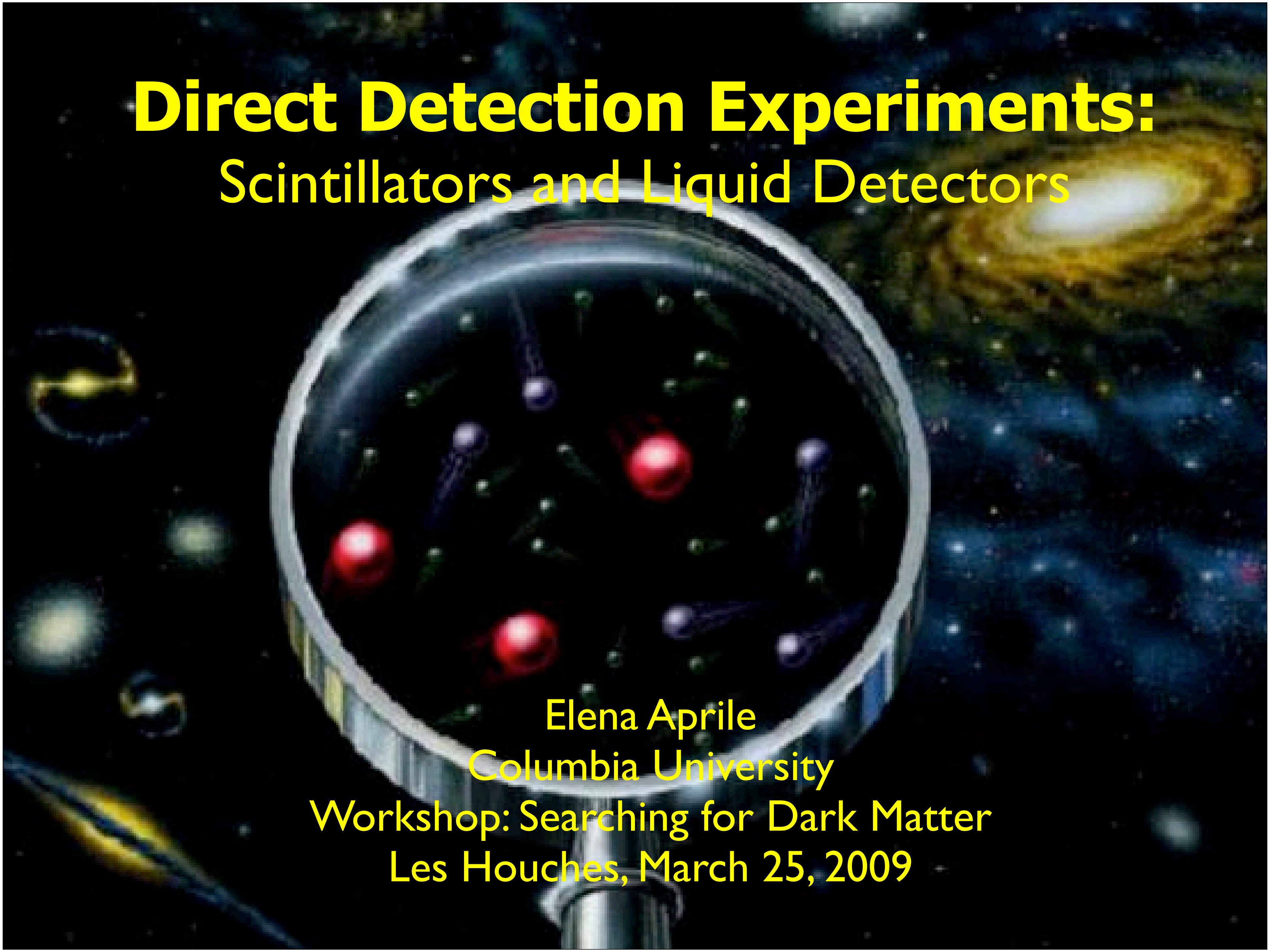


# Direct Detection Experiments:

## Scintillators and Liquid Detectors

Elena Aprile
Columbia University
Workshop: Searching for Dark Matter
Les Houches, March 25, 2009

# Outline of Lectures

Lecture 1:

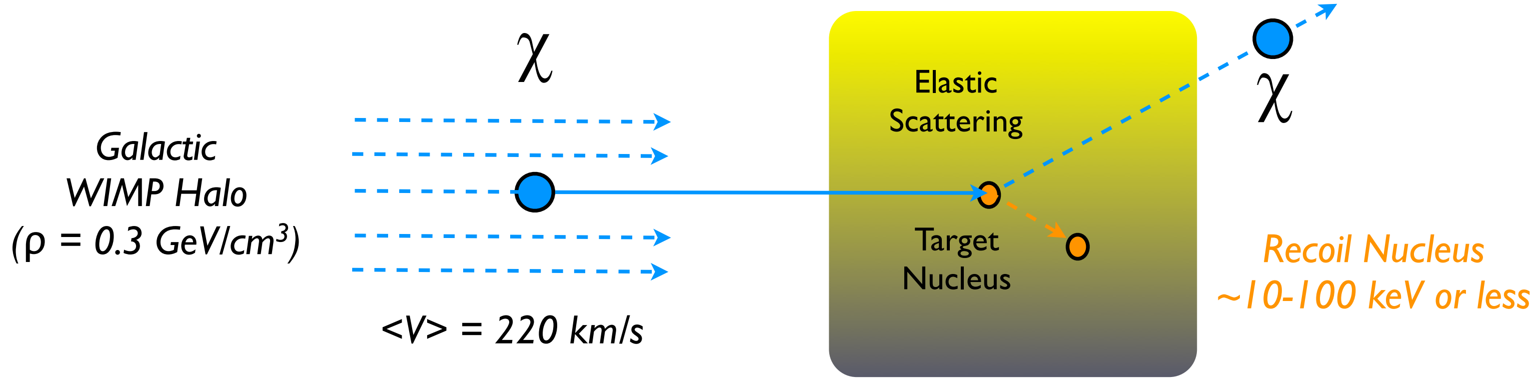
Event Rates
Background Sources
Properties of Noble Liquid Detectors
Liquid Xenon Experiments: XENON, ZEPLIN, LUX, XMASS

Lecture 2:

Liquid Argon Experiments: WArP, ArDM, CLEAN
Properties of Crystal Scintillator Detectors
Experiments: DAMA/LIBRA, ANAIS, KIMS
Directional Experiments: DRIFT, DM-TPC,NEWAGE, MIMAC

# Principle of Direct Detection

WIMPs elastically scatter off nuclei in targets, producing nuclear recoils: *Goodman and Witten (1985)*



*$\sigma_{\chi\text{-}p}$ can be as low as $10^{-46}$ cm$^2$*

The energy of the nuclear recoil is:

$$Q = \frac{|\vec{q}|^2}{2m_N} = \frac{\mu^2 v^2}{m_N}(1 - cos\theta) \leq 100keV$$

The expected rate is:

$$R \propto N \frac{\rho_\chi}{m_\chi} < \sigma_{\chi N} >$$

N = number of target nuclei in detector
$\rho_\chi$ = local WIMP density
$m_\chi$ = WIMP mass
$<\sigma_{\chi N}>$ = scattering cross section

# Energy Spectrum and Rate

Differential event rate for elastic WIMP-nucleus scattering

$$\frac{dR}{dQ} = \mathcal{A}F^2(Q)\int_{v_{\min}}^{v_{\rm esc}}\left[\frac{\boxed{f_1(v)}}{v}\right]dv$$

Astrophysics

Here

$$v_{\min} = \alpha\sqrt{Q}$$

is the minimal incoming velocity of incident WIMPs that can deposit the recoil energy $Q$ in the detector.

$$\mathcal{A} \equiv \frac{\boxed{\rho_0}\boxed{\sigma_0}}{\boxed{2m_\chi m_{\rm r,N}^2}} \qquad \alpha \equiv \sqrt{\frac{m_{\rm N}}{2m_{\rm r,N}^2}} \qquad m_{\rm r,N} = \frac{m_\chi m_{\rm N}}{m_\chi + m_{\rm N}}$$

Particle Physics

$\rho_0$: WIMP density near the Earth

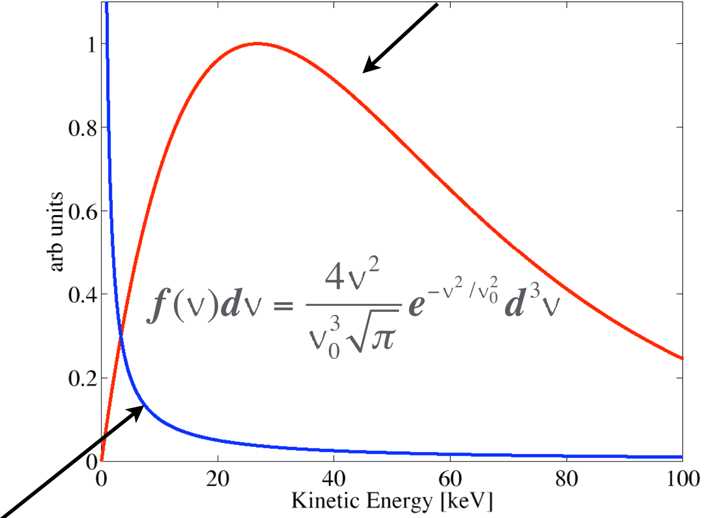
$\sigma_0$: total cross section ignoring the form factor suppression

$F(Q)$: elastic nuclear form factor

$f_1(v)$: one-dimensional velocity distribution of halo WIMPs

$v_0$=230 km/s
$v_{esc}$=650 km/s

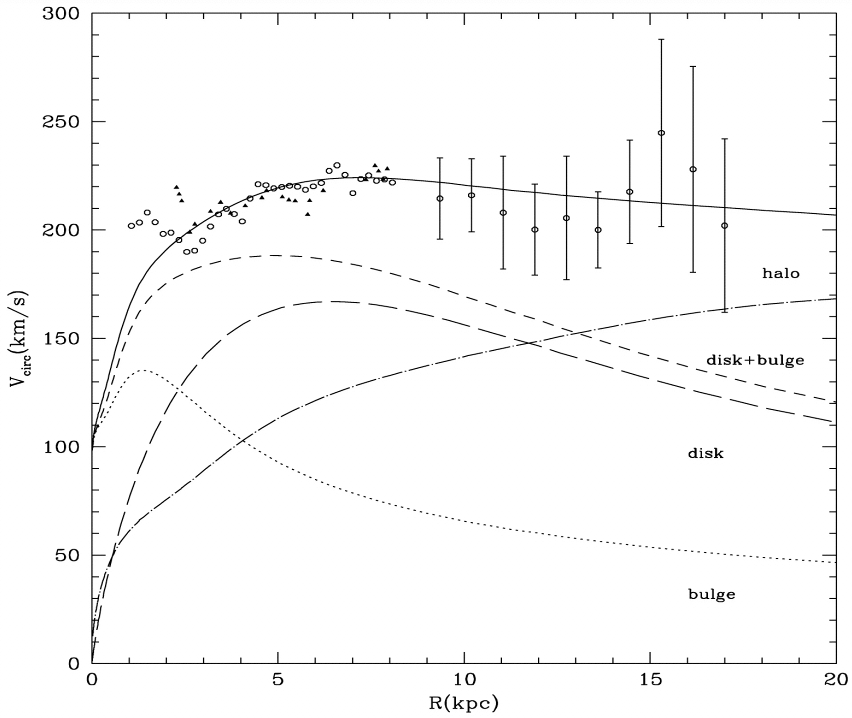
WIMP velocity distribution



Recoil energy spectrum (depends on WIMP mass)

# WIMP Density in the Halo

- Energy spectrum and rate depend on WIMP distribution in dark matter halo
- From the measured galactic rotation curve + modeling of various components (disk, bulge, halo)



(Klypin, Zhao & Somerville 2002)

density $\rho_0 \approx 0.3$ GeV cm$^{-3}$

( x $10^5$ larger than in the universe at large)

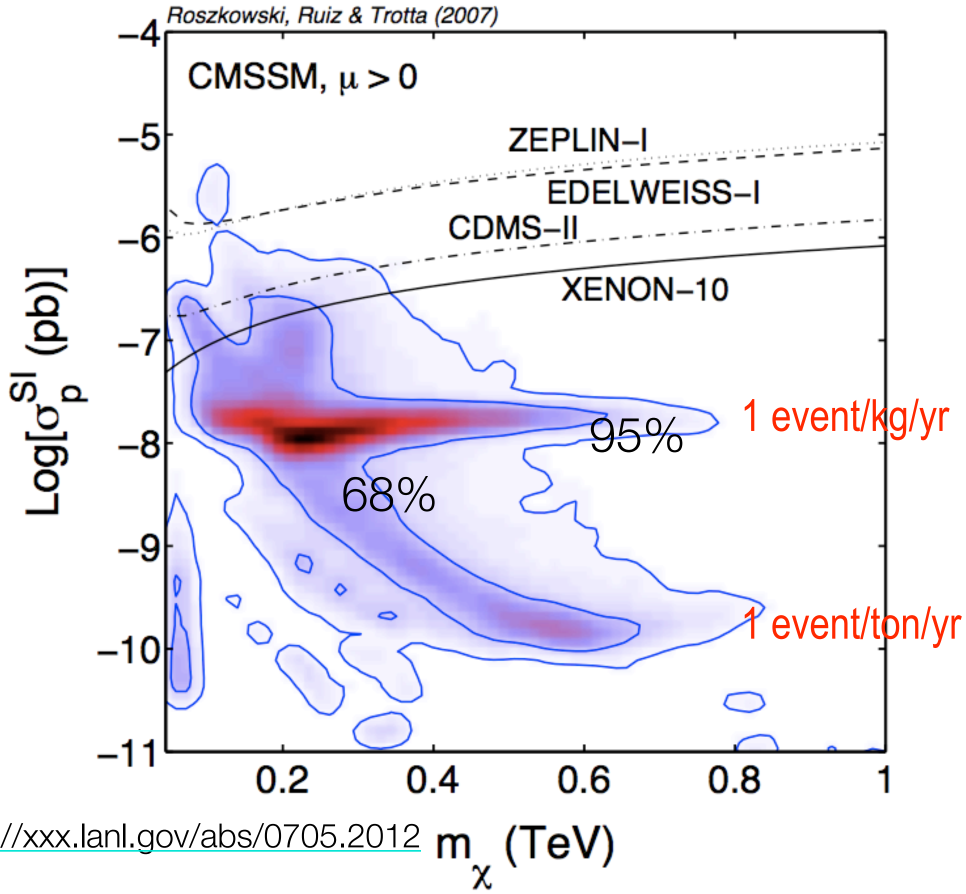
NASA/JPL-Caltech image

# WIMP-Nucleon Cross Section

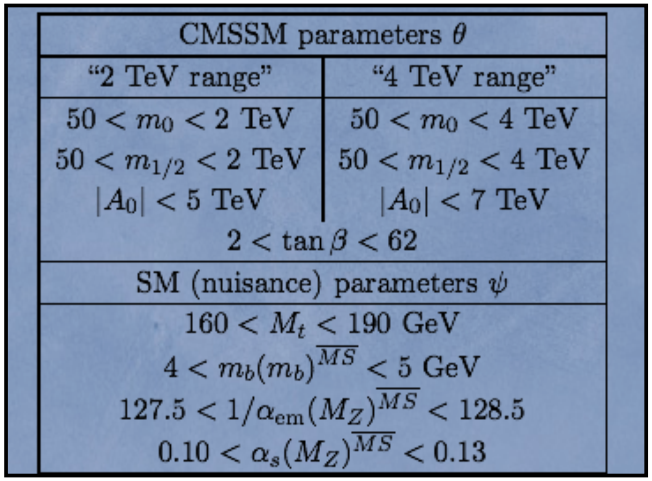
The energy spectrum and rate depend on the scattering cross-section.

To calculate a cross section we need a particle physics model

Example: CMSSM -> scalar cross sections on nucleons between $10^{-11}$ and $10^{-7}$ pb



http://xxx.lanl.gov/abs/0705.2012



| | |
|---|---|
| CMSSM parameters $\theta$ | |
| "2 TeV range" | "4 TeV range" |
| $50 < m_0 < 2$ TeV | $50 < m_0 < 4$ TeV |
| $50 < m_{1/2} < 2$ TeV | $50 < m_{1/2} < 4$ TeV |
| $\|A_0\| < 5$ TeV | $\|A_0\| < 7$ TeV |
| $2 < \tan\beta < 62$ | |
| SM (nuisance) parameters $\psi$ | |
| $160 < M_t < 190$ GeV | |
| $4 < m_b(m_b)^{\overline{MS}} < 5$ GeV | |
| $127.5 < 1/\alpha_{em}(M_Z)^{\overline{MS}} < 128.5$ | |
| $0.10 < \alpha_s(M_Z)^{\overline{MS}} < 0.13$ | |

## In general: a spin-dependent and a spin-independent contribution:

$$\frac{d\sigma_{spin}}{d|\vec{q}|^2} = G_F^2 \frac{C_A}{v^2} F^2(|\vec{q}|) = \frac{\sigma_0}{4\mu^2 v^2} F^2(|\vec{q}|) \qquad \propto J(J+1)$$

$$\frac{d\sigma_{scalar}}{d|\vec{q}|^2} = G_F^2 \frac{C_S}{v^2} F^2(Q) = \frac{\sigma_0}{4\mu^2 v^2} F^2(Q) \qquad \propto A^2$$

$$G_F^2 \approx 10^{-10} GeV^{-4} \qquad \mu = \frac{m_\chi m_A}{m_\chi + m_A}$$ reduced mass

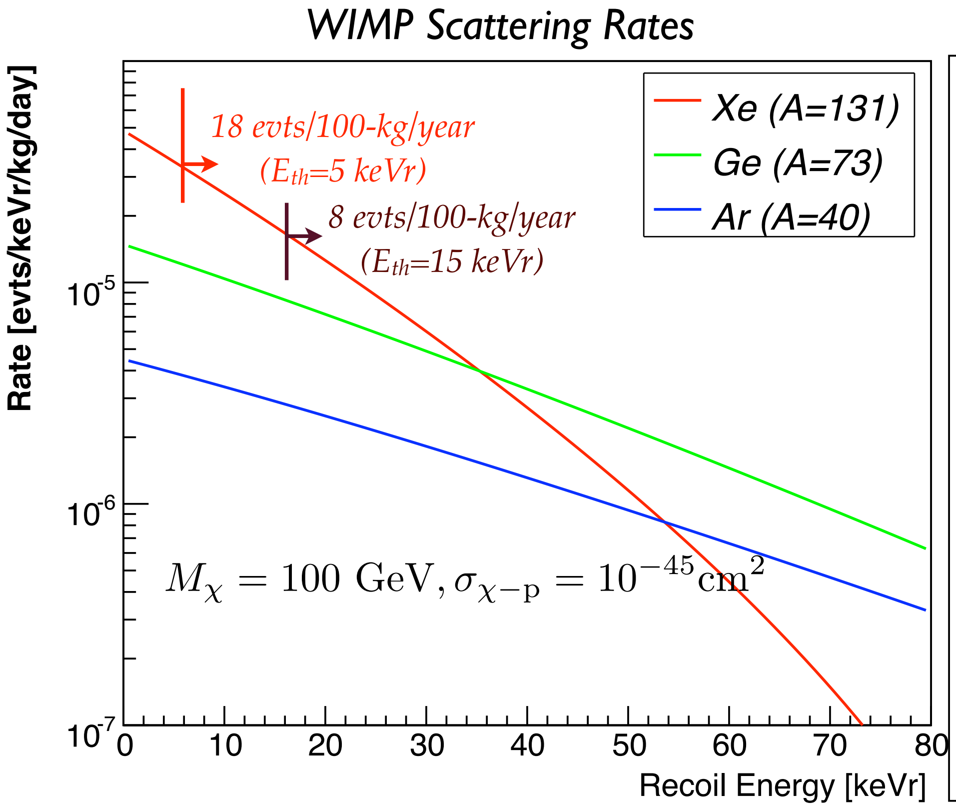
$c_A$, $c_S$ = dimensionless numbers containing the particle-physics model information

$$C_S = \frac{1}{\pi v^2}[Z f_p + (A - Z) f_n]^2$$ for scalar couplings

v = WIMP velocity ~ $10^{-3}$c; $F^2$(Q): nuclear form factor

# Typical WIMP Rate

$$R \sim \frac{M_{det}}{M_\chi} \rho \sigma \langle v \rangle$$

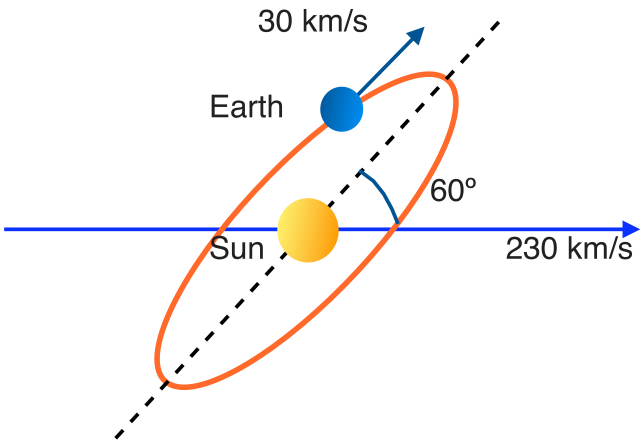


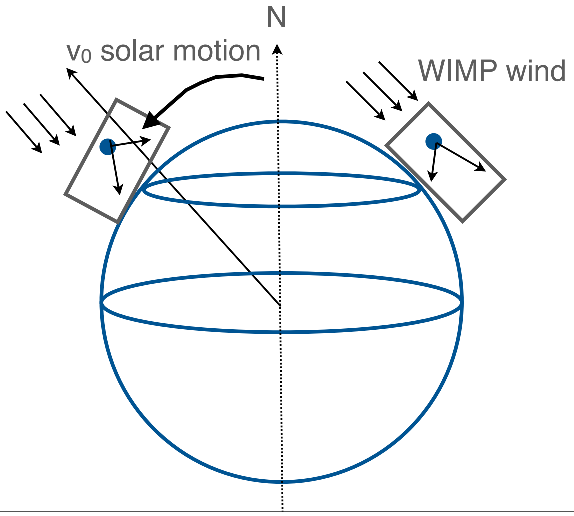
*requirements for direct DM detectors*

- ➡ *large mass (ton scale)*
- ➡ *low energy threshold (a few keV)*
- ➡ *low background noise*
- ➡ *intrinsic S/N discrimination*

