Short Review of WIMP Dark Matter Direct Detection

WARP

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Moriond, March 14 2007

Direct Dark Matter Detection: Very Exciting Moment

WIMP Dark Matter well supported by independent cosmological argument CMB and astrophysical observations, SUSY models

Very High Discovery Potential

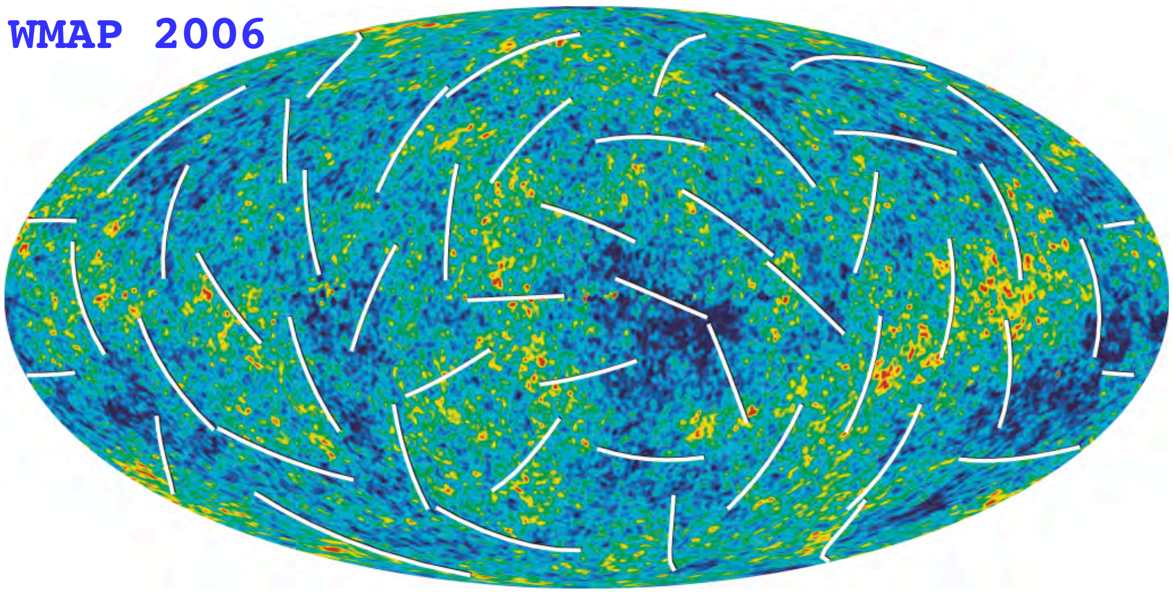
Field set and ready for a “quantum leap” in sensitivity (many orders of magnitude) thanks to liquified noble gas detectors

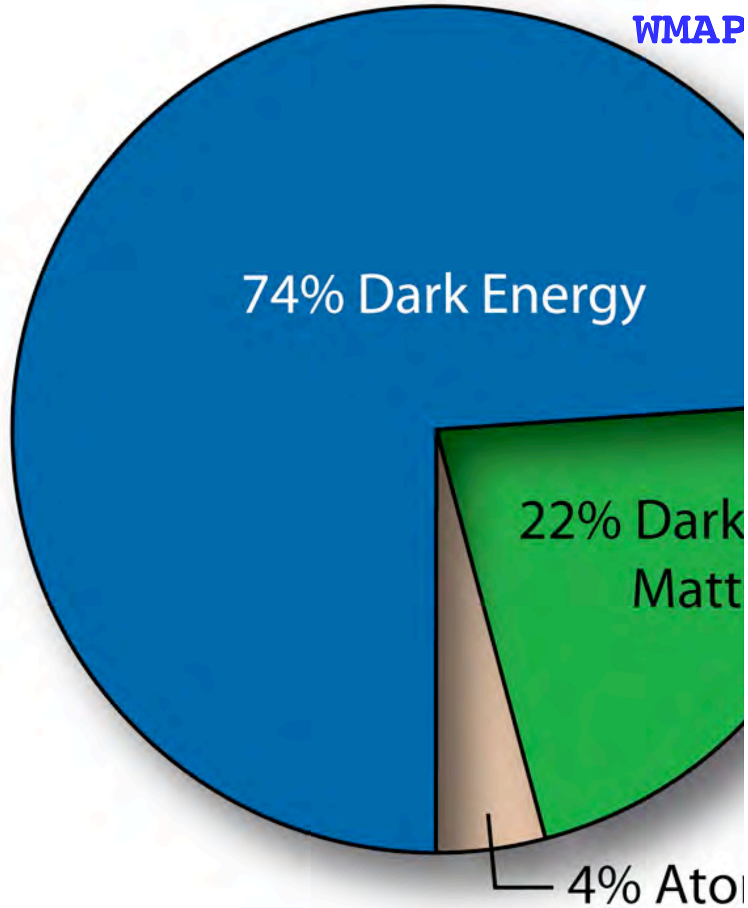
liquified noble gas detector to be scale by x100 - x1000 soon!

Exciting developments in particle, atomic physics and and significant improvements detector technology

Dark Matter

WMAP 2006

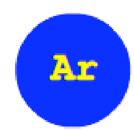




Dark Matter comprises 22% of Universe

Intriguing Hypothesis: Weakly Interacting, Massive Particles (WIMPs)

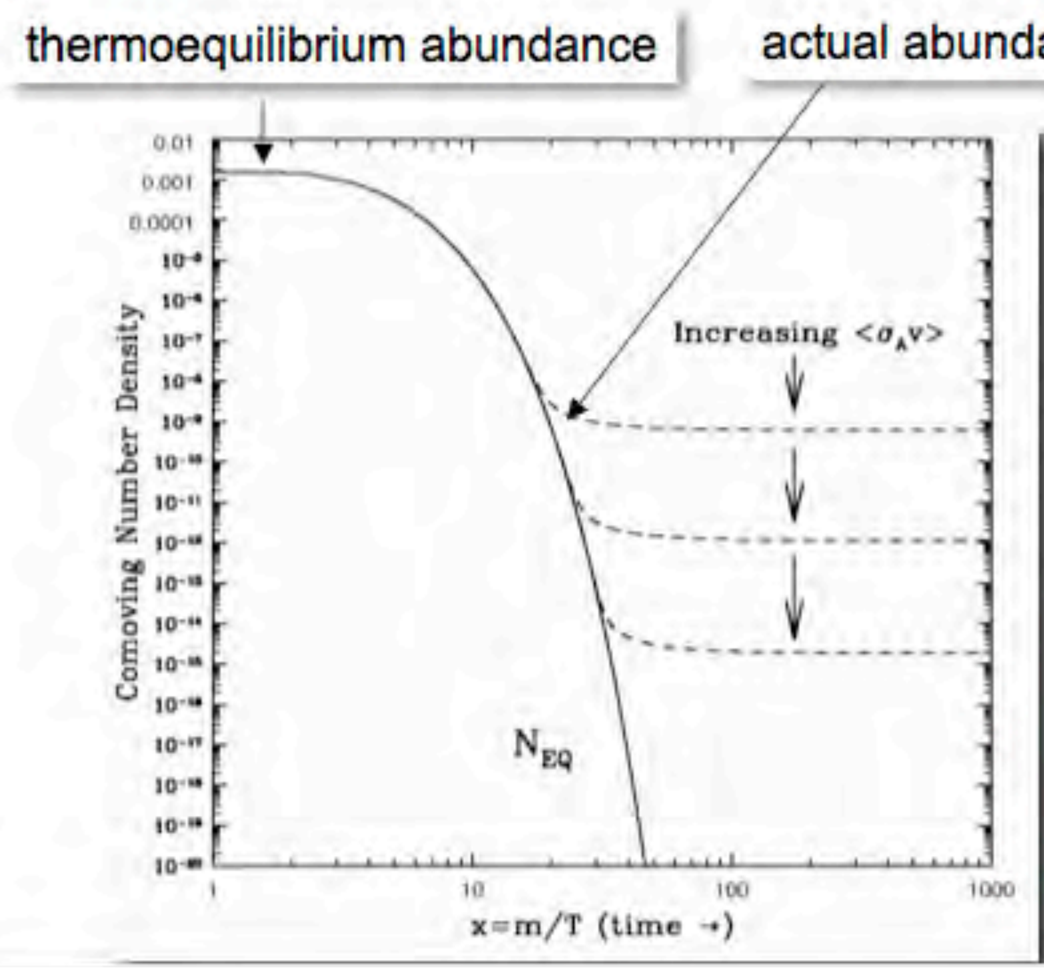
Candidates provided by SUSY theories



How to detect WIMPs?

Weakly interacting massive particles

- long lived or stable particles left over from the BB



$$\Omega_\chi \propto \frac{1}{\langle \sigma_A v \rangle}$$

$$\sigma_A \approx \sigma_{weak}$$

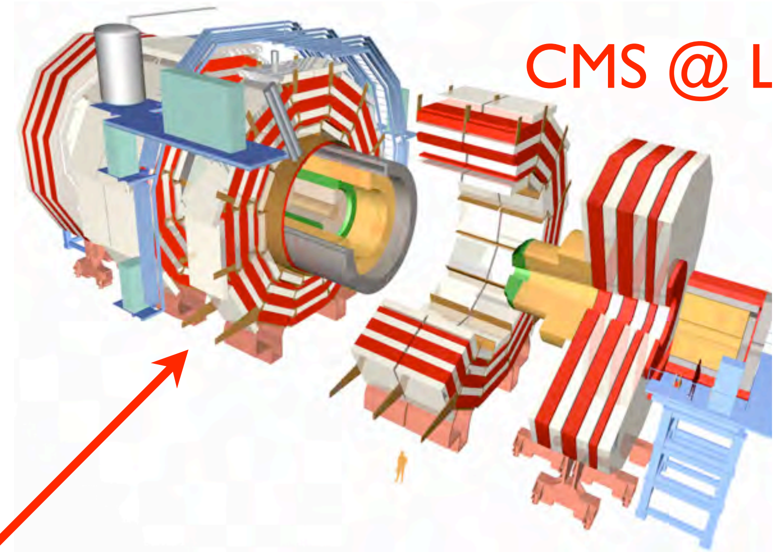
The "WIMP miracle"

$M_W \approx$ 50-500 GeV

$\langle v \rangle \approx$ 250 km/s

$\sigma \approx 10^{-6}$-10^{-10} pbarn

WIMP Dark Matter: Complementary Searches



Three Complementary Methods:

Production of WIMPs at Colliders (ATLAS, CMS)

Indirect WIMPs detection through their decay products (GLAST, WHIPPLE, EGRET, VERITAS, HESS, MAGic)

Detect WIMPs directly when they scatter of nuclei in terrestrial detectors

WIMP Coherent Scattering

The highest sensitivity is obtained by exploiting elastic neutral-current scatt
of nuclei by WIMPs. The idea was originally proposed by Drukier and Stoc
to detect solar and reactos neutrinos [PRD **30**, 2295, 1985)].

Sensitivity to hypothetic WIMPs detailed by Goodman and Witten [PRD **3**
3059 (1985)].

