- I still have a couple of slides that are empty (Work In Progress)
- I borrowed some material from some of you (citations still missing)

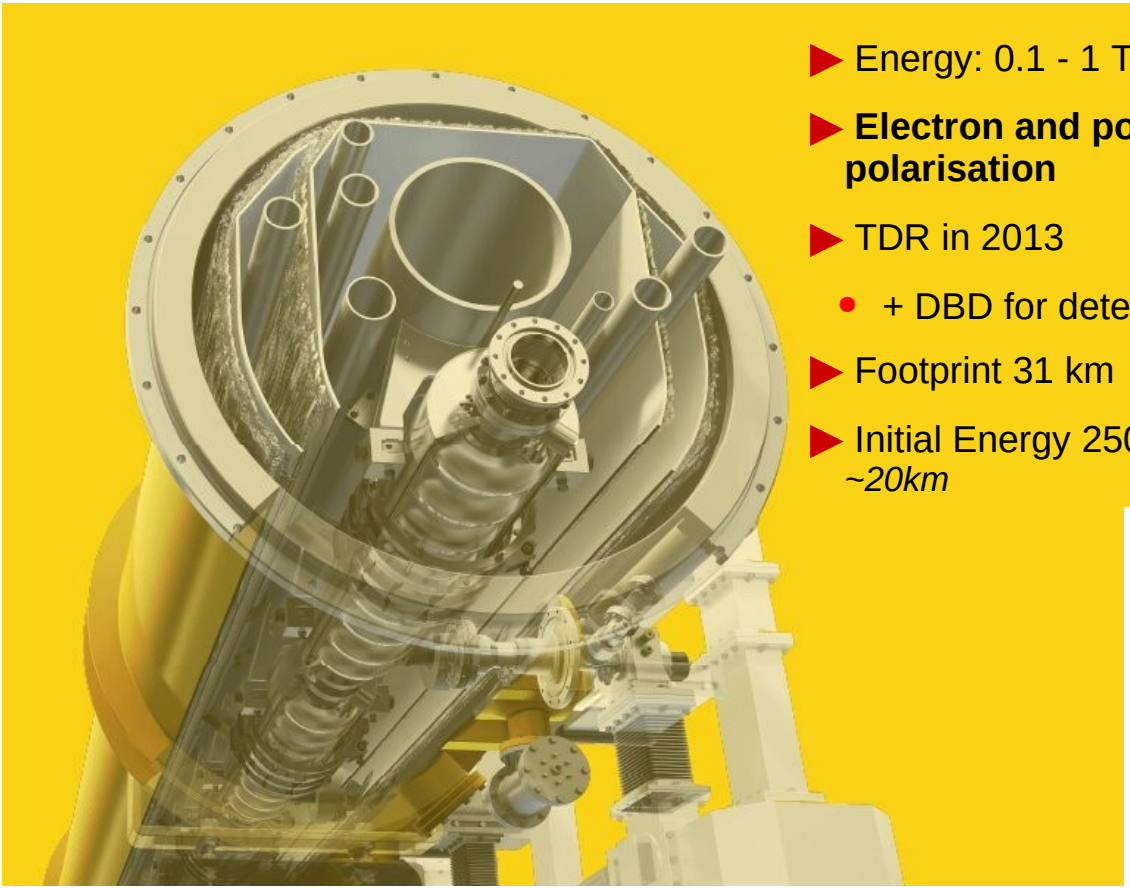
ILD: a Detector for the International Linear Collider

A. Irles* on behalf of the ILD concept group

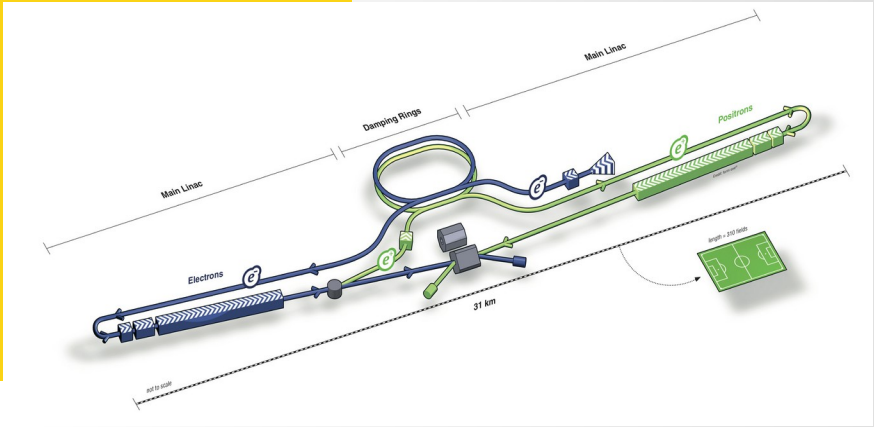
TIPP2021 - 25th May 2021

** AITANA group at IFIC - CSIC/UV*

The International Linear Collider



- Energy: 0.1 - 1 TeV
- **Electron and positron polarisation**
- TDR in 2013
  - + DBD for detectors
- Footprint 31 km
- Initial Energy 250 GeV – *Footprint ~20km*



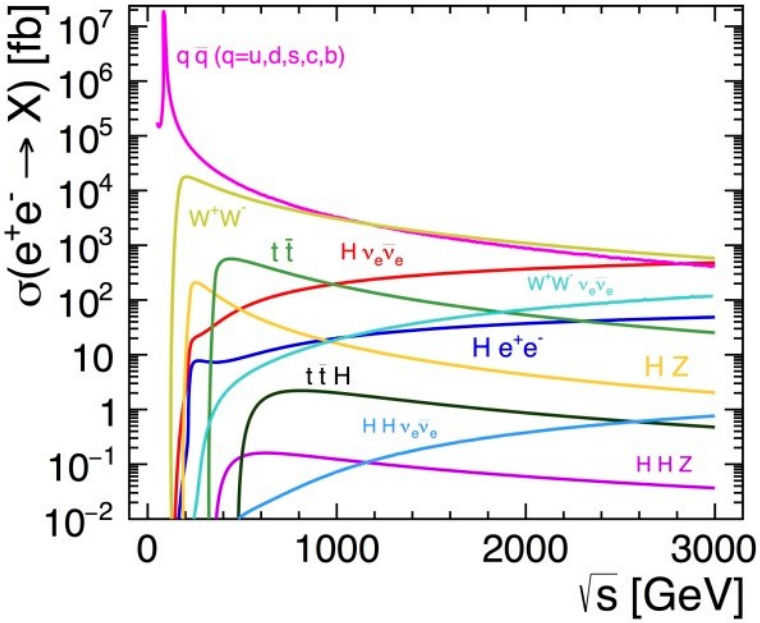
Under discussion in Japanese Government and international community

Higgs factories (and EW, and top-quark and…)

