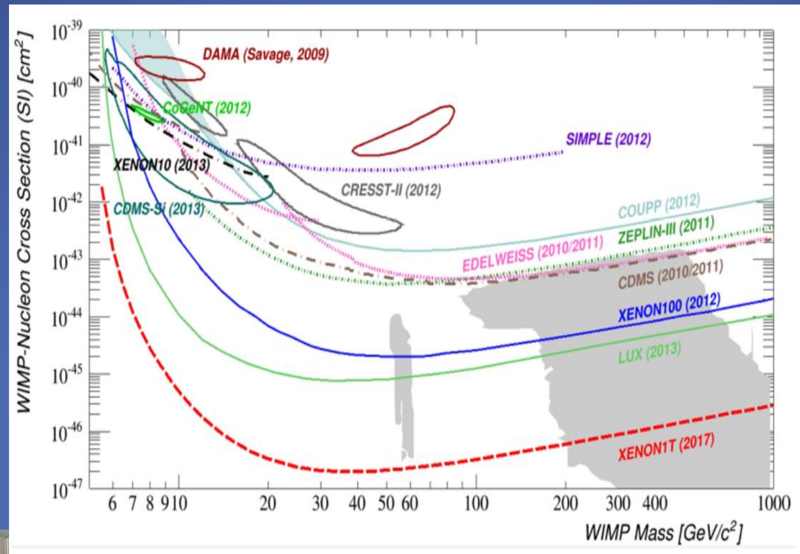
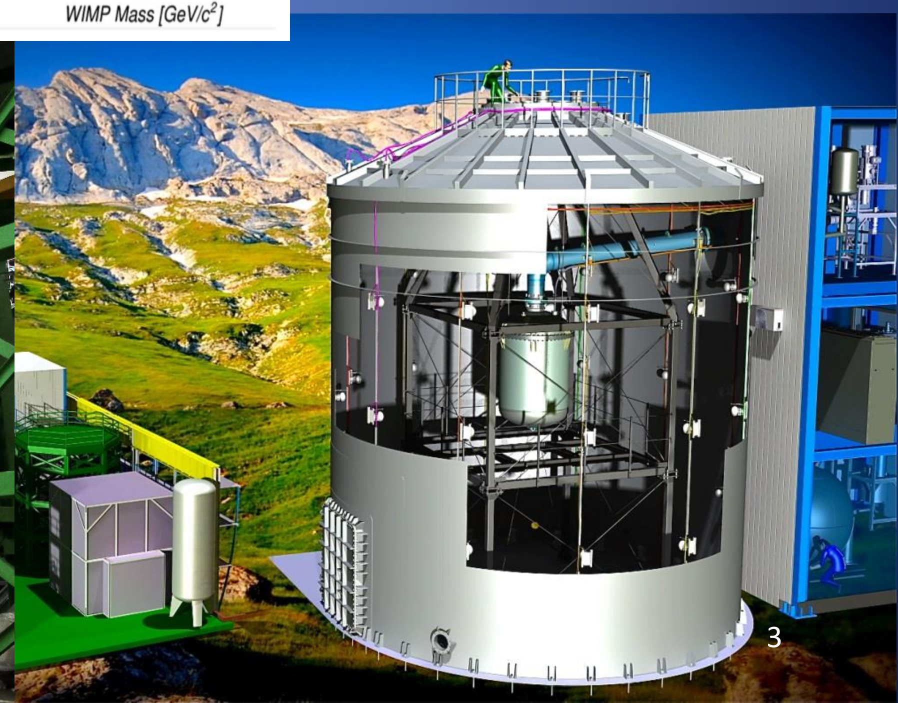
Strong and Weak Interactions - from Hadrons to **Dark Matter**

DFG Research Training Group 2149 Retreat – 24.11.15

Alexander Fieguth (AG Weinheimer)

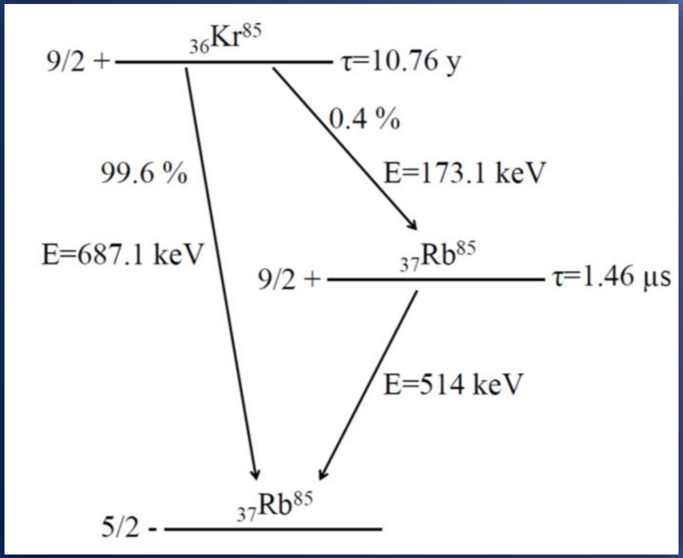
XENON Dark Matter Project





Krypton is a radioactive background

- Trace amounts of ^{85}Kr are abundant in the atmosphere due to nuclear bomb tests and nuclear reprocessing
- Decays via β-decay with an endpoint enegy of 687 keV



Xenon extraction from atmosphere leads to natural krypton contamination!

$$\frac{^{85}Kr}{^{nat}Kr} \sim 10^{-11}$$

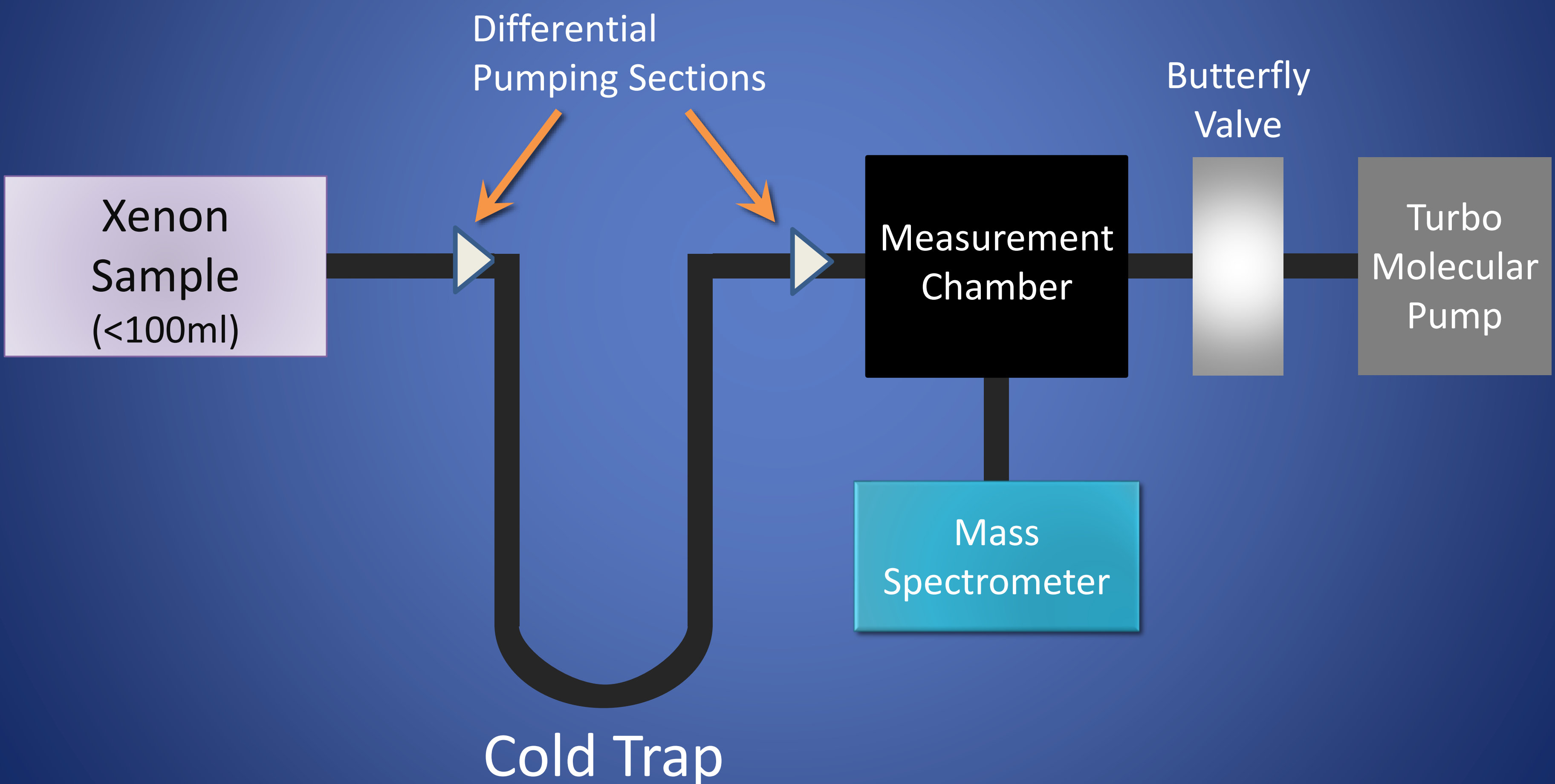
Removal & Detection

- Removal of krypton via cryogenic distillation
- Necessary purity below the **ppt-level** of natural krypton
- Distillation column build in Muenster & delivered at the experiment site

- Knowledge of krypton background important for background modeling
- Information on the column performance requires online diagnostics
- Measuring at and below the ppt-level is not trivial

