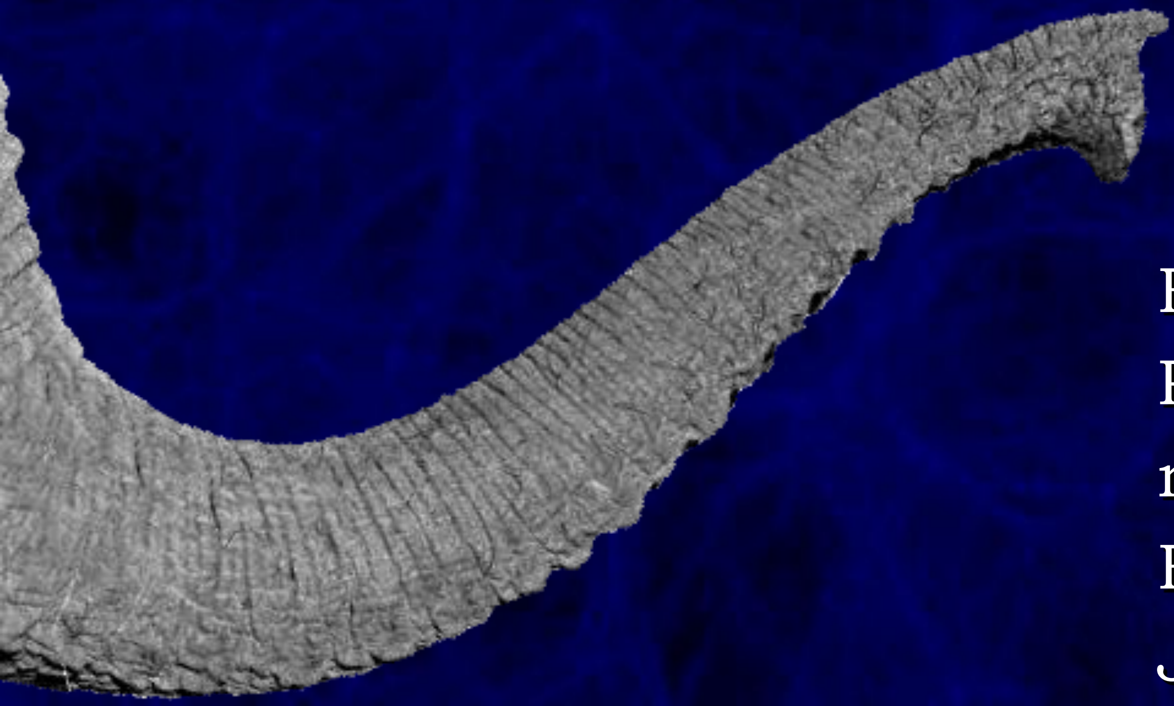
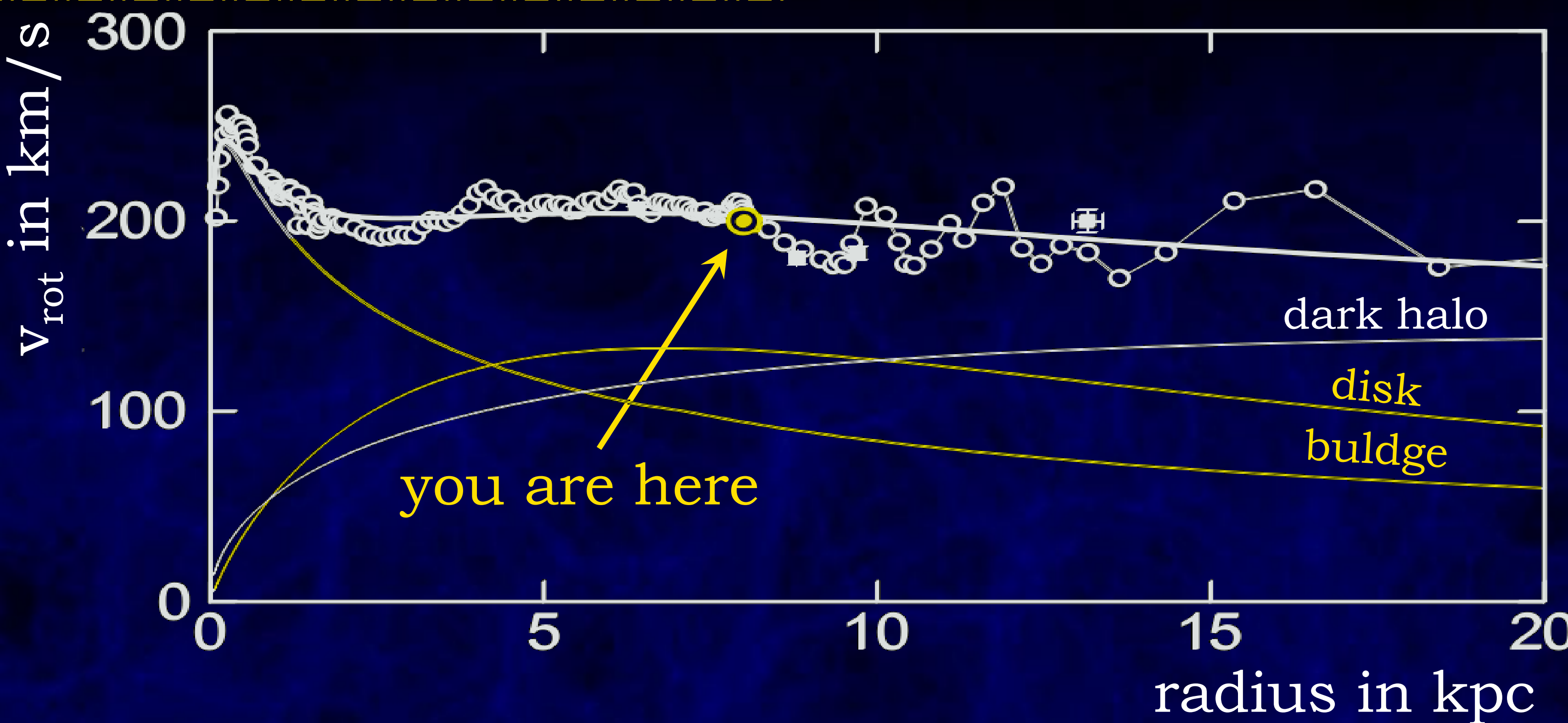
Direct Dark Matter Safari

Basics, Status 2015, Outlook



Rafael F. Lang
Purdue University
rafael@purdue.edu
Rencontres de Blois,
June 4, 2015

Evidence for Dark Matter in Your Lab



Sofue 1110.4431

Pato,Iocco,Bertone 1504.06325

- Local density $\varrho_{\chi,\odot} = (0.42 \pm 0.06)\,\mathrm{GeV/cm^3} \approx 0.3\,\mathrm{GeV/cm^3}$
- Fly through Dark Matter halo, $v_\odot \approx 232\,\mathrm{km/s} \approx 10^{-3}c$
- Detect scattering in laboratory target

Axions and ADMX

Axions

Peccei & Quinn 1977, Wilczek 1978, Weinberg 1978

- Idea: effective strong CP violating term $\bar{\Theta}$ is small because it's a field. Corresponding particle is the Axion.

- Interaction strength $\frac{f_a}{10^{12}\,\mathrm{GeV}} = \left(\frac{m_a}{6\,\mu\mathrm{eV}}\right)^{-1}$

- If $m_a < 40\,\mathrm{eV} \rightarrow t_{1/2} > t_{\mathrm{Universe}}$: a Dark Matter candidate

- With $\Omega_a \propto m_a^{-7/6} \rightarrow m_a > \sim 1\,\mu\mathrm{eV}$ to prevent overclosure

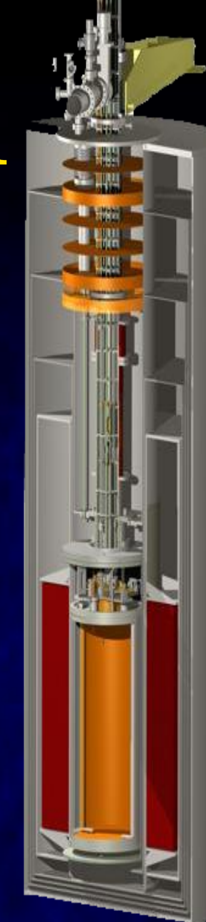
- Detect via Primakov-effect:

Sikivie 1983

ADMX Resonant Axion Search

- Microwave cavity, up to 8T, down to 100mK

Carosi Aspen2013

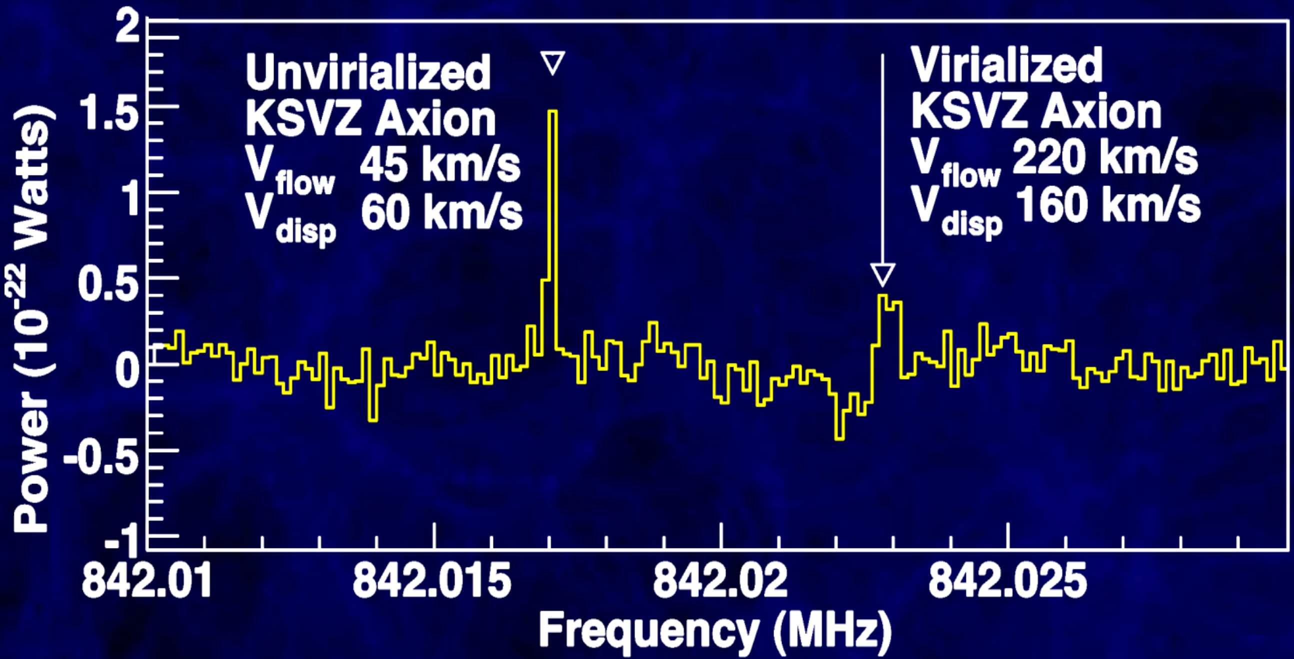


Rosenberg UCLA2014

ADMX Resonant Axion Search

- Microwave cavity, up to 8T, down to 100mK
- Very rich signature

simulated signal:



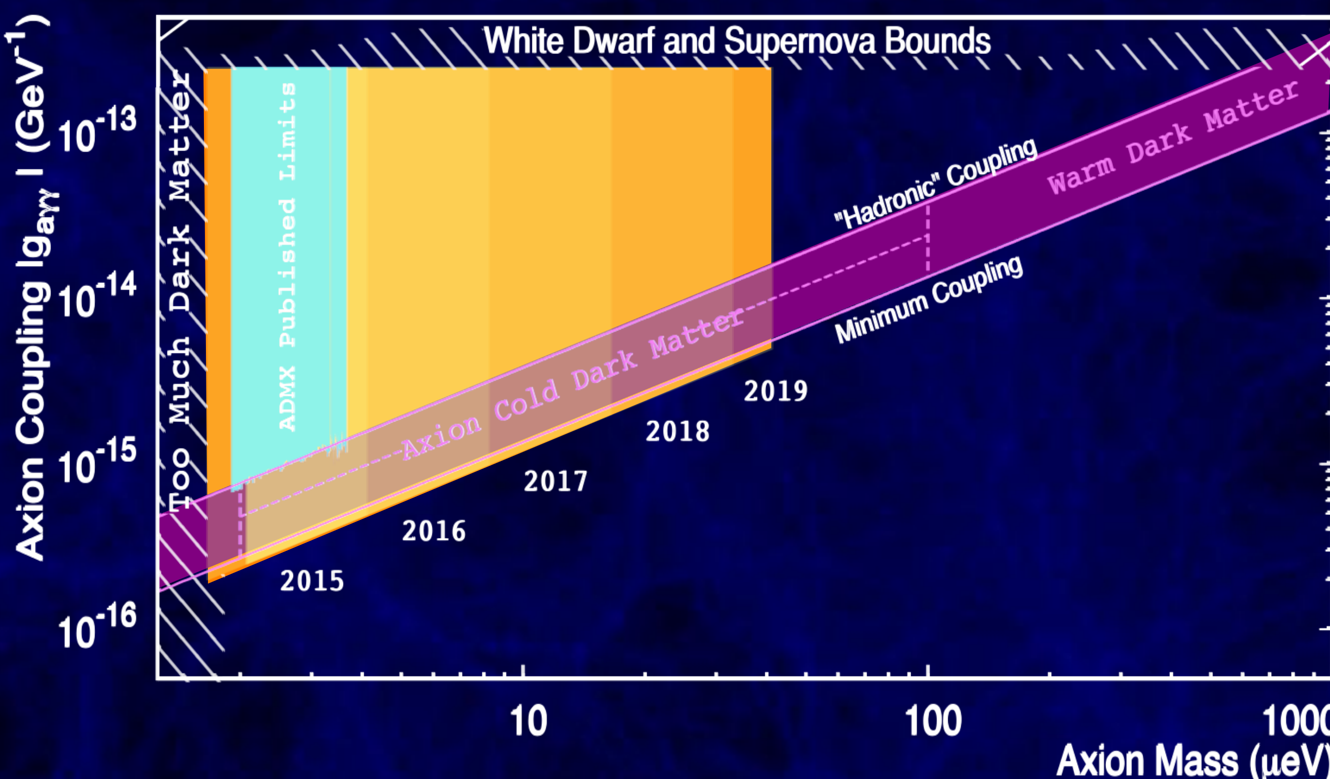
Carosi Aspen2013

Rosenberg UCLA2014

ADMX Resonant Axion Search

- Microwave cavity, up to 8T, down to 100mK
- Very rich signature
- Initial data this summer, then scan frequencies

