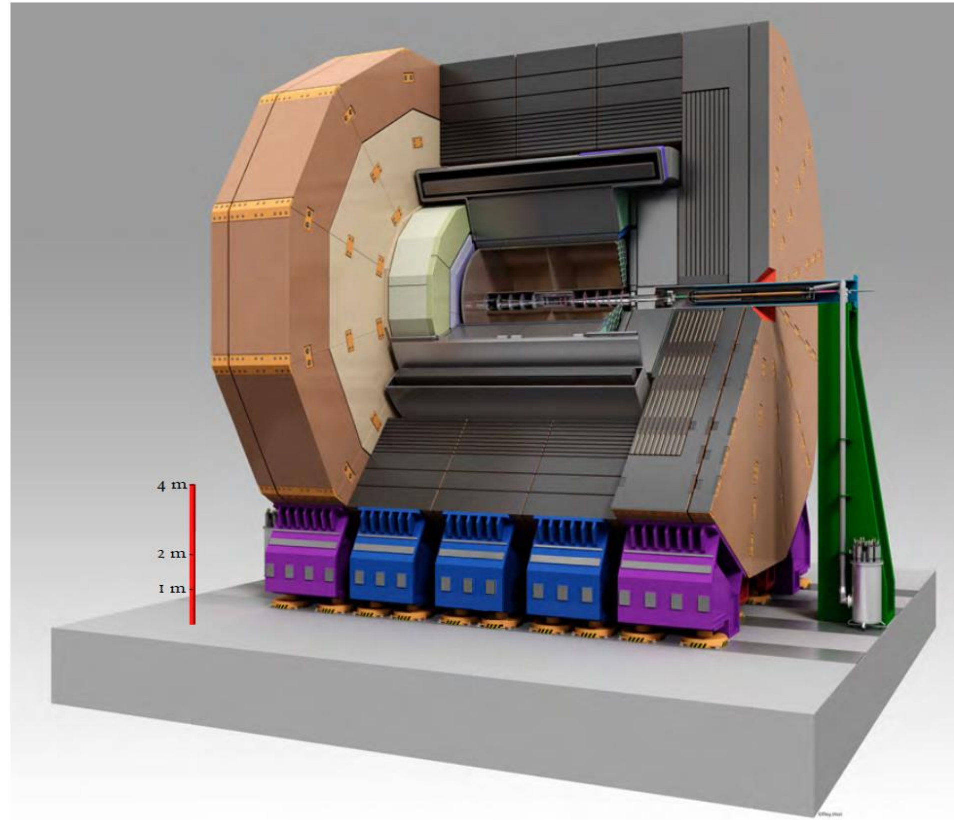
ILD: Status and Plans



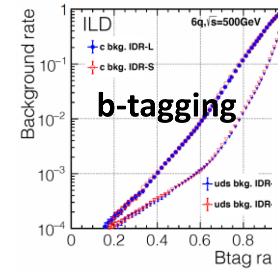
Ties Behnke

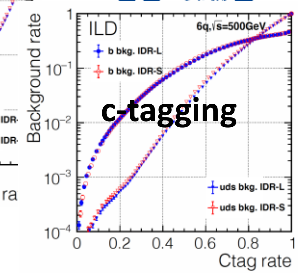
31.5.2024

For the ILD group

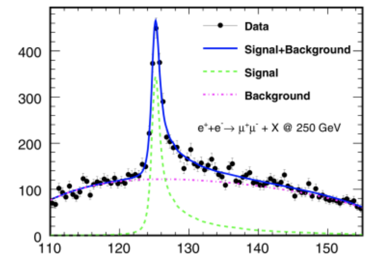
ILD: a detector for precision

Slide heavily borrowed from Tomohiko Tanabe's 2020 ICHEP talk



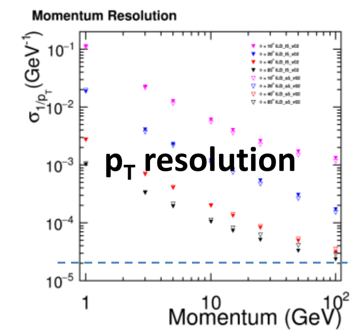


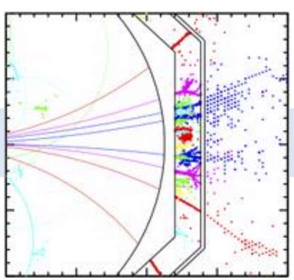
Detector Requirements		**Physics Studies**
• Impact parameter resolution $\sigma(d_0) < 5 \oplus 10 / (p[\text{GeV}] \sin^{3/2}\theta)$ µm	~ LHC / 2	$H \rightarrow bb, cc, \tau\tau$
• Transverse momentum resolution $\sigma(1/p_T) = 2 \times 10^{-5}$ GeV$^{-1} \oplus 1 \times 10^{-3} / (p_T \sin^{1/2}\theta)$	~ LHC / 10	Total $\sigma(e+e- \rightarrow ZH)$
• Jet energy resolution 3-4% (around E_{jet} ~100 GeV)	~ LHC / 2	$Z/W/H \rightarrow jj$; $H \rightarrow$ invisible
• Hermeticity θ_{min} = 5 mrad	~ LHC / 3	$H \rightarrow$ invisible; BSM



Higgs recoil against $Z \rightarrow \mu\mu$

arXiv:2003.01116

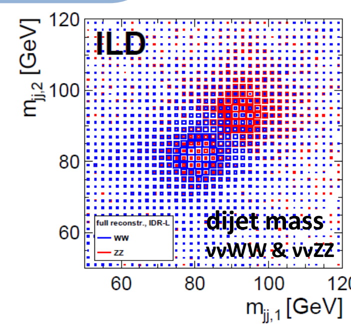


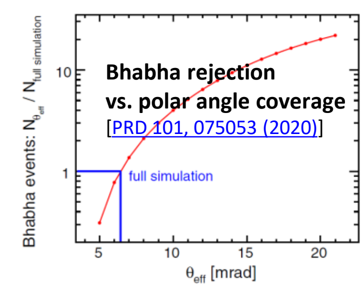


ILD is optimized around **particle flow**:

- Highly granular calorimeters
- Low-mass trackers
- Highly detailed software reconstruction

→ Separation of clusters at particle level





Historically....

