TOP AND ELECTROWEAK PHYSICS AT THE LINEAR COLLIDER FACILITY

Krzysztof Mękała

DESY, Hamburg, Germany

Faculty of Physics, University of Warsaw, Poland

on behalf of the ILD Concept Group

Linear Collider Vision

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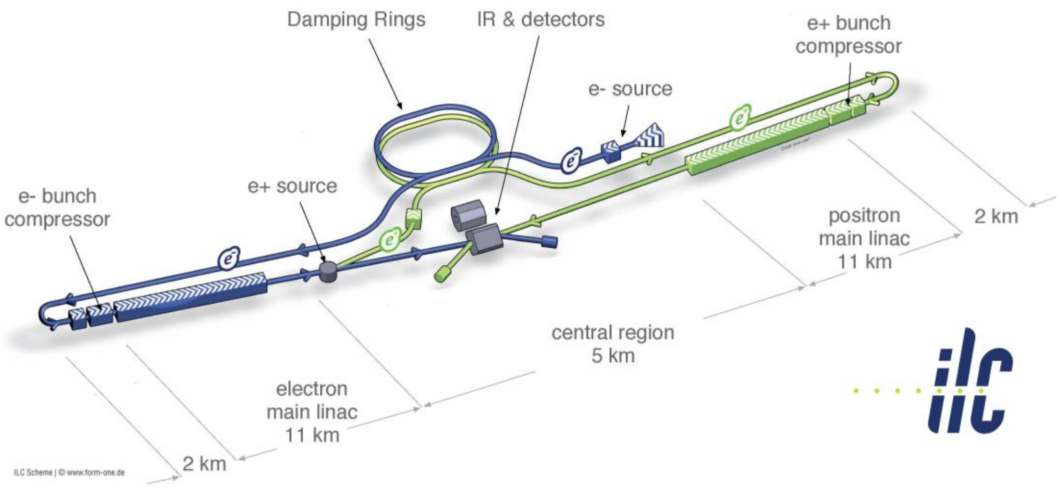
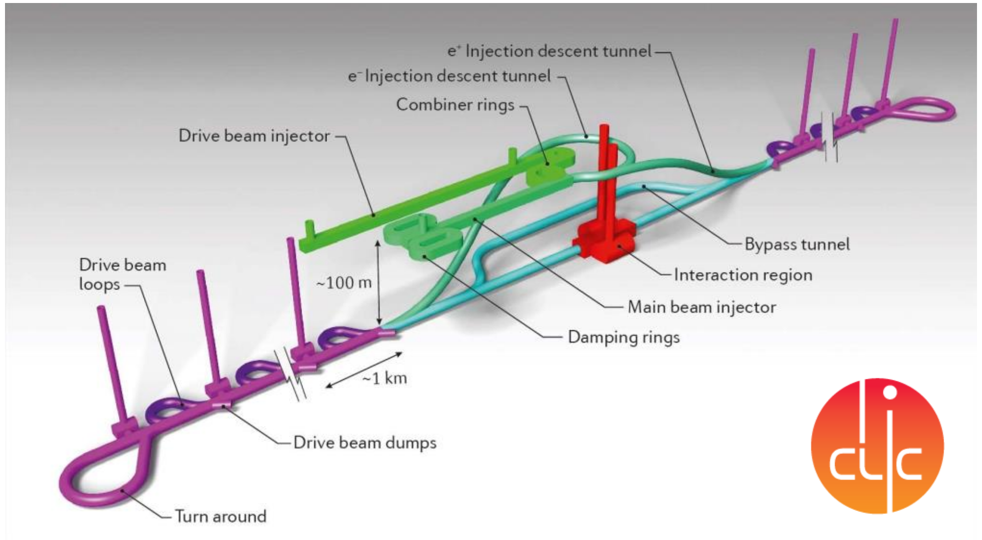
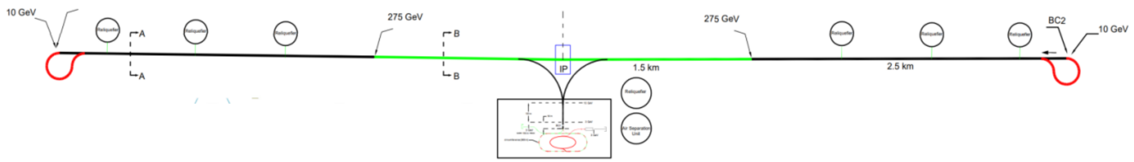
LINEAR COLLIDERS





C^3 - 8 km Footprint for 250/550 GeV (to scale)



+ HELEN, ReLiC/ERLC, HALHF...

LINEAR COLLIDER FACILITY (LCF) @ CERN [2503.24049]

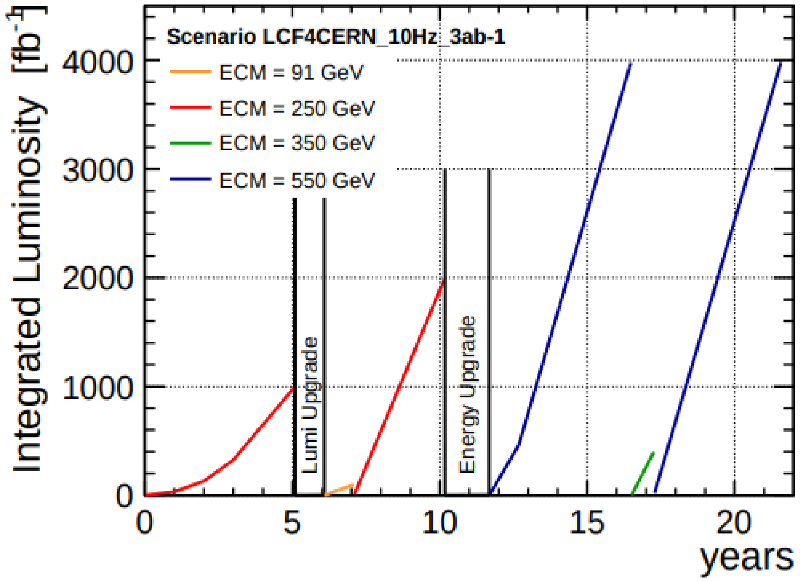
- Idea: leverage all the work done for ILC & CLIC, modernise to turn into a true flagship project for CERN
- ILC technology as a starter, but allow for later upgrades

