TPC Tracking in the ILD Concept

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ILC & more: A miniworkshop for INFN
Como

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Overview

- A TPC for ILD
- Requirements and Performance
- Proposed Solution
- LCTPC collaboration
- Ongoing R&D
- Open Issues

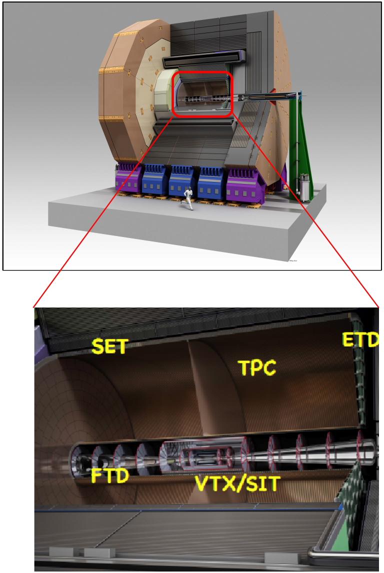
A TPC for ILD

Requirements:

- **Momentum resolution**
  $\sigma(1/p_t) = 2 \times 10^{-5}$ /GeV for Higgs mass measurement (TPC alone 10^{-4} /GeV)
- **Tracking efficiency**
  close to 100% down to low momentum to fulfill Particle Flow Algorithm (PFA) requirements.
- **Minimum material**
  in front of the highly segmented calorimeter

Solution: TPC

- $\approx$ 200 continuous position measurements along each track
- Single point resolution of $\sigma_{r\phi} <$ 100 μm
- Lever arm of around 1.2 m in the magnetic field of 3.5–4 T



ILD Tracking Performance

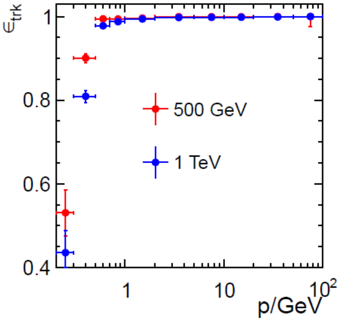
Simulation studies:

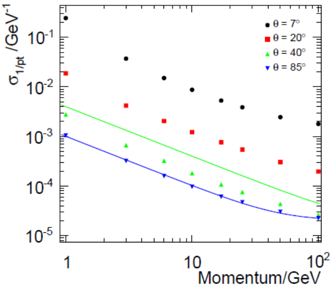
- Very good tracking efficiency
- Also in high multiplicity events (ttbar)
- Good momentum resolution (lines corresponds to $\sigma(1/p_t) = 2 \times 10^{-5} \otimes 1 \times 10^{-3}/(p_t \sin\theta)$)

$\rightarrow$ Tracking system with TPC can fulfill the requirements

R&D:

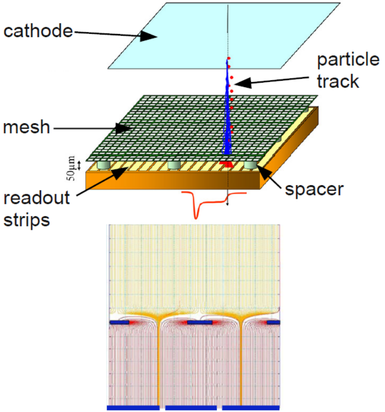
- Proof of principle
- Technical feasibility
- Reach required resolution





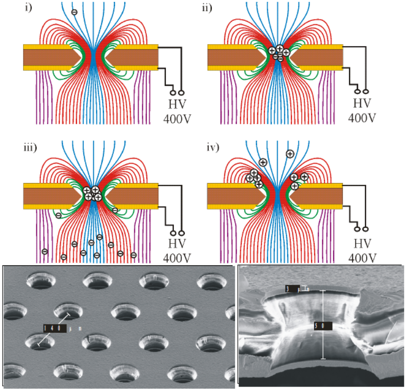
Micro-Pattern Gas Detectors

Micro-Mesh Gaseous Detectors



Y., Giomataris et al.,
Nucl. Instrum. Meth. A376:29-35,1996.

