Characterization of microbulk detectors in argon- and neon-based mixtures

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on behalf of
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Some words about this base research work

Motivation

- Micromegas detectors have been generally tested in Ar + 5% isobutane. This gas is supposed to be the best for a high gain and excellent energy resolution.
- What happens in other gases? What is the relation of gain and energy resolution with the gas and the gap distance?

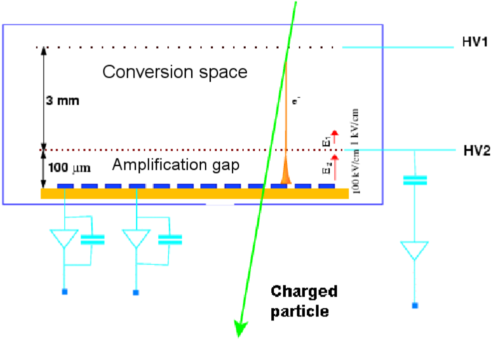
Application

- Results will serve as a reference for Micromegas users.
- Higher gains are envisaged to reduce the energy threshold of detectors to allow its application in sub-keV experiments.

Index

Micromegas and microbulk technology

Micromegas: A Micro-Pattern Gas Chamber detector



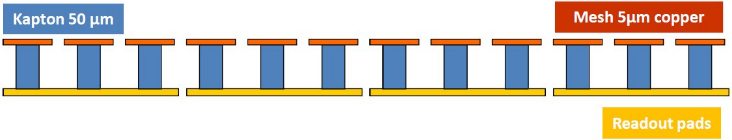
I. Giomataris (1992)

A thin metallic grid and an anode plane, separated by insulated pillars. They define a very little amplification gap (20-300μm).

A support ring or frame adjust the mesh on top of the readout plane, with the help of some screws.

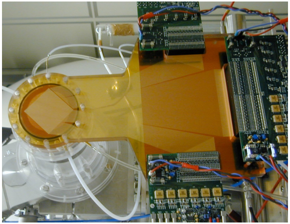
- Good properties: High granularity, good energy and time resolution, stable, easy construction, little mass and radiopure.
- Limitations: Large scale production, dimensions and resolutions.

Micromegas and microbulk technology
The microbulk technology

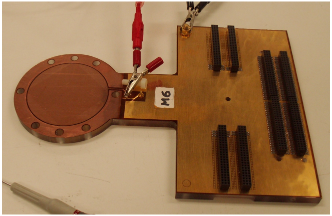


Readout and mesh in one piece: S. Adriamonje *et al.*, *JINST* 5 (2010) P02001

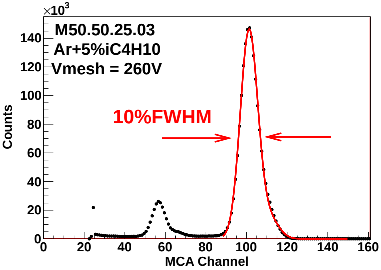
The pillars are constructed by chemical processing on a kapton foil, to which the mesh and the readout plane are attached.

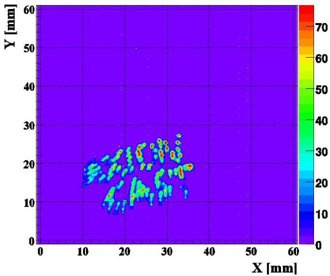


A conventional and a microbulk Micromegas CAST detector



Micromegas and microbulk technology
General features of microbulk detectors





Good features

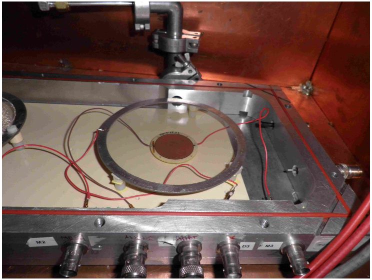
- Excellent energy resolution.
- Low intrinsic background.
- Better particle recognition.
- Low mass and flexible structure.
- Stable gain during long periods.

Being improved

- Higher electrical capacity.
- Large area detectors.
- Mass production.

