



European Research Council
Established by the European Commission

MANCHESTER
1824

The University of Manchester

ELECTROWEAK CORRECTIONS FROM SUDAKOV LOGARITHMS IN THE SMEFT

El Faham, Mimasu, Pagani, CS, Vryonidou, Zaro
240x.xxxxx

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

The LHC is running again

LHC Page1 Fill: 9905 E: 6800 GeV t(SB): 10:31:13 16-07-24 15:47:07

PROTON PHYSICS: STABLE BEAMS

Energy: 6800 GeV | B1: 2.46e+14 | B2: 2.52e+14

Beta* IP1: 0.30 m Beta* IP2: 10.00 m Beta* IP5: 0.30 m Beta* IP8: 2.00 m

Inst. Lumi [(ub.s)⁻¹] IP1: 15549.57 IP2: 8.55 IP5: 15327.94 IP8: 1607.11

FBCT Intensity and Beam Energy Updated: 15:47:06 Instantaneous Luminosity Updated: 15:47:07

ATLAS ALICE CMS LHCb

BIS status and SMP flags		B1	B2
Link Status of Beam Permits		true	true
Global Beam Permit		true	true
Setup Beam		false	false
Beam Presence		true	true
Moveable Devices Allowed In		true	true
Stable Beams		true	true

Comments (16-Jul-2024 13:30:14):
STABLE BEAMS

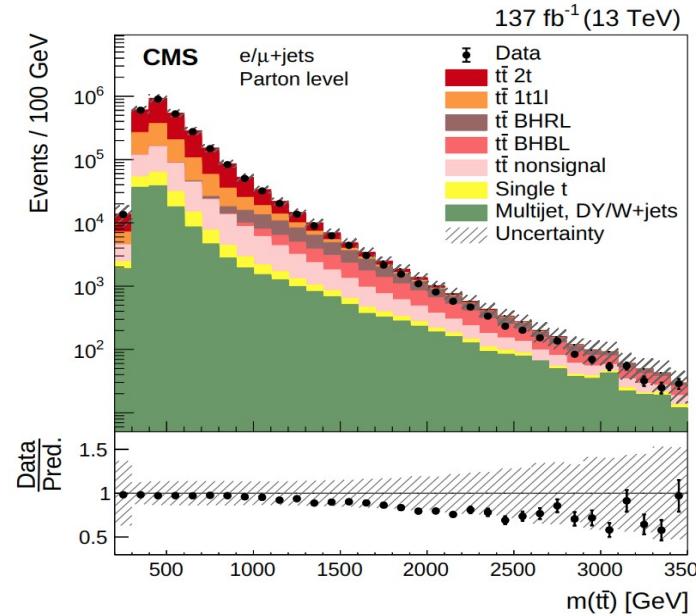
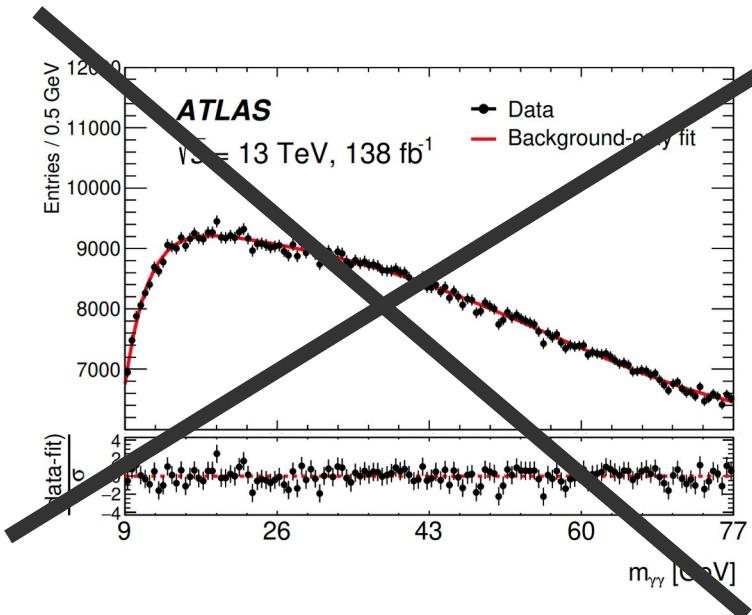
IP2 and IP8 on target
IP1 and IP5 head-on

AFS: 25ns_2352b_2340_2004_2133_108bpi_24inj PM Status B1: ENABLED PM Status B2: ENABLED

New physics?

New physics must be hiding very well!

Change of paradigm: bump hunting \rightarrow precision measurements



SM Effective field theory

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

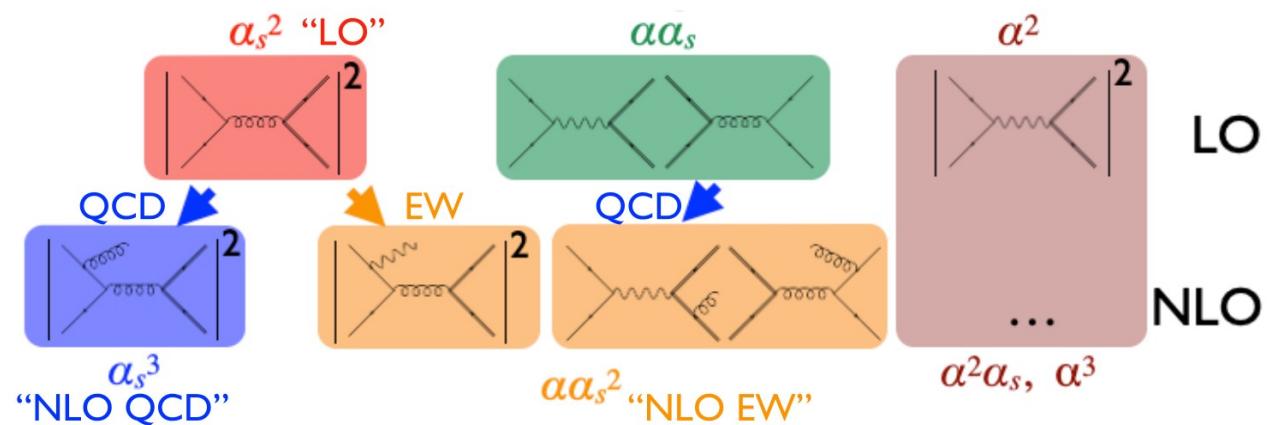
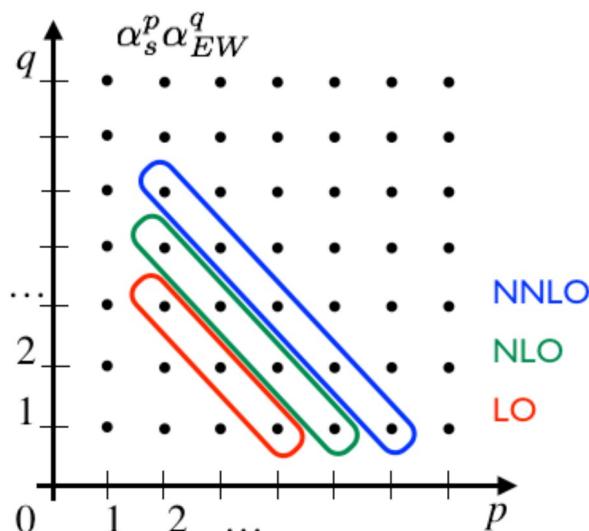
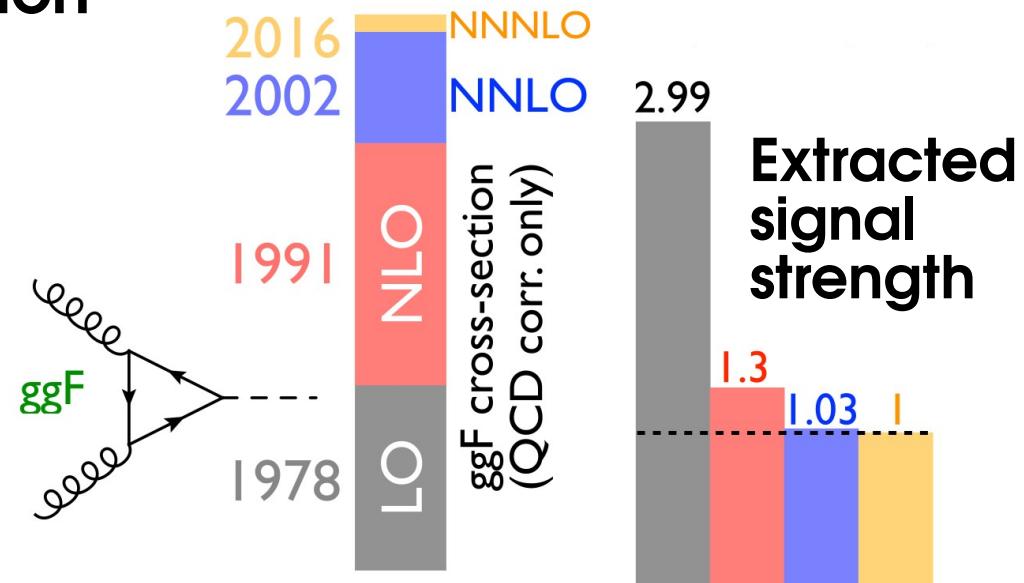
- Consistent way to parameterize deviations across searches
- As model independent as reasonably possible

