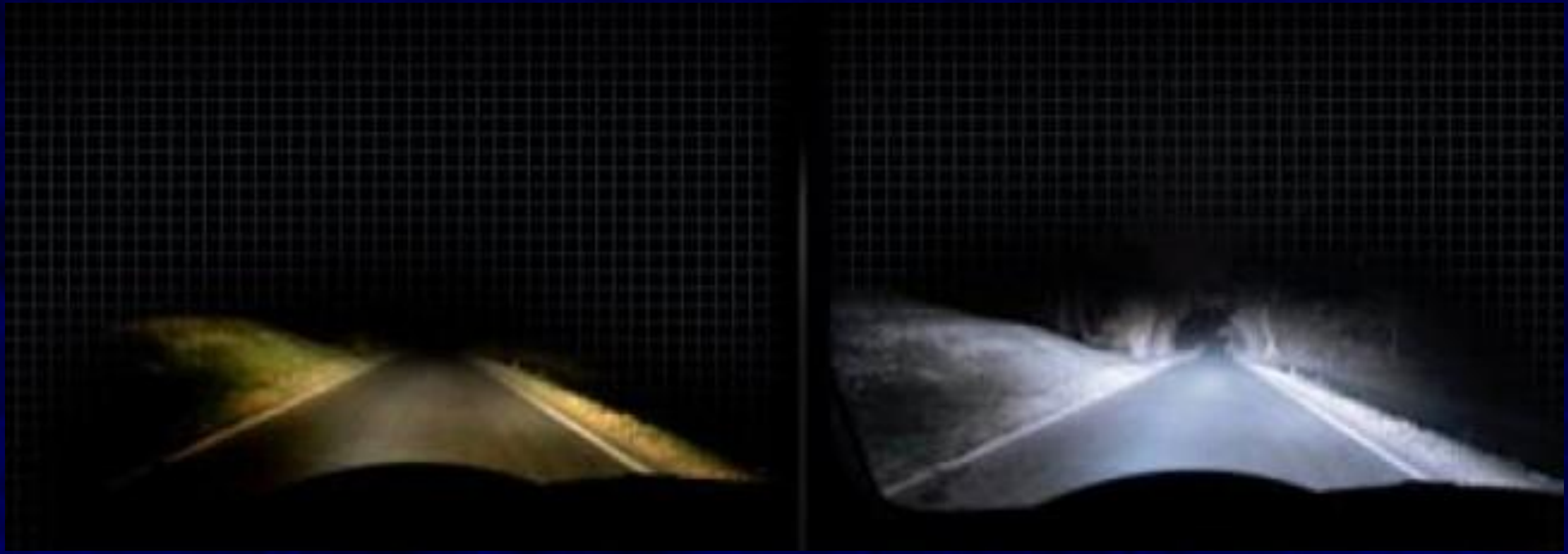
Better Systematics in

XENON100

and Better Statistics with

XENON1T



Rafael F. Lang, Purdue University (rafael@purdue.edu)

KITP Santa Barbara, May 13, 2013

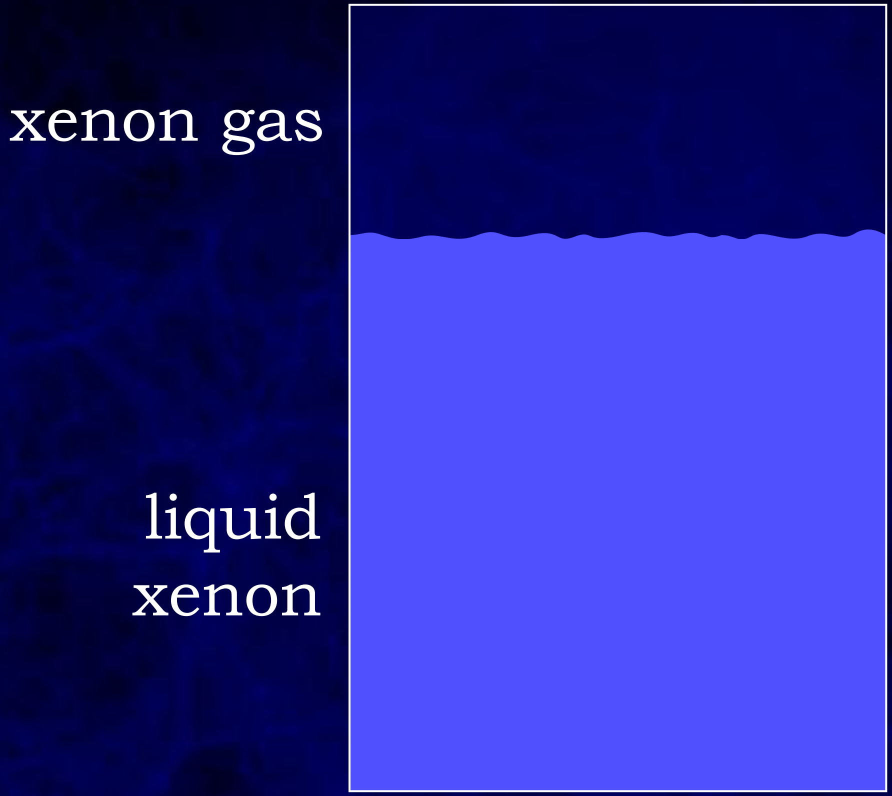
The XENON Collaboration

50% of capital cost
from NSF – thanks!

100 scientists from 16 institutions:

University of California Los Angeles
Rice University Houston
Purdue University
Columbia University New York
Universidade de Coimbra
Subatech Nantes
NIKHEF Amsterdam
Universität Bern
Willhelms Universität Münster
J. Gutenberg-Universität Mainz
Max-Planck-Institut für Kernphysik
Universität Zürich
Laboratori Nazionali del Gran Sasso
INFN e Università di Bologna
Weizman Institute Rehovot

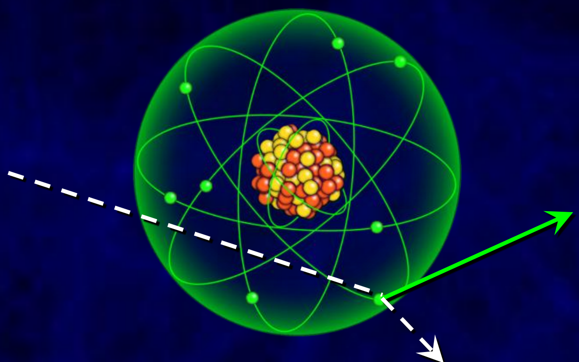
Let’s Build a Xenon Detector



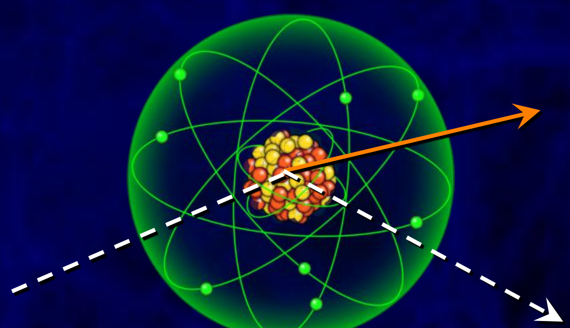
Detect the Recoil

transfer most momentum when masses match:

e^-/γ: electronic recoil

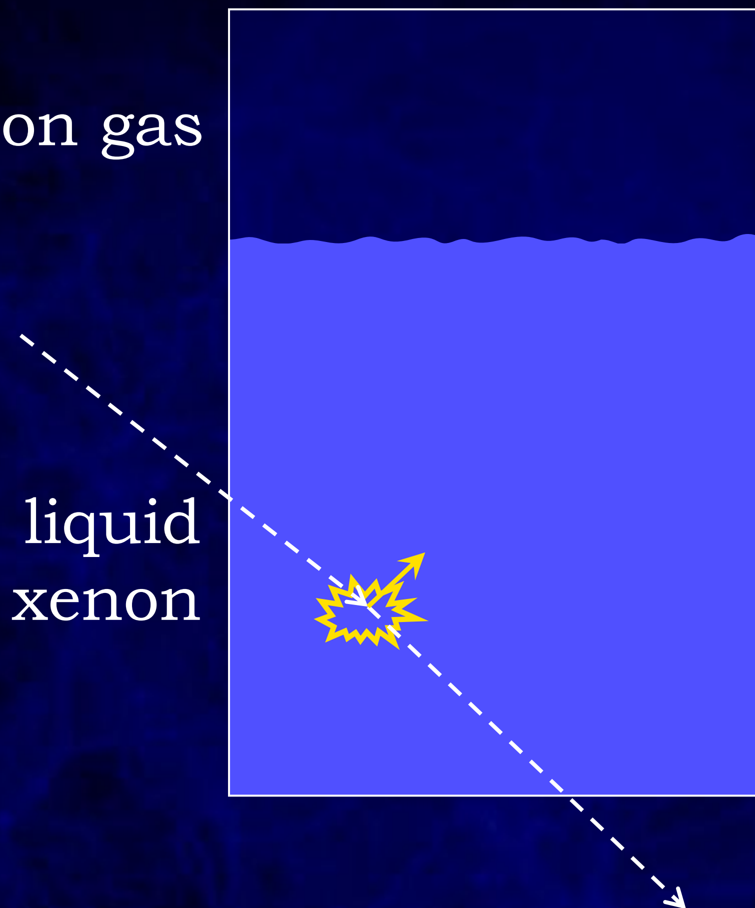


α/n/WIMP: nuclear recoil



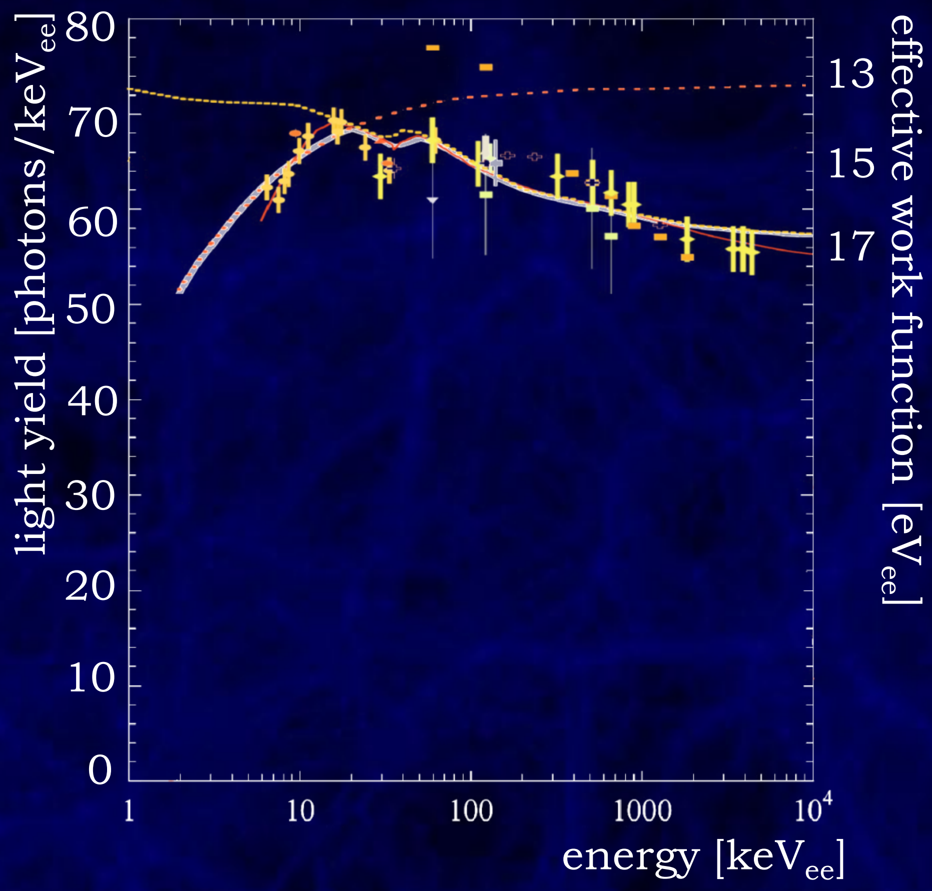
xenon gas

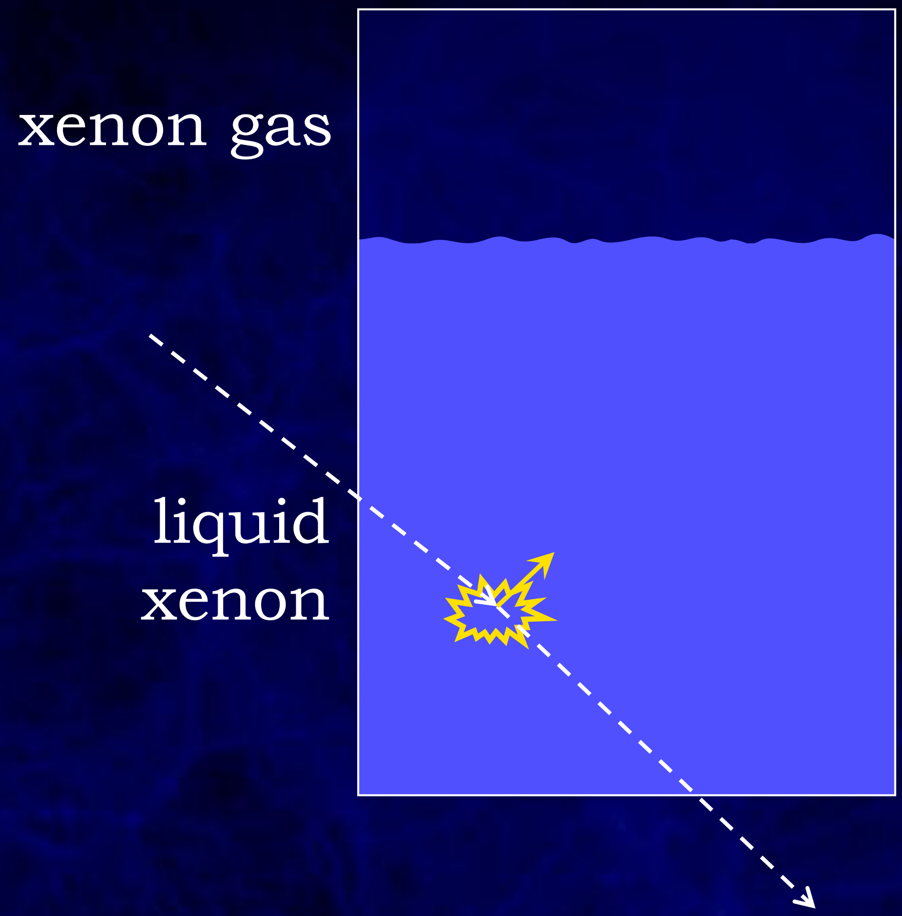
liquid xenon



Signal generation: Ionization

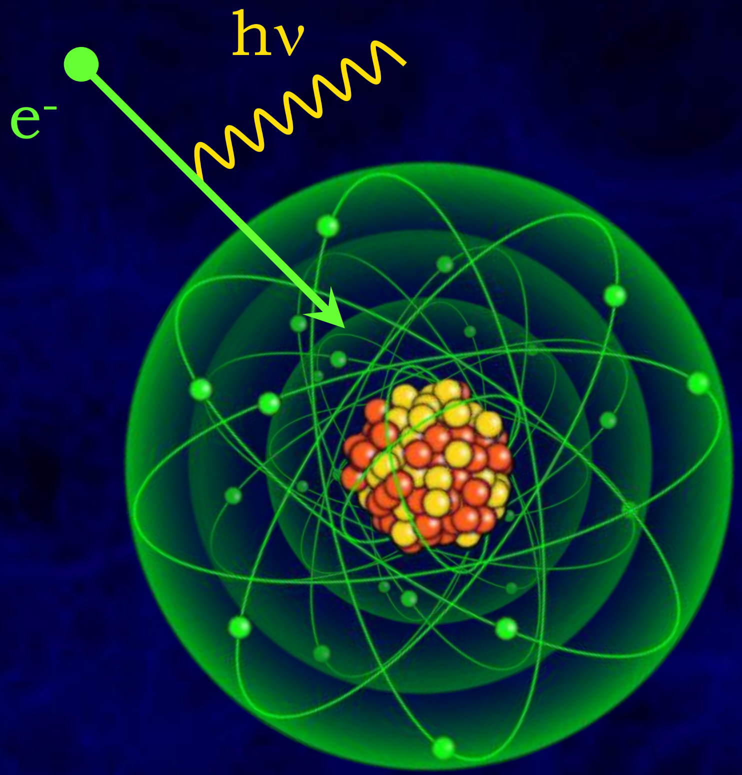
creation of electron-ion pair requires ~15 eV_{ee}