Carosi Aspen2013

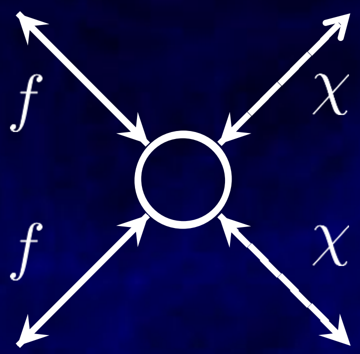


Rosenberg priv. comm. 2015

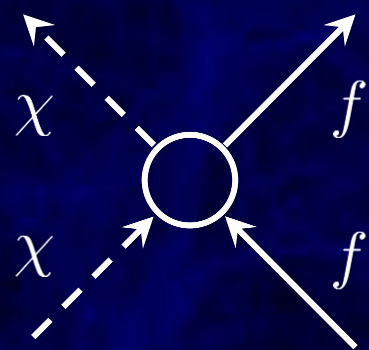
WIMP Search Basics

Thermal Relic Particles

Production:
collider searches



Annihilation:
indirect searches



Scattering:
direct detection

χ χ

f f

WIMP Scattering Basics

Coherent Scattering:

$$\frac{\lambda_{\mathrm{deBroglie}}}{2\pi} = \frac{\hbar}{p} = \frac{\hbar c}{mc^2\, v/c} \sim \frac{197\,\mathrm{MeV\ fm}}{100\,\mathrm{GeV}\ 10^{-3}} \approx \mathrm{fm} \approx r_{\mathrm{nucleus}}$$

Rate:

$$N = n_{\mathrm{target}} \Phi_\chi\, \sigma_{\chi,N}\, A^2 \qquad \text{or } \propto \sigma_{\chi,N}\, J(J+1)$$

few events per year, per kg or ton of target

low rates

Simple non-relativistic kinematics. Recoil:

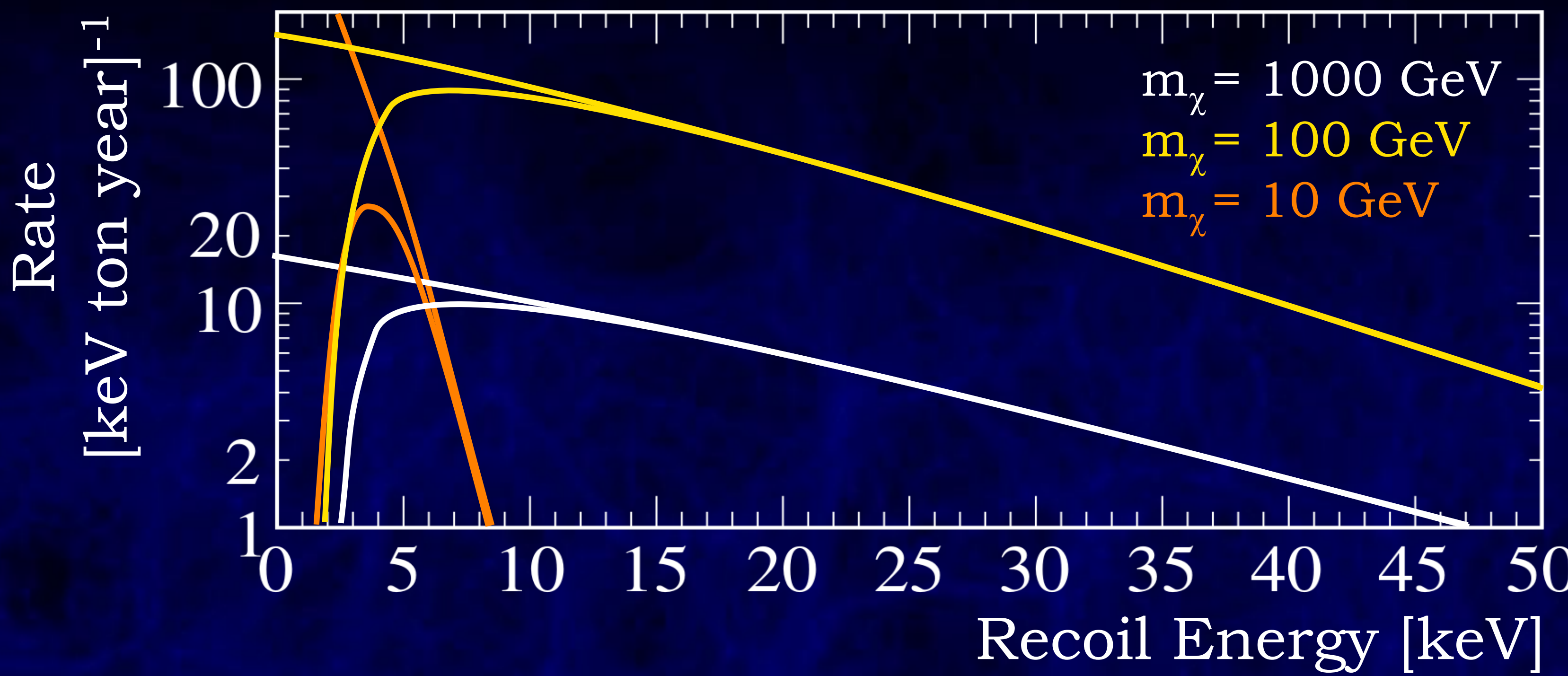
$$E_{\mathrm{r,max}} \sim \frac{p_\chi^2}{2m_{\mathrm{N}}} \sim \frac{\left(100\,\mathrm{GeV/c^2} \times 10^{-3}\mathrm{c}\right)^2}{2 \times 100\,\mathrm{GeV/c^2}} = 50\,\mathrm{keV}$$

low energies

Spectrum falls exponentially:

$$\frac{\mathrm{d}N}{\mathrm{d}E_r} \propto \langle v \rangle \propto \int_{v_{\min}}^{\infty} \frac{\mathrm{MaxwellBoltzmann}(v)}{v}\,\mathrm{d}v \propto \mathrm{e}^{-v_\chi^2} \propto \mathrm{e}^{-E_r}$$

Spectrum: Xe target, $\sigma = 10^{-44} cm^2$

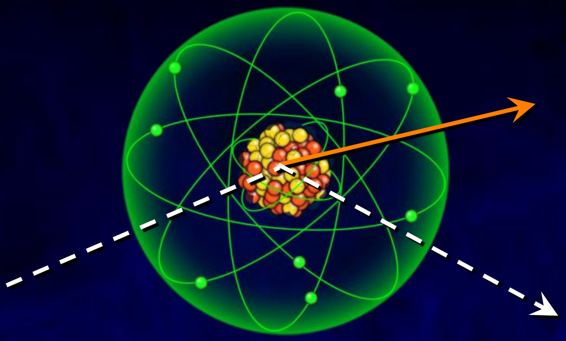


Acceptance necessarily drops to 0 at E_r=0:
Measured signal is a bump after all.

Discrimination: Need Information

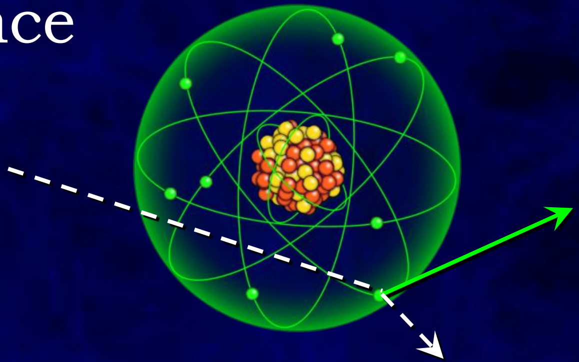
WIMP Signal:

- Nuclear recoils
- Low energy
- Single scatter
- Homogeneous



Particle Backgrounds: Known in advance

- Mostly electronic recoils (β,γ)
- Also at high energy (α,β,γ)
- Also multiple scatters (γ,n)



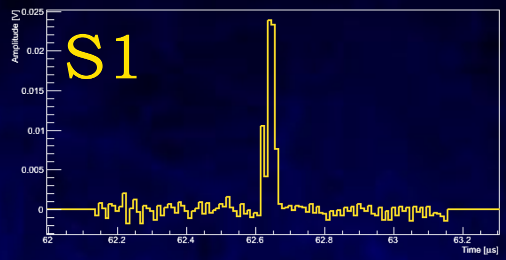
Detector artefacts: Sometimes surprising

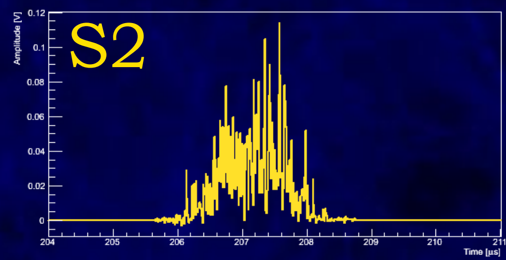
- Surface events
- Pathological pile up
- Noise

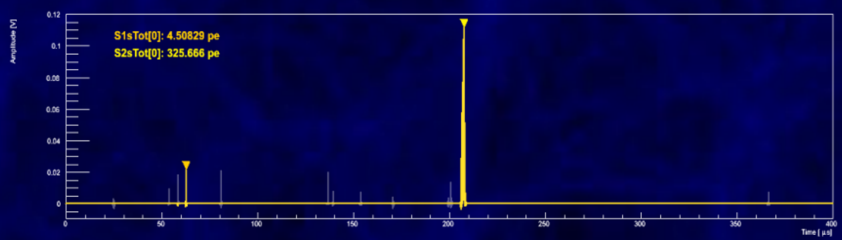
XENON100 Candidate, E~3keV$_{nr}$

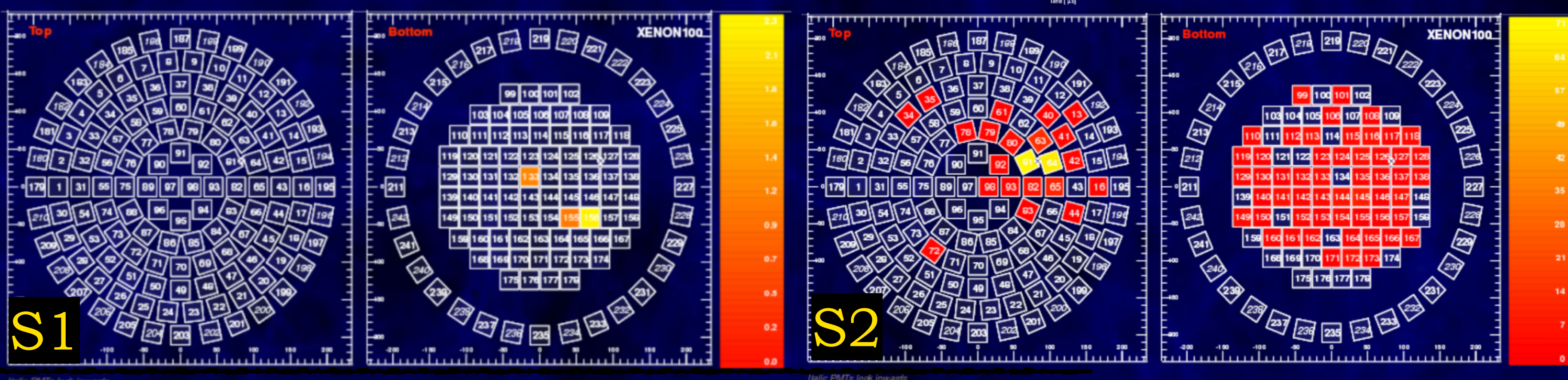
Ample information even at lowest energies:

- Scintillation S1 size and PMT pattern
- Ionization S2 size and PMT pattern
- Single/Multiple Scatter
- Electronic/Nuclear Recoil
- Vertex position
- S2 width
- Time



