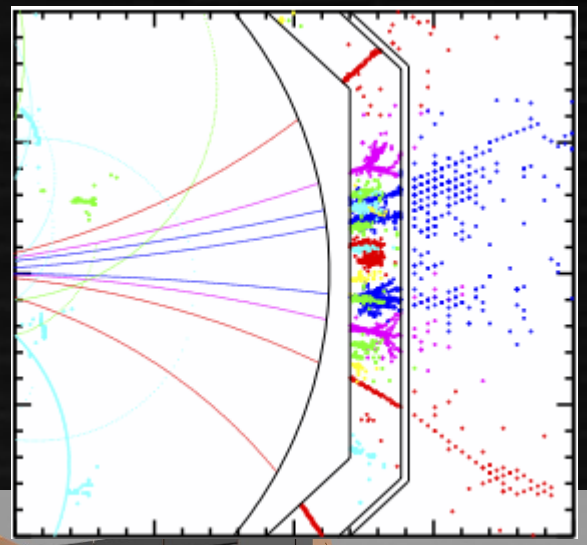
ILD Status and plans

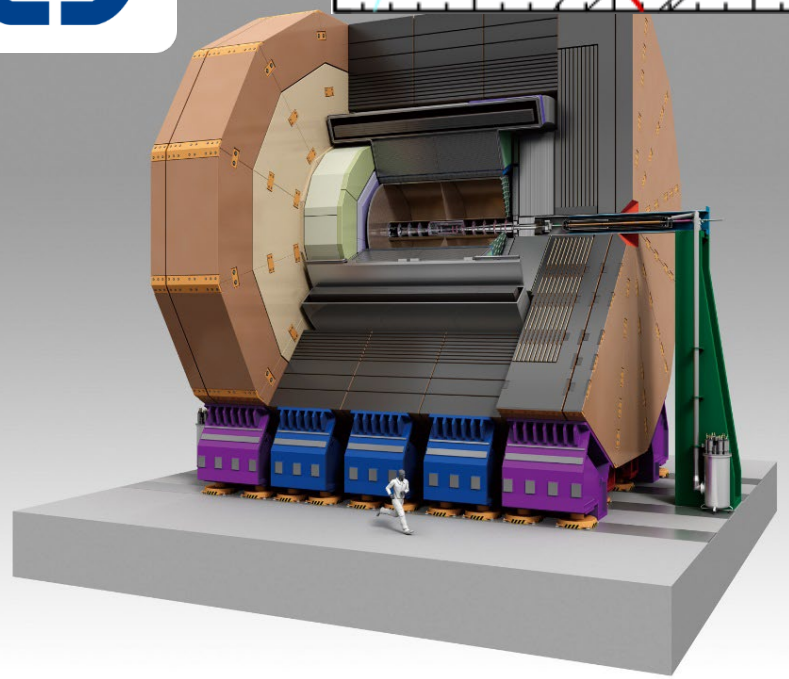
Taikan Suehara
(ICEPP, The University of Tokyo)
on behalf of ILD concept group

Key messages from ILD

- New management being formed, coming with fresh strategies
- ILD gives an excellent performance standards for FCC-ee physics
  - Optimal performance of particle flow (further improving by ML)
  - Consisting of technologically-validated detector components
  - Sufficiently detailed full-simulation models and tools
  - Ready for key FCC-ee physics performance studies!
- Adaptation to Key4hep implemented and more integration possible
- Optimization/performance studies for Z-pole to be done
  - For lower magnetic field and heavy background
- Still a lot of room for new ideas/configurations
  - We welcome new collaborators with new ideas/technologies!

ILD: born for Particle flow





- The first detector concept fully optimized for Particle Flow
  - Standard for PandoraPFA paper in 2009
- Origin of CLICdet (with SiD) → CLD
- Worked as a core of ILC physics studies
  - Letter-of-Intent in 2009
  - Detailed Baseline Design in 2013, also for snowmass and ESU
  - Recent updates in ECFA HTE factory study
- Now being activated for FCC-ee

Detector components

Return yoke and muon detector
- Scintillator bars or RPCs

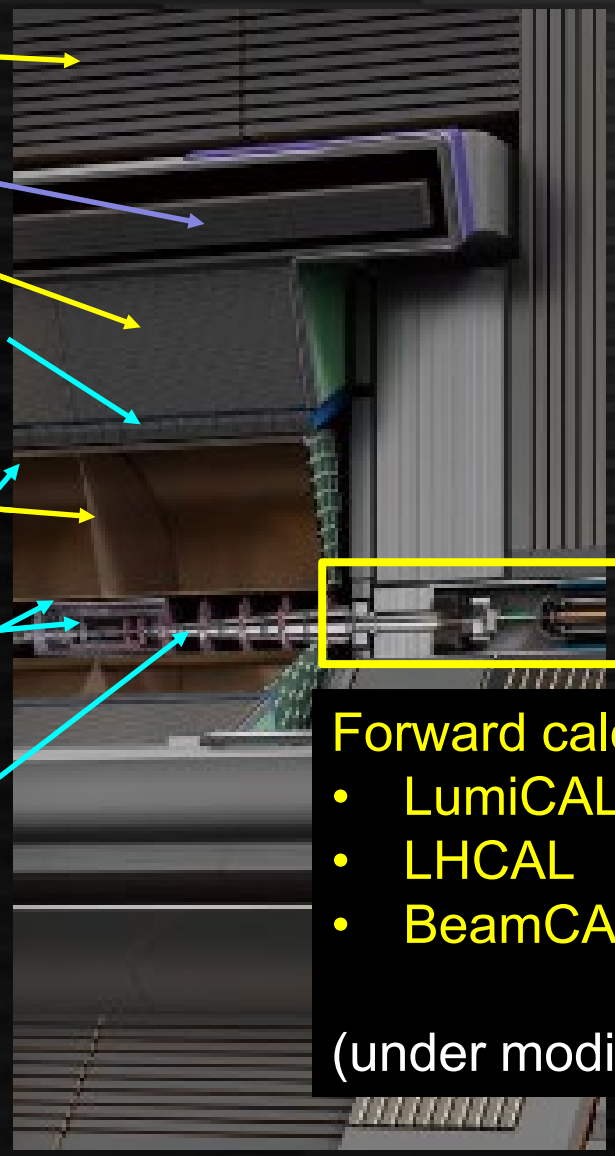
3.5 Tesla superconducting solenoid (outside HCAL)

Highly granular HCAL (Steel absorber, 48 layers, 6 λ_0)
- Scintillator tiles (analog) or RPC (semi-digital: 3 thr.)

