Search for Dark Matter with Liquid Xenon Detectors

David B. Cline
Astrophysics Division
UCLA

1. Dark Matter – Rates for SUSY Dark Matter Detection
2. Properties of Liquid Xenon
3. UCLA/Torino Study for Two Phase Detection
4. ZEPLIN I – Results So Far
5. ZEPLIN II – Status
6. On to a One Ton Detector – ZEPLIN IV

- Summary -

Other Detectors:
Very Long
Liquid Argon
WIMP Detector
being studied
by ICARUS
Team (will not discuss) ~ 5 Tons
at LGNS

Evidence for Dark Matter in the Universe

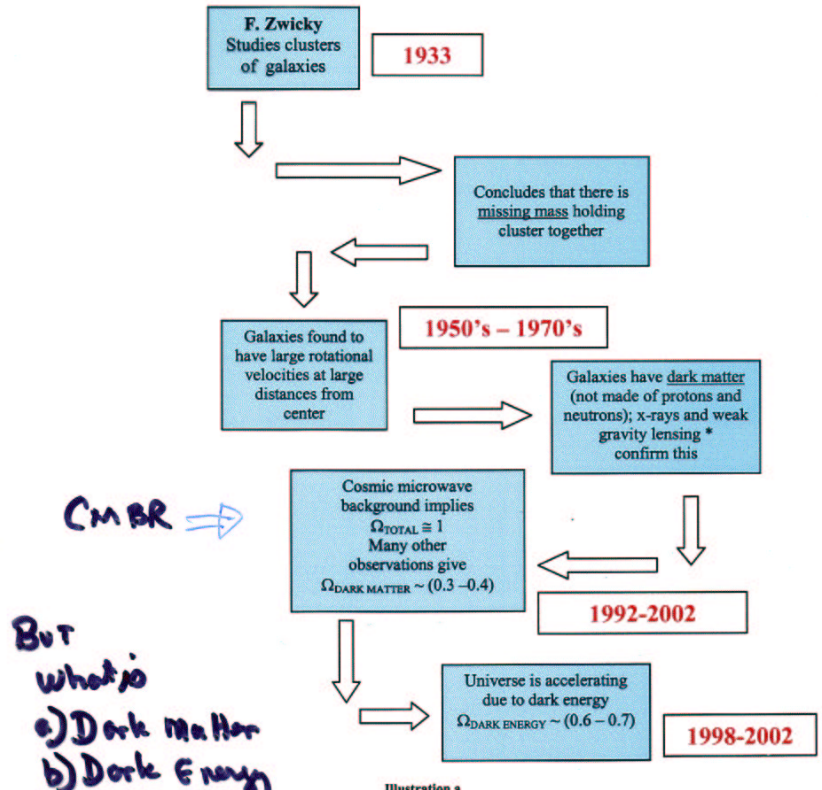


Illustration a

A brief history of the observations that led to the current understanding that the universe is largely composed of Dark Matter and Dark Energy Ω which refers to the ratio of the density of a component of the universe divided by the critical density from Einstein's Theory of General Relativity. The current value of Ω_{total} indicates that the universe will likely expand forever.

* See J. Wambsganss, "Gravitational Lensing", *Scientific American*, November 2001.

SUPER SYMMETRIC Dark matter

DM 02 cf.

$\Omega_\chi h^2$ CAN BE COMPUTED RELIABLY

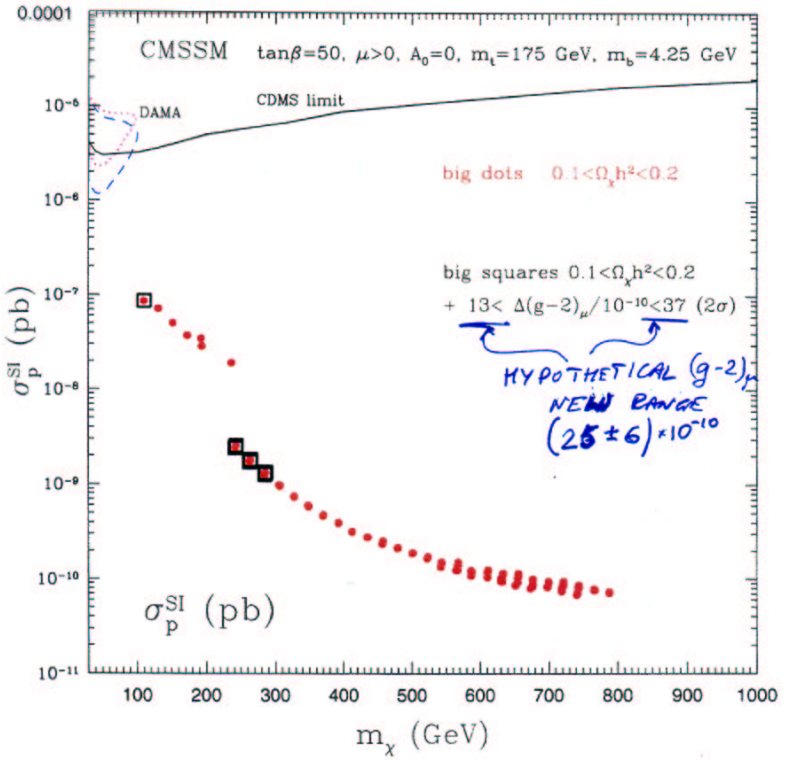
- FEW % ACCURACY
- MATCHES MEASURED ERRORS OF Ω_{CDM}

DM 02

DM 02

Marona Del Rel PRELIMINARY

Roszkowski et al Feb 02 CMSSM



'PREDICTED' CROSS SECTIONS!