ppt = 10^{-12} particles Kr in Xe

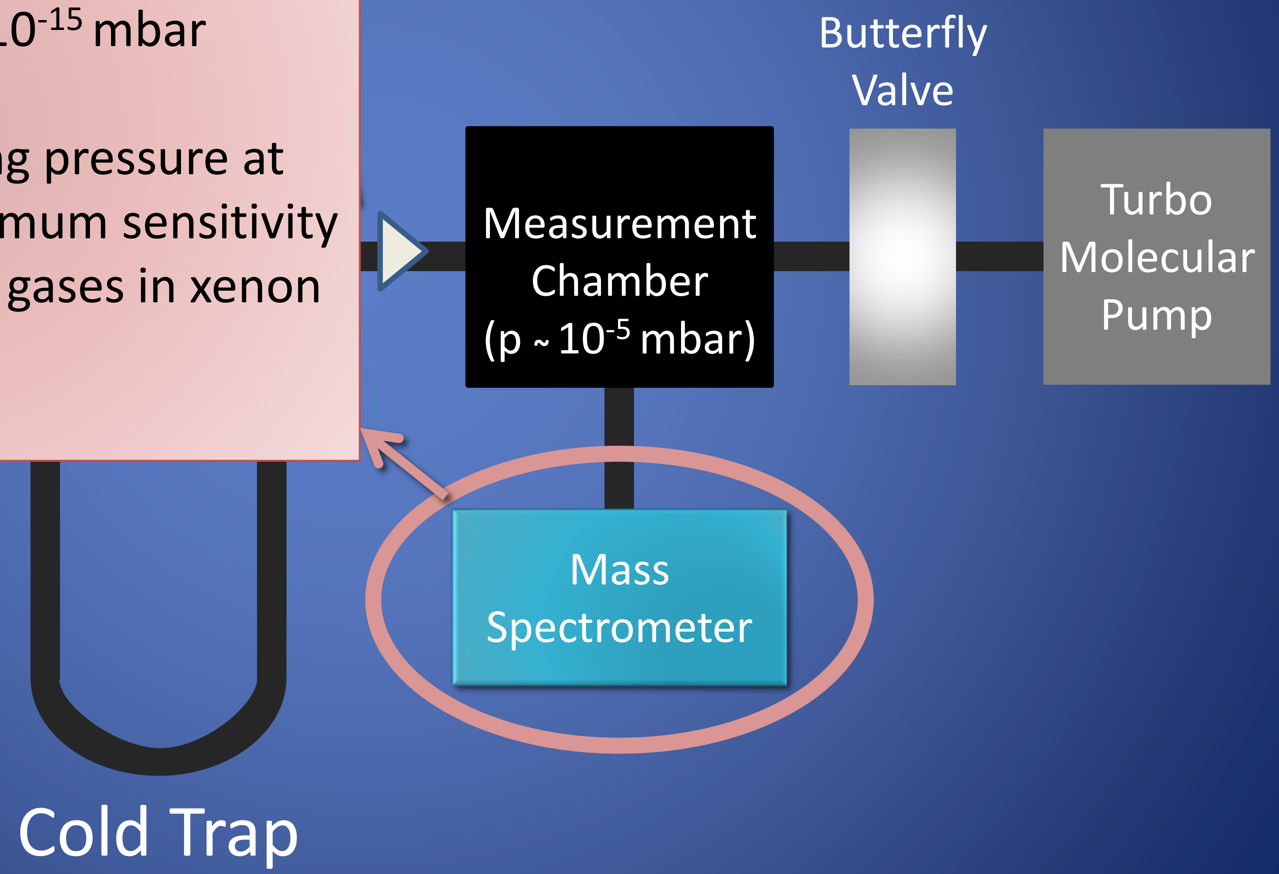
Measurement setup



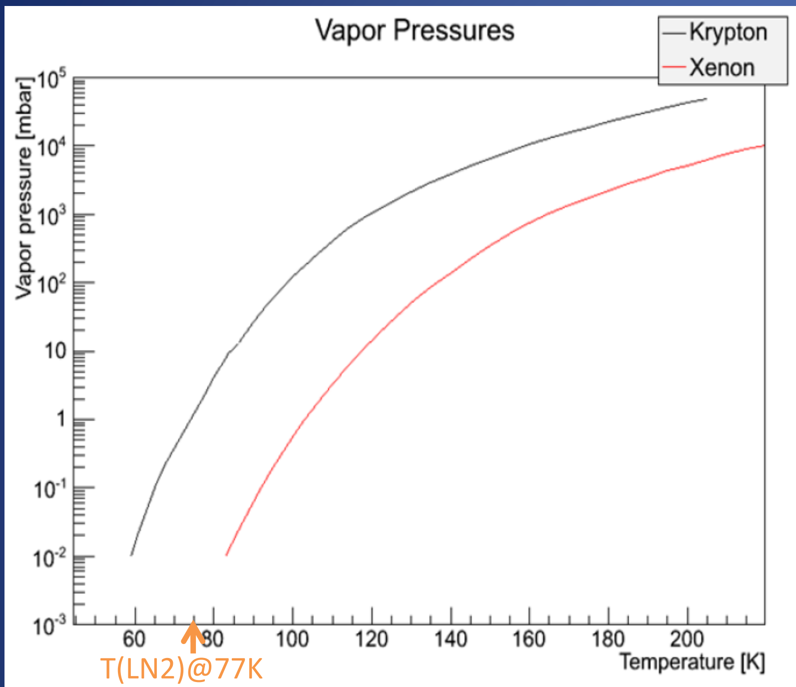
A.Dobi et al. Nucl.Instrum.Meth. A665 (2011) 1-6 & **E.Brown et al., JINST** 8 (2013) P02011

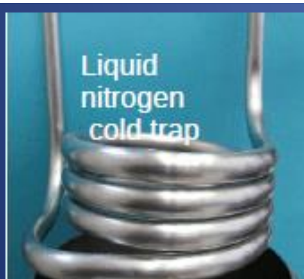
Mass spectrometer

- Using a commercial residual gas analyzer with a partial pressure sensitivity down to ~10^{-15} mbar
- Limitation of operating pressure at 10^{-5} mbar sets a maximum sensitivity when detecting trace gases in xenon at ppb level

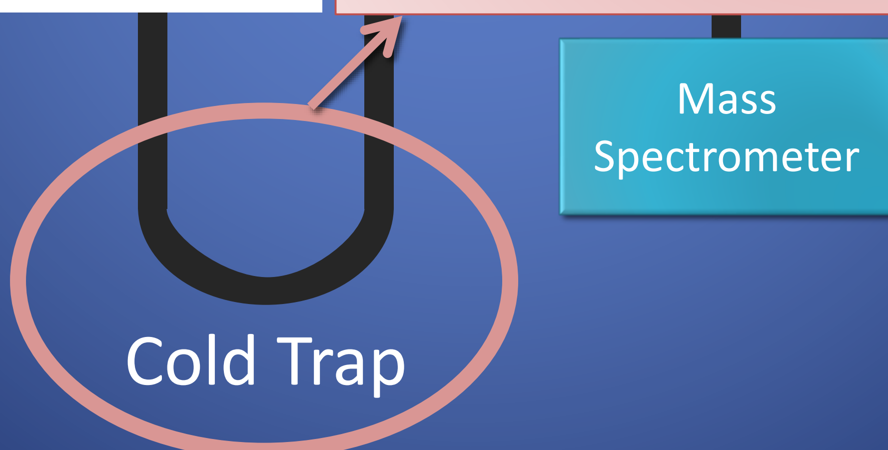


Cold trap



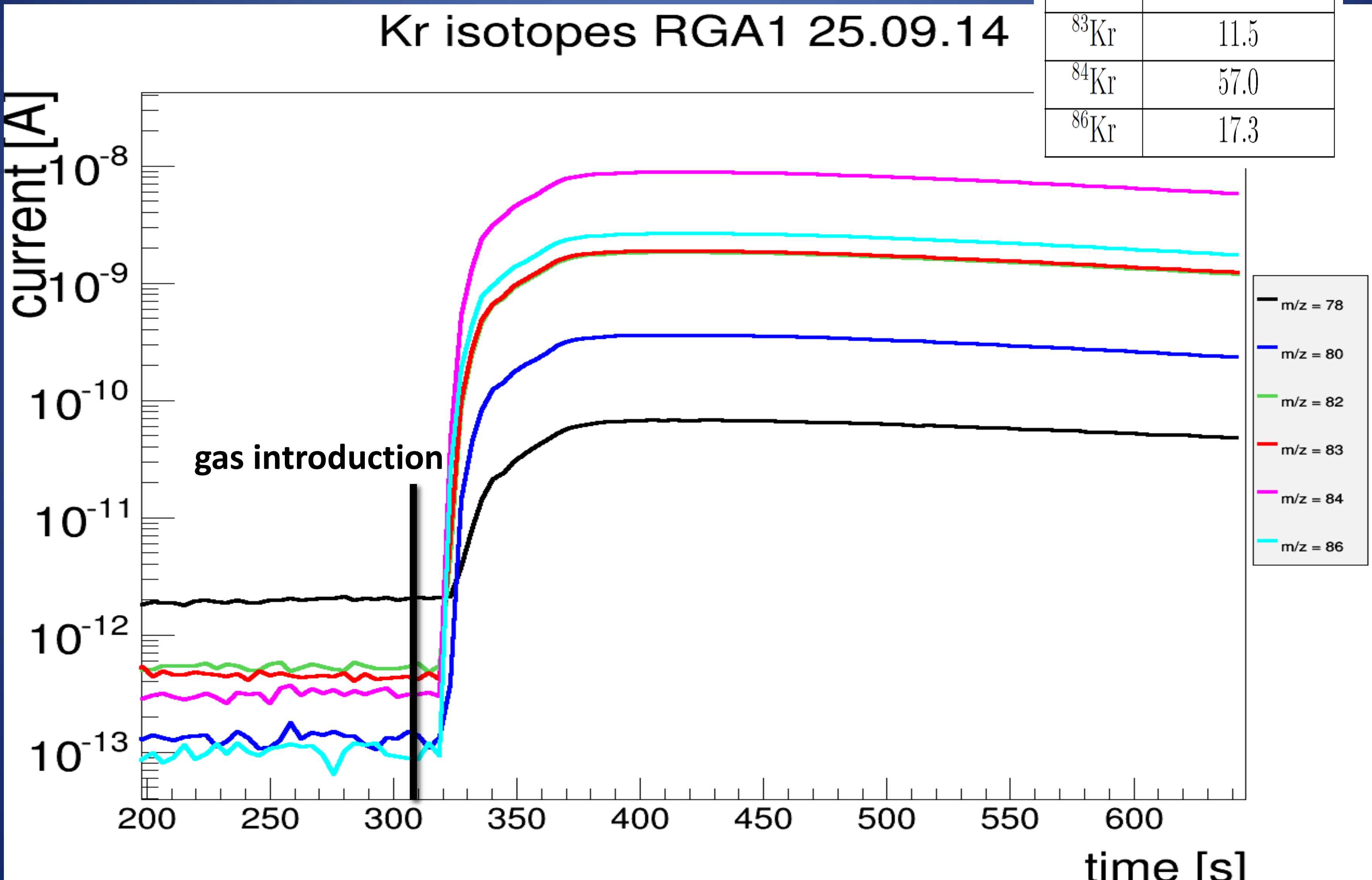


- Cool the stainless steel coil in a liquid nitrogen dewar down to 77K
- Xenon should freeze to the walls until the pressure reaches the vapor pressure of about 3×10^{-3} mbar at 77K
- Due to its low concentration krypton should pass unaffected and therefor the krypton concentration is enhanced

