The International Large Detector (ILD) for a future electron-positron collider: Status and Plans

Ulrich Einhaus for the ILD collaboration
EPS-HEP2023 Conference
22.08.2023, Hamburg
ulrich.einhaus@desy.de

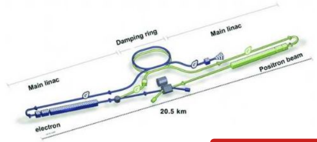
CLUSTER OF EXCELLENCE
QUANTUM UNIVERSE

HELMHOLTZ

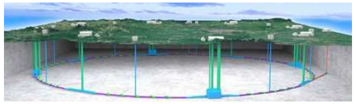
DESY.

The Landscape of Proposed Next-Gen Colliders / Future HTE Factories

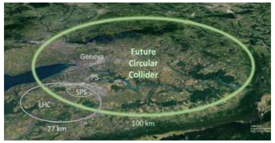
ILC



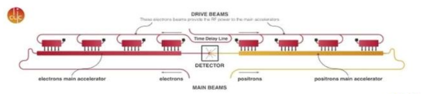
CEPC



FCC-ee



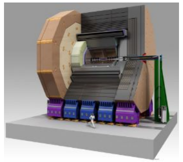
CLIC



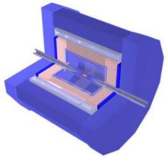
+ C³
+ CERC
+ ReLiC
+ ERLC
+ HALHF
+ ...

This

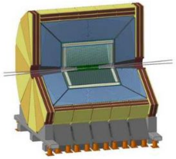
ILD



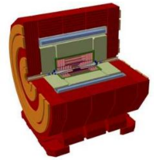
CEPC Baseline



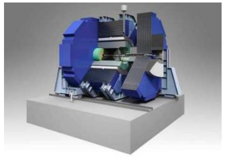
IDEA



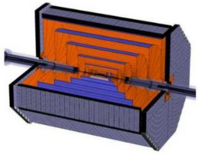
CLICdp



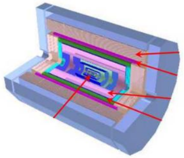
SiD



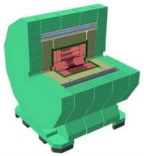
FST



CEPC 4th concept



CLD



slide stolen from B. Dudar

- Many proposals under consideration at various degrees of detail and readiness
- ILD is a driver of hardware developments and has (one of) the most developed detector model, sim/reco and analyses

ILD Layout and Performance

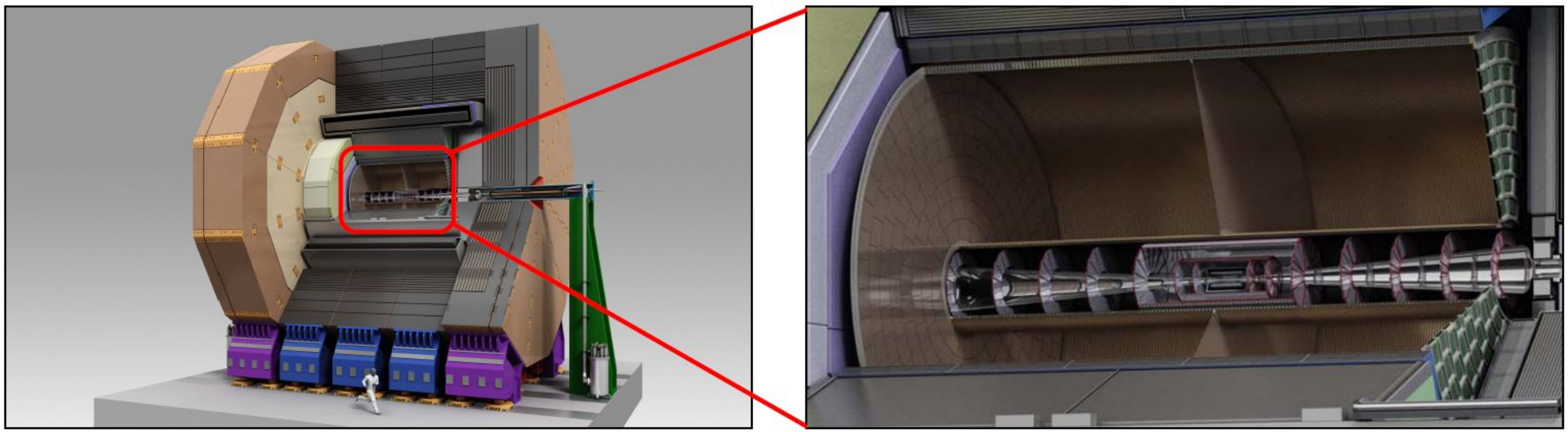
- Multi-purpose detector, nearly 4π hermeticity with elaborate forward region, optimised for particle flow
- Time projection chamber (TPC) as main tracker allows for continuous tracking and dE/dx PID
- High granularity calorimeter with minimal material in front of it inside 3.5 T solenoid
- Resolutions:

