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

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Analysis meeting
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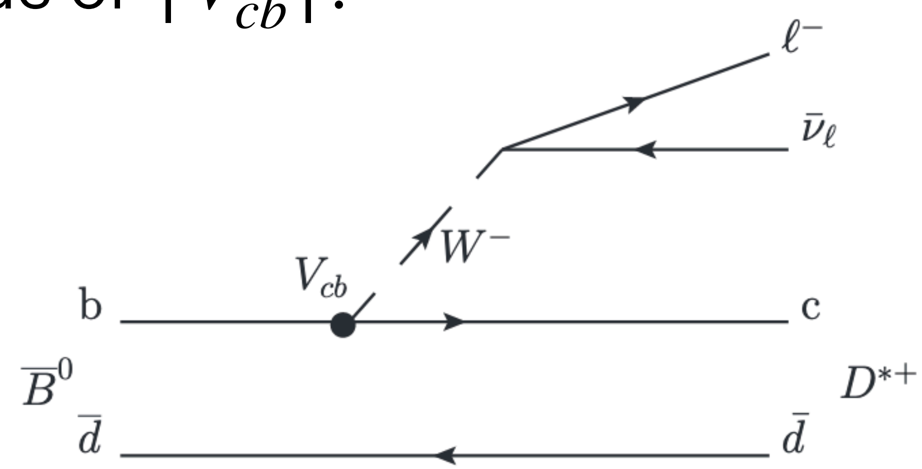
Motivation

$|V_{cb}|$ 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 $|V_{cb}|$.

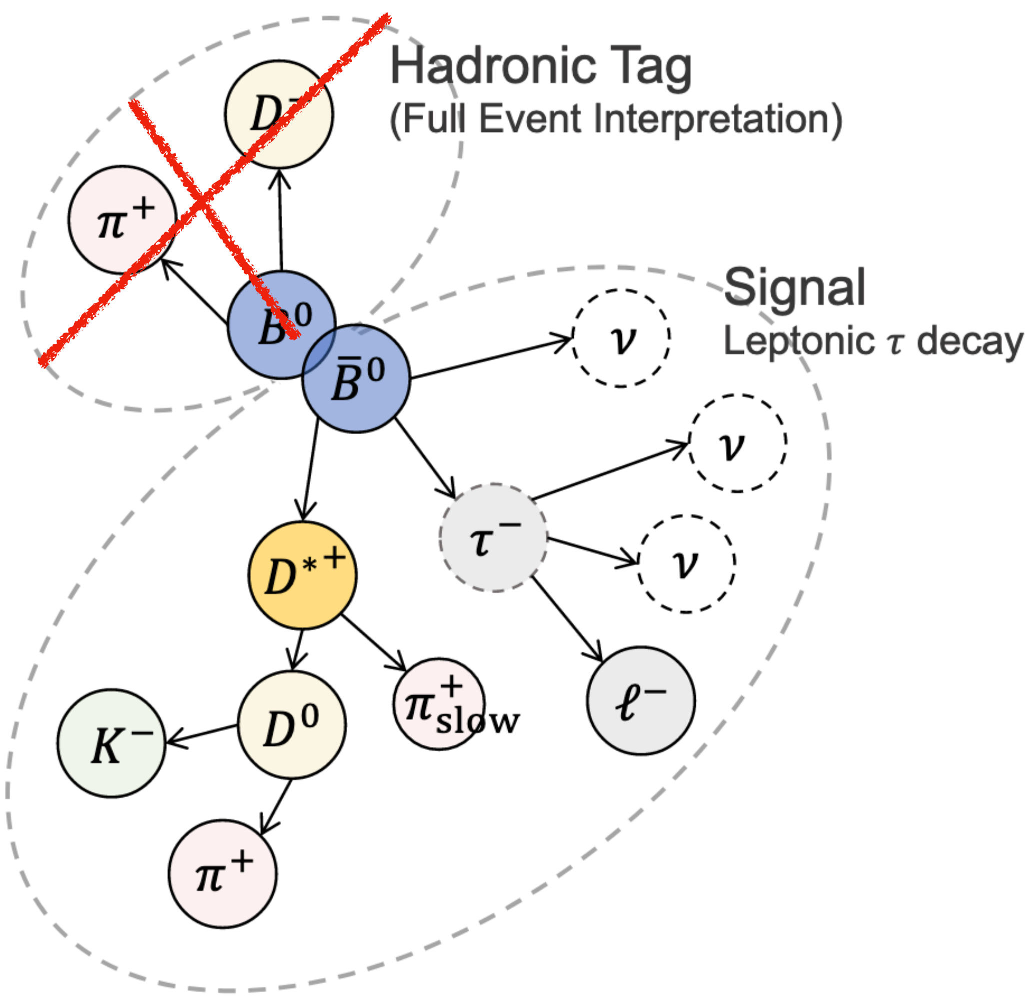
Untagged analysis

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 $e^+e^- \to Y(4s) \to B\bar{B}$ 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) ;

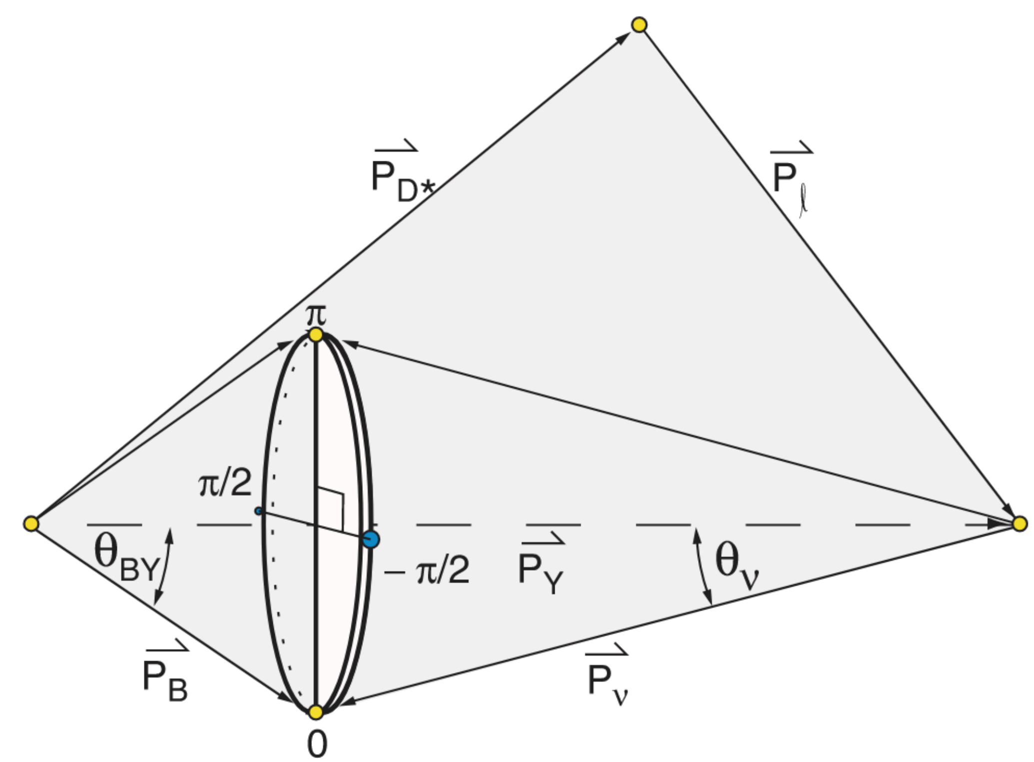
B. B meson is more likely to be perpendicular to the beams (from $Y(4S)$ polarisation).

Three methods to estimate the B's momentum direction:

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

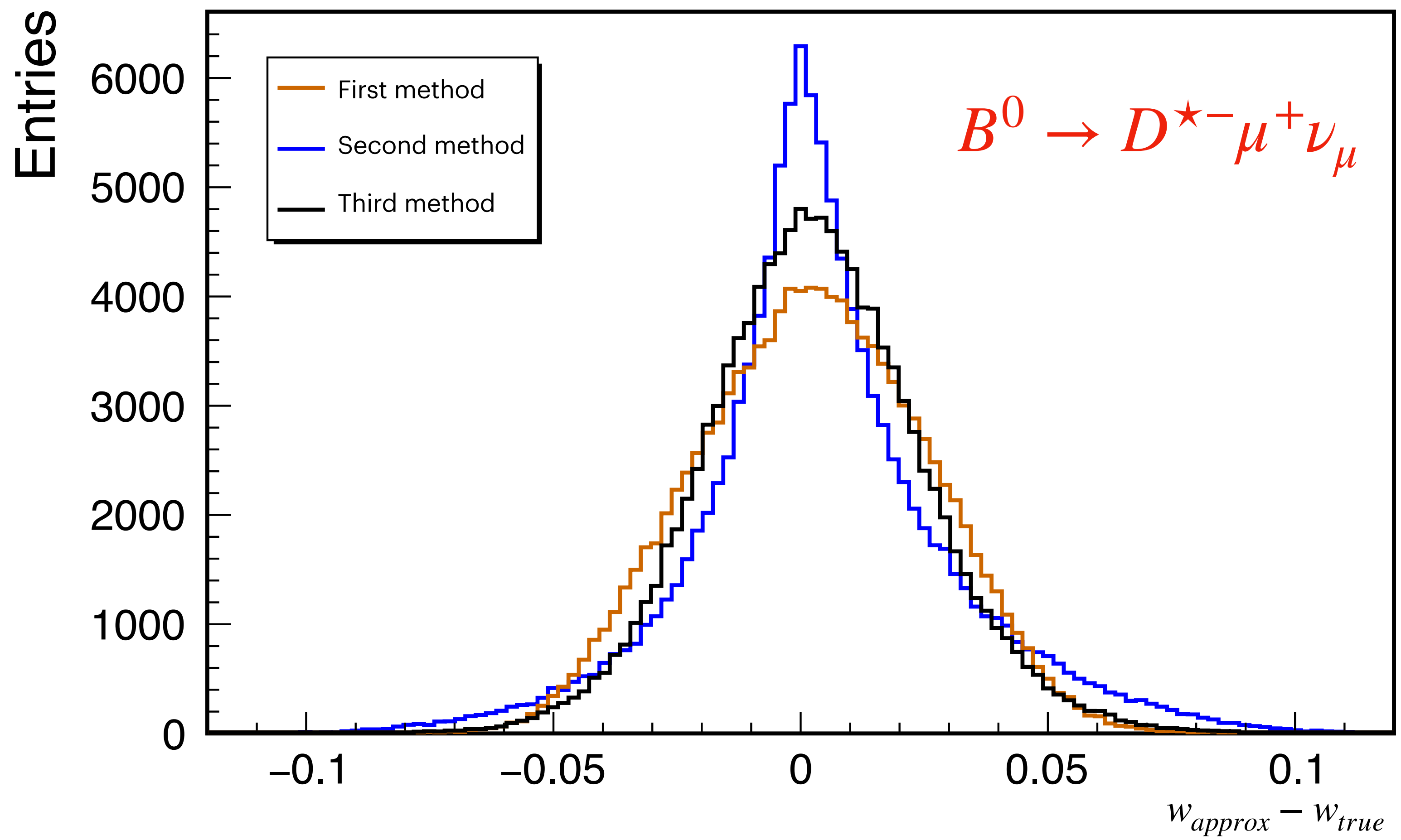
2. Reconstruct the other B inclusively and look for the direction on the cone closest to the opposite direction of the other B.

