WIMP Dark Matter Search with XENON and DARWIN

Xe XENON Dark Matter Project

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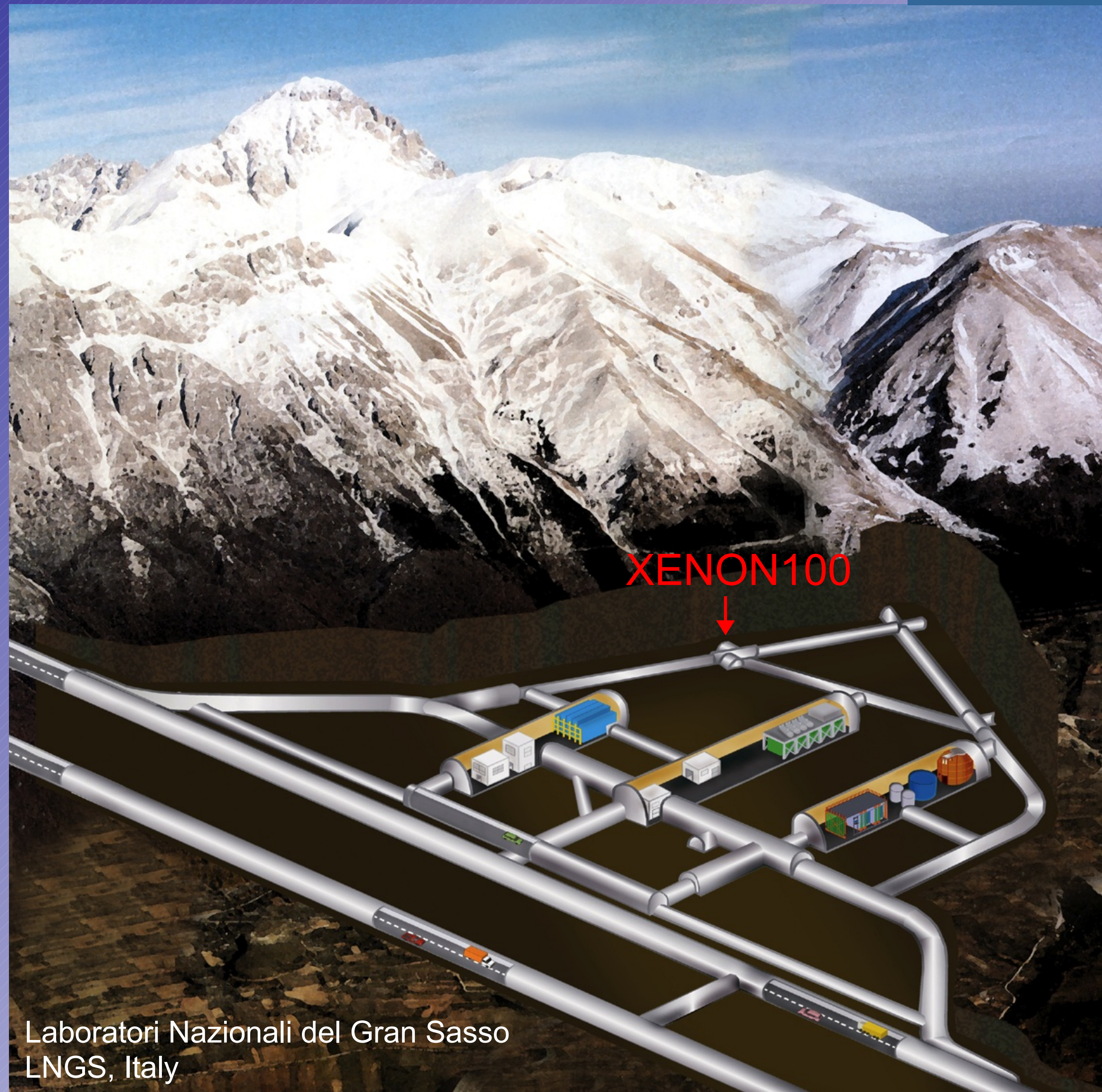
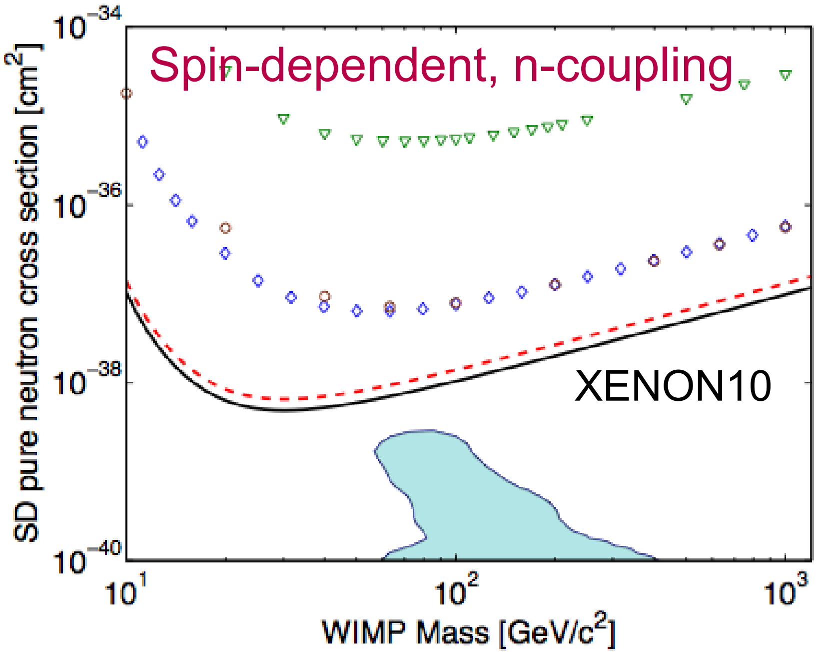
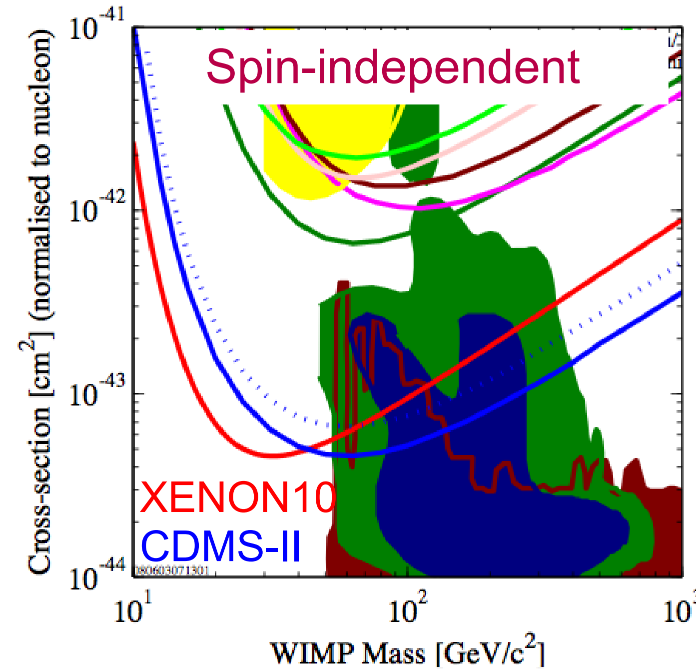
6th Patras Workshop
Zurich
July 7, 2010

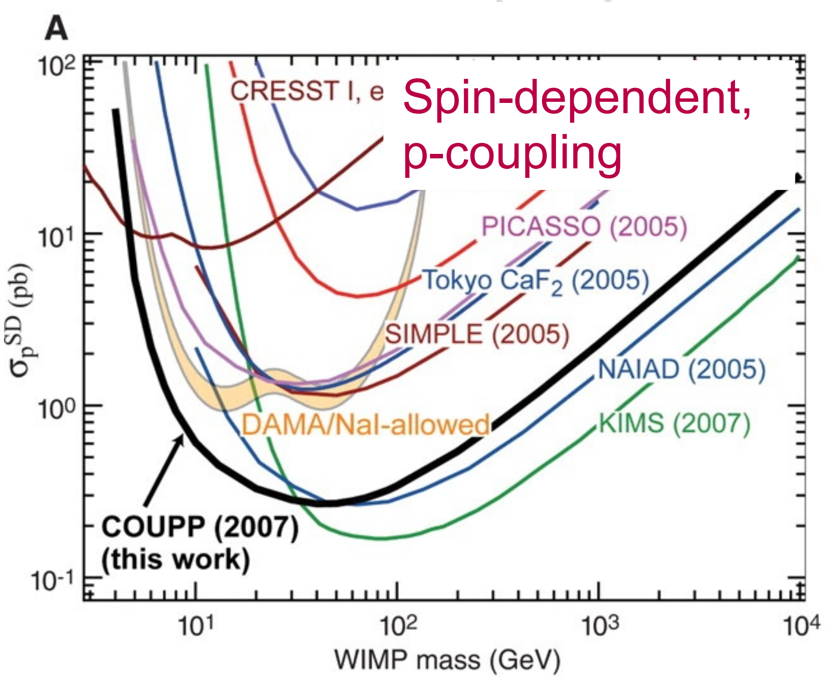


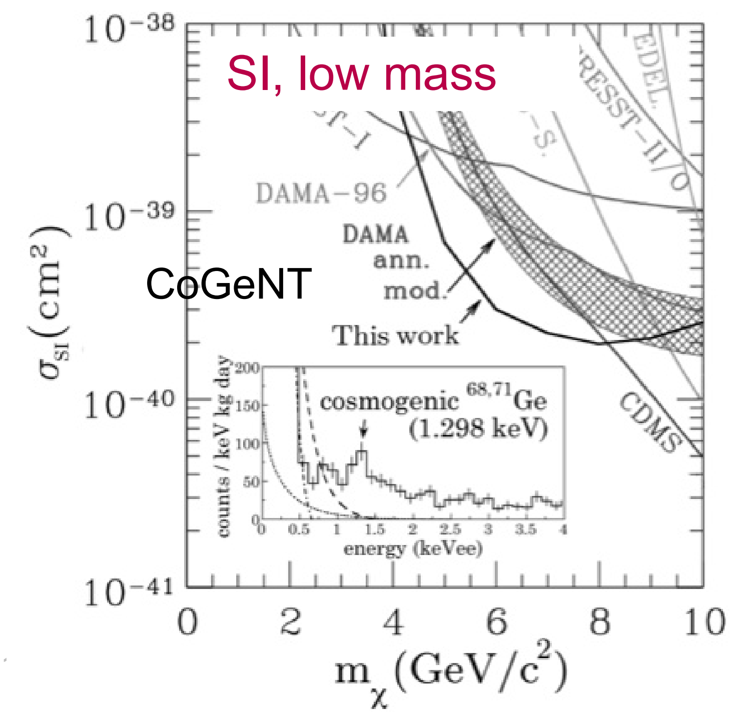
Current Status in WIMP DM Sensitivities (2009)



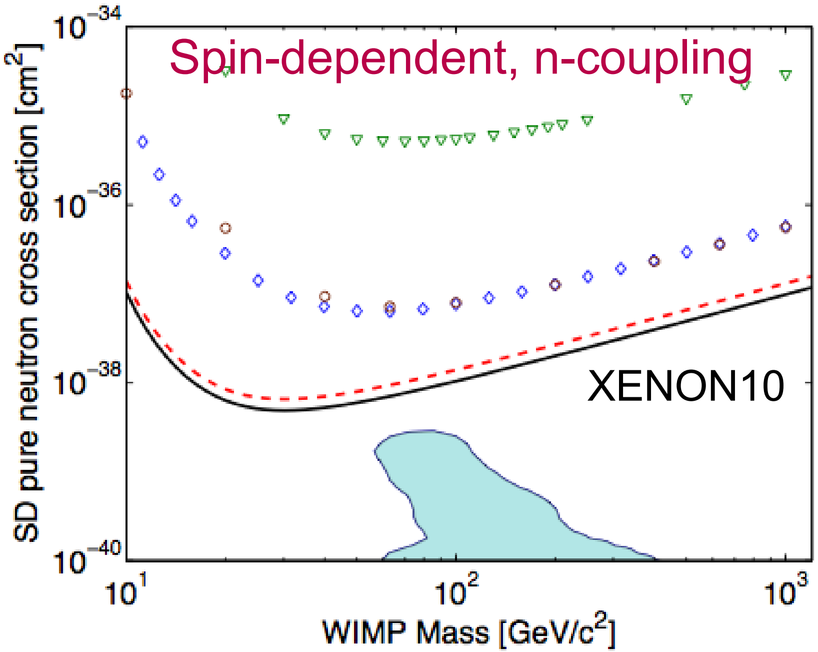


- J. Angle et al., 2008 PRL 101 091301 (XENON10 SD)
- J. Angle et al., 2008 PRL 100 (2) 021303 (XENON10 SI)
- Z. Ahmed et al., arxiv:0802.353v1 (CDMS-II SI)
- C.E. Aalseth et al. arxiv:0807.0879v1 (CoGeNT SI)
- E. Behnke et al., 2008 Science 319, 933 (COUPP SD)
- Recent additions (not plotted): Zeplin-III SI, SD arxiv:08/09 limits ~ Xe10





Current Status in WIMP DM Sensitivities (2010)



XENON10 SD, 2008
PRL 101 091301

XENON10 SI, 2008
PRL 100 (2) 021303

XENON100 SI, 2010:
arxiv:1005.0380,1005.2615

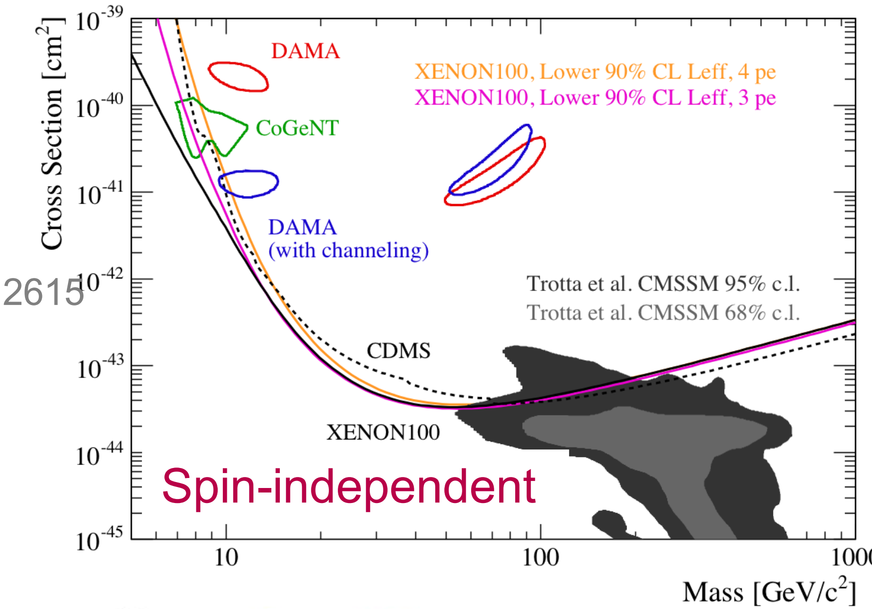
CDMS-II, 2010:
Science 327, 1619

CoGeNT SI:
arxiv:1002.4703

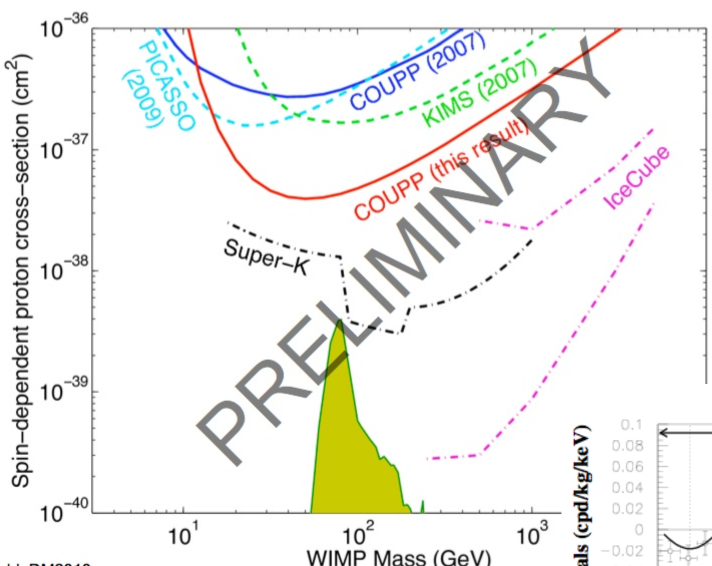
DAMA/LIBRA, 2010:
arxiv:1002.1028

COUPP SD:
2008: Science 319, 933
2010 prelim: DM2010 conf.

