Characterization of a Spherical Proportional Counter in Ar-based mixtures

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Outline

- Principles of the detector.
- Applications of the SPC & NEWS network.
- Setup & motivation of this work.
- Main results: performance & the effect of field corrector.
- Conclusions and prospects.

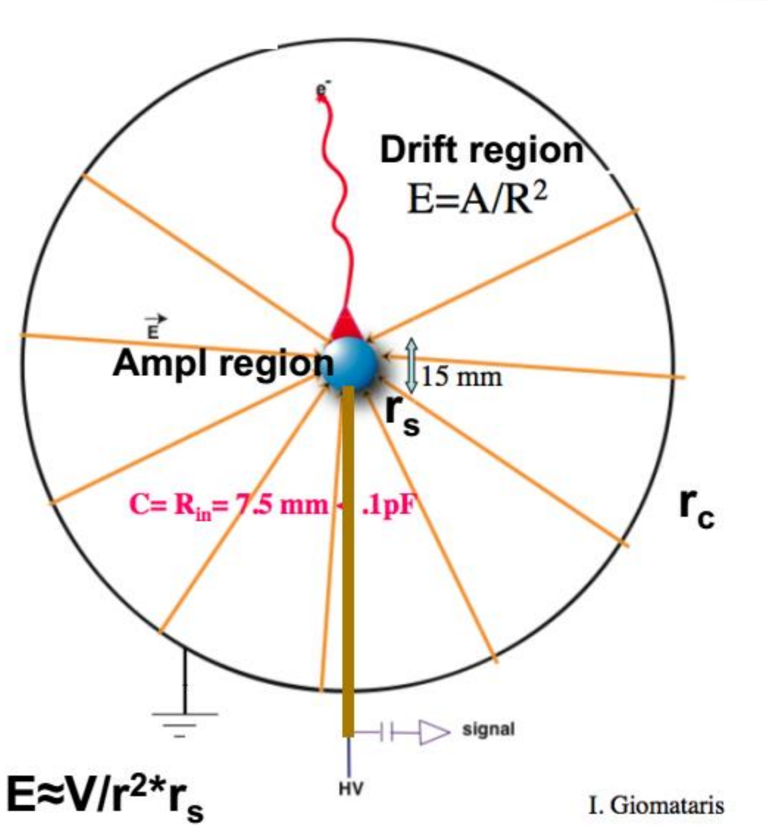
The Spherical Proportional Counter (SPC)

Description

- Sphere cavity + spherical sensor at the center at high voltage.
- Charges created by radiation drift to the central sensor & are amplified in the last milimetres.

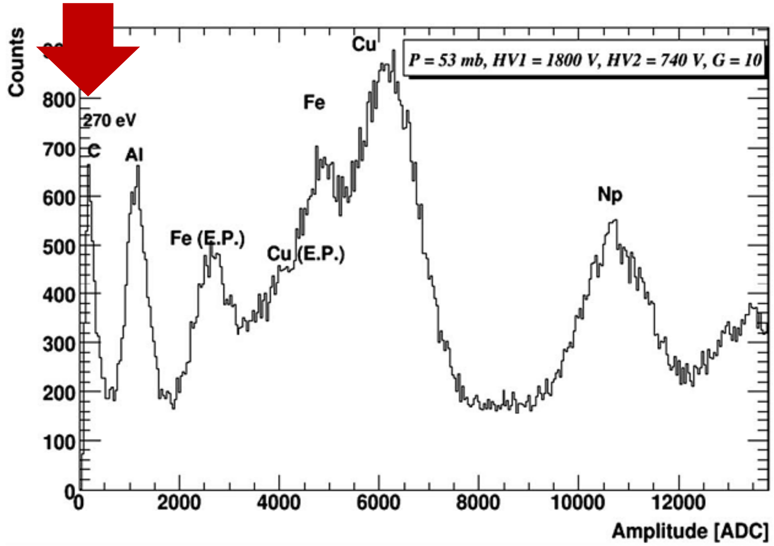
Main features

- Single readout channel reads a big gas volume (big mass).
- Risetime discrimination: fiducial volume & topology.
- Low energy threshold due to its low noise (C ~Rin < 1 pF).
- Good energy resolution.

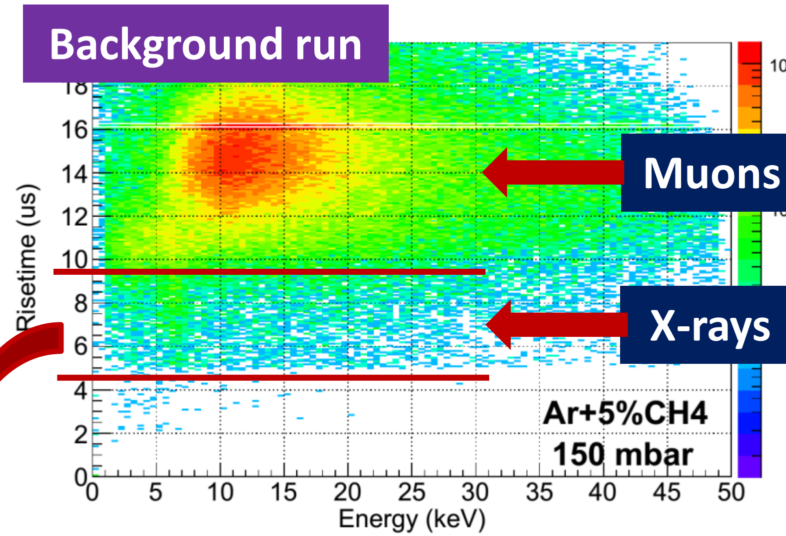


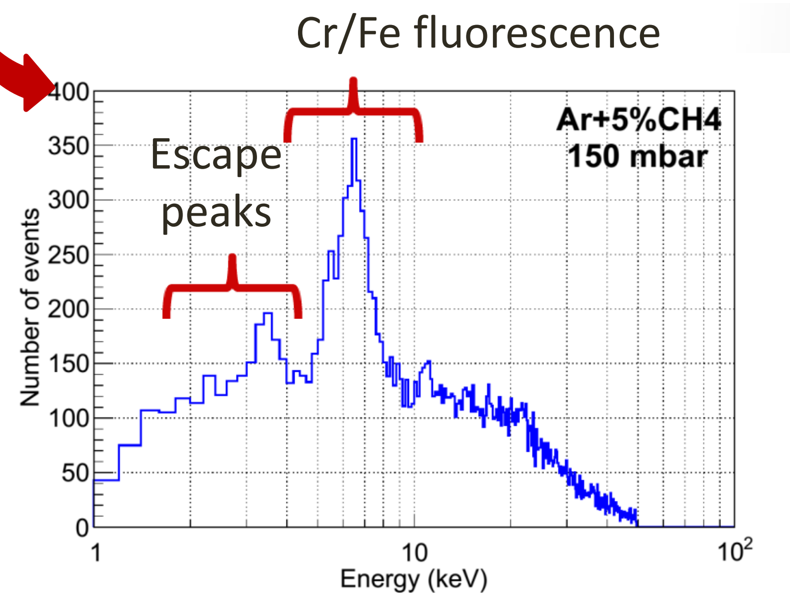
I. Giomataris, *JINST* 3 (2008) P09007

Main features of the SPC



E. Bougamont, *J. Mod. Phys.* 3 (2012) 57





- Energy resolution: **9% FWHM at 22.1 keV.**
- Energy threshold: **< 0.1 keV**.
- Risetime discrimination:
  - Topology: muons vs x-rays.
  - Fiducial volume: risetime is related to the event position by diffusion.

