Electroweak Corrections from Sudakov Logarithms in the SMEFT

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240x.xxxxx

. Denner and Pozzorini hep-ph/0010201
. Denner and Pozzorini hep-ph/0104127
. Pagani and Zaro 2110.03714
Many slides by Marco Zaro

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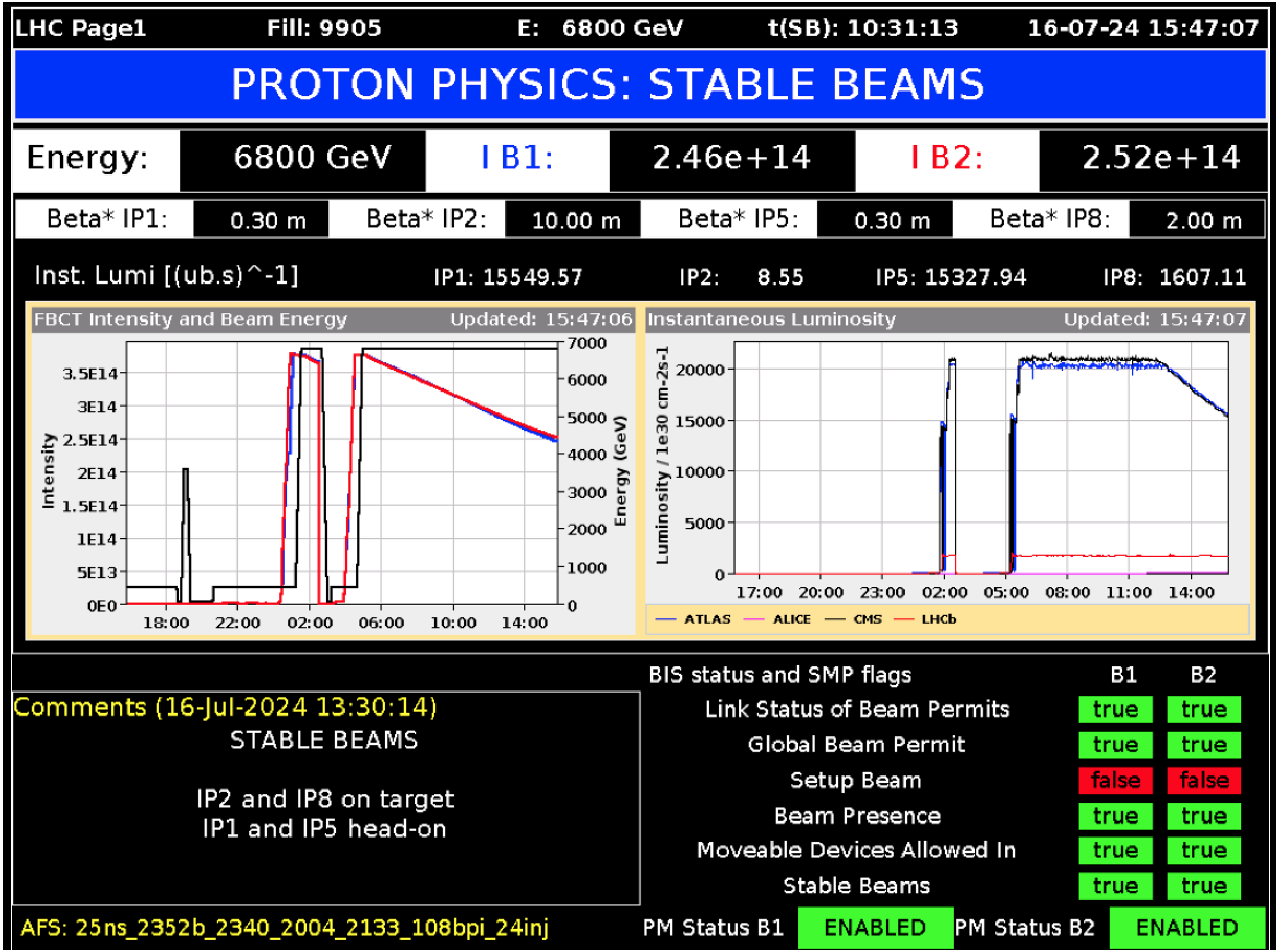
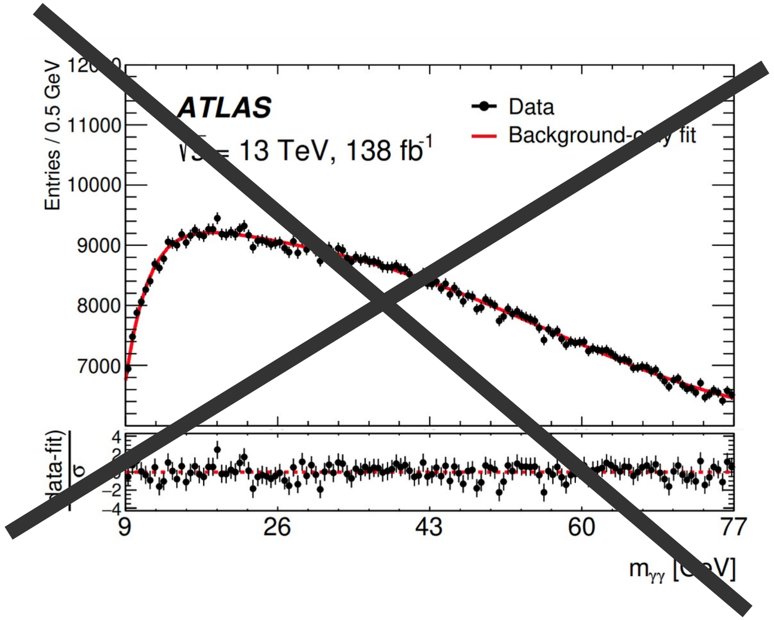
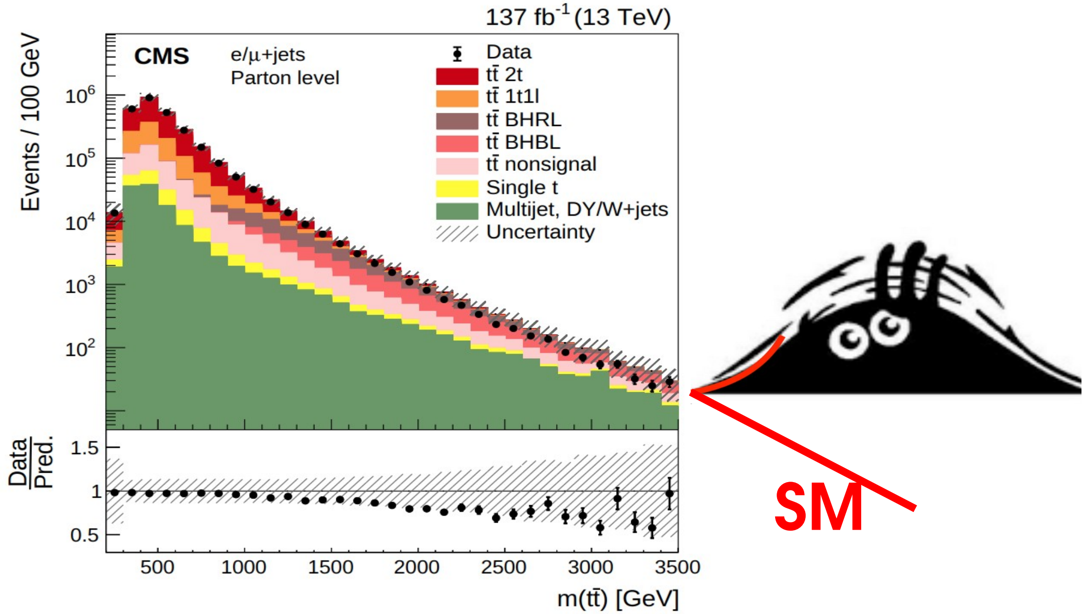
The LHC is running again



New physics?

New physics must be hiding very well!
Change of paradigm: bump hunting → precision measurements





SM Effective field theory

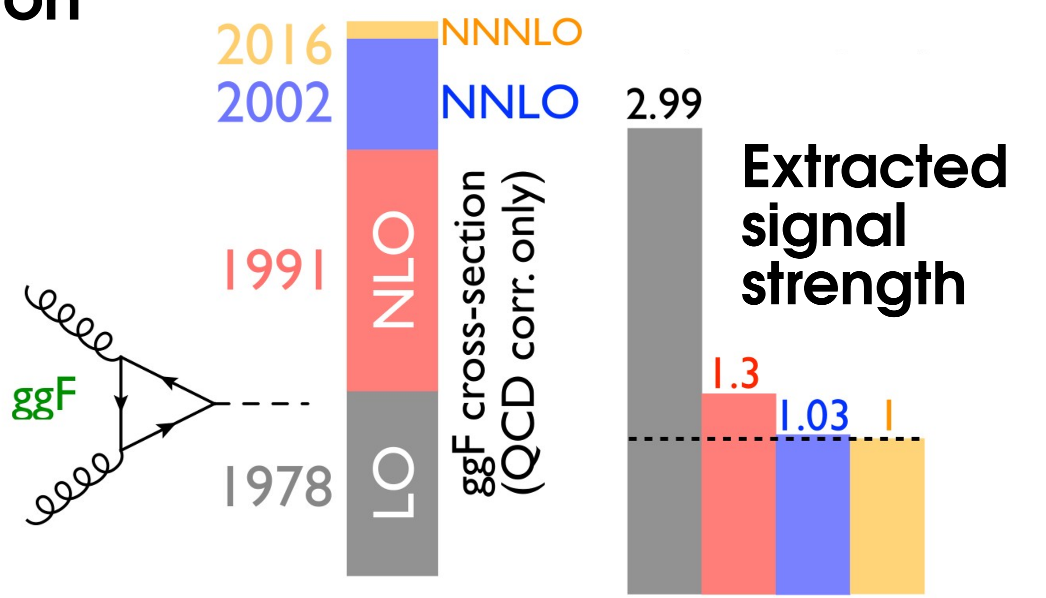
$$\mathscr{L}_{SMEFT} = \mathscr{L}_{SM} + \sum_{d=5}^{\infty} \mathscr{L}_d \,, \qquad \mathscr{L}_d = \sum_i \frac{C_i^{(d)}}{\Lambda^{d-4}} O_i^{(d)} \,.$$

- Consistent way to parameterize deviations across searches
- As model independent as reasonably possible