vertexing:	$\sigma_b < (5 \oplus 10/p\sin^{3/2}\theta)\,\mu m$		~ CMS/4
momentum:	$\sigma_{1/p_T} = 2\cdot 10^{-5} GeV^{-1} \oplus 10^{-3}\sin^{1/2}\theta/p$		~ CMS/40
jet energy:	$\sigma_{E_{Jet}}/E_{Jet} < 3.5\%$	above 100 GeV	~ ATLAS/2
dE/dx:	$\sigma_{dE/dx}/\mu_{dE/dx} < 5\%$		~ ALICE

Interim Design Report 2020

- ILD designed for ILC energies of 250 GeV, 500 GeV and 1 TeV

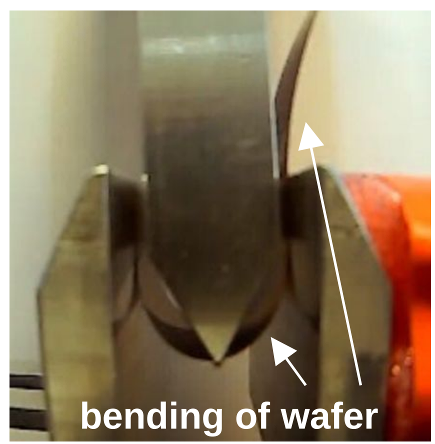
[https://arxiv.org/abs/1306.6329]



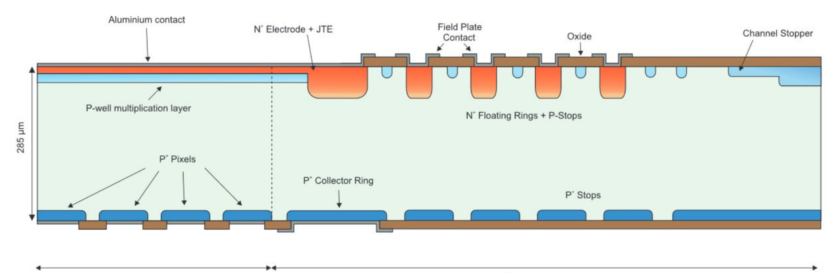
Hardware: Silicon Tracking

- ILD foresees Silicon vertex tracker and TPC envelope and is considering a number of options (CMOS, DEPFET, MAPS, (i)LGADs) and is monitoring the ongoing developments, e.g.

- ALICE ITS3
  - Bendable MAPS, minimal material budget of 0.05% per layer
  - Point resolution < 5 µm



- (i)LGADs
  - Timing resolution O(10 ps)
  - ‘Inverting’ more complex but optimises fill factor

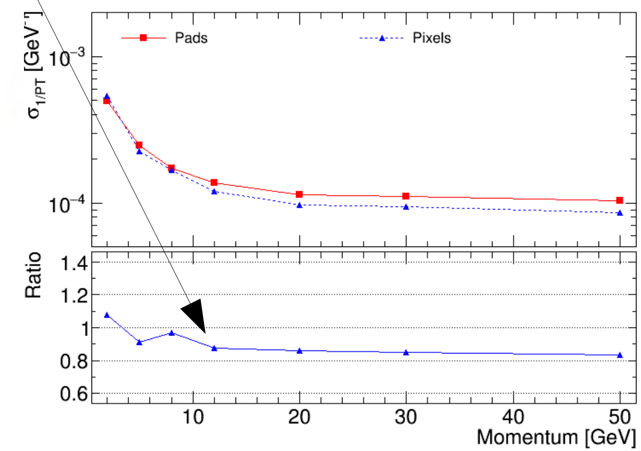


https://doi.org/10.3390/s23073450

https://indico.slac.stanford.edu/event/7467/contributions/5958/

Hardware: Time Projection Chamber

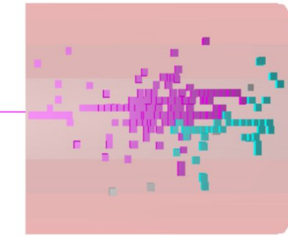
- Development dirven by the LCTPC collaboration
- TPC: pad-based readout (GEMs, Micromegas) well established, ongoing development of PixelTPC readout
- Would improve asympt. momentum resolution by ~15% and dE/dx resolution by ~30%
- A lot more: talk by J. Kaminski



https://indico.slac.stanford.edu/event/7467/contributions/5972/

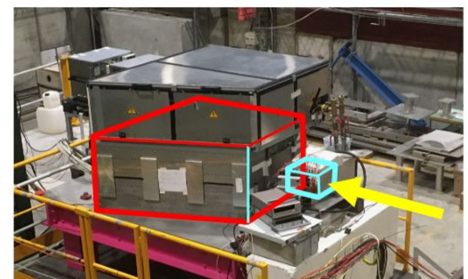
Hardware: Calorimetry Status

- A number of options being developed by the CALICE collaboration:
  - SiW ECAL, Scintillator ECAL
  - AHCAL, DHCAL, SDHCAL, T-SDHCAL