Applications of the SPC & NEWs

- Light WIMPs search with SEDINE (*G. Gerbier, TAUP 2013, arXiv:1401.7902*).
- Thermal & fast neutron detection.
- SuperNovae neutrino detection (*I. Giomataris, Phys. Lett. B 634 (2006) 23*).
- Reactor neutrino coherent scattering (*J.D. Vergados, Phys. Rev. D 79 (2009) 113001*)
- Double beta decay (*I. Giomataris, J. Phys. Conf. Ser. 309 (2011) 0120*10).
- ALPs (Axion Like Particle): decays in 2 photons inside the SPC. Motivated by the solar corona temperature problem (*L. Di Lella, Astro. Part. 19 (2003) 145*).

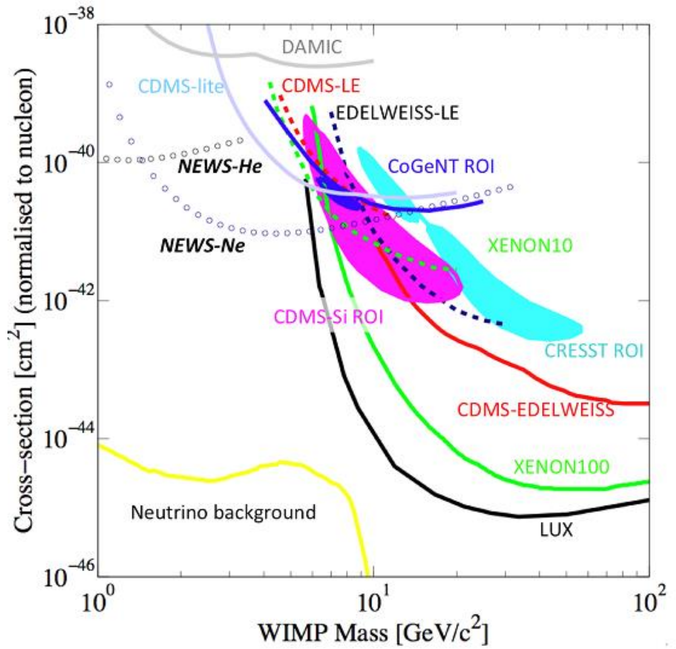
NEWS: New Experiments With Spheres.

- A network to develop the SPC.
- Institutes:
  - France: IRFU/Saclay & Lab. Modane.
  - Greece: University Ioannina, Demokritos, Hellenic Open University.
  - China: University Tsinghua, Sanghai Jiao Tong University
  - Spain: University Zaragoza

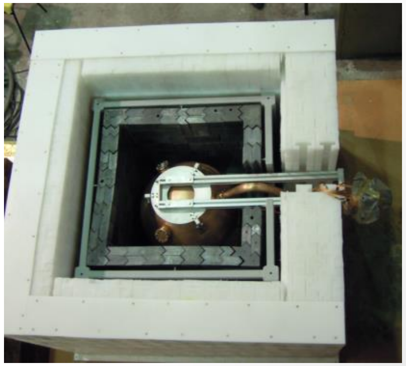
Tessaloniki 2012

SEDINE: a SPC for Dark Matter Searches

- **Motivation: search for very light dark matter particles (< 10 GeV).**
- Favoured by CoGeNT/DAMA-LIBRA claims & LHC results.
- SPC made of radiopure copper vessel & Pb/Pe shielded installed at Modane Laboratory (LSM).
- Taking data since Sep 2012.
- Calibration with ^{37}Ar source for volume response: 260 eV & 2.6 keV.
- Gases: Ne & Ne/He at 2-4 bars.



G. Gerbier, talk at *TAUP 2013*, arXiv:1401.7902

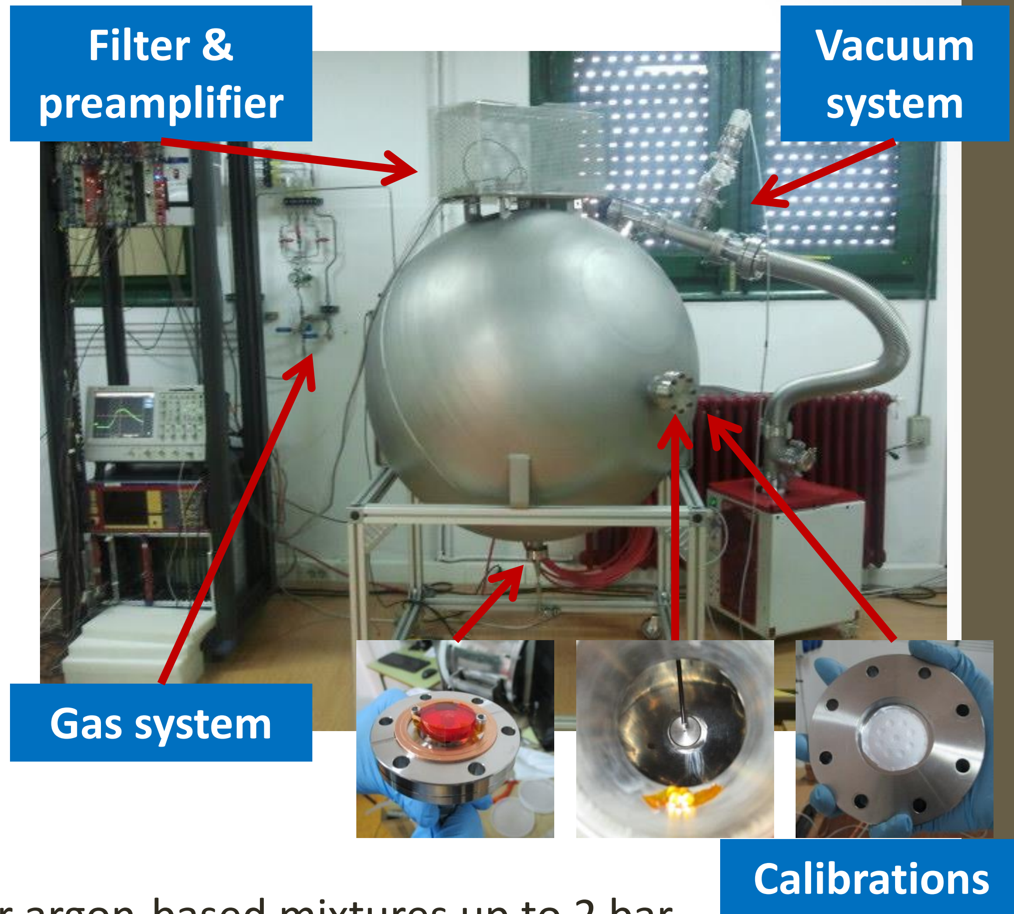


See Ali Dastgheibi-Fard's poster for the latest results!

