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IRN - Terascale, Frascati
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Kicking it Off(-shell)

with Direct Diffusion

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Tilman Plehn

arXiv: 2311.17175

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Why ML?

After high luminosity runs → ~ 20 times as much data

Theoretical predictions needs to be even **more precise**

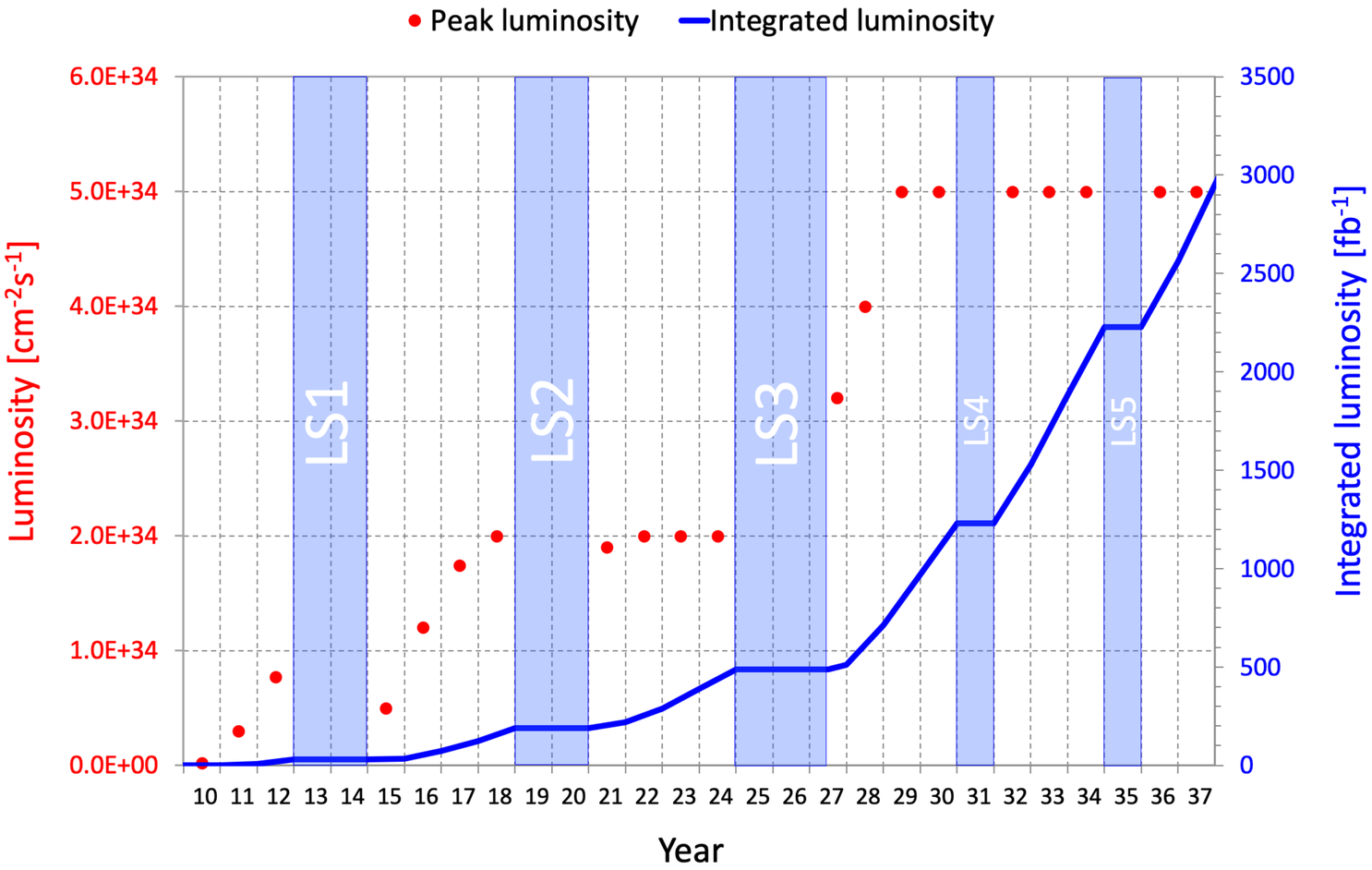


Figure from https://web.archive.org/web/20220706170326/https://lhc-commissioning.web.cern.ch/schedule/images/LHC-nominal-lumi-projection.png

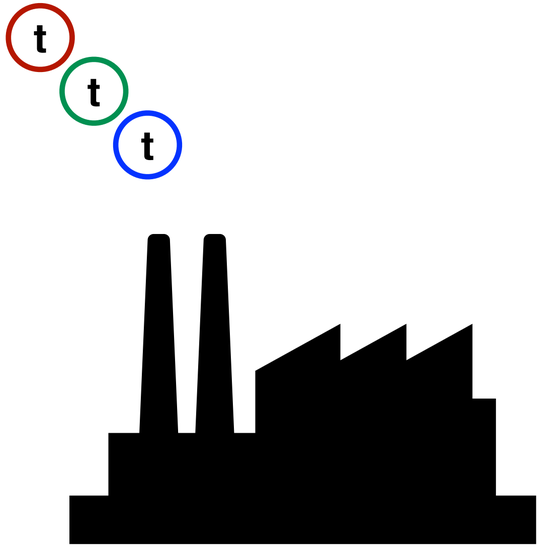
Kicking it Off

LHC = *"Top quark factory"*

Many ongoing physics analyses studying top quarks

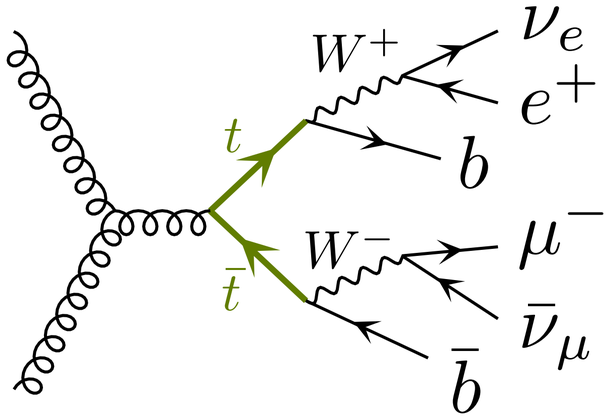
One of the most dominant background

Correct simulation is very important



Example — Leptonic ttbar decay

Leptonic ttbar-decay



Example: Determine top mass from leptonic ttbar decay

No access to neutrino information

→ Use $m_{l\bar{b}}$ to infer top mass

Example — Leptonic ttbar decay

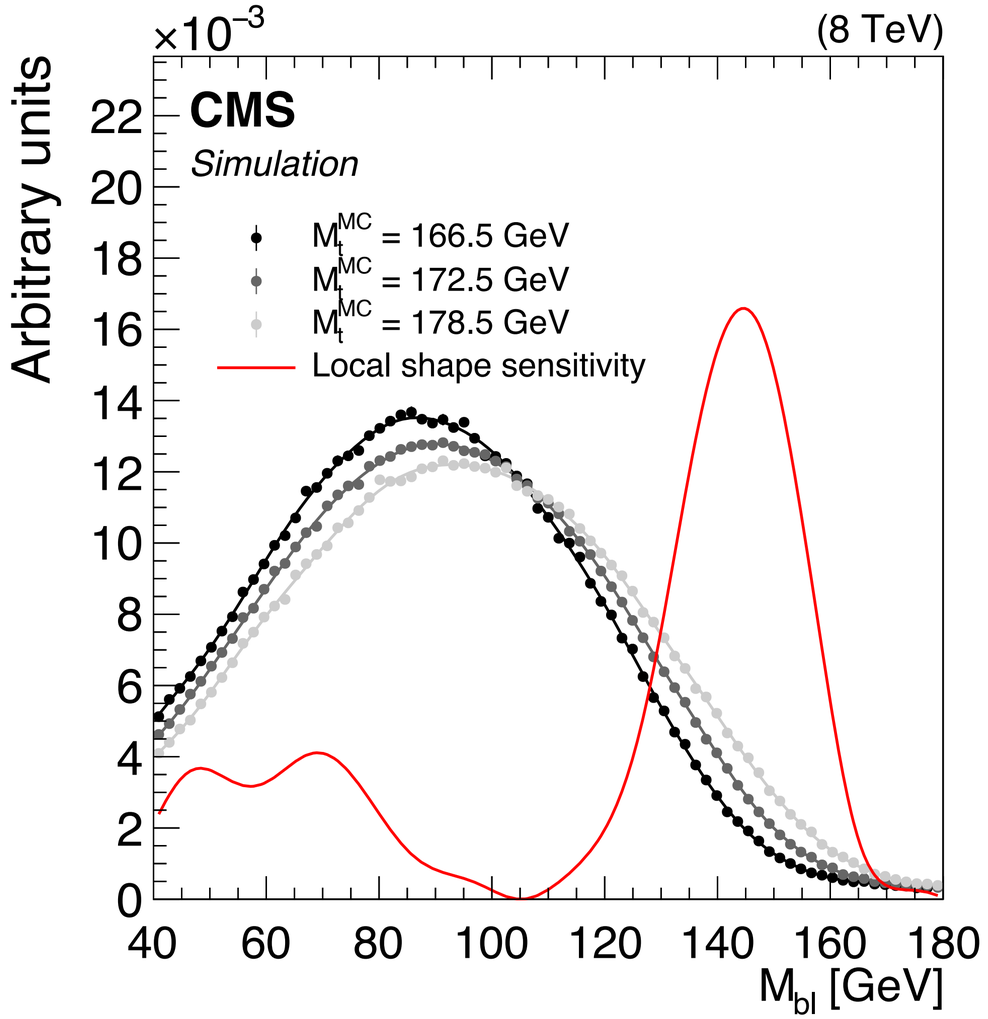


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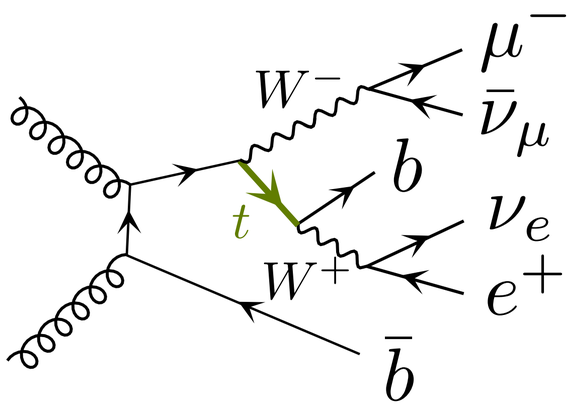
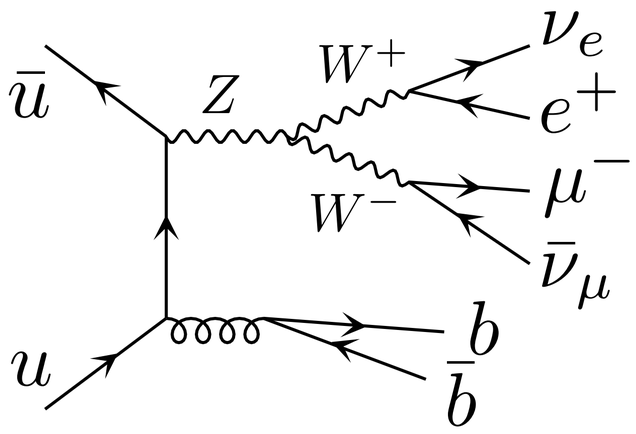
Figure from CMS arXiv:1704.06142v2

