

# WG 1 XS&BR: SUMMARY, OUTLOOK AND PLANS

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BERNHARD MISTLBERGER



## CURRENT CONVENERS:

- ▶ Julie Malclès (CMS) [julie.malcles@cea.fr](mailto:julie.malcles@cea.fr)
- ▶ Roberto di Nardo (ATLAS) [roberto.di.nardo@cern.ch](mailto:roberto.di.nardo@cern.ch)
- ▶ Alexander Karlberg (TH) [alexander.karlberg@cern.ch](mailto:alexander.karlberg@cern.ch)
- ▶ Bernhard Mistlberger (TH) [bernhard@slac.stanford.edu](mailto:bernhard@slac.stanford.edu)

## WORKING GROUP 1

- ▶ **WG1:** Provide recommendations, theoretical predictions, guidance, point for discussions ... for SM Higgs Boson observables at the LHC.

### Sub-Groups:

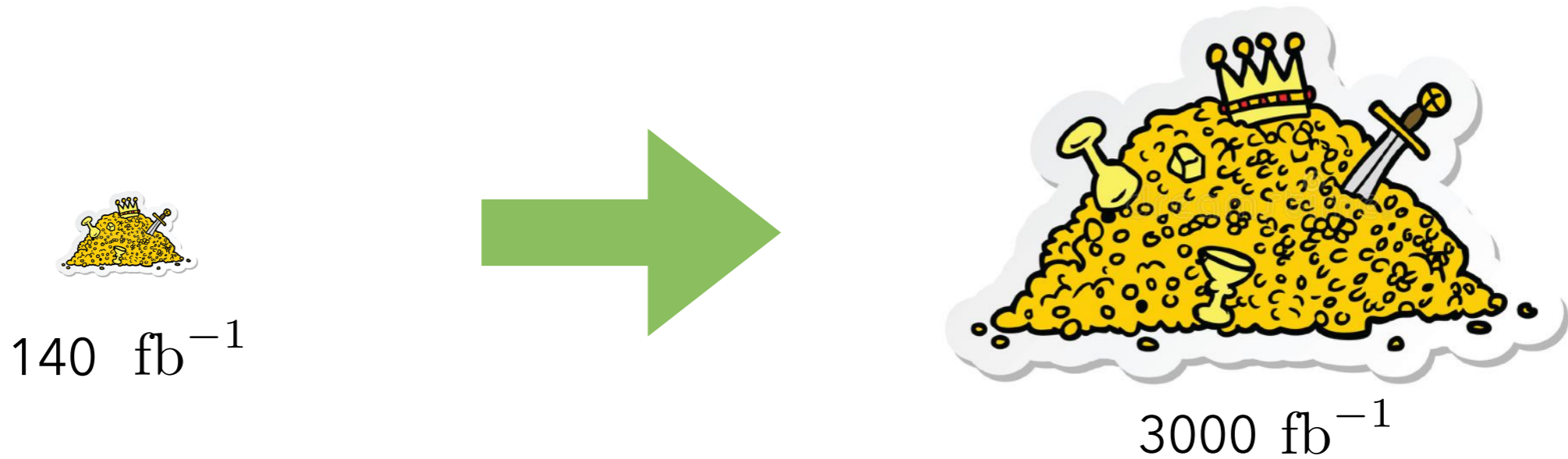
Group TWiki	Group Mailing List	Mail to conveners	ATLAS	CMS	THEORY	
<a href="#">ggF</a>		<a href="#">Mail</a>	<a href="#">Syed Haider Abidi (BNL)</a>	<a href="#">Jonathon Langford (Imperial College)</a>	<a href="#">Alexander Huss (CERN)</a>	<a href="#">Stephen Jones (Durham)</a>
<a href="#">VBF</a>	<a href="#">Mailing List</a>	<a href="#">Mail</a>	<a href="#">Gaetano Barone (Brookhaven BNL)</a>	<a href="#">Stephane Cooperstein (UCSD)</a>	<a href="#">Mathieu Pellen (Freiburg)</a>	<a href="#">Simon Plaetzer (University of Vienna)</a>
<a href="#">VH</a>	<a href="#">Mailing List</a>	<a href="#">Mail</a>	<a href="#">Hannah Arnold (Nikhef)</a>	<a href="#">Alessandro Calandri (ETH Zurich)</a>	<a href="#">Ciaran Williams (Buffalo)</a>	<a href="#">Giancarlo Ferrera (University of Milan)</a>
<a href="#">ttH/tH</a>	<a href="#">Mailing List</a>	<a href="#">Mail</a>	<a href="#">Josh McFayden (University of Sussex)</a>	<a href="#">Sergio Sanchez Cruz (UZH)</a>	<a href="#">Malgorzata Worek (RWTH Aachen Univ.)</a>	<a href="#">Marco Zaro (University of Milan)</a>
<a href="#">Offshell</a>		<a href="#">Mail</a>	<a href="#">Rafael Coelho Lopes de Sa (UMass Amherst)</a>	<a href="#">Savvas Kyriacou (JHU)</a>	<a href="#">Ennio Salvioni (Padua)</a>	<a href="#">Raoul Roentsch (KIT, Karlsruhe)</a>