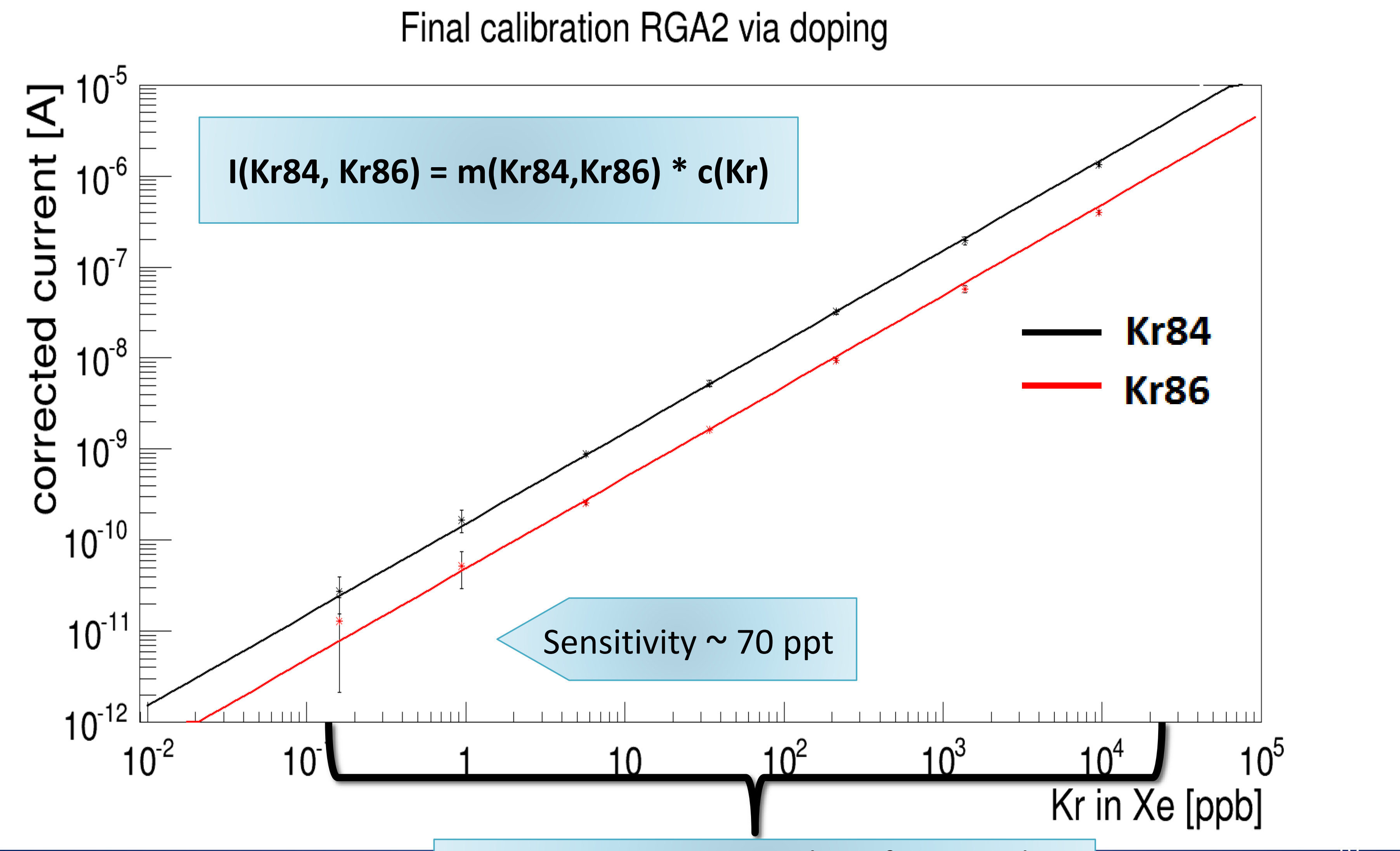


Example signal

Isotope	Abundance in %
^{78}Kr	0.35
^{80}Kr	2.25
^{82}Kr	11.6
^{83}Kr	11.5
^{84}Kr	57.0
^{86}Kr	17.3



Calibration



Dynamic range over 6 orders of magnitudes

Applications

- Fast screening of gas bottles designated for the XENON1T experiment down to sub-ppb on-site (installed in 2015)
- Characterization and controlling of the distillation column online at processing

Measured a separation factor > <u>125 000</u> with artificially doped gas

Scope for PhD - Thesis

Improve the measurement setup in sensitivity

Measure single photon response in VUV-regime

Analysis with XENON100 / XENON1T data

One interesting possibility - double electron capture on ^{124}Xe

$$^{124}\mathrm{Xe} + 2e^- \rightarrow {}^{124}\mathrm{Te} + 2\nu_e$$

- Decay unobserved so far (lower limit on half-life at > 4.7 x 10^{21} a)
- Possible new limit using XENON100 data
- Possible **detection** using XENON1t data
- Due to the high Q-Value of around 2864 ke,V addiontial unobserved decay processes possible (e.g $2\nu\beta^+\beta^+$) , however with higher predicted half-lives

$$^{124}\mathrm{Xe} + 2e^- \rightarrow {}^{124}\mathrm{Te}^*$$

- Neutrinoless double electron capture -> Physics beyond the Standard Model!
- No experimental limit so far (to my knowledge) (Tretyak et al.)
- Predicted half-lives vary by 9 orders of magnitude
- Neutrino mass limit derivable

Thank you for your attention

XENON1T / XENONnT requirements

- Commercial xenon has a krypton content at the ppm to ppb level
- Removal of krypton is done by cryogenic distillation (see talk of M. Murra)
- Desired concentration is in the sub-ppt range
- Knowledge of the content is necessary for background event expectation due to krypton
- Measurement of the krypton concentration in this regime is not trivial

Beyond the limit?!

- Increasing the amount of krypton relative to xenon in a reproducible way (change input flow -> increase DPS conductance)

- Decrease of the background or an better understanding of the background behavior

- Investigating the influence of other impurities on the sensitivity limit

Background ^{85}Kr

- Beta decay of ^{85}Kr into ^{85}Rb is a significant intrinsic background for XENON1T
- Determination of the ^{85}Kr concentration in xenon is of crucial importance for knowledge of the signal background
- Ratio of ^{85}Kr to natural krypton is at 10^{-11}, while natural krypton is aimed to be below <0.5 ppt in the used xenon

Background ^{85}Kr

- Beta decay of ^{85}Kr into ^{85}Rb is a significant

<u>Measuring the Krypton concentration at the sub-ppb level is not trivial!</u>

Possible offline methods used for Krypton detection are e.g. LLC, ATTA, GC-RGMS

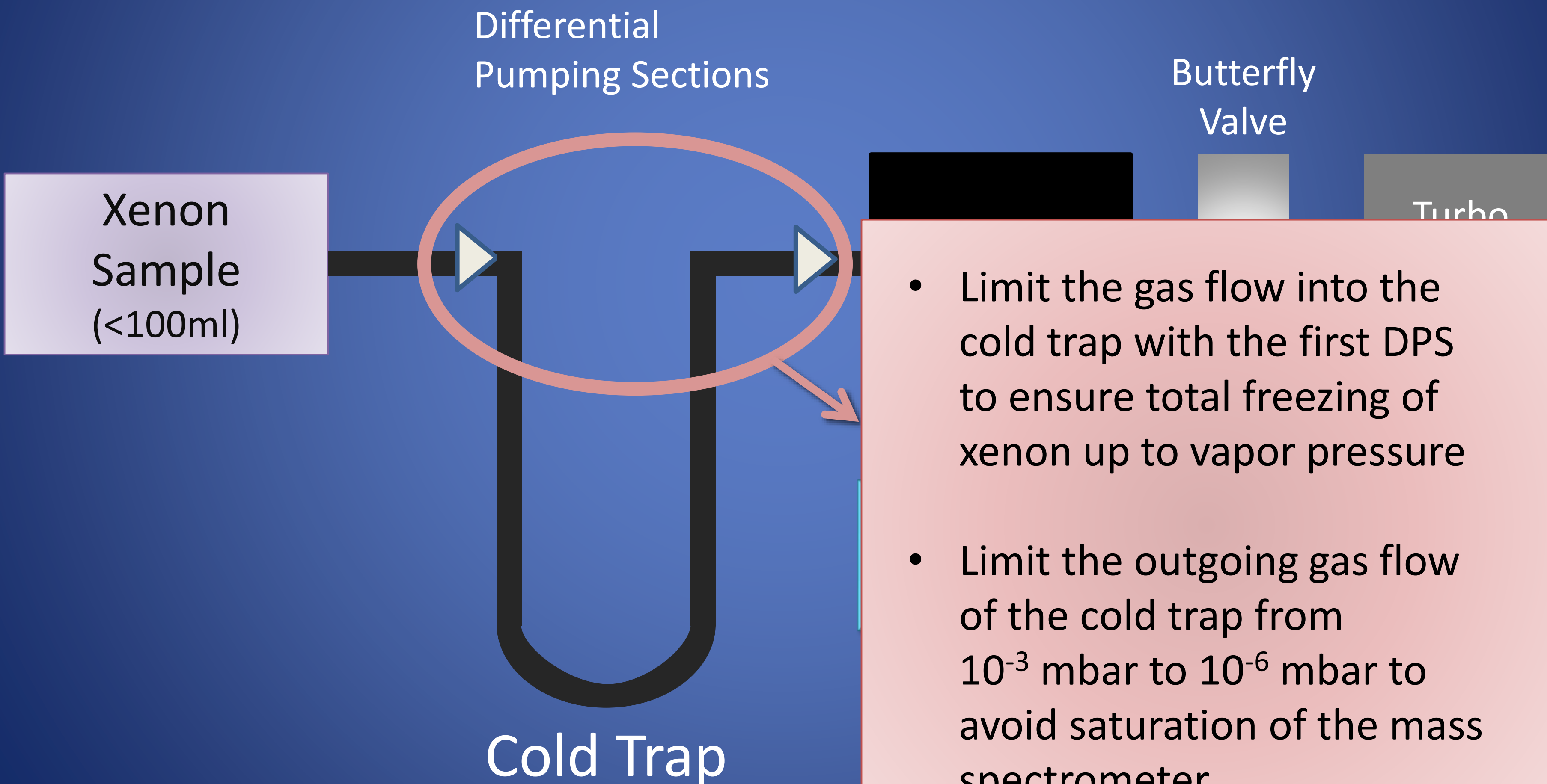
while natural Krypton is aimed to be below <0.5 ppt in the used xenon

Measuring krypton at the sub-ppt level?

- For measurements on the sub-ppt level other methods are available (ATTA, GC-RGMS, Low-level counting (LLC))
- These methods are offline-methods, as they post-analyze a taken sample off-site

→ Purpose of this system is fast characterization and online analysis

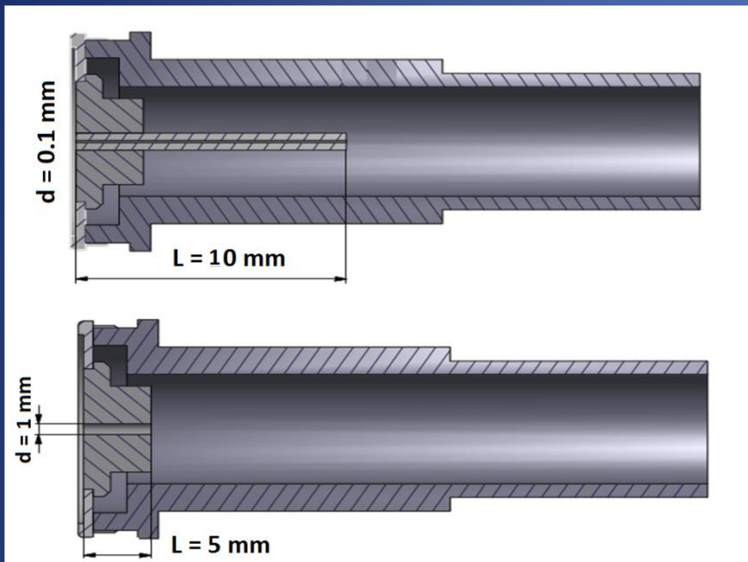
Differential pumping sections (DPS)

