Top-Quark Physics at the International Linear Collider

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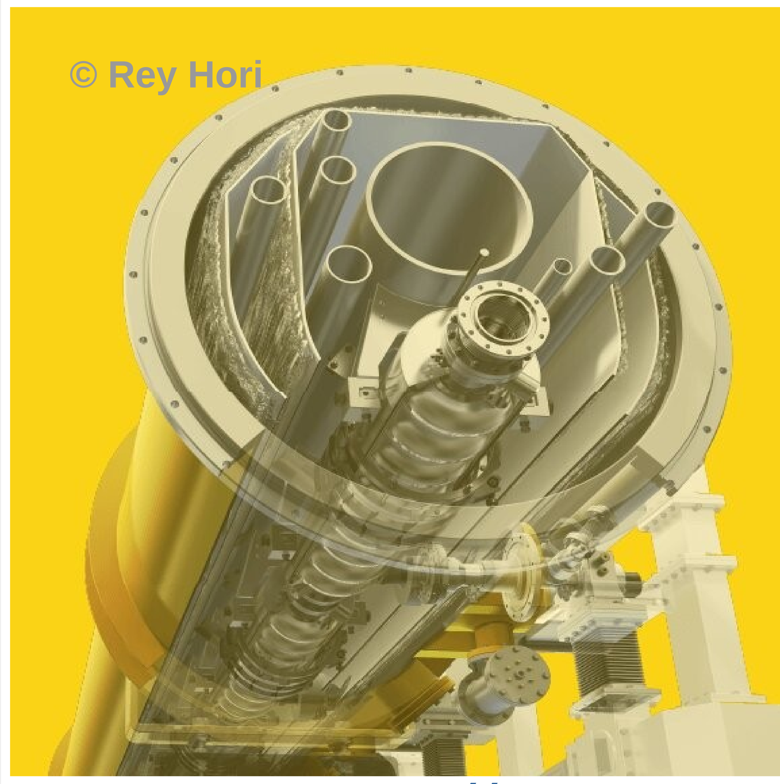
on behalf of the ILC IDT

ilc international development team · AITANA MATTER AND TECHNOLOGY · IFIC INSTITUT DE FÍSICA CORPUSCULAR · VNIVERSITAT DE VALÈNCIA · CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

The International Linear Collider

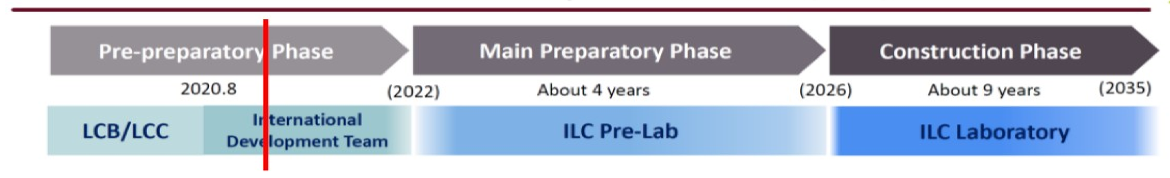


- Energy: from Z-mass to (at least) 1 TeV
- Electron and positron polarization
- TDR in 2013
- + DBD for detectors
- Initial Energy 250 GeV – Footprint ~20km

https://linearcollider.org/

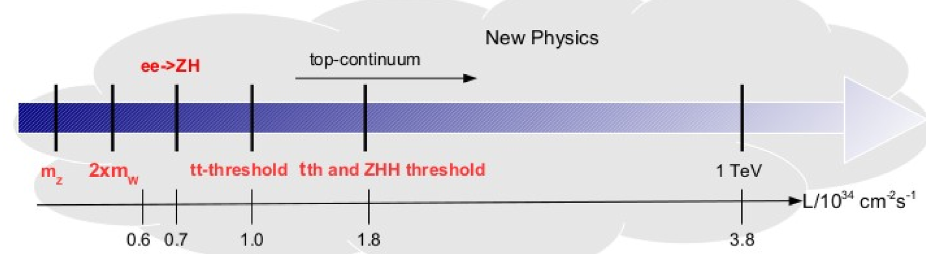
Under discussion in Japanese Government and international community