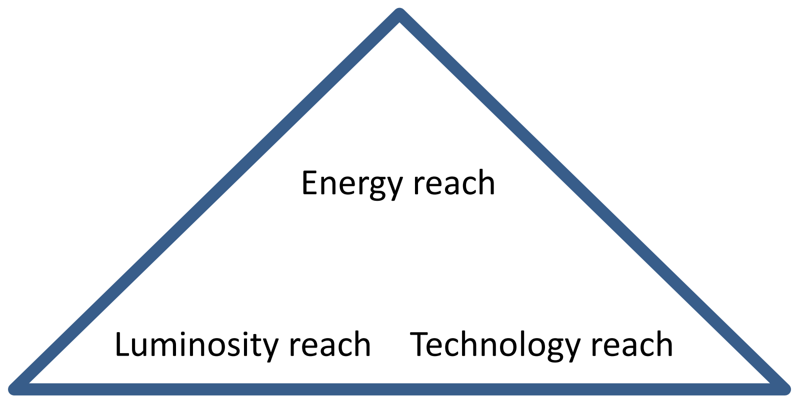
ilc
international linear collider

ILD

The environment

ILC – CLIC - C^3

Linear accelerators



Circular accelerators

FCC CEPC

Novel accelerators

Halfh ERL

The environment

ILC – CLIC - C^3

Linear accelerators

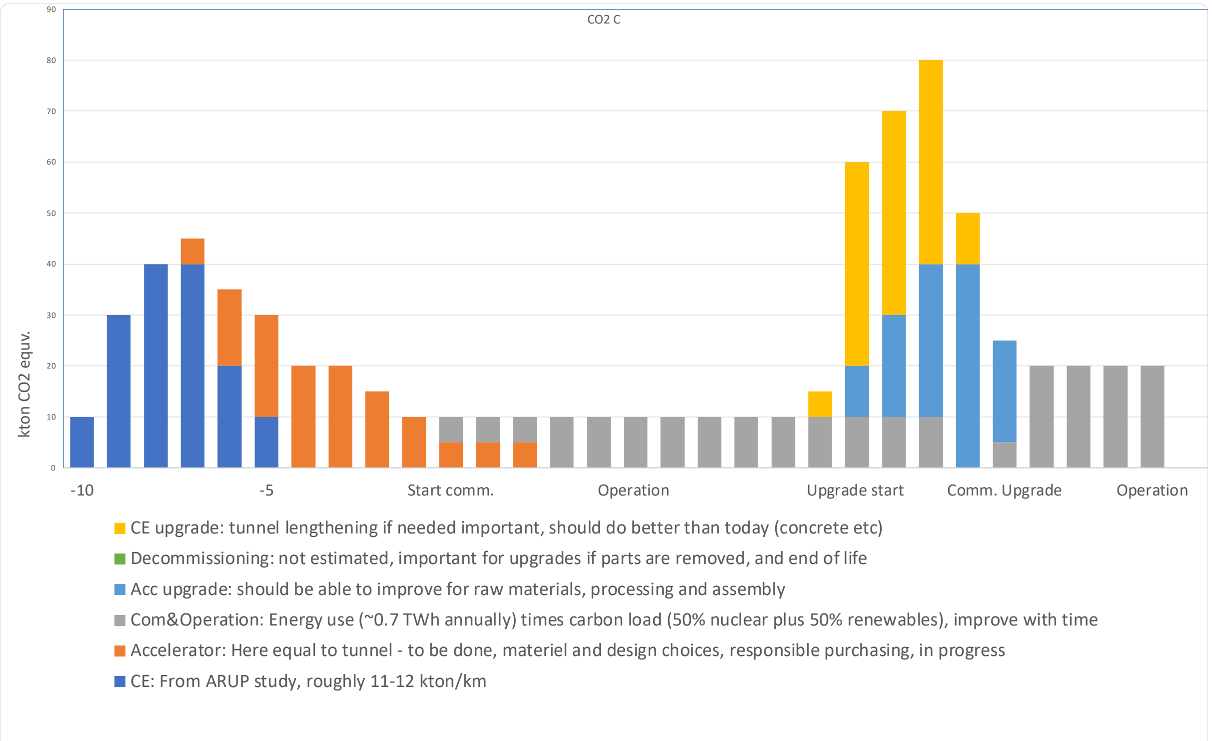
Circular accelerators

FCC CEPC

Novel accelerators

Halfh ERL

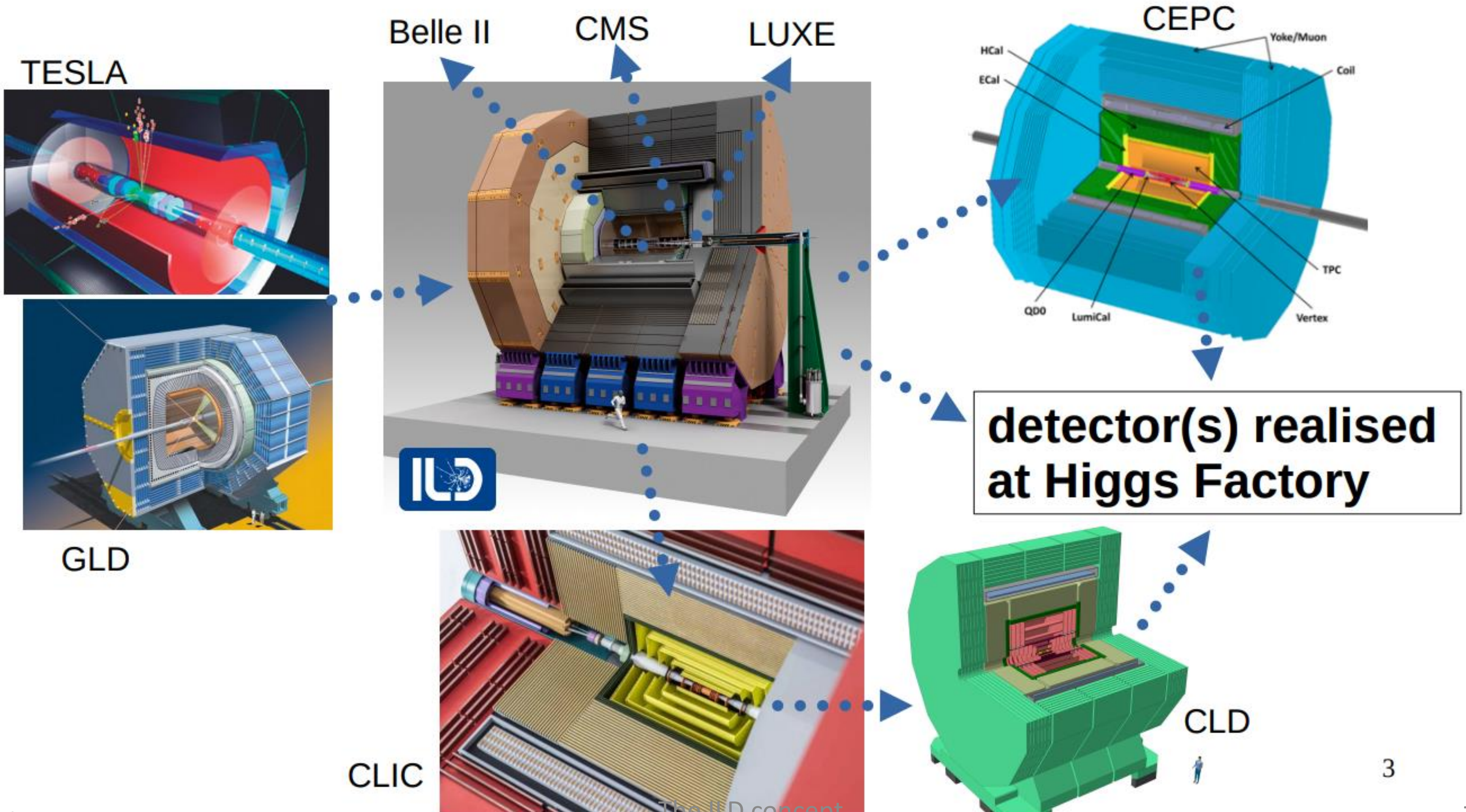
Non Science Drivers



- Environmental impact of our projects
- Politically this is rapidly gaining importance
- This will need to be part of discussions of any project we consider in the future