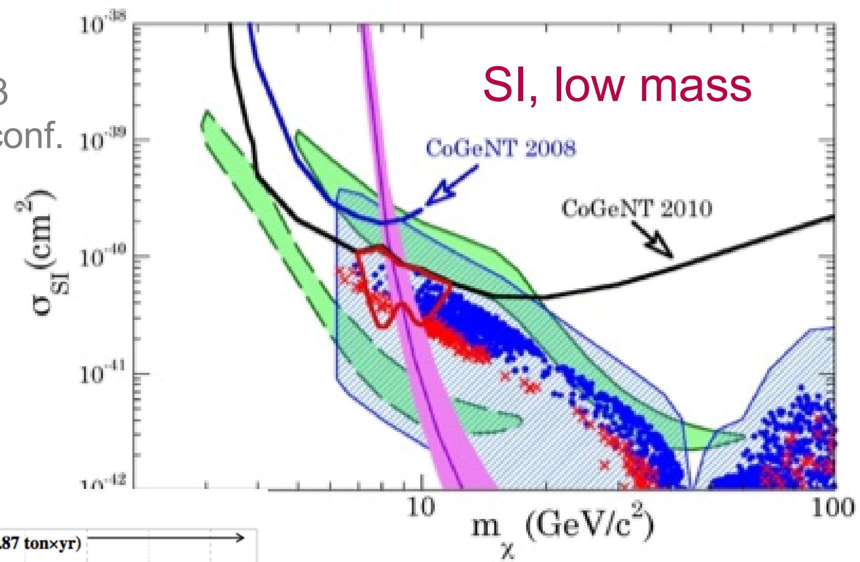
PICASSO SD, 2009:
Phys.Lett. B 682, 185



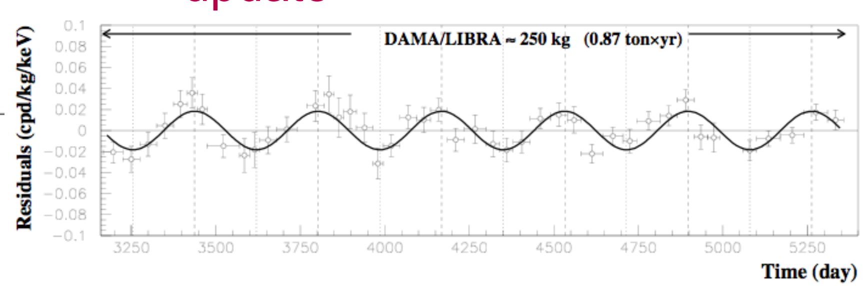
Spin-dependent, p-coupling



C.E. Dahl, DM2010
February 26, 2010

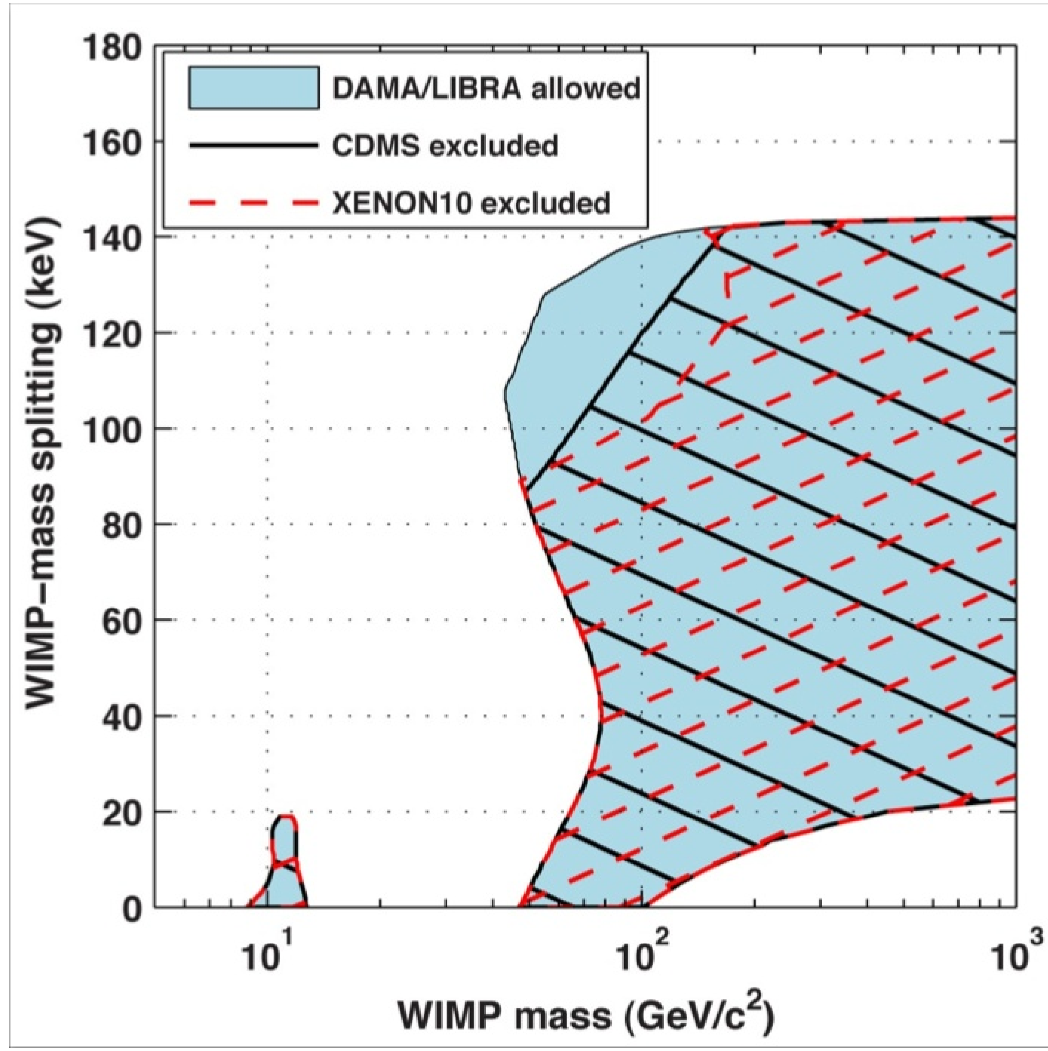


Annual modulation update



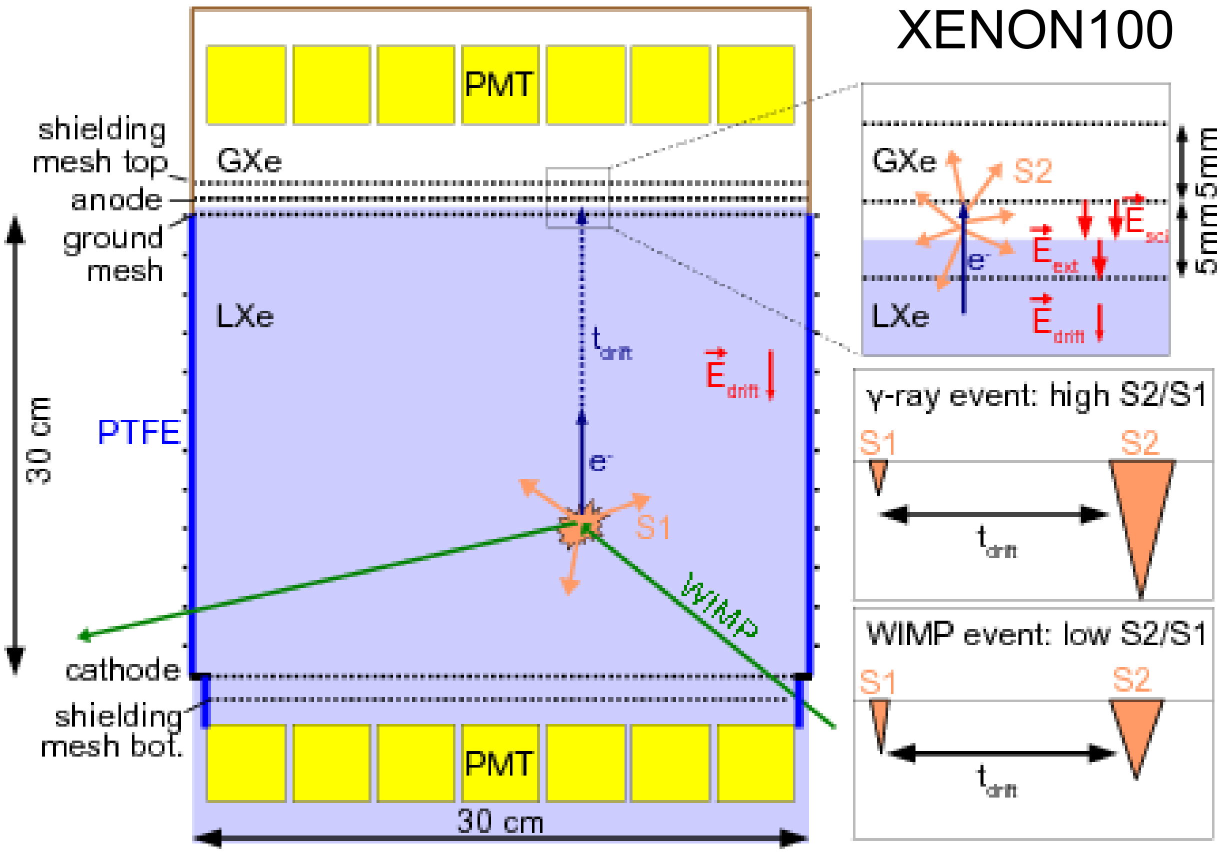
Inelastic Dark Matter Limits

- Assume DM can scatter only in a low-lying excited state, i.e., elastic scattering is suppressed.
- This makes DAMA/LIBRA annual modulation still compatible with XENON10 & CDMS in a parameter space with energy splitting ~90 – 140 keV at WIMP masses 50 – 140 GeV/c².
- XENON100 will cover the entire allowed parameter space.



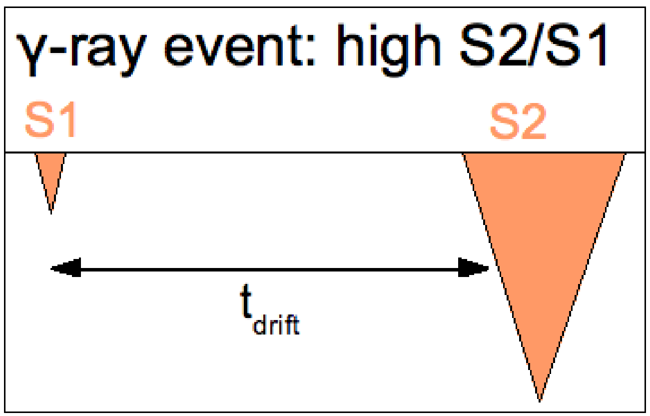
The Liquid Xenon Dual Phase TPC

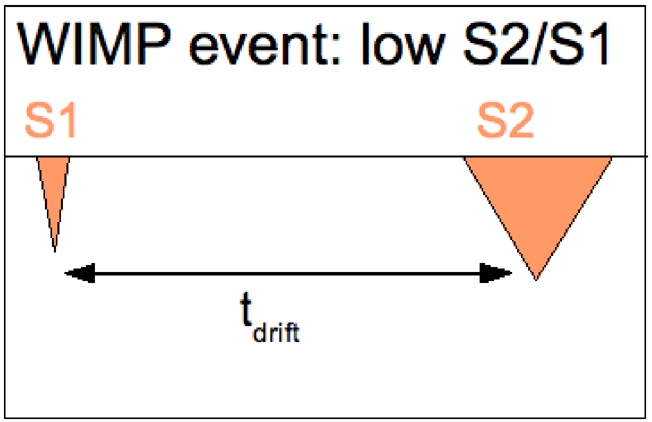
- Wimp recoil on Xe nucleus in dense liquid (2.9 g/cm^3)
  ⟶ Ionization + UV Scintillation
- Detection of primary scintillation light (S1) with PMTs.
- Charge drift towards liquid/gas interface.
- Charge extraction liquid/gas at high field (5 kV/cm) between ground mesh (liquid) and anode (gas)
- Charge produces proportional scintillation signal (S2) in the gas phase (10 kV/cm)
- 3D position measurement:
  - X/Y from S2 signal. Resolution few mm.
  - Z from electron drift time (~1 mm).