- **All Standard Model particles within reach of the ILC project**
- High precision tests of Standard Model over wide range to detect onset of New Physics
- **Machine settings can be "tailored" for specific processes**
  - **Centre-of-Mass energy** & **Beams polarisation** (straightforward at linear colliders)

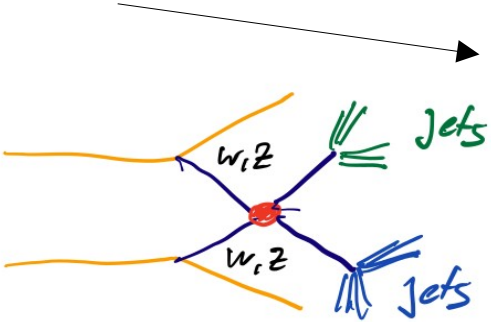
- Higgs factories but also...
  - **"light" qq factory**

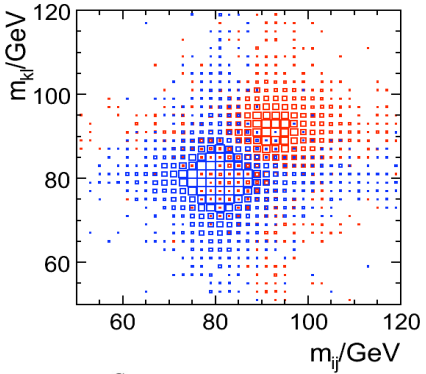
    (and Z-factory at Z-pole)
  - **WW factory**
  - **Top-quark factory**
  - **ttH factory**
  - **…**

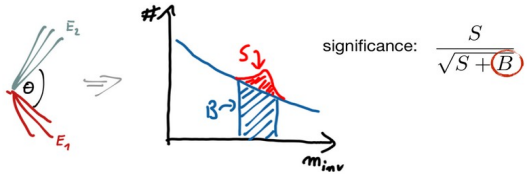


Detector Requirements

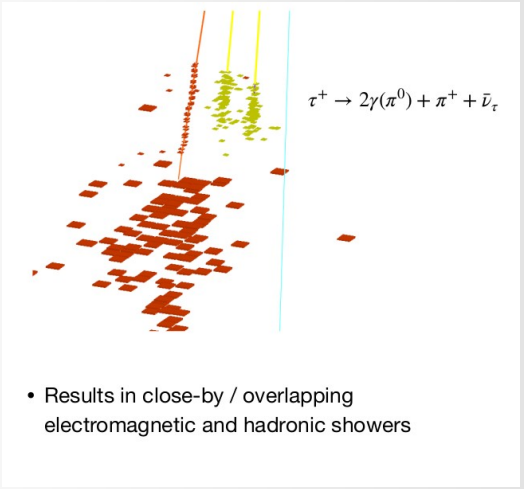
- A comprehensive test of the SM and BSM (specially in the Higgs sectors requires unprecedented performance of the detector and reconstruction techniques
- Excellent trracking + flavour tagging
- Single particle separation
- Excellent energy resolution of ~3%







significance: $\frac{S}{\sqrt{S+B}}$

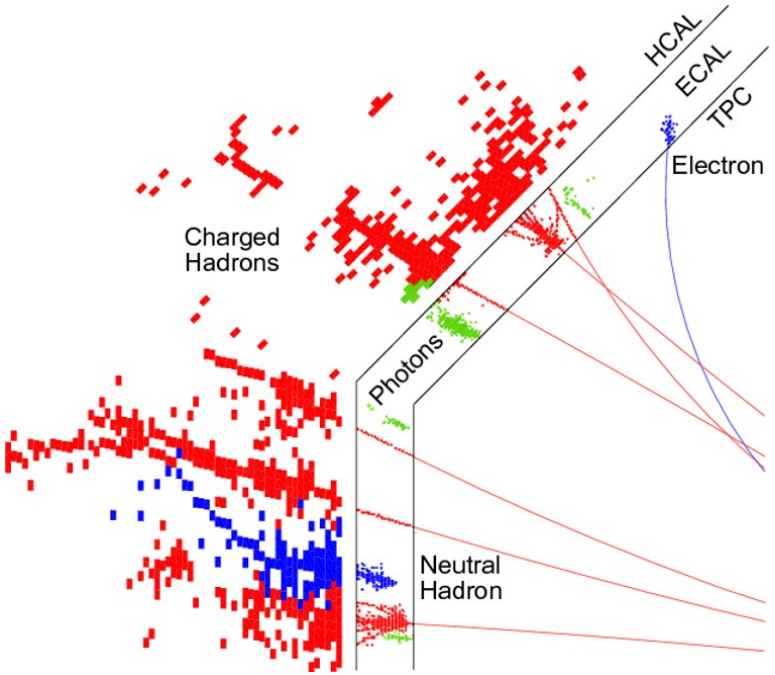


• Results in close-by / overlapping electromagnetic and hadronic showers

How ?

By designing a **Particle Flow** Detector → the **ILD**

Particle Flow Algorithms



Concept

- Base the measurement on the subsystem with best resolution for a given particle type (and energy)
- Separation of signals by charge and neutral particles in the calorimeters
- **Single particle separation**

Technological Challenges

- Need **extremely granular calorimeters** (100 of millions of cells…!)
- Require **very low material budget** in front of the calorimeters and **excellent tracking systems**

Limitations

- Complicated topology by (hadronic) showers
- Overlap between showers compromises correct assignment of calorimeter hits **–> Confusion term**
  - Need to minimize this term as much as possible

The ILD: a Particle Flow Detector

From key requirements from physics:

- **p_t resolution** (total ZH x-section)
  $\sigma(1/p_t) = 2 \times 10^{-5}$ GeV^{-1} $\oplus$ $1 \times 10^{-3} / (p_t \sin^{1/2}\theta)$
- **vertexing** ($H \rightarrow bb/cc/\tau\tau$)
  $\sigma(d_0) < 5 \oplus 10 / (p[\text{GeV}] \sin^{3/2}\theta)$ μm
- **jet energy resolution** ($H \rightarrow$ invisible) 3-4%
- **hermeticity** ($H \rightarrow$ invis, BSM) θ_{min} = 5 mrad

To key features of the **detector**:

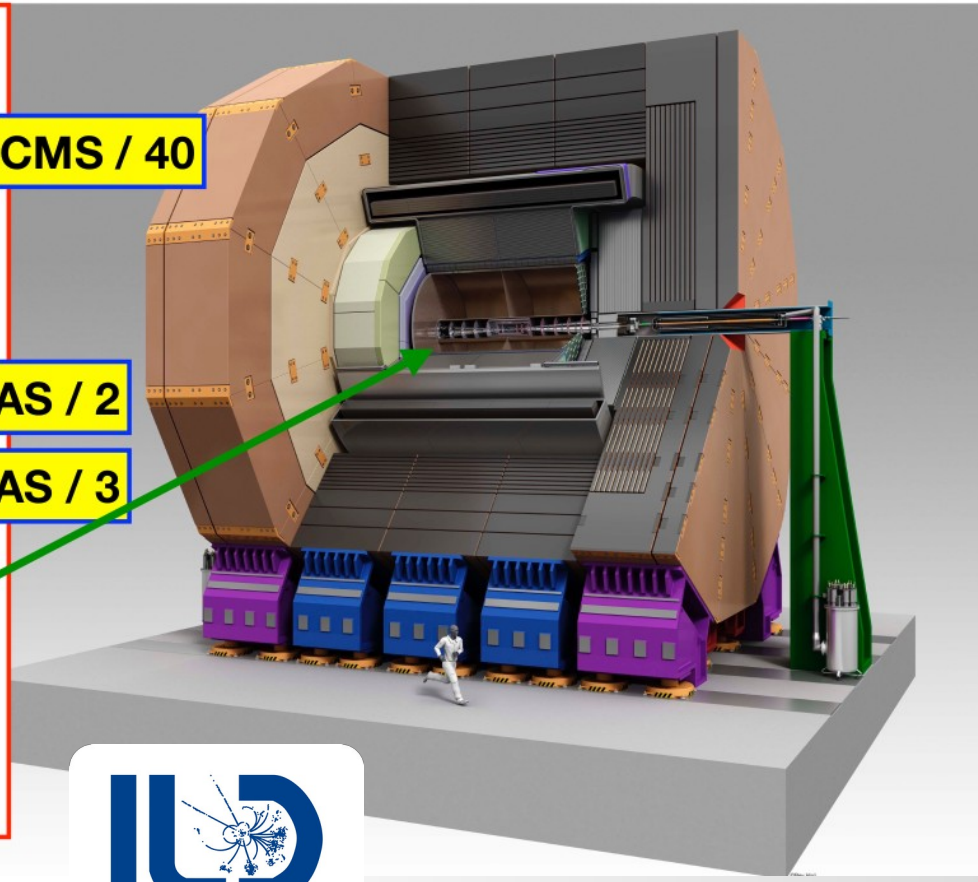
- **low mass tracker:**
  - main device: **Time Projection Chamber** (dE/dx !)
  - add. silicon: eg VTX: 0.15% rad. length / layer)
- **high granularity calorimeters**
  optimised for particle flow

≈ CMS / 40

≈ CMS / 4

≈ ATLAS / 2

≈ ATLAS / 3

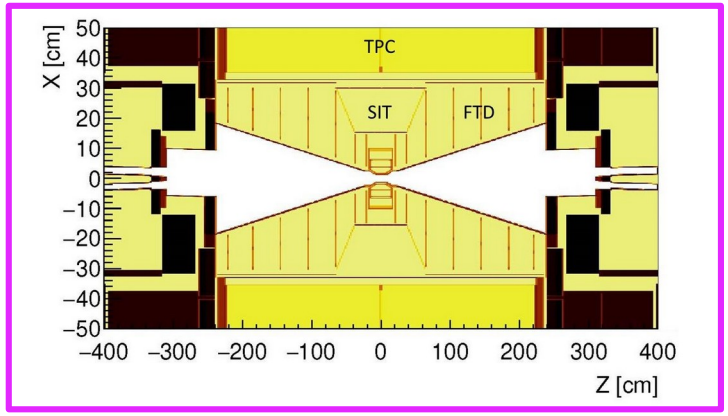


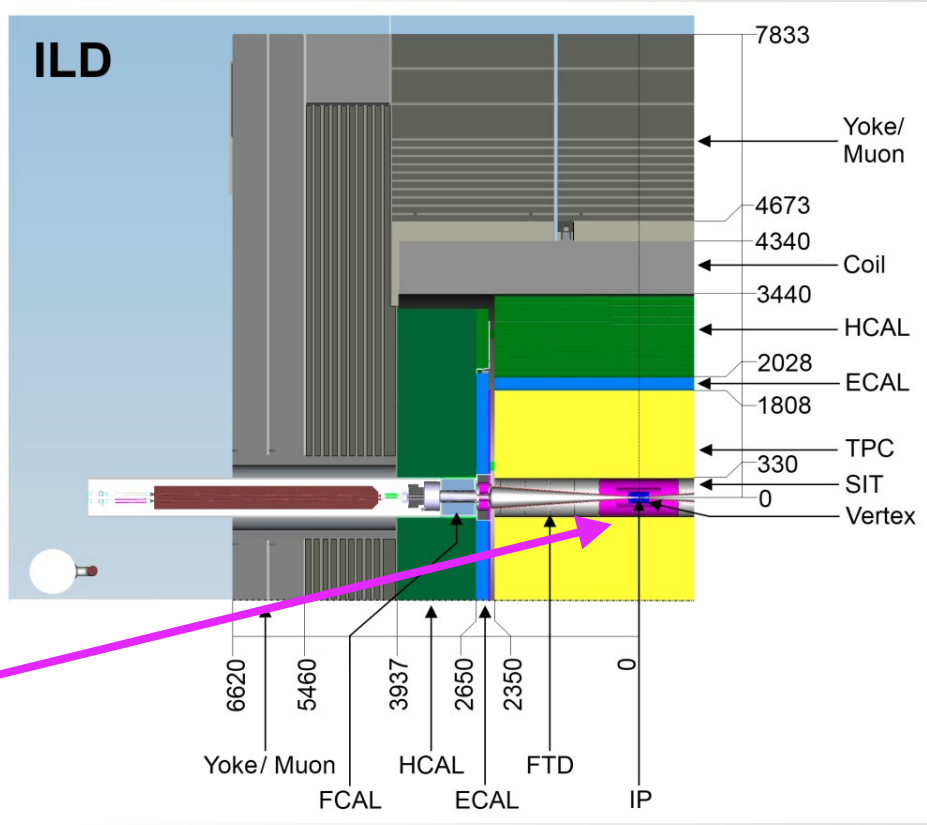
Xxx times more than LHC

The ILD layout

Summary of the ILD layout

- Particle flow as the key design driver
- Excellent vertexing very close to the IP
- Hybrid tracking system optimized for excellent resolution at high energies and ultimate efficiency over a broad momentum range
- High granular calorimetry
- **Up to HCAL, all inside solenoidal coil of 3-4 T**
  - Bhabha rejection



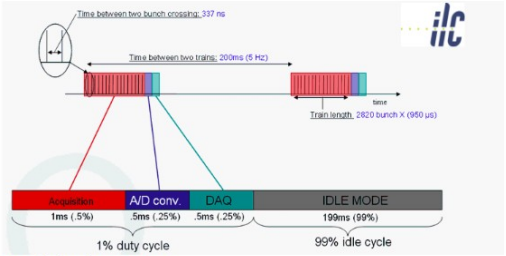


ILC offers a favorable experimental framework

Linear Lepton Colliders favor fully optimized PFA detectors

- Possible since experimental environment at ILC very different from LHC/LEP:
  - much smaller beam spot and beam pipe (first tracking layer at ~1cm of the IP)
  - much lower backgrounds
  - much less radiation
  - Pulsed beam structure

