Single-top rates at 100 TeV

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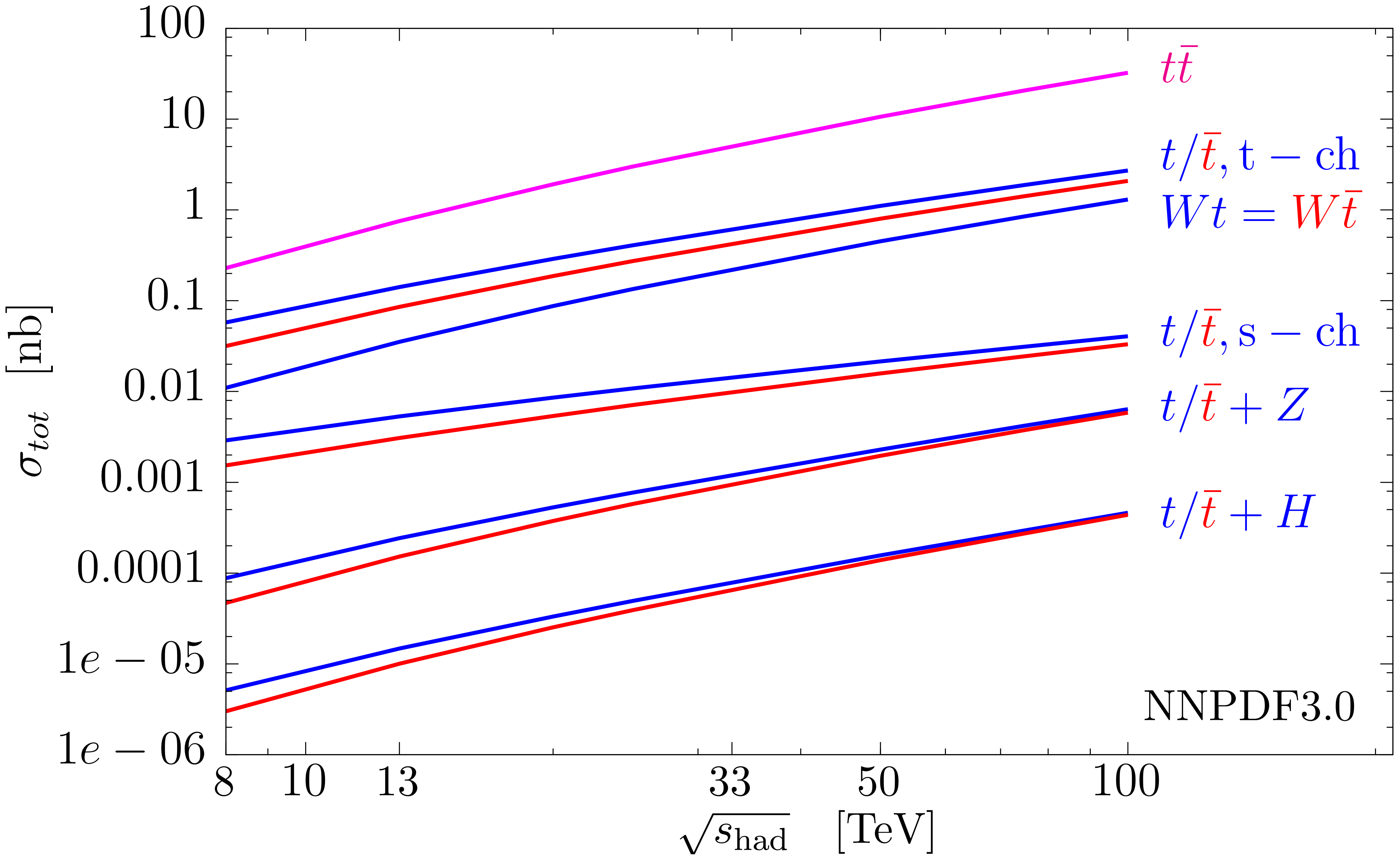
QCD, EW and Tools at 100 TeV, CERN, Oct. 7th 2015