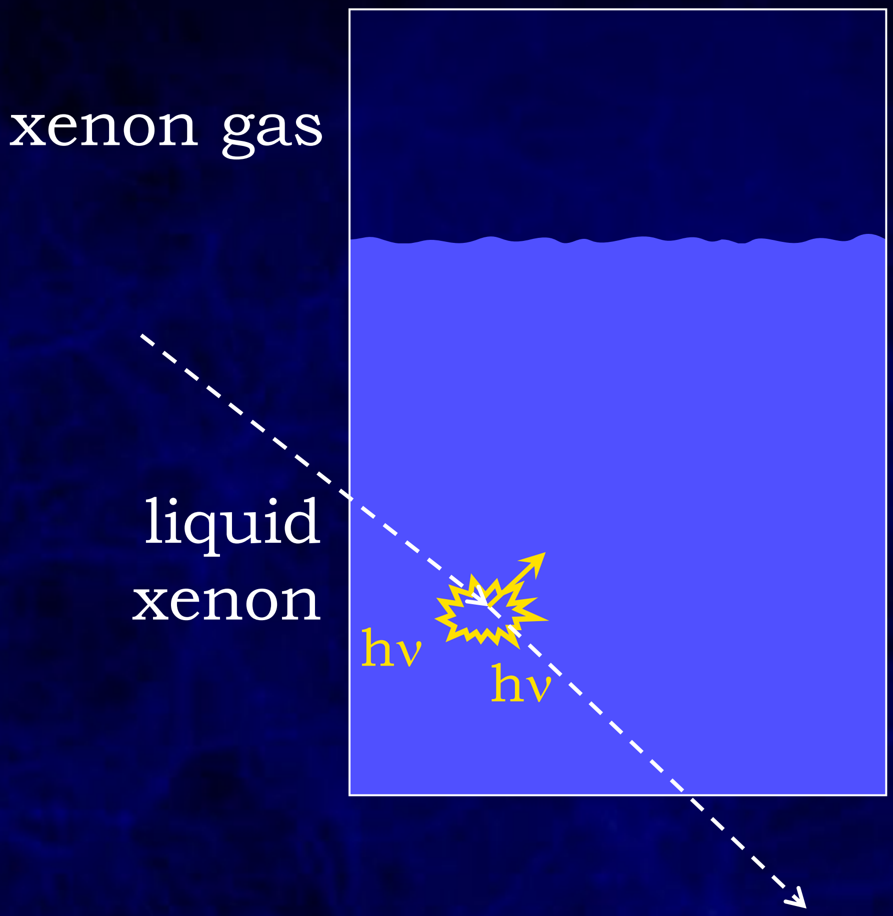




see Szydagis et al., JINST 6 10002 (2011) and refences therein

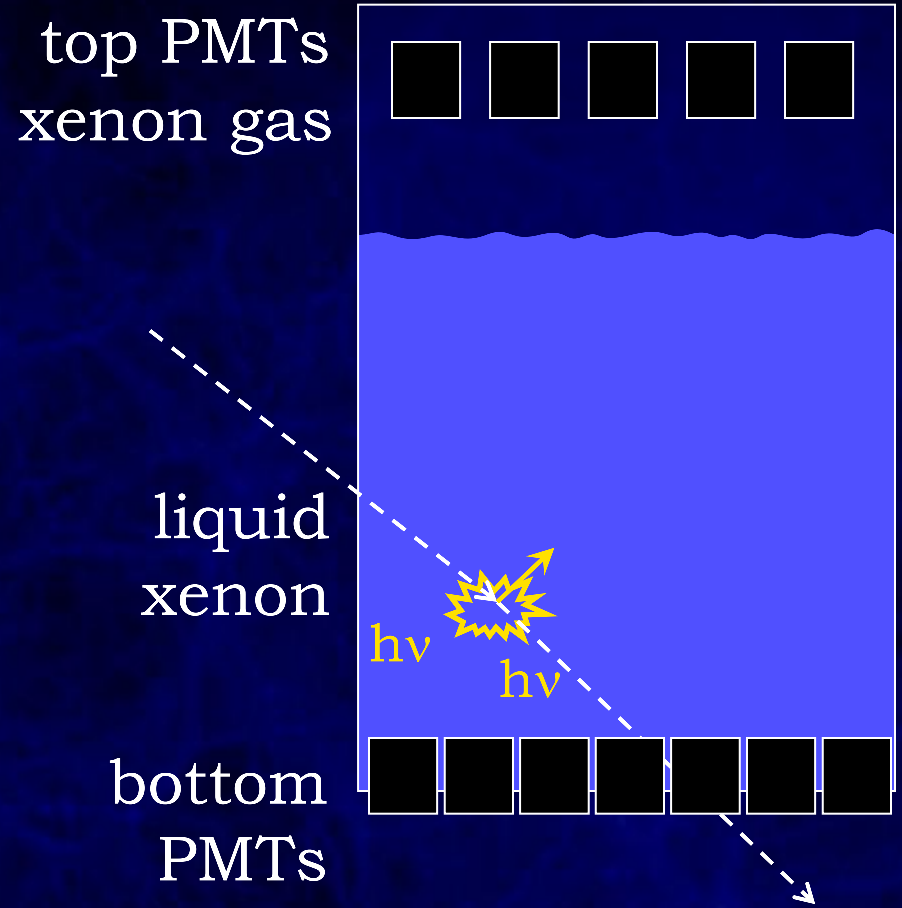
Recombination Gives Scintillation

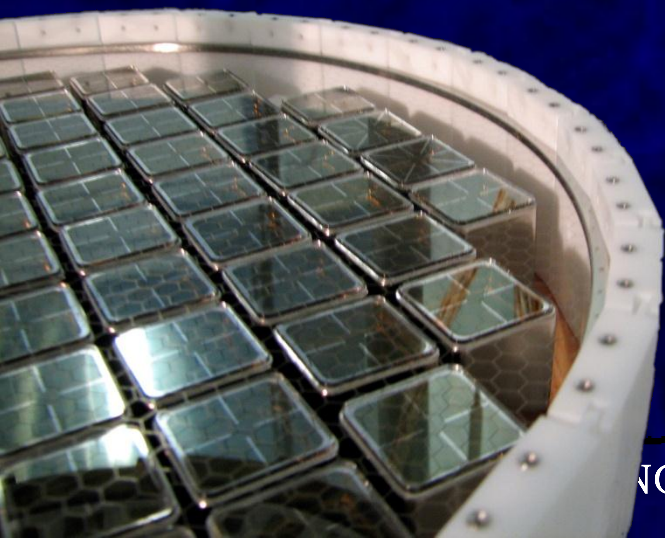




PMT Arrays

98 PMT
top array

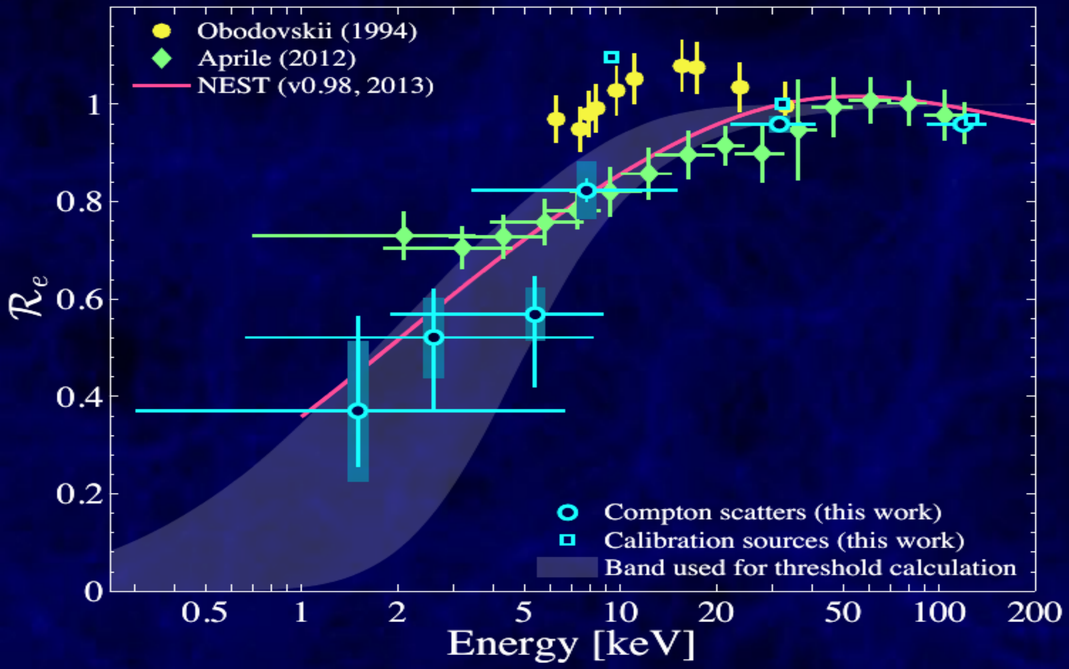


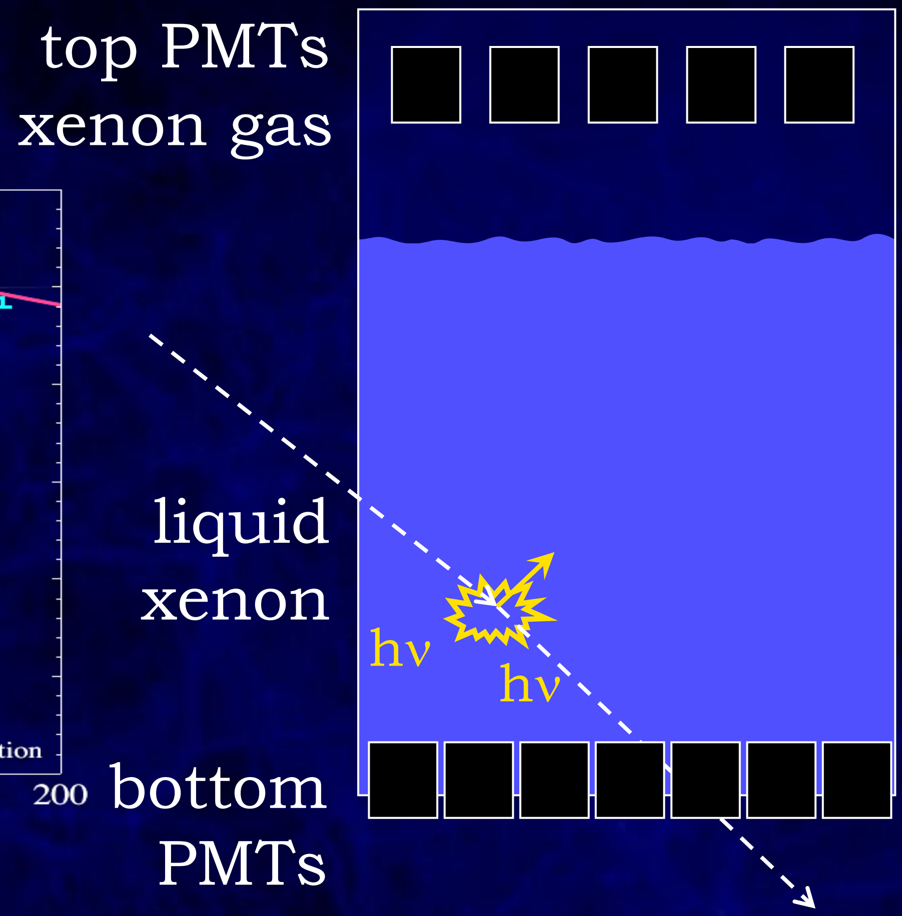


80 PMT
bottom
array

Xenon Electronic Recoil Light Yield

relative measurement
in zero-field
to below 2keV$_{ee}$

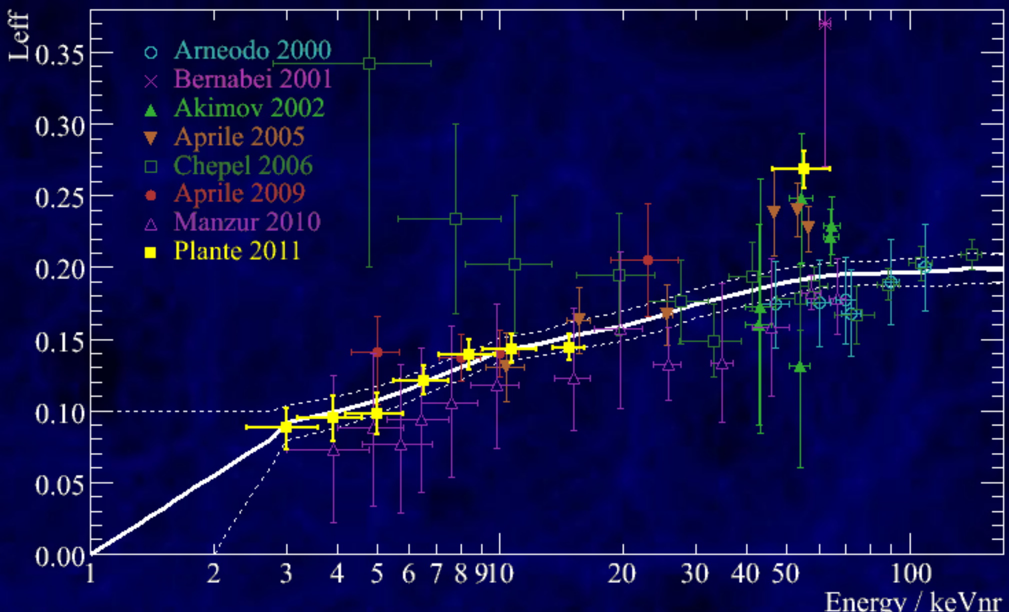




Aprile et al., PRD 86, 112004 (2012),
Baudis et al., arxiv:1303.6891

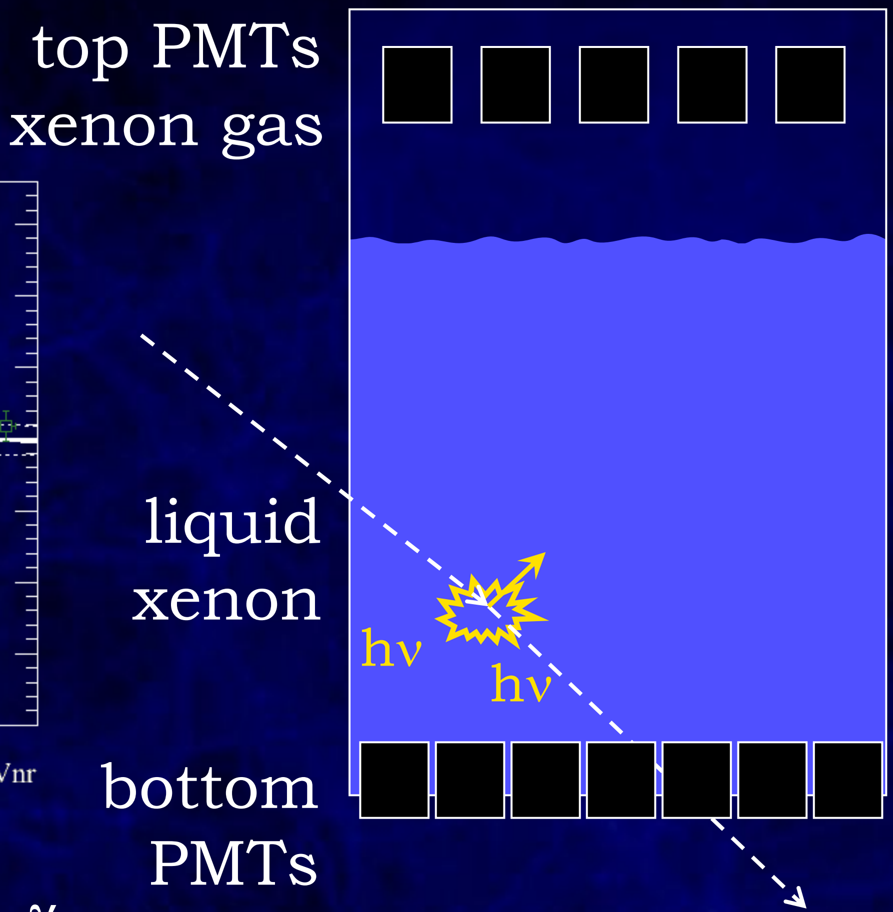
Xenon Nuclear Recoil Light Yield

relative measurement
in zero-field
to below 3keV$_{nr}$

