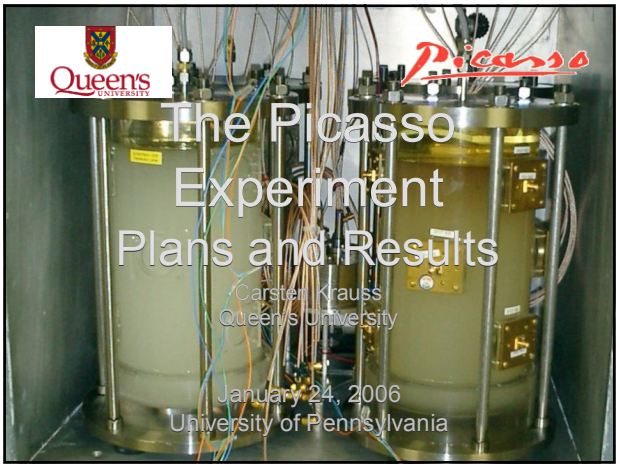


The Picasso Experiment Plans and Results

Carsten Krauss
Queen's University

January 24, 2006
University of Pennsylvania

Overview

QuickTime™ and a GIF decompressor are needed to see this picture.

- Dark Matter
- Superheated Droplet Detector
  - Prototype run results
- SNOLAB
  - PICASSO 32

PICASSO

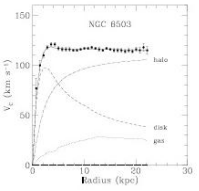
- Project In CAnada to Search for Supersymmetric Objects
- Detect recoils of spin-dependent interactions with dark matter particles

Picasso Collaboration

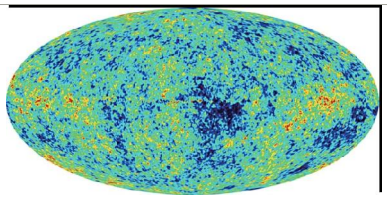
- Indiana University at South Bend
  - I. Levine, W. Feighery, J. Nuerenberg, E. Behnke, C. Muthusi
- Université de Montréal
  - V. Zacek, L. Lessard, C. Leroy, G. Azuelos, J.-P. Martin, U. Wichoski, P. Doane, R. Gornea, M. Bernabe-Heider, M. H. Genest, R. Guenette, F. Aubin, Y. Landry, N. Starinski, G. Richard
- Prague Technical University
  - S. Pospisil, I. Stekl, J. Sodomka, J. Bocan
- Queen's University
  - A. J. Noble, C. B. Krauss, X. X. Dai, K. Clark, C. Storey, C. Hearns
- University of Pisa
  - S. Shore
- Yale University
  - F. d'Errico
- Universita di Lisboa
  - T. Girard, F. Giuliani, T. Morlat, J. G. Marques, A. Fernandes, R. Martins, M. Da Costa
- Paris VI, VII
  - G. Waysand, D. Limagne

Dark Matter

- First hints about discrepancy in cosmological observations in 1933
- Since then more data taken and more hints for existence of dark matter have been found

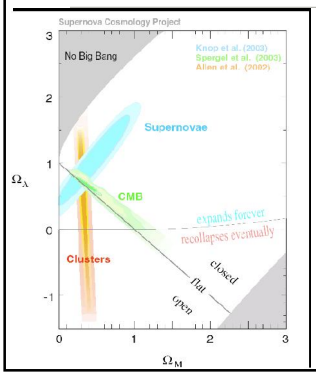


Dark Matter II



- WMAP microwave background picture
- suggests flatness of universe and therefore larger matter density than seen

Dark Matter III



- Cosmological picture is consistent and points towards a missing piece in the understanding of the world
- Hardly anyone is looking for anything but prove for the existence of dark matter

Dark Matter Search Annihilation Signal search

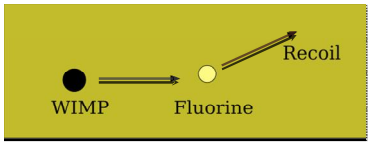
- Alternative to direct observations is observation of annihilation signal which is predicted to occur mainly at galactic cores
- Satellite based gamma ray telescopes like EGRET have not seen conclusive signals
- Promising new experiment GLAST might change the picture

