Rolling TPC (Gas) Calibration

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Various Levels of Calibration

Many effects, which need to be calibrated

Gas Properties

Ionization

Drift

Gas Amplification

- Gas choice
- Density effects
- Reference Conditions

External Input

GMC

Temperature

Pressure

Electronic Properties

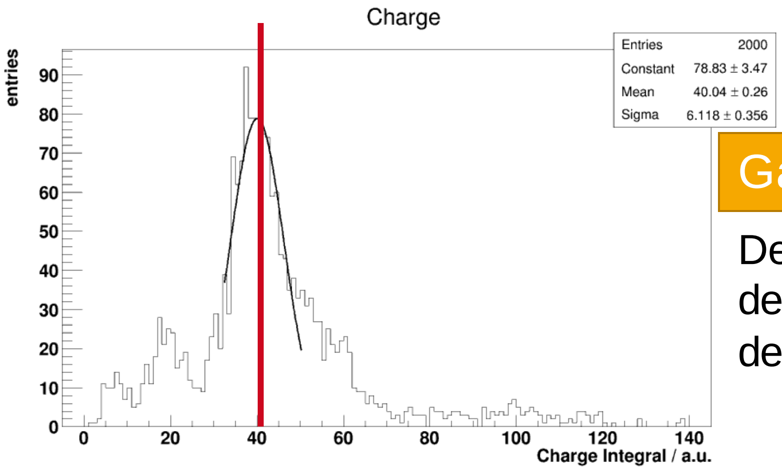
- Electronic Response

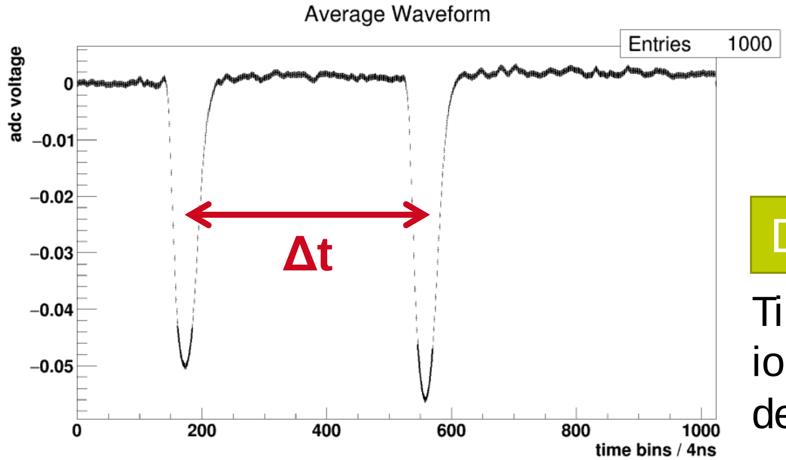
Anode(s)

DAQ

Gas Monitoring System @ ND280

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



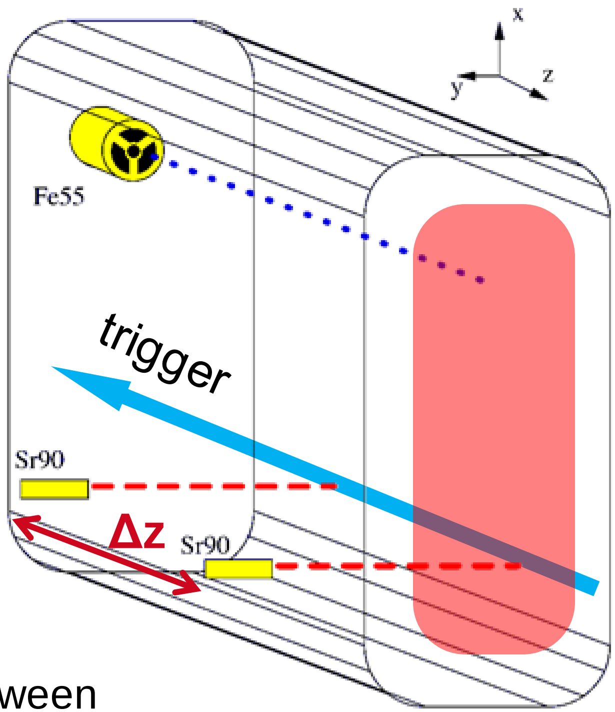


Gain Measurement

Detected charge from defined primary deposition

Drift Velocity

Time difference between ionization tracks of defined distance



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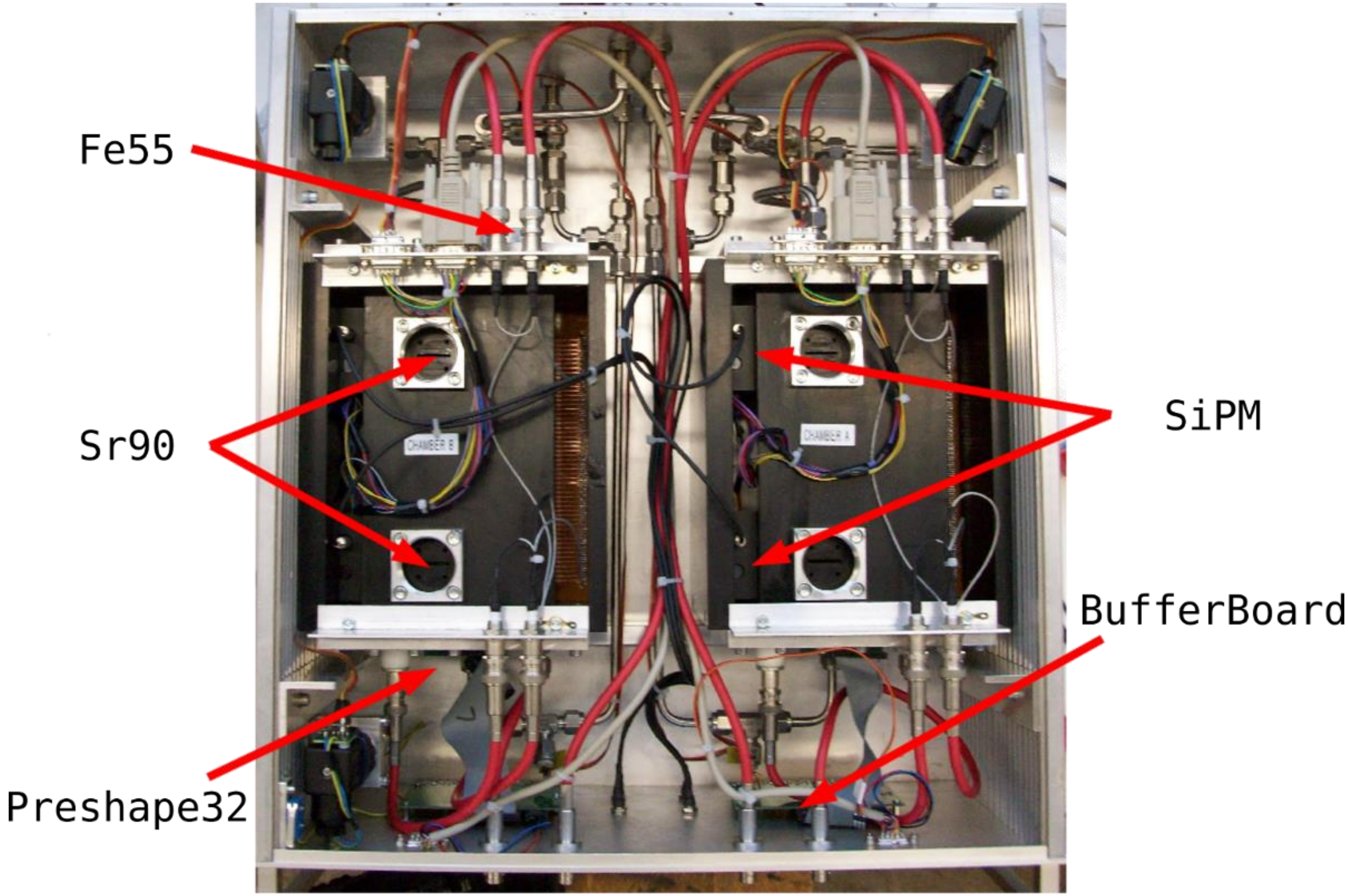
View Inside the GMC Crate

