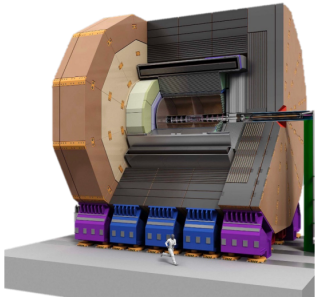
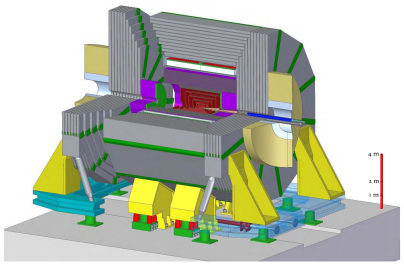
ILD: status and news

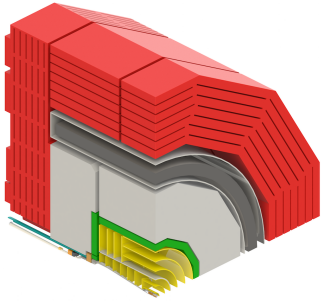
— with an overview of linear collider detector concepts



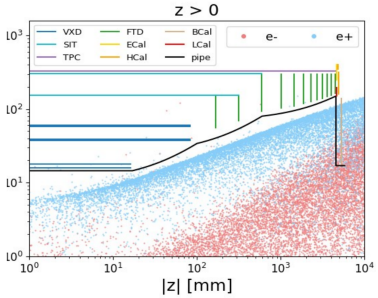
ILD



SiD



CLICdet



e-ILD for HALHF

Junping Tian (U. Tokyo)

— on behalf of the ILD concept group

LCWS 2026, Nov. 9–13 @ KEK

ICEPP
The University of Tokyo

outline

- where we are: the collider landscape after ESPP 2026

- ILD workshop @ CERN, Sep. 14–16: what came out
"a clear focus on FCC-ee — while keeping alternative collider scenarios in view"

- (I) adapting ILD to FCC-ee: MDI, backgrounds, TPC, sub-detectors, software
details —> talks by P. Kluit, W. Ootani, F. Gaede right after this one

- (II) physics highlights, plans, and a new executive team

- (III) ILD at linear colliders: LCF, HALHF

- (IV) the other LC detector concepts: SiD, CLICdp —> CLD

mostly a digest of the ILD workshop at CERN (35 talks) and of recent talks by M.-C. Fouz; apologies to the many efforts I cannot cover in 25 min

the landscape after ESPP 2026

[M. Dam, J. List @ ILD 2026]

- ESG recommendations (Dec. 2025), endorsed by CERN Council (May 2026): **FCC-ee is "the preferred option for the next flagship collider at CERN"**; a descoped FCC-ee the preferred alternative

- on linear colliders: "technologically mature … competitive to FCC-ee when operated at two energy stages and up to 550 GeV"

- CERN option studies 2026–28 (required by some member states): LCF (chair A. Lombardi; 1.5 MCHF + 5.1 FTEy; report end-2027; mandate 380 —> 250 GeV) and LEP3

- FCC-ee reference design phase 2026–28 —> Council decision 2028 —> **detector EoIs Q4 2028** —> LoIs ~2030 —> detector CDRs ~2033; FCC aims at six (or more) EoIs

for the detector concepts: the next two years decide who is at the table when the FCC-ee EoIs are written

ILD at age 20

a look back by T. Behnke, outgoing spokesperson



[T. Behnke @ ILD 2026]

- roots: JLC (Asia) and TESLA (DESY) ~1995; LDC + GLD merged at LCWS 2007 —> 1st ILD meeting Jan. 2008
- LoI 2010 —> TDR 2013 —> IDR 2020 —> input to FCC FSR 2025 & ESPPU 2026
- paradigm: particle flow; low-material, hybrid Si + TPC tracking; imaging calorimeters; **common software and full simulation; technology openness**
- sub-detector technologies validated in beam tests with CALICE / LCTPC / FCAL —> now DRDs

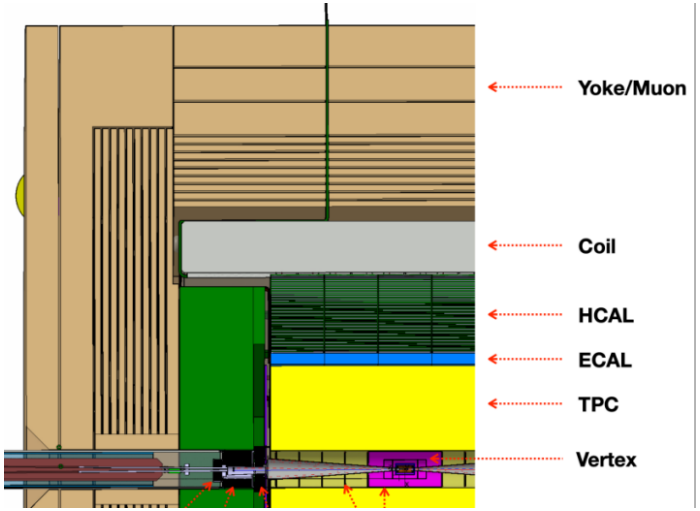
"ILD: an infrastructure for studies of experimentation at future colliders" — T. Behnke

ILD today: a mature concept, a growing community



A. Irles @ ILD workshop, CERN, Sep 2026

58 institutes · 18 countries · 7 guest members



quadrant view

- "a robust and mature detector concept for e^+e^- colliders **up to 1 TeV**, already providing an excellent basis for meeting the physics requirements of FCC-ee" — M.-C. Fouz
- one of six FCC-ee detector concepts: CLD, IDEA, ALLEGRO, **ILD**, ALFA, AGORA ("concepts, not experiment collaborations")
- FCC view: "the ILD reconstruction (e.g. PFA) is the most mature among the concepts: it can be used right away" — M. Selvaggi
- "we are open to new collaborators and also to new ideas"
- lightweight guest member: contact Adrián Irles (**adrian.irles@ific.uv.es**)
- we remember **Tohru Takeshita** (Shinshu University), long-standing member of ILD, whose work on scintillator calorimetry shaped our detector R&D for many years — he left us less than two months ago; his dedication and warmth will be greatly missed

ILD workshop @ CERN, Sep. 14–16, 2026

"A detector for the next CERN flagship project: ILD"

https://agenda.linearcollider.org/event/11033/

- 3 days · 35 talks · 3 main areas: detector, physics, software
- plenaries: history (Behnke), status (Fouz), FCC-ee detector concepts (Dam), FCC physics plans (Selvaggi)
- sub-detector & background sessions (TPC, vertex/Si, calo, muon, TOF, TDAQ, MDI, SR, integration)
- 12 analysis talks; dedicated session on LCF and HALHF
- institute assembly: new executive team

M.-C. Fouz, workshop summary

headline: "a clear focus on FCC-ee — while keeping alternative collider scenarios in view"

strategy and short-term roadmap

- FCC-ee reference design phase 2026–28; Council decision 2028; FCC aims at six (or more) detector EoIs; detector CDR ~2033

- ILD to “become an integral part of the FCC-ee studies”: join FCC-PED detector & physics WGs, take active roles in their coordination

- **detector:** revisit the design for FCC-ee, integrate DRD advances, validate sub-detector operability under Z pole conditions

- **physics:** combine detector R&D with benchmark physics — especially the Z pole, “not yet fully studied within ILD”

- **software:** full Key4hep integration + AI-based reconstruction; revisit data-access policy

goal: be in the best possible position to prepare an EoI for FCC-ee within two years — while not losing sight of LCF / HALHF

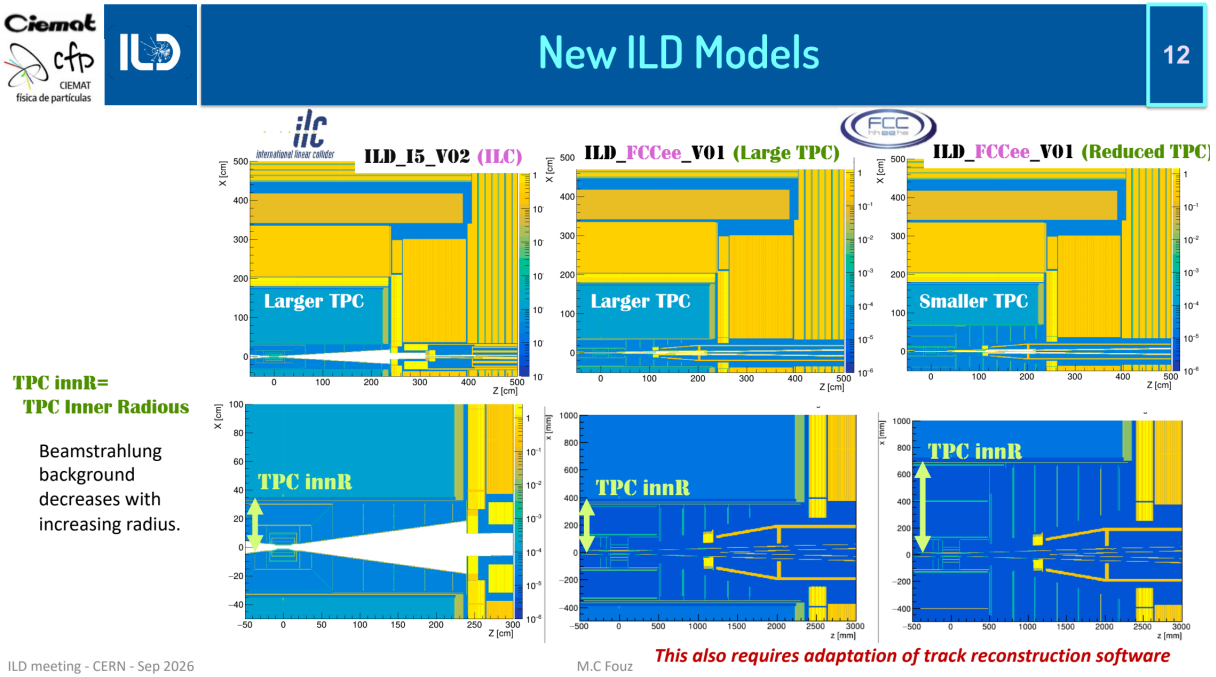
(I) ILC —> FCC-ee: what changes for the detector

