Effects of Humidity on the Gas Gain in MicroMegas Detectors & Consequences for the Operation of the New Small Wheel

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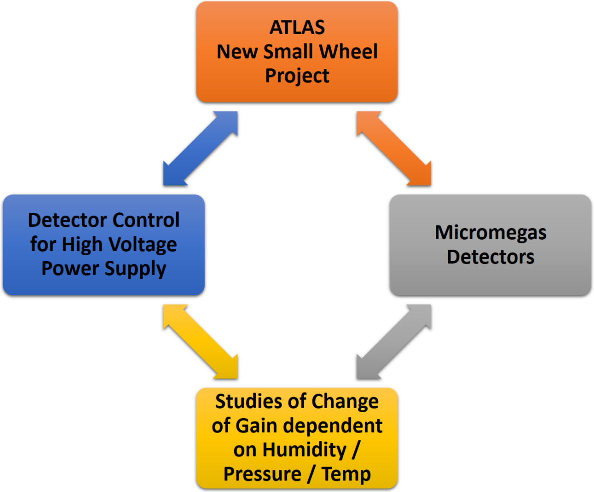
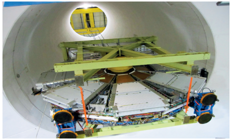
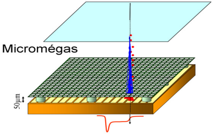
Cycle of Work

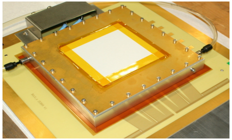


Overview

- New Small Wheel (NSW) &
  Micromesh Gaseous detectors







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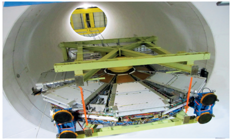

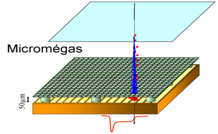

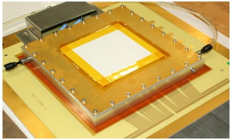

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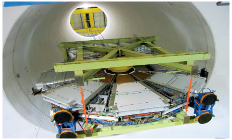
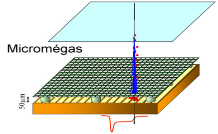
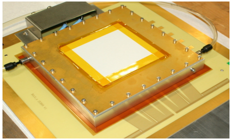
- Experimental Setup in Freiburg
- Simulation Studies on Gas Gain and Drift Velocity







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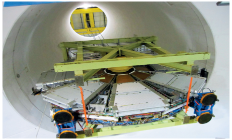

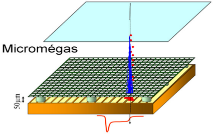

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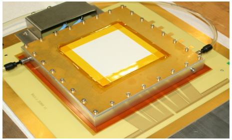


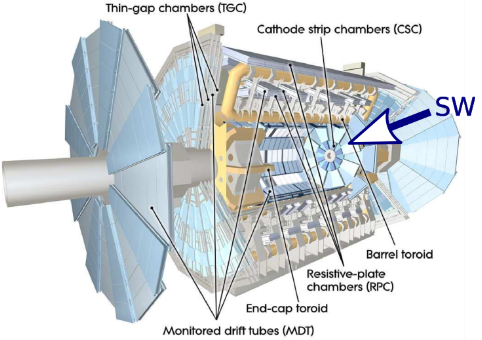
- Simulation Studies on Gas Gain and Drift Velocity

- Detector Slow Control for HV for the NSW

Small Wheel in ATLAS

Part of the muon system in ATLAS

- track and determine momentum of muons
- is composed of:
  - 3 barrel layers
  - 3 end caps at each side
  - → most inner one: **Small Wheel**



ATLAS detector and y-z cut of the ATLAS detector

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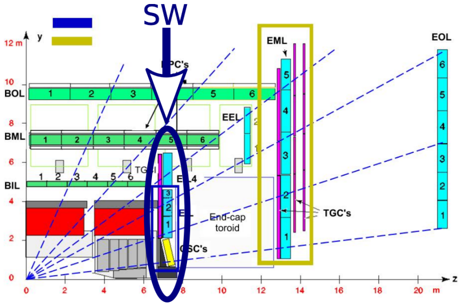
Small Wheel

- ◇ consists of 8 large/small wedges with different layers of detectors (MDT, TGC & CSC) with total area $\sim 150\,\mathrm{m}^2$
- ◇ ok for Phase I upgrade → recommend to upgrade in Phase I in respect to Phase II



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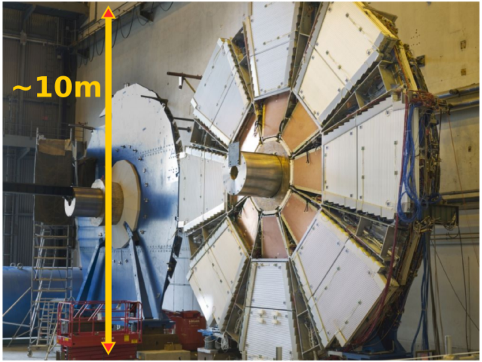
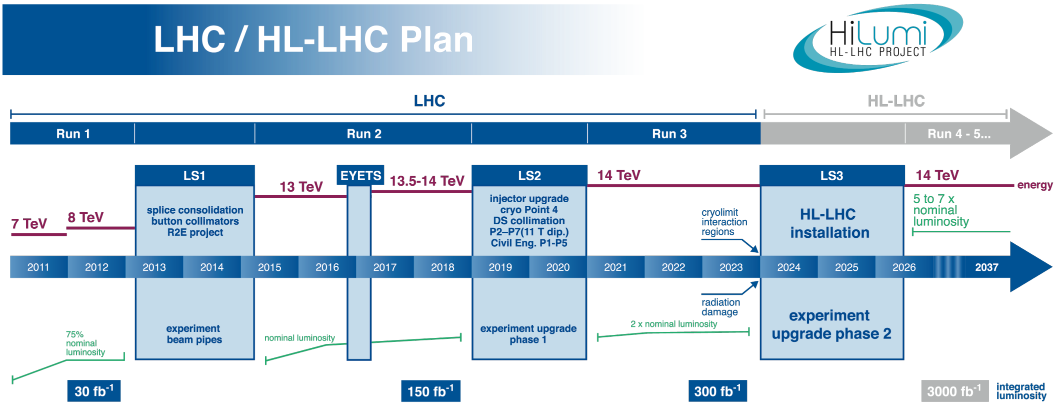


actual Small Wheel

Timeline of LHC and ATLAS Upgrades



ATLAS Upgrade Project: New Small Wheel

Phase 1 upgrade:

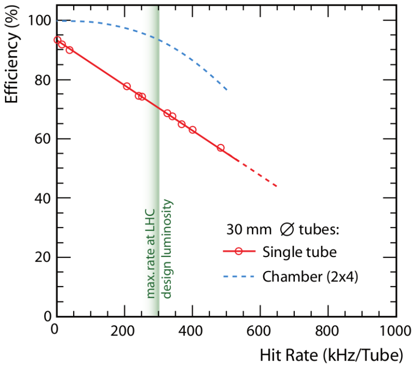
Targeted Performance of NSW

- Rate capability: 15 kHz/cm^2
- Spacial resolution: 100 μm
- Angular resolution $\sigma_\theta \sim 1$ mrad
  → contribution to L1 trigger

L1 trigger contribution

Currently Middle Wheel contributes to L1 trigger by muon reconstruction
⇒ many fake triggers
A better angular resolution $\sigma_\theta \sim 1$ mrad leads to a reduction of fake trigger rate by factor 5

Efficiency of Small Wheel decreases:



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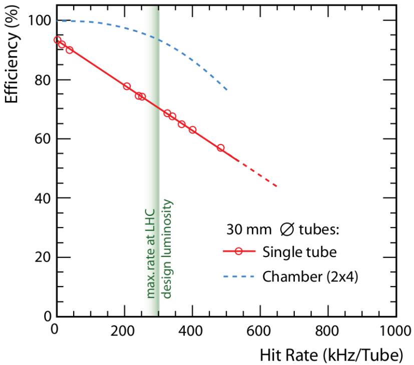
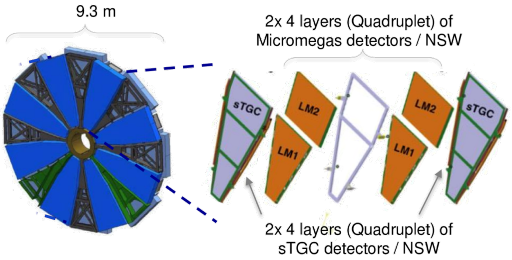


✓ It will be ready for LHC Phase II, too

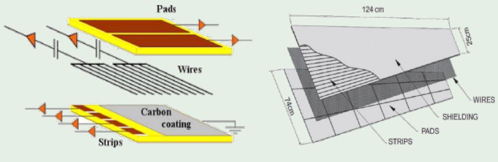
Detector Technologies of the New Small Wheel



- 2 detector technologies will be used:
  1. sTGC: small strip Thin Gap Chambers
  2. MM: Micromegas detectors
- 2 quadruplets (modules of 4 layers of detectors) of sTGC will sandwich 2 quadruplets of MM detectors
- Dubna constructs Large Module 2 for MM detectors, jointly with Thessaloniki

Detector Technologies of the New Small Wheel

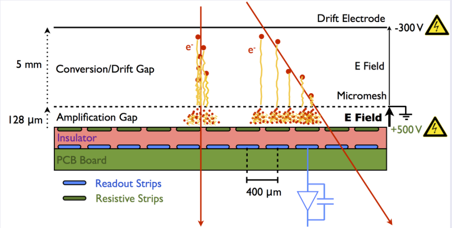
sTGC = small strip Thin Gap Chambers



(a) a (b) b

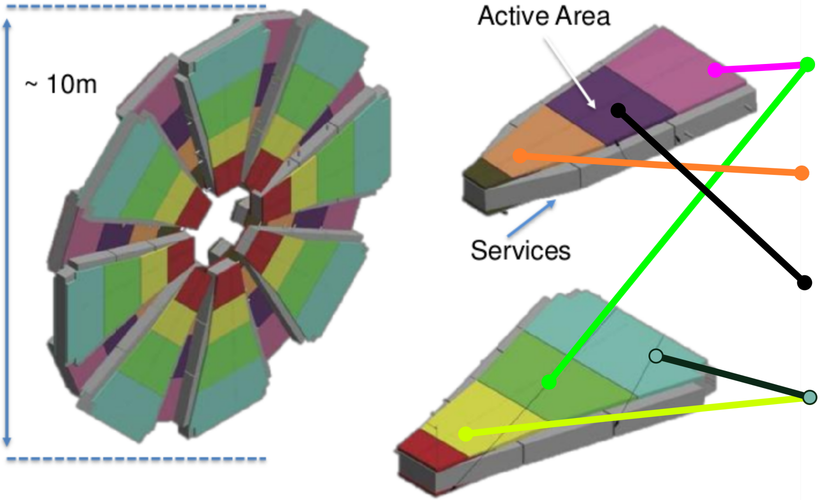
- in total 194 quadruplets
- **well known technology**
- fast, thin gap wire chambers (2.8 mm gap)
- precision coordinate (3.2 mm pitch)
- Good for triggering

