Future Prospects for Detecting Dark Matter

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(Supported by US DOE HEP)

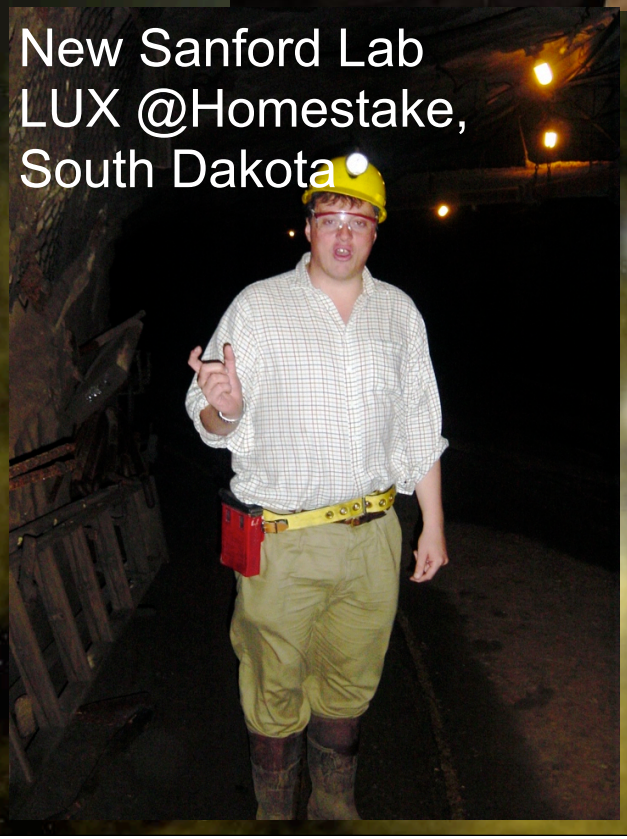
see information at

http://particleastro.brown.edu/
http://gaitskell.brown.edu

Key points

- dark matter
  - a solution in both cosmology and particle physics
- techniques for (in)direct detection
  - is (in)direct detection a realistic way for testing new physics
  - survey status of some of the techniques
    - which are the most competitive ?
- future of the field internationally
- future of the field in US Lab
  - new underground lab @ Homestake
  - 2008-2012 Sanford Lab
  - 2013+ DUSEL

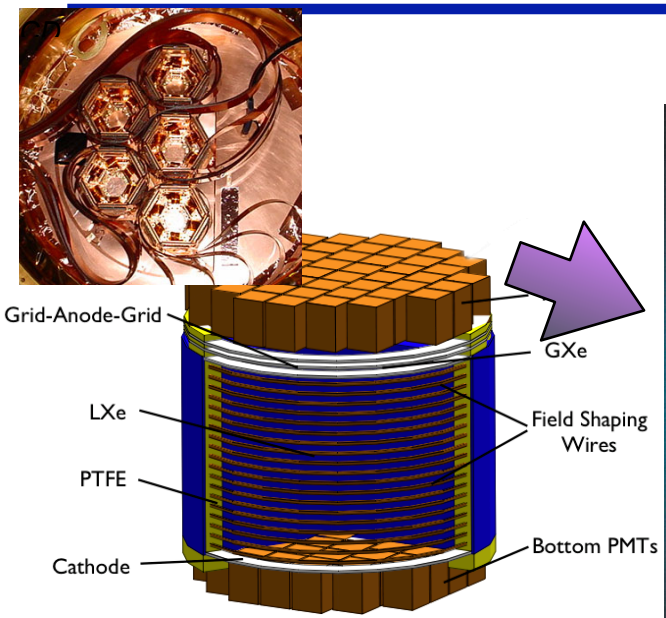
CDMS II: Winter
@Soudan Minnesota



New Sanford Lab
LUX @Homestake,
South Dakota

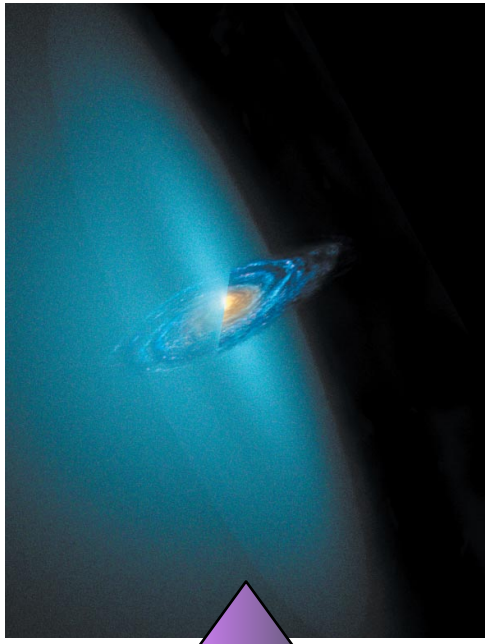
PHYSICS ITALIAN
STYLE XENON10
@ Gran Sasso

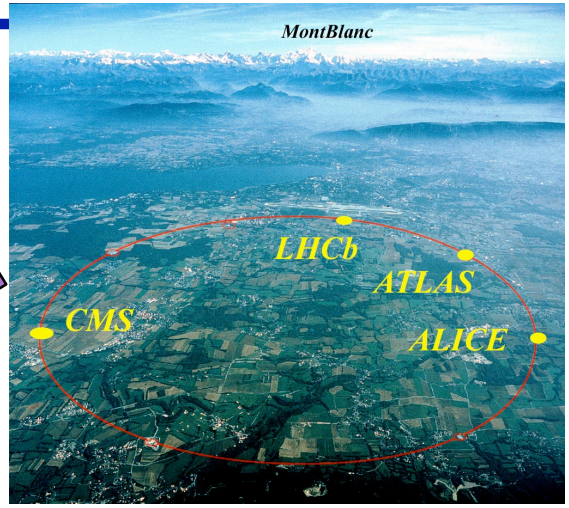
Complementary Approaches



WIMP scattering on Earth:
e.g. CDMS/XENON10 :
currently leading the field

Halo made of WIMPs





WIMP production on Earth

WIMP annihilation in galaxy substructure

Air Cherenkov Telescopes
HESS,MAGIC,Veritas

Also anti-particle sig.
e.g. Pamela / HEAT

Neutrinos
e.g. SuperK / ICE3

GLAST/Fermi
Launched 11 June 2008
γ = 2 - 200 GeV

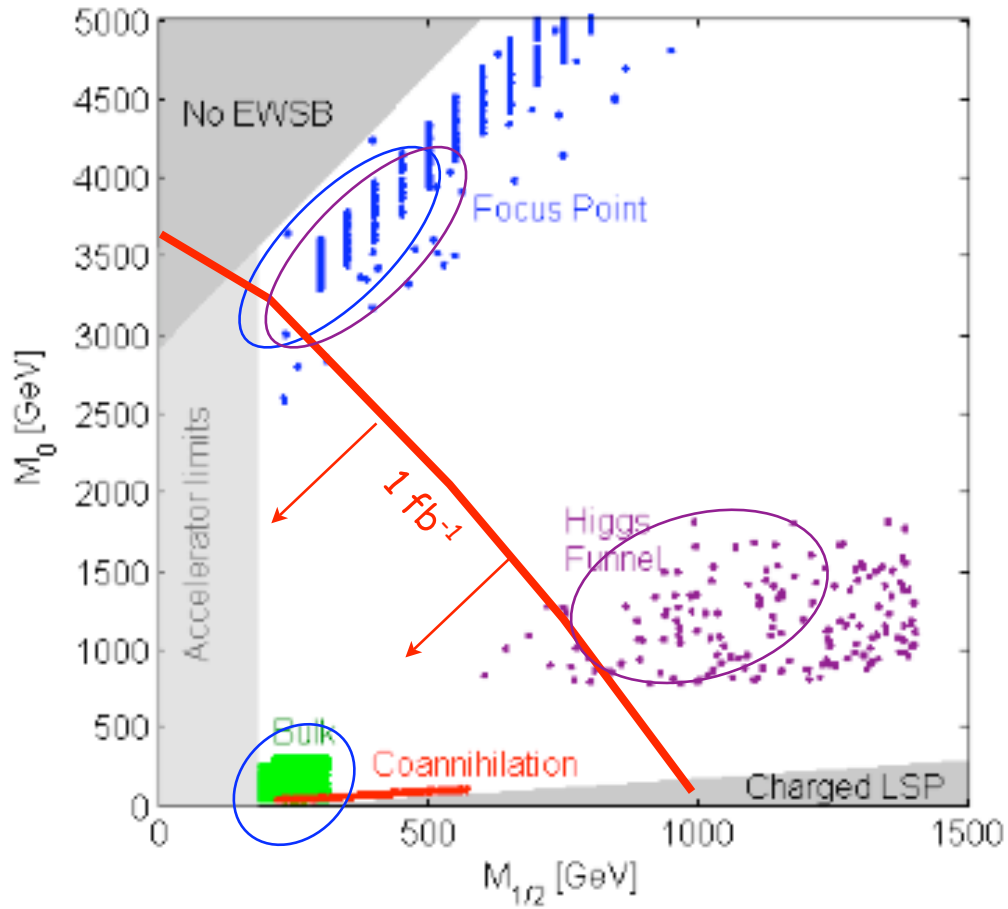
(Thanks to Sadoulet for graphics)

Complementarity mSugra/CMSSM

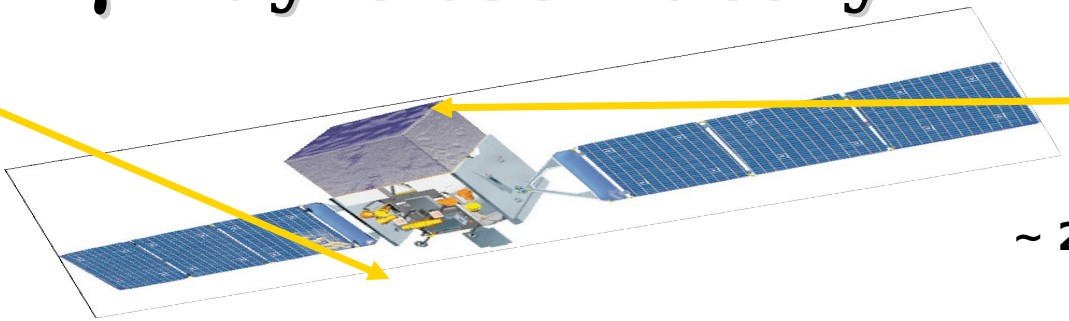
Direct Detection:
Bulk
+Focus point

LHC
"low energy"

GLAST
Focus
+ Higgs funnel



GLAST : next generation γ–ray Observatory



GBM

correlative observations of <u>transient events</u>
~10 keV – 25 MeV

sky coverage
whole unocculted sky

Mission Lifetime
5 years (min)

Compared to EGRET:
- > 100 MeV, 1 yr sensitivity x25
- localization x10^2
- field of view x5
- observing efficiency x2
- deadtime x10^{-3}

Huge field of view, optimized for all sky survey :

full sky covered in 3 hrs, any part exposed for ~30mns

Huge energy range :

including largely unexplored 10 GeV-100 GeV band

Unprecedented sensitivity

Complete renewal of γ-ray catalog :

By > order of mag in # of point sources

Sub-arcmin localization (source dependent)

Resolution of extended sources

LAT

energy range
~ 20 MeV to >300 GeV

sky coverage
20% of the sky (~2.4 sr)

deadtime
as low as 25 μs

Observing modes
All sky survey
Pointed observations

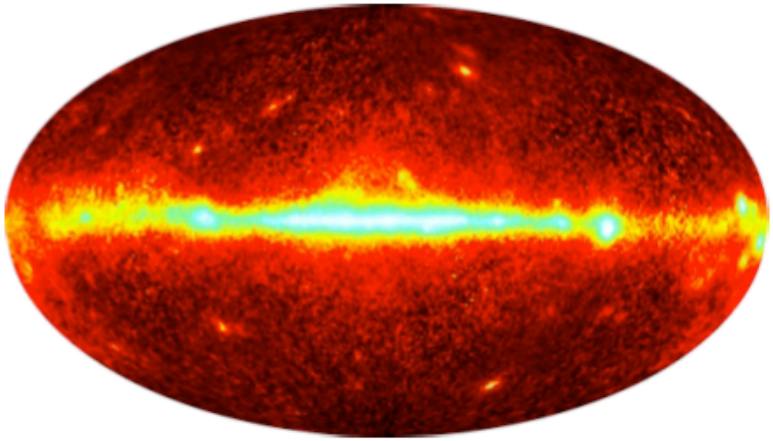
Re-pointing Capabilities
Autonomous
Rapid slew speed
(75° in < 10 minutes)

(Johann Cohen-Tanugi L.P.T.A / Université Montpellier-II, IDM Conference 2008, Stockholm)

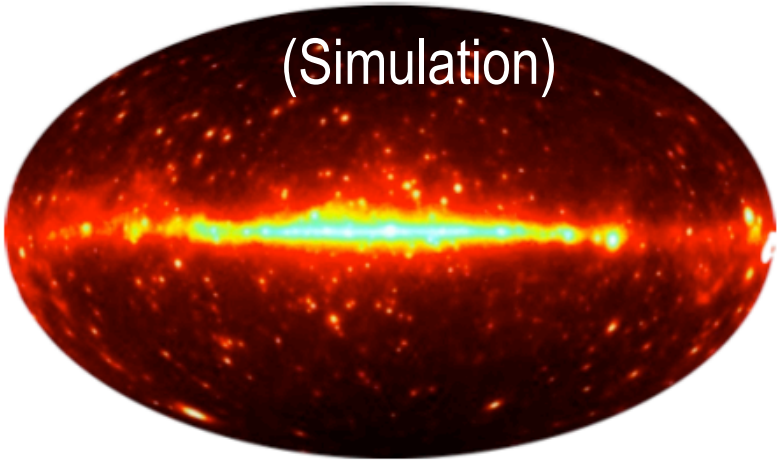
GLAST / Fermi Gamma Ray Space Telescope

Entered 1-year survey mode after L+60 : Aug. 11 2008

9 yrs EGRET



1 yr (sim) GLAST



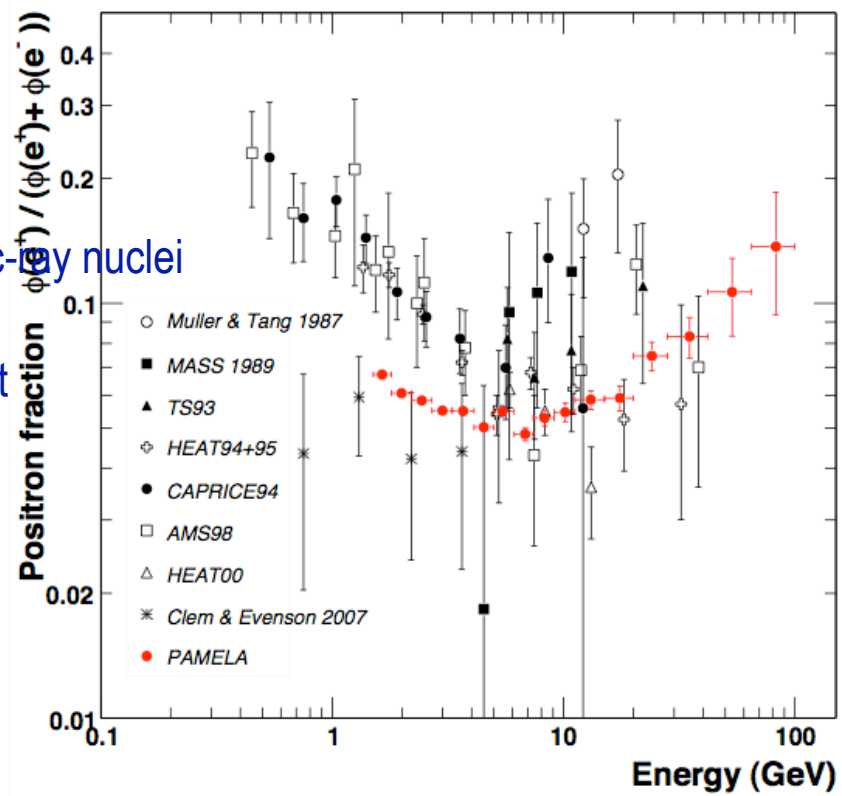
- Pre-Launch paper by the LAT Dark Matter and New Physics working group : JCAP 0807:013,2008
- Possible Dark Matter Signatures from 1st year of data
  - Galactic Center
    - High Dark Matter density foreseen, but complex region with point source foreground possibly limiting LAT sensitivity.
  - Dwarf Spheroids
    - Well localized but expected to be faint. Focus on Sagittarius and Draco first.
  - Gamma Lines
    - Smoking gun but highly suppressed....

