Pulse Shape Discrimination in Liquid Argon and its Implications for Dark Matter Searches Using Depleted Argon

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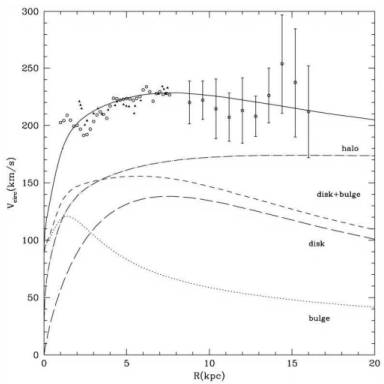
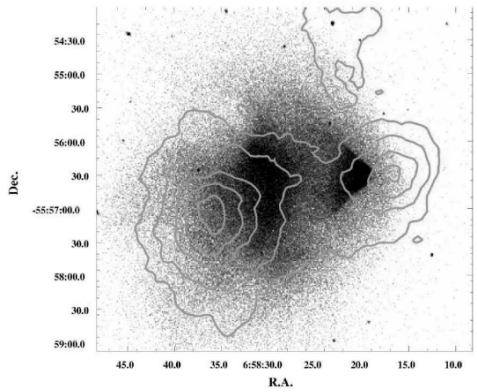
Plan

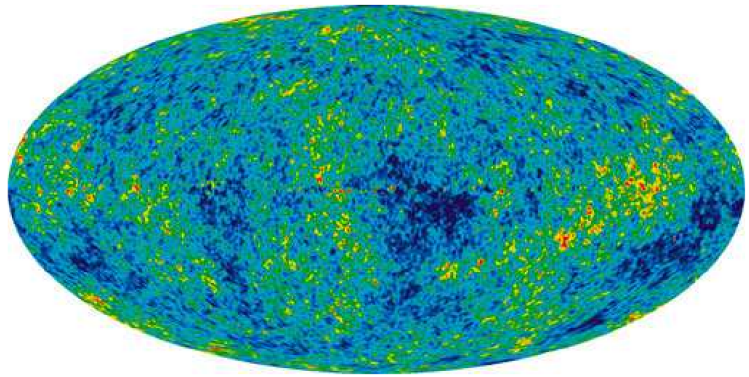
1. Dark Matter Detection.
2. Liquid Argon as a Dark Matter detector.
3. Predicted Sensitivity for a Depleted Argon Detector.

Dark Matter.

- Luminous matter - only 4% of mass - energy of the Universe.
- 74% - Dark Energy (Cosmological Constant).
- 22% - Dark Matter.
  - Evidence for its existence from rotation curves, CMB, Bullet Cluster etc...
  - Nature yet unknown - various candidates (WIMPs, Axions, LKP...).

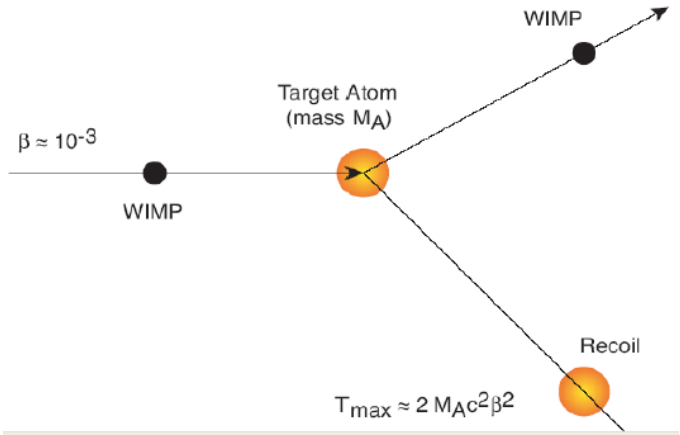


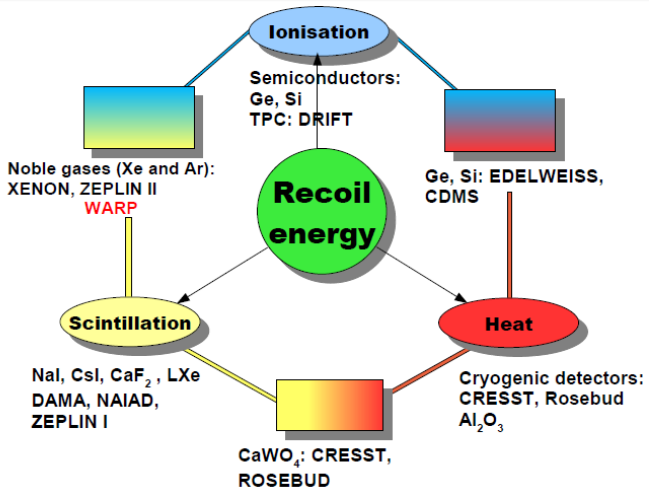




WIMP detection methods.

