WbWb production at the tt threshold

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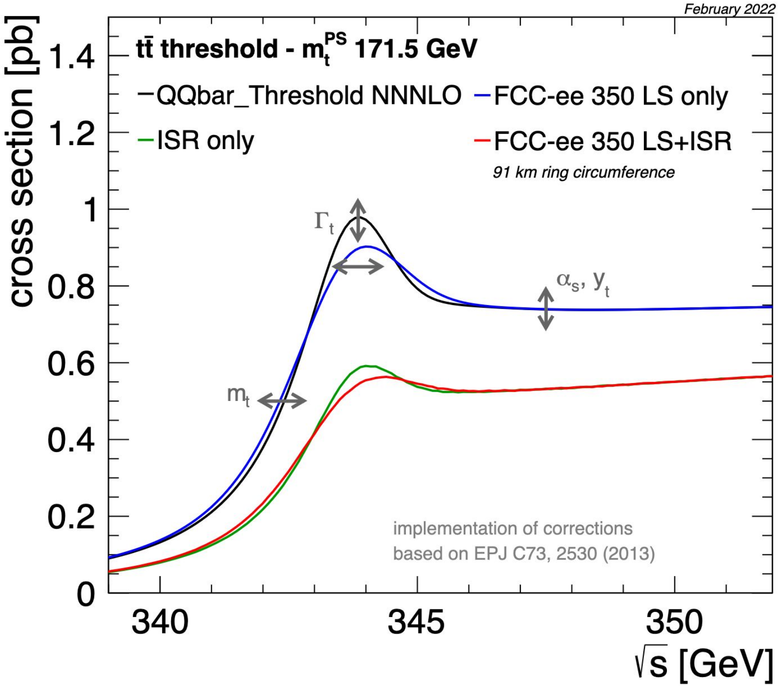
Goal: define a strategy for tt threshold scan at FCC-ee

- Realistic WbWb selection in the presence of backgrounds
  - Currently focussing on l+jets and fully-hadronic channels (~80% of total branching ratio)
  - Focussing on WW background
  - We will consider including hadronic tau decays and di-leptonic channels in the future
- Optimise threshold scan to maximize sensitivity to relevant SM parameters
  - Focus on top mass, total width, Yukawa coupling + strong coupling constant
  - Assume that impact of uncertainty in EW couplings and mW is negligible (to be checked later on)



Simulated samples and event selection

We use centrally-produced FCC-ee samples for WbWb and WW production at 345 GeV (thanks to Louis Portales for producing them quickly!)

Semi-leptonic:

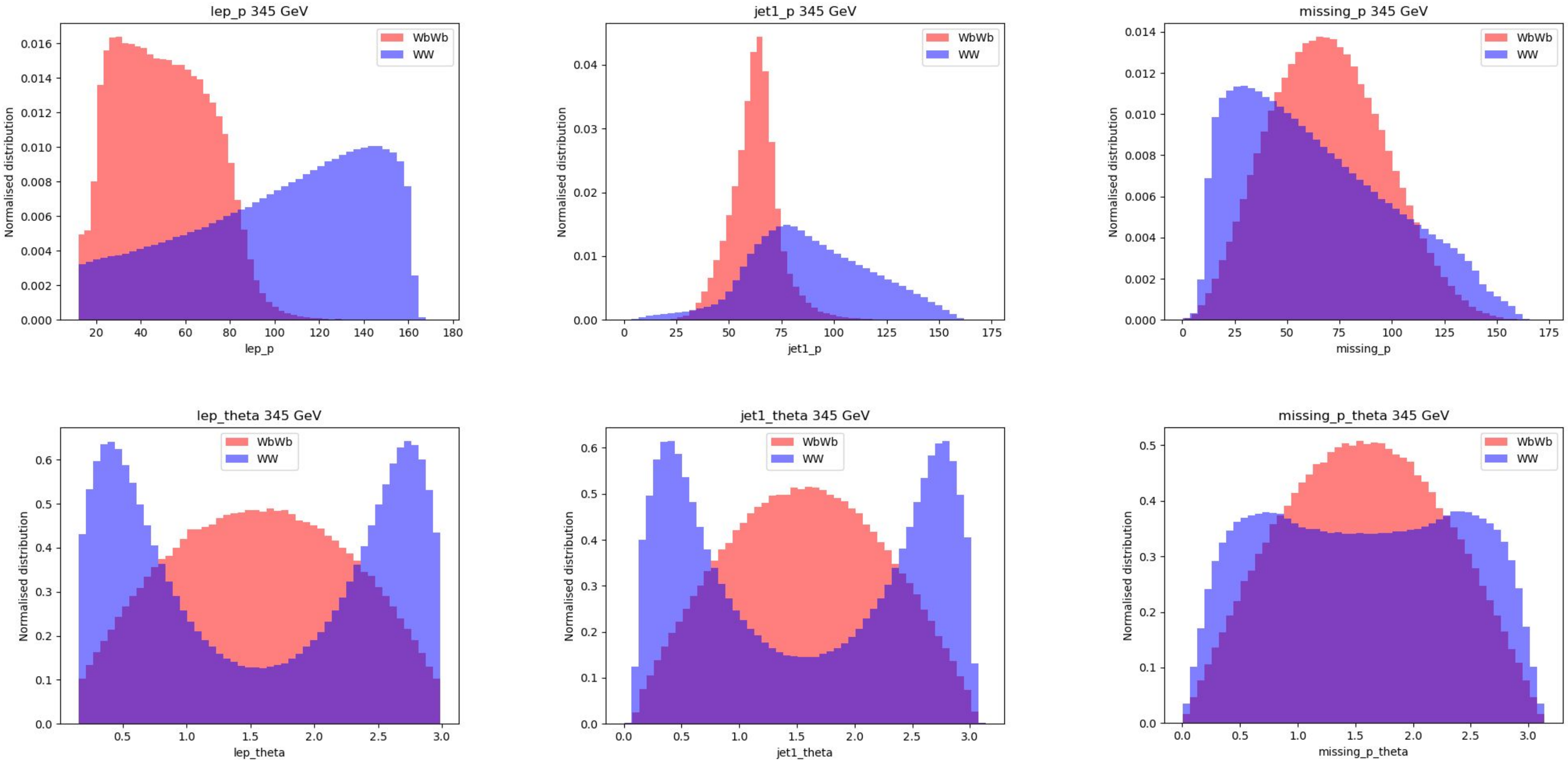
- Exactly 1 isolated lepton (electron, muon) with $p > 12$ GeV
- Exclusive jet clustering with n-jet = 4

Fully hadronic:

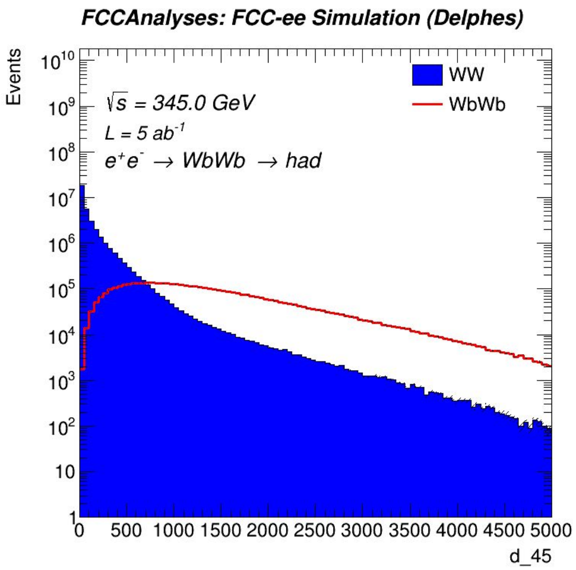
- Zero isolated leptons with $p > 12$ GeV (no other selection)
- Exclusive jet clustering with n-jet = 6

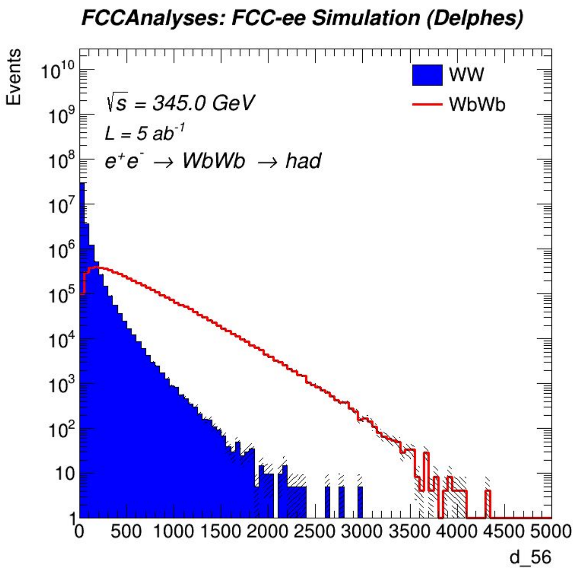
Heavy flavour tagging information used for event classification