Highly granular ECAL (Tungsten absorber, 30 layers, 24 X_0)
- 5 x 5 mm^2 silicon pads or 5 x 45 mm^2 scintillator strips

Time Projection Chamber (TPC)
- Pad or pixel electrode, GEM or Micromegas

Silicon trackers
- Vertex detector
  - 6 layers, 15-5x mm from IP
  - MAPS (with many options)
- Inner tracker (SIT)
  - 2x2 layers, pixel or strip
- Outer tracker (SET)
  - 1x2 layers, strip, timing capability?
- Forward tracking discs (FTD)
  - 2 pixel + 5 strip layers



Forward calorimeters (for LC)
- LumiCAL
- LHCAL
- BeamCAL

(under modification for FCC)

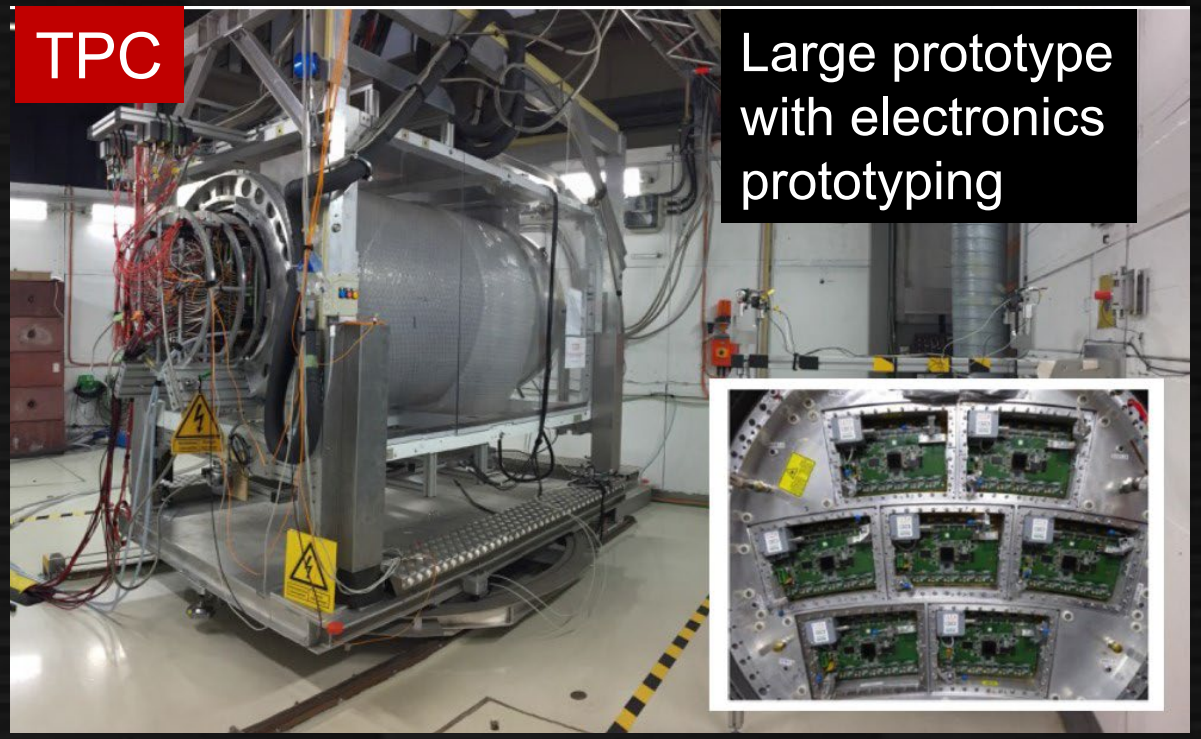
Technology highlights (selection)

Strong connection with DRDs (1,3,6)

Silicon tracking

Chips produced and tested in the past
Current design seems bit outdated
Good for new collaborations!

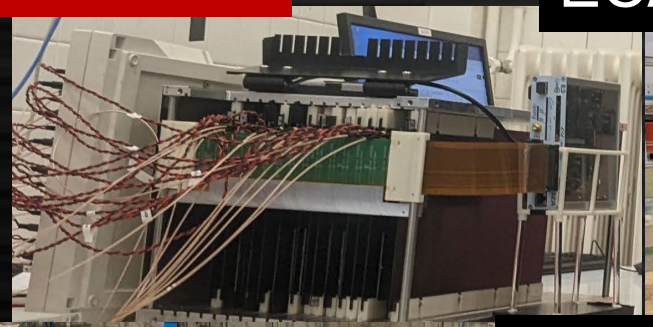
TPC



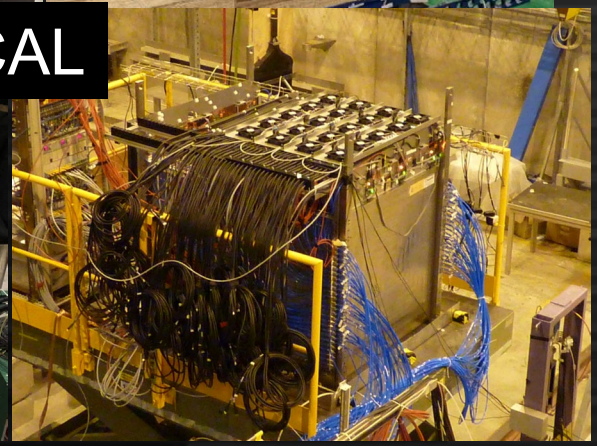
Large prototype with electronics prototyping

