Extending dark matter searches with a spherical TPC

Axions and friends (AFPs)

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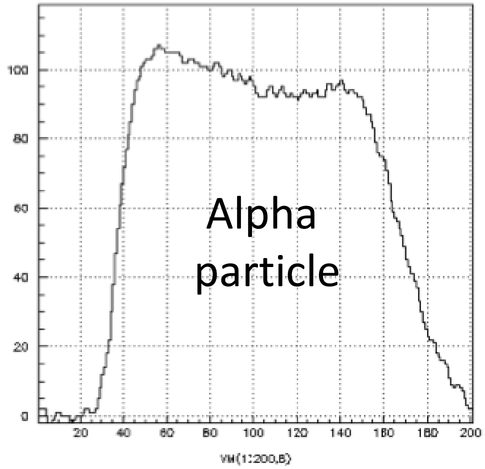
In collaboration with Thessaloniki, Univ. Zaragoza, Tsighua university,(HEP Beijing) Shanghai Jiao Tong University, and LSM (Modane).

Physics with Spherical TPC (Low energy threshold)

- **Simple and cheap**
- **Large volume**
- **single read-out**
- **Robustness**
- **Good energy resolution**
- **Low energy threshold**
- **Efficient fiducial cut**
- **High dinamic range**

Good capability for particle recognition

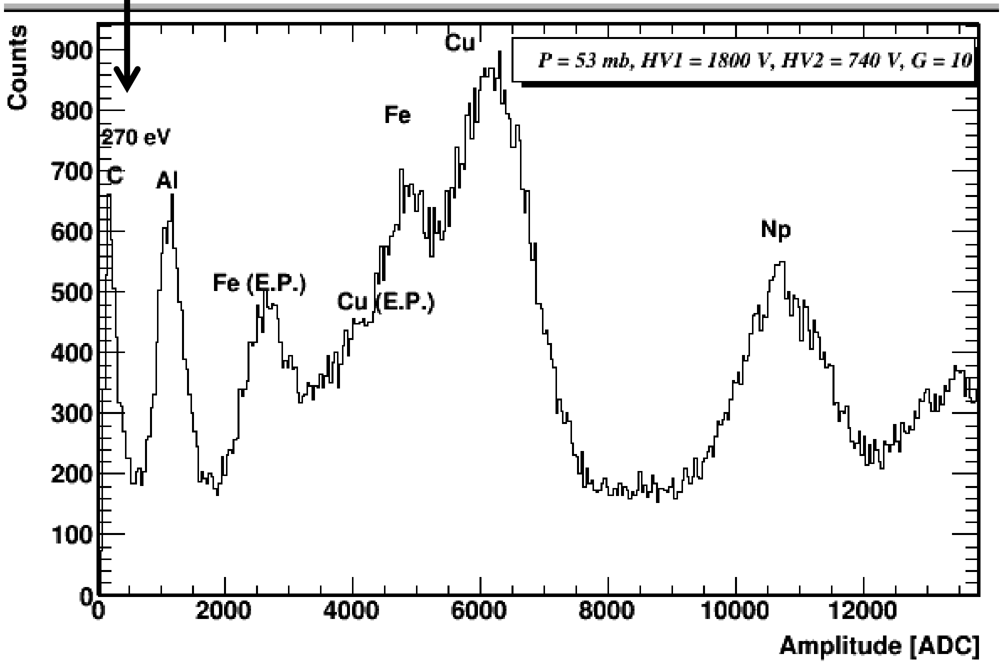


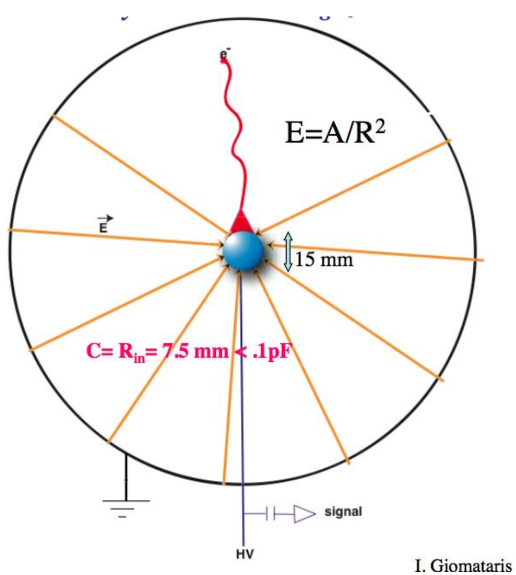
Great flexibility (P, gaz)
Allows to play with parameters used for discrimination and background

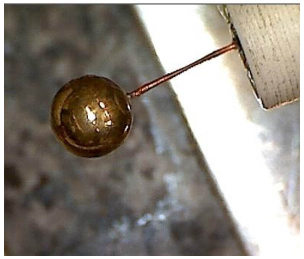
Long drift times (few hundred of microseconds).
Fiducial selection by risetime

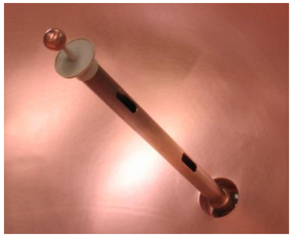
World record with TPC (C peak @270eV)

Am241 source with polypropylene foil









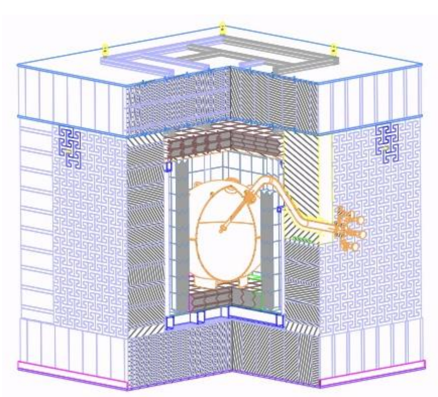
A Novel large-volume Spherical Detector with Proportional Amplification read-out, I. Giomataris *et al.*, JINST 3:P09007,2008

Spherical TPC calibration and set-up

Existing spheres running in ground and undergraound laboratories

2 LEP cavity 130 cm Ø
1 low activity 60 cm Ø in operation @ LSM

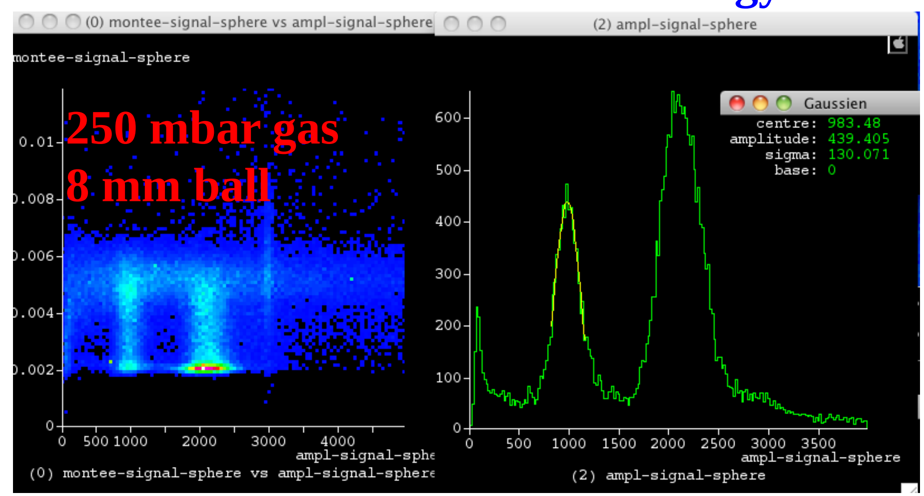
SEDINE set-up at Modane (LSM) 30 cm sphere
Underground
Radiopure copper sphere
10-15 cm lead
25 cm poliethilene
Purified air (Radon free)

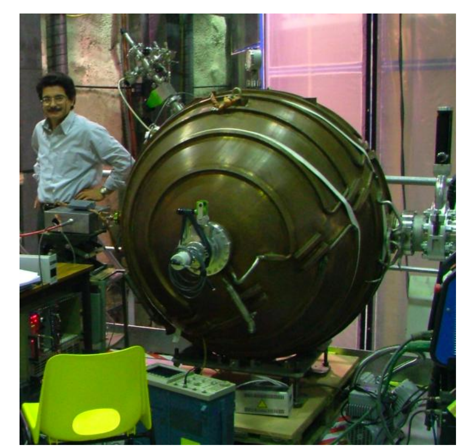


Home made Ar-37 source: irradiating Ca-40 powder with fast neutrons 7x10^{6}neutrons/s

Irradiation time 14 days. Ar-37 emits K(2.6 keV) and L(260 eV) X-rays (35 d decay time)

Total rate 40 hz of low energy lines

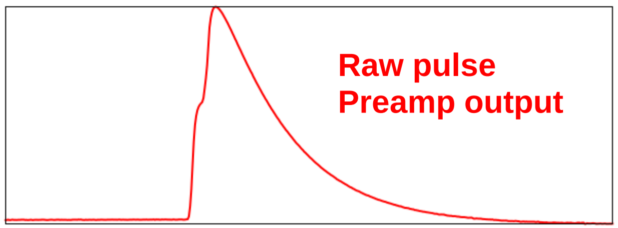


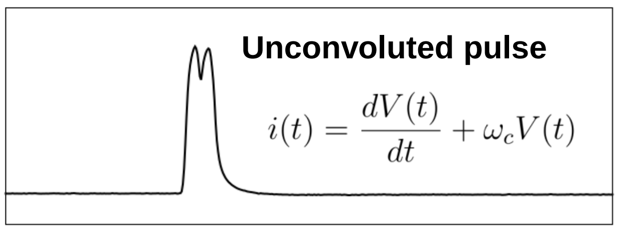


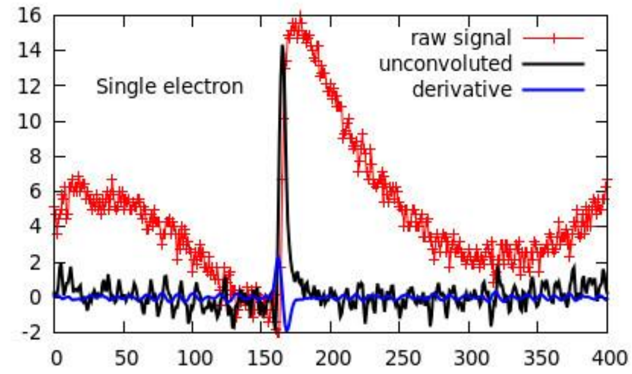
Signal discrimination for double decay detection

