High-energy EFT probes: the DY process

Multi-Boson Interactions 2021

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Based on:

[LR, Torre, Wulzer (2020)]

[Panico, LR,Wulzer (2021)]

High-energy EFT probes: Introduction

Low-energy effects of heavy new physics are naturally described by the EFT language

$$E \ll \Lambda$$

$$\mathcal{L}_{SMEFT} = \mathcal{L}_{SM} + \sum_i \frac{c_i^{(6)}}{\Lambda^2} O_i^{(6)} + \dots$$

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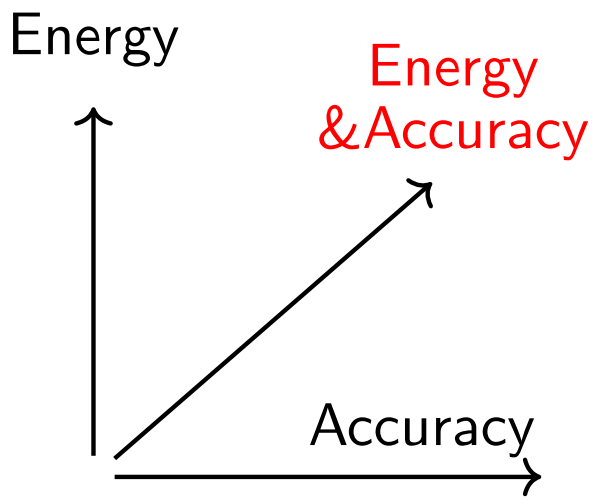
Deviation from the SM can grow with the energy:

$$\boxed{\frac{\Delta \mathcal{O}}{\mathcal{O}} \sim \frac{E^2}{\Lambda^2}}$$

High-energy EFT probes

EW precision physics from high energy measurements

- Energy improves the accuracy
- Effects can overcome the systematics
- LHC can be more accurate then LEP



High-energy EFT probes: To-do list

→ Growing-with-energy targets

- Define the observables and design the analyses
- Assess sources of uncertainties

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- "Fast" BSM predictions
- PDF uncertainties reduction

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→ Interpret the results

- EFT validity
- Reach tables and translation to UV models

High-energy EFT probes: To-do list

→ Growing-with-energy targets ← (Fully-diff analysis including the 7 quark-lepton interactions)

- Define the observables and design the analyses
- Assess sources of uncertainties

→ Accurate theoretical predictions

- NLO∼automated, NNLO∼available, NLO-EW∼available
- "Fast" BSM predictions (NLO_{QCD}+1L-EW_{logs} events by reweighting)
- PDF uncertainties reduction

→ Dedicate experimental measurements X

→ Interpret the results ←(Projections)

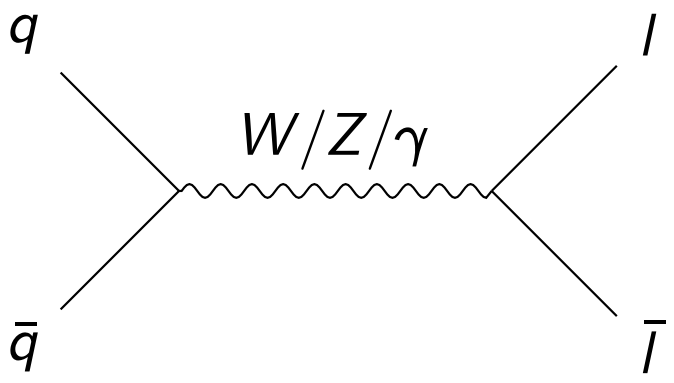
- EFT validity
- Reach tables and translation to UV models

Dilepton DY@(HL-)LHC

[LR, Torre, Wulzer (2020)]

[Panico, LR, Wulzer (2021)]

High-energy EFT probes: the DY process



l^+l^- or $l\nu$

+ Large cross-sections
+ "Easy" signal: the final state is fully characterized by fully differential distributions
+ LO interference between SM and BSM

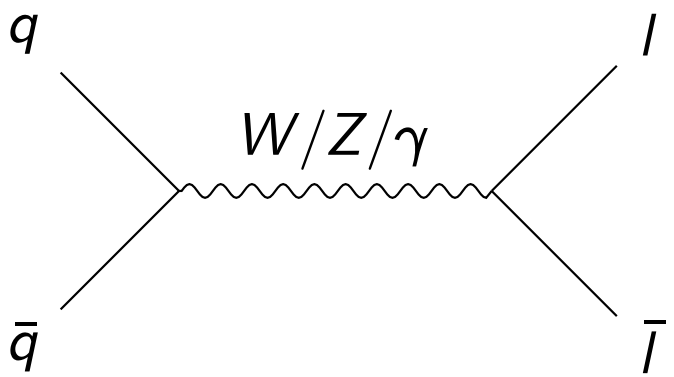
= The ideal high-energy probe

See also:

[Blas, Chala, Santiago (2013)]

[Farina et al. (2017)]

High-energy EFT probes: the DY process



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$$\frac{(\mathcal{A}_{SM}+\mathcal{A}_{BSM})^2}{\mathcal{A}_{SM}^2} \sim 1 + \#c_i \frac{E^2}{\Lambda^2}$$

$\xrightarrow{+\text{ Universal NP}}$ W & Y [Barbieri, et al. (2004)]

$\xrightarrow{+\text{Flavour universality}}$ [Grzadkowski, et. al (2010)]