Calorimeters

ECAL



HCAL

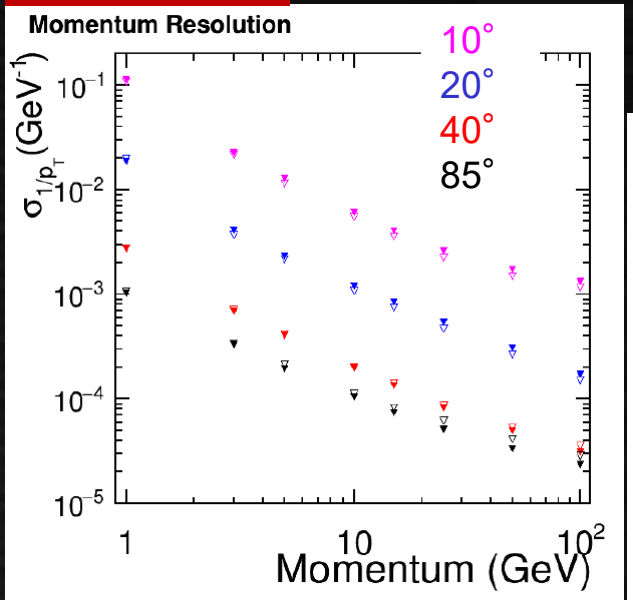


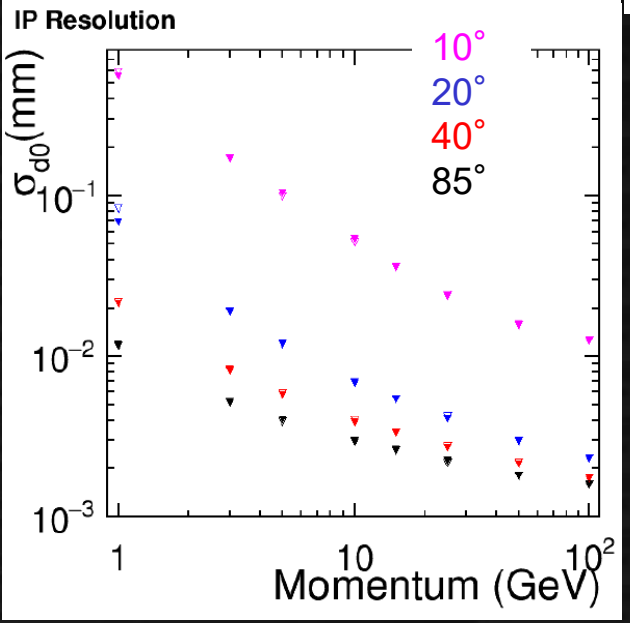
Performance of key components has been already demonstrated with prototypes
Working for continuous readout

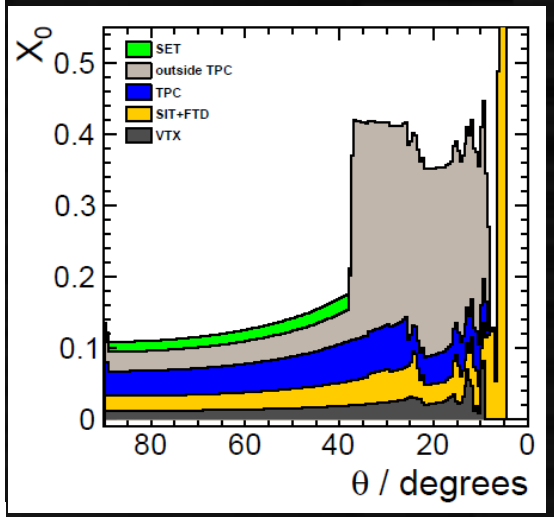
Performance of ILD

IDR: arXiv:2003.01116

Tracking



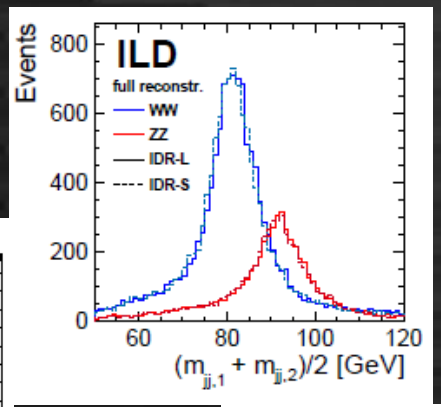


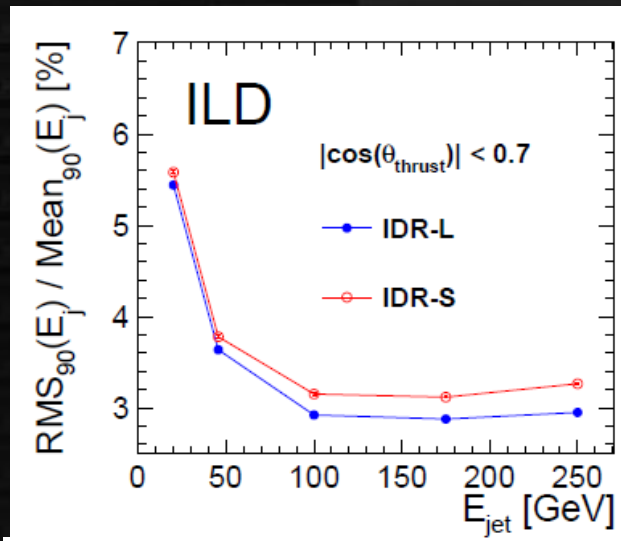


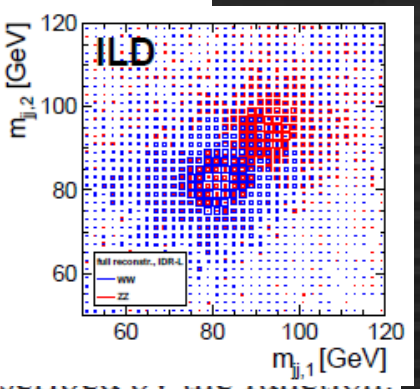
~0.1% p_T resolution
with vertical tracks
d_0 reso of a few μm

0.1 X_0 (barrel)
0.4 X_0 (endcap) before calo

Particle flow







The jet energy resolutions are reasonably well de[illegible]

$$\frac{\mathrm{rms}_{90}}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E$$

$$\oplus\, 2.1 \left(\frac{R}{1825}\right)^{-1.0} \left(\frac{B}{3.5}\right)^{-0.3} \left(\frac{E}{100}\right)^{0.3} \%,$$

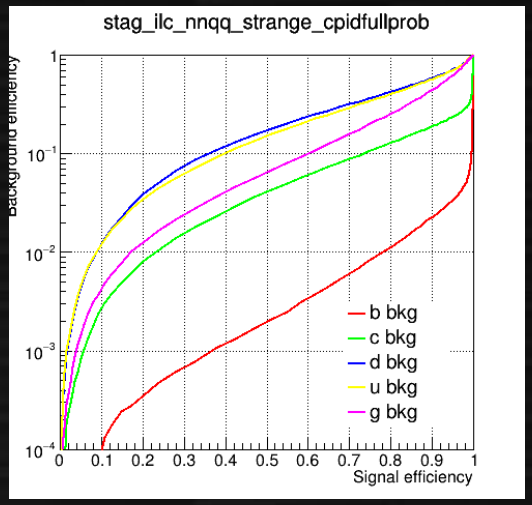
arXiv:0907.3577

Effect of 2 Tesla from 3.5 Testa w/ formula
JER @ 100 GeV: 3.08 → 3.35%?
cf. 3.8% @ 100 GeV with CLD