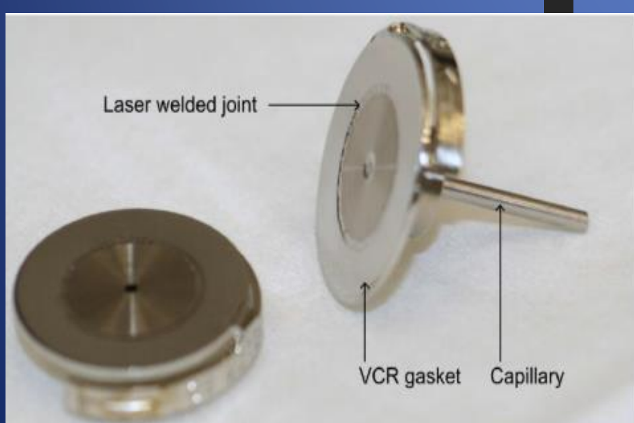


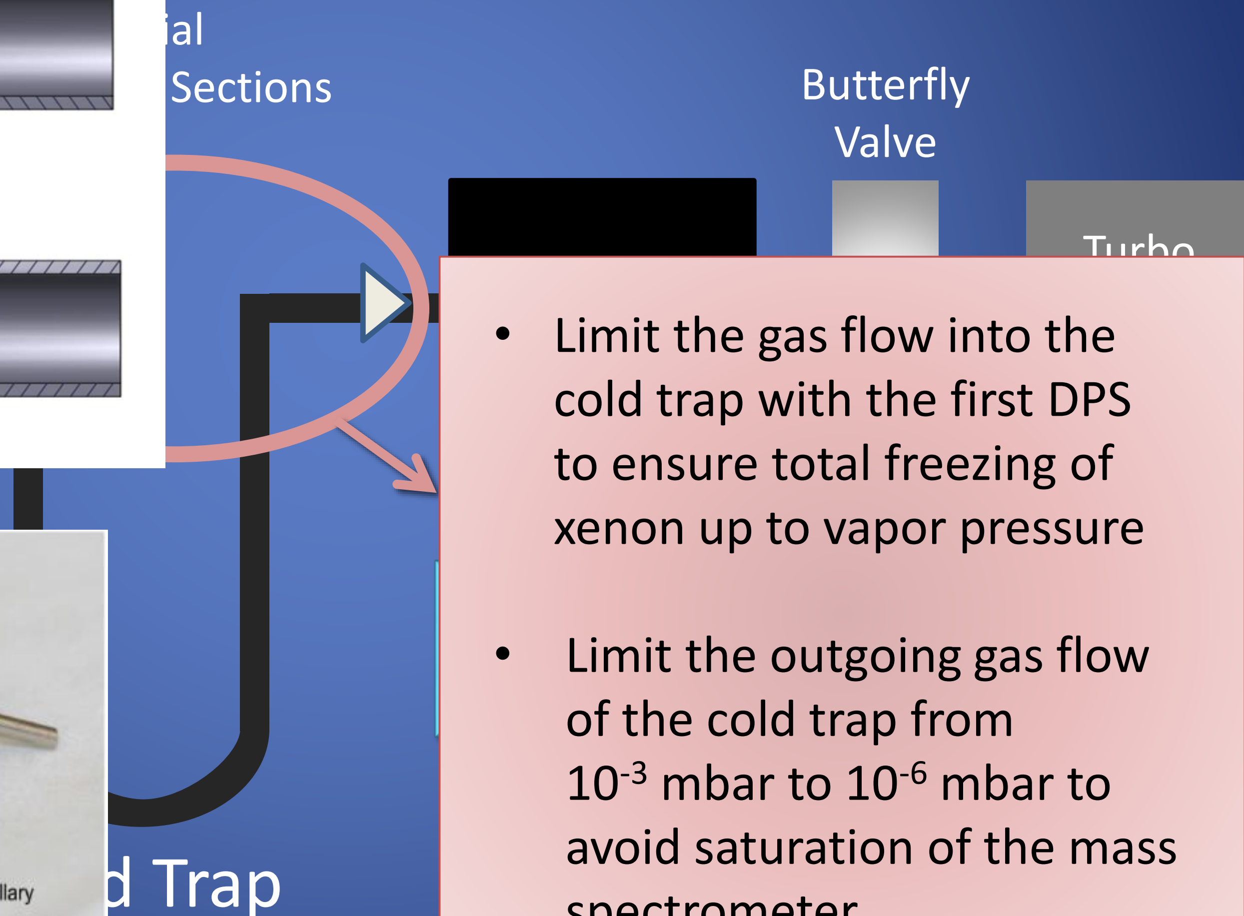
- Limit the gas flow into the cold trap with the first DPS to ensure total freezing of xenon up to vapor pressure

- Limit the outgoing gas flow of the cold trap from 10^{-3} mbar to 10^{-6} mbar to avoid saturation of the mass spectrometer

Differential pumping sections (DPS)



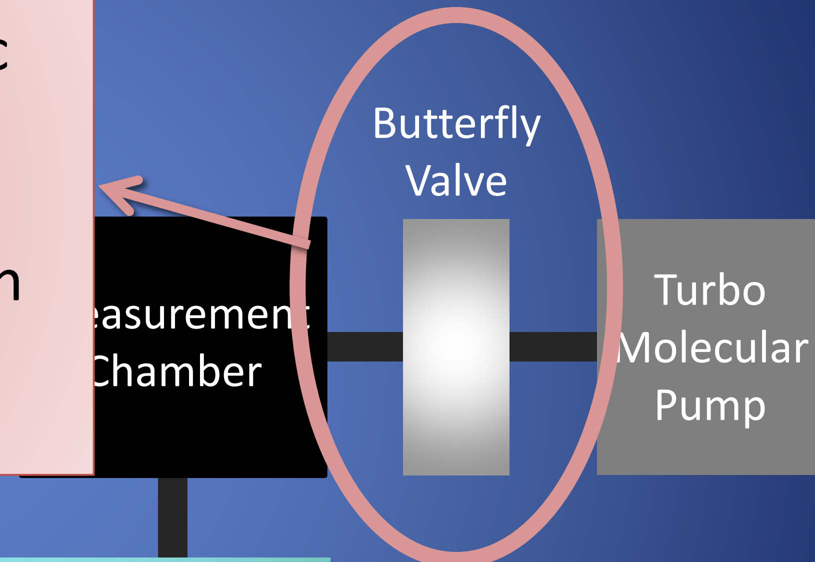


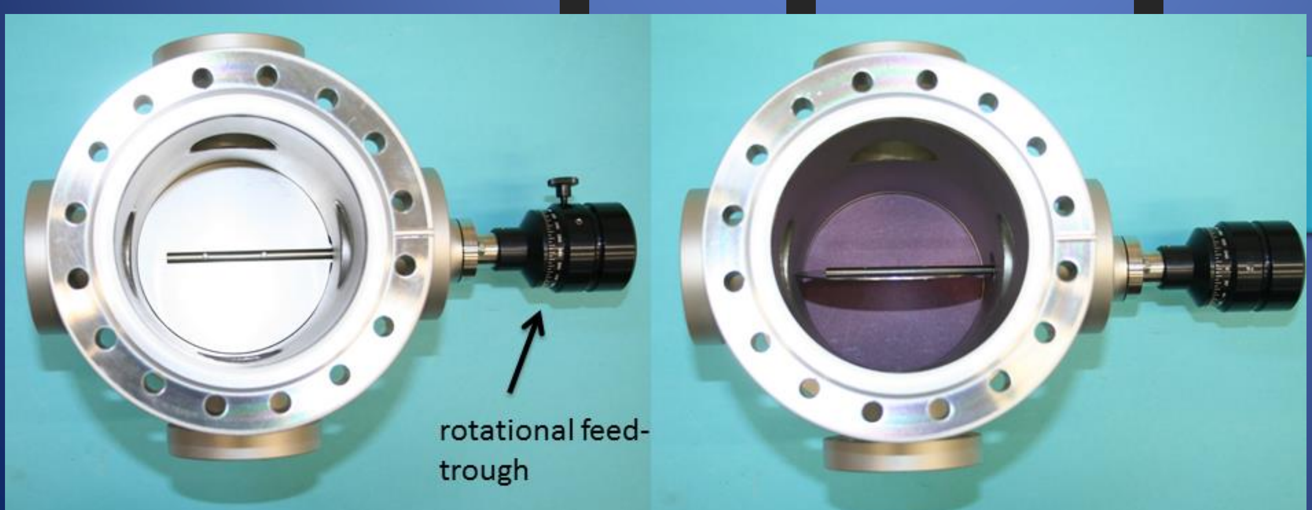


- Limit the gas flow into the cold trap with the first DPS to ensure total freezing of xenon up to vapor pressure
- Limit the outgoing gas flow of the cold trap from 10^{-3} mbar to 10^{-6} mbar to avoid saturation of the mass spectrometer

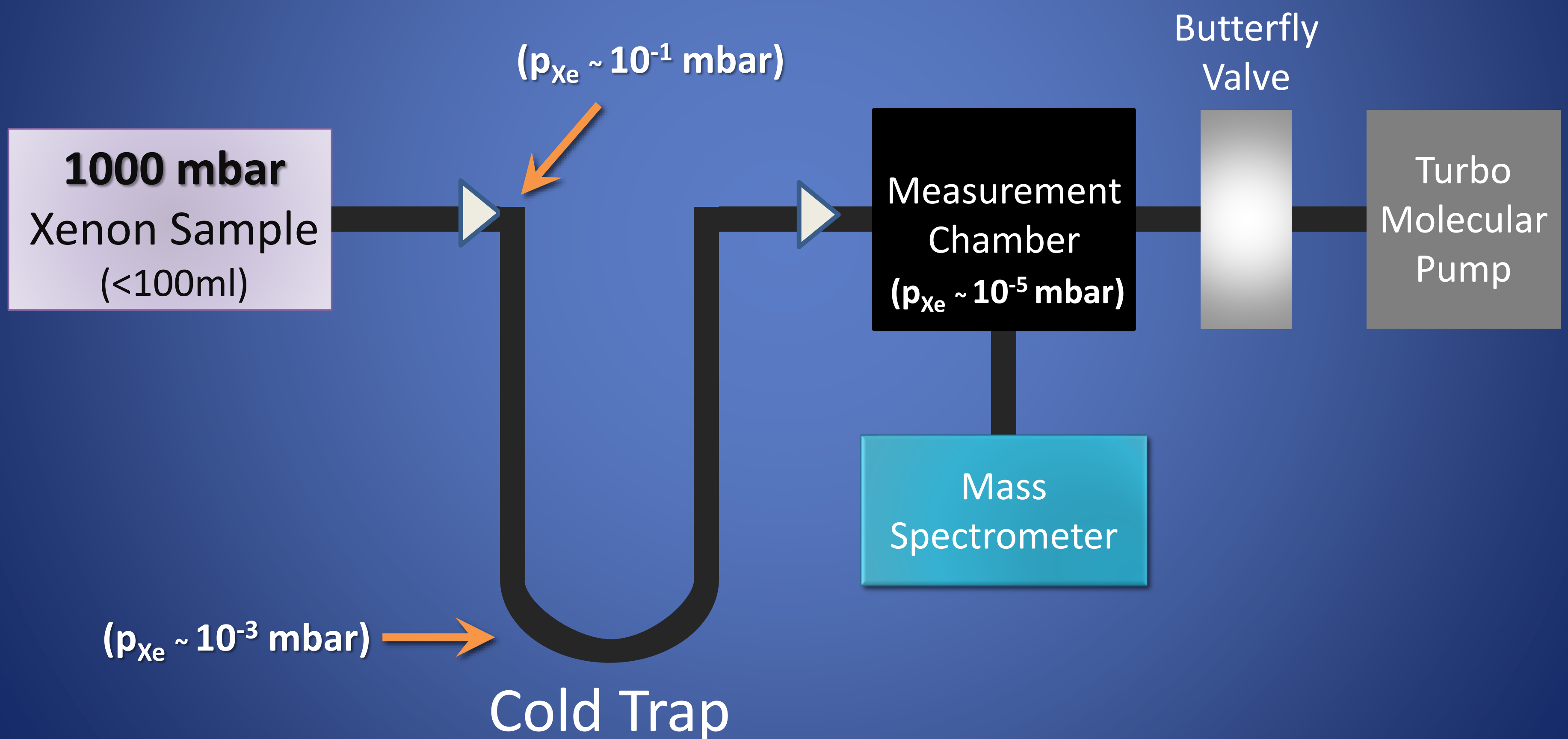
Custom made butterfly valve

- Using a custom made butterfly valve allows to have a dynamic range of effective pumping speed (from 300 l/s down to 6l/s) and therefore a regulation of gas load going to the mass spectrometer



