International Large Detector for a future e^+e^- collider

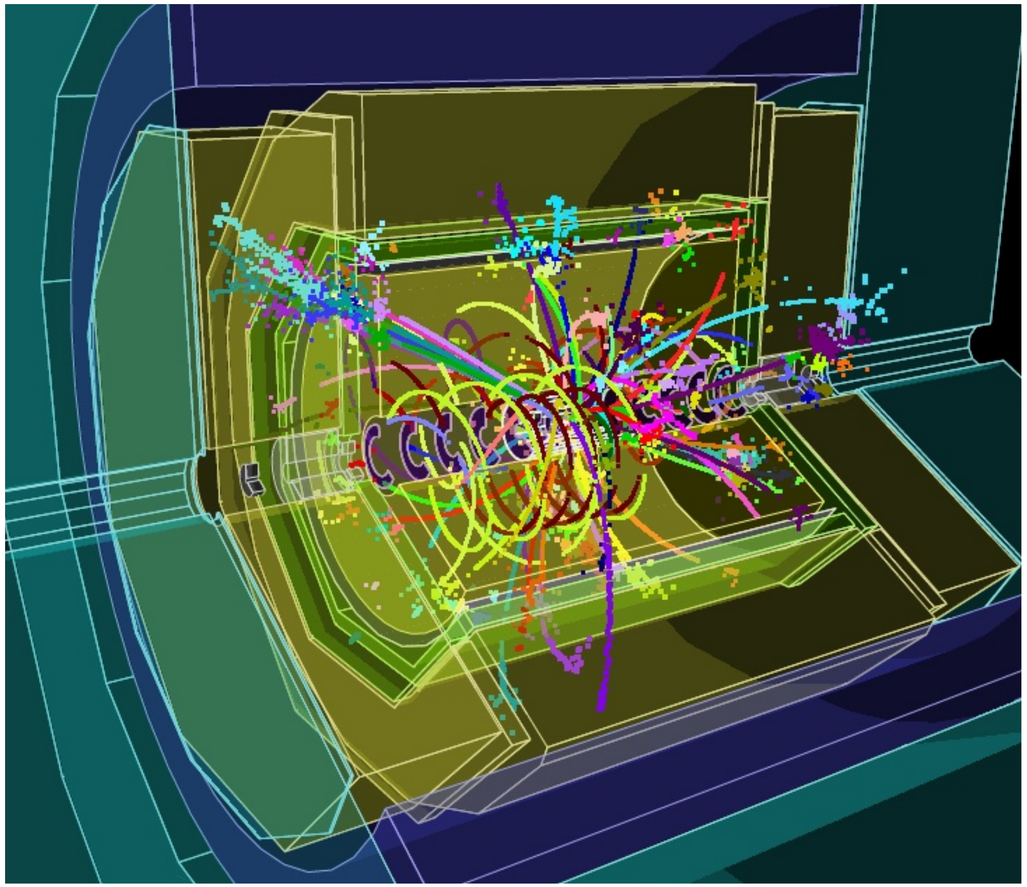
Toshinori MORI, on behalf of the *ILD Concept Group*
ICEPP, The University of Tokyo

XLIII ICHEP, Natal, Brazil, 31 July 2026

ILD for “Particle Flow”

Steadily Evolving as a Versatile Detector Concept for Higgs Factory

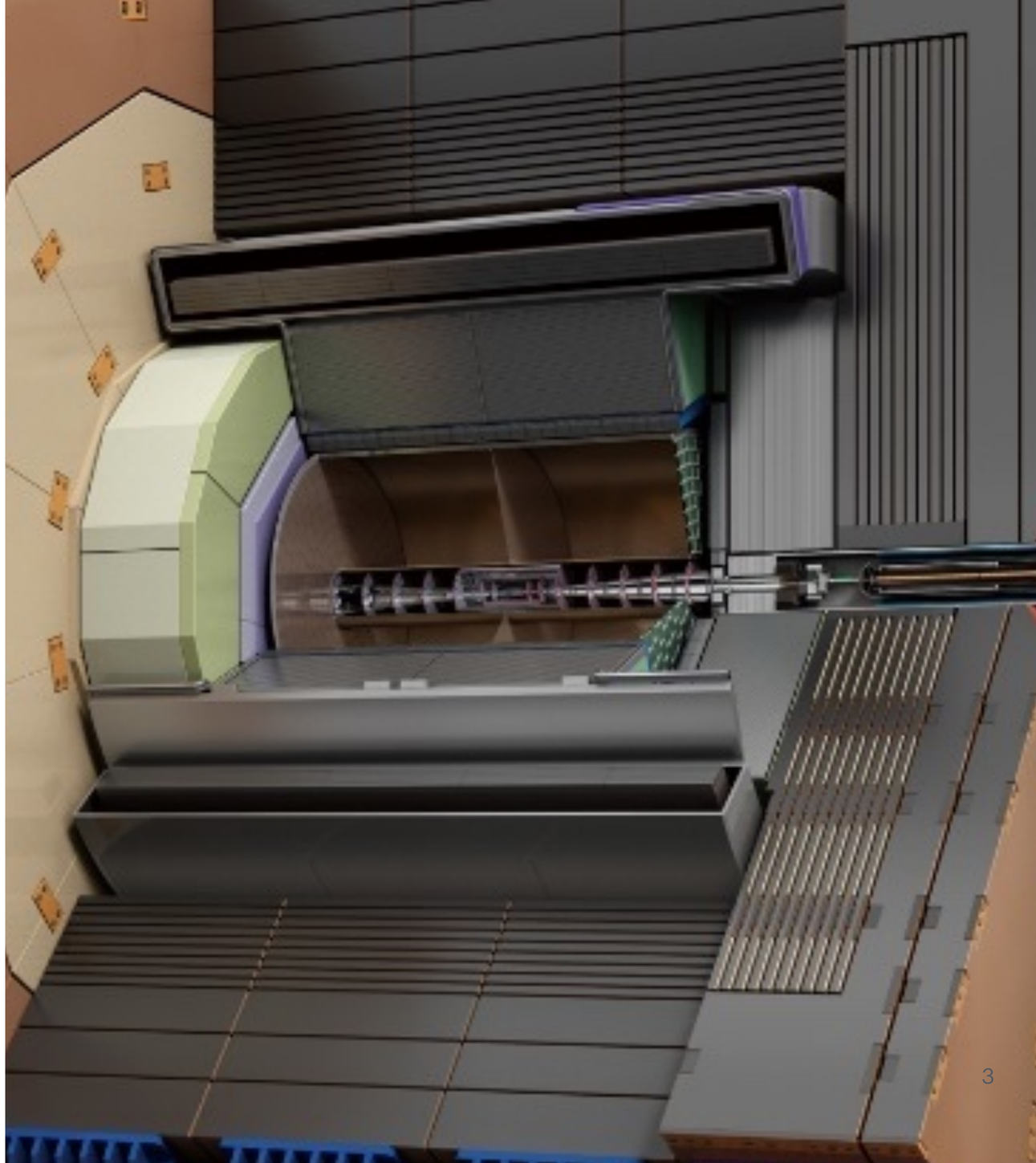
- The first detector concept fully optimised for Particle Flow Algorithm
- TESLA and GLC detectors merged into ILD in 2007
- Has worked as a core of ILC physics studies
- Letter-of-Intent in 2009
- Detailed Baseline Design in 2013 with the ILC TDR
- Contributions to ECFA Higgs/Top/EW Factory study
- Currently being adapted to FCC-ee