Off-Shell processes

Off-Shell processes



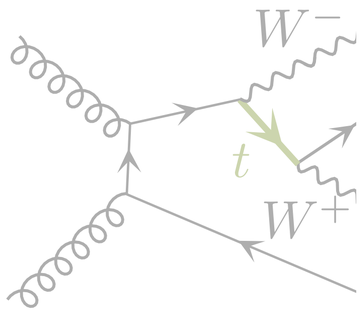


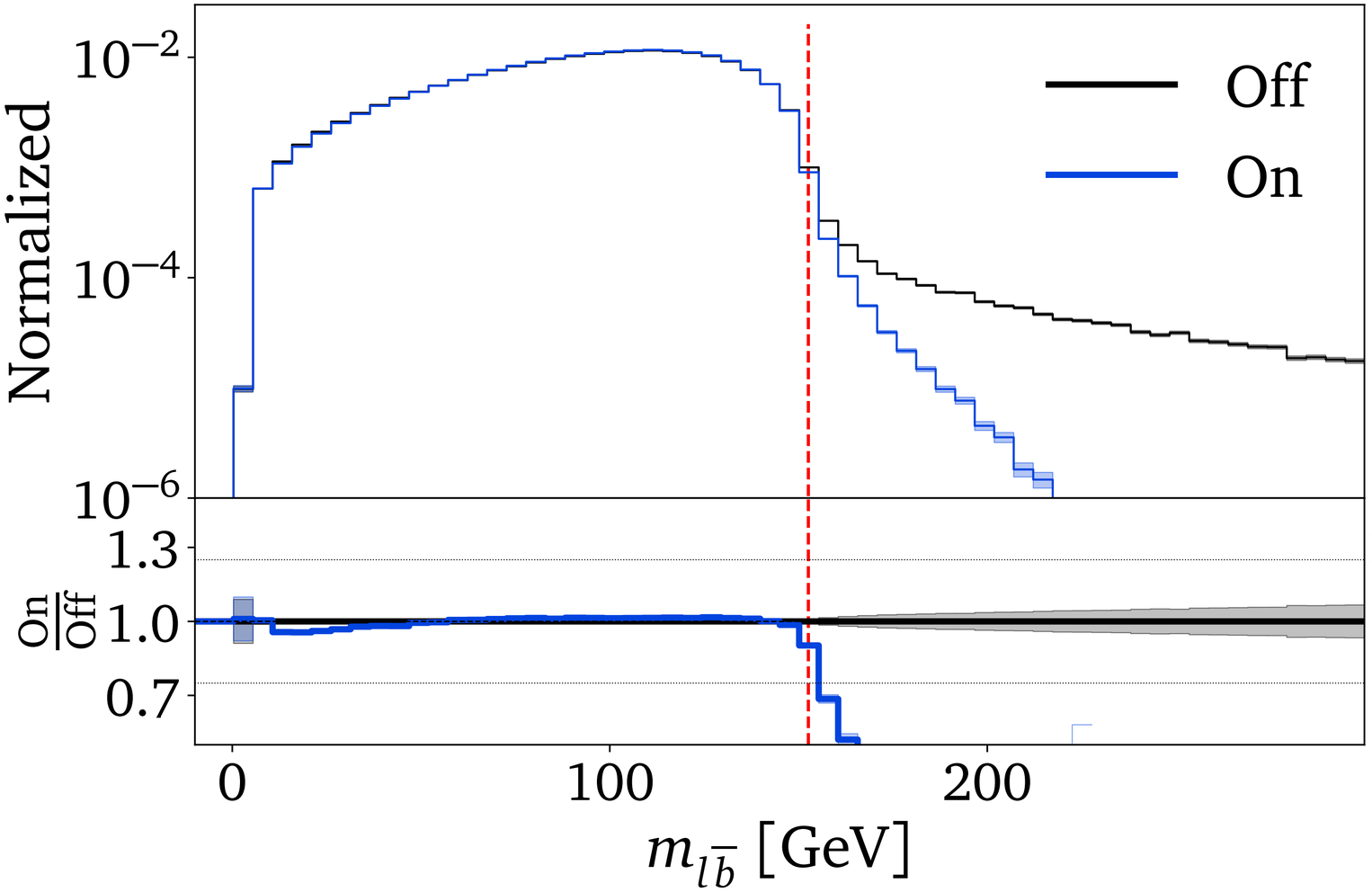
To be precise
→ account for off shell processes

Including off-shell processes
→ extremely costly

Off-Shell processes

Off-Shell processes





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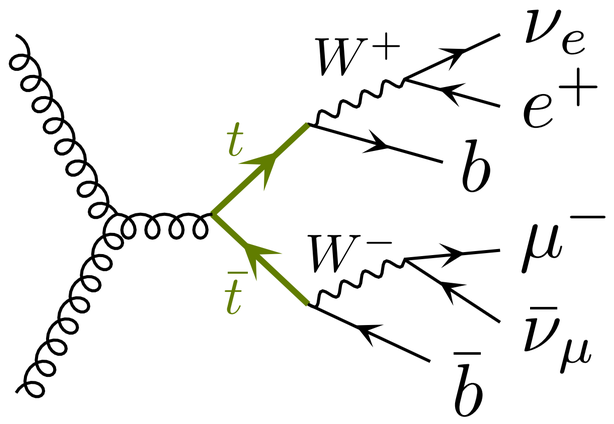
Off-Shell processes



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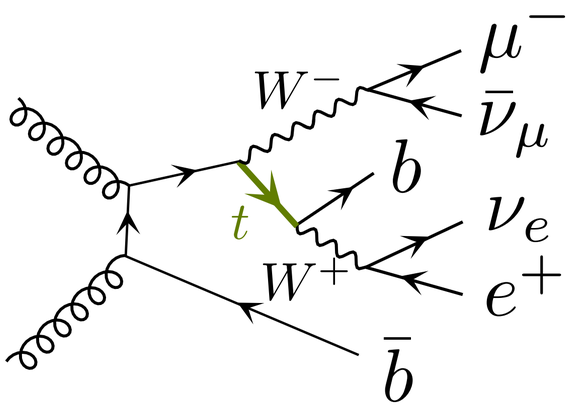
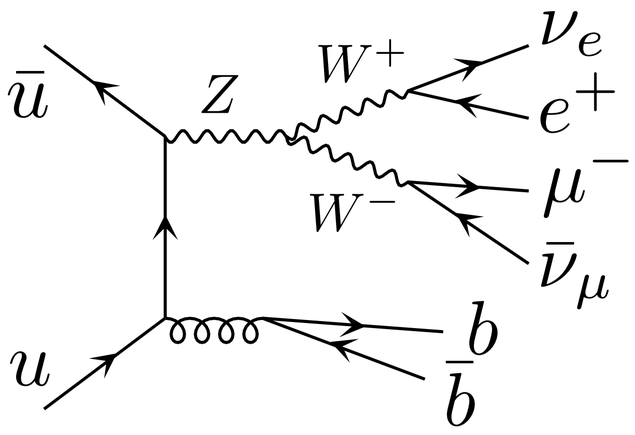
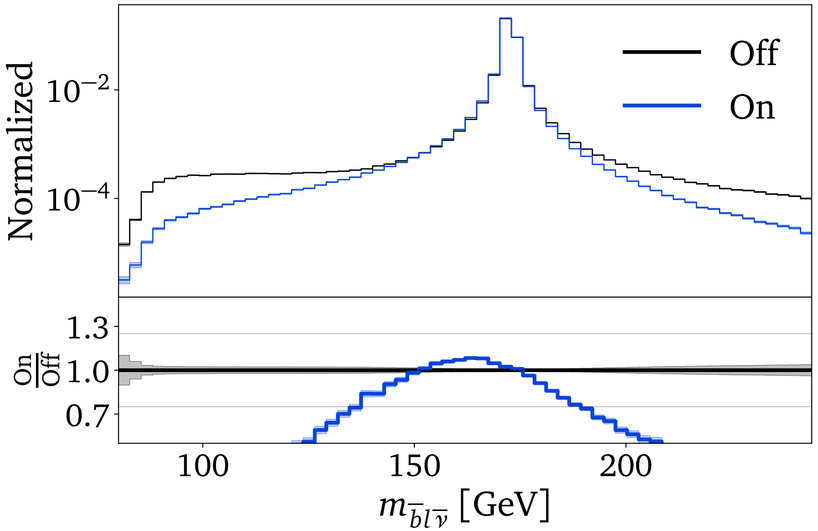