Super-Symmetry and Dark Matter

- Dark matter particle can very likely be the LSP or Neutralino
- Interesting convergence between interests of SUSY theorists and cosmological dark matter

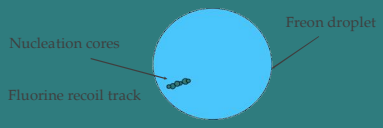
Standard Model particles and fields		Supersymmetric partners			
		Interaction eigenstates		Mass eigenstates	
Symbol	Name	Symbol	Name	Symbol	Name
$q = d, c, b, u, s, t$	quark	$\tilde{q}_L, \tilde{q}_R$	squark	$\tilde{q}_1, \tilde{q}_2$	squark
$l = e, \mu, \tau$	lepton	$\tilde{l}_L, \tilde{l}_R$	slepton	$\tilde{l}_1, \tilde{l}_2$	slepton
$\nu = \nu_e, \nu_\mu, \nu_\tau$	neutrino	$\tilde{\nu}$	sneutrino	$\tilde{\nu}$	sneutrino
g	gluon	$\tilde{g}$	gluino	$\tilde{g}$	gluino
$W^\pm$	W-boson	$\tilde{W}^\pm$	wino	$\tilde{\chi}^\pm_{1,2}$	chargino
H^-	Higgs boson	$\tilde{H}^-_1$	higgsino		
H^+	Higgs boson	$\tilde{H}^+_2$	higgsino		
B	B-field	$\tilde{B}^0$	bino	$\tilde{\chi}^0_{1,2,3,4}$	neutralino
W^3	W^3-field	$\tilde{W}^3$	wino		
H^0_1	Higgs boson	$\tilde{H}^0_1$	higgsino		
H^0_2	Higgs boson	$\tilde{H}^0_2$	higgsino		
H^0_3	Higgs boson				

Recoil Signal



- WIMP only interacts by elastic nuclear recoils
- For spin dependent interactions Fluorine is the most favourable target material because its nuclear matrix element is the largest
- Recoil energy in keV range
- Expect less than 1 count/day/kg active mass

Superheated Droplets



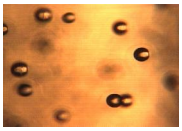
- Freon droplets suspended in gel matrix
- Each droplet is like a mini-bubble chamber
- Nuclear recoils trigger phase transition

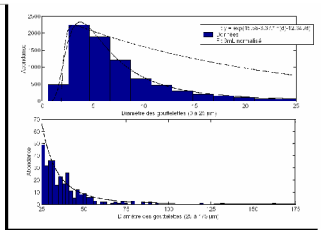
Detector Principle

- SDDs originally developed for neutron dosimetry and are in use at nuclear facilities
- Active material is C_4F_{10} in superheated form
- Only fissions, alphas and nuclear recoils are detected
  - Insensitive to minimally ionizing particles and gammas
- Seitz bubble chamber limit:
  - critical energy inside critical radius leads to formation of bubble in superheated medium

$$R_c = \frac{2\sigma(T)}{(p_v - p_0)} \qquad E_c = \frac{16\pi}{3}\frac{\sigma(T)^3}{(p_v(T) - p_0)^2}$$

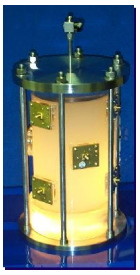
Superheated Droplet Detector





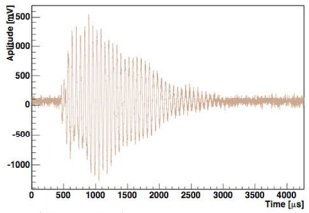
- Bubble size is crucial for background rate and sensitivity
- Average bubble size increased by factor of six since

