Theory predictions for tZj production

mainly based on *JHEP* 08 (2020) 082 (arXiv:2006.10086),
DP, Tsinikos, Vryonidou

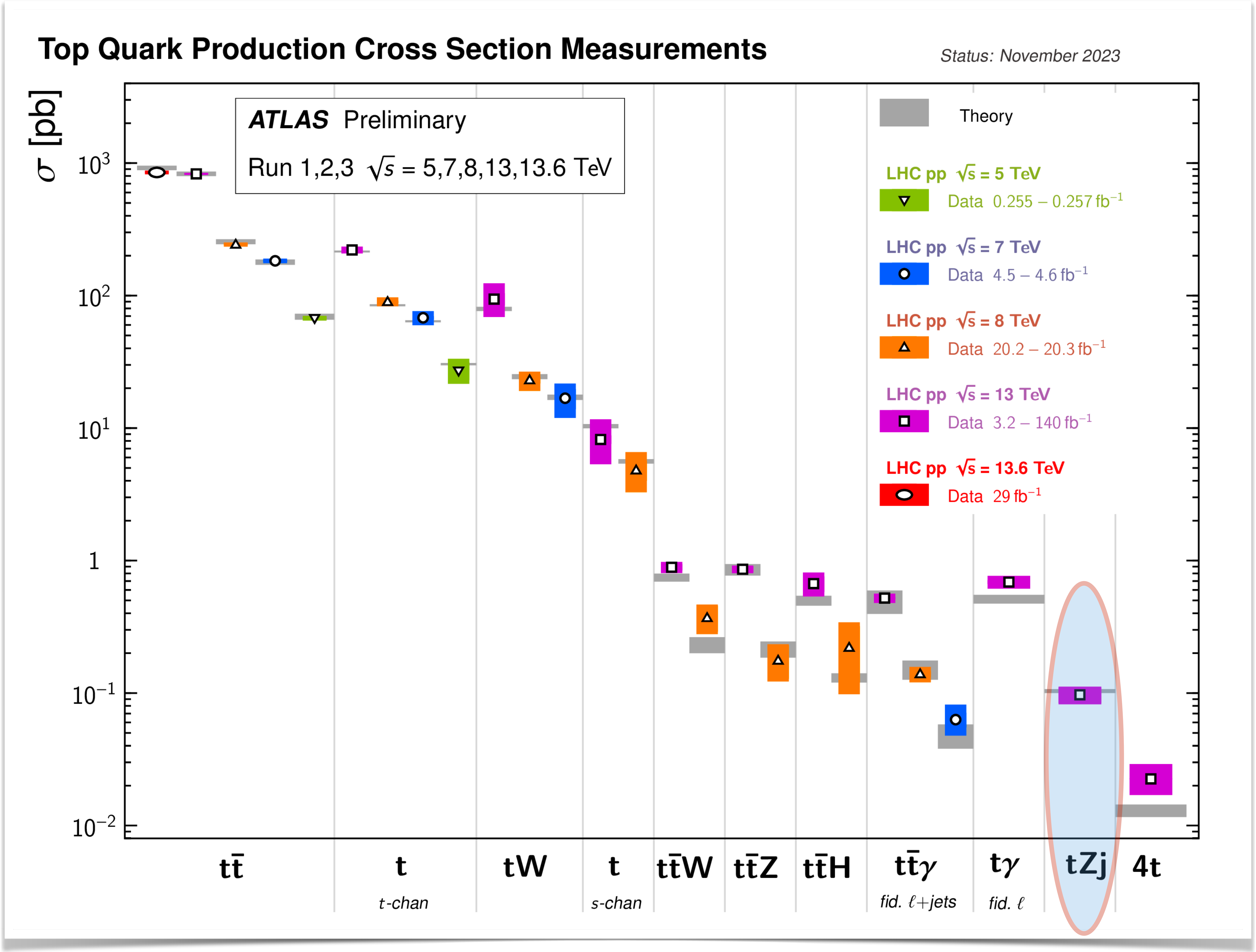
Istituto Nazionale di Fisica Nucleare
SEZIONE DI BOLOGNA

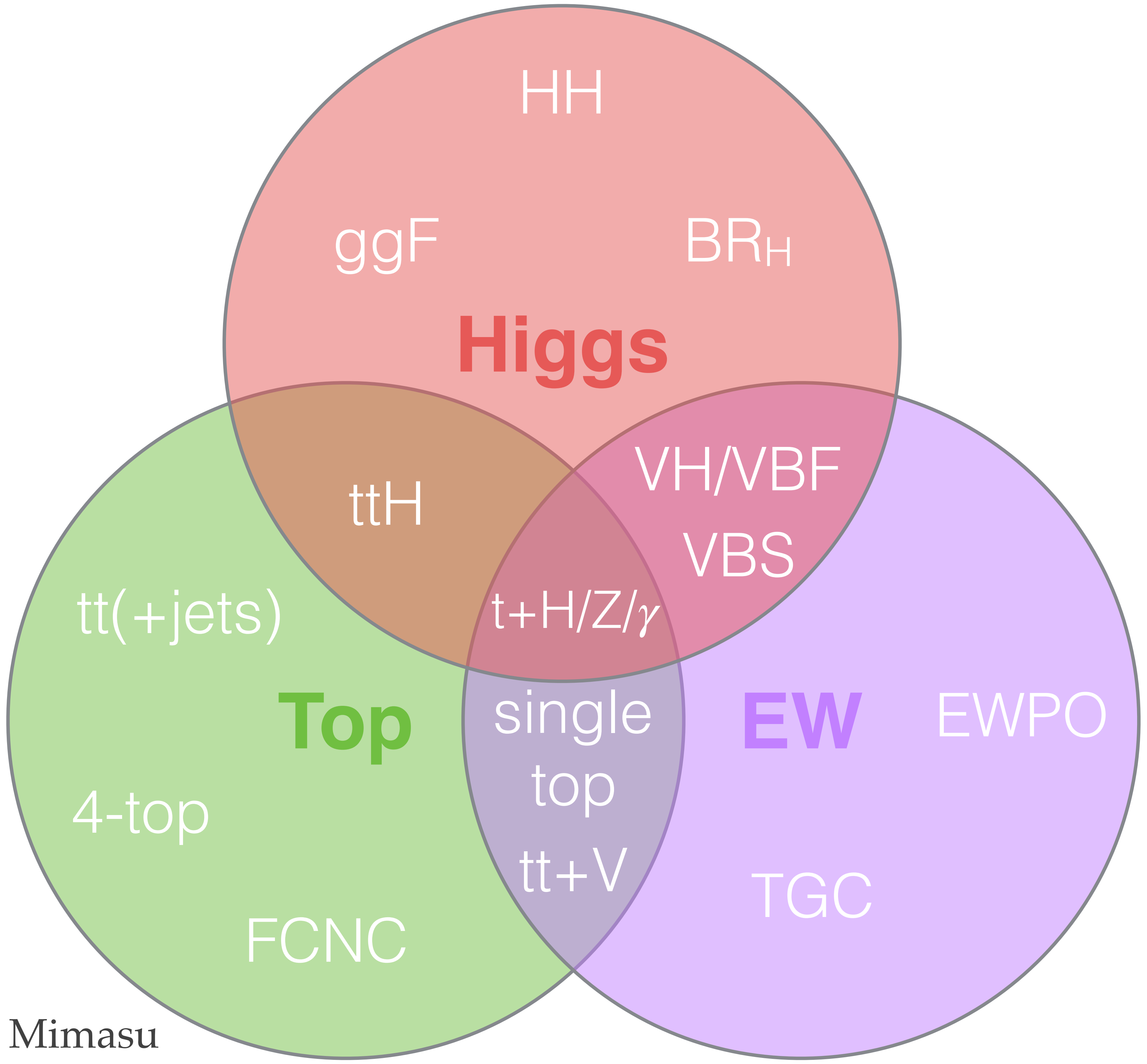
Theory and Phenomenology of Fundamental Interactions
UNIVERSITY AND INFN · BOLOGNA

Davide Pagani

25-04-2024,
LHC Top WG
CERN

Single-top Z, a rare but special process





Rare but observed

Observation of single top quark production in association with a Z boson in proton-proton collisions at $\sqrt{s} = 13$ TeV

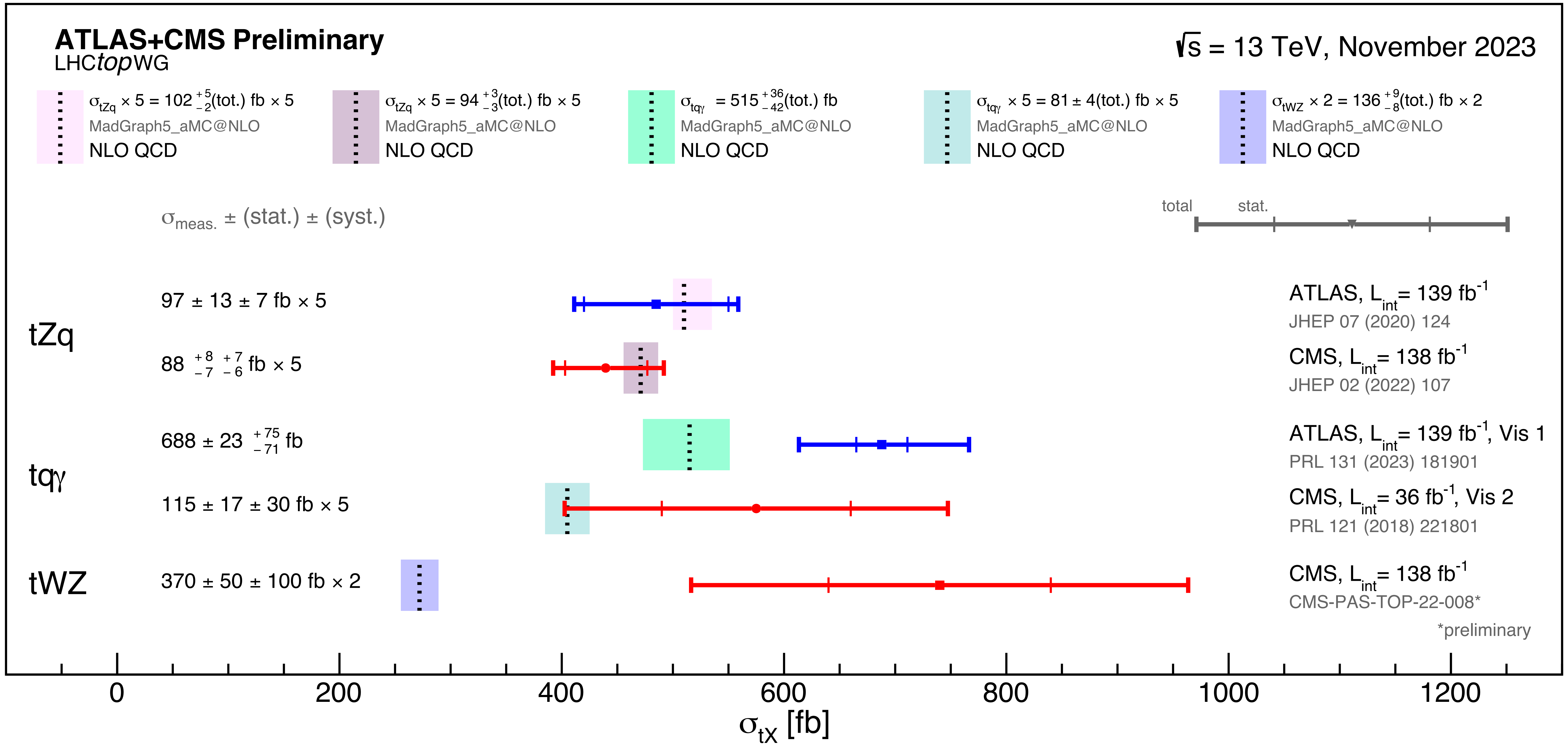
The CMS Collaboration*

Observation of the associated production of a top quark and a Z boson in pp collisions at $\sqrt{s}$ = 13 TeV with the ATLAS detector

The ATLAS Collaboration

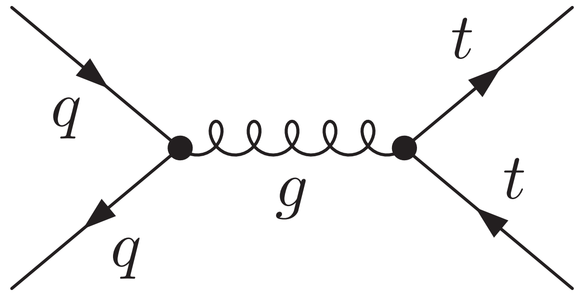
Inclusive and differential measurement of top quark cross sections in association with a Z boson

The CMS Collaboration

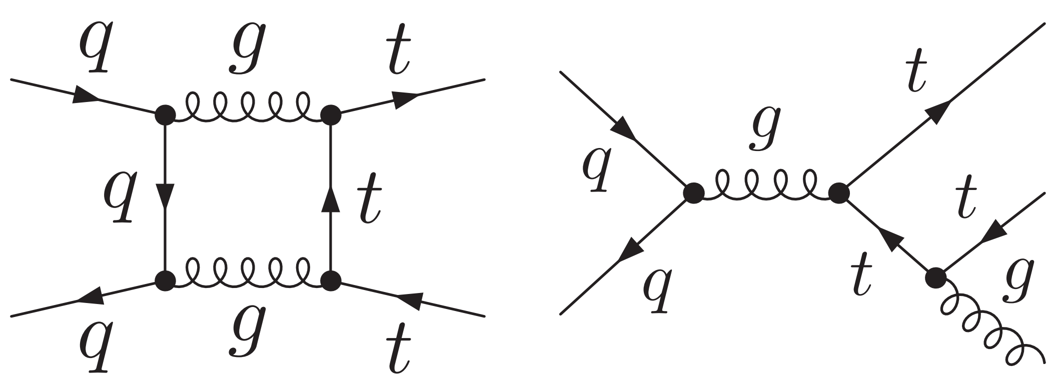


Perturbation Theory

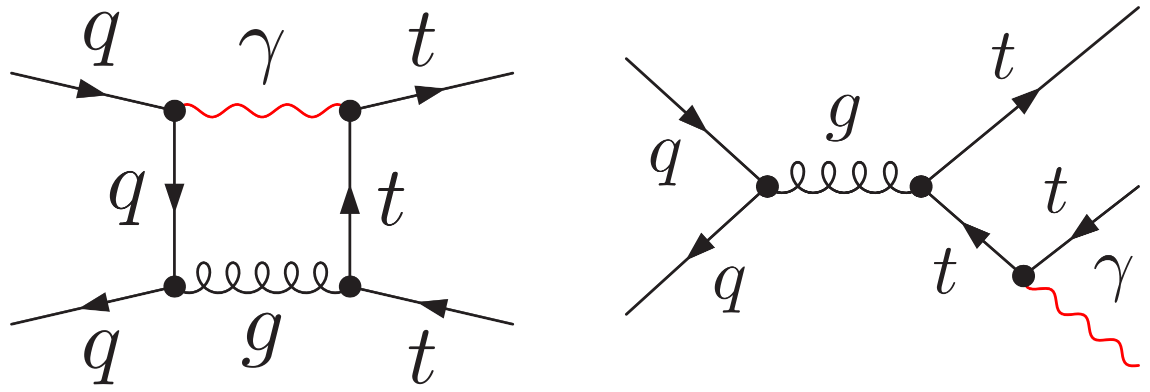
In the SM, contributions to the partonic cross sections can be organized according to the powers of α_s and α (number of loops).



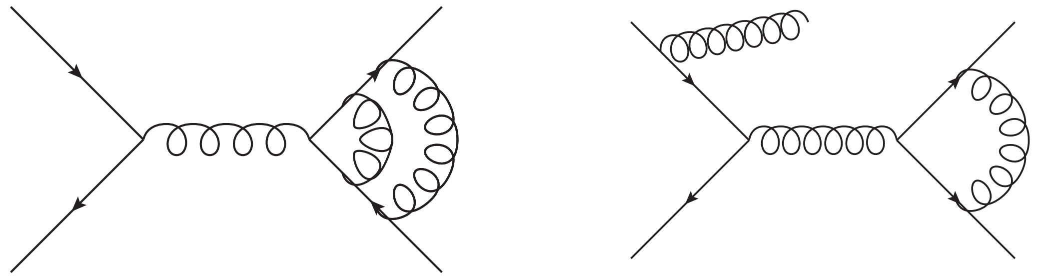
Born LO



NLO QCD
$\mathcal{O}(\alpha_s)$ corrections



NLO EW
$\mathcal{O}(\alpha)$ corrections



NNLO QCD
$\mathcal{O}(\alpha_s^2)$ corrections

NNLO EW,
NNNLO QCD
.....

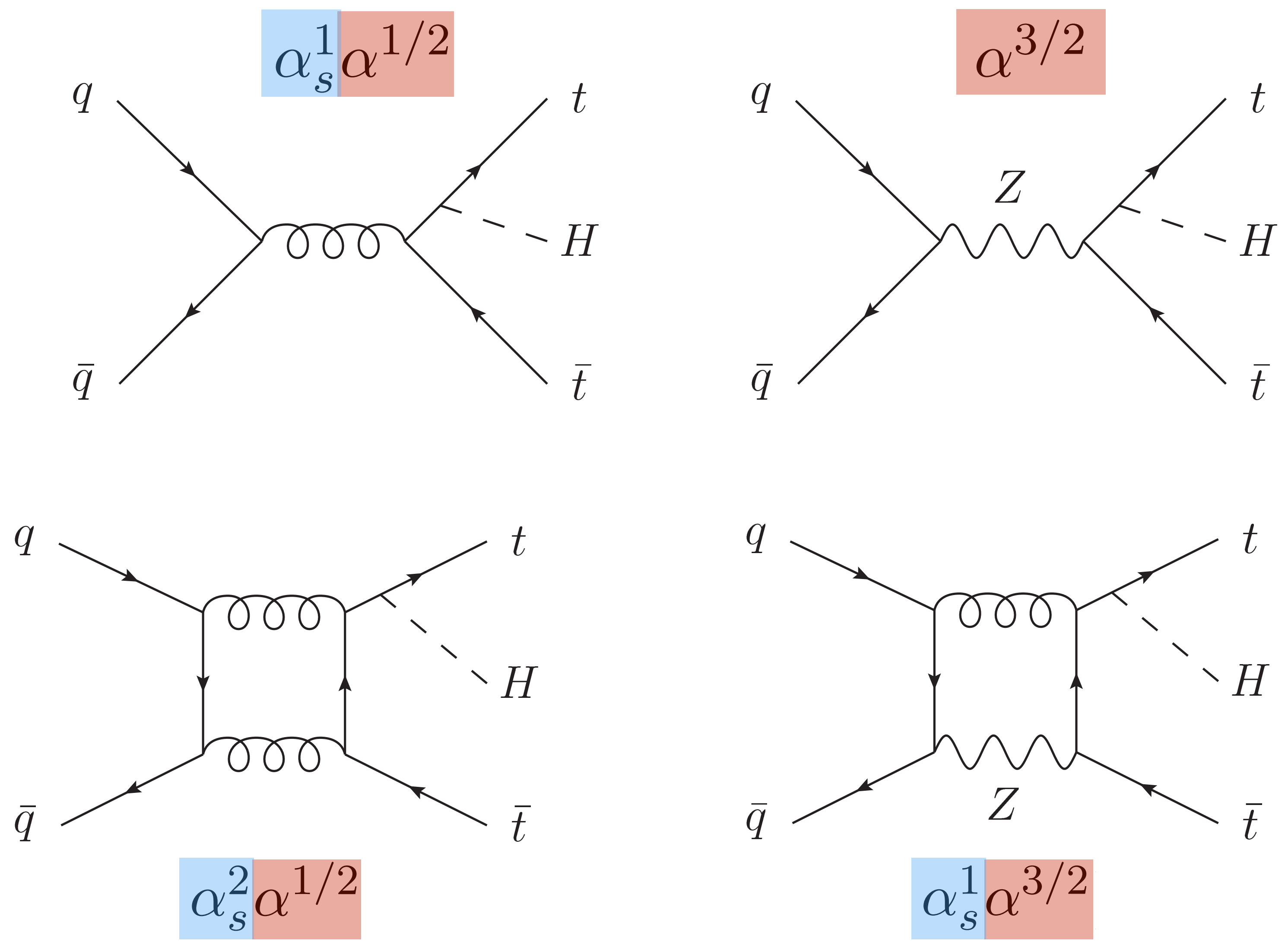
At the LHC, reliable SM predictions must be calculated at **NLO QCD** accuracy or beyond.

NNLO QCD is expected to be of the **same order** of **NLO EW** $\alpha_s^2 \sim \alpha$.

EW corrections grow large and negative for large pt's (**Sudakov logs**). Moreover they in general **involve all the SM masses and couplings.**

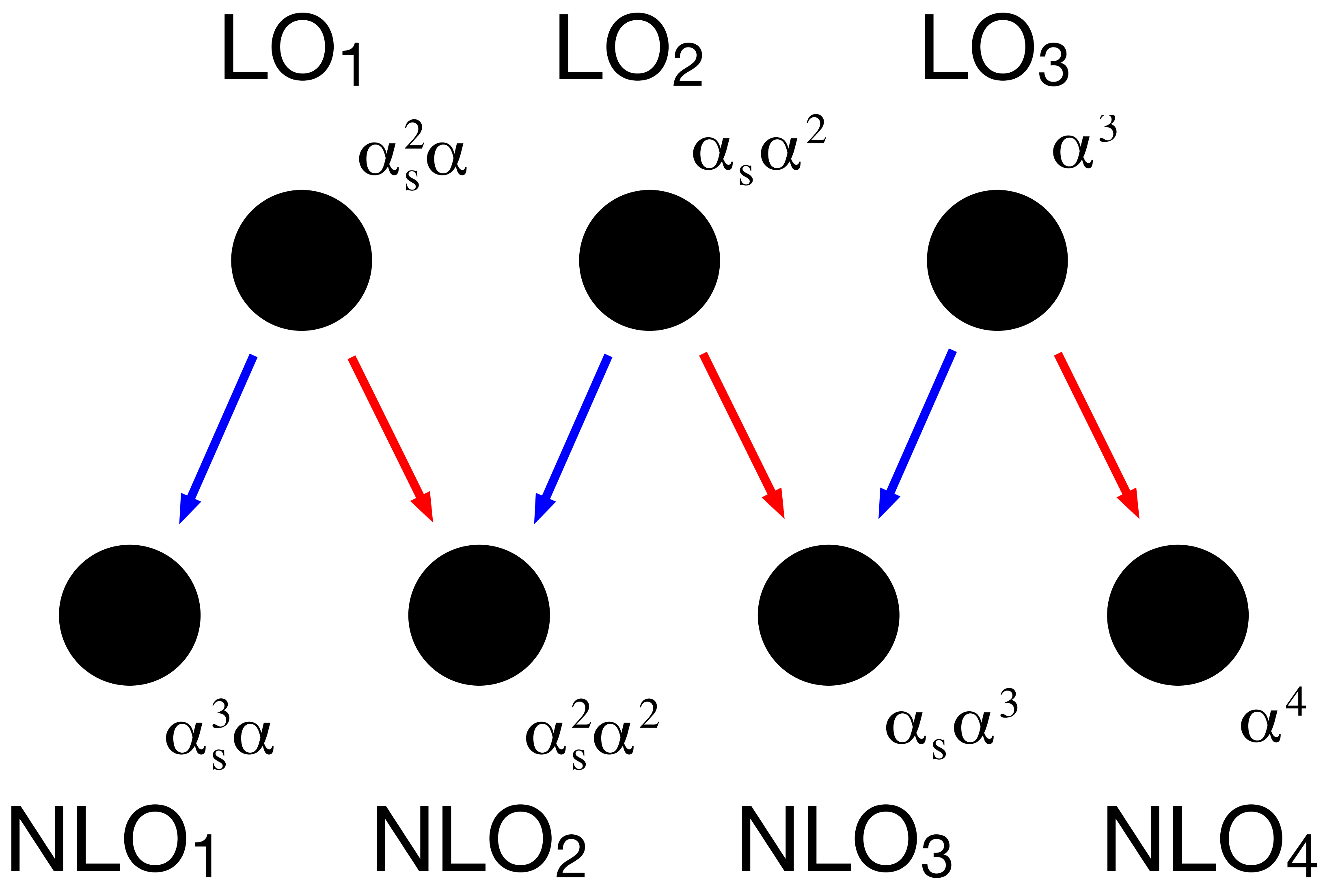
NLO QCD and EW corrections: the Complete-NLO

The complete set of $\mathrm{LO_i}$ and $\mathrm{NLO_i}$ is denoted as **“Complete-NLO”**.



$$t\bar{t}V$$

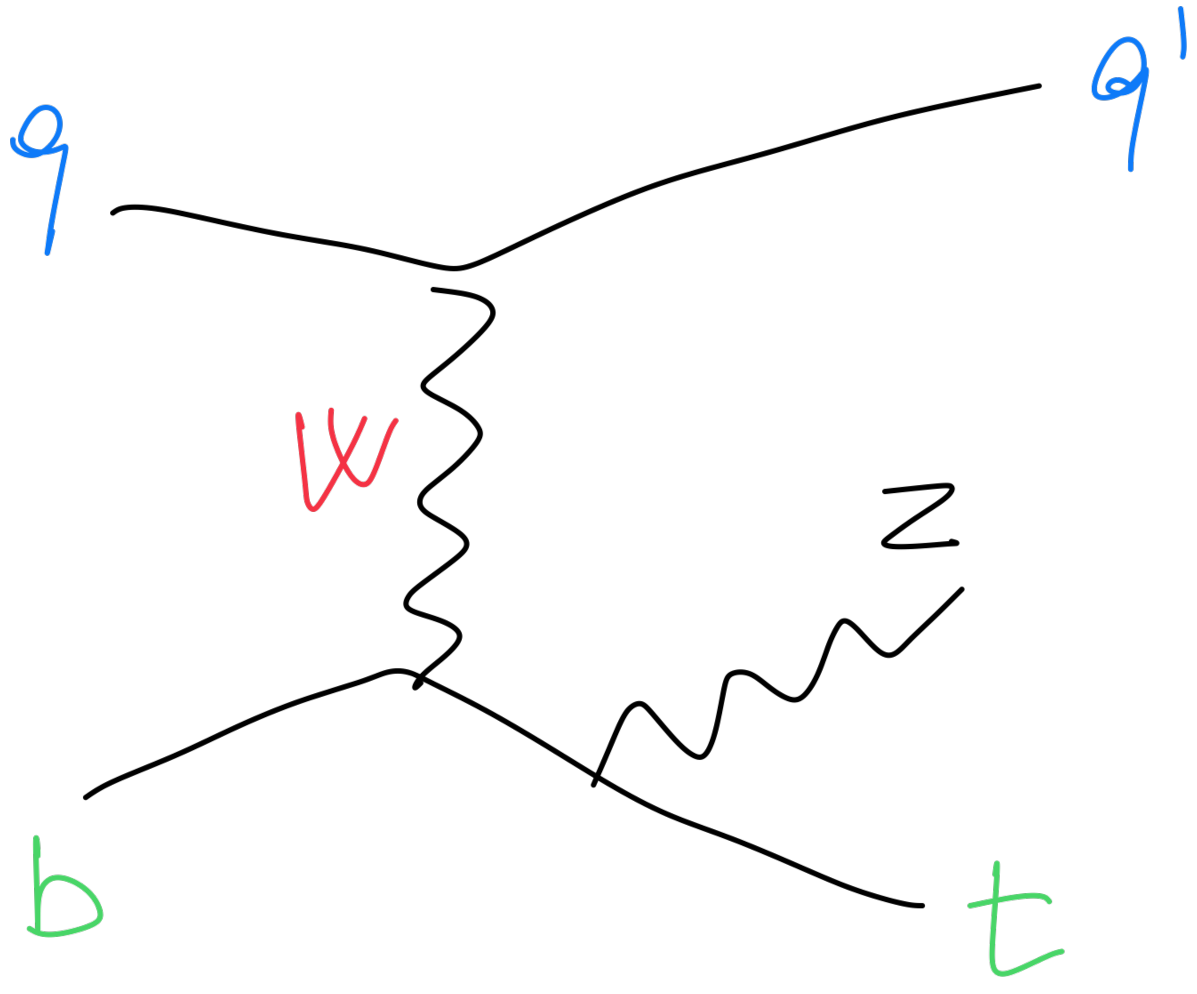
(as example)



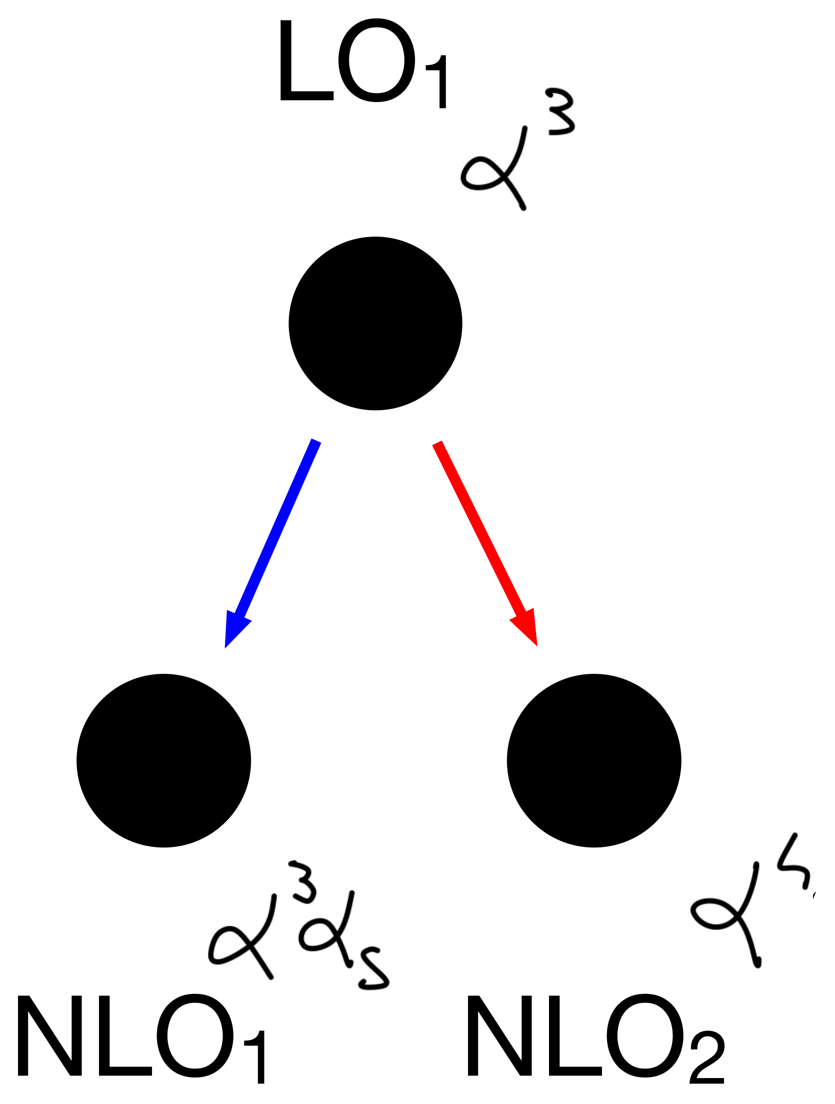
$\mathrm{NLO_1}$ = NLO QCD
$\mathrm{NLO_2}$ = NLO EW

In general, $\mathrm{NLO_3}$ and $\mathrm{NLO_4}$ are **negligible,**
but there are important exceptions as $t\bar{t}W$ or $t\bar{t}t\bar{t}$.

