TPC Calibration

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Workshop on Neutrino Near Detectors based on gas TPCs

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TPCs in a real world environment

Nothing is perfect, but calibration can make it a bit more perfect

- **Changing gas composition**
  - Variations in mixture
  - Contamination from outside (e.g. air, water, other gases)

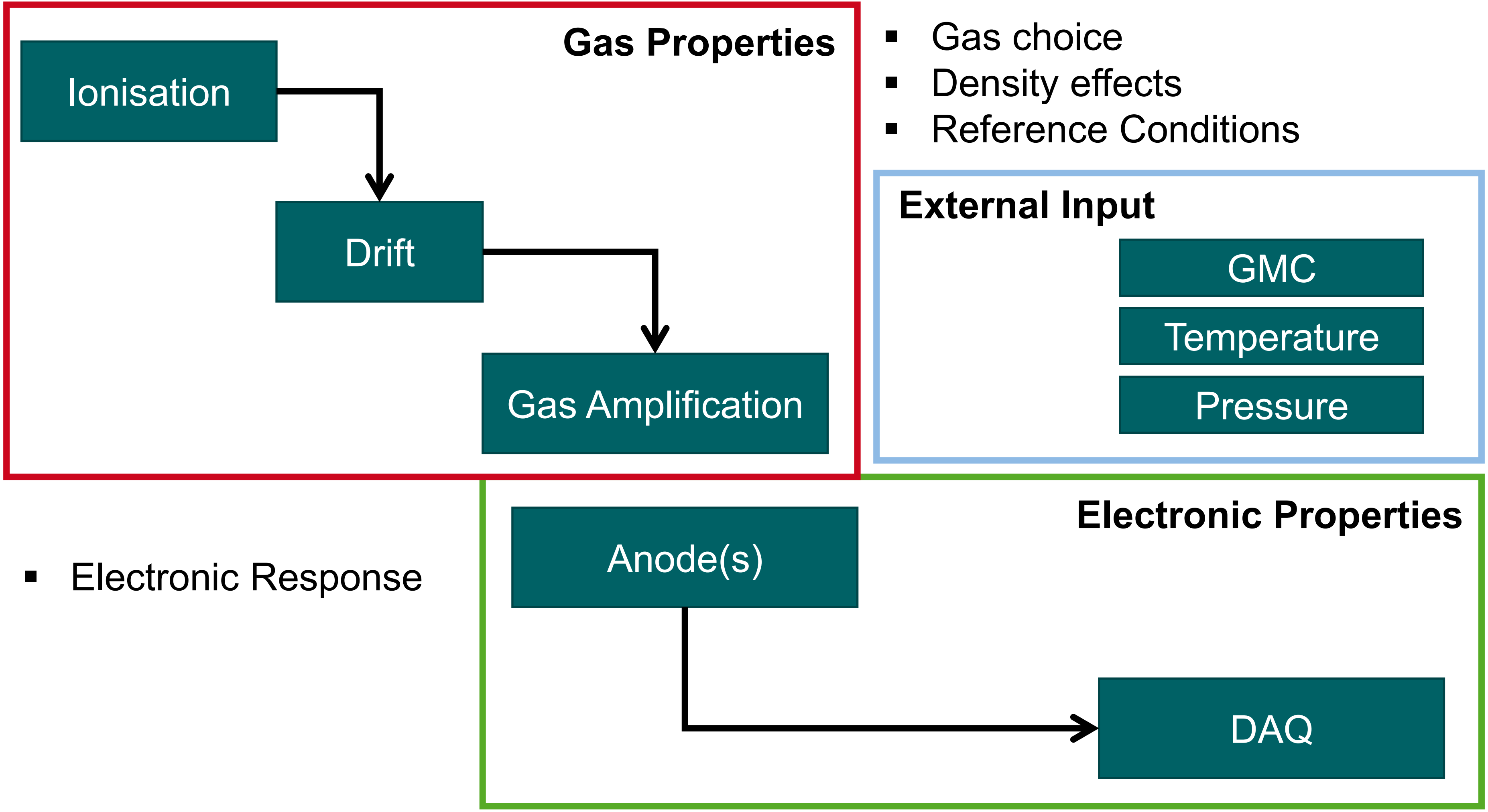
- **Changing gas properties**
  - Temperature and pressure not regulated. TPC sees changes of the weather
  - Changing gas density affects all processes in the gas

- **Detector imperfections**
  - Construction tolerances -> deviations from ideal geometry
  - Electric and Magnetic field not perfectly homogenous and aligned

