ECFA Higgs Factory Focus Topics
… and ILD

Jenny List
ILD General Meeting
7 March 2023

Motivation

What can ECFA HF Study add beyond state-of-the-art?

- Unclear which project will be built - but to get any, a strong e+e- community is required!
  => How can HEP community engage in e+e- Higgs Factory studies after Snowmass?
- Most can only spend only a small fraction of their time on “future topics”

  => lower threshold to contribute as far as possible
  => avoid duplication
- ECFA Study is not tied to a specific e+e- project:
  - for people who hesitate to “sell their soul” to FCC or ILC or … this could be the ideal place!
  - minimum:
    forum to present work and discuss science and detector requirements across projects
  - even better: **trigger actual joint work => focus topics**
  - support the use of common software and exchange of data-sets via Key4HEP

=> How can ILD engage and contribute?

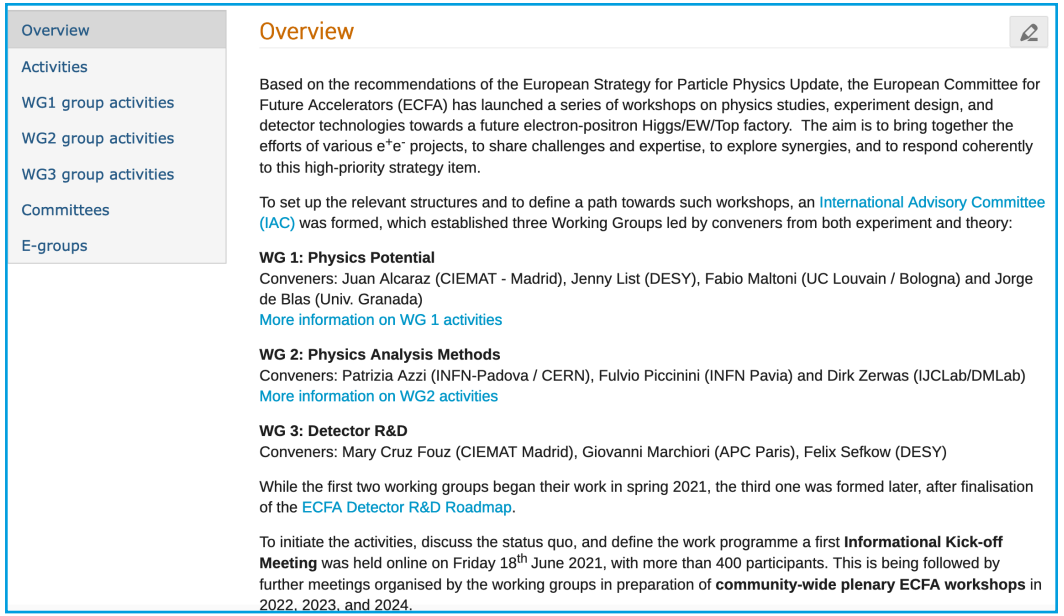
Purpose of Focus Topics - in the words of Aidan Robson

Chief Editor of the final report of the ECFA HF Study

- Strategic priority is an e+e– collider
  –> we need a strong e+e– community preparing it
  (1) to encourage approval of a project
  (2) to allow it to move forward immediately once green-lit
  (experimental programme, detector systems)
- Effort is limited and each individual project is under-resourced
  –> projects should work together where possible
  (1) to make scientific progress
  (2) to stimulate new engagement and expand the community
- The focus topics are intended:
  (1) to bring people across projects to work *together* (i.e. even more than "coherently")
  (2) to bring attention to areas where analyses and analysis tools can be developed cooperatively for the mutual benefit of all projects
  (3) to provide a clear entry point and concrete studies to attract people to join the e+e– effort
- The focus topics can therefore act as a vehicle for enhanced collaboration and new engagement
- The *detailed* choice of topics attempts to highlight areas of shared interest across projects, where there is interesting new scientific work to be done, which could be particularly attractive to new participants by leading to small-author papers / thesis chapters. Tools (and person-skills) developed along the way would naturally be expected to have a wider application/impact, beyond the physics of the focus topic itself.

Overview

and reminder on structure of ECFA HF study



- central entry point: https://indico.cern.ch/event/1044297/
- three (top-level) WGs
- WG1 Physics Potential opted for a substructure
- 16 focus topics
  - for each, one sub-area within WG1 takes the lead
  - WG2 and WG3 contribute on the relevant performance aspects
- currently, expert teams are being formed on each of the topics, will define the more detailed work program
  => we (ILD) should support this by helping to find currently (or in the past? or possibly future?) active people in ILD
- ILD people in ECFA-HF-WG1 (besides JL):
  - Junping, Marcel => GLOBal Interpretations
  - Filip => SeaRCHes
  - Adrián => PRECision

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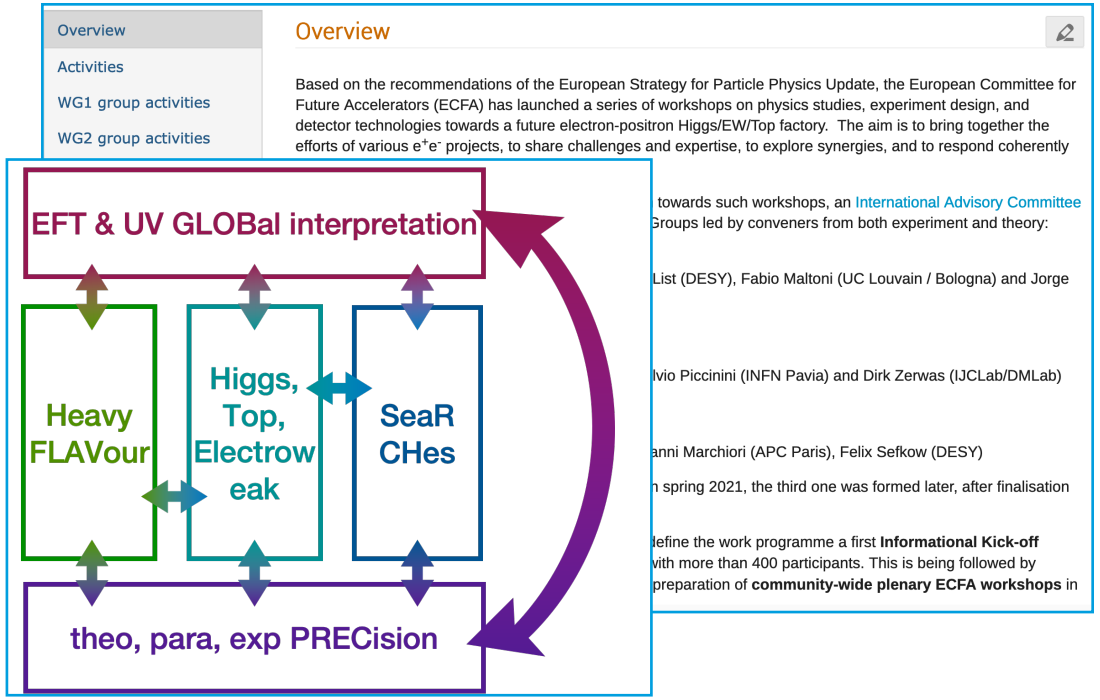