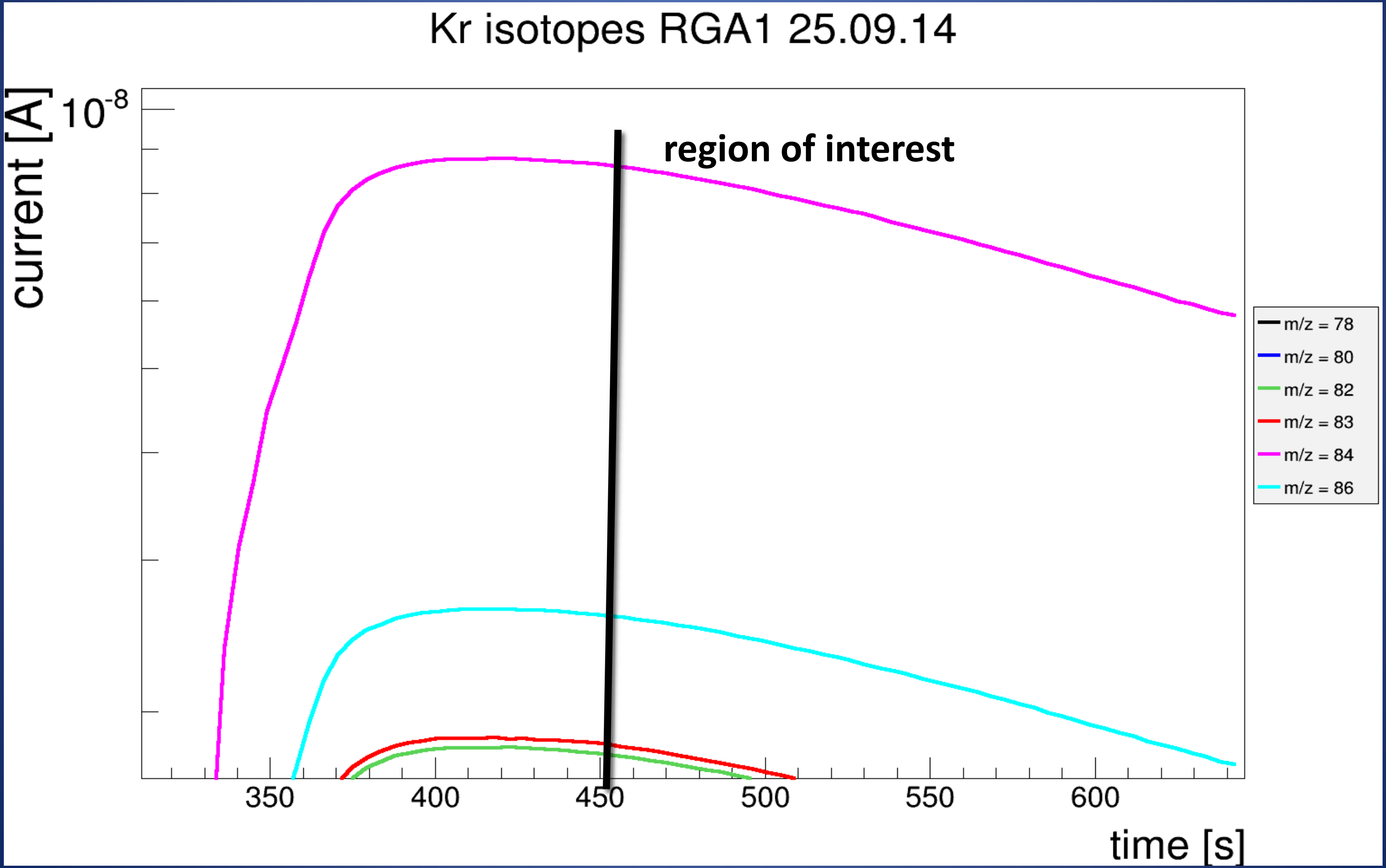


Measurement setup



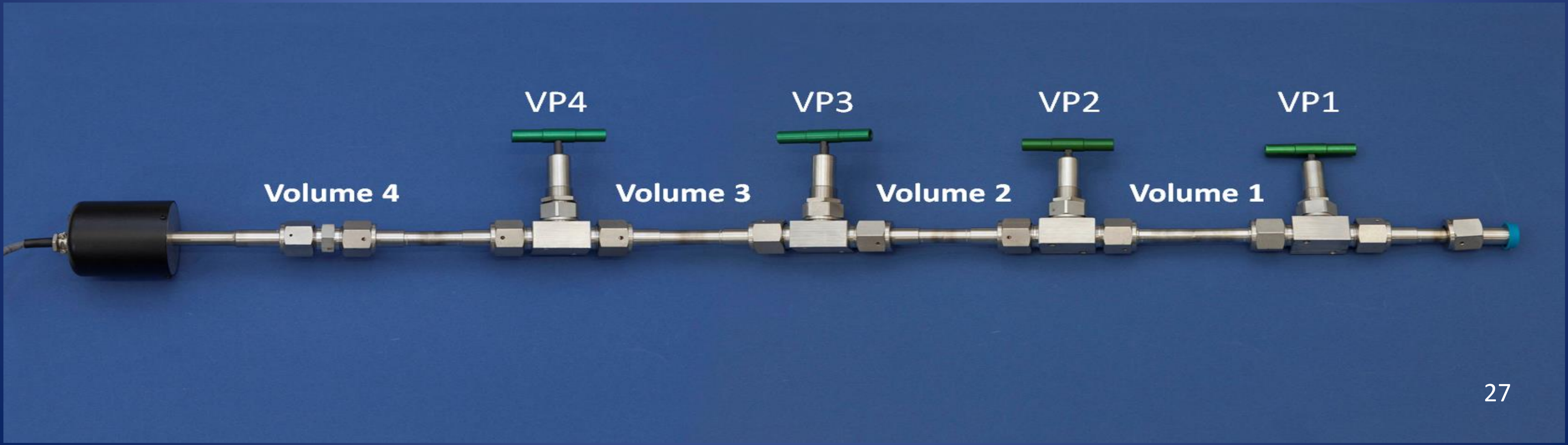
A.Dobi et al. Nucl.Instrum.Meth. A665 (2011) 1-6 & **E.Brown et al., JINST** 8 (2013) P02011

Example signal (~ 6ppm)

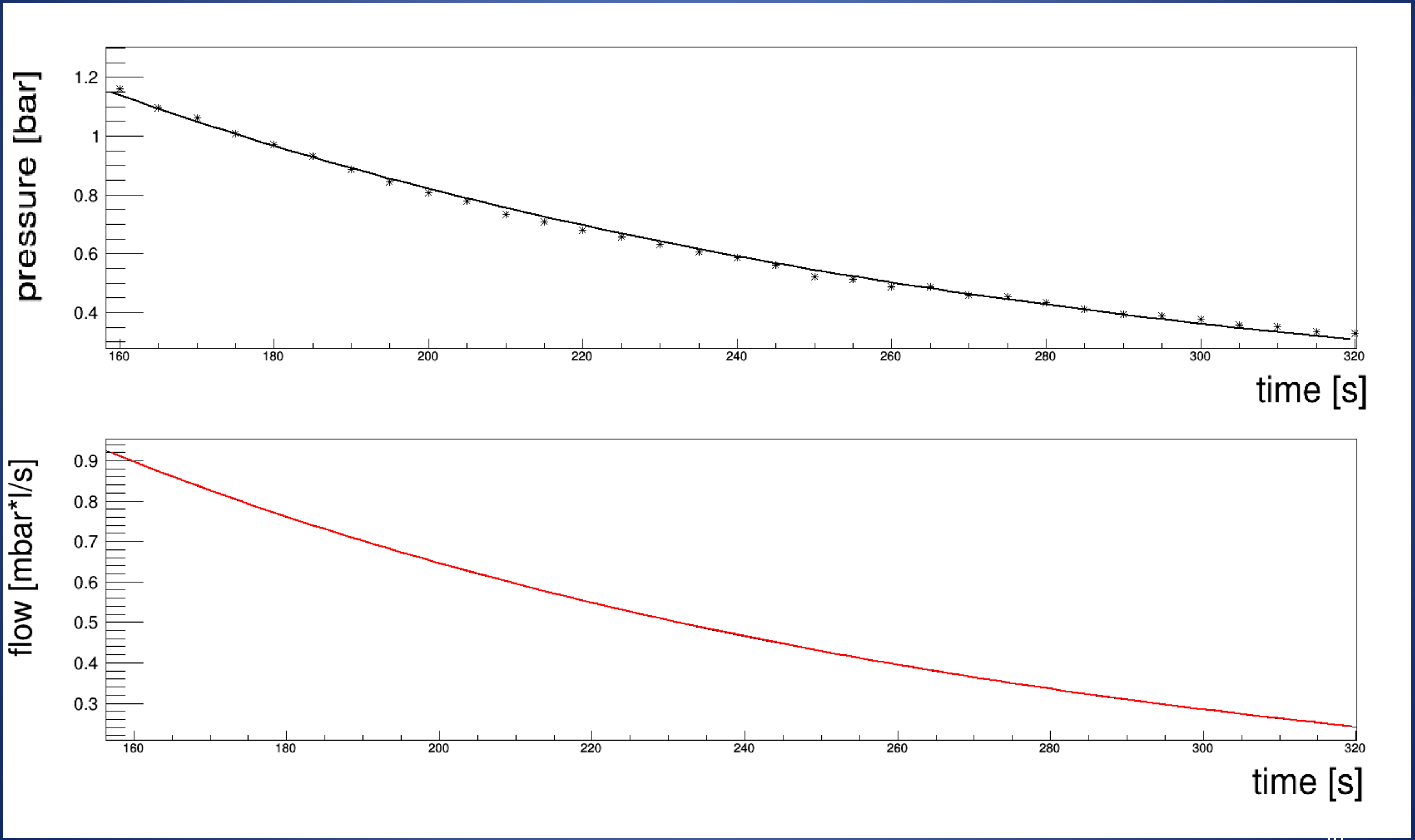


Calibration

- Artificially enhance the krypton concentration in xenon gas samples
- Using volume expansion for mixtures with known concentrations (“doping”)
- Advantage of a running distillation column allows for gas mixtures down to ppt



