General physics meeting
2018/04/14

Matrix Element application
for ZZH coupling study

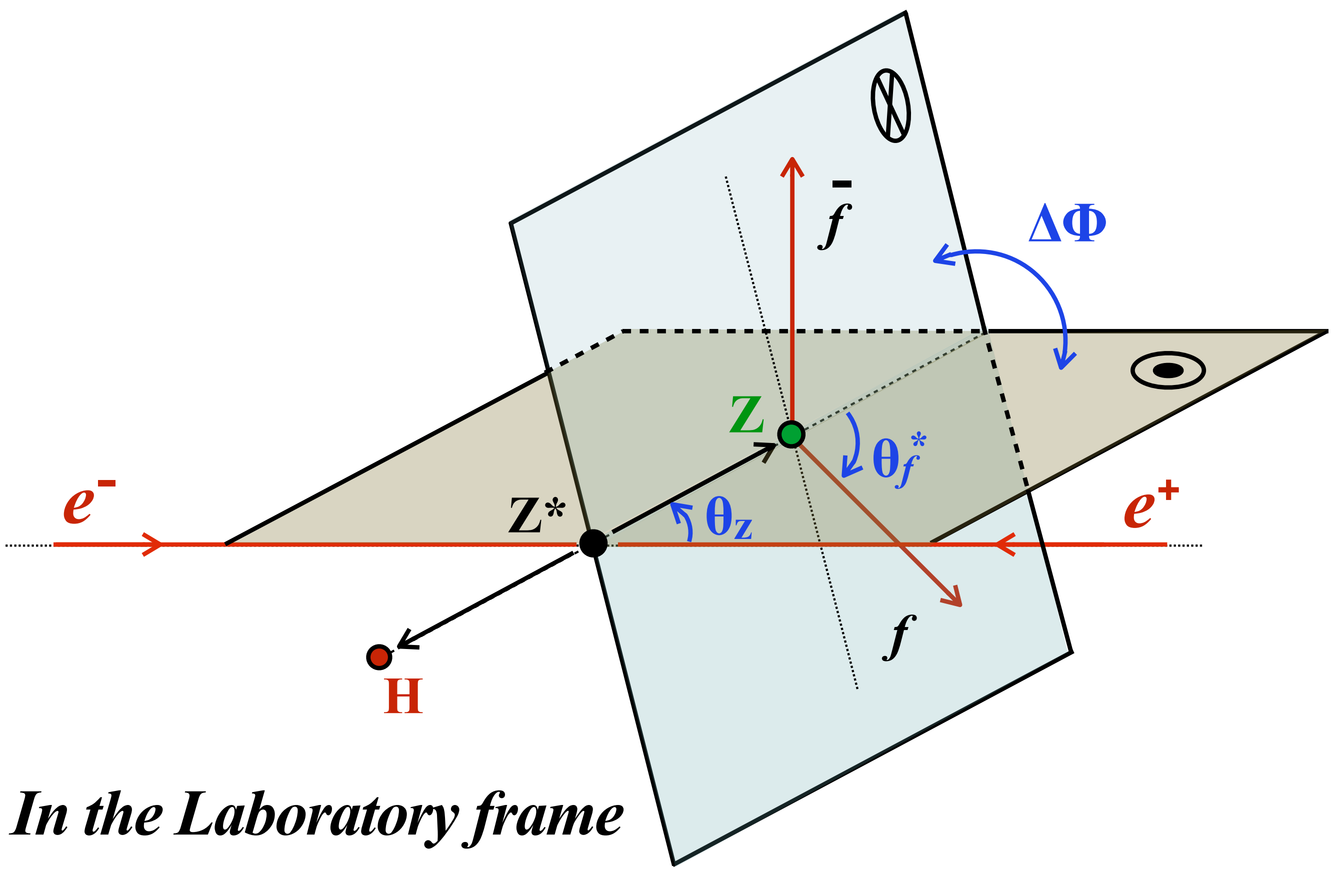
$e^+e^- \to ZH \to \mu^+\mu^- H$ at 250 GeV

focusing on a signal process

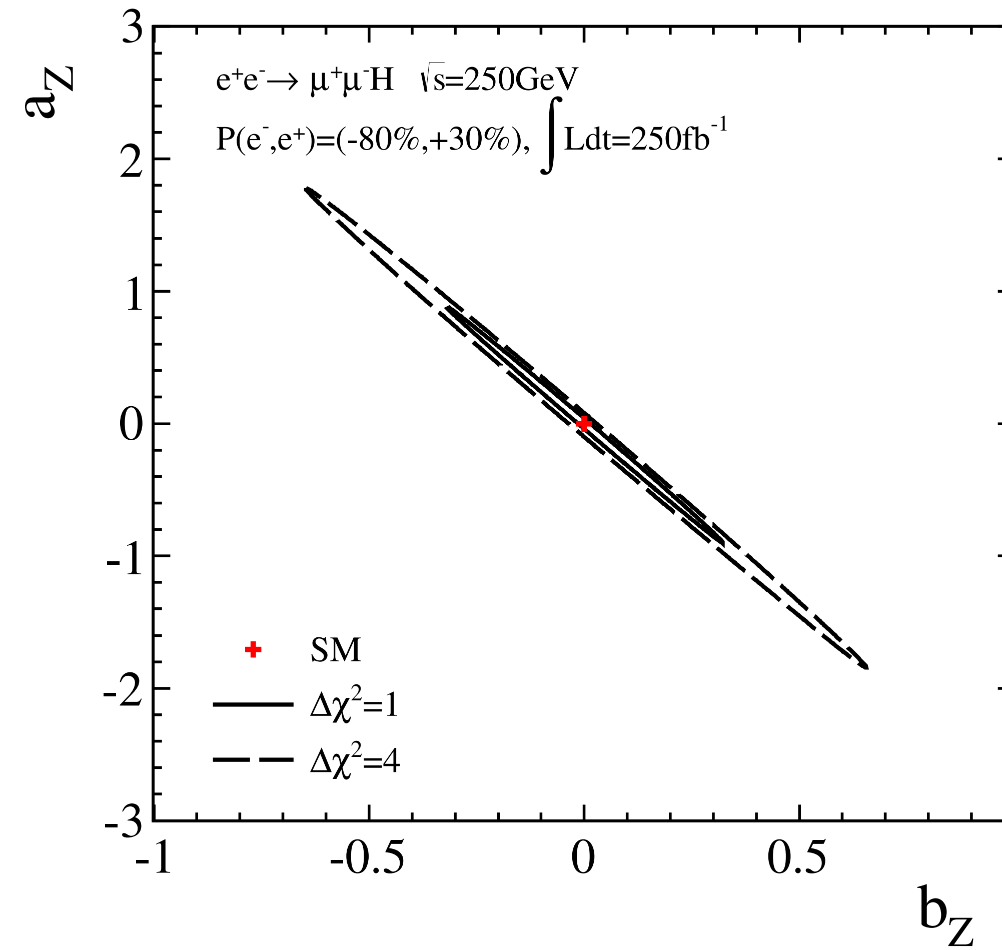
Anomalous ZZH couplings study with distributions

Determination of Lorentz structures between the H and Z

$$\mathcal{L}_{ZZH} \;=\; M_Z^2\left(\frac{1}{\mathrm{v}}+\frac{a_Z}{\Lambda}\right)Z_\mu Z^\mu H+\frac{b_Z}{2\Lambda}\hat{Z}_{\mu\nu}\hat{Z}^{\mu\nu}H+\frac{\tilde{b}_Z}{2\Lambda}\hat{Z}_{\mu\nu}\tilde{\hat{Z}}^{\mu\nu}H$$



In the Laboratory frame



Construction of the multi-dimensional distribution have difficulty

$\sqrt{s} = 250$ GeV with $\mathrm{L_{int}} = 250\ \mathrm{fb}^{-1}$ and $\mathrm{P}(e^-, e^+) = (-80\%, +30\%)$