Precision for measurements

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

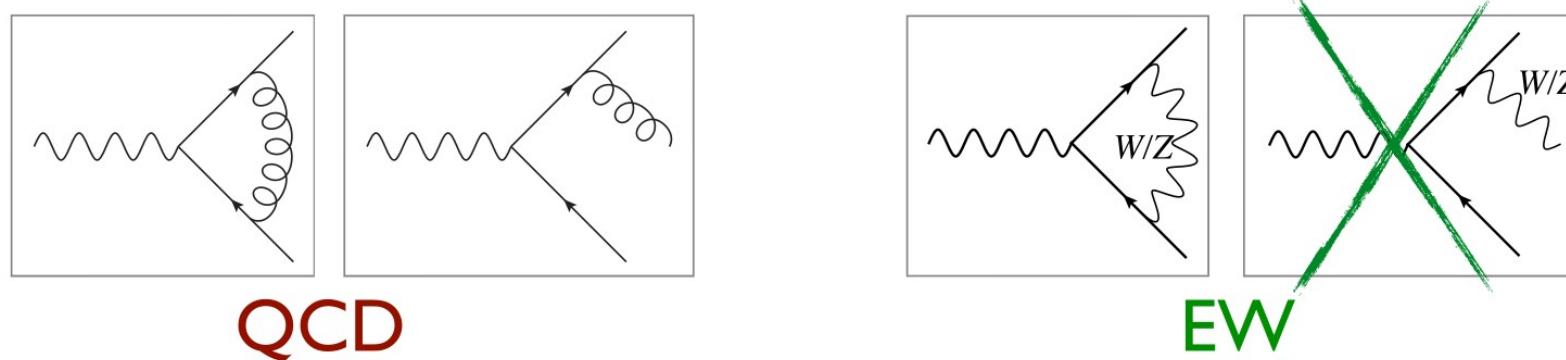
Higgs physics gives a clear example: without higher orders the measured rate for $gg \rightarrow H$ would be 3x the “SM prediction”

Also, $\text{NLO} \neq \text{QCD}$



Large EW corrections

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



Sudakov logarithms $\alpha \log^2 s/m_W^2$ and $\alpha \log s/m_W^2$
NLO EW is $O(10\%)$ at $\sim \text{TeV}$ 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 four-fermion operators, we looked at top pair production at the LHC and in a lepton collider.

$$\mathcal{O}_{tu}^8 = \sum_{f=1}^2 (\bar{t} \gamma_\mu T^A t) (\bar{u}_f \gamma^\mu T_A u_f),$$

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

$$\mathcal{O}_{tq}^8 = \sum_{f=1}^2 (\bar{t} \gamma^\mu T^A t) (\bar{q}_f \gamma_\mu T_A q_f),$$

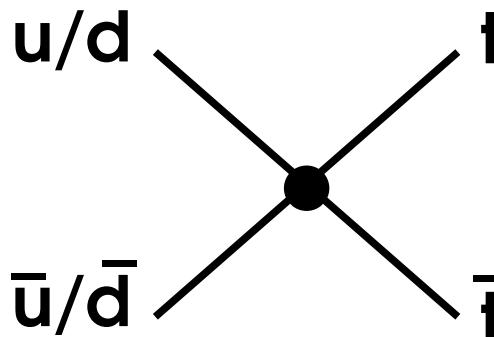
$$\mathcal{O}_{Qu}^8 = \sum_{f=1}^2 (\bar{Q} \gamma_\mu T_A Q) (\bar{u}_f \gamma^\mu T^A u_f),$$

$$\mathcal{O}_{Qd}^8 = \sum_{f=1}^3 (\bar{Q} \gamma_\mu T_A Q) (\bar{d}_f \gamma^\mu T^A d_f),$$

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

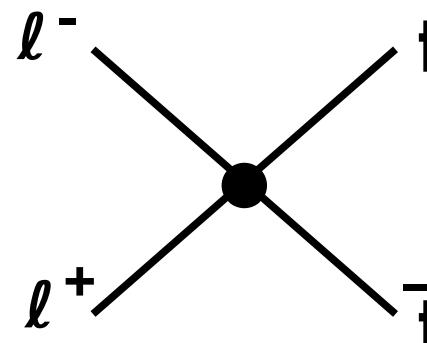
$$\mathcal{O}_{Qq}^{3,8} = \sum_{f=1}^2 (\bar{Q} \gamma_\mu T^A \sigma_I Q) (\bar{q}_f \gamma^\mu T_A \sigma^I q_f),$$

$$f = u, c / d, s, b$$



$$[\mathcal{O}_{te}]_{ff} = (\bar{t} \gamma^\mu t) (\bar{e}_f \gamma_\mu e_f),$$

$$[\mathcal{O}_{Qe}]_{ff} = (\bar{Q} \gamma_\mu Q) (\bar{e}_f \gamma^\mu e_f),$$



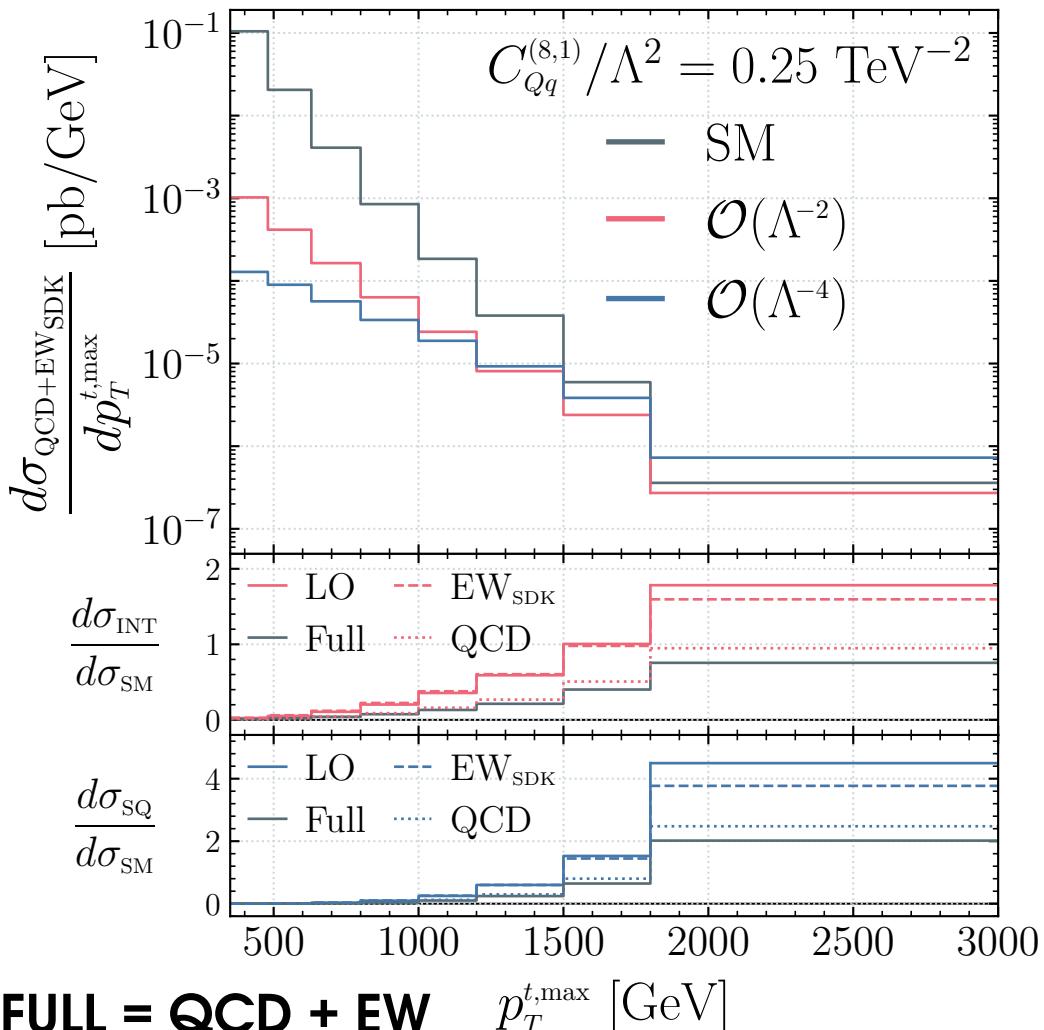
$$[\mathcal{O}_{t\ell}]_{ff} = (\bar{t} \gamma^\mu t) (\bar{\ell}_f \gamma_\mu \ell_f),$$

$$[\mathcal{O}_{Q\ell}^{(-)}]_{ff} = (\bar{Q} \gamma^\mu Q) (\bar{\ell}_f \gamma_\mu \ell_f),$$

