Finite Width Effects in Higgs Searches

Nikolas Kauer
University of Edinburgh

Physics at TeV Colliders Workshop, Les Houches

May 26–June 6, 2003

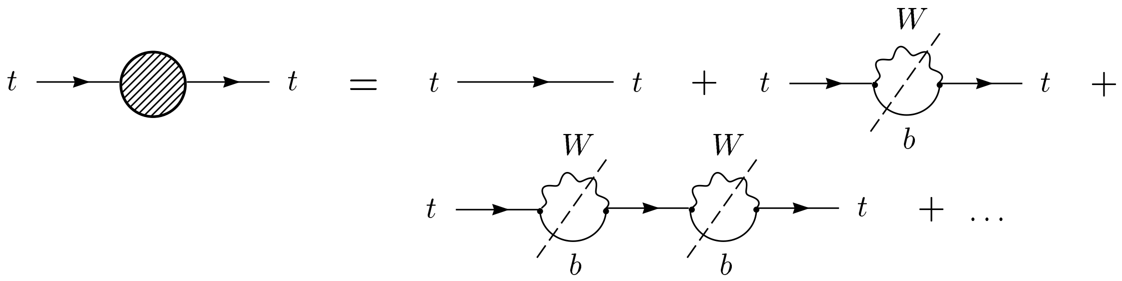
Overview

Unstable Particles in Perturbation Theory

LO propagators for heavy SM particles (W, Z, t):

$$\frac{-i}{p^2-m^2}\left(g_{\mu\nu}-\frac{p_\mu p_\nu}{m^2}\right)\ ,\quad \frac{i(\not{p}+m)}{p^2-m^2}$$

Fixed-order propagator: real pole @ $p^2=m^2$



$$\frac{i}{\not{p}-m_t}\sum_{n=0}^{\infty}\left((-i\Pi_t)\frac{i}{\not{p}-m_t}\right)^n=\frac{i}{\not{p}-m_t-\Pi_t}$$

$$\mathrm{Im}\,\Pi_t=-\frac{1}{64\pi}\frac{g^2}{m_W^2}\left(1-\frac{m_W^2}{p^2}\right)^2(2m_W^2+p^2)\,\not{p}\,P_L$$

Resonant region: $-\mathrm{Im}\,\Pi_t\approx m_t\Gamma_t$

Breit-Wigner propagator:

$$\frac{i(\not{p}+m_t)}{p^2-m_t^2+im_t\Gamma_t}$$

Dyson-resummed prop.: complex pole @ $p^2=m^2-im\Gamma$

► Physical fixed-order amplitudes with unstable particles include contributions from all orders in perturbation theory

Practical Finite Width Schemes (FWS)

Narrow Width Approximation (NWA)

$$\frac{1}{(p^2-m^2)^2+(m\Gamma)^2} \xrightarrow{\Gamma\to 0} \frac{\pi}{m\Gamma}\,\delta(p^2-m^2)$$

unsafe for exclusive cross sections

Fixed Width Scheme (FWS)

$$\frac{1}{p^2-m^2} \longrightarrow \frac{1}{p^2-m^2+im\Gamma}$$

gauge variant

Complex Mass Scheme (CMS)

$$m \longrightarrow \sqrt{m^2 - i\,m\,\Gamma}$$

Overall Factor Scheme (OFS)

$$\mathcal{M}_{\Gamma=0}\cdot\frac{p^2-m^2}{p^2-m^2+im\Gamma} = \mathcal{M}_{\Gamma\neq 0} + \mathcal{M}_{\Gamma=0}\cdot\frac{p^2-m^2}{p^2-m^2+im\Gamma}$$

