

Analysis of the MicroBooNE argon by ICPMS



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on behalf of the
CIEMAT Dark Matter group

in collaboration with the **MicroBooNE** experiment



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“Quick facts”

- The chemical contamination of the argon can impact both light and charge collection in a TPC
 - Electronegative impurities
 - Non radiative dissociation of the excimer state
 - Direct quenching / shifting of the 128 nm
- The precise measurement of the argon purity is mandatory, particularly for large detectors
- Monitoring the argon purity in real time would reveal possible leaks in an early stage
- In most cases, the argon contamination can only be revealed through the data analysis

A “simple” idea

- ICP-MS typically uses GAr for the analysis of the sample (after previous digestion)
- A blank run (w/o the sample injection) provides naturally the mass spectrometry analysis of the GAr
- This analysis can be used to identify (and possibly quantify) the contaminants in the gas used by the argon experiments
- Detection limits significantly better than the RGA
- It can provide results in “real time”
- Quantification depending on the availability of calibrated samples

ArDM in

- ArDM was an experiment for the direct search of dark matter in operation in the **Canfranc underground laboratory**.
- With **1-ton** of argon in the active volume, it has been the first tonne-scale dual-phase electroluminescent TPC in operation.
- It achieved several milestones for the Ar-TPC technology (NR vs ER discrimination power in a large size detector....etc) but it suffered of **“low light yield”** (~half of the expected LY).



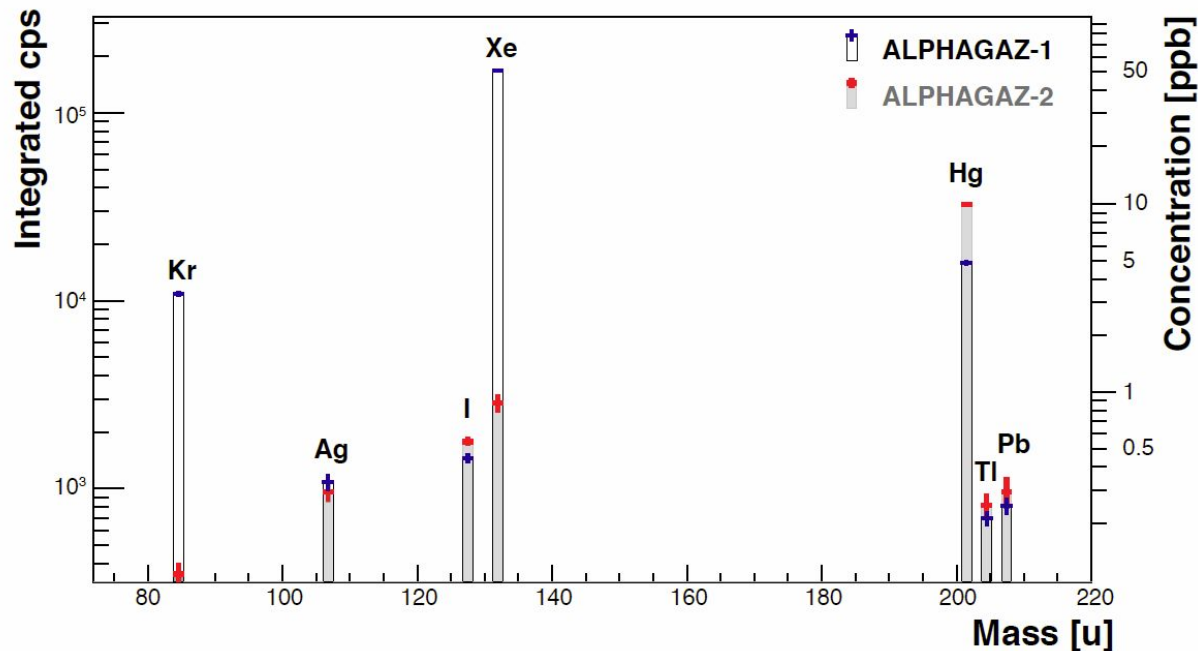
- Bayesian analysis of the data/MC compatibility (using ^{39}Ar and $^{83\text{m}}\text{Kr}$ sets) → **“Short” VUV light attenuation length: ~ 50 cm**
- Optically active impurities?

Ar – ICPMS (mostly comparative analysis)

Alphagaz™ 1 (Level of purity N50) and Alphagaz™ 2 (Level of purity N60) from AirLiquide

ICP-MS analysis:

