A mobile gasmixing unit

Creating precise gas mixtures

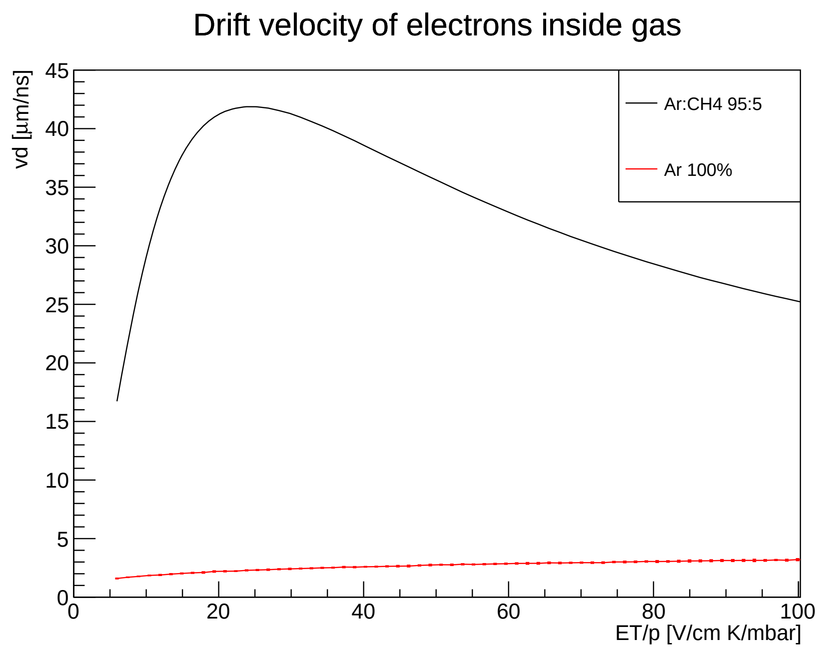
Jochen Steinmann
Physics Institute III B, RWTH Aachen University
8th Terascale Detector Workshop – 05.03.2015

Which gases are used inside a TPC?

Most mixtures used inside TPCs consist of two or three components!

Gas effects:

- Drift velocity:
  electrons and ions
- Diffusion:
  size of drifting electron cloud



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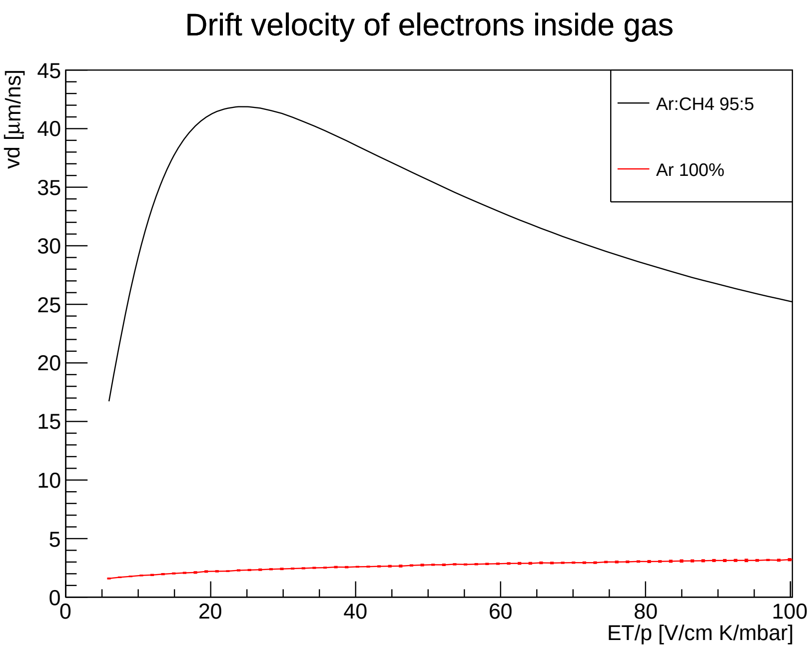
Gas choice depends on:

- limits from environment
  (flammable gases allowed?)
- operating costs
- needed properties v_D and $D_{T,L}$
- interaction with detector materials
- ionisation properties
  (main component / nobel gas)



Need for a Gas System

Requests from R & D of gaseous detectors

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quick tests of new detectors with different mixtures and variations

$\Rightarrow$ no long changeover times
$\Rightarrow$ no limitation on the gases

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for avoiding systematic effects, the gassystem should travel with the detector
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gas free of oxygen and water

⇒ purification & low leakage system

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Why a gassystem?

“Gas system? I’m using bottles!”

Bottled gases

Advantages

- high pressure (~200 bar)
- requires only little space

Disadvantages

- only fixed mixtures, no variations possible
- exotic mixtures have long delivery times
- normal precision only 10 %

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Gas system

Advantages

- variation of the mixture
- high precision < 0.1 vol.-%
- gas consumption can be reduced
- analysis, pressure regulation

Disadvantages

- space needed

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Costs for 1 m^3 P10 (Ar:CH_4 90:10)

1 m^3 P10 ≙ 8.26 €

ordering 10 ℓ 200 bar

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Costs for 1 m^3 P10

0.9 m^3 Ar + 0.1 m^3 CH_4 ≙ 4.19 €

if you don't have to pay for the system itself

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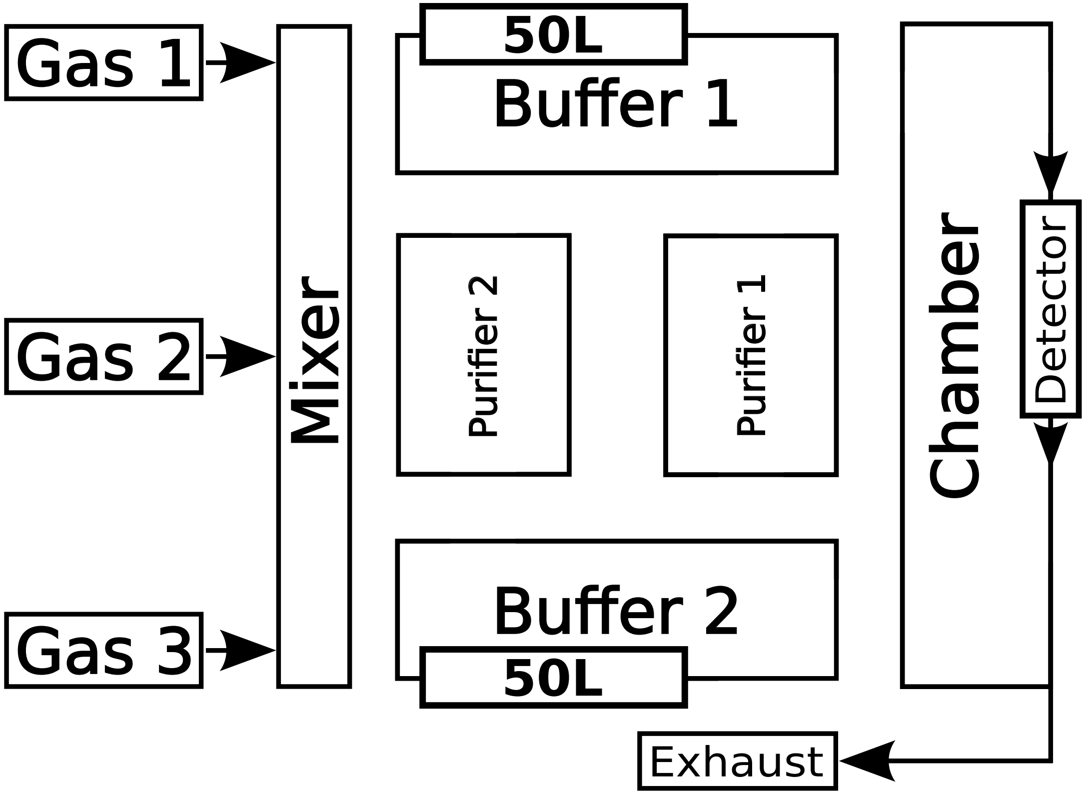
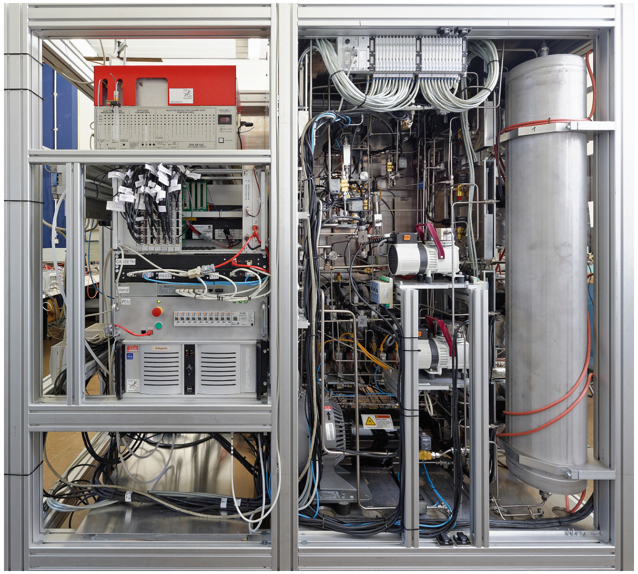
UGMA

Universelle - Gas - Misch - Anlage
Universal - Gas - Mixing - Apparatus

Very basic schematic





Overview of the assembly groups

Mixer (3 lines input)

- two lines have three MFCs
  max. 1, 10, 100 ℓ_n/h Ar
- one only 100 ℓ_n/h Ar main component

O_2 and H_2O Purifier (2×2 pcs.)