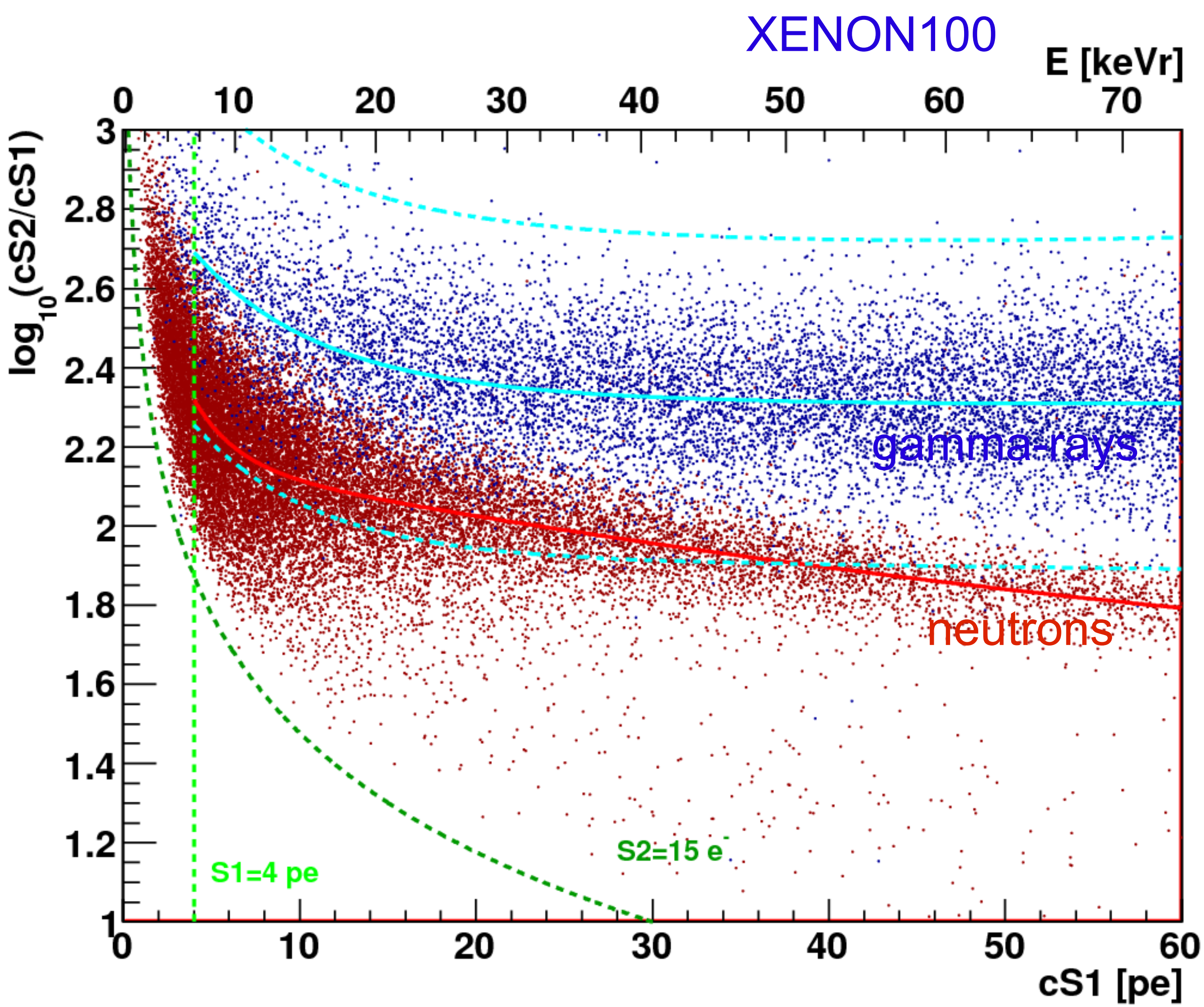


Background Discrimination in Dual Phase Liquid Xenon TPC's

Ionization/Scintillation Ratio S2/S1

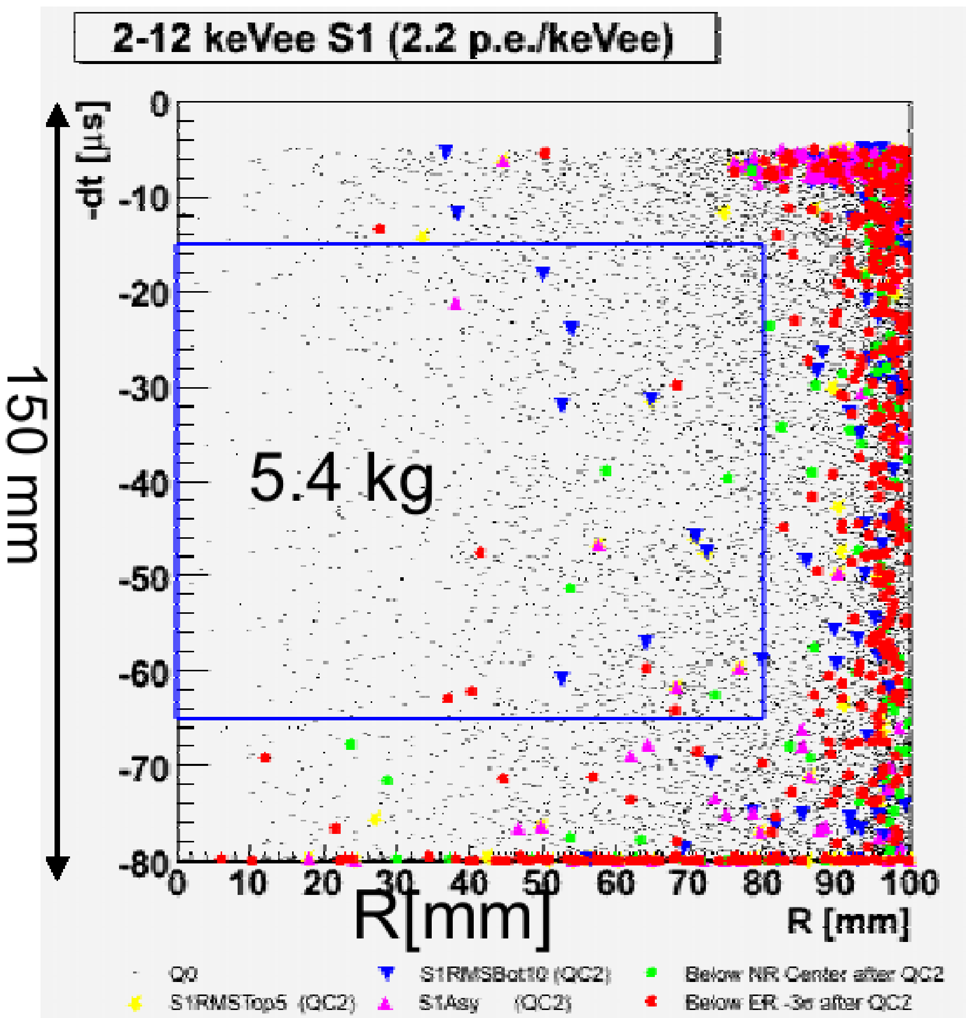




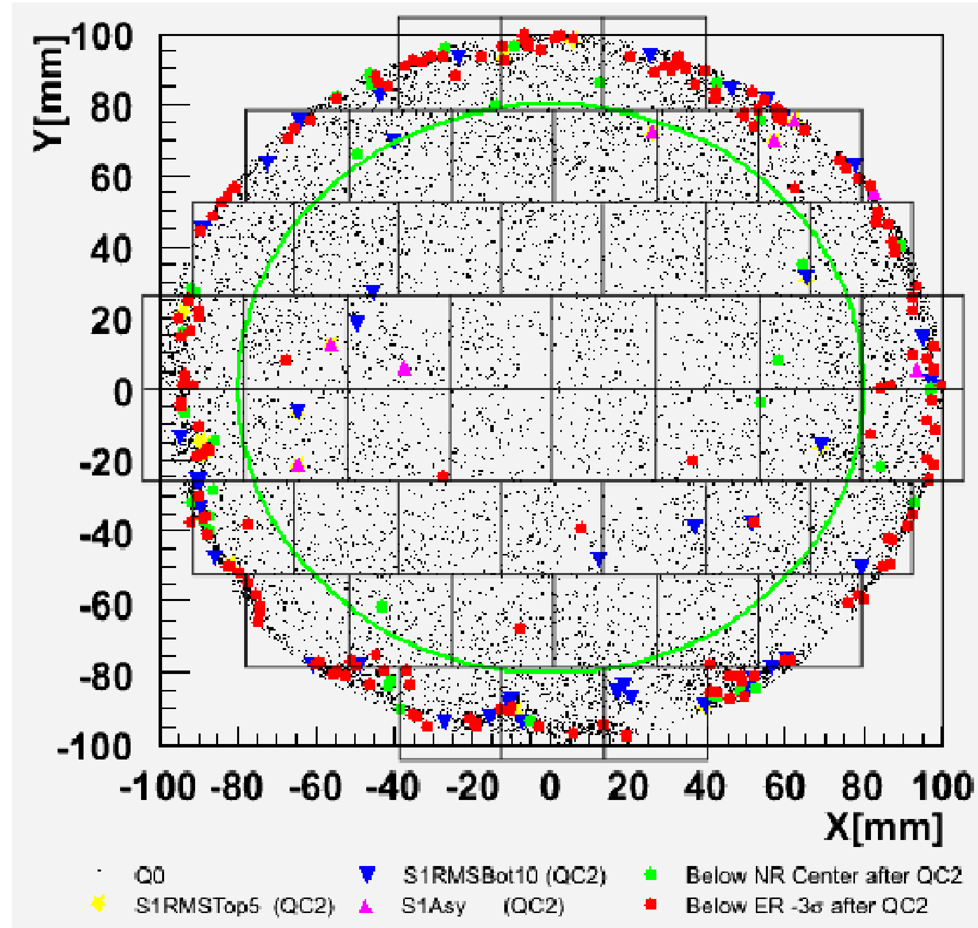


Background Discrimination in Dual Phase Liquid Xenon TPC's

3D Position Resolution: fiducial cut, singles/multiples

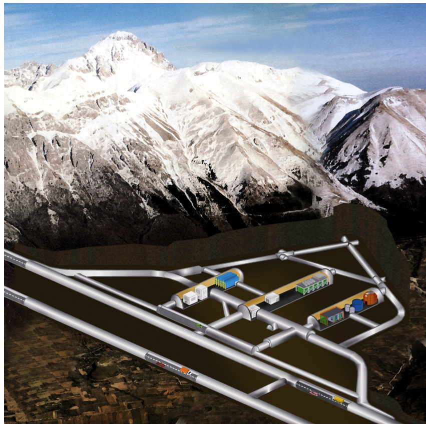


XENON10



The XENON Program

Collaboration: US (3) + Switzerland (1) + Italy (2) + Portugal (1) + France (1) + Germany (3) + China (1) + Netherlands (1) + Israel (1)



GOAL: Explore WIMP Dark Matter with a sensitivity of σ_s~10^{47} cm^2.

- Requires ton-scale fiducial volume with extremely low background.

CONCEPT:

- Target LXe: excellent for DM WIMPs scattering.
  - Sensitive to both axial and scalar coupling.
- Detector: two-phase XeTPC: 3D position sensitive, self-shielding.
- Background discrimination: simultaneous charge & light detection (>99.5%).
- PMT readout with >3 pe/keV. Low energy threshold for nuclear recoils (~5 keV).

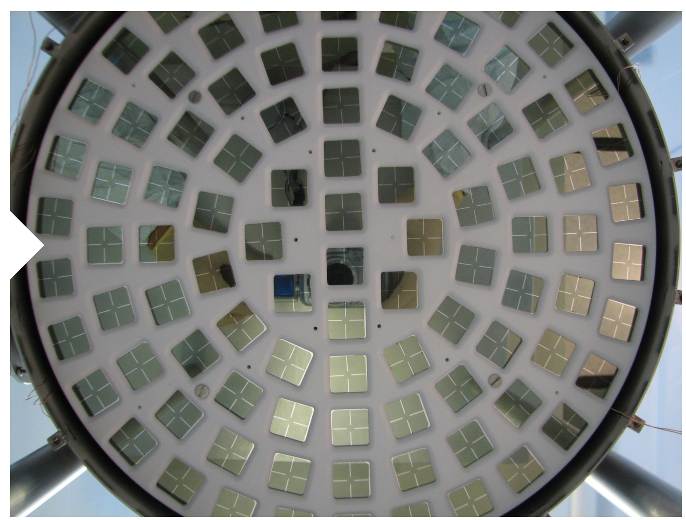
PHASES:

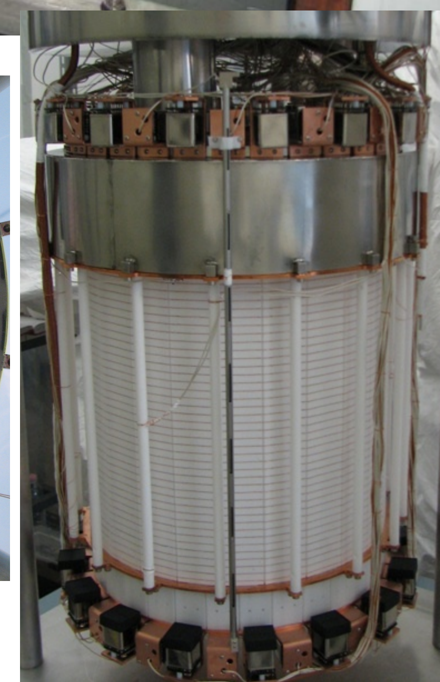
R&D	XENON10	XENON100	XENON1T
Start: 2002	2005-2007	2008-2011	2011-2015
	Proof of concept. Total mass: 14 kg 15 cm drift. Best limit in '07: σ_s~10^{43} cm^2	Dark Matter run ongoing. Total mass: 170 kg 30 cm drift. 11 days: σ_s ~ 3 x 10^{44} cm^2 Goal: σ_s ~ 2 x 10^{45} cm^2	Technical design studies. Total mass: ~2.4 t 90 cm drift. Goal: σ_s ~ 3 x 10^{47} cm^2

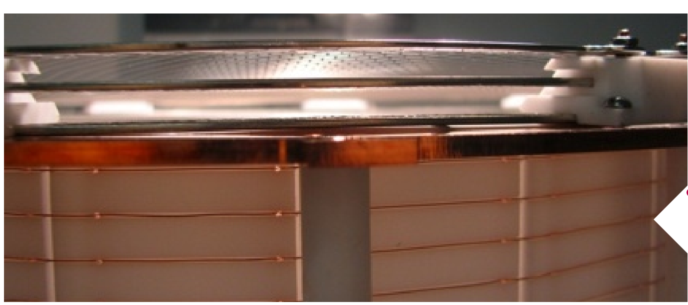
The Current Generation: XENON100 (2008-2011)

- 100 times lower background than XENON10
  - Material screening
  - Active LXe Veto
  - Upgrade of XENON10 shield (Cu, water)
  - Cryocooler/Feedthroughs outside shield
  - Low activity stainless steel
  - LXe self-shielding
- ~7 times larger target mass
  - 62 kg in target volume, 165 kg total LXe
- New PMTs with lower activity and high QE
- Improved electronics, grids, ...
- Gamma & neutron calibrations.
- DM search since Jan/13/2010.

first results!

