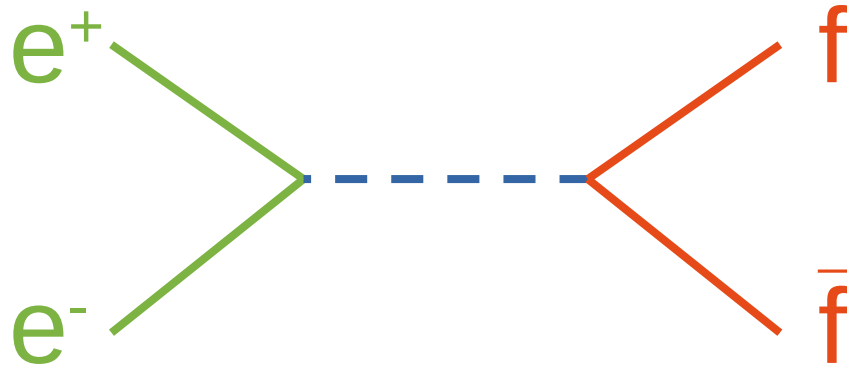


2-fermion production at future Higgs factories



Emi KOU

Roman POESCHL

Francois RICHARD

Dirk ZERWAS

Xin XIA

IJCLab

IJCLab

IJCLab

DMLab

IJCLab

Daniel JEANS

Akimasa ISHIKAWA

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Junping TIAN

Tomoyuki SANUKI

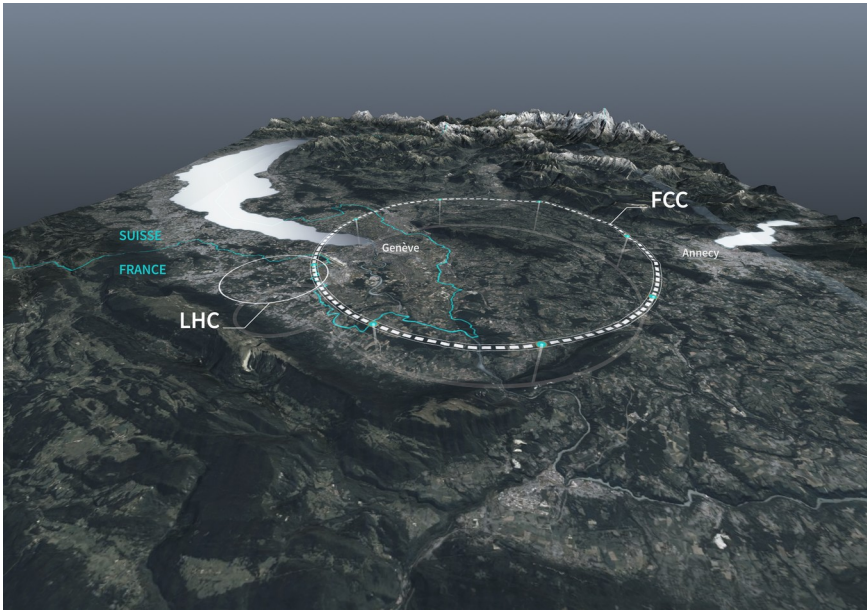
KEK