- WIMP - one of the most interesting DM candidates.
- Expected mass from 10 - 1000 GeV, nonrelativistic velocities
- Cross sections about $10^{-40} cm^2$
- Detected recoil energies should be of keV order
- Expected rate ~ 0.02 ev/day/kg

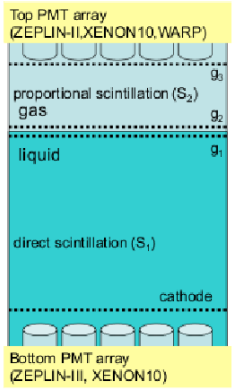


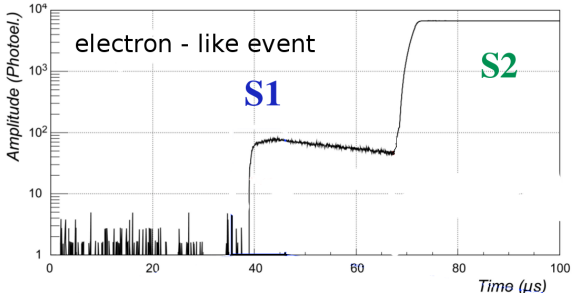


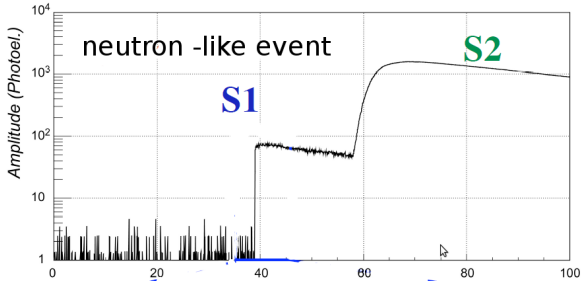
Liquid Argon as a Dark Matter detector.

- Result of the particle - Ar interaction - two possible excited states of the Ar dimers - (decay times ~ 7 ns for singlet state and ~ 1500 ns for triplet state).
- Different interaction of electrons and neutrons (and WIMPs!) - discrimination possible.

- Double phase working principle - Signal/background discrimination based on two signals: ionisation (S2) and scintillation (S1).
- Single phase - different proportions of resulting singlet and triplet excited states for interacting electrons and neutrons (and WIMPs) resulting in different shapes of S1 pulse.
- Background understanding and supression is crucial to be sure that registered events are the true signal.



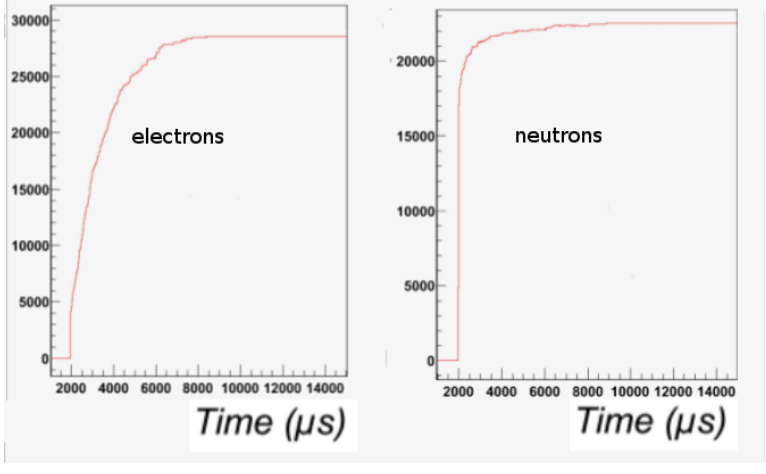




Background supression in LAr.

- Main intrinsic background - electrons from ^{39}Ar decays.
- S1/S2 discrimination - for two phase mode.
- For single phase (used in presented analysis) - Pulse Shape Discrimination.
- FPrompt parameter (Fp) used to separate the signal (neutrons/WIMPs) and background (electrons).

$$F_p = \frac{S_{F_p}}{S_1} = \frac{\int_{T_i}^{T_{F_p}} V(t)dt}{\int_{T_i}^{T_F} V(t)dt}$$



WArP 2.3l detector.

