LHC Higgs Cross Section Working Group:

Vector Boson Fusion

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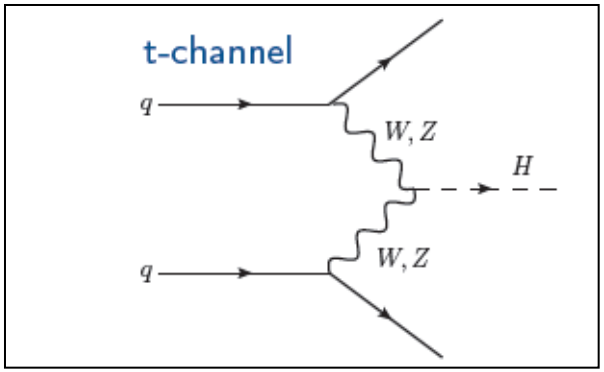
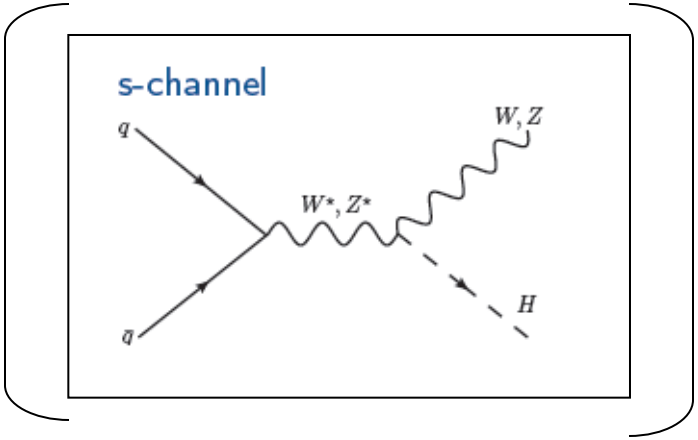
VBF Process

- **Vector boson fusion**
  - Second to gg fusion in LHC Higgs production
  - Important in low mass region
  - Distinctive signature





  - s-channel shares same initial and final states → interference
    - Some of the calculations include this effect
    - Typical analysis cuts minimse this contribution

The Aim

- **From Reisaburo Tanaka:**
  1) "Get the first complete set of inclusive Higgs cross sections at 7 TeV with different p.d.f. sets"
  2) "Come to agreement on the central values together with scale and PDF+ α_s uncertainties with PDF envelope method if any"

Calculations / Generators

- **Process is pure EW at LO**
  - QED corrections calculated at NLO ~ 5-10%
  - QCD corrections calculated at NNLO ~5-10%
- **Codes:**
  - HAWK ★
    - NLO QCD and EW corrections
    - s and t channels and interference between them
  - VBFNLO ★
    - NLO QCD and EW (soon) corrections
    - t channel only
  - VBFNNLO (See previous talk for details)
    - NNLO QCD
    - t channel only
  - Pythia/Herwig
    - t channel only, LO
  - Sherpa
    - s and t channel, LO

★ = Results in this talk

The Results

- **Some notes on the results shown today**
  - Inclusive cross sections at √s=7TeV
    - LHC input parameters used
    - No kinematic cuts applied
    - Used recommended mass range and binning
  - Several configurations of EW/QCD corrections, s-channel/t-channel
  - Cross sections calculated for several p.d.f.'s
    - P.d.f. error treatment does not yet include α_s errors

CTEQ/MSTW prescription:

$$\Delta X = \left|\vec{\nabla} X\right| = \frac{1}{2}\sqrt{\sum_{i=1}^{N}\left(X_i^{(+)} - X_i^{(-)}\right)^2}$$

NNPDF prescription:

$$\langle \mathcal{F}[f(x)] \rangle = \frac{1}{N_{\rm rep}} \sum_{k=1}^{N_{\rm rep}} \mathcal{F}[f^{(k)(\rm net)}(x)]$$

$$\sigma_{\mathcal{F}[f(x)]} = \sqrt{\langle \mathcal{F}[f(x)]^2 \rangle - \langle \mathcal{F}[f(x)] \rangle^2}$$