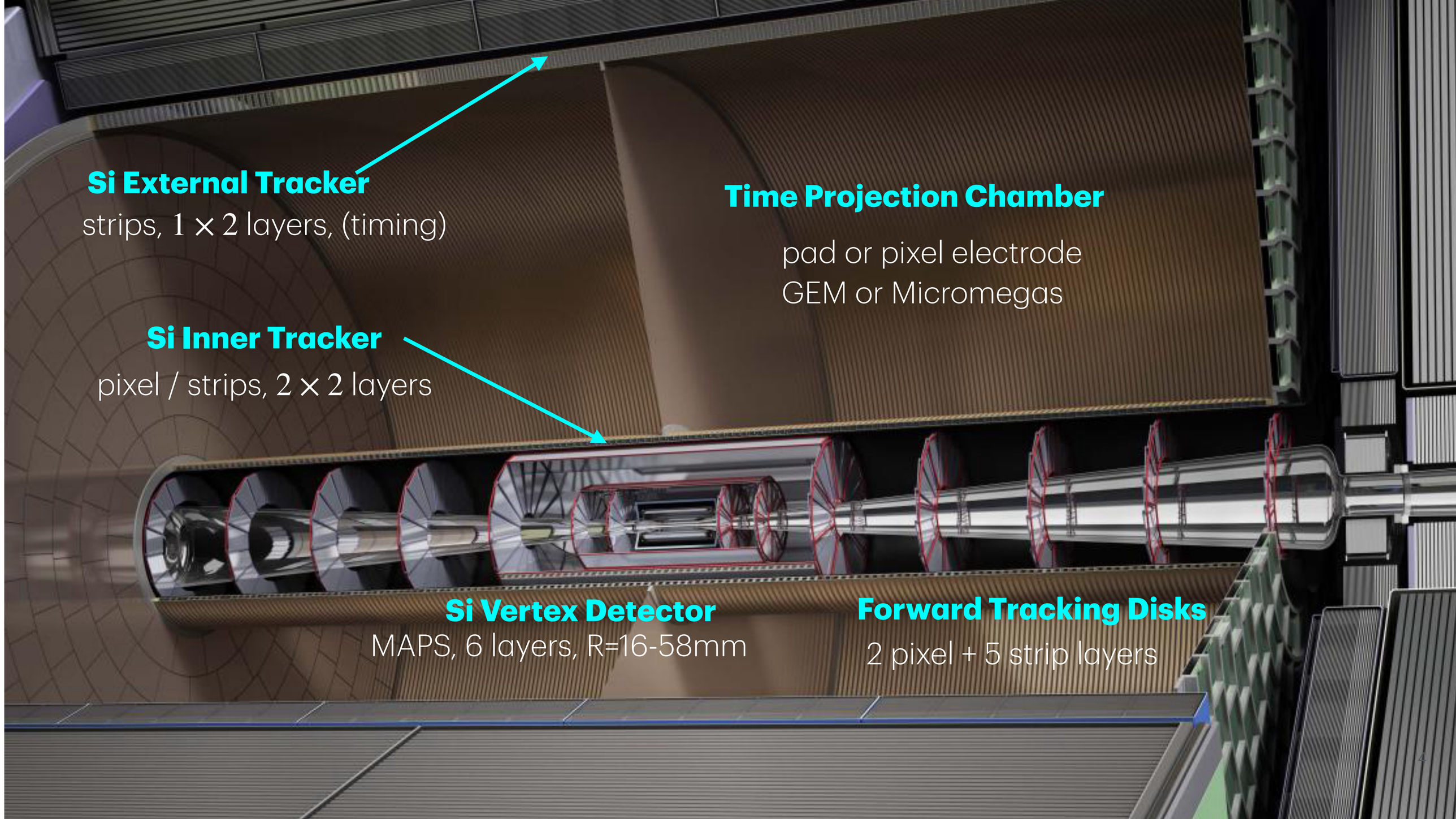


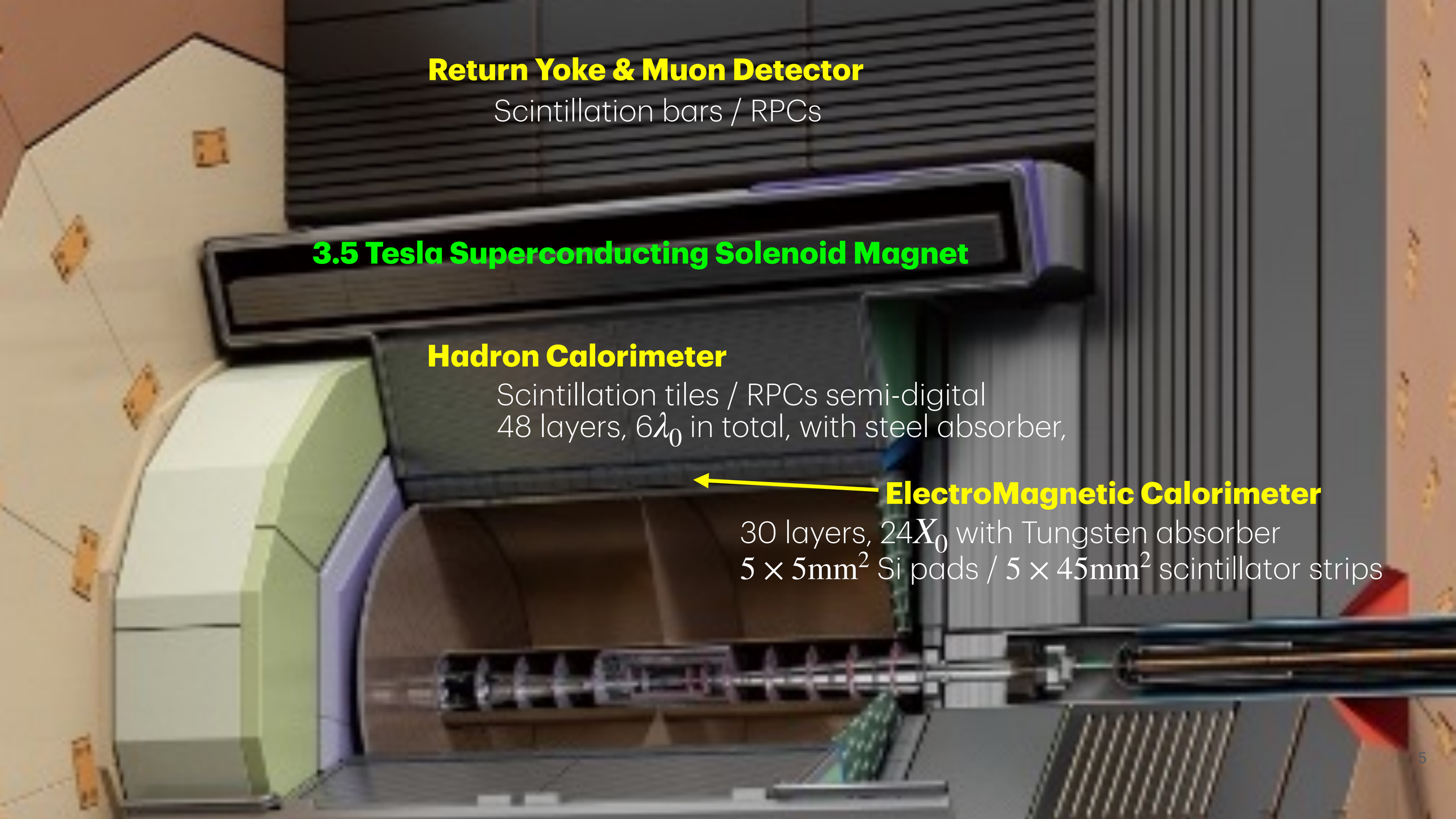
ILD

Design Philosophy

- **Particle flow** paradigm
- **3.5 Tesla solenoid outside the calorimeter**
- Powerful inner detector systems:
  - **Hybrid Si -TPC tracking**
  - High precision **low mass Si system**
- **Highly granular calorimeter**
  - ECAL: Si/Scinti-W sampling
  - HCAL: Scintillator/RPC sampling
- **Particle ID**