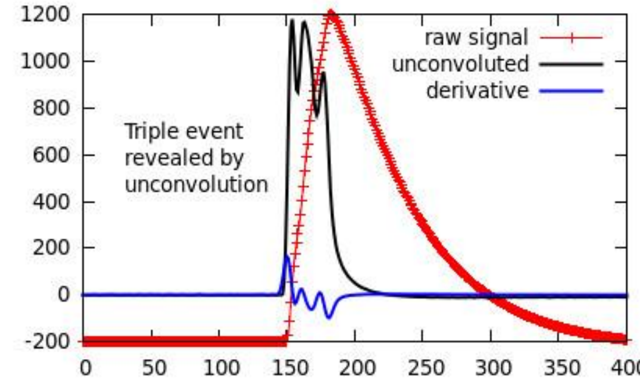
Digitisation @ 1 MHz, soft trigger

RC integration removed







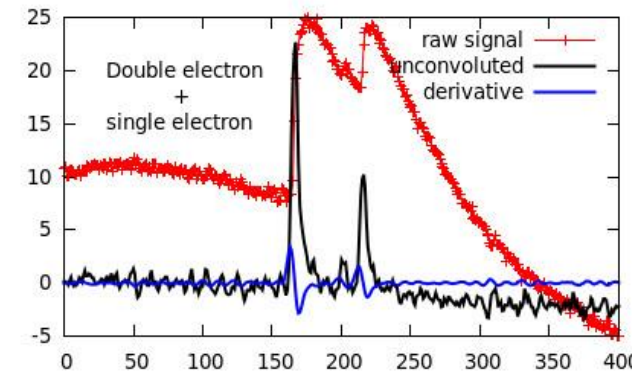


Close hist (within 5us) can be identified

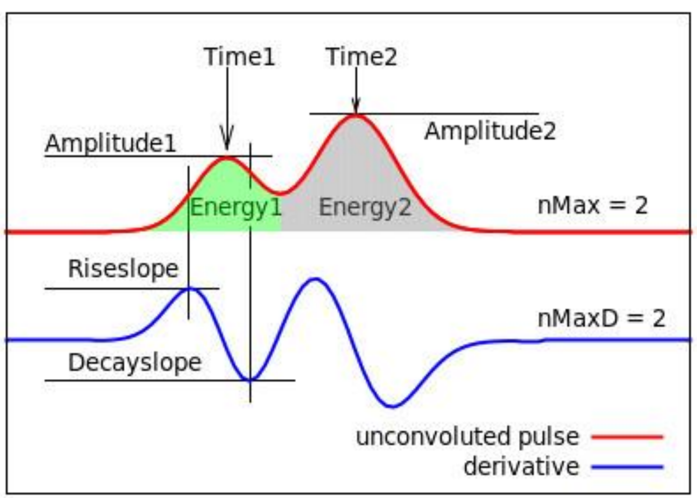
Pulse unconvolution is used to identify peak position in time.

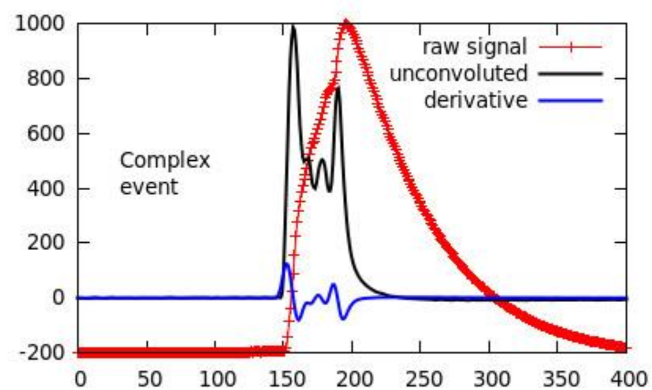
Derivative helps to discover profile variations or very close events.

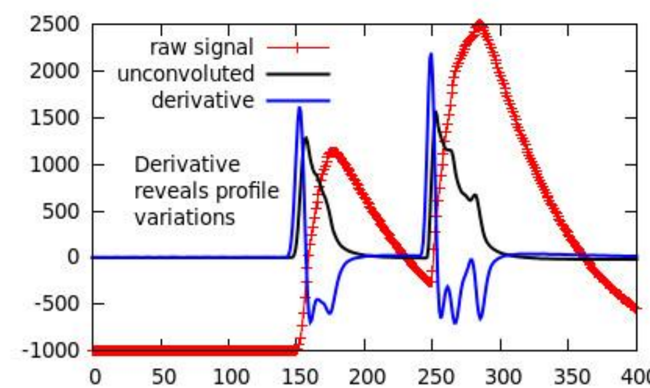
Extremely low electronic noise! 1 electron equivalent energy is observed clearly!



Pulse parameters definition

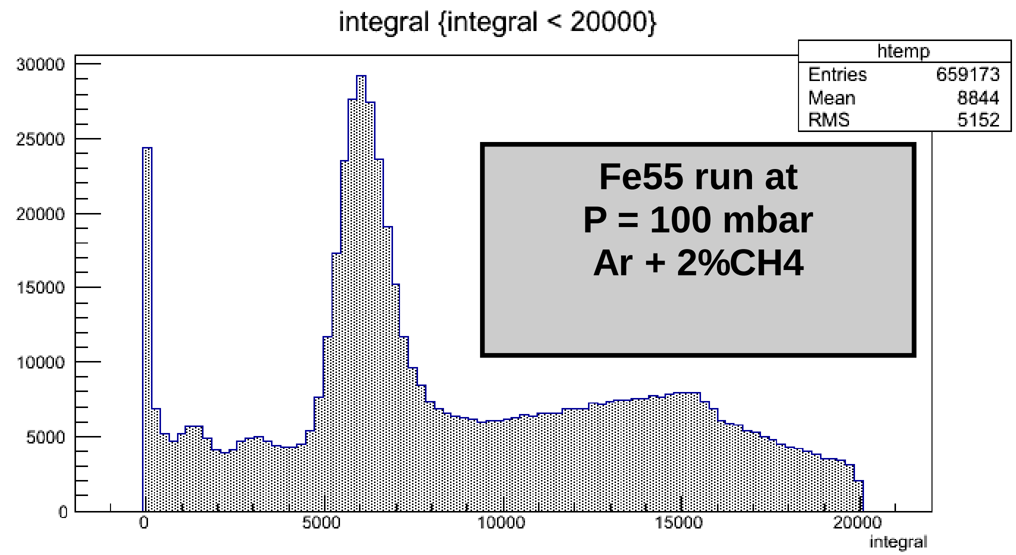




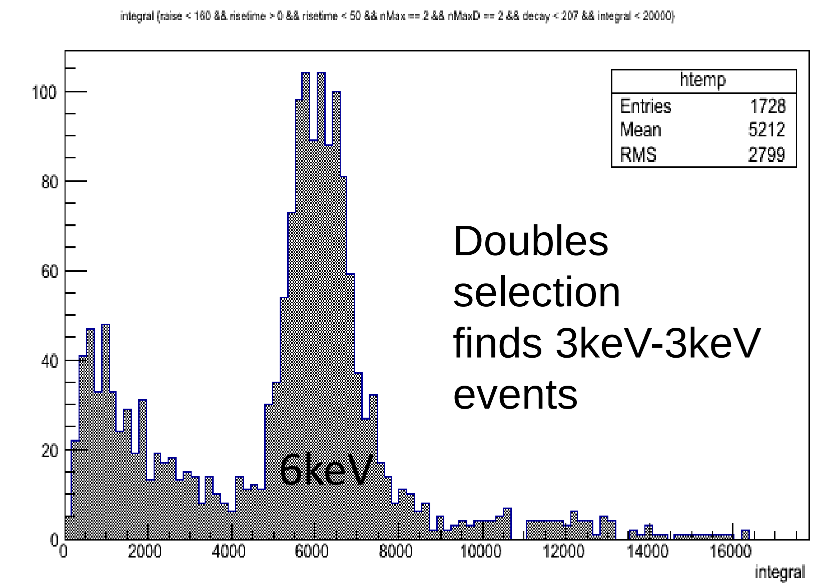


Doubles from Fe55 are observed

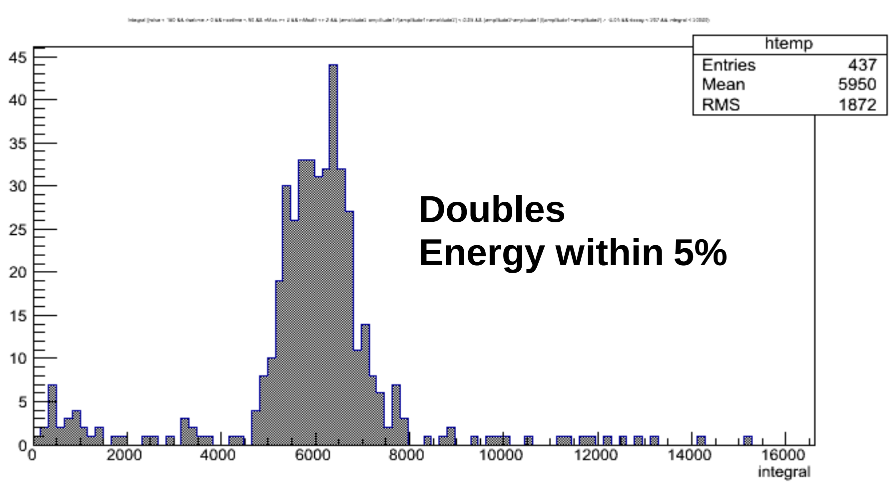
Full Spectrum without cuts (Cosmics + Fe55 peak)



Only doubles spectra

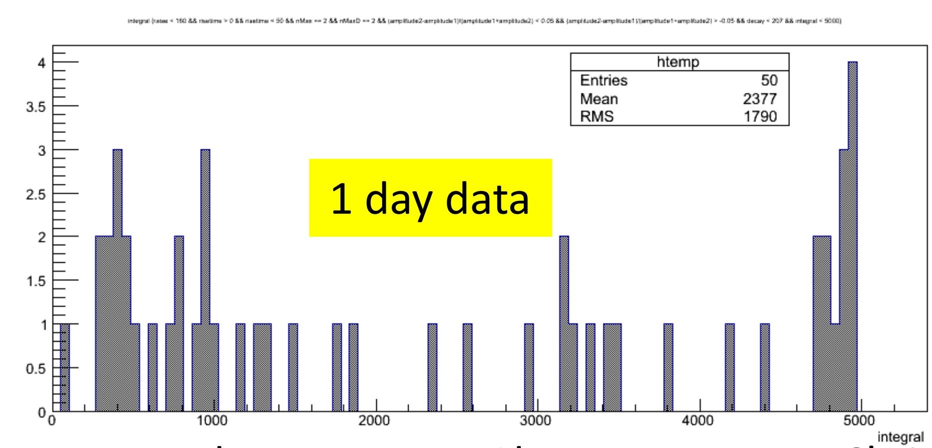


Enhancement for decay search
we only need VOLUME



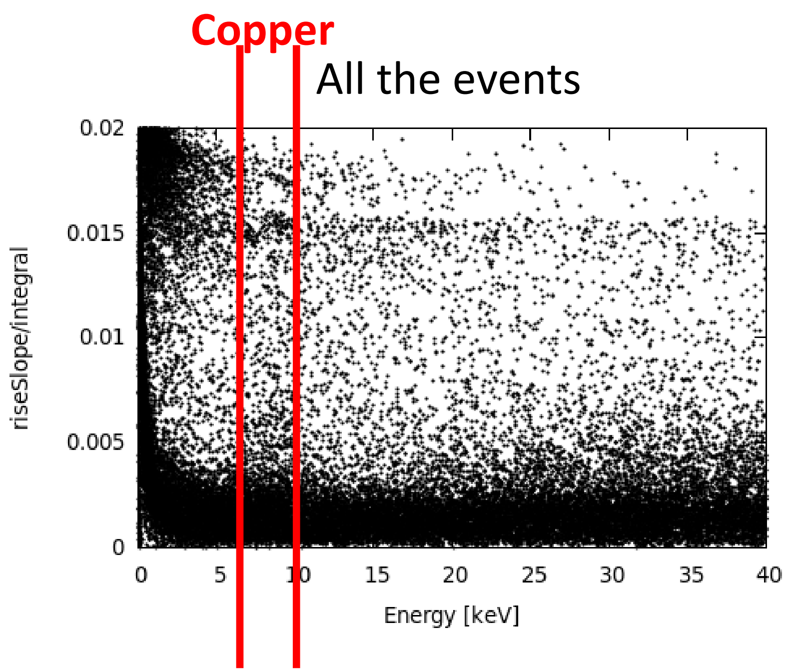
6keV

Very low background rates for doubles events even at ground level



1keV 3keV 6keV

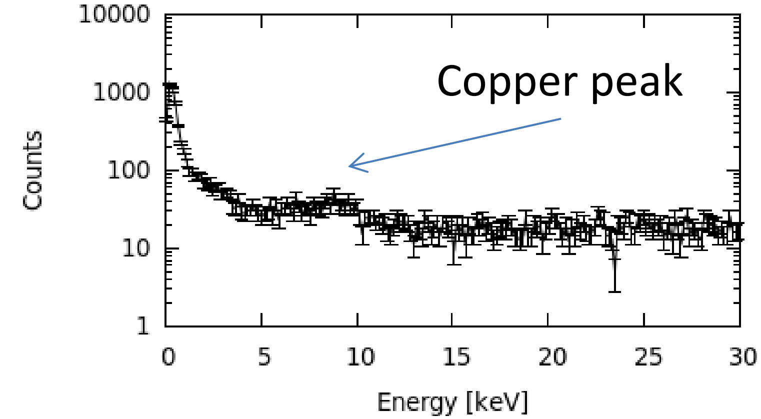
Background discrimination (LSM) 500 mbar Ar+2%CH4