- Will show comparisons of HAWK/VBFNLO

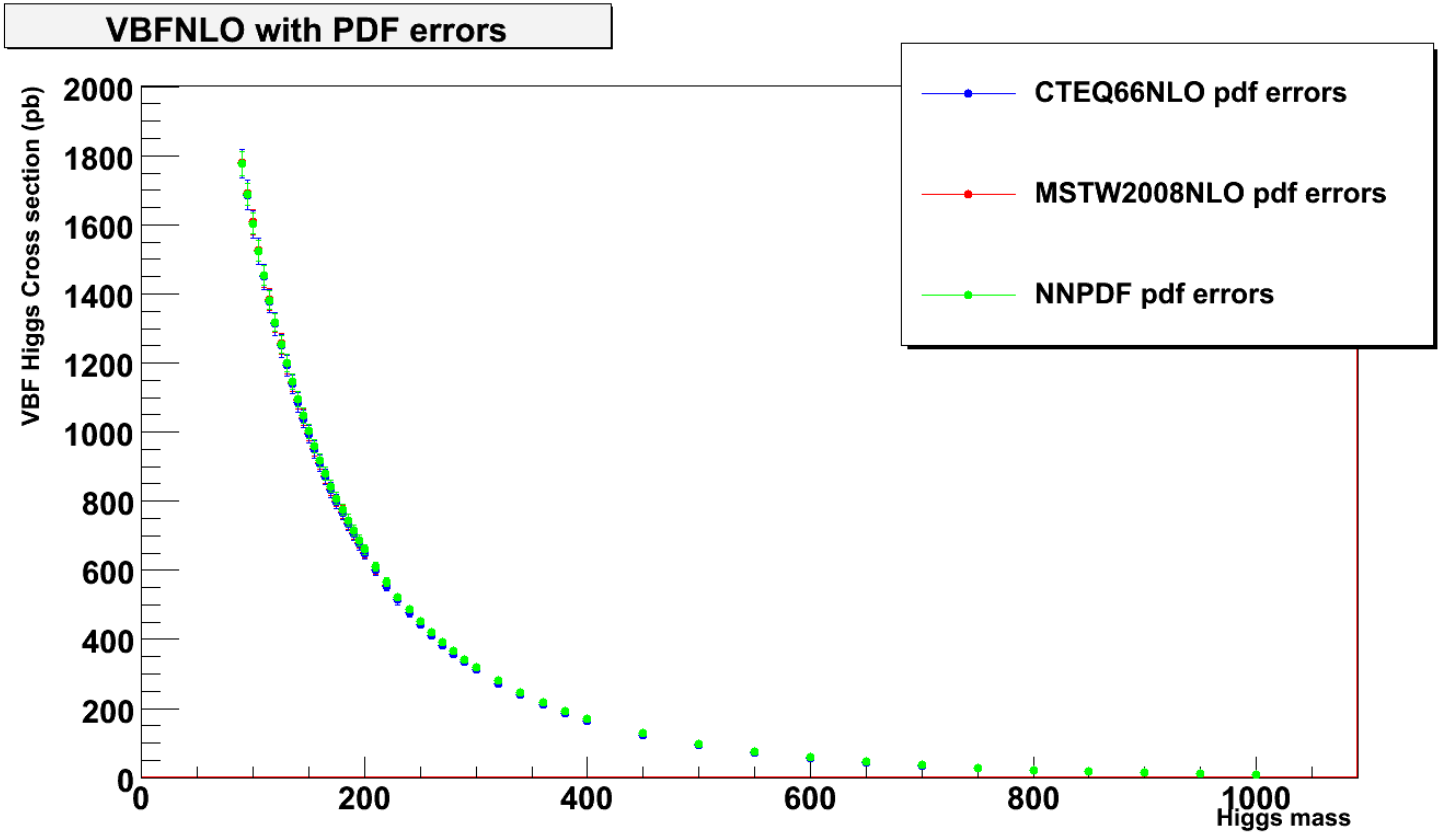
- **“Like measuring the width of a valley from the displacement of a flock of sheep…”**

VBFNLO

- **Implements NLO QCD corrections**
- **t-channel only**

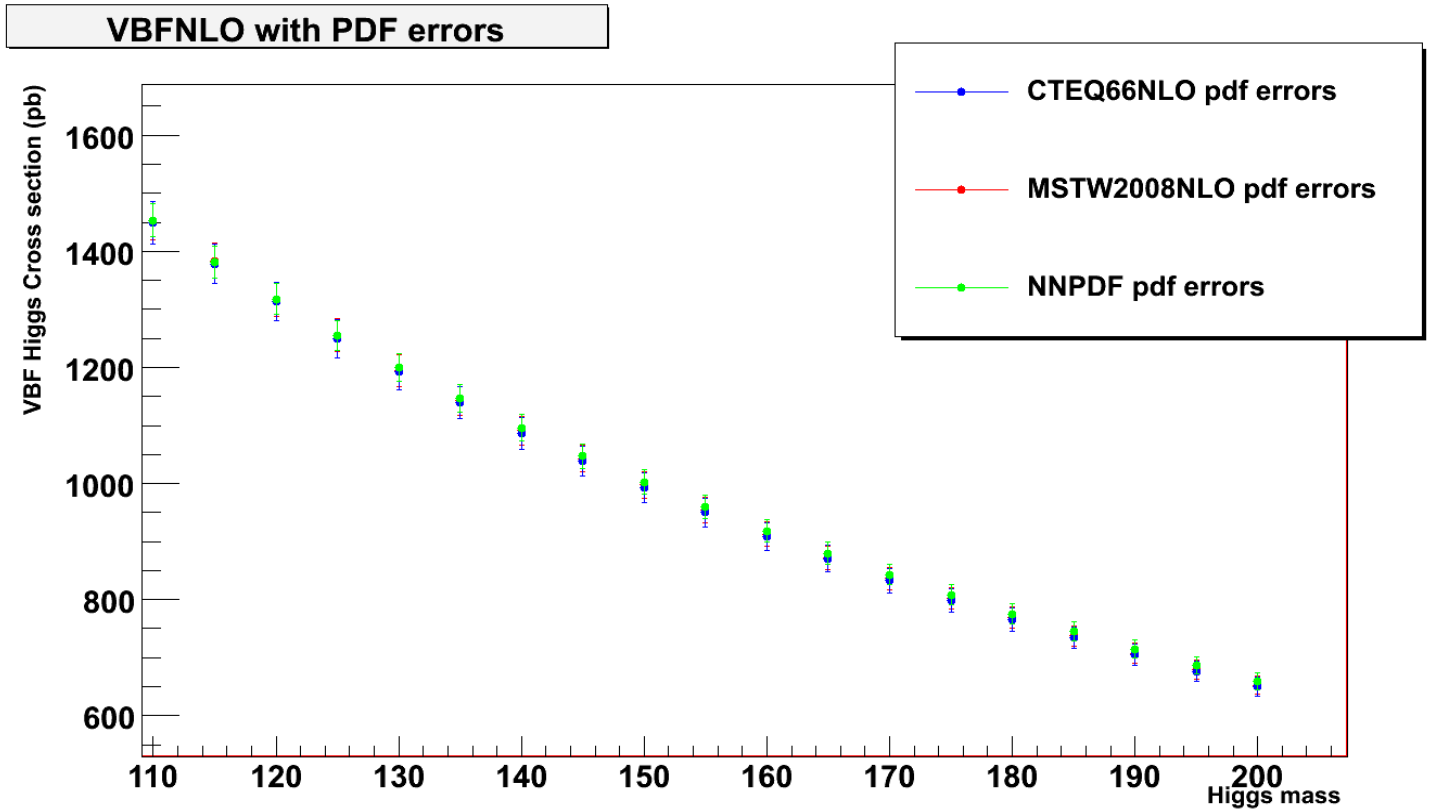
- **Developments**
  - Improved phase space treatment to allow zero jet pt calculations
  - NLO EW corrections available soon
  - Scale variation studies available soon