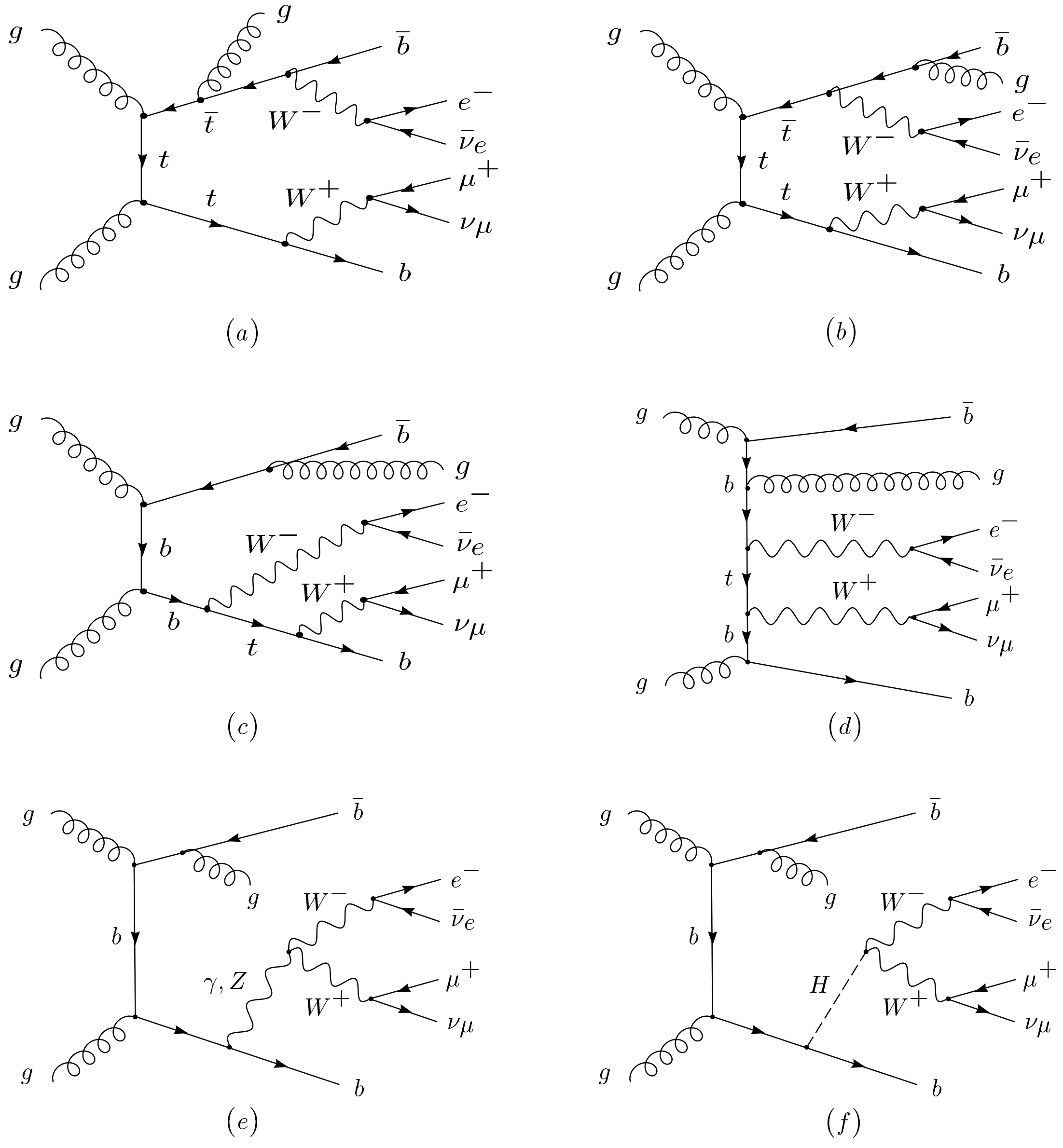
$$\frac{1}{p^2-m^2}\cdot\frac{p^2-m^2}{p^2-m^2+im\Gamma} \longrightarrow \frac{1}{p^2-m^2+im\Gamma}$$

unsafe for cross sections with complex resonance structure

Top Pair Production @ LHC

N. K., *Phys. Rev.* **D67** (2003) 054013

FWS comparison with **complete** tree-level matrix elements:



- complex resonance structure
- important background to many Higgs searches

Parton-Level Processes

$t\bar{t}$ production:

$$gg \to b\bar{b}\,\mathcal{W}\,, \quad q\bar{q} \to b\bar{b}\,\mathcal{W}$$

$t\bar{t}$ + 1 jet production:

$$gg \to b\bar{b}\,\mathcal{W}\;g\,, \quad q\bar{q} \to b\bar{b}\,\mathcal{W}\;g$$

$$qg \to b\bar{b}\,\mathcal{W}\;q\,, \quad \bar{q}g \to b\bar{b}\,\mathcal{W}\;\bar{q}$$

$t\bar{t}$ + 2 jet production:

$$gg \to b\bar{b}\,\mathcal{W}\;gg\,, \quad q\bar{q} \to b\bar{b}\,\mathcal{W}\;gg$$

$$qg \to b\bar{b}\,\mathcal{W}\;qg\,, \quad \bar{q}g \to b\bar{b}\,\mathcal{W}\;\bar{q}g$$

$$gg \to b\bar{b}\,\mathcal{W}\;q\bar{q}\,, \quad q\bar{q} \to b\bar{b}\,\mathcal{W}\;q\bar{q}$$

$$qq \to b\bar{b}\,\mathcal{W}\;qq\,, \quad \bar{q}\bar{q} \to b\bar{b}\,\mathcal{W}\;\bar{q}\bar{q}$$

di-lepton and single-lepton decay modes:

$$\begin{aligned} \mathcal{W}_{\text{di-lepton}} &= \ell^+\nu\;\ell^-\nu \\ \mathcal{W}_{\text{single-lepton}} &= \ell^+\nu\;q_d\bar{q}_u \end{aligned}$$

computational complexity:

increases by factor > 10 for each additional jet

Inclusive Effects

Collider	σ_{NWA}	σ_{FWS}	$\frac{\sigma_{\text{FWS}}}{\sigma_{\text{NWA}}}$
LHC	5.86×10^3	6.19×10^3	1.06
Tevatron	63.0	62.9	1.00

Collider	$\frac{\sigma_{gg,\text{FWS}}}{\sigma_{gg,\text{NWA}}}$ $\left(\frac{\sigma_{gg,\text{FWS}}}{\sigma_{\text{FWS}}}\right)$	$\frac{\sigma_{q\bar{q},\text{FWS}}}{\sigma_{q\bar{q},\text{NWA}}}$ $\left(\frac{\sigma_{q\bar{q},\text{FWS}}}{\sigma_{\text{FWS}}}\right)$
LHC	1.06 (88%)	1.00 (12%)
Tevatron	1.10 (05%)	0.99 (95%)

PDF set	σ_{NWA}	σ_{FWS}	$\sigma_{\text{FWS}}/\sigma_{\text{NWA}}$
CTEQ6L	5.86×10^3	6.19×10^3	1.06
CTEQ4L	7.18×10^3	7.58×10^3	1.06

Scheme	σ	$\sigma/\sigma_{\text{NWA}}$
NWA	5.86×10^3	1.00
FWS	6.19×10^3	1.06
CMS	6.19×10^3	1.06
OFS	6.18×10^3	1.06

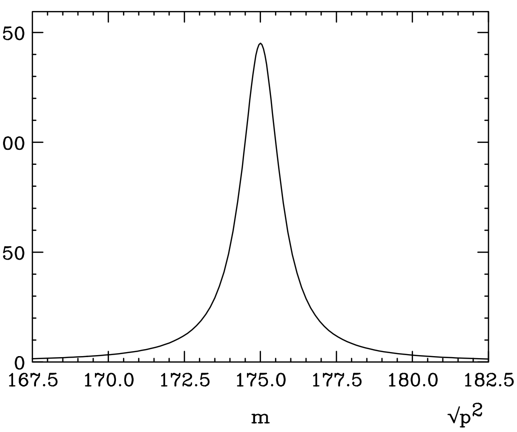
Narrow Width vs. Leading Pole Approximation