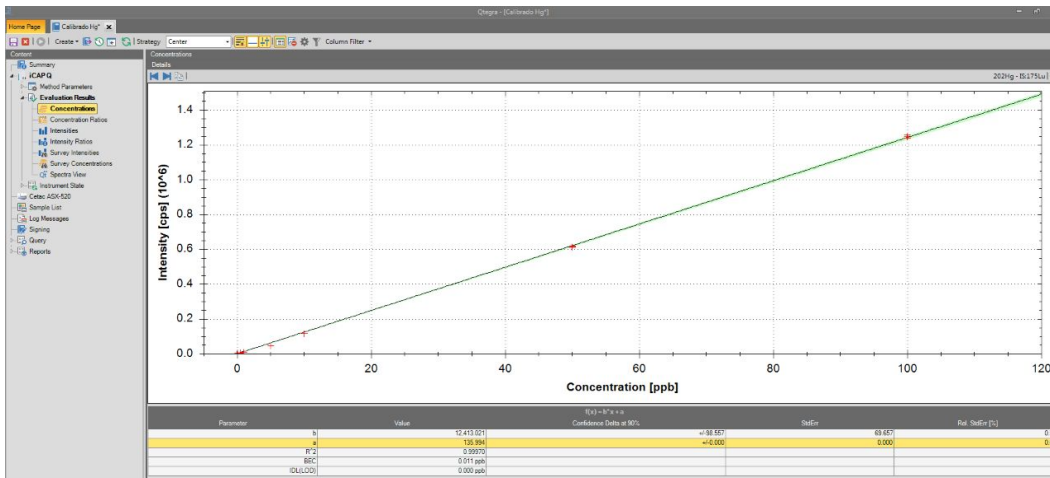
- Xe and Kr excluded (<1ppb)
- Hg dominant contamination (~ 10 ppb)



Dominant contamination (by far): Hg at the level of 10 ± 5 ppb. The Hg identification was surprising, but is clearly established by the relative natural abundance of different isotopes.

Hg calibration

Sample List	199Hg	200Hg	202Hg
Label	cps	cps	cps
Blank (4% HNO ₃)	66	104	137
Standard 0.1	571	772	1037
Standard 0.5 ppb	2717	3482	4427
Standard 1 ppb	5343	7586	9762
Standard 5 ppb	26936	37026	47739
Standard 10 ppb	66033	91098	117621



*“Measurement of the attenuation length of argon scintillation light in the ArDM LAr TPC”
Astropart.Phys. 97 (2018)*

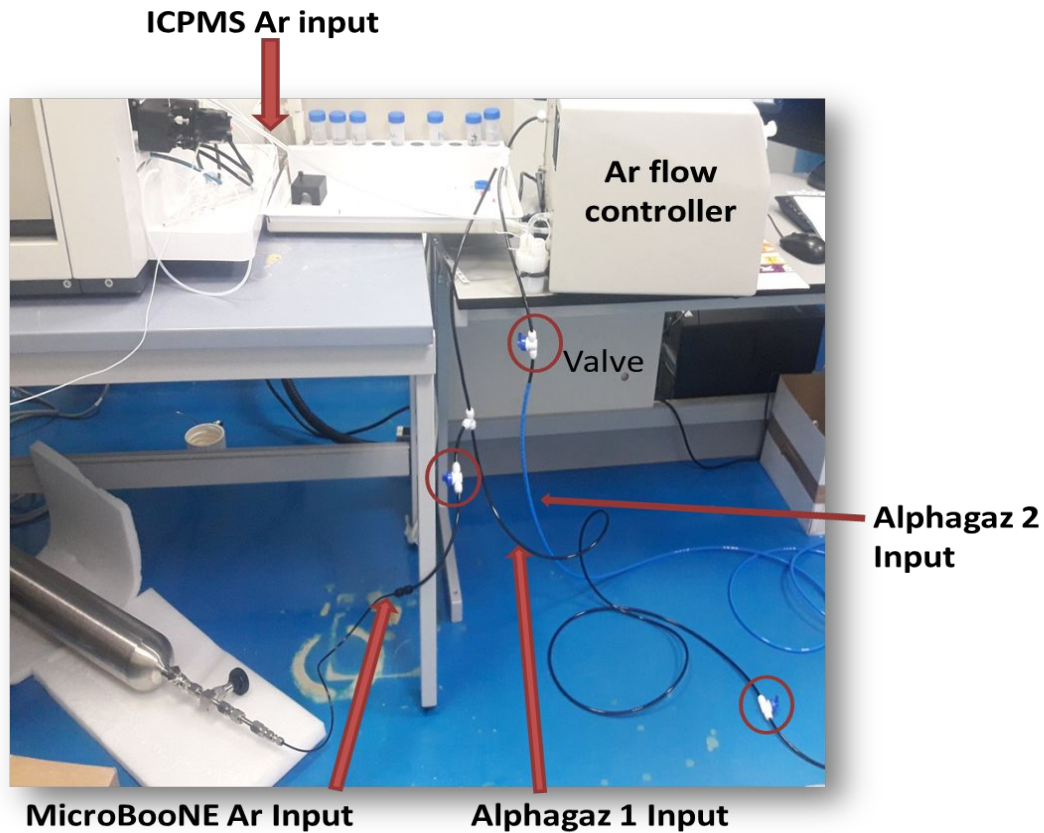
MicroBooNE Ar – ICPMS

ICPMS analysis in comparison with Alphagaz™ 1 (Level of purity N50) and Alphagaz™ 2 (Level of purity N60) from AirLiquide

