

From Continuum to Threshold: Off-shell top pair production at a lepton collider

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Introduction

QCD corrections to $t\bar{t}$ S -wave production at lepton colliders are known to N³LO [1506.06864] and resummed to NNLL [1309.6323]

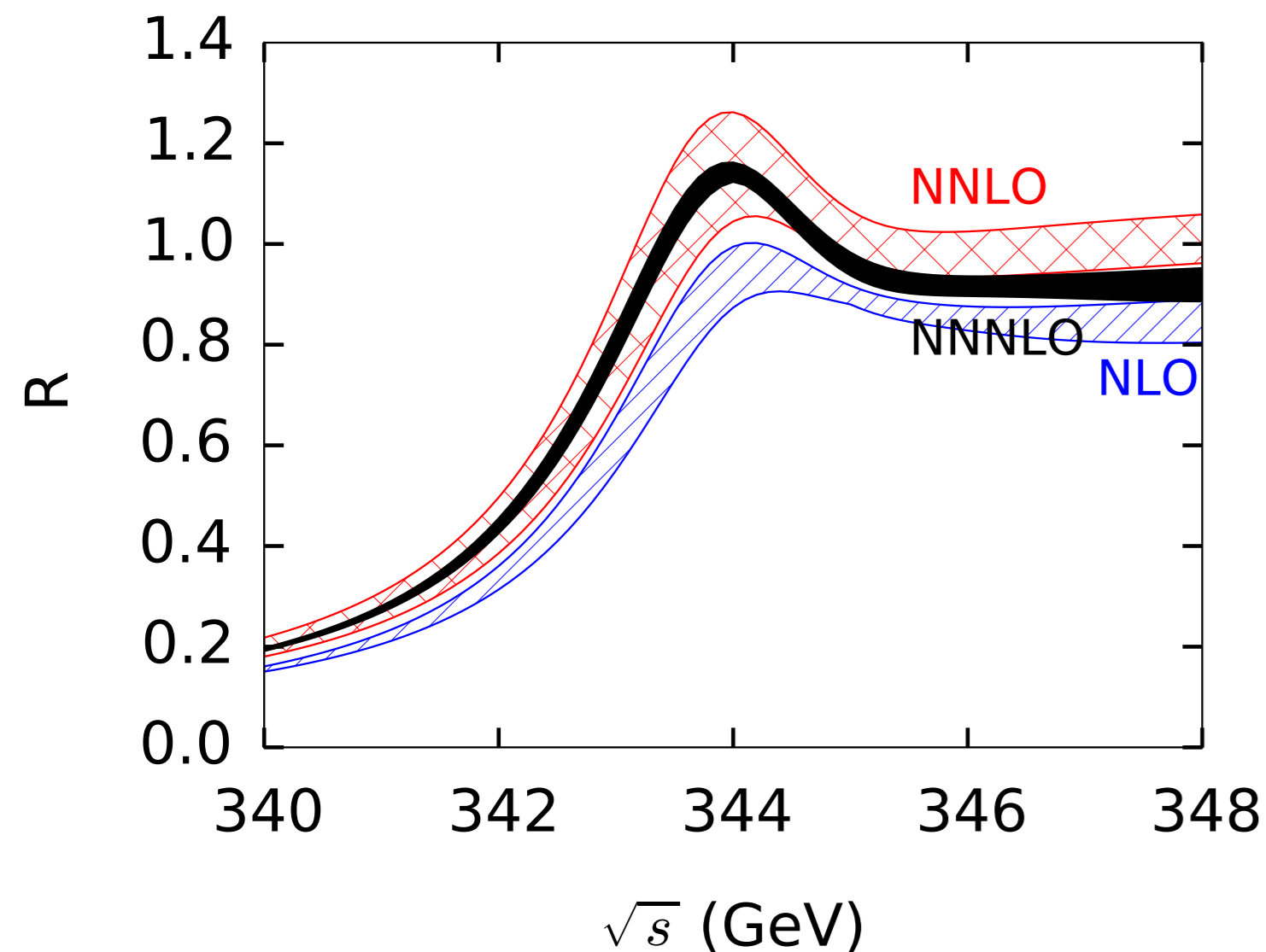


Figure 1: Cross section at threshold, from [1506.06864].

Very sensitive to top mass and width. However, only applicable directly at threshold

How to combine inclusive nonrelativistic NRQCD with differential, fixed-order predictions for $e^+e^- \rightarrow W^+bW^-b\bar{b}$?