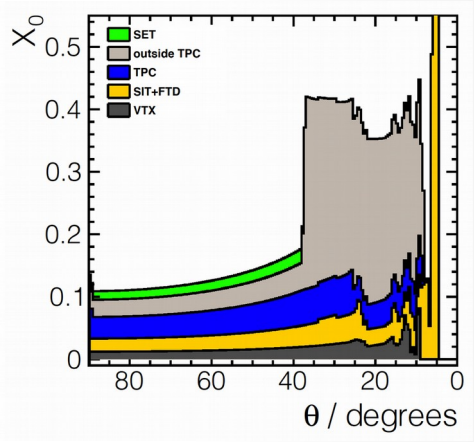
Power pulsed electronics → low material budget !
triggerless operation ! –> ALL events are recorded



N.B. Final numbers may vary

- Electronics switched on during > ~1ms of ILC bunch train and data acquisition
- Bias currents shut down between bunch trains

Mastering of technology is essential for operation ofILC detectors



The ILD performance

Tracking performance

Jet Energy Resolution

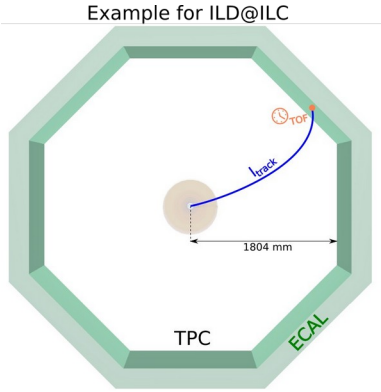
Flavour tagging

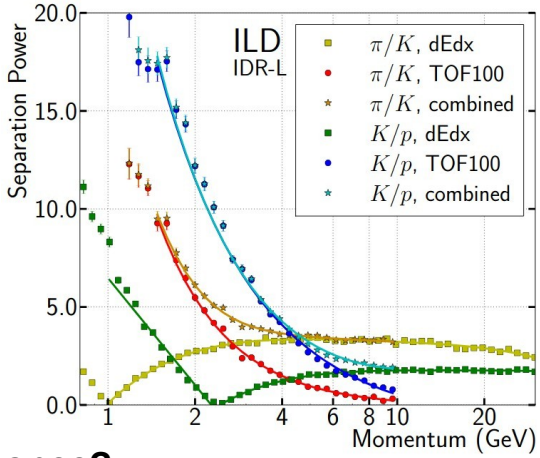
PID: hadron Id (TPC)
And photon ID (PFA)

The ILD performance: timing ?

TOF in the ECAL

- "Standard@ silicon sensors could reach O(100ps)
- LGAD sensors could get us to O(10ps) Drawback: high power consumption.



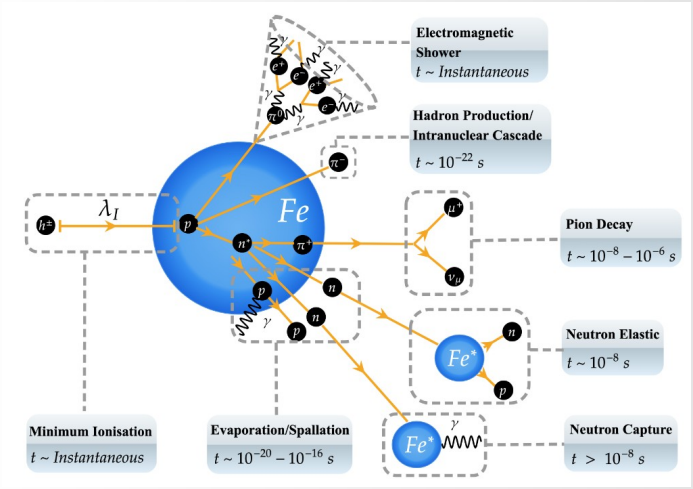


Impact in the performance?

- "Only" improvements at relatively low momentum
- But could be a game changer for s-quark measurements
  - Z/γ-→ ss or H→ ss

Timing measurements for shower developments

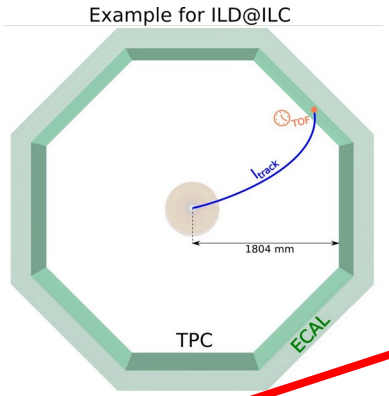
- Neutral and slow components
  - Require ~ns precision
  - Reachable today with "standard" silicon, scintillators calorimeters
- ~0.1 ns scale: near the corner
  - with "standard" silicon sensors (HGCAL)
  - GRPC (20ps)

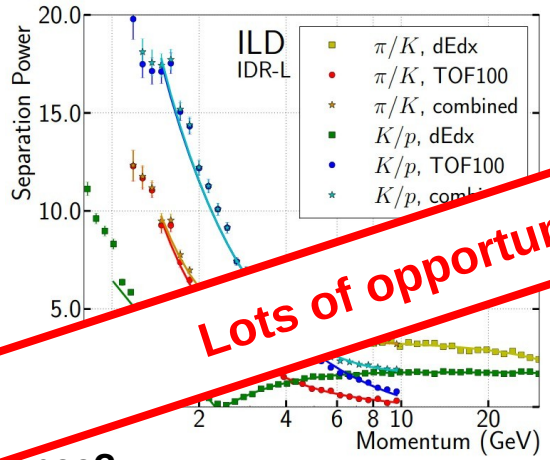


The ILD performance: timing ?

TOF in the ECAL

- "Standard sensors" could reach 100-200ps
- LGAD sensors could get us to 10ps Drawback: high power consumption.





Lots of opportunities in this field

Impact in the ...mance?