Detector



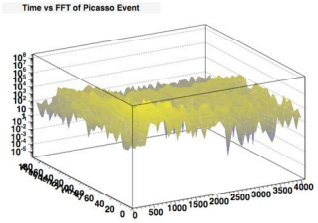
- Contains gel matrix to keep superheated bubbles suspended
  Use CsCl to match density of bubbles to gel
- Started feasibility studies with commercial 5ml detectors
- inceased size and purity since

Signal Processing



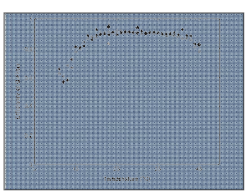
- acoustic shock-wave is picked up by piezo
- Typical bubble signal sampled with 960kHz (4096 samples)

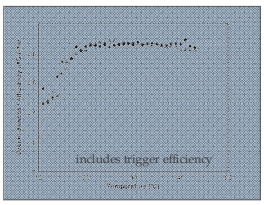
Filter & Event Selection



- 2 dimensional Fourier transformation used to distinguish bubbles from background noise
- If enough power is concentrated in trigger window and frequency range 20-90kHz, signal is identified as bubble

Filter Efficiency



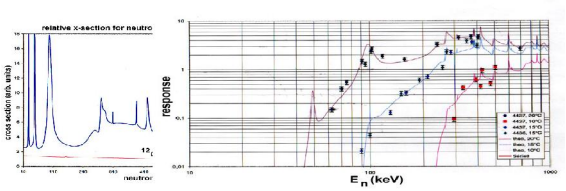


- Filter has been tested over full temperature range
- Response is fairly high and uniform

Calibration

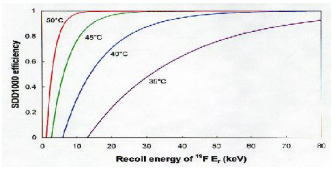
- Tandem accelerator in Montreal used to calibrate detectors with mono-energetic neutrons (^{7}Li(p,n) reaction)
- Beam-line upgraded to run with lower energy, narrower energy spread

Neutron Calibration



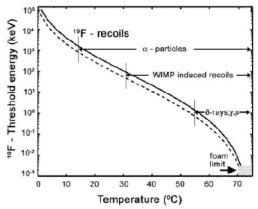
- Neutron cross-section well known, modeled and reproduced in detector response

Temperature Dependence



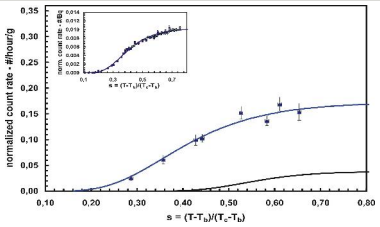
- Threshold and response changes with temperature

Detection Threshold



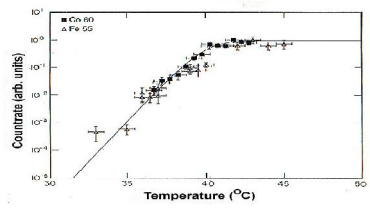
- Detector only becomes sensitive to background at high temperatures
- α-particles are a problem over the entire range of operation

Alpha Response



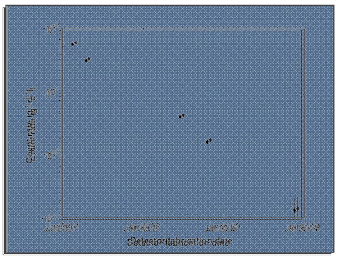
- Spiked detector gives alpha response
- Identical results from Ac and Th spike
- Extremely important input for understanding of background

Gamma Response



- Response curve modeled well
- (This is the response for another type of detector with a different gas mixture)

Successful Purification

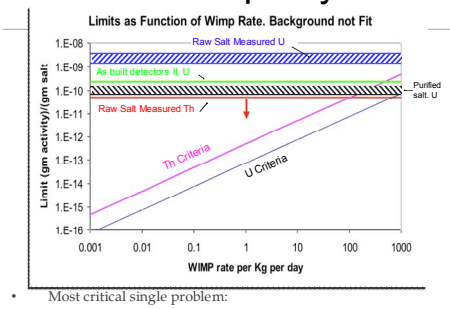


- Development since the start of purification efforts

Internal Background

- This is the most difficult challenge PICASSO faces for the next steps
- Currently purifying detector ingredients with methods developed by SNO and refined for PICASSO
- New and more efficient methods are needed