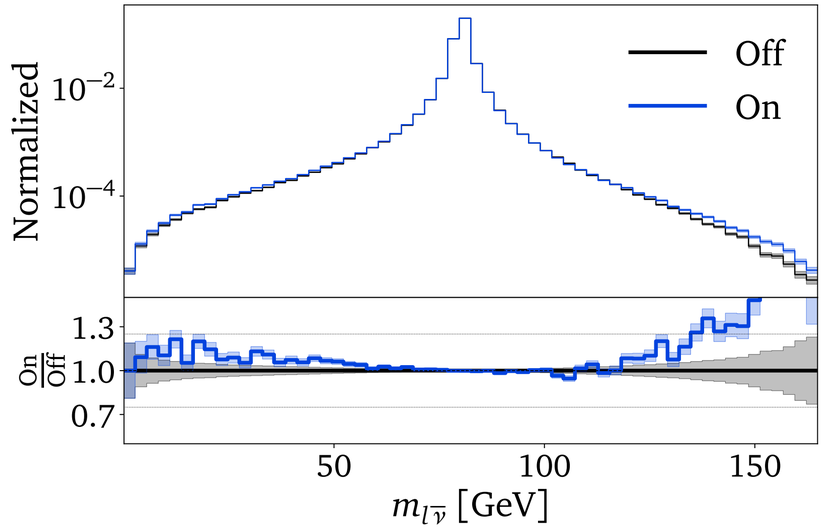


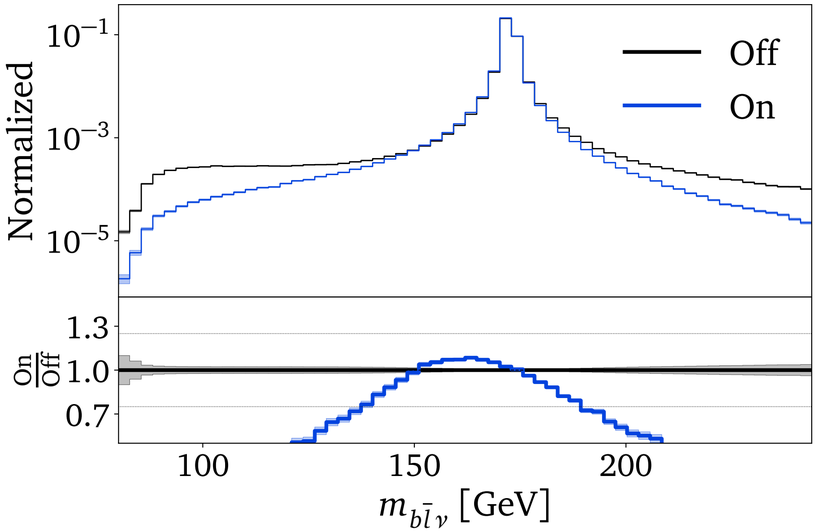
Need: Fast event generator

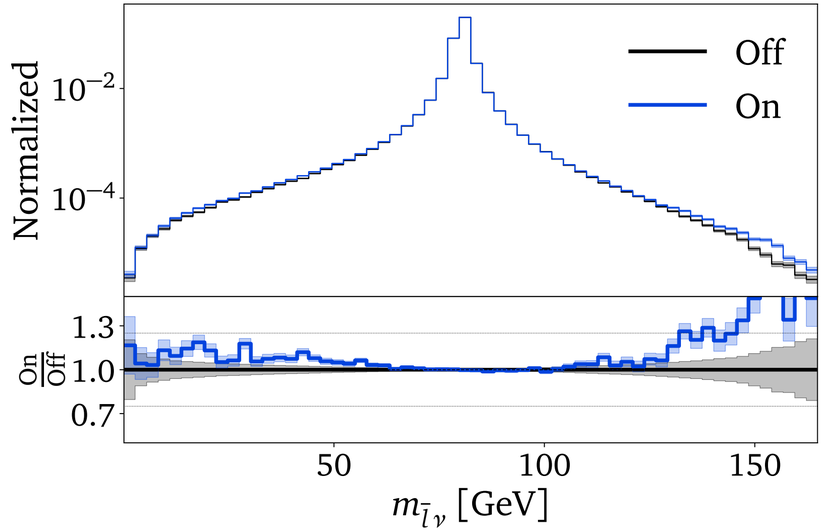
Problem: Multiresonant phase space in 24 dimensions

What's the problem?









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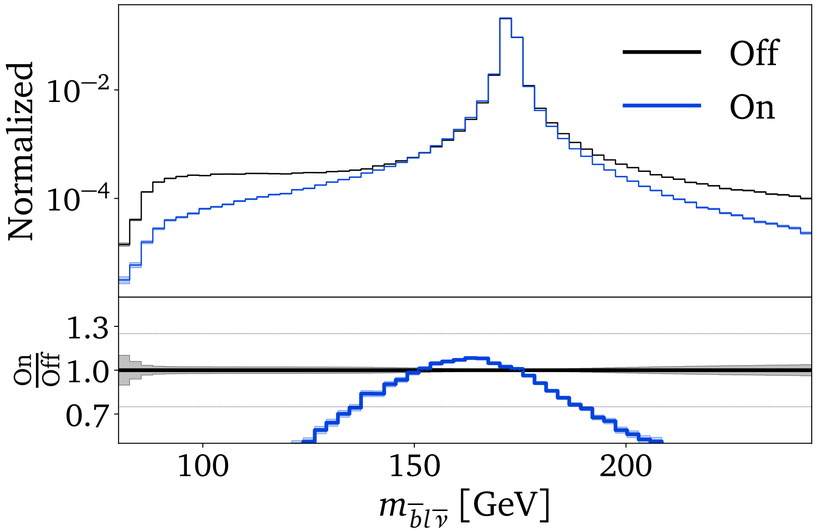
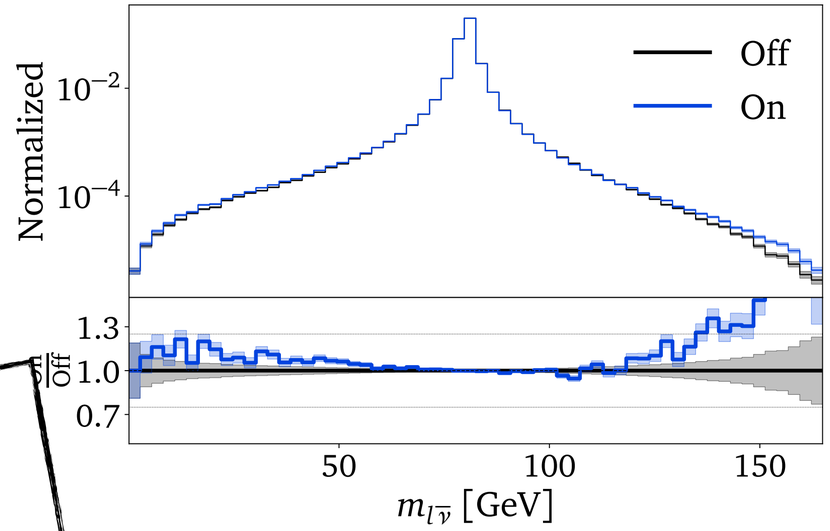
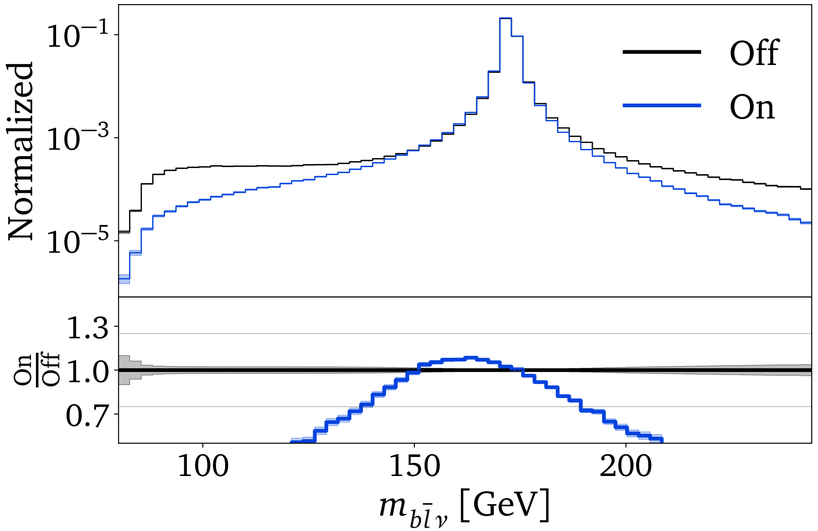
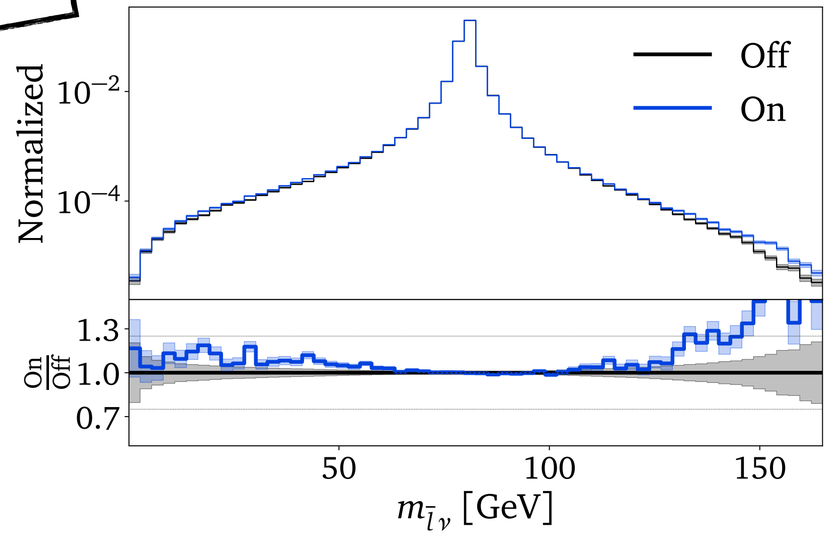




Can we just learn correction?





