First Science Results from the Large Underground Xenon (LUX) Dark Matter Experiment

Harry Nelson

KITP

October 30 , 2013

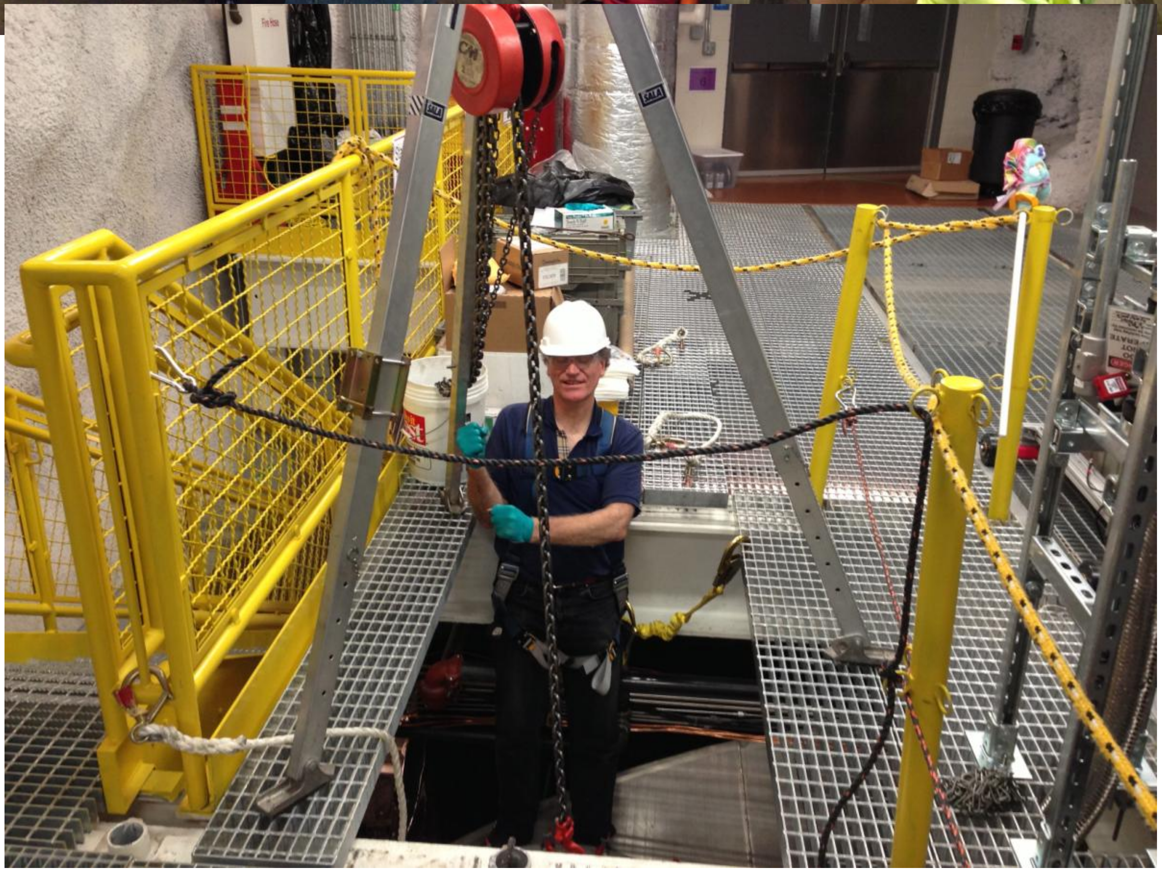
LUX@UCSB: HN, María del Carmen Carmona Benítez, Scott Haselschwardt, Susanne Kyre, Curt Nehrkorn, Dean White, Mike Witherell

Scientific Christening of the new Sanford Laboratory

Old Homestake Mine (Hearst)
Now SURF (Sanford Underground Research Facility)
4850' underground


Carmen
Carmona

Curt Nehrkorn Helping Test Xenon Recovery Balloon



The LUX Collaboration

Brown

Richard Gaitskell	PI, Professor
Simon Fiorucci	Research Associate
Monica Pangilinan	Postdoc
Jeremy Chapman	Graduate Student
David Malling	Graduate Student
James Verbus	Graduate Student
Samuel Chung Chan	Graduate Student
Dongqing Huang	Graduate Student

Case Western

Thomas Shutt	PI, Professor
Dan Akerib	PI, Professor
Karen Gibson	Postdoc
Tomasz Biesiadzinski	Postdoc
Wing H To	Postdoc
Adam Bradley	Graduate Student
Patrick Phelps	Graduate Student
Chang Lee	Graduate Student
Kati Pech	Graduate Student

Imperial College London

Henrique Araujo	PI, Reader
Tim Sumner	Professor
Alastair Currie	Postdoc
Adam Bailey	Graduate Student

Lawrence Berkeley + UC Berkeley

Bob Jacobsen	PI, Professor
Murdock Gilchriese	Senior Scientist
Kevin Lesko	Senior Scientist
Carlos Hernandez Faham	Postdoc
Victor Gehman	Scientist
Mia Ihm	Graduate Student

Lawrence Livermore

Adam Bernstein	PI, Leader of Adv. Detectors Group
Dennis Carr	Mechanical Technician
Kareem Kazkaz	Staff Physicist
Peter Sorensen	Staff Physicist
John Bower	Engineer

LIP Coimbra

Isabel Lopes	PI, Professor
Jose Pinto da Cunha	Assistant Professor
Vladimir Solovov	Senior Researcher
Luiz de Viveiros	Postdoc
Alexander Lindote	Postdoc
Francisco Neves	Postdoc
Claudio Silva	Postdoc

SD School of Mines

Xinhua Bai	PI, Professor
Tyler Liebsch	Graduate Student
Doug Tiedt	Graduate Student

SDSTA

David Taylor	Project Engineer
Mark Hanhardt	Support Scientist

Texas A&M

James White †	PI, Professor
Robert Webb	PI, Professor
Rachel Mannino	Graduate Student
Clement Sofka	Graduate Student

UC Davis

Mani Tripathi	PI, Professor
Bob Svoboda	Professor
Richard Lander	Professor
Britt Holbrook	Senior Engineer
John Thomson	Senior Machinist
Ray Gerhard	Electronics Engineer
Aaron Manalaysay	Postdoc
Matthew Szydagis	Postdoc
Richard Ott	Postdoc
Jeremy Mock	Graduate Student
James Morad	Graduate Student
Nick Walsh	Graduate Student
Michael Woods	Graduate Student
Sergey Uvarov	Graduate Student
Brian Lenardo	Graduate Student

UC Santa Barbara

Harry Nelson	PI, Professor
Mike Witherell	Professor
Dean White	Engineer
Susanne Kyre	Engineer
Carmen Carmona	Postdoc
Curt Nehrkorn	Graduate Student
Scott Haselschwardt	Graduate Student

University College London

Chamkaur Ghag	PI, Lecturer
Lea Reichhart	Postdoc

Collaboration Meeting, Sanford Lab, April 2013

University of Edinburgh

Alex Murphy	PI, Reader
Paolo Beltrame	Research Fellow
James Dobson	Postdoc

University of Maryland

Carter Hall	PI, Professor
Attila Dobi	Graduate Student
Richard Knoche	Graduate Student
Jon Balajthy	Graduate Student

University of Rochester

Frank Wolfs	PI, Professor
Wojtek Skutski	Senior Scientist
Eryk Druszkiewicz	Graduate Student
Mongkol Moongweluwan	Graduate Student

University of South Dakota

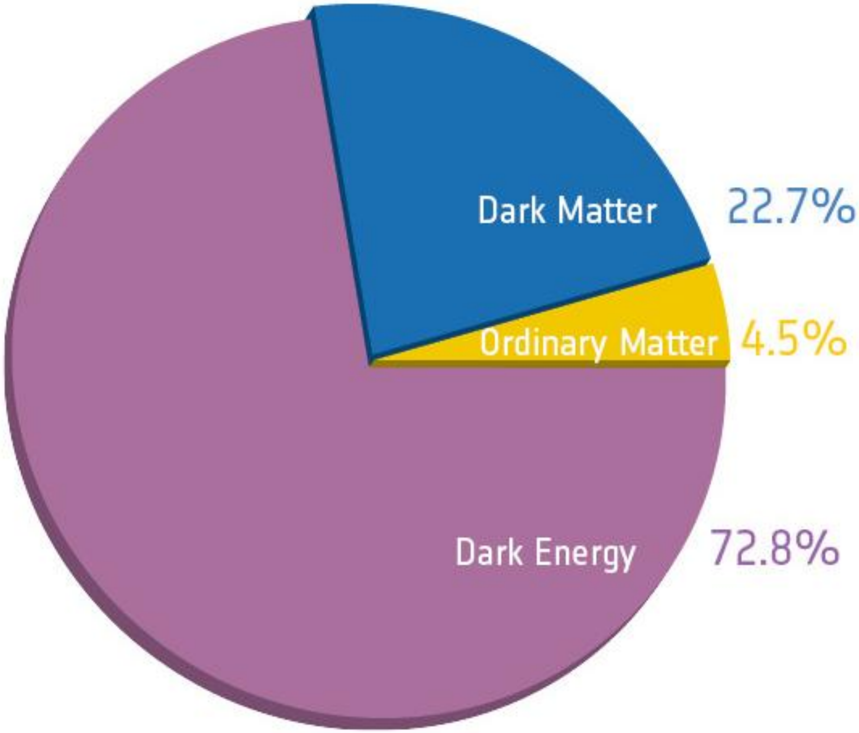
Dongming Mei	PI, Professor
Chao Zhang	Postdoc
Angela Chiller	Graduate Student
Chris Chiller	Graduate Student
Dana Byram	*Now at SDSTA

Yale

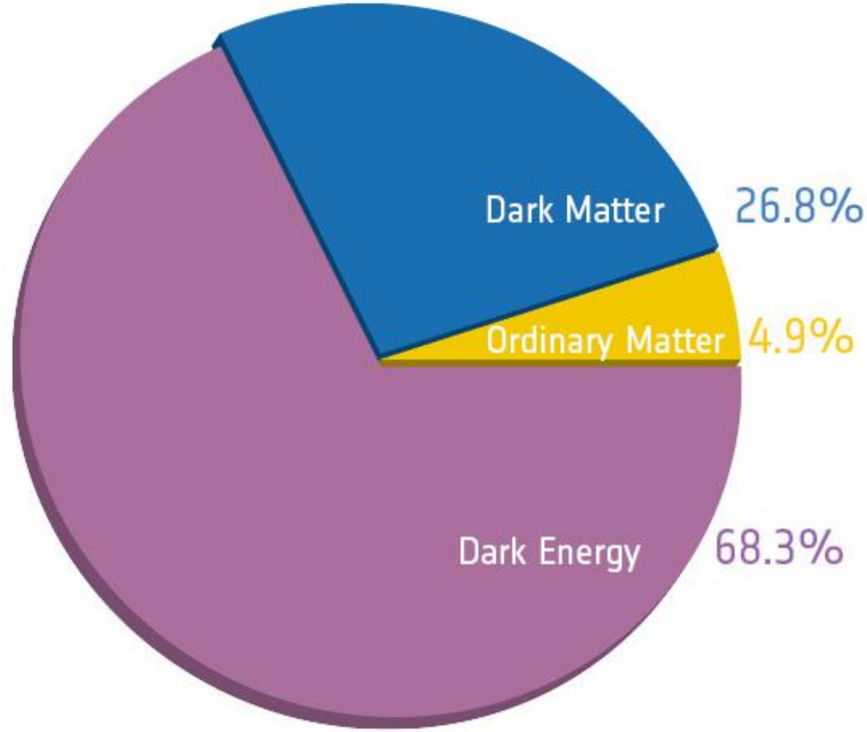
Daniel McKinsey	PI, Professor
Peter Parker	Professor
Sidney Cahn	Lecturer/Research Scientist
Ethan Bernard	Postdoc
Markus Horn	Postdoc
Blair Edwards	Postdoc
Scott Hertel	Postdoc
Kevin O'Sullivan	Postdoc
Nicole Larsen	Graduate Student
Evan Pease	Graduate Student
Brian Tennyson	Graduate Student
Ariana Hackenburg	Graduate Student
Elizabeth Boulton	Graduate Student

LUX Collaboration in Isla Vista 2012

Energy in Our Universe



Before Planck



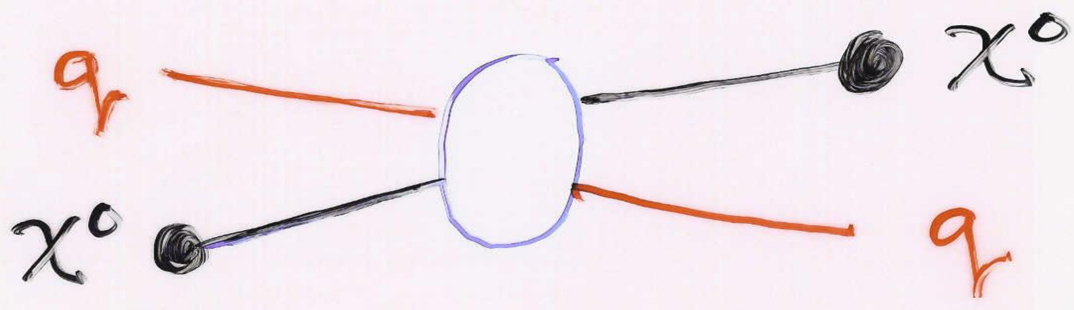
After Planck

$$\frac{\text{Dark Matter}}{\text{Our Matter}} \approx 5.44 \pm 0.14$$

`The WIMP Miracle' (weakly interacting massive particle)

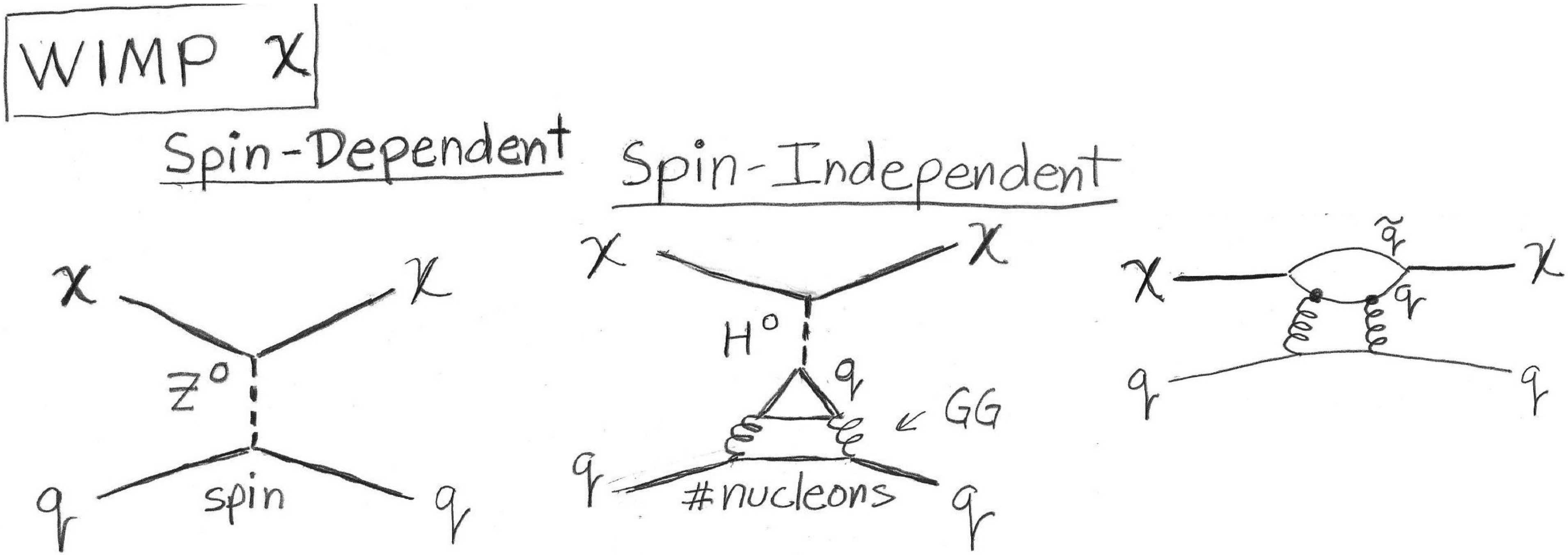
1) SUSY restored at about weak scale gives LSP (χ^0) with weak interaction with our matter

2) Cross the diagram!



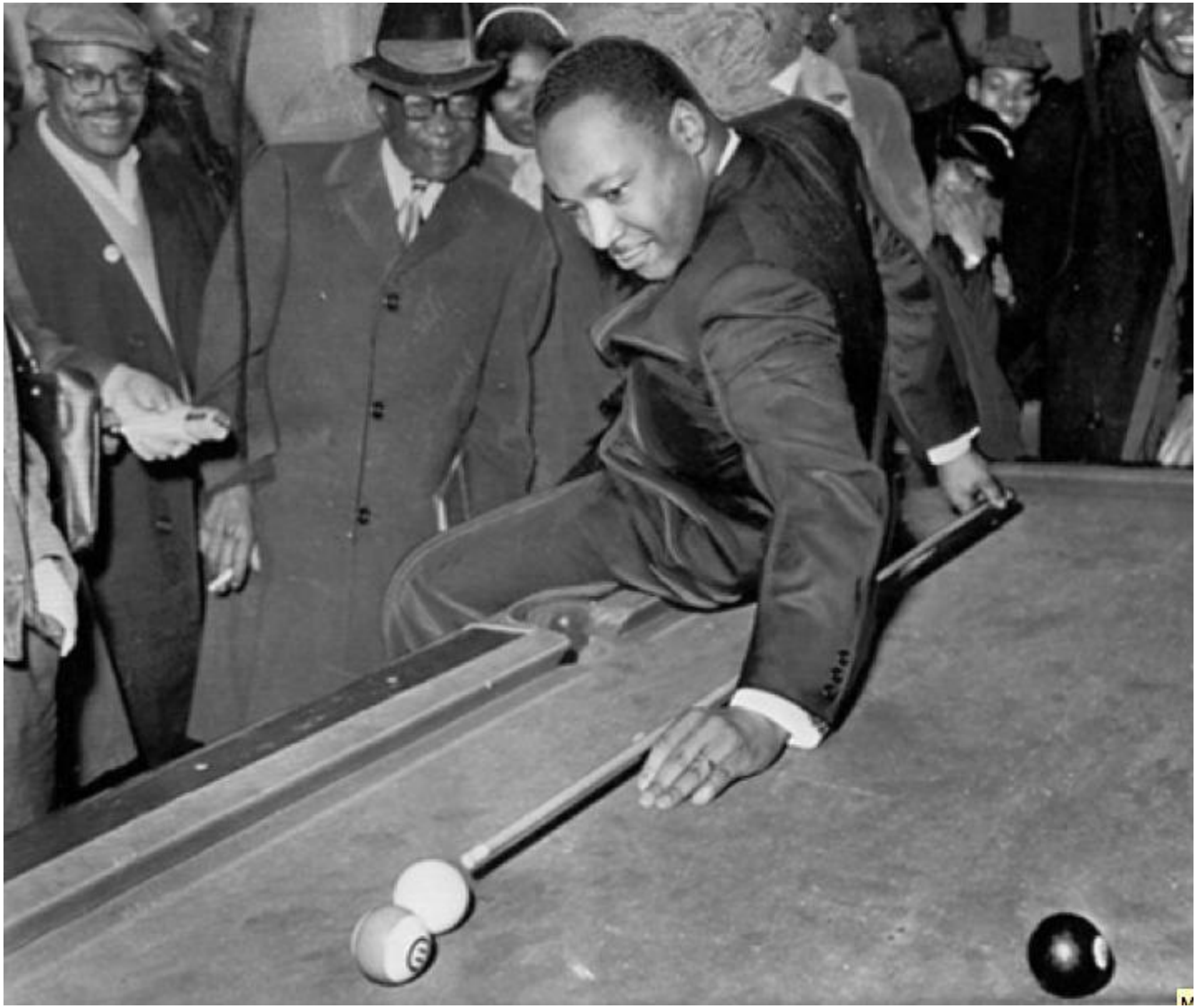
χ^0 will push on our nuclei, making them recoil!