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



Resolution plots

The first step of this study is to determine the resolution of the kinematic variables for each method using a simulation .

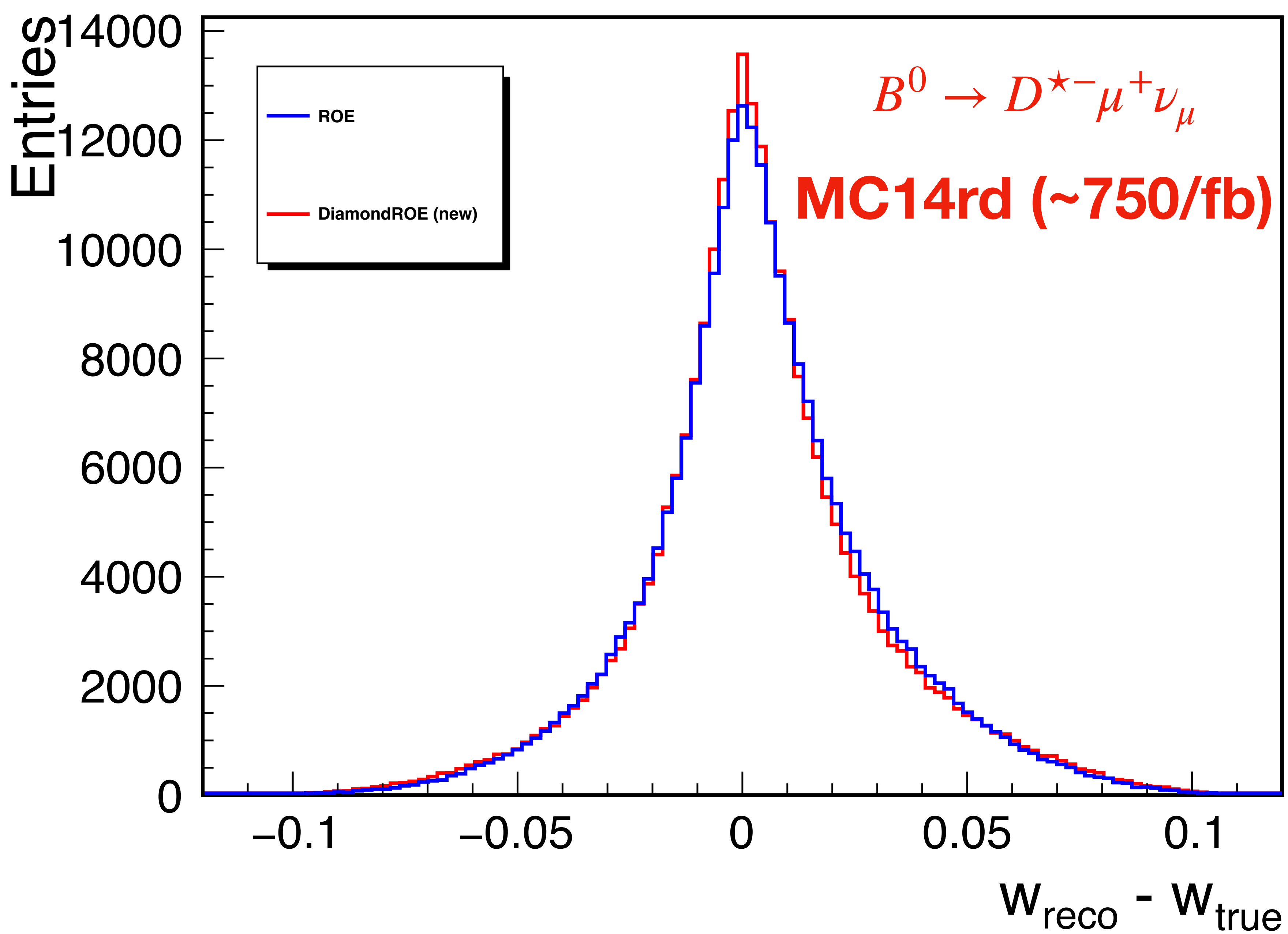


Second method gives a better result.

Next step: try adding information of the other B and combining it into a MVA regression algorithm to see if we get something better.

Resolution plots: ROE vs new Diamond+ROE

I modified the classical Diamond+ROE method by taking, for each event, the ϕ_i of B that has the highest weight. I compared the new resolution plots with the resolution plots obtained using the ROE method.



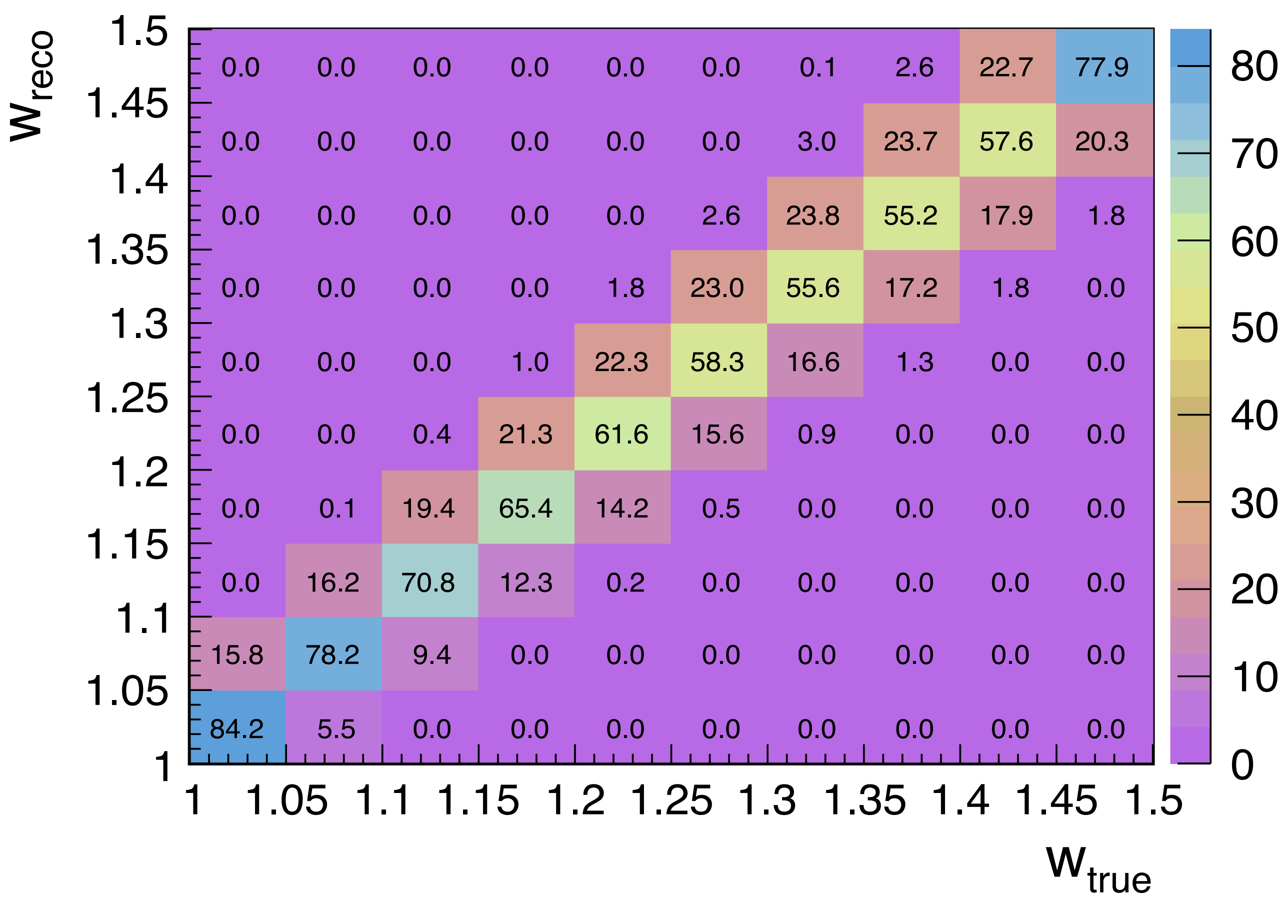
The new method reproduces a little better results respect to the ROE method.