Radiopurity



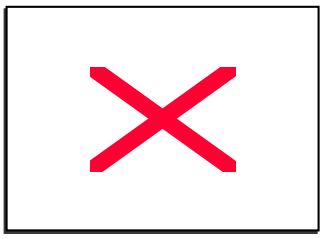
- Most critical single problem:
  - Internal activity from CsCl has to be purified
- Two possible ways: Replacing CsCl salt - breakthrough in purification

Radiopurity

Large scale purification system for SDD ingredients in Montreal

- Status: Improvement by
  - better handling (cleanroom, procedures)
  - larger size handling system, cover gas system
  - New method of purification
- Problem: long turn-around times

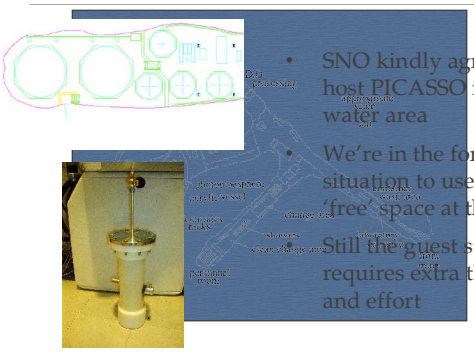
Spacial Reconstruction



- Very promising studies to reconstruct the location of the exploded bubble to be able to suppress hot-spots and surface events
- (Here only 4 piezos, final new detectors will have up to 9)

Sudbury

Installation At SNO



- SNO kindly agreed to host PICASSO in the water area
- We're in the fortunate situation to use to only 'free' space at the lab
- Still the guest status requires extra thought and effort

Data Taking in 2004

60t tank area in the SNO water utility area

- 0.27 μ/m^2/day
- 6 1 liter detectors were operated for 7 months
- 2 independent temperature control systems
- 2 readout channels for each detector
- 1 foot water cubes for neutron shielding
- 4096 12bit samples for each trigger with a sampling rate of 960kHz
- Data taken remotely

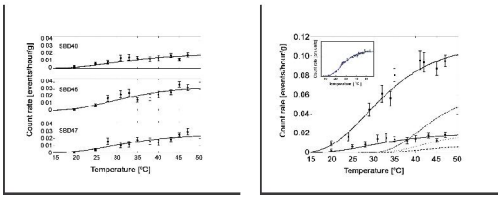
SNO Phase Detector

- 1 liter containers
- SNO developed polypropylen
- Mineral oil between gel and pressure line
- Droplet sizes between 10-100µm
- Data-taking for ≈30h; re-pressureization for 10-15h
- Two piezo-electric sensors on each detector

Data Analysis

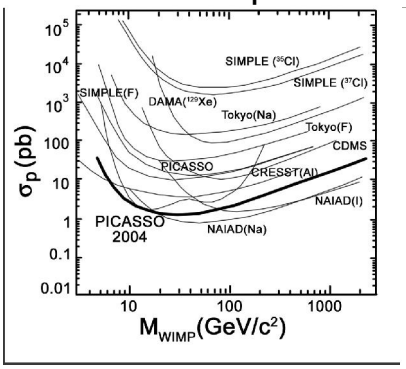
- Data with 3 detectors used for analysis with an active mass of 7.45, 6.62 and 5.35g
- Total exposure was 1.98±0.19kg d
- used local WIMP matter density of $0.3GeV/c^2/cm^3$, v_{rel}=244km/s and v_{esc}=600km/s (standard parameters)