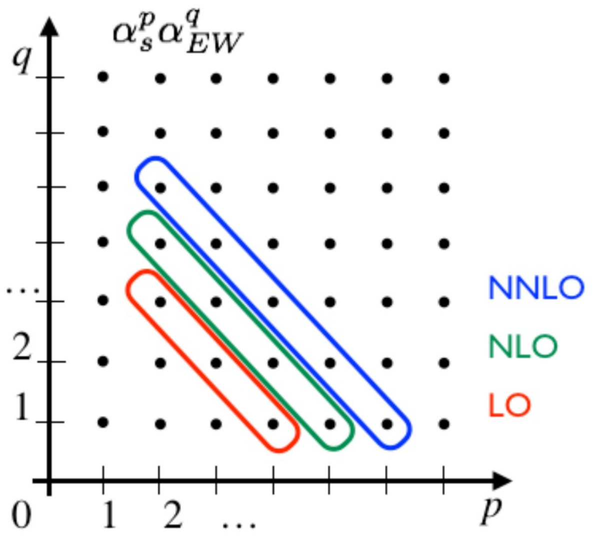
Precision for measurements

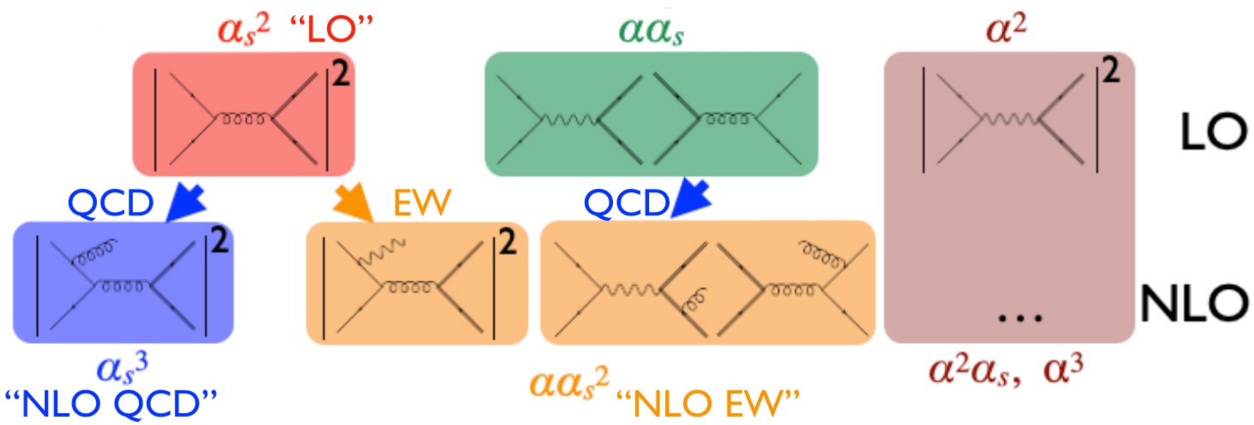
Our ability to make measurements and discoveries is limited by the goodness of our theory prediction

Higgs physics gives a clear example: without higher orders the measured rate for gg→H would be 3x the "SM prediction"



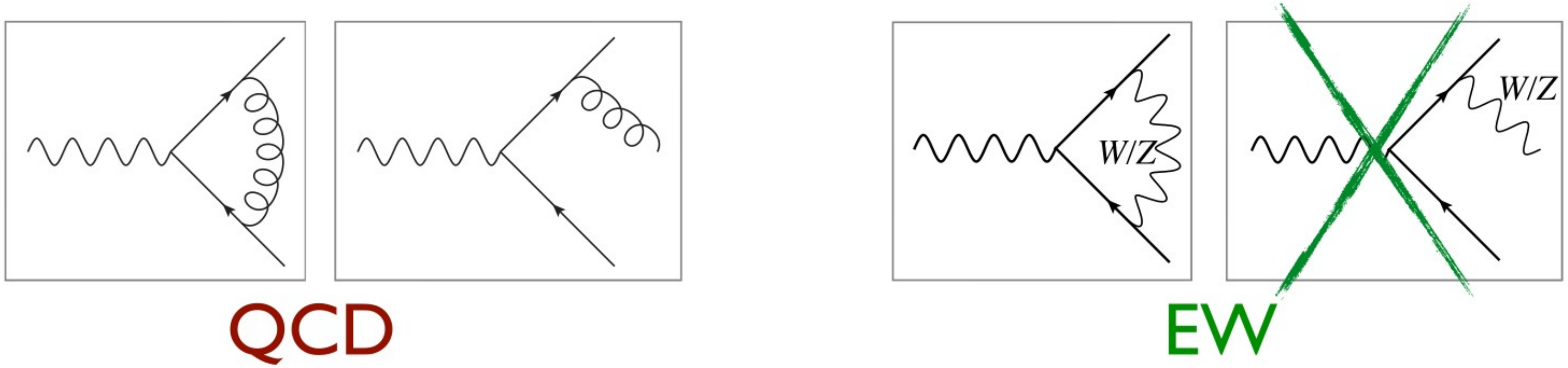
Also, NLO ≠ QCD





Large EW corrections

Electroweak corrections grow with energy because of miscancellations between loops and real-emission diagrams.



<u>Sudakov logarithms</u> $\alpha \log^2 s/m_W^2$ and $\alpha \log s/m_W^2$
NLO EW is O(10%) at ~ TeV and keeps growing.

Exact NLO EW corrections are not available in the SMEFT in general

An approximate-NLO based on Sudakov logs is adequate to describe the physics at high energy, the region where EW effects become important.

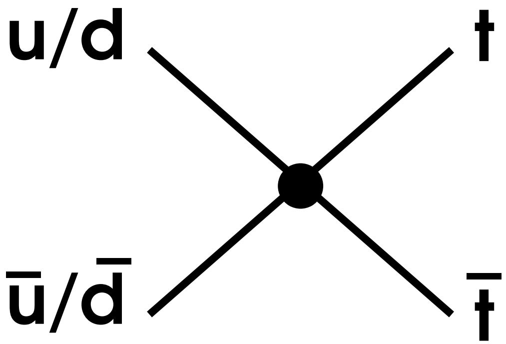
The high energy region is also the most sensitive to SMEFT.

SMEFT@NLOEWSUD

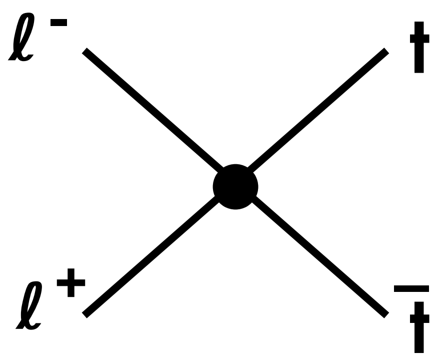
We extracted NLO EW corrections to selected SMEFT operators in the high-energy limit.
Our focus is on <u>four-fermion operators</u>, we looked at top pair production at the LHC and in a lepton collider.

$$\mathcal{O}^8_{tu} = \sum_{\mathrm{f}=1}^{2} (\bar{t}\gamma_\mu T^A t)(\overline{u}_{\mathrm{f}}\gamma^\mu T_A u_{\mathrm{f}}),$$
$$\mathcal{O}^8_{td} = \sum_{\mathrm{f}=1}^{3} (\bar{t}\gamma_\mu T_A t)(\bar{d}_{\mathrm{f}}\gamma^\mu T^A d_{\mathrm{f}}),$$
$$\mathcal{O}^8_{tq} = \sum_{\mathrm{f}=1}^{2} (\bar{t}\gamma^\mu T^A t)(\overline{q}_{\mathrm{f}}\gamma_\mu T_A q_{\mathrm{f}}),$$
$$\mathcal{O}^8_{Qu} = \sum_{\mathrm{f}=1}^{2} (\overline{Q}\gamma_\mu T_A Q)(\overline{u}_{\mathrm{f}}\gamma^\mu T^A u_{\mathrm{f}}),$$
$$\mathcal{O}^8_{Qd} = \sum_{\mathrm{f}=1}^{3} (\overline{Q}\gamma_\mu T_A Q)(\bar{d}_{\mathrm{f}}\gamma^\mu T^A d_{\mathrm{f}}),$$
$$\mathcal{O}^{1,8}_{Qq} = \sum_{\mathrm{f}=1}^{2} (\overline{Q}\gamma_\mu T^A Q)(\overline{q}_{\mathrm{f}}\gamma^\mu T_A q_{\mathrm{f}}),$$
$$\mathcal{O}^{3,8}_{Qq} = \sum_{\mathrm{f}=1}^{2} (\overline{Q}\gamma_\mu T^A \sigma_I Q)(\overline{q}_{\mathrm{f}}\gamma^\mu T_A \sigma^I q_{\mathrm{f}}),$$