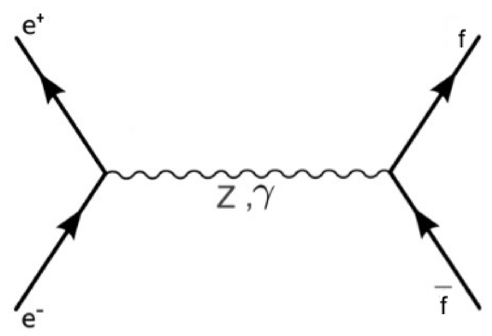
International Development Team (IDT)



- **Lepton – lepton interactions (no PDFs involved)**
- **All SM particles within reach of the ILC project**
- High precision tests of the SM over wide range to detect onset of new physics
- Machine **settings can be "tailored"** for specific processes → **straightforward at the ILC**
  - Center-of-Mass energy
  - Beams polarization (±80% e-, ±30%e+)
- **Triggerless operation:** 100% of the interactions will be recorded.

Top quark production at ILC





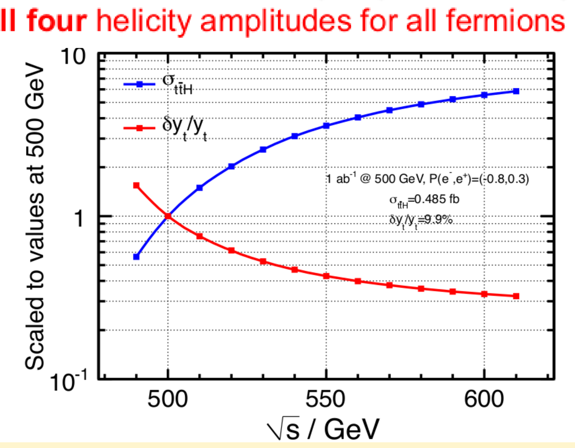
Differential cross sections for (relativistic) di-fermion production*:

$$\frac{d\sigma}{d\cos\theta}(e^-_L e^+_R \to f\bar{f}) = \Sigma_{LL}(1+\cos\theta)^2 + \Sigma_{LR}(1-\cos\theta)^2$$

$$\frac{d\sigma}{d\cos\theta}(e^-_R e^+_L \to f\bar{f}) = \Sigma_{RL}(1+\cos\theta)^2 + \Sigma_{RR}(1-\cos\theta)^2$$

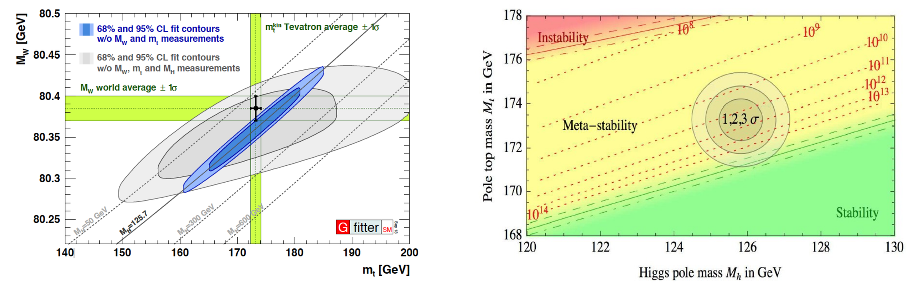
*add term ~$\sin^2\theta$ in case of non-relativistic fermions e.g. top close to threshold

Σ_{IJ} are helicity amplitudes that contain couplings g_L, g_R (or F_V, F_A)
$\Sigma_{IJ} \neq \Sigma_{I'J}'$ => (characteristic) asymmetries for each fermion
Forward-backward in angle, general left-right in cross section
All four helicity amplitudes for all fermions **only available with polarised beams**