One GMC each for recirculated gas and supply gas



Reason why we calibrate: Gas Density

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

$$p\,V = N\,R\,T = const$$
$$\frac{p}{T} = \frac{NR}{V} = const$$

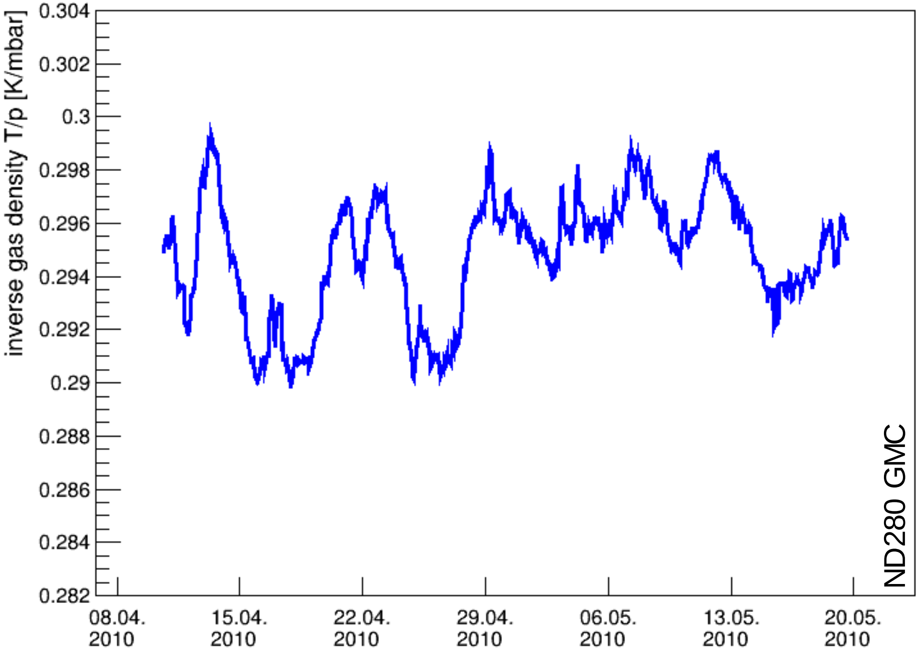
  - by using corrections in p/T we can correct for density changes

Multiplicative corrections:

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

Typically detectors are not controlled in:
- Temperature
- absolute Pressure

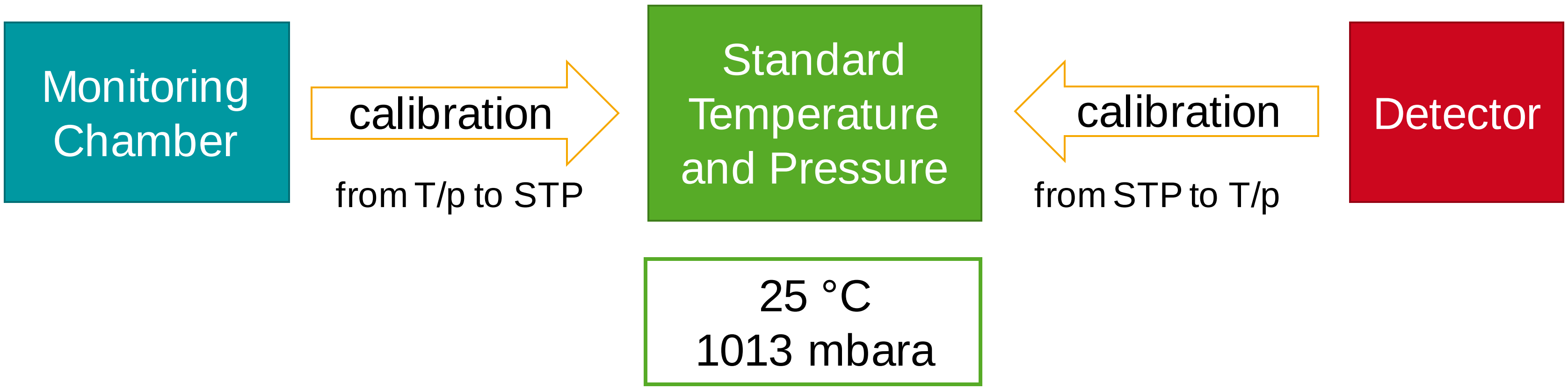
Time depended density changes



Including a Monitoring Chamber

Doing the calibration twice

- Monitoring chamber and detector are operating under different ambient conditions