Halo particle of mass *m* (100 GeV), velocity *v* = 300 km/s on nucleus of ma
(100 GeV):

$p = 2mv$ (max possible value)

$\lambda = hbar/p = hbar/(2mv) =$

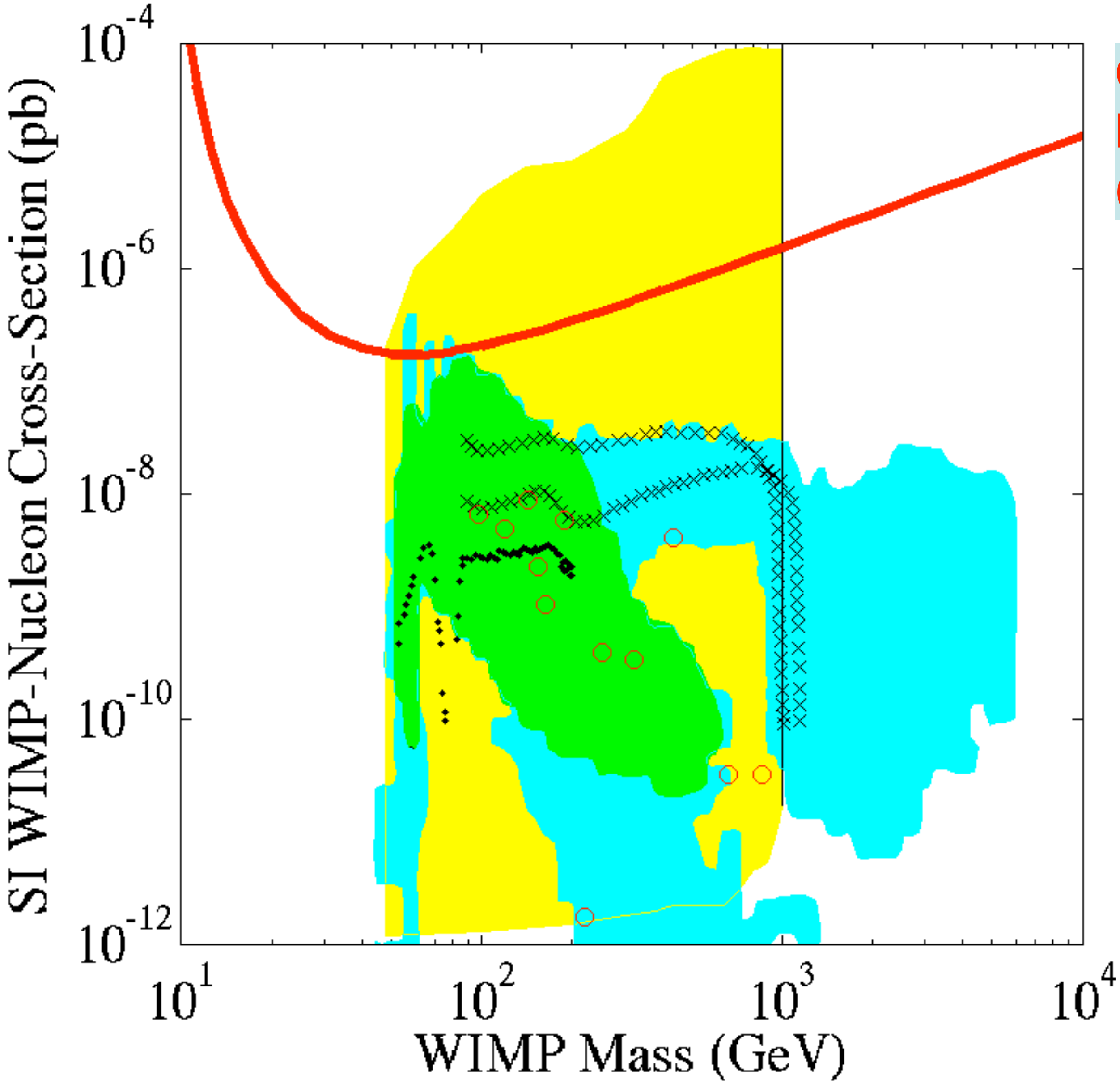
$= (197 \text{ MeV fm } c^{-1})/(2 \times 100 \text{ GeV } c^{-2} \times 10^{-3}\ c) \sim \text{fm}$

$R_A = 1.0 \times A^{1/3}$ fm

$E_{kin} = (2mv)^2/2M \sim 2mv^2 =$

$= (2 \times 100 \text{ GeV } c^{-2} \times 10^{-3}\ c)^2 = 200 \text{ keV}$

Supersymmetry Reach



Current CDMS II limit
PRL 96, 011302 (2006)
(~20 attobarn^{-1})

Kim et al. 2002
yellow (MSSM scan)

Baltz & Gondolo 2004
cyan (mSUGRA)
green (with g-2 constrain

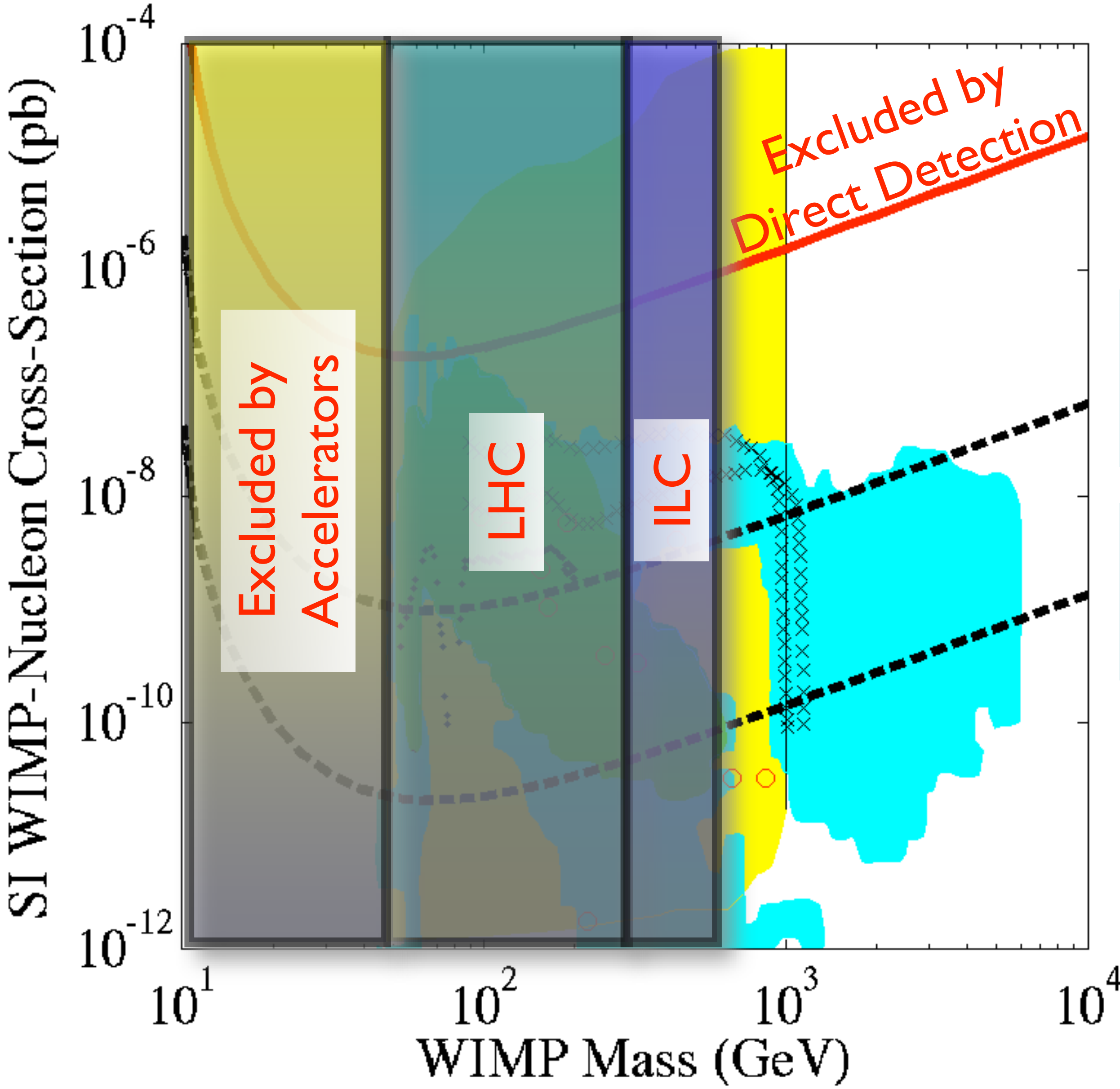
Battaglia et al. 2004
red circles (post-LEP bench
points)

Guidice & Romanino 200
black crosses (split SUS

Pierce 2004
black dots (split SUSY)

Many models 10^{-8}-10^{-10} p

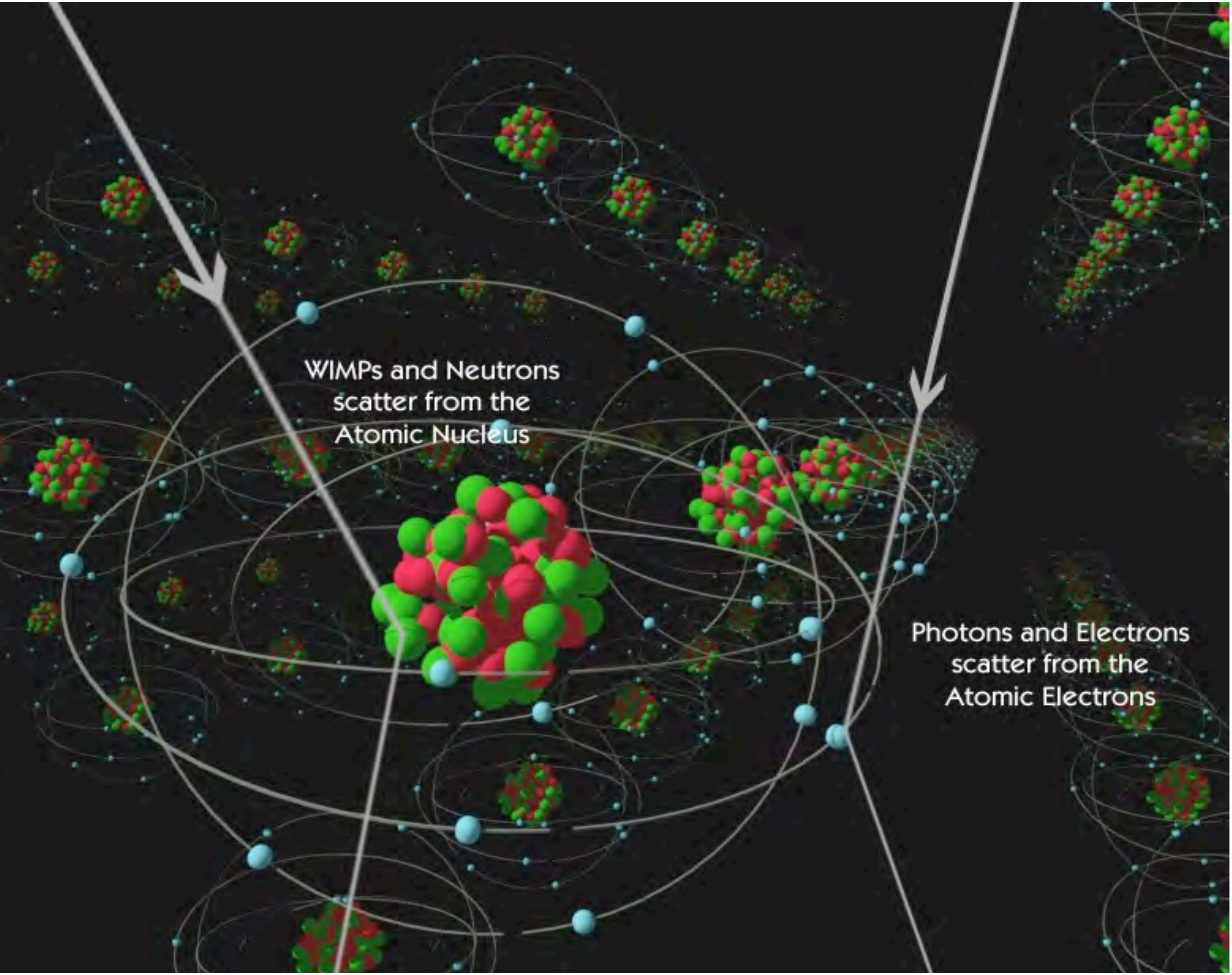
Supersymmetry Reach



Current CDMS II limit
PRL 96, 011302 (2006)
(~20 attobarn^{-1})

Zero-background Sensitivi
25 kg of Ge (or Xe, I, W)
100 kg Ar or 200 kg Ne

Zero-background Sensitivi
1000 kg of Ge (or Xe, I, W
4000 kg Ar or 2000 kg Ne


WIMPs and Neutrons
scatter from the
Atomic Nucleus
Photons and Electrons
scatter from the
Atomic Electrons

Possible WIMP Signatures

Induces nuclear recoils, instead of electron recoils induced by the ordin
radioactive background
Need detector with excellent selectivity in favor of nuclear recoils against betas and gammas

WIMP signals do not have multiple interactions sites
May be used to discriminate against other sources of nuclear recoils, neutrons

Recoil energy spectrum shape
Very weak: exponential shape, similar to typical background

Annual Flux Modulation
Very tricky, modulation is present only close to threshold!
Requires exceptional stability of threshold!