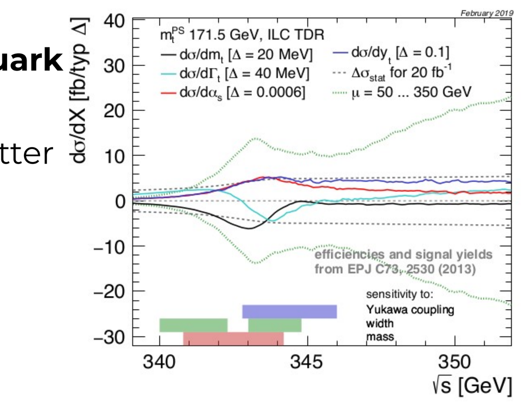
- **Linear colliders energy upgradability** is crucial to study the **ttH** toploogies

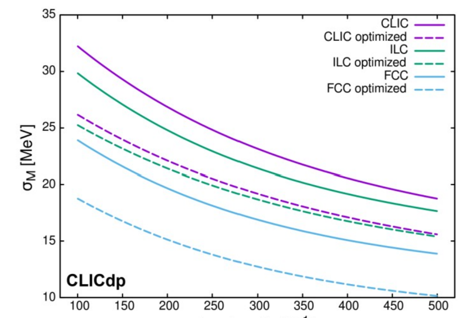
Top-quark mass



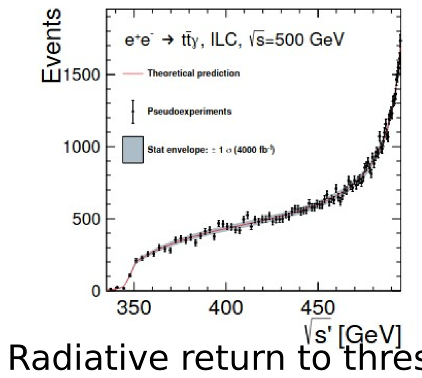
A key parameter in the SM.

- **The top threshold provides excellent sensitivity to the mass and other top quark properties**
  - (more than) one order of magnitude better than HL-LHC
  - using **well-defined mass scheme**
  - **Sensitivity to : top-quark mass, width, yukawa coupling, strong coupling constant**





Optimizing top-quark threshold scan at ILC using genetic
K. Novak, A. Zarnecky et al



Radiative return to threshold in e+e- → tt γ
Gomis, Fuster et al

Detector concepts

From key requirements from physics:
- **p_t resolution** (total ZH x-section)
  $\sigma(1/p_t) = 2 \times 10^{-5}$ GeV^{-1} $\oplus$ $1 \times 10^{-3} / (p_t \sin^{1/2}\theta)$ ≈ CMS / 40
- **vertexing** (H → bb/cc/ττ)
  $\sigma(d_0) < 5 \oplus 10 / (p[\mathrm{GeV}] \sin^{3/2}\theta)$ μm ≈ CMS / 4
- **jet energy resolution** (H → invisible) 3-4% ≈ ATLAS / 2
- **hermeticity** (H → invis, BSM) θ_{min} = 5 mrad ≈ ATLAS / 3

To key features of the detector:
- **low mass tracker:**
  - main device: Time Projection Chamber (dE/dx !)
  - add. silicon: eg VTX: 0.15% rad. length / layer)
- **high granularity calorimeters** optimised for particle flow