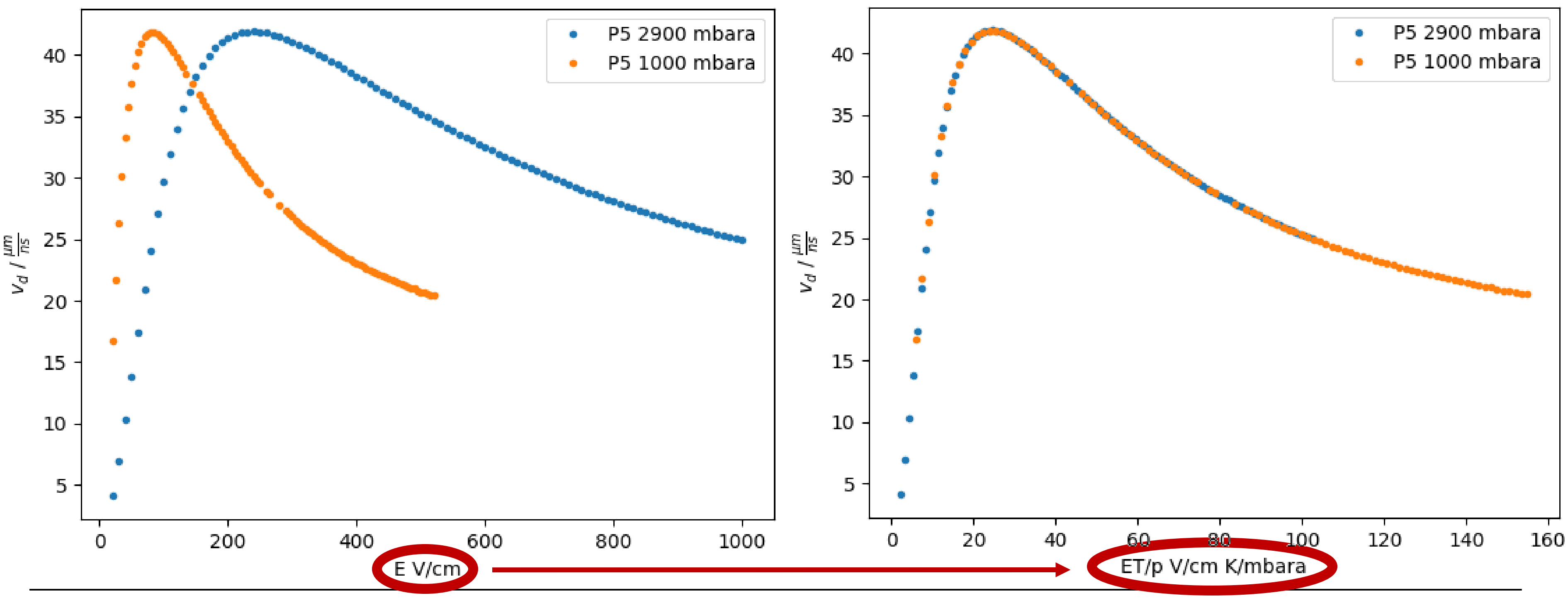
Driftvelocity:
- GMC operating at same driftfield

Gain:
- Use miniature version of large MM
- Apply same amplification voltage
- Determine calibration constant

Operation in a Changing Environment and Higher Pressures

- Gas density affects electron propagation
  - reduces gain at constant voltage
  - shifts drift velocity curve
  - shifts and scales diffusion
  - e.g. Ar, N_2, CH_4, CF_4, CO_2, …

Most TPC gases behave nearly ideal below 10 bar



Drift Velocity

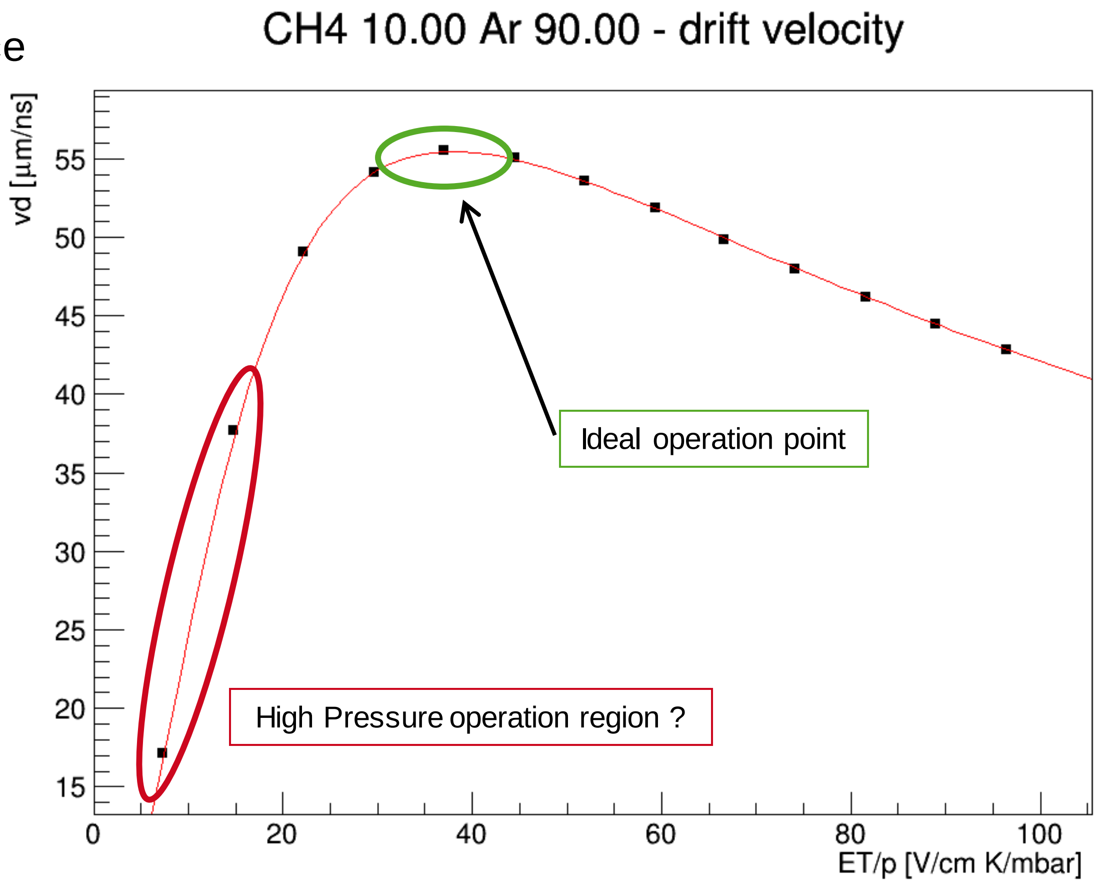
- When the detector is operated in the ideal field region
  - Drift velocity is at maximum
  - There is no density dependence

At higher pressures, an equally higher E-field is needed to reach the max drift velocity.

Examples:

- ND280 (drift length 1m, 25 kV)
  - 275 V/cm @ 1 bara
  - *2750 V/cm @ 10 bara*
- ALICE (drift length 2.5m, 100 kV)
  - 400 V/cm @ 1 bara
  - *4000 V/cm @ 10 bara*

Will become a critical point in HPTPC applications!