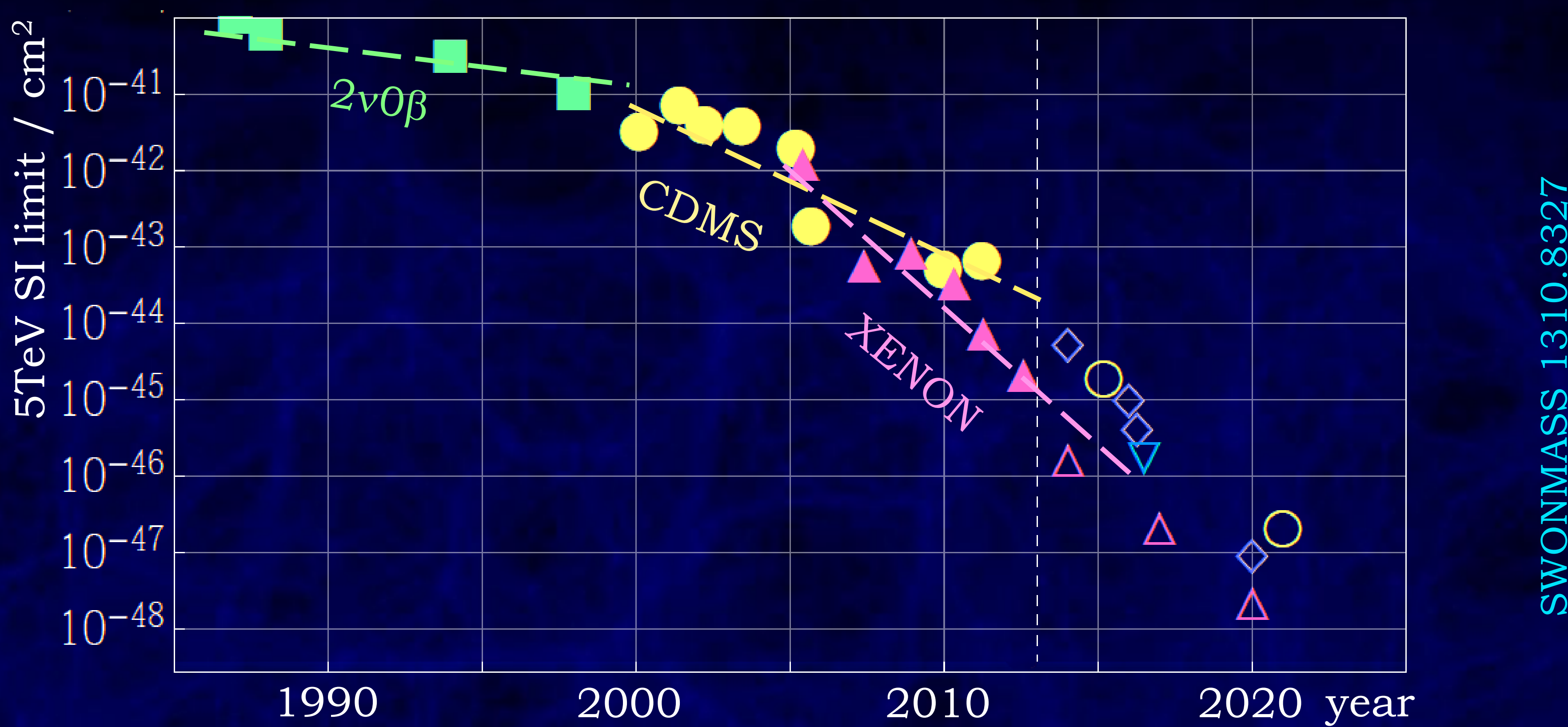






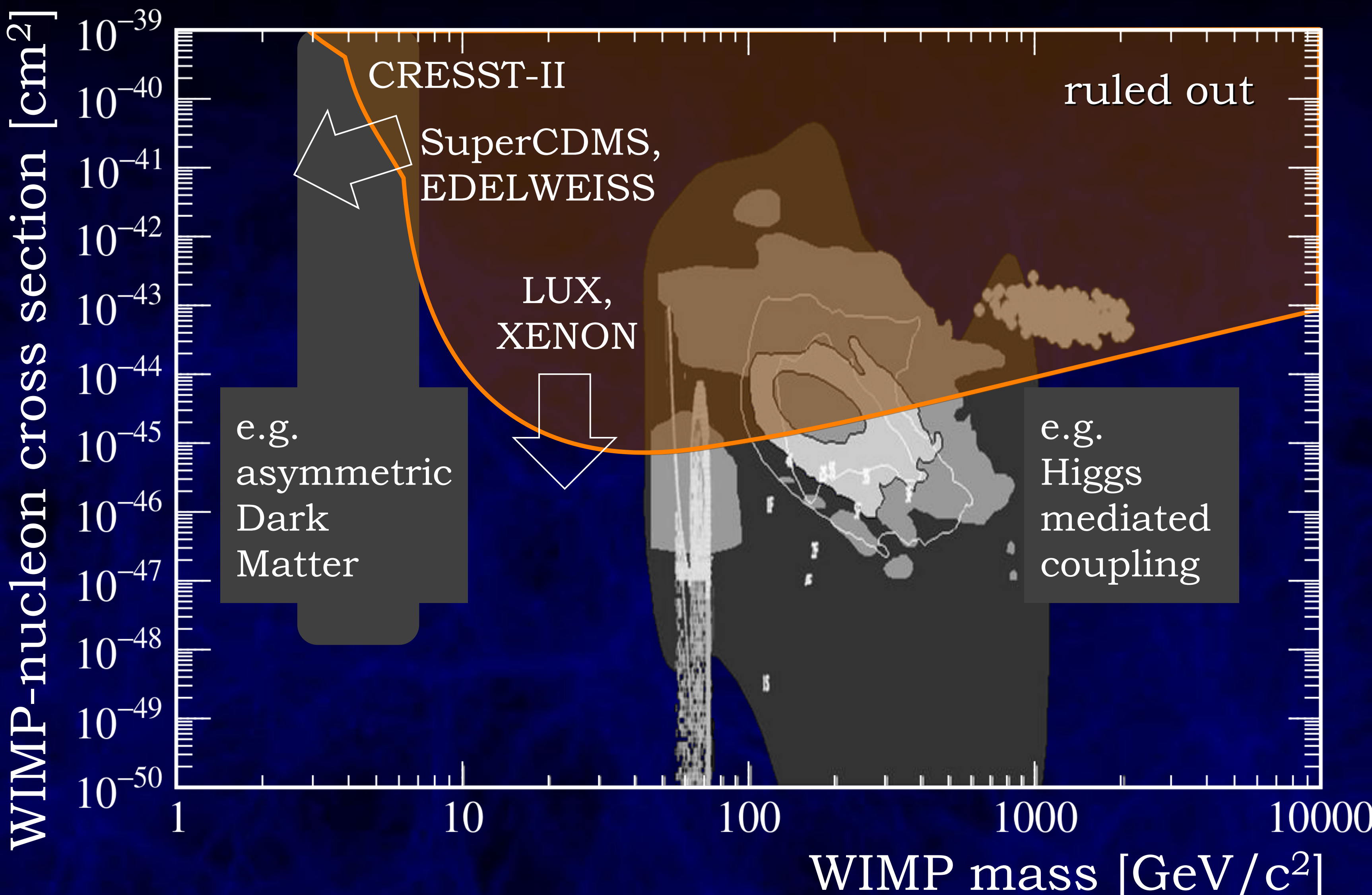
Outstanding Performance

- Sensitivity doubles every year (exceeding Moore's law)



- Very good control of systematic uncertainties (%-level)
- Elaborate & versatile analyses (many other channels)

Spin-Independent Channel



SNOWMASS 1310.8327

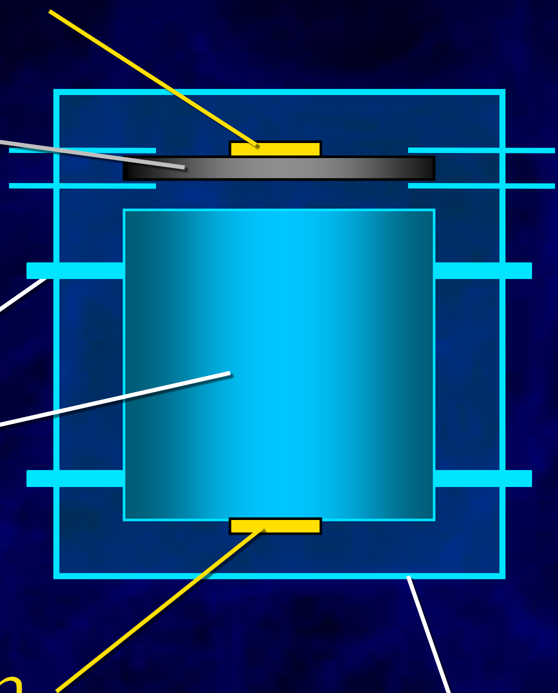
Baltz&Gondolo,Roszkowski+,
Kadastik+,Buchmueller+,Burgess+