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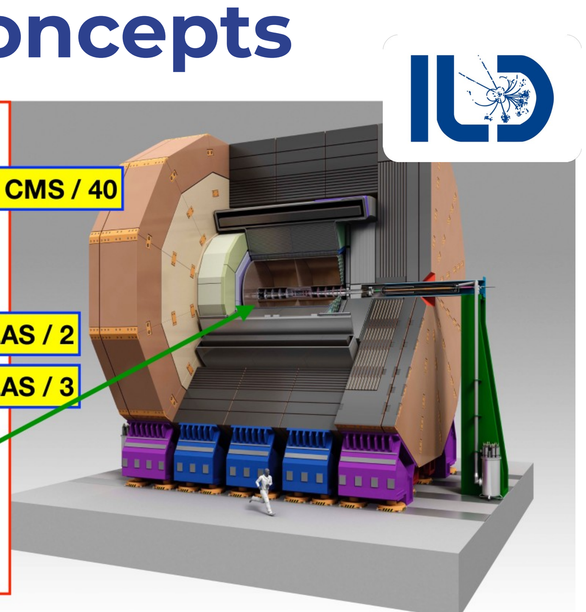
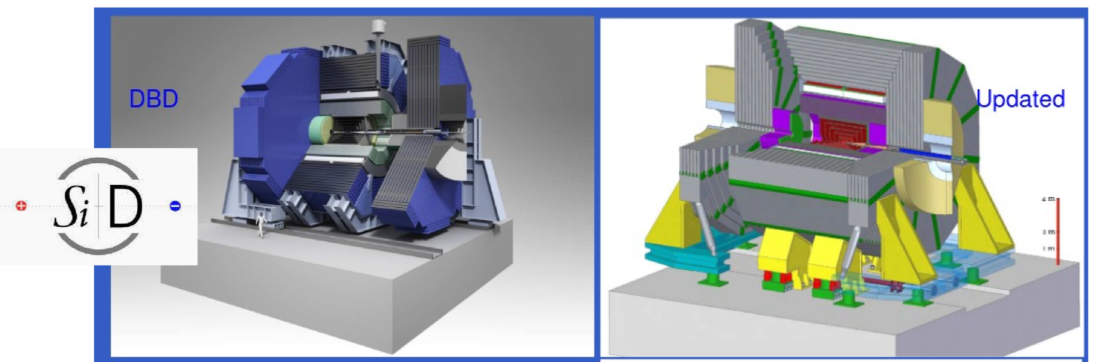


Recent review of detector concepts potential and R&D status: ILD & SiD



SiD Barrel	Technology	In rad	Out rad	z extent
Vtx detector	Silicon pixels	1.4	6.0	± 6.25
Tracker	Silicon strips	21.7	122.1	± 152.2
ECAL	Silicon pixels-W	126.5	140.9	± 176.5
HCAL	RPC/steel	141.7	249.3	± 301.8
Solenoid	5 Tesla SC	259.1	339.2	± 298.3
Flux return	Scint-steel	340.2	604.2	± 303.3

SiD Endcap	Technology	In z	Out z	Out rad
Vtx detector	Silicon pixels	7.3	83.4	16.6
Tracker	Silicon strips	77.0	164.3	125.5
ECAL	Silicon pixel-W	165.7	180.0	125.0
HCAL	RPC/steel	180.5	302.8	140.2
Flux return	Scint/steel	303.3	567.3	604.2
LumiCal	Silicon-W	155.7	170.0	20.0
BeamCal	Semicond-W	277.5	300.7	13.5

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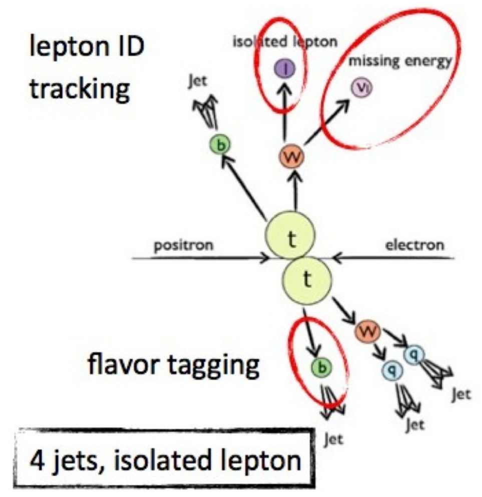
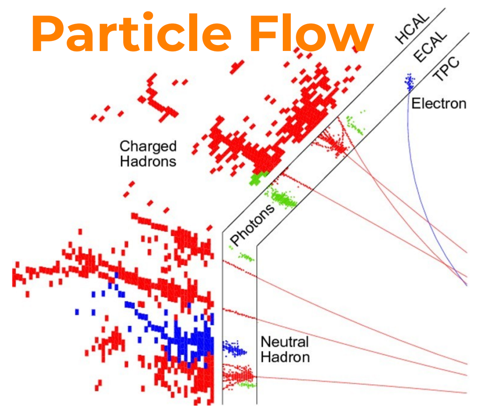
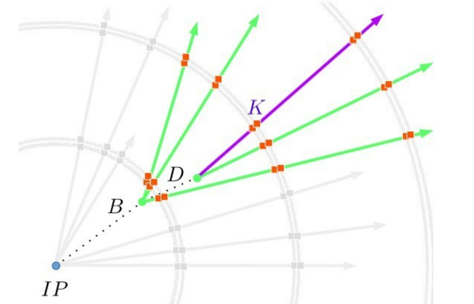
Experimental capabilities

