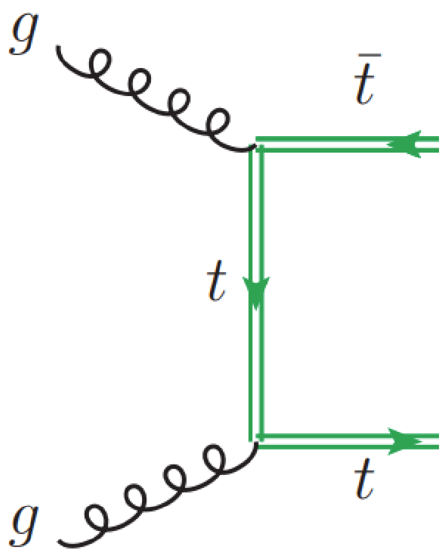
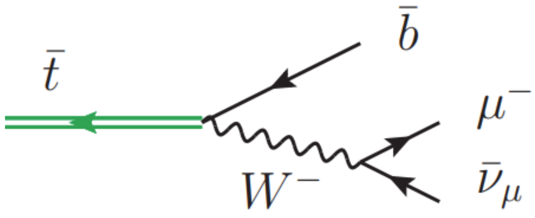
Combined tt and tW analyses

M. Czakon, A. Mitov, R. Poncelet, D. Stremmer, M. Worek

Top-quark pair production

Onshell top-quark picture:





+ top-quark decays

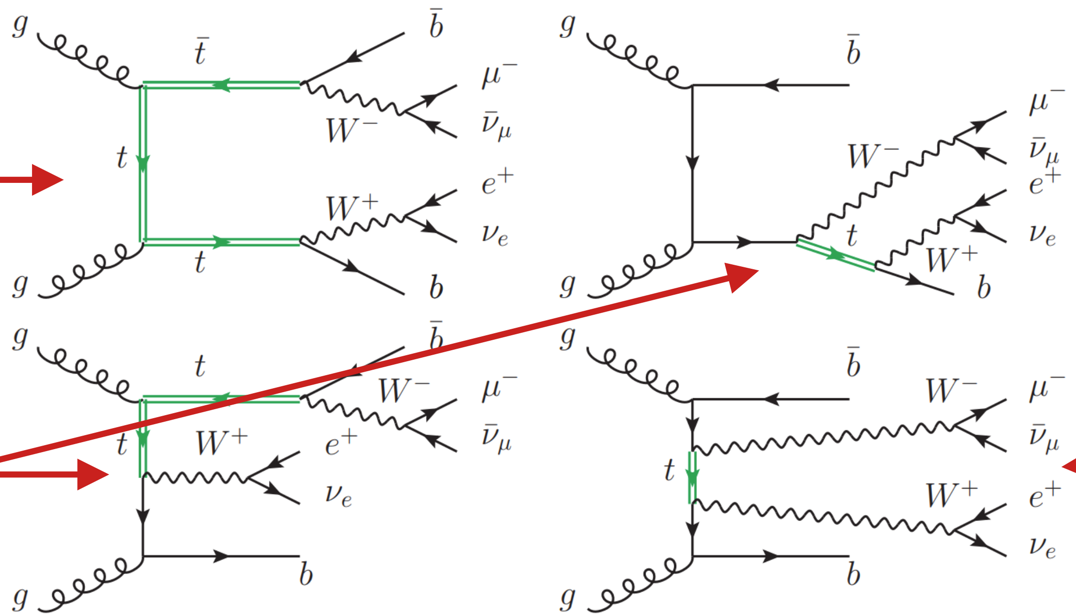
Observed in experiment

Top-quark pair production

Closer to what actually happens and what we observe in the detector: $pp \to \ell^+\ell^-\nu\bar{\nu}b\bar{b}$

Top-pair

Single top



no top

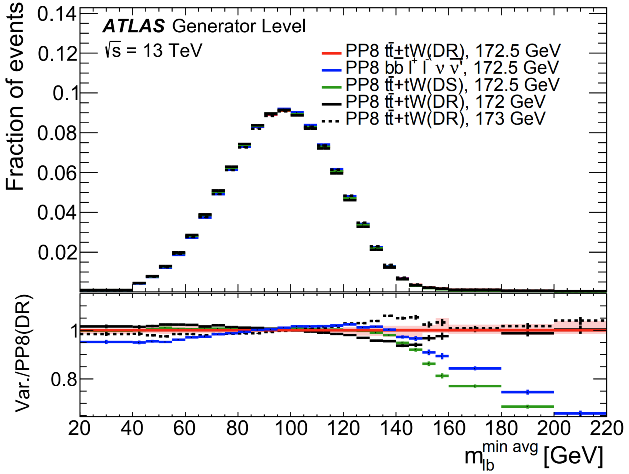
[1012.4230]

