Effective K-factors for $gg \rightarrow H \rightarrow WW \rightarrow l\nu l\nu$ at the LHC

(for details see: G.Davatz, G.Dissertori, M.Dittmar, M.Grazzini, F.Pauss, *hep-ph/0402218*)

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MC Tools, HERA LHC Workshop, 27 March 2004

Outline

- Motivation: include higher order QCD corrections
- Reconsider Higgs search
  $gg \to H \to WW \to l\nu l\nu$, $M_H \approx 165$ GeV
- Method to include QCD corrections:
  Reweight PYTHIA with effective K-factors
- HO QCD results for this channel

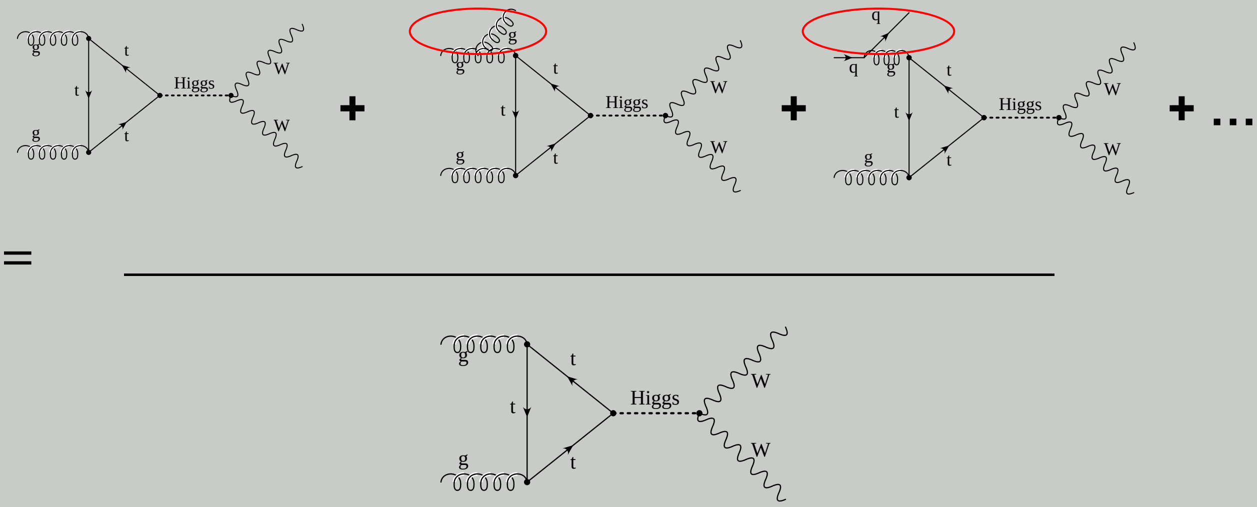
Motivation

- Many reactions now known to NLO
- **gg→H** σ_{tot} known to **NNLO**
  (about a factor 2 larger than LO cross section!)
- However: so far **no complete higher order MC**
- Old method: scale MC results with K_{inc}

  this method ok if cuts **not dependent on kinematics**

Motivation

$$K_{inc} = \frac{\sigma(\text{higher order})}{\sigma(\text{LO})} =$$



Motivation

- **gg→ H→WW →lνlν requires jetveto**
  (Dittmar, Dreiner, Phys.Rev. D 55 (1997) 167)

- **once a jetveto used, simple scaling with K_{inc} wrong!**
  (Catani, de Florian, Grazzini, jhep 0201 (015))

→ Want a realistic inclusion of HO corrections!

Some Definitions

- LO = Leading order

  For theorists: parton level LO → p_T Higgs =0
  For experimentalists (using parton shower Monte Carlos): p_T Higgs ≠0

- N(N)LO= next to (next to) leading order
  up to N jets → p_T Higgs ≠ 0

  Consider use of jetveto in e.g. PYTHIA:
  high p_T Higgs will never be seen, efficiency dependent on p_T Higgs

→ determine efficiency with PYTHIA as function of p_T Higgs,
use NNLO p_T Higgs spectrum → cuts on weighted events

apply method to e.g **gg→H→WW→lνlν**

Some Definitions

K-factors:

1. $$k(p_T) = \frac{\sigma(p_T)(\text{higher order})}{\sigma(p_T)(\text{LO PYTHIA})}$$

2. $\int k(pT)\, dpT = K_{inc}$

3. $\int k(p_T) \cdot \varepsilon(p_T)\, dp_T = K_{eff}$, $K_{eff} \leq K_{inc}$

   $\varepsilon(p_T)$ = efficiency per p_T bin

$gg \to H \to WW \to l\nu l\nu$ signal selection, M_H = 165 GeV

Cuts based on Phys. Rev. D 55 (1997) 167 and CMS Note 1997-083, M.Dittmar, H.Dreiner

Signal:

$gg \to H \to WW \to l\nu l\nu$

2 isol. leptons, missing p_T, no jets

easy removable background:

$pp \to ZZ \to 4l, 2l2\nu, 4\nu$
$pp \to WZ \to l\nu l\bar{l}$
$pp \to Z^*/g^* \to l\bar{l}$