VBFNLO Results



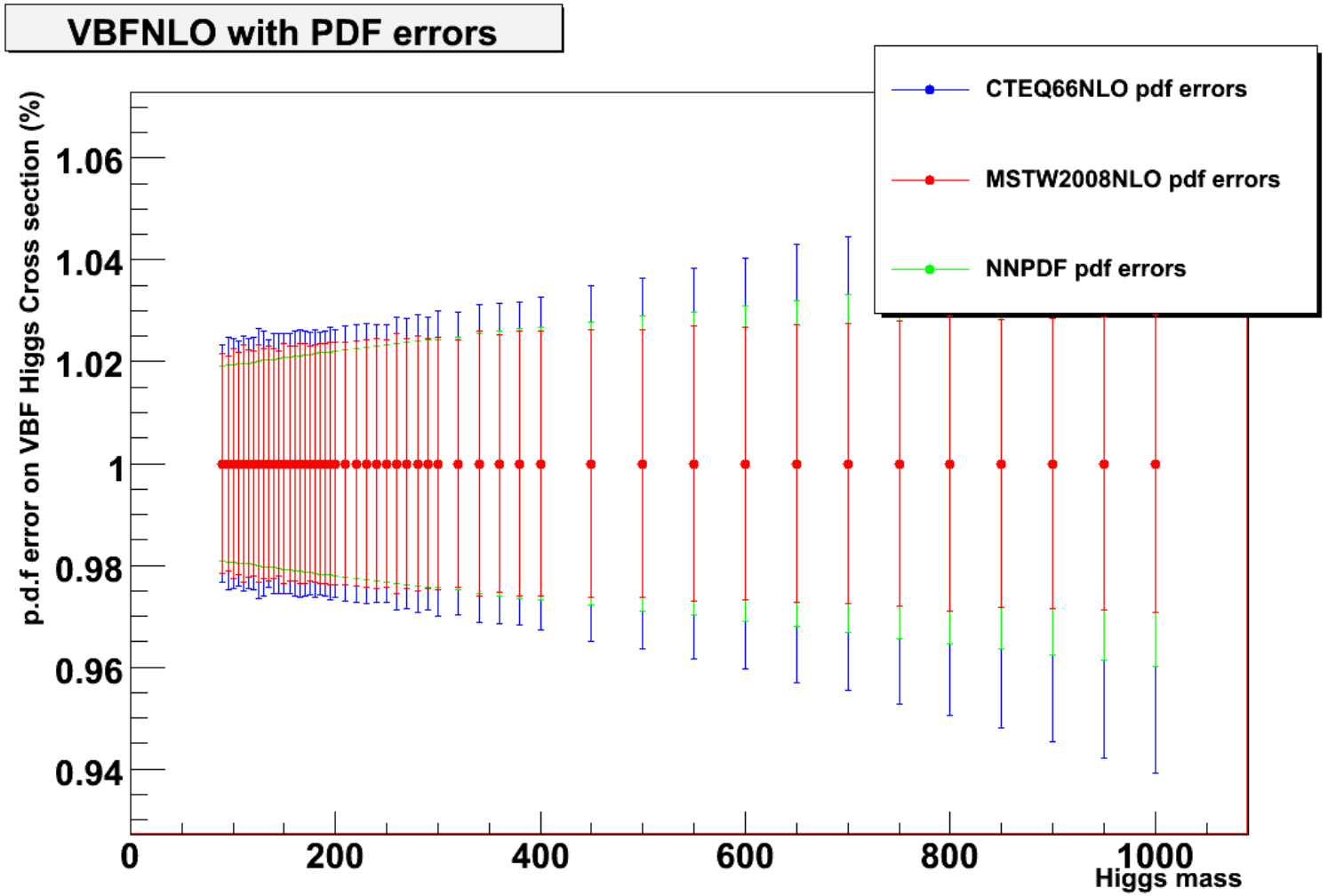
- **Cross sections evaluated for CTEQ66 / MSTW2008 / NNPDF2.0**
  - Using each set's α_s value; μ_R, μ_F =W mass
  - Calculation robust against p.d.f. variation
  - Used 100 NNPDF replica sets

VBFNLO Results



- **Cross sections evaluated for CTEQ66 / MSTW2008 / NNPDF2.0**
  - Using each set's α_s value, renormalisation scale =W mass
  - Calculation robust against p.d.f. variation
  - Used 100 NNPDF replica sets