### Points-of-Contact:

<a href="#">BR (WG1)</a>	<a href="#">Mail</a>	<a href="#">Daniela Rebuszi (Pavia) (08/2014)</a>	<a href="#">Ivica Puljak (Split) (05/2014)</a>	<a href="#">Michael Spira (PSI) (10/2021)</a>	<a href="#">Sven Heinemeyer (IFCA) (08/2014)</a>	<a href="#">Alexander Mück (Aachen) (08/2014)</a>
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<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCHWG1>

- ▶ This is the beginning of the golden age of precision Higgs Boson physics!

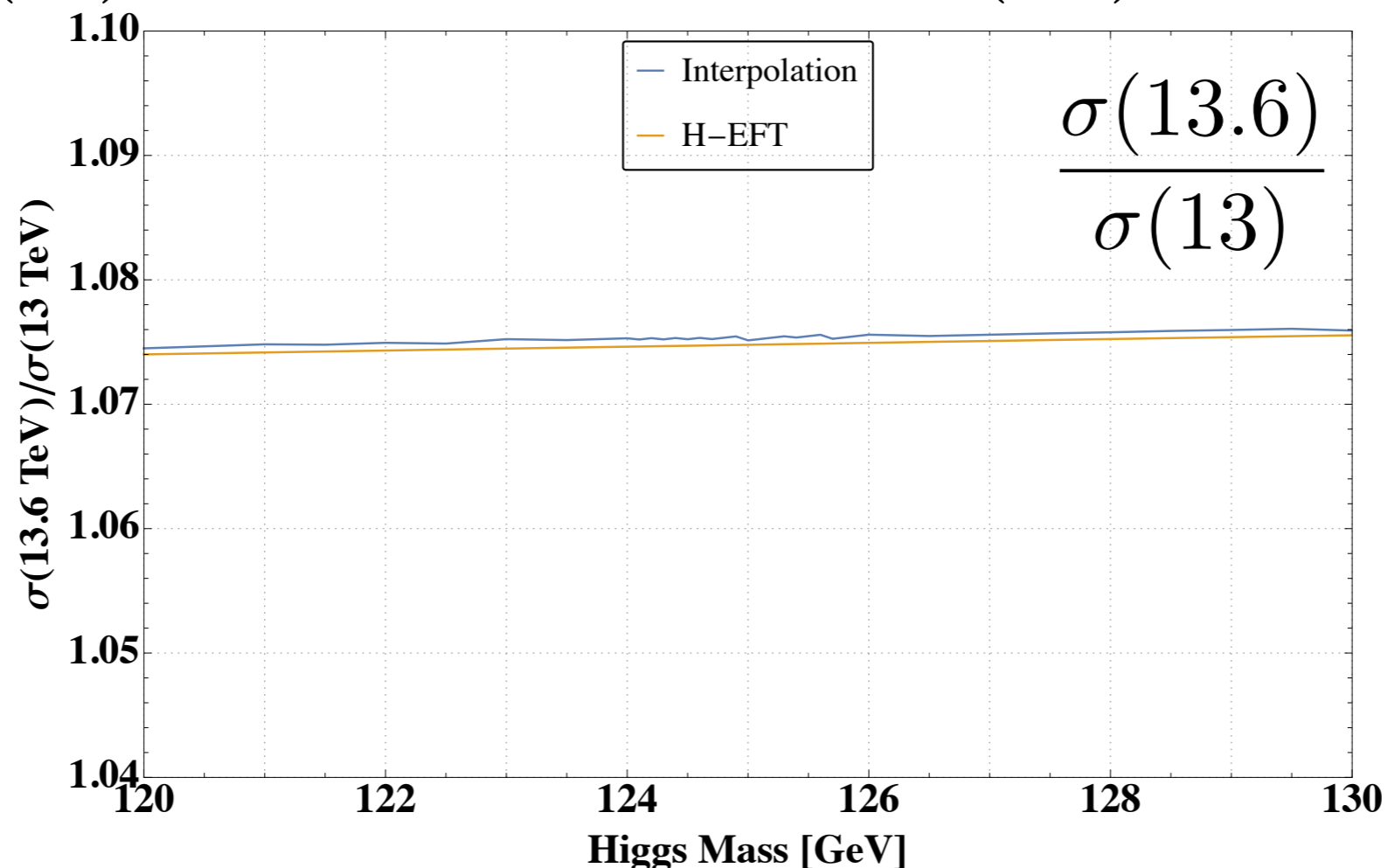


- ▶ Run 3 with 13.6 TeV and planned 300 fb<sup>-1</sup>
- ▶ Opportunity to study properties of the Higgs Boson at percent level.
- ▶ Huge challenge for the experimental and theoretical community and progress spearheaded by many activities within our working group!

- ▶ [Yellow Report 4](#): Produced in 2016 in a huge community effort.