Flow correction



Isotopic fraction (~ 6ppm)

Isotope	Abundance in %
^{78}Kr	0.35
^{80}Kr	2.25
^{82}Kr	11.6
^{83}Kr	11.5
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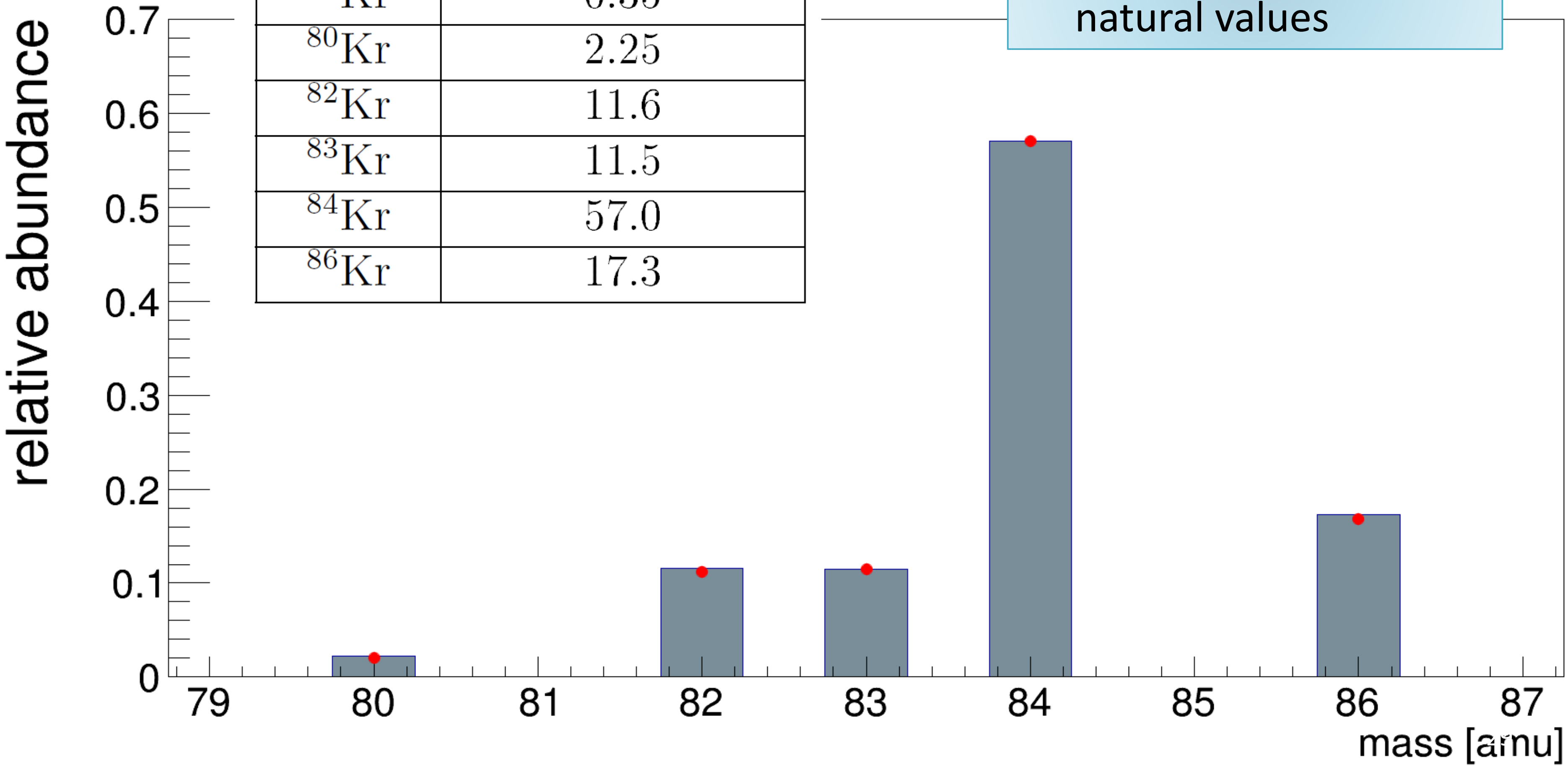
^{86}Kr	17.3

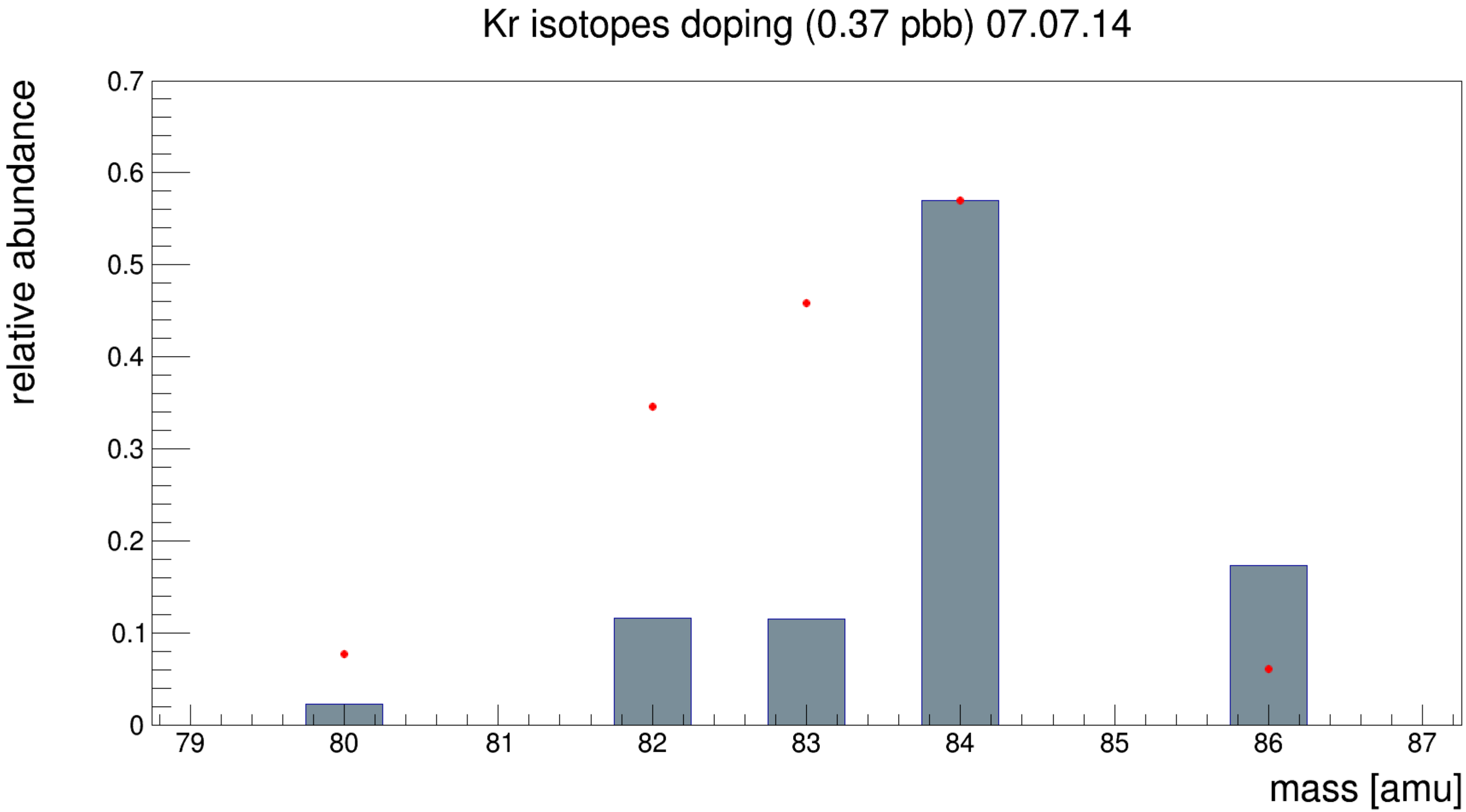
Isotopic abundance is **matching** with natural values



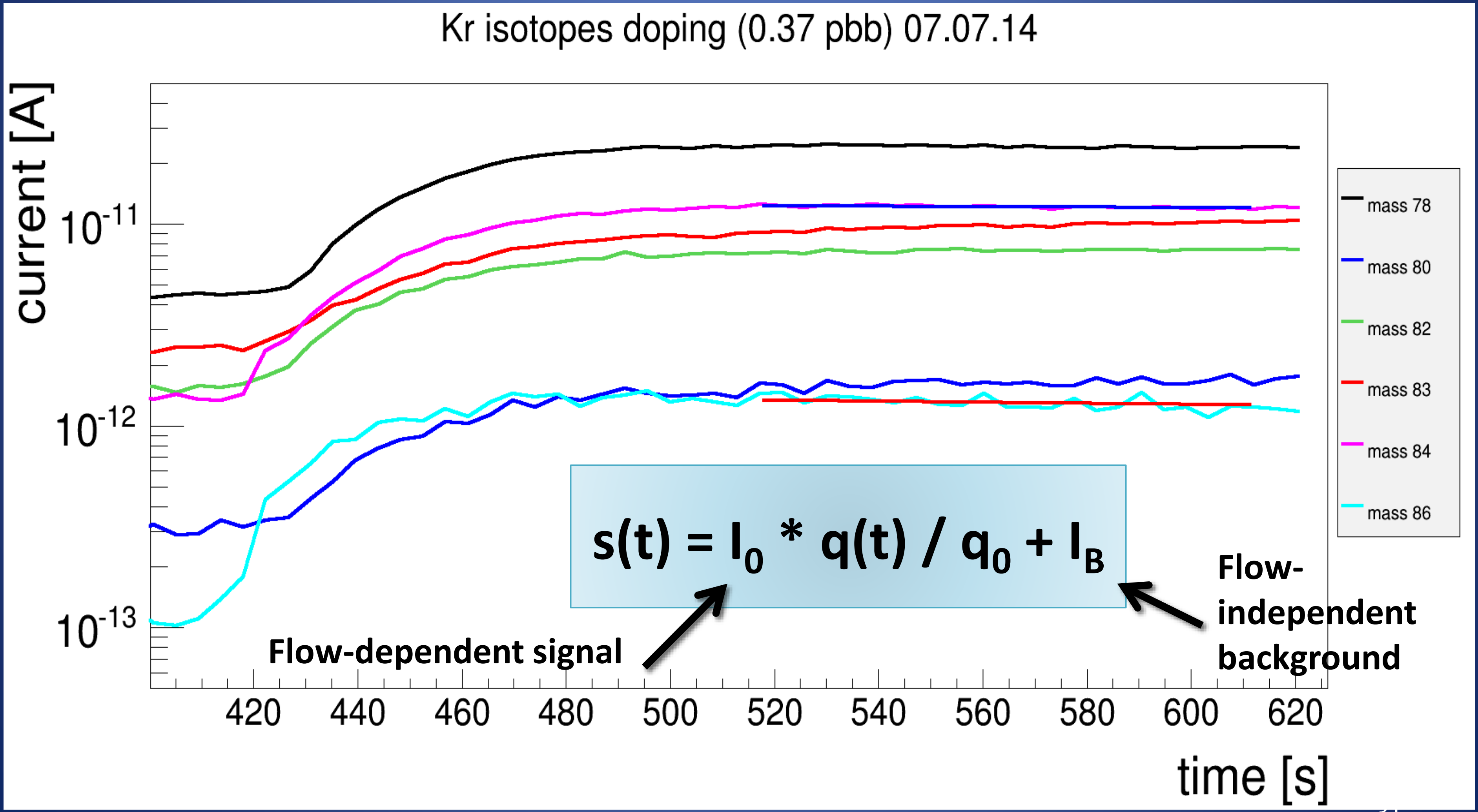
Isotopic fraction low doping (~ 0.3 ppb)

NO MATCH!