KEK

U. Tokyo

U. Tokyo

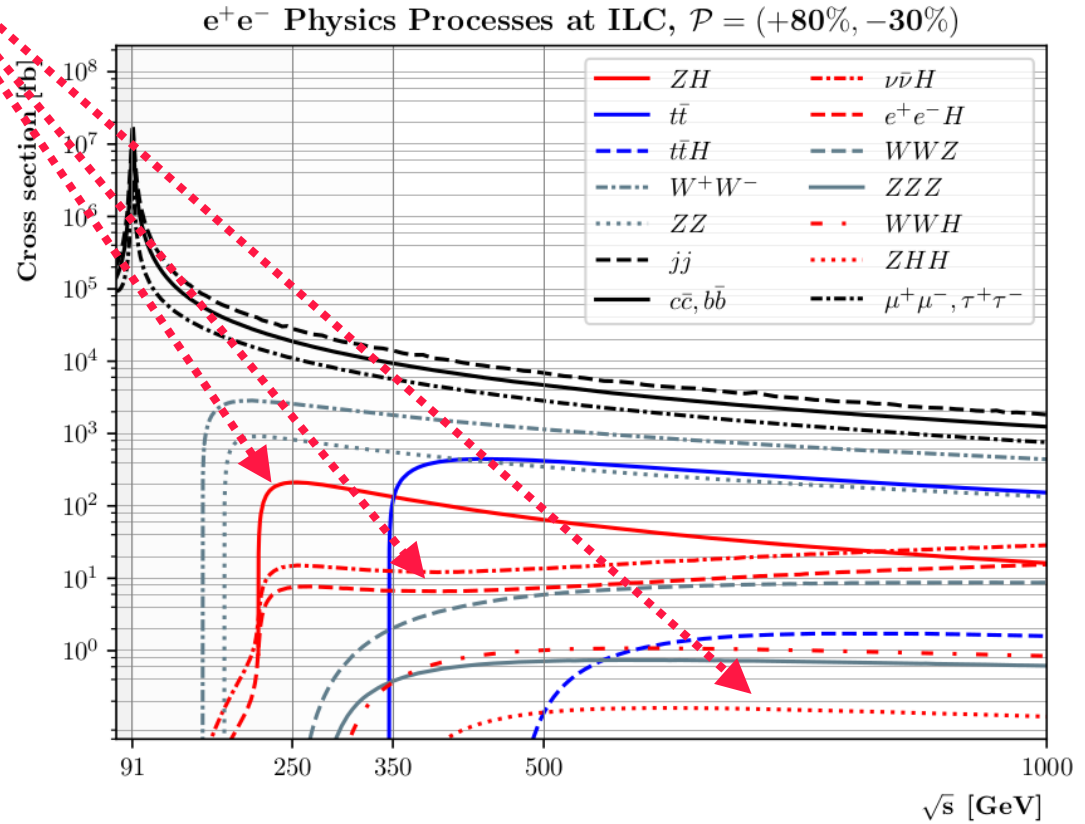
Tohoku U



Future Higgs Factory projects



Future Higgs factories such as the ILC and FCCee are primarily designed to produce **Higgs bosons**.



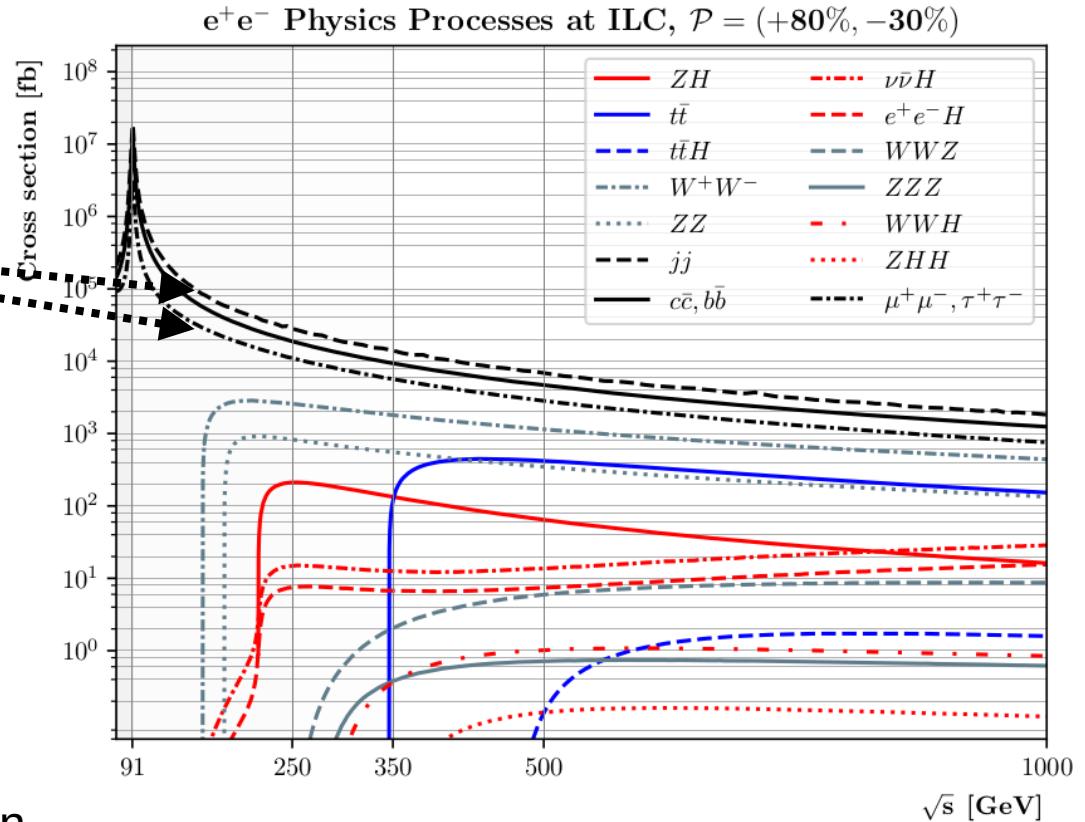
Future Higgs factories such as the ILC and FCCee are primarily designed to produce **Higgs bosons**.