- Two phase LAr DM detector.
- First publication reporting DM search results in LAr (Benetti et al).
- 2.3 l detector still used for R&D purposes.
- Detector upgrade and new tests performed in 2010/2011 - results presented in this talk.

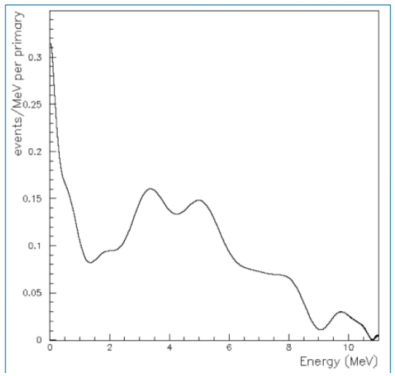
WArP 2.3l R&D detector after modifications(2010/2011) .

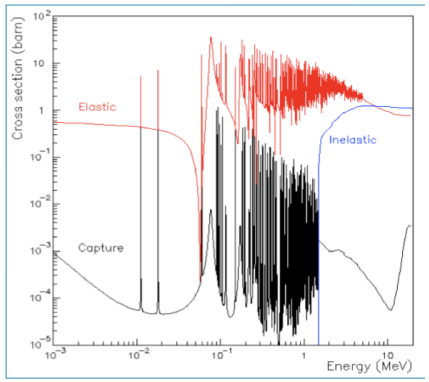
- New photomultipliers - higher light yield (6.1 phe/keV measured vs. 1.5 phe/kev for the previous setup) - access to lower energies of electrons and neutrons.
- New DAQ electronics with broader dynamic range - less saturated events - insight in high energy range of electrons and neutrons.

2011 data analysis.

- Runs with Am/Be source to test the new setup.
- 2009 analysis results with the old setup used as a reference - an intermediate population was observed in the FPrompt spectrum and connected with inelastic neutron interactions.
- Intermediate population fitted with a convolution of exponential and gaussian.

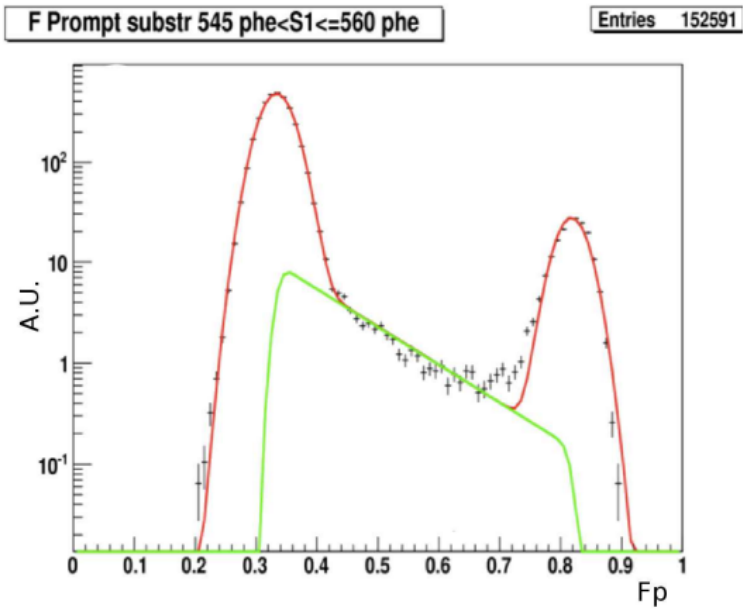
$$G_n(F_p; < F_{p_n} >; \sigma_n) \oplus G_\gamma(F_p; < F_{p_\gamma} >; \sigma_\gamma) \oplus (G_i \otimes E_i)$$