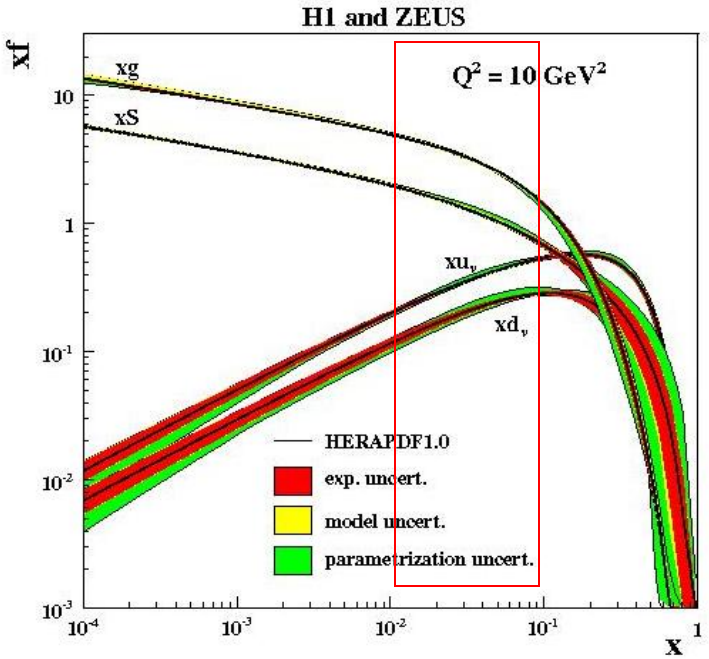
p.d.f. Percentage errors



- **MSTW errors ~ NNPDF Errors**
- **CTEQ errors larger**

p.d.f and α_s errors

- **Expect VBF process to have small p.d.f. uncertainty since probing $x \sim 10^{-2} - 10^{-1}$:**



- **α_s errors: Evaluated cross sections of CTEQ / MSTW / NNPDF with one another's α_s value**
  - Largest error was ~1% x p.d.f error

HAWK

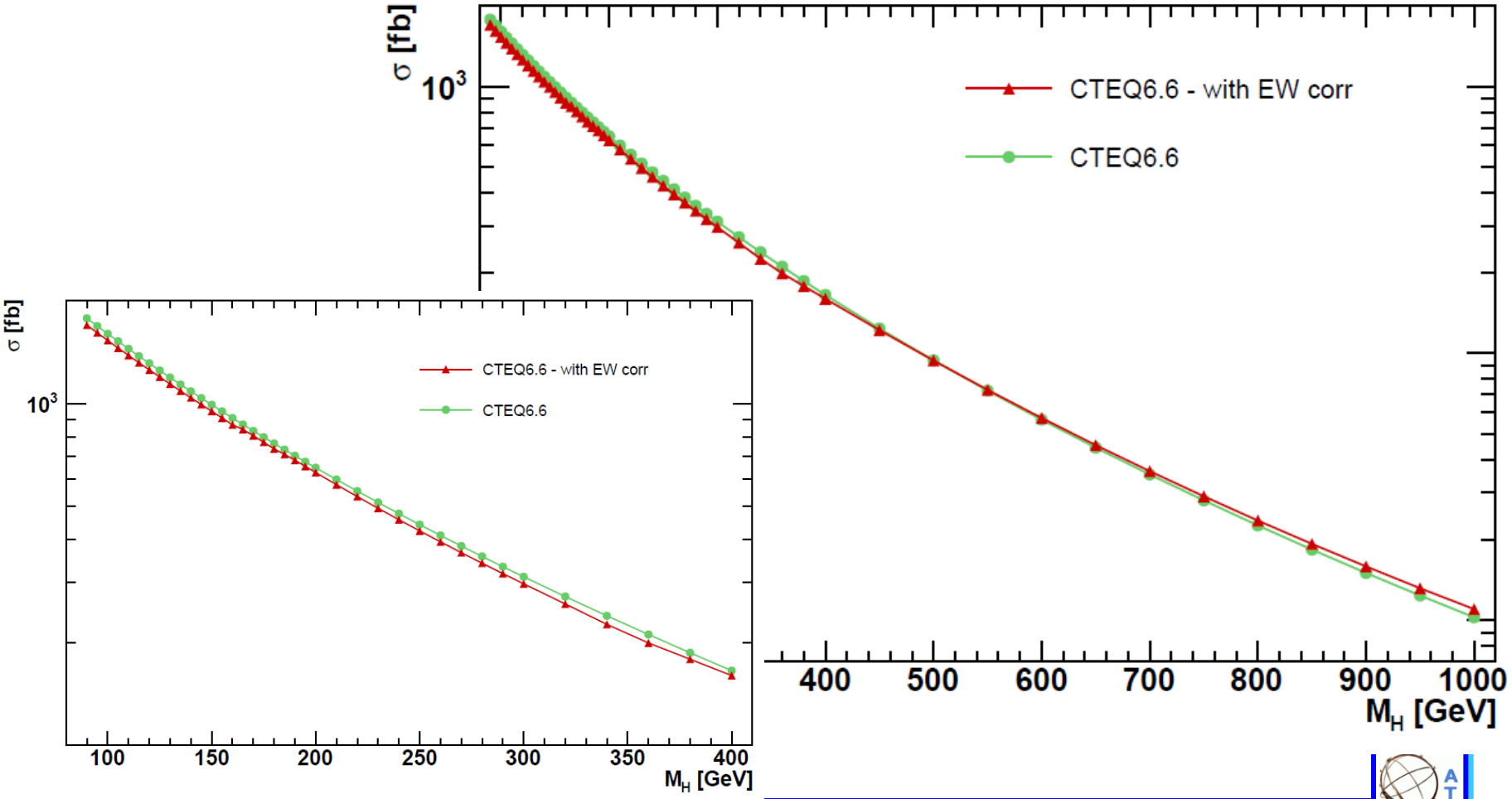
- **Implements NLO QCD and EW corrections**
- **s and t channels**
- **Developments:**
  - Version 1.1 released 10th June
  - Production of off-shell Higgs boson
    - Higgs invariant mass distributed according to Breit-Wigner
  - Option to decay isotropically into pair of singlets
    - Used to mimic any two body decay e.g. $H \rightarrow \gamma\gamma$
    - Required input: Higgs decay width; branching ratio into singlets
    - Cuts on decay singlets possible
  - Gauge invariance requires on-shell projection of matrix element in EW corrections
    - Not required for QCD LO/NLO corrections