Result



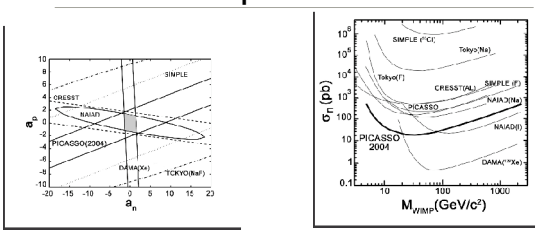
- Count rate for 3 used detectors
- Alpha rate of cleanest and older type of detector (with expected neutralino signal for m_{WIMP}=50GeV and σ=2pb, 5pb, 10pb)

Interpretation I



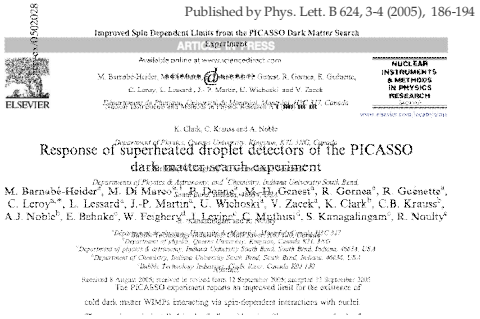
- Exclusion plot for spin-dependent neutralinos
- lowest point in parameter space σ_p=1.31pb and σ_n=21.5pb for a WIMP with 29GeV mass

Interpretation II



- Limits in spin-independent sector less stringent
- Effective coupling strength a_n for neutrons and a_p for protons for a WIMP mass of 50GeV

Papers - in Press



Published by Phys. Lett. B 624, 3-4 (2005), 186-194

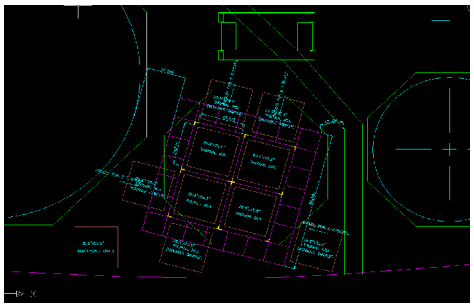
Improved Spin-Dependent Limits from the PICASSO Dark Matter Search Experiment

ELSEVIER

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH

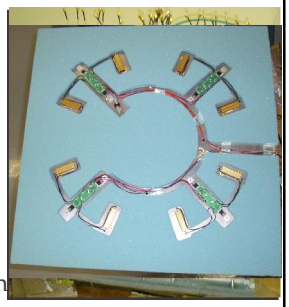
Response of superheated droplet detectors of the PICASSO dark matter search experiment

PICASSO 32 System



Temperature and Pressure Control System

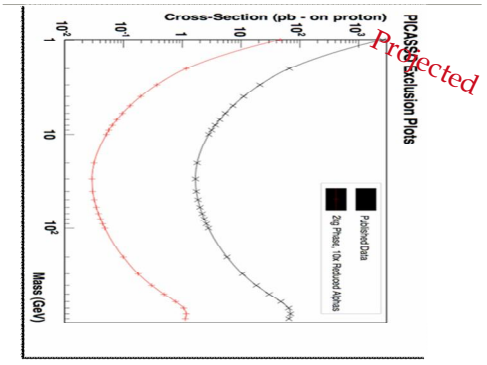
- Developed at Queen's
- Houses 4 detectors
- Operates between 20 and 55°C
- Stable at 1/16 of a degree Celsius
- all 8 are currently in production