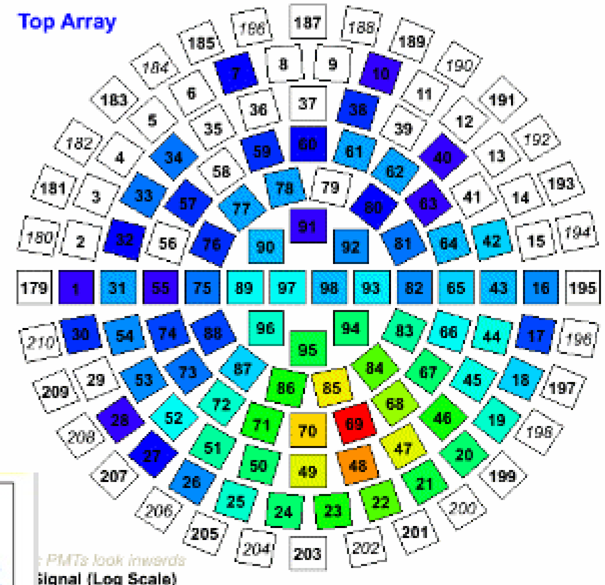


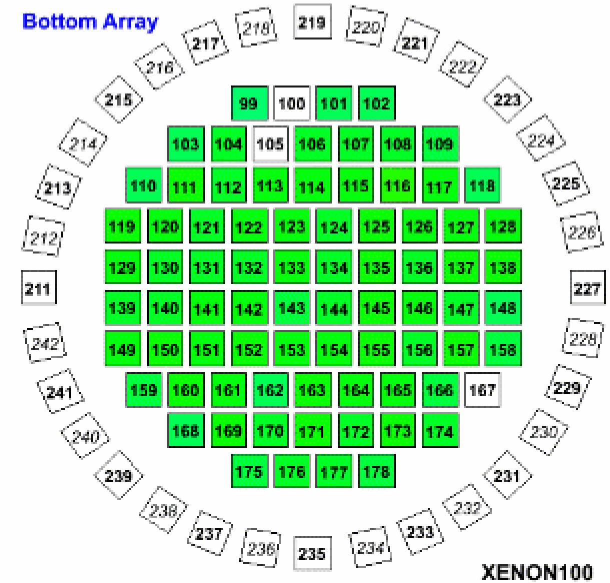


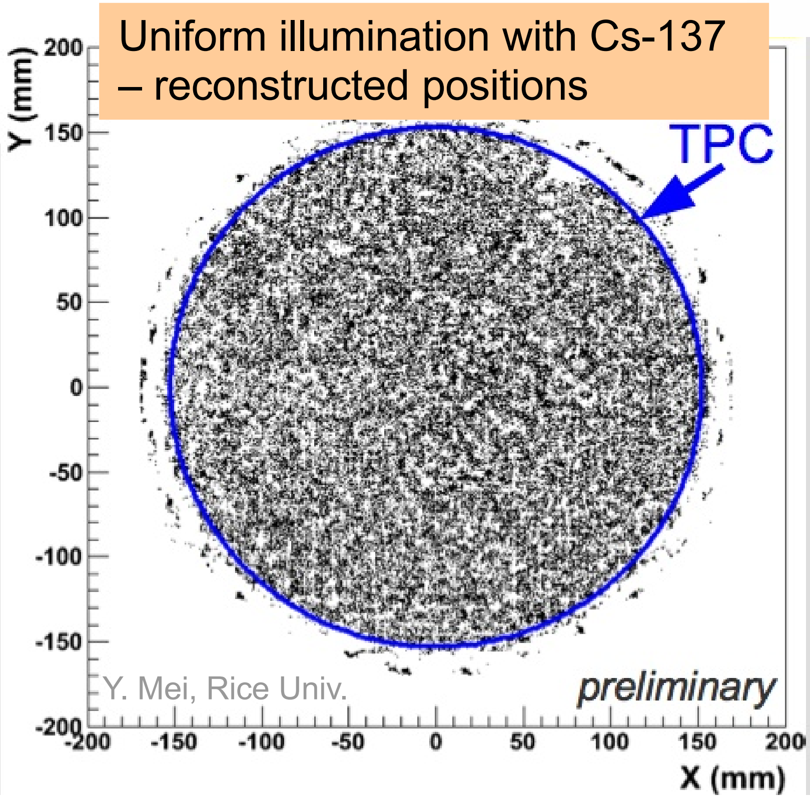


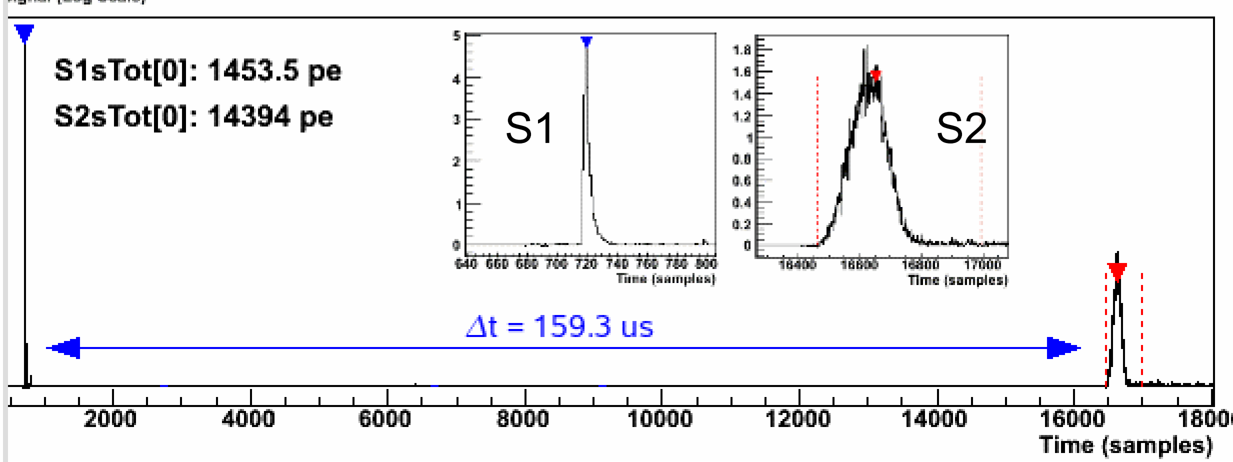
Event Signatures in XENON100

- Position Reconstruction with S2 signal on top PMT array.



