# ILD concept studies at FCCee - Opportunities for a TPC

**7th FCC physics workshop**

Thomas Madlener
Annecy, Jan 31 2024

# The International Large Detector (ILD)

## An overview

**Multipurpose detector with outstanding physics performance for e+e- collisions from 90 GeV to 1 TeV**

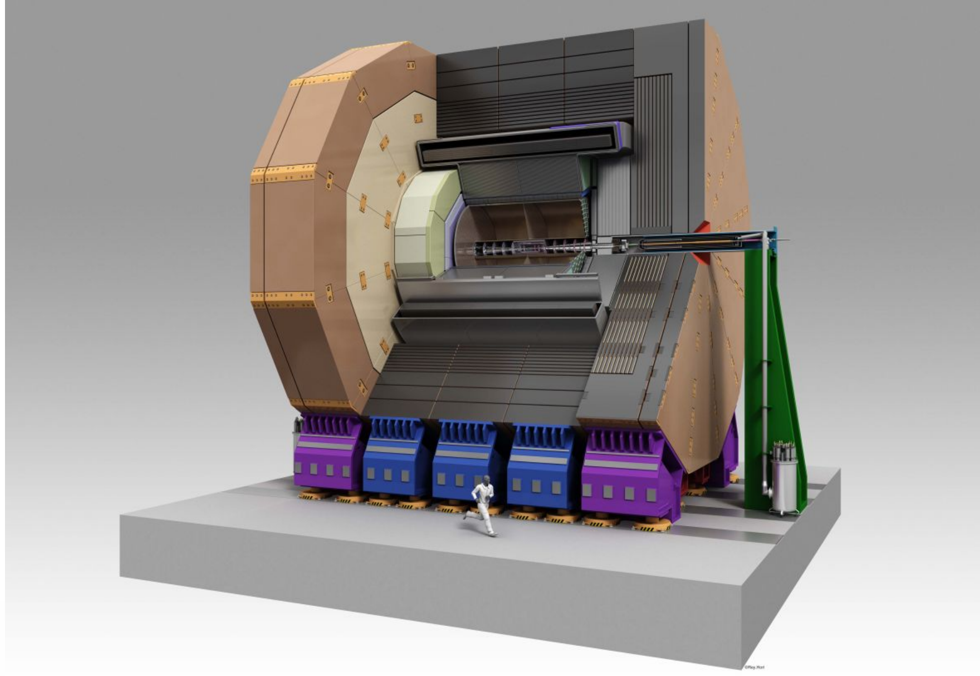
- Optimized for 250, 500, … GeV
- Designed for particle flow reconstruction of all final state particles
- Highly efficient tracking capabilities and excellent vertex resolution
- Highly granular and compact calorimetry
- Flexible design in order to adapt to detector R&D developments

**Detector layout**

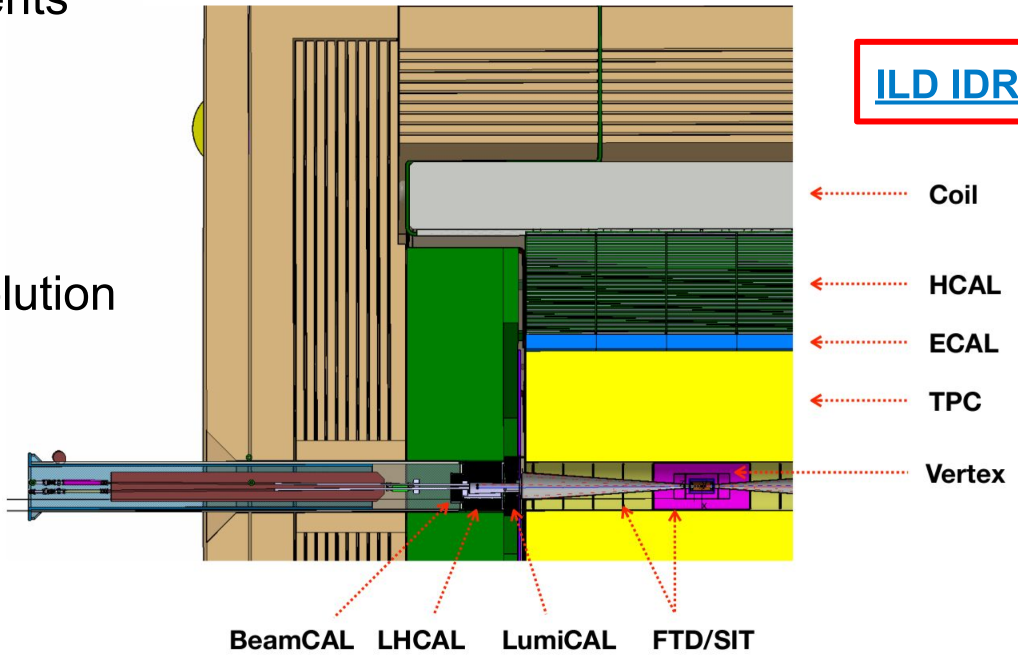
- Silicon Vertex (VTX), inner (FTD/SIT)
- **Time Projection Chamber (TPC) as main tracker**
- Silicon External Tracker (SET) for improved momentum resolution
- CALICE-like calorimetry inside coil (provides 3.5 T) field
- SET or first layers of ECAL for TOF measurements