Characterization in argon-based mixtures

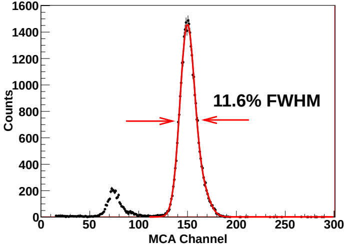
Setup description

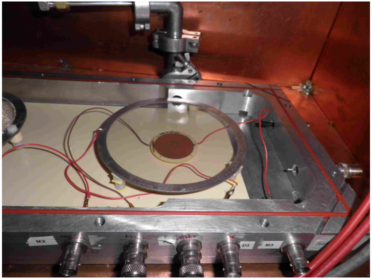


- Setup designed to characterized a maximum of three Micromegas detectors in the same gas conditions.
- A mesh frame is used as drift cathode: drift distance = 10 mm.
- The top cap contains several holes, covered by an aluminized mylar film, used to calibrate the detectors.

Characterization in argon-based mixtures

Procedure description





- Two microbulk detectors (diameter: 35 mm, a single anode) with respectively gaps of 50 and 25 μm have been tested in argon-based mixtures, using as a quenchers isobutane, cyclohexane and ethane. We focus on the first detector.
- Calibrated with an iron source (^{55}Fe, x-rays of 5.9 keV).
- Electronic chain: ORTEC 142C preamplifier + ORTEC 472A amplifier + AMPTEK MCA-8000A.

Characterization in argon-based mixtures

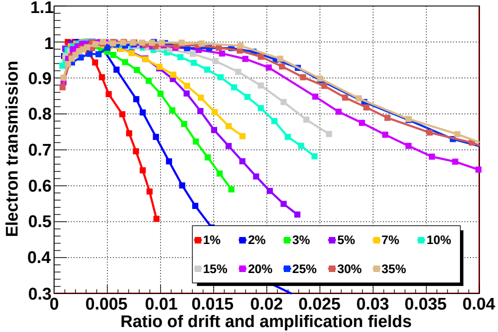
Motivation

- The effect of quenchers was already studied with proportional counters in Agrawal & Ramsey, *Nucl. Instrum. Meth. A* **273** (1988) 331.
- Lower gains and worse energy resolutions are expected for quenchers whose ionization threshold is more different from the 1st metastable levels of argon (11.4 eV).
- Note that the cyclohexane has a lower ionization threshold for ionization (9.9 eV) than isobutane (10.7 eV) and ethane (11.7 eV).

Quencher	I_e (eV)	Energy Res. 10^2	10^3	10^4
Methane	13.0	14.9	15.0	16.1
Carbon dioxide	13.8	15.8	16.5	16.8
Propane	11.2	13.6	14.3	14.5
Ethane	11.7	14.0	14.0	14.4
Isobutane	10.7	13.8	14.0	14.5
Propylene	9.7	14.3	14.8	15.8
Trans-2-butene	9.2	14.5	14.8	15.2

Characterization in argon-based mixtures

Mesh electron transmission for a gap of 50 μm



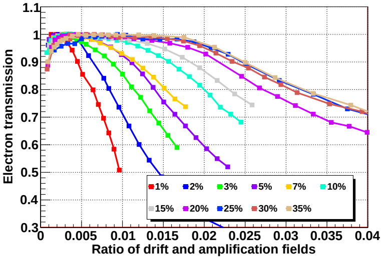
Procedure

The drift voltage is varied for a fixed mesh voltage and the peak position is normalized by the maximum value.

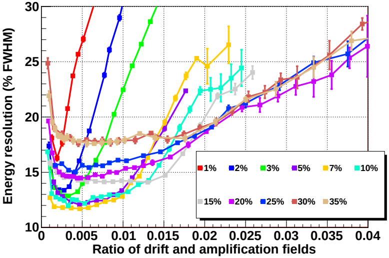
- For E_{drift}/E_{mesh} lower than a specific value, there is a maximum in the electron transmission (A=0.01 for a 5%). For higher drift fields, the mesh stops being transparent for primary electrons.
- The plateau widens with the percentage of isobutante and seems to be correlated with the diffusion coefficients.

Characterization in argon-based mixtures

Mesh electron transmission and energy resolution



Electron tranmission

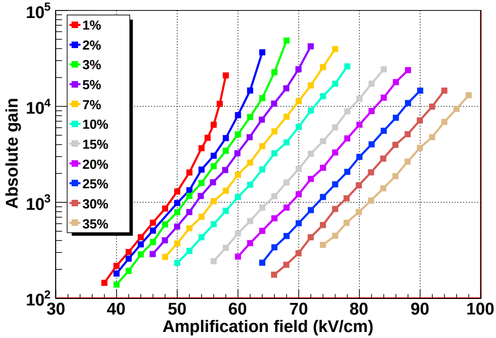


Energy resolution

- The energy resolution is correlated with the electron transmission. Best values at the maximum of the mesh transparency.
- At high isobutane quantities, there is a continuous degradation.
- Best values respectively obtained at 5% and 7% iC_4H_{10}.