Implementation of latest AI technologies

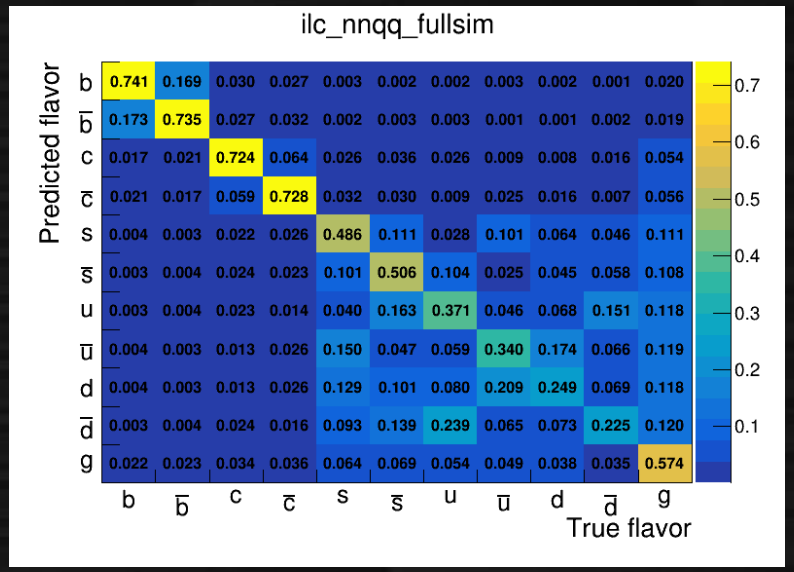
arXiv:2603.18814

Flavor tagging with Particle Transformer



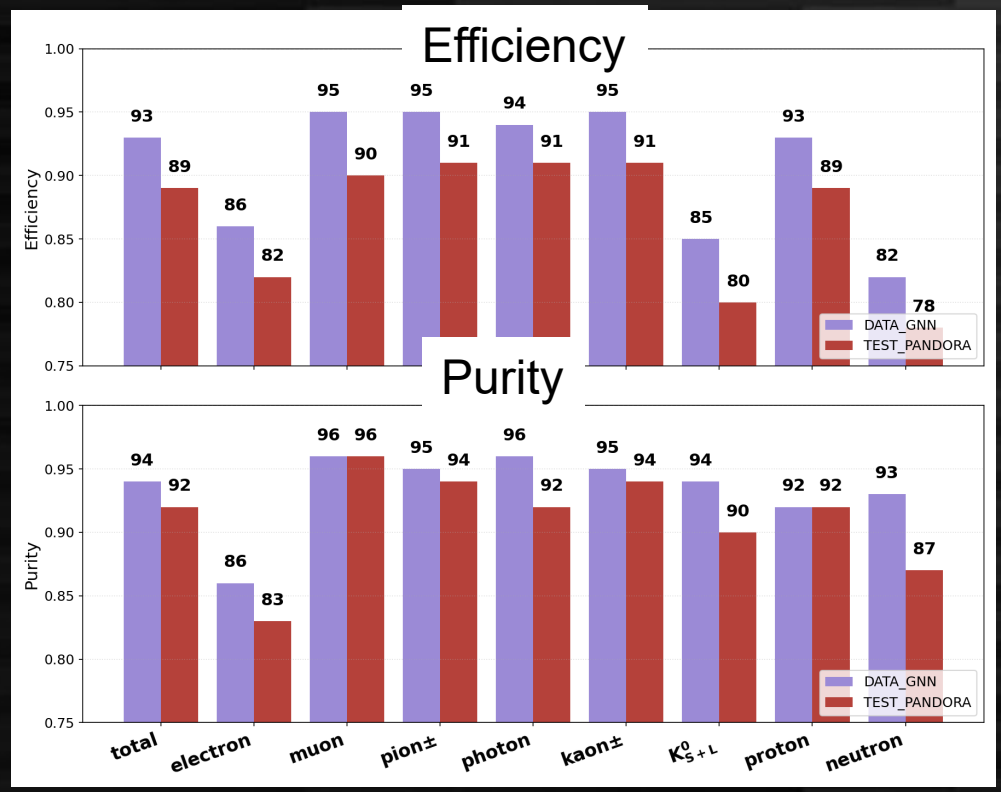
Realistic tracking should be important

Neutral particles are also important
→ calorimeter



11-category tagging with ILD full simulation

Particle flow with GNN (+ more)



GNN

Pandora

νν̄qq sample at 250 GeV

Better performance of the clustering seen
Still working on energy regression (& timing)

Only full simulation can do the clustering study

Recent physics studies with ILD

Example: ZH, H → ss (,bb,cc,gg) study

Applying 11-category flavor tag with ParT for cuts and jet paring (in Z→qq case)

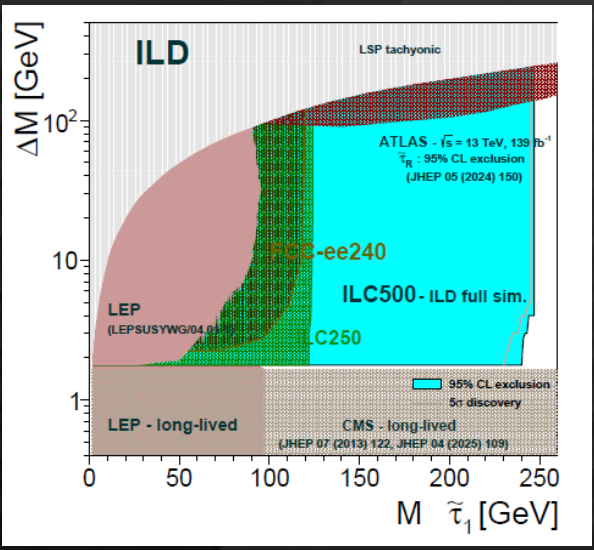
ILC	$Z \to \nu\bar{\nu}$ eLpR	$Z \to \nu\bar{\nu}$ eRpL	$Z \to e^+e^-$ eLpR	$Z \to e^+e^-$ eRpL	$Z \to \mu^+\mu^-$ eLpR	$Z \to \mu^+\mu^-$ eRpL	$Z \to q\bar{q}$ eLpR	$Z \to q\bar{q}$ eRpL
Signal	3.86	2.19	0.506	0.406	0.584	0.434	4.90	3.62
Bkg	1074	196.9	104	59	103	46	14170	3970
Sig.	0.118	0.156	0.049	0.053	0.057	0.063	0.041	0.057

Sensitivity to g_{Hss}: ~130% in ILC250 2ab-1

Example of low δm stau

arXiv:2604.06103

Low δm stau → forward
ISR photons to be tagged
Degradation of FCC-ee due to limited forward coverage (depending on MDI)