Linear Collider Vision

→ see talk by Gudrid Moortgat-Pick for details

LCF @ CERN PARAMETERS

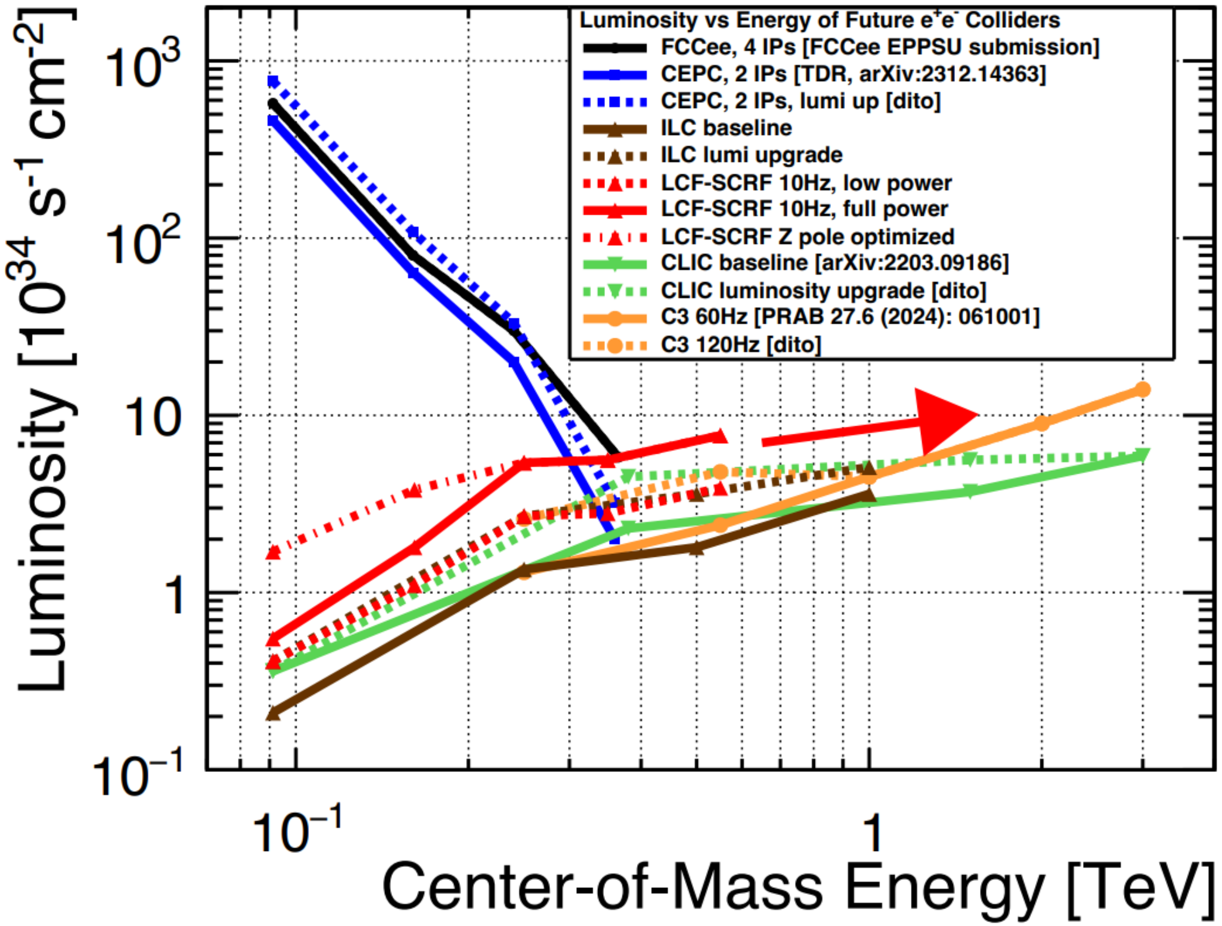
Quantity	Symbol	Unit	Initial-250	Upgrades		Initial-550	Upgrade
Centre-of-mass energy	$\sqrt{s}$	GeV	250	250	550	550	550
Inst. Luminosity	$\mathscr{L}$	$(10^{34}\text{cm}^{-2}\text{s}^{-1})$	2.7	5.4	7.7	3.9	7.7
Polarisation	$\lvert P(e^-)\rvert / \lvert P(e^+)\rvert$	(%)	80 / 30	80 / 30	80 / 60	80 / 30	80 / 60



[2503.24049]

Linear Collider Vision

LINEAR VS. CIRCULAR



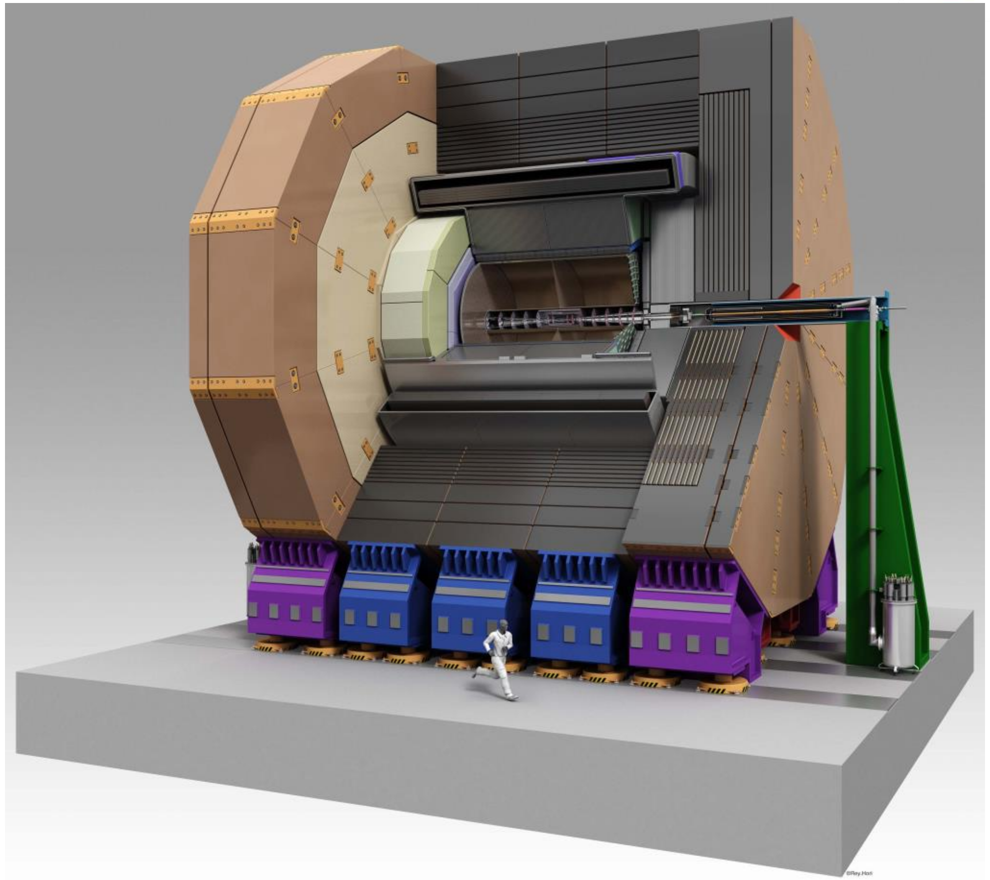
Linear colliders typically advantageous at higher energies, above the top threshold, but a lot can also be measured at initial stages

This talk: EW & top

Jan Klamka's talk: BSM

INTERNATIONAL LARGE DETECTOR (ILD)

- Optimised for particle flow
- 3.5 T solenoid placed outside of calorimeters
- (Almost) 4π coverage (5 mrad)
- Silicon vertex det., TPC tracker, high-granularity calorimeters

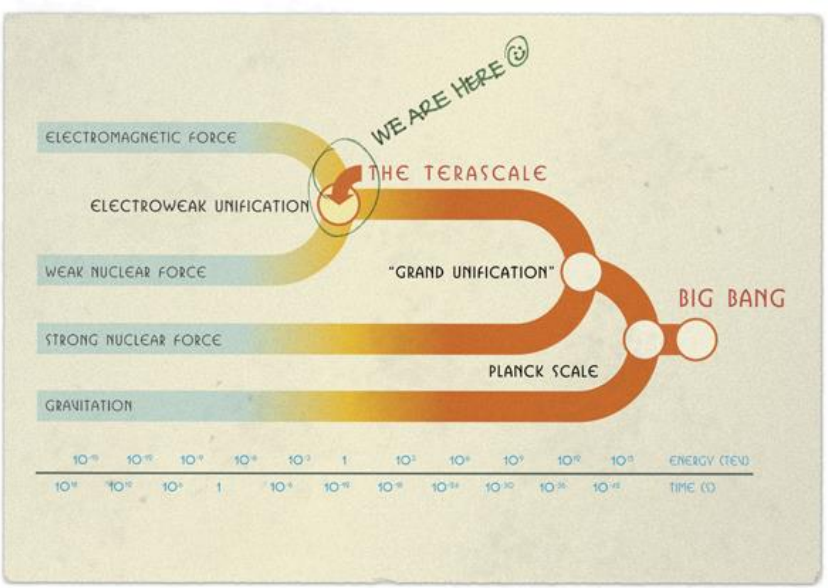


→ see talk by Vincent Boudry for details

ELECTROWEAK PHYSICS

Electroweak physics is interesting because...