Characterization in argon-based mixtures

Absolute gain for a gap of 50 μm



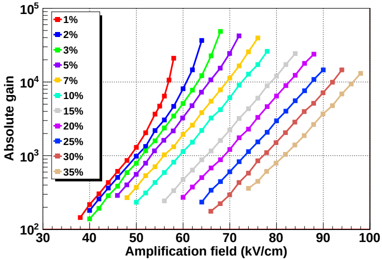
Procedure

The ratio E_{drift}/E_{mesh} is fixed so as the mesh showed the maximum electron transmission. The mesh voltage is varied and the peak position registered.

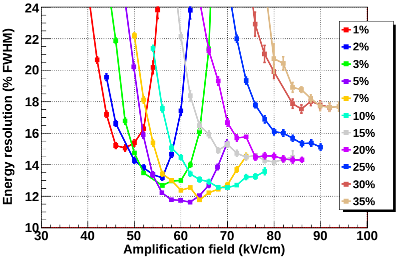
- An absolute gain greater than 10^4 is reached before the spark limit.
- At low quantities of isobutane, there is an over-exponential behaviour due to UV photons (P. Fonte *et al.*, *NIMA* **305** (1991) 91 and I. Krajcar Bronic *et al.*, *NIMB* **142** (1992) 219).

Characterization in argon-based mixtures

Absolute gain and energy resolution



Gain curve

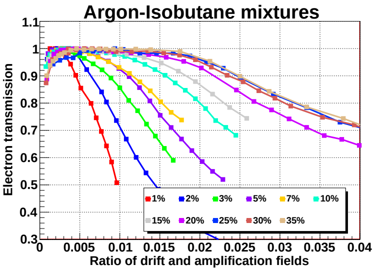


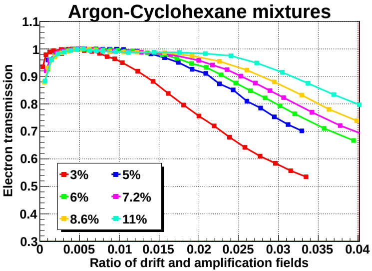
Energy resolution

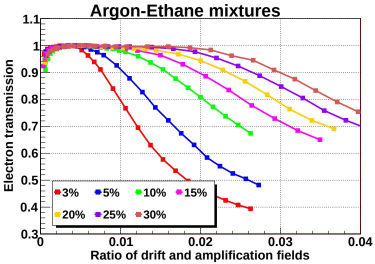
- It is constant for a wide range of amplification fields.
- For low fields, bad resolution due to the worse signal-noise ratio.
- For high fields, the resolution worsens due to the gain fluctuations. This effects doesn't appear for high quantities of isobutane.

Characterization in argon-based mixtures

Electron tranmission curves for a gap of 50 μm



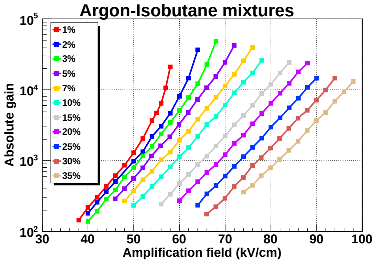


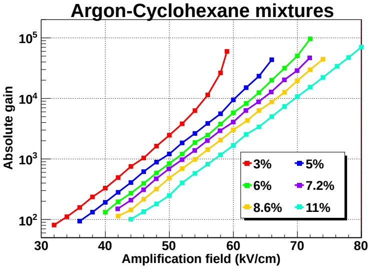


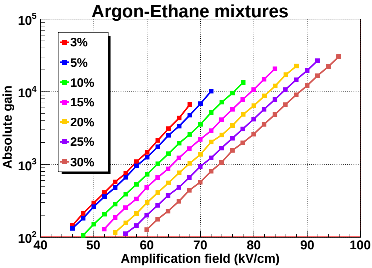
The plateau of maximum transmission is wider in argon-cyclohexane mixtures than in other gases. It is similar for the other two mixtures.