In parallel, they will produce vast numbers of **f-f** pairs

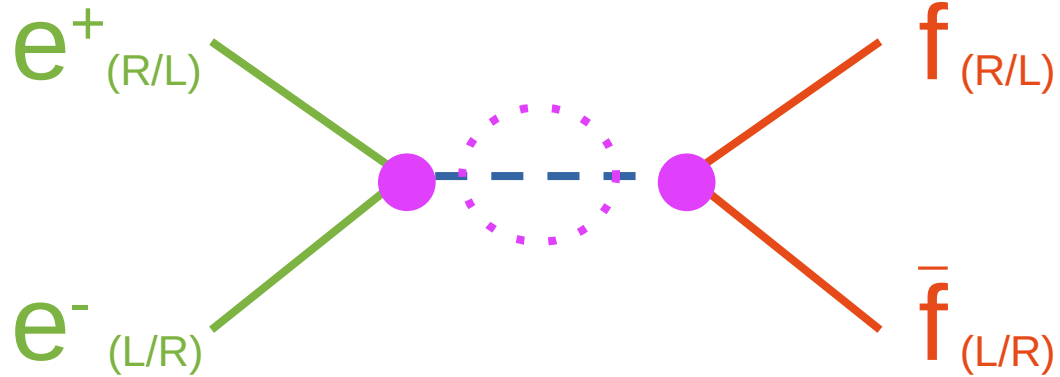
in an experimentally clear environment

at much higher energies (up to x5)
and integrated luminosities (up to $\times 10^3$)
than at previous e+e- experiments

This will provide a dataset in which to probe particle interactions with great precision



beam
polarisation



final state
polarisation

new propagators ?
unexpected couplings ?

Initial State Radiation

beam
polarisation

e^+
(R/L)

e^-
(L/R)

f
(R/L)

\bar{f}
(L/R)

final state
polarisation

probe at both
full CM energy
and lower energies (principally m_z) via **ISR**

In this TYL project and its predecessors, we have investigated a complete set of final state fermions (*except the neutrinos)

for QUARKS, from the top → down

for LEPTONS, from tau → electron

MC studies using full detector simulation of the ILD concept

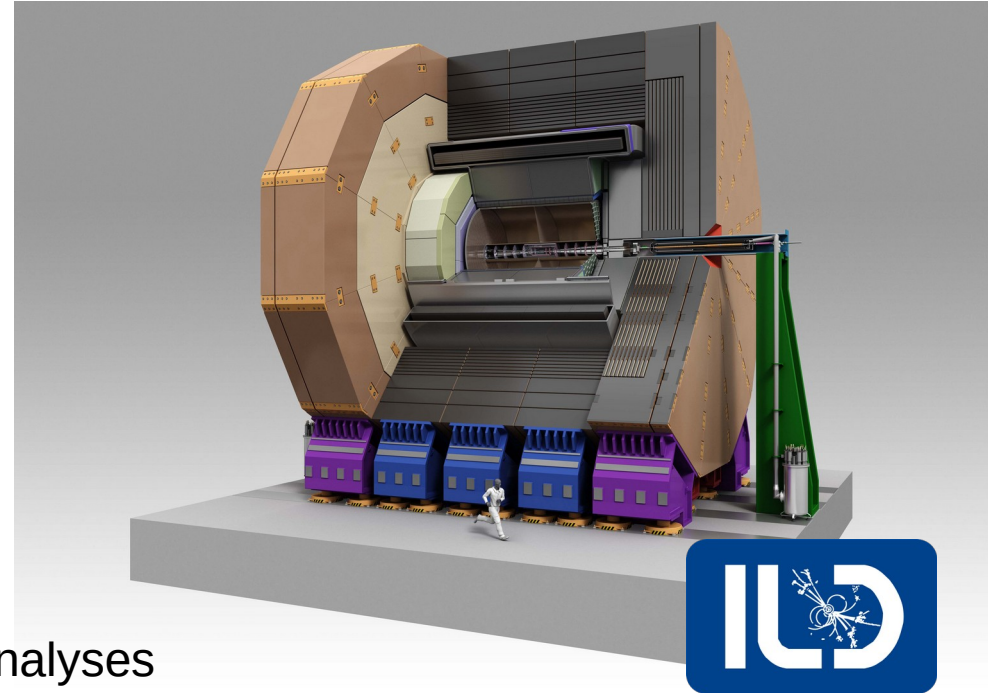
using, developing, and improving several reconstruction techniques needed in these analyses

