The XENON100 Dark Matter Search

Elena Aprile
on behalf of the XENON collaboration

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XENON Collaboration

USA, Switzerland, Portugal, Italy, Germany, France, China, Netherlands

COLUMBIA

RICE

UCLA

ZURICH

COIMBRA

LNGS

MPIK

BOLOGNA

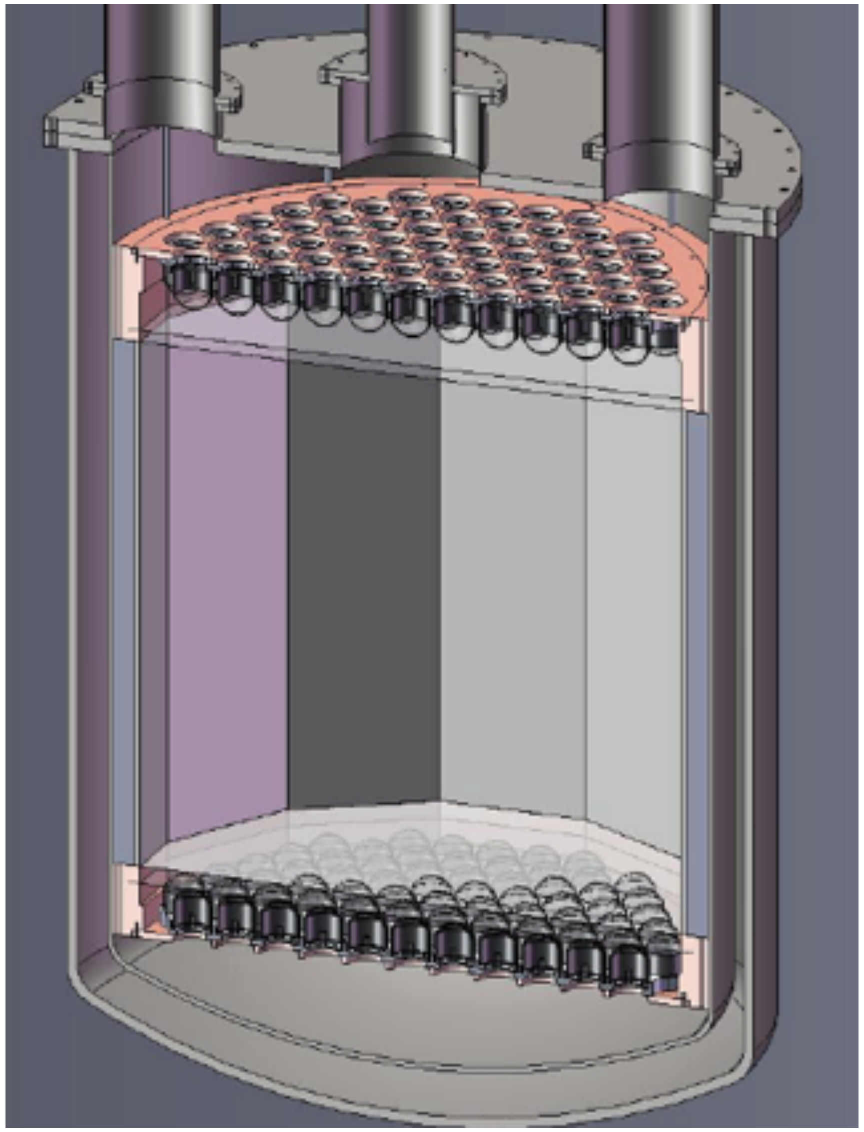
SHANGHAI

MUENSTER

SUBATECH

NIKHEF

The XENON Roadmap

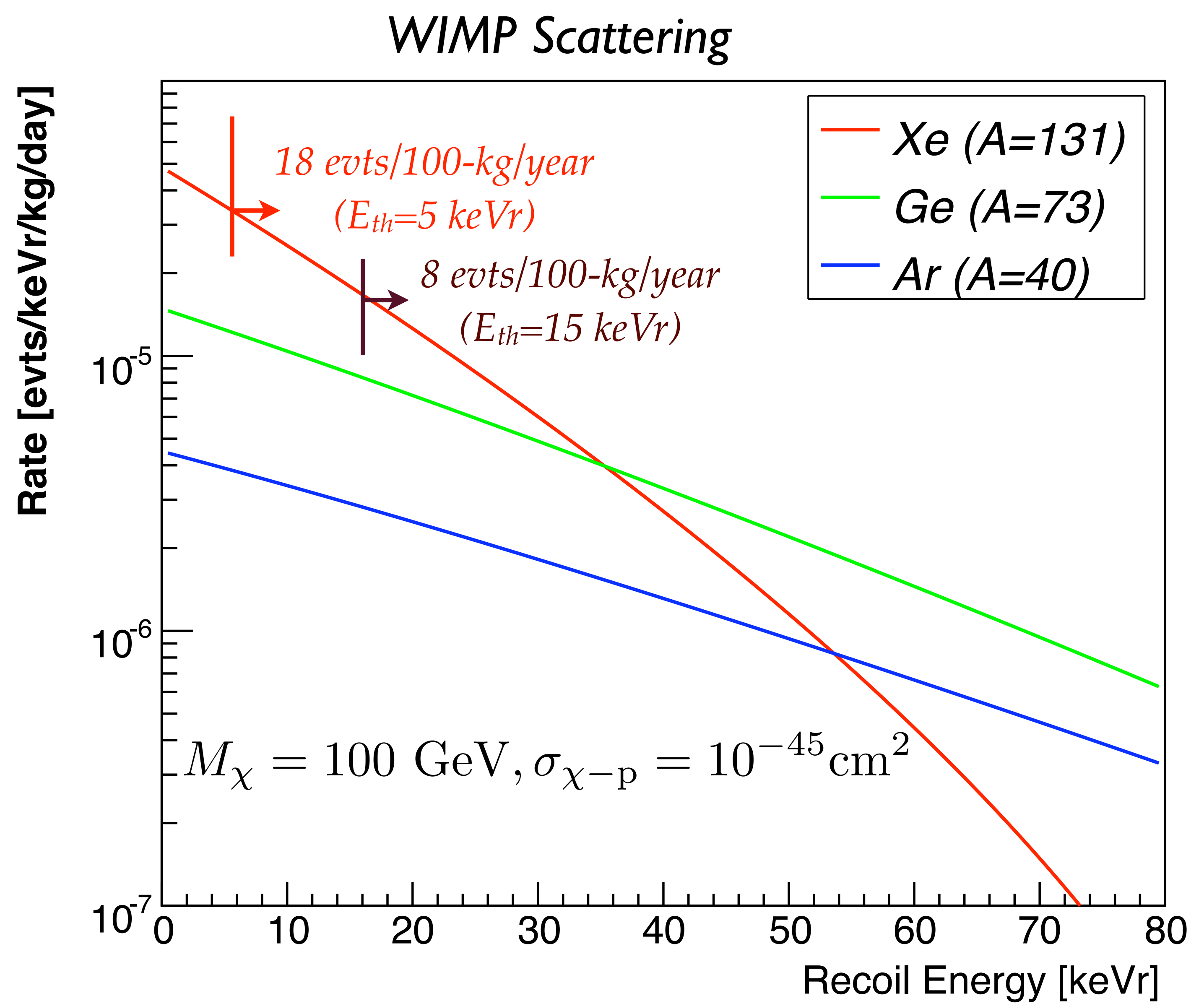
past (2005 - 2007)	*current* (2008-2010)	*future* (2011- 2015)
		
XENON10	**XENON100**	**XENON1T**
Achieved (2007) σ_{SI}=8.8 x10^{-44} cm^2	*Projected (2010)* σ_{SI}~2x10^{-45} cm^2	*Goal:* σ_{SI} <10^{-46} cm^2

Phys. Rev. Lett. ***100***, *021303 (2008)*
Phys. Rev. Lett. ***101***, *091301 (2008*

Liquid Xenon for Dark Matter

- *scalability: relatively inexpensive for very large detector (today < $800/kg)*
- *Large mass number (A~131): high rate for SI interactions if NR threshold is low*
- *~50% odd isotopes: SD interactions*
- *Excellent Stopping Power: active volume is shelf-shielding*
- *Excellent Scintillator and Ionizer: highest yield among noble liquids*
- *Intrinsically pure: no long-lived radioactive isotopes; Kr/Xe reduction to ppt level with established methods*
- *NR Discrimination: by simultaneous charge and light measurement*

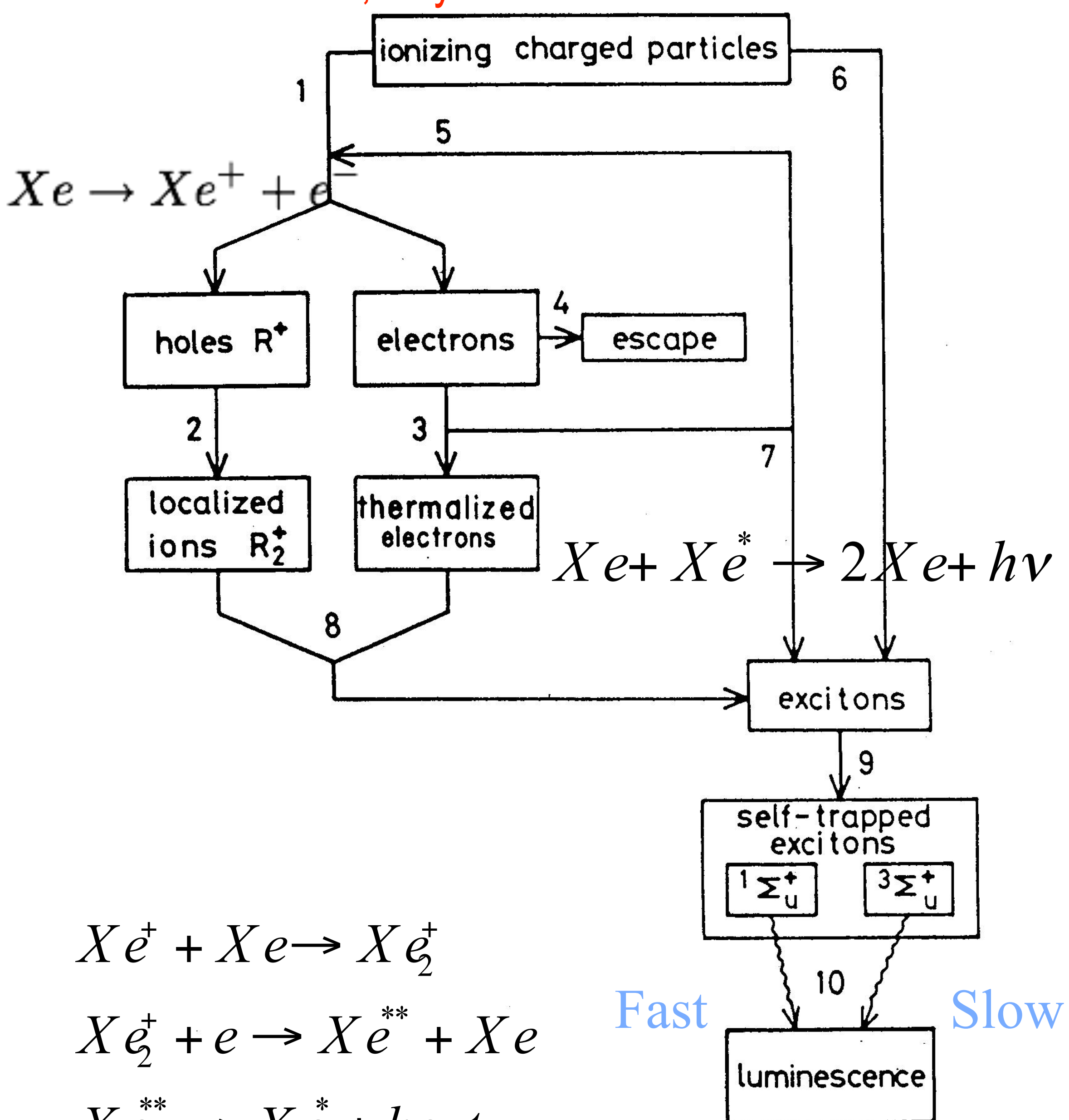
$$R \sim \frac{M_{det}}{M_\chi} \rho \sigma \langle v \rangle$$