Migration matrix: ROE vs new Diamond+ROE

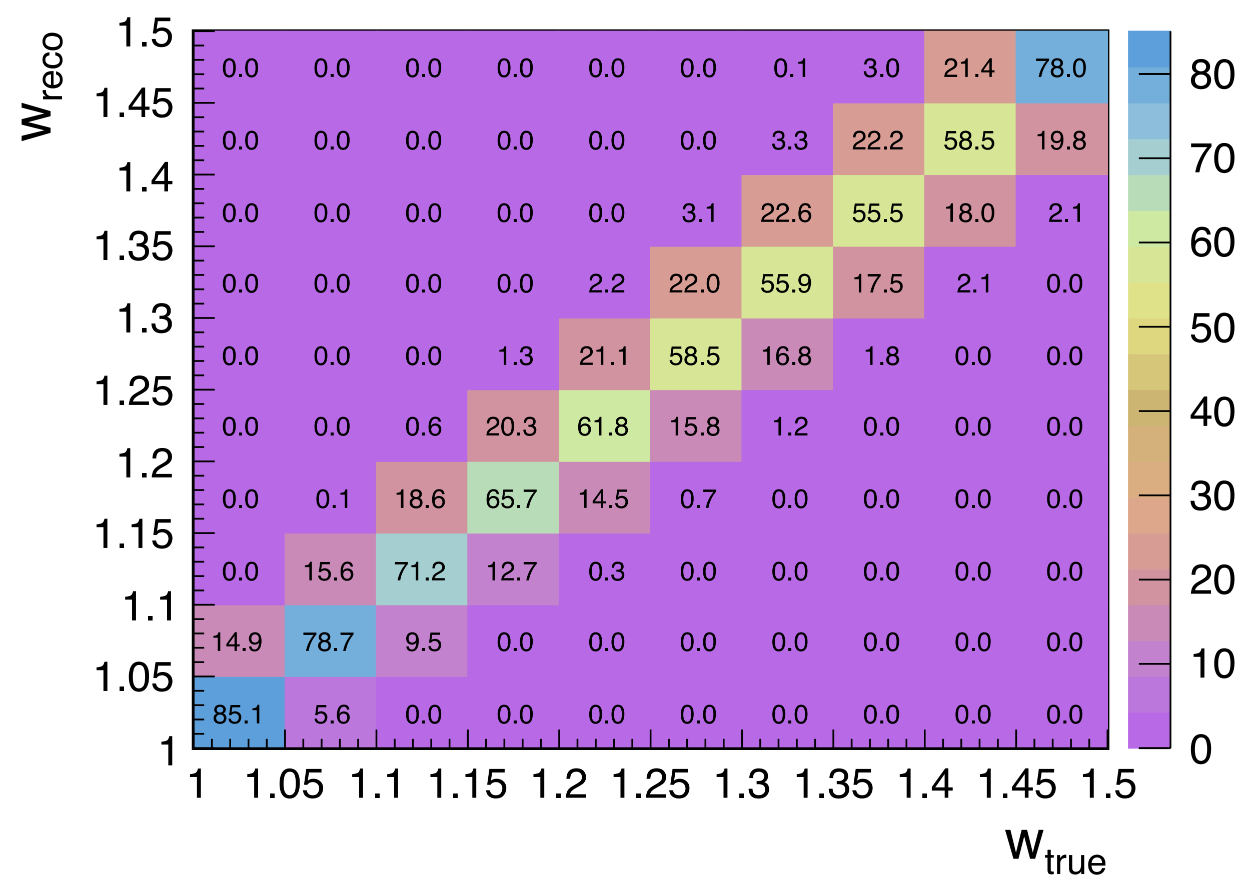
To evaluate the performance of the two methods we can see at the migration matrices of the kinematic variables. The migration matrix elements are defined as conditional probabilities:

$$\mathcal{M}_{ij} = \mathcal{P}(\text{measured value in bin } i | \text{ true value in bin } j)$$

ROE method



New diamond + ROE method



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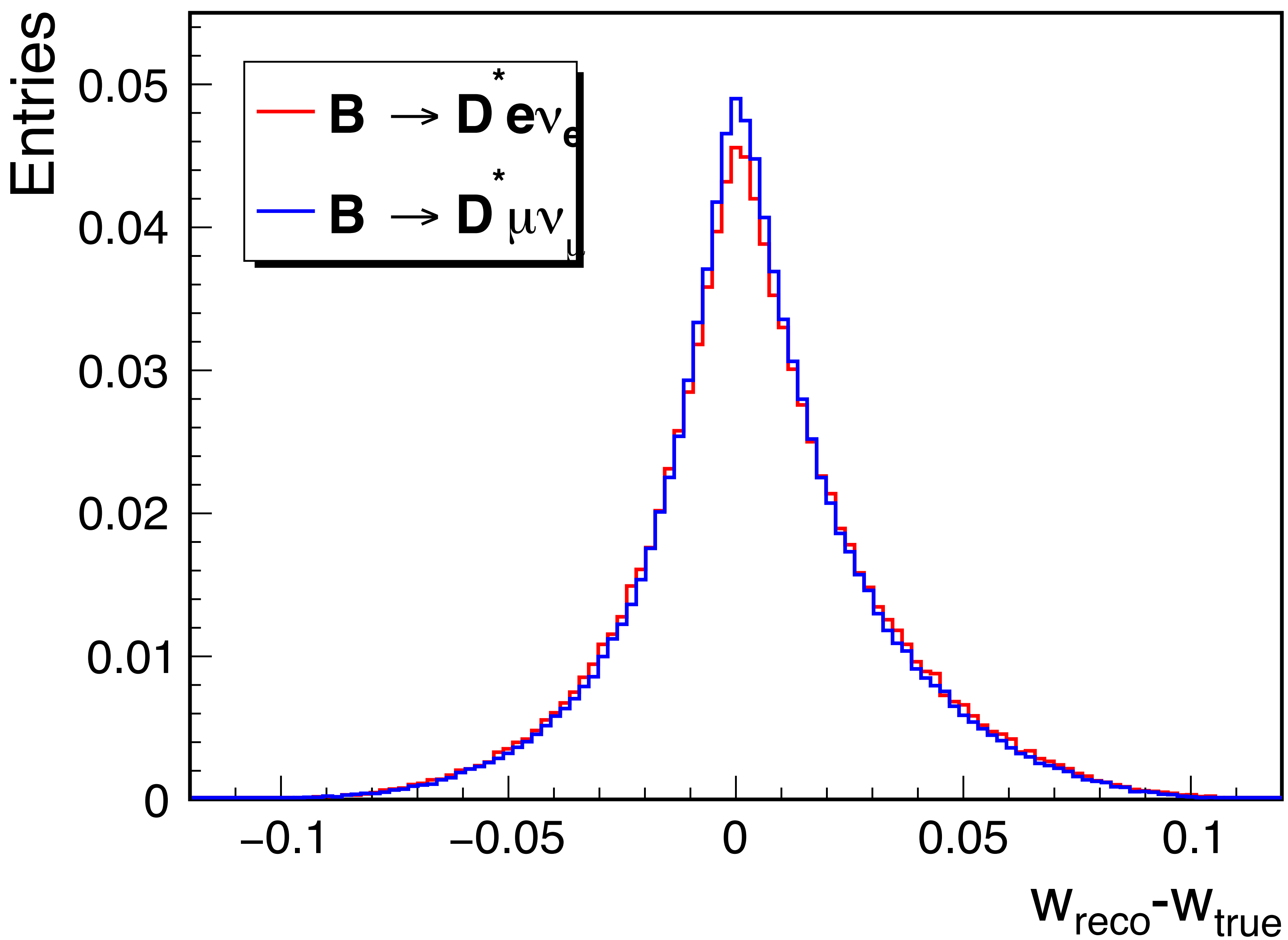
w resolution: $B^0 \to D^{\star -}\mu^+\nu_\mu$ vs $B^0 \to D^{\star -}e^+\nu_e$

Comparison of w resolution between $B^0 \to D^{\star -}\mu^+\nu_\mu$ and $B^0 \to D^{\star -}e^+\nu_e$ decays.

MC14rd (~750/fb only mixed)