**Collaboration**

- 58 institutes + ~10 institutes as guest members



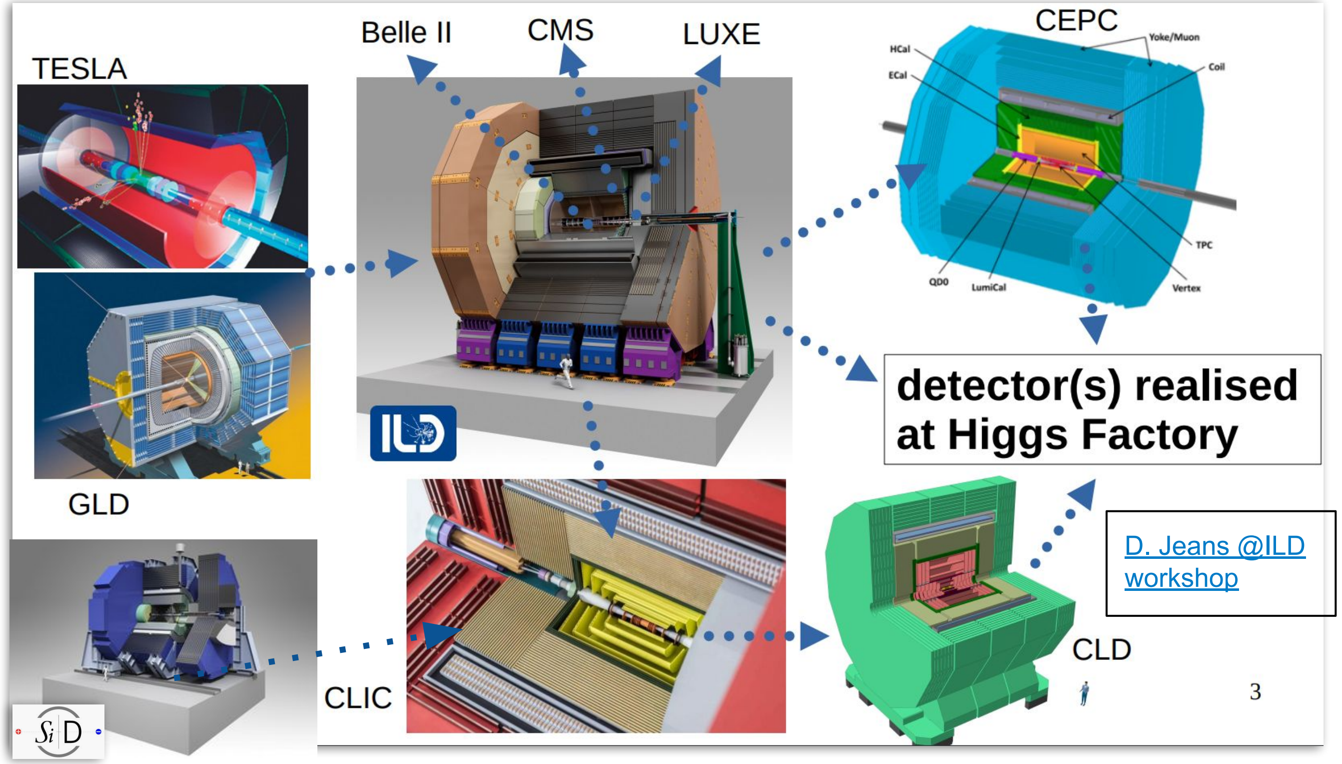
ILD IDR

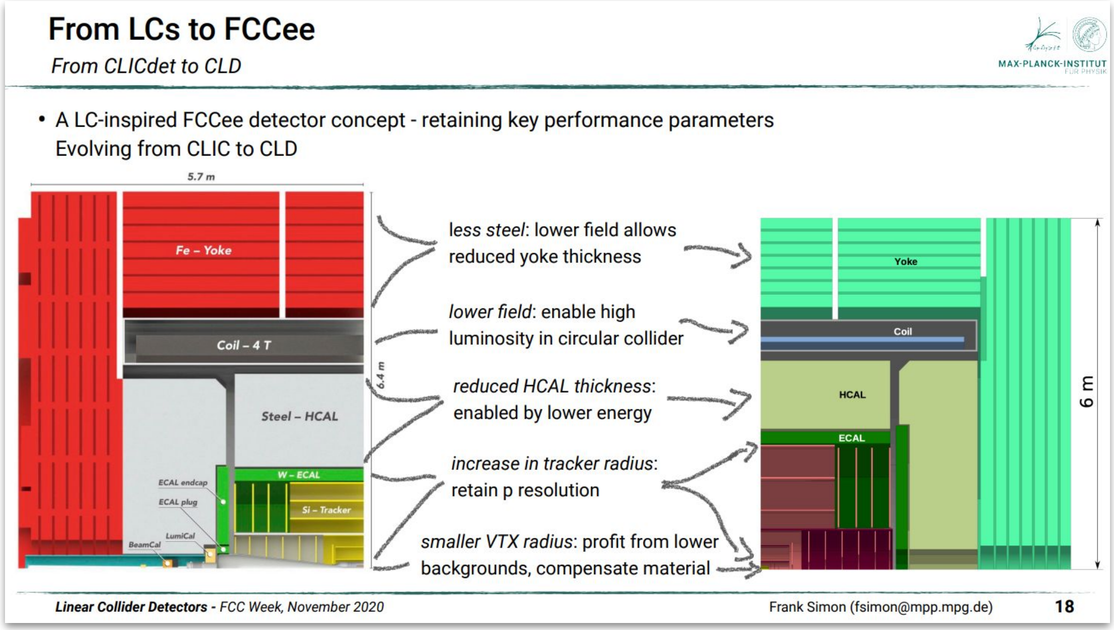


# ILD and other concepts

## "Detector ancestry"

- Many components of ILD shared with other concepts
  - Common implementations in DD4hep / k4geo
- **Detailed models include services & supports**
- See [ILD IDR (arXiv:2003.01116)] for more info




- Possible adjustments for operation at FCCee, e.g. as done for CLD
  - Lower energies → Thinner calorimeter
  - Lower B-field → Larger tracker
  - Lower beam bkg → Reduced VTX radius
  - Higher BX frequency → More cooling
- Retain physics performance in the process

# The case for gaseous detectors

## Low material budget and PID capabilities

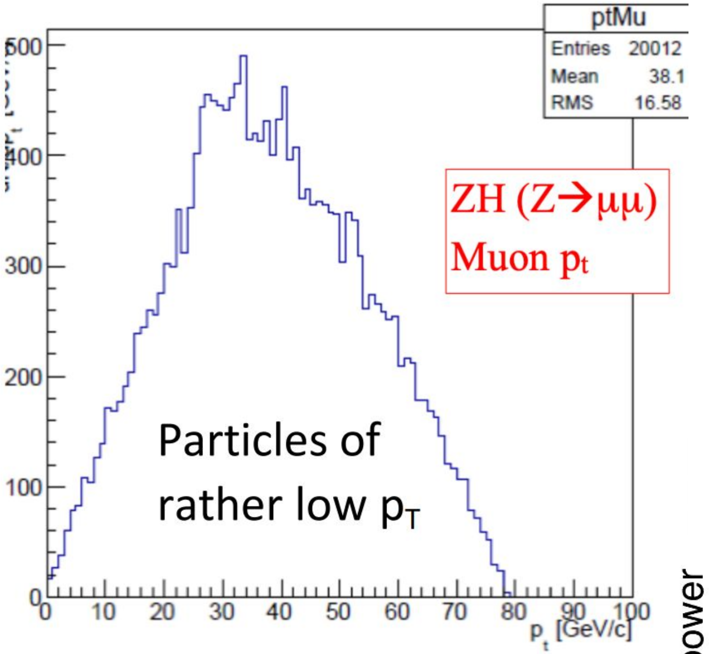
**Tracking system should be as light as possible**