$$f = e, \text{ mu, tau}$$

NLOEW in $t\bar{t}$ bar

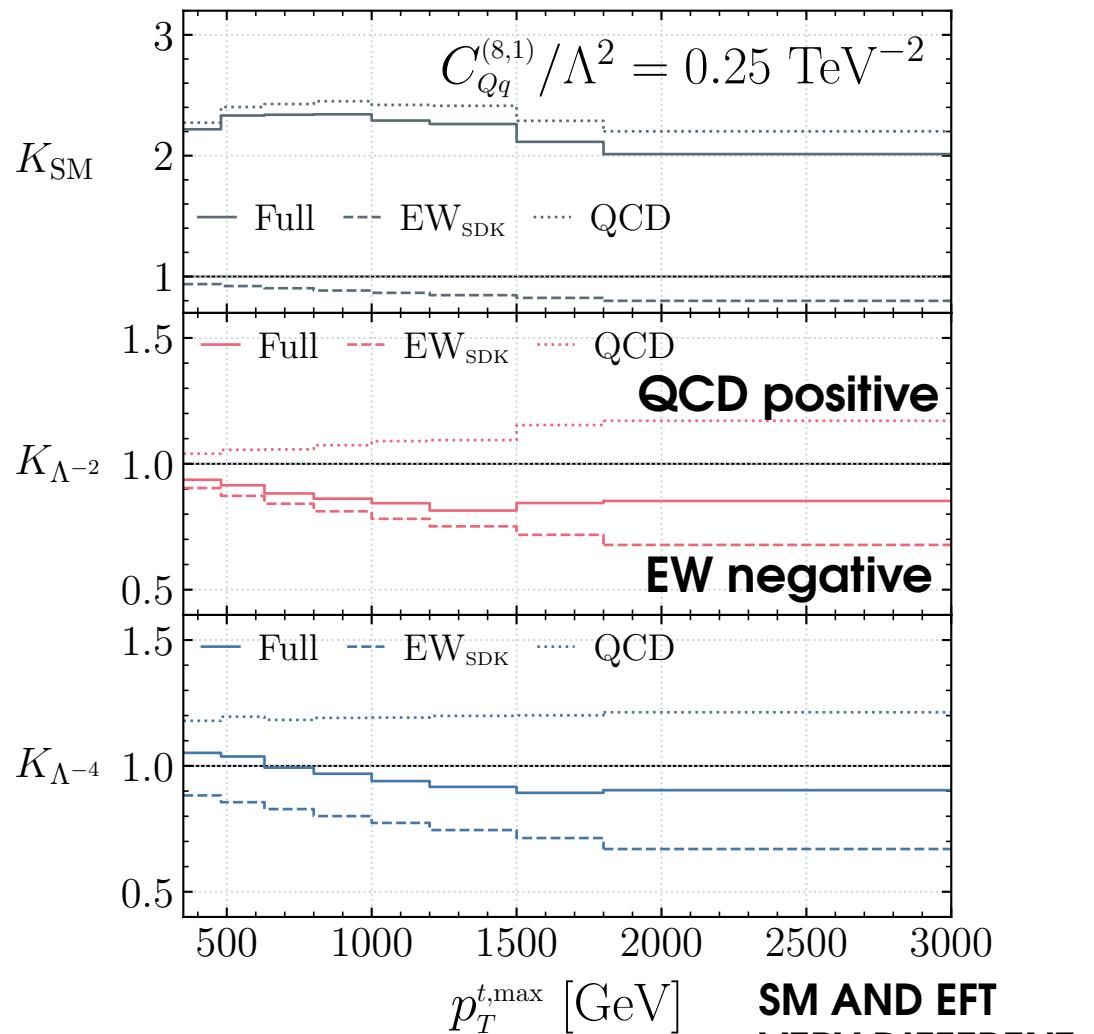
PRELIMINARY



Distribution

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

PRELIMINARY

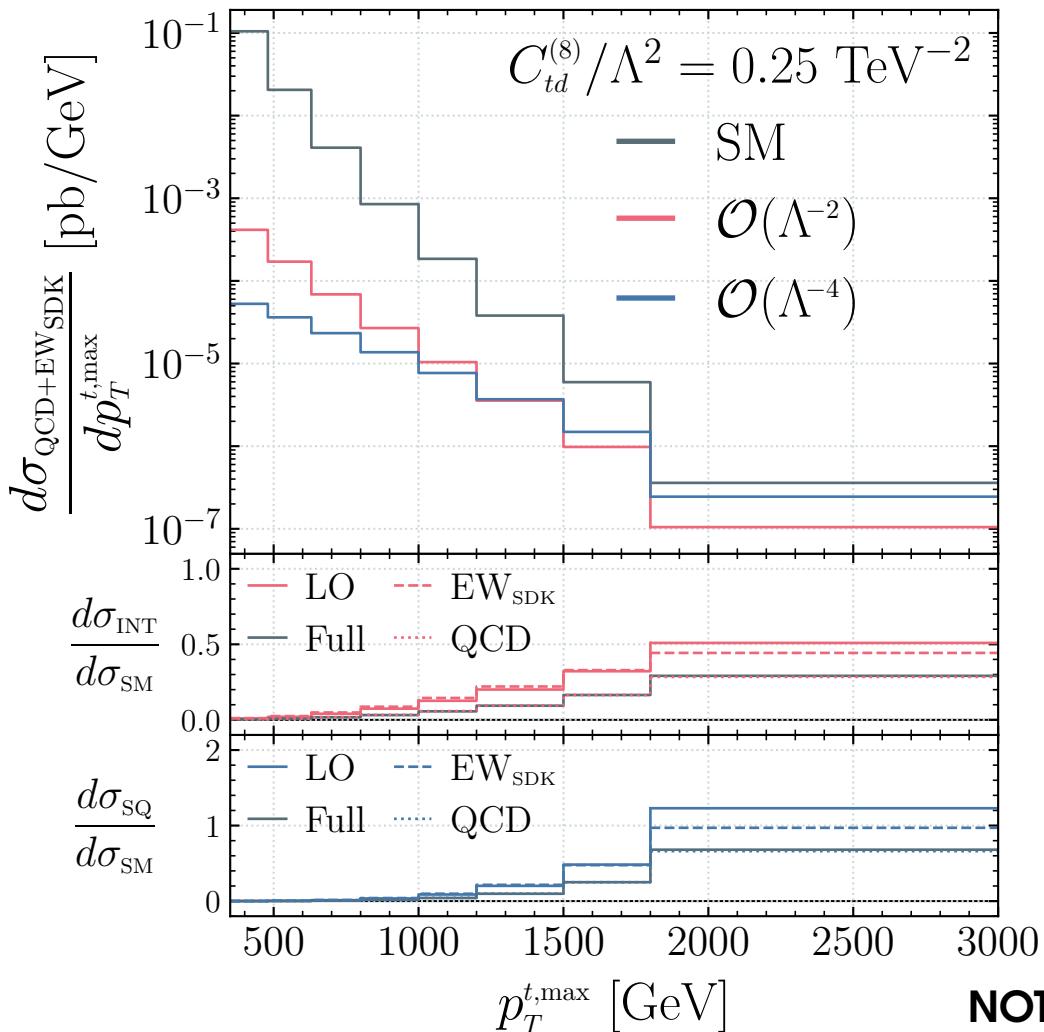


K-factor

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

NLOEW in $t\bar{t}$ bar

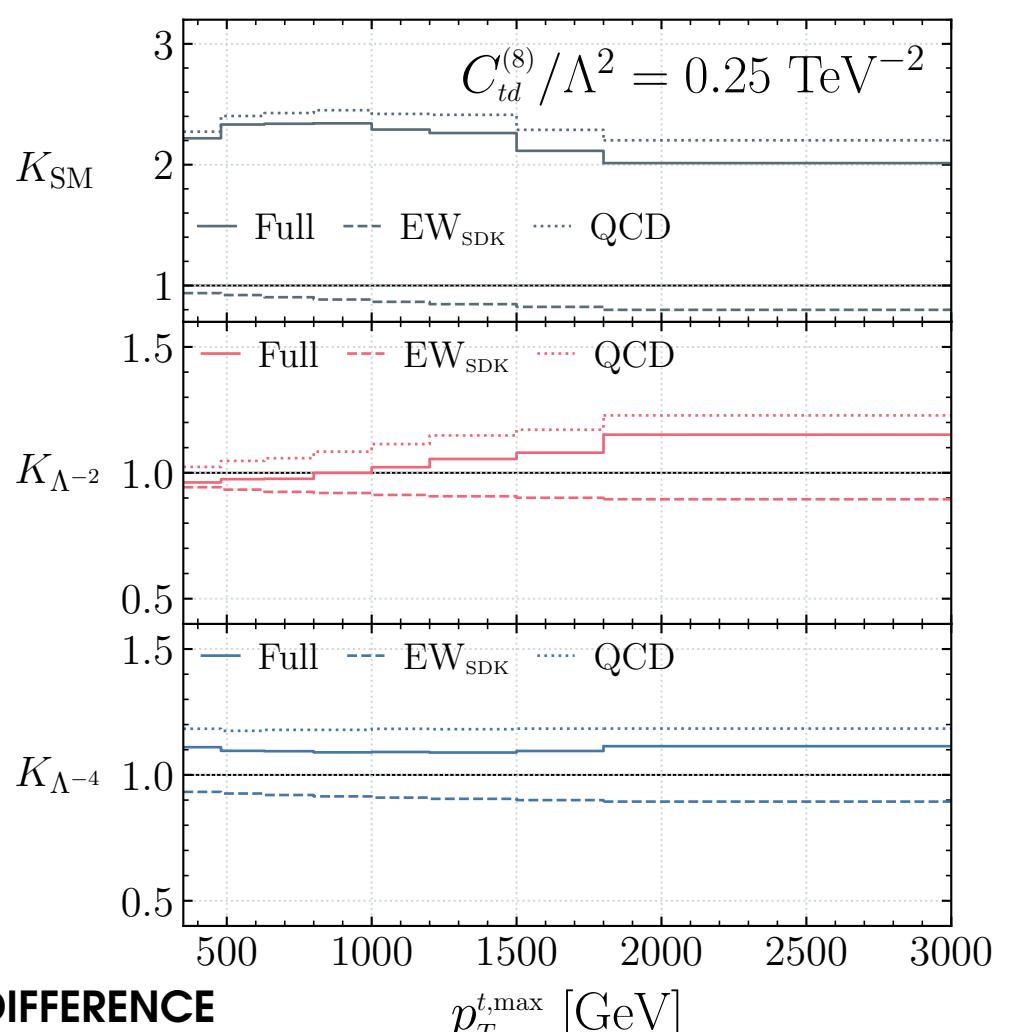
PRELIMINARY



Distribution

NOTE DIFFERENCE
