ECFA Focus Topic: CKMWW

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IDT-WG3-Phys Open Meeting
22./23.02.2024

**HELMHOLTZ**
RESEARCH FOR GRAND CHALLENGES

ILD

DESY.

- Use W decays to measure CKM matrix elements $\left|V_{ij}\right|$, ~ directly by counting

- Allows for direct, model-independent access to 6 CKM elements (without top)

- Of particular interest: $V_{cb}, V_{cs}, \left(V_{ub}\right)$

  - test of unitarity of the CKM matrix

  - V_{cs} for comparison with indirect leptonic charmed meson decays

  - V_{cb} to resolve discrepancy between in- & exclusive determinations via semilep. B decays, controls unitarity triangle normalisation
    → already systematically limited at Belle!

  - V_{ub} as test of lattice QCD needed for results from Belle II

- With 100% reconstruction efficiency: $\delta_{V_{ij}}^{th} = \frac{1}{2} N_{ev}^{-1/2}$

from M. De Cian

for 10^8 W:

$W^- \to$	$\bar{u}d$	$\bar{u}s$	$\bar{u}b$	$\bar{c}d$	$\bar{c}s$	$\bar{c}b$
BR	31.8%	1.7%	4.5×10^{-6}	1.7%	31.7%	5.9×10^{-4}
N_{ev}	64×10^6	3.4×10^6	900	3.4×10^6	63×10^6	118×10^3
$\delta_{V_{ij}}^{th}$	0.0063 %	0.027 %	1.7 %	0.027 %	0.0063 %	0.15 %

- More details: talk by S. Monteil

ECFA Study Team
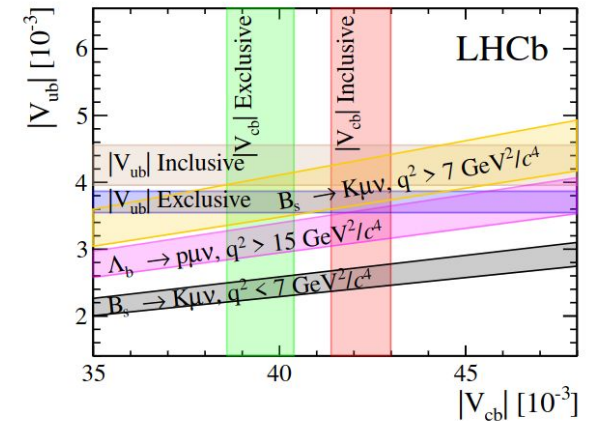
- Team set up to define and work on study:

  M. Bordone, UE, P. Goldenzweig, P. Koppenburg, Z. Ligeti, D. Marzocca, M. Selvaggi

  ([ECFA focus topics doc](), subscribe to [email list]())

- Determine ultimate precision prospects on matrix elements at Belle II and LHCb as well as future HTE factories

- Study application of flavour tagging tools and supplying algorithms (e.g. PID), including calibration methods and systematics

DESY.

Necessary Tools

- Theory predictions needed!
  No sufficient higher-order corrections incl. QCD colour-reconnection at WW threshold or higher, good case for lattice QCD

- Identify quark flavours → flavour tagging tools

  – LCFIPlus is well-established standard
    → first estimate V_{cb} precision: 0.4%

  – a number of new taggers based on neural networks (1, 2, 3, 4) are being developed, full integration in key4HEP (hopefully) soon
    → first estimate V_{cb} precision: 0.15% (close to limit)

  – Important: calibration of flavour taggers, ideally at Z pole

- b, c-tagging need vertexing, well established tools part of reconstruction chains, profit from new tracking algorithms and hardware developments (ALICE ITS3)

- s-tagging needs PID, likely the reason why ILD and IDEA (with dE/dx / dN/dx) in particular are working on s-tagging, RICHs under discussion for CLD and SiD; new tool (CPID) being established

Necessary MC Samples

- Center of mass energies

  - threshold scan around 160 GeV interesting for W mass, rather low cross section, no contamination from ZZ

  - 250/240 GeV is default working point for Higgs factory and has a good WW cross section

  - at higher energies lower cross section, more boost which is probably helpful for vertex-based tagging, but less so for PID, at some point JER worsens

- Typical expected numbers of W at 250 GeV at ILC and 160 GeV at FCC-ee: $O(10^8)$

  - ILC profits from ca. factor 2 due to polaristion

  - multiply with number of detectors for FCC-ee

- FCC-ee MC samples are needed

- ILD MC samples with full sim/reco exist, 250 GeV is ca. 12 ab^{-1} (exceeds H-20 by >3 in each pol. channel) and good to go, 500 GeV is ca. 0.5 ab^{-1} and missing some newer reconstruction aspects; might need dedicated samples for V_{ub}

DESY.