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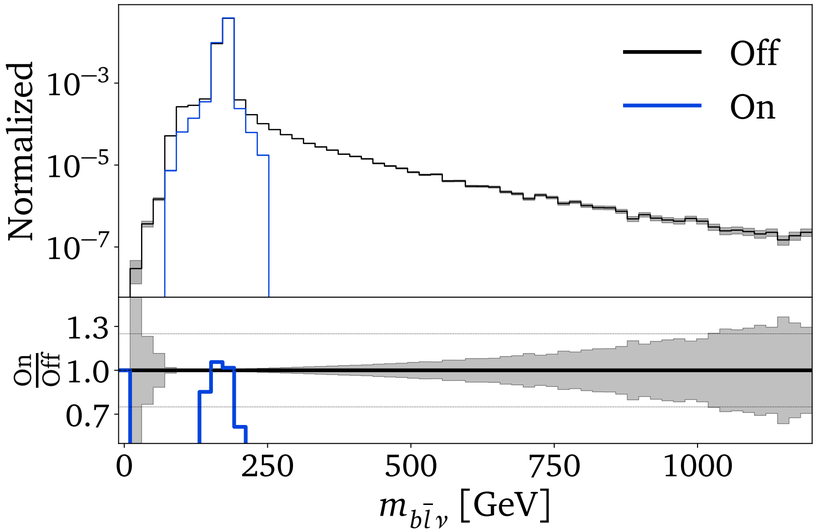

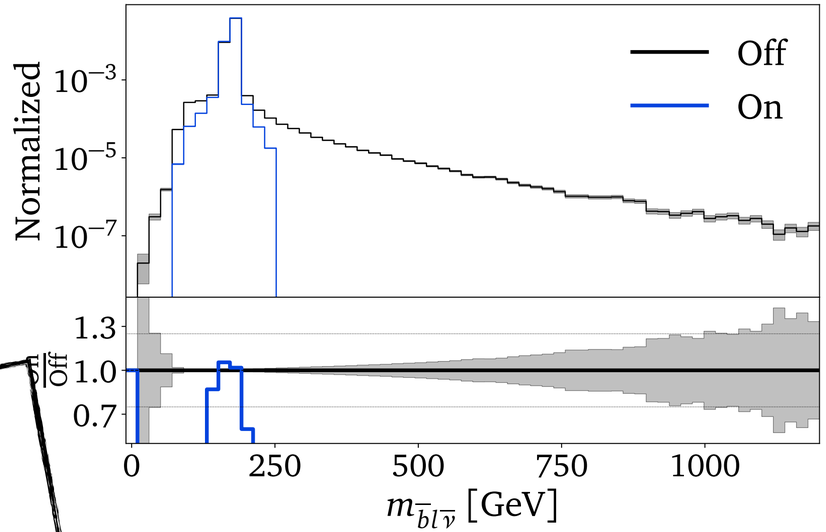

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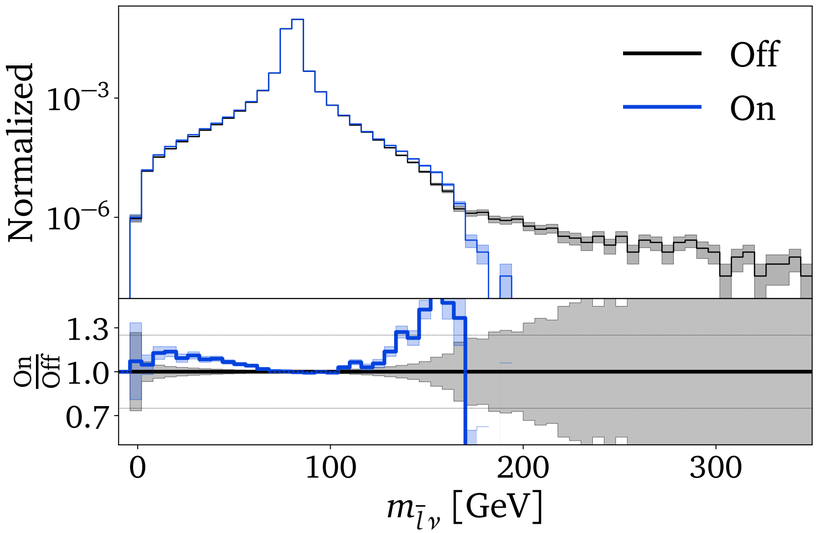
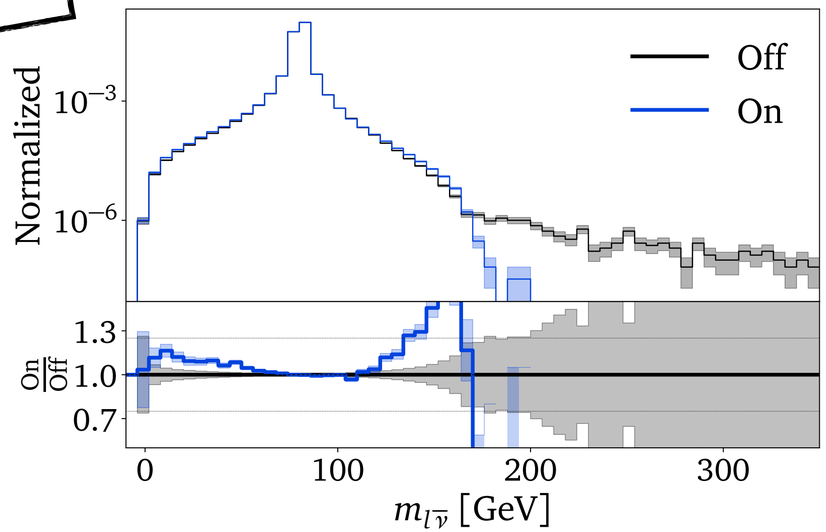




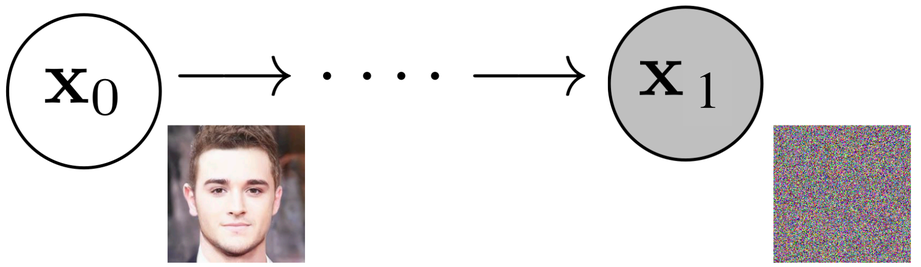
Diffusion Models (CFM)

Phase Space

$x_0 \sim p_0(x_0)$

Latent Space

$x_1 \sim p_1(x_1) (= \mathcal{N}(0,1))$

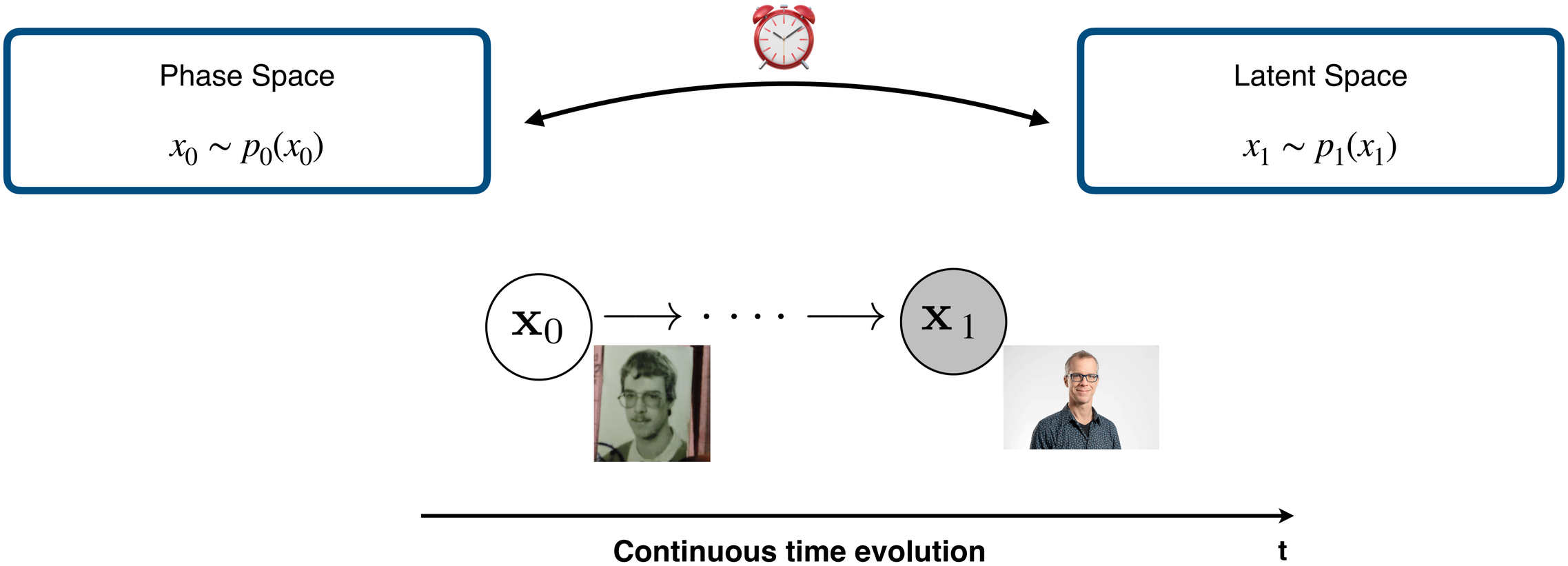


Continuous time evolution **t**

Evolution governed by $v \equiv \frac{dx}{dt}$

Figure from J.Ho et al.: arXiv:2006.11239

Diffusion Models (CFM)



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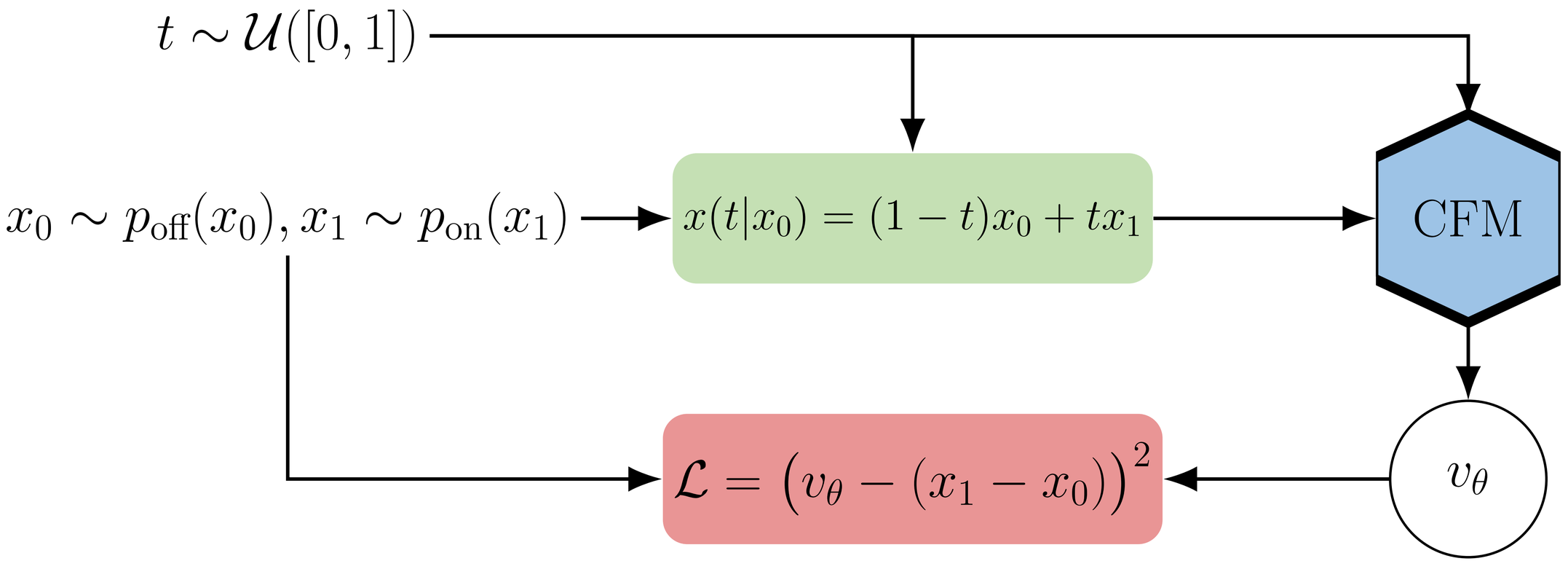

