Focus Topic:

2-fermion final states ($\sqrt{s} = M_Z$ and beyond)

2-fermion expert team

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e+ e- → f f-bar

“simple” process

theoretically → “precise” predictions

experimentally → “small” exp. systematics

large cross-sections

very large at Z-pole

still one of largest at higher energies

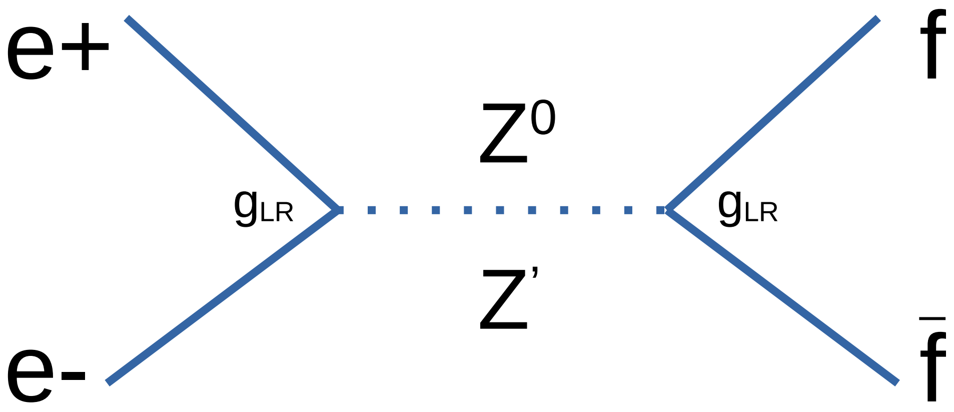
Z(') boson couplings

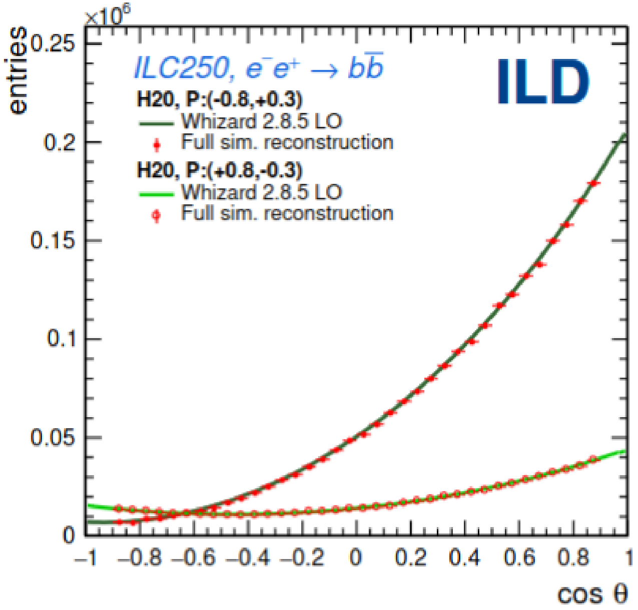
from the Z-pole, …, 240, …, 1000 GeV

search for effects of other, BSM, interactions

main observable → differential cross-section with scattering angle → A_{FB}

for different fermion flavours (polarisation), at different CM energies





with the great statistics comes a great responsibility !

on theorists to make similarly precise predictions

on experimenters to squeeze out maximal information,
and to control systematic detector effects