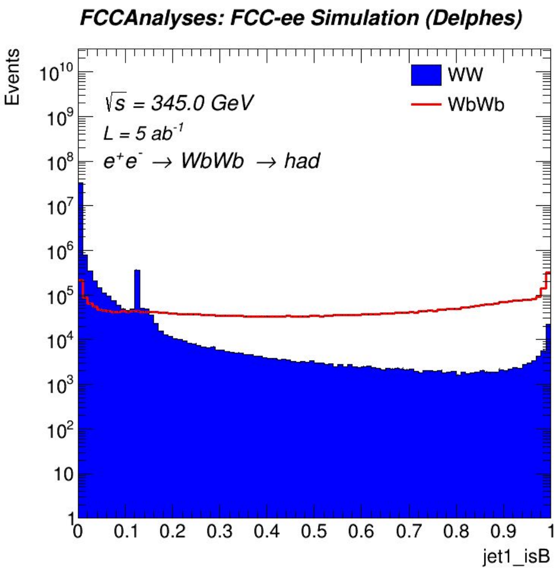
Kinematics: e.g. with semi-leptonic



Jets: e.g. with hadronic

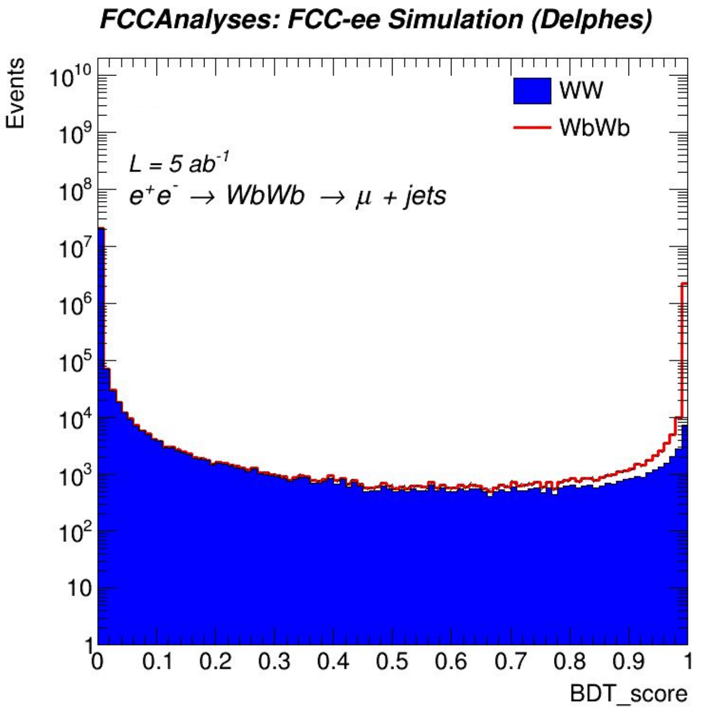


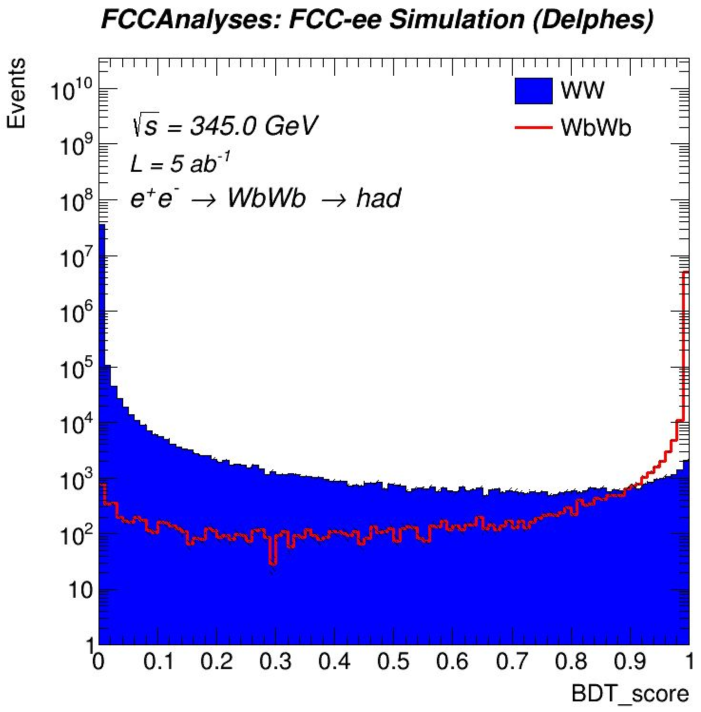




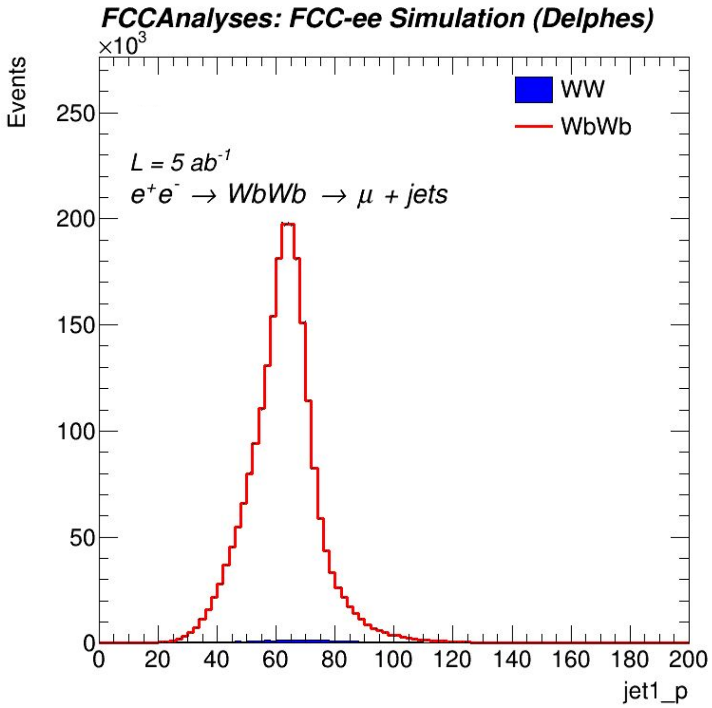
Note: for next iteration we will remove HF score from BDT and use a b-jet multiplicity categorisation instead

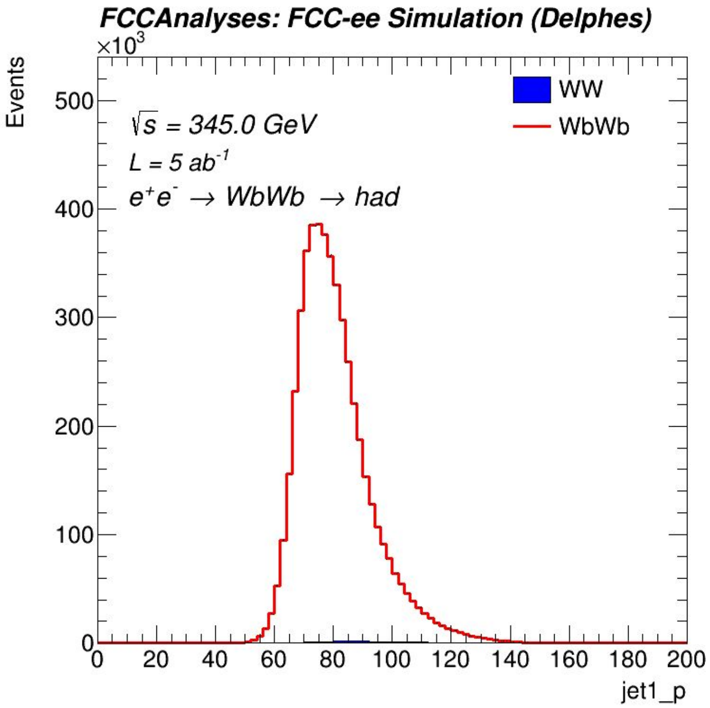
“Brute force” BDT with all variables





Distributions after BDT cut > 0.5





Summary and outlook of reco-level studies

- Extremely pure WbWb sample can be obtained in l+jets and all-jet channels
    - Only considered WW for now
    - Expect some DY contribution, especially in the all-had channel (will add for next time). However we doubt that this would change the picture significantly

- For practical purposes (parameter extraction), we can assume we can have a pure WbWb selection in all decay channel
    - Assume 100% efficiency and acceptance, 100% pure WbWb selection
    - We are now checking how much the lepton selection impacts the overall efficiency
    - We will check if the picture changes at higher/lower energies (above/below threshold)