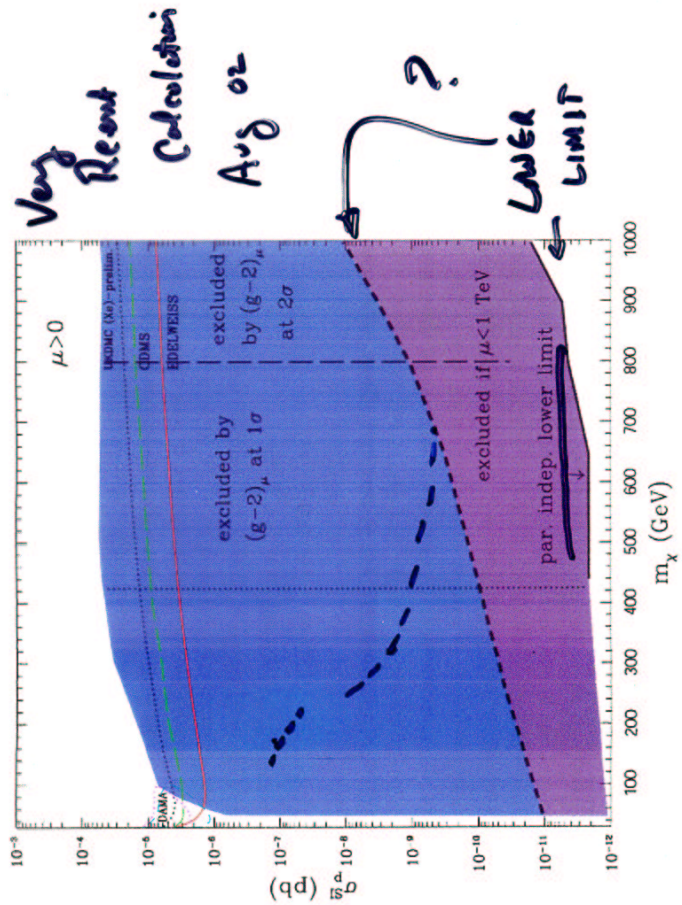


Figure 5: Ranges of σ_p^{SI} in the general MSSM *vs.* m_χ for $\mu > 0$, which are allowed by collider bounds, $b \to s\gamma$ and $0.1 < \Omega_\chi h^2 < 0.2$. Also marked are some results of recent experimental WIMP searches. The thick black line indicates a *parameter–independent* lower bound. The region below the dashed line is excluded if one imposes the constraint $\mu < 1$ TeV. The ranges of m_χ to the

TABLE I. Liquid Xenon as a WIMP Detector

1. Large mass available - up to tons.

- Atomic mass: 131.29
  - Density: 3.057 gm/cm^3
  - W_i value (eV/pair) 15.6 eV
  - No long-lived isotopes of xenon

2. Drift velocity: 1.7 mm/μ.s @ 250V/cm field

  - Decay time: 2 ns → 27 ns

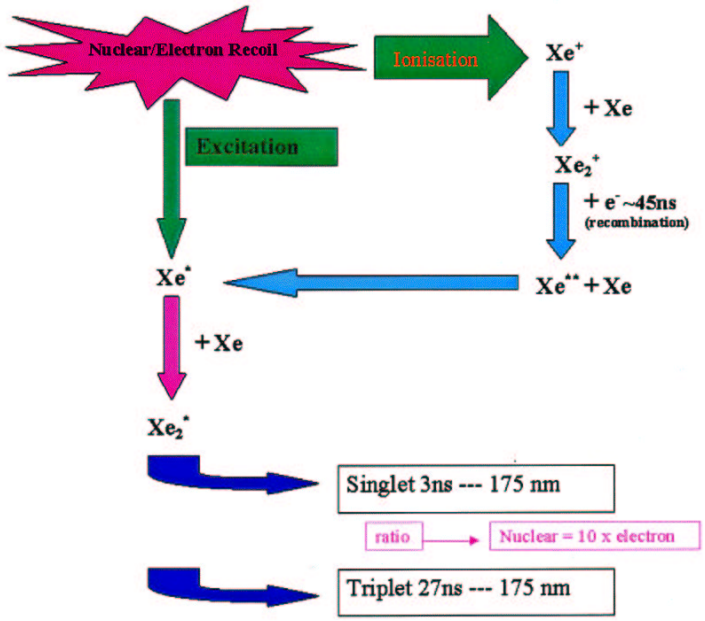
3. Light yield > NaI, but intrinsic scintillator (no doping)

⇒ Excimer process very well understood

→ First excimer laser was liquid xenon in 1970!

PROPERTIES OF LIQUID XENON

Liquid Xenon Scintillation Mechanism



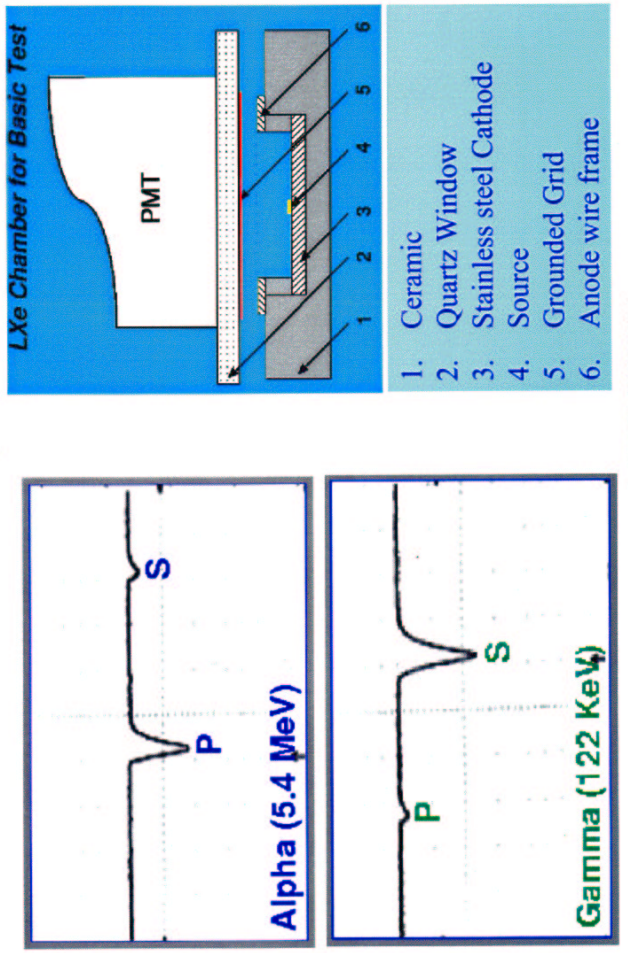
Very Fast Signals

⇒ Pulse Time Discrimination (ZEPLIN I)