} removed with $M_{ll} \neq M_Z$

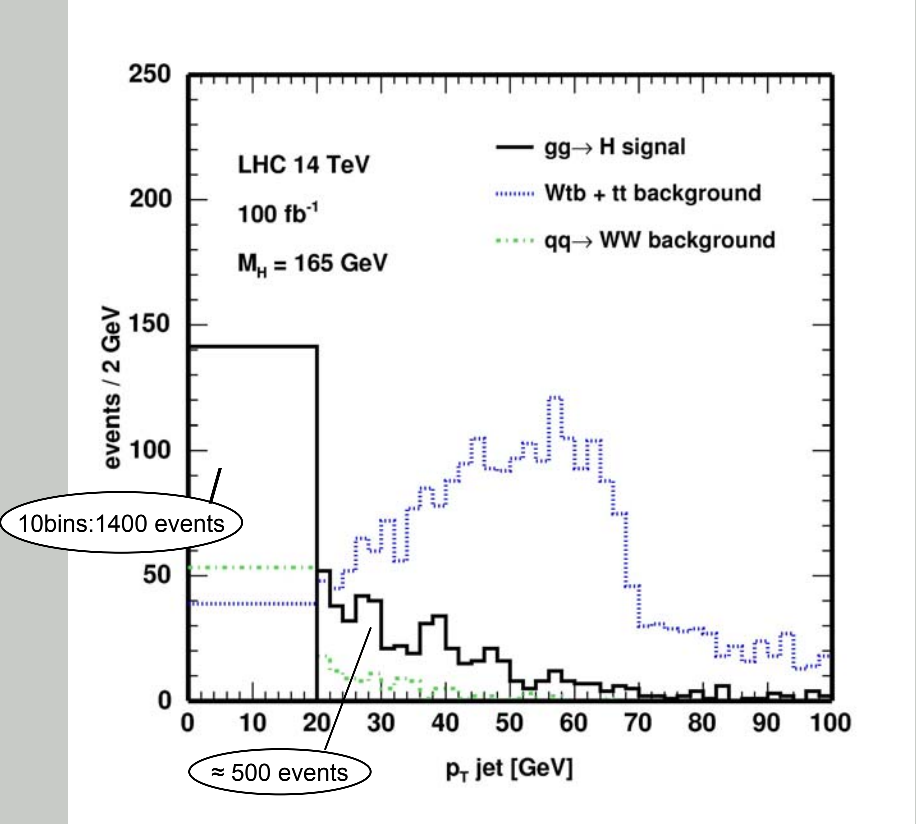
'irreducible' background

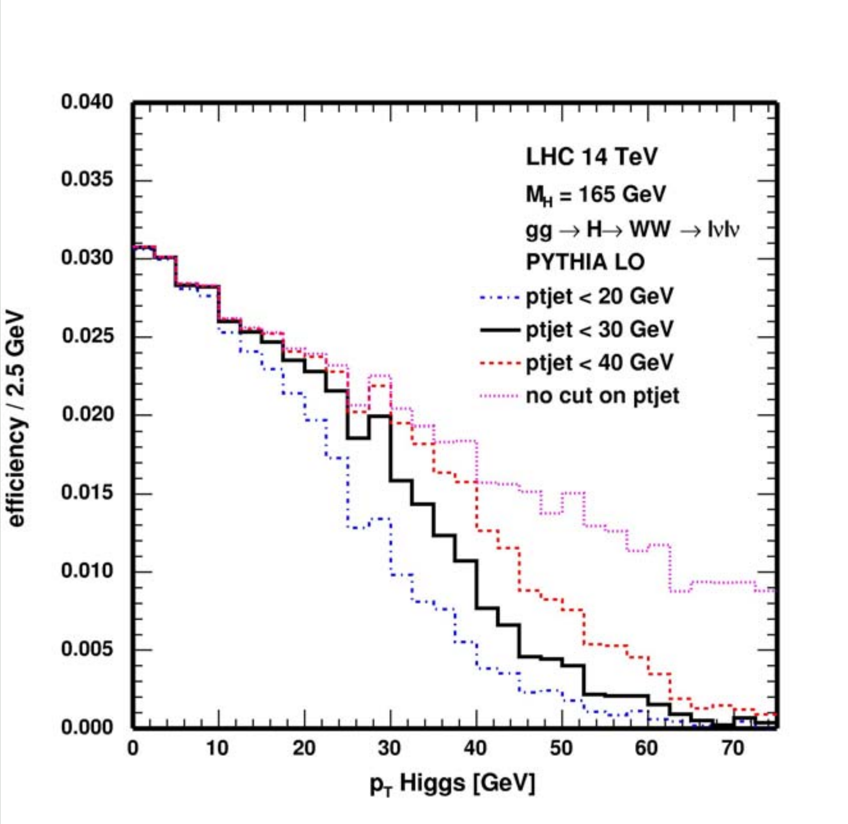
Nonresonant **WW** production, **ttbar** and **Wtb** :

$pp \to WW \to l\nu l\nu$	[7.38 pb]	cut on angle betw. l's, M_{ll}, p_T l's
$pp \to ttbar \to bWbW \to bl\nu\ bl\nu$	[52 pb]	} jetveto (cut on p_T jet)
$pp \to Wtb \to WbWb \to l\nu bl\nu b$	[5.2 pb]	

Study with PYTHIA 6.210 and simple CMS geometrical acceptance

All cuts applied except jetveto:





Proposed jetveto: 30 GeV

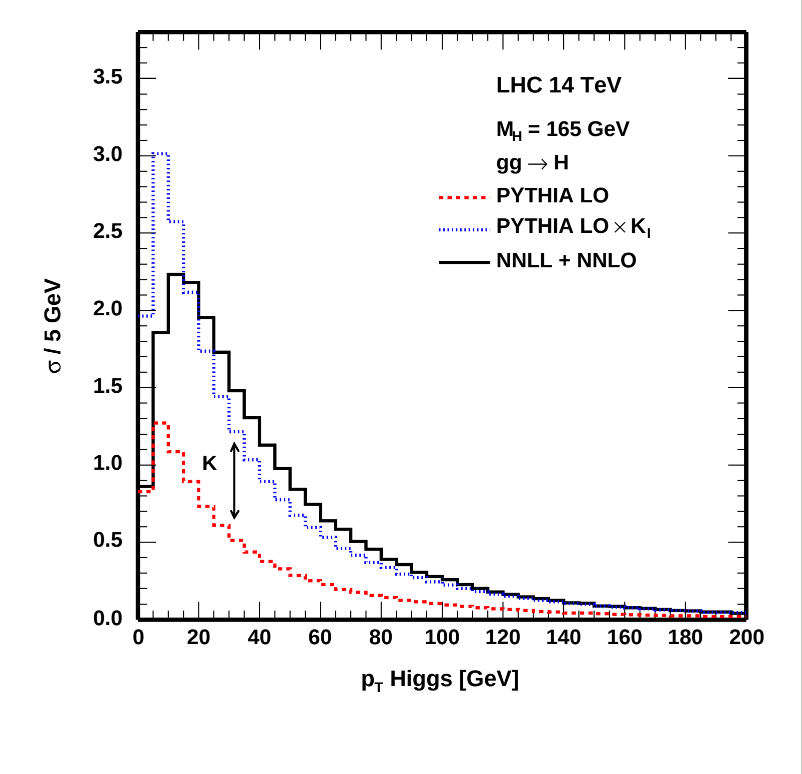
$p_T$jet ≈ p_THiggs

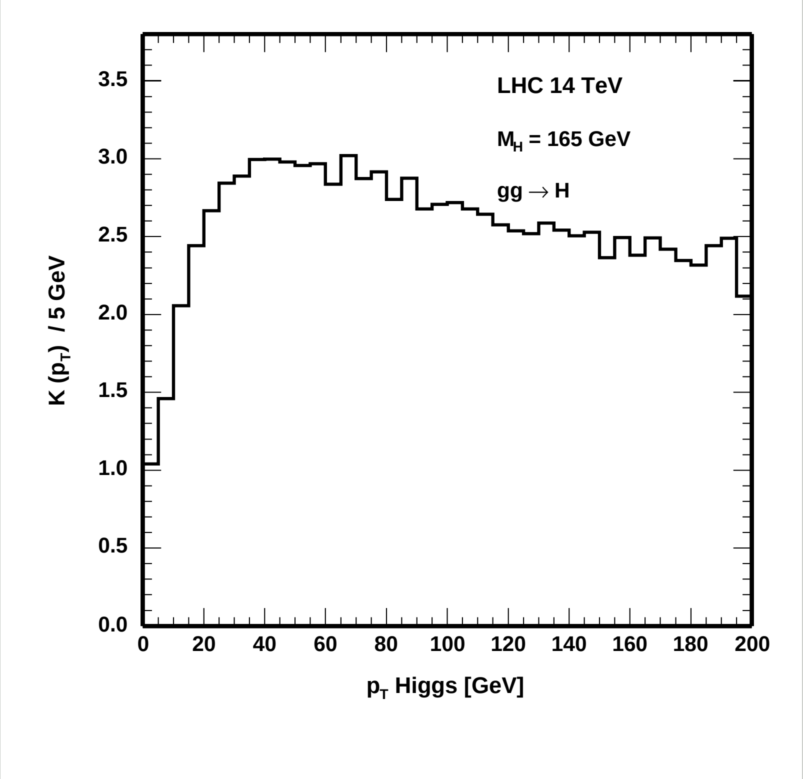
Number of events for 5 fb^{-1}:

Process M_H = 165 GeV	$\sigma_{LO\ PYTHIA}$ * BR² [pb]	All cuts applied except cut on p_T lepton	$35 < p^l_{Tmax} < 50$ GeV	25 GeV $< p^l_{Tmin}$
gg→H→WW	1.06	176	110	80
qq→WW	7.38	243	83	30
ttbar	52	47	15	5
Wtb	5	87	46	26