- "Only" improvements at relatively low momentum
- But could be a game changer for s-quark measurements
  - Z/γ-→ ss or H→ ss

Timing measurements for shower developments

- Neutral and slow components
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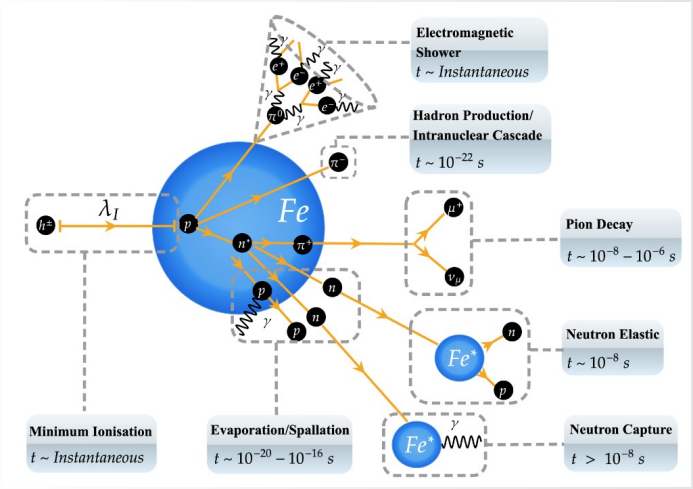
- ...dard" silicon sensors (HGCAL)
- GRPC (20ps)

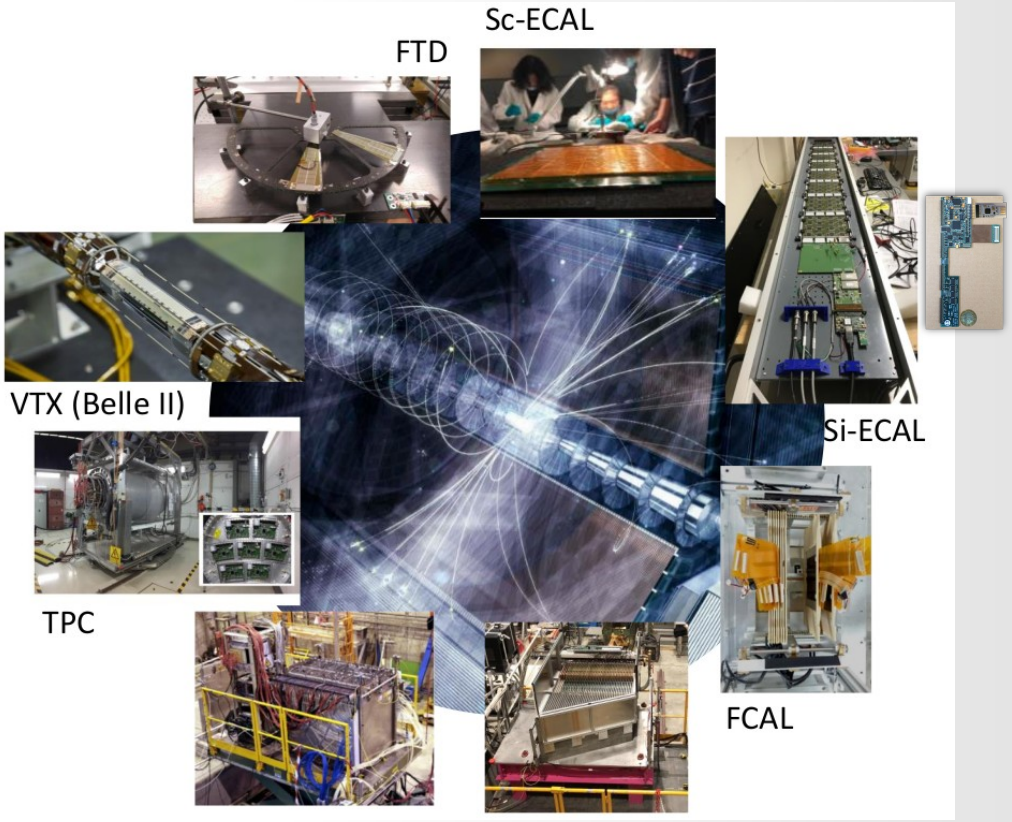


Status of the R&D

R&D 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.

Application of our technologies: CMS Calo upgrade, Belle VTX, T2K TPC, ALICE TPC

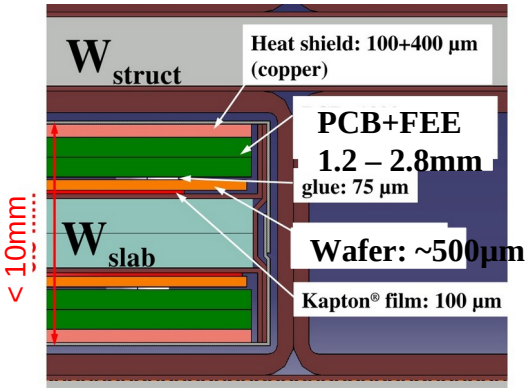


Slide borrowed from T. Benhke (ILD spokeperson)

Tracking Systems: R&D status

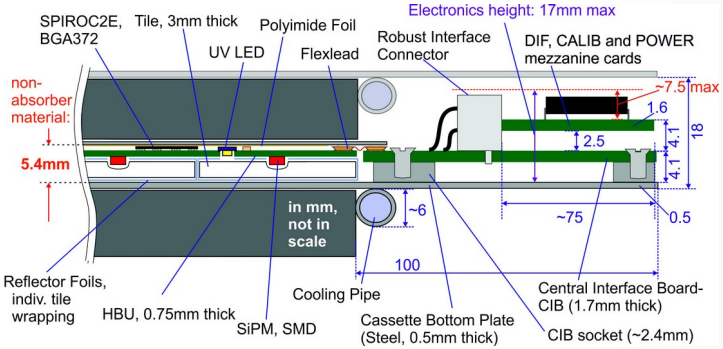
HG Calorimetry: Technological solutions I

SiW Ecal



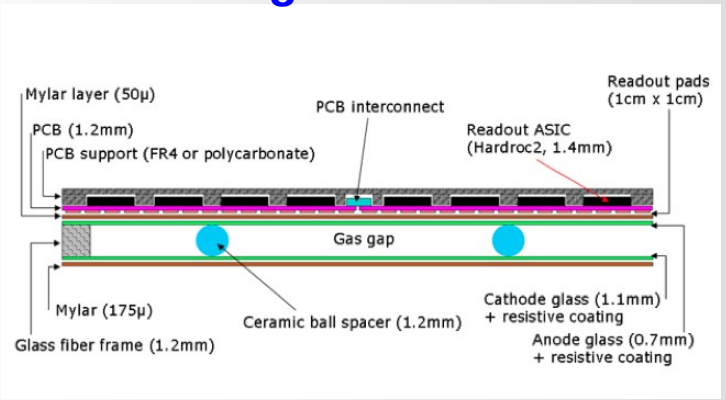
Semi-conductor readout
Typical segmentation: 0.5x0.5 cm^2