Setup & motivation of this work

Setup description

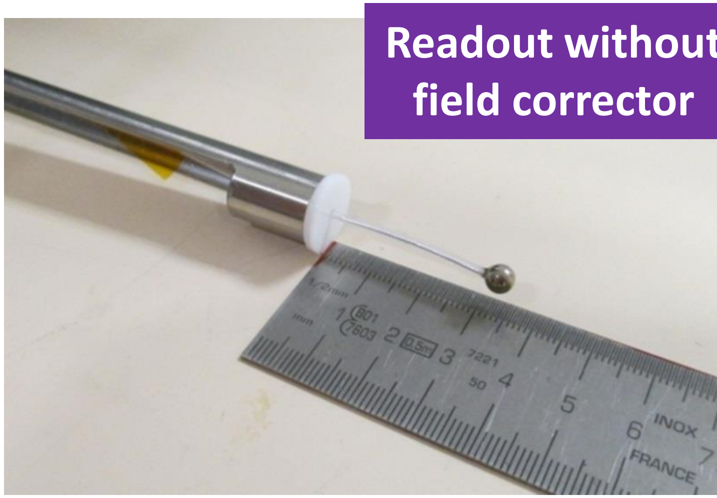
- 530 liter stainless steel vessel.
- Outgassing < 10^{-6} mbar l/sec.
- Operation in seal-mode > 1 week.
- A filter decouples the signal from the High Voltage.
- DAQ: Tektronix oscilloscope.
- Two central electrodes tested: with & without field corrector.
- Calibrations from inside (bottom & lateral) and outside.

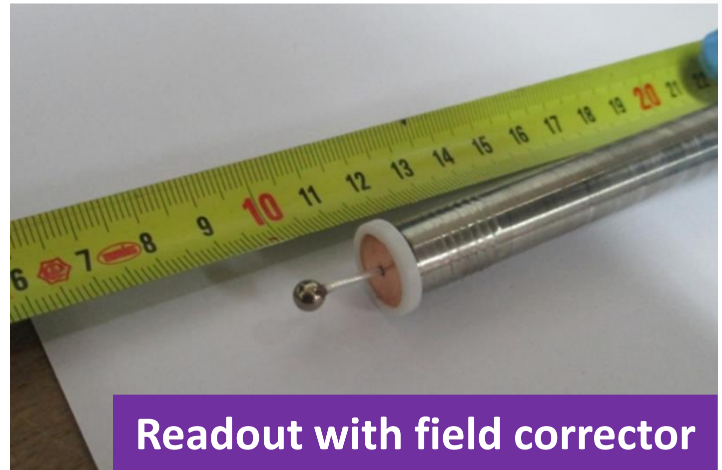


Goals of this work

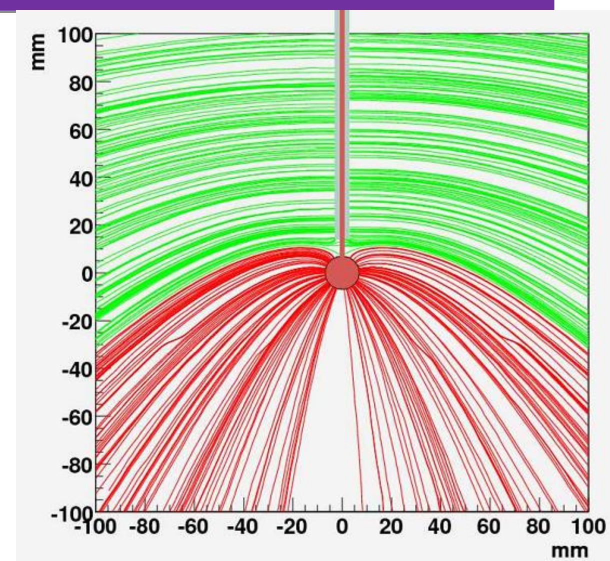
- Study of the SPC performance for argon-based mixtures up to 2 bar. Important for the sensitivity studies of SPC applications.
- Study of the effect of field corrector on the SPC performance.

Central electrode with(out) field corrector



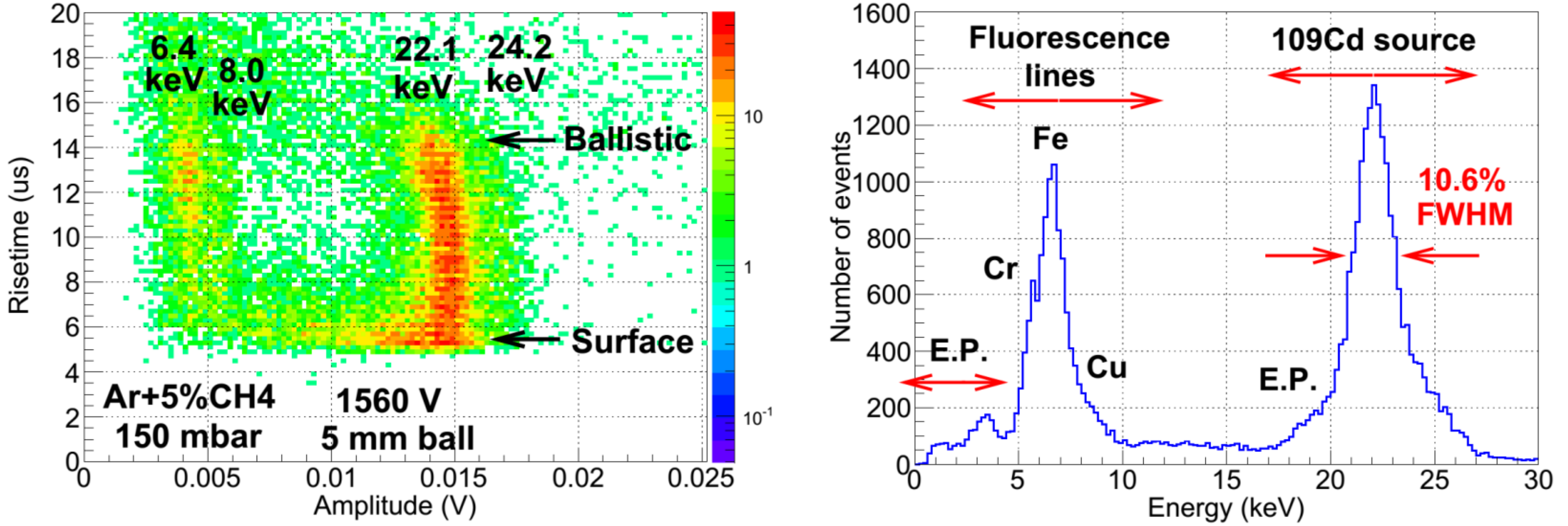


- Central electrodes tested with a **5 mm ball**:
  - Without field corrector (teflon at 30 mm).
    (Good data only calibrating from bottom part)
  - With field corrector (situated at 20 mm).
- Clearly degradation in SPC performance **without field corrector** for lateral calibrations. The energy resolution goes from **10% to 25% FWHM at 22.1 keV**.



