A noble endeavor: the hunt for 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 particle solution
- techniques for direct detection
  - what can we learn from the past?
  - is direct detection a realistic way for testing new physics
  - survey status of a few techniques
- future of the field in US
  - new underground lab @ Homestake
  - 2008-2012 Sanford Lab
  - 2012+ DUSEL

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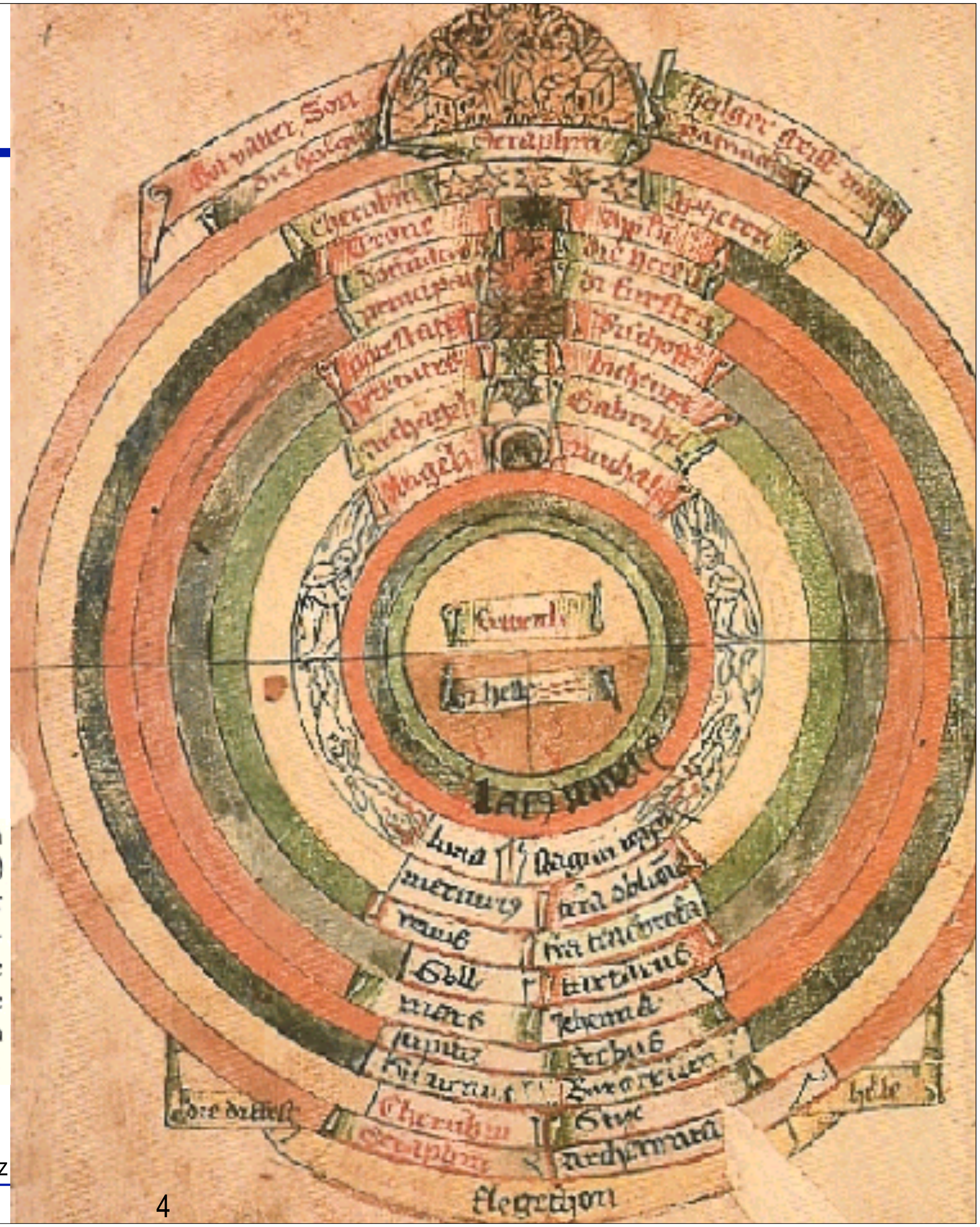
LEVEL NO. 27
2341 FEET BELOW THE SURFACE.
689 FEET BELOW S LEVEL
Winter
@Soudan Minnesota
New Sanford Lab
@Homestake, South
Dakota
PHYSICS ITALIAN
STYLE
@ Gran Sasso

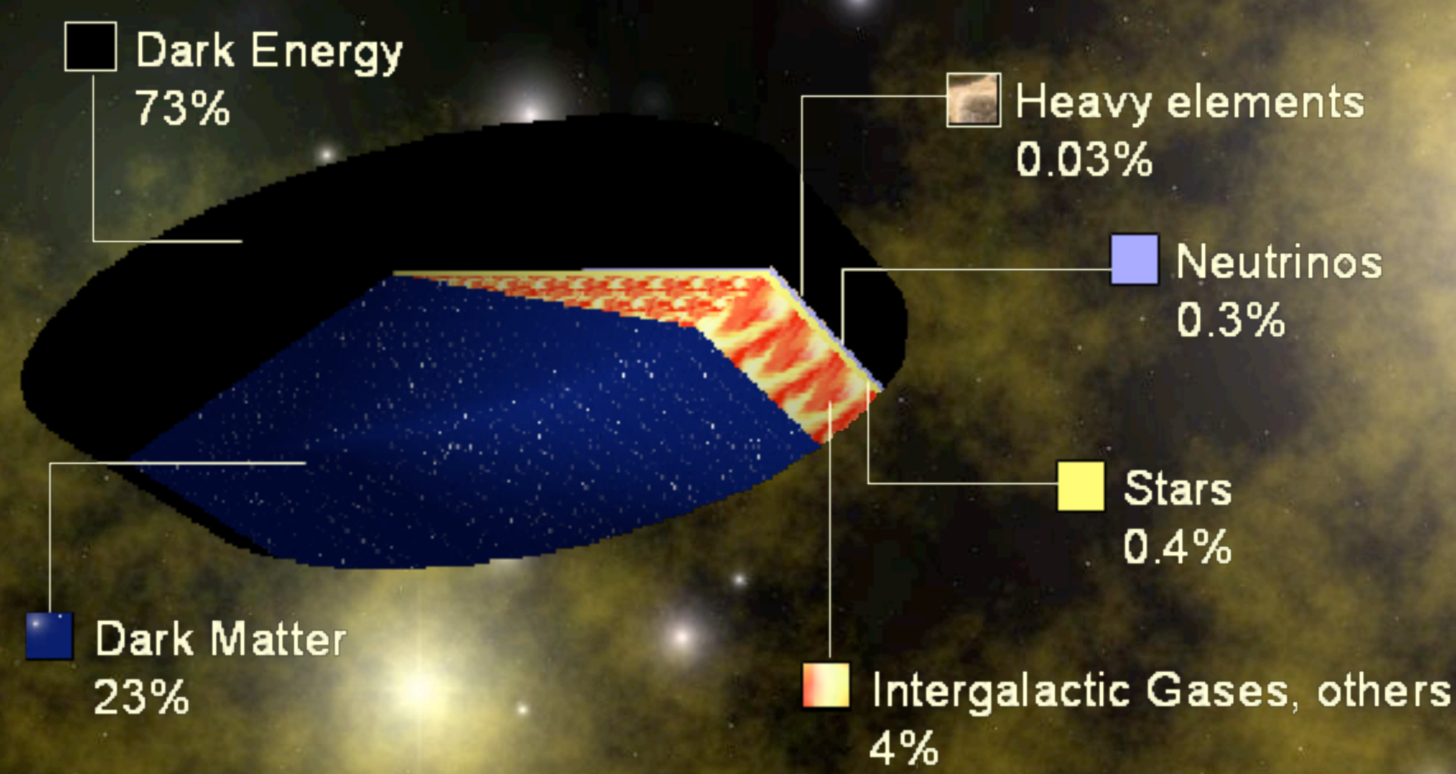
Medieval Universe

The geocentric pre-Copernican Universe in Christian Europe. At center, Earth is divided into Heaven (tan) and Hell (brown). The elements water (green), air (blue) and fire (red) surround the Earth. Moving outward, concentrically, are the spheres containing the seven planets, the Moon and the Sun, as well as the "Twelve Orders of the Blessed Spirits," the Cherubim and the Seraphim. German manuscript, c. 1450.

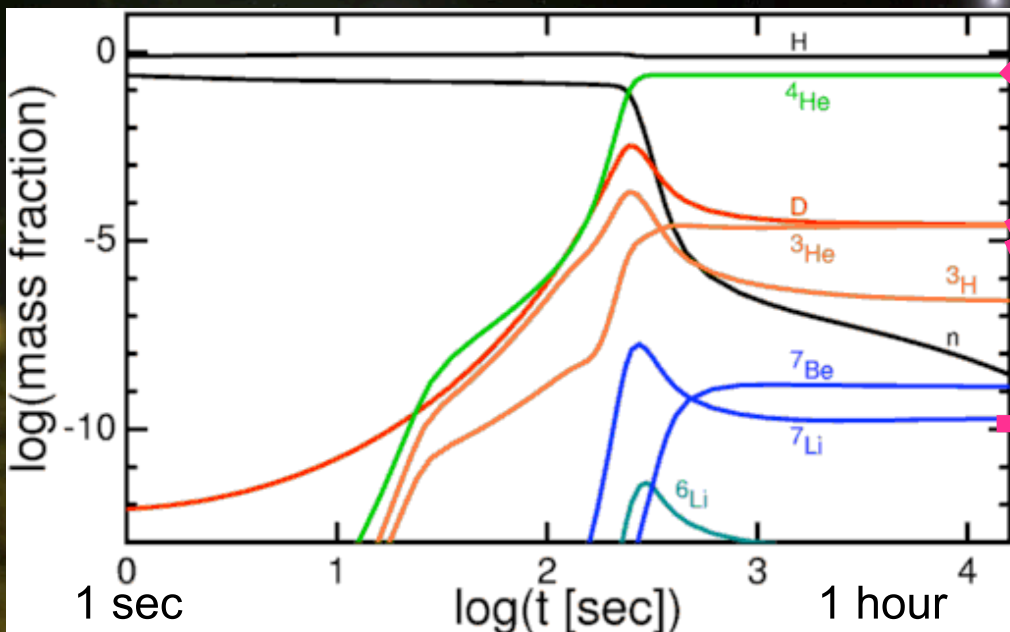


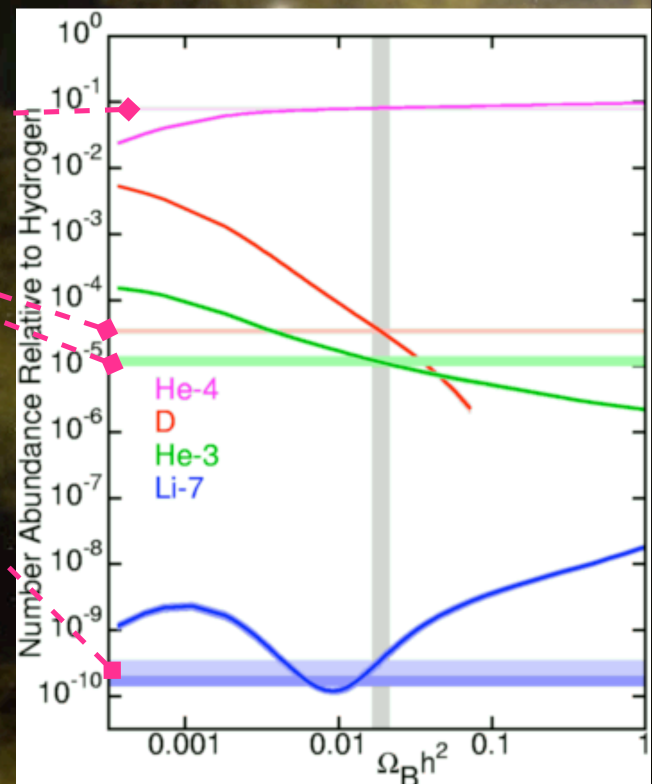
From Joel Primack, UC Santa Cruz

What is the Universe made of ?



Big Bang Nucleosynthesis





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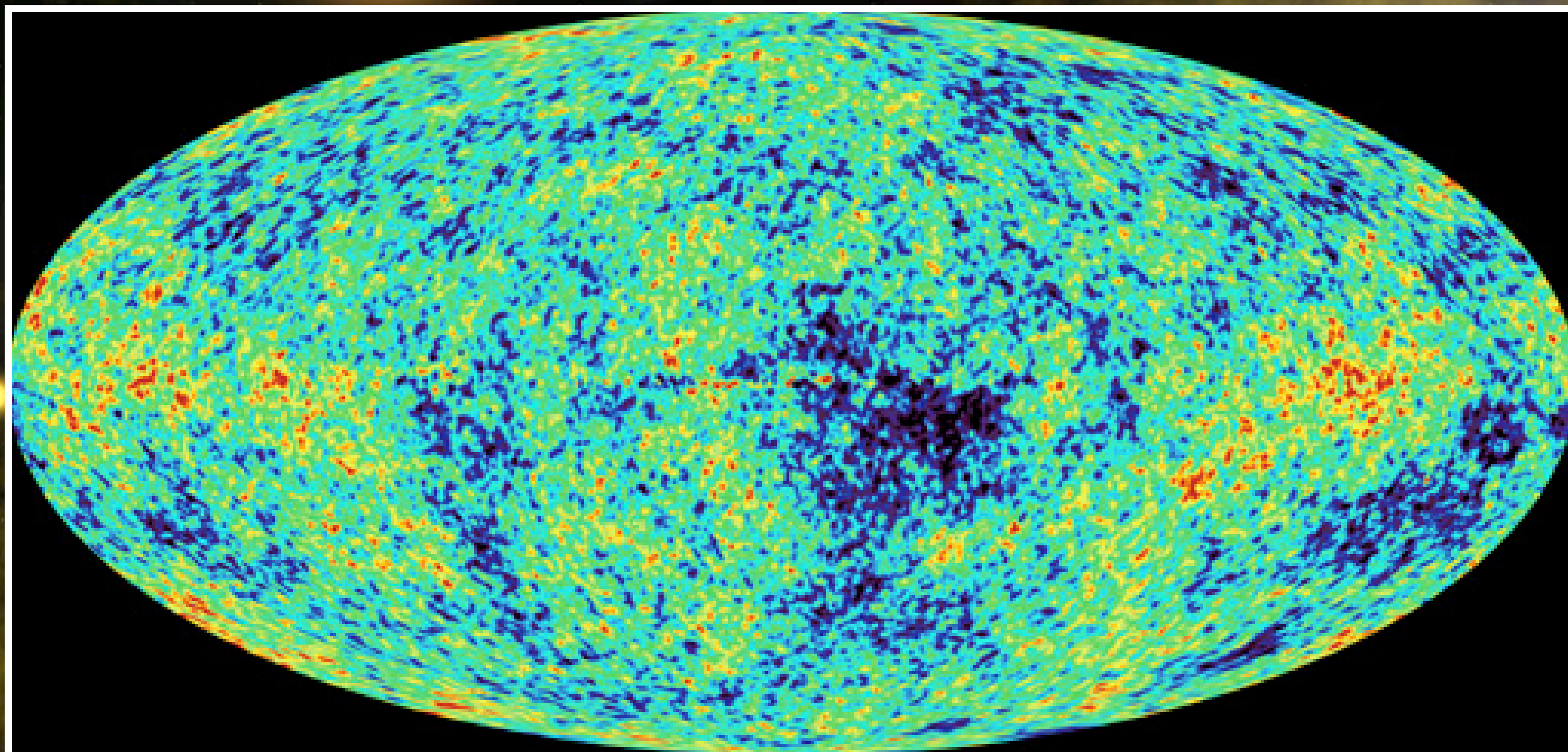
Plots from Ned Wright (UCLA)

Growth of Structure



$\Delta T/T \sim 10^{-5}$

10 μK / 2.7K

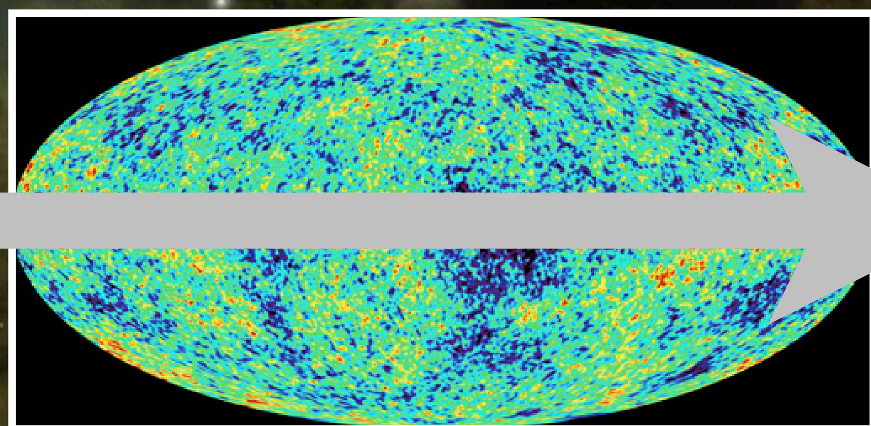
7

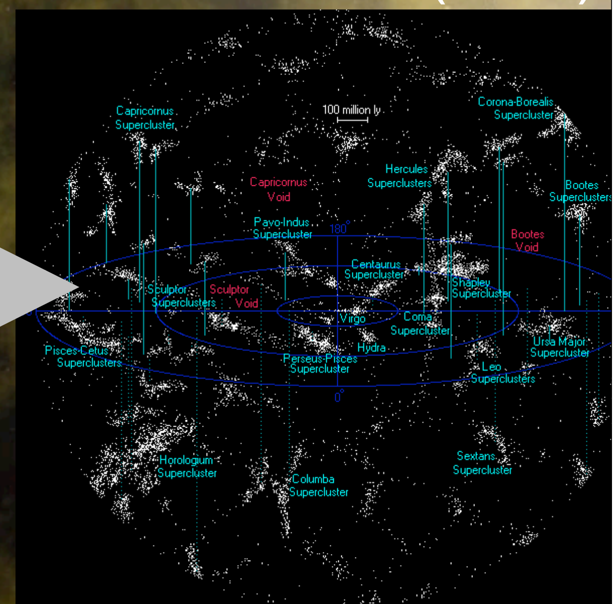
Growth of Structure

z~1000 , 380 kyrs

z~0 , 14 GYr (Now)