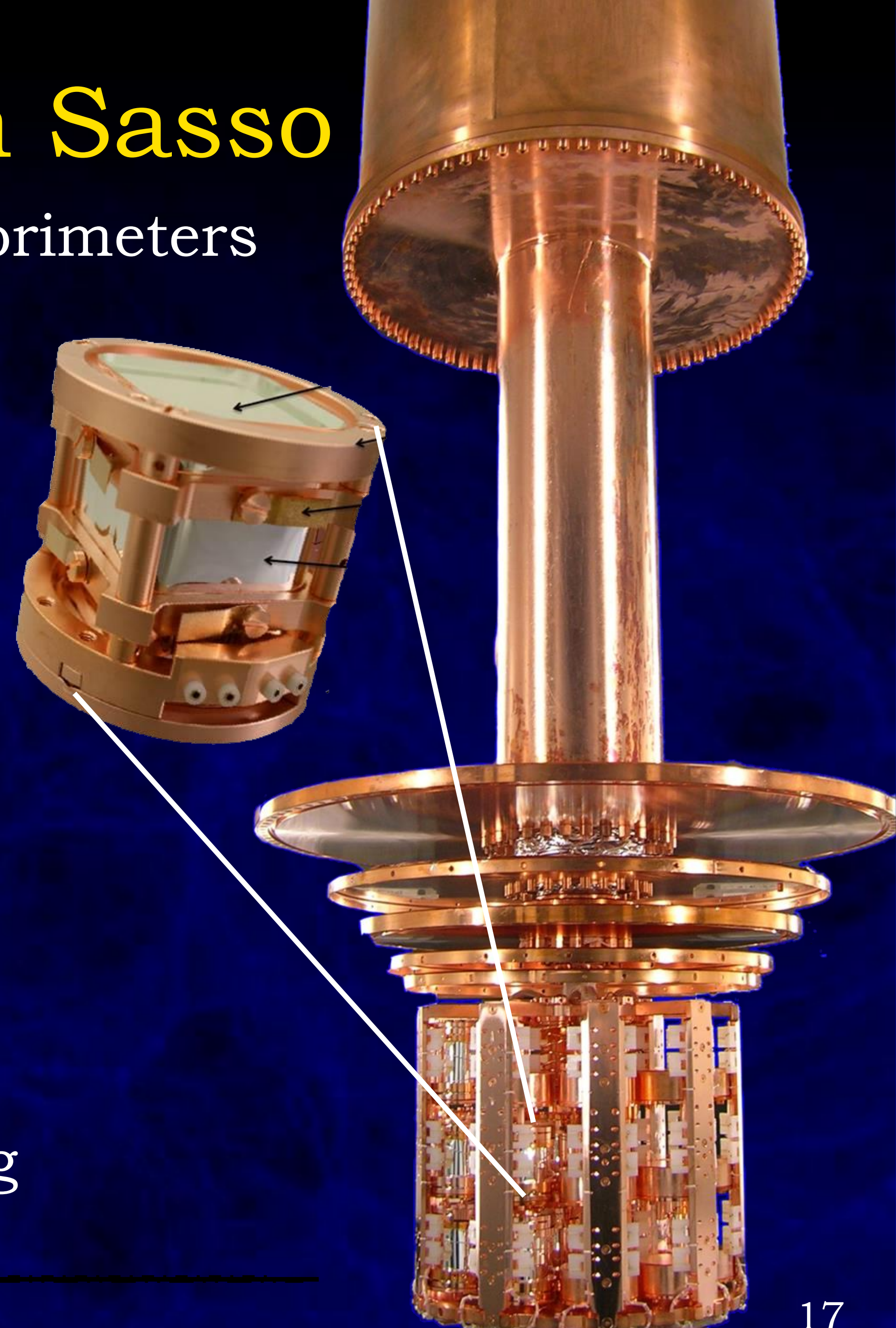
$CaWO_4$, Ge, Xe

CRESST-II @Gran Sasso

Scintillating 300g $CaWO_4$ calorimeters

thermometer threshold <20eV

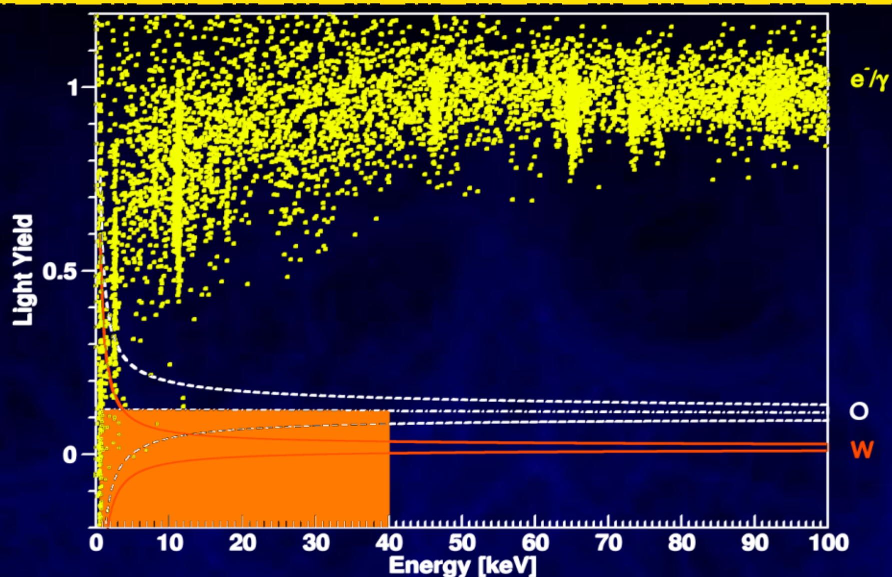


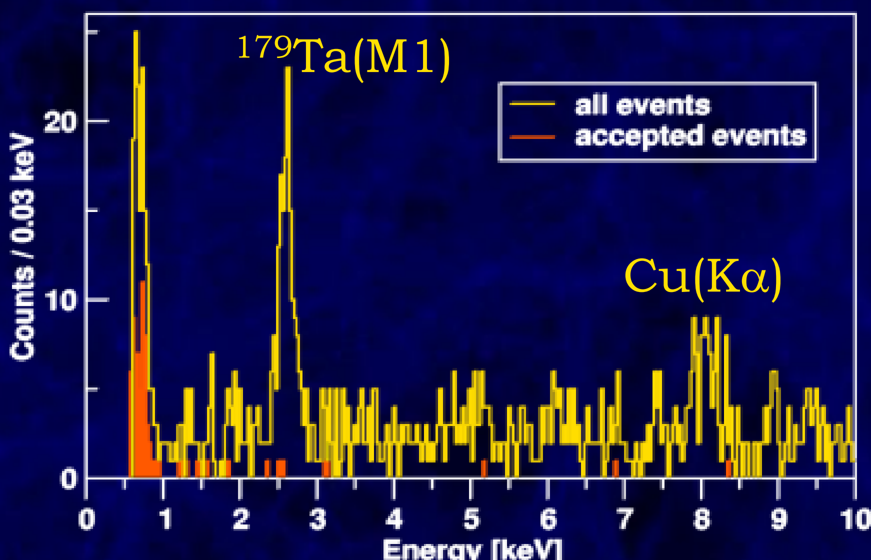


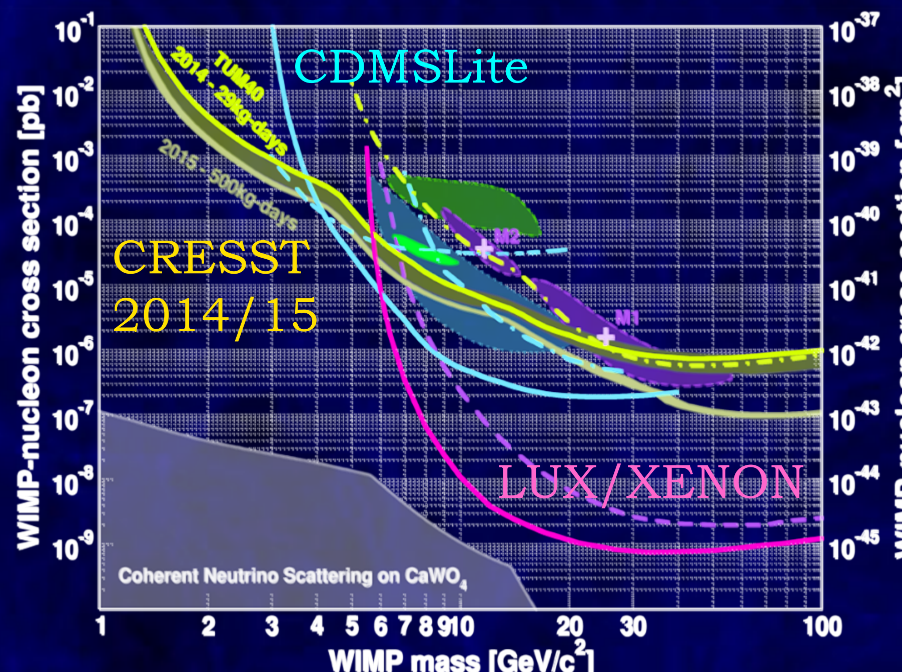
CRESST-II: Multi-Target Built-In

- 29 kg days
- Ca, O for light WIMPs, W for heavy WIMPs
- Threshold ~600eV
- Expect better limit 2015

CRESST 1407.3146







F. Petricca priv.comm. 2015

EDELWEISS & SuperCDMS

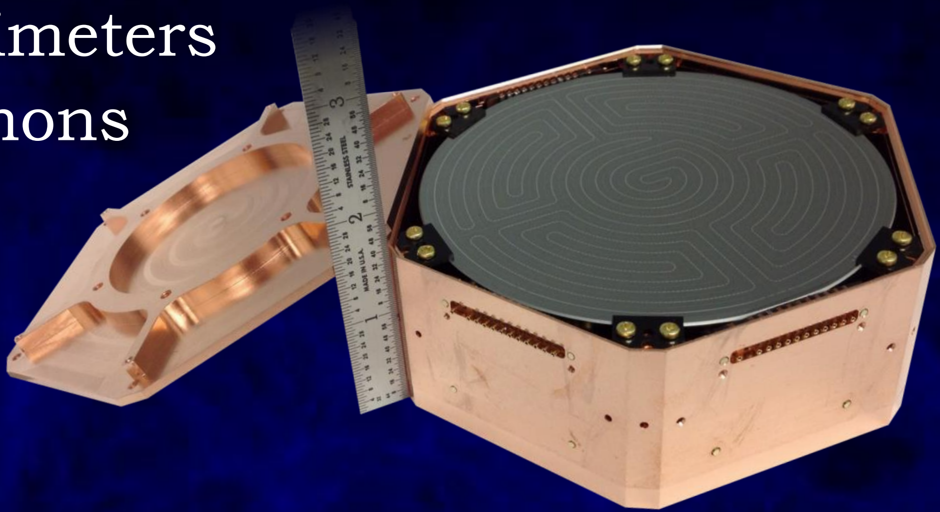
Segmented detector, up to 1.4kg Ge each & 60kg total

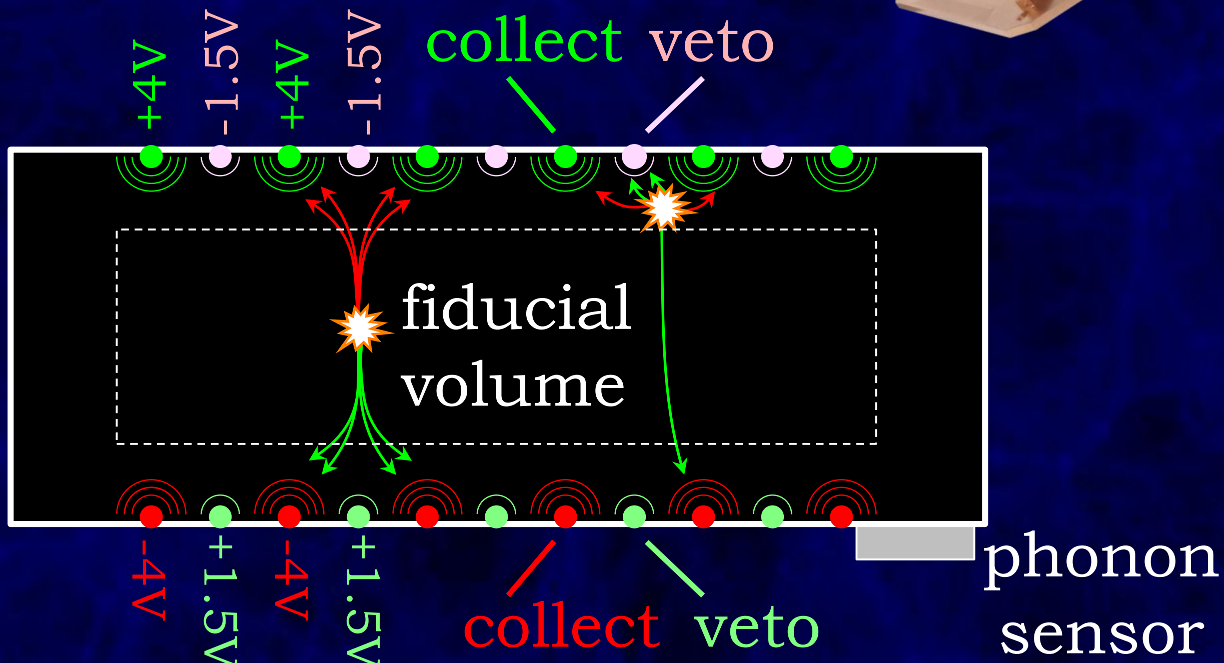
Germanium or Silicon calorimeters

Cooled to mK to collect phonons

Interleaved electrodes

for ionization

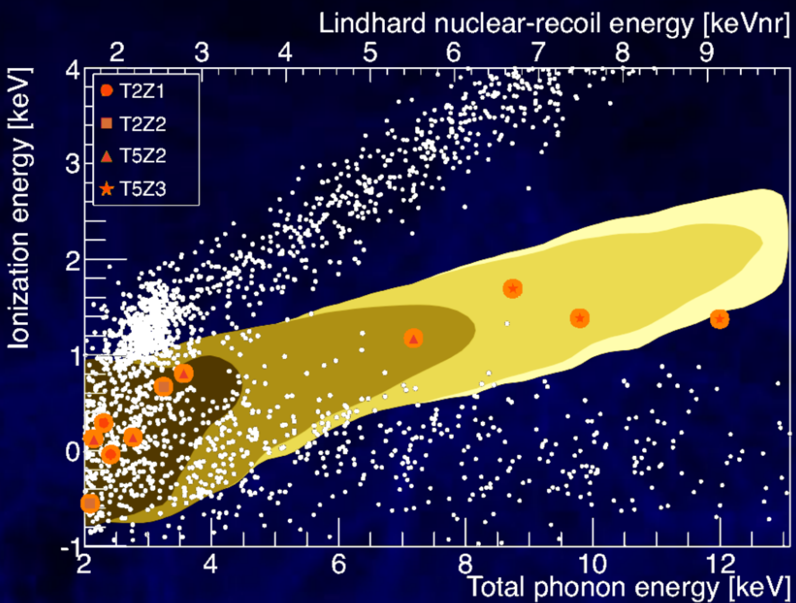




cdms.berkeley.edu

SuperCDMS first analysis

577 kg days optimized for ~GeV WIMPs:

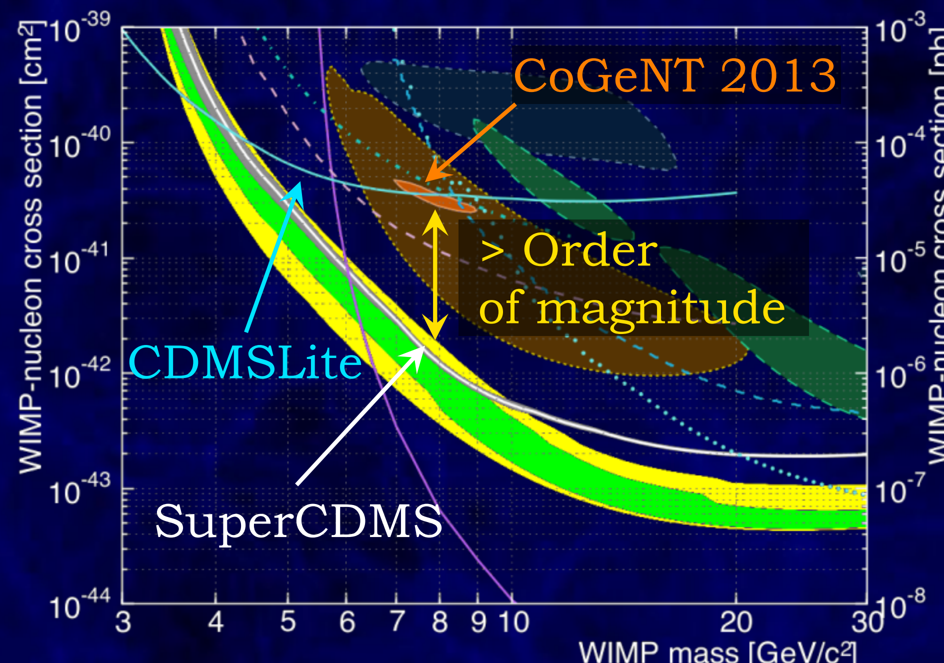


Expect $6.2^{+1.1}_{-0.8}$ events

Observe 8 (11-3)