Gas Electron Multipliers



F. Sauli, Nucl. Instrum. Meth. A386:531-534,1997.

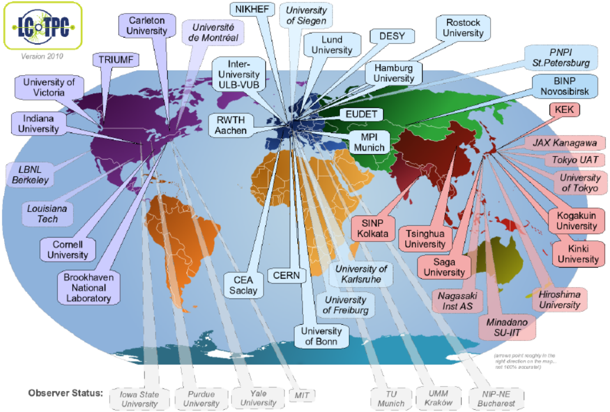
Advantages of MPGD

- Small pitch of gas amplification regions (i.e. holes)
  $\Rightarrow$ improves spatial resolution, reduction of E$\times$B-effects
- No preference in direction (as with wires)
  $\Rightarrow$ all 2 dim. readout geometries can be used
- No or very small ion tail
  $\Rightarrow$ very fast signal ($\mathcal{O}$(20 ns))
  $\Rightarrow$ good timing and double track resolution
- Direct e^--collection on pads
  $\Rightarrow$ small transverse width
  $\Rightarrow$ good double track resolution
- Ion back flow can be reduced significantly
  $\Rightarrow$ continuous readout is possible

LCTPC - Collaboration

31 Institutes from 12 countries have signed MoA
13 institutes have an observer status R&D in 3 phases:

1. Demonstration Phase
   Test feasibility with small scale detectors at individual labs
2. **Consolidation Phase**
   A medium size prototype was built to compare results and study integration issues
3. Design Phase
   Design of final detector



Options of MPGD TPC

After the initial stage of R&D with many small TPC prototypes,
we have four options of MPGD to be tested at Large prototype (LP) TPC

1. Multi layer **GEM** with the standard **pads** to readout the signal charges spread on the pad plane by the diffusion.
2. **MicroMegas** with resistive-anode **pads** to spread the very narrow charge on the pad plane.
3. Multilayer **GEM** with **pixel** readout. A pixel readout can help to cope with high occupancy.
4. **MicroMegas** mesh with **pixel** readout detecting individual primary electrons with close to 100% efficiency.
   (There are a lot of applications of different purposes for this microscopic imaging capability.)

Infrastructure @ DESY Testbeam Facility

Currently installed and/or operational:

Field cage & Mechanics
(EUDET: DESY)

Magnet: PCMAG
(EUDET/AIDA, LC TPC KEK,CERN, DESY)

Test beam & Facility (DESY)

Gas system
(EUDET:DESY)

DAQ & Monitoring
(EUDET)

Endplate
(LC TPC/Cornell)

MPGD Detector Modules
(LC TPCs)

Cathode Laser Calib.
(LC TPC/Victoria)

Beam Trigger
(LC TPC/NIKEFH)

Cosmic trigger
(LC TPC/KEK, Saclay)

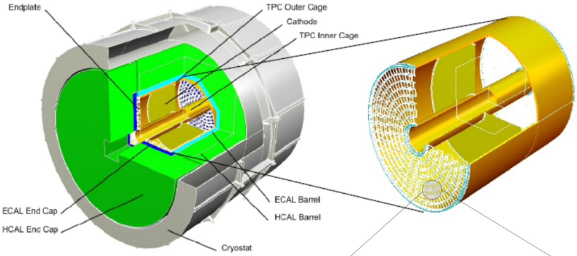
Two types of Readout electronics
(EUDET/AIDA ; LC TPC/Lund, DESY, KEK, Scalay)

Software development
(EUDET/AIDA & LC TPCs)

other developments ongoing, e.g. S-Altro, Timepix3

The Large Prototype

Large Prototype has been built to compare different detector readouts under identical conditions and to address integration issues

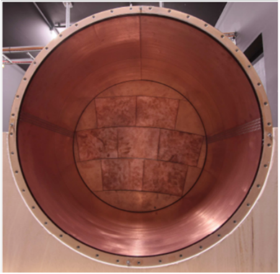


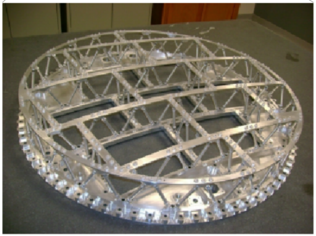
LP field cage parameters:

- $L = 61$ cm
- $D = 72$ cm
- up to 25 kV $\Rightarrow E \approx 350$ V/cm
- made of composite materials $\Rightarrow 1.24\ \%\ X_0$

Modular endplate

- 7 module windows
- $\approx 22 \times 17\ \text{cm}^2$

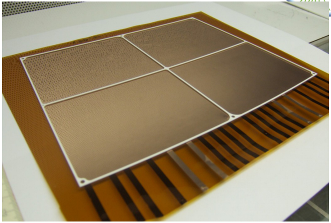




Module Development: DESY GEM Module

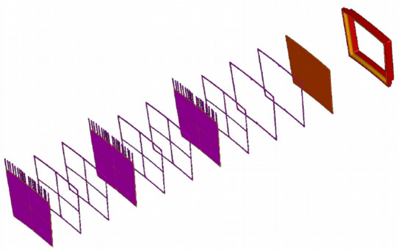
Goals:

- minimal dead space
- minimal material budget
- smooth and even surface of GEM
- stable HV operation



Solution:

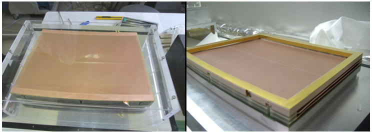
- divide anode side of GEM into 4 sectors
  $\Rightarrow$ HV stability
- no division on cathode side
  $\Rightarrow$ better field homogeneity
- thin ceramic mounting grid
  $\Rightarrow$ good flatness of GEM



GEMs with Pads

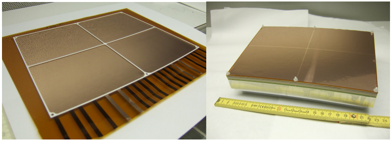
Asian GEM module:

- 2 GEMs, 100μm thick, without side support
- 1.2×5.4 mm^2 pads, 28 pad rows



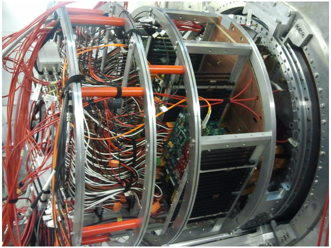
DESY GEM module:

- Triple CERN GEM with thin ceramic frame
- 1.26×5.85 mm^2 pads, 28 rows



About 5000 pads per module for both module types

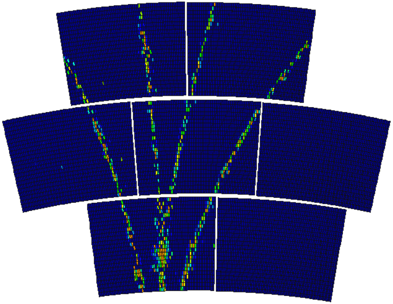
ALTRO readout electronics
$\approx$ 10000 channels

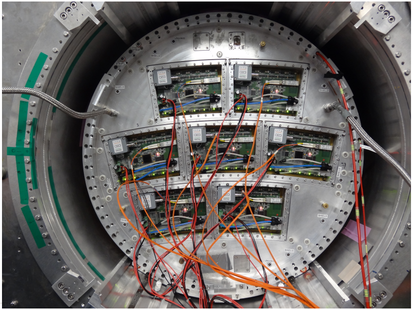


Next step: S-Altro (better integration)

MicroMegas with Pads

Compact T2K electronics mounted directly on the back side of each MicroMegas module





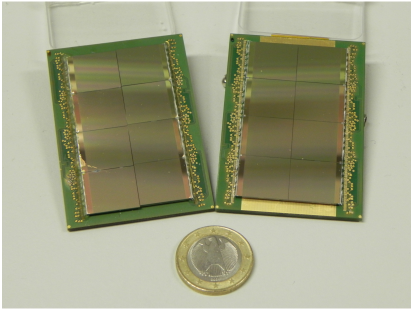
- 3×7 mm^2 large pads
- 24 rows with 72 pads
- 1728 pads per module
- Resistive foil to spread charge

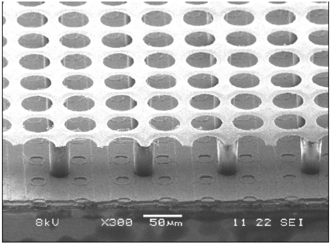
Fully equipped endplate with 7 modules with 12k channels