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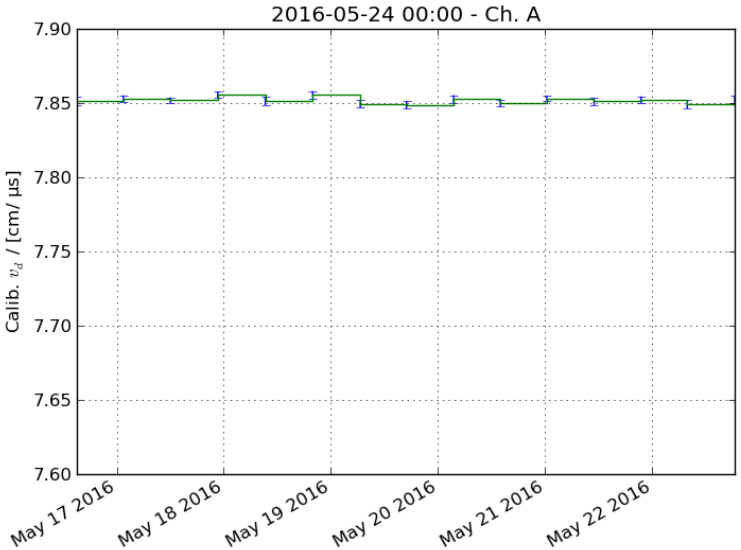
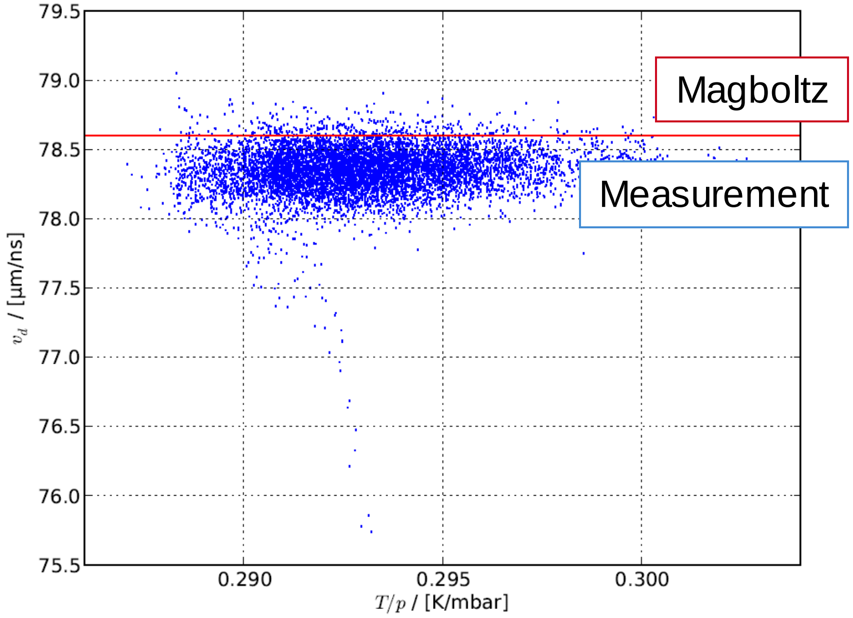
Drift Velocity Measurements at ND280

Operating at the right drift field

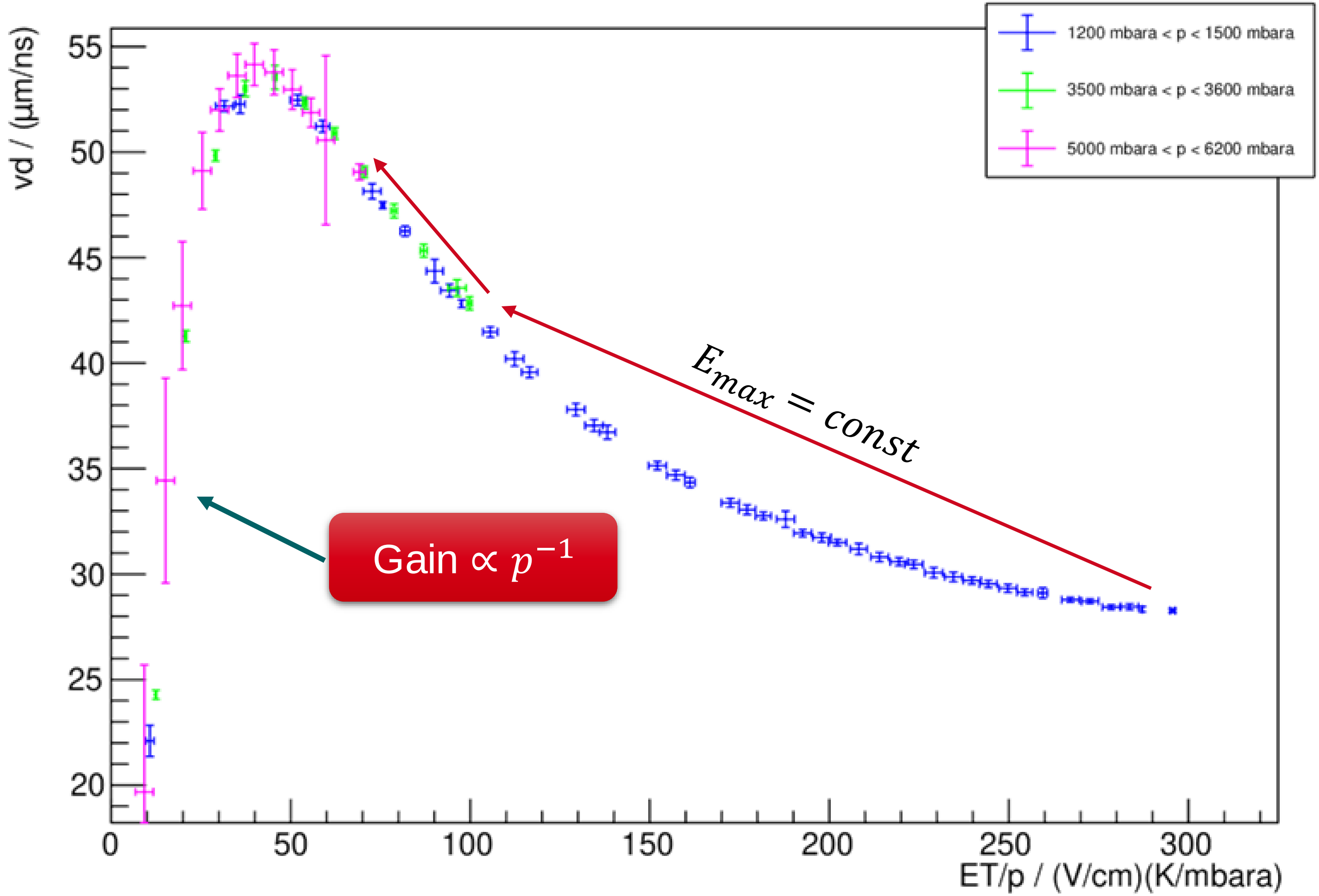
- No temperature dependency observable
- Slight deviation to simulation due to
  - Mixing uncertainty
  - Contamination / imperfection
  - Switching on procedure
- Sufficient to store average over ~10h





Drift Velocity Measurement with P10 (90 % Ar : 10% CH4)

5 bar span, but $^{ET}/_{p}$ holds!