Excludes CoGeNT

(and CDMS-Si) excess



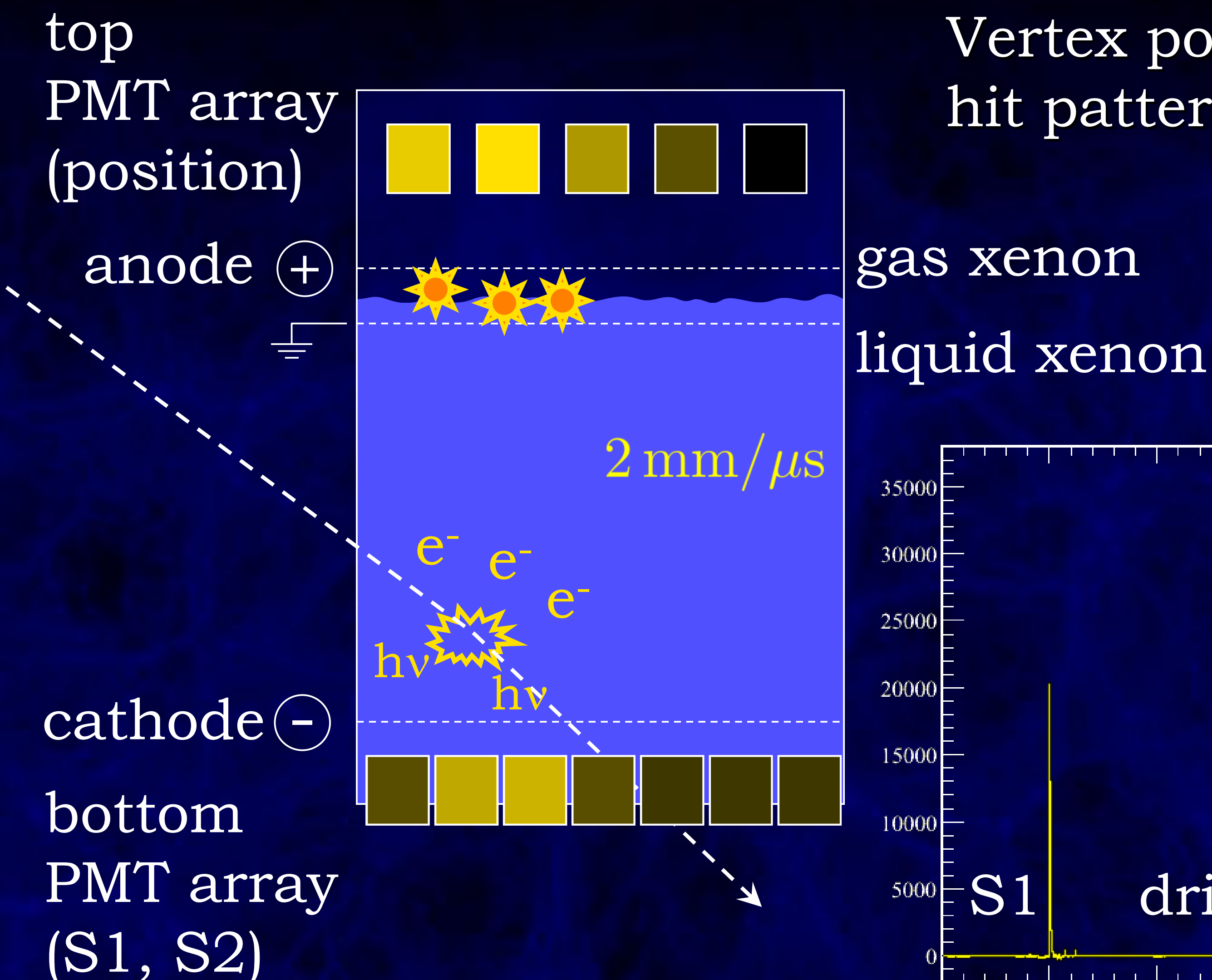
Expect more data from EDELWEISS and CDMSLite this year

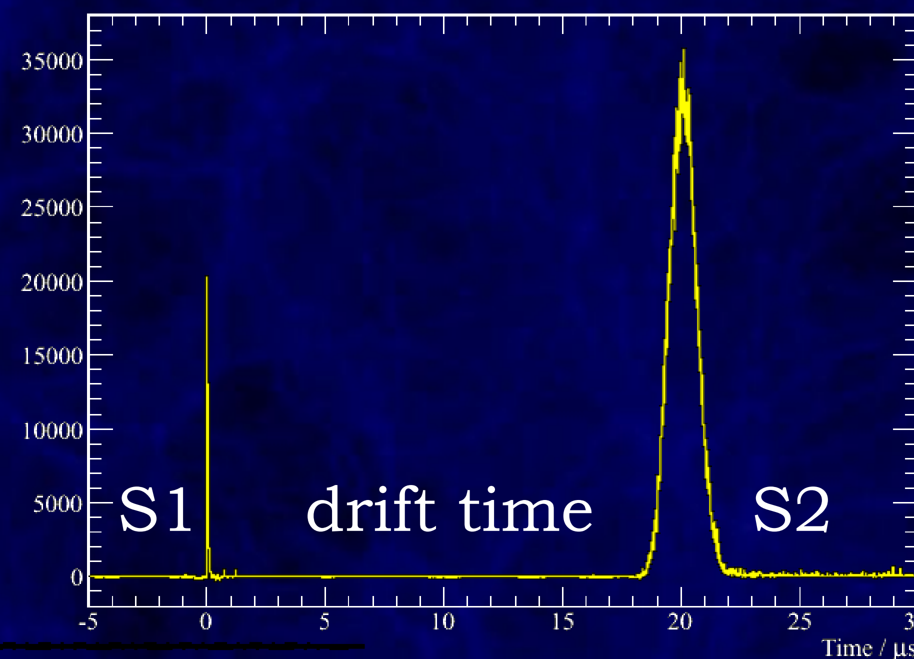
B. Cabrera priv. comm. 2015

SuperCDMS 1402.7137

Xenon Time Projection Chambers

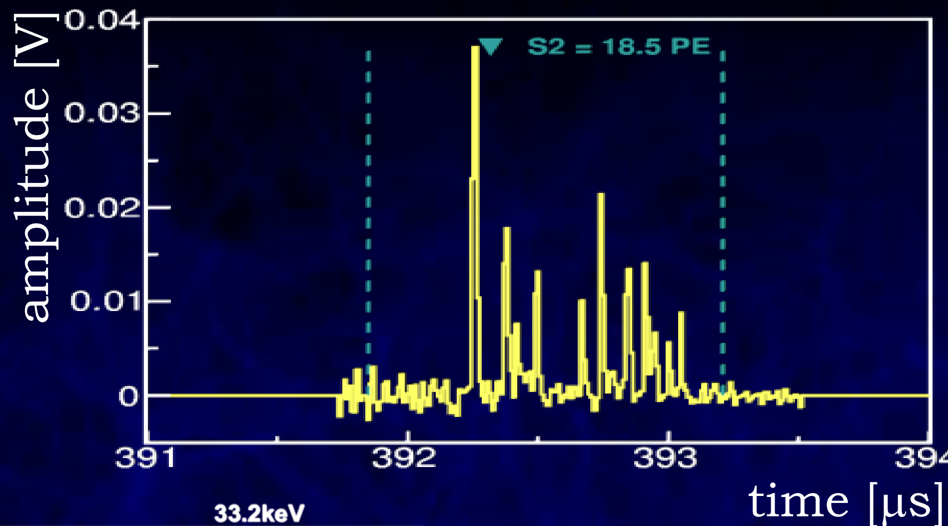
Vertex position from S2 hit pattern & drift time



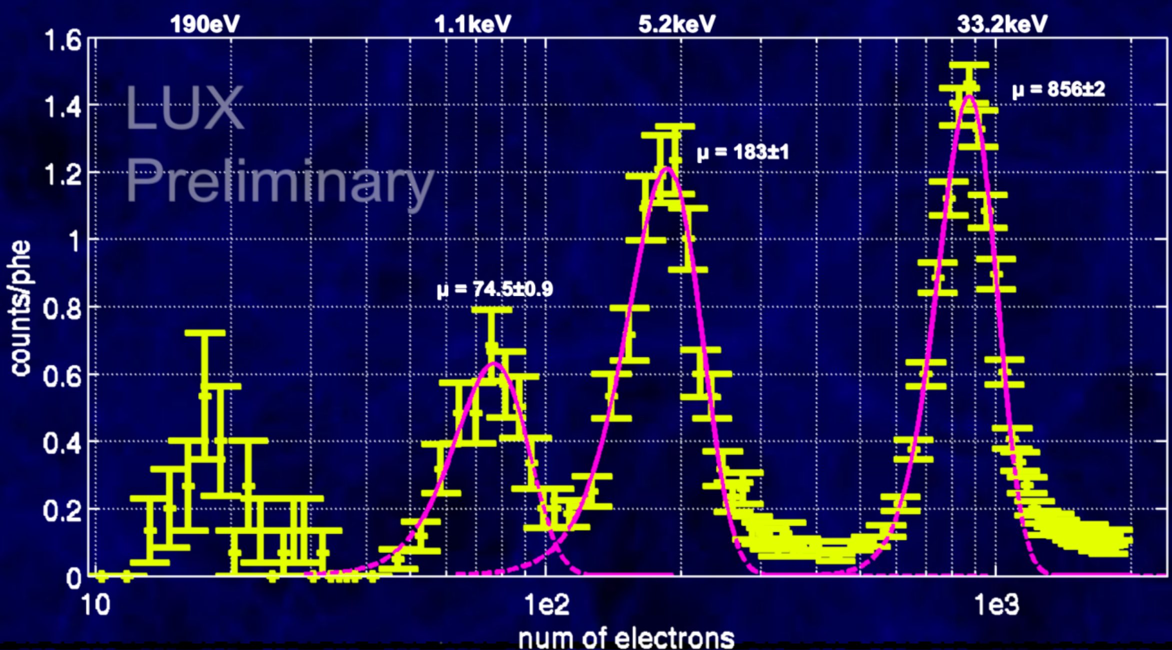


Extreme Low-Energy Sensitivity

Detect even individual electrons liberated in an interaction:



XENON100 1311.1088

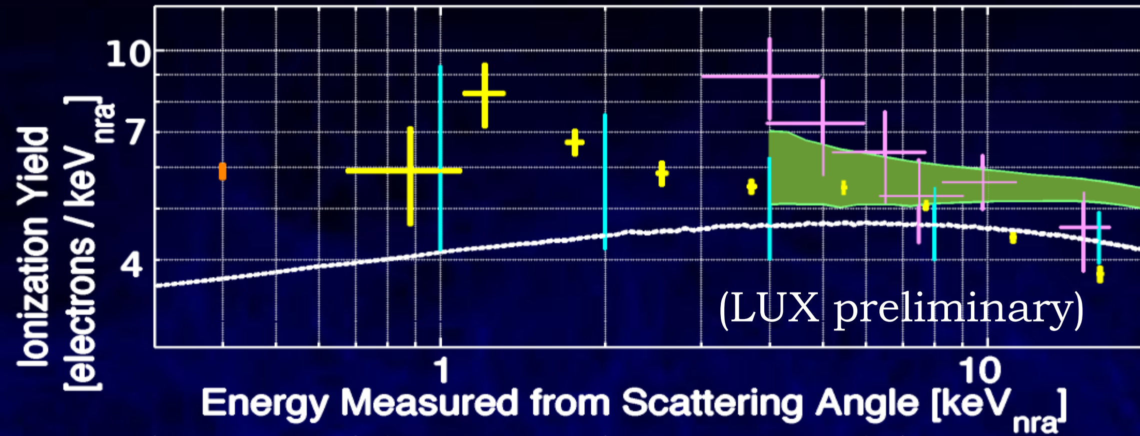


LUX D.Huang APS2015

^{127}Xe EC calibration as low as 190eV

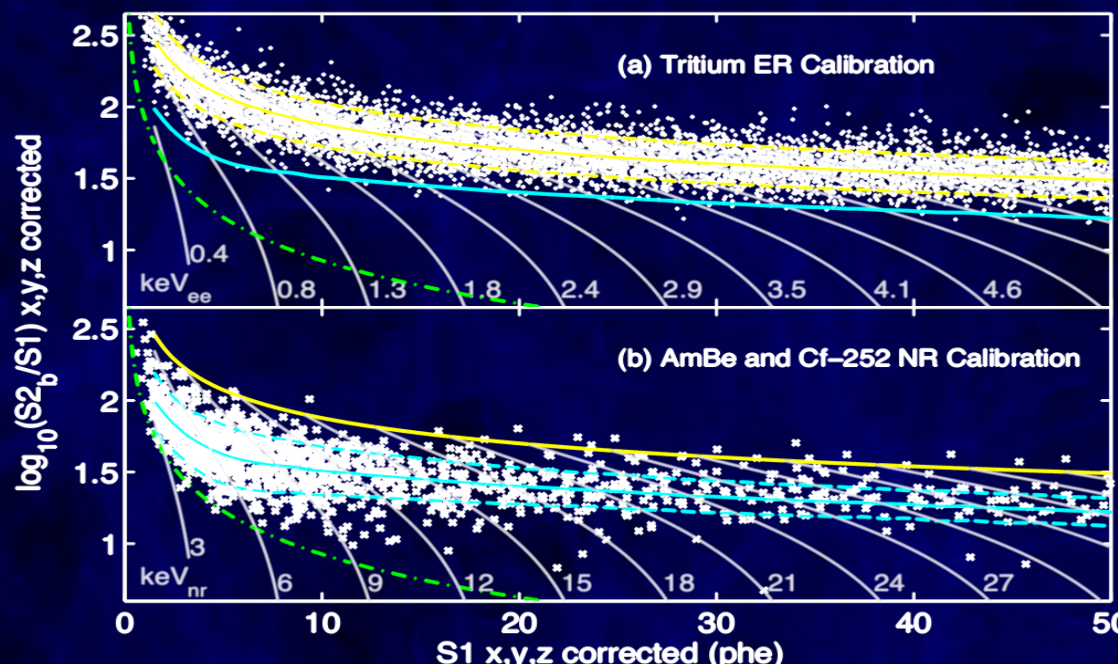
LUX @Soudan

in situ nuclear recoil energy calibration



Verbus UCLA2014

tritium electronic recoil background calibration

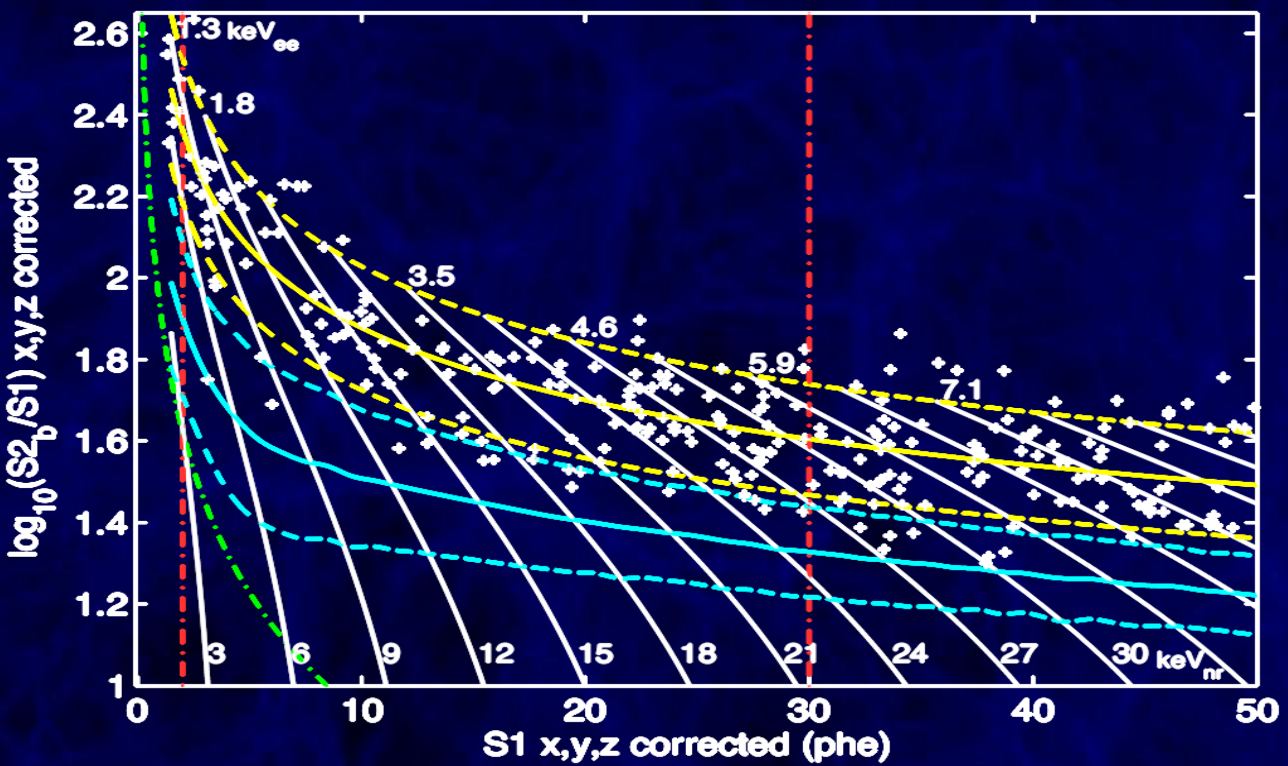


LUX 1310.8214

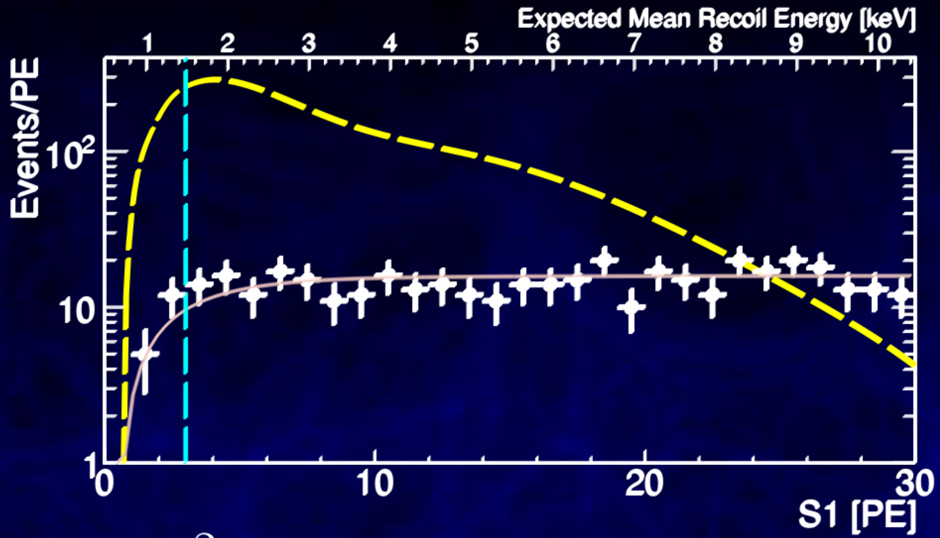
LUX @Soudan

first results: 85 live days, 118 kg
non-blind analysis, strongest limit to-date
expect re-analysis this month
& 300 days data late this year

LUX 1310.8214



XENON100 Solar Axion Search



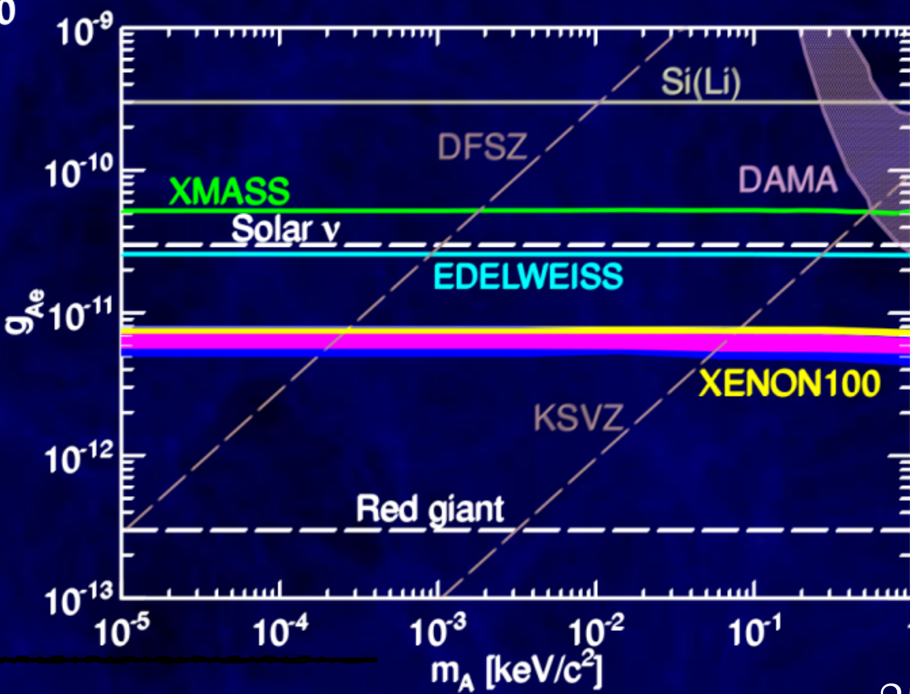
use ER background to search for axions coupling via axio-electric effect g_{Ae}