	ILC (ILD baseline)	FCC-ee
crossing angle	14 mrad	30 mrad
L* (final quadrupole)	4.1 m, outside detector	2.0–2.2 m, inside detector
solenoid	3.5–4 T	≤ 2 T (3 T w/ non-local compensation under study)
LumiCal / beam pipe radius	~2.5 m / 16 mm	~1 m / 10 mm
tracker acceptance	$\cos\theta \approx 0.996$	$\cos\theta \approx 0.984$
bunch structure	1312 bunches, 554 ns, 5 Hz trains (0.5 % duty)	continuous, 25 ns at Z (100 % duty)
event rate / readout	buffered in train	~100 kHz physics at Z, 100–200 kHz recorded
power pulsing	yes	no —> 100–200× power, active cooling
luminosity / IP at Z (×10^{34})	0.23 (GigaZ)	140–180 (Tera-Z)
polarisation	80 % / 30 %	none ($\sqrt{s}$ to 10^{-6} by resonant depolarisation)

[M.-C. Fouz, V. Boudry, M. Selvaggi, M. Dam @ ILD 2026; D. Jeans, arXiv:2604.04512]

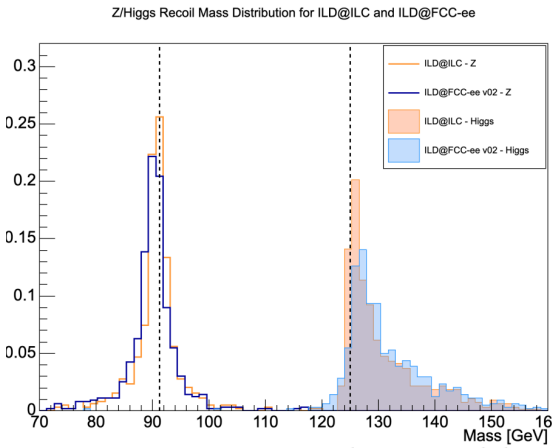
IR & forward region to be redesigned; lower B field; continuous readout and cooling —> a very different detector environment, same ILD DNA

new ILD detector models for FCC-ee



M.-C. Fouz @ ILD workshop, CERN, Sep 2026

- ILD_FCCee_v01 / v02 in DD4hep / Key4hep: FCC-ee MDI + CLD-like Si vertex & inner tracker + ILD TPC and calorimeters
- TPC inner radius is the knob: 365 mm (v01) vs 701 mm (v02); pair background falls with radius
- v01 used for physics studies for now; 3.5 —> 2 T loss “not compensated for the moment”



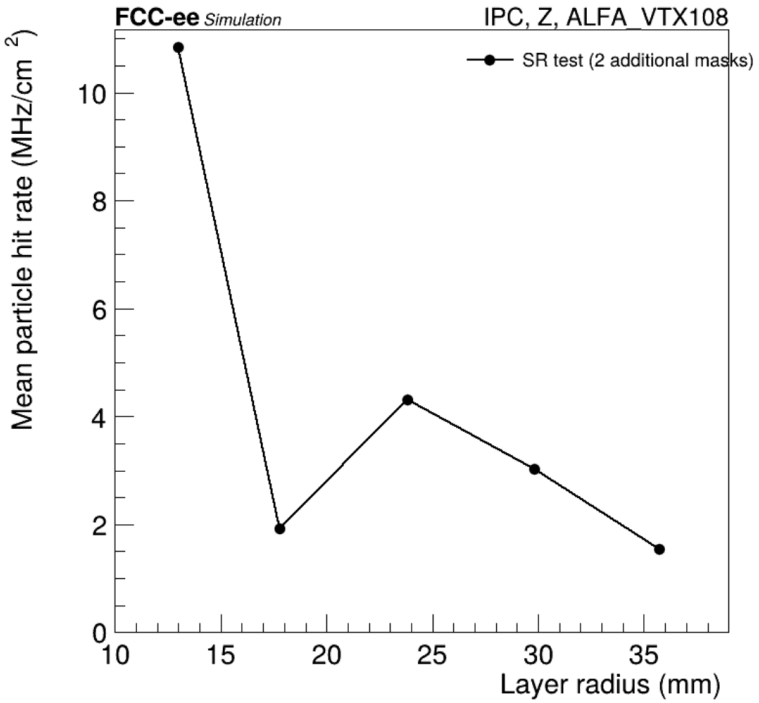
- news: first Gaudi-based full reconstruction of ILD@FCC-ee (Z —> μμ recoil mass) — “successful!”
- requires adaptation of track reconstruction (TPC + Si merging), digitisers, Pandora re-calibration

Z-pole backgrounds: from “impossible” to “challenging”

@ 91 GeV	Silicon Tracker pixel rate @ 3 pix/hit	Drift Chamber occupancy	TPC typical distortion
IPC	10 kHz / cm²	~7%*	few mm
SR Daniel’s back-of-envelope	~GHz / cm²	>1000%	few m

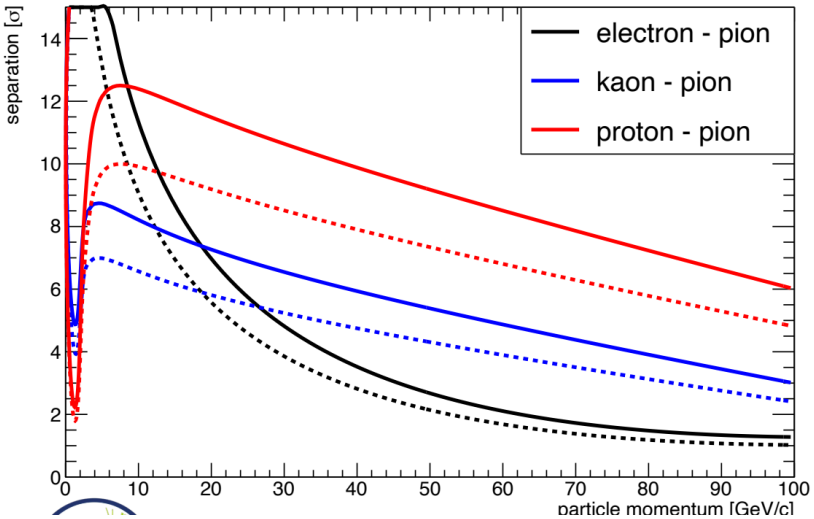
V. Schwan (D. Jeans) @ ILD 2026

- incoherent pairs (LCC v106 optics): Si 10 kHz/cm², TPC distortions of a few mm —> comfortable —> challenging
- synchrotron radiation halo: up to ~20 GHz/cm² in the vertex detector, metre-size TPC distortions —> extremely challenging —> impossible
- SR task force: Geant4 angular-sampling bug fixed (core SR “expected to be fully suppressed”); alternative final doublet ×10; mask at 1.3 m from IP ×100
- —> “SR is now at the level of the IPC” for the vertex detector: O(1–10) MHz/cm²
- still to be shown for the main trackers (the TPC!) and with X-ray reflections — “good understanding of backgrounds is essential”



G. Nigrelli, SR task force

the TPC question: can it run at Tera-Z?



separation at cos θ = 0, ILD TPC dimensions; two dE/dx resolution scenarios from the 1 T beam test: **solid** = template fit, 2.5 % (2.9 % measured); **dashed** = truncated mean, 3.0 % (3.6 % measured)

P. Kluit, NIM A 1081 (2026) 170849

- ions drift ~0.5 s ≈ 10^7 bunch crossings at the Z; no gating; SR the largest ion source; ion backflow 1.3 % —> 3×10^{-4} with a double grid; Ne gas?
- pixel TPC (GridPix / Timepix3): 13 µm (rφ), 20 µm (z) at 1 T in beam test; dE/dx —> 2.4 % in ILD; **K/π > 5.5σ for 2.5–45 GeV**
- "well suited to the WW, ZH and $t\bar{t}$ programme; for Tera-Z the MDI must be optimised and backgrounds reduced by several orders of magnitude" — P. Kluit
- tools: ACTS for the TPC (as AGORA/CEPC, sPHENIX), realistic TPC digitiser with drift & IBF, ML event-by-event distortion corrections, Si timing layers to pin distortions

"establishing operability of a TPC at FCC-ee is the key goal in the next years" — T. Madlener; details —> talk by P. Kluit

sub-detectors: adapting to continuous running

one line each — details in the talks by P. Kluit and W. Ootani

vertex & Si tracking

- FCC-SEED: curved, stitched MAPS, R_0 ≈ 10–12 mm, 0.5–0.6 % X_0 at 90°
- pull request made to FCC-SEED as option for ILD; ILD's 3 double ladders + discs to be revisited

calorimeters

- technologies mature "but with the old electronics": new ASICs (KLauS7, CALOROC) < 100 ps
- continuous running: 100–200× power —> active cooling (ECAL slab 210 W, AHCAL 80 mW/ASIC)

timing: "it's time for timing!"