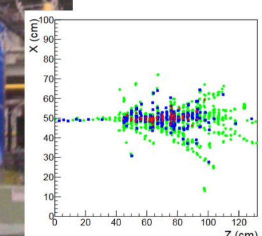
Magenta: Charged Hadron
Cyan: Neutral Hadron
Grey: Unclustered Hits

- All using high granularity (~ 0.5 cm ECAL, ~ 3 cm HCAL; 10^8 channels) for particle flow as well as power pulsing for ILC beam structure with passive cooling
- SiW ECAL and AHCAL technology used for CMS HGCAL, recently combined test beam; possible application at LUXE
- SDHCAL: 1 cm gran., 3 thresholds
- Sci ECAL: 45x5 mm² strips reduce channels by 10



SiW-ECAL
- 15 layers 18×18 cm²
- 0.5×0.5 cm² Si cells
- 2.8+5.6 mm W (24 X0)

AHCAL :
- 38 layers 72×72 cm²
- 3×3 cells scintillator + SiPM
- 1.7 cm Stainless Steel (~4λ)

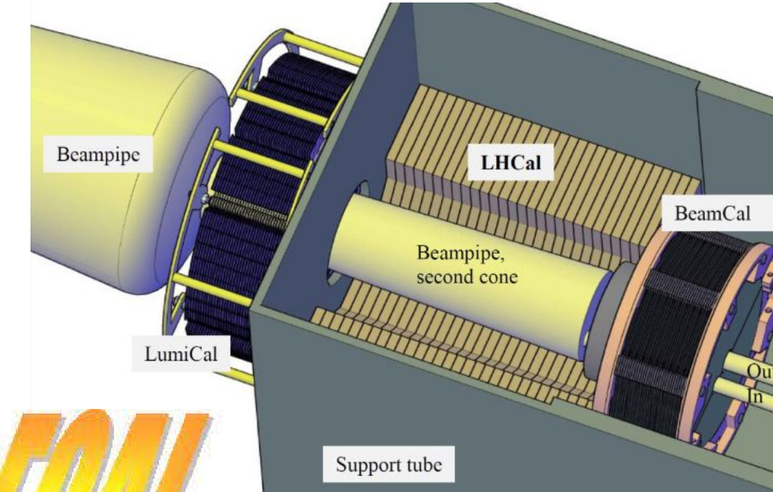


Hardware: Calorimetry Plans

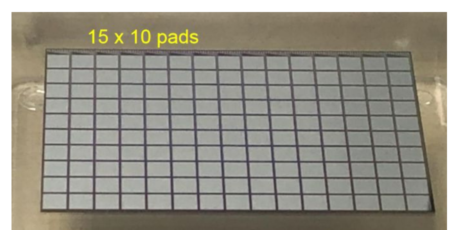
- Several proposals for new European Detector R&D collaboration for calorimetry (DRD6) underway
- SiW ECAL, Sci ECAL, AHCAL and (T-)SDHCAL each propose development of (new) prototypes & integrating design for continuous operation (→ bandwidth, power, cooling) and timing (→ pile-up, time-of-flight, particle flow)
- SiW ECAL: new PCB to 'finish' ILD-ready design, common readout with AHCAL
- AHCAL: tungsten absorber; continue 'Megatiles' development to cope with ILD channel count
- SDHCAL: large prototype (1x1x3 m^3), pat of ILD @CEPC
- Sci ECAL: common test beam with CEPC HCAL
- See also overview by A. Irles

Hardware: Forward Calorimeter System

- Devlopment by the FCAL collaboration
- LumiCal: precise luminosity measurement counting Bhabhas
- BeamCal: fast luminosity measurement using beamstrahlung
- Both: large polar angle coverage, i.e. hermiticity (new particle searches, particle flow)
- Design done, detailed simulations, prototype for LumiCal with Si
- Spin-offs went into CMS luminometer and beam condition monitor
- New technology: GaAs sensors with integrated routing, to be applied at LUXE