HAWK Developments (cont'd)

- Improved PDF error estimation
  - Simultaneous evaluation of cross section for all members of a p.d.f. set
  - Evaluation of error set of 40 p.d.f.'s only ~ doubles run time compared to running central value p.d.f. only for all LHgrid sets
  - Not yet supported for distributions but easy to implement if needed
  - For *LHpdf sets repeated initialisation kills improvements

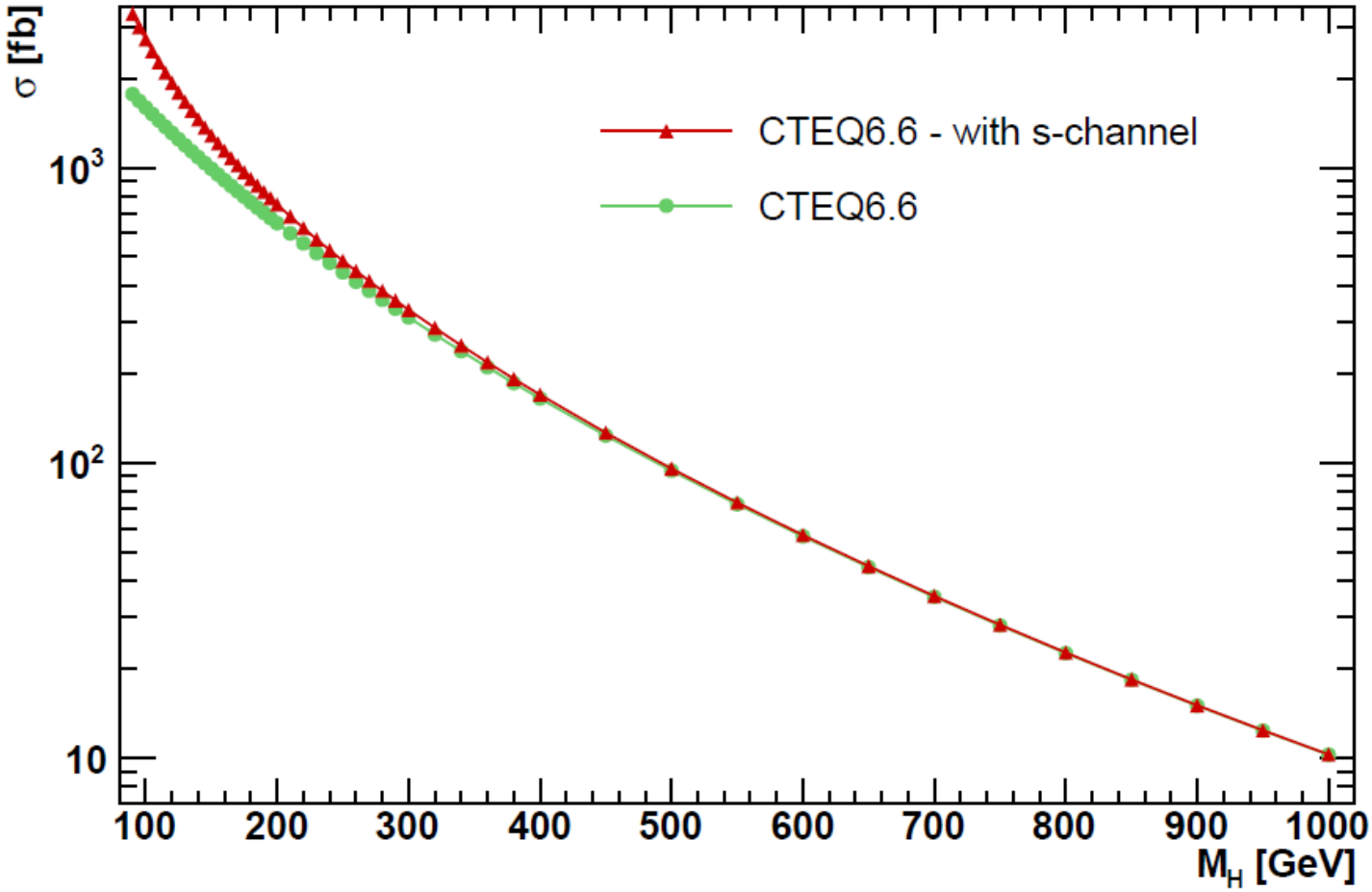
HAWK Results

- **Effect of EW corrections at NLO**
  - ~5% decrease in cross section for low masses