Total rates: overview



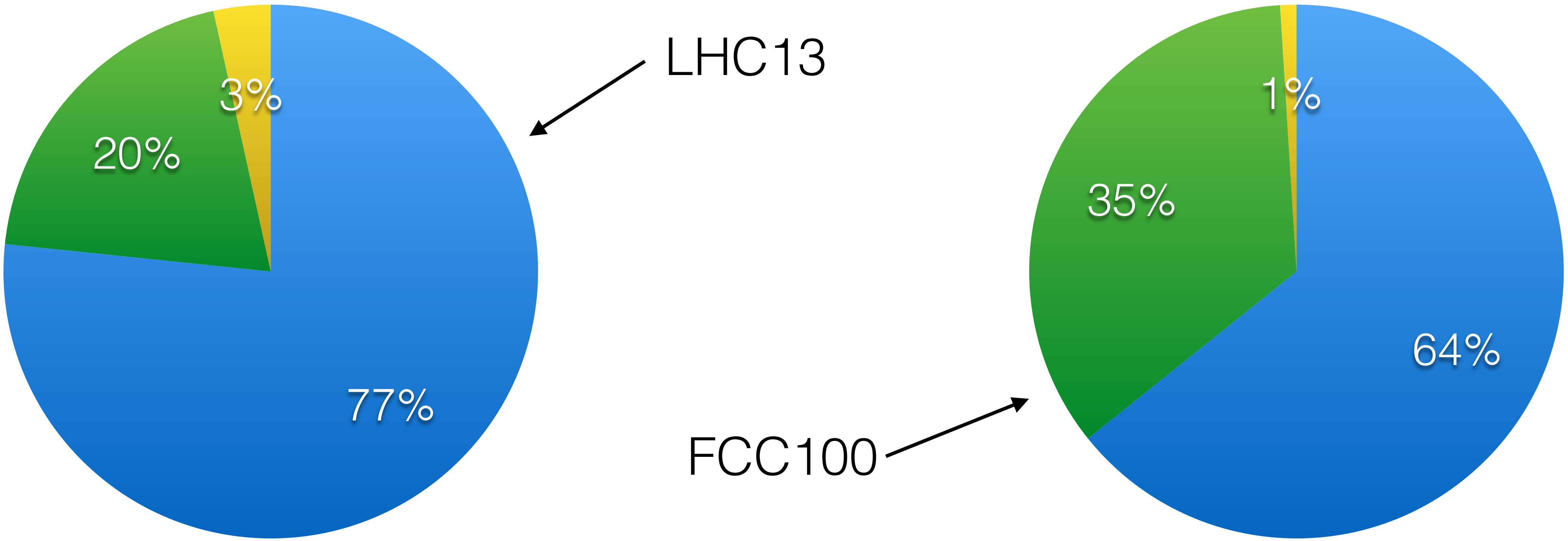
~40
~20
~35

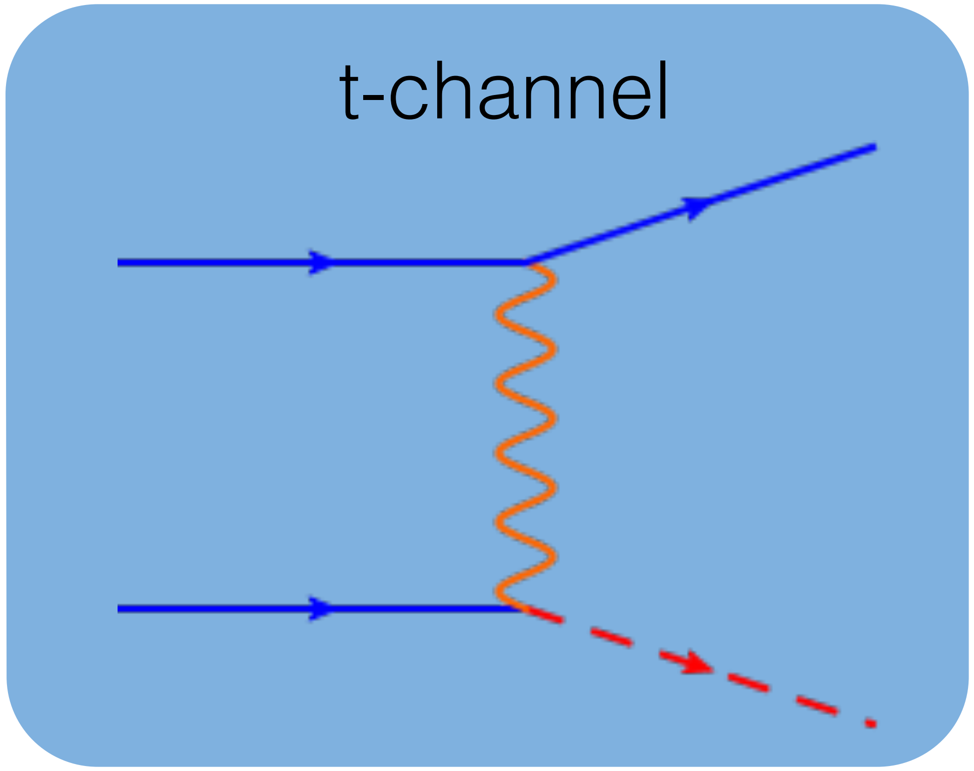
~10
~25
~30

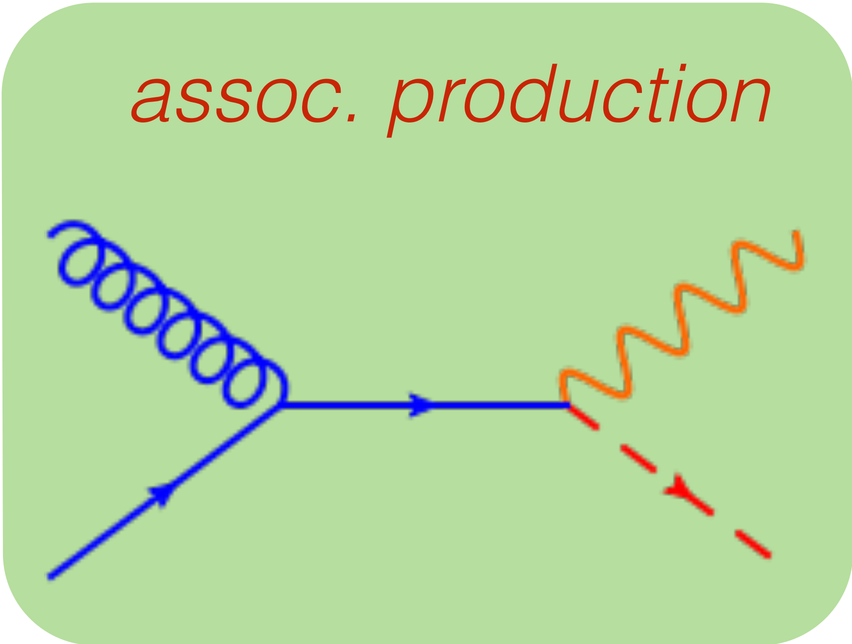
Ratios 100/13

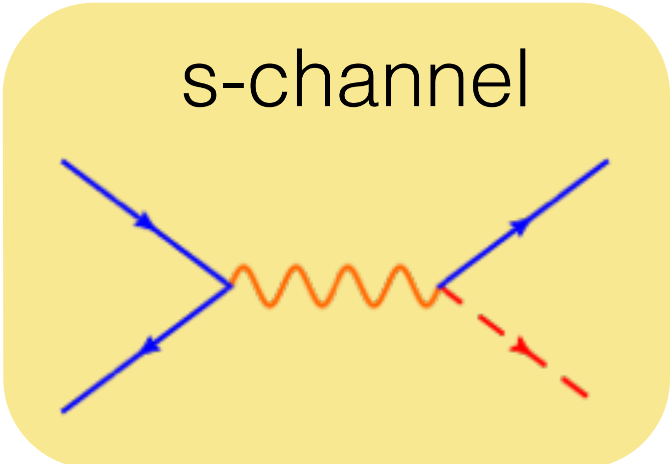
- top processes: NLO, from MCFM / Hathor / MadGraph5_aMC@NLO. 5FNS, m_t = 172.5 GeV
- t+Z/H: LO, from MCFM

Single-top: composition



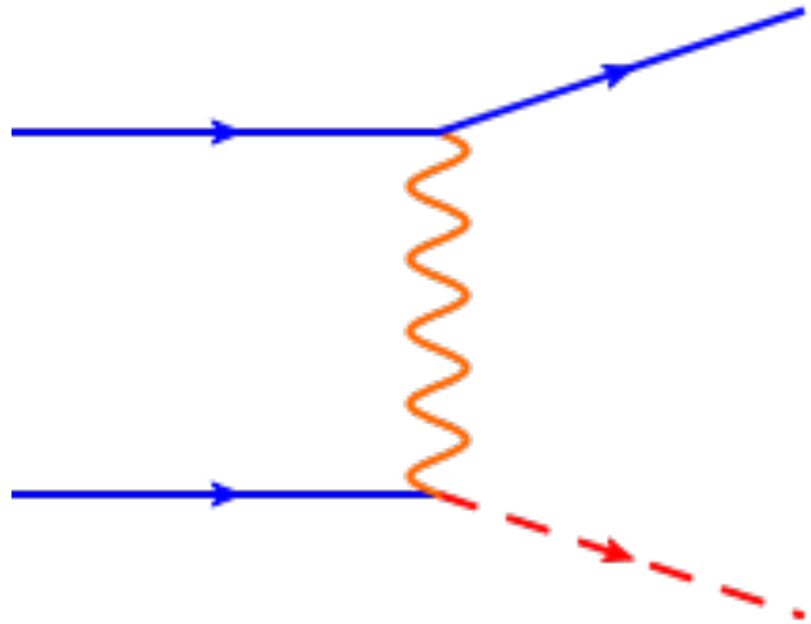






t-channel single-top

NNLO, 5FNS, total rates



$$\sigma^{t}_{\rm NNLO}(13\ {\rm TeV}) = 0.14\ [{\rm nb}]$$

$$\sigma^{t}_{\rm NNLO}(100\ {\rm TeV}) = 2.6\ [{\rm nb}]$$

x20

$$\sigma^{\bar{t}}_{\rm NNLO}(13\ {\rm TeV}) = 0.08\ [{\rm nb}]$$

$$\sigma^{\bar{t}}_{\rm NNLO}(100\ {\rm TeV}) = 2.0\ [{\rm nb}]$$

x25

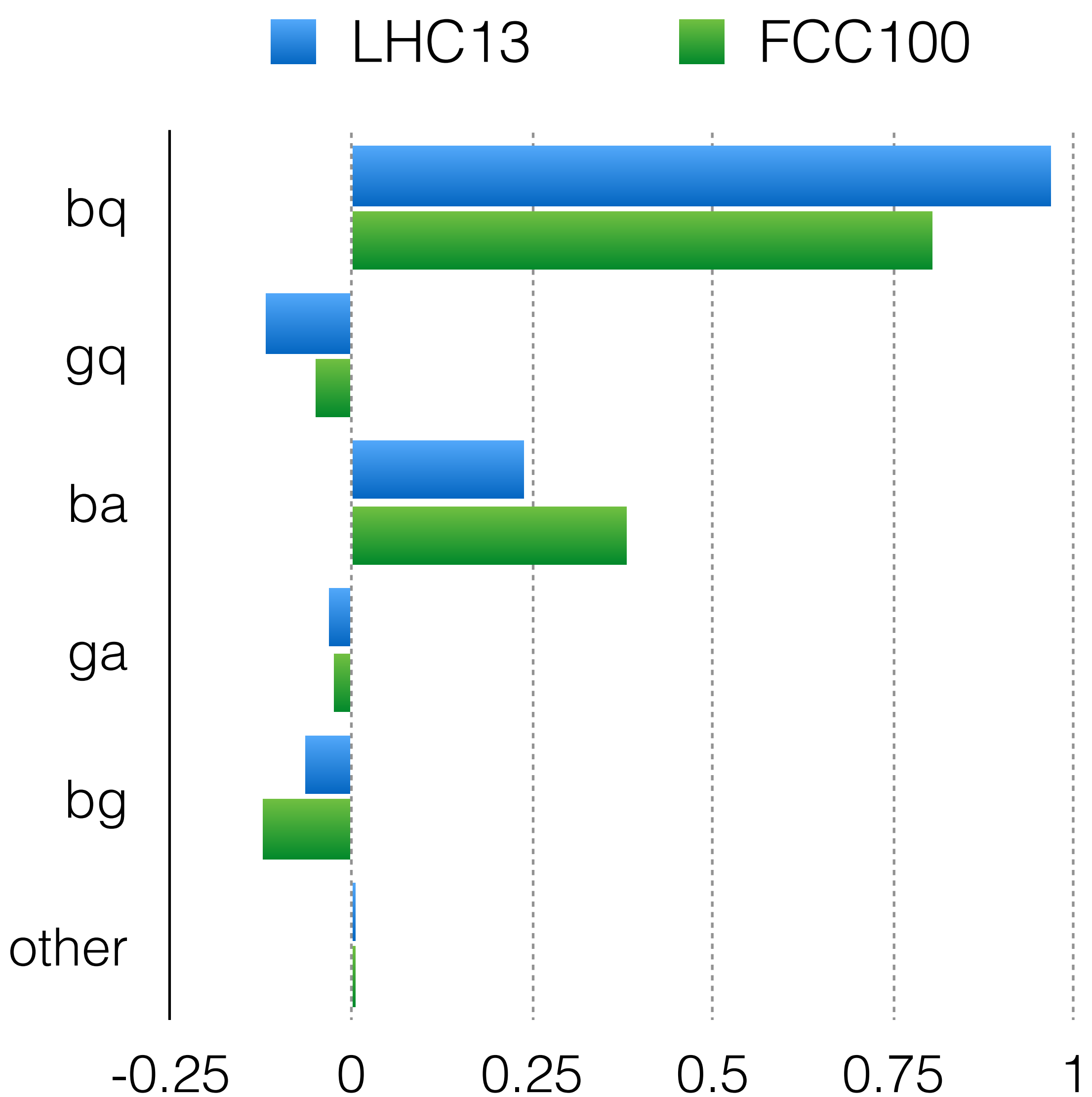
Backgrounds:

- tt -> x40
- W+jets -> x15

t-channel single-top

$$\sigma^t_{\mathrm{NNLO}}(13\ \mathrm{TeV}) = 0.14\ [\mathrm{nb}]$$

$$\sigma^t_{\mathrm{NNLO}}(100\ \mathrm{TeV}) = 2.6\ [\mathrm{nb}]$$



Flavor separation, $\mu_F = m_t$

- gluon growth
- diff. valence/sea less relevant

Main uncertainties

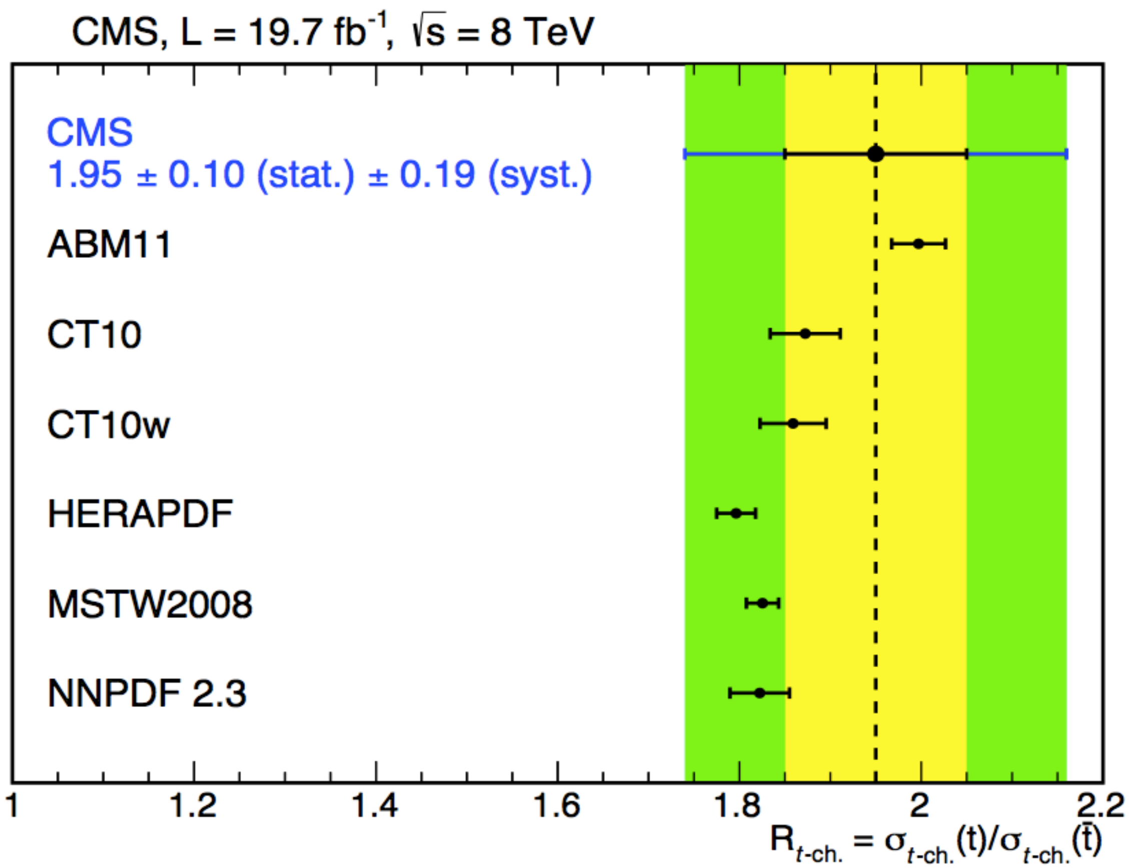
	LHC13	FCC100
Scale	~1%	~2%
PDF_{NNPDF}	~1%	~2%
$m_{b,PDF}$	~4%	~3%
m_t	~1%	~1%