Weak Interaction Diagrams

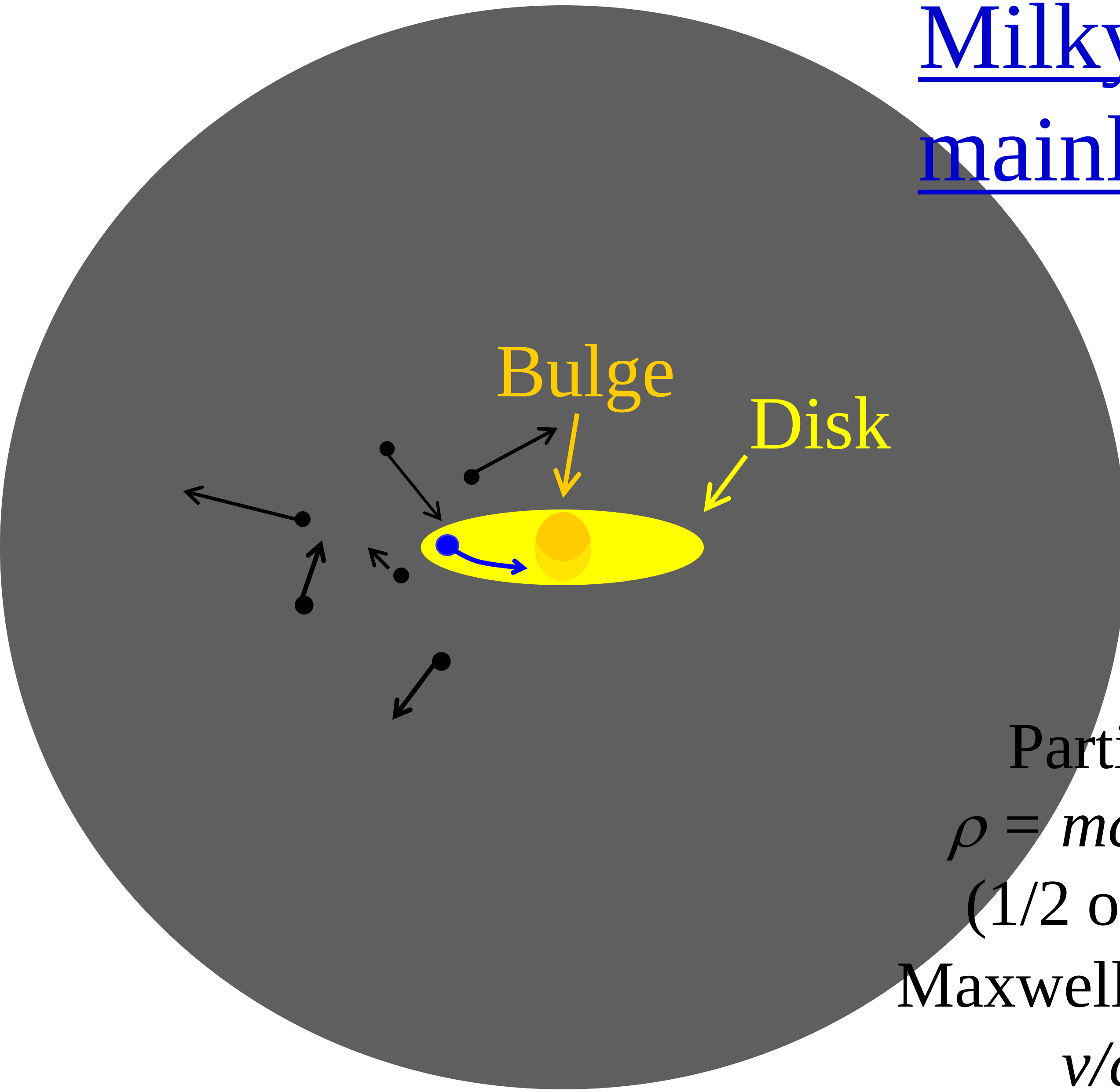


$$\sigma_{nucleon} \approx 10^{-38} \text{ to } 10^{-50} \text{ cm}^2$$

Experimental Method



Milky Way: mainly a dark cloud



Sun: moves in plane of disk

$v/c = \beta \simeq 0.7 \times 10^{-3}$

Particles in `halo' : 3-d

$\rho = mc^2 \times n \simeq 1/3\ GeV/cm^3$

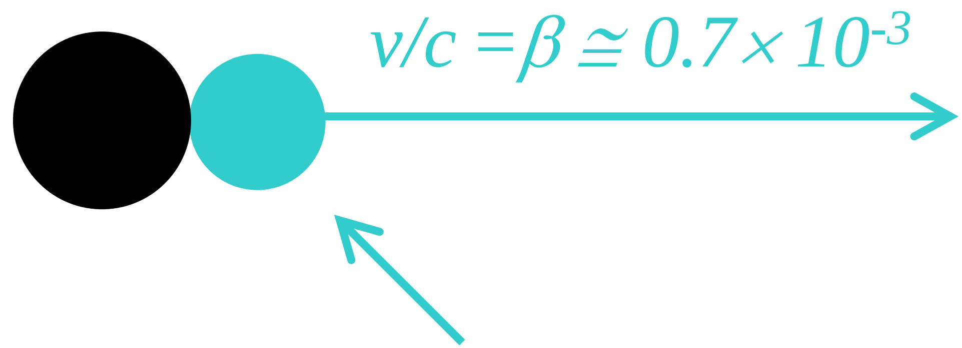
(1/2 of total mass density)

Maxwellian/Gaussian (simple)

$v/c = \beta \simeq 0.7 \times 10^{-3}$

Billiard Ball Scattering

χ^0



Massive: $M_\chi c^2 \approx 100$ GeV

`Weak Scale'

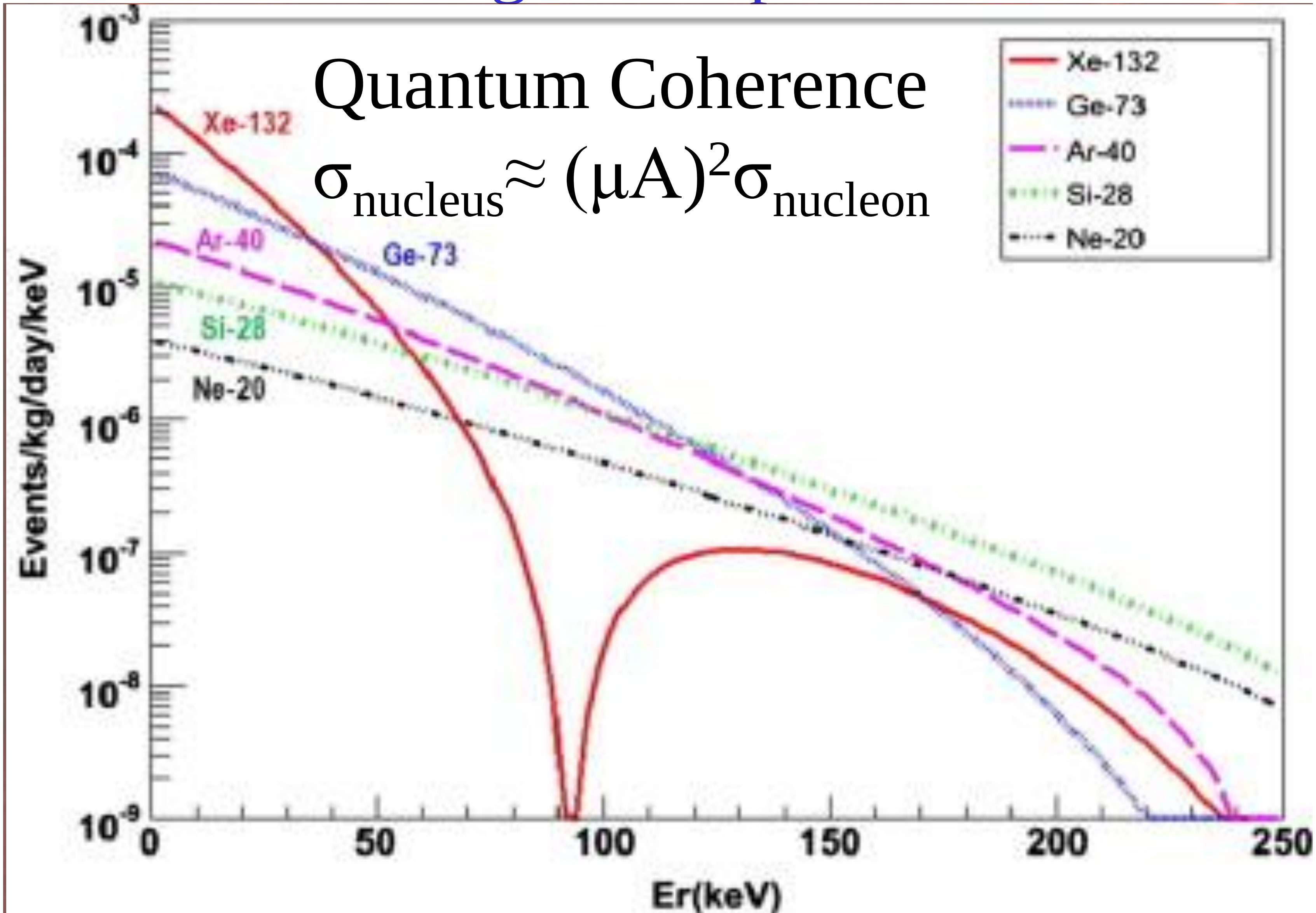
We use Xenon,
A=131, mc^2=122 GeV
others: Si, S, I, Ge, W

$E_R \approx \frac{1}{2}\, m_{Xe}c^2\, \beta^2$
$\approx (1/4)122\ \text{GeV}/(10^6)$
$\approx$ 30 keV
$\approx$ x-ray energy ! Easy!

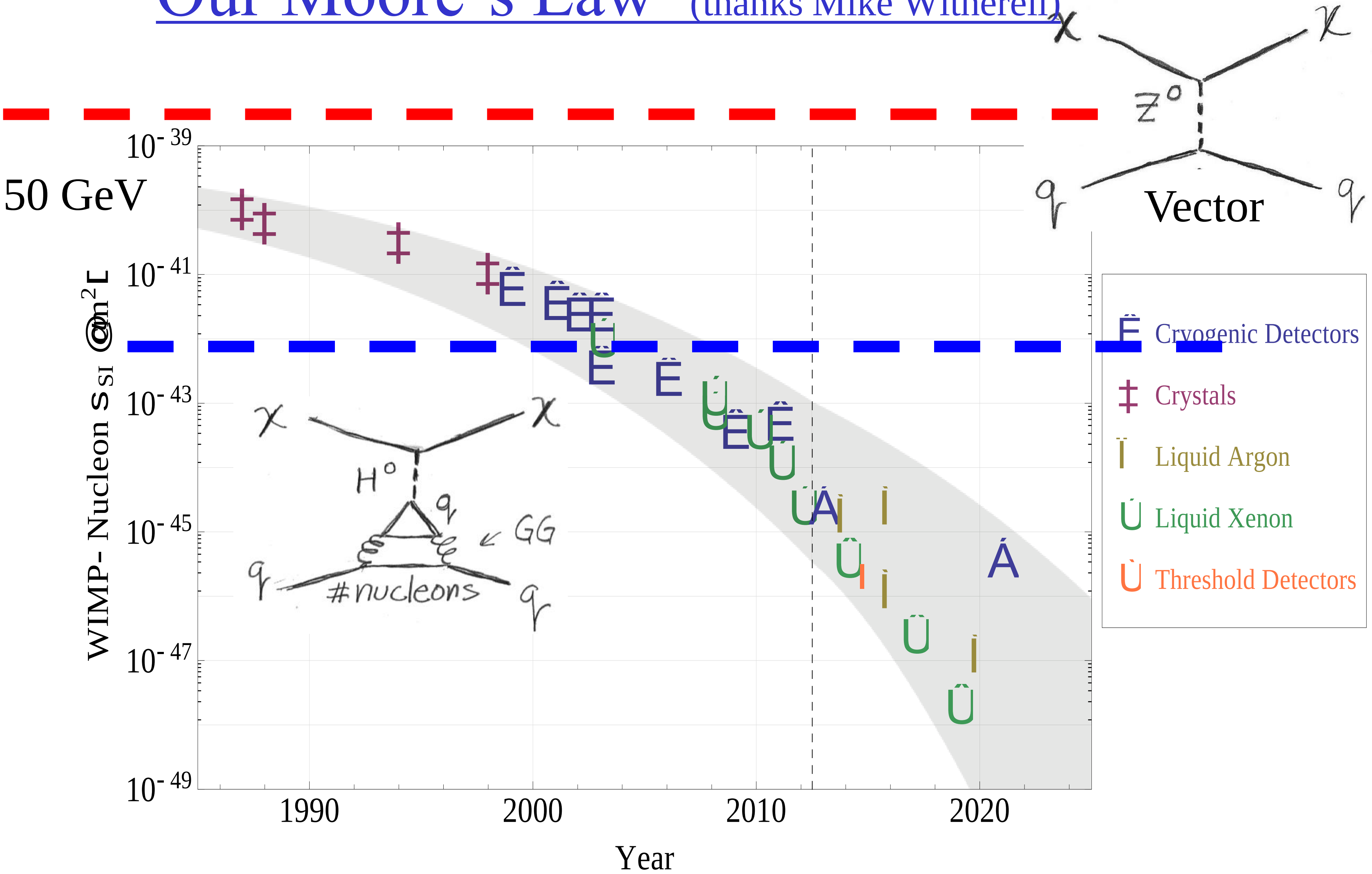
Signal Shape

Quantum Coherence

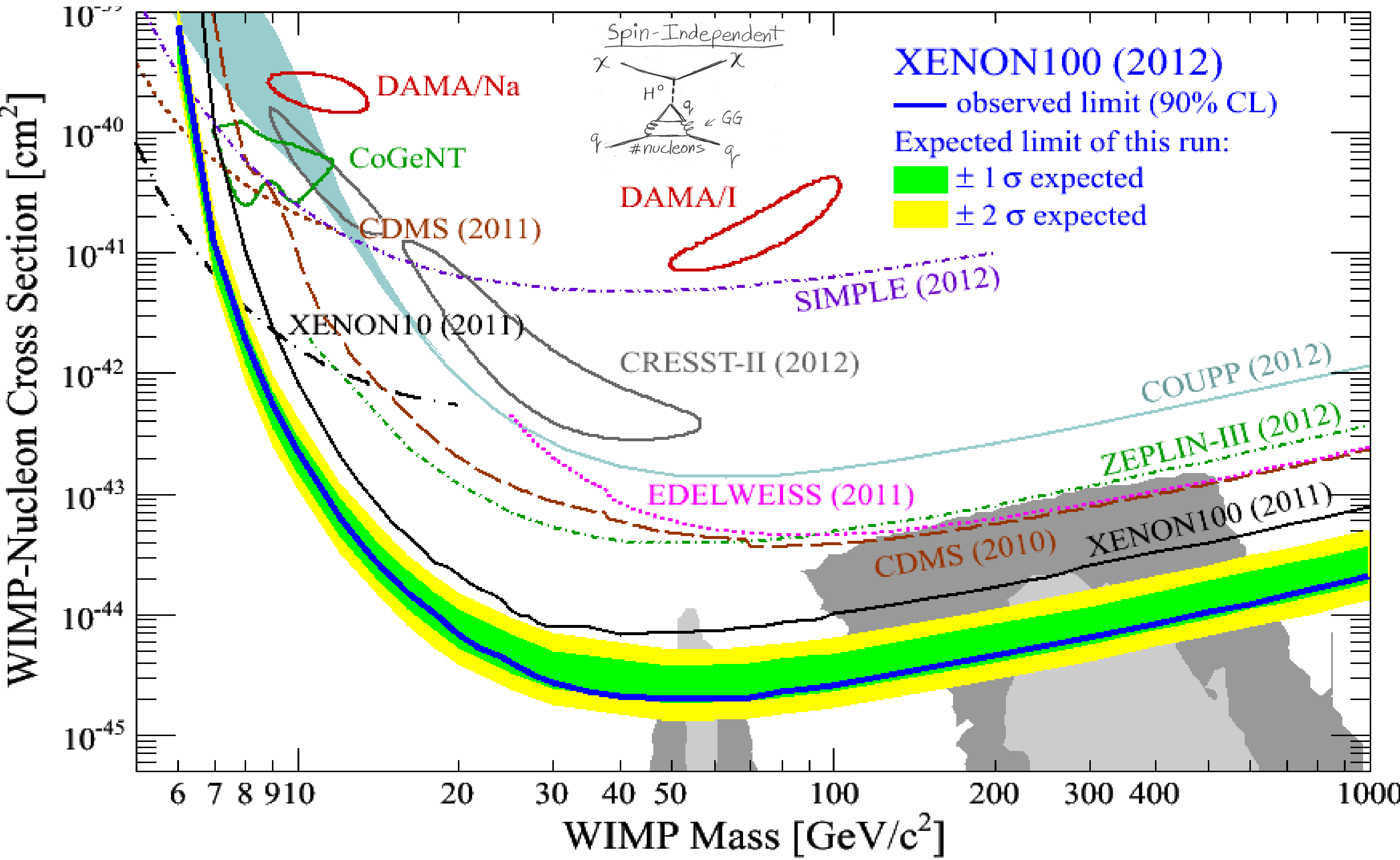
$\sigma_{nucleus} \approx (\mu A)^2 \sigma_{nucleon}$