MicroMegas Detectors = MicroMesh Gaseous Detectors



- Precision measurement detectors & trigger
- **novel technology**
- Cover an active area of 1280 m^2
- Primary Precision Tracker: Spatial resolution: 100 µm

sTGC Construction Sites



Canada
64 quadruplets
+6 spares

Chile
32 quadruplets
+ 3 spares

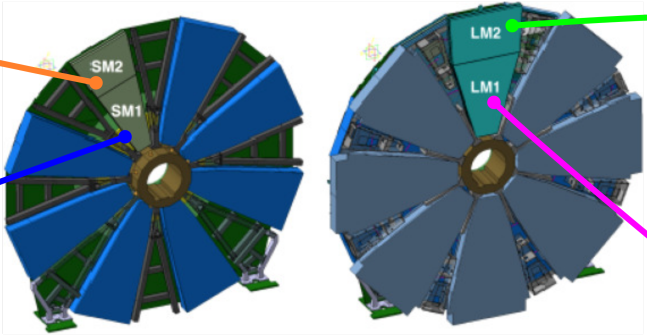
China
32 quadruplets
+ 3 spares

Israel
64 quadrupelts
+ 6 spares

Micromegas Construction Sites

SM2
Germany:
Mainz
Munich
Würzburg

SM1
Italy:
INFN



LM2
CERN
Greece:
Thessaloniki
Russia:
Dubna

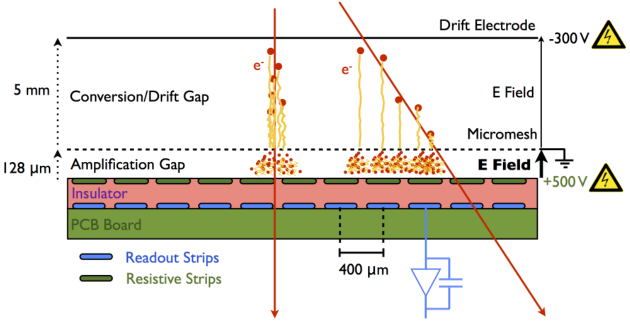
LM1
France:
Saclay

MicroMeGas Detectors

Micromesh Gaseous detectors are parallel-plate chambers with thin amplification gap
⇒ ✓ well suited for high-rate applications

- Developed in 1996 by Y. Giomataris et al.
- Gain up to: 10^5
- Rate capability: $10^6/(\mathrm{mm}^2\,\mathrm{s})$
- Small amplification gap: 128 μm
- Dead area $\approx 1\,\%$

- High field in amplification region allows a fast charge collection and a short deadtime
- Angle of incidence → μTPC method



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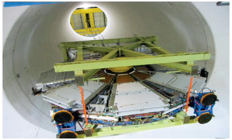
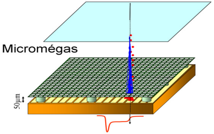
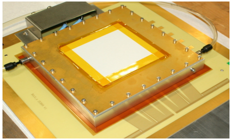






Motivation of Contamination Studies

Freiburg is responsible for the high voltage power system of the NSW including the development of monitoring and control software.

Upcoming Task for NSW

- Programming of the detector contol software for the operation of HV power supply
- Balancing out the influences of pressure, temperature and gas contamination to ensure a stable gas gain and performance, as the detector is operated in proportional mode

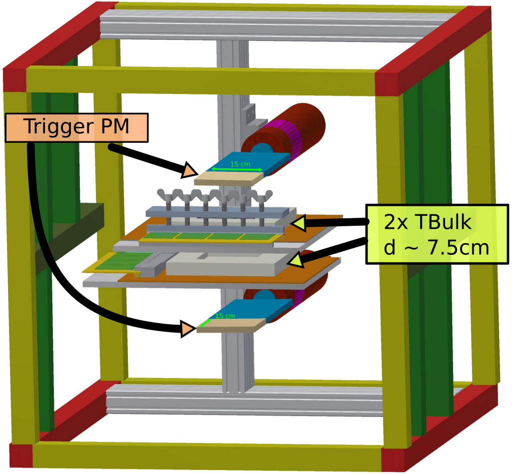
Aim of these studies:

- Key parameters for the reliable operation: **amplification factor & drift velocity**
- Investigation of their change due to small variations of **pressure**, **contamination** of **air** and **water**

Already performed tests by collaboration(selection):

- ✓ Aging Tests (MAMMA)
- ✓ Angle in B-Field †
- ✓ Gas compositions: 93:7, 93.5:6.5,
- ✓ Height of amplification gap ...

Experiment: Muon Test Setup



- Use of cosmic muons
- 2 photomultipliers for trigger
- 2 Micromegas detectors (TBulk type)
- Readout: use `Scalable Readout System` developed at RD51 at CERN in combination with *mmdaq* software
- Gas supply with Ar:CO_2 (93:7) → possibility to contaminate with water or air

Experiment: Micromegas in Freiburg

Test Micromegas Detectors

TBulk: the test micromegas

- Bulk resistive MM with 10 cm × 10 cm active area

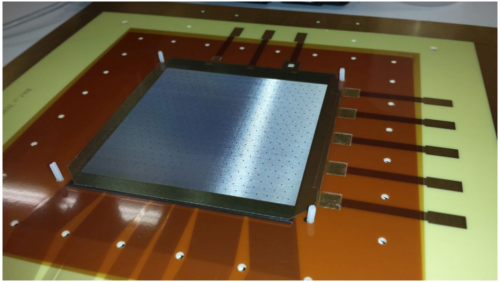
Strip:

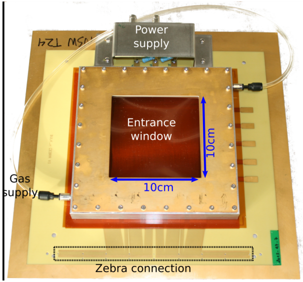
- Width: 150 μm
- Pitch: 250 μm

Mesh:

- Wire diameter: 18 μm
- Wire pitch: 63.5 μm

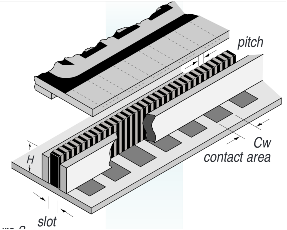
Readout Connectors: ZEBRA - elastomeric connectors with connectors pitch of 200 μm