Diurnal detection modulation
Excellent signature (500% to 2000%) [Spergel PRD **37**, 1353 (1988)]
Extreme technical challenge; not demonstrated!

Consistency between different targets!

WARP Collaboration

INFN and Università degli Studi di Pavia
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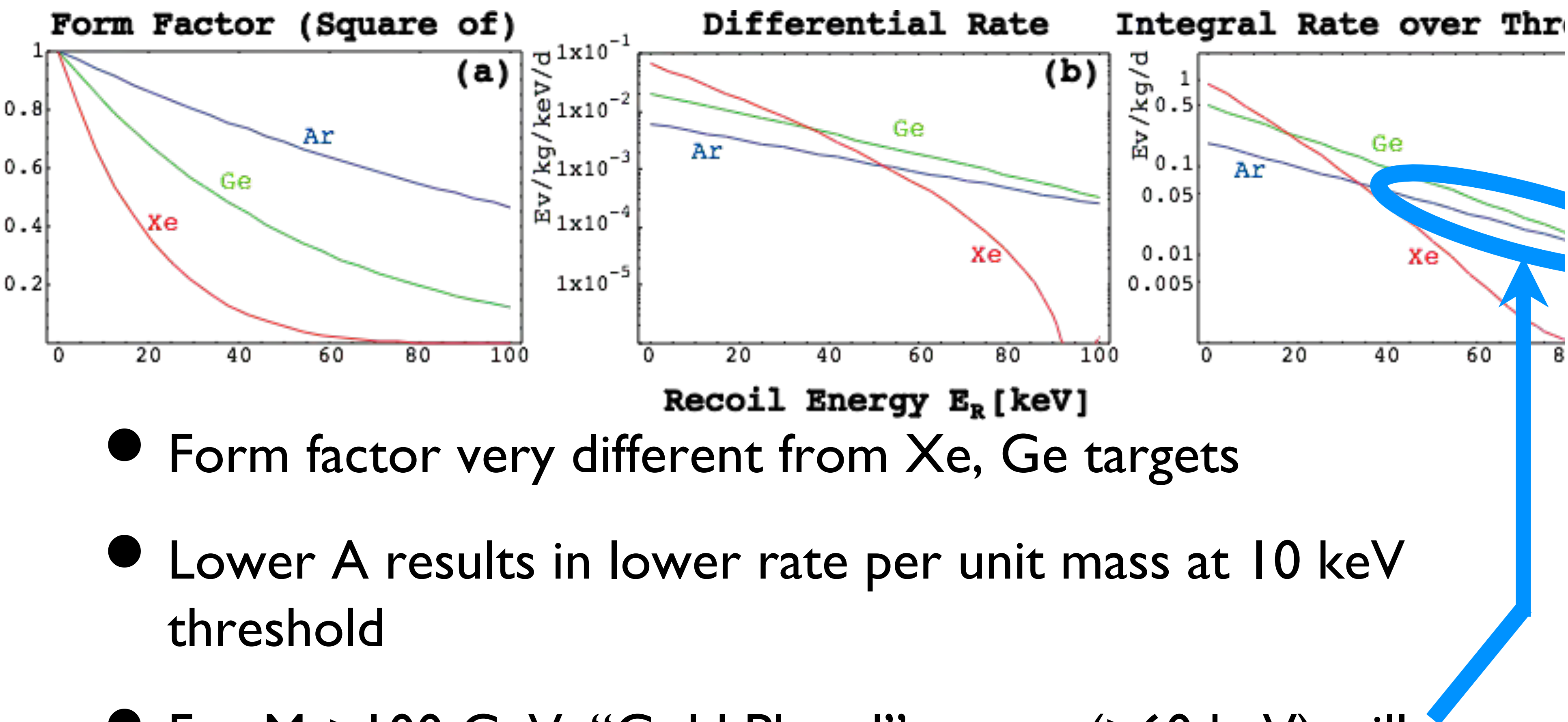
G. Meng, F. Pietropaolo, S. Ventura

WARP: the Motivation

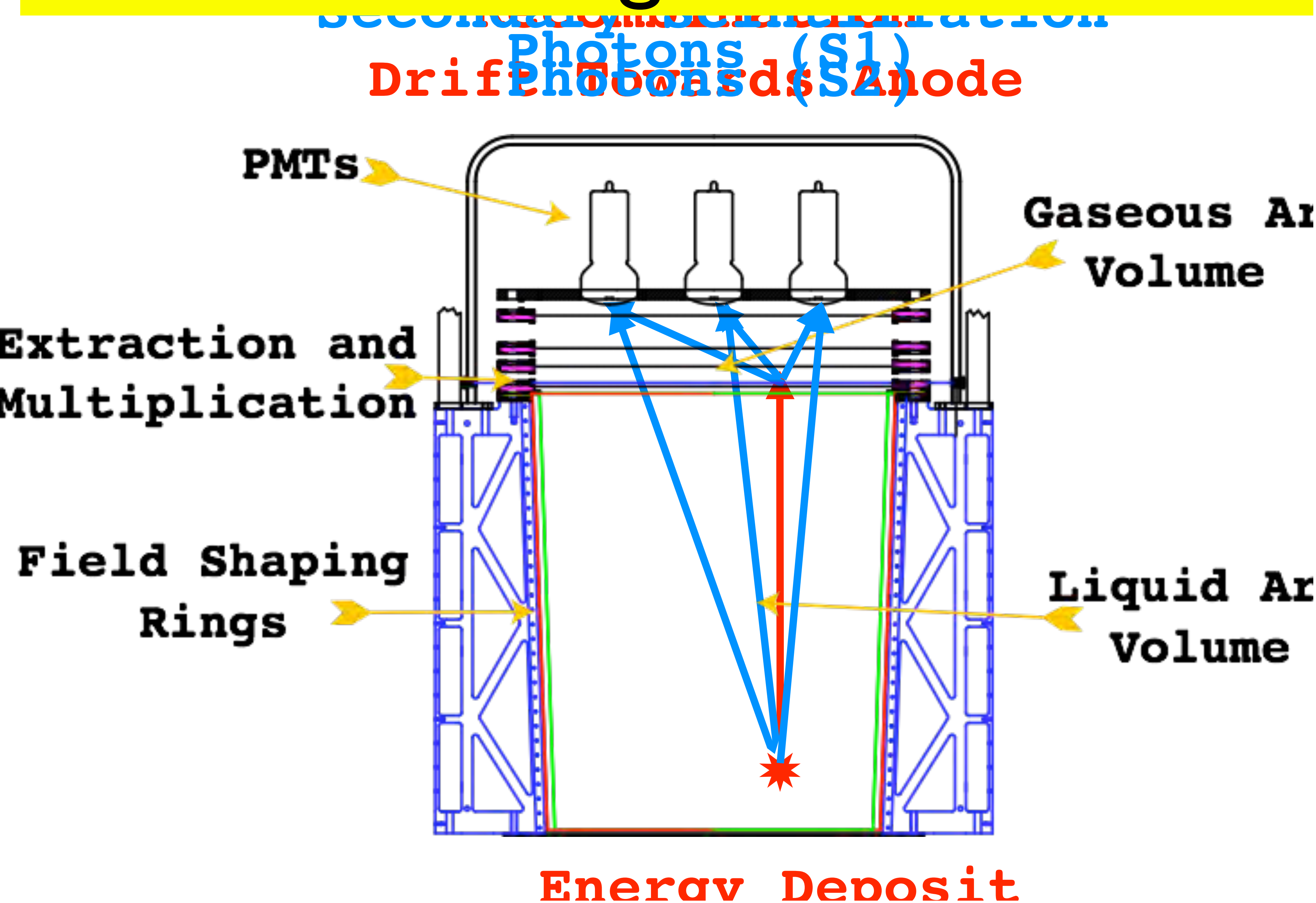
- TARGET: Atomic number 40
  - No loss of coherence at intermediate energies
  - Complete retention of gold plated events (60-120 keV)
- WIMP CANDIDATES IDENTIFICATION: Highest discrimination between nuclear recoils and beta/gamma-like background
  - ^{39}Ar, 1 Bq/kg → need 3×10^8 rejection against betas (for 140 kg detector)
  - WARP Collaboration, Benetti *et al.*, astro-ph/0603131
- Spin 0 for ^{40}Ar:
  - Sensitive only to spin-independent interactions

WARP: the Target



- Form factor very different from Xe, Ge targets
- Lower A results in lower rate per unit mass at 10 keV threshold
- For M_X>100 GeV, “Gold Plated” events (>60 keV) still abundant!
- Can run with a significantly higher threshold than other experiments and be very competitive

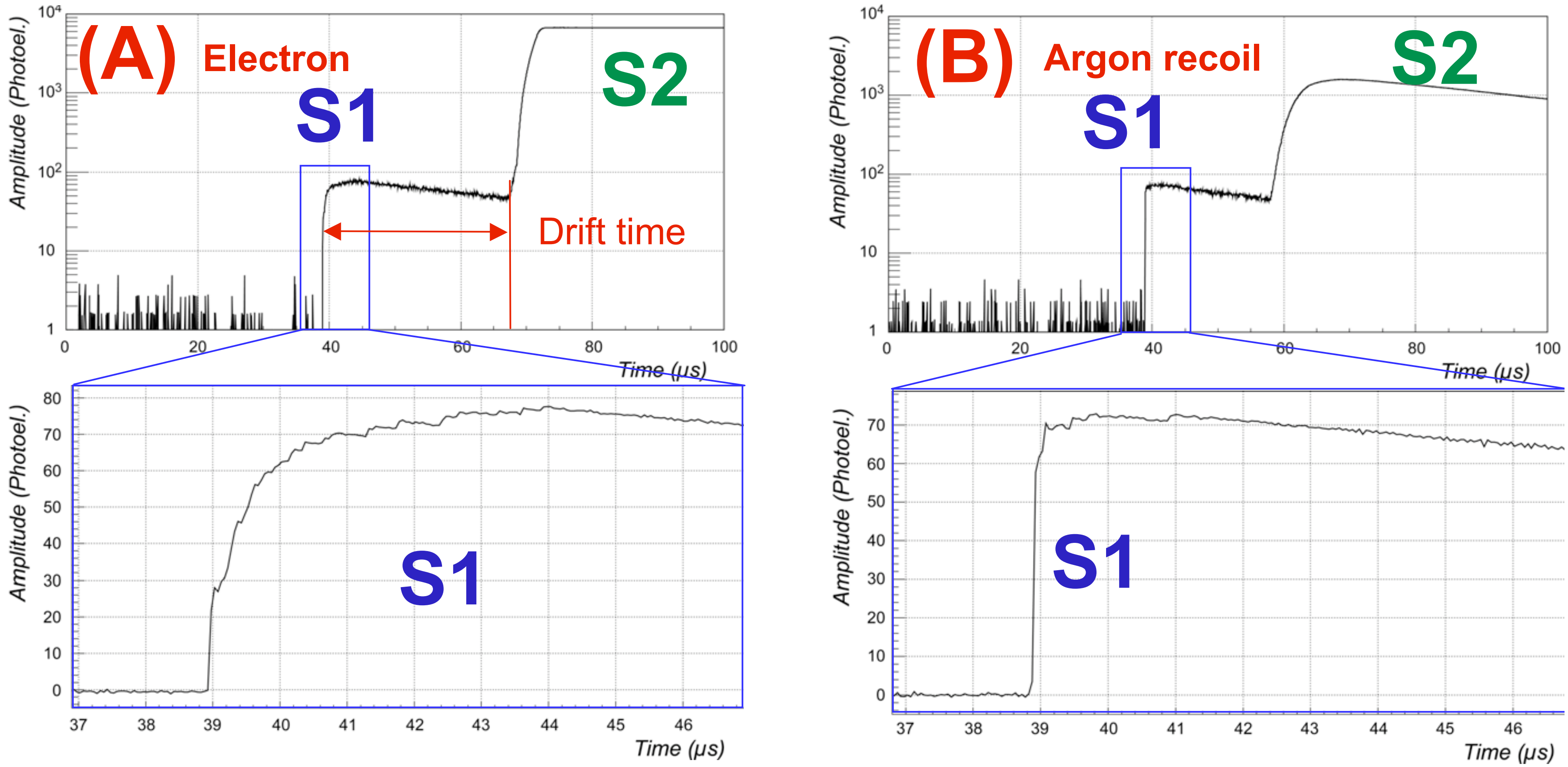
Two-Phase Argon Drift Chambe



The WARP Technology

- Highest discrimination of minimum ionizing events, in favor of potential WIMP recc with three simultaneous and independent criteria:
  - Pulse shape discrimination of primary scintillation (S1) based on the very large difference in decay times between fast (≈ 7 ns) and slow (1.6 μs) components of emitted UV light
    - Minimum ionizing: slow/fast ~ 3/1
    - Nuclear recoils: slow/fast ~ 1/3
    - Theoretical Identification Power exceeds 10^8 for > 60 photoelectrons
  - Both prompt scintillation (S1) and drift time-delayed ionization (S2) are simultan detected with a pulse ratio strongly dependent from recombination of ionizing t
    - Rejection ~ 10^2-10^3
  - Precise determination of events location in 3D: 5 mm x-y, 1 mm z
    - Additional Rejection for multiple neutron recoils and γ background