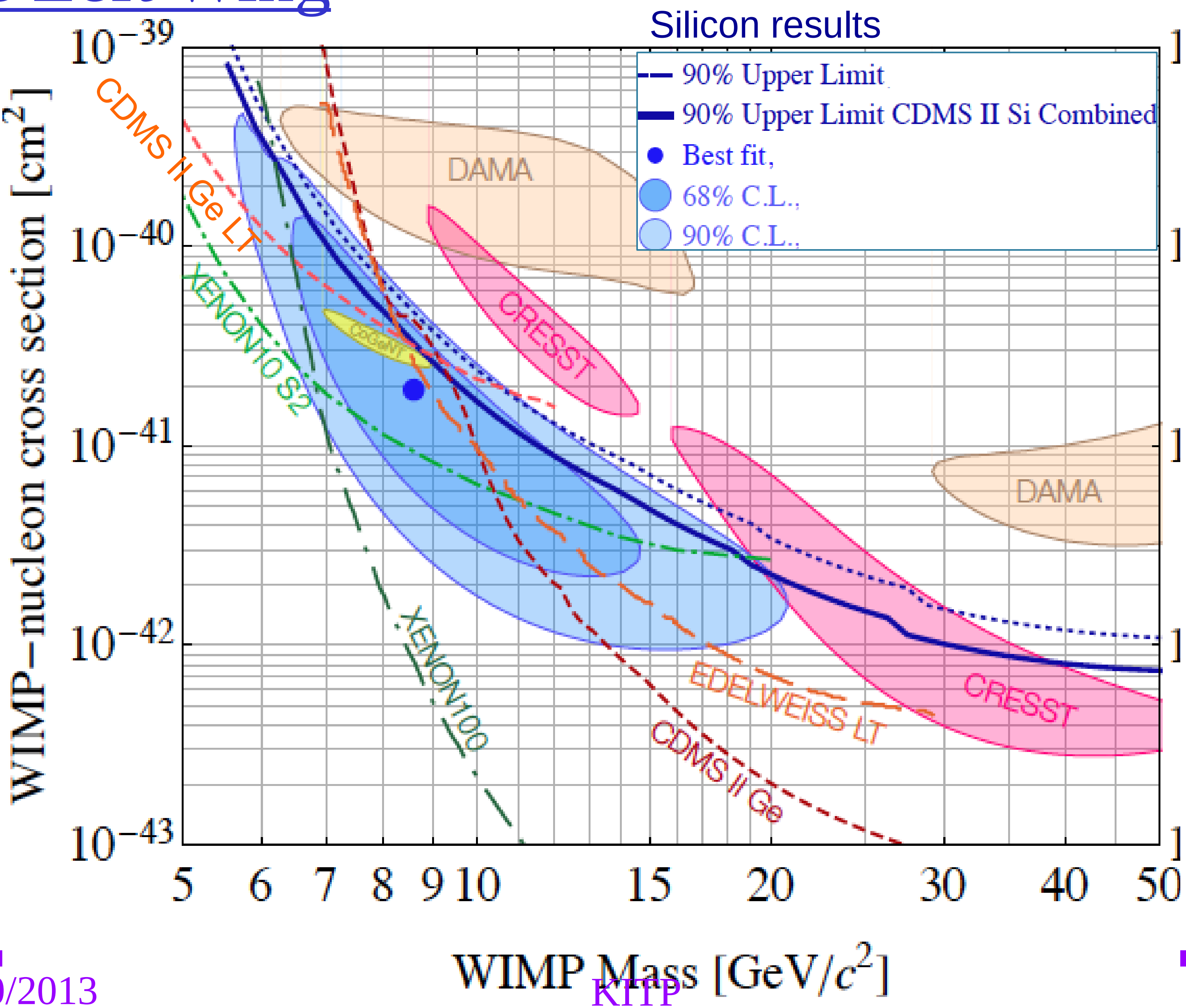
Our Moore's Law (thanks Mike Witherell)



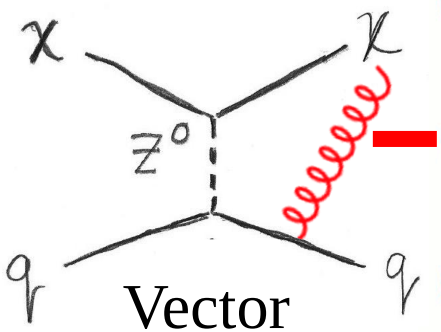
State of Play in the "race to the bottom"



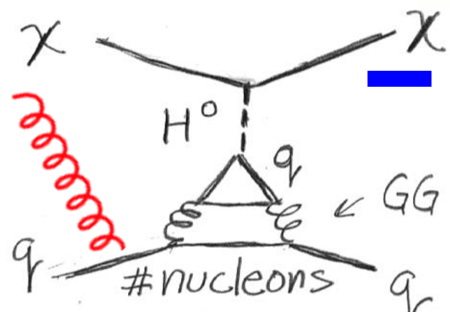
The Left Wing



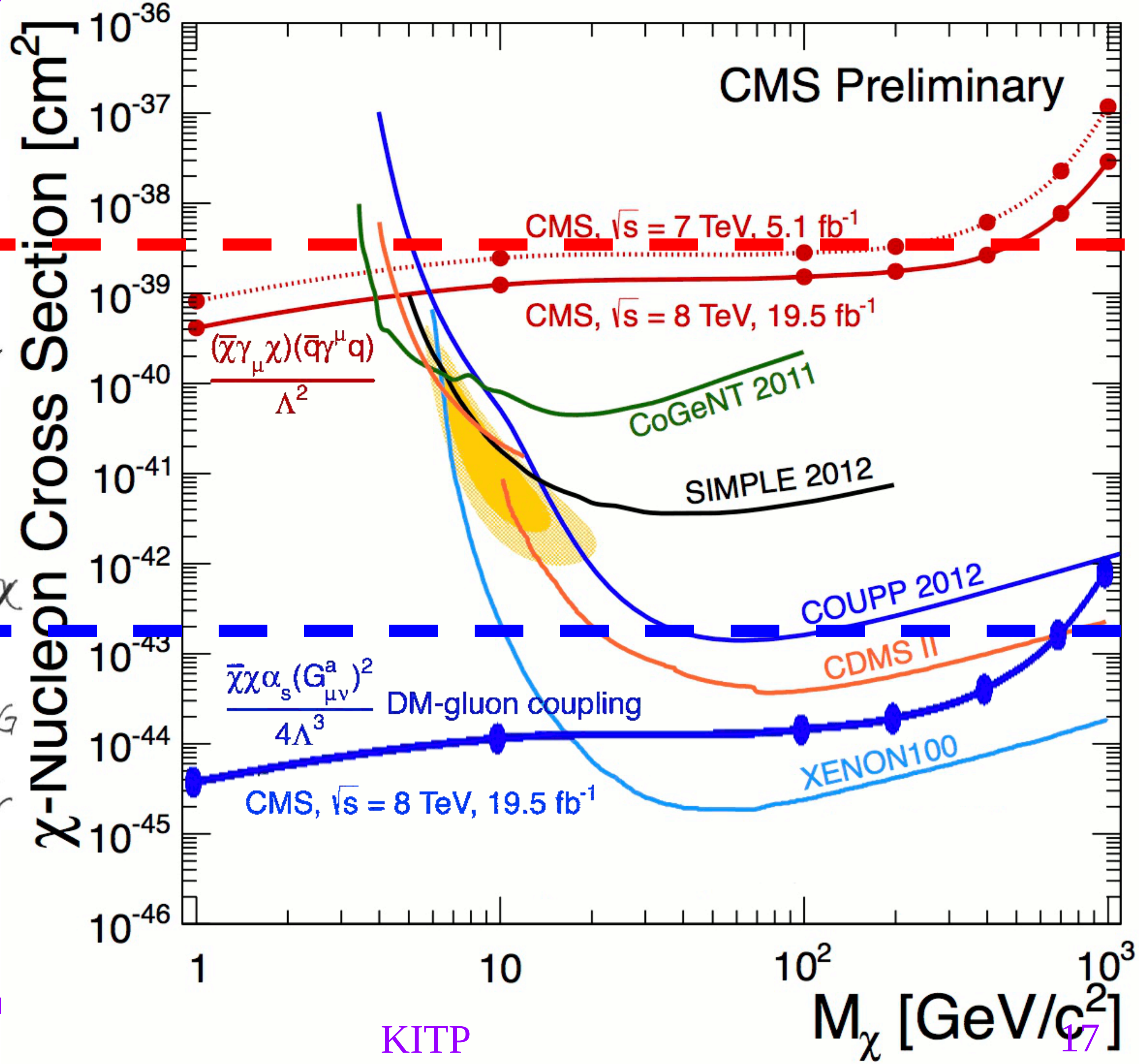
LHC!!



Vector



Scalar

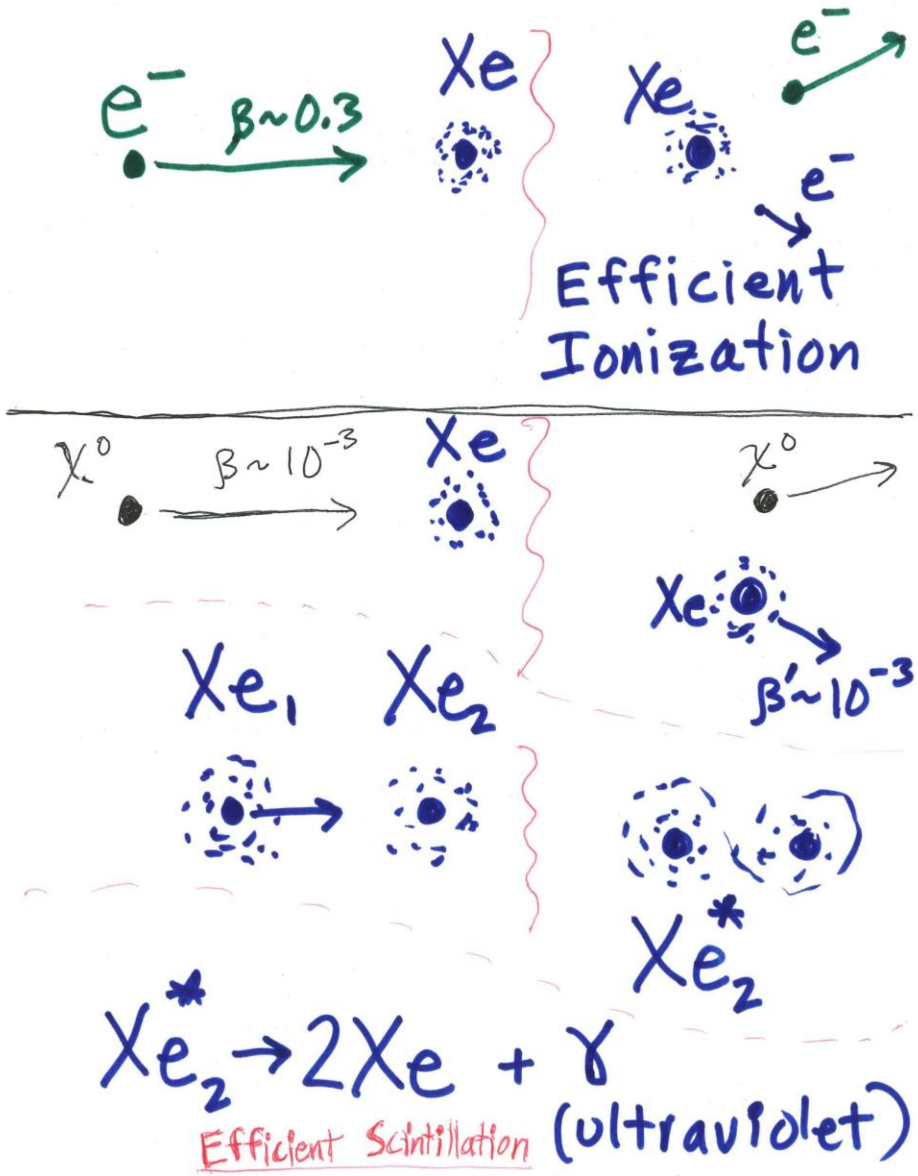



百花齊放
a hundred flowers blossoming
花

The Attractions of Xenon

- Large atomic weight, A, about 131
- No long lived radioactive isotopes (not Ar, Kr) (!)
- Scintillates all by itself with no additives (!)
  - Response different for electron vs. nuclear recoils (!!)
  - UV easier than Kr, Ar, Ne, He – glass, no wave shifter
- Boiling point (165K) above liquid nitrogen (77K)
- Liquid can be continuously Purified
  - Heat, Clean, Condense… LUX Thermosyphon, Heat Ex.
- One big detector, self shields... aluminum floats
  - 2-phase time projection chamber (TPC)

Discrimination



S2

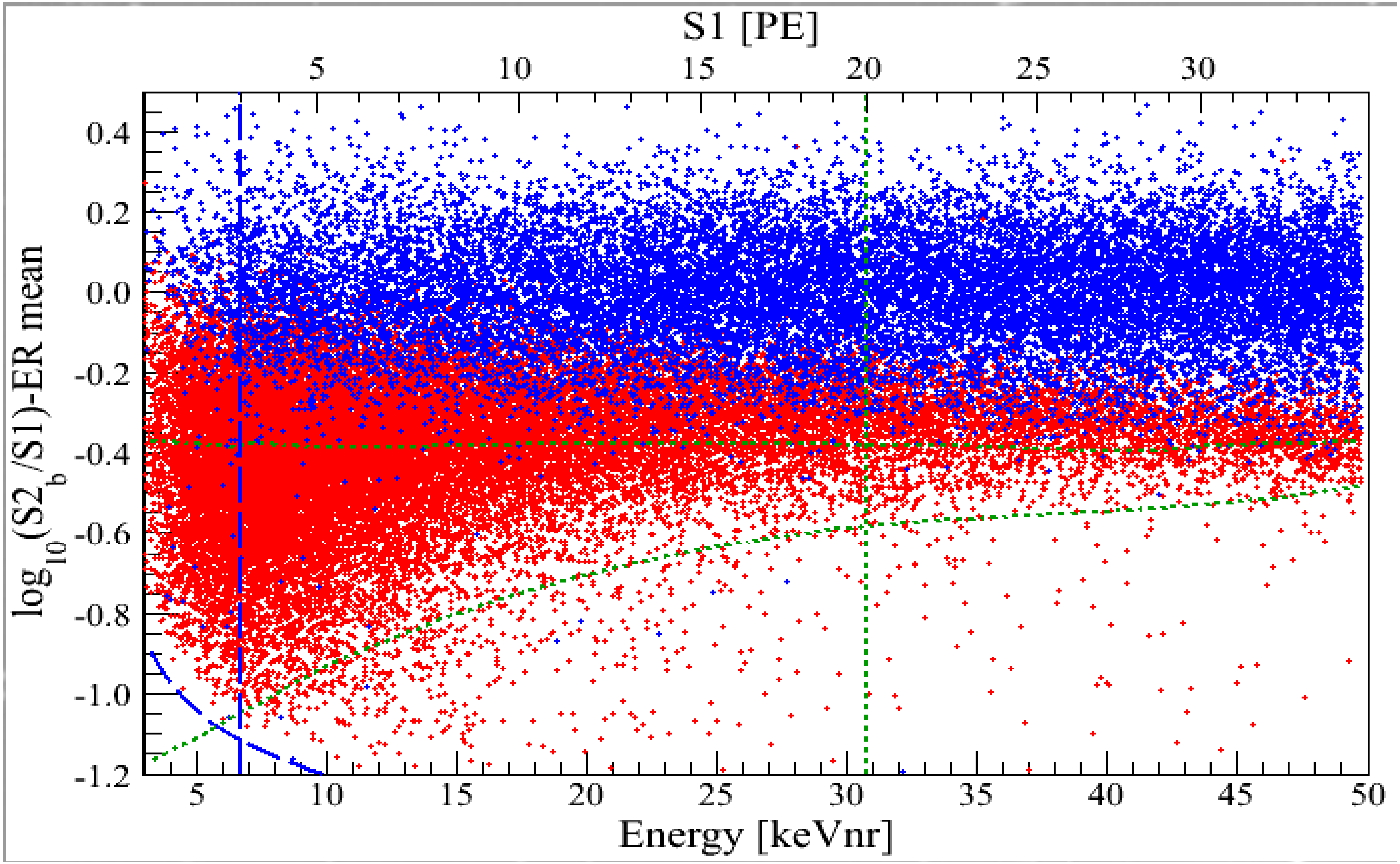
S1

2 Energy Scales

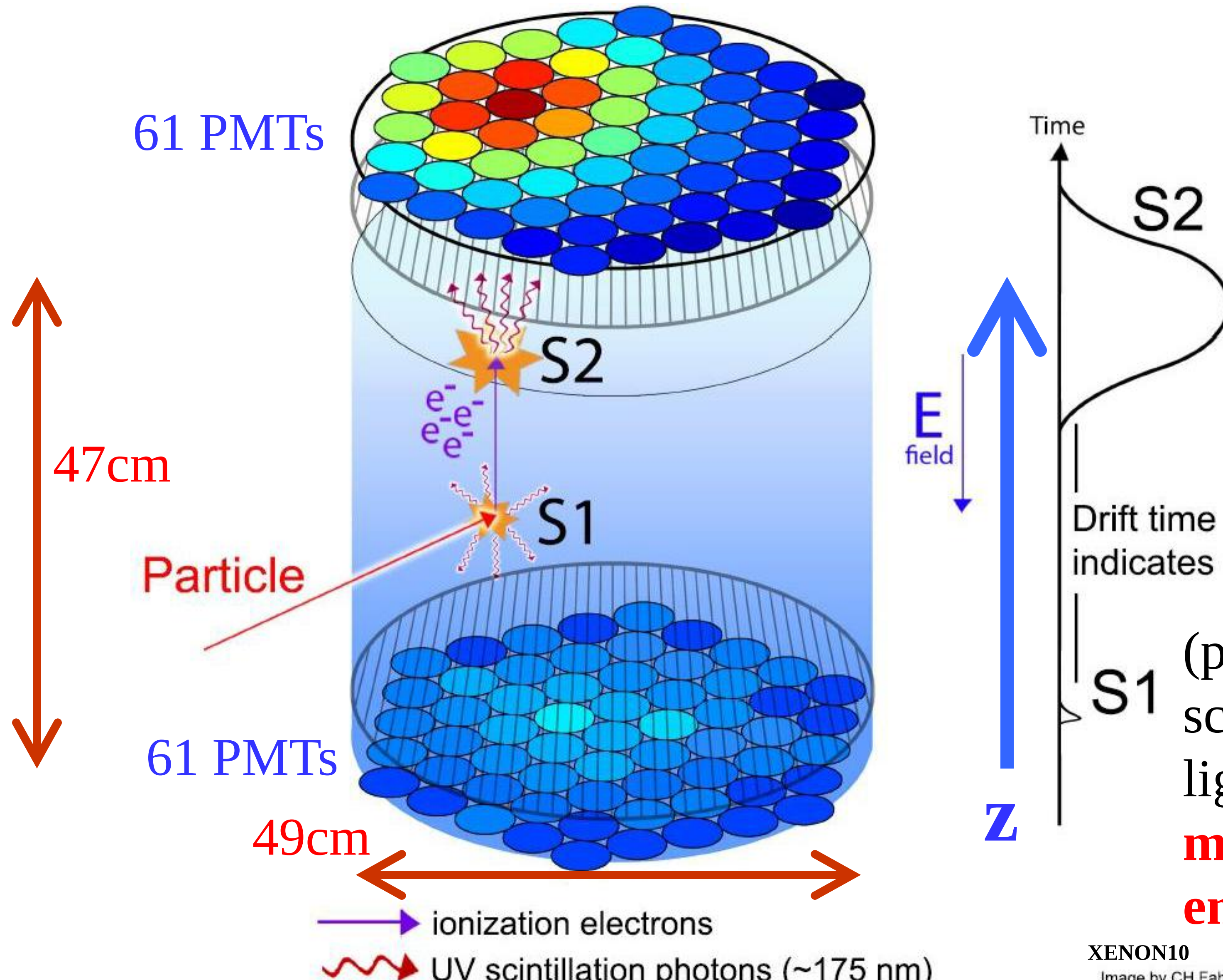
keVee

keVnr

Xenon 100 Separation (flattened)