Characterization in other argon-based mixtures

The gain curves for a gap of 50 μm



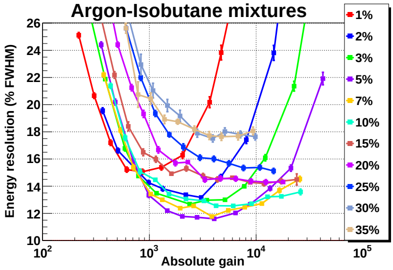


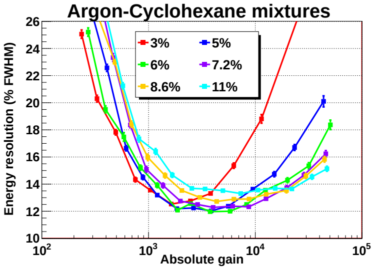


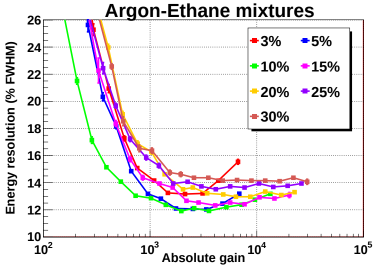
- A gain of 4×10^4 is reached in argon-cyclohexane before the spark limit.
- Amplification fields for 10% of quencher and a gain of 10^4: 61 (cyclohexane), 65 (isobutane) and 72 kV/cm (ethane).

Characterization in argon-based mixtures

The dependence of the energy resolution with the gain for a gap of 50 μm



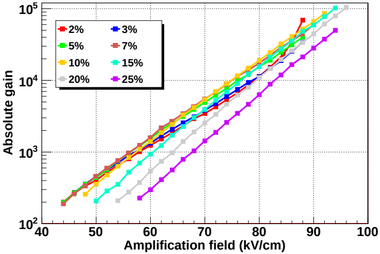




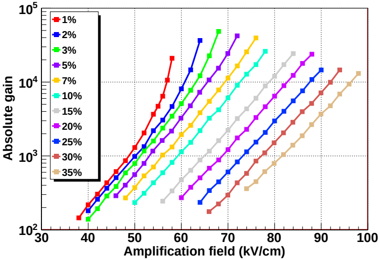
- There is a degradation at high gains due to over-exponential behaviours. It disappears for high quencher concentrations but the best value worsens.
- 12% FWHM for gains 10^3-10^4, independently of the quencher.

Neon-based mixtures for sub-keV applications

Comparison of the gain curves



Neon-Isobutane mixtures

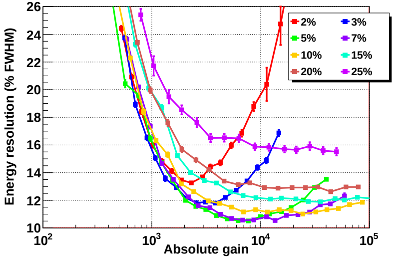


Argon-Isobutane mixtures

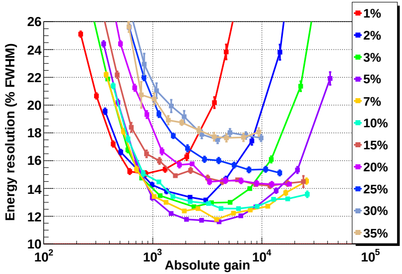
- Gains up to 10^5 are reached in neon-based mixtures (a factor 2).
- The amplification field needed for a fixed gain does not increase with the quencher concentration as in argon-isobutane mixtures.
- Amplification fields for 5% of quencher and a gain of 10^4: 65 (argon-isobutane) and 75 kV/cm (neon-isobutane).

Neon-based mixtures for sub-keV applications

Dependence of the energy resolution with the gain



Neon-Isobutane mixtures



Argon-Isobutane mixtures

- The energy resolution of the 50 μm-thickness-gap detector improves: from 11.6% FWHM in Ar+5% Iso down to 10.5% FWHM in Ne+7% Iso.
- Good values are also obtained at gains as high as 5×10^4.
- This effect can not be explained by the primary ionization but by the fluctuations in the avalanche.