# WIMP Signatures

- **WIMP interactions in detector should be:**
  - nuclear recoils
  - single scatters, uniform throughout detector volume
  - as we sweep the WIMP halo, interaction rate is low and modulated
- **Spectral shape** (exponential, however similar to background)
- **Dependance on material** ($A^2$, $F^2(Q)$, test consistency between different targets)
- **Annual flux modulation** (~ 3% effect, most events close to threshold)
- **Diurnal direction modulation** (larger effect, requires low-pressure gas target)





# Sources of Background

- Detector related:
  - intrinsic radioactivity (U, Th, K, Co, etc.) in materials: a source of gammas and neutrons background--> careful screening and selection
  - intrinsic radioactivity in target itself (U, Th, Rn, Kr85, Ar39, etc.) --> purification and careful handling

- Environment related:
  - radioactivity of environment materials (gammas and neutrons from (alpha,n) and muon-spallation): shielding (Pb, Cu, PE, H2O, etc.)
  - cosmic ray muons: go underground
  - fast neutrons induced by muons (ultimate background)

- Other physics processes related:
  - solar neutrinos, double beta decay --> start to be relevant for very sensitive DM searches and as threshold is lowered

# Example: XENON1T

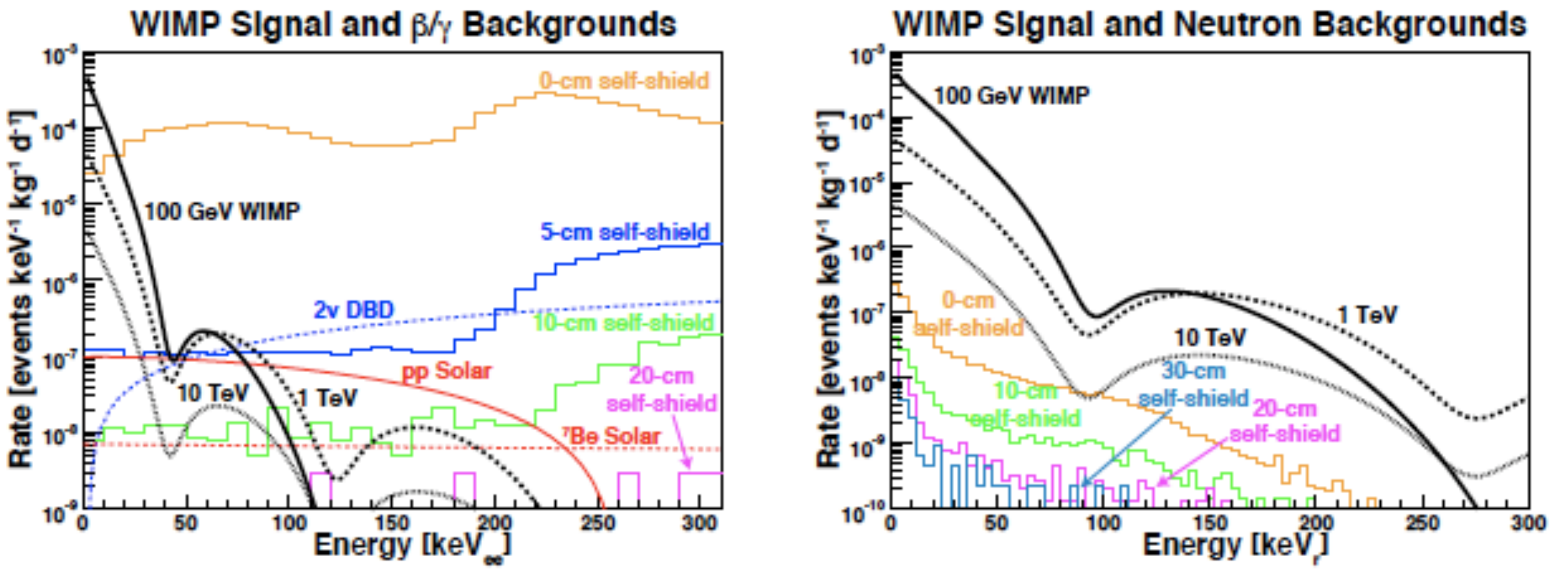
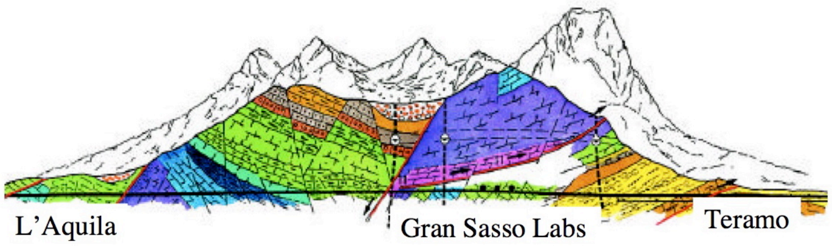
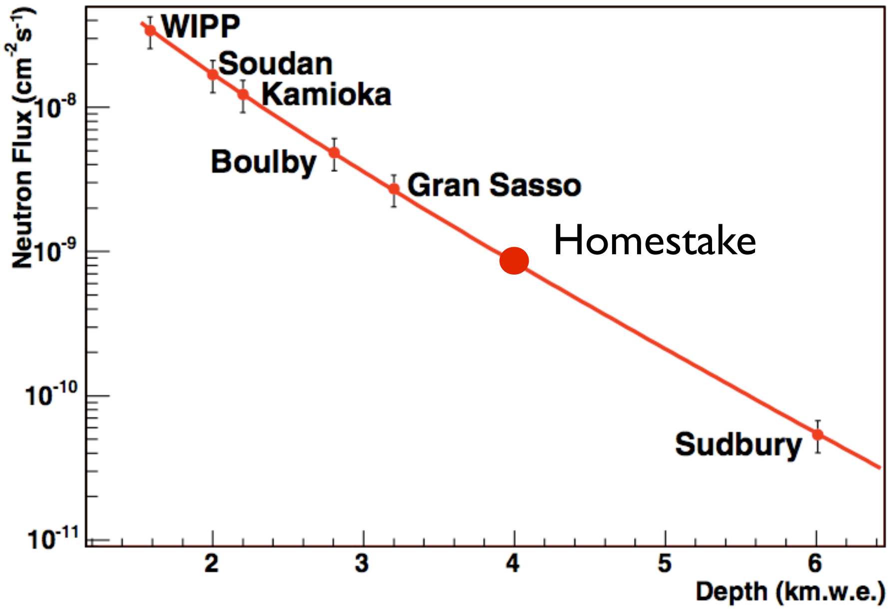


FIG. 8: Expected energy spectra of WIMP interactions, solar neutrinos, two-neutrino double beta decays from $^{136}$Xe (assuming $\tau$=$10^{22}$ yr) and gamma ray backgrounds as a function of self-shielding cuts (after $S2/S1$ and multiple-scattering cuts.)

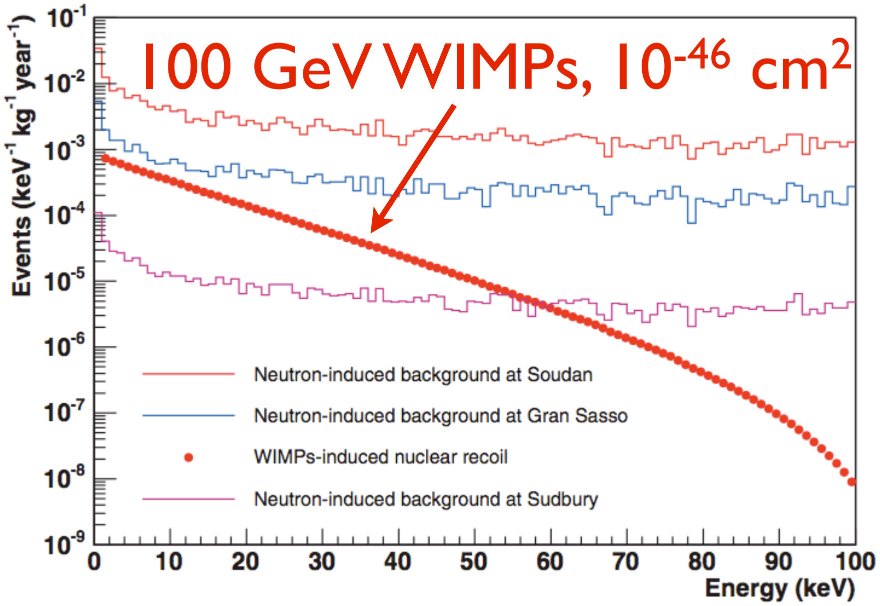
Figure 8 shows the expected rate of WIMP signal (for masses of 0.1, 1, 10 TeV and $\sigma_{\chi N}=10^{-44}$ cm$^2$), compared with the total $\gamma$-ray background rate, and neutron background rate after $S2/S1$ and multiple-scattering cuts. The expected background from $pp$ solar neutrinos and $^{136}$Xe 2-$\nu$ double-$\beta$ decay is also shown. The power of the LXe self-shielding is apparent. A cut of only ~10 cm of active LXe is sufficient to reduce the overall background rate below $10^{-7}$ events/keV/kg/d. Figure 7b shows the spatial distribution of the overall $\gamma$-ray and neutron backgrounds in the TPC. With the ~10 cm self-shielding cut, the residual backgrounds are 0.15 $\gamma$/yr and 0.13 $n$/yr, with pp-chain solar neutrinos becoming the irreducible background at a level of 0.5 event/ton/year.

# *Neutron Background: the need for deep underground laboratories*



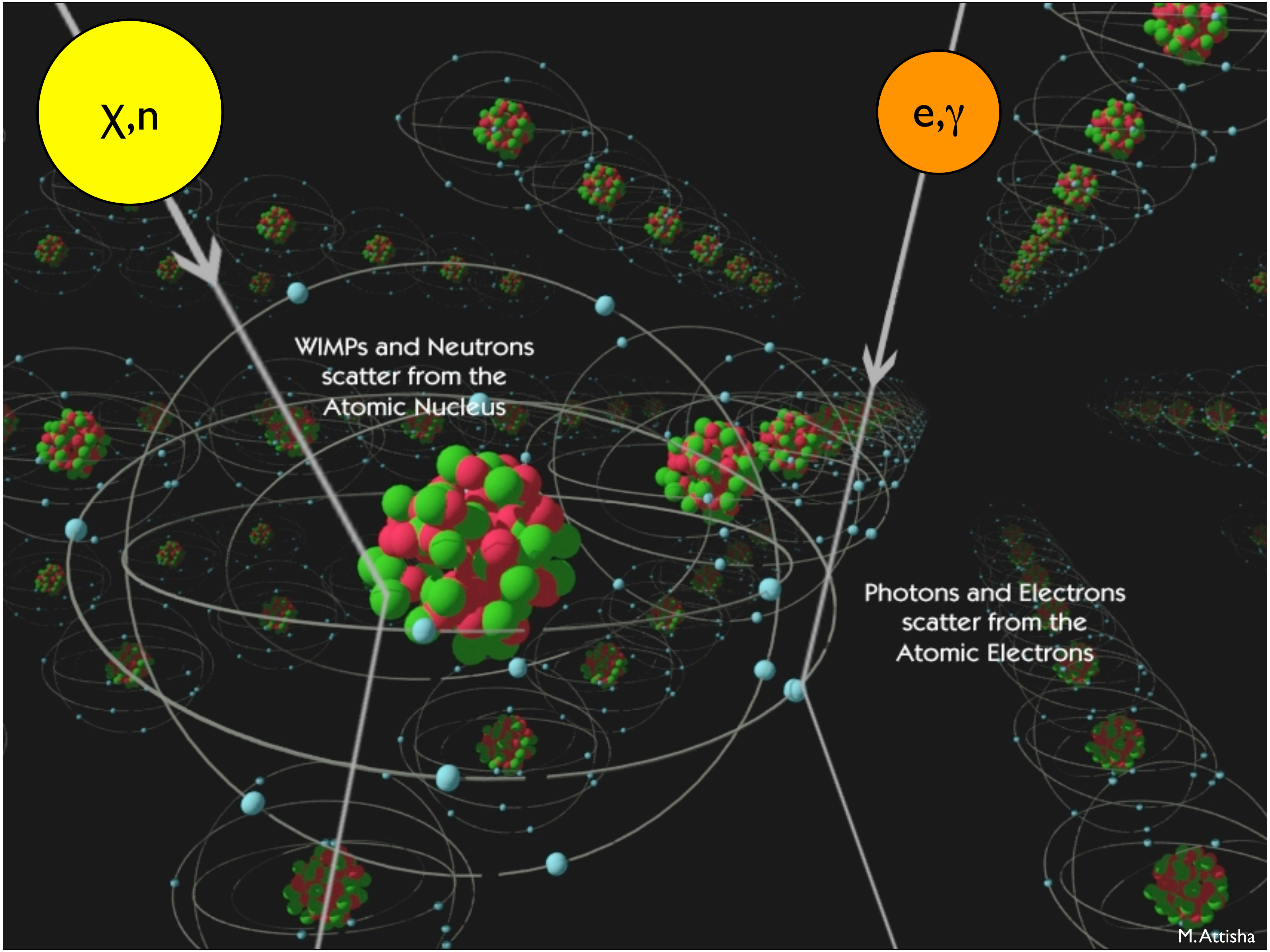


*muon induced neutron flux*


100 GeV WIMPs, $10^{-46}$ cm$^2$

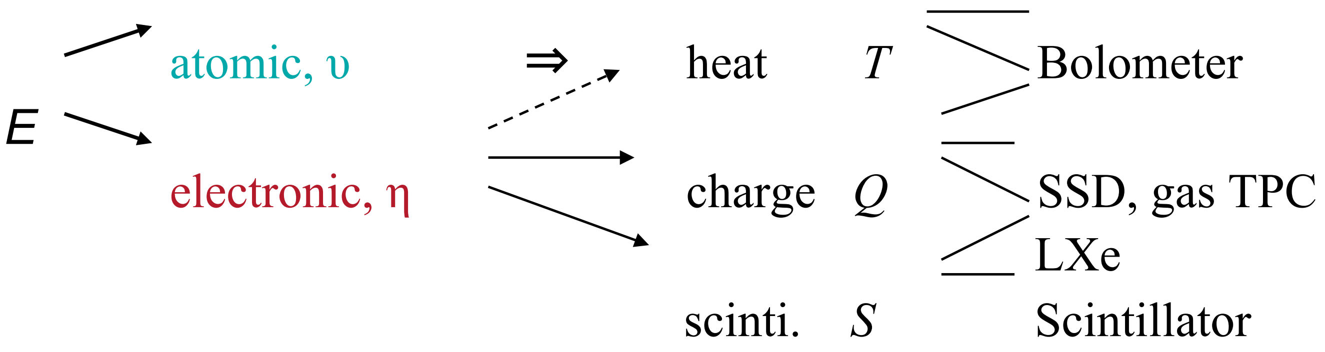
*signal/background event rates*

*Mei and Hime, PRD (2006)*


χ,n
e,γ
WIMPs and Neutrons scatter from the Atomic Nucleus
Photons and Electrons scatter from the Atomic Electrons
M.Attisha

# Energy sharing for low energy ions

For slow ions, $v < v_0 = e^2/\hbar$, electronic $S_e$ and nuclear $S_n$ stopping powers are similar in magnitude. The secondaries, recoil atoms and electrons, may again suffer collisions and transfer the energy to new particles and so on. After this cascade process is complete, the energy of the incident particle $E$ is given to atomic motion ν and electronic excitation η.



*E*

atomic, υ

electronic, η

⇒

heat $T$

charge $Q$

scinti. $S$

Bolometer

SSD, gas TPC

LXe

Scintillator

Nuclear quenching factor $$q_{nc} = \frac{\text{Electronic energy}}{\text{Ion energy}} = \eta / E$$

# Quenching factor and discrimination

WIMPs (and neutrons) scatter off nuclei

Most background noise sources (gammas, electrons) scatter off electrons

Detectors have a different response to nuclear recoils than to electron recoils!

Quenching factor = describes the difference in the amount of visible energy in a detector for these 2 classes of events

- keVe = measured signal from an electron recoil
- keVr = measured signal from a nuclear recoil
- => for nuclear recoil events:

Evisible (keVe) = QF x Erecoil (keVr)

the energy scale is calibrated with gamma and neutron sources

# Quenching factor and discrimination

the quenching allows to distinguish between electron and nuclear recoils if two simultaneous detection mechanisms are used

example:

charge and phonons in Ge

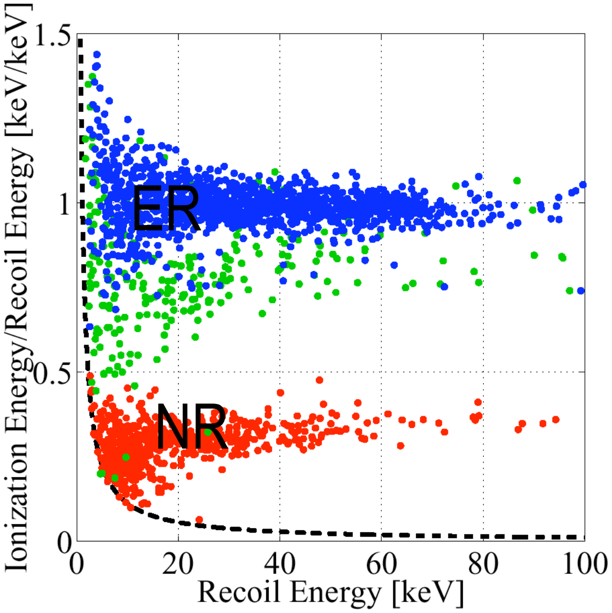
$E_{visible} \sim 1/3\ E_{recoil}$ for NR

(=> QF ~ 30% in Ge)

ER = background

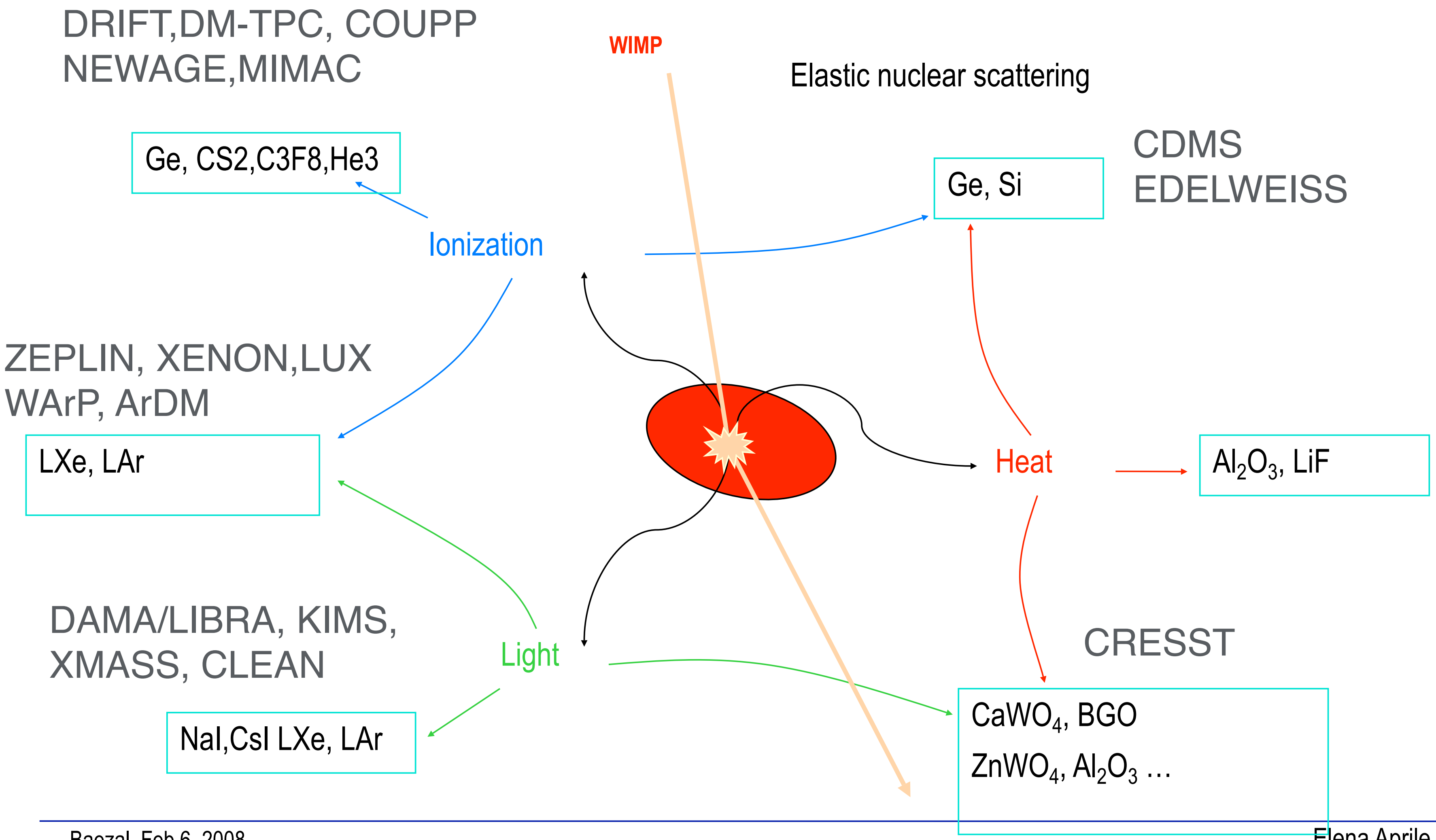
NR = WIMPs or neutrons (background)

Similarly in noble liquids ..