From talk by Steinar Stapnes, Monday plenary

The ILD anchestry

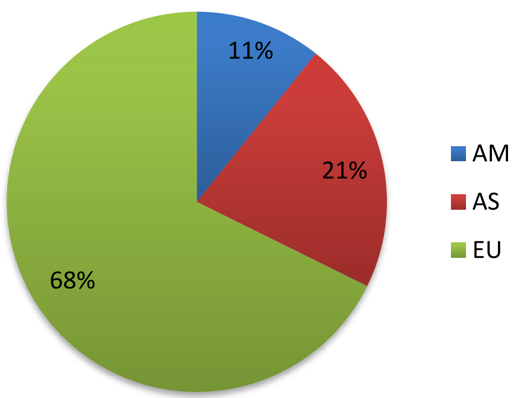


The Collaboration

Result of recent membership confirmation:

- 58 institutes confirmed ILD membership
- Around 10 institutes as guests members

institutes per region

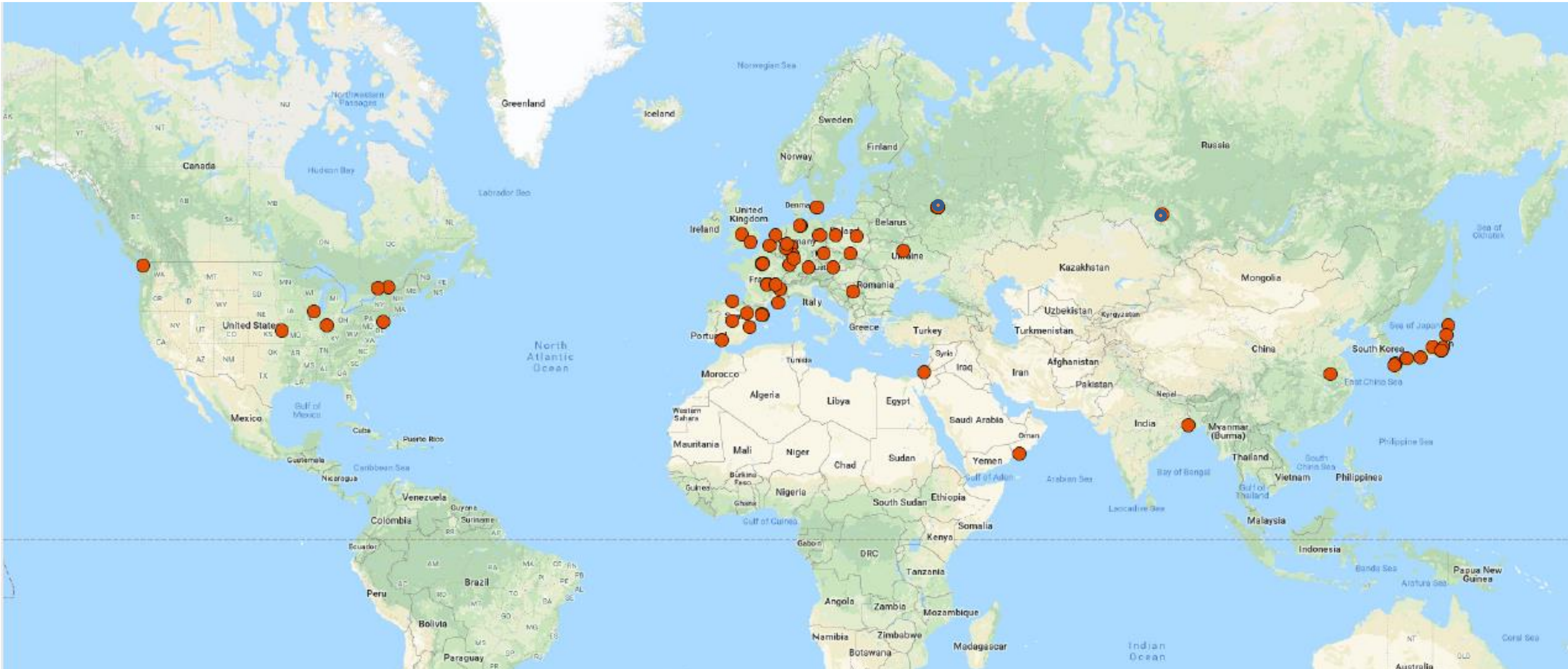


ILD as a group got started around 2008

ILD’s roots are linear colliders, ILC in particular

ILD’s main objective is to develop the best possible experiment for a Higgs/ Electroweak and beyond facility

ILD around the world

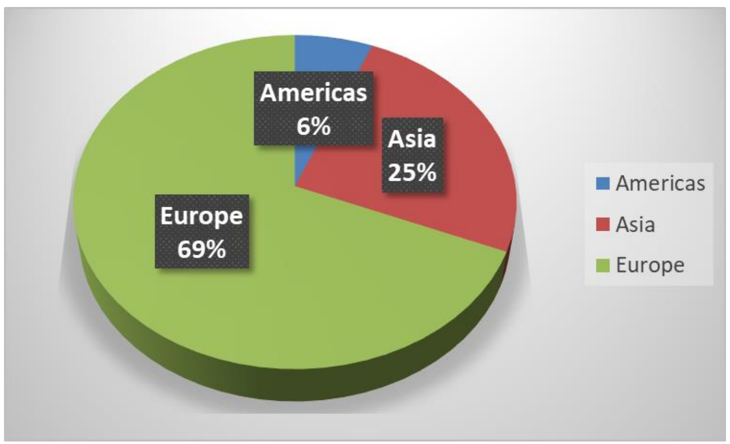


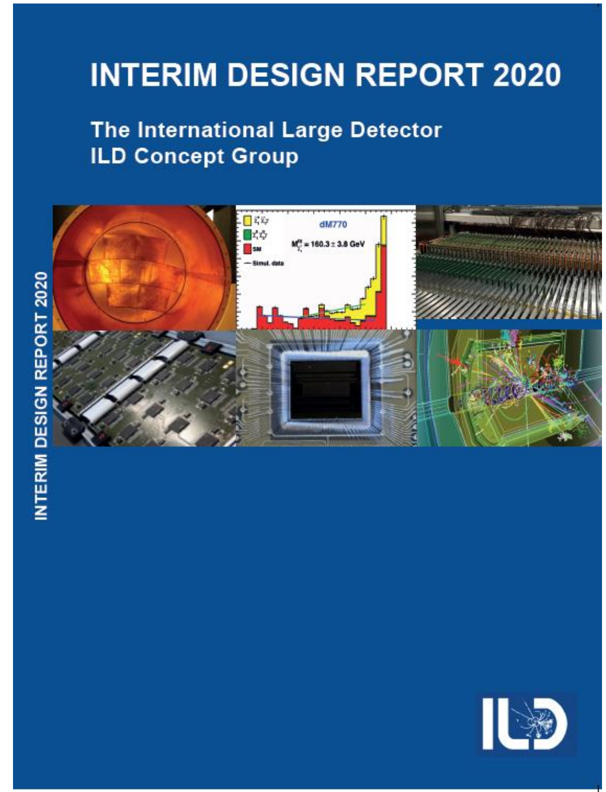
Memberships od Russian groups is currently suspended