f = u, c / d, s, b

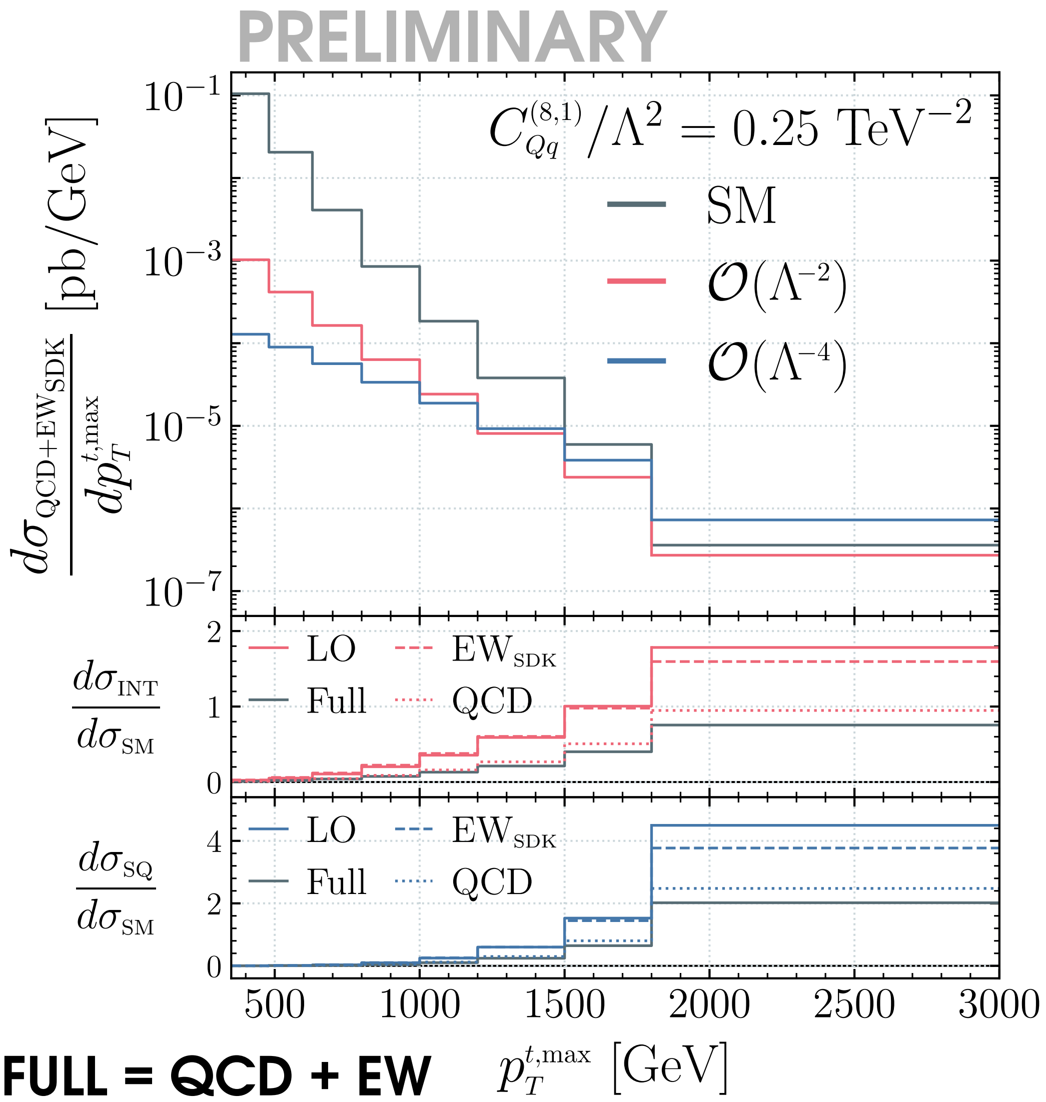


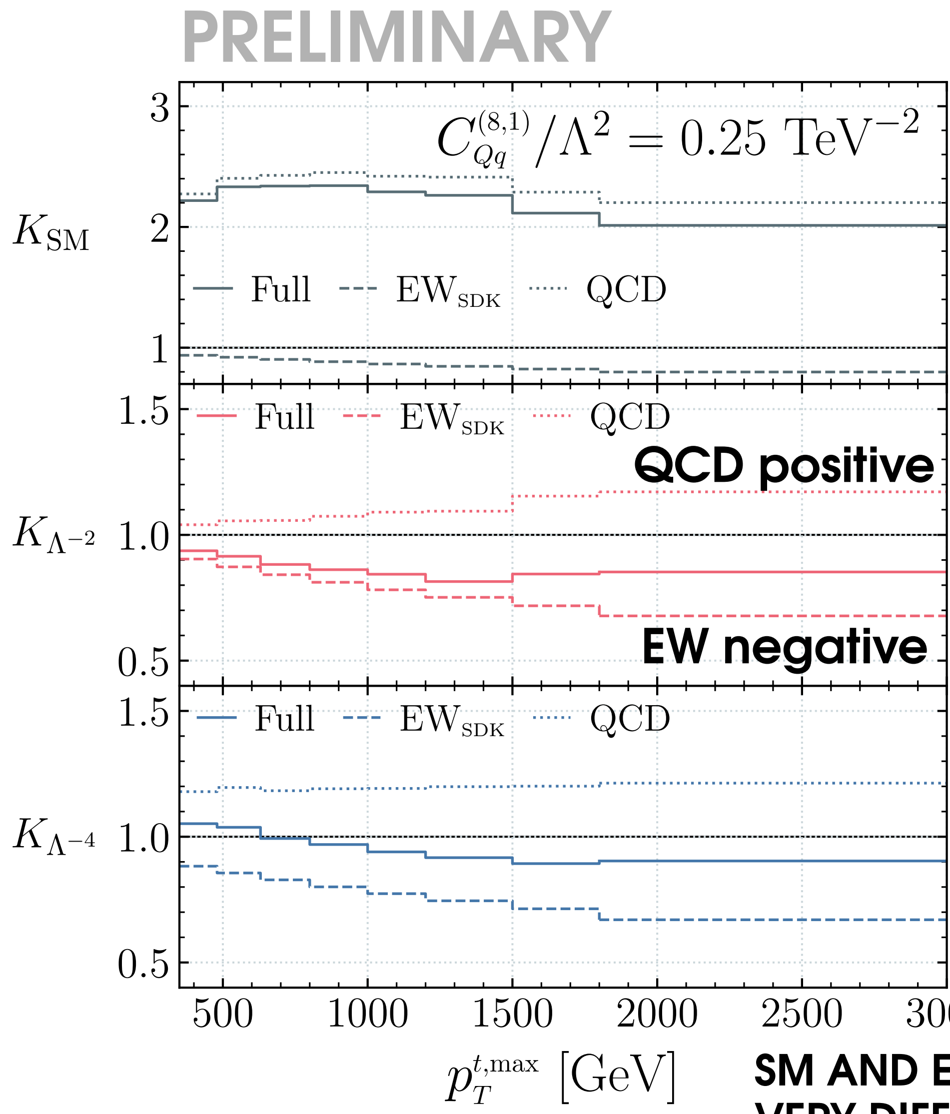
$$[\,\mathcal{O}_{te}\,]_{\mathrm{ff}} = (\bar{t}\gamma^\mu t)(\overline{e}_{\mathrm{f}}\gamma_\mu e_{\mathrm{f}}),$$
$$[\,\mathcal{O}_{Qe}\,]_{\mathrm{ff}} = (\overline{Q}\gamma_\mu Q)(\overline{e}_{\mathrm{f}}\gamma^\mu e_{\mathrm{f}}),$$
$$[\,\mathcal{O}_{t\ell}\,]_{\mathrm{ff}} = (\bar{t}\gamma^\mu t)(\bar{\ell}_{\mathrm{f}}\gamma_\mu \ell_{\mathrm{f}}),$$
$$[\,\mathcal{O}^{(-)}_{Q\ell}\,]_{\mathrm{ff}} = (\overline{Q}\gamma^\mu Q)(\bar{\ell}_{\mathrm{f}}\gamma_\mu \ell_{\mathrm{f}}),$$



f = e, mu, tau

NLOEW in ttbar





FULL = QCD + EW

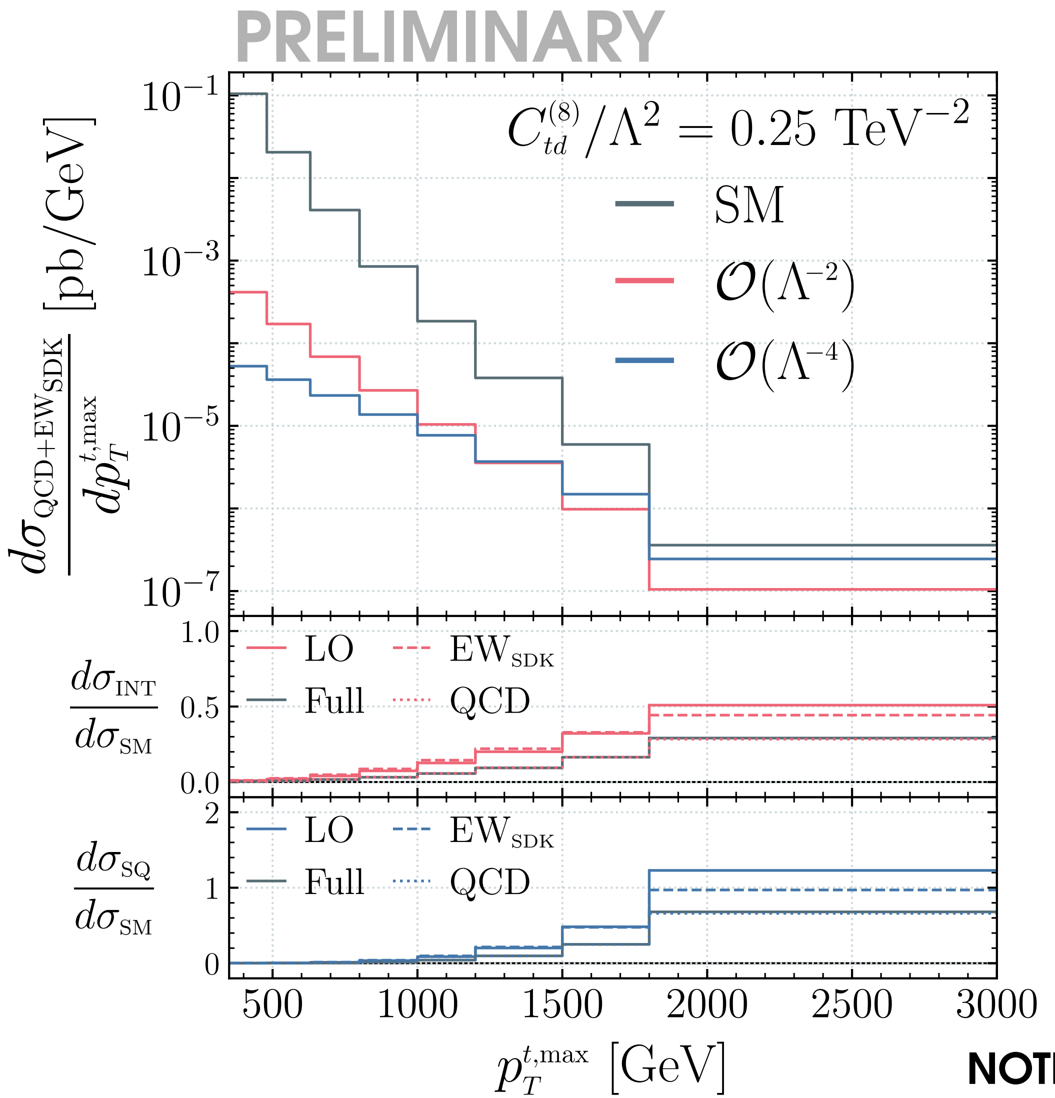
Distribution

K-factor

SM AND EFT VERY DIFFERENT
SM +100%
EFT int. −15%
EFT sqr. −10%

$$\mathcal{O}_{Qq}^{1,8} = \sum_{\mathrm{f}=1}^{2}(\overline{Q}\gamma_\mu T^A Q)(\overline{q}_{\mathrm{f}}\gamma^\mu T_A q_{\mathrm{f}})$$