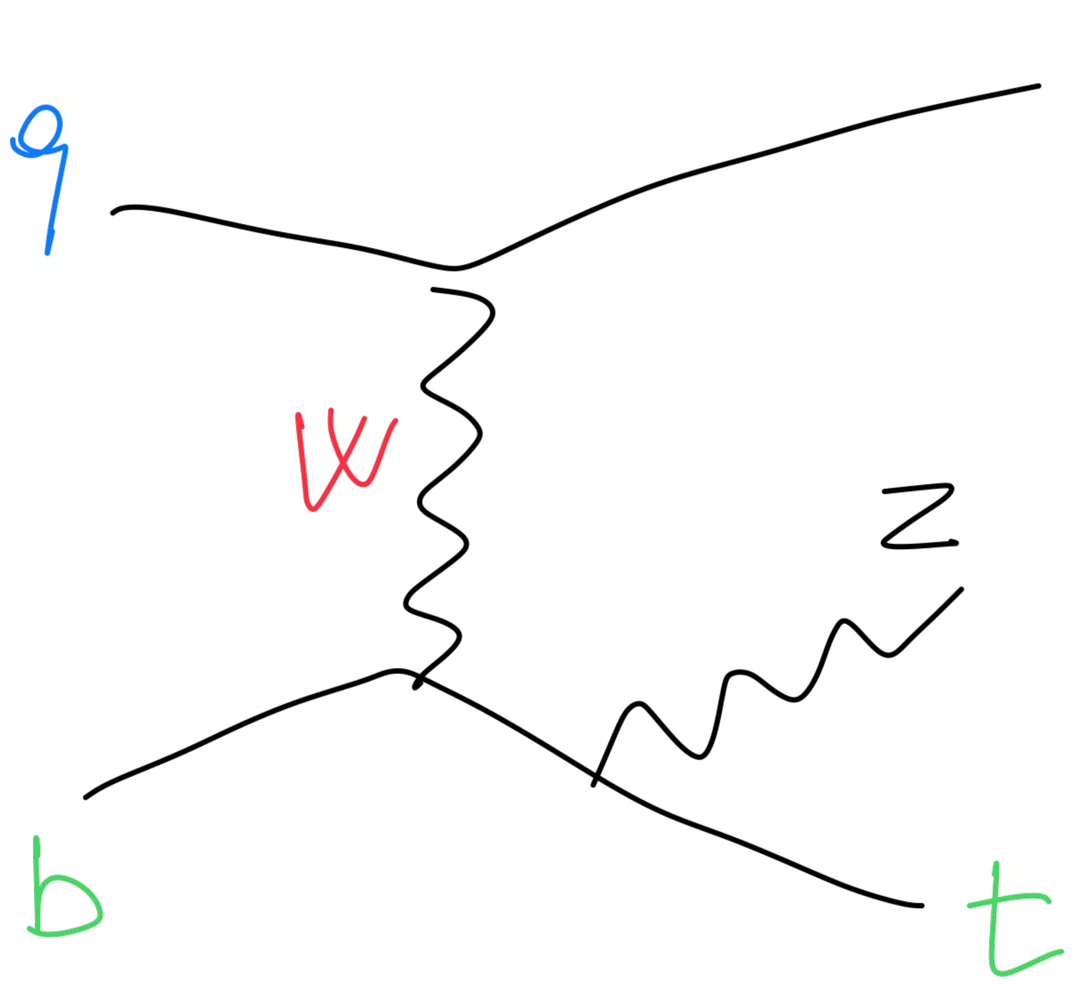
Complete-NLO in tZj



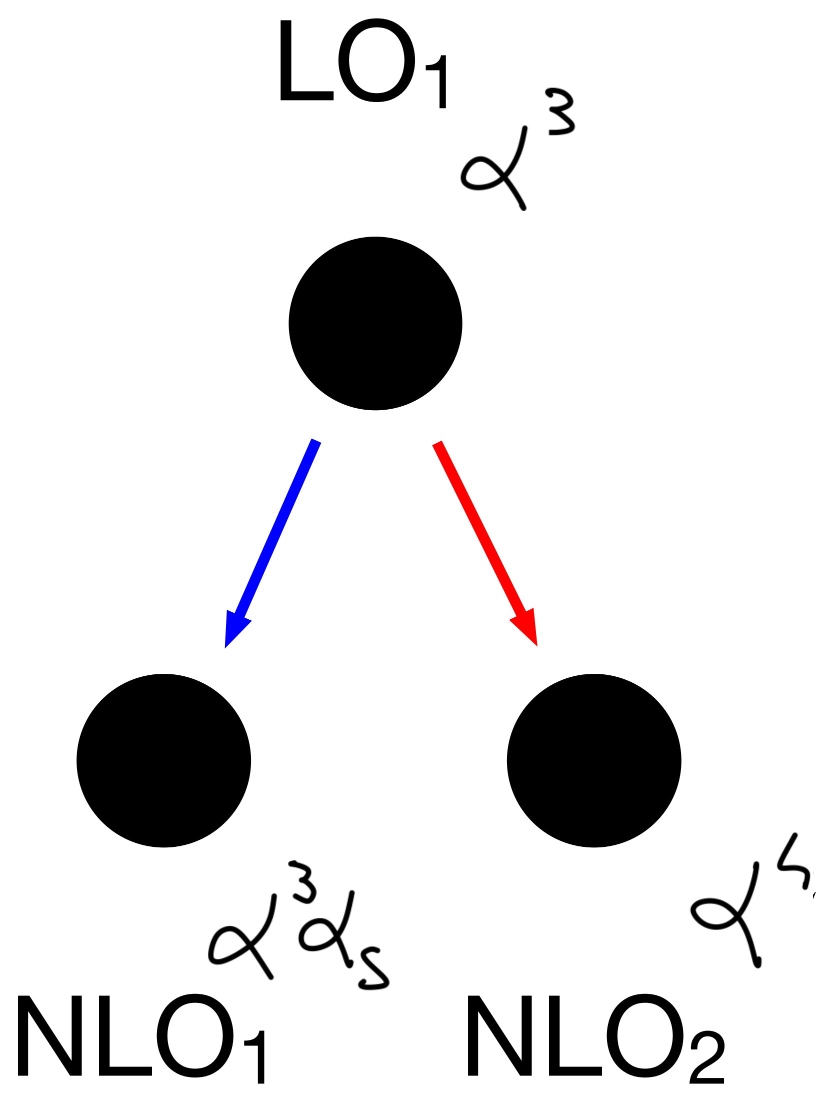
- There is only one LO, with no QCD.
- There is a bottom in the initial state.
- Renormalisation-scale dependence appears only at NLO QCD.
- NLO_3 and NLO_4 are not present. *Complete-NLO=NLO QCD+EW*



Complete-NLO in tZj



- There is only one LO, with no QCD.
- There is a bottom in the initial state.
- Renormalisation-scale dependence appears only at NLO QCD.
- NLO_3 and NLO_4 are not present. *Complete-NLO=NLO QCD+EW*



Several complications:

- Which flavour-scheme, 4FS or 5FS?
- Is scale variation alone reliable?
- Which scale should I use?
- Can/should I separate t-channel, s-channel and tW production?
- Are radiative effects for tZj and tl^+l^-j equivalent?

Before our recipe, than rationale behind it

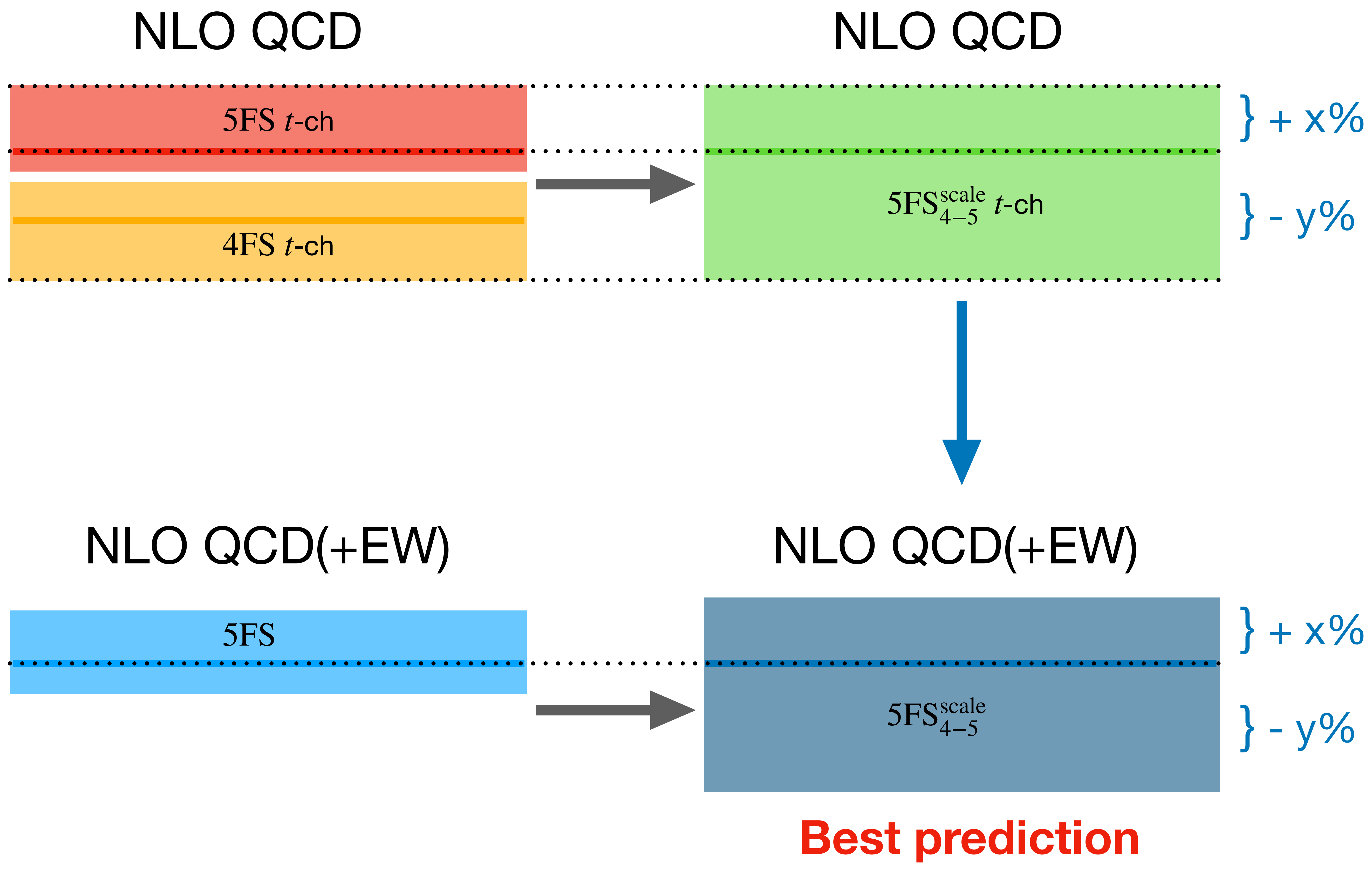
Central scale for μ_F, μ_R

$$\mu_0 \equiv H_T/6 = \frac{\sum_i m_{T,i}}{6}\,, \quad i = t, Z, j_b$$

based on the findings of Demartin, Maltoni, Mawatari, Zaro '15 for tHj

For t-channel only:

For all channels:



The $5\text{FS}^{\text{scale}}_{4-5}$ prediction has:

- s-channel and tW contributions.
- scale and flavour scheme unc. from t-ch in QCD.
- 5FS central value

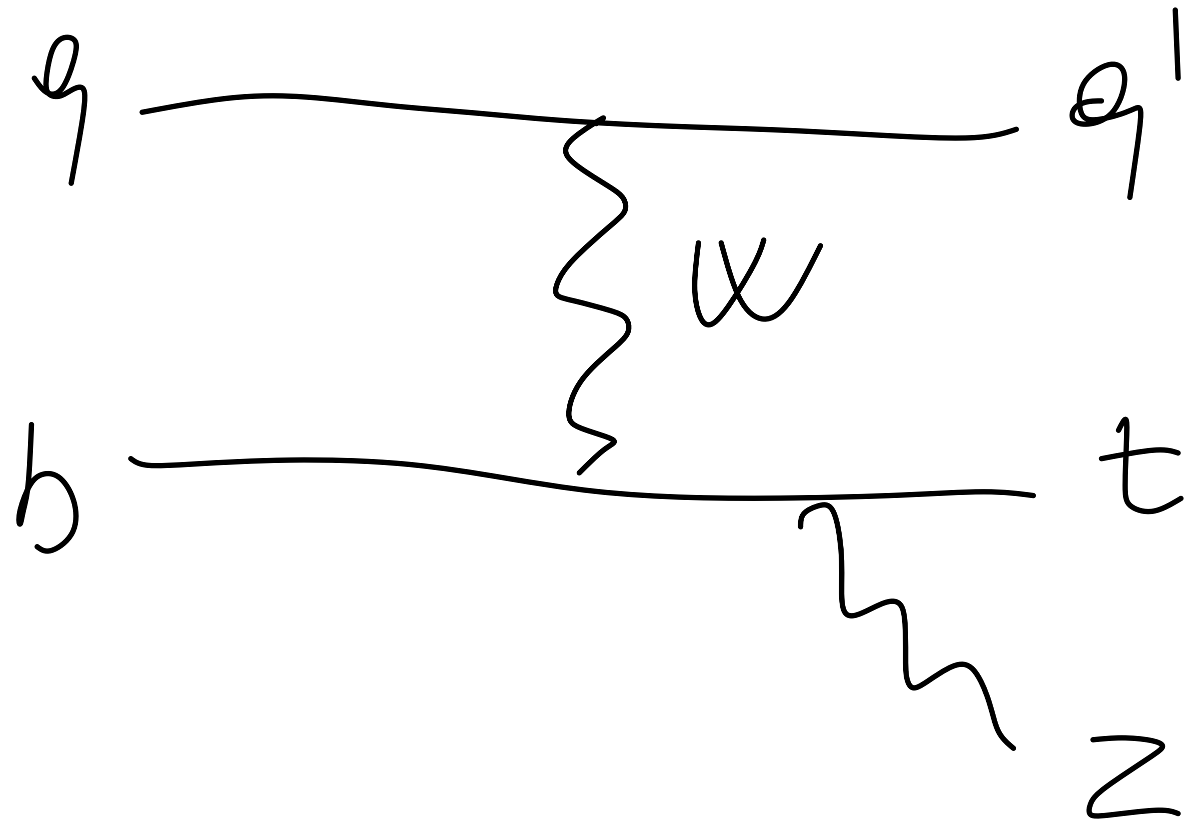
The pictorial representation in words:

In order to combine scale and flavour-scheme uncertainties at NLO QCD accuracy, we consider the t-channel only and we define the quantity $(\text{NLO}^{\text{5FS}}_{\text{QCD,t-ch.}})^{+\Delta_+^{4-5\text{FS}}}_{-\Delta_-^{4-5\text{FS}}}$ via the envelope of the two bands given by $(\text{NLO}^{\text{4FS}}_{\text{QCD,t-ch.}})^{+\Delta_+^{4\text{FS}}}_{-\Delta_-^{4\text{FS}}}$ and $(\text{NLO}^{\text{5FS}}_{\text{QCD,t-ch.}})^{+\Delta_+^{5\text{FS}}}_{-\Delta_-^{5\text{FS}}}$, where the central value is set equal to the one in the 5FS. The quantities $\Delta_+^{4-5\text{FS}}$ and $\Delta_-^{4-5\text{FS}}$ are then propagated to the $\text{NLO}_{\text{QCD+EW}}$ prediction in the 5FS. In conclusion, in order to combine flavour-scheme and scale uncertainties and take into account EW corrections, not only for t-channel, we will employ as reference prediction the quantity $(\text{NLO}^{\text{5FS}}_{\text{QCD+EW}})^{+\Delta_+^{4-5\text{FS}}}_{-\Delta_-^{4-5\text{FS}}}$ and in the case of QCD only corrections, in order to be consistent, we will use the quantity $(\text{NLO}^{\text{5FS}}_{\text{QCD}})^{+\Delta_+^{4-5\text{FS}}}_{-\Delta_-^{4-5\text{FS}}}$, where in the quantity $\text{NLO}^{\text{5FS}}_{\text{QCD}}$ the requirement of t-channel only is not applied.

Let me sketch it!

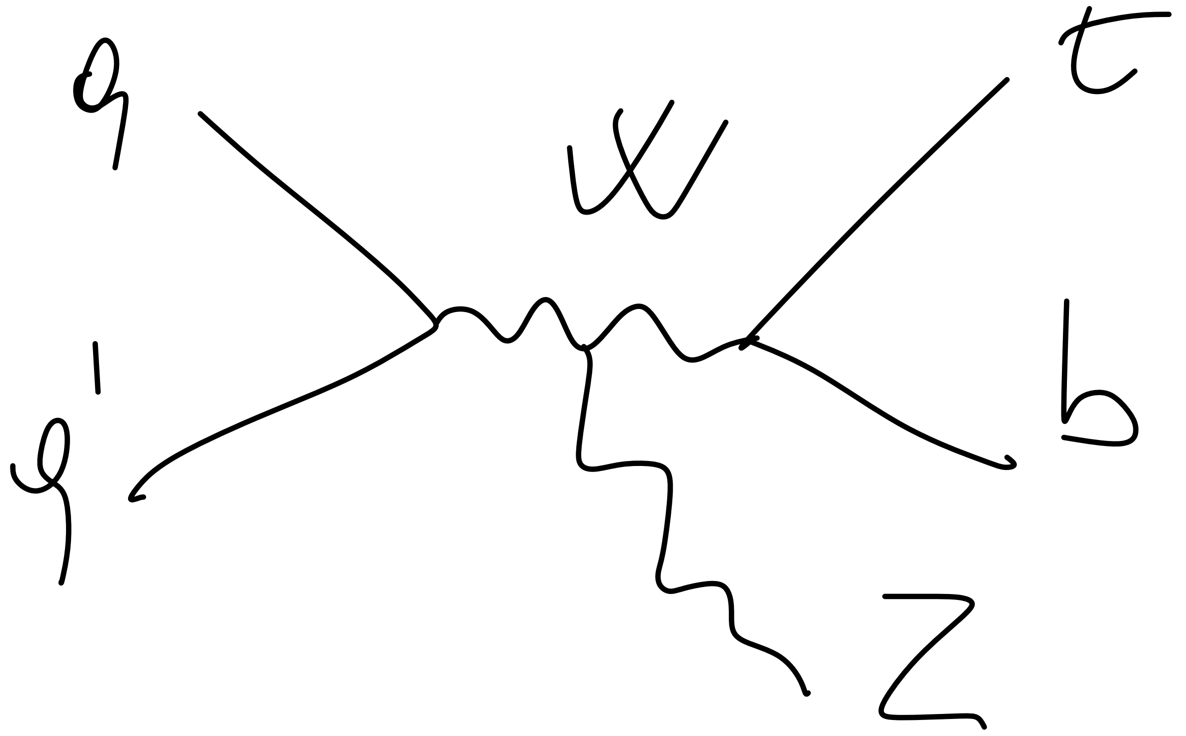
tree level SFs

t-channel



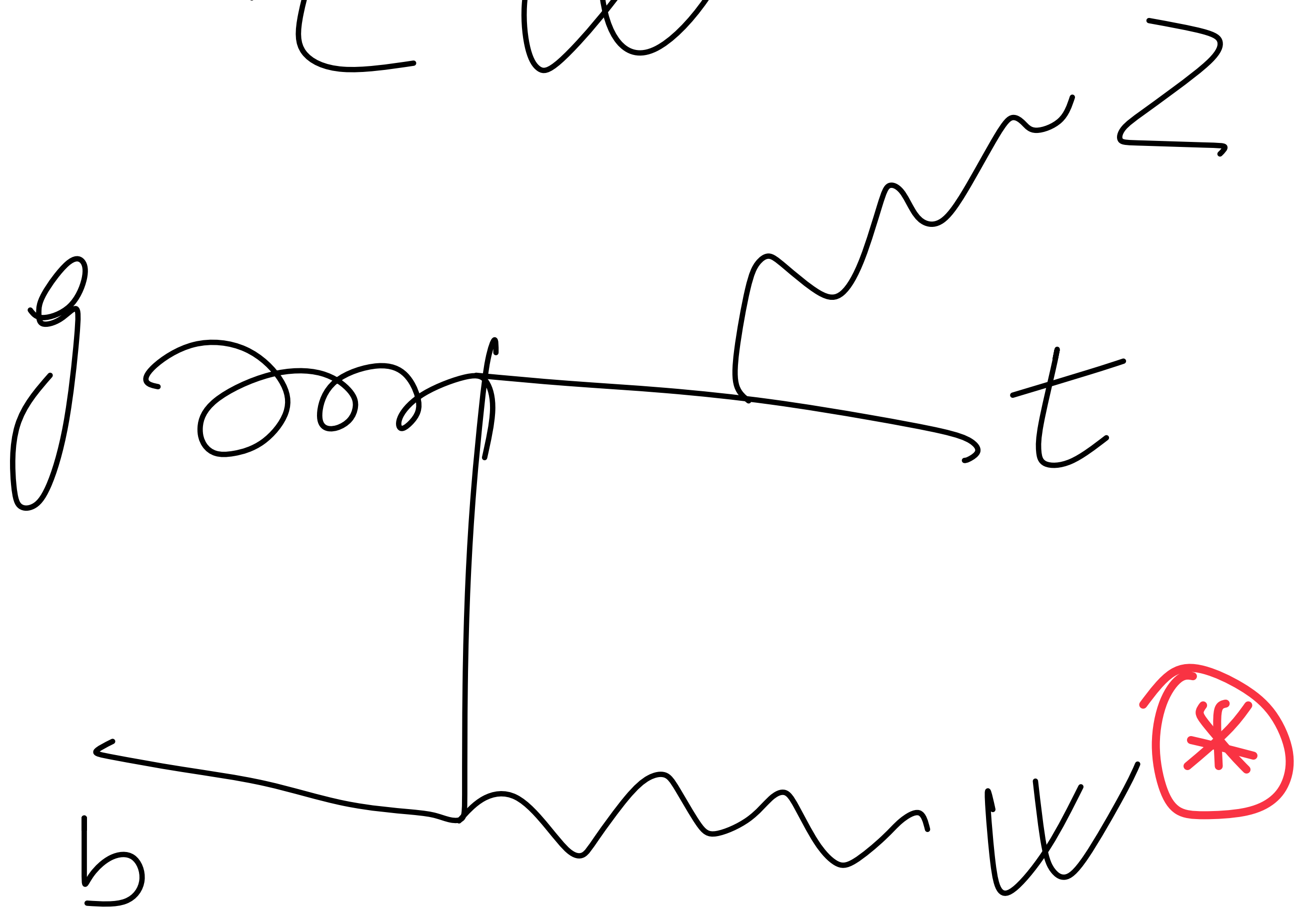
$LO \sim \alpha^3$

s-channel



$LO \sim \alpha^3$

tW



but also with γ instead of g

$LO \sim \alpha_s \alpha^2 \Leftarrow g$

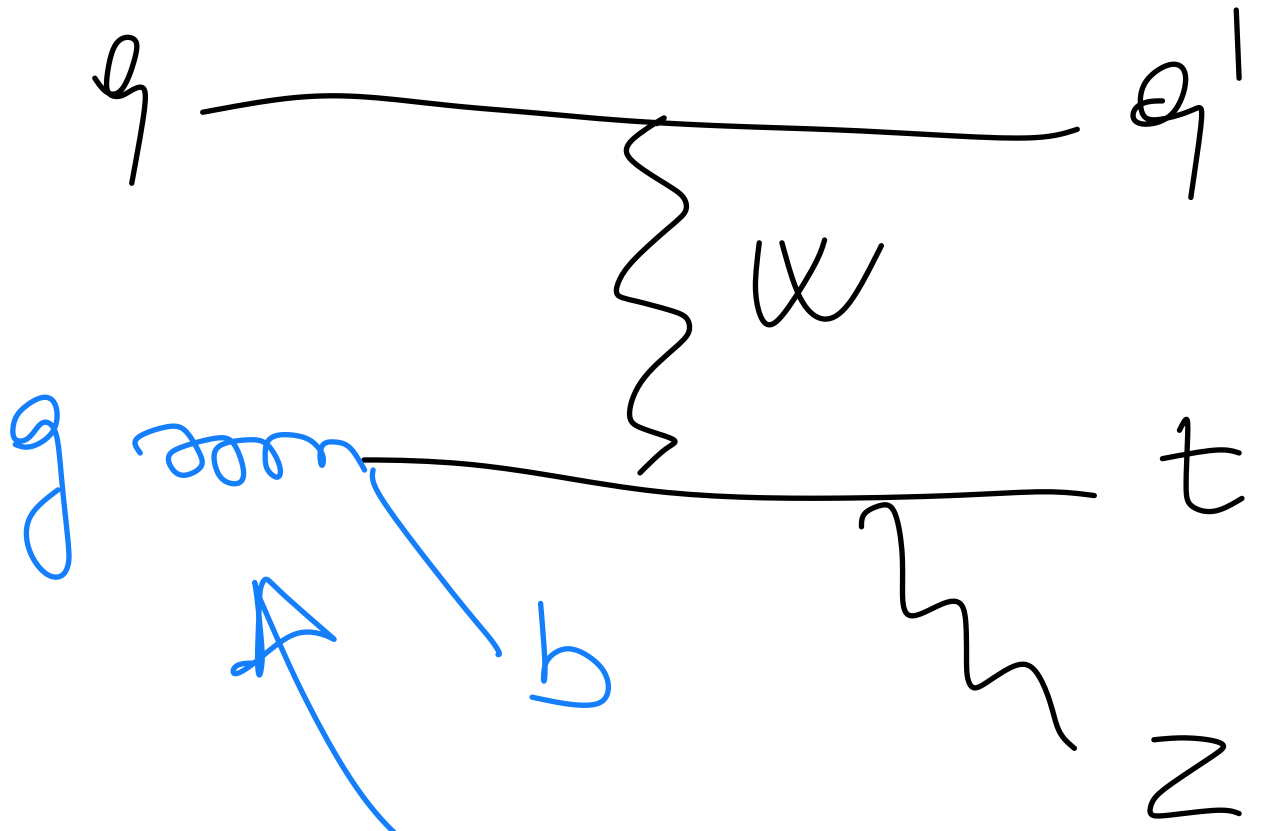
$\alpha^3 \leftarrow \gamma$

(*) NOTE THAT WITH $W \to q\bar{q}'$ DECAY I GET THE SAME OF t-ch + 1 Jet AND IT IS OF ORDER $\sim \alpha_s \alpha^3$ SO IT IS PART OF NLO QCD OF t-ch