FCAL Collaboration
High precision design

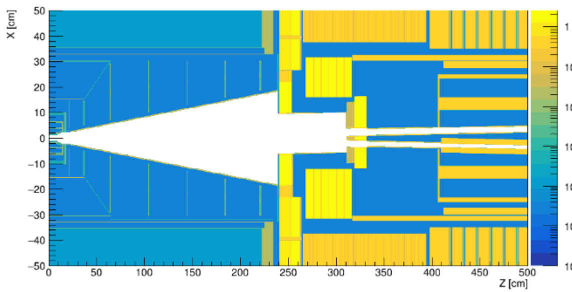


https://agenda.linearcollider.org/event/9625/#1-status-and-plans-of-the-fcal

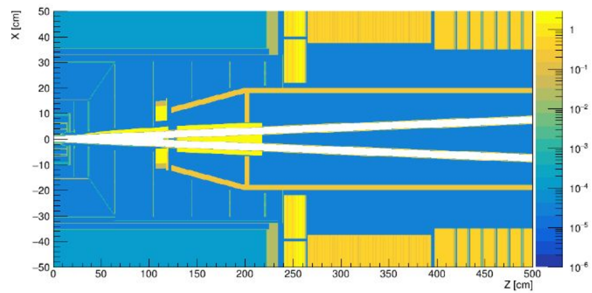
ILD at a Circular Collider?

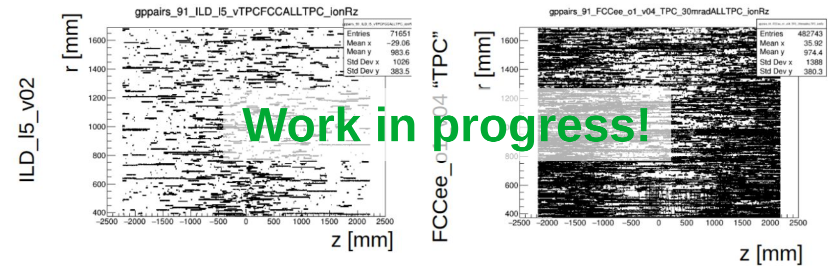
- ILD was developed to work at the International Linear Collider (ILC)
- At a circular collider (FCC, CEPC) conditions are different:
  - continuous beams instead of trains → no power pulsing, no TPC gating
  - different beam delivery system and beam stability requirements→ redesign of forward region
  - B = 2 T, while ILD @ILC has B = 3.5 T → mom. res. (lever arm, TPC drift diffusion)
- Distortions in TPC due to ions from physics (hadronic Z decays) are O(100 μm), but stable at O(1 μm); however, 2 orders more ions come from beam background
- Studies are ongoing to address these and study the viability (so far it looks reasonable)

ILC



FCC

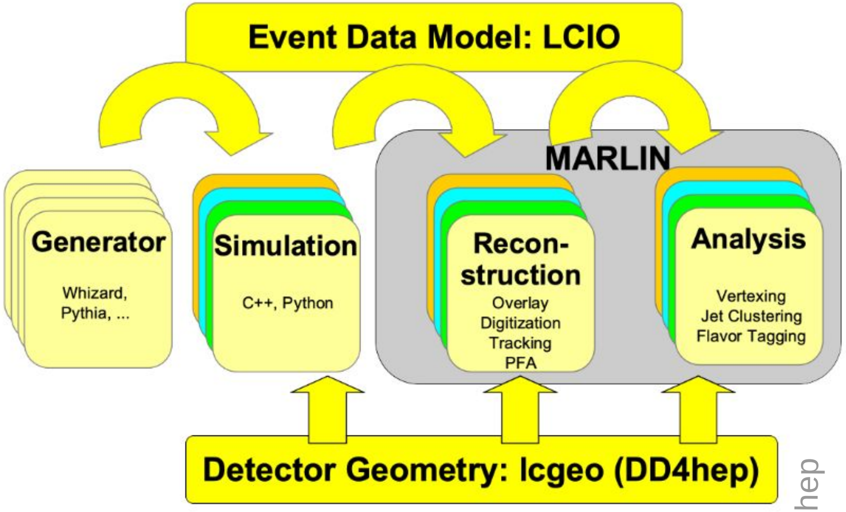


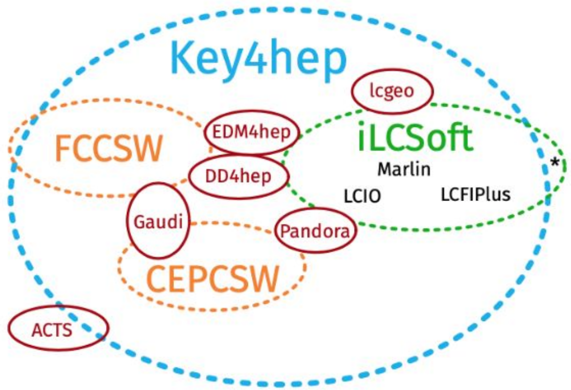


https://agenda.linearcollider.org/event/9903/#12-update-on-tpc-tera-z

Software Environment

- Extensive software framework iLCSoft, including detector model, driving simulation, reconstruction, detector optimisation and physics studies
- Several large MC productions, most recent one in 2020 for 250 GeV E_{CM}
- Detector model being updated for usage at a circular collider
- Future collider community has agreed on common framework: Key4hep
- iLCSoft is part of the common environment, central reconsturction tools are usable via a wrapper and the plan is to move to native Key4hep in the future