ACT Ground Based Gamma Observatories

- Air Cherenkov Telescopes
  - Hess II, Magic, Veritas
- Extend Mirror Sizes >>10 m, increase array #
  - Improve efficiency for <100 GeV gamma rays
  - Improve angular resolution

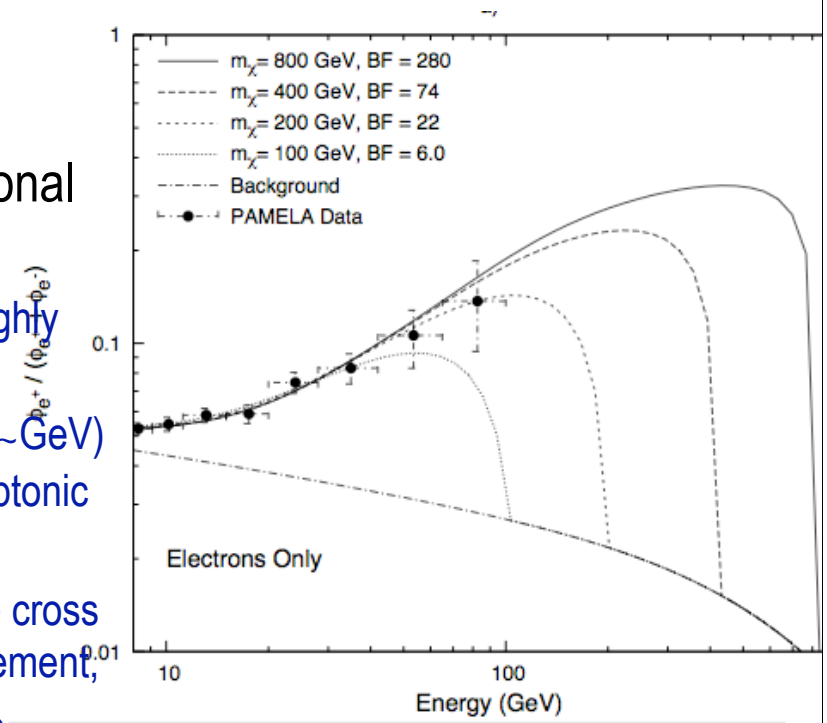
PAMELA (launched in June 2006) - (Antiproton & positron)

- Observation of an anomalous positron abundance in the cosmic radiation
  - Just posted - Nature submission available at arXiv:0810.4995
  - earlier indications from HEAT and AMS-01.
- Rising Positron Excess Compared to Electrons 1.5 - 100 GeV
  - low energies produced in interactions between cosmic-ray nuclei and interstellar matter ("secondary production").
  - However, hard rising spectrum evidence for new effect
    - dark matter particle annihilations in the galactic halo or
      - Must suppress antiprotons in decay since not observed
      - Requires significant boost in annihilation rate ~10-100
    - in the magnetospheres of near-by (<kpc) pulsars.
- Prospects - Continue data >Dec 09
  - Increase statistics will allow study up to 300 GeV
    - This may allow observation of a hard edge -> dm
  - Testing for anisotropy consistent with a single local dominant astrophysical source

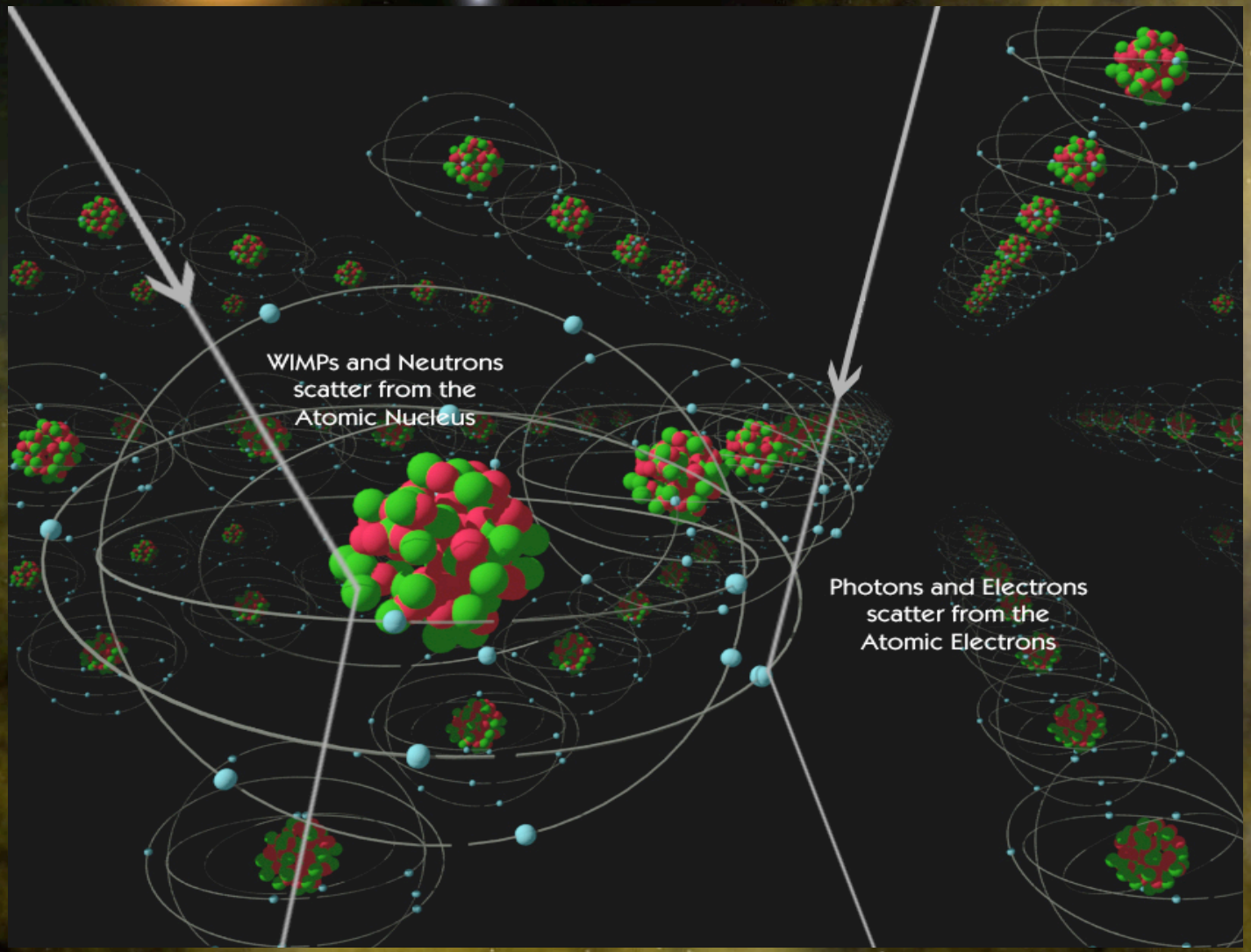


Hard Spectrum - Positron Fraction - DM interpretation

- Cholis, Finkbeiner, Goodenough, Weiner arXiv:0809.1683
- Antiparticle signal is generally expected from dark matter annihilations.
- However,the hard positron spectrum and large amplitude are difficult to achieve in most conventional WIMP models.
  - The absence of any associated excess in anti-protons is highly constraining on models with hadronic annihilation modes.
  - Alternative in the dark matter annihilates into a new light (<~GeV) boson φ, which is kinematically constrained to goto hard leptonic states, without anti-protons or π0 's.
  - Light boson naturally provides a mechanism by which large cross sections can be achieved through the Sommerfeld enhancement,
  - Depending on the mass of the WIMP, the rise may continue above 300GeV, the extent of PAMELA's ability to discriminate between electrons and positrons.



Interaction with Ordinary Matter

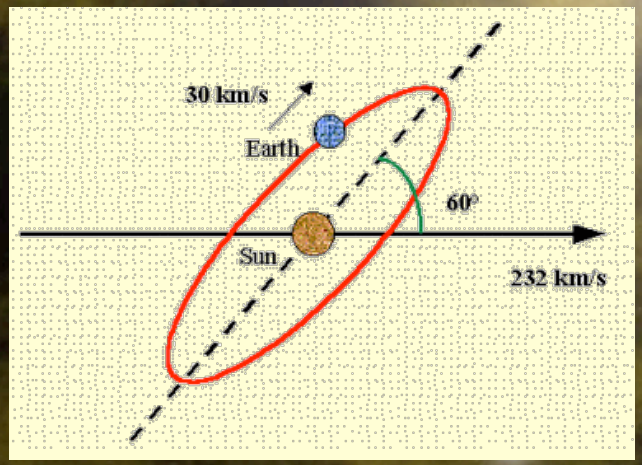


The Supersymetric Candidate

$$\chi = \alpha\tilde{\gamma} + \beta\tilde{Z} + \gamma\tilde{H}_1^0 + \delta\tilde{H}_2^0$$

→ **The Neutralino:**
Lightest Supersymetric Particle (LSP) and its own antiparticle

- **Indirect detection:**
  - Detection of WIMP annihilation products
- **Direct detection:**
  - WIMP scattering on nuclei
- **Possible Signatures:**
  - Nuclear vs electronic recoil
  - Recoil energy spectrum shape
  - Directionality of interactions (earth, sun)
  - Annual flux modulation
  - Diurnal direction modulation
  - No multiple interactions
  - Consistency between targets of different natures

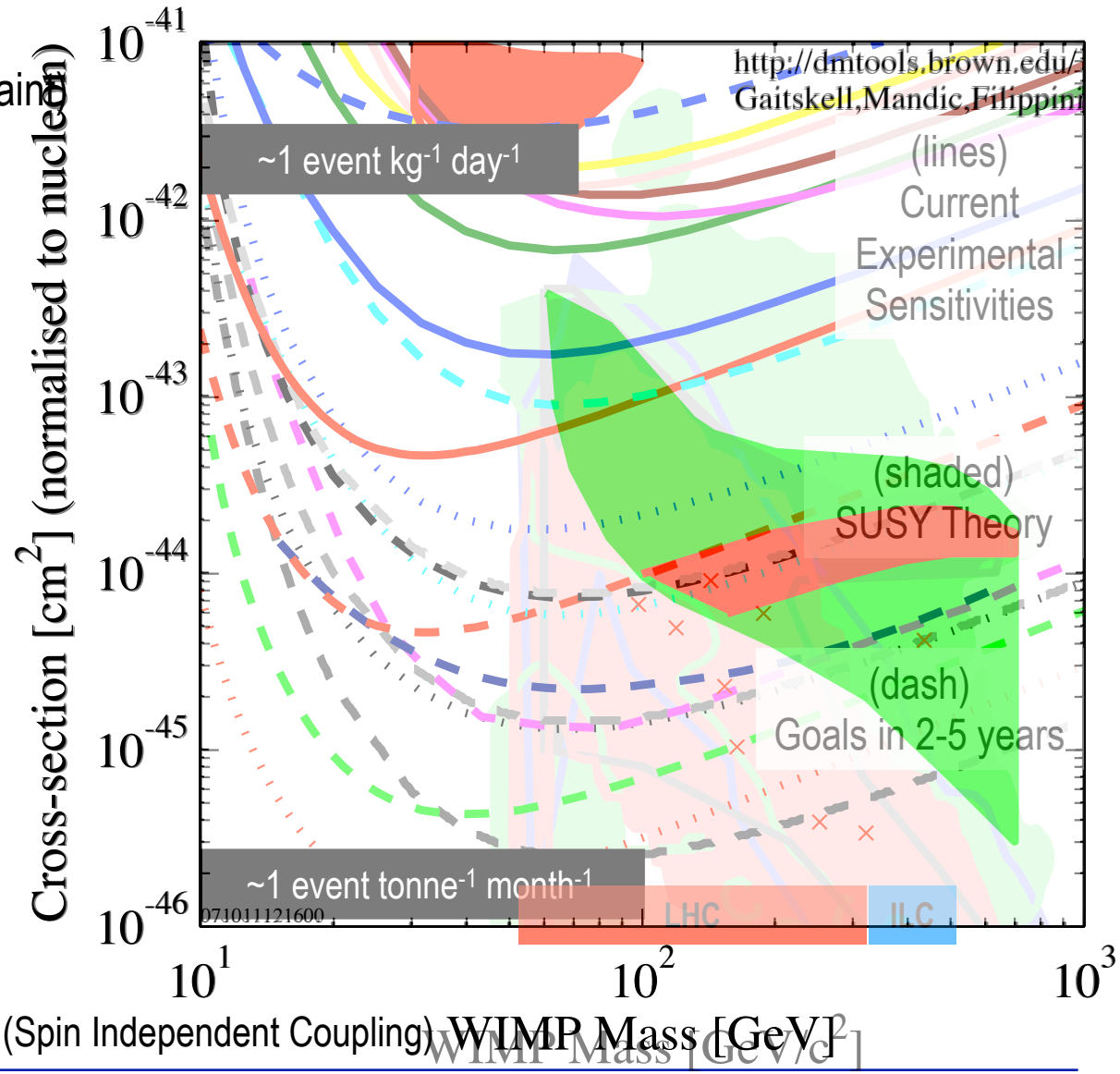


Dark Matter Theory and Experiment

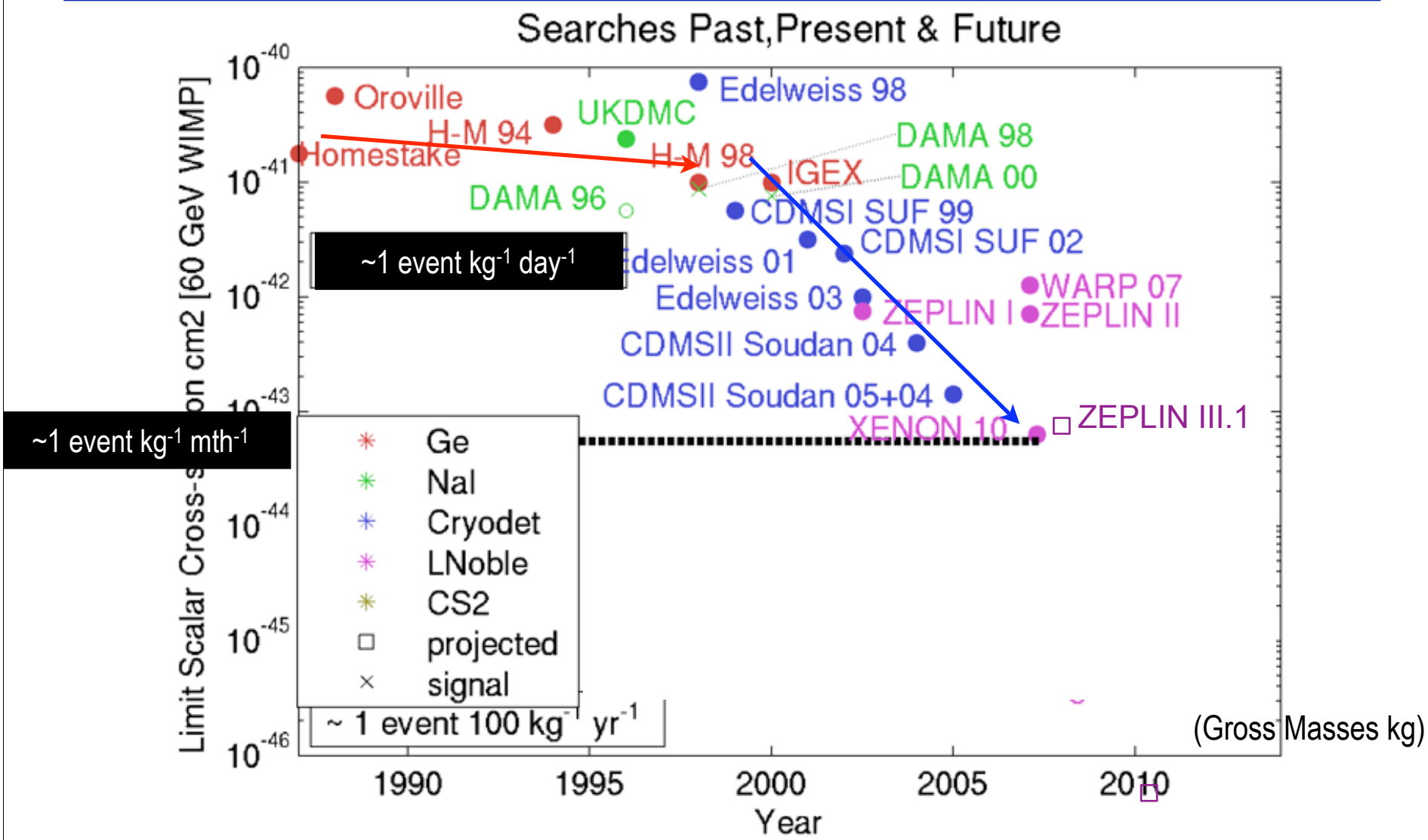
[Green] + [Red] inc :Ωh^2~0.1 constraint
Well Tempered Neutralino
(Hyperbolic Branch / Focus Point)
Baer et al.
JCAP 0701:017,2007
hep-ph/0611387