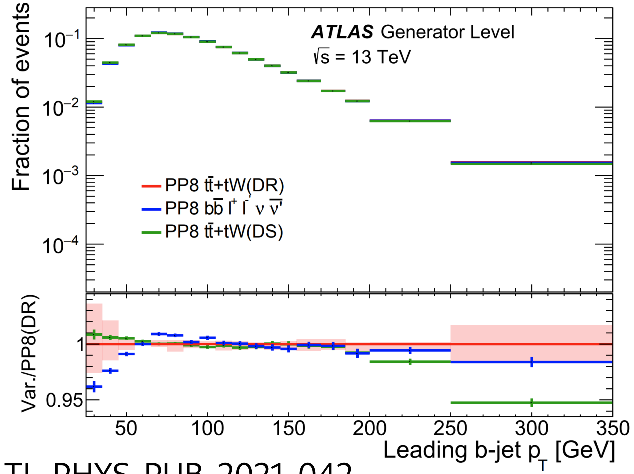
Quantum mechanics → Interference → we can't tell them apart

Removal of tW

Typical idea of top-quark pair analyses:

- Certain phase space regions are dominated by specific topologies
  → treat the others as background
- This requires to define an *ad hoc* scheme to remove interferences with tW
  → Diagram removal (DR) or Diagram subtraction (SR)
  → These come with large uncertainties/ambiguities!
  → One of the largest systematic model uncertainties
- Okay, as long as the “background” contributions to a specific observable are small
- Counter examples:
  - Kinematical edges: mlb
  - High pT tails: pT(b-jet) or pT(lep)





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"Starting point" for discussion

(Not too new) idea:

Combined analysis of tt and tW in (di-leptonic) final states

- Advantages with respect to standard "top-quark pair" analysis:
  - Reduced systematics since no tW removal necessary.
  - A more complete picture of top-quark production including interferences etc…
- Theory perspective: a full NNLO QCD off-shell computation is not yet feasible :(
  - But we can do:

$$\mathrm{NNLO\ QCD}_{\mathrm{NWA}} + \mathrm{NLO}_{\text{off-shell}} = \frac{\mathrm{d}\sigma^{\mathrm{NNLO\ QCD}}_{\mathrm{NWA}}}{\mathrm{d}X} + \frac{\mathrm{d}\delta\sigma^{\mathrm{NLO\ QCD}}_{\text{off-shell}}}{\mathrm{d}X} + \frac{\mathrm{d}\delta\sigma^{\mathrm{NLO\ EW}}_{\text{off-shell}}}{\mathrm{d}X}$$

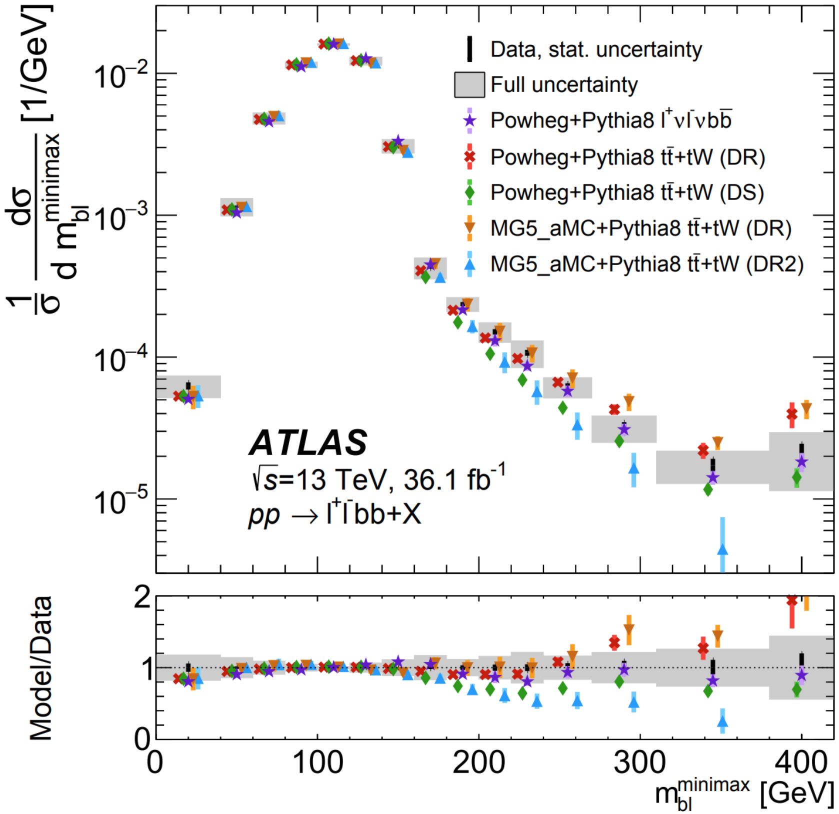
$$\frac{\mathrm{d}\delta\sigma^{\mathrm{NLO\ QCD}}_{\text{off-shell}}}{\mathrm{d}X} = \frac{\mathrm{d}\sigma^{\mathrm{NLO\ QCD}}_{\text{off-shell}}}{\mathrm{d}X} - \frac{\mathrm{d}\sigma^{\mathrm{NLO\ QCD}}_{\mathrm{NWA}}}{\mathrm{d}X}$$