LUX Dual Phase Xe Detector

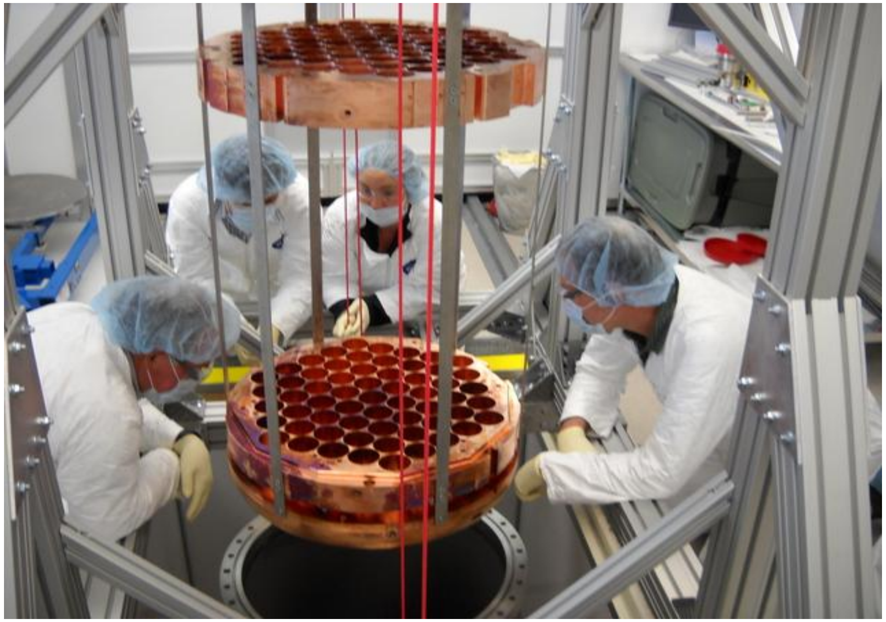


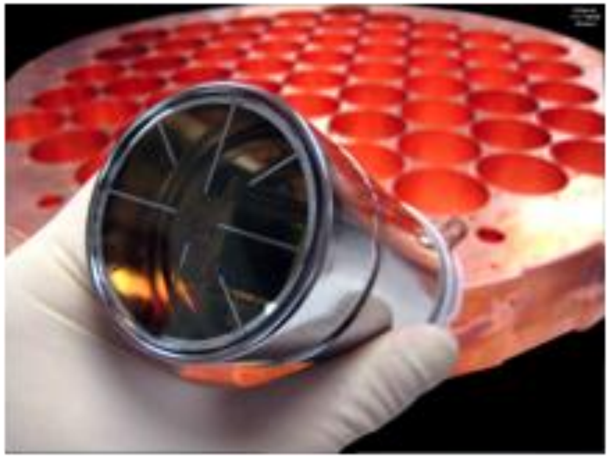
XENON10
Image by CH Faham (Brown)

(secondary scintillation light, **measures ionization,** enables signal/background separation)

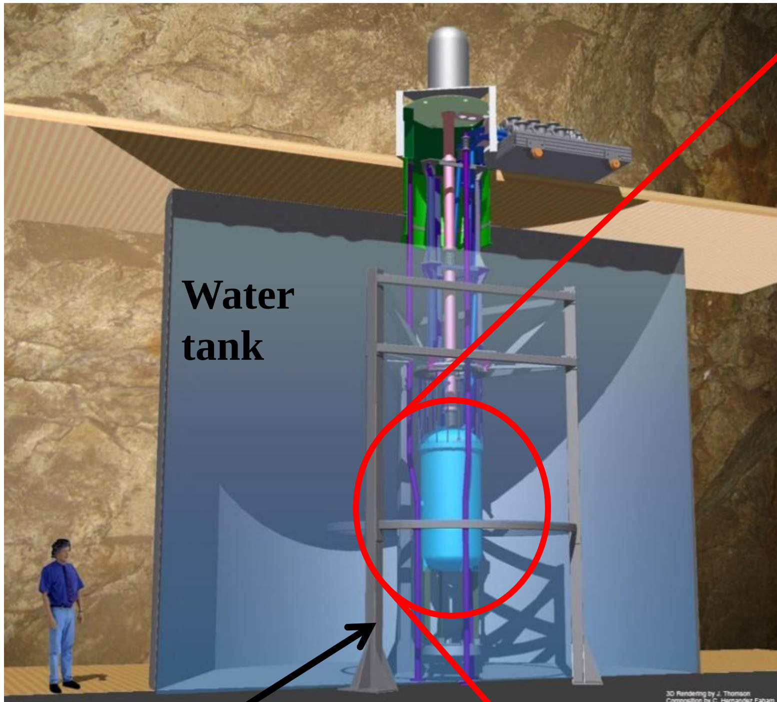
(primary scintillation light, **measures energy**)

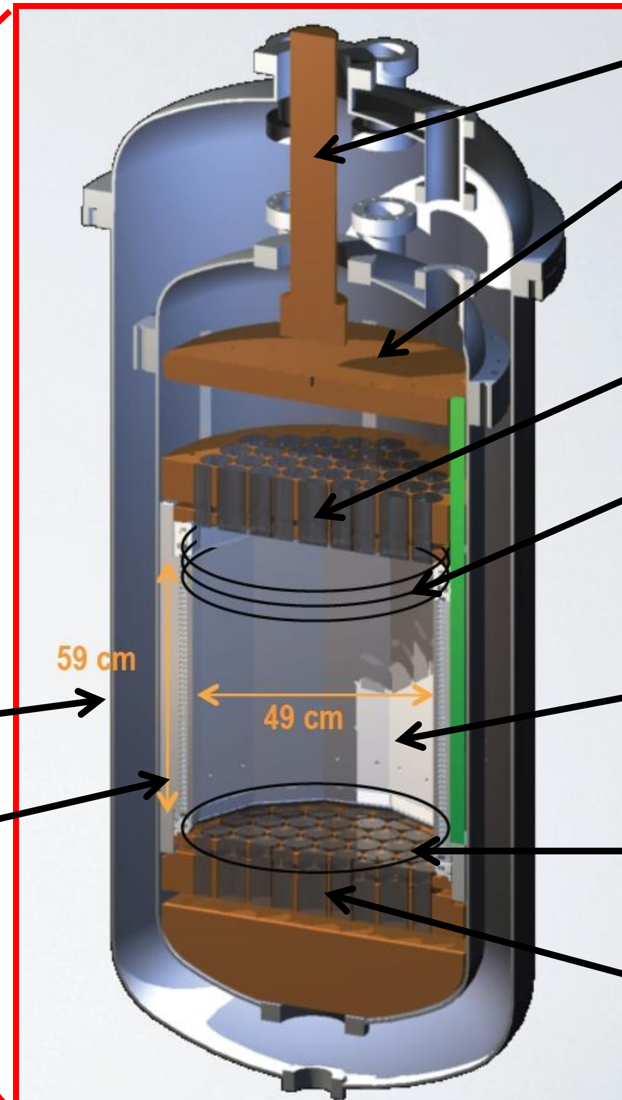
LUX being built





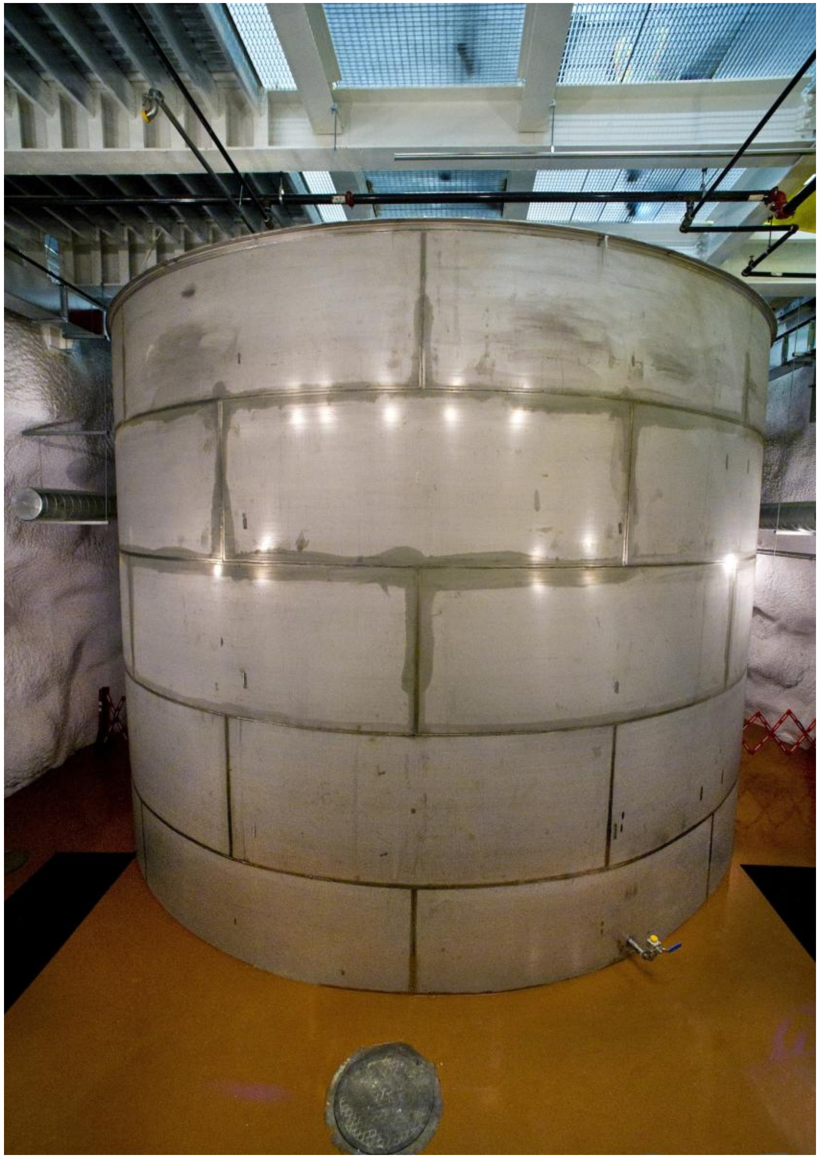
In the tank and detailed cross section





- 370 kg xenon
  - 250 kg active region
  - 118 kg fiducial mass

The LUX Water Tank



1 mile underground near Mount Rushmore in SD (Lead, Homestake Mine)

25 foot diameter
20 foot height
Stainless/pickled

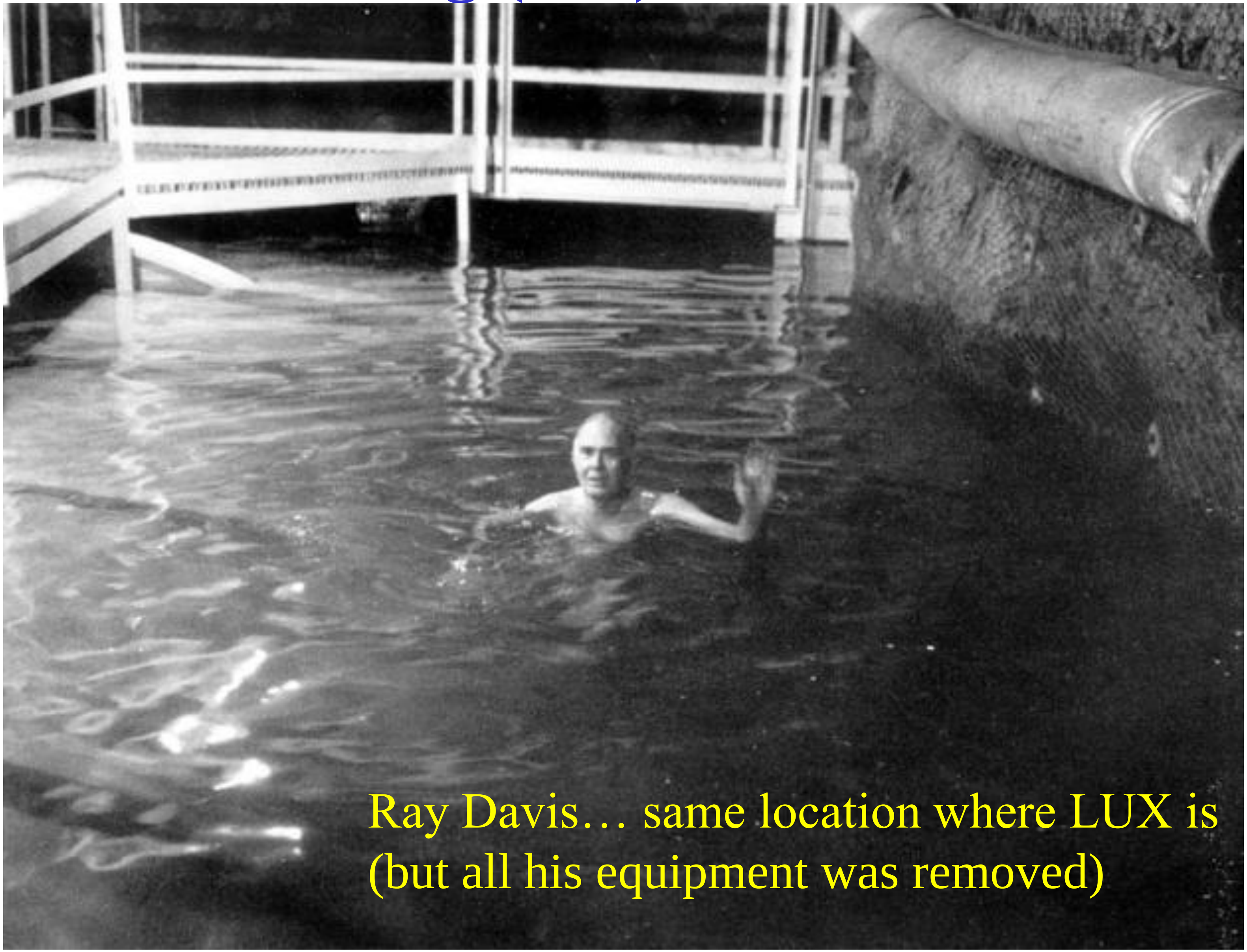
70,000 gallons of ultrapure water
(>18 MegaOhm-cm)

Recirculated/cleaned once/week

LUX Is Installed (Fall 2012)

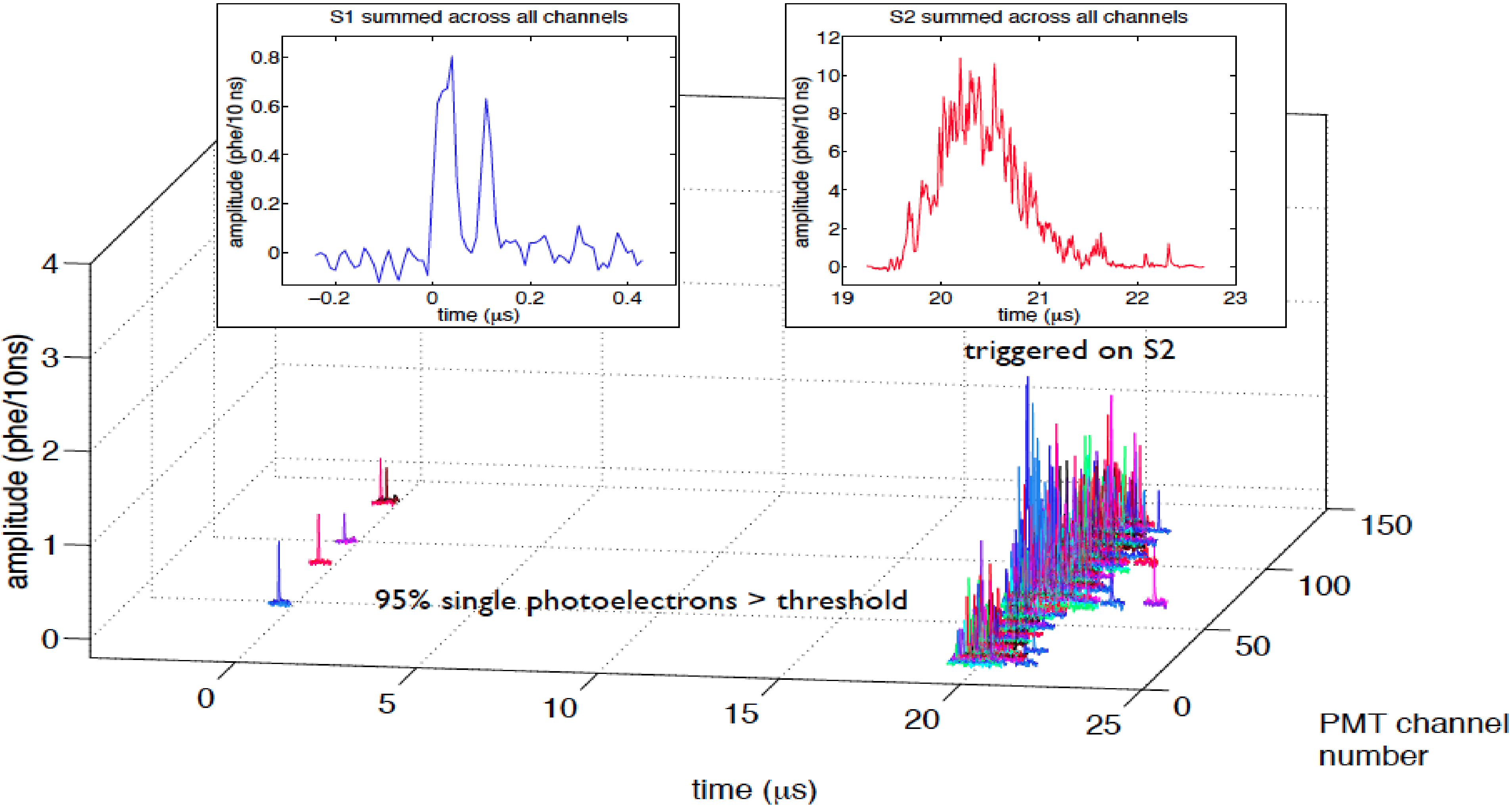
LUX Is Underwater (Fall 2012)

No Swimming (Yet)