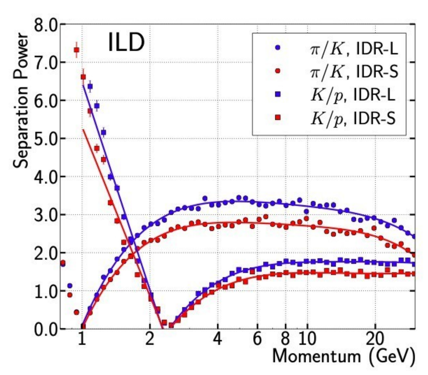


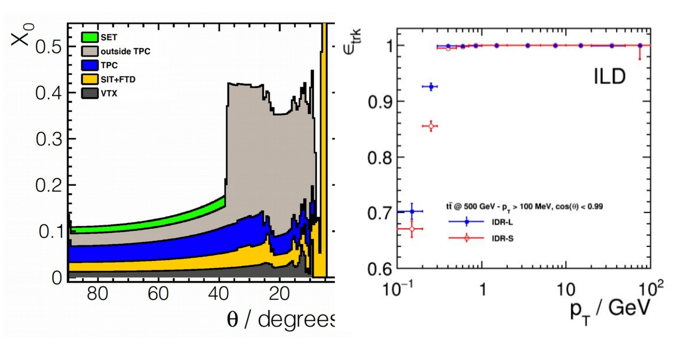
- **High efficient jet reconstruction and single particle separation** Particle FLOW .
  - ~3% energy resolution
- **Excellent tracking capabilities (>99% efficiency)**
- **Excellent Flavor tagging**
  - Bottom and charm
- **Quark charge measurements**
  - Vtx charge and Kaon Identification. High purity → control of the migrations
  - High efficiency (double tagging)

Particle Flow









- **Why this luxury ?**
  - ILC offers tiny beam spot.
  - Tracking detector technologies are in continuous evolution since LEP.
  - First vertexing layer at ~1cm distance of the beam pipe.
  - Minimum dead material (no cooling systems)

	FCCee	ILC	SLC	LEP
σ_x[nm]	13700	516	1500	200000
σ_y[nm]	36	7.7	500	2500

Source SLC, LEP, PDG

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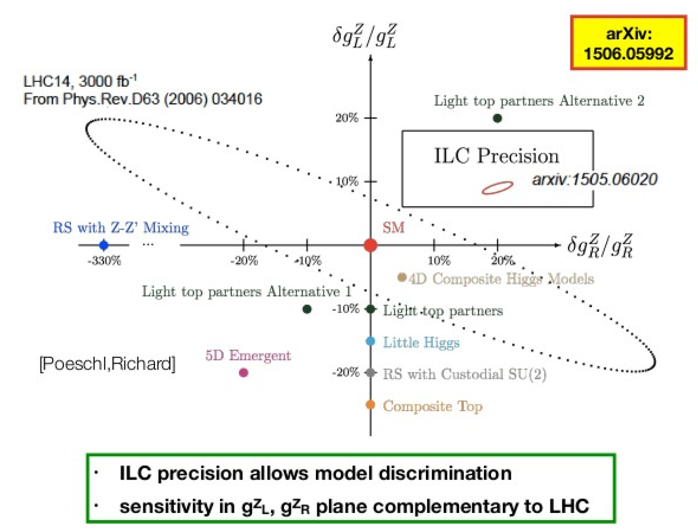
Top-EW couplings and BSM

