Future Prospects for Directly Detecting Dark Matter

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Particle Astrophysics Group, Brown University, Department of Physics

(Supported by US DOE HEP)

see information at

http://particleastro.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

Key points/2

- Dark Matter
  - Next 5 years will be very exciting
  - Hot topic
    - LHC
    - Pamela, ATIC
    - Fermi/GLAST , HESS
    - Direct Detection
- Direct Detection
  - Field is very competitive

atter

CDMS II: Winter
@Soudan Minnesota

New Sanford Lab
LUX @Homestake,
South Dakota

PHYSICS ITALIAN
STYLE XENON10
@ Gran Sasso

Key points. I'm going to ...

- declare my ignorance
- demonstrate why an particle astrophyicist can do his best work 1 mile underground
- explain why it is worth paying attention in this lecture

Questions

- What is a realistic projection of sensitivity for direct detection experiments?
  – Talk specifically about Xe TPC
  – XENON10/LUX/LZ3/LZ20
- Is it the right “channel” for tuning into dark matter?
- Challenges to convince community that a cluster of low energy recoil events is really a dm signal?
- Non-standard signatures & searches?

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

Confession

>95% of the Composition of the Universe is still unknown

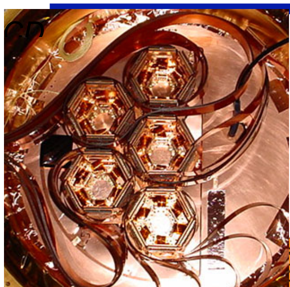
Introduction

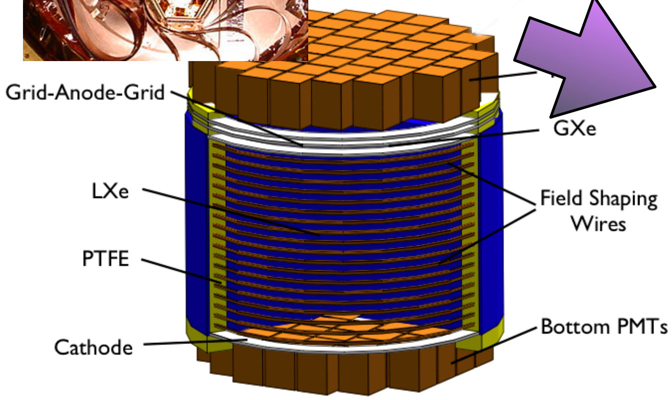
- --> 1990's For many a "known known" was that $\Omega_{Total} = 1$
  - This being matter dominated, $\Omega_m = 1$
- We have had to revise this view partially: $\Omega_{Total} = 1$, but $\Omega_m \sim 0.30$
  - Dark Matter now has to share the shadows with Dark Energy
  - Indeed it is convenient to split into 3 Dark Problems
    - Baryonic Dark Matter - Mostly known
    - Non-Baryonic Dark Matter - **Known Unknown**
    - Dark Energy - Only God knows, right now
- It has been a Problem in Cosmology that astrophysical assumptions often need to be made to interpret data/extra parameters
  - Now many independent/increasingly precise techniques are being used
  - This now enables disentanglement of "Gastrophysics"
- Ultimately new solutions will be related to Fundamental/Particle Physics
  - Non-baryonic dark matter - New Particles - SUSY, neutrinos, baryogenesis
  - Dark Energy - Gravity / Extra Dimensions

Dark Energy + Dark Matter

- Dark Energy
  - SN - Supernova Type Ia Standard Candles - distance as a function of z. Future missions to collect 1000's, z<~0.8 from ground, z<~1.5 from space
  - WL - Weak Gravitational Lensing - narrow but deep & full sky surveys - large statistical samples: 3D mass tomography/shear correlation function vs z
  - CL - # of clusters of galaxies as a function of z. Combine with x-ray survey. SZ effect.
- Dark Matter
  - DM Direct Searches - larger detectors, deeper underground
  - DM Indirect Searches - Annihilation products (as energy line and continuum) in gamma and neutrino
  - (Accelerator - Particle Searches)
- Cosmological Parameters
  - LSS Large Scale Structure - surveys of galaxies (e.g. SDSS, 2dF)
  - CMB Cosmic Microwave Background

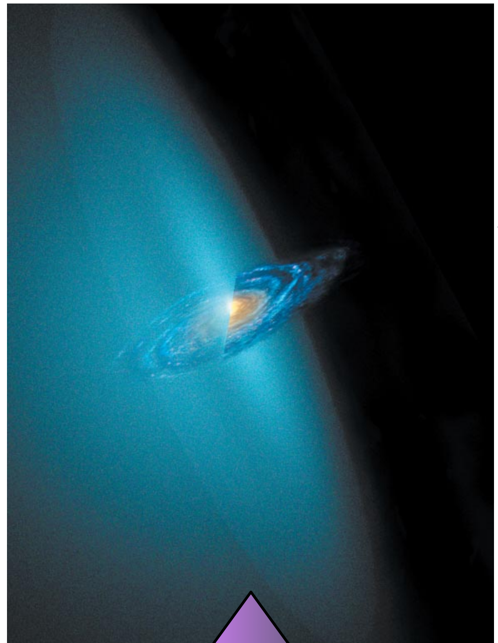
Complementary Approaches

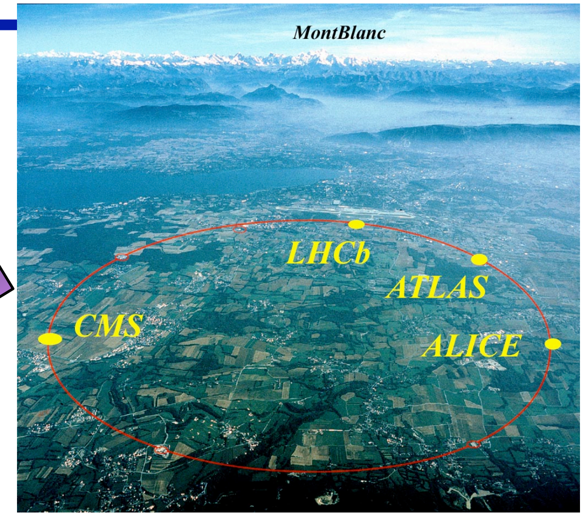




WIMP scattering on Earth:
e.g. CDMS/XENON10/ ZEPLINIII : currently leading the field

Halo made of WIMPs





WIMP production on Earth

WIMP annihilation in galaxy substructure

Air Cherenkov Telescopes
HESS,MAGIC,Veritas

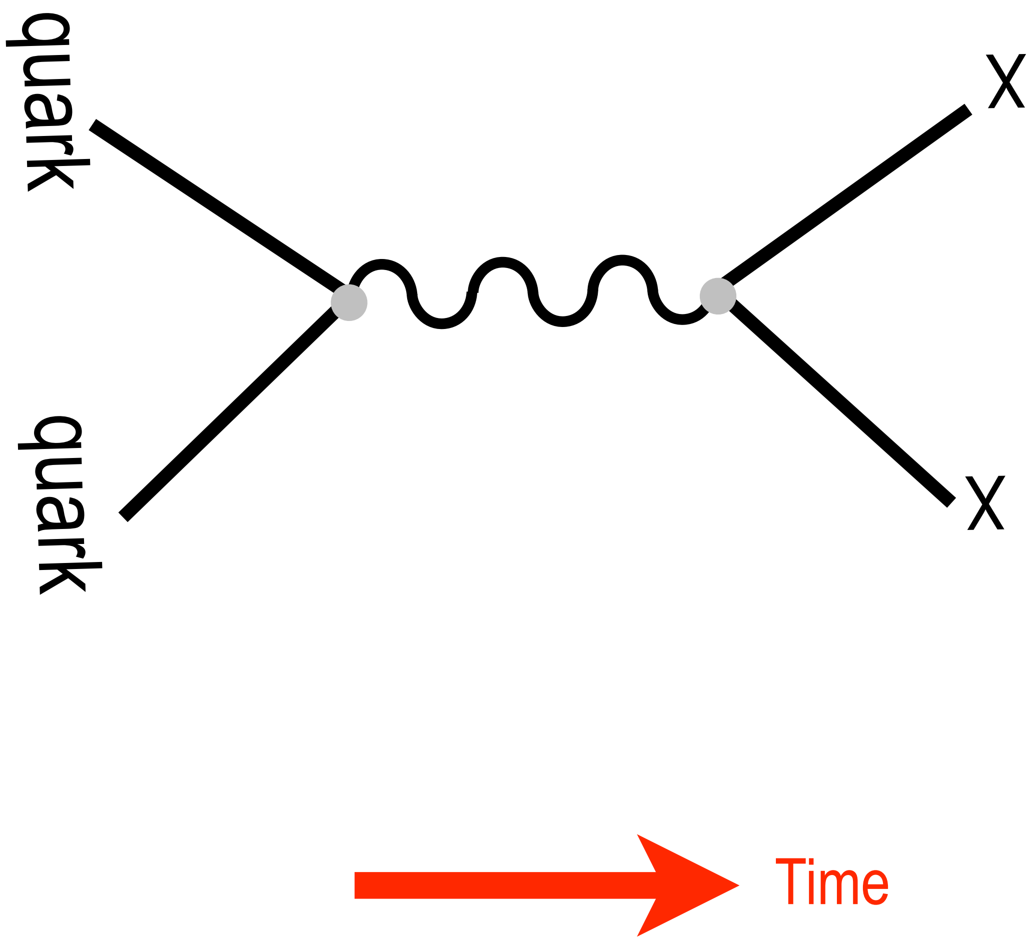
Also anti-particle sig.
e.g. Pamela / HEAT

Neutrinos
e.g. SuperK / ICE3

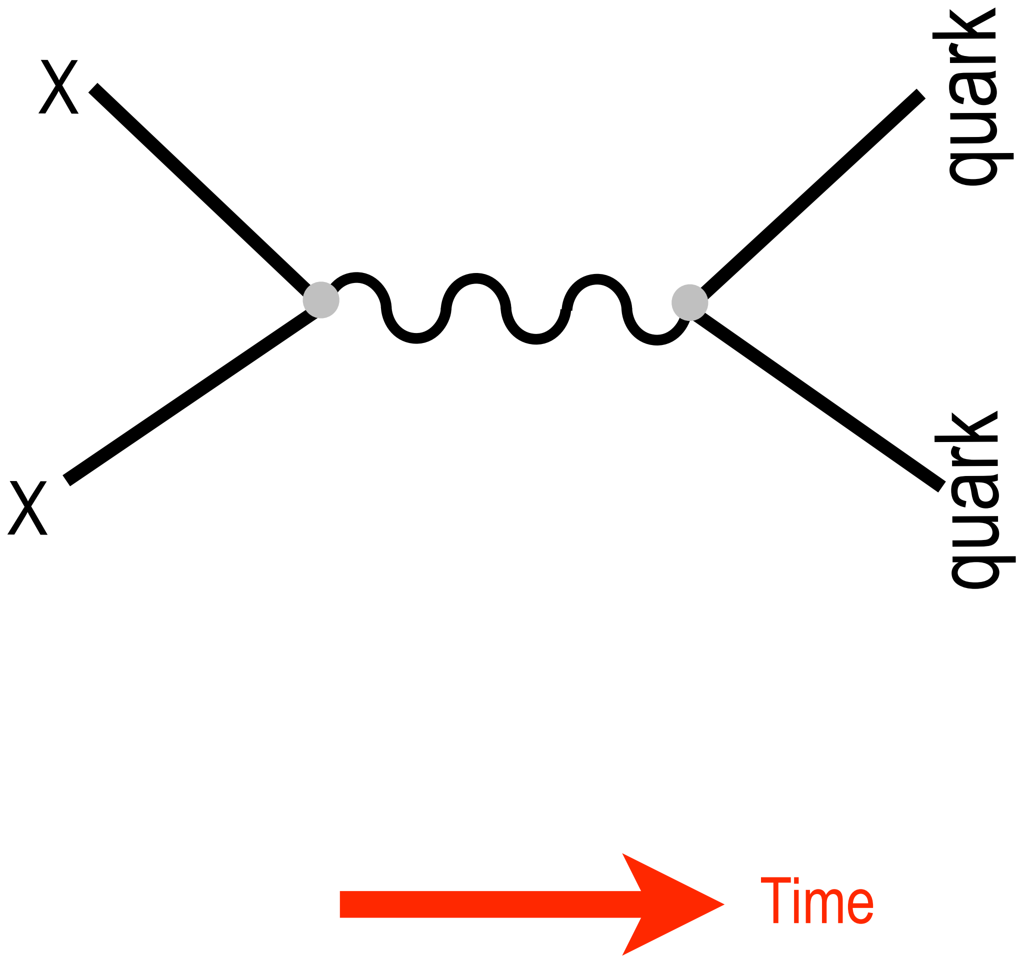
GLAST/Fermi
Launched 11 June 2008
γ= 2 - 200 GeV

(Thanks to Sadoulet for graphics)

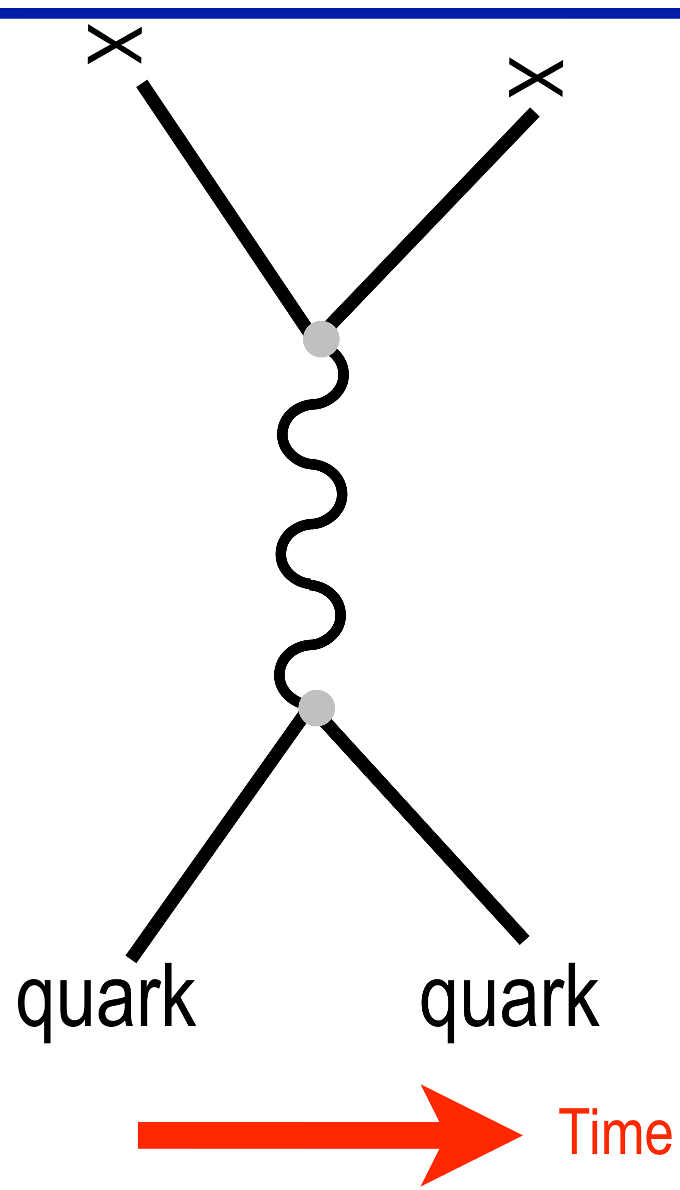
Accelerator



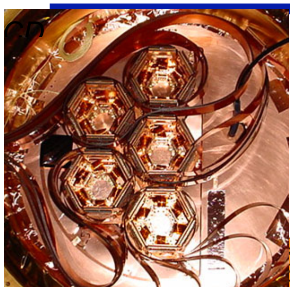
Annihilation

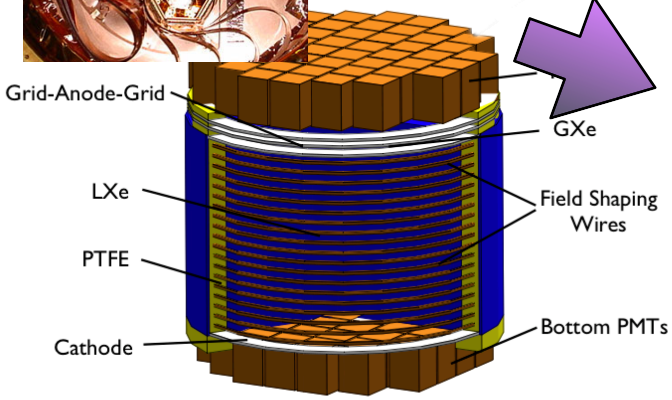


Direct Detection



Complementary Approaches





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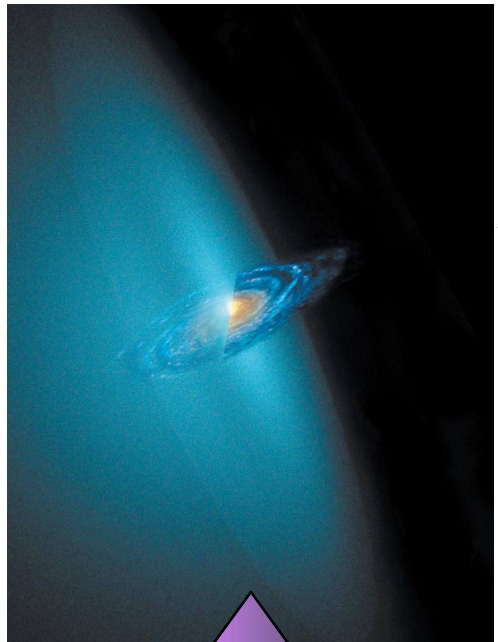

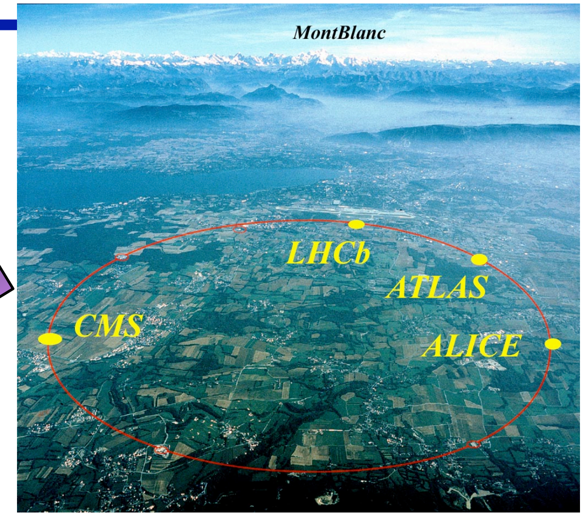

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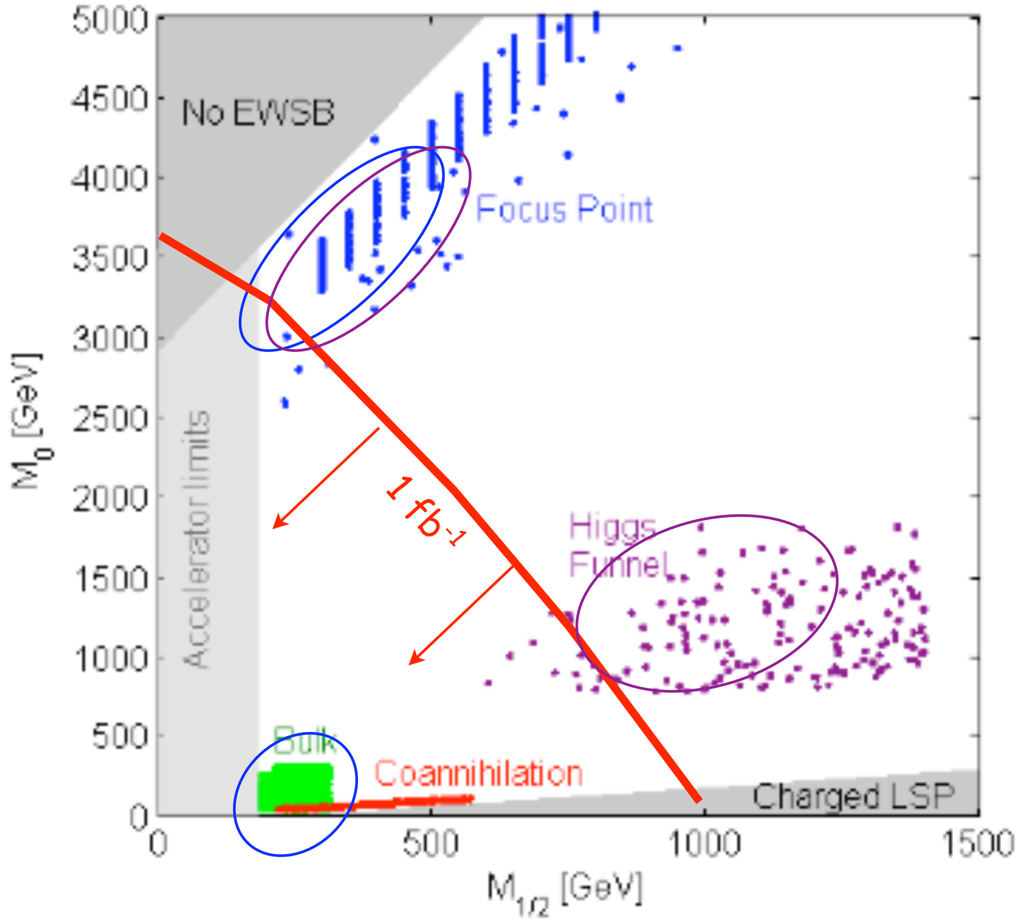
(Thanks to Sadoulet for graphics)

Complementarity mSugra/CMSSM

Direct Detection:
Bulk
+Focus point

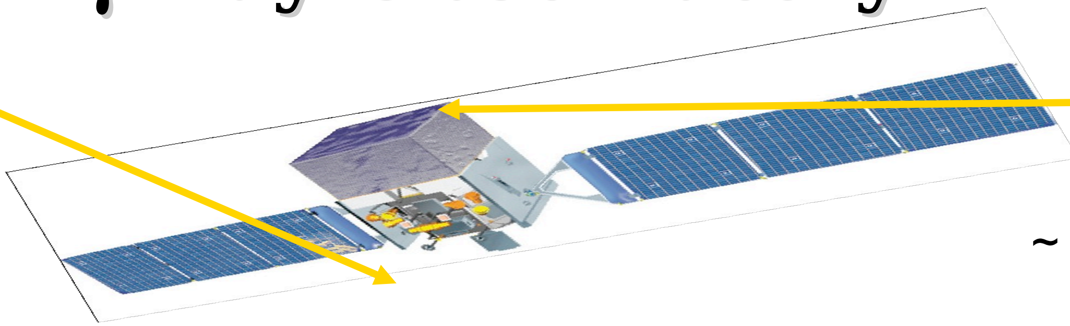
LHC
"low energy"

GLAST
Focus
+ Higgs funnel



GLAST : next generation γ–ray Observatory

GBM



LAT

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

sky coverage
whole unocculted sky

Mission Lifetime
5 years (min)

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

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

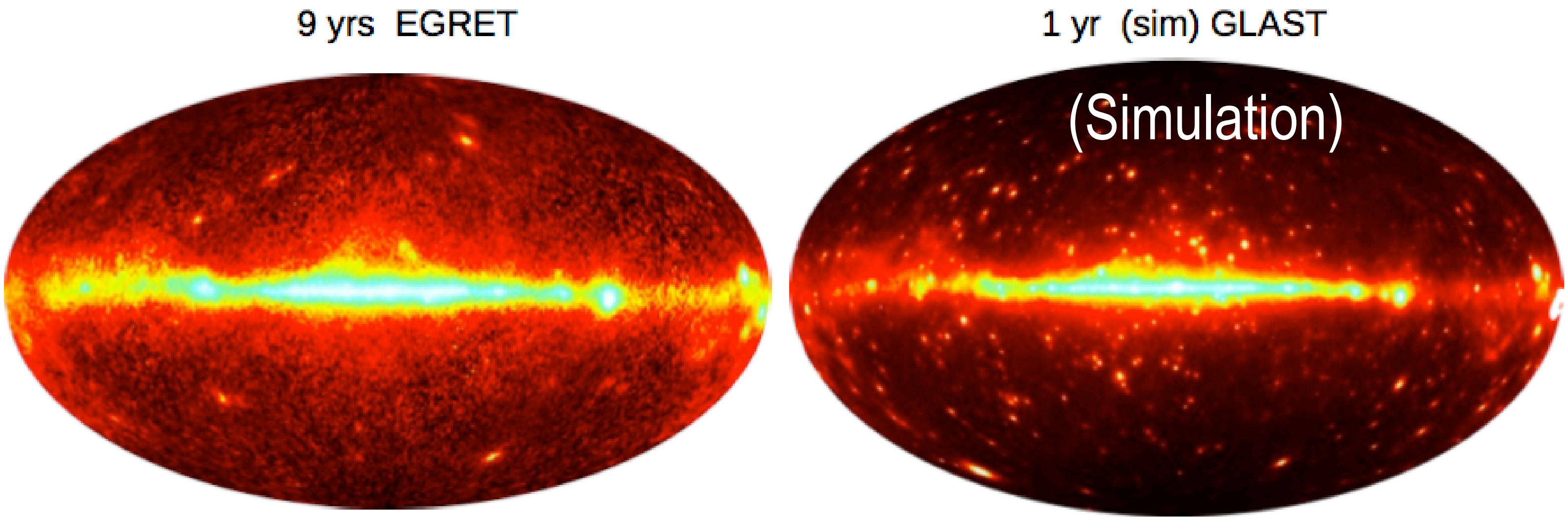
Re-pointing Capabilities
Autonomous
Rapid slew speed
(75° in < 10 minutes)

-
- l c l z x25 x 2
- f l f w x5
- b g ff c c x2
- x -3

(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



- 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....