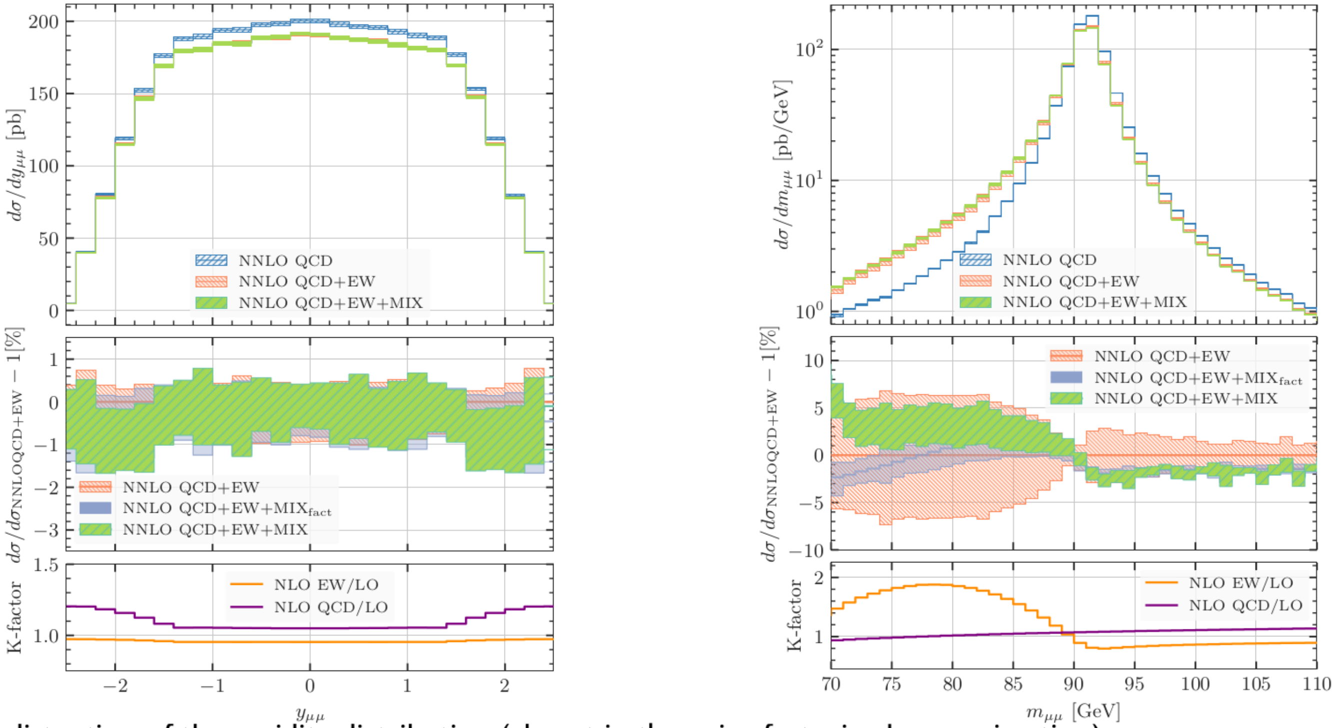
Higher order calculations of Drell-Yan

QED, QCD, EW corrections and their mixing

development of new tools and methods, applicability at both LHC and HF

Phenomenology of Neutral Current Drell-Yan including exact NNLO QCD-EW corrections

R.Bonciani, L.Buonocore, S.Devoto, M.Grazzini, S.Kallweit, N.Rana, F.Tramontano, AV, arXiv:2106.11953 , Phys.Rev.Lett. 128 (2022) 1, 012002 and work in preparation



Non-trivial distortion of the rapidity distribution (absent in the naive factorised approximation)

Large effects below the Z resonance (the factorised approximation fails) → impact on the $\sin^2\theta_{eff}$ determination

O(-1.5%) effects above the resonance → ongoing precision studies in the CERN EW WG

Alessandro Vicini - University of Milano 11 Frascati, October 2nd 2024

A. Vicini

experimental tools: jet flavour tagging

a few years ago, this meant identification of jets initiated by b- and c-quarks

  based mostly on reconstruction of secondary vertices and leptons within jets

several groups have made impressive progress in extension to other jet flavours

  more general kinematic observables

  identification of Kaons

    → extend 2f measurements to exclusive quark flavours

  distinguishing quarks from anti-quarks

    → essential for full (unfolded) 2f scattering angle measurement arXiv:2406.08590v3

impact of kaon ID efficiency on s-jet tagging

Jet Flavour Tagging at FCC-ee with a Transformer-based Neural Network: DeepJetTransformer