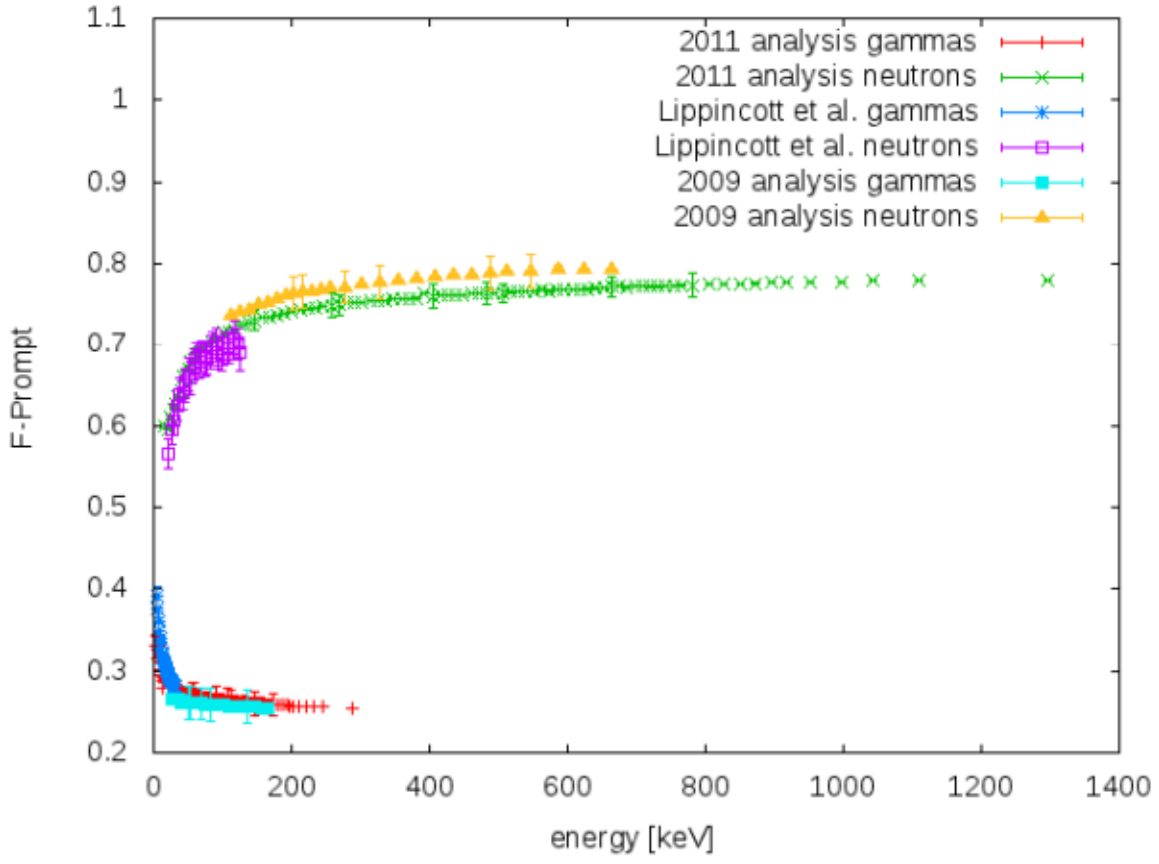


2011 data analysis.

- Modifications of the analysis software.
- Intermediate population observed.



Results of the data analysis .

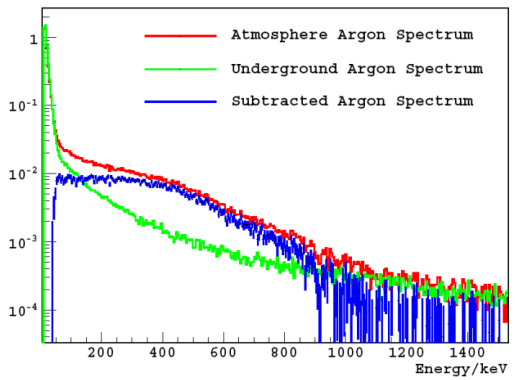


Calculating the Sensitivity of a Dark Matter Detector.

- Even if a DM detector does not see signal it can still explore the allowed sigma vs WIMP mass parameter space.
- Comparison with obtained exposition and calculations for various nuclear recoil energies gives sensitivity plot.
- Earth motion in galaxy, velocity distribution in galactic halo, seasonal DM flux change and detector parameters (exposition, efficiency) included in the model.
- J.D.Lewin, P.F.Smith, Review of mathematics, numerical factors, and corrections for dark matter experiments based on elastic nuclear recoil, Astropart. Phys. 6 , (1996) 87-112
- Another, statistical approach - takes account of event energy distribution.
- S. Yellin, Finding an upper limit in the presence of an unknown background , Phys.Rev. D66 032005, arXiv:physics/0203002v2 [physics.data-an], (2002)

Depleted Argon.[2]