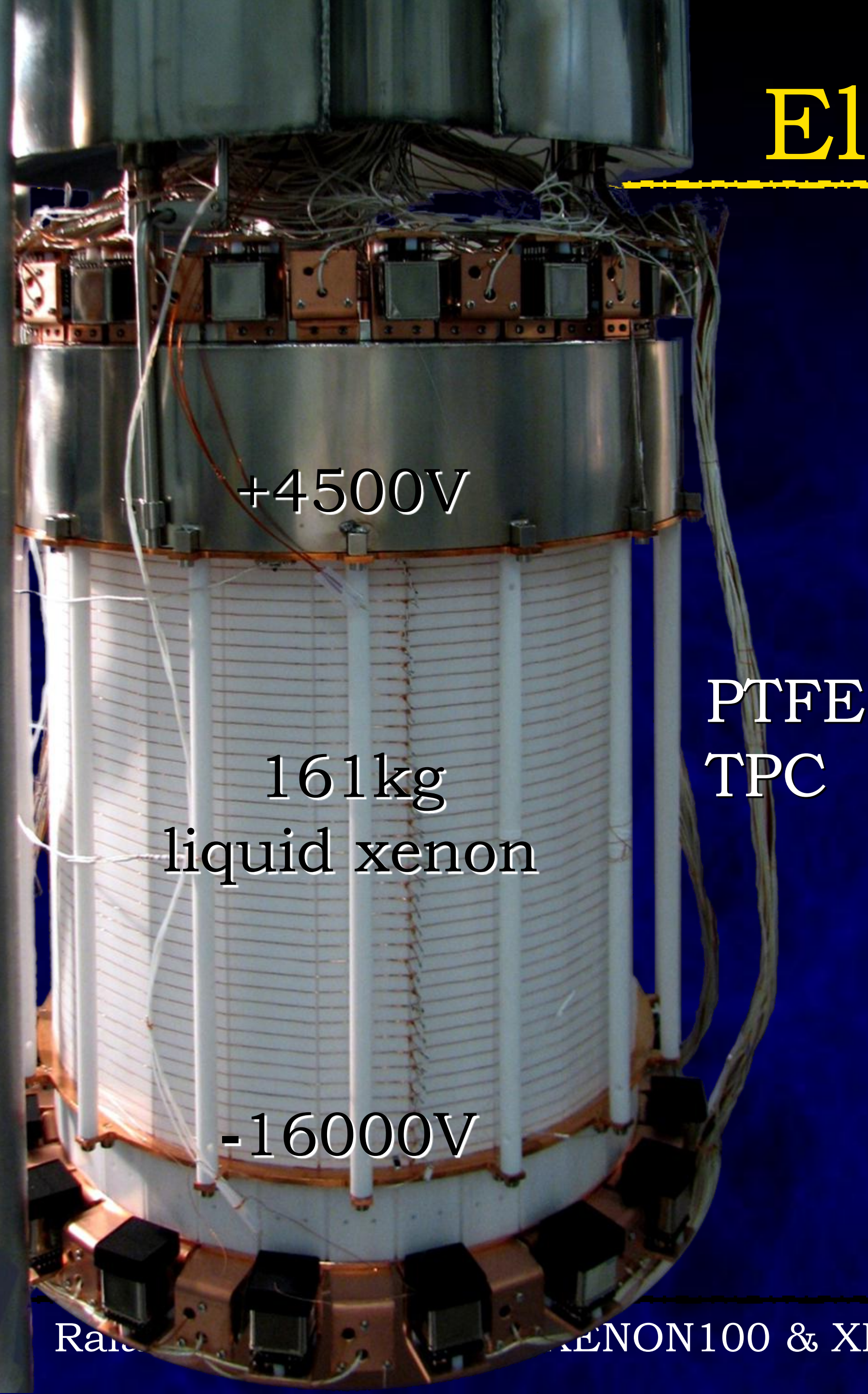


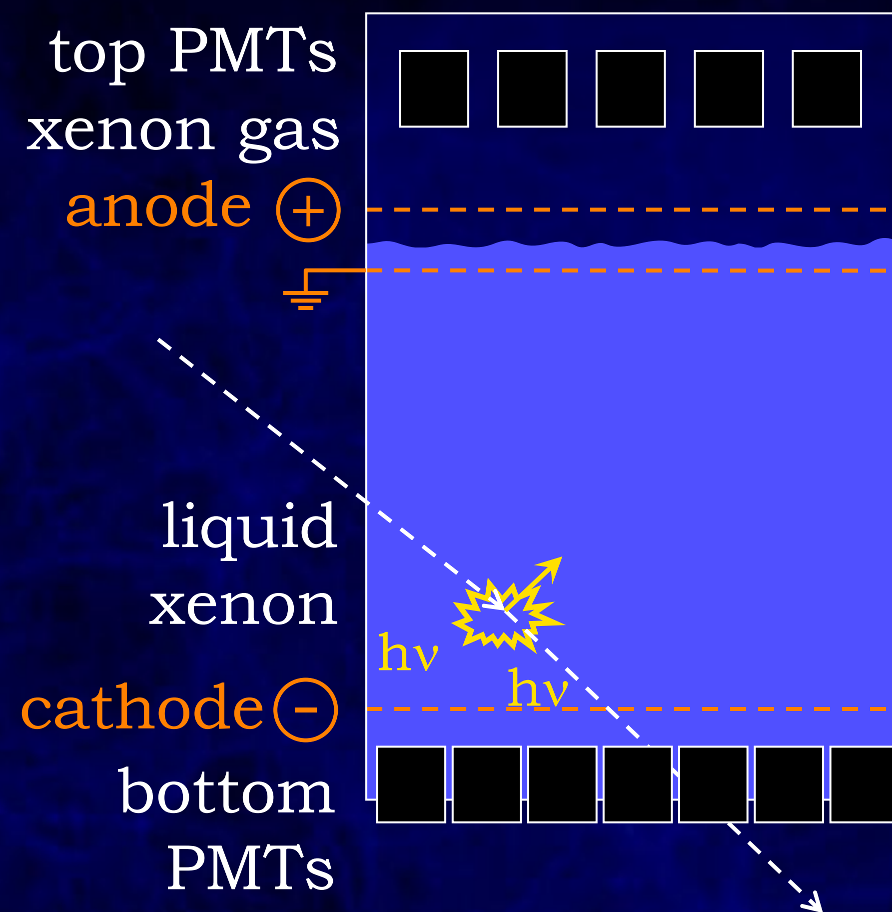
L_{eff} not a quenching factor:
light yield relative to 122keV$_{ee}$ γ

Aprile et al., PRD 86, 112004 (2012)

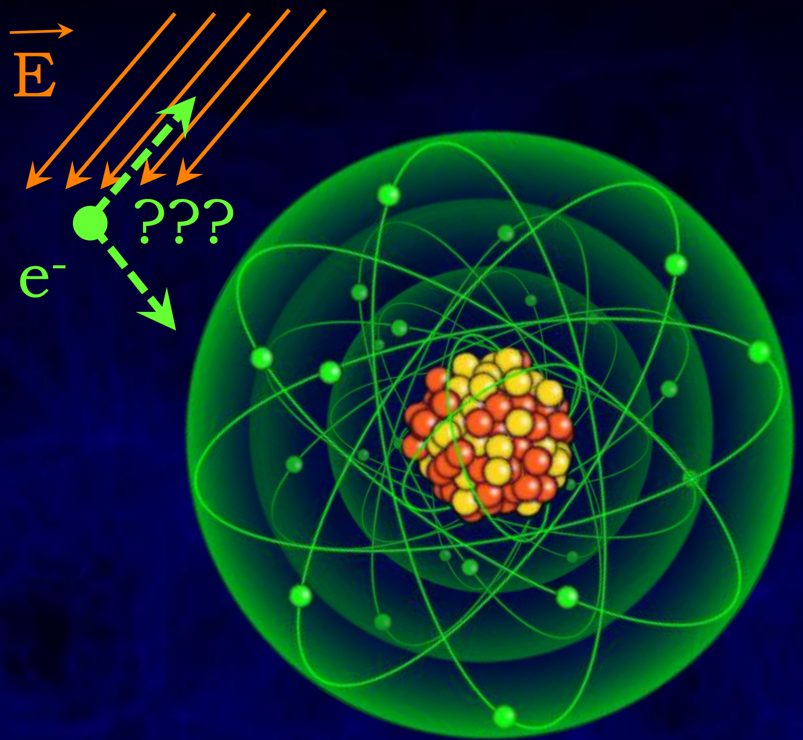


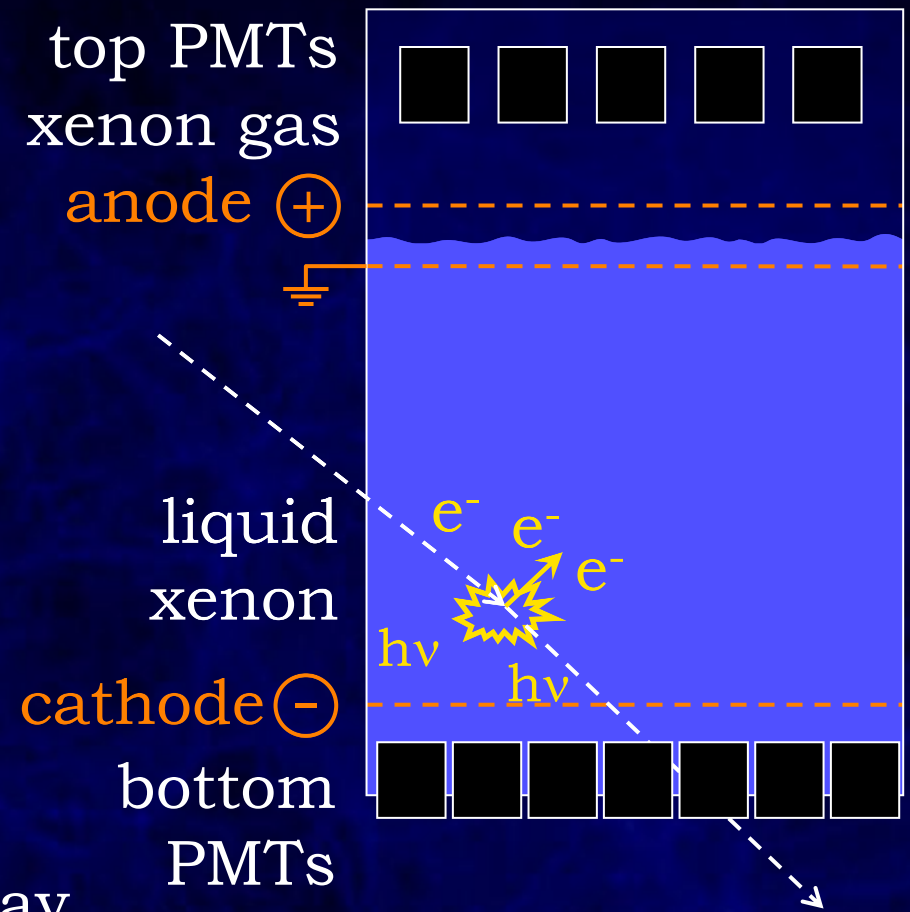
Electric Fields





Recombination - or Not

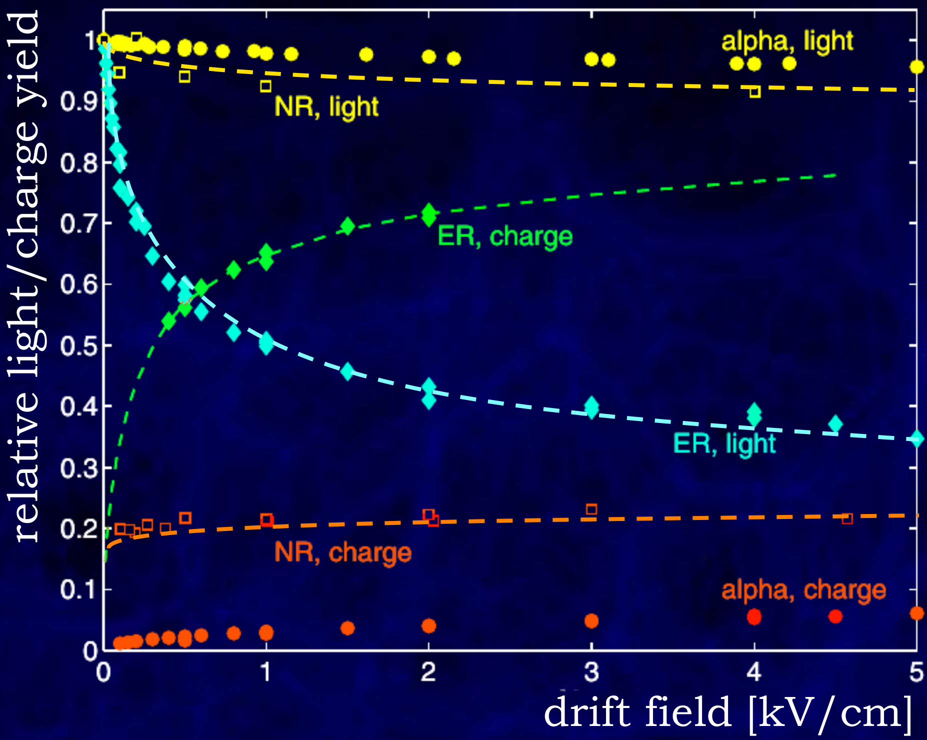


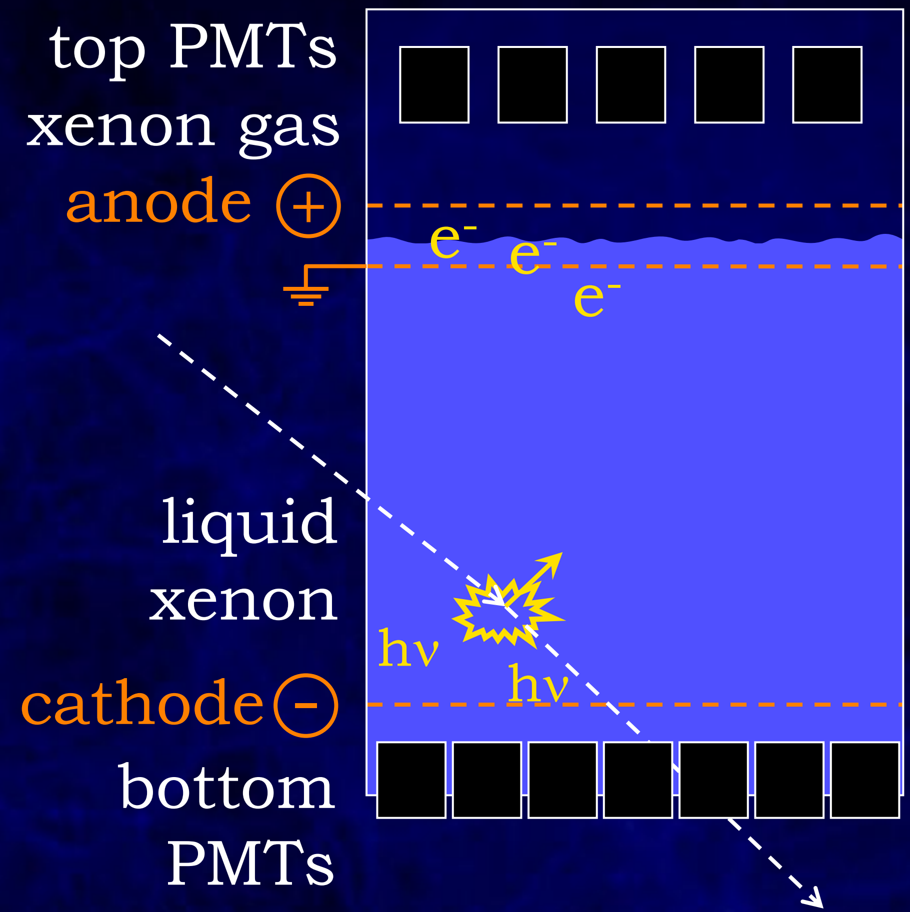


depending on field strength
and ionization density
some electrons get drifted away
and can not recombine

Dependence on Ionization Density

allows discrimination between electronic & nuclear recoils



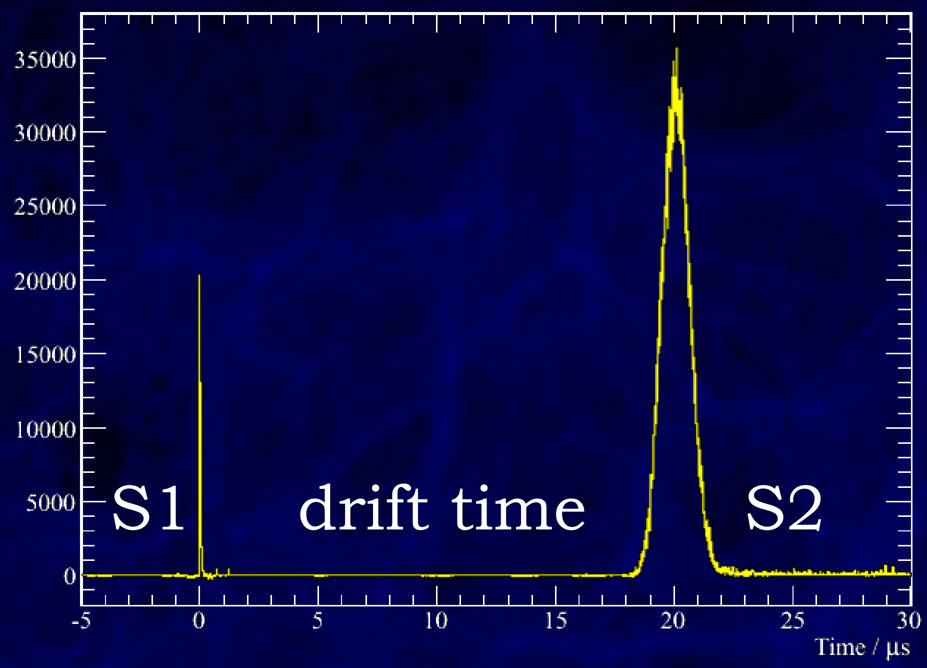


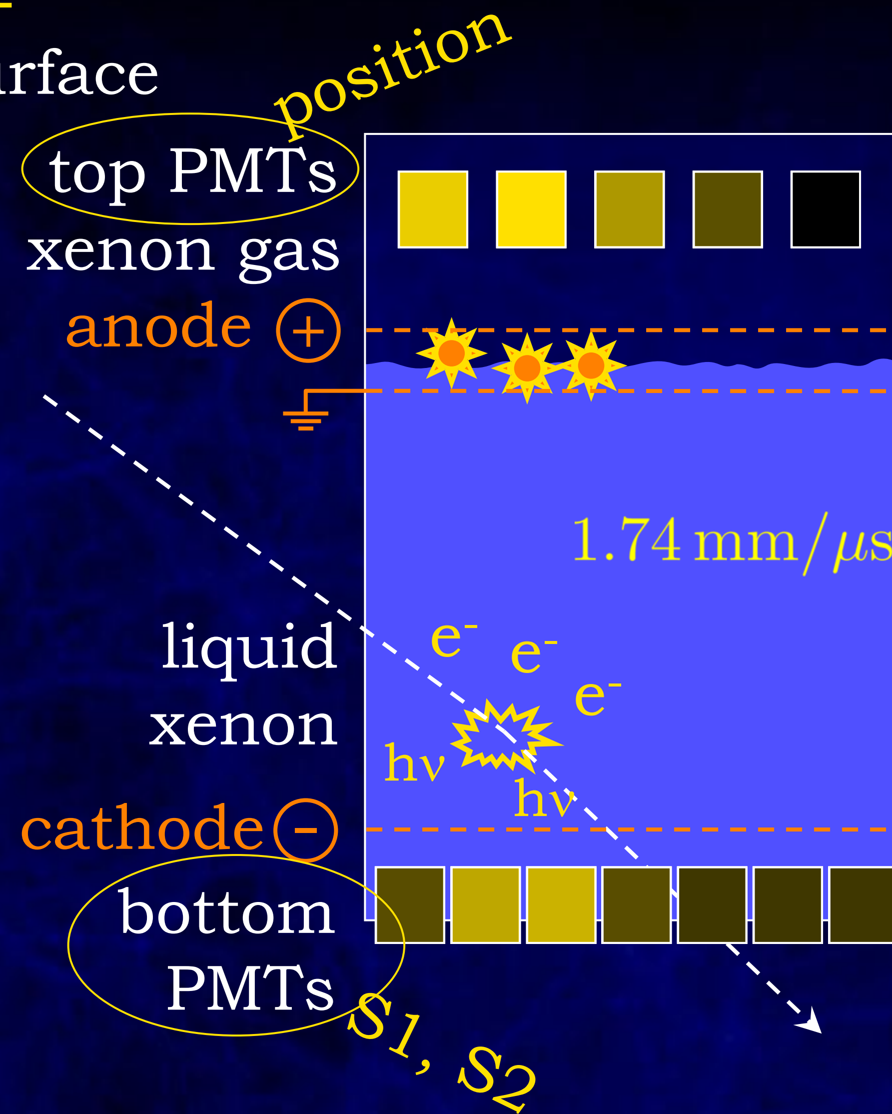
higher drift field
= better discrimination