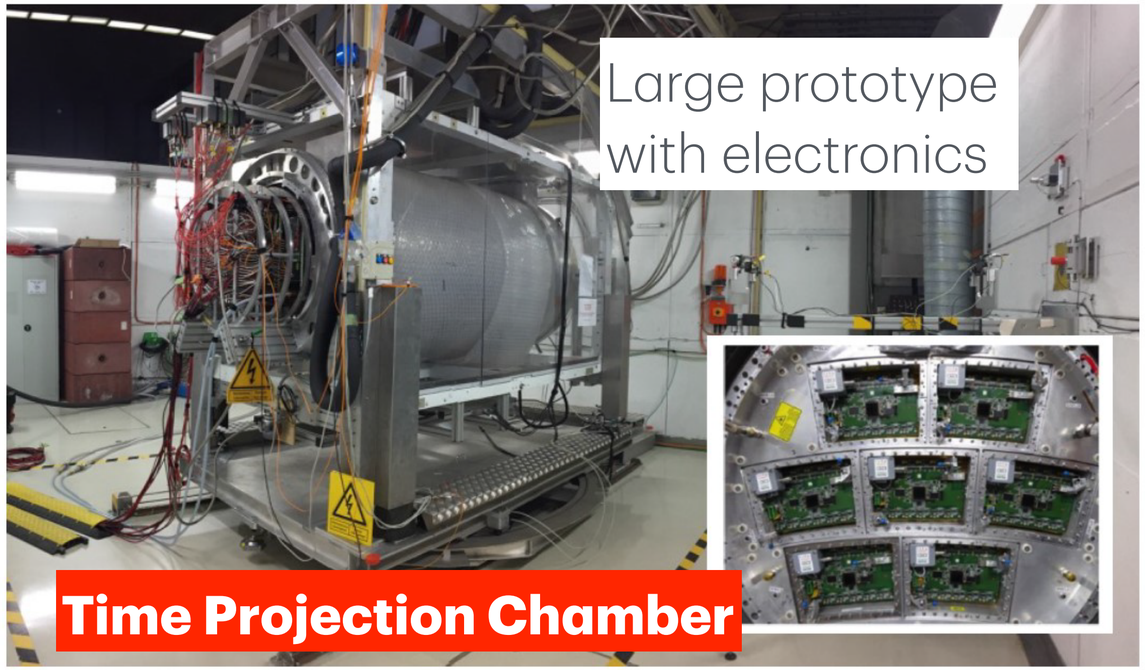

Si External Tracker
strips, 1 × 2 layers, (timing)
Time Projection Chamber
pad or pixel electrode
GEM or Micromegas
Si Inner Tracker
pixel / strips, 2 × 2 layers
Si Vertex Detector
MAPS, 6 layers, R=16-58mm
Forward Tracking Disks
2 pixel + 5 strip layers


Return Yoke & Muon Detector
Scintillation bars / RPCs
3.5 Tesla Superconducting Solenoid Magnet
Hadron Calorimeter
Scintillation tiles / RPCs semi-digital
48 layers, $6\lambda_0$ in total, with steel absorber,
ElectroMagnetic Calorimeter
30 layers, $24X_0$ with Tungsten absorber
$5 \times 5\text{mm}^2$ Si pads / $5 \times 45\text{mm}^2$ scintillator strips

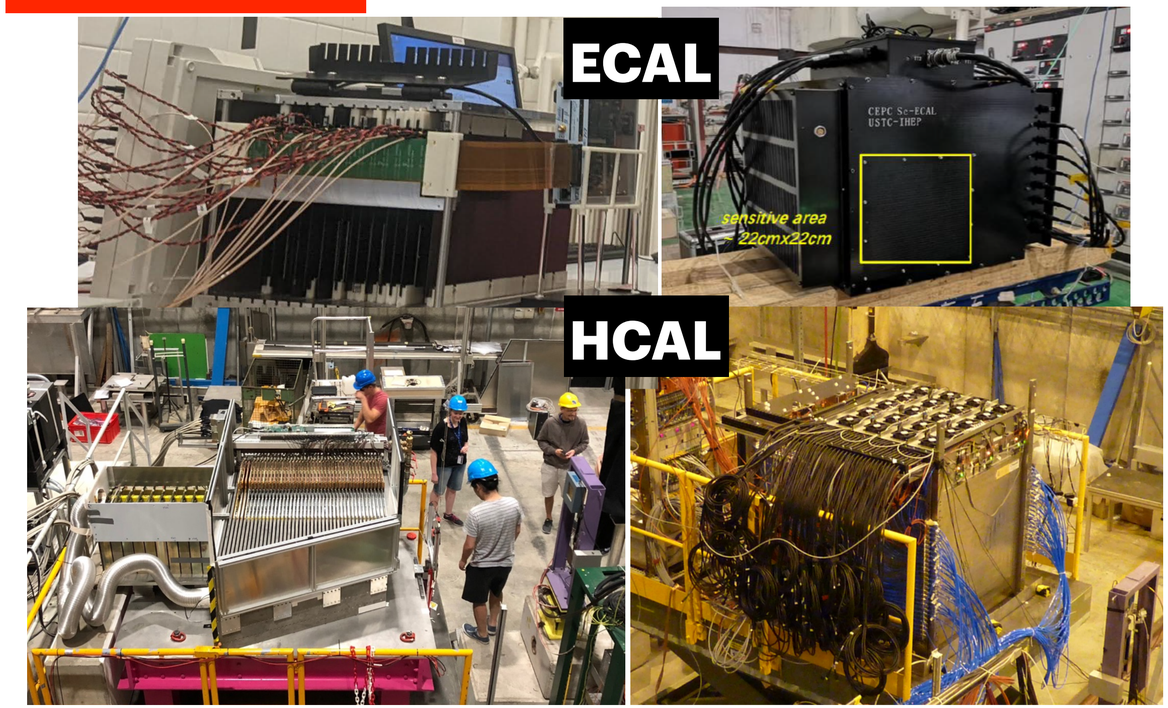
Highlights of Key Technology Demonstrations
in close collaboration with DRD collaborations

Silicon Trackers

- Chips produced and demonstrated
- Current design needs to be updated
  - Open for new collaborations



Calorimeters



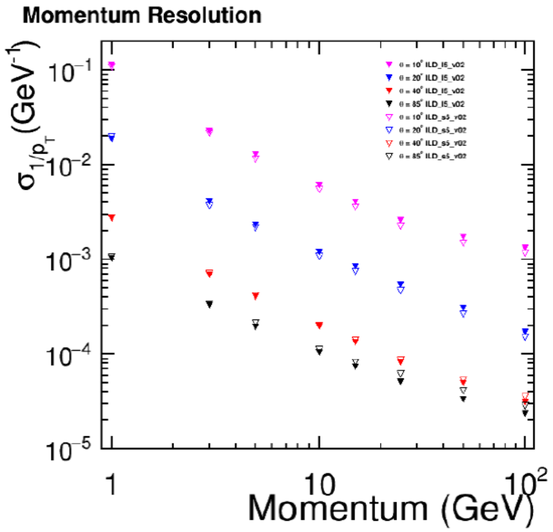
Performance of key components has been already demonstrated with prototypes
Work in progress on continuous readout