UCLA/Torino/ITEP Tests ~1990-92

Principle Tests Setup

NIM A327 (1993) 203



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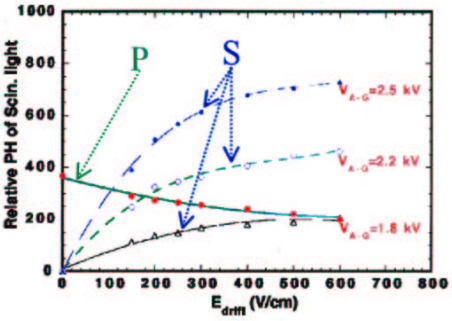
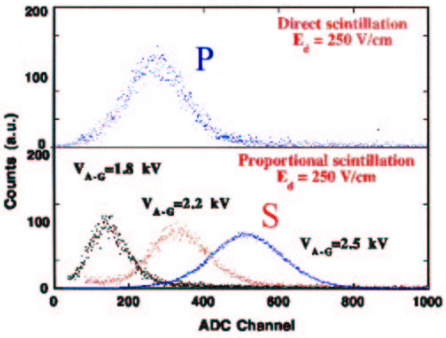
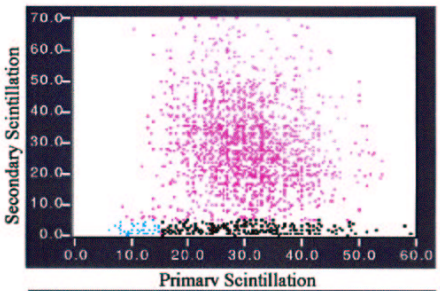
→ 2 Kg Detector at CGRN

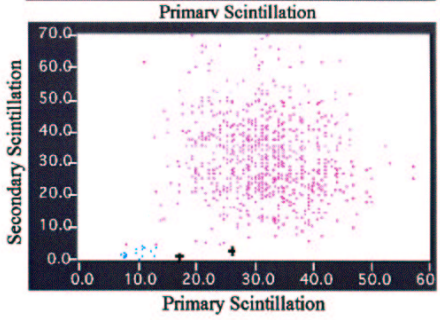
Proportional scintillation vs field







← ν_μ Beam



Single phase 99.8% rejection

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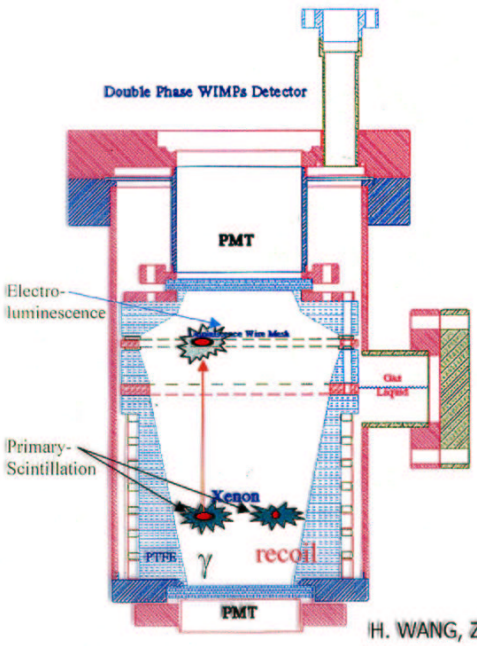
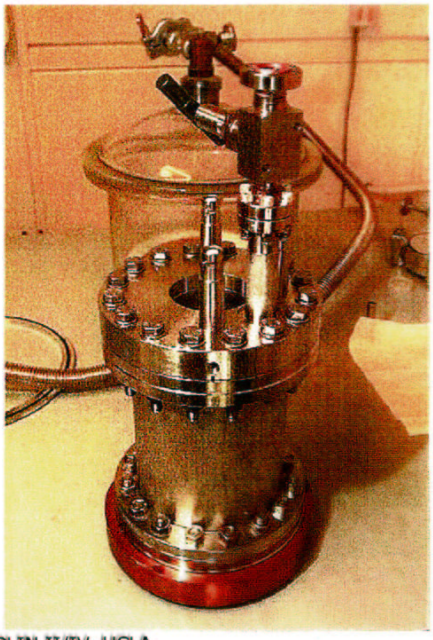
UCLA Fermilab 1995

Xenon Two-Phase Prototype Detector





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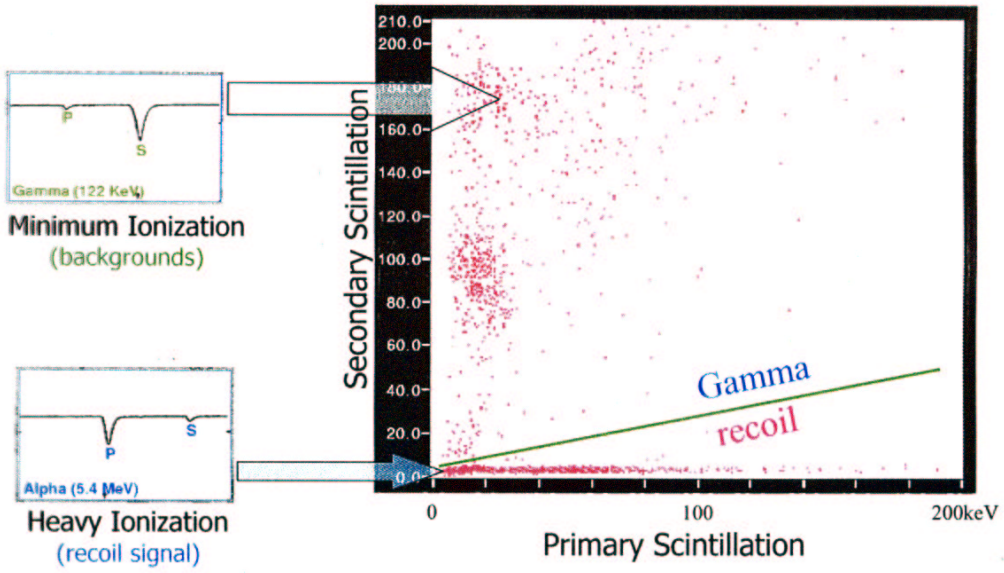
Background and recoil separation