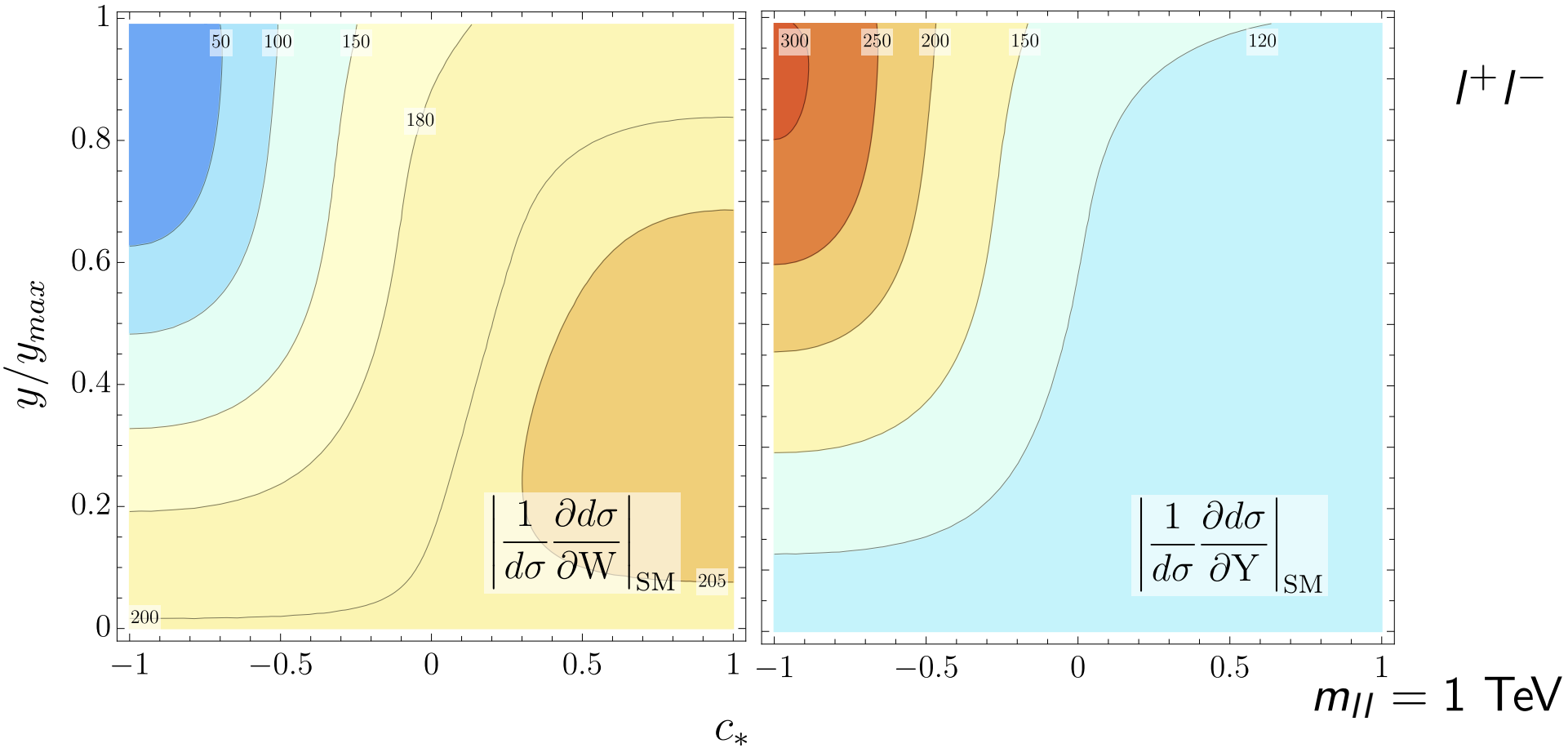
$$\underbrace{\left\{\mathcal{O}_{lq}^{(3)}, \mathcal{O}_{lq}^{(1)}, \mathcal{O}_{qe}, \mathcal{O}_{ue}, \mathcal{O}_{de}, \mathcal{O}_{ul}, \mathcal{O}_{dl}\right\}}_{\subset \mathcal{L}_{SMEFT}^{d=6}}$$

High-energy DY: Sensitivity to Universal NP

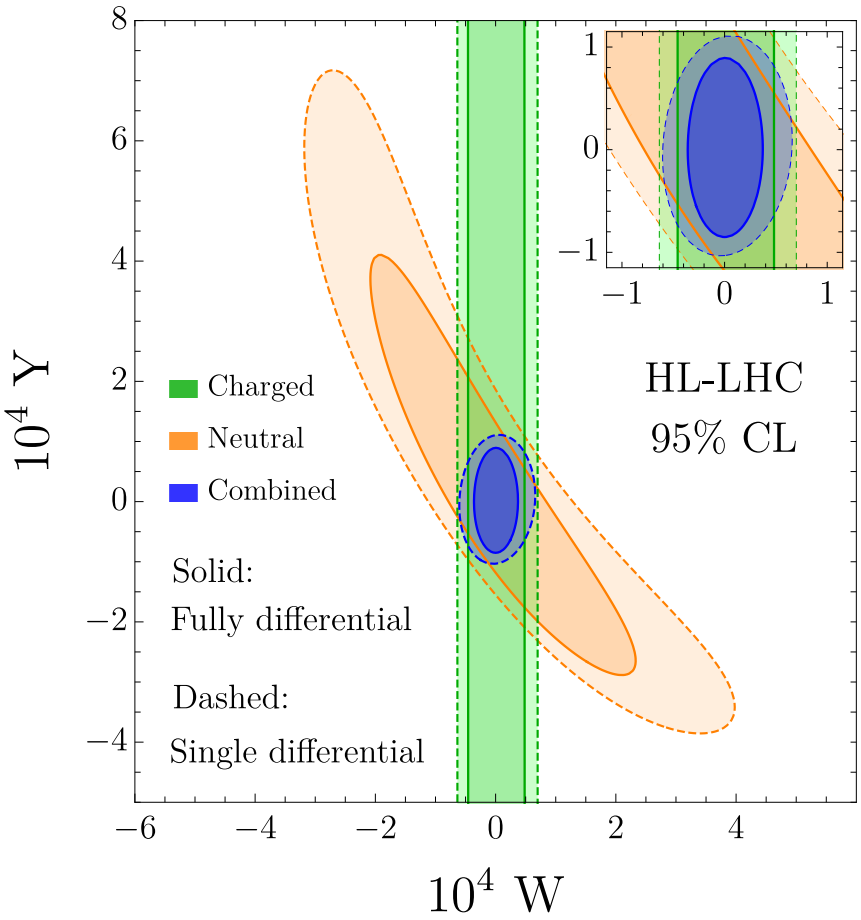
The DY final state is so simple that it can be properly characterized by triple (l^+l^-) and double ($l\nu$) differential measurements.