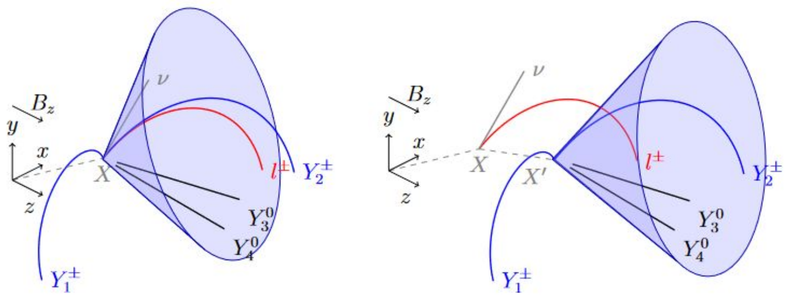




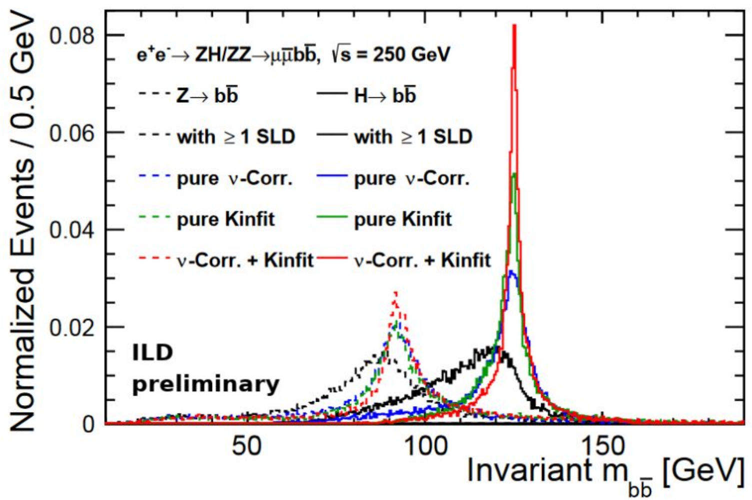
https://indico.cern.ch/event/1283129/#8-overview-of-key4hep

Neutrino Correction & ErrorFlow for Higgs Self-Coupling

- Primary Higgs decay channel is $b\bar{b}$, often with 1 or 2 semi-leptonic decays (SLDs) of the b- or consecutive c-hadrons
- Less prevalent but still an issue in $c\bar{c}$, WW or ZZ channels
- Neutrinos of SLDs carry invisible energy, broaden invariant-mass peak of the reconstructed Higgs
- New: dedicated reconstruction of the missing energy/momentum using knowledge of initial state in e+e- collisions



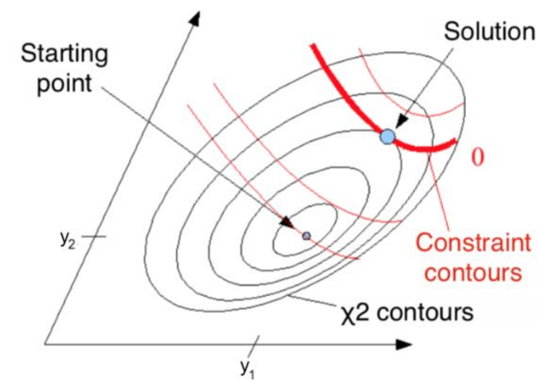
https://agenda.linearcollider.org/event/10079