- each purifier is present twice
- one regenerating & one in use

Buffer (2 pcs.)

- $V_0 = 50\,\ell$ equipped with pump
- partial pressure mixing
- gas storage

Chamber (detector interface)

- flow regulation (0 - 100 ℓ_n/h)
- pressure regulation (0 - 3 bara)
- continuous setpoint of the
  gas recycle ratio 0-100 %

Analysis

- can be connected to every loop
- special sensors for O_2 & H_2O content
- gas chromatograph

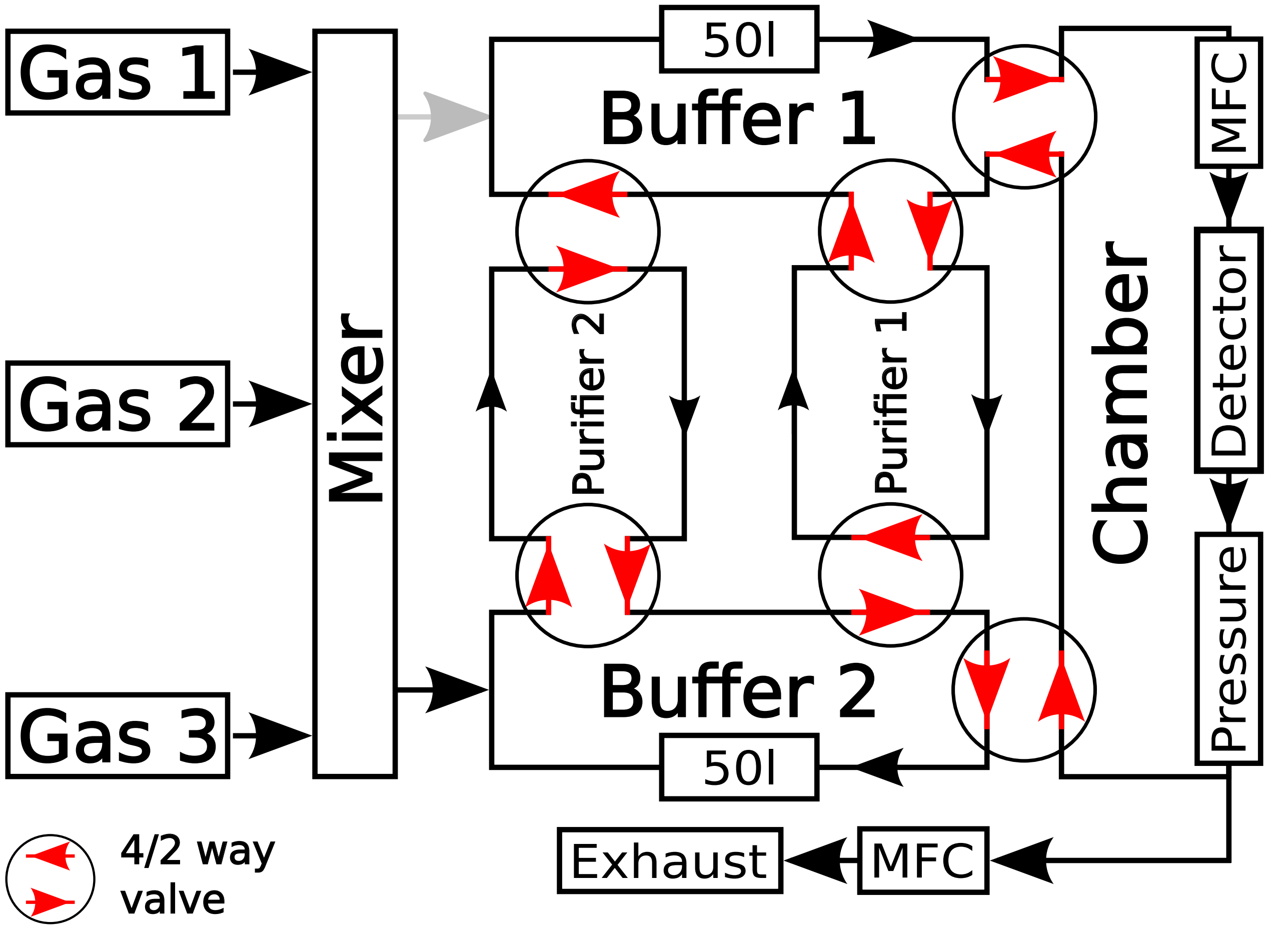
Safety

- flammable gas sensor
- interlock system

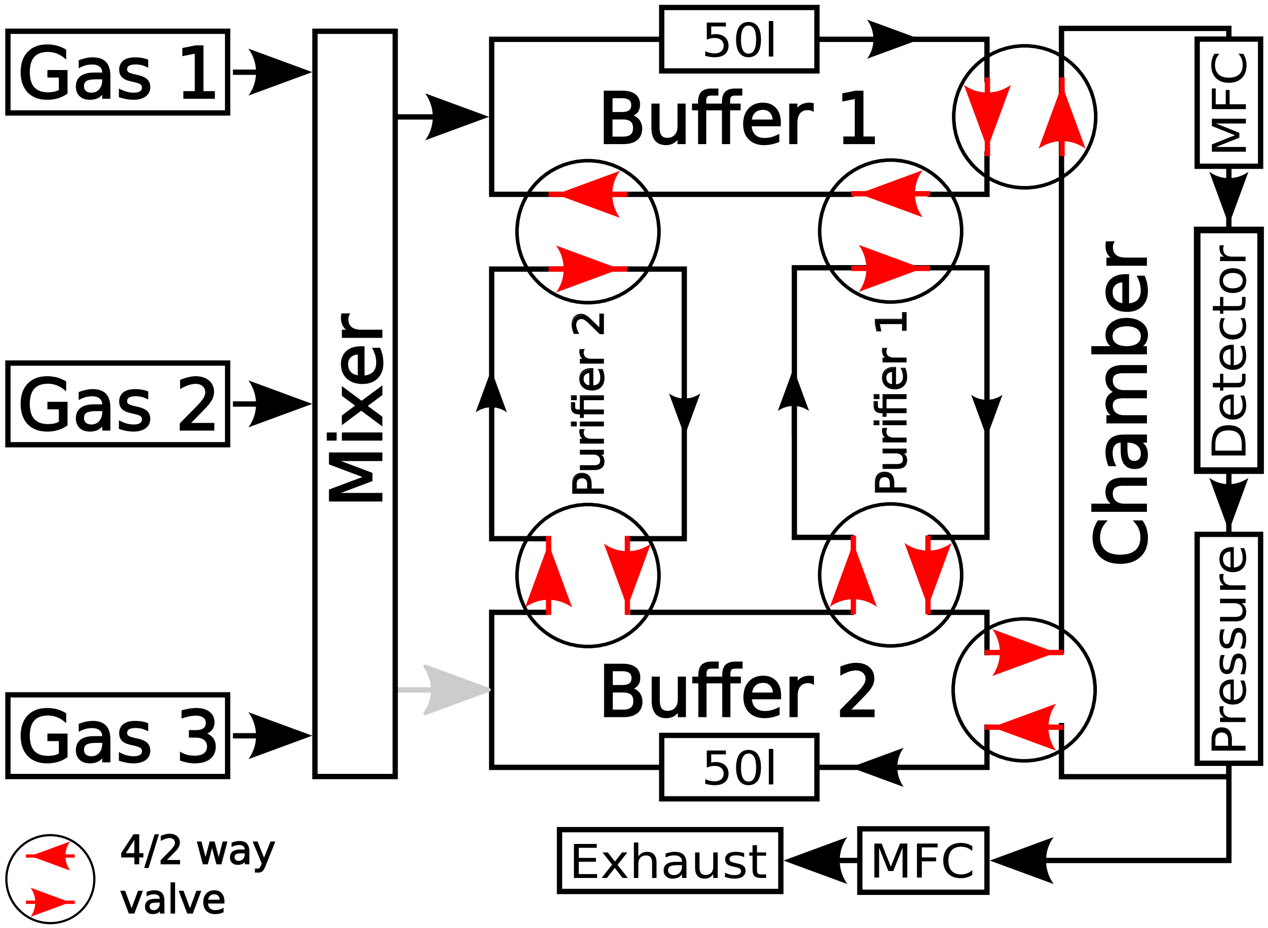
Monitoring:

temperature and pressure monitoring in all assembly groups

Looping


Gas 1
Gas 2
Gas 3
Mixer
50l
Buffer 1
MFC
Purifier 2
Purifier 1
Chamber
Detector
Pressure
Buffer 2
50l
Exhaust
MFC
4/2 way
valve