# Direct Detection Experiments

**After Drukier and Stodolsky, PRD 30 (1984) 2295**
**(and Goodman and Witten (1985) )**



DRIFT,DM-TPC, COUPP
NEWAGE,MIMAC

Ge, CS2,C3F8,He3

WIMP

Elastic nuclear scattering

Ionization

Ge, Si

CDMS
EDELWEISS

ZEPLIN, XENON,LUX
WArP, ArDM

LXe, LAr

Heat

$Al_2O_3$, LiF

DAMA/LIBRA, KIMS,
XMASS, CLEAN

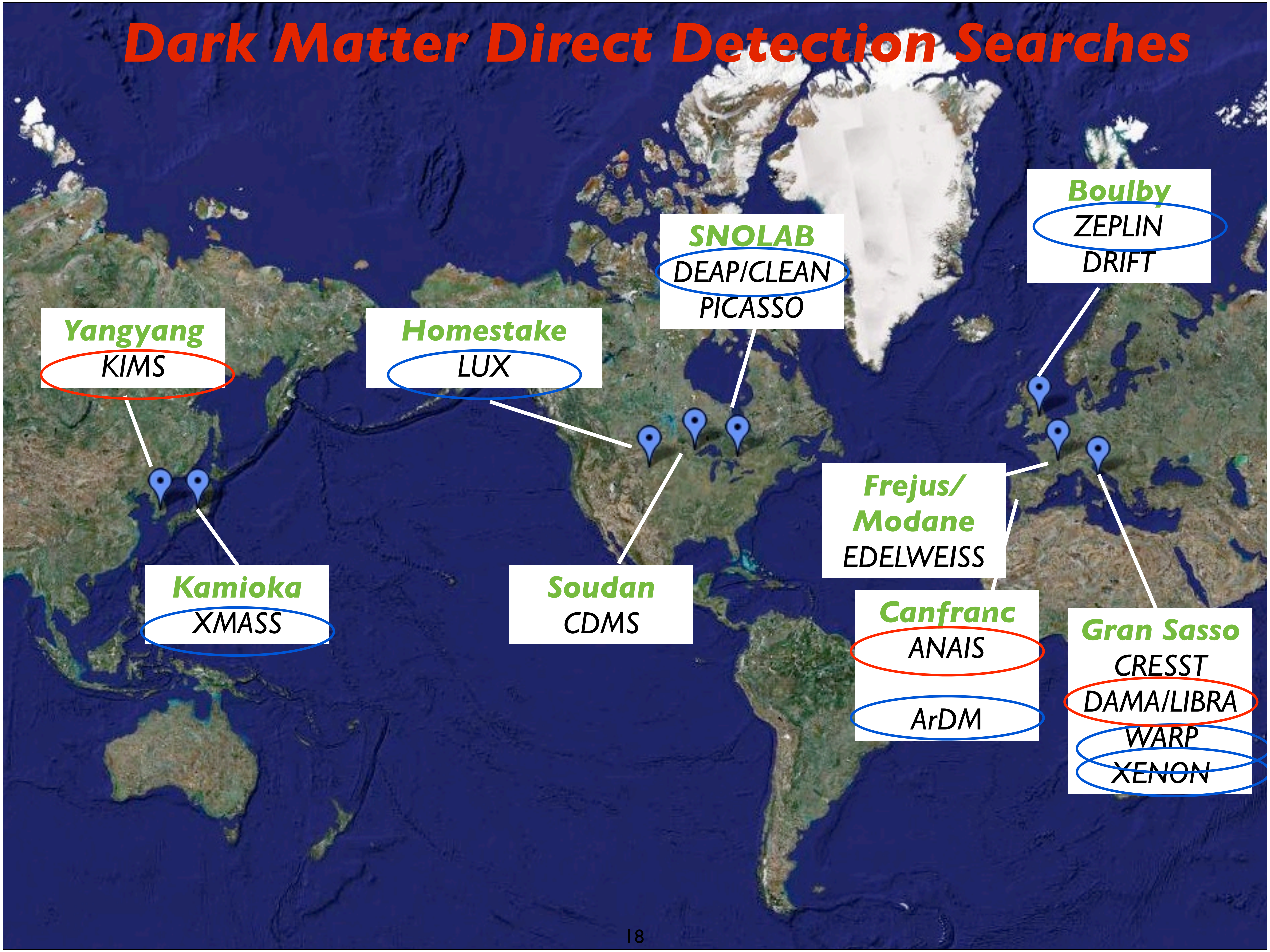
Light

NaI,CsI LXe, LAr

CRESST

$CaWO_4$, BGO
$ZnWO_4$, $Al_2O_3$ …

# Dark Matter Direct Detection Searches



**Yangyang**
KIMS

**Homestake**
LUX

**SNOLAB**
DEAP/CLEAN
PICASSO

**Boulby**
ZEPLIN
DRIFT

**Kamioka**
XMASS

**Soudan**
CDMS

**Frejus/ Modane**
EDELWEISS

**Canfranc**
ANAIS

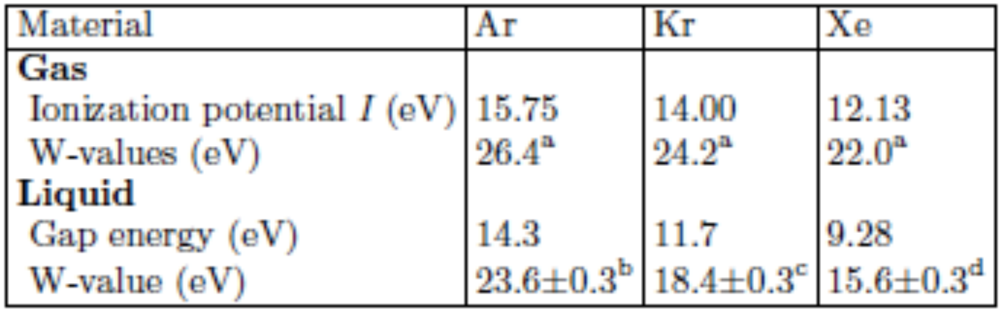
ArDM

**Gran Sasso**
CRESST
DAMA/LIBRA
WARP
XENON

# Liquified Noble Gases: Basic Properties

Dense and homogeneous
Do not attach electrons, heavier noble gases give high electron mobility
Easy to purify (especially lighter noble gases)
Inert, not flammable, very good dielectrics
Bright scintillators

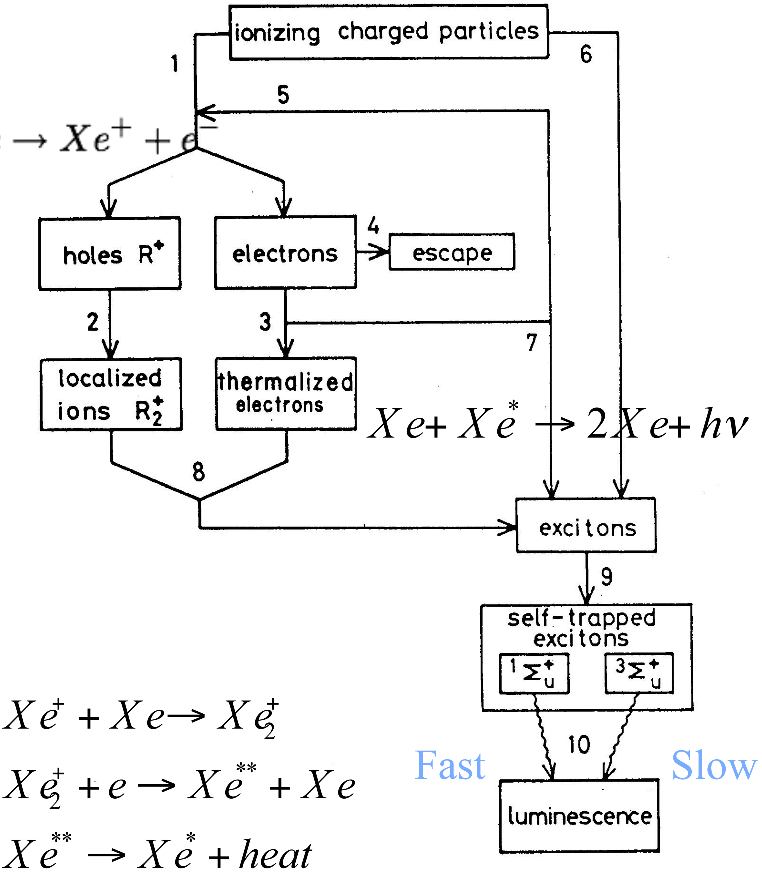
| | Liquid density (g/cc) | Boiling point at 1 bar (K) | Electron mobility (cm$^2$/Vs) | Scintillation wavelength (nm) | Scintillation yield (photons/MeV) | Long-lived radioactive isotopes | Triplet molecule lifetime (μs) |
|---|---|---|---|---|---|---|---|
| LHe | 0.145 | 4.2 | low | 80 | 19,000 | none | 13,000,000 |
| LNe | 1.2 | 27.1 | low | 78 | 30,000 | none | 15 |
| LAr | 1.4 | 87.3 | 400 | 125 | 40,000 | $^{39}$Ar, $^{42}$Ar | 1.6 |
| LKr | 2.4 | 120 | 1200 | 150 | 25,000 | $^{81}$Kr, $^{85}$Kr | 0.09 |
| LXe | 3.0 | 165 | 2200 | 175 | 42,000 | $^{136}$Xe | 0.03 |



| Material | Ar | Kr | Xe |
|---|---|---|---|
| **Gas** | | | |
| Ionization potential $I$ (eV) | 15.75 | 14.00 | 12.13 |
| W-values (eV) | 26.4[a] | 24.2[a] | 22.0[a] |
| **Liquid** | | | |
| Gap energy (eV) | 14.3 | 11.7 | 9.28 |
| W-value (eV) | 23.6±0.3[b] | 18.4±0.3[c] | 15.6±0.3[d] |

# Ionization/Scintillation Mechanism in Noble Liquids

Kubota et al. 1979, Phys. Rev.B



$Xe \rightarrow Xe^+ + e^-$

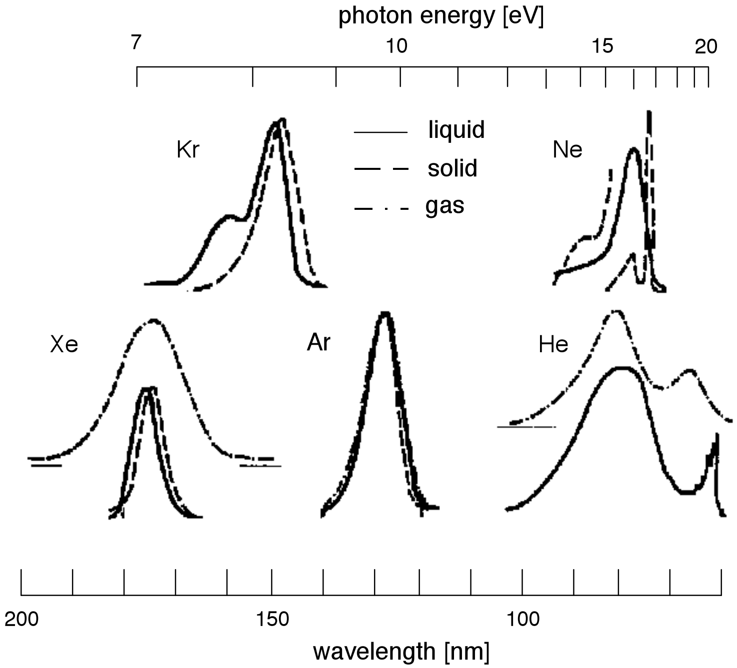
$Xe + Xe^* \rightarrow 2Xe + h\nu$

$Xe^+ + Xe \rightarrow Xe_2^+$

$Xe_2^+ + e \rightarrow Xe^{**} + Xe$

$Xe^{**} \rightarrow Xe^* + heat$

$Xe + Xe^* \rightarrow Xe_2^* \rightarrow 2Xe + h\nu$



$\lambda \sim 128_{LAr}$

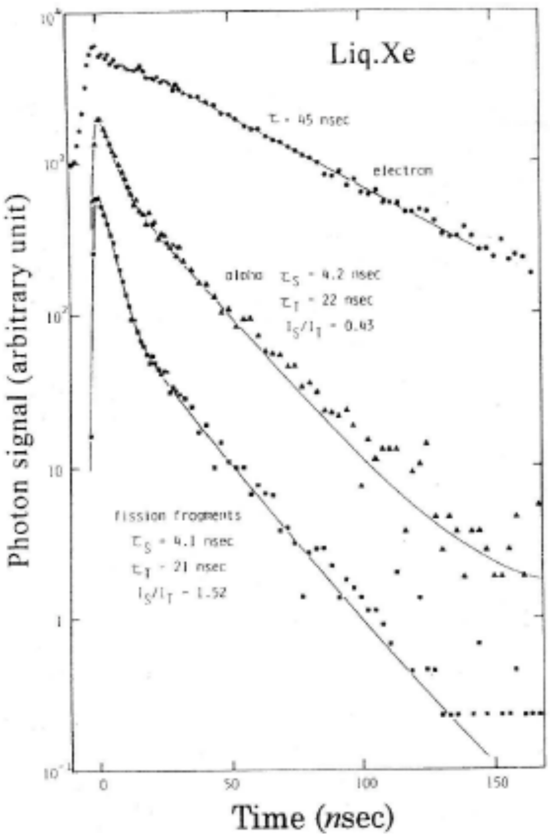
$\lambda \sim 175_{LXe}$

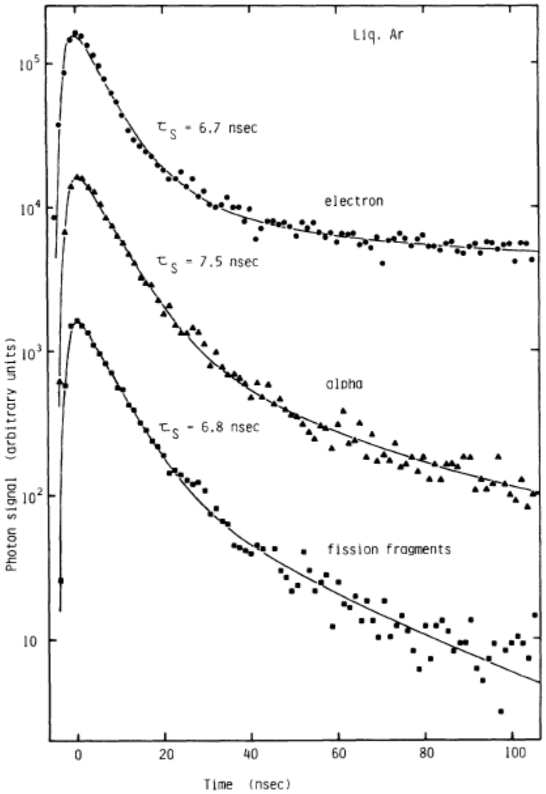
$\lambda \sim 77.5_{LNe}$

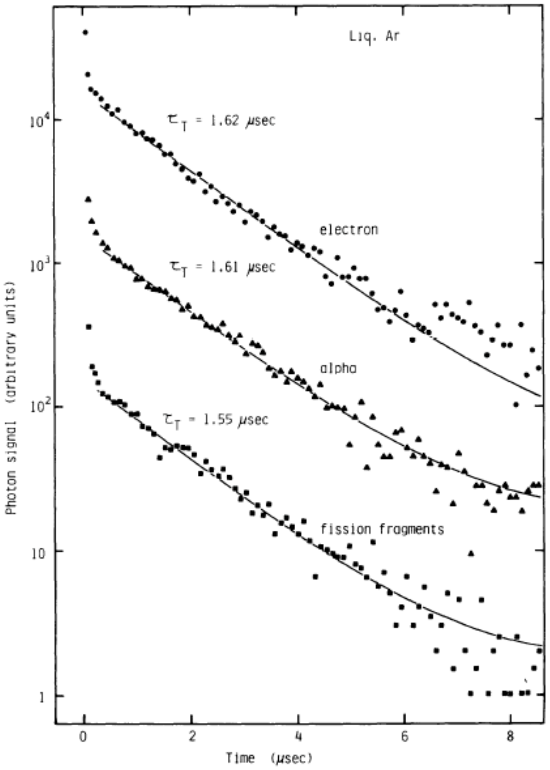
# Scintillation Pulse Shape

- Two decay components from de-excitation of singlet and triplet states of dimers
- While the singlet/triplet lifetimes do not depend on the ionization density of particle, their intensity ratio does: it is larger for heavily ionizing particles allowing particle ID
- LXe: the fastest of all noble liquid scintillators (4ns / 22ns)
- LAr: large separation b/w singlet/triplet decay times allow easy PSD

Hitachi, 1983

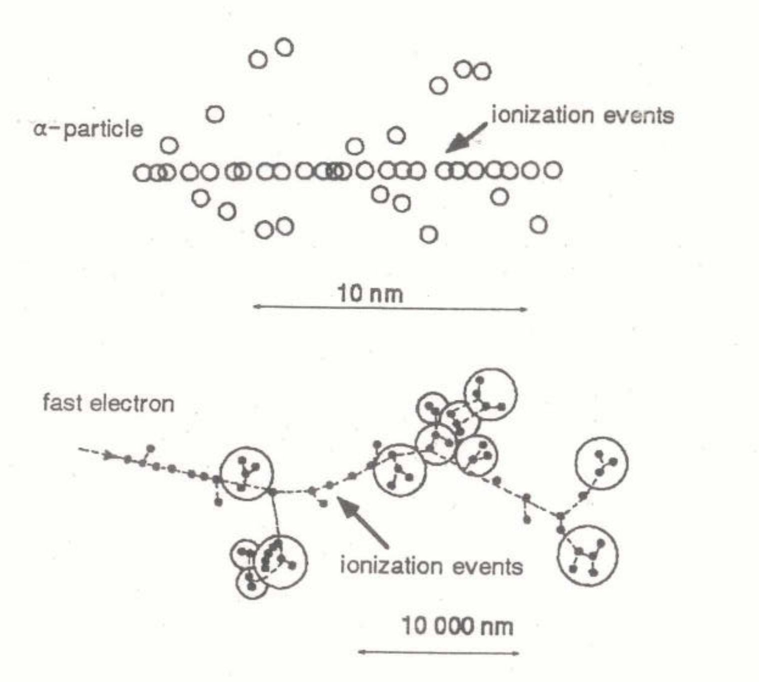




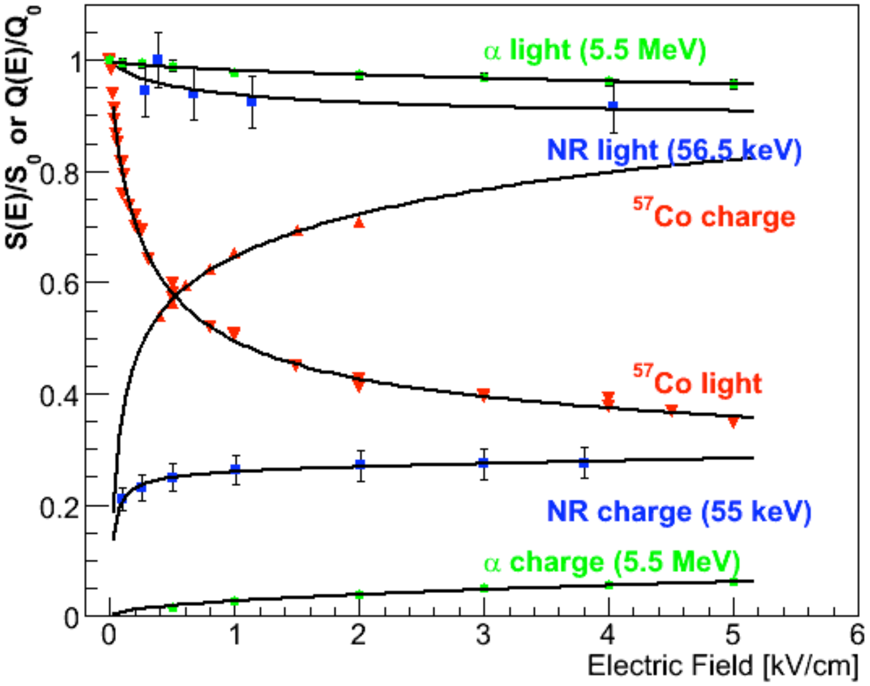


# Charge and Light response of different particles in LXe

**Charge/Light (electron) >> Charge/Light (non relativistic particle)**



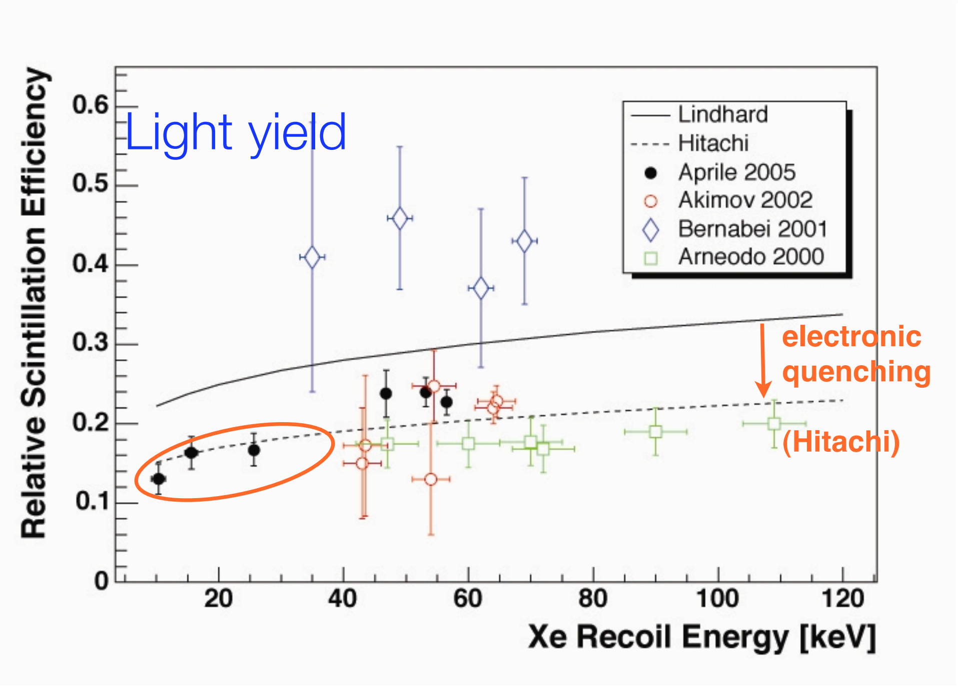
Distribution of ionization around the track of a high energy a-particle or electron

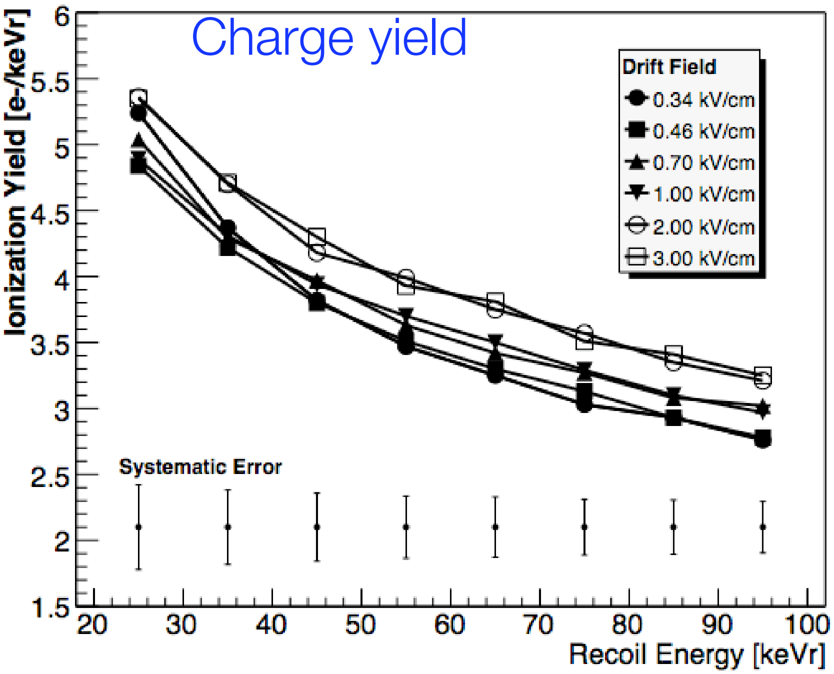


*Aprile et al., Phys. Rev. D 72 (2005) 072006*

# Charge and Light Yield of Nuclear Recoils in LXe

- these quantities are essential for LXe as DM target/detector
- yields measured at **low nuclear recoil energies** for the first time (XENON R&D)