Neon-based mixtures for sub-keV applications

The energy resolution and the primary ionization

- The energy resolution of a Micromegas detector can be expressed as

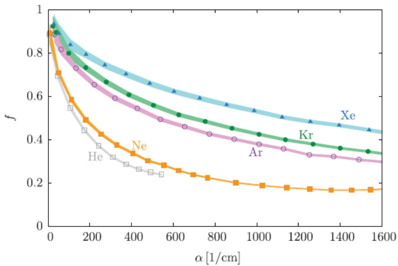
$$R(\%\ \mathrm{FWHM}) \ = \ 2.35 \sqrt{\frac{W}{E_0}\ (F+b)}$$

where E_0 is an energy reference, F is the gas Fano Factor, W is the mean ion-electron energy and b is the detector contribution.

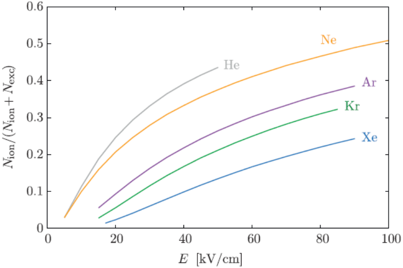
- Note that W = 36.4 eV for Ne and 26.3 eV for Ar and the Fano factor is 0.17 for Ne and 0.22 for Ar. Then $W \times F$ is 6.19 for Ne and 5.79 for Ar.
- The energy resolution should be worse in neon than in argon mixtures!!

Neon-based mixtures for sub-keV applications

The energy resolution and the avalanche fluctuations



Fluctuations vs Townsend coefficient



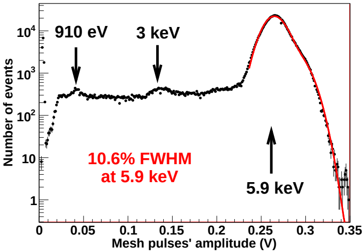
Ionization yeld vs the amplification field

H.Schindler *et al.*, *Nucl. Instrum. Meth. A* **624** (2010) 78

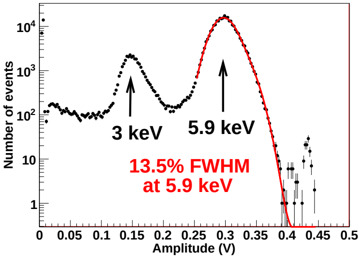
There are less avalanche fluctuations due to a higher ionization yield, i.e., the energy acquired by the electrons of the avalanche creates more than electrons than atom excitations in neon than in argon-based mixtures.

Neon-based mixtures for sub-keV applications

The energy threshold of micromegas detectors



Energy spectrum in Ne+7%Iso



Energy spectrum in Ar+8.6%Cyclo

- Mesh pulses were acquired by a LeCroy WR6050 oscilloscope. The energy spectrum has been generated with the pulses's amplitude.
- In neon-based mixtures, the neon escape peak at 910 eV has been observed. The energy threshold is at 400 eV.
- In argon-cyclohexane mixtures, the threshold is at 300 eV.
- Next step: CAST detector (1.257 nF vs 300 pF of detectors used).

Conclusions

Summary

- Microbulk detectors have been tested in argon- and neon-based mixtures. The maximum gain was respectively 4×10^4 and 10^5 and the energy resolution 11.6% and 10.5% FWHM at 5.9 keV.
- Three different quenchers have been used: isobutane, cyclohexane and ethane. The first one increases the gain and the other reduces it. They have no effect in the best energy resolution value.
- The energy threshold of microbulk detectors have been studied and values as low as 300 eV have been observed.

Outlook

- Characterization of microbulk detectors with a gap of 12.5 and 25 μm and different holes and pitch in argon-isobutane mixtures.
- Study of the energy threshold of bigger detectors like CAST.
- Possible quenchers like cyclohexene and other ideas are welcomed.

Back-up slides.

Micromegas and microbulk technology

How a 2D microbulk detector is built

Kapton foil (50µm), both sides Cu-coated (5µm)

Construction of readout (strips/pads)

Added a single-side Cu-coated kapton foil (25/5)

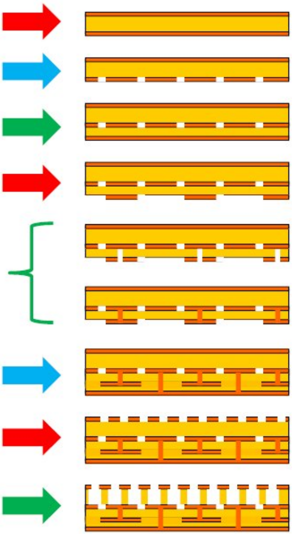
Construction of one direction readout lines