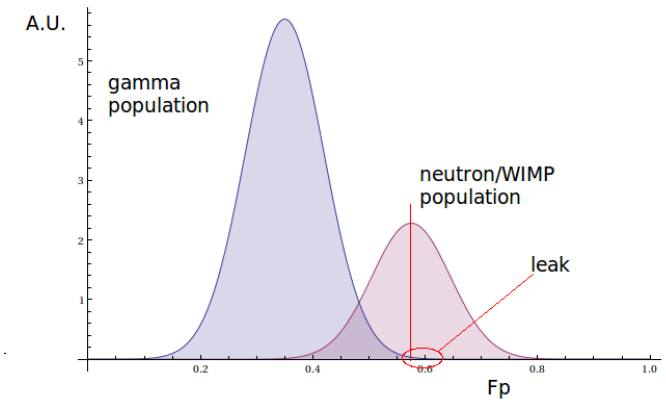
- About 10^{-16} ^{39}Ar in atmospheric Argon .
- Produced mainly by interaction of ^{40}Ar with cosmic rays.
- In argon found in underground sources the contamination is smaller, but distillation is necessary to extract clean argon - depletion of 39 Ar abundance by at least factor of 25 obtainable.
- Depletion of atmosferic argon by centrifuges is possible but much more costly.

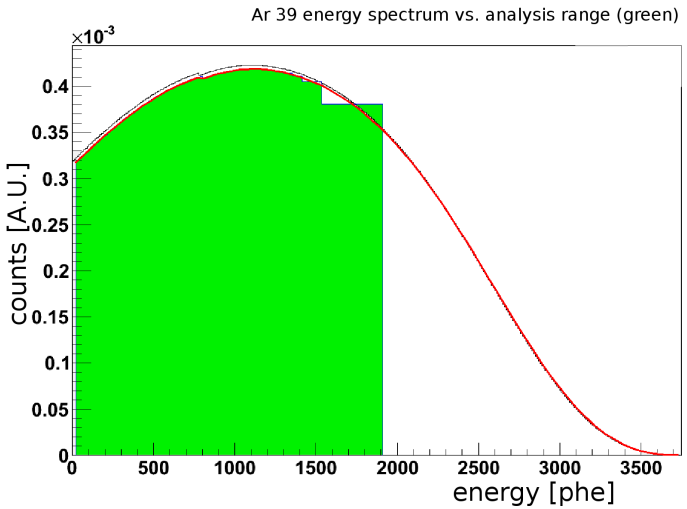


[2] Presentation by A. Pocar at Dark Matter Workshop, Aspen Physics Institute, 7-11 February, 2011

Predictions for depleted Argon.

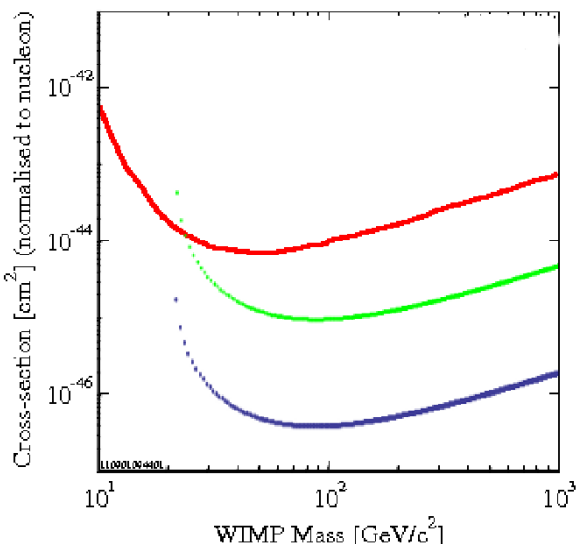
- Exposure calculation based on the ^{39}Ar activity.
  - estimating the maximum exposure before "gamma leak"
- Sensitivity derived with the use of the Smith & Lewin method.





Predictions for depleted Argon II.

- ^{39}Ar assumed to be only background; energy treshold set at 32.78 keV.
- Different cases:
  - Standard Argon used and the S2/S1 background discrimination applied (green curve), possible exposure ~1.1 $\times 10^4$ kg $\times$days
  - Depleted Argon (depletion factor 25) used and the S2/S1 background discrimination applied (blue curve) possible exposure ~1.1 $\times 10^6$ kg $\times$days
- Xenon 2011 results used for comparison (red curve)



Continuation of the analysis.

- Test systematic effects.
- Understand lowest energy bins by:
  - Developing an MC test to test reconstruction efficiency
  - Refine analysis

Thank you!