- ▶ Benchmark for production cross sections, decay rates, properties and much more.
- ▶ Simple Extrapolation to 13.6 TeV:

$$\sigma(E) = a * E + b = 0.4\sigma(13) + 0.6\sigma(14)$$

ggF:



- ▶ [Yellow Report 4](#): Produced in 2016 in a huge community effort.
- ▶ A **LOT** has happened since 2016 - we would like an “update” for inclusive production cross sections.

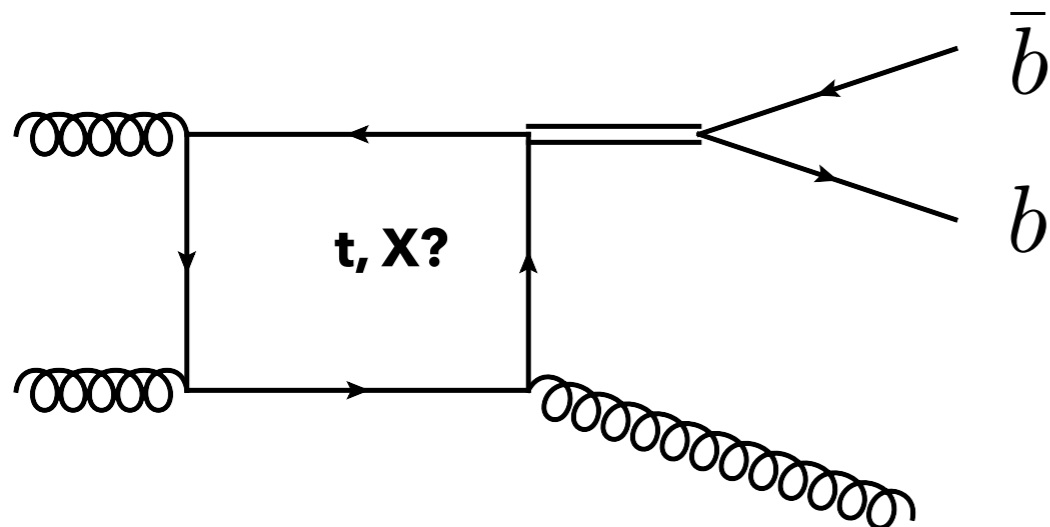
- ❖ New Parton Distribution Functions: MSHT20, CT18, NNPDF3.1-4.0, PDF4LHC21.
- ❖ PDFs at approximate N3LO.
- ❖ Tremendous progress for individual production mechanisms:

ggF	VBF	ttH	VH
❖ Top at NNLO	❖ N3LO QCD	❖ NNLO QCD	❖ NLO gg->ZH
❖ Mixed QCD-EWK		❖ NNLL soft resummed	❖ N3LO(*) QCD
❖ Exact N3LO in HTL		❖ NLO EWK	
❖ N3LO-PDF uncertainty		❖ tH - EWK	

- ▶ More discussion on how to combine cross sections based on “old” and updated predictions.