WITH PREVIOUS
OPERATOR

PRELIMINARY



K-factor

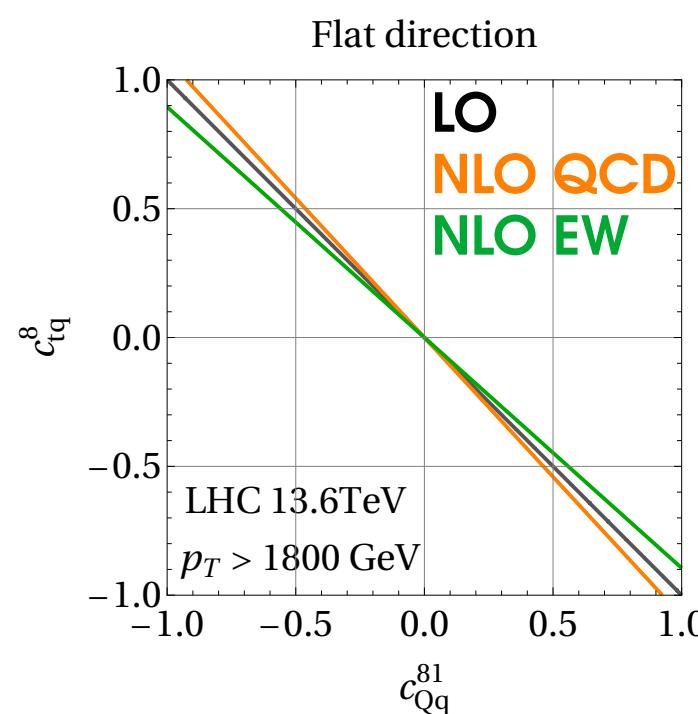
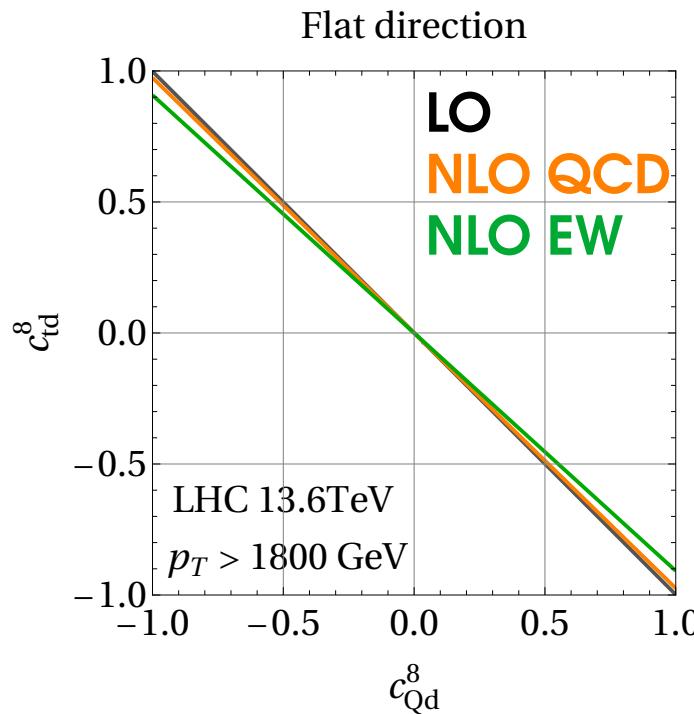
$$\mathcal{O}_{td}^8 = \sum_{f=1}^3 (\bar{t} \gamma_\mu T_A t)(\bar{d}_f \gamma^\mu T^A d_f)$$

NLOEW in ttbar

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

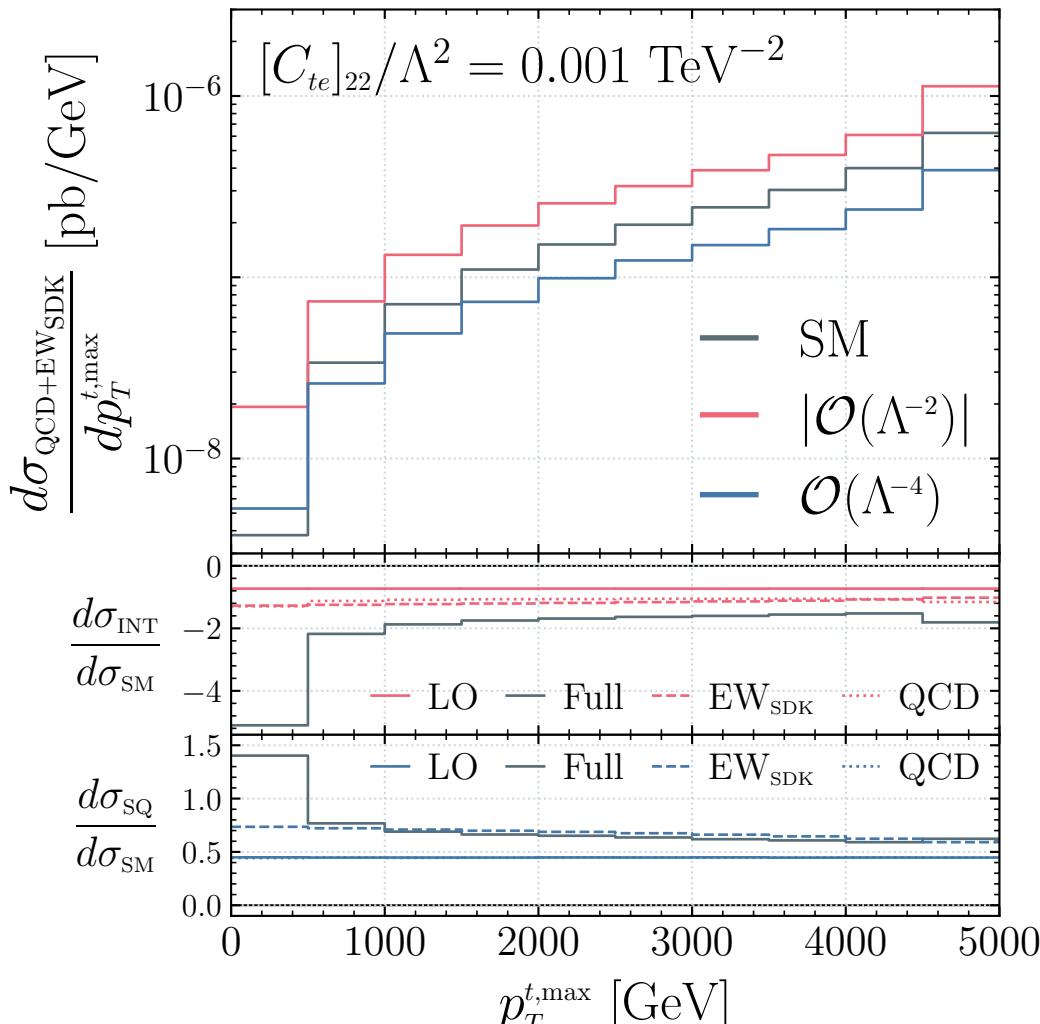
$$c_{Qd}^8 = -c_{td}^8 \quad \text{and} \quad c_{Qq}^{8,1} = -c_{tq}^8$$