The current state of the art in ILD

The work of ILD over the last years has been documented in the IDR and published in 2021.

Signed by 302 authors from 62 institutes



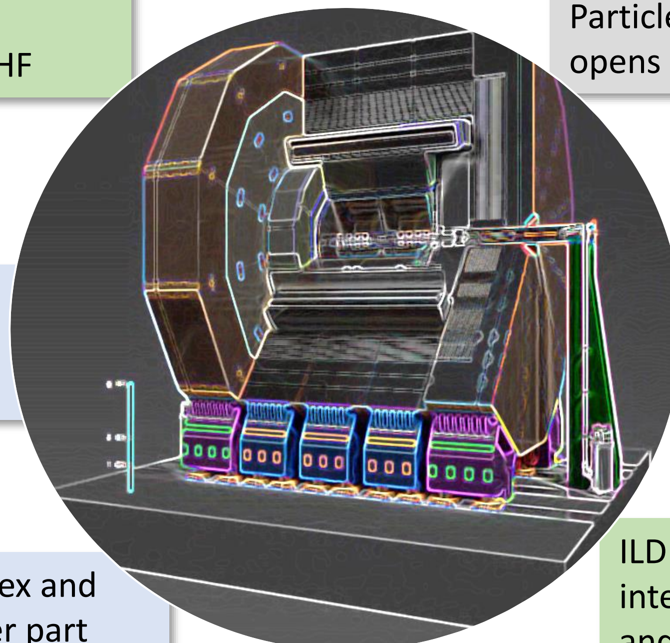


https://arxiv.org/abs/2003.01116

ILD: fundamental choices

Particle flow is the central paradigm to optimally reconstruct events at a HF

Particle ID in particular at the lower energies opens the route to an excellent flavor program



A gaseous central tracker ensures high efficiency high resolution tracking

A highly granular sampling calorimeter inside the coil ensures excellent particle flow performance

A high precision low mass vertex and tracking system forms the inner part

ILD is designed to be easily moved from the interaction point to allow for fast maintenance and open the possibility of push-pull

ILD will run without trigger and with minimum external cooling

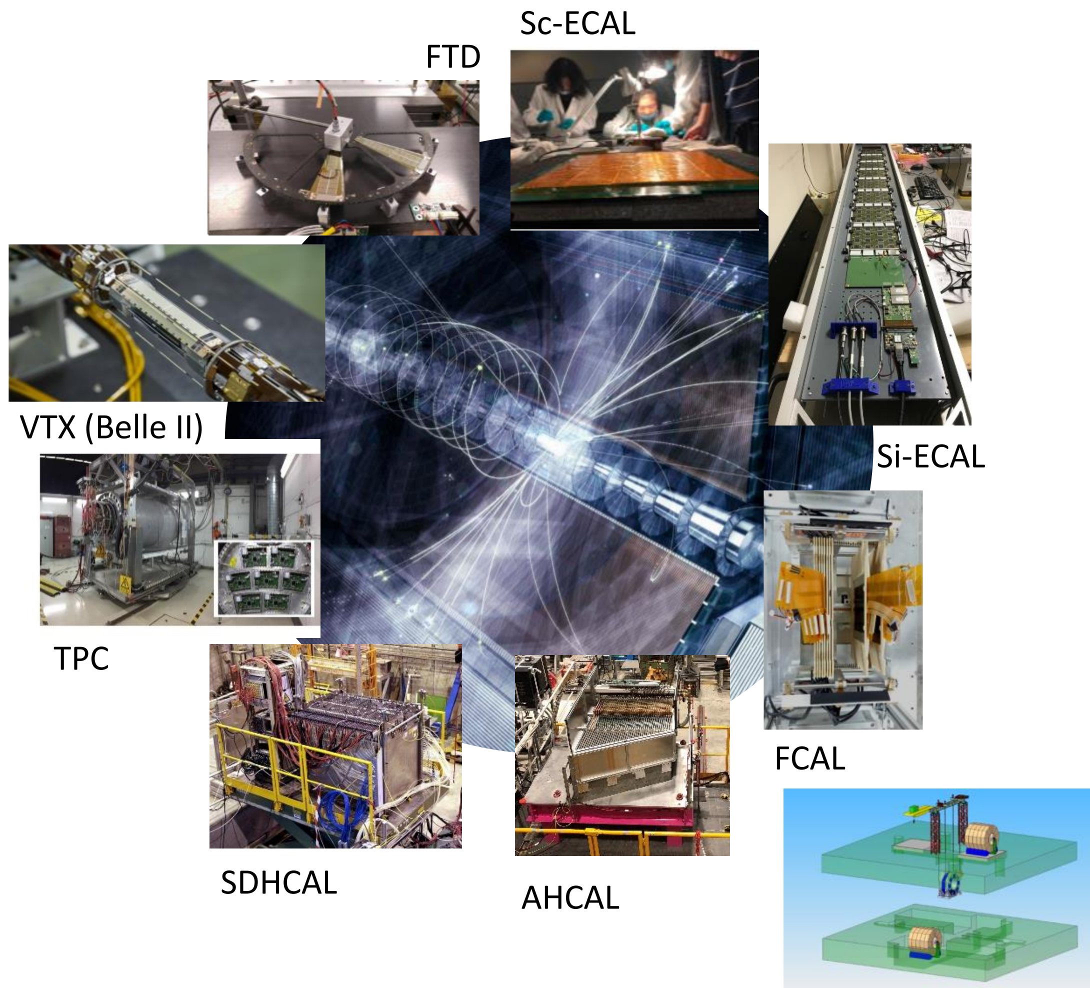
Subdetector Status

ILD has a concept of the detector,
well defined
with technological options where sensible

The main components of ILD
have been validated and
beam-tested.

A coherent System design has
been developed.