Gas Amplification

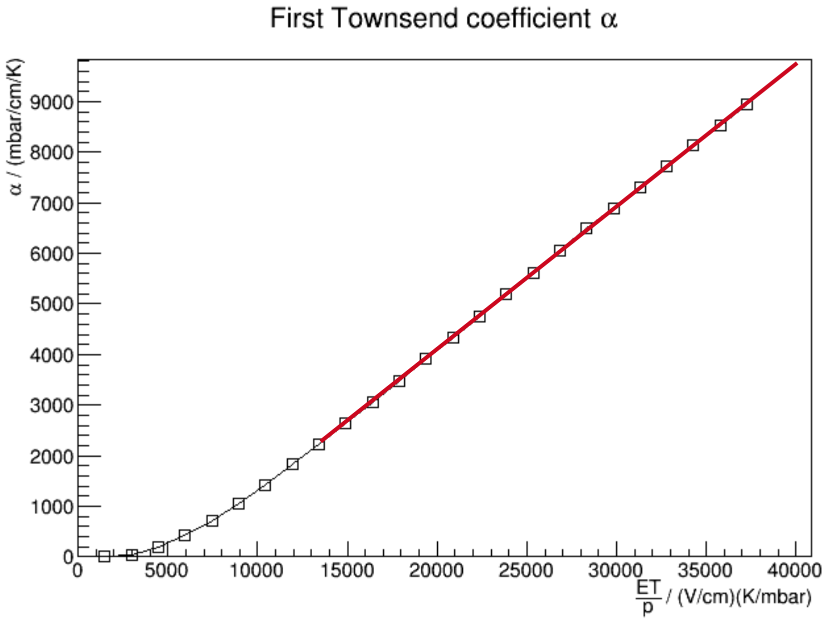
Described by Townsend coefficient

- 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

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



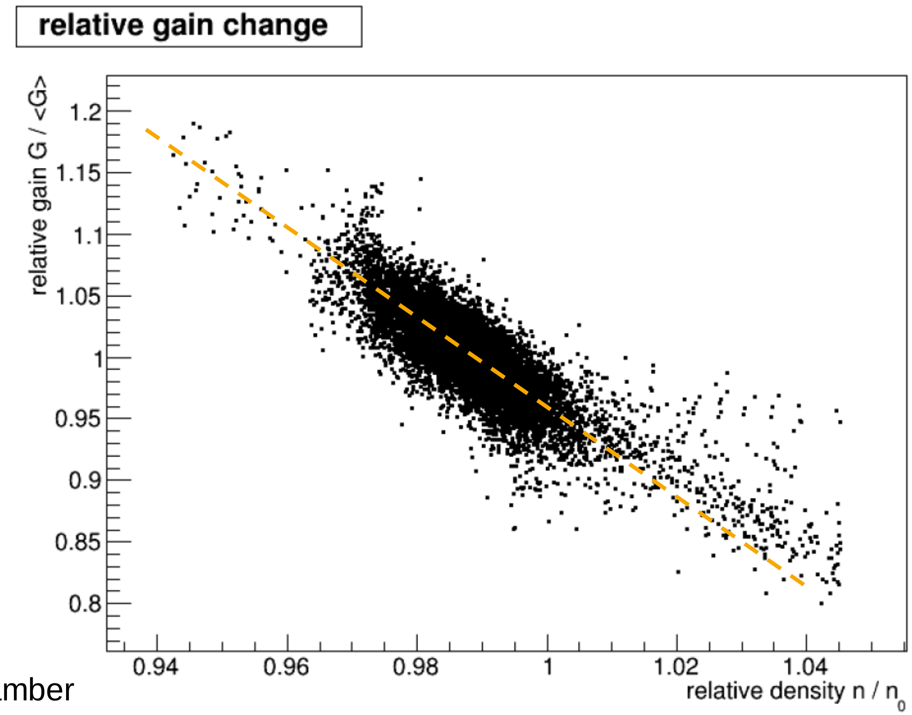
Gain Calibration…

How it can be done

- Correction depends on amplification technology
- Micromegas Pixel / pad detectors use homogenous amplification field