Data down to 10 keVr; yield: 13% - 20% from 10 keVr to 60 keVr. Good agreement with prediction by Hitachi (Astrop. Phys. 24, 2005) at low recoil energies

**Aprile et al., Phys. Rev. D 72 (2005)**

Weak dependence on electric field
Yield increases at low recoil energies

*Aprile et al., Phys. Rev. Lett, 97 (2006)*

# Why Noble Liquids for Dark Matter

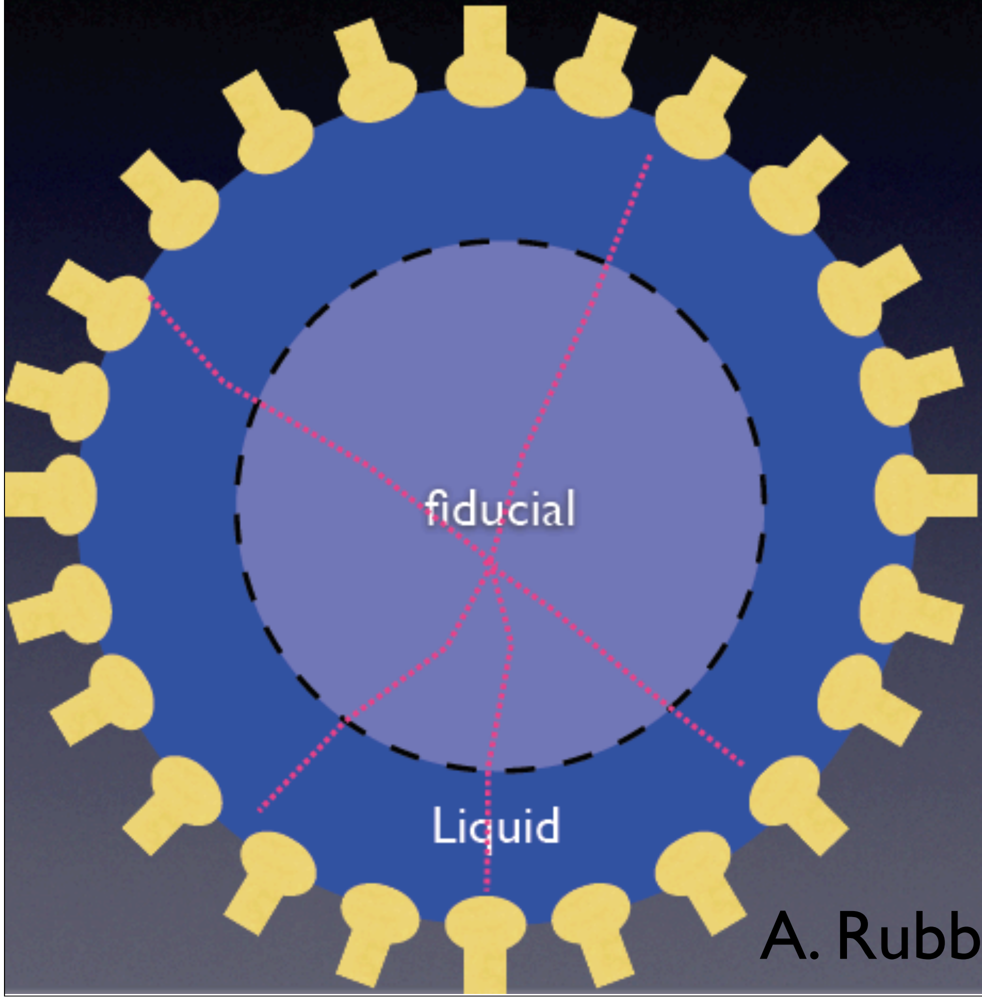
- ✦scalability : relatively inexpensive for large scale (multi-ton) detectors
- ✦easy cryogenics : 170 K (LXe), 87 K (LAr)
- ✦self-shielding : very effective (especially for LXe case) for external background reduction
- ✦low threshold : high scintillation yield (similar to NaI(Tl) but much faster timing)
- ✦n-recoil discrimination: by charge-to-light ratio and pulse shape discrimination
- ✦Xe nucleus (A~131) : good for SI plus SD sensitivity (~50% odd isotopes)
- ✦For Xe: no long-lived radioactive isotopes (Kr-85 can be removed)
- ✦For Ar: radioactive Ar-39 is an issue but there are ways to overcome it

# Two basic detector concepts

## Single phase:

No drift (E=0)

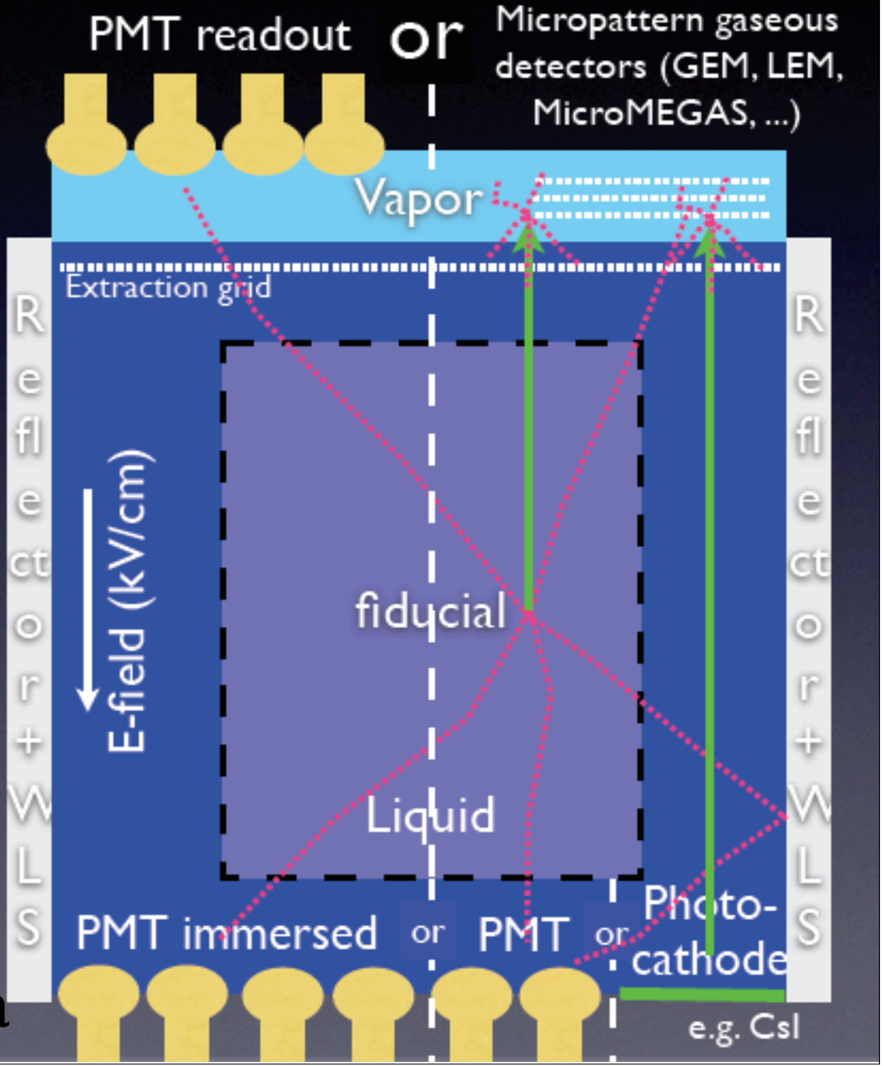
*(XMASS, CLEAN/DEAP)*



## Double phase:

Ionization e$^-$ drift (E≠0)

***XENON,*** *LUX,ZEPLIN II/III,WARP,ArDM)*



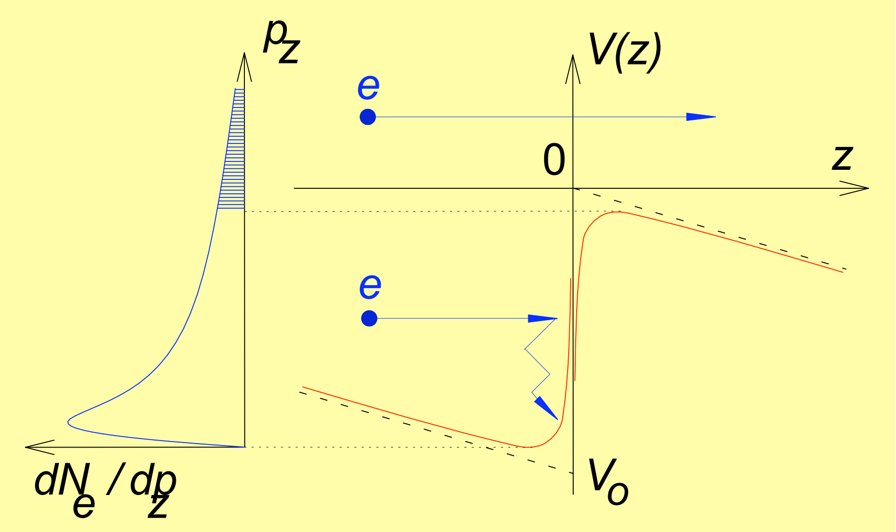
A. Rubbia

# Quasi-free Electron Emission from Noble Liquids

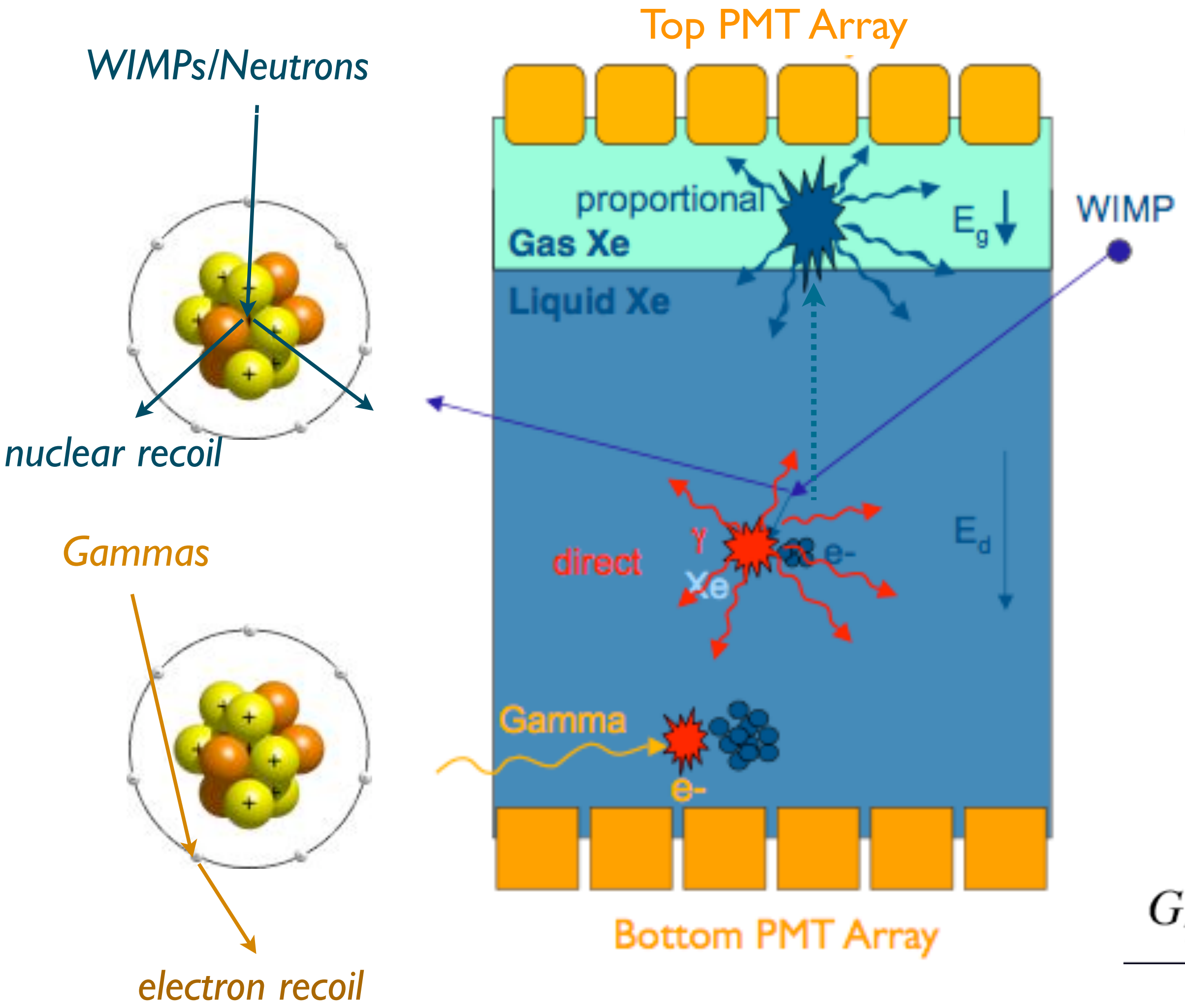
- Excess electrons liberated by ionizing radiation can exist in a quasi-free state.
- The potential energy distribution near the interface of two-phase dielectrics favors emission of excess electrons from the quasi-free state
- In LAr the height of the potential barrier is comparable with the thermal energy of excess electrons. Electrons with $p_z > p_0$ have sufficient energy for emission
- In LXe the potential barrier $|V_0| \gg kT$ and spontaneous emission is not easily achieved. However, with a high electric field, electrons are heated and when $p_z > p_0$ they escape from the condensed phase
- Electrons drifting in the gas, under a high electric field (>1kV/(cm bar) in Xe, generate electroluminescence or proportional scintillation. One electron in gas Xe can produce more than 1000 UV photons/cm of drift path

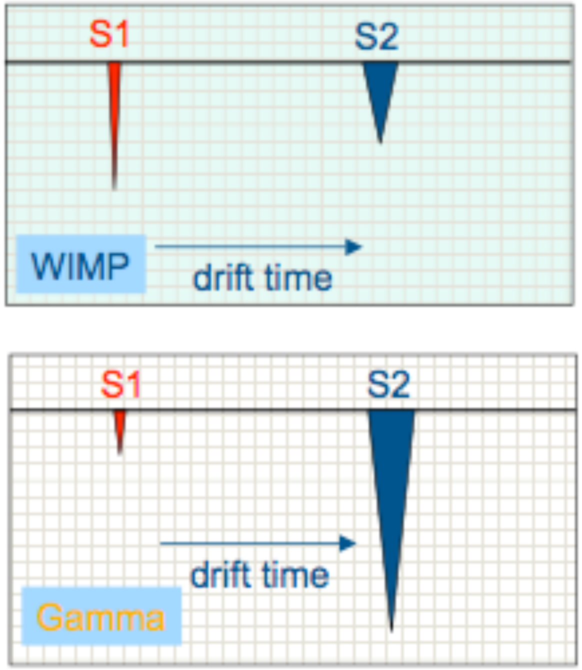
B. Dolgoshein et al. JETP Lett. 11 (1970) 513

A. Bolozdynya, NIM A422 (1999) 314



# *Noble liquid two-phase TPC*



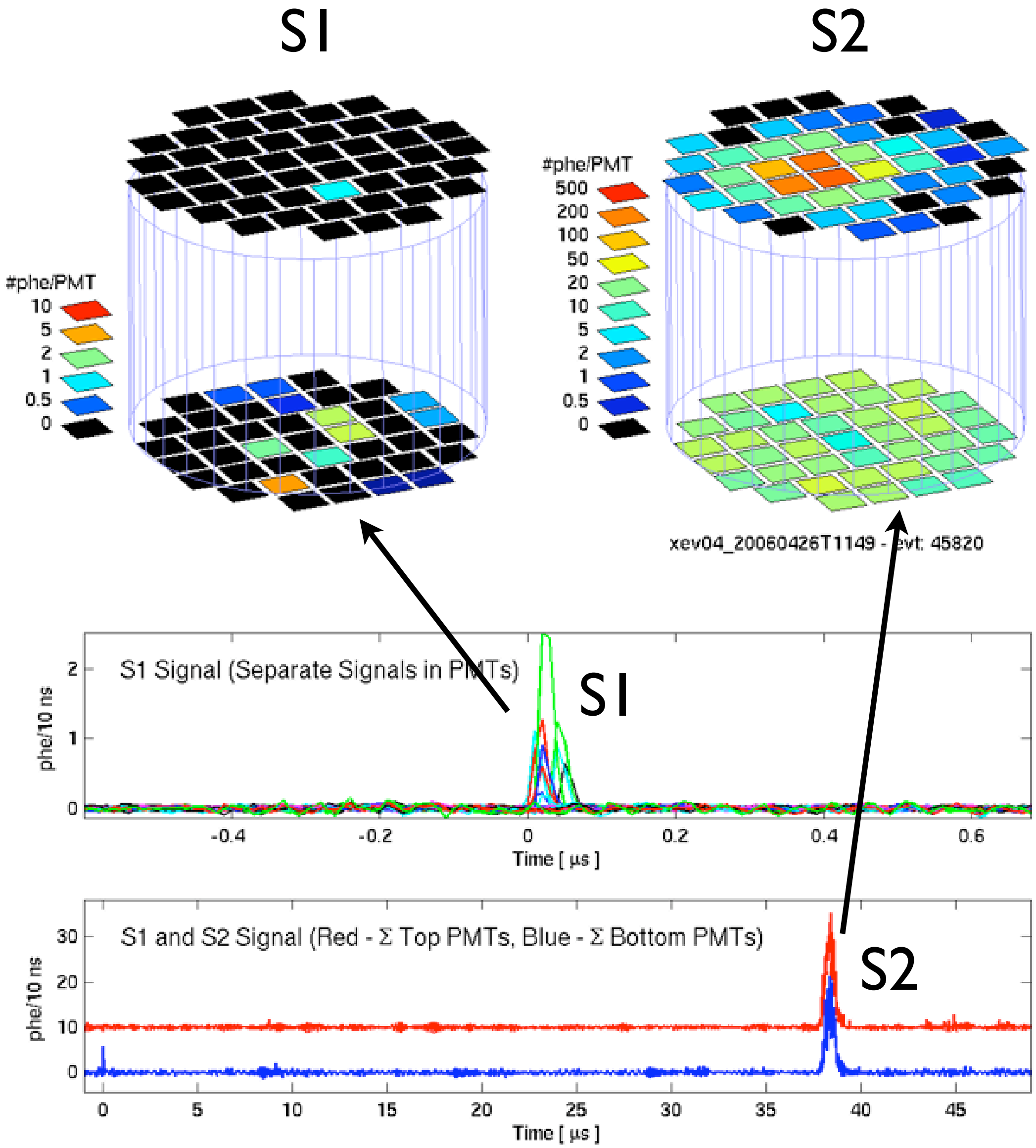


$(S2/S1)_{wimp} \ll (S2/S1)_{gamma}$

$$G_\gamma \approx \alpha\left(E/p - \varepsilon_{thresh}\right)\cdot x \cdot p$$

$$\alpha_{LXe} = 70\ \gamma / kV \qquad \varepsilon_{thresh}^{LXe} = 1.3 kV / cm / atm$$