→ **S/B = 1.3, required Luminosity for 5 S/√B : 1.1 fb^{-1}**

Higgs p_T spectrum in PYTHIA and NNLL + NNLO, M_H=165 GeV

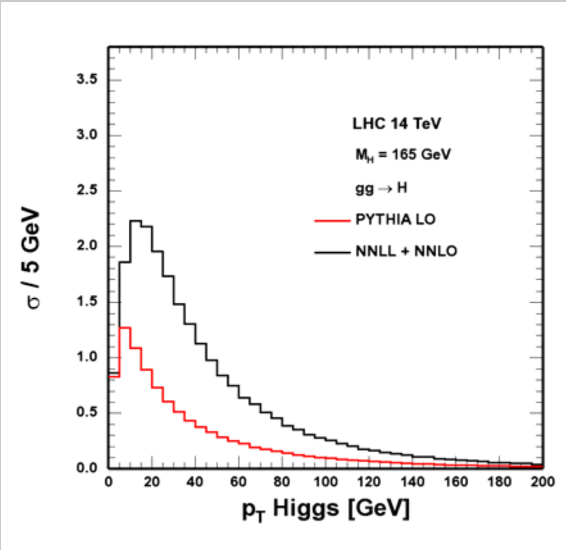


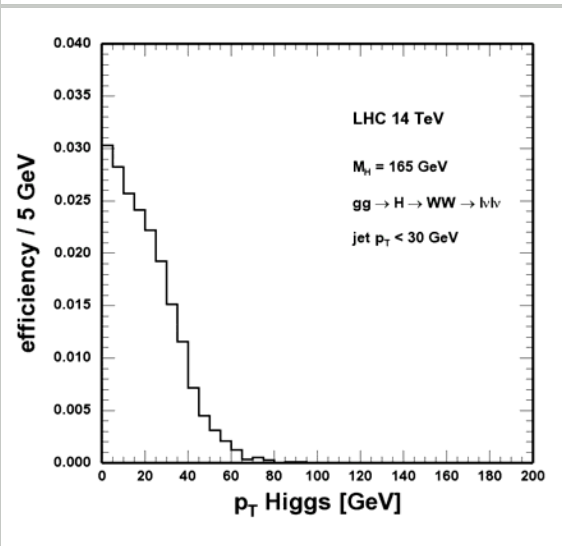


Higgs production σ in NNLL+NNLO and LO PYTHIA

k(p_T) depends strongly on p_T Higgs

Combine p_T-spectrum with efficiency





→

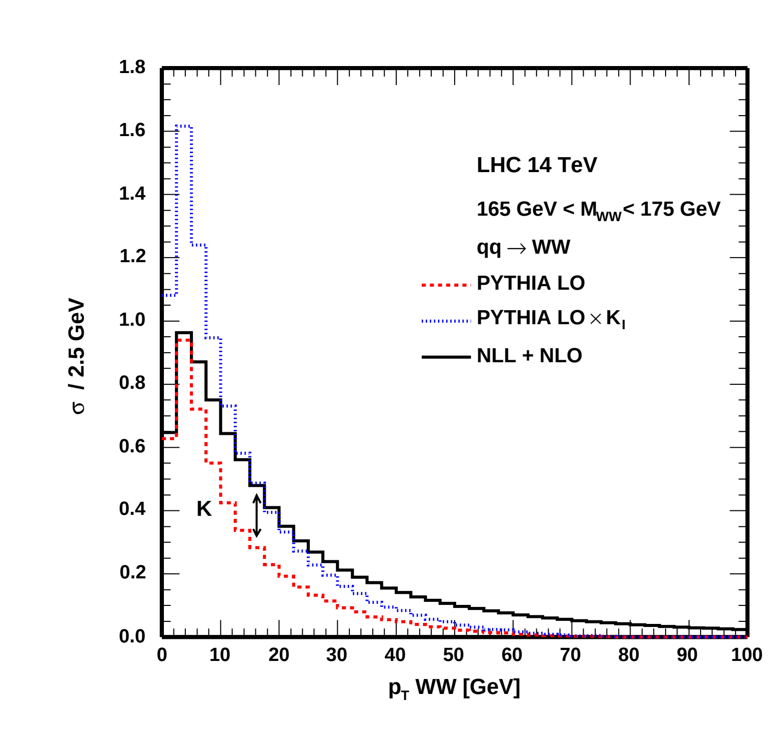
High p_T Higgs:
Even if σ HO 10 mb would not matter!

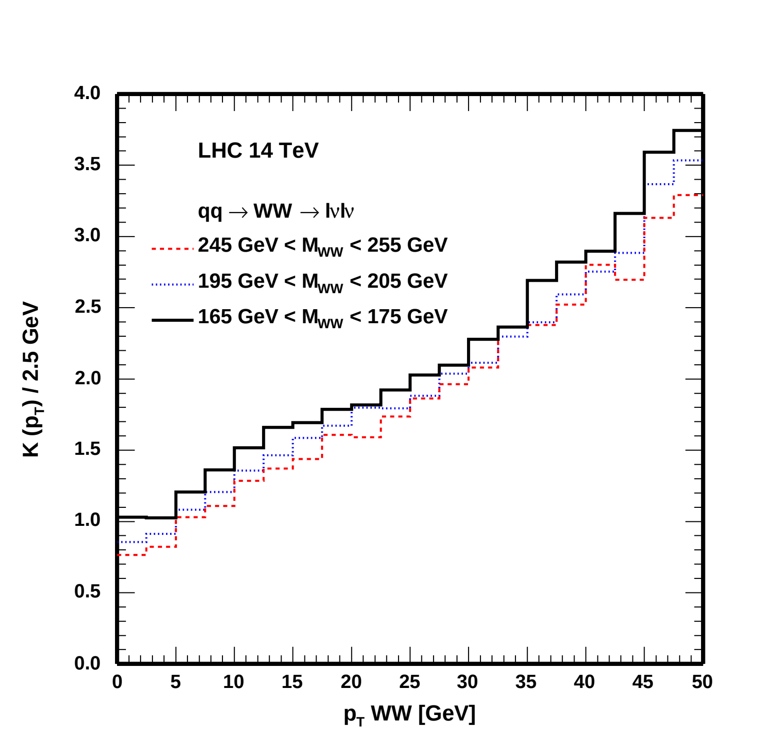
$$\int k(p_T) \cdot \varepsilon(p_T)\, dp_T = K_{eff}$$