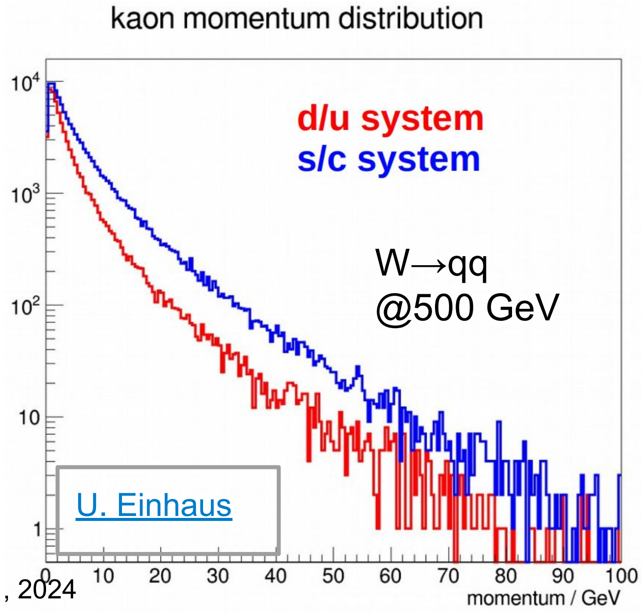
- Momentum resolution dominated by multiple scattering at low momentum
- Particle Flow requires as little material as possible in front of ECAL

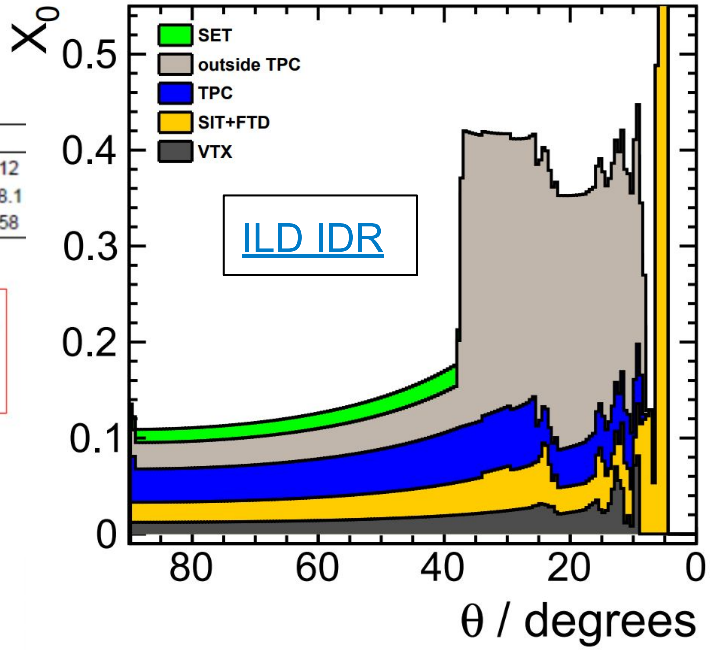
**Flavor studies require PID over wide momentum range**

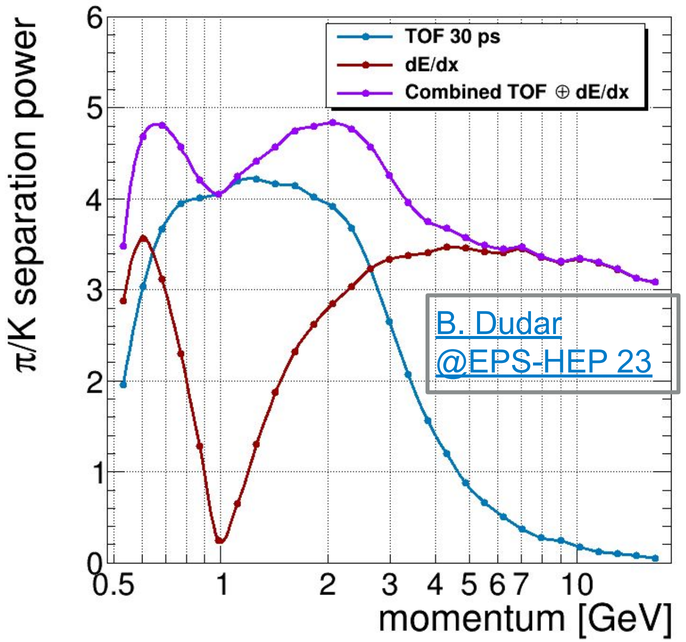
- Many studies require excellent charged hadron separation
- dE/dx or dN/dx possible up to 50 GeV
- Lower momentum ranges can be augmented with TOF based measurements