Two Discrimination Methods

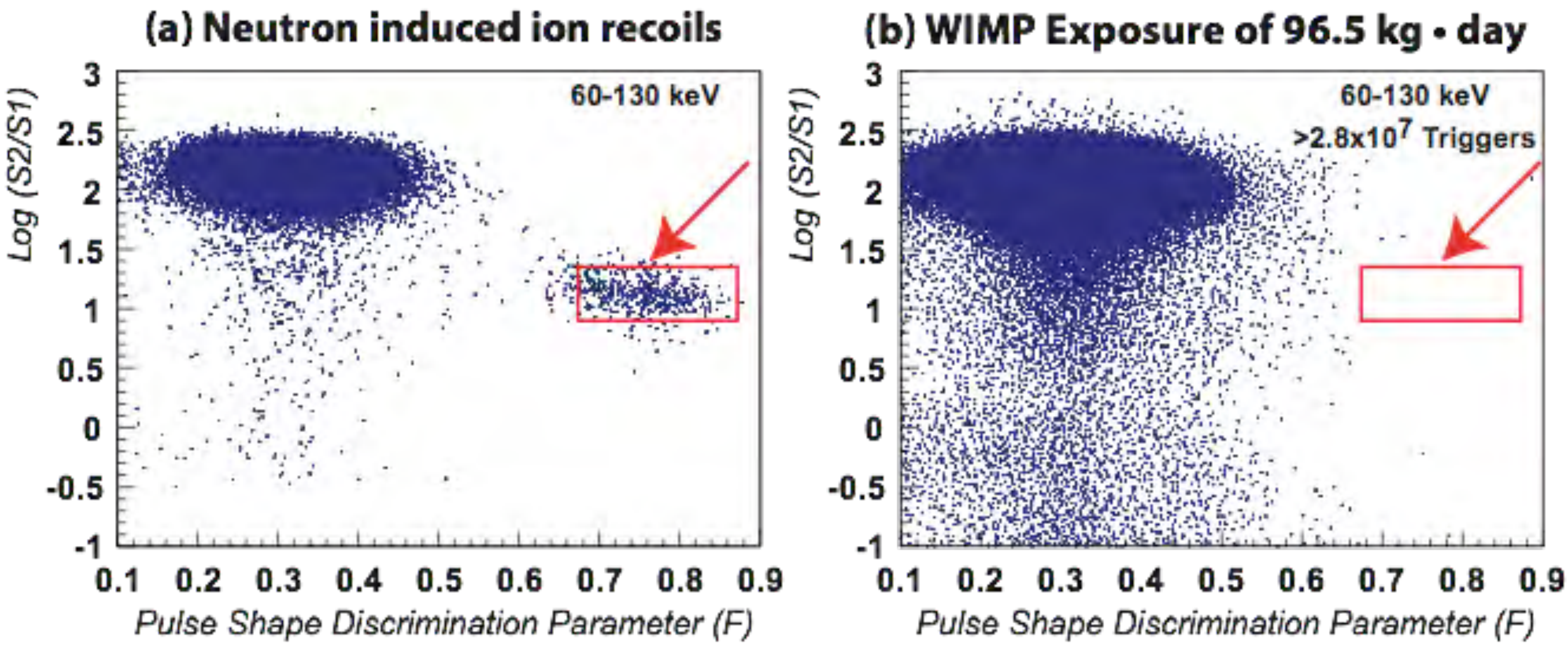


Events are characterized by:
the ratio S2/SI between the primary (SI) and secondary (S2)
the rising time of the SI signal

Minimum ionizing particles: high S2/SI ratio (~100) and by slow SI signal

Alfa particles and Ar recoils: low (<5) S2/SI ratio and fast SI signal

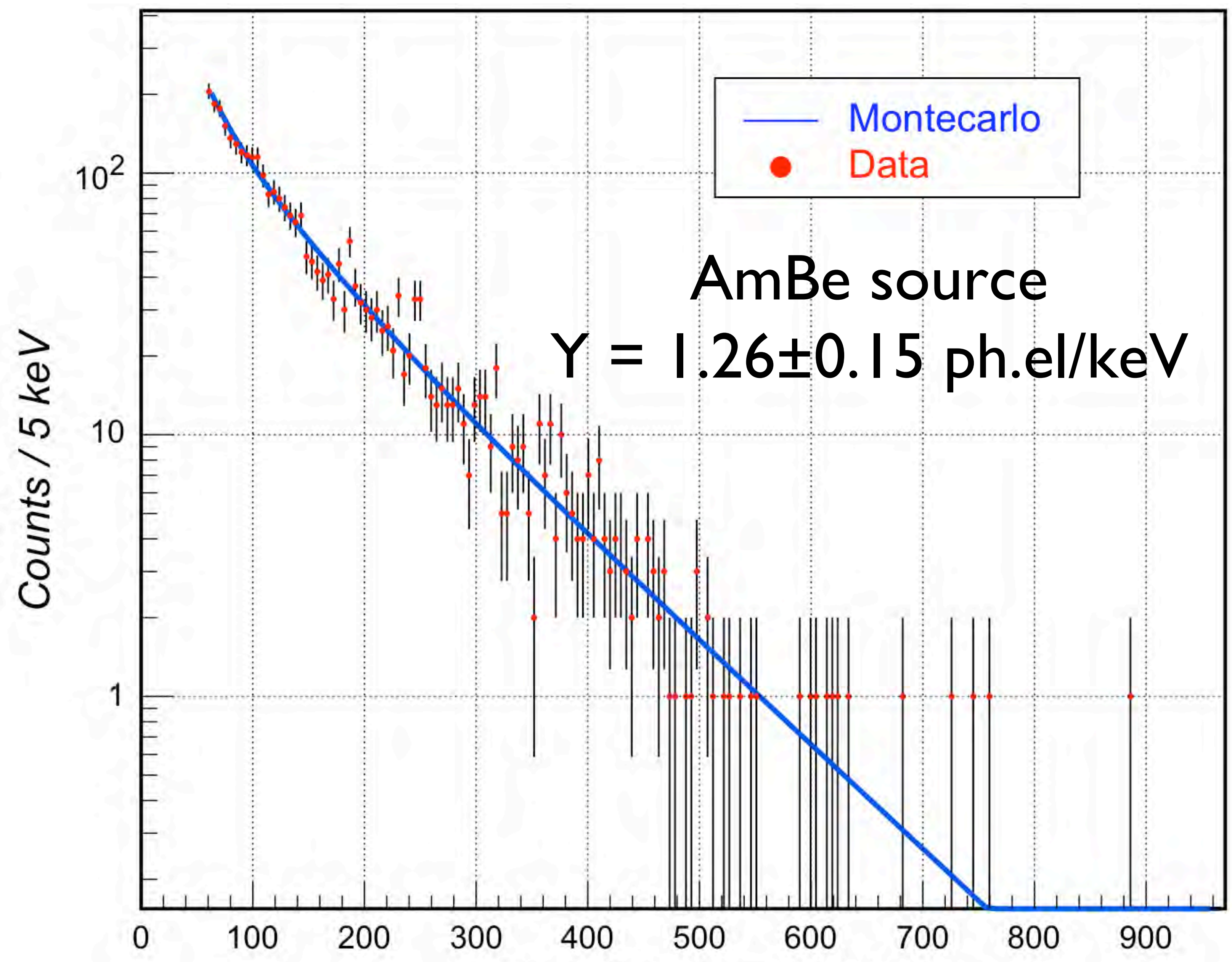
First Dark Matter Results



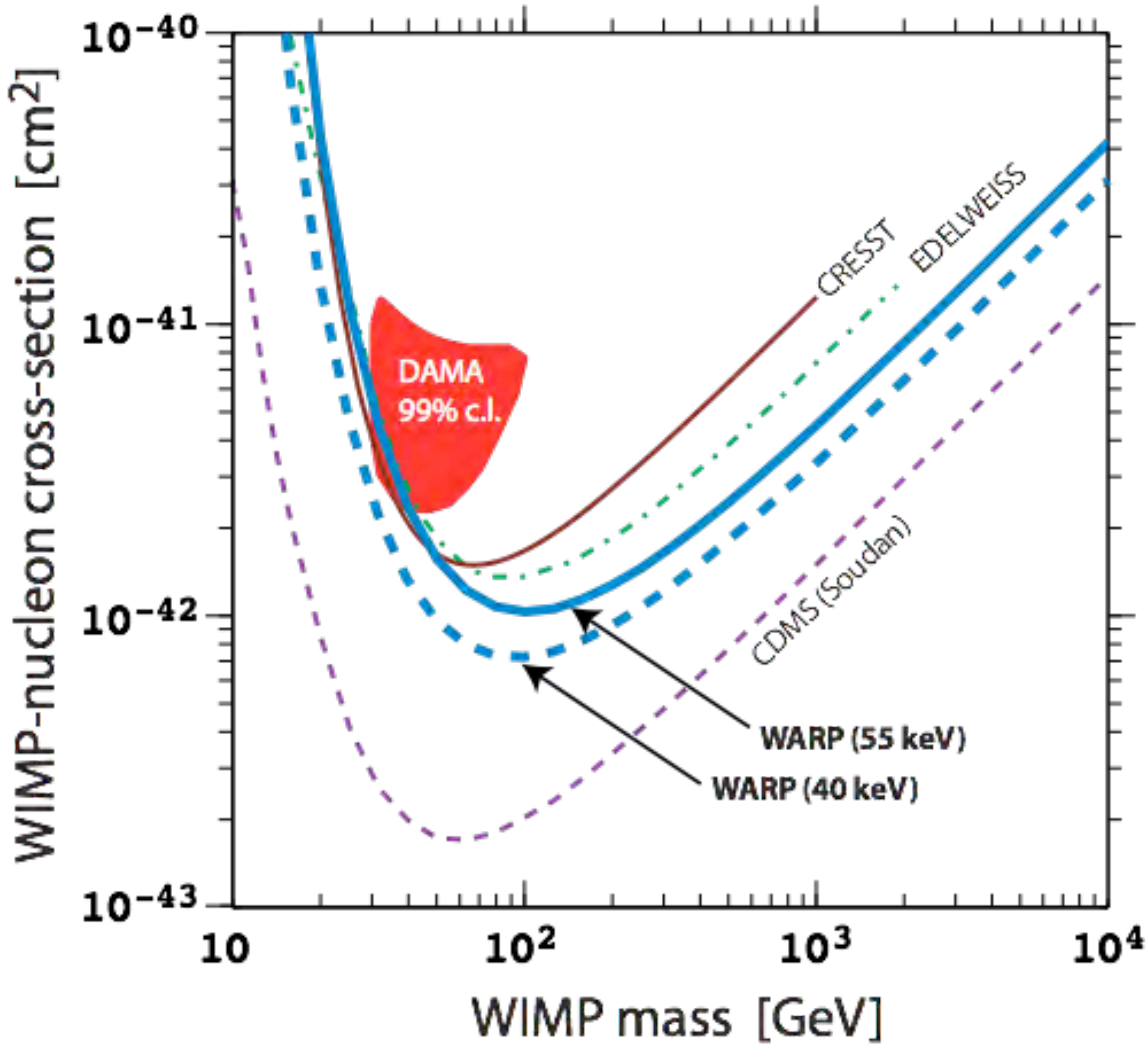
Selected events in the n-induced single recoils window during the WIMP search run