World Wide Dark Matter Searches: ~50% use Noble Liquids

Ionization/Scintillation Mechanism in Noble Liquids

Kubota et al. 1979, Phys. Rev.B

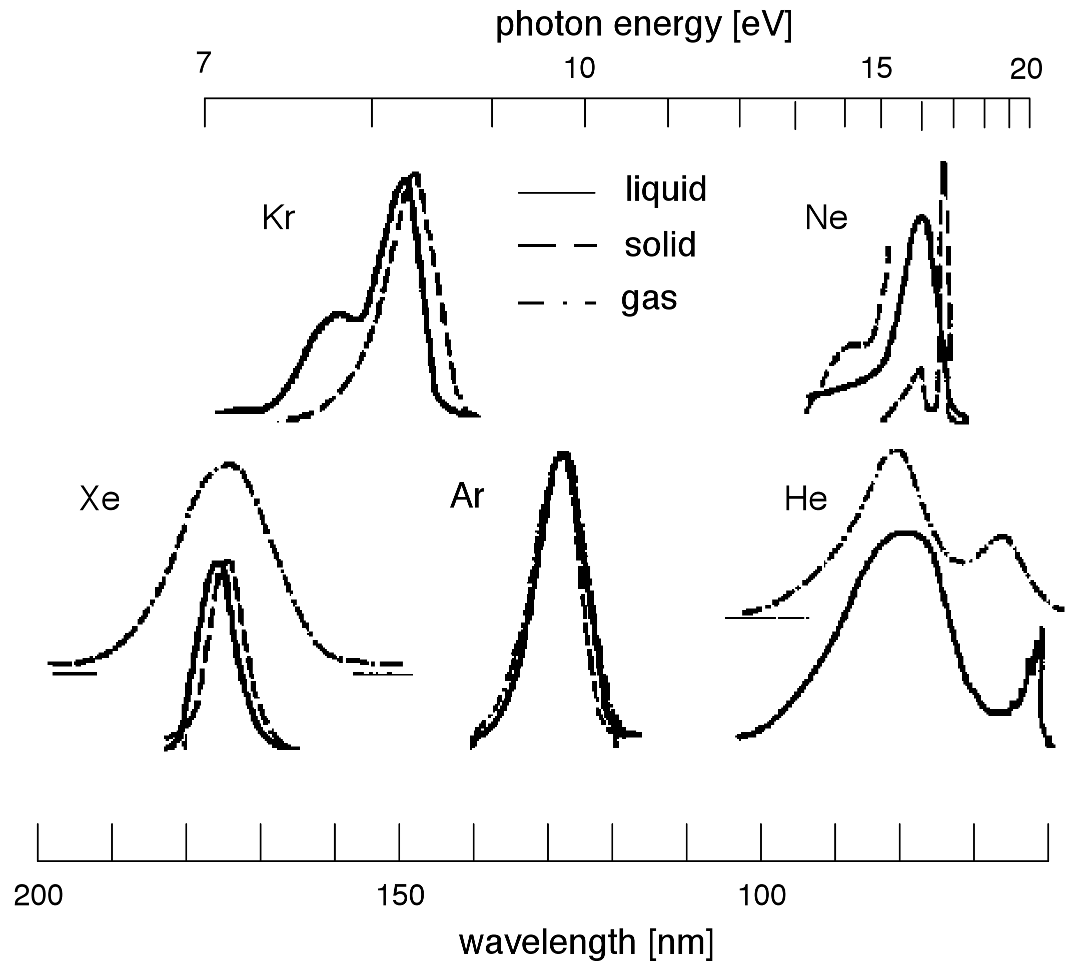


$$Xe^+ + Xe \rightarrow Xe_2^+$$

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

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

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



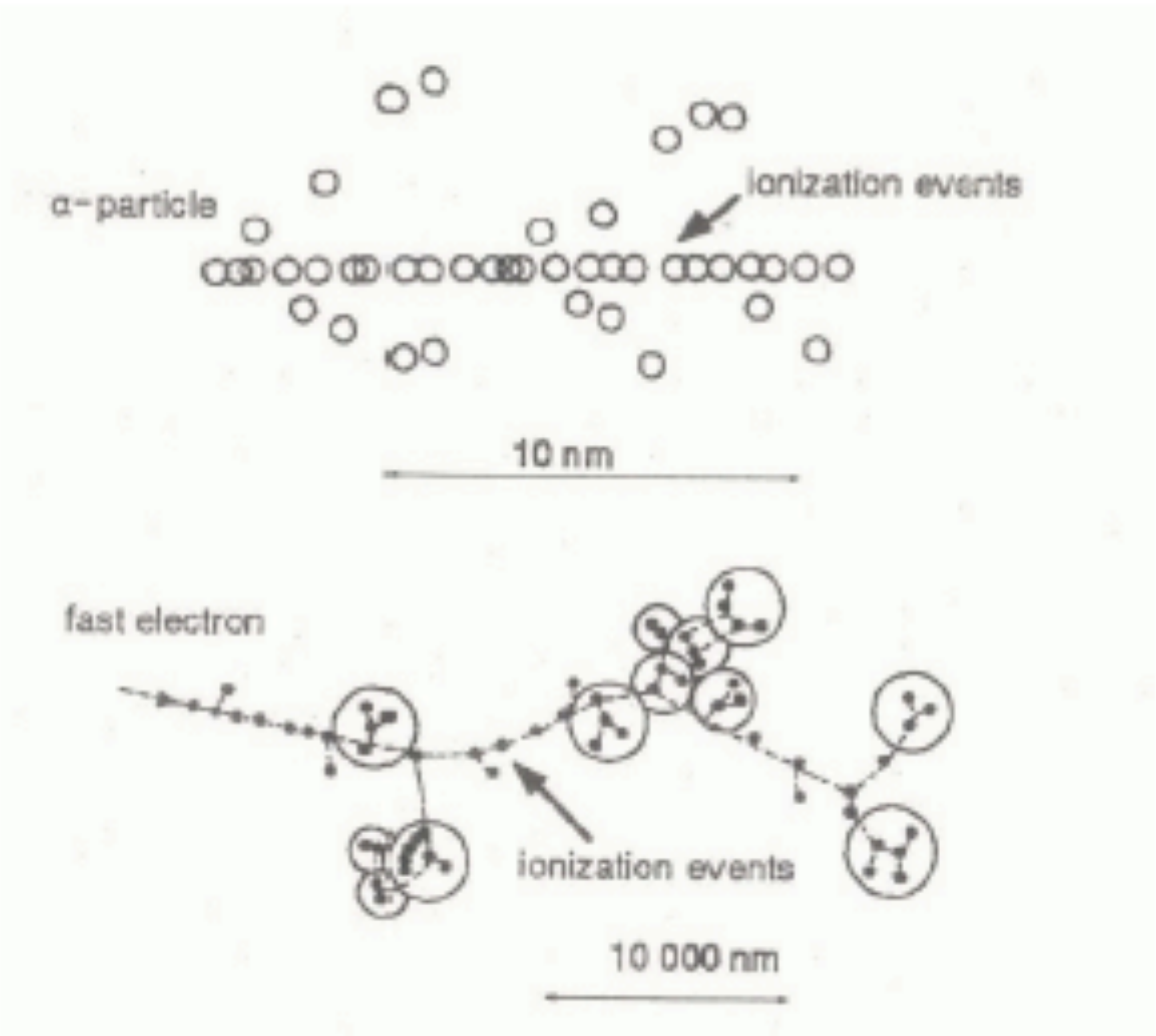