Aprile et al., PRL 97, 081302 (2006)

3D Vertex Resolution

background interacts near surface
Dark Matter everywhere





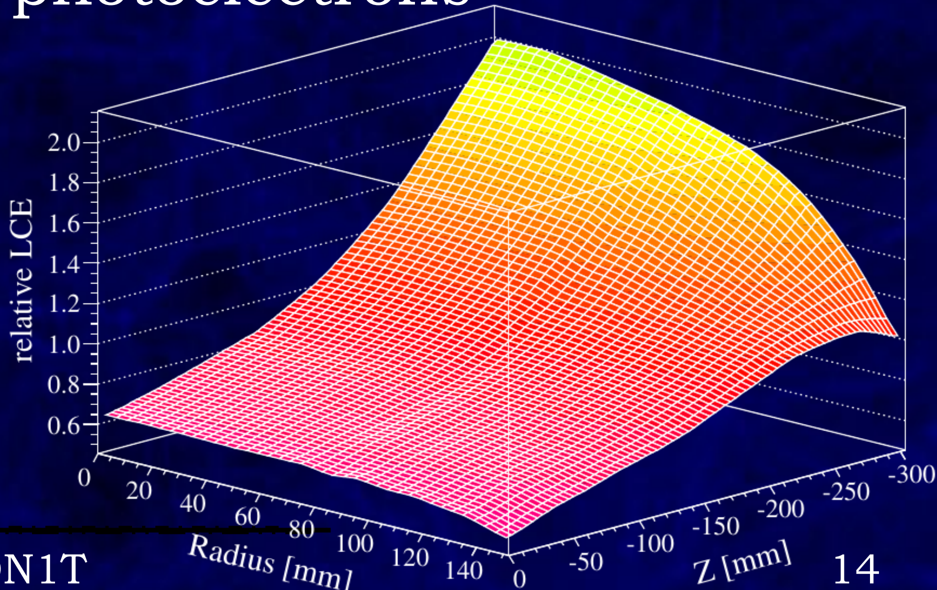
XENON100 resolution
S2 hit pattern: $\delta r < 3\,\mathrm{mm}$
drift time: $\delta z < 300\,\mu\mathrm{m}$

Example: 122keV$_{ee}$ Electronic Recoil

- W = ~15eV
  → produce 8000 e$^-$/ion pairs

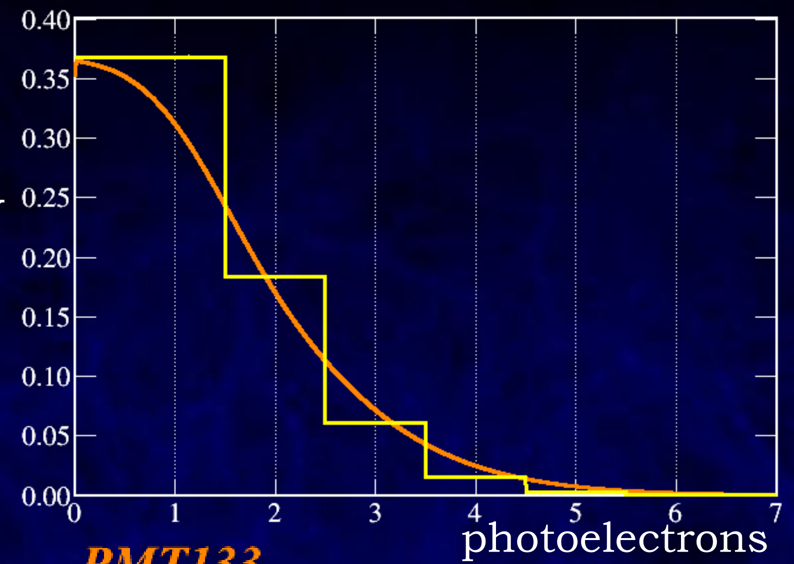
- drift field E = 0.53 kV/cm
  (ER quenching = 0.58)
  → produce 4600 photons

- on average, detect only 278 photoelectrons
  → average light
  collection efficiency 6%
  (light absorption,
  PMT quantum efficiency)



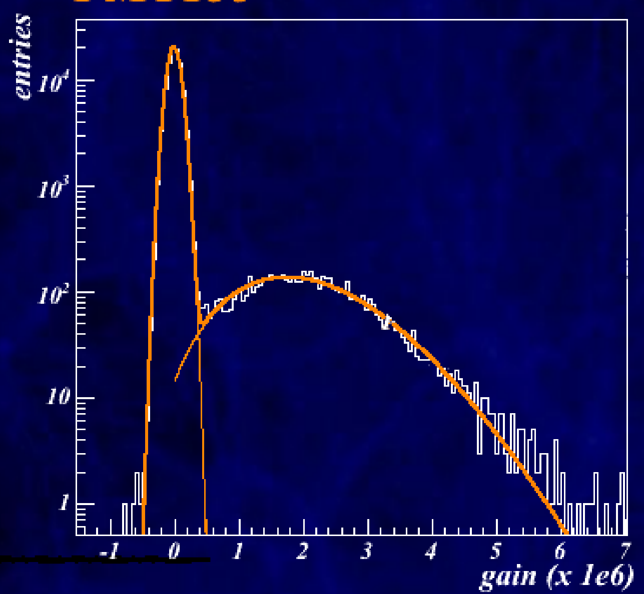
Example: 3keV$_{nr}$ Nuclear Recoil

NR quenching = 0.95, L_{eff} = 0.092
→ produce ~17 photons
detect each with 6% probability
→ Poisson process with
expectation of 1 photoelectron



we do not account for
any recoils below 3keV$_{nr}$

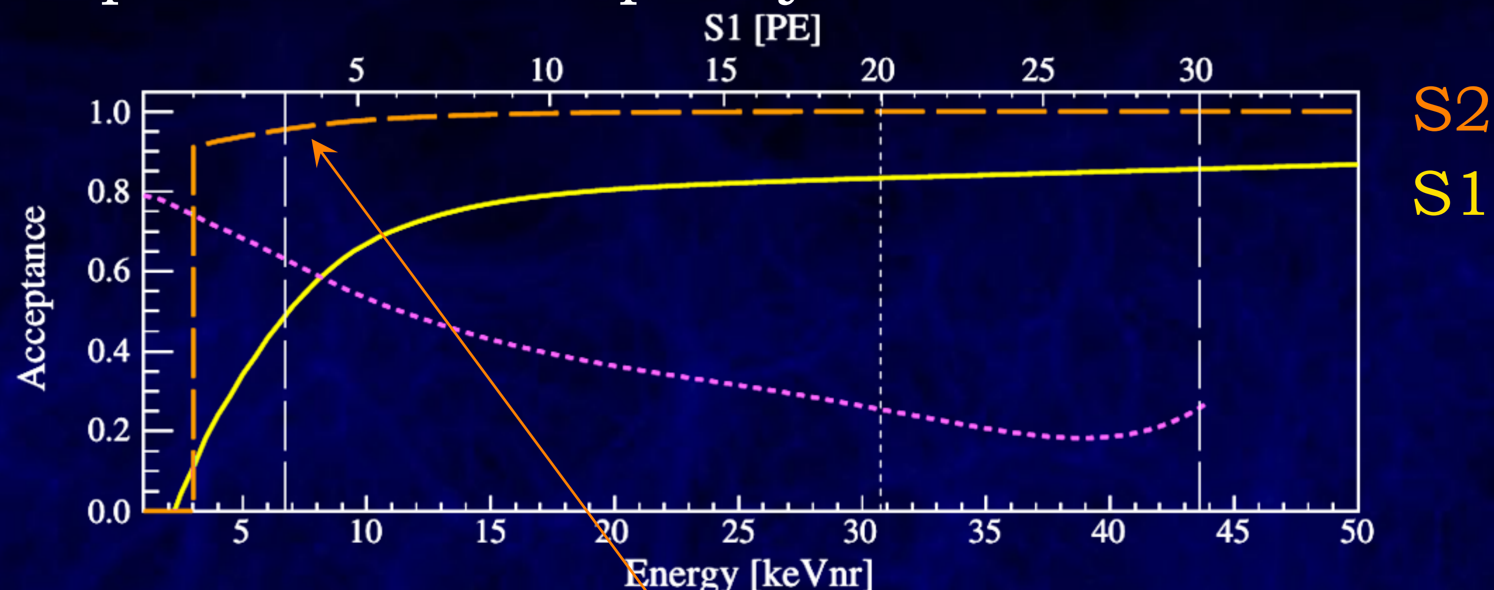
PMT133



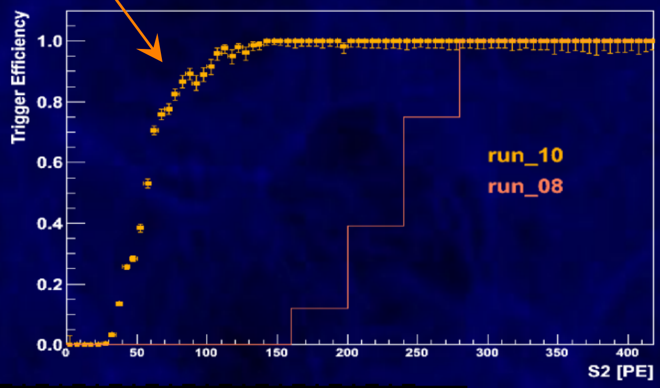
convert integer
photoelectrons to floating-
valued signal: PMT resolution
(Gaussian, σ=½)

Cut Acceptances

finite acceptances of data quality cuts:

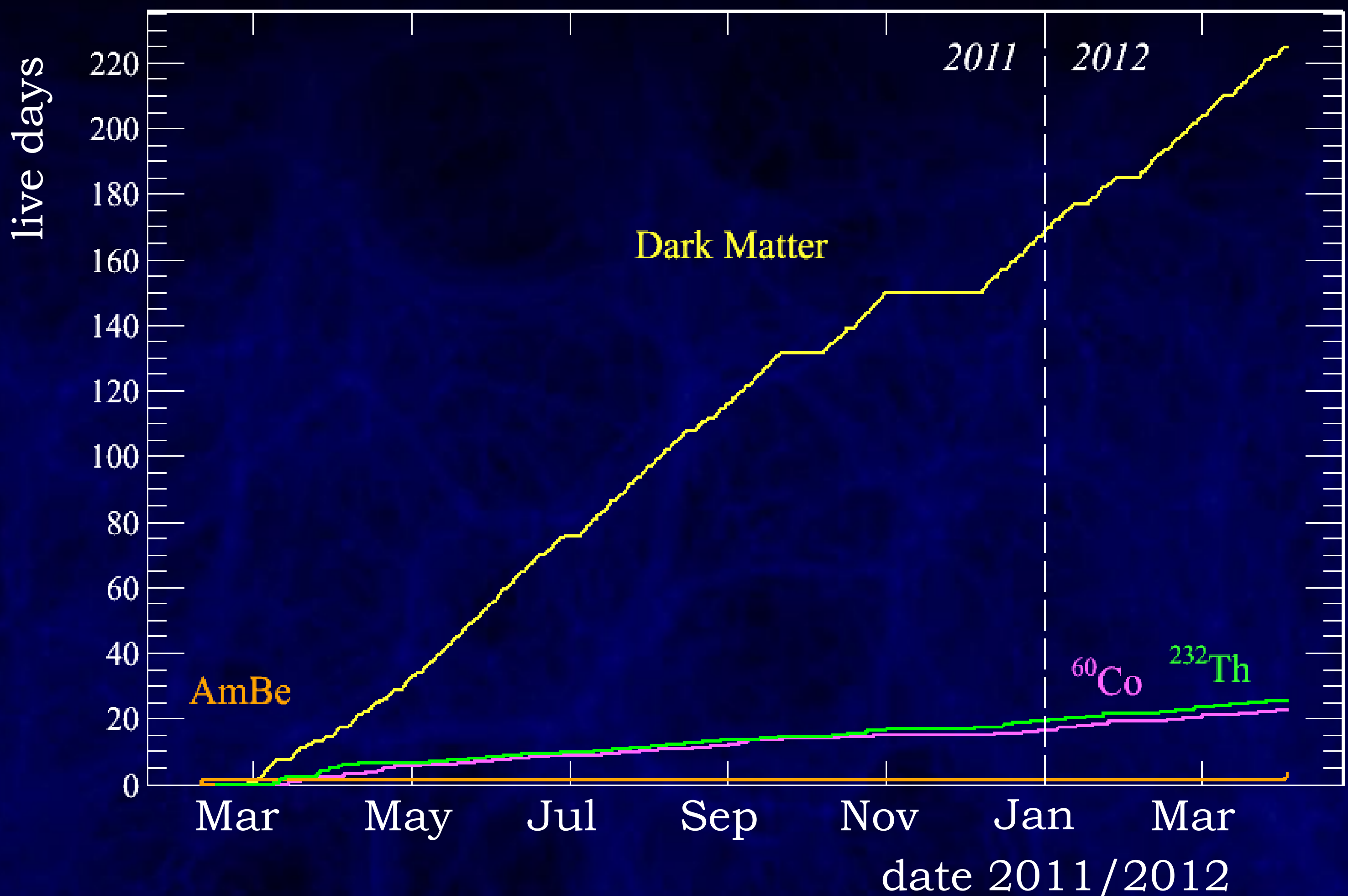


note: S1 and S2 signals fluctuate independently: consider S2 acceptance before S1 fluctuations



XENON100, PRL 109, 181301 (2012)