Dean & Susanne

Typical Event in LUX

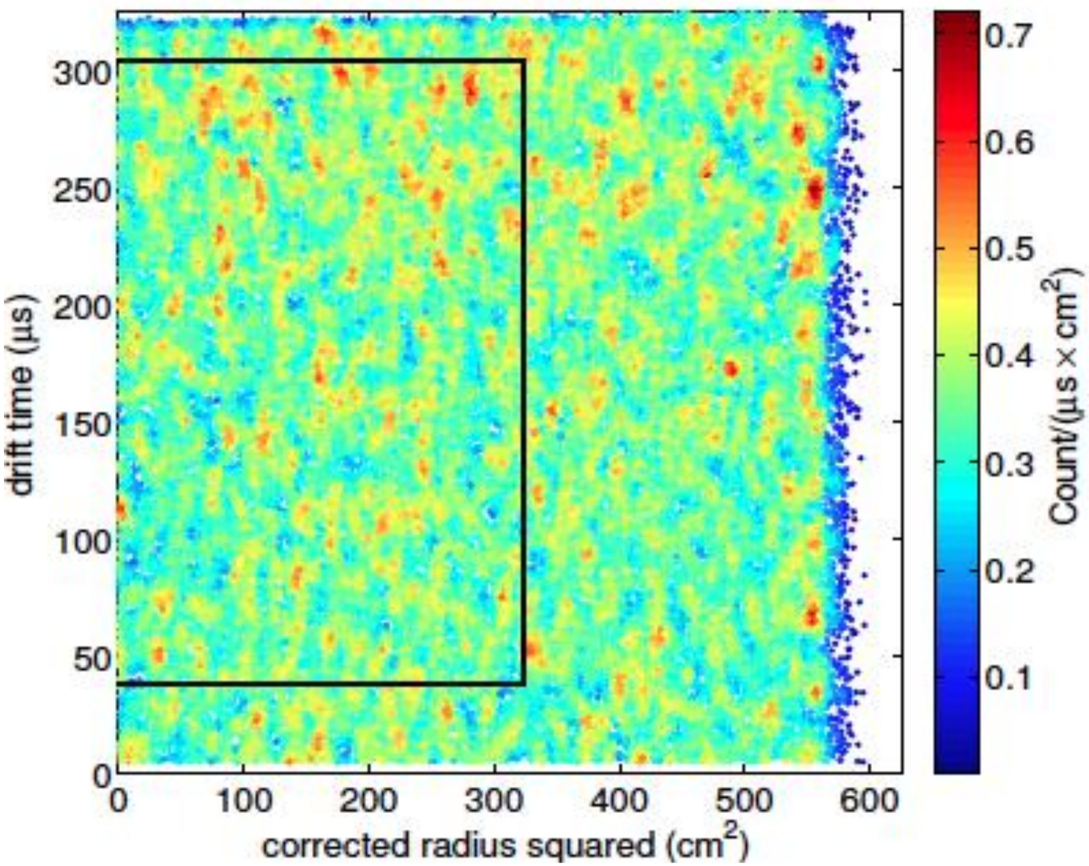


Kr-83m Calibration

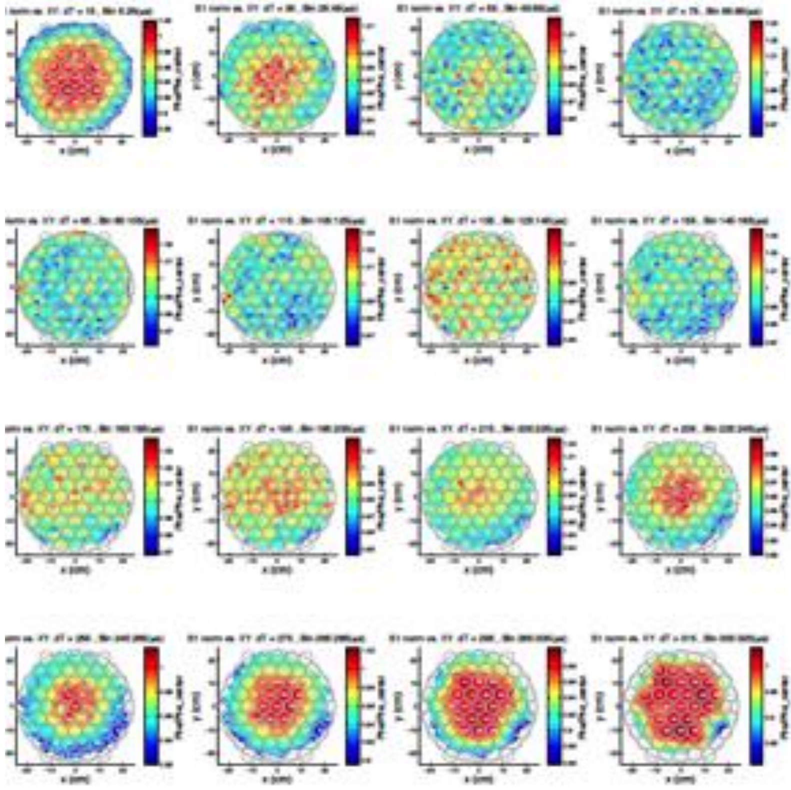
- Over 1 million Kr-83m events, giving over 10 events/cc

Kr-83m – 1.8 h 1/2 life – injected into the detector (like Radon), decays

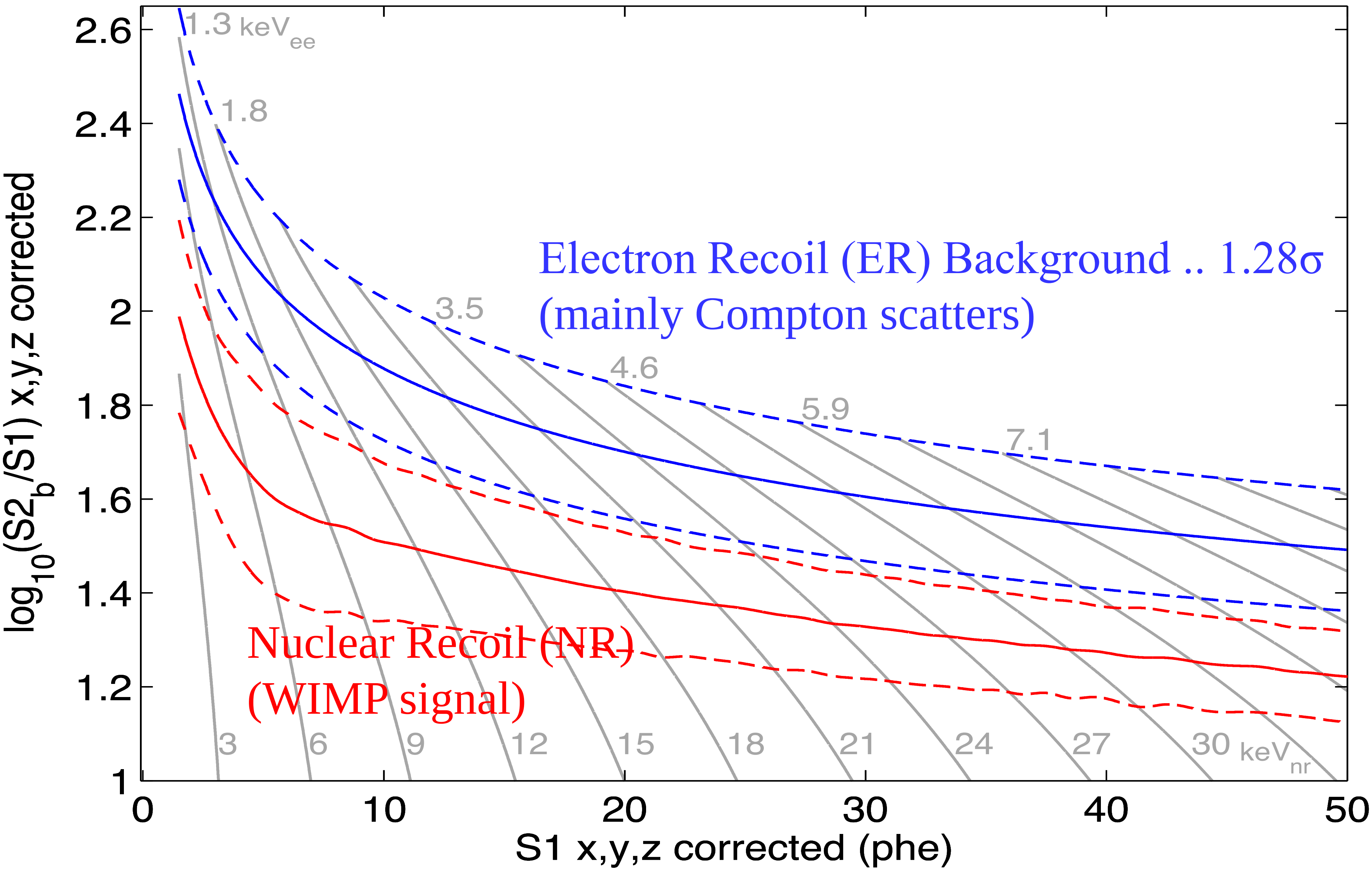
Fiducial volume determination



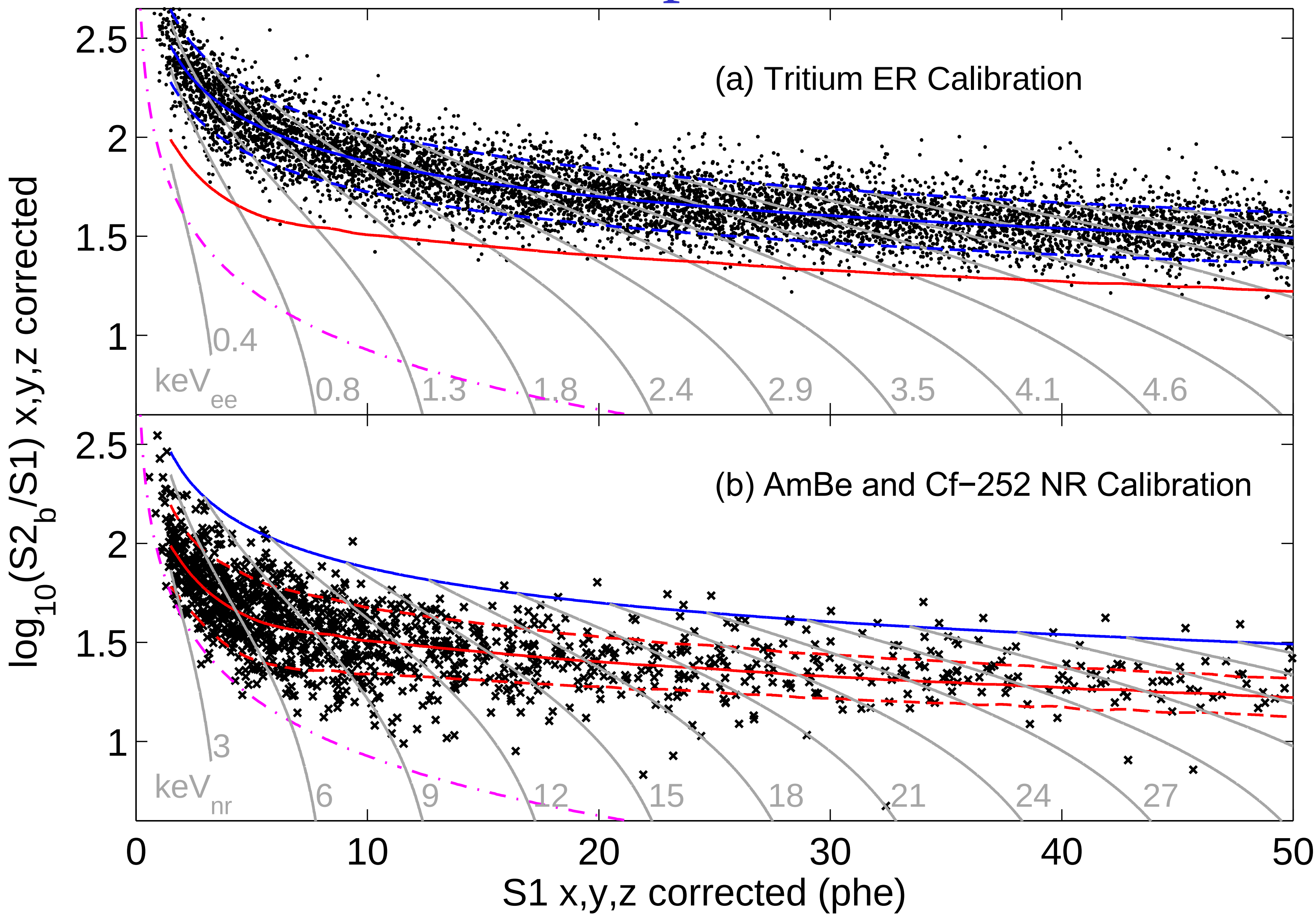
Position-based S1 corrections



Key Plot For Search

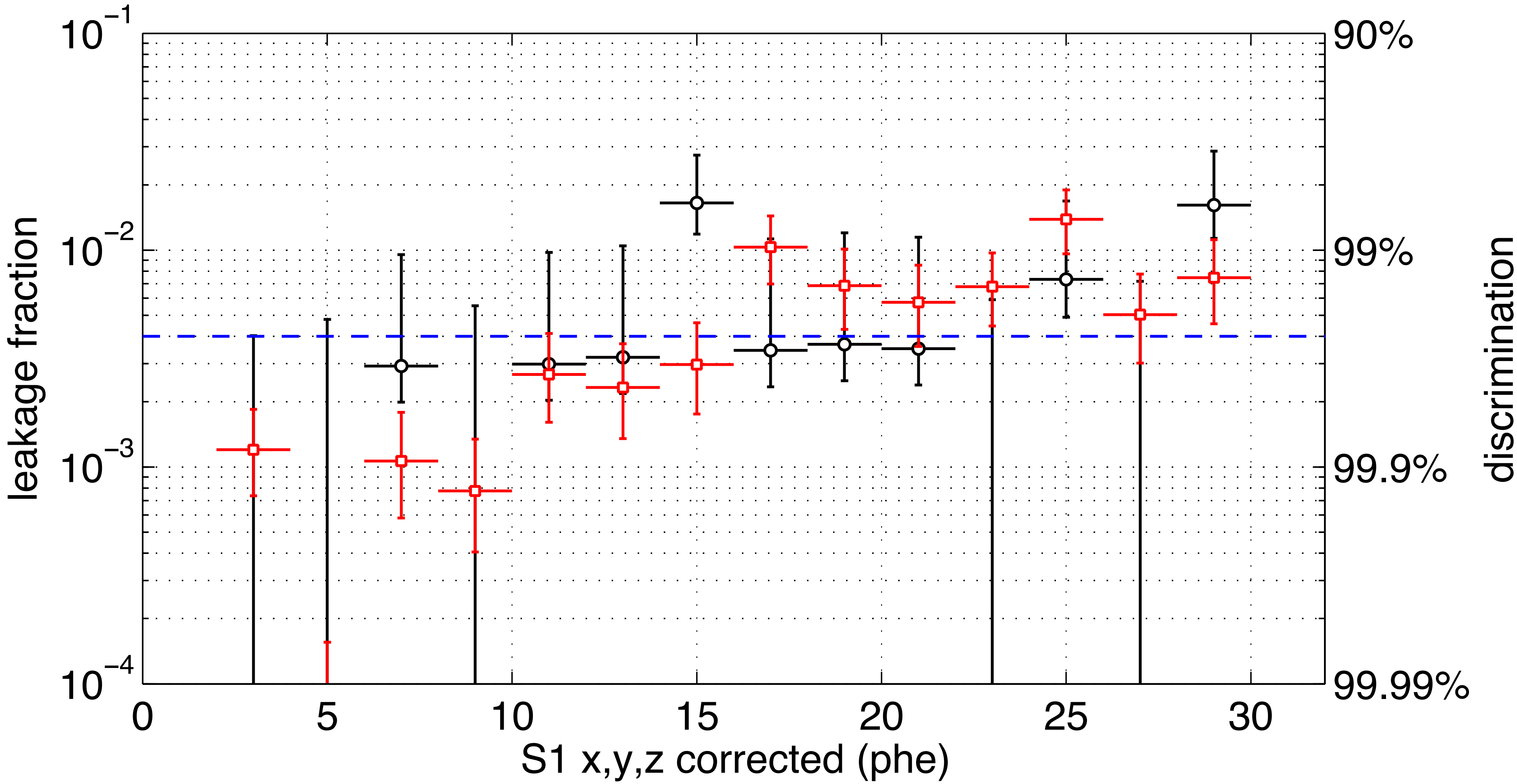


Calibration of LUX Response



Rate of Confusing ER as NR (`Discrimination')

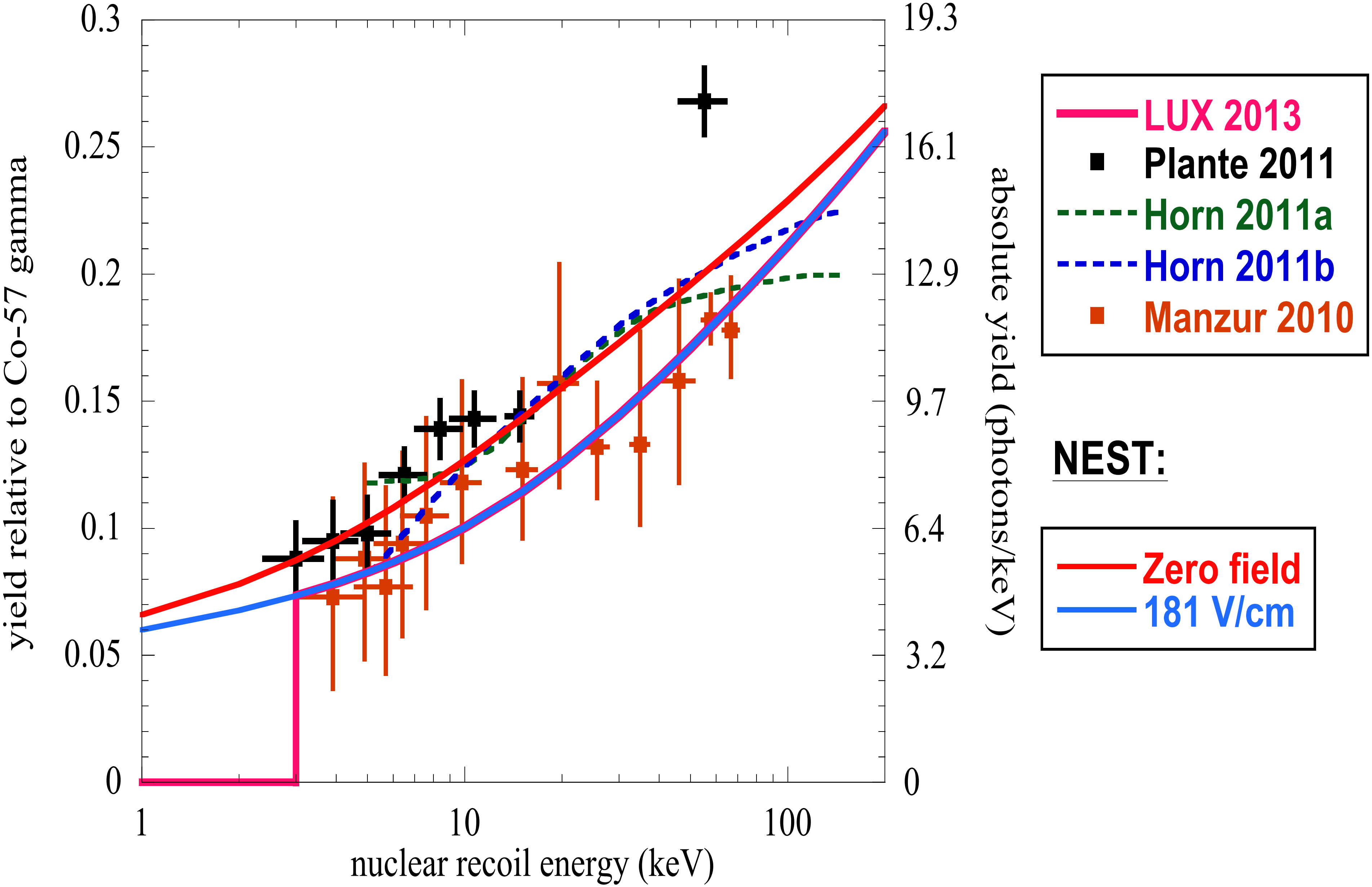
Average discrimination from 2-30 S1 photoelectrons measured to be 99.6% (with 50% nuclear recoil acceptance)