$$\lambda \sim 128_{LAr}$$

$$\lambda \sim 175_{LXe}$$

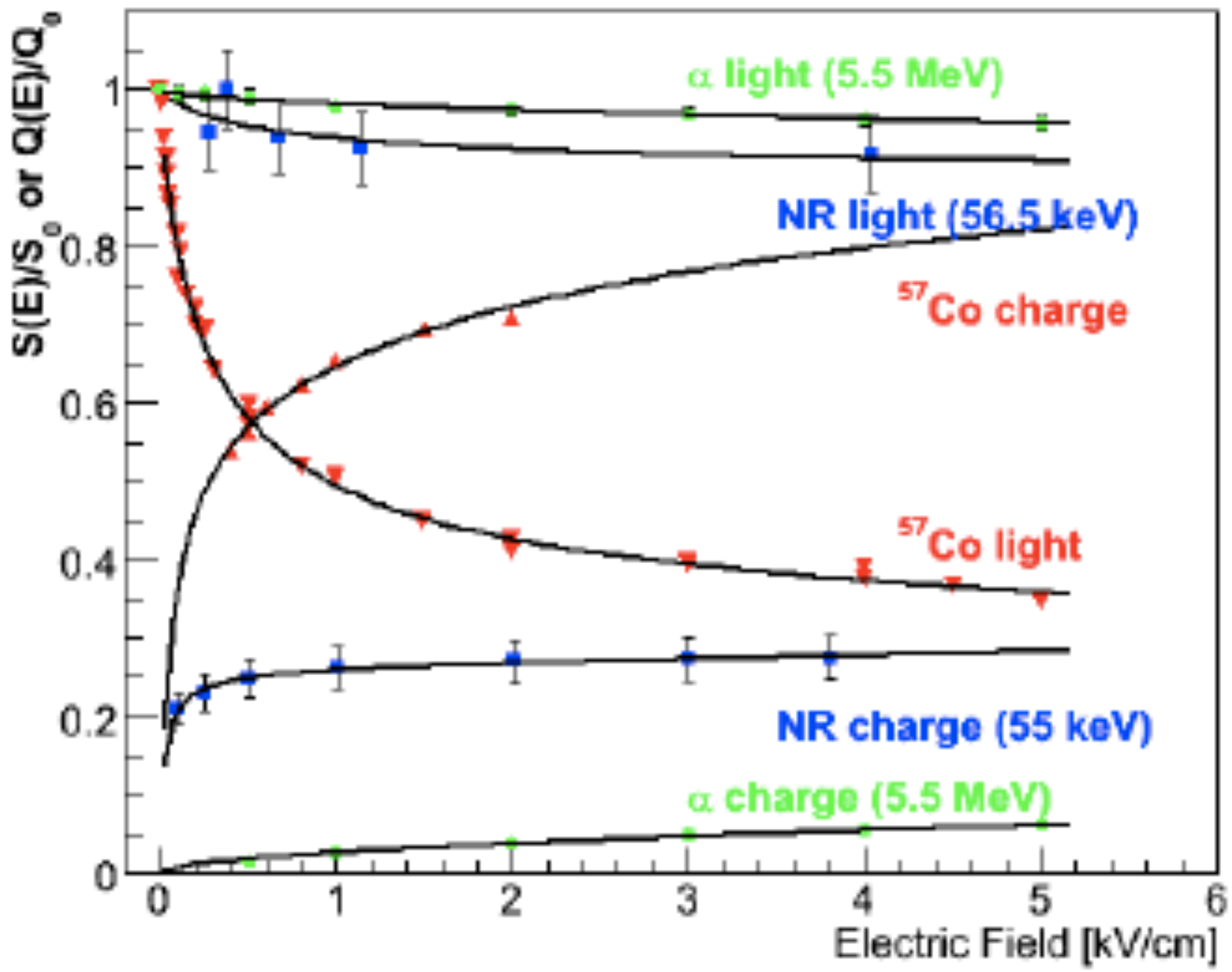
$$\lambda \sim 77.5_{LNe}$$

Charge and Light response of different particles in LXe

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

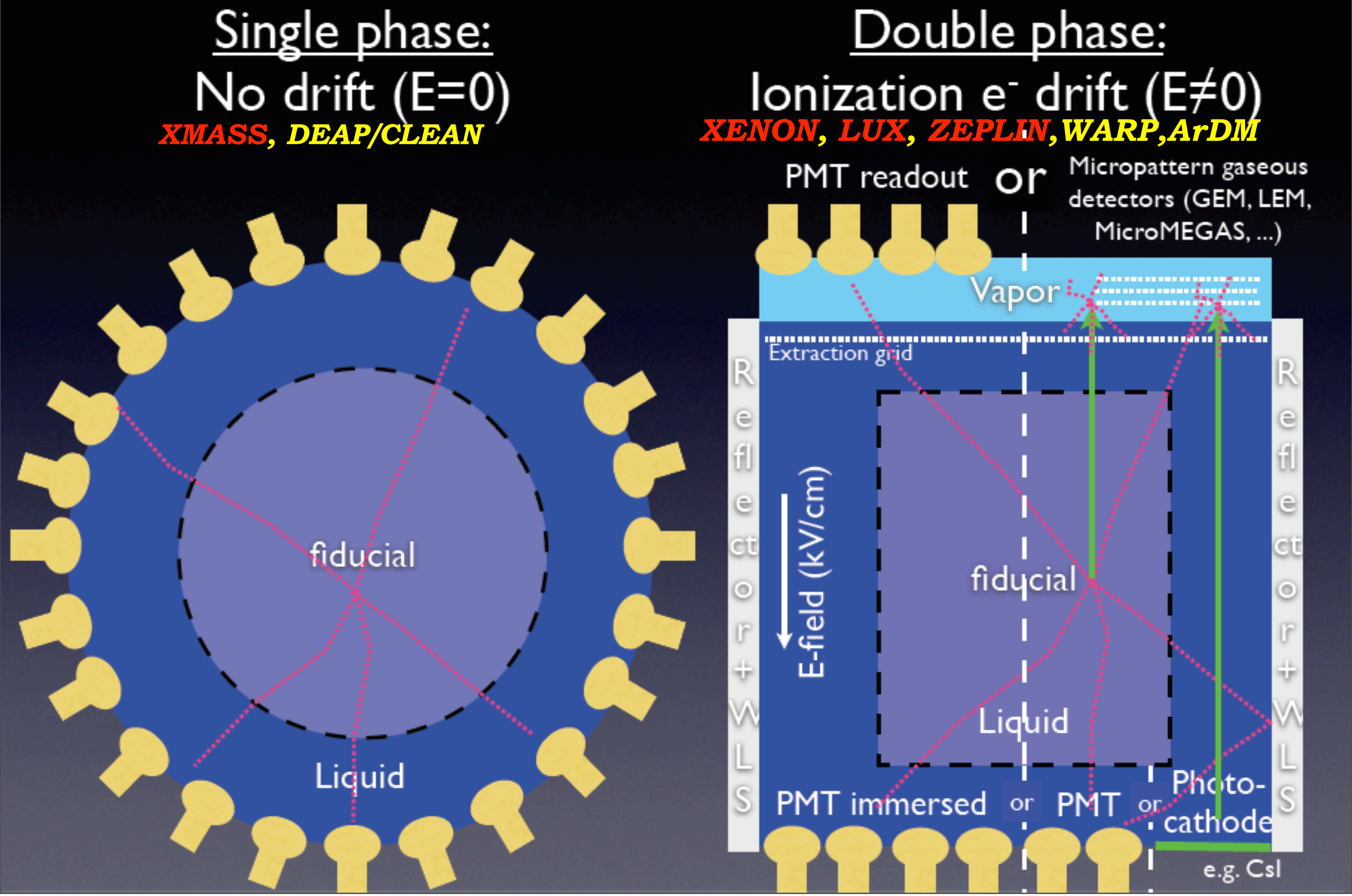


Distribution of ionization around the track
of a high energy a-particle or electron



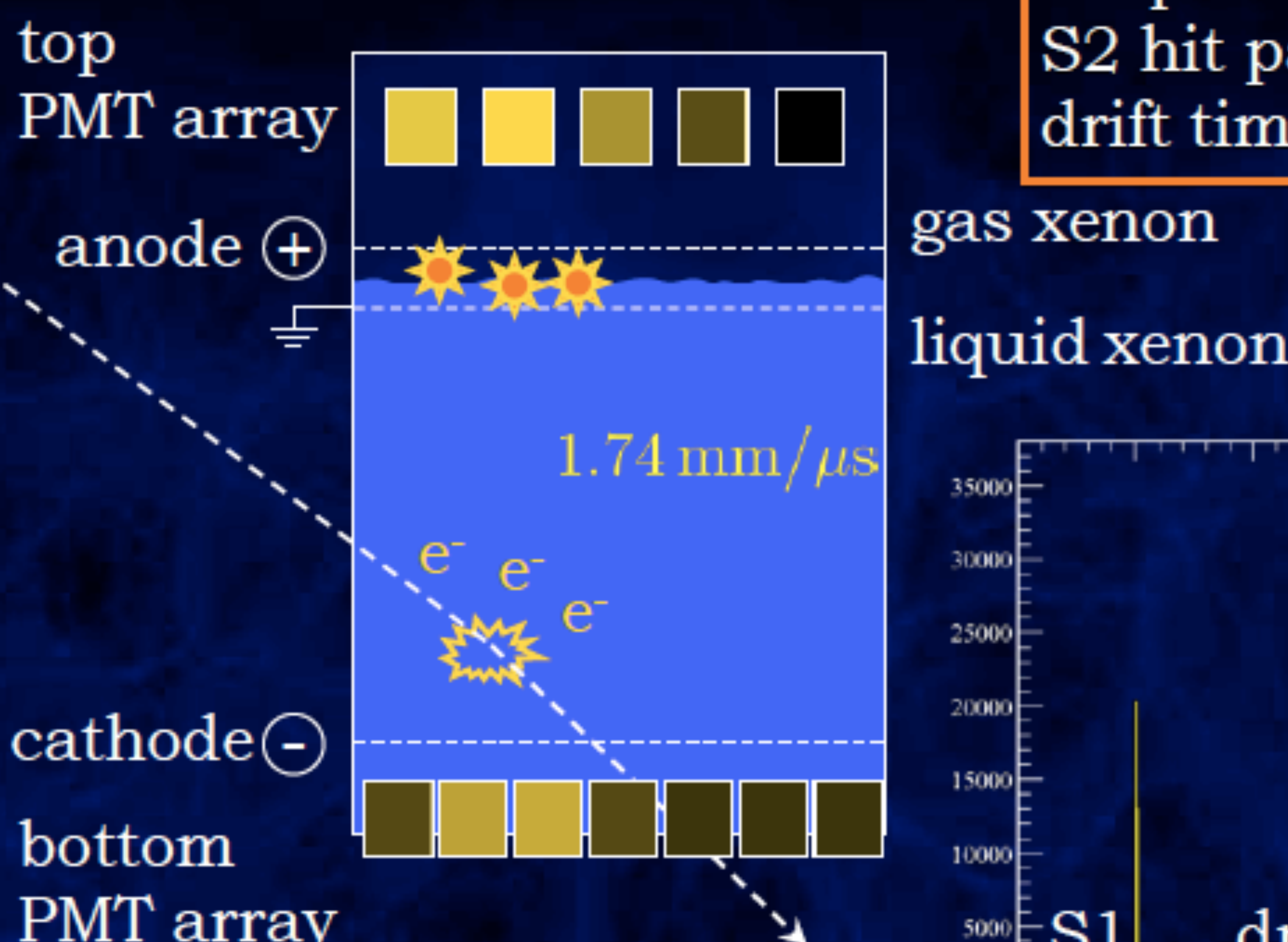
Aprile et al., Phys. Rev. D 72 (2005) 072006

