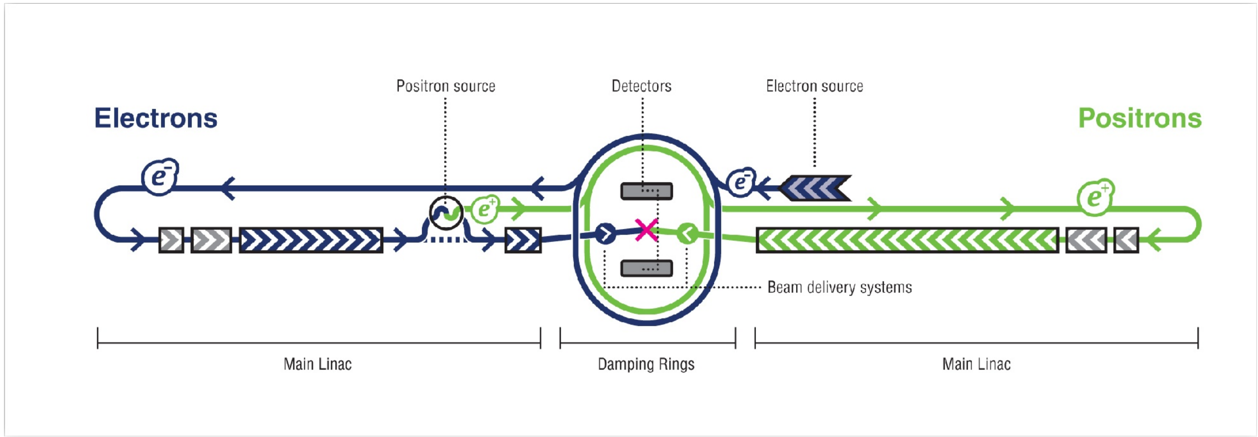
Development of a TPC for an ILC Detector

Technology and Instrumentation
in Particle Physics '11

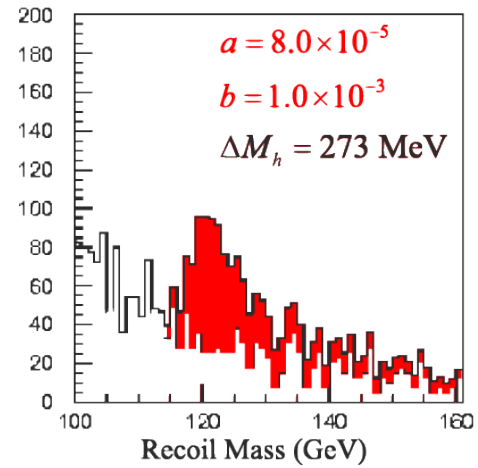
June 11th 2011

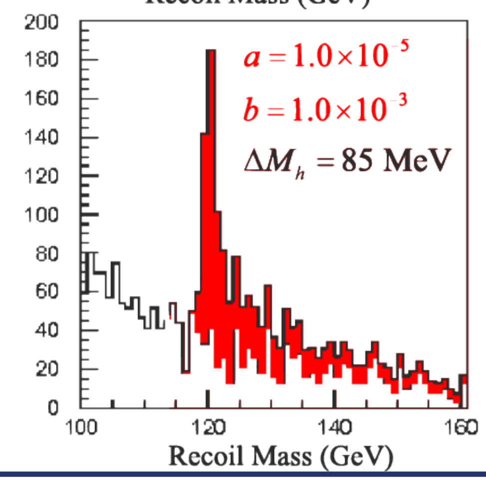
Ralf Diener on behalf of the LCTPC collaboration

- Linear electron positron collider, length: ~ 31km
- Tunable center of mass energy of 200-500 GeV (option to run at Z peak, 1 TeV)
- Two detectors with push-pull concept