None

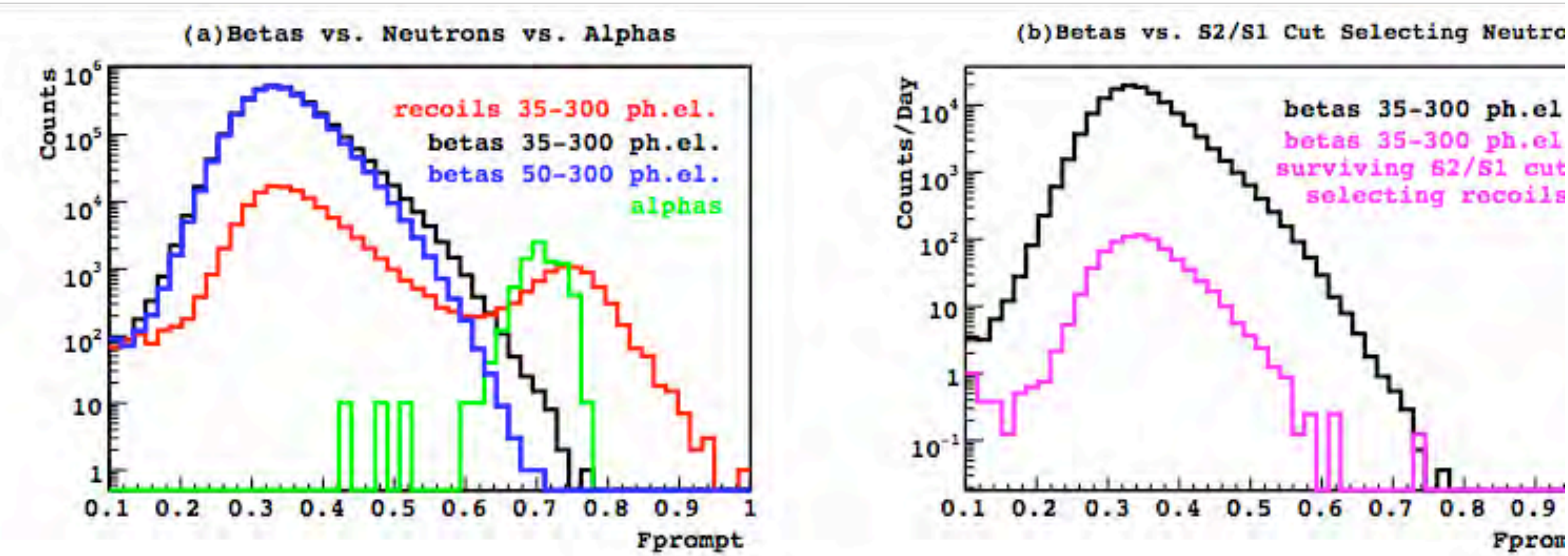
Energy Calibration



First Dark Matter Results



Most Recent Results on Discrimination



After recent electronics upgrade, pulse shape discrimination between m.i.p. and nuclear recoils better than 3×10^{-7}
Shape of distribution does not change by applying S2/S1 cut.
Two discriminations seemingly independent.

WARP 140-kg Detector

The WARP 140-kg detector to be installed and commissioned at LNGS

140 kg active target, to reach into 10^{-45} cm^2 and cover critical part of SUSY parameter space

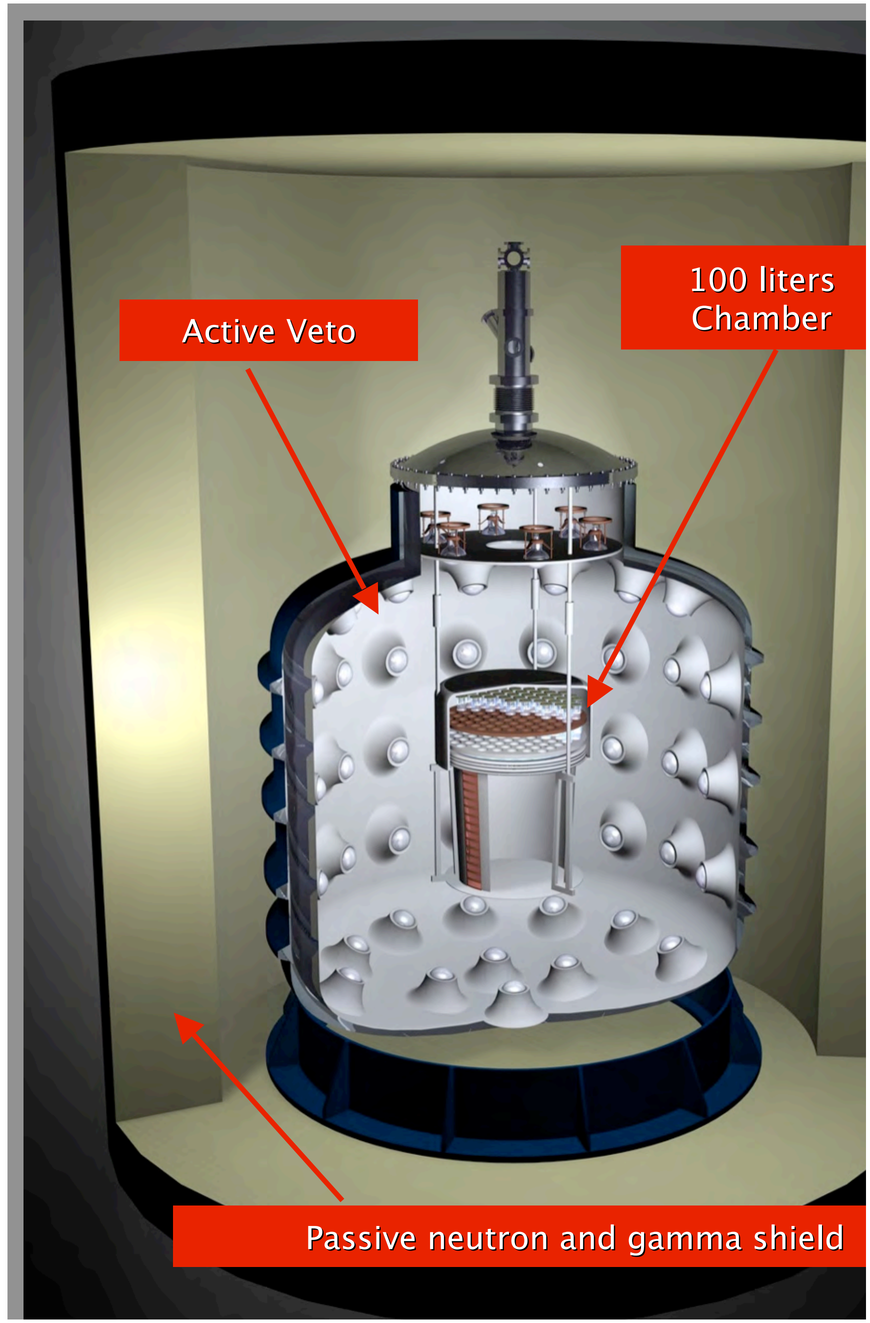
Complete neutron shield!

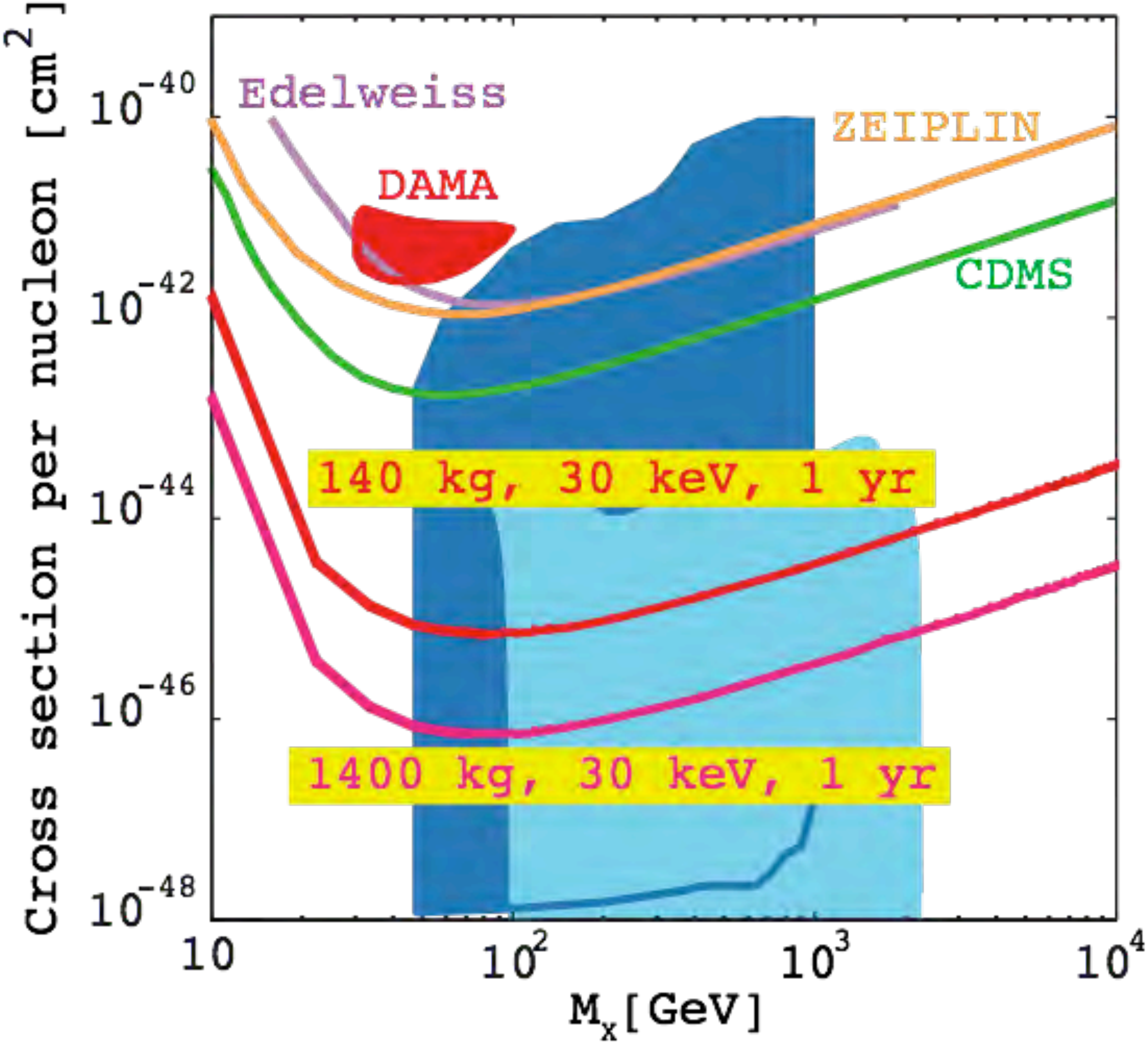
4π active neutron veto (9 tons Liquid Argon, 300 PMTs)

3D Event localization and definition of fiducial volume for surface background rejection
Detector designed for positive confirmation of a possible WIMP discovery

Active control on nuclide-recoil background, owing to unique feature (LAr active veto)