- No need for kinematic reconstruction to measure cross section

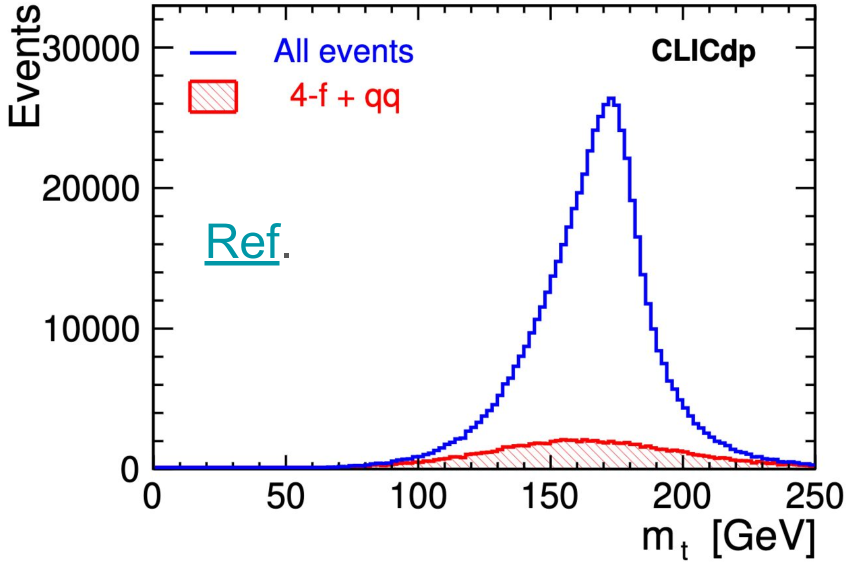
Comparison with previous studies

Somewhat larger background contamination (similar BDT method)

Considered background is (presumably) WW->4f + ISR/FSR -> qq

To which extent our WW sample includes to ISR->qq contribution?

One difference: they require 2 b-tagged jets, and they don’t use the HF-score in the BDT. This may make some difference



Setting up fit of SM parameters using threshold scan

JCPC

Using QQbar_Threshold fixed-order calculation (WbWb)

- Full N3LO corrections to tt potential at the threshold (toponium bound state), including EW, Higgs, and non-resonant contributions
- Yt modifier implemented as effective dim-6 operator

$$\texttt{Yukawa\_factor} = 1 + \frac{c_{\mathrm{NP}}}{\Lambda^2}\frac{v^3}{\sqrt{2}m_t}.$$

- Top mass implemented in potential subtracted (PS scheme)
- mt(PS) ~ mt(pole) - 1 GeV (assume 171.5 GeV)

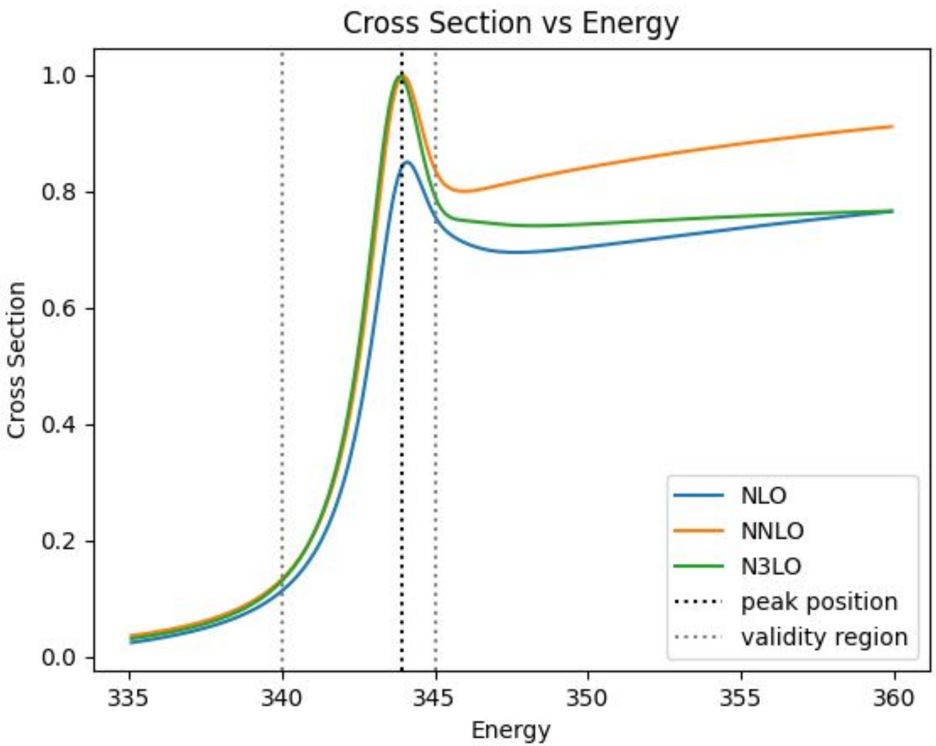
N.B. calculation only valid in the vicinity of the threshold