tree level 4FS

* NOTE THAT ALSO $t\bar{t}$ vs tW PROBLEMS APPEAR

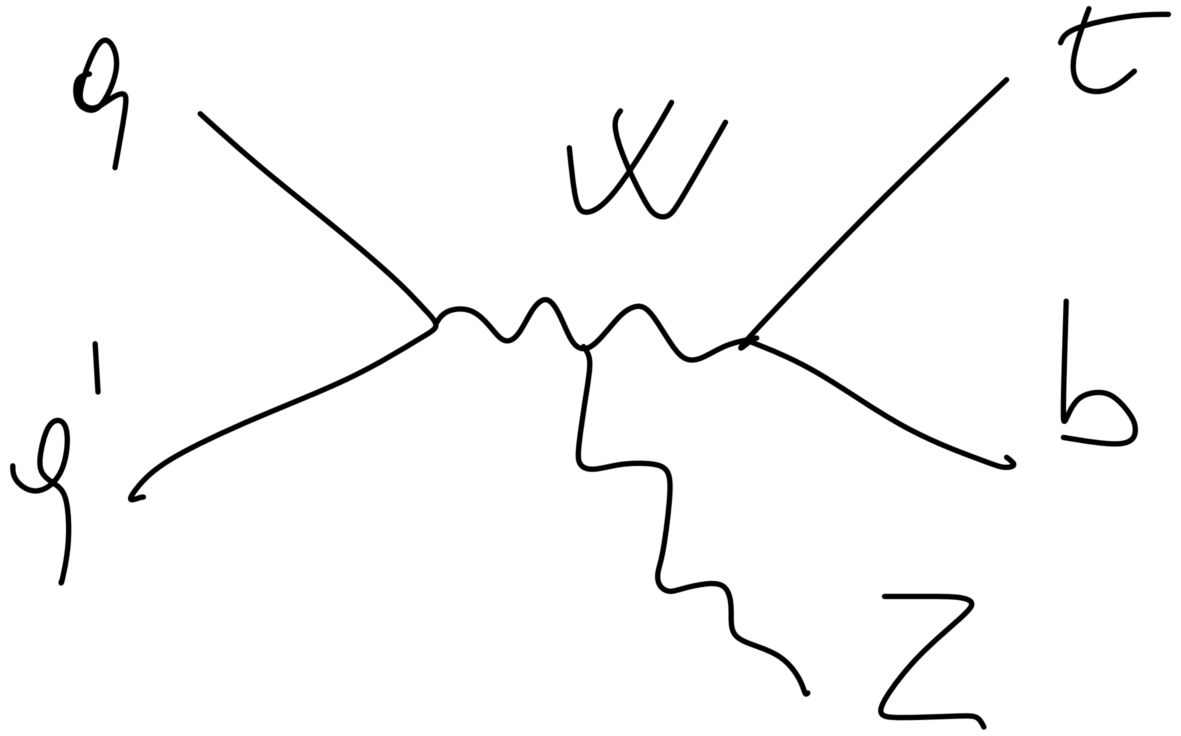
t-channel



$LO \sim \alpha^3 \alpha_s$

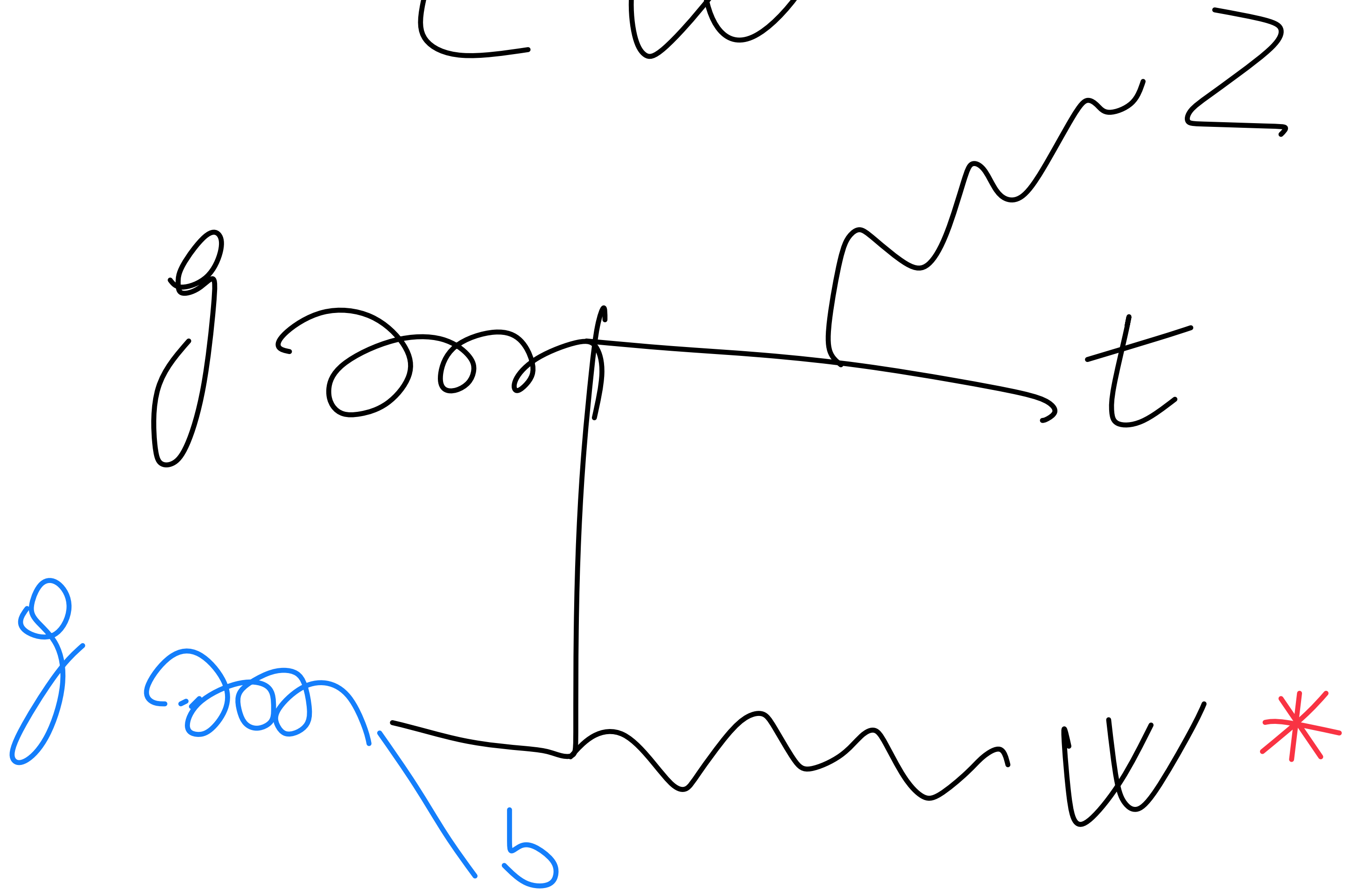
α^4

s-channel



$LO \sim \alpha^3$

tW



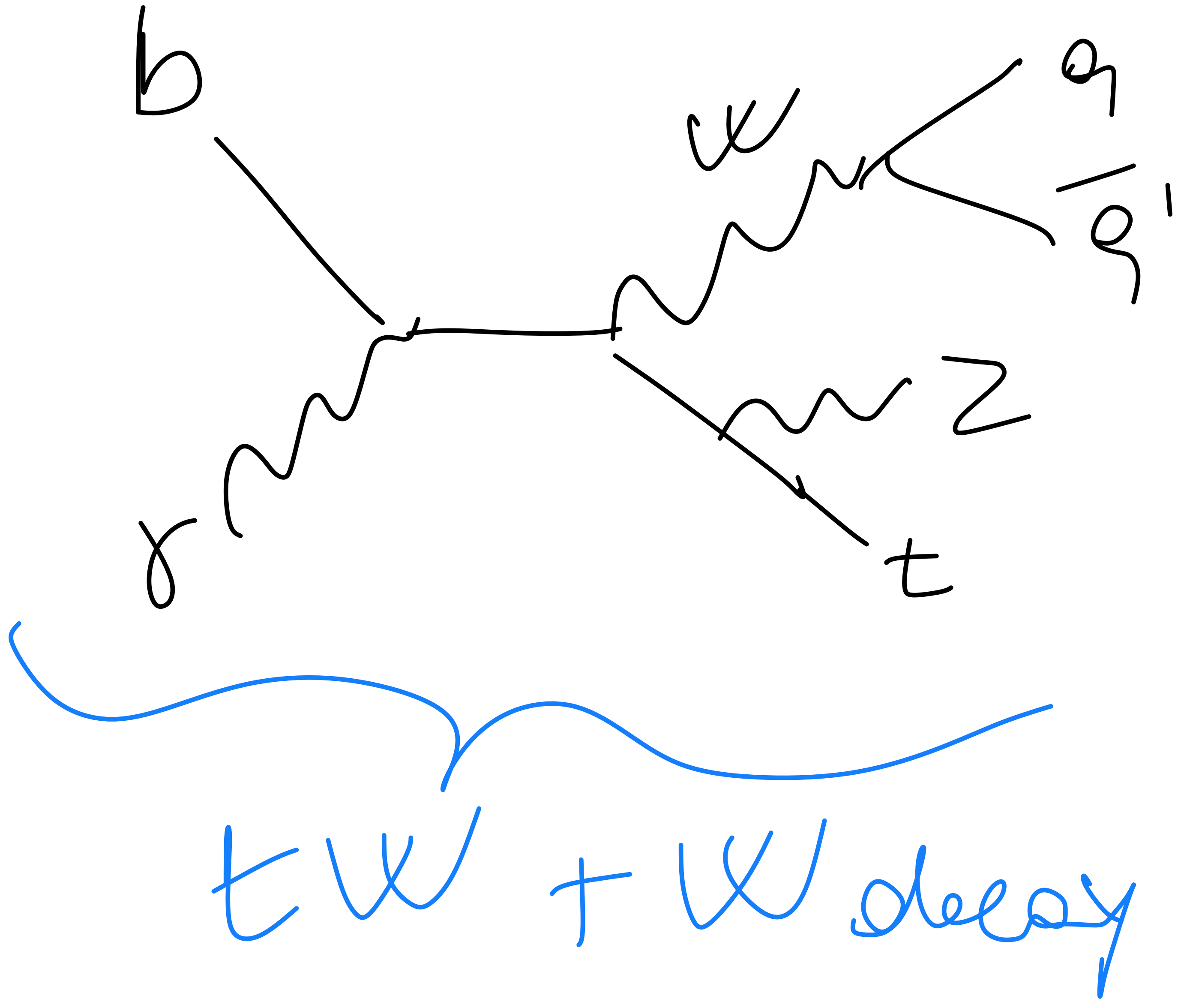
but also with γ instead of g → ALSO THERE

$LO \sim \alpha_s^2 \alpha^2, \alpha_s \alpha^3$
$\alpha^3 \alpha_s, \alpha^5$

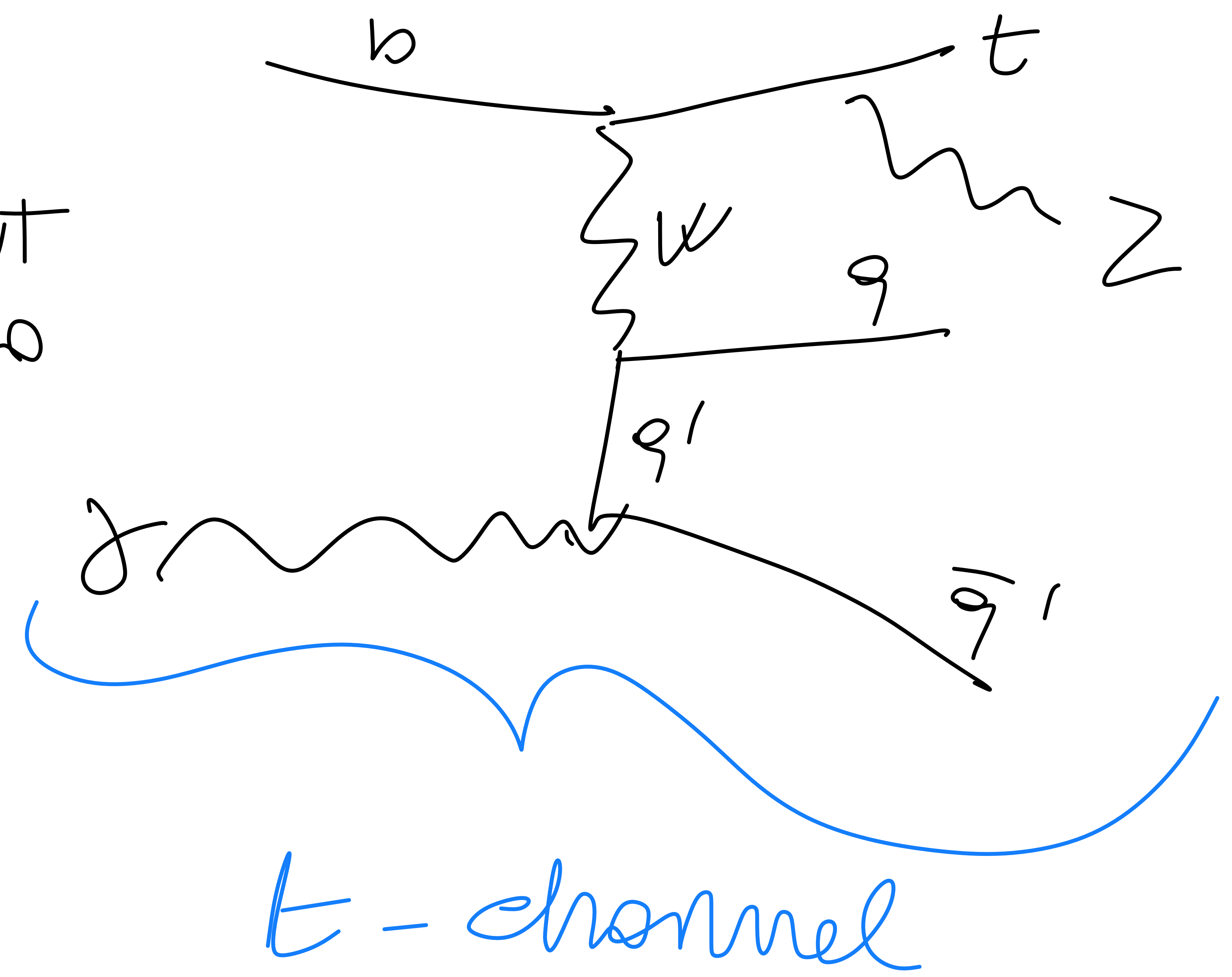
Let's go now to NLO EW in 5FS

LO t-ch. $\sim \alpha^3 \longrightarrow$ NLO EW $\sim \alpha^4$

The process $\gamma b \to t q \bar{q}' Z$ is part of it:



but also

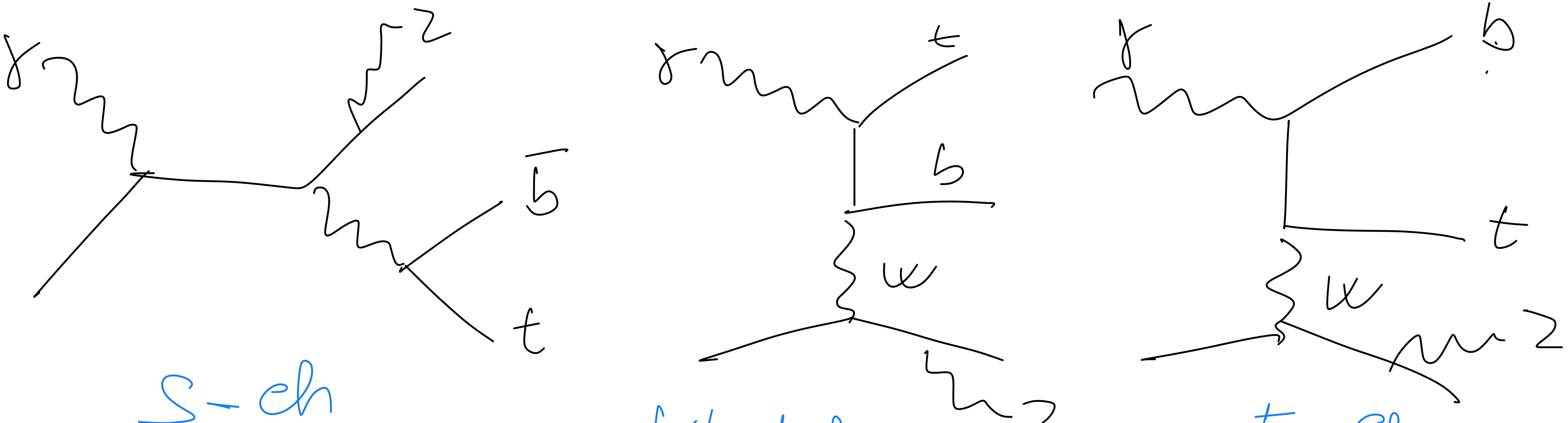


THEY ARE NOT GAUGE INVARIANT, SEPARATELY!

THEY INTERFERE!

LO t-ch. $\sim \alpha^3 \longrightarrow$ NLO EW $\sim \alpha^4$

Also the process $\gamma q \to q' \bar{b} t Z$ is part of it



s-ch | Kind of t-ch | t-ch

Same as before, They mix – ~~Gauge inv.~~

Especially, why separate them?

It is similar to tW/$t\bar{t}$ story, but here $tZj > tWZ$ while $t\bar{t} \gg tW$.

Keep in mind that going to NNLO QCD or to 4FS would be even worse!

In 4FS NLO QCD t-ch interferes with NNLO QCD S-CHANNEL AND tW, $W \to q\bar{q}'$

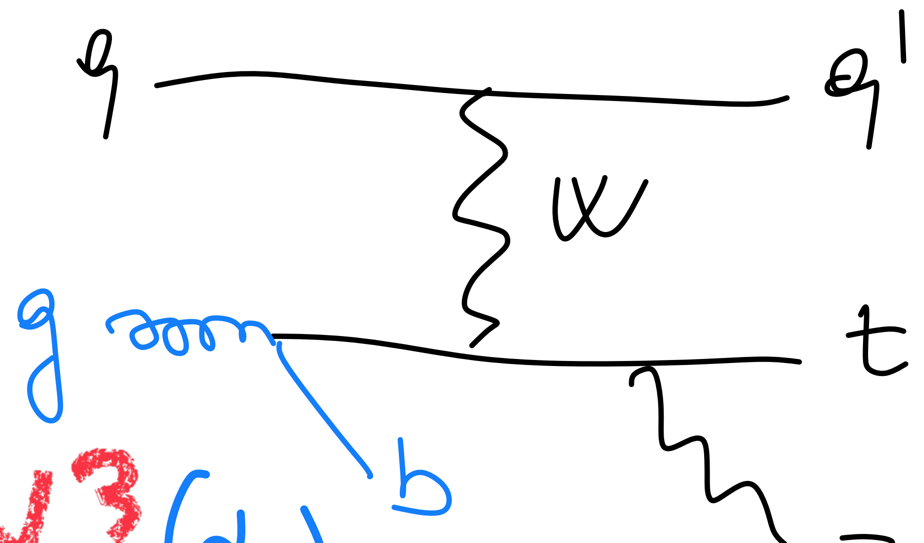
5FS vs. 4FS, what is the difference?

4FS: $m_b \neq 0$, but $\log\left(\frac{Q}{m_b}\right)$ not resummed

5FS: $m_b = 0$, but logs resummed within PDF_5

IMPORTANT

t-channel



$\alpha^3 (\alpha_s)$

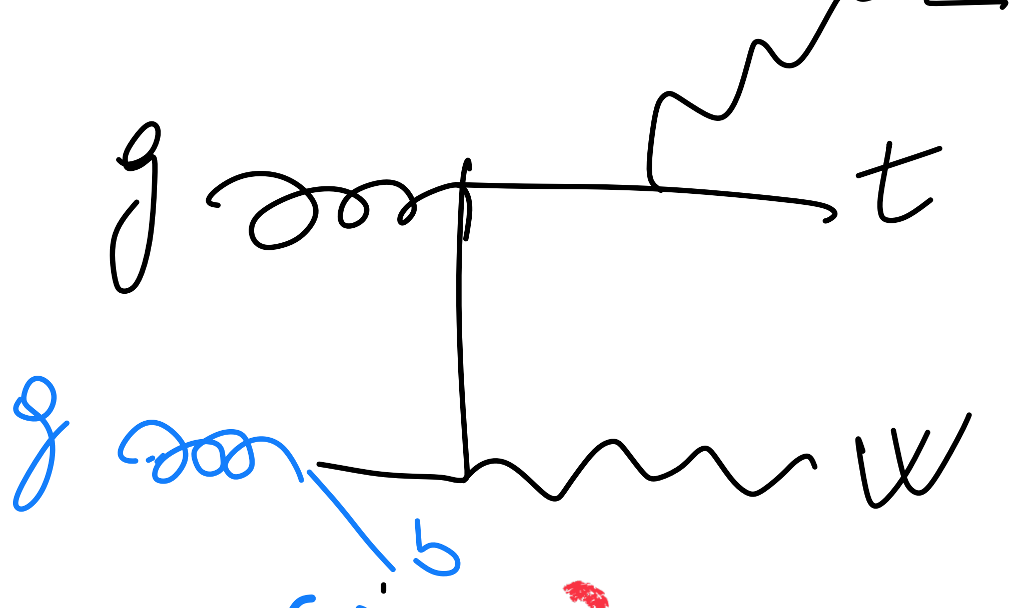
IRRELEVANT (no b)

s-channel

α^3

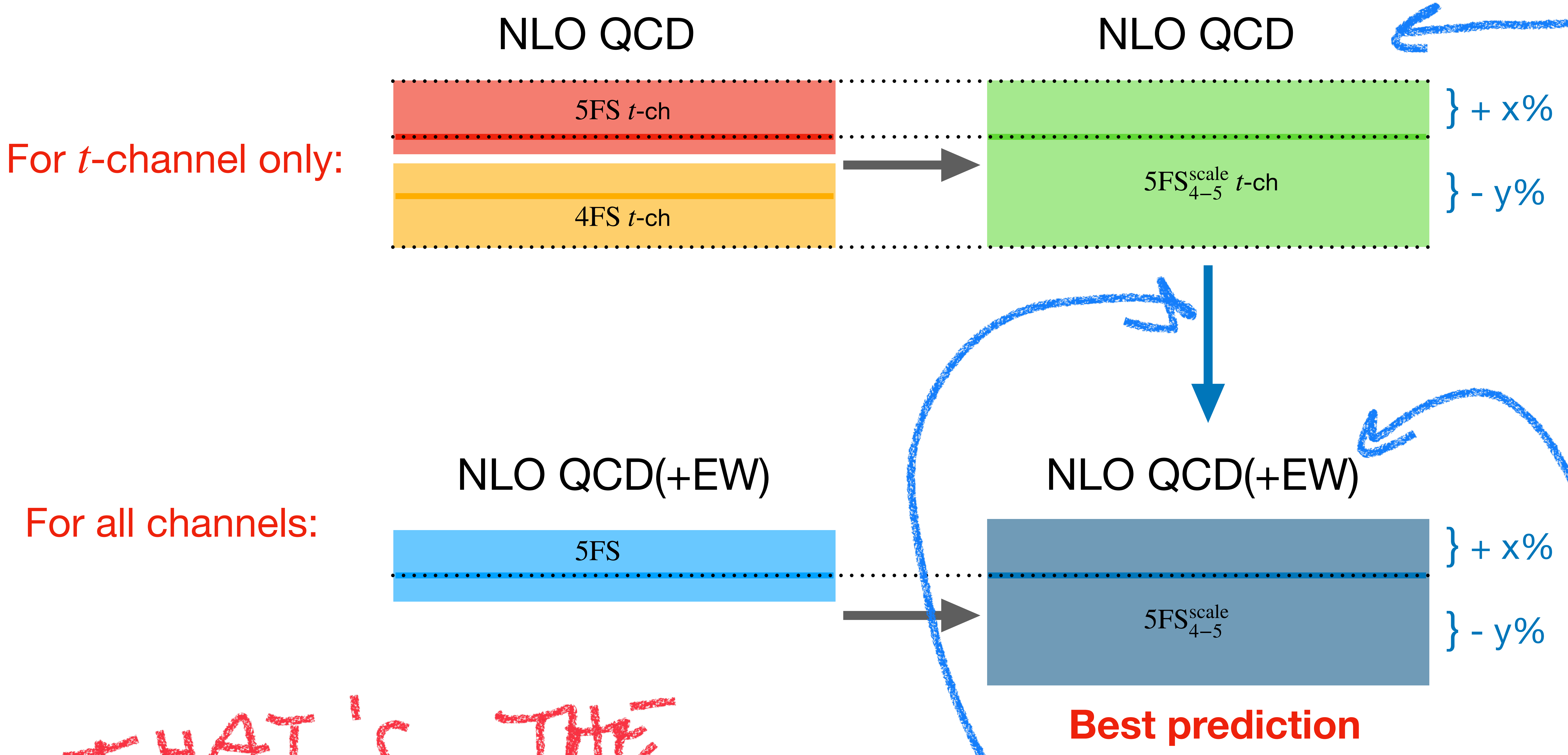
IT ENTERS VIA $W \to q\bar{q}'$ ONLY FROM NLO QCD CORRECTIONS