Analogue Scintillator HCAL and ECAL



Optical readout
Typical segmentation: 3x3cm^2

Semi Digital HCAL



Gaseous readout
Typical segmentation: 1x1cm^2

Integrated front end electronics

No drawback for precision measurements *NIM A 654 (2011) 97*

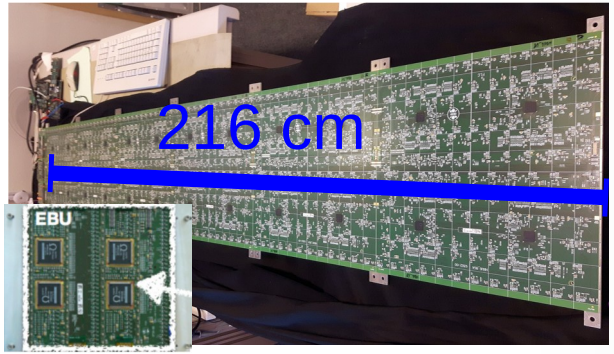
CALICE Calorimeter for ILC

HG Calorimetry: Technological solutions II

SiW Ecal

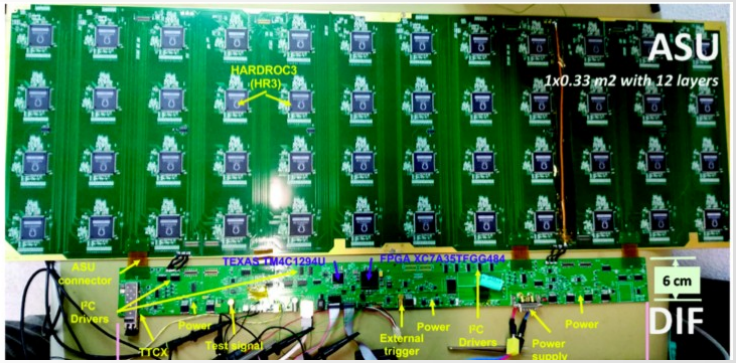
Semi-conductor readout

Analogue Hcal and Scintillator Ecal



Optical readout

Semi-digital Hcal



- Realistic detector dimensions
  - Structures of up to 3m in length (more than 10000 cells)
  - With compact external components
- Challenge for the power pulsing techniques (for the power consumption management)

HG Calorimetry: Technological solutions II

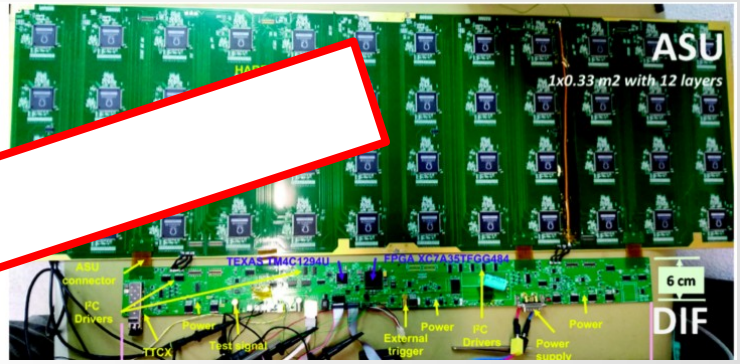
SiW Ecal

Semi-conductor readout

Analogue Hcal and Scintillator Ecal

ptical readout

Semi-digital Hcal



VERY LONG DETECTORS

stic detector dimensions

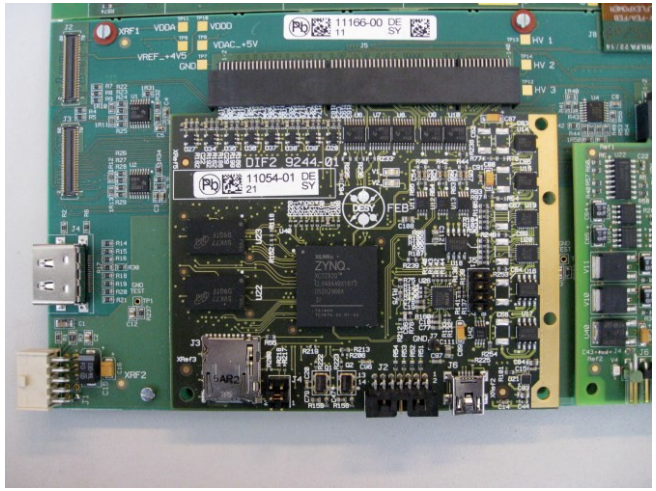
- Structures of up to 3m in length (more than 10000 cells)
- With compact external components

- Challenge for the power pulsing techniques (for the power consumption management)

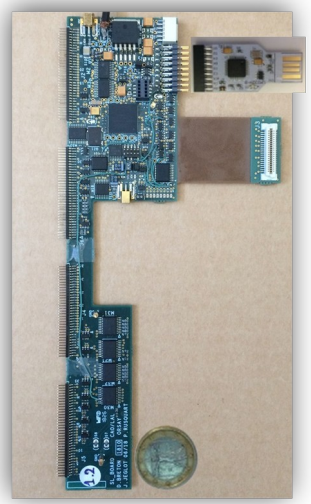
CALICE Calorimeter for ILC

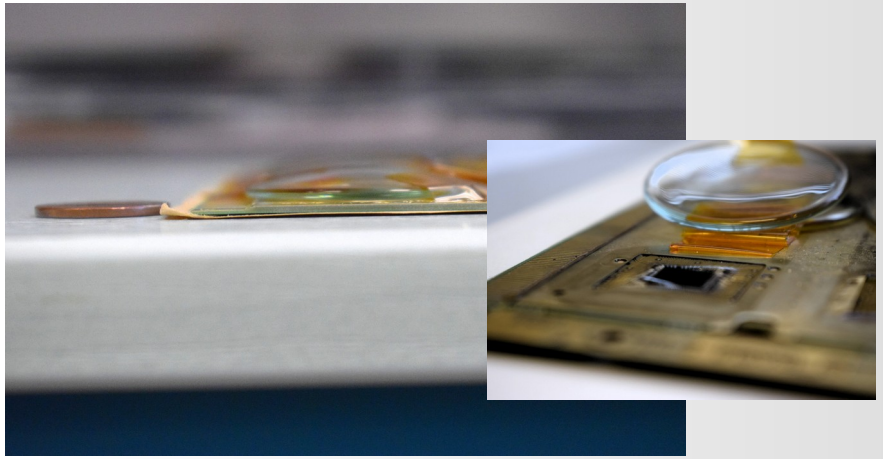
HG Calorimetry: Technological solutions III