The ZEPLIN II Collaboration

DB Cline, M Atac, Y Seo, F Sergiampietri[a], H Wang (ZEPLIN II, IV)
Physics and Astronomy, UCLA , [a] Pisa
JT White, J Gao (ZEPLIN II, IV)
Department of Physics, Texas A&M University
P Picchi, L Periale, G Mannocchi, C Castagnoli, F Pietropaolo (ZEPLIN II)
ICGF-CNR-Torino/INFN-Padova
GJ Alner, SP Hart, JD Lewin, RM Preece, JW Roberts, NJT Smith, PF Smith (ZEPLIN I, II)
Particle Physics Department, Rutherford Appleton Laboratory, Chilton, Oxon

B Ahmed, A Bewick, D Davidge, JV Dawson, AS Howard, I Ivaniouchenkov, WG Jones, MK Joshi, V Lebedenko, I Liubarsky, R Lüscher, T J Sumner, J J Quenby (ZEPLIN III)
Blackett Laboratory, Imperial College of Science, Technology and Medicine, London
MJ Carson, T Gamble, VA Kudryavtsev, TB Lawson, MJ Lehner, PK Lightfoot, JE McMillan, B Morgan, SM Pealing, M Robinson, NJC Spooner, DR Tovey
Department of Physics and Astronomy, University of Sheffield
U Cotti, M Reyes, L Villasenor
Institute of Phys. and Maths., UMSNH, Morelia, Mexico
A Zepeda
Physics Department, CINVESTAV, Mexico City
CJ Hailey, WW Craig, M Sileo, P Graham, J Hong
Astrophysics, Columbia University

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Xenon outs WIMPs

Dark-matter detector could pin down the Universe's missing mass.
1 May 2002

PHILIP BALL

The UK's Dark Matter Collaboration's detector lab in Buolby Mine, Yorkshire.

Researchers in London are building a cheap dark-matter detector that should be able to spot the exotic particles called WIMPs that are suspected of hiding most of the Universe's missing mass[1].

A prototype of the detector has just shown, for the first time, that it can spot something as close to a WIMP as it's possible to produce in the lab.

WIMP stands for 'weakly interacting massive particle'. If WIMPs exist at all, they are thought to be hefty compared to the protons and neutrons in an atomic nucleus, but to barely interact with these components of normal matter.

Physicists believe that WIMPs make up as much as 99% of the total mass of the Universe. Astronomers can't see this matter - hence its 'dark' moniker - but they can see its gravitational effects on the way the stars and gas in galaxies rotate.

Even if billions of WIMPs are streaming through our bodies, they don't have any effect. So WIMP-hunting could be a frustrating affair - like trying to fish for shrimps using the net from a football goal.

Several experiments are currently going to great lengths in the search for WIMPS. The problem is that detectors capable of WIMP-spotting will probably pick up other cosmic particles, too, swamping the WIMP signal. Cosmic rays - high-energy particles of normal matter from space - and radioactive emissions would also register.

To shield a WIMP-detector from cosmic rays, it must be placed deep underground. The UK Dark Matter Collaboration (UKDMC) houses detectors at a depth of 1,100 metres in a salt mine in Yorkshire. Another array in Italy is buried in a tunnel beneath a

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click here to let us know by filling in the Nature Science Update online questionnaire

Boulby Mine
North Yorkshire, UK

ZEPLIN I : Status and Preliminary Results Dark Matter 2002 Marina del Rey, CA USA Feb-22-2002