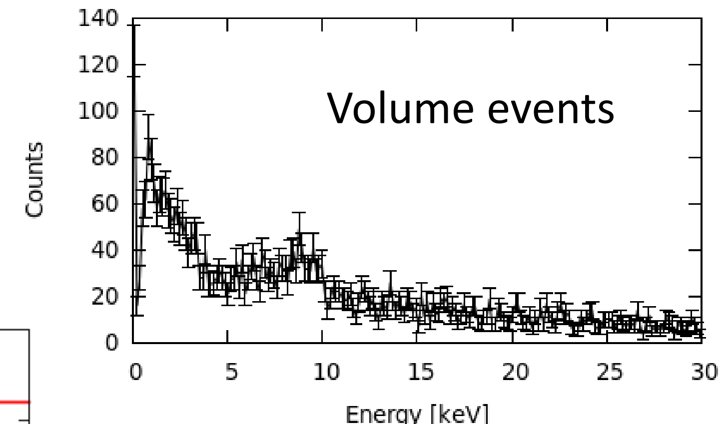


Riseslope depends strongly on the distance to the sensor, due to diffusion.

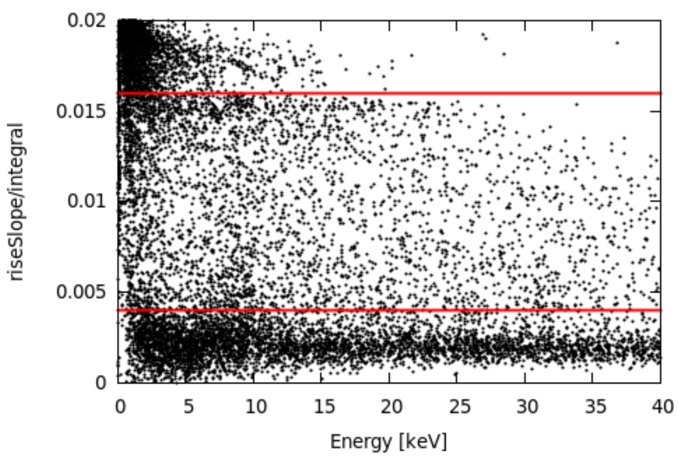
Enhances for selection of a fiducial volume

Pure single events spectra

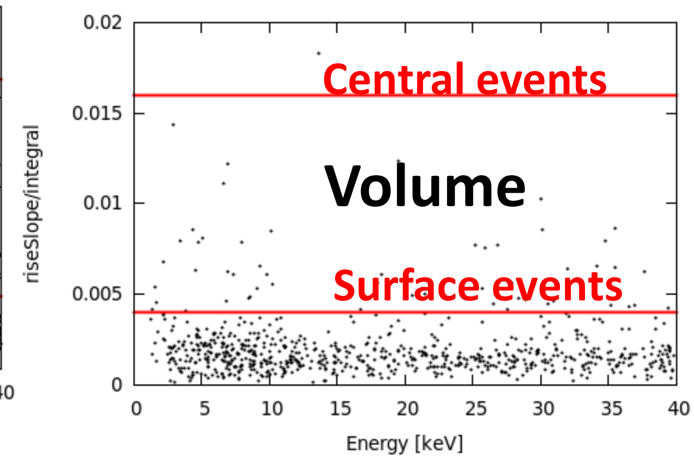


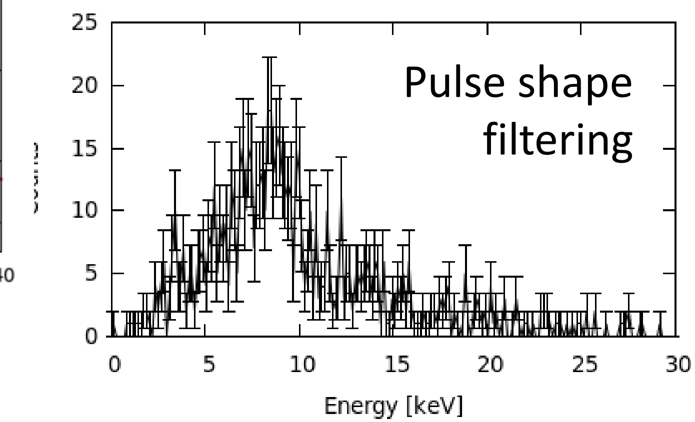


Pure single events



Pure double events

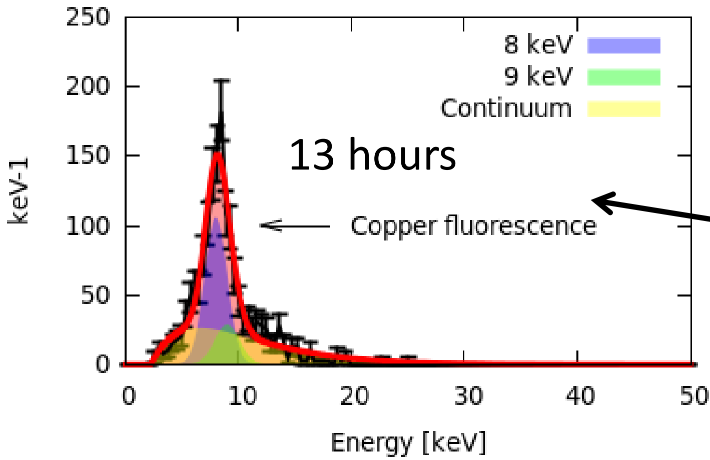




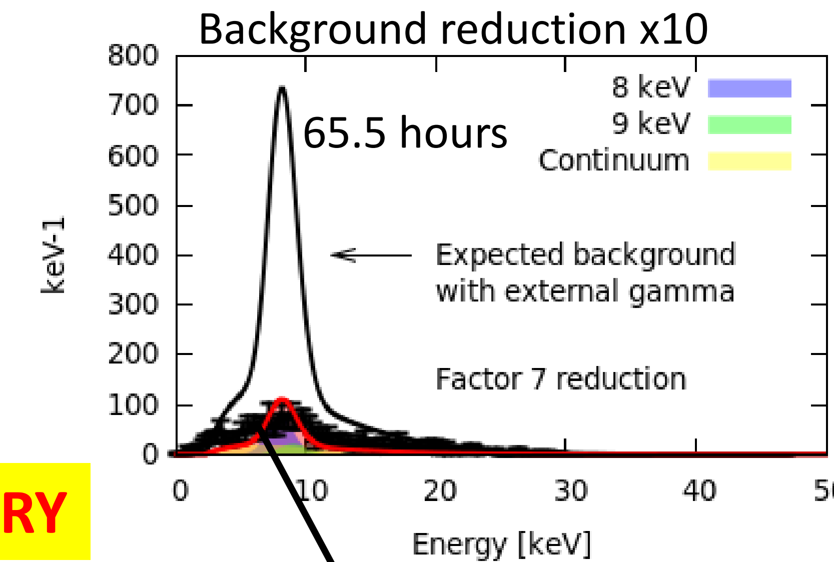
Background data in Sedine (LSM) 500 mbar Ar+2%CH4 (~3days data)

Background run dominated by external Gamma due to enviromental Radon

Purified air around the detector radon free environment

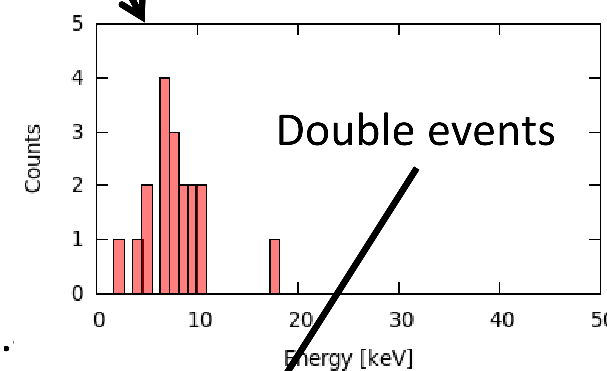


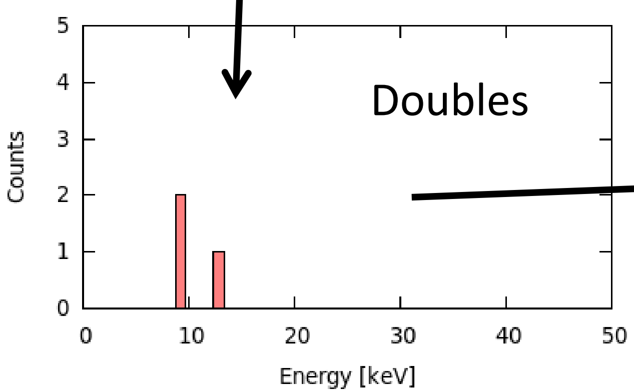
Can be used to define background model

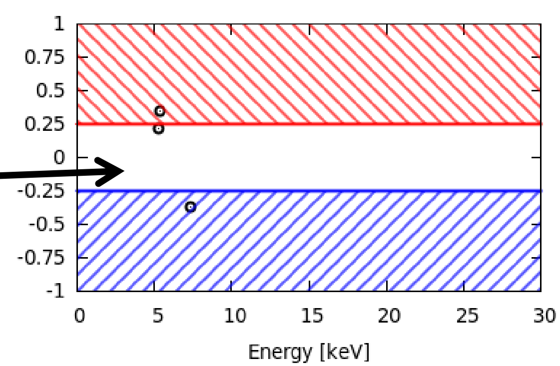


PRELIMINARY

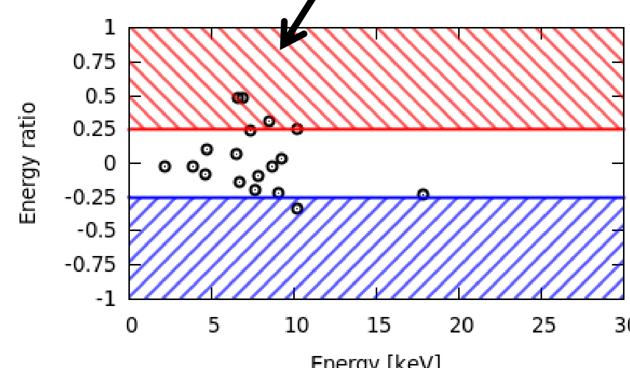
Rest mass decay -> Energy ratio = 0
Copper doubles. Typical energy ratio 0.25
3 keV + 5 keV







3.