Vias construction by etching the kapton

Construction of the second direct readout lines and vias

Photochemical production of mesh holes

Kapton etching and cleaning



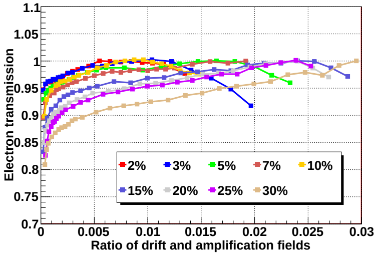
Characterization in argon-based mixtures

Description of the refrigerator

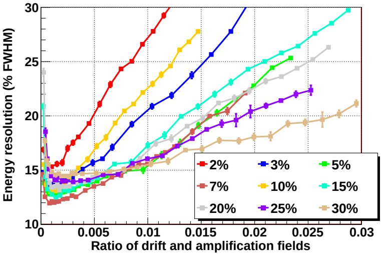
- The base gas is forced to pass by a glass vessel, filled with the liquid quencher like cyclohexane.
- The gas concentration is defined by the temperature of the liquid, which is fixed by the refrigerator in which the vessel is kept.
- The temperature can not be higher than the ambient one to avoid condensations inside the gas chamber, which may damage the microbulk detectors.

Characterization in other argon-based mixtures

Some ideas about the 25 μm-thickness-gap detector



Electron transmission curve

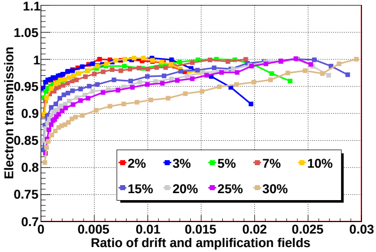


Energy resolution versus ratio of fields

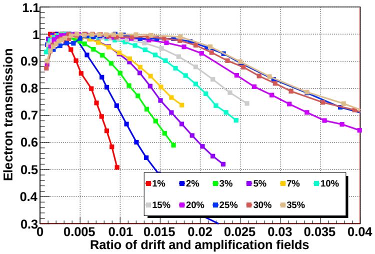
- There is no real plateau of maximum electron transmission plateau.
- There is a narrow range of fields for an optimum energy resolution.
- Gains $> 10^4$ are reached for all mixtures before the spark limit.
- 11.7% FWHM for gains 10^3-10^4 and all quenchers.
- The optimum is at higher quencher concentrations (iso: 7-15%).

Characterization in argon-based mixtures

Comparison of electron transmission in argon-isobutane



25 μm-thickness-gap detector

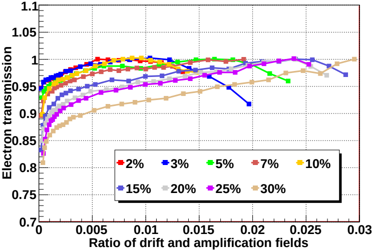


50 μm-thickness-gap detector

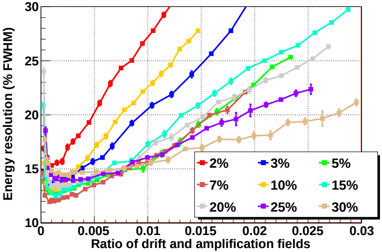
- At low isobutane quencher concentrations, there is a plateau of maximum transparency but is reached at higher drift fields.
- At high quencher concentrations, there is an endless increase of the gain.
- Energy resolution is not more correlated with electron transmission. There is a narrow range of fields for which is the optimum.

Characterization in argon-based mixtures

Comparison of electron transmission in argon-isobutane



Electron transmission curve

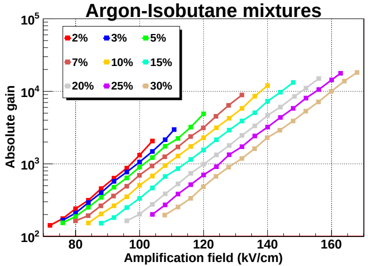


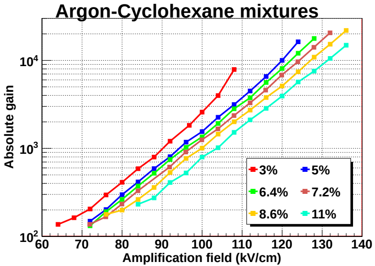
Energy resolution versus ratio of fields

- At low isobutane quencher concentrations, there is a plateau of maximum transparency but is reached at higher drift fields.
- At high quencher concentrations, there is an endless increase of the gain.
- Energy resolution is not more correlated with electron transmission. There is a narrow range of fields for which is the optimum.