NNLO+NNLL and LO PYTHIA σ's, corresponding K_{inc} and K_{eff} for M_H =140, 165 and 180 GeV

M_H [GeV]	$\sigma_{NNLO+NNLL}$ [pb]	σ_{PYTHIA} [pb]	K_{Incl}	K_{eff}
140	31.79	12.82	2.48	2.25
165	23.08	9.74	2.37	2.04
180	19.38	8.40	2.30	2.03

Same procedure for dominant background





qq→WW σ in NLL+NLO and LO PYTHIA, M_{WW} = 170±5 GeV

p_T WW dependent K-factor for 3 different WW masses

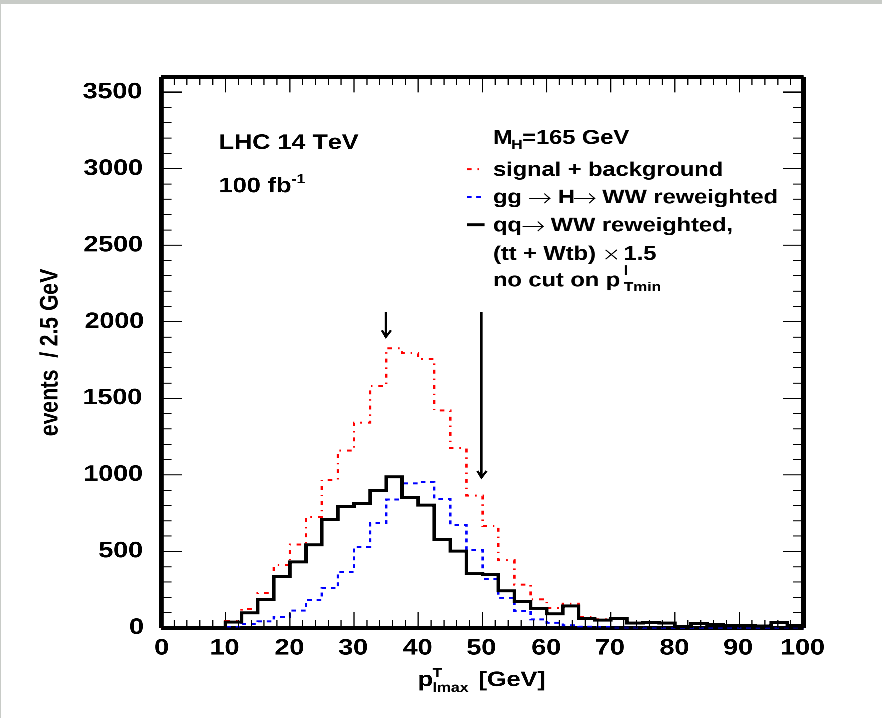
High p_T→ K would be very large

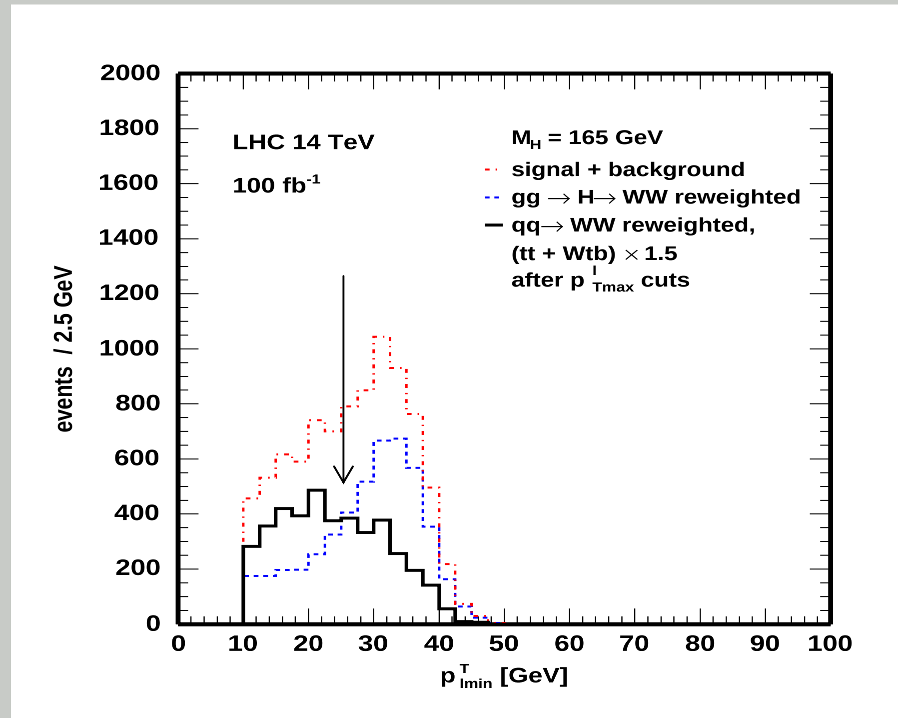
K-factor depends slightly on M_{WW}

For Wtb and ttbar background: no p_T spectra in higher order

→ Wtb and ttbar background weighted with incl. K-factor of 1.5

Signal shows Jacobian peak