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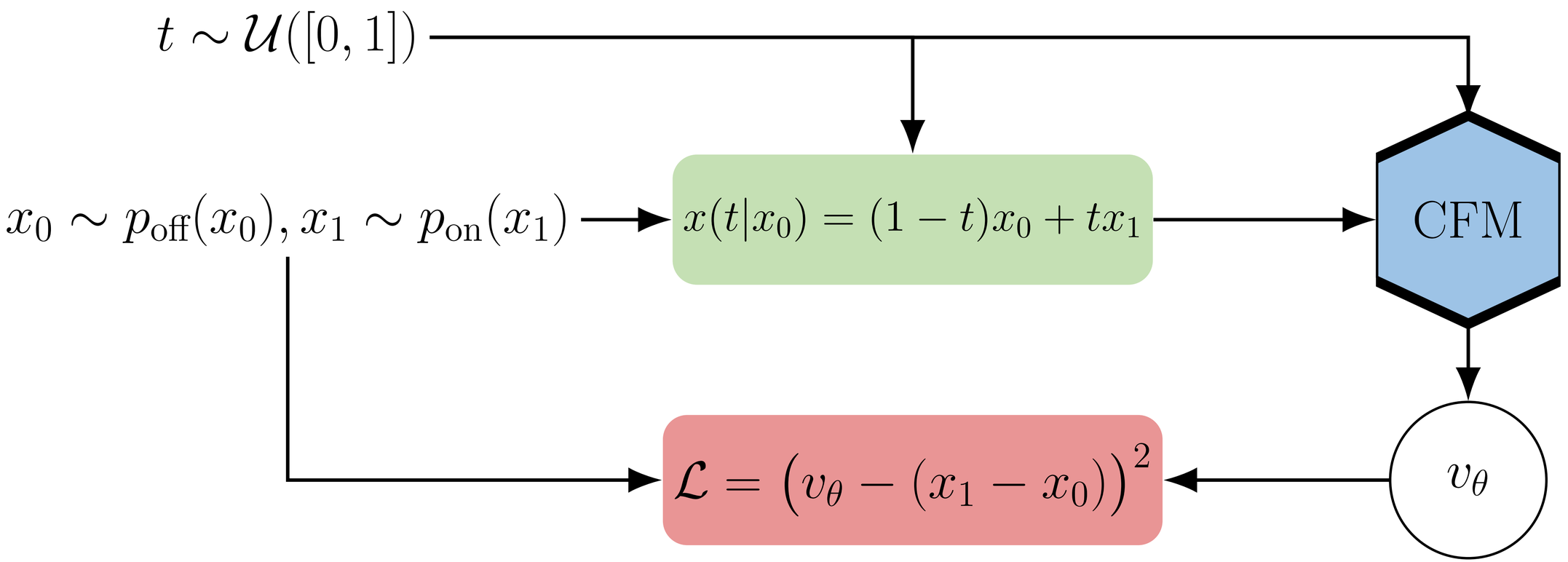

Direct Diffusion (DiDi)

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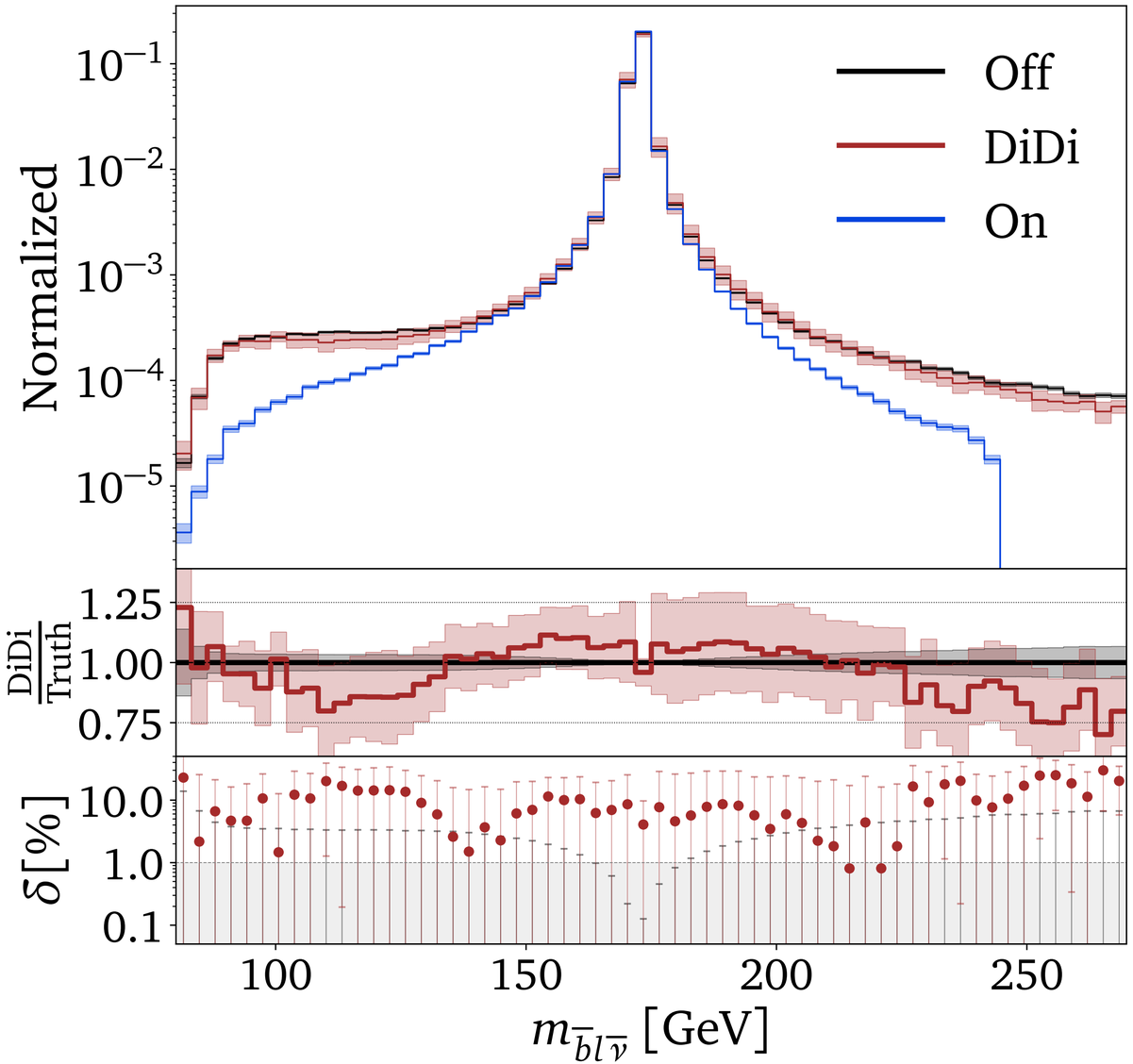
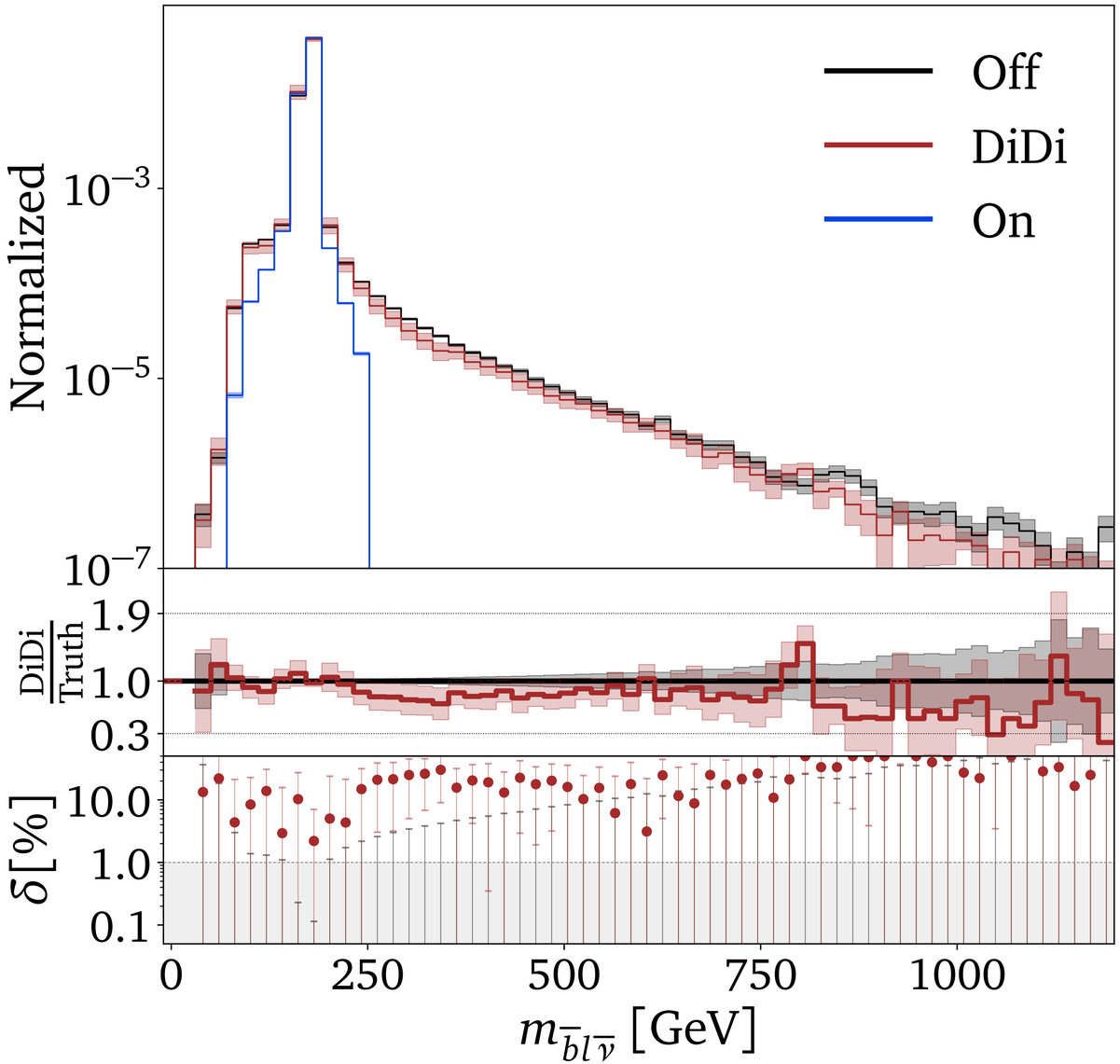