**Detection of in-flight decays via continuous pattern recognition**



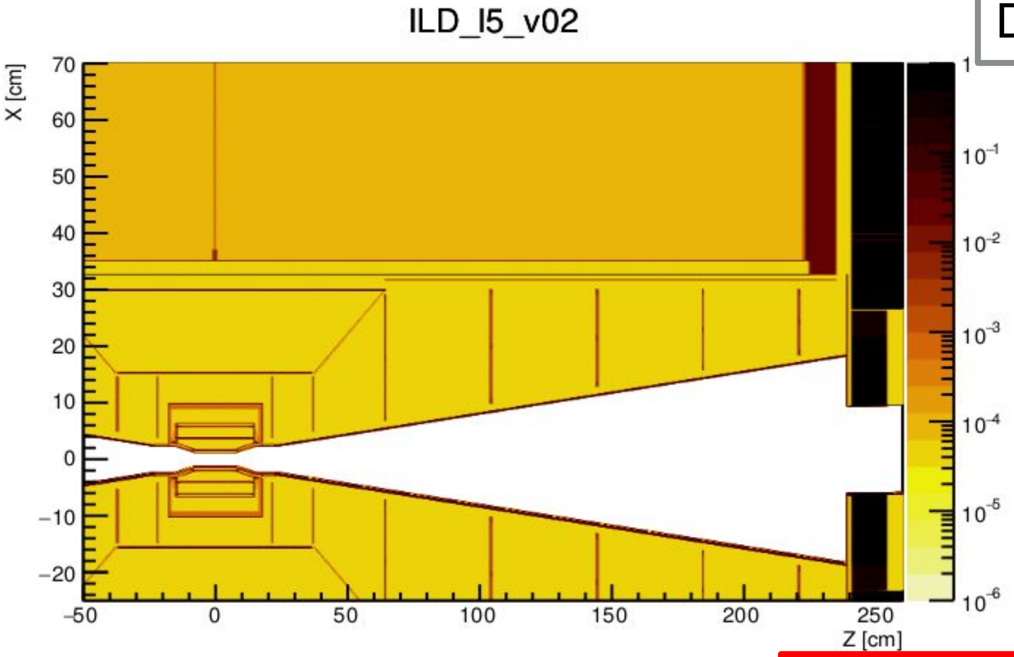
# ILD and FCCee MDI

## Reconfiguring ILD

Daniel Jeans

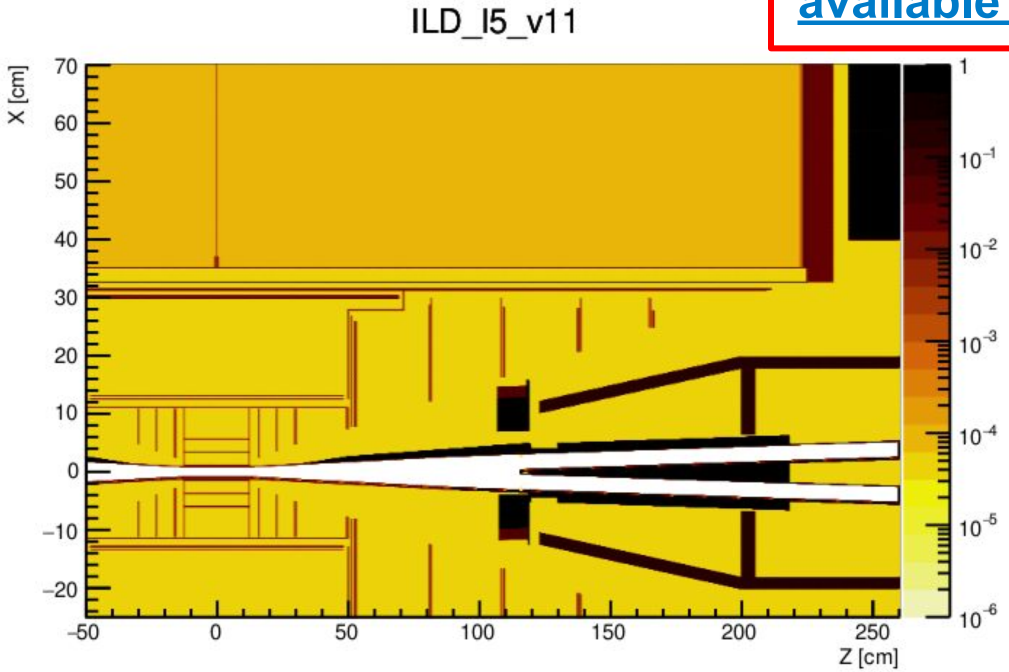
| | ILC | FCCee |
|---|---|---|
| **crossing angle** | 14 mrad | 30 mrad |
| **L*** | 4.1 m | 2.0 m |
| **detector solenoid** | 3.5 T | 2.0 T |
| **additional fields / components** | anti-DID (proposed) | compensating, screening |

- Take FCCee MDI from CLD
- Take CLD inner Si tracker layout
  - Squeeze / stretch to fit into available space
- Lower field strength affects backgrounds in VTX and TPC resolution
- **No re-optimization of this configuration yet**
  - Forward tracking, endcap calorimeters, …
  - Review of subdetector layout, material, …




- ILC MDI
- ILD inner tracker

available in k4geo!