iCAP Q, Thermo Fisher Scientific

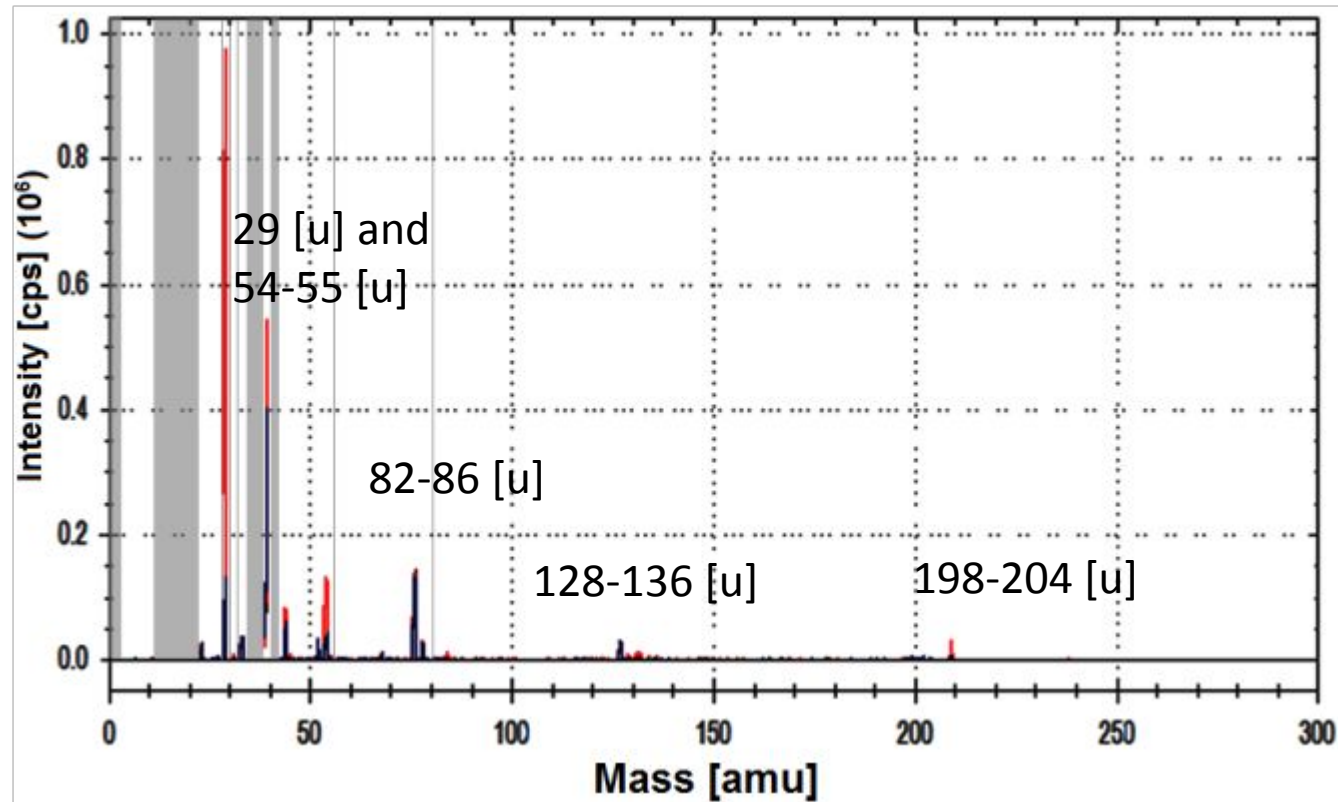


Setup

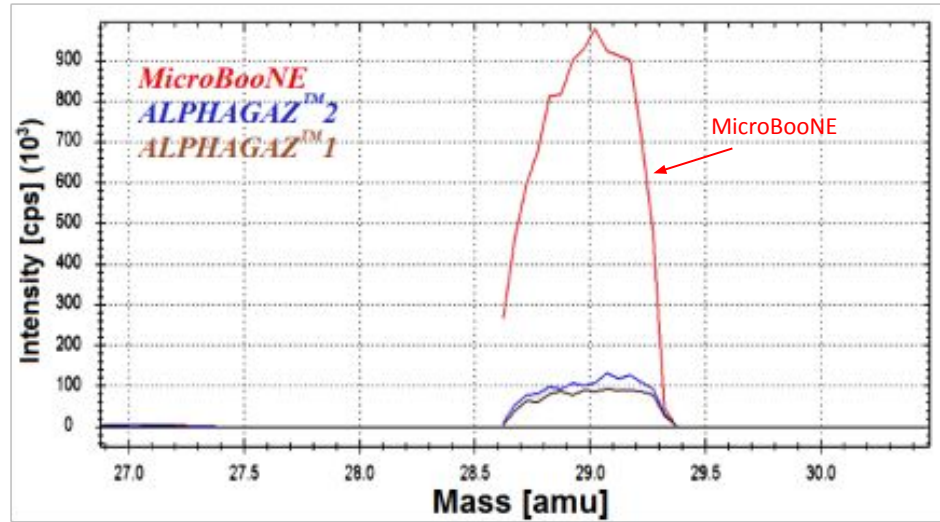


mass flow meter (CETAC Aridus I)