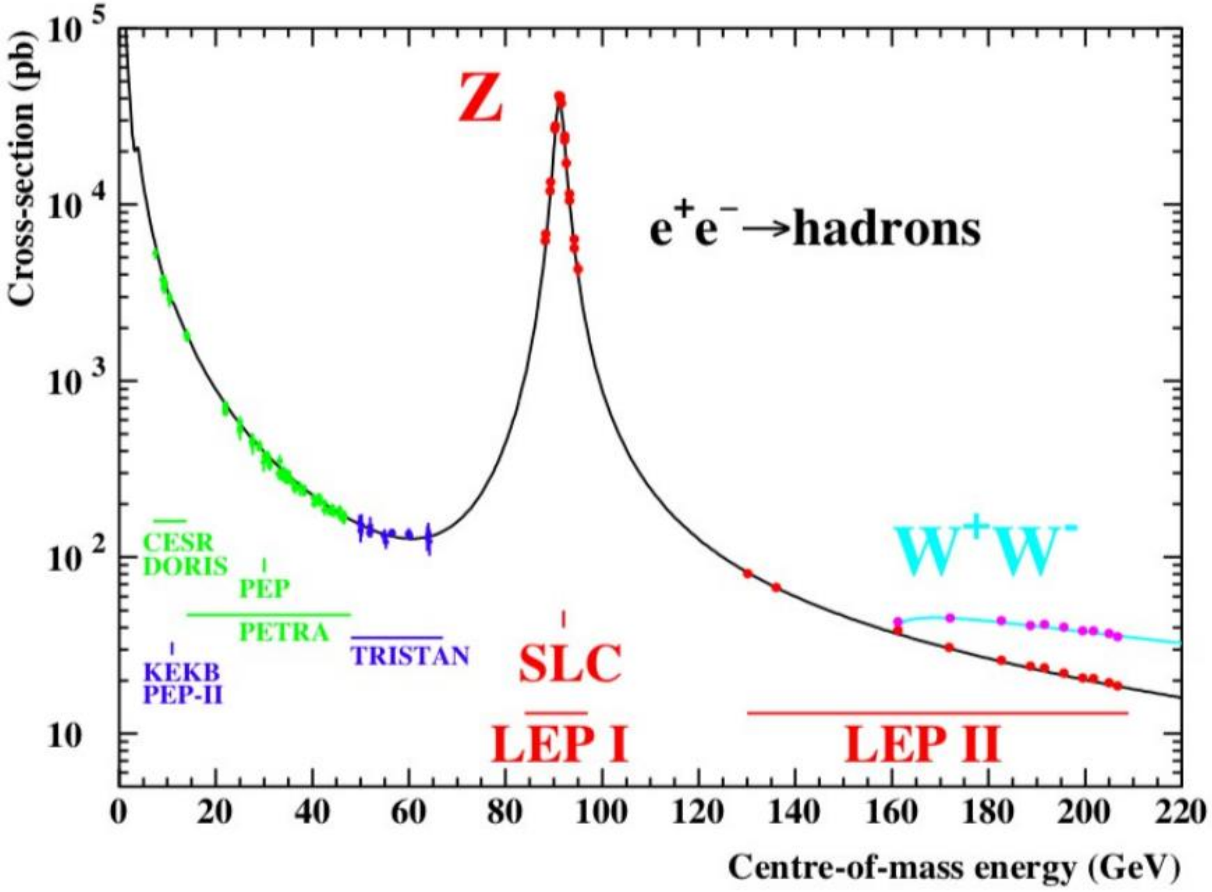
- electromagnetic and weak forces are unified,
- it has been both tested at colliders and computed precisely,
- precise measurements can reveal deviations from the theory and provide clues about BSM,
- ...



(Credit: Symmetry magazine)

Z-POLE RUN

- LCF at the Z-pole would produce $5x10^9$ Z events.
- Orders-of-magnitude improvement w.r.t. LEP
- **Lesson** from the past: SLC achieved better precision than LEP in some measurements thanks to beam polarisation, despite of 30x lower lumi.



ELECTROWEAK PRECISION: $\sin^2\theta_{EFF}$

- The Z decay polarisation asymmetries are defined as:

$$A_f = \frac{g_{Lf}^2 - g_{Rf}^2}{g_{Lf}^2 + g_{Rf}^2}$$

- Specifically, for an electron, one can define an *effective mixing angle*:

$$A_e = \frac{(\frac{1}{2} - \sin^2\theta_{eff})^2 - (\sin^2\theta_{eff})^2}{(\frac{1}{2} - \sin^2\theta_{eff})^2 + (\sin^2\theta_{eff})^2} \approx 8(\frac{1}{4} - \sin^2\theta_{eff})$$

- With polarised beams, it can be measured as left-right asymmetry:

$$A_e = A_{LR} \equiv \frac{\sigma_L - \sigma_R}{(\sigma_L + \sigma_R)}$$

- For beams, which are not perfectly polarised:

$$P_{eff} = (P_{e^-} - P_{e^+})/(1 - P_{e^-}P_{e^+})$$

Rates and asymmetries

Partial fermion width:

$$R_f = \frac{N_f}{N_{had}} = \frac{(g_f^L)^2 + (g_f^R)^2}{\sum_{i=1}^{n_q}[(g_i^L)^2 + (g_i^R)^2]}$$

- Sensitive to sum of coupling constants
- Available at linear and circular colliders

Left-right asymmetry:

$$A_{LR} = \frac{1}{|\mathcal{P}_{eff.}|}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = \mathcal{A}_e = \frac{(g_f^L)^2 - (g_f^R)^2}{(g_i^L)^2 + (g_i^R)^2} \sim 1 - 4\sin^2\theta^\ell_{eff.}$$

- Direct sensitivity to Zee vertex
- Only available at linear colliders due to beam polarisation
- Circular colliders need auxiliary measurement
  - e.g. $P_\tau \sim A_e$

Forward-backward asymmetry:

$$A_{FB}^f = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f \quad \text{for} \quad \mathcal{P}_e = 0.$$

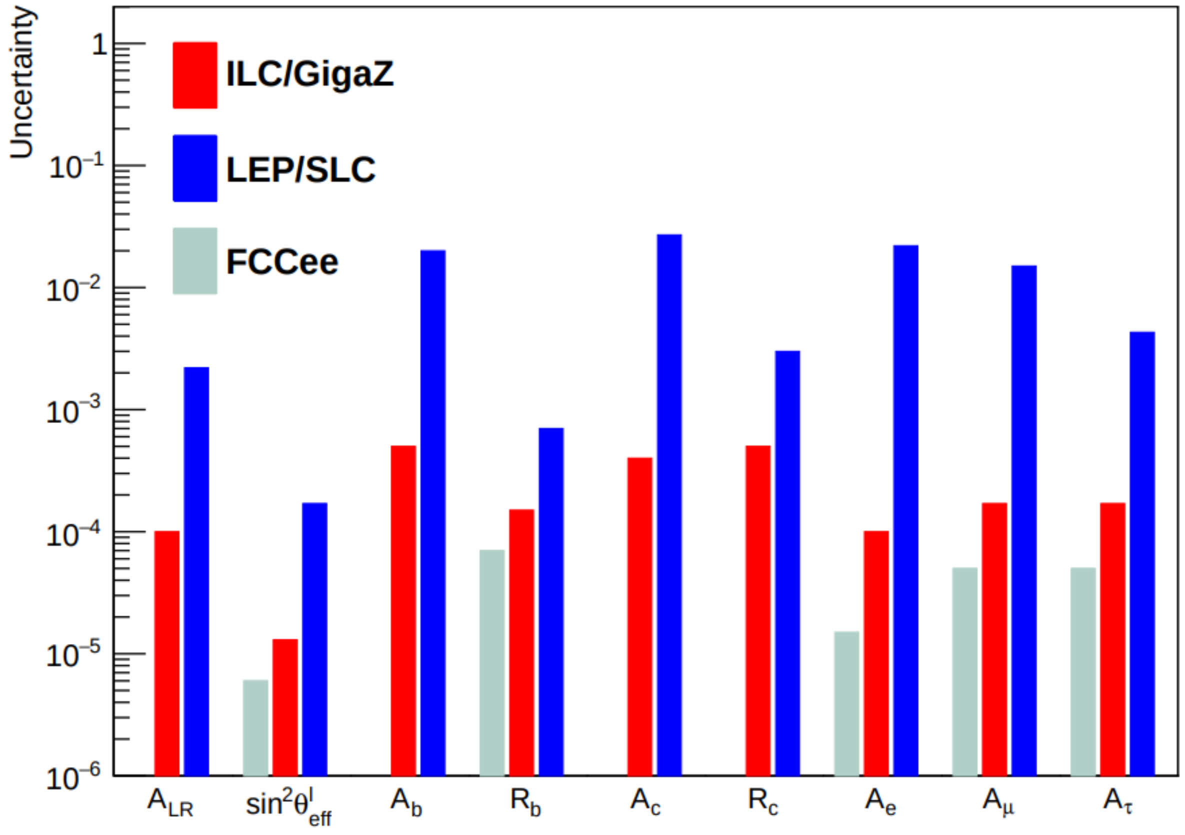
- "Classical" observable to study P-violating effects in ee->ff
- Available at circular and linear colliders
- **Without** beam polarisation interpretation is **always model dependent**