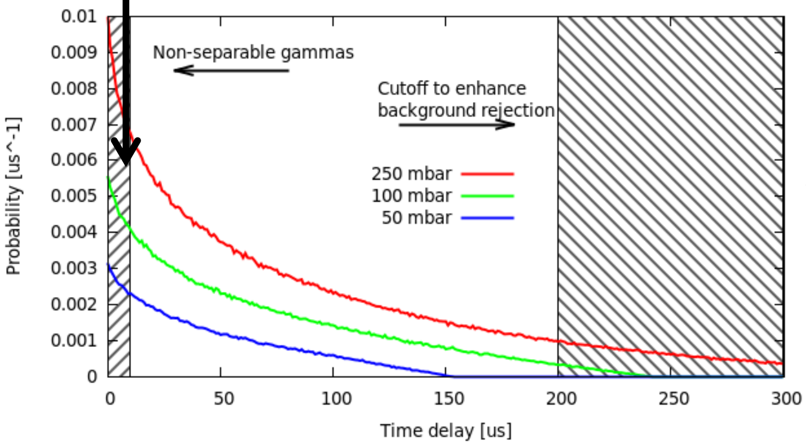
J. Galan 27/June/2013 9th Patras workshop

Optimum pressure including doubles diffusion integration

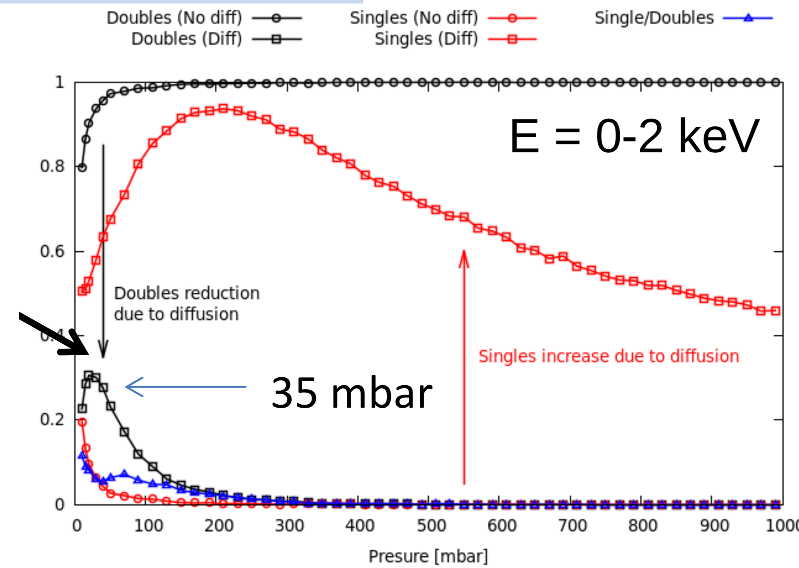
Great flexibility in gas mixture and pressure

Too close events (< 5us)

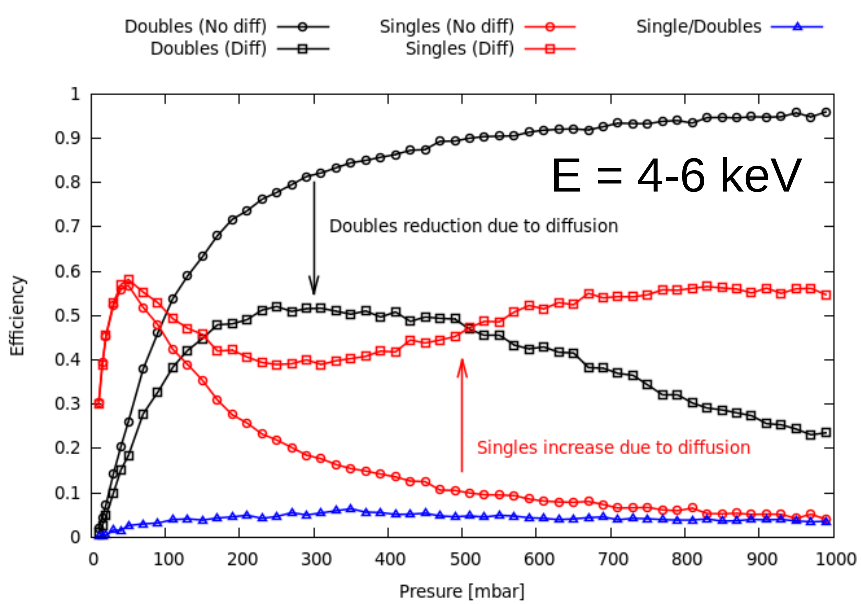
Drift time difference between 2 gammas

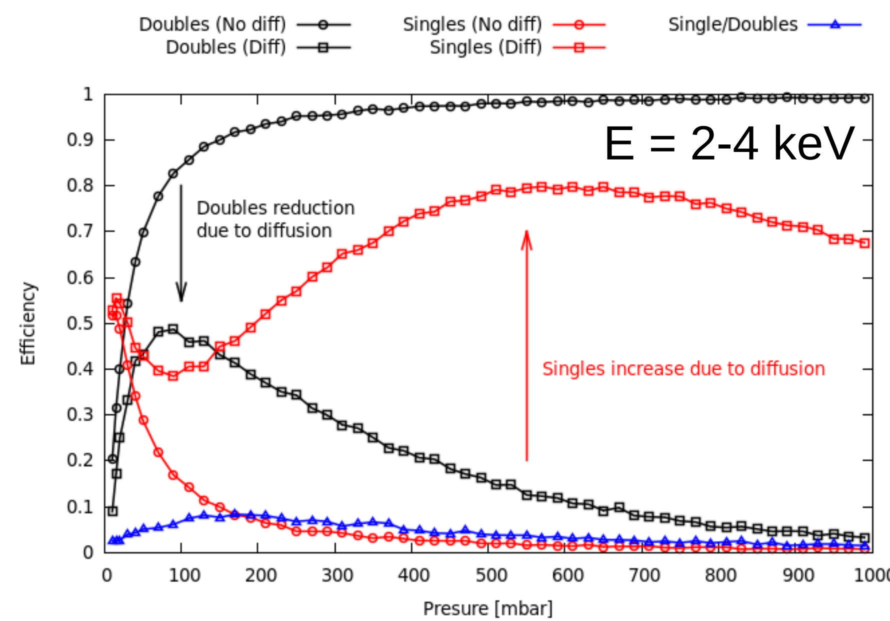


Double det.
At low E
Requires
Low P

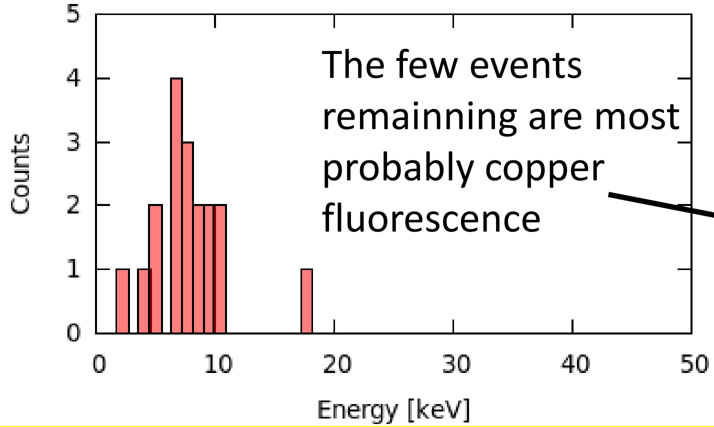


Pressure changes are equivalent to switch OFF/ON the signal!!

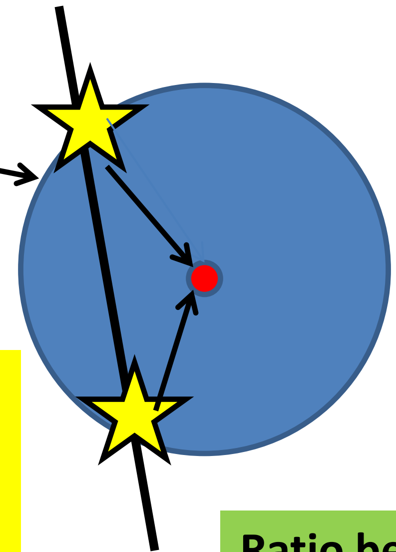




Double decay signal identification



Cosmic event produces copper fluorescence



These two hits cannot be distinguished with single Readout, similar drift times

Certain probability

To produce

3keV+3keV

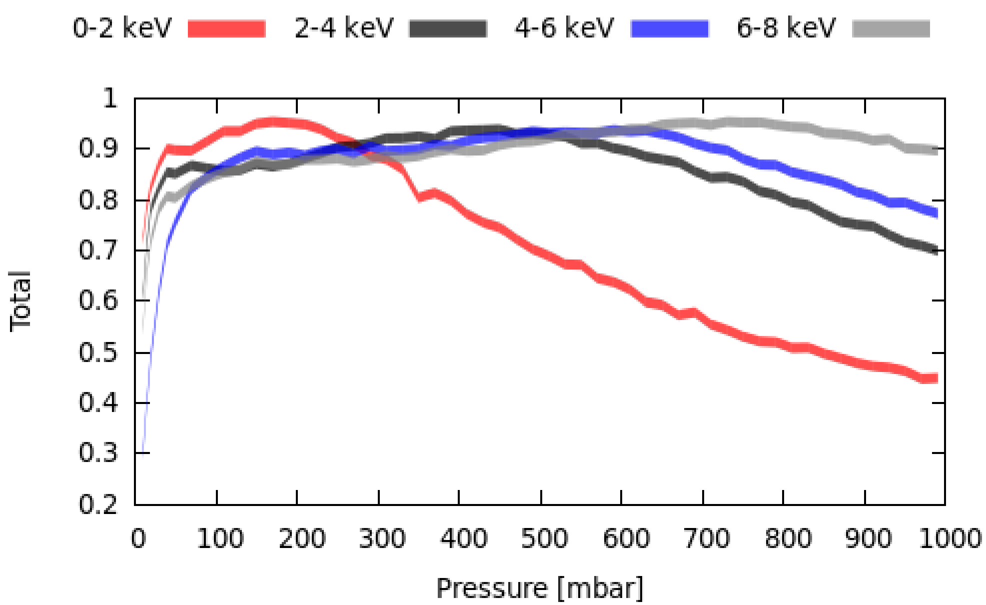
3keV+5keV

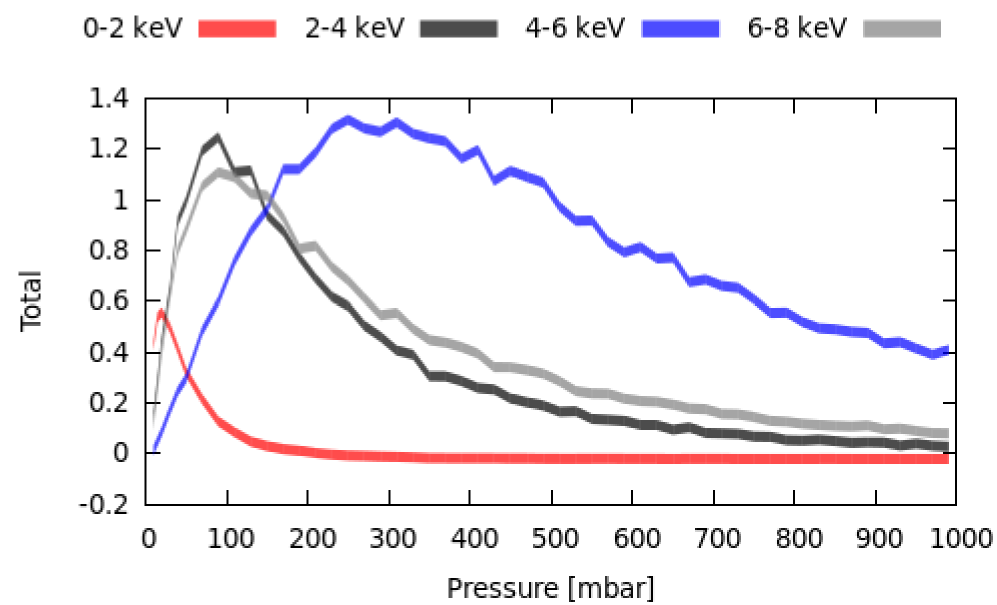
5keV+5keV

Furthermore, a decay detection has 3 independent contributions. Singles, Doubles + Hybrid.