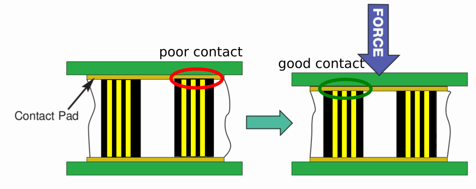




ZEBRA Connectors

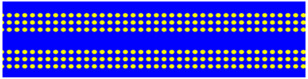
= elastomeric connectors → very flexible + small pitch between the contacts ⇒ **a lot of signals at a very small space** (Commonly used in flat screens or phones)





For the NSW:

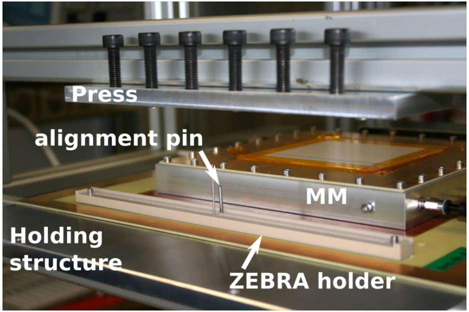
- Pitch: 50 µm
  Pitch of pads = size of pads = 200 µm
- Dimensions: $6.4 \times 3 \times 105.2$ mm
- Need to be compressed by $\approx 20\,\mathrm{kg}$

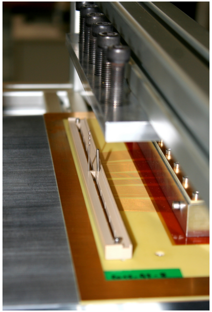


Pin layout for NSW Zebra Connectors

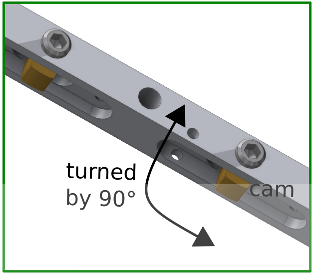
Experiment: Muon Test Setup

Zebra Compression System





compression system with stamp and screws



NSW design

- ZEBRA holder is fixed on MM board and holding structure
- Alignment pin goes from the holding structure up to press
- Readout board is fixed in all directions by ZEBRA holder and press

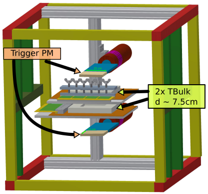
! Second TBulk connected with NSW compression bar

Experiment: Muon Test Setup

Gas Mixing

Gas supply with Ar:CO_2 (93:7) → possibility to contaminate with water or air

- Precise mixing system from MDT production for Ar:CO_2
- Humidity regulation with flow meter
- Humidity monitoring with 2 humidity meters: before and after the detectors
- Pressure stability: $\sim 0.25\,\text{mbar}$
- Gas Flow: $\sim 20\,\text{L/h}$ → proper operation of humidity meters

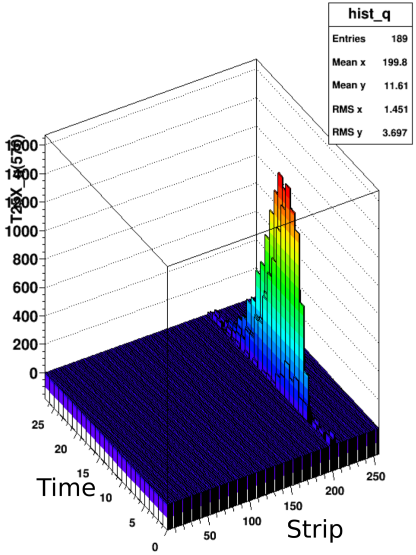


- $V_{drift} = 300\,\text{V}$
- V_{amp}: $480\,\text{V} - 540\,\text{V}$
- Angle on incidence up to ±20°

Possibilities to determine *gain* in dependence on

- Pressure (Temperature)
- Amplification voltage
- Humidity

Experiment: Analysis



Criteria

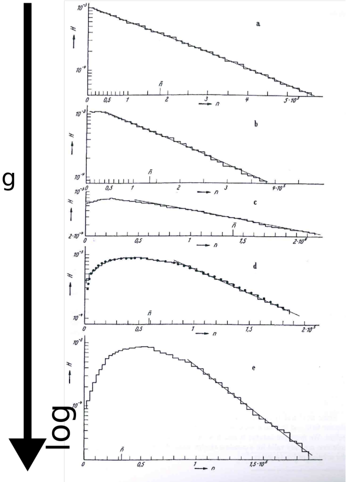
- Cuts can be made on humidity variations e.g. $<\pm 100\,\text{ppm}$
- Consideration of temperature for pressure correction
- Pressure variation is $< 0.5\,\text{mbar}$

Determination of

- Strip position: Weighted mean $x_c = \frac{\sum S_i \cdot x_i}{\sum S_i}$
- Charge: Sum up the charge of cluster considering neighboring strips around the highest peak

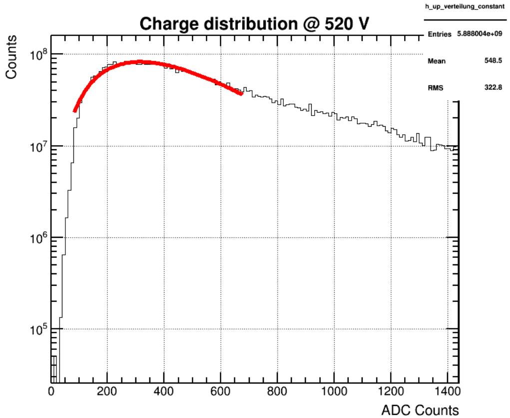
Experiment: Determination of Gain

increasing electric field



- Distribution: exponential
  → small signals more probable
- e^- has 2 possibilities
  1. ionising collision → e^- + Ion
  2. e– attach to ion → depleted Ion^-
- Plot at the left shows:
  - Weak Field: exponential distribution
  - High field: Depletion increases
    → exponential decrease