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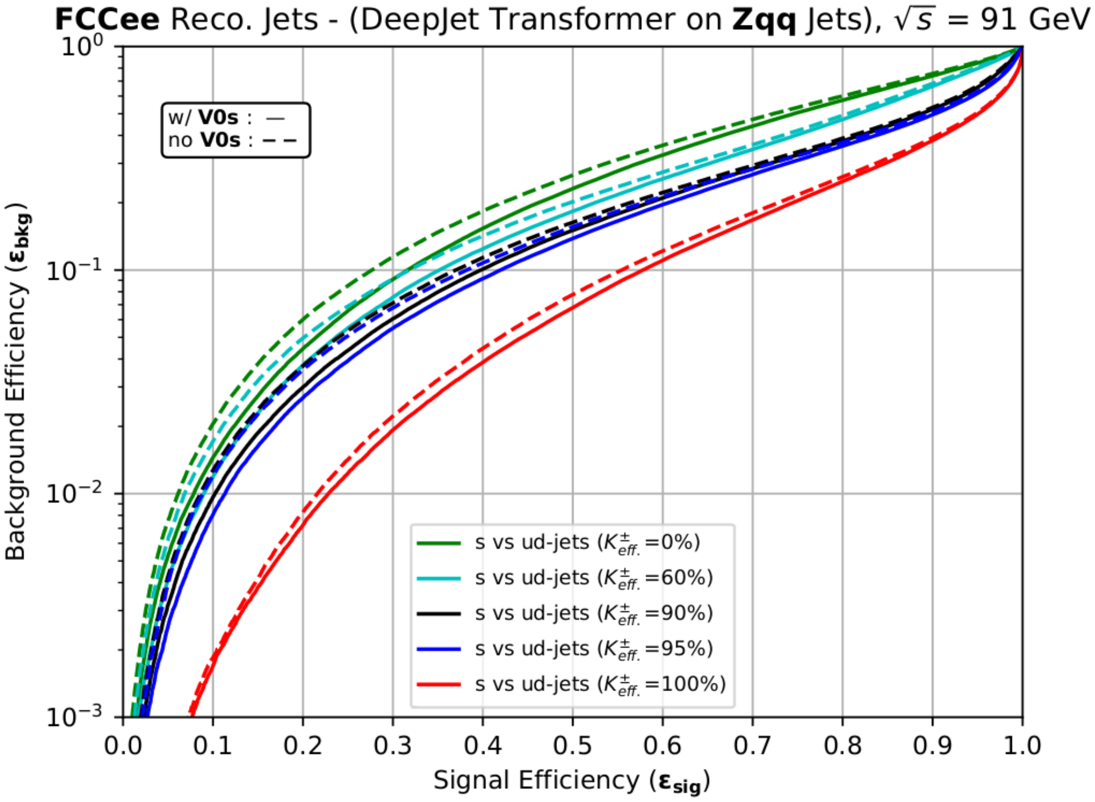
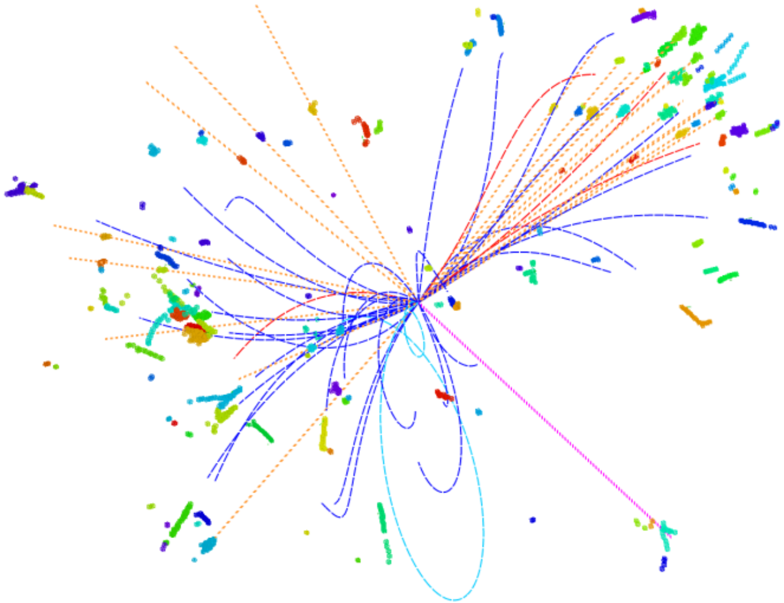
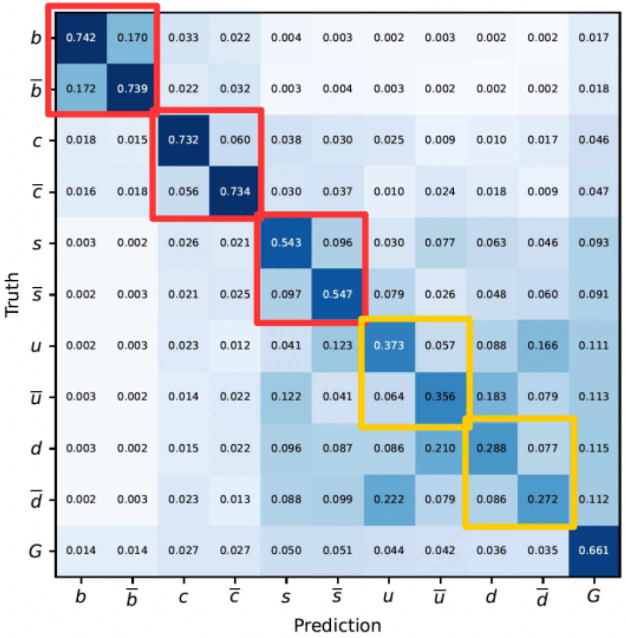
Freya Blekman [1,2,4] Florencia Canelli [3] Alexandre De Moor [1] Kunal Gautam [1,3] Armin Ilg [3] Anna Macchiolo [3] Eduardo Ploerer [1,3]