tt+tW combinations - Experiment

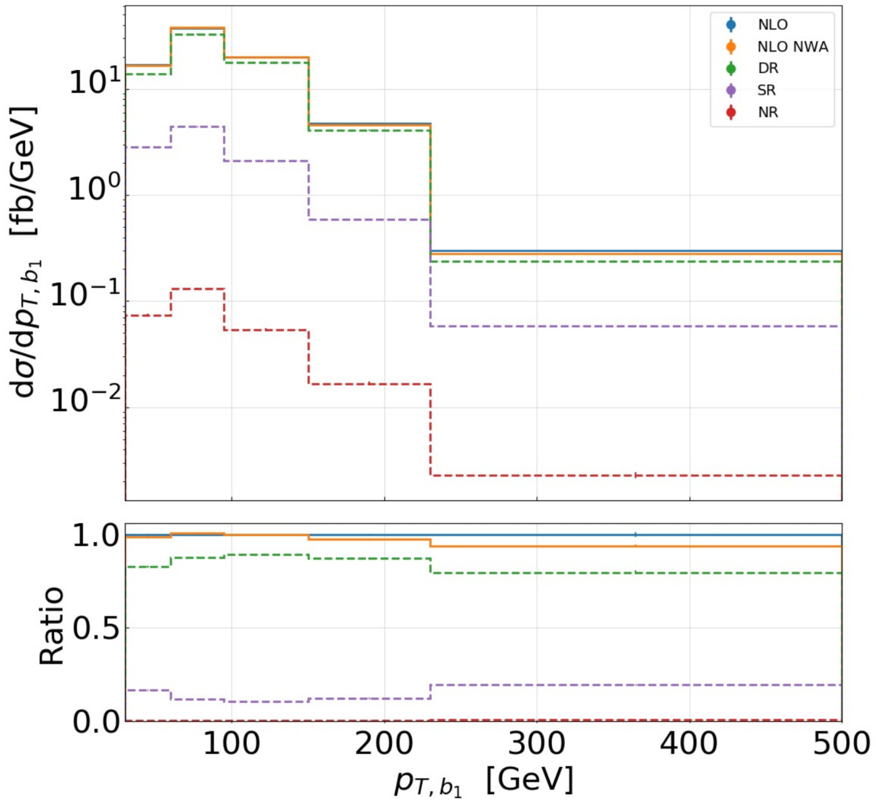
Such a measurement does exist:

Probing the quantum interference between singly and doubly resonant top-quark production in pp collisions at \sqrt{s}=13 TeV with the ATLAS detector,
ATLAS 1806.04667

- focus on m_bl where the effect is most dramatic



Example: tW effects in b-jet pT



NLO: Off-shell NLO QCD

DR: Double resonant PS region

$$|m_t - m(t)| < n\Gamma_t \quad \& \quad |m_t - m(\bar{t})| < n\Gamma_t$$

SR: Single resonant PS region

$$|m_t - m(t)| > n\Gamma_t \quad \& \quad |m_t - m(\bar{t})| < n\Gamma_t$$
$$|m_t - m(t)| < n\Gamma_t \quad \& \quad |m_t - m(\bar{t})| > n\Gamma_t$$