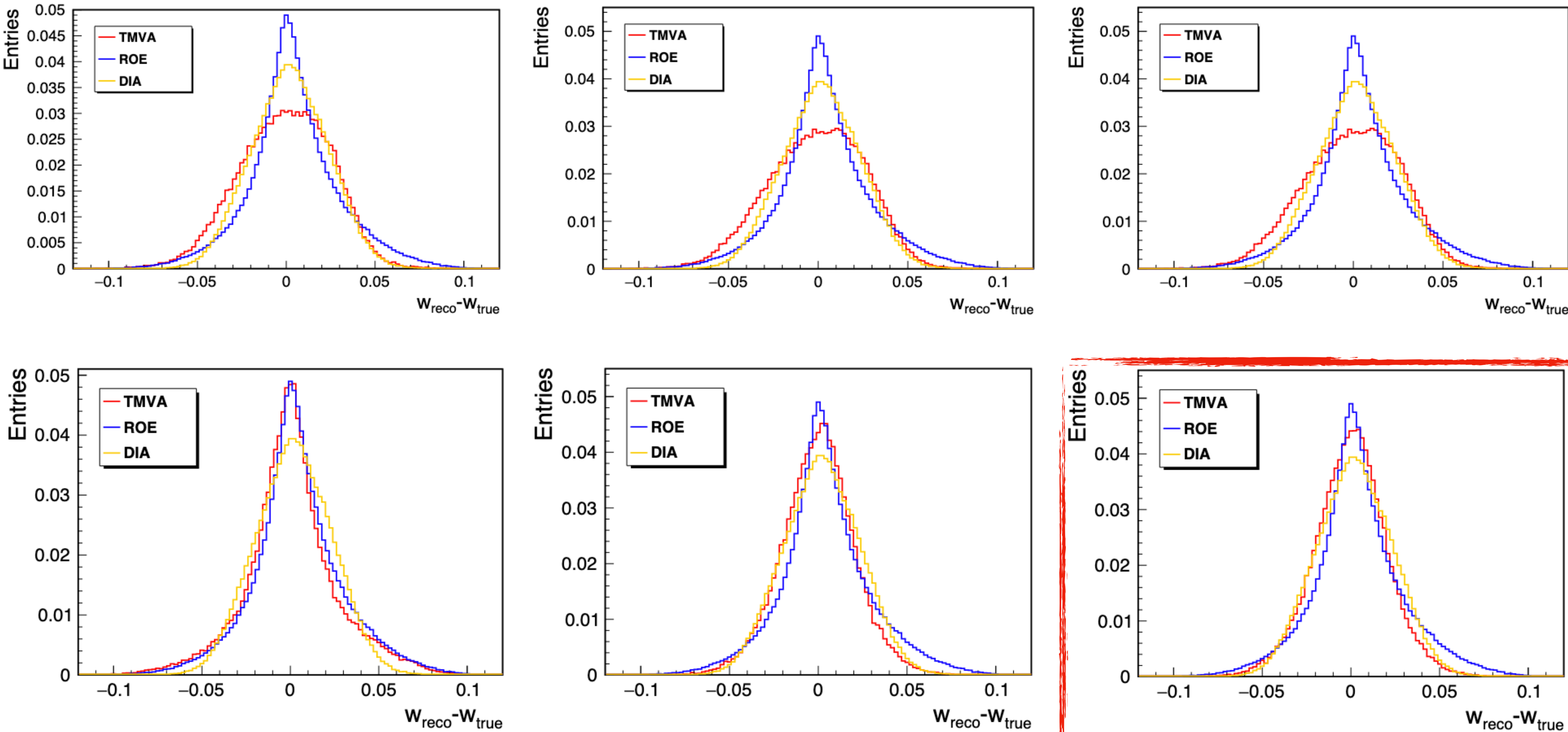


As expected the resolution is a little better for the $B^0 \to D^{\star -}\mu^+\nu_\mu$.

TMVA

Goal: find a MVA regression algorithm for w ($w = E_{D*}/m_{D*}$).

Construct a TMVA in which the input variables are the variables for which a greater correlation with w is observed (e.g. E^{D*}_{CMS}, pt^{D*}_{CMS}, w_{ROE} ...).



Input variables: $E_B, m_B, w_{ROE}, E^{D*}_{CMS}, p^{D*}_{tCMS}, w_{CMS}, q^2_{ROE}$ ← **The best so far**

Migration matrix: ROE vs new TMVA

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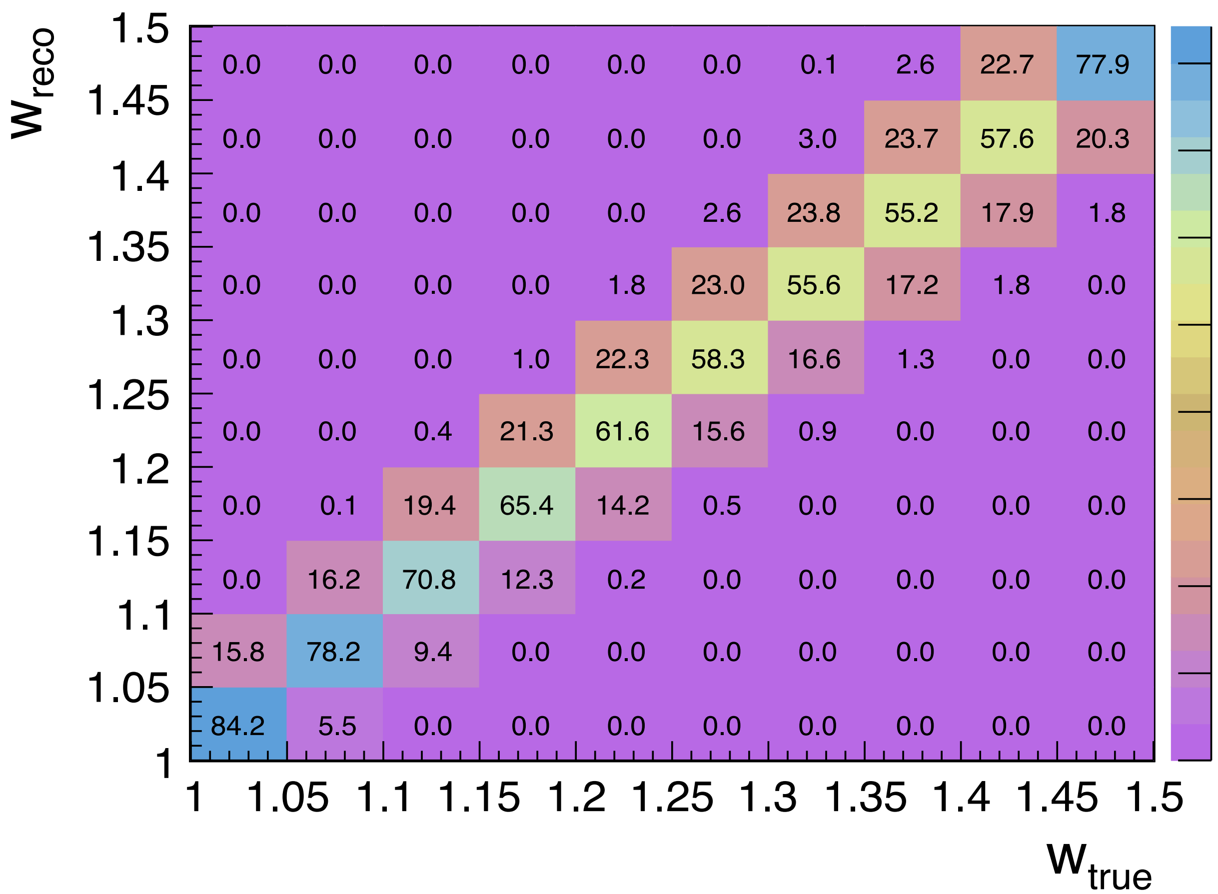
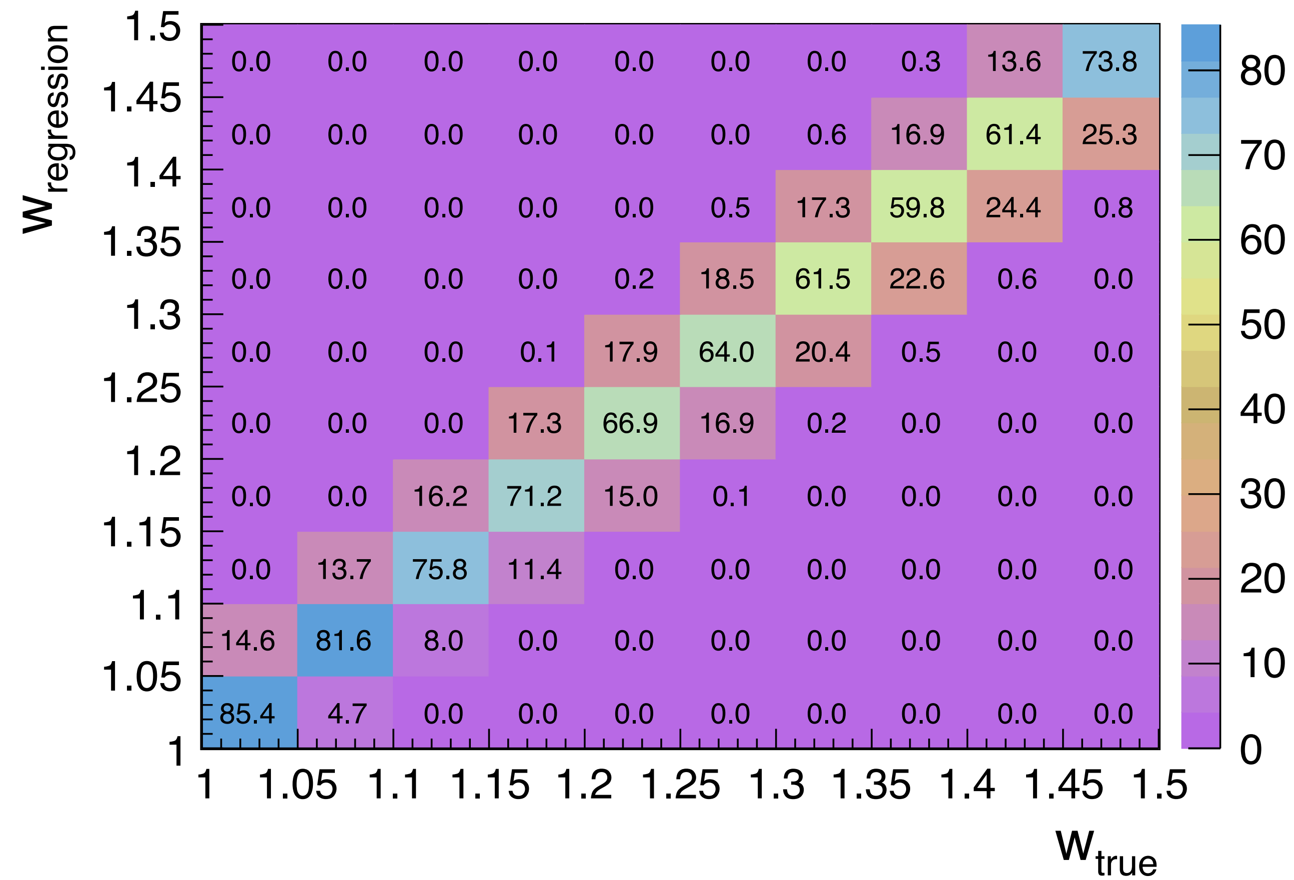
ROE method



TMVA



TMVA reproduces a better results respect to the ROE method.