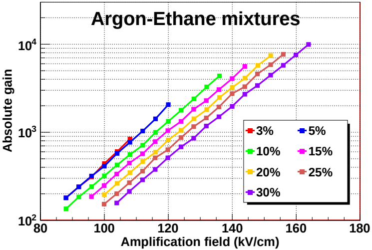
Characterization in argon-based mixtures

The gain curves for a gap of 25 μm



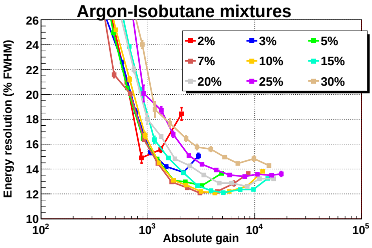


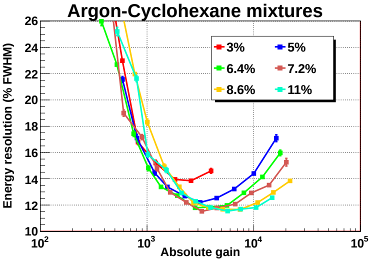
- A gain of 10^4 is reached for all mixtures before the spark limit.
- However, higher quencher concentrations are needed.
- For the same % and field, higher gain with cyclohexane than with isobutane and ethane.



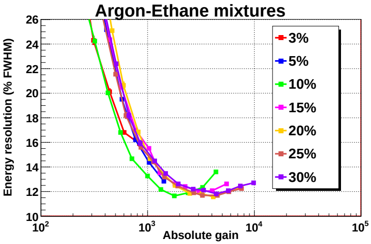
Characterization in argon-based mixtures

The dependence of the energy resolution with the gain for a gap of 25 μm





- There is a degradation at high gains and low concentrations.
- The optimum is at higher quencher concentrations (isobutane: 7-15%).
- 11.7% FWHM for gains 10^3-10^4, independtly of the quencher.



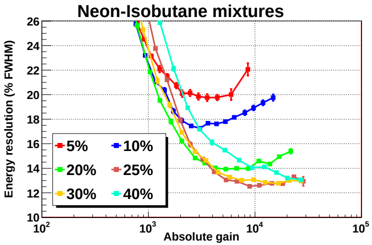
Neon-based mixtures for sub-keV applications

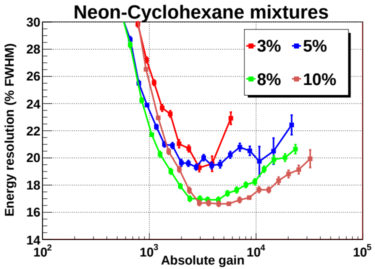
Motivation

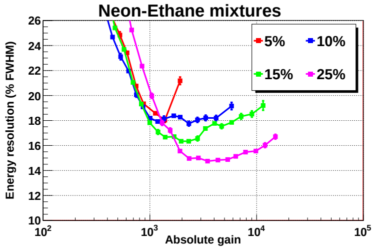
- Micromegas detectors have been tipically operated in argon-isobutane mixtures, as they are well adapted for measurements in the 1-10 keV range, providing an excellent energy resolution and gains up to 2×10^4.
- Other gases are being studied to increase its sensitivity in the sub-keV region, which could allow its application in synchroton radiation and Dark Matter searches where the low energy threshold is crutial.
- The signal to noise ratio must be increased and higher gains are needed.
- Neon as base gas has been studied as the charge per single avalanche increases and approaches the Rather limit (10^8 electrons).

Neon-based mixtures for sub-keV applications

The dependence of the energy resolution with the gain for a gap of 25 μm

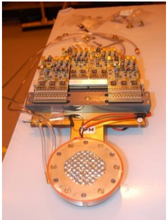
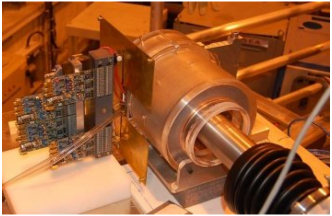






- The energy resolution is worse in neon-based mixtures for a gap of 25 μm and a high quencher concentration is required.
- Best values: 12.7% (25% iso), 17% (10% cyclo), 14.8% FWHM (25% ethane).