SOME SUSY MODELS

- [gray] Baer et al. ('03+upd '07)
- [red] T. Baltz and P. Gondolo, Markov Chain Monte Carlos. JHEP 0410 (2004) 052, (hep-ph/0407039)
- [blue] J. Ellis et al. CMSSM, Phys.Rev. D71 (2005) 095007, (hep-ph/0502001)
- [red crosses] J. Ellis et al., LHC Benchmark Points
- [green] Ruiz de Austri/Trotta/ Roszkowski (2007) CMSSM Markov Chain Models (95% CL)



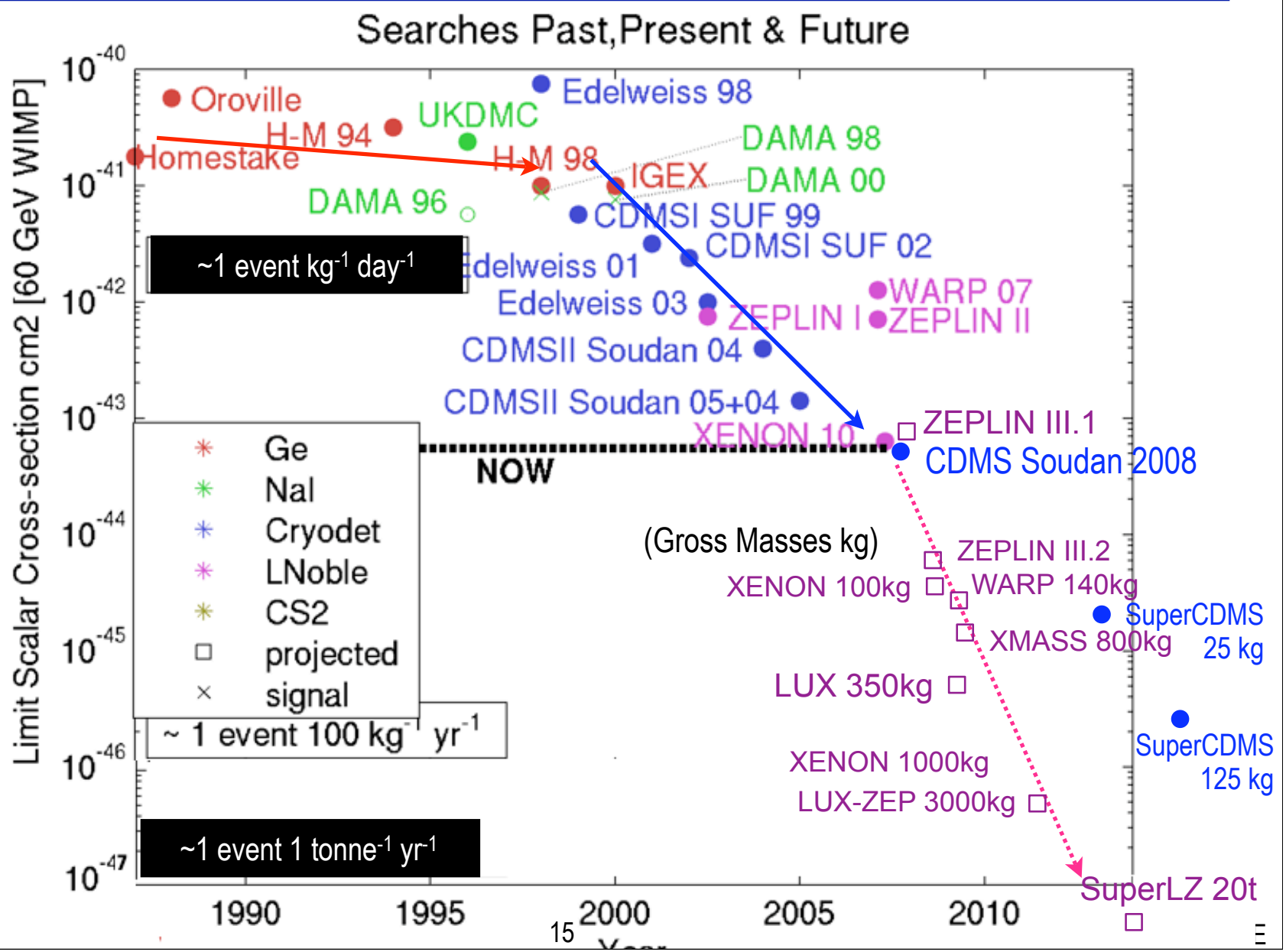
DM Direct Search Progress Over Time (2008)



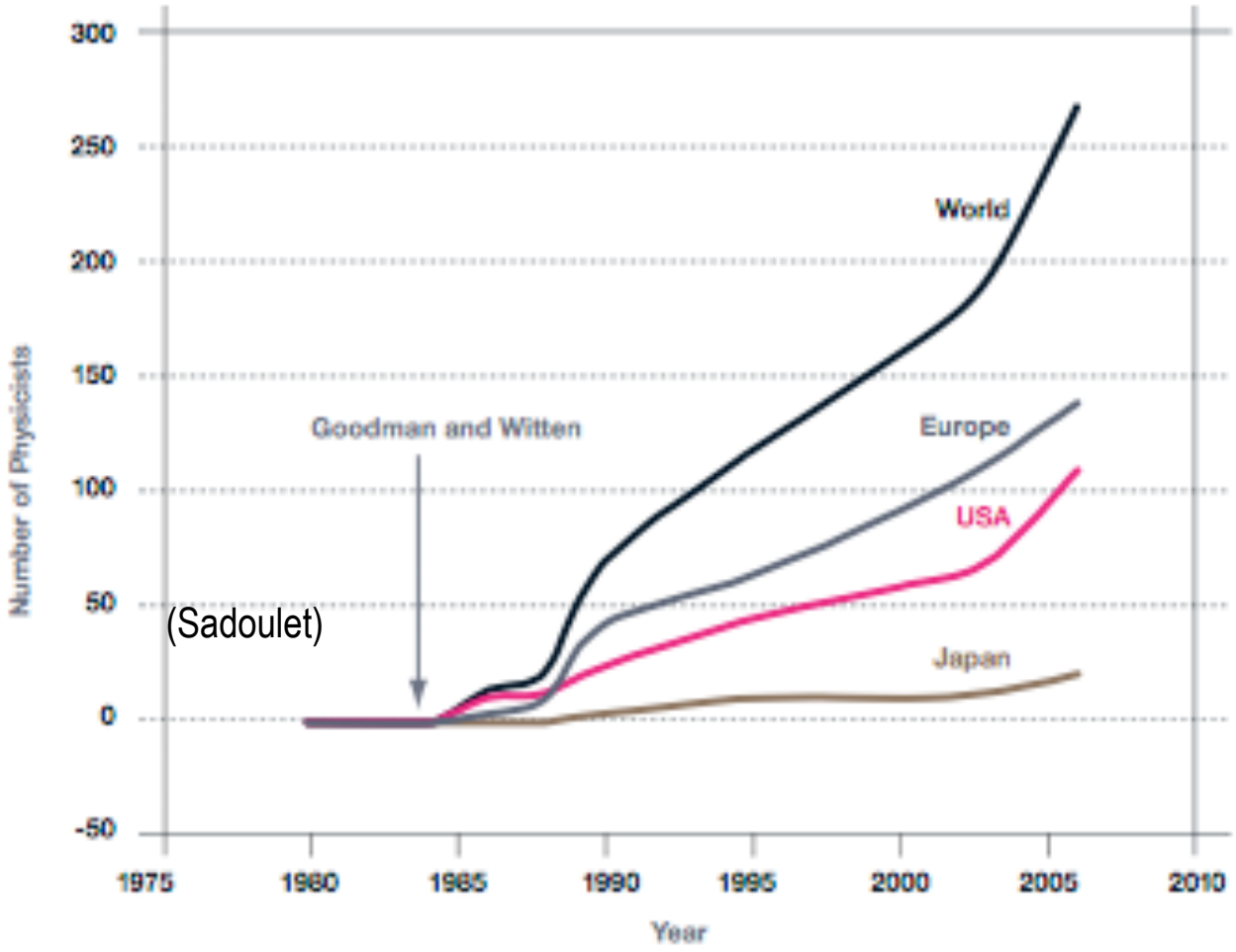
Plot updated from that in DM Review Article:

R J Gaitskell, Ann. Rev. Nucl. and Part. Sci. 54 (2004) 315-359

DM Direct Search Progress Over Time (2008)



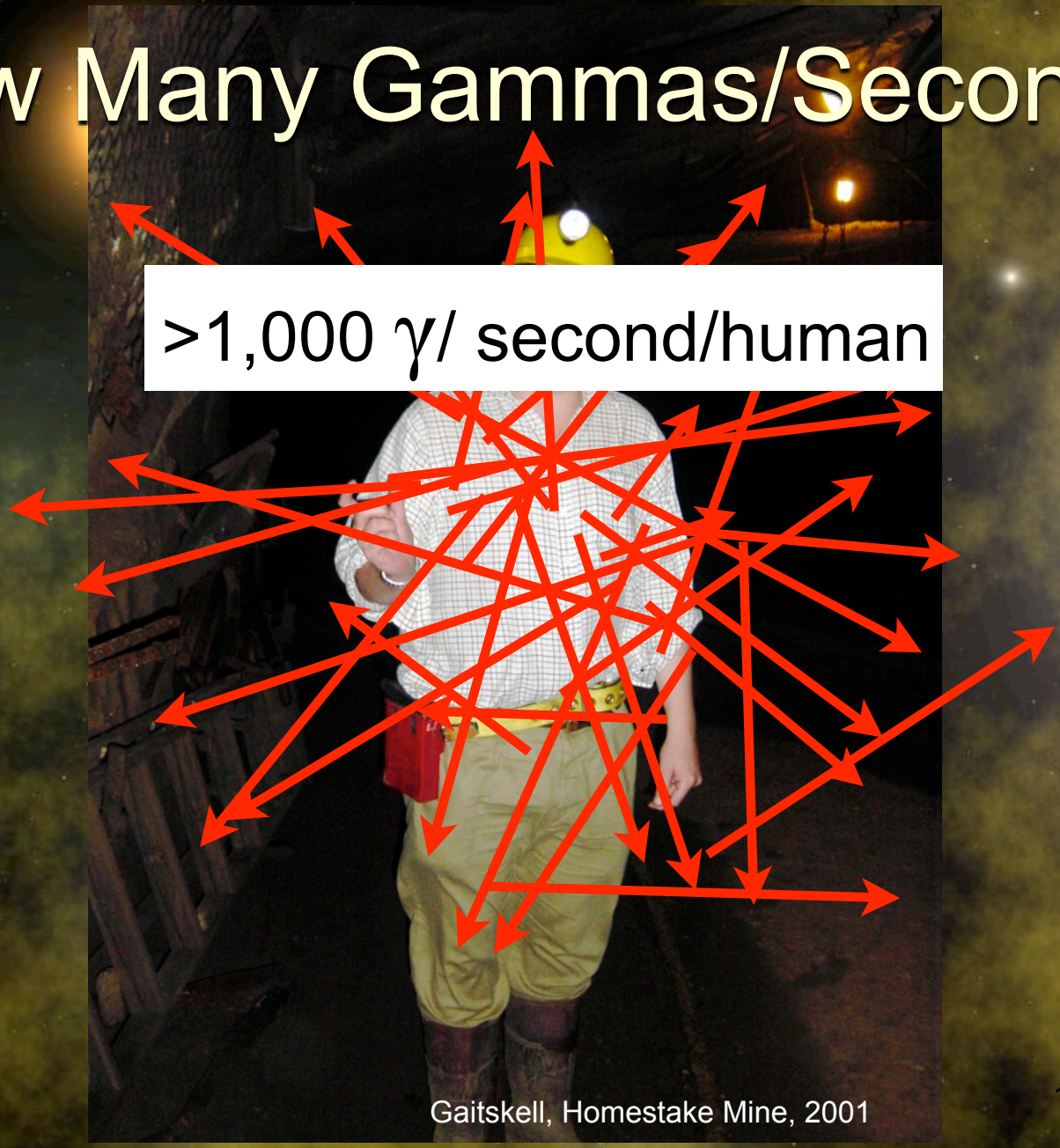
Direct Detection



Radioactive Background Challenges

- Search sensitivity (low energy region <<100 keV)
  - Current Exp Limit < 1 evt/kg/month, ~< $10^{-1.5}$ evt/kg/day
  - Goal < 1 evt/tonne/year, ~< 10^{-5} evt/kg/day
- Activity of typical Human?

How Many Gammas/Second?