Experiment: Determination of Gain

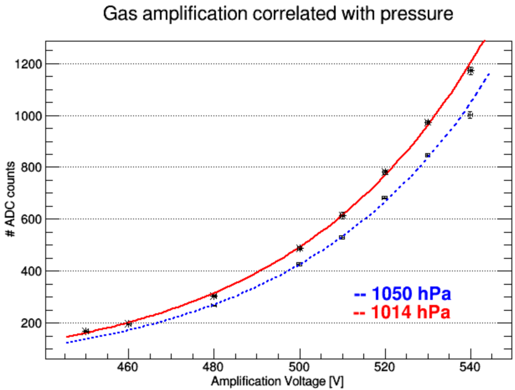


Fill all determined charges into one histogram and perform fit

- The polya function
- Parameters:
  - Q = number of electrons in the avalanche
  - $< Q >$ = mean value of the amplification $\approx$ most propable value
  - β is related to the relative gain variance $g = 1/(1+\beta)$ $\rightarrow \beta = 0 \Rightarrow$ pure exponential function

$$f\left(\frac{Q}{< Q >}, \beta\right) = C \cdot \left(\frac{Q}{< Q >}\right)^{\beta} \cdot \exp\left(-(1-\beta)\frac{Q}{< Q >}\right)$$

Experiment: Dependence on Amplification Voltage



- Trendplot → expected behaviour wrt. amplification voltage confirmed
- Systematic errors under investigation
  Perform polya fit at different ranges around maximum → mean and deviation

Collected data

- 1020 mbar: 0 ppm,
- 1030 mbar: 1500 ppm, 2400 ppm, 2800 ppm
- 1040 mbar: 2600 ppm
- ...
- Evaluation in progress

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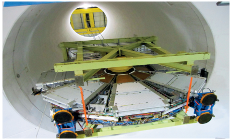

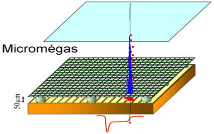

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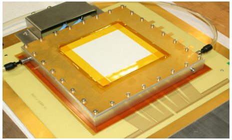

- Simulation Studies on Gas Gain and Drift Velocity

- Detector Slow Control for HV for the NSW

Studies on Water and Air Contamination in the Gas

1. Simulation software

- Gas Gain: Theories and Simulation
- Drift velocity: Theories and Simulation
- Conclusion

Simulation Software

MagBoltz

Numerical integration of the Boltzmann transport equation to determine drift gas properties of gaseous detectors

→ Simulation of the gas parameters for drift and amplification region

Garfield++

Toolkit for detailed simulation of particle detectors that use gas or semi-conductors as sensitive medium

- Simulation the electron avalanche for different gas mixtures and amplification voltages
- Quite long computation time: $\sim$ weeks

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1. Simulation software
2. Gas Gain: Theories and Simulation

- Drift velocity: Theories and Simulation
- Conclusion

Theory: Gas Amplification Concepts

1. First Townsend coefficient α:

$$G \propto \exp[\alpha(E,p) \cdot x]$$

$\alpha \sim 1/\lambda$, λ = mean free path

2. Rose-Korff (1941):

$$G(E,p) \propto \exp\left[p \cdot A \cdot \exp\left(\frac{-B \cdot p}{E}\right) \cdot x\right]$$

x = travelled distance
p = pressure
E = electric field

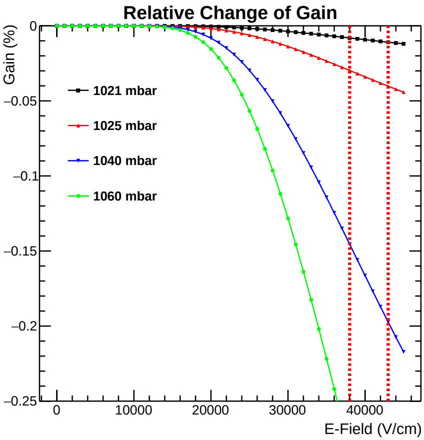
Rose-Korff parameters (1944):

Gas	Ar	CO_2
A [1/(cm Torr)]	14	20
B [V/(cm Torr)]	180	466

→ **use them for estimations!**

Theory: Gas Amplification Concepts

Pressure Dependence of Gain with Rose-Korff



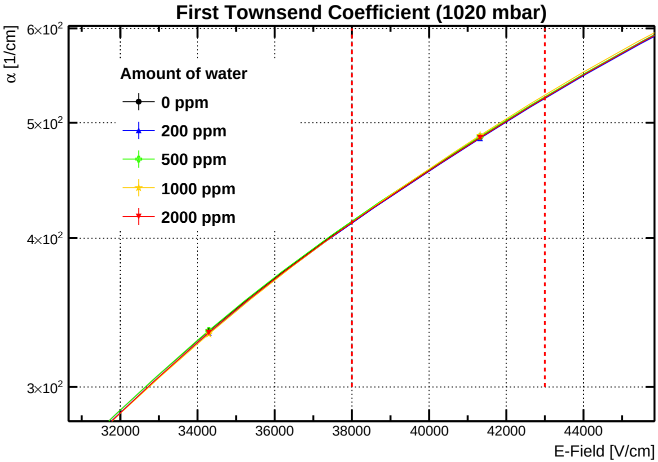
- Use of literature values for Ar and CO_2
- Calculation of the relative change of gain due to pressure in respect to 1020 mbar
- Relative change of gain @ 40 kV/cm

mbar	change
→ 1021	−0.009 %
→ 1025	−0.033 %
→ 1040	−0.166 %
→ 1060	−0.324 %

⇒ Expection confirmed: higher gas density → less gain

Simulation: Townsend Coefficient

H_2O Contamination



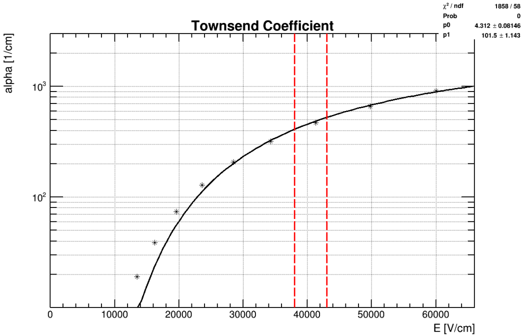
- Simulated with MAGBOLTZ
- MicroMegas working point of ~40 kV/cm in the amplification region almost not influenced by small contamination of water.
- ✓ No larger impact on the amplification