- optical TOF layers, 50 ps/MIP target (OPAL 250 ps, CDF 125 ps); hermetic wrapper layer?
- 4D tracking toy model: 30 ps after time-walk; timing layers still not in the baseline

muon system

- 14 barrel / 12 endcap layers — ×2–3 more than other concepts; lose 2–3 layers at 2–3 T
- "time to bring it back into focus"; reference design input due end-2027

trigger & DAQ

- 100 kHz physics / ~200 kHz with background at the Z; trigger bias must be < 10^{-6}
- streaming 0.2 MB × 200 kHz ≈ 10 Tb/s is feasible — "to TDAQ or to DAQ"

luminometer & integration

- 10^{-4} (abs) – 10^{-5} (rel) seems achievable; 1 µm mechanics; FCAL "revived"
- ILD is the largest FCC-ee concept (R 7.8 m, 3300 t piece); is 3.5 T still needed? "no personpower!"

[J. Andrea, A. Ilg, V. Boudry, G. Wilson, P. Martínez, R. Farinelli, Z. Demiragli, T. Wengler, Y. Benhammou, K. Buesser @ ILD 2026]

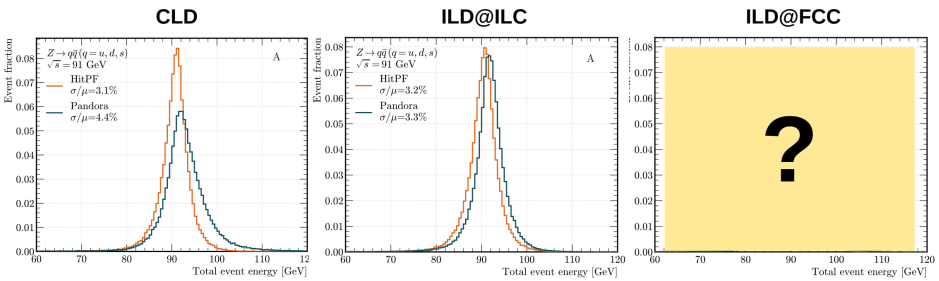
software and AI: ILD is entirely in Key4hep

- full simulation & reconstruction in Key4hep, EDM4hep output; reconstruction via Marlin wrapper, new developments in Gaudi; new samples produced within Key4hep
- **ParT flavour tagging**: c-jet background at 80 % b-efficiency 6.3 % —> 0.48 % vs LCFIPlus; ~+50 % on the ZHH benchmark; no saturation up to 20 M training jets
- **ML particle flow**: JER similar or better than Pandora for CLD, ILD@ILC, ILD@FCC; GNN PFA clustering 0.954 vs 0.921; timing helps even at 1 ns
- align with FCC-ee processes — central production, sample sharing (by-laws?), common digitisers; FCC MC production this autumn
- people are “stretched very thin” — we will have to prioritise

	b-tag 80% eff.		c-tag 50% eff.	
background	c jets	uds jets	b jets	uds jets
+LCFIPlus (BDT)	6.3%	0.79%	7.4%	1.2%
*ParT (initial)	1.3%	0.25%	1.0%	0.43%
**ParT (improved)	0.48%	0.14%	0.86%	0.34%

T. Suehara @ ILD 2026

MLPF JER is similar ot better than Pandora



credit: Dolores Garcia et al.
a paper is in the process.

MLPF yields a similar or better JER than PandoraPFA.
Cross-detector comparison is important.

B. Dudar @ ILD 2026

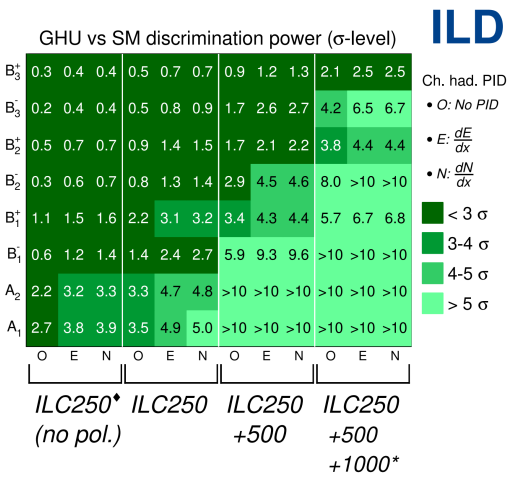
makes ILD “more accessible and attractive to external users”; details —> talk by F. Gaede

(II) physics: what ILD delivered in 2024–26

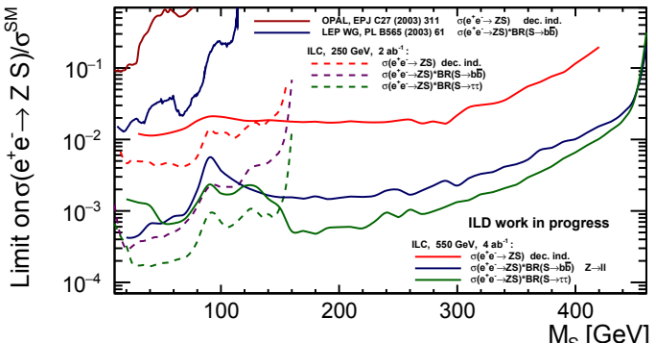
- 14 ECFA focus topics; 21 contributions to the final ECFA report; **8 published papers and 64 talks in 2.5 years** [F. Żarnecki, I. Božović]
- **Higgs self-coupling (ZHH):** Δλ/λ = 18 % (ILC500, 4 ab^{-1}) —> 15 % (550 GeV) —> 11 % (LCF550, 8 ab^{-1}); lepton channel S/√(S+B) 0.82 (2014) —> 1.47; first ZHH/WBF separation below 1 TeV [J. Torndal, arXiv:2509.14148]
- **top Yukawa at 550 GeV:** 2 % (semileptonic), ~2× better than 2011; CP: pseudoscalar coupling ≤ 0.41 (68 % CL) [Y. Zhang]
- **Higgs hadronic BRs at ILC250 with ParT:** bb 0.5 %, gg 2.0 %, cc 4.8 % [R. Sawada]
- **gauge–Higgs unification via b/c forward–backward asymmetries** at 250/500 GeV (full ILD sim, quark charge from vertex charge + kaon ID): stat. σ(A_FB) ≈ 1.4×10^{-3} (b), 2×10^{-3} (c) at ILC250; ILC250+500 separates 3 of 8 GHU benchmarks at > 5σ, 6 of 8 with +1 TeV; PID (dE/dx —> dN/dx) adds up to ~1σ [Irles, Márquez, Pöschl, Richard, Saibel, Yamamoto, Yamatsu, EPJC 84 (2024) 537]
- **CP mixing in Higgs production via ZZ fusion at 1 TeV** (8 ab^{-1}): Ψ_CP to 3.8 mrad, f_CP to 1.4×10^{-5} — first e$^+$e$^-$ sensitivity to CPV in the HVV production vertex [Vukašinović et al., PRD 110 (2024) 032011]
- **dark photons e$^+$e$^-$ —> γ A′ —> γ μμ in full simulation:** the EPPSU mass-resolution assumption does not hold — event-by-event simulation essential; recast to LCF250/550/1000 [M. Berggren, S. Hosseini-Senvan]
- also: LLPs in the TPC (JHEP 02 (2025) 112), exotic scalars to 10^{-4}–10^{-3} σ_SM, first-generation quark couplings at the Z (JHEP 11 (2025)), stau reach [arXiv:2604.06103], hidden-sector angular correlations

500 GeV, 4 ab^{-1}, (80%,30%): $\Delta\lambda_{SM}/\lambda_{SM} \rightarrow 18\%$
550 GeV, 4 ab^{-1}, (80%,30%): $\Delta\lambda_{SM}/\lambda_{SM} \rightarrow 15\%$
550 GeV, 8 ab^{-1}, (80%,60%): $\Delta\lambda_{SM}/\lambda_{SM} \rightarrow 11\%$

J. Torndal, ILD note arXiv:2509.14148



Irles et al., EPJC 84 (2024) 537



F. Żarnecki @ ILD workshop, CERN, Sep 2026

physics: plans and first FCC-ee results

- new physics coordination (T. Suehara, G. Wilson): Higgs/EW (I. Božović, J. Tian), top/QCD/HF (R. Pöschl, A. Irles), BSM (M. Berggren) — to be aligned with FCC physics groups
- **“analysis of FCC benchmark channels should include ILD”**; needs a robust ILD-FCC model / reco / calibration with FCC generator configuration
- Z-pole: no full-sim ILD study yet, neither at ILC nor at FCC-ee — “do both and compare”; “systematic control more important than super precision” [G. Wilson]
- news: first full-sim ILD vs CLD comparison, Z —> ττ at FCC-ee: τ-polarisation observables agree within ±3 %; ILD ~10 % higher τ-reconstruction efficiency (3π, e) [O. Arquero et al.]
- LC physics continues: ZHH / vvHH at 550 GeV, ttH CP, exotic scalars, H —> bs, mb from H —> bb

Conclusions and next steps

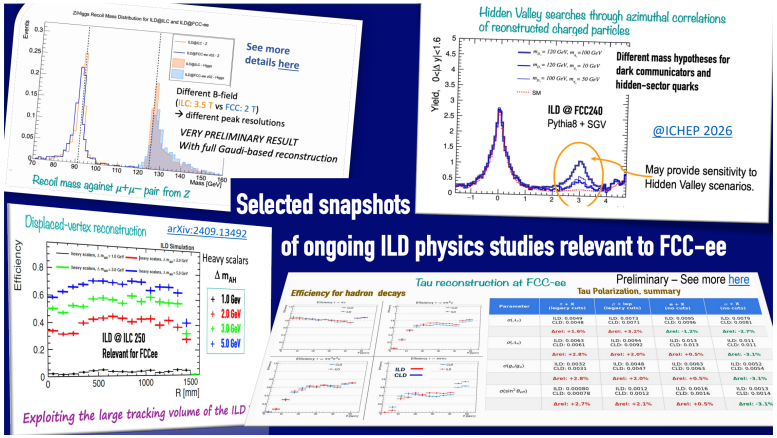
In this work ILD and CLD are compared in the context of Full Simulation FCCee $Z \to \tau^+\tau^-$.