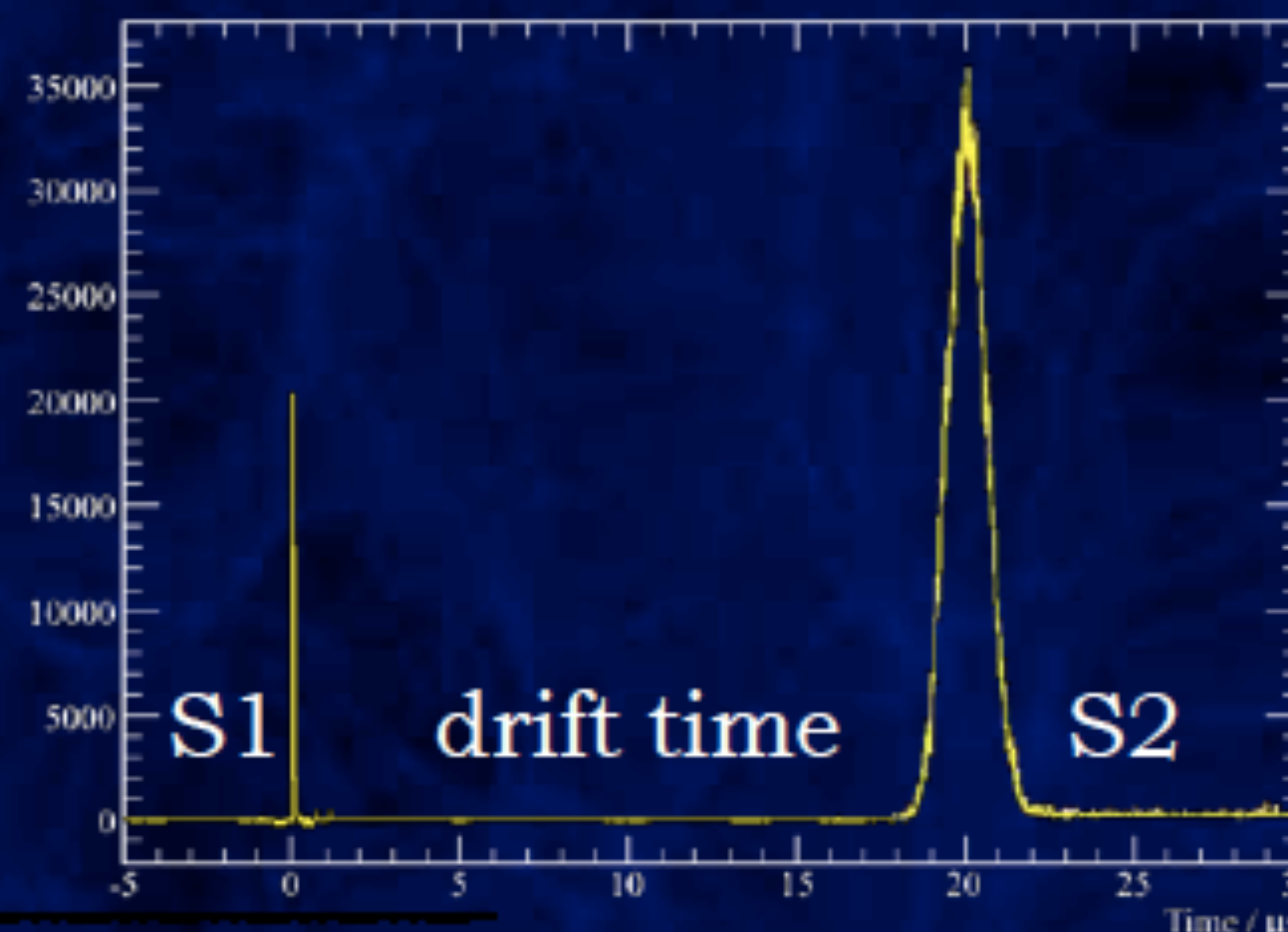
Two basic detector concepts



Dual-Phase Xenon TPC

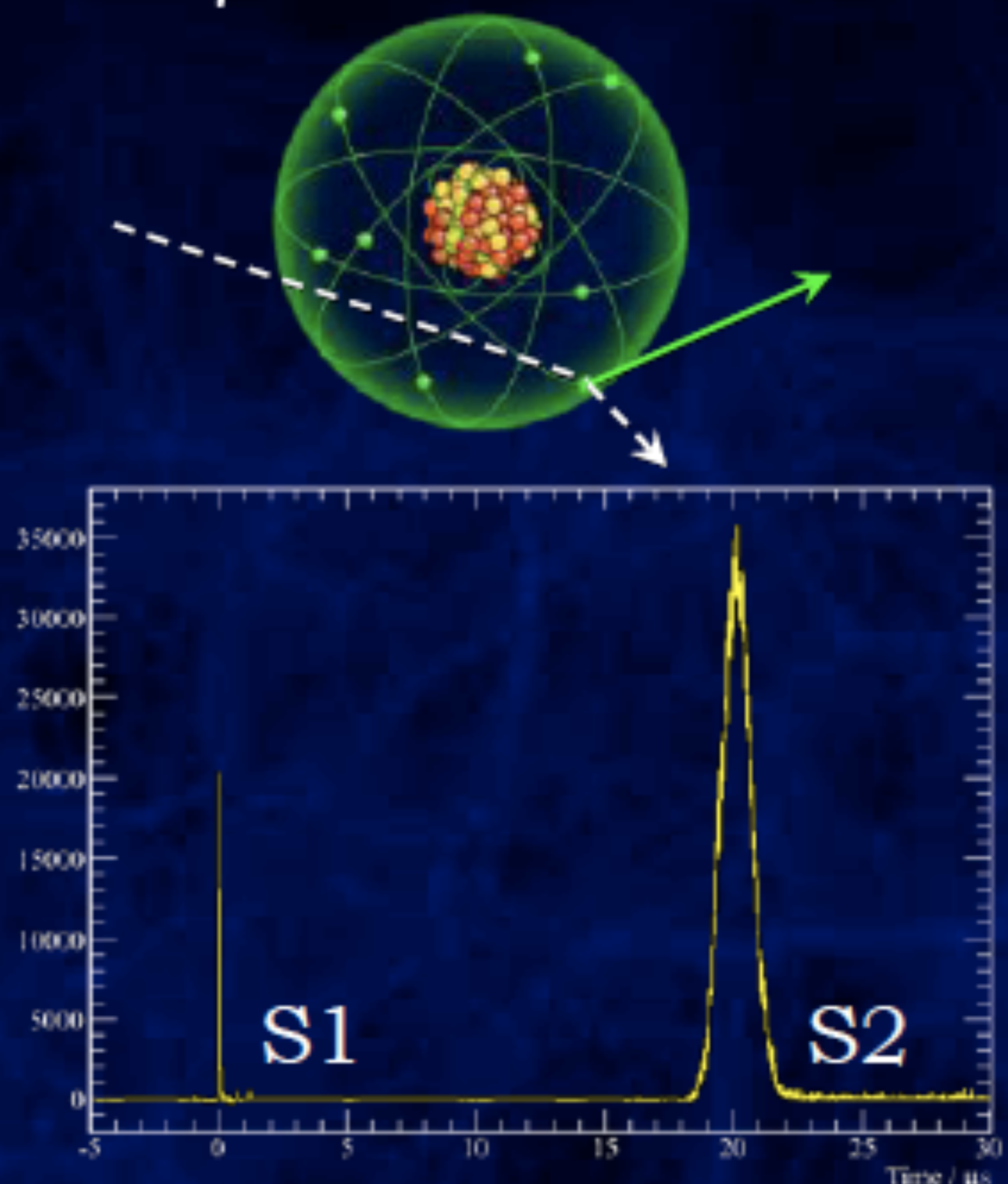
3D position information
S2 hit pattern: $\Delta r < 3\,\mathrm{mm}$
drift time: $\Delta z < 2\,\mathrm{mm}$



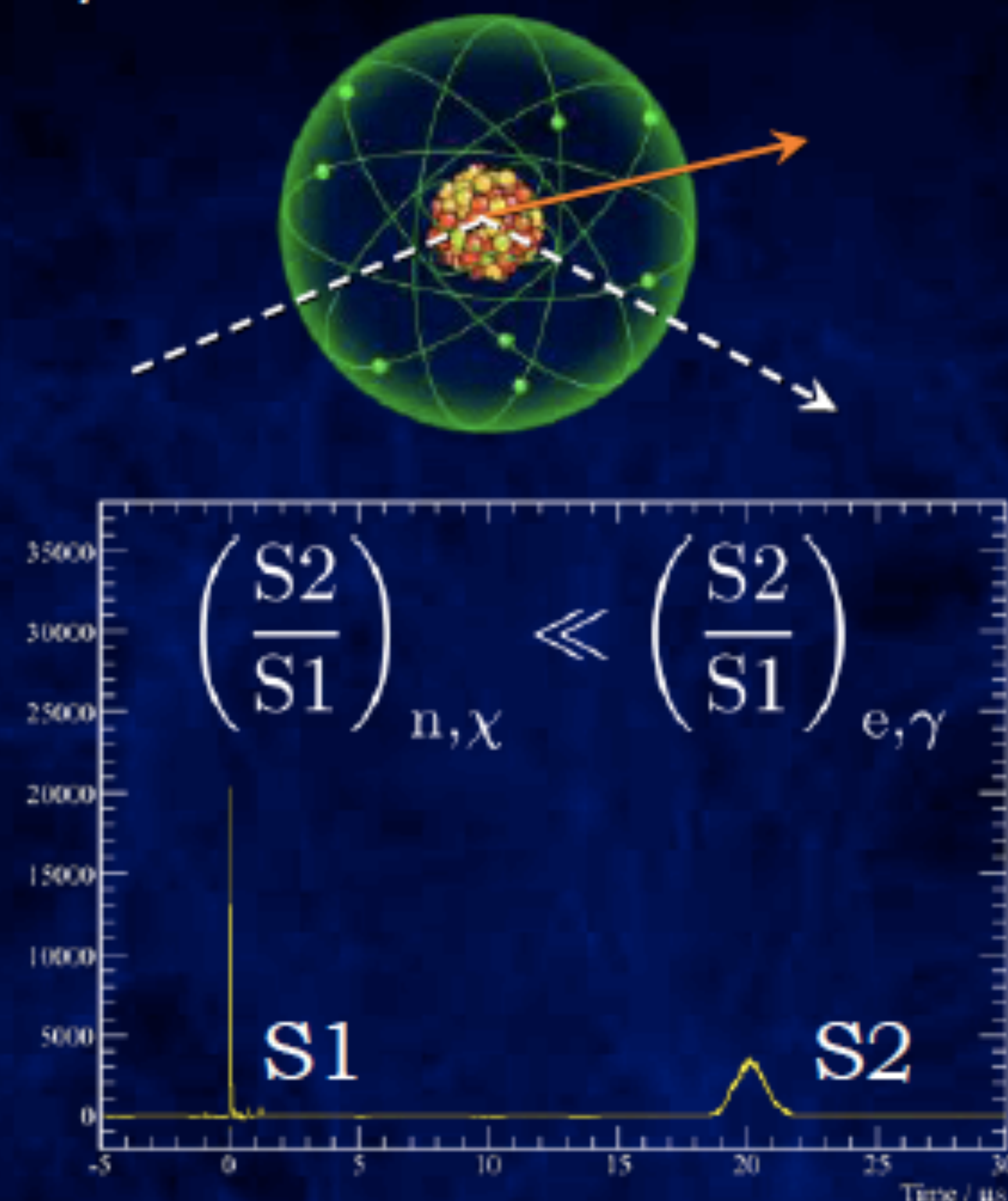


Recoil Discrimination > 99%

e^-/γ: electron recoil



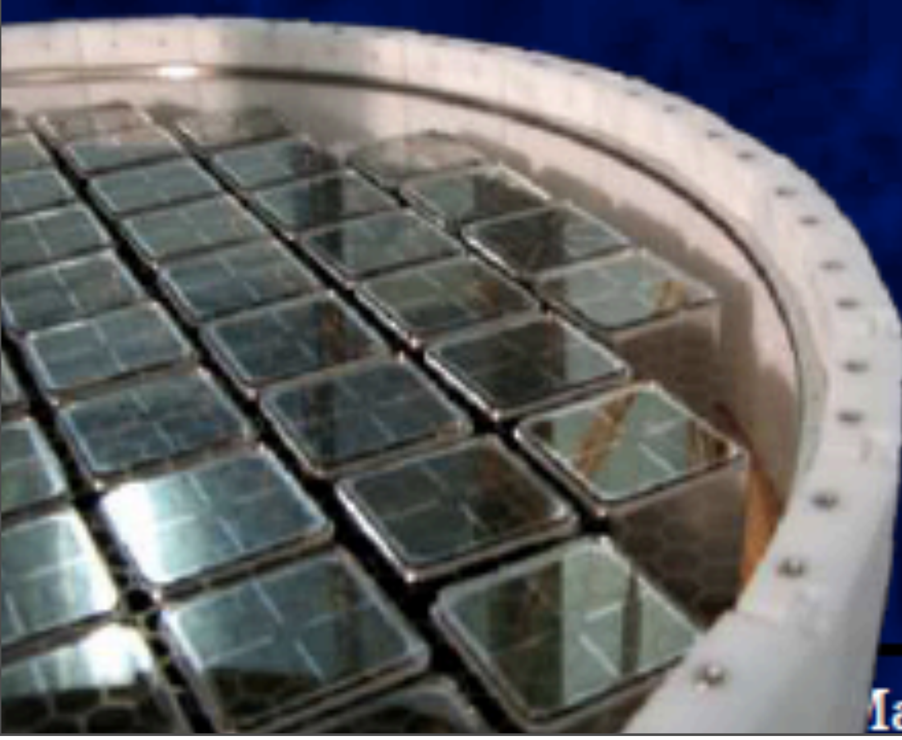
n/WIMPs: nuclear recoil



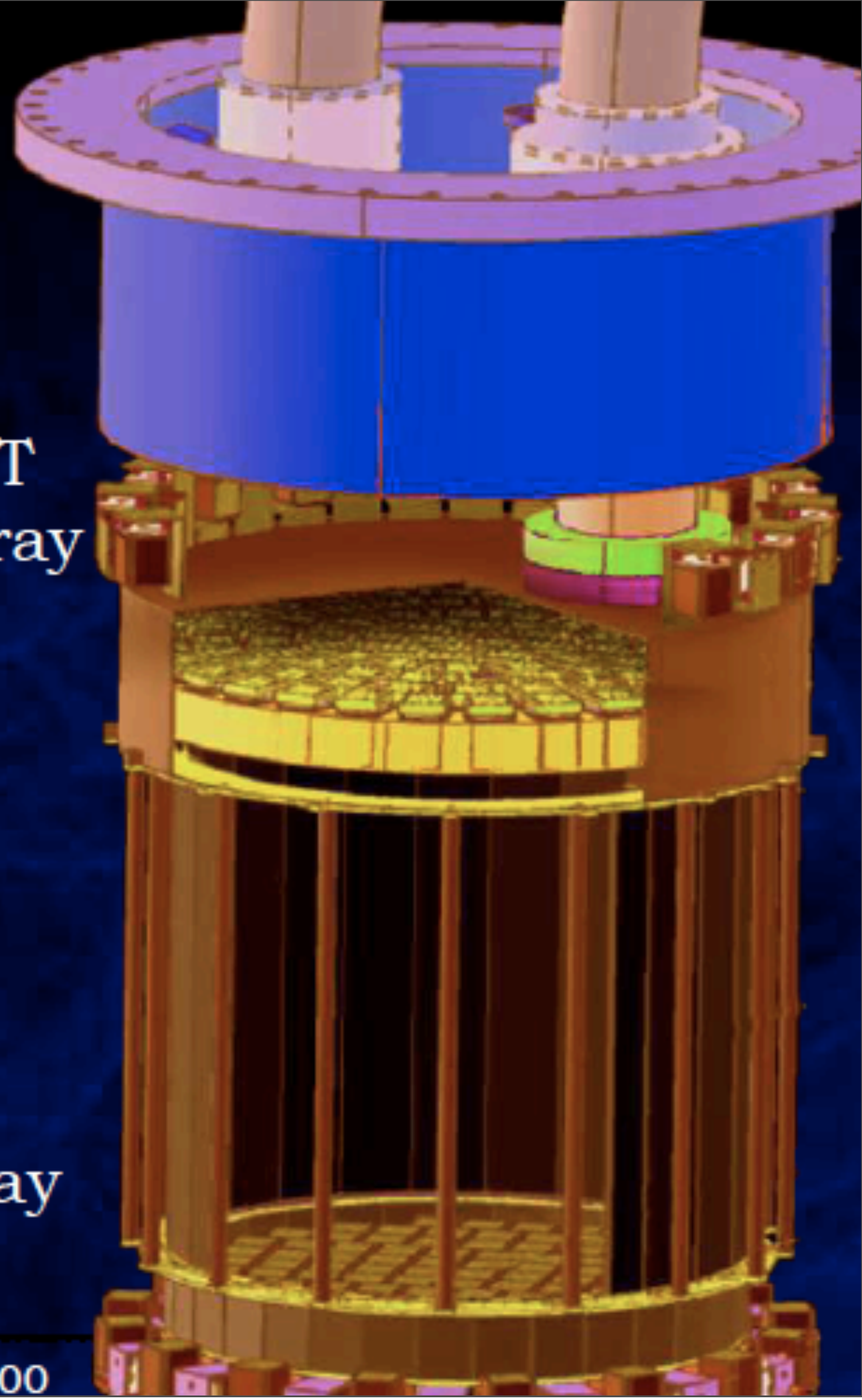
$\rightarrow$ lots of information for each event