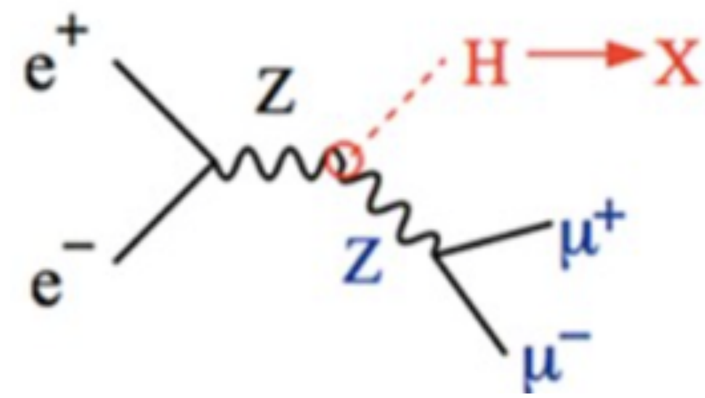
$$\begin{cases} a_Z = [-0.912,\ \ 0.896] \\ b_Z = [-0.324,\ \ 0.326] \\ \tilde{b}_Z = [-0.155,\ \ 0.155] \end{cases},\quad \rho = \begin{pmatrix} 1 & -0.9992 & -0.0176 \\ - & 1 & 0.0158 \\ - & - & 1 \end{pmatrix}$$

Theory knows everything

Try to encode all available kinematical information on an event into a single observable .

Observation an event
in terms of differential σ

LO

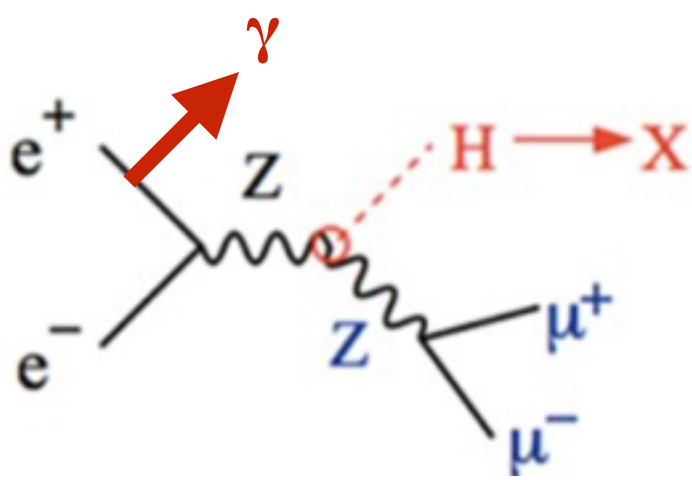
Probability = |  |^2 dΦ

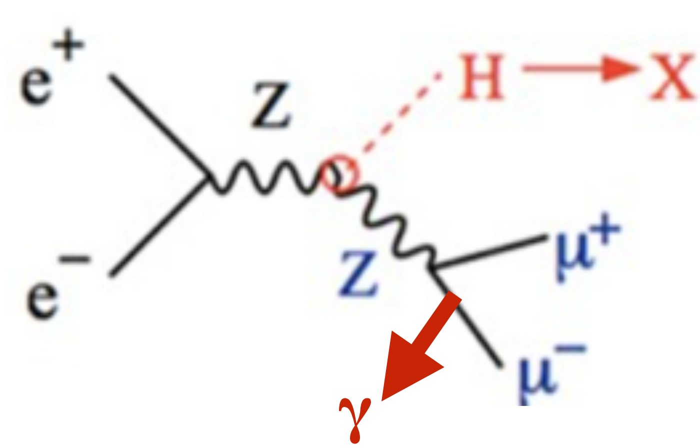
$$P(\vec{p}^{\,\mu}) = \frac{|\mathcal{M}(\vec{p}^{\,\mu})|^2}{\sigma} d\Phi$$

ISR, beamstrahlung, and FSR

NLO effects

Matrix Element doesn't fit reaction anymore





General probability function

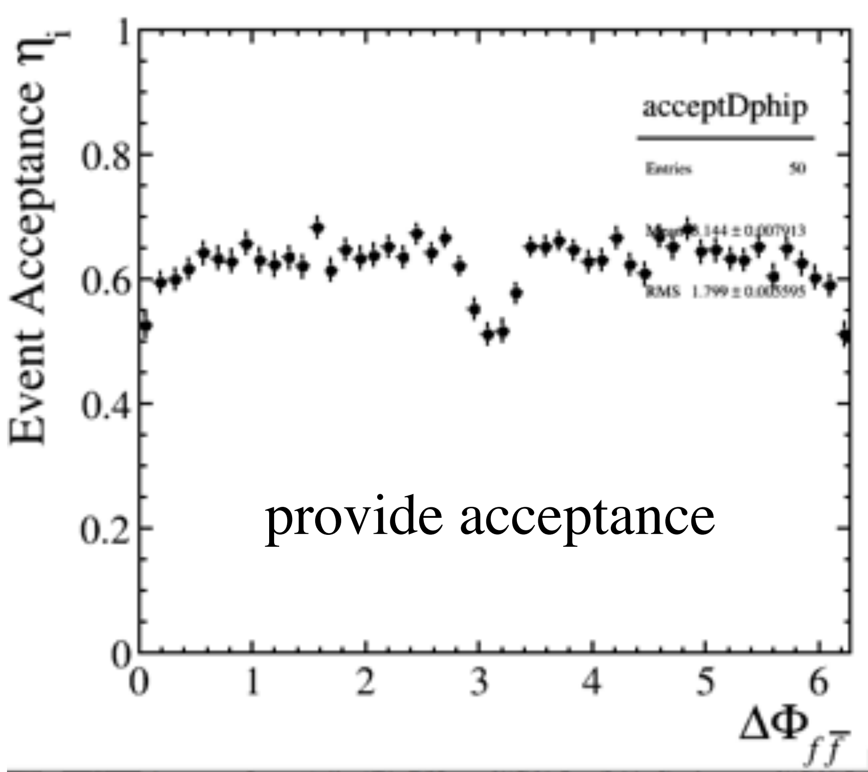
Event probability based on diff. cross-section

Integration over phase-space for four momenta

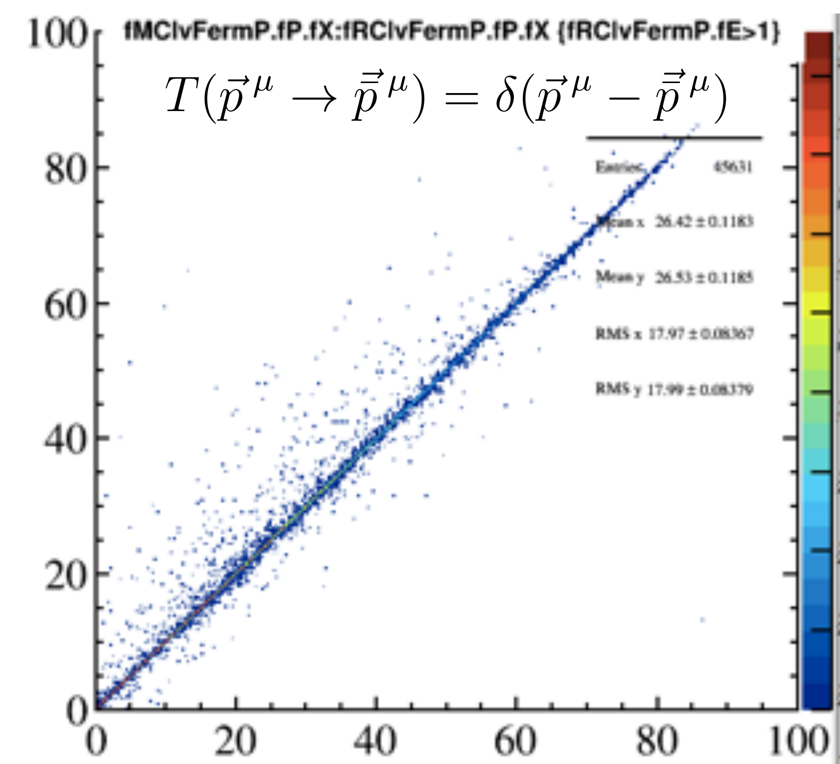
Acceptance function

$$P_{\text{shape}}(\vec{p}^{\,\mu};\vec{a}_V) = \frac{1}{A_{cc}(\vec{p}^{\,\mu})\ \sigma(\vec{a}_V)} \int d\bar{\Phi}\ |\mathcal{M}(\vec{\bar{p}}^{\,\mu};\vec{a}_V)|^2\ T(\vec{p}^{\,\mu} \to \vec{\bar{p}}^{\,\mu})\,A_{cc}(\vec{p}^{\,\mu})$$