Analysis strategy

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

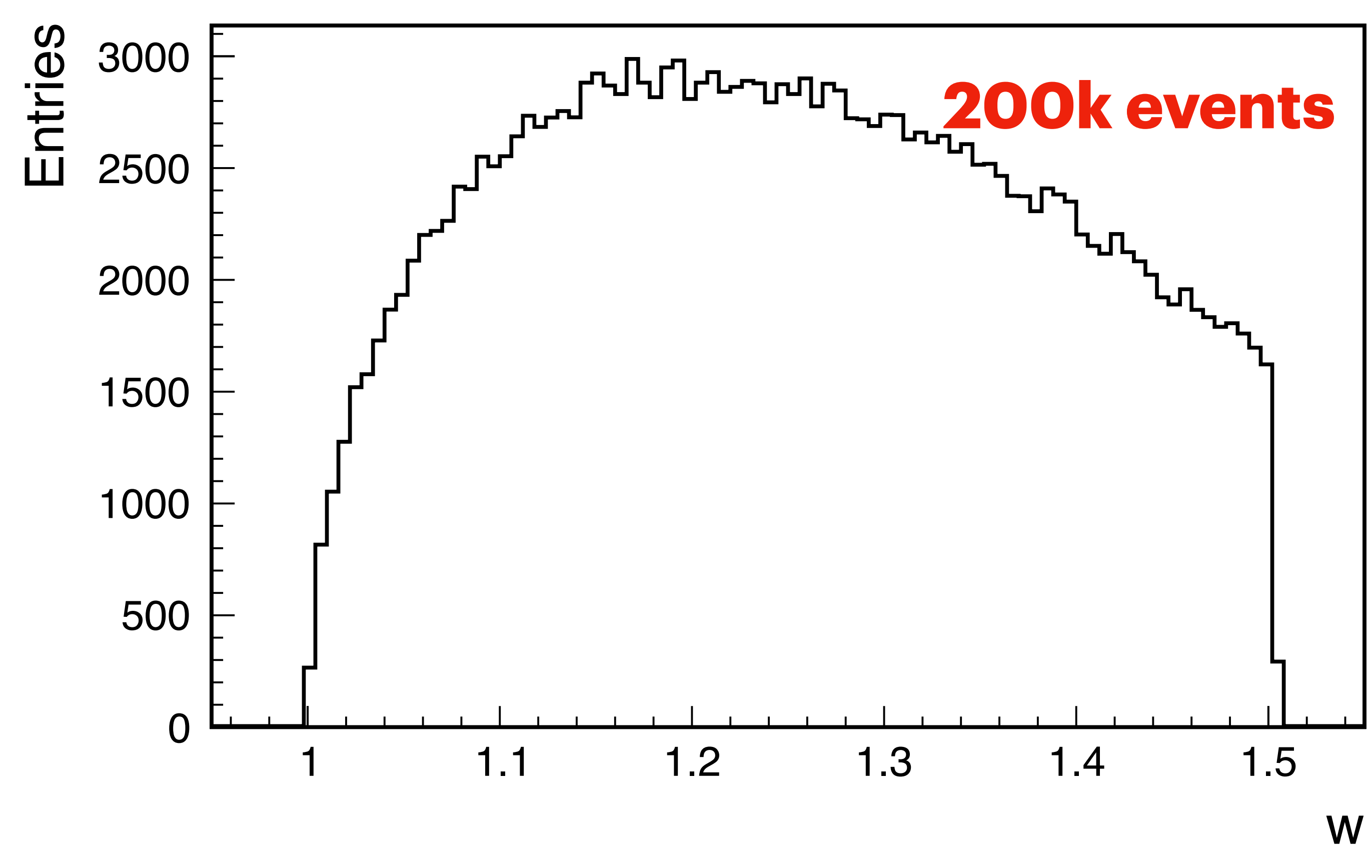
Done!

Generate events according to the differential decay rate

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

To do!

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



To do!

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

Next steps

- Continue the fit strategy;
- Improve the TMVA for the determination of ϕ angle of B meson;
- LeptonID and fake rates corrections.

Backup

Resolution plots: ROE vs new diamond+ROE

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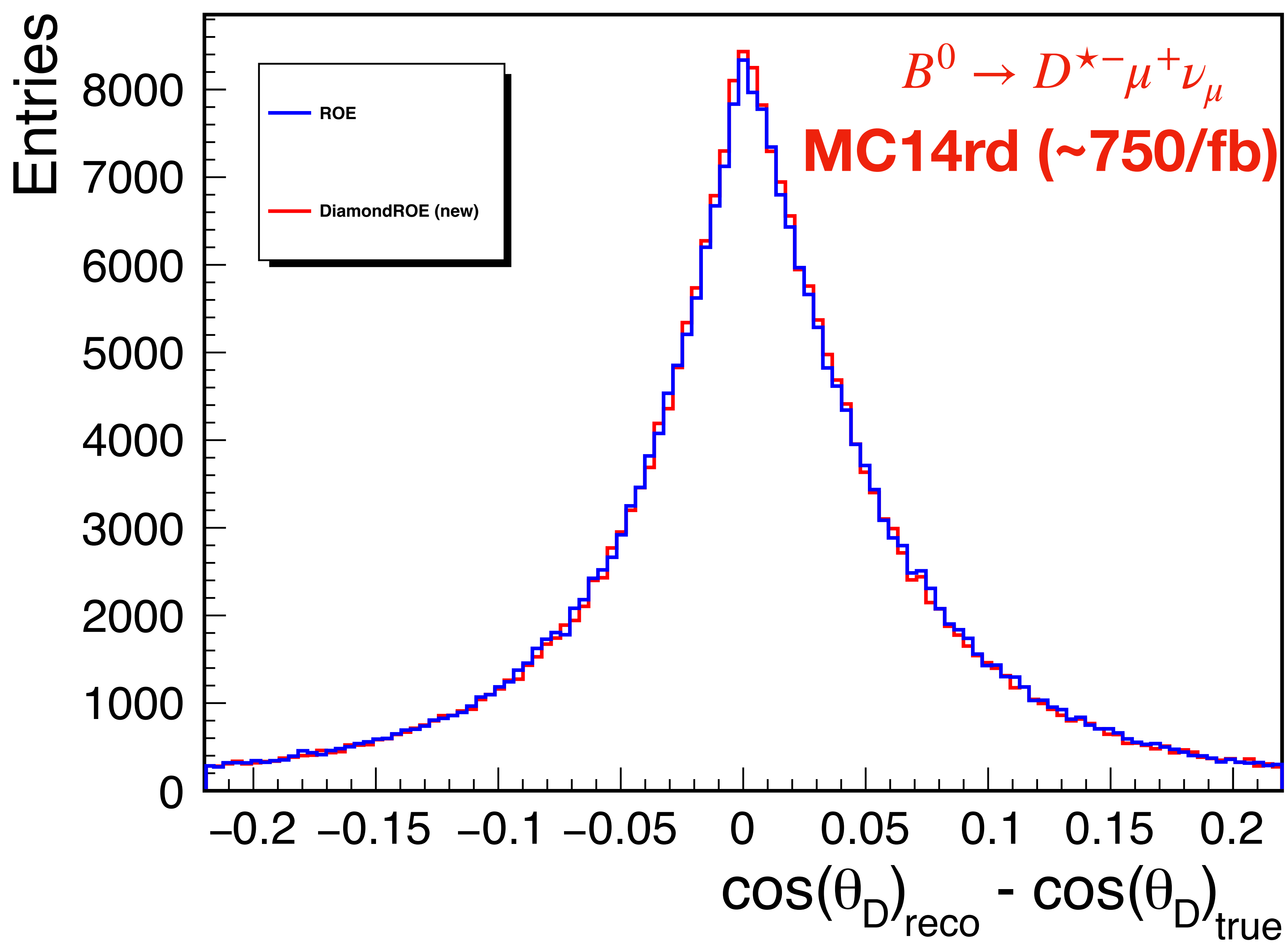