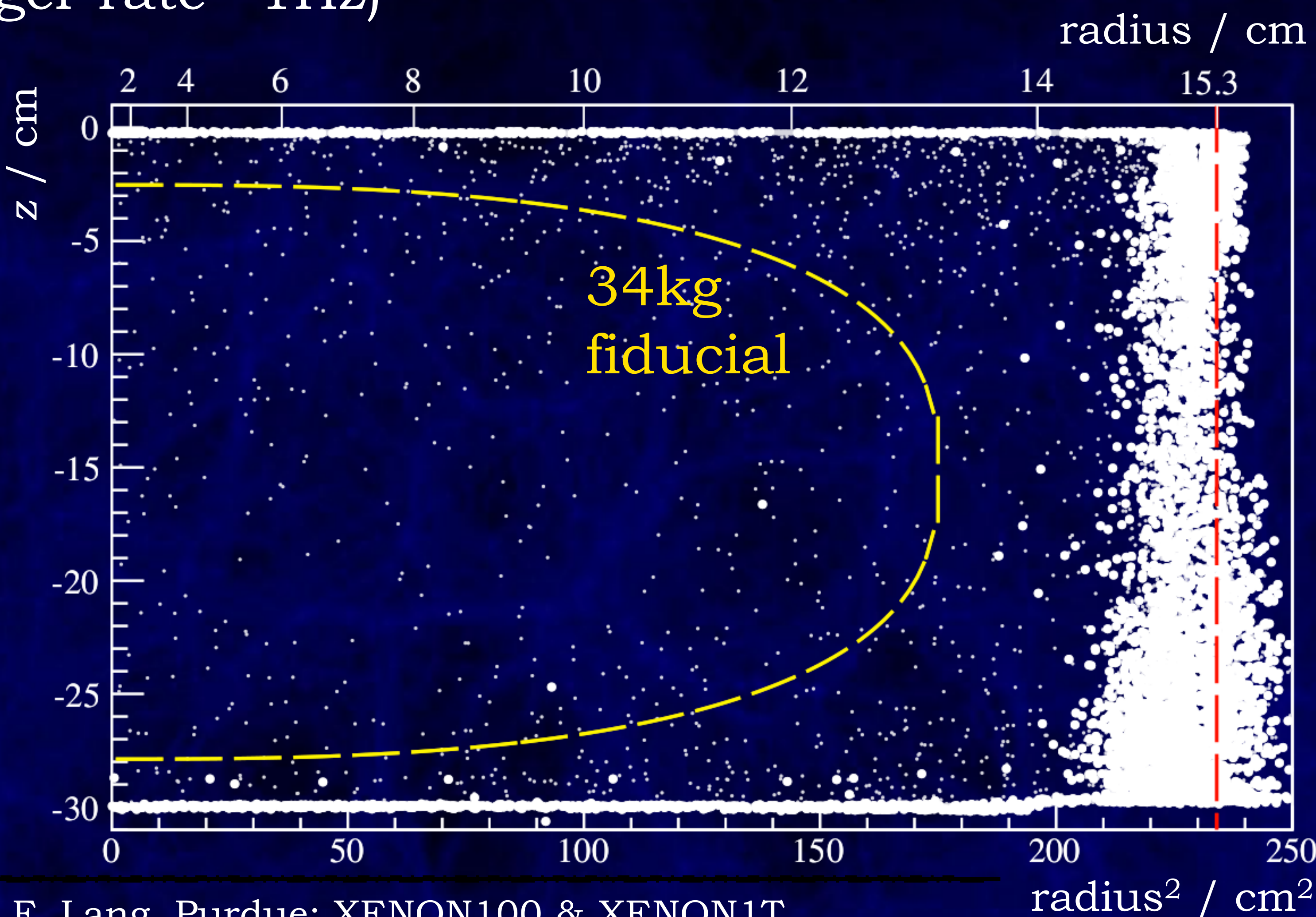
Run10 Data: 225 Live Days!



raw exposure 7650 kg · d

The Power of Fiducialization

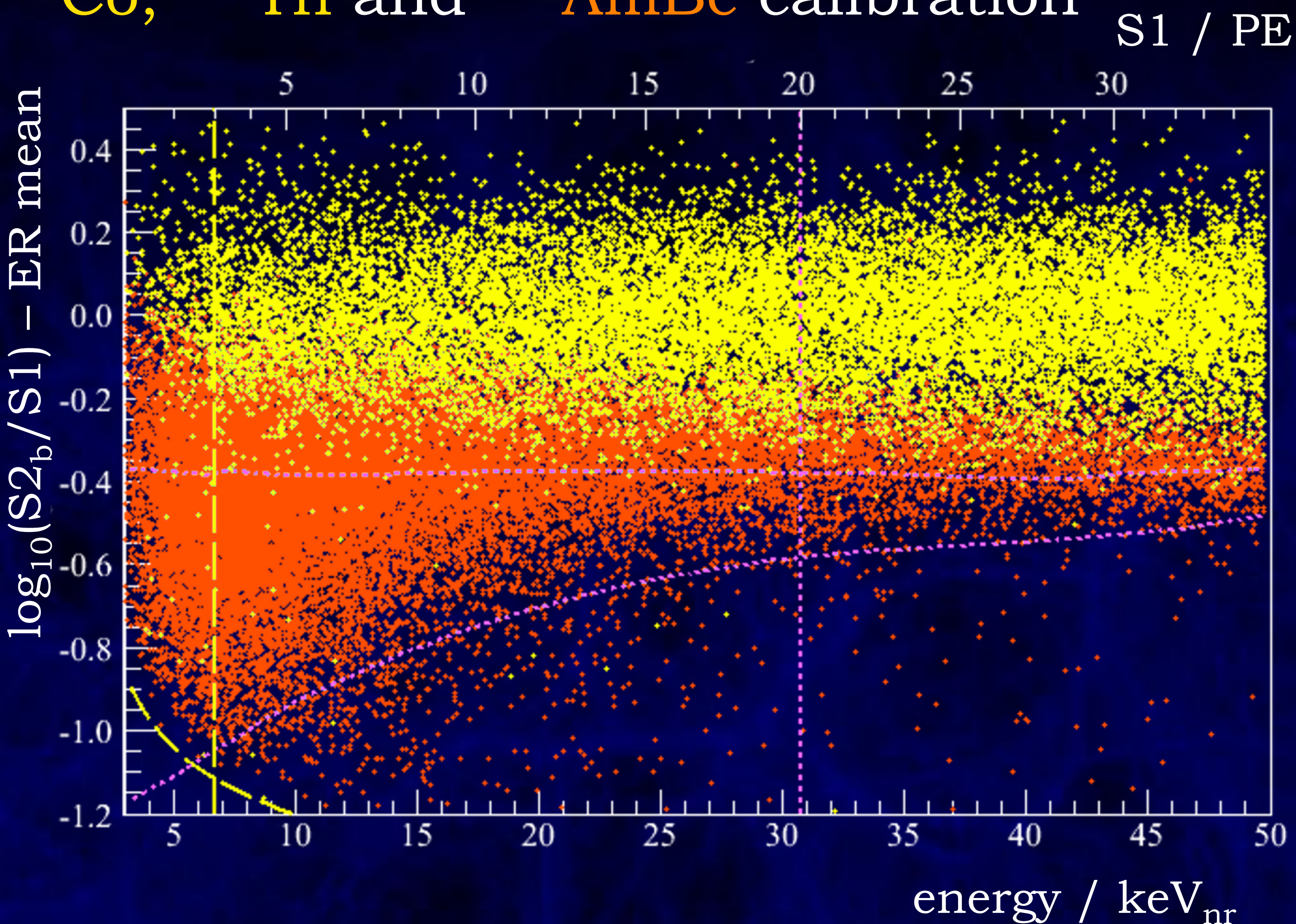
events after 225 live days of data taking 2011/2012:
(trigger rate ~1Hz)



XENON100, PRL 109, 181301 (2012)

Discrimination using S2/S1

^{60}Co, ^{232}Th and ^{241}AmBe calibration



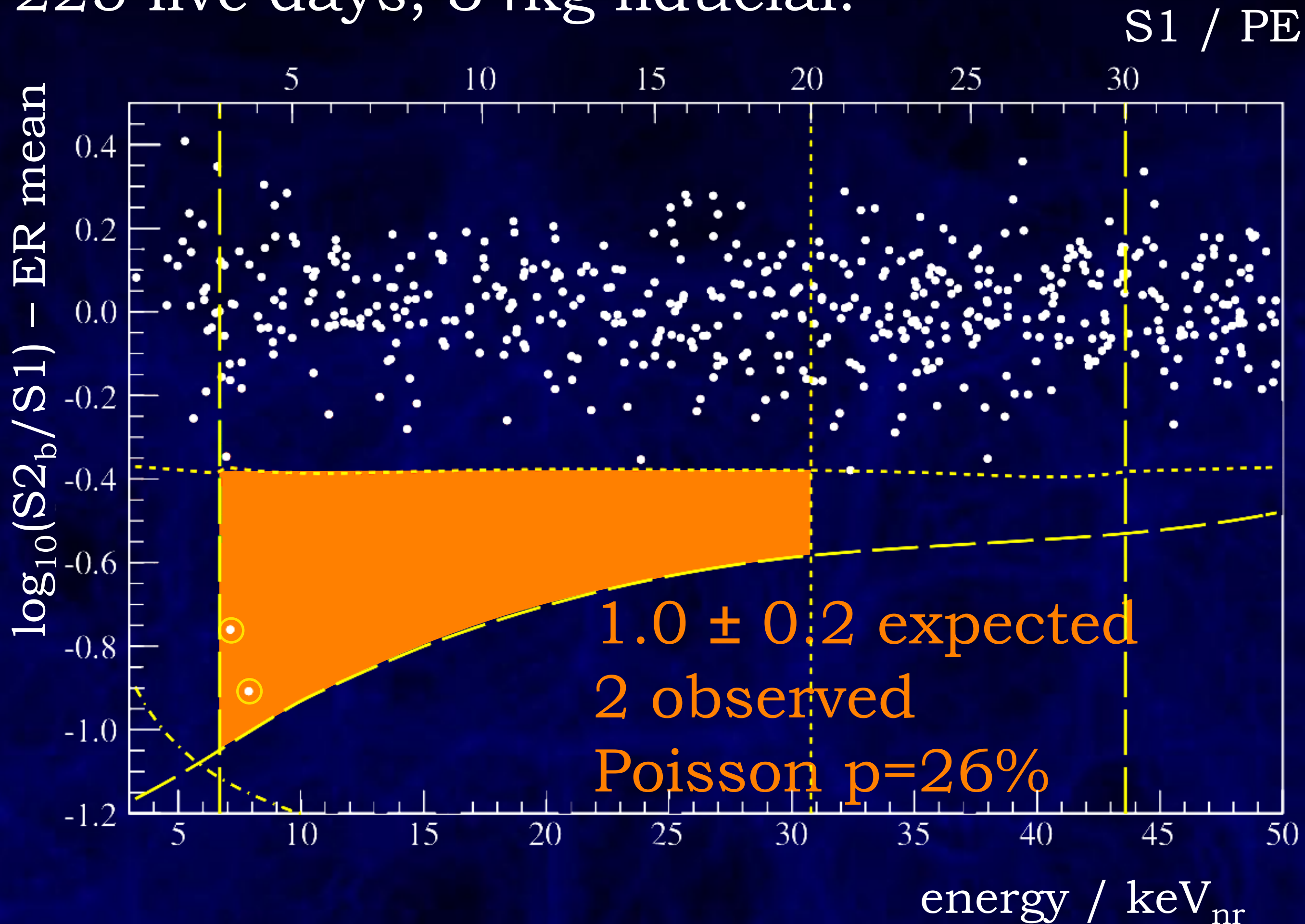
electronic recoils (background)

nuclear recoils (calibration)

~99.5% ER rejection @ 50% NR acceptance

No Signal Observed

225 live days, 34kg fiducial:

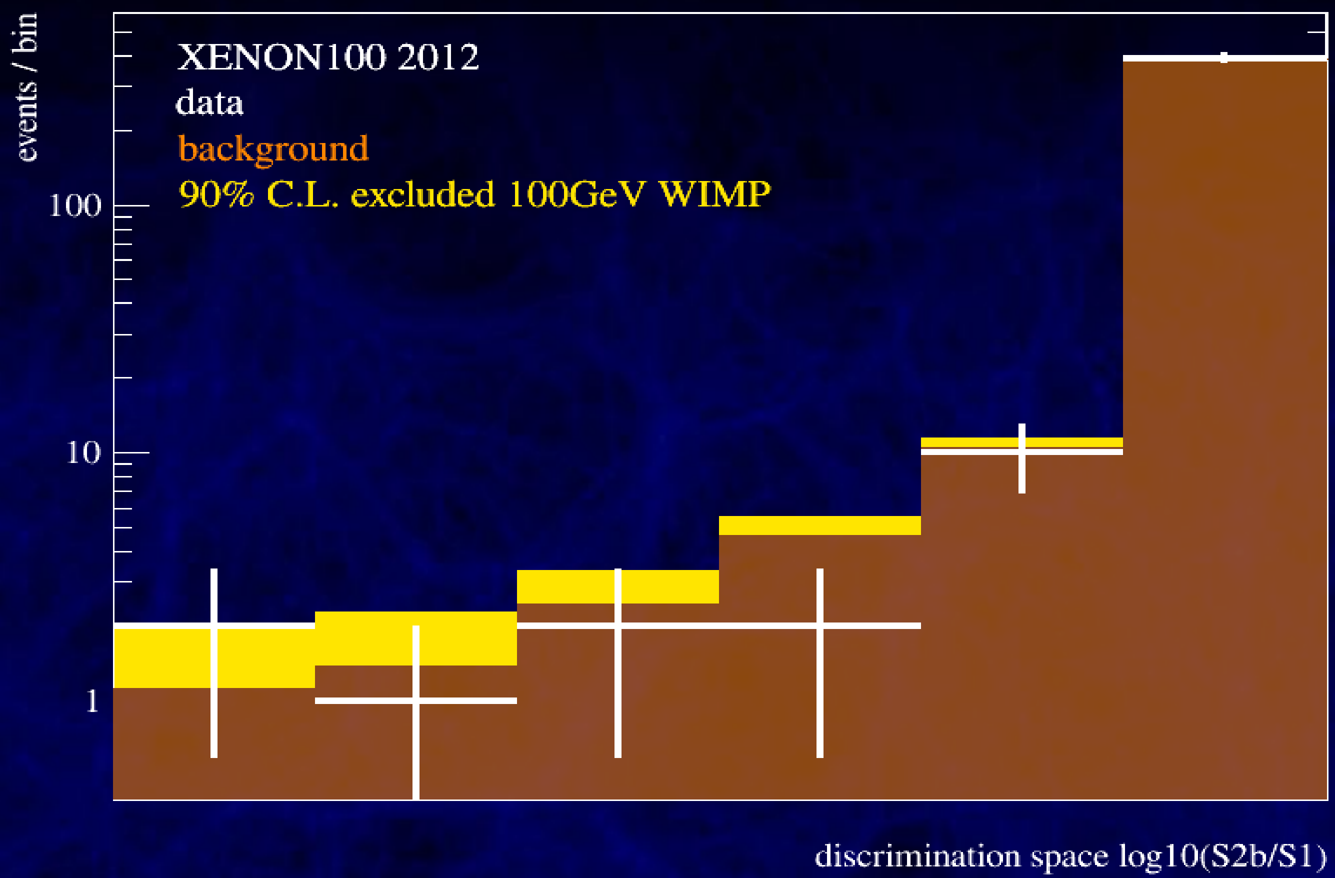


electronic recoils (background)

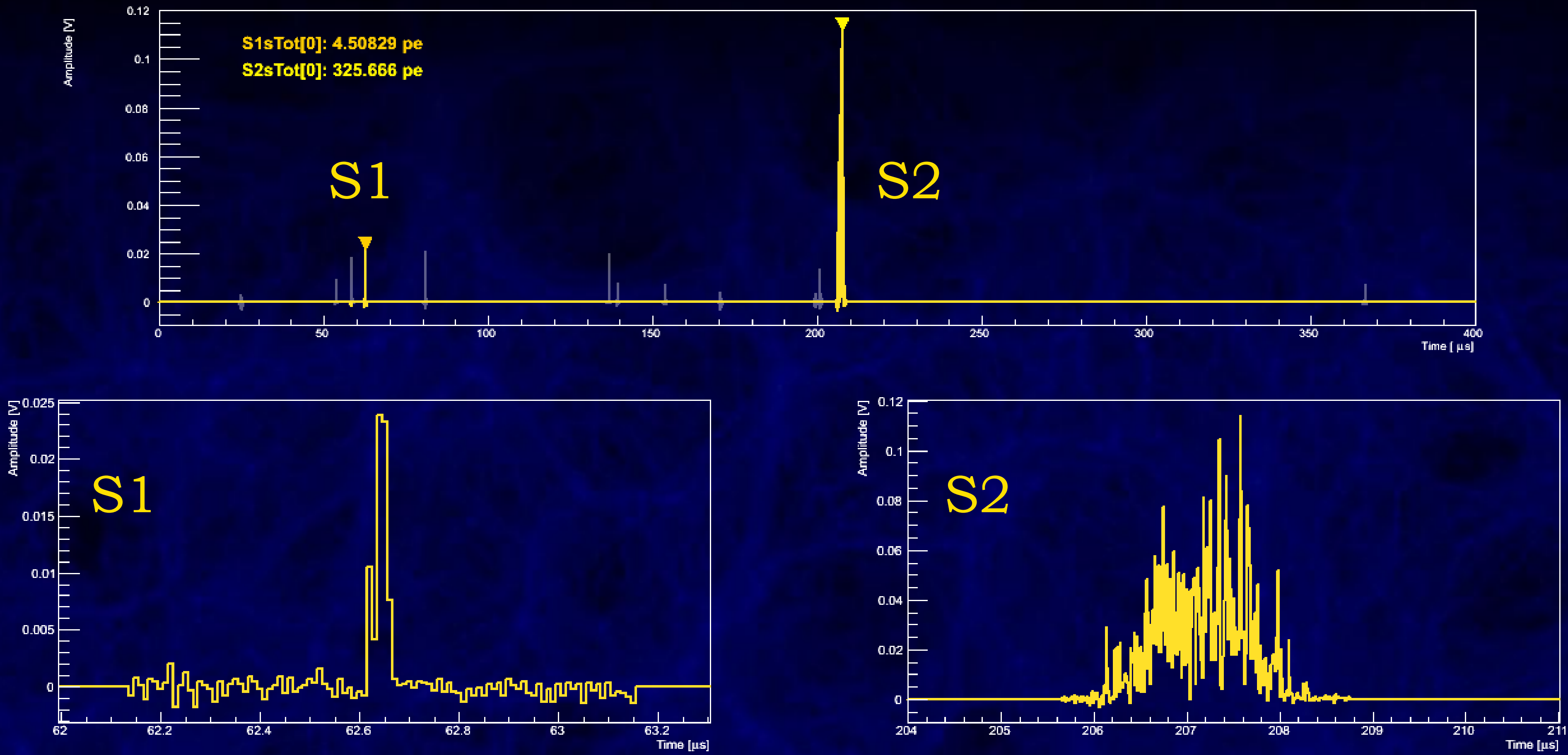
XENON100, PRL 109, 181301 (2012)

likelihood analysis: background-only p-value $> 5\% \; \forall m_\chi$

Projection along Energy



Candidate Event: Waveform

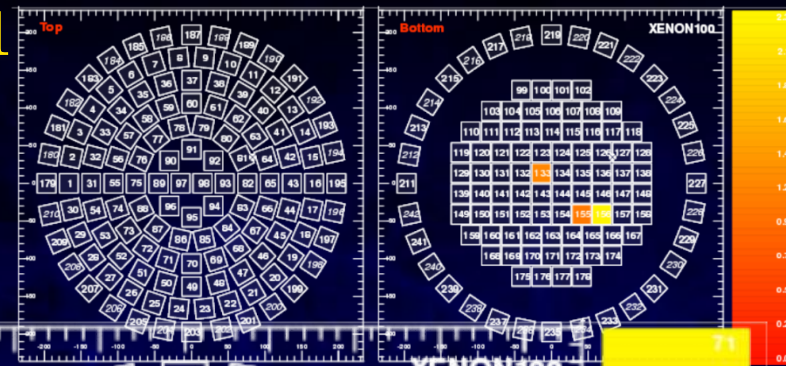


lots of information for each event: S1&S2, energy, pulse shapes, ER/NR, hit patterns, 3D vertex, multiples