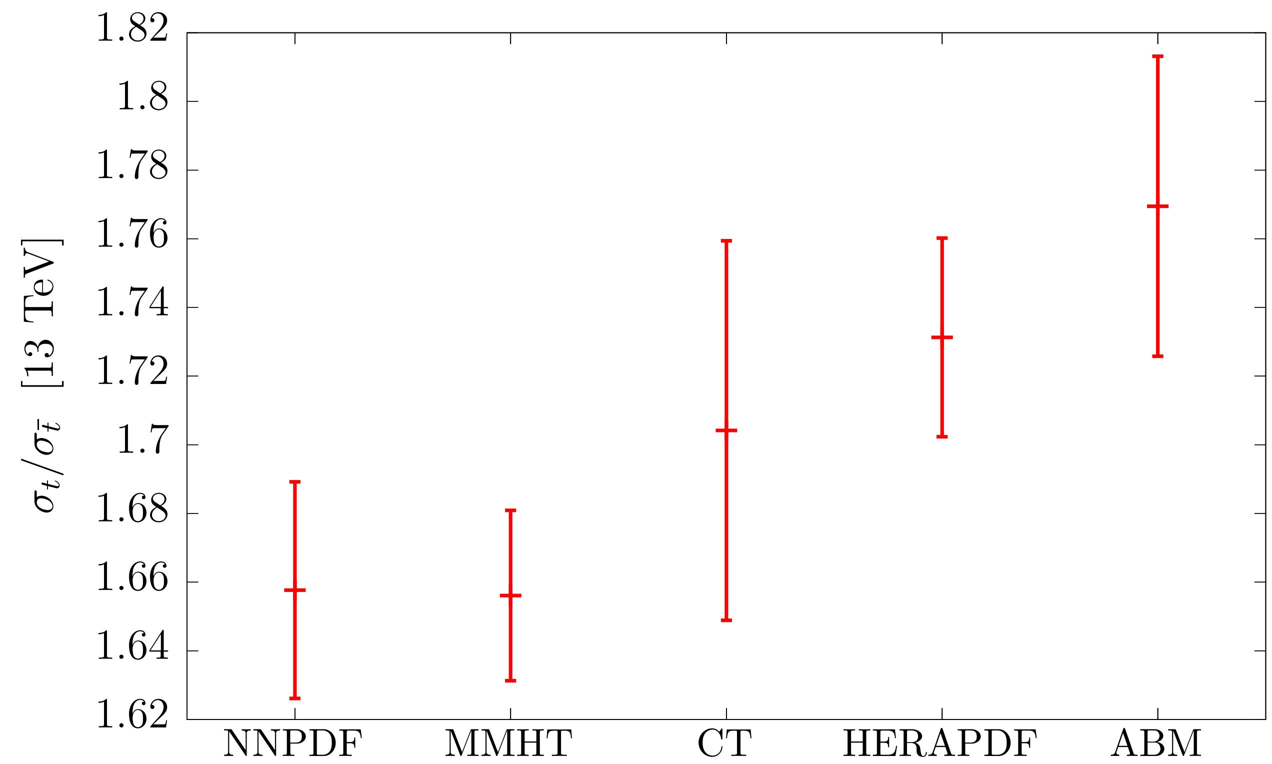
Parametric uncertainty dominates

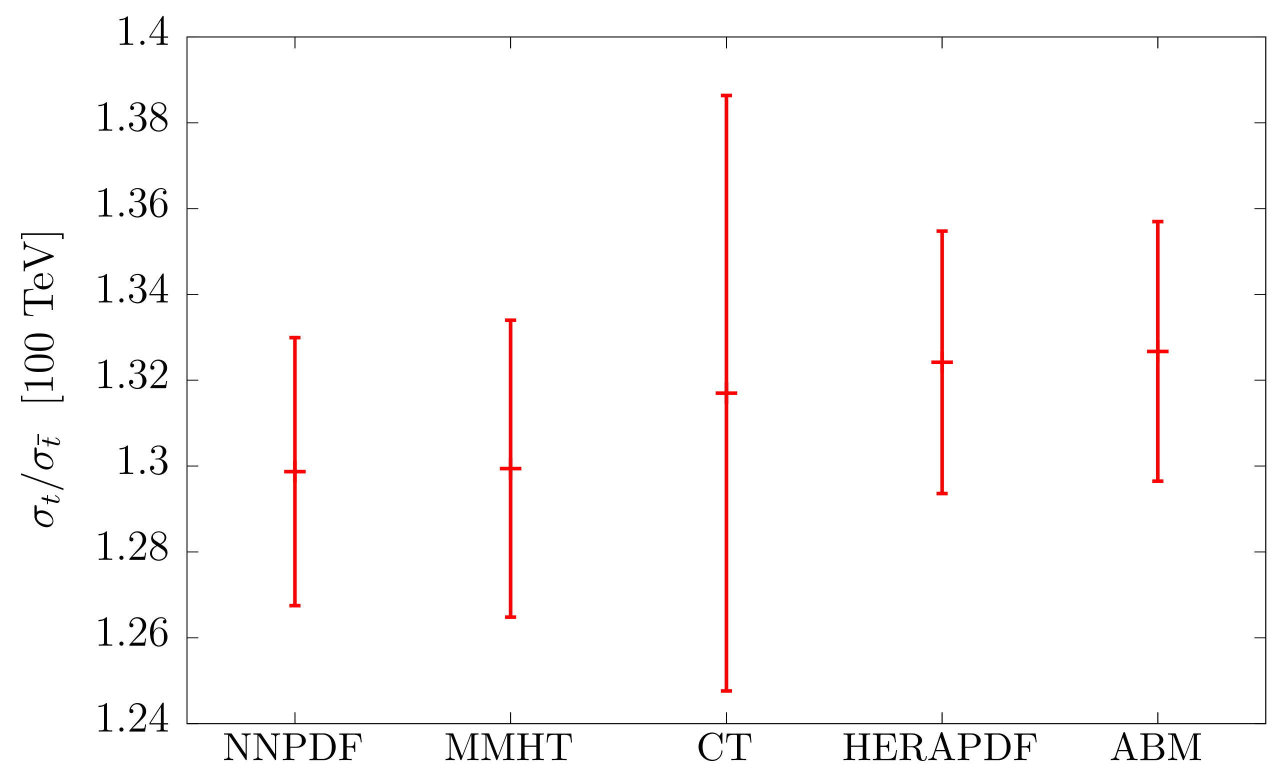
t-channel: top/anti-top ratio

Top/anti-top ratio very stable

-> discriminant for PDF





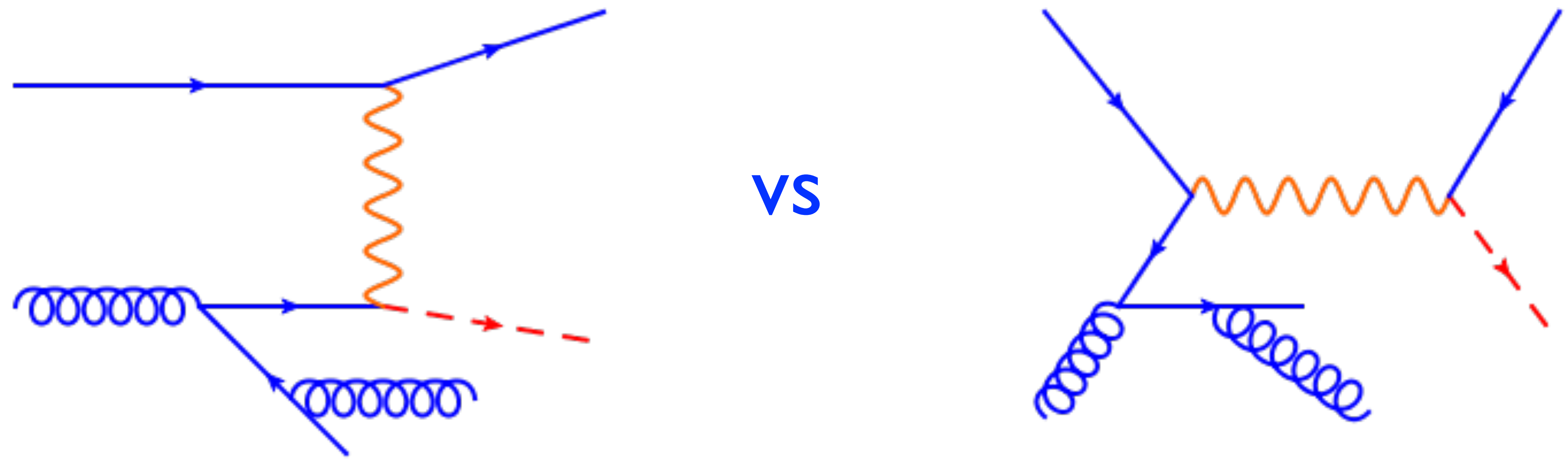


With the new sets,

VERY GOOD AGREEMENT

(especially at 100 TeV)

t-channel: s/t interferences?



In principle:

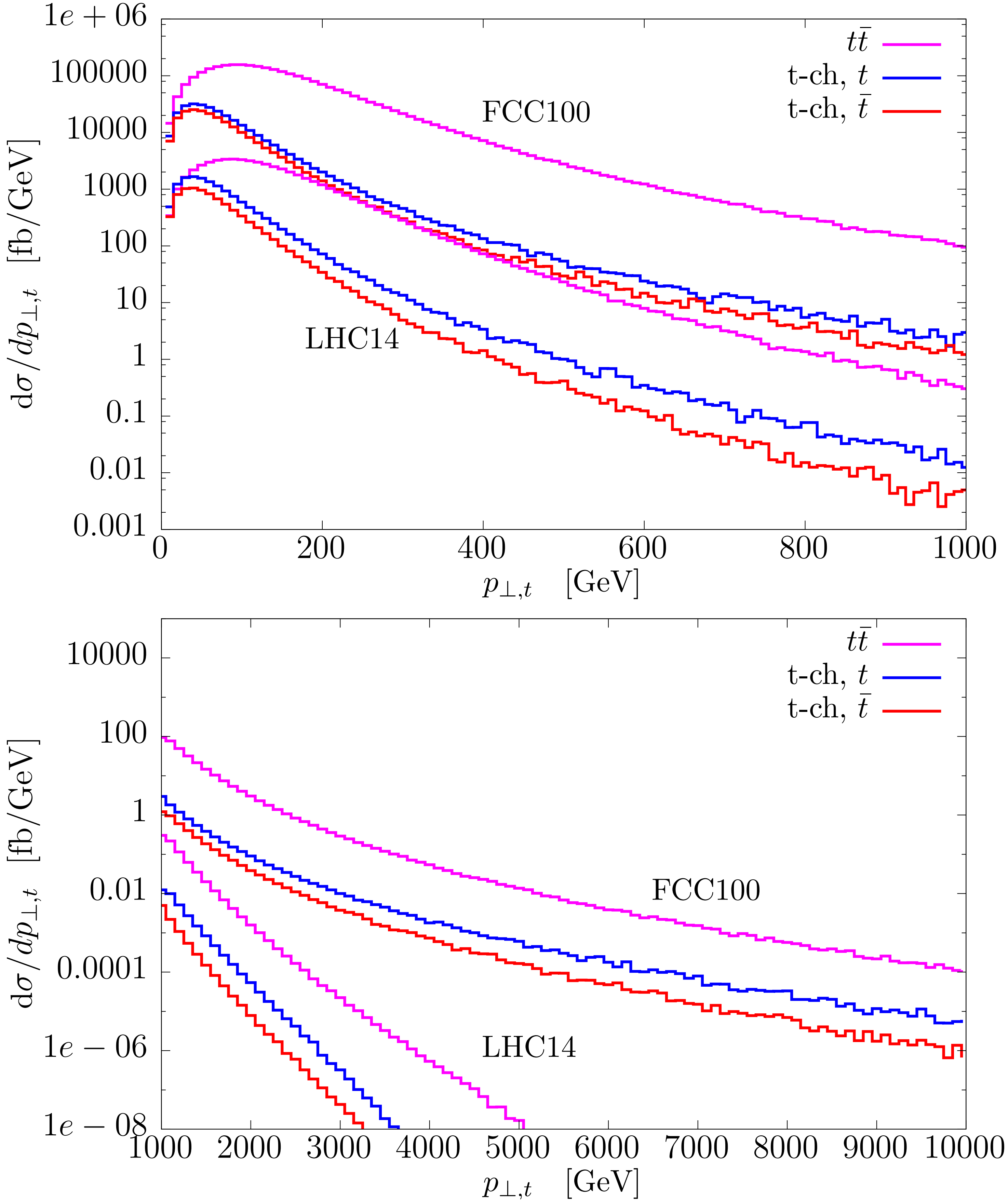
- beyond LO, t- and s- channels same initial/final states -> interferences, no well-defined distinction

However in practice:

- thanks to color, interference starts at NNLO (5FNS)
- strongly suppressed (color/kinematics)

Given the slow growth of the s-channel with collider energy, EVEN LESS A PROBLEM AT 100 TEV