$$\frac{\delta p_T}{p_T^2} = a \oplus \frac{b}{p_T \sin(\vartheta)}$$

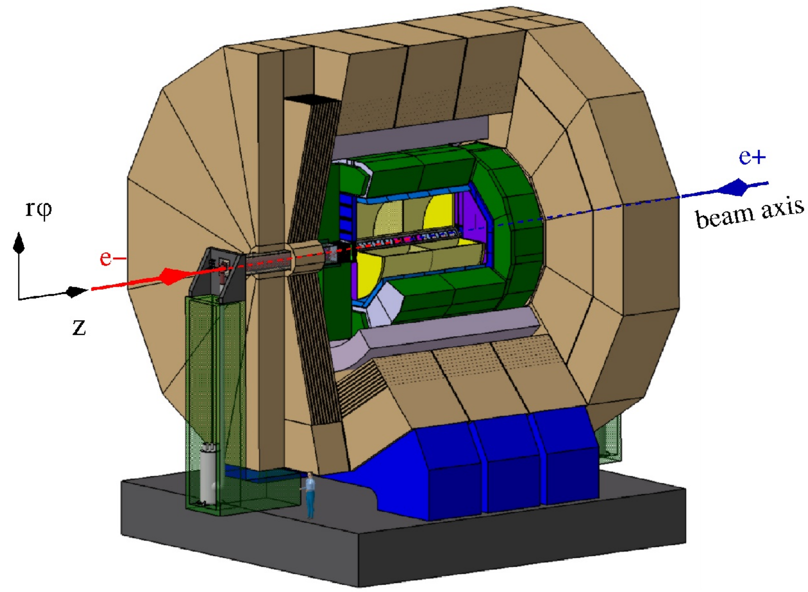


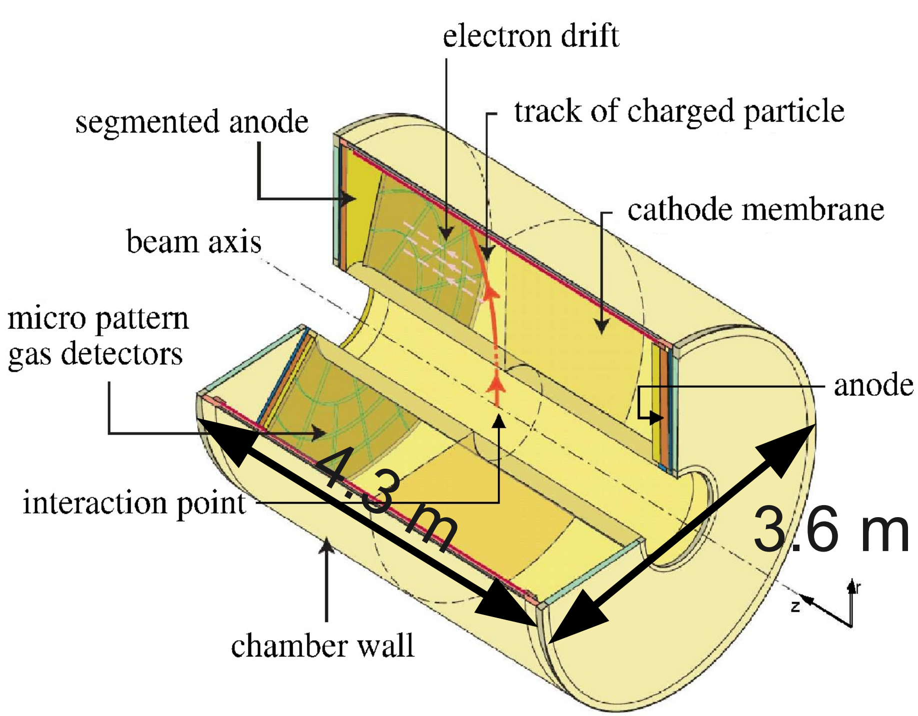


- Momentum resolution: $\sigma_{1/p}$ < 9×10^{-5}/GeV/c (TPC only) (1/10 x LEP)
  $\sigma_{1/p}$ < 2×10^{-5}/GeV/c (complete ILD tracking)
- Higgs recoil mass: $e^+e^- \rightarrow ZH$ ($Z\rightarrow\mu\mu/ee$) + X
- Needs to fit into Particle Flow [*] concept:
  [*] Particle flow: the aim to reconstruct every particle in the best suited sub detector
  - Good track separation
  - Very light weight (limited material in front of calorimeters)
  - Good pattern recognition
    In $e^+e^-\rightarrow ZZ$, WW, hZ and HA more than half of the events contain one or more K^0_S or Λ^0

A TPC at the ILD

- ILD: a multi purpose detector for the ILC
  - TPC as main tracker
  - Robust tracking, ~ 200 space points per track:
    - Easy pattern recognition
    - Robust towards machine backgrounds
    - dE/dx-measurement input to particle ID
    - $\sigma \leq 100\mu m$ ($r\varphi$) @ 3.5 T and $\leq 500\mu m$ (rz)
  - Well suited for Particle Flow concept:
    - Good track separation
    - Good pattern recognition
    - Very lightweight (material budget < 0.04 X_0)

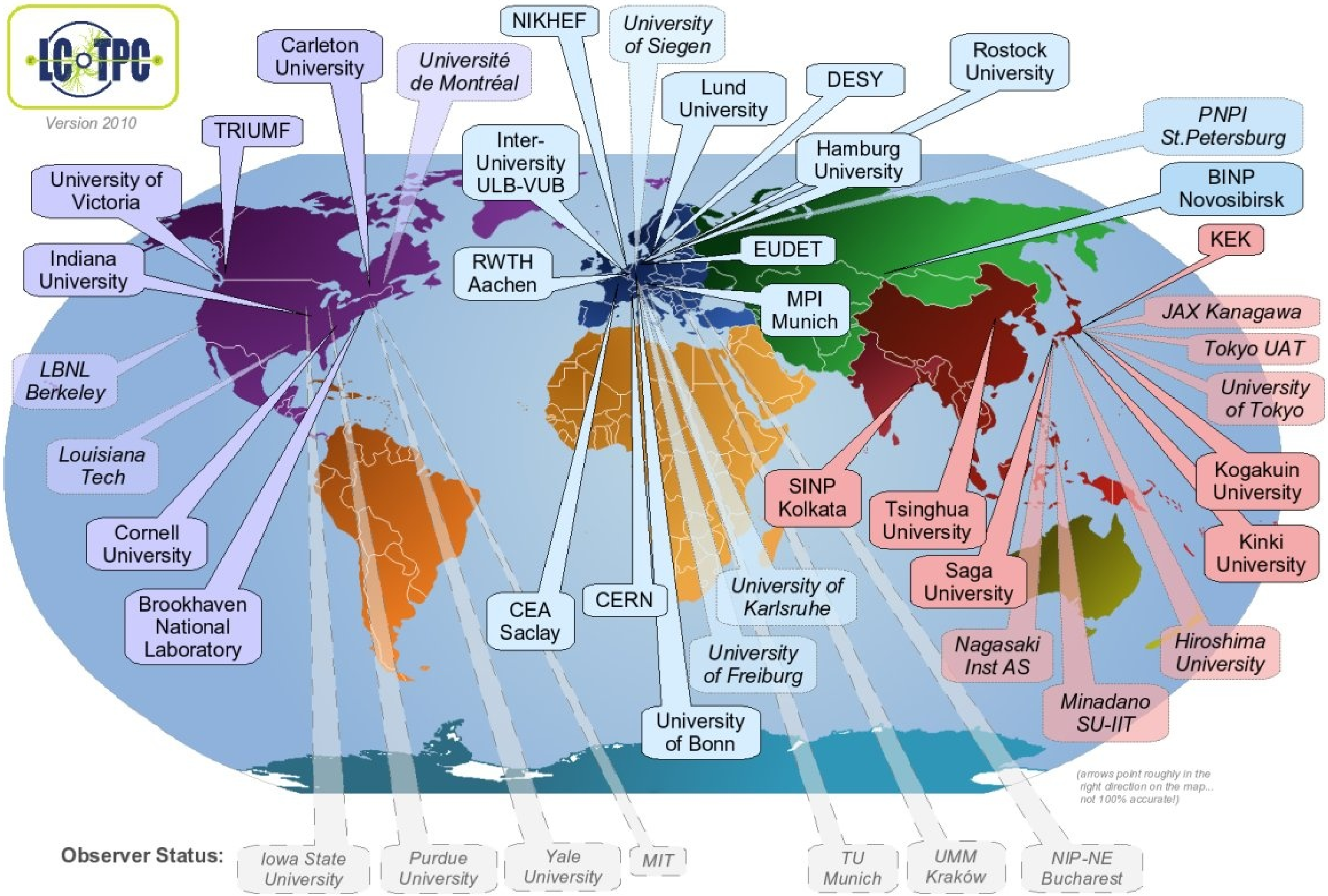




Design Challenges

Field cage **Endplate** **Cathode**	Mechanical properties (field quality) Material budget Electrical stability
Amplification structure	Technology choice: MPGD Electrical and mechanical stability Integration: large area coverage ↔ dead space Ion back-drift
Readout structure	Pad or pixel based Compactness and integration Cooling, power pulsing
Reconstruction	Calibration and alignment Correction of field inhomogeneities

LCTPC Collaboration



Overview of LCTPC R&D Plan

Small Prototypes

Proof of Principle of MPGD Detector

Ionization and Diffusion (TPC gas)

Electronics

First field cage designs

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Point resolution

Large Prototype

Tracking including all corrections:

- E- & B-field
- Alignment
- Calibrations

Electronics

Software

↓

Momentum resolution

Track separation

dE/dX

LC TPC

Advanced end plate

Electronics

More simulations (ion disks)