Looping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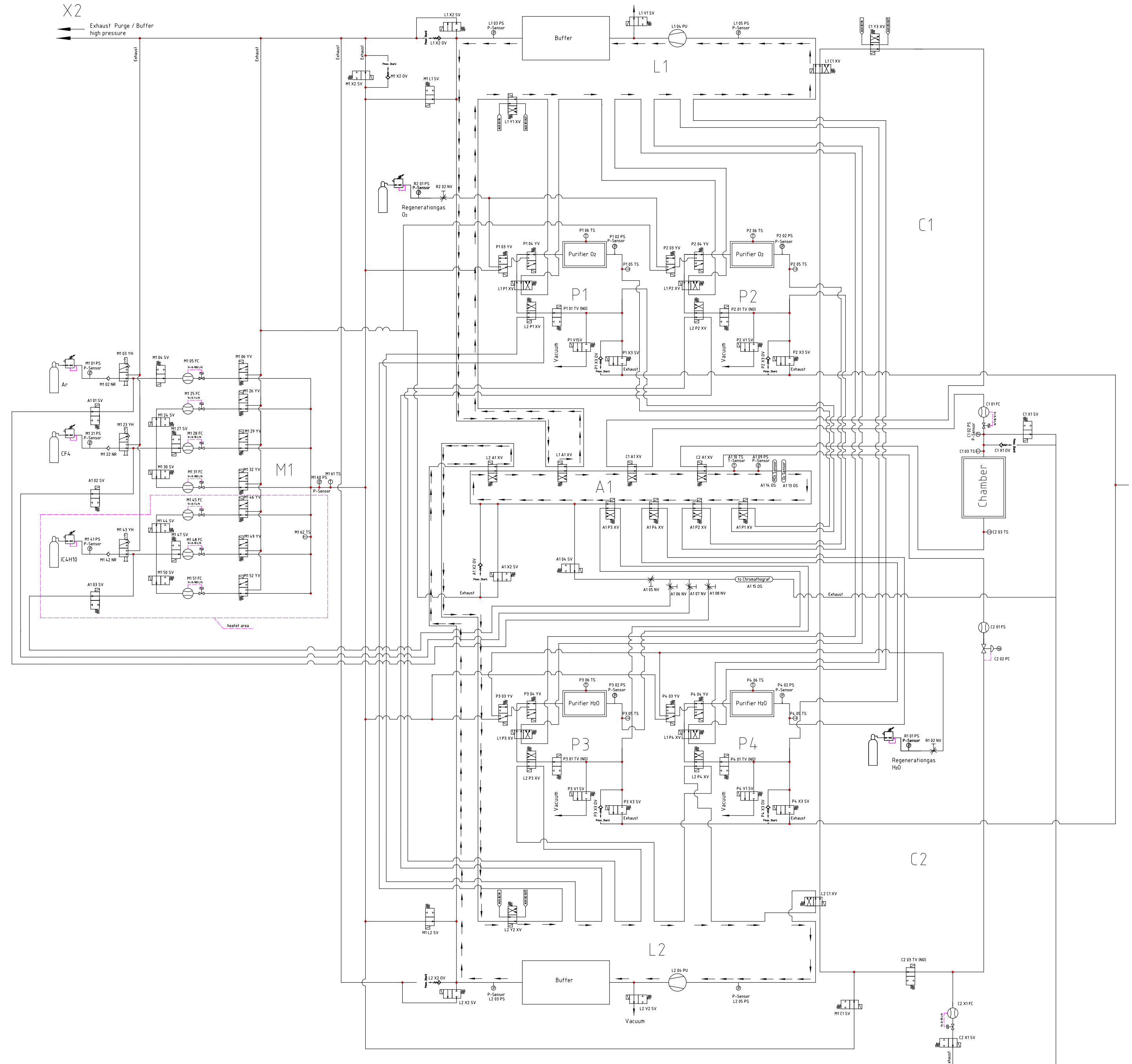
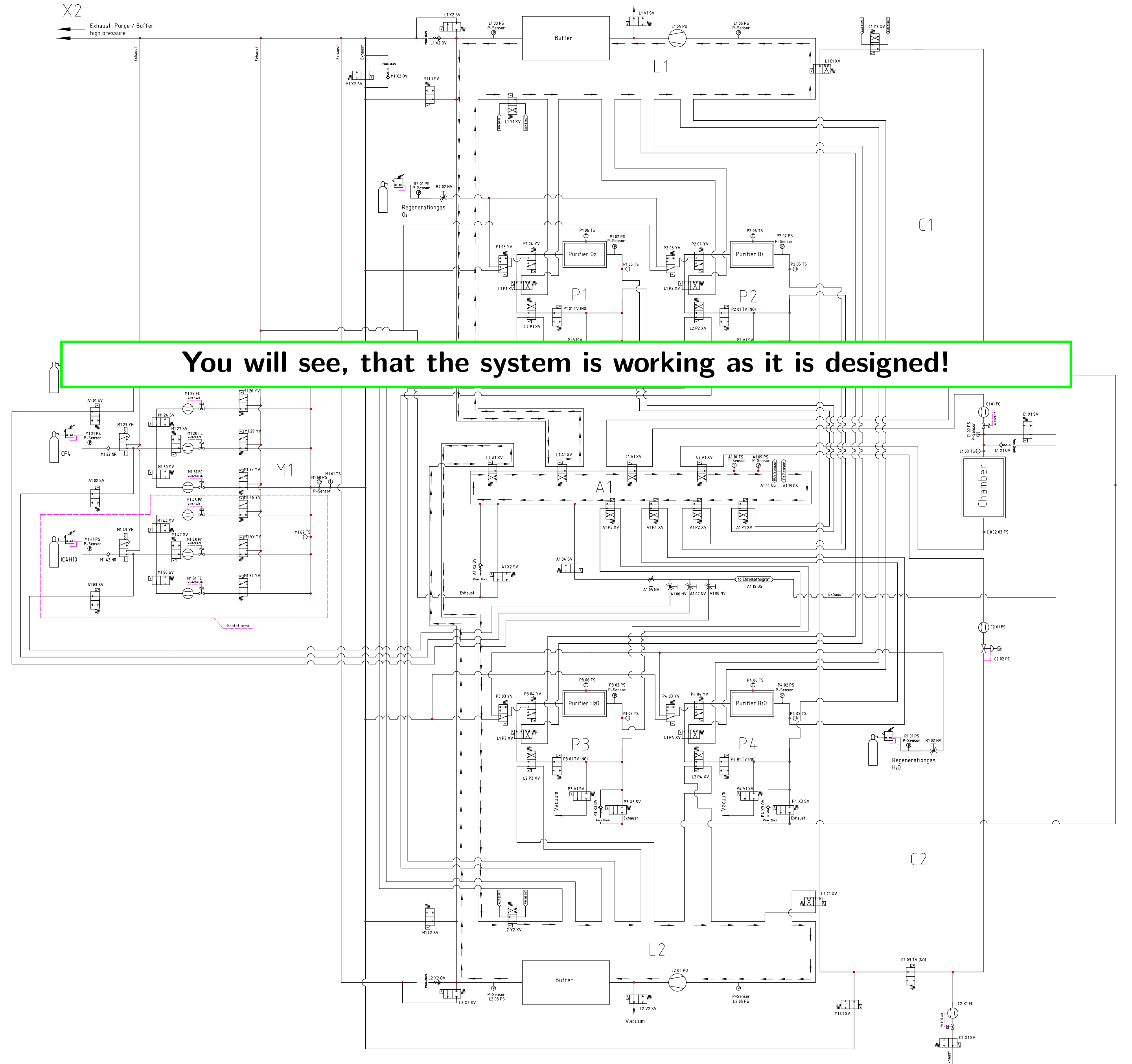
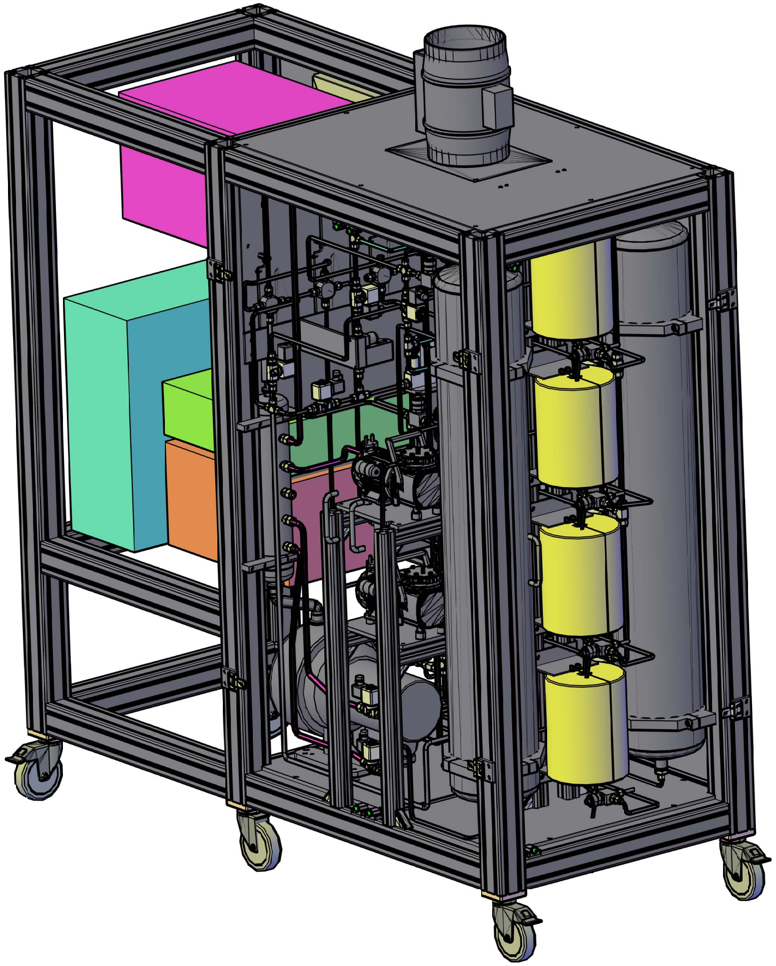