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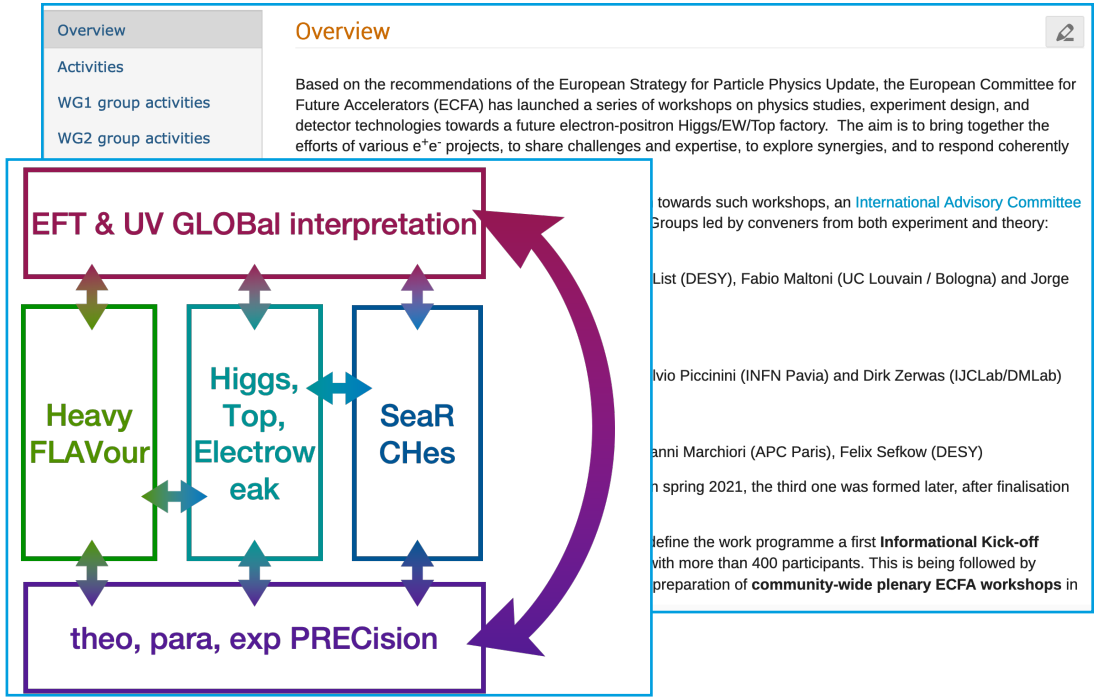

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Caveat: all the following is work in progress, presentation here is meant to trigger discussion!

Focus Topics

at a glance

Table 1: Overview of focus topics and relevant center-of-mass energies.

topic	lead group	relevant $\sqrt{s}$ 91 GeV	161 GeV	240/250 GeV	350-380 GeV	$\geq$ 500 GeV [a]
1 HtoSS	HTE			X	X	x
2 ZHang	HTE (GLOB)			X	X	x
3 Hself	GLOB			X	X	X
4 Wmass	PREC		X	X	X	
5 WWdiff	GLOB			X	X	x
6 TTdet	HTE				X	
7 TTscan	GLOB (HTE)				X	
8 LUMI	PREC	X	x	x	x	x
9 EXscalar	SRCH	x	x	x	x	x
10 LLPs	SRCH	x	x	x	x	x
11 EXtt	SRCH				x	x
12 CKMWW	FLAV		x	X	x	x
13 BKtautau	FLAV	X				
14 TwoF	HTE	X	x	X	X	x
15 BCfrag	FLAV (PREC)	X	x	X	X	x
16 Gsplit	PREC (FLAV)	X	x	X	X	x

[a] not main target (apart from topic 3), listed for completeness

1 e+e− → Zh with h → ss (Z → anything) at √s = 240..250 GeV

HtoSS, HTE

theoretical, phenomenological and MC generator targets

- BSM models predicting deviations in $h \to s\bar{s}$, e.g. SUSY
- $s\bar{s}$ vs. $b\bar{b}$ in BSM models: gain from $s\bar{s}$?
- flavor assumptions in EFTs: decouple 3rd from 1st/2nd family?

target physics observables

- $e^+e^- \to Zh$ with $h \to ss$ ($Z \to$ anything) at $\sqrt{s} = 240/250\,\text{GeV}$
- projected precision on branching fraction, and differential cross-section in $\cos\theta_s$
- BR($h \to bs$)?

target methods to be developed

- charged hadron ID from dN/dx, dE/dx, ToF, RICH
- reconstruction of in-flight decays, e.g. $K^0_S \to \pi^+\pi^-$
- strangeness-tagging
- s vs $\bar{s}$ separation
- control of strange-tagging related systematic uncertainties

target detector performance aspects

- dependence of the precision on physics observables on particle ID and reconstruction capabilities

- joined SiD / ILD Snowmass study:
  - Valentina Cairo, Matt Basso, Jan Strube
    => first study based on ILD full sim + **cheated Kaon-ID**
  - Ulrich Einhaus, Bohdan Dudar
    => realistic Kaon ID, with dE/dx and ToF; algorithmic developments, PID tools

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target methods

- charged ha
- reconstruc
- strangenes
- s vs $\bar{s}$ sepa
- control of

target detector

- dependenc

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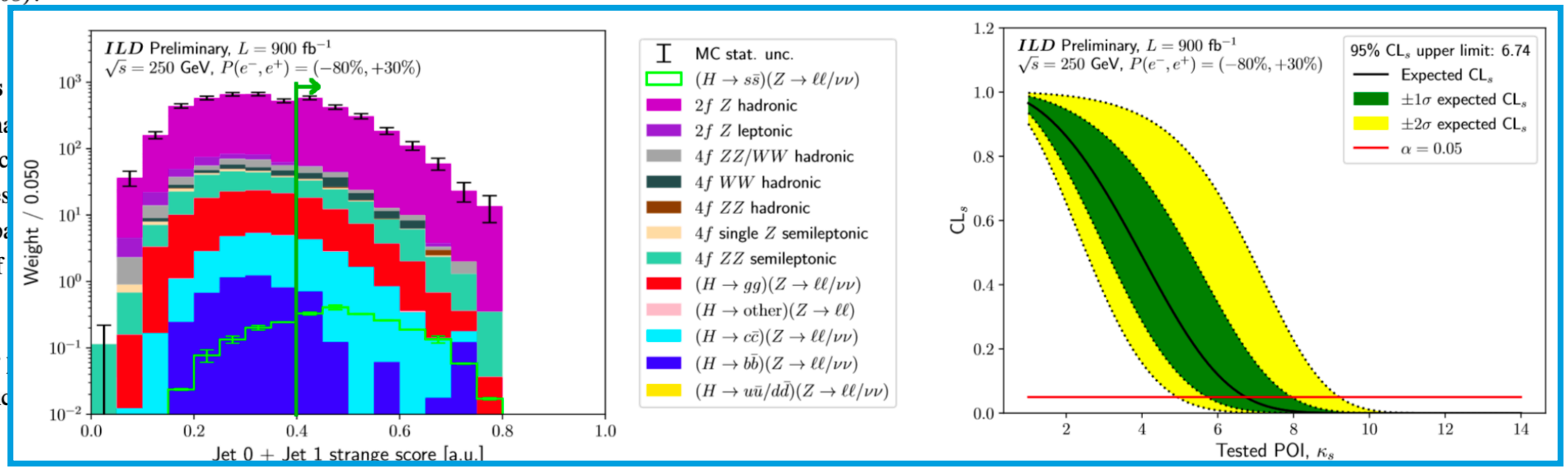