A complete and detailed
Geant4 model of ILD exists
and is used

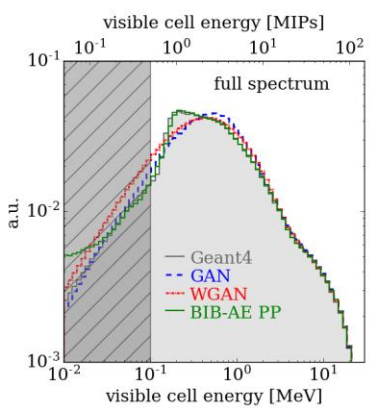


ILD and Software

ILD has done a lot on the software and reconstruction side:

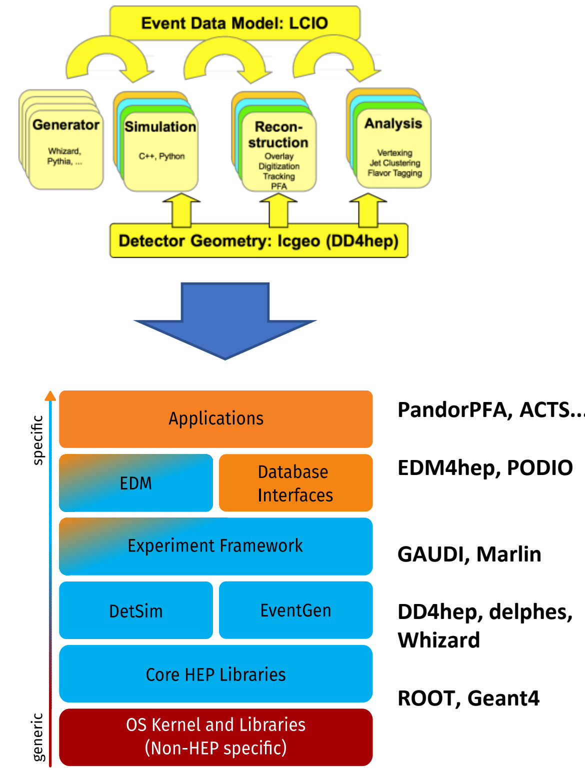
- We are a central player in pushing community wide software solutions in particular with **iLCSoft** (LCIO, DD4hep, etc) developed over 15 years
- We are deeply engaged already with communities (linear, circular, FCC-hh) to modernize our software stack: **key4hep** (DD4hep, EDM4hep,...)

There is enormous progress out there in the community on computing, computing models, computing implementations, analysis methods and tools:



- parallelisation, multi-threading
- GPU based computing
- Machine Learning and AI
- Quantum computing

F. Gaede, E.Eren et al.:
Use of GAN's to simulate photon showers in the ILD Calorimeter (2005.05334)

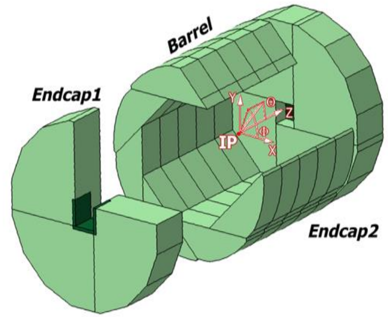


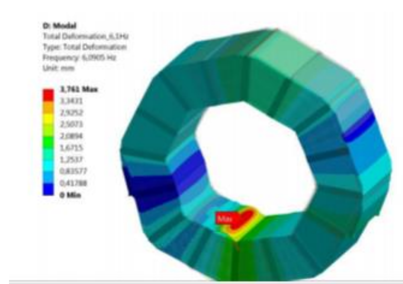
Reality

Prototyping

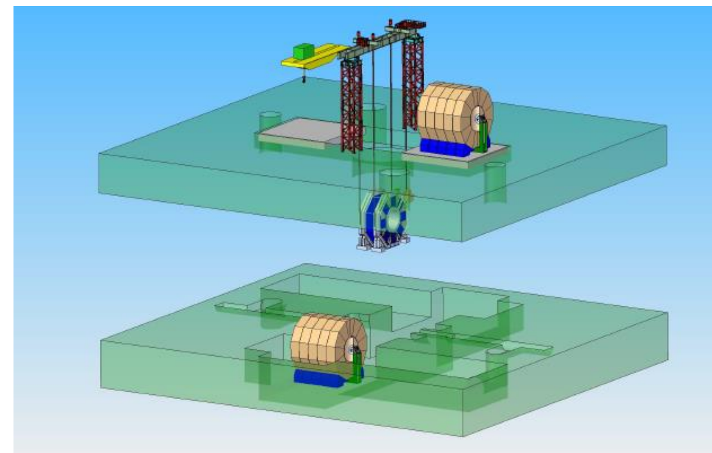
Demonstrating

Engineering



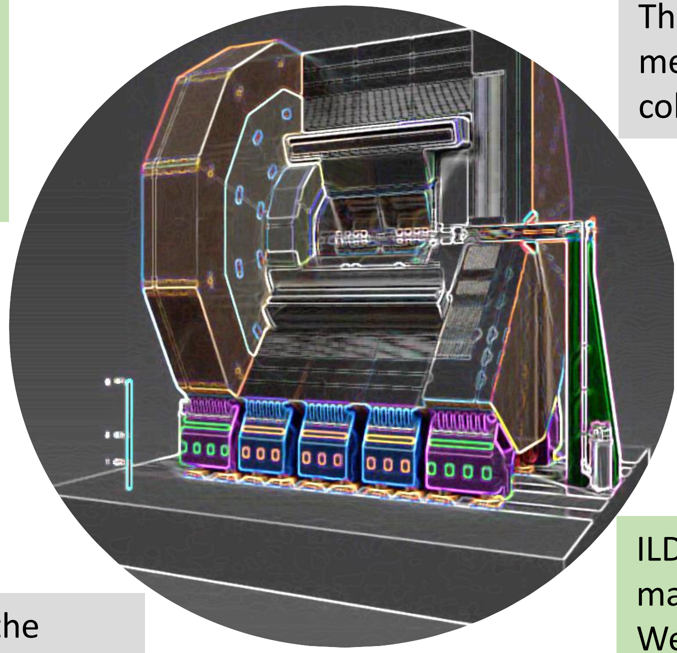


Integration



ILD: a range of opinions

ILD has been conceived about 10 years ago It is now time to re-visit many of the choices and “modernize” ILD. There is no need to fundamentally change ILD



The well-known R&D collaborations are merging into the much larger DRD collaborations.

Is particle flow still the right paradigm for a detector at a Z or Higgs factory?

ILD is past its prime and has been made redundant by history.
We should re-converge and all collect behind one collider concept

The conditions in particular for the inner part of the detector are very different for different collider concepts

ILD at other collider concepts

1. **The forward tracking** region of ILD has a number of shortcomings. A dedicated optimization for this region, in particular of the acceptance of the vertex detector, should be done. This region will also be heavily affected by different environmental conditions at different collider projects, and might need dedicated solutions for each proposal.