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

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



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

from calibration DB

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

Measured by monitoring chamber

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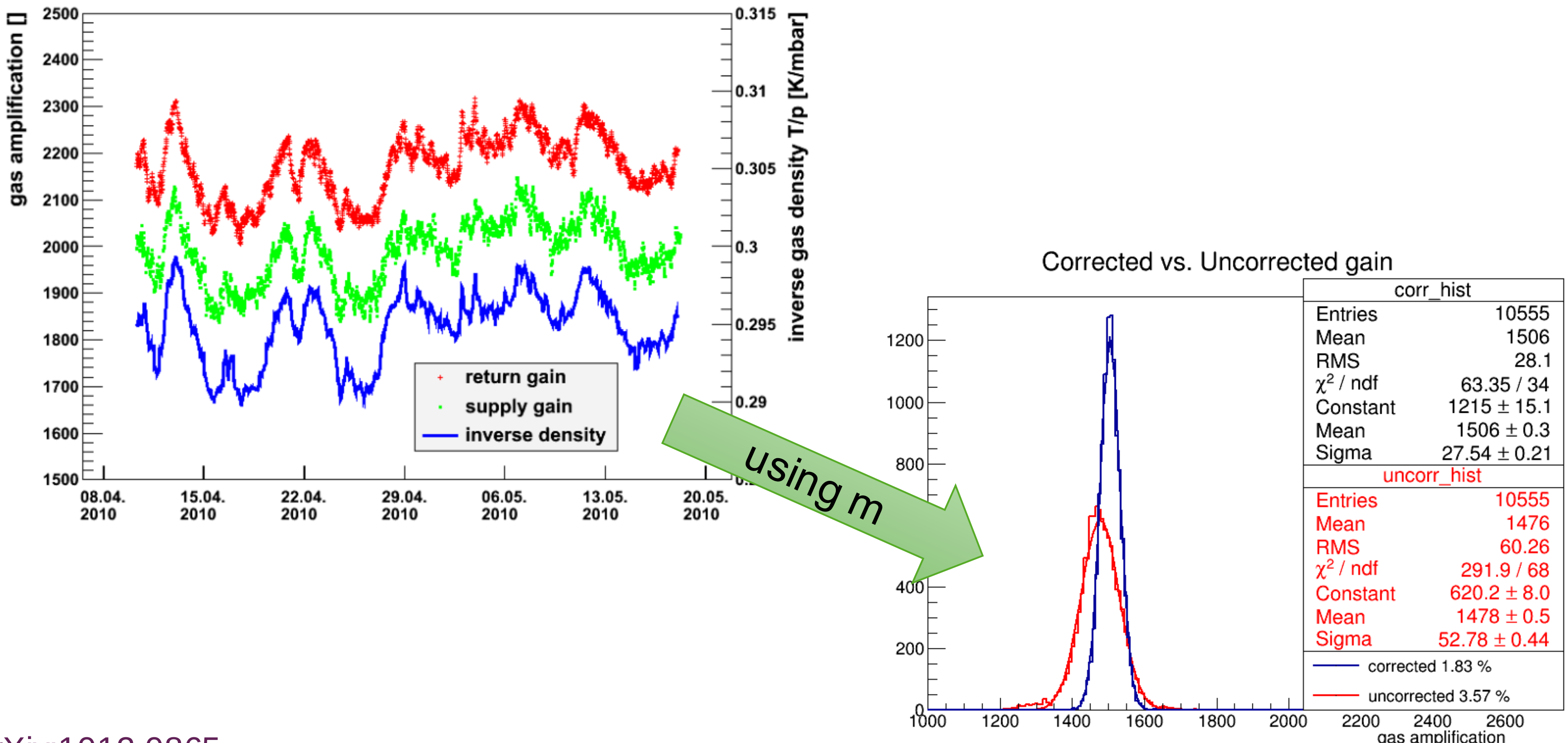
Gas Amplification

Density effects

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



arXiv:1012.0865

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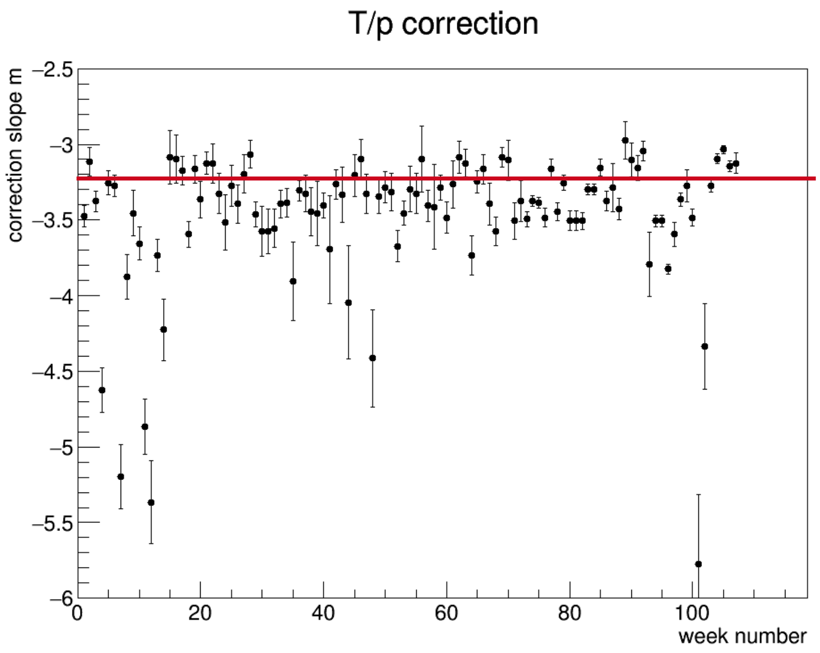
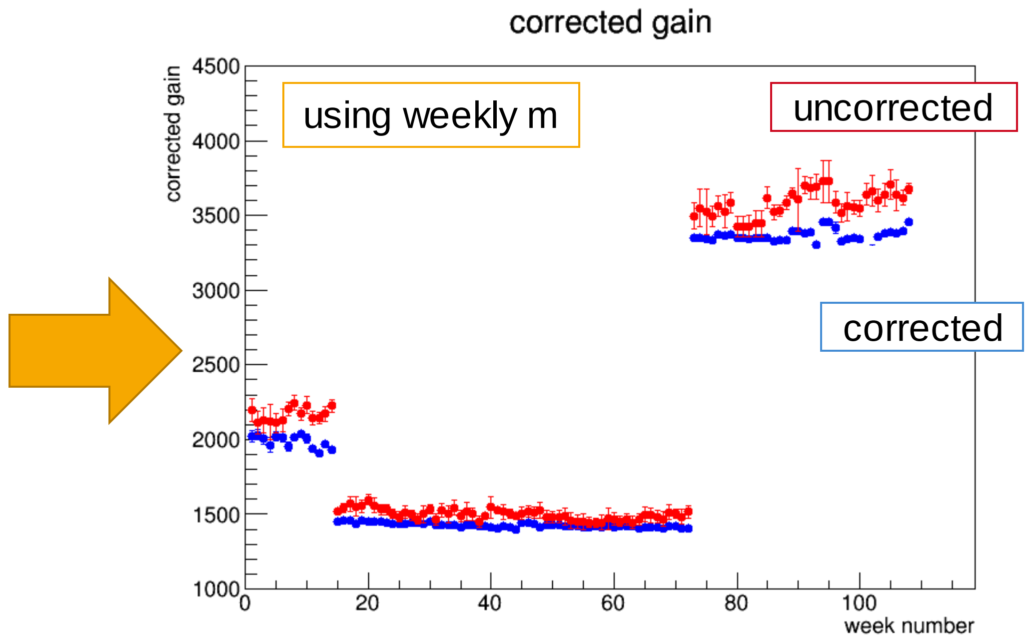
Application of the Gain Calibration