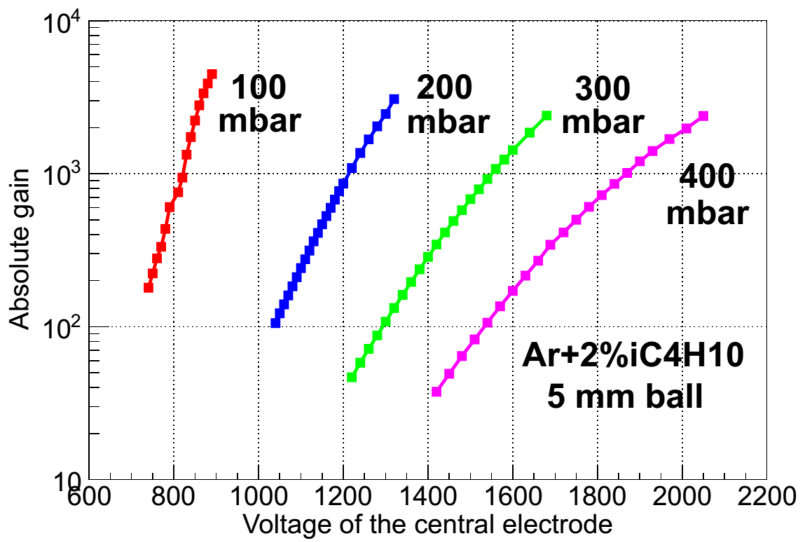
I. Giomataris, *JINST* 3 (2008) P09007

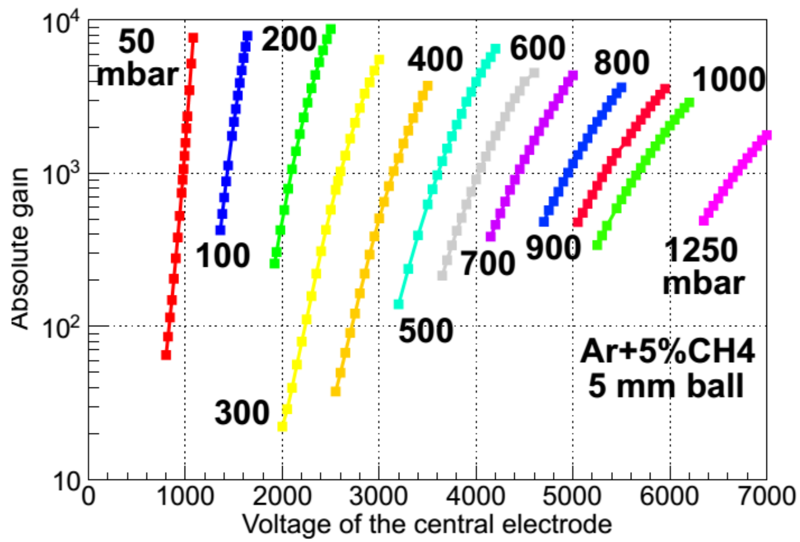
Performance study: procedure & analysis



- Calibration with ^{109}**Cd** (**22.1 keV** line) used to study the SPC performance.
- Pulses recorded by oscilloscope for an offline analysis (amplitude, risetime…)
- **Risetime selection:**
  - Upper bound: to remove muons & ballistic effects.
  - Lower bound: to remove ball surface effects (without field corrector).
- Finally, the 22.1 keV line is fitted to a gaussian: mean & sigma.
- Fluorescence lines of **Cr (5.5), Fe (6.4) & Cu (8.0 keV)** are also observed.

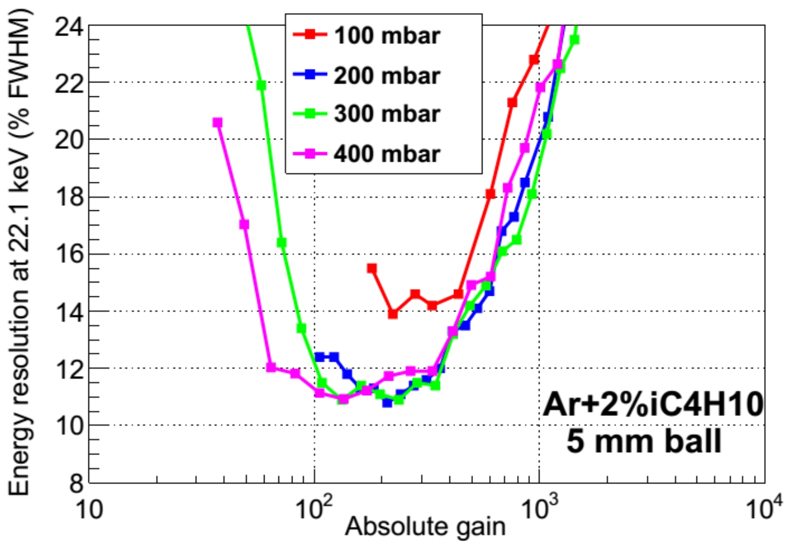
Results without corrector: gain curves

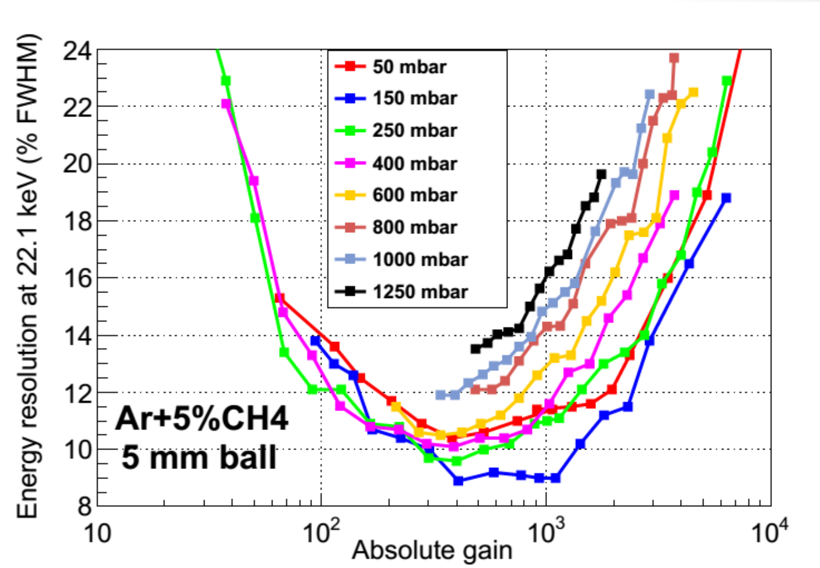




- Argon-based mixtures: **isobutane** (100-400 mbar) & **methane** (50-1250 mbar).
- Gains > **$2x10^3$** (similar values than MWPC, lower than MPGD). No sparks seen. Data-taking resumed when energy resolution degraded (see next slide).
- At high gains the gain curves do not follow the Rose-Korff model. Saturation effect: reduction of the effective field?
- Lower voltages needed for isobutane than methane for the same gain.