2 Differential cross-sections in e+e− → Zh at √s = 240..250 GeV and 350 GeV

ZHang, HTE

theoretical and phenomenological targets

- definition of CP observables
- inclusion in EFT fitting codes
  provide benchmark(s) for new operators to be probed
- global interpretation of CP properties in Yukawa couplings and couplings to vector bosons
- comparison of theory predictions and MC generators for $e^+e^- \to f\bar{f}h$

target physics observables

- $e^+e^- \to Zh$: precision on differential cross-sections wrt production and decay angles, with $h \to ZZ^*/WW^*/Z\gamma$
- $e^+e^- \to Zh$: precision on differential cross-sections wrt CP angles from $Z \to ee/\mu\mu$ – and $Z \to \tau\tau/qq$

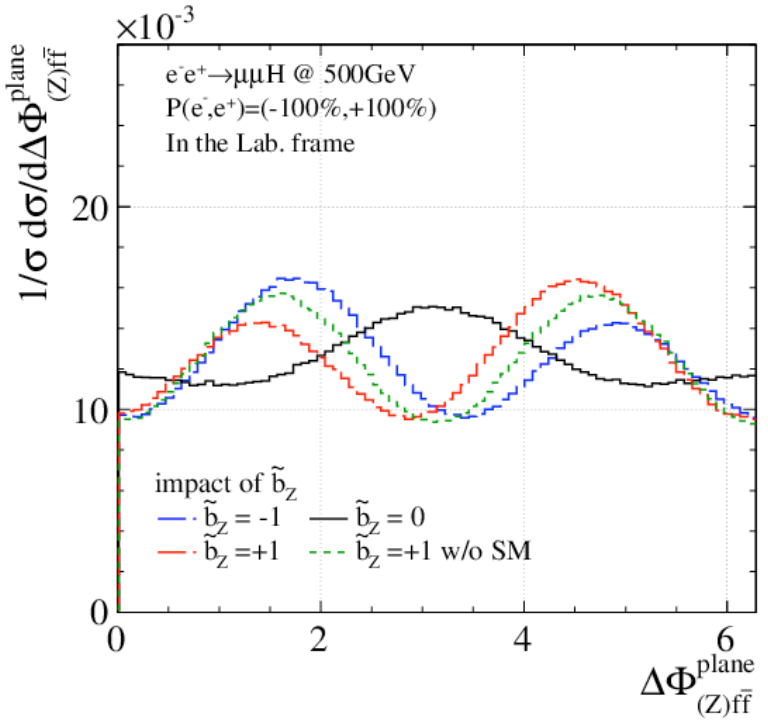
target methods to be developed

- τ reconstruction
- q vs $\bar{q}$ separation (jet charge, leading hadron charge etc)
- angular reconstruction
- optimal observables?

target detector performance aspects

- dependence of selection efficiencies / purities and of precision of angular reconstruction (production, decay, CP), precision of h restframe reconstruction on vertexing, tracking, hermeticity, calorimeter granularity, availability of charged hadron ID and/or $V0$ reconstruction

- CP study H->tautau by Daniel
- anomalous HVV couplings by Tomohisa
- H->ZZ* by Evgeny
- H->WW* by Mila
- … ?



3 Determination of the Higgs self-coupling

HSelf, GLOB

theoretical, phenomenological and MC generator targets

- Interpretation of triple Higgs couplings assuming measurements are either around values close to the SM or far away (at BSM values for specific models).
- Multi-Higgs interactions involving additional Higgs bosons (in specific BSM models).

target physics observables

- Single Higgs observables at 250 + 350/365 GeV:
  - for indirect determination of $\kappa_\lambda = \lambda_3/\lambda_{3,\mathrm{SM}}$): EFT approach ($\kappa_\lambda \approx 1$) vs. concrete models ($\kappa_\lambda \neq 1$)
  - for indirect determination of multi-Higgs interactions involving also extra Higgs bosons. Can these contributions be disentangled from the SM-like Higgs selfcoupling? Study the distributions. Is there are an optimal energy scan?
- What can be improved substantially by using diHiggs production measurements?
- Di-Higgs production of light BSM Higgses?

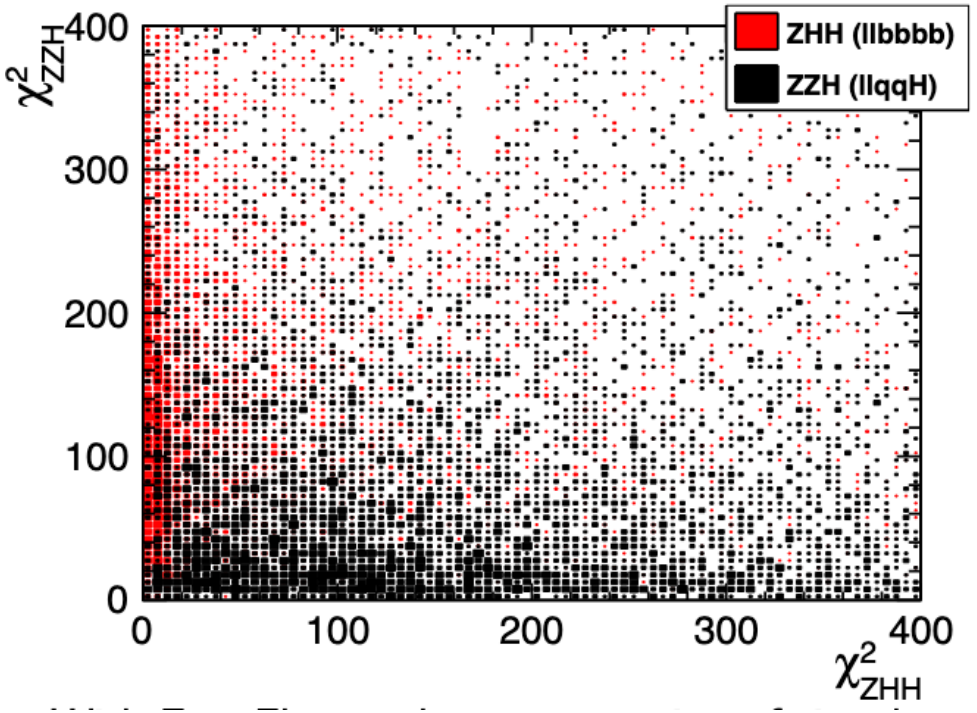
target methods to be developed

- Precision in determination of single Higgs processes
- EFT: effects from other operators entering in single Higgs at NLO that can affect the determination of the Higgs selfcouplings

target detector performance aspects

- b-tagging, reconstruction, . . .

