Discovery of underground reservoir of argon with low level of ^{39}Ar

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Cristiano Galbiati, on behalf of …

Discovery of underground argon with low level of radioactive ^{39}Ar and possible applications to WIMP dark matter detectors

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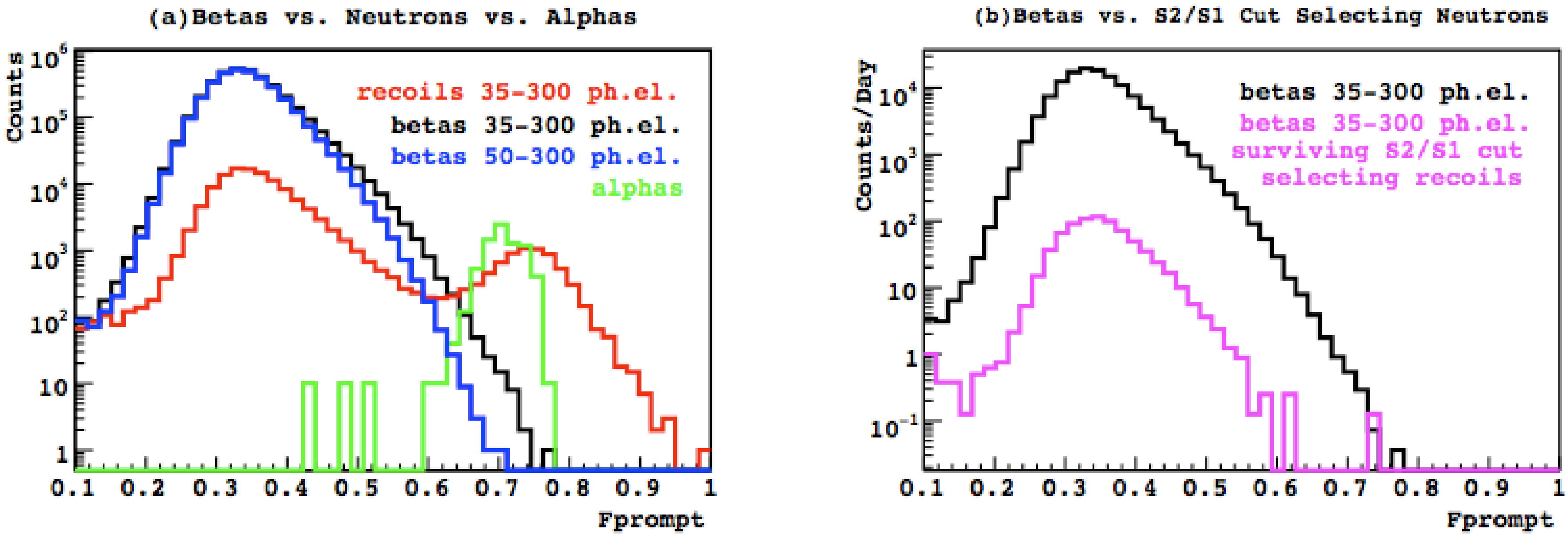
Outline

- Part of research program funded by NSF
- Motivation for exploration of underground argon
- Status and development of analytical techniques
- Sample collection and preparation
- Discovery of first source with low level of ^{39}Ar
- Next step: massive collection of low background argon for large WIMP detector

Argon as target for WIMP detection

- Liquid argon excellent material for WIMP and neutrino detection:
  - Copious scintillation
  - Excellent target for ionization detector
  - Best beta/recoil discrimination among energy-sensitive detectors. See next slide with last WARP records
- Large-scale argon WIMP detectors under development
- WARP 3.2-kg delivered first Ar-limit on WIMP detection (2006)
- WARP 140-kg operating next year at LNGS

Recent WARP Results on Discrimination



After recent electronics upgrade, pulse shape discrimination between m.i.p. and nuclear recoils better than 3×10^{-7} for > 35 photoelectrons, better than 10^{8} for > 50 photoelectrons

Shape of distribution does not change by applying S2/S1 cut (reduction 5×10^{2}).