XENON100

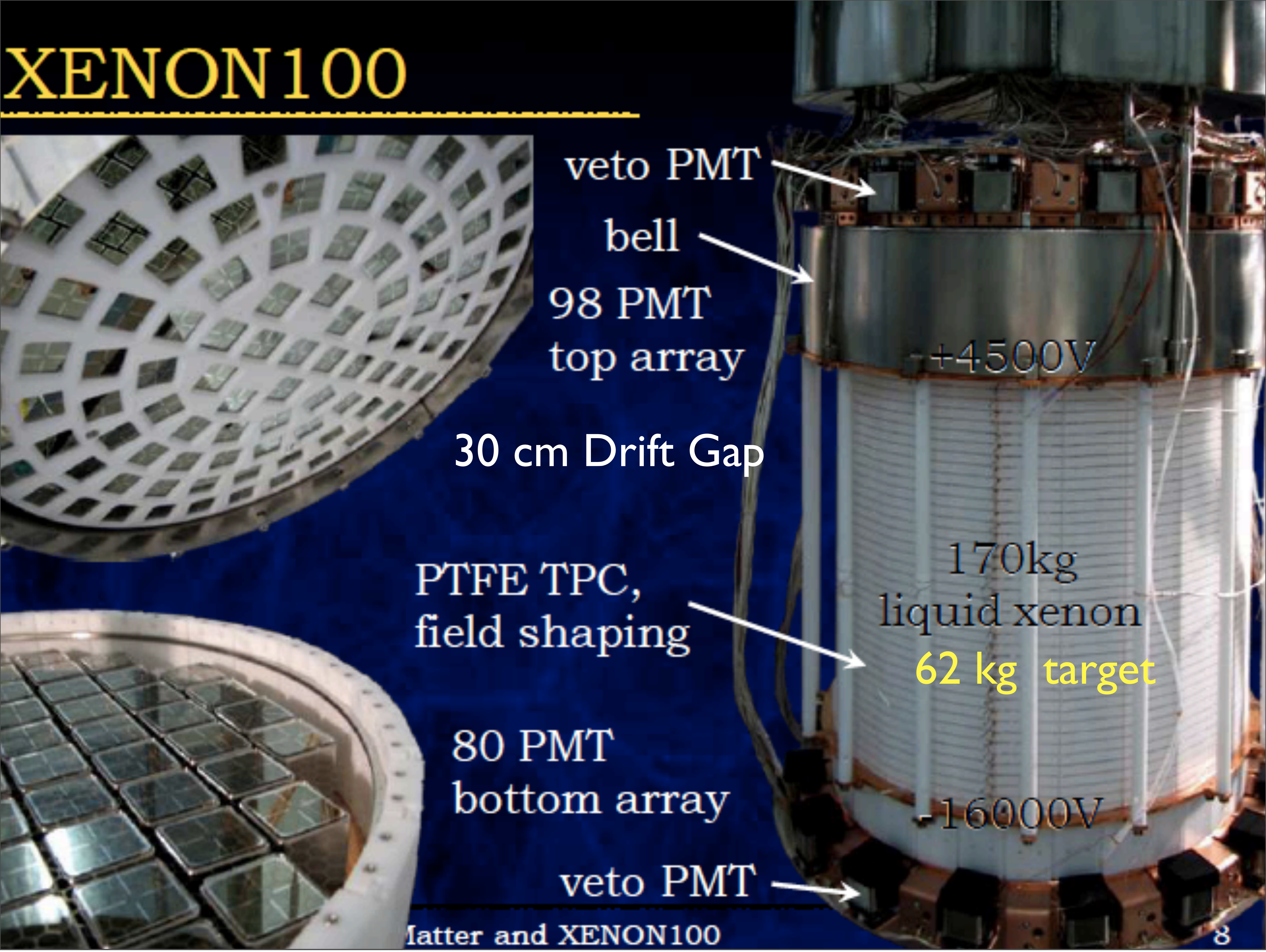
98 PMT
top array



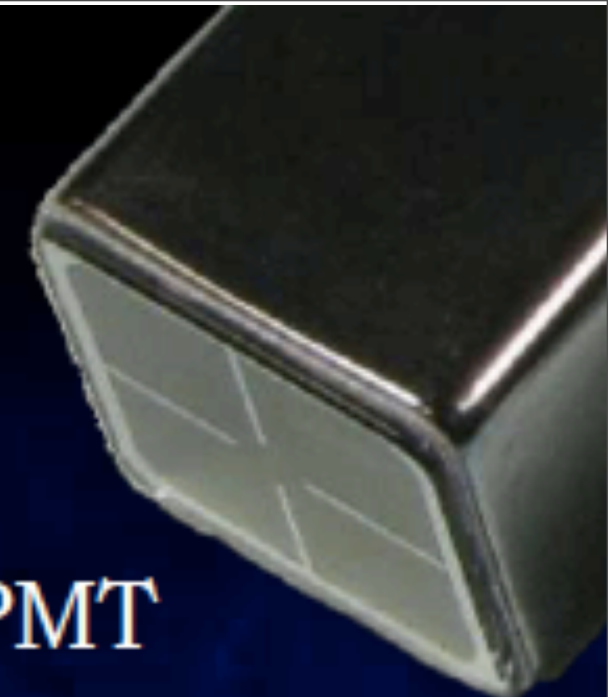
80 PMT
bottom array



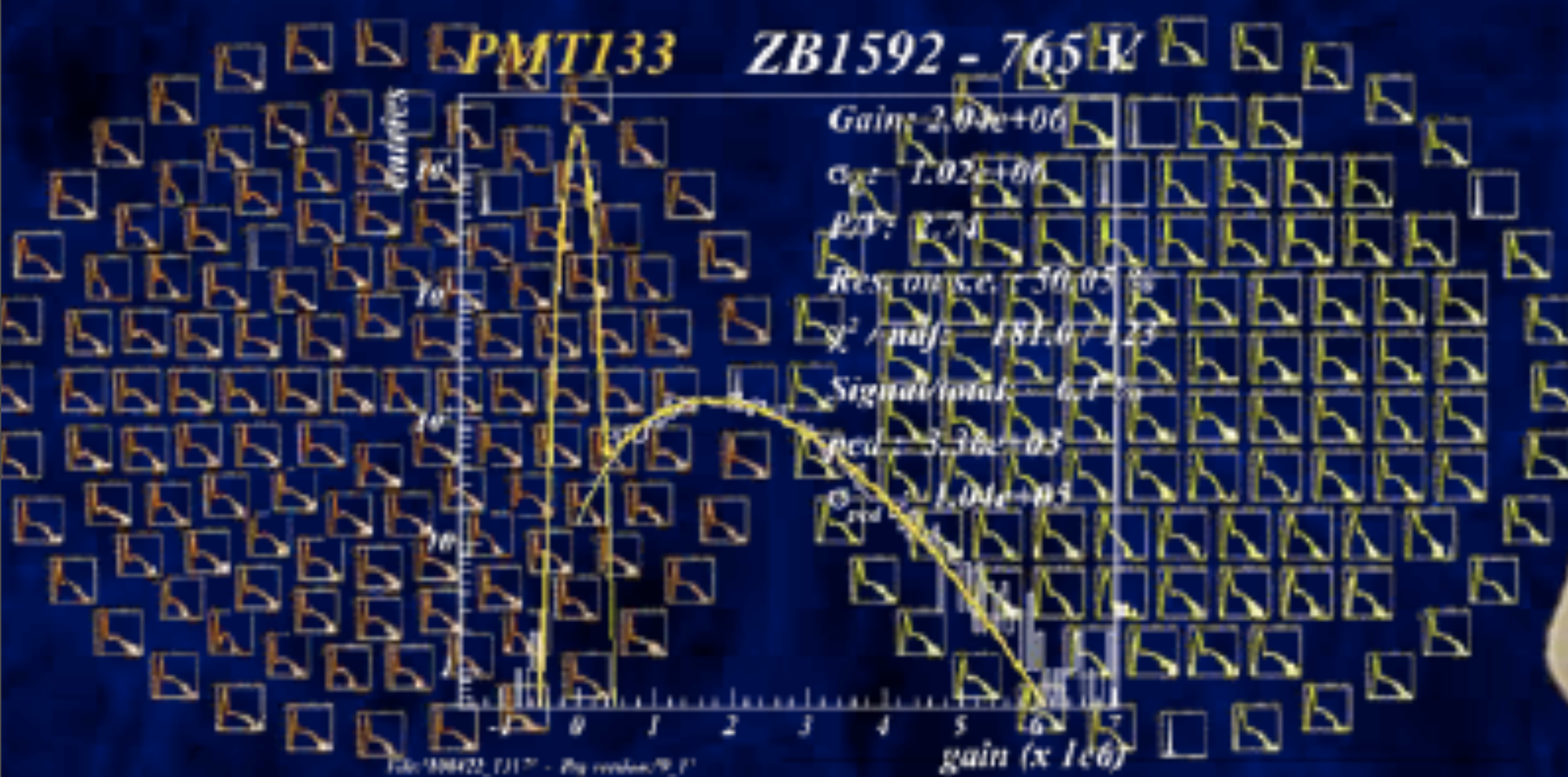
XENON100


veto PMT
bell
98 PMT
top array
+4500V
30 cm Drift Gap
170kg
liquid xenon
62 kg target
PTFE TPC,
field shaping
80 PMT
bottom array
-16000V
veto PMT

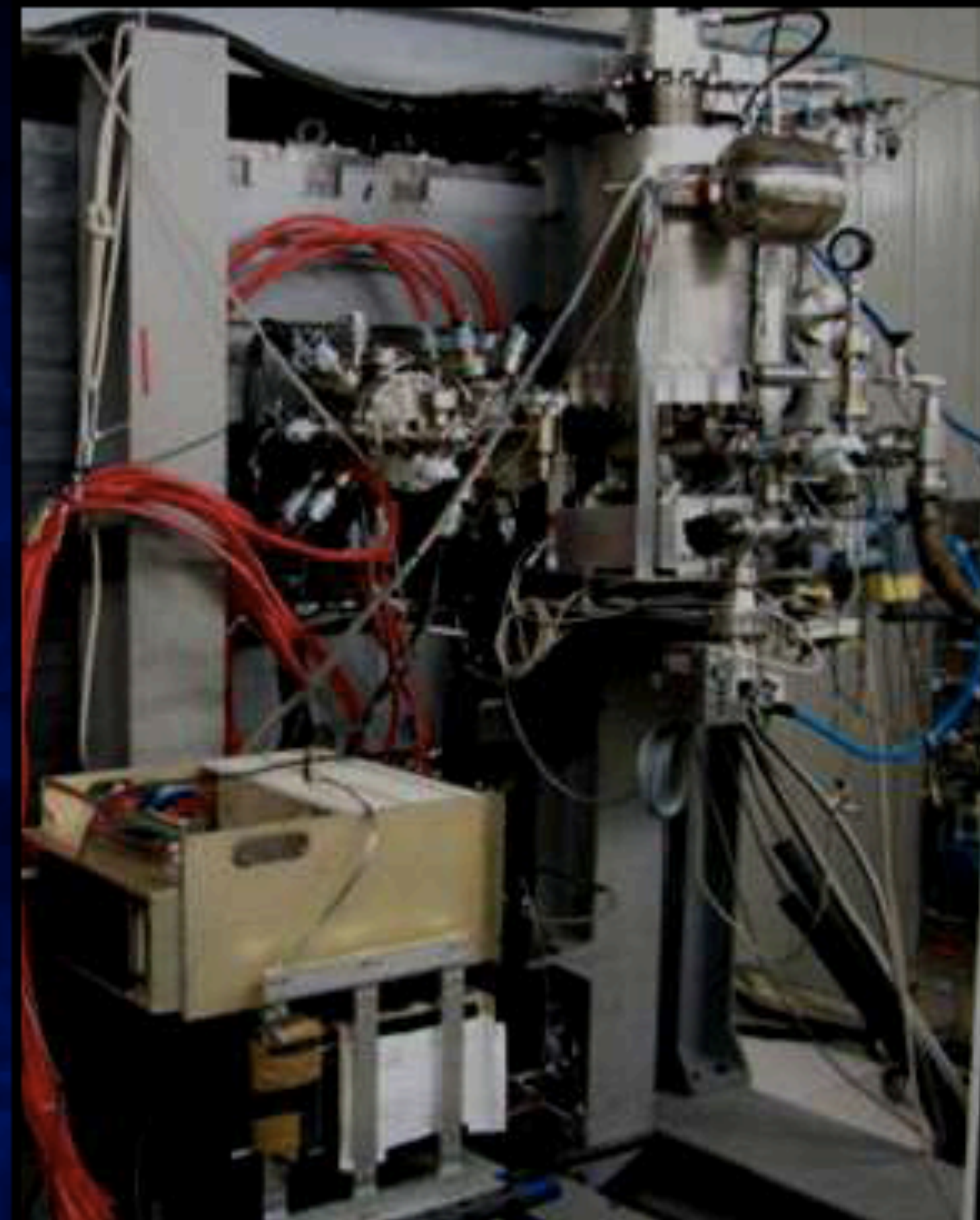
PMTs & Gain Calibration



- 1" square metal-channel R8520-06-Al
- optimized for 178nm, low T, high p
- low radioactivity <1mBq in $^{238}U/^{232}Th$ per PMT
- 98 top PMTs, optimized for good r resolution
- 80 bottom PMTs, optimized for filling factor, QE ~33%
- 64 in veto looking up, down and inward
- regular gain monitoring