Particle Flow reconstruction improvements
jet flavour and charge identification

for b, c, s; recently also u vs. d

Kaon identification with dE/dx & timing, vertex charge, ...

tau lepton reconstruction, polarisation measurement



highlights during FY2023

Yuichi Okugawa graduated PhD (co-supervised Tohoku, Paris-Saclay)

“Analysis of test beam data using a technological prototype of a highly granular calorimeter and study of light quark production at a future linear collider”

Keita Yumino graduated PhD (SOKENDAI)

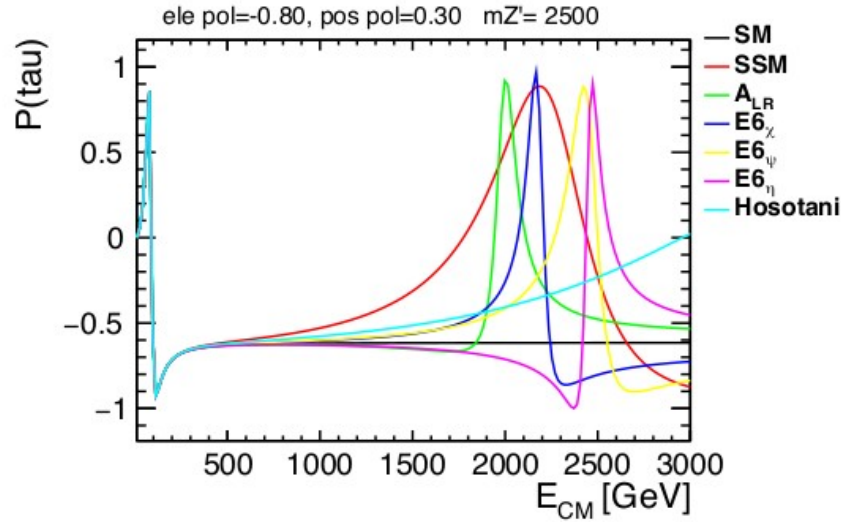
“Measuring the tau polarisation at the ILC and Optimisation study of the Asian GEM Module”

Koushi Nagae graduated Master (Kyushu)

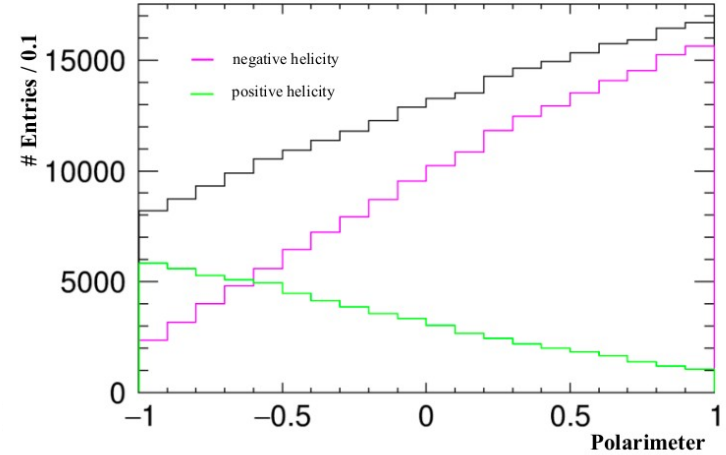
“国際リニアコライダーにおけるフェルミ粒子対生成の精密測定による新物理探索の研究”

~ Research on new physics exploration through precise measurement of fermion pair production at the International Linear Collider ~

“Measuring the tau polarisation at the ILC and Optimisation study of the Asian GEM Module”