- **This preliminary comparison show very similar performances at particle level:**
  - **Similar efficiencies and purities** for the analyzed particles (note that this sample has almost no neutrons).
  - **Compatible resolution**, non comparable now because of the status of ILD reconstruction.
- **At tau reconstruction level, ILD improves the efficiency for almost every decay.**
  - **Three pions and electron decays** are the most affected, with a **~10% increase**.
- **Polarization analysis results in similar fits for both detectors.**
  - Depending on the decay one detector is better. Need to study pion decay.

Next steps:

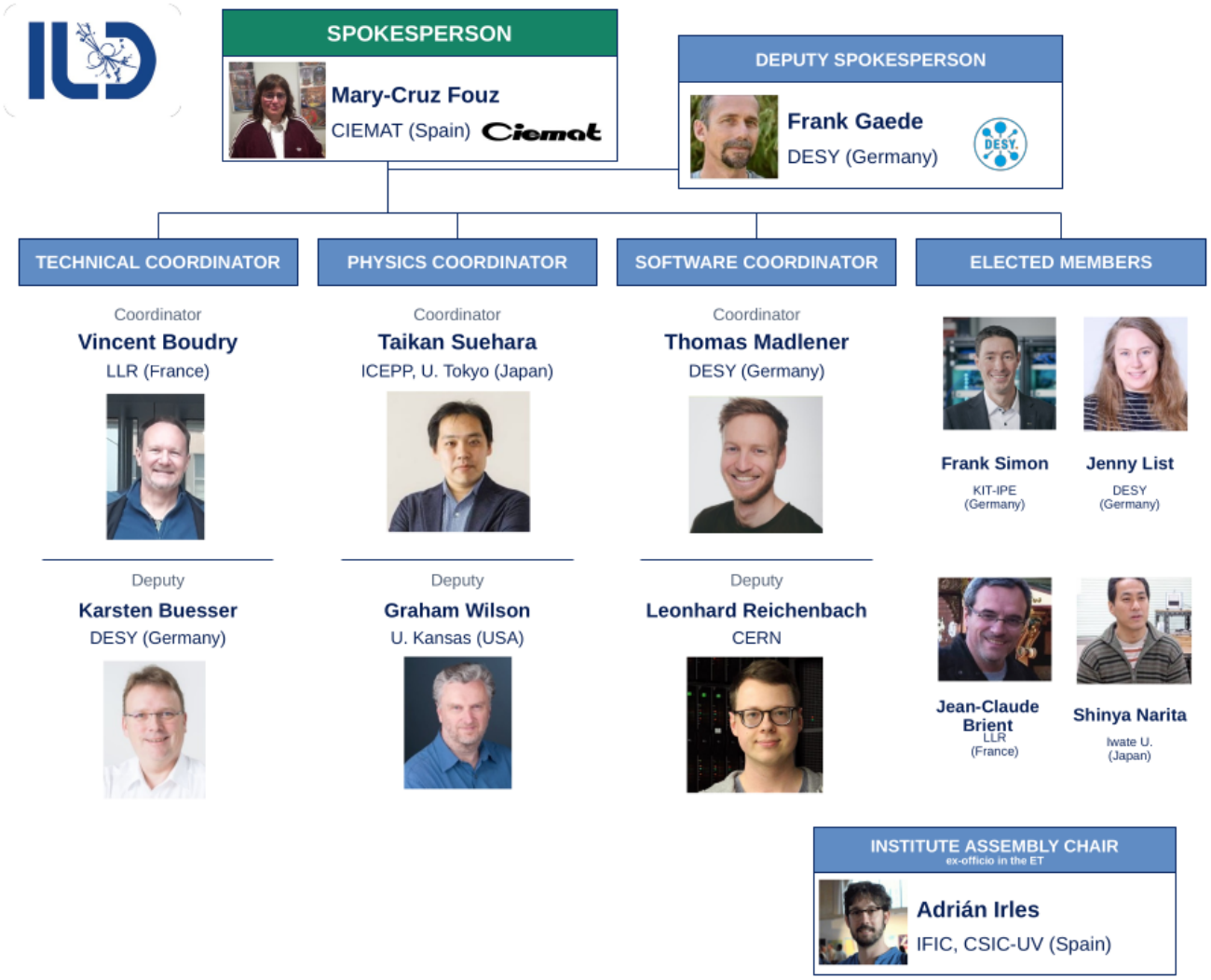
- Optimize tau reconstruction for ILD (now the applied cuts are customized for CLD).
- **Extend polarization analysis to $a_1 \to \pi\pi\pi$** (now possible with the statistics).
- Repeat the analysis with optimized version of tracking fitting.
- Compare with others generators (KKMCee or Whizard, WIP)

O. Arquero et al. @ ILD 2026



M.-C. Fouz @ CEPC WS, Shanghai, Oct 2026

organisation: a new executive team (Sep. 2026 – 28)



• many thanks to Ties Behnke for leading ILD for over two decades, and to K. Kawagoe, D. Jeans, F. Żarnecki and M. Vos — “same detector, same questions, different ideas, same passion”

(III) ILD at linear colliders: LCVision and LCF

J. List @ ILD 2026

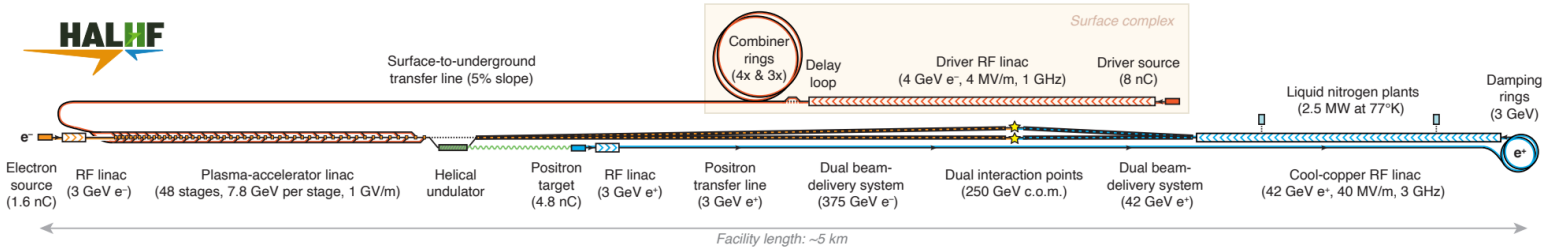
- 2nd LC@CERN workshop, Jan. 7–9 2026: 221 registrants; LCVision report published, EPJ ST 235 (2026) 1641 [arXiv:2503.19983]
- CERN LCF option study 2026–28: dual BDS, CFS, cost, risk; report end-2027; mandate changed 380 —> 250 GeV
- IDT: ITN funded to spring 2028; ICFA asked IDT-EB for a successor organisation with wider scope — proposal early Nov. 2026

detector implications for the next two years:

- two IRs, no push-pull; L*, crossing angle, (anti-)DID, backgrounds all to be redone
- “modernise the classic LC detector concepts, or come up with new ones”; physics at 550 GeV and above; γγ option

“in full understanding that ILD’s main focus has to be on FCC-ee now … LCs remain a technologically mature and financially stageable option” — J. List

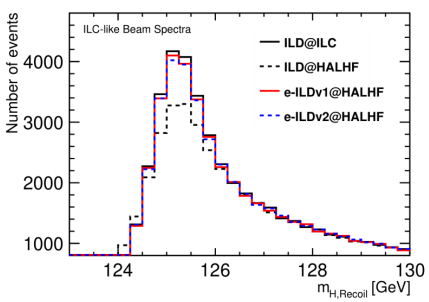
ILD for HALHF: an asymmetric e-ILD?