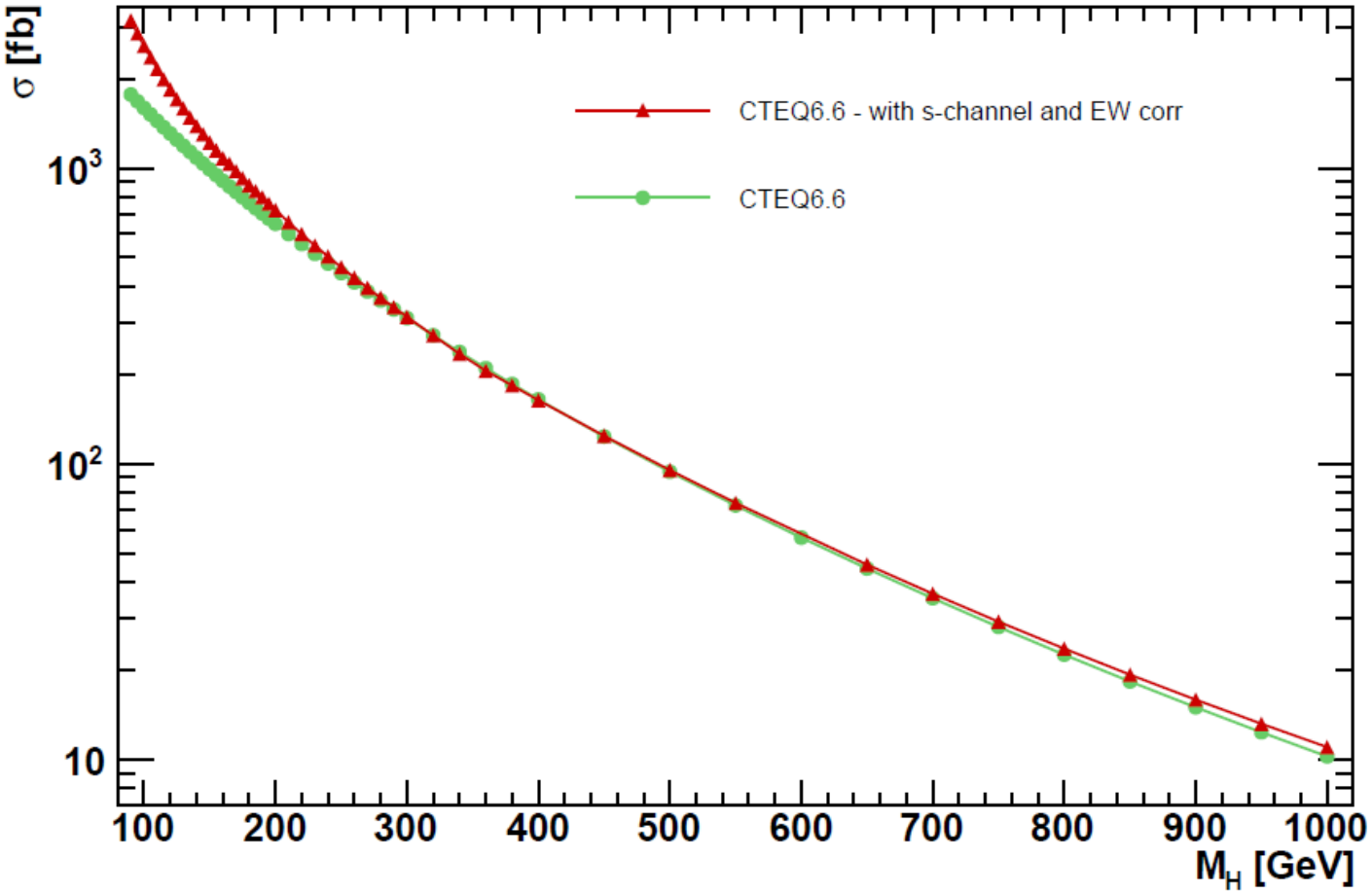
HAWK Results

- **Effect of s-channel inclusion**
  - ~100% increase for low masses (<400GeV)