Dataset: on- & off-shell events on Parton level simulated with POWHEG

Reconstructed tbar mass learned to $\mathcal{O}(1\%)$ - $\mathcal{O}(10\%)$ precision

Direct Diffusion (DiDi) — Tails



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Also true for tails, with very little training statistic

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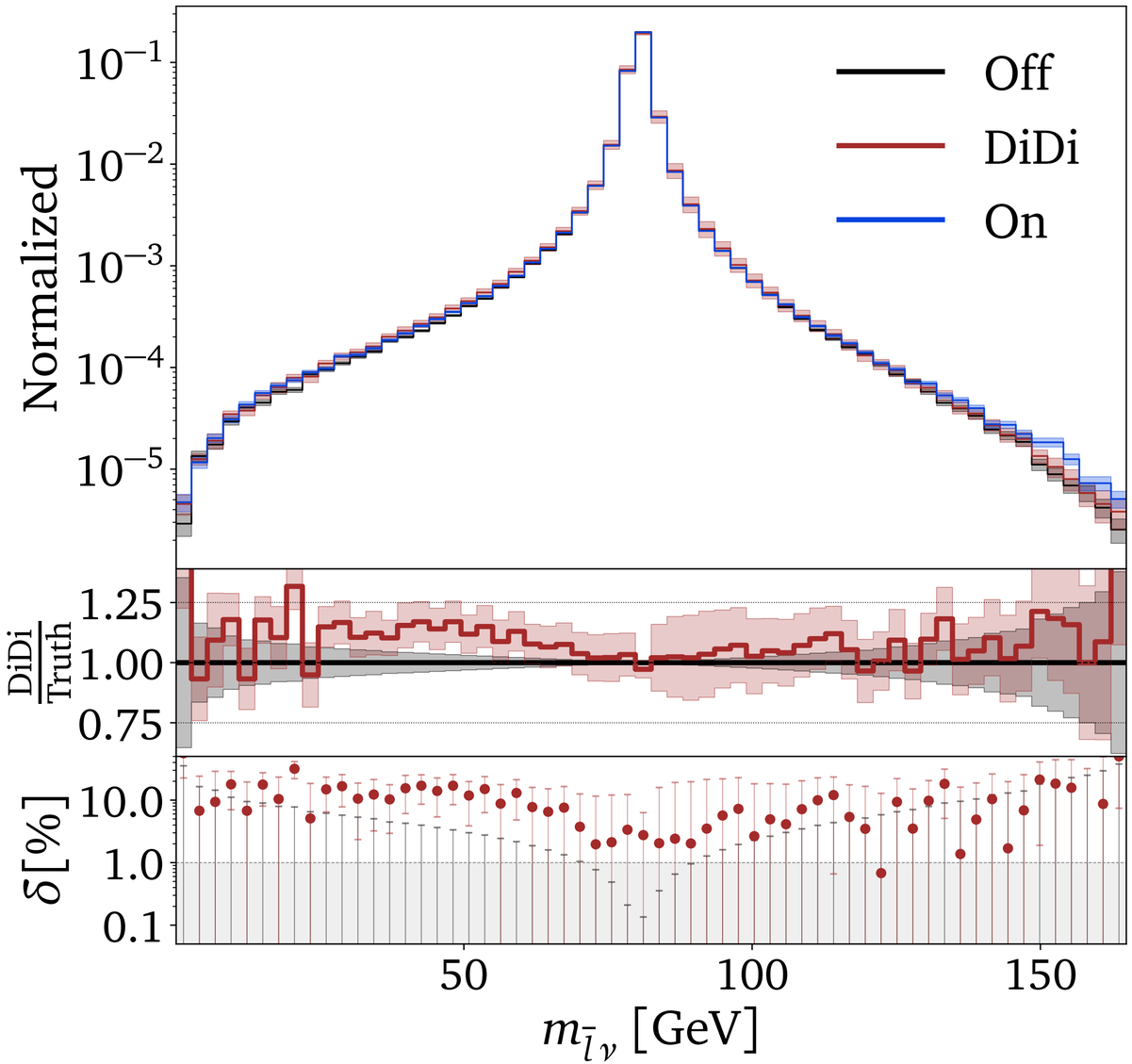

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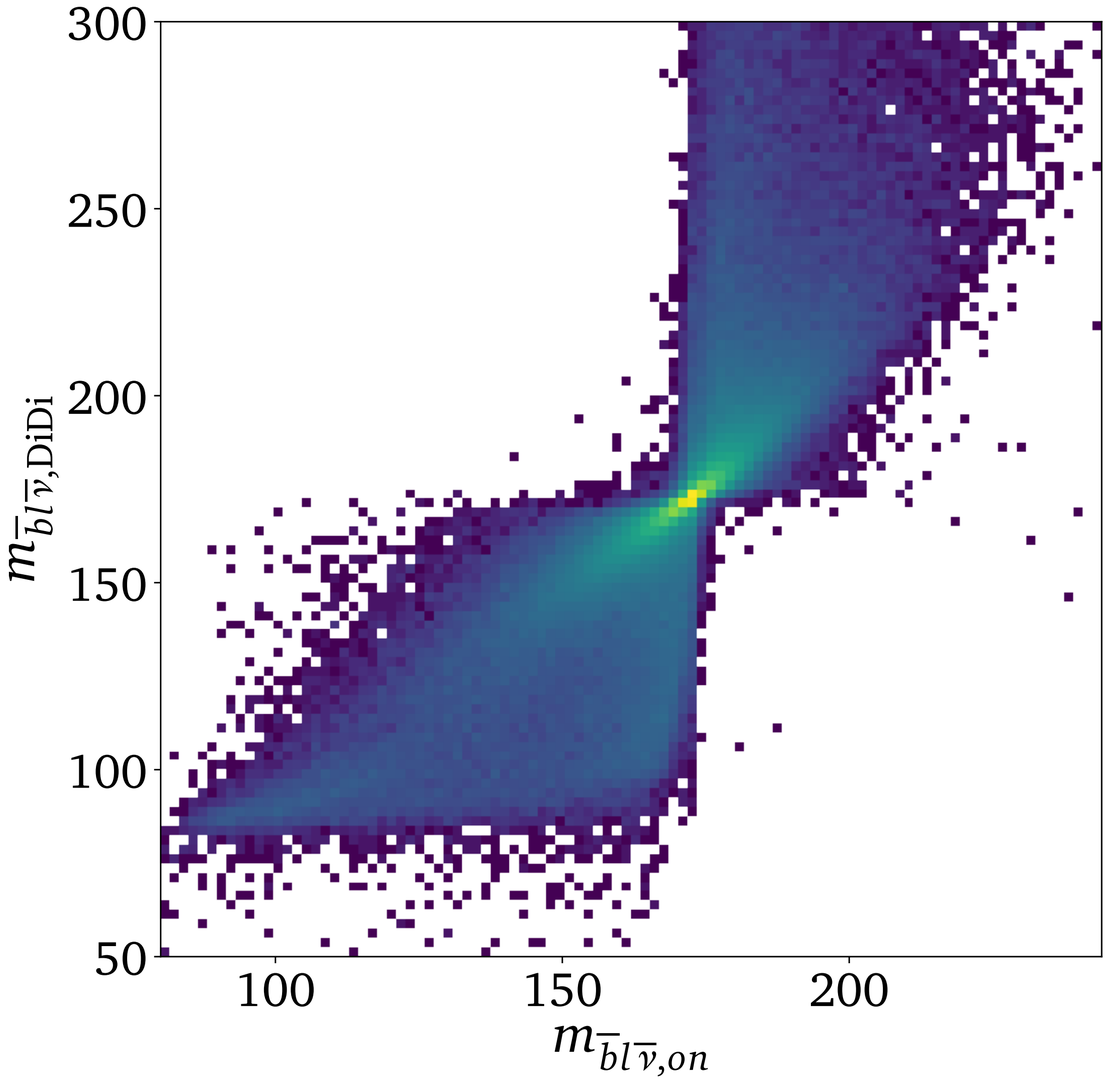
Multiresonant structure taken into account