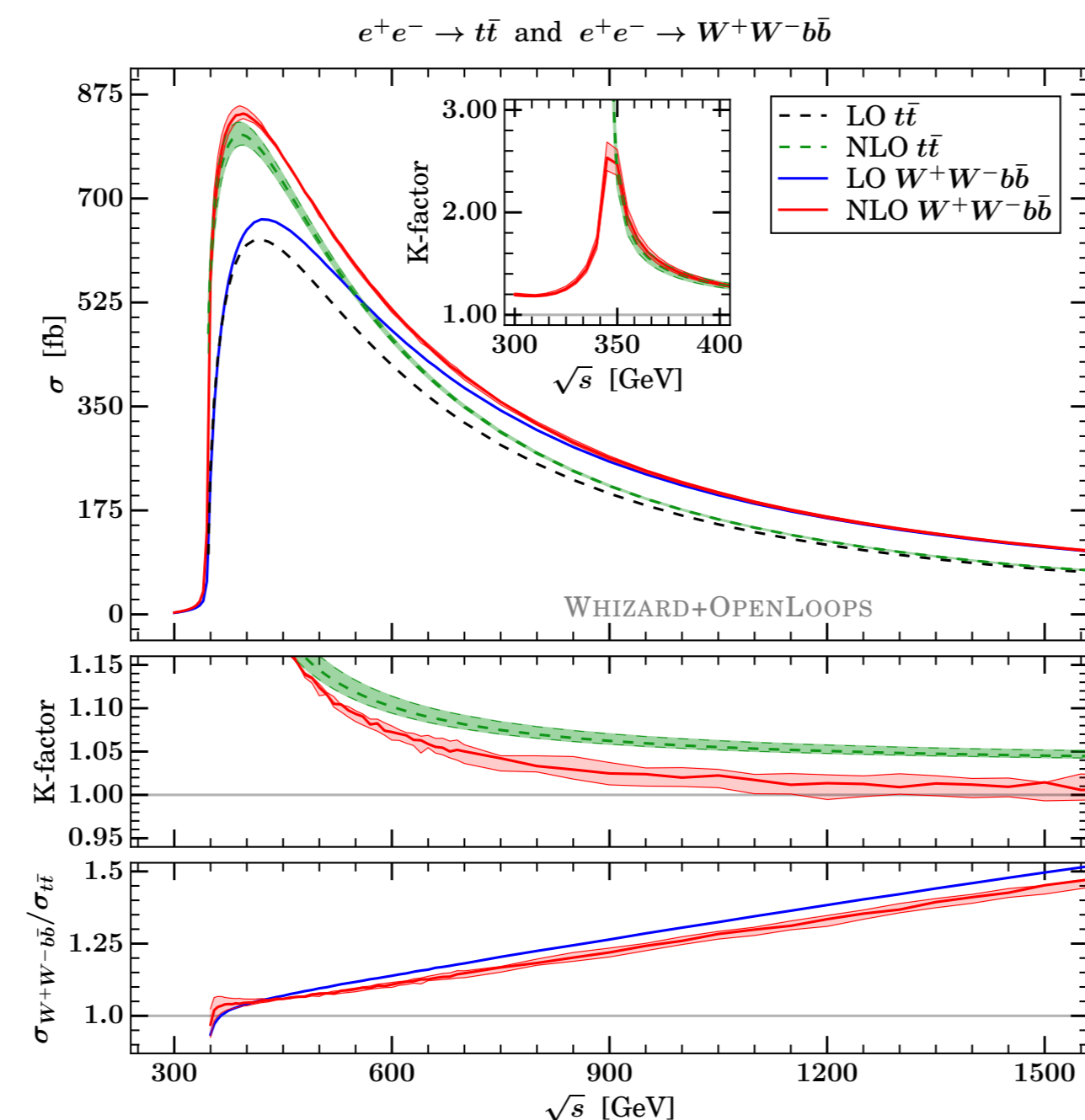


Figure 2: Relativistic cross section from threshold to continuum in fixed-order QCD [1].