Acceptance function — Normalization — Matrix Element — Transfer function (detector resolution)



Transfer is δ



Momentum X of μ- [Gev]
Reco vs MCtrue

$$P_{\text{shape}}(\vec{p}^{\,\mu};\vec{a}_V) = \frac{A_{cc}^{\mu\mu H}(\vec{p}^{\,\mu})|\mathcal{M}_{ZH\to\mu\mu H}(\vec{p}^{\,\mu};\vec{a}_V)|^2}{A_{cc}^{\mu\mu H}(\vec{p}^{\,\mu})\sigma_{ZH\to\mu\mu H}(\vec{a}_V)}$$

Samples and an intermediate goal

$$P_{\text{shape}}(\vec{p}^{\,\mu};\vec{a}_V) = \frac{A_{cc}^{\mu\mu H}(\vec{p}^{\,\mu})|\mathcal{M}_{ZH\to\mu\mu H}(\vec{p}^{\,\mu};\vec{a}_V)|^2}{A_{cc}^{\mu\mu H}(\vec{p}^{\,\mu})\sigma_{ZH\to\mu\mu H}(\vec{a}_V)}$$

Matrix Element Calculator can handle (probably) the LO diagram

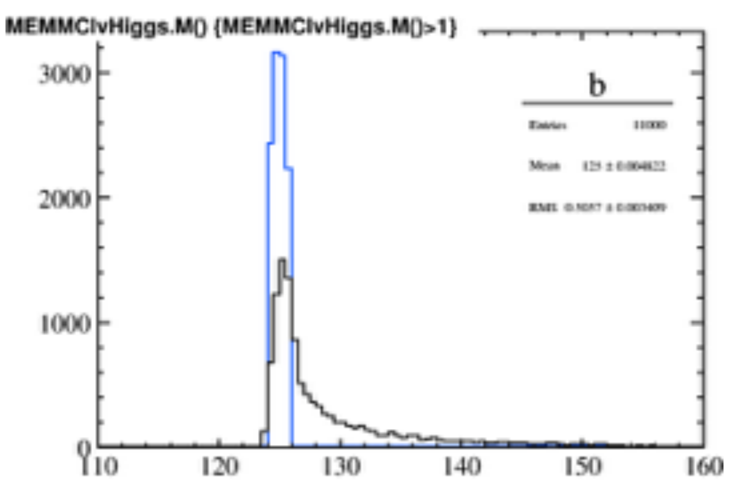
Two signal samples

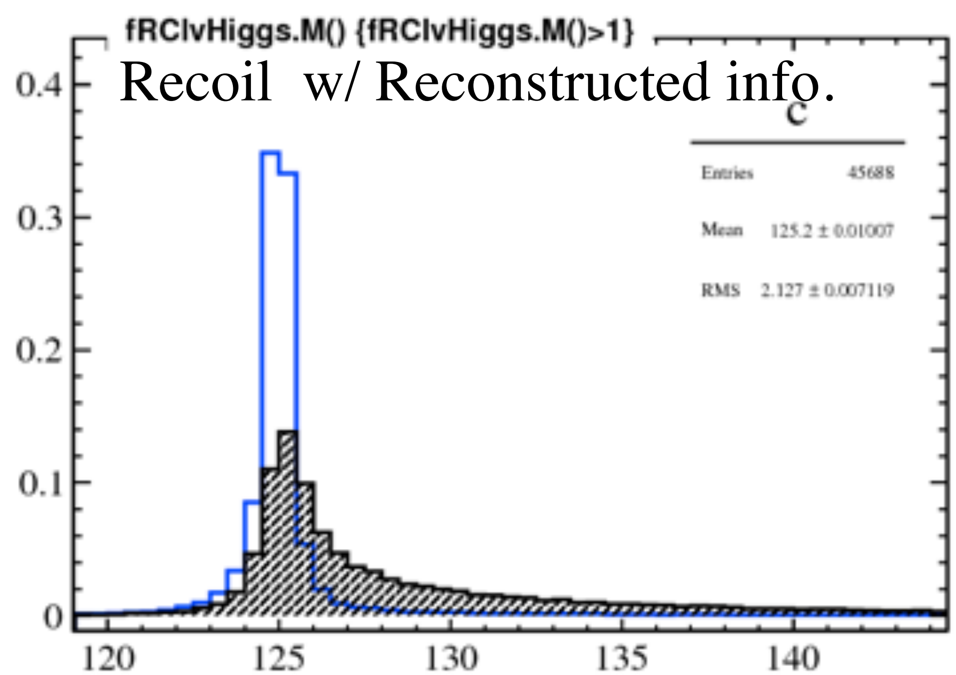
with ISR and BSL | **without ISR and BSL**

```
USER_spectrum_on    =  T
USER_spectrum_mode  =  22
```

```
USER_spectrum_on    =  F
ISR_on              =  F
CIRCE_on            =  F
```

Recoil Generator





worst performance

If ME handle NLO,
a result will be
around here.

intrinsic performance

Analytic calculation of the denominator

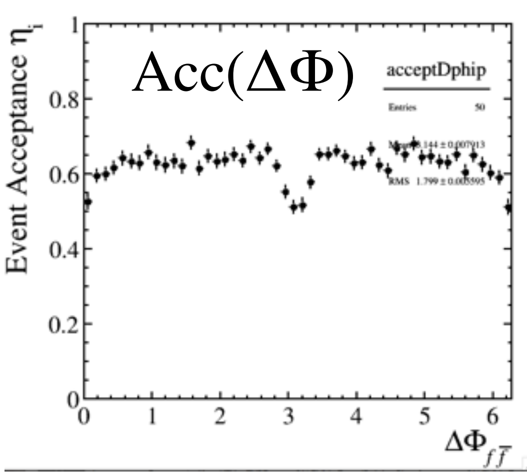
$$P_{\text{shape}}(\vec{p}^{\,\mu};\vec{a}_V) = \frac{A_{cc}^{\mu\mu H}(\vec{p}^{\,\mu})|\mathcal{M}_{ZH\to\mu\mu H}(\vec{p}^{\,\mu};\vec{a}_V)|^2}{A_{cc}^{\mu\mu H}(\vec{p}^{\,\mu})\sigma_{ZH\to\mu\mu H}(\vec{a}_V)}$$

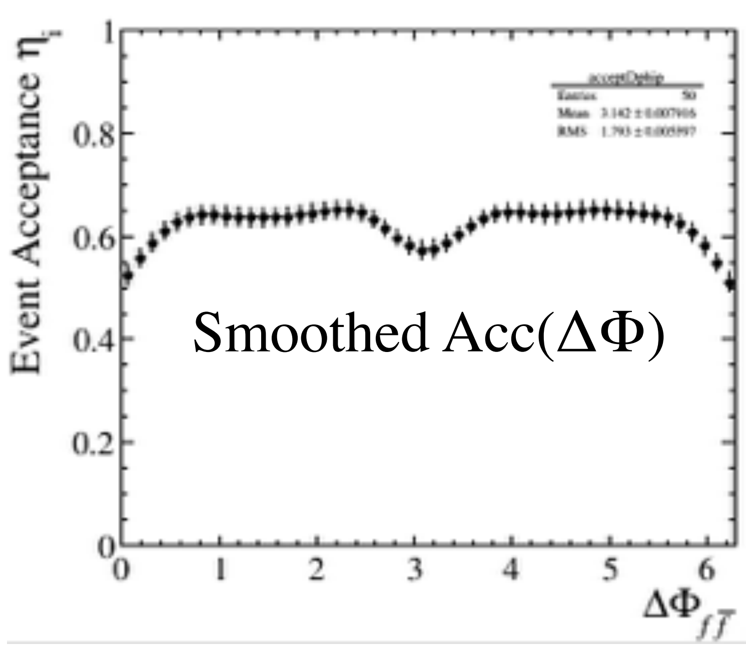
Cross-section depends on av
av can vary momentum of Z, affecting its daughters consequently.