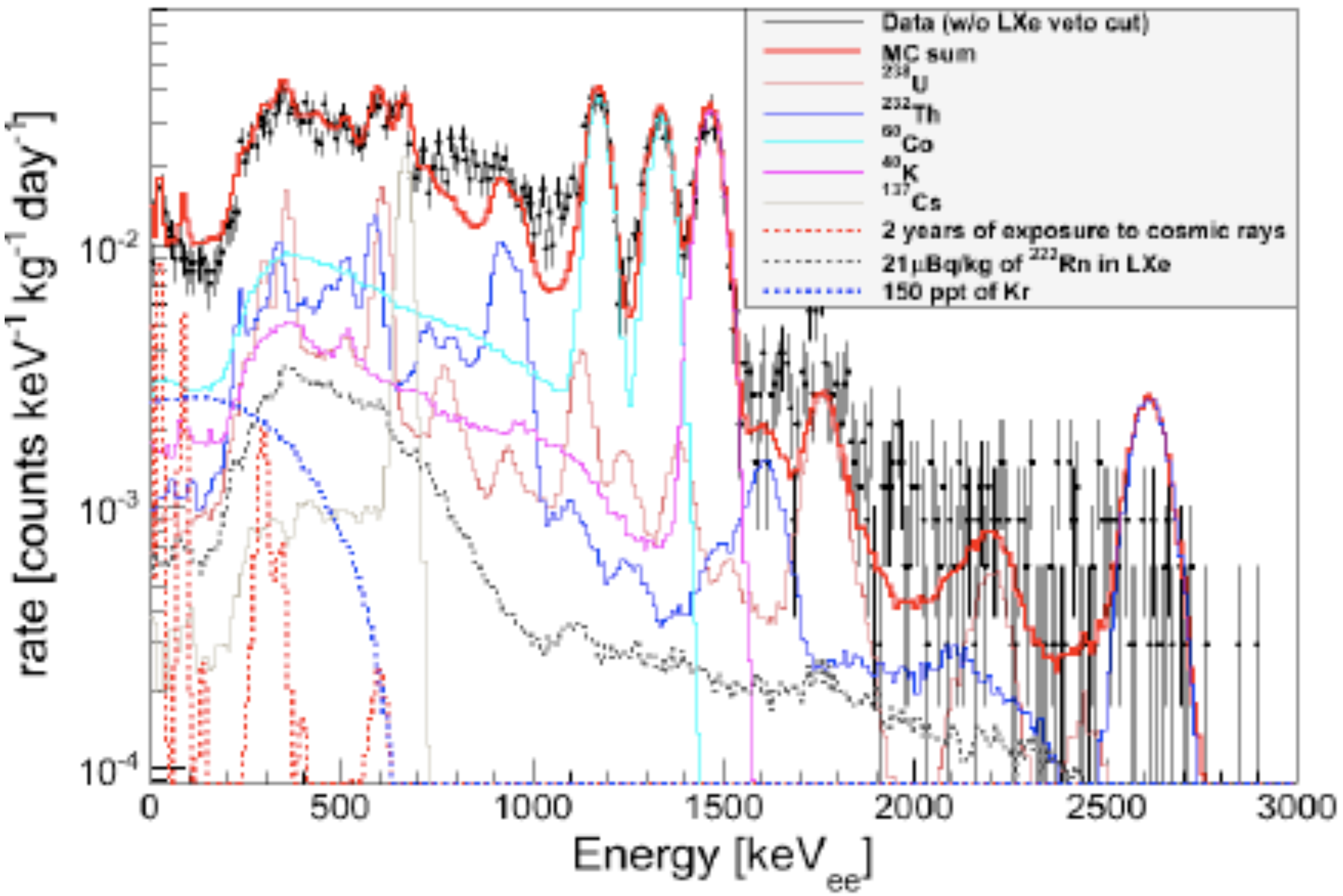


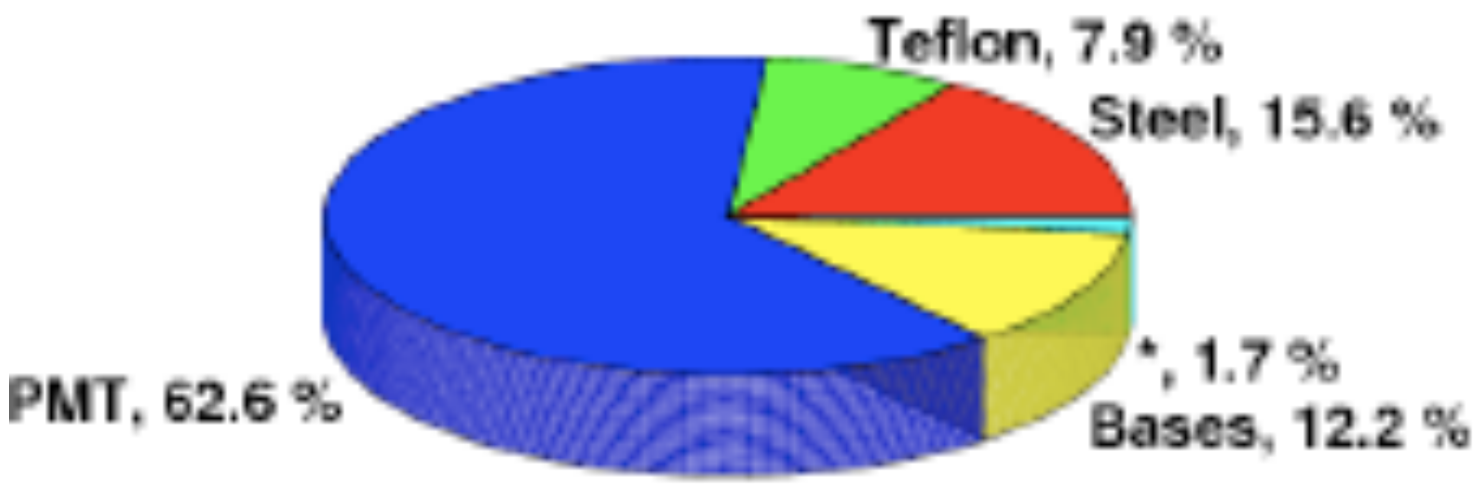
XENON100 Shield



20cm H_2O, 15cm Pb, 5cm French Pb, 20cm PE, 5cm Cu

XENON100: Measured Background





XENON100: Summary of Predicted Backgrounds

- Electron and nuclear backgrounds from various sources are predicted

Electron recoils

(before S2/S1 discrimination and active veto cut)

Source of BG	events/(kg·day·keVee) 50 kg FV	30 kg FV
Detector and shield materials	< 21.01	< 7.73
^{238}U and ^{232}Th in LXe	<5.57	<3.24
^{85}Kr in LXe	< 11.85	< 7.05
^{222}Rn in the cavity	< 2.56	< 1.24
All sources	< 40.99	< 19.26

Nuclear recoils

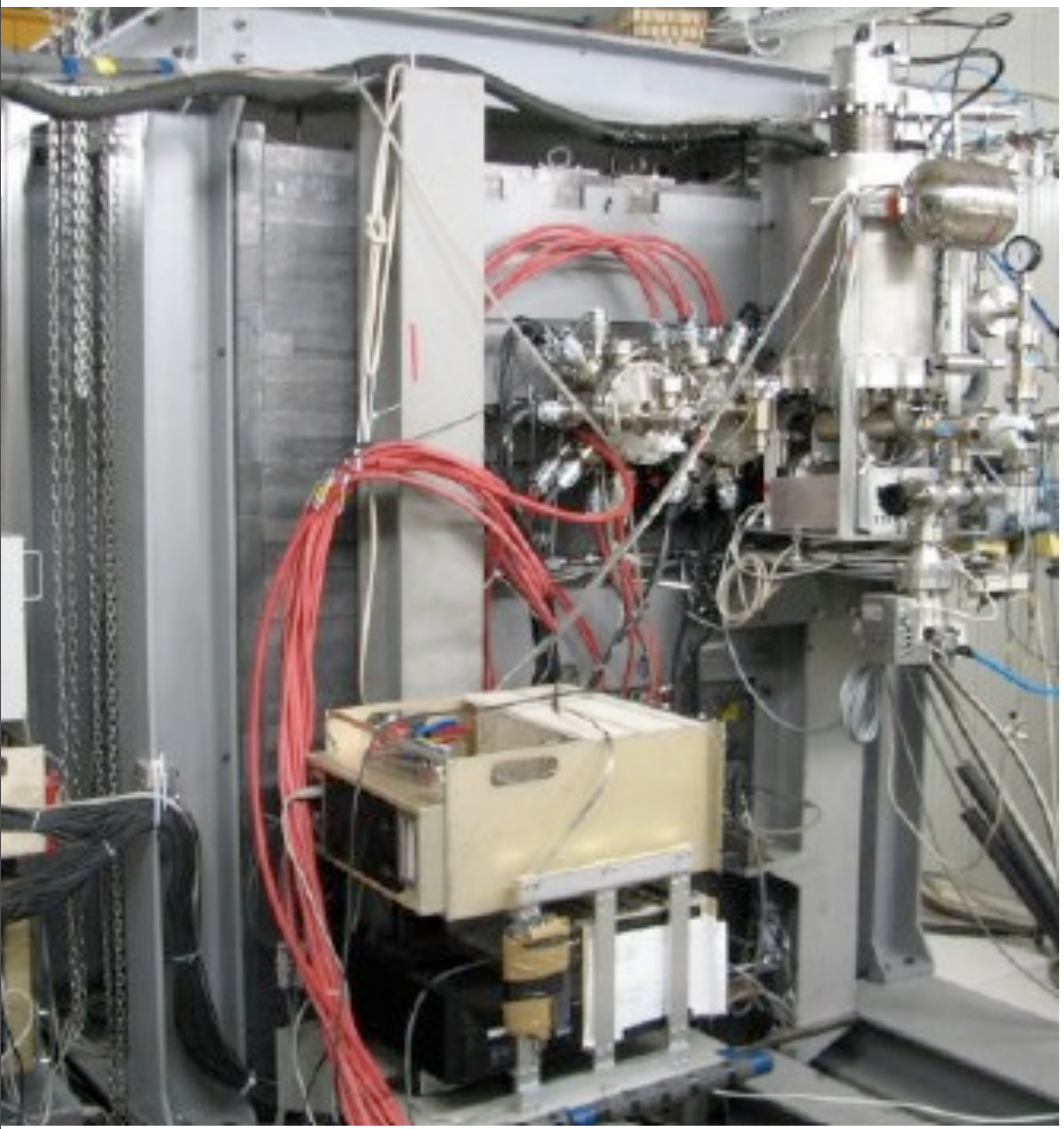
Neutron source	Single nuclear recoils per year in 50 kg FV	30 kg FV
Detector and shield materials	< 0.68	< 0.28
Cavern	0.48 ± 0.15	0.20 ± 0.09
Cosmic ray muons	0.27 ± 0.13	< 0.07
All sources	< 1.43	< 0.55