System engineering

Cooperation with other detectors

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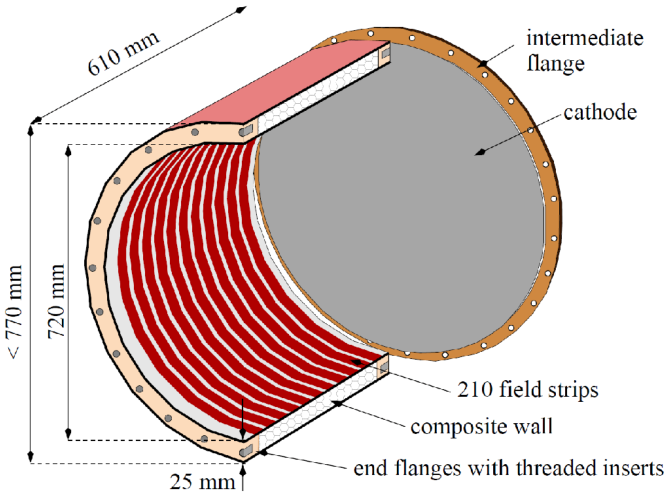
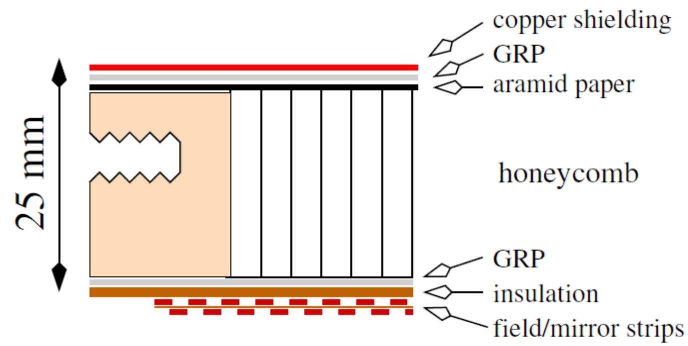
“Conceptual”

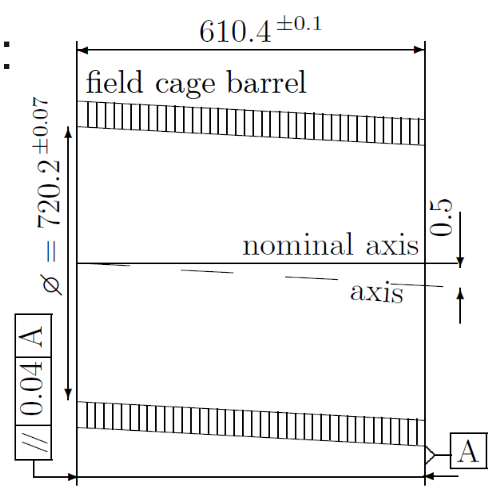
engineering design

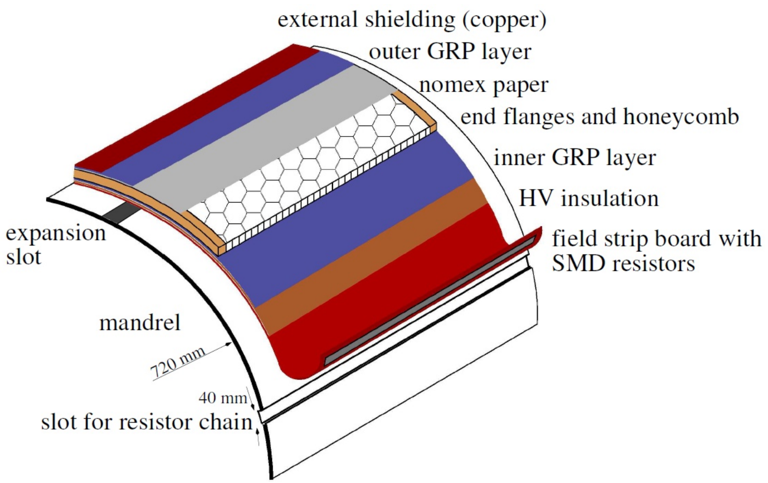
- Based on experience with small prototypes
  - Made of composite materials
  - Ø 72cm, L=61cm





- Due to fabrication imperfection:
  - Field homogeneity requirements ($\Delta E/E \approx 10^{-4}$) not met
  - 2nd field cage planned
  - Mandrel worked over and measured

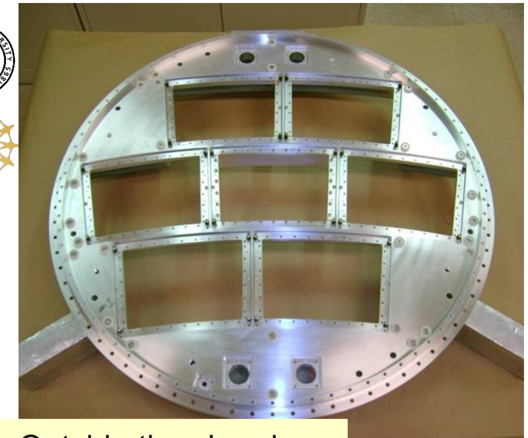




Large TPC Prototype Endplate

- LP1 endplate
  - Developed to provide the precision required for ILD:
  - Precision features are accurate to ~30 µm
  - Accuracy achieved with a 5-step machining process developed at Cornell

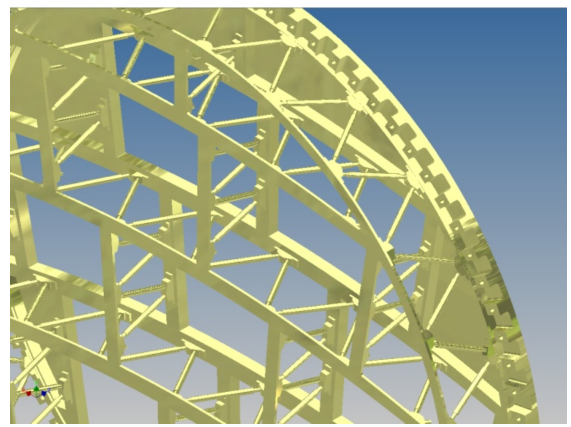
Inside the chamber



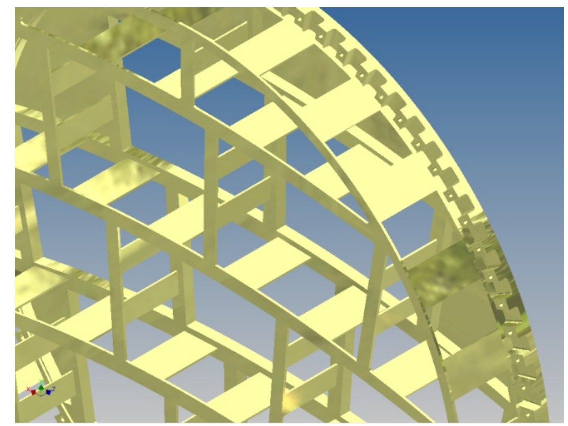
Outside the chamber

  - Does not to meet the material limit specified for the ILD TPC: 16.9% X_0 (~2x too large, goal: 8%)