Extraction of Rose-Korff-Parameters

H_2O Contamination

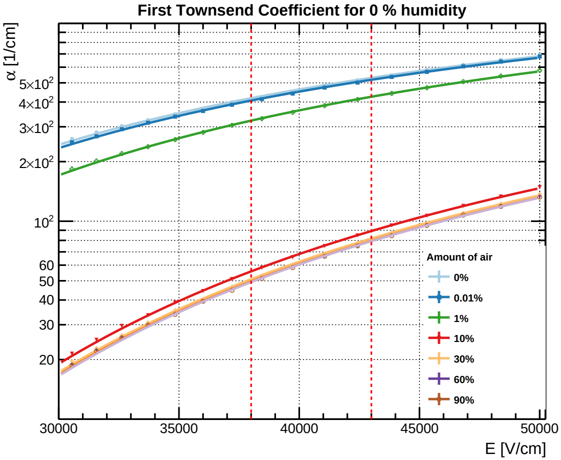
- The simulated Townsend coefficient can be used to determine the Rose-Korff parameters for different gas mixtures.
- Fit performed close around the ROI

H_2O	$A\left[\frac{1}{\text{cm Torr}}\right]$	$B\left[\frac{\text{V}}{\text{cm Torr}}\right]$
0 ppm	4.316(80)	101.54(112)
200 ppm	4.298(77)	101.34(109)
500 ppm	4.324(81)	101.64(114)
1000 ppm	4.312(81)	101.50(114)
Ar	14	180
CO_2	20	466



Simulation: Townsend Coefficient

Air Contamination



- Simulated with MAGBOLTZ
- Relative change (@40 kV/cm):

air contamination	change
0 → 0.01 %	2.43 %
0 → 1 %	21.6 %
0 → 10 %	85.5 %
0 → 30 %	86.6 %

✗ Small amount of air ⇒ large impact

Studies on Water and Air Contamination in the Gas

1. Simulation software
2. Gas Gain: Theories and Simulation
3. Drift velocity: Theories and Simulation

- Conclusion

Theory: Drift Velocity

Impacts on μTPC reconstruction method:

Drift velocity is used to calculate the angle of incidence in the Micromegas Detectors.

Ions

- Ion mobility μ in gases

→ Drift velocity: $v_D = \pm\mu \cdot \vec{E}$

- Blanc's rule:

$$\frac{1}{\mu} = \sum_i \frac{f_i}{\mu_i}$$

f_i = fraction of gas in mixture

Ar^+ in $Ar^\dagger$	$\mu = 1.57\,cm^2/(Vs)$
CO_2^+ in $Ar^\dagger$	$\mu = 1.72\,cm^2/(Vs)$
H_2^+ in $H_2^{+\dagger}$	$\mu = 13\,cm^2/(Vs)$
H_2O ‡	$\mu = 0.7\,cm^2/(Vs)$

†Kolanoski (2016), ‡F. Sauli (1977)

Electrons

- Based on Boltzmann transport equation

$$\vec{v_D} = \langle\vec{v}\rangle = \int \vec{v}\, f(\vec{v})\, d^3\vec{v}$$

Influence of water contamination

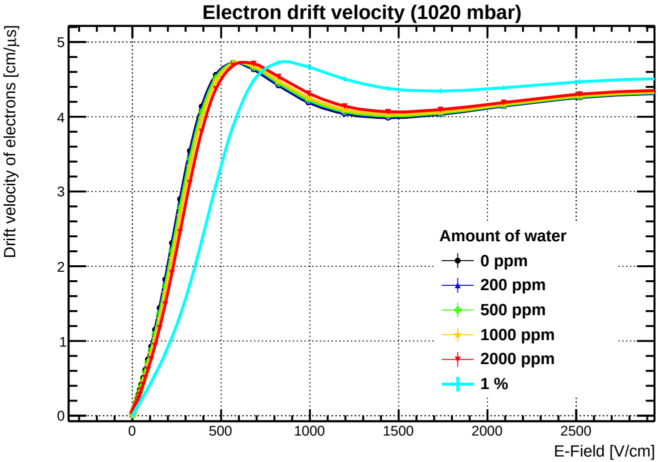
Water molecule has a static electric dipole moment

⇒ Enlargement of inelastic scattering cross-section for low-energy electrons

⇒ **Reduction of drift velocity**

Simulation: Drift Velocity

H_2O Contamination

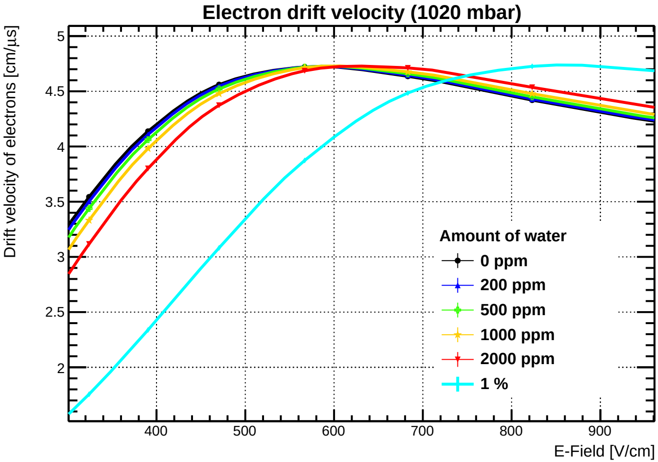


- Simulation with MAGBOLTZ
- MicroMegas working point of 600 V/cm in the drift region almost not influenced by small contamination of water.
- Relative change (@600 V/cm):

H_2O contamination	change
0 → 200 ppm	+0.13 %
0 → 500 ppm	+0.23 %
0 → 1000 ppm	-3.8 %
0 → 10000 ppm (1%)	-12.9 %