**are related by $t_L \leftrightarrow t_R$ 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

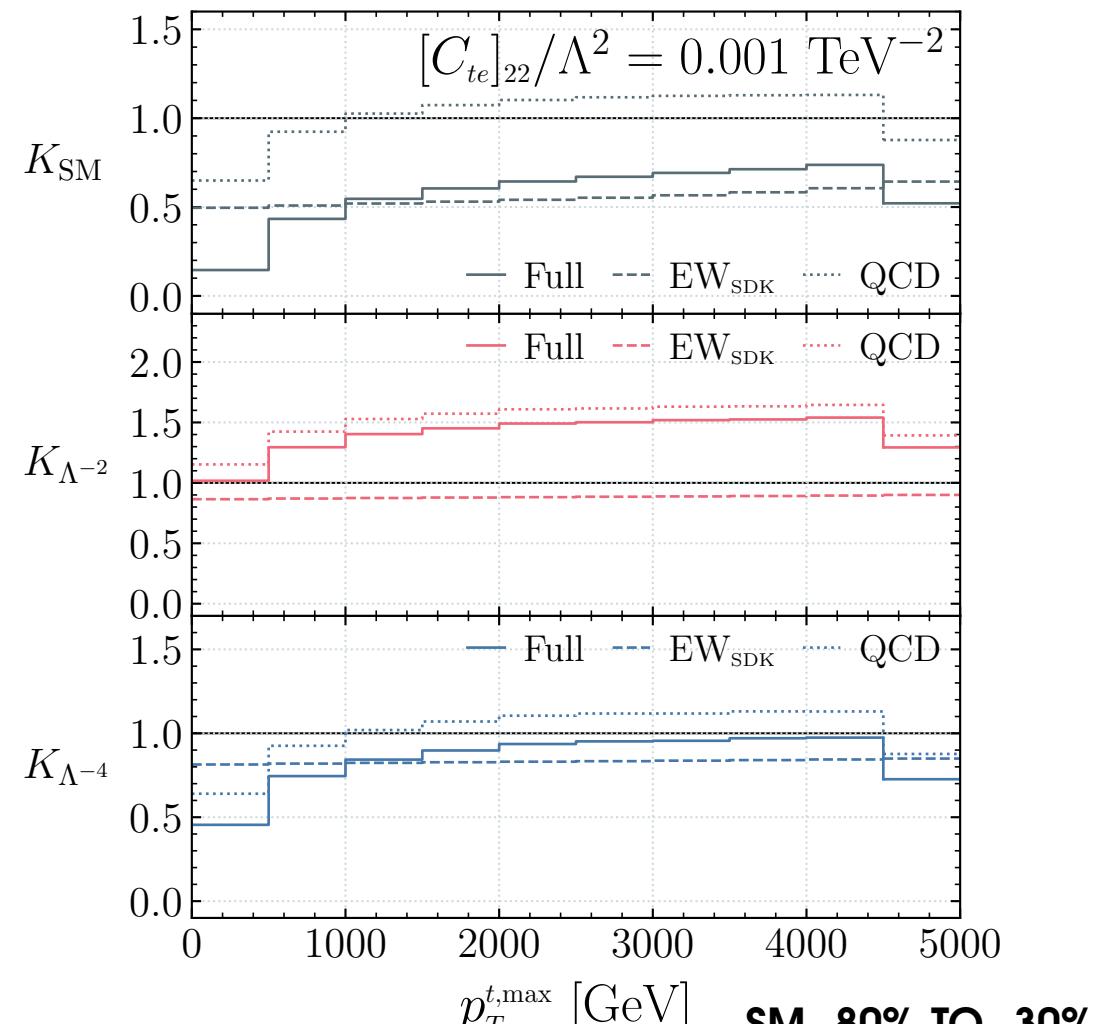
PRELIMINARY



Distribution

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

PRELIMINARY

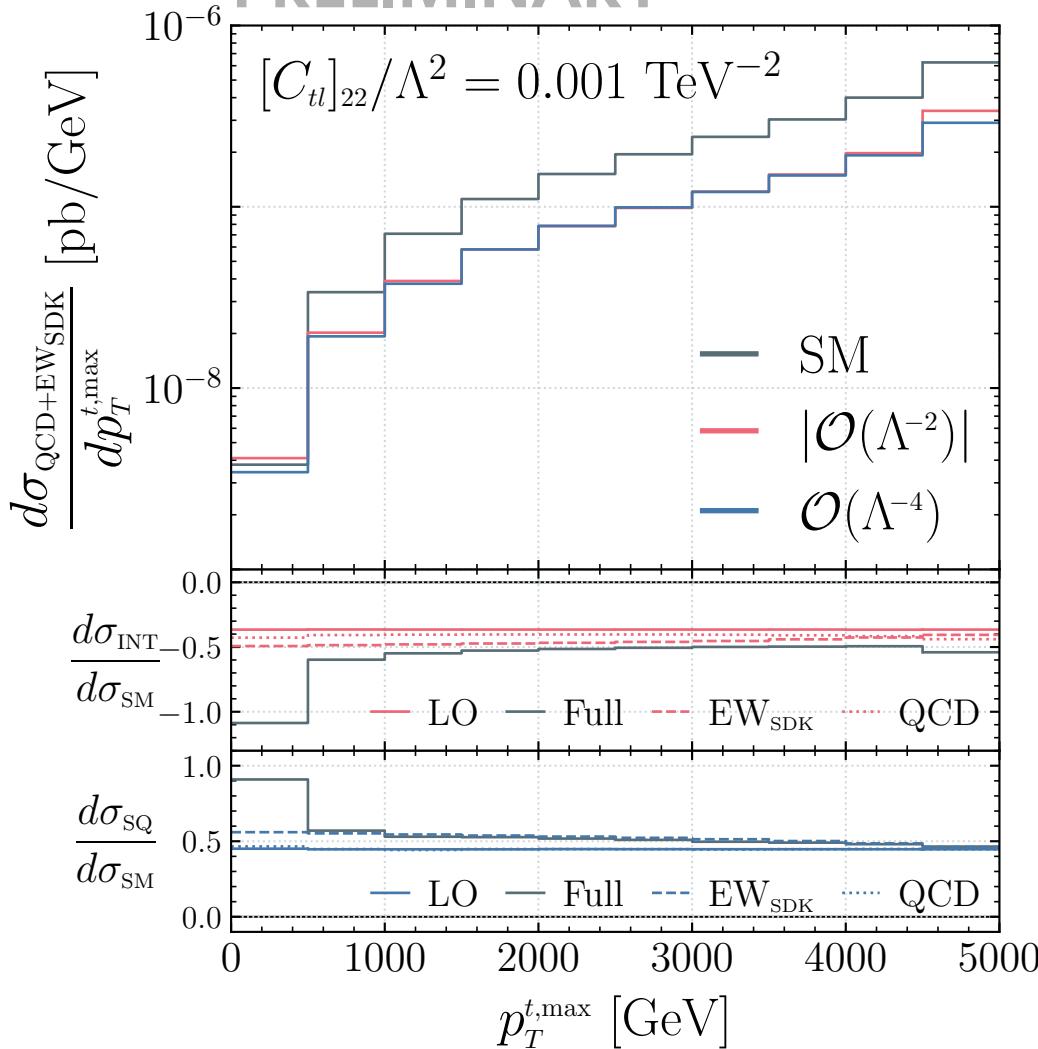


K-factor

SM -80% TO -30%
1/ Λ^2 POSITIVE
1/ Λ^4 -60% TO 0

NLOEW in a 10 TeV muon collider

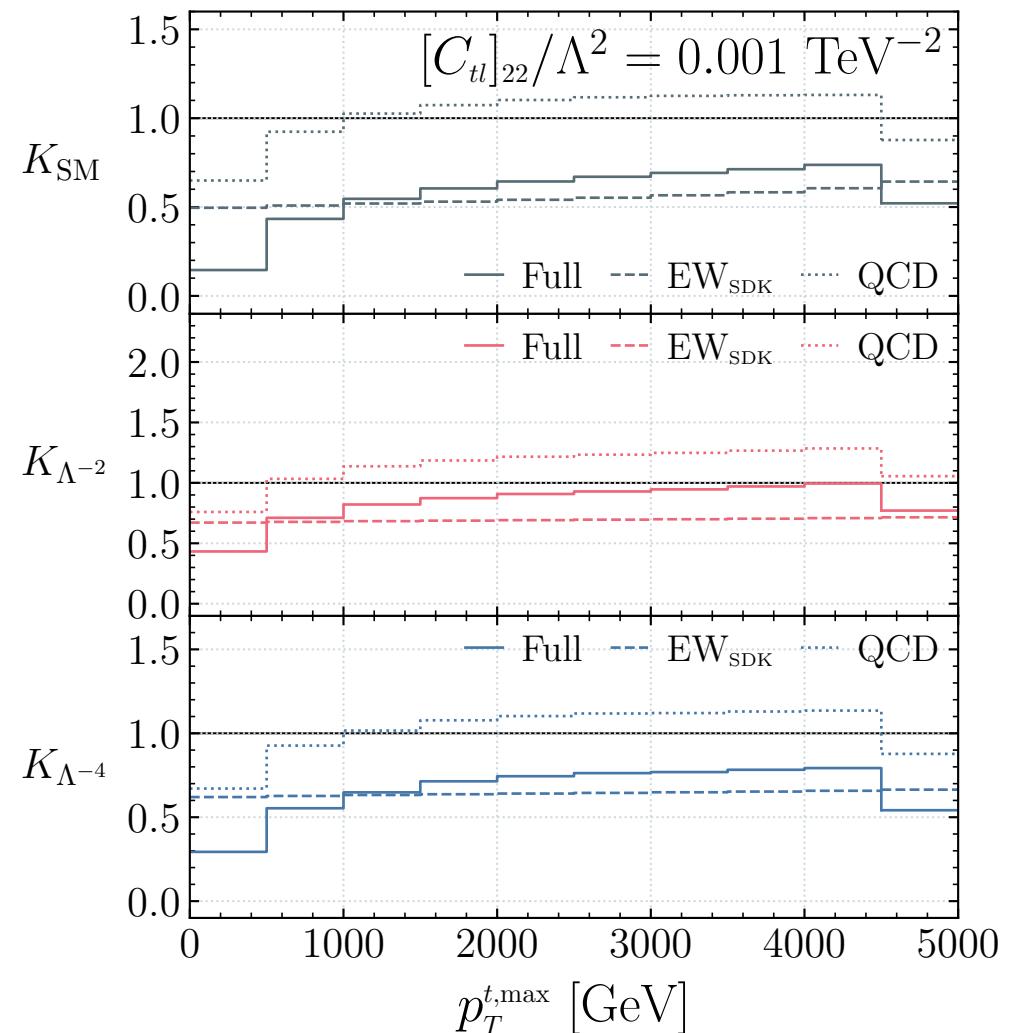
PRELIMINARY



Distribution

$$[\mathcal{O}_{t\ell}]_{\text{ff}} = (\bar{t}\gamma^\mu t)(\bar{\ell}_f\gamma_\mu \ell_f)$$