X2
Exhaust Purge / Buffer
high pressure
Buffer
L1
L2
C1
C2
P1
P2
P3
P4
A1
M1
Chamber
Purifier O2
Purifier H2O
Regenerationgas O2
Regenerationgas H2O
Ar
CF4
IC4H10
Vacuum
Exhaust
heater area
to Chromatograf



You will see, that the system is working as it is designed!

3D design



Overview - Mechanics

78 Valves

- 22 pneumatic 4/2-way valves
- 56 3/2-way & 2/2-way solenoid-valves

38 Sensors

- 18 pressure sensors
- 18 temperature sensors PT100
- 2 other sensors (H_2O, O_2)

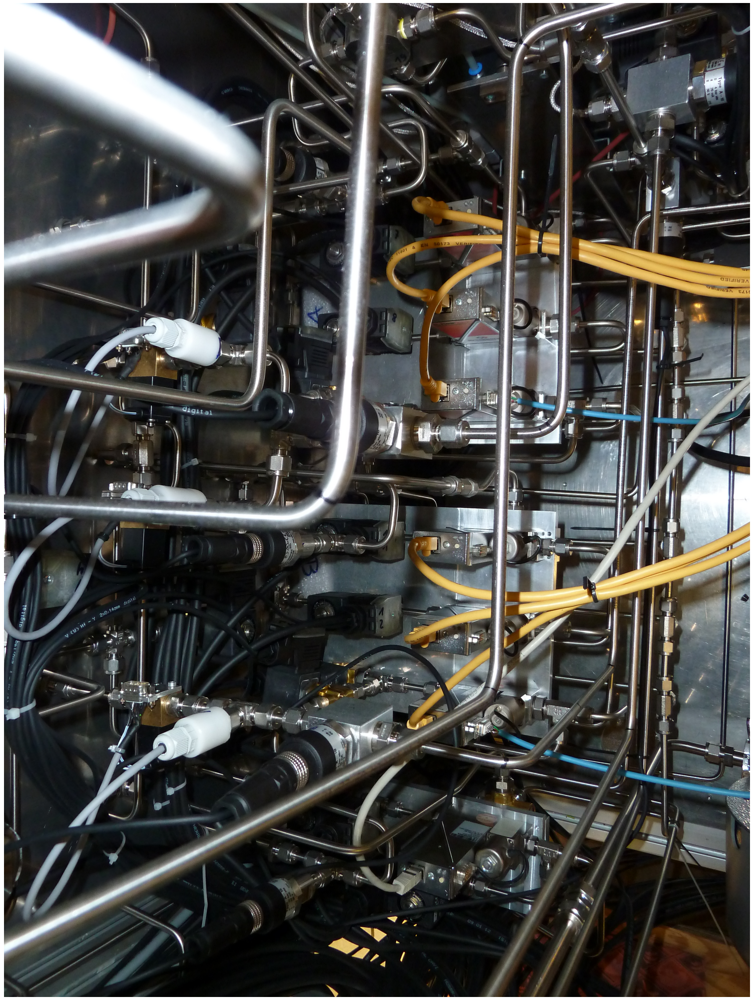
200 m Pipes

Stainless steel (for gas handling):

- ca. 120 m 6 mm
- ca. 20 m 10 mm

Flexible PU-tubing (for pneumatic valves):

- ca. 65 m 6 mm



Overview - Electronics

500 m Cables

- 240 m power cable
- 260 m signal cable

Data collection

- sampling all sensors with 0.5 Hz 12 Bit
- Data transfer via CAN-Bus and Ethernet

Power

- need three phase 230 V 16 A CEE
- only low voltage inside gas volume

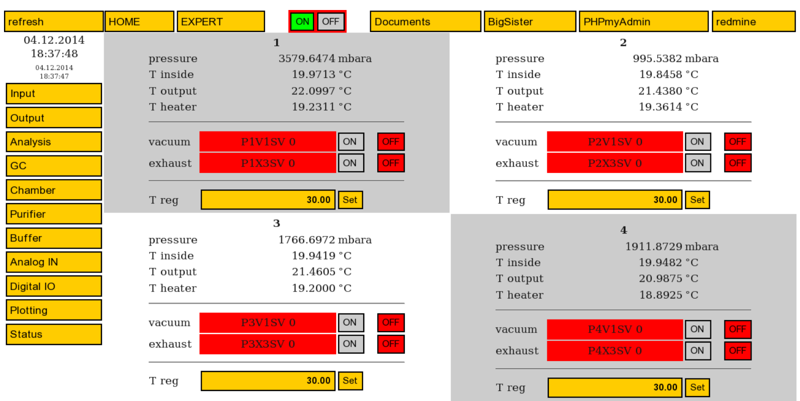
Control

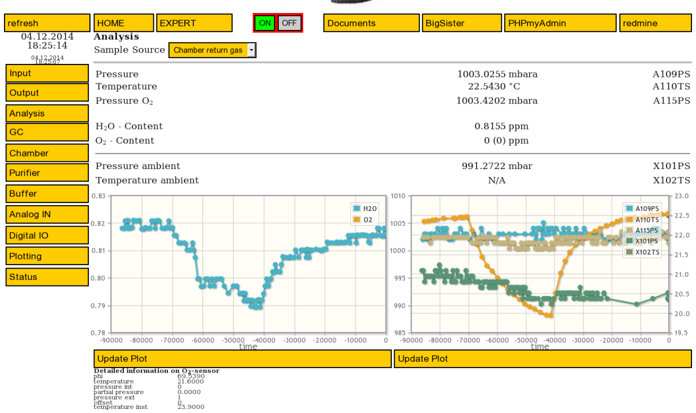
using a normal PC and some software

User Interaction

Control:

- remotely via web-browser
- locally via touch-screen
- same interface





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Mixing Mode

Direct Flow Mixing

Application

- quick mix tests
- no changeover time

Method

Divide requested flow by fractions

$$\dot{V}_i = \eta_i \dot{V}_{\text{total}}$$

Gas dependence

Calibration in MFC or ext. conversion factor

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- high precision mixtures
- long stable supply $\approx 12\,\mathrm{h}$ @ $5\,\ell_\text{n}/\text{h}$

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for ideal gas $V_i = p_i V_{\text{buffer}}$

further

$$p_i = \eta_i p_{\text{total}} \Rightarrow V_i = \eta_i V_{\text{total}}$$

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for real gas using Redlich-Kwong equation

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Mixtures specified at:

$T_0 = 273.15\,\mathrm{K}$ and $p_0 = 1013.25\,\mathrm{mbar}$ $\equiv$ STP conditions DIN 1343

$\dot{V}$ is also given in norm-liters per hour ℓ_n/h

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Universal Gas Mixing Apparatus

Feature summary

Universal & Mobile

- can be moved through a normal office door
- has rolls to be moved easily
- can mix up to three gases each from 0 - 100 vol.-%

Gas Mixing - to be shown

- mixing better than commercial gas suppliers (10 %)
- accuracy $\leq$ 0.1 vol.-%

Apparatus

- using state of the art parts
- industrial standards

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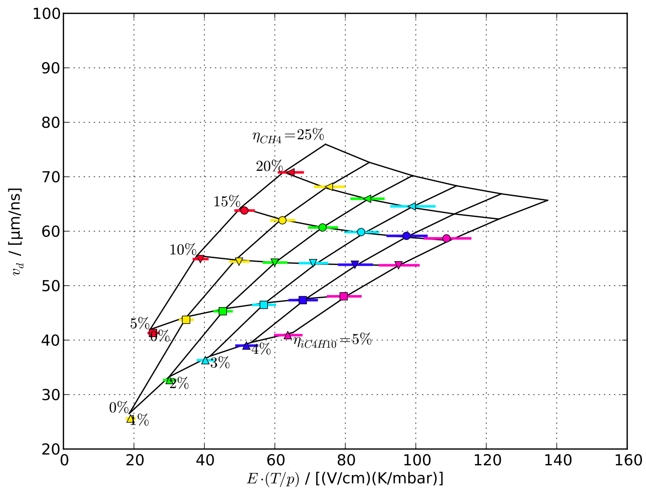
back to physics ...