Direct Diffusion (DiDi) — Migration

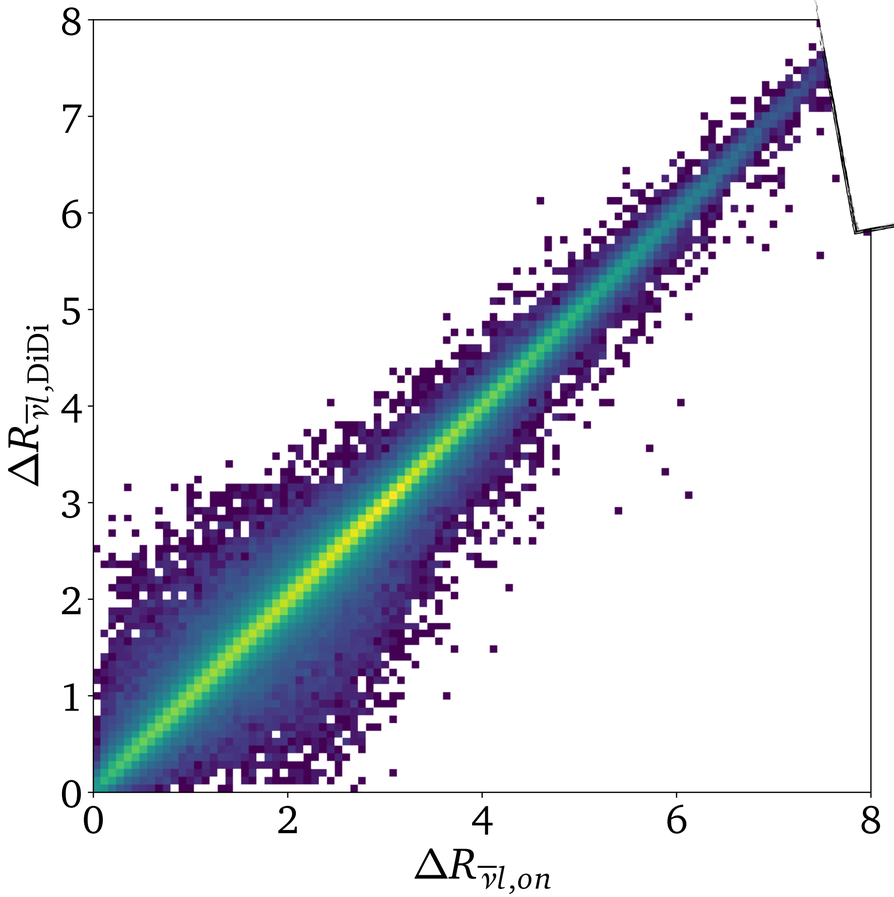


How does our mapping look like?

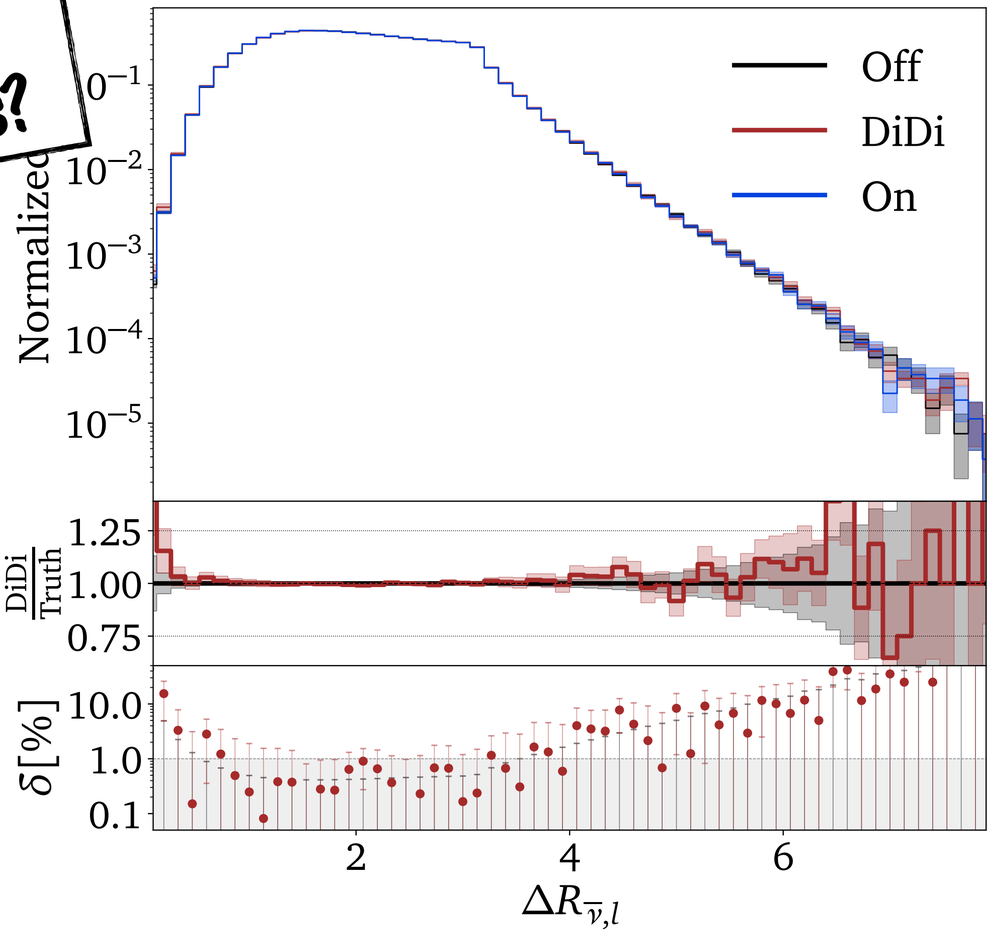
Biased to “optimal” transport (learned by DiDi)

No migration over peak

Direct Diffusion (DiDi) — Staying put

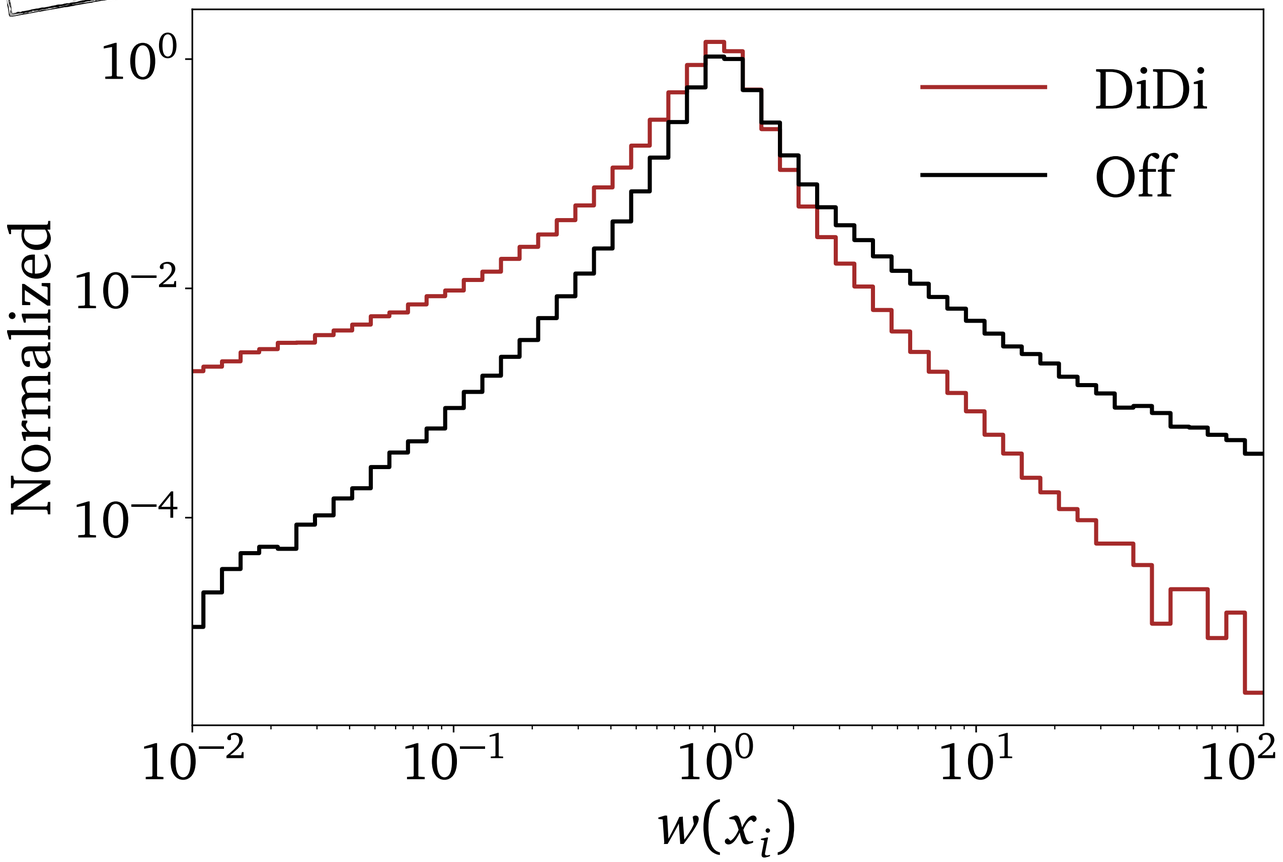


What about similar distributions?