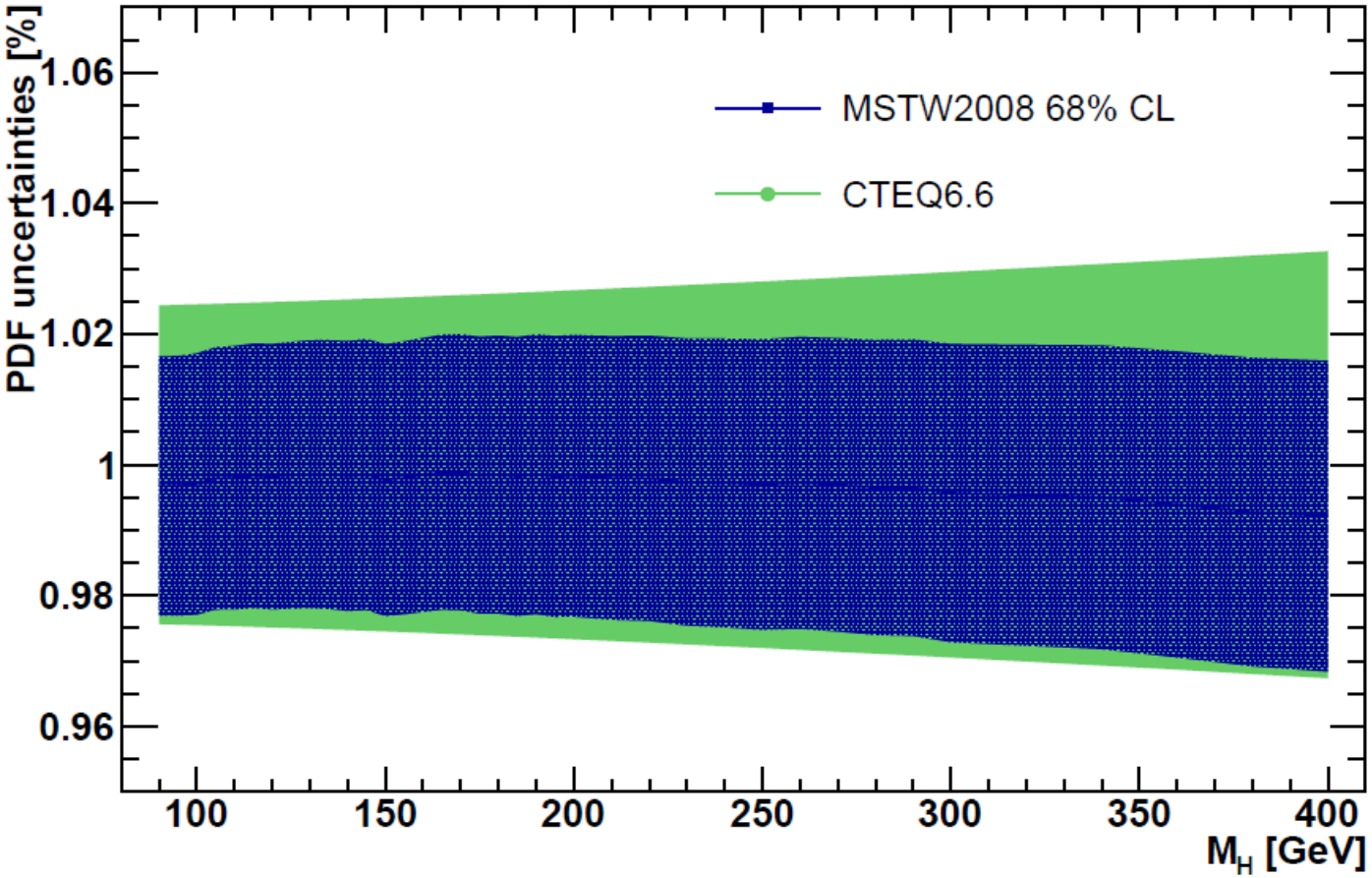
HAWK Results

- **Effect of EW corrections at NLO and s-channel**



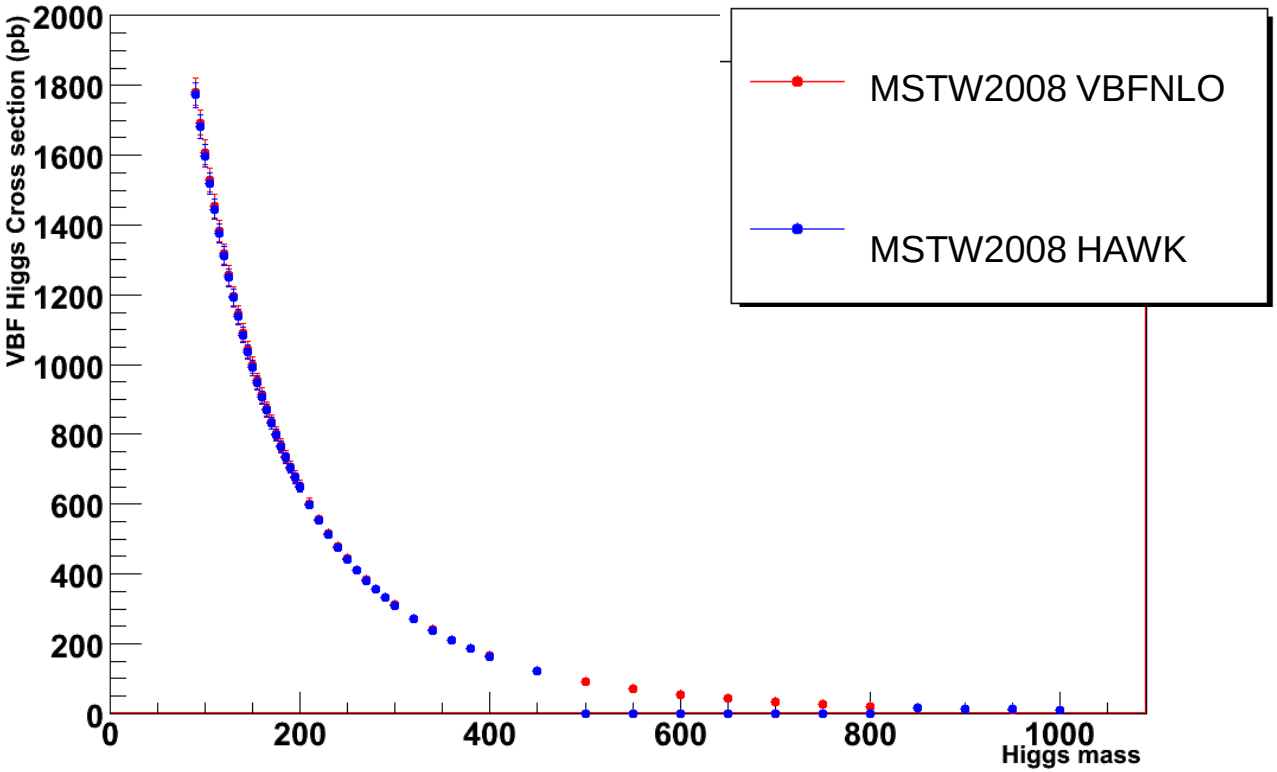
HAWK Results

- **Similar errors to those in VBFNLO**
  - MSTW central values normalised to CTEQ central values
  - MSTW and CTEQ determinations agree within p.d.f. errors