t-channel: p_t dependence

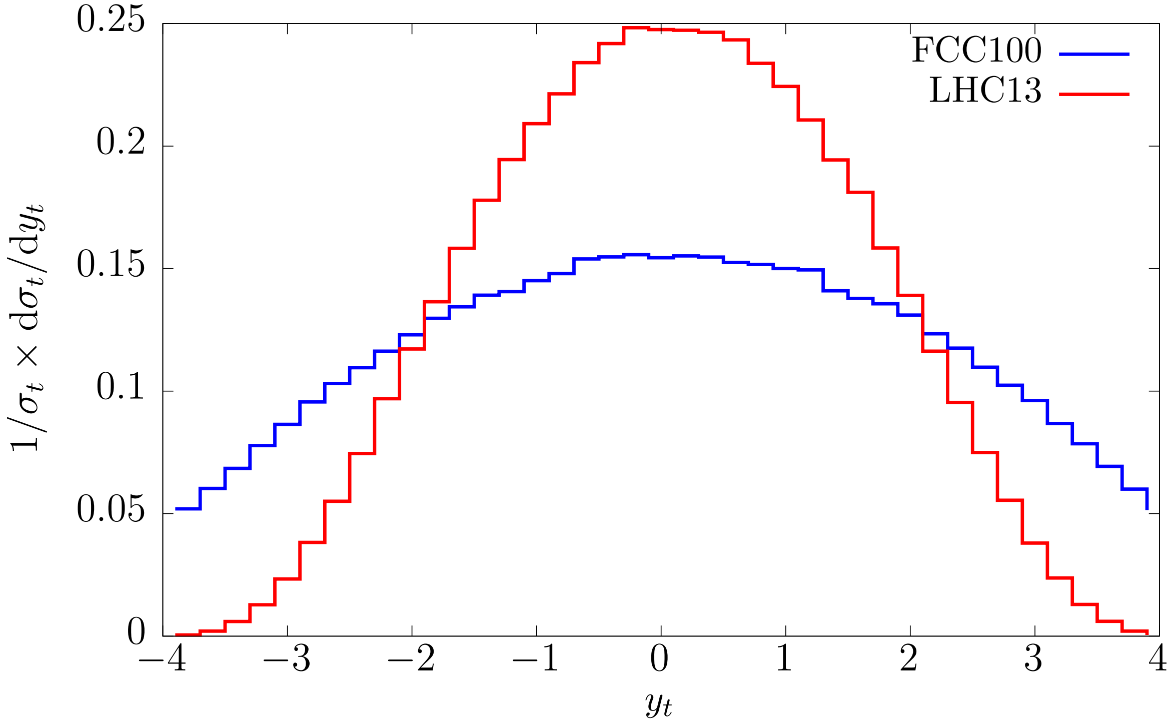


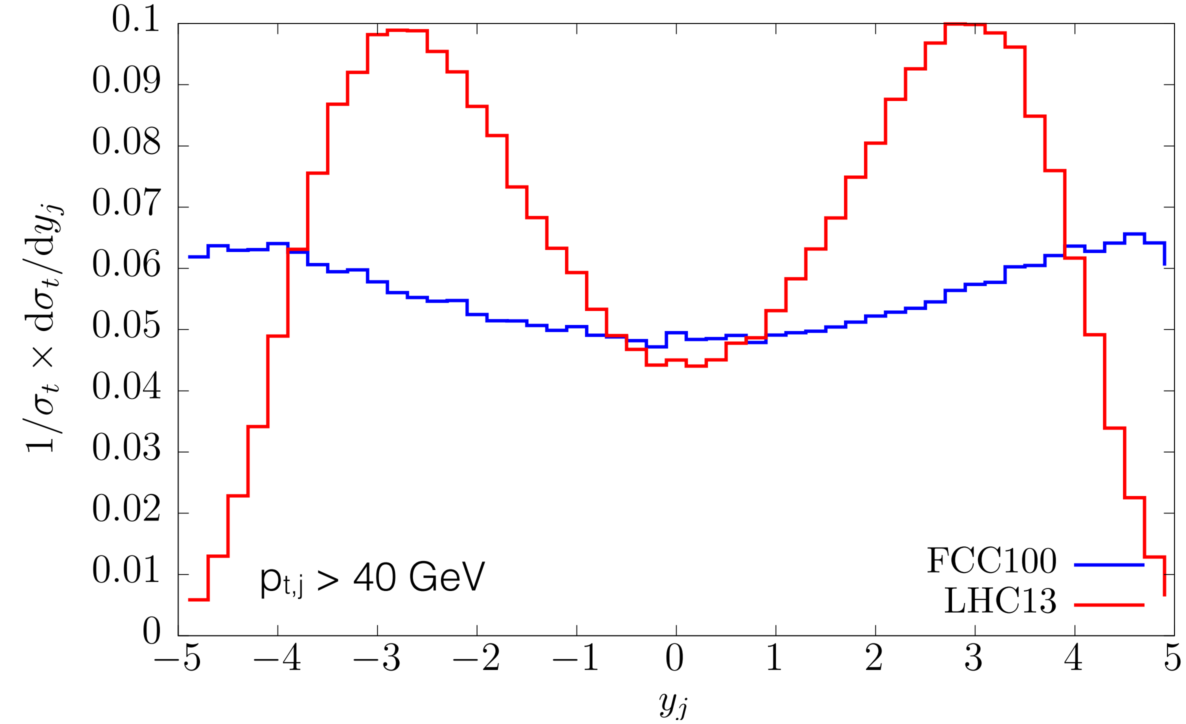
Cumulative cross-section

	top_{NLO}	anti-top_{NLO}
$p_t > 0$ TeV	2.7 nb	2.0 nb
$p_t > 1$ TeV	1.0 pb	0.57 pb
$p_t > 5$ TeV	0.5 fb	0.2 fb

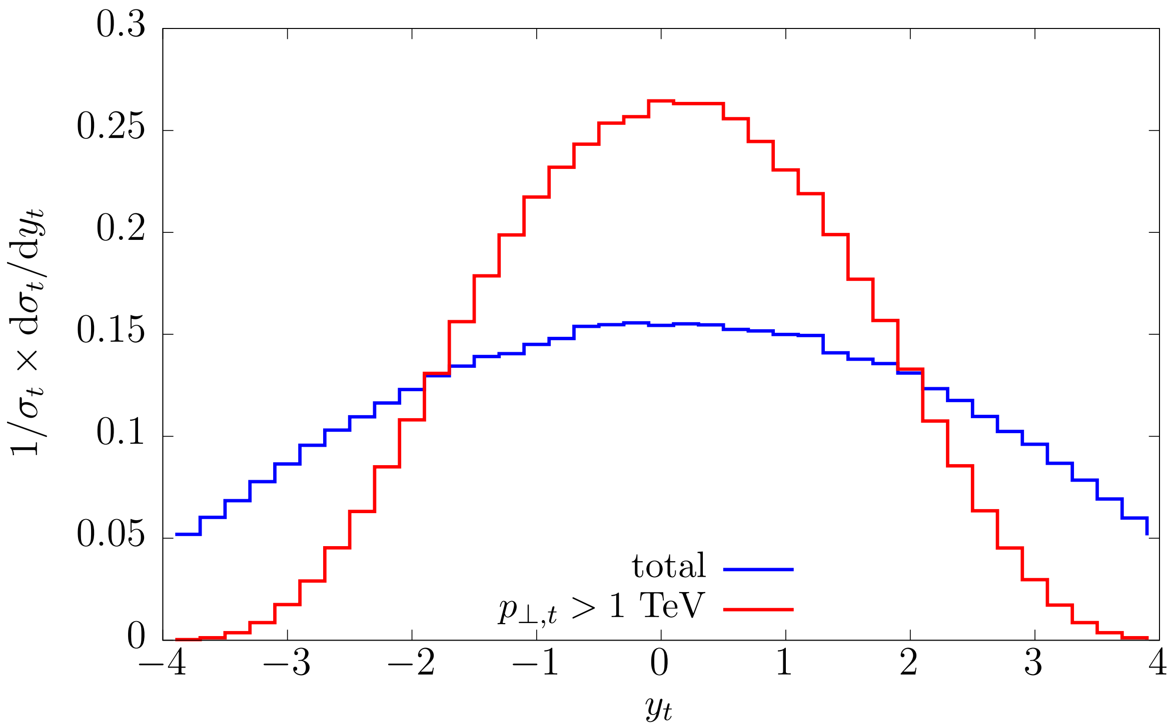
t-channel: rapidity

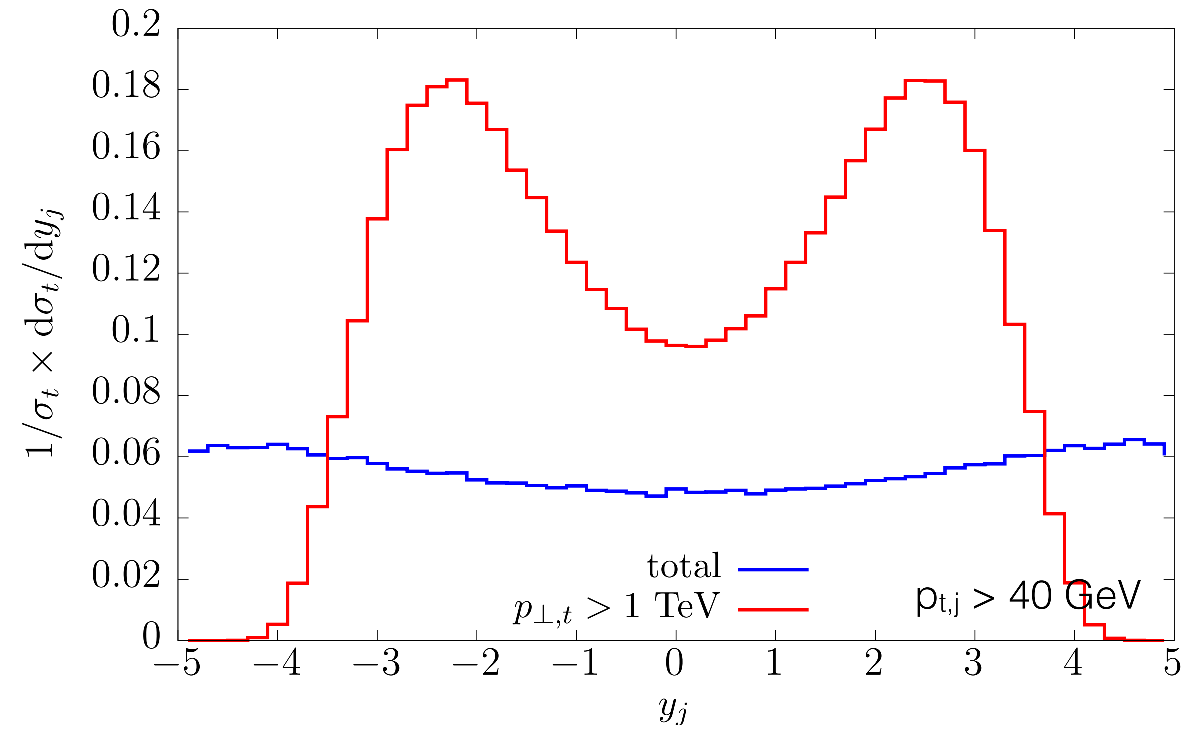
LHC13 vs FCC100





100 TeV: full vs high p_t

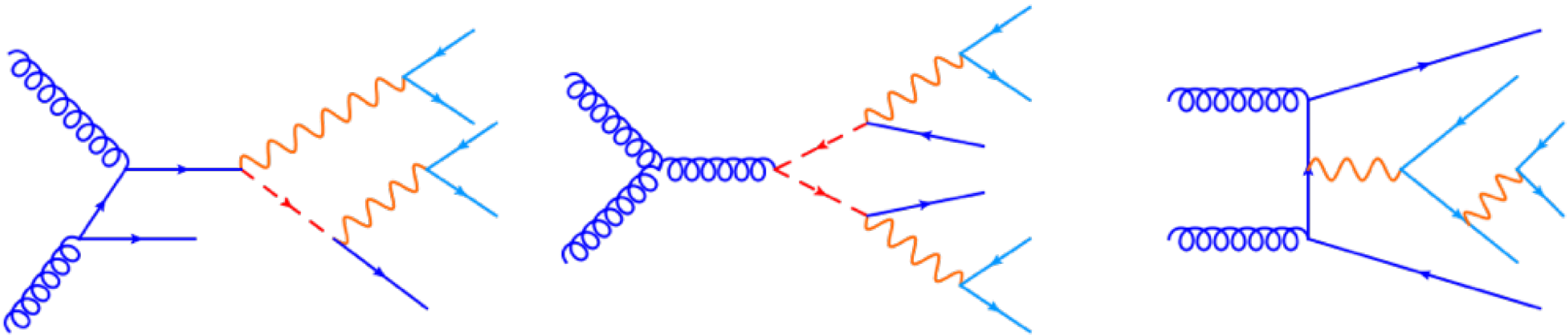




Wt associated production

Already at NLO, Wt, tt and WW share the same initial/final states ->

interferences, cannot be separated. Wt is not a well-defined quantity



If (low p_t) b-quark dynamics is relevant -> massive b

4FNS, interferences already at LO

Old techniques (DR,DS,PR) are not fully theoretically sound.