Understanding our Shortcomings

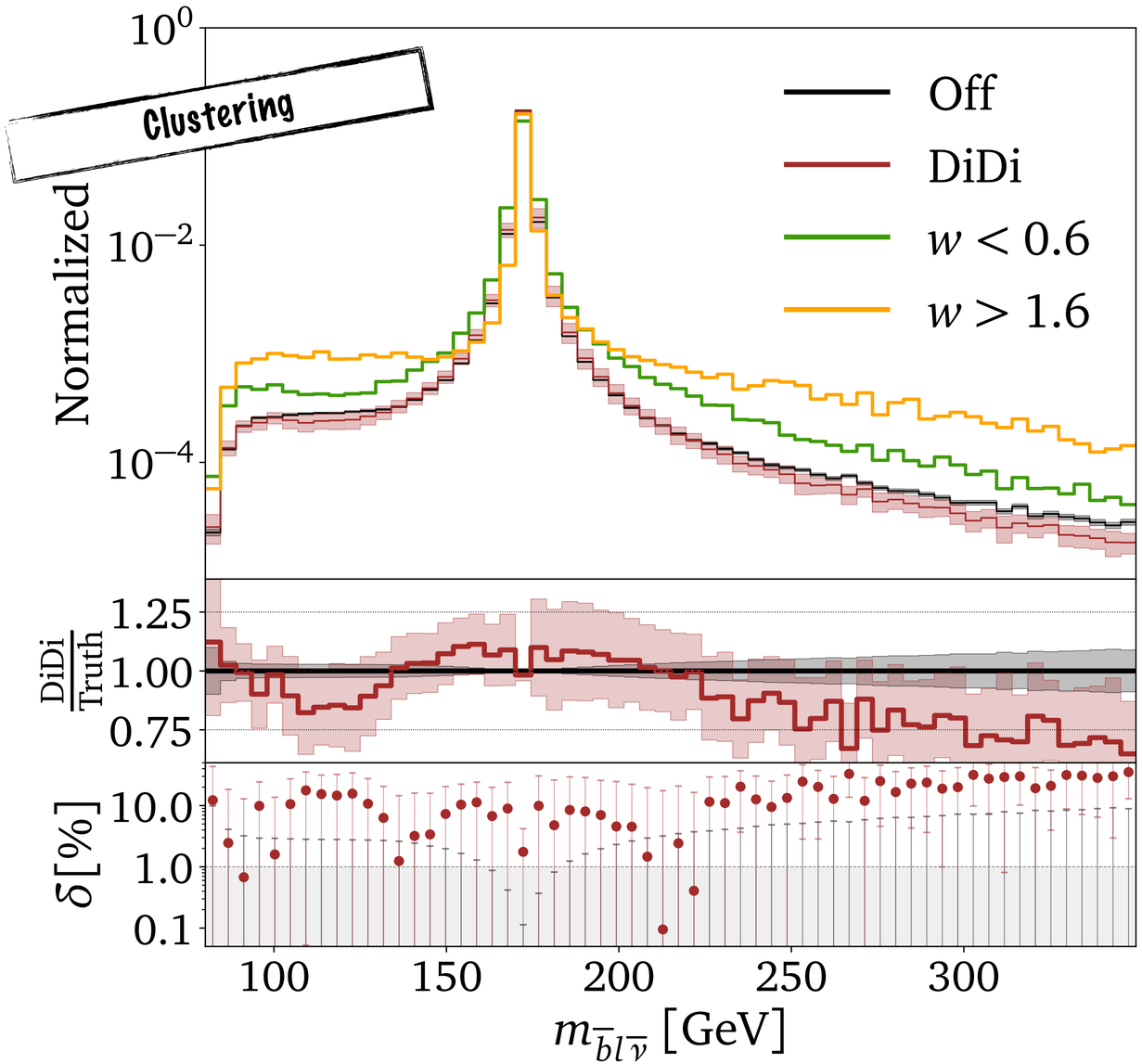
Performance



Train classifier to learn $w = \frac{p_{off}}{p_{gen}}$

Allows us to check performance, clustering and reweight distribution

Understanding our Shortcomings



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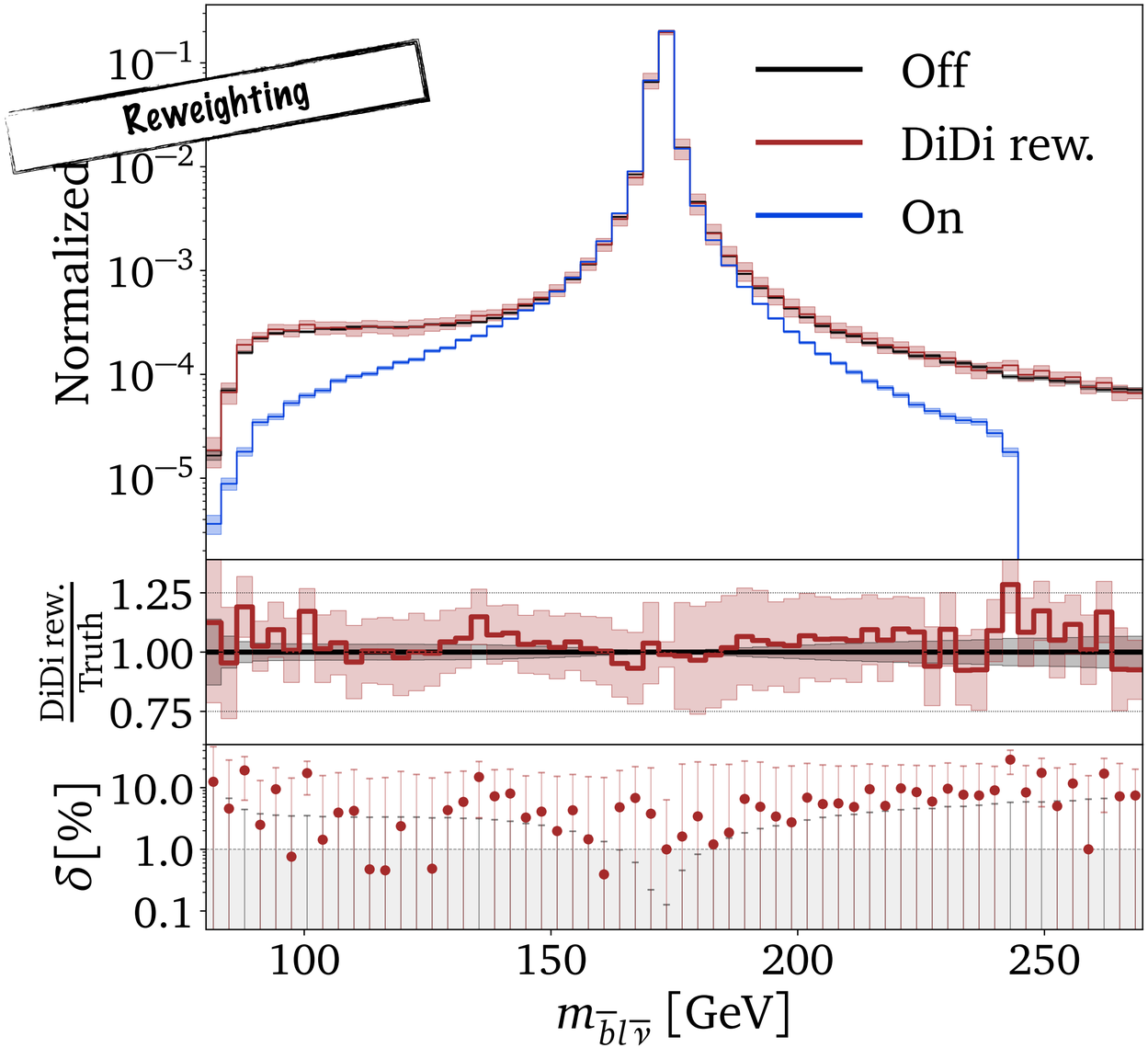

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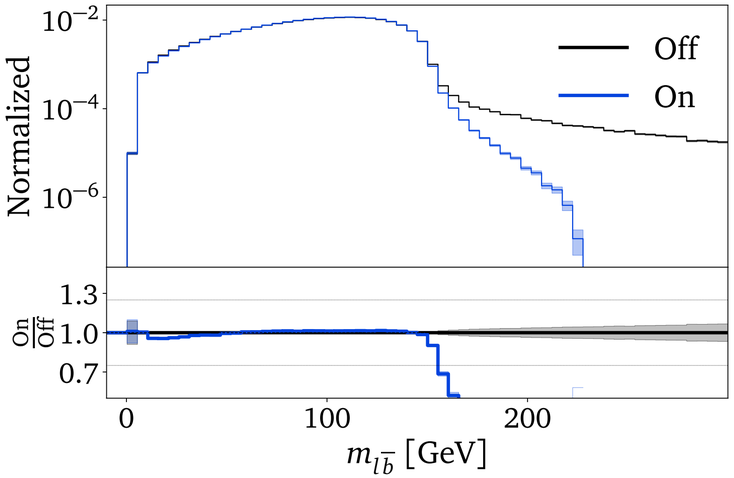
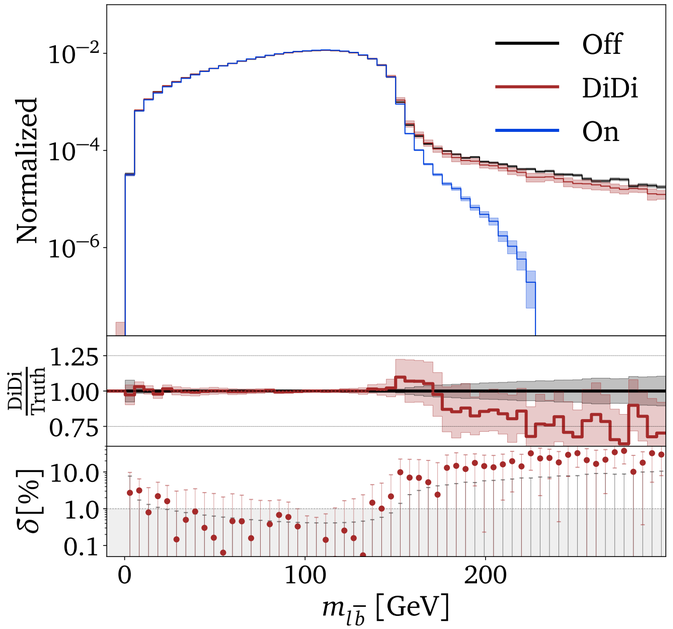
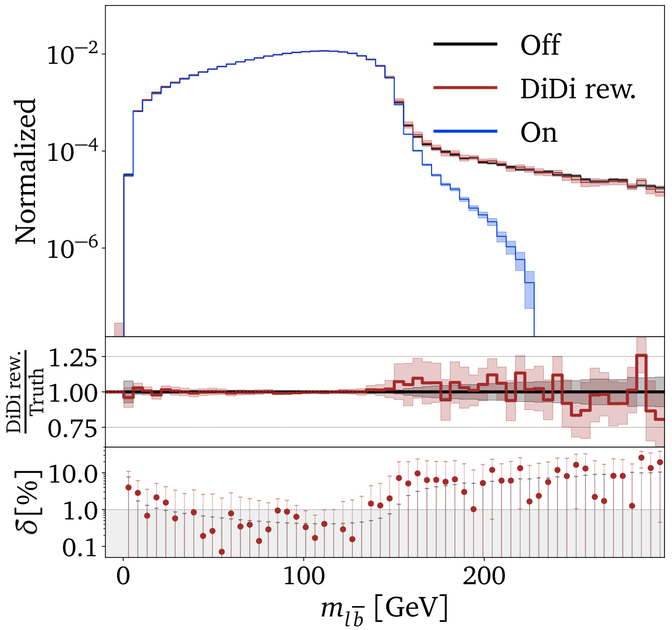
Summary


Normalized
Off
On
On/Off
$m_{l\bar{b}}$ [GeV]


Normalized
Off
DiDi
On
DiDi/Truth
δ[%]
$m_{l\bar{b}}$ [GeV]


Normalized
Off
DiDi rew.
On
DiDi rew./Truth
δ[%]
$m_{l\bar{b}}$ [GeV]

And now what?

Generative ML shows great potential to **speed-up** LHC event generation

Direct Diffusion allows to **morph two unknown, intractable distributions** onto each other while reaching **state-of-the-art precision**

Successfully applied to **generate full off-shell distributions** from on-shell distributions

Next steps: Apply setup to NLO + NNLO