Results

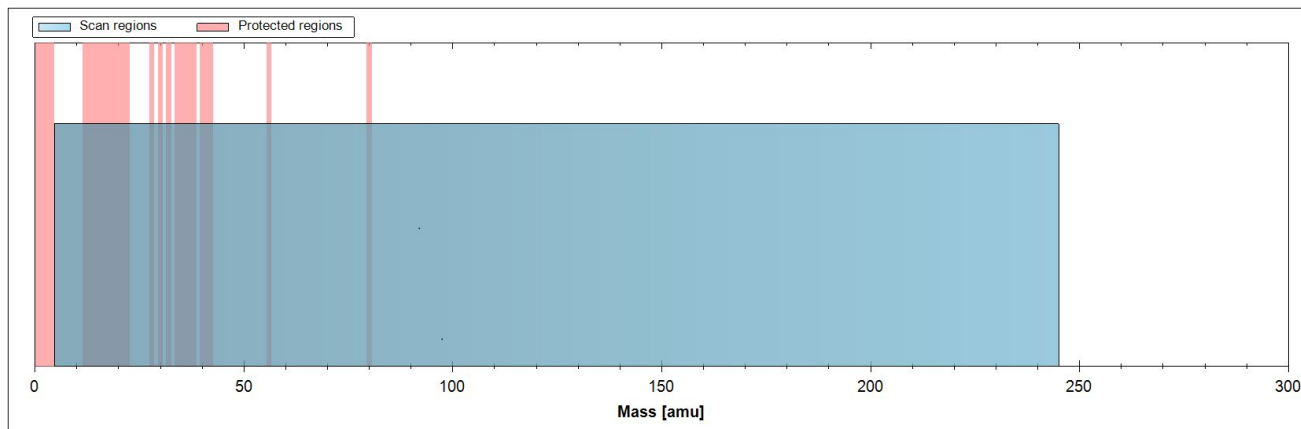


Results: 29 u



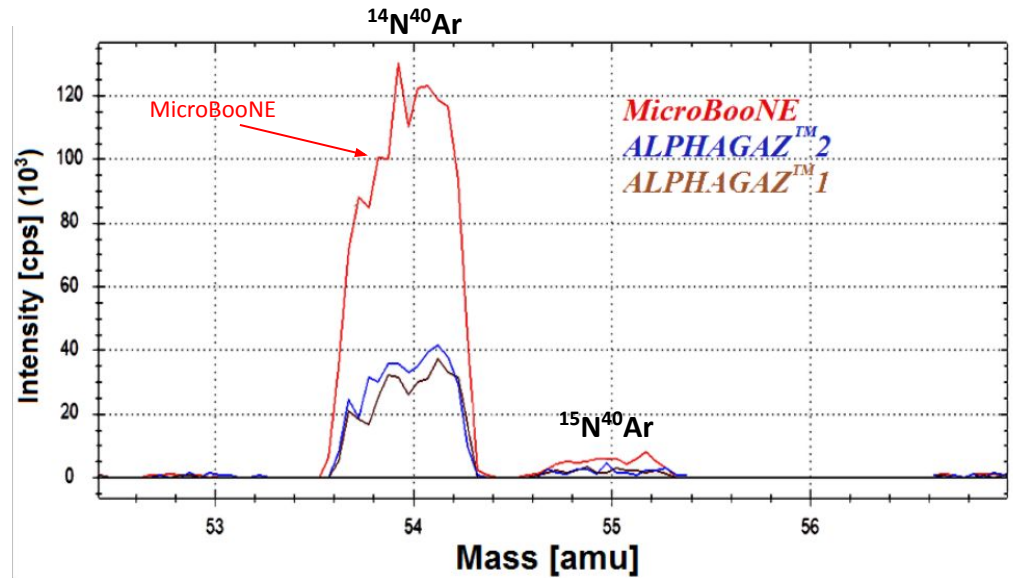
- Silicon isotope? (^{29}Si , 4.7% natural abundance) -> unlikely
- Polyatomic ion formed by the two nitrogen isotopes (N-14 and N-15)
⇒ Nitrogen contamination?
- It is in the bottle (no difference switching lines and valves: leak in the gas line unlikely)
- In the original gas? At the time the bottle was filled?