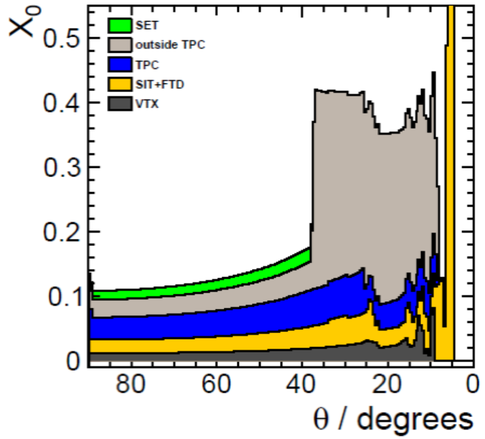
ILD Performance

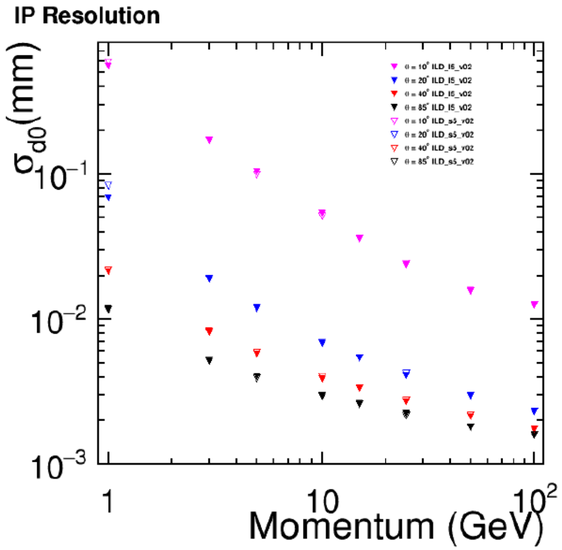
Demonstrated

IDR: arXiv:2003.01116

Tracking

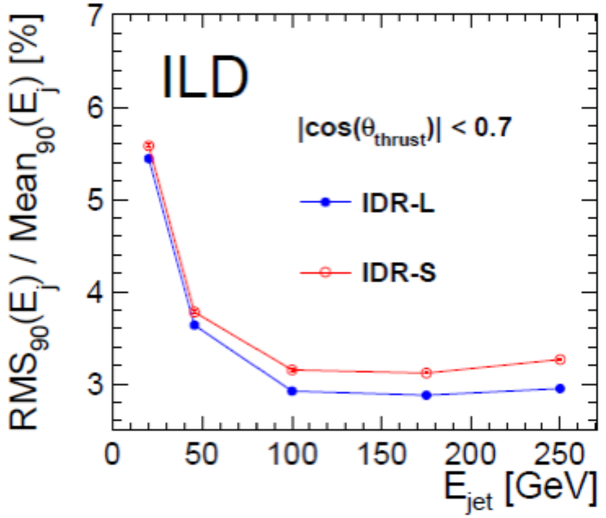


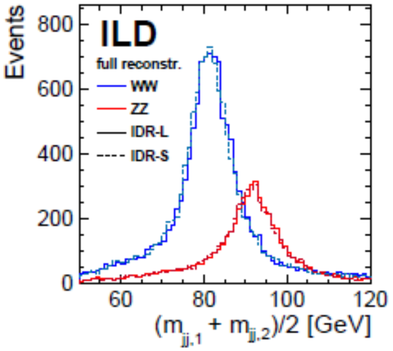


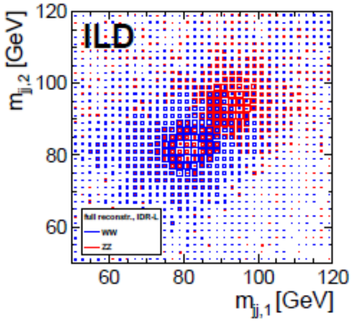


- ~0.1% p_T resolution for vertical tracks
- d_0 resolution a few μm
- material in front of Calo:
  - 0.1 X_0 for barrel
  - 0.4 X_0 for endcap

Particle Flow







The jet energy resolutions are reasonably well described by the function:

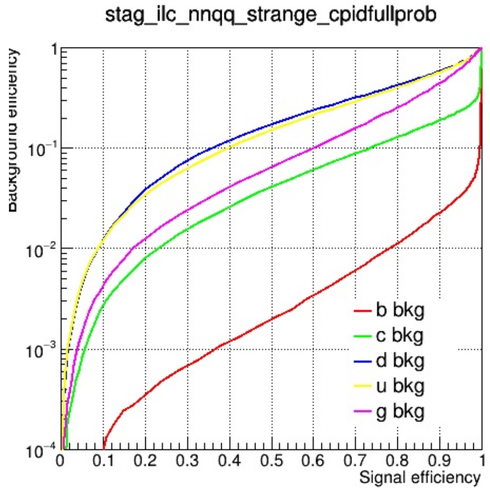
$$\frac{\mathrm{rms}_{90}}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1\left(\frac{R}{1825}\right)^{-1.0}\left(\frac{B}{3.5}\right)^{-0.3}\left(\frac{E}{100}\right)^{0.3}\ \%,$$

arXiv:0907.3577

Effect of 3Tesla —> 2Tesla (Z pole at FCC-ee):
Jet energy resolution @100GeV: 3.08% —> 3.35%?
cf. CLD: 3.8%