variation of tau polarisation with E_{CM} in different BSM scenarios



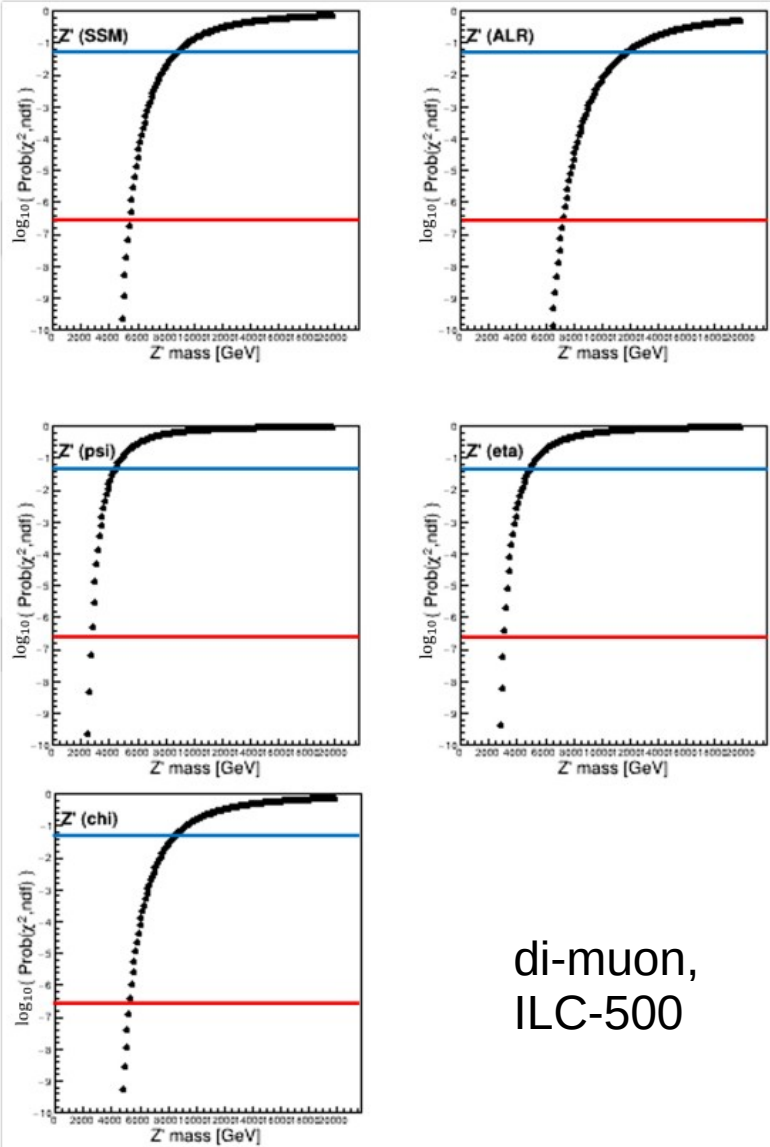
reconstructed polarimeter distribution in tau \rightarrow rho decays

Koushi Nagae (Master ,Kyushu)

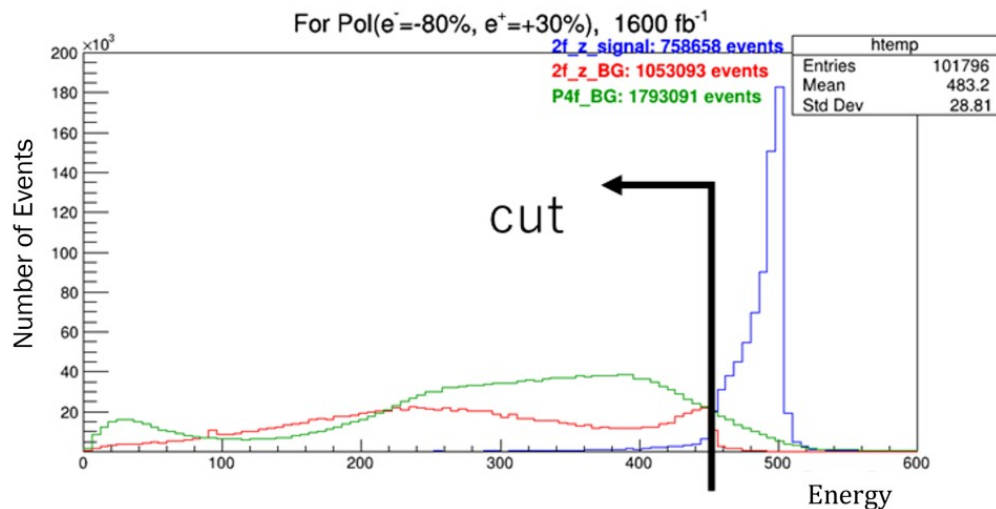
“ 国際リニアコライダーにおけるフェルミ粒子対生成の精密測定による新物理探索の研究”

~ Research on new physics exploration through precise measurement of fermion pair production at the International Linear Collider ~