- **Detector limitations**
  - Finite resolution and dynamic range

Various Level of Calibration

Many effects, which need to be calibrated

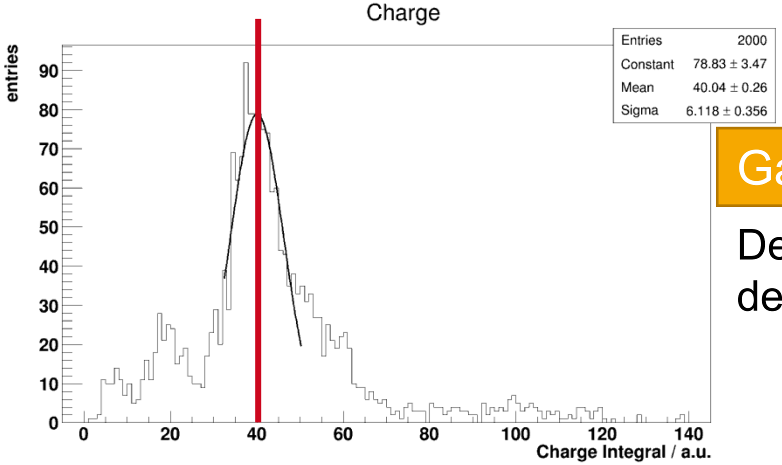


- Gas choice
- Density effects
- Reference Conditions

- Electronic Response

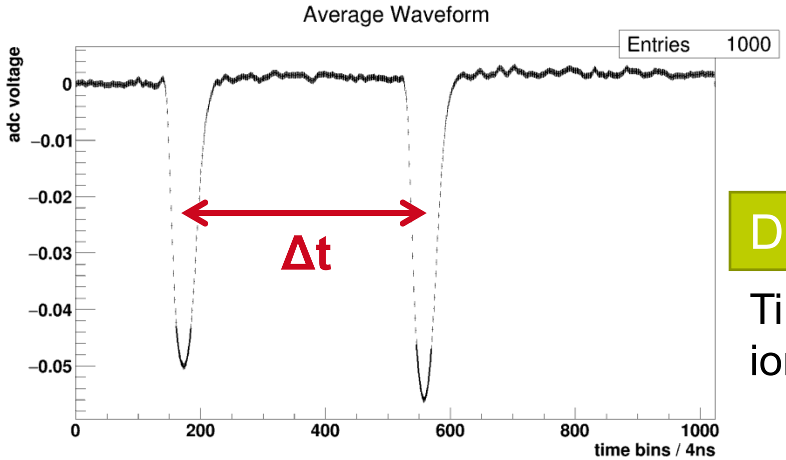
Gas Monitoring System (ND280)

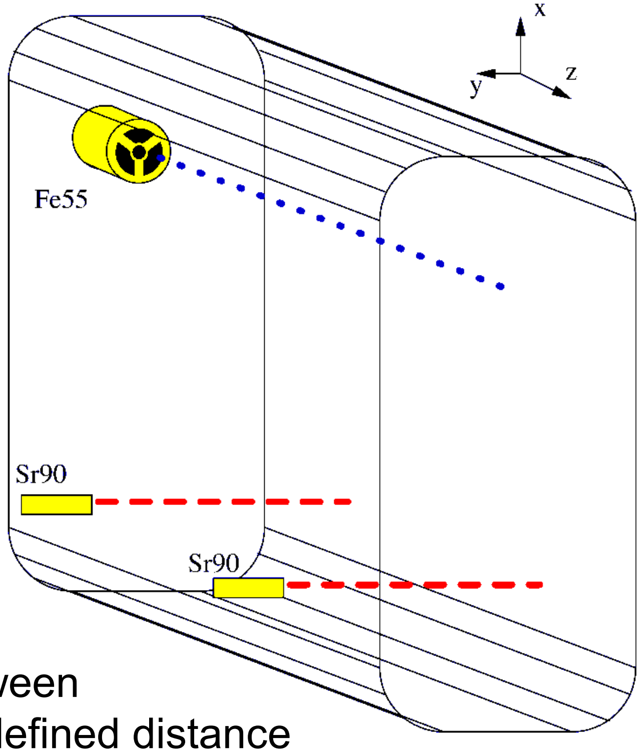
- Two identical chambers for supply and return gas
- Sequential measurement of drift velocity and gain



Gain Measurement

Detected charge from defined deposition





Drift Velocity

Time difference between ionization tracks of defined distance

Gas Density

- Most gas related corrections depend on the density of the gas
  - Ideal gas law

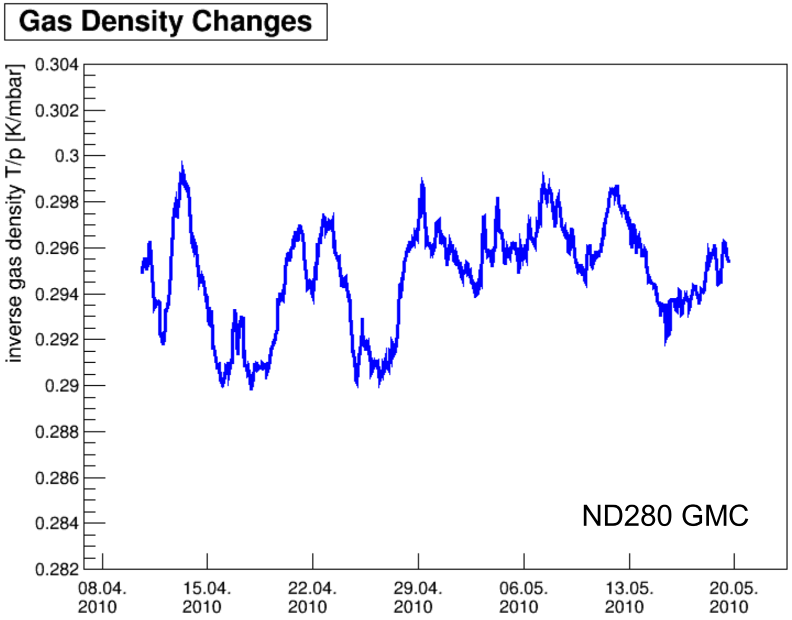
$$p\,V = N\,R\,T = const$$

$$\frac{p}{T} = \frac{NR}{V} = const$$

  - by using corrections in p/T we can correct for density changes

Multiplicative corrections

$$\frac{p}{T} \cdot \frac{T_0}{p_0}$$



Typical detectors are not well controlled in:

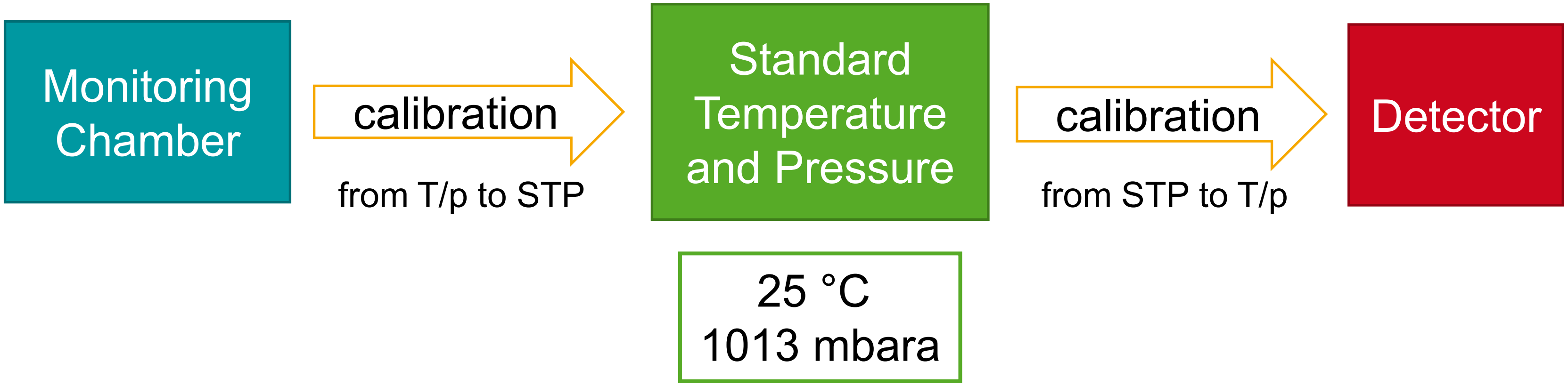
- Temperature
- absolute Pressure

Time depended density changes

Including a Monitoring Chamber

Doing the calibration twice

- Monitoring chamber and detector are operating under different ambient conditions



Monitoring Chamber

calibration

from T/p to STP

Standard Temperature and Pressure

25 °C
1013 mbara

calibration

from STP to T/p

Detector

Driftvelocity:

- GMC running at the same driftfield

Gain:

- Determine calibration constant

Ionisation

Specific energy loss

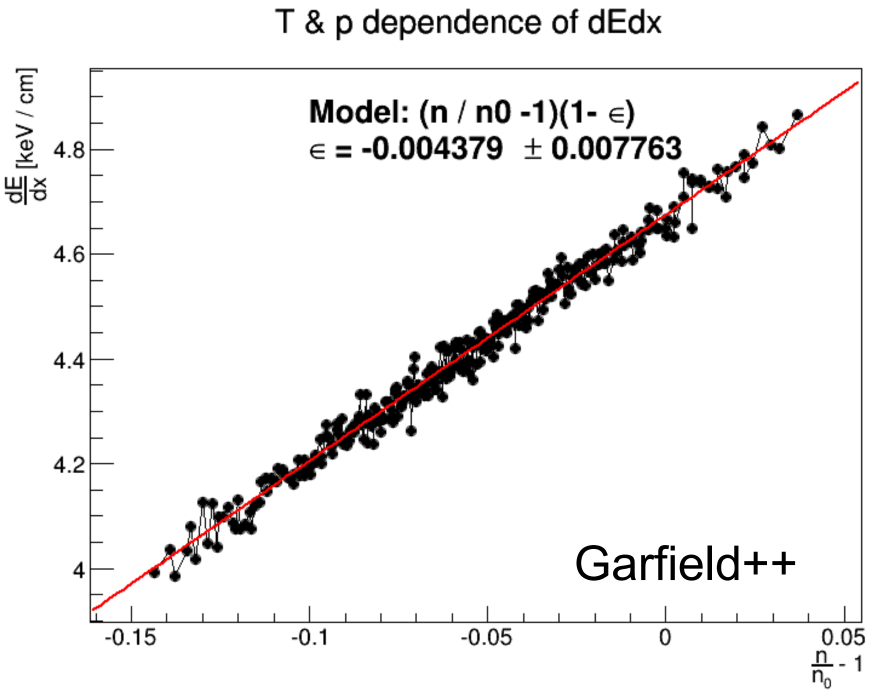
- Energy loss of charged medium-momentum particles by ionisation

$$\frac{\mathrm{d}E}{\mathrm{d}x} = \frac{4\pi N e^4}{mc^2}\frac{1}{\beta^2}z^2\left(\ln\frac{2mc^2}{I}\beta^2\gamma^2 - \beta^2 - \frac{\delta(\beta)}{2}\right)$$

$$\propto N \propto \frac{p}{T}$$

- This can be easily corrected in the data

$$\boxed{\left.\frac{\mathrm{d}E}{\mathrm{d}x}\right|_{\mathrm{STP}} = \left(\frac{T}{p}\frac{p_0}{T_0}\right)\frac{\mathrm{d}E}{\mathrm{d}x}}$$



Drifting the electrons in the detector

Drift velocity

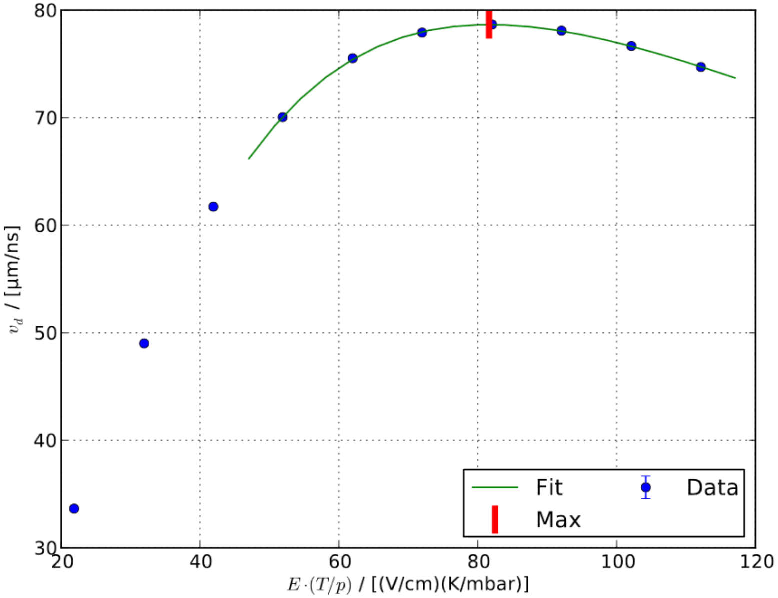
- Function of reduced electric field

$$v_d = f(E^*) = f(ET/p)$$

- Not trivial to describe
    - Has to be measured and / or simulated (e.g. Magboltz)
- Usually the drift velocity shows a maximum and can be parametrized as

$$v_d = (a + bE^*) \cdot e^{-dE^*} + c$$

Empirical parametrization fits for many drift gases around the maxima region



Ref: Masterthesis L. Koch RWTH Aachen

Drift

Drift velocity

- When the detector is operated in the ideal field region
  - Drift velocity is maximal
  - There is no density dependence