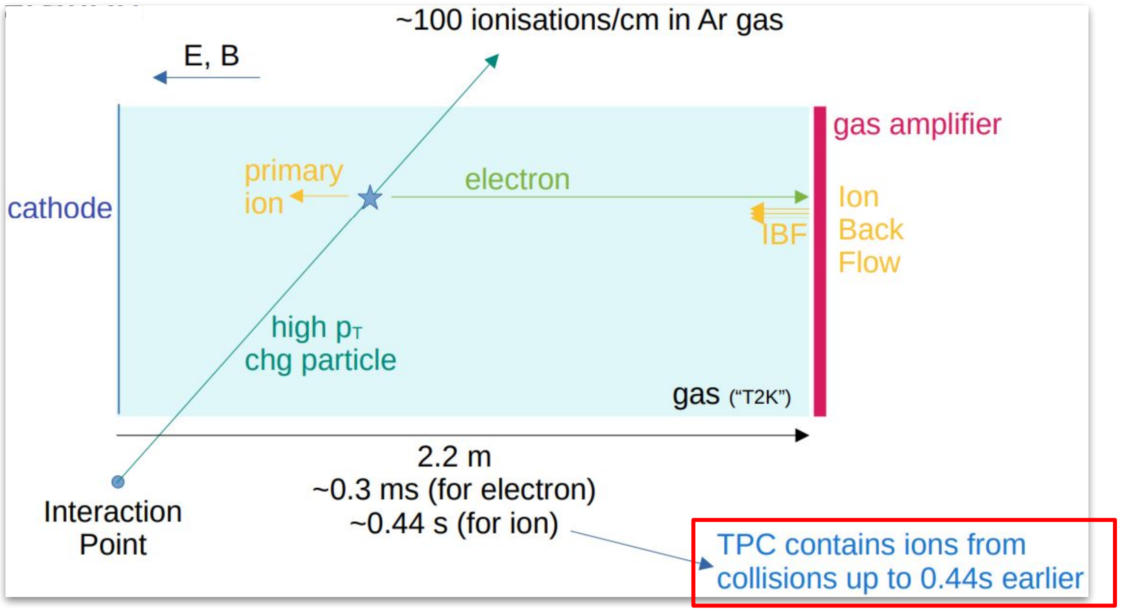

- FCCee MDI
- CLD inner tracker

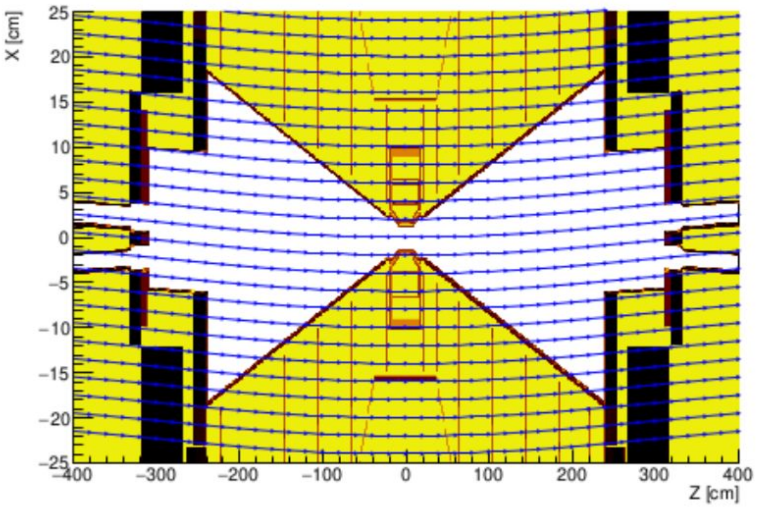
# TPC operation considerations

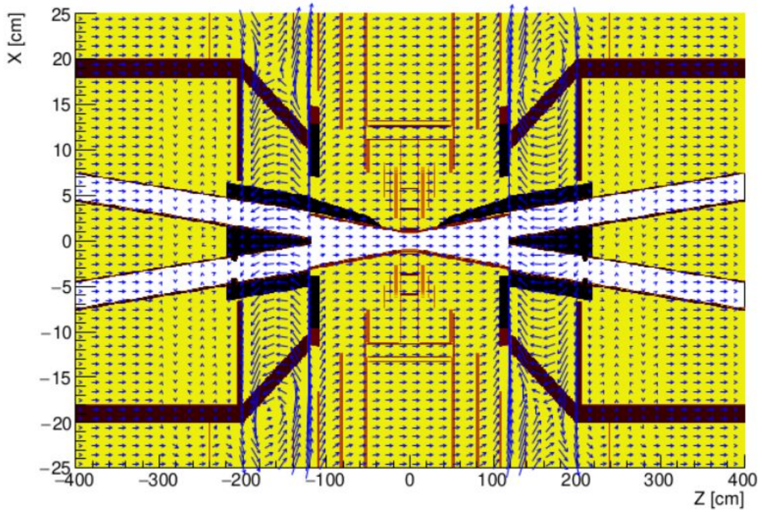
Daniel Jeans

## Comparing ILC and FCCee

- Beam backgrounds
  - Low $p_T$ → usually no direct hits in TPC
  - Backscatter from hitting (MDI) material
- Bunch structure, materials and fields in forward region
- TPC "integration time"
  - Primary ions from many BXs in TPC at any given time
- Ion Back Flow (IBF) from amplifier
  - Possible mitigations depend on bunch structure
- Ions in TPC distort drift of electrons
  - Impacts rφ resolution



# Primary ion density in the TPC

Daniel Jeans

## Backgrounds

- GuineaPig for simulating beamstrahlung pairs
  - ILC-250 (ILD/M. Berggren)
  - FCCee-91, FCCee-240 (A. Ciarma)
- Full simulation of different ILD models via ddsim
  - Vary MDI and magnetic fields
  - Special config to correctly track low $p_T$ particles
- Estimate number of **primary ions produced in TPC per BX**
- Estimate **number of primary ions in TPC volume at any time**
  - primary ions/BX * BX freq * max drift time * 0.5
    (some primary ions already @cathode)

**PRELIMINARY RESULTS!**

| model | B-field [T] | MDI | FCCee-91 | FCCee-240 | ILC-250 |
|---|---|---|---|---|---|
| | | | thousand ions / bunch crossing mean ± RMS | | |
| ILD_l5_v02 | 3.5 (uniform) | ILC | $6.5 \pm 19.9$ | $14 \pm 14$ | $960 \pm 150$ |
| ILD_l5_v02_2T | 2.0 (uniform) | ILC | $6.9 \pm 11.1$ | $15 \pm 11$ | $4700 \pm 300$ |
| ILD_l5_v03 | 3.5 (map) | ILC | $5.7 \pm 7.9$ | $14 \pm 11$ | $1100 \pm 200$ |
| ILD_l5_v05 | 3.5 (map, anti-DID) | ILC | $0.6 \pm 1.5$ | $3.7 \pm 9.7$ | $450 \pm 110$ |
| ILD_l5_v11$\beta$ | 2.0 (uniform) | FCCee | $390 \pm 120$ | $1000 \pm 170$ | $110000 \pm 2400$ |
| ILD_l5_v11$\gamma$ | 2.0 (map) | FCCee | $270 \pm 100$ | $800 \pm 140$ | $100000 \pm 1900$ |

**ILC and FCCee similar: O(100k) - O(1M) primary ions / BX**

| Collider | FCCee-91 | FCCee-240 | ILC-250 |
|---|---|---|---|
| Detector model | ILD_l5_v11$\gamma$ | ILD_l5_v11$\gamma$ | ILD_l5_v05 |
| average BX frequency | 30 MHz | 800 kHz | 6.6 kHz |
| primary ions / BX | 270 k | 800 k | 450 k |
| primary ions in TPC at any time | $1.8 \times 10^{12}$ | $1.4 \times 10^{11}$ | $6.5 \times 10^{8}$ |
| average primary ion charge density $\mathrm{nC/m^3}$ | 6.8 | 0.54 | 0.0025 |

