ECFA Studies towards a Higgs/EW/Top factory

WG1 ("Physics Potential") report

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Overview

Based on the recommendations of the Update of the European Strategy for Particle Physics, the European Committee for Future Accelerators (ECFA) has decided to organise a series of workshops on physics studies, experiment design and detector technologies towards a future electron-positron Higgs/EW/Top factory. The aim is to bring together the efforts of various e+e- projects, to share challenges and expertise, to explore synergies and to respond coherently to this high-priority strategy item.

To set up the relevant structures and to define a path towards such workshops, an International Advisory Committee (IAC) has been formed. It suggested to establish three Working Groups, led by conveners from both experiment and theory:

WG 1: Physics Potential
WG1 ("Physics Potential") mandate

- Set up a forum on physics potential of future Higgs and top/EW factories to collect, compare and harmonise the work of the different project-specific coordinated efforts, as well as independent theoretical and experimental research on the subject. The perspectives of the (HL-)LHC on physics targets, that are in common or in synergy with those of the future Higgs and top/EW factory, are part of the mandate.
- Identify thematic areas or specific topics where concrete work should be organised in the context of the ECFA Working Group, in coordination with the existing project-specific Working Groups. The main focus should be on problems that are common to several Higgs and top/EW factories, and/or relevant to identify synergies. Small thematic groups/task forces could be appointed to carry out concrete work and deliver notes and/or original publications.
- Propose ideas for new observables, new experimental tests, new ancillary measurements
## WG1/WG2 Kick-off meeting (18 Jun)

### AM

**2:00 PM**  
Introduction of the ECFA study - Jakobs, Karl (Albert Ludwigs Universitaet Freiburg (DE)) (40/S2-D01 - Salle Dirac)

### PM

**2:15 PM**  
**Working Group 1** - Alcaraz Maestre, Juan (Centro de Investigaciones Energéticas, Medicambiente y Tecnológicas (CIEMAT, Madrid)) Maltoni, (Deutsches Elektronen-Synchrotron (DE)) Wells, James Daniel (University of Michigan (US)) (until 3:30 PM) (40/S2-D01 - Salle Dirac)

**2:15 PM**  
Experimental challenges at future e+e- colliders - Perez, Emmanuel Francois (CERN) (40/S2-D01 - Salle Dirac)

**2:40 PM**  
Challenges in global interpretation of data from future e+e- colliders and interplay with HL-LHC - de Blas, Jorge (Universidad de Granada (ES))

**3:05 PM**  
Theoretical challenges for future e+e- colliders - Peskin, Michael (SLAC) (40/S2-D01 - Salle Dirac)

**3:30 PM**  
--- Coffee / tea break ---

**3:45 PM**  
**Working Group 2** - Zerwas, Dirk (Université Paris-Saclay (FR)) Piccinini, Fulvio (Pavia University and INFN (IT)) Azzi, Patrizia (INFN Padova (IT))

**3:45 PM**  
Physics Event Generators, BeamConditions (Beamstrahlung, Polarization), Standard Candles and Luminosity - Kilian, Wolfgang (University of Siegen)

**4:05 PM**  
Physics Performance (reco Pflow, Kinematic fit, tracking, PID) - Roloff, Philipp (CERN) (40/S2-D01 - Salle Dirac)

**4:25 PM**  
Detector Simulation (FastSim and Full Sim etc.) - Jeans, Daniel (KEK) (40/S2-D01 - Salle Dirac)

**4:45 PM**  
Software Ecosystem - Ganis, Gerardo (CERN) (40/S2-D01 - Salle Dirac)

**5:05 PM**  
Way-ahead with the WG1 and WG2 activities - List, Jenny (Deutsches Elektronen-Synchrotron (DE)) (40/S2-D01 - Salle Dirac)
WG1 focuses on:

- EFT (global) interpretation of Higgs factory measurements, including EW, Z pole and top physics, and its impact on concrete new physics scenarios and models.
- Extend the study of the impact also on specific models that cannot be matched onto EFT.
- Exploration of different flavour scenarios and interplay with flavour data.
- Identification of measurements that HL-LHC can do in order to increase the physics potential of the future Higgs and top/EW Factory.
- HL-LHC precision physics interplay with the Higgs and top/EW factory potential, including the not-yet-complete assessment of the high-\(p_T\) probes potential at the HL-LHC. Comparative attention should also be paid to the potential of other future colliders.
- Requirements for accuracy in theoretical calculations and parametric uncertainties, and perspectives to achieve it.
- Perspectives for experimental uncertainties.
- Broad exploration of the new physics discovery potential of the future Higgs and top/EW factory, including the search for Feebly Interacting Particles also in connection with “Physics Beyond Colliders” activities.
- Availability and development of Monte Carlo generators required to achieve the physics goals.