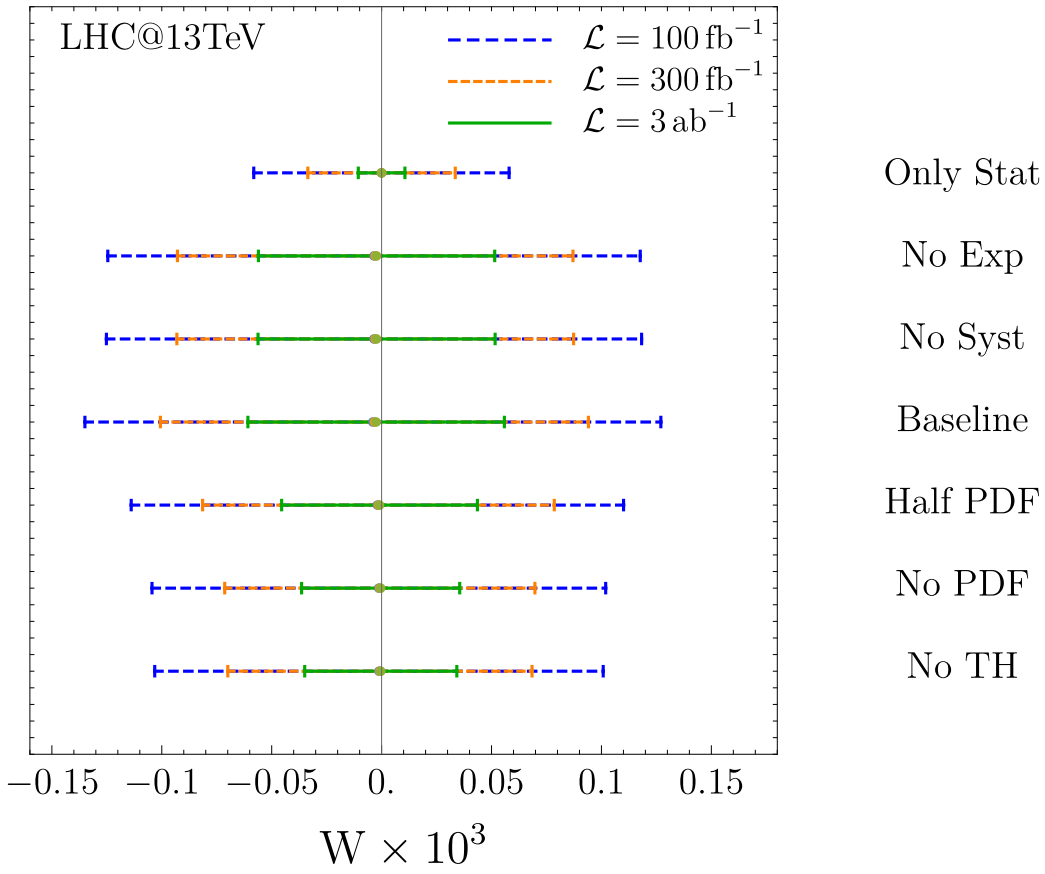
Can we exploit the fully-differential distributions to learn new physics?

(m_{ll}, c_*, y)



High-energy DY: Sensitivity to Universal NP



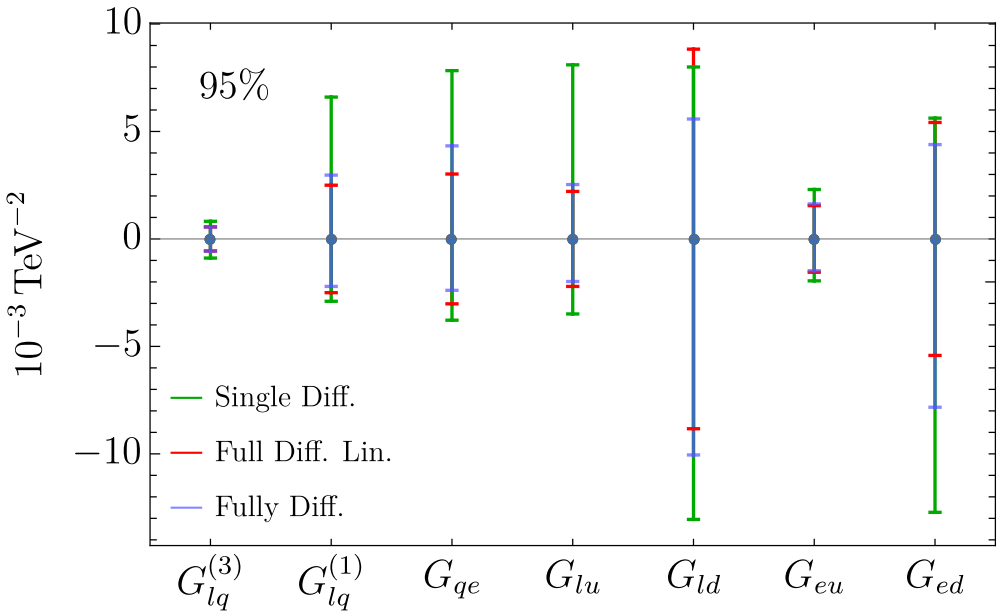


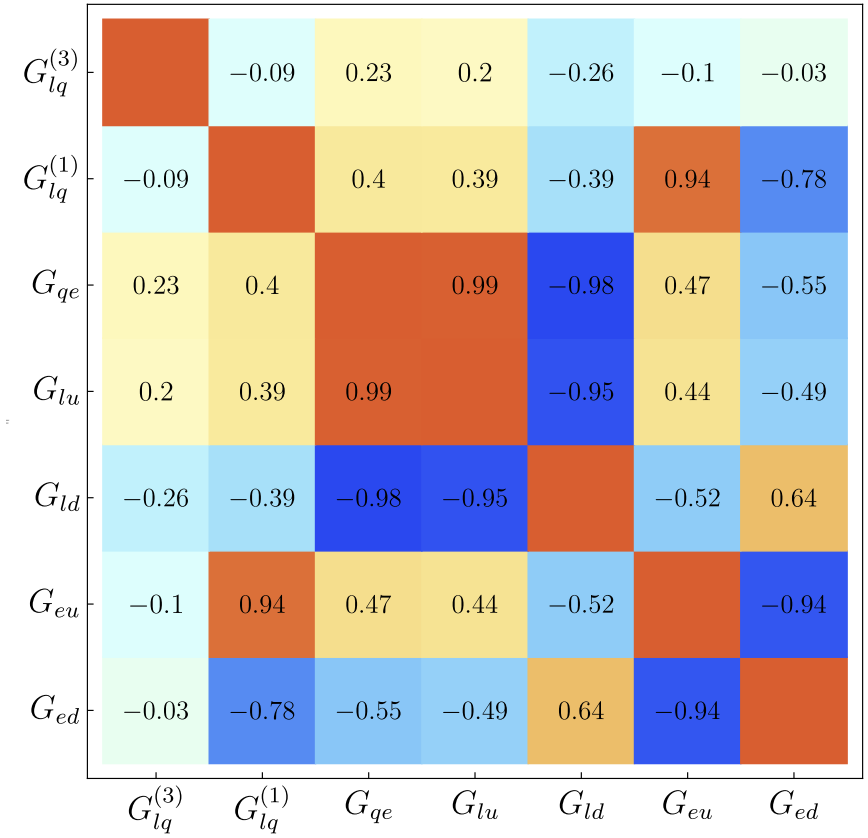
- BSM predictions at $\mathrm{NLO_{QCD}}$+PS+1L-$\mathrm{EW_{Logs}}$
- Among the different sources of theoretical uncertainties (missing h.o., α_{st}, PDF) the PDF unc. are the largest