# *Signals from XENON10*

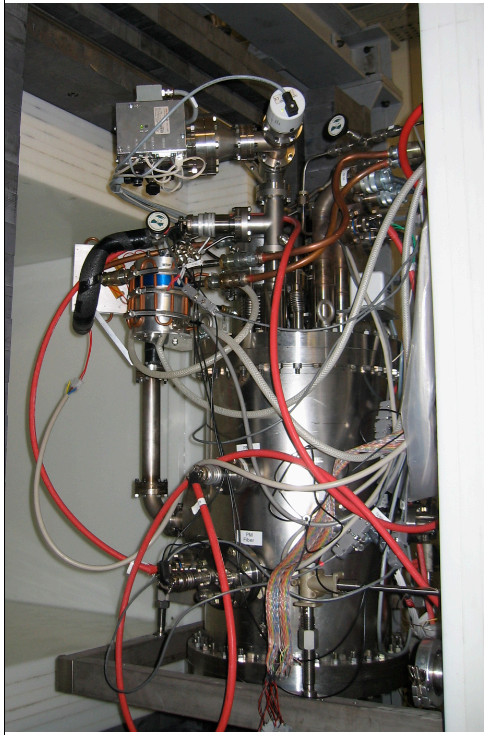


# The XENON Dark Matter Search Phases

*the past*
*(2005 - 2007)*

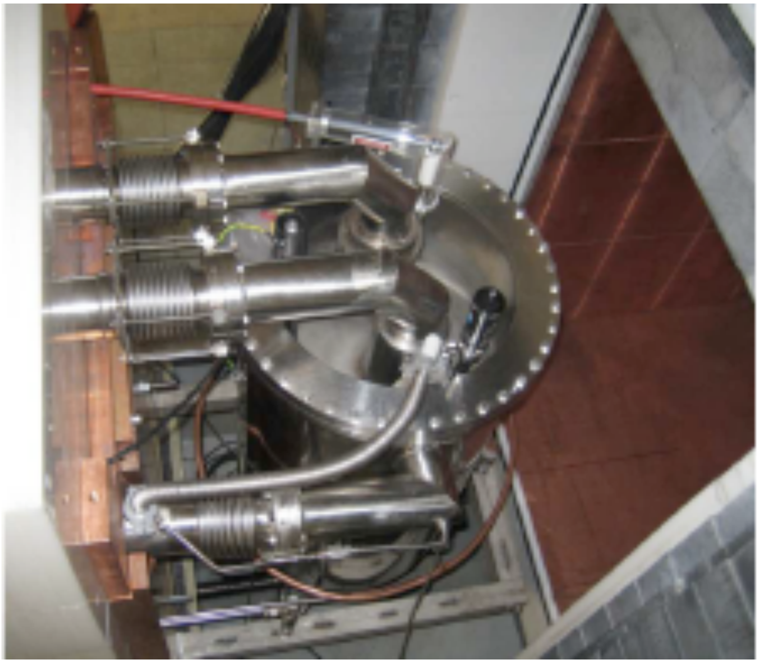
*the current*
*(2007-2010)*

*the future*
*(2010-2014)*



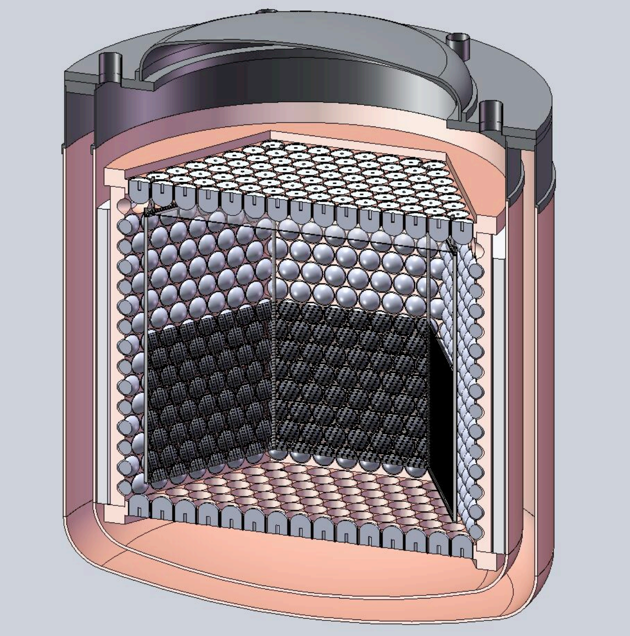
XENON10

*Achieved (2007)* $\sigma_{SI}=8.8 \times 10^{-44}\ cm^2$



XENON100

*Projected (2009)* $\sigma_{SI}\sim 2\times10^{-45}\ cm^2$



XENON1T

*Projected (2014)* $\sigma_{SI}\sim 10^{-47}\ cm^2$

# XENON10 @ LNGS

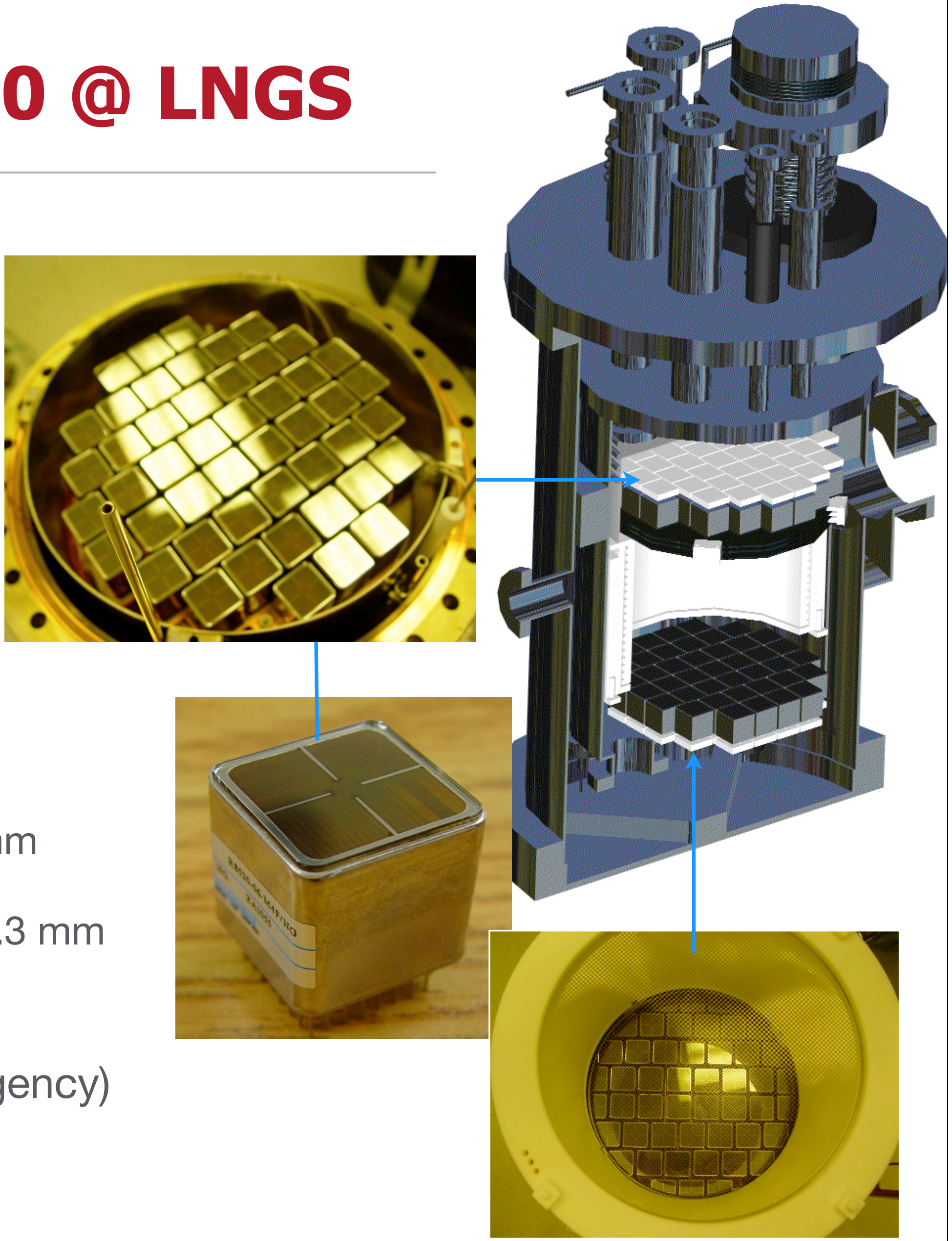
- **22 kg of liquid xenon**
  - ➡15 kg active volume
  - ➡20 cm diameter, 15 cm drift
  - ➡PTFE walls for VUV reflectivity
- **89 Hamamatsu R8520 1”×3.5 cm PMTs**

  bialkali-photocathode Rb-Cs-Sb,

  Quartz window; ok at -100°C and 5 bar

  Quantum efficiency > 20% @ 178 nm
  - ➡x-y position from PMT hit pattern; $\sigma_{x-y} \approx 1$ mm
  - ➡z-position from $\Delta t_{drift}$ ($v_{d,e-} \approx 2$mm/μs), $\sigma_Z \approx 0.3$ mm
- **Cooling: Pulse Tube Refrigerator (PTR),**

  90W, coupled via cold finger ($LN_2$ for emergency)



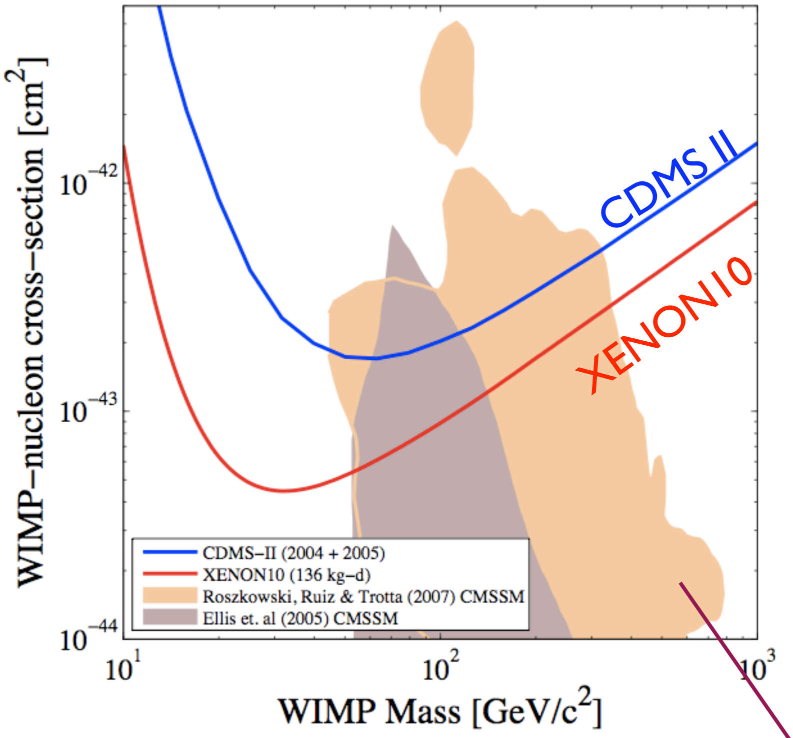
# *XENON10 WIMP-Nucleon Cross-Section Upper Limits*

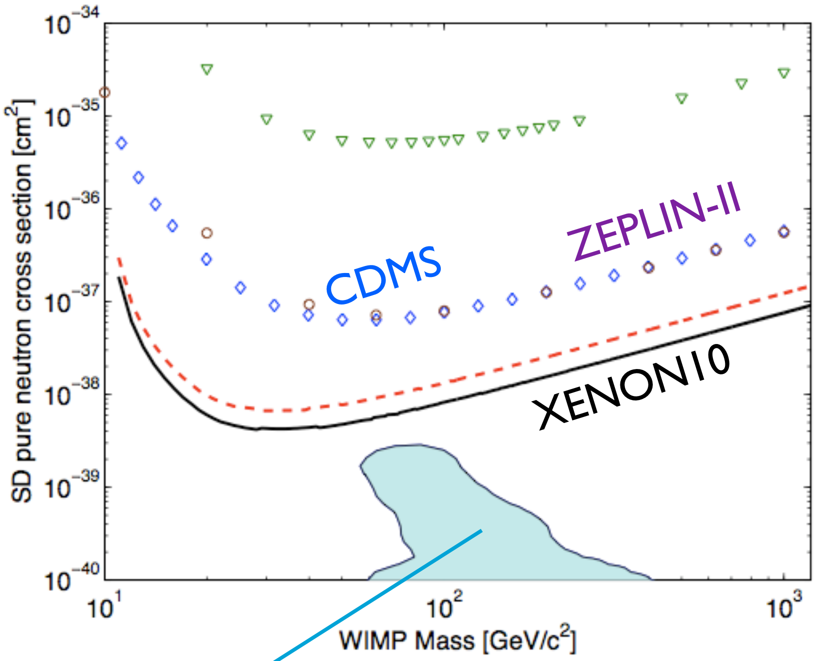
***Spin-independent***

*Phys. Rev. Lett.* ***100****, 021303 (2008)*

***Spin-dependent***

*Phys. Rev. Lett.* ***101****, 091301 (2008)*





*(NO BKG SUBTRACTION)*

*8.8 x $10^{-44}$ cm$^2$ at 100 GeV*

*4.5 x $10^{-44}$ cm$^2$ at 30 GeV*

*Constrained Minimal Supersymmetric Model*

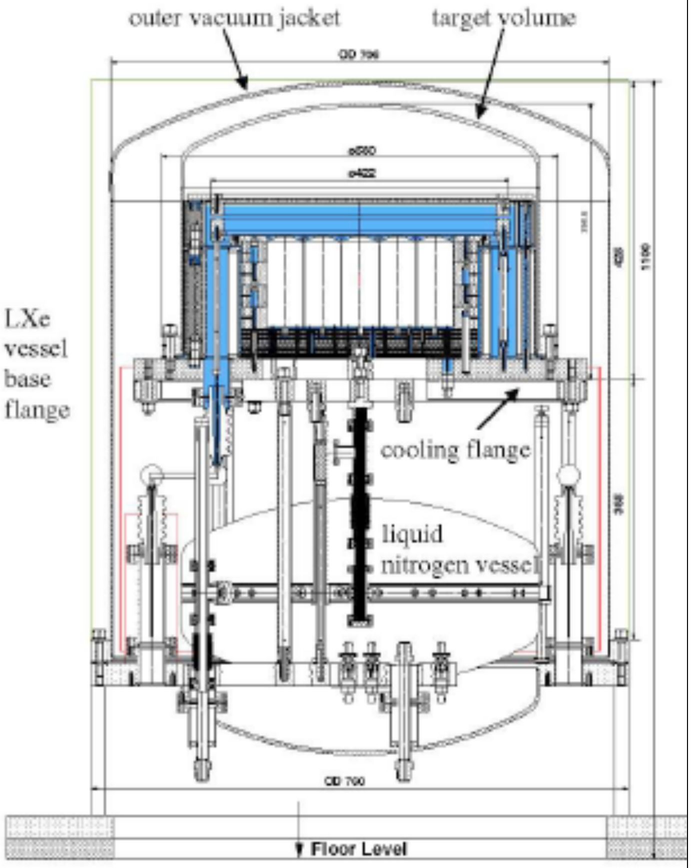
*(NO BKG SUBTRACTION)*

*6 x $10^{-39}$ cm$^2$ at 30 GeV*

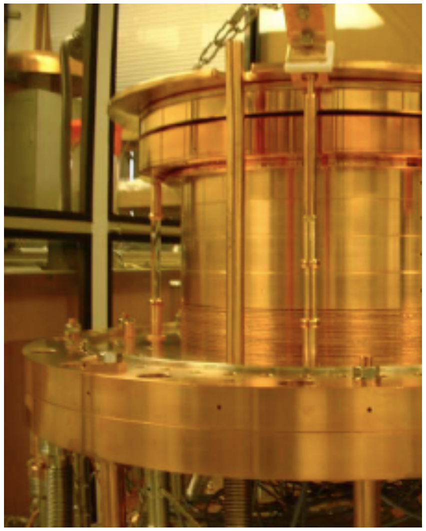
# ZEPLIN III @ Boulby Mine

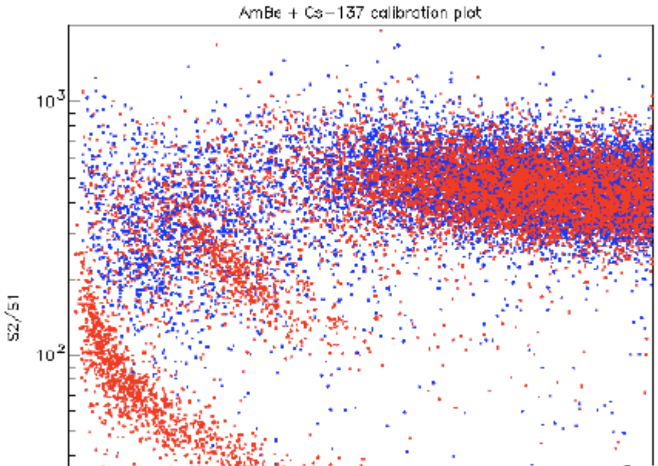
## ZEPLIN III Features

- 8kg fiducial mass
- PMTs in liquid to improve light collection
- 3.5 cm drift depth – higher E-field
- 0.5 cm electroluminescent gap
- 31 small PMTs for fine position sensitivity
- open plan – no surfaces - reduced feedback
- Lower-background PMTs available
- Copper construction
- Low-background xenon (from ITEP)



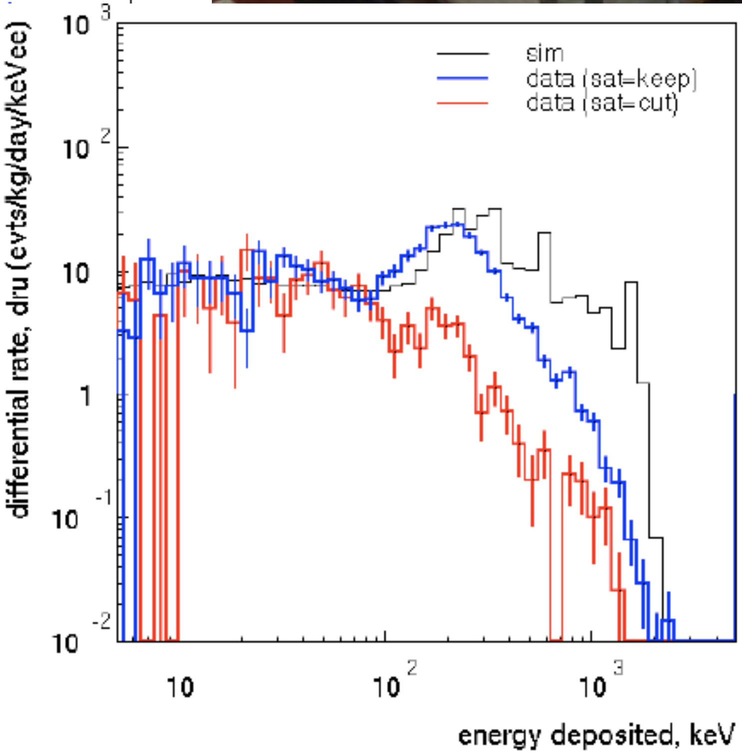
# ZEPLIN III: First Data from Boulby



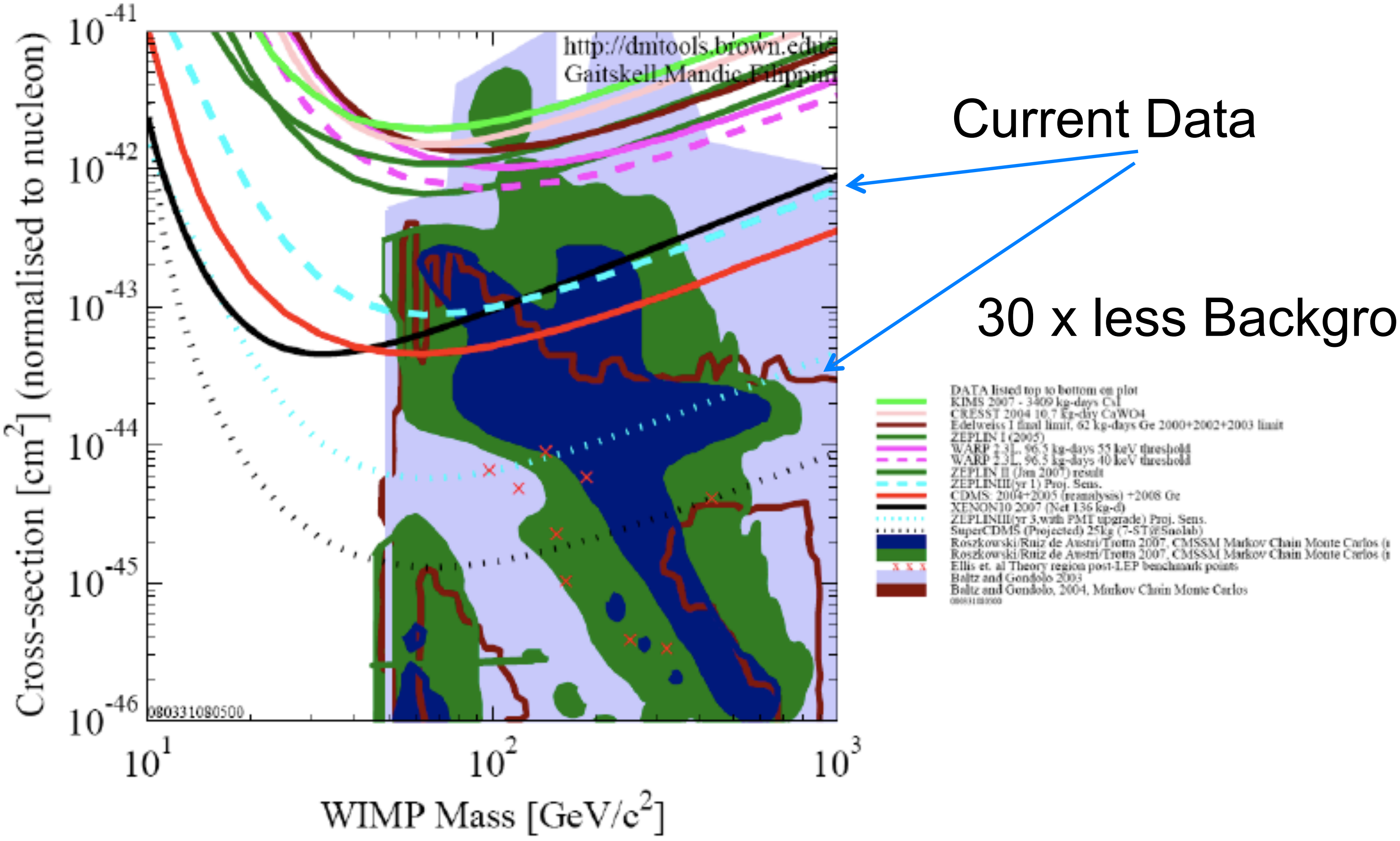


February 28th ….

Fully Shielded Science Runs… commenced!