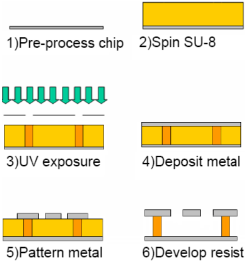
InGrid: MicroMegas with Pixel

MicroMegas on top of a pixelized readout chip:
bump bond pads for Si-pixel detectors serve as charge collection pads

2 Oktoboards with bare Timepix chips:





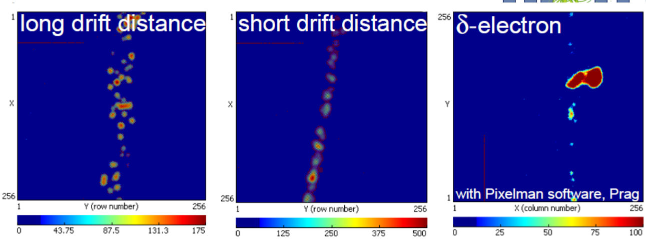


256×256 pixel of size 55×55 μm^2
Each pixel can be set to:

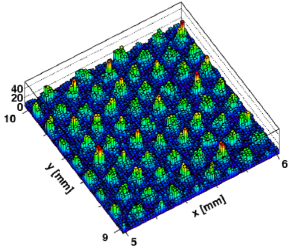
- Hit counting
- Charge measurement
- Time measurement

GEMs with Pixel

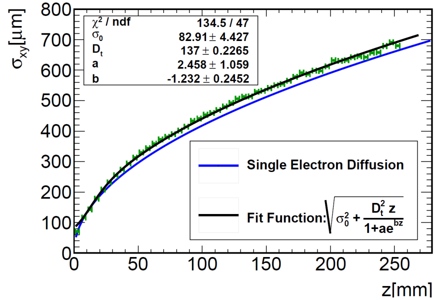
Triple GEM stack + Timepix



Electron-Tomography of GEM



Spatial resolution, B=0 T, $HeCO_2$ 70:30



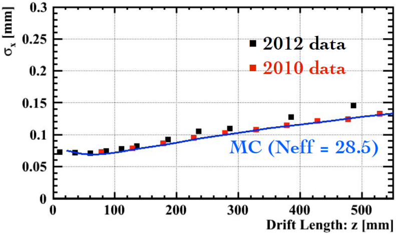
Results: Point Resolution

Different modules in the LP

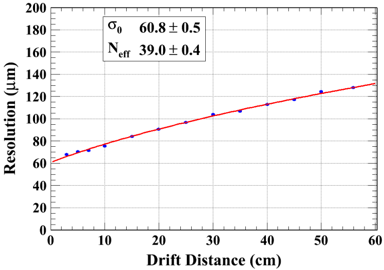
- B=1 T
- T2K Gas: $Ar(95\%)CF_4(3\%)iC_4H_{10}(2\%)$

All modules show similar results in agreement with requirements.

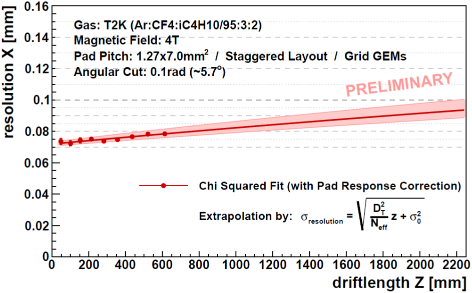
GEM module



MicroMegas, resistive anode



Small DESY prototype with B=4T



Software

Important to have common software!

- For the whole ILC community: ILCSoft
  - Data format: LCIO
  - Geometry description GEAR (simple, parameter based)
  - Analysis and reconstruction: MARLIN
  - Tracking Framework: MarlinTrk
- MarlinTPC: Specialized tools and Marlin processors for the TPC community
- Testbeam software: For quick data quality checks (depends on/uses all of the above)

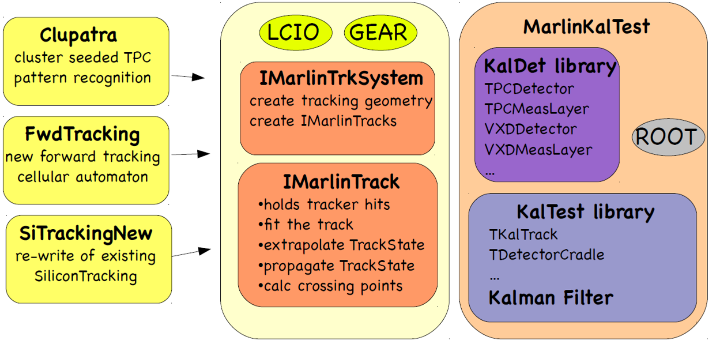
New developments (within AIDA):