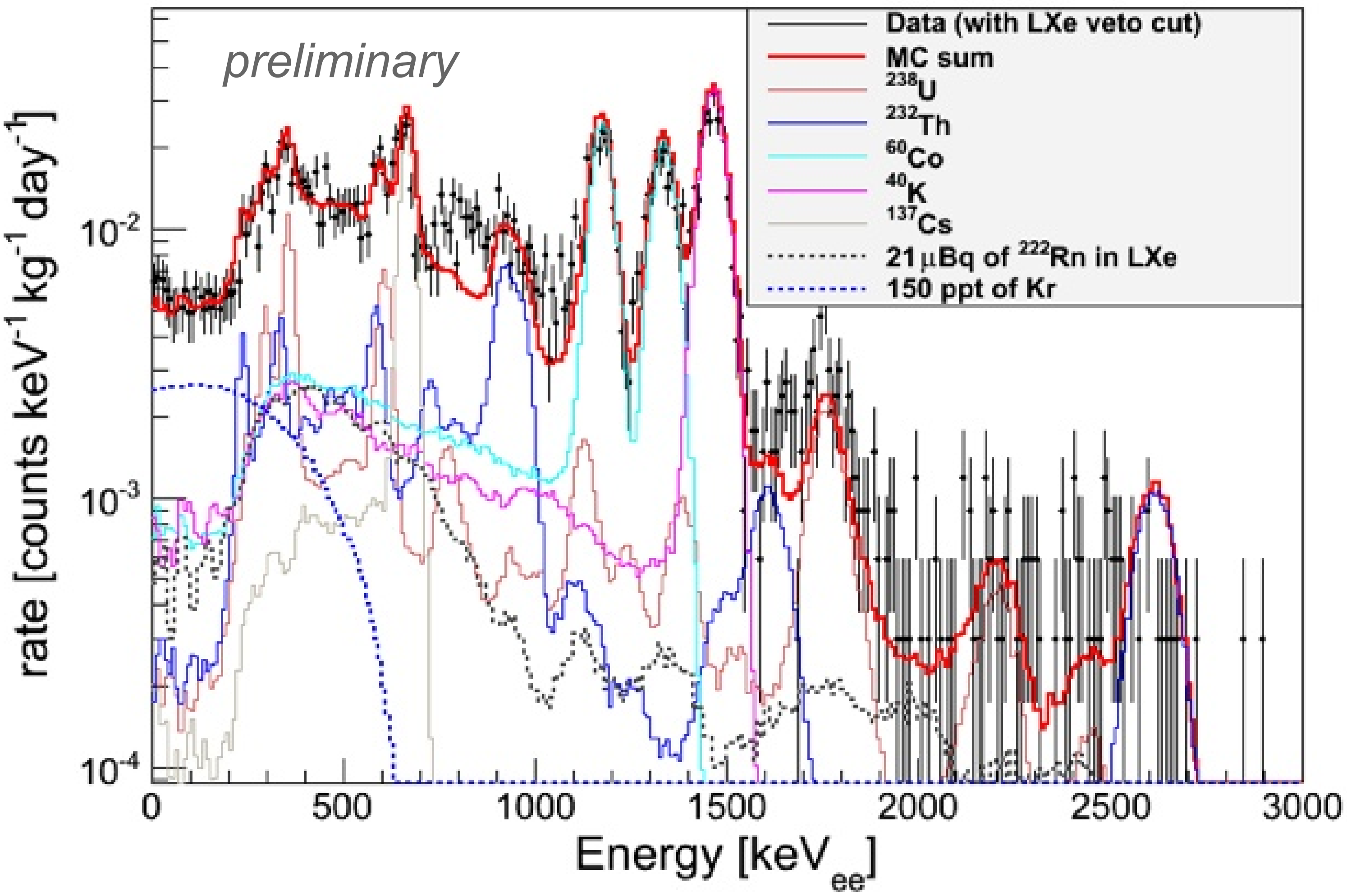




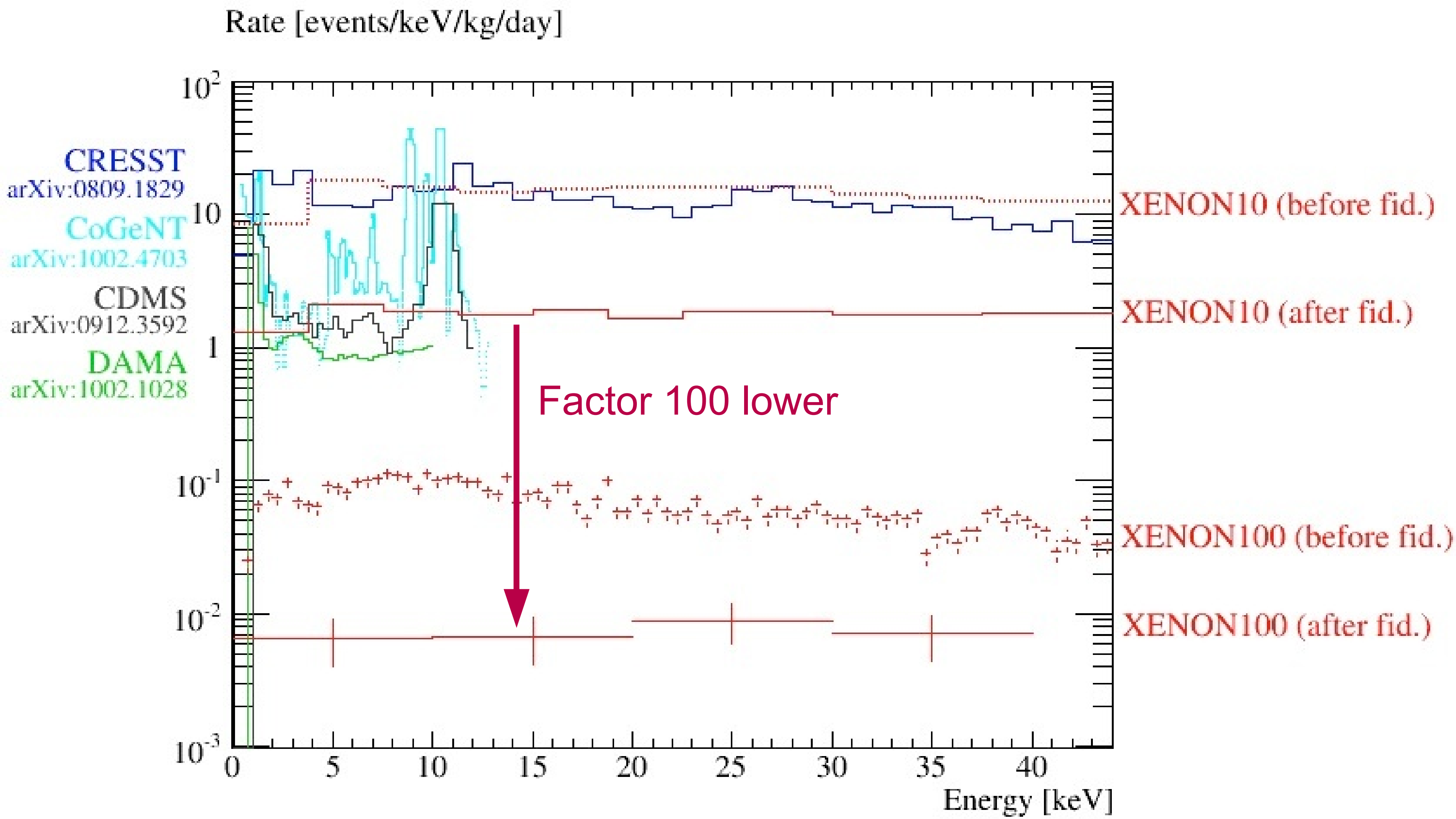


Drift length = 1.84 mm/μs × 159.3 μs = 293 mm

XENON100: Understanding the Background

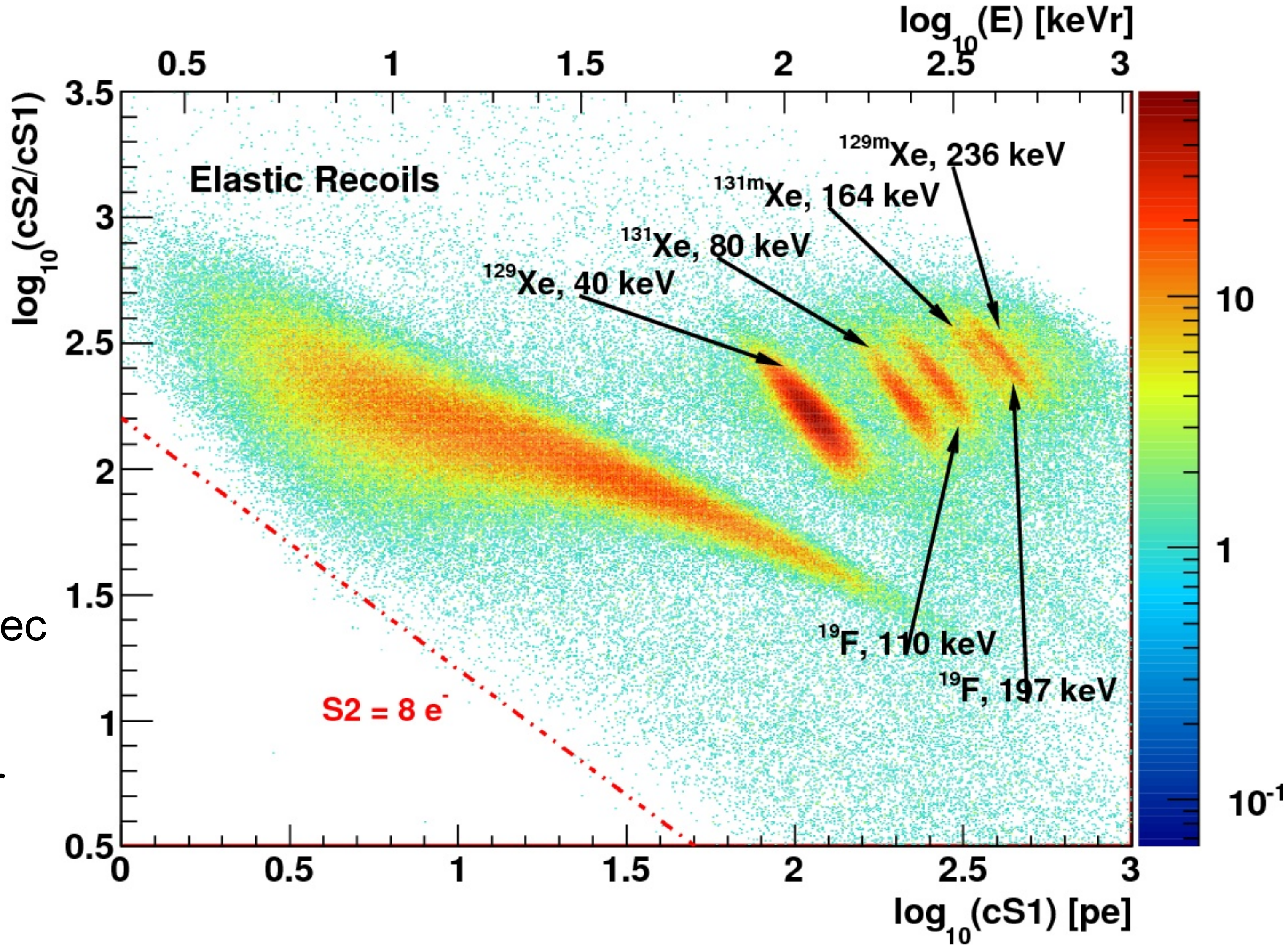


The Lowest Background Dark Matter Detector



XENON100 “First Light” data

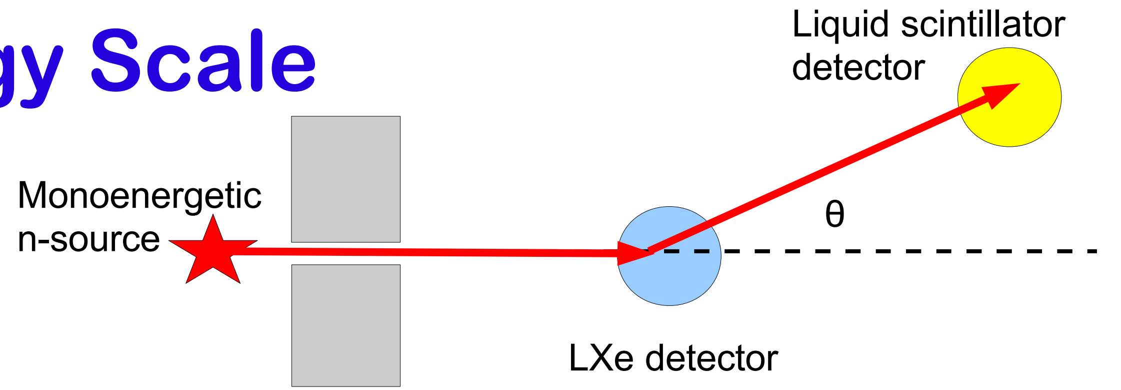
Neutron Calibration of XENON100



- 3.7 MBq (220 n/s) AmBe source from Dec 15-18 '09
- 3 × 10^6 events in 3 d
- 5 × 10^4 single scatter nuclear recoils <100 keVr.

- High statistics to be able to describe the nuclear recoil band up to higher energies.
- Neutron calibration also gives gammas from inelastic recoils and activation: used to infer the spatial dependence of S1 and S2 signals.

Nuclear Recoil Energy Scale



$$E_n \times L_{eff}(E_n) = \frac{S1}{L_e} \times \frac{S_e(\vec{\epsilon})}{S_n(\vec{\epsilon})}$$

$$L_{eff}(E) = \frac{L_n(E)}{L_e(E_0)}$$

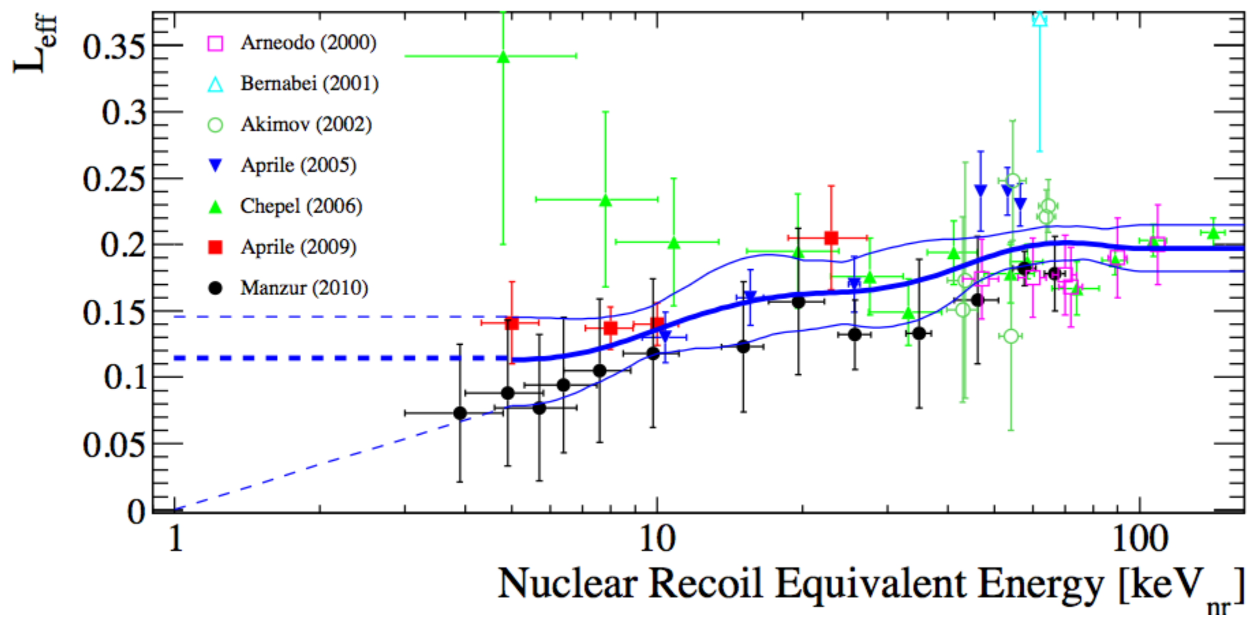
L_{eff}: Relative scintillation efficiency of nuclear recoils at zero field

L_e: Light yield [p.e./keV] for electron recoils at reference energy E_0 (122 keV)

$S1$: primary scintillation signal

S_e: Light quenching due to field for electron recoils at energy E_0

S_n: Light quenching due to field for nuclear recoils

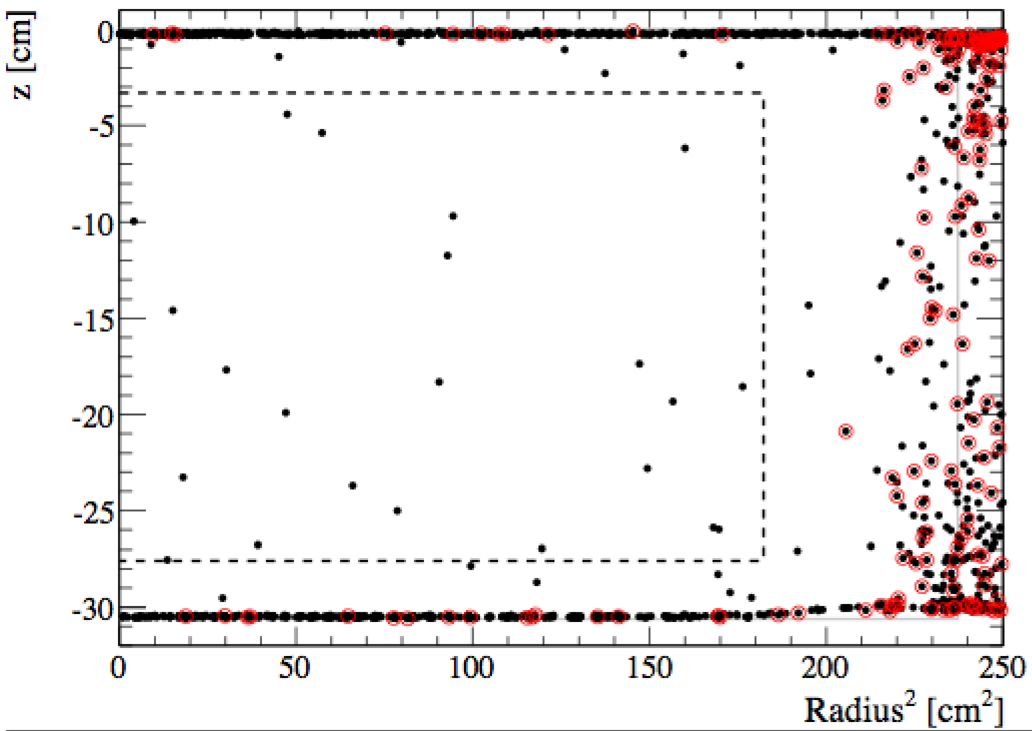


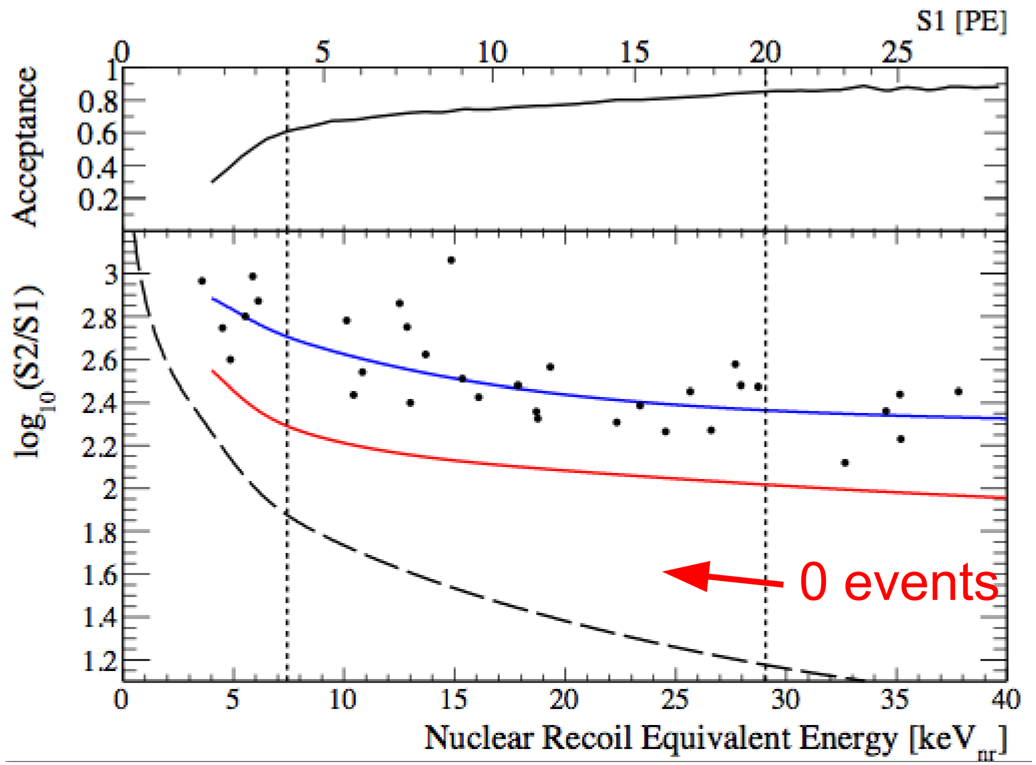
- Fit of available data to relative scintillation efficiency for nuclear recoils.
- Ongoing efforts to measure L_{eff} with higher accuracy.
- XENON100: [4-20] pe ~ [8.7-32.6] keVr

Data:
Arneodo 2000
Bernabei 2001
Akimov 2002
Aprile 2005
Aprile 2009
Sorensen 2009
Manzur 2010

Analysis of “First Light” XENON100 Data

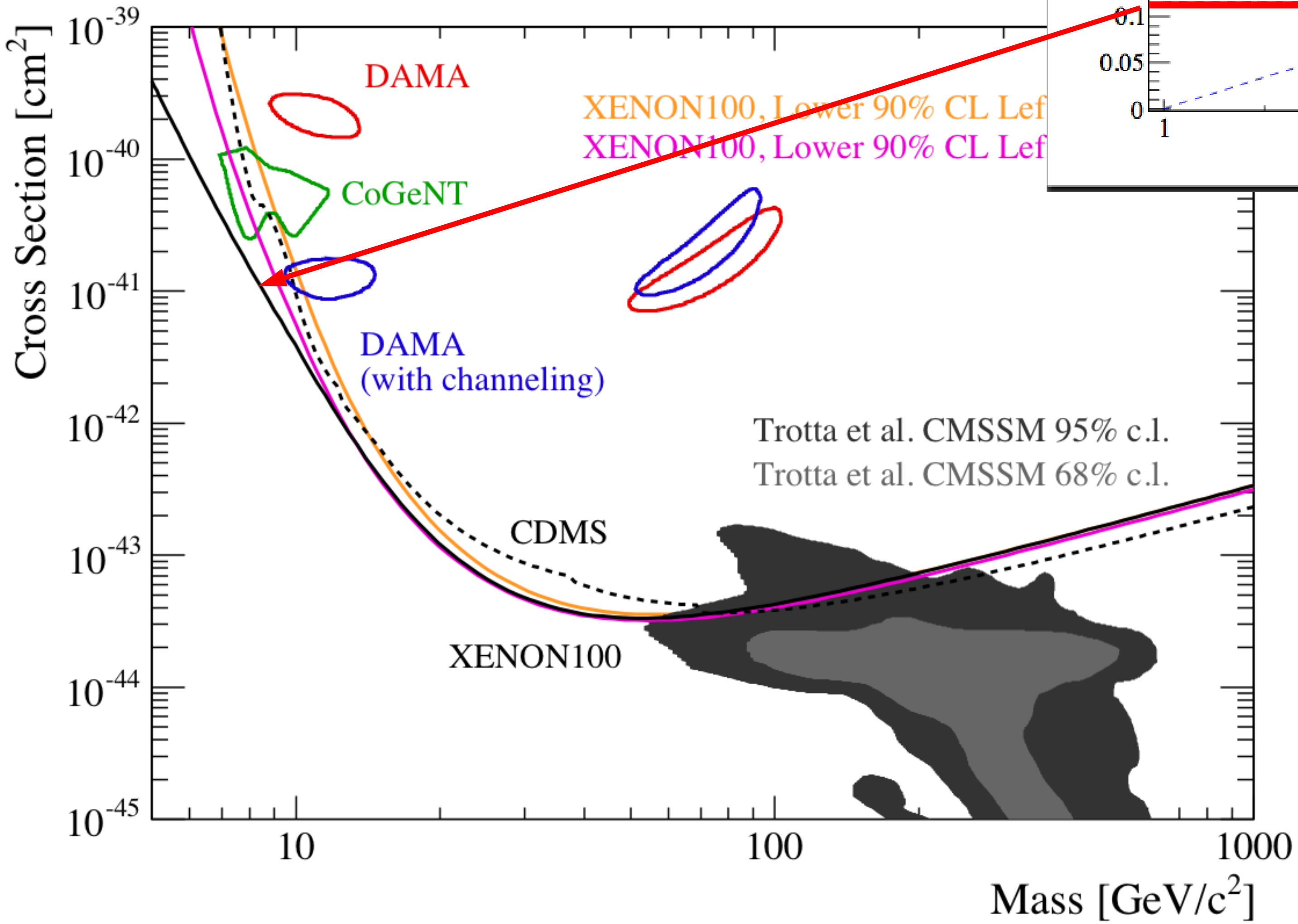
- 11.2 live days of background data from October-November 2009
- Non-blind analysis: but cuts optimized on neutron and gamma calibration data.
- Only basic event selections are applied.
- 170 kg days exposure **background-free**.