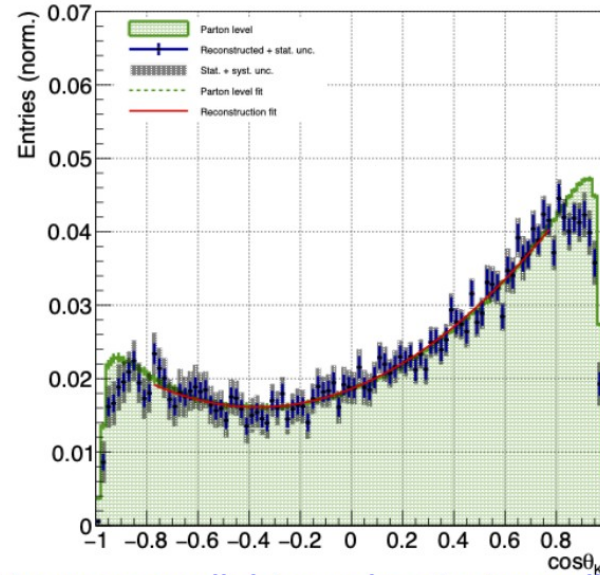
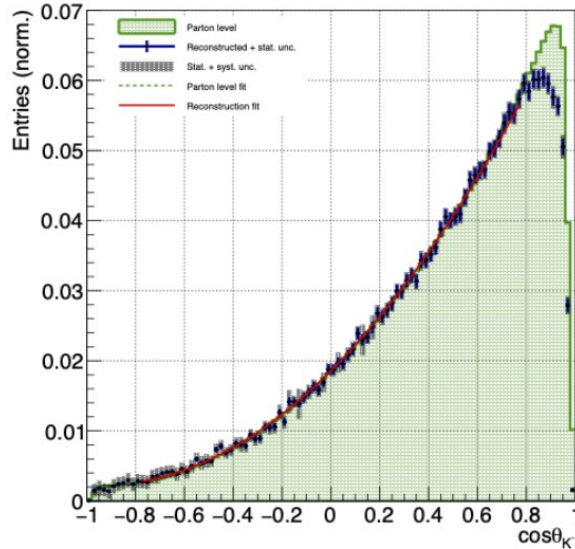
Global fit to all light 2-f channels, in various Z' scenarios



di-muon,
ILC-500



$$e^+e^- \rightarrow s\bar{s} \text{ at } 250 \text{ GeV}$$



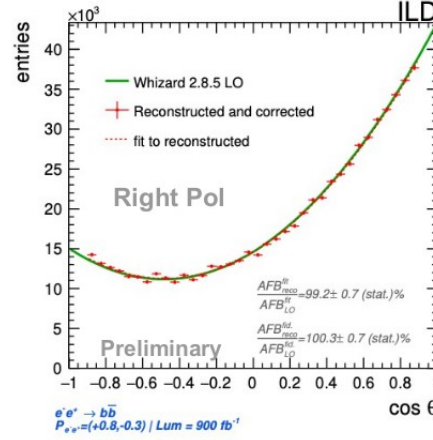
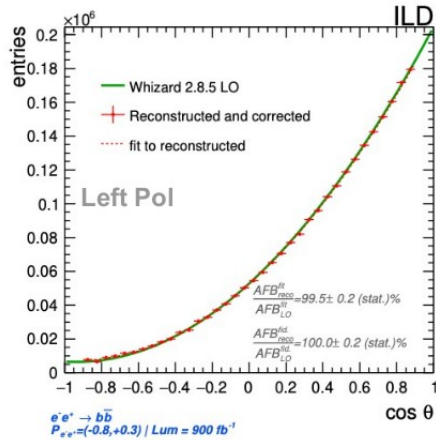
Yuichi Okugawa (PhD)

(co-supervised Tohoku, Paris-Saclay)

“Analysis of test beam data using a technological prototype of a highly granular calorimeter and study of light quark production at a future linear collider”

- The current analysis shows the potential to measure light quarks at e+e- colliders
- Even more than others light quarks rely on excellent particle ID
 - ... over full solid angle
- The hard cuts to get a clean sample in this analysis results in a small efficiency O(1%)
- Clear room for improvement beyond “collider flavors”

Full simulation study within ILD Concept at $\sqrt{s}=250$ GeV allows for educated guess on uncertainties on Z-Pole