Analysis situation

- FCC: Nothing yet, benchmark case for flavour tagger by M. Selvaggi e.a. (IDEA)

- CEPC: [Talk](#) by T. Liu at CEPC Workshop Oct. 2023:

  benchmark case for flavour
  tagger by M. Ruan e.a.

  - A CEPC version will be very informative
  - Relevant inputs are still missing
  - A task for next stage work

Analysis situation

- One analysis in ILC/ILD being set up by UE

  – use new [Comprehensive Particle ID](#) (CPID) for particle identification

  – use new [neural network tagger](#) (M. Meyer) for flavour tagging

  – use 250 GeV ILD MC production from 2020

  – target: statistical uncertainty on $\left|V_{ij}\right|$ including reconstruction efficiencies and backgrounds

  – focus on V_{cs} (impact of PID on s-tagging)

- CPID: calibration for ILD has been performed, is currently in [pull request](#) for ILDConfig for MarlinStandardRecoMiniDST.xml for 2020 MC production

- Aim is a tagged ilcsoft version end of March (?) incl. flavour tagger, potentially use this to make MiniDSTs of the full 2020 production

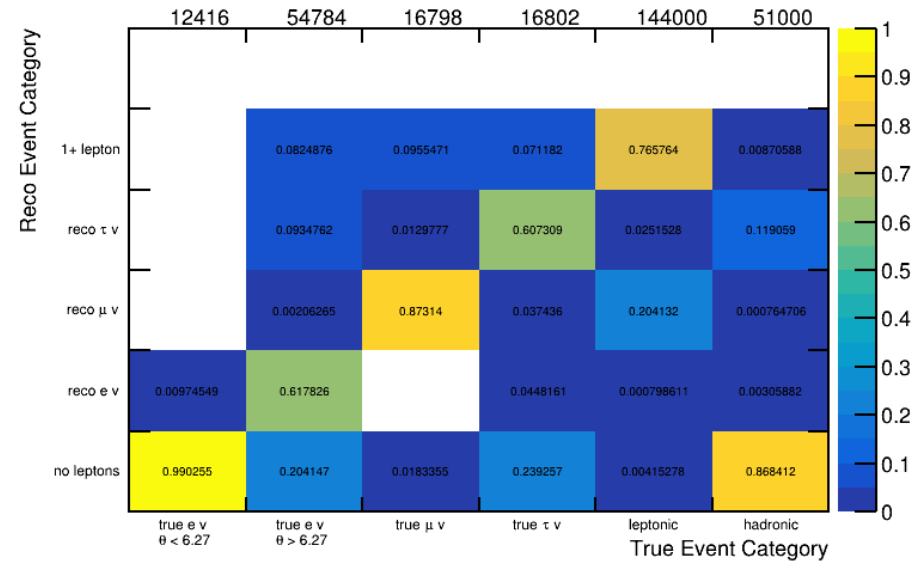- In future reconstructions would become part of MarlinStandardReco.xml, next to LikelihoodPID

- First step of analysis: event categorisation and preselection, plots by A. Silva