tW



$\alpha_s^{(2)} \alpha^2$

Rationale behind it

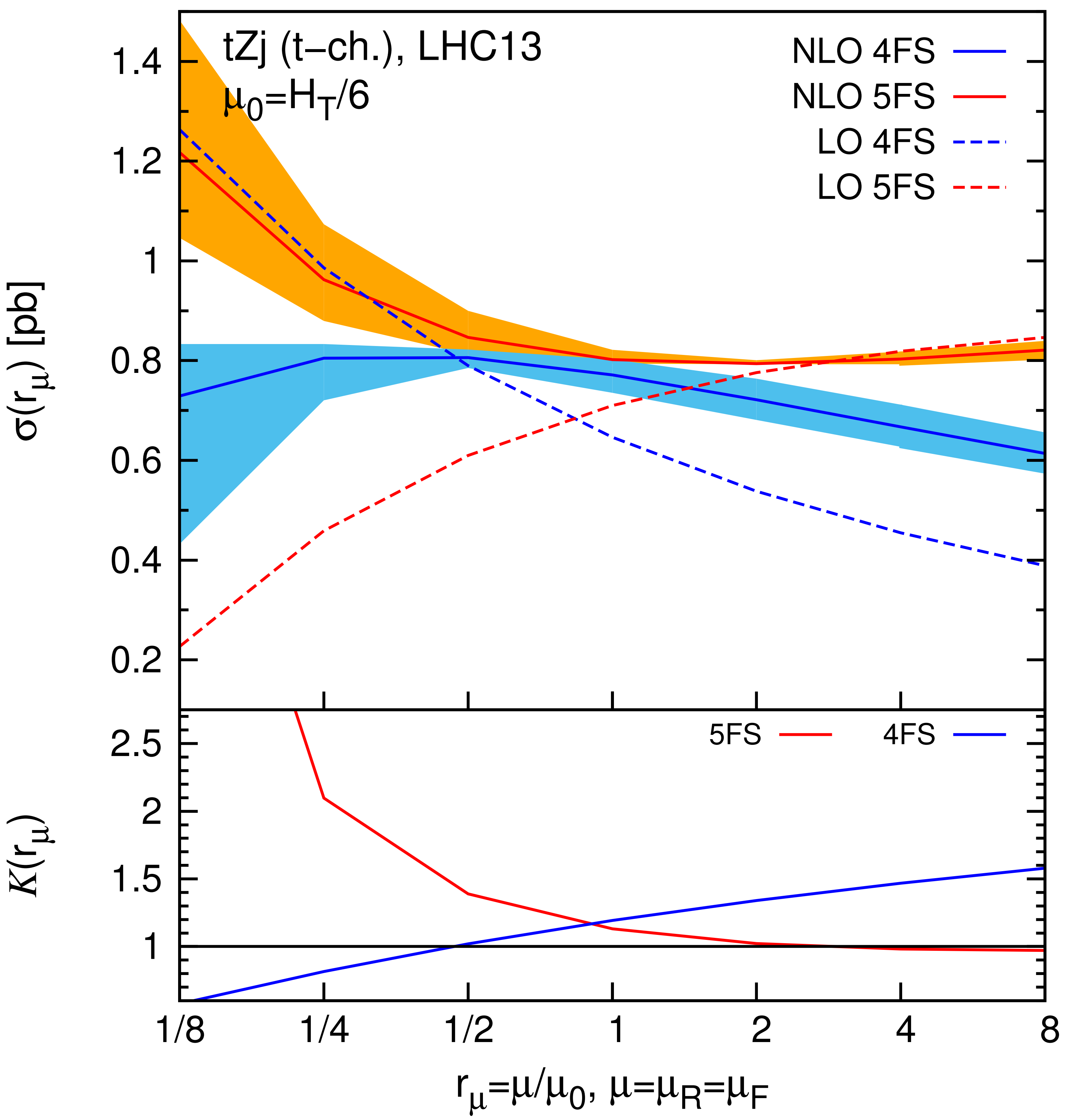


FLAVOUR UNC. FOR t-ch ONLY

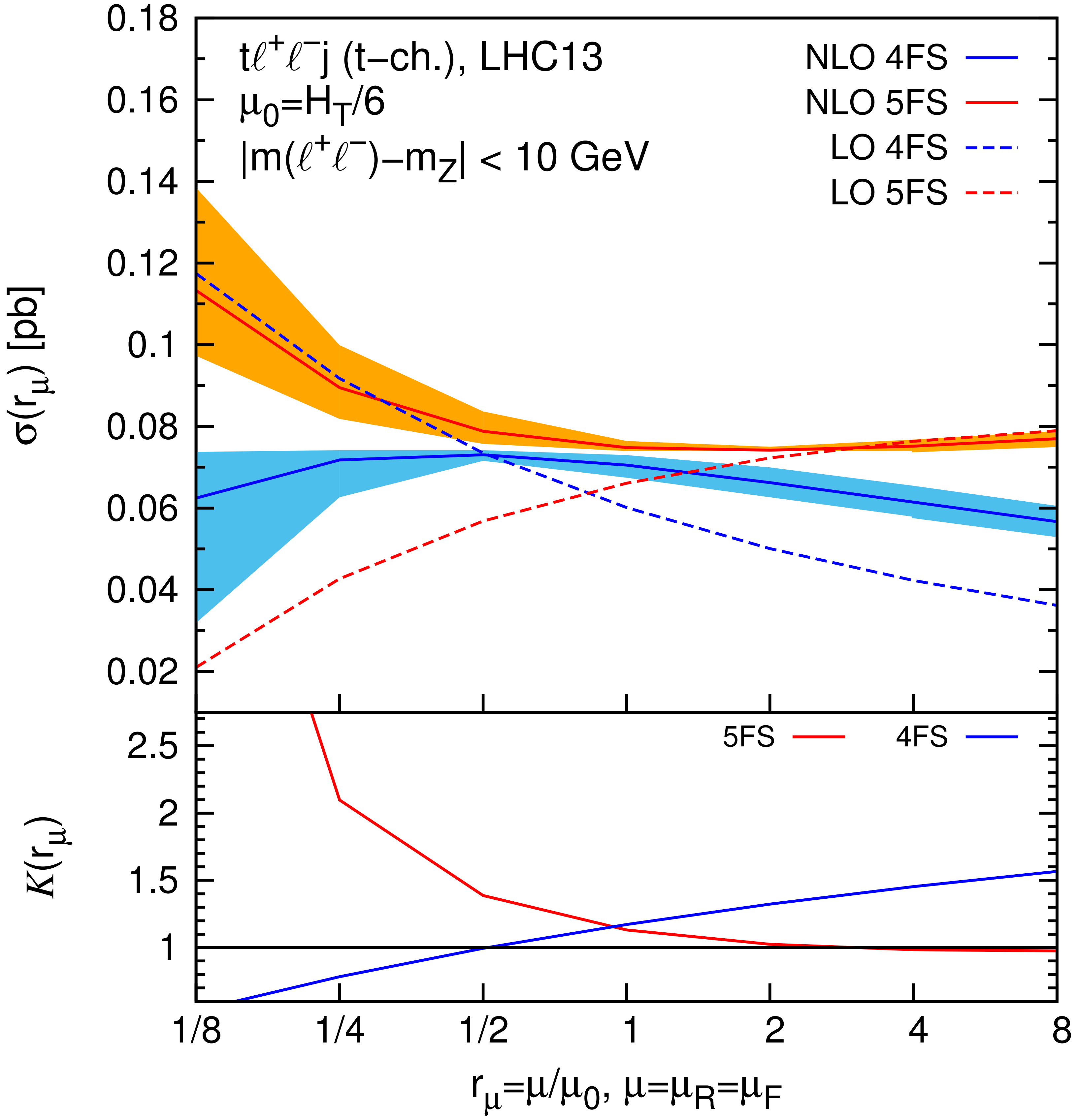
All channels together, (QCD + EW and flavour unc. from t-ch.

THAT'S THE 'MOTIVATION'

Scale variations

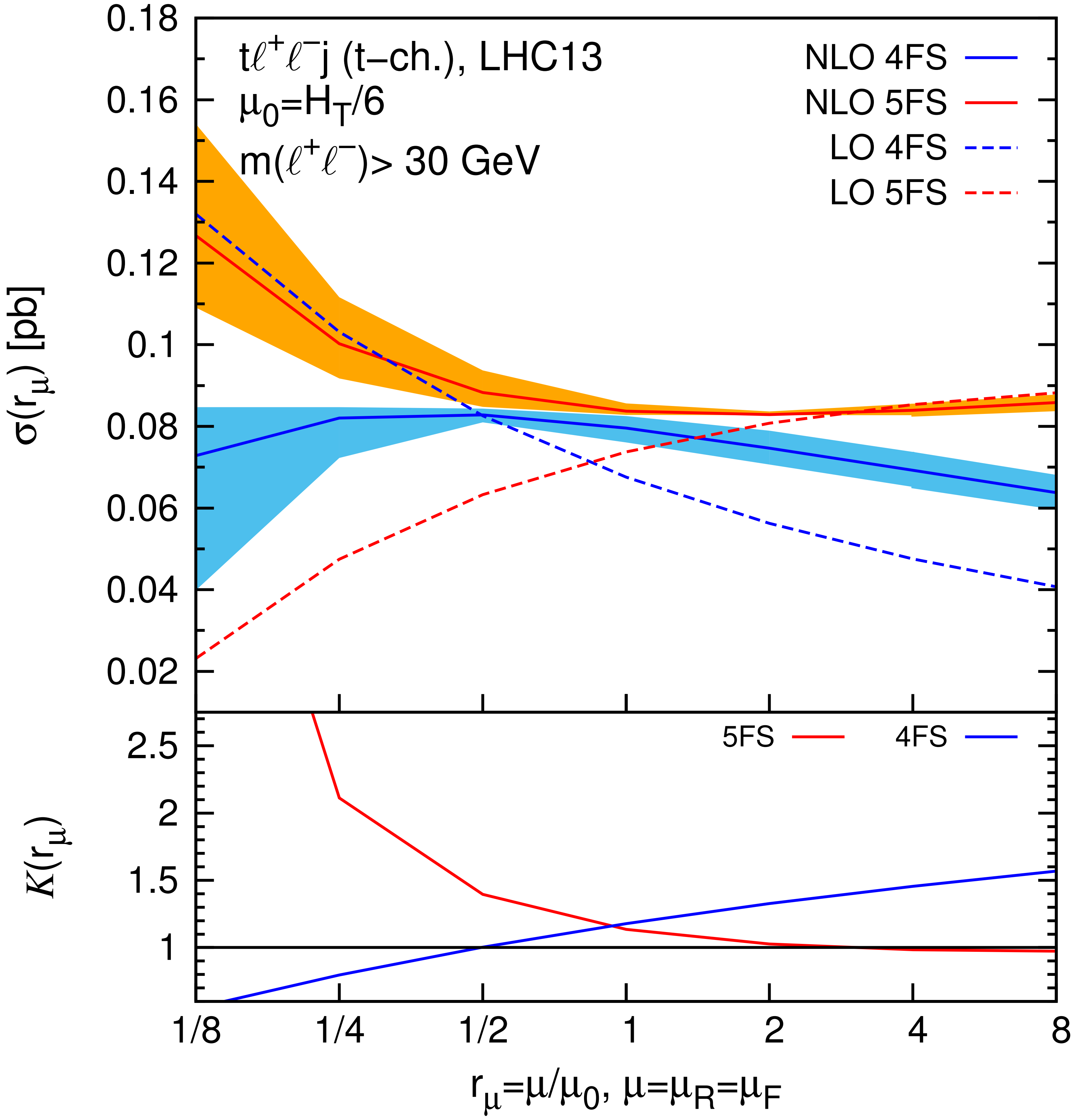


tZj



$t\ell^+\ell^-j$

peak



$t\ell^+\ell^-j$

inclusive

Inclusive results

Accuracy	Channel	FS	tZj	$t\ell^+\ell^-j$ ("inclusive")	$t\ell^+\ell^-j$ (Z-peak)
$\mathrm{NLO_{QCD}}$	t-ch.	4FS	$764(1)^{+33(+4.3\%)\ +3(+0.4\%)}_{-48(-6.2\%)\ -3(-0.4\%)}$	$80.2(2)^{+3.7(+4.6\%)\ +0.3(+0.4\%)}_{-5.0(-6.2\%)\ -0.3(-0.4\%)}$	$70.9(2)^{+3.1(+4.3\%)\ +0.3(+0.4\%)}_{-4.4(-6.2\%)\ -0.3(-0.4\%)}$
		5FS	$805(1)^{+45(+5.5\%)\ +3(+0.4\%)}_{-8(-1.0\%)\ -3(-0.4\%)}$	$84.0(1)^{+4.7(+5.6\%)\ +0.3(+0.4\%)}_{-0.9(-1.0\%)\ -0.3(-0.4\%)}$	$75.0(1)^{+4.2(+5.6\%)\ +0.3(+0.4\%)}_{-0.8(-1.0\%)\ -0.3(-0.4\%)}$
		$\mathrm{5FS^{scale}_{4-5}}$	$805(1)^{+45(+5.5\%)\ +3(+0.4\%)}_{-89(-11.1\%)\ -3(-0.4\%)}$	$84.0(1)^{+4.7(+5.6\%)\ +0.3(+0.4\%)}_{-8.7(-10.4\%)\ -0.3(-0.4\%)}$	$75.0(1)^{+4.2(+5.6\%)\ +0.3(+0.4\%)}_{-8.5(-11.3\%)\ -0.3(-0.4\%)}$
$\mathrm{NLO_{QCD}}$	t-ch., s-ch., tW_h	5FS	$895(2)^{+46(+5.1\%)\ +4(+0.4\%)}_{-16(-1.8\%)\ -4(-0.4\%)}$	$93.7(2)^{+4.9(+5.2\%)\ +0.4(+0.4\%)}_{-1.7(-1.8\%)\ -0.4(-0.4\%)}$	$83.4(2)^{+4.3(+5.1\%)\ +0.4(+0.4\%)}_{-1.5(-1.8\%)\ -0.4(-0.4\%)}$
		$\mathrm{5FS^{scale}_{4-5}}$	$895(2)^{+50(+5.5\%)\ +4(+0.4\%)}_{-99(-11.1\%)\ -4(-0.4\%)}$	$93.7(2)^{+5.2(+5.6\%)\ +0.4(+0.4\%)}_{-9.7(-10.4\%)\ -0.4(-0.4\%)}$	$83.4(2)^{+4.6(+5.6\%)\ +0.4(+0.4\%)}_{-9.4(-11.3\%)\ -0.4(-0.4\%)}$
$\mathrm{NLO_{QCD+EW}}$	t-ch., s-ch., tW_h	5FS	$904(2)^{+42(+4.7\%)\ +4(+0.4\%)}_{-19(-2.1\%)\ -4(-0.4\%)}$	$89.6(2)^{+5.1(+5.7\%)\ +0.4(+0.4\%)}_{-1.7(-1.9\%)\ -0.4(-0.4\%)}$	$77.2(2)^{+4.9(+6.3\%)\ +0.3(+0.4\%)}_{-1.5(-1.9\%)\ -0.3(-0.4\%)}$
		$\mathrm{5FS^{scale}_{4-5}}$	$904(2)^{+50(+5.5\%)\ +4(+0.4\%)}_{-100(-11.1\%)\ -4(-0.4\%)}$	$89.6(2)^{+5.0(+5.6\%)\ +0.4(+0.4\%)}_{-9.3(-10.4\%)\ -0.4(-0.4\%)}$	$77.2(2)^{+4.3(+5.6\%)\ +0.3(+0.4\%)}_{-8.7(-11.3\%)\ -0.3(-0.4\%)}$

Lepton photon recombination

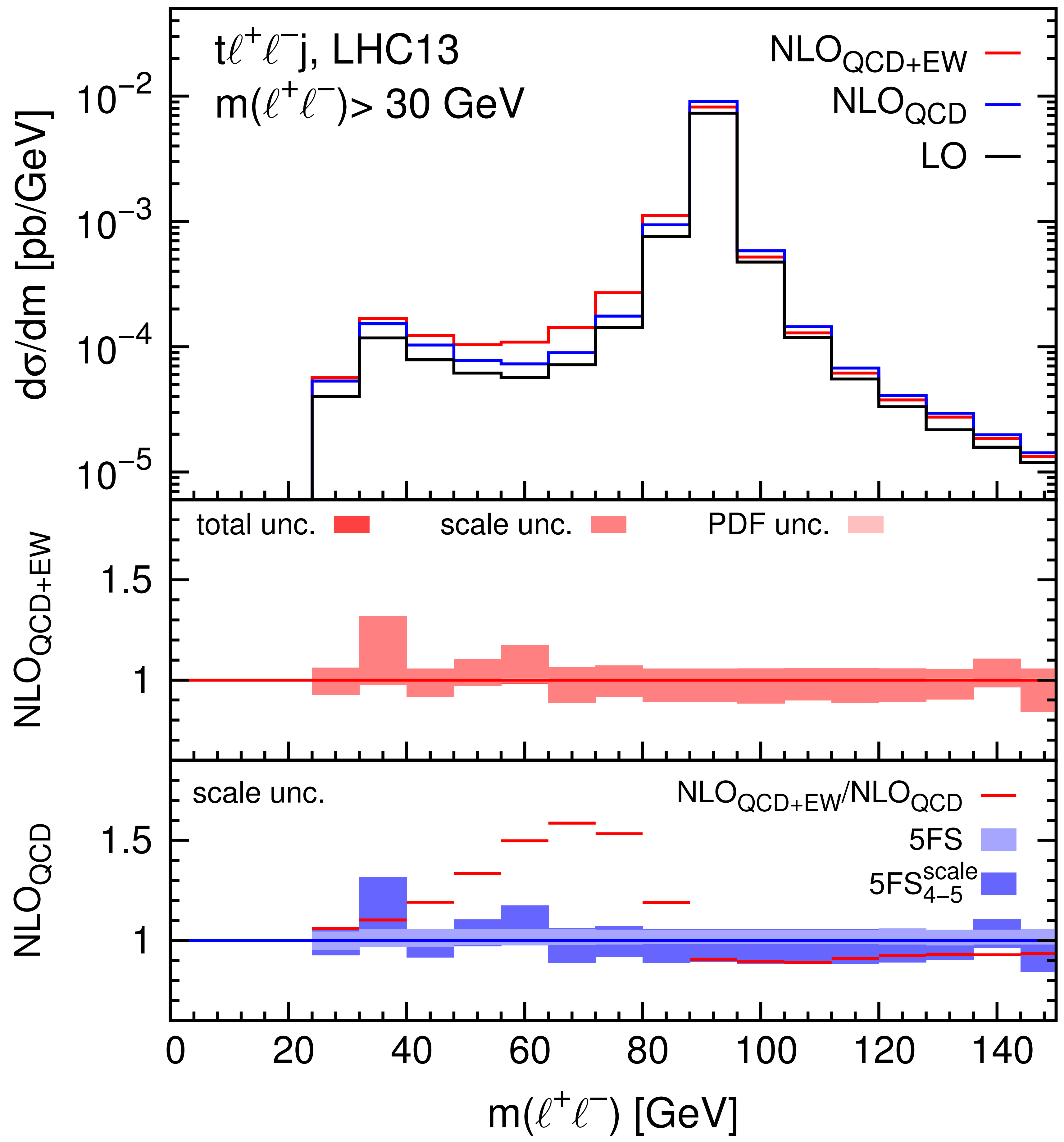
$$\Delta R(\ell,\gamma) < 0.1$$

jets: anti-kt with $p_T^{\min} = 25\ \mathrm{GeV}\,, \qquad R = 0.5$

Inclusive results

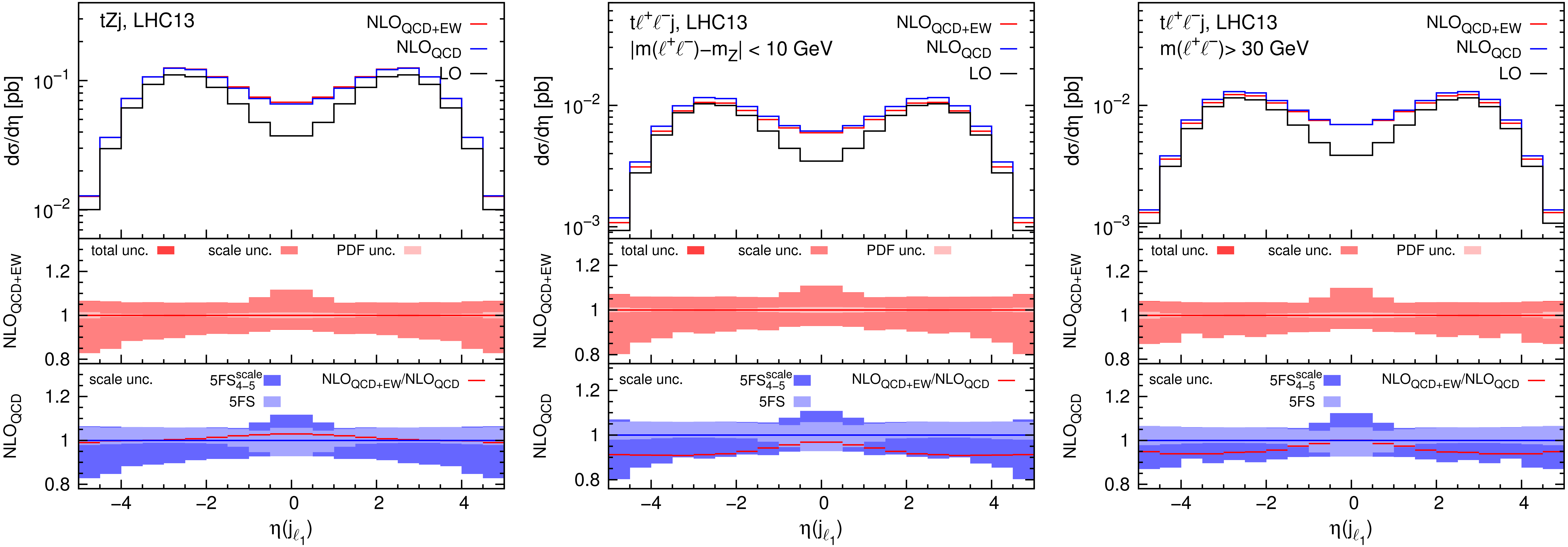
FS	Channel	K-factor	tHj	tZj
4FS	t-ch.	$\mathrm{NLO_{QCD}/LO}$	1.1[illegible]	1.18
5FS			1.[illegible]0	1.13
5FS	t-ch., s-ch., tW_h	$\mathrm{NLO_{QCD}/LO}$	[illegible].37	1.24
		$\mathrm{NLO_{QCD+EW}/NLO_{QCD}}$	0.97	1.01

FS	Channel	K-factor	$t\ell^+\ell^-j$ ("inclusive")	$t\ell^+\ell^-j$ (Z-peak)
4FS	t-ch.	$\mathrm{NLO_{QCD}/LO}$	1.18	1.18
5FS			1.13	1.13
5FS	t-ch., s-ch., tW_h	$\mathrm{NLO_{QCD}/LO}$	1.24	1.24
		$\mathrm{NLO_{QCD+EW}/NLO_{QCD}}$	0.96	0.93



In both cases NLO EW corrections are larger than the scale unc. in pure 5FS, but not in the $\mathrm{5FS}^{\mathrm{scale}}_{4-5}$!