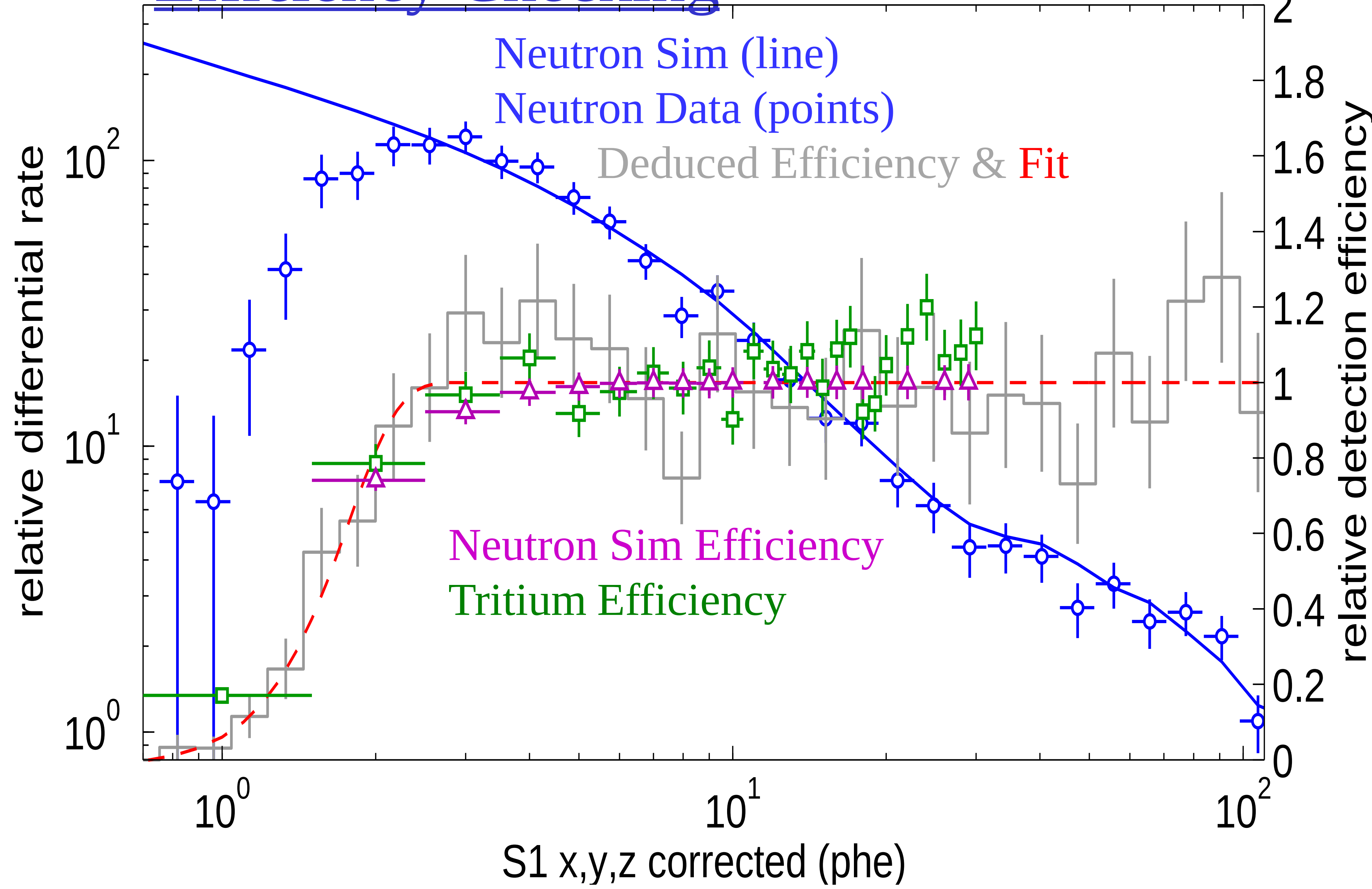
Black circles show leakage from counting events from the dataset

Red circles show projections of Gaussian fits below the nuclear recoil band mean

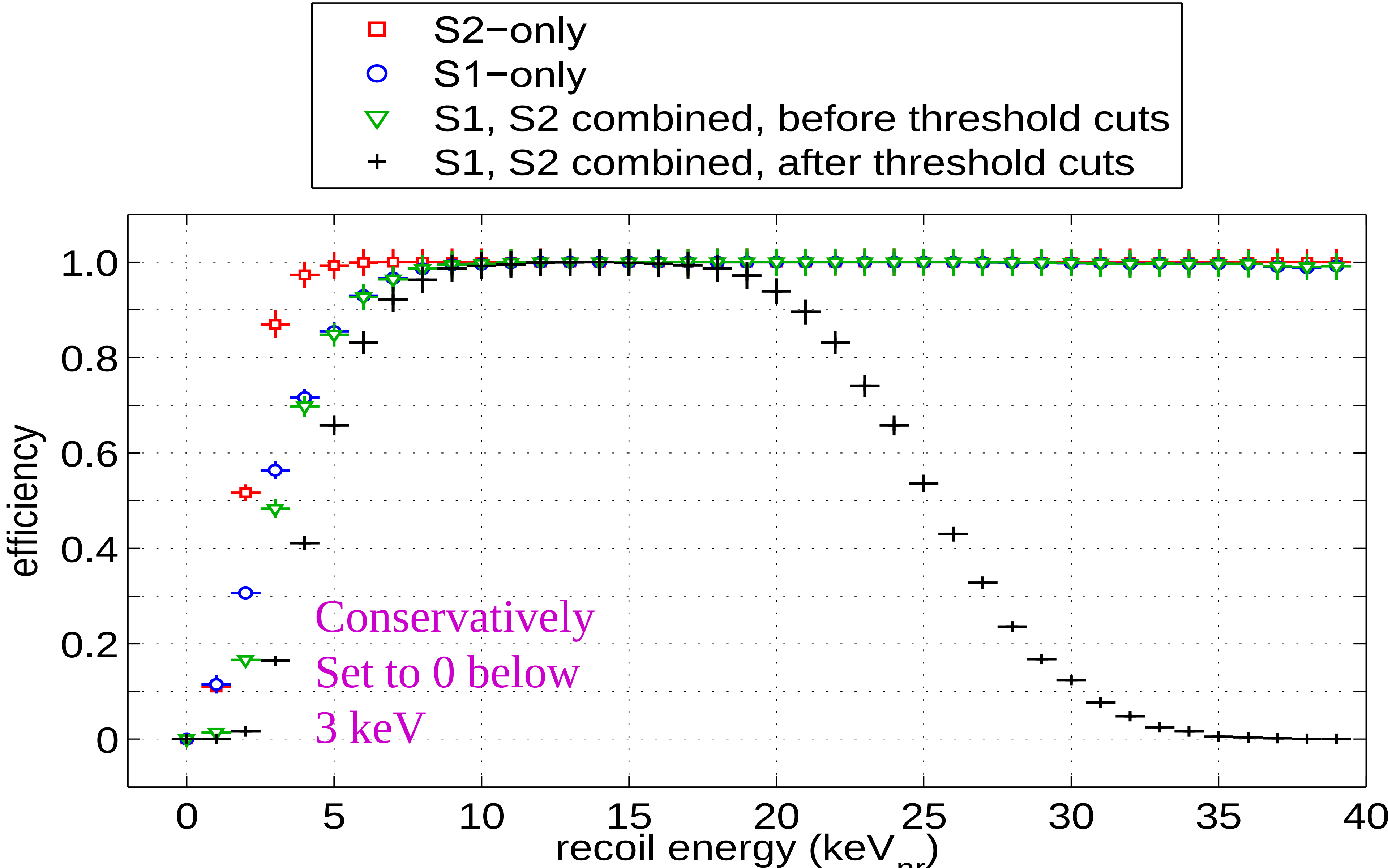
Model of Detector Response



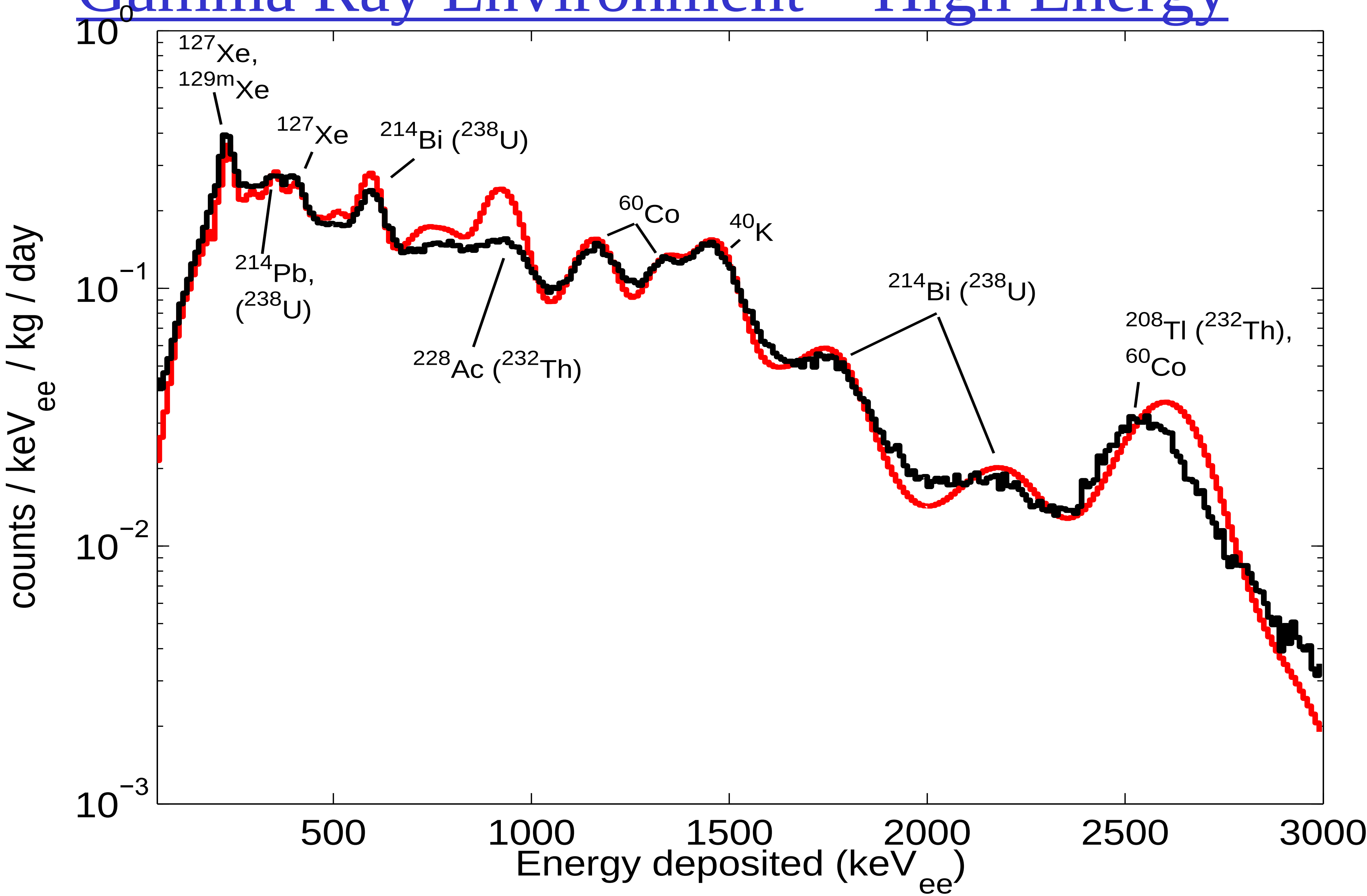
Efficiency Checking



Efficiency


S2−only
S1−only
S1, S2 combined, before threshold cuts
S1, S2 combined, after threshold cuts
efficiency
1.0
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
30
35
40
recoil energy (keV_{nr})
Conservatively
Set to 0 below
3 keV

Gamma Ray Environment – High Energy



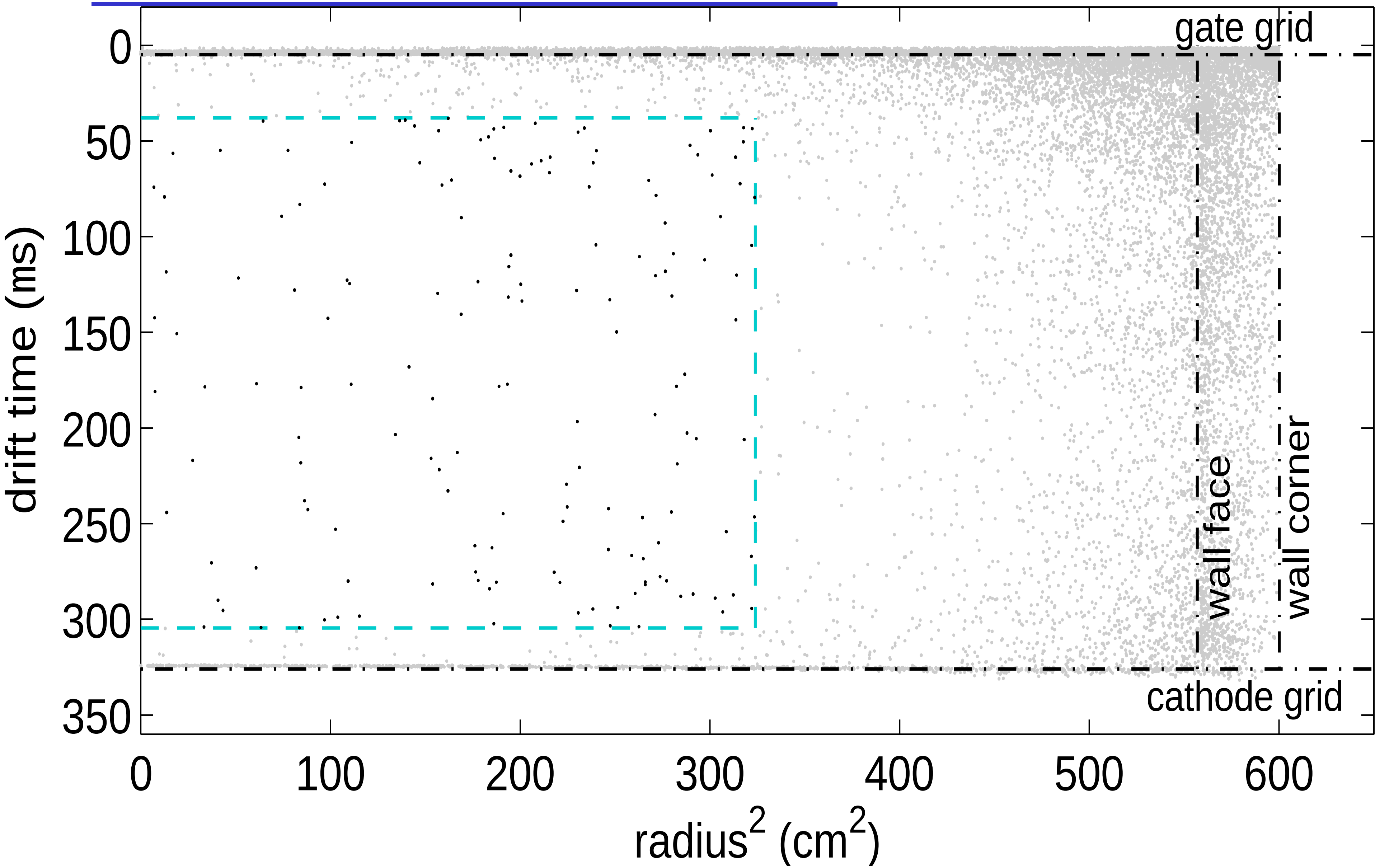
Gamma Ray Environment

Background Component	Source	10^{-3} x evts/keVee/kg/day
Gamma-rays	Internal Components including PMTS (80%), Cryostat, Teflon	$1.8 \pm 0.2_{stat} \pm 0.3_{sys}$
^{127}Xe (36.4 day half-life)	Cosmogenic 0.87 -> 0.28 during run	$0.5 \pm 0.02_{stat} \pm 0.1_{sys}$
^{214}Pb	222Rn	$0.11\text{-}0.22_{(90\%\ CL)}$
^{85}Kr	Reduced from 130 ppb to 3.5±1 ppt	$0.13 \pm 0.07_{sys}$
Predicted	Total	$2.6 \pm 0.2_{stat} \pm 0.4_{sys}$
Observed	Total	$3.1 \pm 0.2_{stat}$