inv. mass of PFOs wo. isolated leptons
or photons, with and wo. overlay cuts
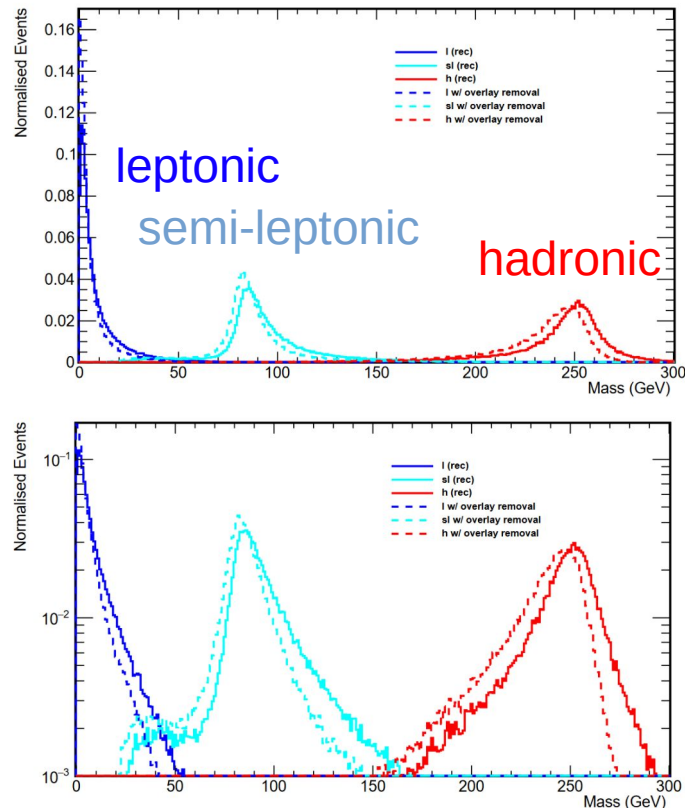
confusion matrix of event
categorisation truth vs. reco

Colour reconnection

- Quarks from one W decay have colour connection

- But: also the quark pairs from WW can reconnect after both W decays (W decays: 0.1 fm vs. QCD: 1 fm) → impact on flavour needs careful consideration in theory and ongoing study

from A. Moutoussi

- Impact known from LEP: charged jet constituent multiplicity reduced by (probably) ~5% in hadronic WW compared to semileptonic WW, 2.8 σ effect still open for final discovery
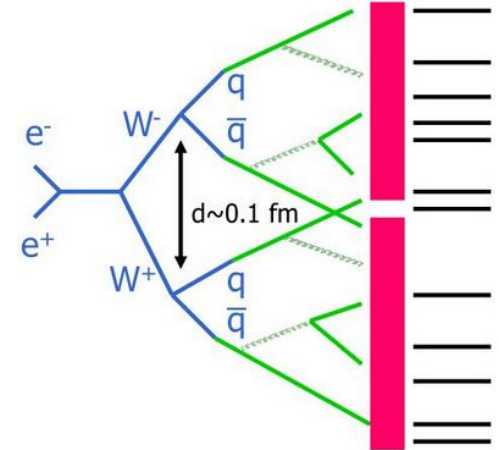
- Effect seen in ILD MC data: ratio of ~0.94
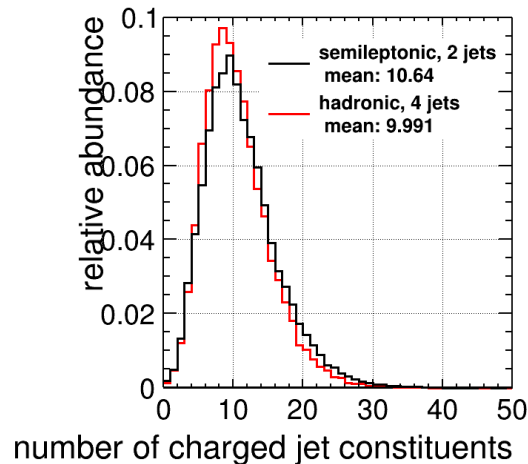
Experiment	$\sqrt{s}$	Studied Quantity	Result
ALEPH	183 GeV		1.31±0.74±0.37
ALEPH	189 GeV	$\langle n_{ch}^{4q} \rangle - 2\langle n_{ch}^{qq\ell\bar{\nu}} \rangle$	0.47±0.44±0.26
L3	183 GeV		-1.0± 0.8 ± 0.5
OPAL	183 GeV		0.7 ± 0.8 ± 0.6
DELPHI	183 GeV	$\langle n_{ch}^{4q} \rangle / 2\langle n_{ch}^{qq\ell\bar{\nu}} \rangle$	0.941±0.025±0.023
DELPHI	189 GeV		0.977±0.017±0.027

M. Hapke: QCD at LEP 2 and WW final state interactions

Summary

- Working group on CKM precision prospects from W decays set up, targets defined

- First study has started

- Looking for more people to join and carry out the task, ideal case for new flavour tagging tools!

- Contact us or [sign up](#)!