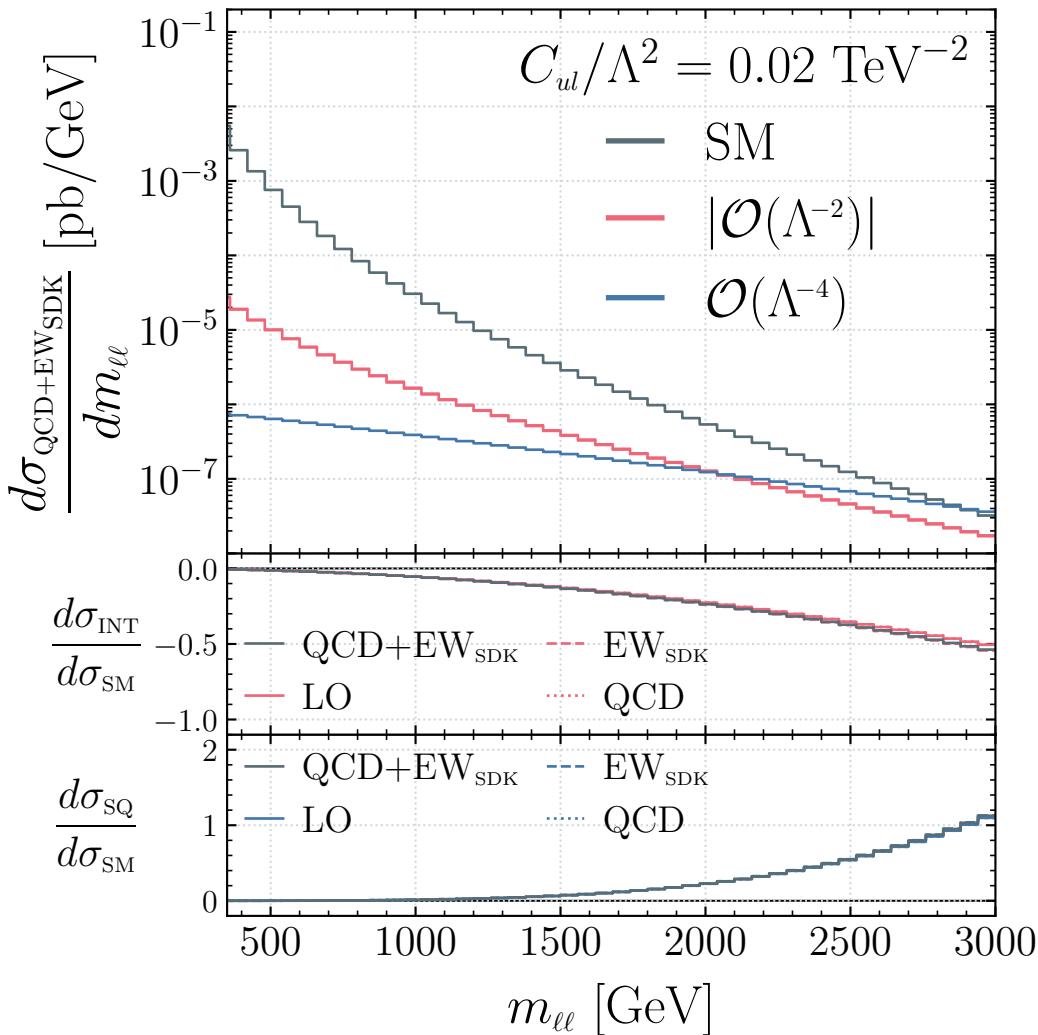
PRELIMINARY



K-factor

A fun example: $pp \rightarrow e^+e^-$

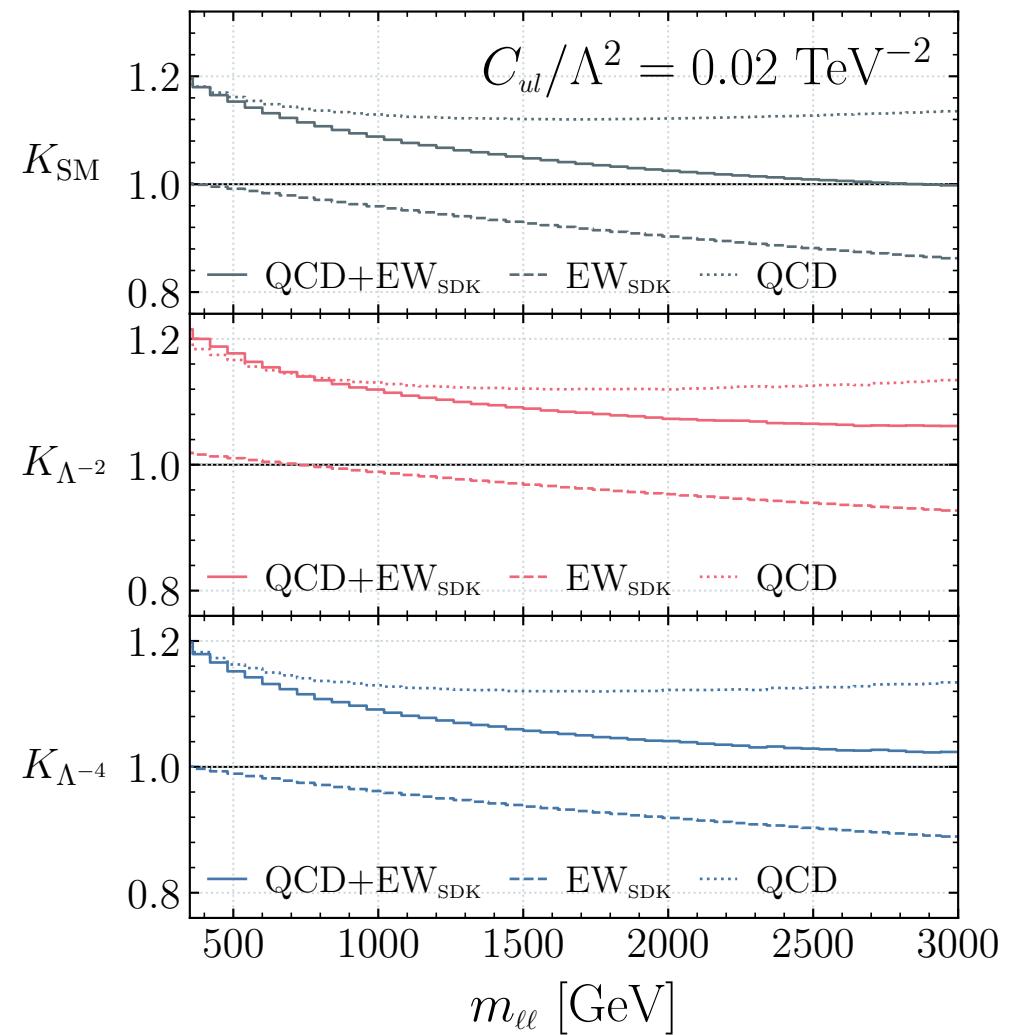
PRELIMINARY



Distribution

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

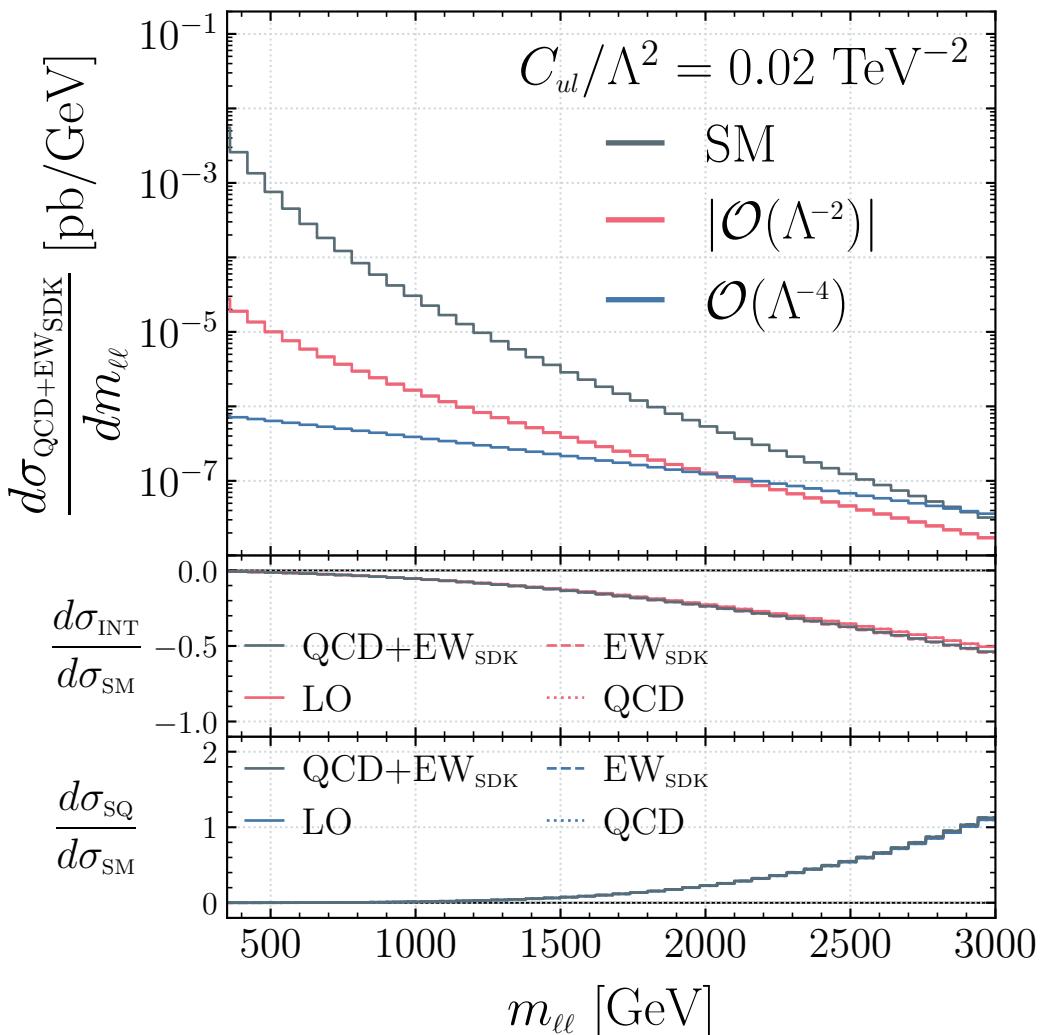
PRELIMINARY



K-factor

A fun example: $\text{pp} \rightarrow e^+e^-$

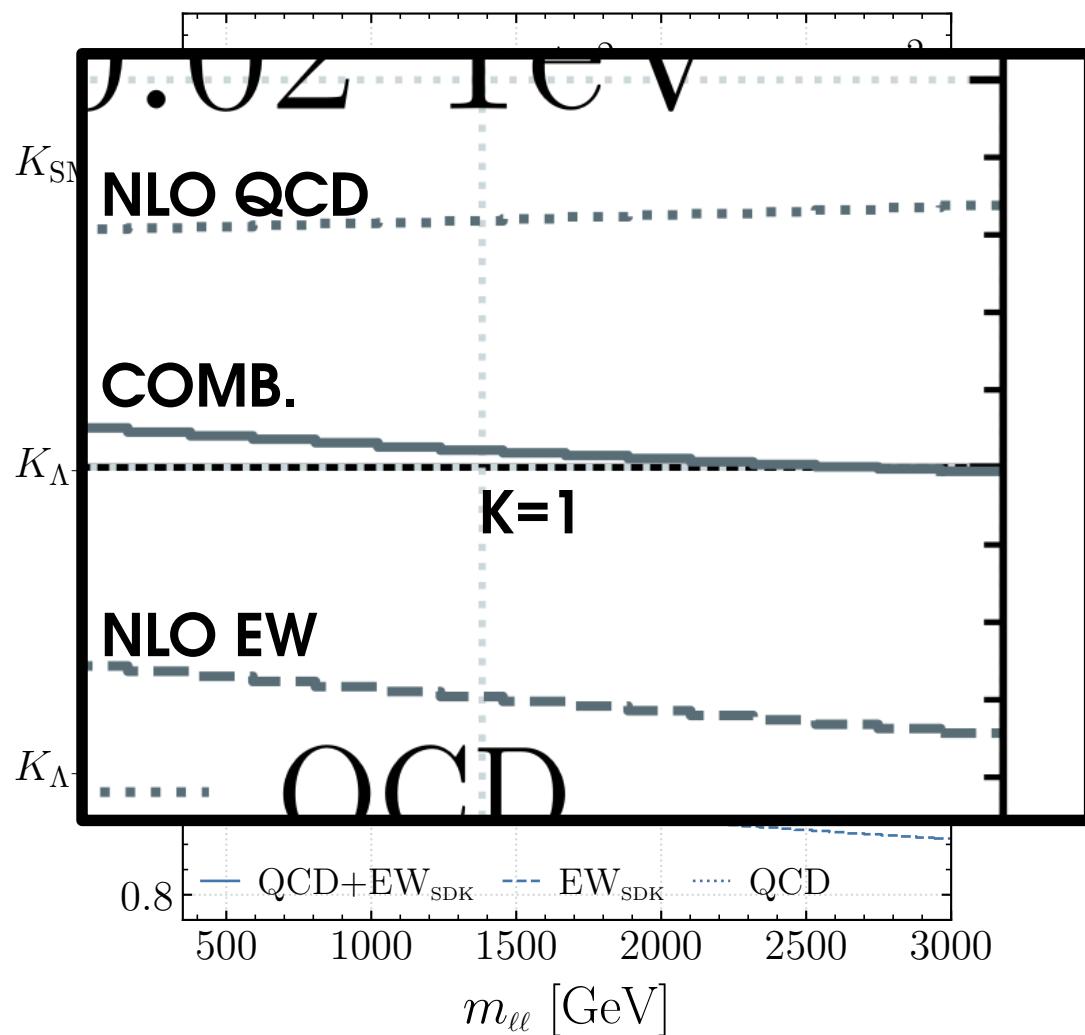
PRELIMINARY