	$\sigma_{\text{CMS}}/\sigma_{\text{NWA}}$ ($\sigma_{\text{CMS}}/\sigma_{\text{DPA}}$)		
	di-lepton	single-lepton	all-jet
Tevatron	1.00 (1.01)	1.01 (1.02)	1.01 (1.02)
LHC	1.06 (1.06)	1.07 (1.07)	1.07 (1.07)
VLHC	1.06 (1.06)	1.07 (1.06)	1.08 (1.07)

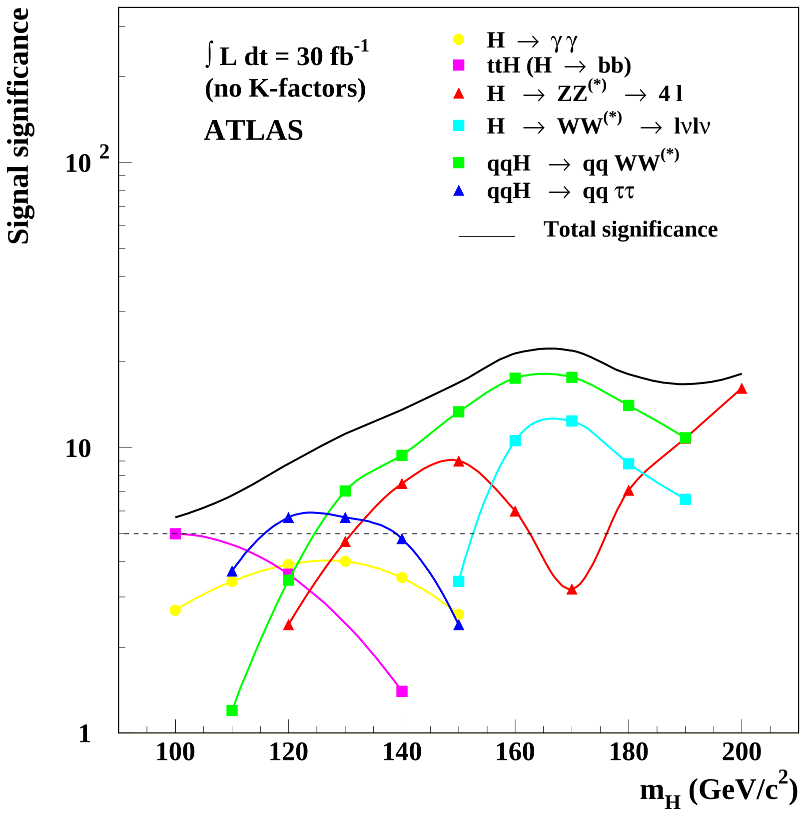
$$\Gamma_t/m_t = 0.009$$

$$\frac{1}{(p^2-m^2)^2+(m\Gamma)^2} \xrightarrow{\Gamma\to 0} \frac{\pi}{m\Gamma}\,\delta(p^2-m^2)$$

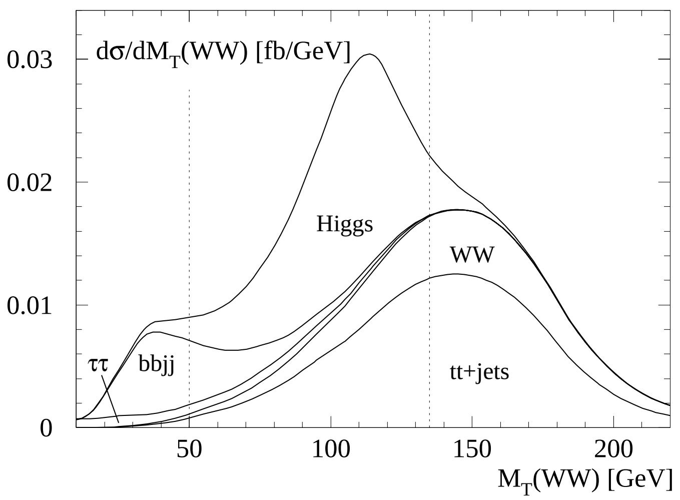
$$\int \frac{1}{(p^2-m^2)^2+(m\Gamma)^2}\; dp^2 = \frac{\pi}{m\Gamma}$$