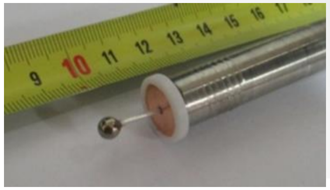
Results w/t corrector: energy resolution

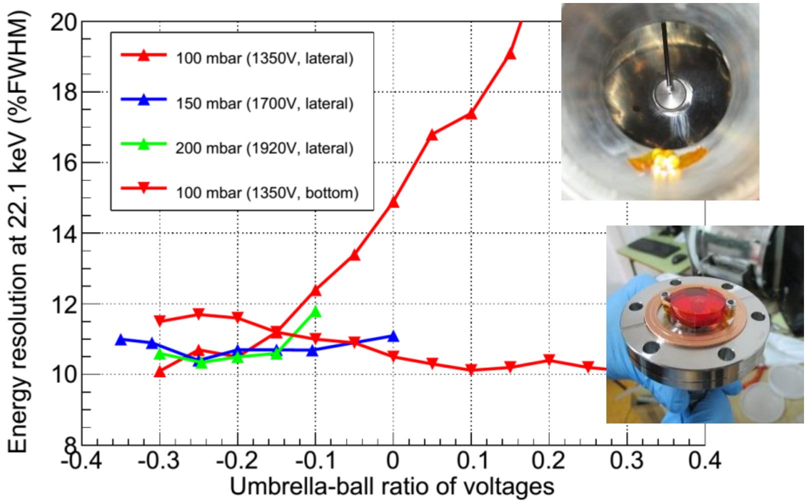


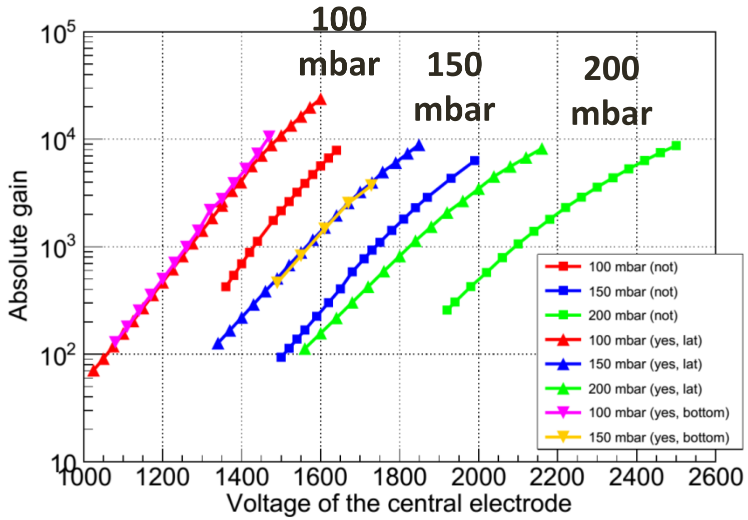


- Energy resolution shows a region of best values for each gas/pressure.
- Limits: noise & ballistic effect (low gain) and saturation effect (high gain). Ranges: **0.1-0.3 x 10^3** for isobutane; **0.2-1.0 x 10^3** for methane.
- Best values: **11% FWHM** for isobutane**, 9% FWHM** for methane at 150 mbar.
- Energy resolution slightly degrades with pressure for methane.