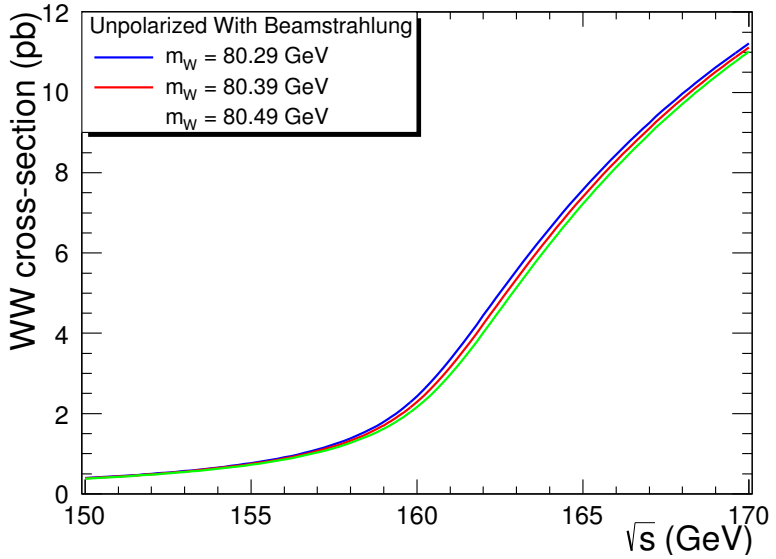
- existing ZHH / vvHH by Claude, Masakazu, Junping
- EFT fitting: Junping…
- new ZHH analysis by Julie
- SiD/ C^3: Caterina & student
- …

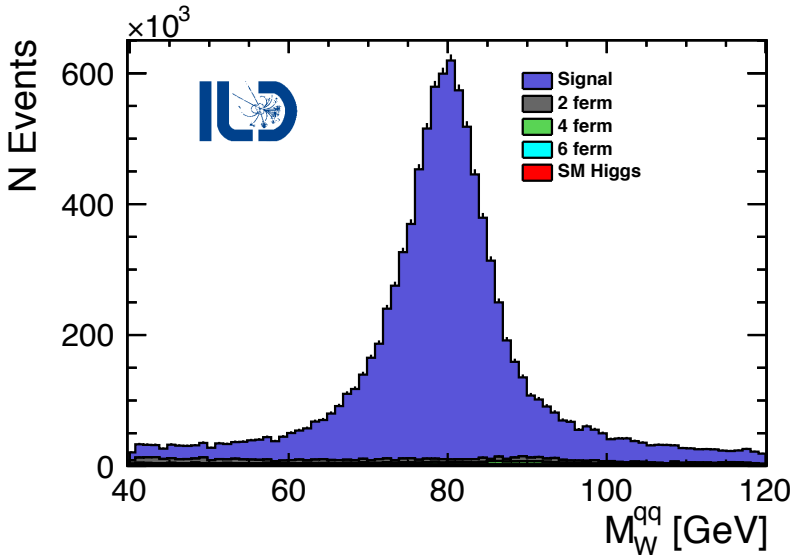


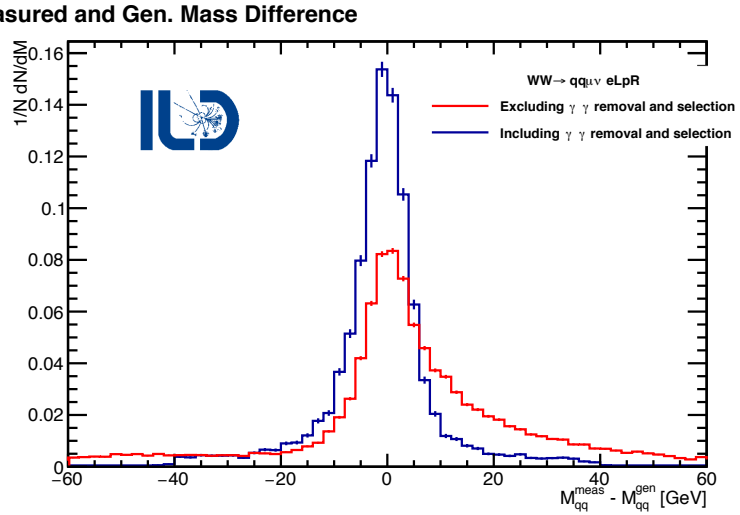
4 W Mass from Threshold and Continuum

WMass, PREC

- theory predictions and MC generators
- detector-level studies including mass reconstruction techniques
- systematic limitations and calibration strategies
    - ILD: Graham & Justin





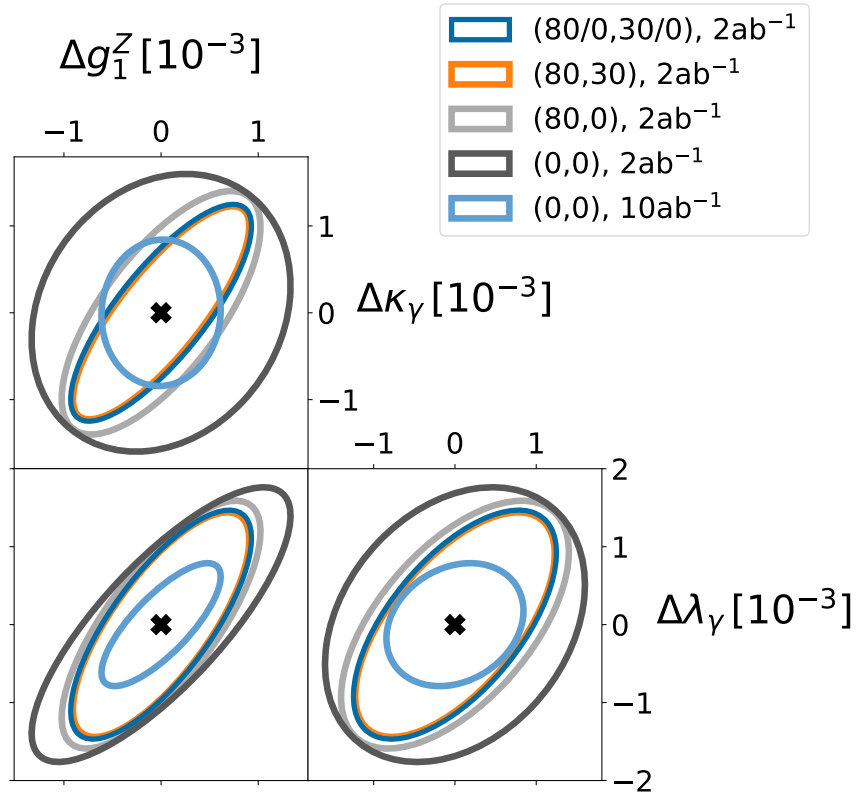


5 Differential Cross-sections in WW and evW

WWdiff, GLOB

- comparision of theory predictions and MC generators
- detector-level studies including full differential angular information
- reconstruction of CP angles
- optimal observables
- interface to global interpretations
- CP violating operators and other effects beyond “standard” TGCs

