PSI

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Charged Higgs Pairs at the LHC: A NLO Analysis

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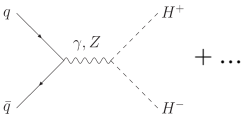
see talk by M. Spira
on Thursday

22nd Workshop of the LHC Higgs Working Group

Charged-Higgs Pair Production

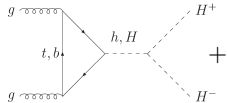
- **Charged scalars** arise naturally in extended Higgs sectors, e.g. in the **Two-Higgs-Doublet Model** (2HDM)
- Production of charged-Higgs **pairs** via:

Drell-Yan like (DY-like)

e.g. 

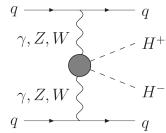
$+ \ldots$

Gluon Fusion (GF)

e.g. 

$+ \ldots$

Vector-Boson Fusion (VBF)



⭐ **Status**:

+ DY @ LO [Lane, '82; Eichten et al., '84; Deshpande et al., '84]
+ DY @ NLO-QCD [Hong-Sheng et al., '05; Alves, Plehn, '05]
+ DY @ approximate N^2LO- and N^3LO-QCD (soft-gluon correct.) [Kidonakis, Tonero, '24]

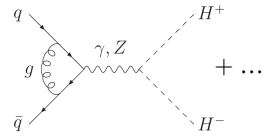
+ GF @ LO [Willenbrock, '86; Foot et al., '87; Spira et al., '97; Yi et al., '97; Bendezú, Kniehl, '99; Brein, Hollik, '99]
+ GF @ NLO-QCD [Hespel et al., '14]

+ VBF @ LO [Moretti, '01; Arroyo-Ureña et al., '25]

🌟 **NLO-QCD** corrections to DY-like, GF and VBF + analysis of uncertainties ⟵ *our work*

NLO-QCD Corrections to Charged-Higgs Pair Production

Drell-Yan like (DY-like)

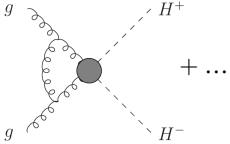
e.g. 

+ …

→ NLO-QCD known from DY

[Altarelli, Ellis, Martinelli, ’79; Kubar-Andre, Paige, ’79]

Gluon Fusion (GF)

e.g. 

+ …

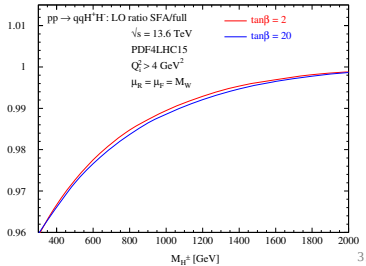
→ NLO-QCD calculated in **heavy-top limit** (HTL) from effective Lagrangian

Vector-Boson Fusion (VBF)

$$F_i(x, \mu_F^2) + \Delta F_i(x, \mu_F^2, Q^2)$$

→ NLO-QCD calculated in **structure-function approach** (SFA)

→ SFA agrees with full calculation within 3 % @ LO for $m_{H^\pm} \geq 400\,\text{GeV}$



→ 2HDM Type-I scenarios with **low**/**high** tan β

→ Obtained/checked with `ScannerS`/`HiggsTools`

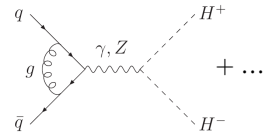
[Sampaio, Santos et al., ’13/’22; Bahl, Biekötter et al., ’23]

$\{\tan\beta = 2,\ \lambda_1 = 6.499,\ \lambda_3 = -1.459,\ \lambda_4 = 1.106,\ \lambda_5 = -0.362\}$
$\{\tan\beta = 20,\ \lambda_1 = 2.651,\ \lambda_3 = 0.2799,\ \lambda_4 = 2.392,\ \lambda_5 = 2.412\}$

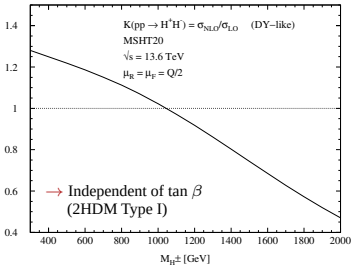
NLO-QCD Corrections to Charged-Higgs Pair Production

Drell-Yan like (DY-like)

e.g.



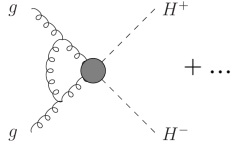
$+ \ldots$



⇒ **Moderate K-factor** up to 30 % and down to -50 % for large charged Higgs masses
(depending on used PDF set)

Gluon Fusion (GF)

e.g.



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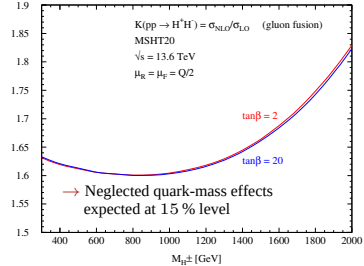
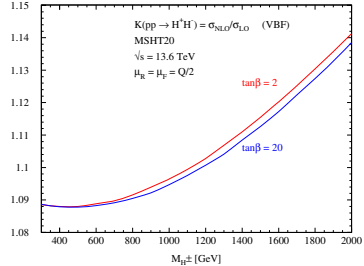