Can give an idea, but one should gradually move to WWbb analysis

Given the large relative yield, likely to be relevant for a 100 TeV collider

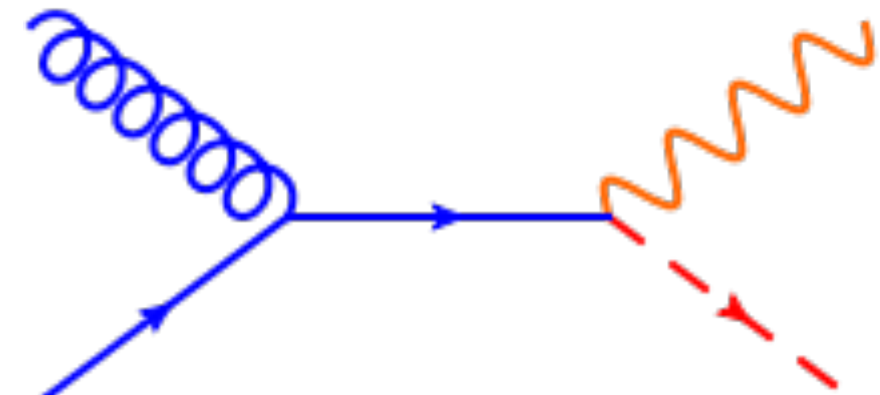
Wt: rough estimates

To reduce a top-contamination: additional b-veto
(see e.g. hep-ph/0506289)

$$\sigma^{Wt}_{\rm NLO}(13\ {\rm TeV}) = \sigma^{W\bar{t}}_{\rm NLO} = 0.035\ [{\rm nb}]$$

$$\sigma^{Wt}_{\rm NLO}(100\ {\rm TeV}) = \sigma^{W\bar{t}}_{\rm NLO} = 1.3\ [{\rm nb}]$$

x35



5FNS, $p_{t,veto}$=80 GeV

$\mu \sim p_{t,veto}$

	δ_{scale}	$\delta_{PDF,NNPDF}$
LHC13	~5-10%	~2%
FCC100	~5-10%	~2%

Complete (massive) WWbb study highly desirable

Wt: main uncertainties

Systematic Uncertainty	$\Delta\sigma$ (pb)	$\frac{\Delta\sigma}{\sigma}$
ME/PS matching thresholds	3.25	14%
Q^2 scale	2.68	11%
Top quark mass	2.28	10%
Statistical	2.13	9%
Luminosity	1.13	5%
JES	0.91	4%
$t\bar{t}$ cross section	0.87	4%
Z+jet data/MC scale factor	0.56	2%
tW DR/DS scheme	0.45	2%
PDF	0.33	1%
Lepton identification	0.31	1%
JER	0.27	1%
B-tagging data/MC scale factor	0.20	$< 1\%$
$t\bar{t}$ Spin Correlations	0.12	$< 1\%$
Top Pt Reweighting	0.12	$< 1\%$
Event pile up	0.11	$< 1\%$
E_T^{miss} modeling	0.07	$< 1\%$
Lepton energy scale	0.02	$< 1\%$
Total	5.58	24%

CMS-PAS-TOP-12-040

[8 TeV analysis]

It would be interesting to see whether the higher statistics would allow to move to theoretically cleaner analysis

- 'high p_t' physics, minimize use of (uncontrolled) PS
- old DR/DS… would become obsolete in favor of WWbb

Still, large parametrical uncertainty from m_t.

s-channel

Central region (|η|<2.5):

$$\sigma^{t}_{\mathrm{NLO}}(13\ \mathrm{TeV}) = 5.3\ [\mathrm{pb}]$$

$$\sigma^{t}_{\mathrm{NLO}}(100\ \mathrm{TeV}) = 40.5\ [\mathrm{pb}]$$

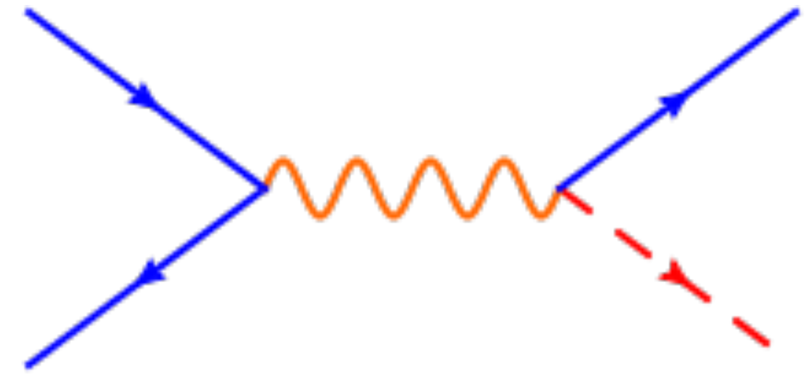
x7

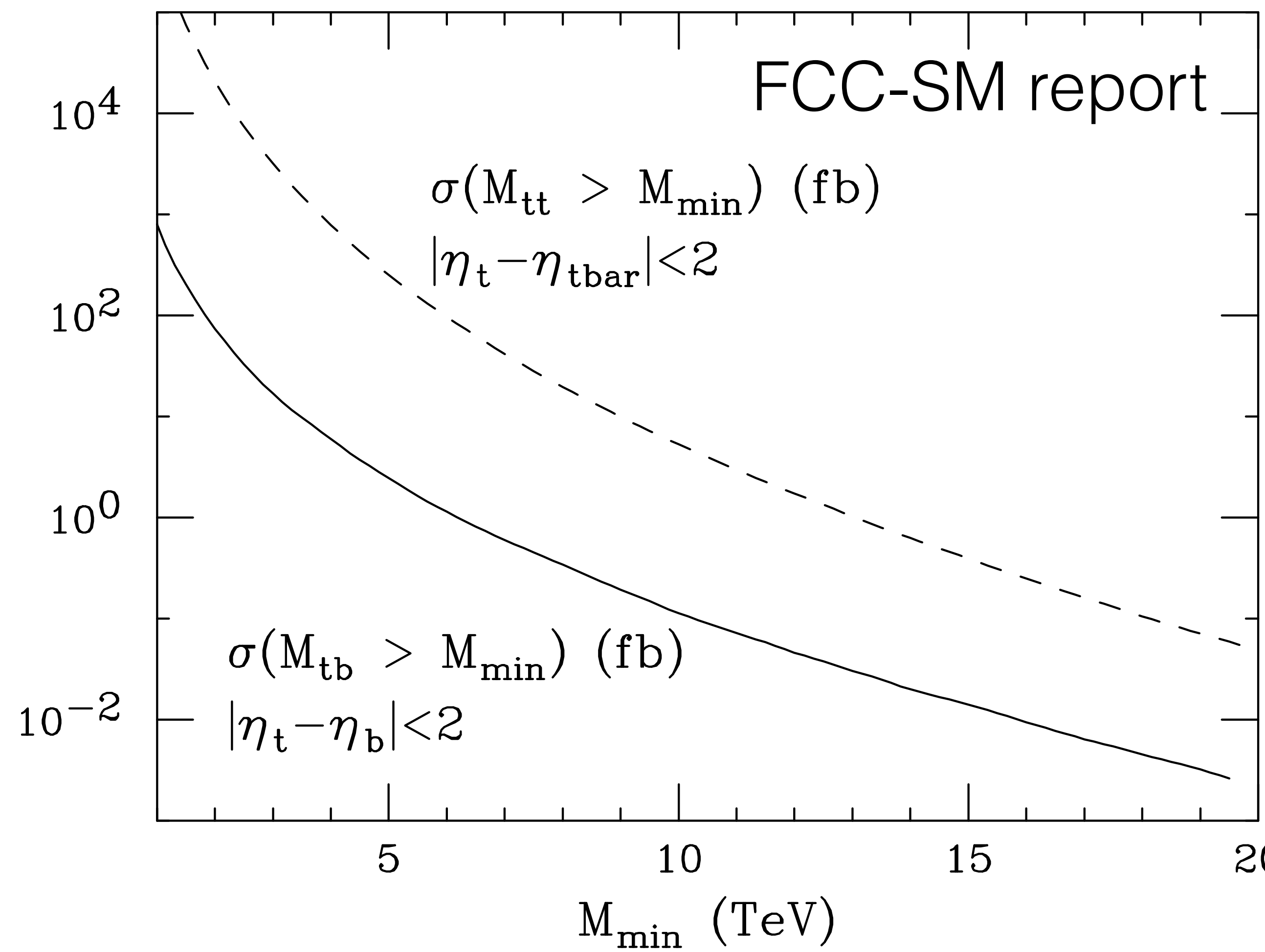
$$\sigma^{\bar{t}}_{\mathrm{NLO}}(13\ \mathrm{TeV}) = 3.1\ [\mathrm{pb}]$$