- past activities at DESY (Jakob…), none currently
- new PhD student in CERN EP-SFT on e- reconstruction, evW one benchmark application, but not exclusively ILD



6 Detector-level simulation study at a typical ttbar threshold energy
7 ttbar threshold scan optimisation

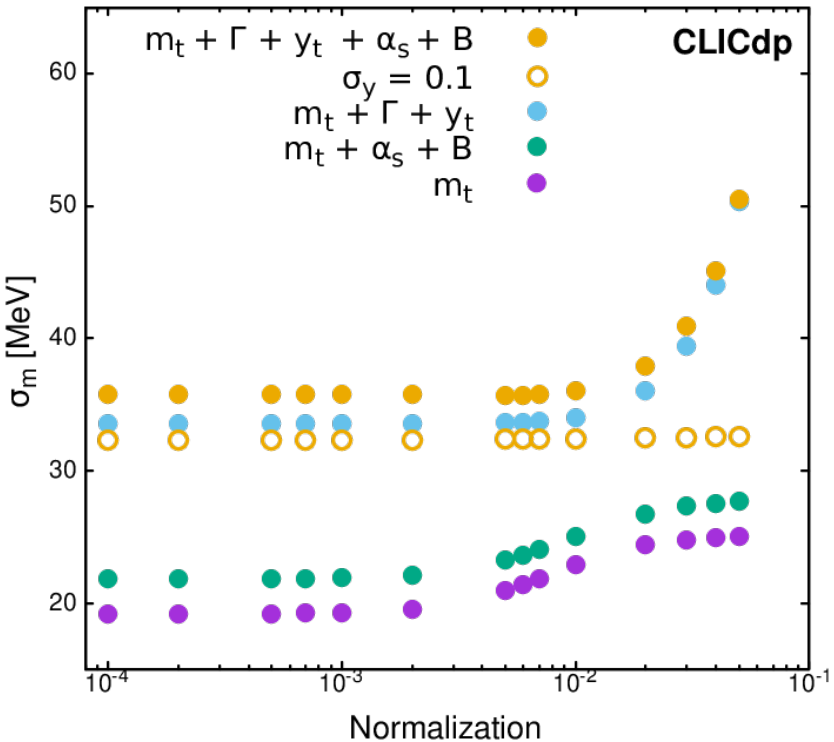
TTdet, HTE + GLOB

- detector-level studies of total & differential cross-section, asymmetries, CP observables
- detector requirements and reconstruction/analysis methods
- interface to global interpretations

- theory predictions and MC generators
- backgrounds, polarisation, energy-step optimisation
- interpretation incl. “classic” threshold scan parameters as well as electroweak coupling parameter extraction, also CPV

ILD

- ttbar 500 GeV studies by Roman’s group
- past activities at
  - MPI (Frank Simon / Katja Seidel)
- CLICdp: Warsaw (Filip et al)
- in context of ECFA study, Marcel volunteered to take the lead on these topics



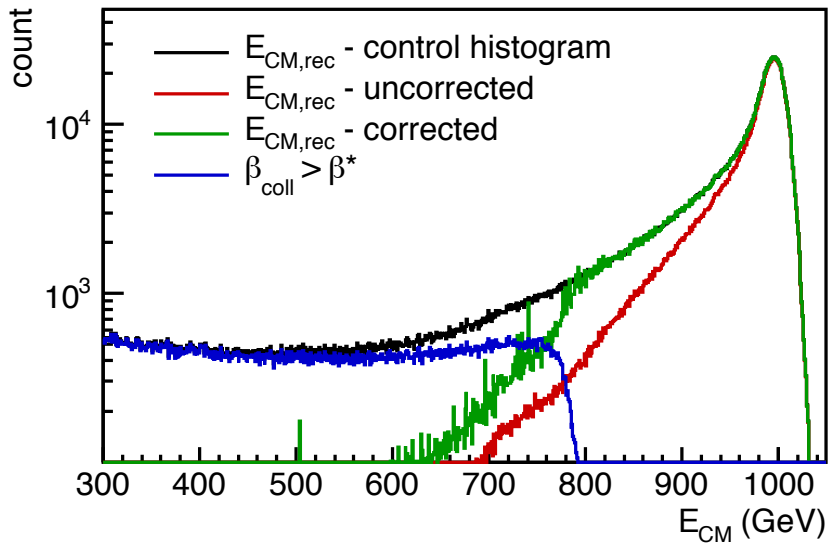
8 Luminosity measurements from low-angle Bhabhas

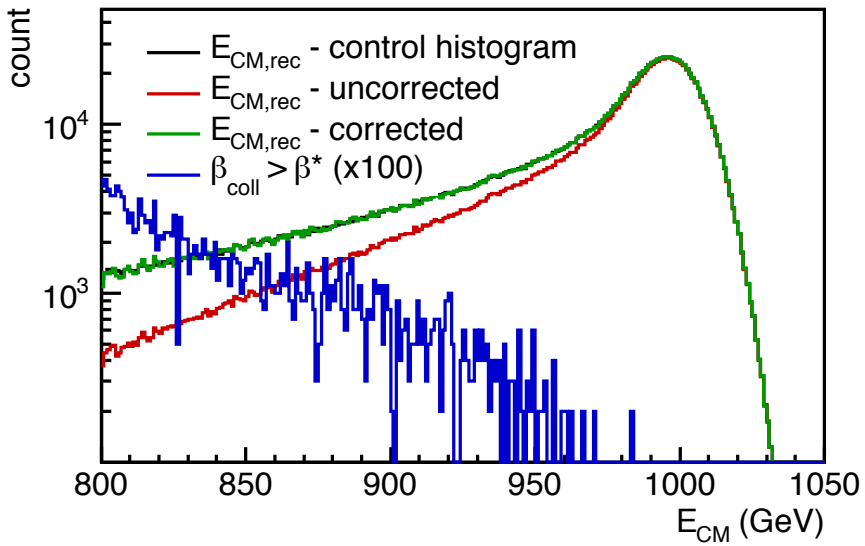
LUMI, PREC

- theory and MC generators: comparison of state-of-the-art and ultimate requirements
- detector-level simulations at all √s, including backgrounds etc
- measurement strategies
- requirements on LumiCal: resolutions, alignment