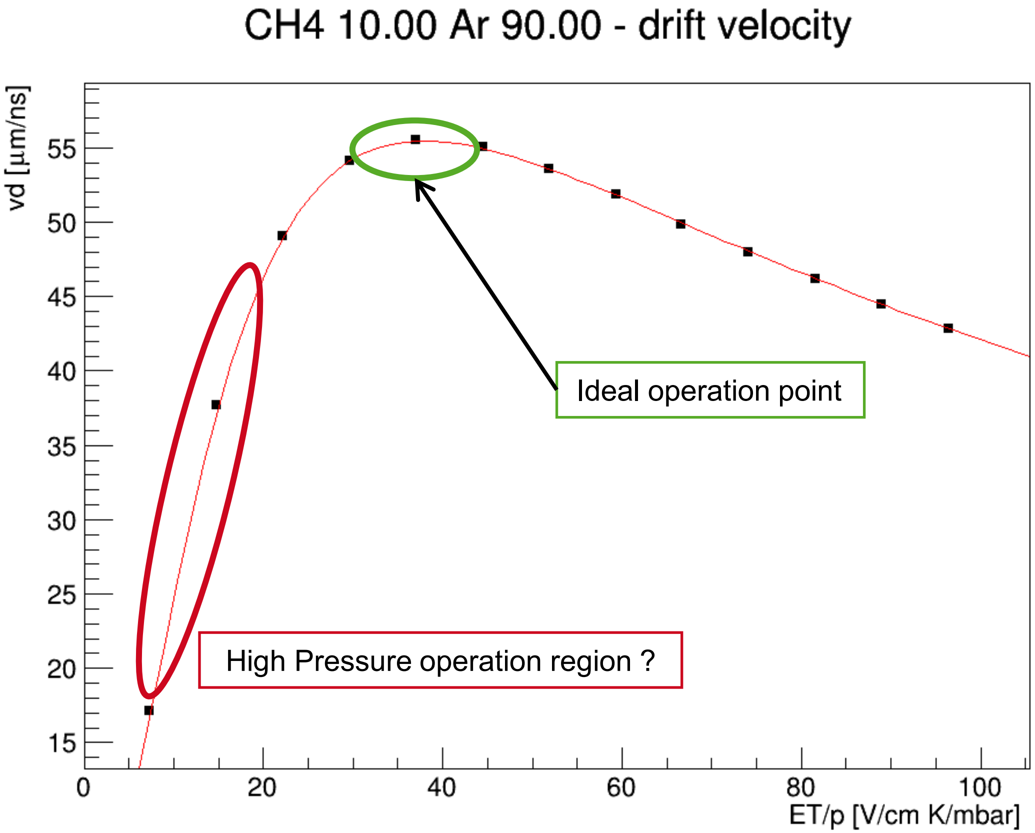
If aiming for higher pressure an higher E-field is needed to reach the drift velocity maximum

Examples:

- ND280 (drift length 1m)
  - 275 V/cm @ 1 bara
  - *2750 V/cm @ 10 bara*

- ALICE (drift length 2.5m)
  - 400 V/cm @ 1 bara
  - *4000 V/cm @ 10 bara*

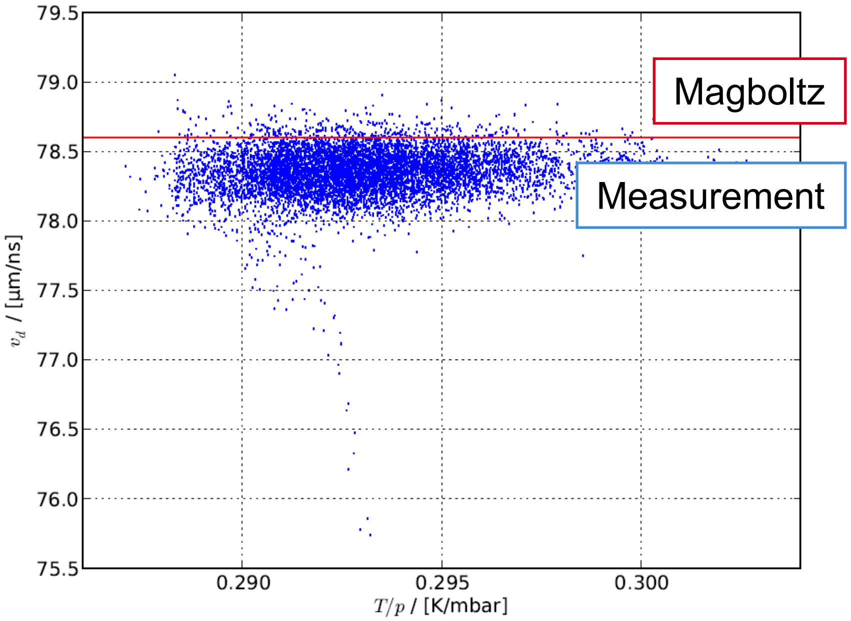
Will become a critical point in HPTPC applications!