$$\sigma^{\bar{t}}_{\mathrm{NLO}}(100\ \mathrm{TeV}) = 33\ [\mathrm{pb}]$$

x10

	δ_{scale}	$\delta_{\mathrm{PDF,NNPDF}}$
LHC13	~2%	~1%
FCC100	~5%	~2%





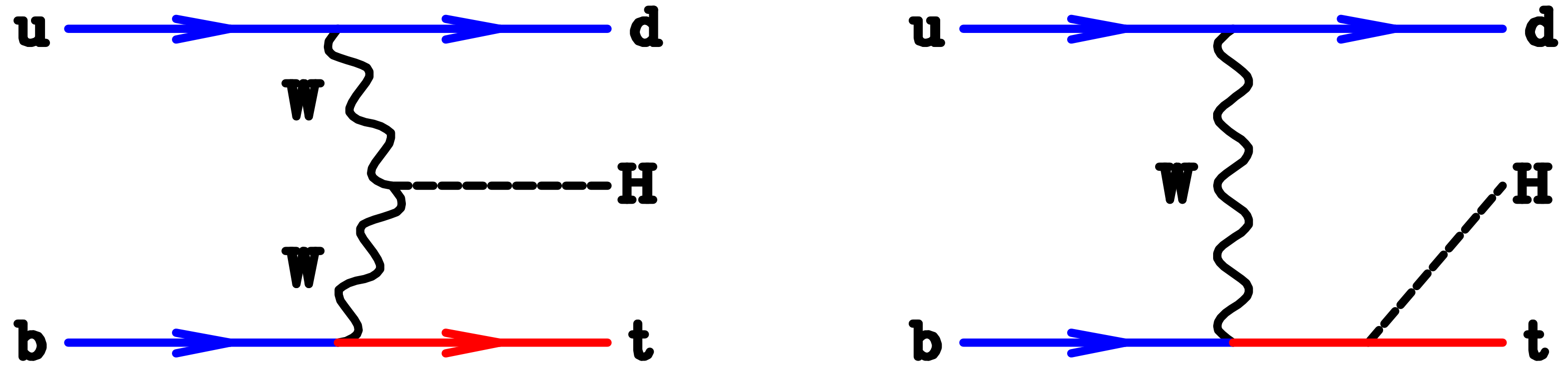
High invariant-mass events

Associated production: tH

LO rates, in the SM:

$$\sigma^{tH}_{\rm LO}(13\ {\rm TeV}) = 14\ [{\rm fb}]$$

$$\sigma^{tH}_{\rm LO}(100\ {\rm TeV}) = 0.4\ [{\rm pb}]$$



$$\sigma^{\bar{t}H}_{\rm LO}(13\ {\rm TeV}) = 10\ [{\rm fb}]$$

$$\sigma^{\bar{t}H}_{\rm LO}(100\ {\rm TeV}) = 0.4\ [{\rm pb}]$$

Non negligible rate

Unitarity in the Higgs/top sector

- if for example y_t with opposite sign w.r.t. SM: unitarity loss at ~ 6 TeV
- interesting to study at 100 TeV

$$a_0 = \frac{1}{16\pi\sqrt{2}\sqrt{s}}(c_F - c_V)\frac{g m_t}{m_W v}\int_{-s}^{0} A(t/s, \varphi; \xi_t^R, \xi_b^L) = -\frac{1}{24\sqrt{2}\pi}(c_F - c_V)\frac{g m_t \sqrt{s}}{m_W v}e^{i\varphi}$$

(see e.g. hep-ph/0106293, hep-ph/1211.3736, hep-ph/1302-3856)

Thank you very much for your attention

Back-up: jet-vetoed cross-section

	total	1-jet	2-jet
$p_t > 0$ TeV	2.7 nb	1.3 nb	0.8 nb
$p_t > 1$ TeV	1.0 pb	-0.4 pb	1.4 pb
$p_t > 5$ TeV	0.5 fb	-1.3 fb	1.8 fb
$p_t > 10$ TeV	3 ab	x	x

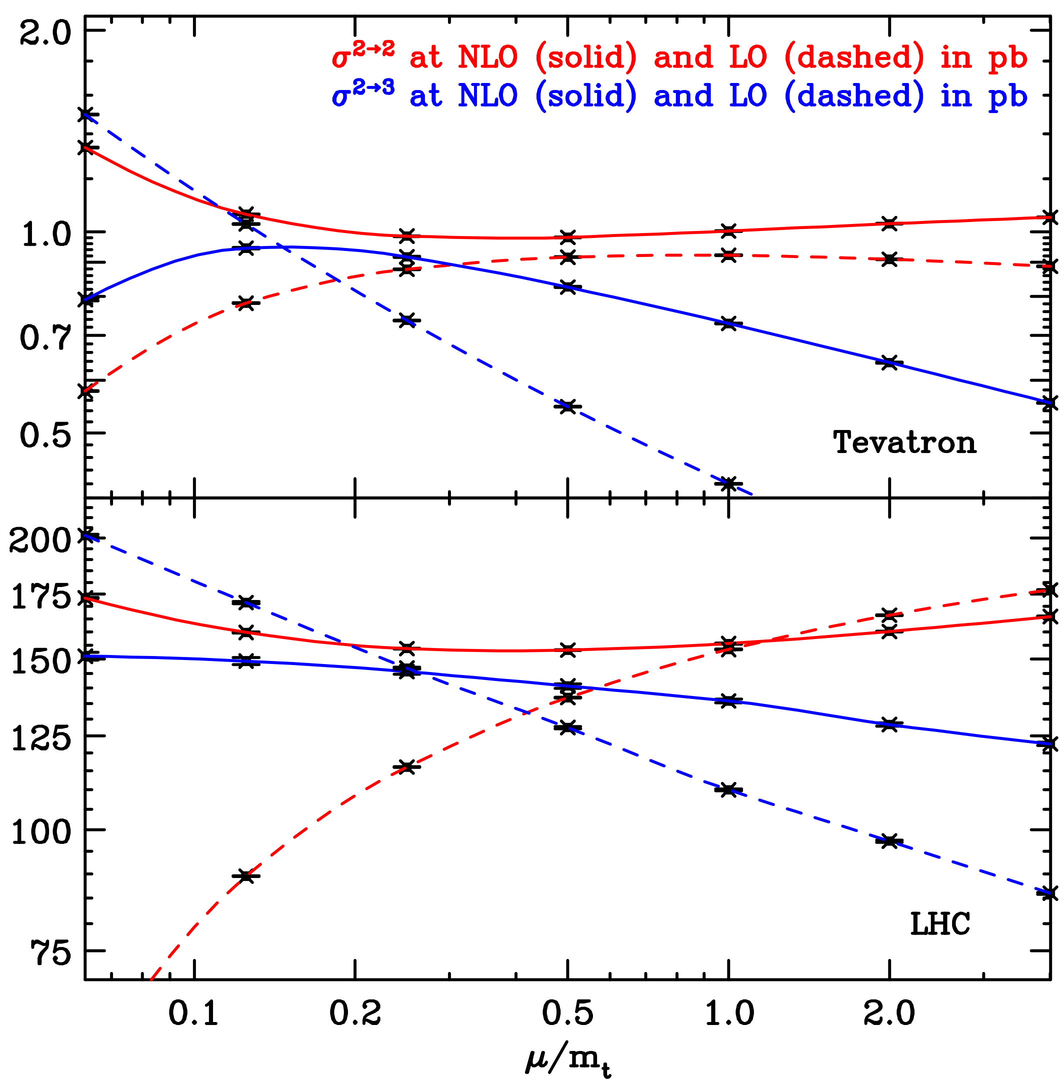
Negative 1-jet bin cross-section!

T-channel single top: do we need NNLO?

The total cross section at the 8 TeV LHC: A CLOSER LOOK

$$\sigma_{\rm LO} = 53.77 + 3.03 - 4.33 \text{ pb}$$

$$\sigma_{\rm NLO} = 55.13 + 1.63 - 0.90 \text{ pb}$$



[Campbell et al (2009)]

- Scale variation (-> h.o. est.) similar to corrections
- ~ percent difference between 4FNS/5FNS calculations

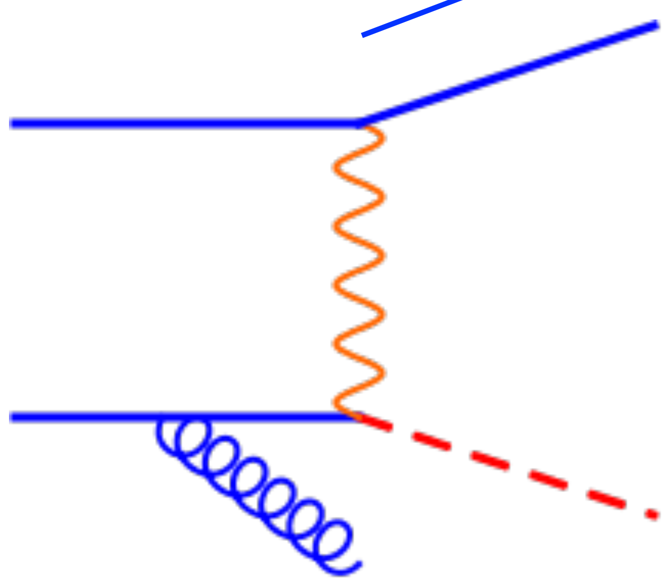
Residual perturbative uncertainty at the percent-level

t-channel single top: do we need NNLO?