Gaitskell, Homestake Mine, 2001

Background Challenges

- Search sensitivity (low energy region <<100 keV)
  - Current Exp Limit < 1 evt/kg/month, ~< $10^{-1.5}$ evt/kg/day
  - Goal < 1 evt/tonne/year, ~< 10^{-5} evt/kg/day
- Activity of typical Human?
- ~10 kBq (10^4 decays per second, 10^9 decays per day)
- Environmental Gamma Activity
  - Unshielded 10^7 evt/kg/day (all values integrated 0–100 keV)
  - This can be easily reduced to ~10^2 evt/kg/day using 25 cm of Pb
- Main technique to date focuses on nuclear vs electron recoil discrimination
  - This is how CDMS II experiment went from 10^2 -> 10^{-1} evts/kg/day (continue push for >>99.99% rejection)
- Moving below this
  - Reduction in External Gammas: e.g. High Purity Water Shield 4m gives <<1 evt/kg/day
  - Gammas from Internal components - goal intrinsic U/Th contamination toward ppt (10^{-12} g/g) levels
  - Detector Target can exploit self shielding for inner fiducial if intrinsic radiopurity is good
- Environmental Neutron Activity / Cosmic Rays => DEEP
  - (α,n) from rock 0.1 cm^{-2} day^{-1}
  - Since <8 MeV use standard moderators (e.g. polyethylene, or water, 0.1x flux per 10 cm
  - Cosmic Ray Muons generate high energy neutrons 50 MeV - 3 GeV which are tough to moderate
  - Need for depth (DUSEL) - surface muon 1/hand/sec, Homestake 4850 ft 1/hand/month

Techniques for dark matter direct detection

TYPE	DISCRIMINATION TECHNIQUE	TYPICAL EXPERIMENT	ADVANTAGE
Ionization	None (Ultra Low BG)	MAJORANA, GERDA	Searches for ββ-decay, dm additional
Solid Scintillator	pulse shape discrimination	LIBRA/DAMA, KIMS	low threshold, large mass, but poor discrim
Cryogenic	charge/phonon light/phonon	CDMS, CRESST EDELWEISS	demonstrated bkg discrim., low threshold, but smaller mass/higher cost
Liquid noble gas	light pulse shape discrimination, and/or charge/light	ArDM, Depleted Ar, LUX, WARP, XENON, XMASS, ZEPLIN	large mass, good bkg discrimination
Bubble chamber	super-heated bubbles/ droplets	COUPP, PICASSO	large mass, good bkg discrimination
Gas detector	ionization track resolved	DRIFT, NEWAGE, MIT-Boston-Brandeis	directional sensitivity, good discrimination

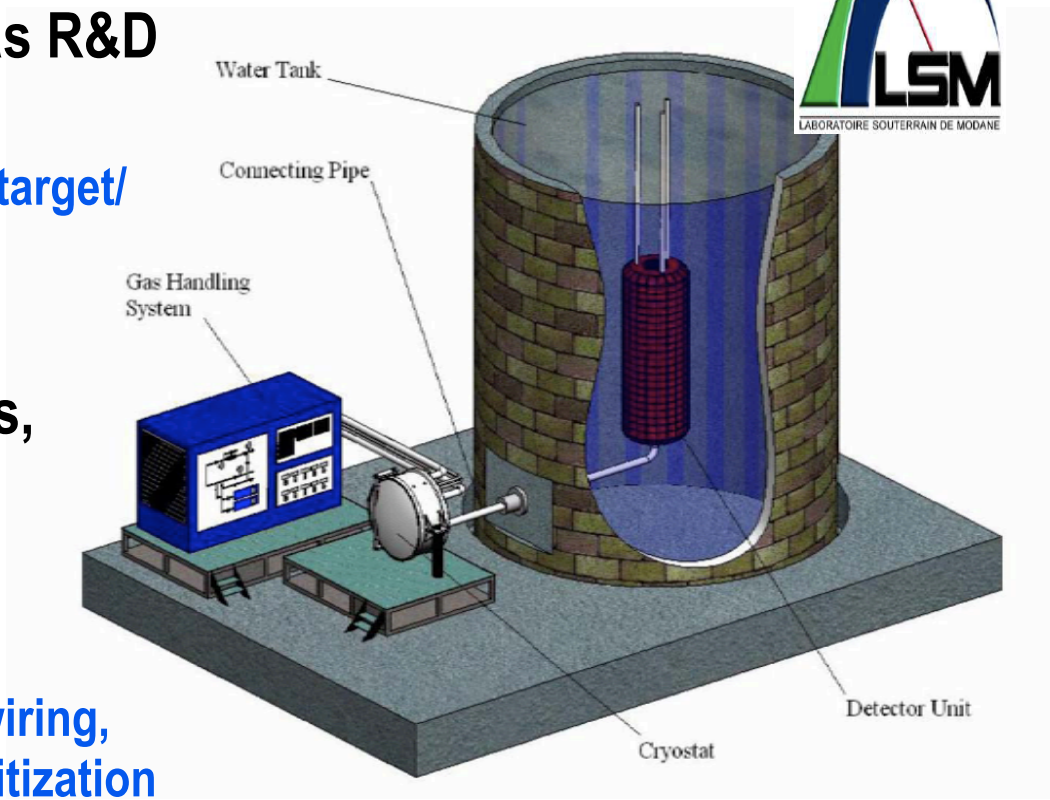
R.J. Gaitskell, Ann. Rev. Nucl. Par. Sci, 54 (2004) 315

Future of Direct Detection

- Experiments under construction, to release results in 2009-2010
  - Target masses 10-300 kg
  - Expect 10-100x better reach than existing limits.
- Next Round, for results in 2011-2013
  - Target masses 1-3 tonne, 10^3 x better reach
  - Project cost $5-15M
- "Ultimate" Detectors, for results ~2014+
  - Target masses 3-50 tonne, 10^4 x better reach
  - Project cost $20-50M
- Labs with 1-20 tonne dm experiments on roadmap
  - Gran Sasso, Italy
  - Frejus, France
  - Canfranc, Spain
  - Kamioka, Japan
  - SNOLab, Canada
  - Homestake, US

Eureca: scale up plans for European Cryo.

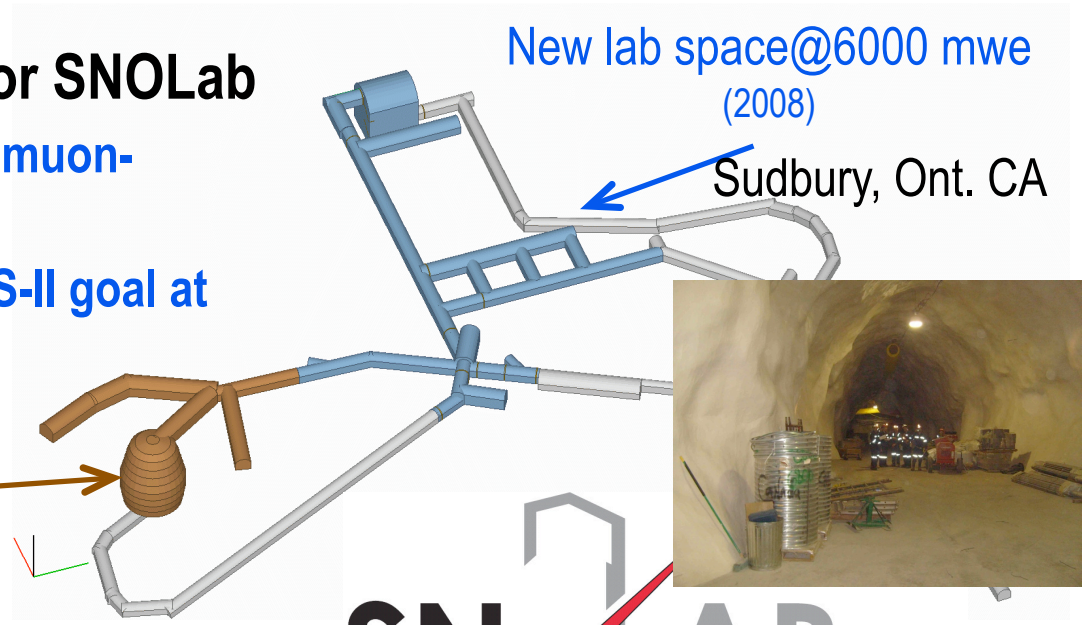
- European Underground Rare Event Calorimeter Array
- Cresst-II and Edelweiss-II as R&D progenitors for scale up
  - +Rosebud collab: variety of target/ bolometric techniques
- 100-kg to 1-tonne
- Roadmap: variety of targets, couplings, etc.
  - Ge & $CaWO_4$
- Design Study 2009/2010
  - ~10,000 channels: R&D on wiring, multiplexing, in-cryostat digitization
- Deploy 2014
  - 10^{-46} cm^2 sensitivity goal



Modane Lab at Frejus:
Deepest in Europe @ 4800 m.w.e.

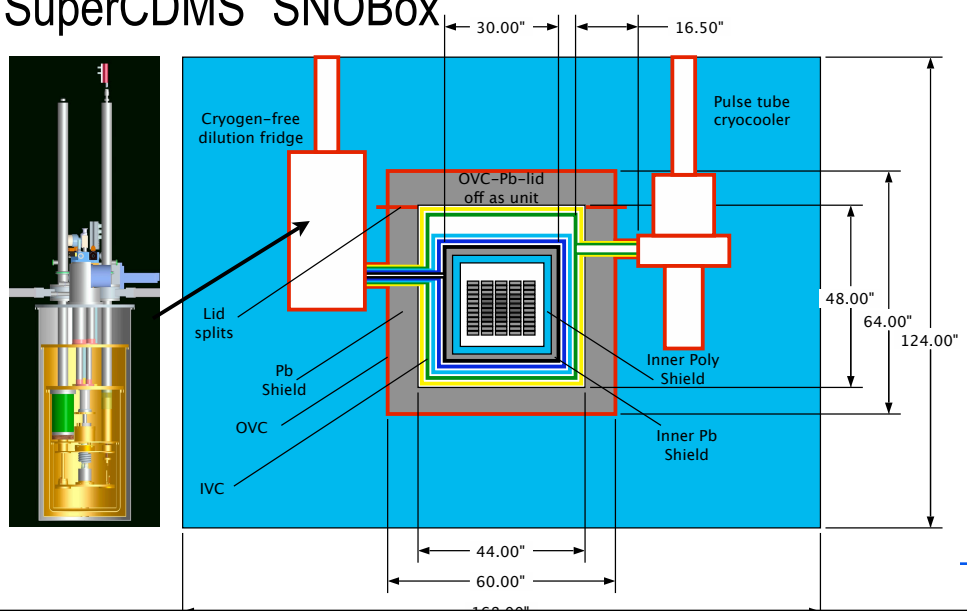
SuperCDMS 25 kg experiment

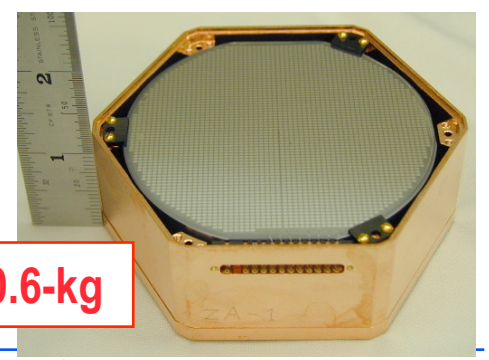
- **New experiment proposed for SNOLab**
  - **Depth required to drive down muon-induced neutron background**
  - **15x more sensitive than CDMS-II goal at Soudan**



SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

SuperCDMS "SNOBox"





42 1"-thick 0.6-kg

Noble Liquids

- Why Noble Liquids?
  - Nuclear vs Electron Recoil discrimination readily achieved
    - Scintillation pulse shapes
    - Ionization/Scintillation Ratio
  - High Scintillation Light Yields / Good Light Transmission (Dimer emission ≠ atomic absorption)
    - Low energy thresholds can be achieved
    - Have to pay close attention to how discrimination behaves with energy
  - Ionization Drift >>1 m, at purities achieved (<< ppm electronegative impurities)
  - Large Detector Masses are easily constructed and behave well
    - Shelf shielding means Inner Fiducial volumes have very low activity (assuming intrinsic activity of target material is low)
      - BG models get better the larger the instrument
    - Position resolution of events very good in TPC operation (ionization)
    - Dark matter cross section on nucleons goes down at least to $\sigma \sim 10^{-46}$ cm^2 == 1 event/100 kg/year (in Ge or Xe), so need a large fiducial mass to collect statistics
  - Cost & Practicality of Large Instruments
    - Very competitive / Simply Increase PMTs
- "Dark Matter Sensitivity Scales As The Mass, Problems Scale As The Surface Area"

Noble Liquids as detector medium

	Z (A)	BP (T_b) at 1 atm [K]	liquid density at T_b [g/cc]	ionization [e-/MeV]	scintillation [photon/MeV]
He	2 (4)	4.2	0.13	39,000	22,000
Ne	10 (20)	27.1	1.21	46,000	30,000
Ar	18 (40)	87.3	1.40	42,000	40,000
Kr	36 (84)	119.8	2.41	49,000	25,000
Xe	54 (131)	165.0	3.06	64,000	46,000

- Scintillation Light Yield comparable to NaI 40,000 phot/MeV
- liquid rare gas gives both scintillation and ionization signals

Noble Liquids as detector medium

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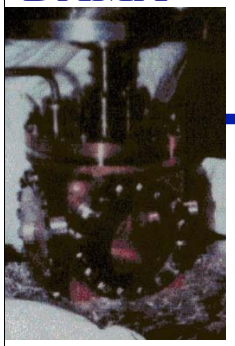
Ar	18 (40)	87.3	1.40	42	40
Kr	36 (84)	119.8	2.41	49	25
Xe	54 (131)	165.0	3.06	64	46

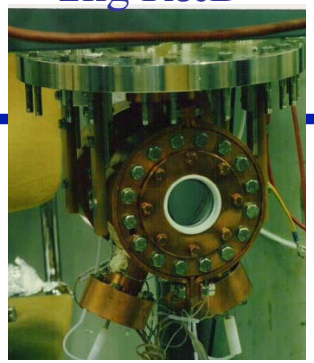
- liquid rare gas gives both scintillation and ionization signals
- Scintillation is decreased (~factor 2) when E-field applied for extracting ionization

In LXe ~30% of electron recoil energy appears as scintillation light (7 eV photons)