Other topics in ILD physics meeting in a year

https://agenda.linearcollider.org/category/131/

- Quantum decoherence measurements
- Extra scalar searches
- Exotic scalar decays into tau lepton pairs
- $e^+e^- \to$ s sbar
- Probing CPV in H → ττ
- Leptophilic Z' searches
- Charged LLP analysis
- Higgs self-coupling (ZHH)

Critical physics topics for FCC-ee

Topics which full simulation is critical

- Exotic BSMs
  - Long-lived particles
  - non-pointing photons
- Tau reconstruction

Flavor physics (detailed reconstruction necessary)

- Best performance in particle separations
- Need studies for Z-pole (2 Tesla, background)

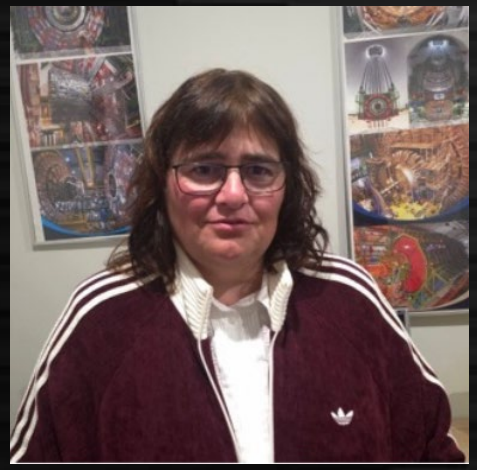
New management for ILD

Current management

Deputy spokesperson:
K. Kawagoe (Kyushu)
Physics coordinator:
A. F. Zarnecki (Warsaw)
Software coordinator:
F. Gaede (DESY)
Technical coordinator:
MC. Fouz (CIEMAT)

Spokesperson: Ties Behnke (DESY)

Management from Sep. 2026



Other management members are now finalizing

New spokesperson: Mary-Cruz Fouz (CIEMAT)

18 countries
59+7 institutes

ILD simulation framework

Event generation

- Whizard v2.8.5 (and 3.0.3) for ME calculation
  - Beam energy spread / beamstrahlung can be properly included
- Pythia v6/8 for hadronization (LEP tuning)
- Tauola for tau decay (whizard-tauola interface)

Reconstruction

- Based on Marlin/LCIO
  - Gaudi wrapper available
- Native PandoraPFA
- ParT-based flavor tag available

Detailed detector simulation

- DDSim
  - Steering file provided in ILDConfig
- Geometry description in compact file
  - Incl. all detector elements
- SGV (“detailed” fast simulation)
  - Track hit pattern & full covariance
  - Parametrized confusion of PFlow

Mass production

- Full SM background centrally produced
  - 250/500/1000 GeV, total ~1B events
  - Using ILCDirac / kept in grid
  - All DST and partial REC (w/hits) kept
- ILD MC production active by request
  - 10M/flavor sample for DNN study
  - PFA sample being processed

How to access ILD simulation data?

- In the current policy, ILD (guest) membership is needed to access the full-simulation data (central production)
- Lightweight guest membership possible
  - Either a group in the university/institute or individual can apply
  - Simple approval by management only required (with simple statement)
  - 2 years of term, can be renewed or promoted to full membership
- Access right from FCC-ee physics study can be considered
  - No regulation yet, to be discussed upon request
- May have open “benchmark” data for AI/reconstruction studies
  - To be discussed among new management

What to be done for FCC-ee studies

- ILD-2 Tesla is not well studied
  - Degradation of PFA performance expected, physics effect to be examined
  - For Z-pole we understand 2 Tesla might be maximum mag. Field
    - Performance to be checked with critical physics processes
  - We still highly prefer 3 or 3.5 Tesla for 240 GeV operation
- Beam background studies ongoing
  - Effect to vertex detector
  - Effect to TPC (esp. for Z-pole operation)
    - Heavily depend on MDI structure: optimization necessary
  - Lesson from SuperKEKB: prepare for (much) higher background