Simon Hart: RAL PPD s.p.hart@rl.ac.uk

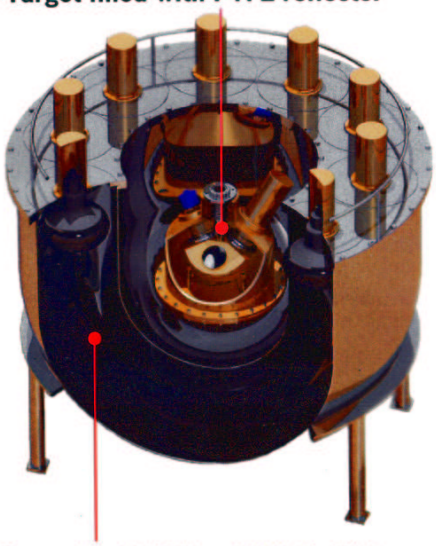
4 Kg

ZEPLIN I

Design

OPERATING NOW AT BNL84

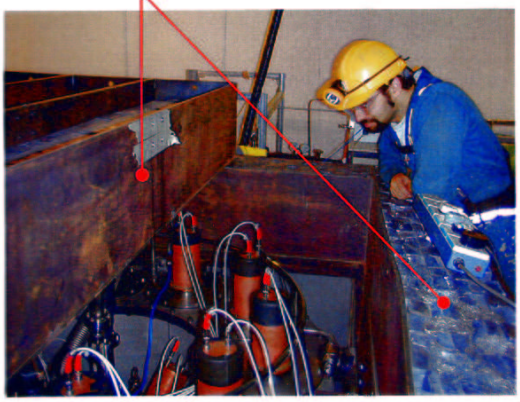
Xe Target lined with PTFE reflector



1 Tonne liquid PXE scintillator Veto

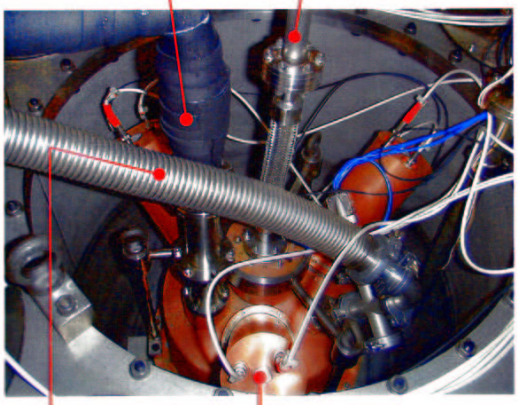
Installation Underground

Lead Shielding



Coolant line

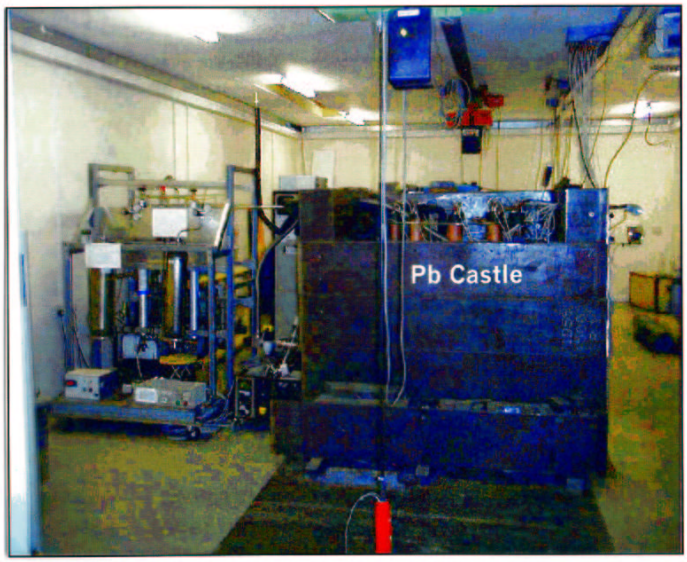
Xe line



Vacuum pump on insulation jacket

Photomultiplier

Installation Underground

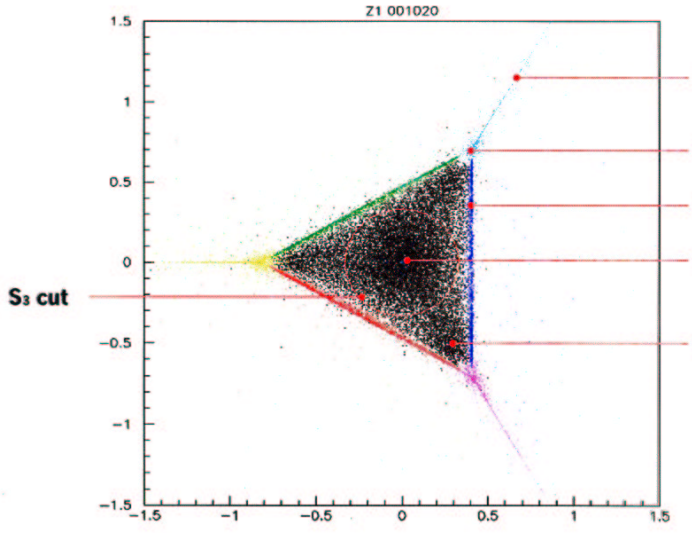


Xe Purification:
Oxysorb and pumping
on solid Xe

Xe capture
(beer barrels)