DAMA



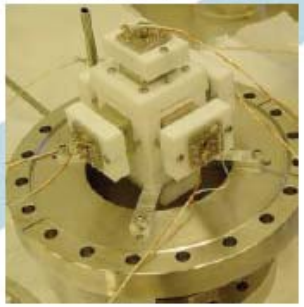
2kg R&D



ZEPLIN I

ZEPLIN II

XENON R&D

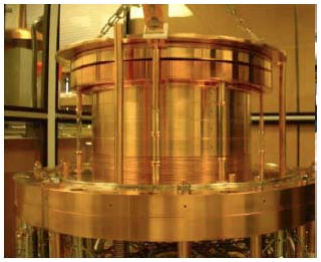


XENON10

2006-2007

XMASS

ZEPLIN III

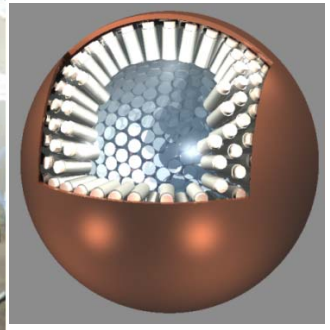


XENON100

2007-2010

LUX

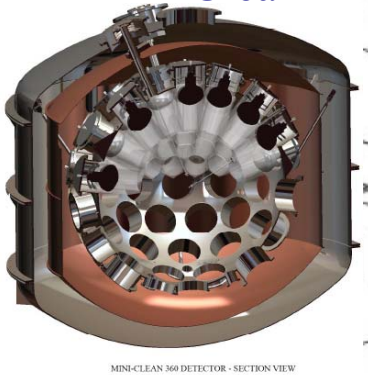
XMASS



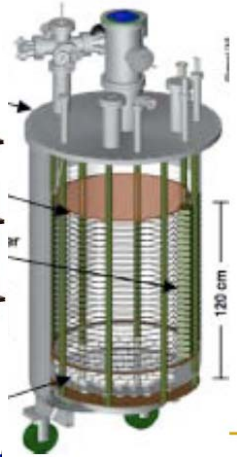
XENON1T

2009-2013
design studies ongoing

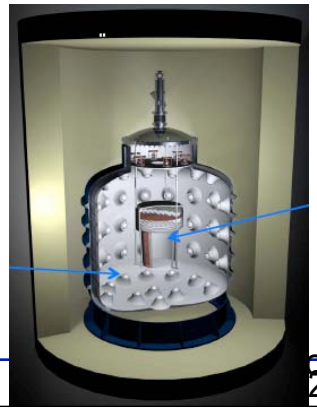
MiniClean



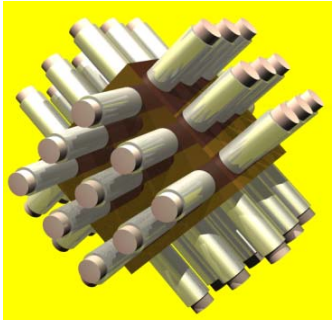
ArDM

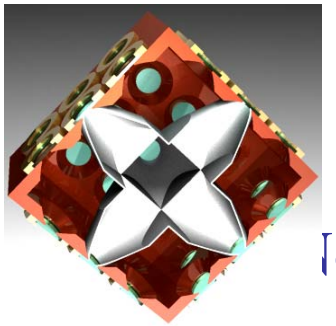


WARP



XMASS



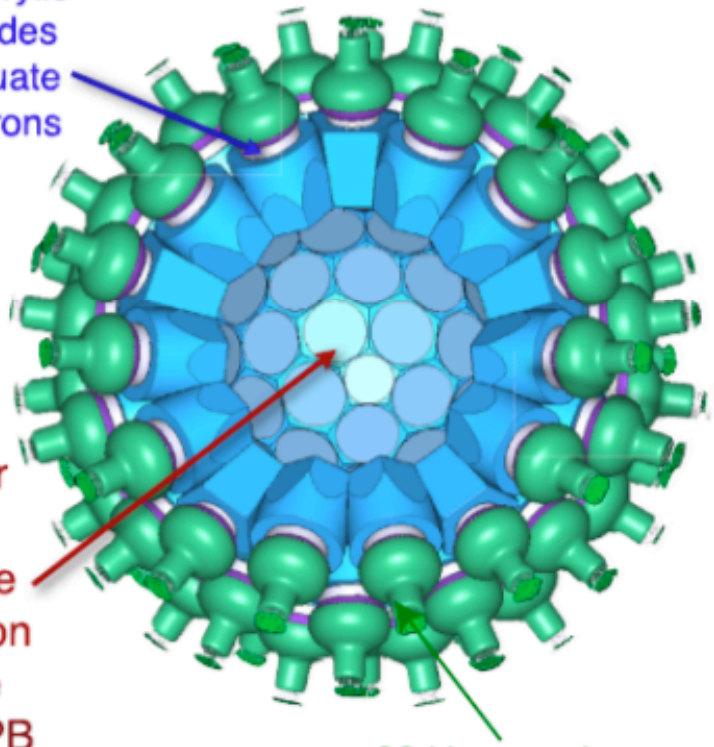


Noble
Gas Detectors

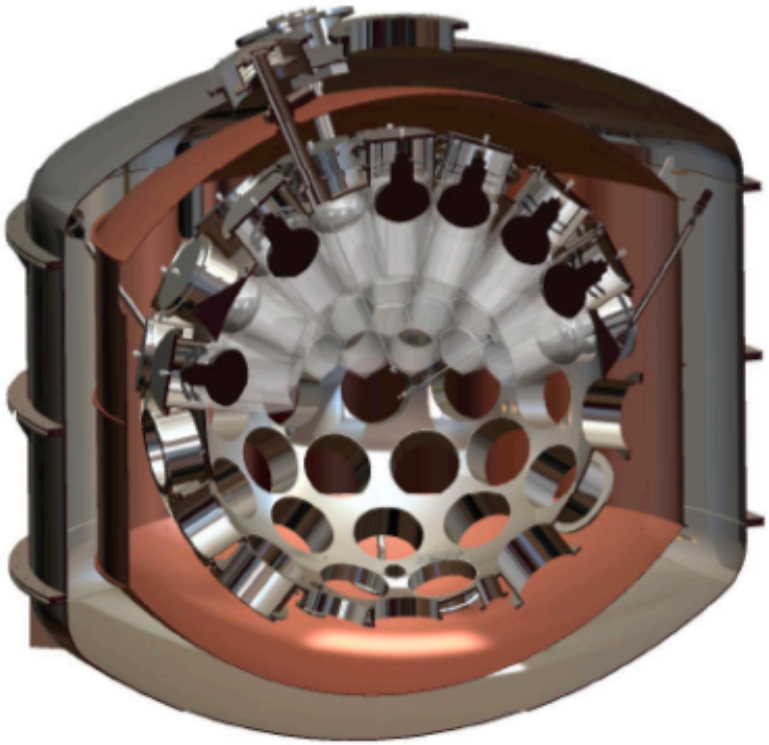
Mini-CLEAN central detector

(under construction)

View of internals

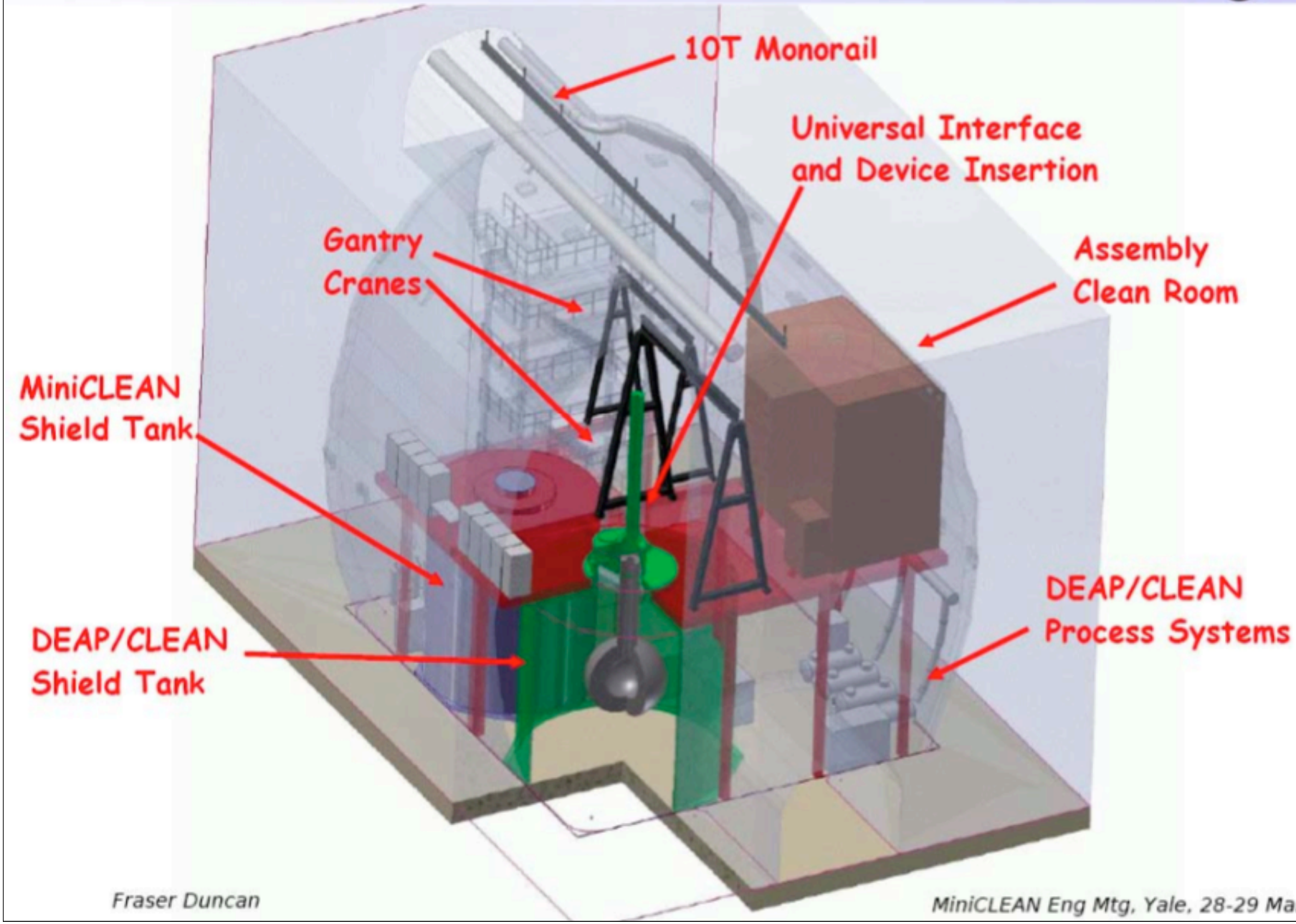


View of cryostat



MINI-CLEAN 360 DETECTOR - SECTION VIEW

Cube Hall


10T Monorail
Universal Interface
and Device Insertion
Gantry
Cranes
Assembly
Clean Room
MiniCLEAN
Shield Tank
DEAP/CLEAN
Process Systems
DEAP/CLEAN
Shield Tank

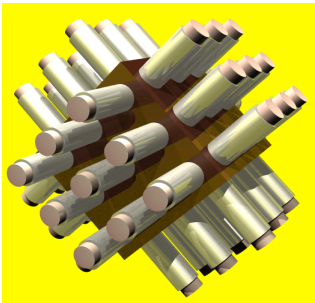
miniCLEAN 360 kg and DEAP/CLEAN 3600 kg

- 360 kg miniCLEAN (Ar/Ne) and 3600 kg DEAP/CLEAN
  - Both are under design/construction
  - Ultimate goal for 50 tonne target 2013+
- Backgrounds
  - Uses Pulse Shape Discrimination in scintillation light
    - Demonstrated to work well at high energies >100 keVr. Still require high stats low energy data.
  - PMT Gammas
    - Requires better than 10^{-8} rejection of ER at 50 keVr
    - Currently demonstrated 10^{-5} >50 keVr (limited by neutron bg in lab)
  - PMT neutrons
    - Difficult to reject since poor multiple scatter cut when based on PMT hit patter alone
    - Use acrylic light guides to moderate neutrons
    - Proportionally less of problem in larger target
  - Position Reconstruction
    - At low energies
    - How well can events leaking from outer be rejected?
  - Alpha-Daughter Recoil Events on inner surface of chamber
    - Major concern - requires very low Rn exposure

XMASS: strategy for scaling up

Phase 2
~10 ton detector

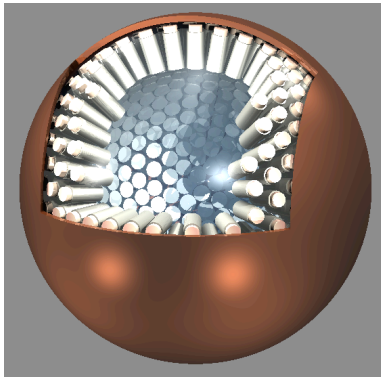
R&D phase
100kg Prototype



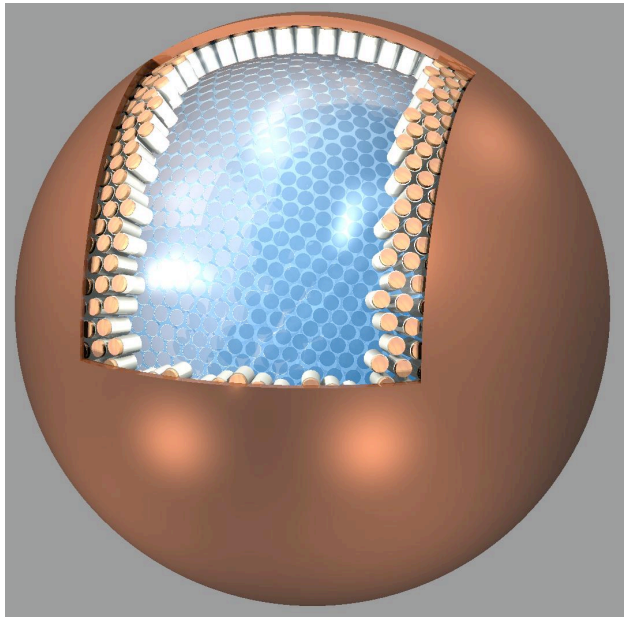
~30cm

R&D

Phase 1
800kg detector



~80cm



~2.5m

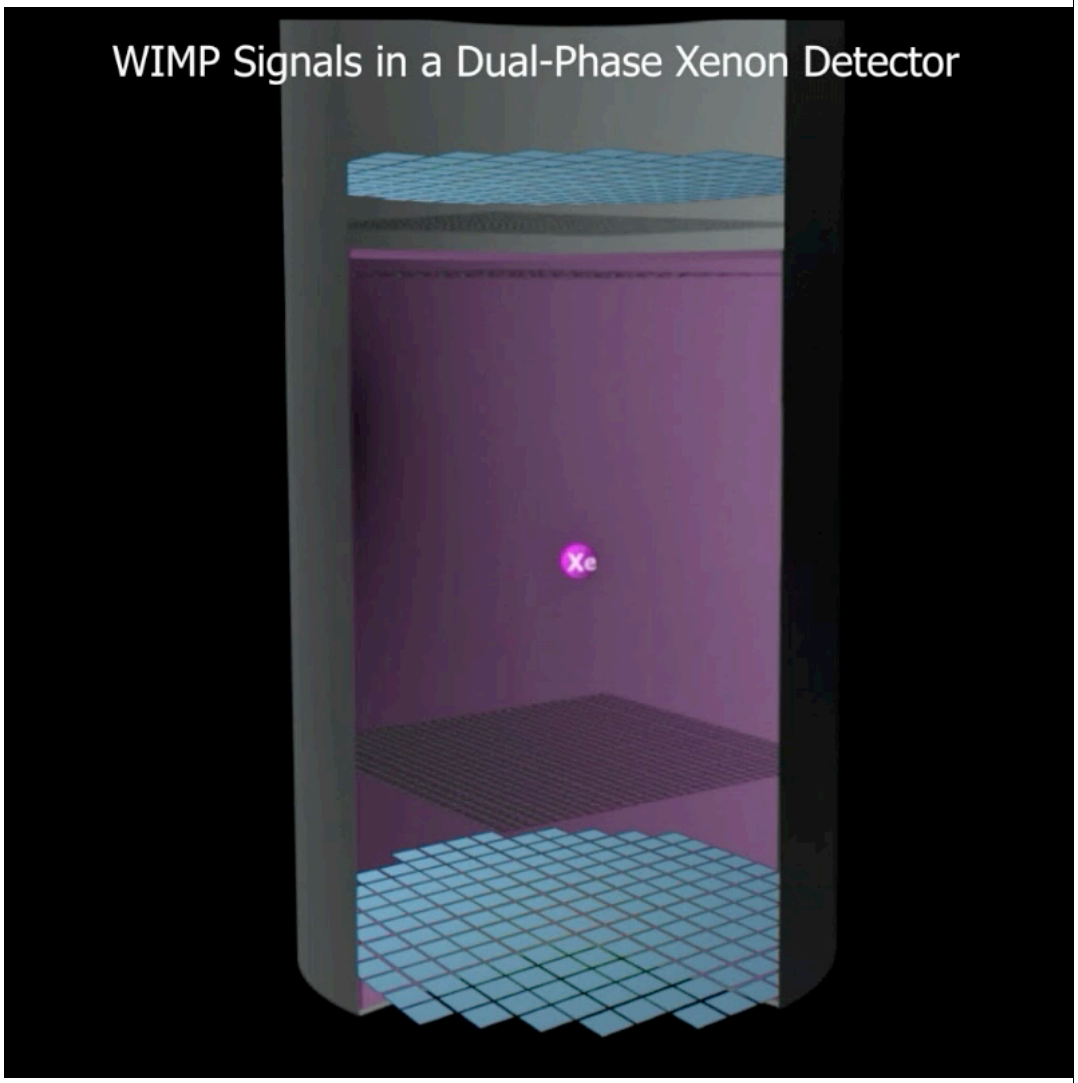
Dark matter search

Multipurpose detector
(solar neutrino, ββ …)

- Phase 1: Cavern Completed.
  Now installing ø10 m water shield.

