

# **Standard Model at the LHC 2021**

Monday, 26 April 2021 - Friday, 30 April 2021

# **SM@LHC 2021**

## **Book of Abstracts**



# Contents

Electroweak corrections to the angular coefficients of Z-boson production and decay at finite-pT . . . . .	1
Parton-shower effects in Higgs production via Vector-Boson Fusion . . . . .	1
Probing Higgs self coupling at the future upgraded LHC . . . . .	1
The anomalous Zbb couplings: From LEP to LHC . . . . .	2
Triboson Measurements in CMS . . . . .	2
Measurement of Higgs to WW in association with a vector boson using the full Run 2 dataset at CMS . . . . .	3
Observation of electroweak production of two jets and a Z-boson pair with the ATLAS detector at the LHC . . . . .	3
Measurement of the vector-boson transverse momentum distributions with ATLAS . . . . .	3
NNLO QCD Predictions for Triphoton Production . . . . .	4
LHCb: Search for CP violation in D0->KS0KS0 decays . . . . .	4
Hot topics in PDF fits (role of jet and top data, higher-orders, modelling of experimental correlations) . . . . .	4
Recent results in NNLO and N3LO calculations . . . . .	5
Jet measurements (including Lund-plane) and PDF/alphaS interpretations at the LHC . . . . .	5
Jet Fragmentation and Central Exclusive Production at LHCb . . . . .	5
Progress in MC event generators (with focus on NLL showers) . . . . .	5
Role of mass corrections in pQCD calculations . . . . .	5
Jet substructure (with possible ML) at the LHC . . . . .	5
On the treatment of correlated theoretical uncertainties in LHC data analysis . . . . .	6
State of the art in SM Higgs physics . . . . .	6
Higgs Couplings and properties (incl. mass, CP): current status . . . . .	6
Resonant and non-resonant HH channel . . . . .	6

Progress in $t\bar{t}$ @NNLO+PS . . . . .	6
ATLAS and CMS results latest results on $t\bar{t}$ and single-top cross-section measurements	6
ATLAS/CMS Top properties (mass, spin corr., asymm. $V_{tb}, \dots$ ) . . . . .	7
Higgs and flavour . . . . .	7
Rare SM Higgs channels ( $\mu\mu$ , $Z\gamma$ , $c\bar{c}$ ) . . . . .	7
ATLAS/CMS latest results on $t(t)+X$ ( $X=t\bar{t}, b\bar{b}, Z, W, \gamma$ ) . . . . .	7
ATLAS and CMS results latest results on $t\bar{t}/t\bar{t}$ . . . . .	7
$t\bar{t}+X$ ( $X=H, t\bar{t}, b\bar{b}, Z, W, \gamma$ ): status and perspectives of precision predictions . . . . .	7
New results on $b \rightarrow s \ell\ell$ . . . . .	7
NP implications & connections with high- $p_T$ . . . . .	8
CMS/ATLAS rare decays: new results & prospects . . . . .	8
Progress in NLO EW Monte Carlo . . . . .	8
Electroweak corrections for precision weak mixing angle measurements at LHC . . . . .	8
Drell-Yan measurements / weak mixing angle . . . . .	8
Multiboson measurements . . . . .	8
Lattice QCD inputs for SM . . . . .	8
Analytic QCD inputs for SM . . . . .	9
CKM measurements and hadronic form factors . . . . .	9
ATLAS and CMS results on CP-Violation: new results & prospects . . . . .	9
Latest results on spectroscopy . . . . .	9
Status of theory predictions for single bosons, diboson, and multiboson production . . . . .	9
Differential cross section measurements of $WW + 1$ or more jets with ATLAS . . . . .	9
Electroweak production of $Z\gamma$ and two jets at 13 TeV and constraints on EFTs . . . . .	9
STXS vs. Fully fiducial measurements: limitations and possible future improvements . . . . .	10
Differential Higgs measurements . . . . .	10
BSM Higgs . . . . .	10
QCD & MC challenges for VBF/VBS measurements . . . . .	10
VBS/VBF Boson measurements . . . . .	10
Recent EFT developments: what we should be doing and why . . . . .	10
Top plus Higgs: towards a global EFT fit . . . . .	11