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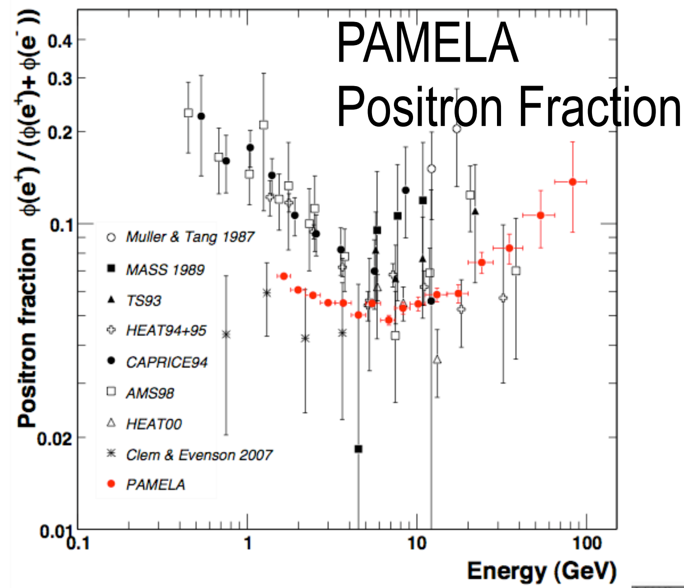
Uncertainties in the underlying particle physics model and DM distribution affect all analyses

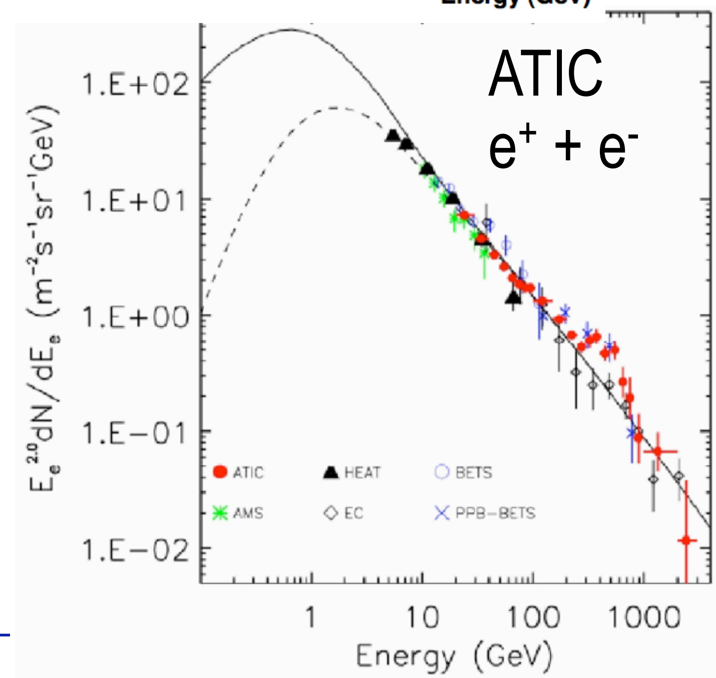
ACT Ground Based Gamma Observatories

- 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)

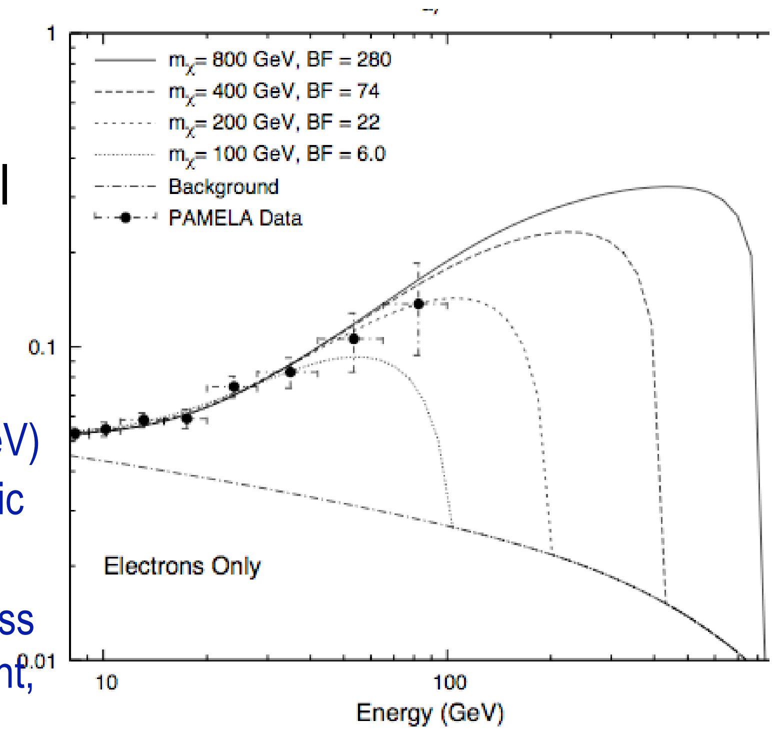
- Observation of an anomalous positron abundance in the cosmic radiation
  - Just posted - Nature submission available at arXiv:0810.4995
  - earlier indications from HEAT and AMS-01.
- Rising Positron Excess Compared to Electrons 1.5 - 100 GeV
  - low energies produced in interactions between cosmic-ray 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





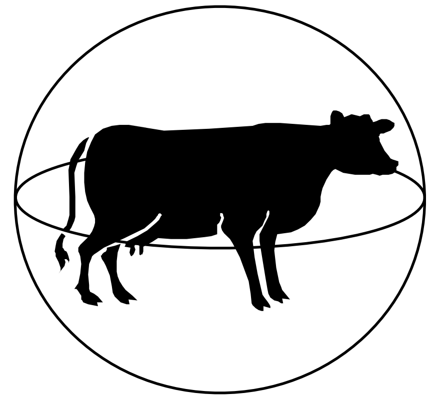
Hard Spectrum - Positron Fraction - DM interpretation

- 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.



Direct Detection Astrophysics of WIMPs

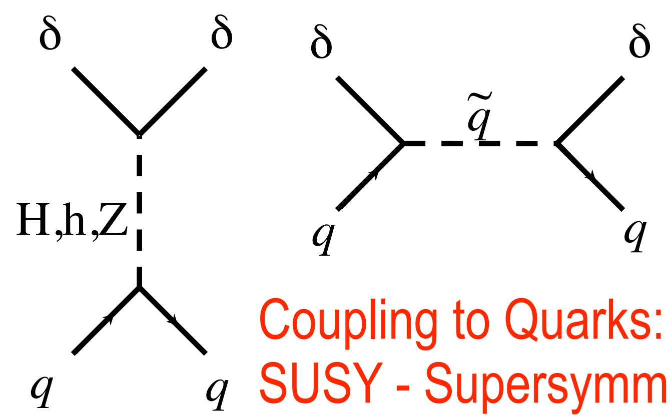
- **Energy spectrum & rate depend on WIMP distribution in Dark Matter Halo**
  - **"Spherical-cow" assumptions: isothermal and spherical, Maxwell-Boltzmann velocity distribution**
  - **V_0= 230 km/s, v_{esc}= 650 km/s,**
  - **ρ = 0.3 GeV / cm^3**



- **Energy spectrum of recoils is featureless exponential with $\langle E \rangle$ ~ 30 keV**

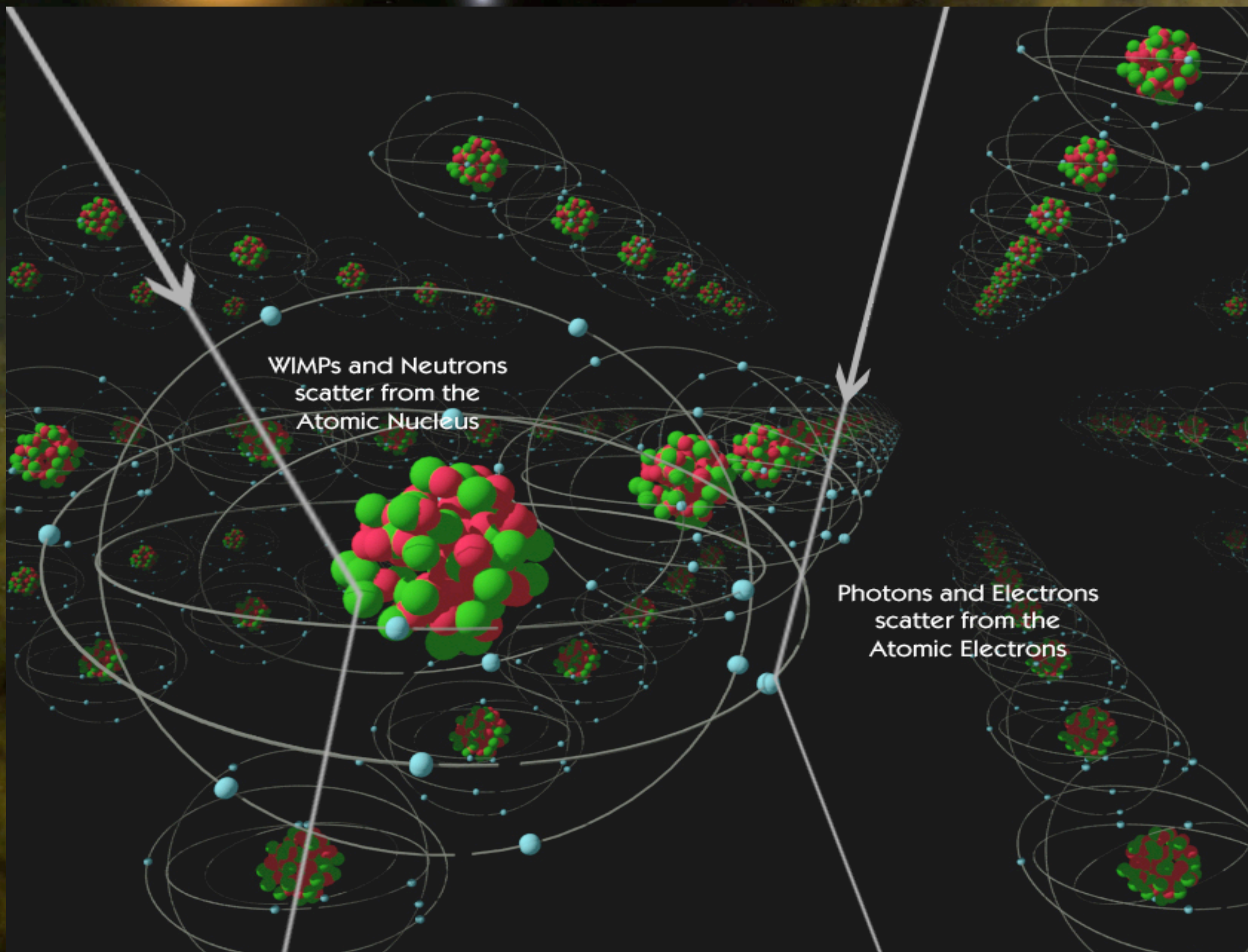
"Contains ten 100-GeV WIMPs on average. 20 billion WIMPs pass through each second."

- **Rate (based on $\sigma_{n\chi}$ and ρ) is fewer than 1 event per kg of detector per week**
- **Nucleus recoils (not electron)**



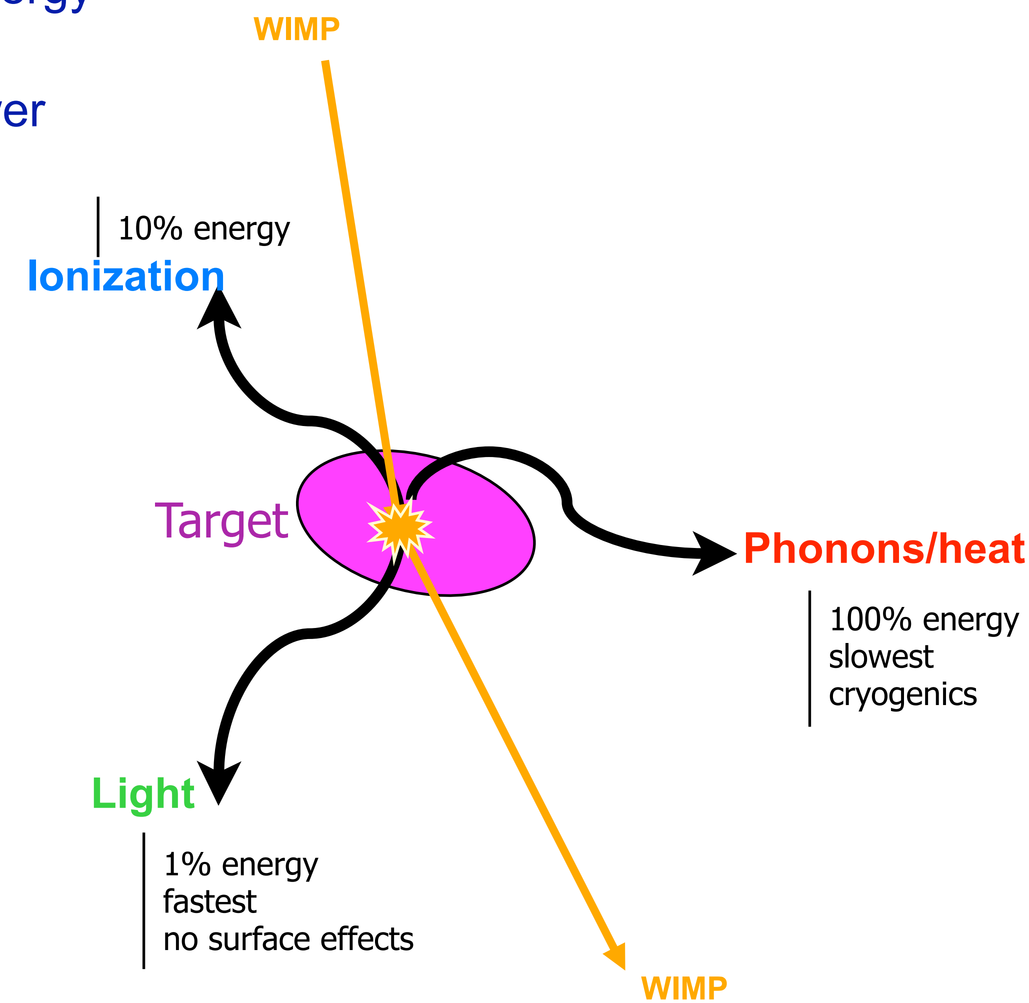
Coupling to Quarks:
SUSY - Supersymmetry

Interaction with Ordinary Matter



Getting rid of the 'haystack': Recoil Discrimination

- Nuclear recoils vs. electron recoils
  - Division of energy
  - Timing
  - Stopping power



(Dan Akerib)

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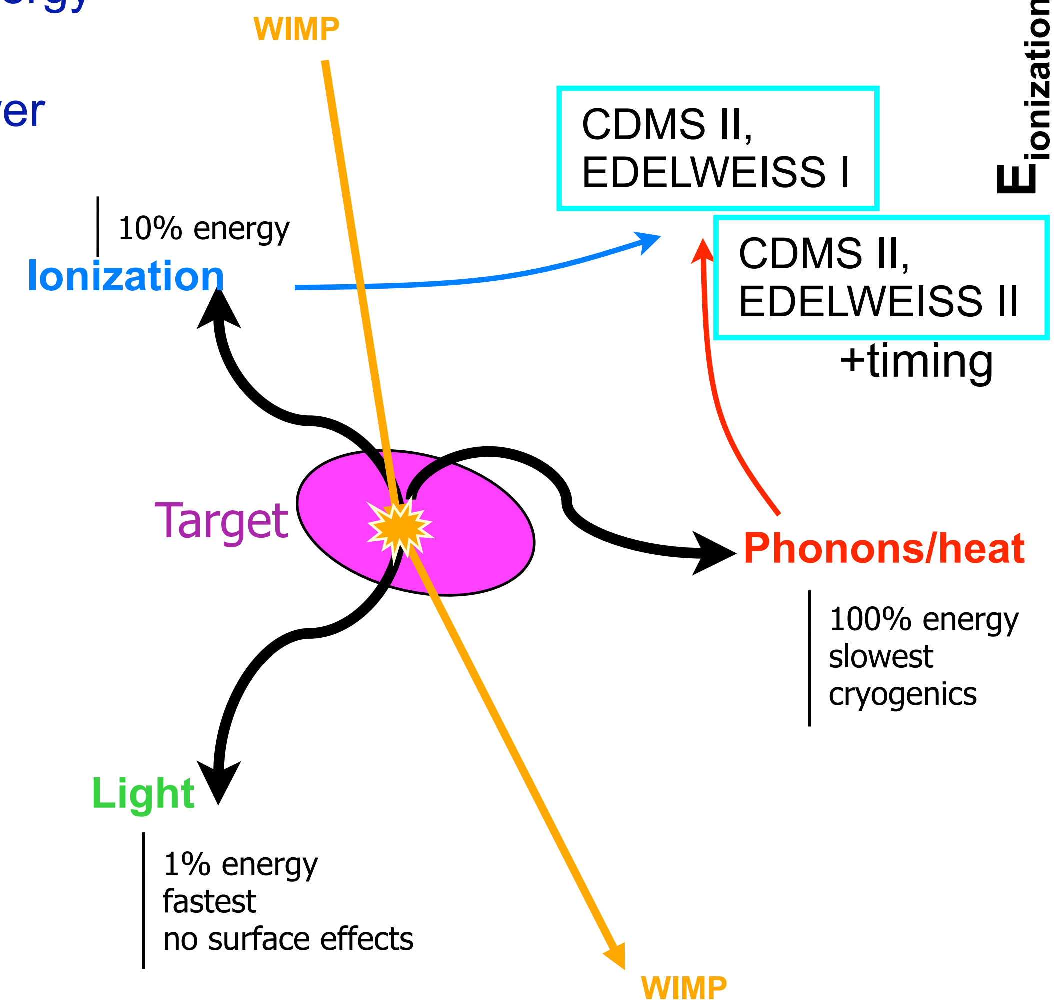

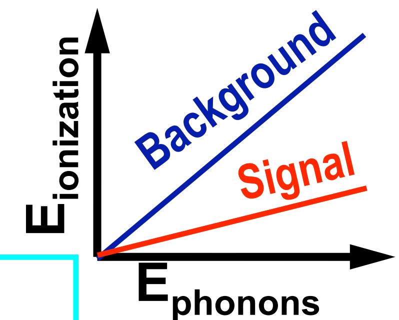

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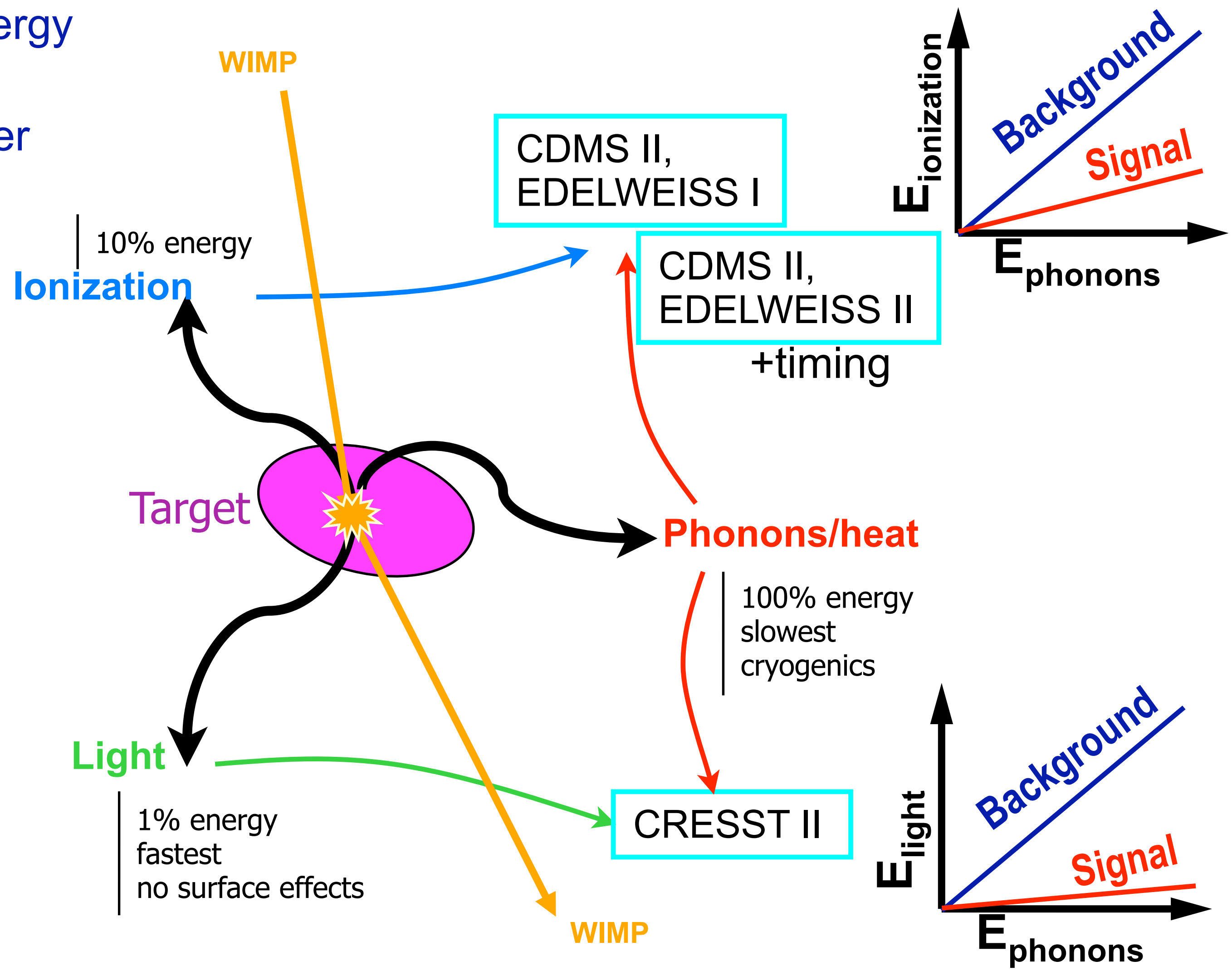

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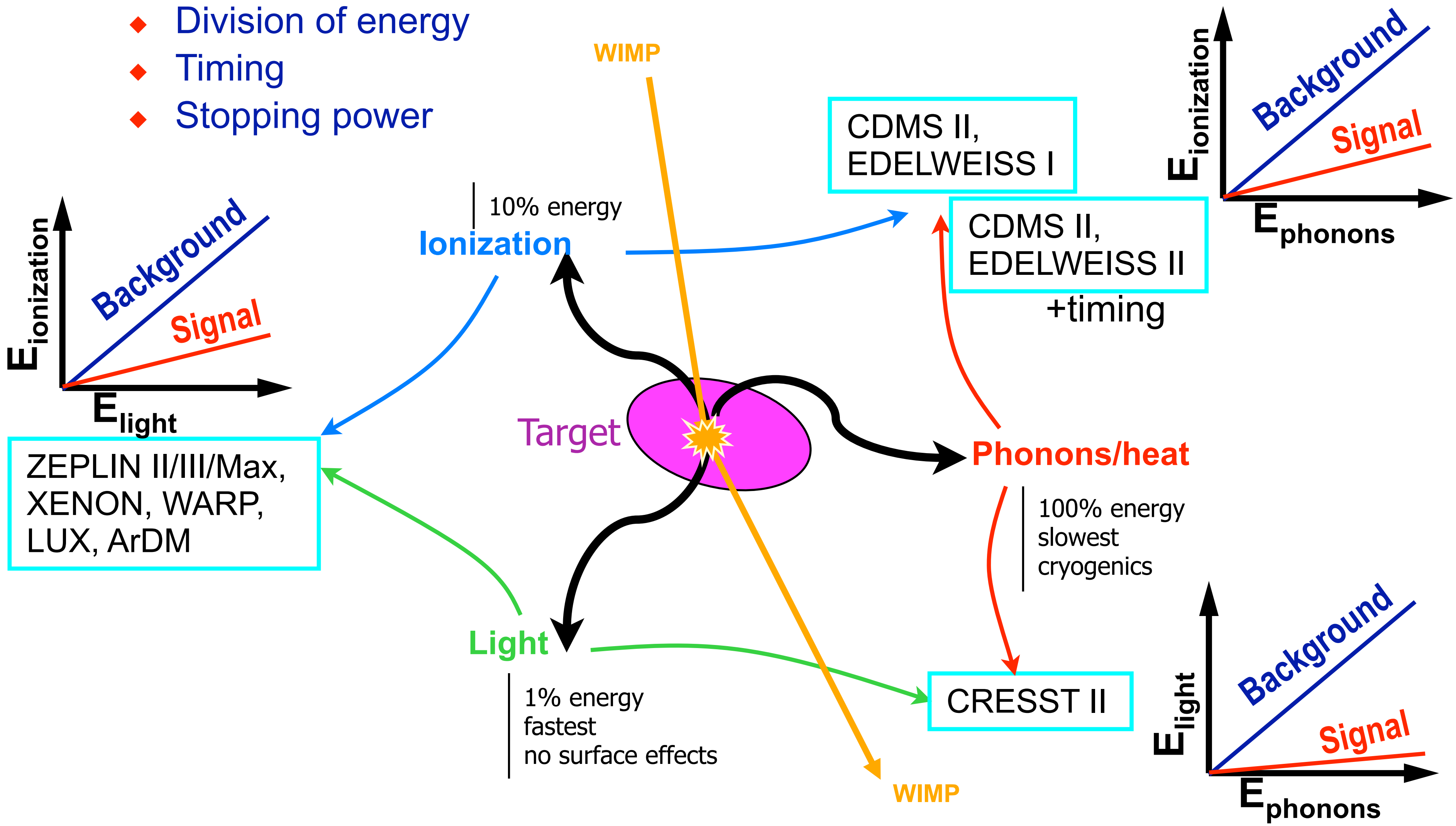