ILD

- detailed study by Ivanka at 500 GeV / 1 TeV
- lower energies: for CEPC





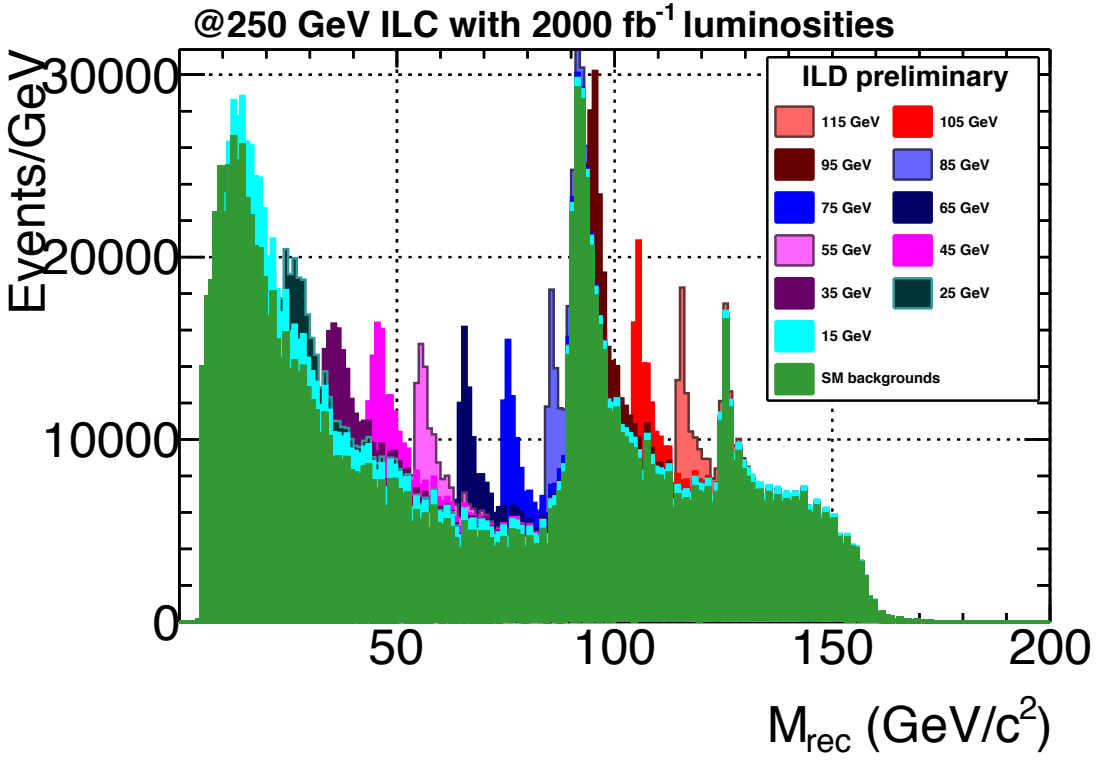
9 New Exotic Scalars

EXscalar, SRCH

ILD

- past study by Yan Wang (recoil)
- staus by Teresa
- … ?

Have direct contact with Filip



Theoretical and phenomenological targets

Search for invisible Higgs boson decays will be one of the primary targets of the precision Higgs studies. Any excess above the invisible BR of about 0.1% predicted by SM ($H \to ZZ^\star \to 4\nu$) will be a direct evidence for BSM contribution. Additional invisible Higgs decay channels are predicted in many models, in particular in those with extended Higgs sector.

Many scenarios have been proposed where additional scalar particles can be light, with masses of the order of, or even below the mass of the Higgs boson observed at the LHC [5, 6]. Searches for additional scalar particles, which could be produced at the Higgs factory, are a natural extension of the Higgs boson studies. Same analysis methods can be used, looking for the similar decay channels (e.g. $b\bar{b}$, $\tau^+\tau^-$ or invisible decays), but relaxing the constraints imposed by the SM predictions. Non-standard decays channels of new scalar (e.g. decays to long-lived particles) can also be looked for, similarly as they should be addressed for the 125 GeV Higgs.

For light new scalars, or for higher collision energies, single scalar production in the WW fusion process

$$e^+e^- \to \nu\,\bar{\nu}\,\phi$$

can also be considered, as well as pair production of new scalars. Depending on the considered model, production processes involving other exotic particles are also possible.

Target physics observables

Recoil mass reconstruction is the primary method for identification of the SM-like Higgs boson production events and can also be used for new scalar searches. In fact, precision of the recoil mass reconstruction is the leading factor determining the search sensitivity.

Target methods to be developed

Target detector performance aspects

Depending on the process/signature considered, different detector performance aspects are relevant. All aspects can be important:

- flavour tagging (in particular b-quark and τ-lepton tagging) for scenarios with new scalar particle decaying to heavy fermions,
- lepton identification for leptonic Z decay reconstruction,
- jet energy resolution for hadronic Z decay reconstruction and background suppression,
- detector hermeticity, for proper reconstruction of invisible decays.

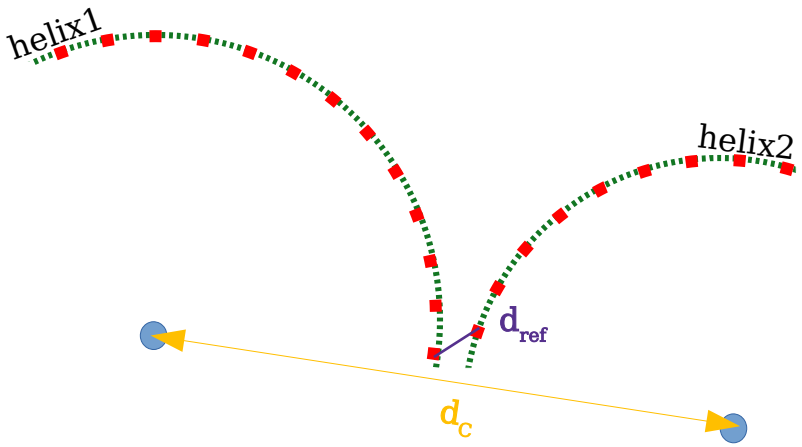
10 Long-lived particles

LLPs, SRCH

ILD

- V0 / Kinked signatures / dE/dx
- DESY / Warsaw / KEK

Have direct contact with Filip



Theoretical and phenomenological targets

LLPs is a signature-driven topic that could connect to most BSM models. In the context of e^+e^- colliders the possible targets include but are not limited to:

- Exotic decays of the Higgs boson
- Heavy Neutral Leptons with low couplings
- Axion-like particles

target physics observables

While LLPs present a variety of non-mainstream signatures, a few target physics pbservables can be identified such as:

- Displaced tracks and vertices in the tracking volume, disappearing tracks
- Uncommon energy loss patterns, seen in dE/dx
- non-pointing, delayed photons in the calorimeters, from which timing would be important
- Out-of-time decays, as jets in later beam crossings, preferably in the empty ones (Slowed-down, stopped particles)
- Uncommon time of flight measured in the muon spectrometers/calorimeters
- Non-standard jets: emerging, track-less