- Geometry toolkit for HEP
  - Common solid library (based on ROOT and Geant4)
  - More powerful geometry framework: DD4hep
- Reconstruction toolkit for HEP
  - Tracking
  - Alignment
  - Particle Flow
  - Pile-Up

Track Reconstruction for ILD

Complex problem:

- Material $\Rightarrow$ multiple scattering
- Correct error propagation
- Inhomogeneous fields



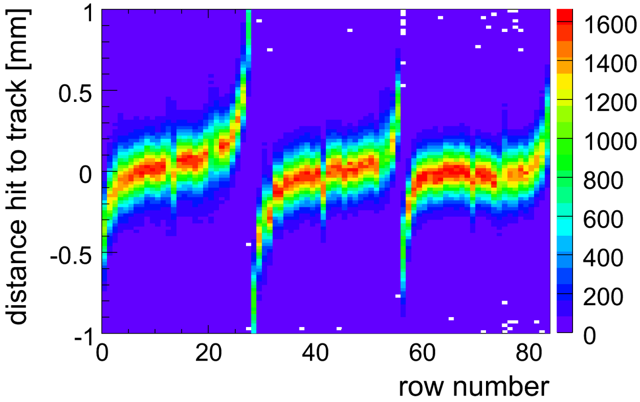
New: We can use the same packages Clupatra + MarlinTrk developed for simulation also for the testbeam data

Open Topics

- Field Distortions:
  - Improve module designs to limit distortion at the borders
  - Apply corrections for electric and magnetic field distortions
  - Needs field maps and dedicated software
- Ion back flow:
  - Study intrinsic suppression of ion back flow inside amplification structure
  - Design and test gating schemes
  - Evaluate effect of remaining ions on field homogeneity
- External reference for momentum resolution
  - Several layers of silicon detectors between the magnet and the TPC
  - Alignment of the two systems
- Electronics development
- Cooling system (CO_2 system close to being installed)
- Endplate integration
- Calibration: drift velocity, temperature, gain
- Software development

Field Distortions

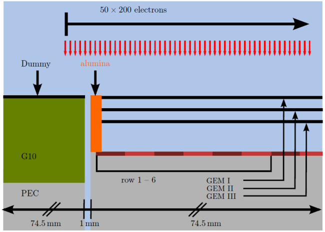
All modules observe field distortions at the boundary due to E×B effects. They can be corrected but should be minimized as much as possible by the module design itself.



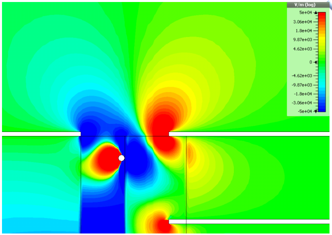
Same behavior seen in electrostatic simulations.

Simulation: Field Distortions

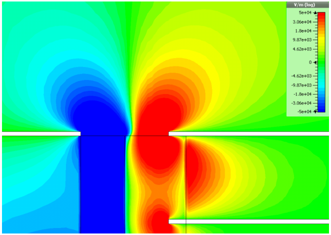
Simulation setup



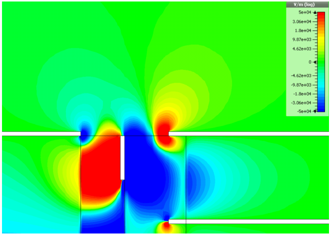
Field shaping wire

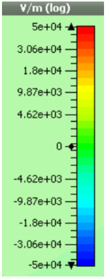


Module without modification



Field shaping strip

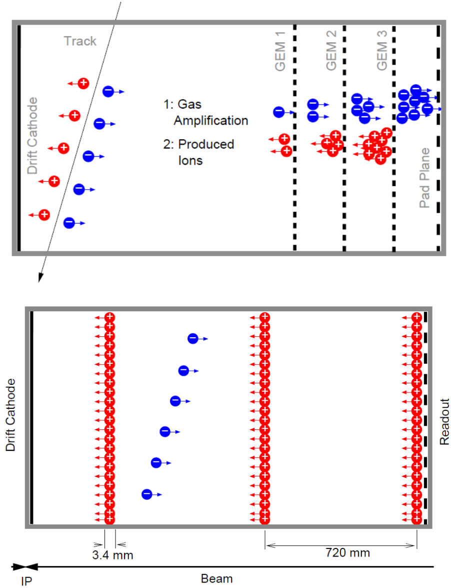




Additional field shaping improves the charge collection efficiency
⇒ simulation verified with testbeam data