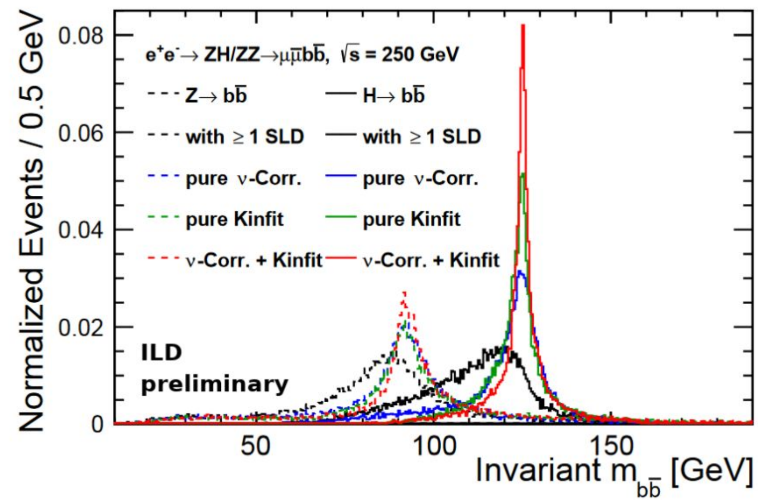


https://arxiv.org/abs/2212.07264

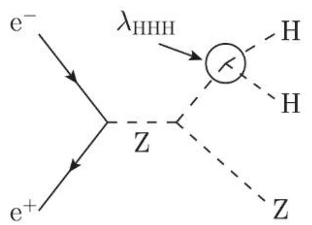
Neutrino Correction & ErrorFlow for Higgs Self-Coupling

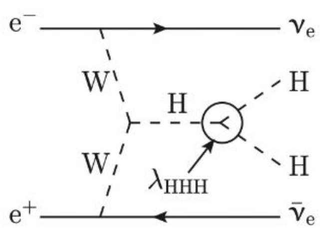
- Use kinematic fit to constrain event reconstruction (incl. inv. mass)
- New: with high-efficiency particle flow assess uncertainty on reconstructed parameters of each fit object (e.g. b-jets) individually and with full covariance matrix to optimise fit performance → ErrorFlow
- Delivers an excellent separation of Higgs peak from underlying Z bkg. in $b\bar{b}$ inv. mass
- Use for Higgs self-coupling in ZHH to suppress ZZH background and measure λ_{HHH} at < 20%
- See [talk by J. Torndal]





https://arxiv.org/abs/2212.07264

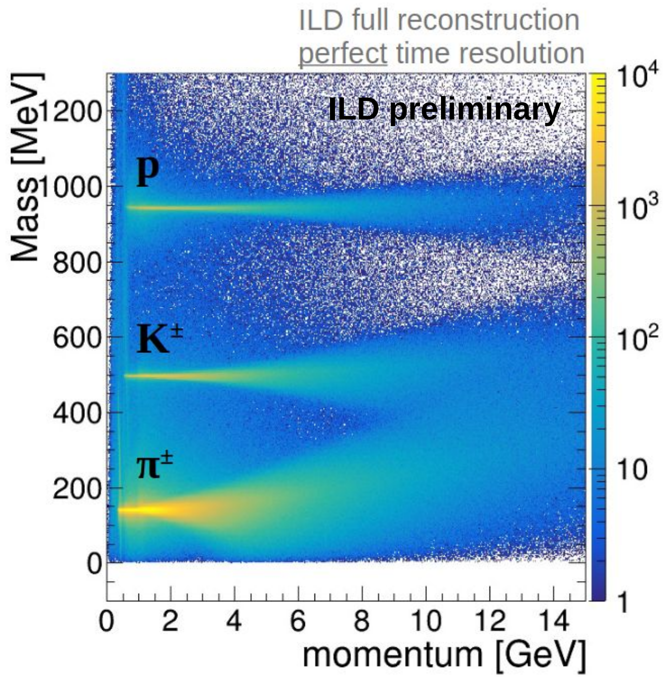




Particle ID: Time-of-Flight

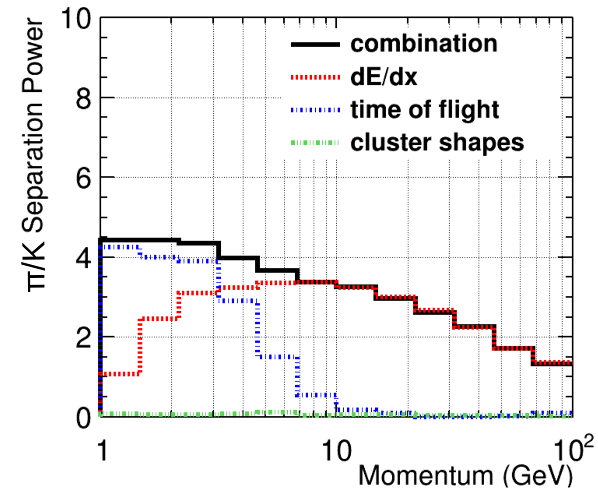
- Particle ID (PID) is of increasing interest in the future collider discussion
- ILD uses PID from cluster shapes (via PandoraPFA), specific energy loss in the TPC (dE/dx, possibly dN/dx) and time-of-flight (TOF)
- New: detailed implementation of TOF, with a variable timing resolution O(30ps) in the first ECal layer and a sophisticated track length reconstruction using the Kalman filter
- One result: track length has similar impact on mass reco as timing, using 220 continuous track hits of the TPC - how does this perform in full Silicon?
- See talk by B. Dudar