fast simulation (Delphes) of IDEA concept

Recent HL: Jet Origin Identification





- **Jet origin identification: 11 categories (5 quarks + 5 anti quarks + gluon)**
  - Jet Flavor Tagging + Jet Charge measurements + s-tagging + gluon tagging...
- Full Simulated ννH, Higgs to two jets sample at CEPC baseline configuration: CEPC-v4 detector, reconstructed with **Arbor + ParticleNet (Deep Learning Tech.)**
- 1 Million samples each, 60/20/20% for training, validation & test

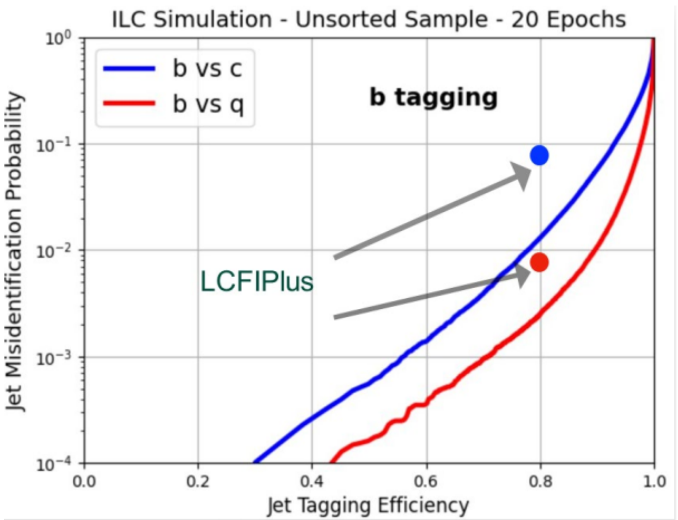
M. Ruan

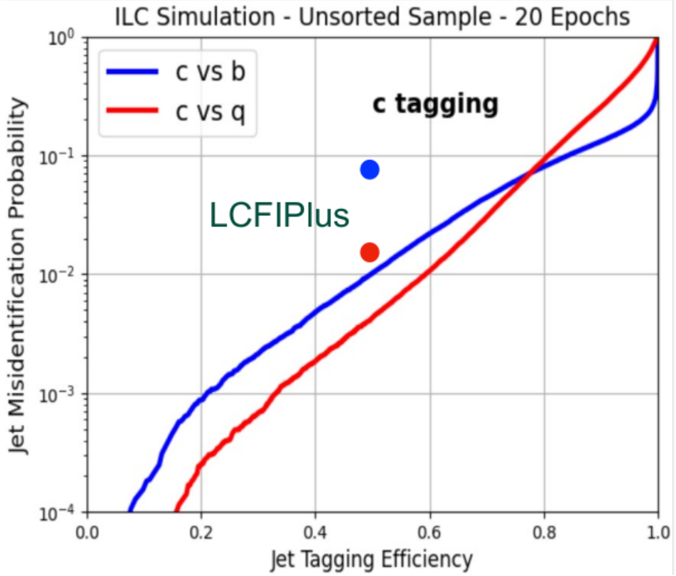
ParticleTransformer on ILD full simulation
T. Suehara et al

significant improvements on previous
generation tool (LCFIPlus)

porting to the
reconstruction framework underway
→ general use in full-sim physics analyses

progress on s-jet tagging,
using *fully reconstructed*
particle ID (esp. K)





Krzysztof Mękała

separating u- and d-type jet events
based on Final State Radiation

Γ_{had} scales as:

$$\Gamma_{had} \sim (3c_d + 2c_u)$$

and $\Gamma_{had+\gamma}$ as:

$$\Gamma_{had+\gamma} \sim \frac{\alpha}{2\pi} f(y_{cut}) \left(3q_d^2 c_d + 2q_u^2 c_u\right)$$

The correction factor $f(y_{cut})$ to be determined for a given value of the resolution parameter y_{cut}.