See [Greljo et al. (2021)] for the impact of NP on the PDF determination

High-energy DY: Sensitivity to Flavour Universal NP

HL-LHC





- BSM predictions at $\mathrm{NLO_{QCD}}$+PS+1L-$\mathrm{EW_{Logs}}$
- (3D+2D)-distributions×7D-param. space (∼200bins×7D)

A top-down perspective: The minimal Z'

New additional vector boson gauging a linear combination of the hypercharge $U(1)_Y$ and $B-L$. The phenomenology of the model is fully described by the three parameters g_Y, g_{BL}, M

$$\mathcal{L}_{Z'} = -\frac{1}{4}F^2 + \frac{1}{2}M^2 A^2 + A_\mu J^\mu \qquad J^\mu = \sum_f \left(g_Y Y_f + g_{BL} BL_f\right) \bar{f}\gamma^\mu f + \frac{i g_Y}{2} H^\dagger \overleftrightarrow{D} H$$

$$\Big\downarrow E \ll M$$

$$\mathcal{L}_{Z'} \simeq -\frac{1}{2M^2} J^2 \subset \mathcal{L}^{(6)}_{SMEFT}$$

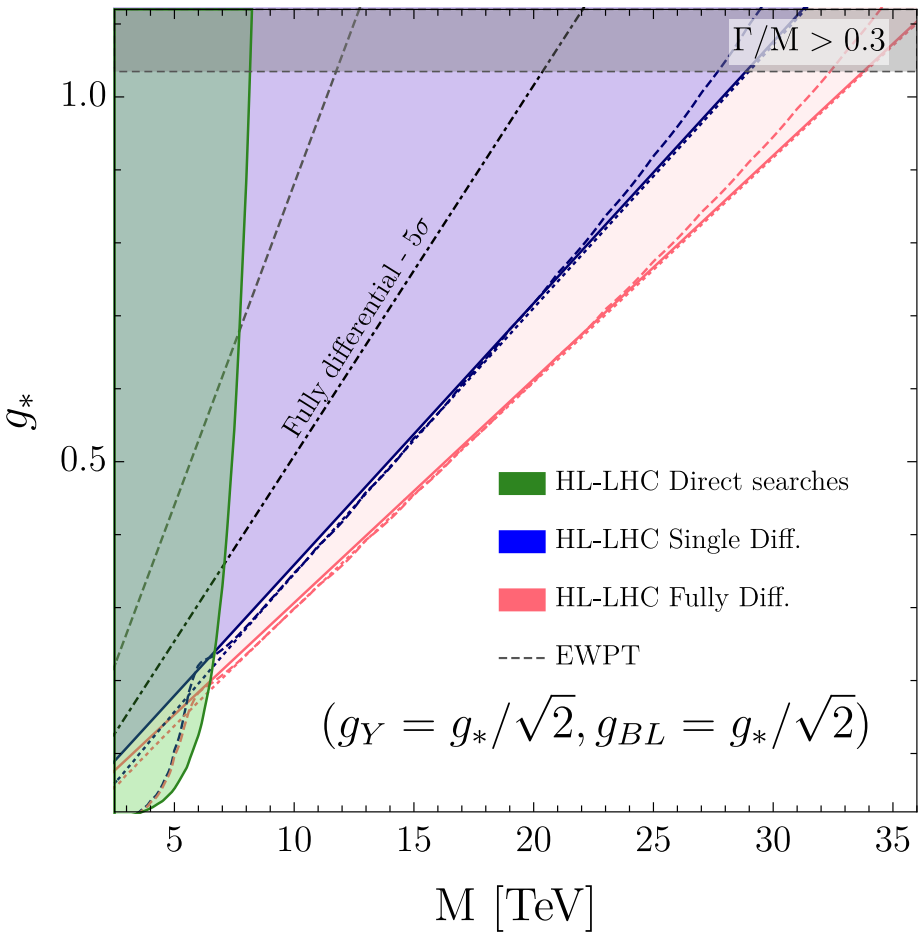
Direct searches at HL-LHC exclude up to $M \sim 6$TeV. For larger masses we can look for the new interactions described by the EFT

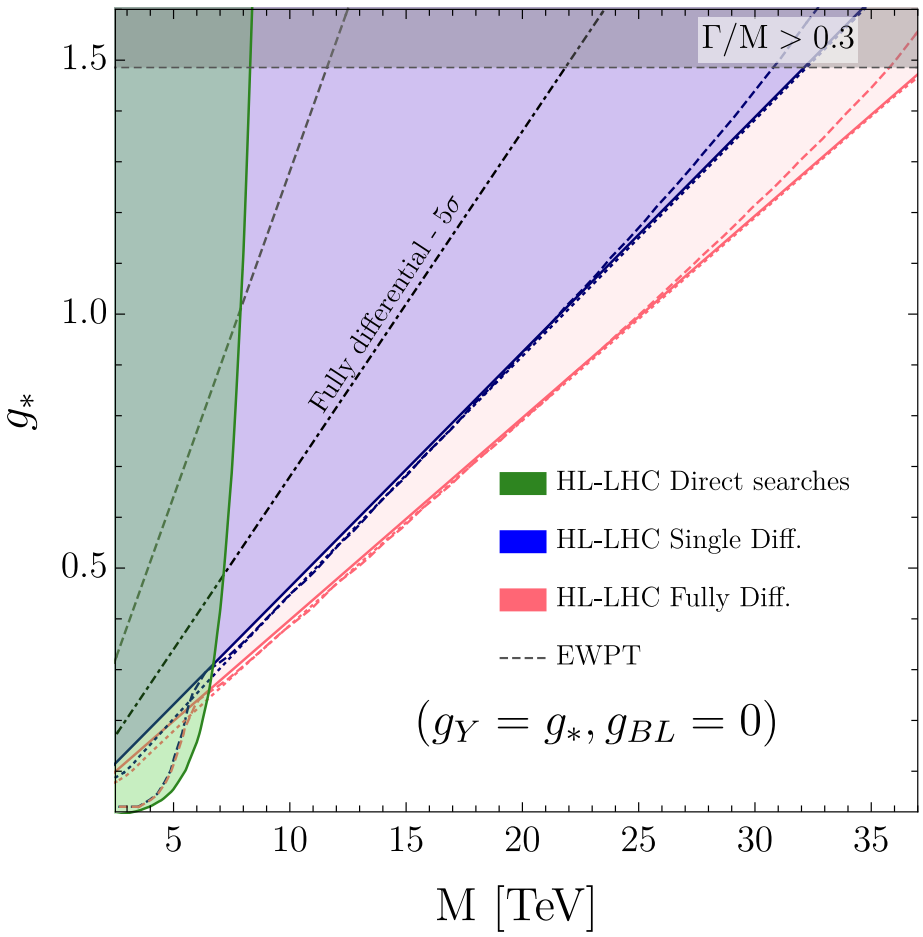
See also:[Salvioni, Villadoro, Zwirner (2009)], [Alioli, Farina, Pappadopulo, Ruderman (2018)]