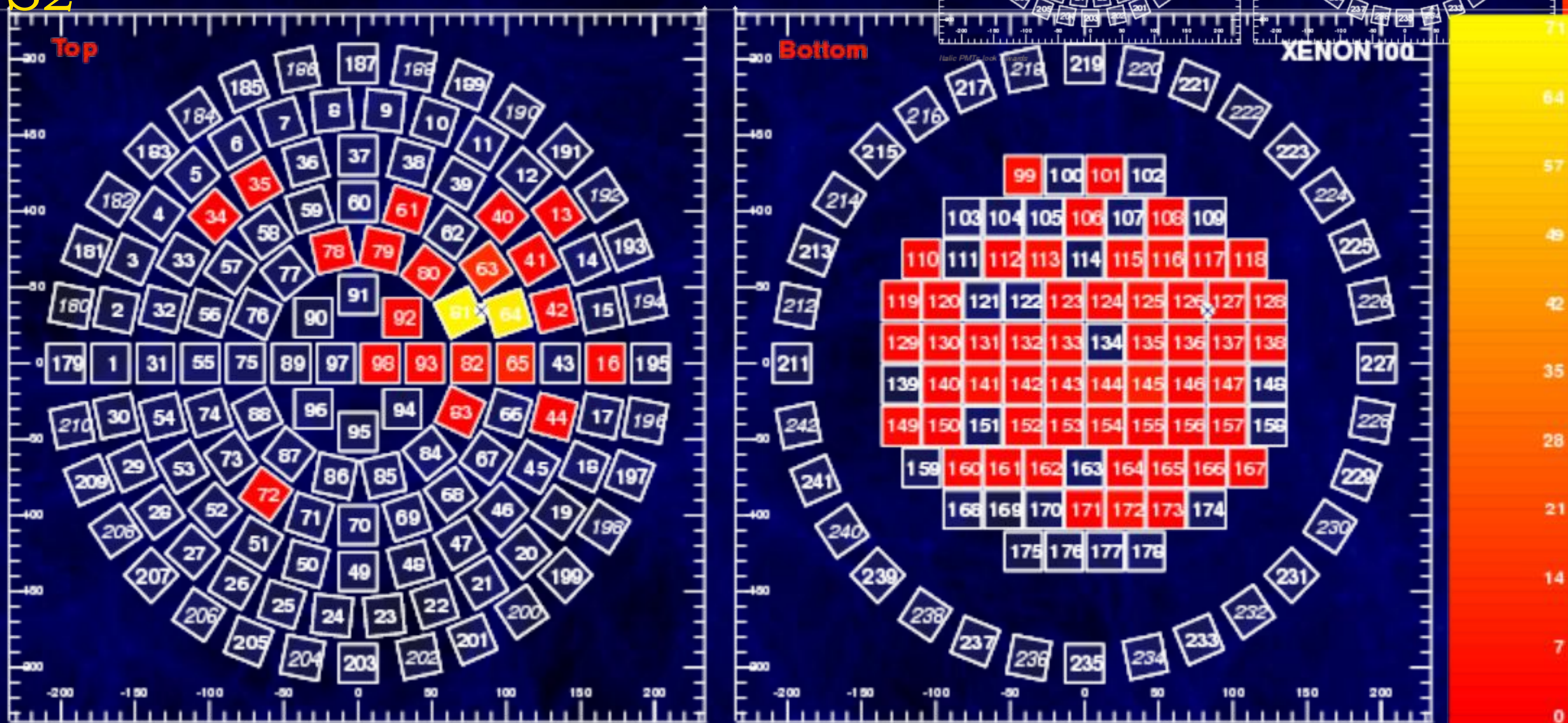
Candidate Event: PMT Pattern

excellent positioning
($\delta r < 3\,\mathrm{mm}$)
even near threshold

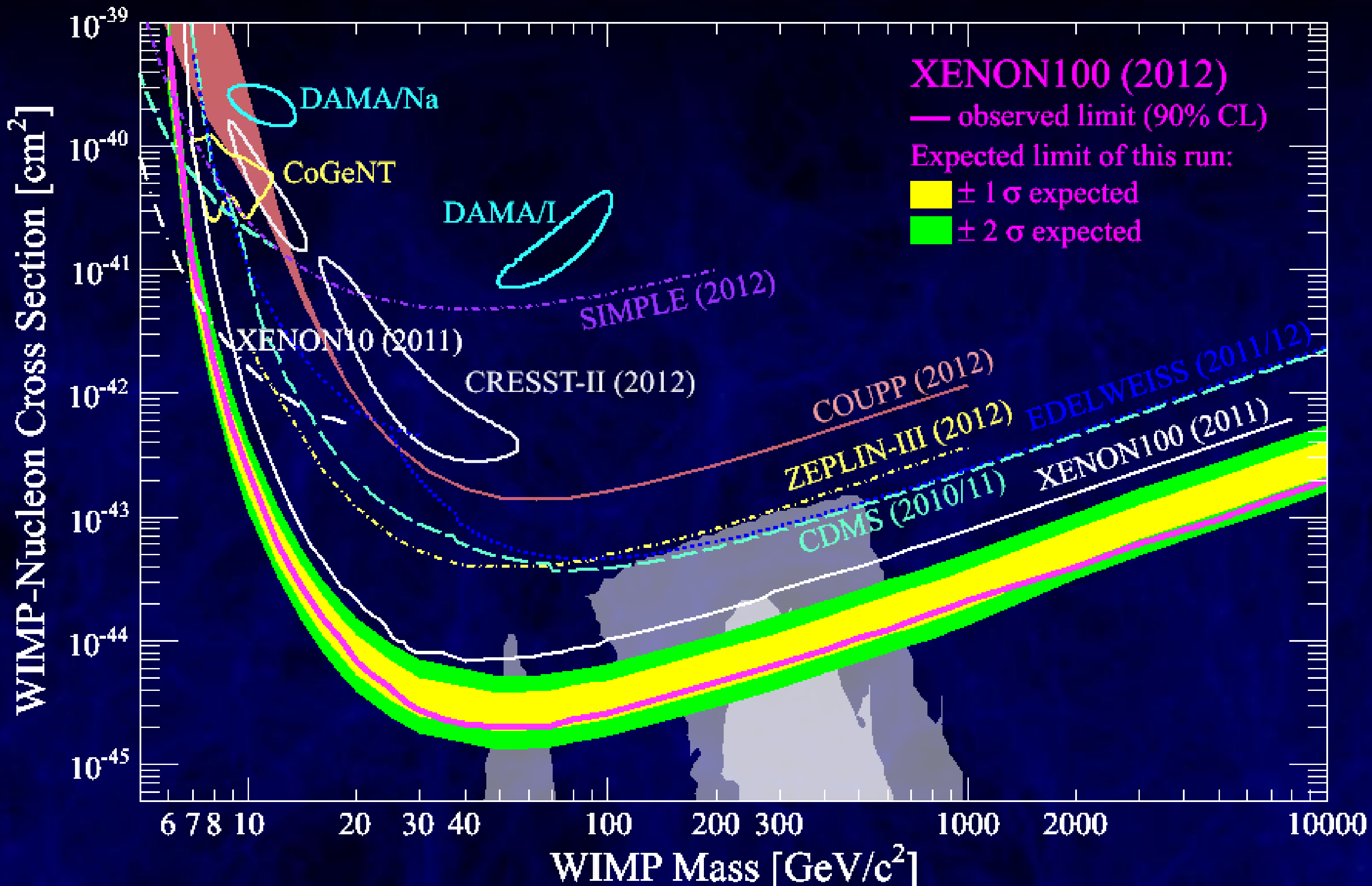
S1



S2



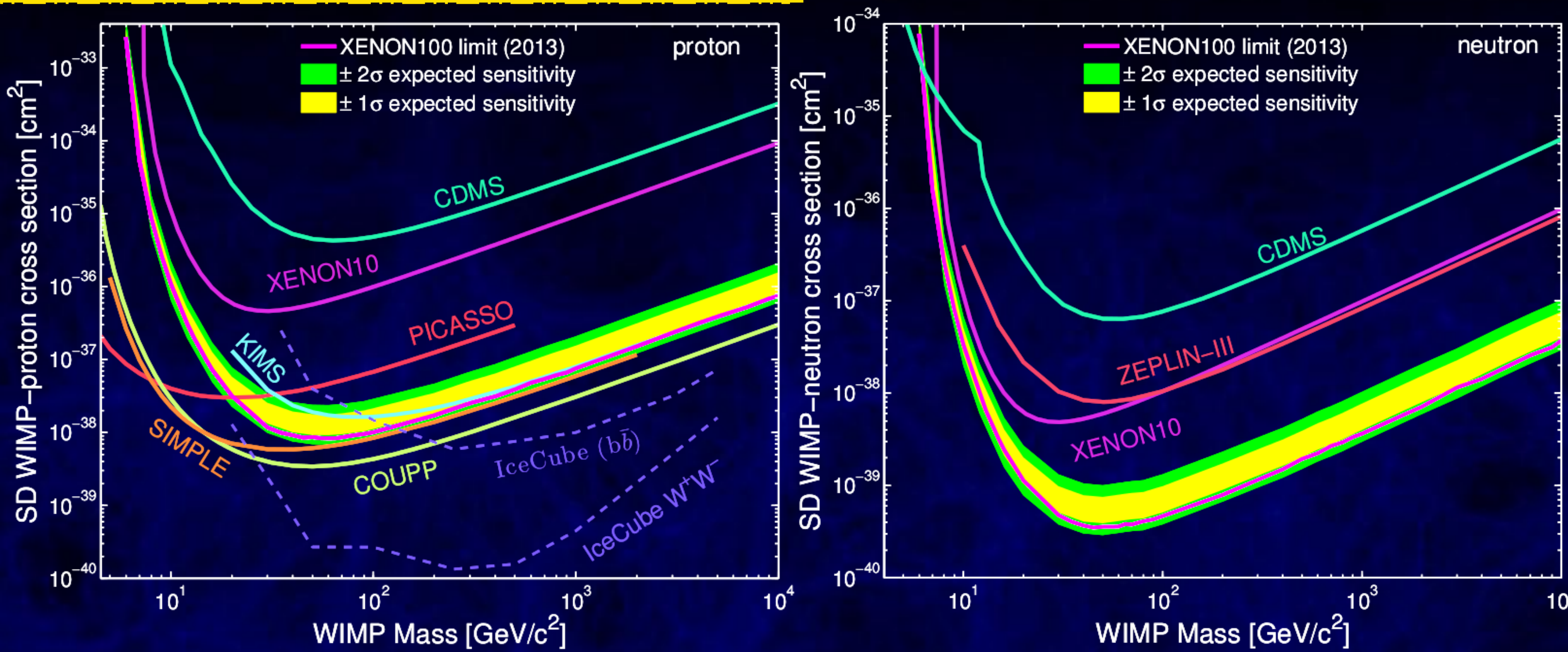
XENON100 SI Limit 2012



XENON100, PRL 109, 181301 (2012)

XENON100 yields strongest limit to date above 10GeV

XENON100 SD Limits

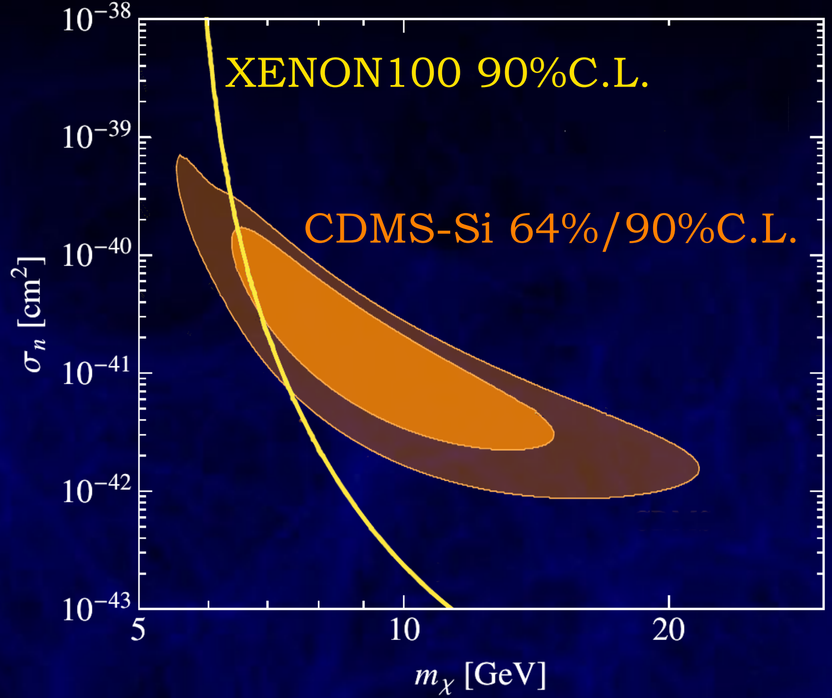


~50% of xenon has spin

- competitive proton-only limits
- leading neutron-only limits

arXiv:1301.6620

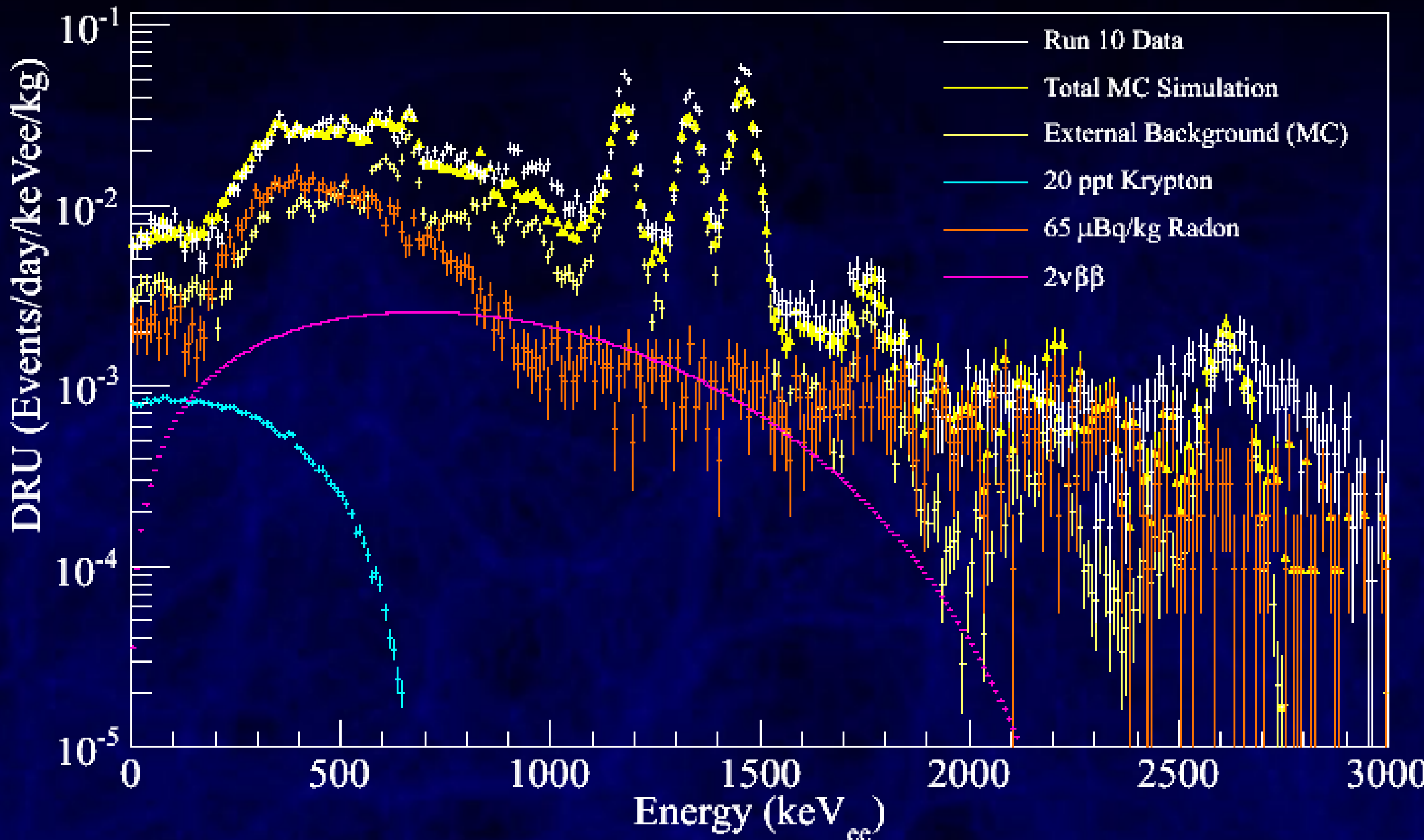
CDMS-Si 2013



Frandsen et al., arXiv 1304.6066

- statistics? compatible at 90% C.L. (see talk by Chris)
- CDMS-Si not WIMPs? ~3σ
- XENON100 acceptance wrong after all? (4 more slides!)
- astrophysics? (see talk by Anne)
- particle physics? (e.g. isospin-violating Dark Matter)