Studies relating to a common approach to systematic uncertainties and the ultimate achievable precision are likely to be undertaken jointly between this group and the Physics Analysis Methods working group.
Implementation of the effort

“In consultation with the IAC, the group conveners will define a work programme, and identify (if/when needed) lead people to take forward each activity. The conveners will facilitate regular working group meetings towards the preparation of general ECFA workshops.”

In the case of WG1 (Physics Potential) the best way to take forward our program is to subdivide the activities with the help of additional lead people (in progress)

We have identified / setup 5 distinct fronts of activity, covering the focus of our mandate ⇔
WG1 activities

- WG1-PREC: Precision calculations and theoretical, parametric and experimental systematic uncertainties
- WG1-EFT: Global interpretation in (SM)EFT and UV complete models
- WG1-HTE: Higgs, top and electroweak physics
- WG1-HF: Flavour Physics
- WG1-SRCH: Direct discovery potential

Important note: strong LHC connections in all activities, plus HF factories for WG1-HF and non-collider experiments for WG1-SRCH
  - Already taken into account when choosing lead people
Activities: WG1-PREC

- Requirements for accuracy in theoretical calculations and parametric uncertainties, and perspectives to achieve it.
- Perspectives for experimental uncertainties

Target subjects:
- assess experimental precision, collect relevant systematics: luminosity, energy, polarization, detector calibration/alignment, acceptance/efficiency,
- define theory precision requirements to reach those precisions, cross-section and decay rate calculations for Higgs / EW / top / BSM, development of strategies,
- measurements needed as input for parametric uncertainties
- techniques to reduce the impact of experimental systematics
- what we have learned from LHC regarding the treatment of calibrations, systematics, ...
- ...

Target members:
- theorists and experimentalists focused on high precision matters
- in coordination with WG2 ("physics methods")
Activities: WG1-EFT

- EFT (global) interpretation of Higgs factory measurements, including EW, Z pole and top physics, and its impact on concrete new physics scenarios and models.
- Extend the study of the impact also on specific models that cannot be matched onto EFT.

Target subjects (basically BSM above the EW scale):

- (SM)EFT fits in Higgs / EW / top sectors
- BSM models (SUSY,...): how can they be distinguished in an EFT context, explicit fits to those models, ...
- usage of differential distributions as inputs,
- beyond dimension six,
- triple gauge boson couplings, four-fermion interactions, longitudinal W scattering, WW->ttbar, ...
- ...

Target members:

- (SM)EFT fitting groups, specific-model fitting groups (SUSY, ...)
- Experimentalists (inputs to be provided, analysis strategies, ...)
- Interaction with WG1-PREC (precision) and WG1-HTE (H/top/EW analyses, LHC connection)
Activities: WG1-HTE

- Identification of measurements that HL-LHC can do in order to increase the physics potential of the future Higgs and top/EW Factory.
- HL-LHC precision physics interplay with the Higgs and top/EW factory potential, including the not-yet-complete assessment of the high-p_T probes potential at the HL-LHC. Comparative attention should also be paid to the potential of other future colliders.

Target subjects:
- Specific analysis items related with Higgs/EW/ttbar physics: analysis details, threshold scans, differential measurements, ...
- connection with similar studies at LHC, paying attention to the high-Q^2 domain, joint studies with ee projections, identify other needs from LHC physics program,
- connection/comparisons with other future projects (muon colliders, ...),
- ...

Target members:
- experimentalists from LHC experiments and e+e- future facilities
- theorists working on all the subjects above
Activities: WG1-HF

- Exploration of different flavour scenarios and interplay with flavour data.

Target subjects:

- Flavour physics potential of future Higgs factories,
- specific/interesting/unique measurements at Higgs factories,
- comparisons/added-value/complementarity with the flavour physics potential of existing colliders (LHC, Belle-II),
- implications/connections with other flavour experiments (g-2, …),
- interpretation of flavour anomalies in BSM models and what they imply for Higgs factories, global interpretation in an EFT context (together with WG1-EFT),
- ...

Target members:

- HF experimentalists (Belle-II, LHCb, ATLAS, CMS, those already working for future e+e- colliders, …)
- Flavour physics model builders
- Flavour fitting groups
Activities: WG1-SRCH

• Broad exploration of the new physics discovery potential of the future Higgs and top/EW factory, including the search for Feebly Interacting Particles also in connection with “Physics Beyond Colliders” activities.