Results: 29 u



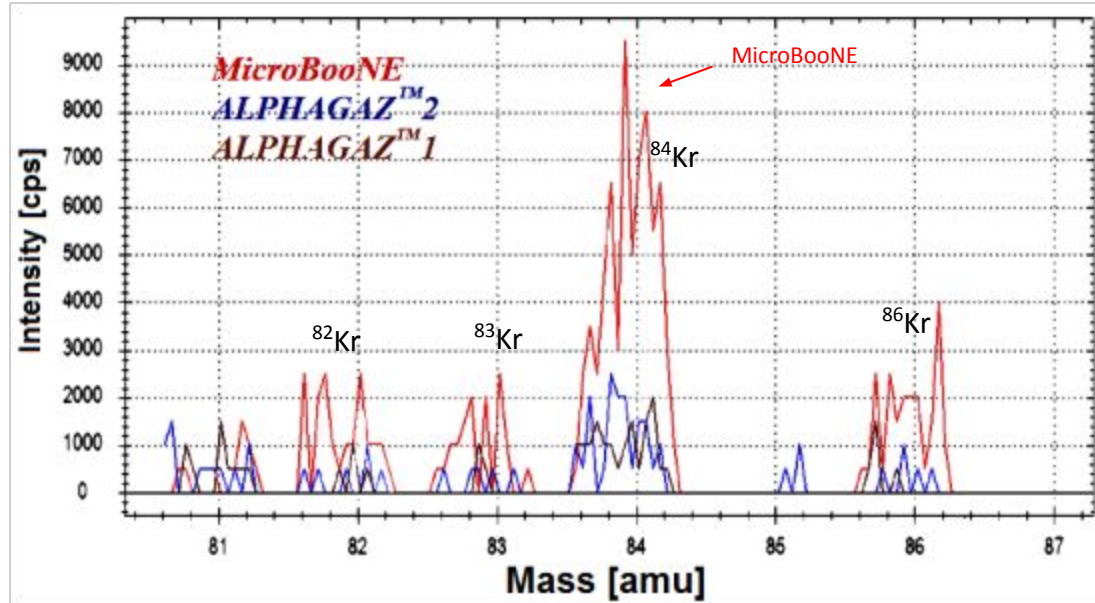
The proof of this “nitrogen hypothesis” could be given by the contemporary detection a peak at 28 u, however this mass value is not measured during the scanning performed by the instrument.

Results: 54-55 u



- Unlikely contamination of some transition metal (Cr, Mn, Fe etc)
- Interference between Ar-40 and the two nitrogen isotopes (N-14 and N-15)?
- The MicroBooNE GAr shows substantially larger peaks

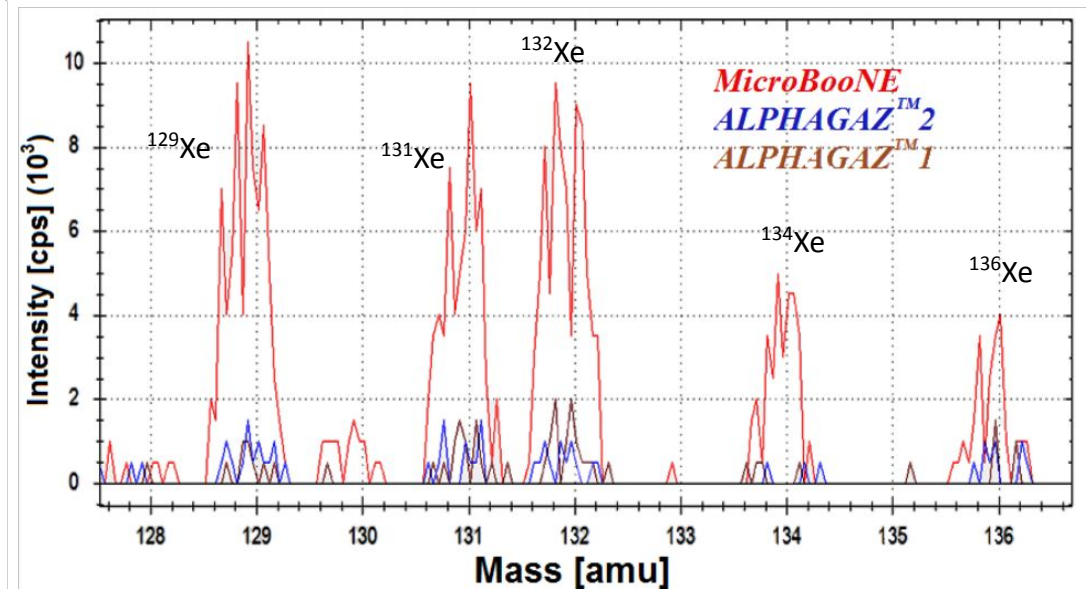
Results: 81-86 u



The identification of Kr contamination is univocal since the intensity of the peaks reflects the natural abundance of the isotopes of this element.