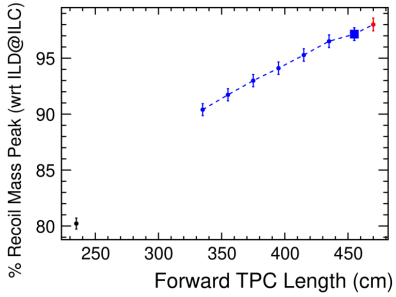


Layout of HALHF

S. Ranjan, J. List, M. Berggren, M. Wing, L. Bishop @ ILD 2026

- HALHF: e^- 375 GeV (PWFA, 48 stages, 1 GV/m) + e^+ 41.7 GeV (RF) —> 250 GeV, boost $\gamma = 1.67$; $L = 1.2\times10^{34}$; ~5 km; dual IPs [arXiv:2503.19880]
- pre-CDR being finalised — input to CERN–DESY directorates, Oct. 2026; "~15-year R&D programme"
- boost: pairs go forward and hit VXD / LumiCal of a symmetric ILD —> **e-ILD**: v1 = 2× forward / ½ backward barrel; v2 = beam pipe above the pair envelope, LumiCal relocated
- recoil mass: e-ILD v2 keeps 97 % (v1: 98 %) of the ILD@ILC peak — "the effect of the boost is overrated"

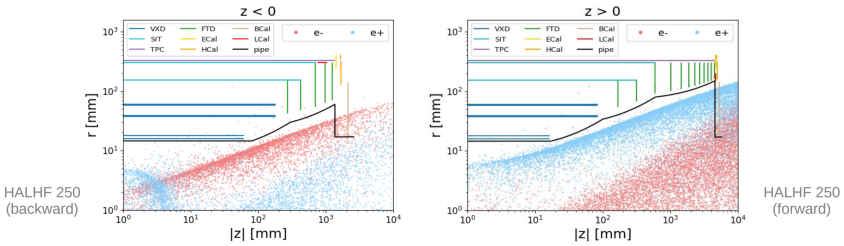




Impact on Detector Design

e-ILD_v2

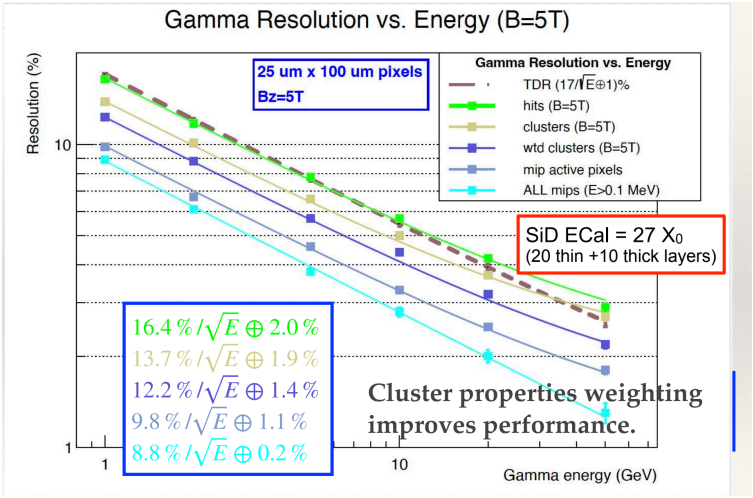
- Newest iteration of e-ILD
- Beampipe above the pair background envelope
- Location of LumiCAL changed to capture the boosted Bhabha-scattered pairs



e-ILD v2 vs pair envelope — S. Ranjan

(IV) SiD: MAPS-based R&D on limited resources

- compact all-silicon tracker + vertex, SiW ECAL, highly segmented HCAL, **5 T solenoid**, instrumented yoke; single-bunch-crossing timing, push-pull [ILC TDR]
- honest status: **very little support in the US to develop SiD** — R&D concentrated in a few focused areas
- **ESPPU-2026 input** [arXiv:2110.09965 v2]: path forward = MAPS in tracker and ECAL, digital cluster-counting ECAL; details of possible developments laid out there
- **digital MAPS ECAL** (J. Brau et al., Oregon/SLAC; CALOR 2026): NAPA-p1/p2 prototypes in 65 nm (CERN WP1.2 runs); simulated 12.2 %/√E ⊕ 1.4 % with weighted clusters vs TDR goal 17 %/√E ⊕ 1 %; 100×100 µm² pixels nearly as good as 25×100
- **MAPS tracking** (C. Vernieri, SLAC): large-area stitched sensors, 7 µm, ~ns timing, < 1 mW/cm² at 1 % duty cycle; ~75 m² tracker + ~1200 m² calorimeter
- **HCAL:** following the DRD Calo AHCAL developments, with ideas for timing layers and front-end intelligence
- SiD is also the full-sim reference for **C³** beam-induced backgrounds [arXiv:2503.20829]



J. Brau et al. @ CALOR 2026

digital MAPS ECAL: counting weighted clusters of pixel hits reaches 12.2 %/√E ⊕ 1.4 %, beating the SiD TDR goal (17 %/√E ⊕ 1 %) at all energies

MAPS everywhere + 5 T + power pulsing: SiD stays a design optimised for the LC bunch structure; the MAPS R&D itself is generic — a MAPS-ECAL with active cooling is now being studied for CLD

with thanks to the SiD group for their input

CLICdp: from CLICdet to CLD at FCC-ee

- **CLIC Readiness Report (2025)** [arXiv:2503.24168]: 380 GeV stage, 11 km, 100 Hz, L = 4.5×10^{34} (×3 vs 2018), ~7.2 BCHF; double BDS with two detectors; ESG: CLIC technology "could offer a more cost-effective implementation"
- **CLICdet:** beam-induced backgrounds reconsidered for the updated CLIC beam parameters / instantaneous luminosity — **found to be under control**; Higgs-coupling reach re-evaluated for the updated luminosities
- **CLD = CLICdet adapted to FCC-ee:** MAPS vertex, full-Si tracker (radius 1.5 —> 2.1 m because of the 2 T limit, ~10 % X_0), SiW ECAL, scint-steel HCAL, 2 T coil outside the HCAL; option o3 with smaller tracker + ARC RICH; k4geo/FCCee/CLD
- "the only detector with a reliably working full reco chain" —> the most used model for FCC-ee full simulation; also hosts sub-detectors lacking their own model [B. Dudar]; CLICdet geometry itself unchanged since the 2018 post-CDR model [arXiv:1812.07337]
- **vertex / tracker R&D in 65 nm TPSCo: OCTOPUS** (lepton-collider vertex detector: demonstrator testing, simulation, ASIC design — most participants now funded via FCC-ee projects, but the target collider is kept open in a staged approach) and **MANTA** (outer tracker, first design studies, explicitly flexible for different use cases) [D. Contardo @ CEPC WS, Oct 2026]; related: ALMIRA for ALICE 3 (65 nm, similar targets except timing); complementary larger-feature-size routes: INFN ARCADIA (110 nm LF), CEPC VTX (180 nm TJ)
- **ILD and CLD are now compared directly**: Z —> ττ within ±3 %, H —> invisible; CLD inner silicon is used inside the ILD_FCCee models — healthy cross-fertilisation

CLD is today the de-facto reference detector for FCC-ee full simulation — a descendant of CLICdet, ILD and SiD; the CLICdp silicon R&D continues, now largely under FCC-ee funding

CLICdp as a collaboration: future scope after ESPP 2026 to be determined; with thanks to the CLICdp colleagues for their input

the detector-concept landscape in one table

	CLD	IDEA	ALLEGRO	ILD	ALFA emerging	AGORA from CEPC, new for FCC-ee
Vertex	Si	MAPS	MAPS	Si	MAPS	MAPS
Tracker	Full Si	Drift Chamber + Si strp	DCH / Straw / SciFi + Si	TPC + Si strips	All MAPS	TPC + Si strips
ECAL	Si-W highly granular	Crystals w. DR	Noble Liquid (LAr)	Si-W highly granular	Grainita (crystal grains)	Crystals
HCAL	Scint. sampling	Fibre DR	TileCal (steel/scint.)	Scint. or RPC	DR + steel	Glass scint. + steel
Muon	RPC in iron yoke	µRWELL	TBD	Scint. in iron yoke	TBD	Scint. in yoke
PID	RICH (option)	tracker dN/dx (+ TOF)	tracker dN/dx (+ TOF)	tracker dN/dx (+ TOF)	Cherenkov ARC	tracker dN/dx (+ TOF)
Coil B-field	Outside HCAL 2T	Inside HCAL 2T (3T HTS R&D)	Inside HCAL 2T	Outside HCAL 3.5 T -> 2-3 T	Inside HCAL 3T	Outside HCAL 3T

M. Dam, FCC-ee detector concepts @ ILD workshop, CERN, Sep 2026

- FCC-ee: CLD, IDEA, ALLEGRO, **ILD**, ALFA (emerging), AGORA (from CEPC) — “concepts, not experiment collaborations”; non-exclusive membership; 39 EoI documents received for ESPPU
- linear colliders: **ILD, SiD, CLICdet** reviewed in LCVision; HALHF studied with e-ILD; C³ backgrounds with SiD
- two TPC concepts (ILD, AGORA), two with coil outside the HCAL — shared problems, shared R&D in DRD1–8
- “detector and accelerator optimisation must proceed together” — “ample room for new ideas and technologies” (M. Dam)

summary

- ILD is 20 years old, mature and productive (8 papers, 64 talks in 2.5 years; 59 institutes in 18 countries), and has a new executive team led by M.-C. Fouz.
- the CERN workshop set the course: a clear focus on FCC-ee — becoming an integral part of FCC-PED towards an EoI in 2028 — while keeping LCF and HALHF in view.
- adapting to FCC-ee means a new IR and forward region, ≤ 2–3 T, continuous readout and cooling; ILD_FCCee models exist and the first full Gaudi reconstruction works.
- the Z pole is the real test: backgrounds (SR mitigation very promising), TPC operability at Tera-Z, and dedicated Z-pole physics studies — none exist yet for ILD.
- AI reconstruction (ParT, MLPF) and Key4hep make ILD attractive beyond its membership; LC physics results keep improving ($\Delta\lambda/\lambda$ —> 11 %, top Yukawa —> 2 %).
- SiD (MAPS), CLICdp (CLD) and HALHF (e-ILD) keep the LC detector options alive; a prioritised ILD work plan is to be prepared — everyone is welcome to join!