I’m sure there’s more ...

## PROPOSED UPDATES:



Predictions and measurements for a Higgs boson at large transverse momentum are difficult but very interesting. Due to the particular complexity and not publicly accessible inputs providing explicit information in a **combined effort from the theory** community is useful.

Extension of the current public note:

<https://arxiv.org/pdf/2005.07762.pdf>

**All production mechanisms contribute - all sub-groups of WG1 should be involved** (currently leadership in ggF sub-group).

- ❖ 13.6 TeV
- ❖ PDF4LHC21
- ❖ Extend pT range to 1.25 TeV
- ❖ QCD / Electroweak corrections for ggF
- ❖ Mass scheme uncertainty for NLO QCD ggF
- ❖ Parton Showers: HJ and HJJ
- ❖ Non-factorizable corrections in VBF
- ❖ NNLO QCD for ttH?
- ❖ ...

▶ [Talk by Stephane](#)

▶ Workshop - "Past, Present and Future of VBF"

<https://indico.cern.ch/event/1186109/>

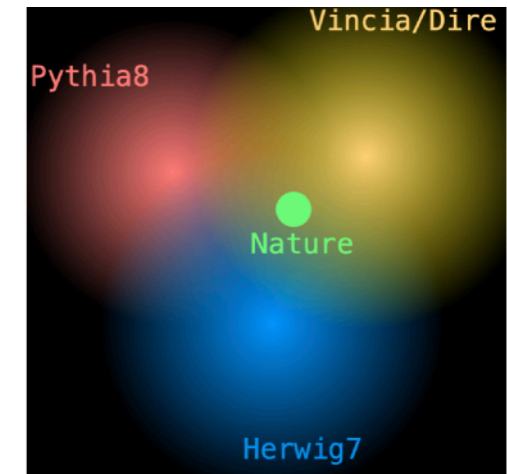
- Variety of topical contributions highlighting various developments in the field:
  - Deep learning techniques in VBFH searches in  $H \rightarrow \text{inv}$  (*Vishal Singh Ngairangbam*)
  - Experimental falsification of SMEFT (*Alexandre Salas-Bernárdez*)
  - Looking at VBF processes from a polarisation perspective (*Giovanni Pelliccioli*)
  - Towards WBF with realistic final states and anomalous couplings at NLO (*Konstantin Asteriadis*)
  - High Energy Jets (HEJ) applied to inclusive Higgs+jets production (*Jérémy Paltrinieri*)
  - A sensitivity study of VBF-V to dimension-6 EFT operators at the LHC (*Flavia Cetorelli*)
  - Experimental potential on CP sensitive STXS splitting. (*Benedict Tobias Winter*)
  - Electroweak corrections and shower effects to Higgs production in association with two jets at the LHC (*Johannes Scheller*)



## ▶ [Talk by Stephane](#)

## ▶ The Precision VBF Era is here!

- ❖ ~10 % measurements in VBF - Theoretical Systematics become critical
- ❖ Parton Showers for VBF - a long-standing discussion on how to set uncertainties! New showers, clear guidelines of how to set uncertainties, how to combine with NNLO/N3LO QCD and NLO EW ...
- ❖ ggF - backgrounds: VBF like region is notoriously hard to describe - use best possible theory for VBF.
- ❖ Benchmarking differential cross sections in addition to inclusive cross sections!