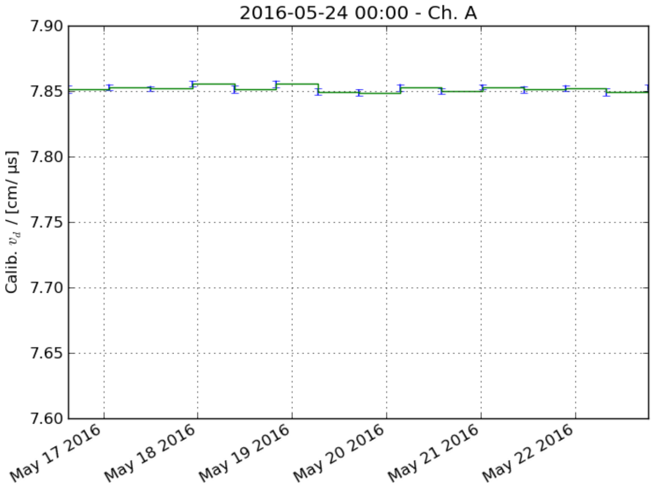


Drift velocity

Operating at the right drift field

- No temperature dependency observable
- Slight deviation to simulation due to
  - Gas imperfections
  - Contamination
  - Switching on procedure
- Sufficient to store average over ~10h





Gas Amplification (Gain)

Multiple Calibrations needed

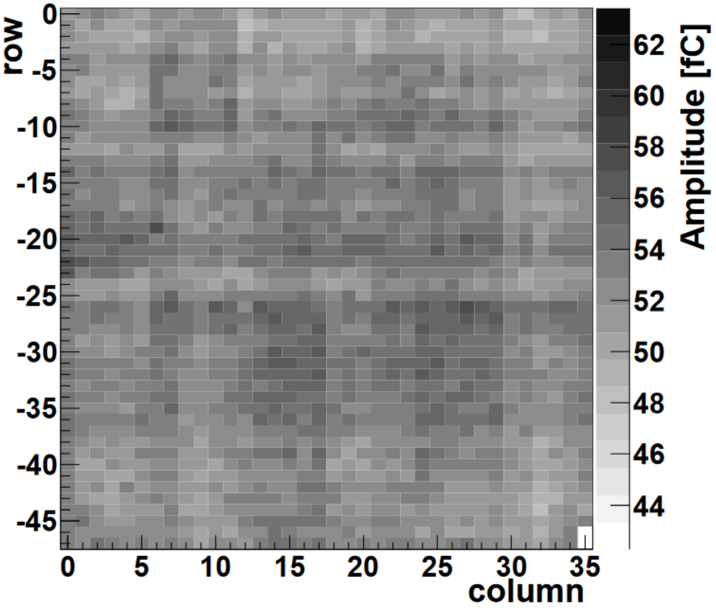
1. **Geometrical differences / Production differences**
   - Pad to Pad calibration
   - Must be done before installation in the detector

   - Deposited charge in detector is given by

$$Q_{\text{primary}} = \frac{E_{\gamma(Fe55)}}{W_{\beta}} \approx \frac{5.9keV}{26\ eV} = 226\ e^{-}$$

   - Gain is given by

$$G = \frac{Q_{\text{measured}}}{Q_{\text{Primary}}}$$



2. **Gas variations / density effects**
   - Continuously changing due to weather
   - Gas mixing variations difficult to calibrate
   - **Density effects**

Reference: NIM Paper Time Projection Chambers for the T2K Near Detectors

Gas effects

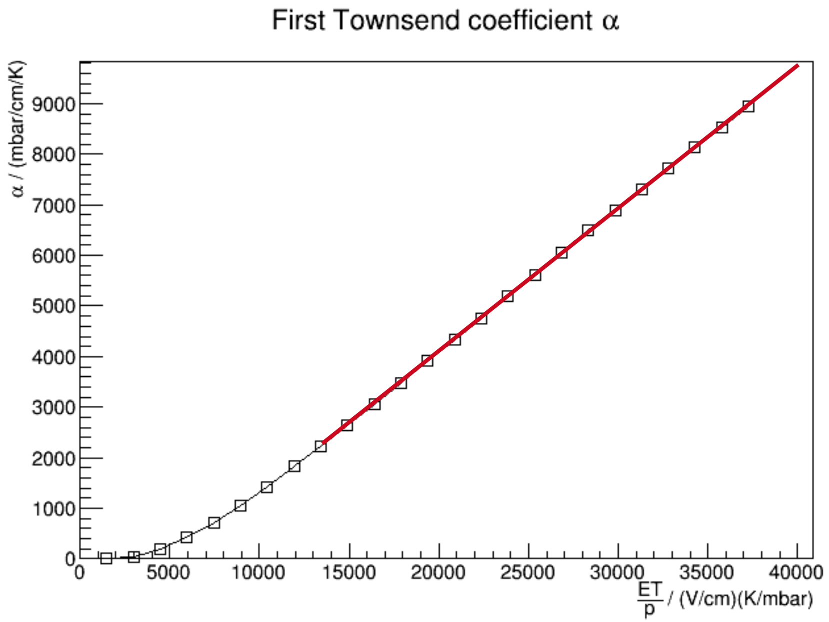
Gas amplification described by Townsend coefficient

- Gas amplification
  - Electron cascade above the readout plane

$$G = \exp\left(\int \alpha(E^*, T/p)\,\mathrm{d}x\right)$$

- Townsend coefficient can be approximated at high electric fields

$$\alpha = \frac{p}{T}\left(aE^* + b\right)$$



Gain calibration…

How it can be done

- Correction depends on amplification technology (E-field shape)
  - Pixel / pad detectors use homogenous amplification field (1st order)
  - After a couple of calculations

$$\frac{\Delta G}{G_{\mathrm{STP}}} = m \frac{\Delta \frac{p}{T}}{\frac{p_0}{T_0}}$$