- Background reduction with fiducial volume cuts and active veto is calculated:

efficiency of fiducial volume cuts >90% (30 kg of LXe)

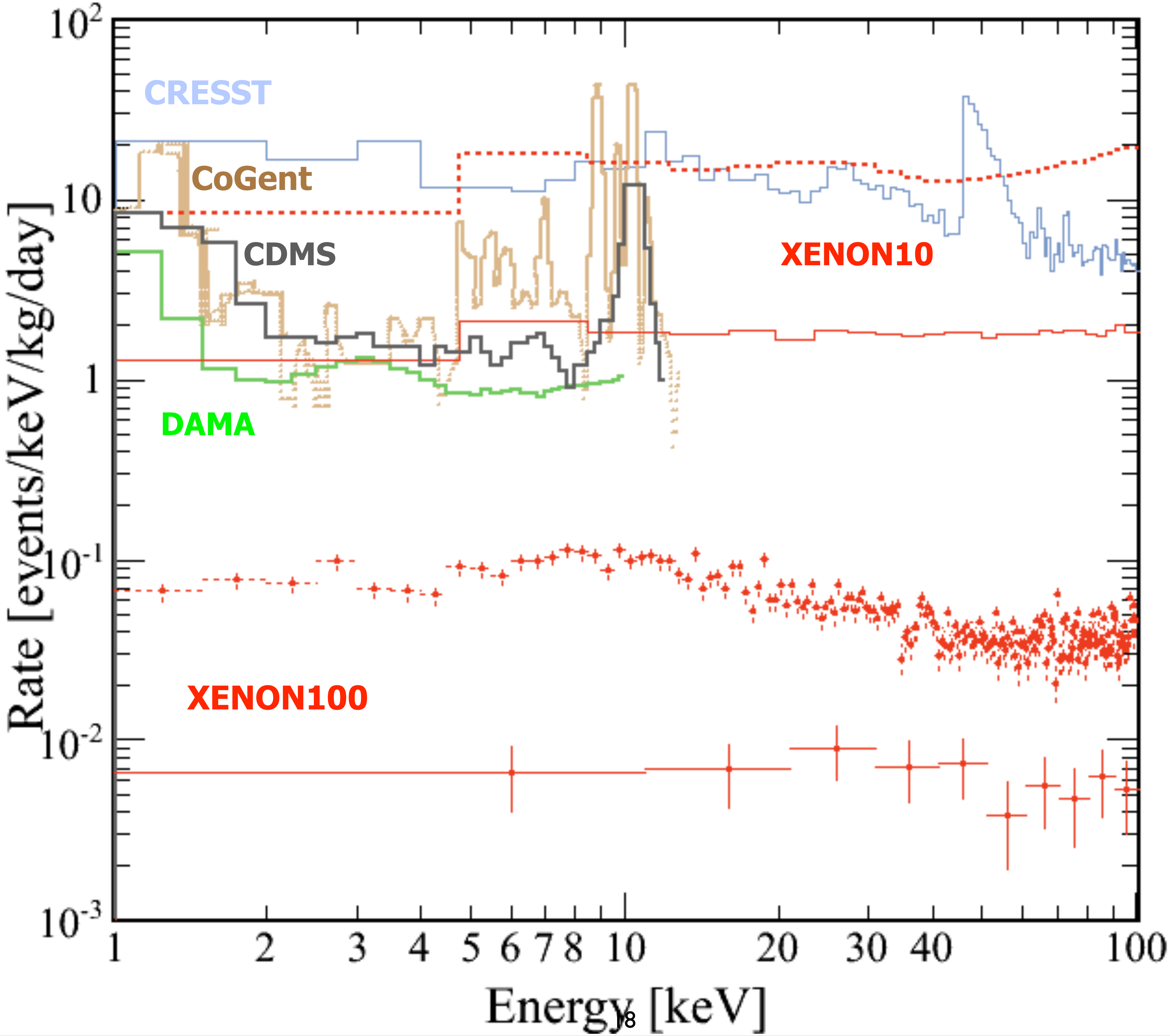
efficiency of the active veto >70%

XENON100: Status

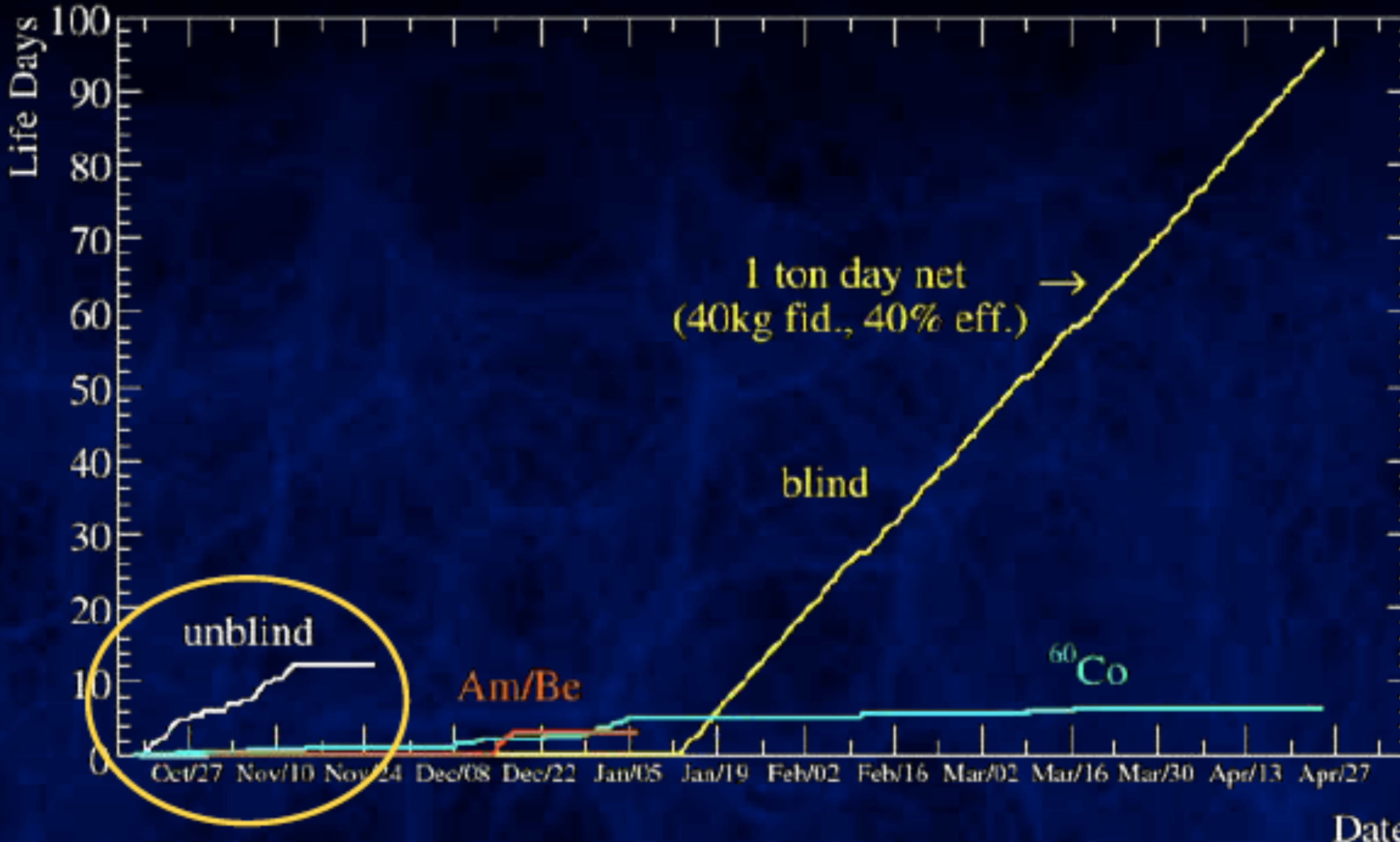


- In continuous operation underground for the past 6 months with high stability
- Neutron calibration performed in mid-December 2009
- Gamma calibrations are performed on regular basis (Cs137 for e-lifetime; Co60 for gamma band)
- Measured background level is consistent with design goal of 100 less than XENON10
- Dark Matter search run started on January 13, 2010: data in ROI “blinded”
- Event selection and cuts developed and optimized on calibration data