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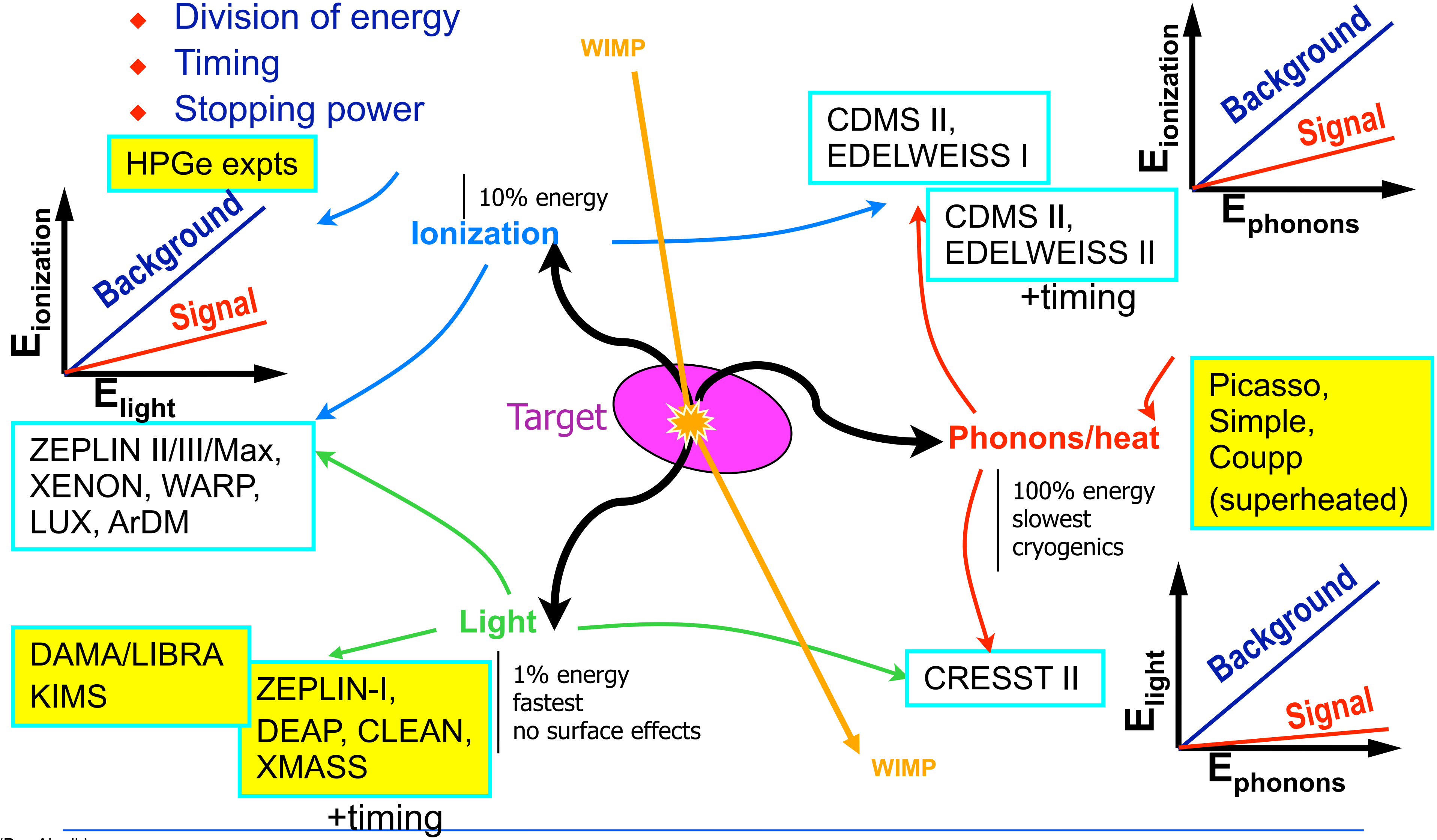

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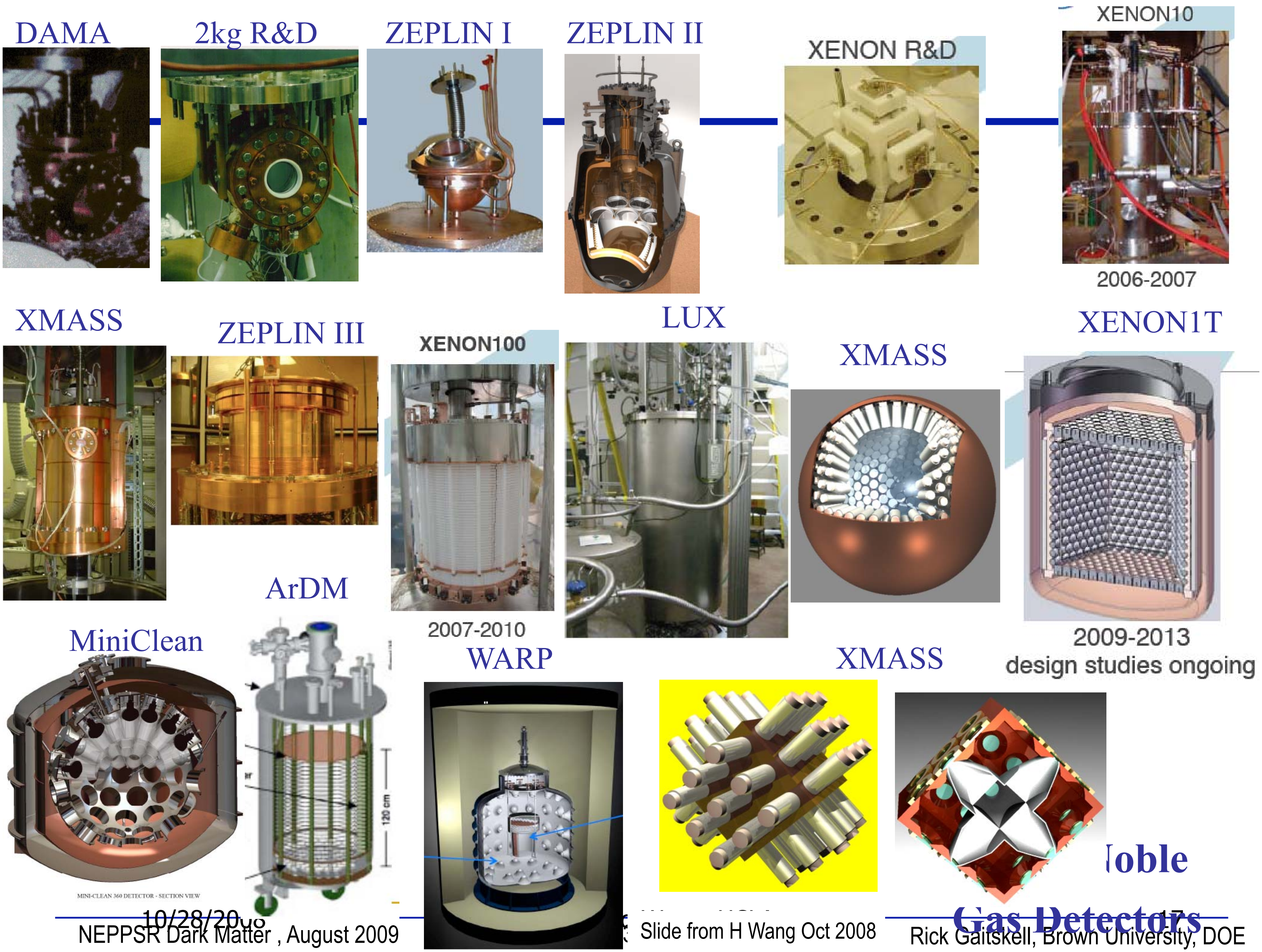

DAMA
2kg R&D
ZEPLIN I
ZEPLIN II
XENON R&D
XENON10
2006-2007
XMASS
ZEPLIN III
XENON100
2007-2010
LUX
XMASS
XENON1T
2009-2013
design studies ongoing
ArDM
MiniClean
MINI-CLEAN 360 DETECTOR - SECTION VIEW
120 cm
WARP
XMASS
loble
Gas Detectors

What Nature has to Offer

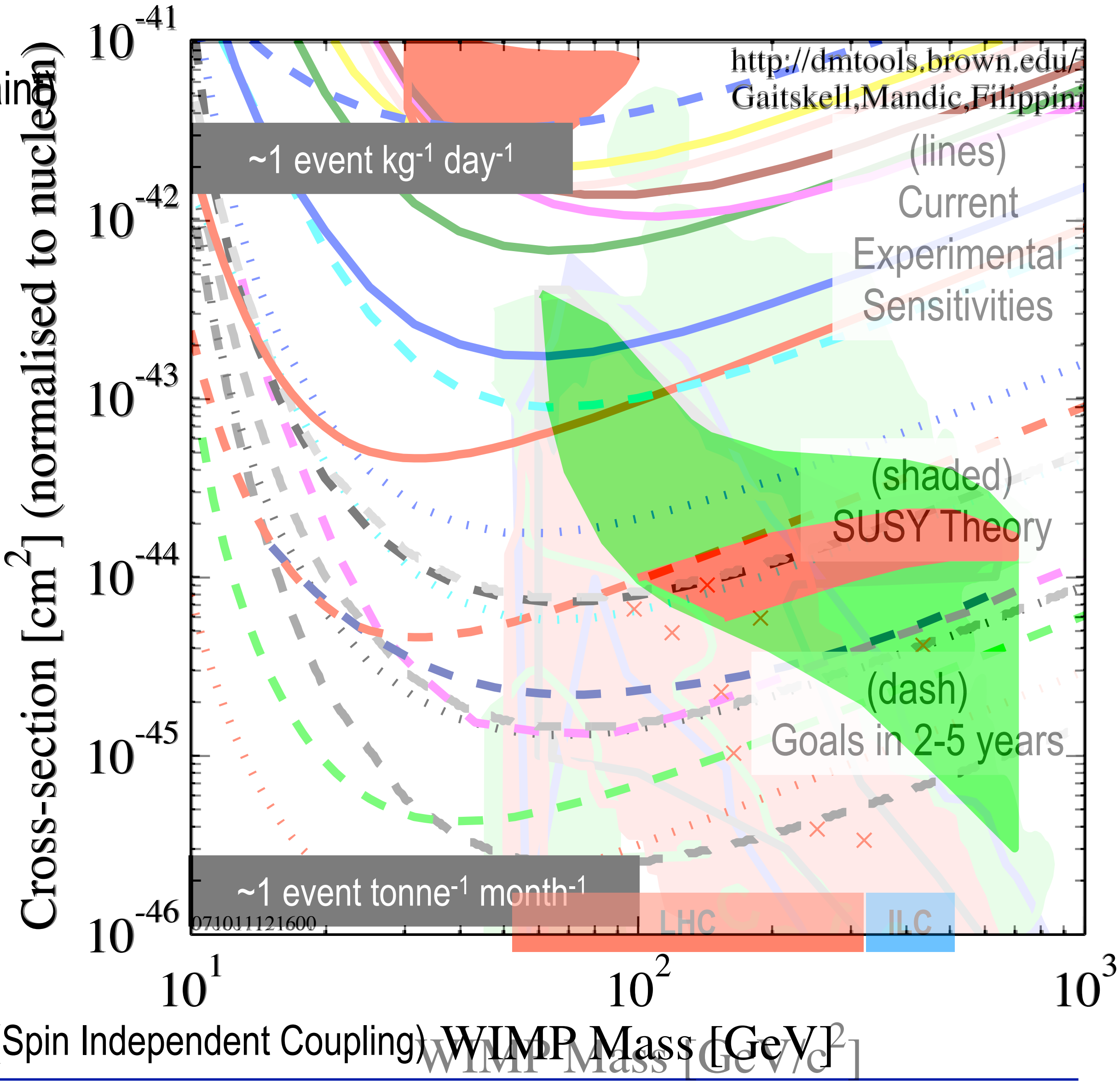
What we hope for!

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

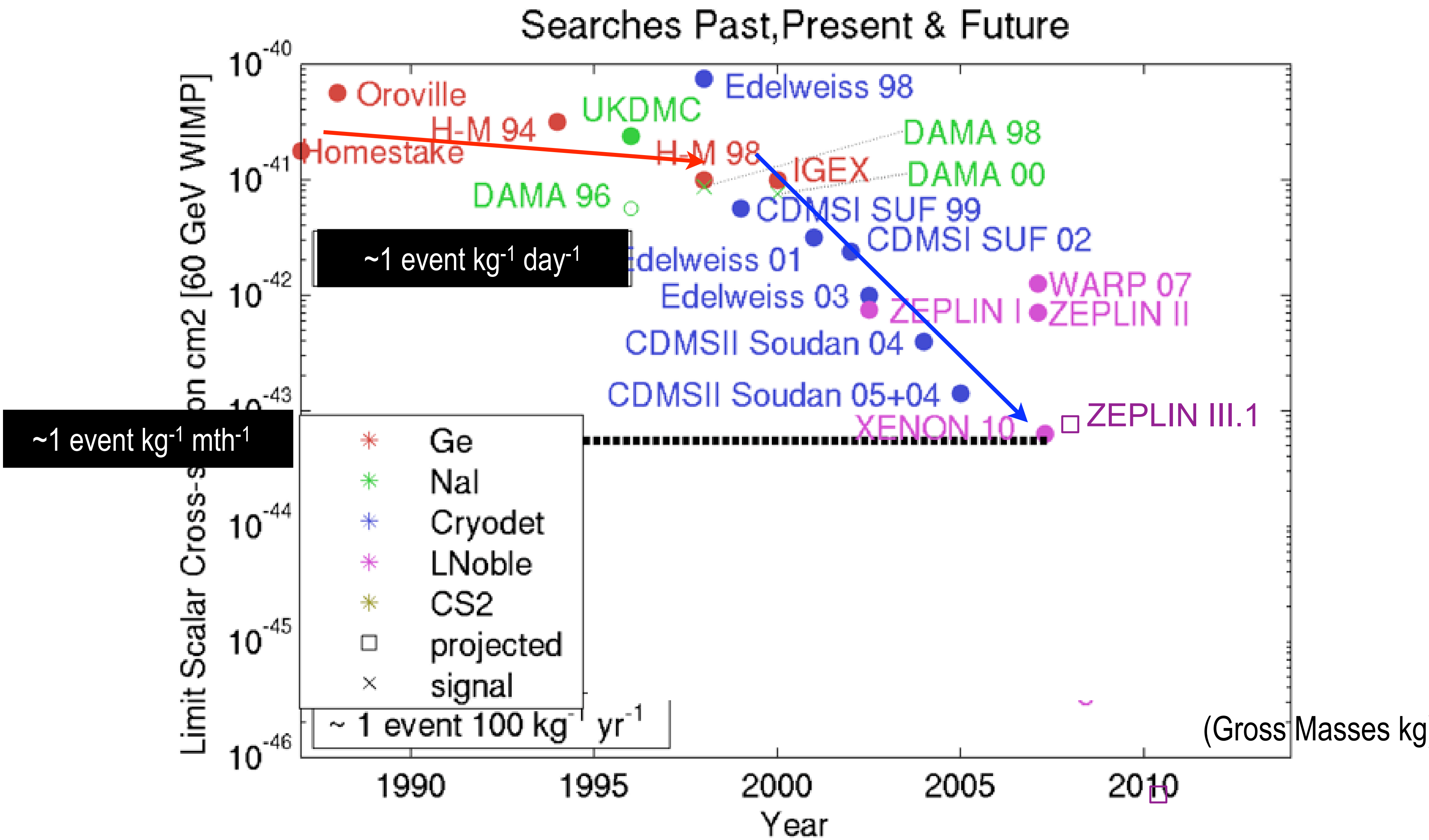
SOME SUSY MODELS

- [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)



(Spin Independent Coupling)

DM Direct Search Progress Over Time (2009)



Plot updated from that in DM Review Article:

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

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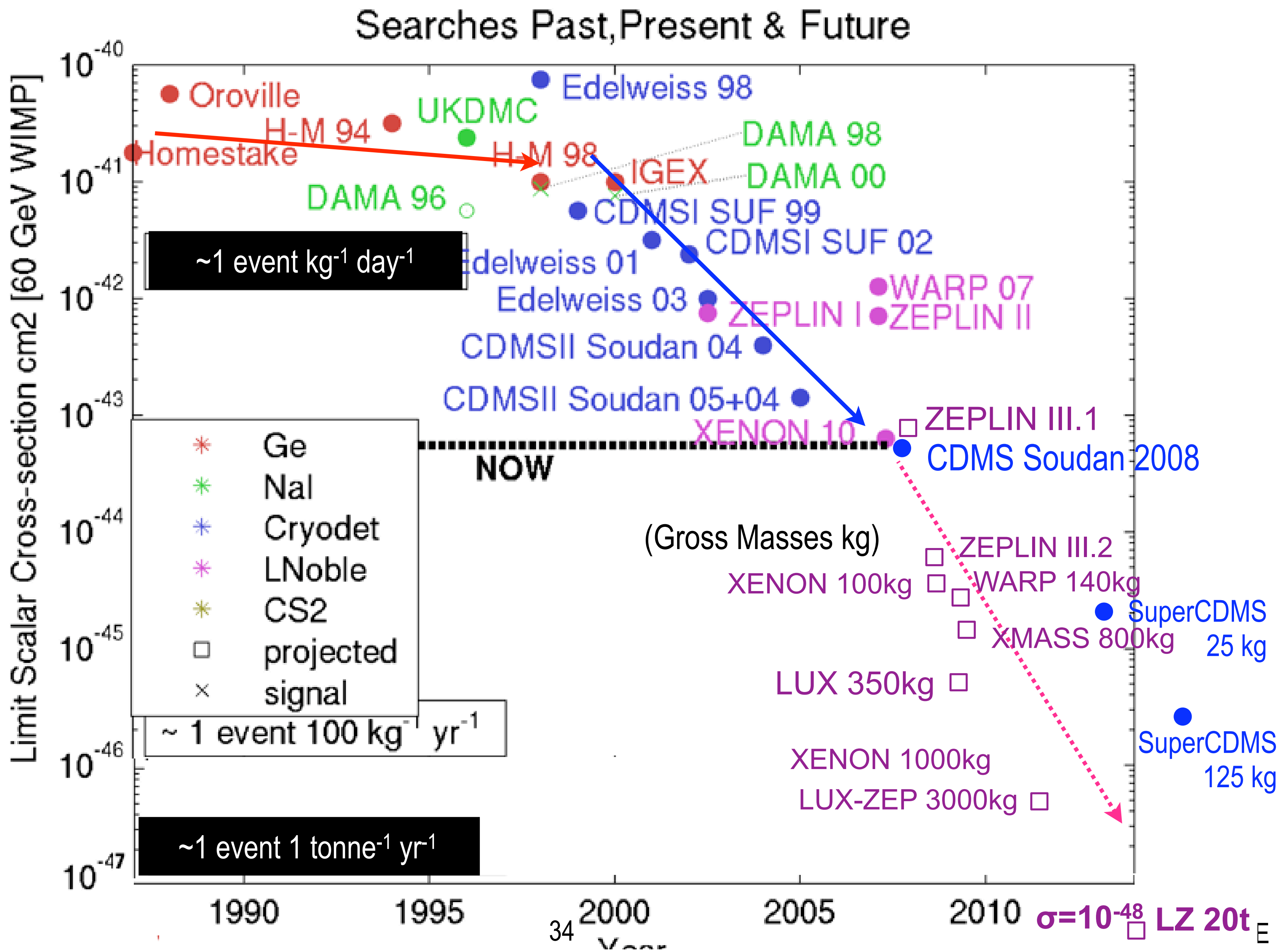
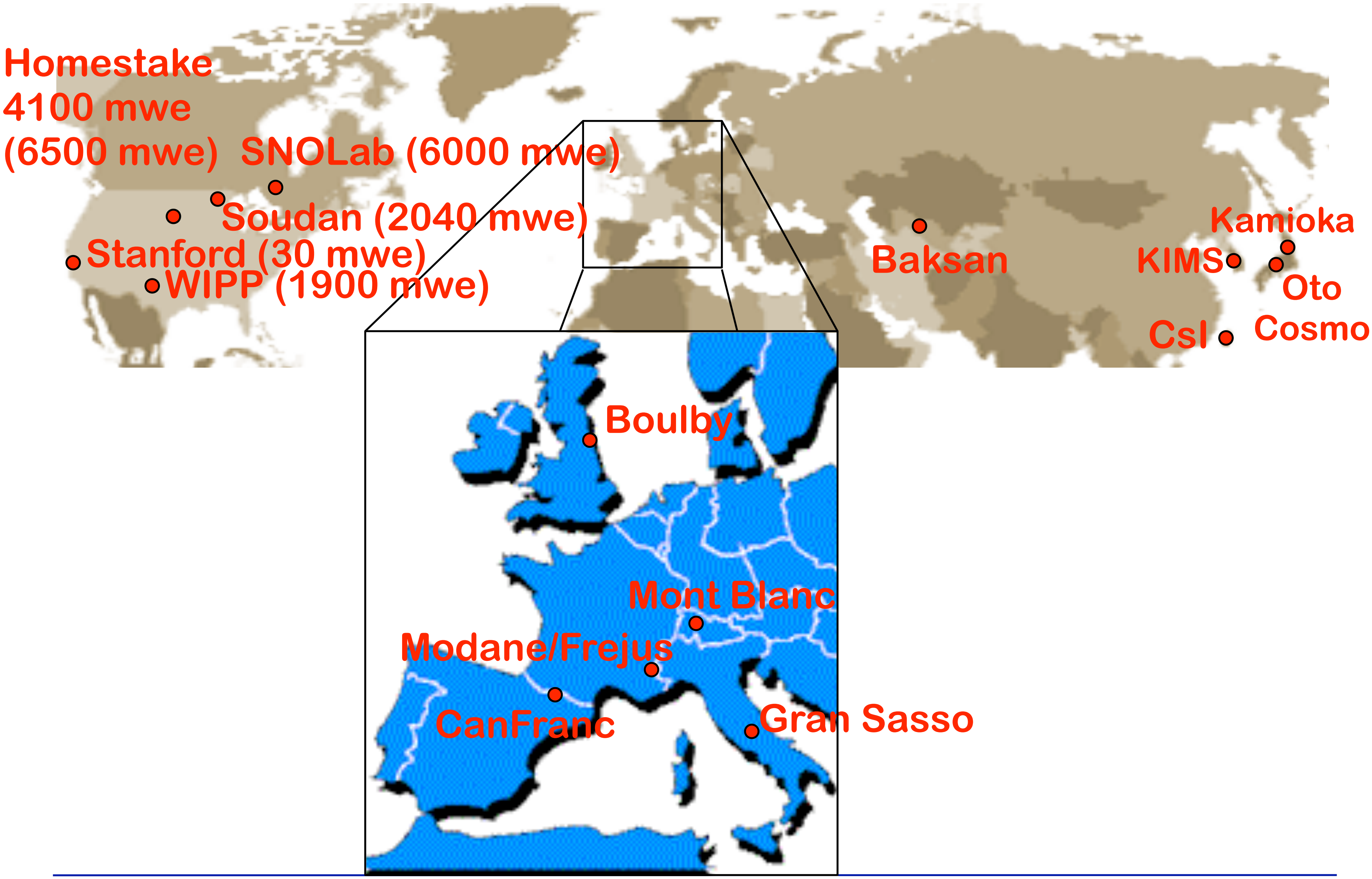


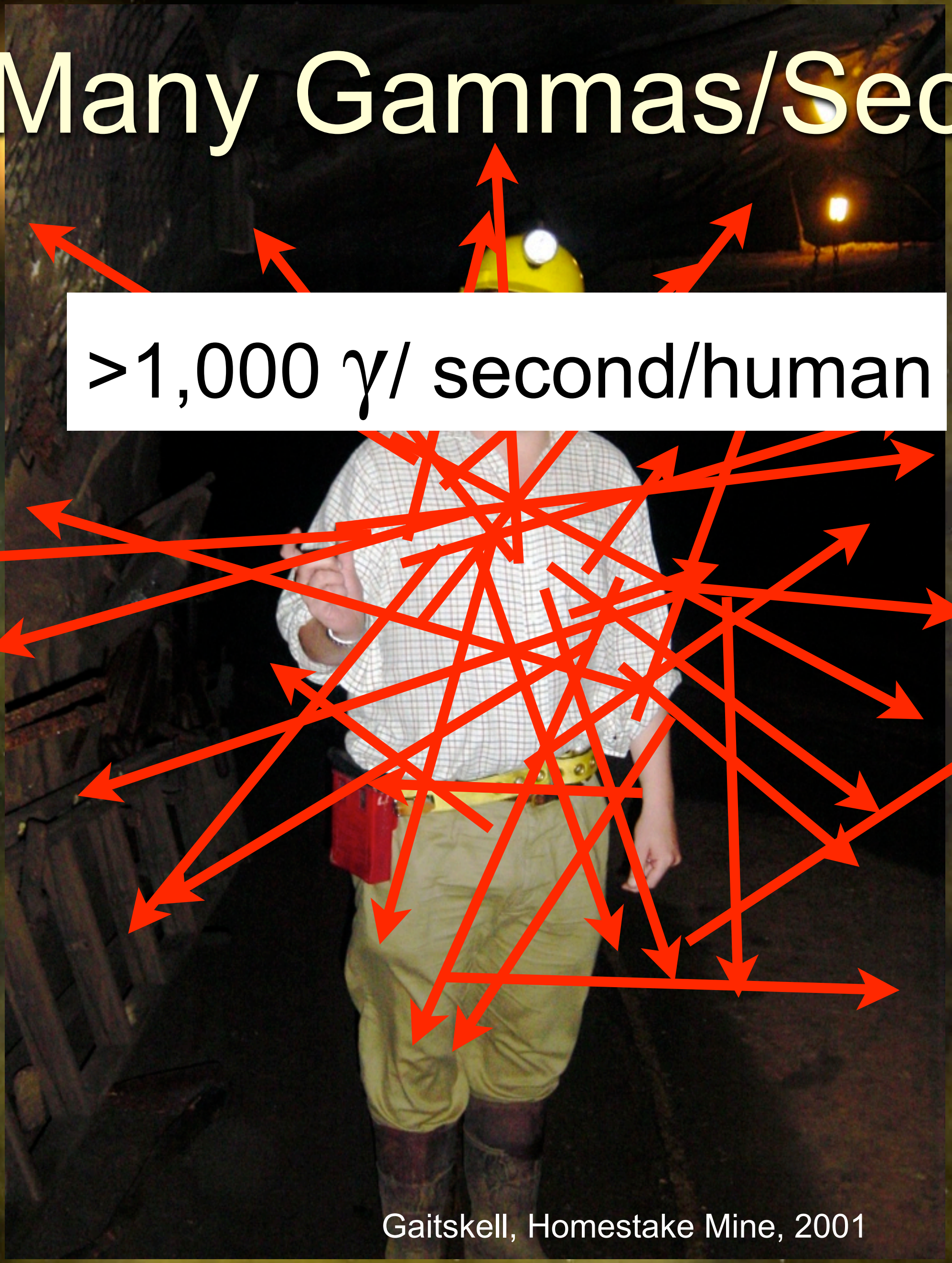
Underground Laboratories Worldwide



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?