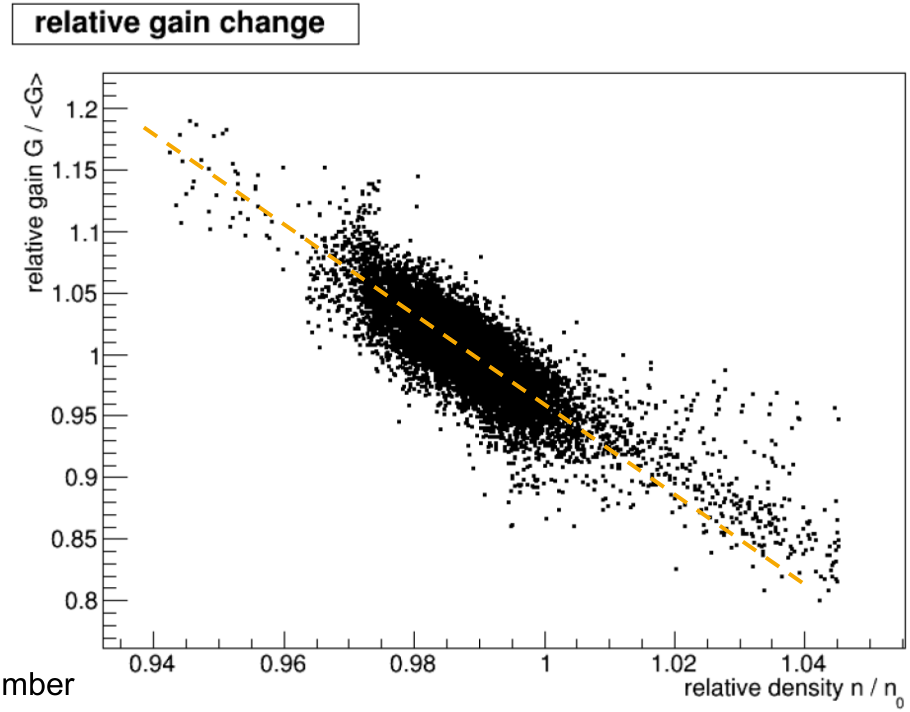
$$G_{STP} = G(T_0, p_0)$$

  - typical values for **m ≈ -3**
  - Application in TPC calibration
  - Calculate current gain for single PAD

from calibration DB

$$\mathrm{G}_{\mathrm{PAD}} = \boxed{\mathrm{G}_{\mathrm{STP}}}\left(m\left(\frac{p/T}{p_0/T_0} - 1\right) + 1\right)$$

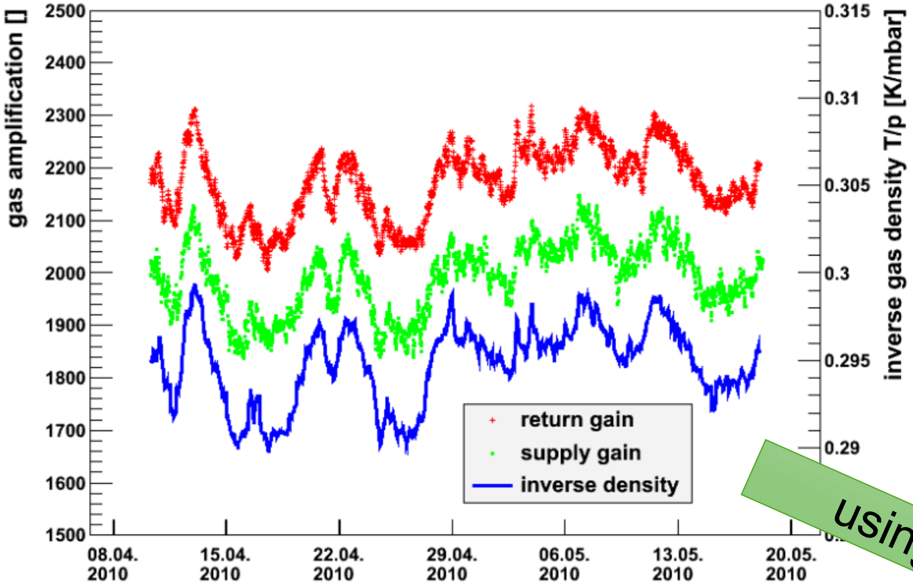
Measured by monitoring chamber

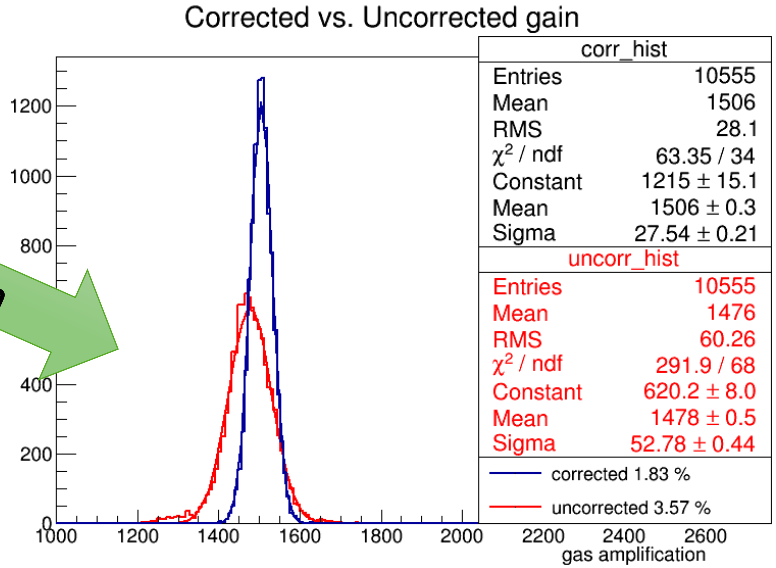


Gas amplification

Density effects

- When looking at the gas amplification over time one observes large changes
- Changes caused by changes in (inverse) gas density