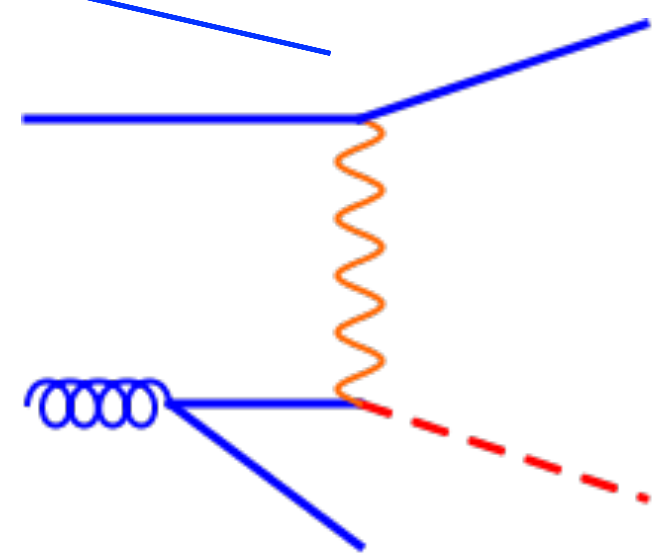
'Typical' NLO corrections are much more ~10%

$$\sigma_{\rm LO} = 53.77 + 3.03 - 4.33 \text{ pb}$$

$$\sigma_{\rm NLO} = 55.13 + 1.63 - 0.90 \text{ pb}$$



+12%



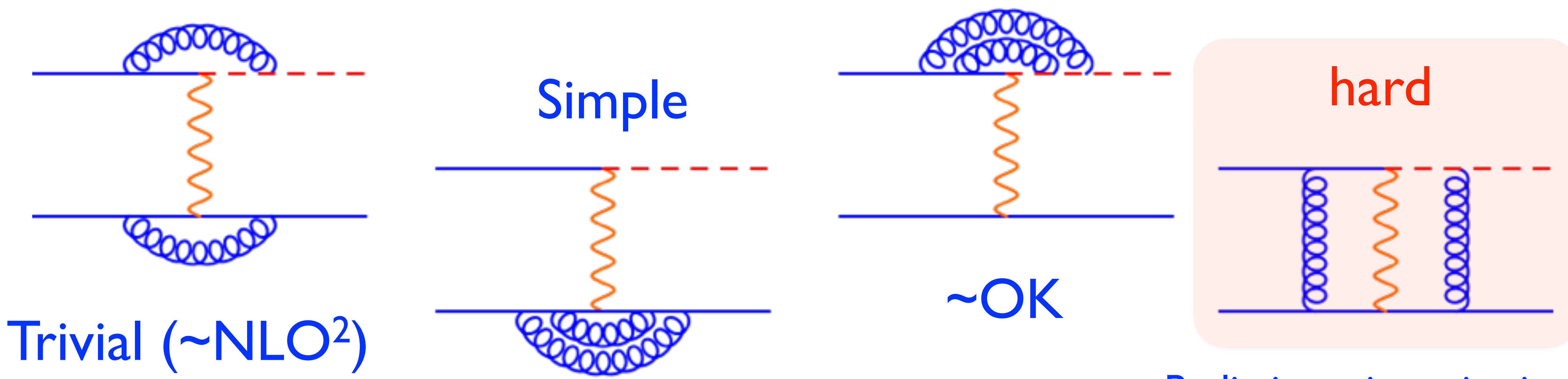
-14%

Large cancellations among channels

(beware of approximations only considering one channel)

Single-top in the 'factorized' approximation

Two-loop amplitudes:



Preliminary investigations:
[Uwer et al (2014)]

Must be interfered with tree-level -> COLOR SINGLET

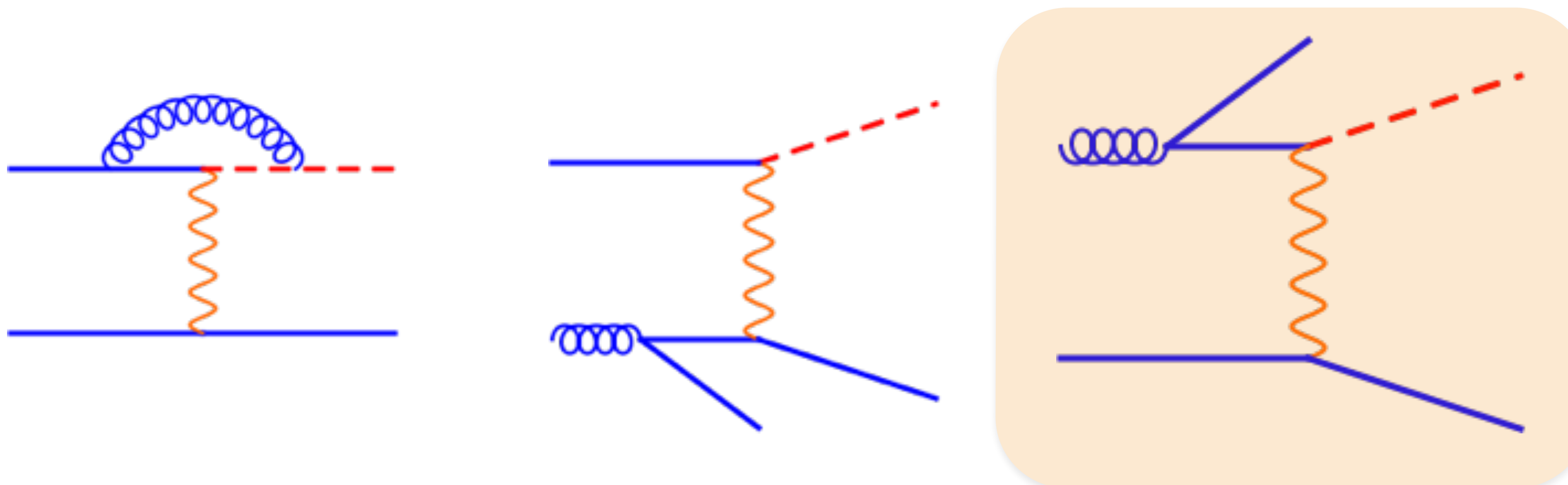
The 'hard' amplitude contribution is suppressed by $1/N_c^2$

NEGLECTED IN OUR COMPUTATION

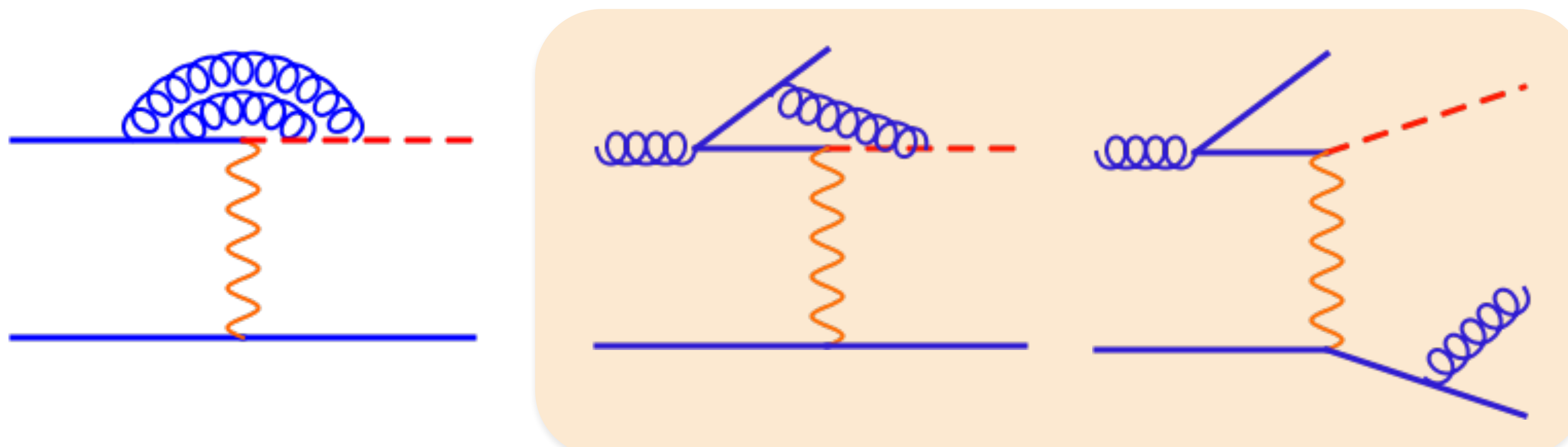
[same for s/t interference]

single-top @ NNLO: 5FNS vs 4FNS@NLO

NLO



NNLO



Inside NNLO 5FNS: ~ NLO 4FNS

- collinear regulator: MSbar vs m_b (log resummed, p.s.t. neglected)
- SLC light/heavy interference neglected in our computation
- 'Nice' features of 4FNS NLO (B-JET MODELING) inherited