Simulation: Drift Velocity

H_2O Contamination

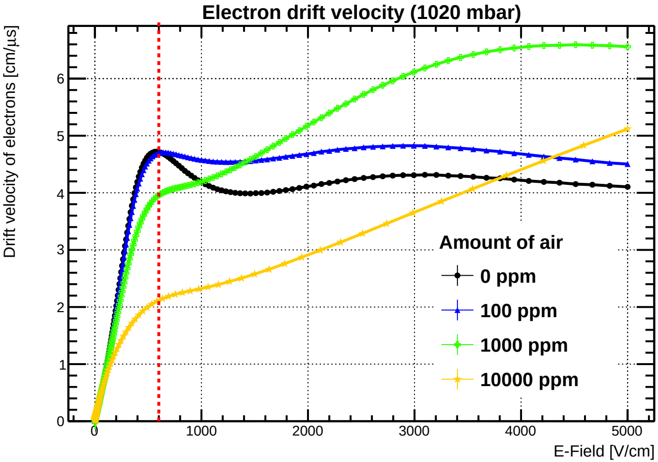


- Simulation with MAGBOLTZ
- MicroMegas working point of 600 V/cm in the drift region almost not influenced by small contamination of water.
- Relative change (@600 V/cm):

H_2O contamination	change
0 → 200 ppm	+0.13 %
0 → 500 ppm	+0.23 %
0 → 1000 ppm	-3.8 %
0 → 10000 ppm (1%)	-12.9 %

✓ Stable working point!

Simulation: Drift Velocity
Air Contamination



- Simulation with MAGBOLTZ
- Influence of air based on the electro negativity of oxygen
- Air mixture used:
  - N: 78%
  - O_2: 21%
  - Ar: 1%
- Relative change (@600 V/cm):

0 → 100 ppm	-0.38 %
0 → 1000 ppm	-16.02 %
0 → 10000 ppm	-55.08 %

✗ larger impact than water

Simulation: Conclusion

Simulation

Simulation of Drift velocity and First townsend coefficent for different H_2O and air contaminations

Indication of

H_2O contamination

- Low impact on amplification
- Moderate impact to drift velocity

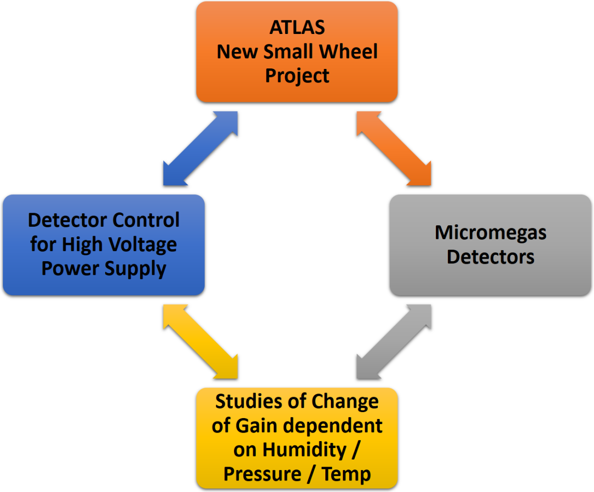
Air contamination

- Larger impact on amplification
- Large impact to drift velocity

Next Steps

- Continue data taking and evaluation
- Comparison of the experimental results with the simulation

Cycle of Work



High Voltage Power Supply for NSW

NSW HV System

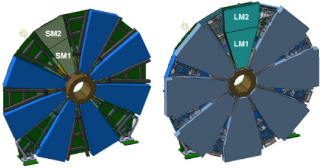
- ~3 kV for sTGC
- + 500 V & −300 V for MM

Participation at service program for the NSW system:

- Selection and procurement of the modules for both detector systems
- Installation of HV modules
- Programming the Control Software

Total number of individual connectors at MM detectors:

channels	positive	negative
MM	4096	1024
sTGC	1024	



High Voltage Power Supply for NSW

NSW HV System

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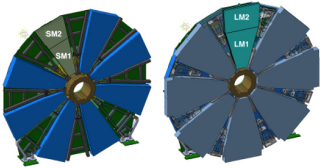
Participation at service program for the NSW system:

- Selection and procurement of the modules for both detector systems
- Installation of HV modules
- Programming the Control Software

Total number of individual connectors at MM detectors:

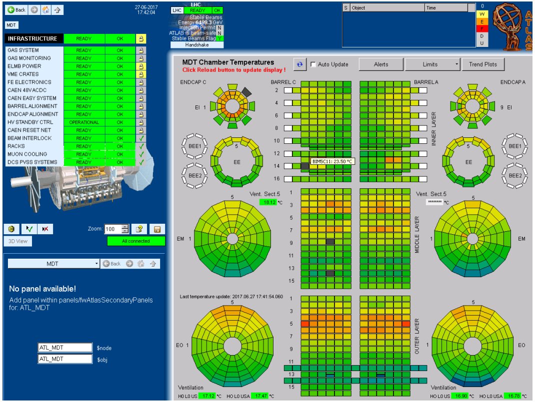
Real HV channels

channels	positive	negative
MM	4096 → 512	1024 → 128
sTGC	1024 → 1024	



Detector Slow Control for High Voltage Power Supply

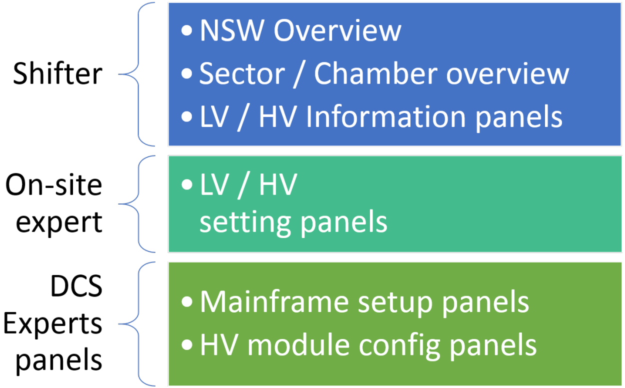
- ATLAS uses SCADA software *"Siemens SIMATIC WinCC SCADA system" (WinCC)* for detector control
- ATLAS has 130 WinCC projects → 12 million datapoints to monitor & control
- Freiburg contributes with the development of the detector slow control for the high voltage power supplies by providing the necessary libraries and panels for the WinCC software for NSW.