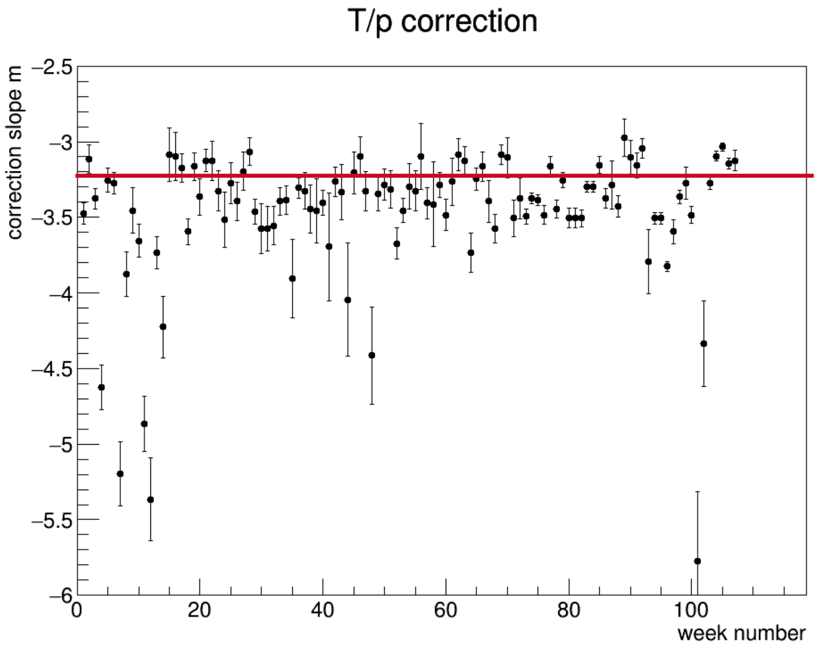


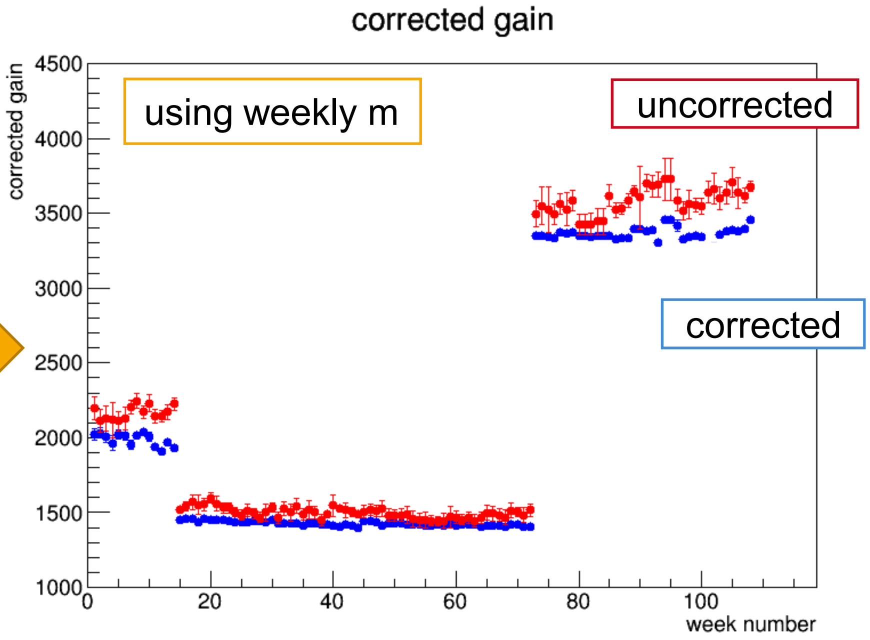
Reference: NIM Paper Time Projection Chambers for the T2K Near Detectors

Application of the GAIN calibration

- Many measurements needed to determine calibration slope m
  - Depends on T/p variation
  - If weather is stable
    - Data spread in T/p is low
    - Quality of the calibration slope suffers

For ND280:
- m is checked every week but not changed
- changed only, if large deviation of m is observed




using weekly m

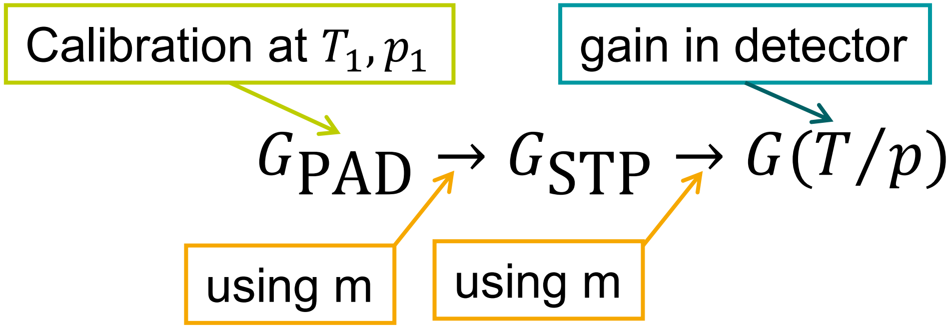
uncorrected

corrected

Charge calibration chain

The whole way from the ADC to the physics

1. The ADC measures a certain charge Q_{DAQ}
2. Divide by the corrected gain factor to get the track charge



Calibration at T_1, p_1

gain in detector

$$G_{\text{PAD}} \to G_{\text{STP}} \to G(T/p)$$

using m

using m

$$Q_{TRACK} = \frac{Q_{DAQ}}{G(T/p)}$$

Track charge inside the detector

3. Correct for changing dE/dx to identify particle due to density corrections

$$Q_{\text{STP}} = Q_{TRACK} \frac{T}{p} \frac{p_0}{T_0}$$

Track charge at STP conditions
► comparable measurements

E-Field & B-Field distortions

Depend a lot on geometry

- Drift of electrons in inhomogeneous E and B fields is getting complicated

$$\vec{v} = \frac{\mu E}{1-\omega^2\tau^2}\left(\hat{E} + \omega\tau(\hat{E}\times\hat{B}) + \omega^2\tau^2(\hat{E}\cdot\hat{B})\hat{B}\right)$$

- There is no general approach how to calibrate for E and B field distortions
  1. You have to know / measure the distortions
     - Data without B-field is helpful
     - Straight tracks, no bending and no B-Field distortions