**primary ion density in TPC (wrt ILC): x2500 @FCCee-91**
**x200 @FCCee-240**

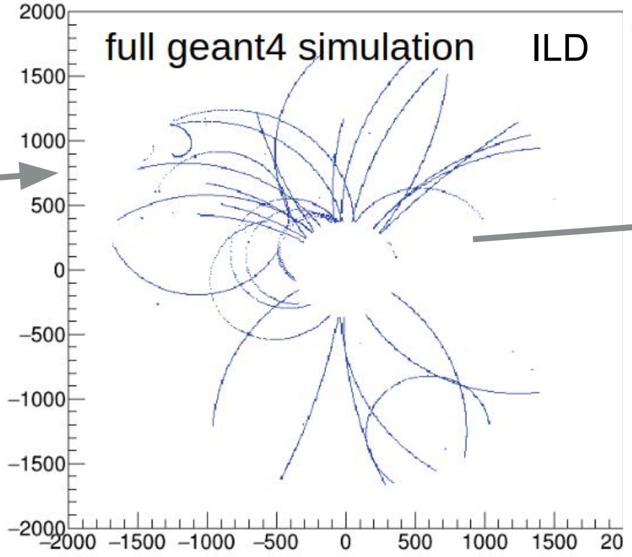
# Estimating distortions in the TPC

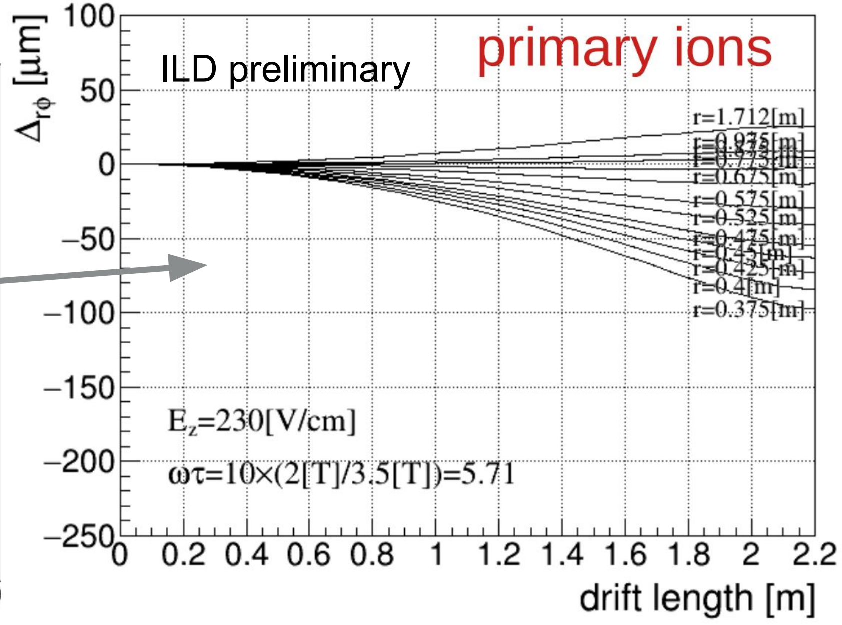
PRELIMINARY RESULTS!

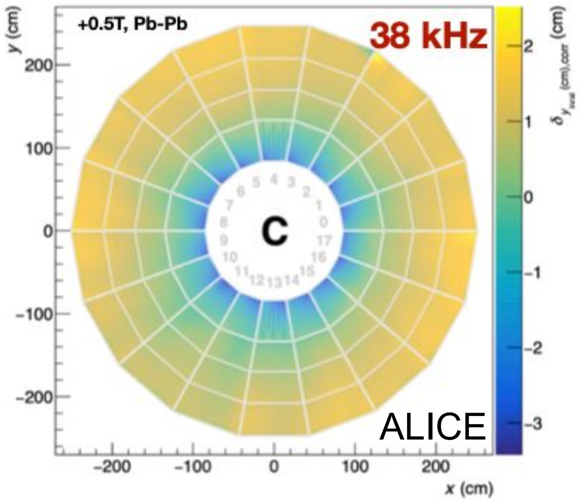
Daniel Jeans

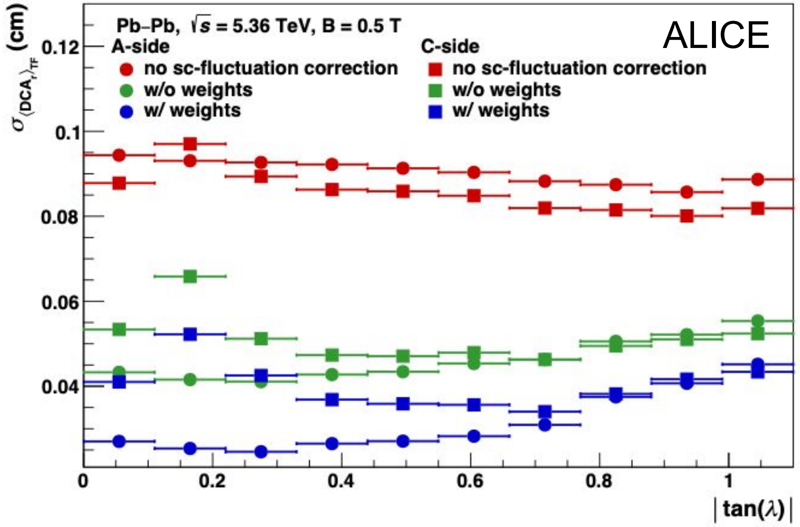
## Preliminary studies

- Physics events with high activity:
  **ee → qq @91 GeV**
  - ~1M primary ions / event
  - ~$10^{10}$ primary ions from physics in TPC at any time (c.f. $2x10^{12}$ from beamstrahlung)
- Primary ions with drift distortions in rφ of ~100 µm (physics only)
  - Naive scaling: expect max distortions ~20 mm
- ALICE TPC (Run3):
  - 20-120 fC/$cm^3$ → cm-level distortions
  - Consistent with our "first principles" estimate
- **Data driven corrections are possible but achievable performance needs studies**
  - Uncertainties after corrections?




Matthias Kleiner - Goethe-Universität Frankfurt

# Summary & Outlook

**Summary**

- ILD is a well established detector concept with “intrinsic” particle flow capabilities for a future collider
  - Highly efficient tracking system and highly granular and compact calorimeters
  - Optimized for ILC running conditions
- Implemented detector model with FCCee MDI and CLD-like inner tracker
- “First principles” studies on using a TPC in FCCee conditions
  - **Not impossible**

**Future plans**

- Optimize and study in more detail the possibilities of a TPC also at TeraZ
  - Mitigation strategies for drift distortions (corrections, redesign MDI elements?, …)
  - Stability of distortions wrt time, operating conditions, …
  - Effect on overall tracking performance (including inner Si tracker)
- **Further studies towards a particle flow driven detector at FCCee in cooperation with CLD**
  - Gas or silicon tracking

# Thank you

T. Behnke

# The Collaboration

Result of recent membership confirmation:

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

The first incarnation of ILD was developed at DESY in the 1996 as TESLA detector for the TESLA CDR (Ron Settles/ Siegfried Schreiber)

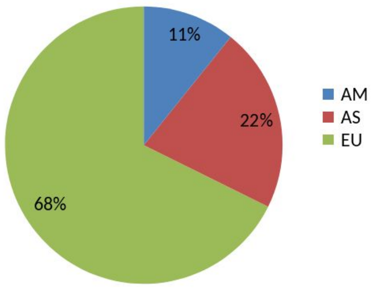
ILD as a group got started around 2008

ILD grew out of two concepts: LDC (Europe) and GLD (Asia/ Japan)