Target subjects:
  ○ projections for FIP searches at future e+e- projects,
  ○ HL-LHC projections on direct searches, in particular for FIPs and low-mass final states: exotic non-SM Higgs decays, dark-matter searches, dark sectors, compressed SUSY spectra, other exotic signatures, …,
  ○ complementarity and implications of LHC and of other non-collider / dark matter search experiments on the FIP e+e- Higgs factory potential,
  ○ …

Target members:
  ○ experimentalists from LHC, non-collider experiments and e+e- projects working on searches of FIP type
  ○ theorists interested/working in this field, model builders
Together with WG2: MC generators

- Availability and development of Monte Carlo generators required to achieve the physics goals.

Generators:
- Target subjects:
  - Development/revival of generators for $e^+e^-$, at the level of the required precision
  - Higher/missing orders of EW/QCD corrections
  - ISR/FSR, full spin-correlation treatment from initial to final state, special treatments (interferences, resonance thresholds, ...), ...

- Target members:
  - representatives of all major MC development teams
  - representatives of all e+e- projects (“user perspective”)

- First topical workshop already took place in coordination with WG2, focused on current availability and technical status (more details in WG2 report)
Current steps in WG1

- Already contacted the leading experts who will help us to take forward the different activities. Discussions with them already started and should be finalized soon.

- Specific tasks of activity leaders:
  - identify crucial to-do items, build community around them when needed,
  - report and organize parallel sessions at the central ECFA workshops,
  - define/organize small topical workshops in coordination with us,
  - contribute to overall seminar series,
  - delivery of the corresponding chapter of a final Yellow Report in 2023
Some key points already noticed

- Many tasks can only be developed efficiently within this initiative:
  - Avoid duplication of efforts in circular and linear collider communities (this we knew already)
  - Current efforts are naturally very LHC-focused and manpower frequently limited:
    - better identify and specify the high priority needs for future ee collider facilities
    - Establish benchmark processes to be considered by the groups (similarly to what was done with LHC in the past)
  - Both theory and experimental groups need a solid/official framework to develop and get involved in these activities
    - New FC CERN group extremely useful in this respect (already coordinating with them)
  - Many missing pieces. Regarding generators, for instance:
    - Some theory developments needed for the required precision, but not available yet (QED radiation, QED-QCD interplay)
    - EWK/higher order effects not available yet
Theory developments to be done...

How KKMCee compares with other QED schemes in MC programs

Order-by-order approach (OLDBIS, MUSTRAL, KORALZ) disfavoured, soft photon resummation mandatory, collinear resummation recommended.

S. Jadach

Collinear resummation of mass logs

Strictly collinear PDFs (kT=0)  Parton shower (finite kT)

1. LO formulas available analytically at any higher order
2. Convenient and useful only for
1. Well developed for QCD but little used in QED
2. Problems the same as in QCD

Soft photon resummation YFS-style

1. Correct soft photon limit for n real or virtual photons
2. Exact Lorentz invariant Phase Space (LIPS)
3. Well defined scheme of including higher order non-soft real and virtual corrections at any order
4. Resummation of collinear logs truncated to finite order, non-singlet transitions out of scope

S. Frixione

Alternatively, one can simulate such effects by means of parton showers as is normally done in (N)LO+PS calculations

We have not (yet) implemented the latter in $e^+e^-$ collisions, because:

- Non-trivial technical matching issues, due to the functional forms of the PDFs
- A genuine physics problem: no current parton shower can handle the NLL $e^\pm$ PDFs
Plans

- **Short term:** workshop on precision requirements (theory + experiment)
  - Details still to be worked out together with subgroup leaders

- **Long term:** progressively organize WG1 workshops from the different activity groups. Detailed schedule to be developed soon
  - **2021:**
    - Kick-off workshop (June),
    - Report at PECFA (19 Nov)
  - **2022:**
    - specific/focused WG1 workshops and seminars,
    - (Big) ECFA initiative workshop (2-3 days)
  - **2023:**
    - specific/focused WG1 workshops and seminars,
    - (Big) ECFA initiative workshop (2-3 days)
    - Specific meetings for finalization of Yellow Report
  - **2024:**
    - Final workshop with Yellow Report presentation
**Summary / Outlook**

- **WG1 activities getting up to full speed now**
  - 5 fields of activity identified:
    - WG1-PREC, WG1-EFT, WG1-HTE, WG1-HF, WG1-SRCH
  - Discussions with identified people to lead/catalyze these activities now going on

- **Need of an effort of this kind becoming increasingly clear**
  - Avoid duplications
  - In many cases the optimal way to accelerate theory/experimental developments that are necessary for future Higgs factories
    - Precision requirements extremely demanding

- **Significant rise of WG1 activities and a substantial involvement of theory/exp. community expected in the next months**