The global impact of EW+H SMEFT probe . . . . . 11

EFT measurements in the EW (+Higgs) sector . . . . . 11

EFT measurements in the top +Higgs sector . . . . . 11

The PDF and EFT Interplay . . . . . 11

Low energy and flavour EFT probes . . . . . 11

EFT constraints with multi-dimensional and multi-variate techniques . . . . . 11

Combined discussion . . . . . 12

Combined TH discussion . . . . . 12

Combined EXP discussion . . . . . 12



YSF / 10

## Electroweak corrections to the angular coefficients of Z-boson production and decay at finite- $p_T$

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The five dominant angular coefficients  $A_i$  parametrizing the Drell-Yan process in the Z-boson mass range is examined, differentially in the dilepton transverse momentum  $p_T$ . The corresponding Lam-Tung relation  $A_0 - A_2$  was previously found at ATLAS and CMS to deviate from SM higher-order QCD corrections. We investigate if this discrepancy can be due to electroweak effects by calculating the fixed-order NLO electroweak corrections to these coefficients and the Lam-Tung relation. This is done by extrapolating to a full phase space coverage of calculations performed with a single lepton transverse momentum cut. The electroweak effects on the distributions are found to be small but not negligible in the low- $p_T$  range. Two of the coefficients are found to be highly sensitive to electroweak parameters. The Lam-Tung relation is found to have a significant contribution in the low- $p_T$  region from these electroweak corrections.

YSF / 11

## Parton-shower effects in Higgs production via Vector-Boson Fusion

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We present a systematic investigation of parton-shower and matching uncertainties of perturbative origin for Higgs-boson production via vector-boson fusion. To this end we employ different generators at next-to-leading order QCD accuracy matched with shower Monte Carlo programs, PYTHIA8, and HERWIG7, and a next-to-next-to-leading order QCD calculation.

We thoroughly analyse the intrinsic sources of uncertainty within each generator, and then compare predictions among the different tools using the respective recommended setups. Within typical vector-boson fusion cuts, the resulting uncertainties on observables that are accurate to next-to-leading order are at the 10% level for rates and even smaller for shapes. For observables sensitive to extra radiation effects, uncertainties of about 20% are found.

We furthermore show how a specific recoil scheme is needed when PYTHIA8 is employed, in order not to encounter unphysical enhancements for these observables.

We conclude that for vector-boson fusion processes an assessment of the uncertainties associated with an NLO+PS simulation at next-to-leading order matched to parton showers based only on the variation of renormalisation, factorisation and shower scales systematically underestimates their true size.

YSF / 13

## Probing Higgs self coupling at the future upgraded LHC

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A direct measurement of the Higgs self coupling is very crucial to understand the nature of electroweak symmetry breaking. This requires an observation of production of Higgs boson pair, which suffers from very low event rate even at the current LHC run. In our work, we study the prospects of observing the Higgs pair production at the high luminosity run of the 14 TeV LHC (HL-LHC) and also the proposed high energy upgrade of the LHC at 27 TeV, namely, HE-LHC. For the HL-LHC study, we choose multiple final states based on the event rate and cleanliness, namely,  $b\bar{b}\gamma\gamma$ ,  $b\bar{b}\tau^+\tau^-$ ,  $b\bar{b}WW^*$ ,  $WW^*\gamma\gamma$  and  $4W$  channels and do a collider study by employing a cut-based as well as multivariate analyses using the Boosted Decision Tree (BDT) algorithm. In case of HE-LHC study, we select various di-Higgs final states based on their cleanliness and production rates, namely,  $b\bar{b}\gamma\gamma$ ,  $b\bar{b}\tau^+\tau^-$ ,  $b\bar{b}WW^*$ ,  $WW^*\gamma\gamma$ ,  $b\bar{b}ZZ^*$  and  $b\bar{b}\mu^+\mu^-$  channels. We adopt multivariate analyses using BDT algorithm, the XGBoost toolkit and Deep Neural Network (DNN) for the signal-background discrimination. Also, we perform a study on the ramifications of varying the self-coupling of Higgs boson from its Standard Model (SM) value. (arXiv: 1712.05346, 2006.11879)

YSF / 14

## The anomalous Zbb couplings: From LEP to LHC

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The bottom quark forward-backward asymmetry ( $A_{FB}^b$ ) data at LEP exhibits a long-standing discrepancy with the standard model prediction. We propose a novel method to probe the Zbb interactions through  $gg \rightarrow Zh$  production at the LHC, which is sensitive to the axial-vector component of the Zbb couplings. We demonstrate that the Zh data collected at the 13 TeV LHC can already resolve the apparent degeneracy of the anomalous Zbb couplings implied by the LEP precision electroweak measurements, with a strong dependence on the observed distribution of the Z boson transverse momentum. We also show the potential of the HL-LHC to either verify or exclude the anomalous Zbb couplings observed at LEP through measuring the Zh production rate at the HL-LHC, and this conclusion is not sensitive to possible new physics contribution induced by top quark or Higgs boson anomalous couplings in the loop.