Background Challenges

- Search sensitivity (low energy region <<100 keV)
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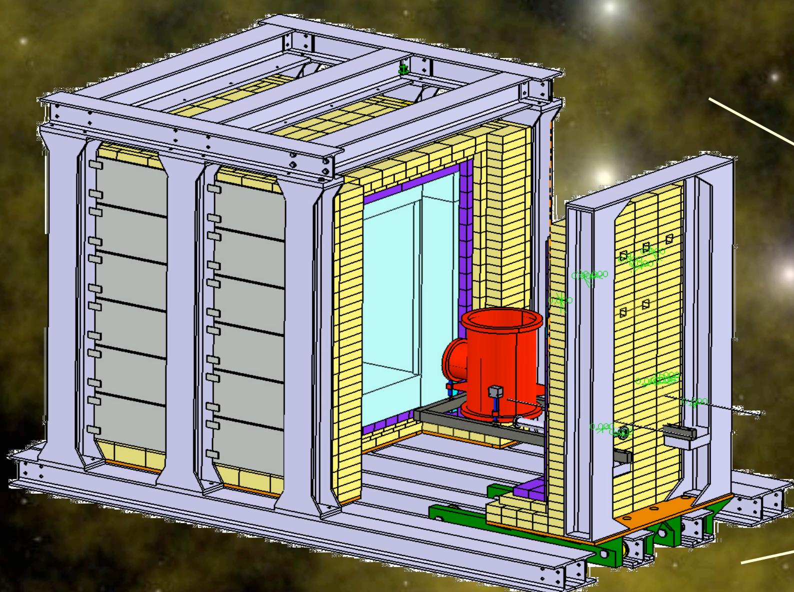
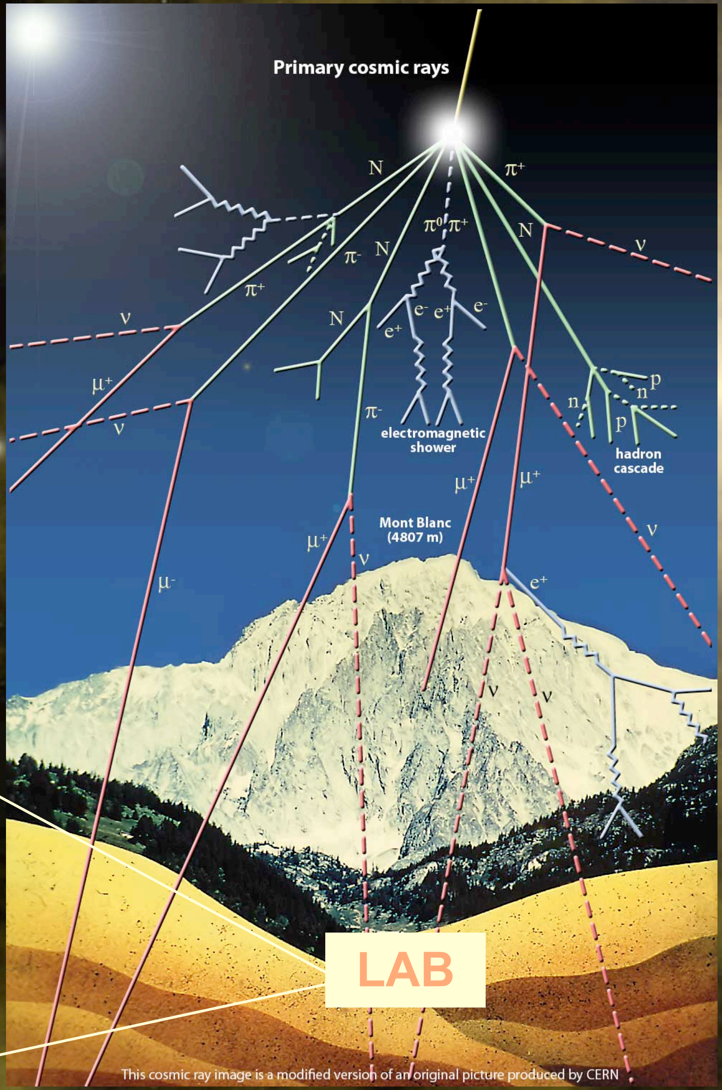
- Activity of typical Human?
- ~10 kBq (10^4 decays per second, 10^9 decays per day)
- Environmental Gamma Activity
  - Unshielded 10^7 evt/kg/day (all values integrated 0–100 keV)
  - This can be easily reduced to ~10^2 evt/kg/day using 25 cm of Pb
- Main technique to date focuses on nuclear vs electron 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

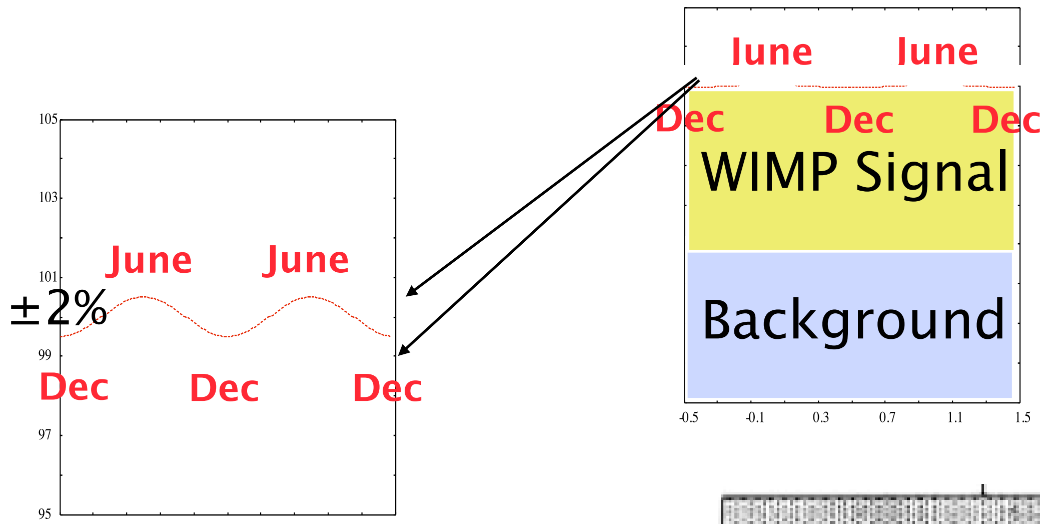
TYPE	DISCRIMINATION TECHNIQUE	TYPICAL EXPERIMENT	ADVANTAGE
Ionization	None (Ultra Low BG)	MAJORANA, GERDA	Searches for ββ-decay, dm additional
Solid Scintillator	pulse shape discrimination	LIBRA/DAMA, KIMS	low threshold, large mass, but poor discrim
Cryogenic	charge/phonon light/phonon	CDMS, CRESST EDELWEISS	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

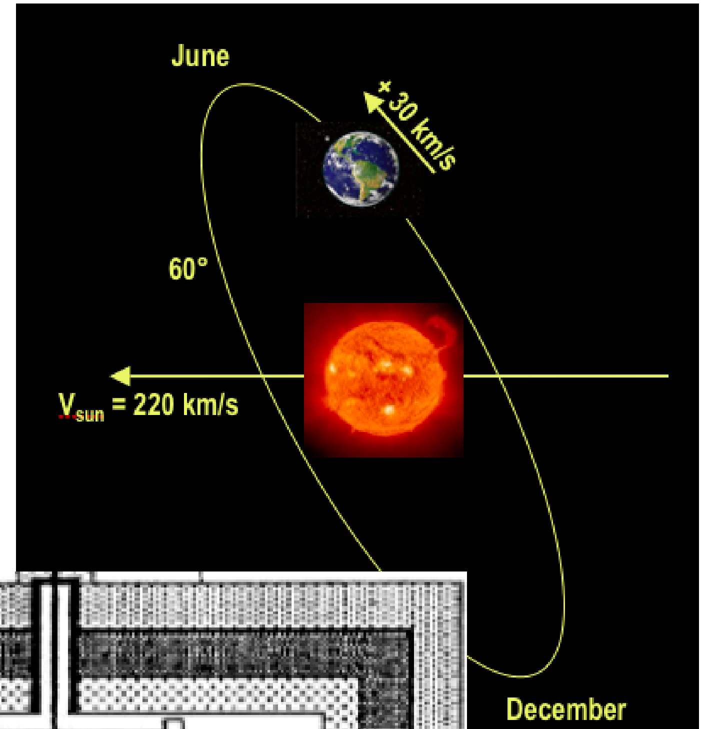
R.J. Gaitskell, Ann. Rev. Nucl. Par. Sci, 54 (2004) 315

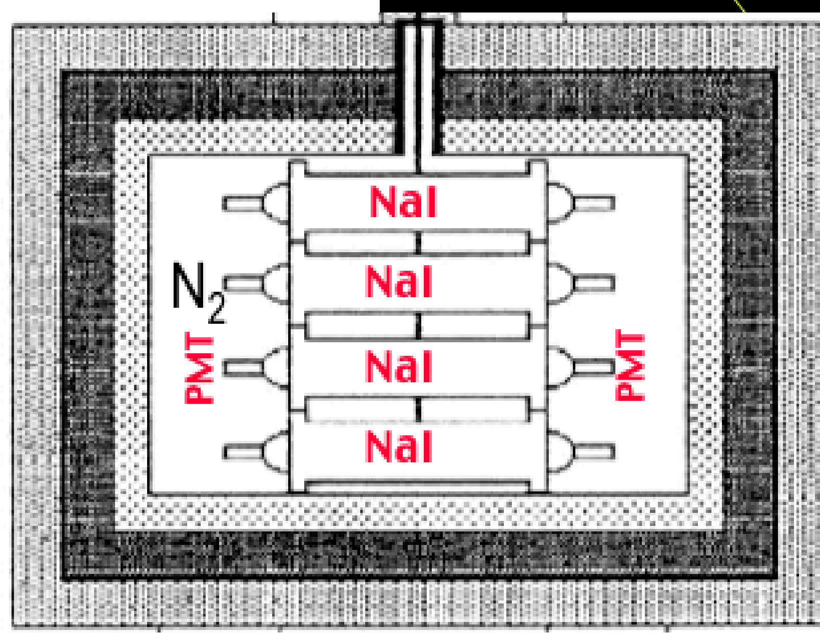
Future of Direct Detection

- 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
  - Sanford Lab/DUSEL (Homestake), US

DAMA: NaI & Annual Modulation



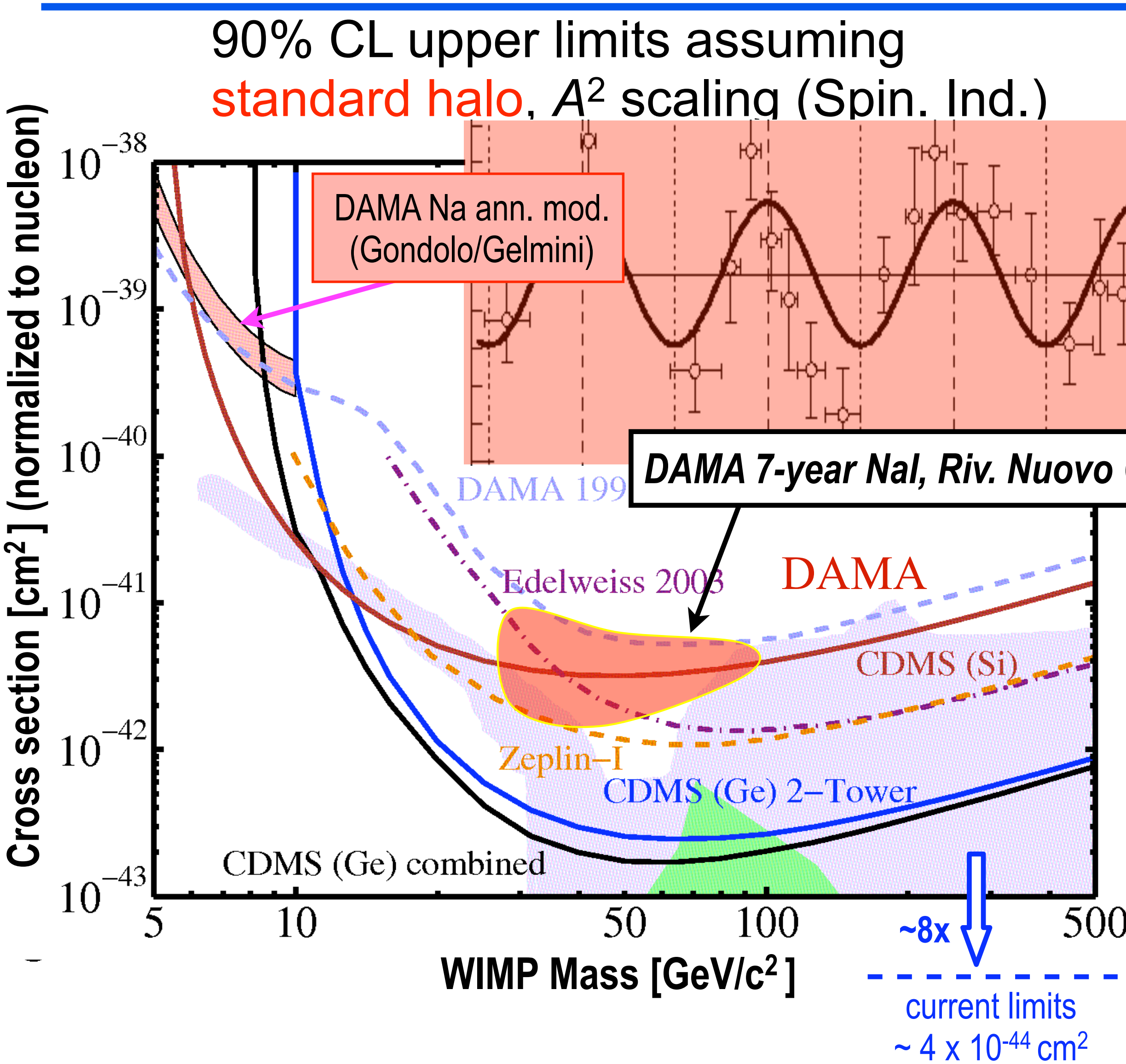




100-kg detector mass: measure energy for each event without discrimination of background

(Dan Akerib)

DAMA Modulation signal & cross checks c.2005

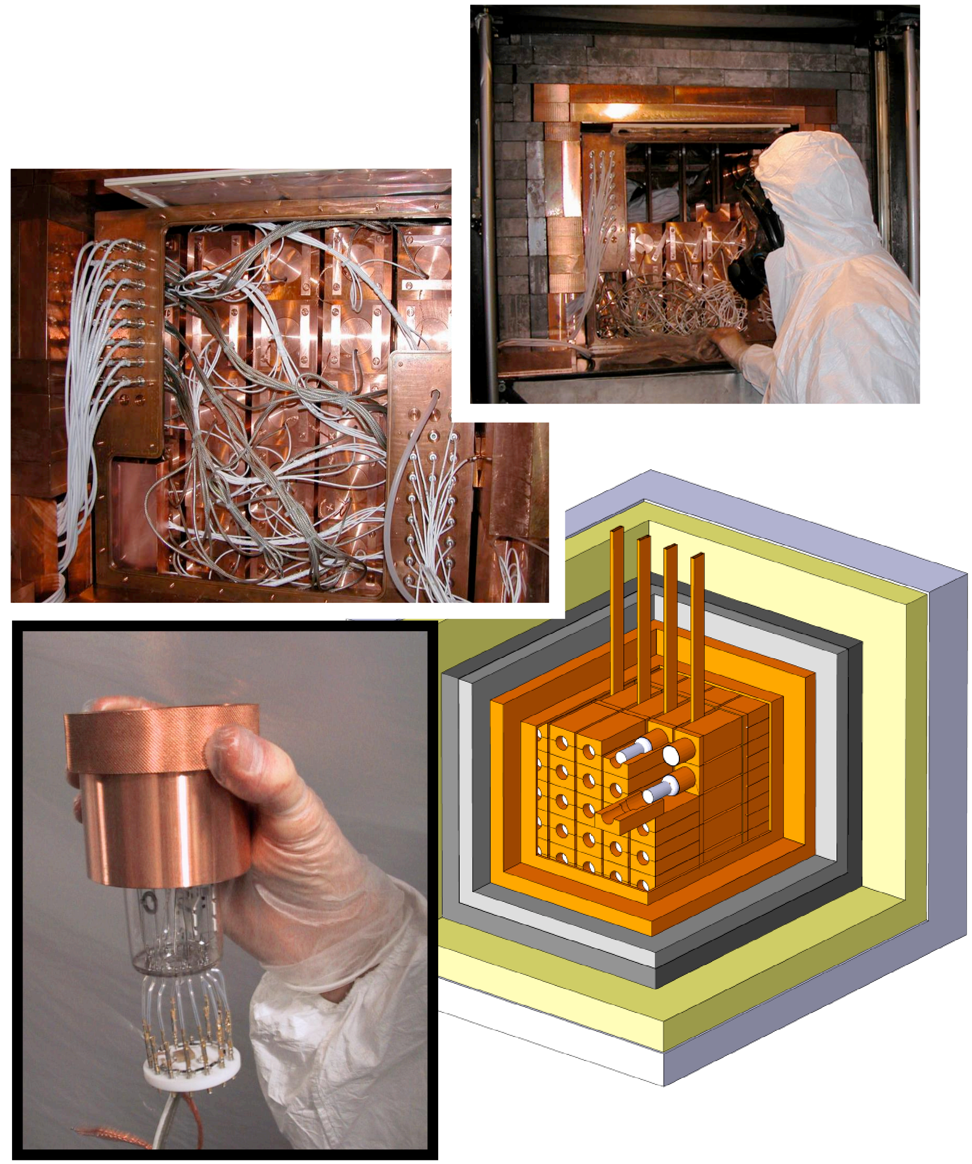


- Iodine-based annual modulation not compatible
- Alternate interpretation: Sodium for low mass almost ruled out
- Further tests for Spin-Dependent couplings...

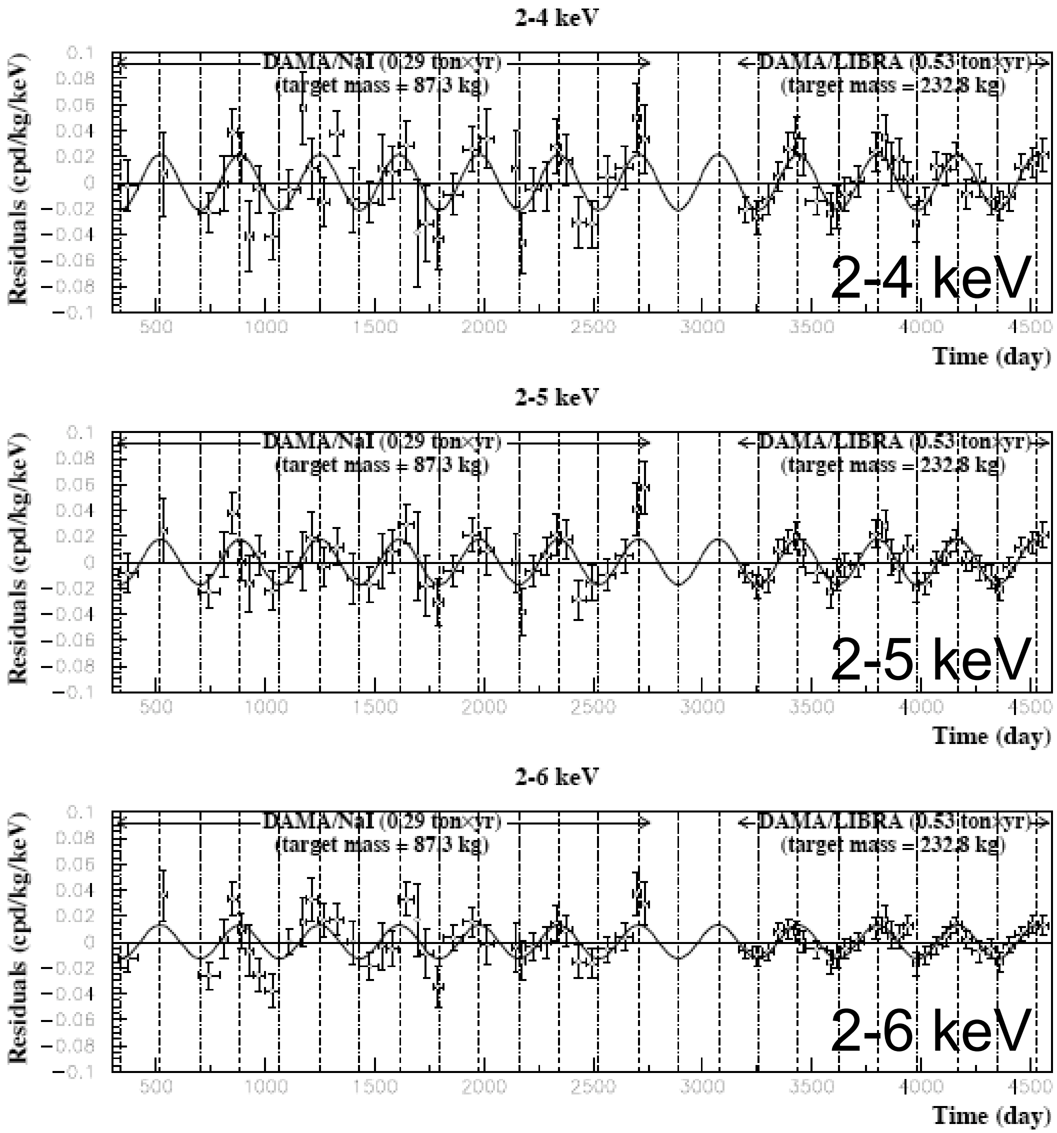
(Dan Akerib)

DAMA (100 kg) → LIBRA (250 kg)

- LIBRA
  - Large sodium Iodide Bulk for RAre processes
  - Operating since 2003 in LNGS
- First results recently reported
  - Modulation persists: +4 cycles



DAMA/Libra Modulation signal



11 annual cycles

Residual rate: modulation signal increases to 8σ

arXiv:0804.2738, arXiv:0804.2741
http://neutrino.pd.infn.it/NO-VE2008/talks-NOVE.html

(Dan Akerib)