A top-down perspective: The minimal Z'

$\{g_Y, g_{BL}, M\}$

95% Exclusion



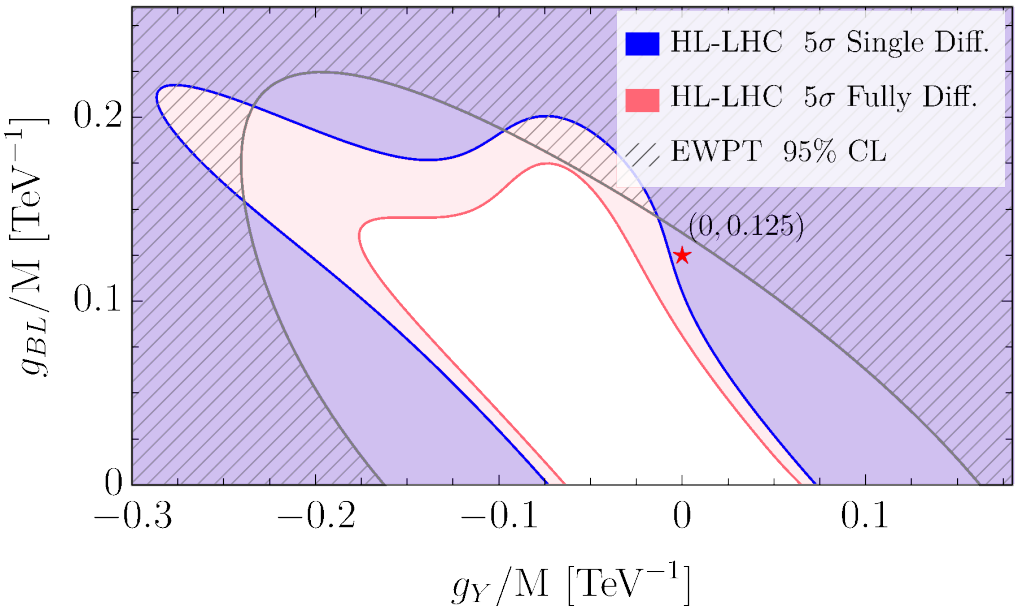


Solid: dim-6, Dotted: dim-8, Dashed: UV theory

A top-down perspective: The minimal Z'

$\{g_Y, g_{BL}, M\}$

Discovery



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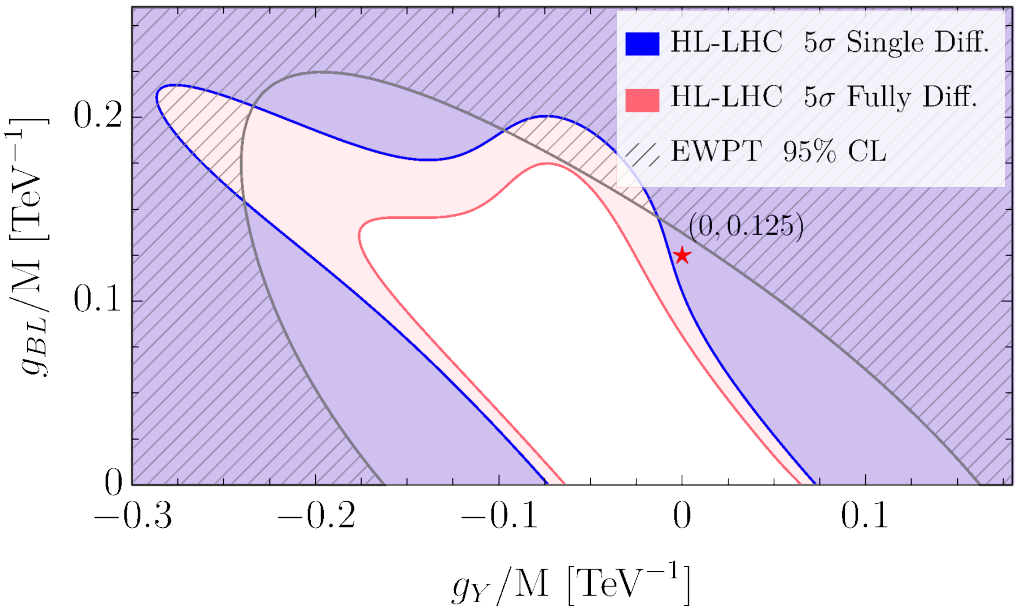
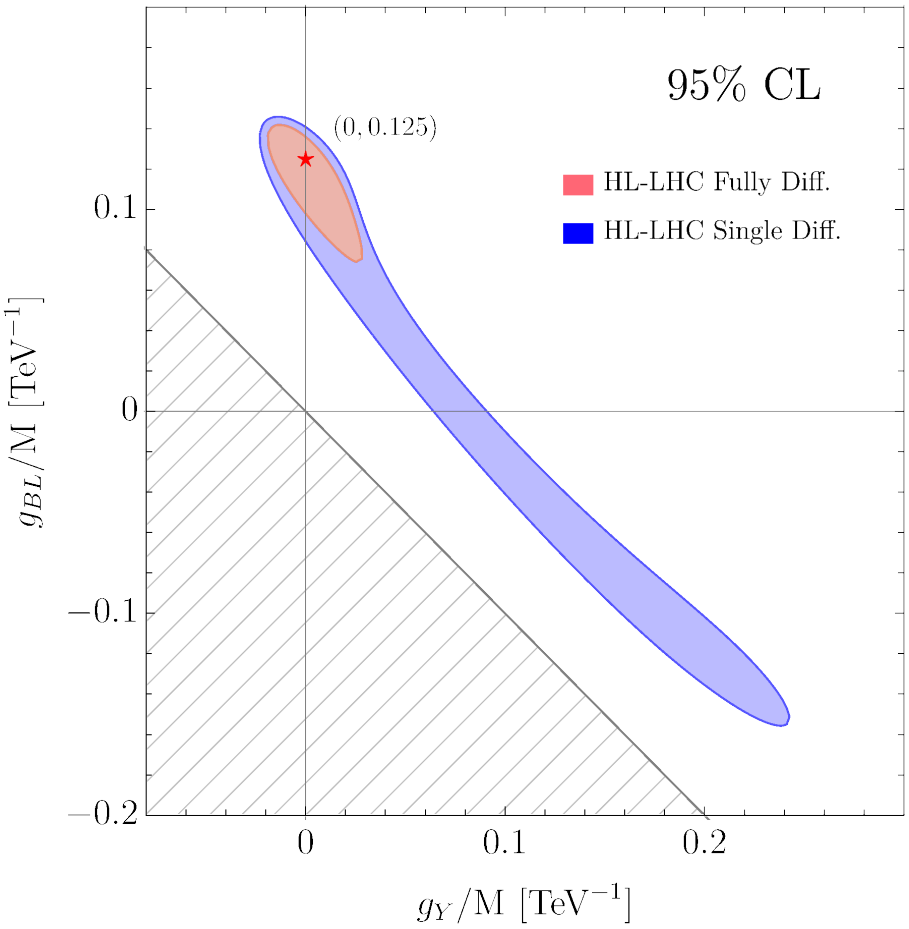