3 detectors in ONE with correlated different signal to background ratios

Ratio between doubles and singles gives us a clear decay signature!

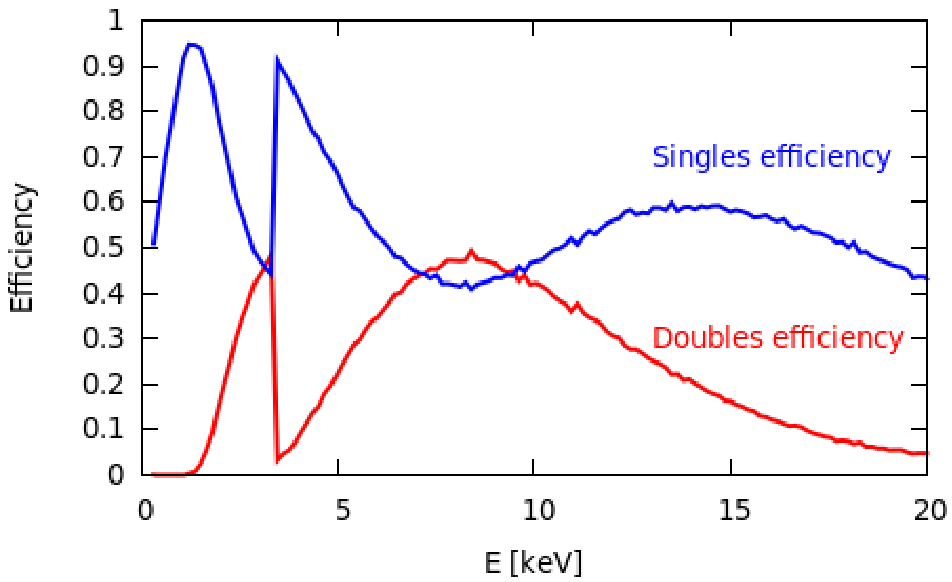




Double signal identification II

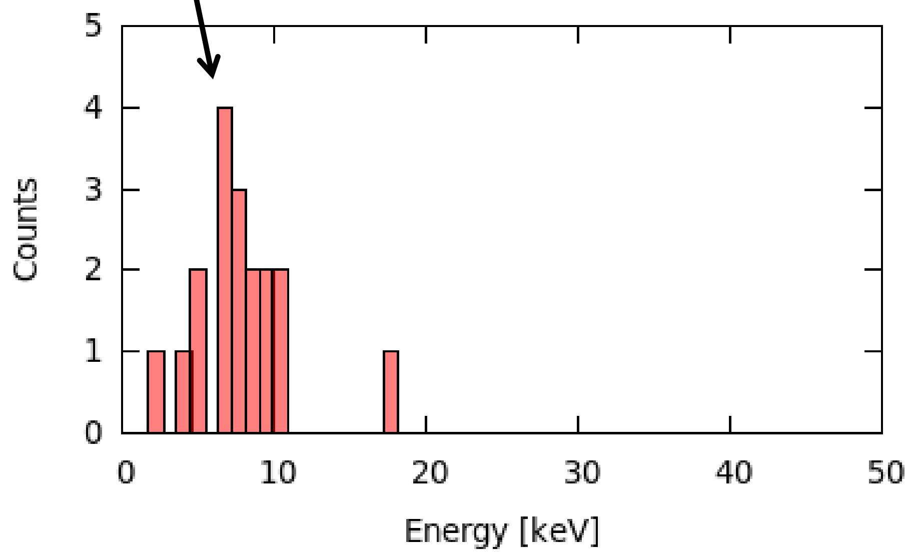
Two main contributions at 8keV. Pure doubles + Pure singles

Doubles and singles efficiency at 500mbar
Argon + 2%CH_4



Background due to Argon scape peak
At 3keV which produces **doubles of about the same energy**

However if we use **Neon the scape peak is at 900 eV** and these doubles would be easily discriminated by energyRatio criteria



Data taking going on today with Neon gas at LSM.

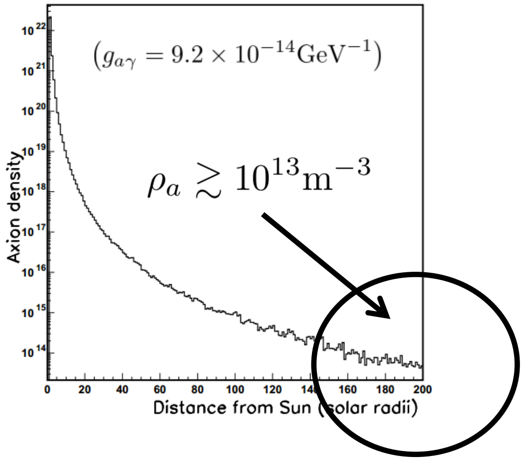
New results coming soon!

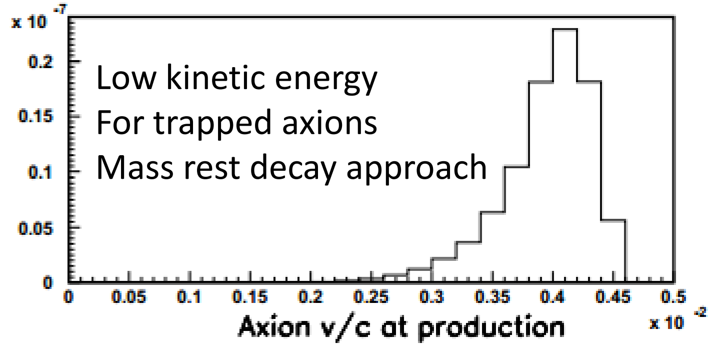
Motivation and sensitivity to KK-axions

Gravitationally trapped massive Axion (like) particles decays

L. Di Lella, K. Zioutas, Astropart. Phys. 19 (2003) 145

$$T_\odot \ll \tau_a$$



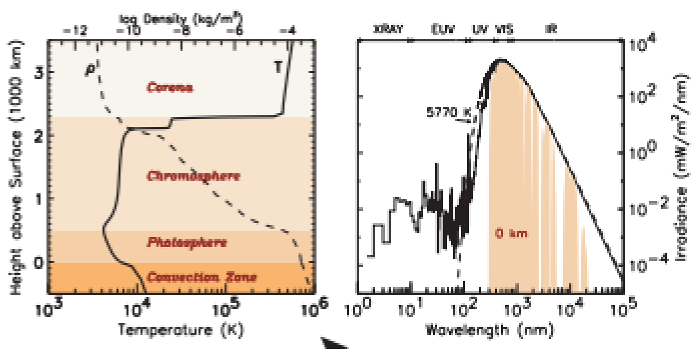


$$\rho_a = 1.18 \times 10^{39} \left(\frac{g_{a\gamma}}{\mathrm{GeV}^{-1}}\right)^2 [\mathrm{m}^{-3}]$$

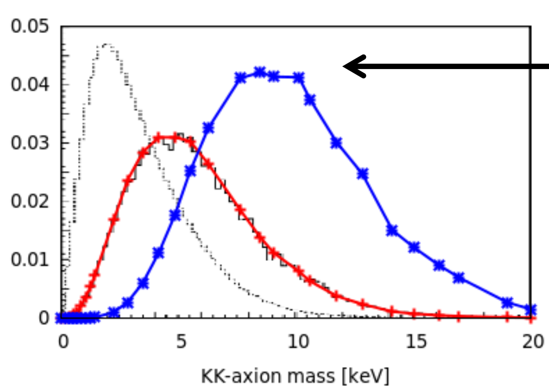
$$\tau_a = 1.35 \times 10^5 \left(\frac{g_{a\gamma}}{\mathrm{GeV}^{-1}}\right)^{-2} \left(\frac{m_a}{\mathrm{eV}}\right)^{-3} \mathrm{s}$$

$$N_\gamma = \tau_a^{-1} \cdot \rho_a \cdot V_{Sph} \cdot T_{exp} \cdot \epsilon_{det}$$