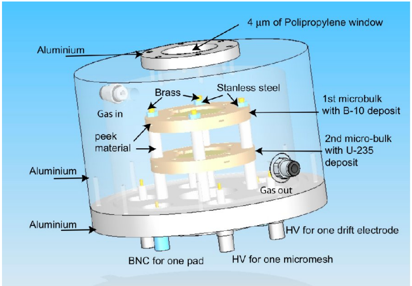
Applications of the microbulk technology
CAST: A solar axion experiment

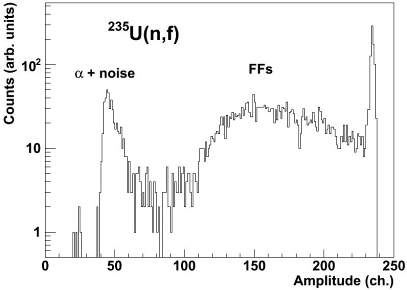




- CAST experiment uses a LHC dipole magnet to detect solar axions.
- Energy range of interest: 1-8 keV.
- 3 Micromegas detectors installed. Readout: 106×106 strips, 550 μm pitch. Gas: Ar + 2.3% Isobutane at 1.44 bar.
- References: *J. Phys. Conf. Ser.* **179** (2009) 012015 and the talks at the TIPP2011 conference: "CAST micromegas background in the LSC" and and "Background rejection of Micromegas readouts".

Applications of the microbulk technology

nTOF: A neutron flux monitor and 2D profiler

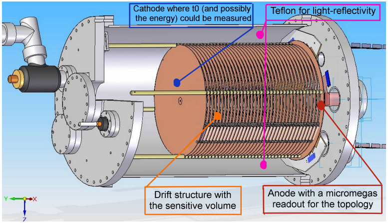


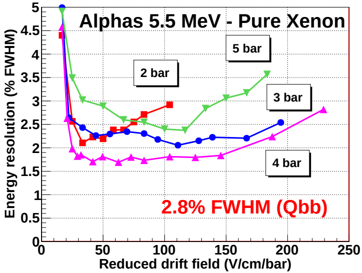


- A thin microbulk detector has been placed in the beam, equiped with a converter (^{10}B or ^{235}U) deposited on the drift electrode.
- Low material budget ⇒ Minimum beam perturbation and induced background.
- Wide energy range, high efficiency and accuracy.
- Future: 2D detector microbulk for an online beam profile monitor.

Applications of the microbulk technology

A ^{136}Xe TPC equiped with a Micromegas readout



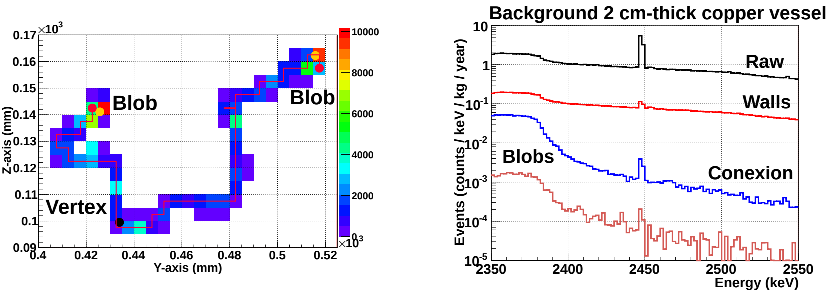


Feasibility studies in NEXT project

- Energy resolution: S. Cebrian *et al.*, *JCAP* (2010) 1010:010.
- Gain: C. Balan *et al.*, *JINST* (2011) **6** P02006.
- Radiopurity: S. Cebrian *et al.* *Astropart. Phys.* (2011) **34** 354.
- Prototypes: T Dafni, talk at 5th Large TPC Conference, Paris, 2010.
- Background: F.J. Iguaz, http://zaguan.unizar.es/record/5731.

Applications of the microbulk technology

A ^{136}Xe TPC equiped with a Micromegas readout



Feasibility studies in NEXT project

- Energy resolutions $< 3\%$ FWHM at 2458 keV ($Q_{\beta\beta}$) in pure xenon.
- Gains greater than 10^2 in pure xenon.
- Low background level due to the detector.
- High background rejection power $\Rightarrow$ Four orders of magnitude.