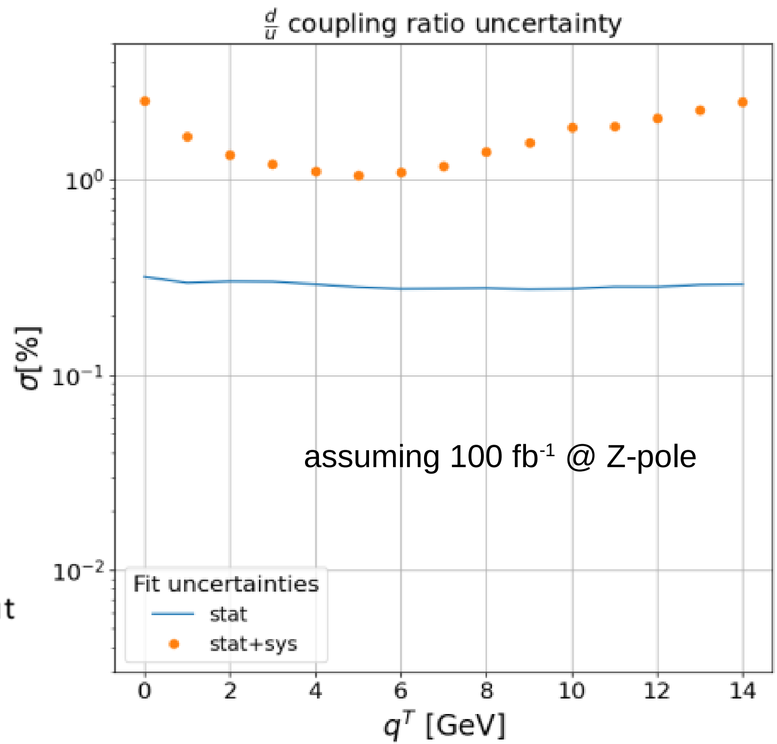
We want to consider:

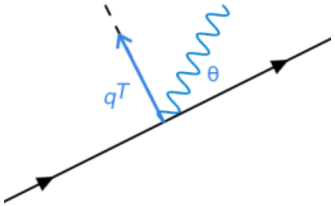
$$e^+e^- \rightarrow q\bar{q}(\gamma)$$

Experimentally measured photons can originate not only from the Final State Radiation but also from the Initial State Radiation, hadronisation and decays...

One may encounter the following issues:

- **Matrix Element** calculations – divergent or very slow for low photon-emission angles;
- **ISR structure functions** – good for small angles, a proper matching procedure needed;
- **FSR showers** – important for QCD emissions, may cause double-counting;
- **hadron decays** – photons to be included properly.





dedicated photon matching procedure essential !

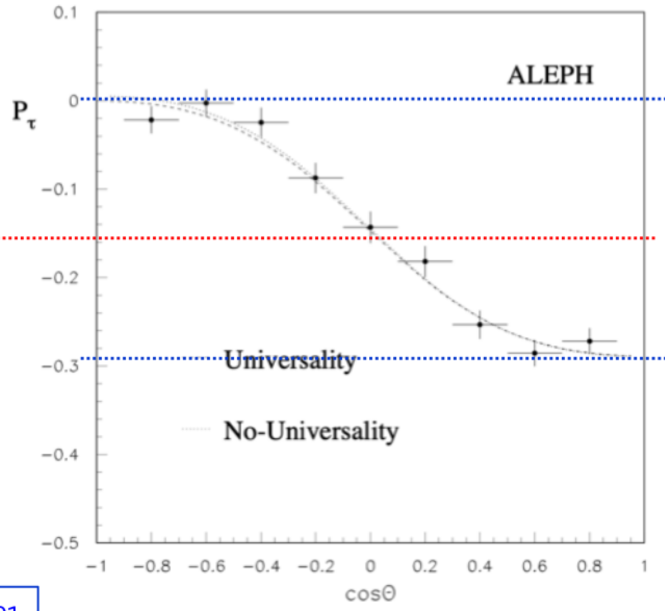
e+e- → tau+ tau- : final state polarisation is an extra handle