The effect of the field corrector

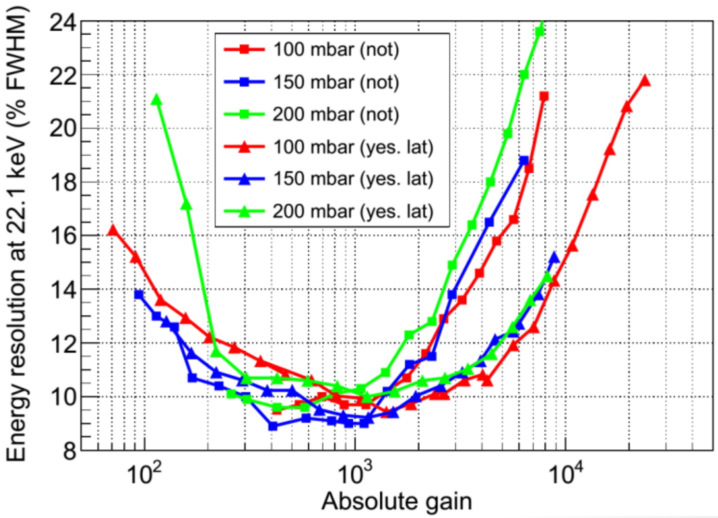






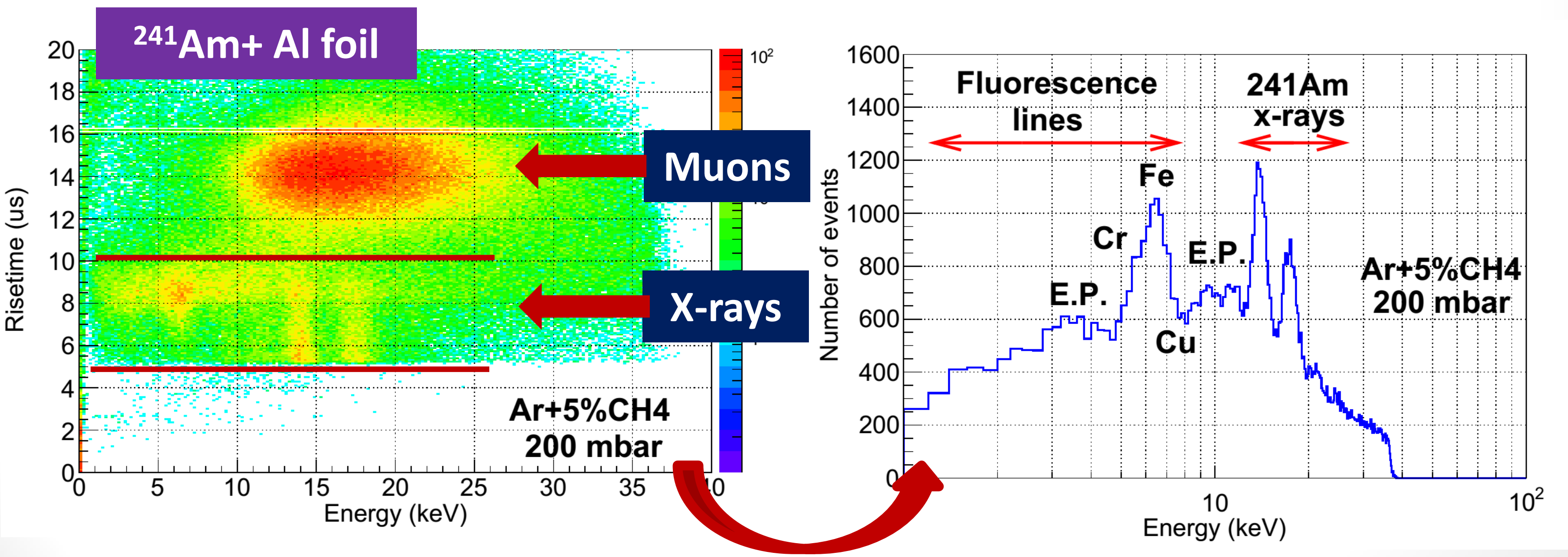
First results with the field corrector

- Lateral calibrations improve when a negative voltage is set to umbrella. Slightly degradation for bottom.
- Higher gains & better homogeneity!
- Energy resolution degrades at higher gains & energy threshold is ~**1 keV**.



Data-taking is ongoing…

- The new electrode is being characterized in Ar+5%CH_4 at 100-1250 mbar.
- Several studies on going…
  - The degradation of energy resolution at high pressure.
  - The muon/x-rays discrimination vs gas pressure.
  - The energy threshold vs gain (using ^{241}Am source & foils).



Conclusions & prospects

Conclusions

- The Spherical Proportional Counter (SPC) is a novel type of radiation detector with low energy threshold, good energy resolution and good discrimination.
- Many applications: **light WIMP search (SEDINE),** neutrons, neutrinos, ββs, ...
- This work: performance at high pressure, as it is a key-feature for sensitivity.
- Energy resolution: **9% FWHM** at **22.1 keV** in Ar+5%CH_4 at 150 mbar. Optimum range: **0.2-1.0 x 10^3**. **11% FWHM** for Ar+2%C_4H_{10}. Degradation with pressure.
- The field corrector is needed: better energy resolution from lateral events.

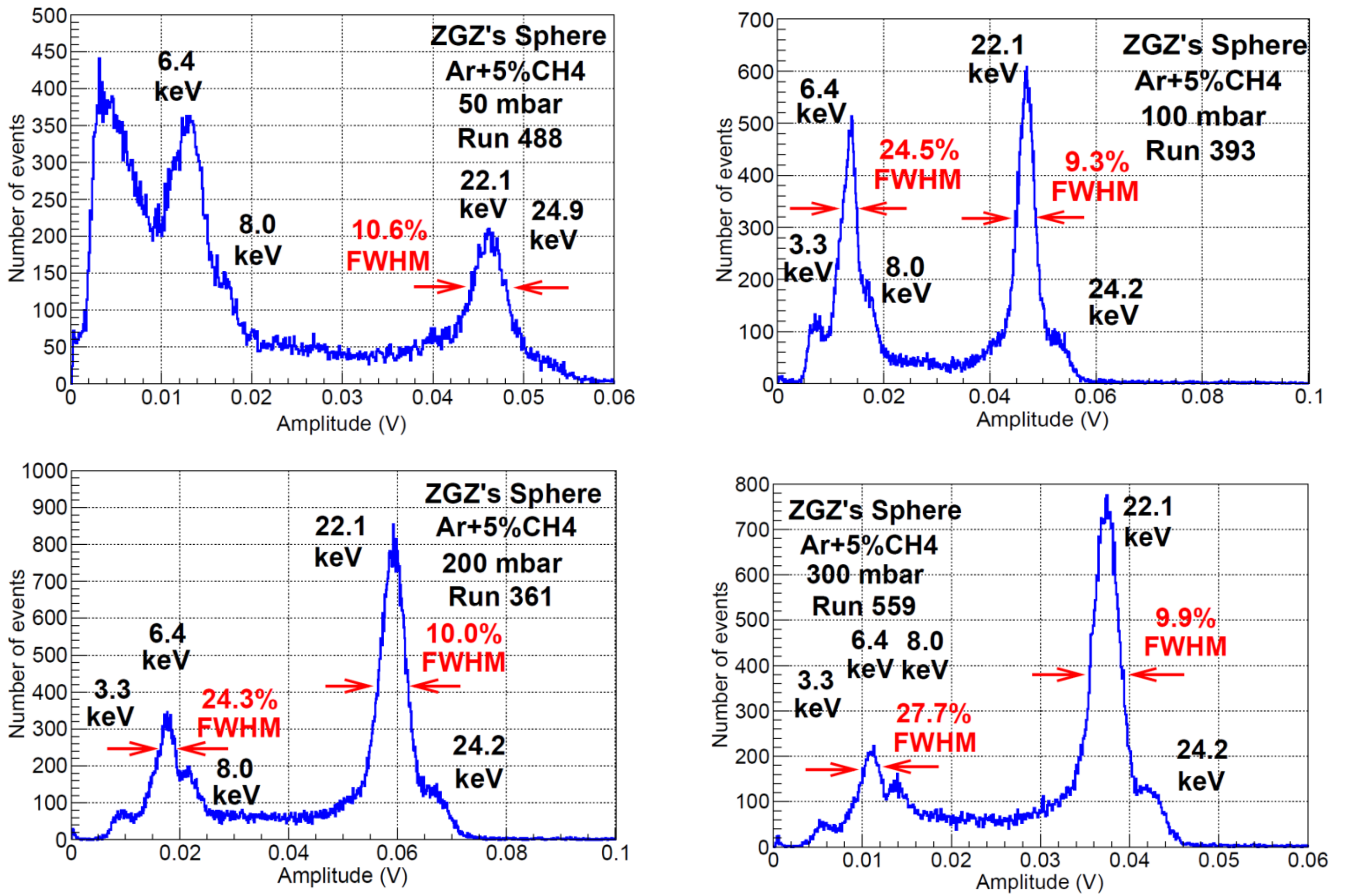
Prospects

- The electrode with field corrector is being characterized in in Ar+5%CH_4.
- Other studies on going: discrimination features & energy threshold.
- Other gases to be tested: Ne & He (for light WIMPs); Xe (for neutrino physics).