apologies to the many efforts I could not cover — all 35 talks: agenda.linearcollider.org/event/11033

back up

ILD contributions to LCWS 2026

13 talks + 2 posters

physics analysis

- Latest news on the Higgs self-coupling prospects at 550 GeV with ILD — B. Bliewert [Tue, Higgs & EW]
- WW-fusion in a ZHH analysis — J. Torndal [Tue, Higgs & EW]
- Higgs coupling accuracy via $e^+e^- \to ZH(jj)$ at the ILC — T. Seino [Thu, Higgs & EW]
- Event reconstruction and $H \to$ invisible with ILD detector models for FCC-ee — V. Schwan [Thu, Higgs & EW]
- Triple gauge couplings: optimal observables at the detector level — L. Reichenbach [Wed, Higgs/EW & global analysis]
- CP violation in $e^+e^- \to t\bar{t}H$ at a 550 GeV LC with machine-learned observables — Y. Zhang [Wed, Flavor, top & QCD]
- Decay-mode independent searches for new light scalars at Higgs factories — M. T. Núñez Pardo de Vera [Wed, BSM]
- Light exotic scalars in $S \to b\bar{b}$ at Higgs factories — B. Brudnowski [Wed, BSM]
- Light exotic scalars in the di-tau channel at Higgs factories — A. F. Żarnecki [Wed, BSM]

software & reconstruction

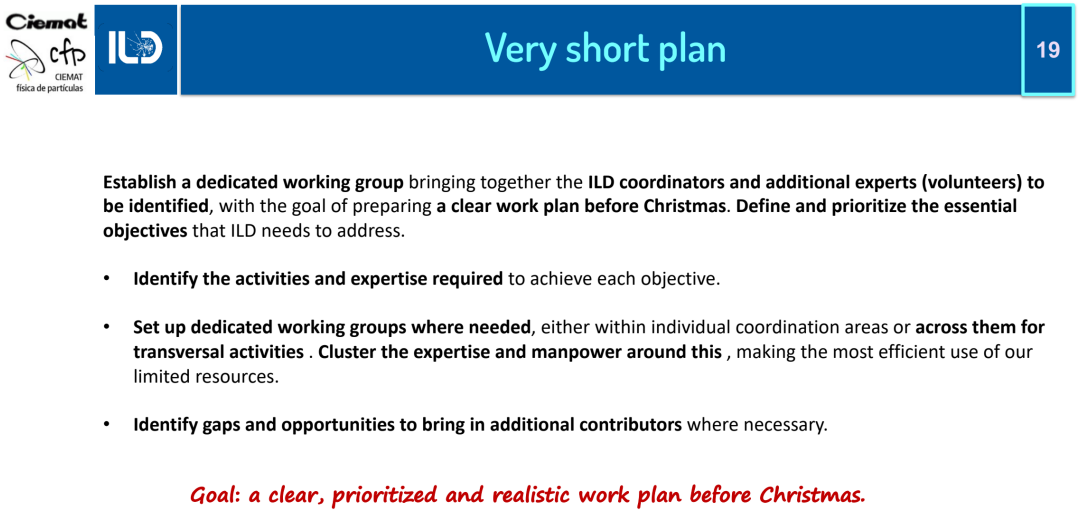
- Transformer-based jet reconstruction for Higgs factories — T. Suehara [Tue, Software & AI]
- GNN-based particle flow algorithm for future Higgs factories — T. Murata [Tue, Software & AI]
- Separating pile-up jets with one-to-one reco–truth mapping and Particle Transformer — Y. Zhang [poster]
- Strange flavour tagging with ILD at FCC-ee: V0 reconstruction and ML approaches — N. Dogishi [poster]

detector R&D

- Performance of the 15-layer SiW-ECAL technological prototype with CERN SPS beam-test data — T. Kamiyama [Thu, Calorimetry & PID]
- Adapting the ILD detector for HALHF — S. Ranjan [Tue, Conventional systems & MDI]

plus the plenaries by P. Kluit, W. Ootani and F. Gaede this morning — please come to the parallel sessions

next step & open questions



- dedicated working group of coordinators + volunteers —> **"a clear, prioritized and realistic work plan before Christmas"**
- set up transversal WGs where needed; identify gaps and bring in new contributors
- limited manpower and funding: identify the most critical areas, align with the FCC roadmap

M.-C. Fouz, workshop summary

open questions on the table:

- B = 2 or 3 T? impact on TPC / PFA; larger tracker if 2 T? is the 4 T magnet + thick yoke still required (stray field 5 —> 10 mT saves ~500 t)?
- TPC inner radius / how much silicon (v01 vs v02)? TPC scenarios: "if — then — else"
- trigger or streaming? where and how precise should timing be, at what power cost? less granular calorimeters at lower energies?
- data-sharing policy and by-laws for the FCC-ee era; relation of ILD meetings to FCC physics groups

FCC-ee vs ILC running conditions

Running conditions: ILC and FCC-ee

	ILC (ILD design)	FCC-ee
√s stages	250 – 500 (1000) GeV	88–95, 157–163, 240, 340–365 GeV
Interaction points	1, two detectors in push-pull	4, permanently installed
Beam structure	1312 bunches, 554 ns apart, 0.73 ms train at 5 Hz	continuous: 11 200 bunches, 27 ns apart at the Z
Duty cycle	0.5%, with a 199 ms gap between trains	100%, no gap
Power pulsing	yes, passive cooling of the calorimeters	not possible, electronics permanently powered
Readout	data buffered during the train, read out during the gap	100–200 kHz recorded continuously
Solenoid field	3.5 T (free choice)	2 T at the Z pole (vertical emittance)
Beam polarisation	e^- 80% / e^+ 30%, fast helicity flip	none for physics, resonant depolarisation gives √s at the 10^{-6} level
MDI	L^* = 4.1 m, 14 mrad, machine elements outside the tracking region	L^* = 2.2 m, 30 mrad, machine elements inside a 100 mrad cone
Z bosons	5×10^9 (GigaZ, 100 fb^{-1})	6×10^{12}

B2

Consequences for the ILD design

- No power pulsing
  - the calorimeter cooling has to be redesigned, with the cooling integrated in the absorber, some longitudinal granularity is lost
- Magnetic field from 3.5 T to 2 T
  - momentum resolution ($\sigma(1/p_T) \propto 1/(B\,L^2)$) and particle-flow separation degrade, ILD_FCCee_v01 keeps the same TPC and calorimeters, so this is not compensated for the moment
  - beamstrahlung pairs reach larger radii, with consequences for the vertex detector
- Machine elements inside the detector
  - L* from 4.1 to 2.2 m, crossing angle from 14 to 30 mrad, the main source of beamstrahlung scattering moves from the BeamCal (z = 4 m) to the beam-pipe crotch at z = 1.3 m, which is less shielded from the tracker
- TPC
  - ions drift at ~5 m/s over 2.2 m, i.e. ~0.5 s: a few thousand bunch crossings at ILC, $O(10^7)$ at the FCC-ee Z pole, gating between trains is not possible
- No beam polarisation
  - the Z-pole programme uses A_{FB} and τ polarisation instead of A_{LR}: the requirements move from polarimetry to momentum scale, acceptance and alignment stability

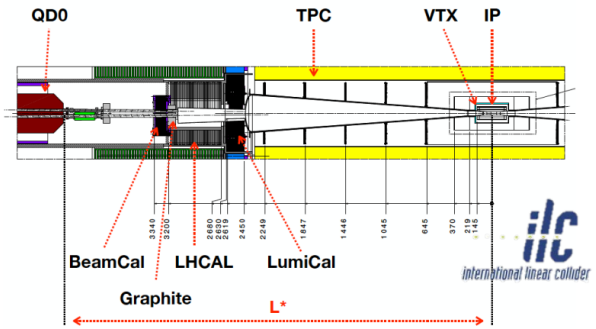
Reference: D. Jeans, *Adapting ILC detector concepts to other facilities*, arXiv:2604.04512

B3

MDI: ILC vs FCC-ee (and LCF380)

MDI: ILC vs FCC-ee & LCF380

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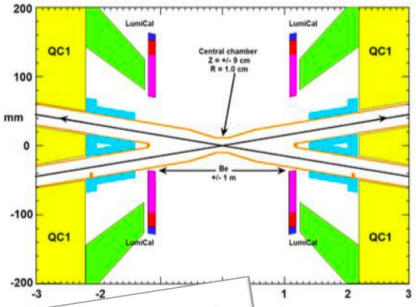