# ZEPLIN III- Sensitivity Projected



Current Data

30 x less Background

# XENON100 @ Gran Sasso Laboratory

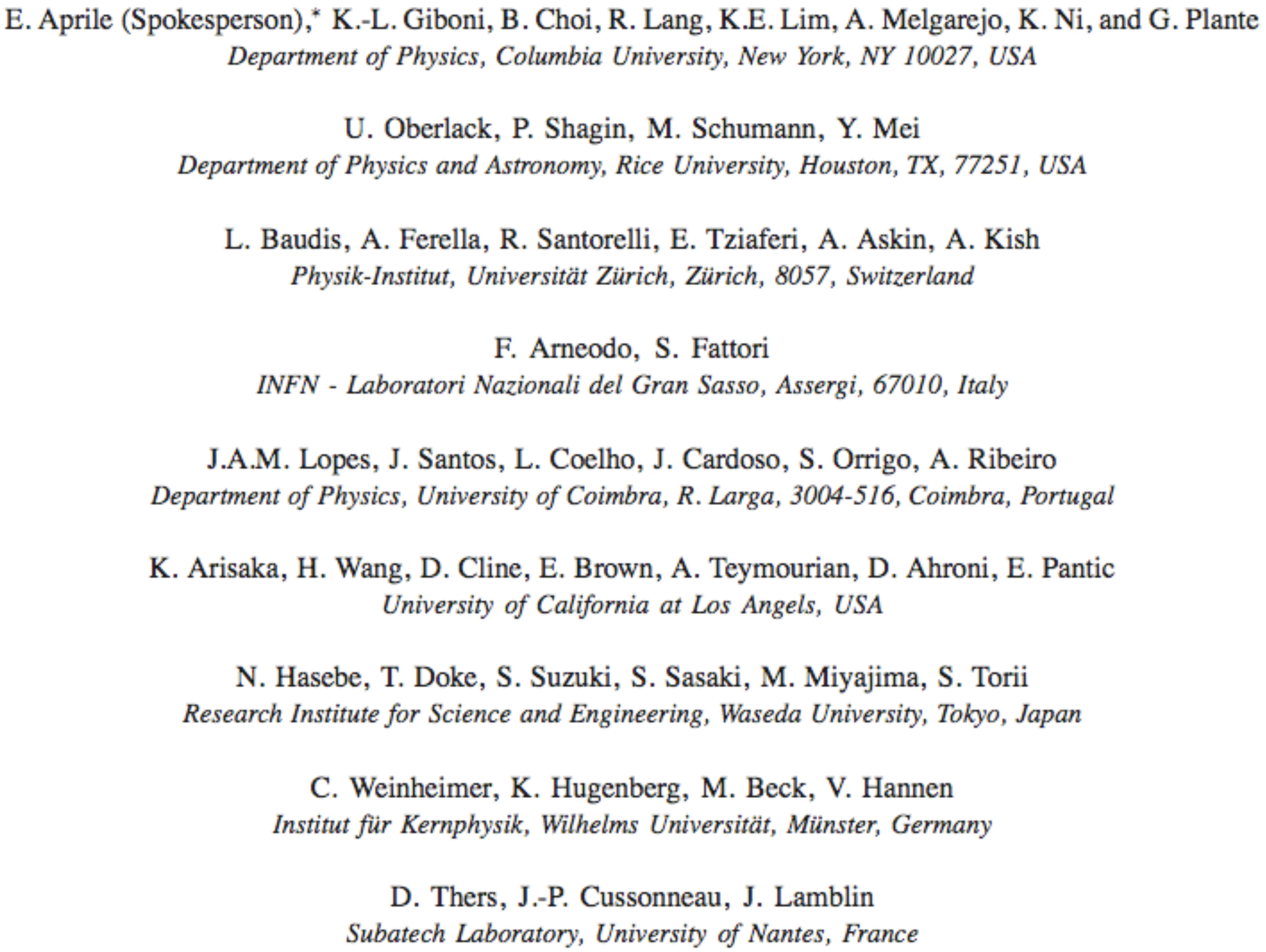
*LNGS 1400 m Rock (3100 w.m.e)*

# XENON100: current phase of the XENON DM Program

- *New TPC with 170 kg Xe (100 kg active shield)*
    - x 10 fiducial mass of XENON10
    - x 2 drift gap (30 cm)
- *Improved PMTs (242 for Target & Veto) and DAQ*
    - *Low activity (U/Th ~1 mBq/PMT)*
    - *QE >30% @ 175 nm (bottom array)*
    - *New Cryostat and Cryogenics System*
    - *Low activity SS (U/Th<1 mBq/kg)*
    - *Cryocooler and Feedthroughs outside shield*
    - *Kr85-removal by distillation tower*
- *Background goal:100 x less than XENON10*
- *Operational: waiting for improved light yield*
- *1st Science Data: Fall 09*

# XENON100 Collaboration

## US - Swizerland - Germany - France - Italy - Portugal -Japan



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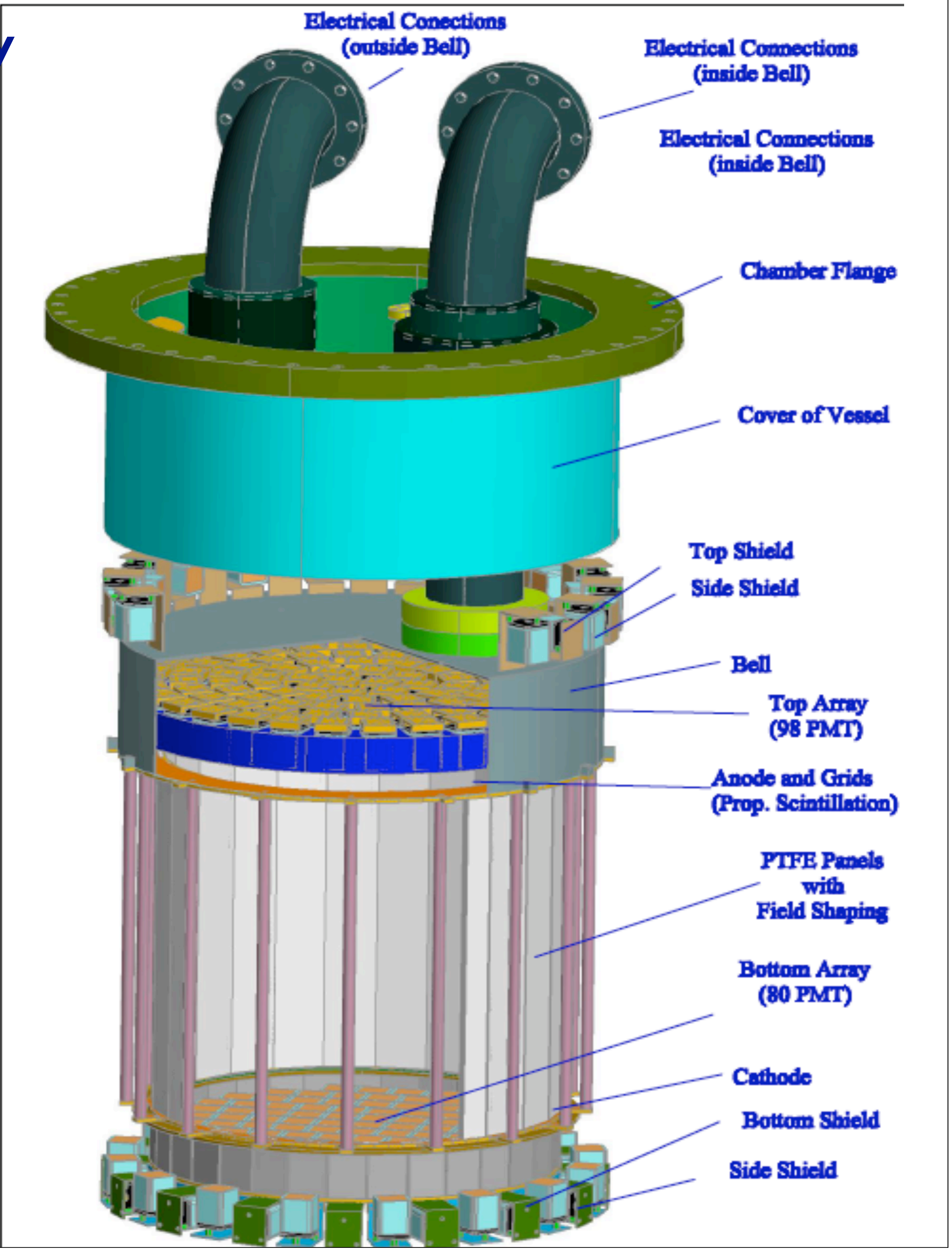
C. Weinheimer, K. Hugenberg, M. Beck, V. Hannen
*Institut für Kernphysik, Wilhelms Universität, Münster, Germany*

D. Thers, J.-P. Cussonneau, J. Lamblin
*Subatech Laboratory, University of Nantes, France*

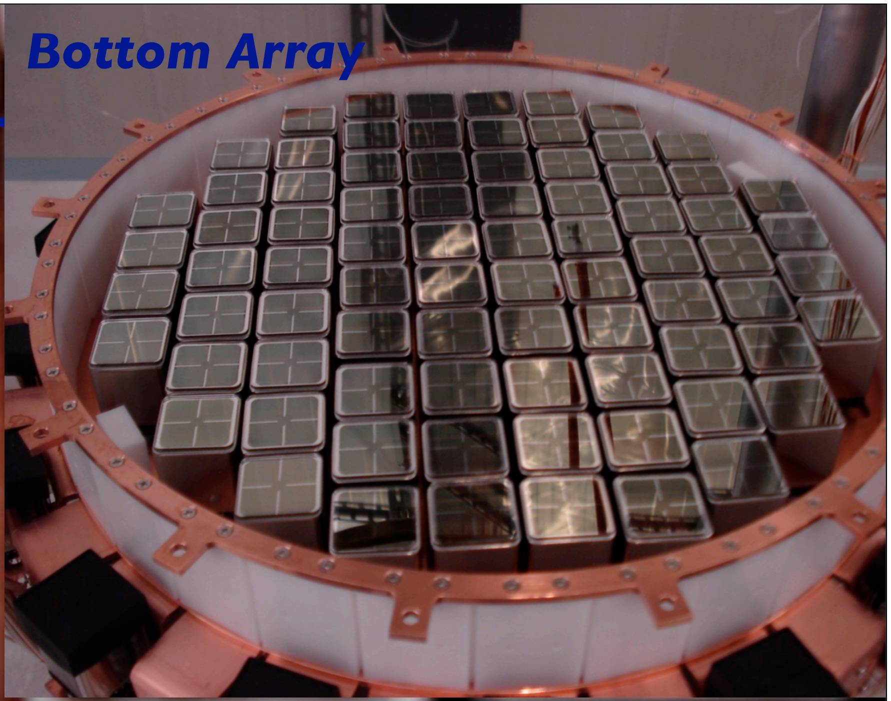
An international collaboration of 46 physicists from 9 institutions

# *XENON100: The TPC Assembly*

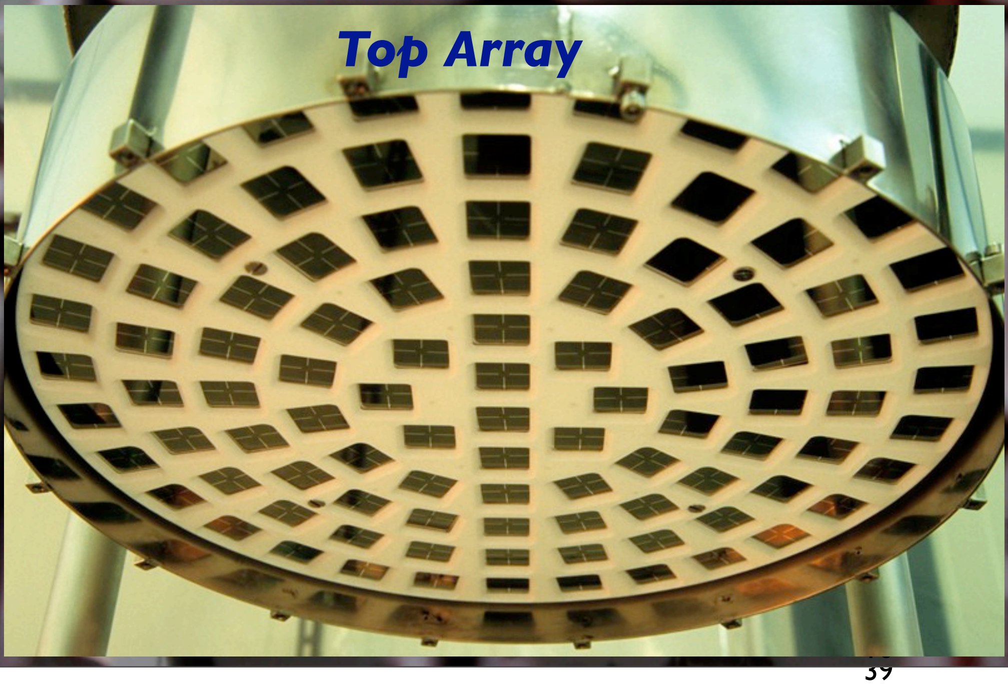


# XENON100: The PMTs

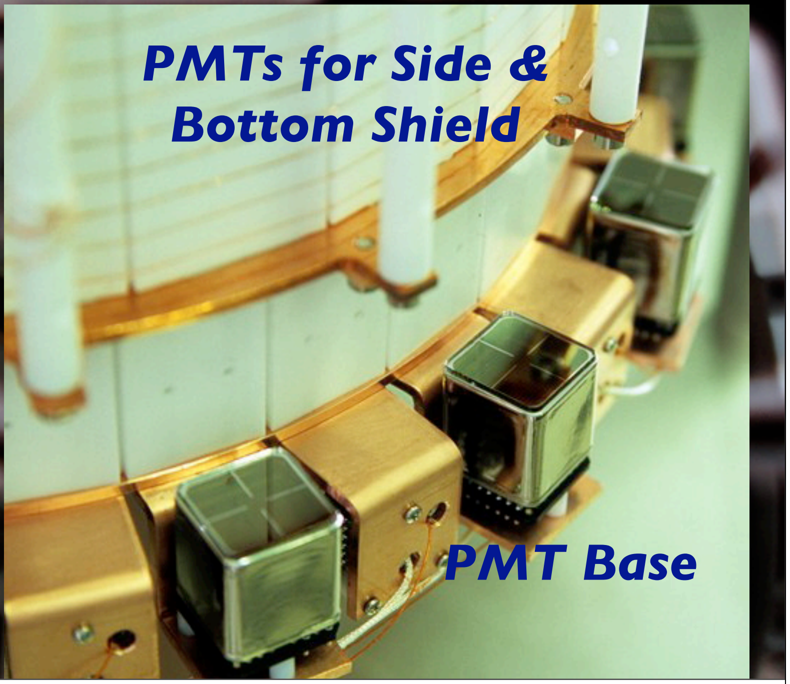
- 242 PMTs (Hamamatsu R8520-06-Al )
- 1 “ square metal channel developed for XENON
- Low radioactivity (<1 mBq U/Th per PMT)
- 80 PMTs for  bottom array  (33% QE)
- 98  PMTs for top array (23% QE)
- 64 PMTs for top/bottom/side Veto (23% QE)



**Bottom Array**



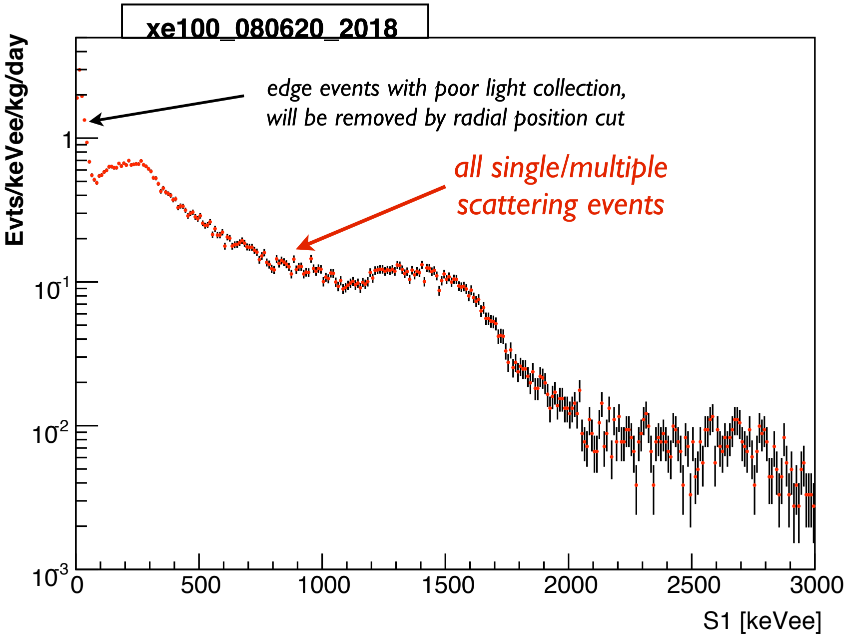
**Top Array**



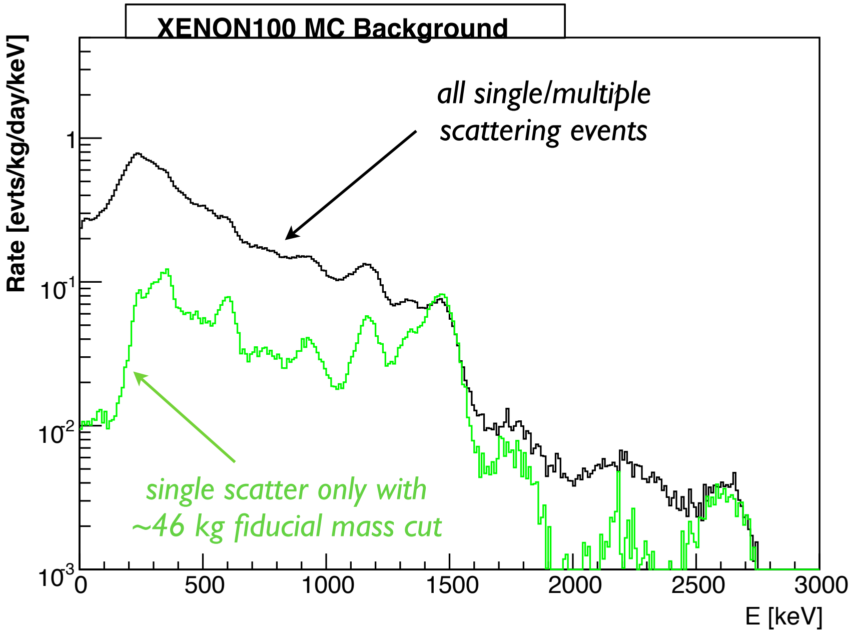
**PMTs for Side & Bottom Shield**

# XENON100 background run

## data

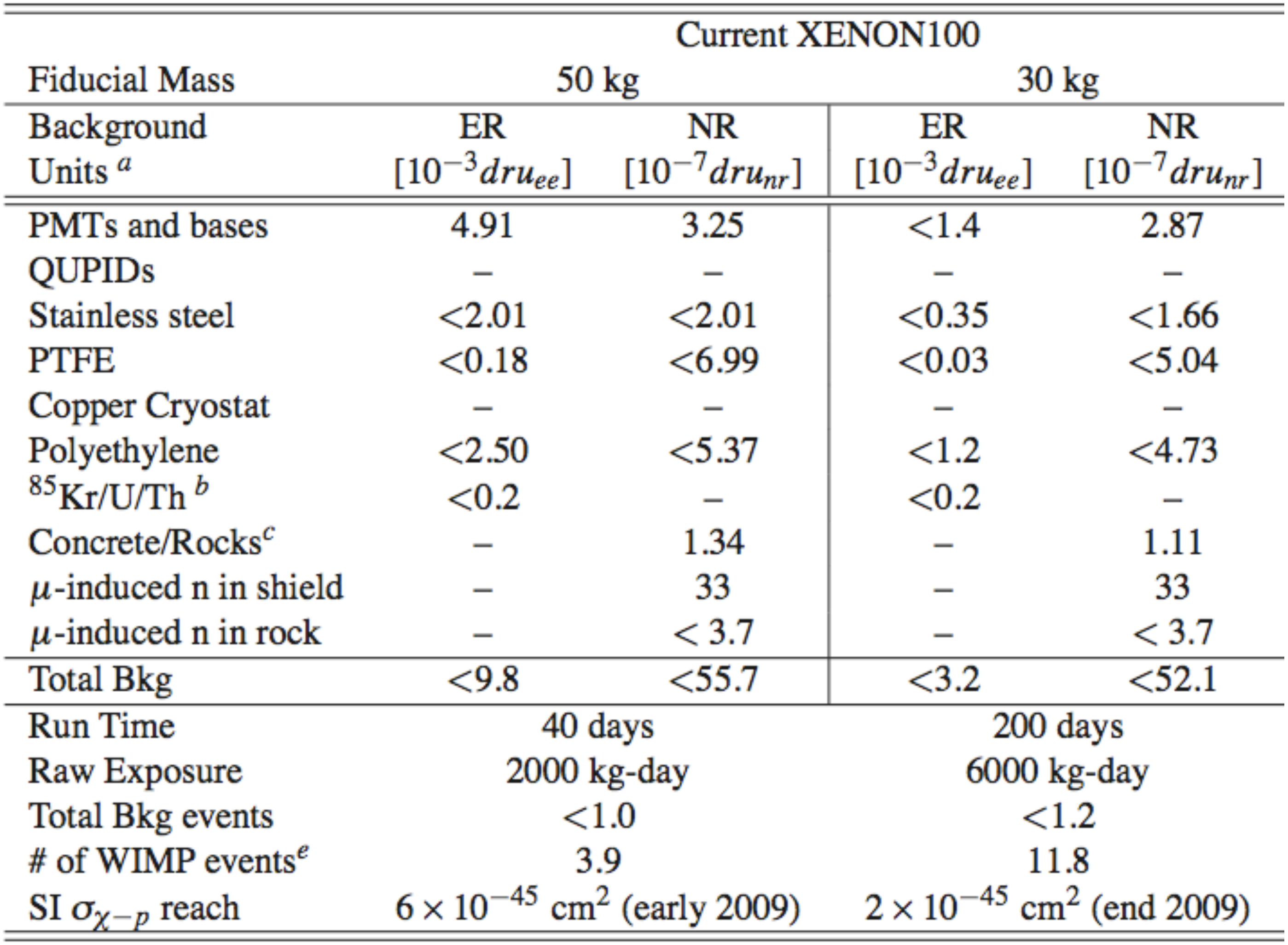


## Simulation



***First Measured background Spectrum with S1 signal only in good agreement with MC prediction.***

# Expected Background and Sensitivity Reach



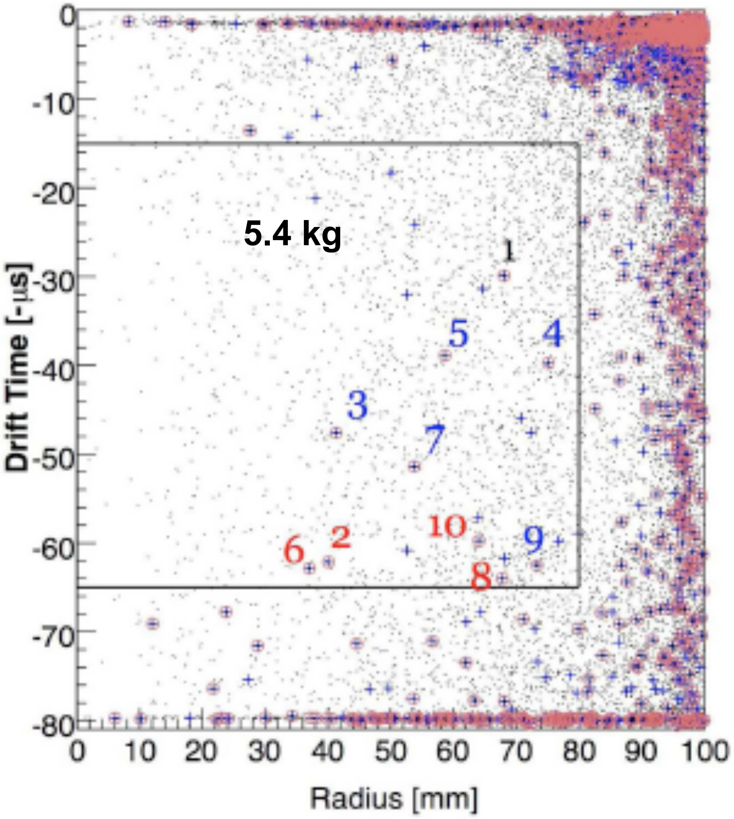
| | Current XENON100 | | | |
|---|---|---|---|---|
| Fiducial Mass | 50 kg | | 30 kg | |
| Background | ER | NR | ER | NR |
| Units [a] | $[10^{-3} dru_{ee}]$ | $[10^{-7} dru_{nr}]$ | $[10^{-3} dru_{ee}]$ | $[10^{-7} dru_{nr}]$ |
| PMTs and bases | 4.91 | 3.25 | $<1.4$ | 2.87 |
| QUPIDs | – | – | – | – |
| Stainless steel | $<2.01$ | $<2.01$ | $<0.35$ | $<1.66$ |
| PTFE | $<0.18$ | $<6.99$ | $<0.03$ | $<5.04$ |
| Copper Cryostat | – | – | – | – |
| Polyethylene | $<2.50$ | $<5.37$ | $<1.2$ | $<4.73$ |
| $^{85}$Kr/U/Th [b] | $<0.2$ | – | $<0.2$ | – |
| Concrete/Rocks[c] | – | 1.34 | – | 1.11 |
| $\mu$-induced n in shield | – | 33 | – | 33 |
| $\mu$-induced n in rock | – | $< 3.7$ | – | $< 3.7$ |
| Total Bkg | $<9.8$ | $<55.7$ | $<3.2$ | $<52.1$ |
| Run Time | 40 days | | 200 days | |
| Raw Exposure | 2000 kg-day | | 6000 kg-day | |
| Total Bkg events | $<1.0$ | | $<1.2$ | |
| # of WIMP events[e] | 3.9 | | 11.8 | |
| SI $\sigma_{\chi-p}$ reach | $6 \times 10^{-45}$ cm$^2$ (early 2009) | | $2 \times 10^{-45}$ cm$^2$ (end 2009) | |