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

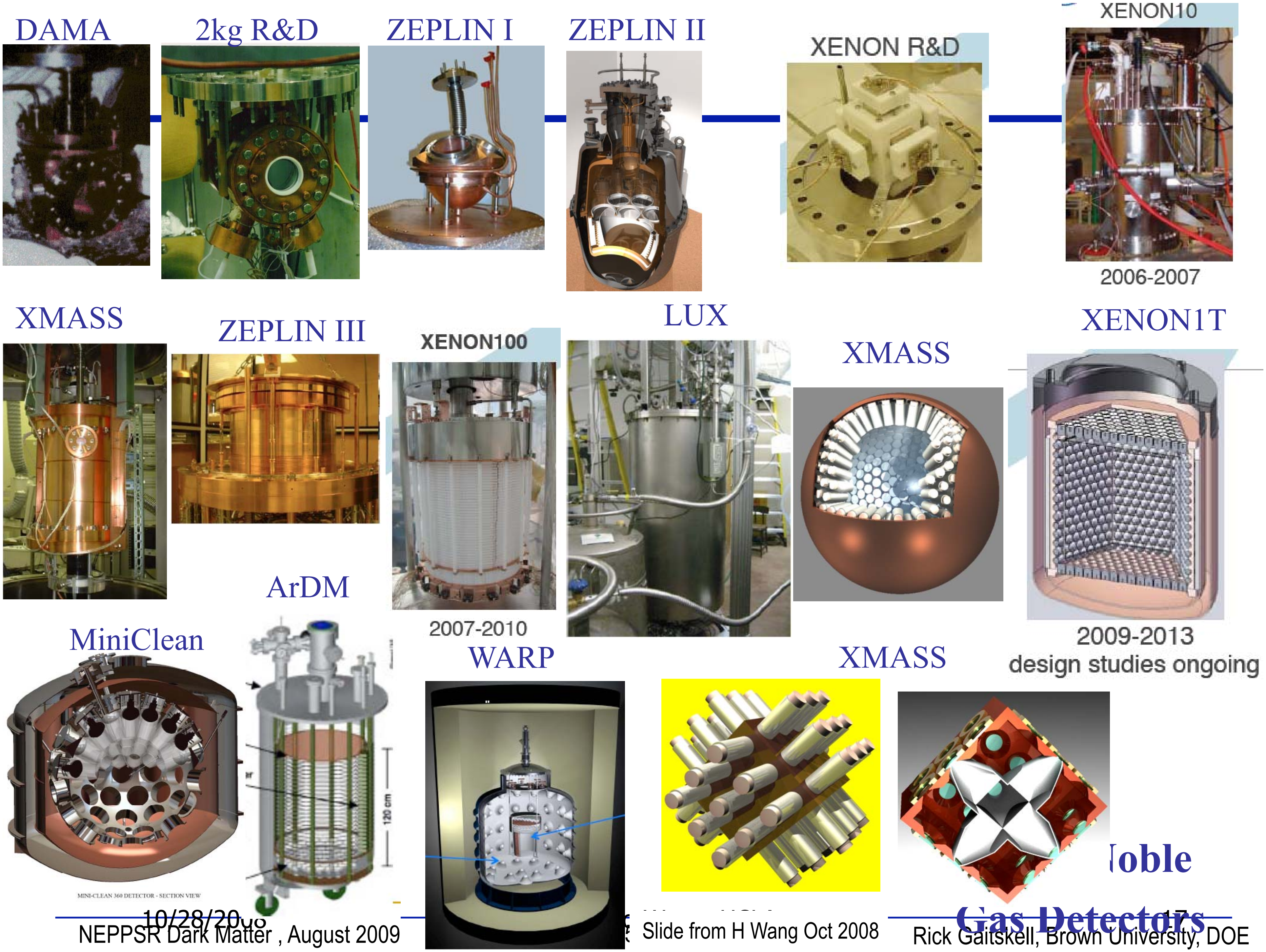
	Z (A)	BP (T_b) at 1 atm [K]	liquid density at T_b [g/cc]	ionization [e-/keV]	scintillation [photon/keV]
He	2 (4)	4.2	0.13	39	22
Ne	10 (20)	27.1	1.21	46	30
Ar	18 (40)	87.3	1.40	42	40
Kr	36 (84)	119.8	2.41	49	25
Xe	54 (131)	165.0	3.06	64	46

- 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)

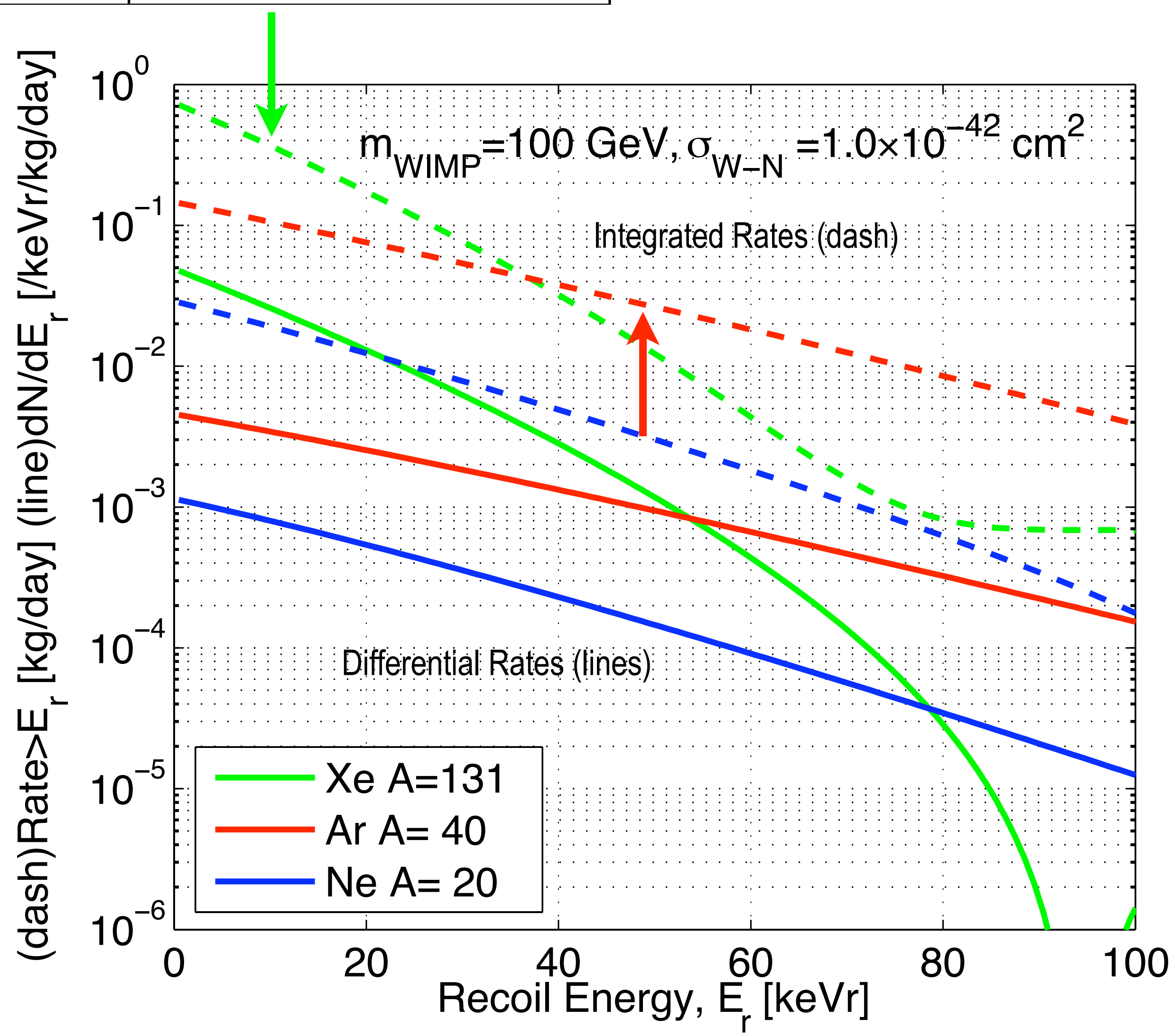
Noble Liquid Comparison (DM Detectors)

	Scintillation Light	Intrinsic Backgrounds
Ne (A=20) $60/kg 100% even-even nucleus	85 nm Requires wavelength Shifter	Low BP (20K) - all impurities frozen out No radioactive isotopes
Ar (A=40) $2/kg (isotope separation >$1000/kg) ~100% even-even	125 nm Requires wavelength shifter	Nat Ar contains ~39Ar 1 Bq/kg == ~150 evts/keVee/kg/day at low energies. Requires isotope separation, low 39Ar source, or very good discrimination (~10^6 to match CDMS II)
Xe (A=131) $800/kg 50% odd isotope	175 nm UV quartz PMT window	136Xe double beta decay is only long lived isotope - below pp solar neutrino signal. Relevant for DM search below ~10^{-47} cm^2. 85Kr can be removed by charcoal or distillation separation.


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
ArDM
MiniClean
MINI-CLEAN 360 DETECTOR - SECTION VIEW
120 cm
WARP
XMASS
loble
Gas Detectors

Noble Liquid Comparison (DM Detectors)

	Scintillation Light	Intrinsic Backgrounds
Ne (A=20) $60/kg 100% even-even nucleus	85 nm Requires waveleng Shifter	
Ar (A=40) $2/kg (isotope separation >$1000/kg) ~100% even-even	125 nm Requires waveleng	
Xe (A=131) $1000-2000/kg 50% odd isotope	175 nm UV quart window	



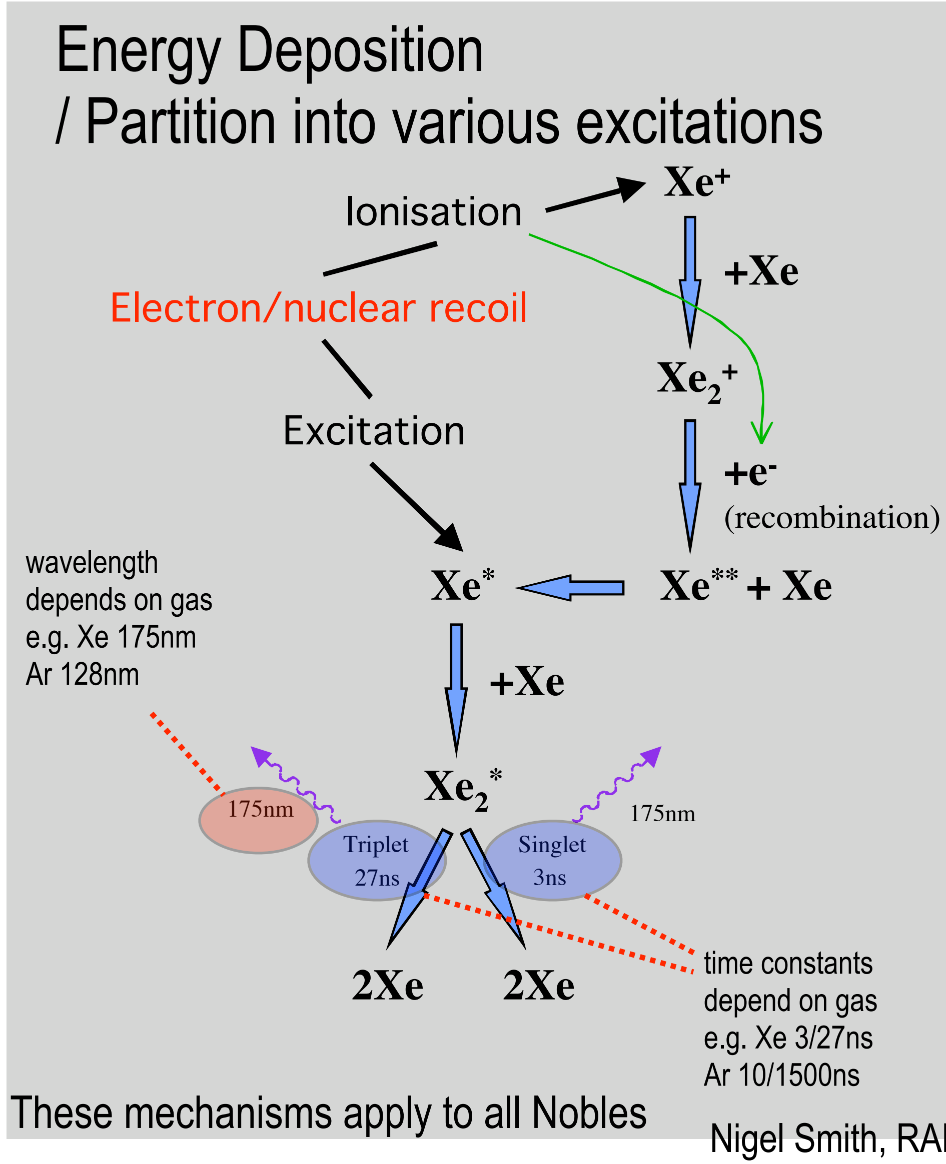
Noble Liquid Comparison (DM Detectors)

	Scintillation Light	Intrinsic Backgrounds	WIMP (100 GeV) Sensitivity vs Ge >10 keVr
Ne (A=20) $60/kg 100% even-even nucleus	85 nm Requires wavelength Shifter	Low BP (20K) - all impurities frozen out No radioactive isotopes	Scalar Coupling: Eth>50 keVr, 0.02x Axial Coupling: 0 (no odd isotope)
Ar (A=40) $2/kg (isotope separation >$1000/kg) ~100% even-even	125 nm Requires wavelength shifter	Nat Ar contains ~39Ar 1 Bq/kg == ~150 evts/keVee/kg/day at low energies. Requires isotope separation, low 39Ar source, or very good discrimination (~10^6 to match CDMS II)	Scalar Coupling: Eth>50 keVr, 0.10x Axial Coupling: 0 (no odd isotope)
Xe (A=131) $1000-2000/kg 50% odd isotope	175 nm UV quartz PMT window	136Xe double beta decay is only long lived isotope - below pp solar neutrino signal. Relevant for DM search below ~10^{-47} cm^2. 85Kr can be removed by charcoal or distillation separation.	Scalar Coupling: Eth>10 keVr, 1.30x Axial Coupling: ~5x (model dep) Xe is 50% odd n isotope 129Xe, 131Xe

Noble Liquid Detectors: Mechanism & Experiments

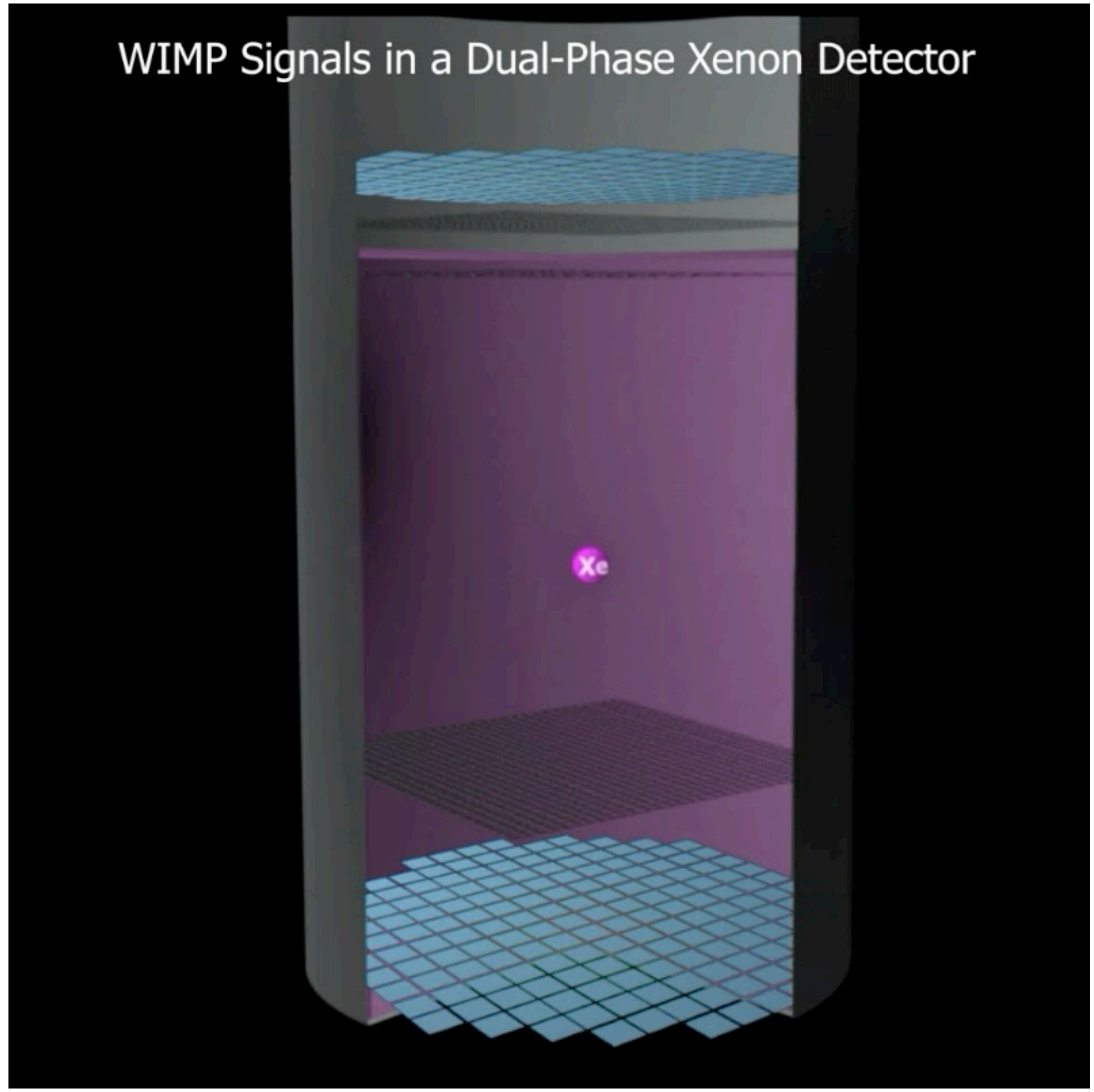
	Single phase (Liquid only) PSD	Double phase (Liquid + Gas) PSD/Ionization
Xenon	ZEPLIN I XMASS	ZEPLIN II+III, XENON, XMASS-DM, LUX
Argon	DEAP/ CLEAN	WARP, ArDM
Neon	CLEAN	

- Single phase - scintillation only
  - e-ion recombination occurs
  - singlet/triplet ratio 10:1 nuclear:electron
- Double phase - ionization & scintillation
  - drift electrons in E-field (kV/cm)



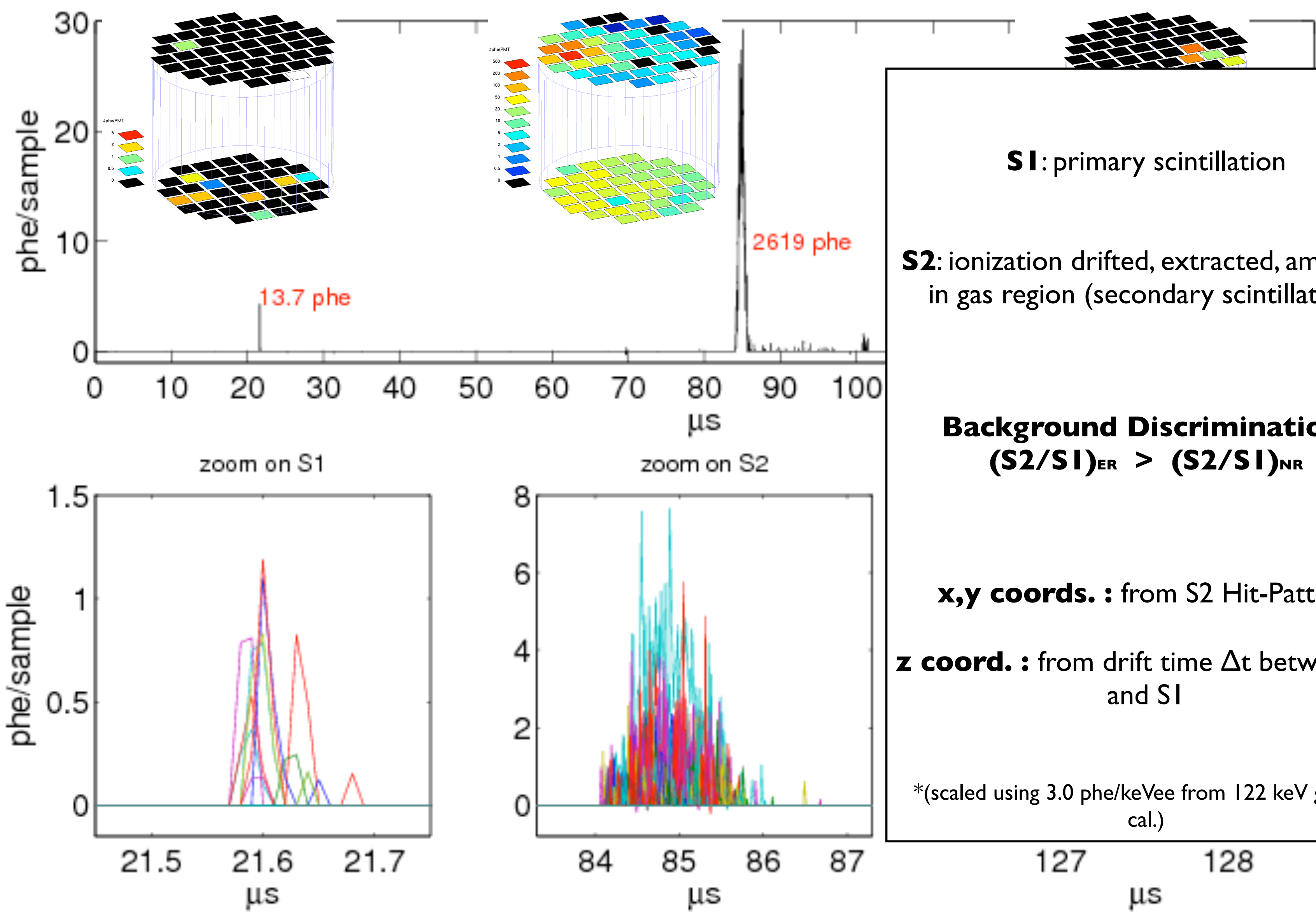
Noble Liquid Dual phase Time Projection Chamber

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



- Recent Results Experiments:
  - XENON10 (2006-2007, Gran Sasso Italy)
  - ZEPLIN II
  - ZEPLIN III
  - WARP 2.5 kg
- Construction/Commissioning
  - XENON100 (Gran Sasso)
  - LUX 350 kg (Sanford Lab, SD)
  - WARP 140 (Gran Sasso)
  - XMASS-DM 10 kg (Kamioka)
  - ARDM (Canfranc)
- Single Phase is a distinct technique
  - XMASS 800 kg
  - CLEAN/DEAP 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:
$(S2/S1)_{ER}$ > $(S2/S1)_{NR}$

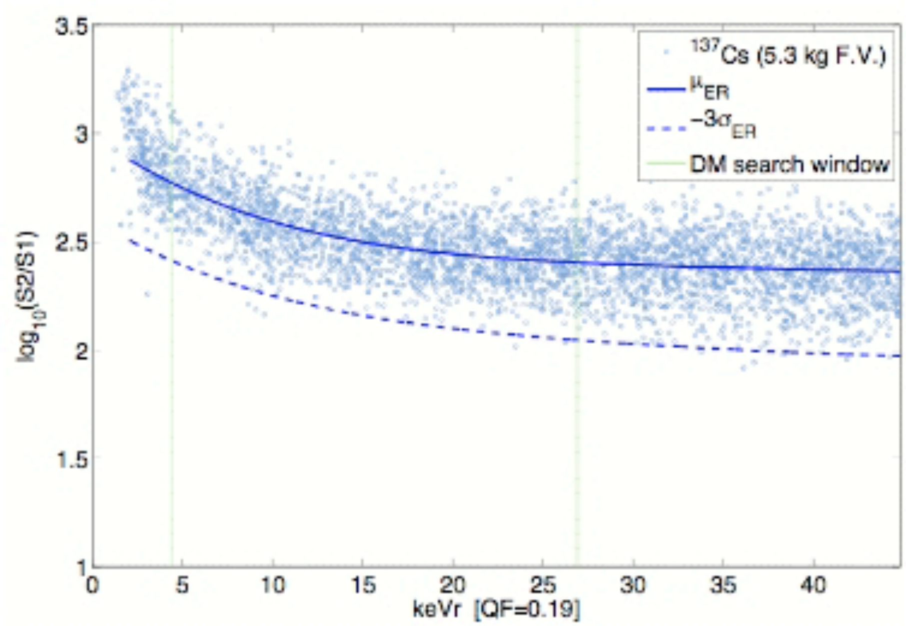
x,y coords. : from S2 Hit-Pattern

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

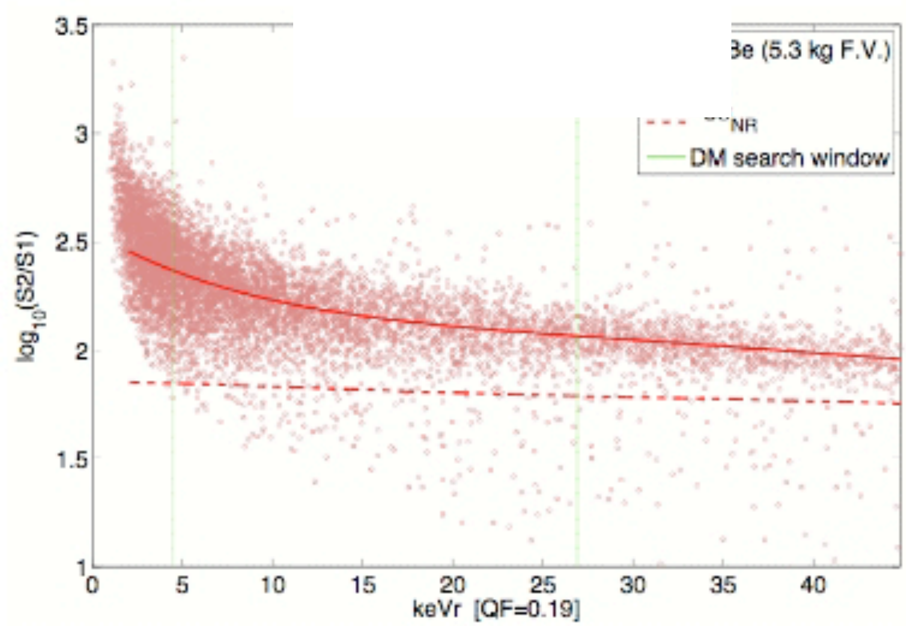
*(scaled using 3.0 phe/keVee from 122 keV gamma cal.)