→ Background?



Analysis with background fit



Volume 1 – Volume 3	Volume 4
2300 mbar xenon	200 mbar krypton

Volume 1 – Volume 3 | **Volume 4**

2300 mbar xenon | 200 mbar krypton

75 mbar krypton + 1250 mbar xenon

→ 1500 mbar Kr + Xe

Volume 1 – Volume 3	Volume 4
2300 mbar xenon	200 mbar krypton
75 mbar krypton + 1250 mbar xenon → 1500 mbar Kr + Xe	
evacuated down to 10^{-5} mbar	1325 mbar Xe with 5% Kr

Volume 1 – Volume 3

Volume 4

2300 mbar xenon

200 mbar krypton

75 mbar krypton + 1250 mbar xenon

→ 1500 mbar Kr + Xe

evacuated down to 10^{-5} mbar

1325 mbar Xe with 5% Kr

570 mbar xenon with 5% krypton

Volume 1 – Volume 3	Volume 4
2300 mbar xenon	200 mbar krypton

75 mbar ...pton + 1250 mbar xenon

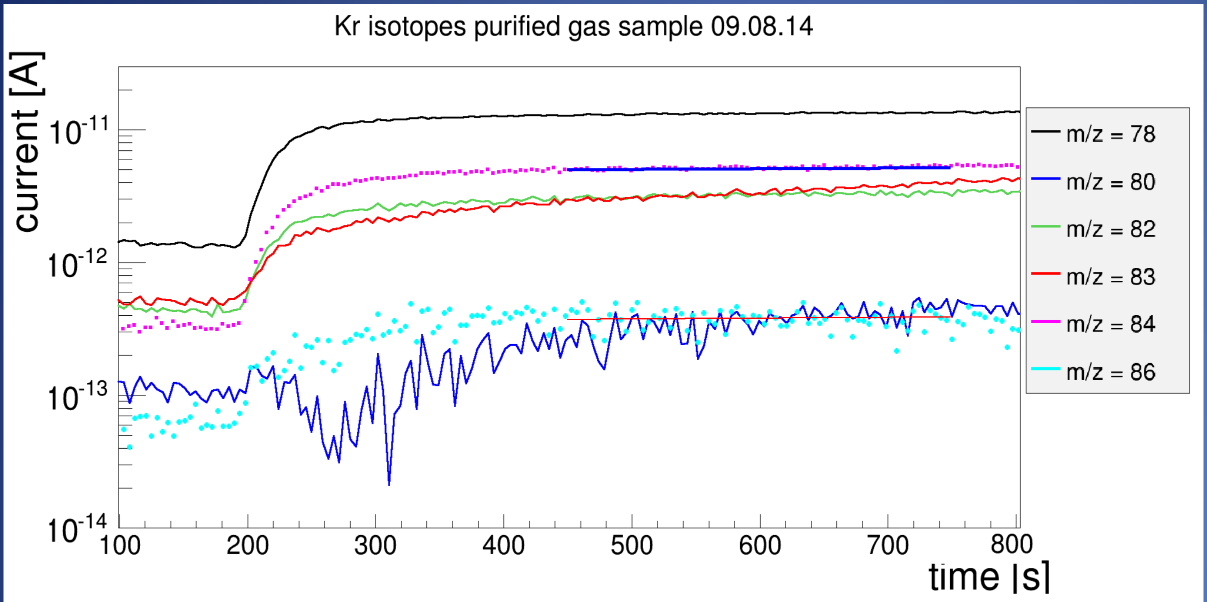
...0 mbar Kr + Xe

Mixing time is in order of hours!

evacuate... ...wn t... ...5 mbar	1325 mbar Xe with 5% Kr

570 mbar xenon with 5% krypton

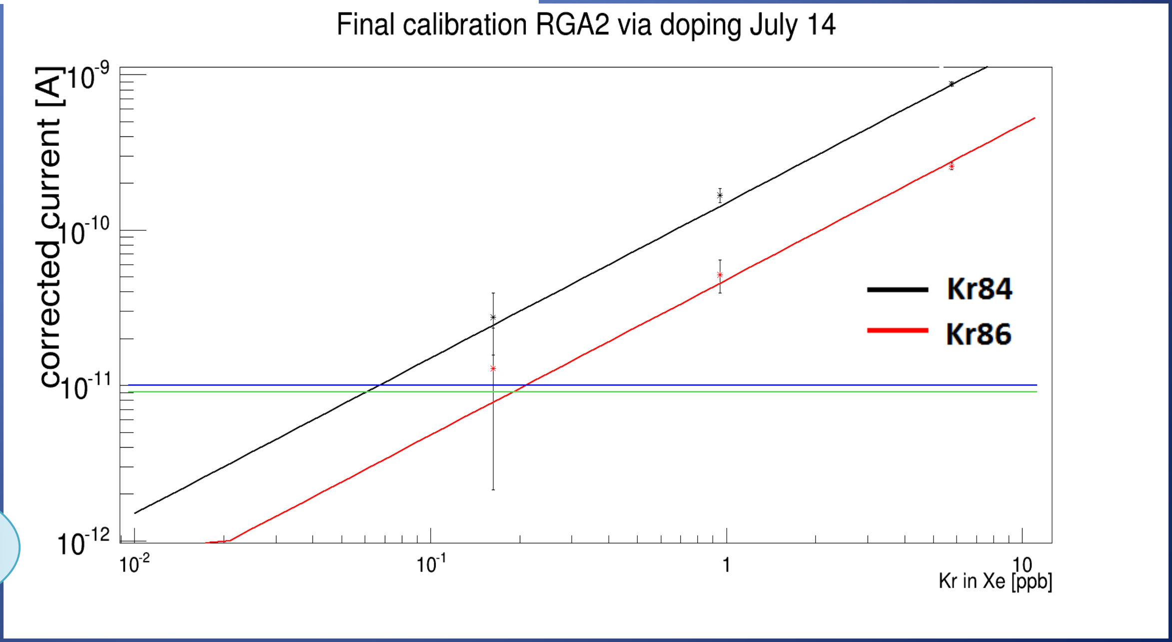
Sensitivity limit



Idea: Use ultrapure gas (sub-ppt) for an estimation of a 1σ-sensitivity limit -> Only background signals!

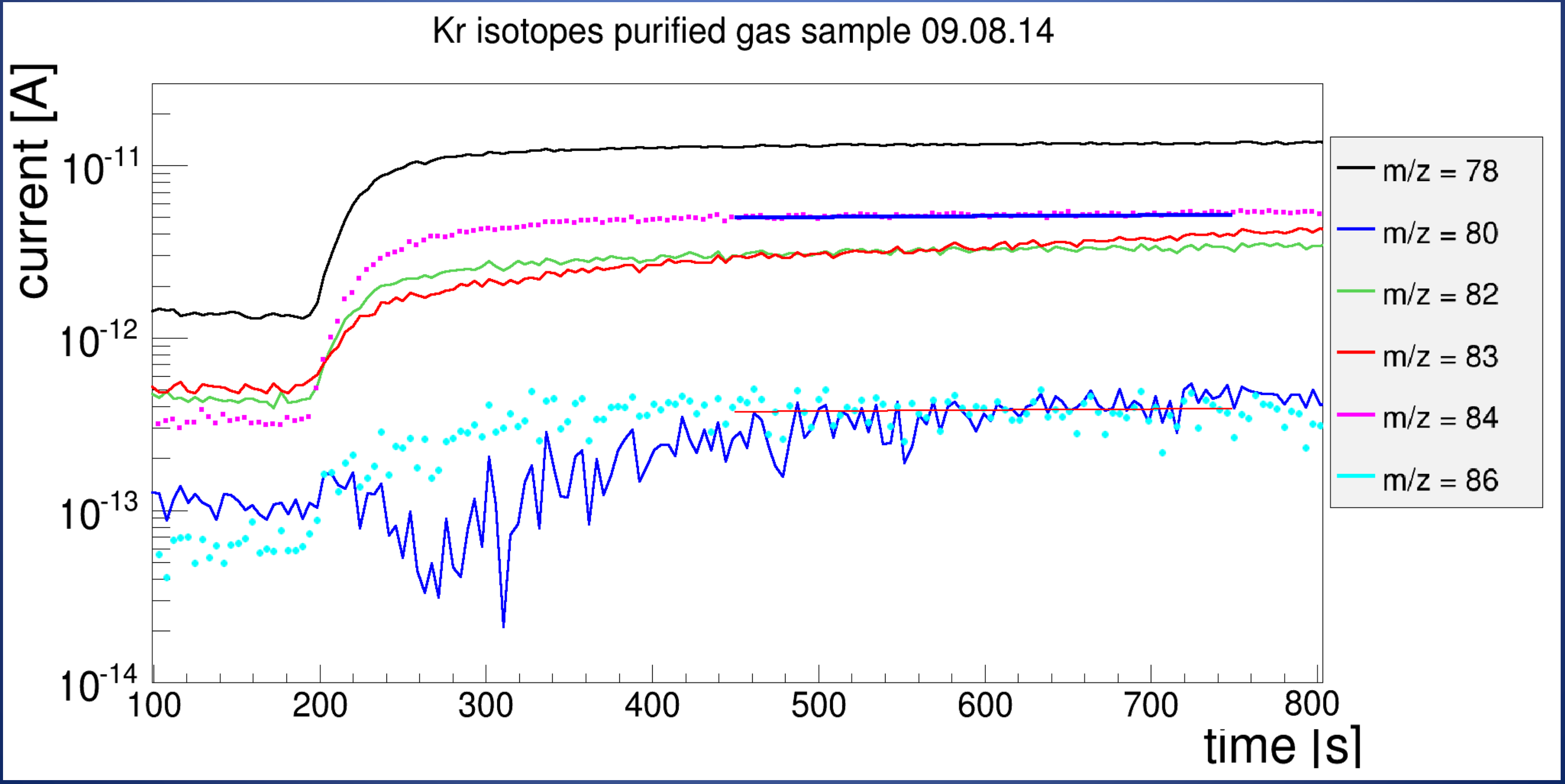
- Deviation of the background signal limits conservatively the detection sensitivity