2. Circular colliders will have a smaller inter-bunch timing difference than ILC, and also do not deliver bunch-trains, but rather continuous beams. This significantly changes the possibility to do **power-pulsing** for the front-end electronics of the ILD sub-detectors. The current design of the ILD sub-detectors depends crucially on their capability to manage the thermal load through power pulsing. Using the ILD sub-detectors at FCC will require a very detailed study of how the systems can perform without power pulsing, and the development of a concept of how the thermal management can work in this new situation, while minimising additional dead material in the system.

3. The close inter-bunch spacing and lack of inter-bunch train quiet periods puts **additional challenges on the operation of a TPC** in this environment. ILD should explore how an ILD-like TPC would perform in these different conditions, and where the limits are for the TPC. Since the TPC adds significant particle identification power in particular at lower center-of-mass energies, this study should focus on the lower range of energies at a Higgs/ EW/Top factory.

4. A focus of experimentation at circular colliders is a **high-luminosity Z program**. ILD should investigate how well the detector performs under these conditions, and identify components which might need replacement or modification.

5. Circular colliders will have a very different forward region, in order to control the **machine backgrounds**, and in order to provide the beam focusing. ILD should develop a concept for a forward region compatible with FCC-ee and study the impact this changed region will have on the detector performance.

6. A central challenge for a detector like ILD, **optimized for precision physics**, is the delivery of an excellent and stable **calibration and alignment environment**. These considerations need to be included from early on in the design. The different running conditions and beam conditions might impact the way the detector is to be calibrated and aligned, and need to be studied.

What is ILD?

Particle Flow:

The central guiding principle for the design of ILD:

- Granularity
- Hermeticity

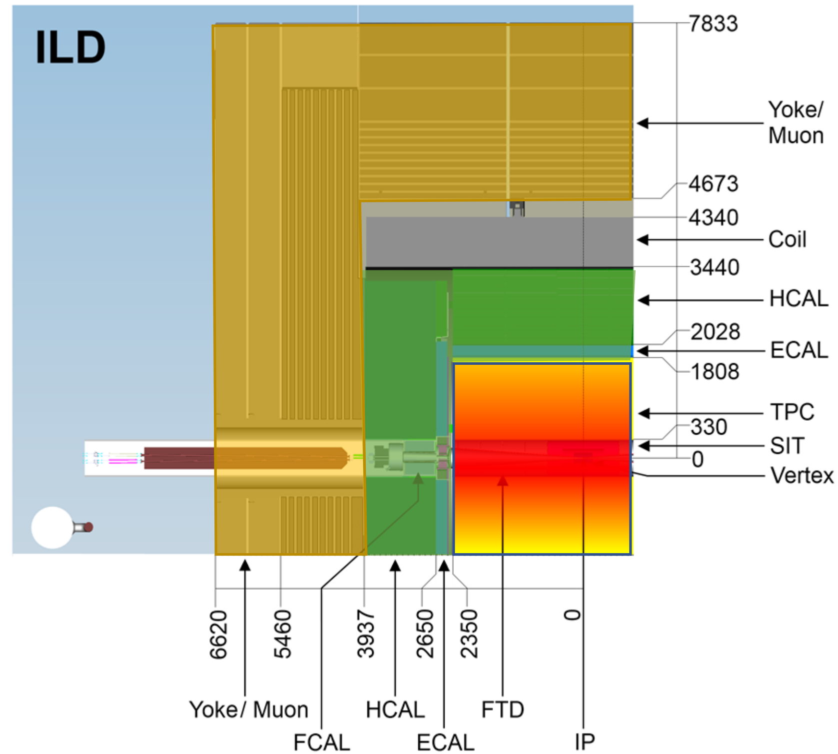
Low material inner region

- Very thin Silicon
- Large volume TPC

Particle ID is important

- PID in TPC
- Timing as additional handle

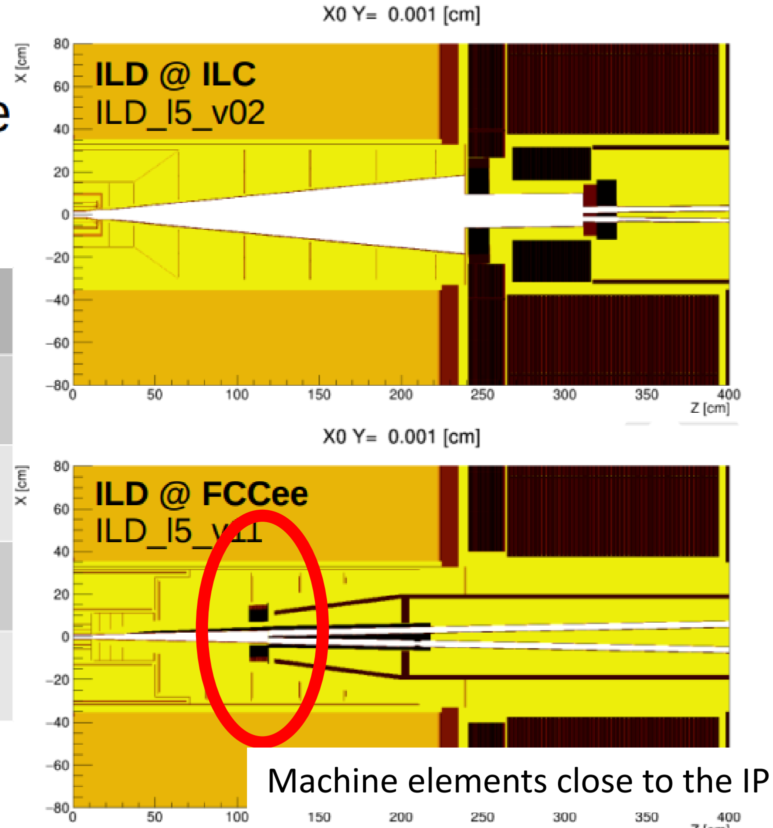
A quarter view of ILD



ILC and FCC-ee

machine-detector interface

	ILC	FCCee
crossing angle	14 mrad	30 mrad
L* [distance from IP to last accel focusing quadupole magnet]	4.1 m	2.0 m
detector solenoid	3.5 T	2.0 T
additional B-fields	anti-DID (?)	- compensating - screening



At FCC-ee (91 GeV):