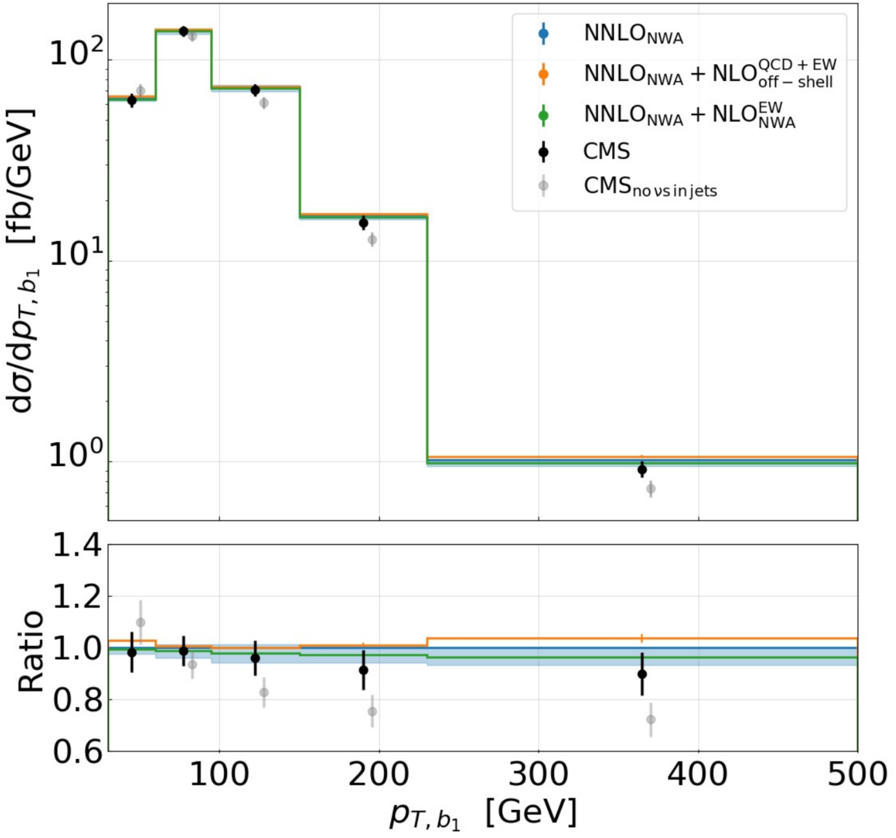
NR: Non resonant PS region

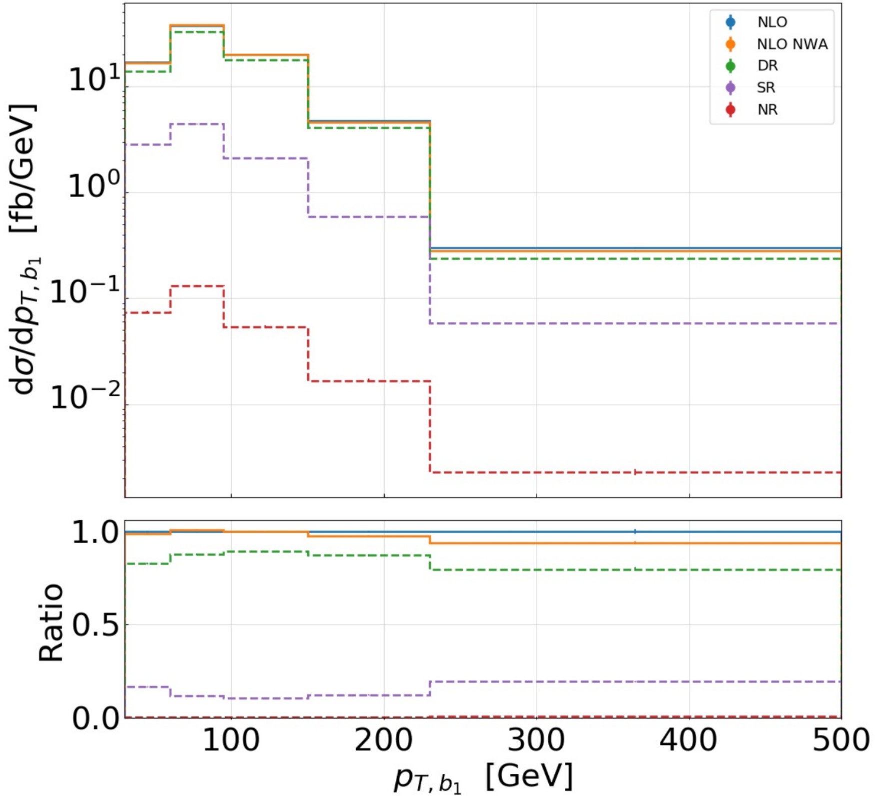
$$|m_t - m(t)| > n\Gamma_t \quad \& \quad |m_t - m(\bar{t})| > n\Gamma_t$$

DR+SR+NR = NLO
(Here: n = 15)

Example: tW effects in b-jet pT

Example: 1811.06625 (CMS data with removed tW)





Summary

- Basically we ask for measurement of final-state observables (pT(lep),pT(b-jet),....) without subtracting tW and/or non-resonant "backgrounds"