Target methods to be developed

- Reconstruction of displaced tracks and vertices
- Tracking algorithms able to reconstruct anomalous dE/dx patterns
- Timing capabilities, precise track timing
- Jet reconstruction algorithms, jet taggers
- Background estimation: instrumental background, cosmics

Target detector performance aspects

- Tracking
- Timing

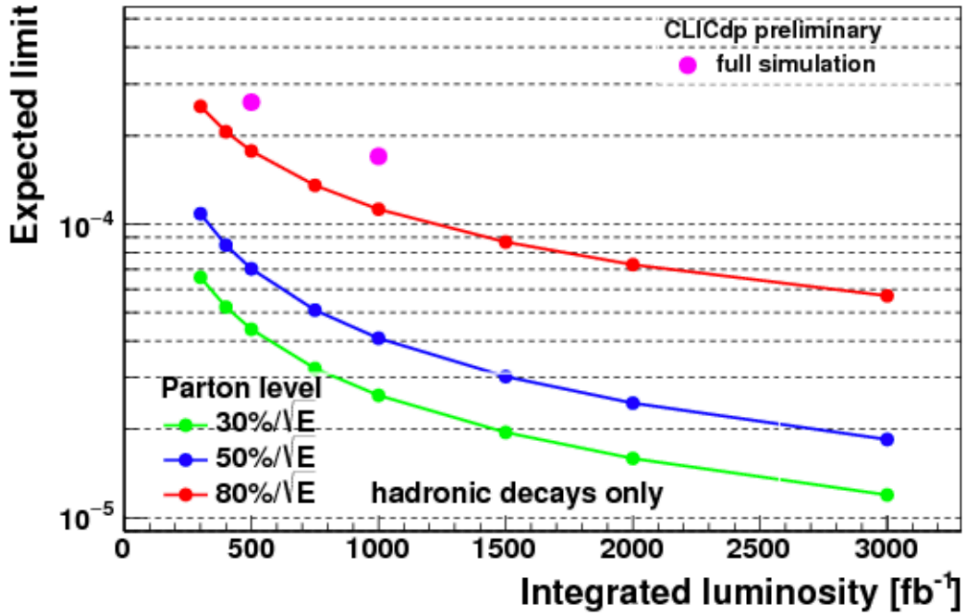
11 Exotic Top decays

EXtt, SRCH

CLICdp (and generic)

- past study on FCNC top decays by Filip

Have direct contact with Filip



11.1 Theory and phenomenological targets

Following the proposal of [1] it is possible to have BSM decays of the top quark into new scalars and light quark flavors.

Most past searches focuses on $\phi = h$, but it is possible to have other scalars as well. Considering scalars other than the Higgs boson also frees up from constraints that may push the interesting level of BR to be too small to be tested at the HTE factory. In general the "generic scalar" search will encompass the Higgs boson as a subcase.

Current search at the LHC on 139 fb^{-1} is presented in Ref. [2]. The case $\phi \to bb$ has been pursued for $q = u, c$, finding an upper limit on the BR around the few 10^{-4} ballpark for 20 GeV $< m_\phi <$ 160 GeV.

Main goal:

- quantify the reach of the HTE factory to go below the HL-LHC limits at $BR(t \to \phi q) \lesssim 10^{-4}$ in the $\phi \to bb$ channel

Possible points for development and contribution:

- Lighter ϕ between 10 and 20 GeV can be explored in the bb channel to extend the reach of LHC
- Other decay modes of ϕ can be considered, e.g. $\phi \to \gamma\gamma$, especially for $m_\phi < 10$ GeV.

11.2 Methods and performances

Tagging of *low-energy* b quarks can be explored for light ϕ search and can be reused in a number of other scenarios where light sources of heavy flavors emerge.

12 CKM matrix elements from WW

CKMWW, FLAV

theoretical and phenomenological targets

The knowledge of the magnitudes $|V_{cs}|$ and $|V_{cb}|$ from W decays provides a consistency check of the unitarity of the CKM matrix. The comparison of the $|V_{cs}|$ magnitude to its indirect determinations inferred from leptonic charmed meson decays is a direct test of the SM decay constant parameters. The measurement of $|V_{cb}|$ with on-shell and boosted W decays might shed light on the longstanding discrepancy observed in exclusive and inclusive determinations of $|V_{cb}|$ obtained from semileptonic decays of b-flavoured particles. Furthermore, the $|V_{cb}|$ magnitude controls the normalisation of the unitarity triangle. A quasi-model-independent global analysis of neutral B-mesons observables will benefit of an improved precision at the horizon of 2040 (Ligeti at al., 2020).

target physics observables

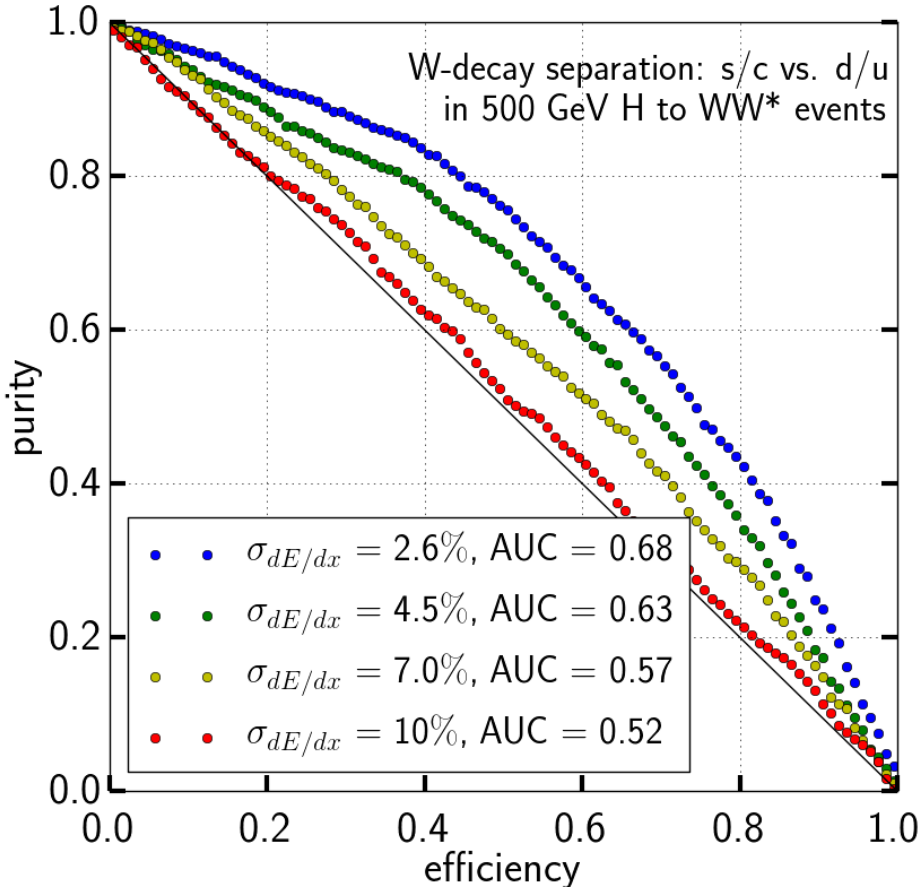
- $|V_{cs}|$: from counting the number of W issuing quark jets from c and s quarks.
- $|V_{cb}|$: from counting the number of W issuing quark jets from c and b quarks.

target methods to be developed

- exercise quark-jet flavour-tagging (s, c, and b-tagging) at $\sqrt{s} \geq m_W$.
- exercise PID with a dedicated Cerenkov detector.

target detector performance aspects

- Question the need for hadronic particle identification $p/K/\pi$.
- Assessment of the required jet flavour-tagging global performance.