$\sigma \propto g_{Ae}^2$

$\phi_A \propto g_{Ae}^2$

$\Rightarrow \text{rate} \propto g_{Ae}^4$

exclude QCD axions
> 0.3 eV (DFSZ)
> 80 eV (KSVZ)
also derived limit on ALPs

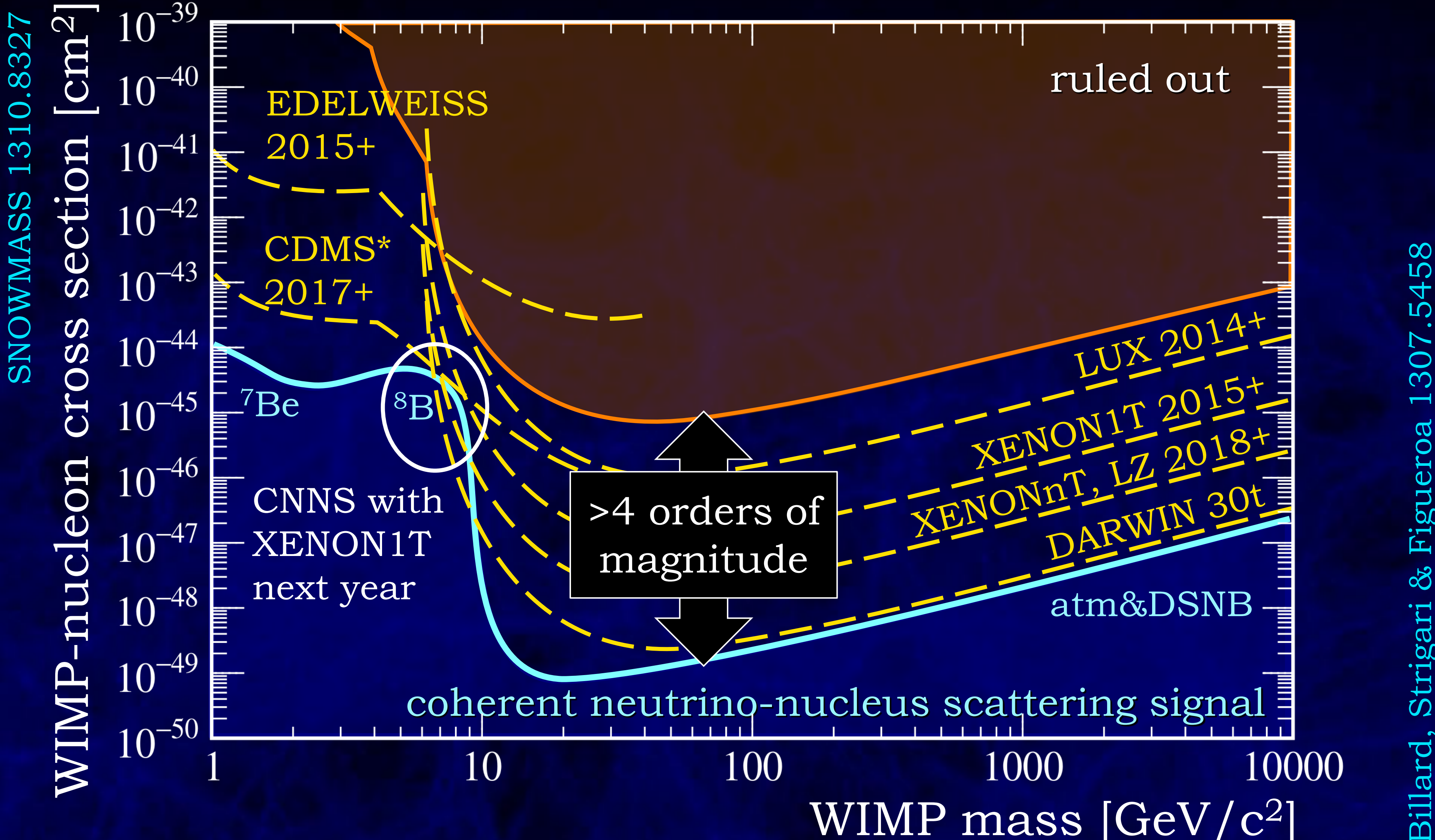


XENON100 1404.1455

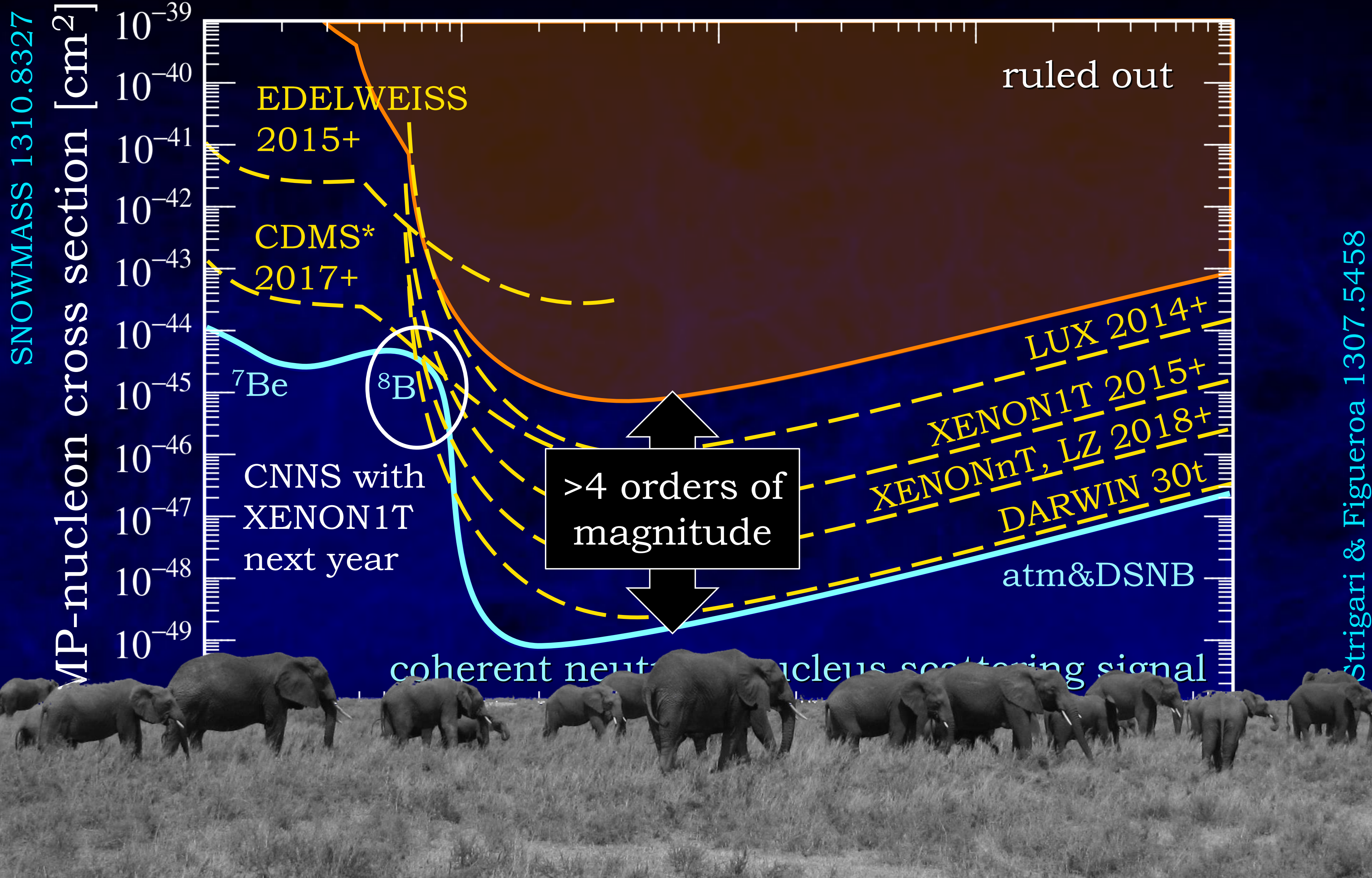
Expect XENON1T Data this Year

2000kg target, 2 orders of magnitude better sensitivity

Marching Forward

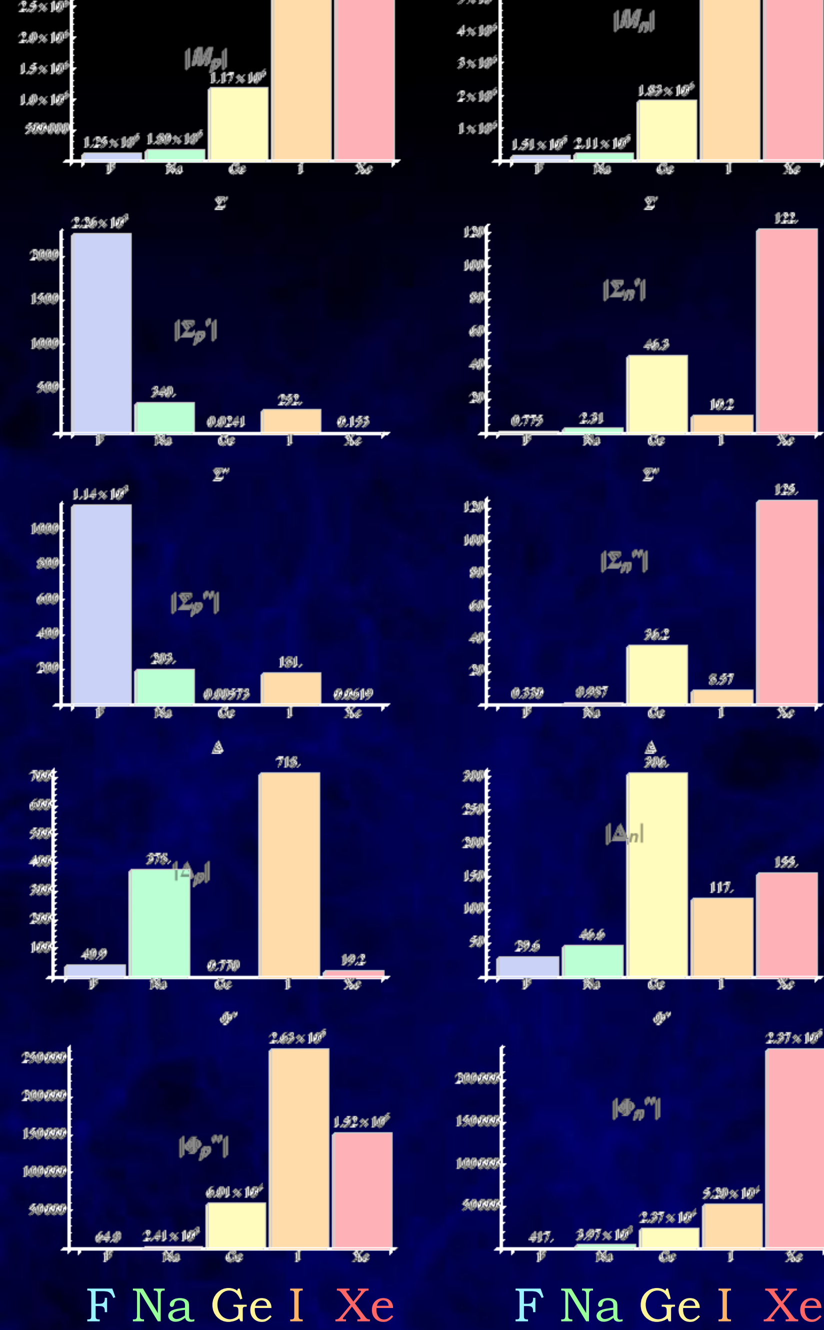


Marching Forward



Effective Theory

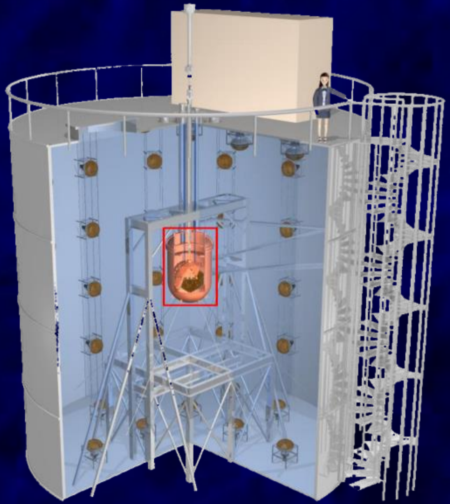
- Vastly different sensitivities of various targets: Variety indispensable
- Some require dedicated analyses
- Use relativistic or non-relativistic operators?
- Present results for each operator individually?



Fitzpatrick+ 1203.3542

XMASS @ Kamioka

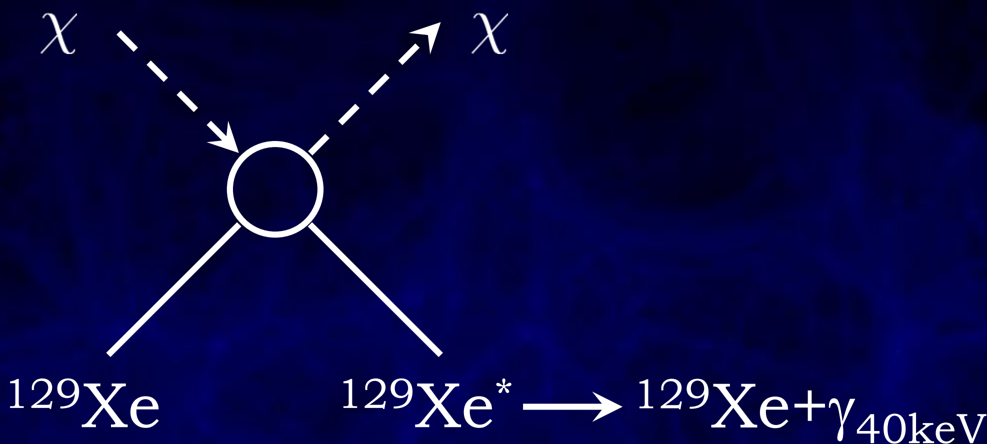
- Single-phase liquid xenon
- 642 2.5” hex PMTs
- 830kg total, 100kg fiducial
- Position from PMT hit pattern; self-shielding
- Patched after initial run, data taking since Nov 2013, rate ~1 evt/keV/ton/day

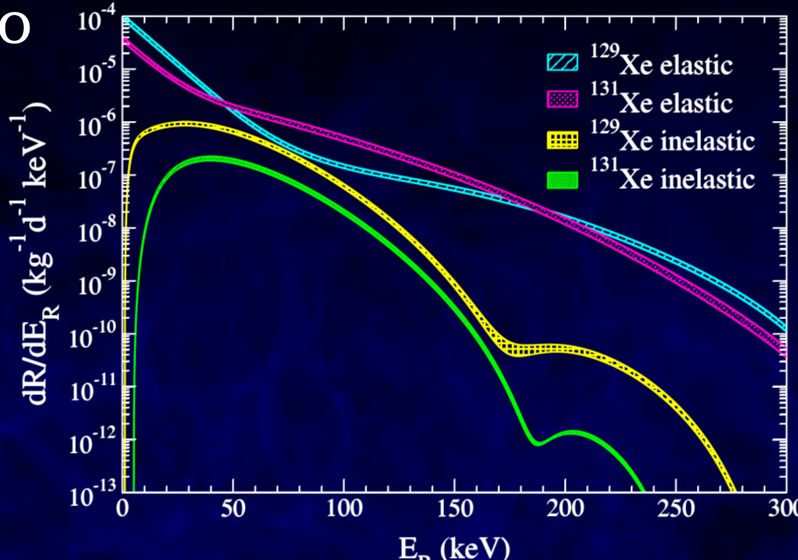


Moriyama, IDM2010

Inelastic Scattering

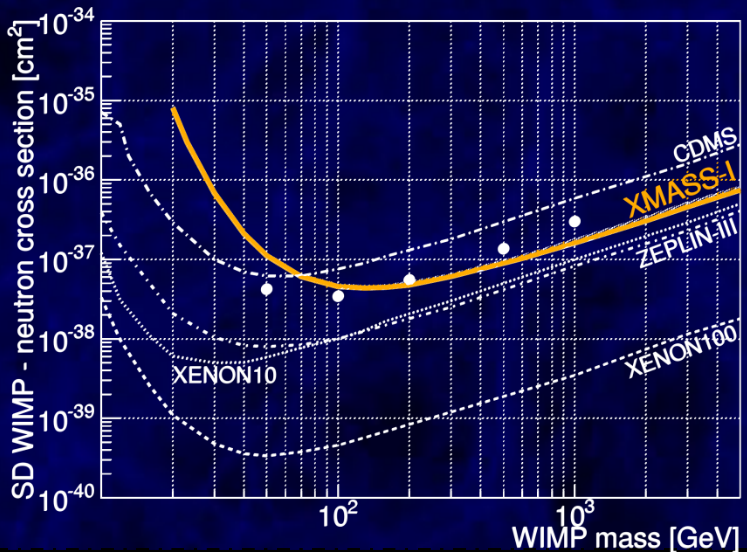
cross-check limits, measure halo

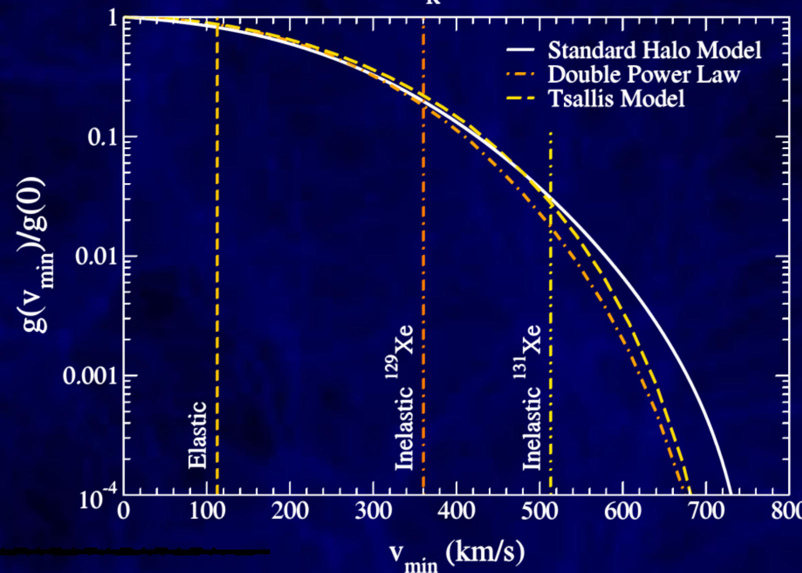




Baudis+ 1309.0825

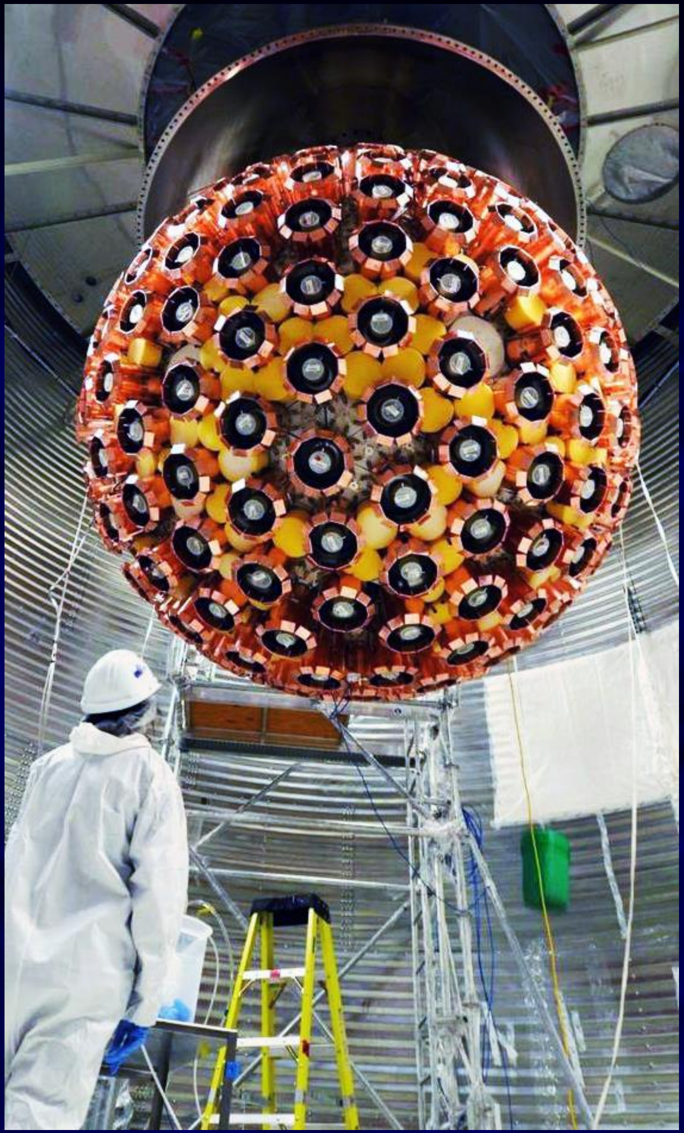
XMASS 1401.4737





DEAP-3600 @ SNOLAB

- Single phase liquid argon
- Acrylic vessel
- 3.6t argon total, 1t fiducial
- 255 8” PMTs
- Pulse shape discrimination
- 10^{-46}cm^2 sensitivity after 3 years
- LAr data this summer