NLOEW in ttbar



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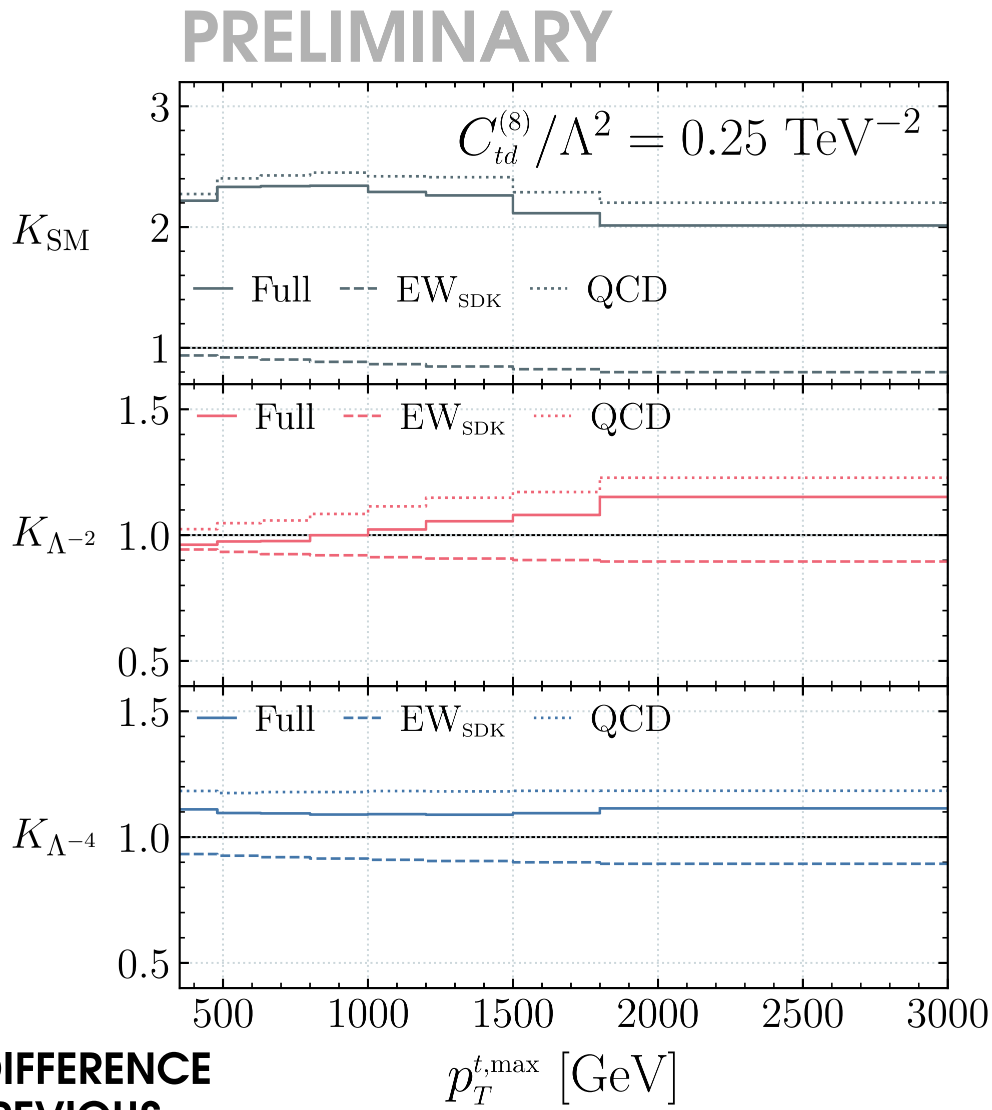


K-factor

NOTE DIFFERENCE WITH PREVIOUS OPERATOR

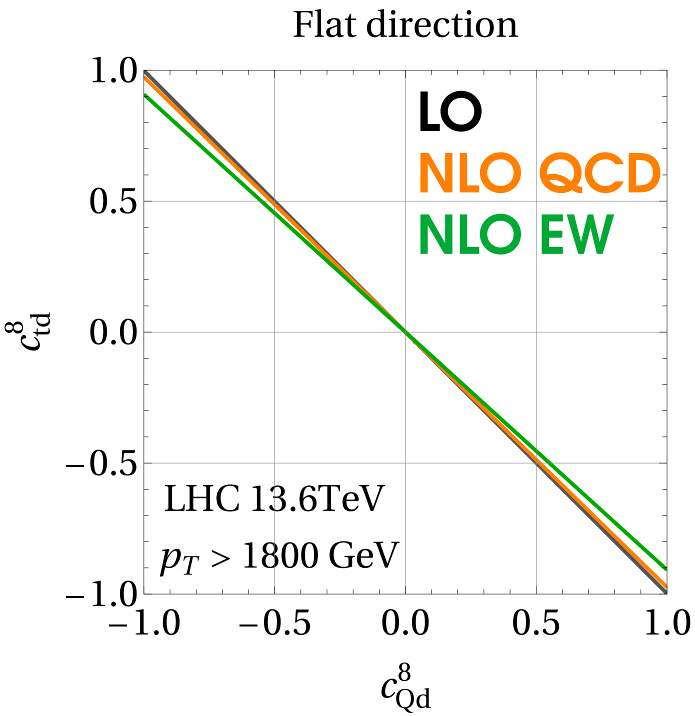
$$\mathcal{O}_{td}^{8} = \sum_{\text{f}=1}^{3} (\bar{t}\gamma_\mu T_A t)(\bar{d}_{\text{f}}\gamma^\mu T^A d_{\text{f}})$$

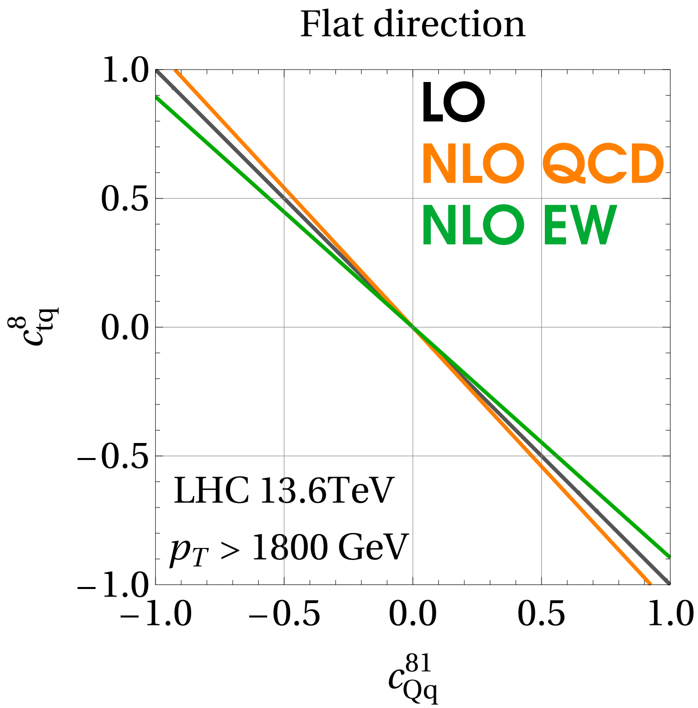
NLOEW in ttbar

**Electroweak corrections introduce new structures.
For example the directions:**

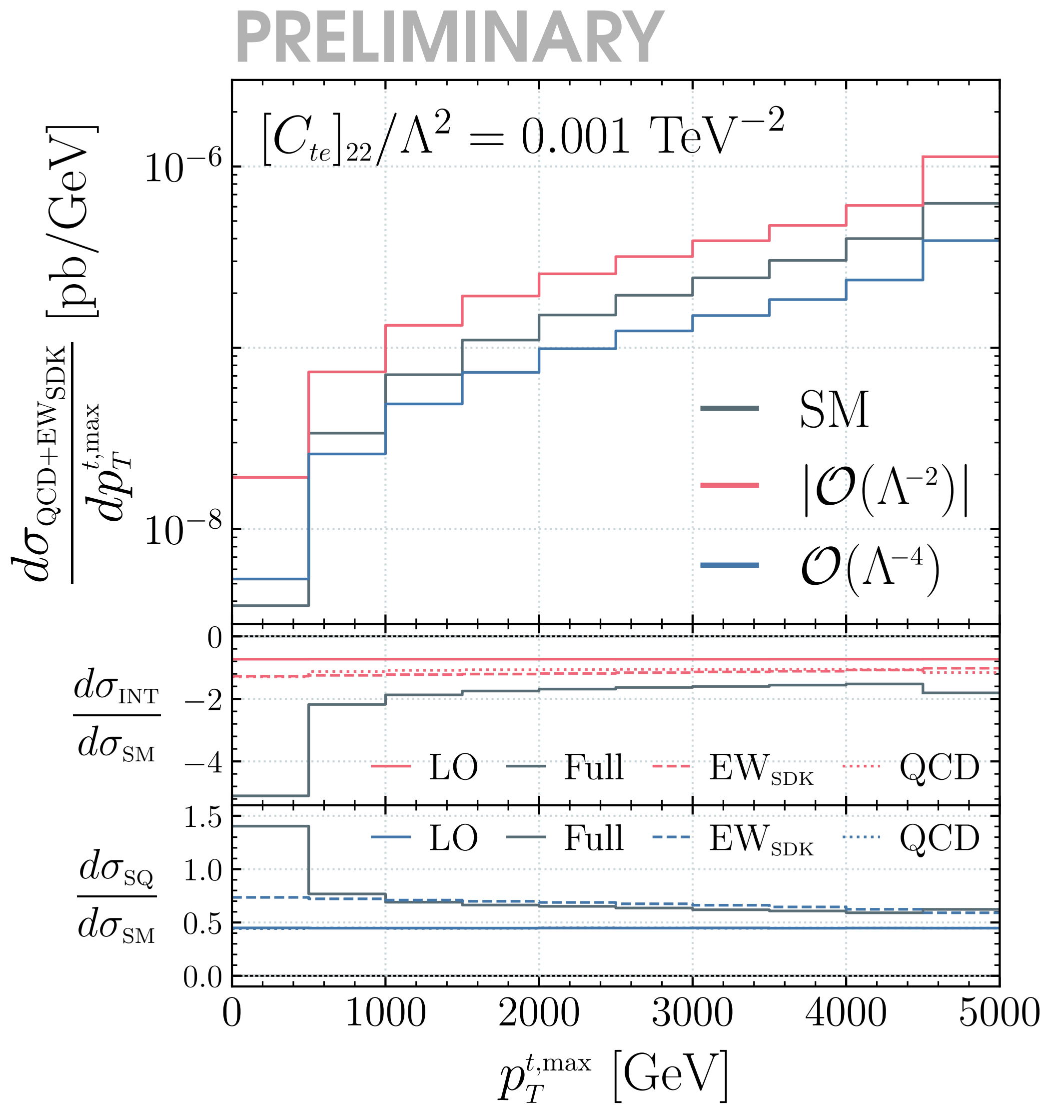
$$c^{8}_{Qd} = -c^{8}_{td} \quad \text{and} \quad c^{8,1}_{Qq} = -c^{8}_{tq}$$

**are related by tL ⇔ tR and are exactly flat at LO.
Strong corrections do not significantly alter this picture, but NLO EW does:**