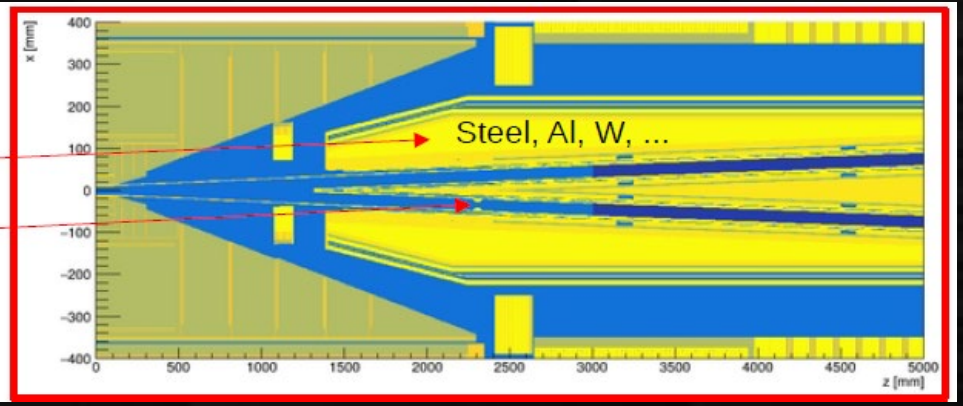
Background studies for FCC-ee

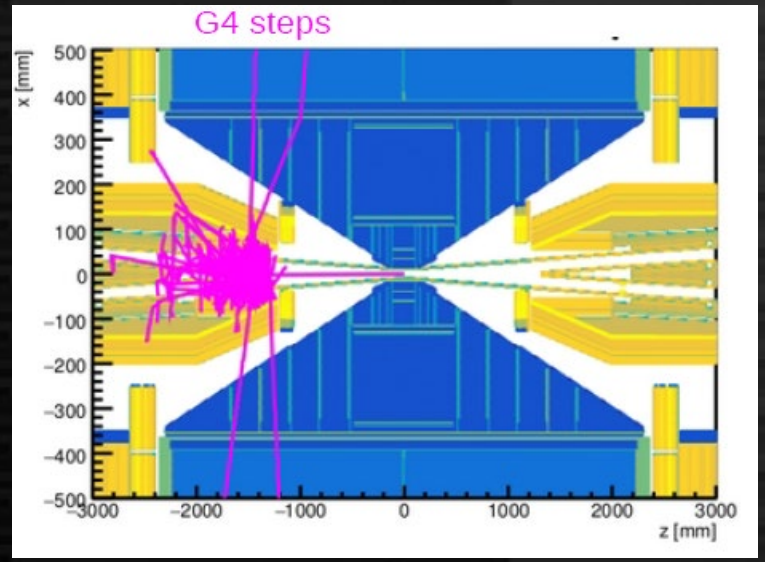
More details by D. Jeans this afternoon

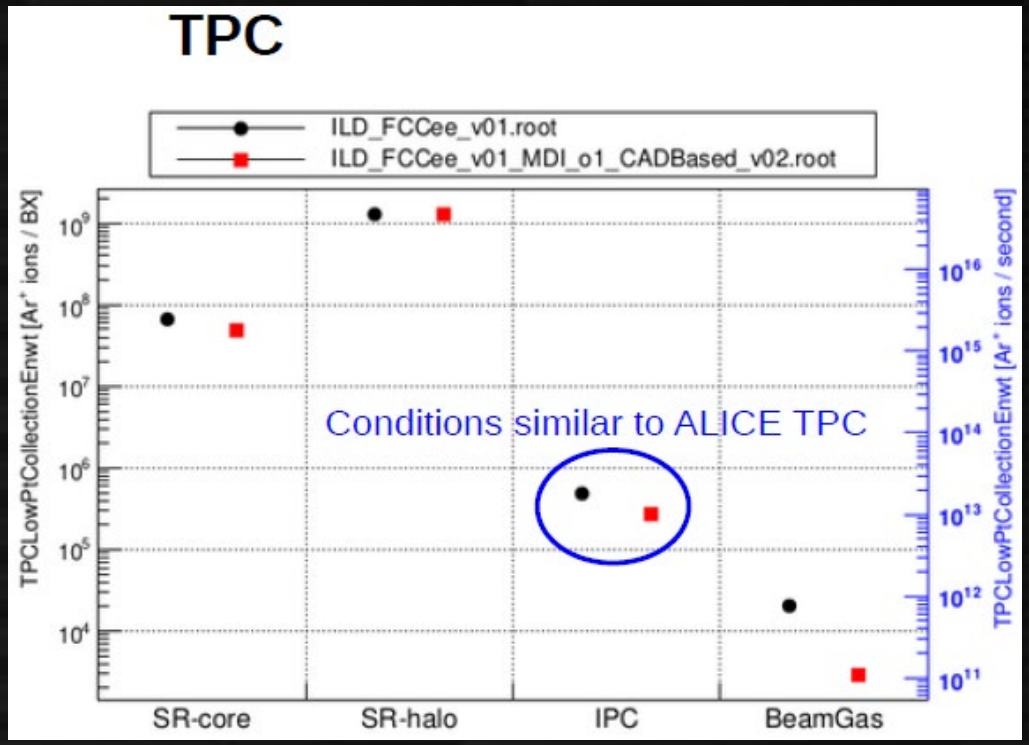
new CAD-based model
MDI_o1_CADBased_v02

Cryostat full of material

SR masks







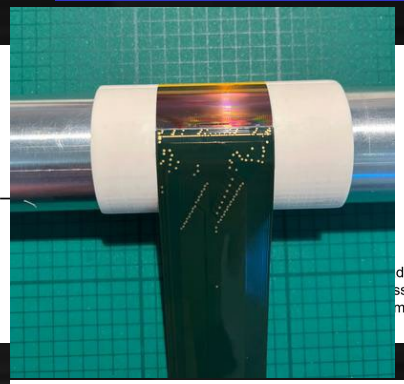
IPC: incoherent pair creation

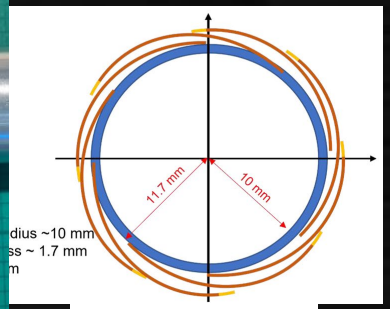
Operation at the Z with the current estimates of SR background is essentially impossible with the current assumptions about subdetector characteristics.
The background levels due to IPC are bearable.

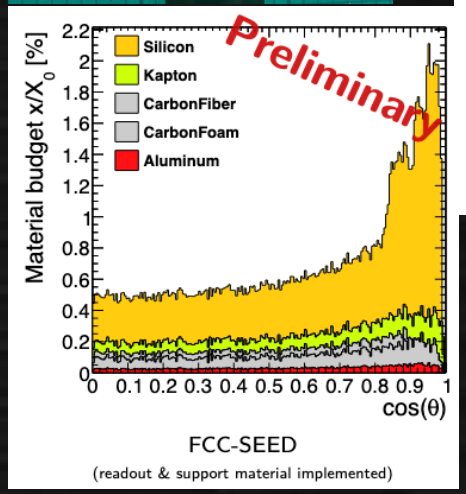
Background heavily depends on IR configuration
Field distortion study is also being conducted

Pursuing new technologies!

Lower material

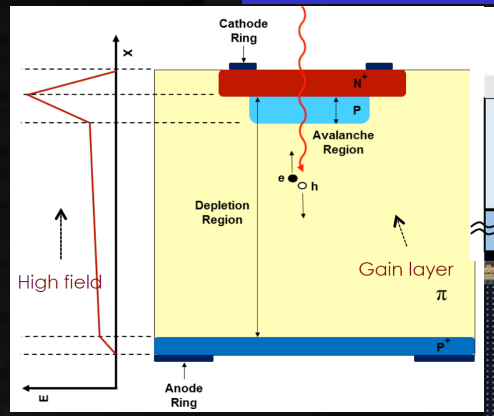


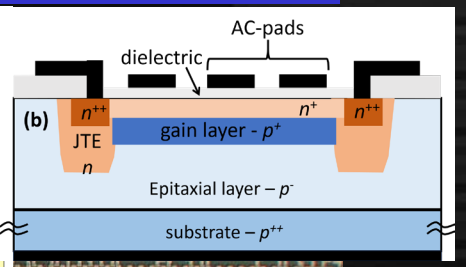




FCC-SEED
VERTEX DETECTOR
FOR FCC-ee

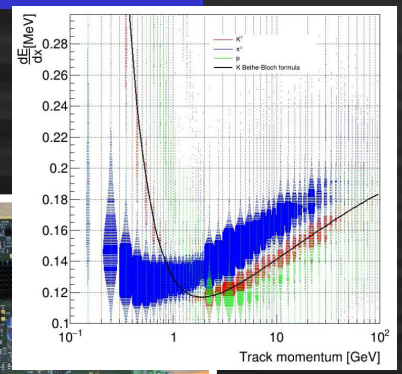
Timing capabilities

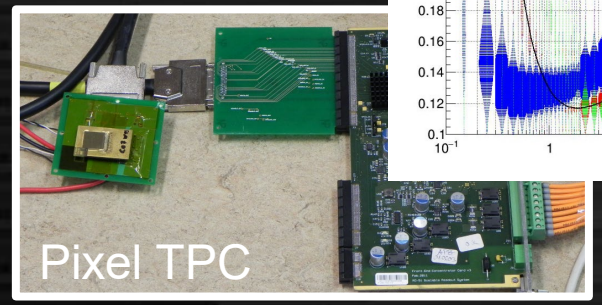




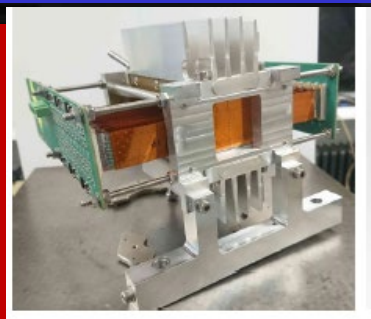
LGADs (variants) / SPADs
Pixel/strip (for tracker)
pixel/pad (for calorimeter)