- 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





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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

$$G_{\mathrm{PAD}} \rightarrow G_{\mathrm{STP}} \rightarrow G(T/p)$$

using m

using m

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

Track charge inside the detector

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

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

Track charge at STP conditions
► comparable measurements

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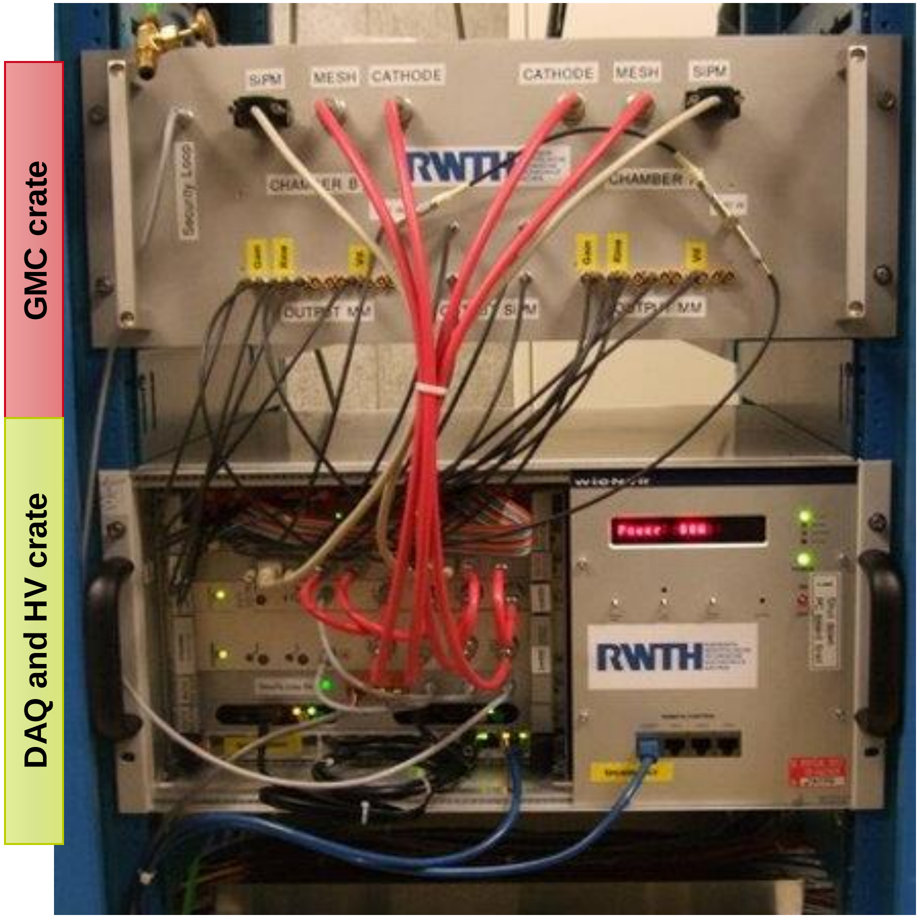
Thank you!

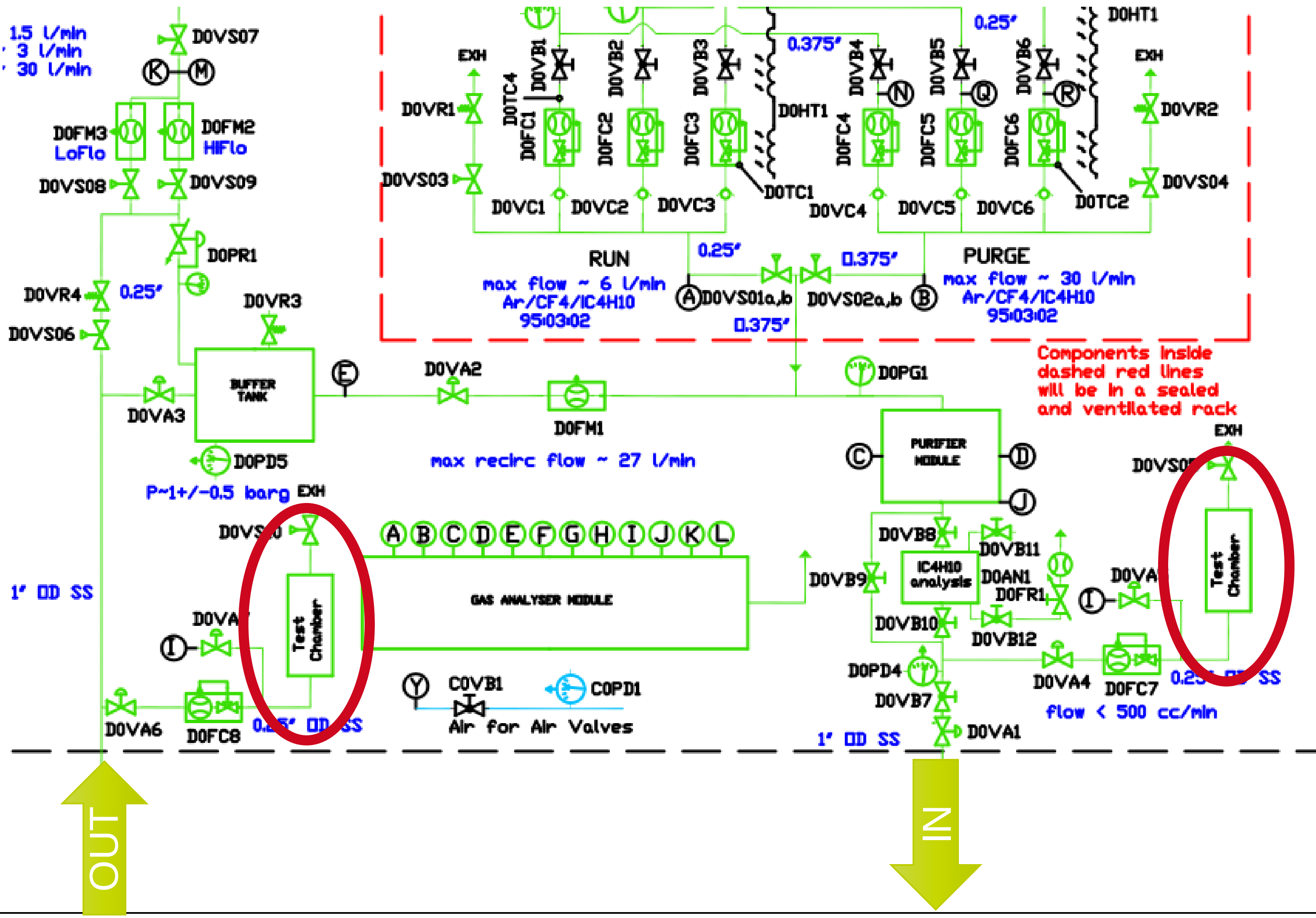
Modular Deployment of GMCs

Only needs gas connection, power and ethernet link

- GMC crate
  - 2 Gas Monitoring Chambers
  - Pressure sensors
  - Temperature sensors
  - Preamps
  - Interlock
- (VME) DAQ and HV crate
  - FADC
  - Programmable Trigger Board
  - SiPM power supply
  - Anode & cathode power supply
  - Security Loop
  - Computer