Cryostat designed to allocate a possible 1400 kg





One year, 140 kg, null measurement, 30 keV threshold

One year, 1400 kg, null measurement, 30 keV threshold

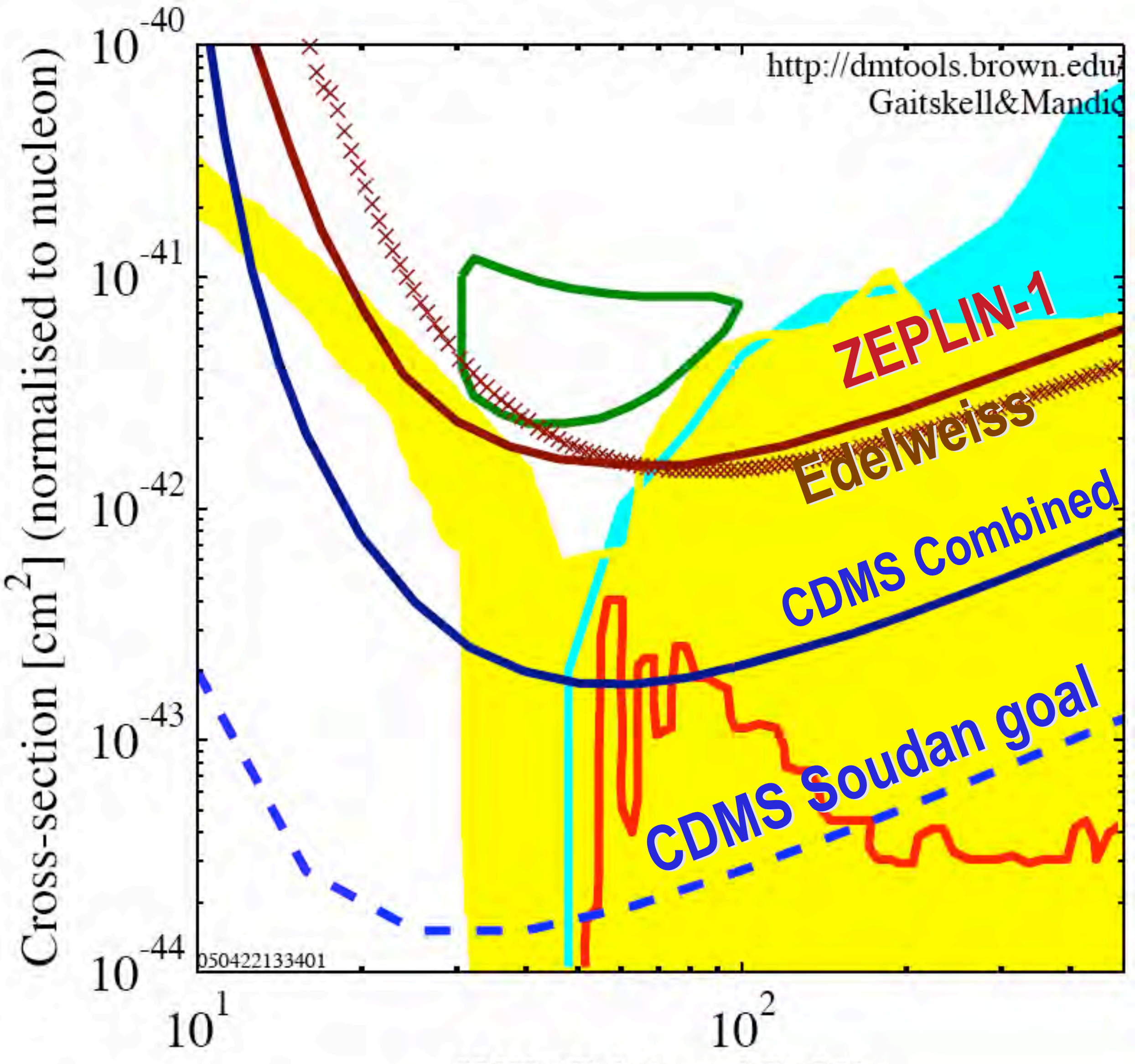
Argon depleted from ^{39}Ar

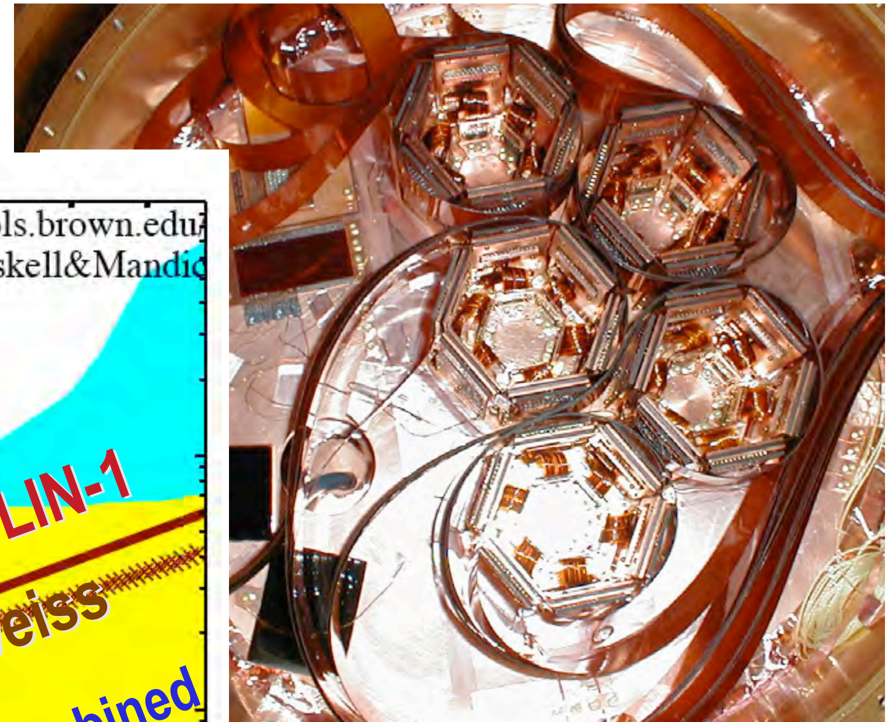
- Centrifugation
  - 5 kg delivered from Russia to LNGS on March 9 2007
- Small samples of argon from geological reservoirs obtained
  - Measurement of activity of ^{39}Ar planned at ANL
  - Survey of sources in spring-summer 2007

CDMS

Projected CDMS Sensitivity

Started 5-Tower Run

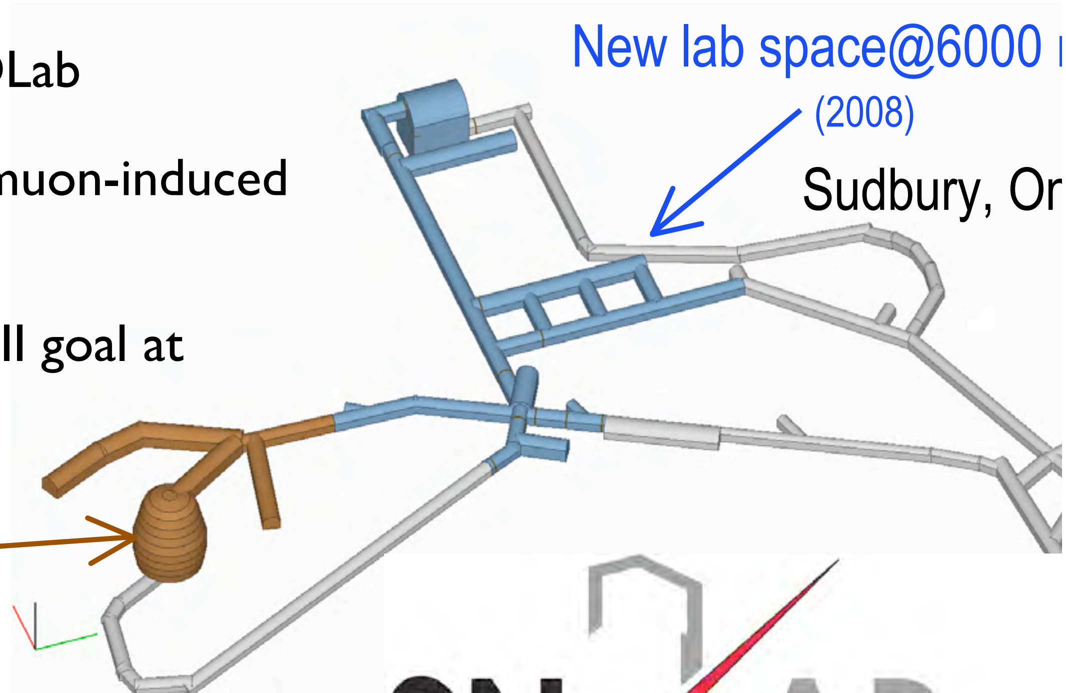




- Additional improvement
  - Cryogenics, backgrounds,
  - Currently commissioning
- 30 detectors in 5 towers
  - 4.75 kg of Ge, 1.1 kg of S through 2006
  - Improve sensitivity x8

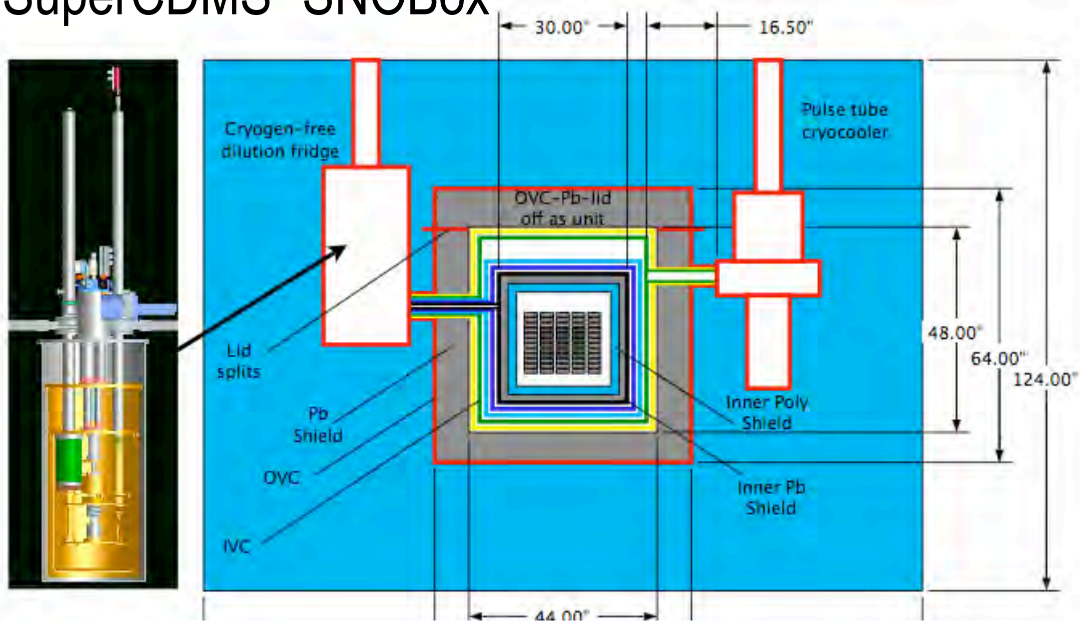
SuperCDMS 25 kg experiment

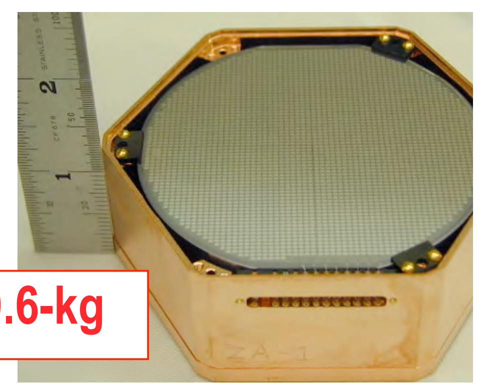
- New experiment proposed for SNOLab
  - Depth required to drive down muon-induced neutron background
  - 15x more sensitive than CDMS-II goal at Soudan



SNOLAB
MINING FOR KNOWLEDG
CREUSER POUR TROUVER... L'EXCELLEN

SuperCDMS “SNOBox”