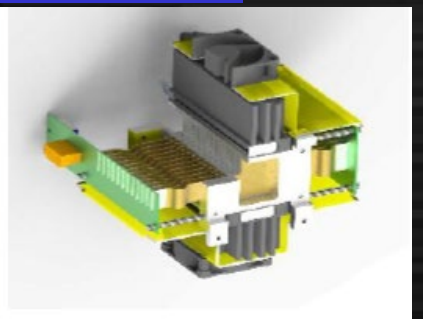
Better dE(dN)/dx





Ultra-high granularity





Still a lot of room to accommodate cutting-edge technologies
Good to know performance with full-simulation studies!
Hardware R&D closely connected with DRDs

And more!

ILD action list for coming years

- Updating/optimizing detector design
  - Full adaptation to circular detectors (continuous readout, active cooling etc.)
  - Improving detector design / accommodating latest technologies
    - More MAPS options with smaller material?
    - Pixel TPC (for better PID)
    - Silicon tracking (timing for outer trackers, MAPS tracking etc.)
    - Timing on calorimeters
    - Detailed design on muon detector
- Performance study with 2 Tesla and Z-pole
- Software integration for common physics studies (analysis chain)
  - Data management policy needs to be revisited
- Critical physics studies for FCC-ee: closer connection to FCC-ee desired
  - 240 GeV mass production with FCC-ee configuration?
  - Z-pole study, precision EW and flavor physics
  - Higgs study update (branching ratios, exotic decay etc.), exotic BSM studies

Advancing the ILD for next Collider

TECHICAL COORDINATION

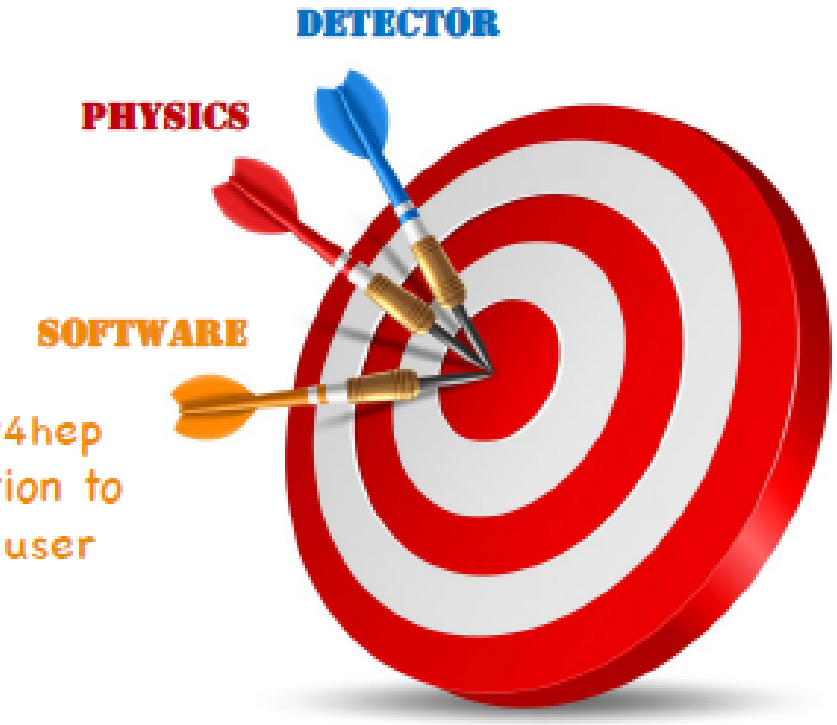
Revisit the **DETECTOR** design to address new challenges and proactively integrate advances emerging from the DRDs, and evaluate and optimise the use of sub-nanosecond timing capabilities to further enhance ILD performance.

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.