Characterization



Conclusions

- Opportunity for NP exclusion or **discovery** in high-energy DY
- Fully-differential measurements improve sensitivity (and reduce impact of quadratic terms)
- PDFs are the dominant source of theoretical uncertainties (the sensitivity floor is well below)
- NP incorporated by analytic reweighting

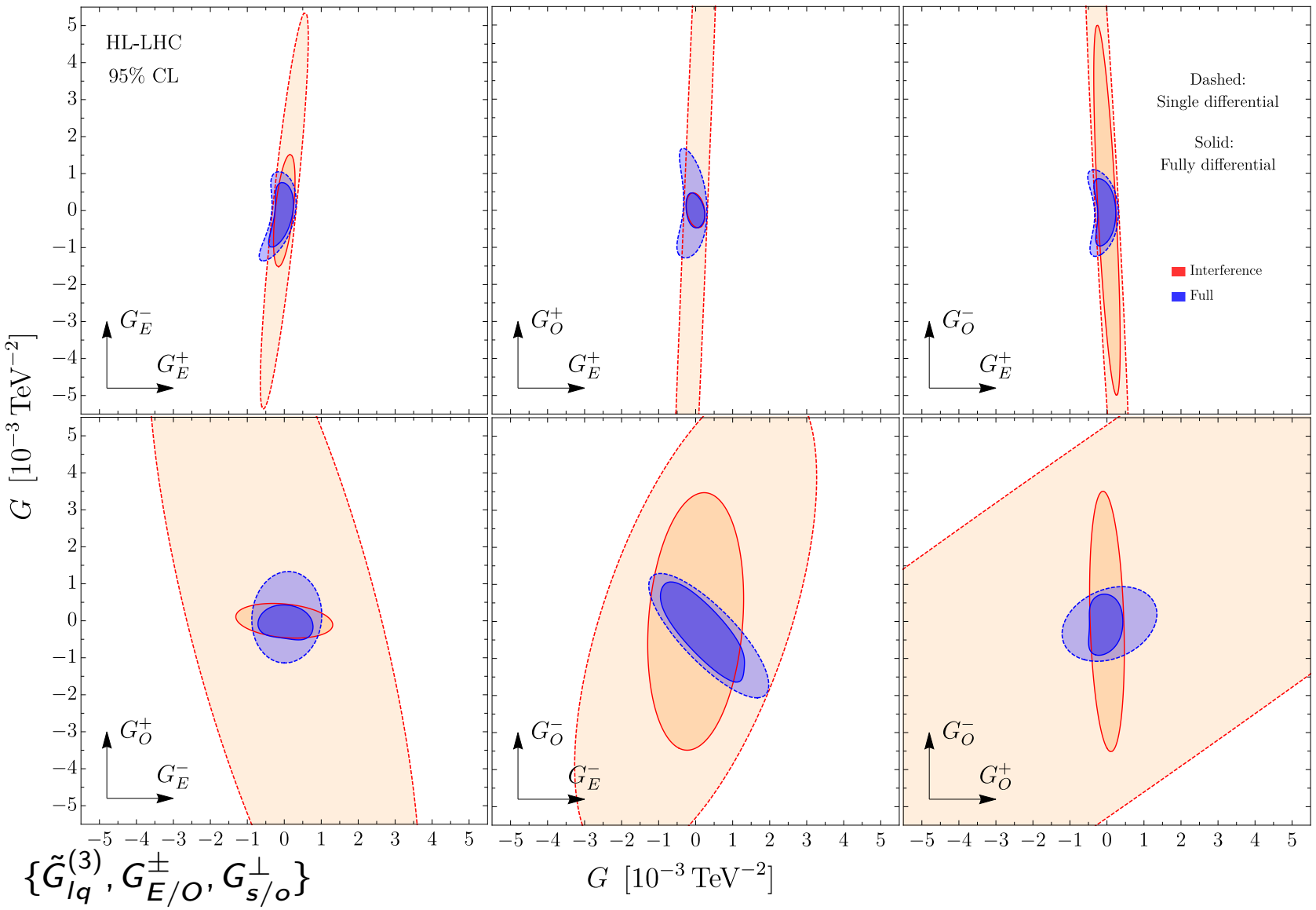
Outlook

- Projections based on state-of-art PDFs and "guessed" experimental errors, progress in both would greatly improve sensitivity.
- Waiting for the measurements

Thank you!