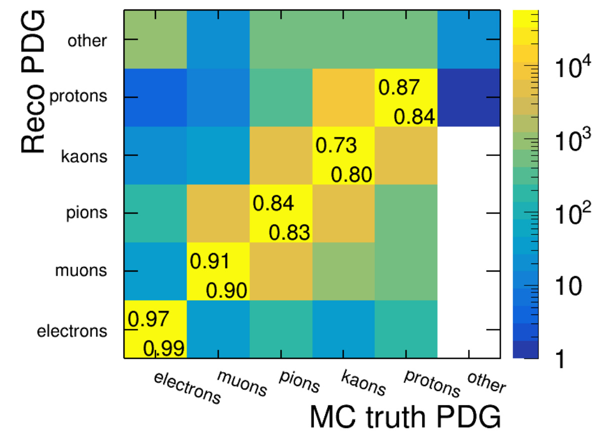
$$L = \sum_{i}^{N_{\text{hits}}} L_i = \sum_{i}^{N_{\text{hits}}} \frac{|z_{i+1} - z_i|}{|\tan \lambda_i|} \sqrt{1 + \tan^2 \lambda_i}$$



Particle ID: Common Framework

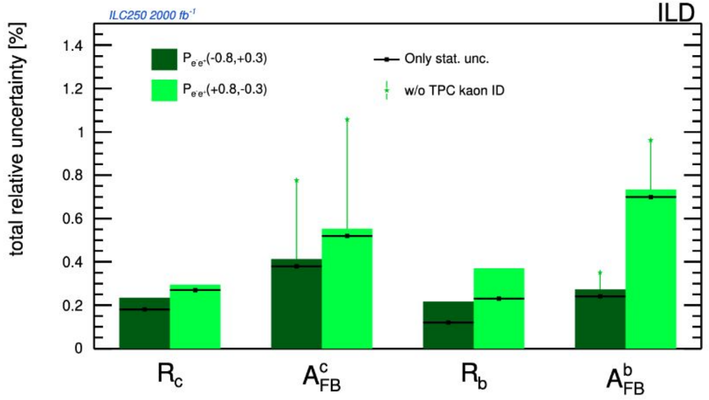
- TOF works up to 3-5 GeV and nicely complements dE/dx: covers 'blind spot' at low momenta where Bethe-Bloch curves cross
- Need for combination of of different PID observables, coherent performance assessment and comparability between detector concepts
- New framework: Comprehensive PID (CPID)
- Built in a modular way both for PID observables as well as combination algorithm (e.g. BDT)
- Part of key4HEP for broad future collider community
- See: poster by UE



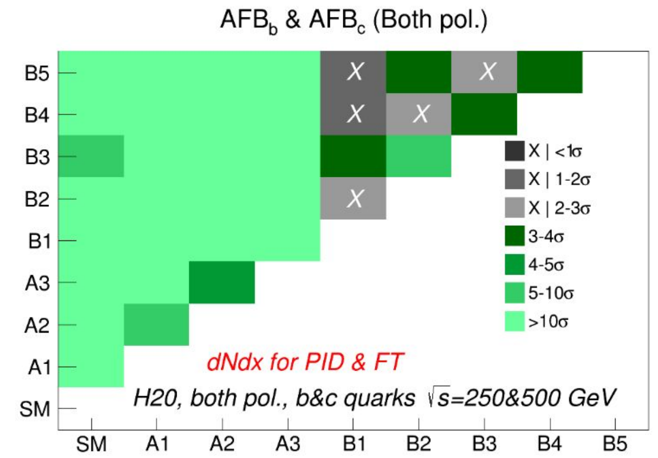


Particle ID for A_{FB}

- Various studies using PID (though not CPID *yet*), e.g.:
- Measurement of forward/backward asymmetry A_{FB} of s-channel quark pairs
- Quark charge ID incl. via ID of kaons from leading hadron decays needed to assign particle/antiparticle direction correctly → significant effect of kaon ID
- Allows to find BSM and differentiate BSM models from each other
- See talk by J. Marquez