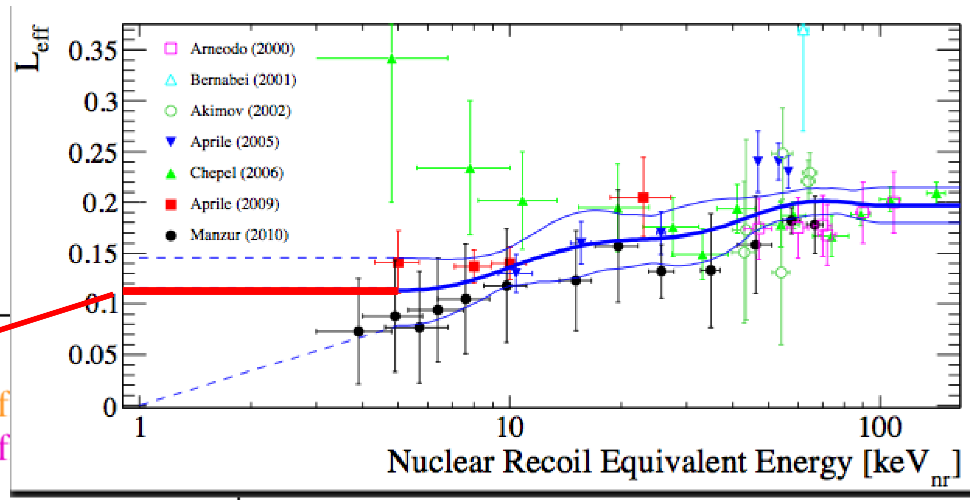




XENON100 Spin-Independent Limit

- 11.2 live days.
- 170 kg d spectrum-averaged exposure.
- Best SI upper limit of
  3.4×10^{-44} cm^2 @ M_{DM} = 55 GeV/c^2





L_{eff} : global fit with constant extrapolation.

XENON100 Spin-Independent Limit

- 11.2 live days.
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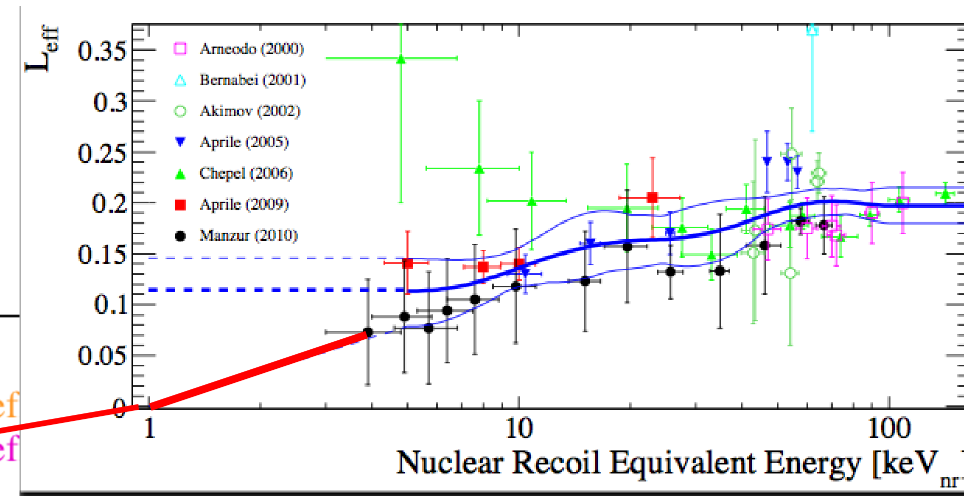
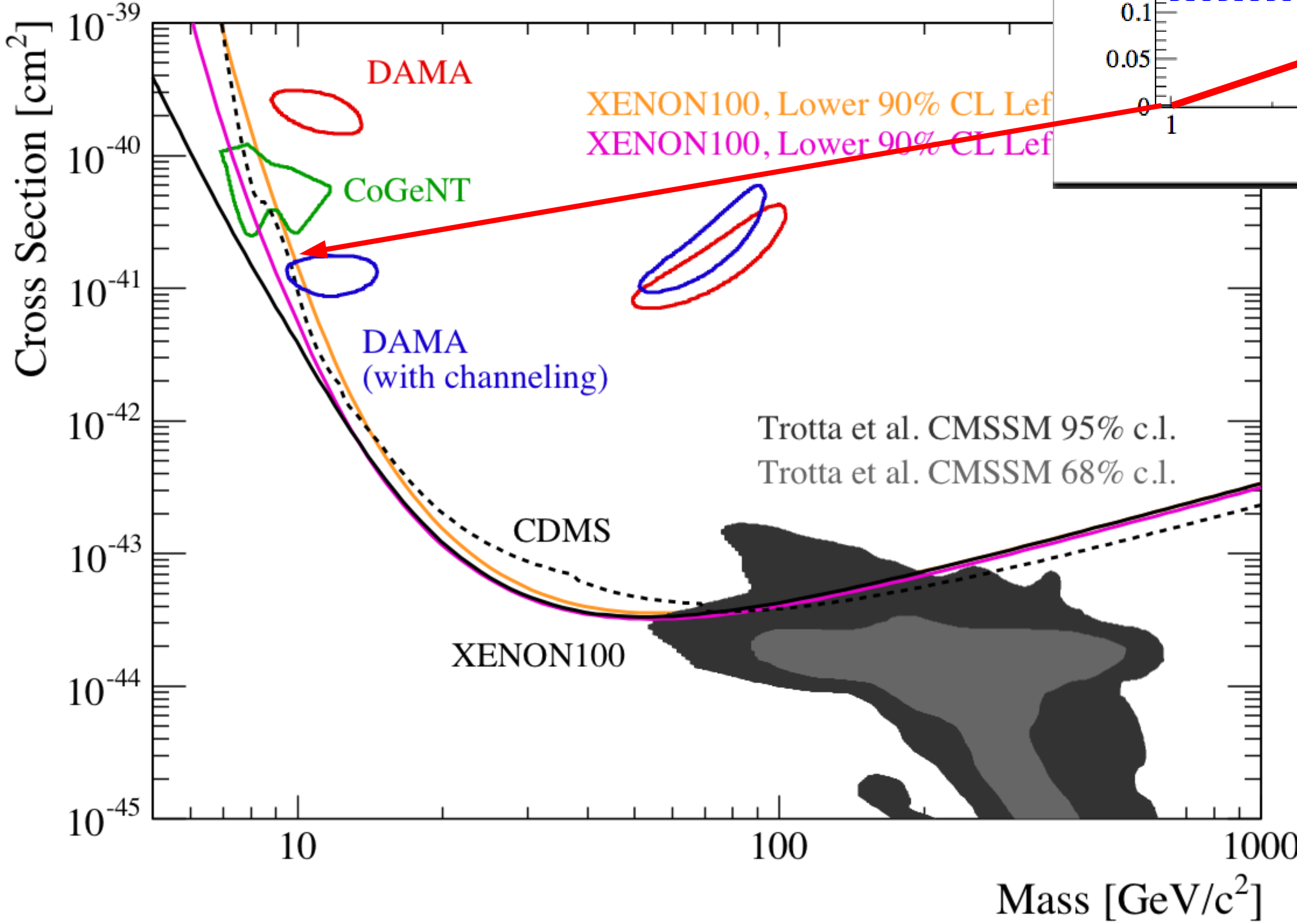
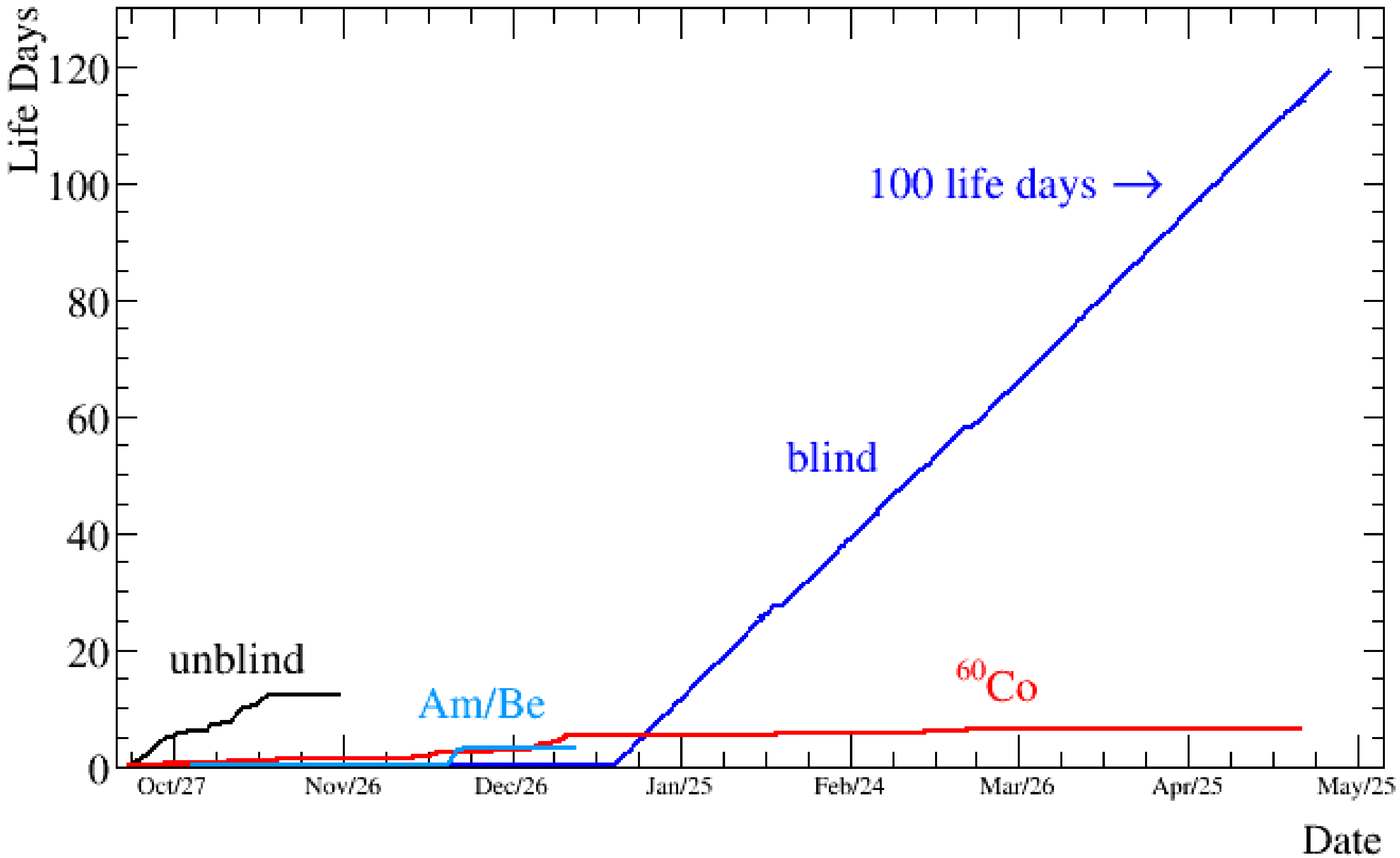




L_{eff} : lower 90%CL contour of global fit with logarithmic extrapolation.