Noble Liquid Dual phase Time Projection Chamber

- Can measure single electrons and photons.
- Charge yield reduced for nuclear recoils.
- Good 3D imaging
  - *Eliminating edges crucial.*

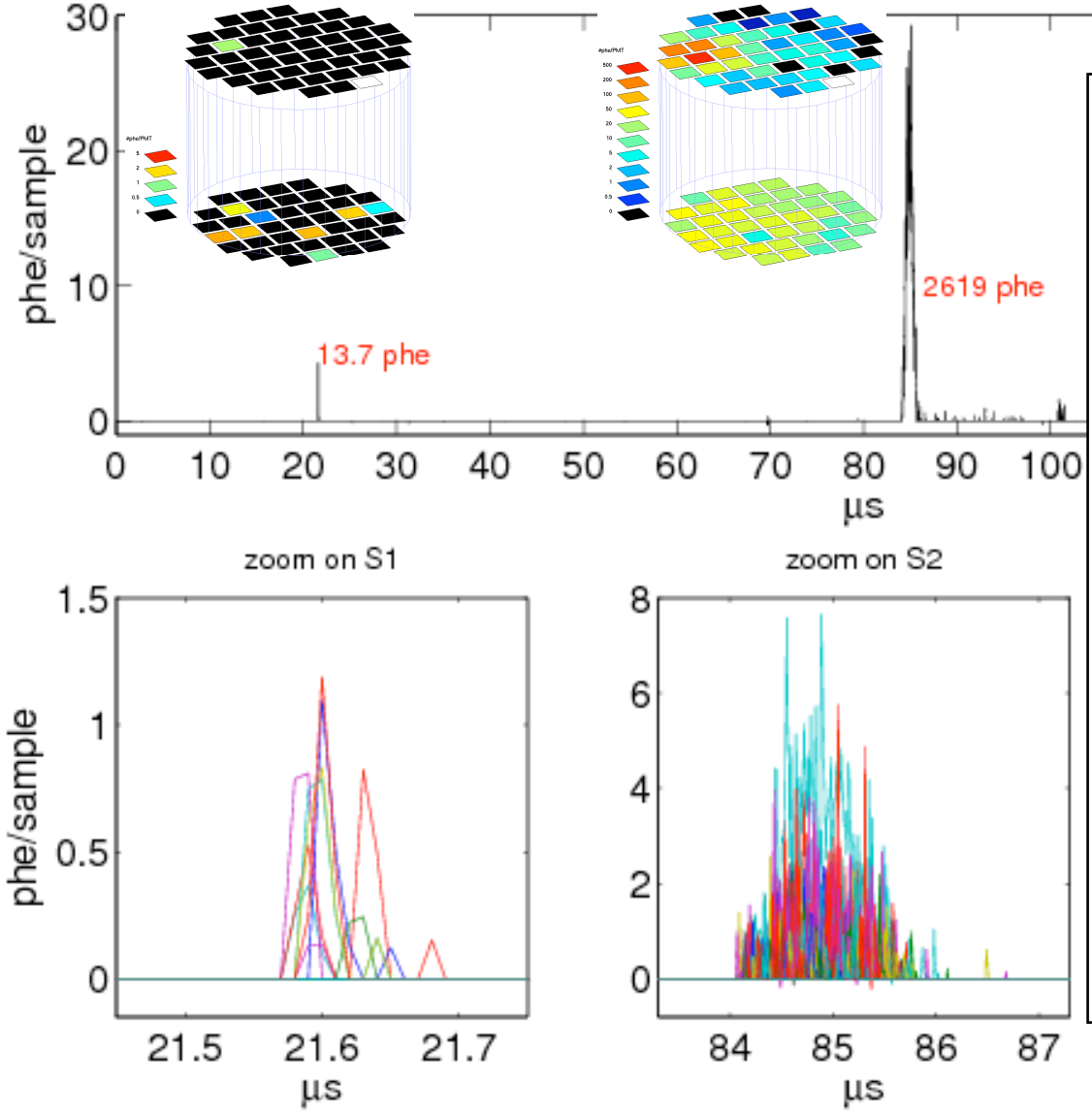


- Current Experiments:
  - XENON10 (2006-2007, Gran Sasso Italy)
  - ZEPLIN II
  - WARP

- New
  - XENON100 (Gran Sasso)
  - ZEPLIN III (Boulby)
  - LUX 350 kg (Homestake Mine, SD)
  - WARP 100 (Gran Sasso)
  - XMASS-DM 10 kg (Kamioka)

- Single Phase is a distinct technique
  - XMASS 800 kg
  - CLEAN/DEAP 7 kg & 350 kg

XENON10 Typical Background Event at 4.5 keVee *



S1: primary scintillation

S2: ionization drifted, extracted, amplified in gas region (secondary scintillation)

Background Discrimination:
$(S2/S1)_{ER} > (S2/S1)_{NR}$

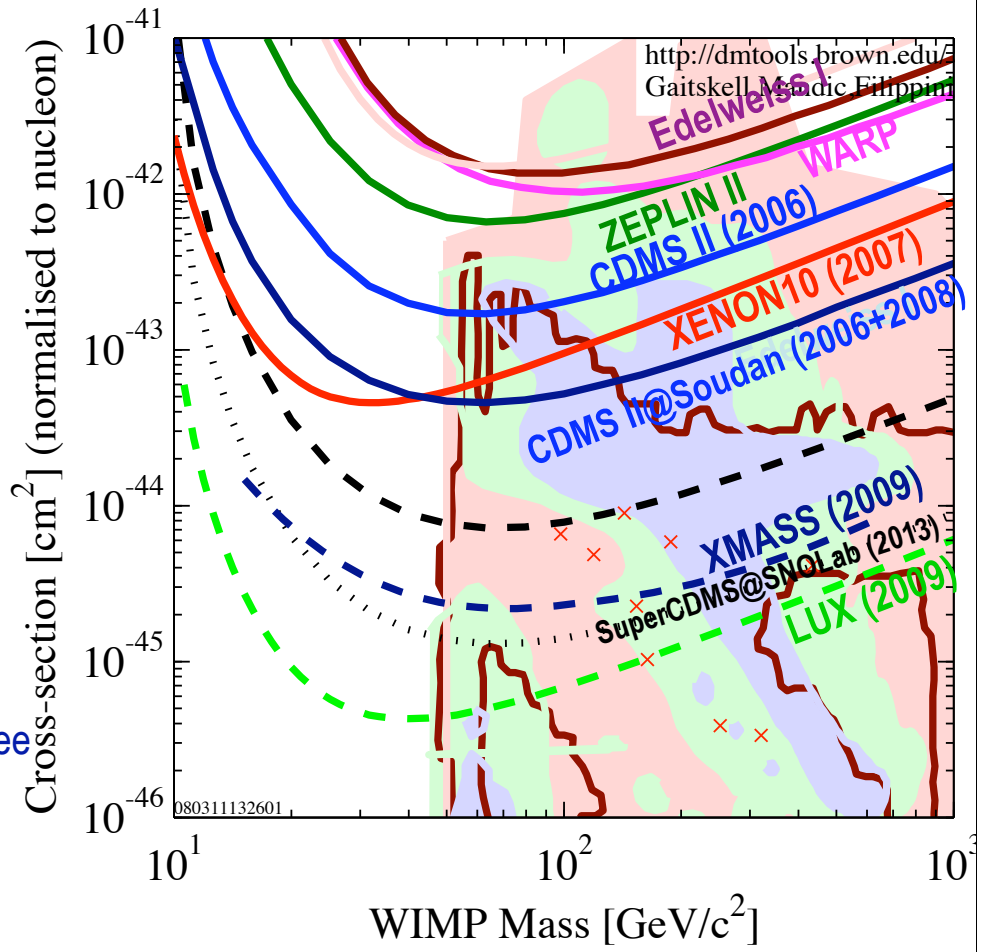
x,y coords. : from S2 Hit-Pattern

z coord. : from drift time Δt between S2 and S1

*(scaled using 3.0 phe/keVee from 122 keV gamma cal.)

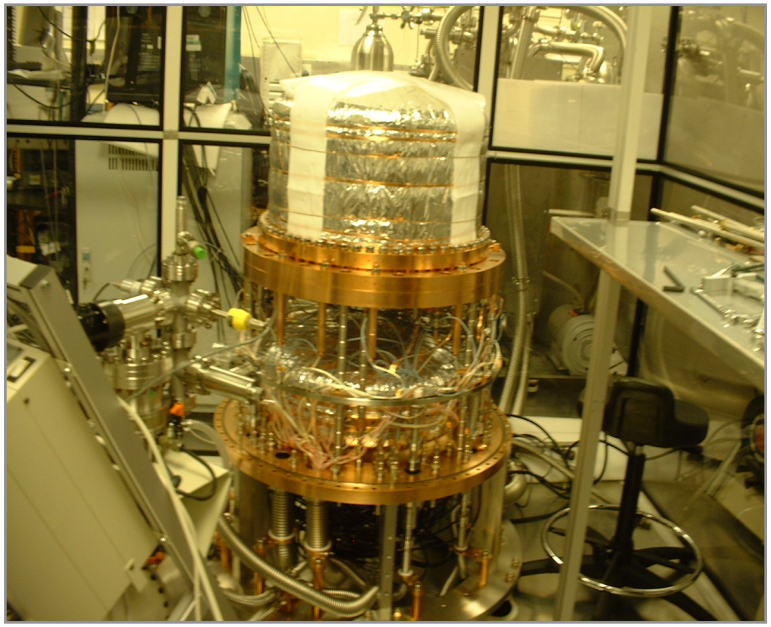
Dark Matter Result & Next Stage

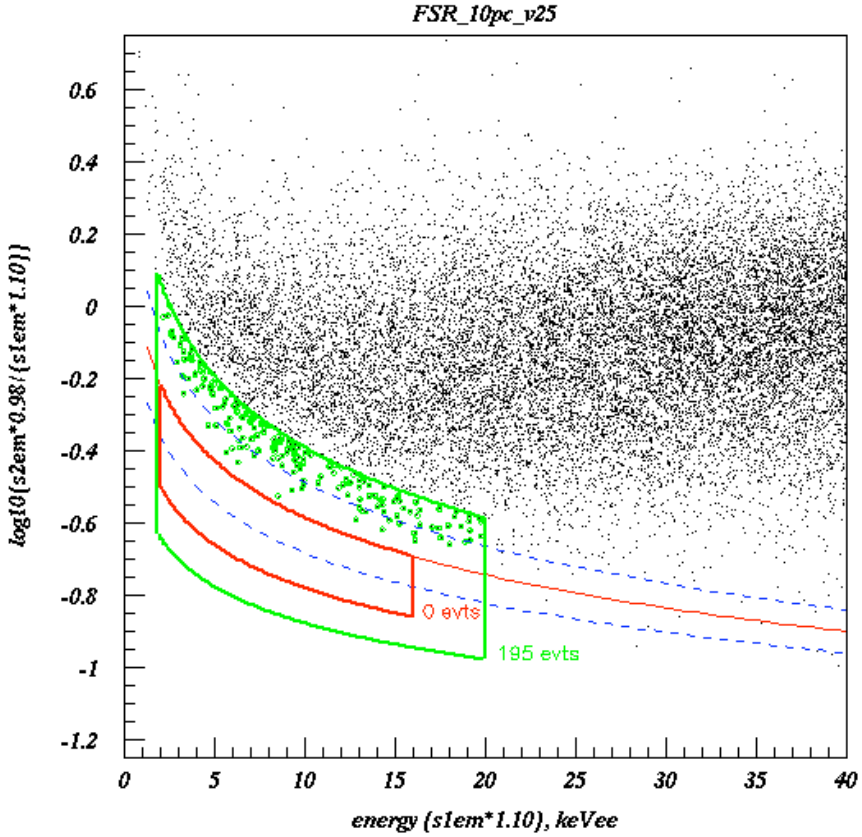
- Dark Matter Goals
  - XENON10
    - ~60 day run (bg limited)
    - 136 kg-days net exposure
  - LUX - Sensitivity curve at 7×10^{-46} cm^2 (100 GeV)
    - Exposure: Gross Xe Mass 300 kg
      Limit set with 300 days running
      x 100 kg fiducial mass x 50% NR acceptance
      - If candidate dm signal is observed, run time can be extended to improve stats
    - <1 background event during exposure assuming XENON10 discrimination performance
      ER 8×10^{-4} /keVee/kg/day and >99.4% ER rejection
      - Intrinsic BG rejection ->99.9% at low energy
      - Improvements in PMT bg will extend background free running period, and DM sensitivity
  - Comparison
    - SuperCDMS Goal @ SNOLab: Gross Ge Mass 25 kg (x 50% fid mass+cut acceptance)
      Limit set for 1000 days running x 7 SuperTowers



This plot has a very limited number of current and projected results.
Please go to http://dmtools.brown.edu

ZEPLIN III WIMP Search LXe 500 kg-days
Recent Report: 20% data (Blind Analysis)





Tim Sumner, Imperial College

IDM 2008 August 19th 2008
Stockholm, Sweden

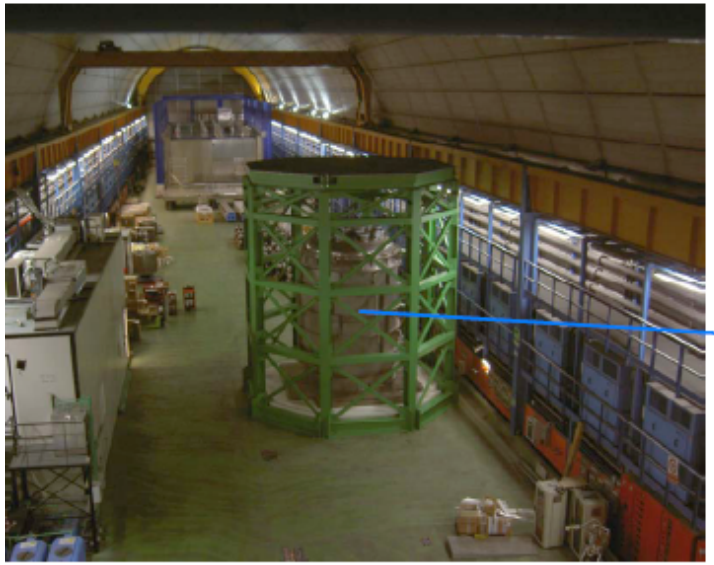
WArP (100 liter) @ LNGS

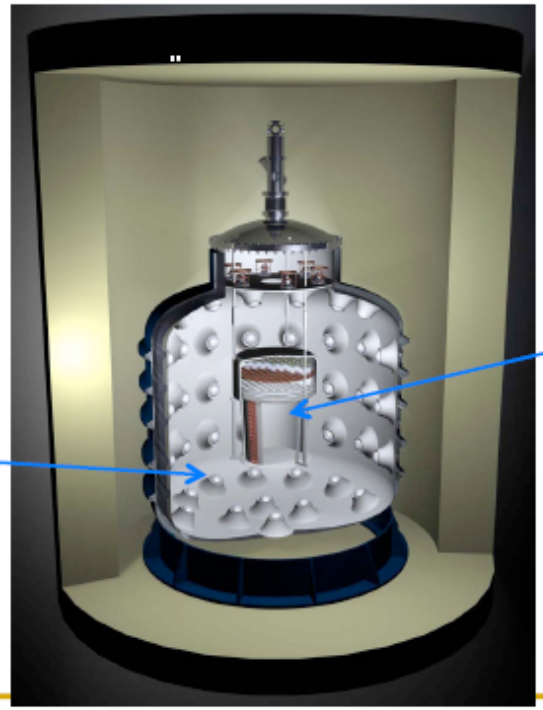
- 140 kg dual-phase ArTPC under construction at LNGS with 10^{-45} cm^2 sensitivity reach
- electron recoil discrimination by S2/S1 and by PSD (5ns and 1.6 micros decay times)
- target surrounded by an active LAr shield (9 tons and 300 PMTs)
- electron recoil discrimination by S2/S1 and by PSD of scintillation light , plus event localization

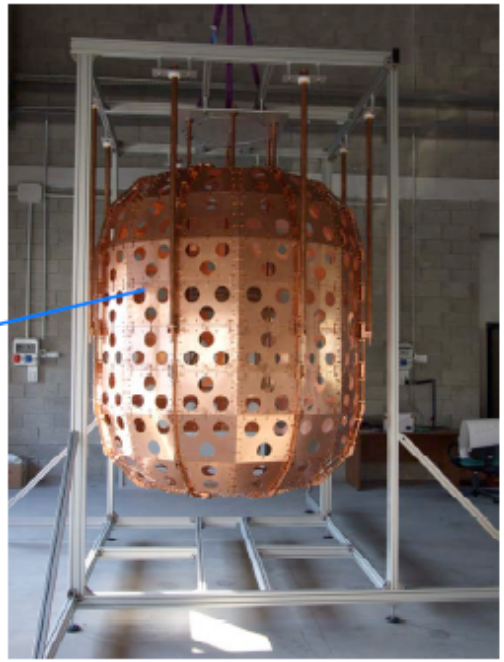
Princeton-Fermilab pursuing new depleted 39Ar detector in US

- Ar gas with low level of radioactive ^{39}Ar from US u.g. reservoir promising for multi-ton expt
- Main Cryostat

after positioning in Hall-B (Jul.'07) inside sustaining structure







XENON100 Installed underground @ LNGS

Shield modification/improvement completed Jan 08; Detector moved underground Feb 08

- *about 25-kg of LXe has been filled; science data expected summer 08*
- *Sensitivity reach 10^{-45} cm^2; ~10 signal events if cross section at 10^{-44} cm^2 in two months*