Current detector interface card - AHCAL



Current detector interface card and thin detection unit – SiW Ecal



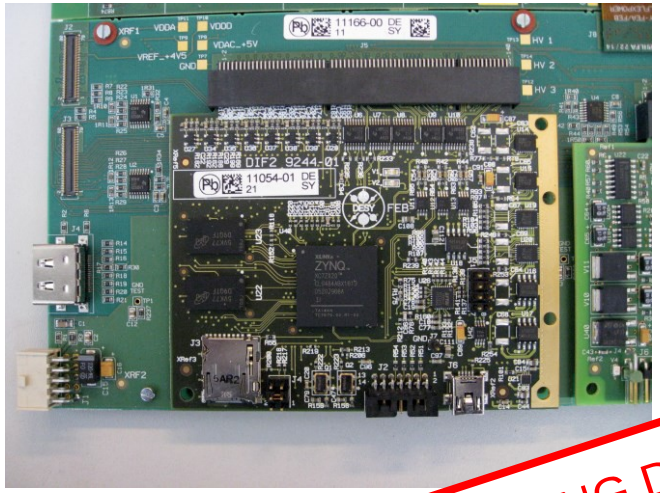


Current detector interface card - SDHCAL

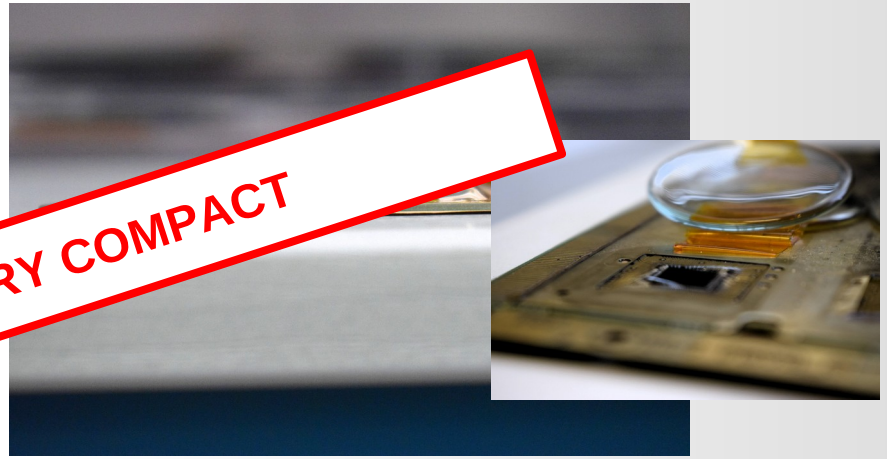
- "Dead space free" granular calorimeters put tight demands on compactness
- Current developments within CALICE meet these requirements
  - Unique successes in worldwide detector R&D
- Can be applied/adapted wherever compactness is mandatory
- Components will/did already go through scrutiny phase in beam tests

HG Calorimetry: Technological solutions III

Current detector interface card - AHCAL

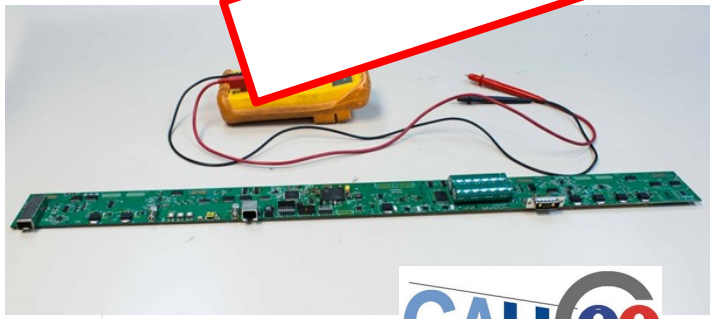


Current detector interface card and thin detection unit – SiW Ecal



LONG DETECTORS **but VERY COMPACT**

Current detector int… …HCAL



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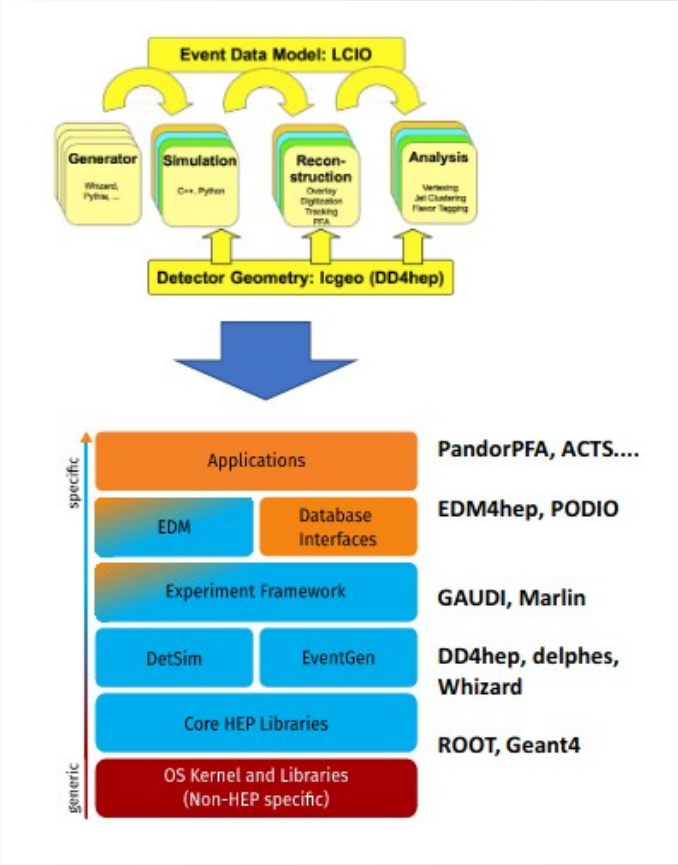
- Current developments within CALICE meet these requirements
  - Unique successes in worldwide detector R&D
- Can be applied/adapted wherever compactness is mandatory
- Components will/did already go through scrutiny phase in beam tests

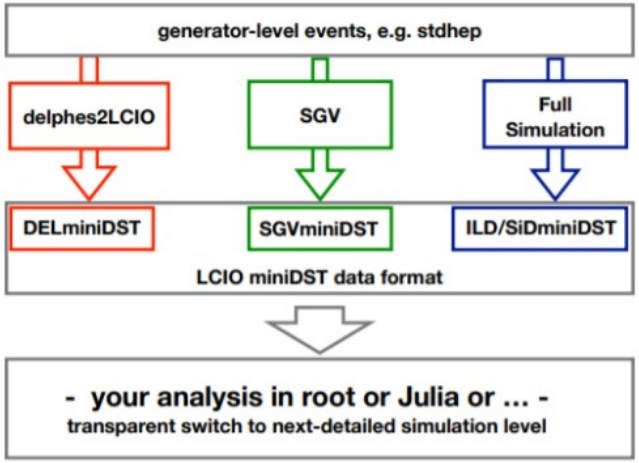
Software

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 reaching out to other communities (linear, circular, FCC-hh) to modernize our software stack: **key4hep** (DD4hep, EDM4hep,…)