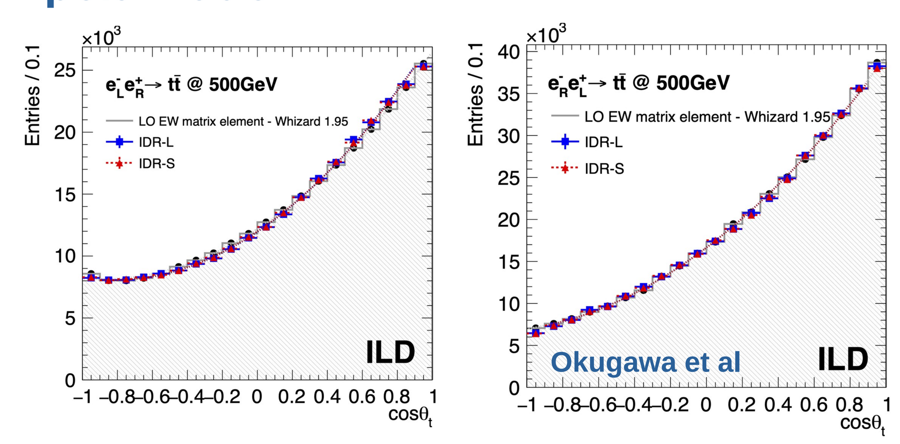
- Many **BSM scenarios** (i.e. Randall Sundrum, compositeness, Higgs unification models...) predict **heavy resonances coupling to the (t,b)** doublet and also lighter fermions (i.e. c/s quarks)
  - **BSM** resonances tend to **couple to the right components.**



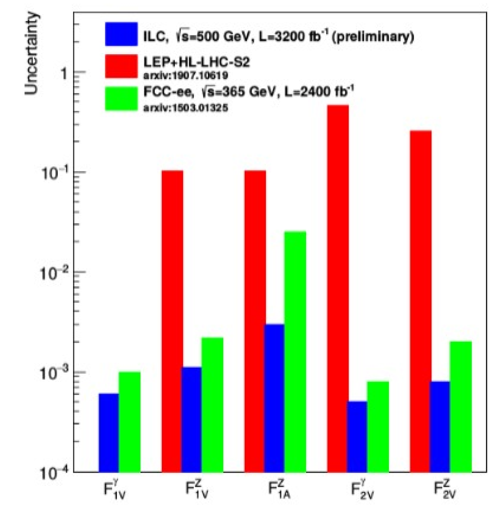
Sensitivity to huge variety of models with **compositeness and/or extra-dimensions** complementary to resonance searches

Also from other e+e- -> ff:
- probe Z' up to ~10 TeV 500fb-1 @ 500 GeV (initial run)
- up to ~17 TeV for 1ab-1 at 1 TeV
- polarised beams gain ~ 2TeV in reach

- Observables: **Forward backward asymmetries, angular cross section, etc**
- **Access to initial and final state polarization**

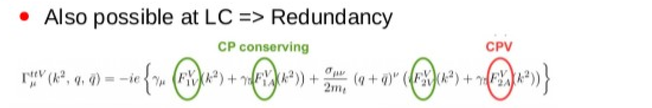


Full simulation studies



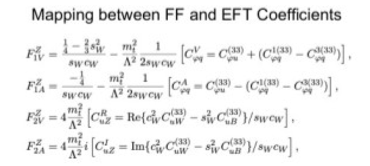
ILD-PHYS-PUB-2019-007

- e+e- collider way superior to LHC (√s = 14 TeV)
- Final state analysis at FCCee (polarisation)
  - Also possible at LC => Redundancy



- Two remarks:
  - 500 GeV is nicely away from QCD Matching regime
    Less systematic uncertainties
  - The determination of axial form factors highly benefit from higher energies

Mapping between FF and EFT Coefficients



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