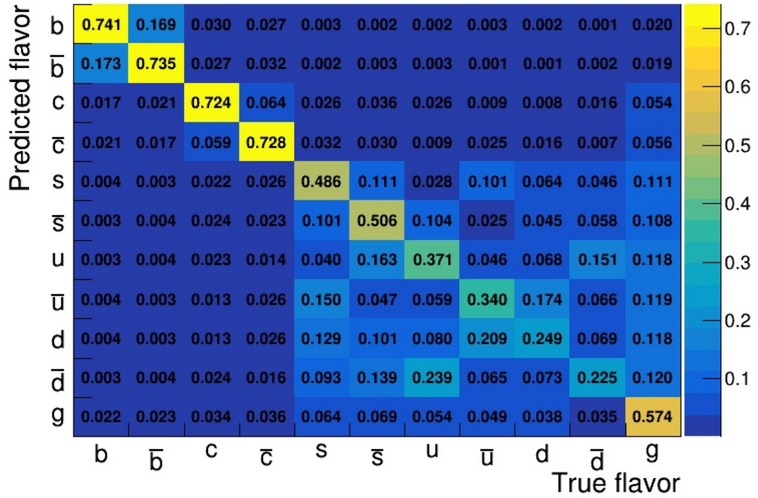
AI Technologies in ILD

Flavor tagging with Particle Transformer



arXiv:2603.18814

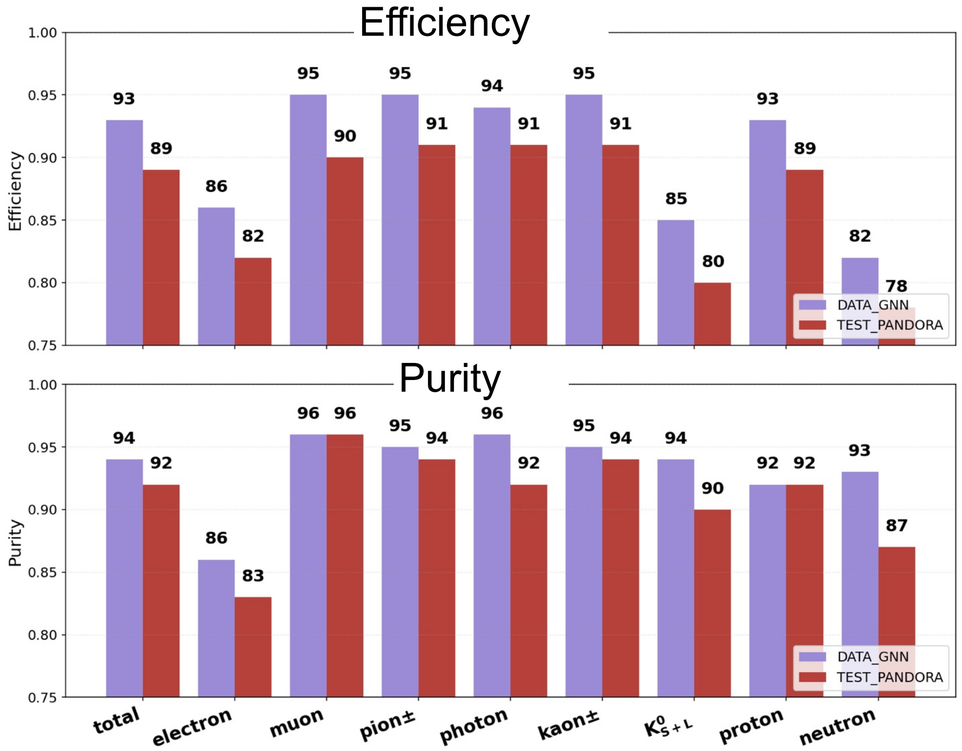
Realistic tracking and neutral particles (calorimeter) are important



11-category tagging with ILD full simulation

Particle flow with GNN (+ more)

$\nu\nu$qq sample at 250GeV Pandora



Better performance of clustering with GNN seen

Work in progress on energy regression & timing

Full detector simulation essential for clustering study

Recent Physics Studies with ILD

- C. Hansel on Higgs
  9:00, 31 July, Rm #12
- T.Mori on Top/EW
  15:00, 01 Aug, Rm #10
- E.Musumeci on BSM
  17:45, 01 Aug, Rm #8

Study of $ZH \to ss, (bb, cc, gg)$

Applying 11-category flavour tagging for $Z \to q\bar{q}$

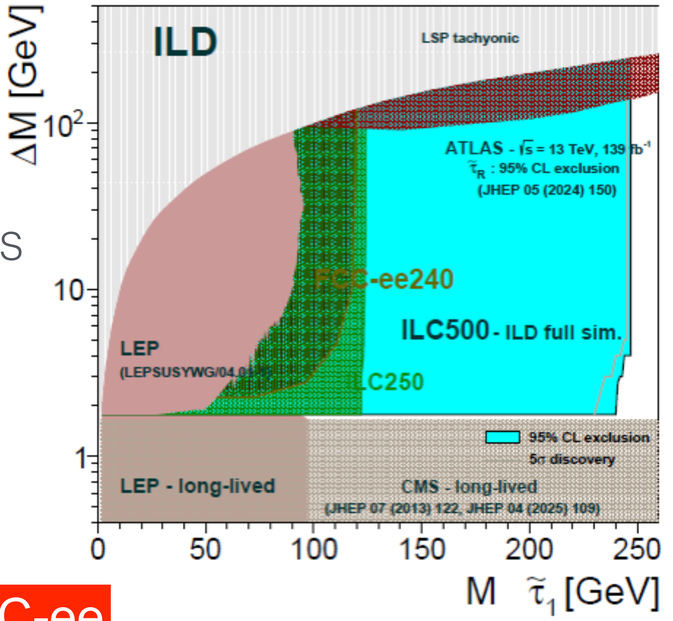
ILC	$Z \to \nu\bar{\nu}$ eLpR	$Z \to \nu\bar{\nu}$ eRpL	$Z \to e^+e^-$ eLpR	$Z \to e^+e^-$ eRpL	$Z \to \mu^+\mu^-$ eLpR	$Z \to \mu^+\mu^-$ eRpL	$Z \to q\bar{q}$ eLpR	$Z \to q\bar{q}$ eRpL
Signal	3.86	2.19	0.506	0.406	0.584	0.434	4.90	3.62
Bkg	1074	196.9	104	59	103	46	14170	3970
Sig.	0.118	0.156	0.049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

sensitivity to g_{Hss} ~130% for 250GeV, 2ab^{-1}

Study of small δm stau

arXiv:2604.06103

Poorer performance in tagging forward remnants at FCC-ee due to limited forward coverage
MDI to be worked out