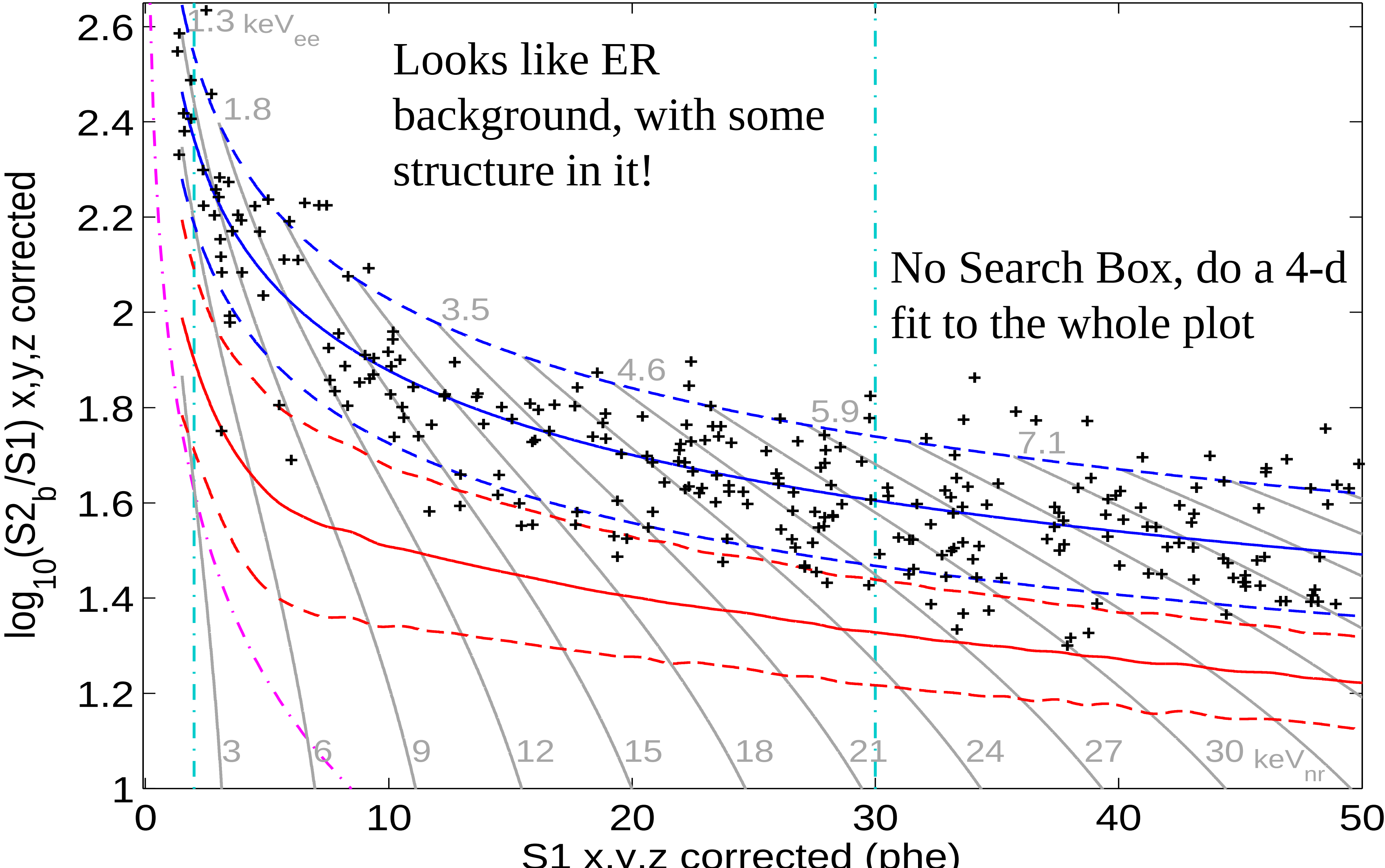
Event & Cuts Summary: 86 live days

Cut	Explanation	Events Remaining
All Triggers	S2 Trigger >99% for S2>200 phe	83,673,413
Detector Stability	Cut periods of excursion for Xe Gas Pressure, Xe Liquid Level, Grid Voltages	82,918,901
Single Scatter Events	Identification of S1 and S2. Single Scatter cut.	6,585,686
S1 energy	Accept 2-30 phe (low energy <5 keVee,<25 keVnr)	26,824
S2 energy	Accept 200-3300 phe	20,989
S2 Electron Trains	Cut if >100 phe outside S1+S2 identified. (0.8% drop in livetime.)	19,796
Drift Time Cut away from grids	Cutting away from cathode and gate regions, 60 < drift time < 324 us	8731
Fiducial Volume	Radius < 18 cm, 38 < drift time < 305 us, 118 kg fiducial	160

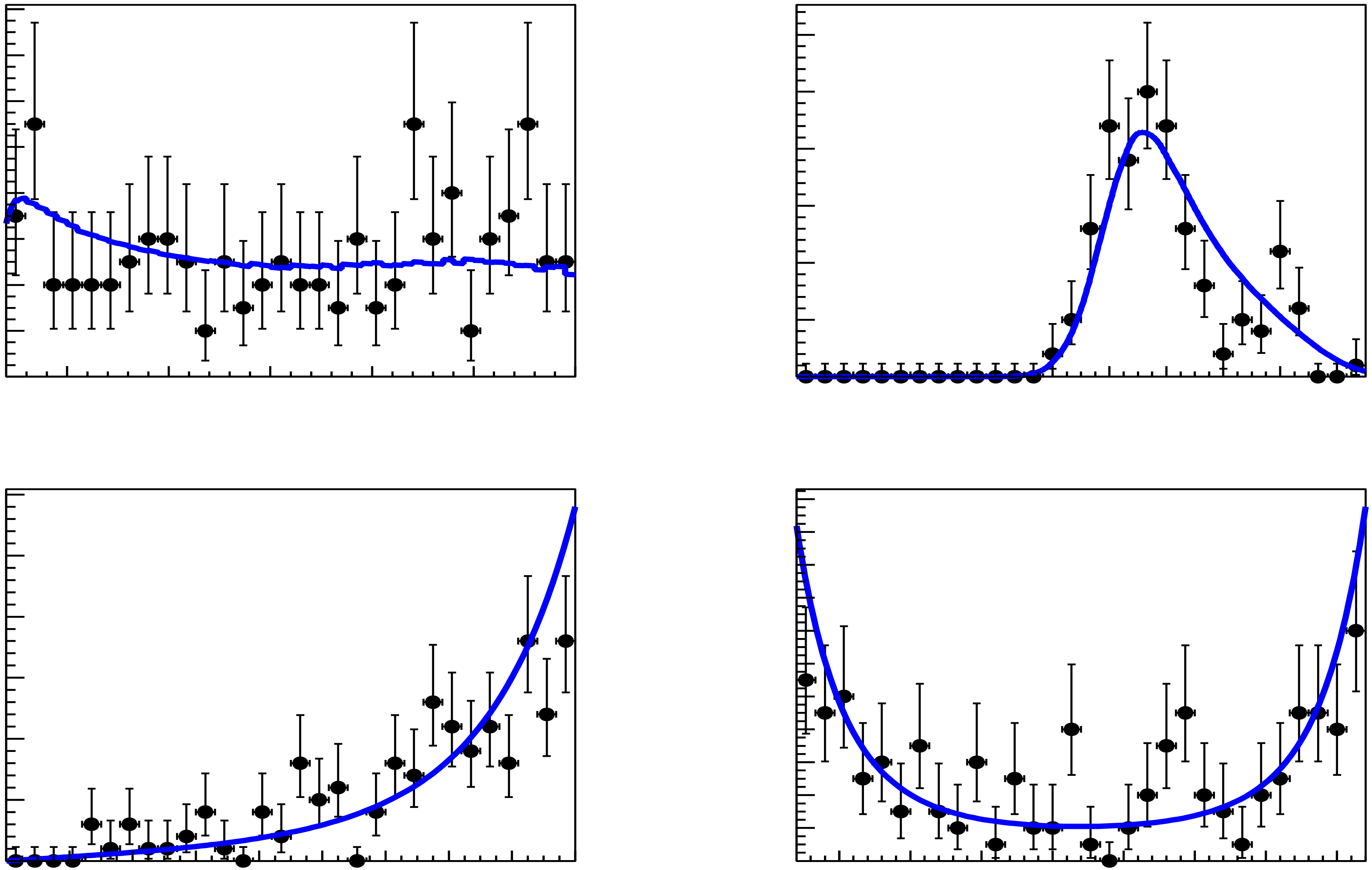
The Events in our Detector



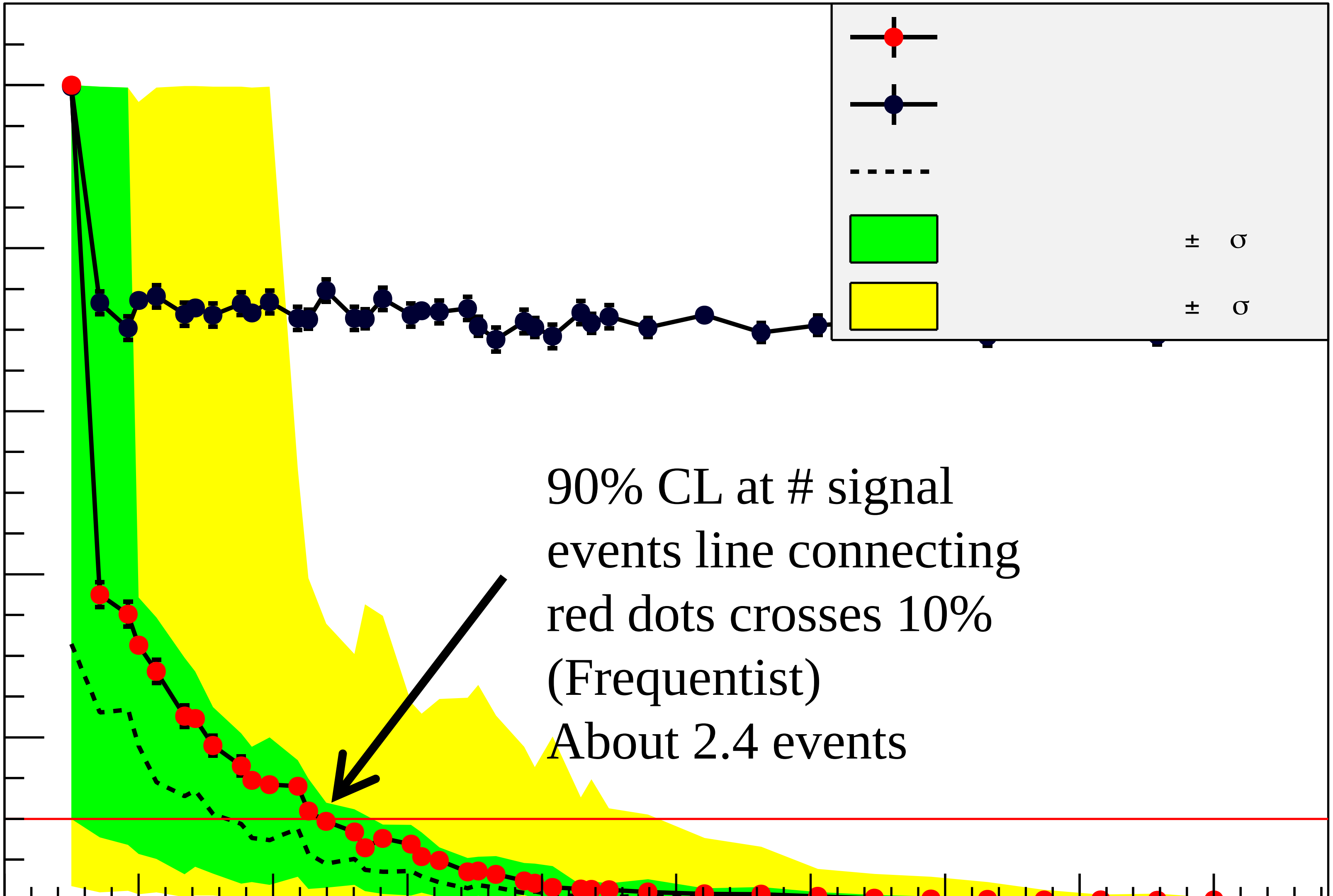
The 160 Events on the Main WIMP Search Plot



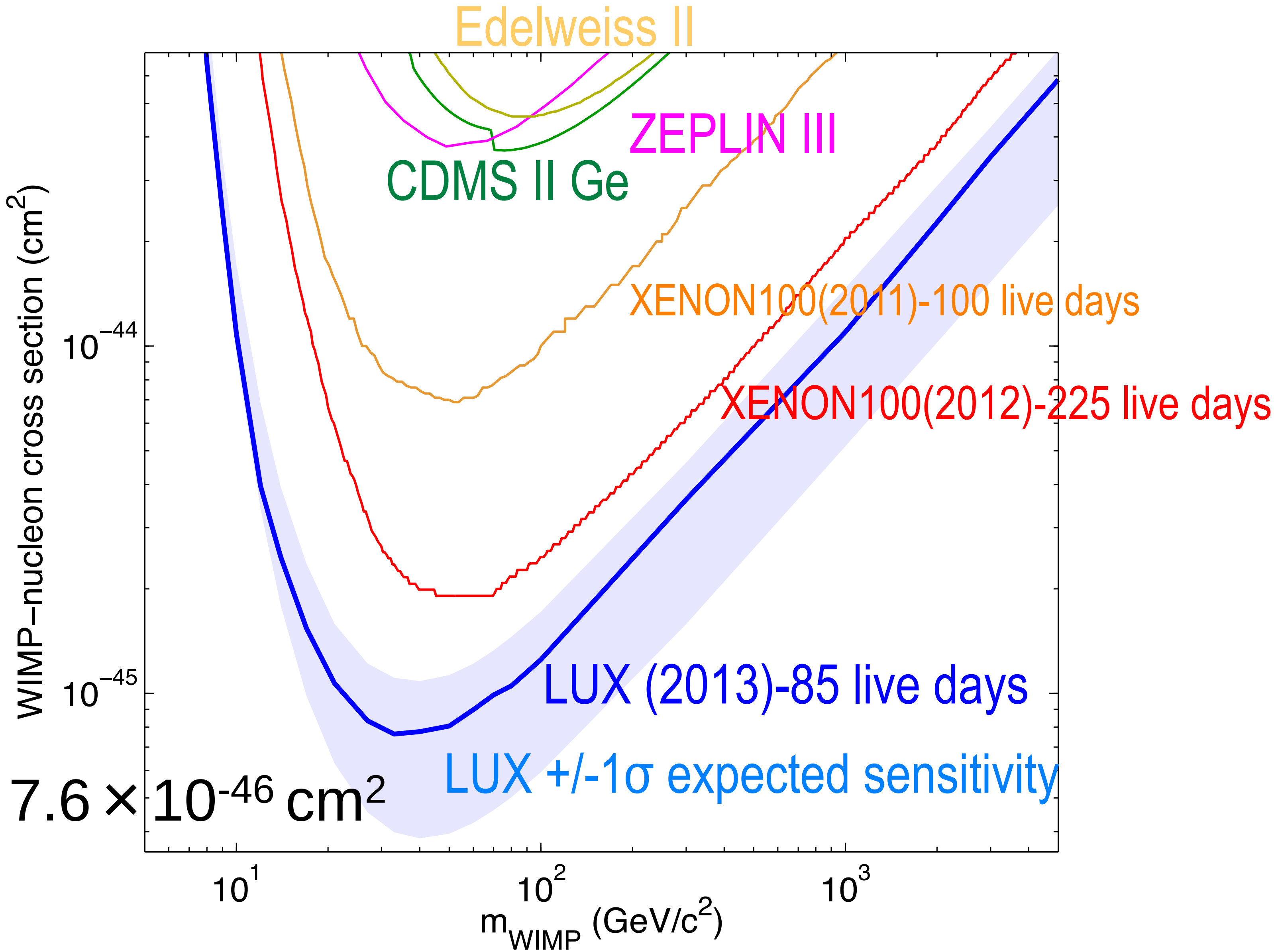
Fit Projections – All Bkgd Rejected at 66% CL



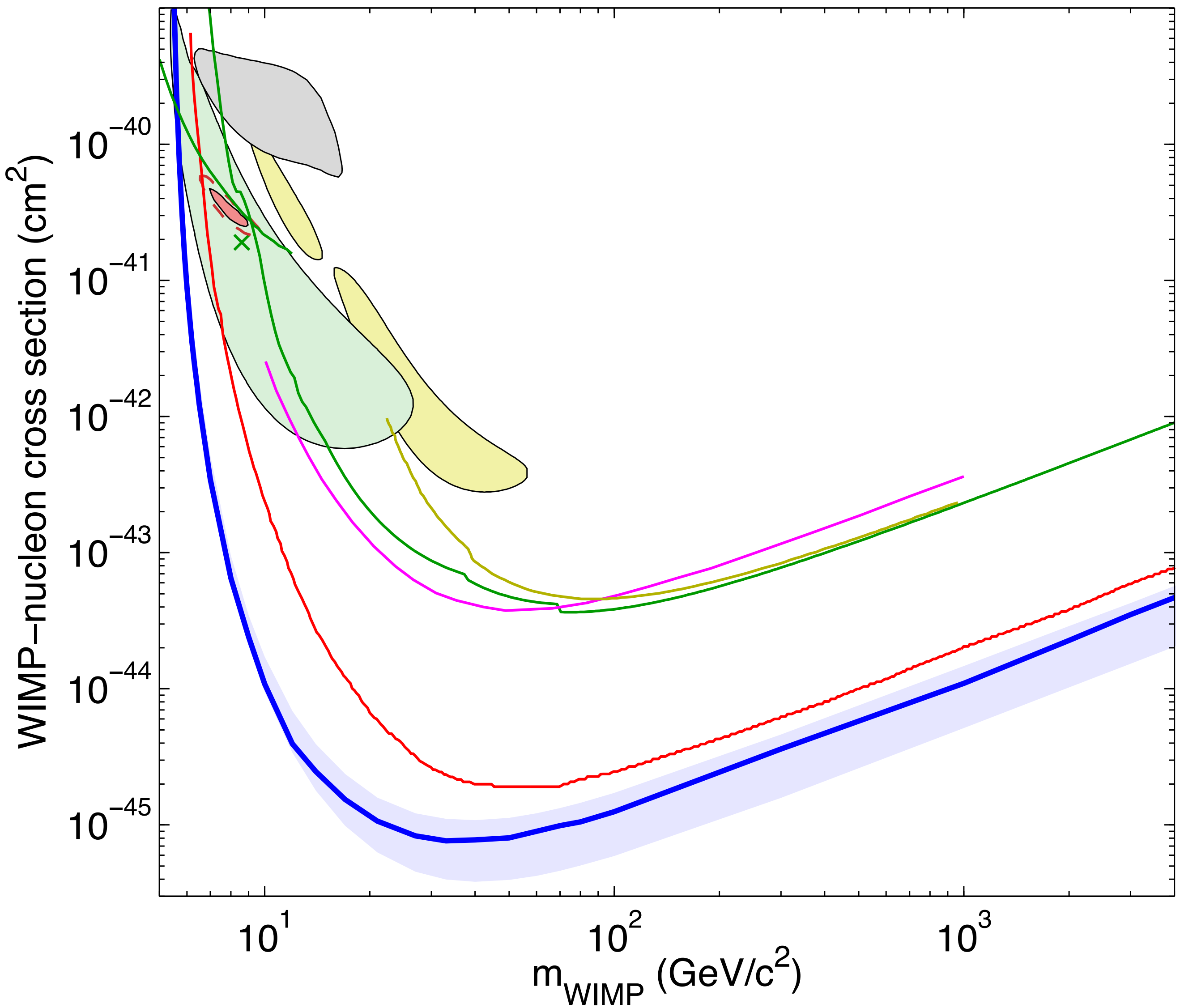
WIMP Mass 7 GeV Limit (Higgs Technology)