Standard Model Higgs Search



March 2003 (ATL-PHYS-2003-005)



Light SM Higgs

115 GeV $< m_H <$ **130 GeV**

$H \to WW \to \ell^\pm \ell^\mp \not{p}_T$ in Weak Boson Fusion

	$t\bar{t}$		$t\bar{t}j$		$t\bar{t}jj$	
	σ	$\sigma/\sigma_{\text{NWA}}$	σ	$\sigma/\sigma_{\text{NWA}}$	σ	$\sigma/\sigma_{\text{NWA}}$
NWA	0.020	1.0	0.94	1.0	0.24	1.0
FWS	0.044	2.1	1.08	1.1	0.24	1.0
CMS	0.044	2.1	1.07	1.1	0.24	1.0
OFS	0.044	2.1	1.07	1.1	0.24	1.0

N. K., T. Plehn, D. Rainwater, D. Zeppenfeld, *Phys. Lett.* **B503** (2001) 113

N. K., *Phys. Rev.* **D67** (2003) 054013

$H \to \tau\tau \to \ell^\pm \ell^\mp \not{p}_T$ in Weak Boson Fusion

	$t\bar{t}$		$t\bar{t}j$	
	σ	$\sigma/\sigma_{\text{NWA}}$	σ	$\sigma/\sigma_{\text{NWA}}$
NWA*	0.00303	1.0	0.257	1.0
OFS	0.00365	1.2	0.293	1.1

* T. Plehn, D. Rainwater, D. Zeppenfeld, *Phys. Rev.* **D61** (2000) 093005

N. K. and D. Zeppenfeld, *Phys. Rev.* **D65** (2002) 014021

Intermediate Mass SM Higgs

150 GeV $< m_H <$ **190 GeV**

$H \to WW \to \ell^\pm \ell^\mp \not{p}_T$ in Weak Boson Fusion

	$t\bar{t}$		$t\bar{t}j$	
	σ	$\sigma/\sigma_{\mathrm{NWA}}$	σ	$\sigma/\sigma_{\mathrm{NWA}}$
NWA*	0.0113	1.0	0.93	1.0
OFS	0.0158	1.4	1.09	1.2

* D. Rainwater and D. Zeppenfeld, *Phys. Rev.* **D60** (1999) 113004

N. K. and D. Zeppenfeld, *Phys. Rev.* **D65** (2002) 014021

$H \to WW \to \ell^\pm \ell^\mp \not{p}_T$ in Gluon Fusion

	$t\bar{t}$	
	σ	$\sigma/\sigma_{\mathrm{NWA}}$
NWA	2.73	1.0
NWA $(t\bar{t} + Wtb)^*$	7.17	2.6
OFS	4.09	1.5

* K. Jakobs and T. Trefzger, ATL-PHYS-2000-015 (2000)

N. K. and D. Zeppenfeld, *Phys. Rev.* **D65** (2002) 014021

Beyond SM Scalar Searches

$$gg \longrightarrow H^{\pm}tb \quad \text{and} \quad H^{\pm} \longrightarrow \tau\nu$$

	σ	$\sigma/\sigma_{\text{NWA}}$
NWA	0.343	1.00
NWA $(t\bar{t} + Wtb)^*$	0.485	1.41
FWS	0.376	1.09
CMS	0.378	1.10
OFS	0.364	1.06

*K. Assamagan and Y. Coadou, ATL-PHYS-2000-031 (2000)

N. K., *Phys. Rev.* **D67** (2003) 054013

$$\text{Radion} \longrightarrow hh \longrightarrow b\bar{b}\tau^{+}\tau^{-}$$

	σ	$\sigma/\sigma_{\text{NWA}}$
NWA*	3.27	1.00
FWS	3.36	1.03
CMS	3.34	1.02
OFS	3.17	0.97