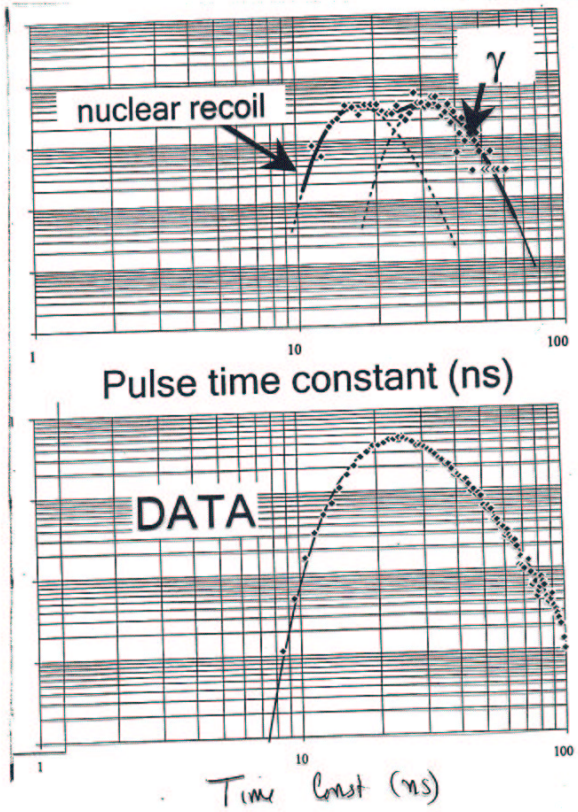
S_3 Fiducial Volume Cut

Project normalised amplitudes of each phototube onto plane

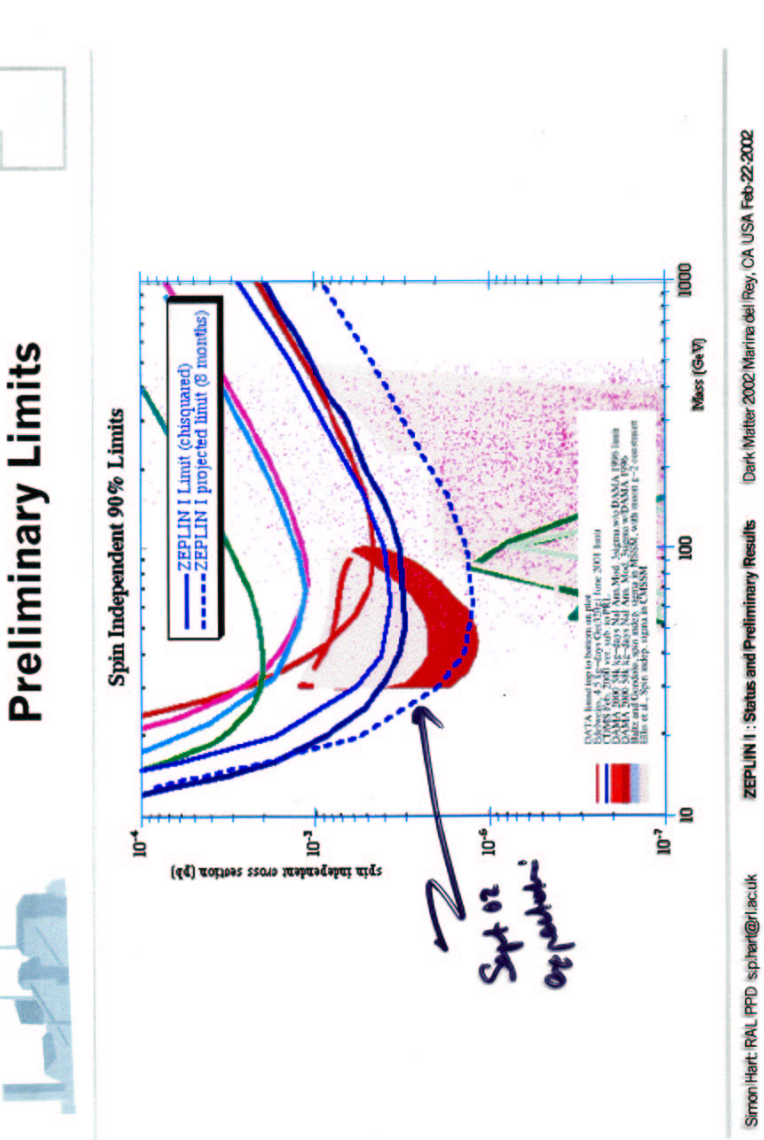


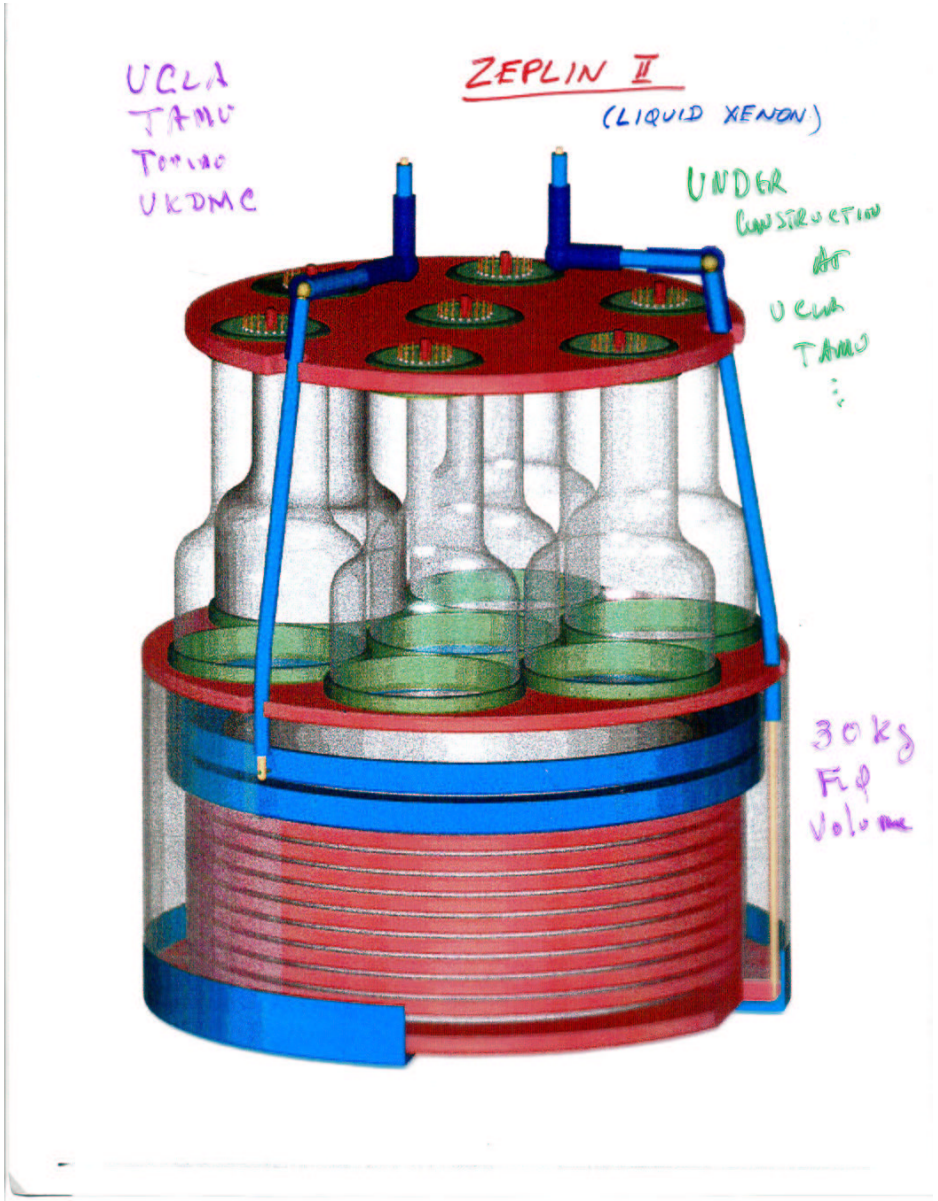
Trigger on one photo-electron in any pmt

ZEPLIN I
– DM02



No 'Hint' of a Signal

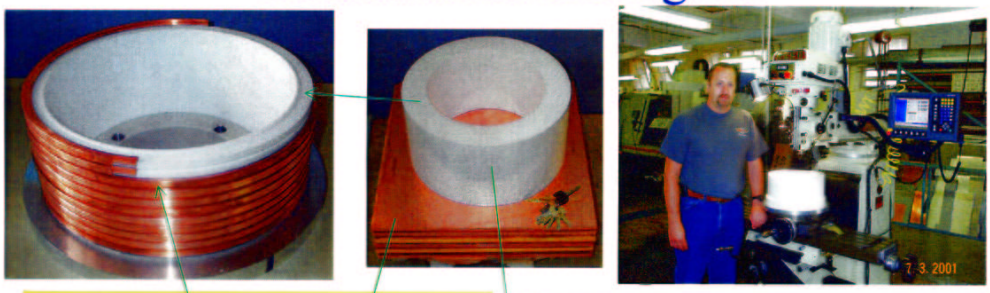



UCLA
TAMU
Torino
UKDMC
ZEPLIN II
(LIQUID XENON)
UNDER
CONSTRUCTION
AT
UCLA
TAMU
30kg
Fid
Volume


Construction at UCLA
ZEPLIN II Detector
cut-away view
of ZEPLIN II
With top
assembly
Vacuum vessel
Target vessel
sensors
source
Vacuum
port
H. WANG, ZEPLIN II/IV, UCLA
Feb. 22, 2002