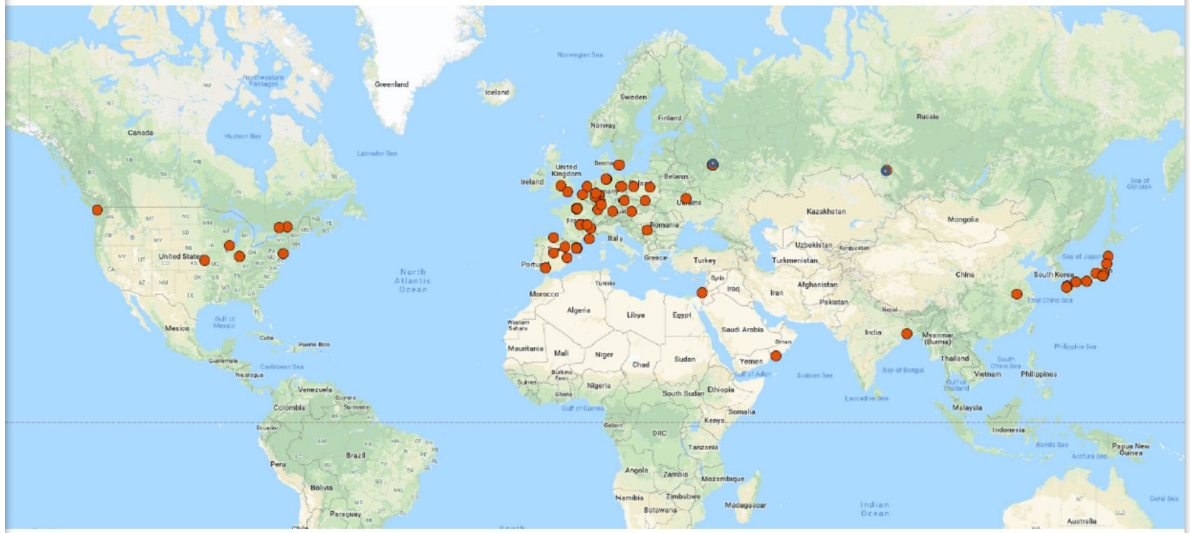
ILD's roots are linear colliders, ILC in particular

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

**institutes per region**




# ILD around the world



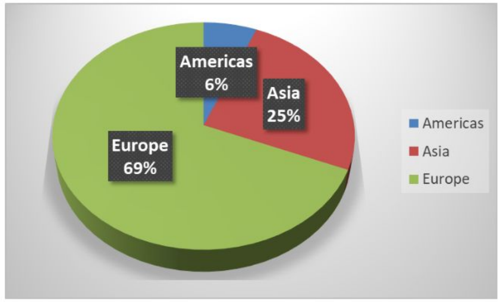
Memberships of Russian groups is currently suspended due to the war in the Ukraine

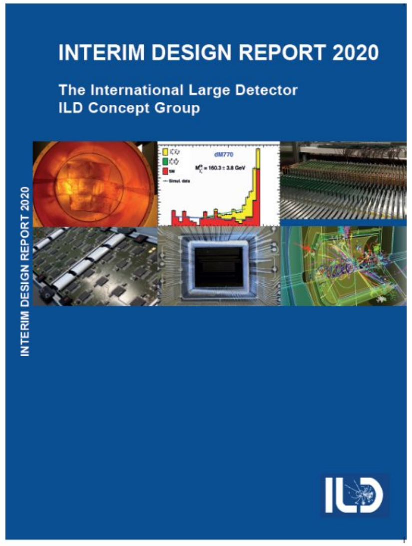
- ILD workshop @CERN, Jan 15-17 2024
- ~40 in person participants, ~30 remote