Example: Aleph at LEP

Mean polarisation

Angular dependence

$\mathcal{A}_\tau$



$\mathcal{A}_e$

Asymmetri-like measurement:
Low systematics

M. Dam

Eur.Phys.J.C20:401-430,2001

$\mathcal{A}_\tau = 0.1451 \pm 0.0052 \pm 0.0029$

$\mathcal{A}_e = 0.1504 \pm 0.0068 \pm 0.0008$

⇒ assuming universality: $\sin^2\theta_W^{eff} = 0.23130 \pm 0.00048$

Results and Precisions – case Aleph

Eur.Phys.J.C20:401-430,2001

Obtained results

Channel	$\mathcal{A}_\tau$ (%)	$\mathcal{A}_e$ (%)
hadron	$15.21 \pm 0.98 \pm 0.49$	$15.28 \pm 1.30 \pm 0.12$
rho	$13.79 \pm 0.84 \pm 0.38$	$14.66 \pm 1.12 \pm 0.09$
a1(3h)	$14.77 \pm 1.60 \pm 1.00$	$13.58 \pm 2.11 \pm 0.40$
a1(h2π^0)	$16.34 \pm 2.06 \pm 1.52$	$15.62 \pm 2.72 \pm 0.47$
electron	$13.64 \pm 2.33 \pm 0.96$	$14.09 \pm 3.17 \pm 0.91$
muon	$13.64 \pm 2.09 \pm 0.93$	$11.77 \pm 2.77 \pm 0.25$
pion inclusive	$14.93 \pm 0.83 \pm 0.87$	$14.91 \pm 1.11 \pm 0.17$
Combined	$14.44 \pm 0.55 \pm 0.27$	$14.58 \pm 0.73 \pm 0.10$

Most precise channels

systematics

Source	h	ρ	$3h$	$h2\pi^0$	e	μ	Incl. h
			A_τ				
selection	-	0.01	-	-	0.14	0.02	0.08
tracking	0.06	-	0.22	-	-	0.10	-
ECAL scale	0.15	0.11	0.21	1.10	0.47	-	-
PID	0.15	0.06	0.04	0.01	0.07	0.07	0.18
misid.	0.05	-	-	-	0.08	0.03	0.05
photon	0.22	0.24	0.37	0.22	-	-	-
non-τ back.	0.19	0.08	0.05	0.18	0.54	0.67	0.15
τ BR	0.09	0.04	0.10	0.26	0.03	0.03	0.78
modelling	-	-	0.70	0.70	-	-	0.09
MC stat	0.30	0.26	0.49	0.63	0.61	0.63	0.26
TOTAL	0.49	0.38	1.00	1.52	0.96	0.93	0.87

Source	h	ρ	$3h$	$h2\pi^0$	e	μ	Incl. h
			A_e				
tracking	0.04	-	-	-	-	0.05	-
non-τ back.	0.11	0.09	0.04	0.22	0.91	0.24	0.17
modelling	-	-	0.40	0.40	-	-	-
TOTAL	0.12	0.09	0.40	0.47	0.91	0.25	0.17

- LEP measurement statistics limited
- At FCC-ee, ~ $10^{5\text{-}6}$ larger statistics: Need (much) reduced systematics

The single most important systematics (on the most precise channels) is due to photon and π^0 identification

excellent and excellently-*understood* photon and π^0 measurement are the key to achieving the required precision

kinematic unknowns and constraints in e e → tau tau

at Z-pole: can assume known tau energy,
back-to-back topology

at higher energies need to take account of
(usually unseen) ISR

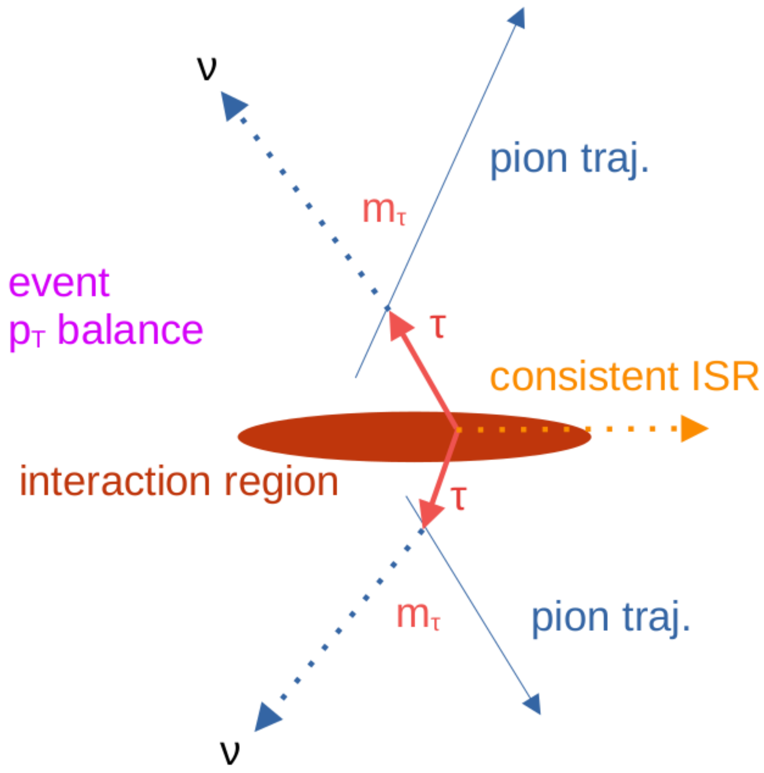
momentum/energy conservation (including ISR)

tau masses

impact parameters, beam spot

interaction region

slightly under-constrained system
→ several possible solutions per event



Updated result on $\sin^2\theta^l_{eff}$ measurement

Table 2. Sensitivity S of different final state particles.