Cold
Dark
Matter





$\Delta T/T \sim 10^{-5}$

$10\ \mu K / 2.7K$

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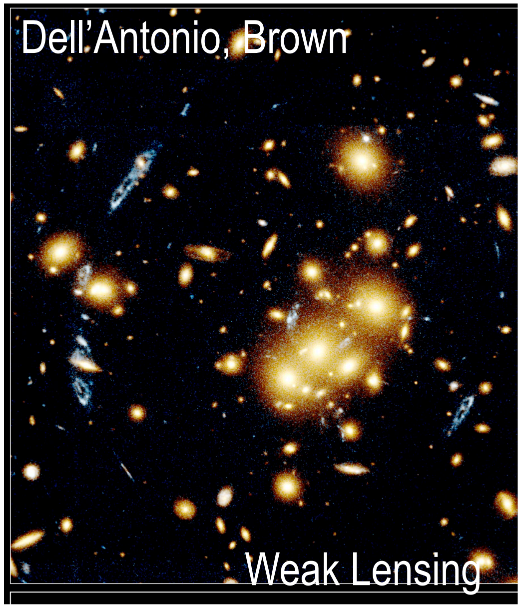
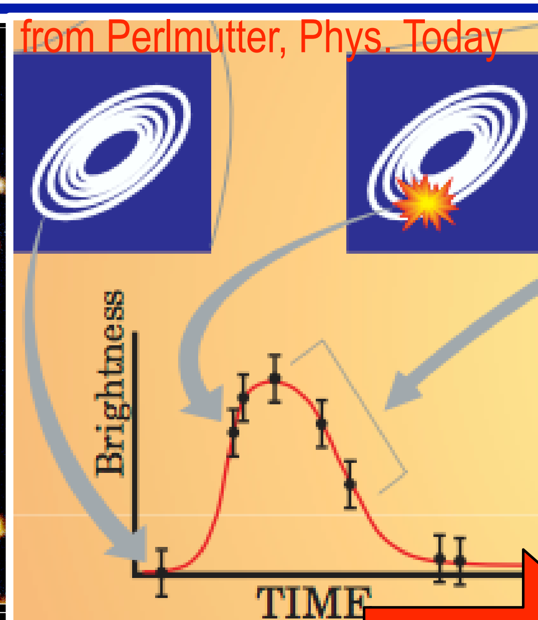
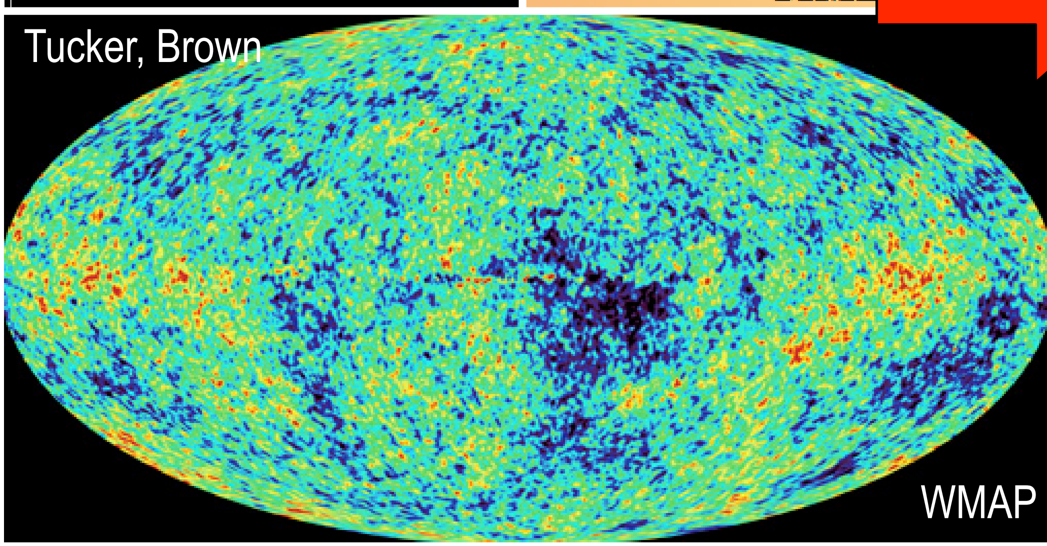
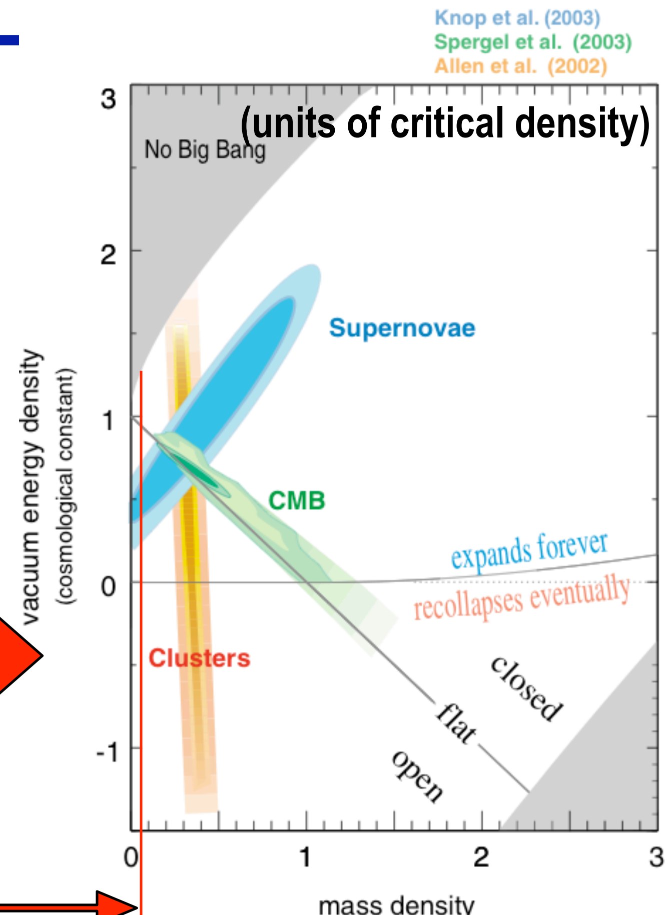
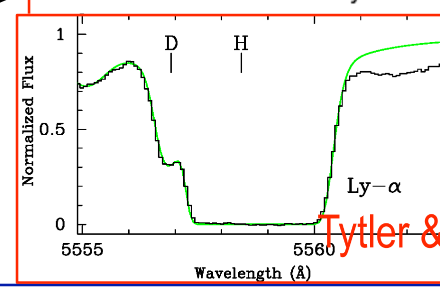
Standard Cosmology





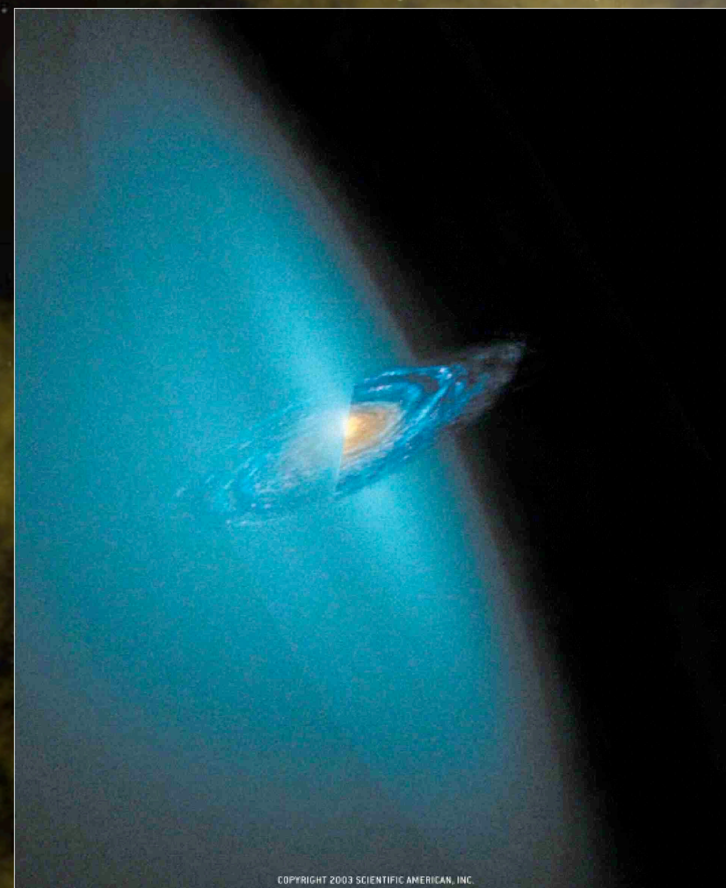




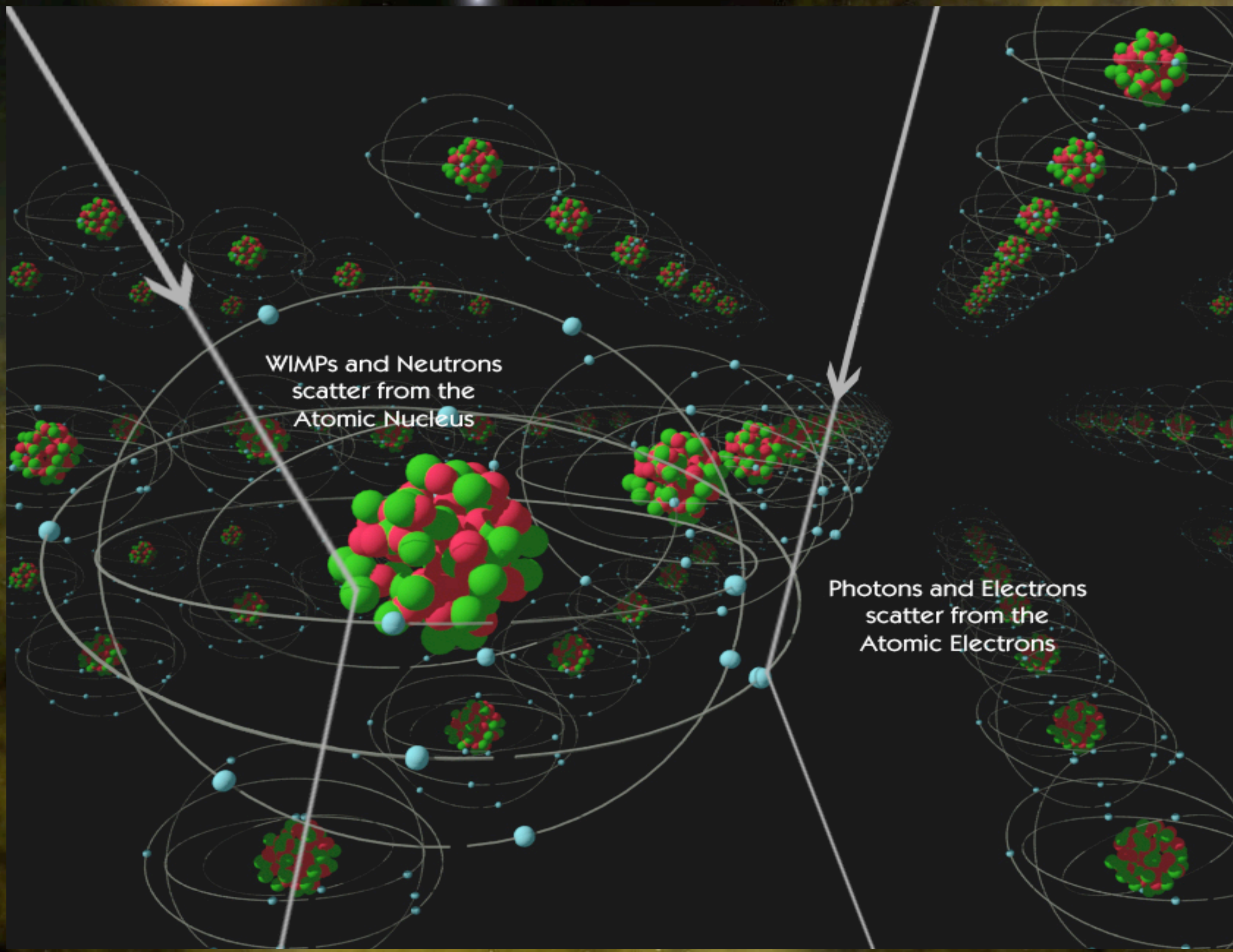


Galactic Dark Matter Halo

- Each galaxy is enveloped by an homogeneous cloud of massive, very weakly interacting particles, with a total mass >5x of everything else
- Such a particle is generically called a **WIMP**, its exact nature remaining to be determined
- Halo's properties dictated by observations
  → We know how much total mass there is, and we can make educated guesses on the velocities distribution, etc…
- Massive neutrino already eliminated



Interaction with Ordinary Matter



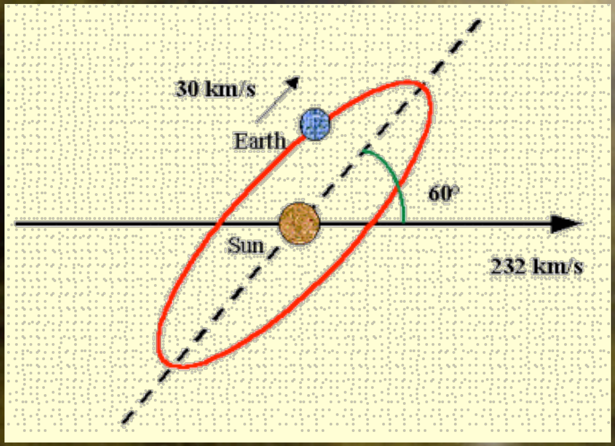
The Supersymetric Candidate

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

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

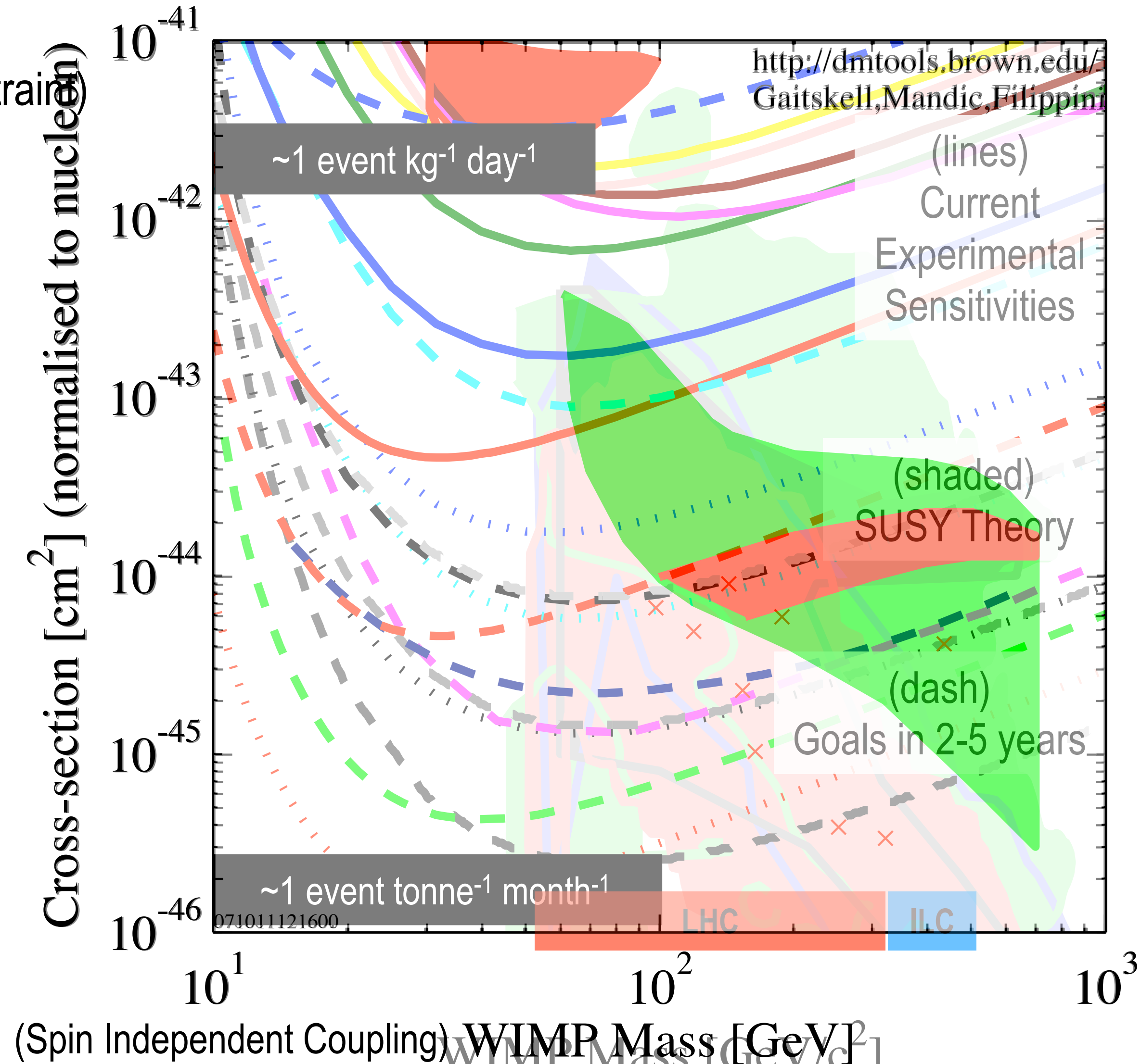
- **Indirect detection:**
  - Detection of WIMP annihilation products
- **Direct detection:**
  - WIMP scattering on nuclei