Two discriminations independent within statistics collected.

Why is underground argon desirable?

- Radioactive ^{39}Ar produced by cosmic rays in atmosphere
  - decays betas, Q = 565 keV, $t_{1/2}$ = 269 years
- In atmospheric argon:
  - $^{39}Ar/Ar$ ratio 8×10^{-16}
  - specific activity 1 Bq/kq
- Limits size and sensitivity of argon detectors

Why is underground argon desirable?

- ^{39}Ar-depleted argon available via centrifugation or thermal diffusion, but expensive at the ton scale!
- ^{39}Ar production by cosmic rays strongly suppressed underground
- Shielding of hydrocarbons in deep underground reservoirs results in low cosmogenic ^{14}C, important for solar neutrino detection
  - Borexino just reported measurement of solar ^{7}Be neutrinos
  - Background from ^{14}C defeated through use of scintillator from petrochemicals
  - In petrochemicals $^{14}C/C \sim 10^{-18}$, six orders of magnitude lower than in atmospheric carbon ($^{14}C/C \sim 10^{-12}$)

Necessary to pre-scan sources of interest for ^{39}Ar

- ^{39}Ar also produced underground by neutron activation, from fission and (α,n) neutrons
  - $^{39}K(n,p)^{39}Ar$
- ^{39}Ar content depends on local content of U, Th, and K, and on rock porosity
- In some groundwater samples $^{39}Ar/Ar$ ratio measured up to a factor 20× (2000%) of the atmospheric ratio
- Cannot rely on ^{39}Ar simply being low. Pre-scan of ^{39}Ar activity on small samples necessary for program.

Analytical techniques to measure ^{39}Ar

- Three main techniques:
  - Counting of argon gas in low-background proportional detectors
  - Accelerator Mass Spectrometry (AMS)
  - Counting of argon in low-background liquid-phase detectors

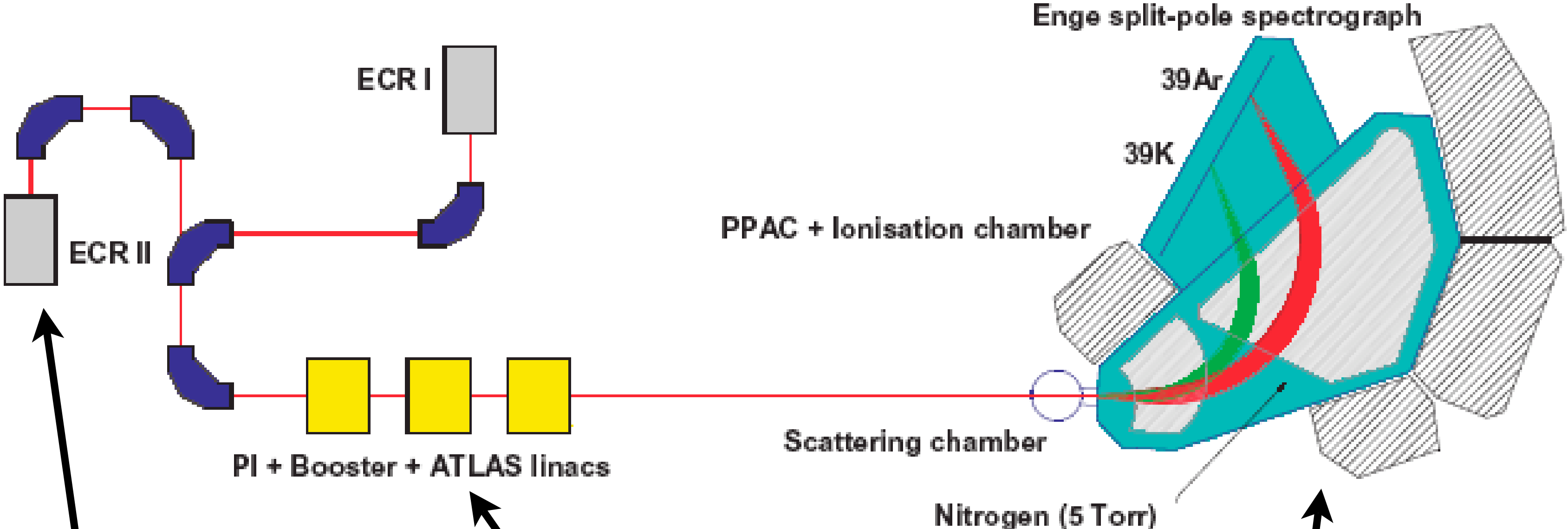
Counting of argon gas in low-background proportional counters