Main observational motivation is to solve solar corona problem

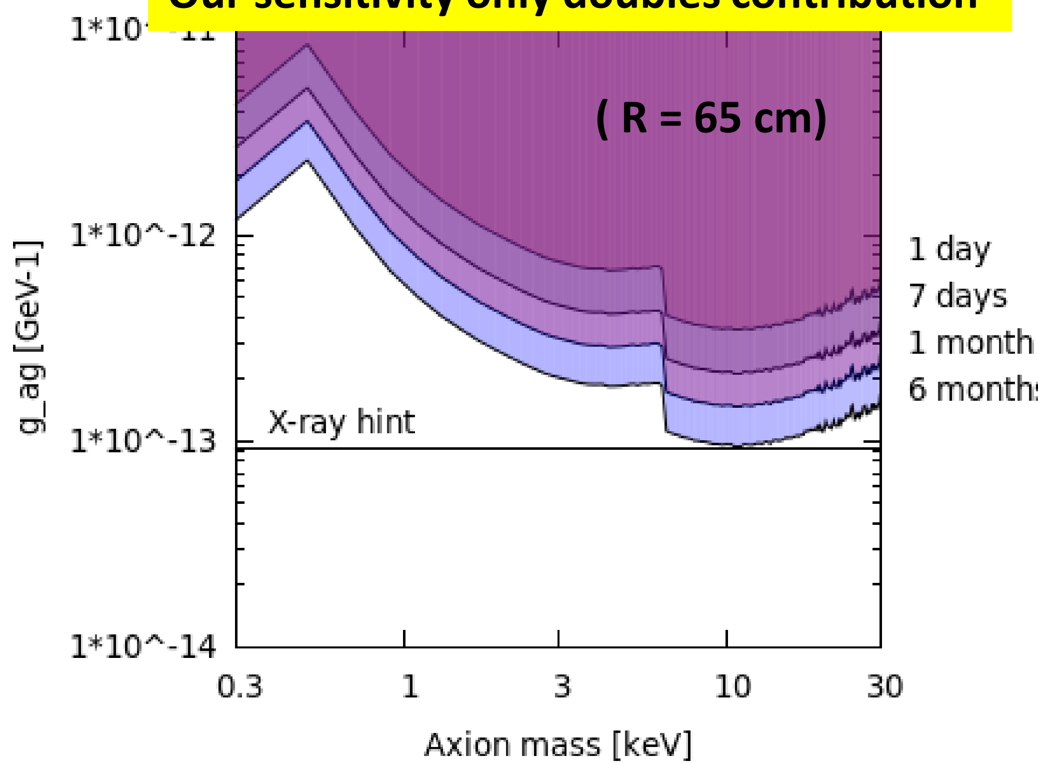


KK-axions tower of mass states



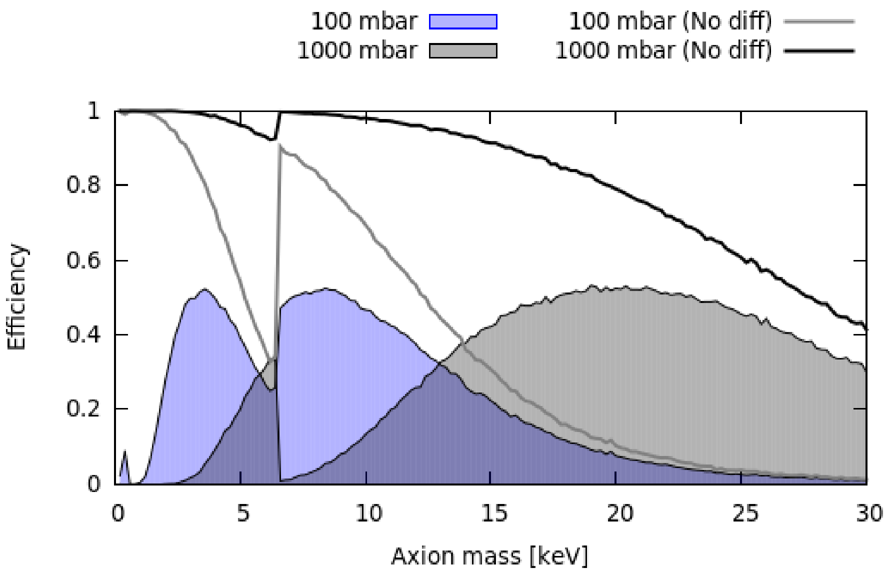
Expected X-ray distribution due to decay dependency with the mass

Our sensitivity only doubles contribution

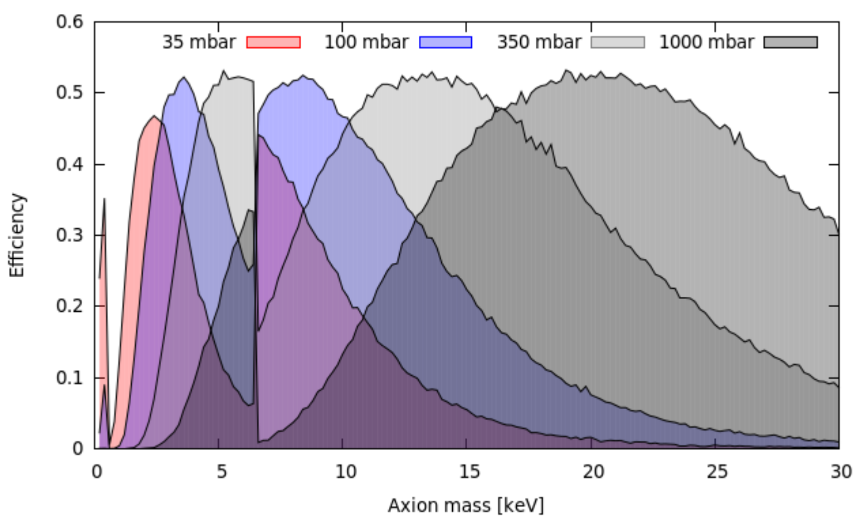


Sensitivity prospects to KK-axions (R = 6.5 m)

Doubles efficiency @1bar



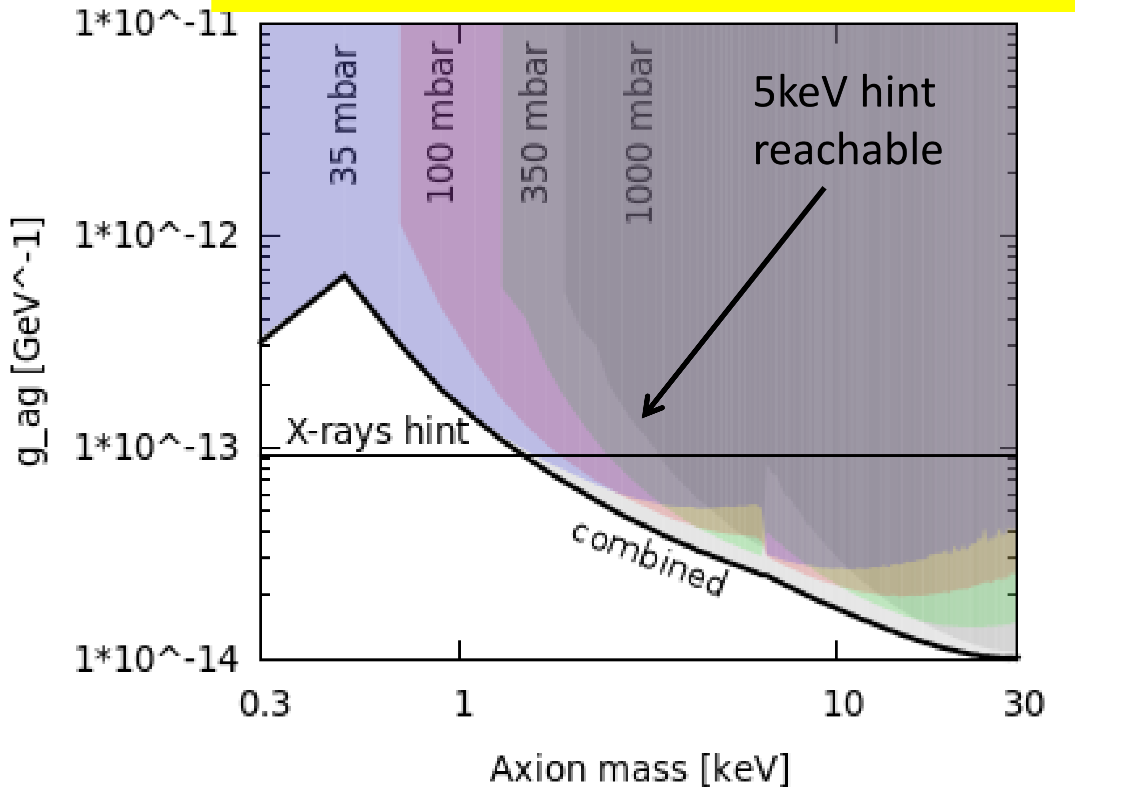
Play with pressure to get a smoother energy scan



A tentative long data run scanning At 4 different pressures

30 days each pressure 6.5 m

Our sensitivity only doubles contribution



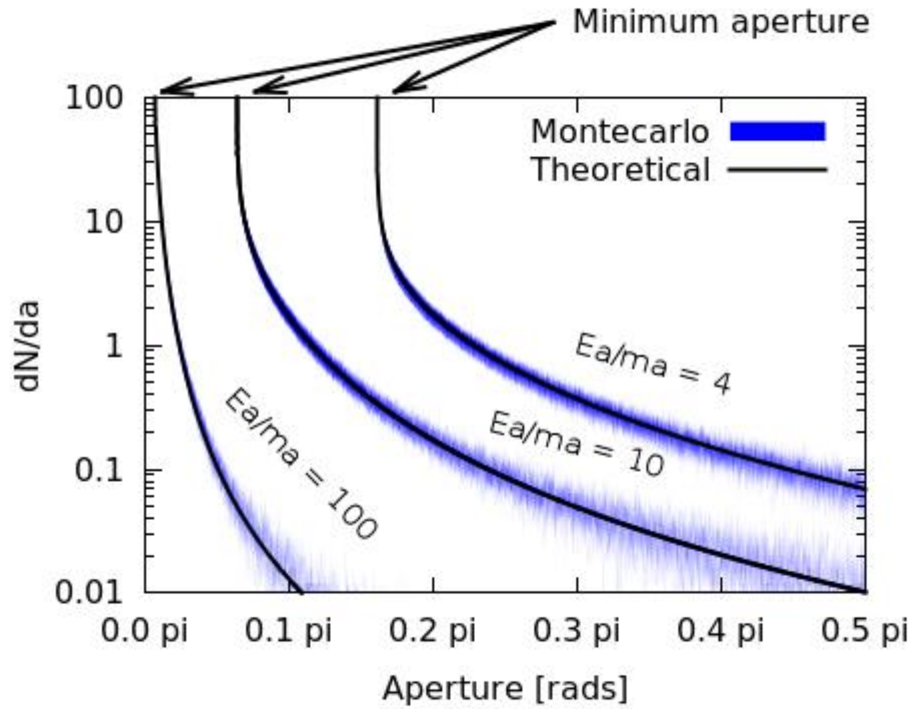
Relativistic decay. Montecarlo simulation.

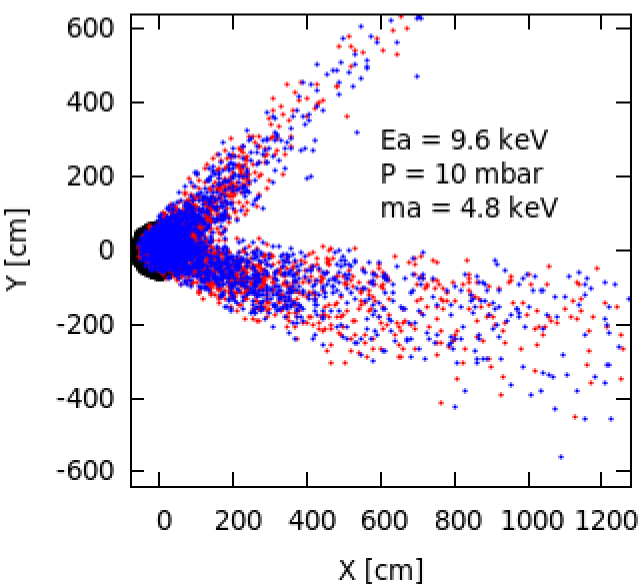
2 Gammas are boosted, harder to distinguish
Decay rate scales with ma/Ea

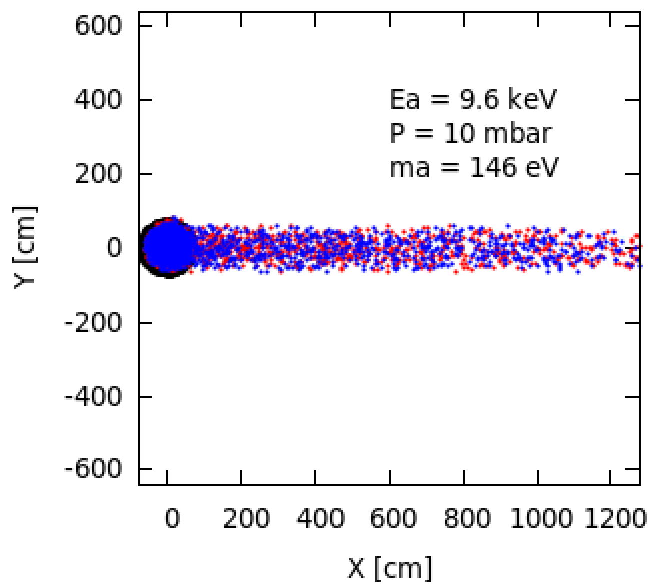
$$\frac{dN}{d\alpha} = \frac{1}{4\gamma\beta}\frac{\cos\alpha/2}{\sin^2\alpha/2}\frac{1}{\sqrt{\gamma^2\sin^2\alpha/2 - 1}}$$