Calibration Data Band Centroid / -3σ

Gamma Response

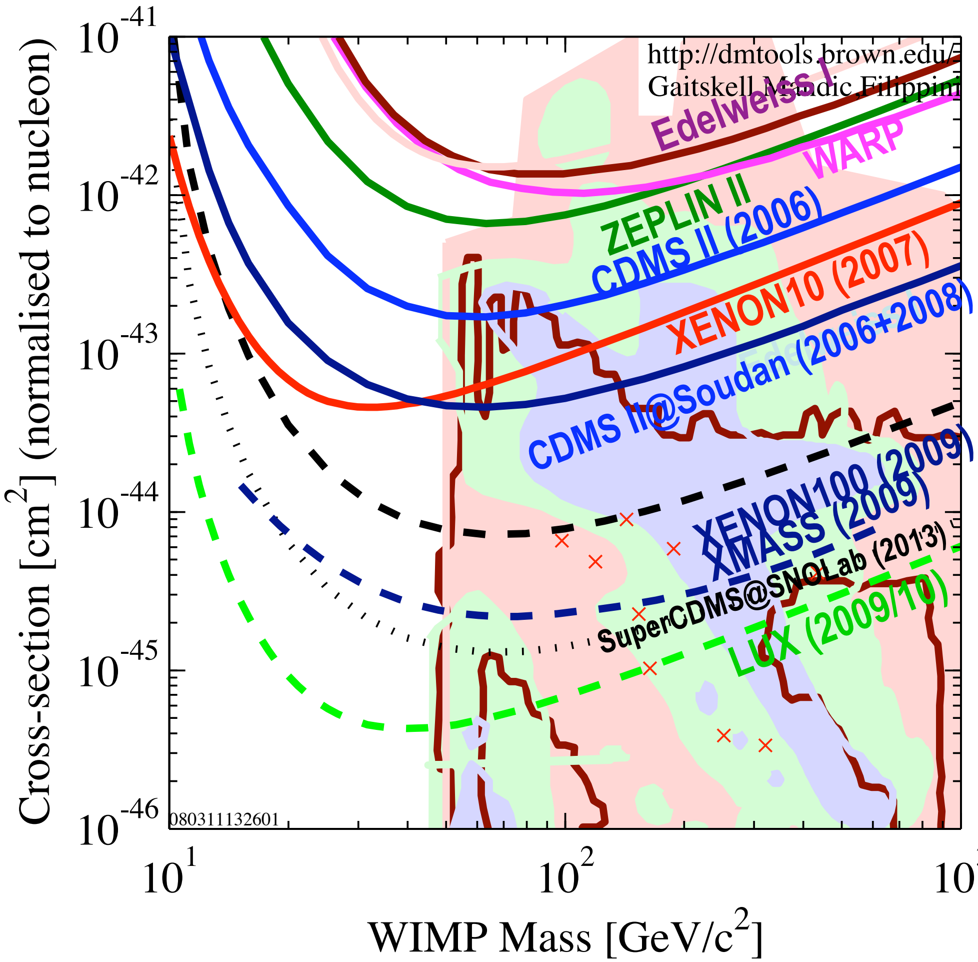


Neutron Response



LUX Dark Matter Sensitivity

- Dark Matter Goals
  - 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 conservative 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 extend background free running period, and DM sensitivity

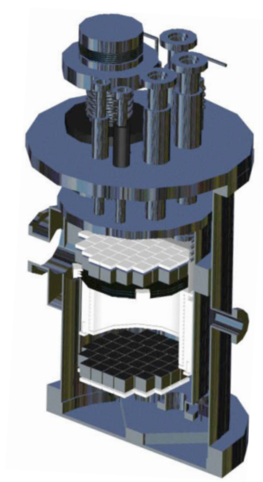


  - Comparison
    - SuperCDMS Goal @ SNOLab: Gross Ge Mass 25 kg
      (x 50% fid mass+cut acceptance)
      Limit set for 1000 days running x 7 SuperTowers

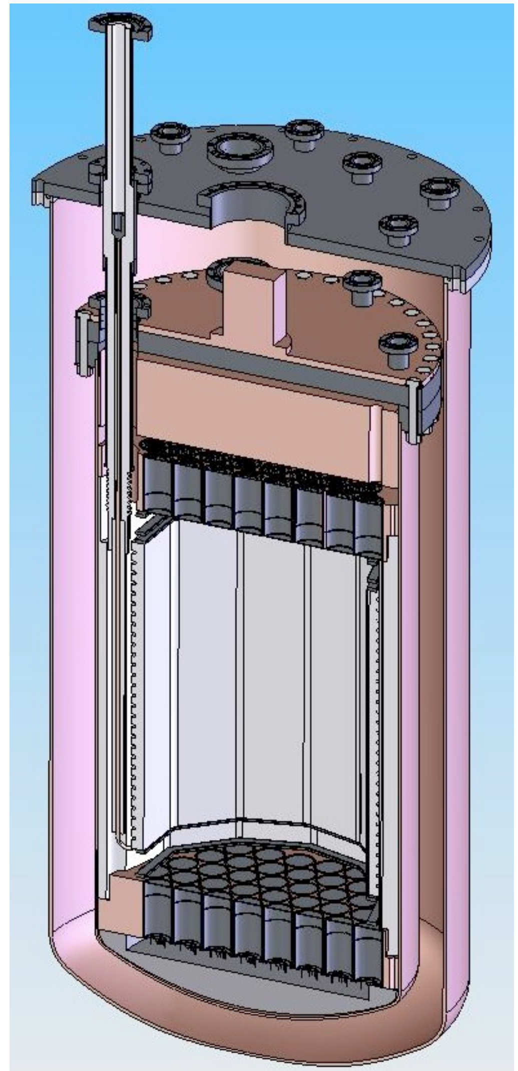
This plot has a very limited number of current and projected results.
Please go to http://dmtools.brown.edu

Evolution

- From XENON10/ZEPLIN to LUX
  - Self shielding much improved
  - Fiducial Region
    - 5 kg -> 100 kg
  - Overall Increase sensitivity by ~100x



XENON10
22 kg / Fiducial 5.4 kg

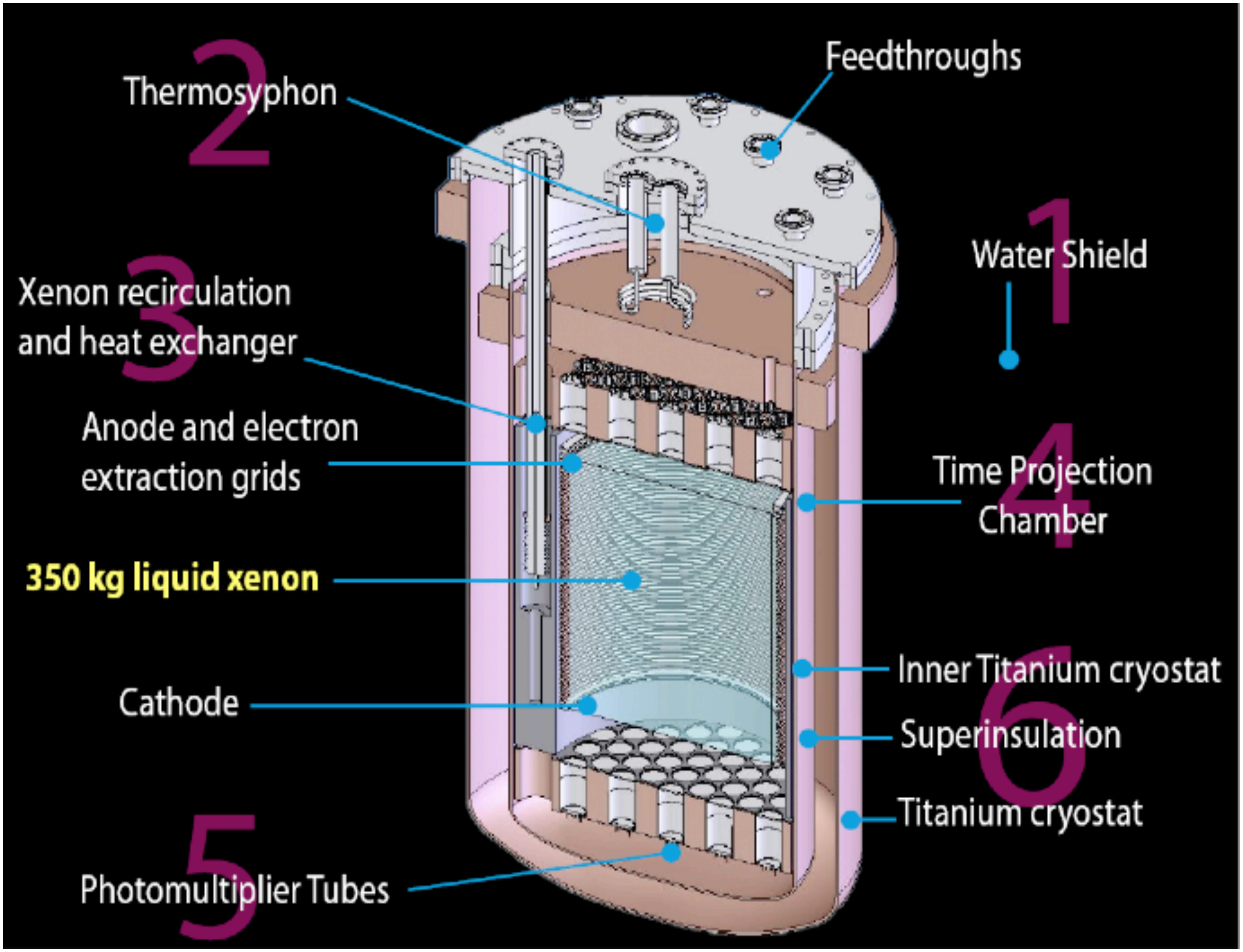


LUX
350 kg / Fiducial 100 kg

The LUX Collaboration

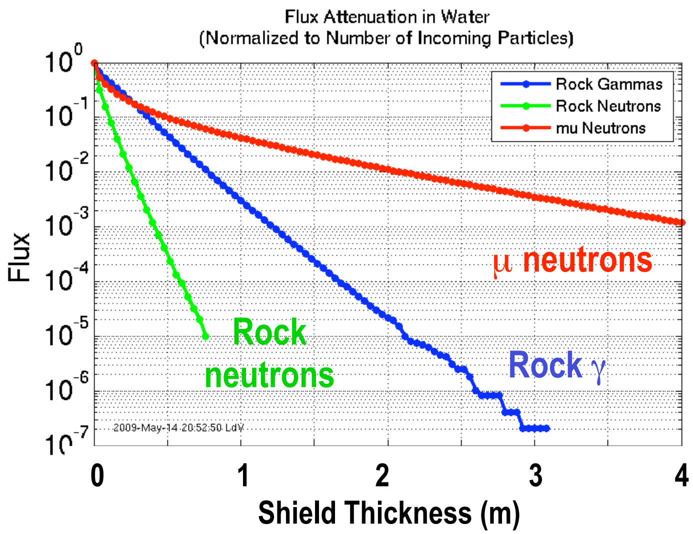
Brown University, Case Western Reserve University, Harvard University, LLNL, LBL/UC Berkeley, University of Maryland, Texas A&M, UC Davis University of Rochester, University of South Dakota, South Dakota School of Mines, Yale University

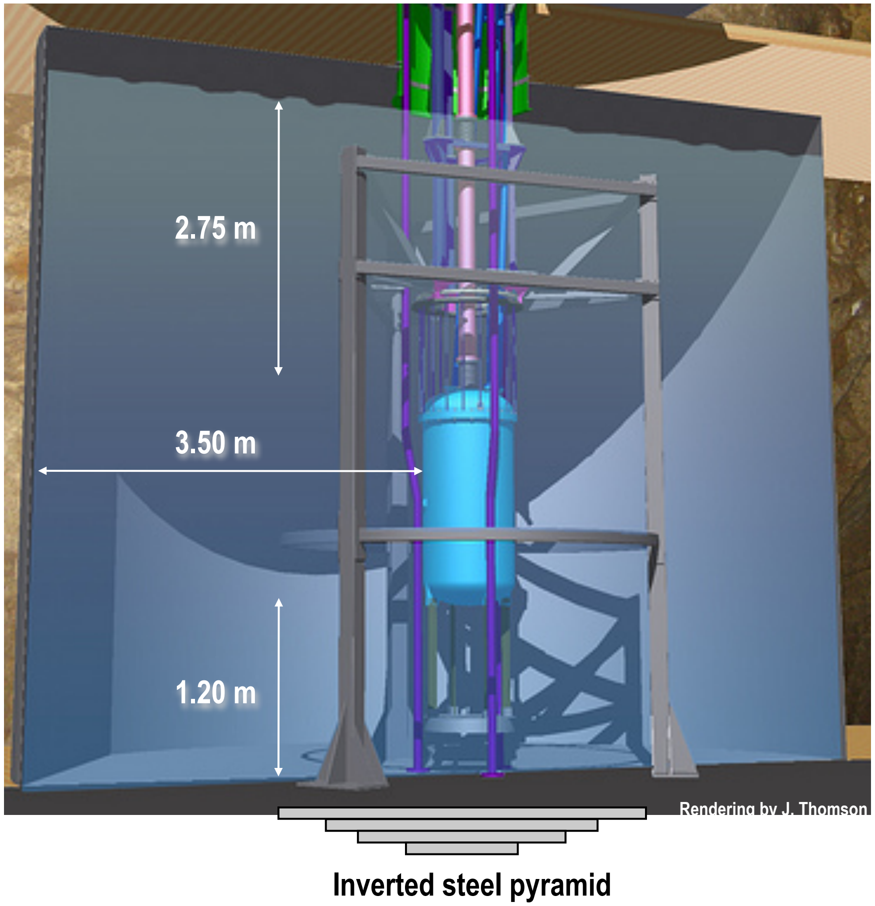
LUX Design – Detector Overview



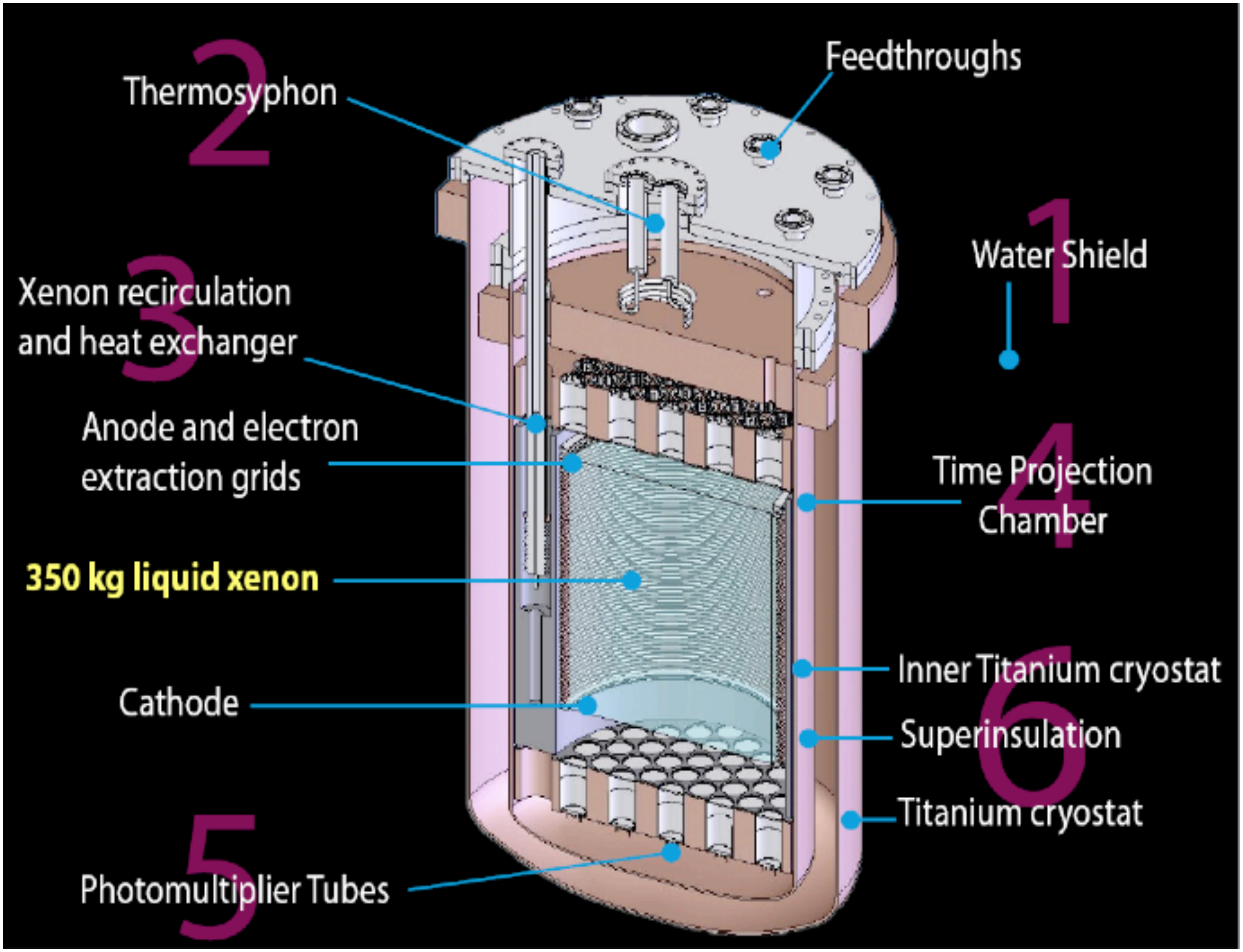
LUX Design – Water Tank

- Water Tank: d = 8 m, h = 6 m
  - 300 tonnes, 3.5 m thickness on the sides
  - Inverted steel pyramid (20 tonnes) under tank to increase shielding top/bottom
- Cherenkov muon veto
- Ultra-low background facility
  - Gamma event rate reduction: ~10^{-9}
  - High-E neutrons (>10 MeV): ~10^{-3}



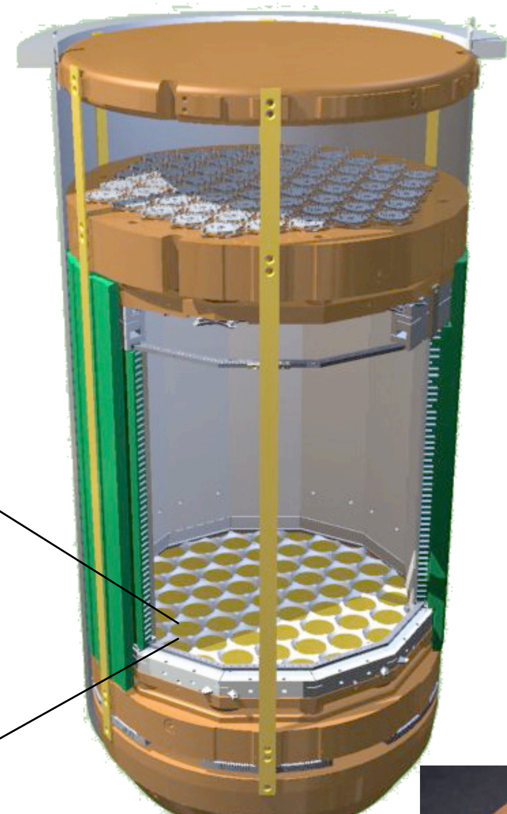


LUX Design – Detector Overview



LUX Design – Active Volume

- 350 kg of liquid Xe
  - Active volume: h=59cm, d=49cm
- Light collection ~2.0 phe/keVr
  - 2x better than Xe10
  - Analysis threshold down to < 3 keVr

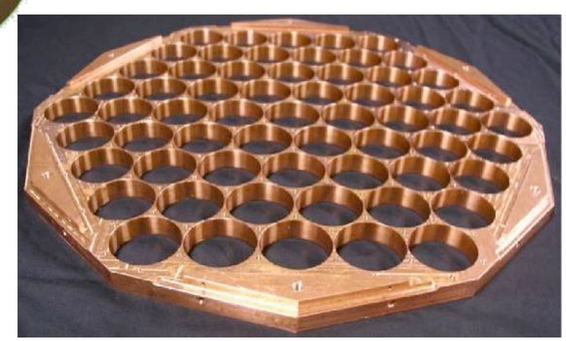


Design by J. White

- Dodecagonal field cage + PTFE reflectors

- 122 PMT R8778
  - 2" diameter
  - 175 nm, QE > ~30%
  - U/Th ~9/3 mBq/PMT

- Cu PMT holding plate



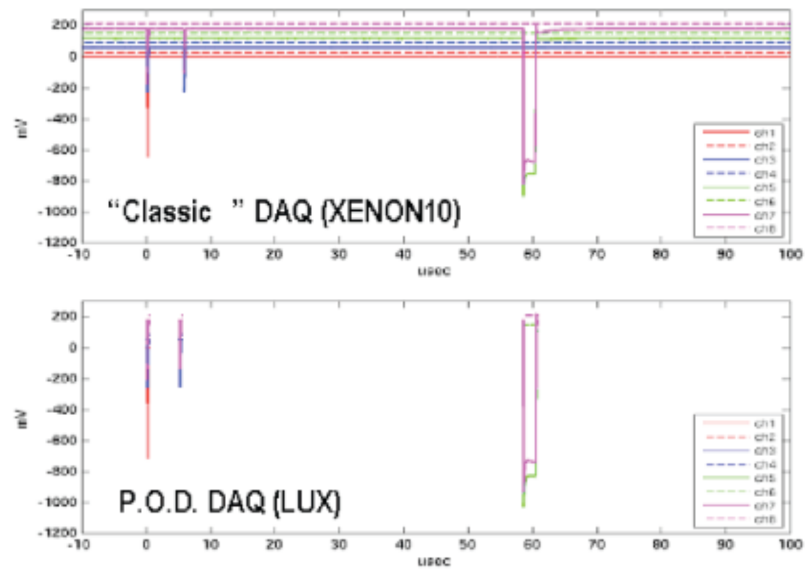
LUX Design – Cryostat

- Inner vessel: 100 kg
  - Rated 60 psig / vacuum
- Outer vessel: 130 kg
  - Rated 45 psig / 30 psi
- Total det mass: ~2.4 t
  - + 350 kg of LXe

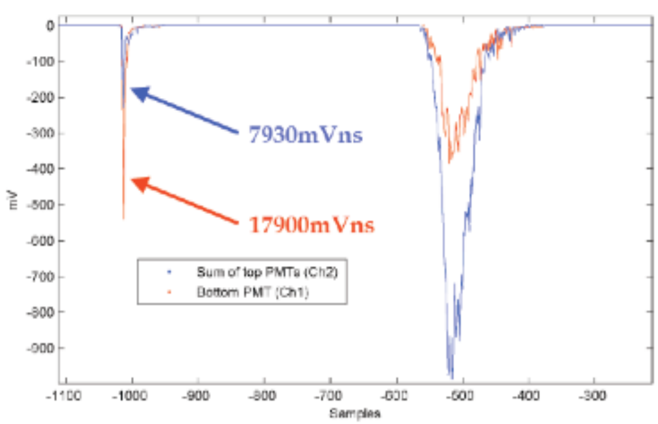
- Ultra-low radioactivity inner and outer Titanium cryostats (high strength, low mass)
  - Activity <0.4 mBq/kg in U+Th
  - Cryostats separated by vacuum + superinsulation film
  - Inner cryostat covered with Cu radiation shield
- Cosmogenic activation of Ti at Homestake altitude gives ^{46}Sc (89 d)
  - Equilibrium level ~15% of LUX ER background budget, ~5% after 130 days underground

LUX Acquisition System

- Struck ADC boards run on "Pulse Only Digitization" mode (POD)
  - Average event size (122 PMTs, 700 μs): 60 kB
    - Comparison Xe10 equivalent: ~17 MB
  - Max event rates (100% livetime):
  - Calibration « multi-event » mode: 1.2 kHz
  - Background « single event » mode: 300 Hz



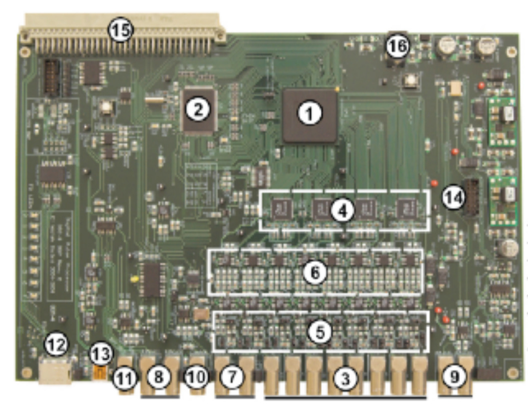
- Trigger through custom DDC-8 logic boards
  - Dedicated 8 channel 14 bit ADCs, sync with DAQ
  - S1/S2 pulse recognition capability
  - Can trigger on either or any combination of both