YSF / 19

## Triboson Measurements in CMS

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We present recent measurements of triboson processes from the CMS experiment at the LHC. Studies of the rare production of three vector bosons constitute a stringent test of the electroweak sector of the Standard Model, and can be used to probe new physics beyond the energy reach of the LHC. We present the first observation of three massive vector bosons and a search for the production of a W or Z boson in association with two photons.

YSF / 25

## Measurement of Higgs to WW in association with a vector boson using the full Run 2 dataset at CMS

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In 2012, the observation of the Higgs Boson was announced by the CMS and ATLAS experiments at CERN. Since the discovery, work has continued to measure the Higgs boson couplings and quantum numbers with greater precision. There are several production channels of the Higgs boson and we are searching for the production of the Higgs boson in association with a vector boson in the  $H \rightarrow WW$  decay channel with the CMS experiment at the LHC. This measurement provides a direct probe of the Higgs boson coupling to vector bosons. The latest CMS results on the Higgs boson decay to a W boson pair are presented. The focus of the presentation will be on the inclusive measurements performed for the VH leptonic channel with full Run 2 data which corresponds to an integrated luminosity of 137.1 fb<sup>-1</sup>, collected by the CMS detector at LHC, as well as the constraints on the Higgs boson couplings to fermions and vector bosons arising from the simultaneous measurement of different production mechanisms.

YSF / 27

## Observation of electroweak production of two jets and a Z-boson pair with the ATLAS detector at the LHC

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The observation of electroweak production of two jets in association with a Z- boson pair using 139 fb<sup>-1</sup> of pp collision data at  $\sqrt{s} = 13$  TeV collected by the ATLAS detector at the LHC is reported. Two different final states originating from the decays of the Z boson pair, 4l and 2l2v, are included in the measurements. A significant data excess from the background-only hypothesis is observed, which corresponds to a statistical significance of  $5.5\sigma$ . The observed excess is compatible with the electroweak production of two jets in association with a Z-boson pair in vector-boson scattering processes. The cross-sections for inclusive production of ZZ plus two jets, as well as the observed signal strength of the EW production, are presented.

YSF / 28

## Measurement of the vector-boson transverse momentum distributions with ATLAS

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The transverse momentum distribution of W/Z bosons produced in hadronic collisions is a traditional probe of strong interaction dynamics. The correct modelling of this distribution is important

in many physics analyses at the LHC for which the production of W or Z bosons constitutes a significant background. Moreover, it is crucial for a precise measurement of the W boson mass. In this talk measurements of the transverse momentum distribution for a Z decaying into an electron or muon pair together with the distribution of an angular variable based on the direction of the two leptons coming from the Z-boson decay are presented. The measurement is done using proton-proton collision data at  $\sqrt{s}=13$  TeV collected with the ATLAS detector. The results are compared to perturbative and resummed QCD calculations and used to constrain the parton shower parameters of Monte Carlo generators. If available a measurement of transverse momentum distributions for W decaying into an electron or muon and a neutrino is also presented.

YSF / 29

## NNLO QCD Predictions for Triphoton Production

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In this talk, I am going to present fully-differential NNLO QCD corrections to the hadroproduction of three isolated photons. We employ an implementation of the  $q_T$  subtraction formalism within Matrix, and the recent analytic computation of the two-loop amplitudes to achieve a fully-flexible calculation of the triphoton production at NNLO accuracy. This process is on the cutting edge of the NNLO multiplicity frontier, being the first  $2 \rightarrow 3$  process for which NNLO QCD predictions have been calculated. We show that the large NNLO QCD corrections are indispensable to describe the experimental measurements in the broad spectrum of observables. We also discuss perturbative convergence of the fixed-order predictions.

YSF / 35

## LHCb: Search for CP violation in $D_0 \rightarrow K_S^0 K_S^0$ decays

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CP violation in the charm system has been observed for the first time by LHCb in 2019. Up to now, the effect has only been seen in a single observable, the Delta-ACP between  $D_0 \rightarrow KK/\pi\pi$ . Further measurements are therefore important for a better understanding of the physics picture in this novel field, and whether it is purely Standard-Model or not. Among the possible decay channels, the  $D_0 \rightarrow K_S^0 K_S^0$  one is very promising for a second observation, having the potential for a CP asymmetry of up to  $\sim 1\%$  in the SM. This channel is much more difficult to pursue at LHCb than its charged analogues, but thanks to recent improvement in the analysis, a measurement of its CP asymmetry on the Run-2 sample has just been completed, that is more precise than all previous measurements combined. We present the current result and the prospects for future LHCb runs.