Left-right-forward-backward asymmetry:

$$A_{FB,LR}^f = \frac{(\sigma_F - \sigma_B)_L - (\sigma_F - \sigma_B)_R}{(\sigma_F + \sigma_B)_L + (\sigma_L + \sigma_l)_R} = -\frac{3}{4}\mathcal{A}_f$$

- Combination of asymmetries above
- Only available linear colliders due to beam polarisation
- Direct and model independent measurement of A_f

PRECISION MEASUREMENTS



	current	**LCF**	FCC-ee
Δm_Z	2 MeV	**200 keV**	100 keV
$\Delta\Gamma_Z$	2 MeV	**125 keV**	12 keV
Δm_W	10 MeV	**2 MeV**	0.4 MeV

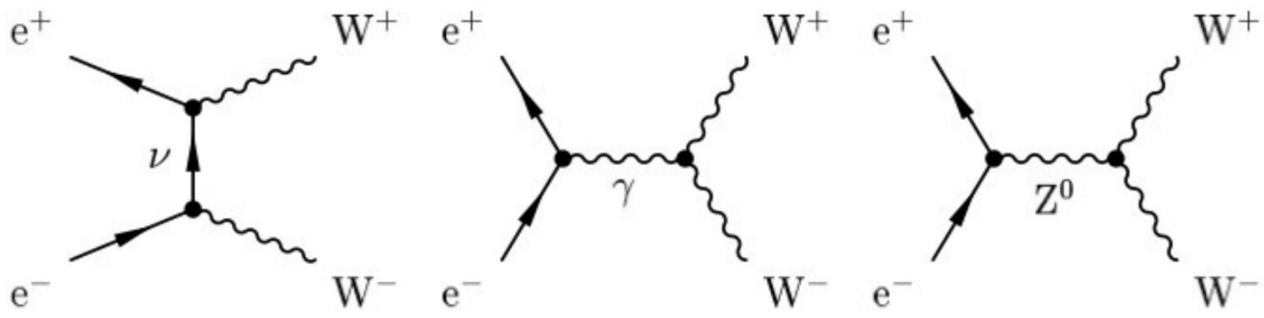
INPUT TO EPPSU2026

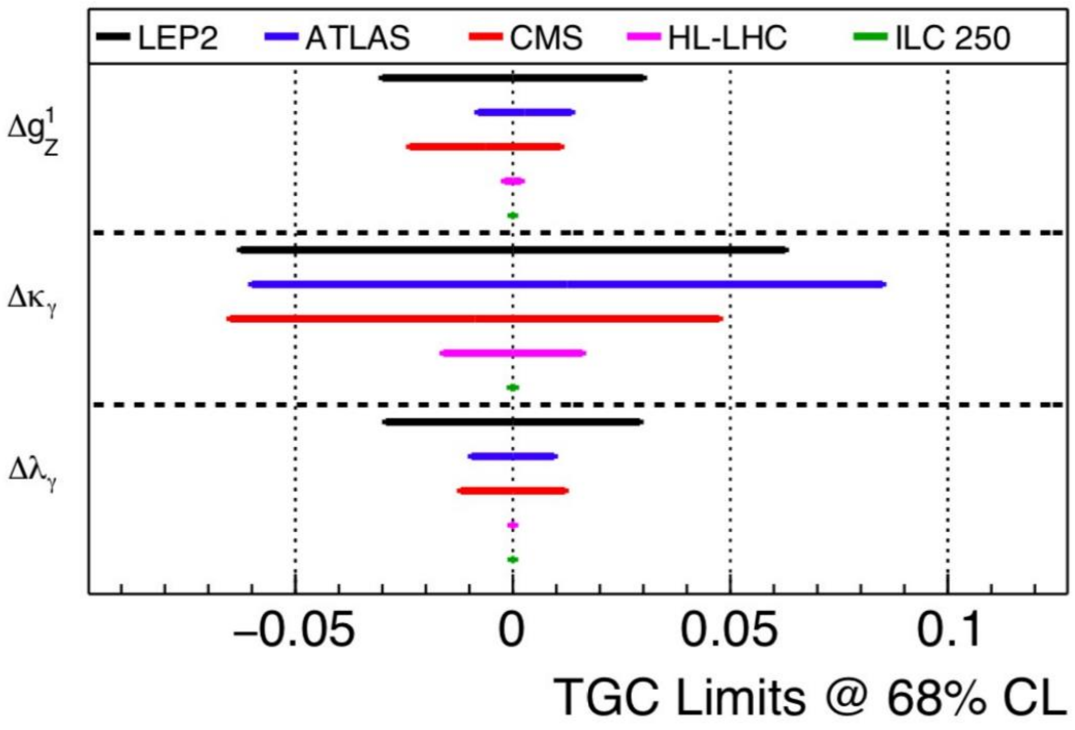
[1908.11299]

ANOMALOUS TRIPLE GAUGE COUPLINGS

Polarisation helps:

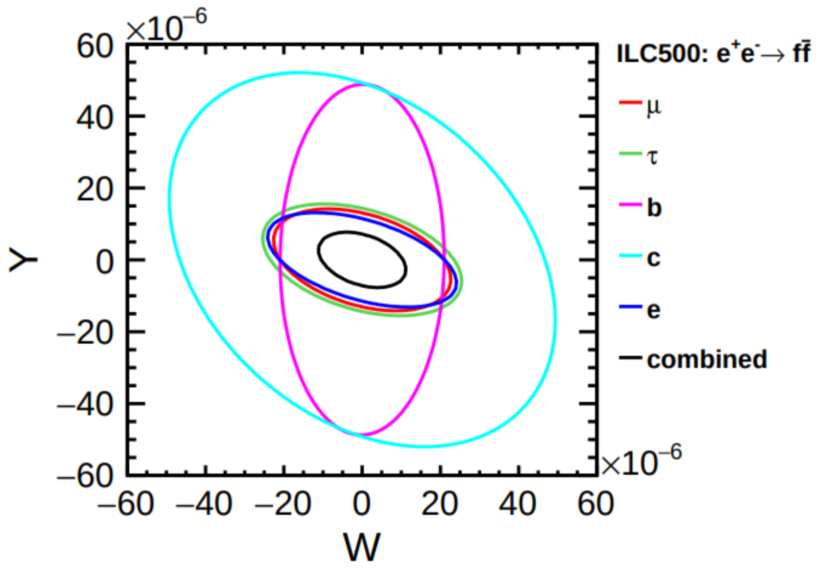
- enhance cross sections
- disentangle Z and γ couplings
- measure luminosity





Z' SEARCHES

Higher-energy runs are particularly well-suited to look for extensions of the gauge sector. The deviation can be expressed in terms of **W** and **Y**:

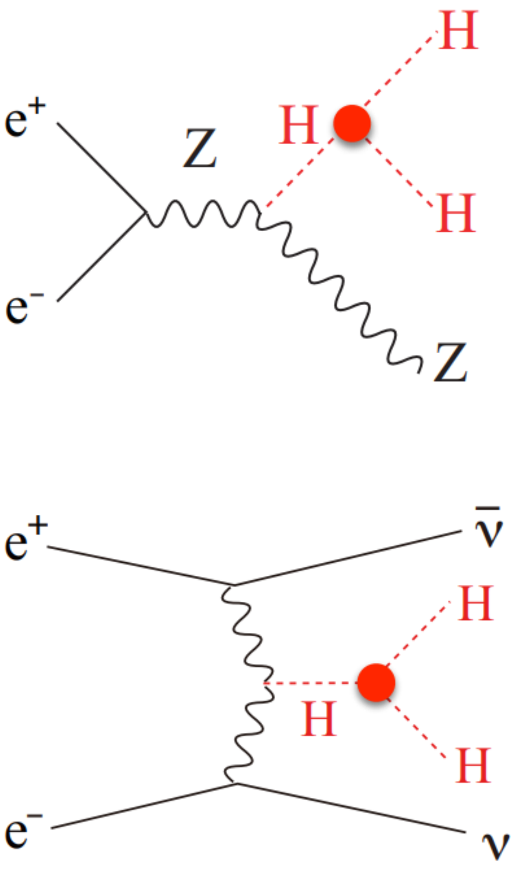


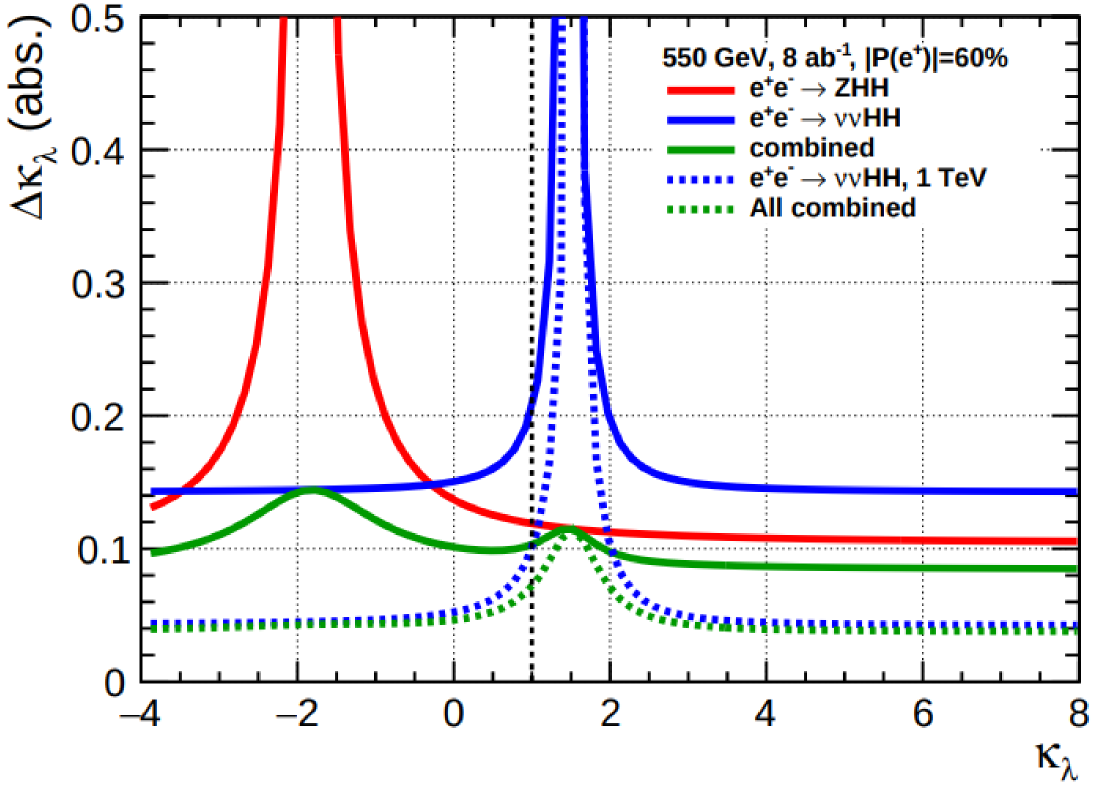
$$\mathcal{L} = \mathcal{L}_{SM} - \frac{g^2\mathbf{W}}{2m_W^2} J^a_{L\mu} J^{a\mu}_L - \frac{g'^2\mathbf{Y}}{2m_W^2} J_{Y\mu} J^\mu_Y$$

$\sqrt{s}$	$\Delta\mathbf{W}$	$\Delta\mathbf{Y}$	ρ
HL-LHC	15×10^{-5}	20×10^{-5}	-0.97
ILC250	3.4×10^{-5}	2.4×10^{-5}	-0.34
ILC500	1.1×10^{-5}	0.78×10^{-5}	-0.35
ILC1000	0.39×10^{-5}	0.27×10^{-5}	-0.38
500 GeV, no beam pol.	2.0×10^{-5}	1.2×10^{-5}	-0.78

[1908.11299]

*HIGGS SELF-COUPLING



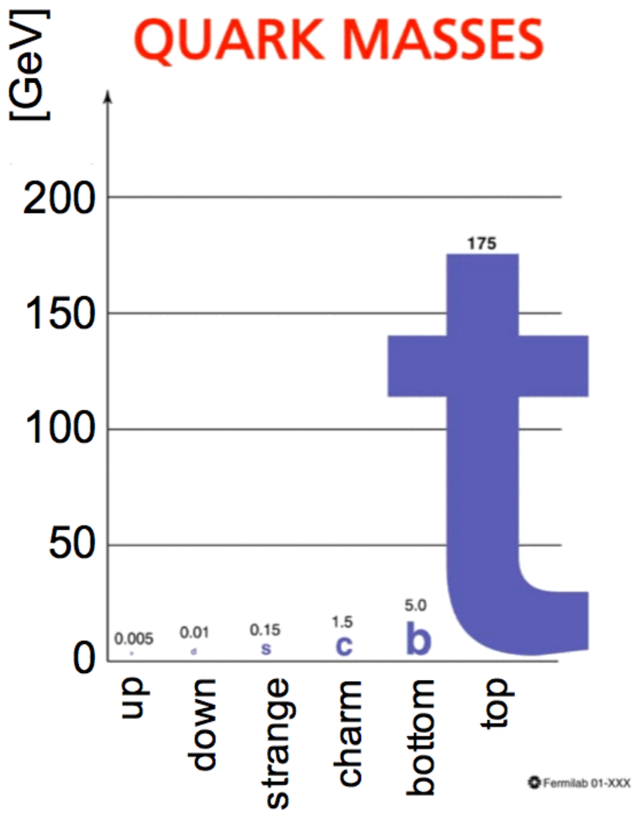


[2503.19983]

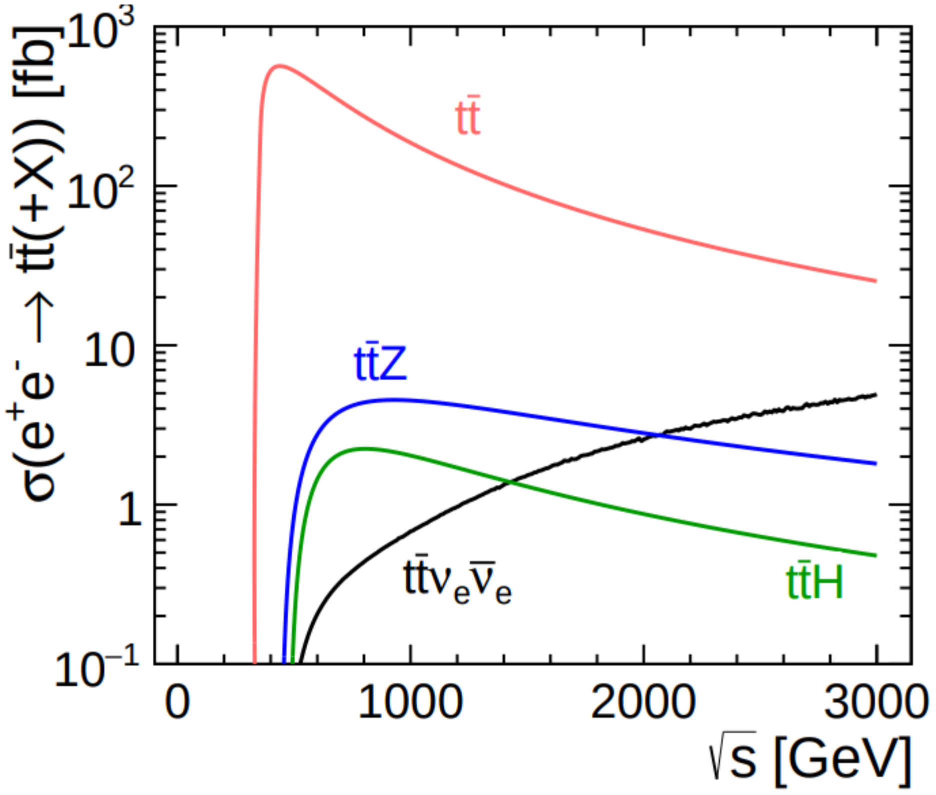
TOP QUARK

Top is interesting because...

- it is the heaviest elementary particle known,
- its Yukawa coupling is large $y_t \approx 1$,
- it is a potential portal to New Physics,
- ...