Arxiv:2306.11413

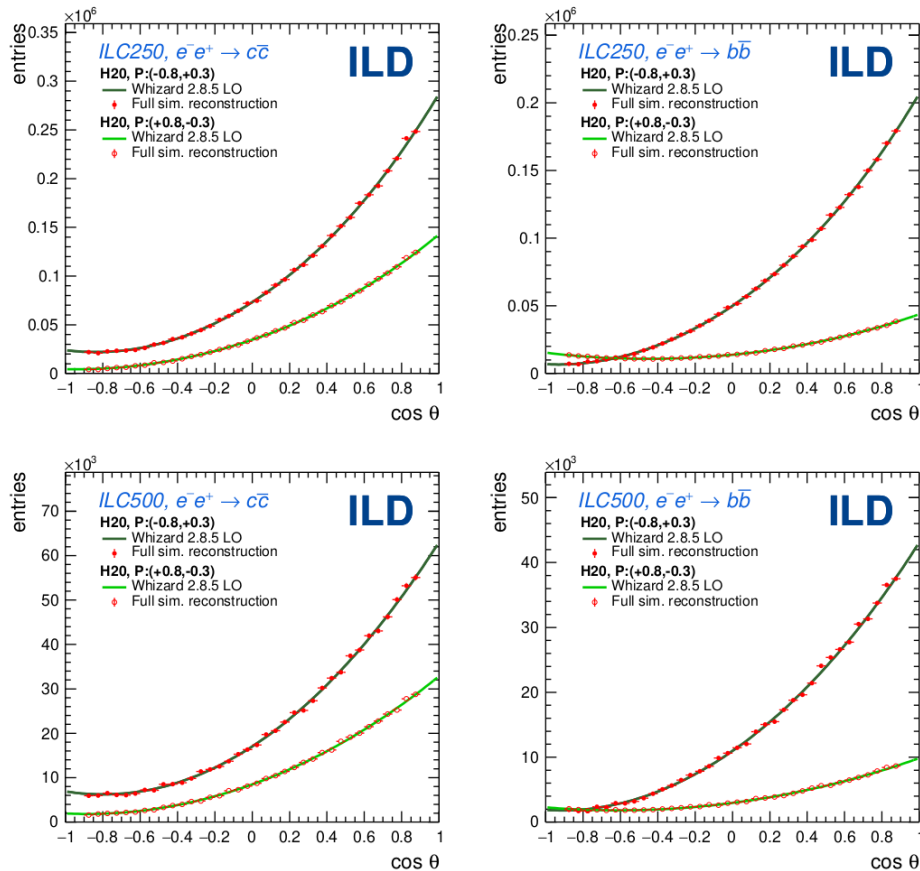
Excellent agreement between predicted and reconstructed distributions

Source	$e^-e^+ \rightarrow c\bar{c}$				$e^-e^+ \rightarrow b\bar{b}$			
	$P_{e^-e^+}(-0.8, +0.3)$	$P_{e^-e^+}(+0.8, -0.3)$	R_c	$A_{FB}^{c\bar{c}}$	$P_{e^-e^+}(-0.8, +0.3)$	$P_{e^-e^+}(+0.8, -0.3)$	R_b	$A_{FB}^{b\bar{b}}$
Statistics	0.18%	0.38%	0.27%	0.52%	0.12%	0.24%	0.23%	0.70%
Preselection eff.	<0.01%	0.12%	0.02%	0.16%	<0.01%	0.08%	0.06%	0.12%
Background	0.01%	0.01%	0.02%	0.02%	0.01%	0.01%	0.06%	<0.01%
heavy quark mistag	0.11%	<0.01%	0.06%	<0.01%	0.12%	<0.01%	0.22%	<0.01%
uds mistag	0.03%	<0.01%	0.02%	<0.01%	0.08%	<0.01%	0.14%	<0.01%
Angular correlations	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%	0.10%
Beam Polarisation	<0.01%	<0.01%	0.02%	0.01%	<0.01%	0.01%	0.03%	0.15%
Systematics	0.15%	0.16%	0.12%	0.19%	0.18%	0.13%	0.29%	0.22%
Total	0.24%	0.41%	0.30%	0.55%	0.21%	0.27%	0.37%	0.73%

Additional complication in continuum compared with Z-Pole:
Rejection of ISR events

“Probing Gauge-Higgs Unification models at the ILC with di-quark forward-backward asymmetry at center-of-mass energies above the Z mass”

arxiv:2403.09144, accepted by EPJC



GHU vs SM discrimination power (σ -level)