# 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

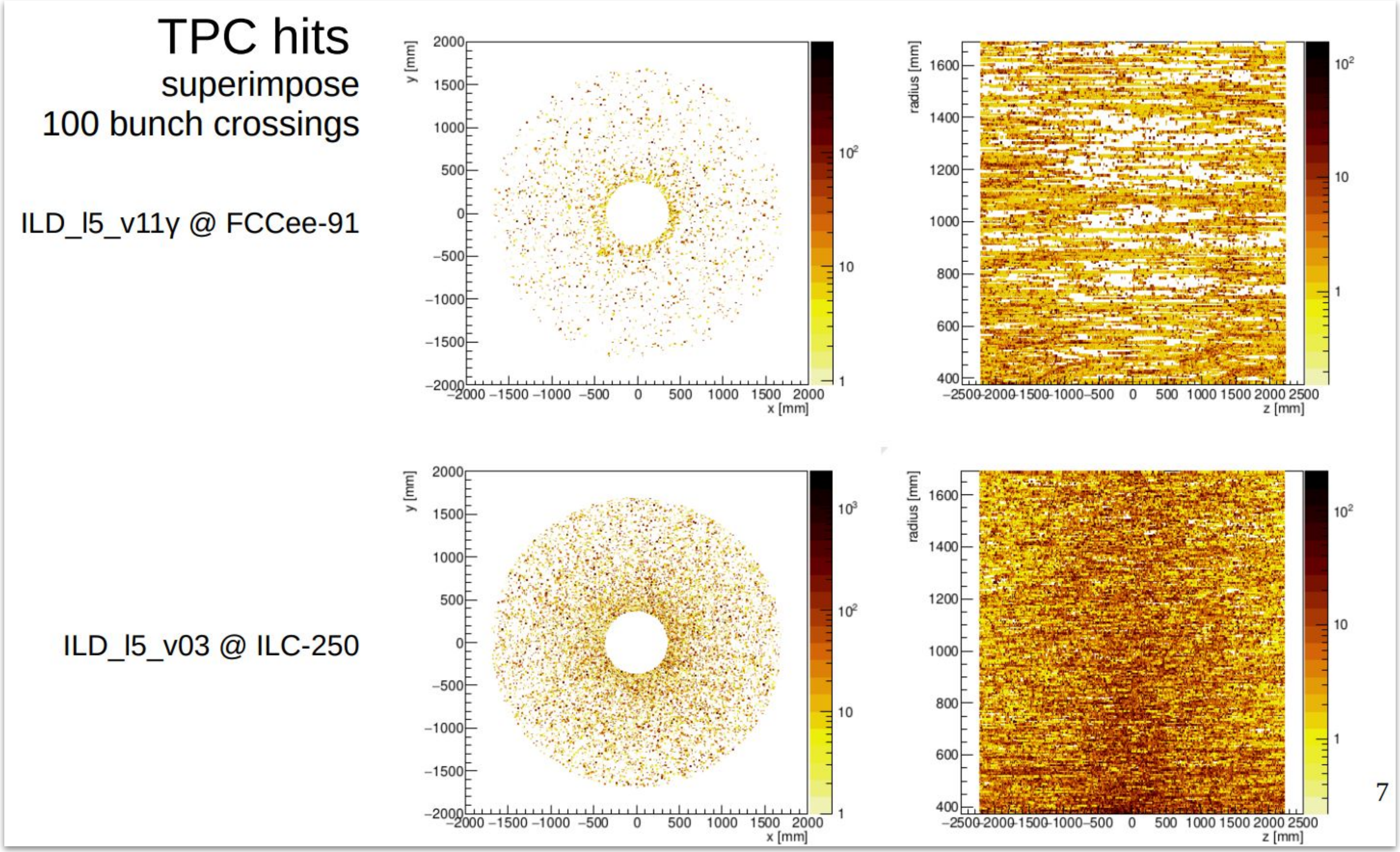



https://arxiv.org/abs/2003.01116

# TPC hits from beamstrahlung

Daniel Jeans

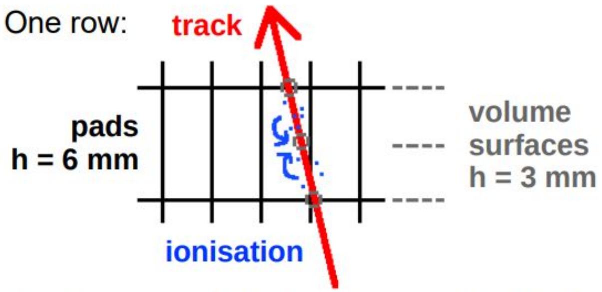


# TPC Simulation

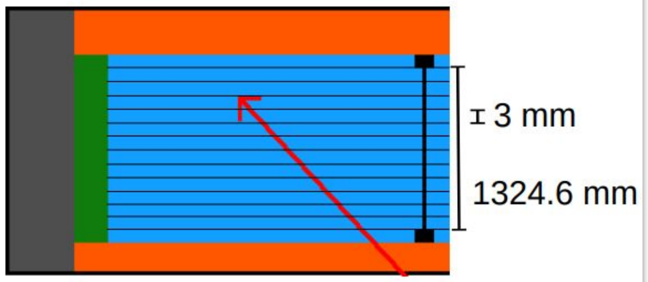
See full details in [U. Einhaus @ECFA simulation workshop]

## TPC segments

- Sensitive volume → ionisation is used for digitisation and reconstruction!
  - One row:




  - Readout granularity in r: 6 mm pad height, 220 rows inside sensitive volume
  - Provide 2 tubes per row and add ionisation of both into one SimTrackerHit per row with precise center position
  - (2 x ) 440 tubes with Δr = 3mm, Δz = 2225 mm






## TPC Digitisation

- Geant4 → SimTrackerHits → TrackerDigi → TrackerHits → TrackerReco → Tracks
- TPC Digitisation takes Sim input and transforms it into an equivalent of what an actual detector would see, taking into account various resolutions
- Hits which are closer than the double-hit resolution $\Delta_{r/\Phi}$ = 2 mm or $\Delta_z$ = 5 mm are merged
- Hit positions are smeared in r/φ and z according to the diffusion which depends on the hit z position, i.e. the drift distance, and the track direction in Φ and θ

$$\sigma^2_{r/\phi} = (50^2 + 900^2 \sin^2\phi + (\frac{25^2}{22} \cdot (\frac{4T}{B})^2 \sin\theta) \frac{z}{cm})\, \mu m^2 \qquad \sigma^2_z = (400^2 + 80^2 \cdot \frac{z}{cm})\, \mu m^2$$

# Conceptual TPC layout and gating

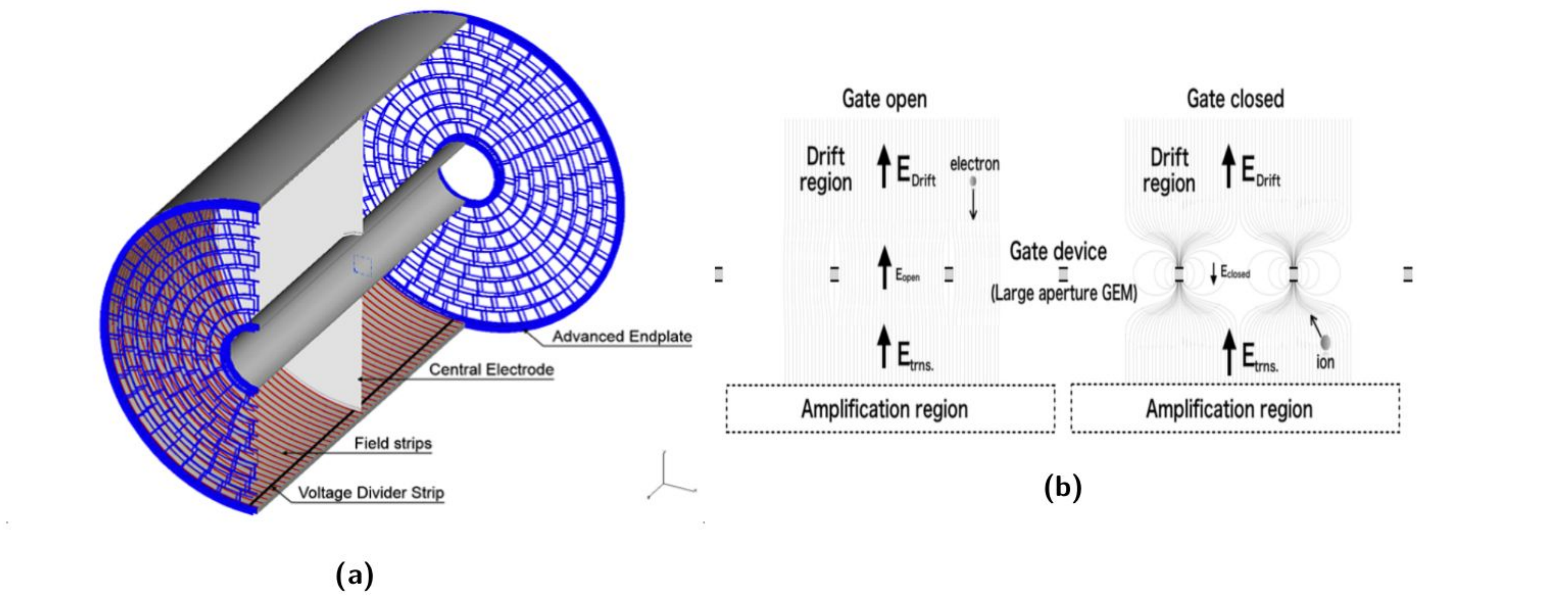



**Figure 5.6.** (a) Conceptional layout of the TPC. (b) Principle of the ion GEM gating scheme showing the two electric field configurations within (left) and outside (right) bunch trains.

ILD IDR

- Ion backflow (IBF) into the drift chamber can be mitigated using a gate device to collect ions produced in the gas amplification region
  - Possible at ILC due to bunch train structure