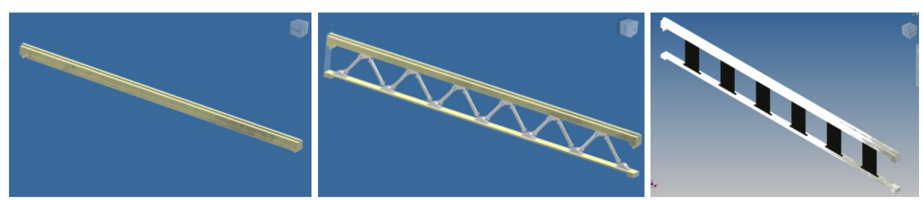
- Next step: lighten structure
  - Design results from several studies:
    - LP1 current endplate
    - LP1.5 space-frame designs, FEA (Finite Element Analysis) of models
    - Small test structures, FEA and measurements
    - 7.5% X_0 material, 23 µm deflection (100N (22lbs) in the center module)
  - Future studies will include construction and measurements using a new LP1.5 endplate



"strut" space-frame design



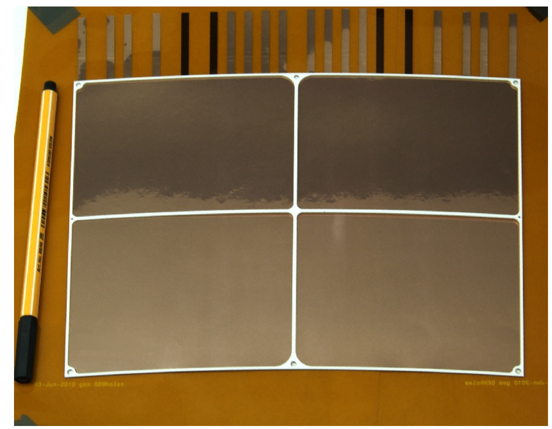
"equivalent plate" space-frame design

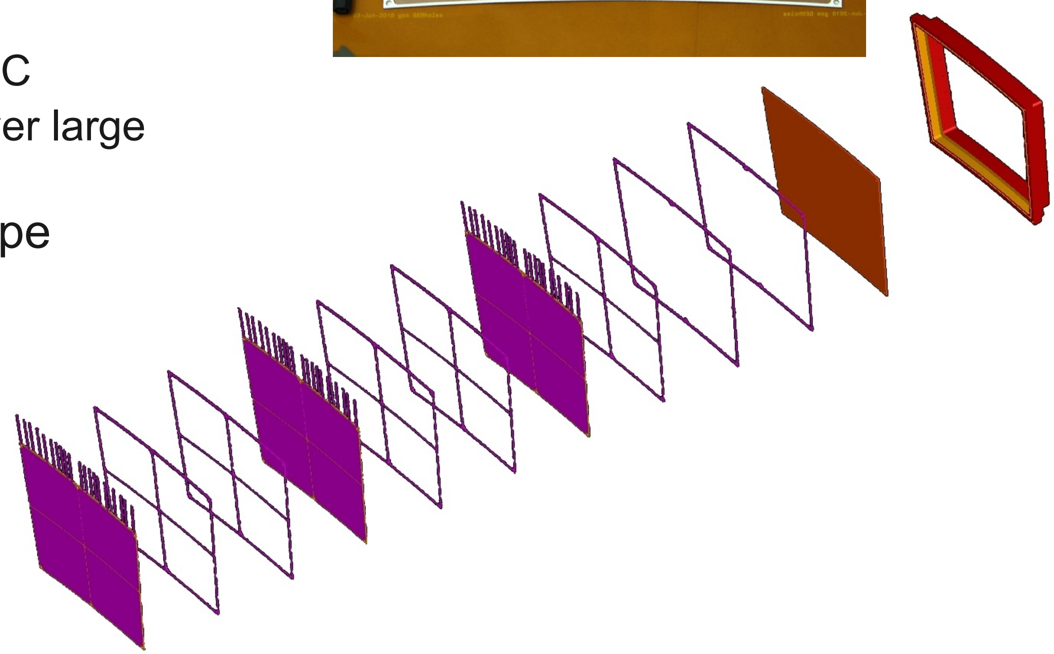


small test beams that represent one diameter of the LP1 endplate

Large TPC Prototype Modules

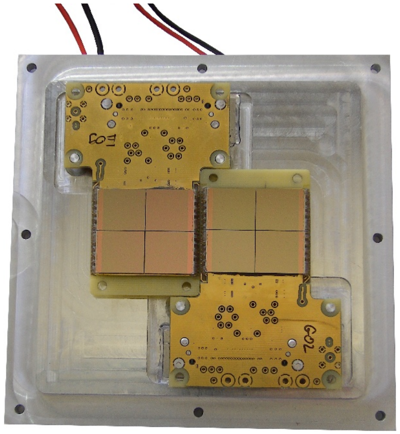
- Designed to be similar to modules to be used in ILD TPC
- Dimensions: ~ $23x17cm^2$
- Several implementations using different gas amplification (Micromegas & GEMs) and read-out combinations available
  - Example: Grid GEMs with pad read-out (ceramic grid to support the GEM foils)
    - Lightweight, integrated structure
    - Improved flatness of GEM foil:
      - less gain variations
      - better electric field homogeneity in the TPC
      - simpler construction and possibility to cover large areas with minimal dead space
    - Currently being tested in Large Prototype

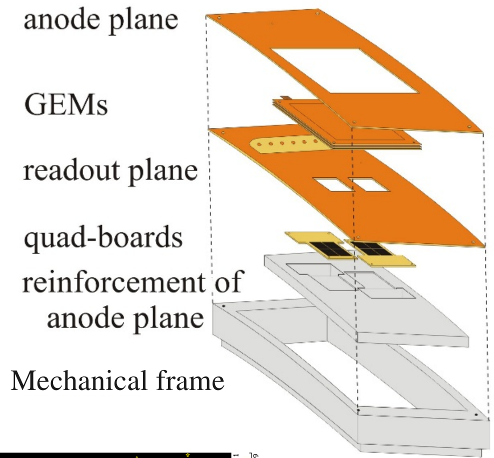


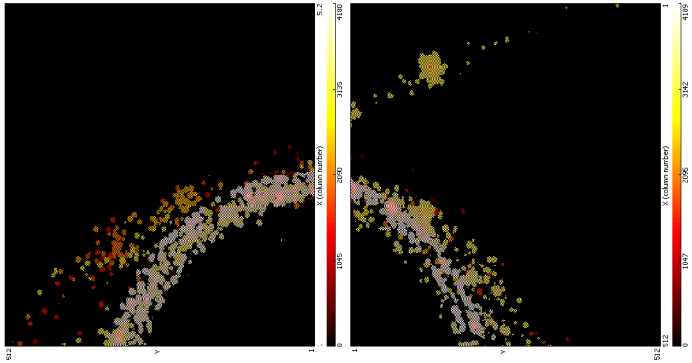


  - "Stretched" GEMs with pad read-out: see talk by Martin Ljunggren
  - Micromegas with pad read-out: see talk by Paul Colas
  - Pixel read-out: next slide

