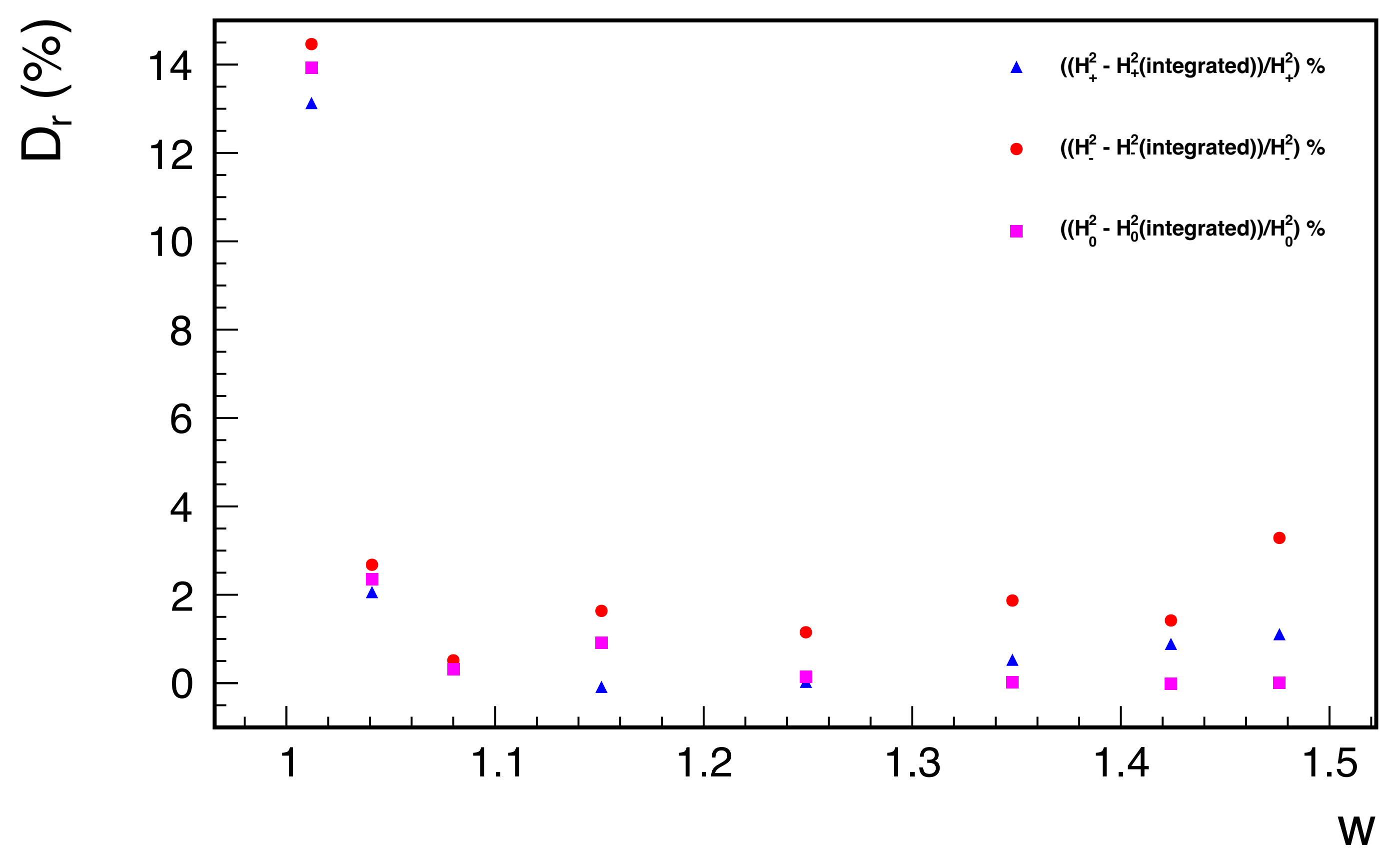


All ratios are compatible with 1.
Problem with the w ratio around the kinematic limit.

Helicity amplitudes

Despite the discrepancy observed on w, for the validation of our strategy we can use our generator (investigate this in future). In fact, our goal is to be able to obtain the same $H(w)$ amplitudes at the generation level.





Next step: fit in each bin of w with the decay rate expression to obtain the $H(w)$ amplitudes and compare them with those obtained at the generation level.

$$
\begin{aligned}
\frac{d^4\Gamma}{dw d\cos\theta_v d\cos\theta_\ell d\chi} &= \frac{3}{16\pi}\Gamma_0(w)|V_{cb}|^2\Big\{ H_+^2(w)\ \sin^2\theta_v\ (1-\cos\theta_\ell)^2 \\
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&+\ 2\ H_-(w)H_0(w)\ \sin2\theta_v\ \sin\theta_\ell\ (1+\cos\theta_\ell)\ \cos\chi \Big\}
\end{aligned}
$$

$cos(\theta_D)$, $cos(\theta_\mu)$ and χ distributions

- $cos(\theta_D)$, $cos(\theta_\mu)$ and χ distributions for different H_+, H_- and H_0 values.