- **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

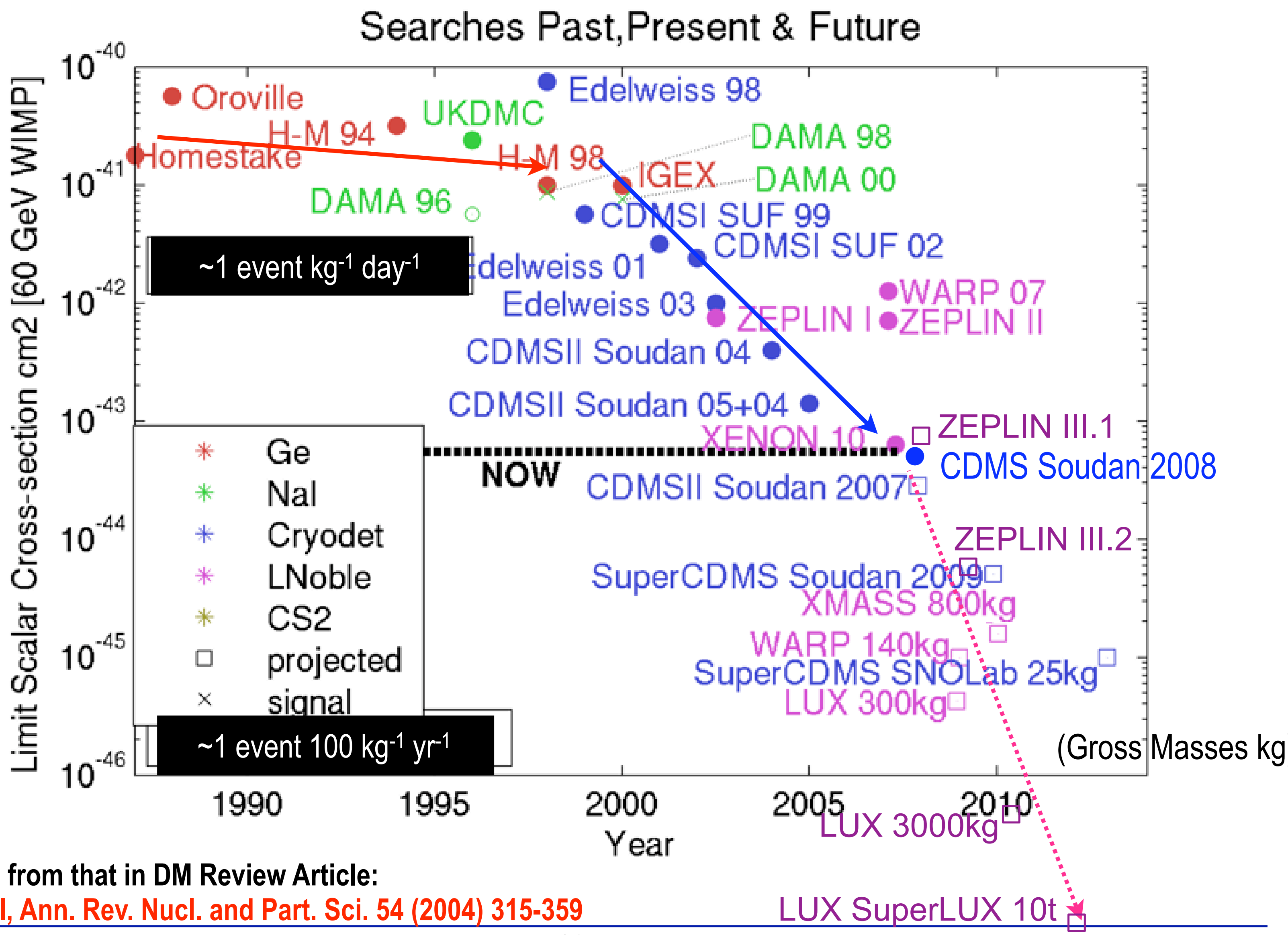
[Green] + [Red] inc :Ωh^2~0.1 constraint
Well Tempered Neutralino
(Hyperbolic Branch / Focus Point)
Baer et al.
JCAP 0701:017,2007
hep-ph/0611387



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)

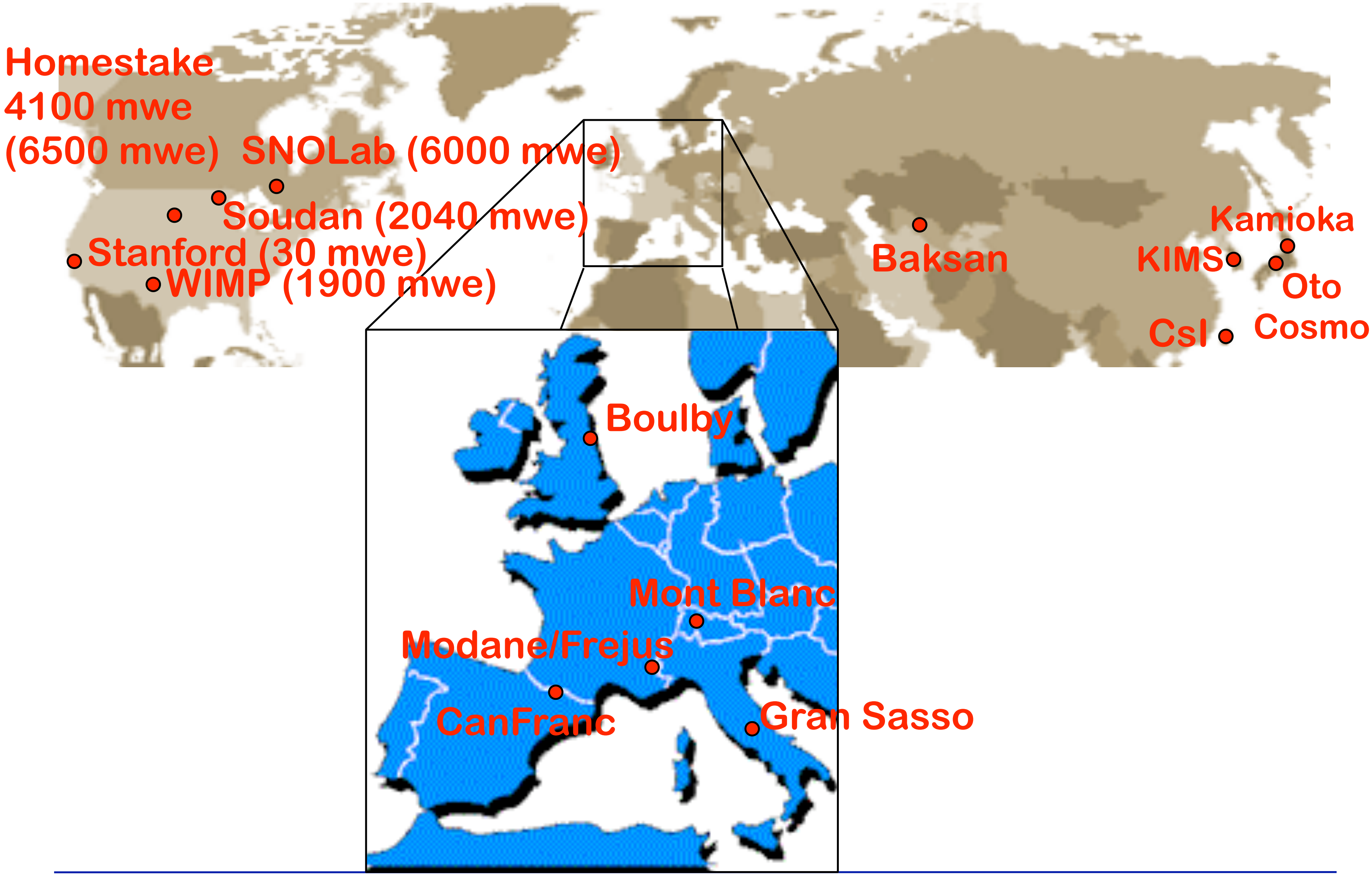
DM Direct Search Progress Over Time (2008)



Plot updated from that in DM Review Article:

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

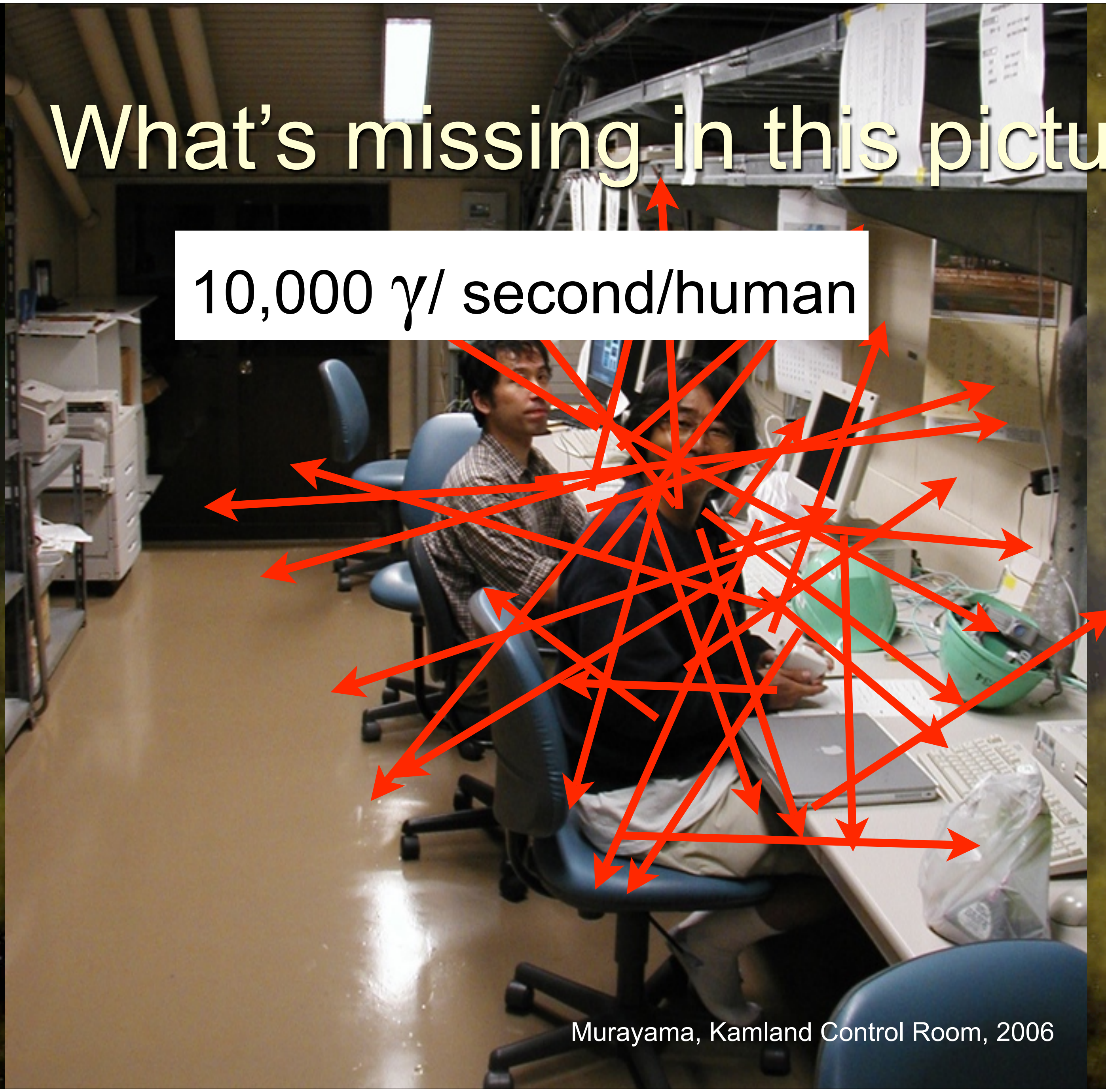
Underground Laboratories Worldwide



Background Challenges

- Search sensitivity (low energy region <<100 keV)
  - Current Exp Limit < 1 evt/kg/20 days, ~< 10^{-1} evt/kg/day
  - Goal < 1 evt/tonne/year, ~< 10^{-5} evt/kg/day
- Activity of typical Human?

What’s missing in this picture?



Murayama, Kamland Control Room, 2006

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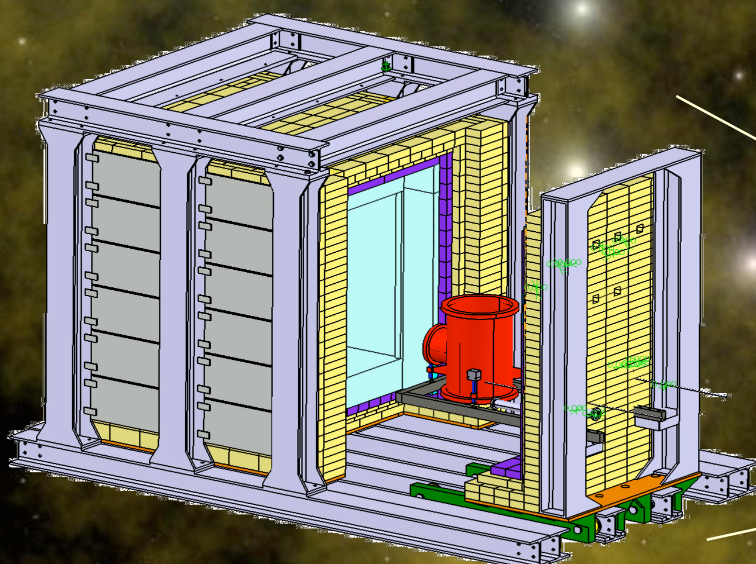
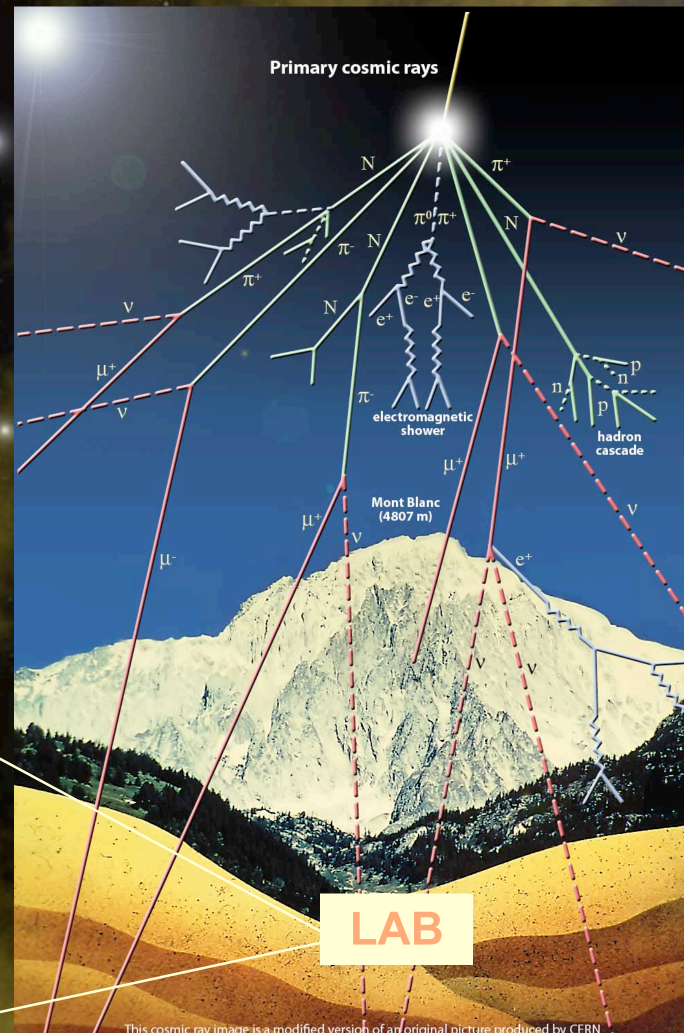
Background Challenges

- Search sensitivity (low energy region <<100 keV)
  - Current Exp Limit < 1 evt/kg/20 days, ~< 10^{-1} 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

The Importance of Shielding

- Interactions remain **very unlikely**
  ~1 /year in 1 kg of detector
  could be as bad as < 1 /year in 1 ton!
- Must eliminate all backgrounds
  - Cosmic rays
  - Gamma rays from radioactivity
  - Neutrons from Radioactivity





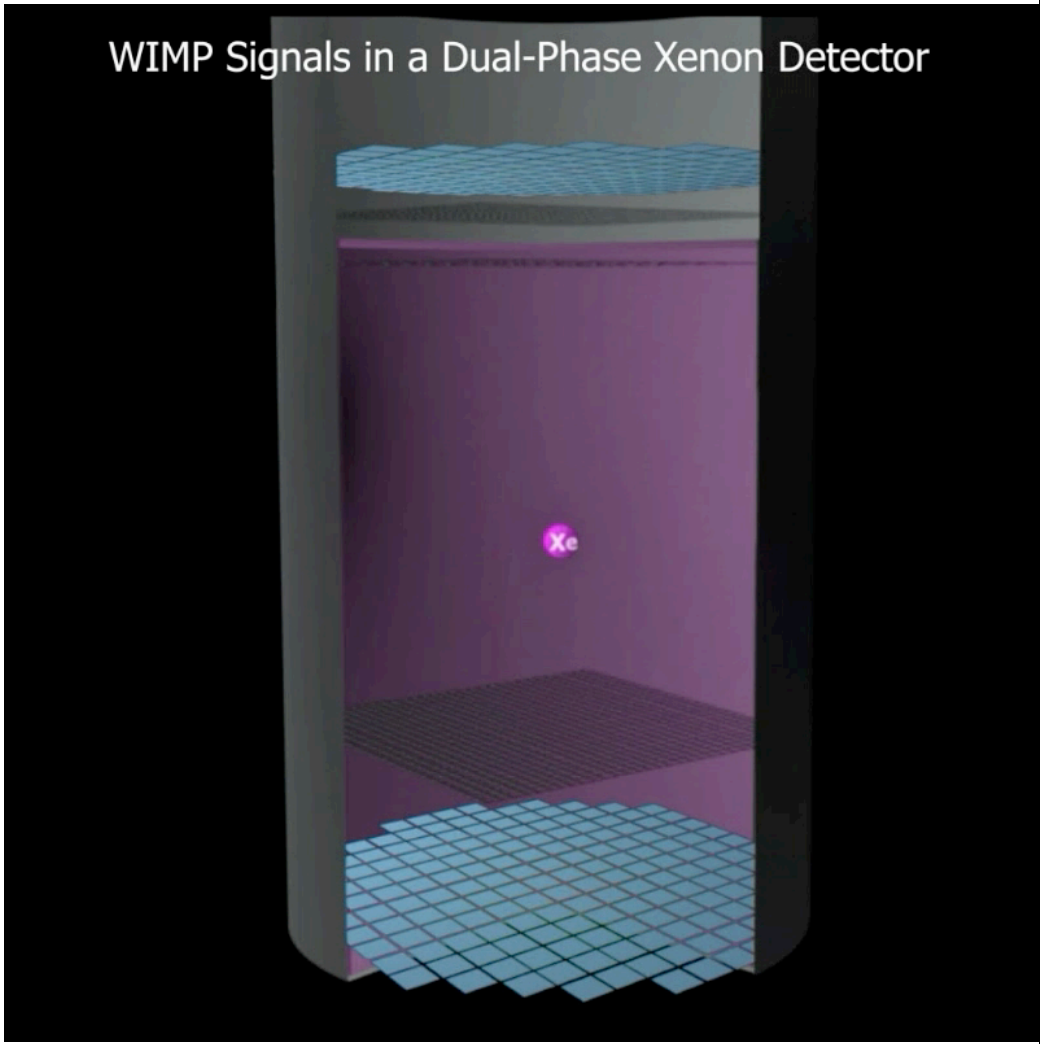
Techniques for dark matter direct detection