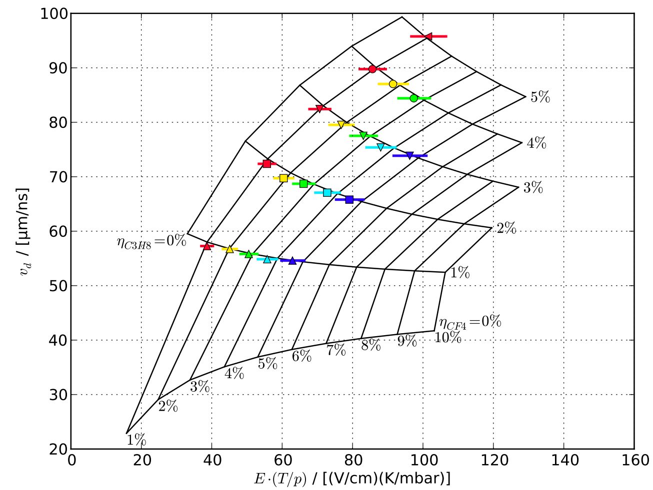
Gas Studies

focussing on electron drift velocity

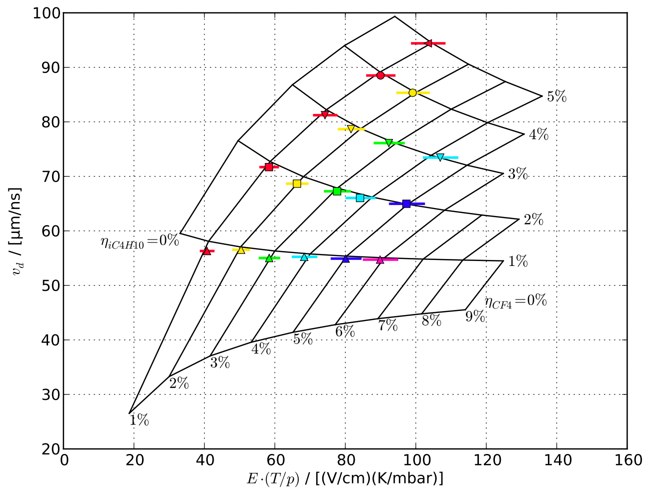
Usable with lots of different gases



Ar CH_4 iC_4H_{10}



Ar CF_4 C_3H_8



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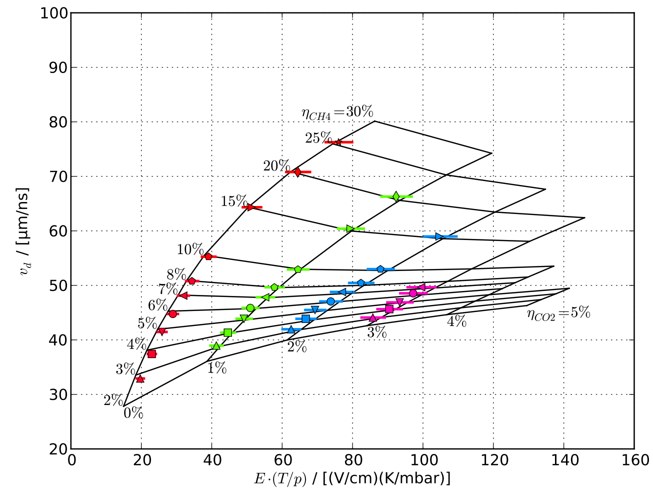
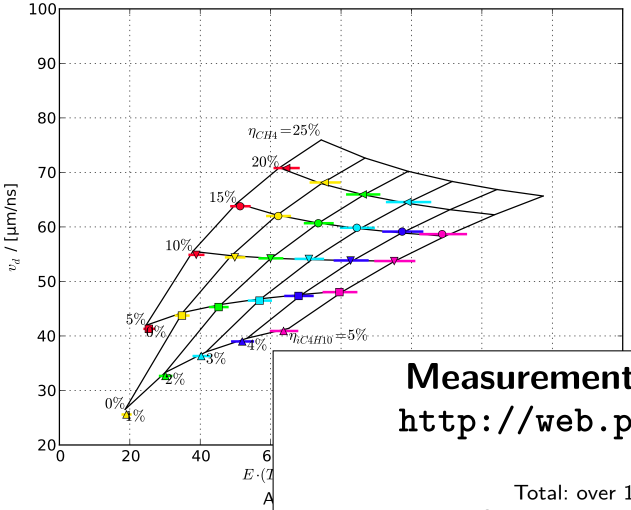
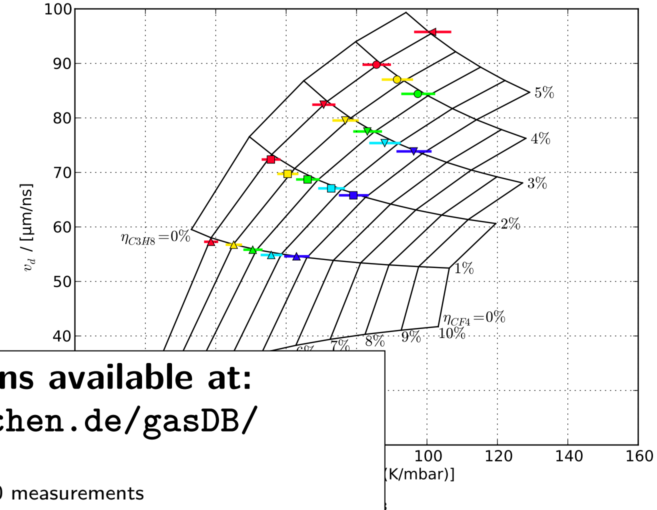


Ar CH_4 CO_2

Usable with lots of different gases

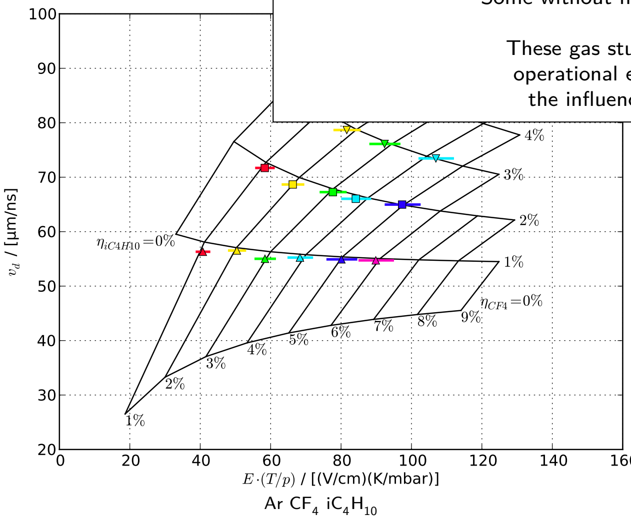


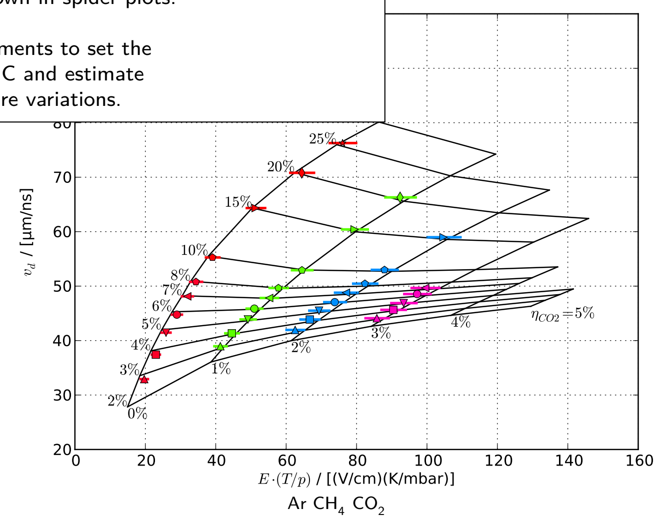


Measurements and Simulations available at:
`http://web.physik.rwth-aachen.de/gasDB/`

Total: over 11200 simulations & over 280 measurements
Some without maximum, so they are not shown in spider plots.