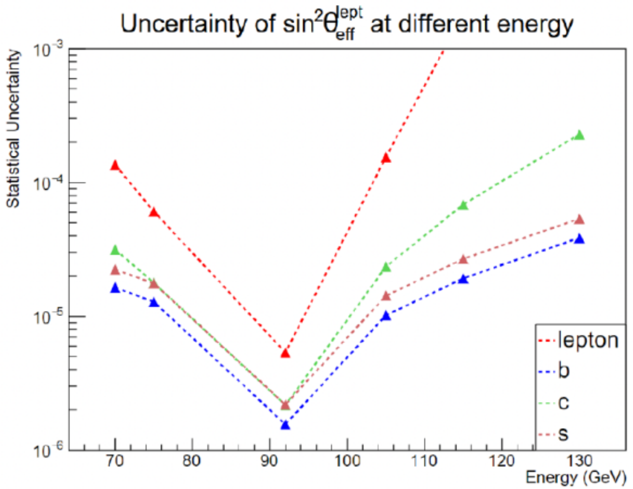
$\sqrt{s}$/GeV	S of $A^{e/\mu}_{FB}$	S of A^{d}_{FB}	S of A^{u}_{FB}	S of A^{s}_{FB}	S of A^{c}_{FB}	S of A^{b}_{FB}
70	0.224	4.396	1.435	4.403	1.445	4.352
75	0.530	5.264	2.598	5.269	2.616	5.237
92	1.644	5.553	4.200	5.553	4.201	5.549
105	0.269	4.597	1.993	4.598	1.994	4.586
115	0.035	3.956	1.091	3.958	1.087	3.942
130	0.027	3.279	0.531	3.280	0.520	3.261

Table 3. Cross section of process $e^+e^- \to f\bar{f}$ calculated using the ZFITTER package. Values of the fundamental parameters are set as $m_Z = 91.1875$ GeV, $m_t = 173.2$ GeV, $m_H = 125$ GeV, $\alpha_s = 0.118$ and $m_W = 80.38$ GeV.

$\sqrt{s}$/GeV	σ_μ/mb	σ_d/mb	σ_u/mb	σ_s/mb	σ_c/mb	σ_b/mb
70	0.039	0.032	0.066	0.031	0.058	0.028
75	0.039	0.047	0.073	0.046	0.065	0.043
92	1.196	5.366	4.228	5.366	4.222	5.268
105	0.075	0.271	0.231	0.271	0.227	0.265
115	0.042	0.135	0.122	0.135	0.118	0.132
130	0.026	0.071	0.068	0.071	0.066	0.069

Verify the RG behavior... using ~1 month of data taking

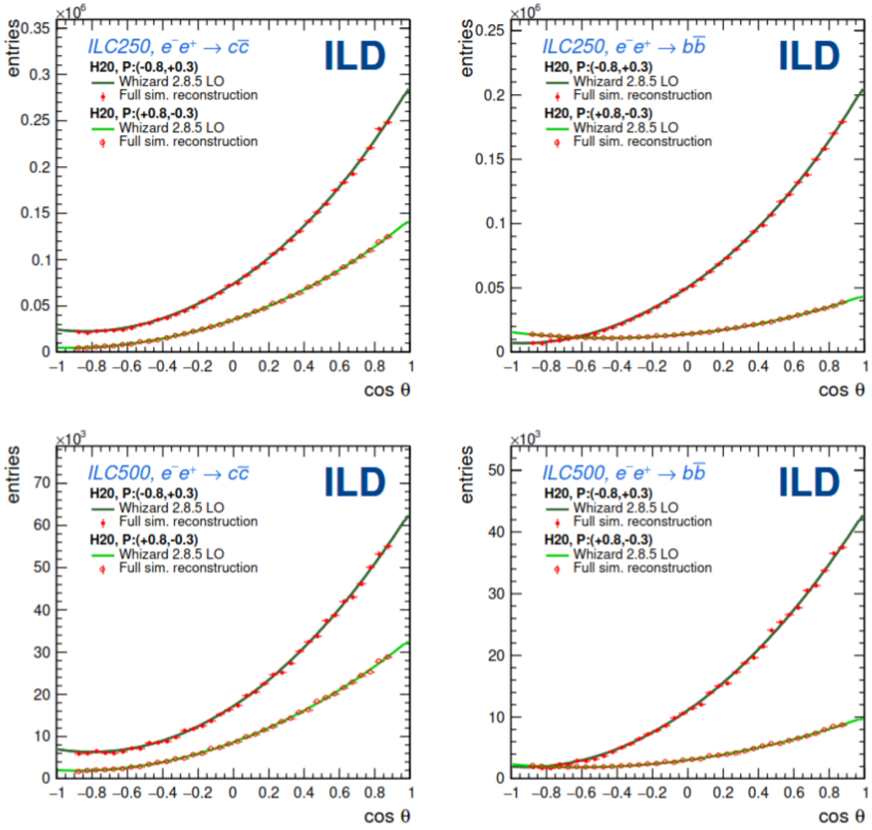
Expected statistical uncertainties on $\sin^2\theta^l_{eff}$ measurement.
(Using one-month data collection, ~ *4e12/24 Z events* at Z pole)