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, LUX, WARP, XENON, XMASS, XMASS-DM, 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

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

The XENON10 Collaboration

Columbia University Elena Aprile, Karl-Ludwig Giboni, Maria Elena Monzani, Guillaume Plante, Roberto Santorelli and Masaki Yamashita

Brown University Richard Gaitskell, Simon Fiorucci, Peter Sorensen and Luiz DeViveiros

RWTH Aachen University Laura Baudis, Jesse Angle, Joerg Orboeck, Aaron Manalaysay and Stephan Schulte **(Aug 2007 Baudis -> ETF Zurich)**

Lawrence Livermore National Laboratory Adam Bernstein, Chris Hagmann, Norm Madden and Celeste Winant

Case Western Reserve University Tom Shutt, Peter Brusov, Eric Dahl, John Kwong and Alexander Bolozdynya

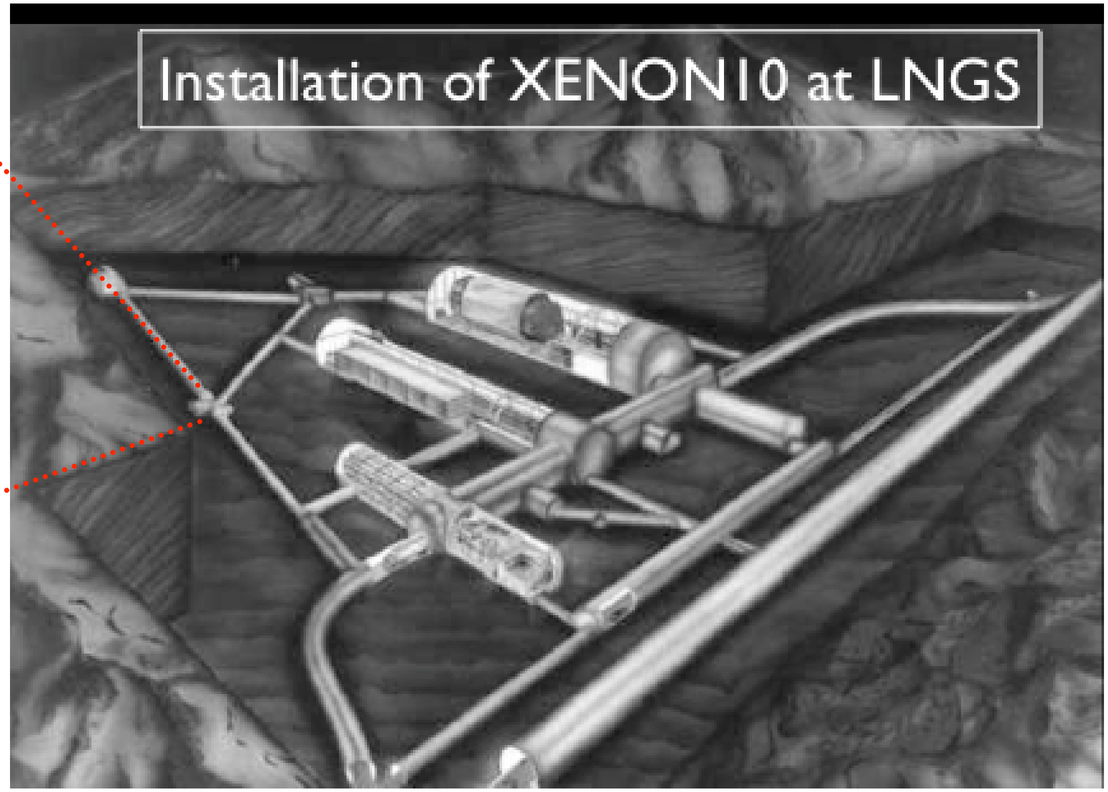
Rice University Uwe Oberlack, Roman Gomez, Christopher Olsen and Peter Shagin

Yale University Daniel McKinsey, Louis Kastens, Angel Manzur and Kaixuan Ni

LNGS Francesco Arneodo and Alfredo Ferella

Coimbra University Jose Matias Lopes, Luis Coelho, Luis Fernandes and Joaquin Santos

XENON10 Underground Installation



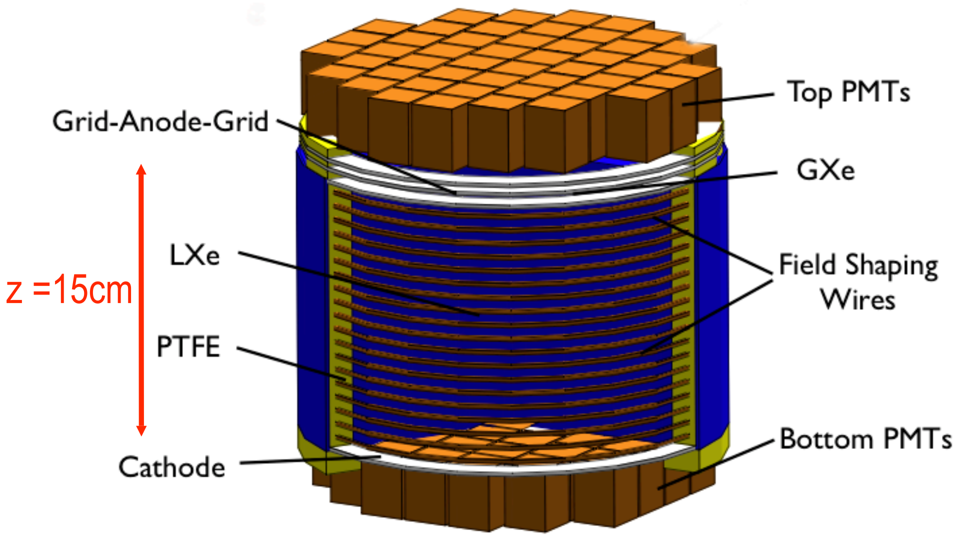
- Installed March 2006 @ LNGS (~3100 mwe)
- Muon flux ~ 24 $\mu/m^2/day$ (10^6 reduction from sea level)
- Began detector calibration end of March
- Began shield installation May 2006
- (bottom left) Installing steel frame on top of 15 cm External HDPE

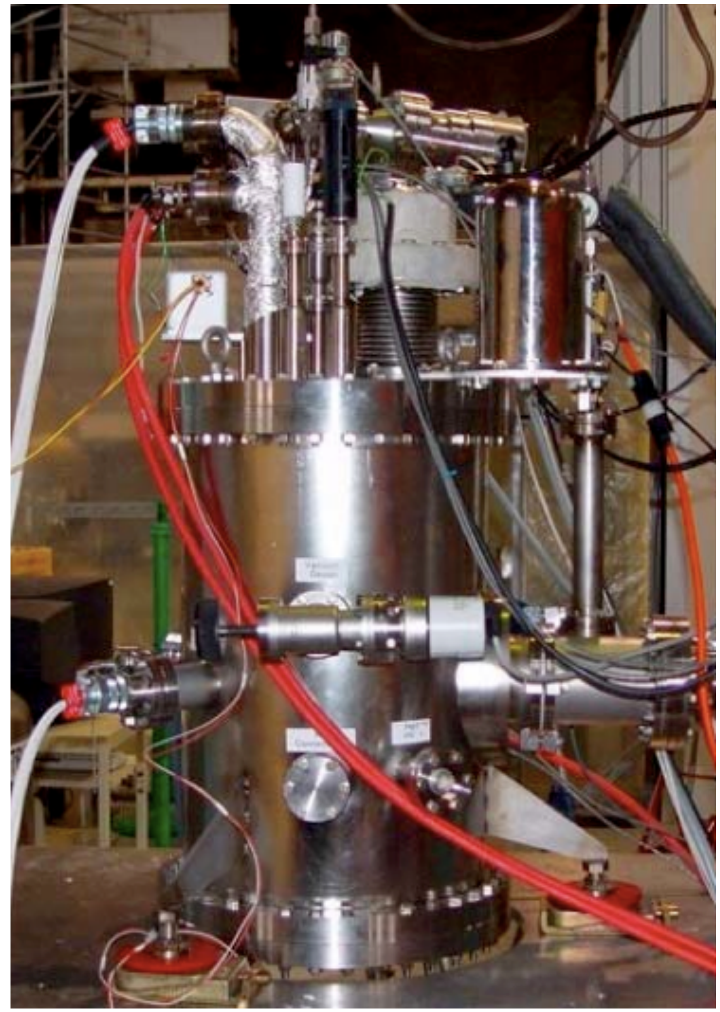
XENON10: Ready for Low Background Operation

Installation of the Detector...

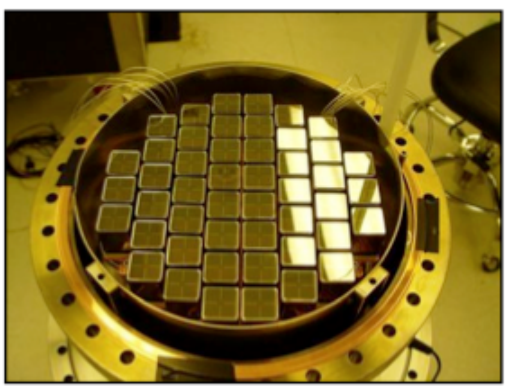
...and we are operational

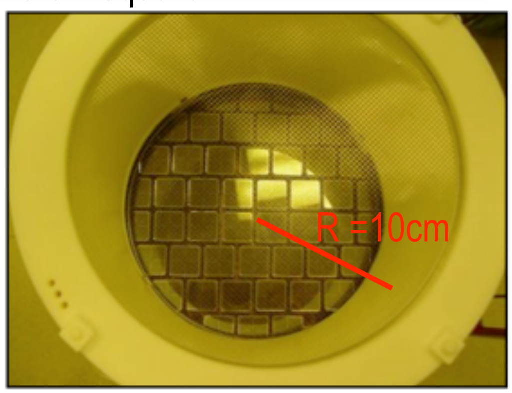
XENON10 Detector





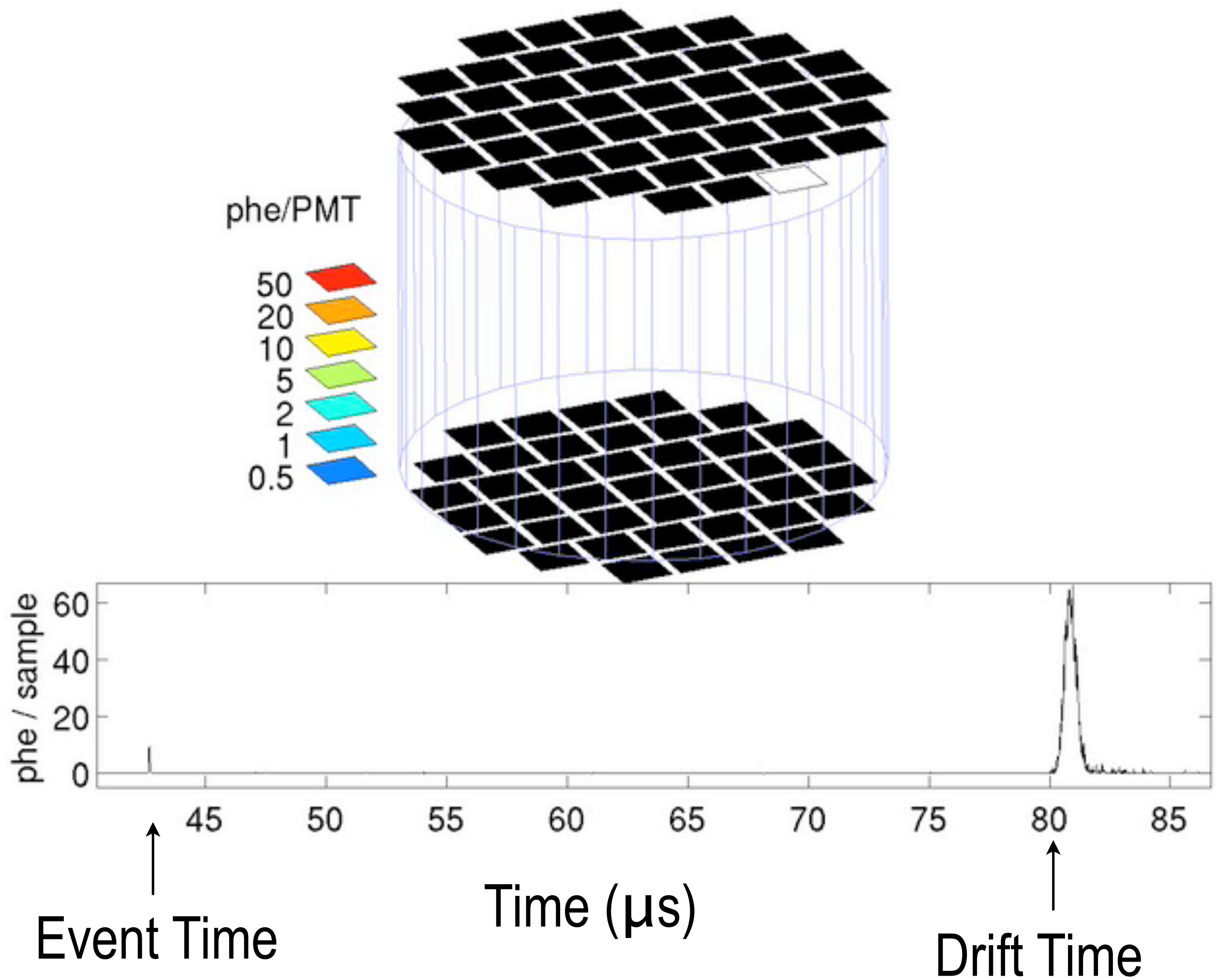
89 PMTs: Hamamatsu R8520-AL 2.5 cm square



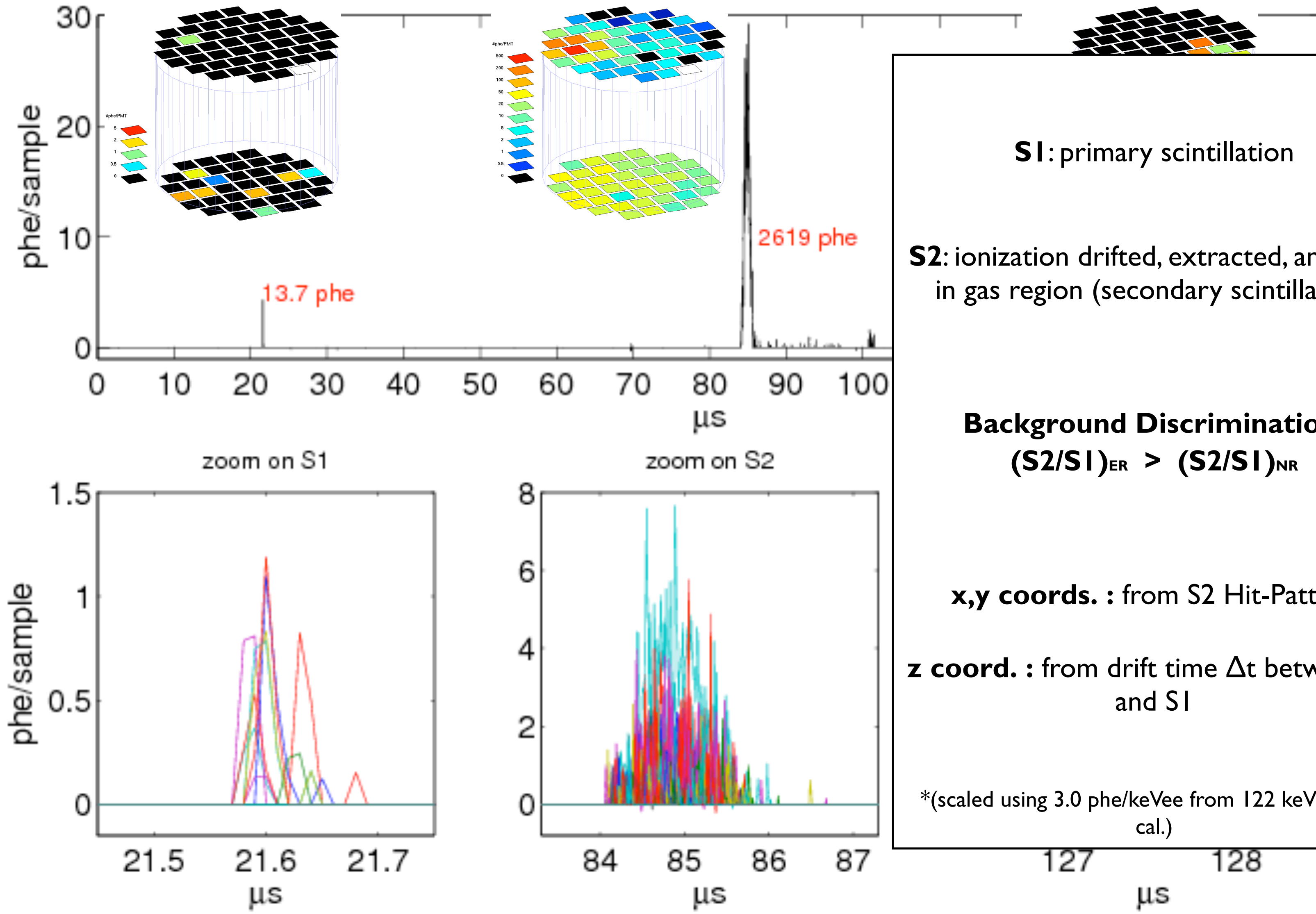


XENON10 Event

- Animation from REAL event
  - Only 5 keVee
- First Signal, S1
  - Primary Scintillation
  - S1 phe ~100 ns wide
  - Bottom PMTs see most phe (Top suffer loss at liq. surf.)
- Second Signal, S2
  - Electron Drift liq. ~30 μs -> extract into gas -> Electroluminescence "z" position
  - S2 phe ~1.5 us wide
  - See "Hot Spot" position "x-y" position