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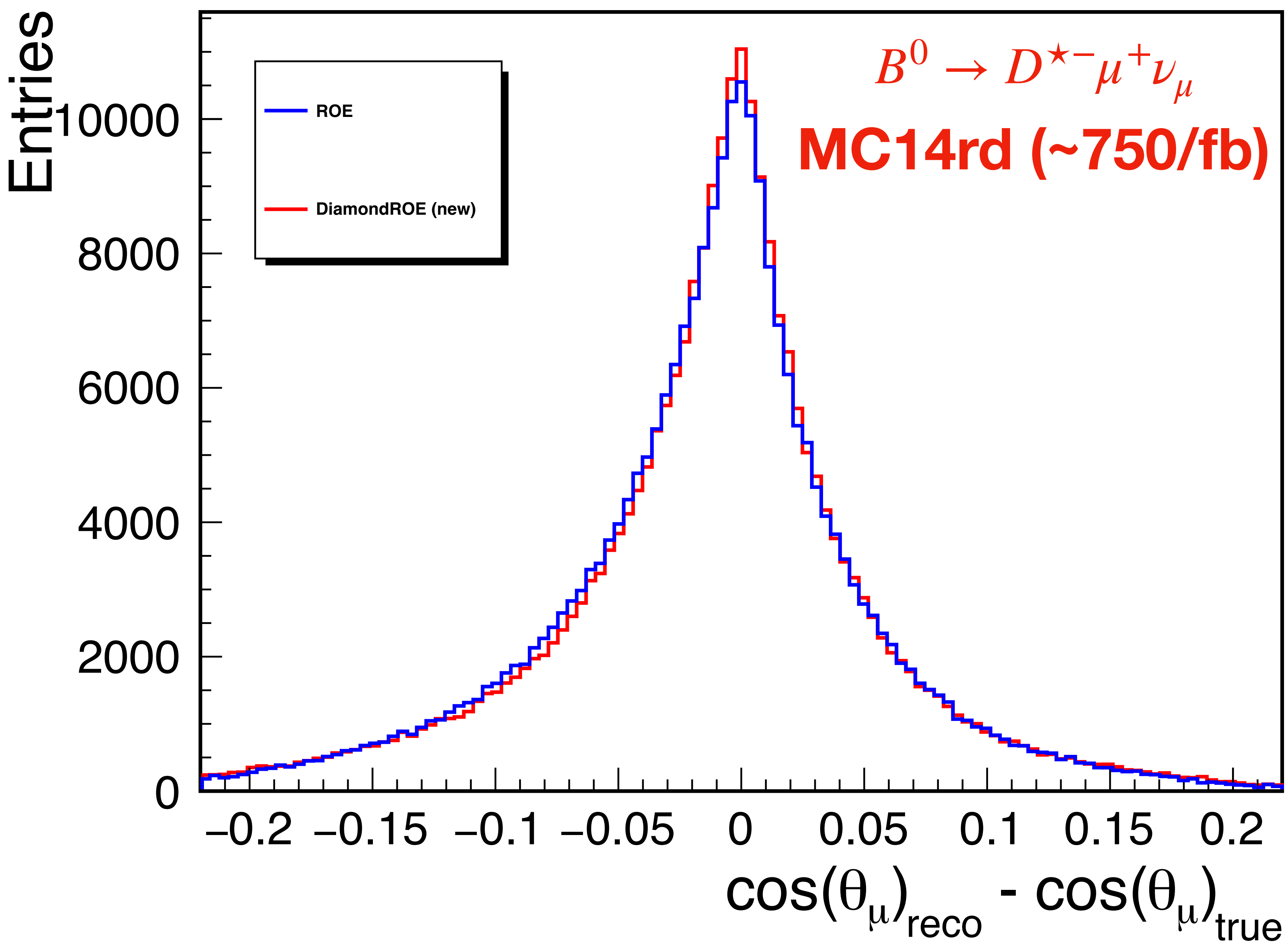

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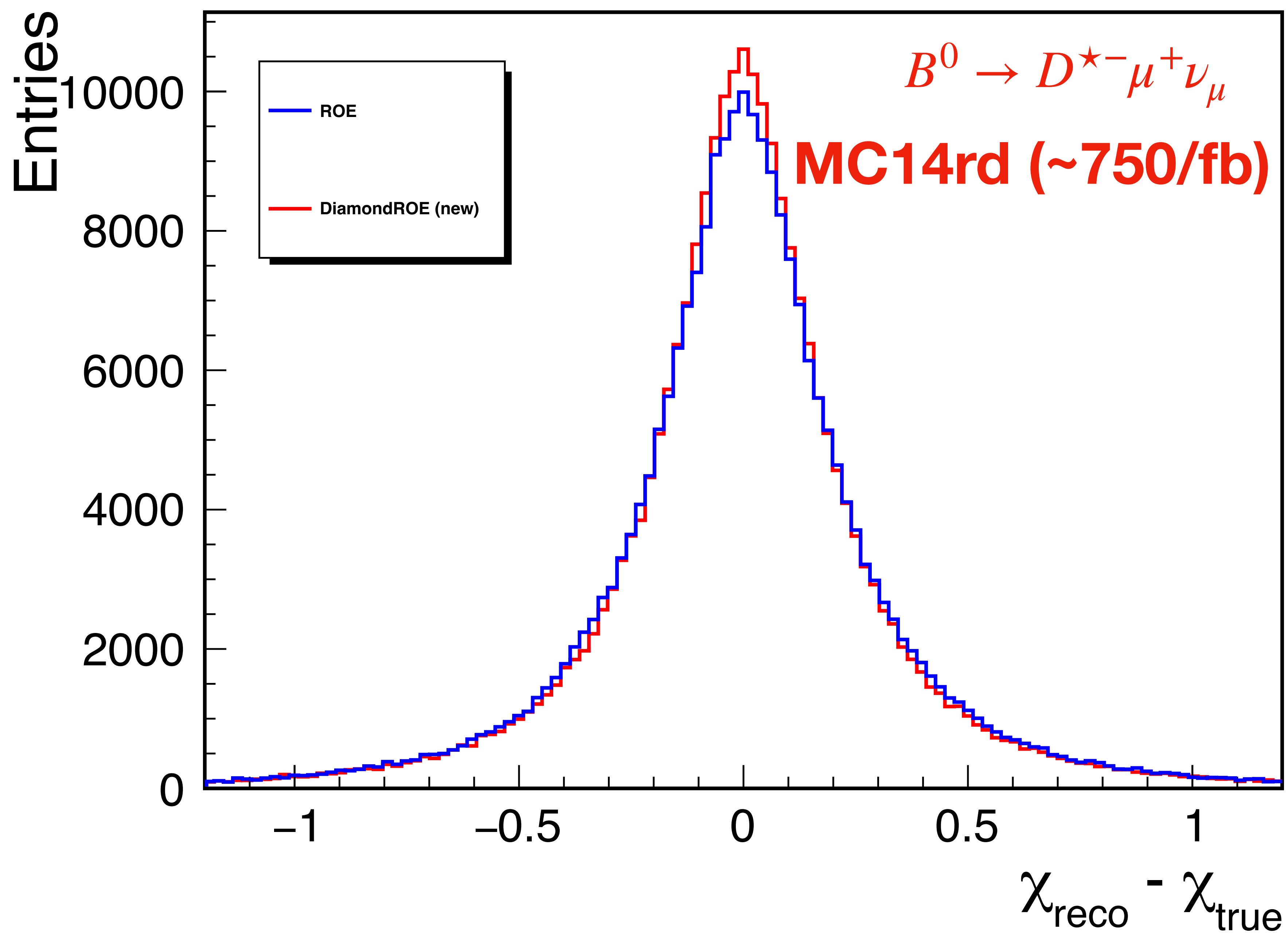

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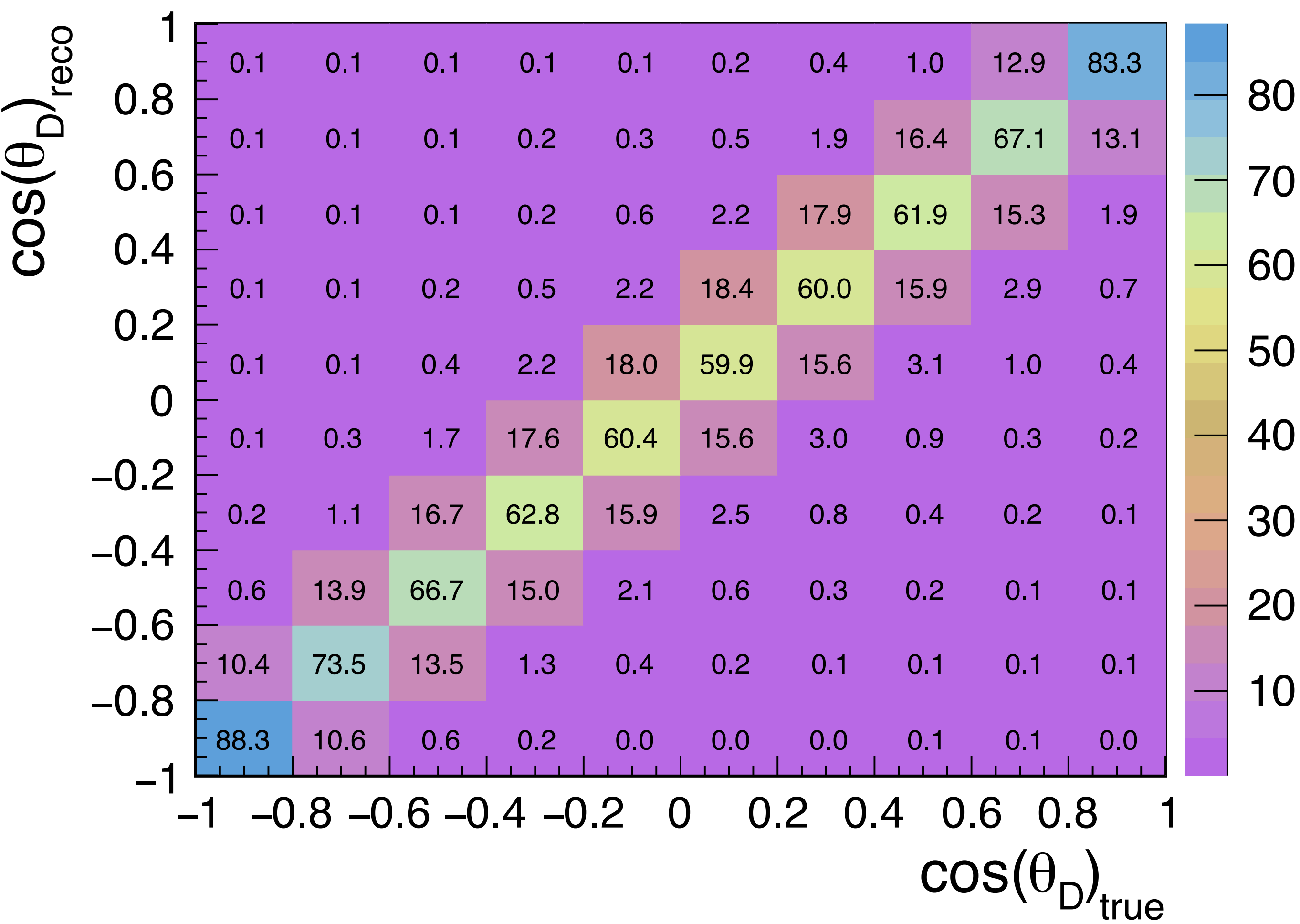