*[e] assume cross section $10^{-44}$ cm$^2$*

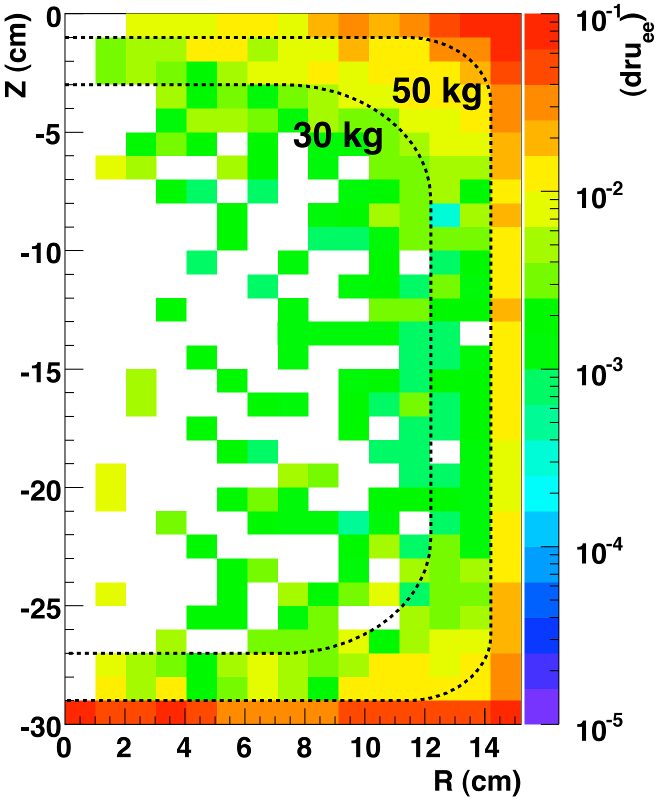
*$dru_{ee}$ = evts/keVee/kg/day*

# XENON: The Power of a TPC

- **3D position sensitivity with a few millimeters resolution in X-Y and sub-millimeter in Z**
- **select fiducial volume with no background events- powerful background reduction**
- **dense LXe has high stopping power for penetrating radiation- powerful self-shielding**



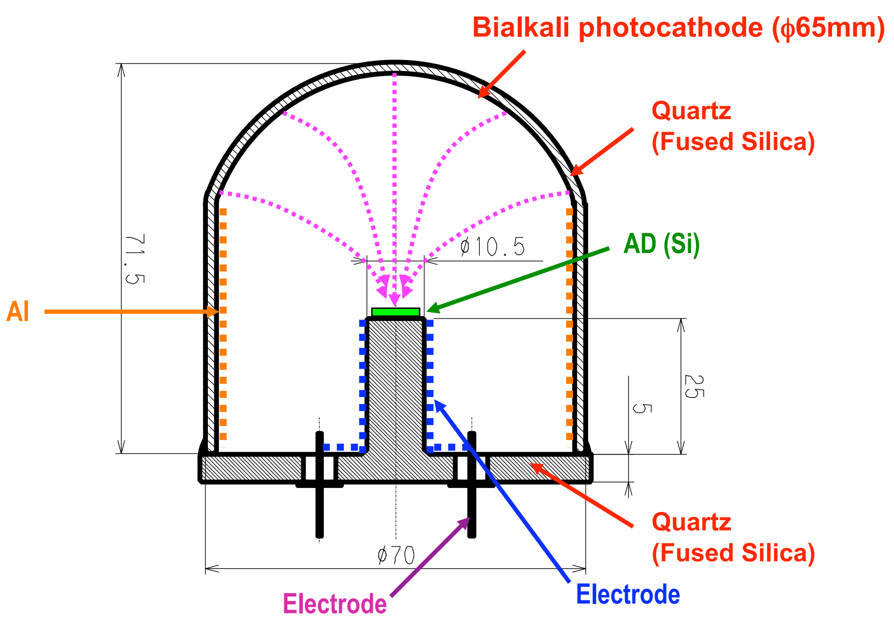
XENON10



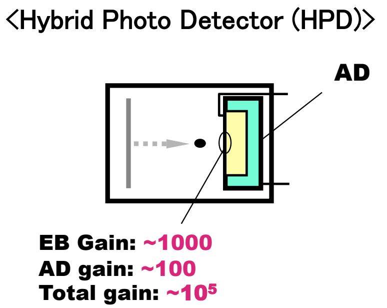
**Current XENON100: gamma bkg**

# *New Photodetector for XENON:*
# *Low Radioactivity - Single Photon Counting - high QE*

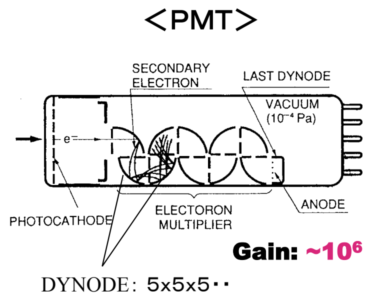
## QUPID



## Approach: HPD, QUPID



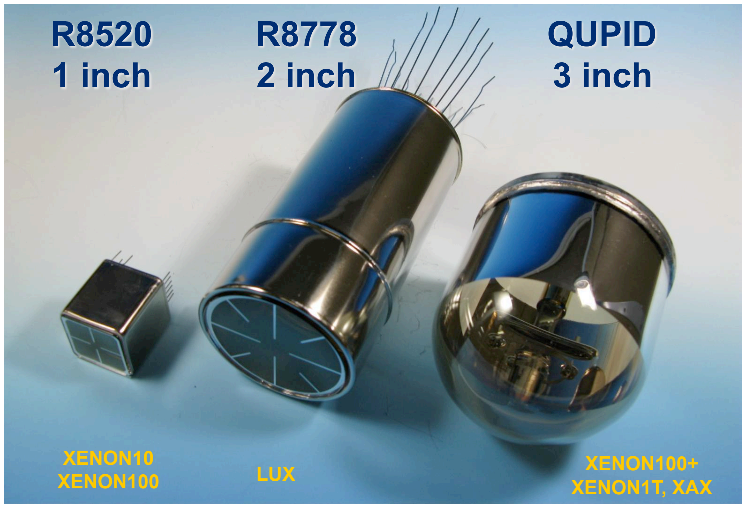
**EB Gain: ~1000**
**AD gain: ~100**
**Total gain: ~$10^5$**



**Gain: ~$10^6$**

DYNODE: 5x5x5・・

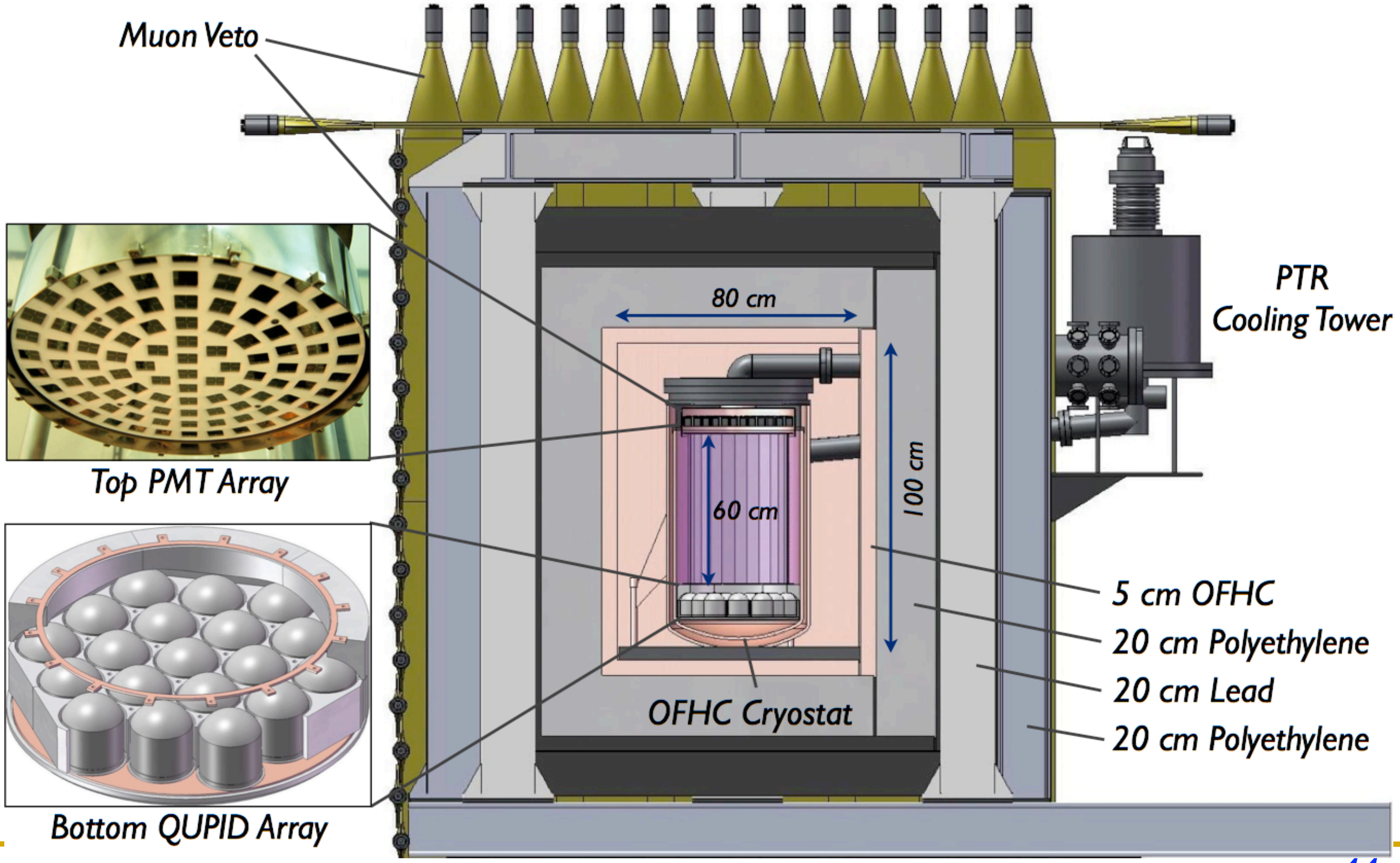
***HPD with low radioactive material***
Quartz, AD, minimum number of pins
=> **QUPID**: Quartz Photon Intensifying Detectors



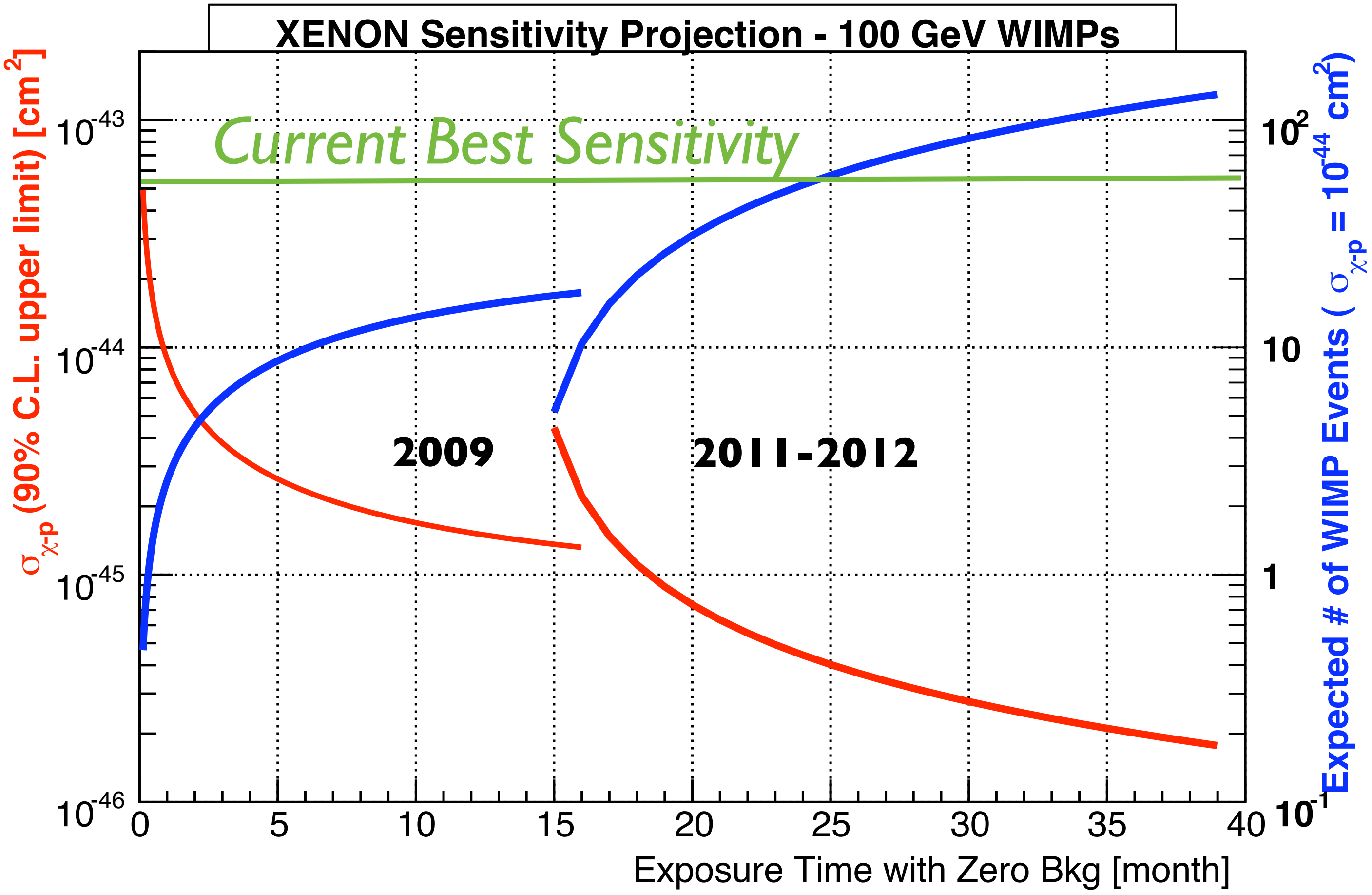
Extremely low radioactivity: << 1mBq
Large area: ~ 3 inch
Single photon detection capability
High QE: > 30 %
Low temperature operation
  Liquid Xenon: -108 °C
  Liquid Argon: -186 °C

# XENON100 Upgrade (2010-12)

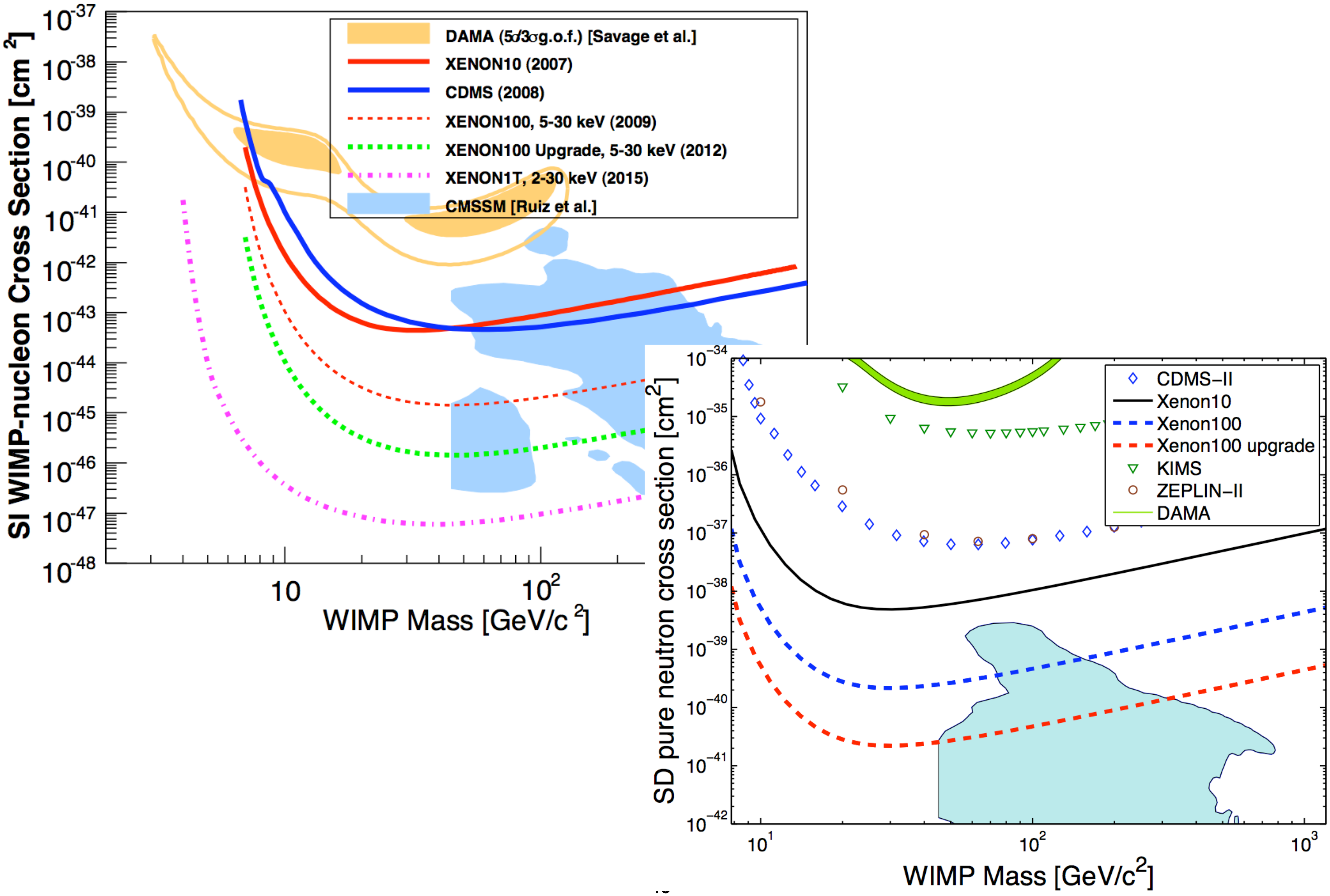
- increase fiducial mass to 100 kg (double drift to 60 cm)
- decrease background with lower activity cryostat and PMTs; 10 x more sensitivity by 2012
- test technologies for XENON1T; larger collaboration: US, Europe, Japan, China
- approved



# *Sensitivity Reach of the XENON100 Program*



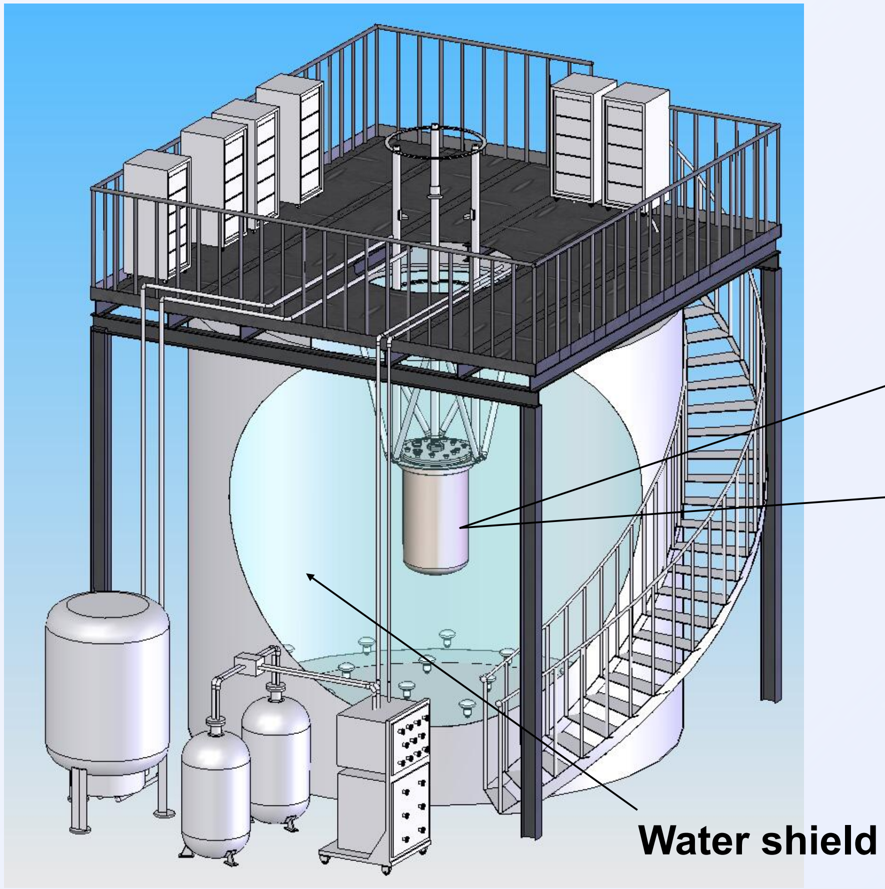
# *XENON Sensitivity Goal*

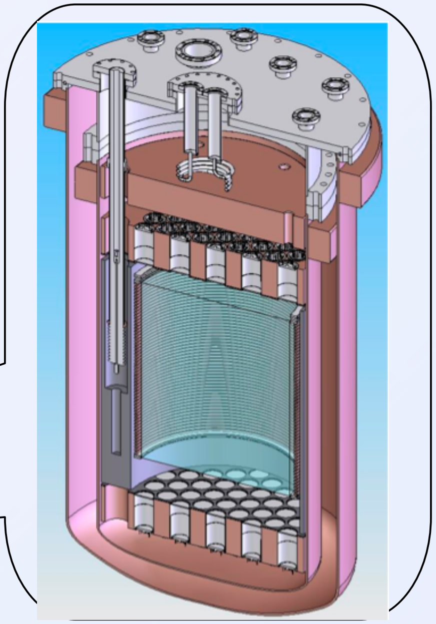


# LUX @ Homestake Mine

- **The LUX Concept**
  - 350 kg total/100 kg fiducial dual phase xenon detector
  - 2.5 m thick purified water shield