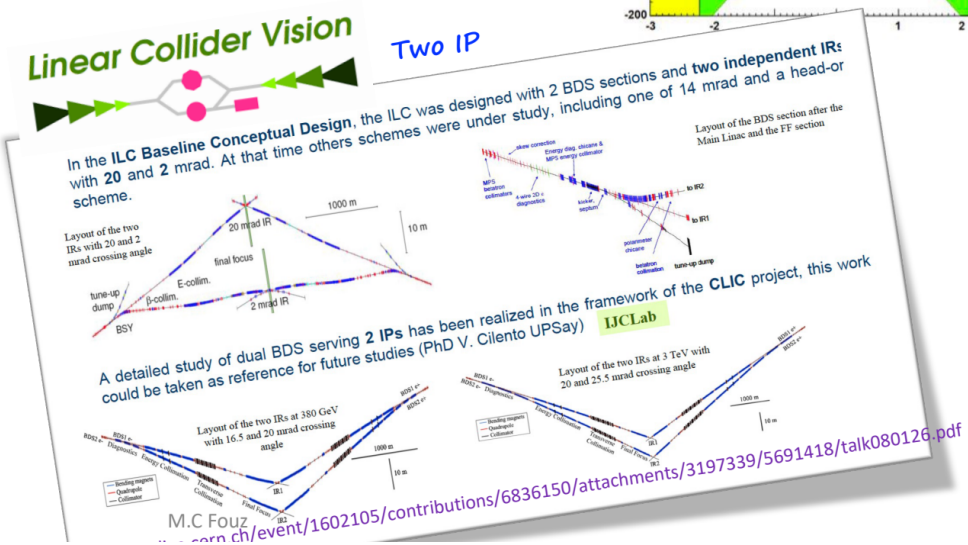
Crossing angle 14 mrad
L* 4.1 m: Final Quadrupole **outside** the detector
Solenoid magnetic field 3.5 – 4 T
Lumical at **~2.5m** from IP
Inner beam pipe radius 16 mm
Conical ➔ Tracker acceptance: cosθ ~ 0.996

VERY DIFFERENT DESIGNS
IR and Forward Region to be redesigned

LOWER B FIELD
Impacts on performance?

Crossing angle 30mrad
L* 2m: Final Quadrupole **inside** the detector
Solenoid B field restricted to 2T maximum
Lumical at **~1m** from IP
Inner beam pipe radius 10mm
➔ Tracker acceptance: cosθ ~ 0.984





ILD meeting - CERN - Sep 2026

M.-C. Fouz @ ILD workshop, CERN, Sep 2026

tentative to-do list towards an EoI / LoI

Tentative To Do List…



Instrumentation

- Continue R&D on detectors ⬌ DRD's
- Foster transverse collaboration on missing parts (e.g. Silicon trackers)
- Involve new partners: e.g maps for calorimeters (Lumi, SiW), Cherenkov / ToF
- Build scenarios for TPC (if;then;else)
- Revise Magnet + Yoke + Muons ← Q? From Karsten: Who ? Major cost issue (material, pit size)

Models

- Update detector descriptions in 2(3?) steps:
  - 1st version simulations with upgraded sub-detectors (⊃ digitisers, timing, cooling for VTX, TPC, Calos) → prelim. Physics performance, rates, granularity, etc (→ EoI ?)
  - 2nd version Sim/CAD for full physics performance / large Production
    - Prelim Cost estimates → LoI ? (beg. 2030)

three key areas, one goal

Three Key Areas, One Common Goal

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TECHICAL COORDINATION

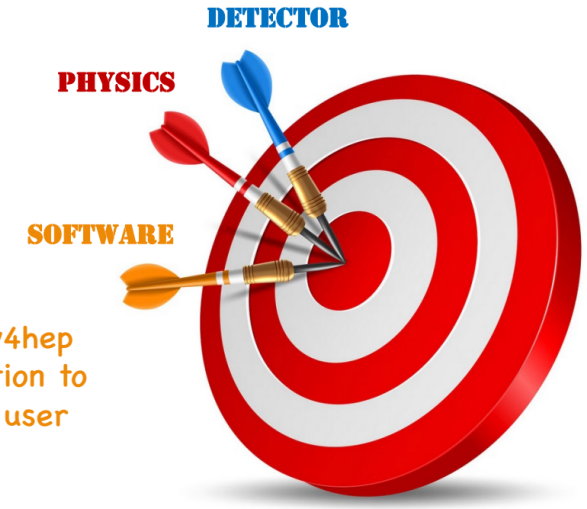
Revisit the **DETECTOR** design to address new challenges and proactively integrate advances emerging from the DRDs, and evaluate and optimise the use of sub-nanosecond timing capabilities to further enhance ILD performance.

PHYSICS COORDINATION

Combine detector R&D with benchmark **PHYSICS** studies to optimise performance and assess ILD's full physics potential, especially at the Z pole.

SOFTWARE COORDINATION

Strengthen ILD **SOFTWARE** through full Key4hep integration and modern AI-based reconstruction to enhance performance and attract a broader user community.



ILD meeting - CERN - Sep 2026 M.C Fouz

M.-C. Fouz @ ILD workshop, CERN, Sep 2026

pixel TPC for ILD at FCC-ee: conclusions

Conclusions: Pixel TPC for ILD @

- The performance of a pixel TPC based on GridPixes has been studied based on prototypes and test beam measurements. It provides
  - high precision continuous tracking with a low material budget
  - very powerful particle identification
- At the FCCee a pixel TPC as a central tracker – sliced between silicon detectors as in the ILD detector - is well suited to carry out the WW, ZH and tt physics program.
- For the Tera Z program the MDI should be optimized and backgrounds should be reduced by several orders of magnitude. No detector can be operated under these harsh conditions.
- R&D on a Pixel TPC with GridPix devices with larger coverage (we now have ~60%) an improved protection layer and reduced ion back flow based on the TPX3 or TPX4 ASICs are part of the DRD1 program
- One could consider to use Ne as a TPC gas for the Tera-Z running

* For detailed studies/questions/answers see backup slides

SR background: conclusions of the task force

Conclusions

- Identified Geant4's SR angular sampling as source of discrepancies
  - **BDSIM SR loss maps now agree with FLUKA and SYNRAD**
- **Beam halo at the FFQs confirmed as the dominant source of SR background at the IP**
  - Halo SR at IP ~2 orders of magnitude above core contribution
- Possible mitigation strategies:
  - **Alternative Final Doublet** (increased QF1-QD0 separation): **factor 10 reduction of SR from halo for direct hits in the central chamber**, with no effect on SR from the core
  - **Additional masking near the IP**: SR at IP mostly intercepted; **halo contribution reduced by at least a factor 100**
- **SR background at the IP can be significantly reduced with the proposed mitigations**
  - **Very promising results for the vertex detectors!**

G. Nigrelli @ ILD workshop, CERN, Sep 2026

ILD integration: envelopes and masses

FCC-ee Detector Envelopes and Masses

Table 4 FCC-ee detectors radial external envelope estimation w/ services and support structures

Detector	Nominal radial envelope [mm]	Individual external radial envelope [mm]	Global external radial envelope w/ integration allowance(250mm) [mm]
CLD	6000	6646	6896
ILD	**7833**	**7833**	**8083**
IDEA	5600	6190	6440
ALLEGRO	5000	6750	7000
ALFA	6000	7250	7500

It is safe to assume **8.1m** global radial envelope for future dimensional considerations. All external envelopes exceed the radius initially considered during the feasibility phase (6m radius).

Table 5 FCC-ee detectors longitudinal external envelope estimation w/ services and support structures

Detector	Nominal longitudinal envelope (half-length) [mm]	Individual external longitudinal envelope (half-length) [mm]	Global external longitudinal envelope (half-length) w/ integration allowance (250mm) [mm]
CLD	5300	5950	6200
ILD	6620	6620	6870
IDEA	5700	6290	6540
ALLEGRO	**6000**	**6750**	**7000**
ALFA	**6000**	**6750**	**7000**

In case of longitudinal envelope, to the largest value with movement tolerance included is 7.0m.
It is therefore safe to assume **7.0m** of half-length global longitudinal envelope for future dimensional considerations.

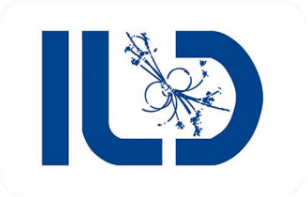
Table 6 FCC-ee detectors largest component for CMS style assembly, estimated dimensions

	Detector	Largest component dimensions		
		Diameter [m]	Length [m]	Weight [t]
FCC-ee	CLD	13.3	7.4	3500
	ILD	15.6	7.8	3300
	IDEA	12.4	5.0	<3500
	ALLEGRO	13.5	7.8	<3500
	ALFA	≈14.5*	-	<3500

With preassembly on the surface similar to CMS, it can be assumed that all the largest components exceed the weight of 2000t, thus may require a special high load gantry. With assembly piece by piece (ATLAS style), the largest FCC-ee detector (ILD) would require lowering the cold mass of 168 down the shaft.