Differential distributions



tZj

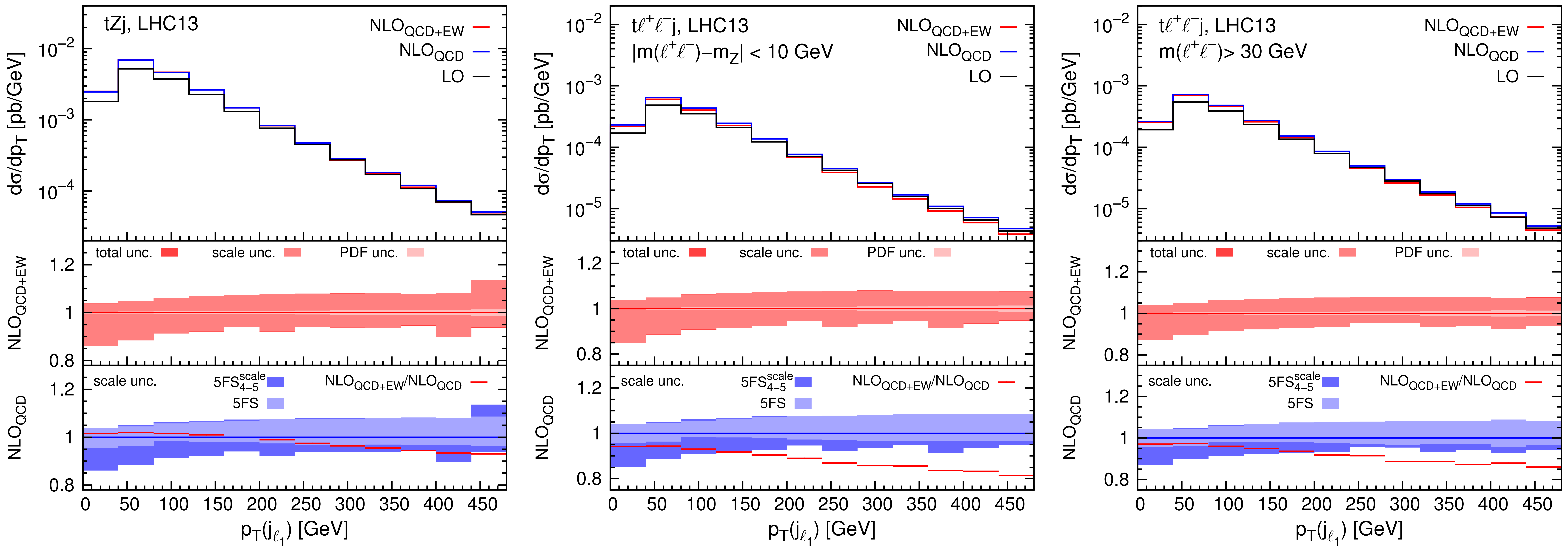
$t\ell^+\ell^-j$

peak

$t\ell^+\ell^-j$

inclusive

Differential distributions

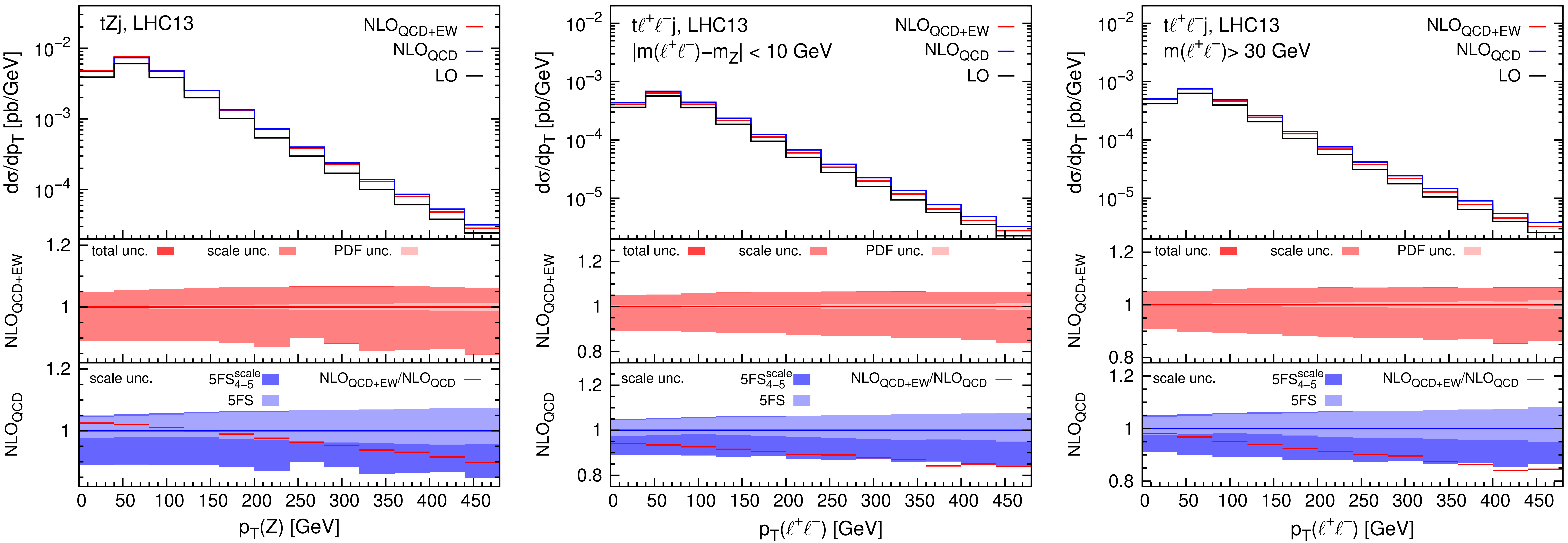


tZj

$t\ell^+\ell^-j$
peak

$t\ell^+\ell^-j$
inclusive

Differential distributions



tZj

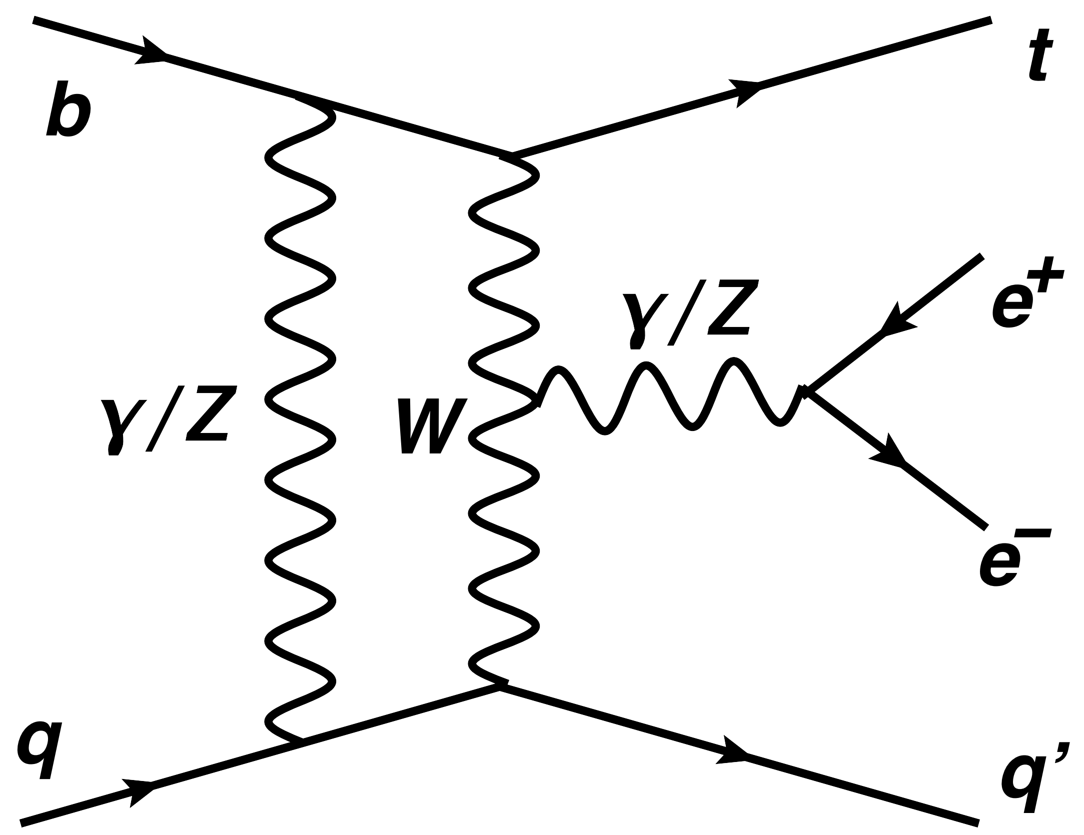
$t\ell^+\ell^-j$
peak

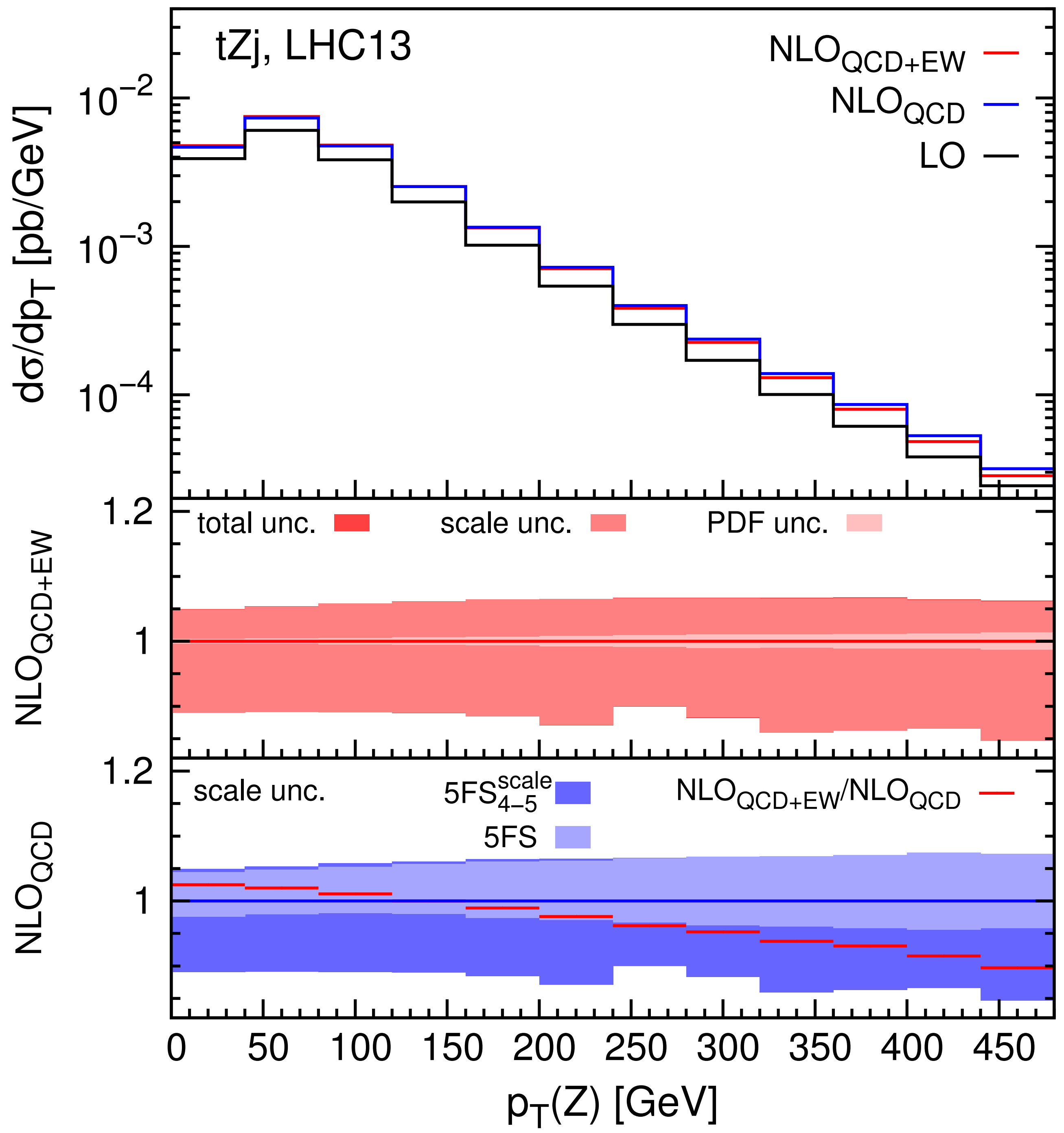
$t\ell^+\ell^-j$
inclusive

Summary FO tZj: NLO QCD+EW predictions

***DP**, Tsinikos, Vryonidou ’20*

Accuracy	Channel	FS	tHj	tZj
$\mathrm{NLO_{QCD}}$	t-ch., s-ch., tW_h	5FS	$85.1(2)^{+5.4(+6.4\%)}_{-2.3(-2.7\%)}\ {}^{+0.5(+0.6\%)}_{-0.5(-0.6\%)}$	$895(2)^{+46(+5.1\%)}_{-16(-1.8\%)}\ {}^{+4(+0.4\%)}_{-4(-0.4\%)}$
		$\mathrm{5FS^{scale}_{4-5}}$	$85.1(2)^{+6.2(+7.2\%)}_{-9.2(-10.9\%)}\ {}^{+0.5(+0.6\%)}_{-0.5(-0.6\%)}$	$895(2)^{+50(+5.5\%)}_{-99(-11.1\%)}\ {}^{+4(+0.4\%)}_{-4(-0.4\%)}$
$\mathrm{NLO_{QCD+EW}}$	t-ch., s-ch., tW_h	5FS	$82.2(2)^{+5.6(+6.8\%)}_{-2.4(-2.9\%)}\ {}^{+0.5(+0.6\%)}_{-0.5(-0.6\%)}$	$904(2)^{+42(+4.7\%)}_{-19(-2.1\%)}\ {}^{+4(+0.4\%)}_{-4(-0.4\%)}$
		$\mathrm{5FS^{scale}_{4-5}}$	$82.2(2)^{+5.9(+7.2\%)}_{-8.9(-10.9\%)}\ {}^{+0.5(+0.6\%)}_{-0.5(-0.6\%)}$	$904(2)^{+50(+5.5\%)}_{-100(-11.1\%)}\ {}^{+4(+0.4\%)}_{-4(-0.4\%)}$





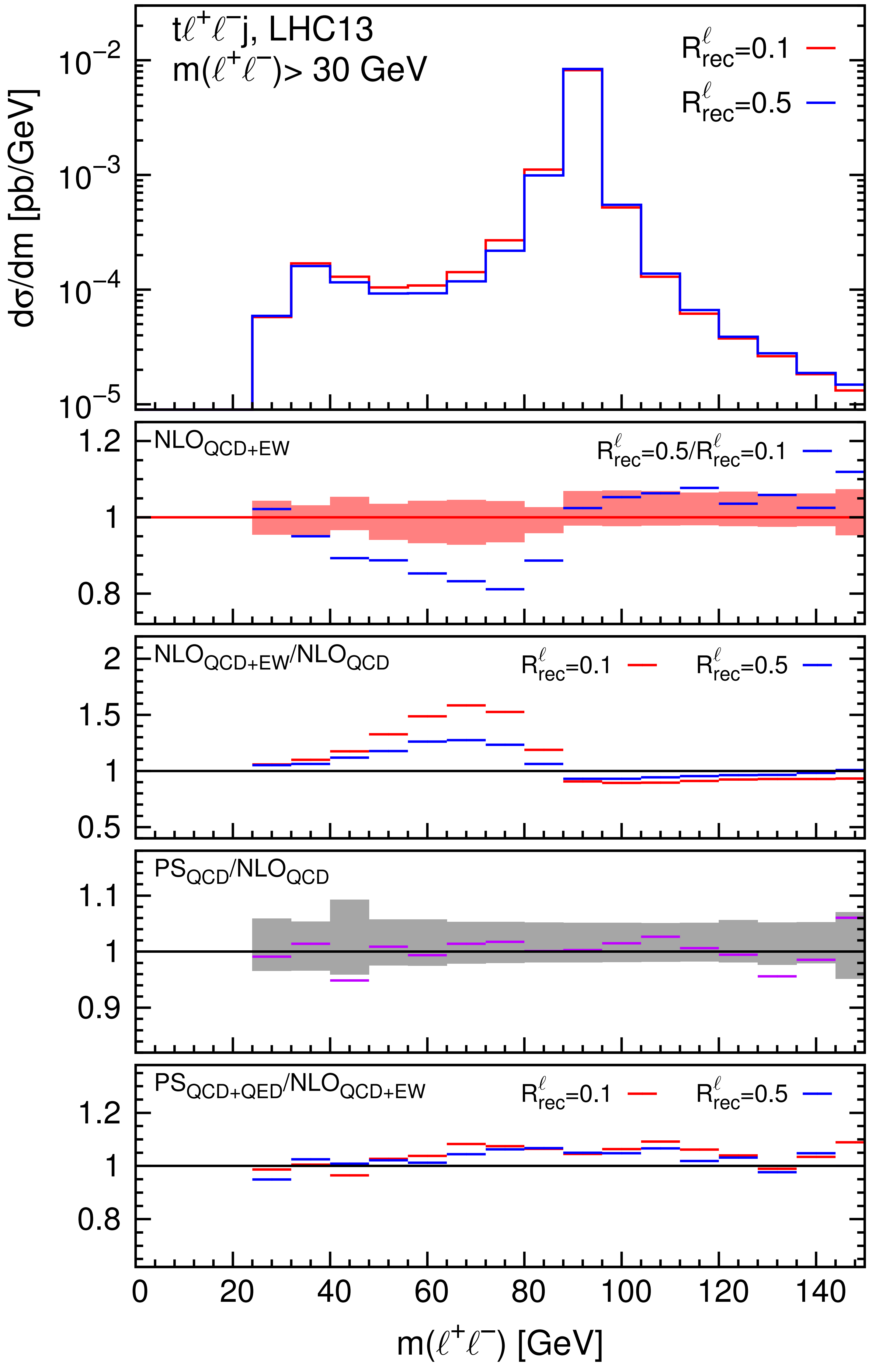
QCD scale and flavour (4FS vs. 5FS) uncertainties combined in the $\mathrm{5FS^{scale}_{4-5FS}}$.

NLO EW corrections are in general within the QCD uncertainty band only taking into account the flavour-scheme dependence.

NLO EW corrections mix the different channels (s, t, tW)

Flavour-scheme uncertainty is essential for a realistic estimate of total uncertainties.

Adding PS with and without QED radiation



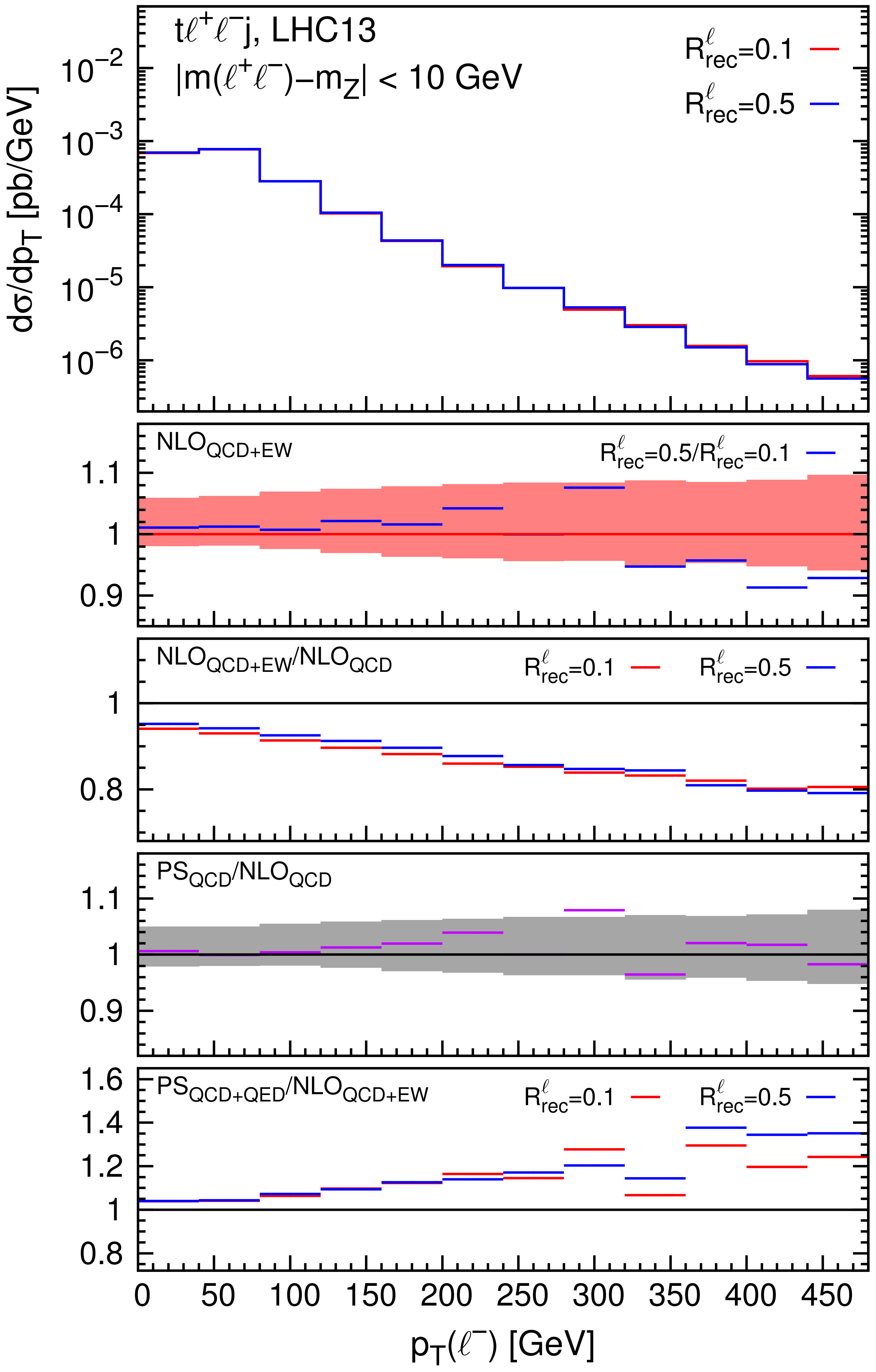
Excluding the tails, dominant EW effects originate from photon radiation from leptons (FSR).

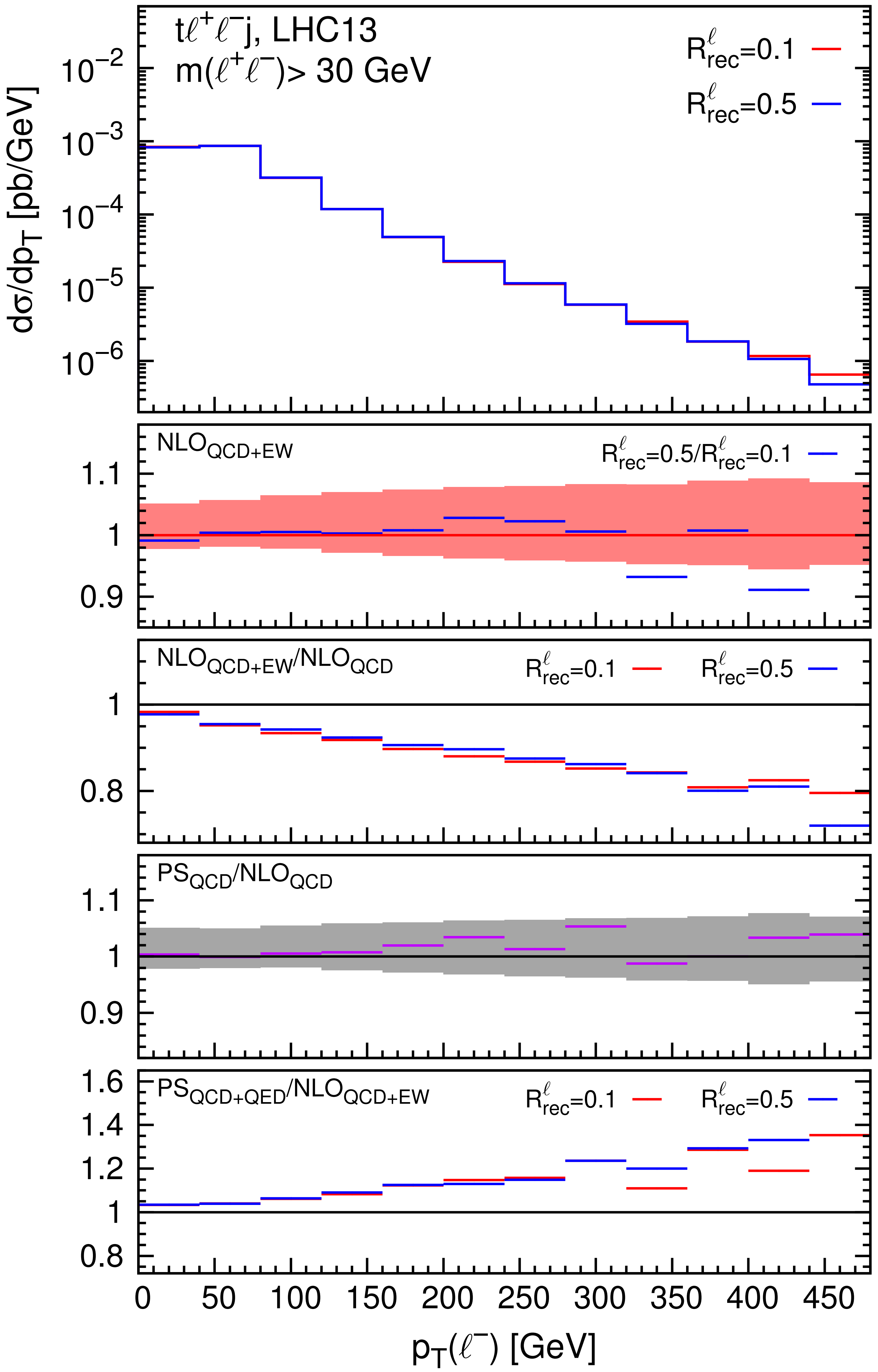
Then, I can simply simulate this effect via QED in the PS, which is typically by default on in e.g. PYTHIA, but I can also turned it off and verify.

The large EW effects from FSR radiation can be simulated simply by QED effects within the PS and therefore they are automatically taken into account

Adding PS with and without QED radiation

The situation is completely different if boosted regimes are considered.





Advertisement / possible solution?

Considering only the dominant contribution from NLO EW: Sudakov and QED FSR.

Matching of NLO QCD + PS + EWSL + QED FSR at the LHC:

Improving NLO QCD event generators with high-energy EW corrections

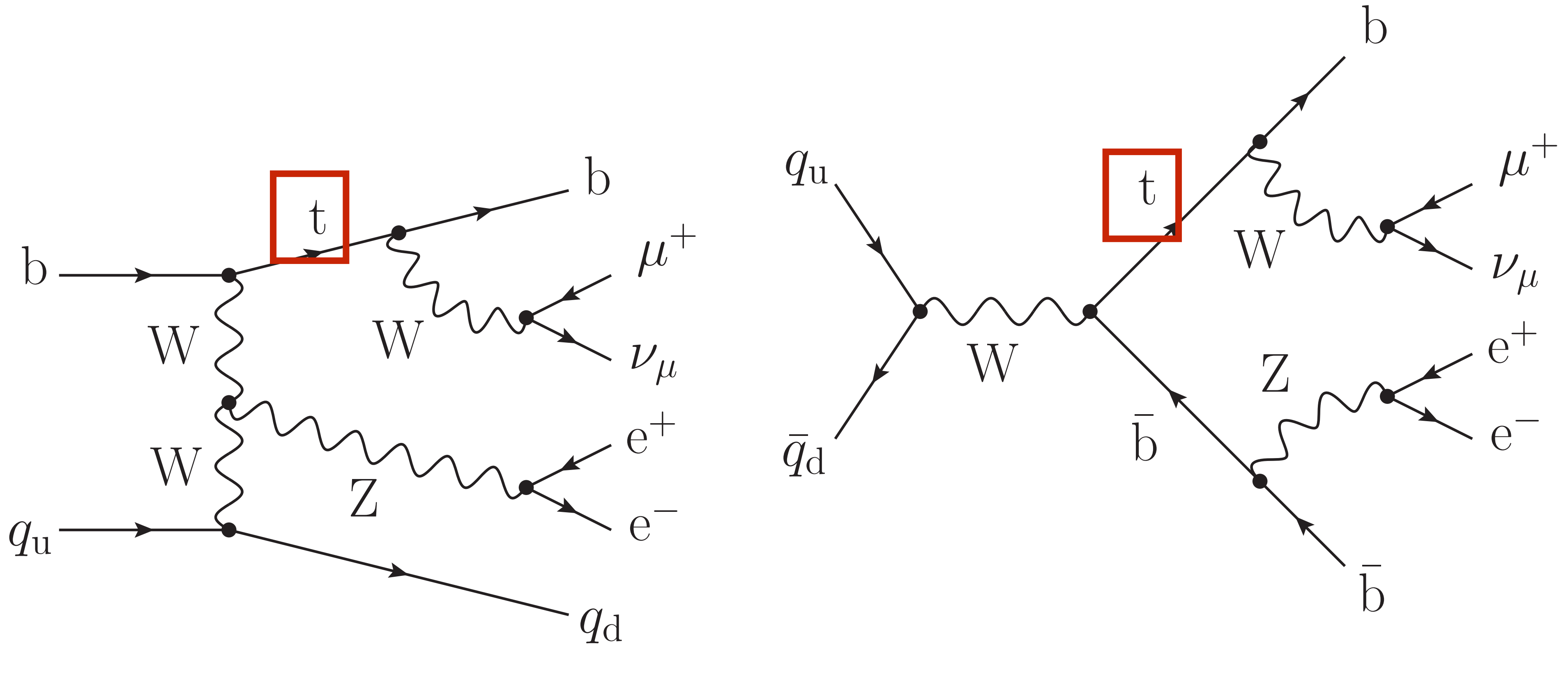
Davide Pagani,[a] Timea Vitos,[b] Marco Zaro[c]

Both Born, QCD virtual and separately real corrections are consistently reweighted via NLO EW Sudakov logarithms. Detail study has still to be done.