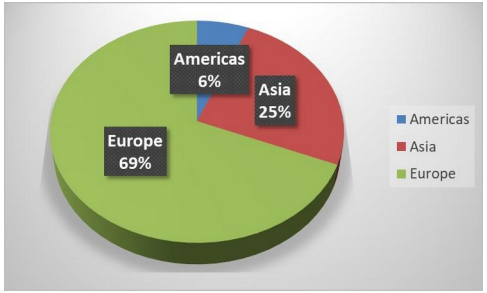


Accessing ILD simulated data



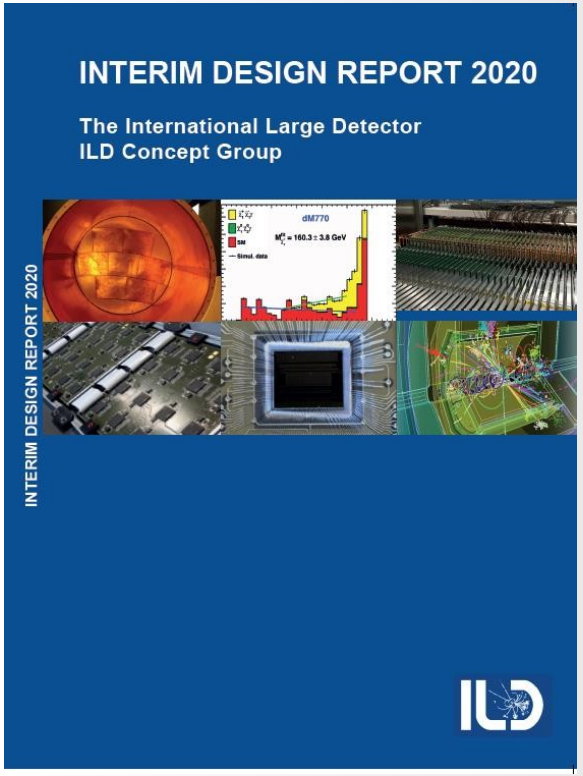
The ILD status: Interim Design Report

The work of ILD over the last years
has been documented in the IDR
and published this year.
Signed by 302 authors from 62 institutes



What promising direction of R&D do we see to further improve ILD

- Timing
- Forward
- ..
- Technology scouting



https://arxiv.org/abs/2003.01116

The ILD concept group

Very exciting moment to join ILD

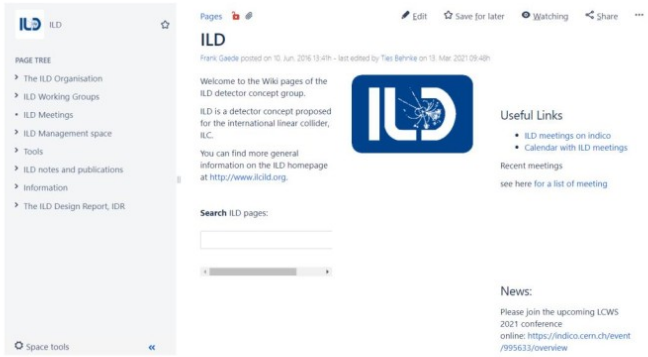
Joining ILD

We welcome new members

- No resource commitments needed
- Key contributions are possible in many areas
- Full participation in the shaping of the ILD program and future

Guest membership

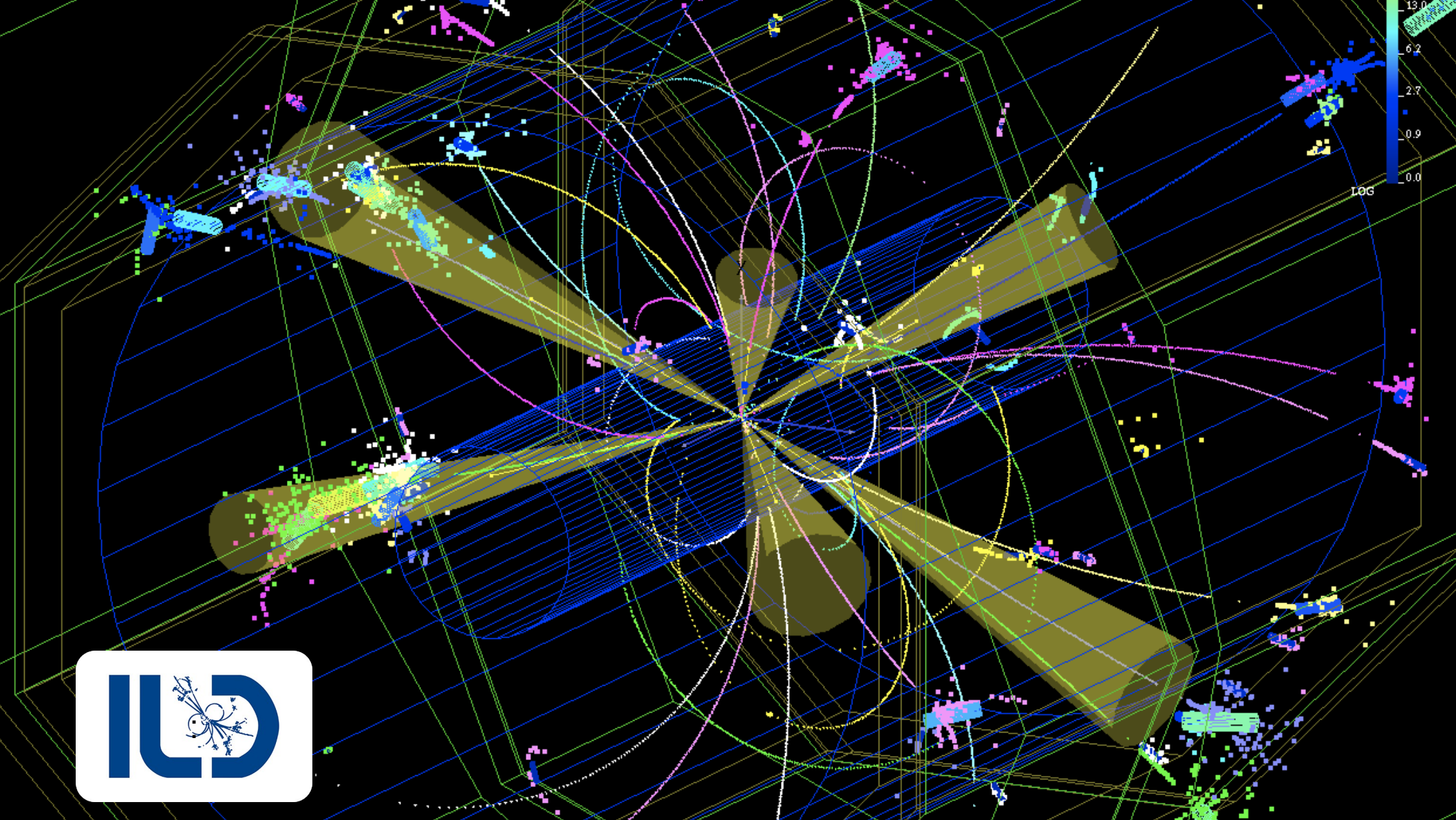
- Very simple access mechanism
- Access to ILD simulated data and tools
- Great to do a study or a feasibility study in the ILD context
- Limited duration



https://confluence.desy.de/display/ILD/ILD

http://www.ilcild.org

Slide borrowed from T. Benhke (ILD spokeperson)


13.0
6.2
2.7
0.9
0.0
LOG

Backup

- Opportunities in ILD
  - And critical areas (use Ties slides, LCWS)
- Costing
- ILD management
- More in R&D status