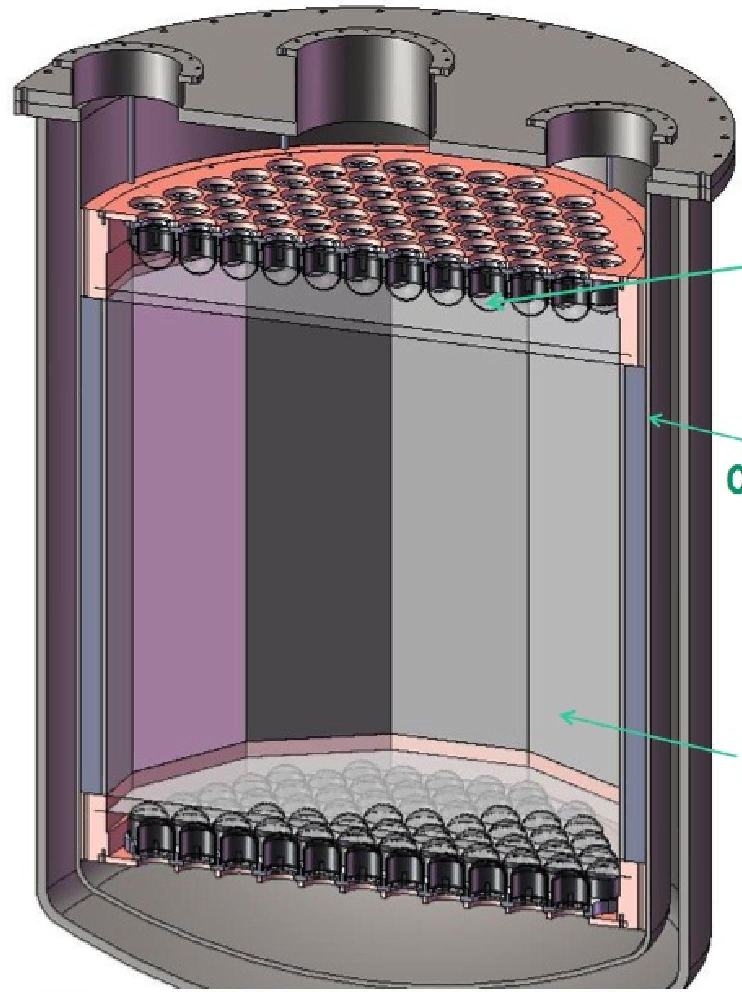
Prospects: XENON100 Blinded Data

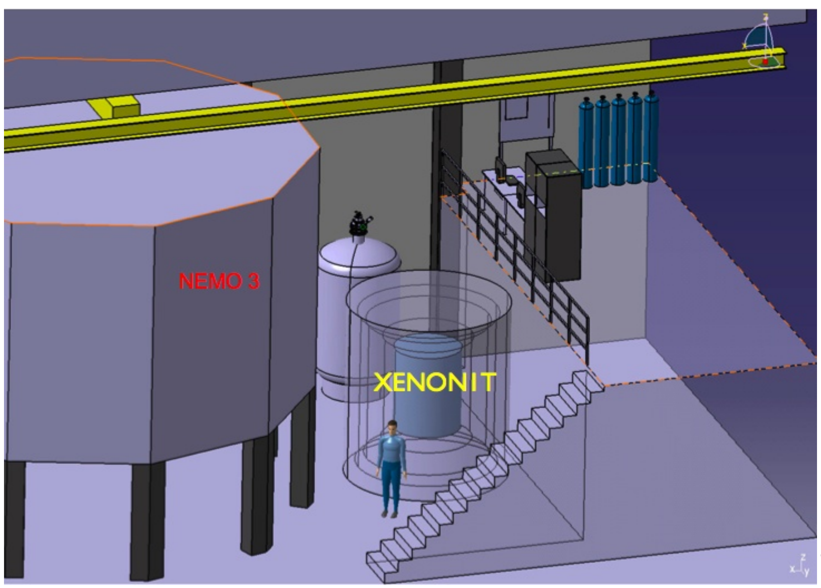


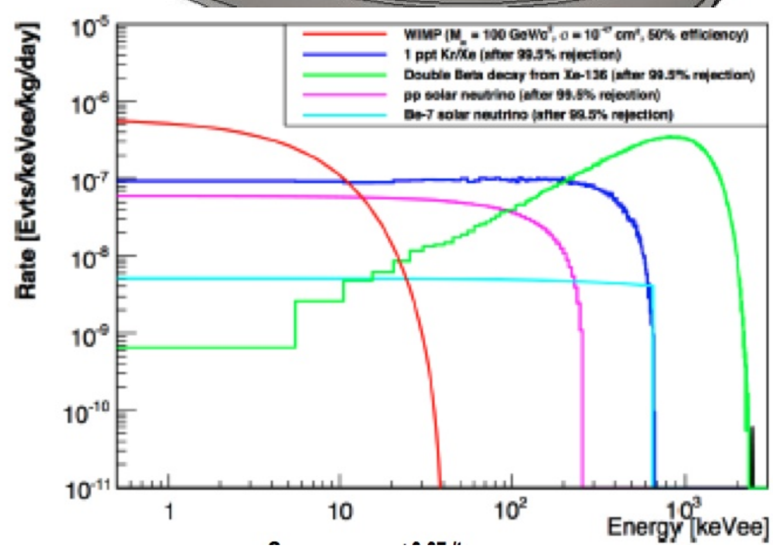
- We have already accumulated 11 times more data (~120 live days blinded) than used in this result.

The Future: XENON-1T
(2011-2015)

- 1t fiducial mass LXe detector to explore $\sigma \sim 3x10^{47}$ cm^2
- Pre-DUSEL “G2” experiment (PASAG)
- Technical proposal in preparation
- Location: LNGS or LSM
- 2 x 121 3” QUPID's
- Capital cost: ~ $8.5M, 50% by US
- Collaboration:
  XENON100 + Bologna + Nikhef + WIS





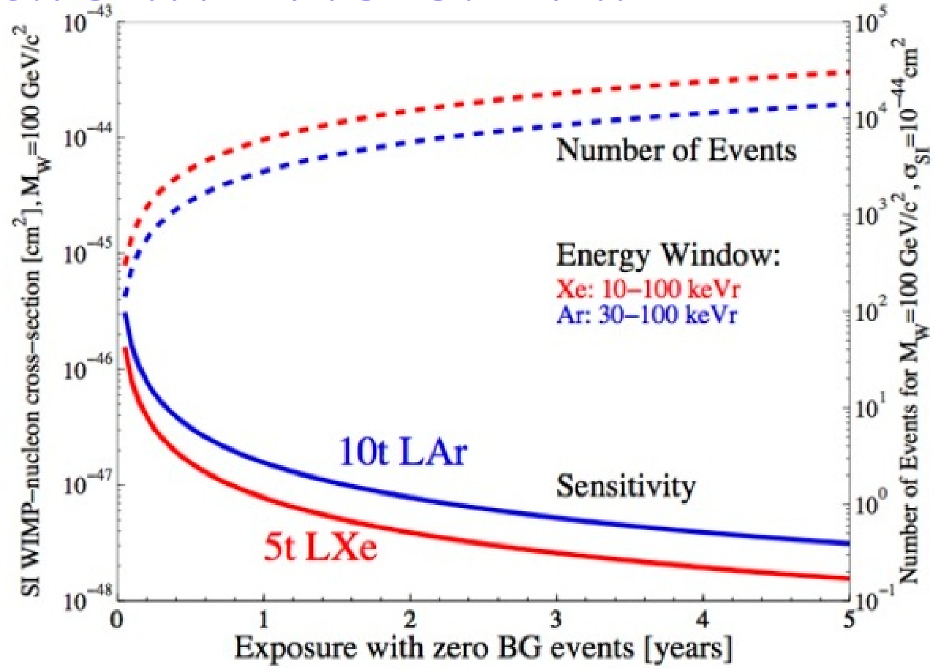


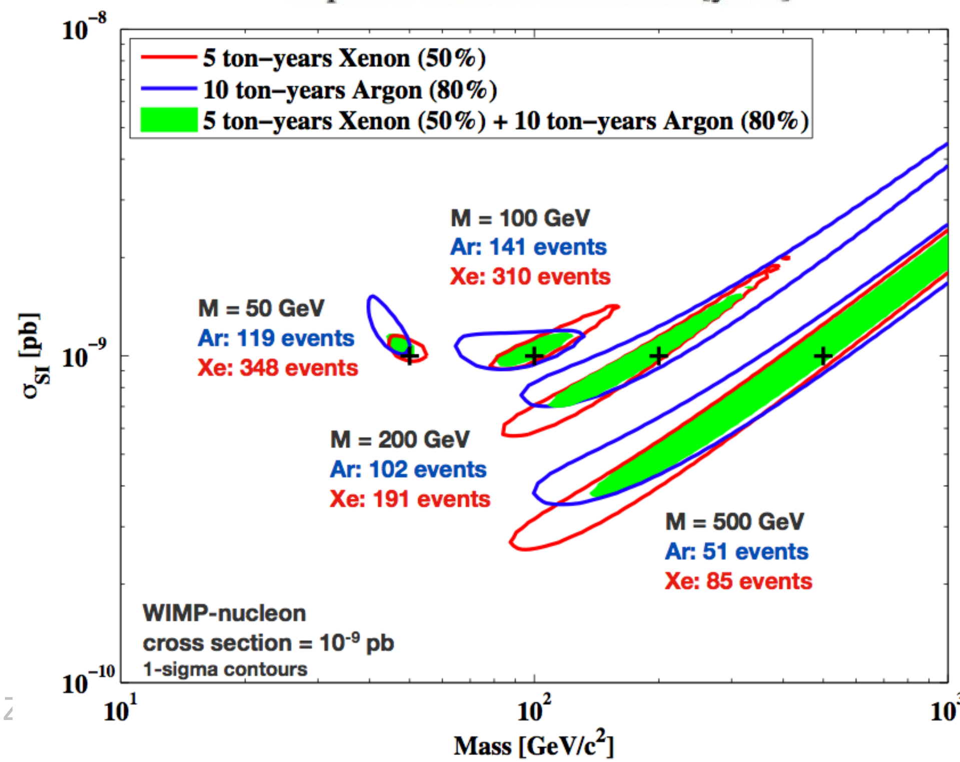
Studying the Multi-ton Scale in LXe & LAr

DARWIN

- R&D and design study over 3 years for a next-generation noble liquid facility in Europe
- Approved by ASPERA (AStroParticle ERAnet) in late 2009
- Funded in Switzerland, Italy, France, Netherlands
- Combine efforts in both LAr and LXe
- Europe: UZH, INFN, ETHZ, Subatech, Nikhef, MPIK, Münster, Mainz, KIT, IFJPAN
- USA: Columbia, Princeton, (Rice), UCLA

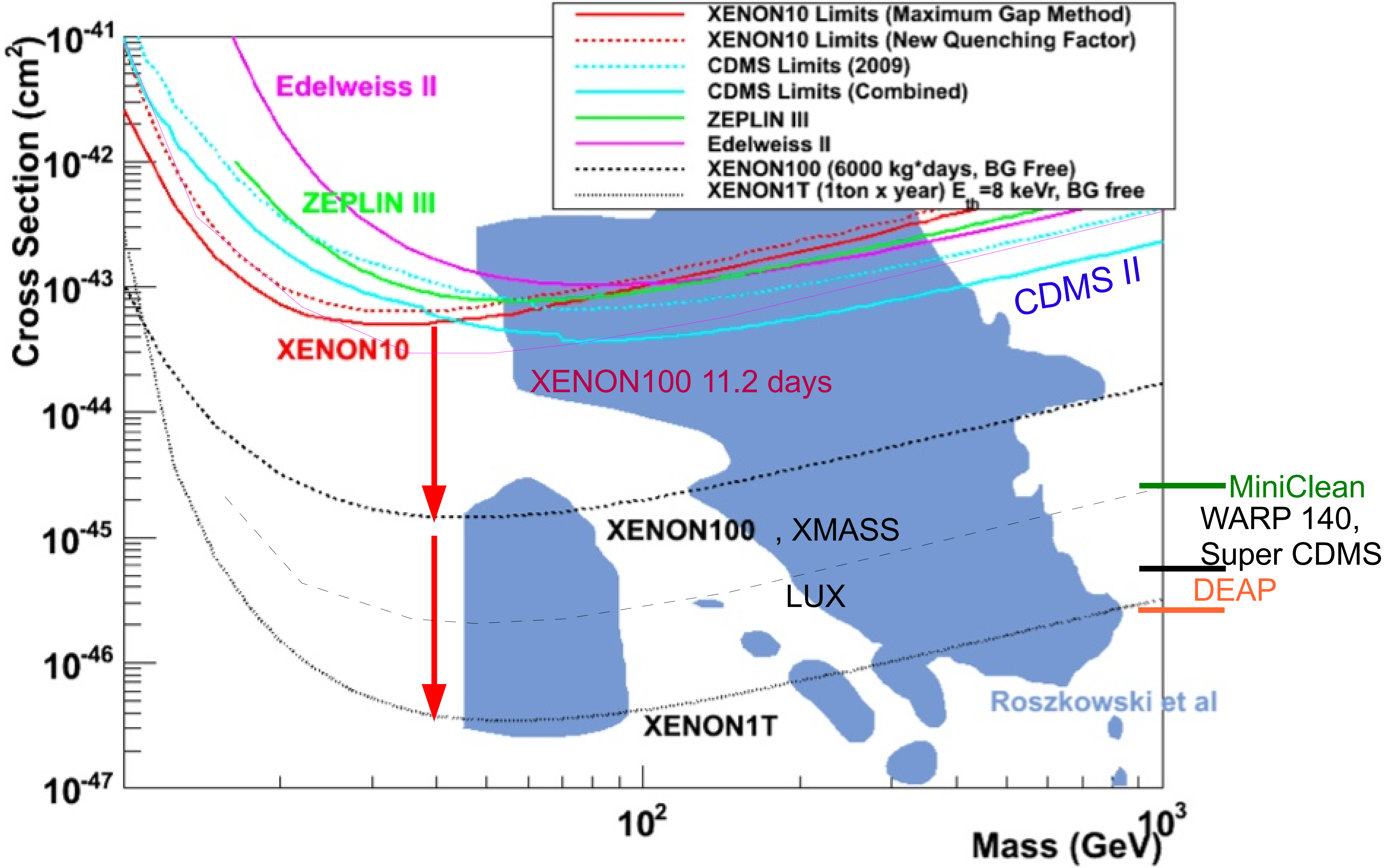
Details: darwin.physik.uzh.ch





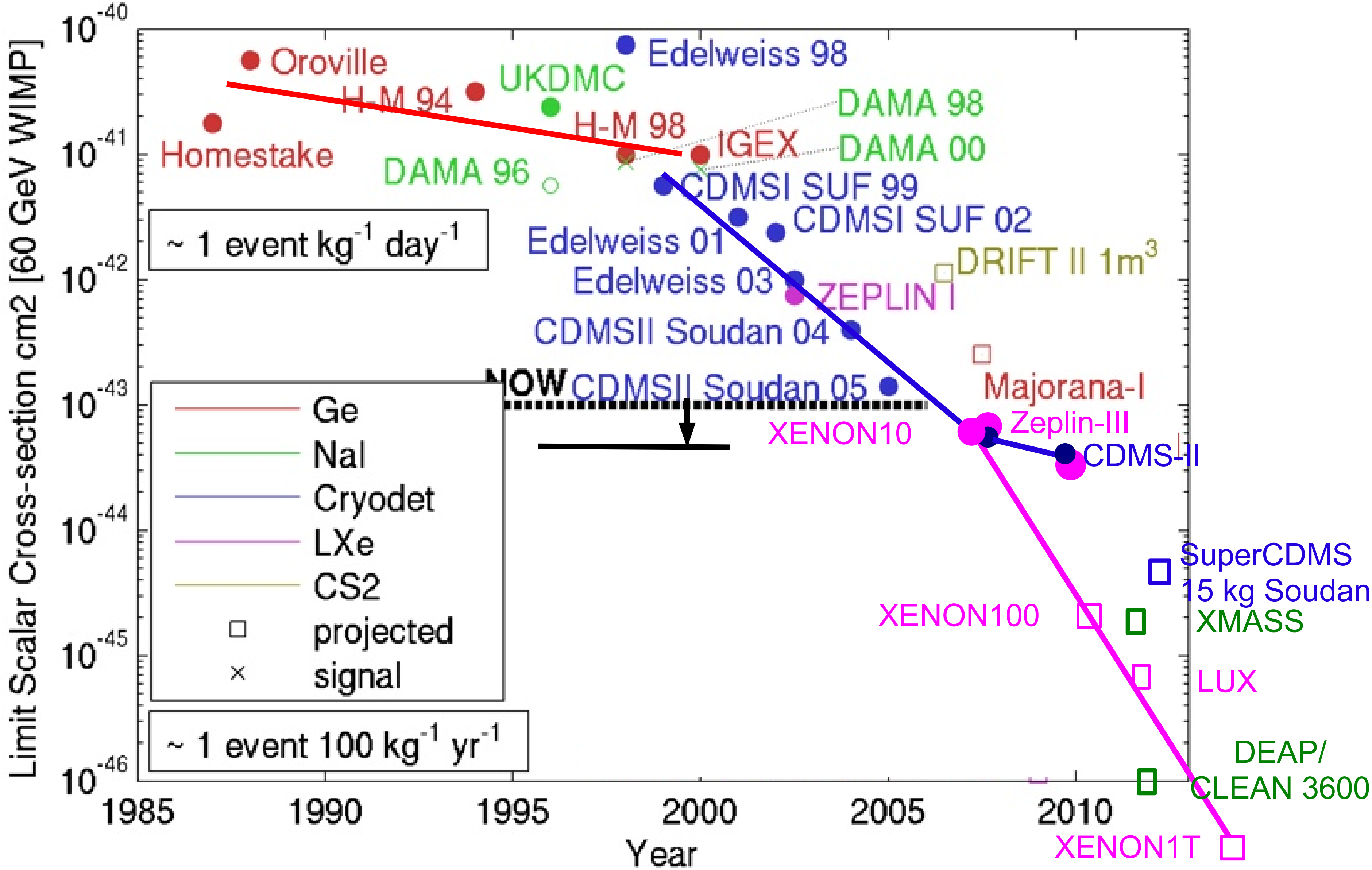
The Future of WIMP Searches

Spin-Independent Sensitivity (indicative)