TOP PHYSICS AT LCF



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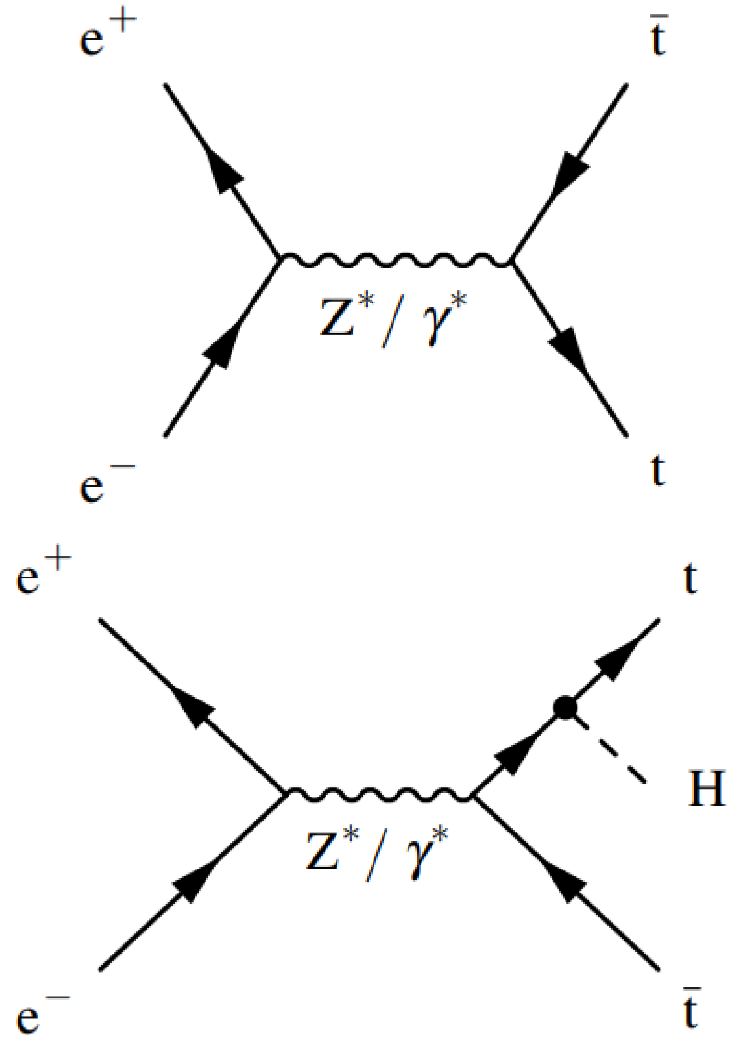
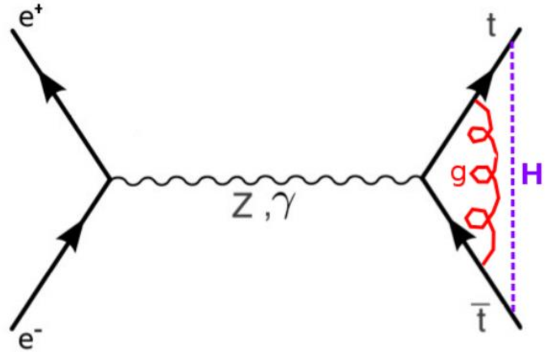
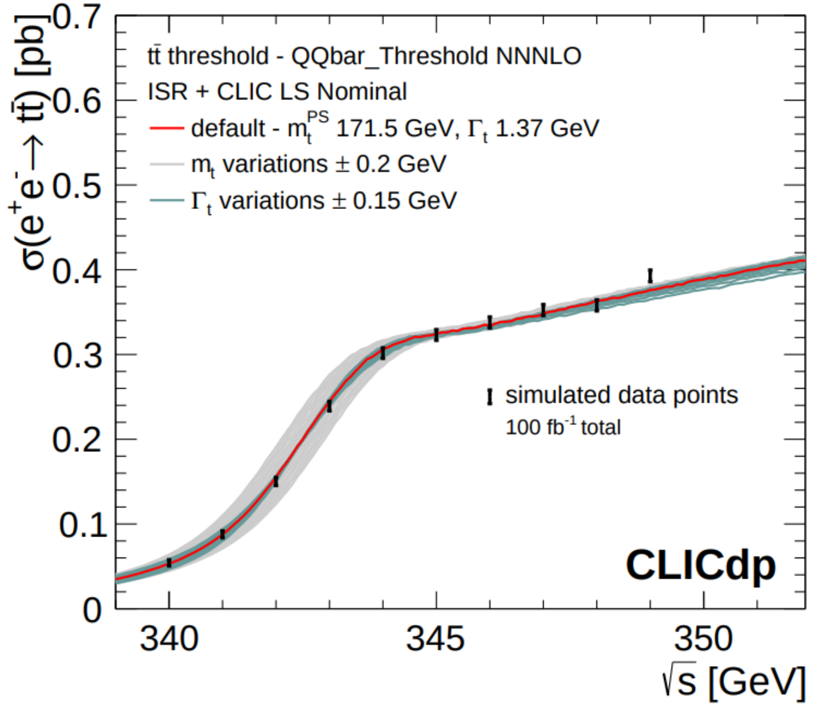


TOP THRESHOLD SCAN

Top pair-production threshold scan sensitive to:

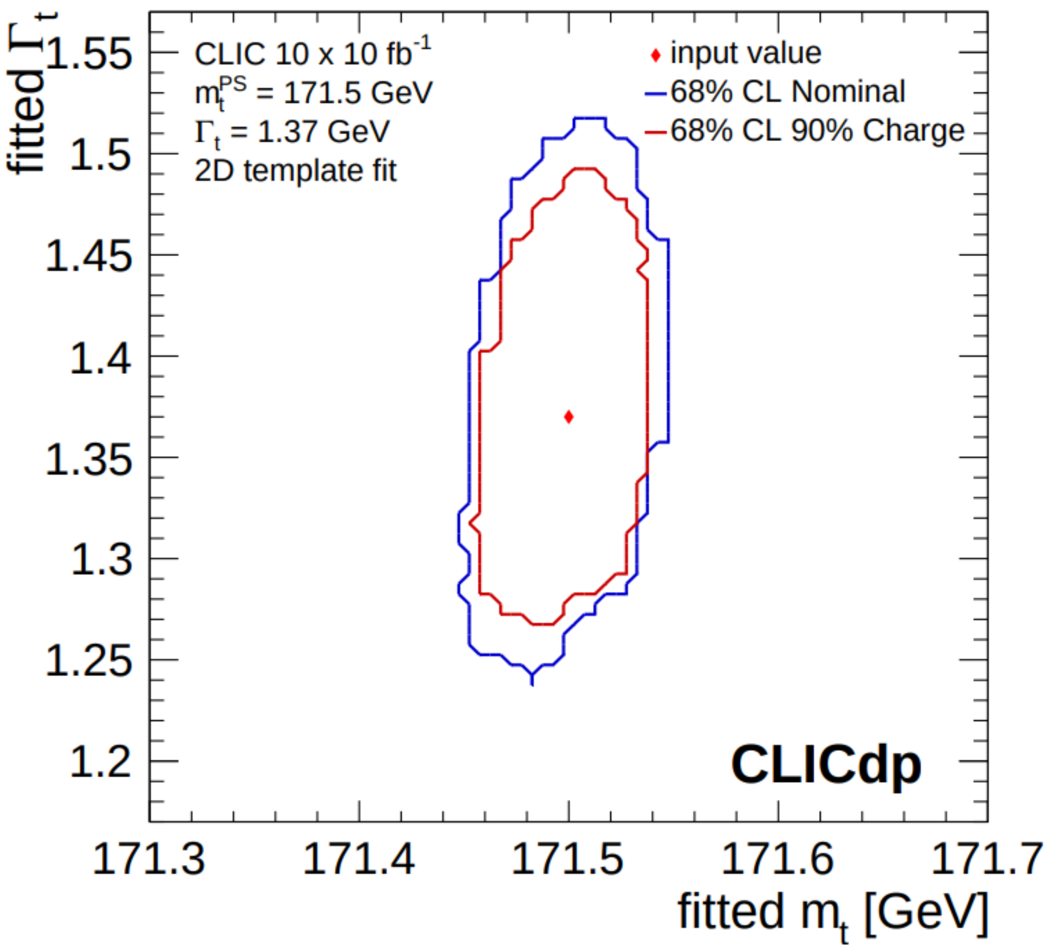


- top quark mass m_t
- top quark width Γ_t
- strong coupling α_s
- top Yukawa coupling y_t