Background Spectrum Understood



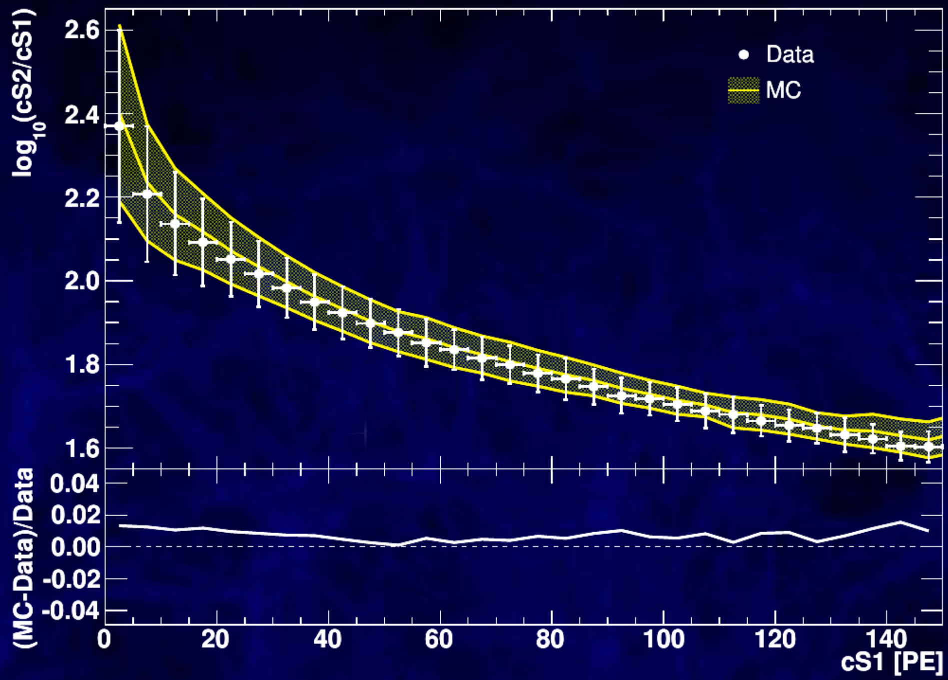
low-energy background before discrimination

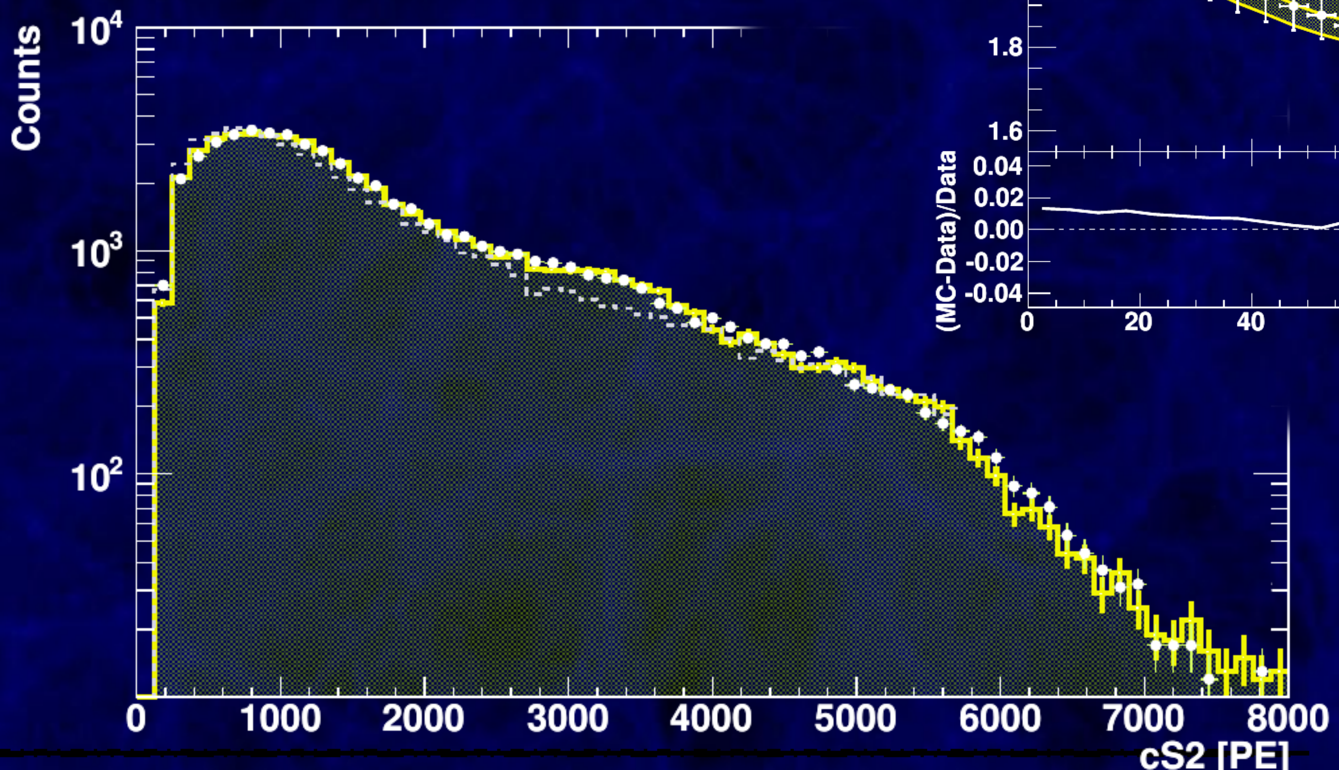
$(5.3 \pm 0.6) \times 10^{-3}$ events/keV$_{ee}$/kg/day

2 orders of magnitude below other Dark Matter searches

Absolute (!) Rate Matching

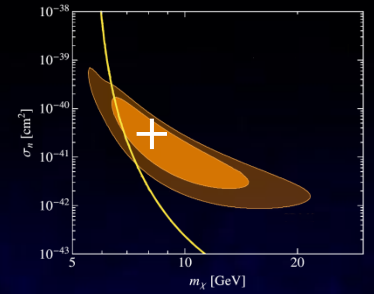
XENON100 AmBe calibration: understand at %-level to 3keV$_{nr}$; fair match even below



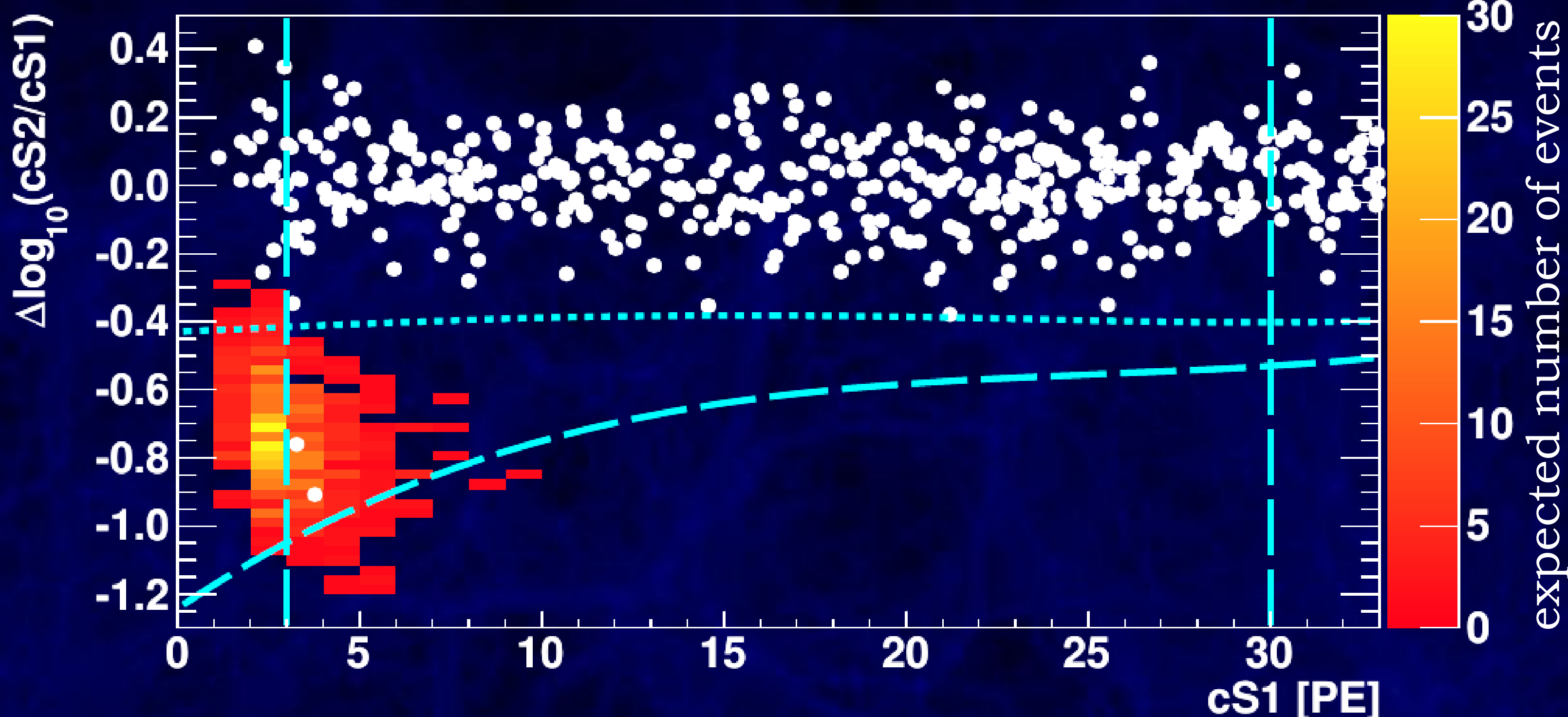


XENON100, arXiv:1304.1427

8GeV, $3\cdot10^{-41}$cm^2 WIMP



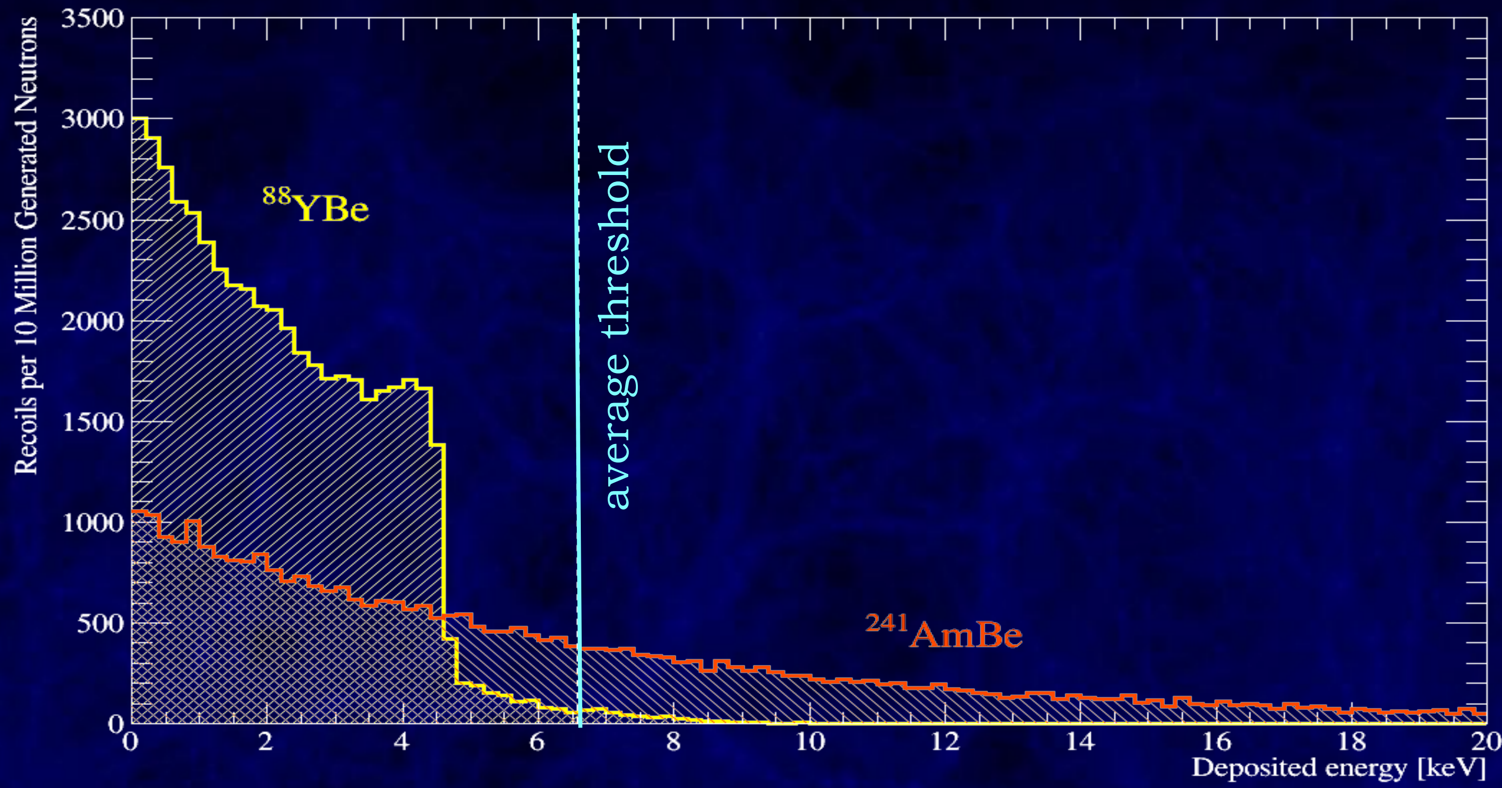
includes cut acceptance
also below analysis threshold



XENON100,
arXiv:1304.1427

How To Calibrate Lowest Recoils?