NLOEW in a 10 TeV muon collider



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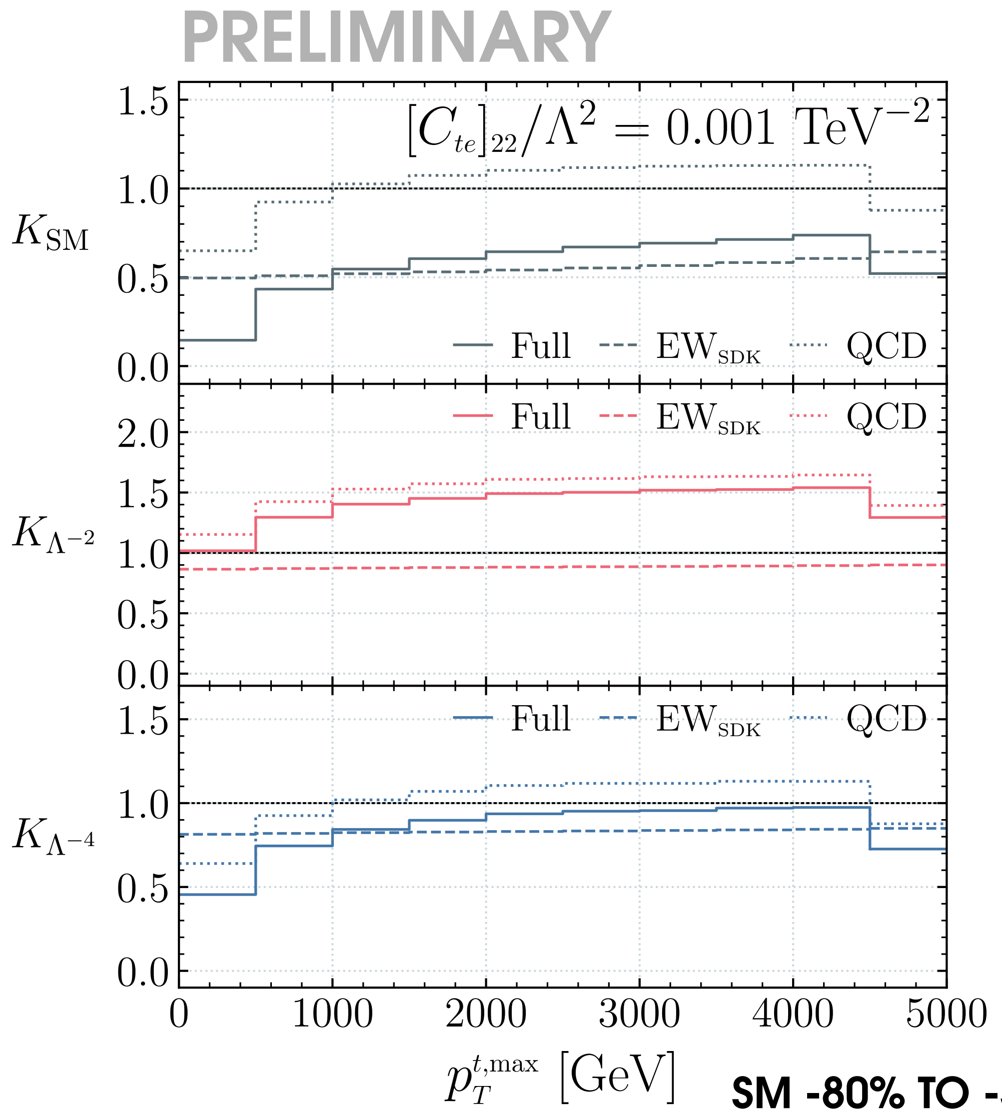
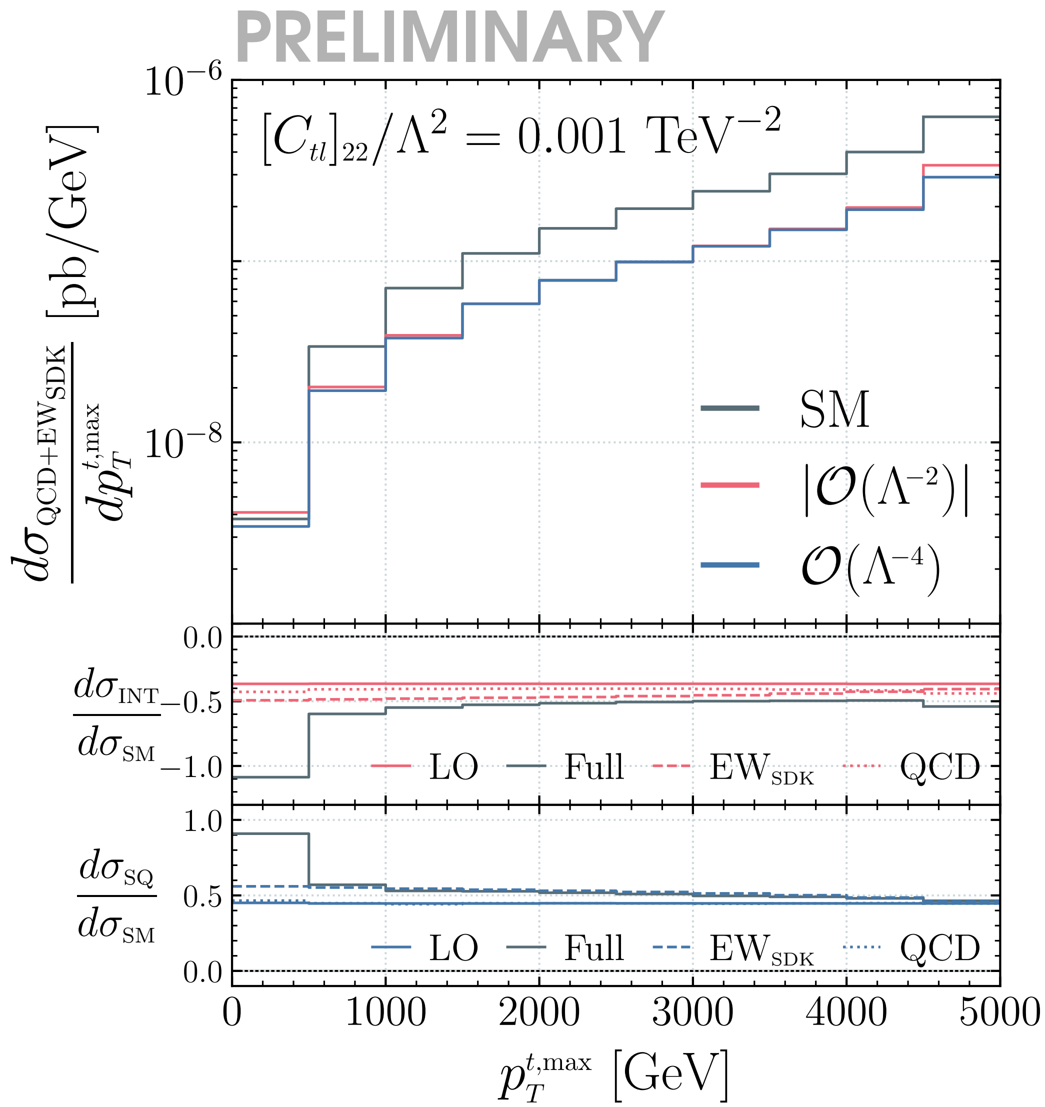


K-factor

SM -80% TO -30%
$1/\Lambda^2$ POSITIVE
$1/\Lambda^4$ -60% TO 0

$$[\mathcal{O}_{te}]_{\text{ff}} = (\bar{t}\gamma^{\mu}t)(\bar{e}_{\text{f}}\gamma_{\mu}e_{\text{f}})$$