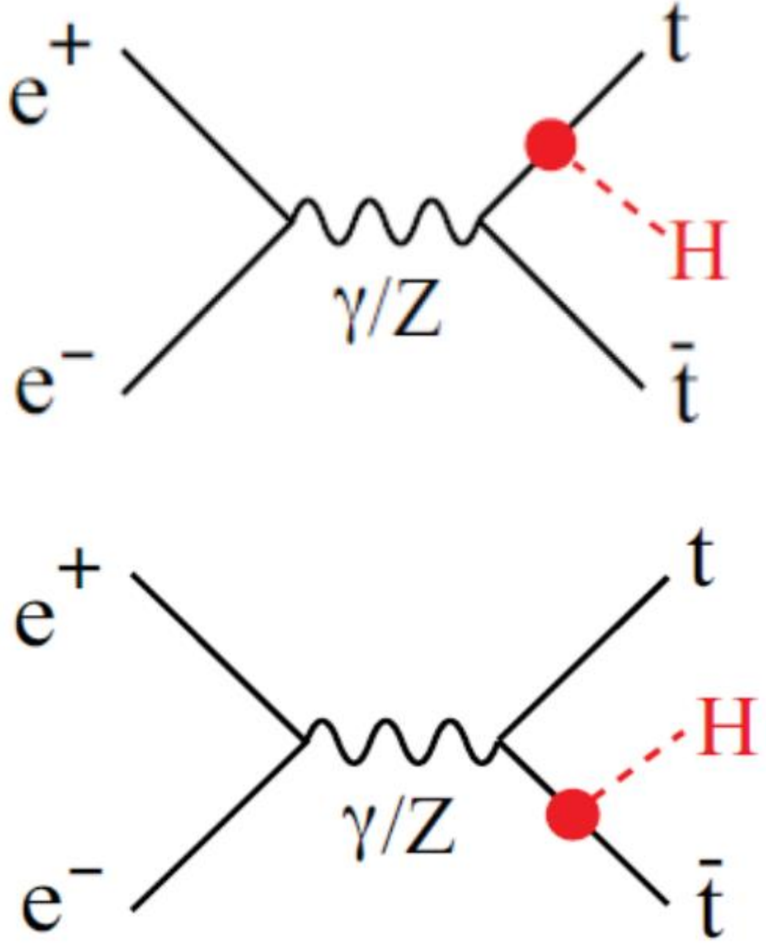
TOP MASS AND WIDTH

- Direct m_t measurements at LHC base on the reconstruction of kinematics from the decay products, currently reach a precision of 0.3 GeV, but MC hadronisation introduces another 0.5-1 GeV uncertainty between m^{MC} and m^{pole}
- A comparison of cross section measurements at several centre-of-mass energies of e^+e^- colliders gives access to the top quark mass in a well-controlled mass scheme.
- If beam energy and luminosity under control, Δm_t ~ **20-40** MeV, $\Delta \Gamma_t$ ~ **50** MeV
- The Yukawa coupling and α_s can be extracted as well, but not competitive when systematics included

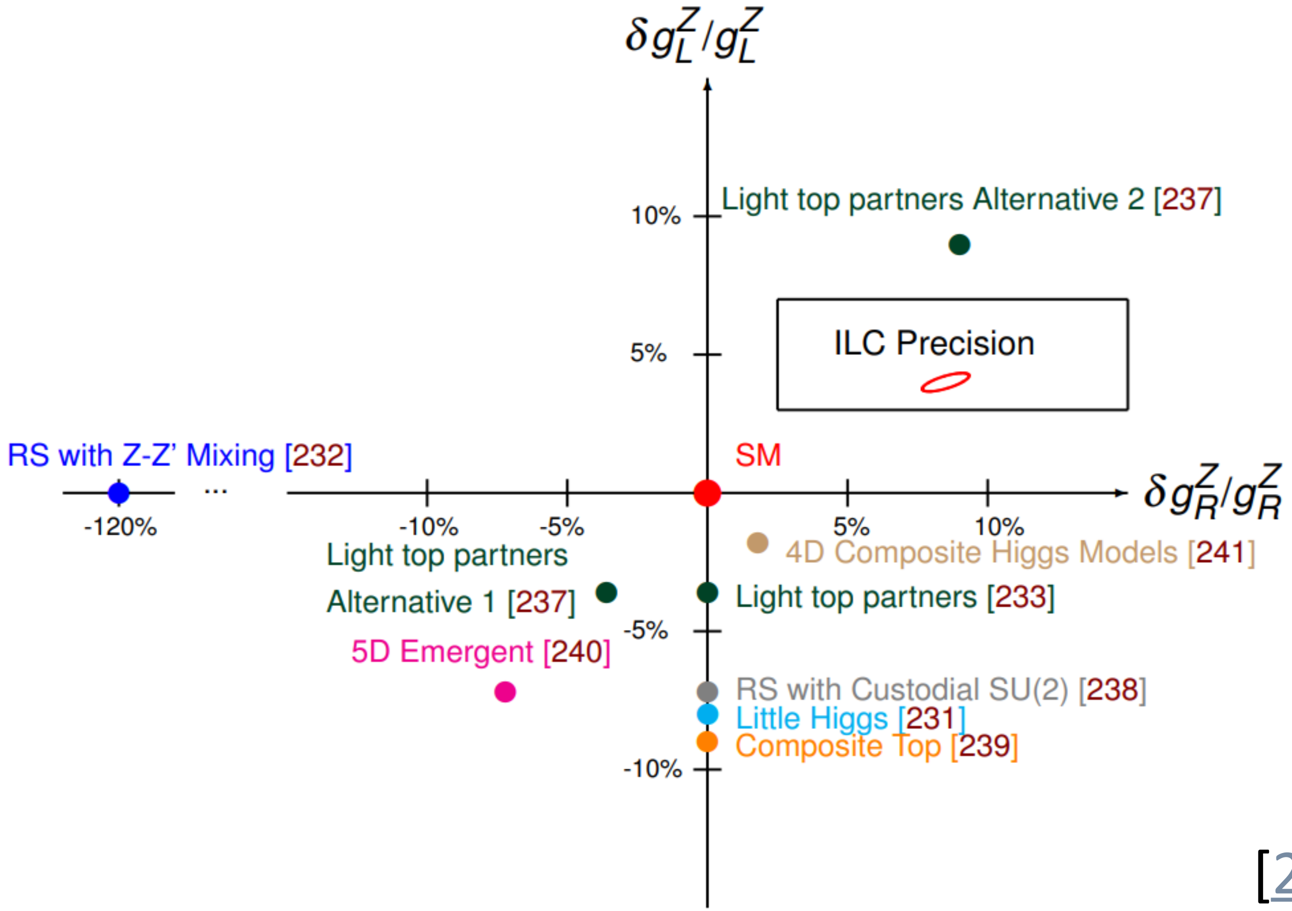


TOP YUKAWA

- The threshold scan can reach an uncertainty of 4%, but additional theoretical uncertainty adds 20%.
- *e+e-* → *ttH* at energies above 500 GeV could probe the Yukawa coupling directly.
- With 4 ab^{-1} at 550 GeV, a precision of **2.8%** is expected, **1%** with 8 ab^{-1} at 1 TeV.