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

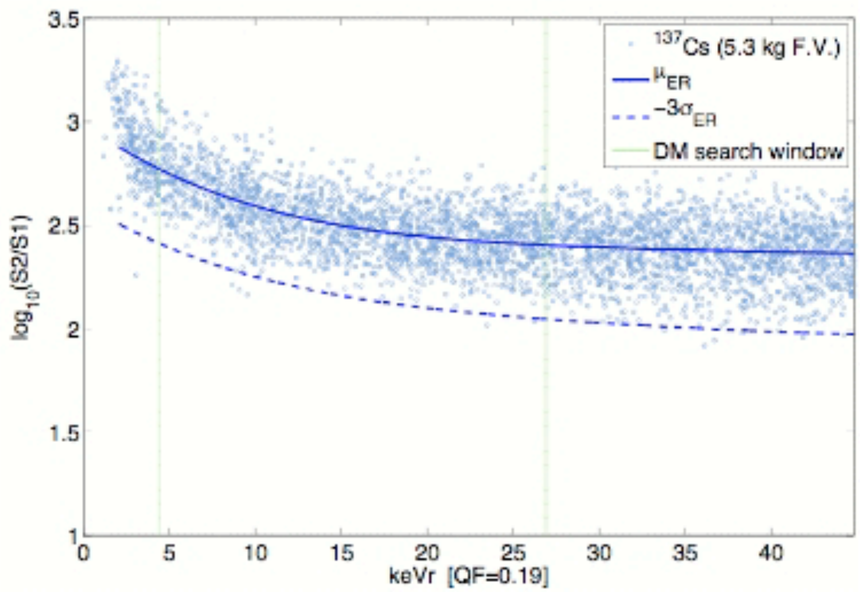
z coord. : from drift time Δt between S2 and S1

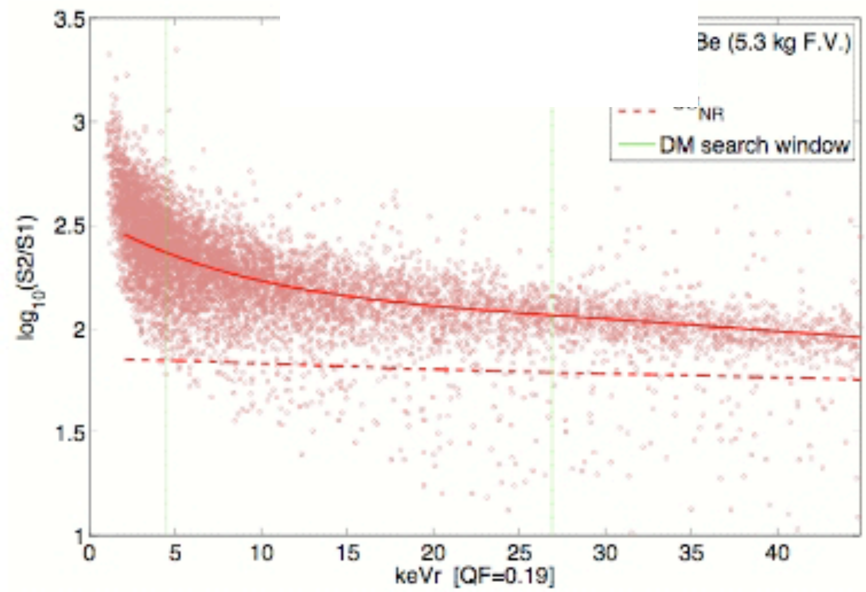
*(scaled using 3.0 phe/keVee from 122 keV gamma cal.)

Calibration Data Band Centroid / -3σ

Gamma Response

Neutron Response





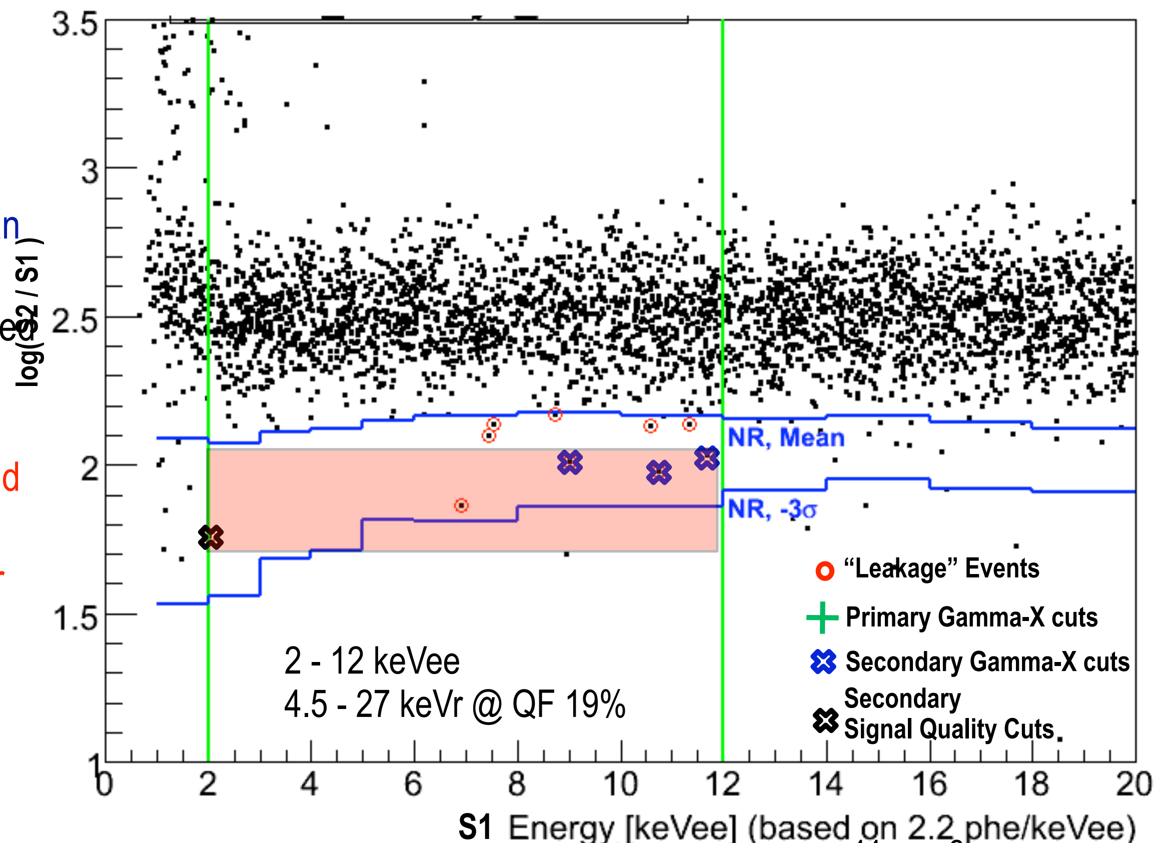
Applying the SECONDARY Gamma-X Cuts to XENON10

- XENON10 Blind Analysis – 58.6 days
  - WIMP "Box" defined at
    - ~50% acceptance of Nuclear Recoils (blue lines): [Centroid -3σ]
    - 2-12keVee (2.2phe/keVee scale)
    - Assuming QF 19% 4.5-27 keVr
  - 10 events in the "box" after all primary analysis blind cuts (o)
  - 5 of events are consistent with gaussian tail from ER band
    - Fits based on ER calibrations projected 7.0 +2.1-1.0 events
  - 5 of these are *not consistent* with Gaussian distribution of ER Background
    - 4 out of 5 events removed by Secondary Blind Analysis (looking for missing S2/Gamma-X events)
    - Remaining event would have been caught with 1% change in cut acceptance : WIMP SIGNAL UNLIKELY

See Peter Sorensen Talk, this afternoon

log (S2 / S1) vs S1

"Straightened Y Scale" – ER Band Centroid => 2.5

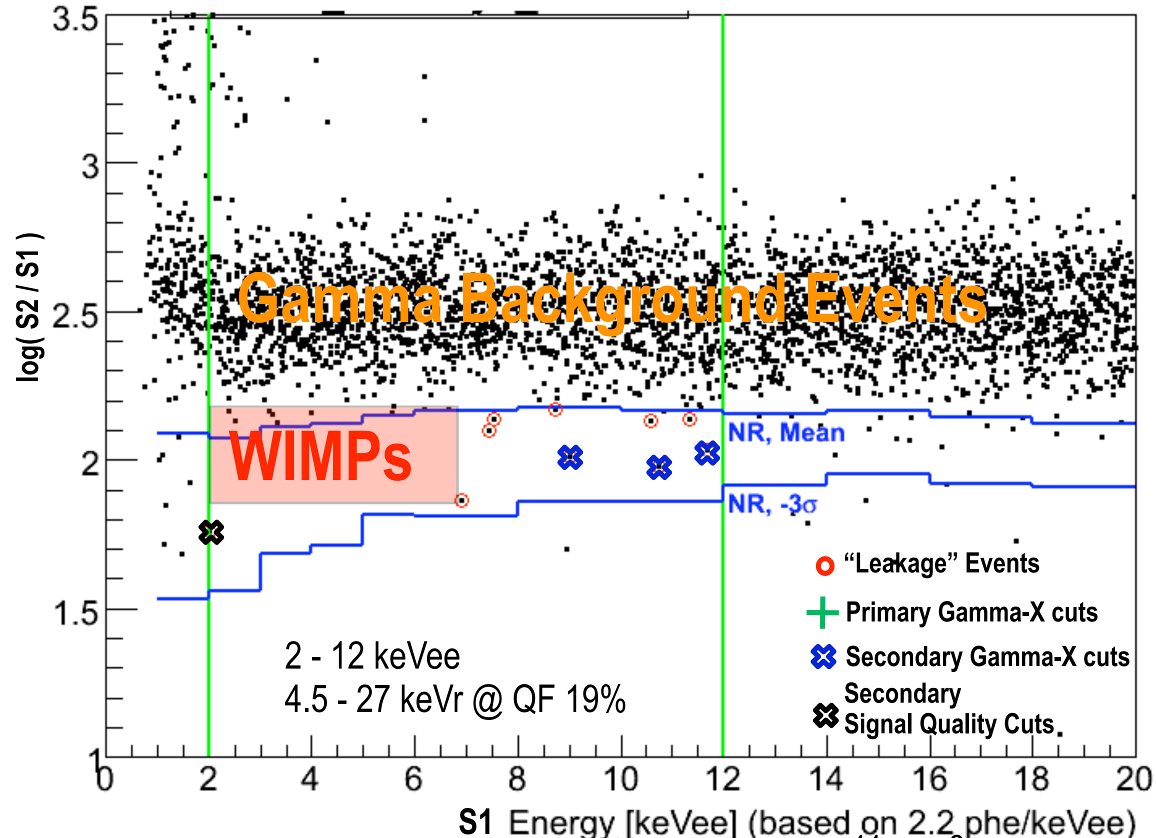


Note 1 event would be expected for $\sigma \sim 2\times10^{-44}$ cm^2

XENON10 Dark Matter Search

- XENON10 Blind Analysis – 58.6 days
  - Expected region for WIMP recoil events

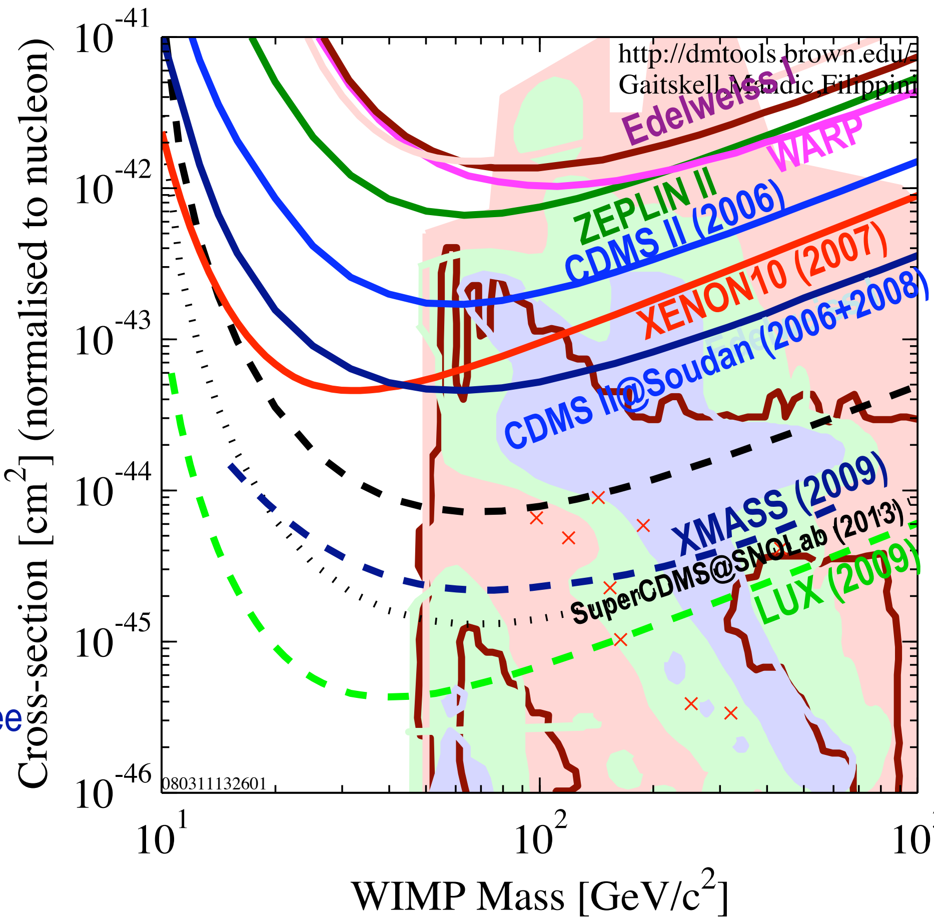
log (S2 / S1) vs S1
"Straightened Y Scale" – ER Band Centroid => 2.5



Note 1 event would be expected for $\sigma \sim 2\times10^{-44}$ cm^2

Dark Matter Result & Next Stage

- Dark Matter Goals
  - XENON10
    - ~60 day run (bg limited)
    - 136 kg-days net exposure
  - LUX - Sensitivity curve at $7x10^{-46}$ 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 $8x10^{-4}$ /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

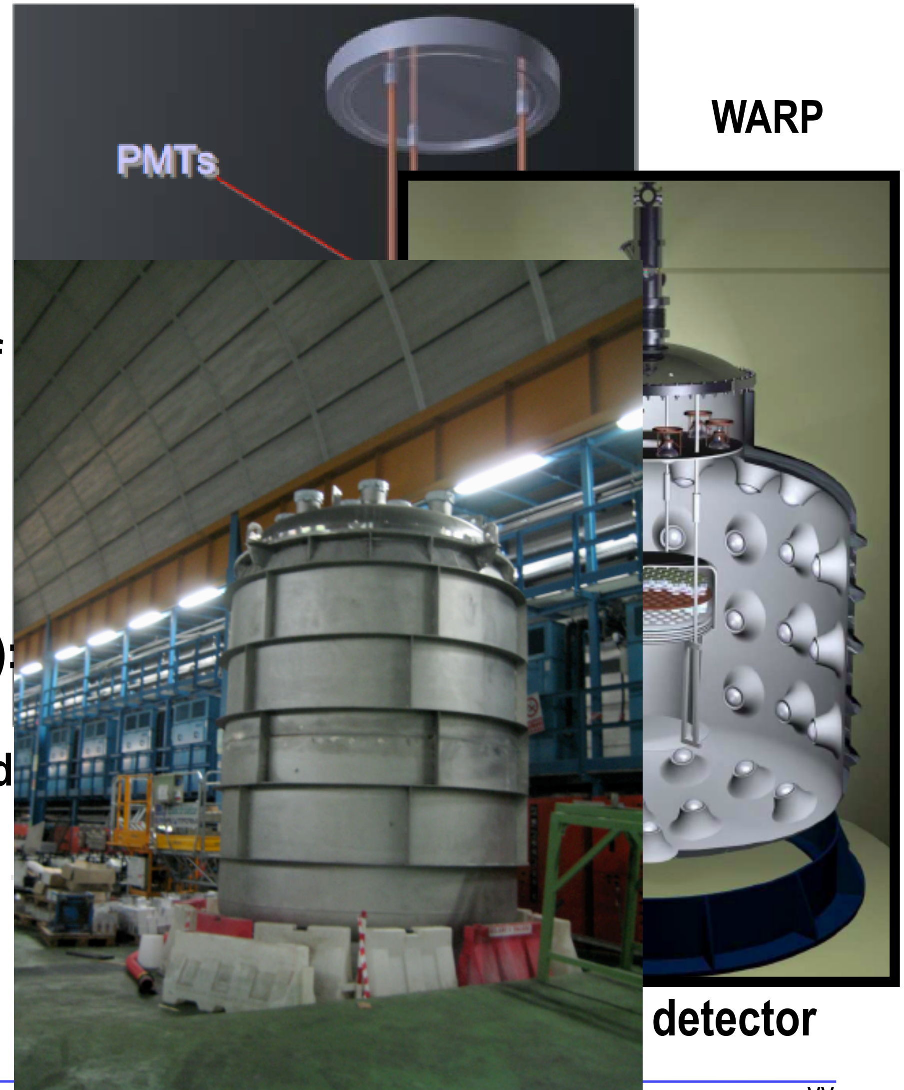
Two-phase Argon Detector: WARP

- PSD and secondary scintillation from ionization drift

- **2005-2007**
  - 3.2 kg prototype run at Gran Sasso
  - Preliminary dm results reported
    - 100 kg.d (55 keVr threshold)
    - Energy Calibration taken from slope of neutron calibration
  - Additional data taken 12/2006:
    - 43 kg.d Improved electronics
      20 MHz --> 100 Mhz
      70% NR acceptance at 50 phe (40 keVr):
      discrimination < 3e-7
    - 5kg of isotopically purified Ar delivered on March 2007 (residual 39Ar 2% of original), results pending
- **2007-**
  - 140-kg detector + 8 tonne active veto being installed , operation in 2008