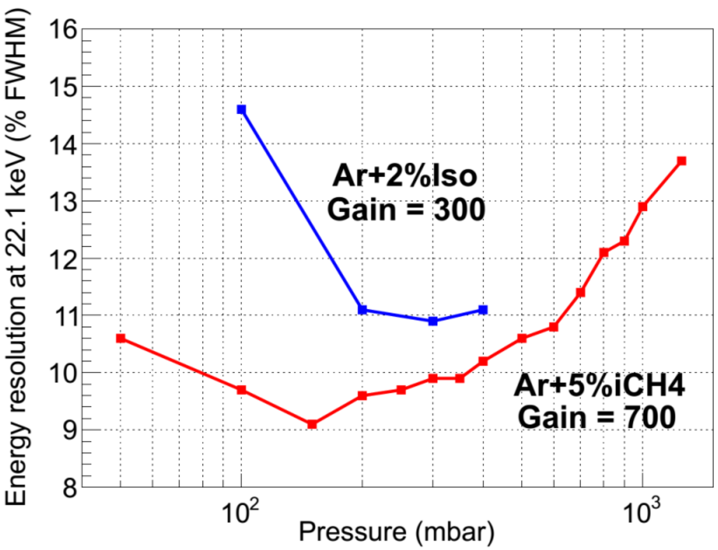
See Ali Dastgheibi-Fard's poster for the latest results in background reduction with a SPC installed at LSM!!

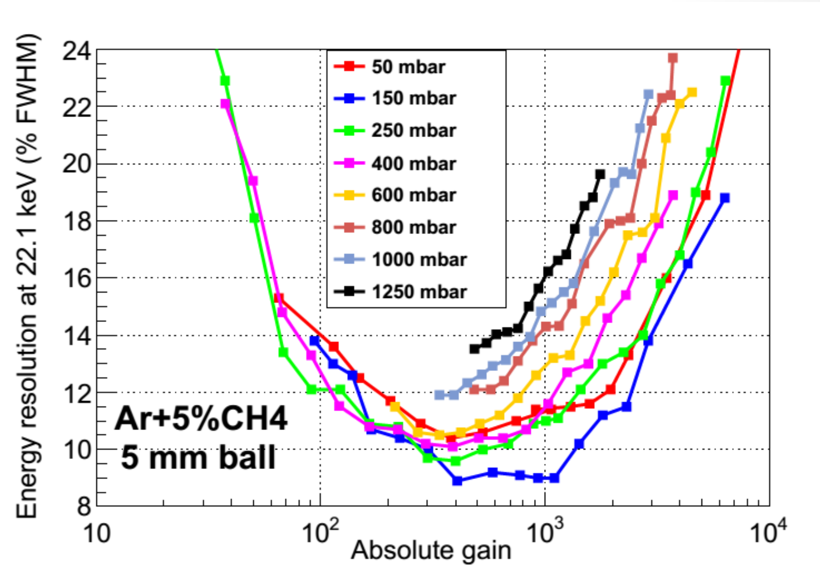
Back-up slides

Fluorescence intensity vs pressure



Results w/t corrector: energy resolution





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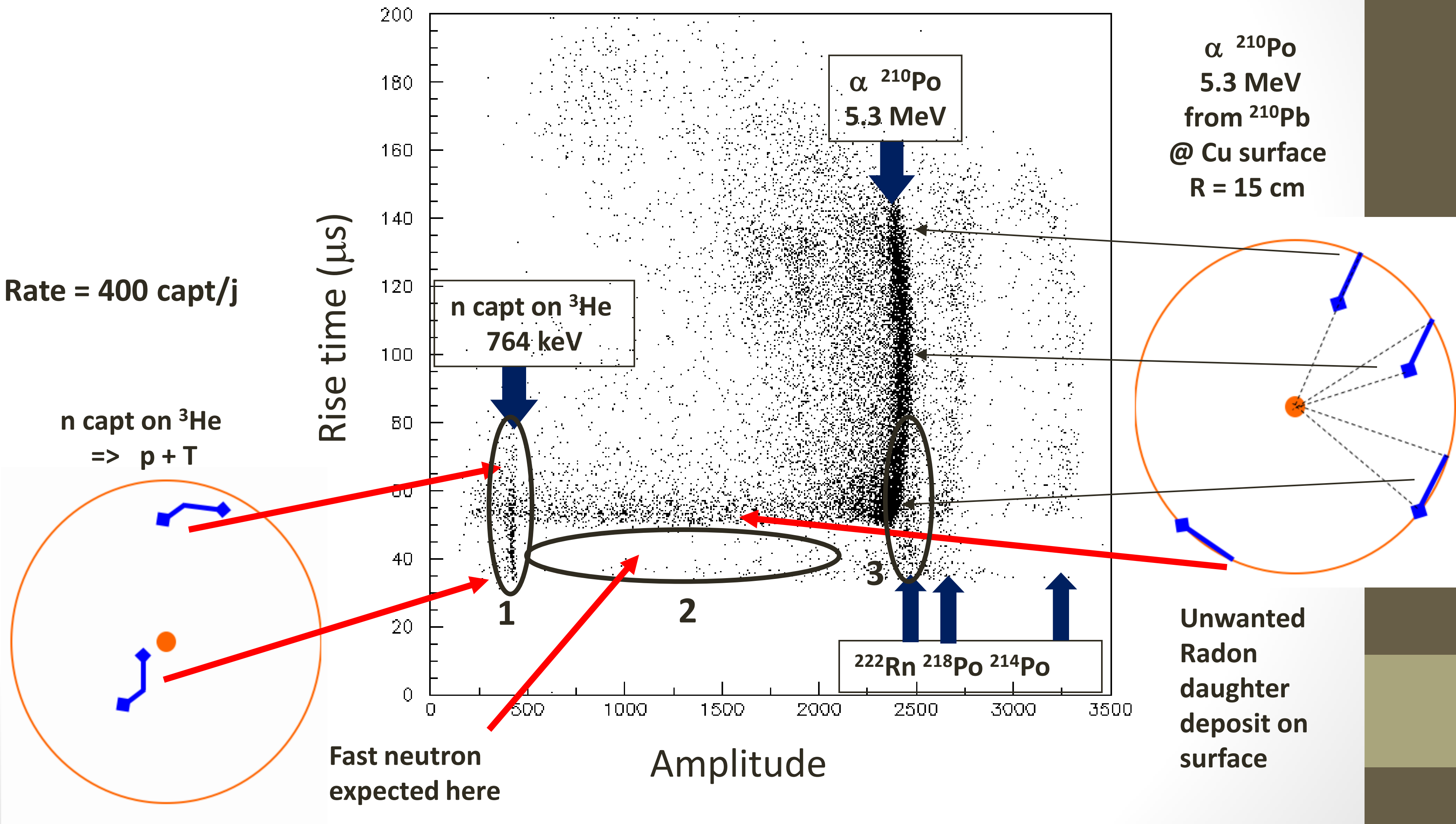
- Best values: **9% FWHM for methane**, **11% FWHM for isobutane**.
- Energy resolution slightly degrades with pressure for methane.