Idea: Include the nonrelativistic form factor in the event generator WHIZARD

Validation against analytic computation

► For validation, we can compare with the nonrelativistic, analytic computation based on the optical theorem

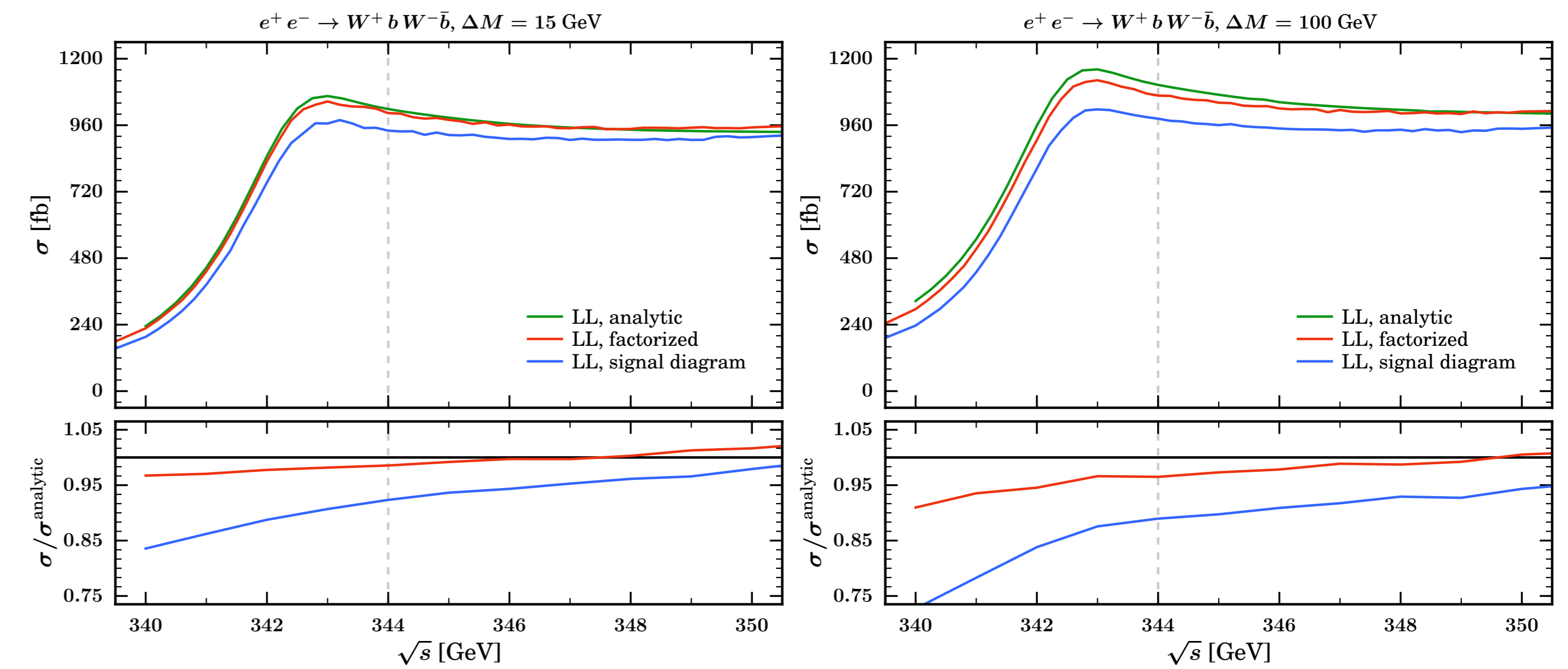


Figure 3: Comparison of analytic results with the implementation in WHIZARD with the factorized and the signal-diagram approach.

- Difference between factorized computation with on-shell projection and gauge-dependent signal diagram clearly visible
- Excellent agreement with analytic computation for reasonable ΔM cuts on the invariant top mass. Deviations for large ΔM are expected [1002.3223]
- Other cross checks have been performed: α_s expanded cross section \checkmark , direct comparison of the form factor \checkmark

Whizard

- Universal event generator for multi-particle states [2]
- Automatic tree-level matrix elements for arbitrary processes from O'MEGA [hep-ph/0102195] (UFO support nearly complete)
- Complete phase space parameterization combined with multi-channel Monte-Carlo integration (VAMP) [hep-ph/9806432]
- Excellent support for lepton collider studies: beam polarization, ISR radiation, beamstrahlung via CIRCE2 [hep-ph/9607454], ...
- Interfaces to LHAPDF5, LHAPDF6, HOPPET as well as built-in PDFs
- Convenient scripting language (SINDARIN) instead of arcane run cards
- Parton shower and hadronization: analytic shower [1112.1039], PYTHIA6, TAUOLA, PYTHIA8 (soon)
- Various event formats: LHEF, HepMC, LCIO, StdHEP, ASCII formats, ...
- Automated NLO QCD corrections to scattering and decay processes, handling IR divergencies with FKS subtraction [0908.4272]
- Virtual amplitudes come from one-loop-providers:

GoSAM [1404.7096],

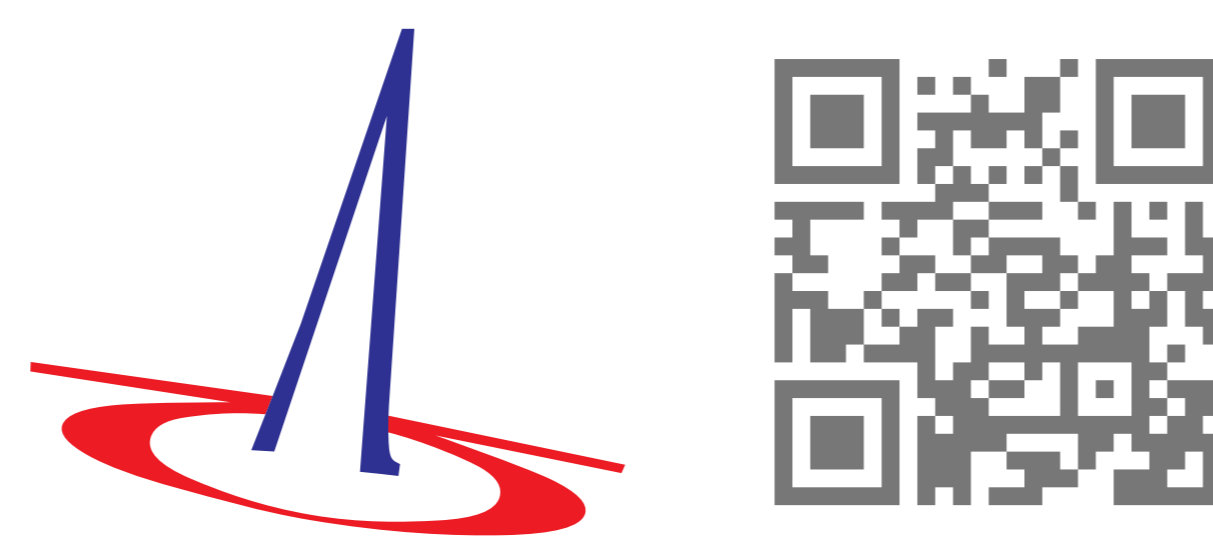
OPENLOOPS [1111.5206],

RECOLA [1605.01090]



Current Release

WHIZARD 2.4.0,
November 28th, 2016,
<https://whizard.hepforge.org/>



Embedding of the form factor in the matrix element

- Resummed form factor from TOPPIK is an on-shell form factor
- What are our requirements?
 - Has to work at, below and above threshold (THR)
 - Be gauge-invariant (GI)
 - Should allow for radiative corrections to the top decay (RADCOR)
 - Take off-shell effects into account (OFF)
- What is on the market?
 - Narrow-Width-Approximation: \checkmark GI, \checkmark RADCOR, \times OFF, \times THR
 - Signal diagram, factorized off-shell: \checkmark THR, \checkmark OFF, \times GI, ? RADCOR
 - Pole approximation (keep off-shell propagator but evaluate residue on-shell): \checkmark GI, \checkmark RADCOR, \checkmark OFF, \times THR
- For this process, we consistently extend the pole approximation, such that it can be also used below threshold

Matching

- Threshold resummation of Coulomb singular $(\frac{\alpha_s}{v})^n$ and large $(\log v)^n$ terms relies on $v \sim \alpha_s$ ∇ this holds true only at threshold
- Need to turn this off with an appropriate switch-off function f_s
- In threshold region we also have to subtract the α_s expansion of the form factor to avoid double counting:

$$\sigma_{\text{matched}} = \sigma_{\text{QCD}}[\alpha_H] + \sigma_{\text{NRQCD}}^{\text{full}}[f_s \alpha_H, f_s \alpha_S, f_s \alpha_{US}] - \sigma_{\text{NRQCD}}^{\text{expanded}}[f_s \alpha_H, f_s \alpha_H],$$

with α_s evaluated at the hard, soft and ultra-soft scales

$$\alpha_H = \alpha_s[\mu_H = m_t], \quad \alpha_S = \alpha_s[\mu_S = m_t v], \quad \alpha_{US} = \alpha_s[\mu_{US} = m_t v^2]$$