$\sqrt{s}$	b	c	s
70	1.6×10^{-5}	3.2×10^{-5}	2.2×10^{-5}
75	1.3×10^{-5}	1.8×10^{-5}	1.8×10^{-5}
92	1.6×10^{-6}	2.2×10^{-6}	2.2×10^{-6}
105	1.0×10^{-5}	2.4×10^{-5}	1.4×10^{-5}
115	1.9×10^{-5}	6.8×10^{-5}	2.7×10^{-5}
130	3.9×10^{-5}	2.3×10^{-4}	5.4×10^{-5}

M. Ruan

AFB – heavy quarks Double Charge Method



- **AFB measured in the continuum (not Z in rest frame)**
  - Sensitivity to Z, gamma, Z`
- At least 4 observables for AFB at ILC250 per energy point
  - 2 quarks and 2 polarisations (eLpR, eRpL)

- **Per mil level statistical uncertainties reachable for the nominal ILC250-500 program**
  - **Smaller exp syst. Uncertainties**
  - **Fragmentation, angular correlations → minimized** thanks to **double tagging** techniques and Data Driven measurement of efficiencies **à la LEP and SLC**

Eur.Phys.J.C 84 (2024) 5, 537
ILD-PHYS-PUB-2023-001
ILD-PHYS-PROC-2023-013
Irles, Marquez, Poeschl, Richard, Yamamoto, Namatsu, Saibel

NEW 2024!

Gauge Higgs Unification models vs SM discrimination power

m_Z'

19.6 TeV
19.6 TeV
14.9 TeV
14.9 TeV
10.2 TeV
10.2 TeV

m_Z'

8.52 TeV
7.19 TeV

ILD

GHU vs SM discrimination power (σ-level)

	ILC250♦ (no pol.)			ILC250			ILC250 +500			ILC250 +500 +1000*		
	O	E	N	O	E	N	O	E	N	O	E	N
B_3^+	0.3	0.4	0.4	0.5	0.7	0.7	0.9	1.2	1.3	2.1	2.5	2.5
B_3^-	0.2	0.4	0.4	0.5	0.8	0.9	1.7	2.6	2.7	4.2	6.5	6.7
B_2^+	0.5	0.7	0.7	0.9	1.4	1.5	1.7	2.1	2.2	3.8	4.4	4.4
B_2^-	0.3	0.6	0.7	0.8	1.3	1.4	2.9	4.5	4.6	8.0	>10	>10
B_1^+	1.1	1.5	1.6	2.2	3.1	3.2	3.4	4.3	4.4	5.7	6.7	6.8
B_1^-	0.6	1.2	1.4	1.4	2.4	2.7	5.9	9.3	9.6	>10	>10	>10
A_2	2.2	3.2	3.3	3.3	4.7	4.8	>10	>10	>10	>10	>10	>10
A_1	2.7	3.8	3.9	3.5	4.9	5.0	>10	>10	>10	>10	>10	>10

Ch. had. PID

- *O: No PID*
- *E: $\frac{dE}{dx}$*
- *N: $\frac{dN}{dx}$*

< 3 σ
3-4 σ
4-5 σ
> 5 σ

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ILD-PHYS-PUB-2023-001
ILD-PHYS-PROC-2023-013

A. Irles et al

Summary

quite some activity related to the 2f focus topic

- higher order theoretical calculations: QED, EW, QCD
- experimental reconstruction tools
- estimates of physics reach

The 2f expert team is preparing to summarise these studies in its section of the ECFA report