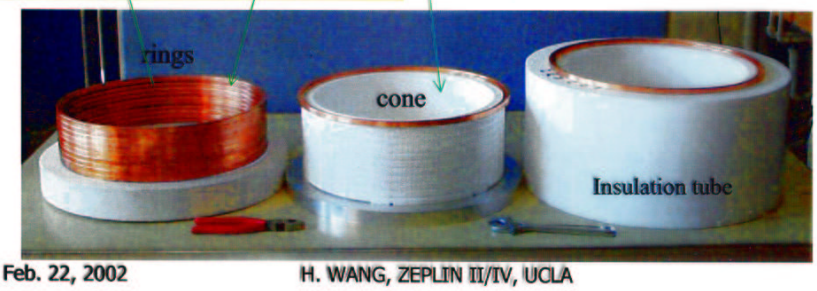
Construction in Progress

AT UCLA



The largest PTFE piece is being machined at the UCLA Physics department machine shop

Field shaping rings are made out of pure Oxygen free copper



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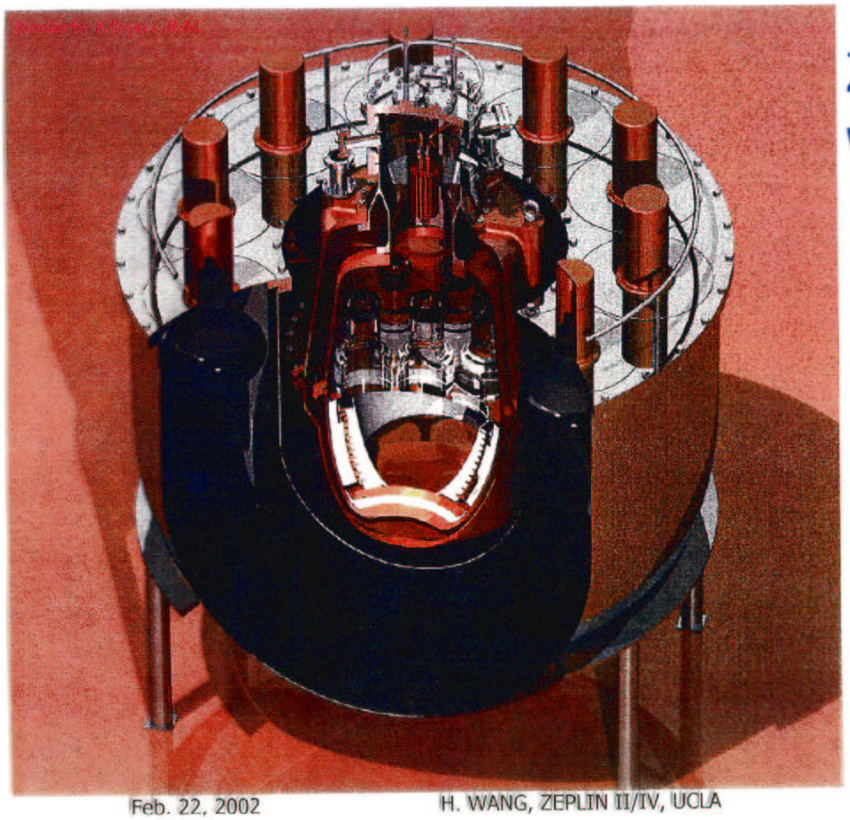

ZEPLIN II with Veto

Final setup to be placed in lead shield

40 kg

30 kg Fid Volume

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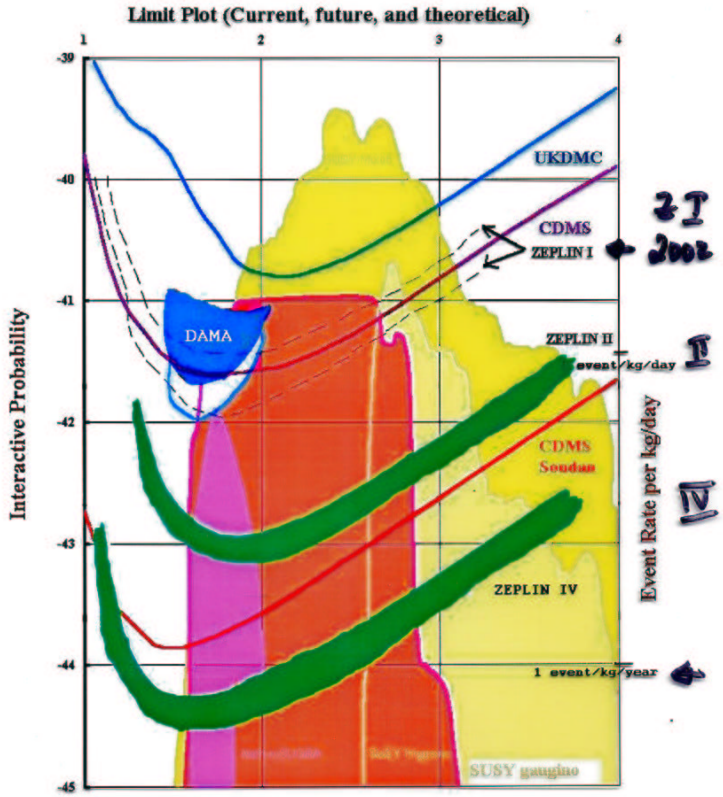
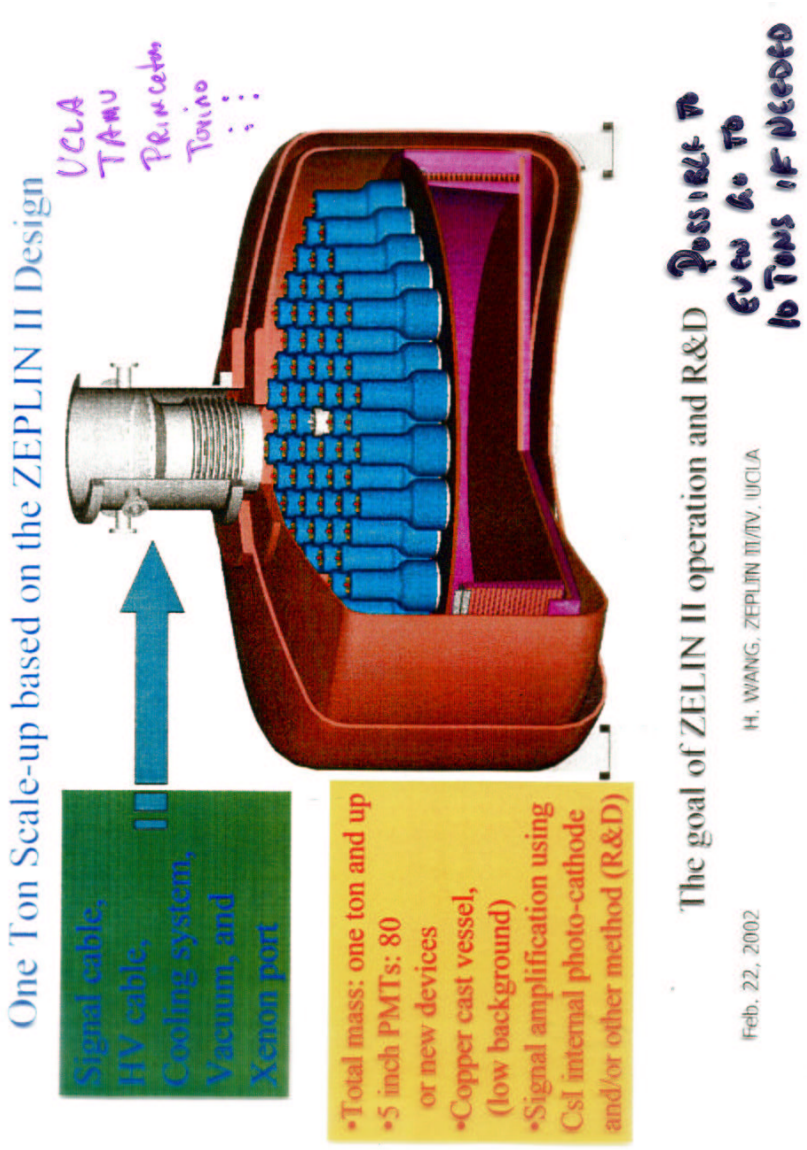
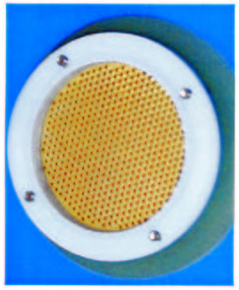
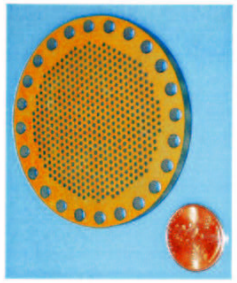