- Typically read-out with pads ca. 1x4-6 mm² → Time Pix chip read-out 55x55 µm²
- 'Ultimate' resolution → limited only by gas diffusion
- GEMs and Time Pix

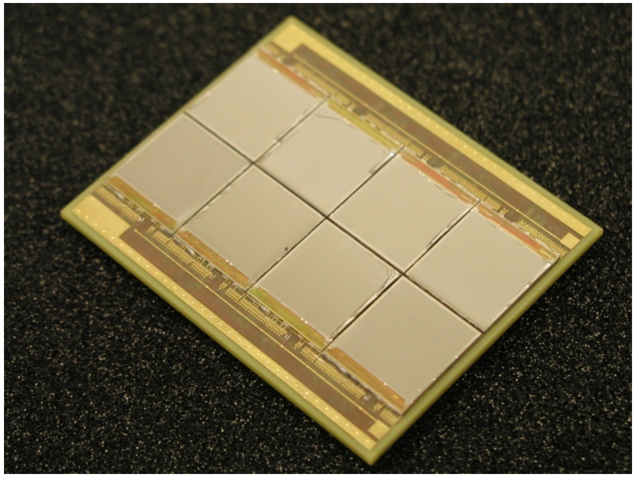


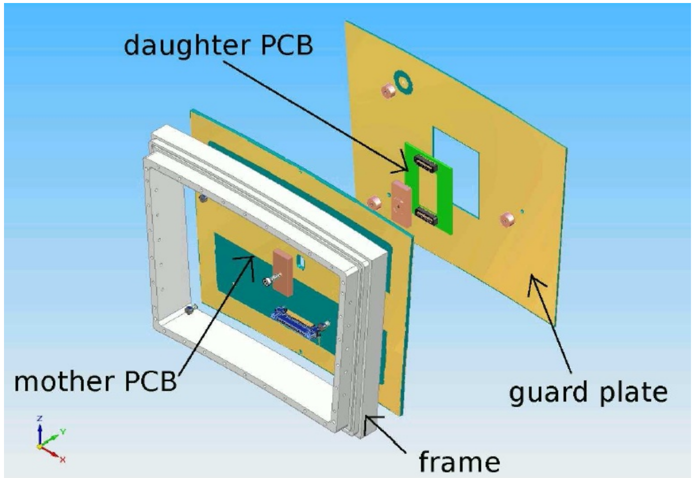




- Due to diffusion between GEMs signal sizes around 40-100 pixels → high gas gains:
- Test larger pixels by combining original pixels to larger pads

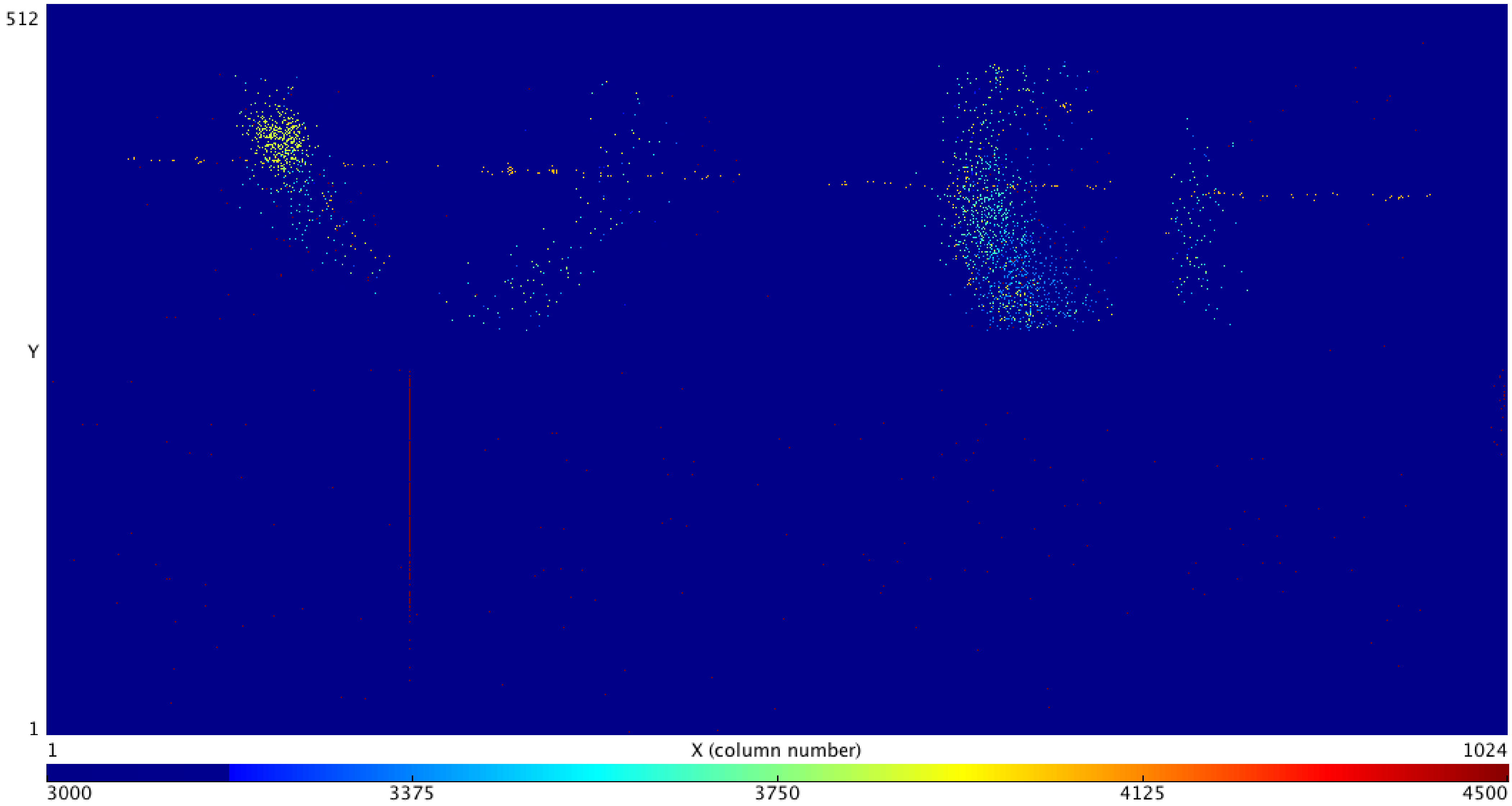
- Ingrids: Micromegas on top of Timepix chip
  - Holes aligned to pixels → Measures single electrons
  - "Octopuce" module:



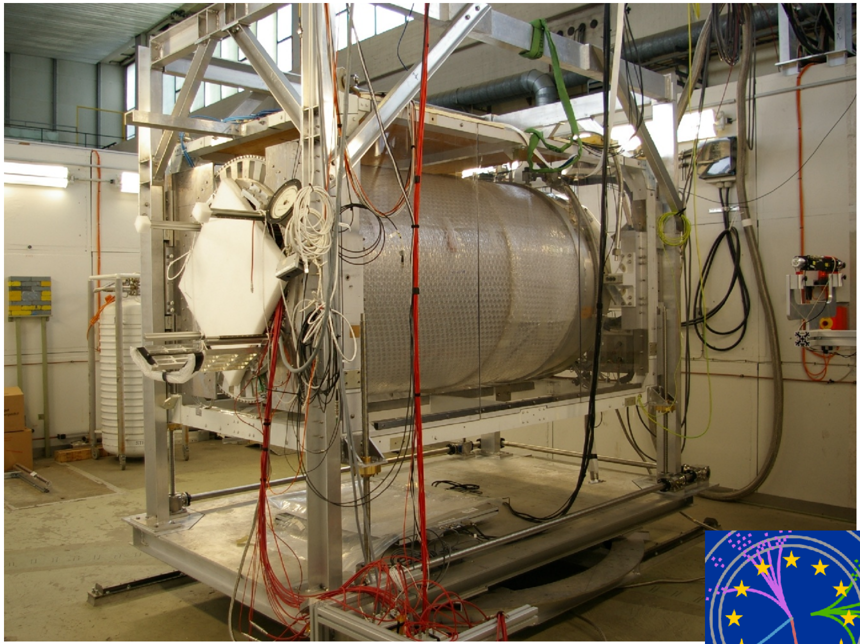


Octopuce Event Display

- He/iC_4H_{10} (80/20), B = 1T (5 GeV beam electron with two delta curlers, Dec 2010)

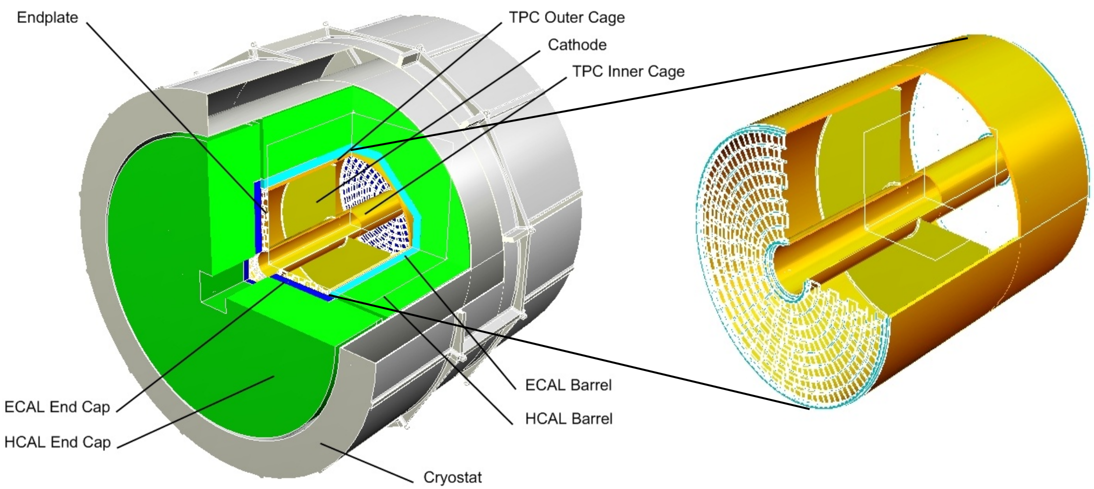


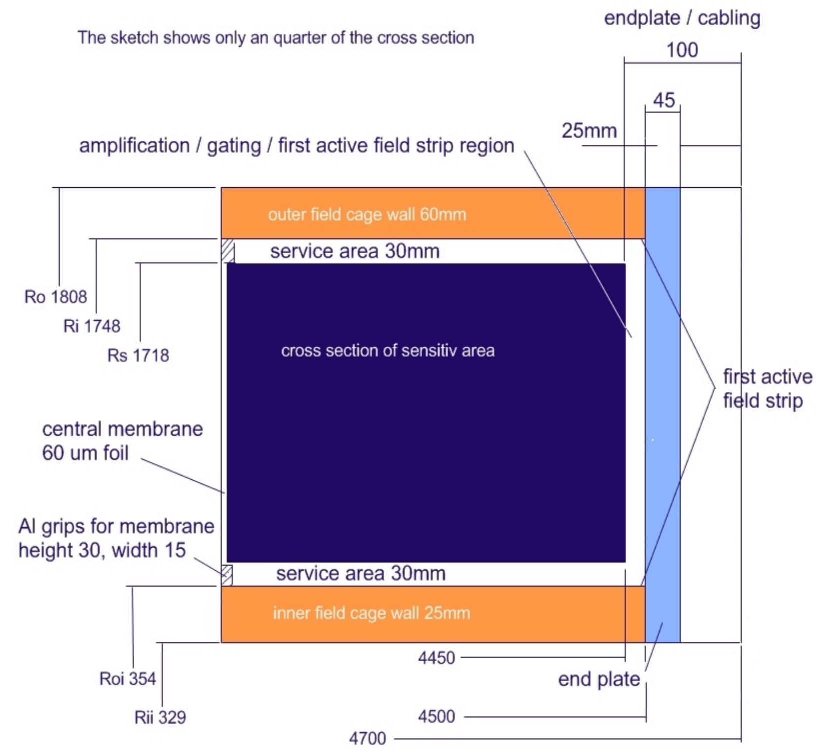
Testbeam Setup at DESY



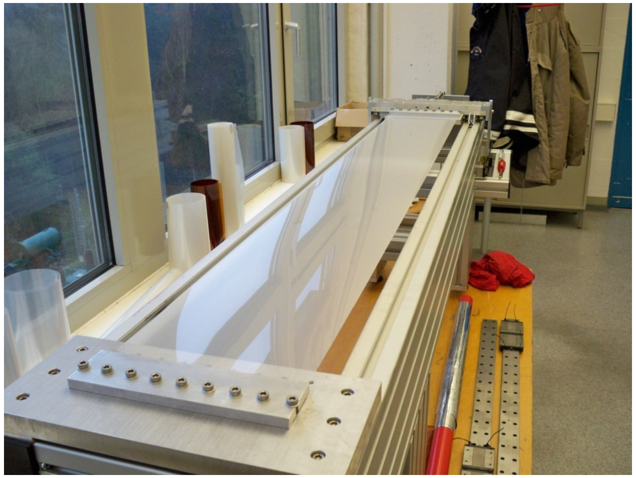
- Set up in DESY II test beam, area T24/1 (e+/e- from 1 to 6 GeV/c)
- Comprises:
  - PCMAG magnet
    - 1.25 T magnet
    - Currently persistent current and LHe reservoir This year modified to run with cryo coolers and closed cooling circle → ½ year break
  - Mounted on movable lifting stage (3 axis)
    - Control and safety system being currently completed
  - HV and gas system including slow control system
    - Constantly under extension
  - Cosmic and beam trigger
    - Cosmic trigger just updated
  - Laser calibration system
- Outer silicon detector for reference
  - Work in progress based on ZEUS vertex detector