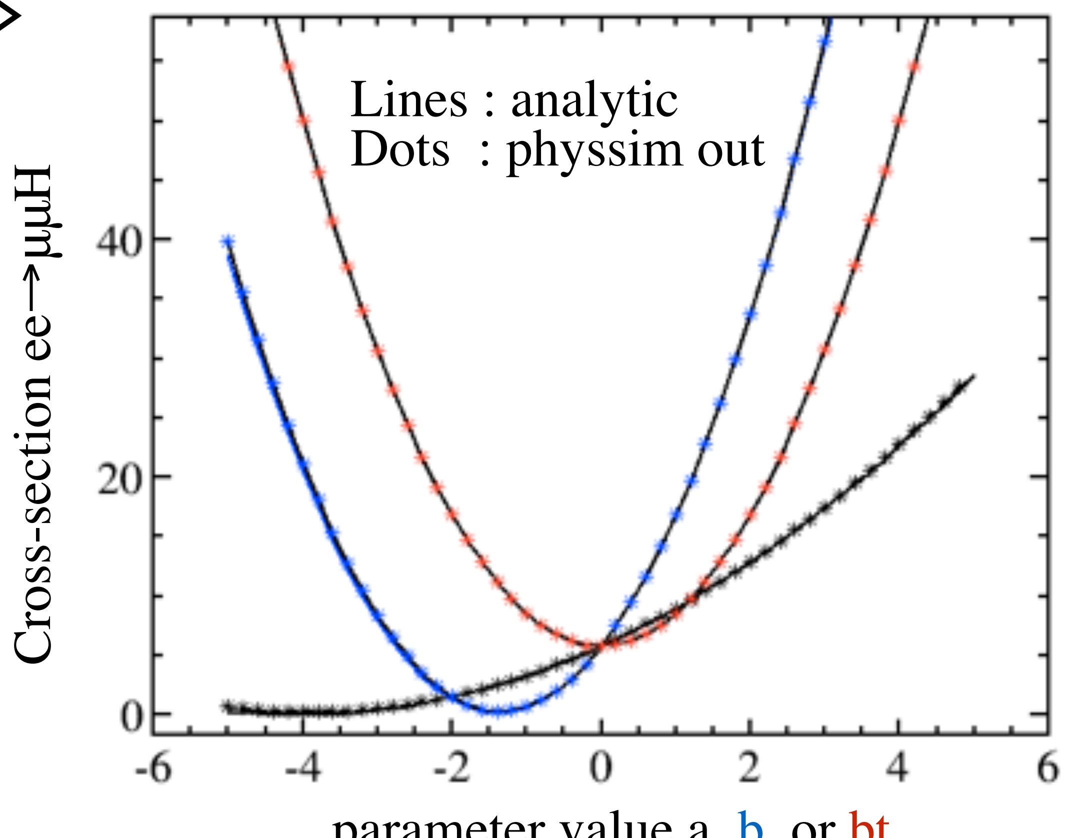
This effects must Correctly handle
when Cross-section is calculated
by integrating possible phase-space

To realize it
Acc is embedded into PHYSSIM generator.
perform integration together with Acc

$\sigma = | A_0 + aA_a + bA_b + btA_{bt} |^2$
provides 10 terms
composed of 1 SM,
3 pure contribution
6 interference each other







Parameter estimation

$$P_{\text{shape}}(\vec{p}^{\,\mu};\vec{a}_V) = \frac{A^{\mu\mu H}_{cc}(\vec{p}^{\,\mu})|\mathcal{M}_{ZH\to\mu\mu H}(\vec{p}^{\,\mu};\vec{a}_V)|^2}{A^{\mu\mu H}_{cc}(\vec{p}^{\,\mu})\sigma_{ZH\to\mu\mu H}(\vec{a}_V)}$$

Chi-squared

w: factor for scaling to #expected ~1623

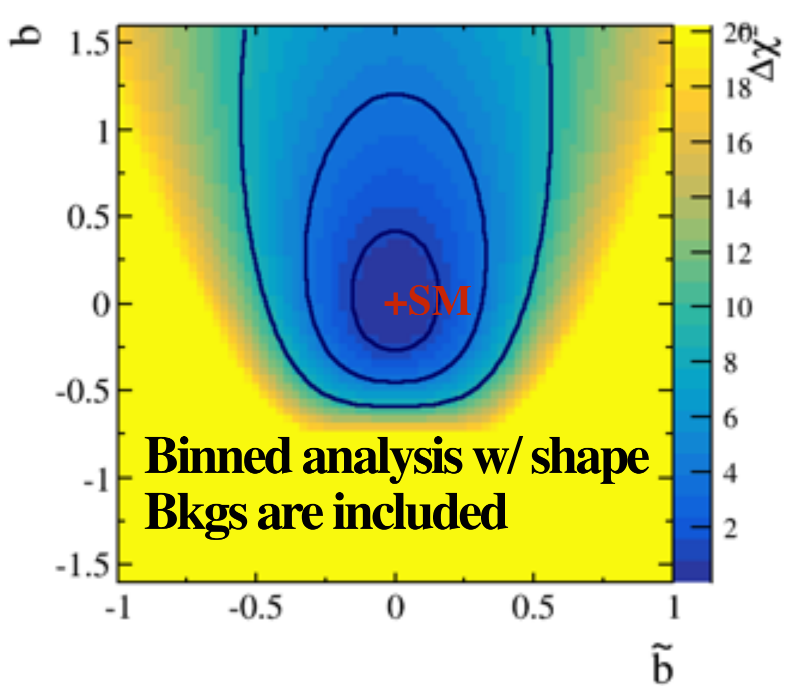
$$\chi^2 = -2\log\Delta\mathcal{L} = -2(\ln\mathcal{L}(\vec{a}_V) - \log\mathcal{L}_{SM})$$

Likelihood function

$$\mathcal{L}(\vec{a}_V) = \mathcal{L}_{\text{shape}}(\vec{a}_V)\cdot\mathcal{L}_{\text{norm}}(\vec{a}_V)$$

$$= \prod_{i=1}^{\text{MCevents}} P_{\text{shape}}(\vec{p}_i^{\,\mu};\vec{a}_V)\cdot P_{\text{norm}}(\vec{a}_V)$$

momenta: μ, μ, and it's recoil info.