p_T spectrum of leptons, higher order QCD corrections included

of S and B for $5\ fb^{-1}$ after reweighting

Signal: M_H =140 GeV: K_{eff} = 2.25

M_H =165 GeV: K_{eff} = 2.04

M_H =180 GeV: K_{eff} = 2.03

K_{eff} for WW background: 1.36

K-factor for ttbar and Wtb backgrounds: 1.5

M_H [GeV]	S	WW	Wtb	ttbar	S/B	$\frac{S}{\sqrt{B}}$
140	106	158	87	34	0.38	6
165	162	44	40	7	1.78	17
180	48	23	17	7	1.02	7

Summary

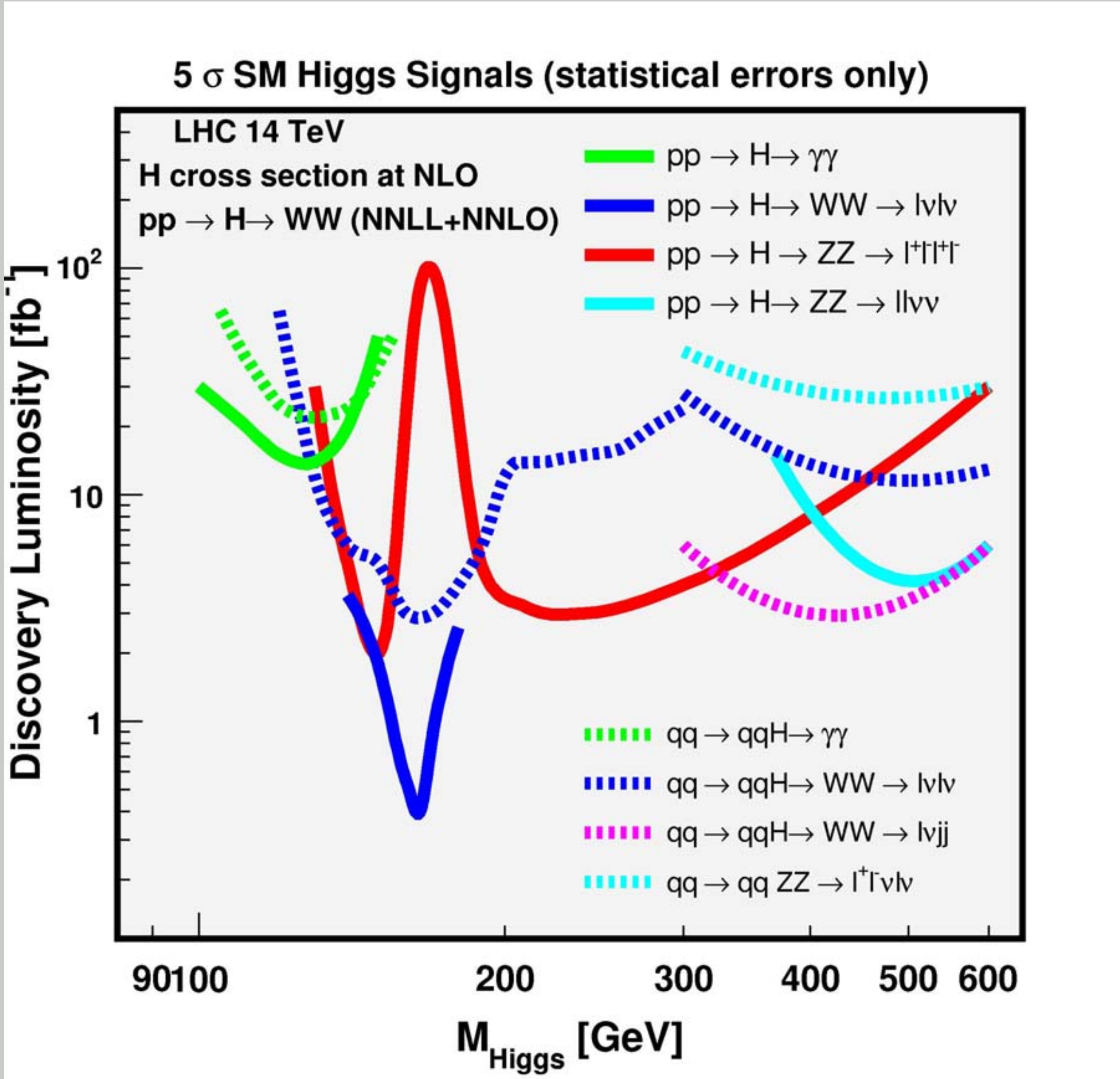
- **Event weighting procedure allows to include higher order corrections in parton shower Monte Carlos**

- **For a Higgs mass between 140 and 180 GeV, effective K-factor only about 15% smaller than inclusive K-factor**