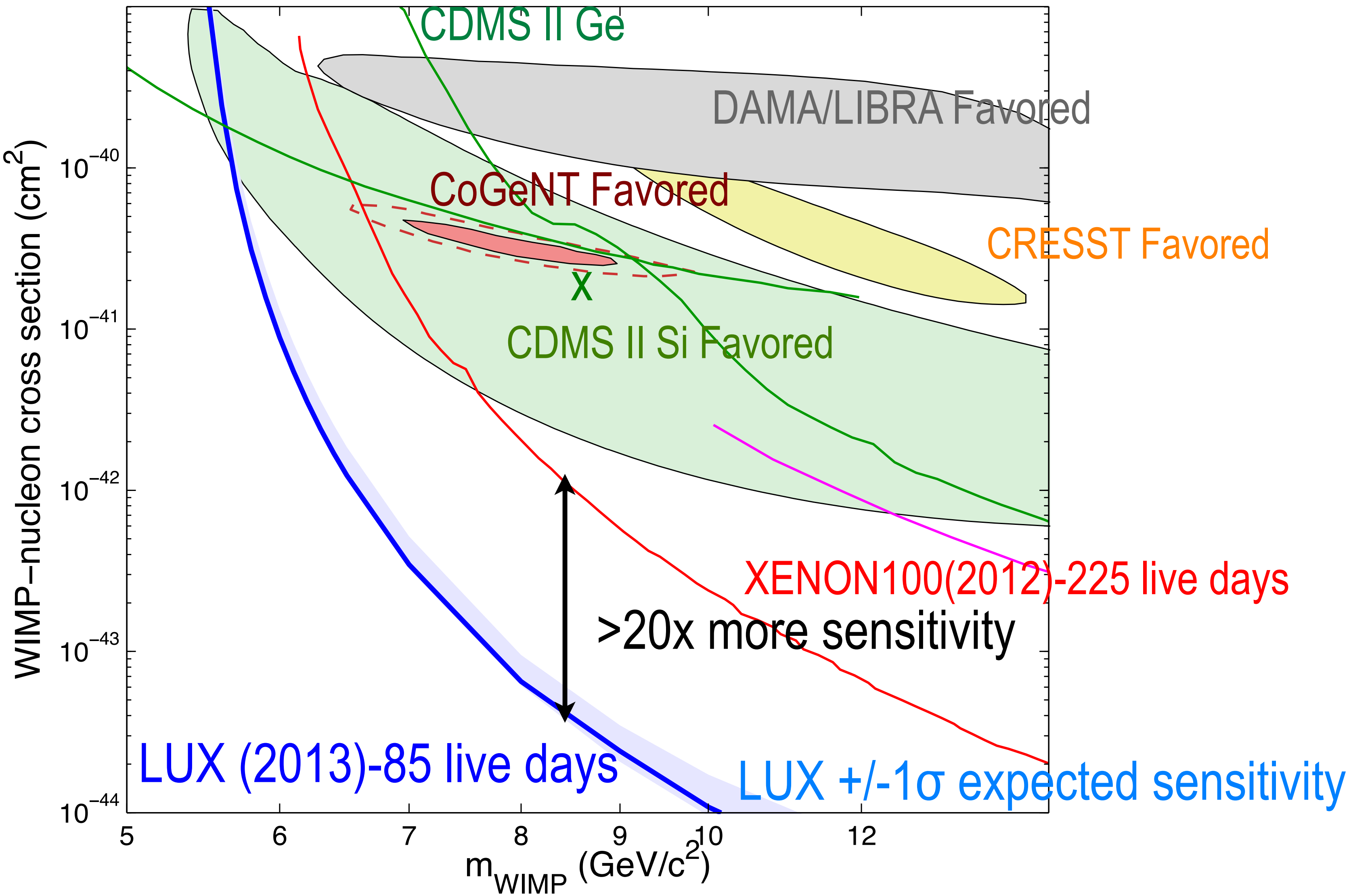
High Mass Limits



Expand the Vertical



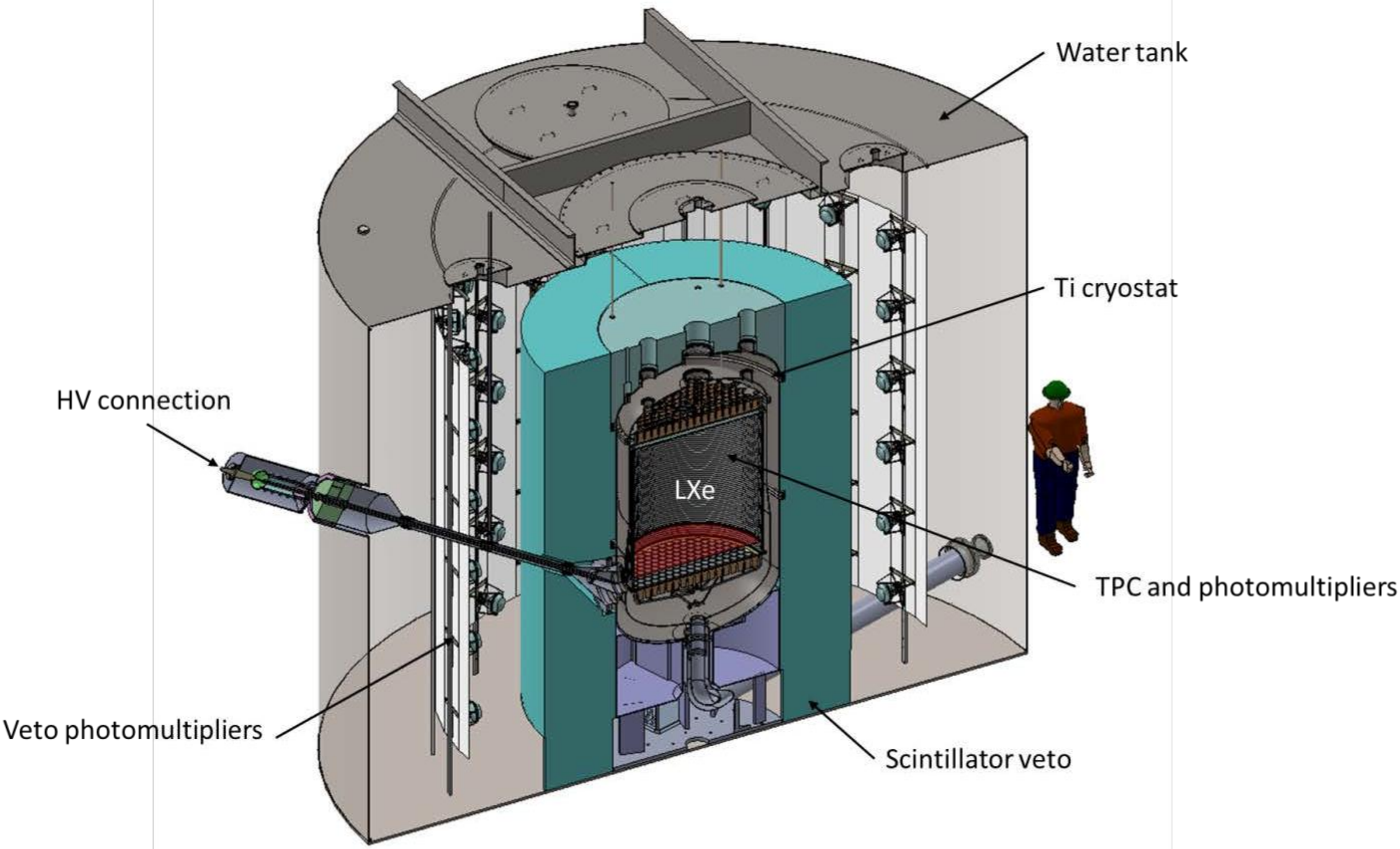
Low Mass Limits



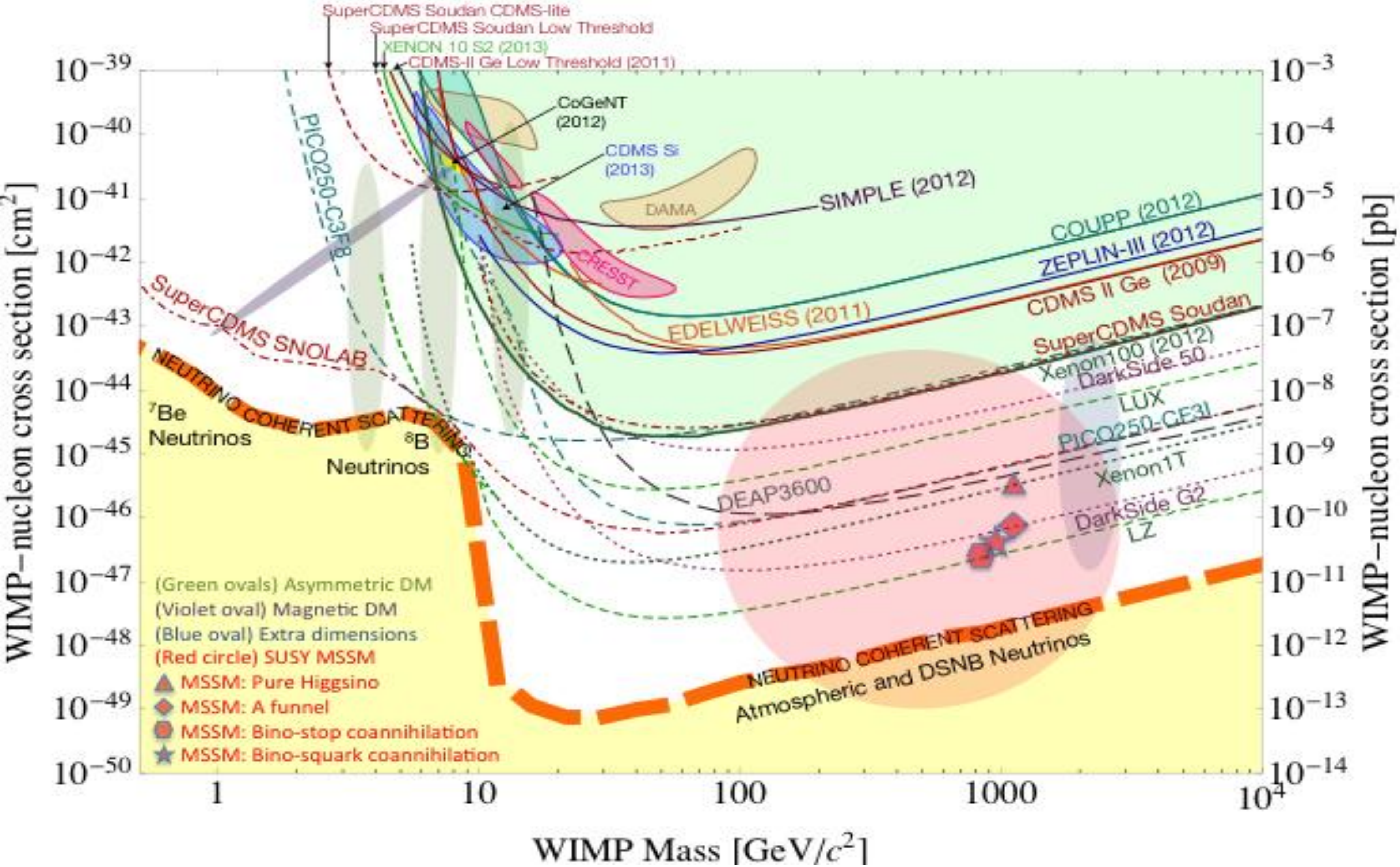
The Future

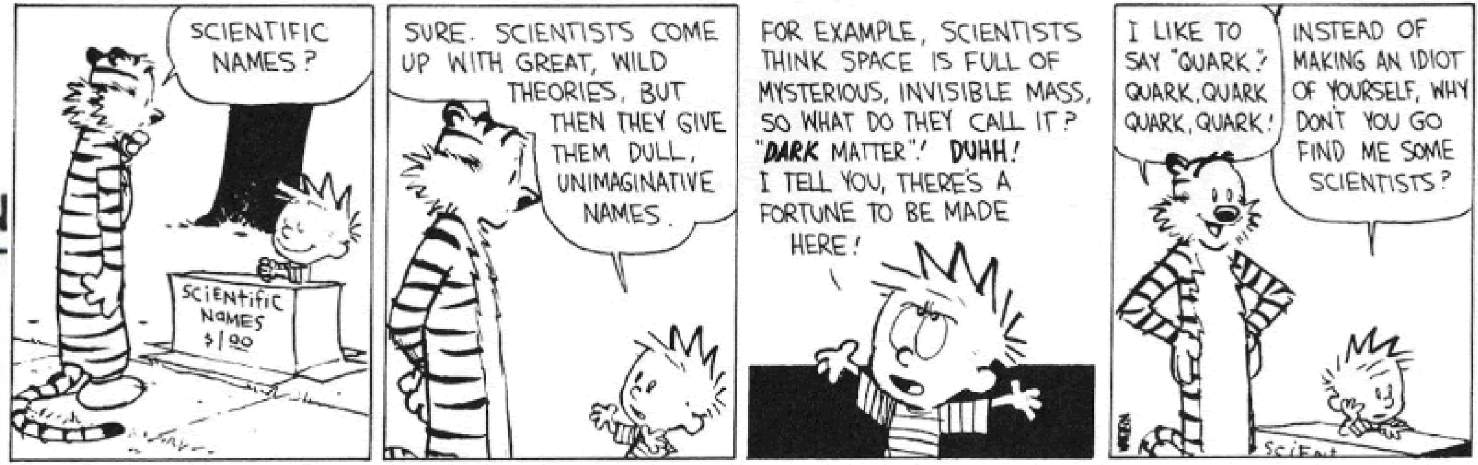
- LUX – 300 day, blinded run, 4X sensitivity in 1 year
- Upgrade… LZ (LUX-ZEPLIN) to 7 tonnes
  - Factor of 20 in mass
  - Factor of 100 in sensitivity… 10^{-48} cm^2
  - Background from atmospheric, solar neutrinos starts to creep in.
  - 2017

LZ – fits in LUX Water Tank



The Future of Direct Detection (SI)




SCIENTIFIC NAMES?
SCIENTIFIC NAMES $1.00
SURE. SCIENTISTS COME UP WITH GREAT, WILD THEORIES, BUT THEN THEY GIVE THEM DULL, UNIMAGINATIVE NAMES.
FOR EXAMPLE, SCIENTISTS THINK SPACE IS FULL OF MYSTERIOUS, INVISIBLE MASS. SO WHAT DO THEY CALL IT? "DARK MATTER"! DUHH! I TELL YOU, THERE'S A FORTUNE TO BE MADE HERE!
I LIKE TO SAY "QUARK." QUARK, QUARK, QUARK, QUARK!
INSTEAD OF MAKING AN IDIOT OF YOURSELF, WHY DON'T YOU GO FIND ME SOME SCIENTISTS?

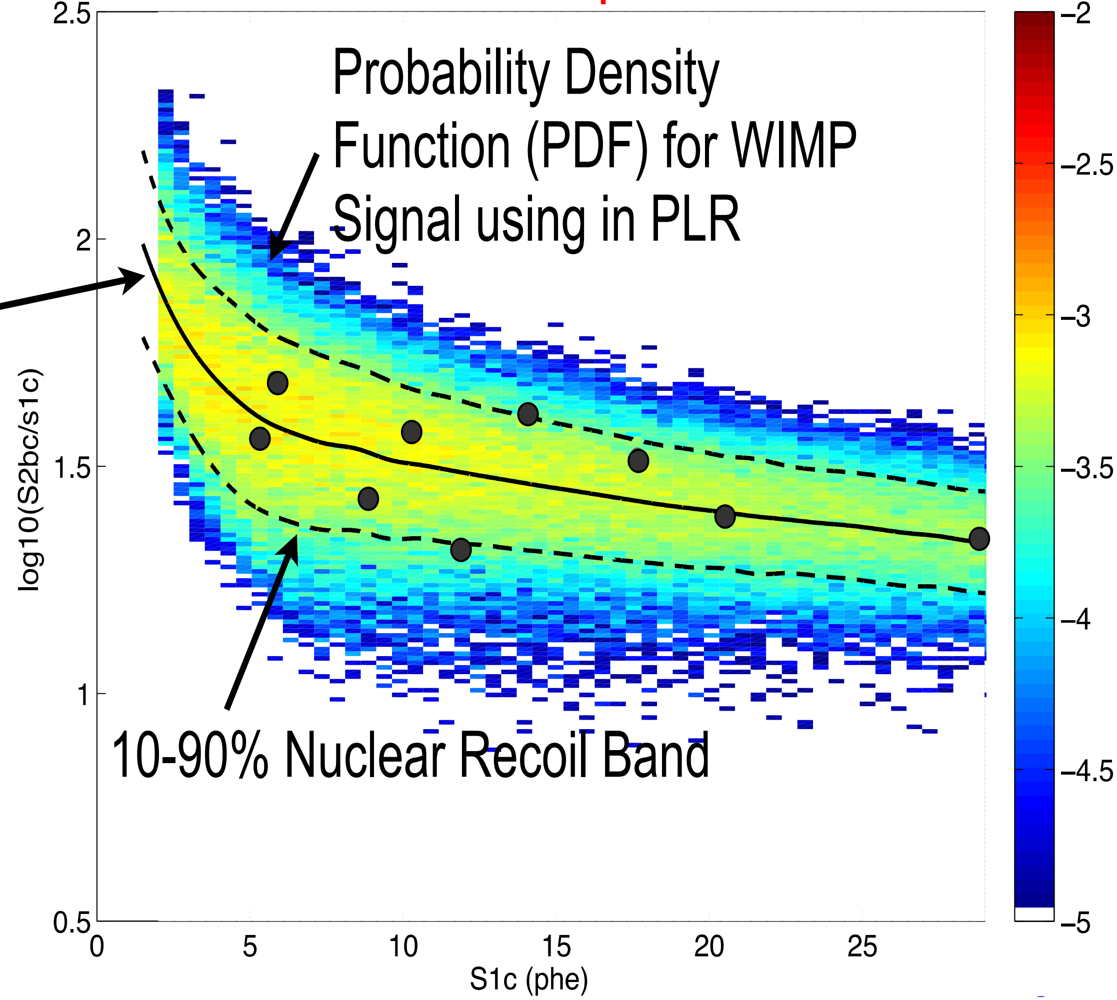

DENNIS the MEN
"LOTS OF THINGS ARE INVISIBLE, BUT WE DON'T KNOW HOW MANY BECAUSE WE CAN'T SEE THEM."

THANKS!

1000 GeV Signal a la Xenon-100

- Pick a mass of 1000 GeV and cross section at the existing XENON100 90% CL Sensitivity 1.9×10^{-44} cm^2 - Would expect 9 WIMPs in LUX Search

Conservatively assume no signal generated for recoils < 3 keVnr to reflect lowest energy for which NR calibration is available.



8.6 GeV Signal a la CDMS Si

- At a mass of 8.6 GeV and cross section favored CDMS II Si (2012) cross section 2.0x10-41 cm2 - Expect 1550 WIMPs in LUX Search

Conservatively assume no signal generated for recoils < 3 keVnr to reflect lowest energy for which NR calibration is available.