NLOEW in a 10 TeV muon collider



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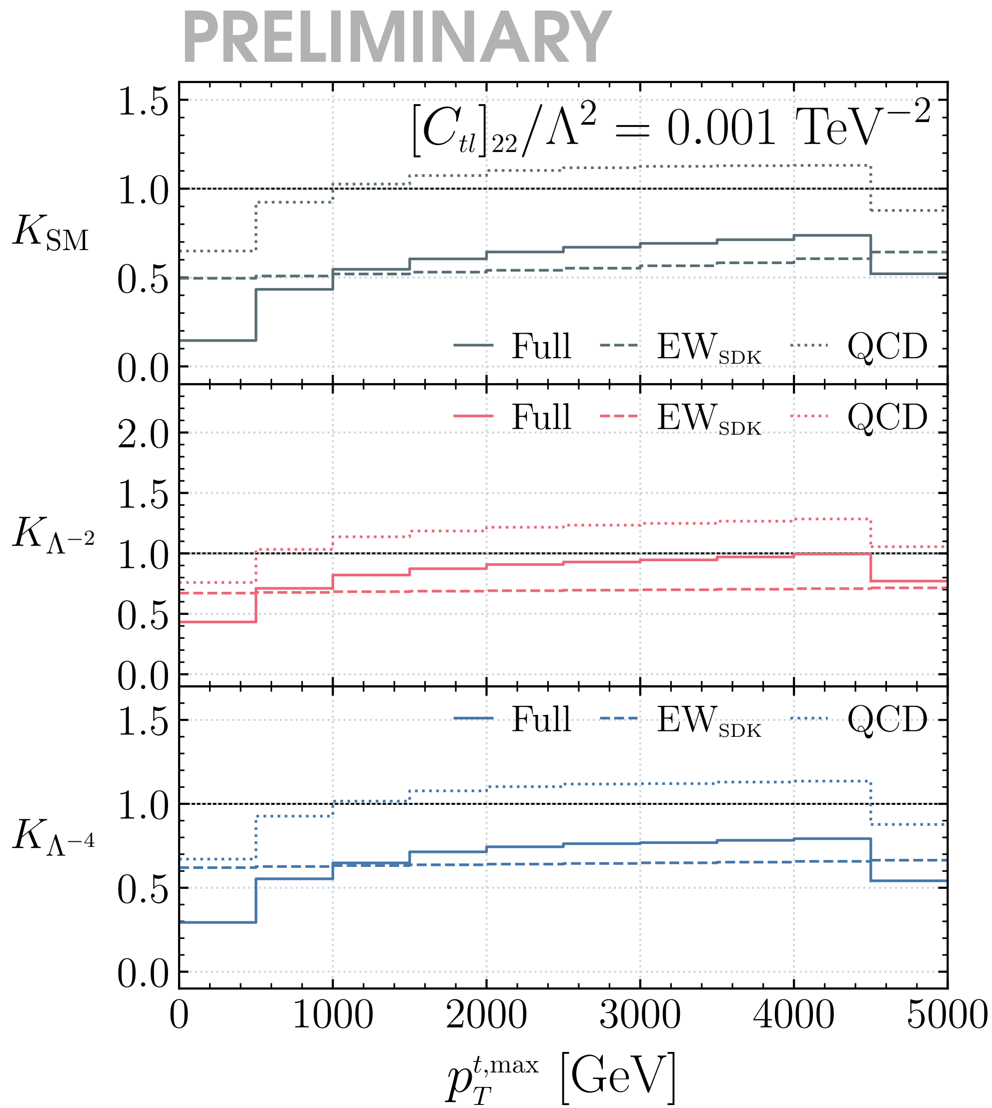
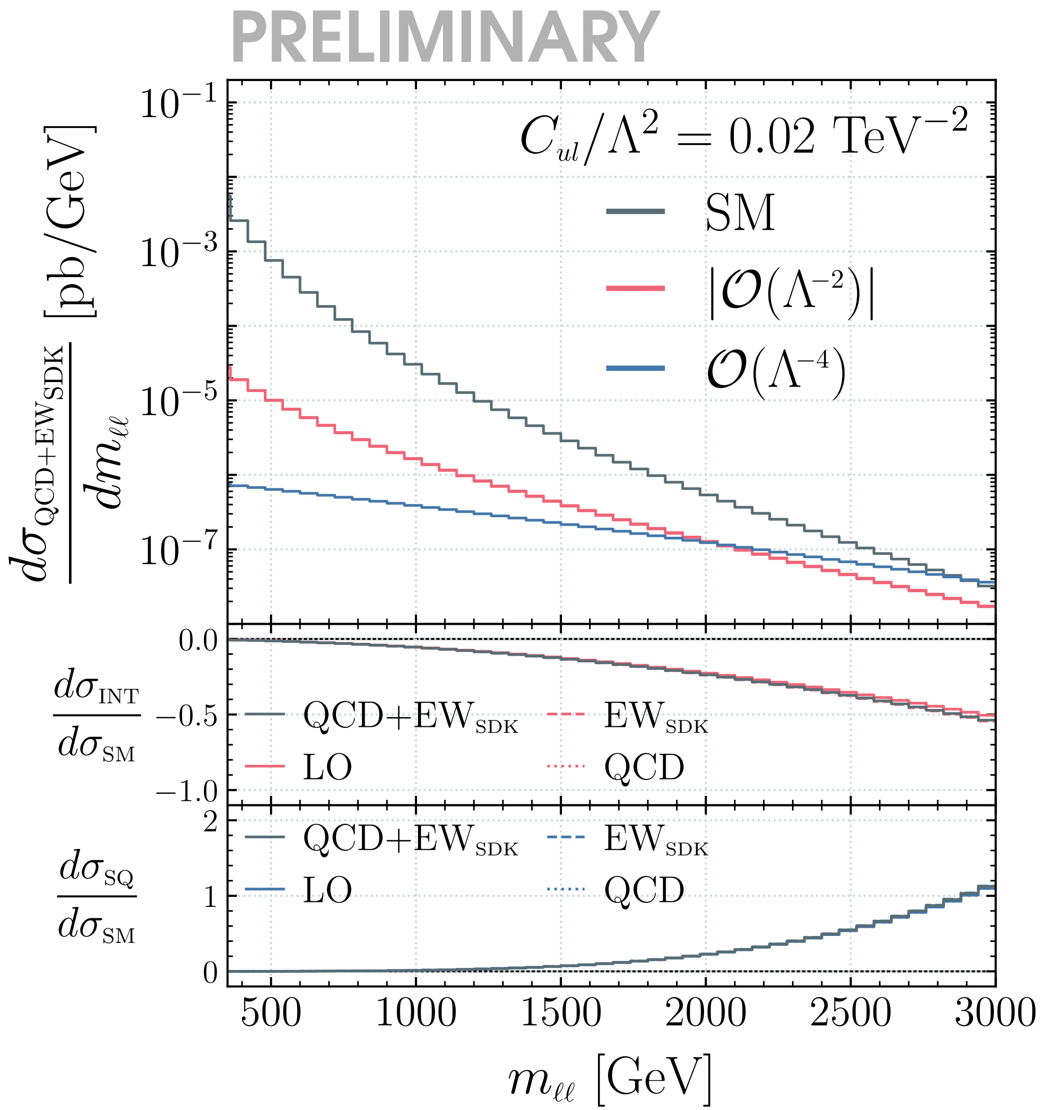


K-factor

$$[\mathcal{O}_{t\ell}]_{\mathrm{ff}} = (\bar{t}\gamma^{\mu}t)(\bar{\ell}_{\mathrm{f}}\gamma_{\mu}\ell_{\mathrm{f}})$$

A fun example: pp→e⁺e⁻



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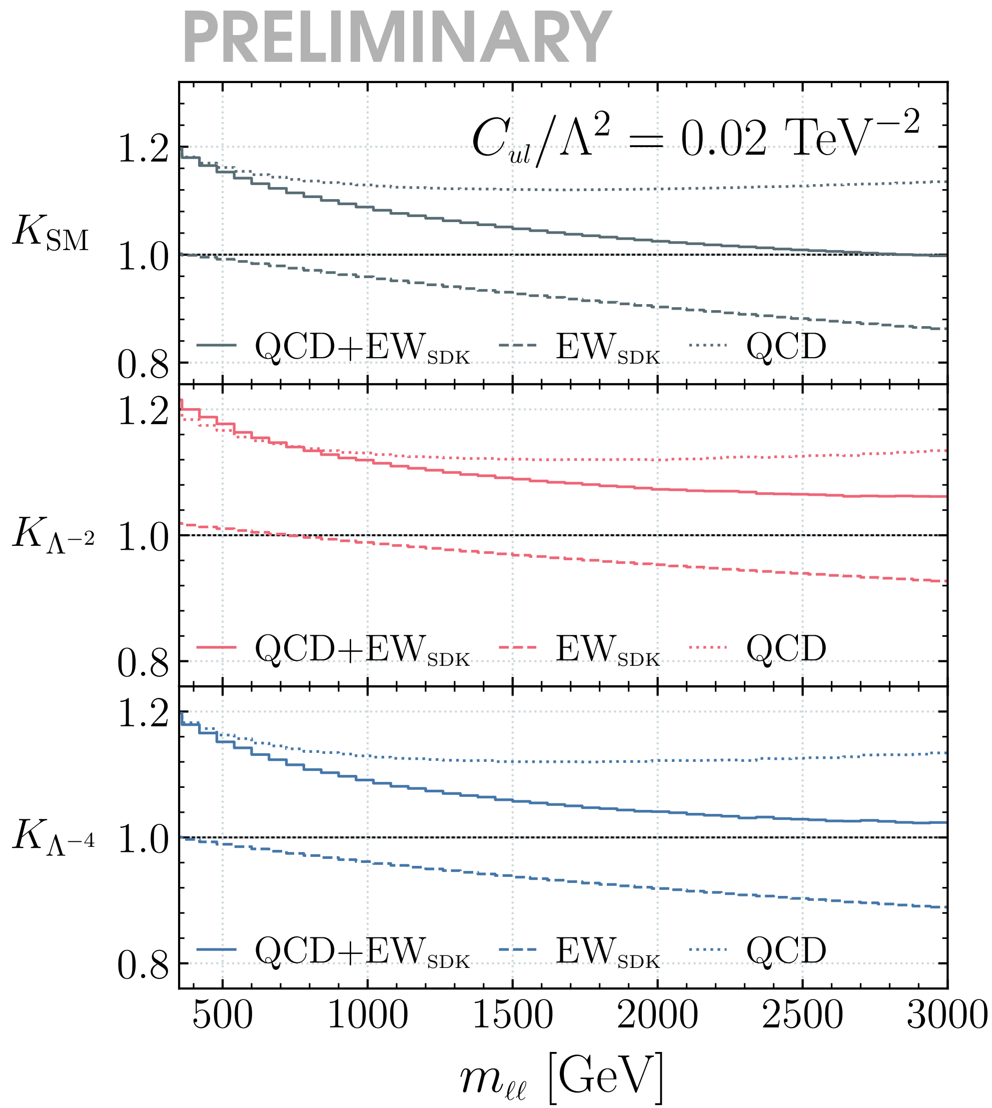

K-factor

$$\mathcal{O}_{u\ell} = \sum_{\mathrm{f}=1}^{2}(\overline{u}_{\mathrm{f}}\gamma^{\mu}u_{\mathrm{f}})(\bar{\ell}\gamma_{\mu}\ell)$$

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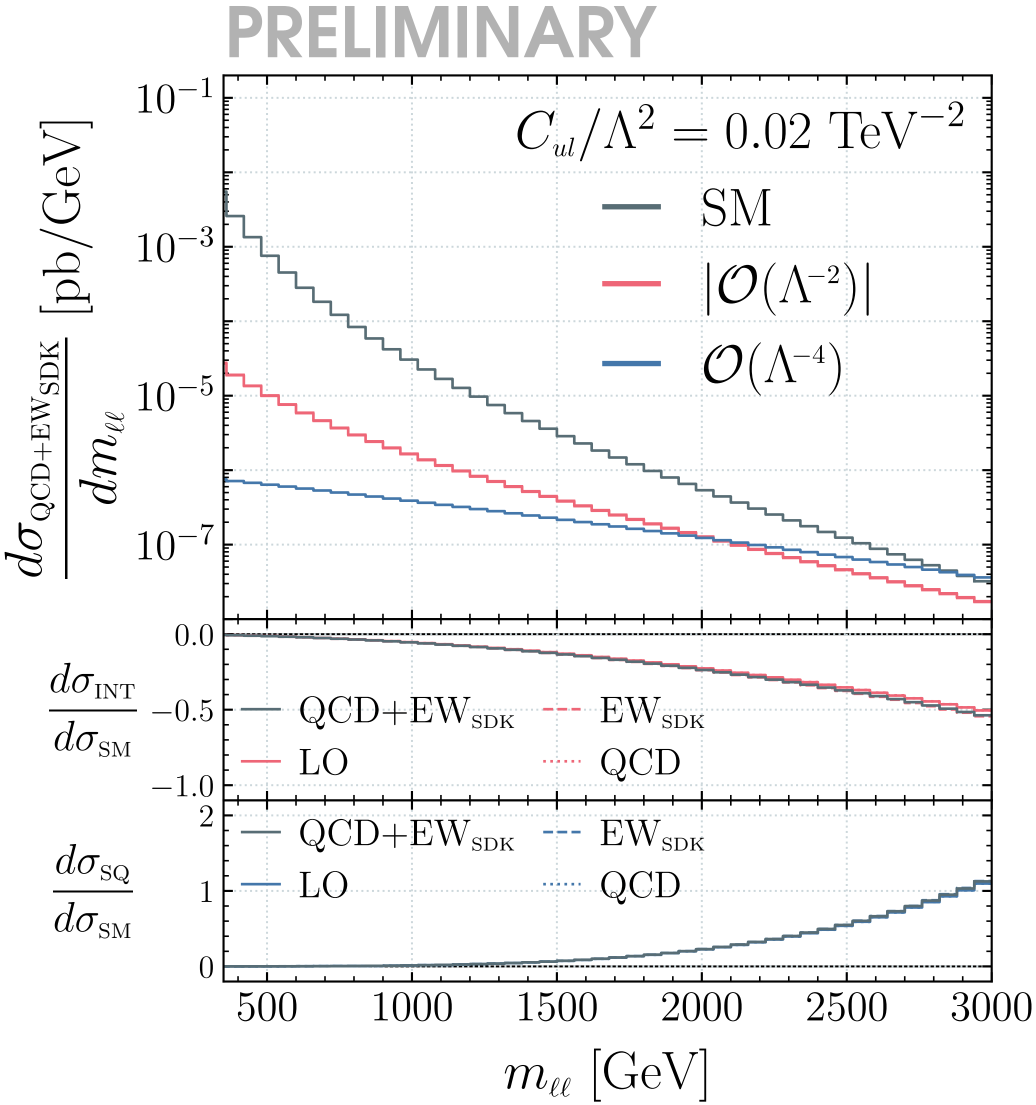