Distribution

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

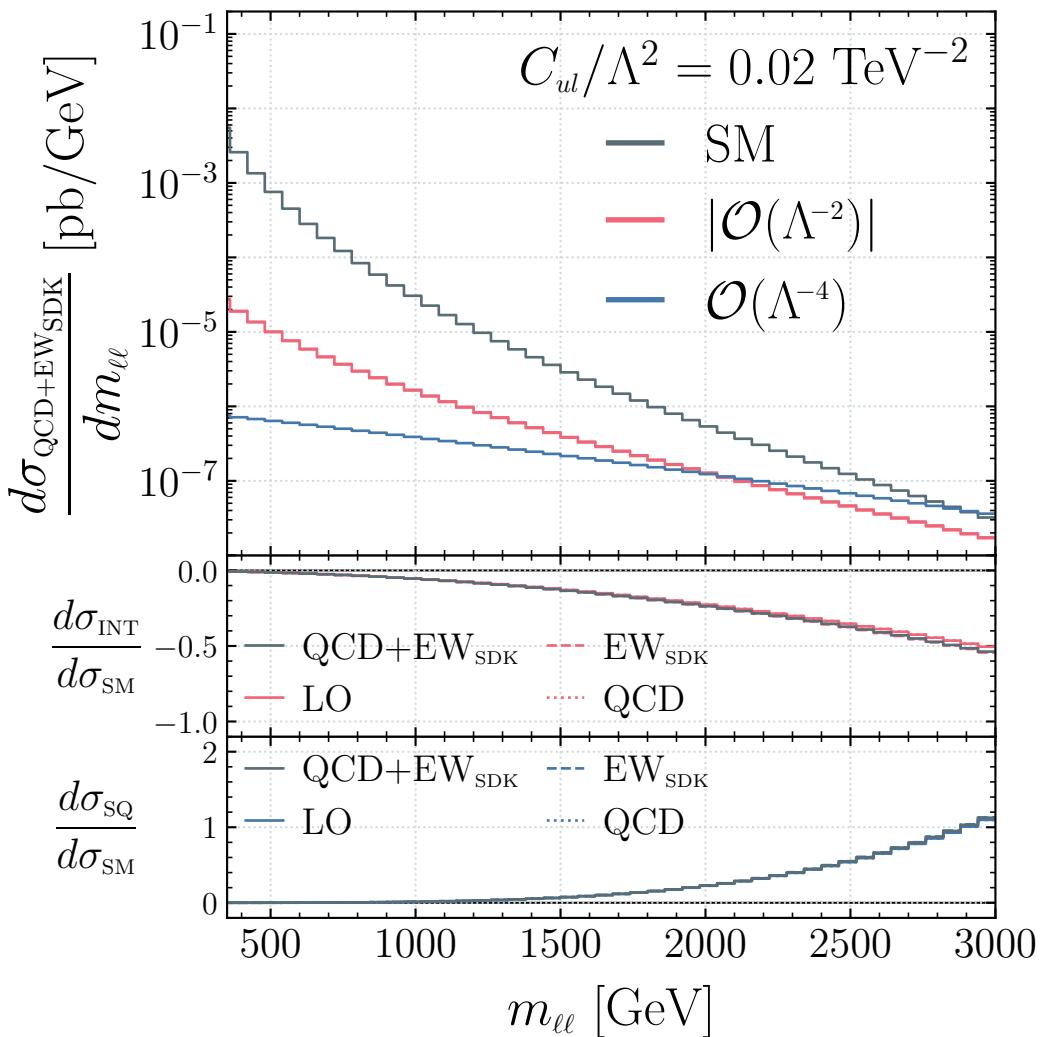
PRELIMINARY



K-factor

A fun example: $pp \rightarrow e^+e^-$

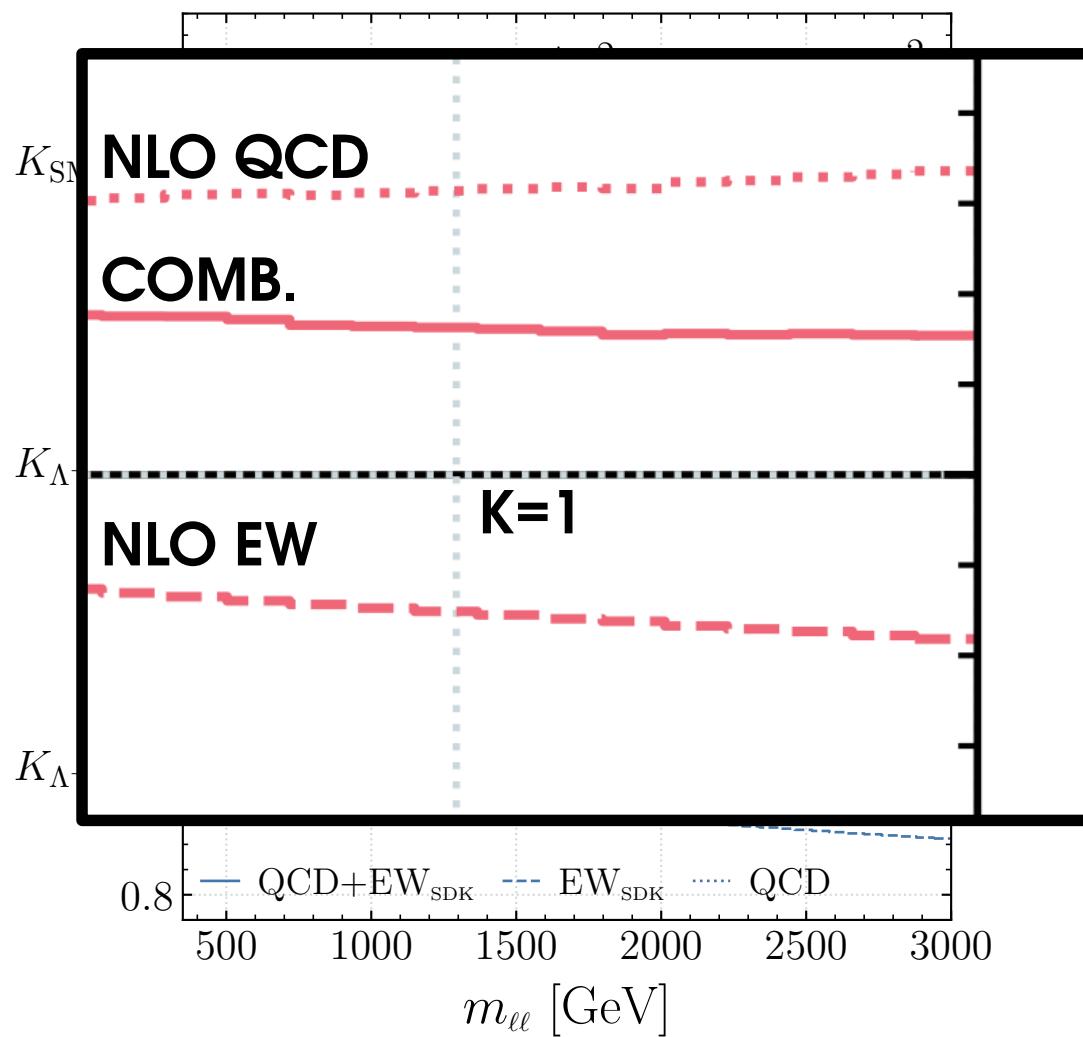
PRELIMINARY



Distribution

$$\mathcal{O}_{ul} = \sum_{f=1}^2 (\bar{u}_f \gamma^\mu u_f) (\bar{\ell} \gamma_\mu \ell)$$

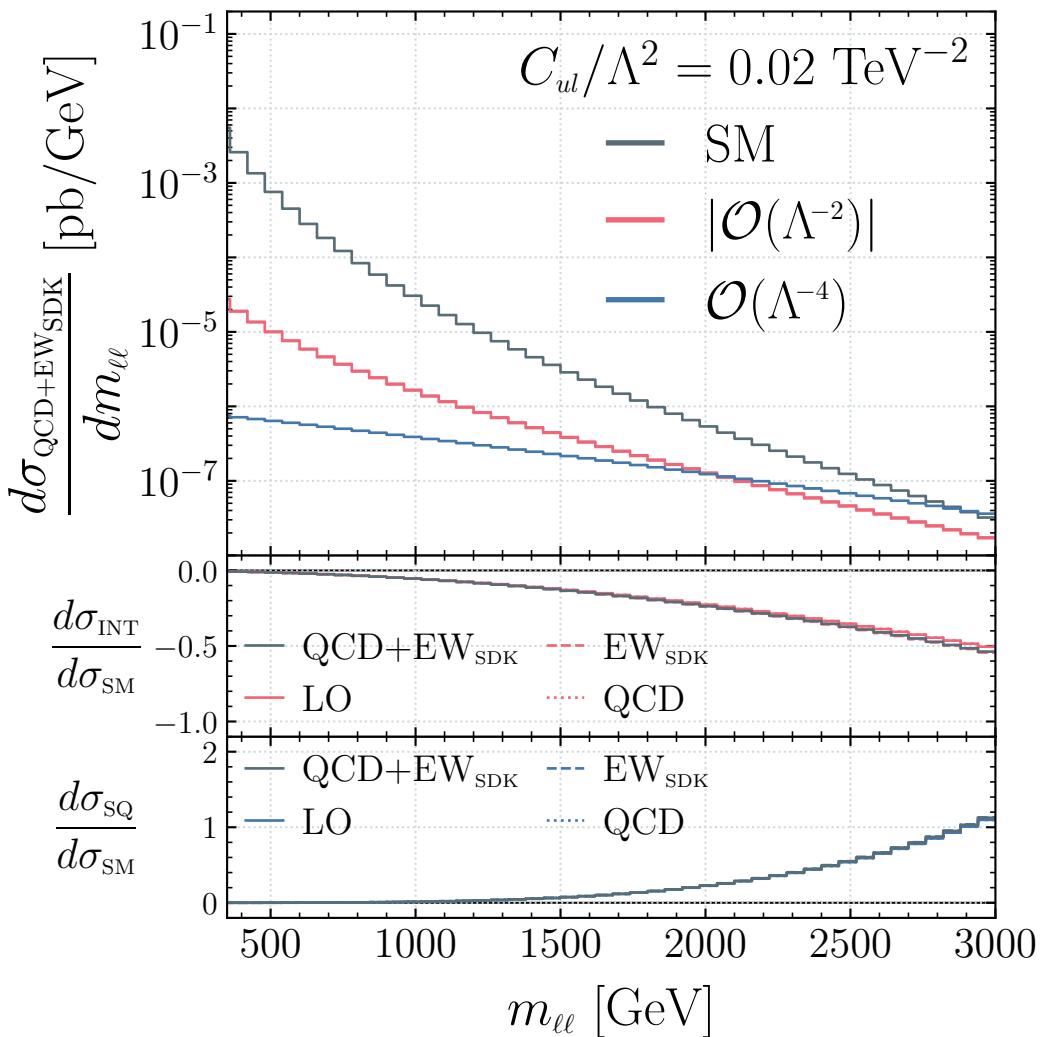
PRELIMINARY