ILD in the eyes of the PSB, 2024–26

2024-2026 in the PSB eyes



- ILD Collaboration (authors) demonstrated tremendous effort, endurance and enthusiasm in (already very long) times of uncertainty of LC (or any other major HEP project)
- No major HEP conference took place without ILD participation (ICHEP2024 – 10 accepted abstracts, EPS-HEP2025 - 7 talks + 1 poster, ICHEP2026 – 4 physics talks + 1 on ILD detector)
- Significant contribution to the EU strategy process - 17 ECFA Higgs/top/EW study notes
- LCWS meetings traditionally get the Collaboration's attention with over 10 talks

The biggest 'Thank you' from the PSB goes to the authors of 8 published papers and conference speakers and volunteers who gave 64 talks in the course of two and half years

Also, very special 'Thank you' from the us goes to Ties who led ILD effort over 2 decades long 'dry season' with wisdom and moderation, keeping ILD international, visible and pleasant community to be a part of

ild-psb@desy.de

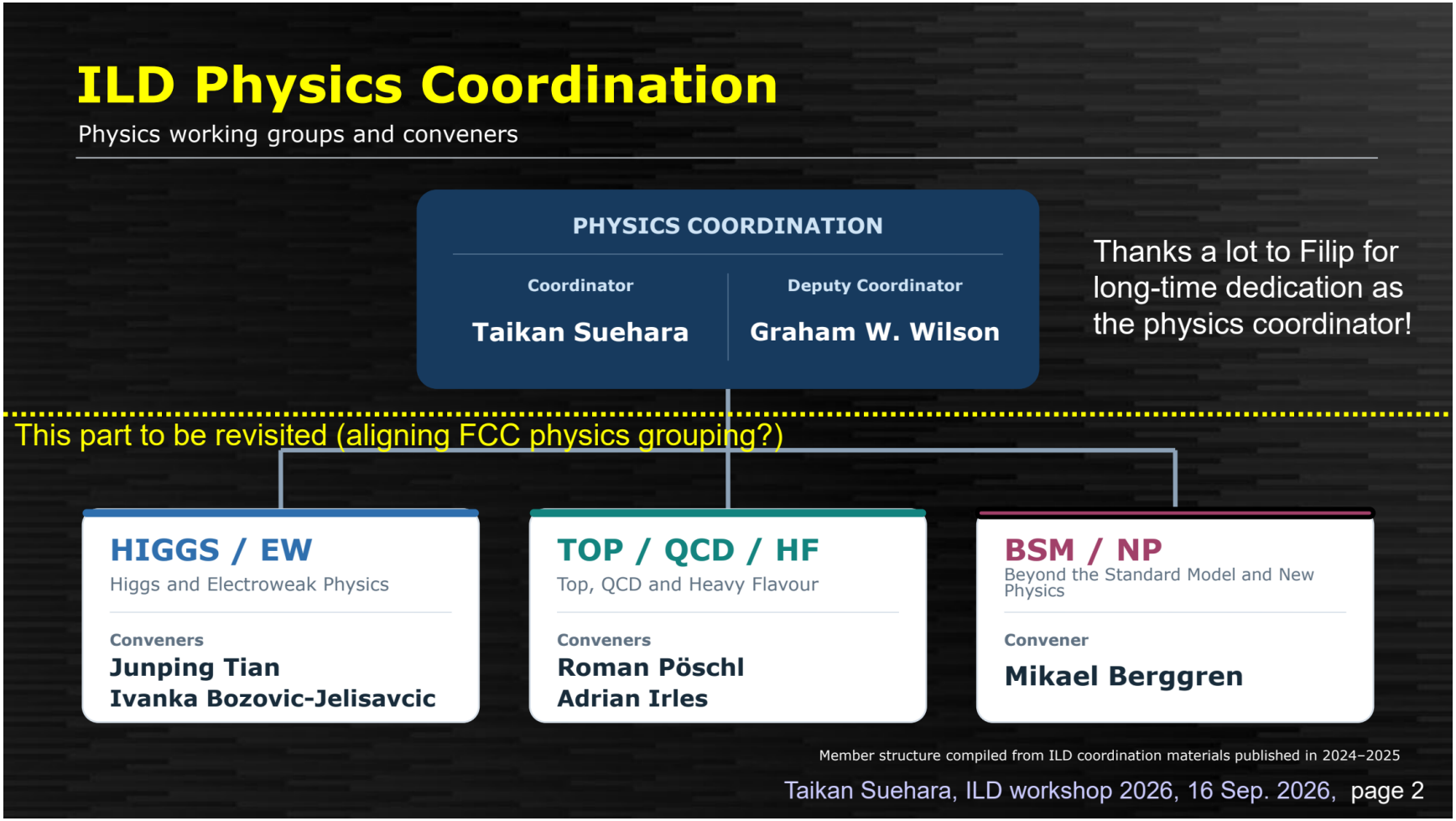
The future is here

- ILD has enter a new and exciting phase
- Main focus is on being integrated and play a leading role in the next Flagship Collider at CERN.
  - Integration in FCC-PED structure is ongoing and should be a priority for the ILD groups. The community is growing.

- (few) coming challenges to be faced by the collaboration that will require close “monitoring” from the IA:
  - The integration in this new (open) framework will pose some challenges to address to the ILD structure.

    Around 2028-29, detector concepts are expected to deliver EoI/LoI… and real collaborations be formed.
  - Maximization of collaboration efforts and opennes during this period.
  - Attraction of new members – update of ILD entry points (webpage, wikis, etc)

ILD physics coordination



T. Suehara @ ILD workshop, CERN, Sep 2026

HALHF parameters (new baseline, ESPP input)

	250 GeV	380 GeV	550 GeV
e^- / e^+ beam energy [GeV]	375 / 41.7	570 / 63.3	825 / 91.7
c.o.m. boost γ	1.67	1.67	1.67
bunches/train × rep. rate	160 × 100 Hz	160 × 100 Hz	160 × 100 Hz
luminosity [10^{34} $cm^{-2}s^{-1}$]	1.2	1.7	2.5
lumi fraction in top 1 %	63 %	53 %	46 %
Y (beamstrahlung)	0.9	1.6	2.8
site power [MW]	106	154	218
site length [km]	4.9	6.5	8.4

[Baseline HALHF input to ESPP 2026, arXiv:2503.19886, Table 1; updated baseline arXiv:2505.21654]

ILD vs CLD at FCC-ee: Z —> ττ

Conclusions and next steps

In this work ILD and CLD are compared in the context of Full Simulation FCCee $Z \to \tau^+\tau^-$.

- **This preliminary comparison show very similar performances at particle level:**
  - **Similar efficiencies and purities** for the analyzed particles (note that this sample has almost no neutrons).
  - **Compatible resolution**, non comparable now because of the status of ILD reconstruction.
- **At tau reconstruction level, ILD improves the efficiency for almost every decay.**
  - **Three pions and electron decays** are the most affected, with a **~10% increase**.
- **Polarization analysis results in similar fits for both detectors.**
  - Depending on the decay one detector is better. Need to study pion decay.

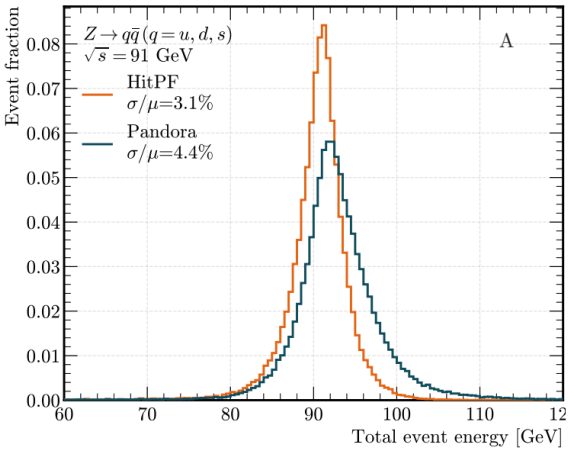
Next steps:

- Optimize tau reconstruction for ILD (now the applied cuts are customized for CLD).
- **Extend polarization analysis to $a_1 \to \pi\pi\pi$** (now possible with the statistics).
- Repeat the analysis with optimized version of tracking fitting.
- Compare with others generators (KKMCee or Whizard, WIP)

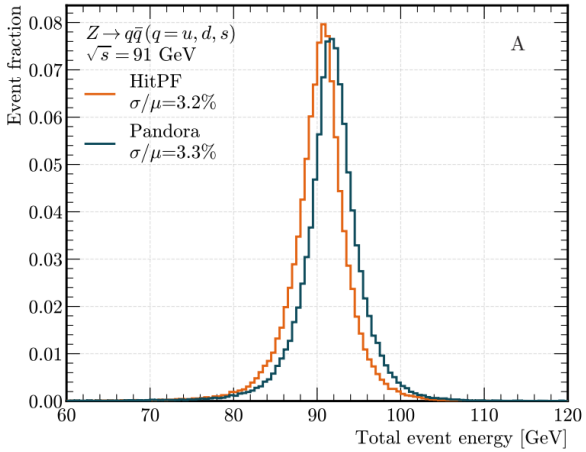
MLPF across detectors

MLPF JER is similar ot better than Pandora

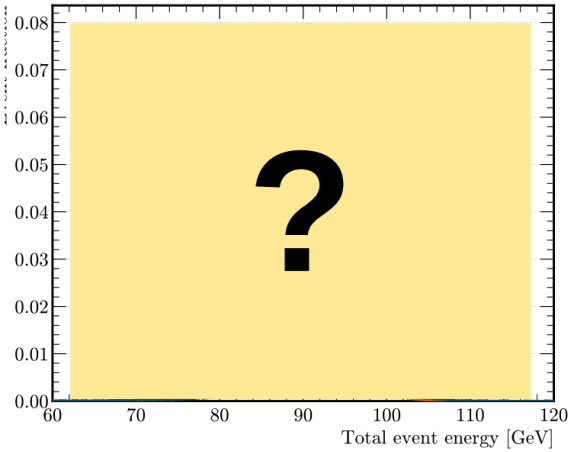
CLD



ILD@ILC



ILD@FCC



credit: Dolores Garcia et al.
a paper is in the process.

MLPF yields a similar or better JER than PandoraPFA.
Cross-detector comparison is important.

B. Dudar @ ILD workshop, CERN, Sep 2026