- Calculate variety of  $N$ -dimensional differential distributions:
  - Single-differential distribution for  $p_{\tau}(H)$
  - Double differential:
    - $m_{jj}$  vs.  $p_{\tau}(H)$
    - $m_{jj}$  vs.  $|\Delta\phi(jj)|$
    - $m_{jj}$  vs.  $|\Delta Y(jj)|$
    - $p_{\tau}(H)$  vs.  $|\Delta Y(jj)|$
    - $p_{\tau}(H)$  vs.  $N_{jet}$
  - Triple differential:
    - $m_{jj}$  vs.  $p_{\tau}(H)$  binning of STXS x 2 bins in  $|\Delta\phi(jj)|$  (0,n/2,n)
  - STXS binning for  $m_{jj}$  and  $p_{\tau}(H)$ , 4-6 bins for other distributions.
- Calculations provided for two selection regions:
  - STXS selections:  $|\eta(j)| < 4.7$ ,  $p_{\tau}(j) > 25/30$  GeV.
  - STXS selections +  $m_{jj} > 300$  GeV,  $|\Delta Y(jj)| > 2.0$

## ► [Talk by Marco](#)

❖ Systematic uncertainties dominate - need to understand signal and background theoretical modeling better!

❖ Recent workshop on ttbb

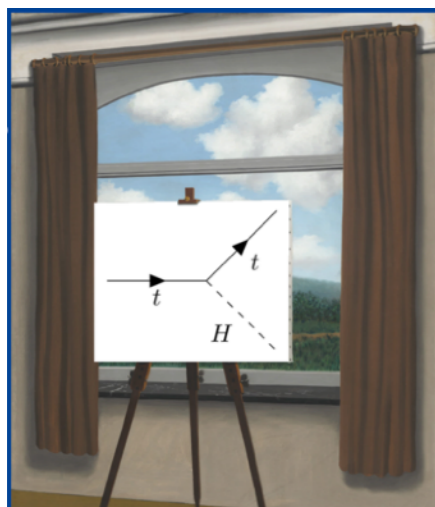
<https://indico.cern.ch/event/1165637/>

❖ **Upcoming** workshop:  
ttW and how to compute it! Dec 9 2022:

<https://indico.cern.ch/event/1219500/>

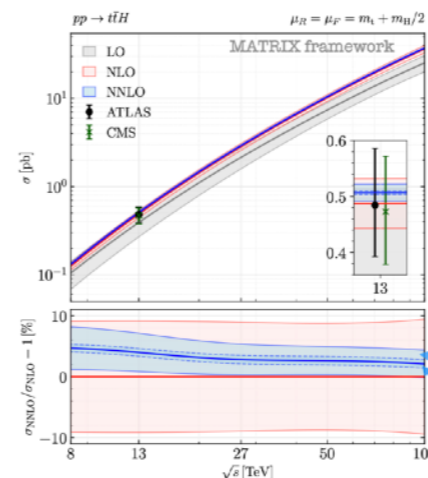
❖ **Fantastic new results:**

Top Quark Fragmentation to Higgs



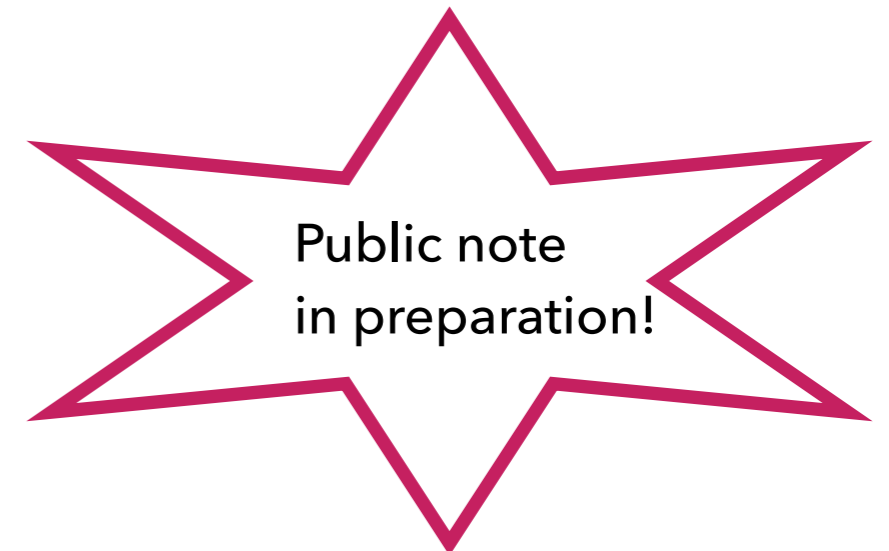
[Colomba's Talk](#)

ttH at NNLO\*



[Chiara's Talk](#)