QCD / 36

### **Hot topics in PDF fits (role of jet and top data, higher-orders, modelling of experimental correlations)**

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QCD / 37

### **Recent results in NNLO and N3LO calculations**

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QCD / 38

### **Jet measurements (including Lund-plane) and PDF/ $\alpha_S$ interpretations at the LHC**

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QCD / 39

### **Jet Fragmentation and Central Exclusive Production at LHCb**

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QCD / 40

### **Progress in MC event generators (with focus on NLL showers)**

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QCD / 41

### **Role of mass corrections in pQCD calculations**

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QCD / 42

## **Jet substructure (with possible ML) at the LHC**

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Joint QCD - EWK / 43

## **On the treatment of correlated theoretical uncertainties in LHC data analysis**

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Higgs / 44

## **State of the art in SM Higgs physics**

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Higgs / 45

## **Higgs Couplings and properties (incl. mass, CP): current status**

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Higgs / 46

## **Resonant and non-resonant HH channel**

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TOP / 47

## **Progress in $t\bar{t}$ @ NNLO+PS**

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TOP / 48

## **ATLAS and CMS results latest results on $t\bar{t}$ and single-top cross-section measurements**

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TOP / 49

## **ATLAS/CMS Top properties (mass, spin corr., asymm. Vtb,...)**

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Higgs / 50

## **Higgs and flavour**

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Higgs / 51

## **Rare SM Higgs channels (mumu, Zgamma, ccb $\bar{c}$ )**

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Joint Top - Higgs / 52

## **ATLAS/CMS latest results on t(t)+X (X=tt,bb,Z,W,gamma)**

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Joint Top - Higgs / 53

## **ATLAS and CMS results latest results on tth/th**

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Joint Top - Higgs / 54

## **tt+X (X=H,tt,bb,Z,W,gamma): status and perspectives of precision predictions**

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FLV / 55

## **New results on b $\rightarrow$ s ll**

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FLV / 56

## **NP implications & connections with high-pT**

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FLV / 57

## **CMS/ATLAS rare decays: new results & prospects**

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EWK / 58

## **Progress in NLO EW Monte Carlo**

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EWK / 59

## **Electroweak corrections for precision weak mixing angle measurements at LHC**

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EWK / 60

## **Drell-Yan measurements / weak mixing angle**

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EWK / 61

## **Multiboson measurements**

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FLV / 62

## **Lattice QCD inputs for SM**

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FLV / 63

## **Analytic QCD inputs for SM**

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FLV / 64

## **CKM measurements and hadronic form factors**

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FLV / 65

## **ATLAS and CMS results on CP-Violation: new results & prospects**

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FLV / 66

## **Latest results on spectroscopy**

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Joint QCD - EWK / 67

## **Status of theory predictions for single bosons, diboson, and multi-boson production**

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Joint QCD - EWK / 68

## **Differential cross section measurements of WW + 1 or more jets with ATLAS**

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Joint QCD - EWK / 69

## **Electroweak production of $Z\gamma$ and two jets at 13 TeV and constraints on EFTs**

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Higgs / 70

## **STXS vs. Fully fiducial measurements: limitations and possible future improvements**

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Higgs / 71

## **Differential Higgs measurements**

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Higgs / 72

## **BSM Higgs**

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Joint QCD - EWK / 73

## **QCD & MC challenges for VBF/VBS measurements**

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Joint QCD - EWK / 74

## **VBS/VBF Boson measurements**

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EFT / 75

## **Recent EFT developments: what we should be doing and why**

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EFT / 76

## **Top plus Higgs: towards a global EFT fit**

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EFT / 77

## **The global impact of EW+H SMEFT probe**

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EFT / 78

## **EFT measurements in the EW (+Higgs) sector**

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EFT / 79

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EFT / 80

## **The PDF and EFT Interplay**

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EFT / 81

## **Low energy and flavour EFT probes**

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EFT / 82

## **EFT constraints with multi-dimensional and multi-variate techniques**

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**FLV / 83**

**Combined discussion**

**FLV / 84**

**Combined TH discussion**

**FLV / 85**

**Combined EXP discussion**