  2. Make a „simple“ model of them
     - e.g. Fourier expansion (solving Laplace equation)

  3. Try to find method / model to correct for them (might be complex)

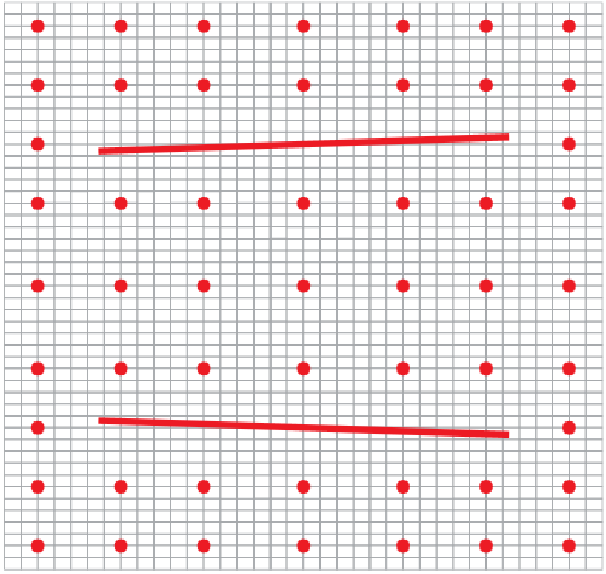
- **BUT: corrections have to match the general physics laws**
  - Maxwell equations etc.

Methods to measure distortions

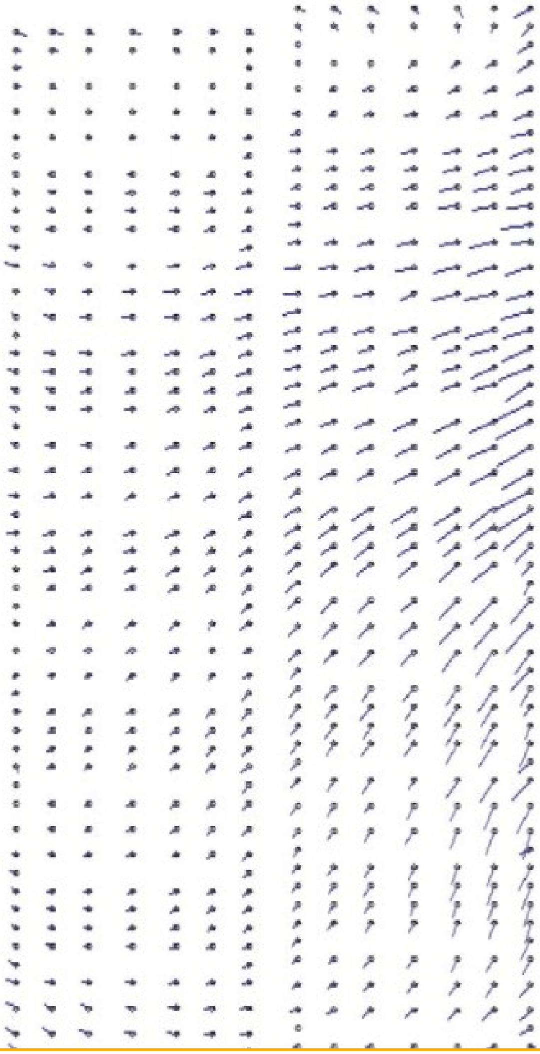
Example 1: ND280

- „Full“ Laser illumination of cathode
- Pattern of Al-dots and stripes

- Distortions caused by inhomogenities in E and B



Cathode pattern of ND280 TPCs



Displacement caused by B-field

Reference: NIM Paper Time Projection Chambers for the T2K Near Detectors

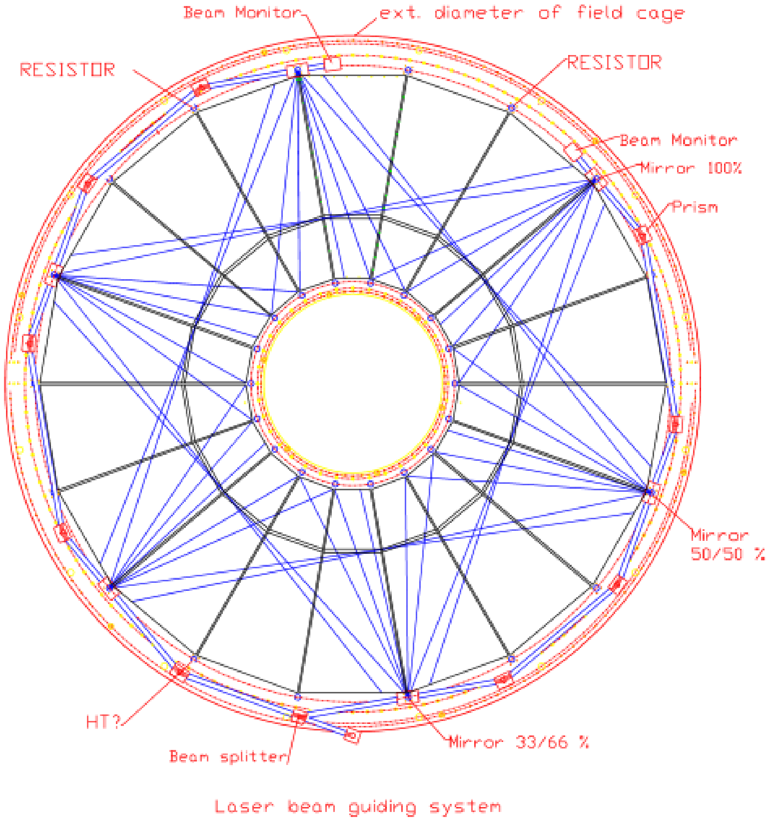
Methods to measure Distortions

Example: ALICE

- 266 nm Laser pulses (E = 4.66 eV)
- Creation of tracks via double photon ionization
  - Organic impurities are ionized (ionization energy 5 - 8 eV)
  - Laser source has to match gas / impurity

- 8 laser patterns along drift direction
  - Tracks are created inside the gas
  - Using laser tracks – straight tracks with B-Field

- Difficulties:
  - Intense Laser beam
  - Reflections and metallic surfaces



Ref: ALICE-INT-2002-22 1.0

Thank you!