$\sigma$ [pb]	$\sqrt{s} = 13 \text{ TeV}$	$\sqrt{s} = 100 \text{ TeV}$
$\sigma_{\text{LO}}$	$0.3910^{+31.3\%}_{-22.2\%}$	$25.38^{+21.1\%}_{-16.0\%}$
$\sigma_{\text{NLO}}$	$0.4875^{+5.6\%}_{-9.1\%}$	$36.43^{+9.4\%}_{-8.7\%}$
$\sigma_{\text{NNLO}}$	$0.5070 (31)^{+0.9\%}_{-3.0\%}$	$37.20(25)^{+0.1\%}_{-2.2\%}$



### ► [Talk by Raoul](#)

#### **Incredible progress in offshell studies over last decade:**

– ATLAS and CMS have **evidence for offshell production.**

– ATLAS:  $\Gamma_H = 4.6^{+2.6}_{-2.5}$  MeV [ATLAS-CONF-2022-068]      CMS:  $\Gamma_H = 3.2^{+2.4}_{-1.7}$  MeV [hep-ex/2202.06923]

❖ Jet Merging for Off-Shell Higgs - Recent Meeting in October:

<https://indico.cern.ch/event/1210357/>

❖ Public note on EFT Interpretation of Off-Shell measurements:  
Impact on BSM interpretation!

<https://arxiv.org/pdf/2203.02418.pdf>

Further goal: Assess systematically which EFT operators are most sensitive to off-shell type measurements!

## ▶ [Talk by Hannah](#)

❖ [3 great talks](#) on VH on Monday:

❖ Uncertainties / modelling of V+flavored jets

❖ Signal uncertainties for  $gg \rightarrow ZH$ :

Very hard to compute NLO corrections - recent results available! Up to 50% of DY type production. 3 theory predictions -> find recommendations for experiment.

❖ NNLOPS for  $VH \rightarrow Vbb$  available - follow up in experiment.


❖ Documentation of latest results?

11:30 AM

### V+jets background modeling in CMS

Speaker: Aliya Nigamova (University of Hamburg (DE))

 LHCHWG1\_VjetsCM...


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11:50 AM

### V+jets background modeling in ATLAS

Speaker: Maria Mironova (Lawrence Berkeley National Lab. (US))


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12:15 PM

### ggZH 0+1J studies in ATLAS

Speaker: Philipp Windischhofer (University of Chicago (US))

 ggZH\_HXSWG.pdf

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## ► [Talk by Stephen](#)

- ✿ Significant updates for ggF cross section on the horizon.
- ✿ Updates for boosted Higgs / Higgs  $p_T$  distribution.
- ✿ Choice of top quark mass scheme plays a substantial role:  
MSbar vs On-Shell - Is one preferred? Is this a genuine uncertainty?  
See talks: [Vittorio's Talk](#) [Javier's Talk](#)

✿ STXS uncertainty scheme in progress.

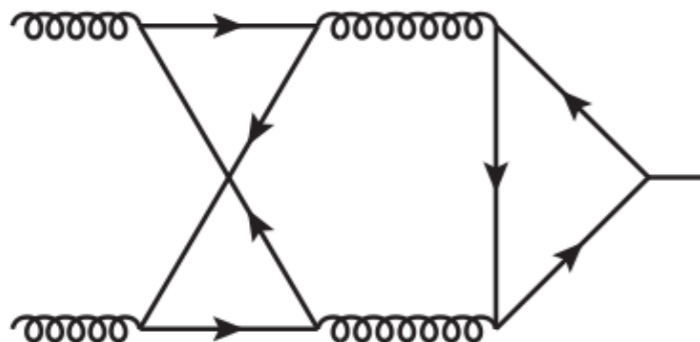
✿ Parton Shower Uncertainties are becoming dominant systematics - **help wanted**.