Twitter @SNOLABscience

PICO @SNOLAB (=COUPP/PICASSO)

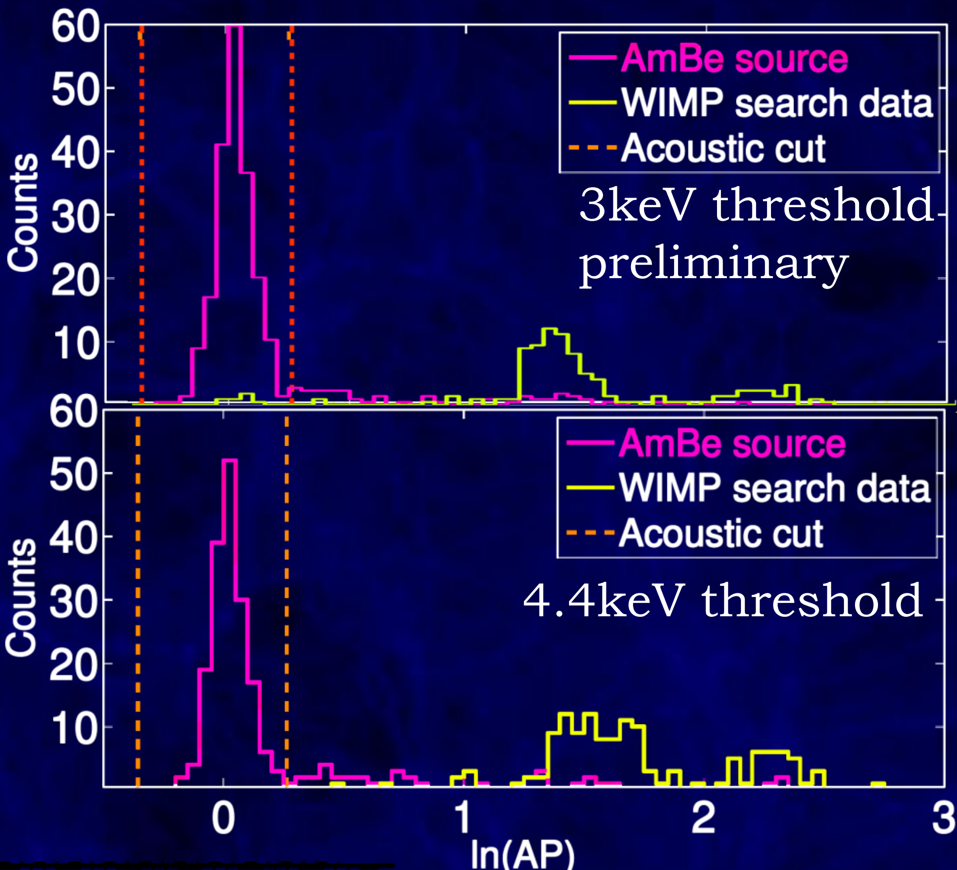
- Bubble chambers
- CF_3I or C_3F_8 targets: spin-dependent / light WIMPs
- Nucleate if $\int_R \mathrm{d}E/\mathrm{d}x$ sufficient
  detector blind ($<10^{-10}$) to electronic recoils
- Only integral energy spectrum; measure with different thresholds

H. Lippincott TAUP2013

PICO Results 2015

Photograph:

Acoustic signal: Alphas pop louder than nuclear recoils, discriminate >98%



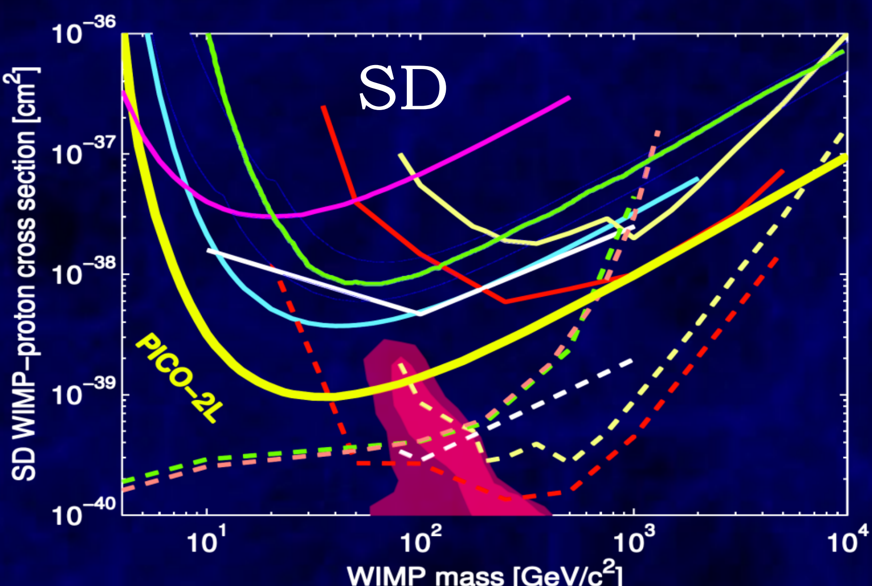
O. Harris LLWI2015

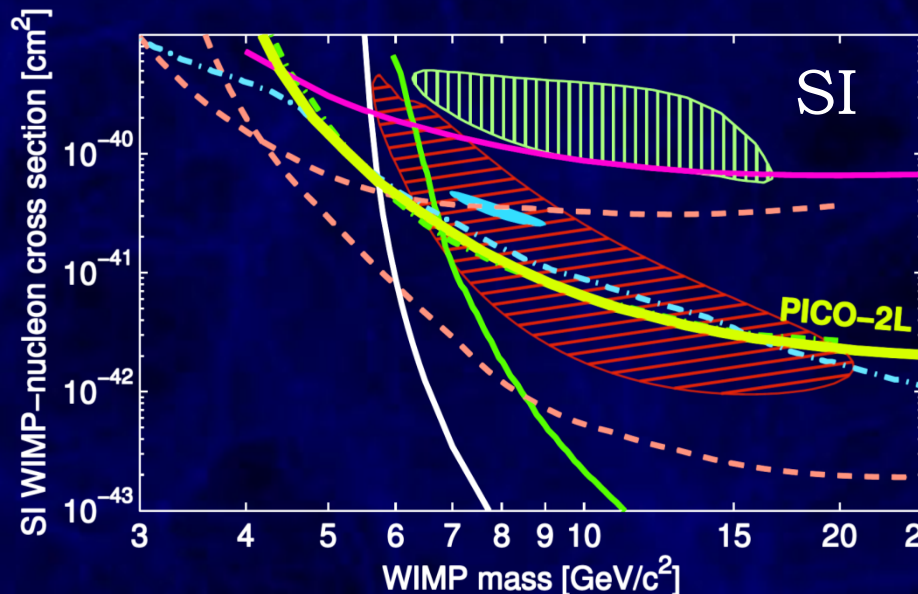
PICO 1503.00008 O.Harris LLWI2015

PICO recent limit and outlook

- Limits from 2.9kg C_3F_8 chamber
- 211 kg days total at 4 thresholds (3-8keV)
- 12 events observed (1 expected), correlated with expansion cycles (corrosion particles?)
- Leading spin-dependent (proton only) limits

PICO 1503.00008



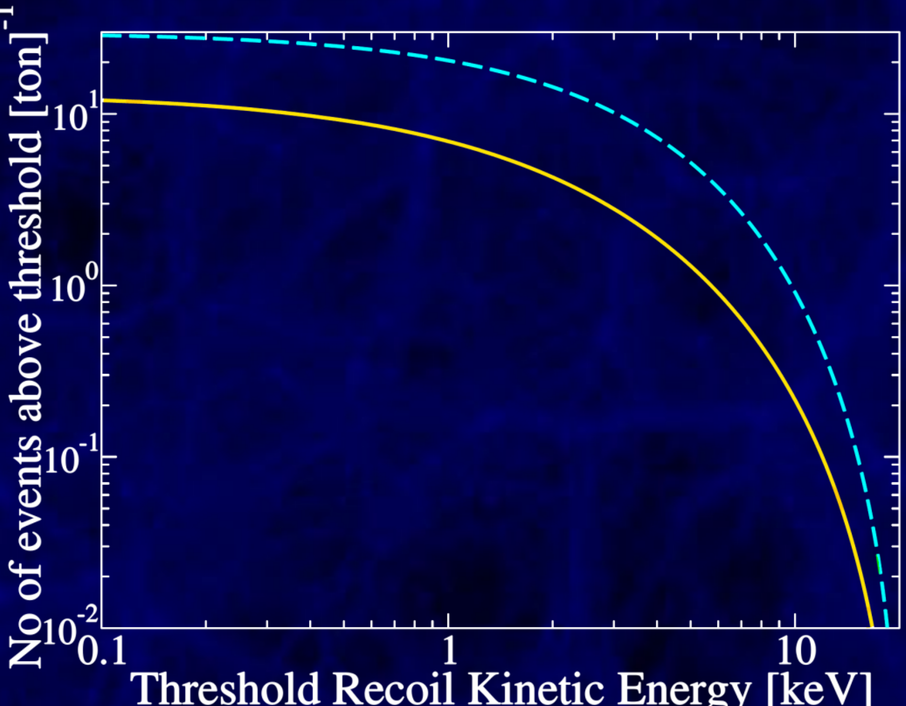


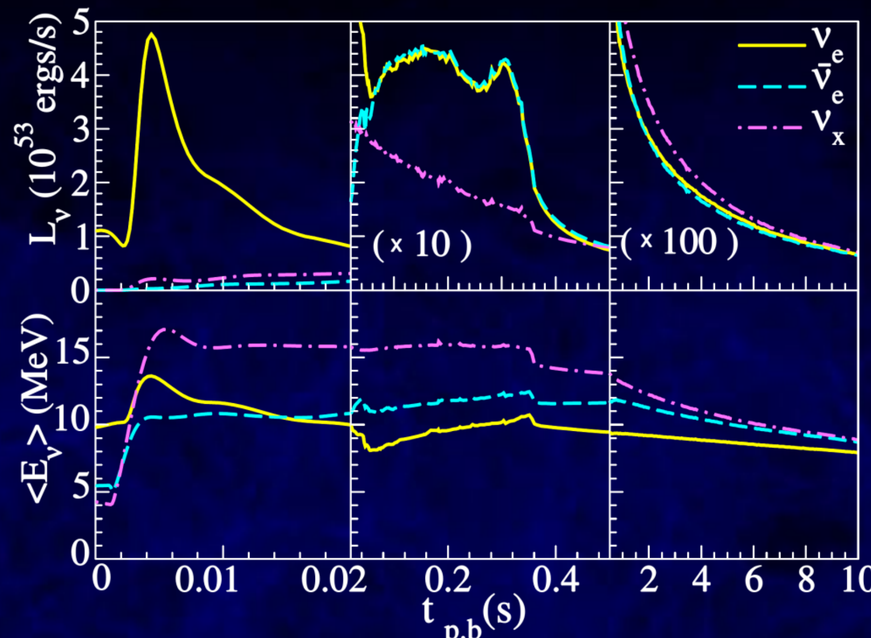
Soon: >3000 kg days from 25kg CF_3I chamber (PICO 60)

Yes, Even Supernovas

Assume Galactic Supernova (10kpc, Basel/Darmstadt)

CC: $\mathcal{O}(0.1)\bar{\nu}_e$ per ton
CNNS: $\mathcal{O}(1)$ per ton





Flavor-independent: complementary information

Chakraborty, Bhattacharjee & Kar 1309.4492