MicroBooNE GAr contamination in the ~ppb range (tbq with calibrated samples)

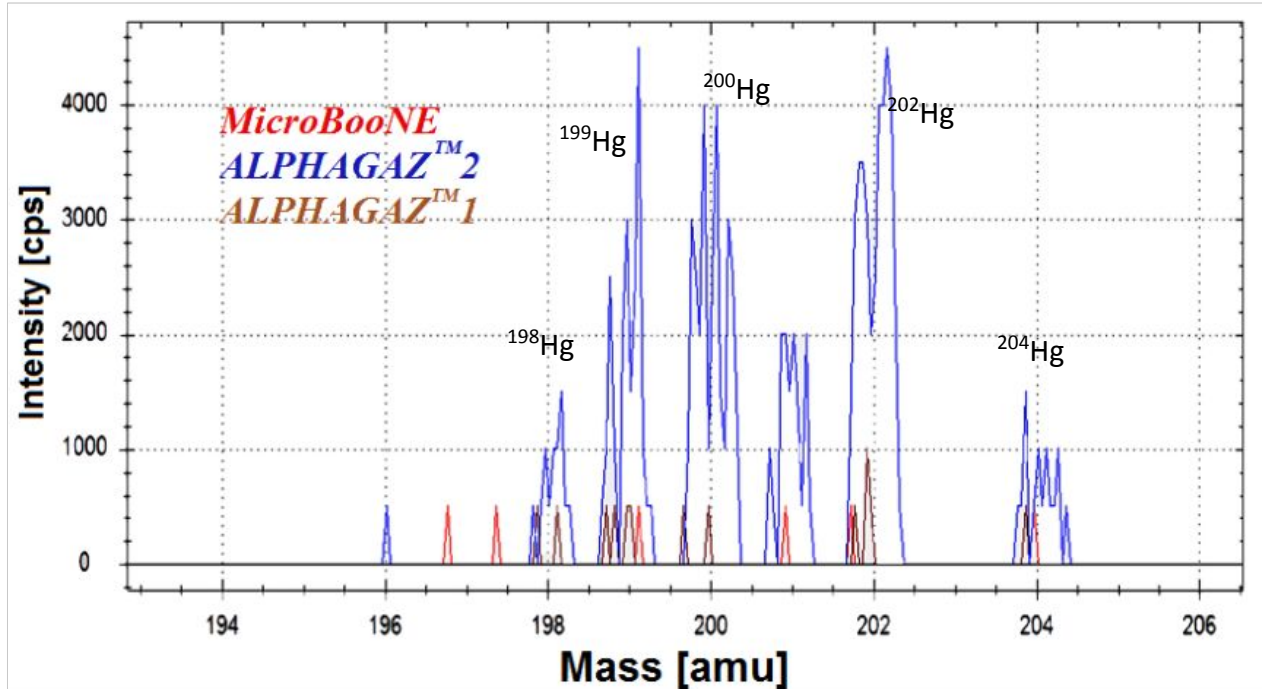
Results: 128-136 u



The identification of Xe contamination is univocal since the intensity of the peaks reflects the natural abundance of the isotopes of this element.

MicroBooNE GAR contamination in the ~ 10 ppb range
(tbq with calibrated samples)

Results: 198-204 u



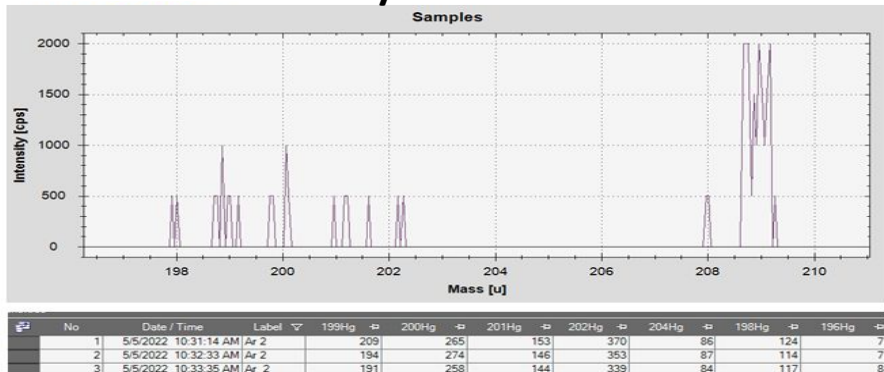
- In the case of mercury the signal is compatible with the background
- There is no mercury in the MicroBooNE gas (limits < ppt)

Polyatomic ions with the collision cell

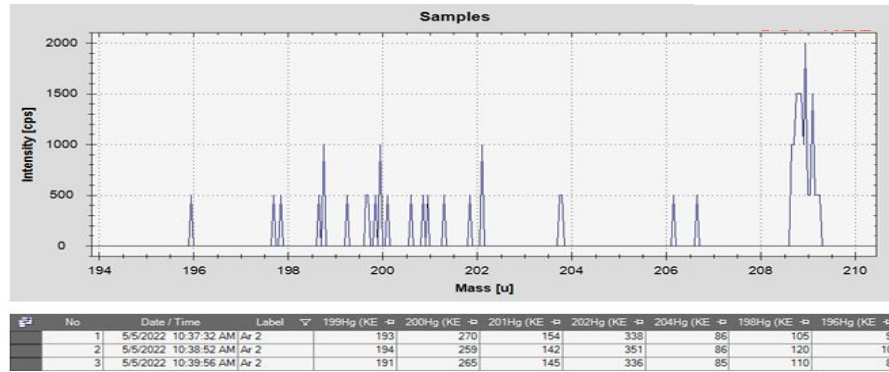
- Additional measurements have been made using kinetic energy discrimination (collision cell mode CCT-KED with He gas)
- A collision cell is a cylinder located between the skimmer and the mass analyzer into which a different **gas is introduced to induce collisions** between the ions from the plasma and the atoms of the He gas
- **Polyatomic ions have larger collision cross-sections:** undergo more collisions and lose more kinetic energy than the atomic ions with the same m/z value
- The atomic ions surmount the energy barrier placed downstream of the cell while the polyatomic ions do not (due to their lower kinetic energy)
- The overall effect is a reduction of the polyatomic interference in the quadrupole