ILD

- PhD thesis Uli Einhaus
- new flavour tagging developments (cf. H->ss, also b/c tagging with ML, Mareike, Taikan et al)

13 B0 -> K0*tau+tau-

BKtautau, FLAV

Target physics observables

The $B^0 \to K^{*0}\tau^+\tau^-$ was considered in Ref. [?] as a mode to test the $b \to s\tau^+\tau^-$ transition. While the two neutrinos emitted from τ decays complicate the experimental search, an excellent reconstruction of all the vertices, considering hadronic τ decays, can help to close the kinematics of the process. Ref. [?] also considers tau polarization as a further observable to disentangle the Standard Model from the possible New Physics contribution.

Target methods to be developed

- At hand but to be refined: topological reconstruction.
- Secondary vertex fitting algorithm.

Target detector performance aspects

- Transverse and longitudinal vertex resolutions
- Pixel pitch, distance to the interaction point, curvature of the layers ...

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- ???
- Z pole full sim?
  with ILC & FCCee variants of ILD???

14 Two-fermion final states (MZ and beyond)

TwoF, HTE

theoretical and phenomenological targets

– Theory predictions on 2-fermion production on and off the Z pole; interpretation of observables including constraints on four-fermion interactions.

target physics observables

– Detector-level study of precisions on total and differential cross-sections as well as asymmetries, for τ's including the τ polarisation.

target methods to be developed

– strange tagging (see topic 1)

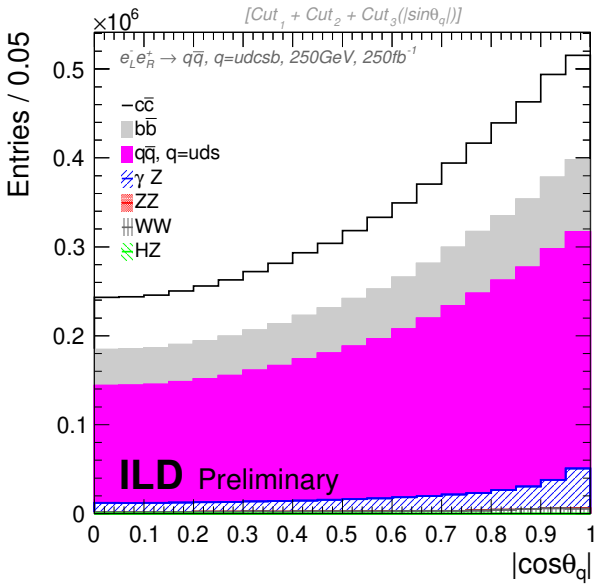
– separating lightest families (u and d) using radiation (after tagging heavy families)?

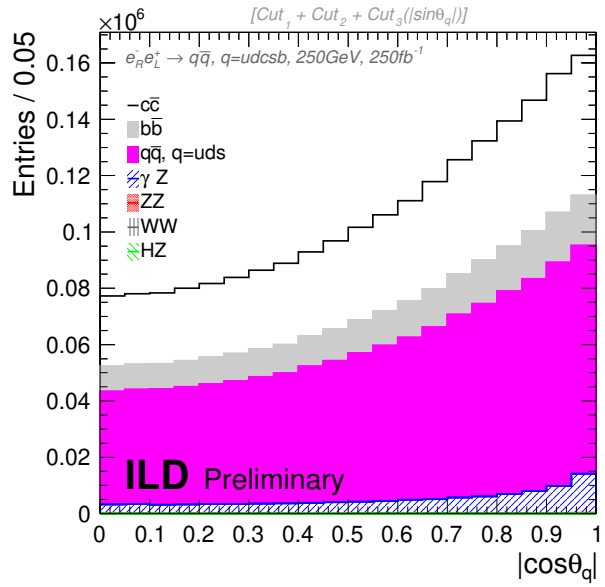
target detector performance aspects

– Dependency on detector performance (vertex charge, Kaon-ID,...)

ILD

- above Z:
  Roman, Adrián, Daniel, Taikan, …
- Z pole full sim?
  with ILC & FCCee variants of ILD???





15 B-/C-fragmentation functions and hadronisation rates

BCfrag, FLAV

theoretical and phenomenological targets (FM)

- Are existing hadronization models (strong fragmentation, cluster fragmentation) flexible enough, or do we need new ideas?
- Identify calibration observables that are well understood theoretically and unaffected by BSM physics.
- Treatment of photons and gluon splitting (see also next section).
- See also https://indico.desy.de/event/33640/contributions/130328/attachments/77658/100472/ECFA22_Hadronization.pdf

target physics observables

- Event shapes, angular distributions
- Fragmentation functions

target methods to be developed

- Demonstration of fit to a respresentative set of observables for hadronization calibration.
- Critically evaluate achievable precision.

target detector performance aspects

- TBD

ILD

- PhD Paul Malek
- PID tool activities (U. Einhaus, B. Dudar, …)

16 Gluon splitting into bb / cc, interplay with H->gg/cc/bb

Gsplit, PREC

theoretical and phenomenological targets

- How to consistently implement gluon splitting in parton shower tools (modeling and free parameters)

target physics observables

- 3/4-jet events with multiple heavy quark ids.
- Jet subtructure observables with hadron tags inside jet.

existing tools / examples

- Pythia (?), Sherpa (?), ...

ILD

- past studies on H->gg/cc/bb by Masakazu, Felix Mueller, Hiroaki
- nothing on gluon splitting?

Conclusions

There's a lot to do - get involved!

- **start discussion how ILD can and would like to contribute => physics coordinators & physics WG conveners**
- **people?**
- **MC?**
  - 250 GeV in good shape (even if PID etc needs reprocessing to get latest & greatest) => anybody could start working
  - 350 GeV "ancient" (DBD) - do we need a re-sim/rec here? At least partially (eg ttbar and dominant backgrounds)? Or even brandnew Whizard 3 + Pythia 8?
  - 161 GeV / Z pole - never done?
    - Do we want to go there in full sim?
    - ILD@ILC and/or ILD@FCCee?
    - SGV ?
- **tie all this strongly to**
  - tool developments, ML, QC, …
  - detector requirements & performance
- pay a lot more attention to **systematics, include techniques for their control**