WARP Prototype

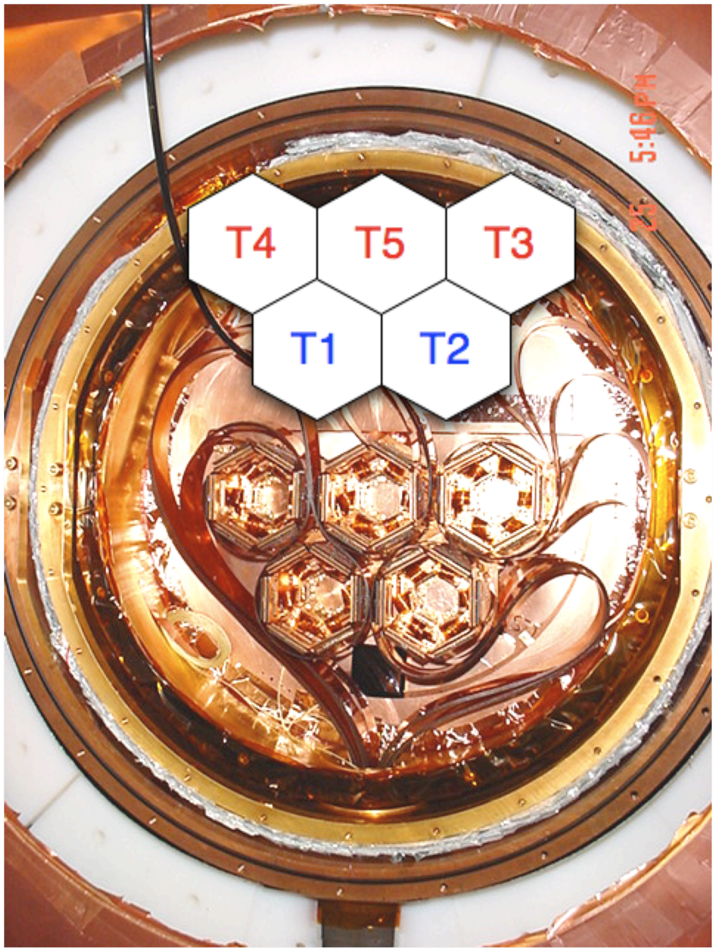
WARP



detector

vv

Five Tower Runs (2006-8)



30 ZIPs (5 Towers) installed in Soudan icebox:

4.75 kg Ge, 1.1 kg Si

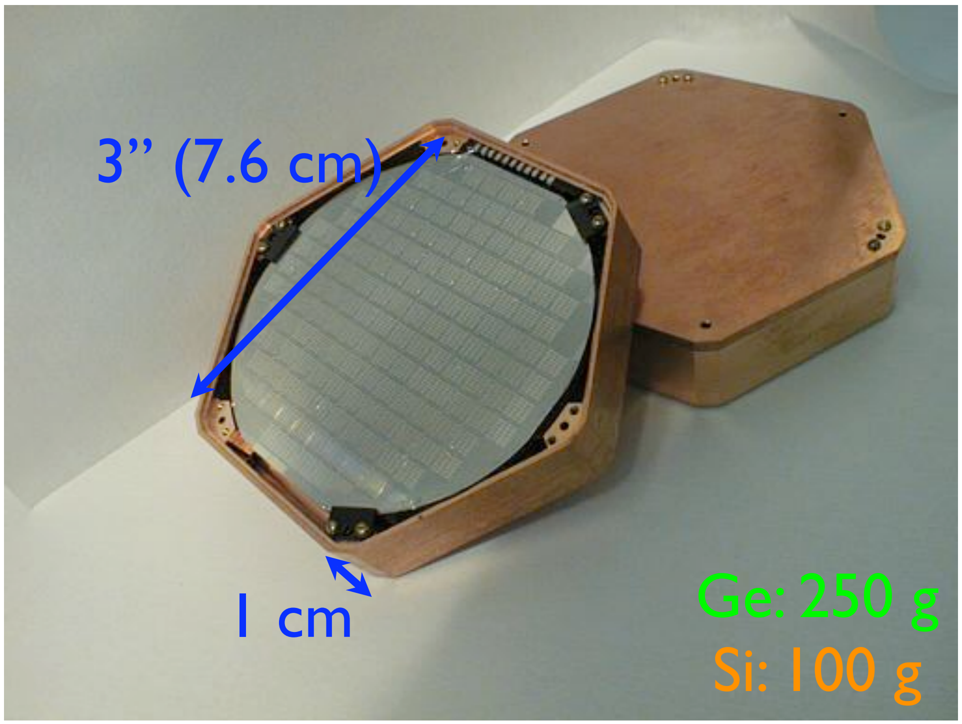
	T1	T2	T3	T4	T5
Z1	G6	S14	S17	S12	G7
Z2	G11	S28	G25	G37	G36
Z3	G8	G13	S30	S10	S29
Z4	S3	S25	G33	G35	G26
Z5	G9	G31	G32	G34	G39
Z6	S1	S26	G29	G38	G24

Side View

Combination of Ge and Si Detectors

- Neutron background measurement
- WIMP Mass Measurement
- Ge more sensitive to higher mass WIMPs. Si to lower mass WIMPs

Z-sensitive Ionization Phonon Detectors



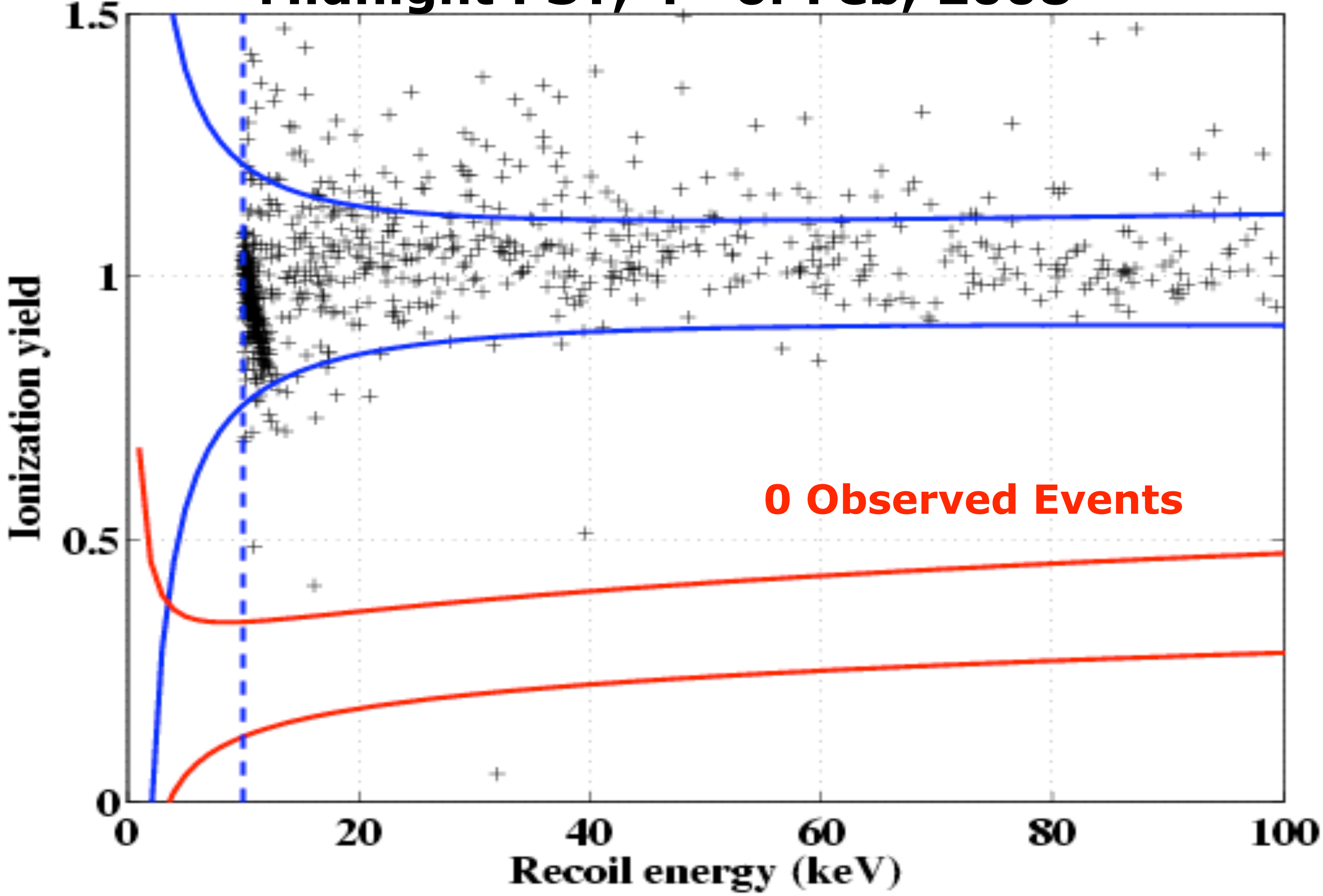
Phonon side: 4 quadrants of athermal phonon sensors
Energy & Position (Timing)

Charge side: 2 concentric electrodes (Inner & Outer)
Energy (& Veto)

Transition Edge Sensors (TES) Operated at ~40 mK for good phonon signal-to-noise

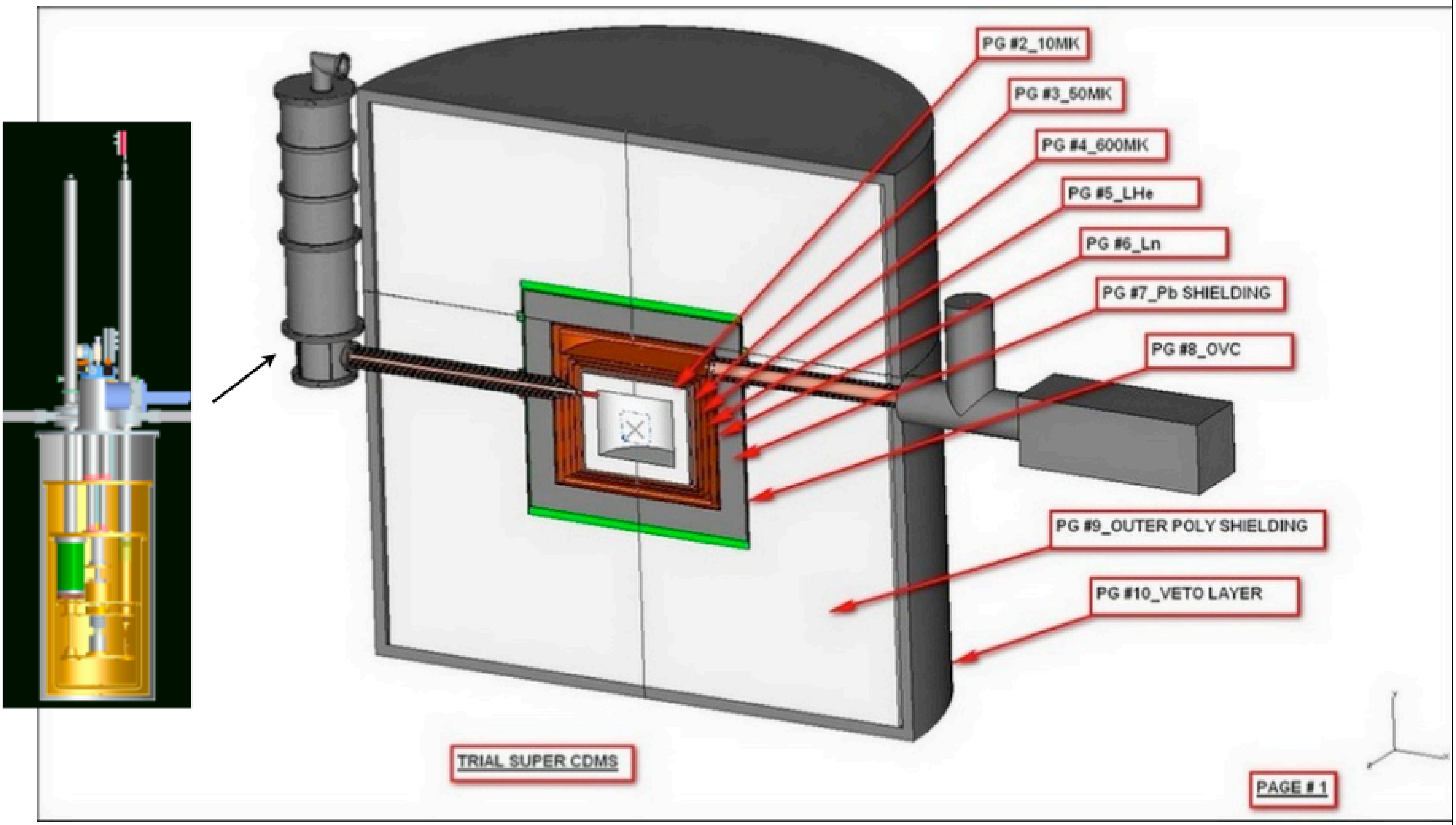
Open The Box: Surface Event Cut

Midnight PST, 4th of Feb, 2008



Expected Background: 0.6 ± 0.5 surface events and < 0.2 neutrons

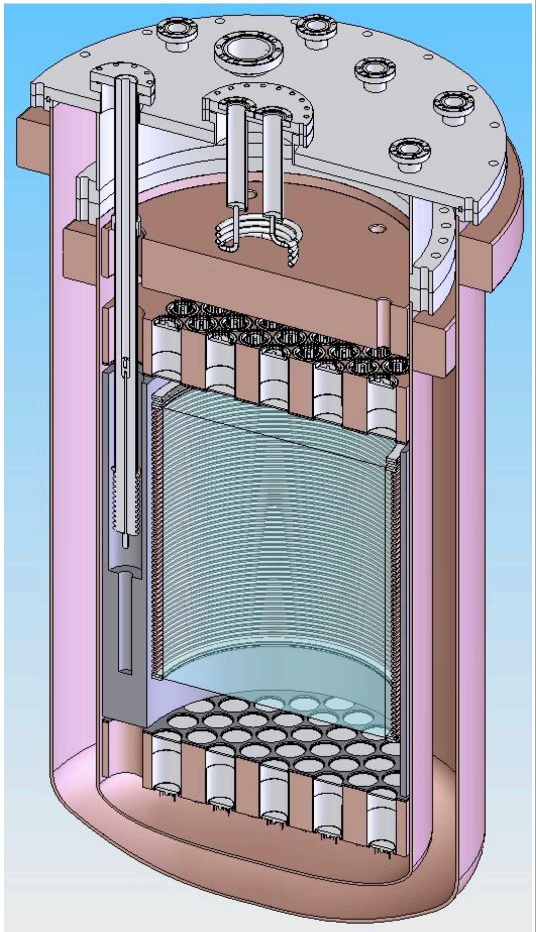
Schematic of new 'SNObox'



LUX Dark Matter Experiment - Summary

- Brown [Gaitskell], Case [Shutt], LBNL [Lesko] , LLNL [Bernstein], Rochester [Wolfs], Texas A&M [White], UC Davis [Svoboda/Tripathi], UCLA [Wang/Arisaka/Cline], Yale [McKinsey]
  - XENON10, ZEPLIN II (US) and CDMS; ν Detectors (Kamland/SuperK/SNO/Borexino); HEP/γ-ray astro
  - (Also ZEPLIN III Groups after their current program trajectory is established)
  - Co-spokespersons: Gaitskell (Brown) / Shutt (Case)
- 300 kg Dual Phase liquid Xe TPC with 100 kg fiducial
  - Using conservative assumptions: >99.4% ER background rejection for 50% NR acceptance, E>5 keVr (ER rejection is energy dependent)

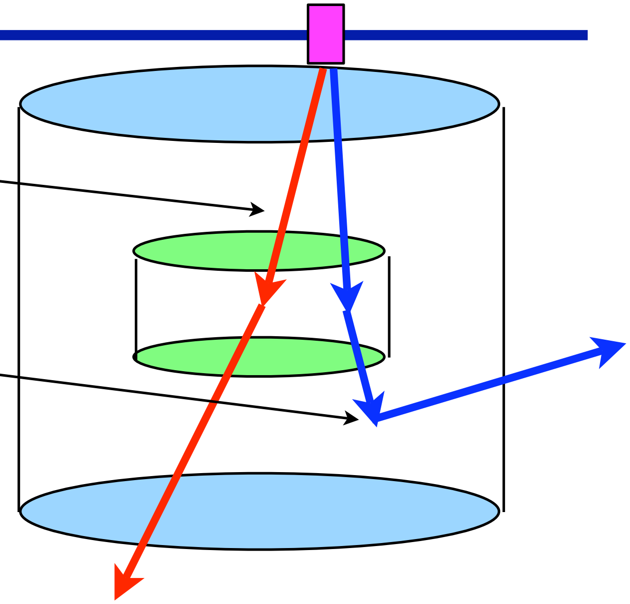
    (Case+Columbia/Brown Prototypes + XENON10 + ZEPLIN II)
  - 3D-imaging TPC eliminates surface activity, defines fiducial
- Backgrounds:
  - Internal: strong self-shielding of PMT activity
    - Can achieve BG $\gamma+\beta < 8\times10^{-4}$ /keVee/kg/day, dominated by PMTs (Hamamatsu R8778).
    - Neutrons (α,n) & fission subdominant
  - External: large water shield with muon veto.
    - Very effective for cavern γ+n, and HE n from muons
    - Very low gamma backgrounds with readily achievable $<10^{-11}$ g/g purity.
- DM reach: 7×10^{-46} cm^2 in 10 months



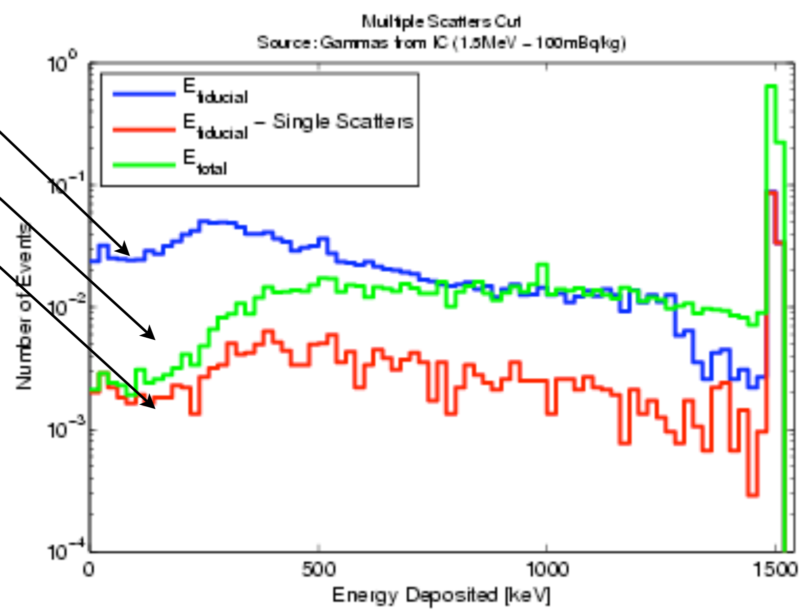
http://www.luxdarkmatter.org

LUX Collaboration Meeting (Jan 2008)