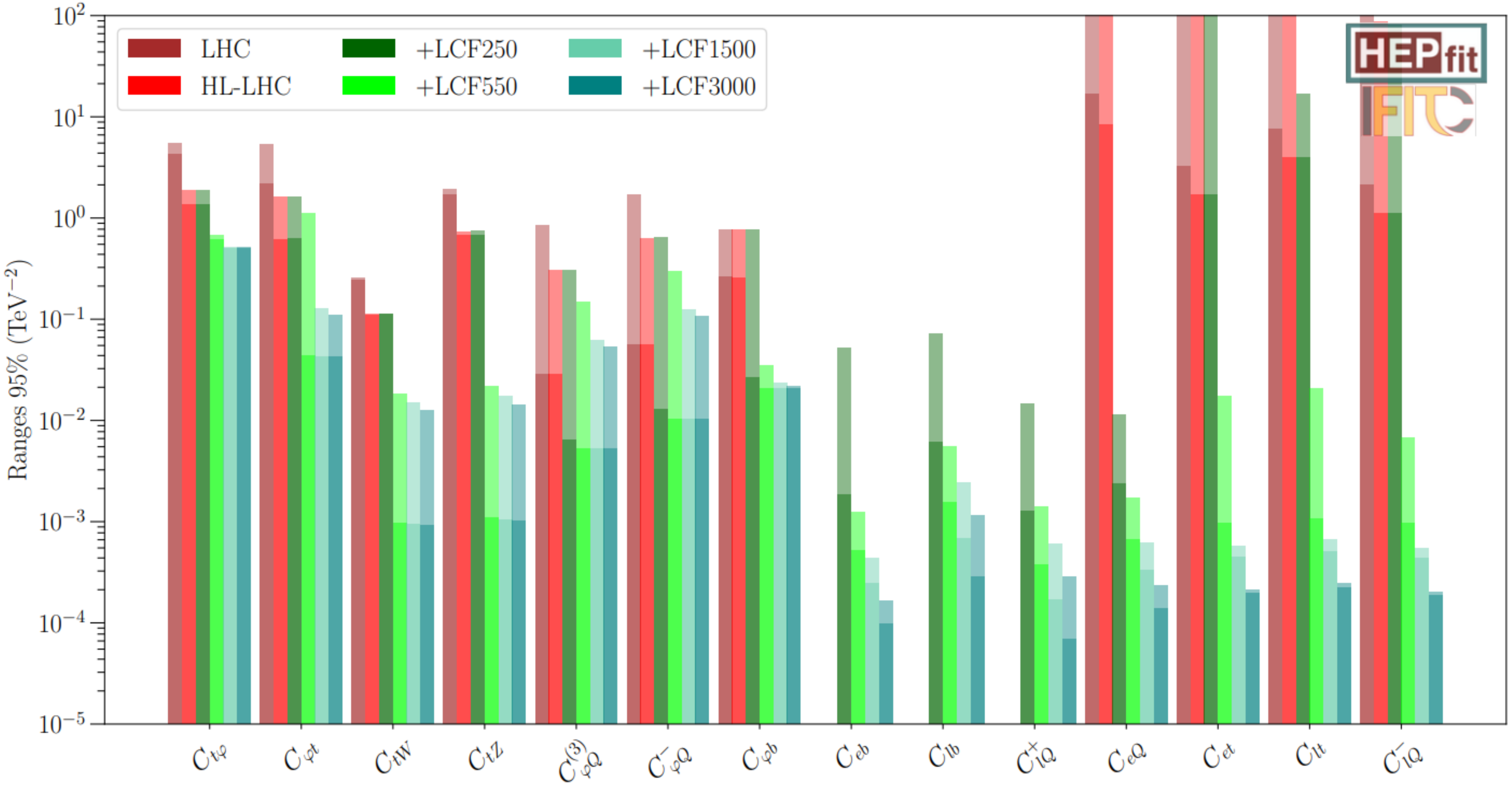
TOP ELECTROWEAK COUPLINGS



[2503.19983]

TOP SMEFT FITS

[2503.19983]



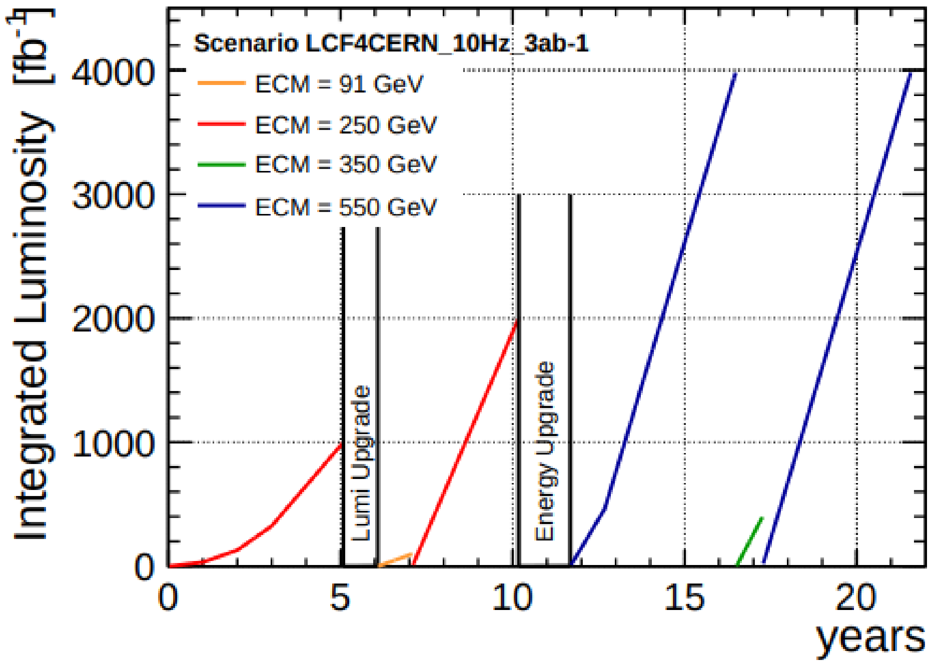
CONCLUSIONS

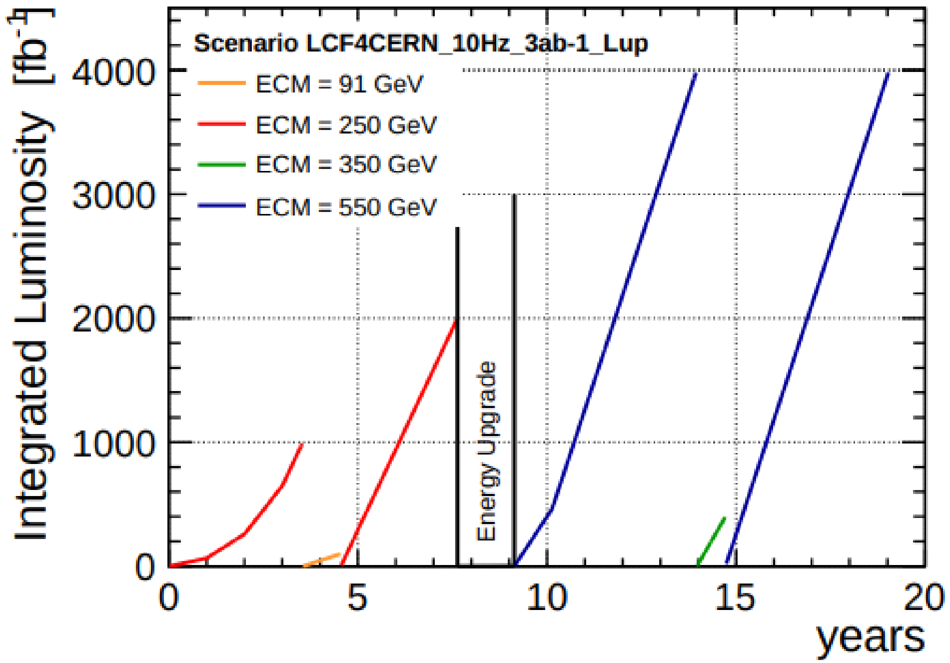
- The Linear Collider Facility has a potential to become the next **flagship collider** at CERN.
- LCF could significantly expand our knowledge in the field of electroweak, top and Higgs physics.

Linear Collider Vision

BACKUP

LCF RUNNING SCENARIOS





[2503.24049]

LCF @ CERN

Quantity	Symbol	Unit	Initial-250	Upgrades		Initial-550	Upgrade
Centre-of-mass energy	$\sqrt{s}$	GeV	250	250	550	550	550
Inst. Luminosity	$\mathscr{L}$	$(10^{34}\text{cm}^{-2}\text{s}^{-1})$	2.7	5.4	7.7	3.9	7.7
Polarisation	$\lvert P(e^-)\rvert / \lvert P(e^+)\rvert$	(%)	80 / 30	80 / 30	80 / 60	80 / 30	80 / 60
Bunches per pulse	n_{bunch}	1	1312	2625	2625	1312	2625
Average beam power	P_{ave}	MW	10.5	21	46	23	46
Site AC power	P_{site}	MW	143	182	322	250	322
Construction cost		BCHF	8.29	+0.77	+5.46	13.13	+1.40
Operation & maintenance		MCHF/y	170	196	342	291	342
Electricity		MCHF/y	66	77	142	115	142
Operating Personnel		FTE	640	640	850	850	850

[2503.24049]

TOP THRESHOLD PARAMETERS