- **Project Cost = 2.8 M$**
- **Fully funded by DOE + NSF**
- **Significant support by Sanford Laboratory @ Homestake**



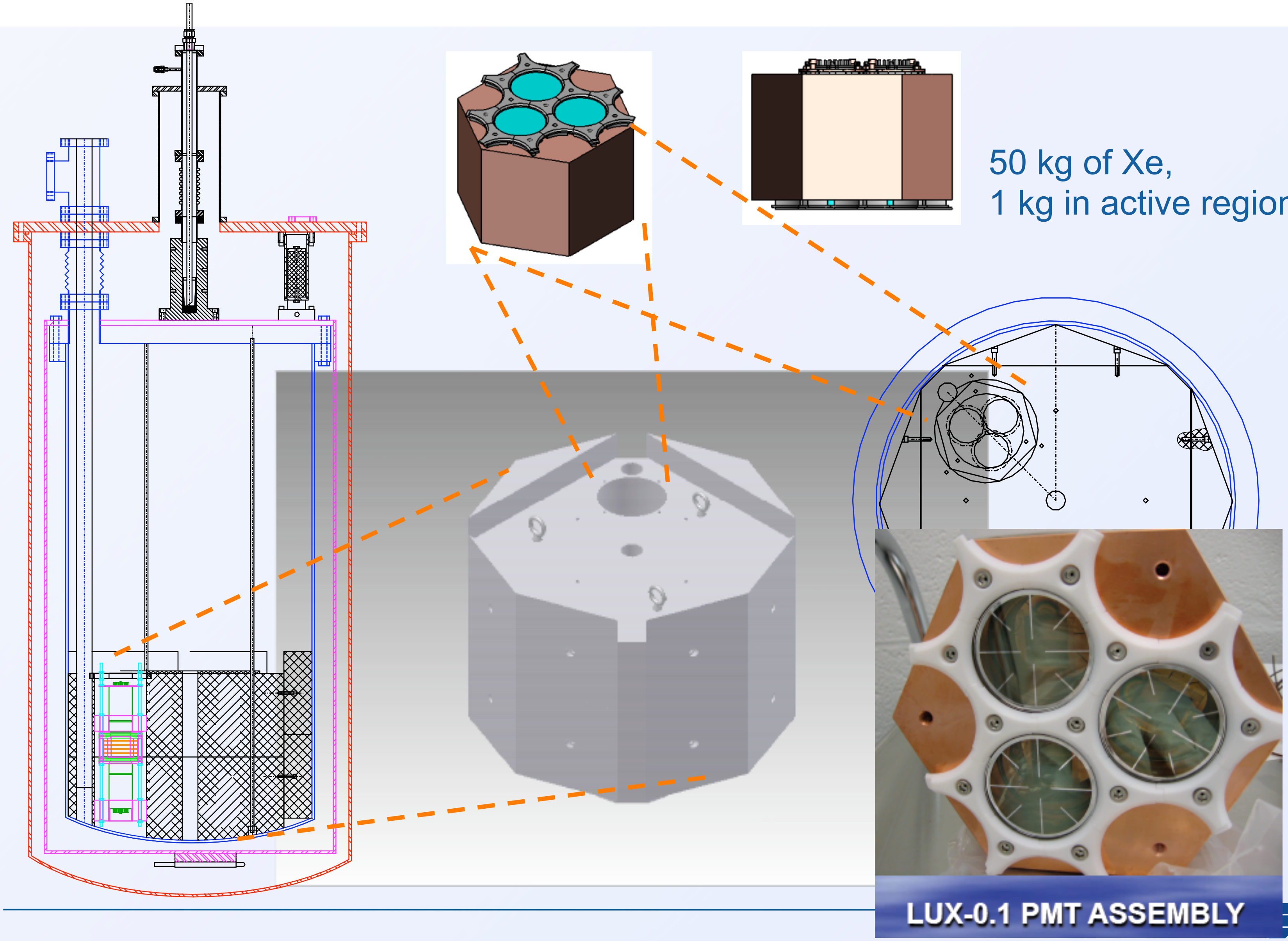


- **Xenon Temperature 170K**
- **Gas Pressure 1.5bar**
- **350 Kg total Xenon**
- **Drift Field 0.5kV/cm**
- **Active region ø50cm x 50cm**
- **120 PMTs**

# Cryostat at Case 2007

# LUX-0.1 installation at Case – full size cryostat: displace most of the Xe volume with an Al filler

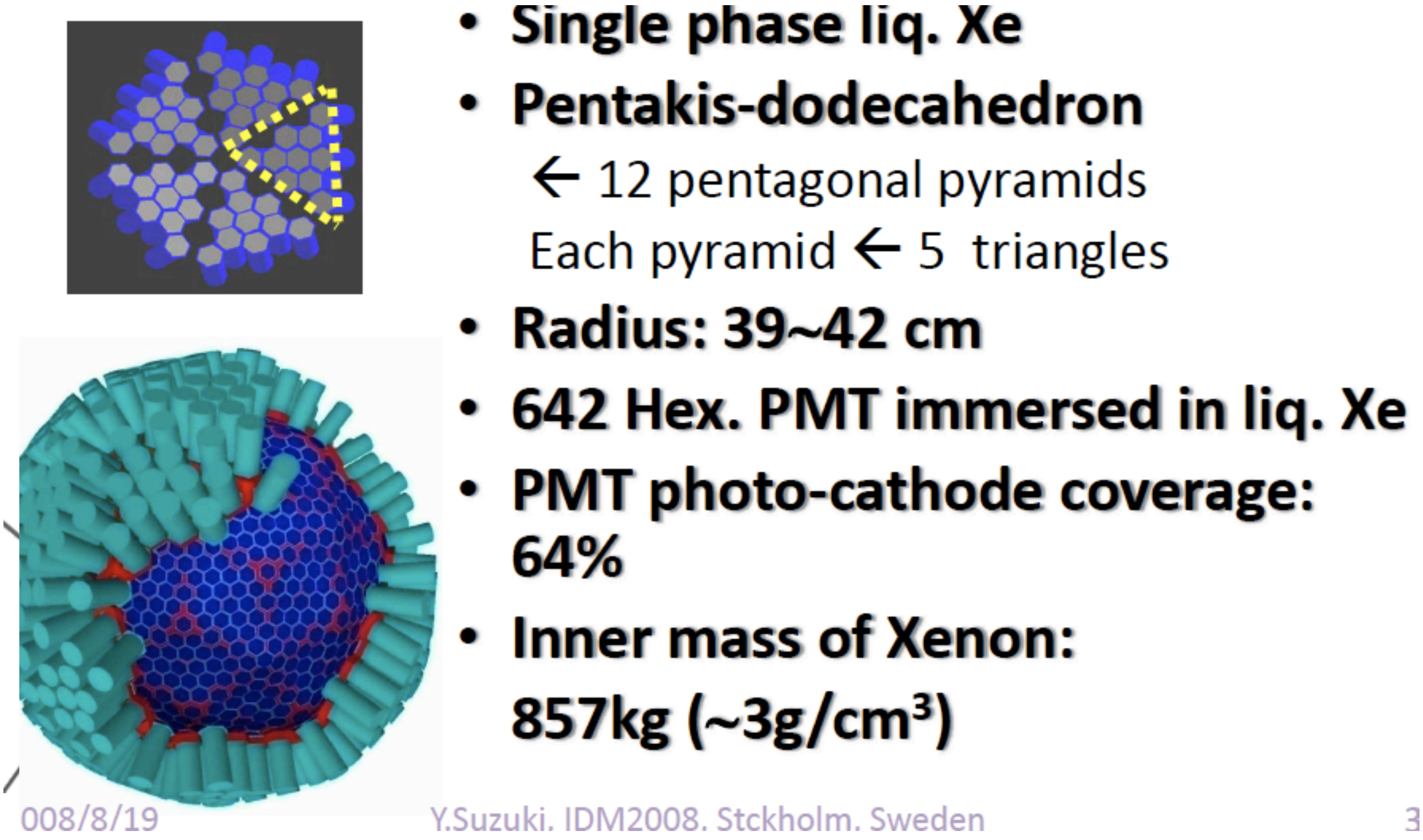
**Hamamatsu R8778 : QE ~30% Summed Background << 50mBq/PMT budget**



50 kg of Xe,
1 kg in active region

**LUX-0.1 PMT ASSEMBLY**

# XMASS @ Kamioka Mine



- Single phase liq. Xe
- Pentakis-dodecahedron

  ← 12 pentagonal pyramids

  Each pyramid ← 5 triangles
- Radius: 39~42 cm
- 642 Hex. PMT immersed in liq. Xe
- PMT photo-cathode coverage: 64%
- Inner mass of Xenon:

  857kg (~3g/cm$^3$)

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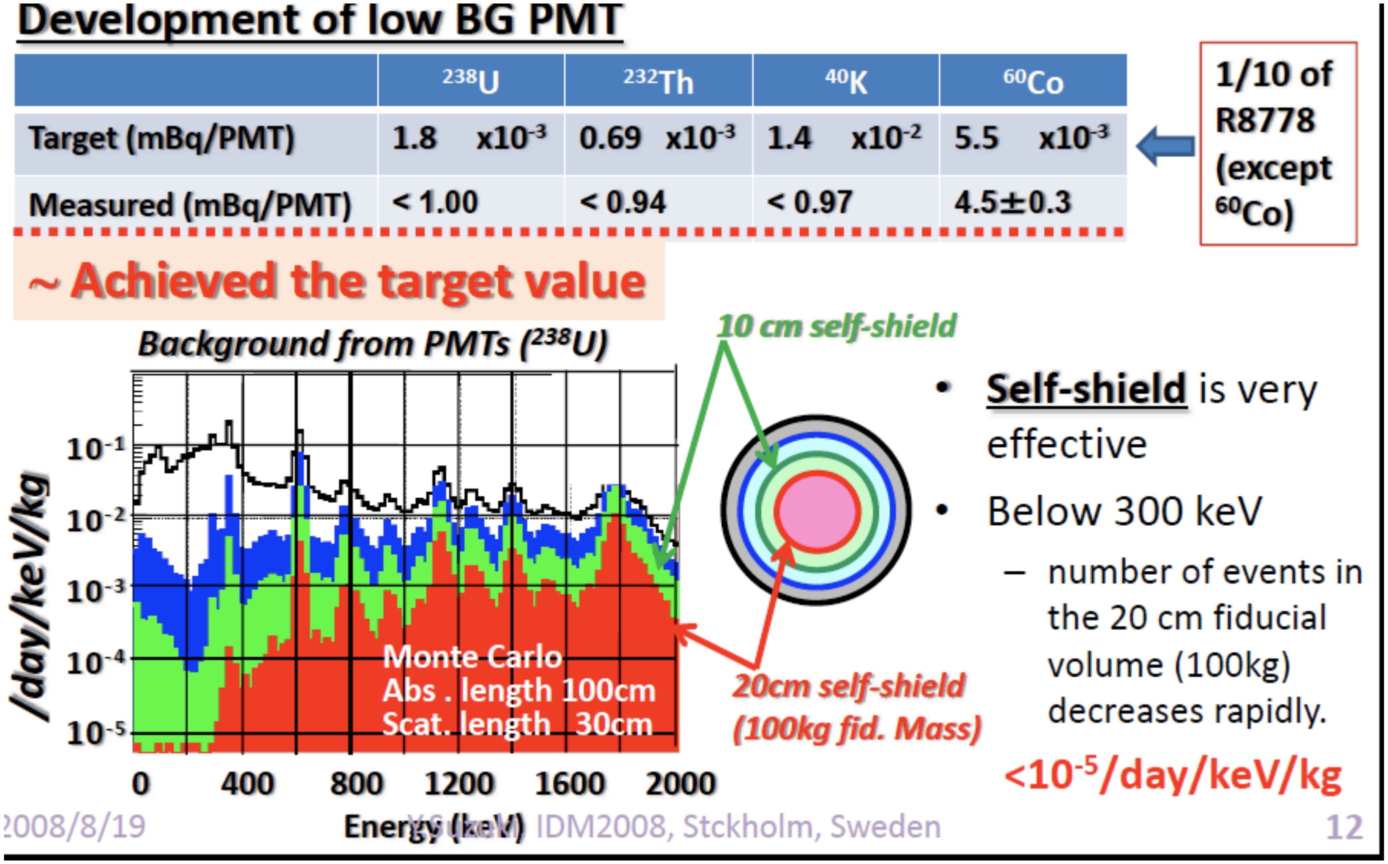
# XMASS PMTs



## Development of low BG PMT

| | $^{238}$U | $^{232}$Th | $^{40}$K | $^{60}$Co |
|---|---|---|---|---|
| Target (mBq/PMT) | 1.8 x$10^{-3}$ | 0.69 x$10^{-3}$ | 1.4 x$10^{-2}$ | 5.5 x$10^{-3}$ |
| Measured (mBq/PMT) | < 1.00 | < 0.94 | < 0.97 | 4.5±0.3 |

1/10 of R8778 (except $^{60}$Co)

~ Achieved the target value

*Background from PMTs ($^{238}$U)*

- **Self-shield** is very effective
- Below 300 keV
  - number of events in the 20 cm fiducial volume (100kg) decreases rapidly.

<$10^{-5}$/day/keV/kg

## ***Aim:***

- **$10^{-4}$ dru (ev/kg/keV/day)** *before any PSD applied*

➔ **$10^{-45}$cm$^2$ SI for ~100GeV WIMPs**

## ***For the signal detection***

- **Low threshold: ~ 5 keV or less**

🡐 8 pe /keV (64% photo-cov.)

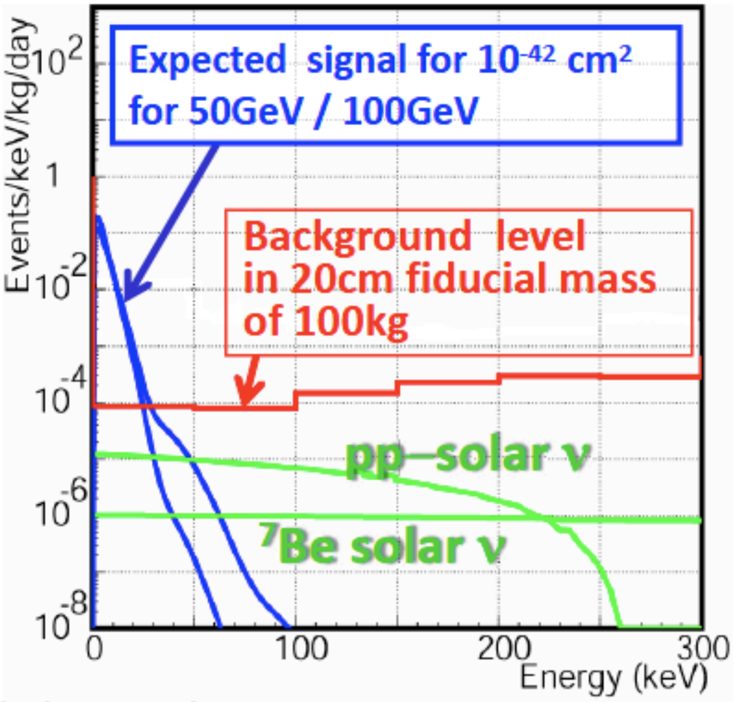
- **Large fiducial volume: 100kg or more**

20cmϕ: 100kg

(20cm self-shield)

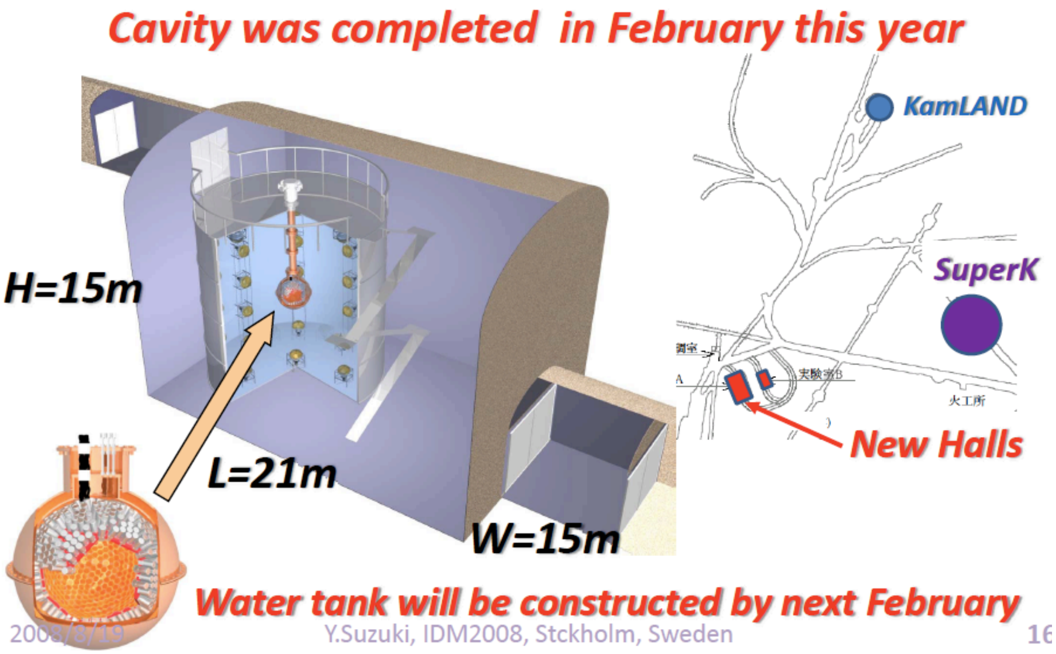
25cmϕ: 200kg

(15cm self-shield)



**Expected signal for $10^{-42}$ cm$^2$ for 50GeV / 100GeV**

**Background level in 20cm fiducial mass of 100kg**



Cavity was completed in February this year

Water tank will be constructed by next February

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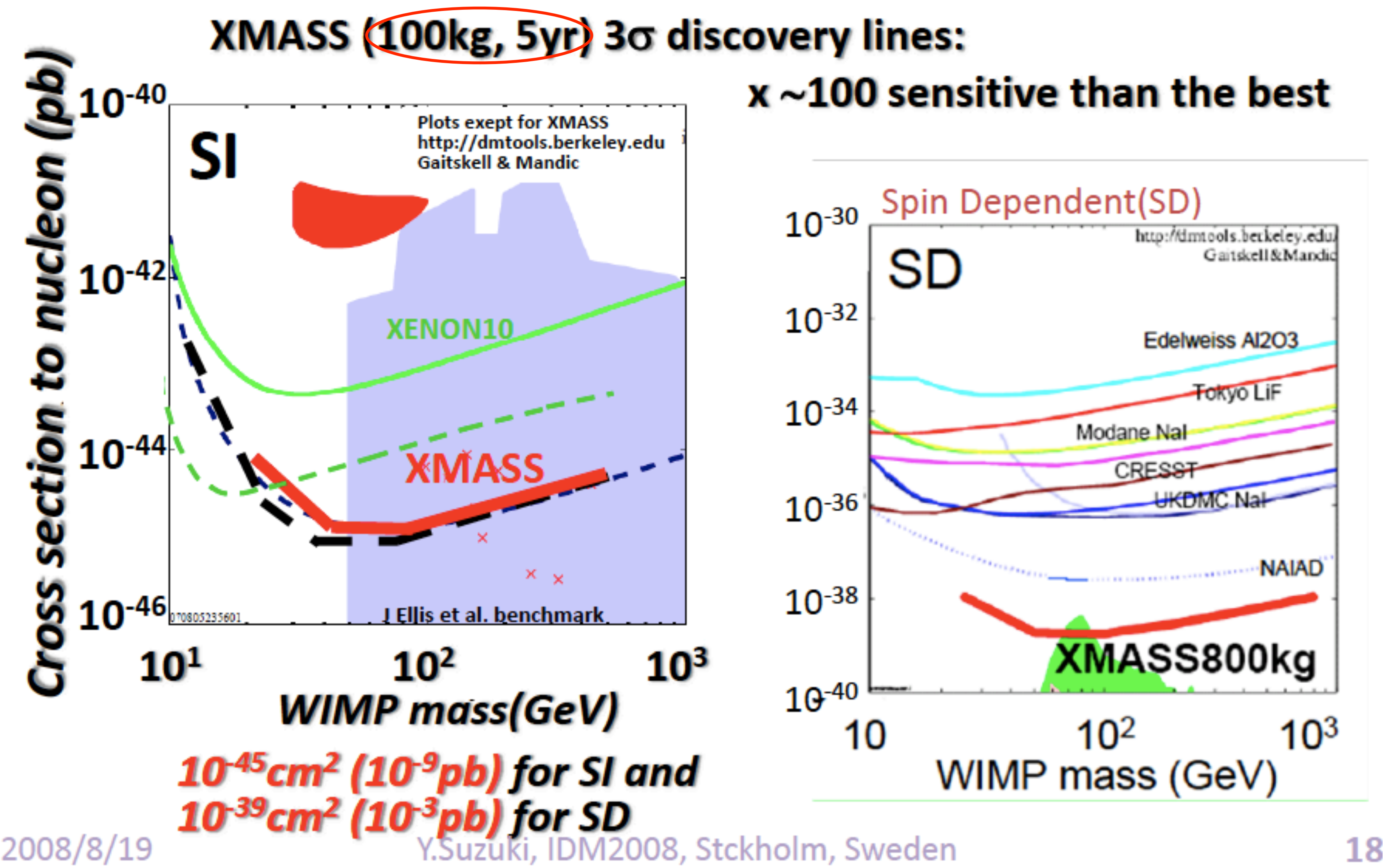
- **Water shields**
  effective to reduce neutrons
- **$\phi_n$(Kamioka)=**
  $(1.2+0.1)\ \text{x}10^{-6}\ /\text{cm}^2/\text{sec}$
- **n events in Liq. Xenon w/ 200cm water**
  $<< 10^{-4}$ counts/day/kg



**XMASS (100kg, 5yr) 3σ discovery lines:**

**x ~100 sensitive than the best**

***$10^{-45}$cm$^2$ ($10^{-9}$pb) for SI and***
***$10^{-39}$cm$^2$ ($10^{-3}$pb) for SD***

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