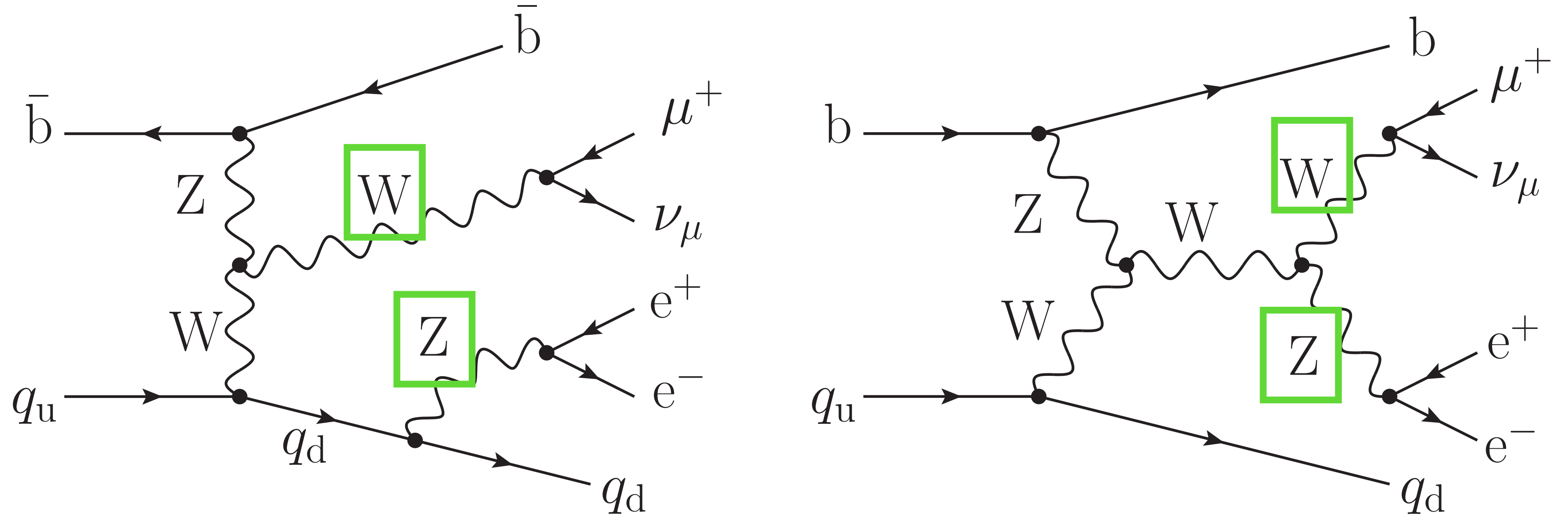
tZj: NLO QCD+EW off-shell effects

Denner, Pellicciolli, Schwan '22

$$\mathrm{pp} \to \mathrm{e}^+\mathrm{e}^-\mu^+\nu_\mu \mathrm{J}\,\mathrm{j_b} + X\,,$$

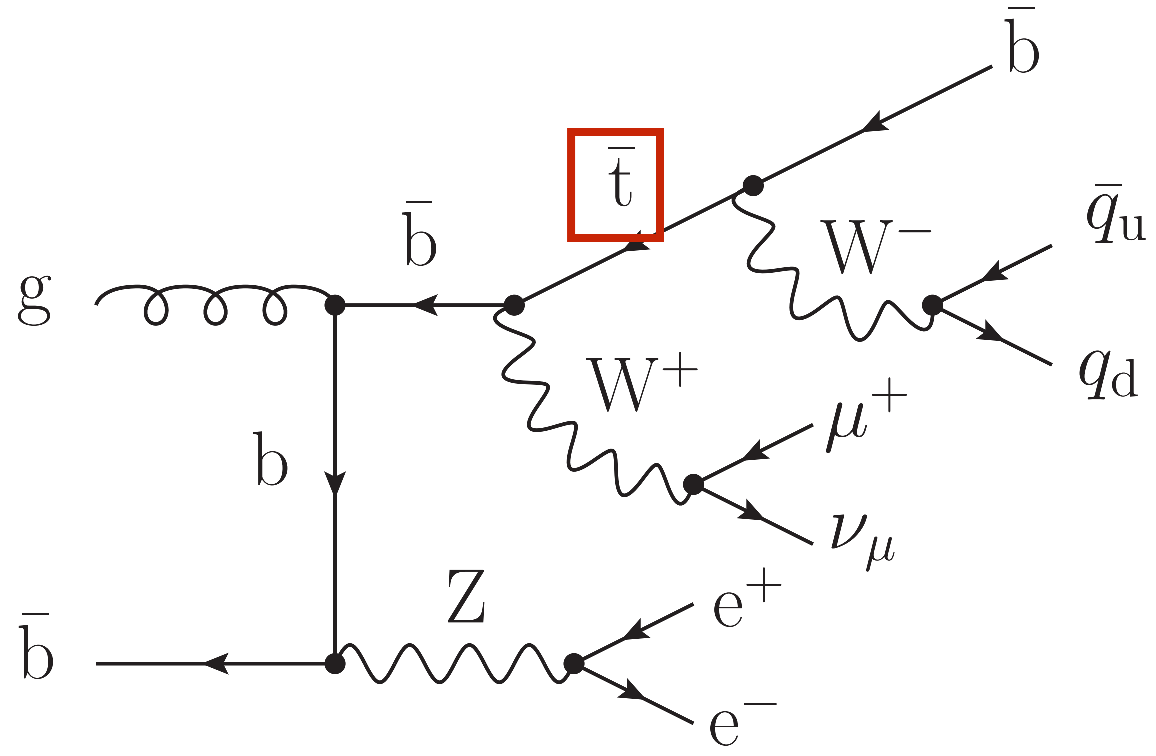


(a) t channel (b) s channel



(c) Non resonant (d) Vector-boson scattering

but also

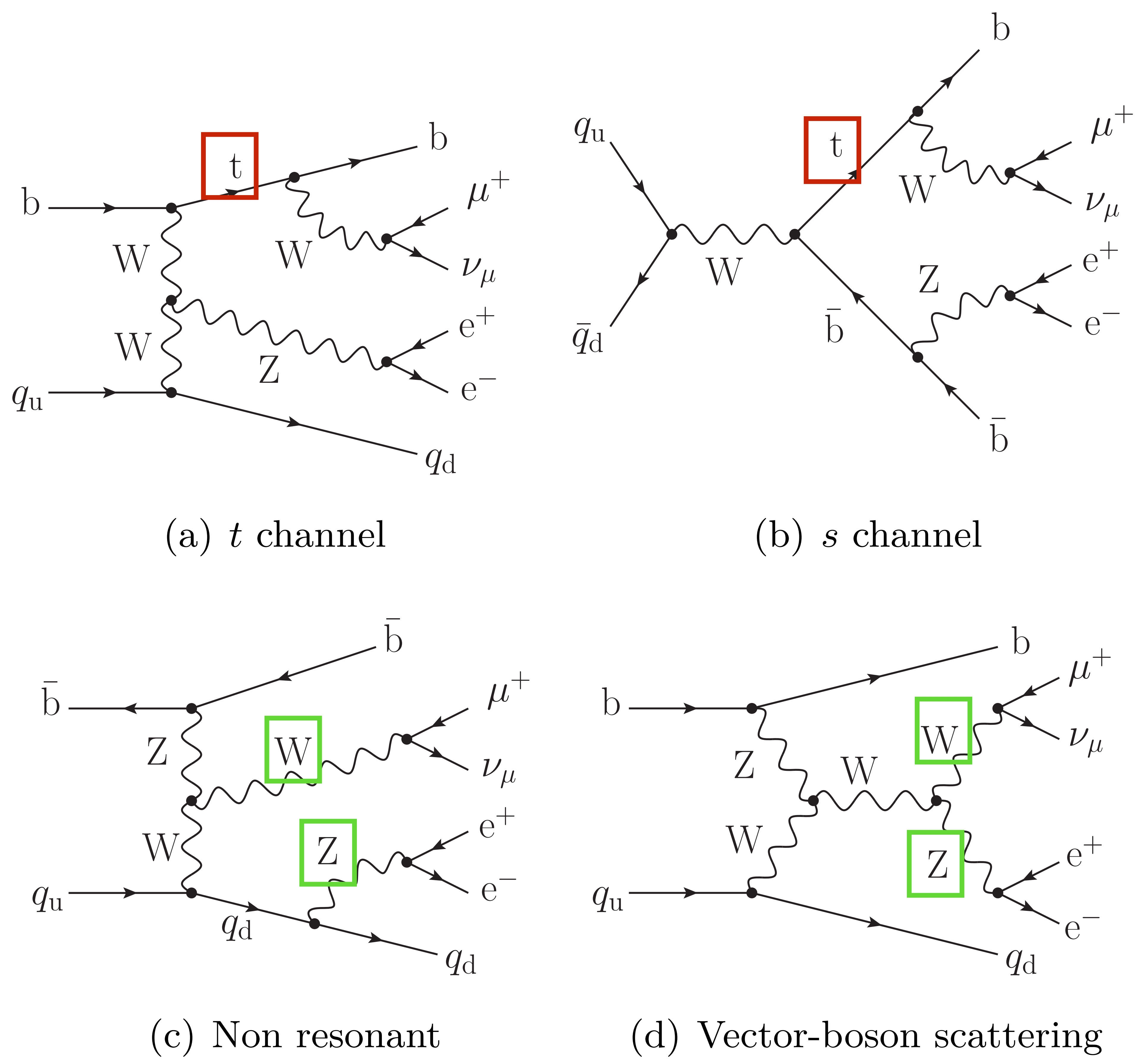


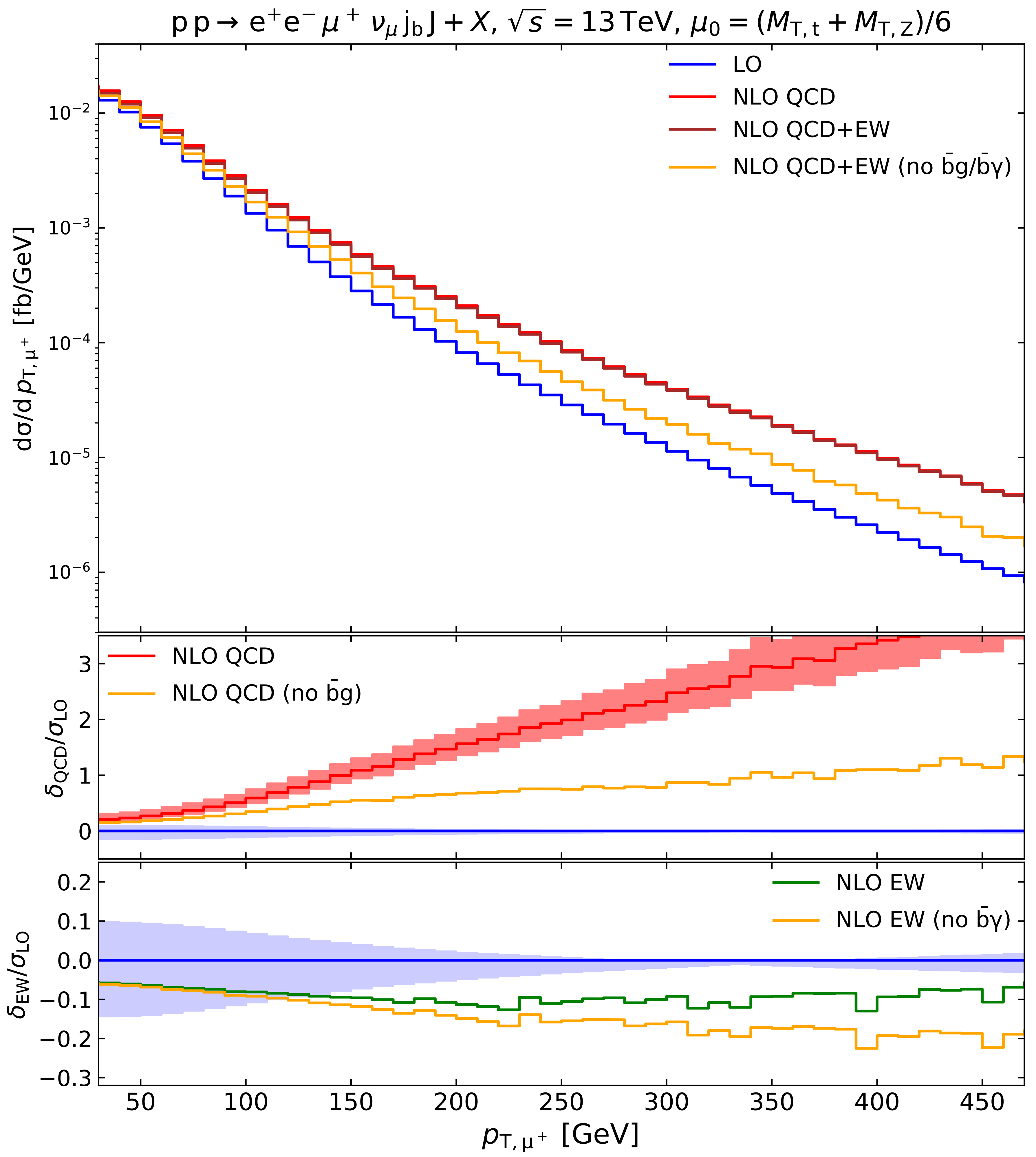
If I start from single-**top** Z production with a leptonically decaying top, NLO QCD corrections give a contribution that is in fact single-**antitop** Z production with a hadronically decaying top!

tZj: NLO QCD+EW off-shell effects

Denner, Pellicciolo, Schwan '22

$$\mathrm{pp} \to \mathrm{e}^+\mathrm{e}^-\mu^+\nu_\mu \mathrm{J}\,\mathrm{j_b} + X\,,$$






OK. SO NOW WHAT?

Conclusions

The ideal Monte Carlo with flavour unc., EW corrections and non-resonant off-shell effects is not available. So the best approach for the simulation depends on the precision that has to be achieved and the kind of observable that are considered.

Boosted regime and precision ≤ 10 %, EW are important and are not available in MC. Bad case: Reiweight with K-factors / or use NLO QCD+PS+EWSL (DP, Vitos, Zaro '23).

Not boosted regime and precision ≤ 10 %, EW are important and mostly from QED radiation which is already simulated in the PS. Better.

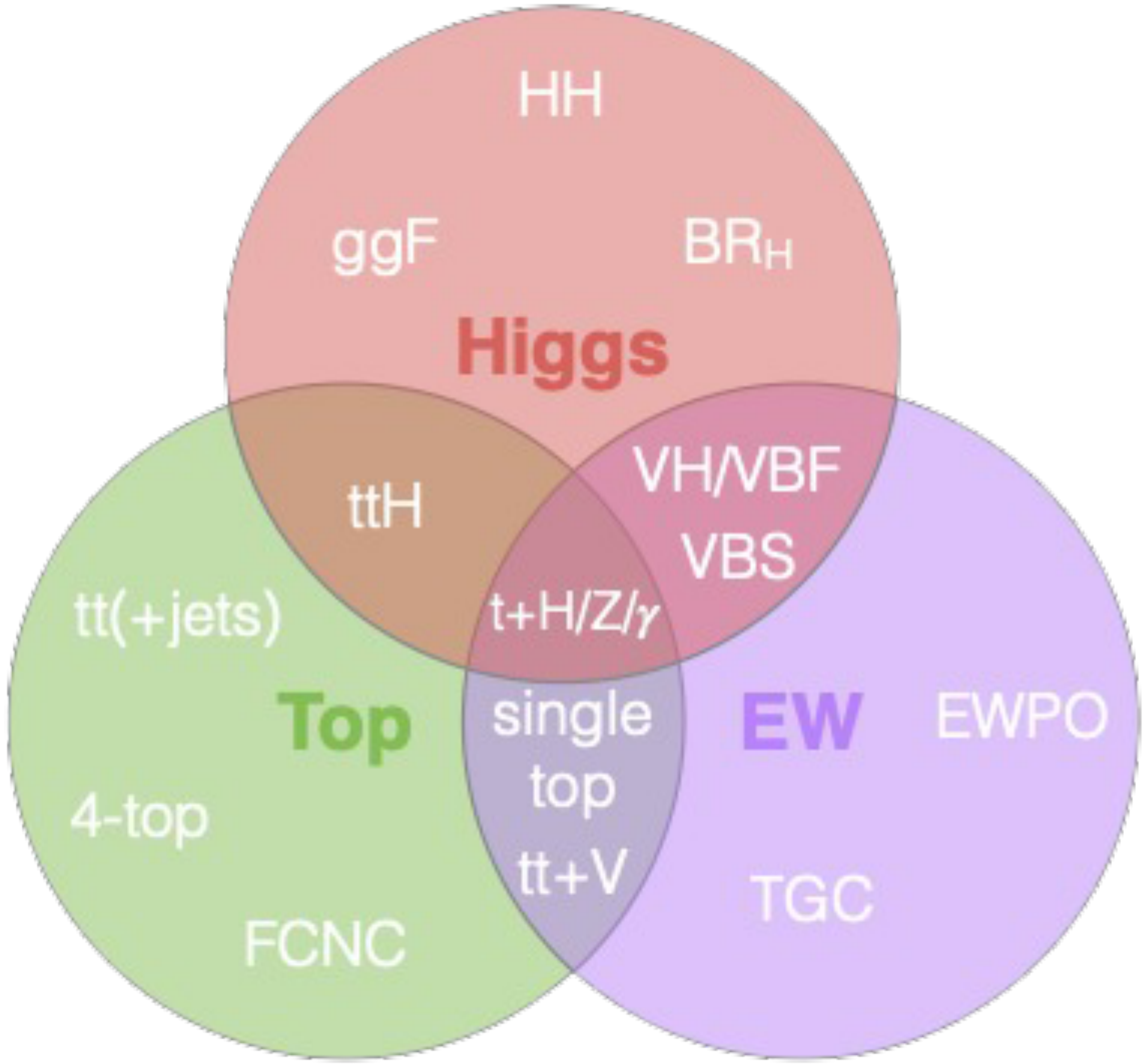
Precision ≤ 10 %, flavour uncertainties cannot be neglected. Simulation possibly in 4FS and 5FS.

In general, not separating different channels is preferable.

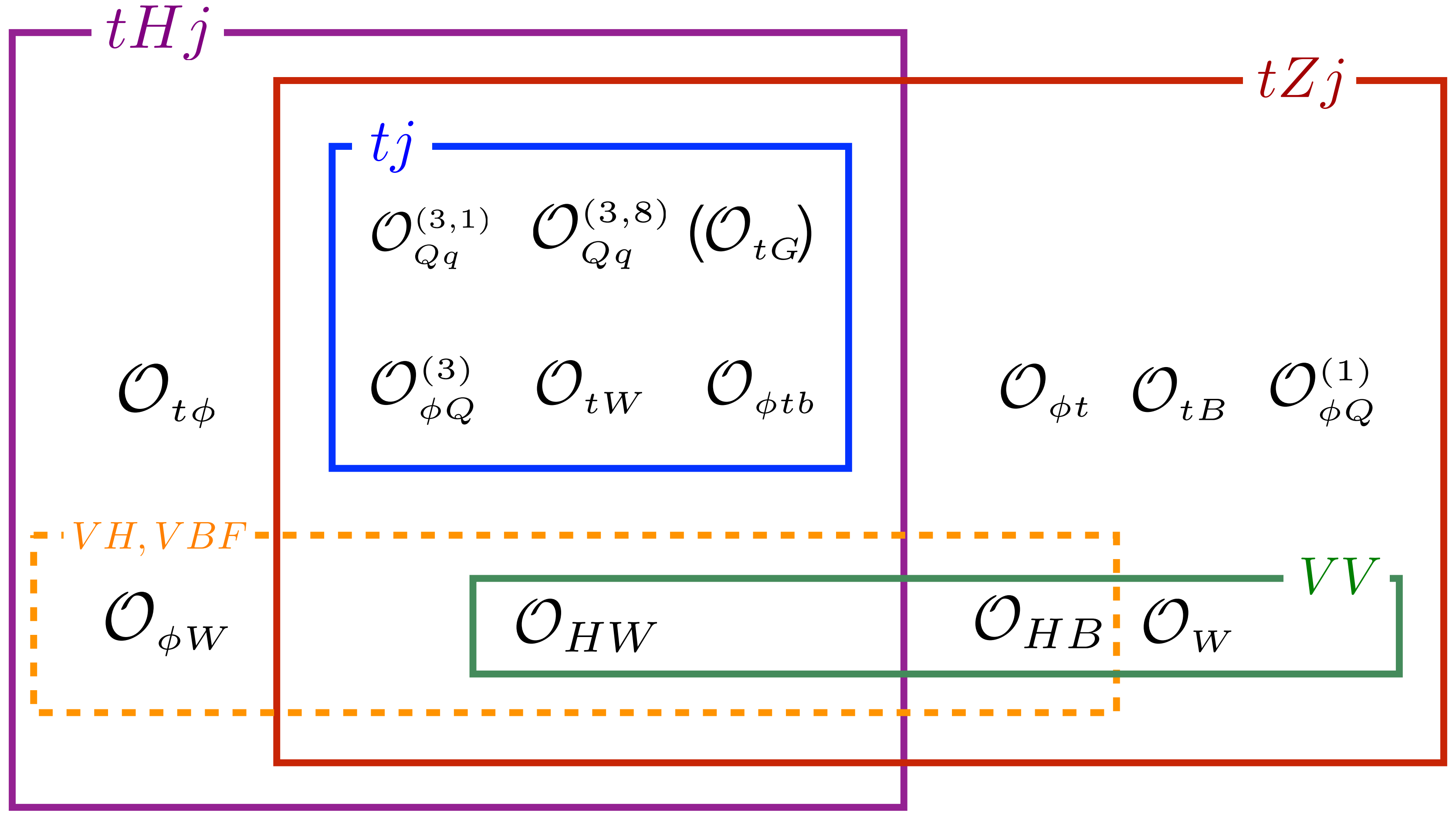
EXTRA SLIDES

Top, EW and Higgs sectors are all connected

Top, EW and Higgs are connected



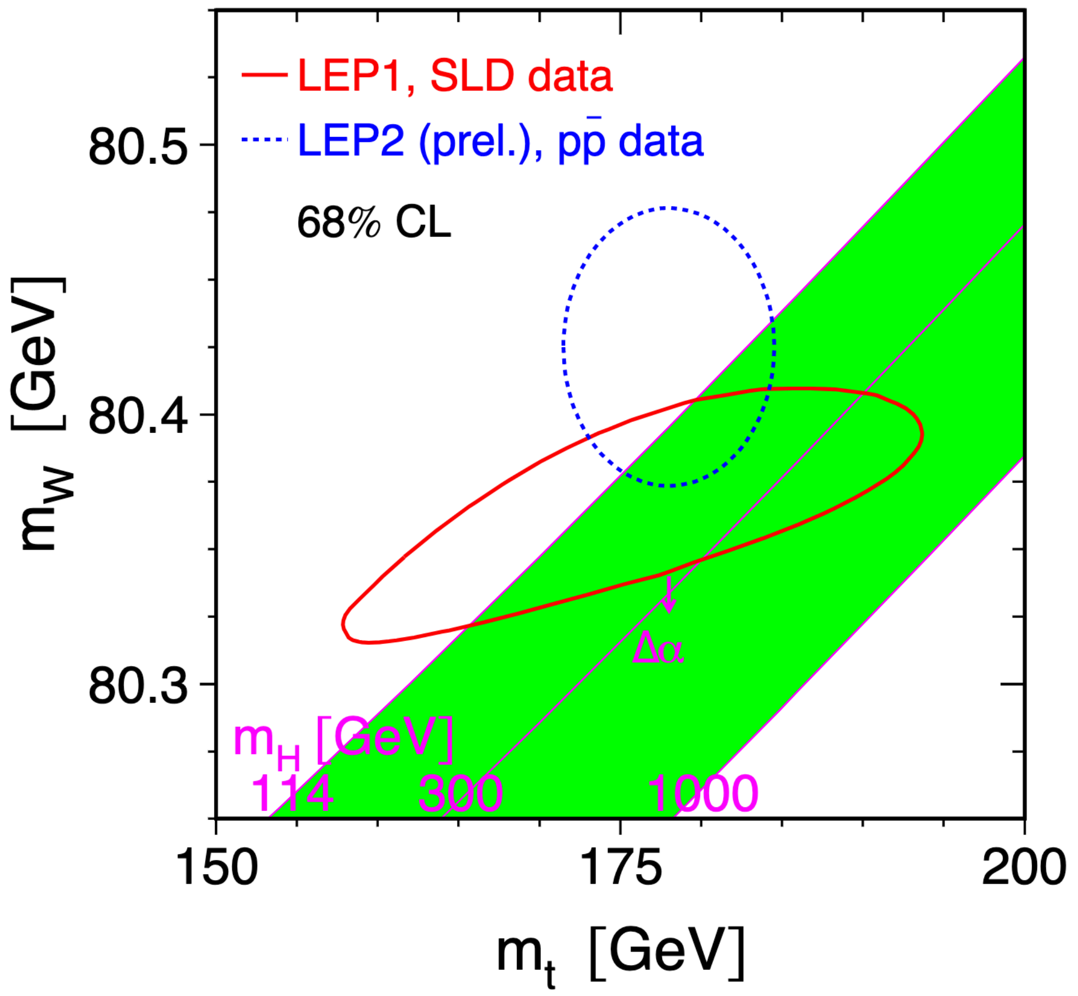
An EFT perspective on BSM (SMEFT)



New Physics in the Top sector has effects in the EW sector and vice versa.