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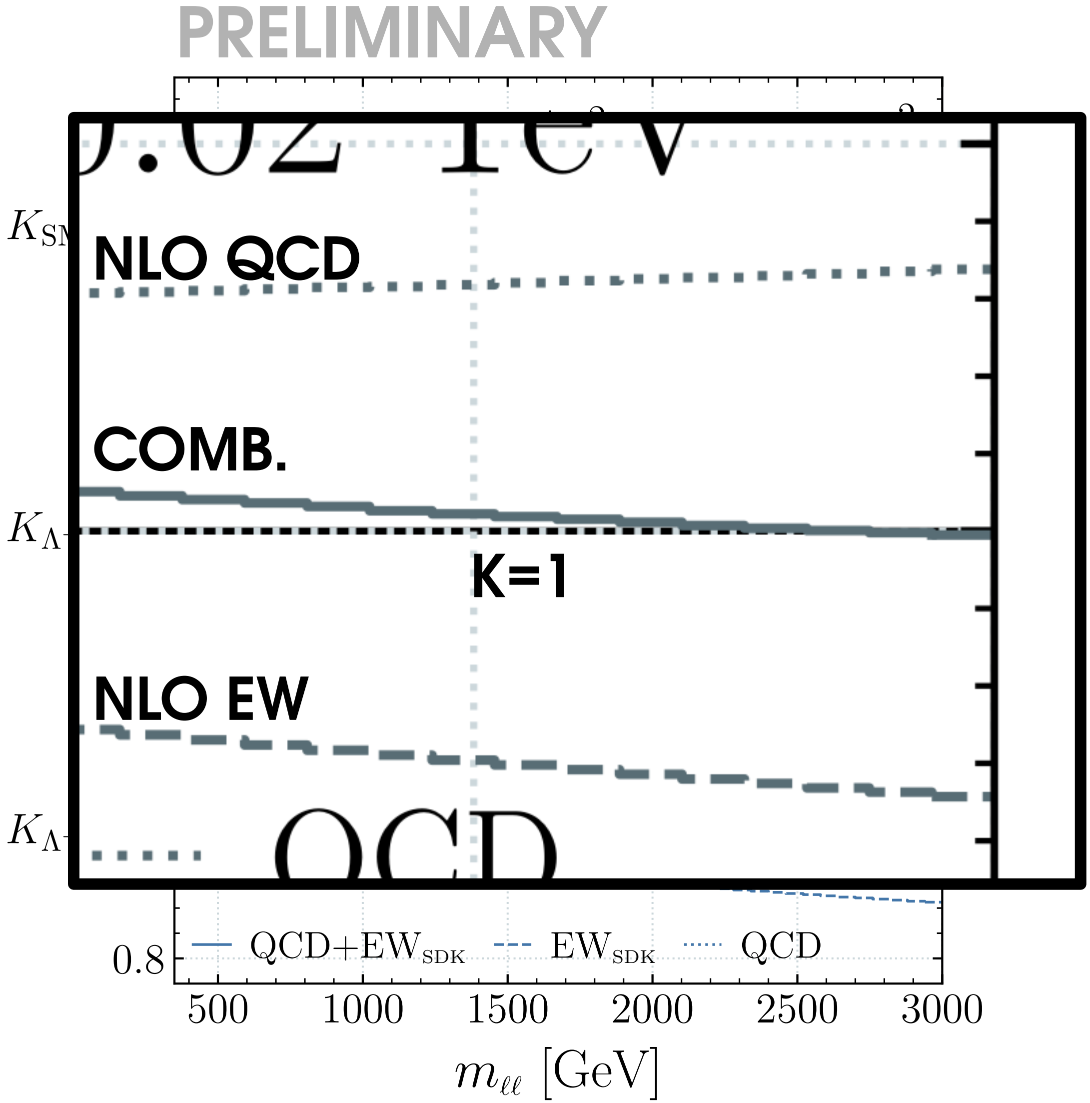

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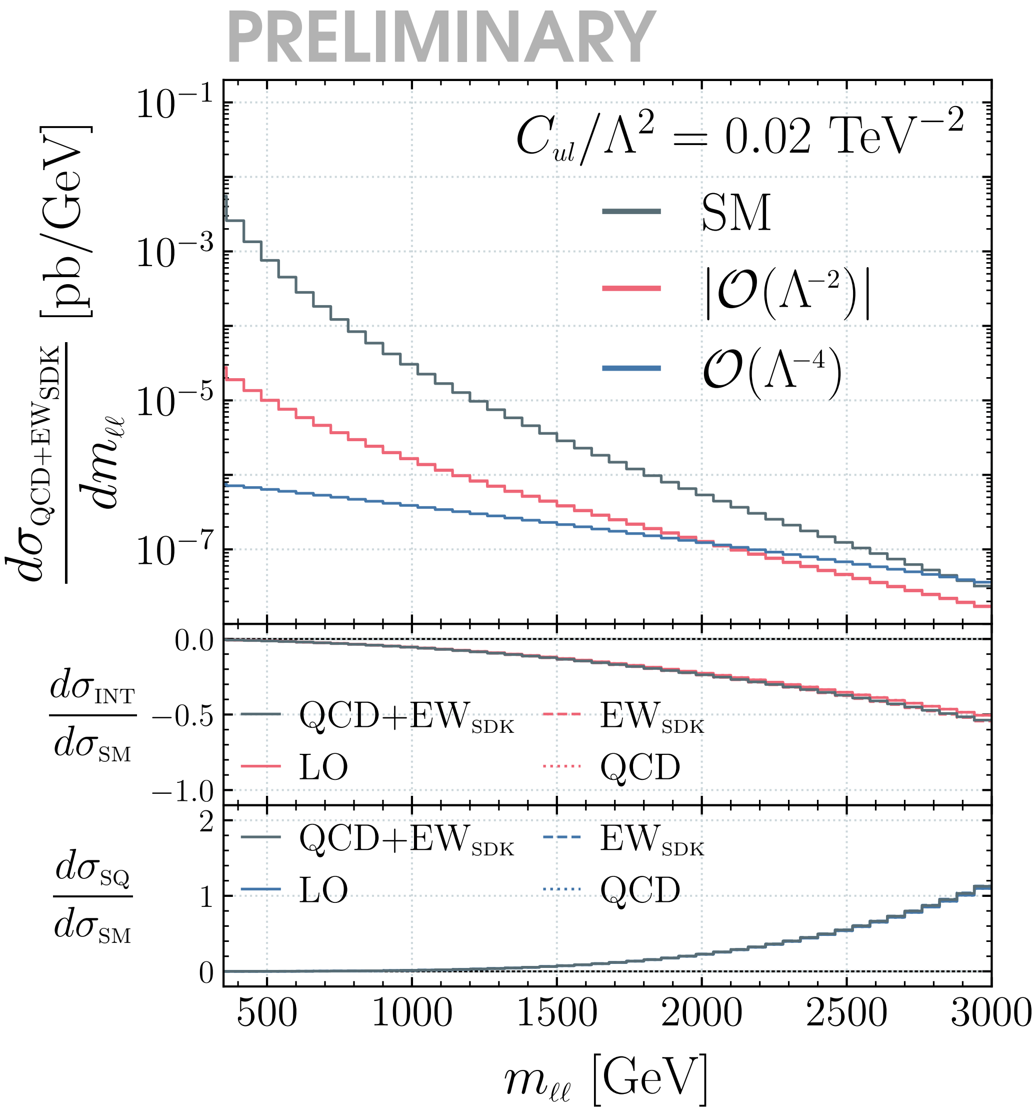

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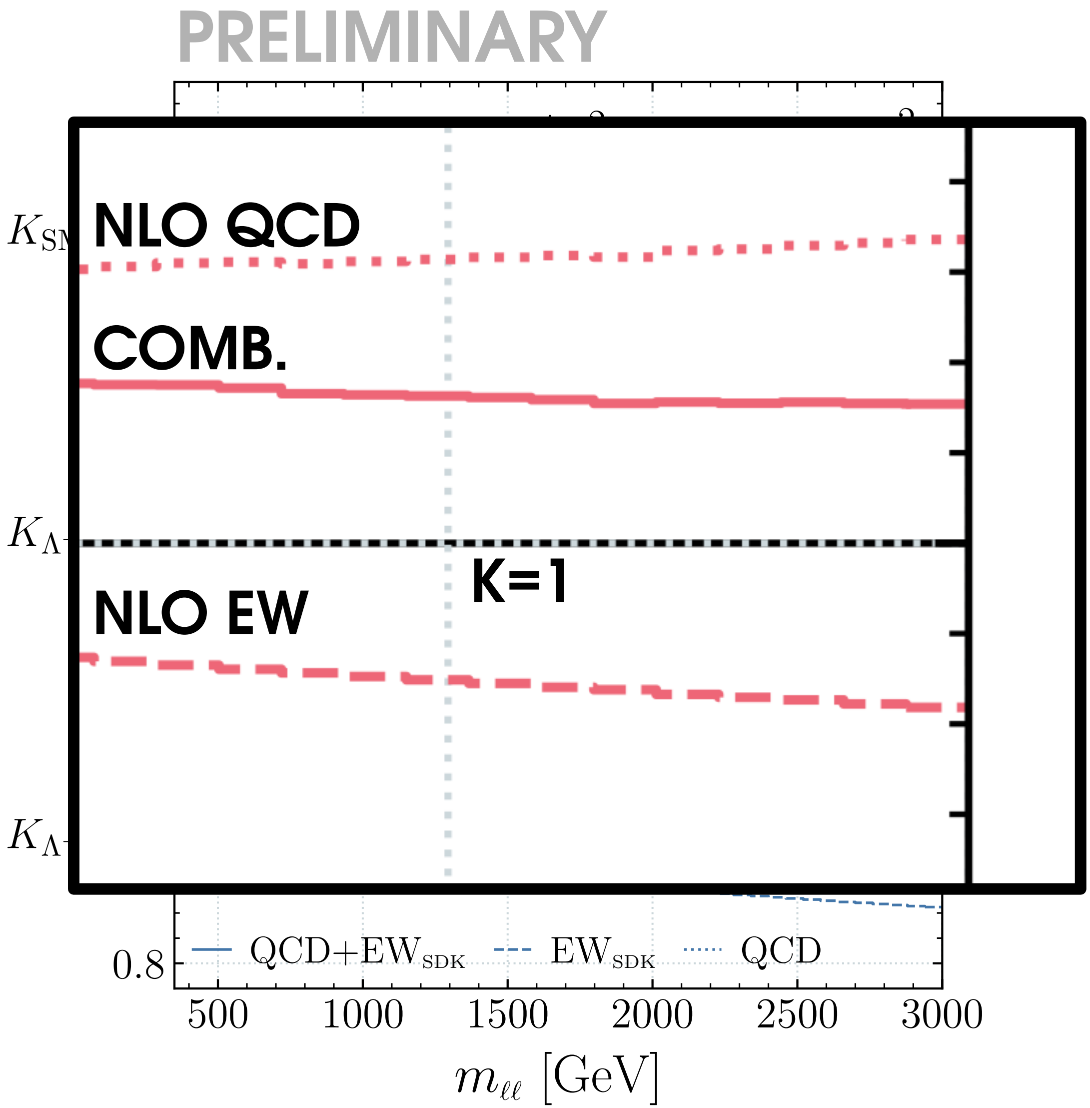