Run requirements:

- S1&S2 trigger mode
- S1 on Ch1 in coincidence with S1 on Ch2
- S1 on Ch1 between 15400 and 88800 mVns
- S1 on Ch2 between 5580 and 32880 mVns

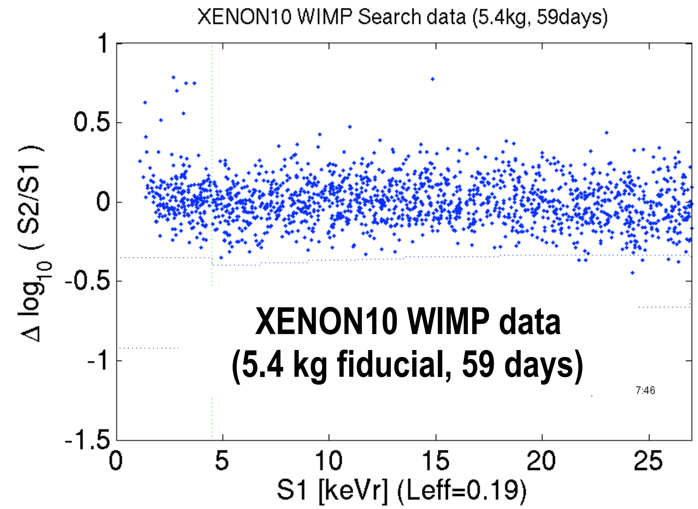
DDC-8DSP



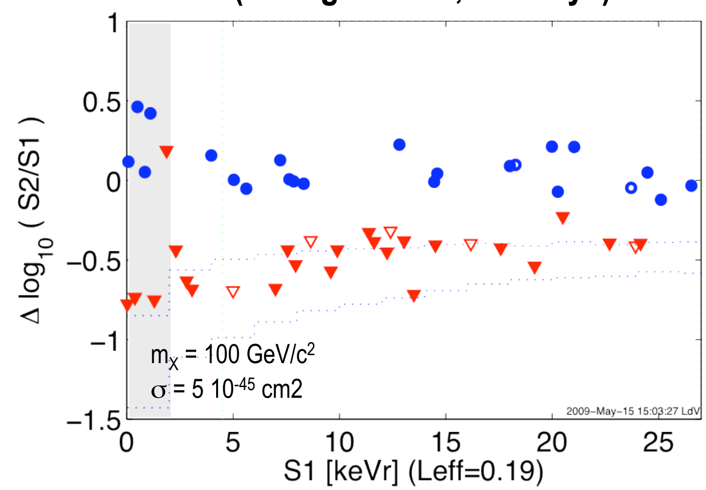
1 - FPGA (XC3SD3400A)
2 - FX2-LP (USB 2.0)
3 - Analog Input Channels
4 - ADCs
5 - Analog passive filters
6 - Analog active filters
7 - NIM-IN
8 - NIM-OUT
9 - NIM-Timestamping (CLK,RST)
10 - External Clock
11 - Spy Channel
12 - HDMI
13 - USB Connector
14 - JTAG Connector
15 - VME Connector (POWER +5V)
16 - External Power (+5V)

LUX Backgrounds and Signals

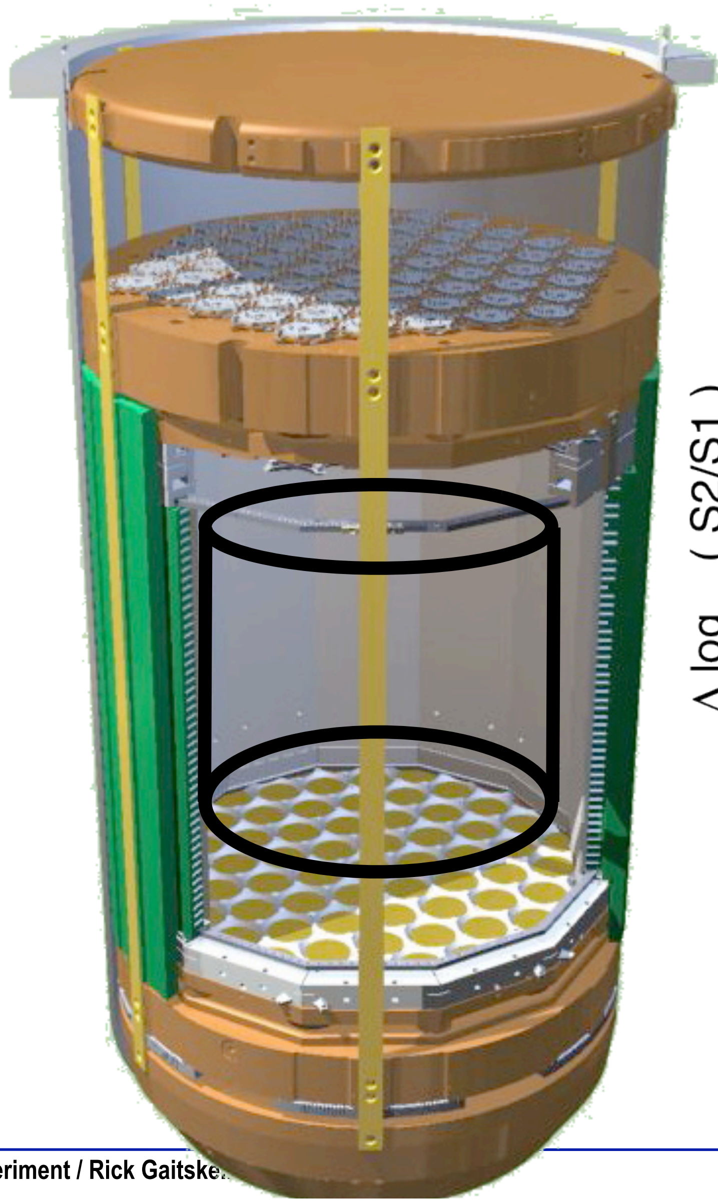
- Goal: < 1 NR event / 100kg / 300 days (50% accept.)
- Expected ER background ~260 μdru
  - PMT contribution dominant / external sources (10^{-4})
  - ^{85}Kr < 2 ppt (~10% of LUX ER background budget)
  - 350 kg = full advantage of Xe self-shielding
- Expected NR background < 500 $ndru_r$
  - Neutrons mostly from (alpha,n) on PMTs
  - Subdominant to gammas after ~99.5% ER discrimination
- Strength of LUX is in the <u>extremely low</u> ER background in the fiducial volume
- No single neutron scatter (~1/20 event expected in entire set of 100 kg x 100 days)



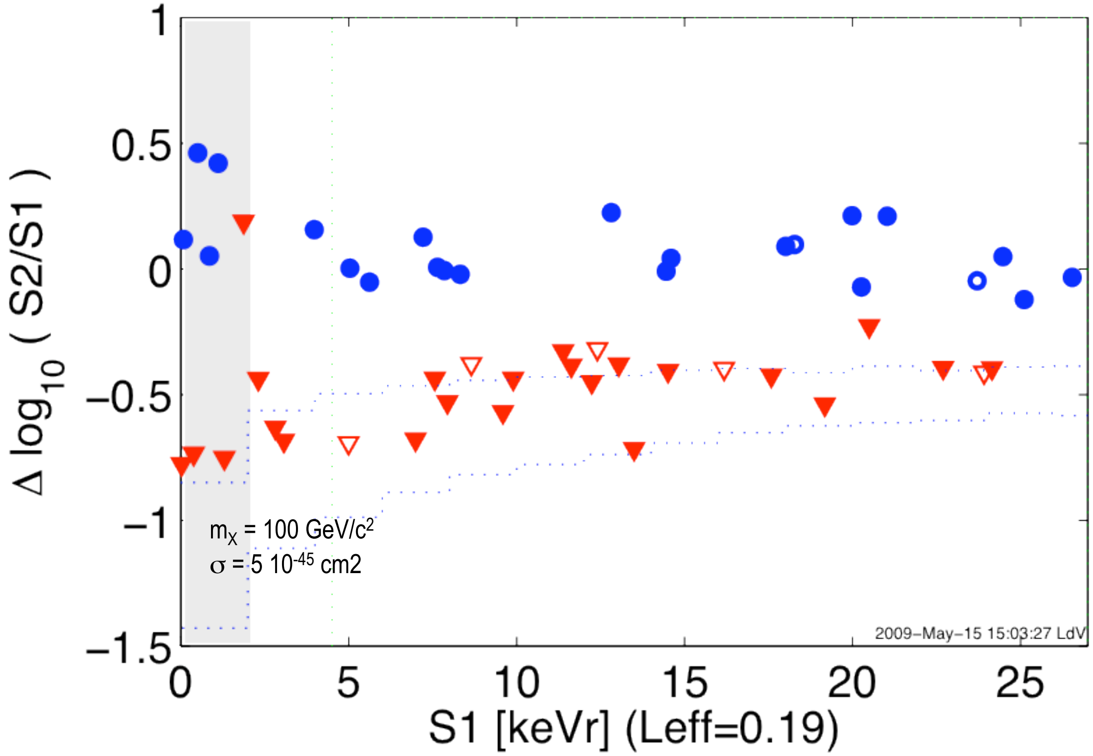
Simulated LUX data
(100 kg fiducial, 100 days)



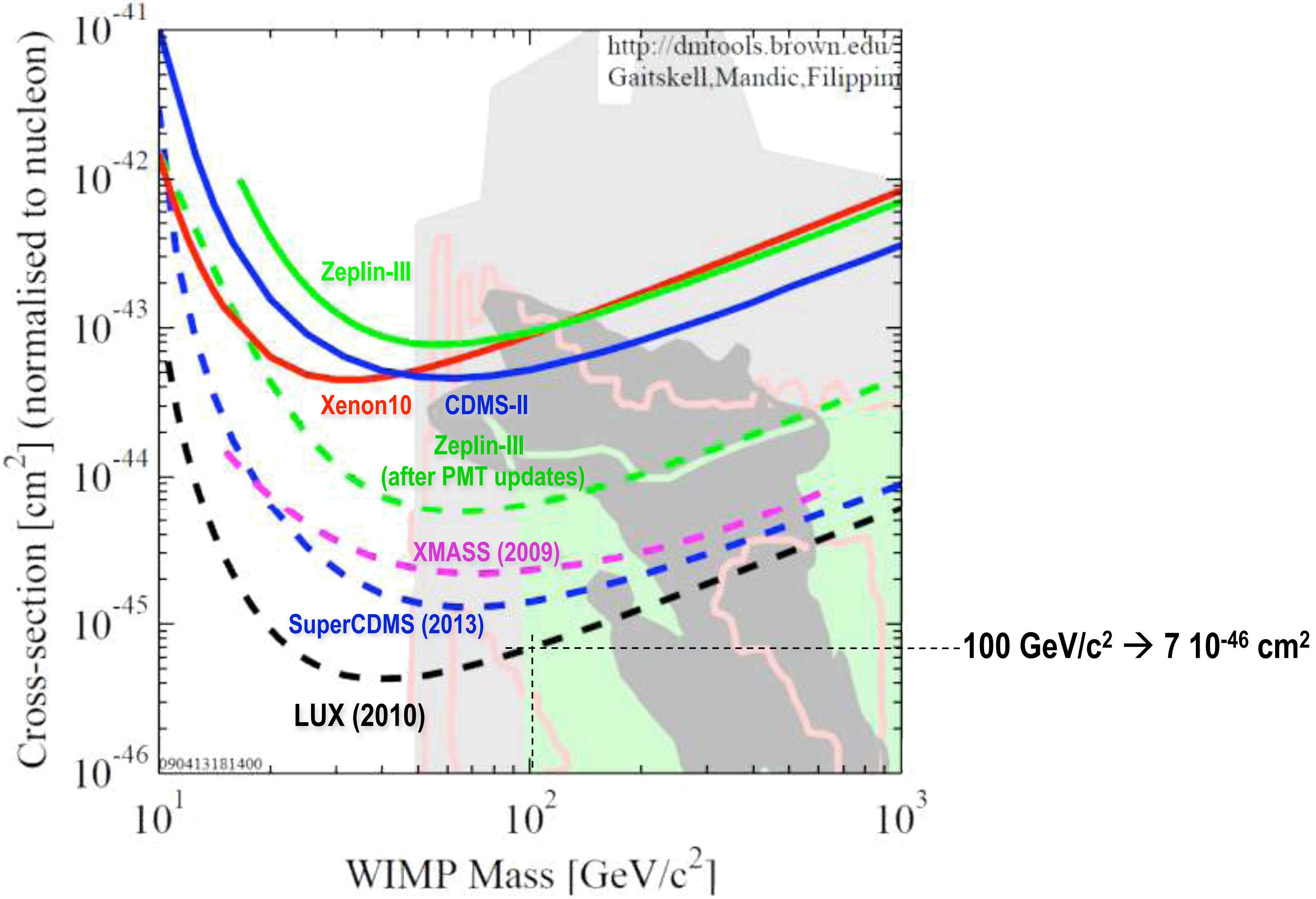
LUX 350 kg / 100 kg Fiducial / WIMP Discovery



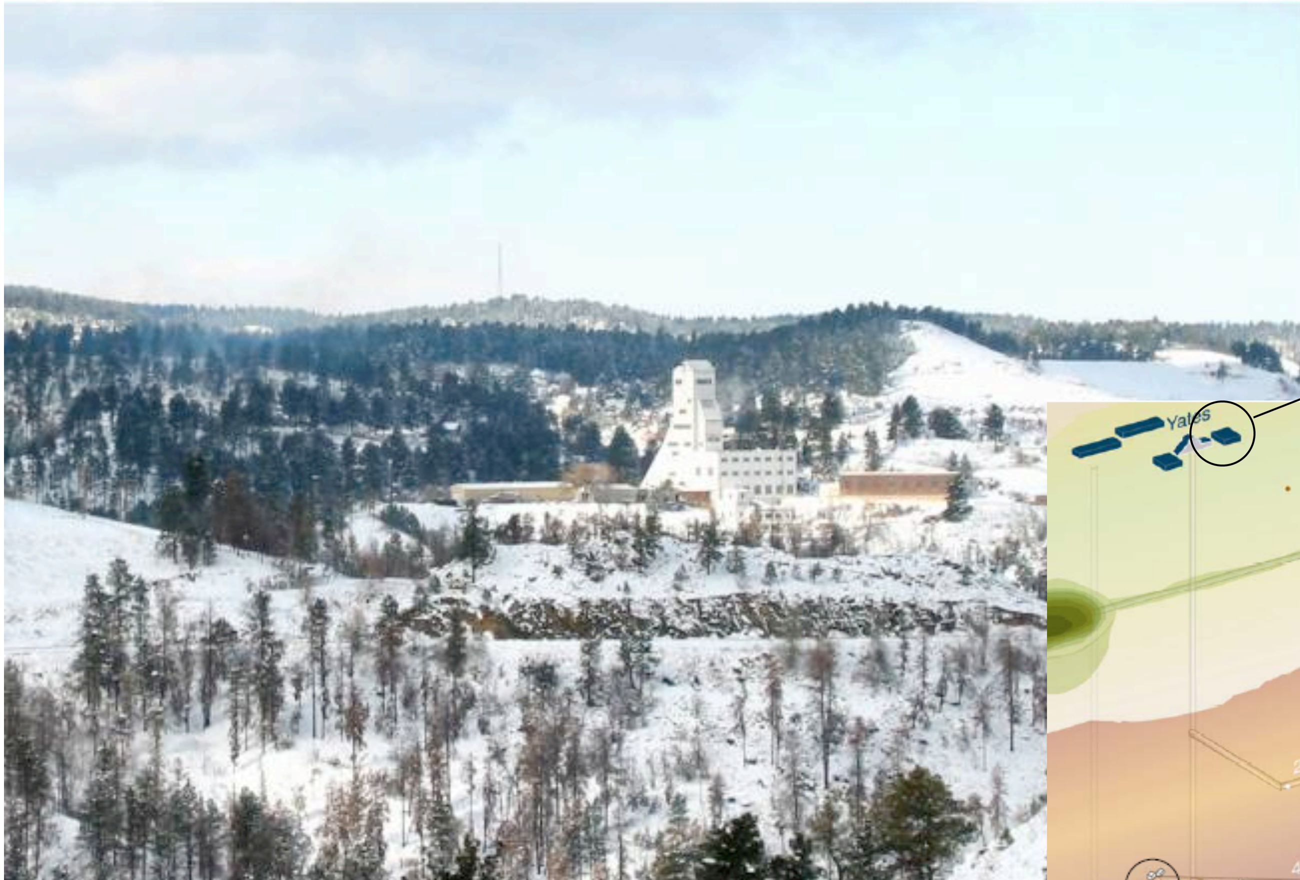
Simulated LUX data
(100 kg fiducial, 100 days)

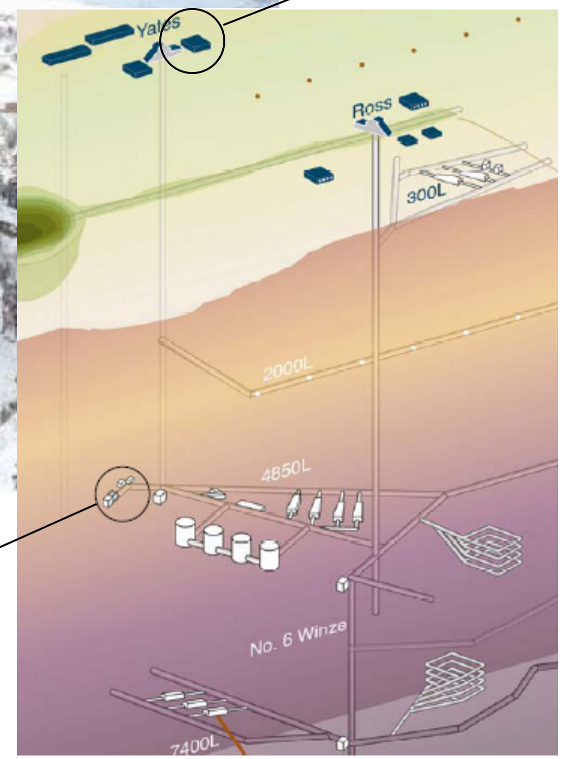


LUX – SI Coupling WIMP Sensitivity



Sanford Lab / DUSEL @ Homestake





Surface Facility

Davis Cavern
4300 m.w.e
→ 4 $\mu/m^2/d$

LUX 1.0 – Surface Facility

- Full-scale test of LUX deployment
  - Liq/gas system
  - PMT testing
  - DAQ testing
  - S1 trigger efficiency
  - Xe purity

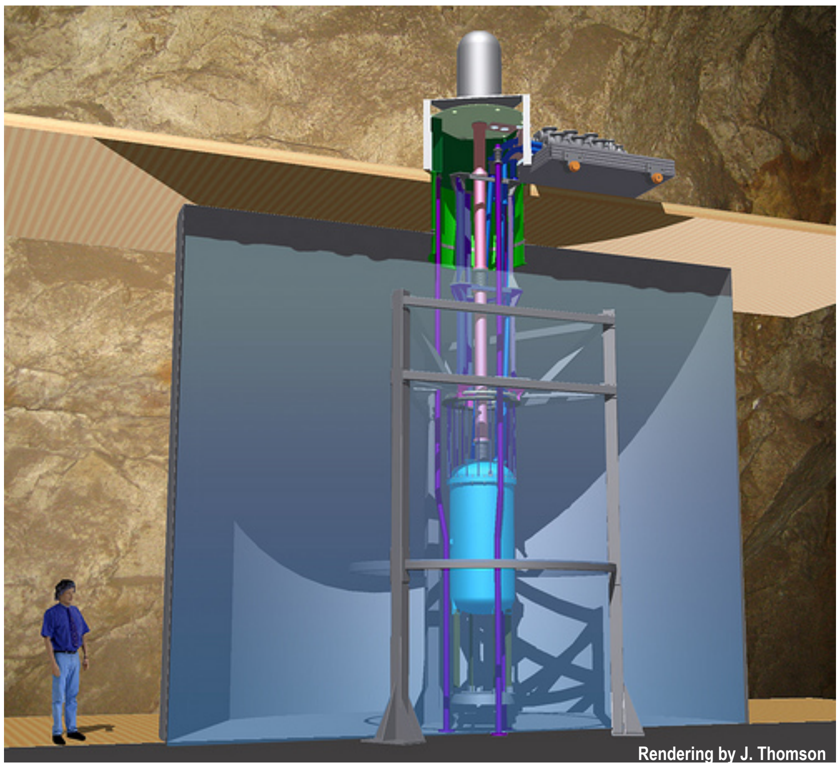
- Exact duplicate of the underground layout for all major systems
- 1 m thick water shield designed to allow limited real data taking, even at the surface
  - Expected Gamma rate ~70 Hz, Neutron rate ~30 Hz, Muon rate ~50 Hz
  - Natural detector limit: 175 Hz (PMT gain stability, < 10% event overlap)
  - Will require: S2 gating, reduced PMT gain
- Beneficial occupancy: End September 2009

Homestake - Access to level 4850

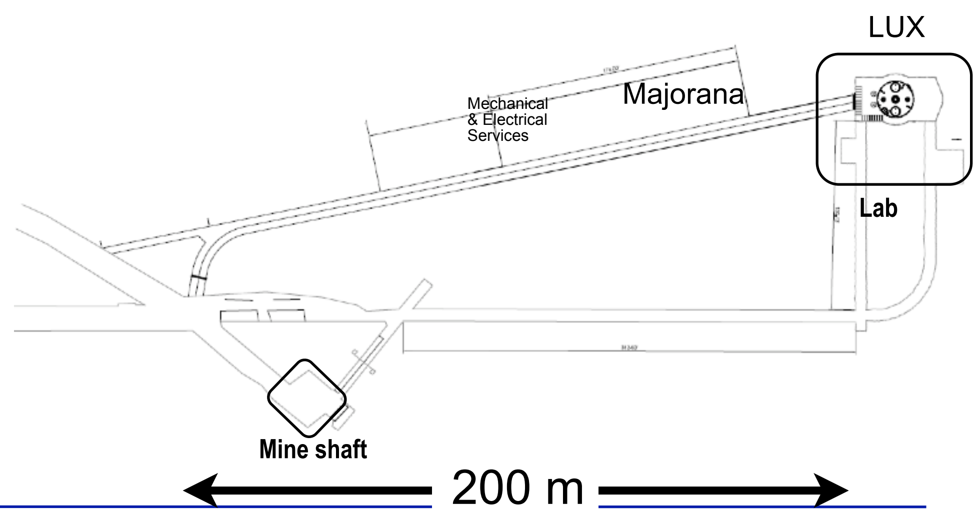
- Level 4850 dry and accessible at the end of May 2009
  - Slower than original schedule
- First assessment of Davis Cavern
  - Condition generally very good!