$e^+e^- \to ZH \to \mu^+\mu^- H$ at 250 GeV

Cut variables	$\mu\mu H$	ϵ	$2f$	$4f$	S_{sig}
No cut	2603	100	$2.9\cdot10^7$	$1.0\cdot10^7$	-
$\mu^+\mu^-$ ID	2433	93.5	$4.3\cdot10^5$	$8.3\cdot10^4$	3.4
$N_{tracks\in[6,60]}$	2246	86.3	6771	$2.4\cdot10^4$	12.3
$E_{Z\in[14.6,111.7]}$ GeV	1740	66.8	156	1470	30.0
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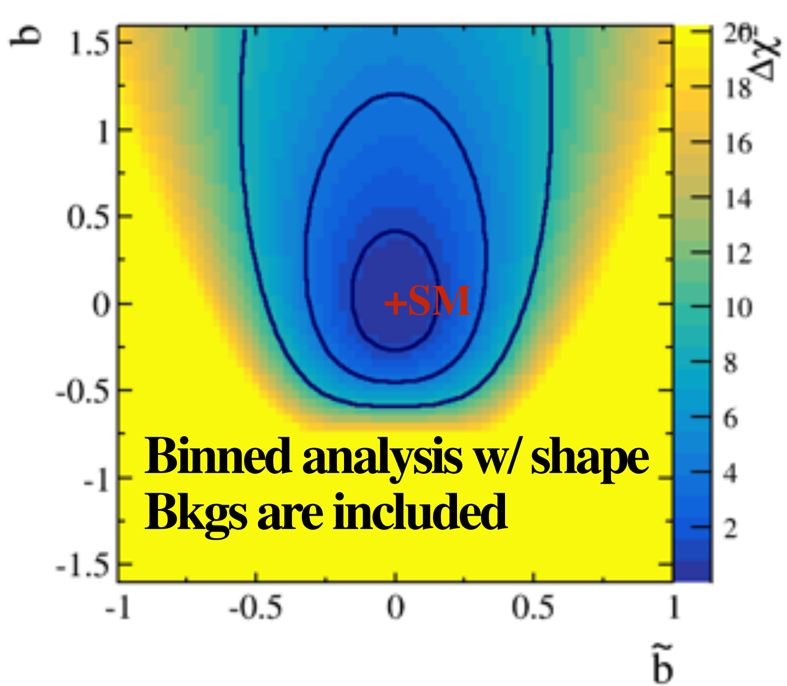
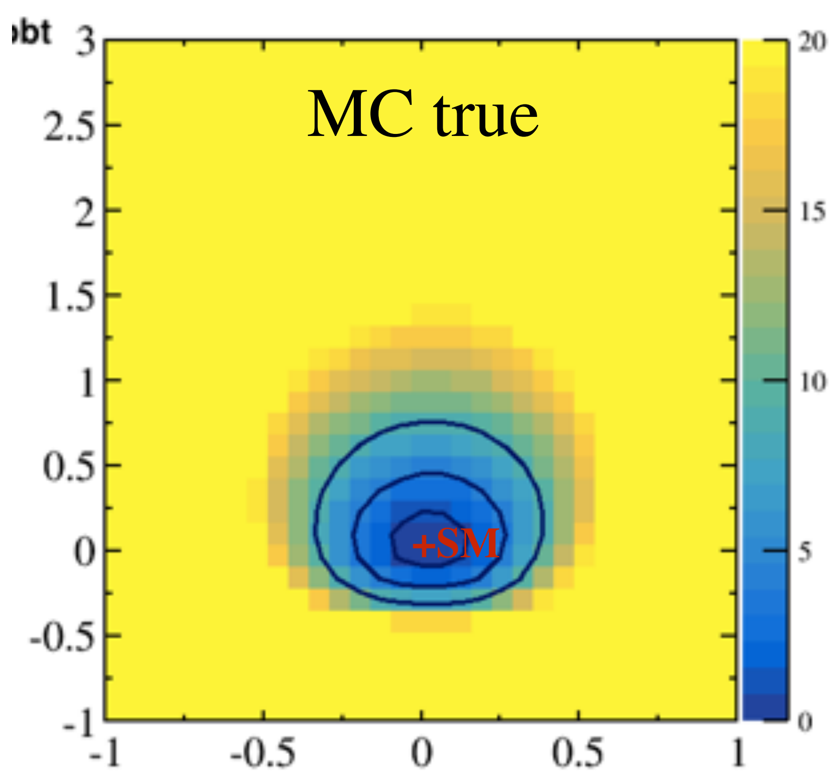
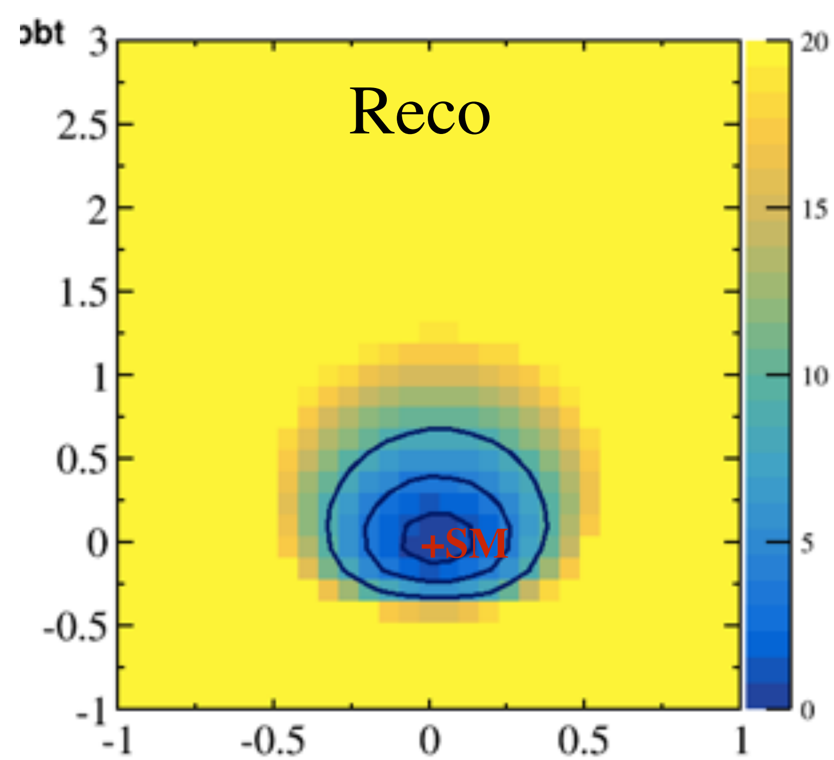
ME : is LO
Sample : no ISR no BSL
Denomi. : is calculated without ISR and BSL

$$\Delta\chi^2 = \chi^2 - \chi^2_{min}$$







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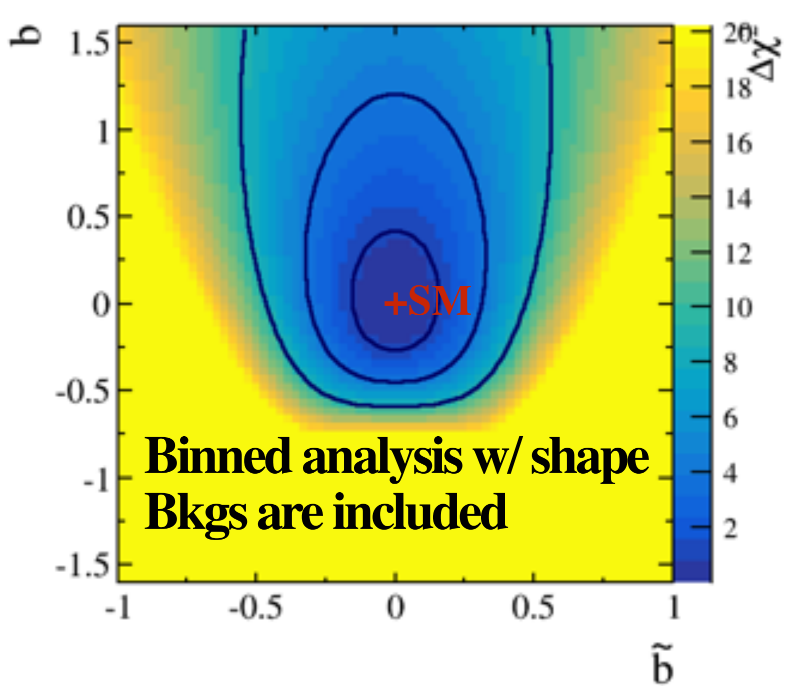