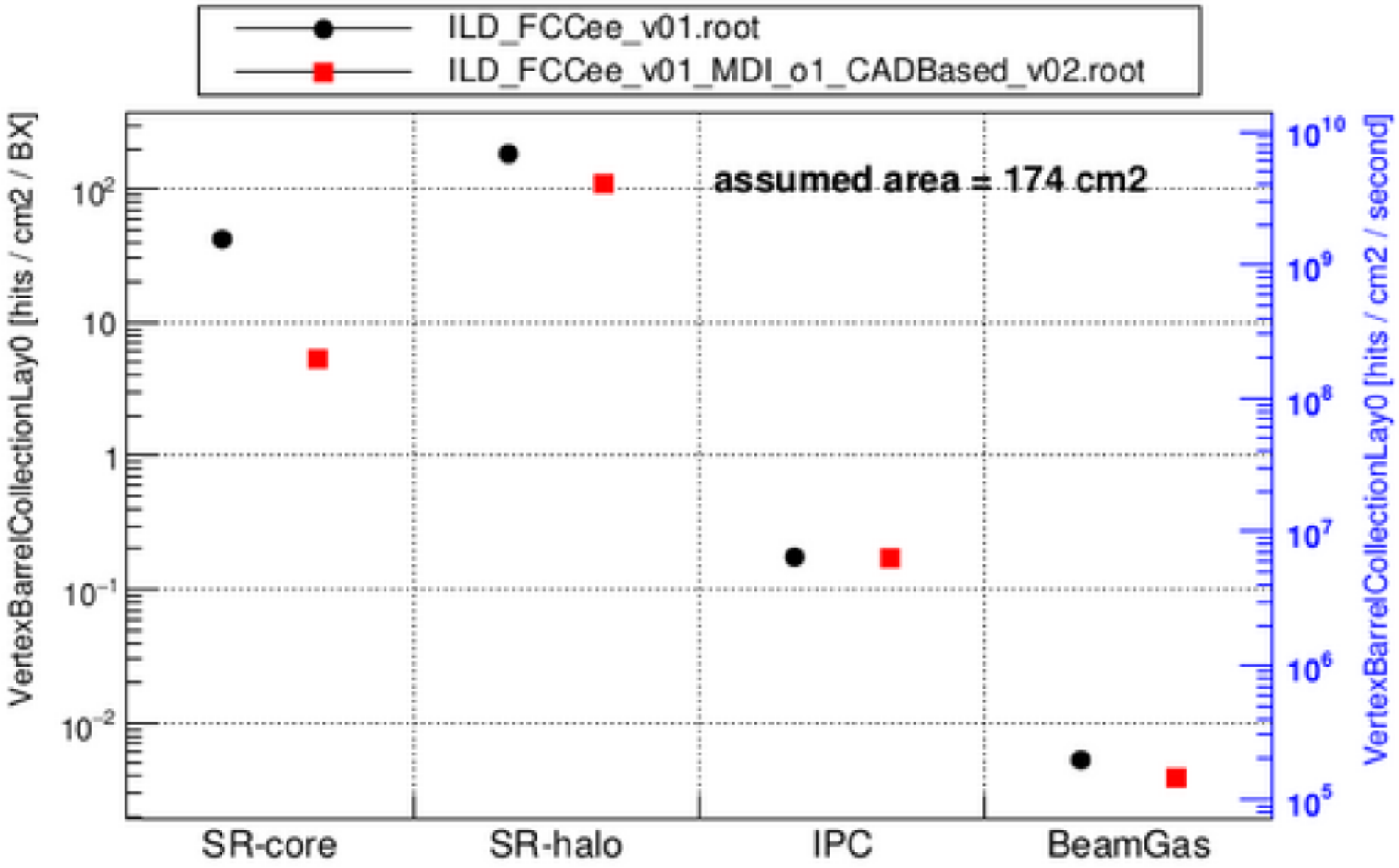
Summary

- New management being formed, coming with fresh strategies
- ILD gives an excellent performance standards for FCC-ee physics
  - Optimal performance of particle flow (further improving by ML)
  - Consisting of technologically-validated detector components
  - Sufficiently detailed full-simulation models and tools
  - Ready for key FCC-ee physics performance studies!
- Adaptation to Key4hep implemented and more integration possible
- Optimization/performance studies for Z-pole to be done
  - For lower magnetic field and heavy background
- Still a lot of room for new ideas/configurations
  - We welcome new collaborators with new ideas/technologies!

ILD (in-person) meeting on 14-16 Sep. at CERN
Non-members of ILD are highly welcome!

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

Vertex barrel : layer 0



new MDI:

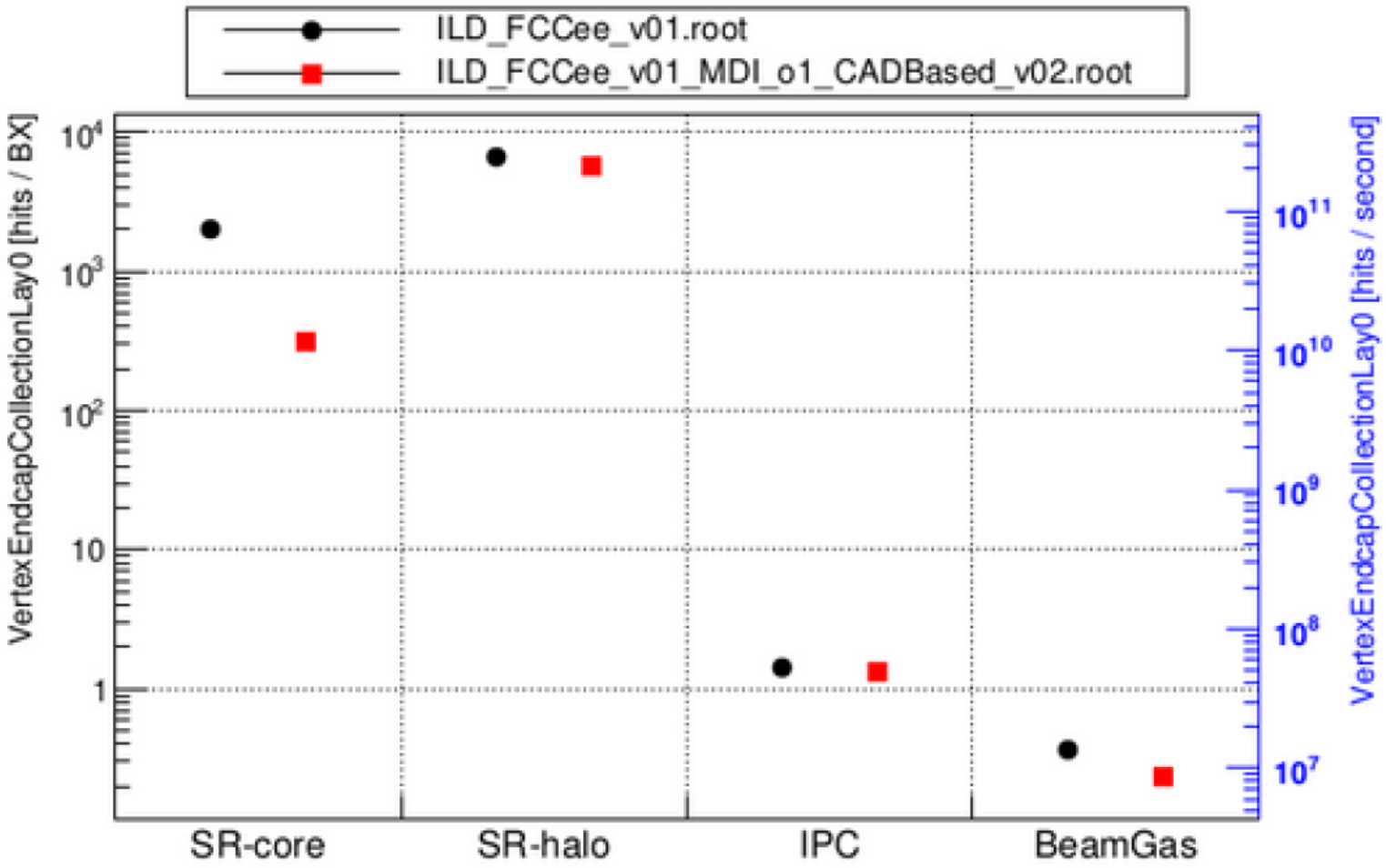
SR background (core)
reduces by ~10

SR background (halo)
reduces by ~2

No effect on **IPC** (beamstrahlung)

beamgas negligible

Vertex endcap : layer 0



new MDI:

SR background (core)
reduces by ~10

SR background (halo)
~no change

No effect on **IPC**

beamgas negligible