ILD

B_3^+	0.1	0.4	0.5	0.1	0.7	0.8	0.5	1.3	1.3	1.6	2.5	2.5
B_3^-	0.1	0.4	0.5	0.3	0.9	0.9	0.9	2.7	2.7	3.3	6.7	6.8
B_2^+	0.2	0.7	0.8	0.3	1.5	1.6	0.9	2.2	2.3	3.0	4.4	4.5
B_2^-	0.2	0.7	0.7	0.5	1.4	1.5	1.7	4.6	4.8	6.3	>10	>10
B_1^+	0.3	1.6	1.7	0.7	3.2	3.5	1.5	4.4	4.7	4.3	6.8	7.0
B_1^-	0.5	1.4	1.4	0.9	2.7	2.8	3.3	9.6	9.9	>10	>10	>10
A_2	0.6	3.3	3.6	0.9	4.8	5.3	4.3	>10	>10	>10	>10	>10
A_1	0.8	3.9	4.2	1.0	5.0	5.5	5.3	>10	>10	>10	>10	>10
	C R Z			C R Z			C R Z			C R Z		

Z-femion couplings
 • C: Current precision
 • R: ILC250 (Rad. Ret.)
 • Z: Giga-Z

 < 3 σ
 3-4 σ
 4-5 σ
 > 5 σ

ILC250* (no pol.) ILC250 ILC250 +500 ILC250 +500 +1000*

towards 2-fermion studies @ circular Higgs factories

machine-related backgrounds (beamstrahlung) and Machine Detector Interface at circular collider

new simulation models with FCCee MDI

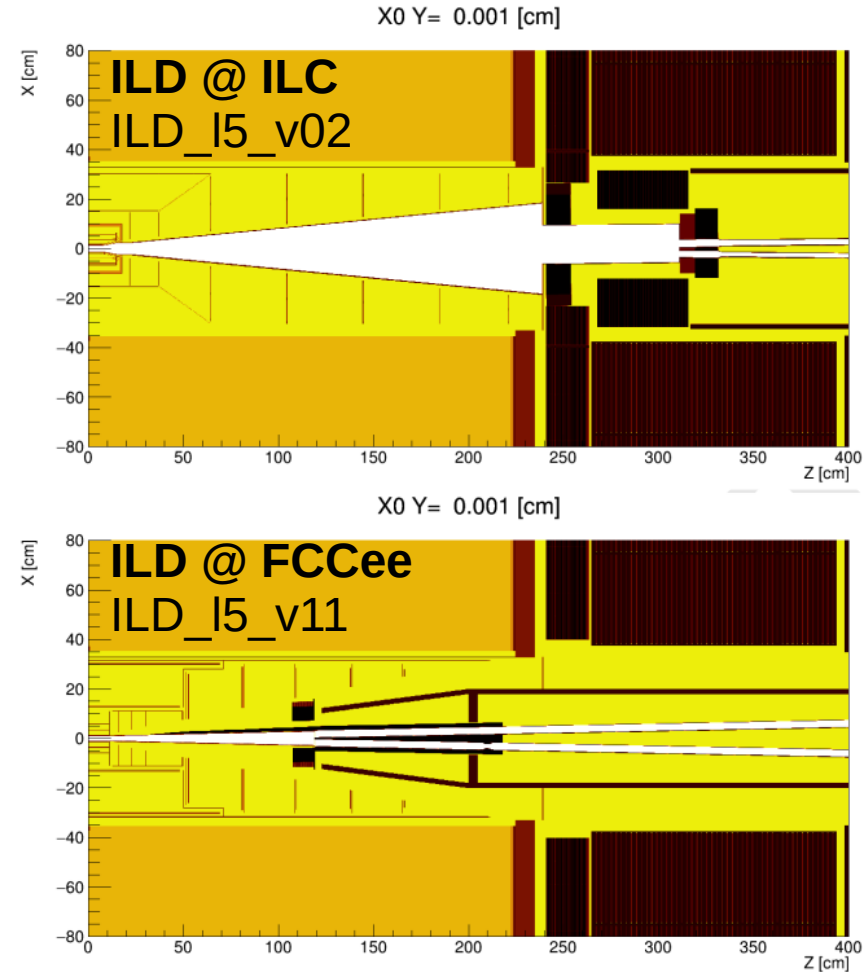
estimate background rates in

vertex detector (crucial for jet tagging)

TPC (crucial for dE/dx Kaon ID)

looks tough at the Z-pole at full FCCee luminosity, especially for the TPC ?

Jeans, Poeschl



main topics for the next year

- move towards interpretation of results in model-independent framework
EFT
- attempt to distinguish up- and down-quark jets
using different FSR probabilities
- measurement of transverse tau polarisation and correlations
connection to weak Electric and Magnetic dipole moments
- further develop ML-based approaches to jet flavour and particle flow reconstruction

working closely within the ECFA Higgs Factory Study, 2-fermion focus study
which aims to provide input to the European Strategy Update for Particle Physics