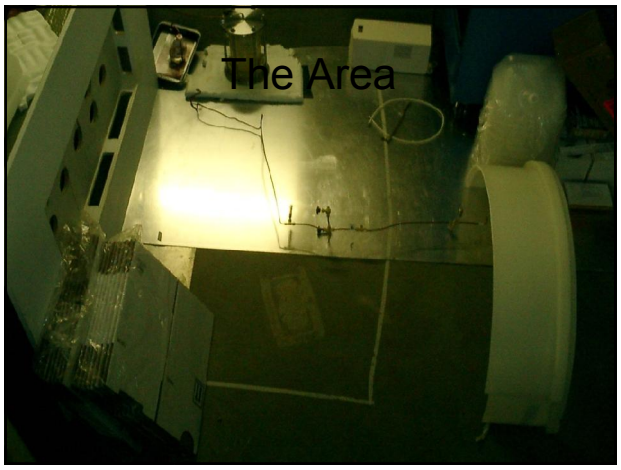


PICASSO 32

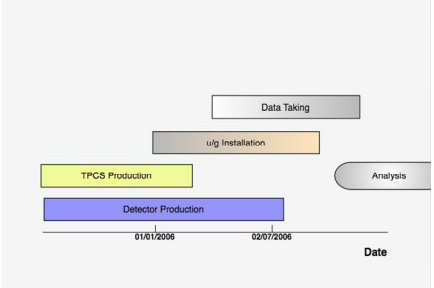
- 4 new detectors are ready for installation (since November)
- α-contamination below sensitivity of surface lab
- Purification method (with HTiO) now stable and reproduceable
- New method has been found and is tested now

Exclusion Limit for PICASSO 32





Installation Schedule



Data Taking

Future Plans

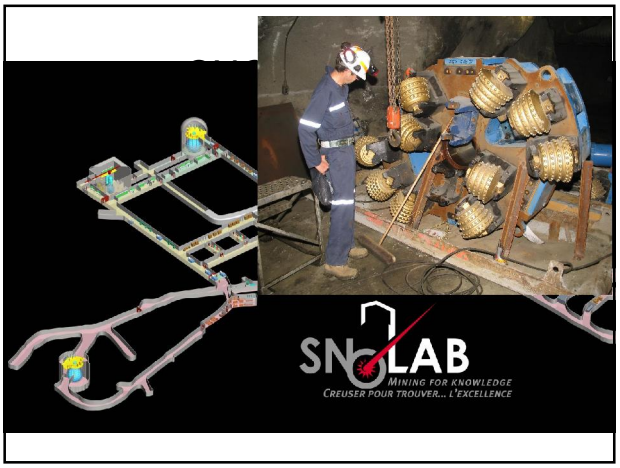
Active mass	Back-ground	Location at SNO	Start data taking	End data taking	Runtime (inc. dead time etc)	Exposure	Limits (pb)
40 g 1l	0.2 cts/g/d	D_2O tank	15.04.04	15.08.04	4 months	2 kgd	1.3 pb
2 kg 32x 4.5l	0.2 cts/g/d 0.03 cts/kg/d	D_2O tank (*)	01.09.04	01.06.06	6 months	194 kgd	0.13 pb 0.05 (*)
3 kg 7 x 30l	0.02 cts/g/d	D_2O tank	01.06.06	01.12.06	6 months	420 kgd	$7x\ 10^{-3}$ pb
10 kg 24 x 30l	0.02 cts/g/d	Lunch room	01.12.06	01.06.07	6 months	1400 kgd	$2x10^{-3}$ pb
10 kg 24 x 30l	0.002 cts/g/d	SNOLAB	01.06.07	01.12.07	6 months	1400 kgd	$2x10^{-4}$ pb
100 kg 240x30l	0.002 cts/g/d	SNOLAB	01.12.07	01.06.08	6 months	14000 kgd	$6\ x10^{-5}$ pb

Phase 1: reach DAMA
Phase 2: reach tip of MSSM predictions
Phase 3: reach core of MSSM predictions

(*) assumes 1/6 alpha background due to 6x larger droplets!

Picasso

SNOLAB

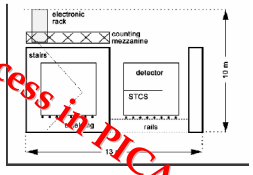


SNOLAB Hopefuls

- SNO+
- Majorana (Majorana/Gerda III)
- GasEXO
- DEAP
- SuperCDMS
- PICASSO

Scaling of Picasso

Pending success in PICASSO 32 phase



- Sketch for the 100kg active mass phase
- Plan to move the system to the rectangular hall of SNOLAB
- All of the details still have to worked out

Summary

- Data taken in 2004 has been analyzed
- PICASSO principle works
- To be competitive background has to be reduced and system has to be scaled up
- PICASSO 32 will be installed in the next months
- New, improved results to be ready next year