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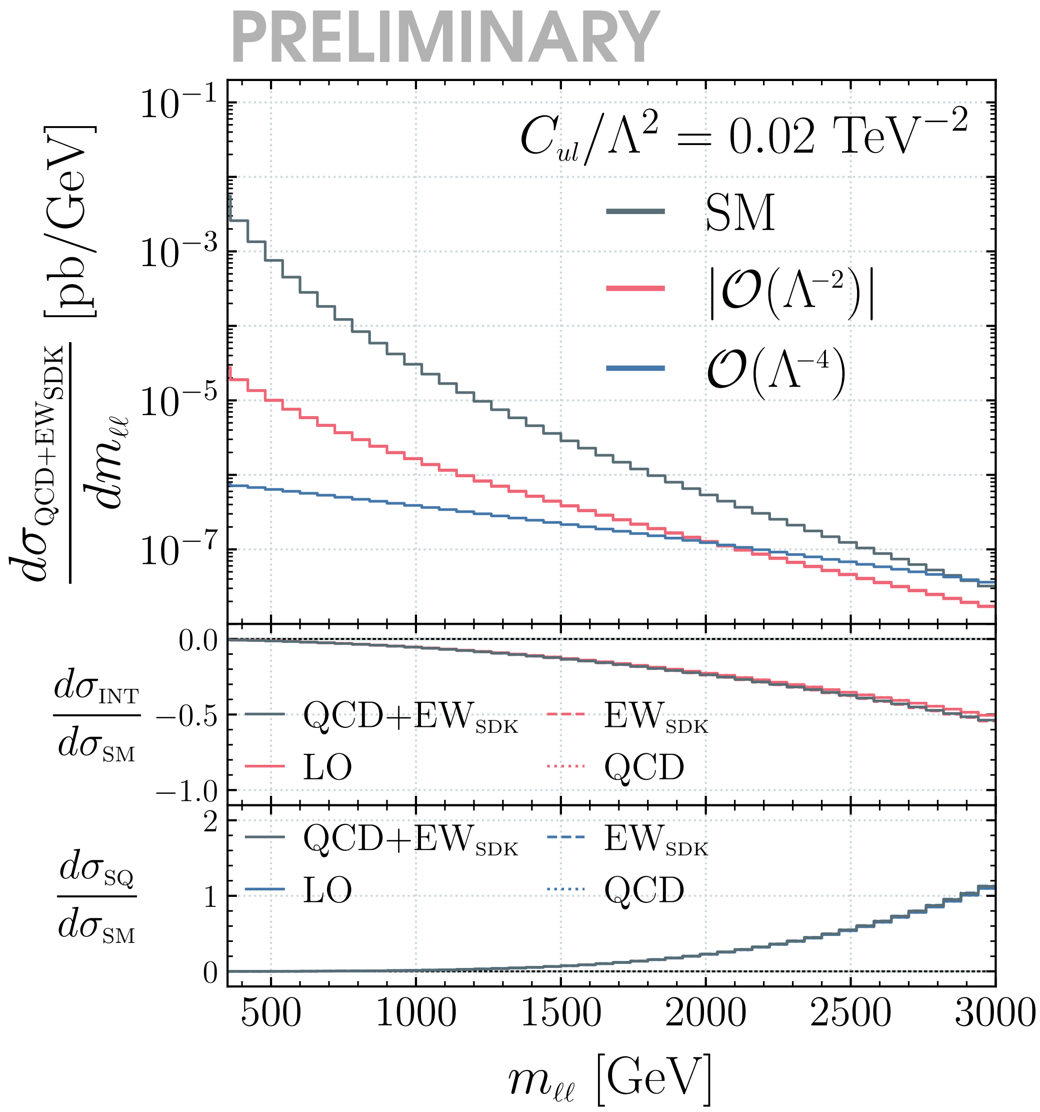

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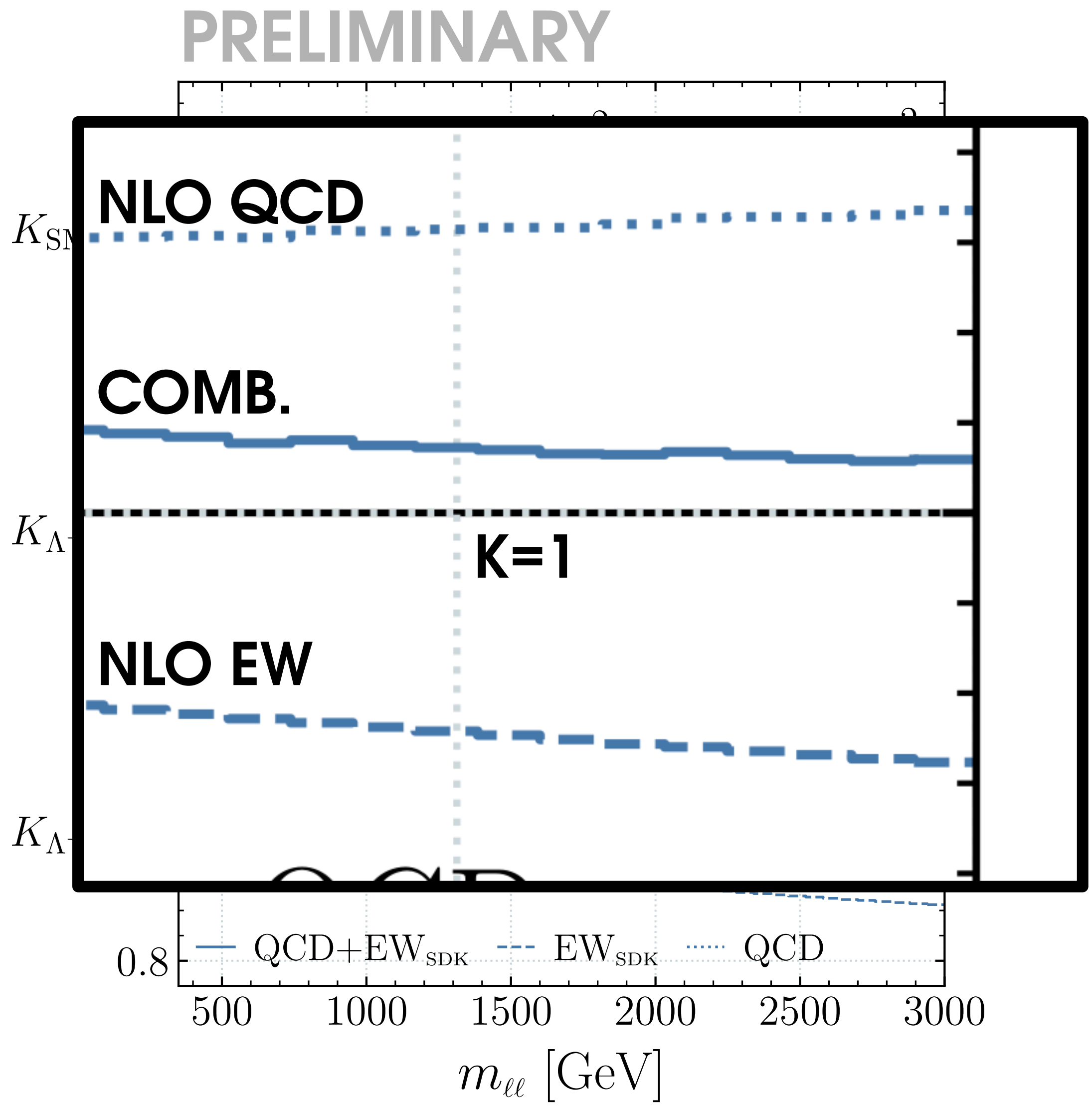

K-factor

$$\mathcal{O}_{u\ell} = \sum_{\mathrm{f}=1}^{2} (\bar{u}_{\mathrm{f}}\gamma^{\mu}u_{\mathrm{f}})(\bar{\ell}\gamma_{\mu}\ell).$$

Some final remarks

We extracted NLO EW corrections to four-fermion SMEFT operators in the high-energy limit, where they are dominated by Sudakov logarithms.

Our approach is fast, numerically stable, and accurate for tails of LHC distributions.

- Relative impact of NLOEW is different between SM, $1/\Lambda^2$, $1/\Lambda^4$ terms. Pattern of corrections depend on operator.

- EFT contributions at NLO show cancellations between QCD and EW.

- It is inaccurate to propagate SM k-factors to the SMEFT.

- Impact of NLO EW small at ~100 GeV, but about 10% at 1 TeV and larger beyond.

in case anyone asks...

Mass suppression

The approximation of NLO EW with Sudakov logarithms assumes the amplitude survives the *vev* → 0 limit.

While in the SM processes with a O(vev) amplitude are very rare, they are quite common in the SMEFT.

Four fermion operators are always ok, some SMEFT operators are not:

$$O_{tG} = \frac{g_S C_{tG}}{\Lambda^2} \bar{Q}_L \tilde{\phi} \sigma^{\mu\nu} G_{\mu\nu} t_R = \frac{g_S C_{tG} v}{\Lambda^2} \bar{t}_L \sigma^{\mu\nu} G_{\mu\nu} t_R + \frac{g_S C_{tG}}{\Lambda^2} h \bar{t}_L \sigma^{\mu\nu} G_{\mu\nu} t_R$$

This gives rise to additional collinear logs that can not be extracted in general.