These gas studies may help further experiments to set the operational electrical field inside their TPC and estimate the influence of temperature and pressure variations.





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Determination of the Performance

Howto determine the performance?

Problem: No analysis device with sufficient precision (0.01 vol.-%) for all gas types is available!

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Problem: No analysis device with sufficient precision (0.01 vol.-%) for all gas types is available!
Solution: We have great working and well understood monitoring chambers!

In addition we have an approved and powerful drift velocity simulation tool.

Magboltz supplies data for over 30 pure gases.

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Use the comparison of measurement and simulation to determine the performance of the UGMA!

Fitting the mixture...

Needed: a sizeable amount of simulations

- Simulations done with Garfield++ which used FORTRAN Magboltz
- step-size for binary mixtures $\Delta\eta = 0.01\,$vol.-%
- simulations around $\pm\,0.5\,$vol.-% of set mixture

$\Rightarrow$ 100 Simulation curves per mixture each having 100 ET/p values

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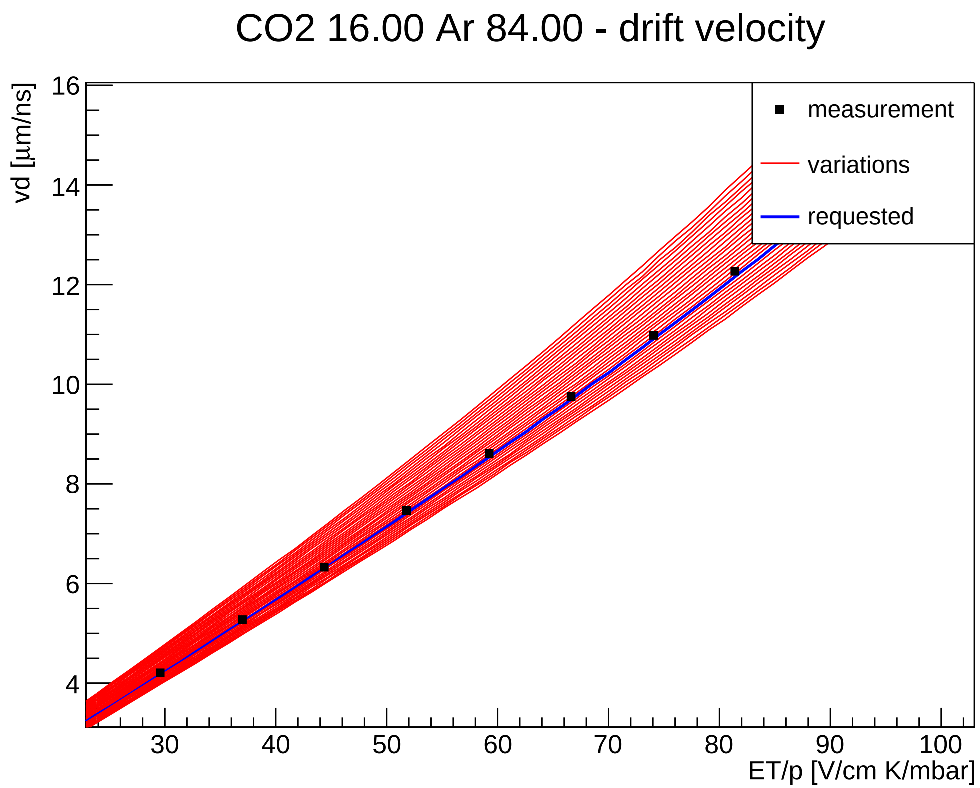

Fit the mixture via χ^2 minimisation:

$$\chi^2 = \sum_n \frac{\left(v_{d,\text{meas}}(E_n) - v_{d,\text{sim}}(E_n)\right)^2}{\sigma^2_{v_d,\text{meas}}(E_n) + \left(v_d'(E_n)\,\sigma_{ET/p,\text{meas}}(E_n)\right)^2}$$

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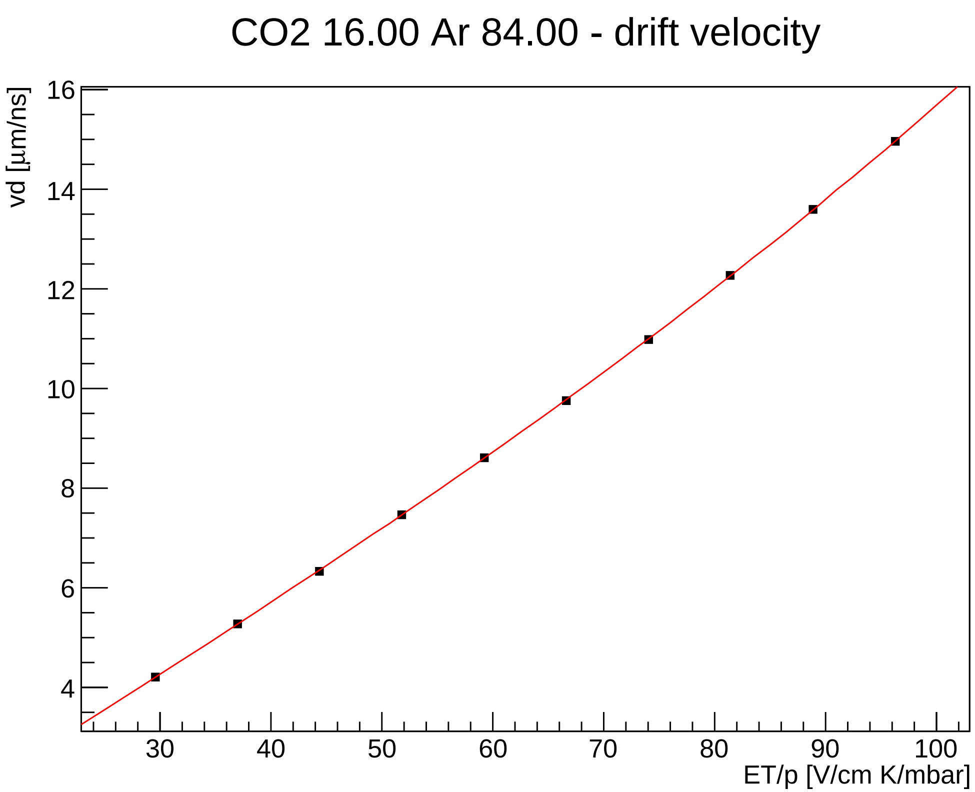

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http://www.daveburchett.com/

First having a look at the UGMA

Calculated mixture

UGMA calculates the mixture from the measured values.

Direct Flow Mixing:

- measured flow of all lines

Partial Pressure Mixing:

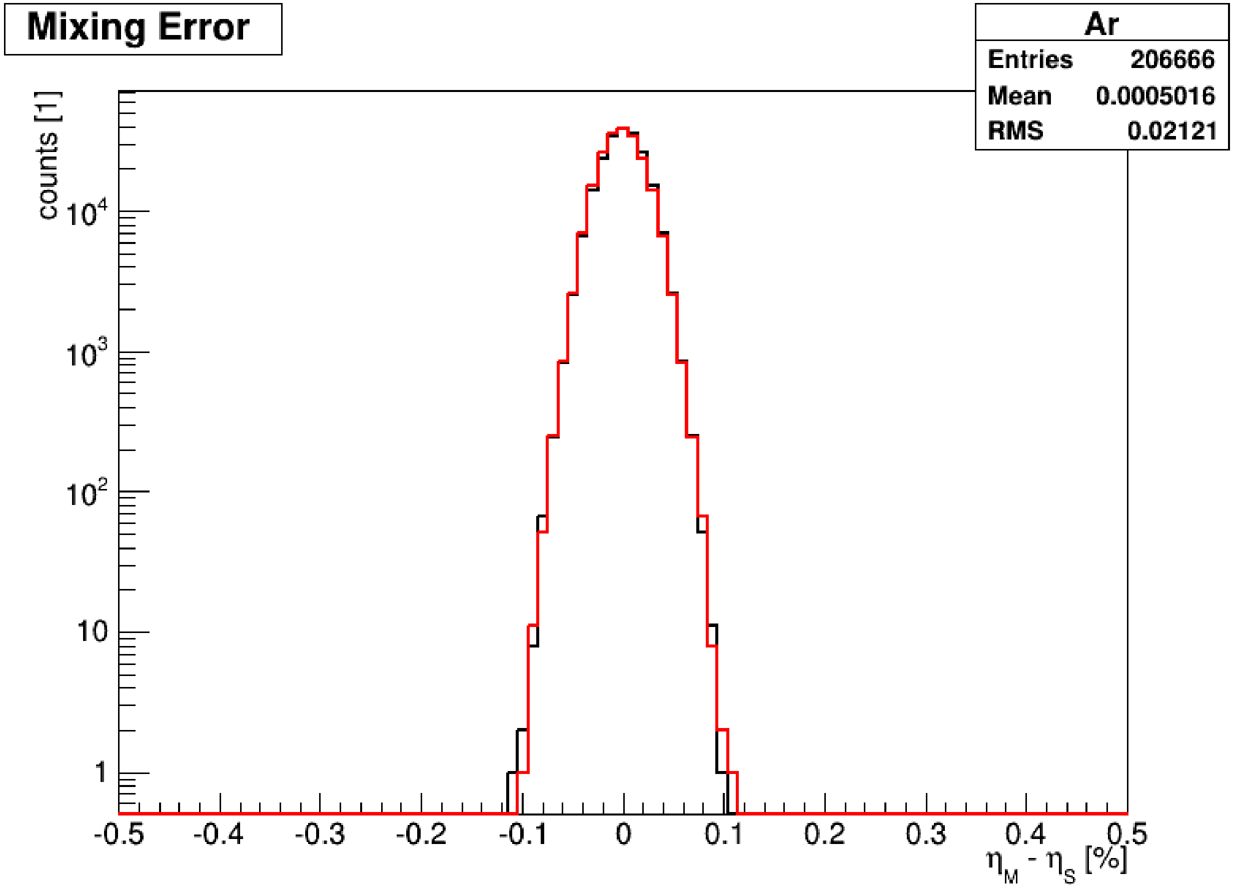
- measured pressure of the filled gases

and

Fitted mixture

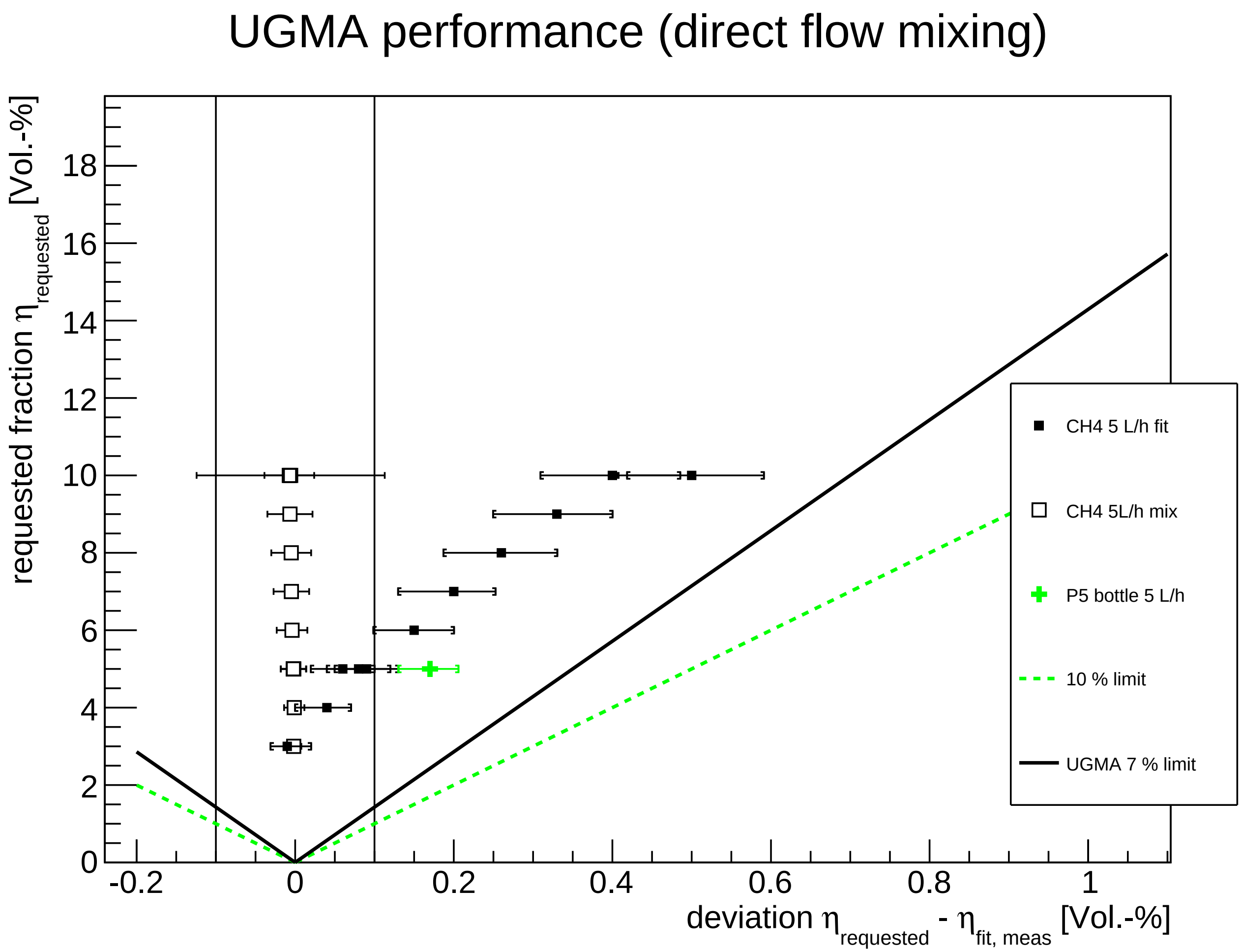
Fitted mixture from comparison with simulation.

Direct Flow mixing



$Ar:CH_4$ 90:10 @ 10 $\ell_n/h \Rightarrow$ RMS of all lines < 0.03 vol.-%

Performance for Ar CO_2 and Ar CH_4



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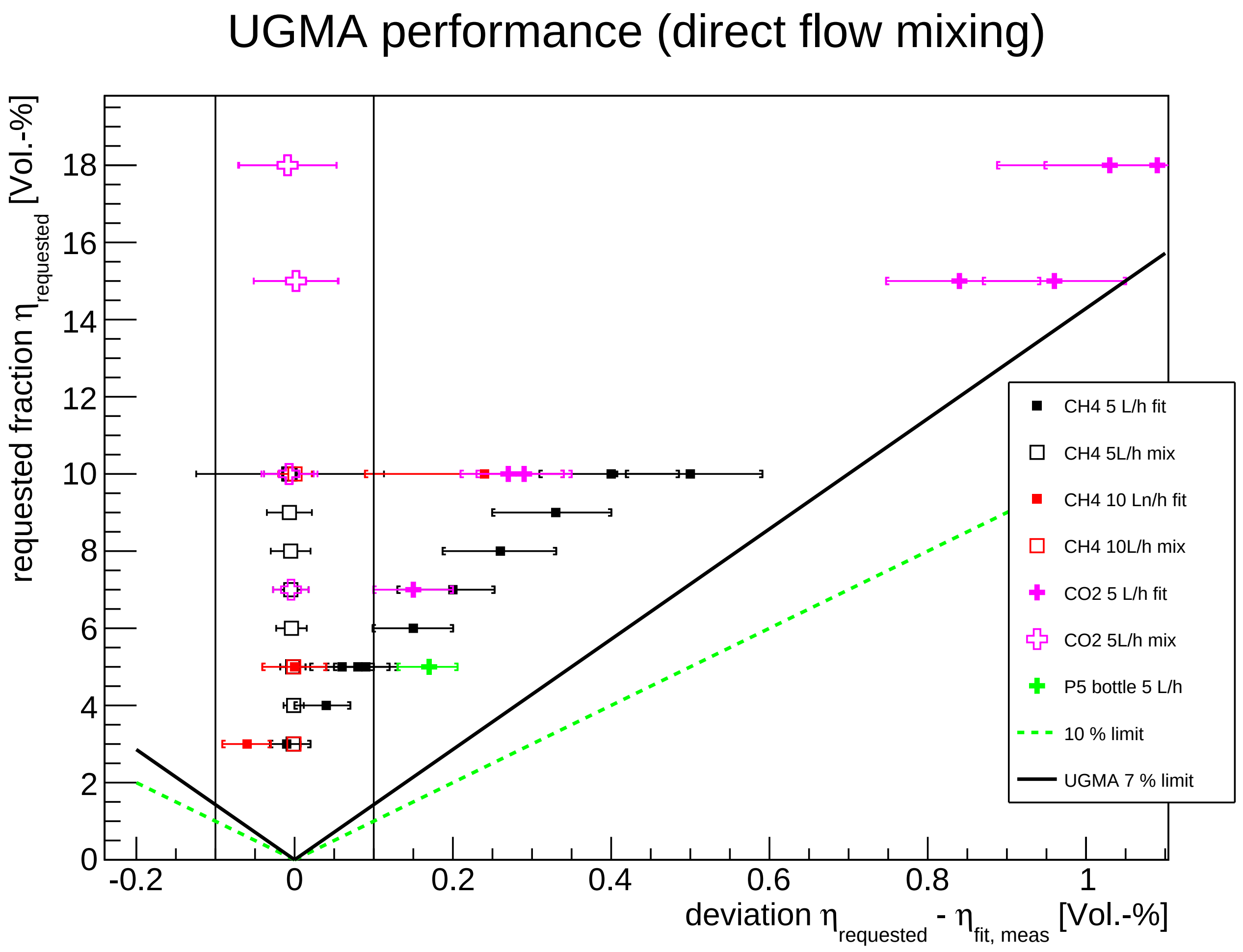