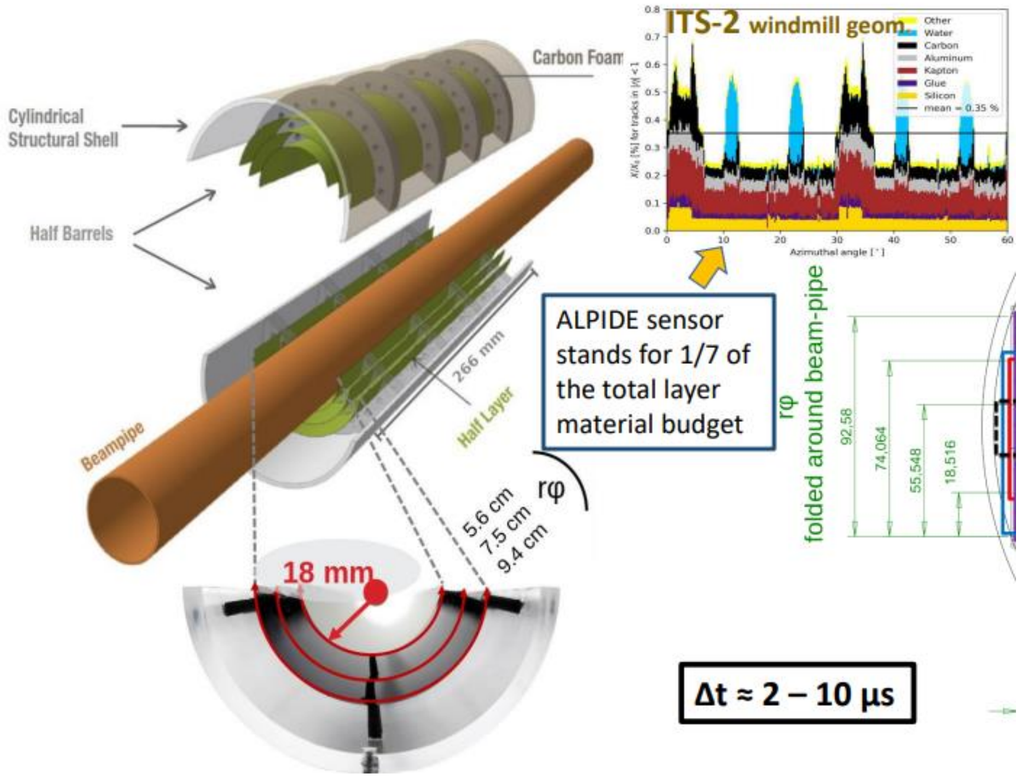
About 50times larger activity/ bunch crossing at FCC-ee than at ILC

Estimated total charge in TPC:

ILC 0.01 nC/m^3
FCC-ee 64 nC/m^3

Significantly challenging environment for inner detectors

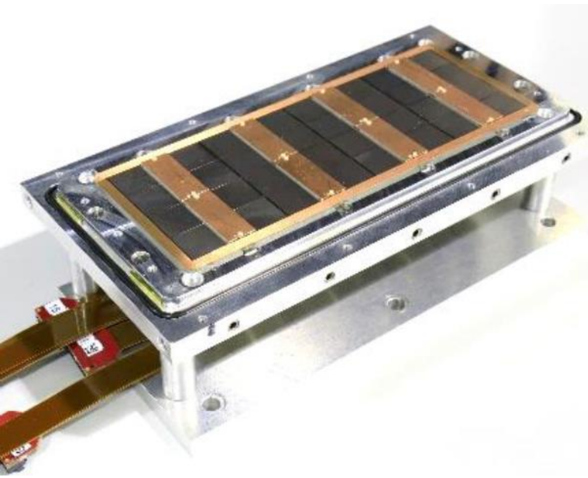
Vertex Technology



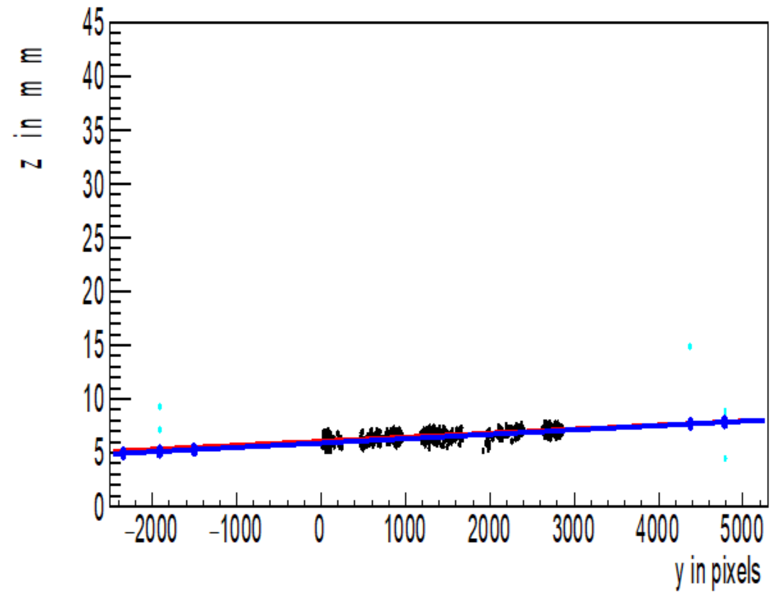
- Goal: ultra-thin fast sensors
- ALICE development:
    - Bent Silicon sensors
    - Unsupported
    - No active cooling
- Challenge: endcap development

Pixel TPC

TPC: baseline option for ILD as the large volume central tracker



Highly pixelated readout plane
Cluster counting possible
But relatively poor area coverage



Example picture of a track recorded at DESY in the pixel TPC.

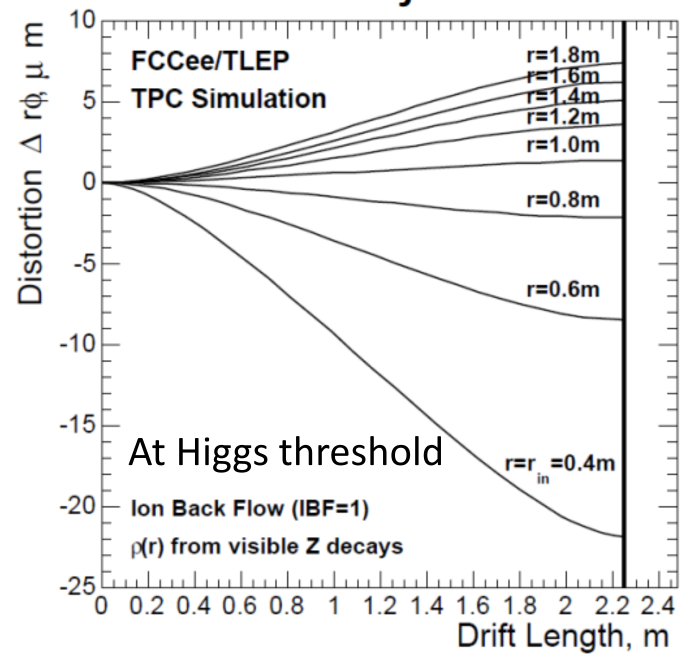
A TPC at a FCC like collider

Several issues

- Inter-bunch spacing much less than at ILC
  - Not a problem
- Occupancy due to physics events and backgrounds
  - Not a problem
- Overall charge buildup in the system
  - problem

Studying the feasibility of a TPC at a FCC-ee remains an issue and requires detailed studies