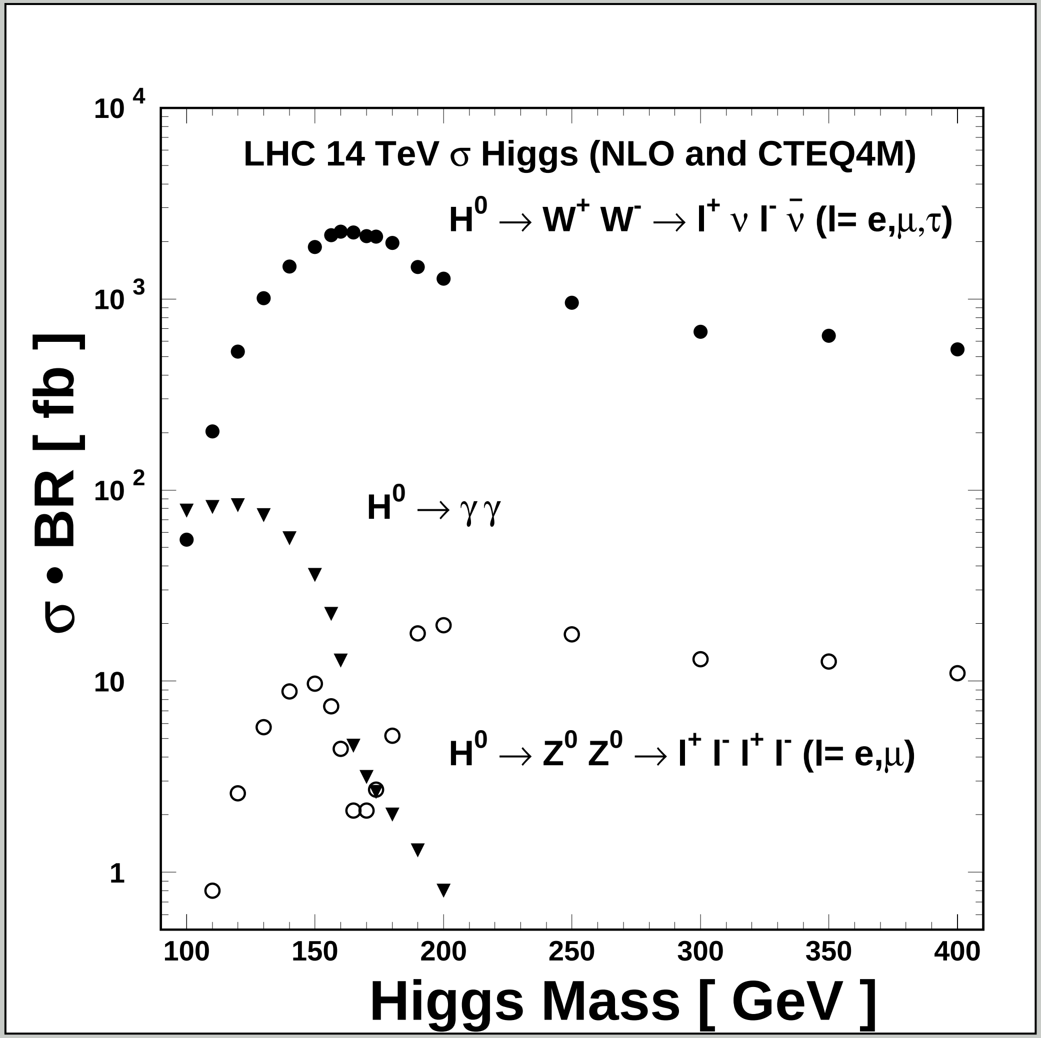
- **Higgs discovery potential in mass range between 140 and 180 GeV increased by about a factor 2 by including higher order corrections**

- **For M_H = 165 GeV, statistical significance of 5 standard deviations can be achieved with an integrated Lumi of 0.4 fb^{-1} !**

backup



5 σ SM Higgs Signals (statistical errors only)
LHC 14 TeV
H cross section at NLO
pp → H→ WW (NNLL+NNLO)
pp → H→ γγ
pp → H→ WW → lνlν
pp → H → ZZ → l+l-l+l-
pp → H→ ZZ → llνν
qq → qqH→ γγ
qq → qqH→ WW → lνlν
qq → qqH→ WW → lνjj
qq → qq ZZ → l+l-νlν
Discovery Luminosity [fb-1]
10²
10
1
90100
200
300
400
500
600
M Higgs [GeV]


LHC 14 TeV σ Higgs (NLO and CTEQ4M)
$H^0 \to W^+ W^- \to l^+ \nu l^- \bar{\nu}$ (l= e,μ,τ)
$H^0 \to \gamma\gamma$
$H^0 \to Z^0 Z^0 \to l^+ l^- l^+ l^-$ (l= e,μ)
σ • BR [fb]
Higgs Mass [GeV]
1
10
10 2
10 3
10 4
100
150
200
250
300
350
400