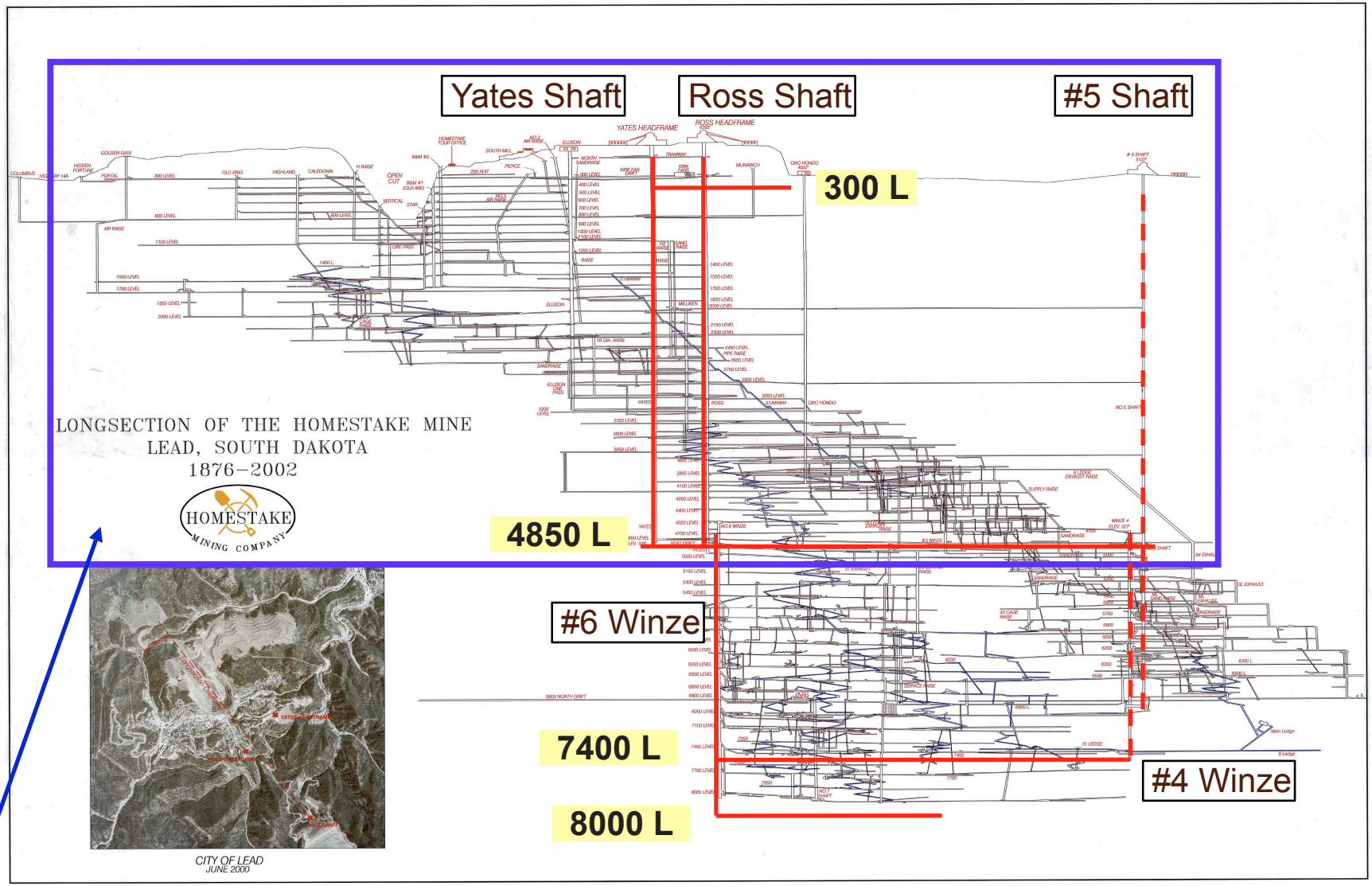
LUX Dark Matter Experiment - Summary

- LUX Experiment
  - Collaboration formed in 2007
  - Fully funded in 2008 by DOE & NSF for construction & deployment
  - 1/3 tonne LXe TPC target - Focus on tech. for even larger
  - Will be operated at 4850 ft level in Homestake Mine, South Dakota
    - Detector cryostat constructed / operating at Case Western
    - Will move to Homestake in Jan 2009
      - Initially in above Ground Lab
    - Pumping of water below 4850 level by Mar 2009
      - Construction in Davis Lab, and then start full LUX operation
- Collaboration
  - Majority of US groups from XENON10 + ZEPLIN II + CDMS + CLEAN/ DEAP + EXO + KAMLand + SuperK + SNO + Borexino + HEP/γ-ray astro
    - Brown [Gaitskell], Case [Shutt], LBNL [Lesko] , LLNL [Bernstein], Maryland [Hall], Rochester [Wolfs], Texas A&M [White], UC Davis [Svoboda/Tripathi], U South Dakota [Mei] , Yale [McKinsey]
- Backgrounds & Sensitivity:
  - Take lesson from NEUTRINO EXPERIMENTS = SELF SHIELD / HIGH PURITY LIQ. TARGET
  - 3D-imaging TPC eliminates surface activity, defines fiducial
- DM reach: 7×10^{-46} cm^2 in 10 months (~100x better than existing)

http://www.luxdarkmatter.org

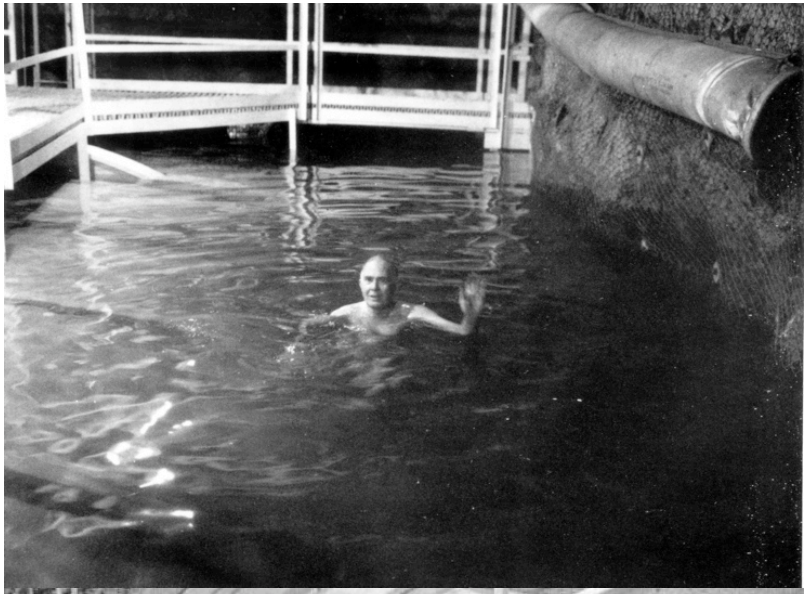
LUX
BARUS AND HOLLEY BUILDING
LUX Collaboration
January, 2008
Brown University

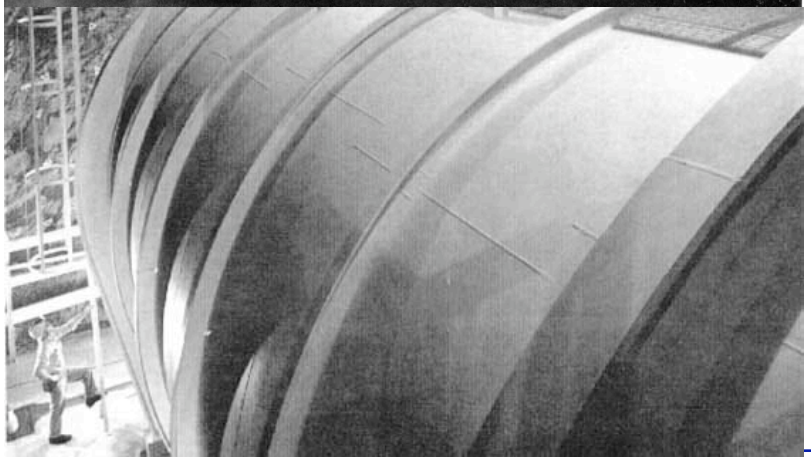
Initial Development of the Sanford Laboratory provides access to mid-levels for early experiments