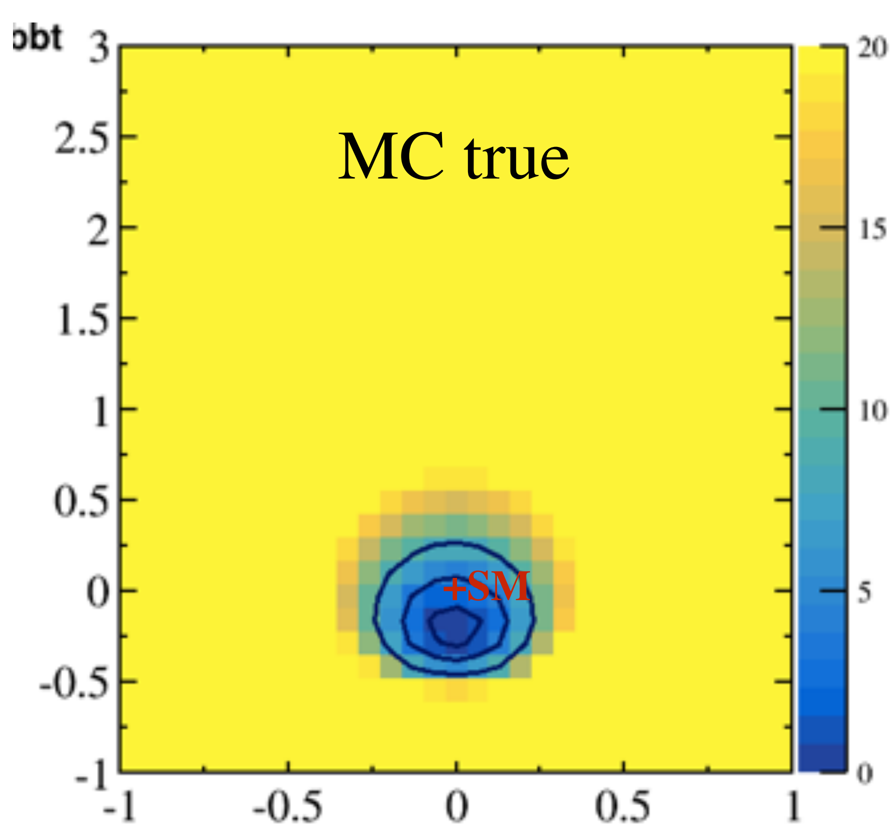

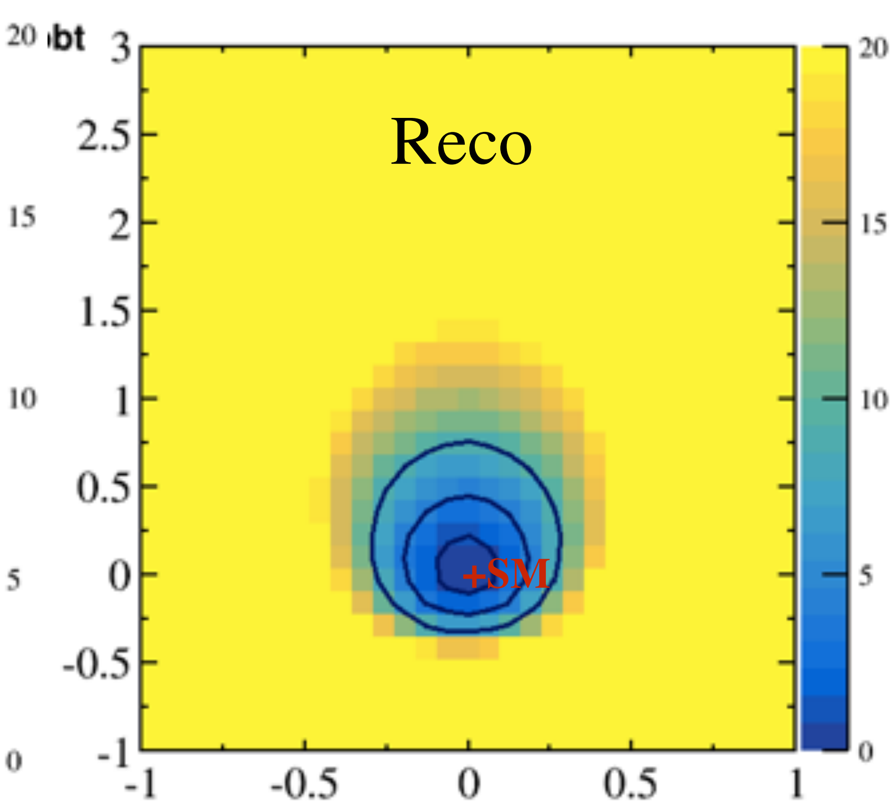

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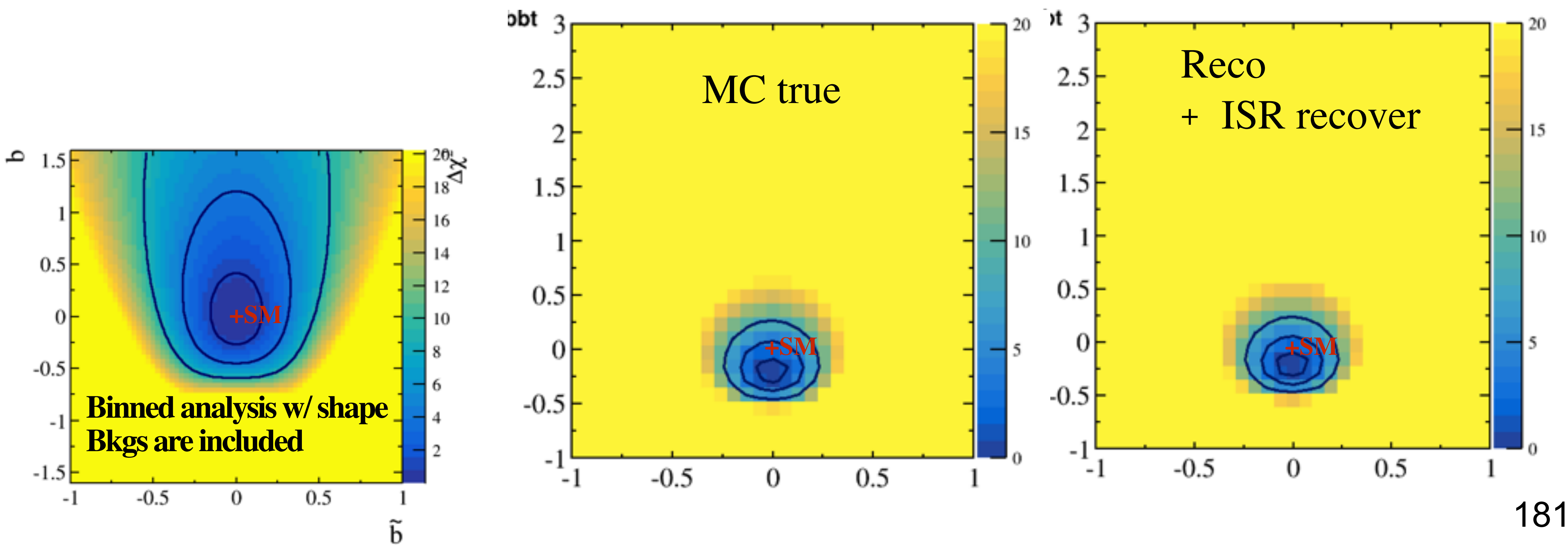