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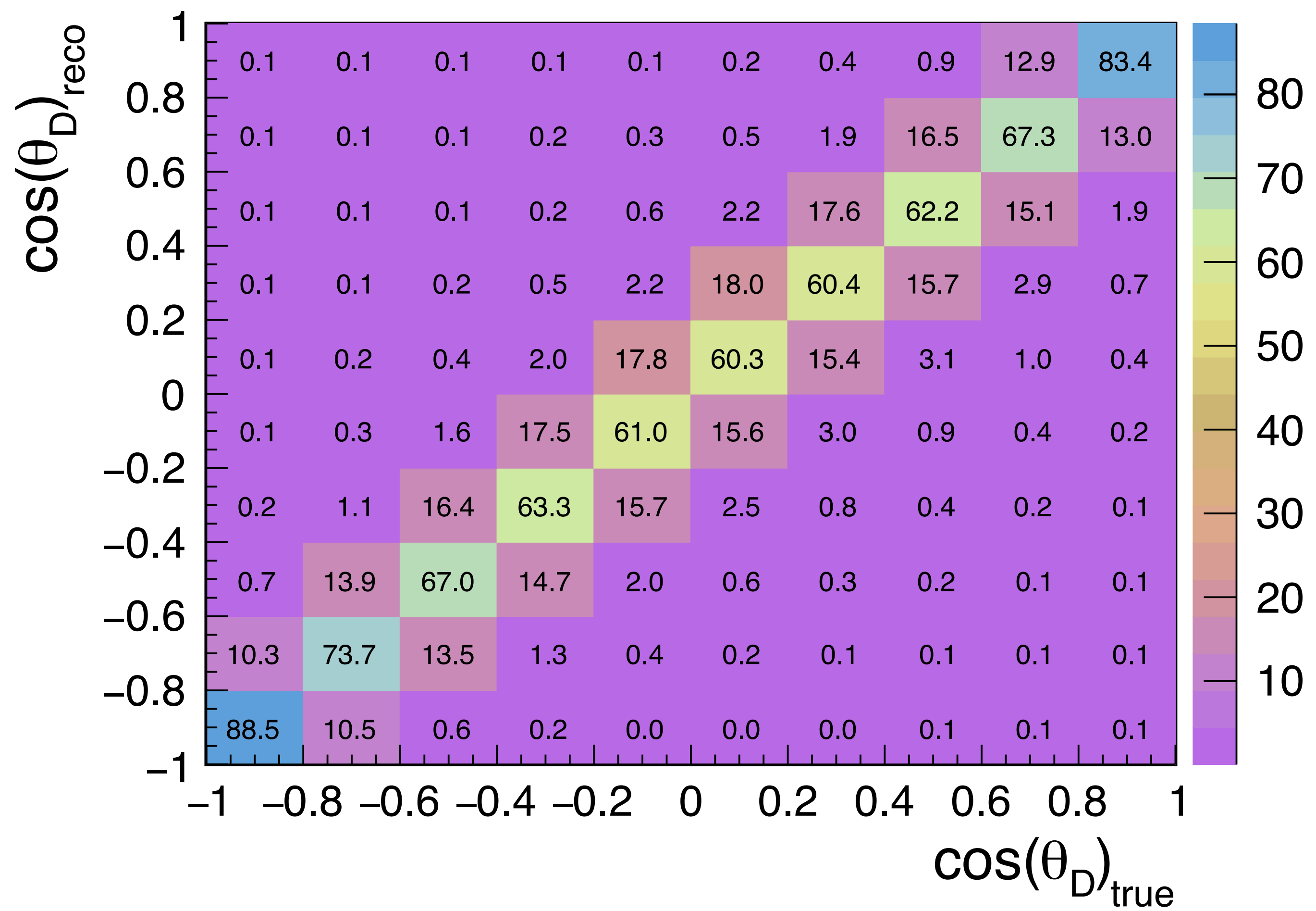

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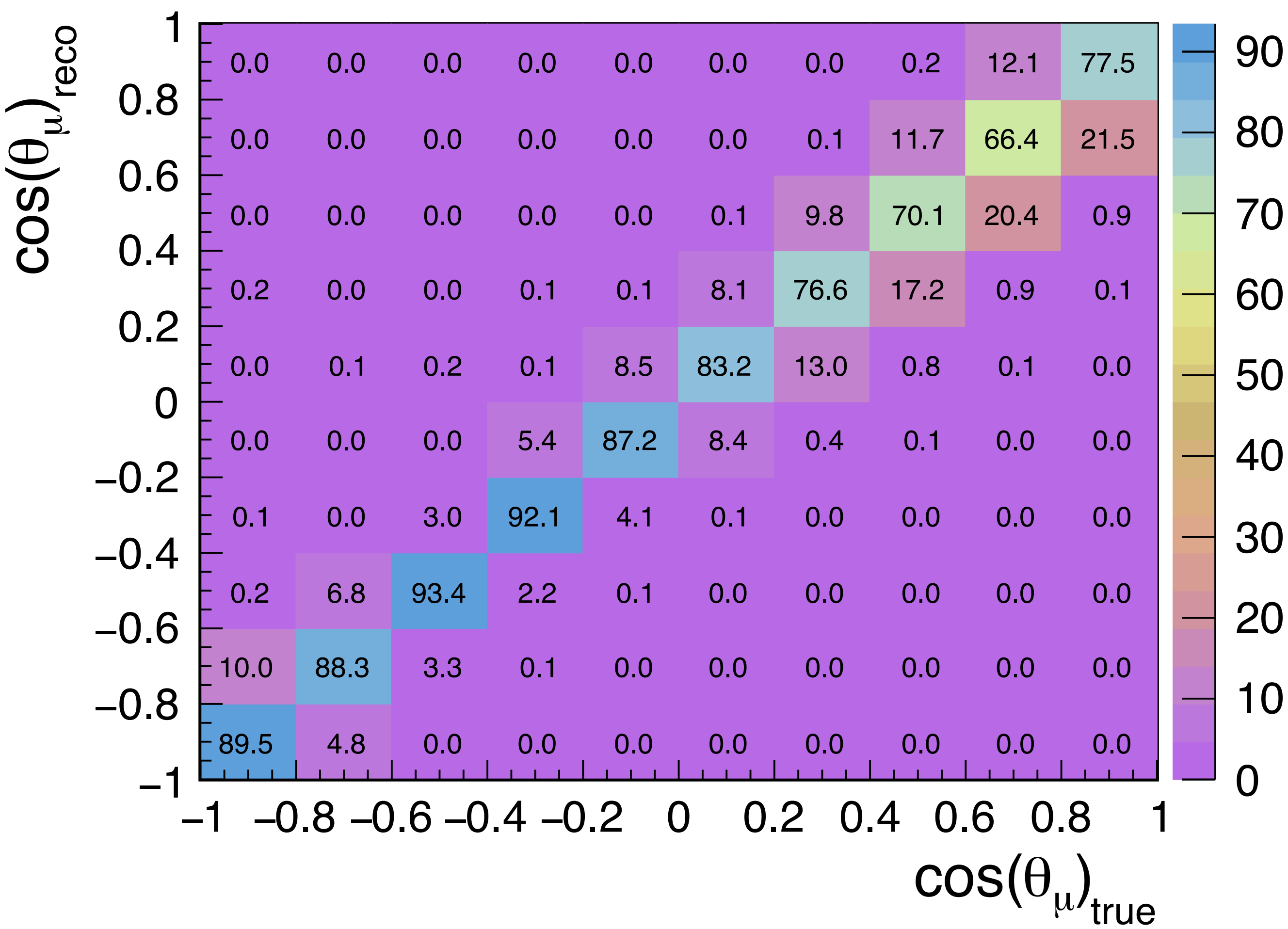