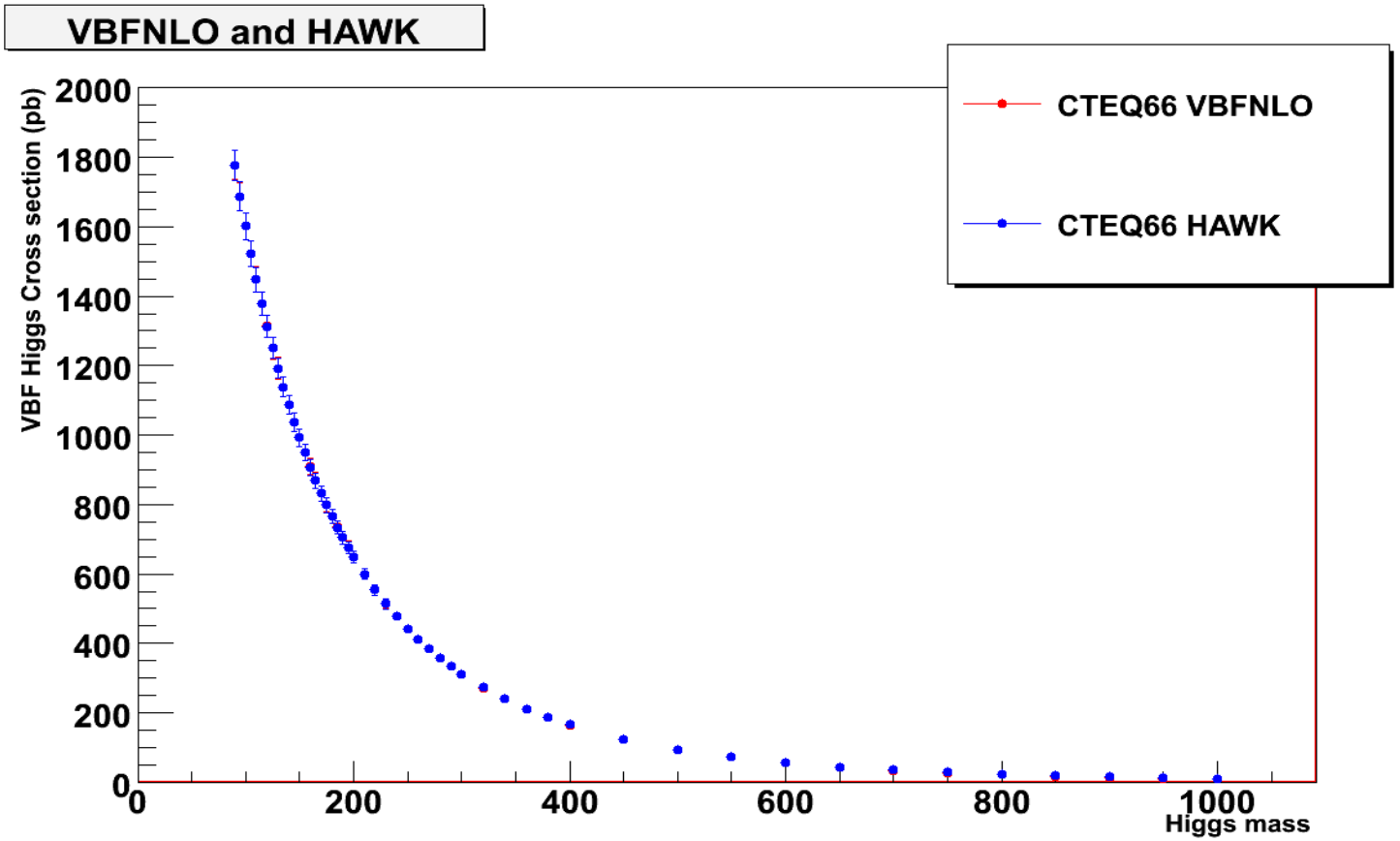
HAWK / VBFNLO Comparison, MSTW

- **HAWK calculated with no EW corrections, no s-channel**
  - Agreement to ~0.5%



HAWK / VBFNLO Comparison, CTEQ

- **HAWK calculated with no EW corrections, no s-channel**
  - Agreement to ~0.5%



Summary

- **VBFNLO and HAWK calculations performed**
  - Uniform input parameters, cuts, mass binnings
  - NNPDF, MSTW, CTEQ p.d.f. errors evaluated
    - α_s errors estimated (though not yet according to recommendation)
  - Tables of these calculations are on the sharepoint
  - Excellent agreement between VBFNLO and HAWK without s-channel or EW corrections
  - More improvements in the pipeline from the packages

- **VBFNNLO comparisons beginning**

To do…

- Evaluate α_s errors with full prescription
- Evaluate renormalisation scale errors
- Finalise comparison between VBFNNLO/VBFNLO/HAWK
- Move to exclusive channels
- Consider theoretical errors on SM backgrounds