Perturbative convergence of calculation

- As expected, perturbative convergence is spoiled above production threshold (missing matching with continuum)

- Based on this, we define a validity region for the calculation between 340 and 345 GeV
  - Will focus on this region in the following

Note: matched calculations are available, but only at NLO QCD [Ref]

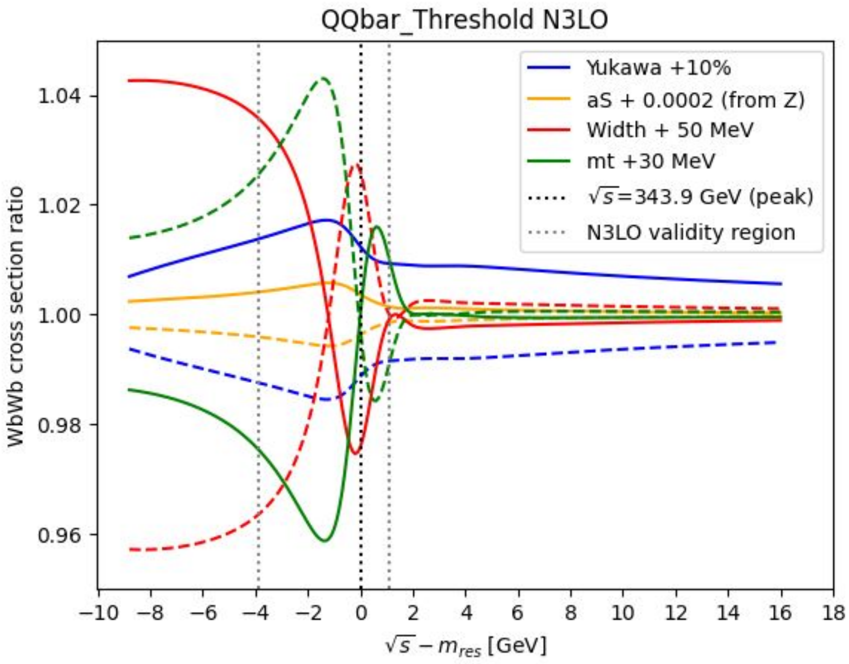


Sensitivity to SM parameters

- Highest sensitivity to mt at around -1.4 GeV from peak
- Total width well constrained below threshold and at the peak
- Some residual sensitivity to Yukawa at peak +1 GeV

- Sensitivity to aS small compared to Z peak (corresponding to variation)

- **IF** sensitivity to aS vanishes above threshold, a measurement at (say) 365 GeV would be very beneficial
  - In contact with Davide Pagani on this point



Note: for mt, width, and yt, very similar picture at lower orders (see backup)

Summary of phenomenological study

- A **simultaneous fit of mt, total width, and yt** seems possible based on a threshold scan of [-4,+1] GeV around the threshold

- 30 (50) MeV shift in mass (width) induce a 4% shift in the xsec
- 10% shift in Yukawa produce a ~1% effect just above threshold
- Limited impact from aS assuming expected precision at Z pole

- Some residual sensitivity to yt above threshold -> we will investigate the possibility of **one additional scan point well above threshold** (continuum)

- Presented studies do not include impact from ISR and beam energy resolution, which can be significant -> will be included at next update

Outlook: putting the pieces together

- We can make realistic scenarios for the tt threshold scan and extract the relevant parameters (including 2 vs 4 IP)
- It will be interesting to see if we can somewhat match HL-LHC for the top Yukawa with 0.58/ab/y * 4y * 4 IP (*.85 eff) ~ 8/ab at 365 GeV

Working point	Z, years 1-2	Z, later	WW, years 1-2	WW, later	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94		157, 163		240	340–350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	70	140	10	20	5.0	0.75	1.20
Lumi/year (ab^{-1})	34	68	4.8	9.6	2.4	0.36	0.58
Run time (year)	2	2	2	0	3	1	4
Number of events	$6\,10^{12}$ Z		$2.4\,10^{8}$ WW		$1.45\,10^{6}$ HZ + 45k WW $\rightarrow$ H	$1.9\,10^{6}$ $t\bar{t}$ +330k HZ +80k WW $\rightarrow$ H	

BACKUP

Parameter variations at NLO and NNLO