→ **Large** corrections up to $+80$ %

⇒ Highly relevant to arrive at reliable prediction

Vector-Boson Fusion (VBF)

$$F_i(x, \mu_F^2) + \Delta F_i(x, \mu_F^2, Q^2)$$



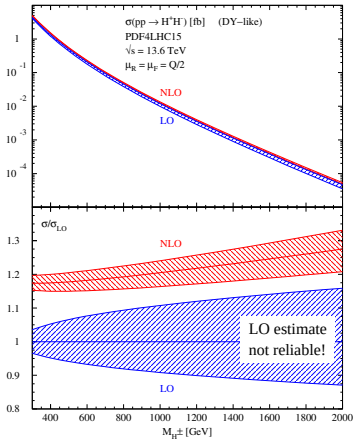
→ **Moderate** corrections of $10 - 15$ %

Scale Uncertainty

= Estimate of missing higher orders

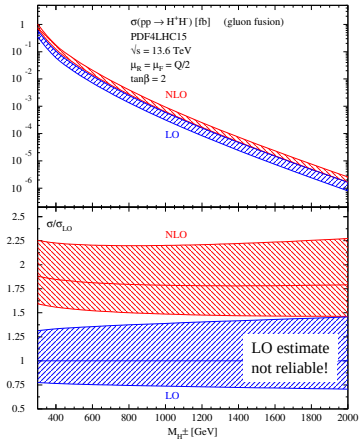
→ Renormalization and factorization scale dependence determined with 7-point method

Drell-Yan like (DY-like)



⇒ Scale uncertainties up to 5 % @ NLO and significant reduction from LO

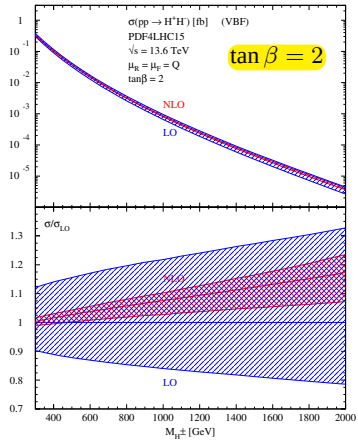
Gluon Fusion (GF)



⇒ Scale uncertainties up to 25 % @ NLO

→ Relative corrs. only minor dependent on tan β, but inclusive cross section strongly dependent on tan β

Vector-Boson Fusion (VBF)



⇒ Scale uncertainty at NLO reduced to less than $2-10$ %

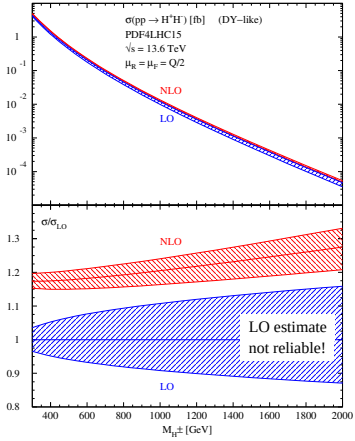
→ No relevant tan β dependence

Scale Uncertainty

= Estimate of missing higher orders

→ Renormalization and factorization scale dependence determined with 7-point method

Drell-Yan like (DY-like)



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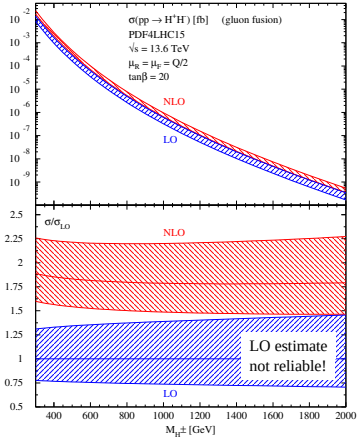

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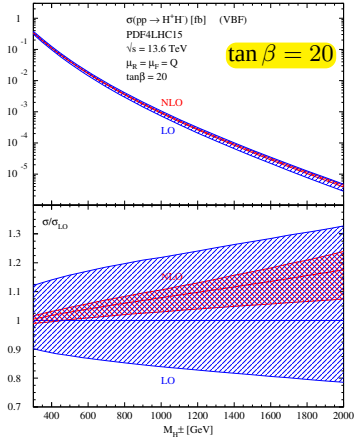
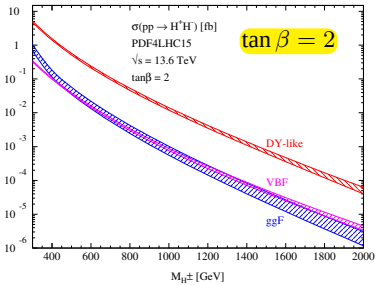
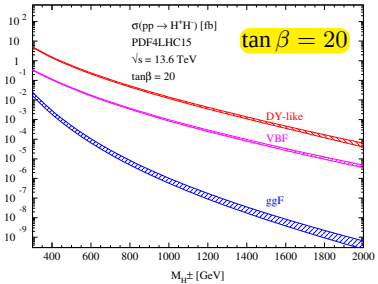


⇒ Scale uncertainty at NLO reduced to less than $2-10$ %

→ No relevant tan β dependence

Results





* charged-Di-Higgs-strahlung $q\bar{q} \to H^+H^- + Z/W$ further suppressed than GF!

- **Uncertainty bands** = PDF+α_S-uncertainty (determined with `PDF4LHC15` NLO PDFs) combined with scale uncertainty

$\to$ Combined theoretical uncertainties: DY-like: $4-22\,\%$, VBF: $3-15\,\%$ + SFA, GF: $25-45\,\%$ + finite top-mass effects

$\to$ Drell-Yan-like dominates over vector-boson and gluon fusion

$\to$ Vector-boson fusion is second largest production process in significant part of mass range (gluon fusion* can compete for small tan β, but is strongly suppressed for large tan β)

$\Rightarrow$ **Improved predictions will allow for quantitative interpretation in case charged Higgs are observed!**

Thanks!