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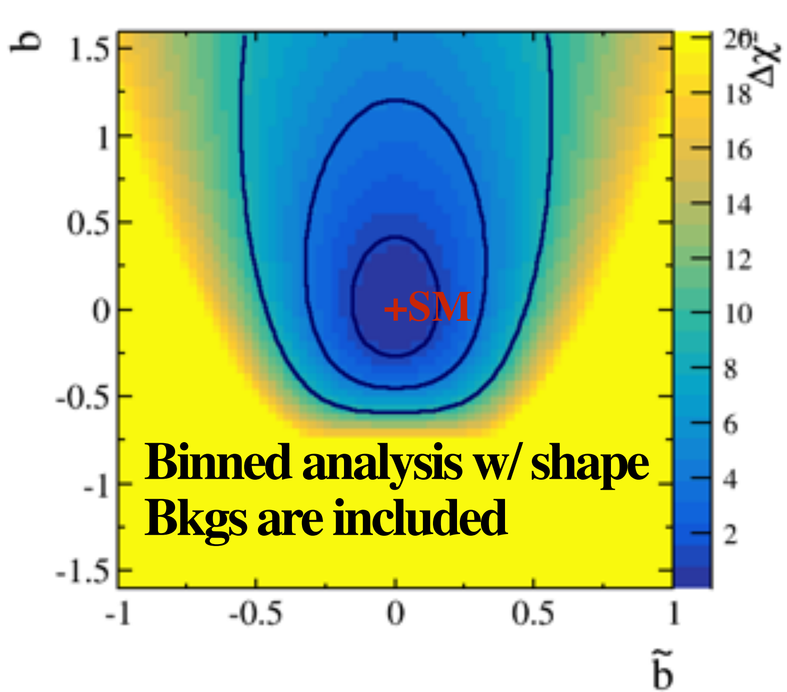
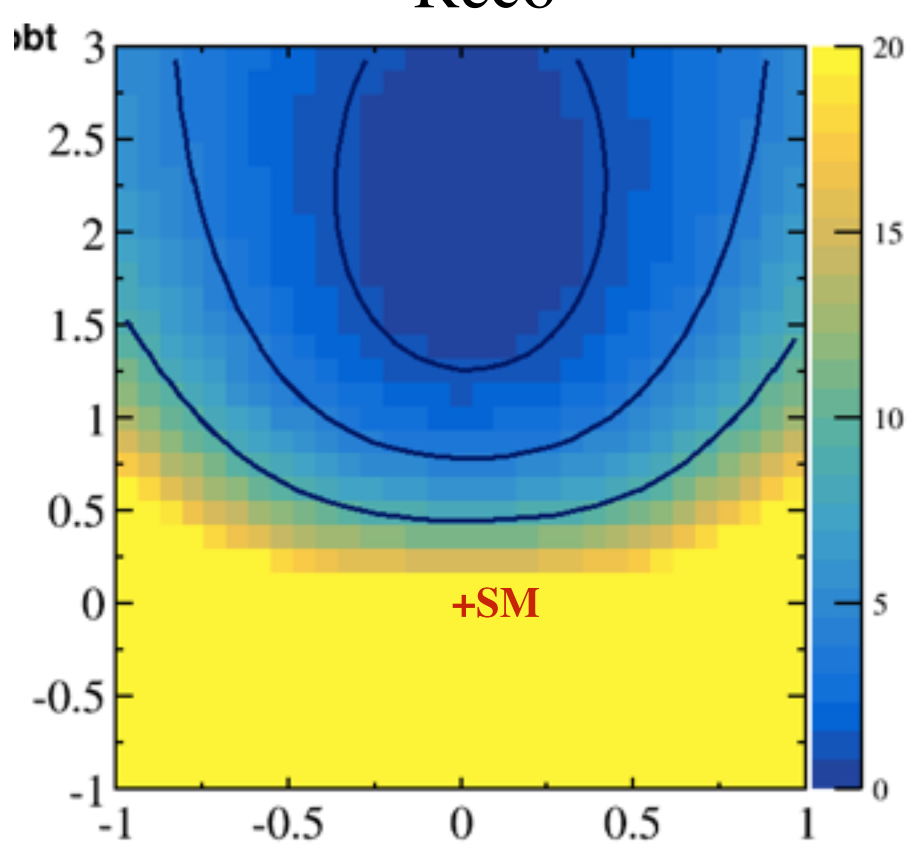
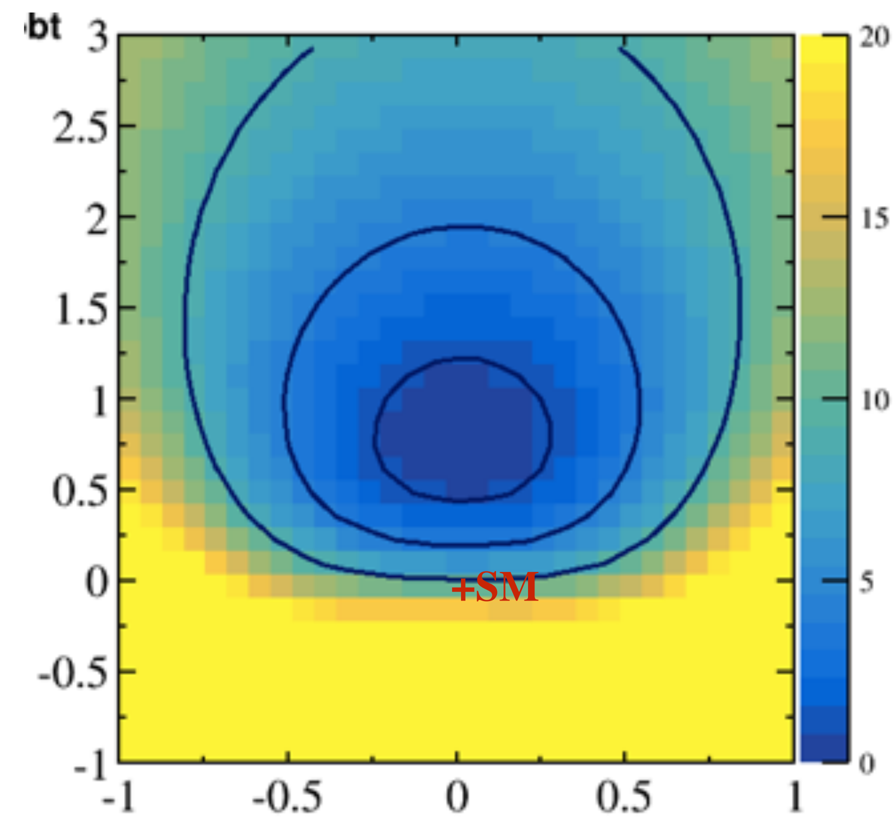


Reco



Reco
+ ISR recover



Summary

ME : is LO

how difficult to handle NLO

$e^+e^- \to ZH \to \mu^+\mu^- H$ at 250 GeV

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Is it possible to submit the study to ALCW

Denominator normalization

$$P_{\text{shape}}(\vec{p}^{\,\mu};\vec{a}_V) = \frac{A_{cc}^{\mu\mu H}(\vec{p}^{\,\mu})|\mathcal{M}_{ZH\to\mu\mu H}(\vec{p}^{\,\mu};\vec{a}_V)|^2}{A_{cc}^{\mu\mu H}(\vec{p}^{\,\mu})\sigma_{ZH\to\mu\mu H}(\vec{a}_V)}$$

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Denominator must be correctly normalized to 1

σ varies depending on av

automatically Acc is included?

$$\text{Denomi} = \sum^{\text{MCremain}} \frac{|M(\text{bsm})|2}{|M(\text{sm})|2} \underbrace{\frac{\boldsymbol{\sigma}\ \textbf{(expect)}*L250}{N\ \text{gene}}}_{\text{MC weight}} / L250 = \sigma\ (\text{remaining})$$

Parameter estimation

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is normalized
with |M|2 of remaining events