Backup

High-energy DY: Sensitivity to Flavour Universal NP



$\{\tilde{G}_{lq}^{(3)}, G_{E/O}^{\pm}, G_{s/o}^{\perp}\}$

High-energy DY: Theoretical predictions

NLO-QCD SM events
[Alioli, Nason, Oleari, Re (2008)]

$\longrightarrow$

NLO-QCD BSM events

Neutral: LL, LR, RL, RR
Charged: LL

$$W_e^{\mathrm{SM}}$$

$$\xrightarrow{\rho_e(m_{ll}, q_{\chi_q}, l_{\chi_l})}$$

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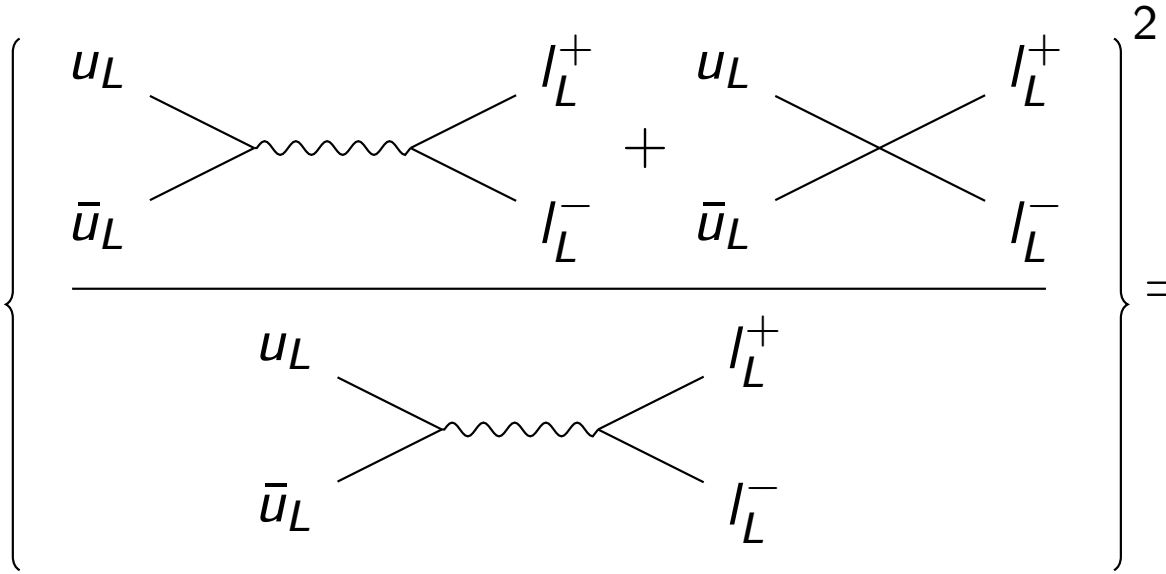
$$W_e^{\mathrm{SM}} \rho_e(m_{ll}, q_{\chi_q}, l_{\chi_l})$$



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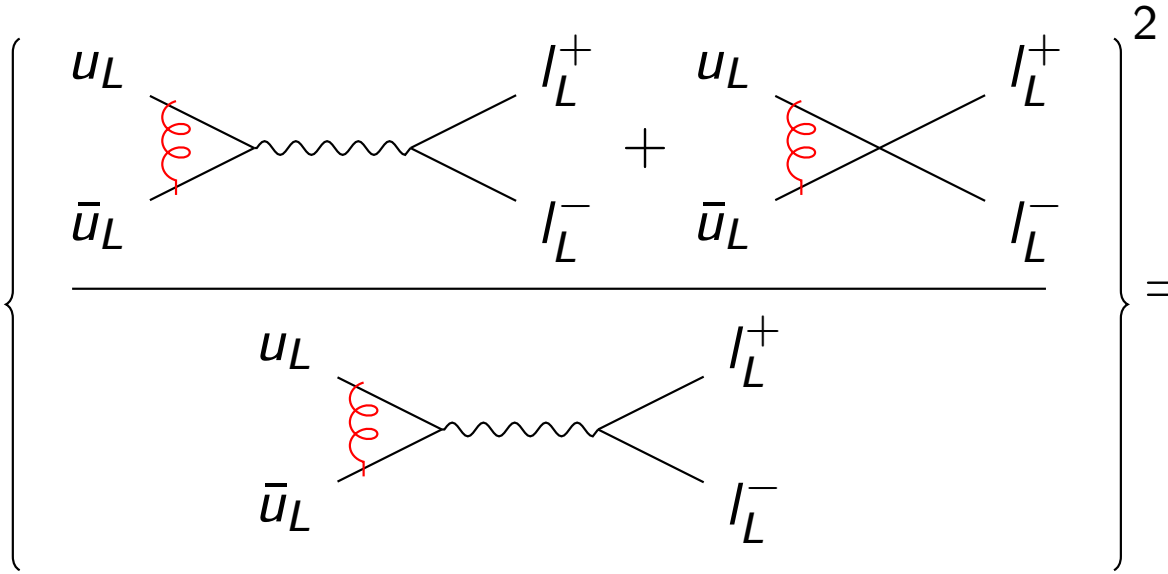

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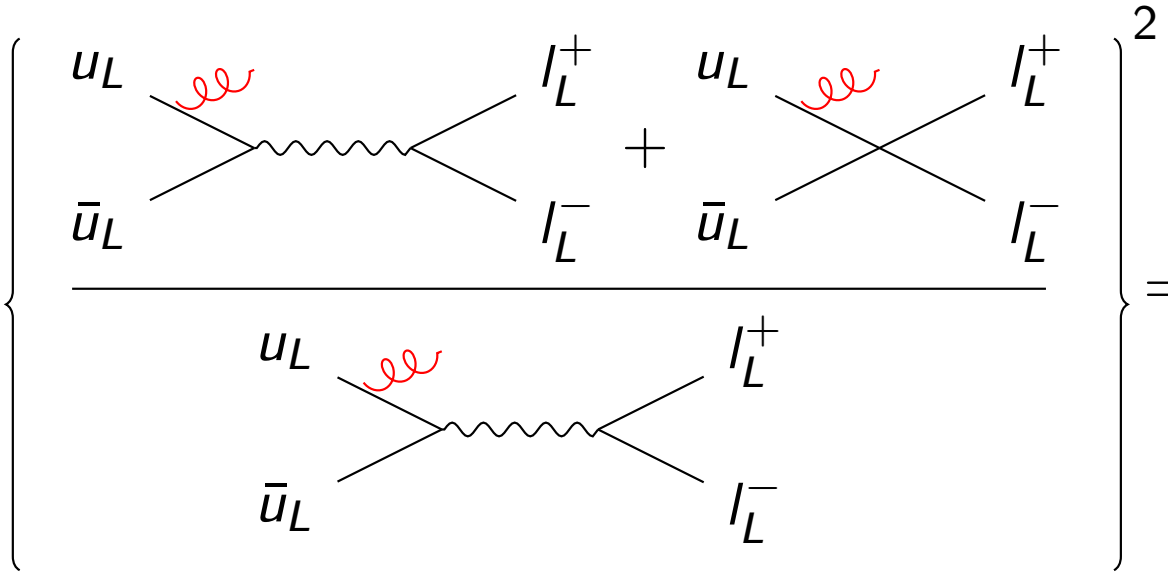