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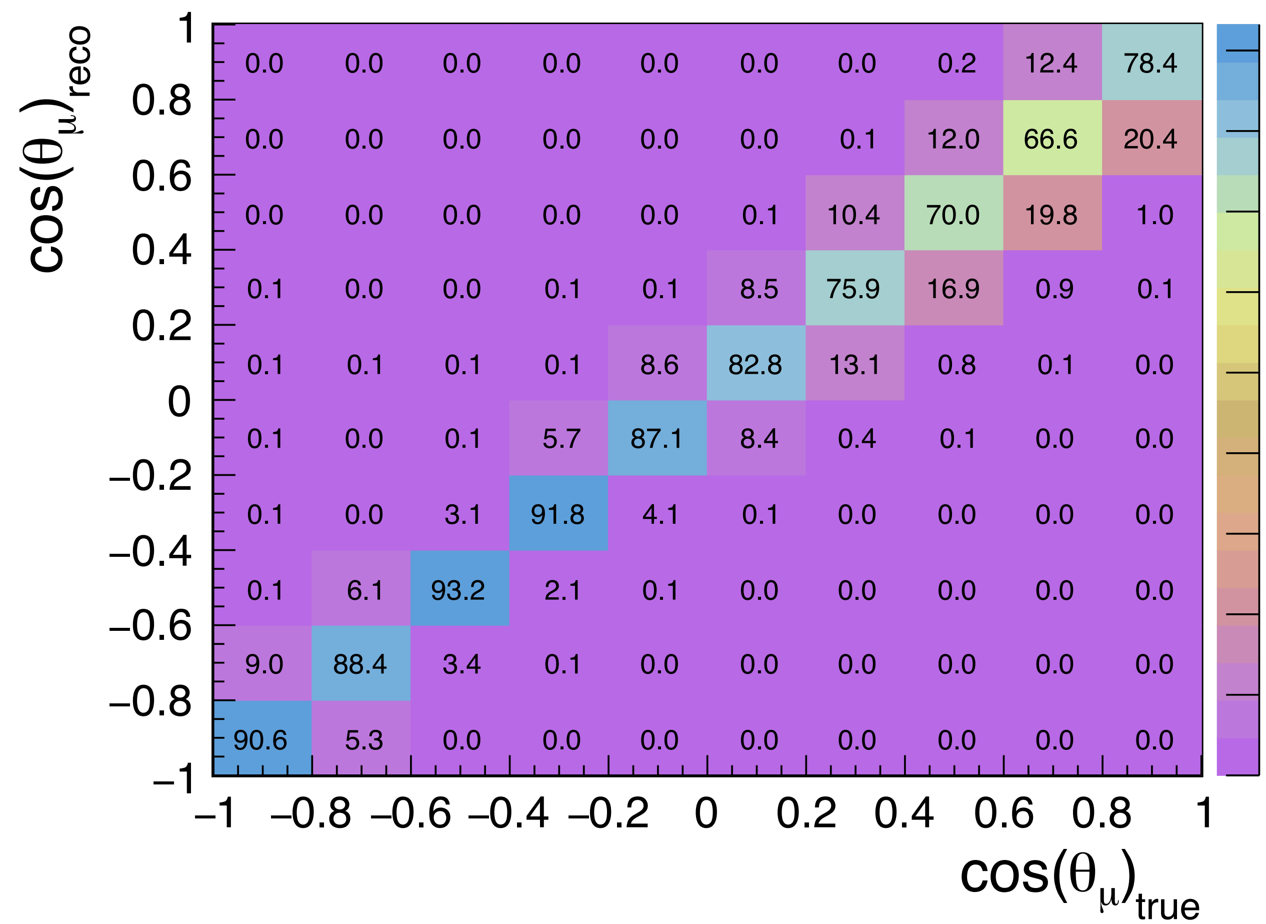

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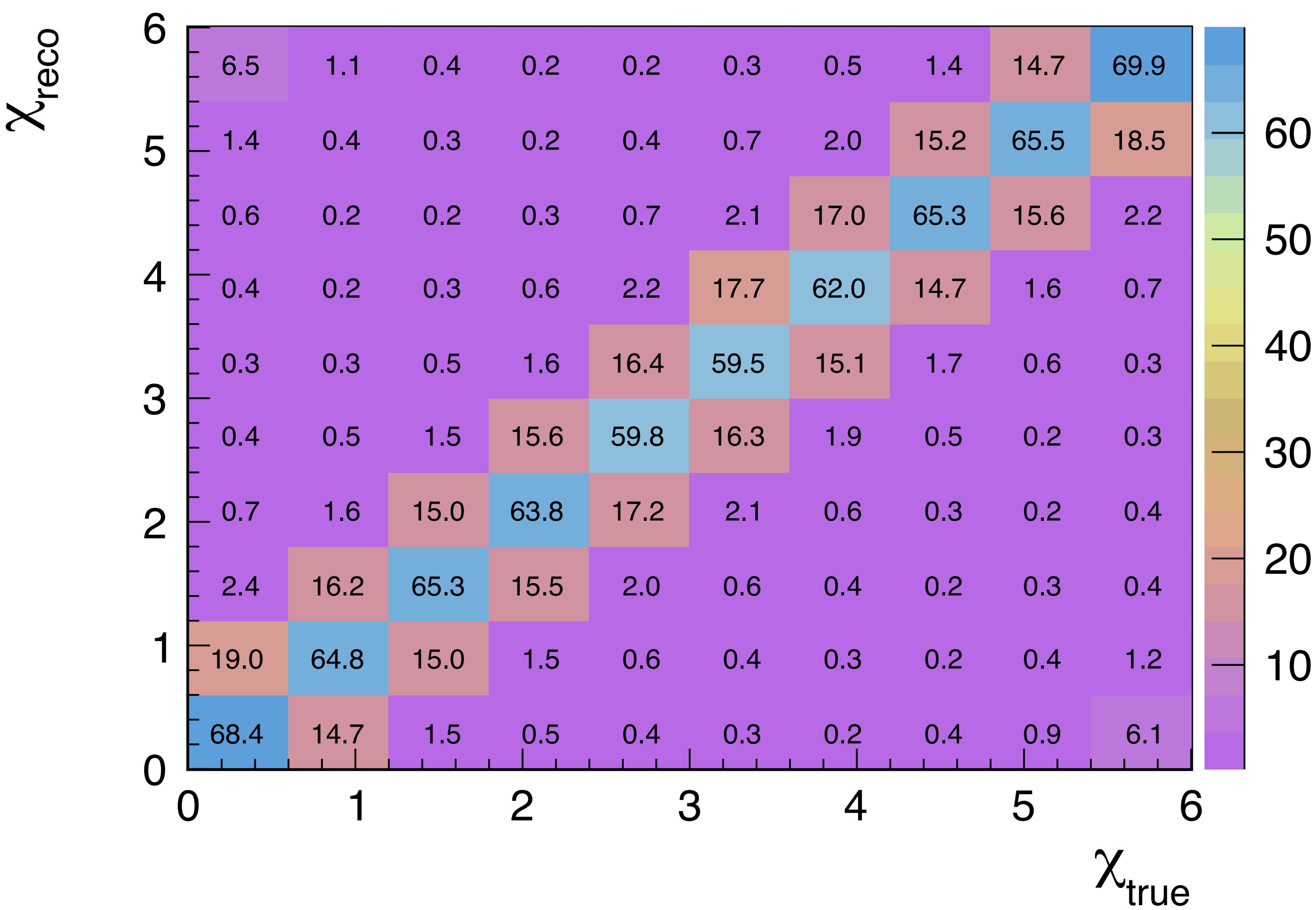

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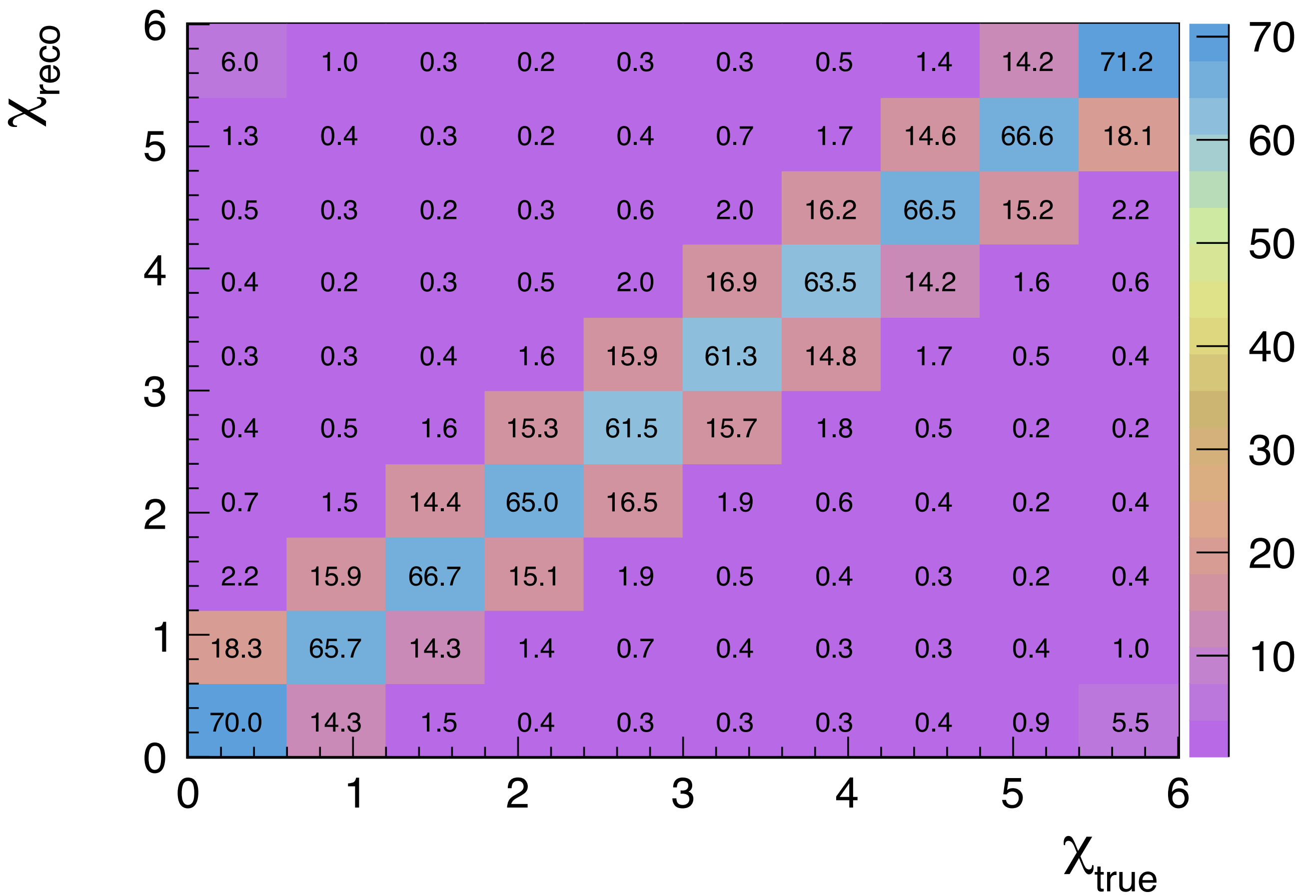

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w_{true} vs $E_t^{CMS}(D^*)$