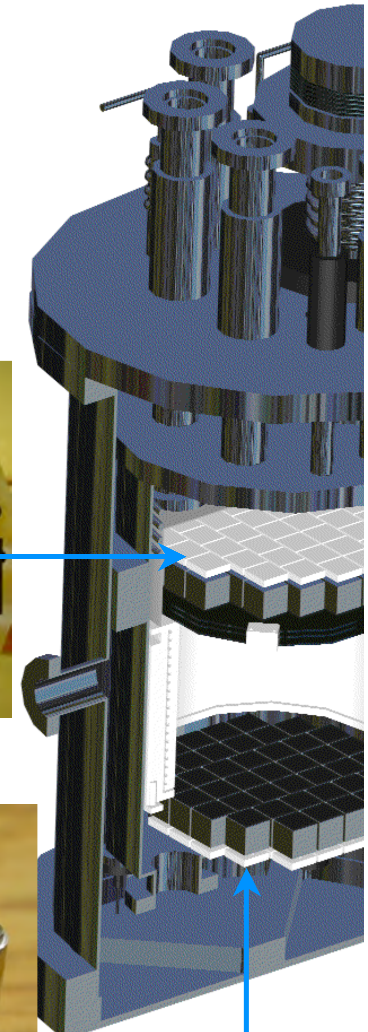


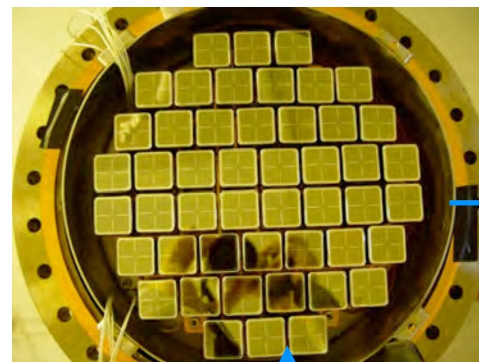


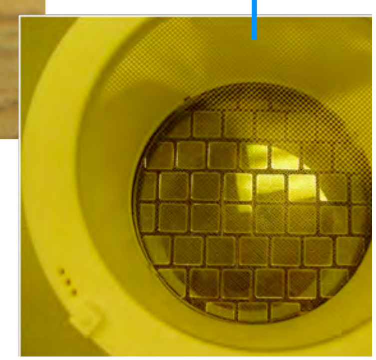
42 1”-thick 0.6-kg

The XENON10 Detector

- **22 kg of liquid xenon**
  - 15 kg active volume
  - 20 cm diameter, 15 cm drift
- **Hamamatsu R8520 1"×3.5 cm PMTs**
- bialkali-photocathode Rb-Cs-Sb,
- Quartz window; ok at -100°C and 5 bar
- Quantum efficiency > 20% @ 178 nm
- **48 PMTs top, 41 PMTs bottom array**
  - x-y position from PMT hit pattern; $\sigma_{x\text{-}y} \approx 1$ mm
  - z-position from Δt_{drift} ($v_{d,e^-} \approx 2$ mm/μs), $\sigma_Z \approx 0.3$ mm
- **Cooling: Pulse Tube Refrigerator (PTR),**
- 90W, coupled via cold finger (LN_2 for emergency)

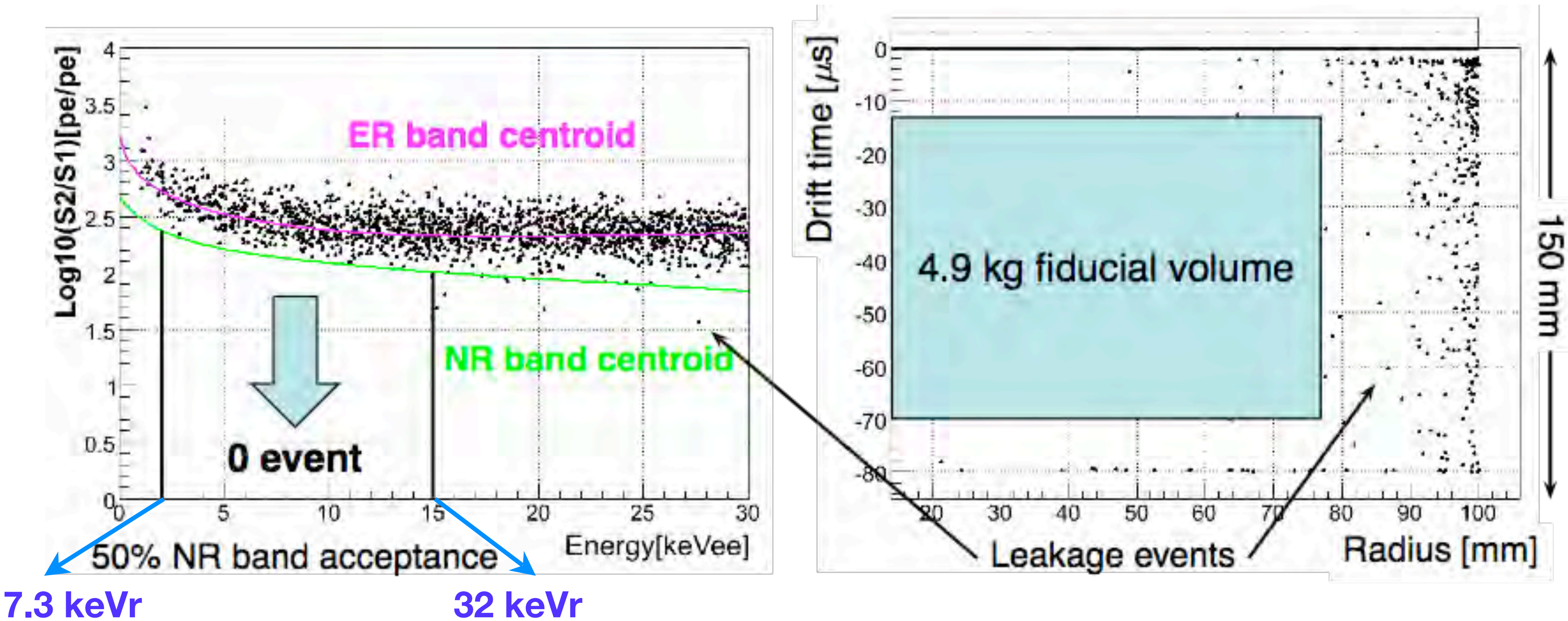






XENON10 Preliminary WIMP Search Data

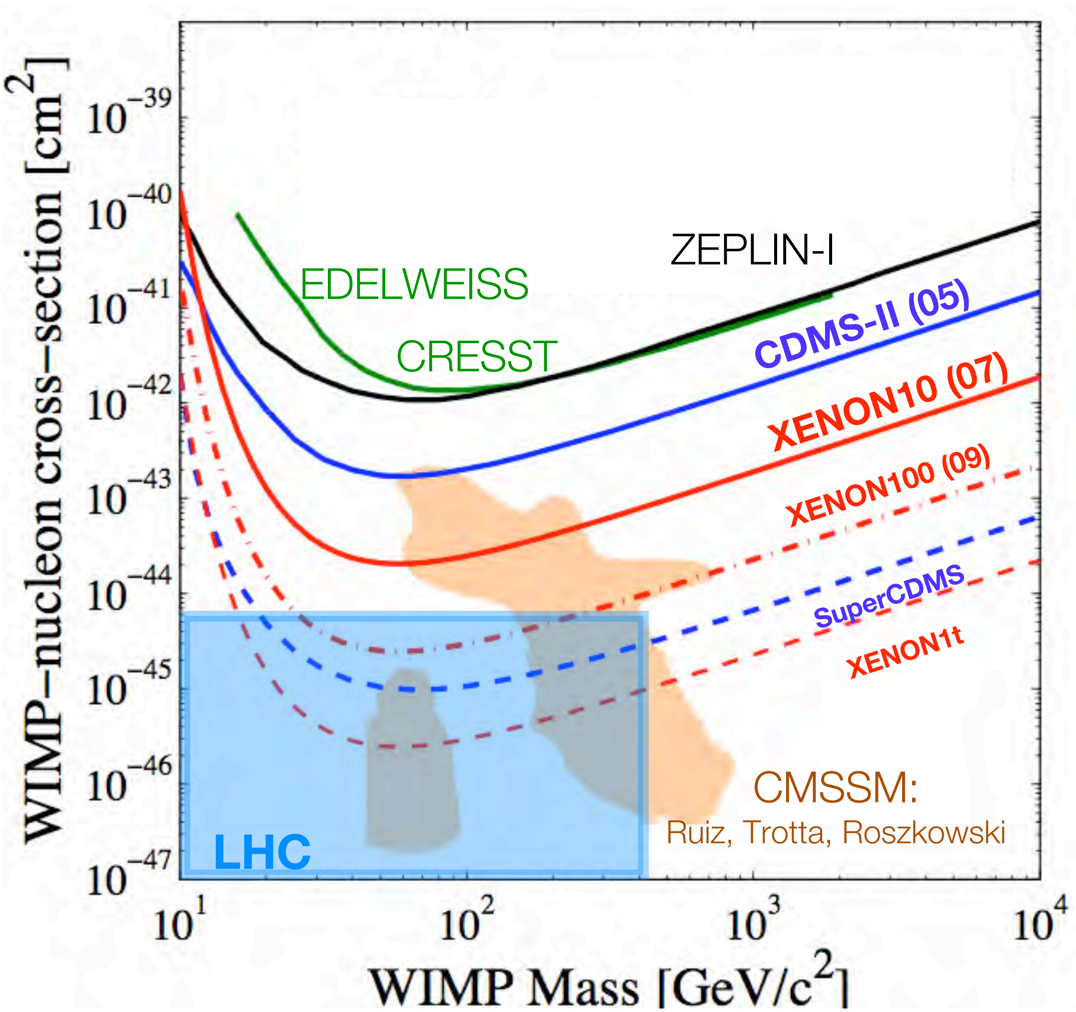
- WIMP search run started Aug. 24. 2006: >10^6 events, > 70 live days
- 2 independent analysis groups (root and matlab based)
- Example: preliminary data from ~ **17 live days**

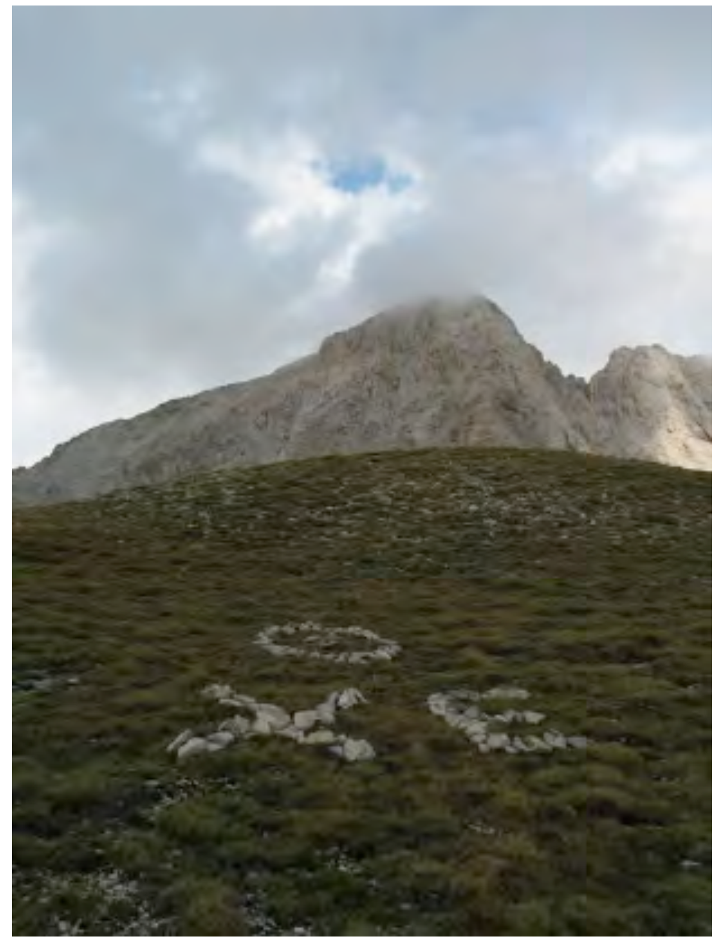


- Full analysis in progress; understand source of leakage events; set cuts and
- calculate efficiencies based on γ- and n-calibration data, ...