*G. Azuelos *et al.*, SN-ATLAS-2002-019 (2002)

N. K., *Phys. Rev.* **D67** (2003) 054013

Additional Jets: PS vs. ME

PYTHIA:

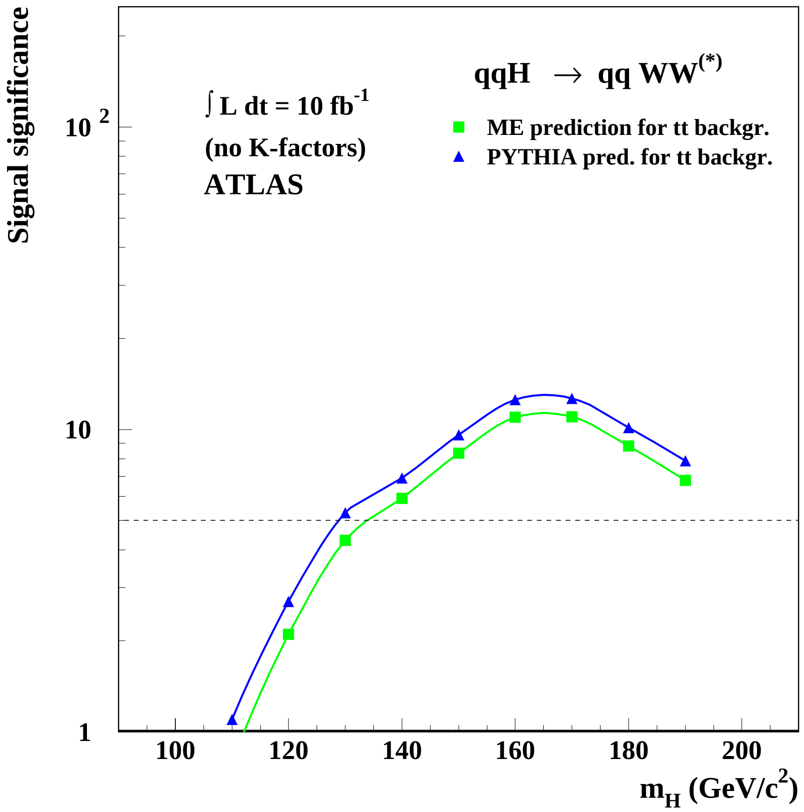
- $t\bar{t}$ matrix element
- additional jets from parton shower

Not appropriate for additional hard jets!

$t\bar{t}$ + jets background in NWA to $H \to WW$ in WBF:

	$t\bar{t}$ + 1 jet	$t\bar{t}$ + 2 jets
PYTHIA	0.40 fb	0.07 fb
ME/PS interface	0.78 fb	0.25 fb

C. Buttar, R. Harper, K. Jakobs, ATL-PHYS-2002-033 (2002)



Les Houches Accord:

generic matrix element/parton shower interface

E. Boos *et al.*, hep-ph/0109068

Matrix elements with additional jets essential!

Conclusions

- complete, exact $t\bar{t}$ + jets cross sections @ LO
- sizable effects for important backgrounds
- narrow width approximation not appropriate
- fixed width and complex mass schemes consistent
- overall factor scheme can be too low
- $\sigma_{\text{NWA}}(t\bar{t}) + \sigma_{\text{NWA}}(Wtb)$ double counts contributions
- matrix elements with additional jets essential

Outlook

- objective: total background rates with 10% accuracy
- larger absolute background uncertainty at LO
- measure background rates outside signal region and extrapolate

$$\sigma_{bkg} = \underbrace{\sigma_{ref}}_{\text{low experim. uncertainty}} \cdot \underbrace{\left(\frac{\sigma_{bkg,\,\text{LO}}}{\sigma_{ref,\,\text{LO}}}\right)}_{\text{low theoret. uncertainty}}$$

Tasks

- optimize background and reference cross sections
- determine theoretical value and uncertainty of $\sigma_{bkg,\text{LO}}/\sigma_{ref,\text{LO}}$ with programs that properly include all important matrix element contributions