Cps variation with and w/o the CCT-KED in the Hg region (ALPHAGAZ 1 and 2)

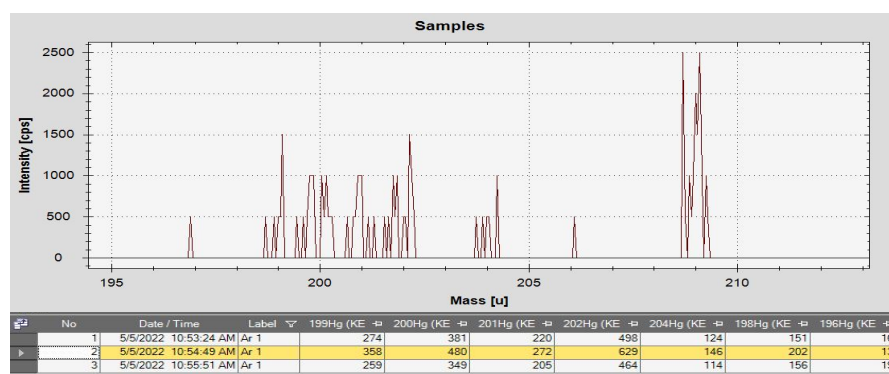
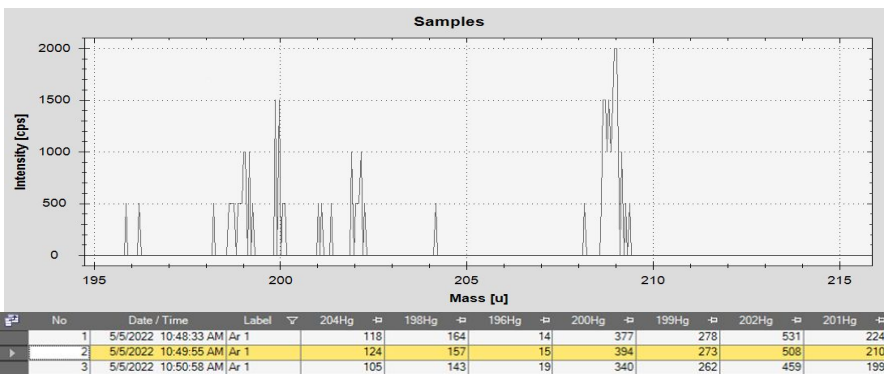
W/O KED