- First established (Loosli 1969) and still today standard method for ^{39}Ar determination
  - Collaborators Loosli and Purtschert run in Bern underground Lab dedicated facility for ^{39}Ar measurements since 1969
- Small samples (1-2 liters STP) of argon and limited depth (100 m.w.e.) required to measure ^{39}Ar at or below atmospheric level
- ^{39}Ar sensitivity limited by detector background. Detector background must be carefully characterized by measurement with reference argon gas depleted in ^{39}Ar
- Current limit on sensitivity at 5% of atmospheric level

Accelerator Mass Spectrometry (AMS)

- Requires special Electron Cyclotron Resonance (ECR) ion source to create positive ions in multiple (7+,8+) ionization states
- Combination of ECR source and ATLAS linear accelerator unique facility at Argonne National Labs
- In 2002 campaign, reached a sensitivity for $^{39}Ar/Ar$ equivalent to 5% of atmospheric level
- Most flexible tool: measurement requires few ml of STP argon

ATLAS at Argonne National Labs



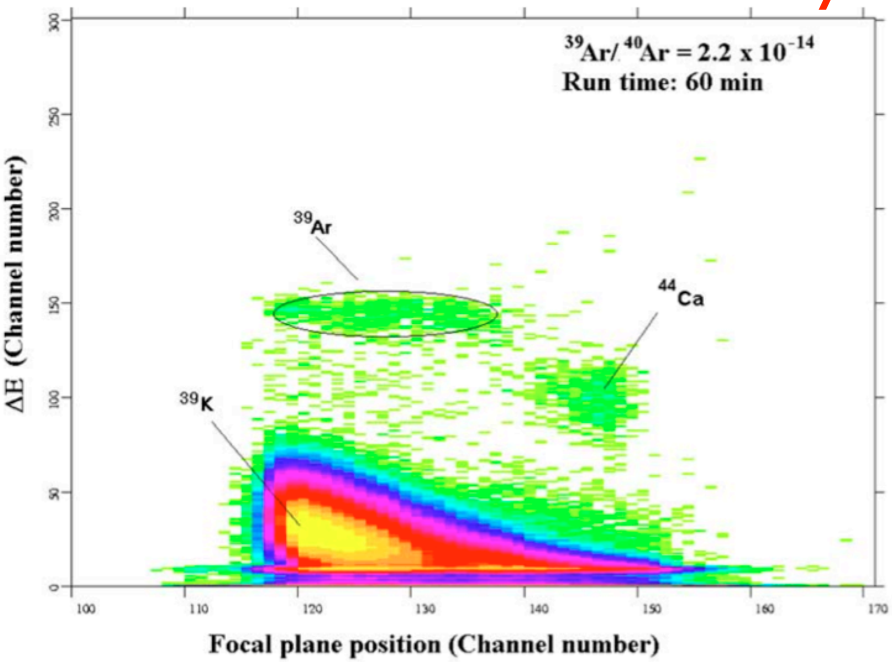
ECR Ion Source

ATLAS Linear Accelerator

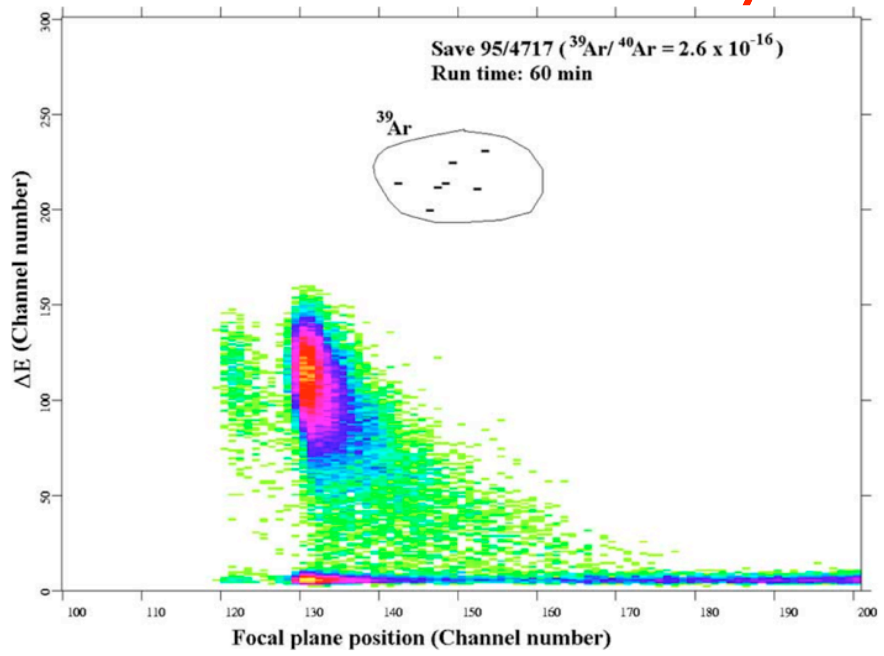
Spectrograph

AMS: 2002 Test

^{39}Ar-spiked argon at 3000% of atm. activity



Deep ocean argon at 30% of atm. activity



Sensitivity limited by presence of ^{39}K background from ion source walls, intrinsic to aluminum

AMS: 2007 Test

- 1 week run in June 2007, ECR source upgraded with addition of high purity aluminum liner
- Reduction of K background by factor 13
- Sensitivity potentially increased to 0.5% of atmospheric level
- Next step:
  - request of additional 2 weeks of time
  - measurement of large pool of samples at 0.5% atm. level