- In consideration of surrounding detectors

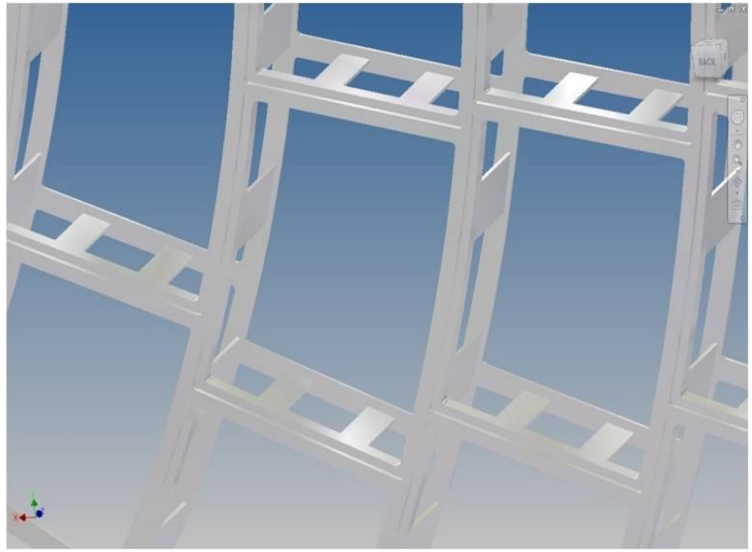


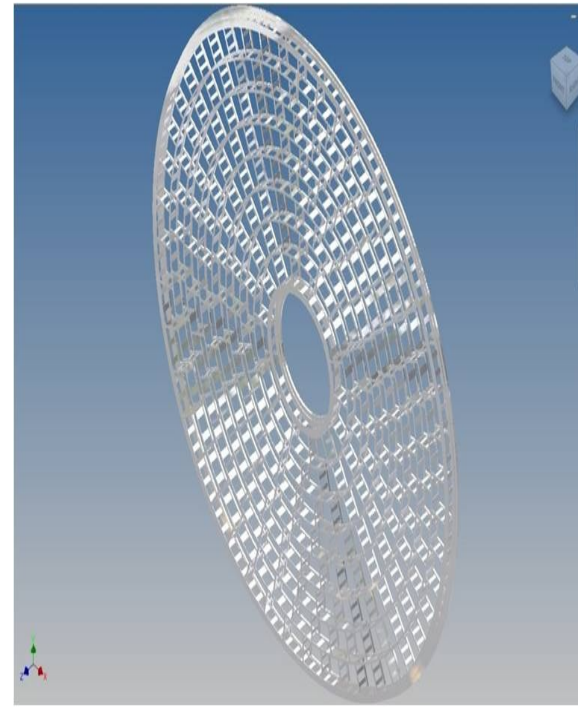


- Fieldcage:
  - Contact to an external company established to calculate mechanical properties of the field cage (composite materials)
- Cathode:
  - Several designs under discussion (foil, honeycomb…)
  - Foil tests with different kind of foils without copper coating
  - First tensile tests for one direction only
    Next: Build a tensile device for two axes



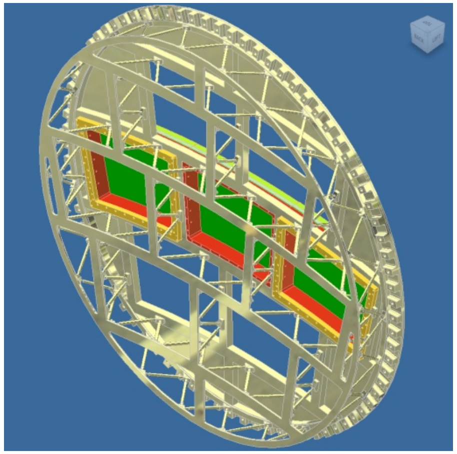
- The ILD endplate design is a space-frame
  - Shown here as the solid model used for the Finite-Element-Analysis (FEA)
  - Full thickness: 100mm
    Radius: 1.8m
    Mass: 136kg
  - Material thickness: 1.34g/cm^2, 6% X_0

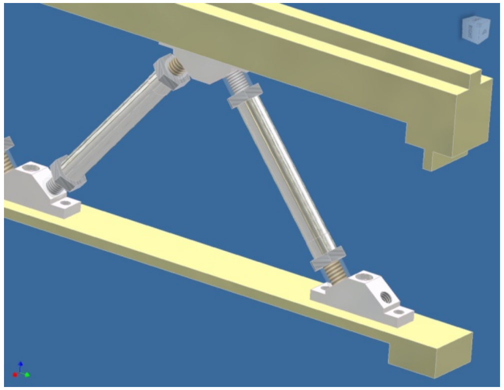




- This is the “equivalent-plate” design space-frame; the separating members are thin plates

- Design has rigidity and material equivalent to a strut design, which will be used for the new LP1 endplate
- Future ILD design can be either “strut” or “equivalent plate” design





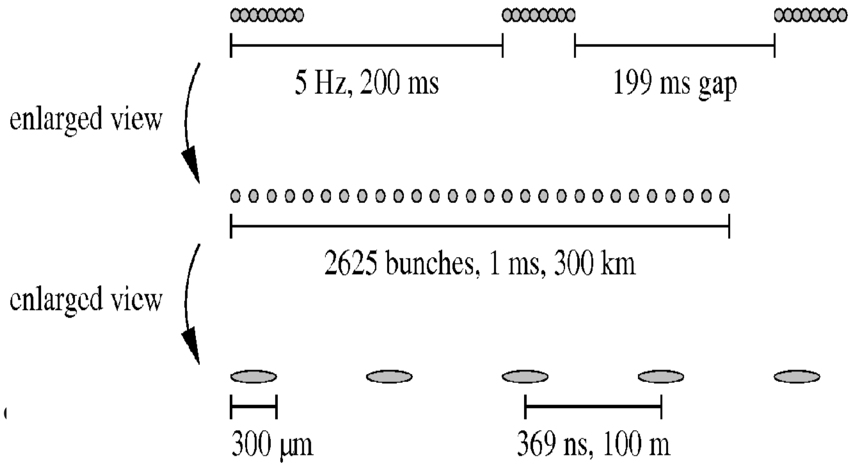
Electronics and Cooling

- Currently in use ALTRO (GEM modules) and AFTER (Micromegas)
- Planned:
  - Continue integration work with PCA16+ALTRO and SALTRO16 or AFTER
    None of these is the final ILD electronics (insufficient packing, protection, too high power consumption, memory depth,…)
  - Start design work on a future GdSP (Gaseous detector Signal Processing) chip using synergy between ILD-TPC and SLHC muon chambers