Other topics during last 1 year

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

- Quantum decoherence
- Extra scalar searches
- Exotic scalar decays into tau lepton pairs
- Leptophilic Z' searches
- Charged LLP analysis
- Higgs self-coupling ZHH
- strange-pair production
- CP violation in $H \to \tau\tau$

Critical physics topics for FCC-ee

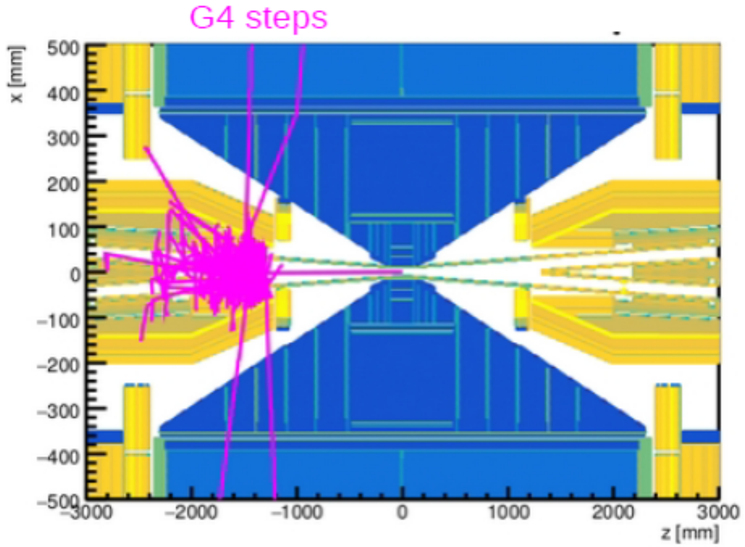
- Topics that requires full simulation:
  - Exotic BSMs
    - Long-Lived Particles
    - non-pointing photons
  - Tau reconstruction
- Flavour Physics
  - Particle separation (PID)
  - Z-pole with 2Tesla & FCC-ee MDI

Want to Work on ILD Simulation Data?

- **Get the ILD “Guest” Membership**
  - **Either as a group or individual**
  - **Two-year term, renewable or promotable to full membership**

To-Do List for FCC-ee Studies

- Study effects of lower magnetic field (**2 Tesla for Z-pole run**) at FCC-ee
  - Some degradation of PFA performance expected; Effects on physics unknown
  - 3 or 3.5 Tesla highly preferred for 240GeV operation
- **Beam background studies** ongoing
  - Effects on the vertex detector
  - Effects on TPC, especially during Z-pole run
    - need **optimisation of MDI**
  - The SuperKEKB lesson: Prepare for much higher background than expected

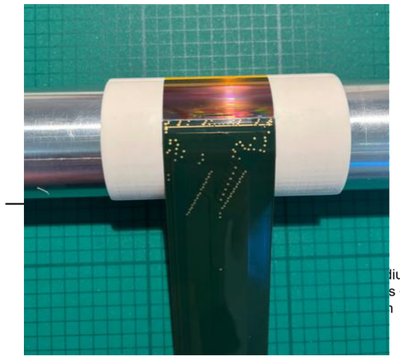


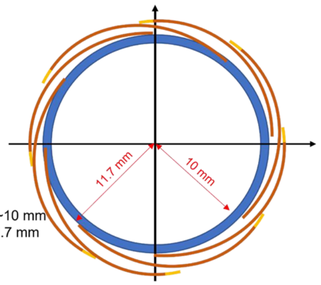
MDI Optimisation necessary for SR background
Incoherent pairs seem tolerable.

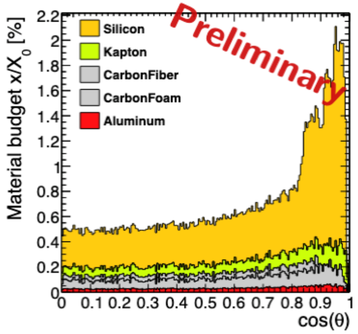
Toward New Technologies

- Large room to accommodate cutting-edge detector technologies
- Study them with ILD's full simulation tools
- Hardware R&D moving ahead with DRD Collaborations

Lower Mass



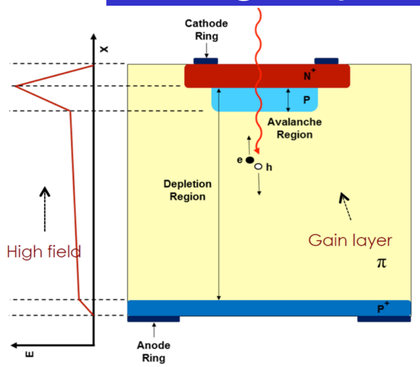


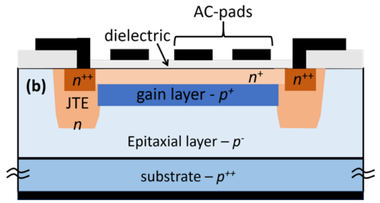


FCC-SEED
(readout & support material implemented)

FCC-SEED
VERTEX DETECTOR
FOR FCC-ee

Timing Capabilities

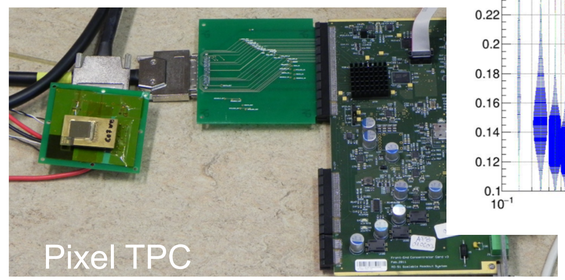


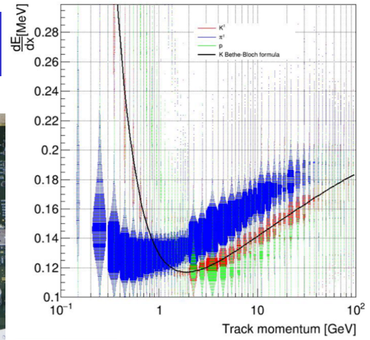


LGADs / SPADs
Pixel / Strip for Tracker
Pixel / Pad for Calo

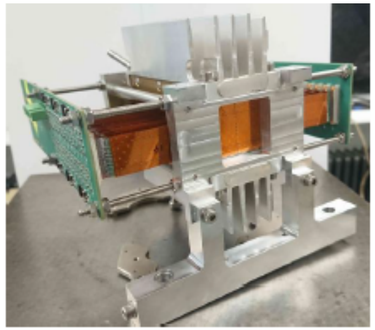
AndMore!