Counting in Liquid-phase detectors

- WARP 3.2-kg reached accuracy of 10% of atmospheric level
- Specially designed low background detector with 10-kg mass could reach below 0.1% of atmospheric level
- Requires first large batch of argon from underground reservoir

Sample Preparation

- Challenge: Ar in subsurface gases typically at few hundred ppm concentration. Needs large quantities with purity >50%
- 1+yr R&D program in Princeton run by graduate student Ben Loer, senior Daniel Marks, freshman Daniel Acosta-Kane
- Resulted in construction of two stages separation plant, deployable on the field
- Chromatographic plant removes strongly adsorbing components (methane, ethane, heavy hydrocarbons, nitrogen, carbon dioxyde)
- Cold trap removes helium, hydrogen
- Achieves production of argon samples with purity exceeding 80%

Discovery of low ^{39}Ar from underground reservoirs

	Count Rate [μBq]
Underground Ar	2036±43
^{39}Ar-Depleted Reference	2035±49
Atmospheric Ar	3625±77
(Under. Ar) - (Ref.)	1±65
(Atm. Ar) - (Ref.)	1589±91
$(^{39}Ar/Ar)_{und} / (^{39}Ar/Ar)_{atm}$	0.00 ±0.05

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Conclusions

- Discovery of underground reservoir with argon low in radioactive ^{39}Ar! Depletion factor at least 20 relative to atmospheric argon.
- No ^{39}Ar detection, represents only upper limit. Motivates development of new, more sensitive techniques
- Reservoir able to supply argon target for multi-ton WIMP/neutrino detector.
- Collaboration developing with industry infrastructure for massive collection and underground storage of depleted argon

WARP Update

Cryostat for 140-kg detector in Hall B, assembly started

Operating 2008