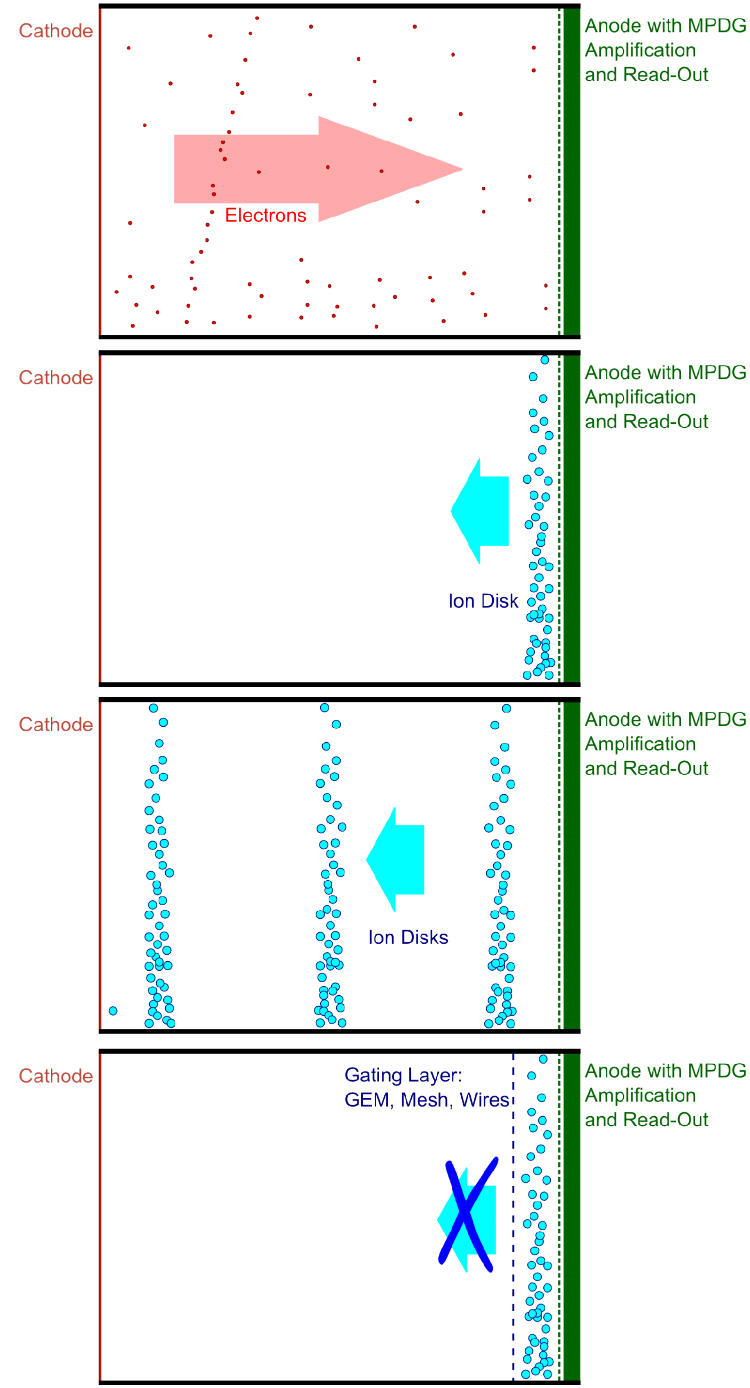
- Cooling R&D: minimize power consumption and scalable cooling solution
  - Cool electronics, keep gas temperature, no heat radiation to surrounding detectors
  - Power pulsing: switch off electronics between bunch trains
  - Cooling by 2 Phase CO_2
  - Test board with equivalent heat production developed
    for R&D to test cooling solutions

Ion Back-Flow

- After each bunch train, a disk of positively charged ions from the amplification stage drifts back into the TPC volume

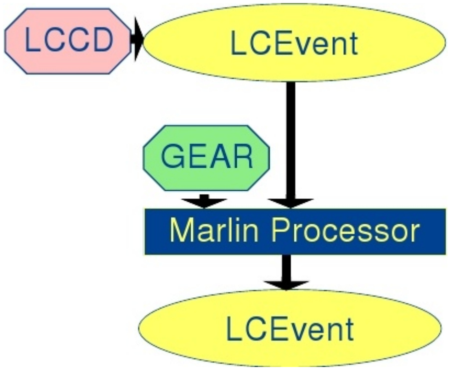


- Due to the very slow drift of ions (O(10^5) slower than e^-) up to three disks simultaneously in the gas volume
  → Field distortions
- Several groups working on simulation and R&D on hardware
- Ideas:
  - Gating with GEMs, Mesh, Wires



Software

- MarlinTPC (LCTPC software package)
  - Based on ILC software frameworks:
    - Data format/Persistency (LCIO), Processing chain (Marlin)
    - Geometry description (GEAR), Conditions Data (LCCD)
  - Goal: enable R&D groups to do detailed studies
  - Comprises simulation, reconstruction and analysis
  - Current efforts – complete basic reconstruction:
    - Complete hit reconstruction implementation for all module types
    - Complete integration of track finding and fitting packages
  - Next Steps – corrections and simulation:
    - Calibration and correction methods for inhomogeneous fields, mechanical alignment
    - Revise and extend the included detailed simulation for TPC prototypes
      Possible solution: Garfield++ in collaboration with RD51



- ILC software:
  - Model of ILD TPC for simulation (Geant4) including digitization (based on R&D results)
  - Complete tracking code currently under revision

Conclusion and Outlook

- Large TPC prototype setup implemented and being used by R&D groups worldwide
- Several module types have been tested and further tests planned:
  - 7 Micromegas modules w. AFTER electronics
  - Tests with S-Altro 16 electronics
  - Farther future: move to hadron test beam
- Next Large Prototype (v1.5) being planned for 2012:
  - New fieldcage
  - Lightened endplate
- Efforts towards a TPC for an ILD detector ongoing
  - Lots of R&D activities on mechanics, electronics, cooling and their integration
  - Several open questions (backgrounds, ion back-flow, gating, …)
- Detailed studies with small prototypes
- Software a step behind hardware, but efforts to close the gap ongoing
- Open issues in hardware and software identified and being addressed

More Information

- LCTPC collaboration homepage:
  http://www.lctpc.org/
- Last collaboration meeting:
  http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=5157
  (more detailed presentations about most topics mentioned here)
- ILD homepage:
  http://www.ilcild.org/
- ILC homepage:
  http://www.linearcollider.org/