Cuts for $gg \to H \to WW \to l\nu l\nu$

1. 2 leptons in event, oppositely charged, with p_T min of 20 GeV, $|\eta| < 2$
2. Isolated leptons
3. Dilepton mass m_{ll} should be smaller than 80 GeV
4. The missing p_T of the event should be larger than 20 GeV
5. The 2 leptons should not be back-to back in plane transverse to beam
6. opening angle between the 2 leptons should be smaller than 45, invariant mass of lepton pair smaller than 35 GeV
7. Events with a jet with p_T larger than 30 GeV and $|\eta|$ smaller than 4.5 are removed (jetveto)
8. For M_H = 165 GeV, **pl_{Tmin} > 25 GeV, 35 < pl_{Tmax} < 50 GeV**
   For M_H = 140 GeV, **pl_{Tmin} > 20 GeV, pl_{Tmax} > 20 GeV**
   For M_H = 180 GeV, **pl_{Tmin} > 25 GeV, pl_{Tmax} > 45 GeV**

- To reduce **top events**:

  jet-veto required → p_T **jet < 30 GeV**

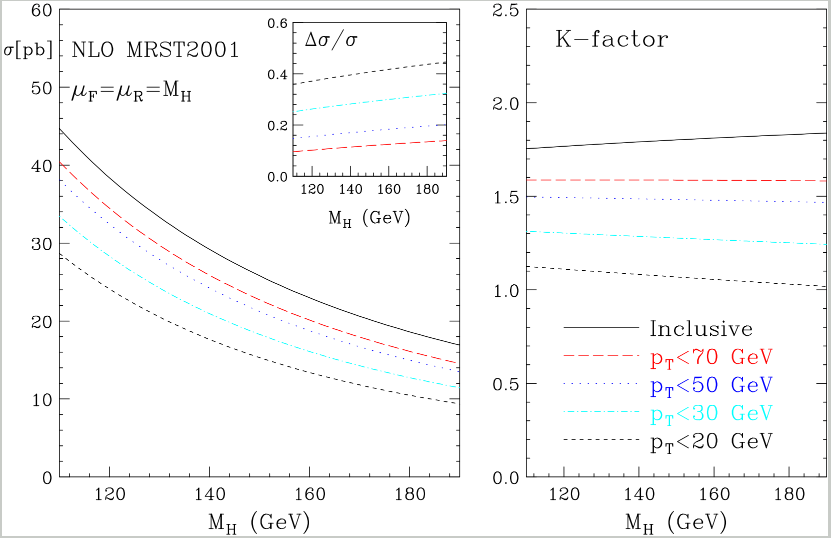
- To reduce **continuous WW** background:

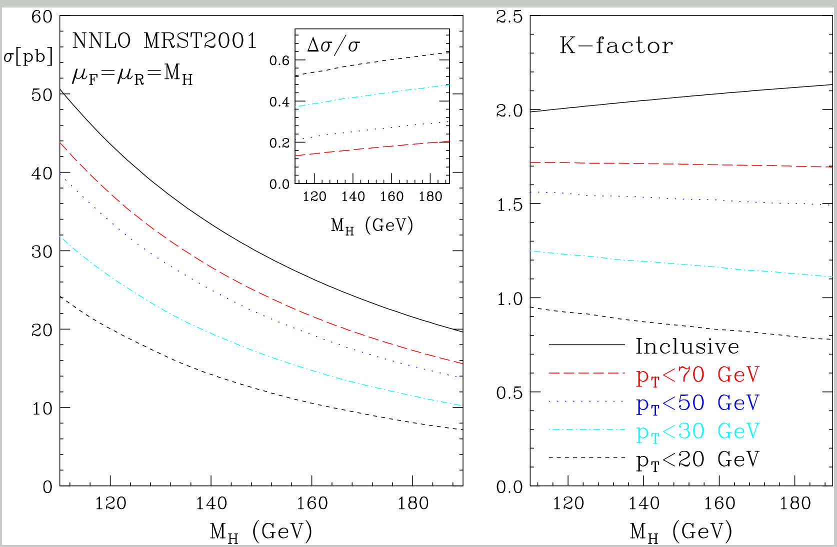
1. Signal has shorter rapidity plateau than bg
2. Spin correlations, mass of resonant and non-resonant WW-system
   → small opening angle and mass-dependent p_T - spectrum required for leptons

→ **opening angle between leptons** in plane transverse to beam axis **< 45°**,
inv. mass of lepton pair < 35 GeV

→ for Higgs mass of **165** GeV, p^l_{Tmin} **> 25 GeV, 35 <** p^l_{Tmax} **< 50 GeV**
→ for Higgs mass of **140** GeV, p^l_{Tmin} **> 20 GeV,** p^l_{Tmax} **> 20 GeV**
→ for Higgs mass of **180** GeV, p^l_{Tmin} **> 25 GeV,** p^l_{Tmax} **> 45 GeV**

Cuts based on *Dittmar/Dreiner, Phys.Rev.D 55 (1997) 167*


σ[pb]
NLO MRST2001
$\mu_F=\mu_R=M_H$
$\Delta\sigma/\sigma$
M_H (GeV)
K−factor
Inclusive
p_T<70 GeV
p_T<50 GeV
p_T<30 GeV
p_T<20 GeV
M_H (GeV)


σ[pb]
NNLO MRST2001
$\mu_F=\mu_R=M_H$
$\Delta\sigma/\sigma$
M_H (GeV)
K−factor
Inclusive
p_T<70 GeV
p_T<50 GeV
p_T<30 GeV
p_T<20 GeV
M_H (GeV)