https://arxiv.org/abs/2306.11413

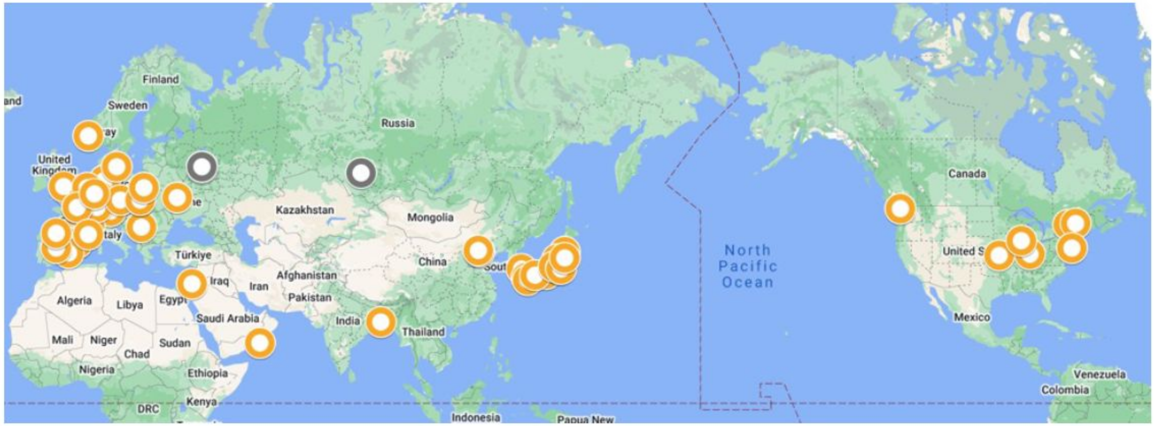


More physics analyses

- EPS-HEP contribution:
- CPV mixing
- Dark photons
- Long lived BSM particles
- Exotic light scalars
- Stau searches

Conclusion & Outlook

- ILD is a mature detector concept, but still very active, both in associated hardware developments as well as reconstruction algorithms and physics studies
- Participating in European Strategy, Snowmass, now DRD integration and ECFA study
- Feasibility study of ILD @FCC
- Looking for more personpower!

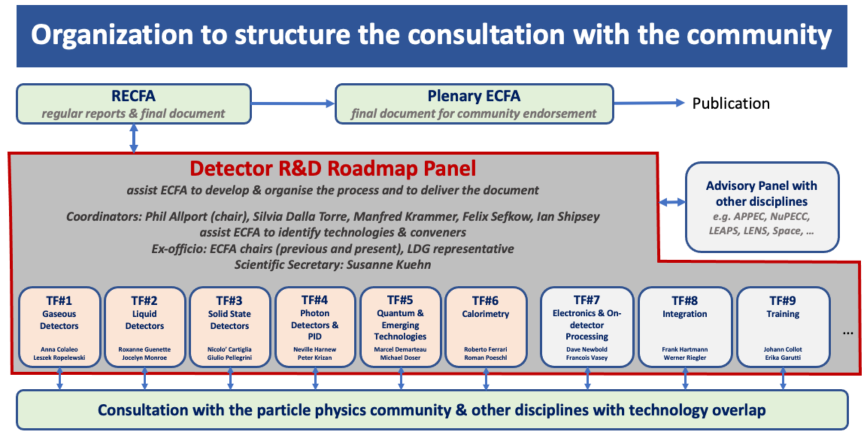


Thank you!

Backup

European Strategy: DRDs & ECFA Study

- Participation of ILD groups in various detector research & development (DRD) collaborations
  - (LC)TPC: DRD1 (gaseous detectors)
  - several groups: proposal of 65 nm CMOS in DRD3 (solid state detectors)
  - some interest in DRD4 (photon detection & PID)
  - CALICE: DRD6 (calorimetry)

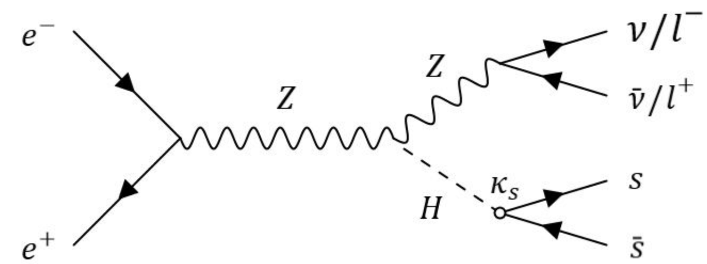


- DRD collaboration should be operational beginning of 2024

- ILD contributing significantly to ECFA Future HTE Factory Study and involved in majority of physics study focus topics

Particle ID for H → $s\bar{s}$

- Various studies using PID (though not CPID *yet*), e.g.:
- Putting limits on strange Yukawa coupling for the first time
- Identification of s-jets by with leading kaons, separation from u/d-jets only possible via PID
- Helps with suppression of Z-to-light quarks background
- Crucial in case of enhanced cross section via BSM models to identify quark generation with enhancement Yukawa coupling



https://arxiv.org/abs/2203.07535