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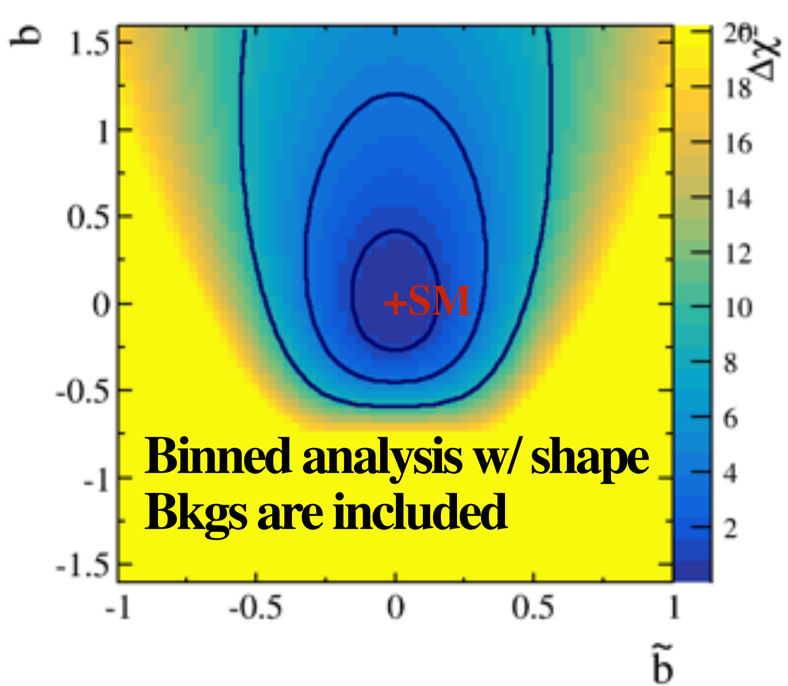

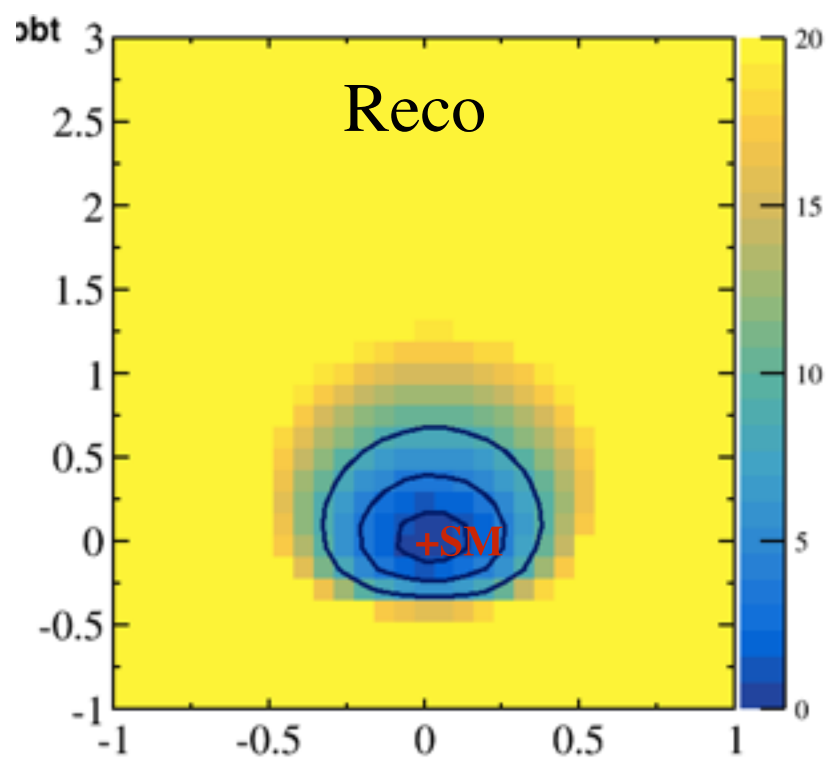

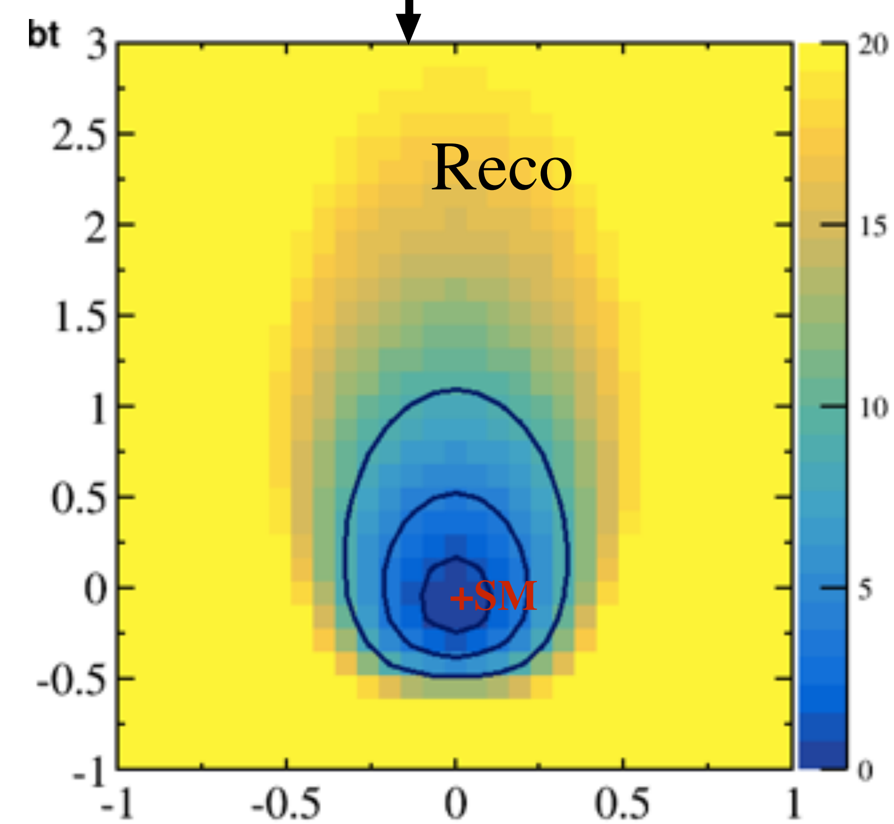

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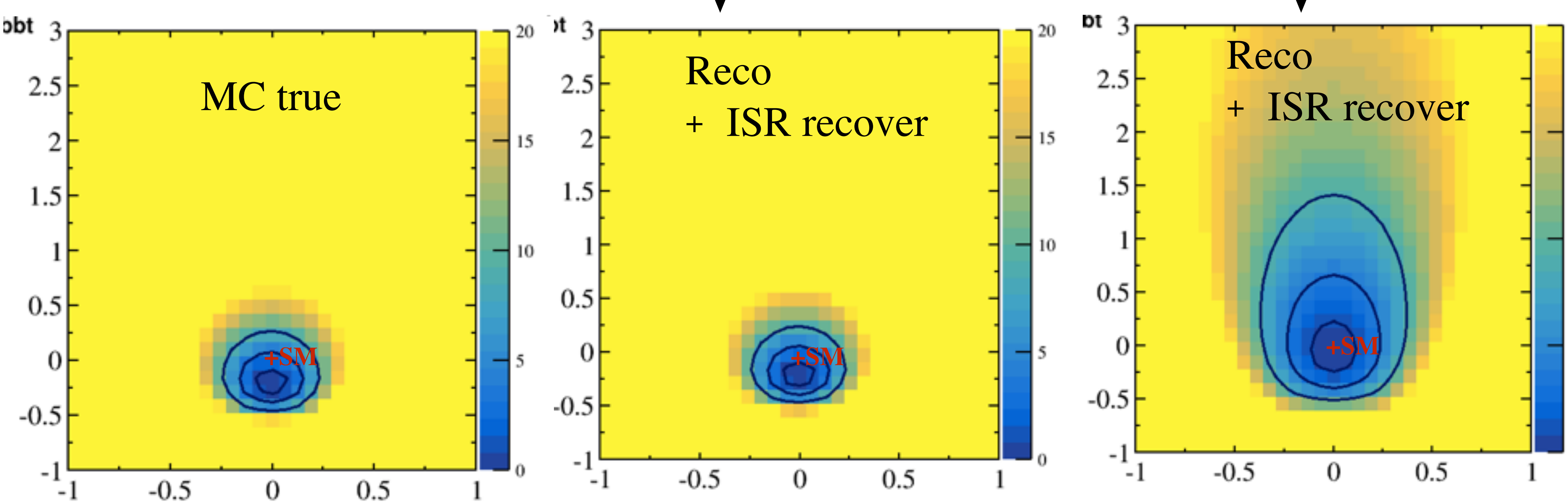

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