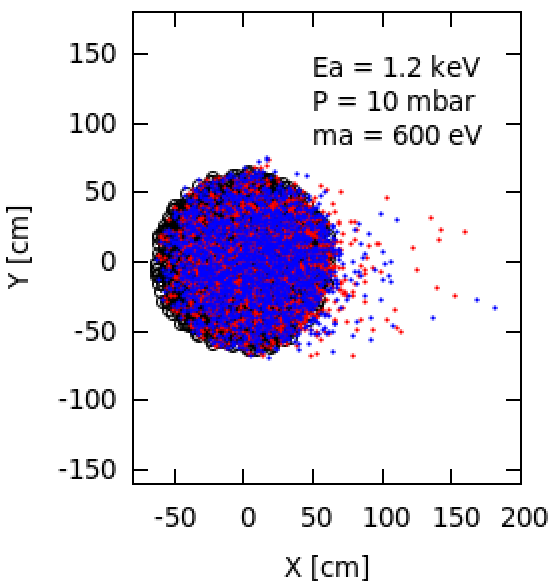
$$E_\gamma = \frac{m_a}{2}\left(\gamma \pm \sqrt{\gamma^2 - \sin^{-2}(\alpha/2)}\right)$$

$$\frac{dN}{dE_\gamma} = \frac{1}{p_a}$$



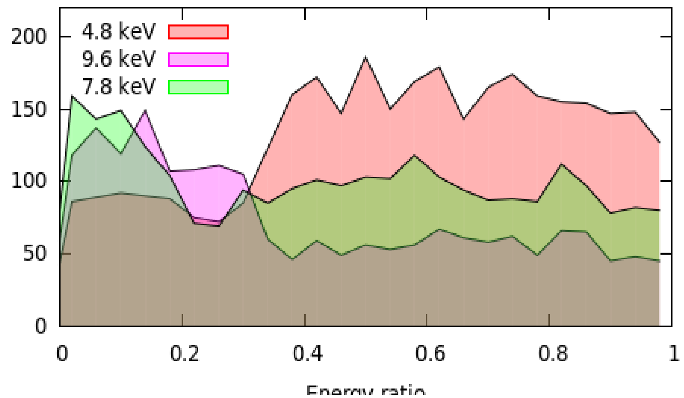




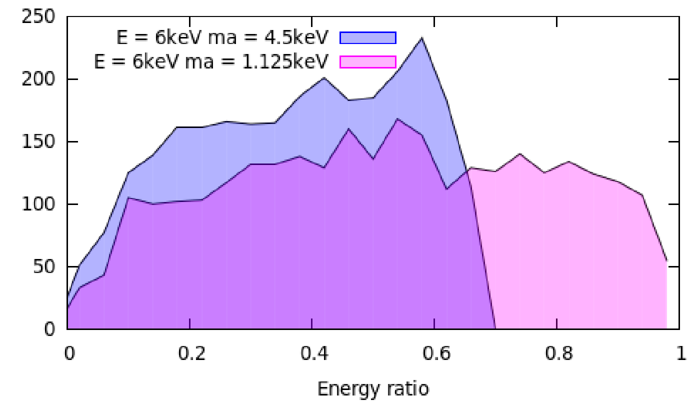


Relativistic decay efficiency and solar QCD-axions sensitivity

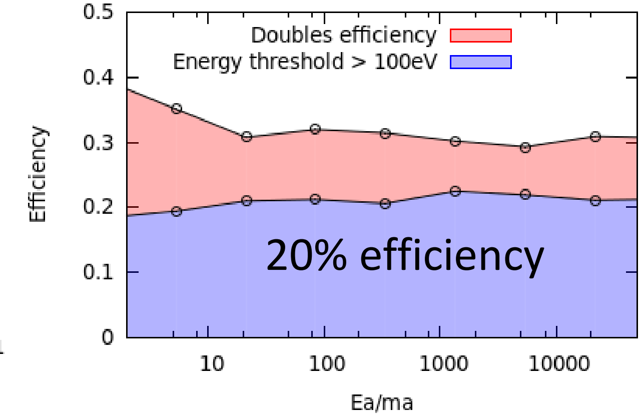
Doubles energy ratio versus E

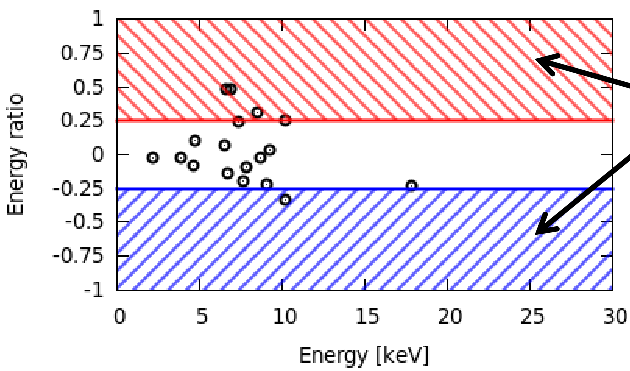


Doubles energy ratio versus m



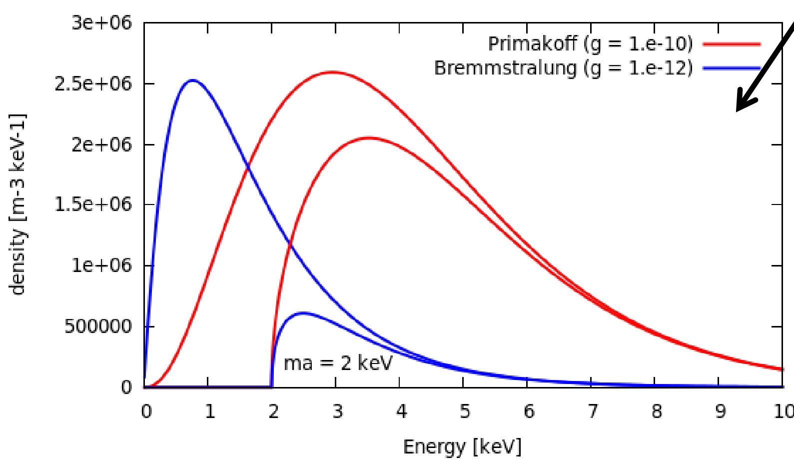
Imposing an energy threshold at 100eV



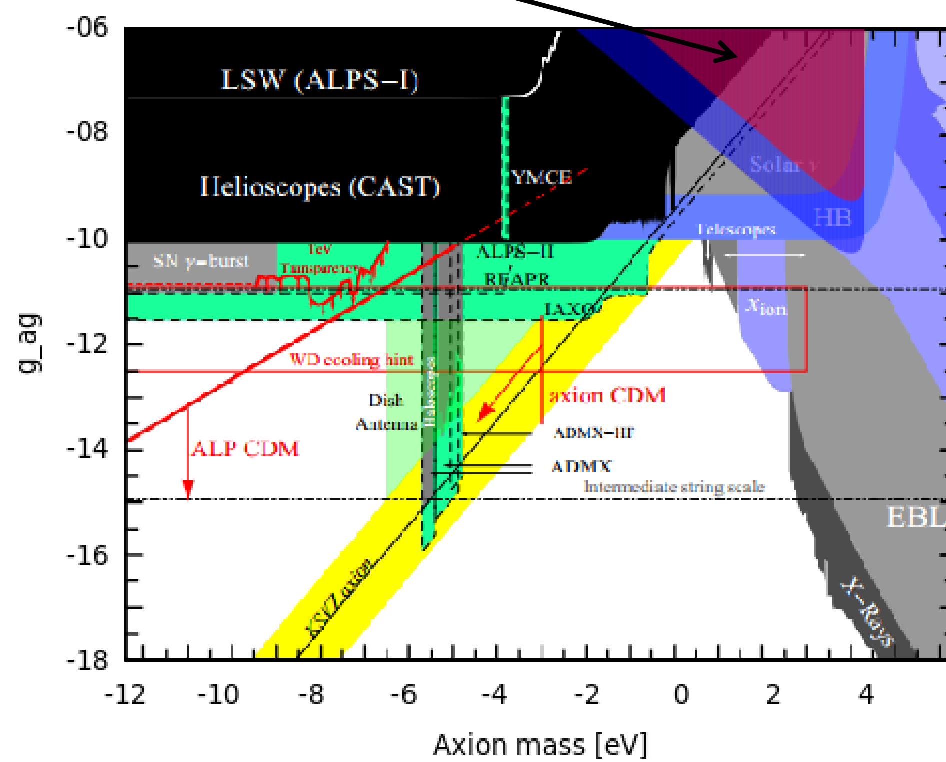


$$\frac{dN}{dE_\gamma} = \frac{1}{p_a}$$

Effective density of solar axions inside the sphere



Our window to QCD axions

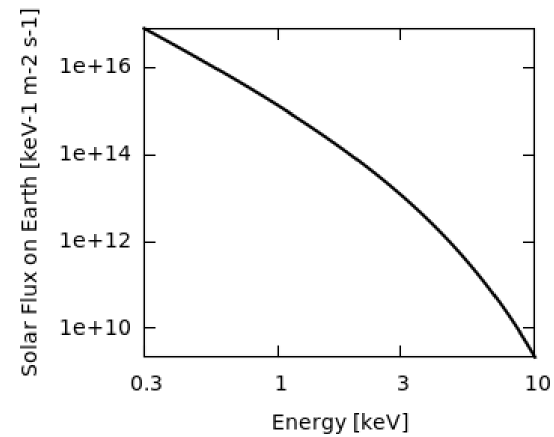


Solar hidden photon sensitivity

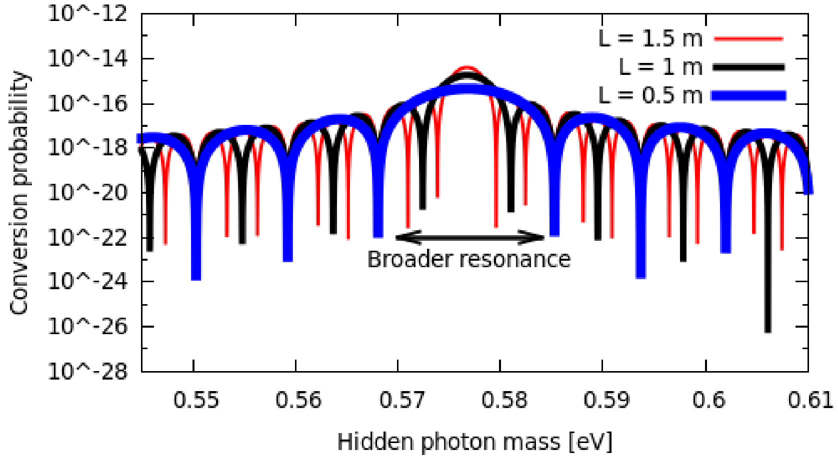
Ref: arXiv:1302.1000v3 (SUMICO)

$$P_{\gamma'\to\gamma}(\omega) = \frac{4\,\chi^2\,m_{\gamma'}^4}{(m_{\gamma'}^2 - m_\gamma^2)^2 + 4\,\chi^2\,m_{\gamma'}^4} \times \sin^2\left(\ell \times \frac{\sqrt{(m_{\gamma'}^2 - m_\gamma^2)^2 + 4\chi^2 m_{\gamma'}^4}}{4\omega}\right)$$

Transversal solar flux (X=1.e10)



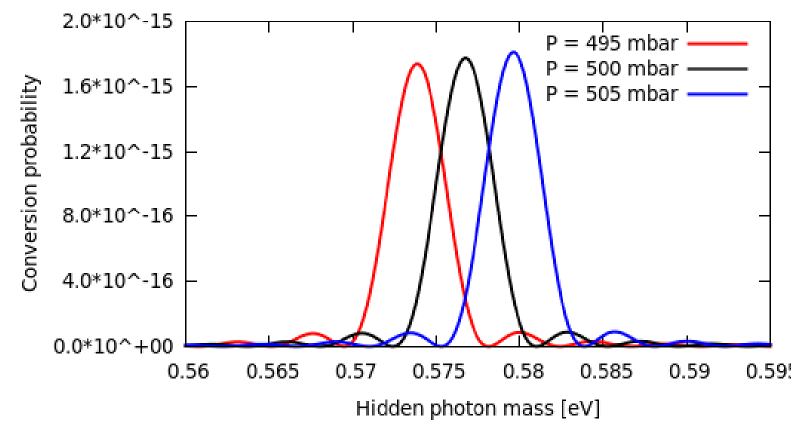
Resonance gets broader for shorter lengths, on a spherical detector the length depends on the impact parameter and it needs to be accordingly integrated with the flux.