DM Direct Searches - Progress Over Time

Spin-Independent Interactions



Plot updated from DM Review: R. Gaitskell, Ann. Rev. Nucl. and Part. Sci. 54 (2004) 315-359

Summary & Outlook

- Dark Matter direct searches have advanced in sensitivity by two orders of magnitude in the last decade, with accelerating progress.
- XENON100 has been operating in DM search mode for several months. Set to provide order of magnitude improvement in sensitivity later this year.
- First analysis of 11.2 live days of XENON100 data: The lowest background DM detector in the world!
- New upper limits for spin-independent WIMP interactions on par with CDMS-II. Min.: 3.4×10^{-44} cm^2 @ M_{DM} = 55 GeV/c^2
- The DAMA/LIBRA annual modulation interpreted as a WIMP signal will be further tested by XENON100:
  - Even without electron recoil suppression.
  - Inelastic DM parameter space will be fully covered.
  - In the spin-dependent channel.
- Low mass WIMPs: Must be < 10 GeV/c^2. Improvements coming: new measurements of scintillation efficiency for low-energy nuclear recoils.
- Noble liquid detectors have matured, currently setting the pace of progress.
- Planing for the future: XENON1T, DARWIN
- *Stay tuned for more results from direct Dark Matter searches!*

Thank you.

The XENON Collaboration XENON100 / XENON1T

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Italy (2)
Germany (3)
China (1)
France (1)
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NIKHEF – P. Decowski
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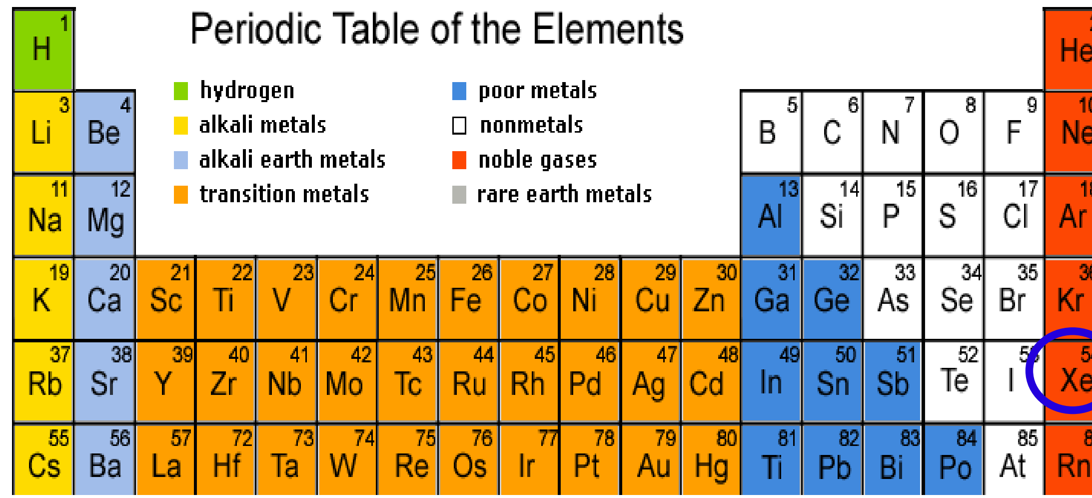
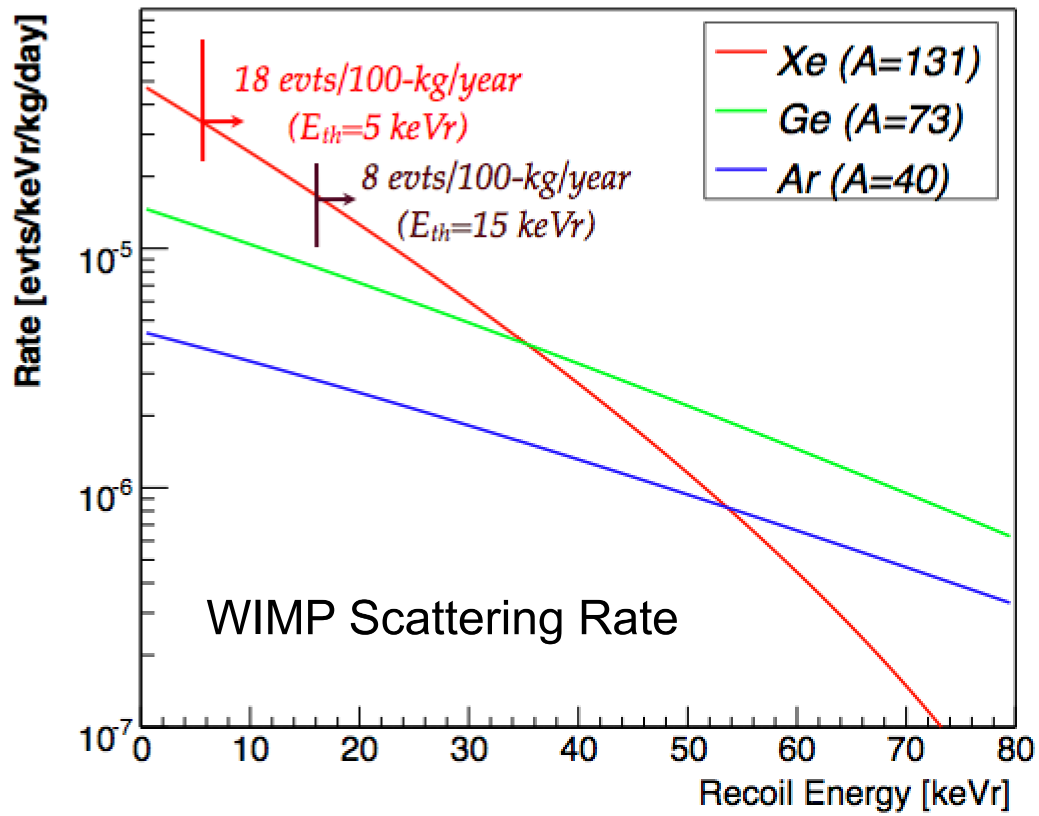
MAINZ – U. Oberlack

BACKUP SLIDES

Liquid Xenon for Dark Matter Search

- Large atomic number A~131 best for SI interactions ($\sigma \sim A^2$).
  Need low threshold.
- ~50% odd isotopes: SD interactions
  If DM detected: probe physics with the same detector using isotopically enriched media.
- No long-lived isotopes.
  Proven Kr-85 reduction to ppt level.
- High Z (54) and density:
  compact & self-shielding
- Scalability to large mass for $\sigma \sim 10^{47}$ cm^2 ~ 1 evt/ton/yr.
- “Easy” cryogenics (-100°C).
- Efficient and fast scintillator.
- Background discrimination in TPC.
  - Ionization/Scintillation
  - 3D imaging of TPC

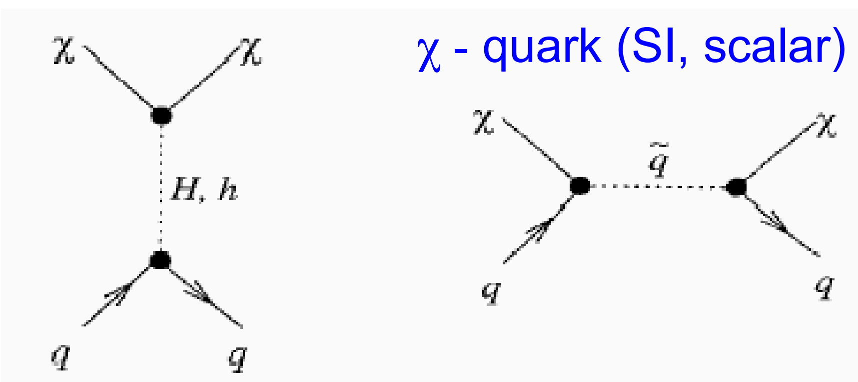


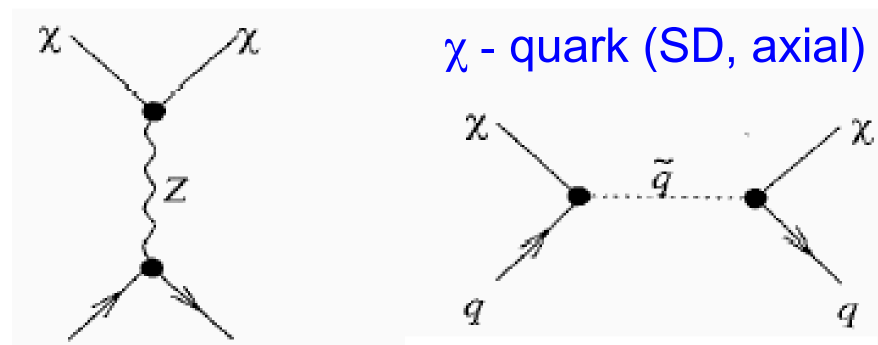


WIMP Scattering Cross Sections

Example: SUSY (but direct searches are sensitive to other models as well)

- Compute cross sections χ – quark and χ – gluon with various SUSY models. Large parameter space, constrained by accelerator and direct search experiments, and cosmology.
  - **spin-independent**: coupling to mass of nucleus. Coherence $\Rightarrow \sigma \propto A^2$
  - **spin-dependent**: coupling of spins of nucleus and neutralino interaction with paired nucleons in the same energy state cancel => no A^2 enhancement

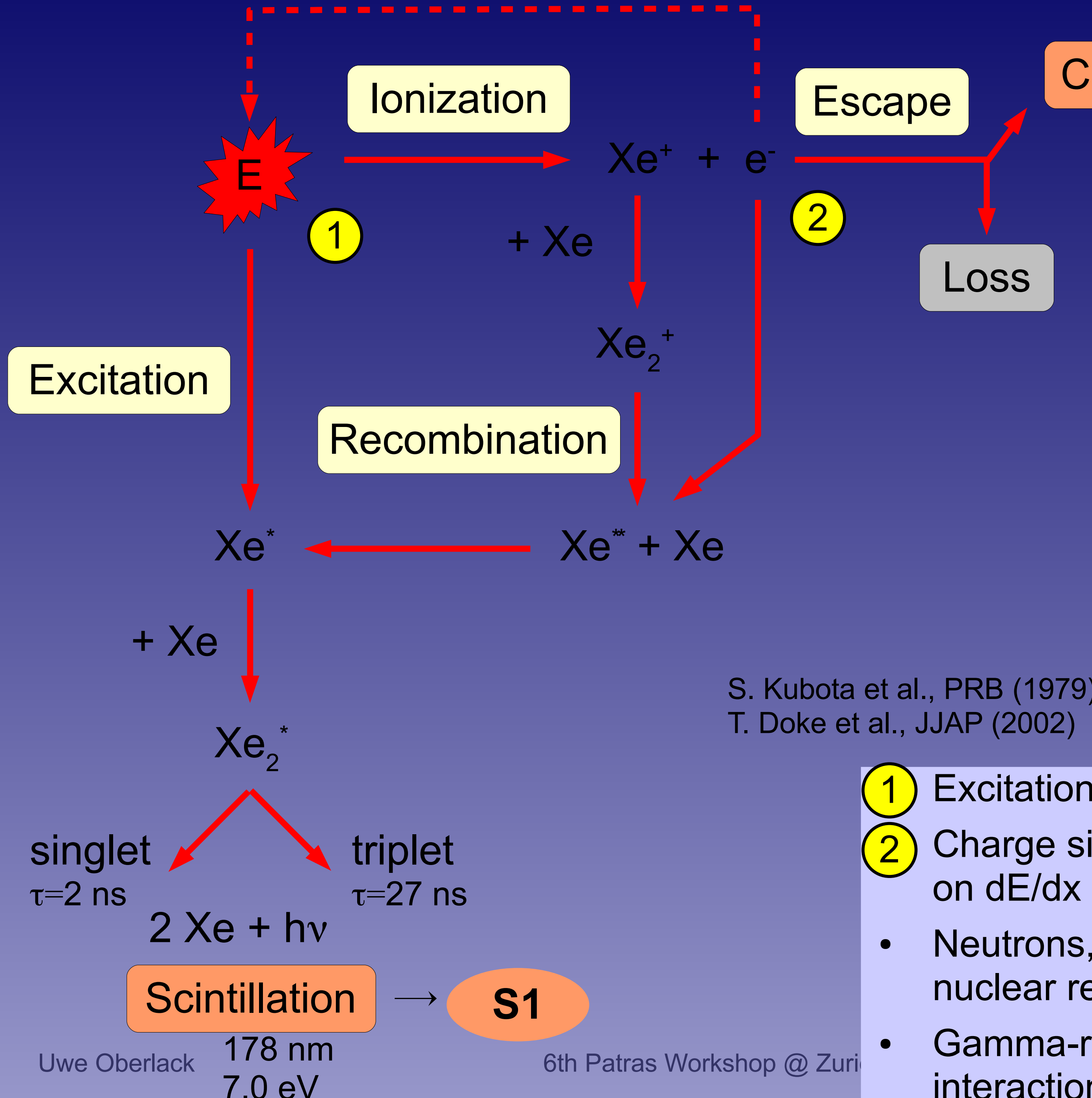




Jungmann et al. '96 Phys.Rep.

- Distribution of nucleons within nucleus: nuclear form factor.
  - SI: Large nuclei gain ~A^2 at small momentum transfer, but lose at higher momentum transfer due to coherence loss.

Ionization and Scintillation in LXe



S. Kubota et al., PRB (1979)
T. Doke et al., JJAP (2002)

Excitation Scintillation:

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

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

Recombination Scintillation:

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

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

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

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

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

1. Excitation / Ionization depends on dE/dx.
2. Charge signal / Recombination depends on dE/dx and electric field.

- Neutrons, WIMPs:
  nuclear recoil O(10 keV), dE/dx high.
- Gamma-rays, betas:
  interactions with electrons, dE/dx low.