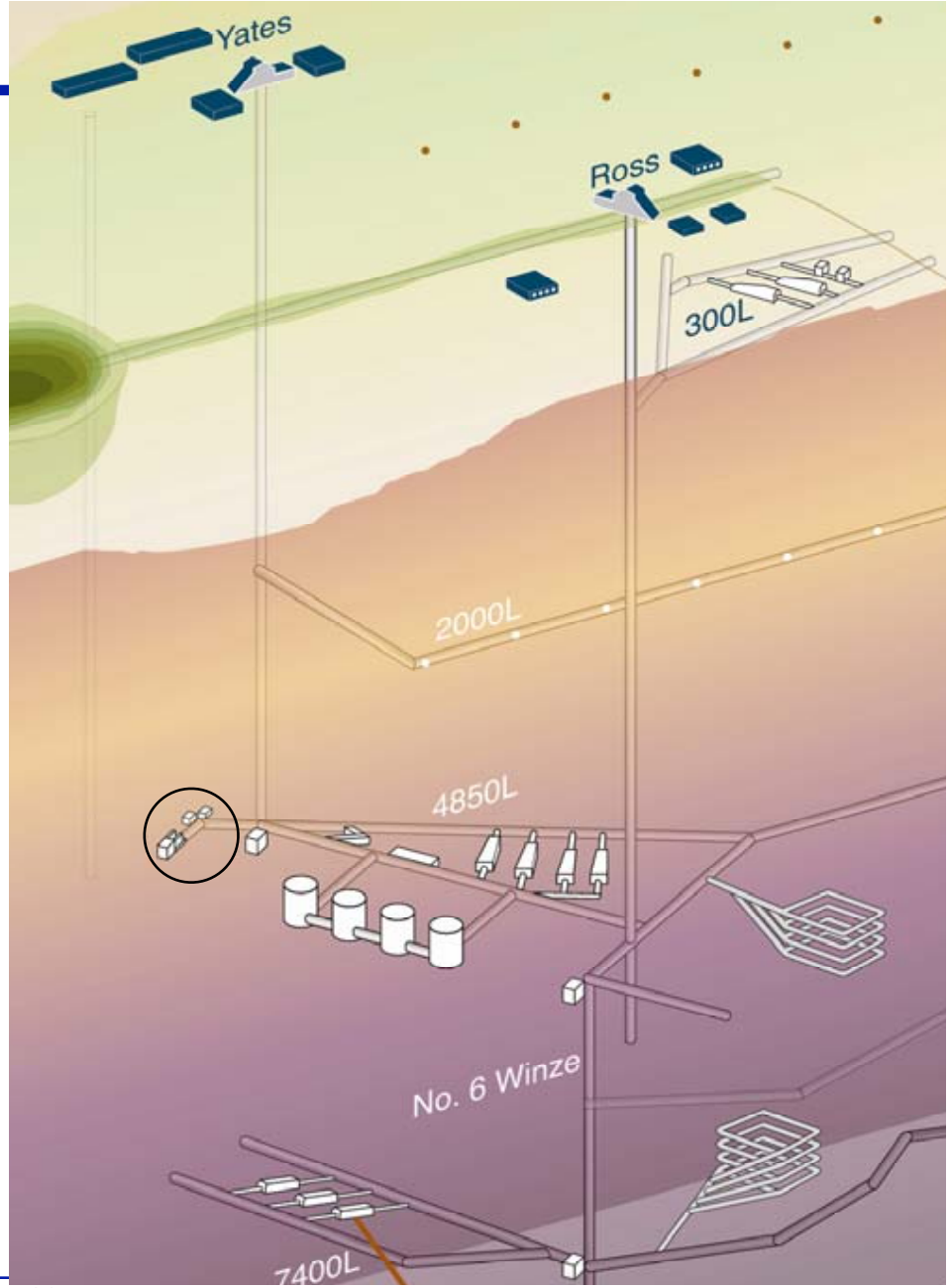


Early access to 4850 Level and above with SDSTA funding for Sanford Laboratory

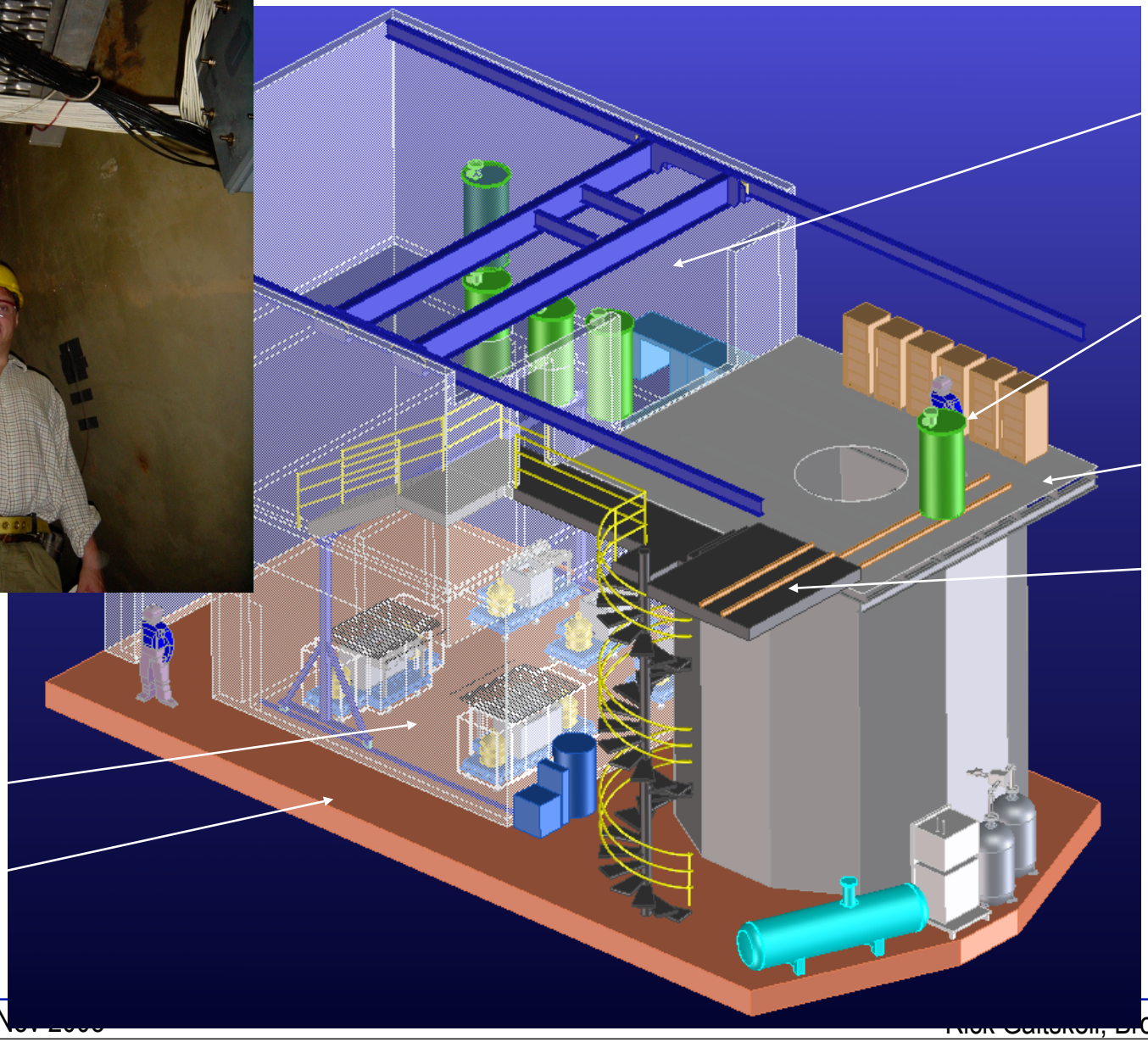
Water Shield - Homestake - Davis Cavern



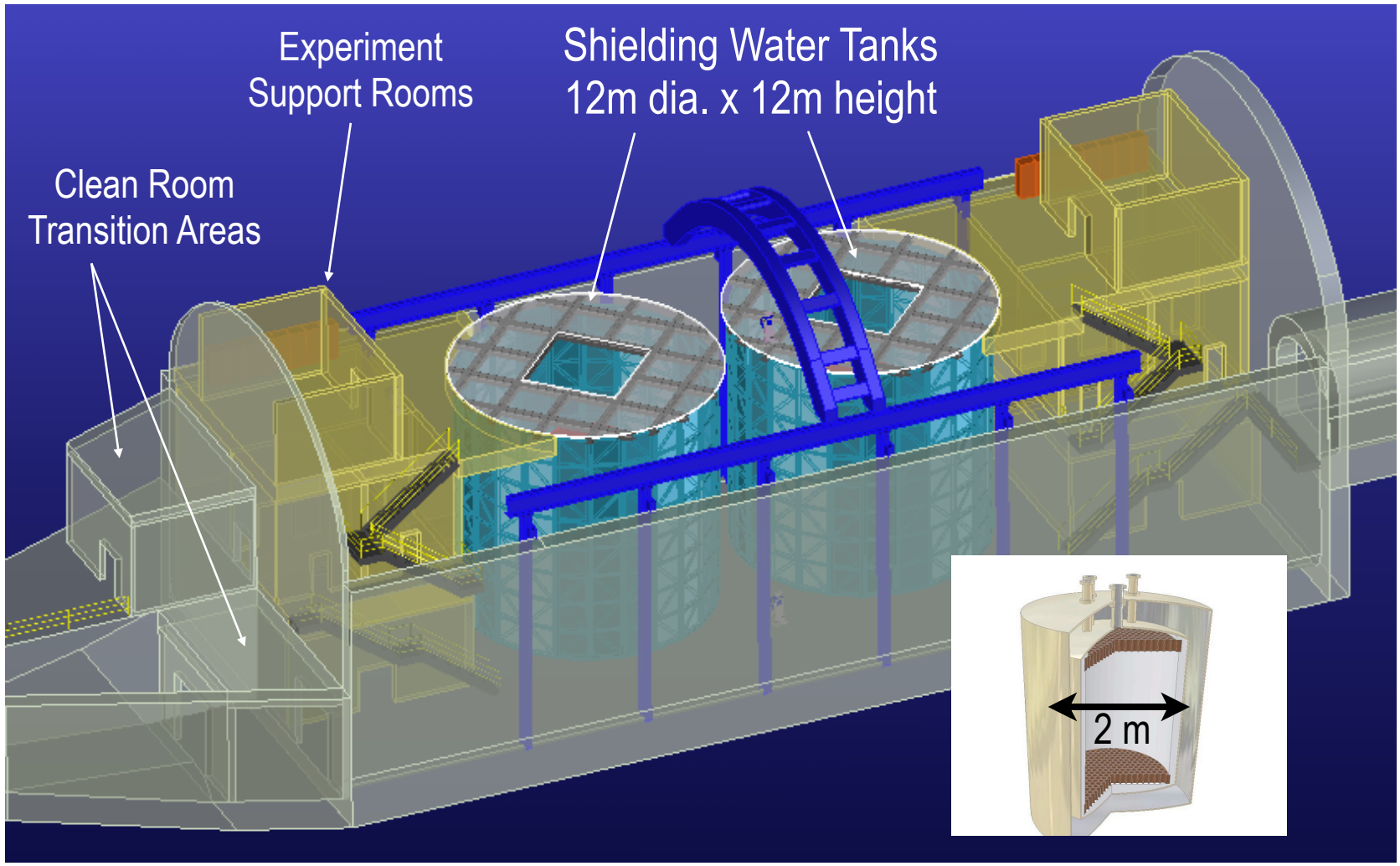




LUX Experiment & Water Tank ø8m in Davis Cavern, Sanford Lab, 2008/9



2013+ DUSEL Lab Module Concept (ø12m) - Scale-up of LUX infrastructure



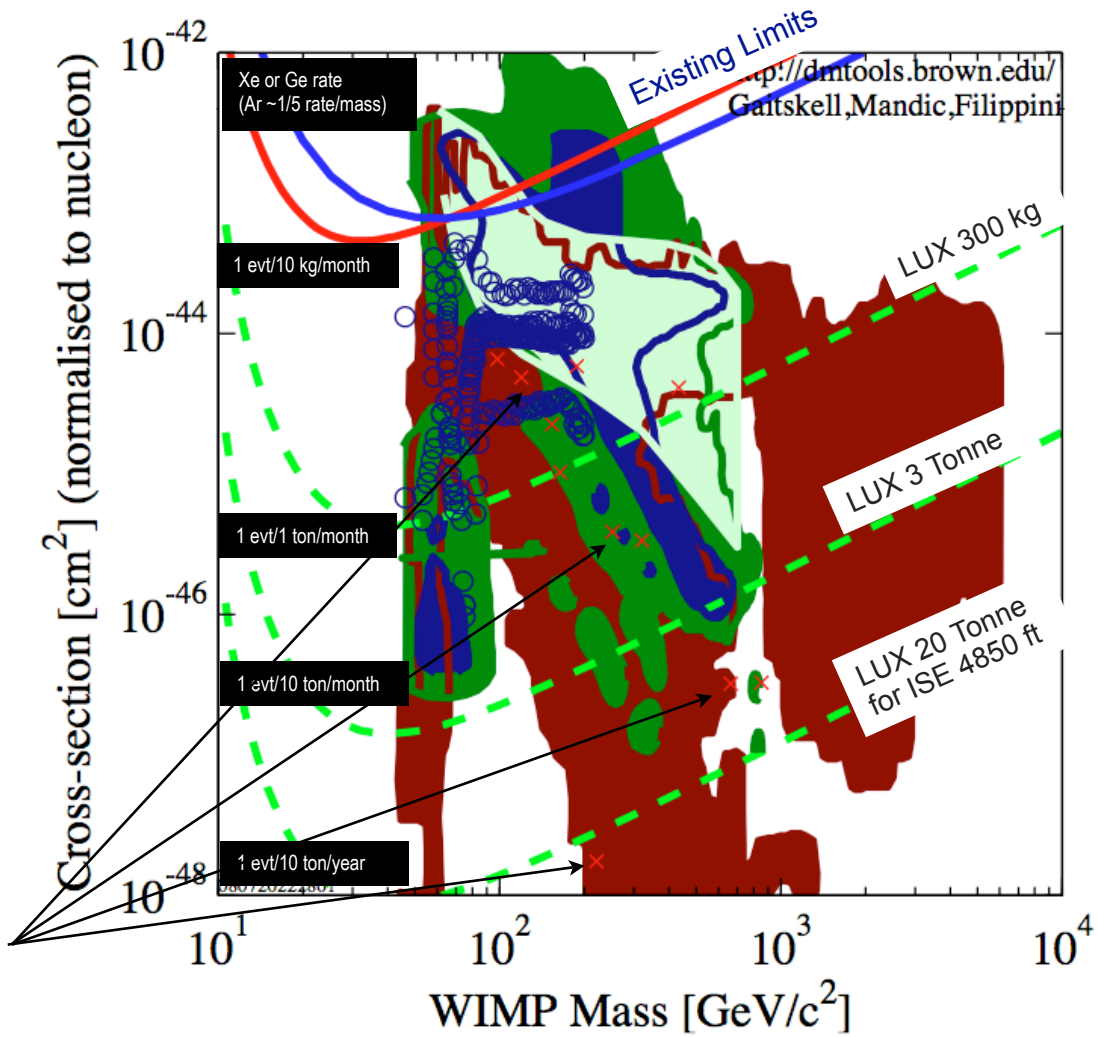
LUX-ZEPLIN Collaboration for 3 Tonne and 20 Tonne@DUSEL

- Brown University
  - *Richard Gaitskell*
- Case Western Reserve University
  - *Thomas Shutt, Dan Akerib, Alexander Bolozdynya, Mike Dragowksi*
- Imperial College, London
  - *Tim Sumner, Henrique Araujo*
- ITEP, Moscow
  - *Dmitri Akimov*
- Lawrence Berkeley National Laboratory
  - *Kevin Lesko, Yuen-Dat Chan*
- Lawrence Livermore National Laboratory
  - *Adam Bernstein*
- LIP, Coimbra
  - *Isabel Lopes, Vitaly Chepel*
- STFC Rutherford Appleton Laboratory
  - *Nigel Smith, Pawel Majewski, George Kalmus*
- Texas A&M
  - *James White*
- UC Davis
  - *Robert Svoboda, Mani Tripathi, Richard Lander*
- University of Edinburgh
  - *Alex Murphy*
- University of Maryland
  - *Carter Hall*
- University of Rochester
  - *Frank Wolfs, Tom Ferbel, Udo Schroeder,*
- University of South Dakota
  - *Dongming Mei,*
- Yale University
  - *Daniel McKinsey*

International collaboration, with expertise in dark matter search, noble gas techniques, water detectors, high energy physics and large scale deployments (under/above grounds).
Includes PIs/Senior Researchers from
EXO, XENON10, LUX, ZEPLIN II, III, CDMS I, II, SNO, SuperK, Kamland, Borexino, IMB.

LUX-ZEPLIN Dark Matter Sensitivity

- Dark Matter Sensitivity
  - LUX 300 kg : 2008-9
  - LUX-ZEP 3T : 2010-2012
  - LUX-ZEP 20T : 2013-2018
    - 4850 ft for initial ISE detector
  - LUX-ZEP : 2018-
    - 7400 ft for larger detector / longer running
  - Green Dashed Lines show asymptotic sensitivity - 90% limit set on zero events. For sufficient event stats for clear discovery/ WIMP characterization corresponds to c-s above lines by factor >5x
  - 20 Tonne detects pp solar neutrinos (low stats).
  - 10% natXe is 136Xe which provides potential for 0vDBD obs., however, background screening requirements ~100x more demanding
- LHC Benchmark Models
  - Red x's show SUSY models under study at LHC with corresponding DM interaction rates



Theoretical predictions based on various SUSY models shown as solid regions + o's and x's

LUX Experiment: 2008-9 Timetable - Summary

- Testing - Commissioning at Case Western
  - Detector is currently being tested with reduced target of 50 kg LXe (+ Al filler for space)
    - Testing new thermosyphon system to allow rapid/stable cooling of large mass
    - Testing new Purification system / Safety systems
    - Full target mass testing will be 350 kg LXe
  - 4 PMTs (of 122 PMTs total) currently installed in detector / testing mounts+basis
    - Rest of Hamamatsu R8778 PMTs delivered and characterized
  - New Electronics, DAQ and Trigger chain built and being tested
    - S1 and S2 measurements from detector
- Homestake
  - Pumping of water from Homestake, to gain access to 4850 ft
    - Water is now being pumped/discharged at >1200 gal/min - net pumping ~0.9 Mgal/day
    - ~120 Mgal to remove. Feb 2009 projection for below 4850 ft
  - Davis Cavern 4850 ft infrastructure will then be installed
    - Includes ø8 m diameter water tank and clean room to be installed in Cavern
  - In parallel - transfer detector to Homestake in January 2009 (per original schedule)
    - Full construction above ground then move to cavern May 2009 once tank/cleanroom is installed

Experiments at Homestake Facility

- Dark Matter - Sanford Lab - Pre-DUSEL 2008-2012
  - 2008-2009 LUX 350 kg
  - 2010-2012 LXe 3 tonne
  - Expect additional call for proposals for Homestake during PreDUSEL period
- Dark Matter - DUSEL - Initial Suite of Experiments
  - Candidate Experiments (expect 2 to be chosen) for ISE PDR++ submission end 2010
    - NSF S4 Announced with deadline Jan 9, 2009, NSF S5 expected Spring 2010
  - Physics reach 10^{-47} cm^2 (Double Beta Decay and Solar Neutrino Detection also)
    - 10-20 ton dual phase liquid Xenon detector (LUX/XENON...)
    - 10-20 ton dual phase liquid Argon with reduced 39Ar (WARP...)
    - 50 ton single phase liquid Argon/Neon detector (DEAP/CLEAN...)
    - 1 ton low temperature Germanium detector (CDMS+++)
  - Expected Project Cost /Experiment ~$25-50M
    - Funded through MREFC funding of $250M in addition to ~$250M for DUSEL infrastructure
  - Experiment Construction would begin 2013->
    - Physics 2014->

Conclusions

- Dark Matter Direct Detection is High Priority
  - e.g. DMSAG (US) - Dark Matter Scientific Assessment Group Report (HEPAP/AAAC)
    - http://www.science.doe.gov/hep/DMSAGReportJuly18,2007.pdf
  - Probing SUSY Particle Models (10 year program very complementary to LHC reach)

- Cryogenic Detectors
  - CDMS -> SuperCDMS (SuperTowers with detectors 0.25->1 kg)
    - 2008 Complete search using existing 30 dets = 5 Tower (5 kg) at Soudan
    - 2009 Initial operation running of 2xSuperTowers (10 kg) at Soudan
    - 2009 Review for approval of 25 kg Experiment at SNOLab
  - Edelweiss (Ge)
    - March 2007-> : 22 x 320g Ge NTD + other dets (June- Interim Result 19 kg-day no WIMP)
    - Funding for phase 30 kg requested. Goal: 10e-44 cm2
  - CRESST (CaWO4)
    - Interim Result 1 kg encouraging / Now installing total 10 kg targets

Conclusion - Noble Liquids for Dark Matter

- Noble Status
  - Past two years we have seen rapid progress in demonstrated performance (NR-ER discrimination/energy resolution/light yields) of Noble Liquid Detectors in low energy regime
  - Competitive WIMP Search Results from WARP (Ar), ZEPLIN II (Xe), XENON10 (Xe)
- Single Phase (Liquid only) - Pulse Shape Discrimination (ER)
  - Ar/Ne demonstrating $>10^6$:1 discrimination at 50 keVr, limitations not fundamental.
    - Will push these tests to 10^8:1 using higher light yields/shielding in test facilities (required for 10^{-45} cm^2 dm reach)
    - 39Ar (160 evts /keVee/kg/day) / Rn daughters on surfaces (major issue)
  - Xe Self-shielding (XMASS) - Constructing 800 kg target
  - Position reconstruction based on photoelectron hit patterns (timing not useful in <=10 tonne scale). Mis-reconstruction is a concern - requires very good PMT coverage
- Dual Phase (Liquid Target/Ioniz Readout in Gas) - Discrim. Ionization/Photons+PSD (Ar)
  - Xe TPC Operation: ZEPLIN II / XENON10 (15-35 kg target)
    - Discrimination established ~10^3:1 (50% NR acceptance), fiducialize to get further bg reduction
      - Xe intrinsically very low activity (cf XMASS) , so scaling works
  - Ar TPC (WARP) - studying use of Ionization + PSD
    - Discrimination Ionization ~10^2:1 + PSD $>10^4$:1 (energy threshold should be improved with better elec.)

Conclusions /3

- Scaling of Technology
  - Detector WIMP sensitivity improves very significantly with size
    - Self shielding can be exploited if use single target volume
    - A number of experiments will deliver x10-100 improvement in sensitivity over existing measurements (in 2009)
  - Noble Liquid Designs are very scalable
    - Better than 1 evt/100 kg/month ($<10^{-45}$ cm^2) in 2009
    - These new experiments will demonstrate if >>1 tonne are reasonable, no obvious "show stoppers" so far
  - Cryogenic Detectors will continue to compete
    - But it requires long exposure periods to stay competitive with Noble targets
    - Major challenge will be cost / feasibility of >>100 kg targets
- Future Direct Detection Experiments 2010-> / In US DUSEL 2013+
  - Future instruments (multi-tonne) for 10^{-46} – 10^{-47} cm^2 also realistic
    - "Attempt to guarantee WIMP discovery if SUSY models are reasonable"
    - Need multiple targets / technologies to confirm observation & study signals
  - Solar Neutrinos will become background (require ER/NR discrimination to beat it down)
  - Expect to form smaller number of large international collaborations
- Many Other Possibilities for Detection of Dark Matter
  - Cosmic Rays / Neutrinos / LHC