Ion Back Flow Principle

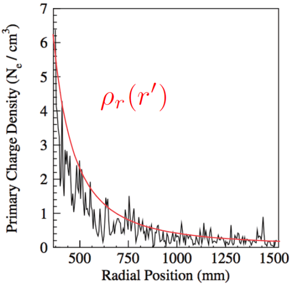
- After each bunch train, a disk of positively charged ions from the amplification stage drifts back into the TPC volume
- Due to the very slow drift of ions up to three disks simultaneously in the gas volume $\Rightarrow$ field distortions
- With adjusted GEM settings, the ion back flow can be minimized, but not to zero
- Gating possibilities: wires, mesh, GEMs, ...?

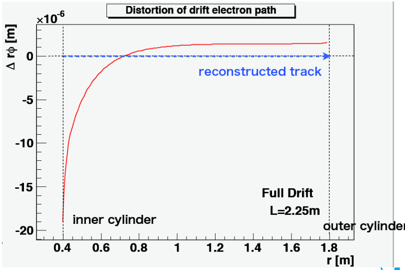


Ion Back Flow Calculation

- The radial profile of the disk is dominated by machine-induced background during a bunch train
- Assumption: ion feed back factor from the amplification of 3 with respect to the primary ion charge
- Calculation of the expected distortion when electron passes through ion disk
  $\Rightarrow$ Maximum of $\approx 20\mu$m per disk
- Results in up to 60 μm distortion

$\Rightarrow$ Gating needed

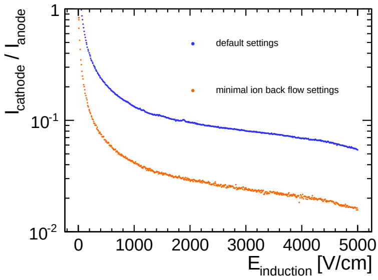




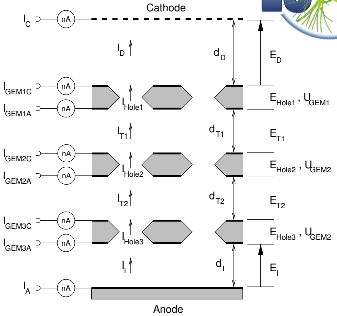
Ion Back Flow: Measurements and Optimization

Setup to measure currents:

- Optimize the GEM setting for minimal ion back flow
- Compare results with Garfield simulation (ongoing)



Both settings have the same gain.



Value	Standard	ion back flow
E_D [V/cm]	250	250
U_{GEM1} [V]	250	230
E_{T1} [V/cm]	1500	2500
U_{GEM2} [V]	250	260
E_{T2} [V/cm]	1500	290
U_{GEM3} [V]	250	290
E_I [V/cm]	3000	4500

Summary & Outlook

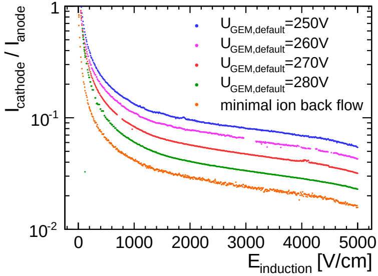
Status:

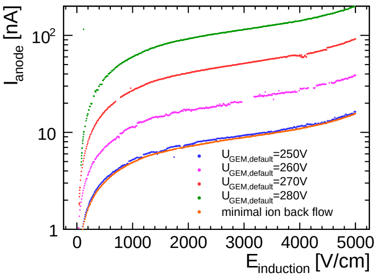
- MPGD technologies established
- First integration tests of modules in the LP successful
- Single point resolution obtained

Things we still need to do:

- Demonstrate momentum resolution → external reference needed
- Understand, minimize and correct field distortions
- Limit ion back flow (intrinsically or gating)
- Study dE/dx
- Design and build next iteration of field cage, endplate and cathode (partially on the way)
- Design and build next generation of electronics (highly integrated, with cooling system)
- Always true: Improve software

Backup: Ion Back Flow





Backup: Event Display InGrid