With KED



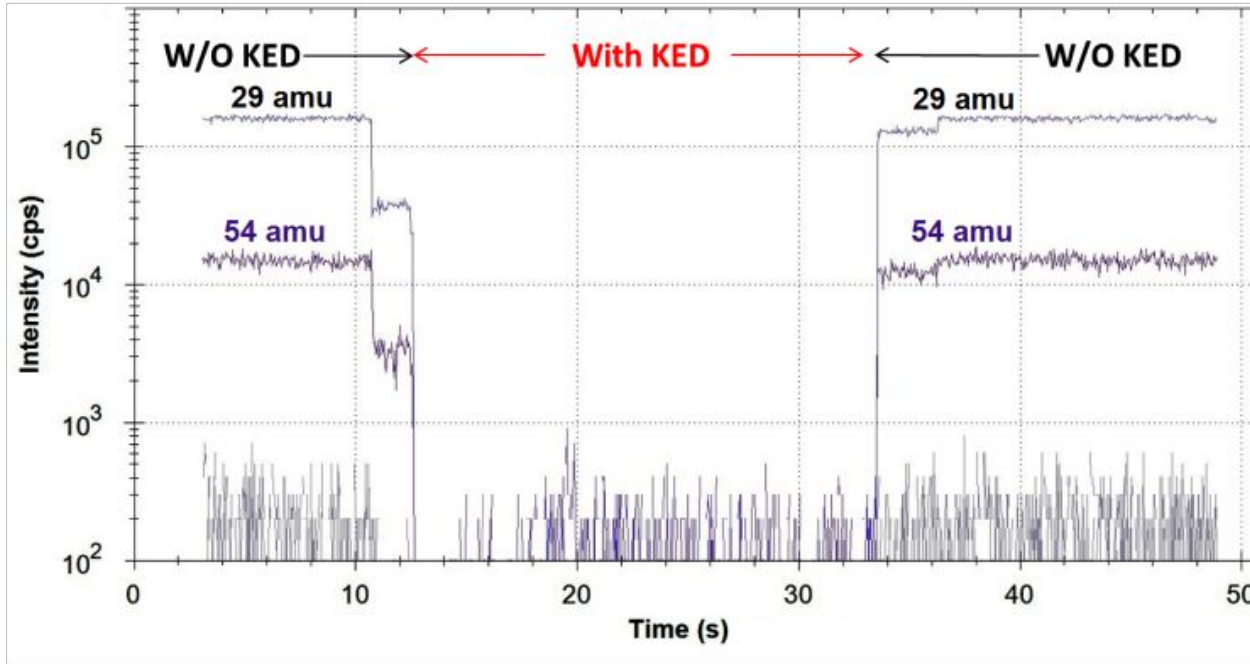
ALPHAGAZ 2



ALPHAGAZ 1

Intensity (Cps) stable within a factor 2 between the two configurations

Interference peaks at 29 [u] and 54 [u]



- Cps reduced by >3 orders of magnitude with KDE

Conclusions

- The identification of Hg in the GAr from ArDM is univocal at a level of 10 ± 5 ppb

- In the MicroBooNE GAr:
 - there is an indication of a meaningful nitrogen contamination (tbq)
 - the identification of Kr contamination is univocal. The Kr contamination is larger than the Airliquide gas (\sim ppb range)
 - the identification of Xe contamination is univocal. The Xe contamination is >10 larger than the Airliquide gas (~ 10 ppb range)
 - there is no evident Hg contamination ($<$ ppt)

- The ICPMS analysis of the GAr seems to be able to provide relevant information on the gas contamination:
 - live time monitoring of the argon quality?

backup

INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY (ICP-MS)

It allows the **determination of elements** with atomic mass ranges 7 to 250 (Li to U).

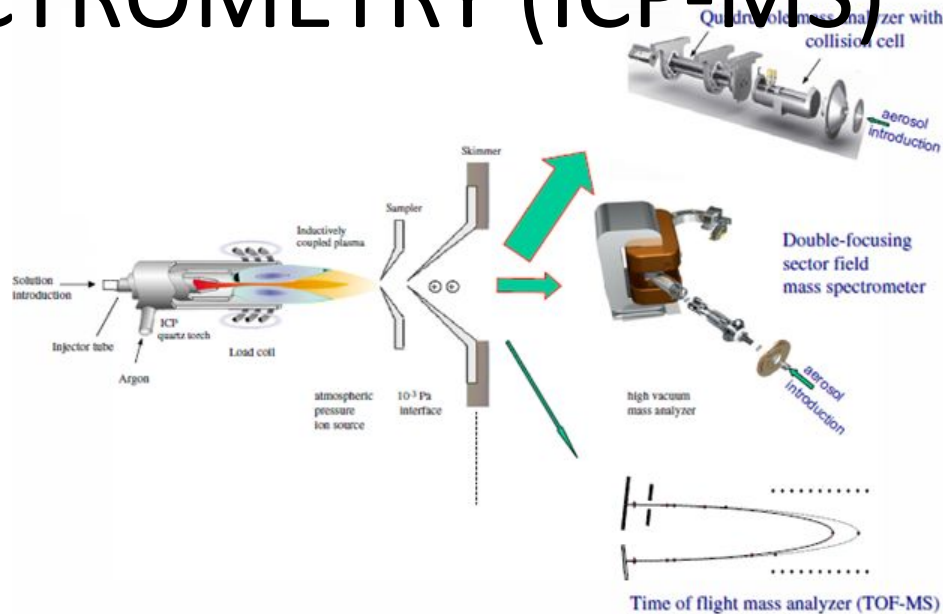
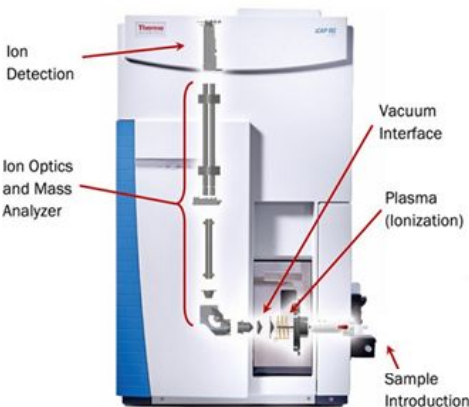
Concentration at very **low level** in a wide variety of samples.

High resolution ICP-MS (HR-ICP-MS), uses a magnetic field and electrostatic analyzer, providing very low detection limits, in the $\text{pg} \cdot \text{L}^{-1}$ range.

Destructive analysis: a **previous sample digestion** is required in order to obtain a liquid solution.

In comparison to other alternative solid-state mass spectrometric techniques is advantageous because liquid solutions **can be easily and rapidly analyzed**.

INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY (ICP-MS)



Perkin, Agilent, Bruker....

- **ICP source**
- Extraction from the atmospheric pressure using an **ion lens** system
- **ICP low-pressure interface region to the high vacuum** of the mass spectrometer
- Three types of **analyzers**