Detector senstivity dynamic range from 100eV to 30-40keV.

5 mbar steps with fixed L=1m

CAST Analogy



Pressure can go from 1 mbar to 5 bar

$$m_\gamma \simeq 28.77\sqrt{\frac{Z}{W_A}\rho\left[\frac{\text{g}}{\text{cm}^3}\right]}\;\text{eV} \qquad m_\gamma = \omega_p = \sqrt{\frac{4\pi\alpha n_e}{m_e}}$$

It enables the detector to make a direct scan between 25 meV and 1.8 eV.

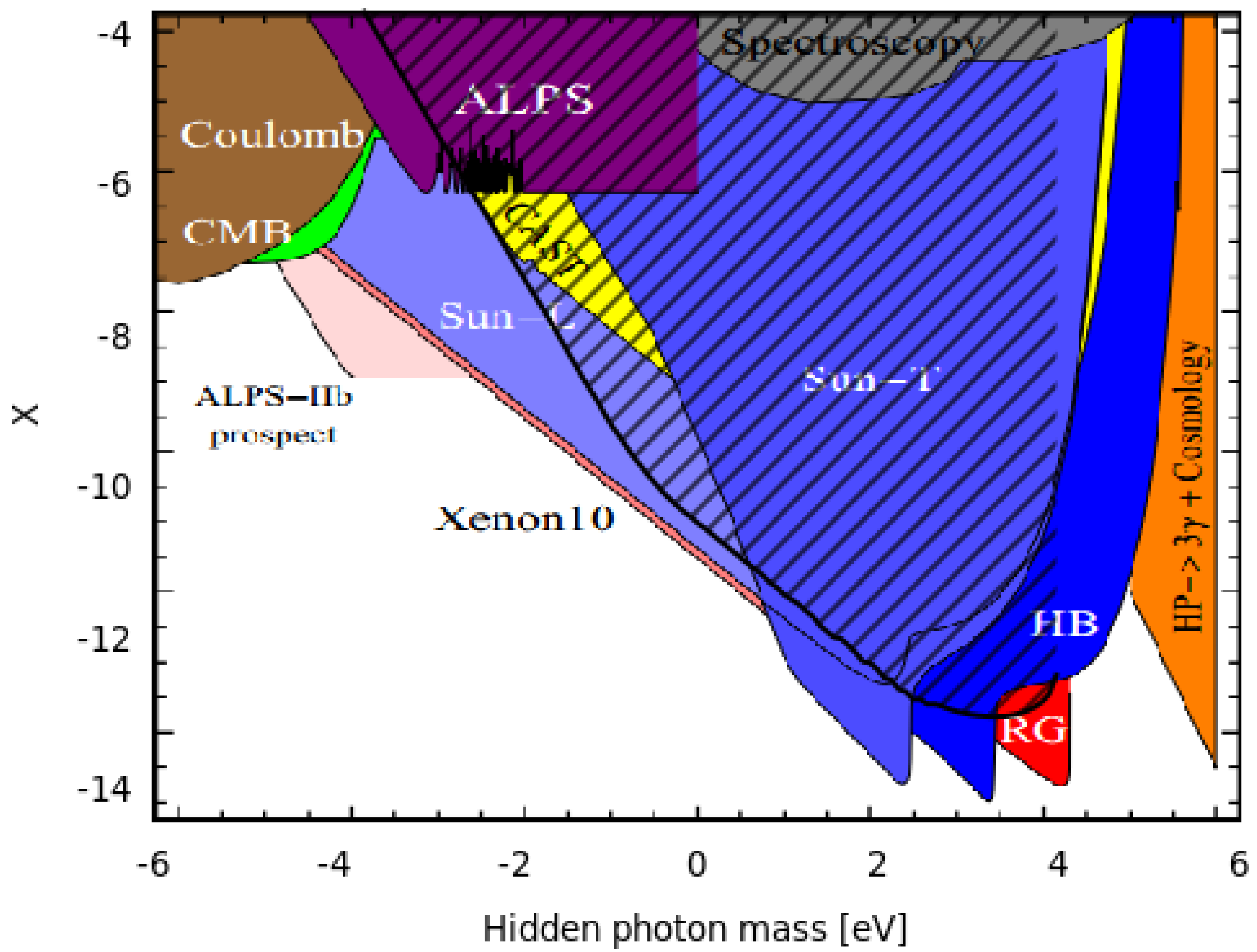
Solar hidden photon sensitivity (Zero background limit)

PRELIMINARY

Limit reachable with actual sphere (Sedine) taking data at LSM (Underground Modane Laboratory)

Pressure scanning from 50mbar to 5 bar (each pressure about 1 day = 1.e5 s)

Steps of 10 mbar



J. Galan 27/June/2013 9th Patras workshop

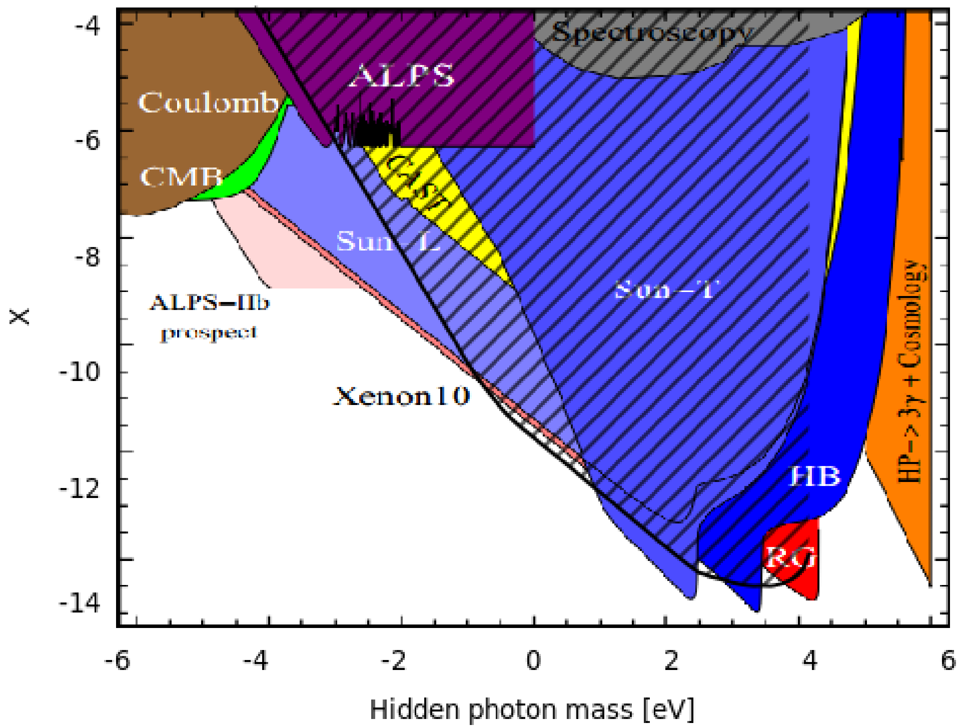
Solar hidden photon sensitivity (Zero background limit)

PRELIMINARY

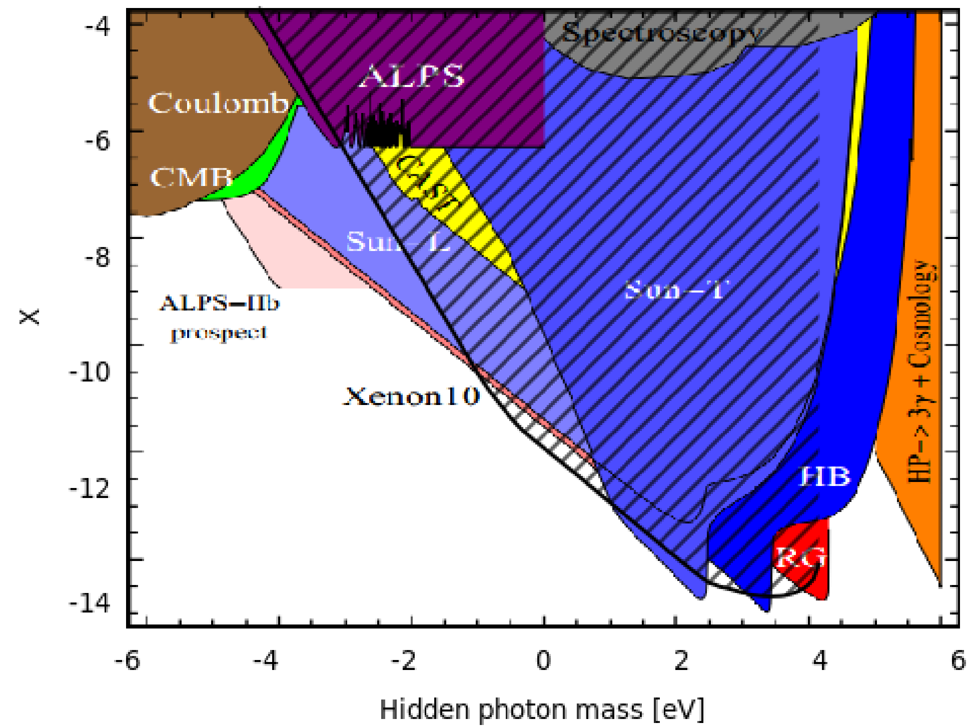
Pressure scanning from 50mbar to 5 bar
(each pressure about 1 day = 1.e5 s)

Steps of 10 mbar

Limit reachable with a 6.5 m Sphere
Same scanning



Limit reachable with a 6.5 m Sphere
Time exposure x5. (2 years data taking)



Single photon search is a single photon detection, so background will be higher than doubles,

However, this exclusion includes only transversal HP solar flux.

Mass is not negligible, so sensitivity to longitudinal flux must be explored.

At 5 bar
30 cm -> 1Kg
65cm -> 10Kg
6.5m -> 10 tones

Conclusions

Model for KK-axions could be tested with the numbers based on solar observations.

We can explore other regions for QCD and Hidden photons for the same price.

Background should be lower with bigger sphere due to the fiducial cut. Segmented readout sensor would provide **additional background discrimination capabilities**

Low energy threshold and particle recognition enhances **additional exciting physics: Supernova neutrino, Low wimp mass, neutrino coherent scattering, neutron detection.**

Still room for improvement on background capabilities.