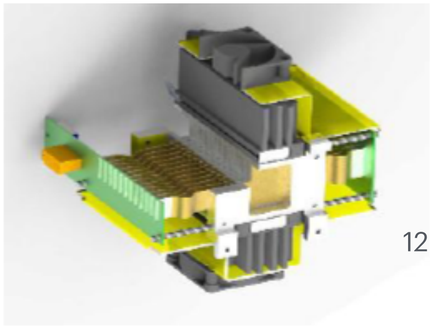
Better dE/dx, dN/dx





Ultra High Granularity





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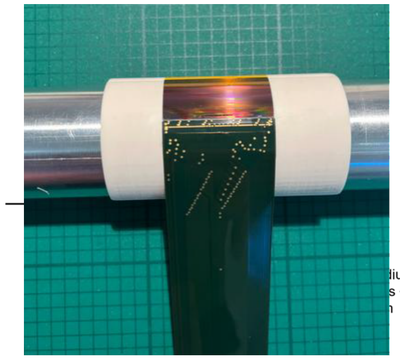

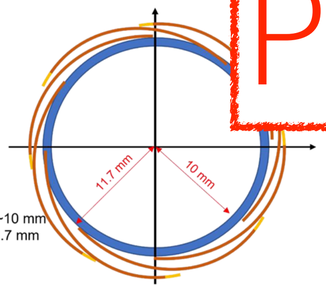

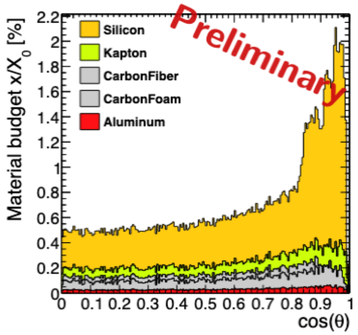

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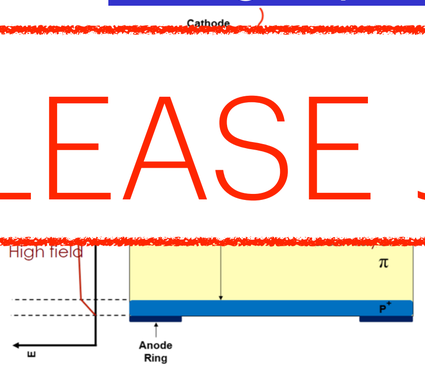

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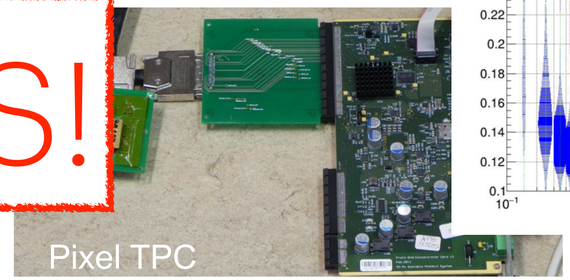

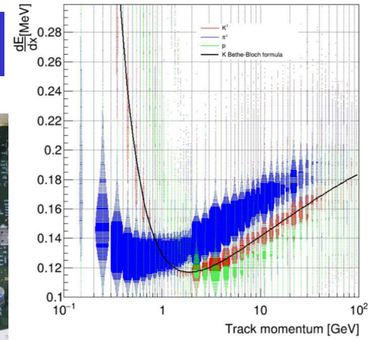

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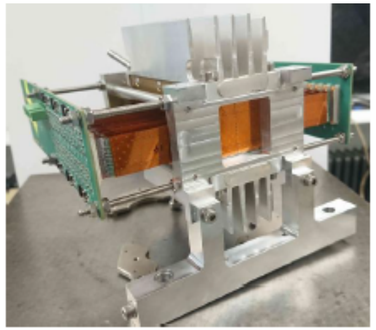
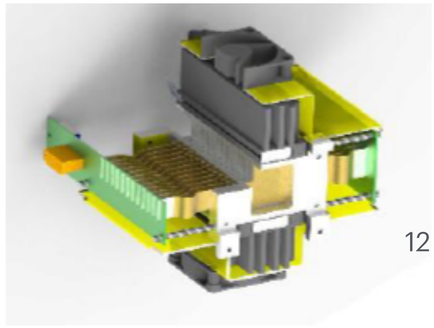




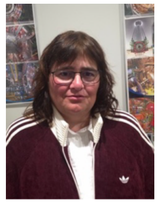
PLEASE JOIN US!

ILD Collaboration From Around the World

18 contries, 59+7 institutes

New Management from September 2026

Ties Behke / DESY



Mary-Cruz Fouz / CIEMAT

Summary

- ILD provides **excellent performance standards** for Higgs Factory physics:
  - Optimal performance of **particle flow**, being further improved by ML/AI
  - Consists of **technologically validated detector components**
  - Sufficiently detailed **full detector simulations** and tools
  - Ready for key **FCC-ee physics performance** studies
- **Key4hep adaptation implemented** and more integration possible
- Optimisation / performance **studies for Z pole** will be carried out
  - Issues: lower magnetic field, heavy background
- Still, have large room for improvements, new ideas and new configurations

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

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New collaborators with New Ideas and Technologies are ALL WELCOME!!

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