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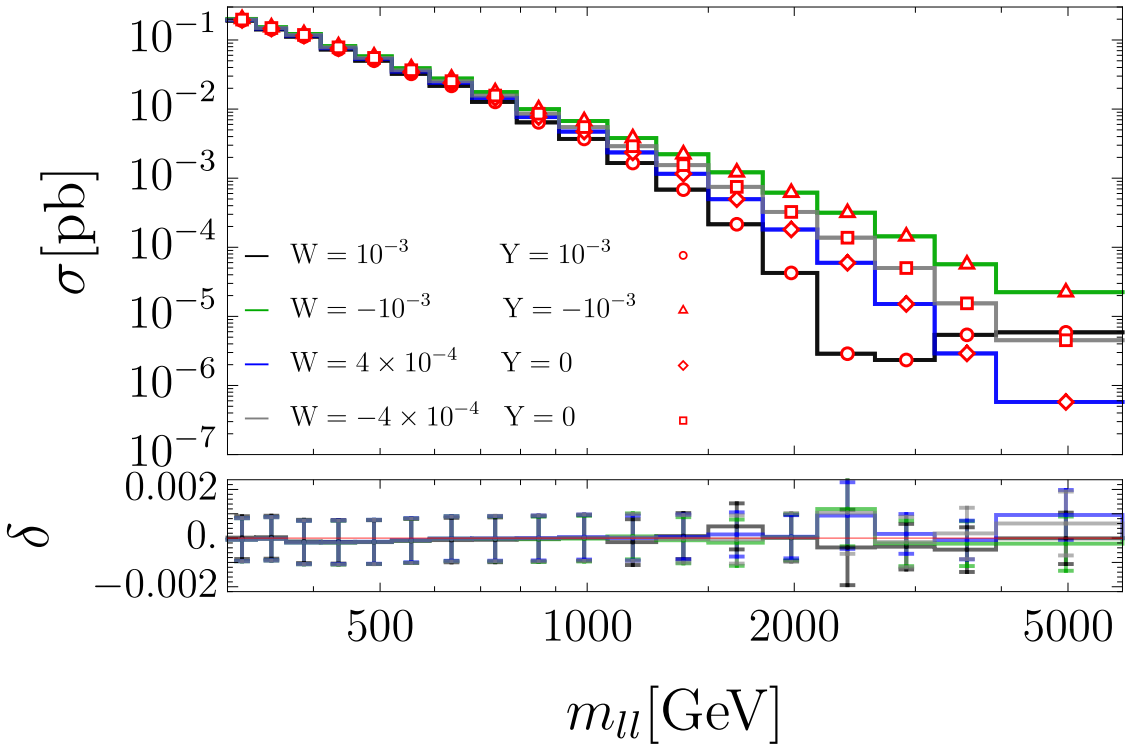

[Alioli, Dekens, Girard, Mereghetti (2018)]

High-energy DY: Theoretical predictions

NLO-QCD +PS SM events
[Alioli, Nason, Oleari, Re (2008)]

$\longrightarrow$

NLO-QCD BSM events
+1L-EW logs+PS

Neutral: LL, LR, RL, RR
Charged: LL

$\xrightarrow{\rho(m_{ll},\ \text{“}t\text{”},\ q_{\chi_q},\ l_{\chi_l})}$

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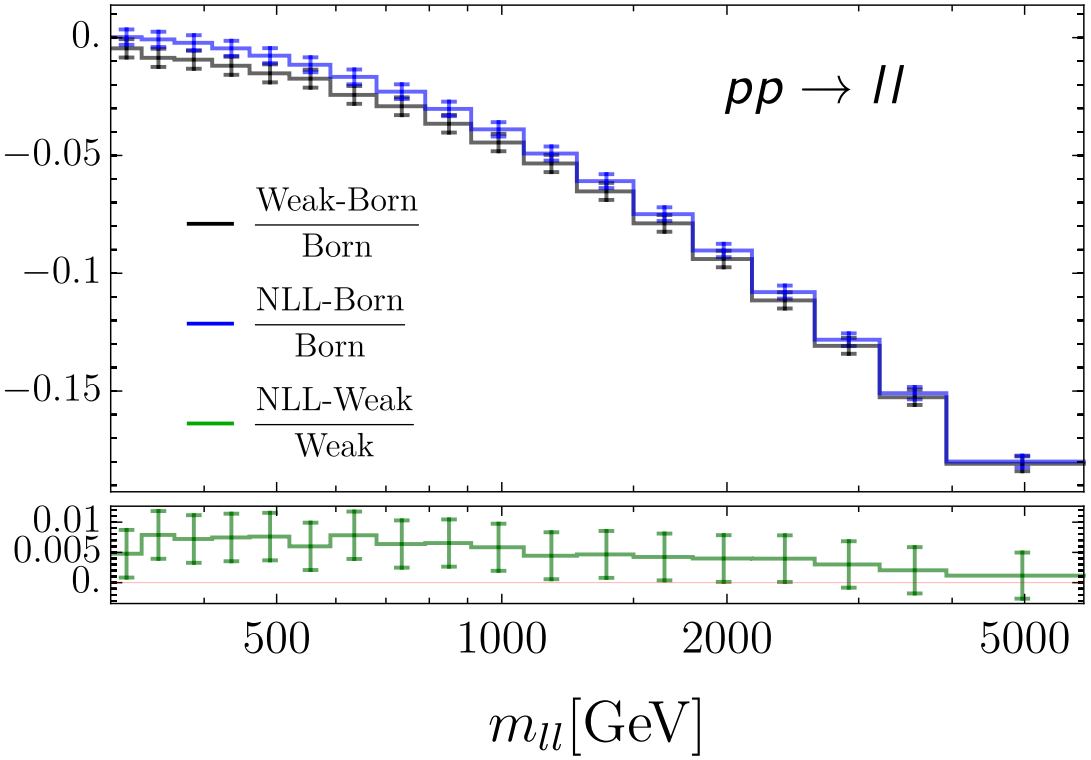

1L-EW logs
[Denner, Jantzen, Pozzorini (2007)], [Kuhn, Moch, Penin, Smirnov (2001)]

POWHEG
NLO-(EW+QCD)
[Carloni Calame et al. (2007)]