K-factor

A fun example: $pp \rightarrow e^+e^-$

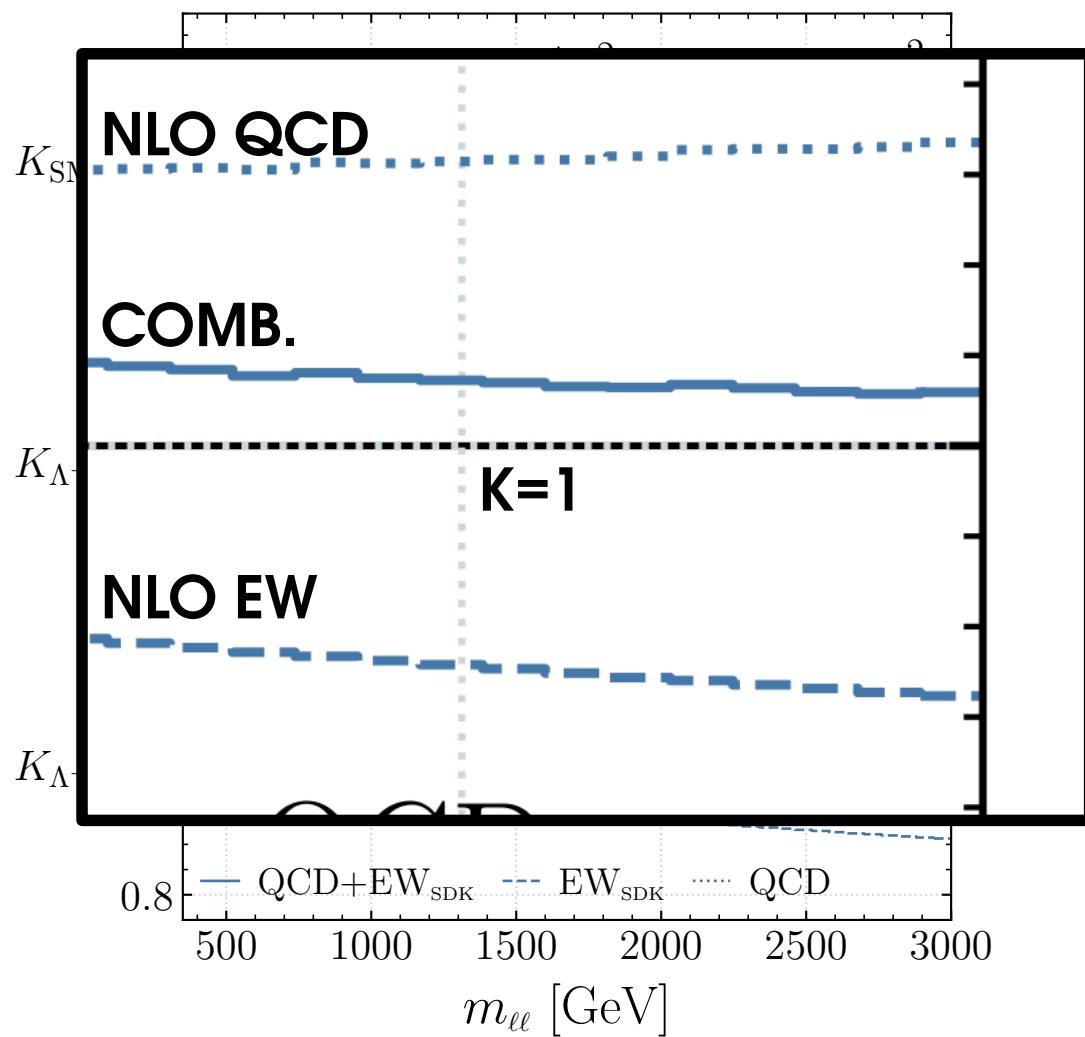
PRELIMINARY



Distribution

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

PRELIMINARY



K-factor

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 $\text{vev} \rightarrow 0$ limit.

While in the SM processes with a $\mathcal{O}(\text{vev})$ 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.