  → "Help us to help you" :)

- We can provide state-of-the-art fixed-order predictions:

  NNLO QCD (NWA) + NLO QCD+EW (off-shell)

- Potential goals and deliverables:

  - ➔ Detailed fixed order theory to data comparison of fiducial phase space without relying on DR/DS/etc → improve on one of the largest systematics
  - ➔ Improved descriptions of observables with single-top contributions
  - ➔ Top-quark mass/width measurement from leptonic distributions
  - ➔ Study of unfolding effects from parton-shower/hadronization/soft-physics

Backup

Resonance analysis

1) Determine most likely resonance history (assuming perfect W reconstruction):

I) $t = W^+ b \quad \& \quad \bar{t} = W^- \bar{b}$

II) $t = W^+ bj \quad \& \quad \bar{t} = W^- \bar{b}$

III) $t = W^+ b \quad \& \quad \bar{t} = W^- \bar{b} j$ (if j is present)

For each compute $Q = |m_t - m(t)| + |m_t - m(\bar{t})|$ and take the history with smallest value

2) Then take determine if this in DR, SR, NR region (plots n = 15)

DR:

$$|m_t - m(t)| < n\Gamma_t \quad \& \quad |m_t - m(\bar{t})| < n\Gamma_t$$

SR:

$$|m_t - m(t)| > n\Gamma_t \quad \& \quad |m_t - m(\bar{t})| < n\Gamma_t$$
$$|m_t - m(t)| < n\Gamma_t \quad \& \quad |m_t - m(\bar{t})| > n\Gamma_t$$

NR:

$$|m_t - m(t)| > n\Gamma_t \quad \& \quad |m_t - m(\bar{t})| > n\Gamma_t$$

Details for examples

1811.06625

- Leptons: pT(l) > 20 GeV and |y(l)| < 2.4
- m(ll) > 20 GeV
- 2 anti-kT R=0.4 jets with pT(j) > 30 GeV and
  |y(j)| < 2.4,
  both b-tagged
  and deltaR(j,l) > 0.4

Theory:

- Scales: H_T/4 where H_T = pT(l+)+pT(l-)+pT(b1)+pT(b2)+pT(mis)

Technical advertisement slide

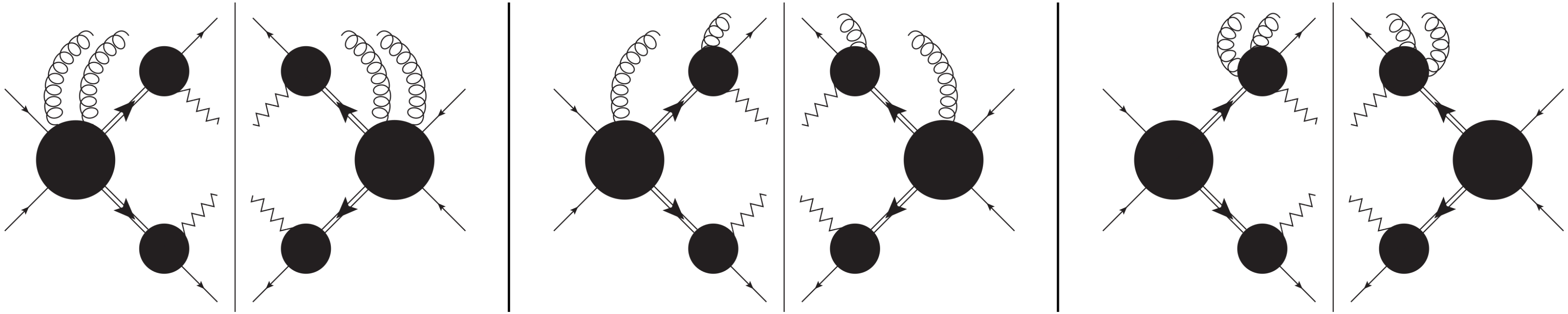
NNLO QCD calculations have been performed with a in-house implementation of the sector-improved residue subtraction scheme.

A novel subtraction scheme for double-real radiation at NNLO Czakon, 1005.0274

Four-dimensional formulation of the sector-improved residue subtraction scheme Czakon, Heymes, 1408.2500

Single-jet inclusive rates with exact color at O(aS^4) Czakon, van Hameren, Mitov, Poncelet, 1907.12911

NNLO QCD Top-quark pair production in di-lepton channel with corrections to decays:



Details about Narrow-Width-Approximation & extensive study of experimental fiducial phase spaces and observables: **NNLO QCD corrections to leptonic observables in top-quark pair production and decay** Czakon, Mitov, Poncelet, 2008.11133