LUX 1.0 – Davis Laboratory (4850L)

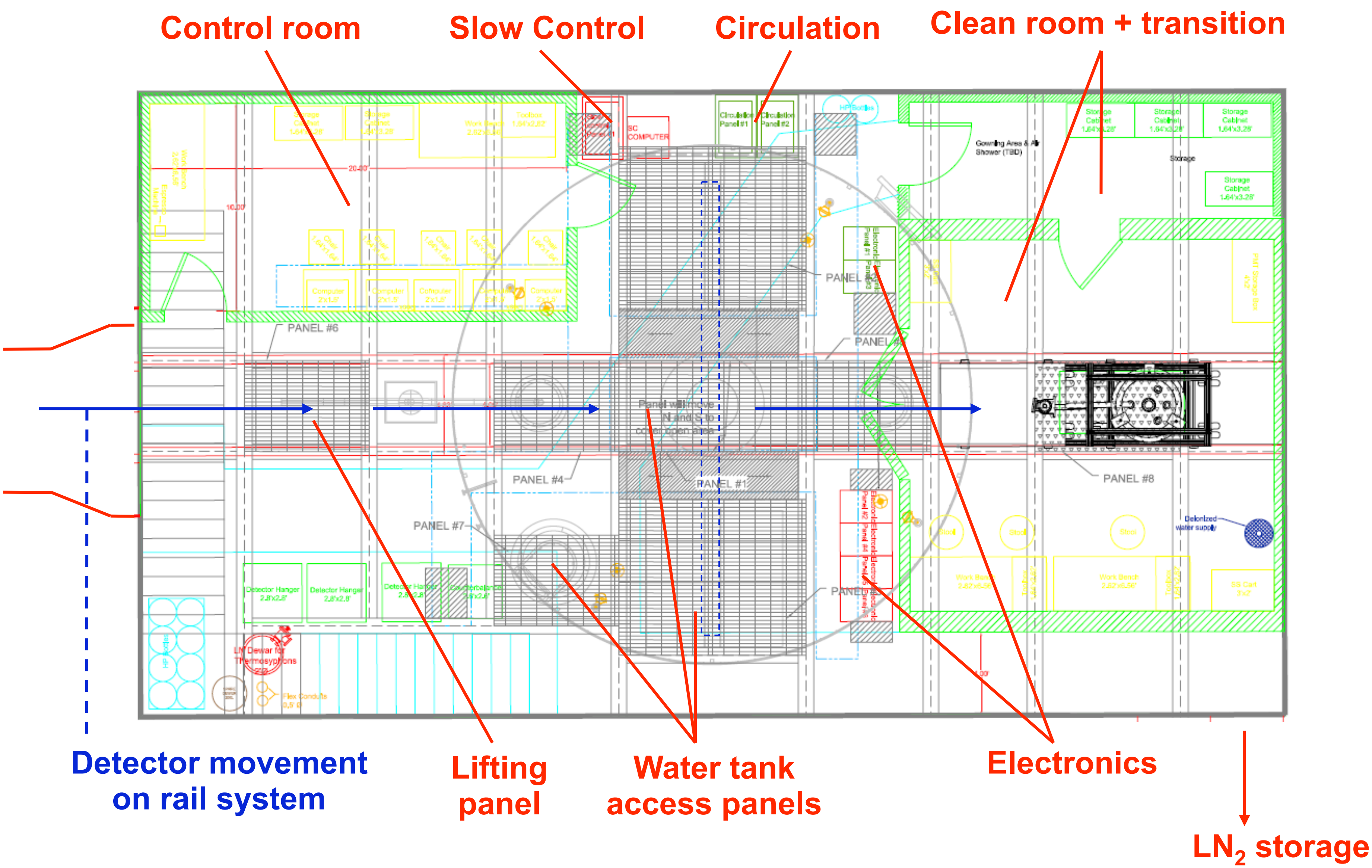
- Construction/excavation design completed
  - New 300' access/safety tunnel to be excavated
  - Shared access with Majorana facility, also to be excavated
- Two storey, dedicated LUX 55' x 30' x 32' facility, CL 100k
  - Includes CL 1k clean room, control room, counting facility



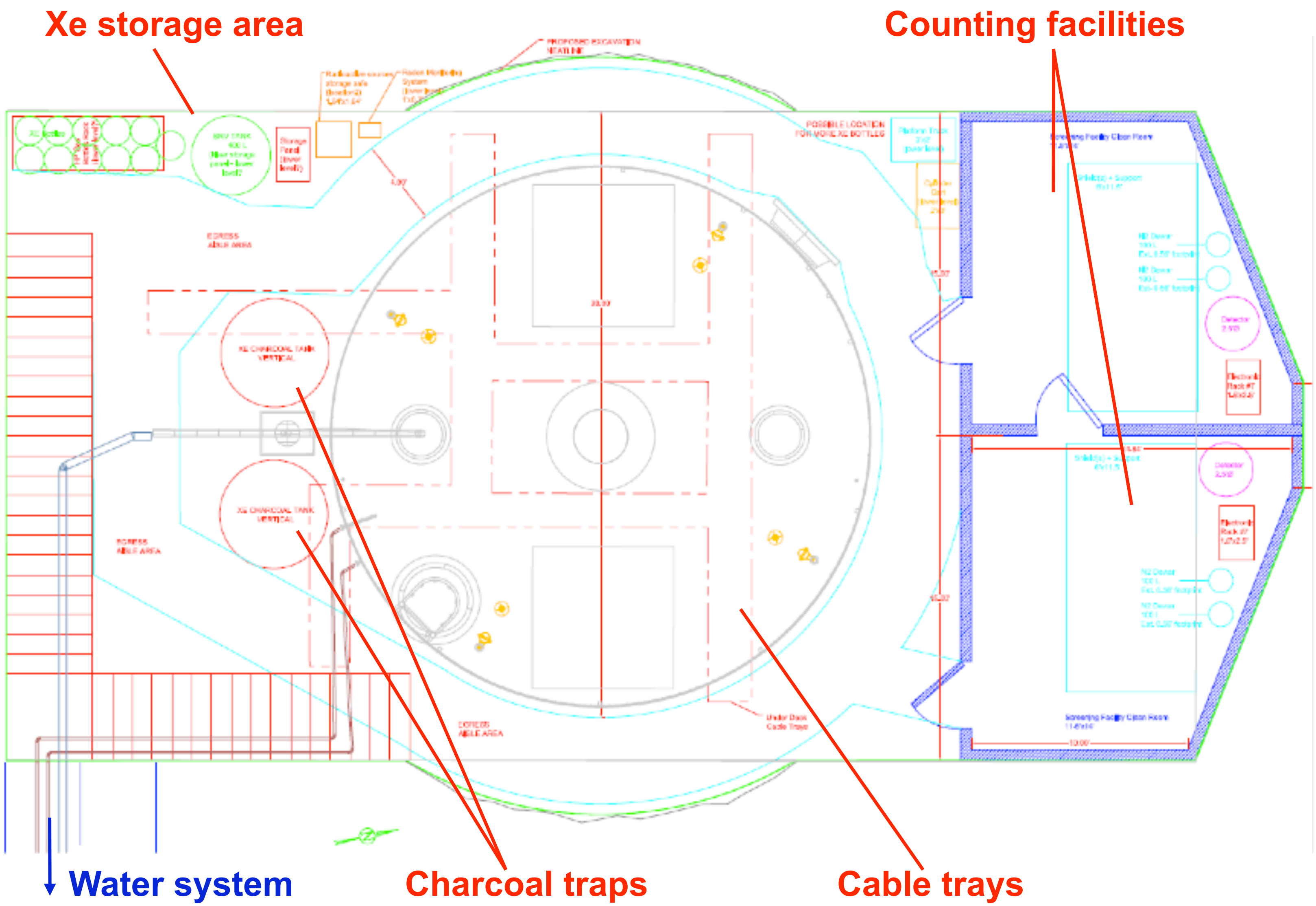
- Beneficial occupancy: Spring 2010



Design Work Summary – Deck Layout

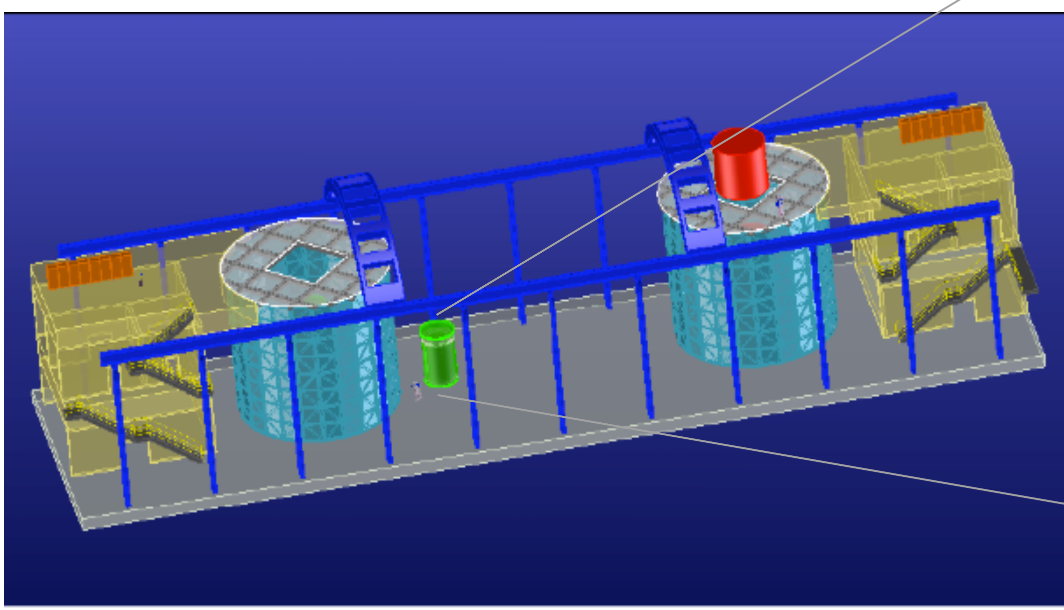


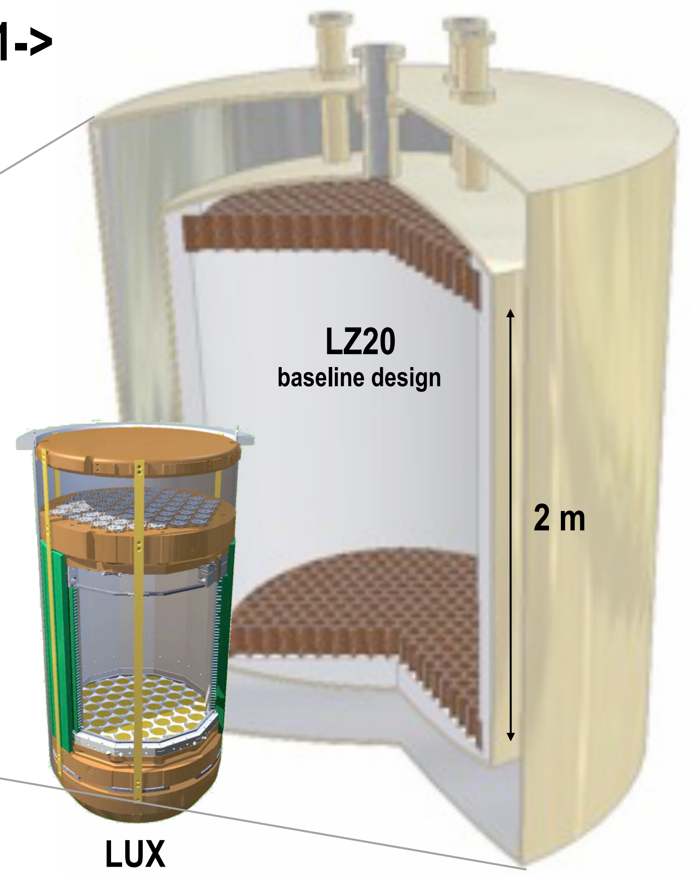
Design Work Summary – Ground Floor



Future LUX-ZEPLIN III (LZ) Program

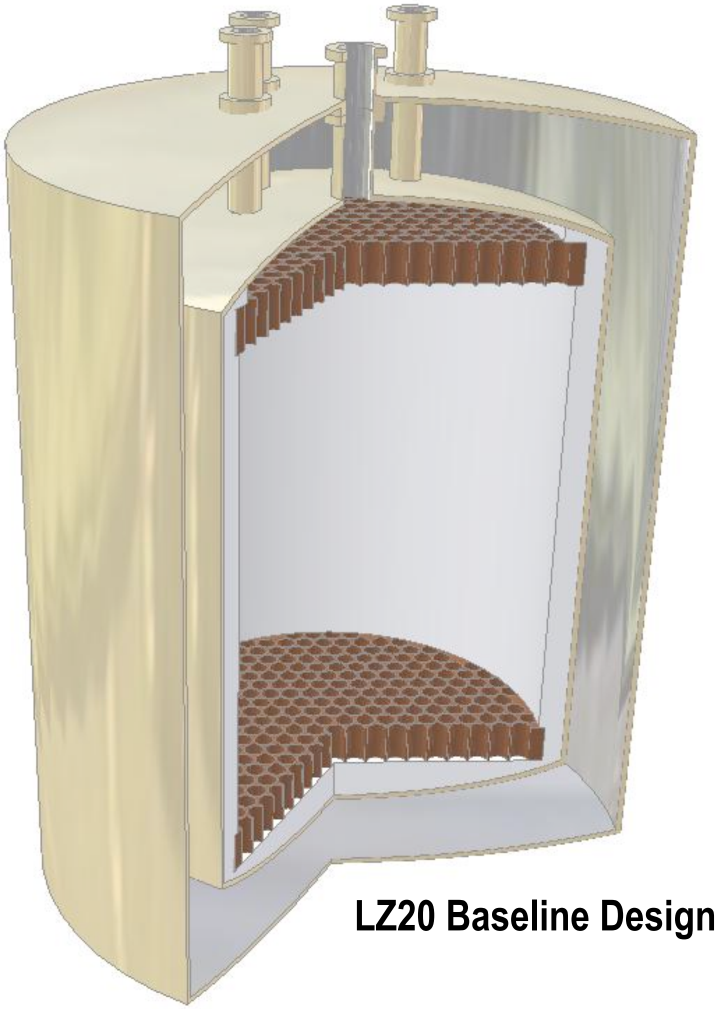
- **New collaborators from Zeplin III and US institutions**
  - Imperial College, London
  - STFC Rutherford Appleton Lab
  - ITEP, Moscow
  - Moscow Engineering Physics Institute
  - LIP, Coimbra
  - University of Edimburgh
  - UC Santa Barbara
  - LBNL
- **Several phases: 3 tonne at Sanford Lab, SUSEL, 2011-> and 20 tonne at DUSEL from 2013 → 2018+**
- **DUSEL Program at Homestake 4850L and 7400L**



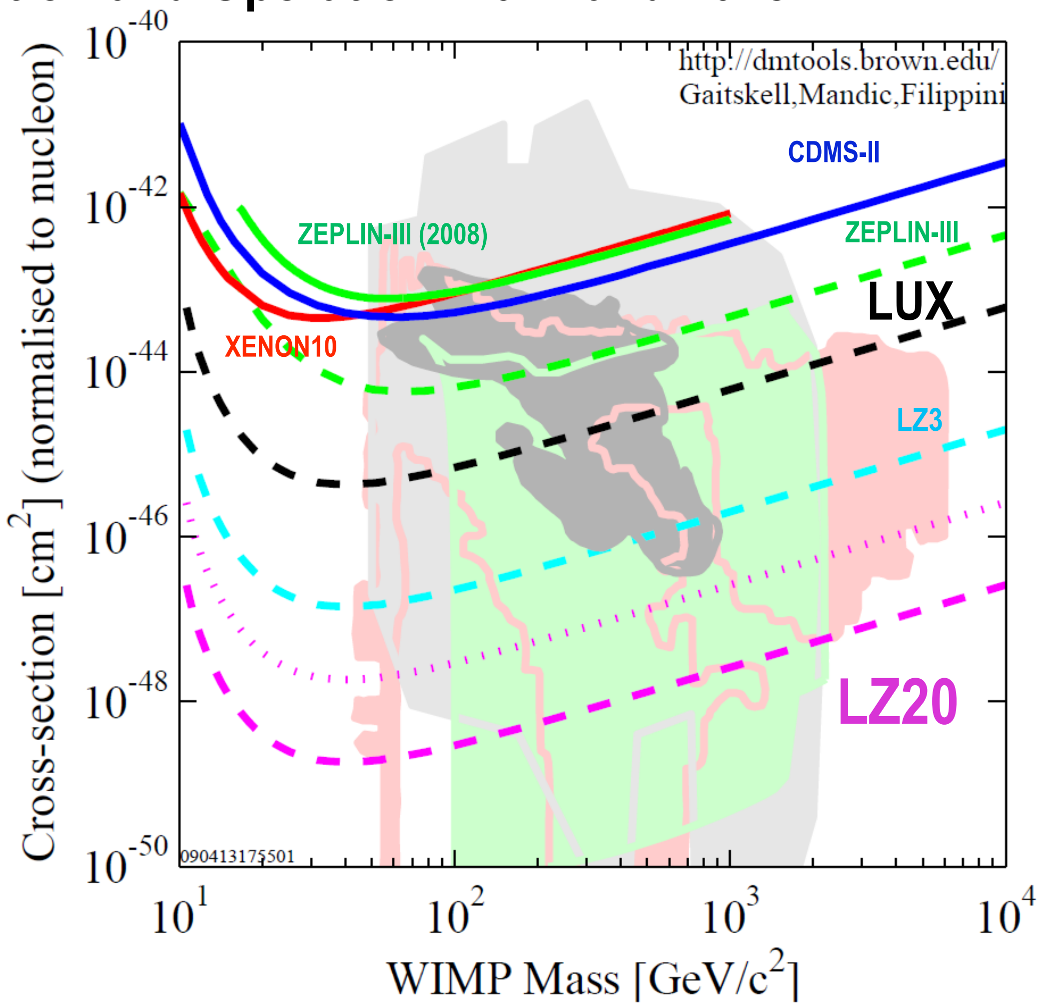


LZ3 / LZ20

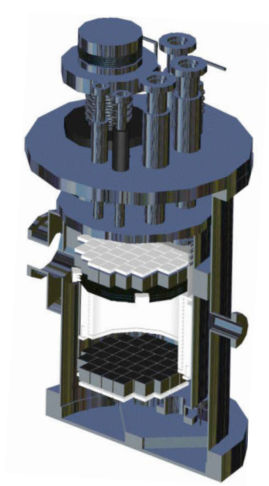
- LUX-Zeplin Collaboration: 20 Tonnes liquid Xe detector
- Estimated Schedule for Construction and Operation: 2012 and 2015



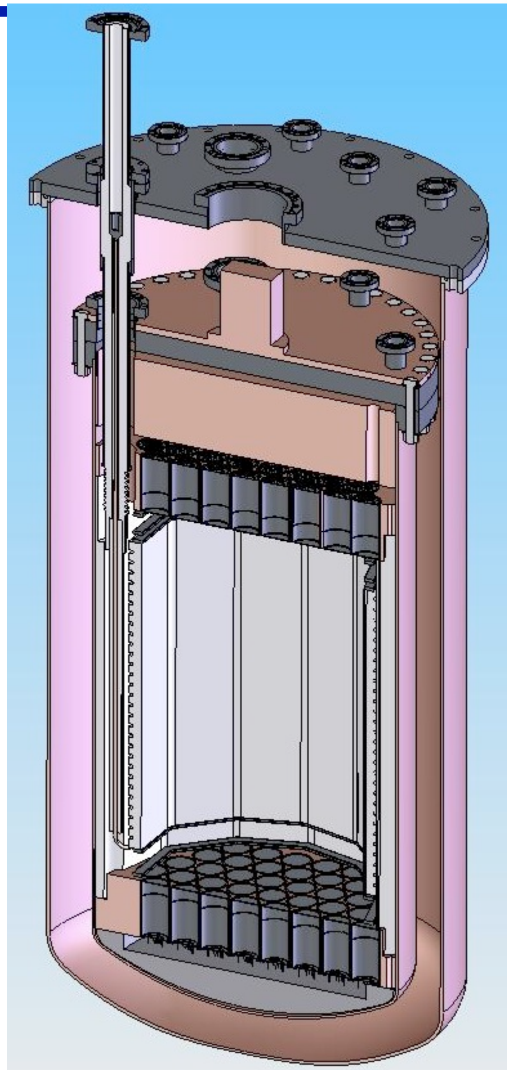
LZ20 Baseline Design



Evolution



XENON10
22 kg / Fiducial 5.4 kg



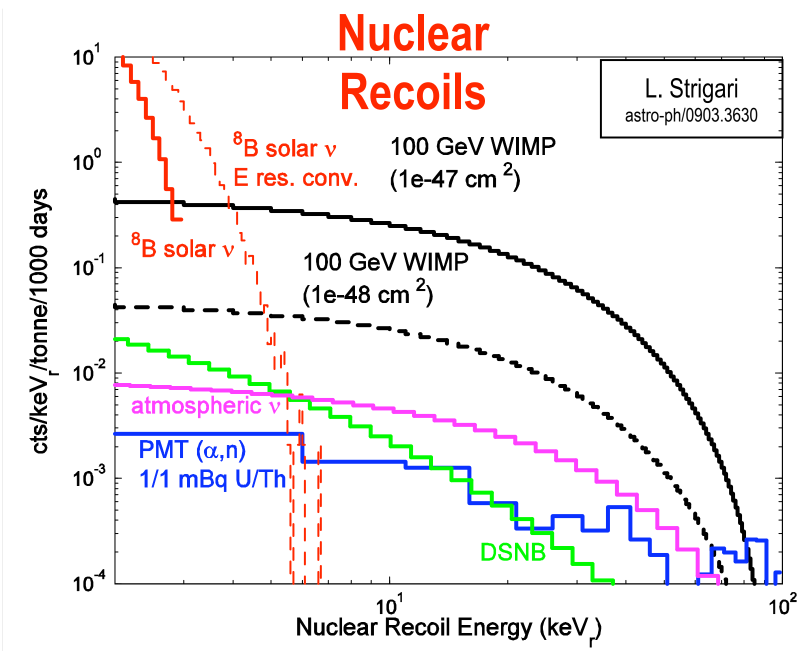
LUX
350 kg / Fiducial 100 kg

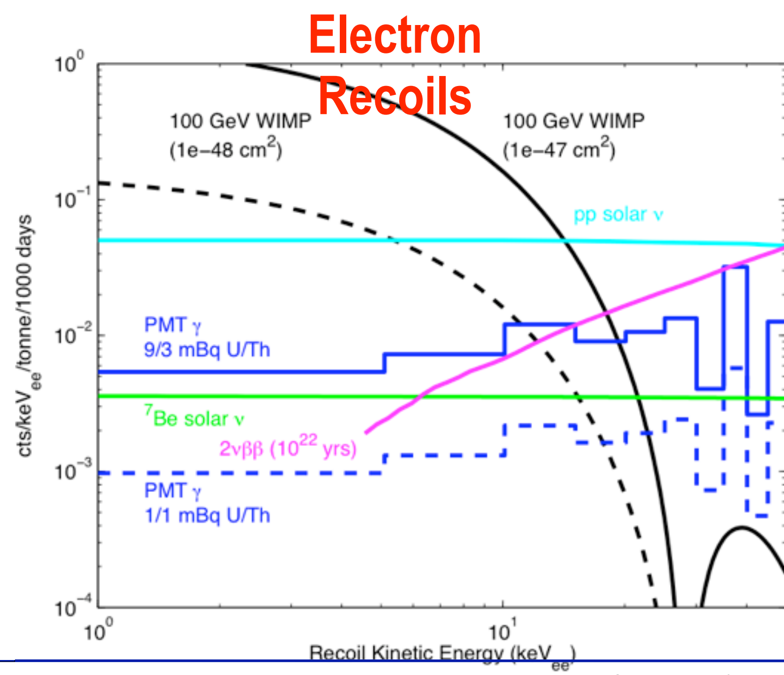
LZ20
20000 kg / Fiducial 16000 kg

LZ Program – LZ20, ultimate search?

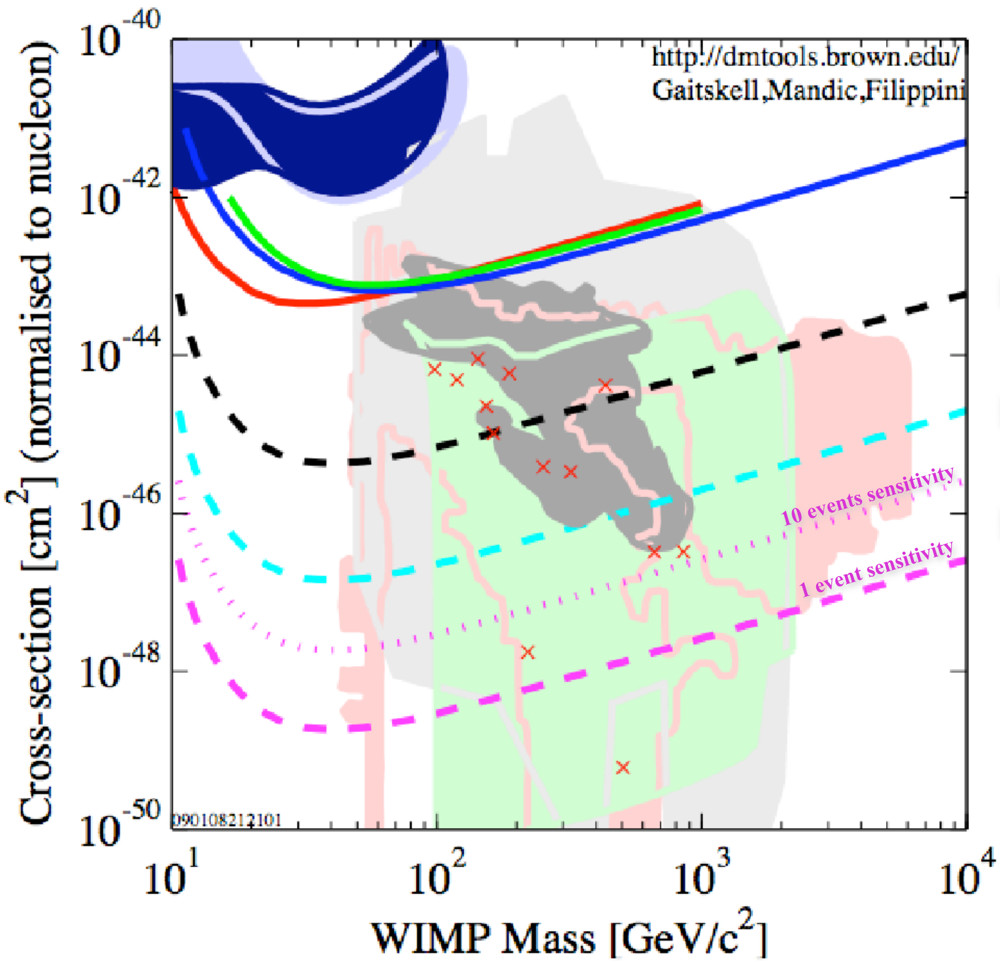
- Electron Recoil signal limited by p-p solar neutrinos
  - Subdominant with current background rejection
- Nuclear Recoil background: coherent neutrino scattering
  - ^{8}B solar neutrinos
  - Atmospheric neutrinos
  - Diffuse cosmic supernova background
- LZ20 reaches this fundamental limit for direct WIMP searches

- LZ20 also sensitive to $\beta\beta0\nu$ decay in natural xenon up to lifetimes of ~1.3 10^{26} years !





LZ Program - WIMP Sensitivity



- Projections based on
  - Known background levels
  - Previously obtained e$^-$ attenuation lengths and discrimination factors

LUX (constr: 2008-2009, ops: 2010-2011)
100 kg x 300 days

LZ3 (constr: 2010-2011, ops: 2012-2013)
1,500 kg x 500 days

LZ20 (constr: 2013-2015, ops: 2016-2019)
13,500 kg x 1,000 days

- Fiducial volumes selected to match < 1 NR event in full exposure