Topology of Gamma Events That Deposit Energy in FV



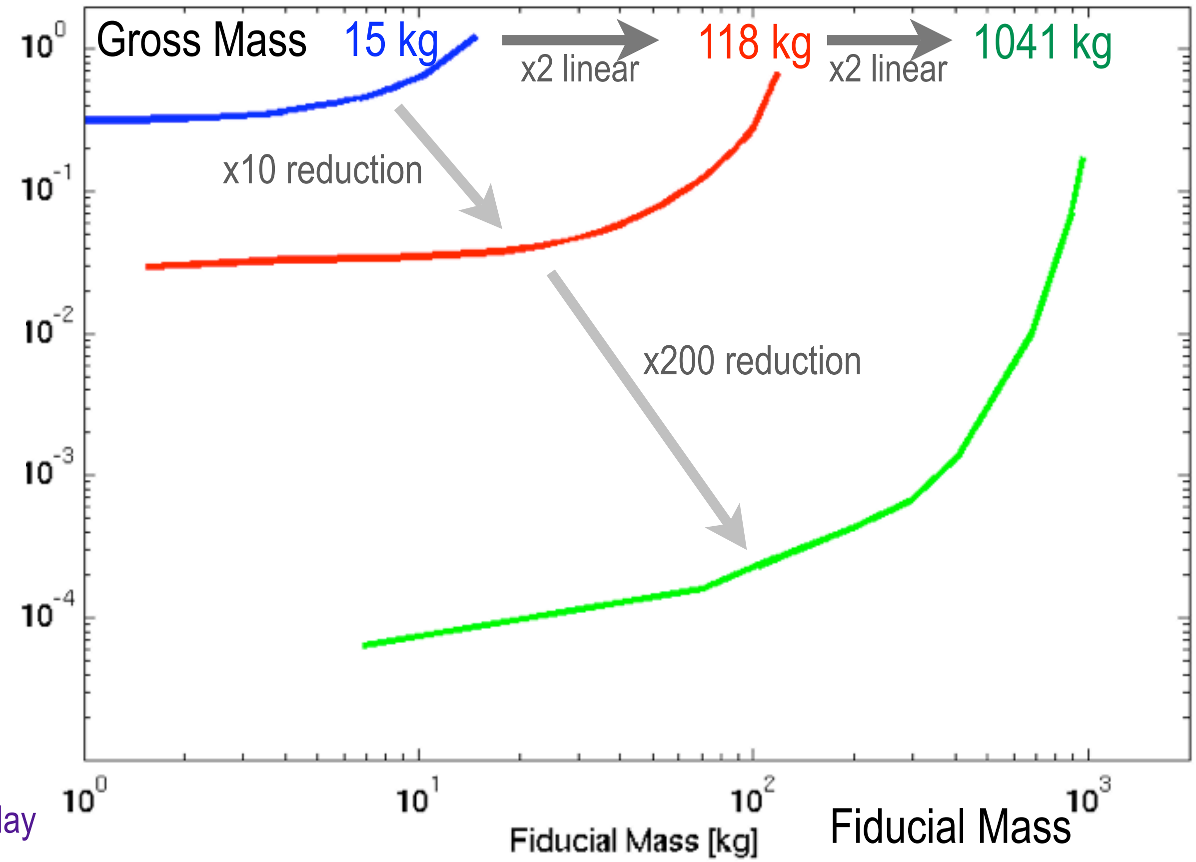
- The rate of ER events in FV is determined by small angle scattering Compton events, that interact once in the FV
  - The rate of above events is suppressed by the tendency for the γ's to scatter a second time. Either on the way in, or way out.
  - The chance of no secondary scatter occurring is more heavily suppressed the more LXe there is
    - The important optimization is to maximize the amount of LXe that lies along a line from the greatest sources of radioactivity (PMTs?) that pass through the FV.
- Example for 1.5 MeV γ from outside LXe volume
  - Energy Spectrum for part of energy deposited in FV
  - Energy spectrum for all energy in detector
  - Additional application of multiple scatters cut has little additional effect on low energy event rate
- Conclusion for Event Suppression
  - xyz resolution of detector is important simply in defining FV. Little additional reduction from locating vertices.
  - (Full xyz hit pattern does assist in bg source identification)



Scaling LXe Detector: Fiducial BG Reduction /1

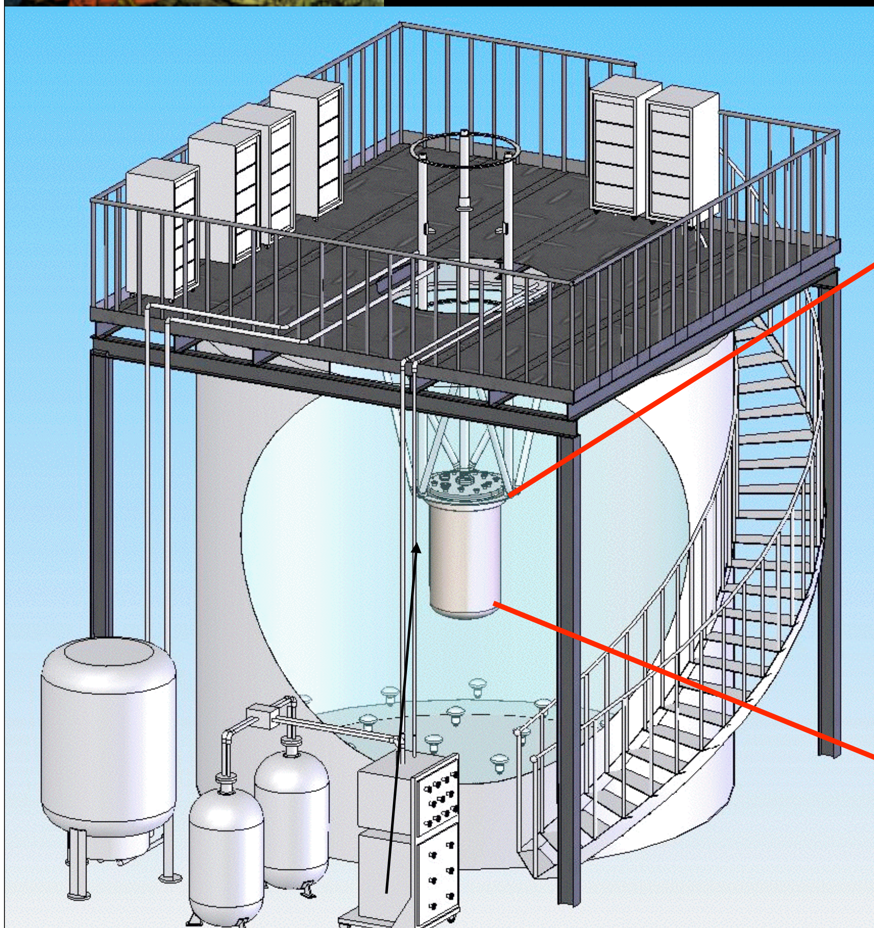
- Compare LXe Detectors (factor 2 linear scale up each time)
  15 kg (ø21 cm x 15 cm) -> 118 kg (ø42 cm x 30 cm) -> 1041 kg (ø84 cm x 60 cm)
  - Monte Carlos simply assume external activity scales with area (from PMTs and cryostat) using XENON10 values from screening

Low energy rate in FV before any ER vs NR rejection /keVee/kg/day

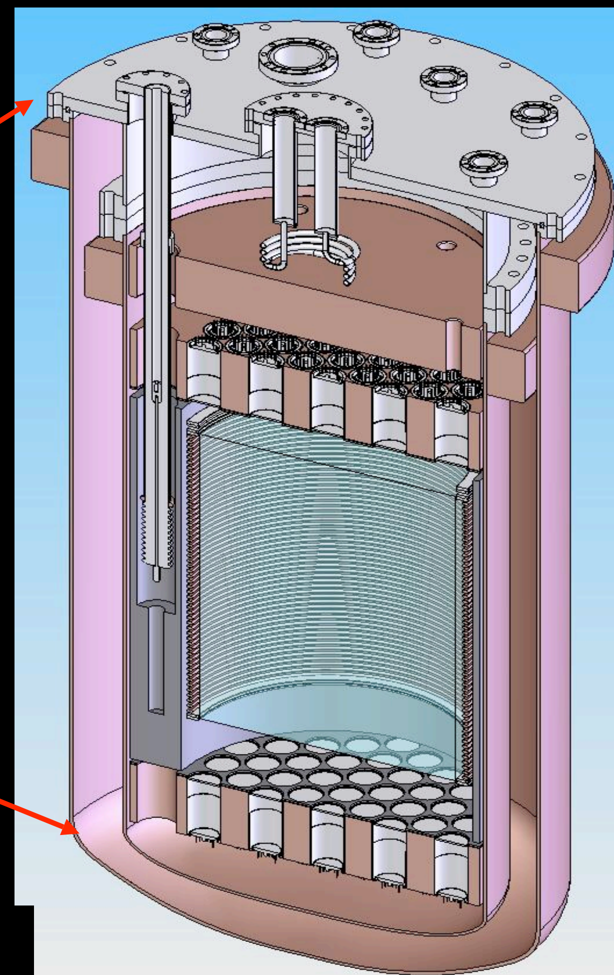


dru = cts/keVee/kg/day

The LUX detector



~ 6m diameter Water Cerenkov Shield

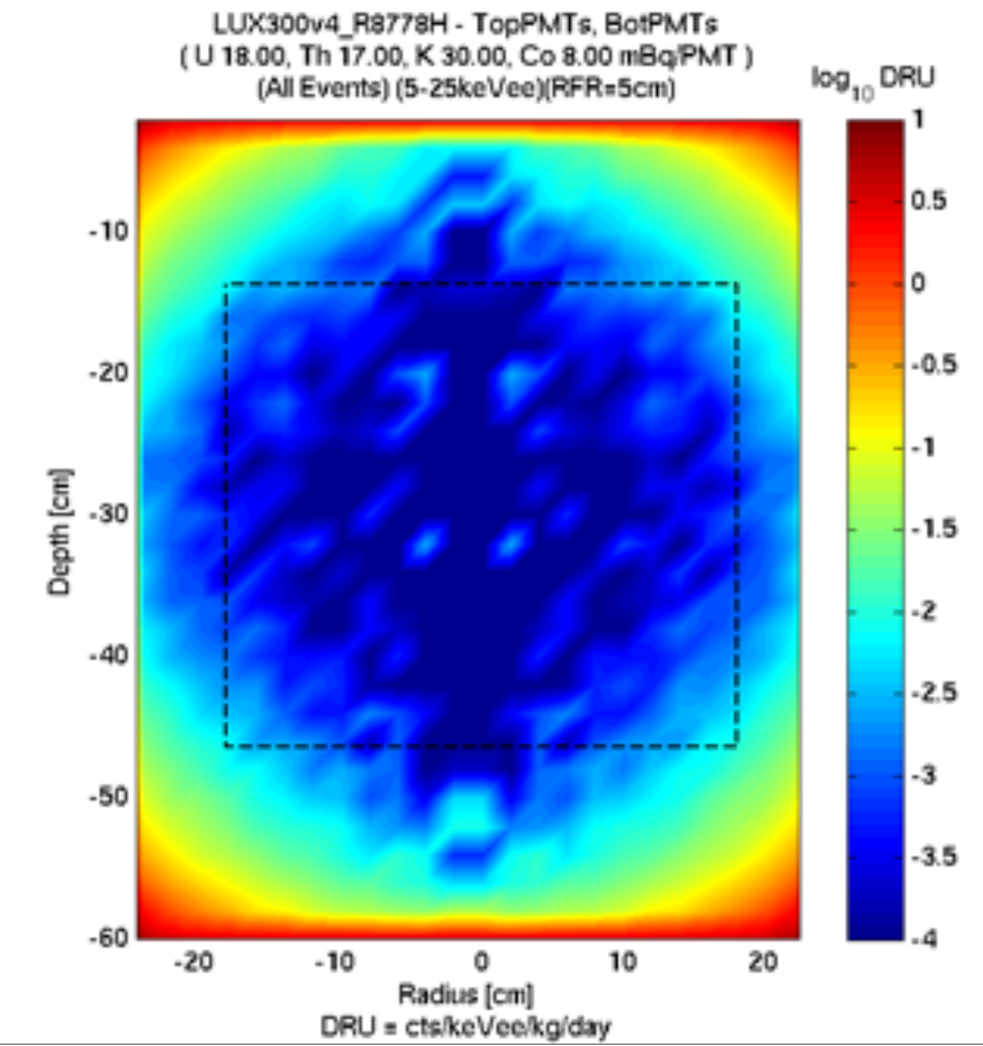


Dual phase detector - aspect ratio ~1.2

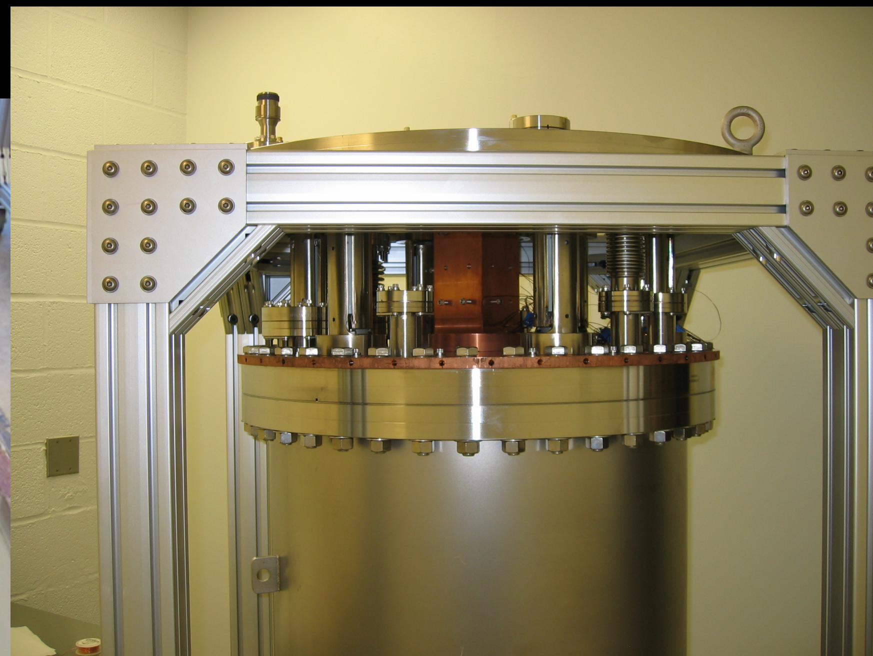
Backgrounds (Gamma)

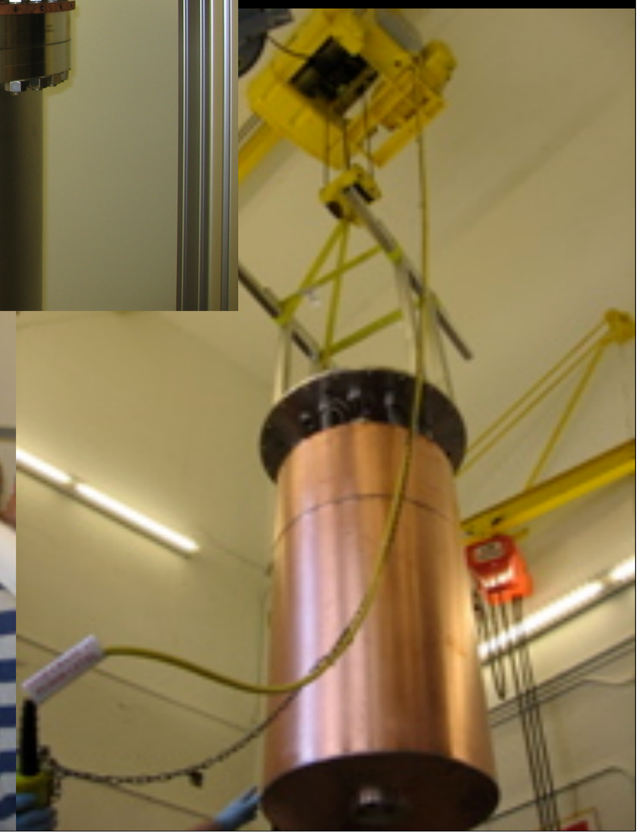
- <u>Internal</u> strong self-shielding against PMT activity (main source of background events). Double Compton scatters are rejected.

- <u>External</u> large water shield with muon veto.
    - Very effective for cavern γ -- Very low gamma backgrounds with readily achievable $<10^{-12}$ g/g purity for water.