Location on the Gas Map



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Drifting Electrons in the Detector

Drift velocity

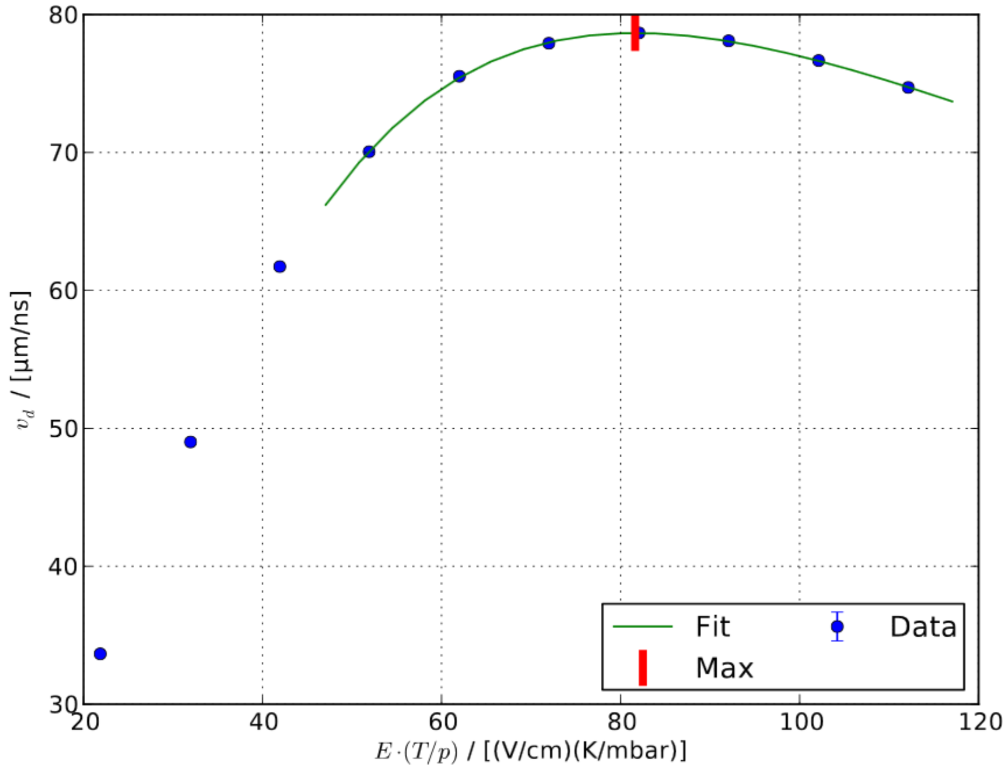
- Function of reduced electric field

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

- Not trivial to describe
  - Must be measured
  - and / or simulated
- Usually the drift velocity shows a maximum that can be parametrized:

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

Empirical parametrization fits for many drift gases around the maxima region



arXiv:1910.08160

Ionisation

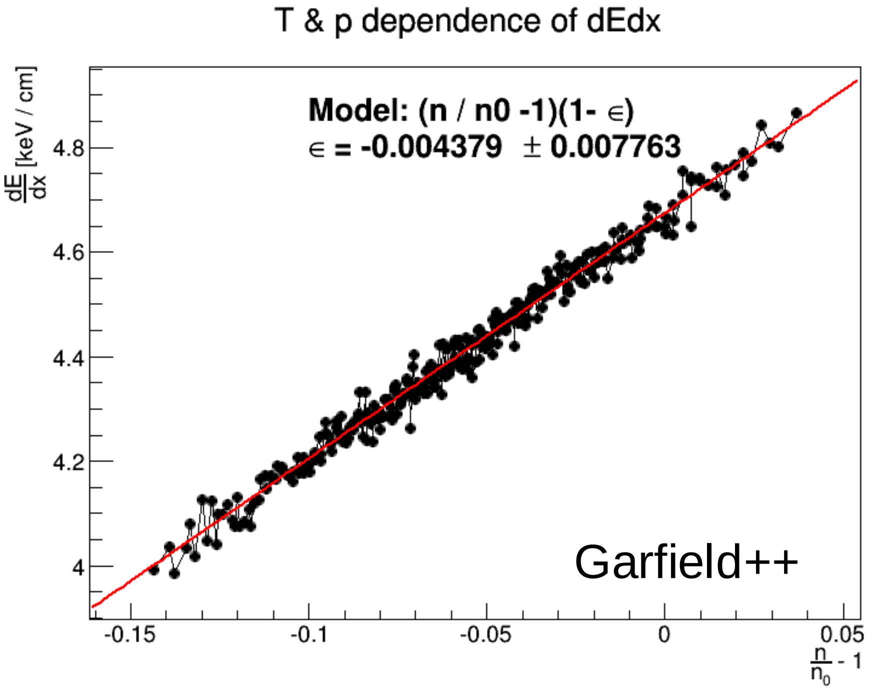
Specific energy loss

- Energy loss of charged medium-momentum particles by ionization

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

- This can be easily corrected in the data

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



Gas Amplification (Gain)

Multiple Calibrations needed

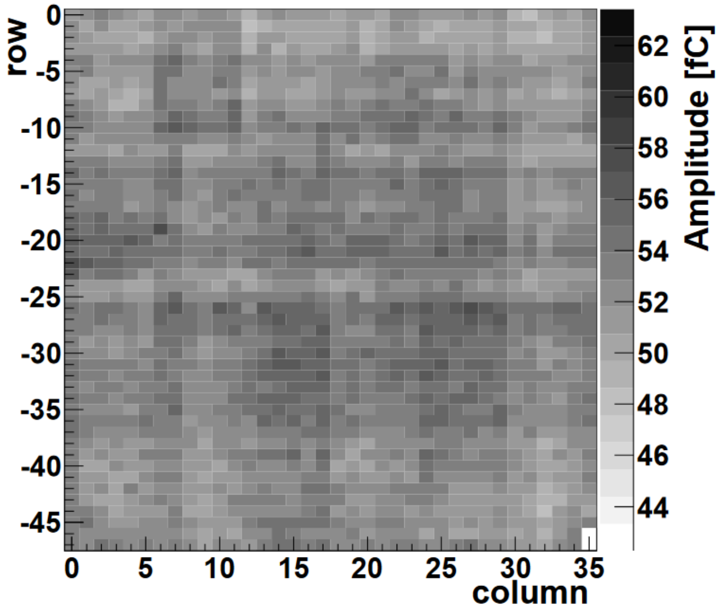
1. **Geometrical differences / Production differences**
   - Pad to Pad calibration
   - Must be done before installation in the detector

   - 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