XENON 10/100 WIMP Search Goals

- Test the elastic, SI WIMP-nucleon σ down to ≈ 2×10^{-44} - 2×10^{-45} cm^2 in 2007/0

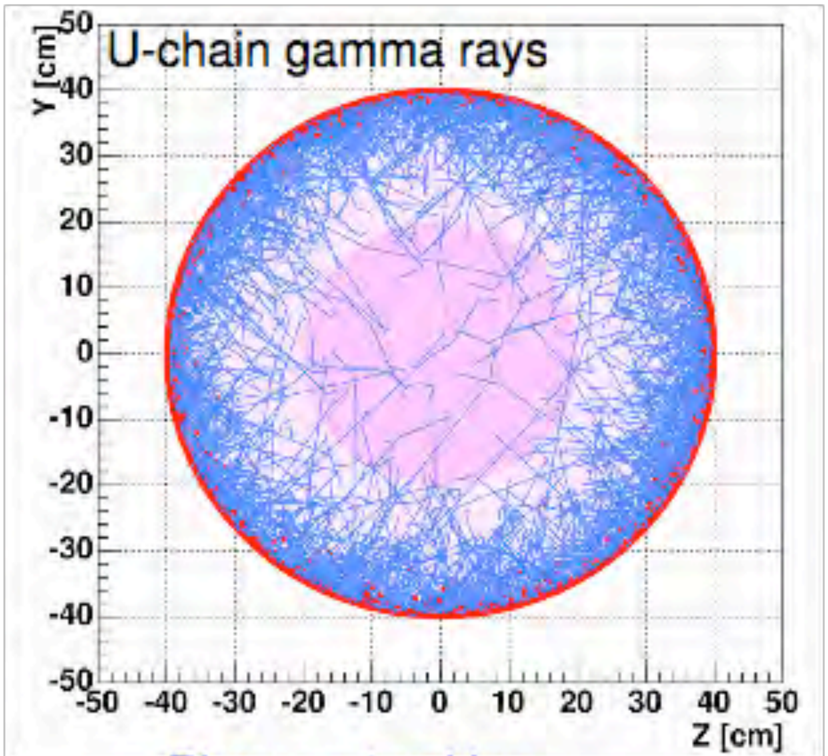




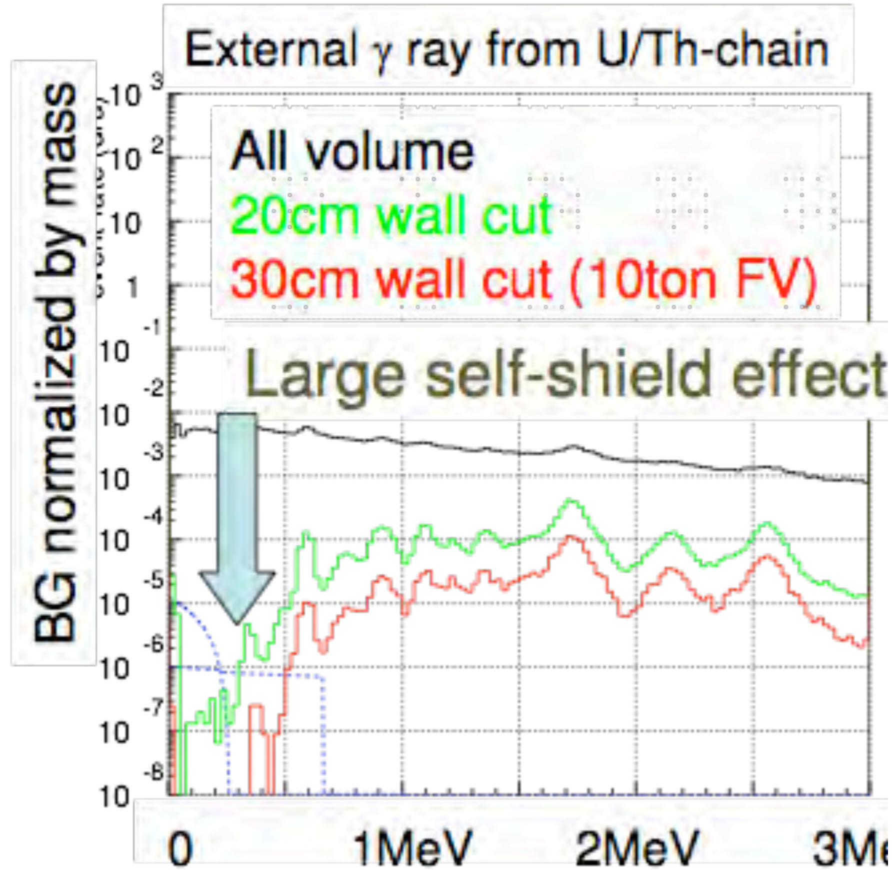
XMASS

- Key idea:
  self-shielding effect for low energy events

γ tracking MC from external to Xenon



Blue : γ tracking
Pink : whole liquid xenon
Deep pink : fiducial volume



Background are widely reduced in < 500keV low energy region

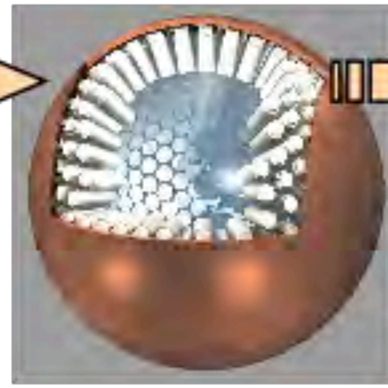
➢ Strategy of the scale-up

100kg Prototype

With light guide

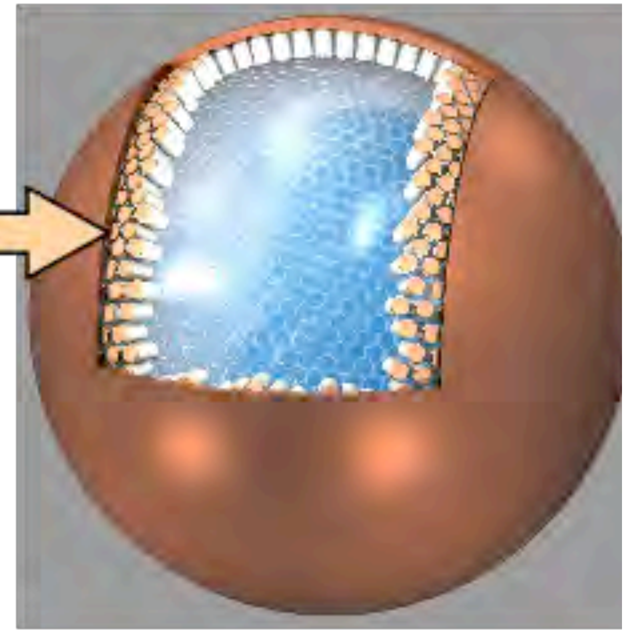
~30cm

800kg detector



~80cm

10 ton detector



~2.5m

R&D

- ✓ Vertex & energy reconstruction
- ✓ Self shielding power
- ✓ BG level

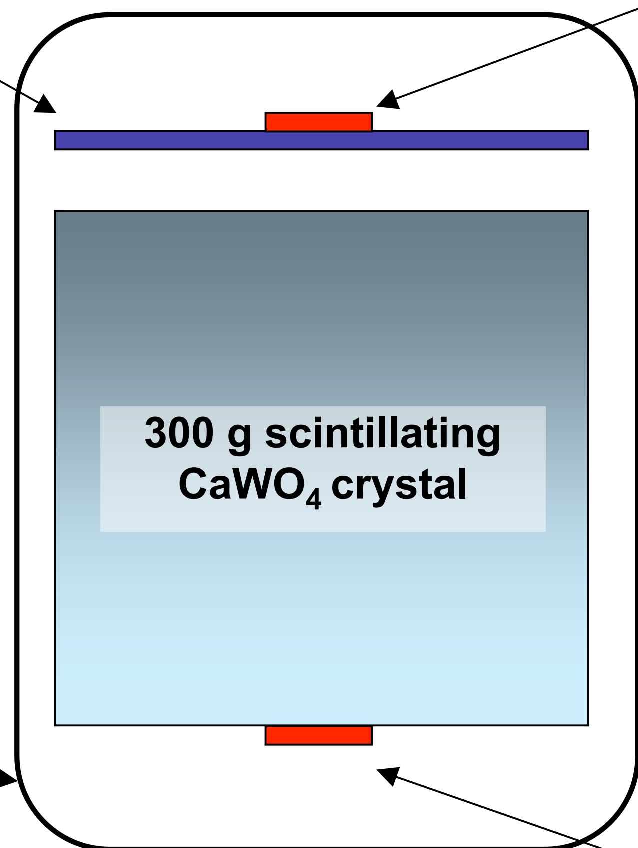
We are here !

Dark matter search

Multipurpose detector
(solar neutrino, ββ …)

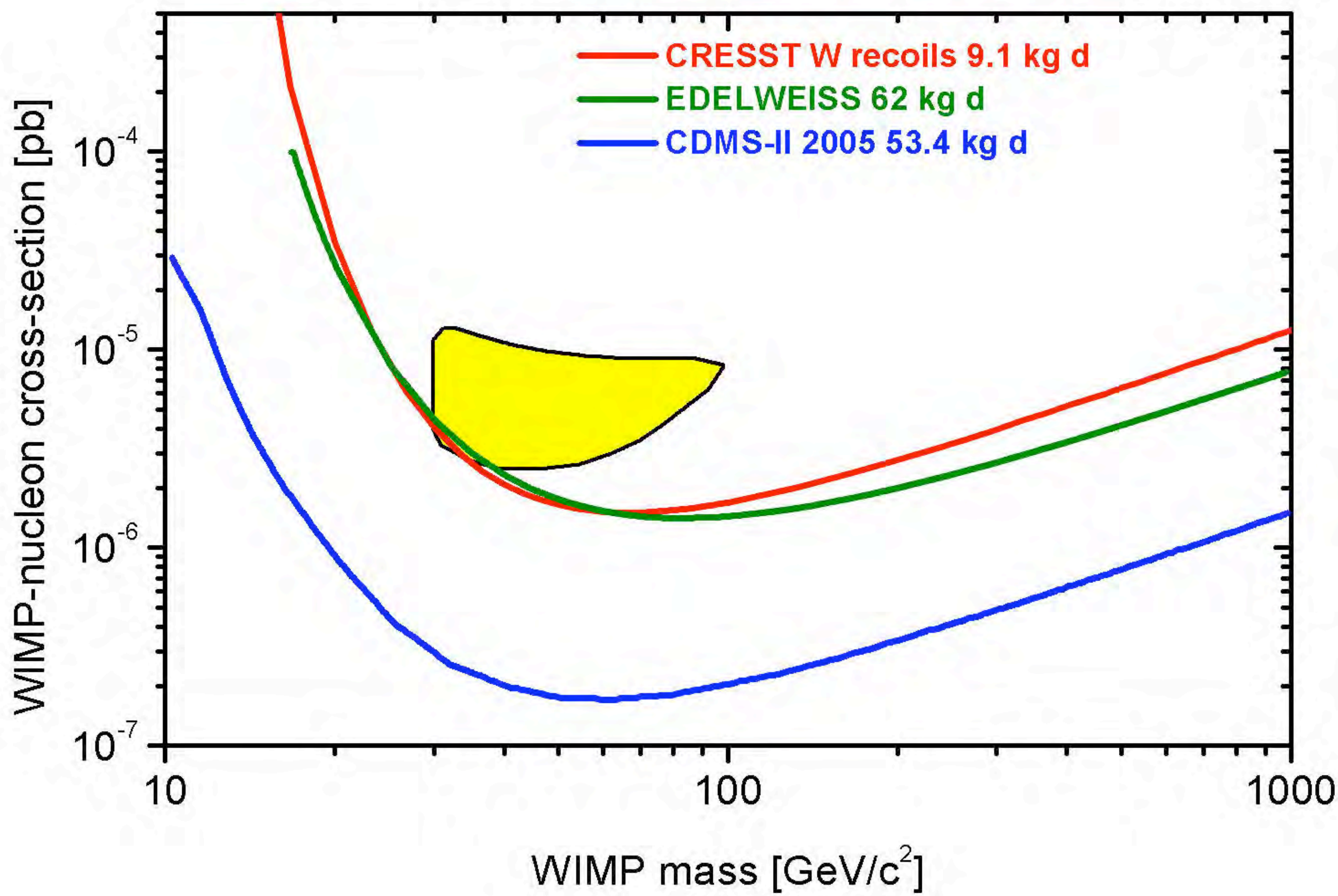
CRESST-II Detector Conce

Discrimination of nuclear recoils from radioactive $\beta+\gamma$ backgrounds by simultaneous measurement of phonons and scintillation light



•Works with $CaMoO_4$, BGO, Al_2O_3, ...

Run 28 limits



Oct. 2006: Mounting 10 Detector Modules