t+b at NLO for Higgs  $p_T$ : [Vittorio's Talk](#)

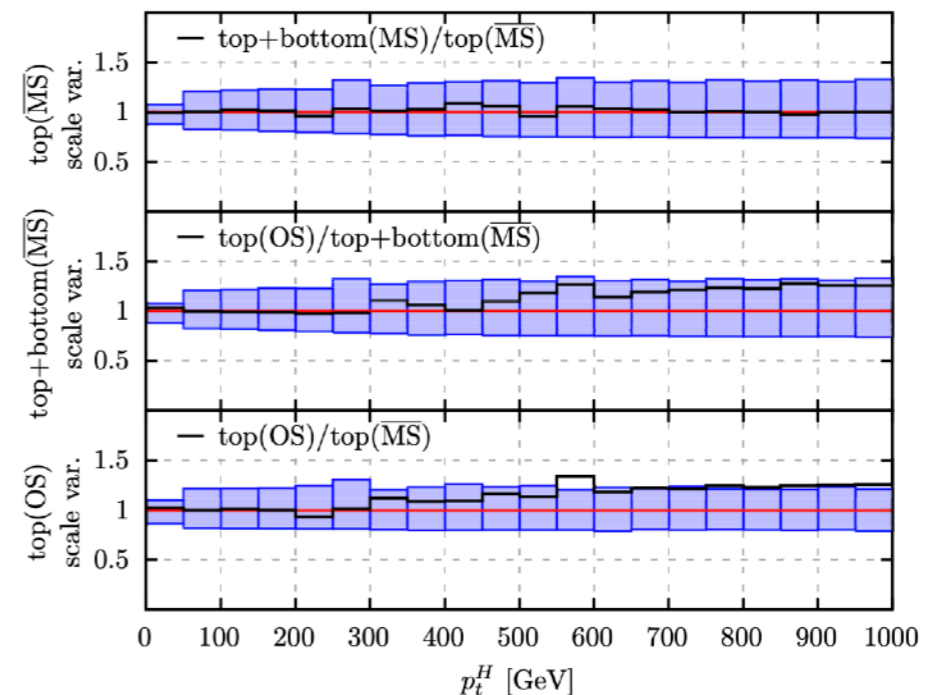
## ✿ Fantastic new results:

Full top quark mass dependence at NNLO

[Marco's Talk](#)



NLO



## SUMMARY

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### ❖ The Precision Higgs Era is here:

We are confronted with an incredible wealth of data and the opportunity to measure Higgs Boson properties in great detail. This ensues a gigantic challenge for the experimental and theoretical community. Only strong collaborative ties throughout the community can make our phenomenological goals a reality.

### ❖ Rapid progress with many interesting and exciting results presented at this workshop!

### ❖ A lot of activity within WG1

WG1: Higgs Cross Sections and Branching Ratios subgroup meetings in 2022

<https://indico.cern.ch/category/5847/>

See Julie Malclès's [talk](#)

09 Dec [Joint session of LHC Top and Higgs working groups: ttW modeling in light of ttH measurements](#)

22 Nov [WG1 - VH subgroup](#)

19 Oct - 21 Oct [Past, present, and future of VBF](#)

17 Oct [WG1 Offshell Subgroup Joint Meeting](#)

10 Oct [WG1 - VH subgroup](#)

28 Sept [LHC-HH Subgroup Meeting](#)

05 Jul [Modelling of the ttbb process at the LHC in light of ttH measurements](#)

12 May [WG1 - VH subgroup](#)

28 Apr [HXS WG Offshell Interpretations 5th Joint Meeting](#)

22 Feb [WG1 - VBF subgroup](#)

03 Feb [WG1 Updated Higgs Cross Sections](#)

### ❖ Specific goals:

- ❖ Further studies and Produce document with updated production cross sections at 13.6 TeV.
- ❖ Study parton showers and their uncertainties - on-going in sub-groups but a problem on a larger scale?
- ❖ All WG1 would like to serve as a communication point among experiment and theory - we would like to encourage everyone to participate!