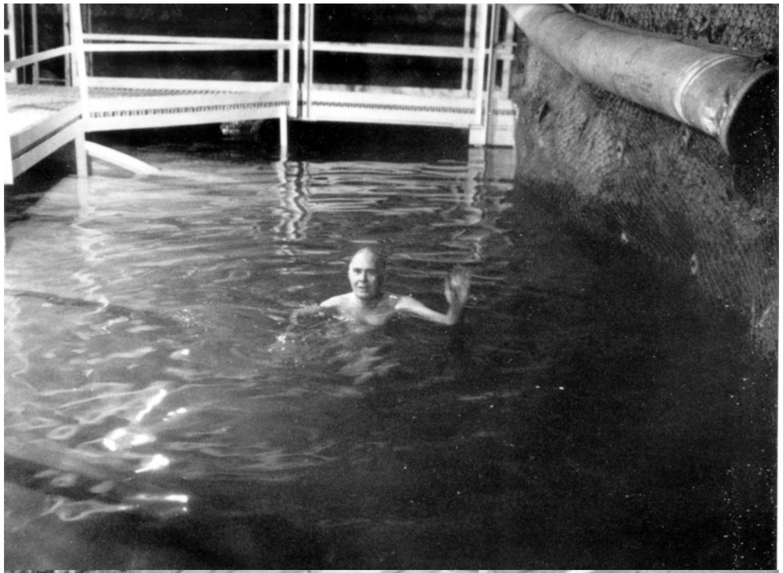


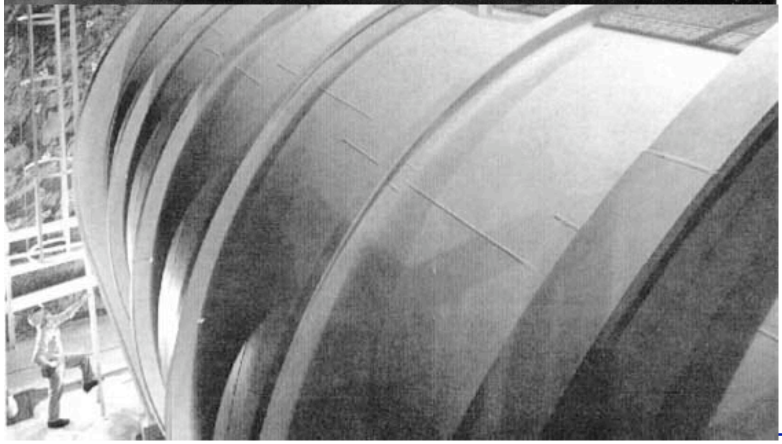
Cryostat Assembly (at Case)

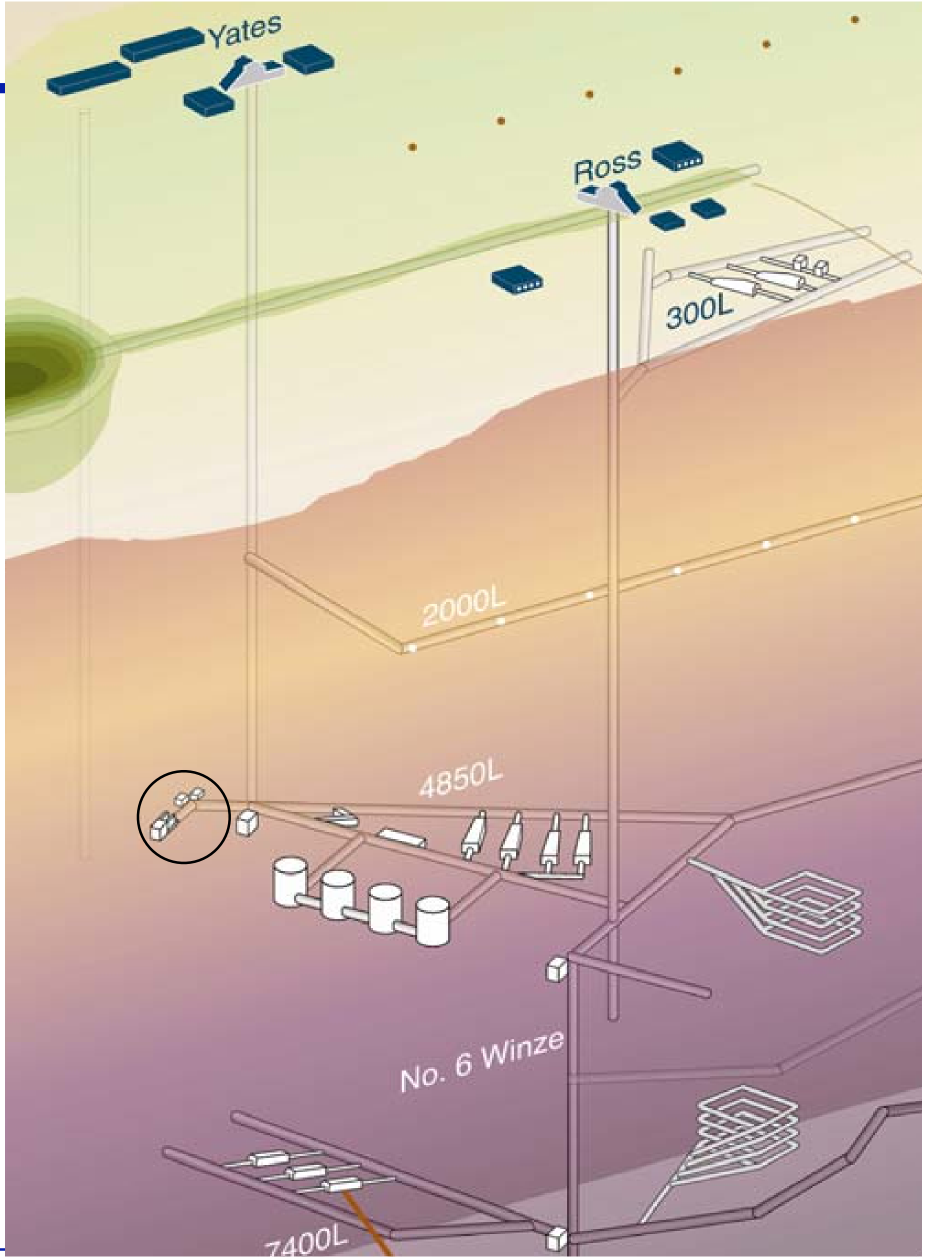




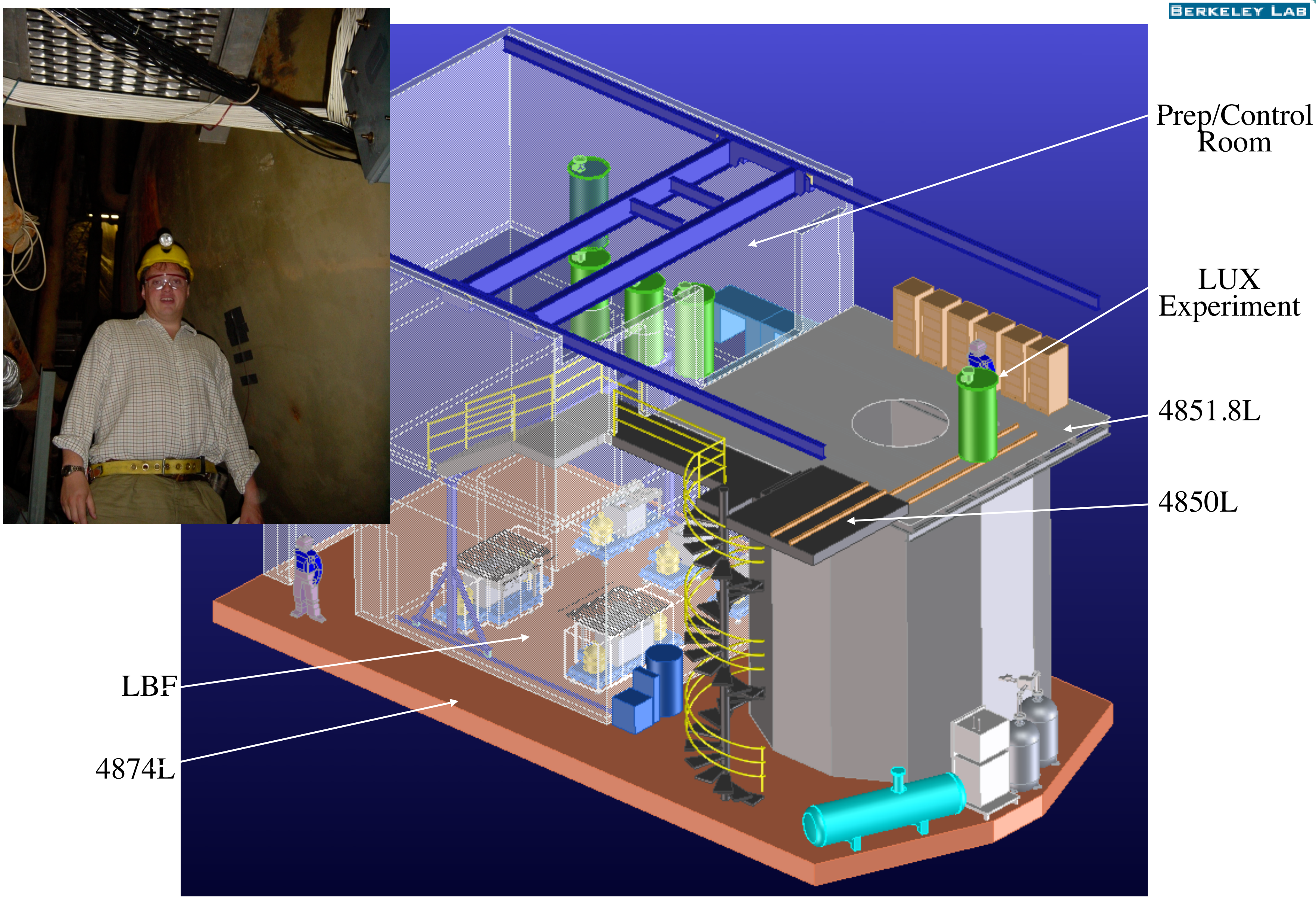
Water Shield - Homestake - Davis Cavern



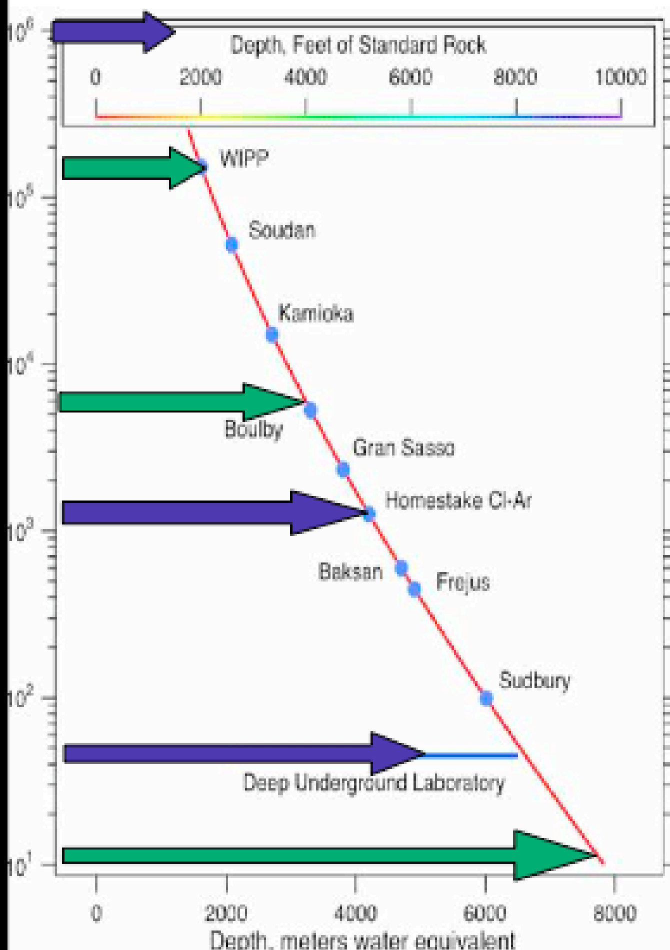




LUX Experiment with LBF (Dave Plate , LBL)



Campus Footprints



300L R&D, E&O 10k ft²

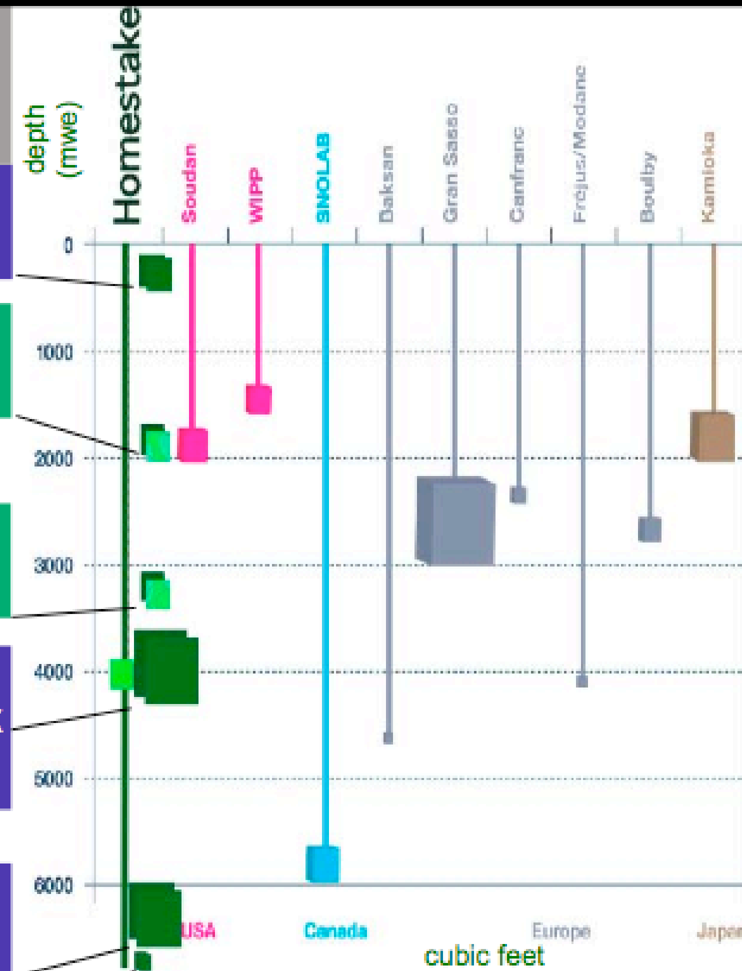
2000L Geo Level

3800L Geo Level

4850L Major Campus 100k ft²

7400L Major Campus 65k ft²

8000L Geo Lab



Estimates do not include MegaTon Detectors

Homestake DUSEL

Homestake DUSEL Project Status (Preconstruction Planning)

- **Objective:**

  To design and build an international, multidisciplinary facility for underground science and engineering research at the site of the former Homestake Gold Mine in Lead, South Dakota.

- **Funding from the State of South Dakota and Private Donations for "Mining-to-Laboratory" Conversion:** **<u>~$110M</u>**

  Work is underway to prepare underground space for early experiments.

- **NSF Pre-Construction Funding:** **<u>$15M</u>**

  We have 3 years of funding for Pre-construction Planning and Development, average $5M per year (FY 2008 – FY2010).

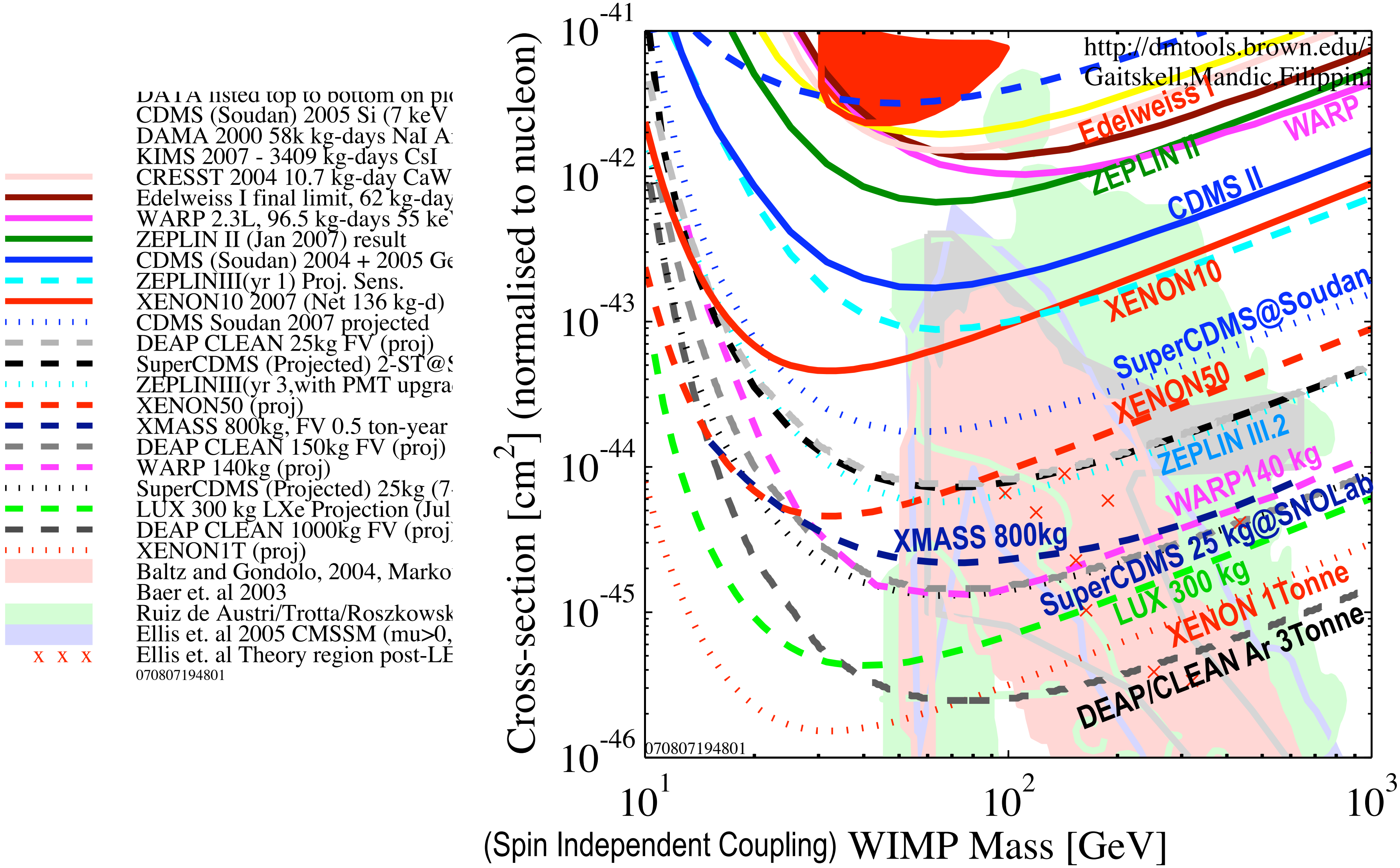
- **Proposed NSF Funding for Construction:** **<u>~$550M</u>**

  ~ 50% is slated to develop an **Initial Suite of Experiments** and

  ~ 50% for **Facility Design and Construction.**

- **The proposed construction duration with NSF Funding is <u>2012 through 2018.</u>**

Dark Matter Projected Experiment Goals 2008-2012



Experiments at Homestake Facility

- Dark Matter - Sanford Lab - Pre-DUSEL 2008-2012
  - 2008-2009 LUX 350 kg
  - 2010-2012 LXe 3 tonne
  - 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 2009
  - 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 2012->
    - 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 (5 year program very complementary to LHC reach)

- Cryogenic Detectors
  - CDMS -> SuperCDMS (SuperTowers with detectors 0.25->1 kg)
    - 2007 Complete search using existing 30 dets = 5 Tower (5 kg) at Soudan
    - 2008 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 in 2007. Goal: 10e-44 cm2
  - CRESST ($CaWO_4$)
    - 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 >10^5:1 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 ~$10^3 10^2$: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
    - LUX will deliver x100 improvement in sensitivity over existing measurements (operating at Homestake in 2008)
  - 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"
  - 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 2012+
  - 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