Taken from *Degrande, Maltoni, Mimasu, Vryonidou, Zhang '18*

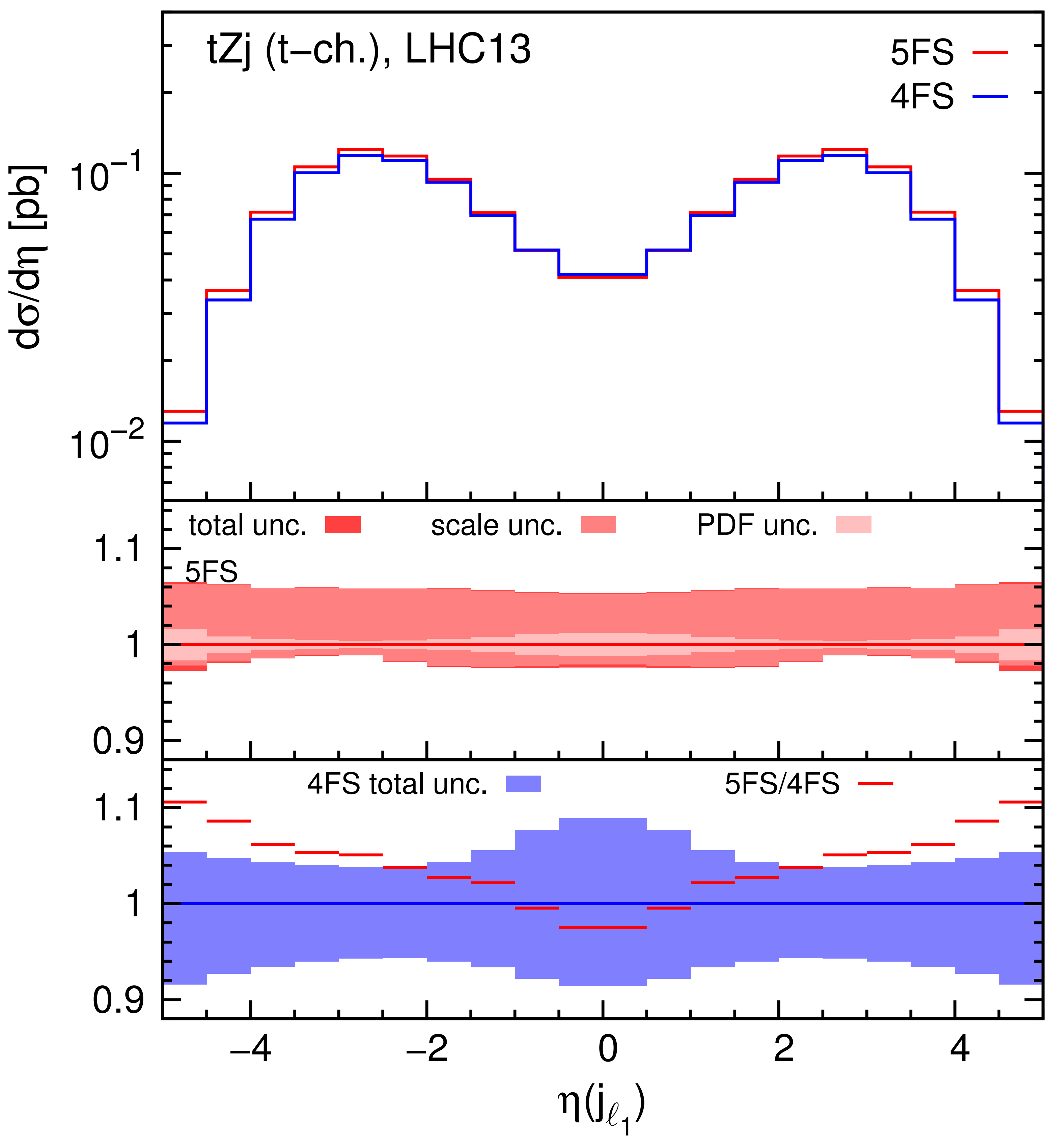
A SM (much older) perspective



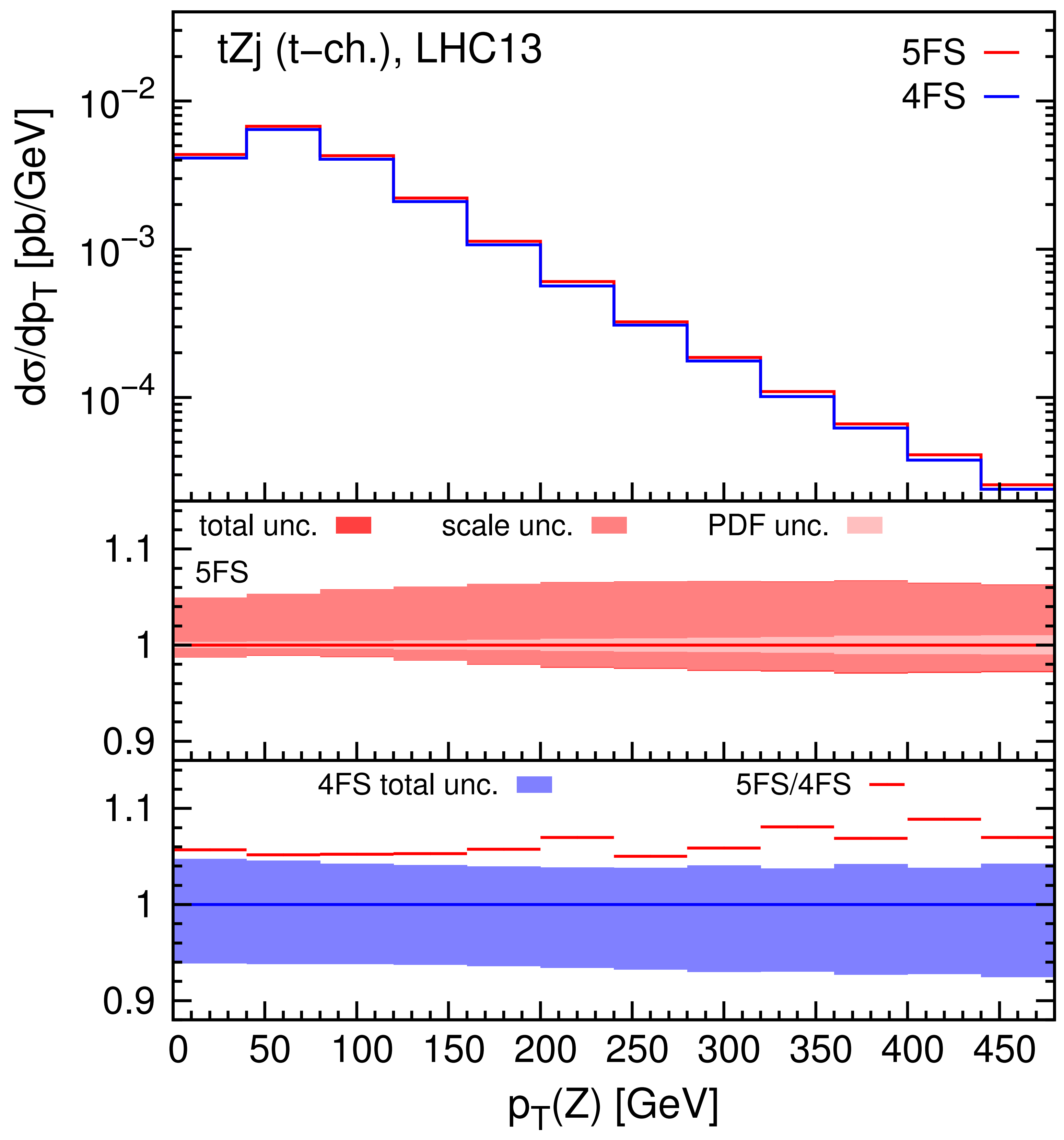
SM as a QFT leads to relations between observables of the three different sectors: EW, Top, Higgs.

Taken from "Precision Electroweak Measurements on the Z Resonance", hep-ex/0509008

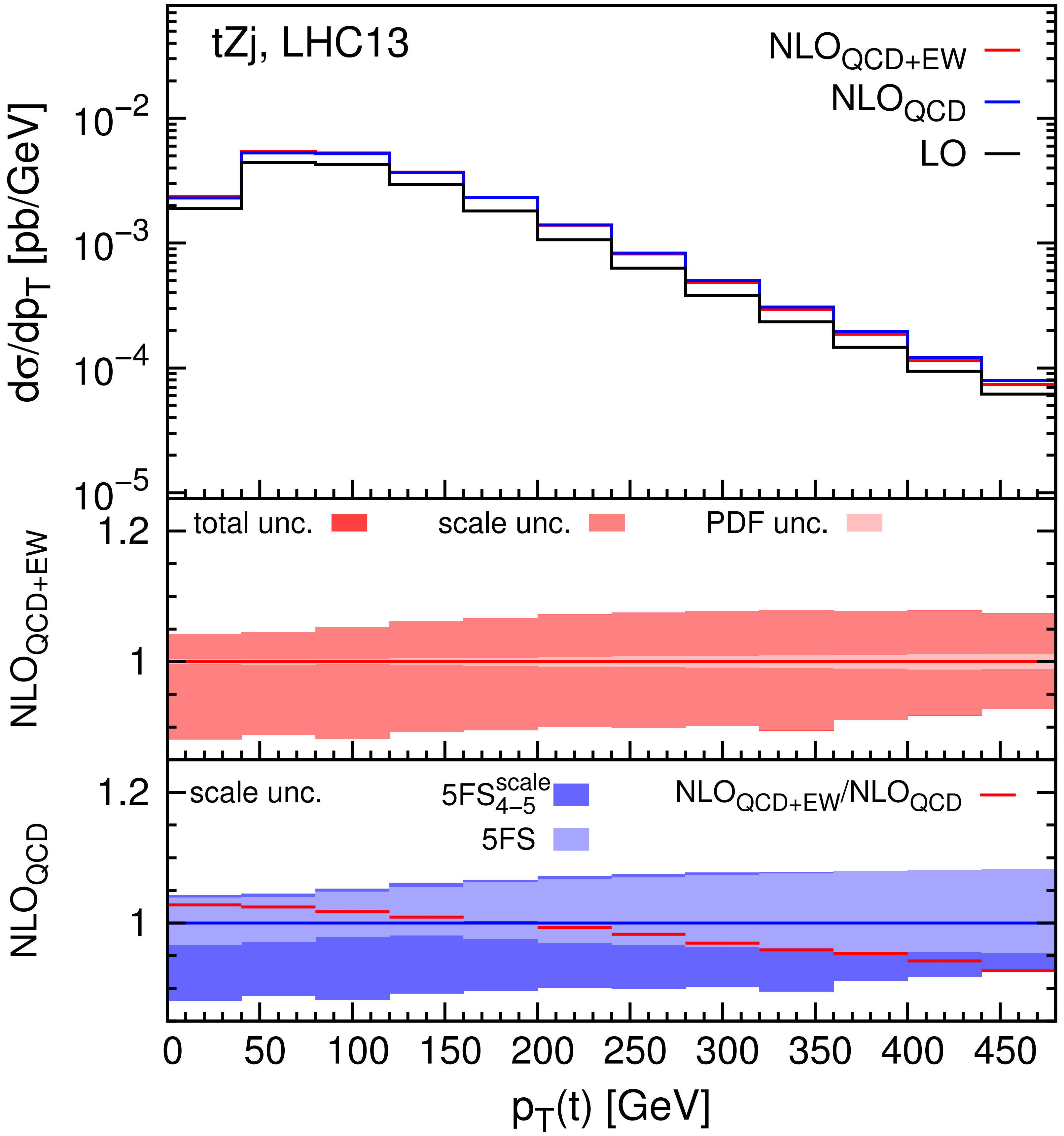
Scale variations



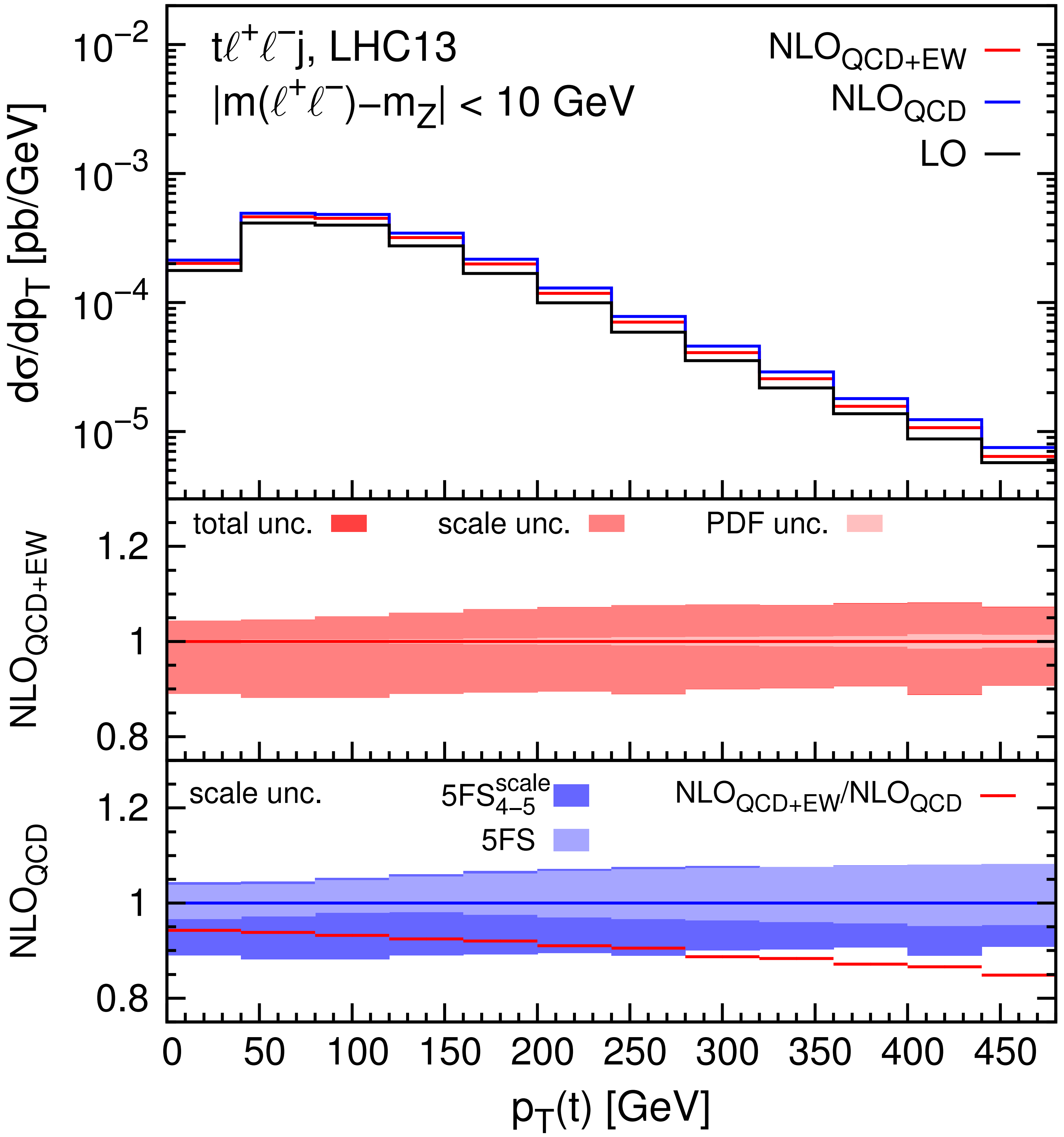
tZj



Differential distributions

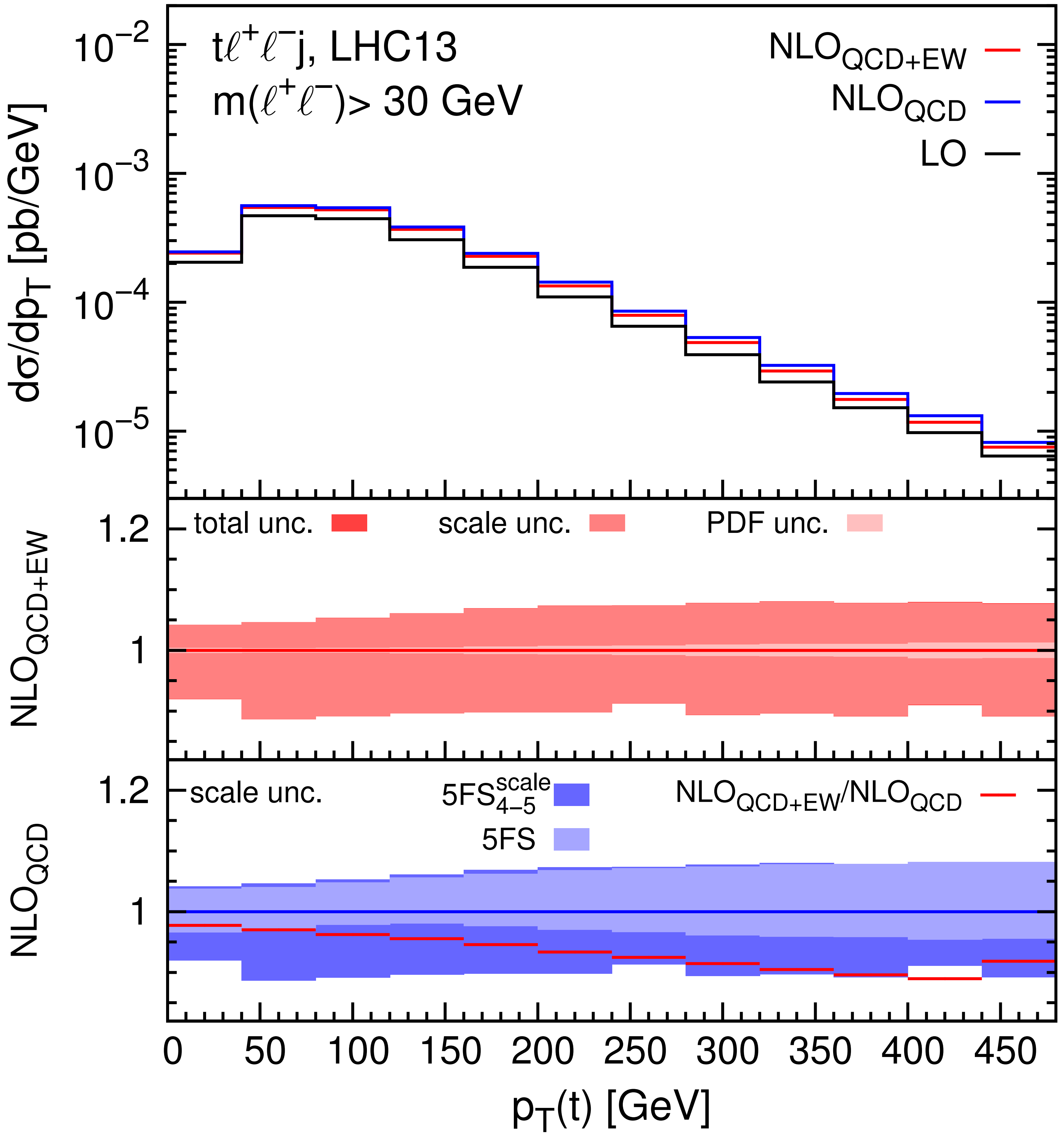


tZj



$t\ell^+\ell^-j$

peak

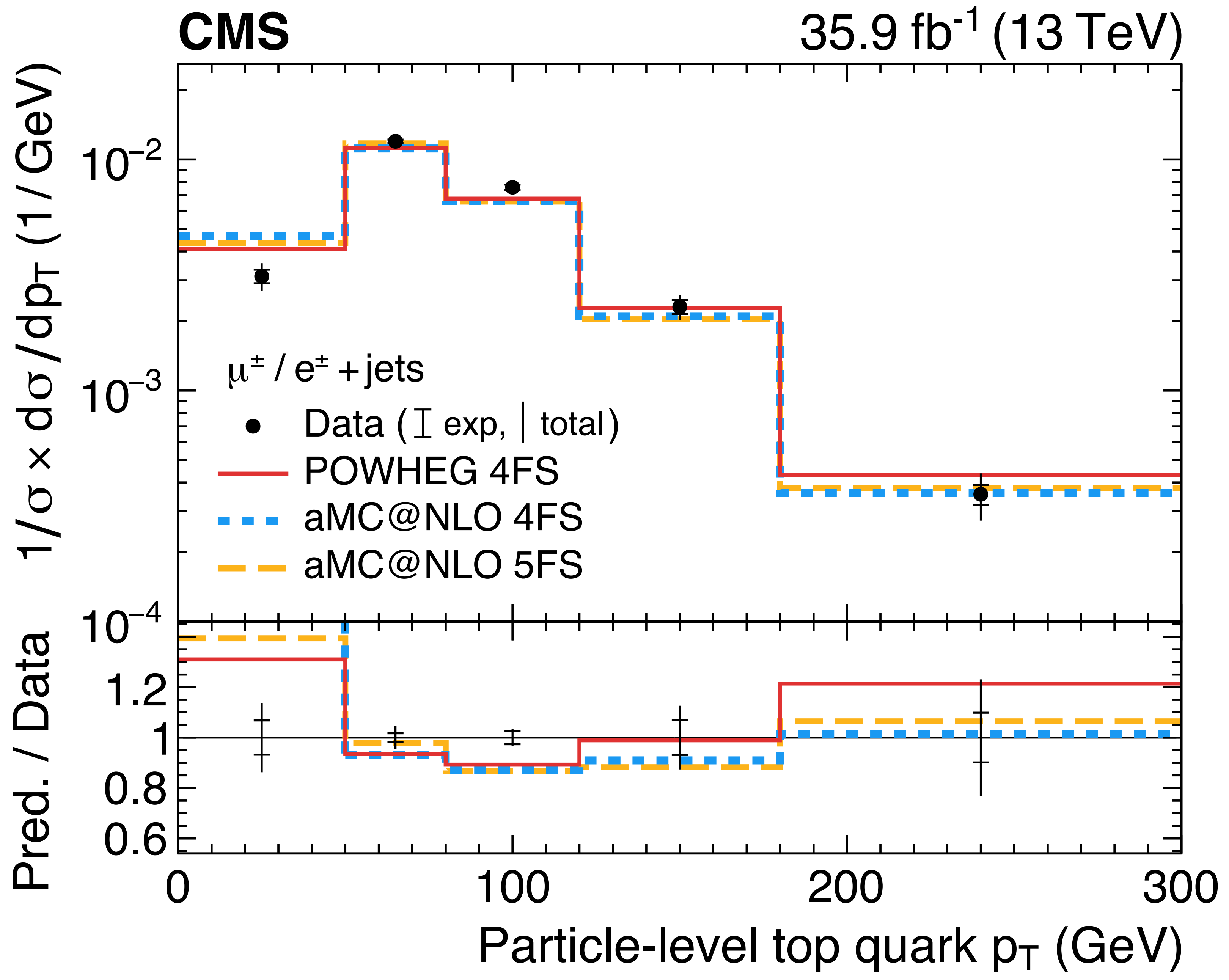


$t\ell^+\ell^-j$

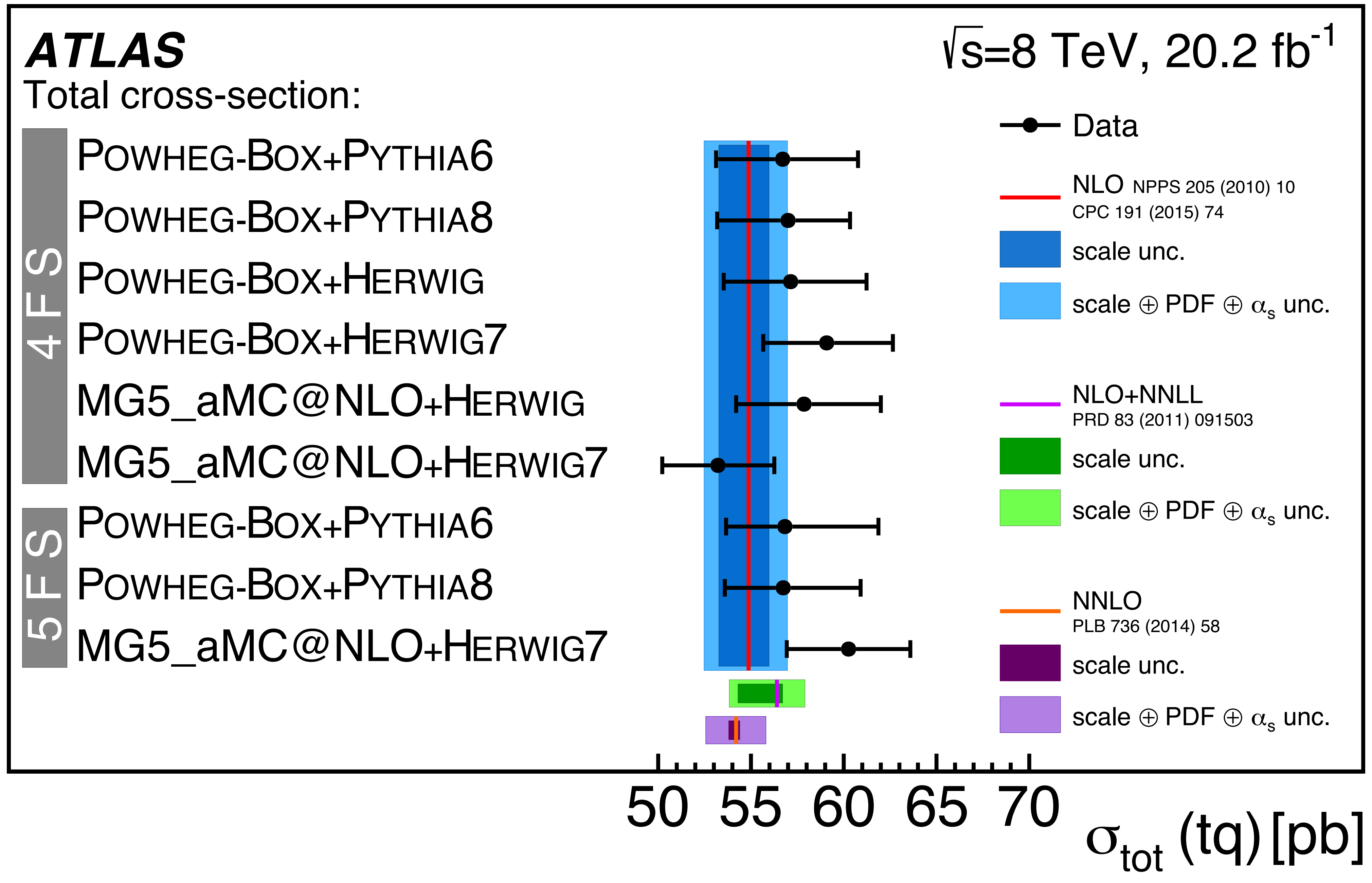
inclusive

Single-Top
(t-channel)

Measurements at the LHC



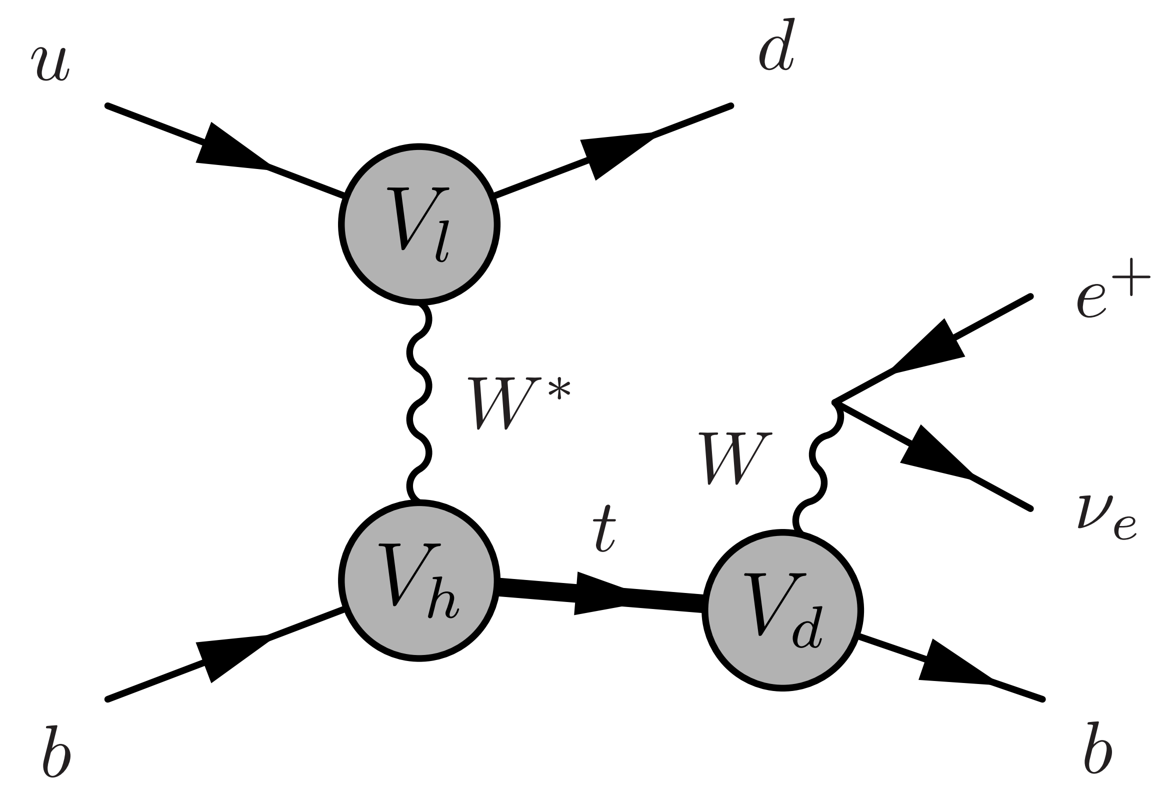
CMS-TOP-17-023



arXiv:1702.02859

- Differential distributions are already probed with precision.
- Extrapolation from fiducial region to the full phase space depends on the underlying theory prediction.

Production and decay at NNLO



fiducial [pb]		LO	NLO	NNLO
t quark	total	$4.07^{+7.6\%}_{-9.8\%}$	$2.95^{+4.1\%}_{-2.2\%}$	$2.70^{+1.2\%}_{-0.7\%}$
	corr. in pro.		-0.79	-0.24
	corr. in dec.		-0.33	-0.13
$\bar{t}$ quark	total	$2.45^{+7.8\%}_{-10\%}$	$1.78^{+3.9\%}_{-2.0\%}$	$1.62^{+1.2\%}_{-0.8\%}$
	corr. in pro.		-0.46	-0.15
	corr. in dec.		-0.21	-0.08

Berger, Gao, Zhu '17

Fiducial: exactly 2 jets of which one b-tagged.

$$D = 0.5,\ p_T(j) > 40 \text{ GeV}, |\eta(j)| < 5, |\eta(j_b)| < 2.4$$
$$p_T(\ell) > 40 \text{ GeV}, |\eta(\ell)| < 2.4$$

LO, NLO, NNLO do not overlap and scale unc. decrease.