Limit Plot (Current, future, and theoretical)
Interactive Probability
Event Rate per kg/day
UKDMC
CDMS
ZEPLIN I
DAMA
ZEPLIN II
event/kg/day
CDMS
Soudan
ZEPLIN IV
1 event/kg/year
SUSY gaugino
2002

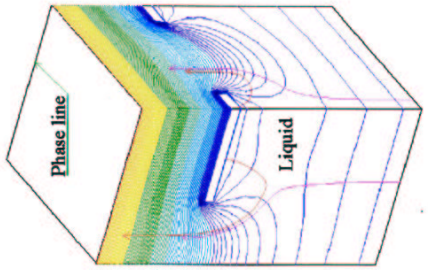

One Ton Scale-up based on the ZEPLIN II Design
UCLA
TAMU
Princeton
Torino
Signal cable,
HV cable,
Cooling system,
Vacuum, and
Xenon port
•Total mass: one ton and up
•5 inch PMTs: 80
or new devices
•Copper cast vessel,
(low background)
•Signal amplification using
CsI internal photo-cathode
and/or other method (R&D)
The goal of ZELIN II operation and R&D
H. WANG, ZEPLIN III/IV, UCLA
Feb. 22, 2002

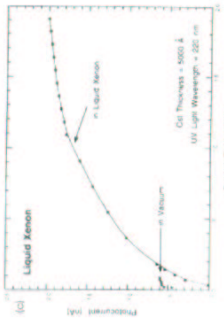
Possible Gamma Amplification

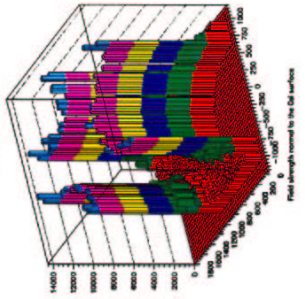




R&D for ZEPLIN IV or ton scale xenon detector







M Atac[1], D B Cline[1], K T McDonald[4], P Picchi[2], Y Seo[1], F Sergiampietri[1], T A Shutt[4], P F Smith[1], H Wang[1], J T White[3], J Gao[3]
[1]Physics and Astronomy Department, University of California, Los Angeles, California 90095-1547,
[2]ICGF-CNR, Corso Fiume 4, Torino, Italy,
[3]Texas A&M University, College Station, TX 77843-4242,
[4]Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544-0708

H. WANG, ZEPLIN II/IV, UCLA

Feb. 22, 2002

Other Liquid Xenon Detectors

1) DAMA — Liquid Xenon 7 kg of enriched Xenon. No discrimination

2) ZEPLIN III — 6 kg of highly discriminating liquid Xenon — high |E| field to obscure primary ionization
IC + UKDMC

3) XENON — Test detector for eventual 1 ton detector discrimination (2 phase +)
Columbia U +

4) XMAS — Large liquid Xenon detector for solar neutrinos and DM search
Japan

LIQUID XENON DARK matter Detectors

Xenon discriminating detector

- Available in Large Quantities ⇒ 10 Tons! Full SUSY DM
- High Atomic Number (Z_{Xe}=54, $\sigma_{WIMP\text{-}Nucleon} \propto A^2$)
- High Density (~ 3g/cm^3 liquid)
- High Light (175nm) & Ionization Yield
- Can be Highly Purified
  - long light attenuation length (~m)
  - long free electron life time (~5ms)
- Gamma & Recoil signal Discrimination
- Easy to Scale up to Large Volume ⇒ 30kg
- No Long Lived Radioactive Isotopes

ZEPLIN I ⇓ II ⇓ IV (1 Ton)

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