Preliminary Results

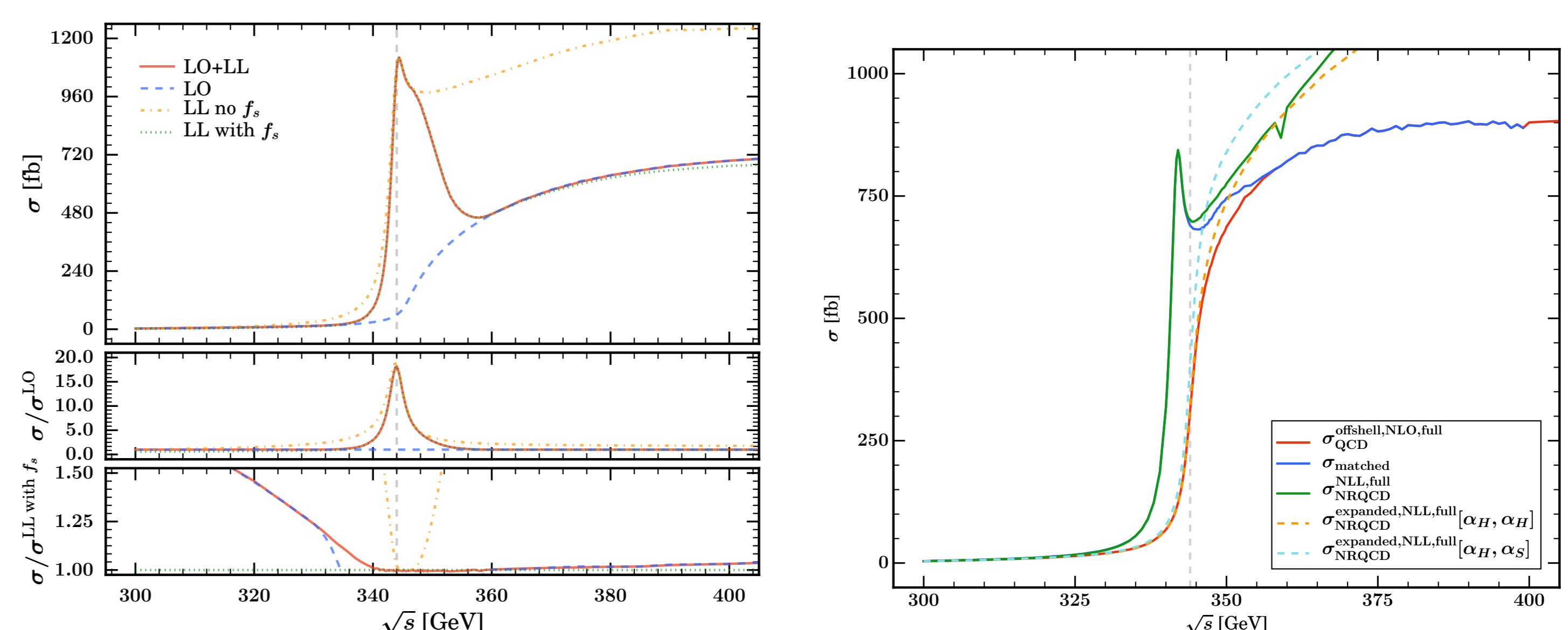


Figure 4: Inclusive cross section around threshold. Comparison of fixed order, resummed and matched computation at (N)LO, (N)LL and (N)LO+(N)LL. For the resummed results, we show the result with and without the switch-off function f_s . The dashed line indicates the short distance mass $2M_t^{1S}$, which serves as input to compute the pole mass $2m_t$.

- Biggest absolute effect on (N)LL curve is the switch-off function f_s
- Away from threshold, full fixed-order result deviates significantly from factorized computation

References

- [1] Bijan Chokouf  Nejad et al. NLO QCD Predictions for off-shell $t\bar{t}$ and $t\bar{t}H$ Production and Decay at a Linear Collider. *accepted for publication at JHEP*, (2016). arXiv: 1609.03390
- [2] Wolfgang Kilian, Thorsten Ohl, and J rgen Reuter. WHIZARD—simulating multi-particle processes at LHC and ILC. *The European Physical Journal C*, **71**:9 (2011), p. 1742. arXiv: 0708.4233