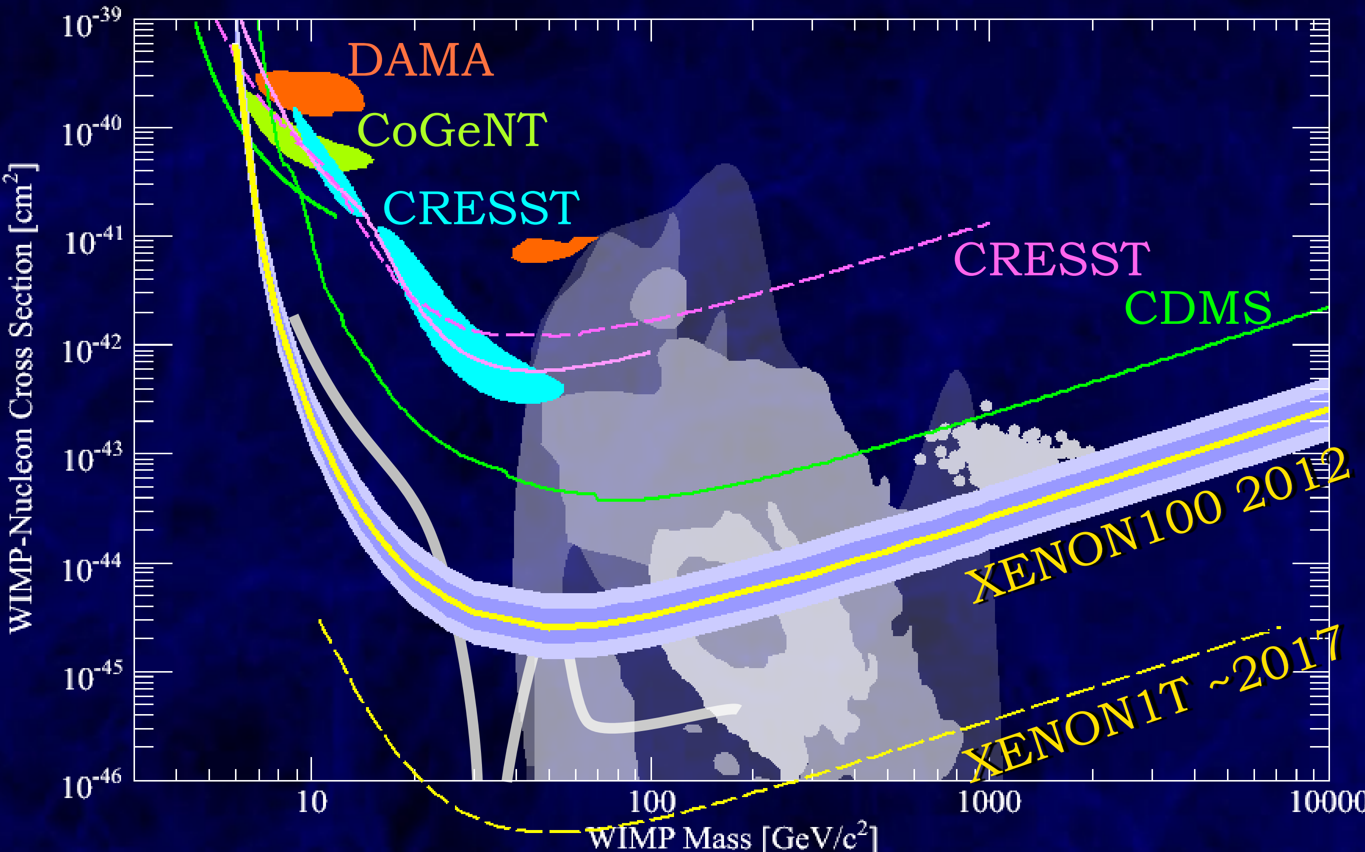
calibrate with ^{88}YBe (tricky: 1.8MeV γ vs. 152keV n)



in addition, optimized analysis to low-mass/high-rate signal → systematic uncertainty reduced even further

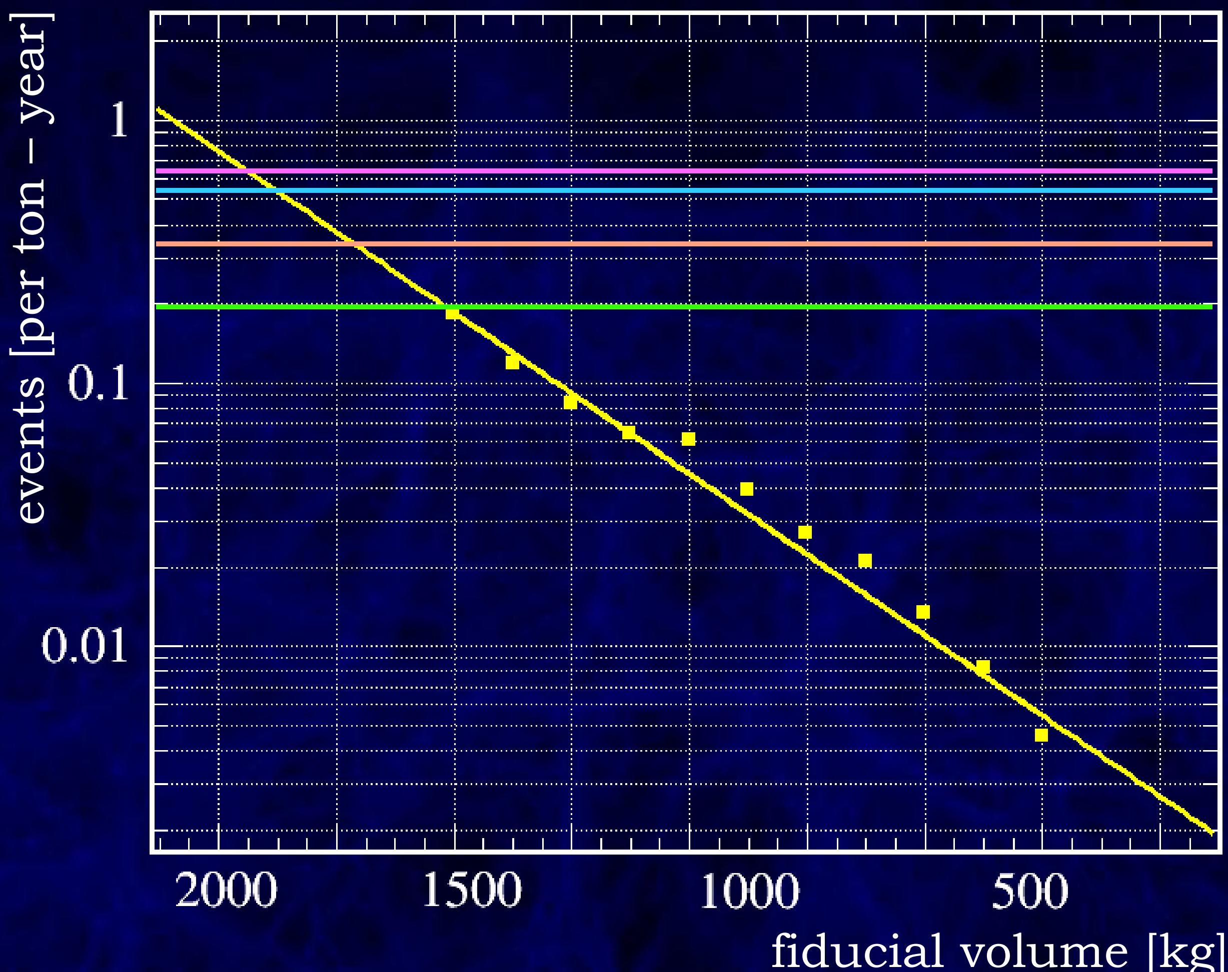
Better Statistics: XENON1T

- 3 tons of xenon, up to 2 tons fiducial
- sensitivity 1 event/ton/year, $2 \cdot 10^{-47}$ cm^2
- data taking 2015 at Gran Sasso: approved & funded



XENON1T: pp Neutrinos!

background after 99.5% ER/NR discrimination:



^{222}Rn (1μBq/kg)

^{85}Kr (0.5ppt)

pp solar ν

^{136}Xe 2ν2β

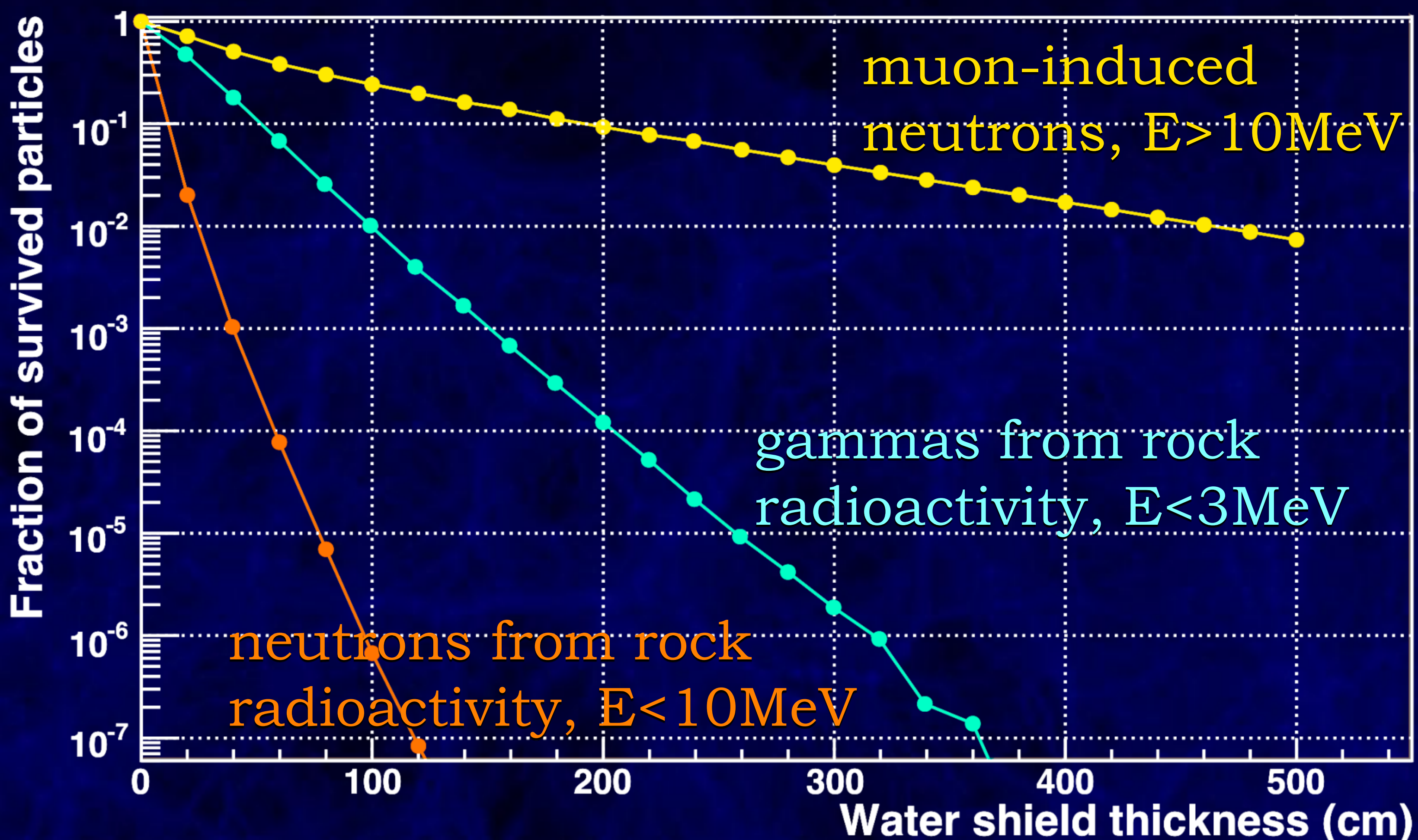
PMTs (dominant external back-ground)

Key Challenges

	XENON100	XENON1T
• liquid xenon	161 kg	~3500 kg
• background	$5 \cdot 10^{-3}$ dru	$5 \cdot 10^{-5}$ dru
• krypton/xenon	(19±4) ppt (<1.3ppt)	<0.5 ppt
• radon/xenon	~65 μBq/kg	~1 μBq/kg
• electron drift	30 cm	1 m
• cathode	-16 kV	-100 kV
• filling-to-search	several months	2 months

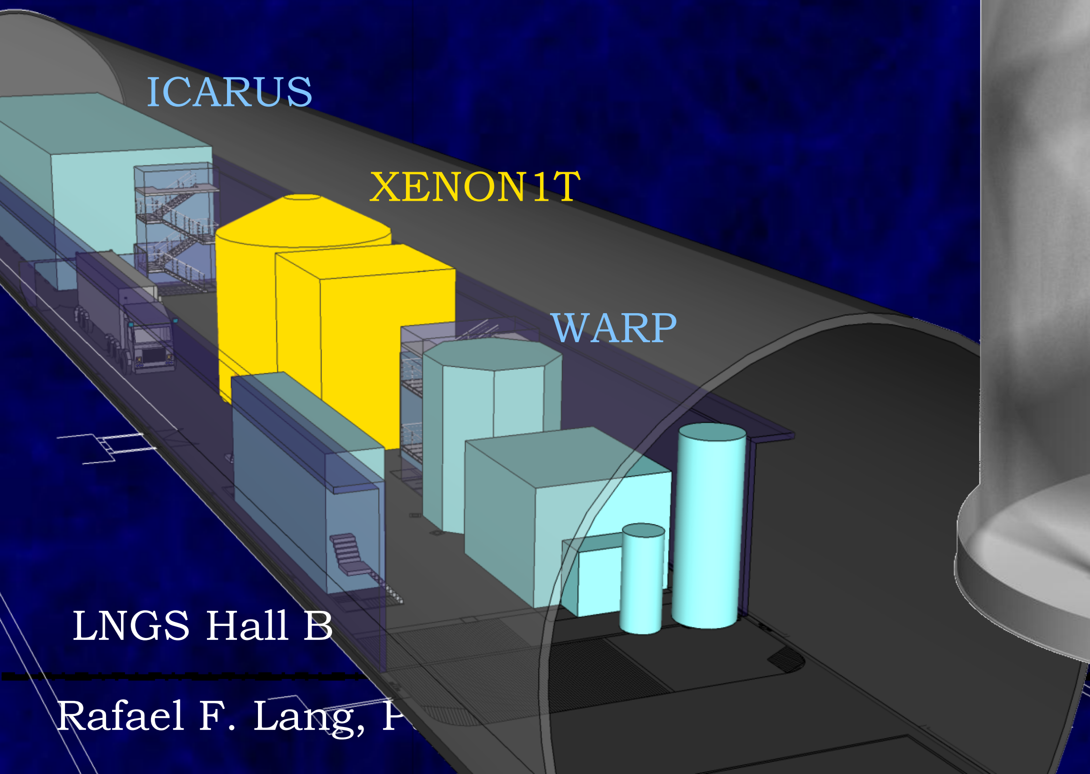
The Need for a Muon Veto

shielding of high-energy n insufficient: requires veto

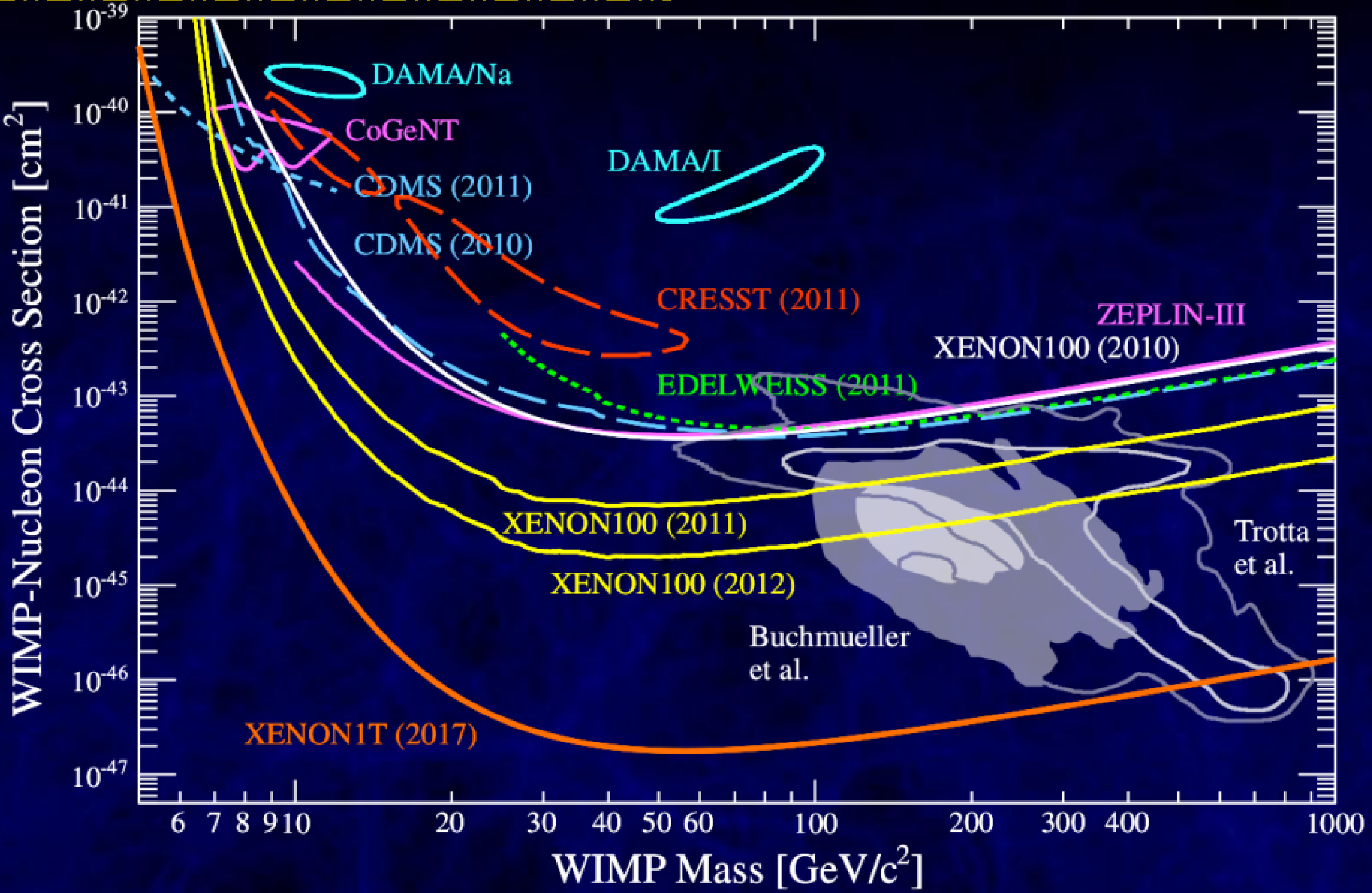


XENON1T @ Gran Sasso

- water tank
  10m high, Ø 9.6m
- active μ-veto
- construction started
- data taking 2015



A Bustling Field of Research



improve by 2 orders of magnitude within 5 years