→ **67 ppt**



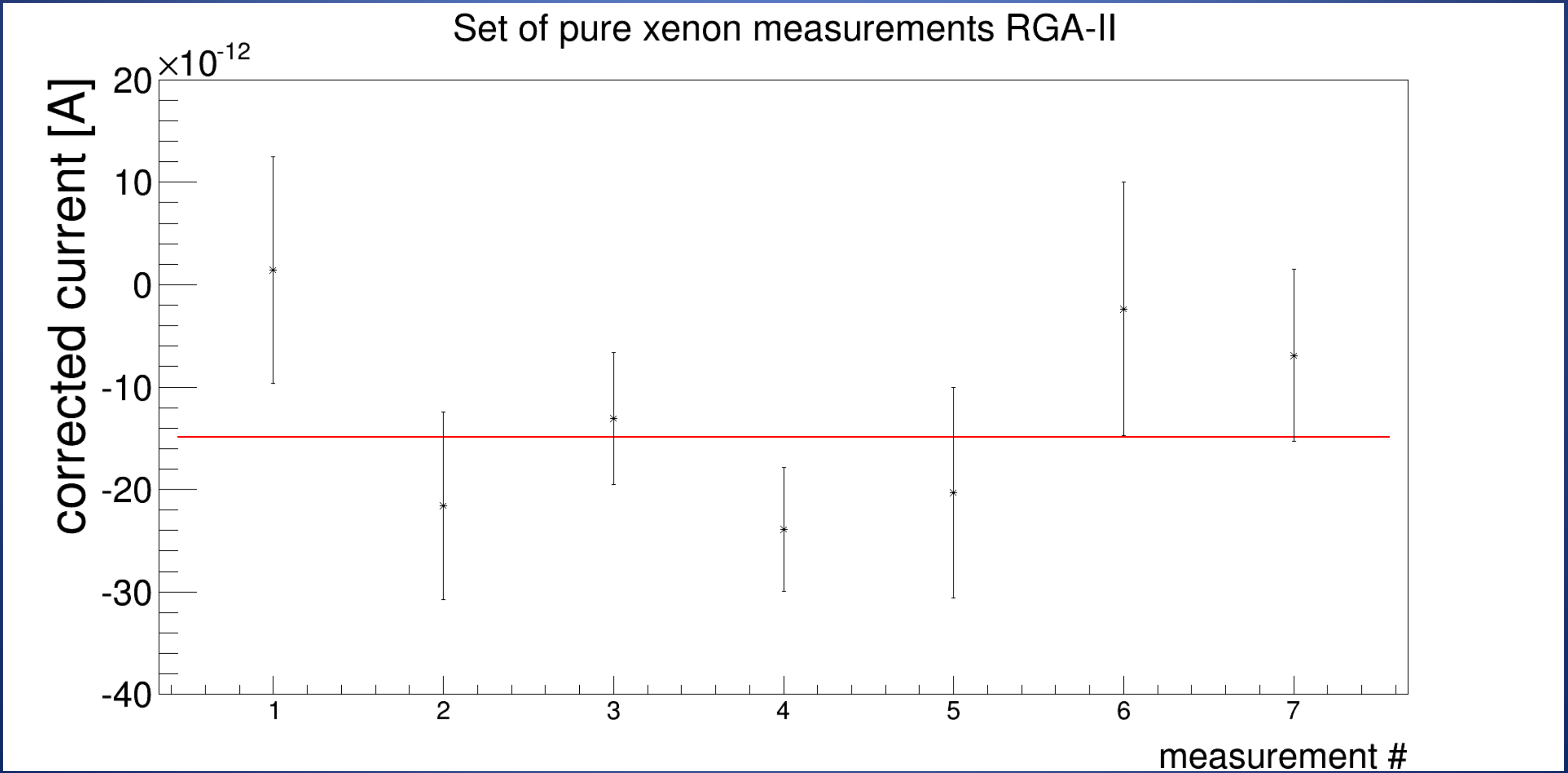
Sensitivity limit

- Idea: Use ultrapure gas (sub-ppt) for an estimation of a 1σ-sensitivity limit -> Only background signals!

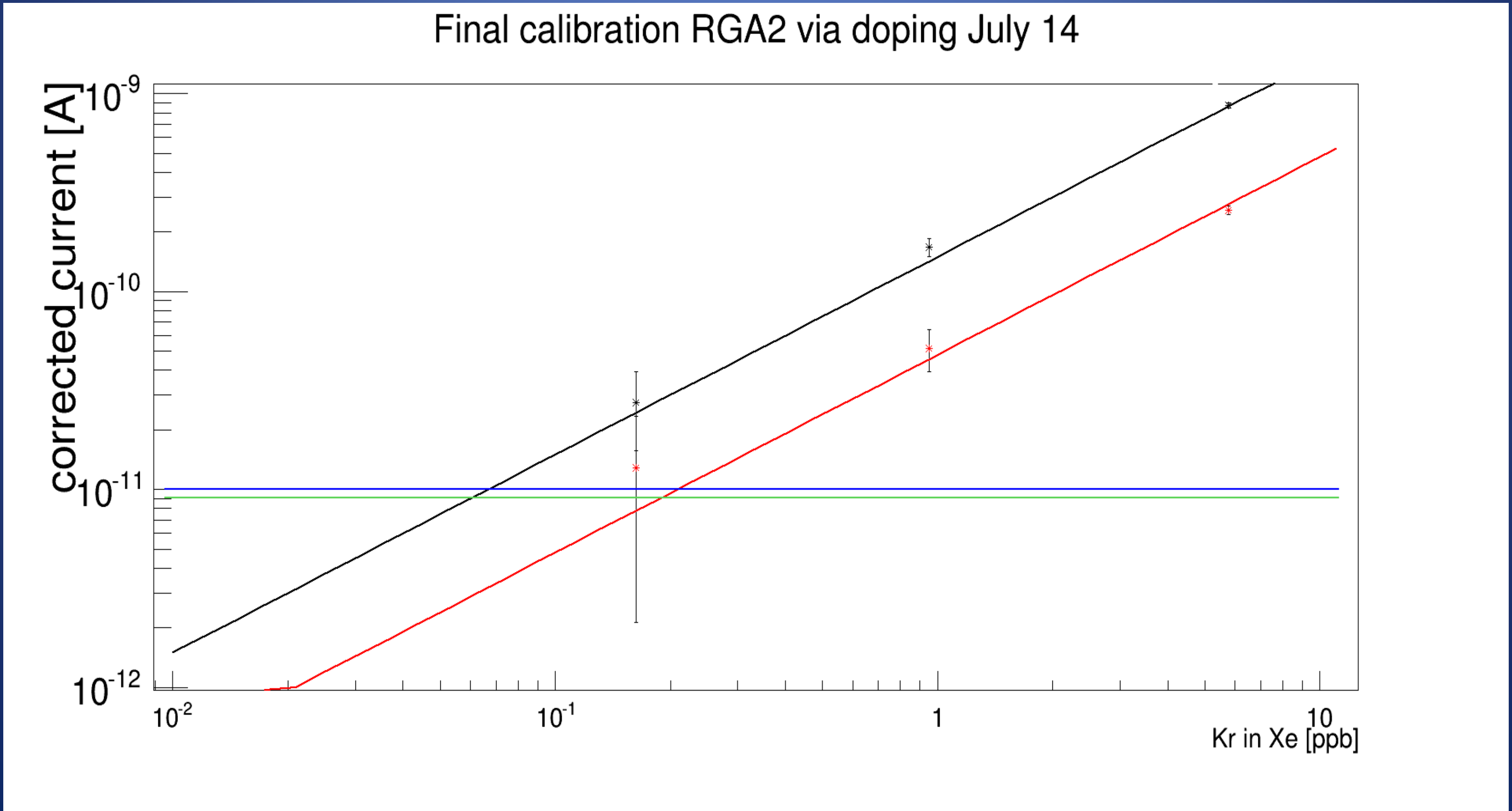


Sensitivity limit

- The uncertainty of the pure measurements determine the minimum detectable signal



Sensitivity limit



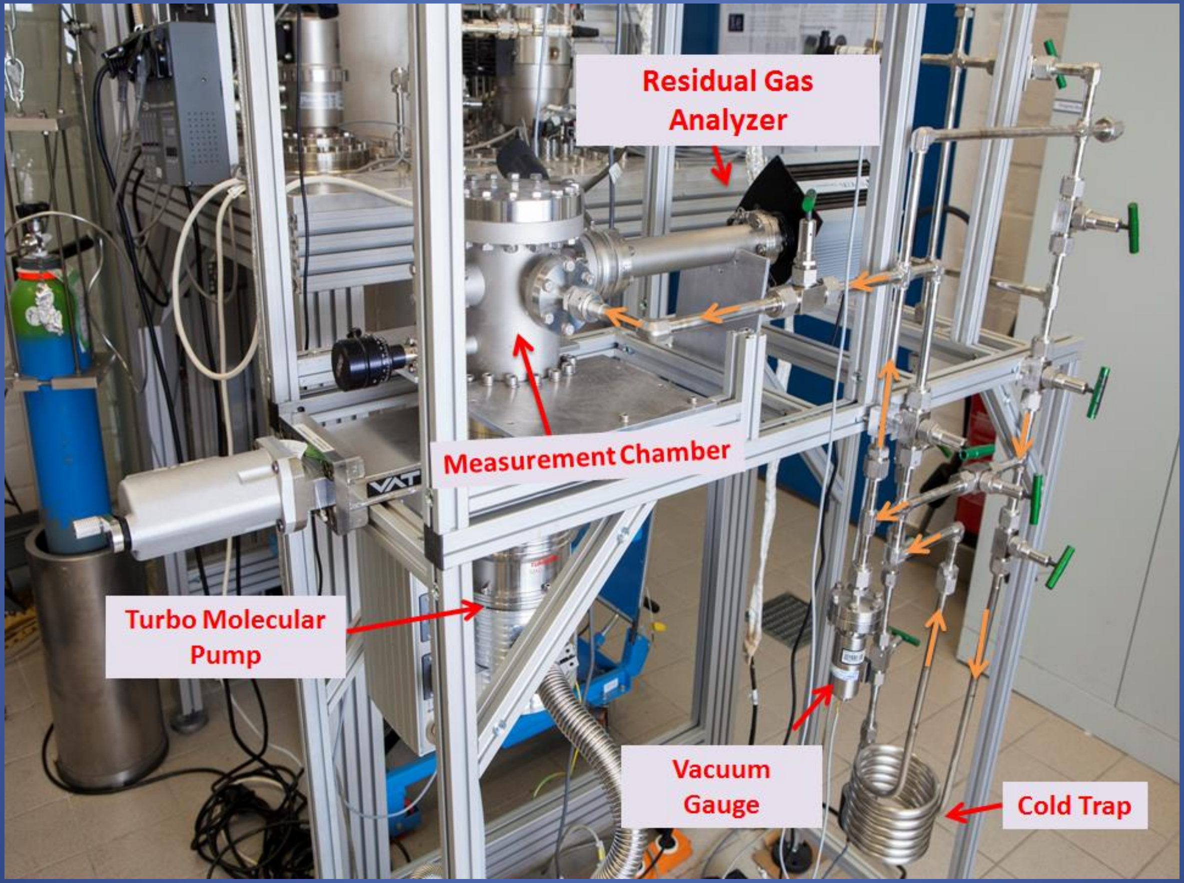
Background ^{85}Kr

- Beta decay of ^{85}Kr into ^{85}Rb is a significant intrinsic background for XENON1T
- Determinati … tation in xenon is of cr…

Sensitivity is limited above the desired value of 0.5 ppt

Make use of fast results and minimal consumption advantages for other applications!

- R… natur…
  below <0.5 ppt in the used xenon
- Natural krypton abundance is measured and the ^{85}Kr concentration is derived from this value
- Can be removed along with cryogenic distillation


Residual Gas Analyzer
Measurement Chamber
Turbo Molecular Pump
Vacuum Gauge
Cold Trap