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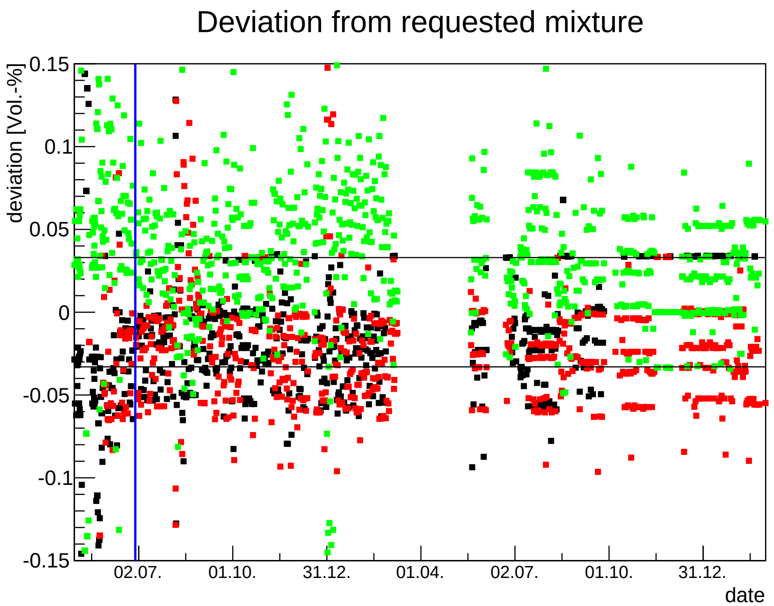
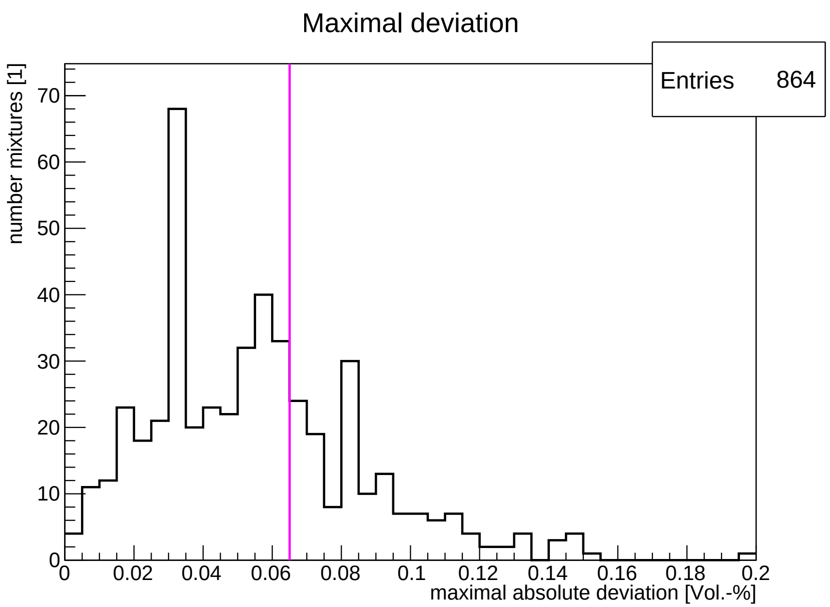
Partial pressure mixing



green - Argon, red and black - admixtures
black lines limit given by pressure sensors

$$\Delta\eta_{\text{limit}} = \frac{\Delta p}{p_{\text{max}}} = \frac{1\,\text{mbara}}{3000\,\text{mbara}} = 0.033\,\text{vol.-\%}$$



magenta 68 % limit

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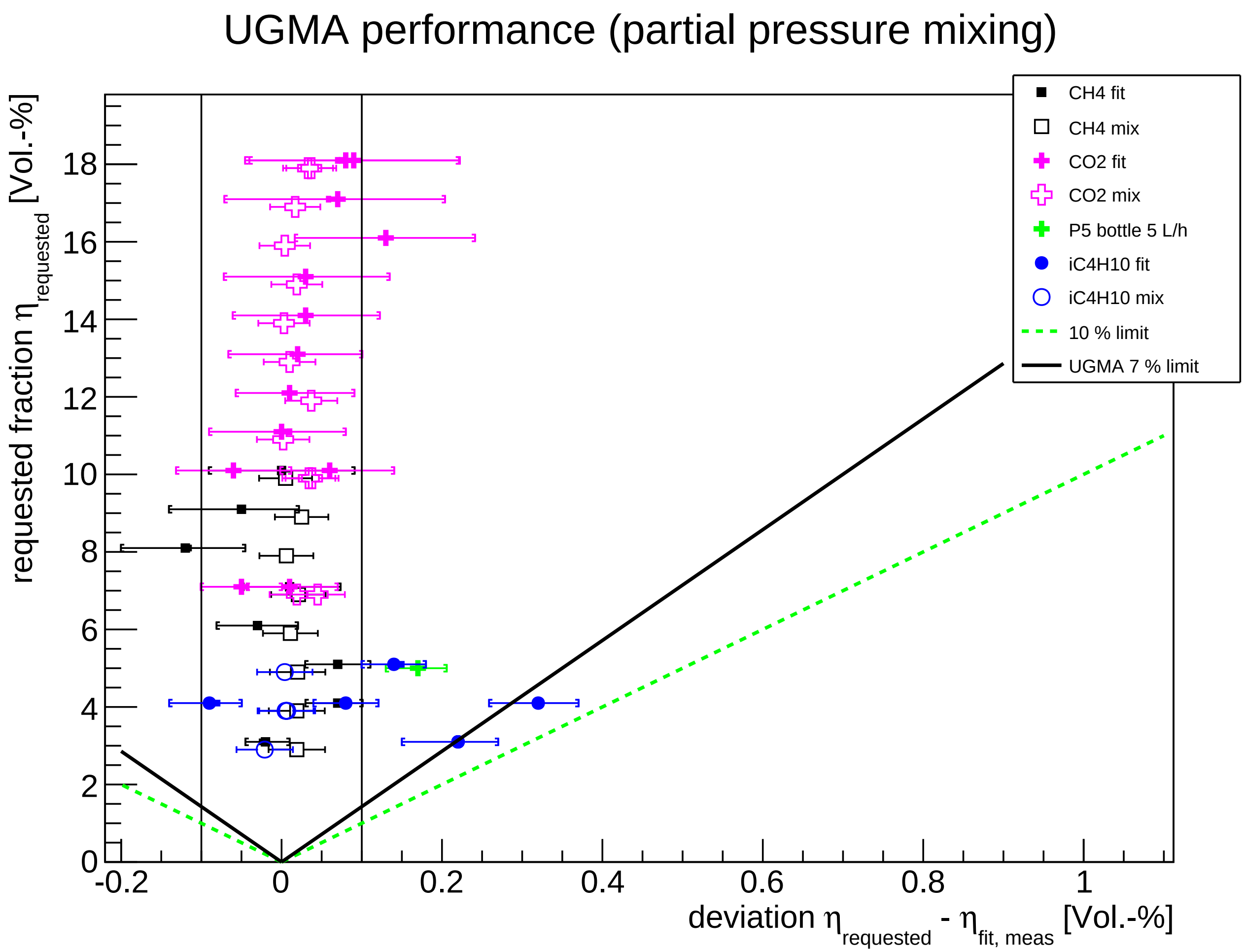
Performance for CO_2, CH_4 and iC_4H_{10}



iC_4H_{10} is rated within Magboltz with only 3 of 5 stars

Summary

Flexible Gas Mixing

Using Fitting the Mixture results (Tested within 3 - 18 vol.-%)

- Parallel Flow mixing

$$\frac{\Delta\eta}{\eta} < 7\,\%$$

- Partial Pressure mixing

$$\Delta\eta < 0.1\,\text{vol.-\%}$$

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Mobile & Clean

- Mobile Gas System, can be moved easily
- Water and Oxygen Contaminations well under control ($\leq 1\,\mathrm{ppm}$)

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User Friendly

- can be operated remotely via Web browser and locally via Touchscreen
- except of changing gas bottles it can run without user-interaction

Summary

System is safe

matches limitations from law & provisions:

- VDE, DIN, EU
- TA-Luft, ExSchV, BetrSichV, etc.

System is ready ...

- to do further gas studies
- to supply gas to new detectors and prototypes

Hopefully the system will be used and run over several years.
Further improvement of the system is not excluded ...

You can always make things better!

Jochen Steinmann
Physics Institut 3B
RWTH Aachen University
jsteinmann@physik.rwth-aachen.de