Ar/CH_4 + 3g ^{3}He @ 200 mb SPC 130cm Ø @ LSM

G. Gerbier, talk at *TAUP 2013*, arXiv:1401.7902

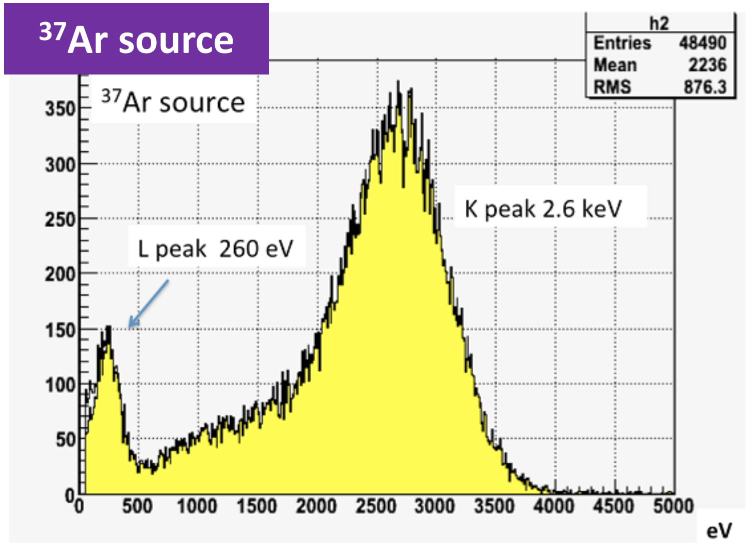
Rate = 400 capt/j



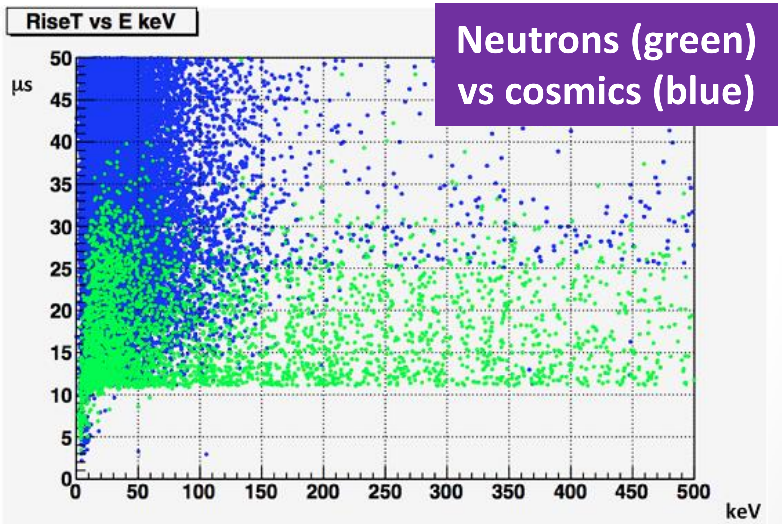
Recent developments at SEDINE

- Decrease high radioactive contamination: surface Radon descendants .
- Improve pulse shape analysis: calibration, templates…
- Perform calibration with neutron & ^{37}Ar.
- Perform quenching factor measurements in <keV region at Grenoble.
- Decoupling of amplification from drift: new ideas currently tested.

^{37}Ar source



Neutrons (green) vs cosmics (blue)



G. Gerbier, talk at *TAUP 2013*, arXiv:1401.7902

SPC as Supernova detector

I. Giomataris, CERN 2012

Supernova detector

Through neutrino-nucleus coherent elastic scattering

Supernova neutrino detection with a 4 m spherical detector

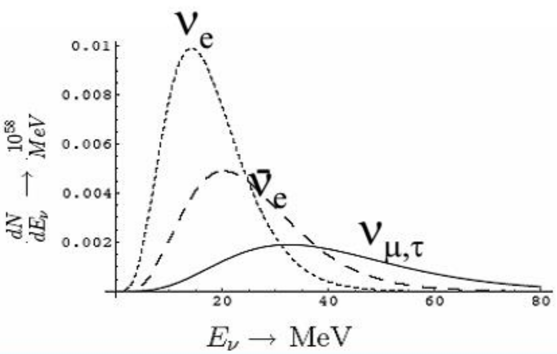
Y. Giomataris, J. D. Vergados, Phys.Lett.B634:23-29,200

The average nuclear recoil energy is:

	He	Ne	Ar	Kr	Xe	
$\langle E_r \rangle$:	0.576	0.117	0.058	0.029	0.017	MeV

The threshold neutrino energy (for nuclear recoil energy E_{th}=250 eV) is

	He	Ne	Ar	Kr	Xe	
$(E_\nu)_{th}$	0.70	1.58	2.24	3.16	4.05	MeV



Sensitivity for galactic explosion

For p=10 Atm, R=2m, D=10 kpc, U_ν=0.5x10^{53} ergs

 # Number of events (no quenching, zero threshold)

He	Ne	Ar	Kr	Xe	Xe (with Nuc. F.F)
.16	3.95	19.1	76.8	235	179

 # Number of events (after quenching, E_{th}=0.25 keV)

He	Ne	Ar	Kr	Xe	Xe (with Nuc. F.F)
0.08	1.5	**6.7**	23.8	68.1	**51.8**

Idea : A world wide network of several (tenths or hundreds) of such dedicated Supernova detectors robust, low cost, simple (one channel)

To be managed by an international scientific consortium and operated by students

SPC: neutrino-nucleus coherent scattering

I. Giomataris, CERN 2012

Neutrino-nucleus coherent elastic scattering

$\nu + N \rightarrow \nu + N \quad \sigma \approx N^2 E^2$, *D. Z. Freedman, Phys. Rev.D,9(1389)1974*

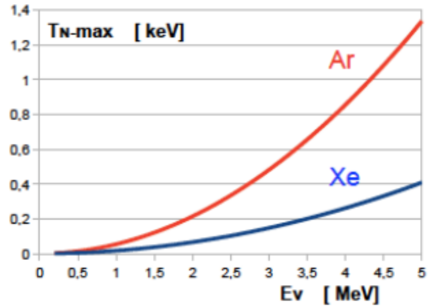
A. Druikier, L. Stodolsky, Phys.Rev.D30:2295,1984, JI Collar, Y Giomataris - NIMA471:254-259,2000, H. T. Wong, arXiv:0803.0033-2008, PS Barbeau, JI Collar, O Tench - Arxiv preprint nucl-ex/0701012, 2007

High cross section but very-low nuclear recoil

$T_N = 2\, m_N (E_n \cos\theta)^2 / \{(m_N + E_n)^2 - (E_n \cos\theta)^2\}$

Illustration: using the present prototype at 10 m from the reactor, after 1 day run

target	anti ν_e (QF, no Thr)	anti ν_e (QF) Thr = 1 electron	anti ν_e (QF) Thr = 2 electron
Xe	2325	**825**	**275**
Ar	430	**292**	**210**



Argon is a good candidate

Challenge : Very low energy threshold
We need to calculate and measure the quenching factor
Application : Remote control of nuclear reactor