Example ATLAS DCS display

DCS Development

Requirements:



Requirements to the final DCS System

Adjustment of voltage to compensation of change of

- pressure
- temperature
- humidity

to ensure a stable operation point

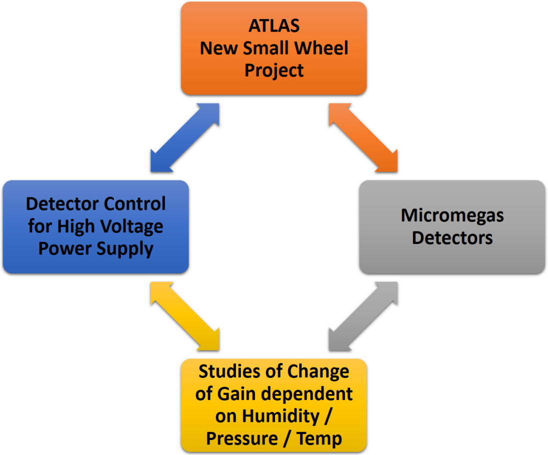
DCS Development

Development of a Quality Assurance System

- Before installation each module will be tested in a stress test
- Based on the former system an upgrade to the newest WinCC version will be done

→ new modules types will be added

Conclusion & Prospect



Status

- Simulation for different gas mixtures done and/or in progress
- Experimental setup ready to continue measurements with small variations in the H_2O contamination of the operation gas

Prospect

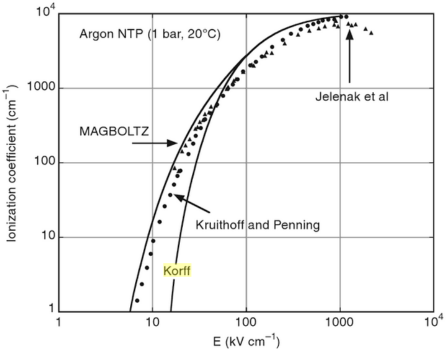
- Estimation of impacts to the operation points of the Micromegas detectors for the NSW
- Realisation of the DCS high voltage programming for the NSW

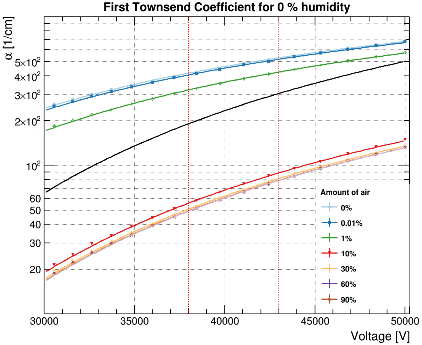
→ Consideration of the determined effects and effects of *pressure* and *temperature* in the programming of the NSW HV control

Thank you for the invitation and the possibility to visit Dubna!

Backup

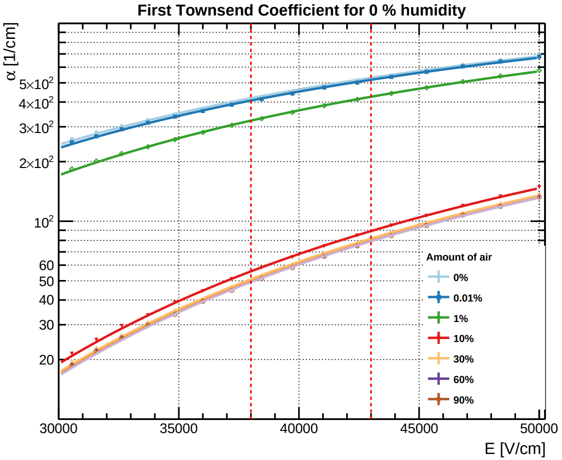
Simulation: Rose-Korff vs MAGBOLTZ





left: Taken from F. Sauli, Gaseous radiation detectors, 2014
right: Magboltz simulation with different air contamination and Rose-Korff function (black)

Extraction of Rose-Korff-Parameters
Air Contamination

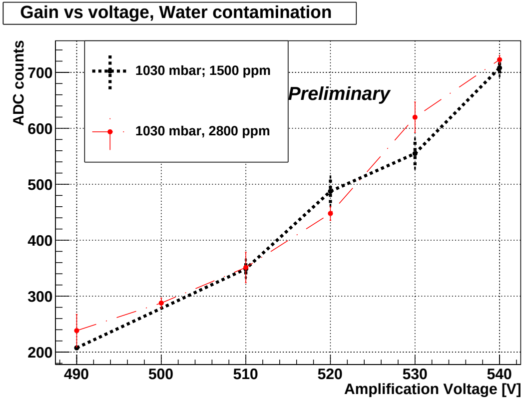


Air contamination

- The simulated Townsend coefficient can be used to determine the Rose-Korff parameters for different gas mixtures

air	A $\left[\frac{1}{\text{cm Torr}}\right]$	B $\left[\frac{\text{V}}{\text{cm Torr}}\right]$
0 %	4.101(65)	99.10(83)
0.01 %	4.158(59)	101.13(74)
1 %	4.493(57)	116.27(68)
10 %	4.033(64)	196.44(88)
30 %	3.807(70)	198.39(102)

Experiment: Dependence on Amplification Voltage



- Trendplot → expected behaviour wrt. amplification voltage confirmed leaving aside pressure and H_2O contamination for the moment.
- Systematic errors under investigation Perform polya fit at different ranges around maximum → mean and deviation

Collected data

- 1020 mbar: 0 ppm,
- 1030 mbar: 1500 ppm, 2400 ppm, 2800 ppm
- 1040 mbar: 2600 ppm
- Random samples:
  - 1020 mbar: 0 ppm, 520 ppm, 800 ppm
  - 1060 mbar: 0 ppm
- Evaluation in progress