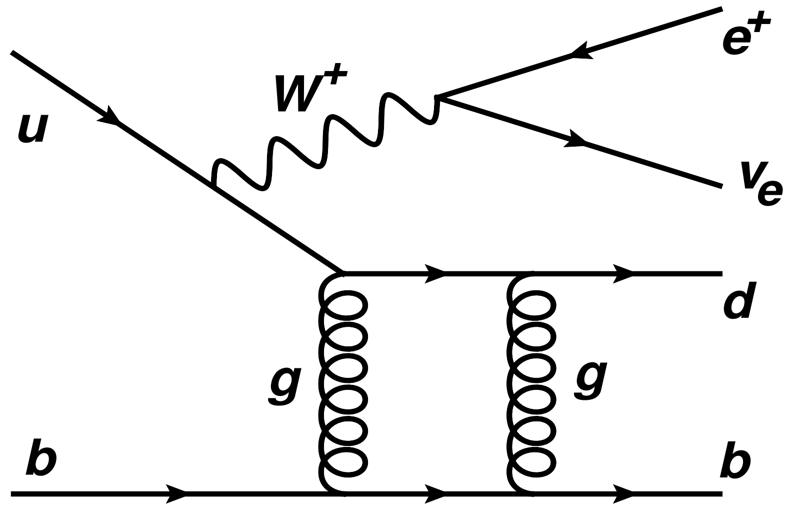
How much does it depend on the cut?
Are the EW corrections important?

Our study (fixed-order part)

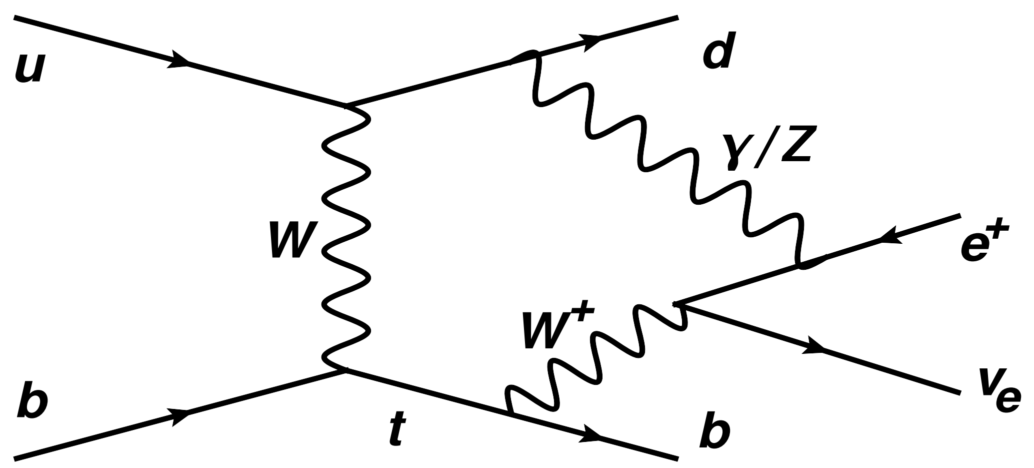
t-channel signature: $e^+,\ 1\text{ light jet},\ 1\ b\text{–jet},\ \not{E}_T$ and no additional jets

Complete NLO corrections to the $pp \to \nu_e JJJ$ **contribution to the t-channel signature, in the five-flavor-scheme.**

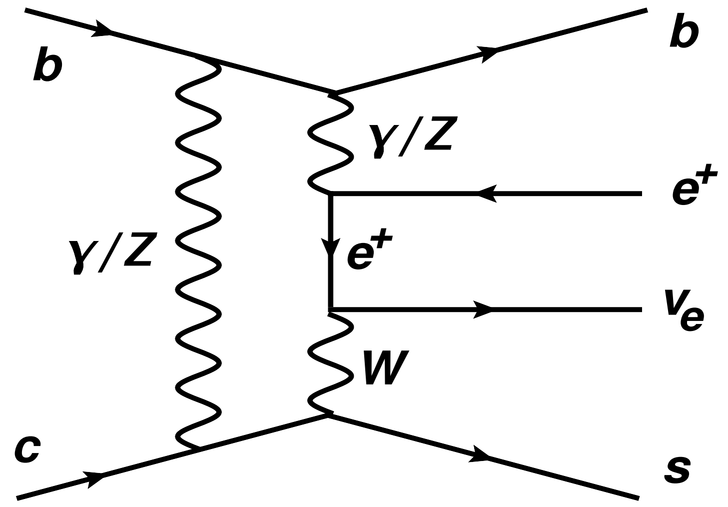
J is any particle that may potentially enter in a fully-democratic jet



W+jets

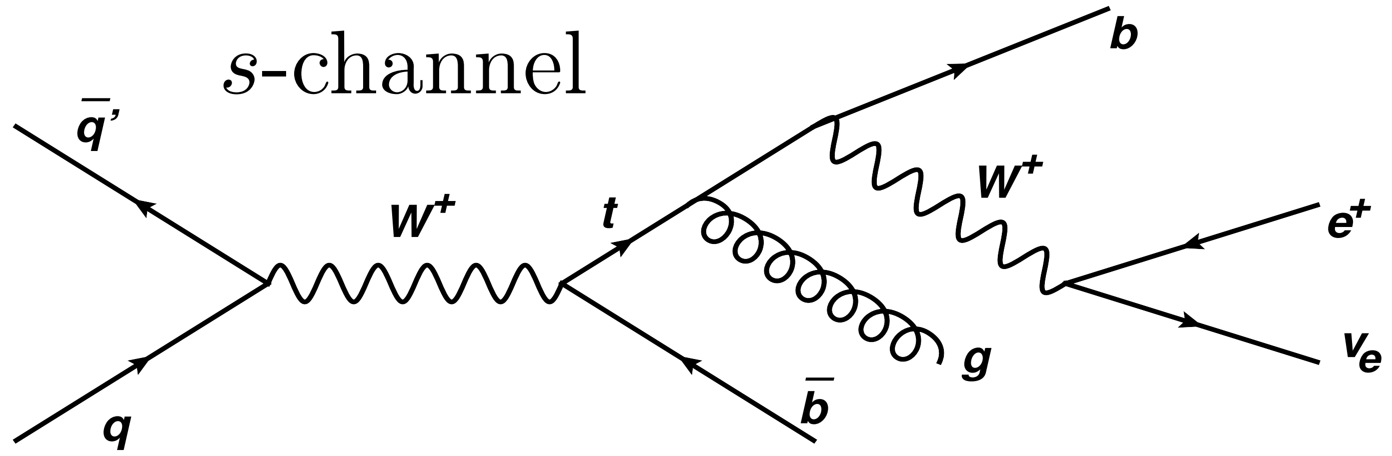


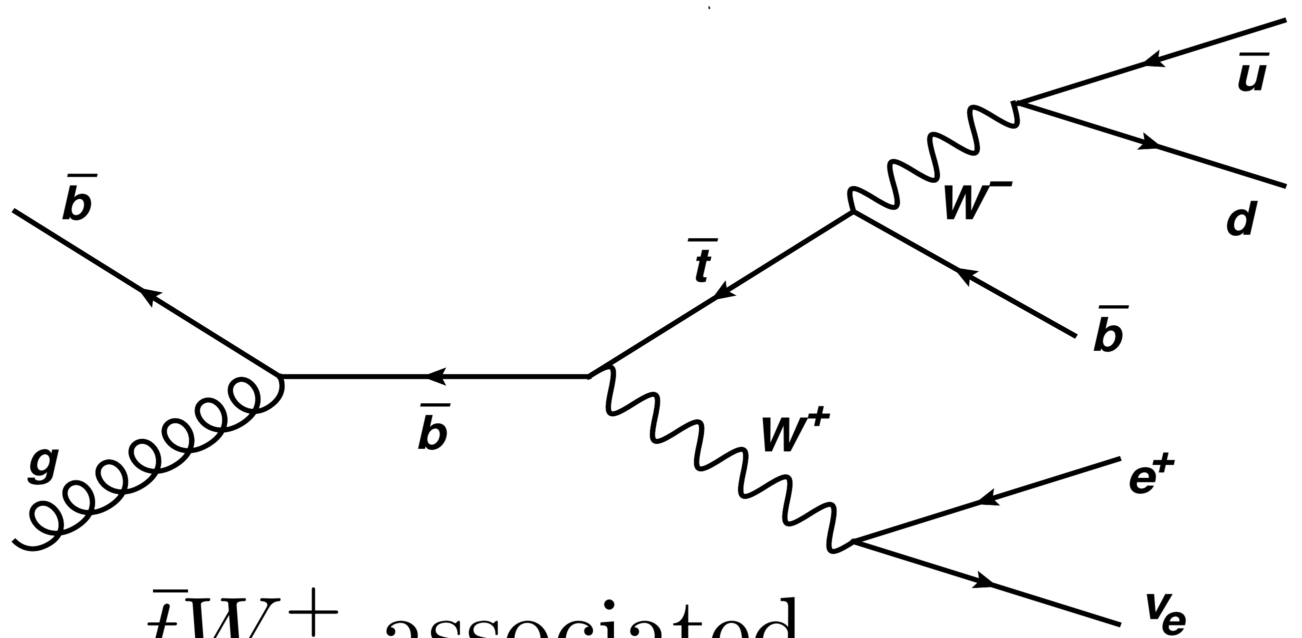
single-top



non-resonant

s-channel

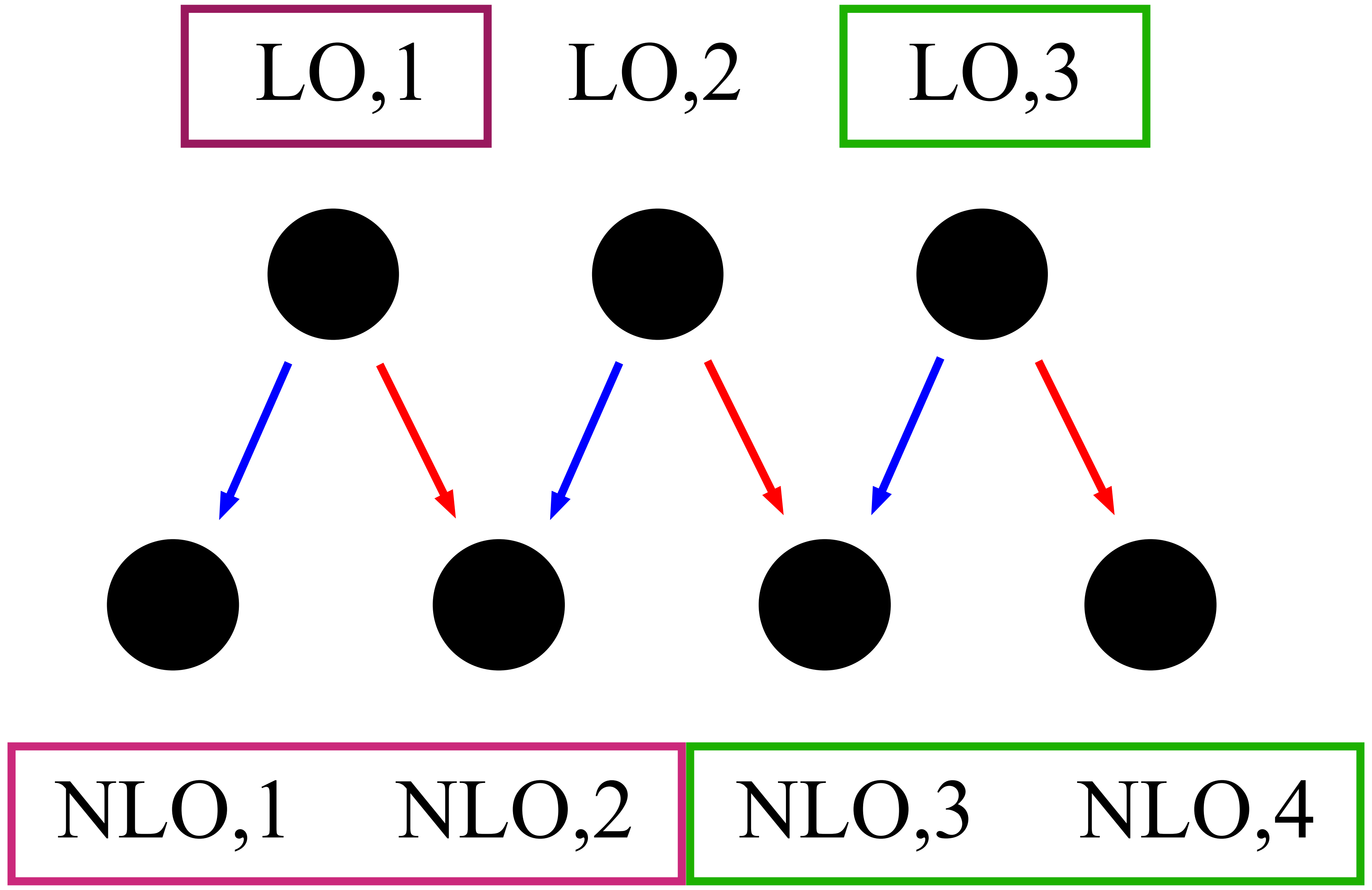




$\bar{t}W^+$-associated

Our study (fixed-order part)

$pp \to \nu_e JJJ$



Perturbative order	Resonant processes
LO_1 $(\alpha_s^2\alpha^2)$	W + 2 jets
LO_2 $(\alpha_s\alpha^3)$	-
LO_3 (α^4)	single-top (t- and s-ch.), WZ
NLO_1 $(\alpha_s^3\alpha^2)$	W + 2 jets
NLO_2 $(\alpha^2\alpha^3)$	W + 2 jets
NLO_3 $(\alpha_s\alpha^4)$	single-top (t- and s-ch.), WZ, tW, $\bar{t}W$ and $WW + b$-jet
NLO_4 (α^5)	single-top (t- and s-ch.), WZ, tW, $\bar{t}W$ and $WW + b$-jet

Single-Top $\longrightarrow$

$$\mathrm{LO} = \mathrm{LO}_3\,,$$
$$\mathrm{NLO\ QCD} = \mathrm{LO}_3 + \mathrm{NLO}_3\,,$$
$$\mathrm{NLO\ QCD+EW} = \mathrm{LO}_3 + \mathrm{NLO}_3 + \mathrm{NLO}_4\,,$$

W + jets $\longrightarrow$

$$\mathrm{LO} = \mathrm{LO}_1(+\mathrm{LO}_2)\,,$$
$$\mathrm{NLO\ QCD} = \mathrm{LO}_1 + \mathrm{NLO}_1\,,$$
$$\mathrm{NLO\ QCD+EW} = \mathrm{LO}_1 + \mathrm{NLO}_1 + \mathrm{NLO}_2\,,$$

Inclusive results

Calculation performed with MadGraph5_aMC@NLO

Single-Top	cross section
LO	$4.623(1)^{+0.415(+9.0\%)}_{-0.533(-11.5\%)}$ pb
NLO QCD	$2.762(6)^{+0.226(+8.2\%)}_{-0.240(-8.7\%)}$ pb
NLO QCD+EW	$2.676(6)^{+0.229(+8.6\%)}_{-0.236(-8.8\%)}$ pb
(NLO QCD)/LO	0.60(1)
(NLO QCD+EW)/(NLO QCD)	0.97(1)

W+jets	cross section
LO	$0.7656(6)^{+0.3002(+39.2\%)}_{-0.2265(-29.6\%)}$ pb
NLO QCD	$1.612(3)^{+0.323(+20.1\%)}_{-0.309(-19.2\%)}$ pb
NLO QCD+EW	$1.597(3)^{+0.318(+19.9\%)}_{-0.305(-19.1\%)}$ pb
(NLO QCD)/LO	2.11(1)
(NLO QCD+EW)/(NLO QCD)	0.99(1)

t-channel signature (details):

$\Delta R^{\text{QCD}} = 0.4$ and $p_{T,\min}^{\text{QCD}} = 30$ GeV

$|\eta(j)| > 2.5$ a jet is always considered as a light jet

$\Delta R^{\text{QED}} = 0.1$

- exactly one lepton: $|\eta(\ell)| < 2.5$ and $p_T(\ell) > 25$ GeV
- exactly one light jet: $|\eta(j_l)| < 4.5$ and $p_T(j_l) > 30$ GeV,
- exactly one b-jet: $|\eta(j_b)| < 2.5$ and $p_T(j_b) > 30$ GeV,
- missing transverse-energy: $\not{E}_T > 30$ GeV,
- positron and jets separation: $\Delta R(e^+, \ell) > 0.4$,
- positron and b-jet system: $m(e^+ j_b) < 160$ GeV,

In Single-Top scale uncertainties do not decrease from LO to NLO —> 1st sign that shower effects are necessary! Reason: jet-veto

Inclusive results

Calculation performed with MadGraph5_aMC@NLO

Single-Top	cross section
LO	$4.623(1)^{+0.415(+9.0\%)}_{-0.533(-11.5\%)}$ pb
NLO QCD	$2.762(6)^{+0.226(+8.2\%)}_{-0.240(-8.7\%)}$ pb
NLO QCD+EW	$2.676(6)^{+0.229(+8.6\%)}_{-0.236(-8.8\%)}$ pb
(NLO QCD)/LO	0.60(1)
(NLO QCD+EW)/(NLO QCD)	0.97(1)

W+jets	cross section
LO	$0.7656(6)^{+0.3002(+39.2\%)}_{-0.2265(-29.6\%)}$ pb
NLO QCD	$1.612(3)^{+0.323(+20.1\%)}_{-0.309(-19.2\%)}$ pb
NLO QCD+EW	$1.597(3)^{+0.318(+19.9\%)}_{-0.305(-19.1\%)}$ pb
(NLO QCD)/LO	2.11(1)
(NLO QCD+EW)/(NLO QCD)	0.99(1)

t-channel signature (details):

$\Delta R^{\rm QCD} = 0.4$ and $p_{T,\rm min}^{\rm QCD} = 30$ GeV

$|\eta(j)| > 2.5$ a jet is always considered as a light jet

$\Delta R^{\rm QED} = 0.1$

- exactly one lepton: $|\eta(\ell)| < 2.5$ and $p_T(\ell) > 25$ GeV
- exactly one light jet: $|\eta(j_l)| < 4.5$ and $p_T(j_l) > 30$ GeV,
- exactly one b-jet: $|\eta(j_b)| < 2.5$ and $p_T(j_b) > 30$ GeV,
- missing transverse-energy: $\not{E}_T > 30$ GeV,
- positron and jets separation: $\Delta R(e^+, \ell) > 0.4$,
- positron and b-jet system: $m(e^+ j_b) < 160$ GeV,

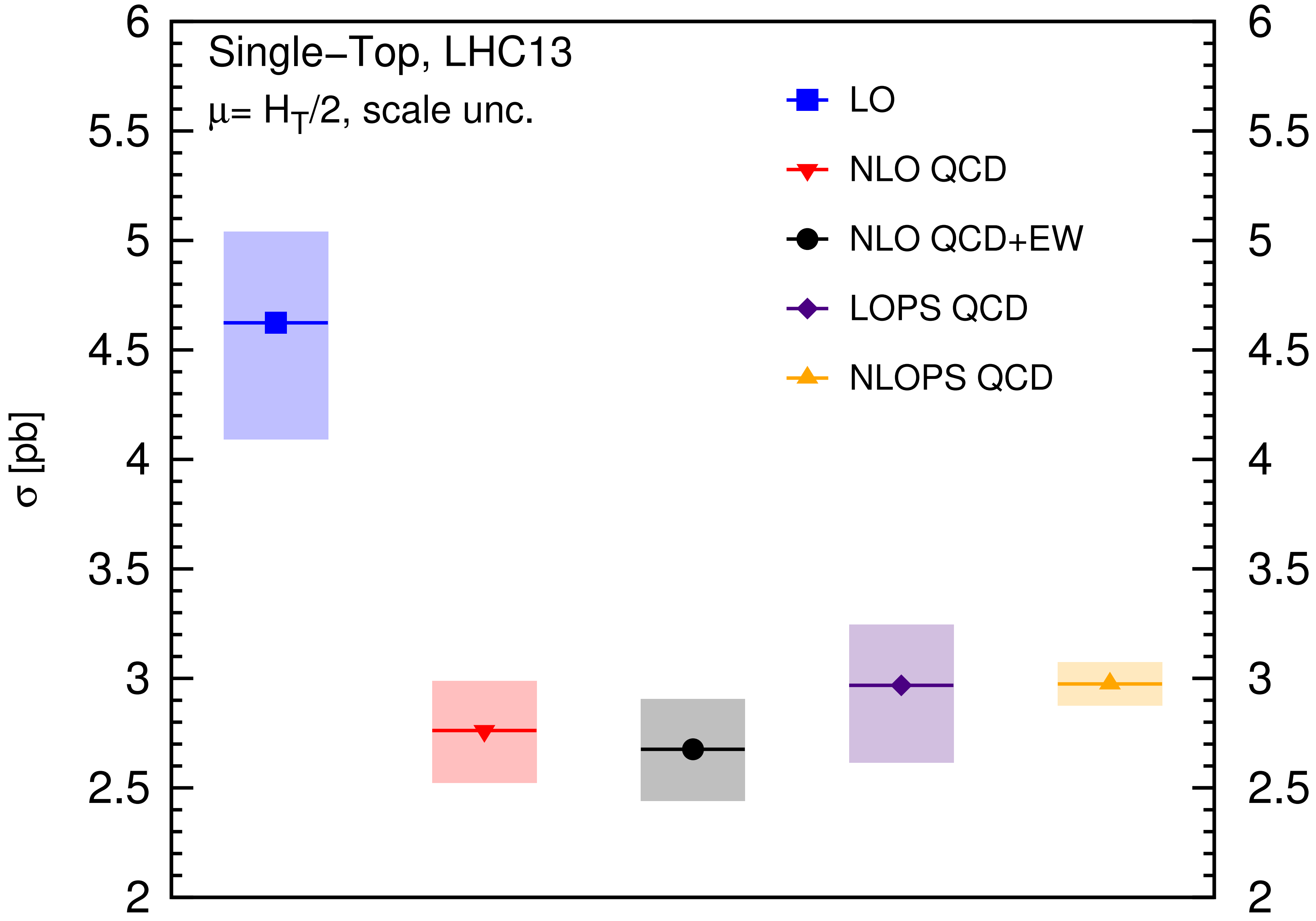
W+jets: g->bb splittings convert $e^+\nu_e gg$ events into $e^+\nu_e g b\bar{b}$.
Only the latter contribute to the signature —> large corrections.

Inclusive results

Calculation performed with MadGraph5_aMC@NLO (QCD)

Single-Top

Single-Top	cross section
LO	$4.623(1)^{+0.415(+9.0\%)}_{-0.533(-11.5\%)}$ pb
LOPS QCD	$2.968(3)^{+0.28(+9.3\%)}_{-0.35(-11.9\%)}$ pb
NLO QCD	$2.762(6)^{+0.226(+8.2\%)}_{-0.240(-8.7\%)}$ pb
NLOPS QCD	$2.974(9)^{+0.098(+3.3\%)}_{-0.098(-3.3\%)}$ pb
(NLOPS QCD)/(LOPS QCD)	1.00(1)
(LOPS QCD)/LO	0.64(1)
(NLOPS QCD)/(NLO QCD)	1.08(1)



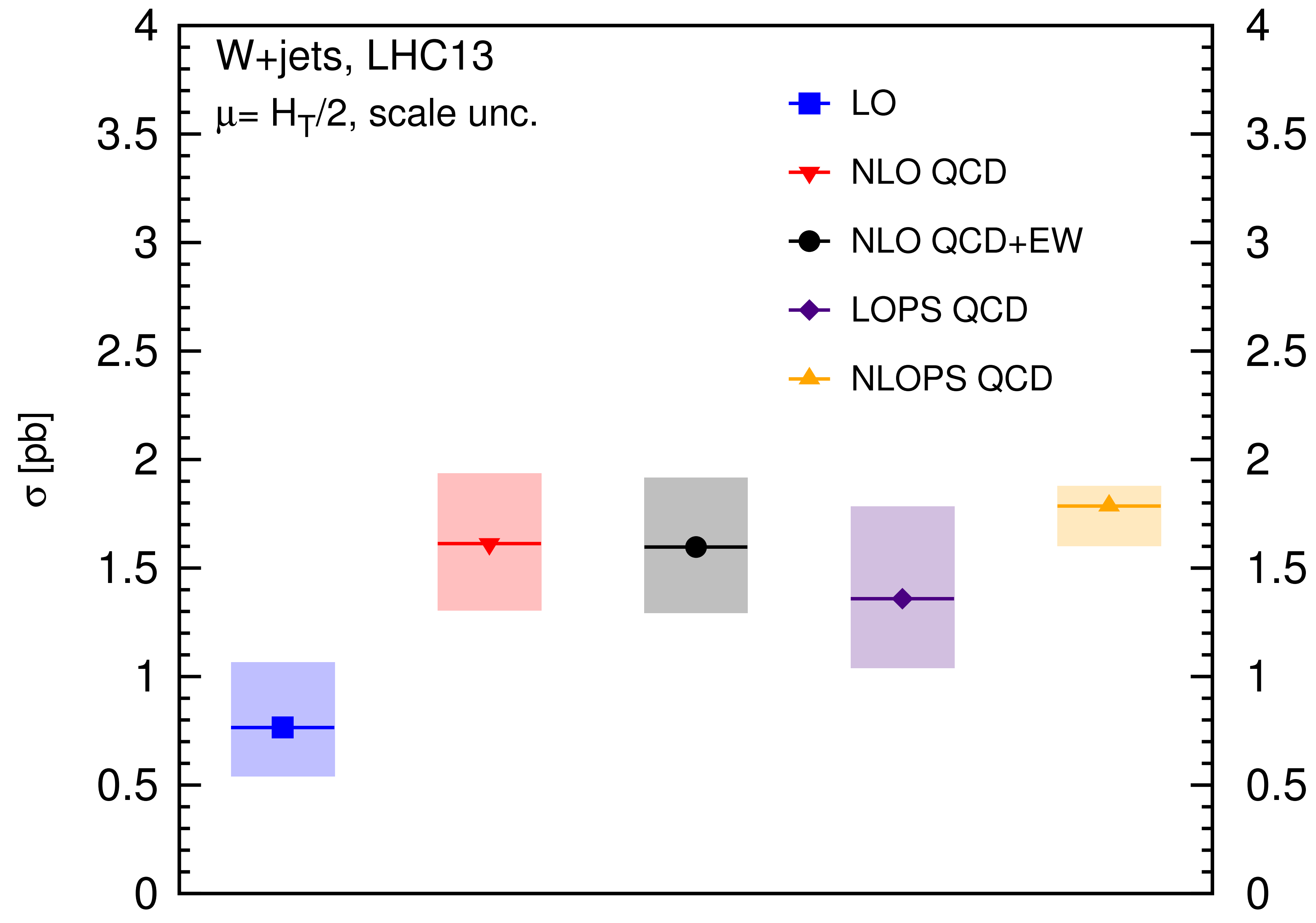
LO is completely off. From LOPS to NLOPS we do see a reduction of scale unc. to 3%, i.e., the same size of NLO EW corrections. ***QCD+EW+PS would be desirable already at inclusive level.***

Inclusive results

Calculation performed with MadGraph5_aMC@NLO (QCD)

W+jets

W+jets	cross section
LO	$0.7656(6)^{+0.3002(+39.2\%)}_{-0.2265(-29.6\%)}$ pb
LOPS QCD	$1.36(2)^{+0.42(+31.1\%)}_{-0.32(-23.6\%)}$ pb
NLO QCD	$1.612(3)^{+0.323(+20.1\%)}_{-0.309(-19.2\%)}$ pb
NLOPS QCD	$1.79(5)^{+0.09(+5.1\%)}_{-0.18(-10.3\%)}$ pb
(NLOPS QCD)/(LOPS QCD)	1.31(4)
(LOPS QCD)/LO	1.78(3)
(NLOPS QCD)/(NLO QCD)	1.11(3)



LO is again off. From LOPS to NLOPS we see a reduction of scale uncertainties.

QCD+EW+PS seems not necessary for W+jets.