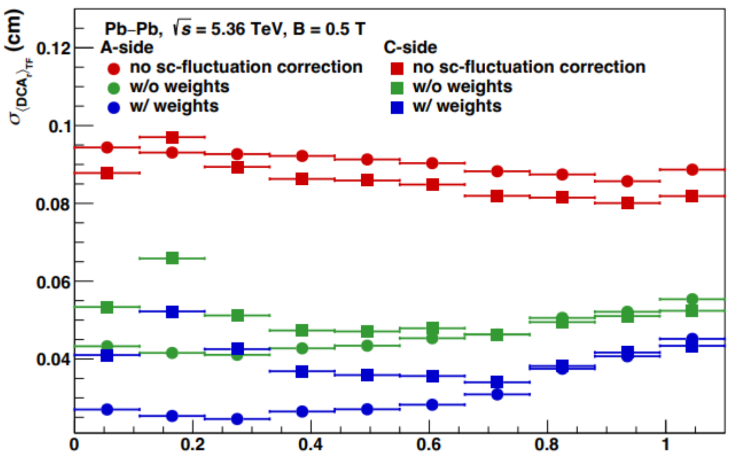
Electron trajectories

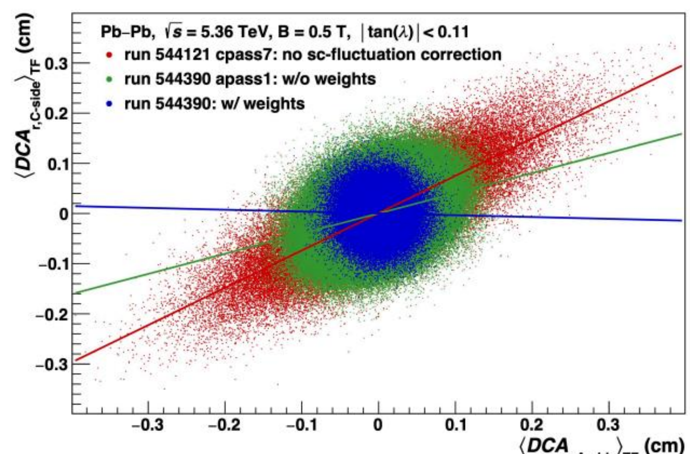


When running on the Z: around factor of 20 worse: max distortions close to 1 mm

Calibration Concept

- In general we have not made progress in this area over the past few years
- Calibration at FCC-ee for E>91 GeV will be similar to ILC
- Calibration at FCC-ee (91 GeV) will be a real challenge
  - Need to understand the limits
  - The combination of high backgrounds with extreme stability requirements is highly non-trivial

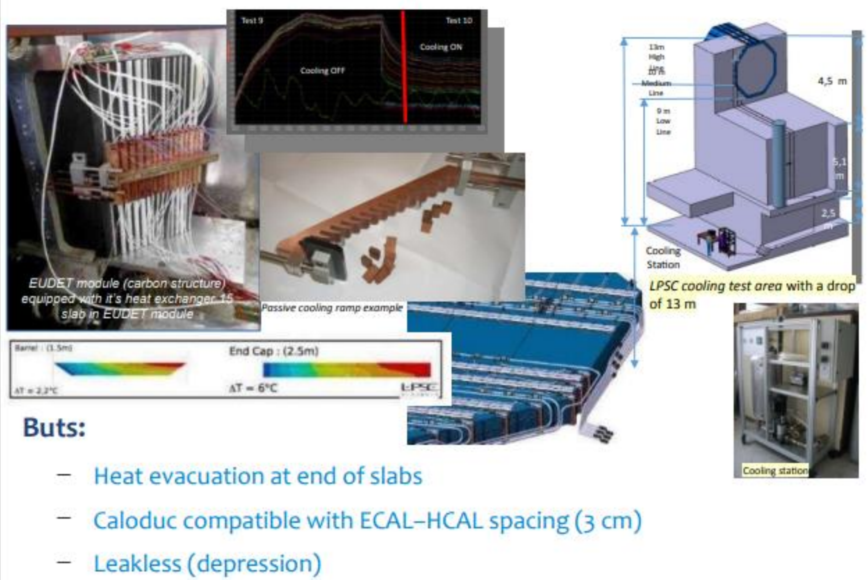




ALICE: see talk on Monday by Matthias Kleiner

Calorimetry

- Have a well developed system for ILC-like environment
- Major proof-of-concept experiments through HK-LHC (e.g., CMS upgrade)
- Major challenge if we go to a high repetition rate collider: cooling



Ongoing R&D on a cooling system for the Si-W ECAL as one example of current key R&D

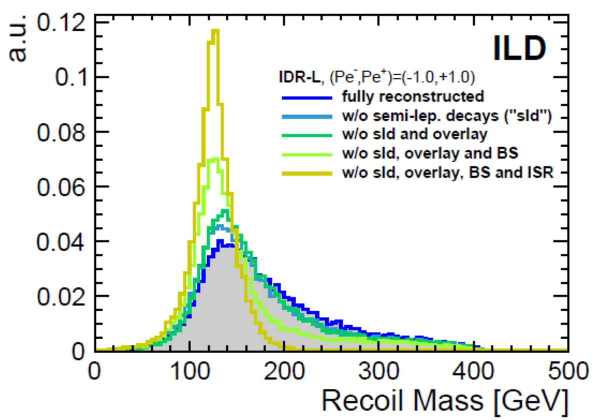
Triggering

- ILD currently is untriggered
  - Stream data from the detector
    - Need large bandwidth
    - Need large computing power to process the stream
- Is a minimum triggering scheme thinkable
  - Problem with biases
  - But potentially more “environmentally friendly”?
- Does out scheme scale to the Z-running
  - At ILC: probably yes
  - At FCC-ee: I am not so sure

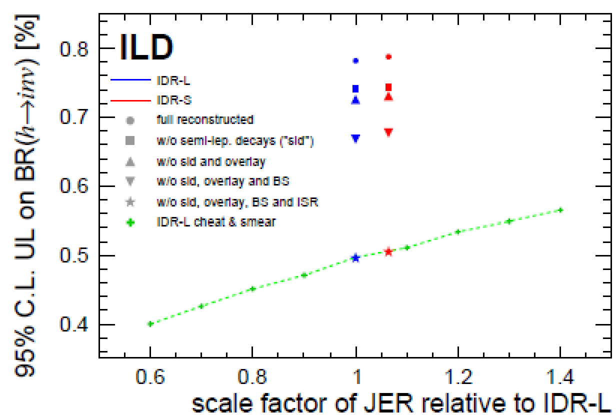
Physics

Continued strong effort on analysis in the ILD context;

- Nearly all analyses done in full simulation
- Very active role by ILD in intn’l processes like snowmass, LCC, now IDT
- Comprehensive list of projects: [ILD collection of projects]



Recoil mass spectrum (invisible Higgs searc
for different reconstruction conditions



Impact of a detector indicator (JER resolution) on physics observable

Summary/ Outlook

The ILD group is maintaining and developing a modern particle-flow based detector concept

ILD is very interested to contribute to the studies of such detectors at linear and circular collider concepts, to develop the best possible experimental proposal for a future Higgs factory

ILD is engaging with any concept for a Z/Higgs/ EW factory


Recent Collaboration meeting at CERN, Feb 2024