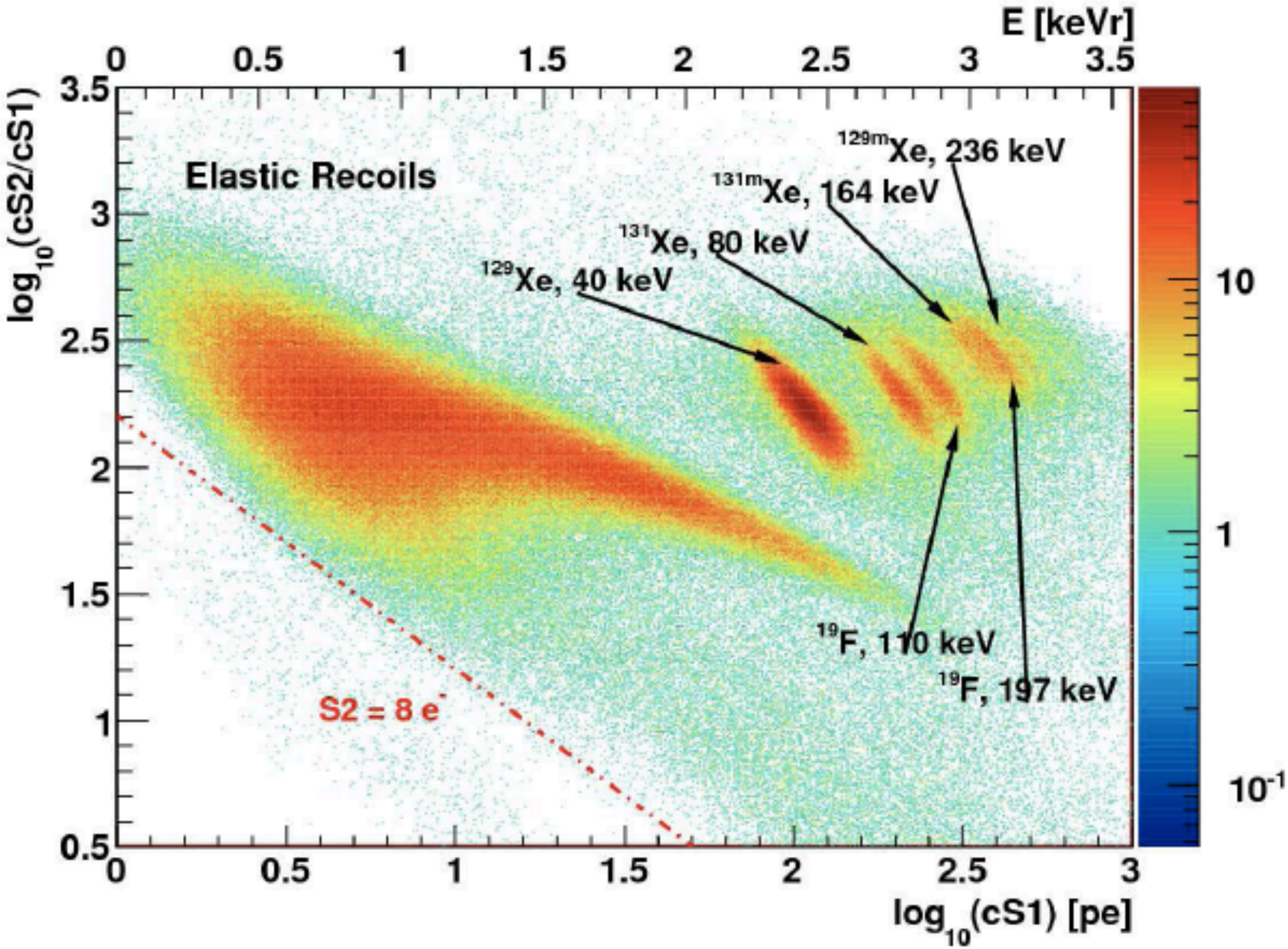
XENON100: ultra-low background detector



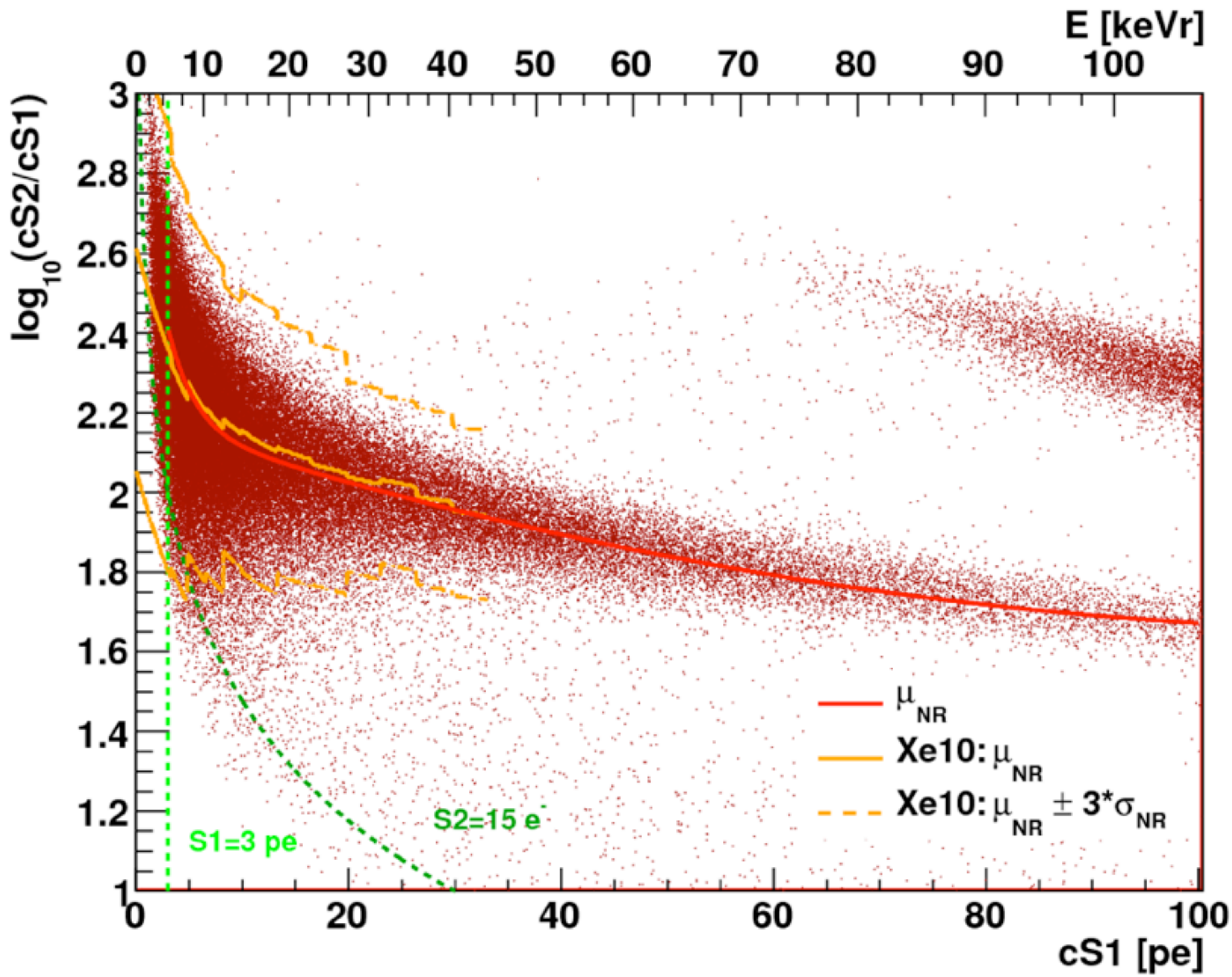
XENON100 Data Taking



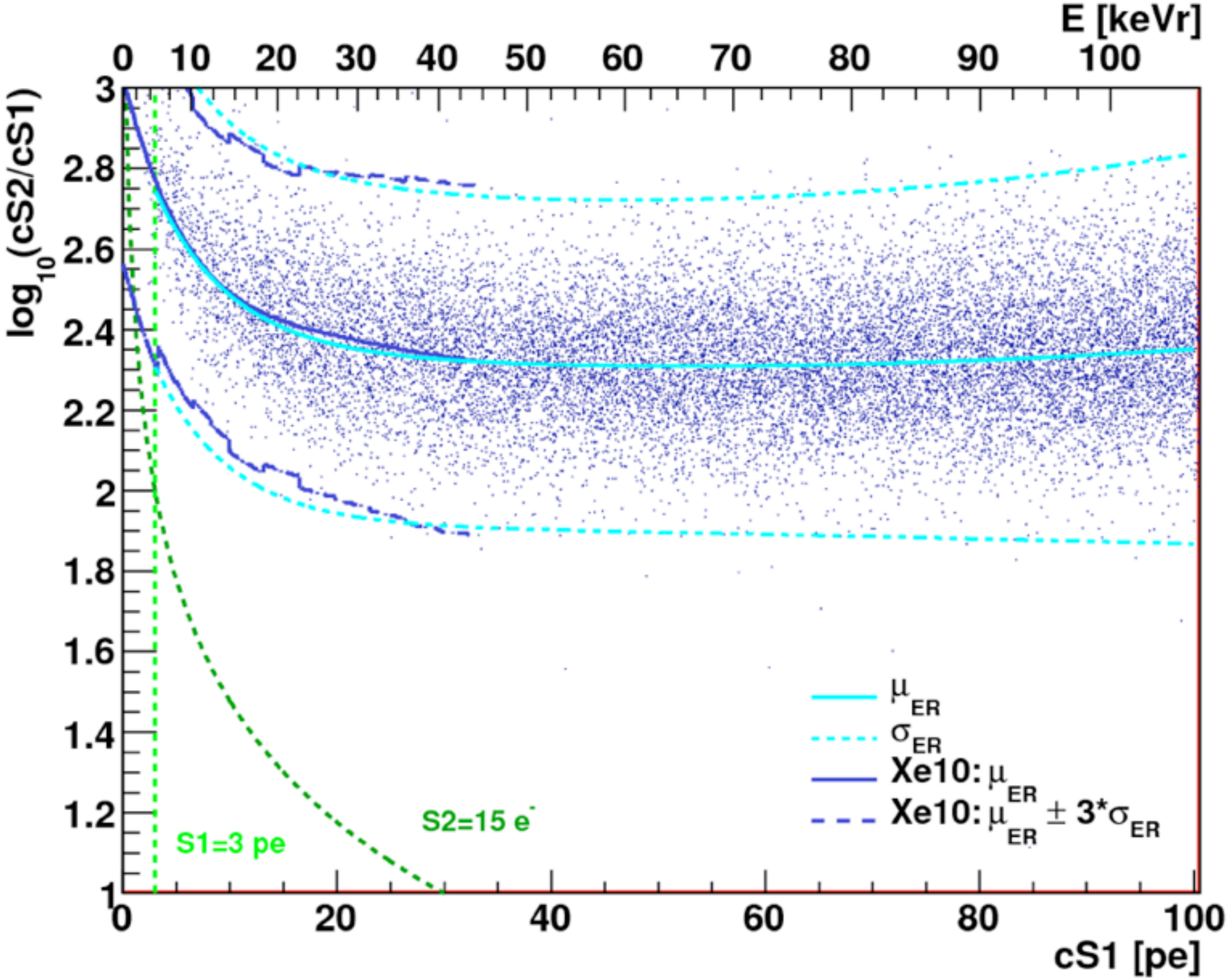
XENON100: Neutron Calibration



XENON100: Neutron Recoil Band



XENON100: Gamma Recoil Band



Nuclear Recoil Equivalent Energy Scale

Energy of nuclear recoil (NR)

quenching of scintillation yield for 122 keV γ due to drift field

measured signal in p.e.

$$E_{nr} = \frac{S1}{L_y L_{eff}} \times \frac{S_e}{S_r}$$

light yield for 122 keV in p.e./keV

scintillation efficiency of NR relative to 122 keV γ at zero field

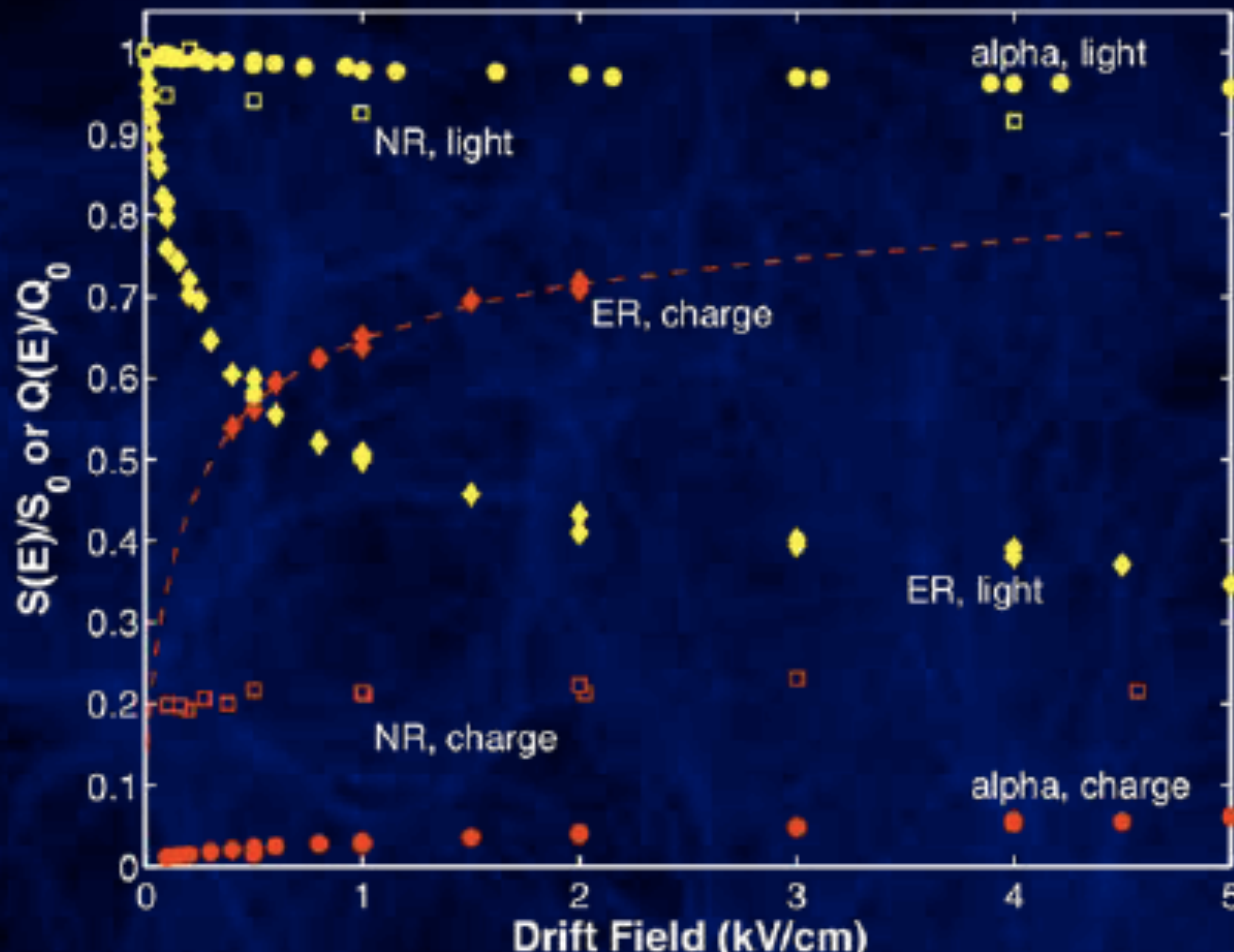
quenching of scintillation yield for NR due to drift field

Nuclear Recoil Equivalent Energy

Nuclear Recoil Energy: $E_{nr} = \frac{S1}{L_y} \cdot \frac{S_{ee}}{S_{nr}} \cdot \frac{1}{\mathcal{L}_{eff}}$

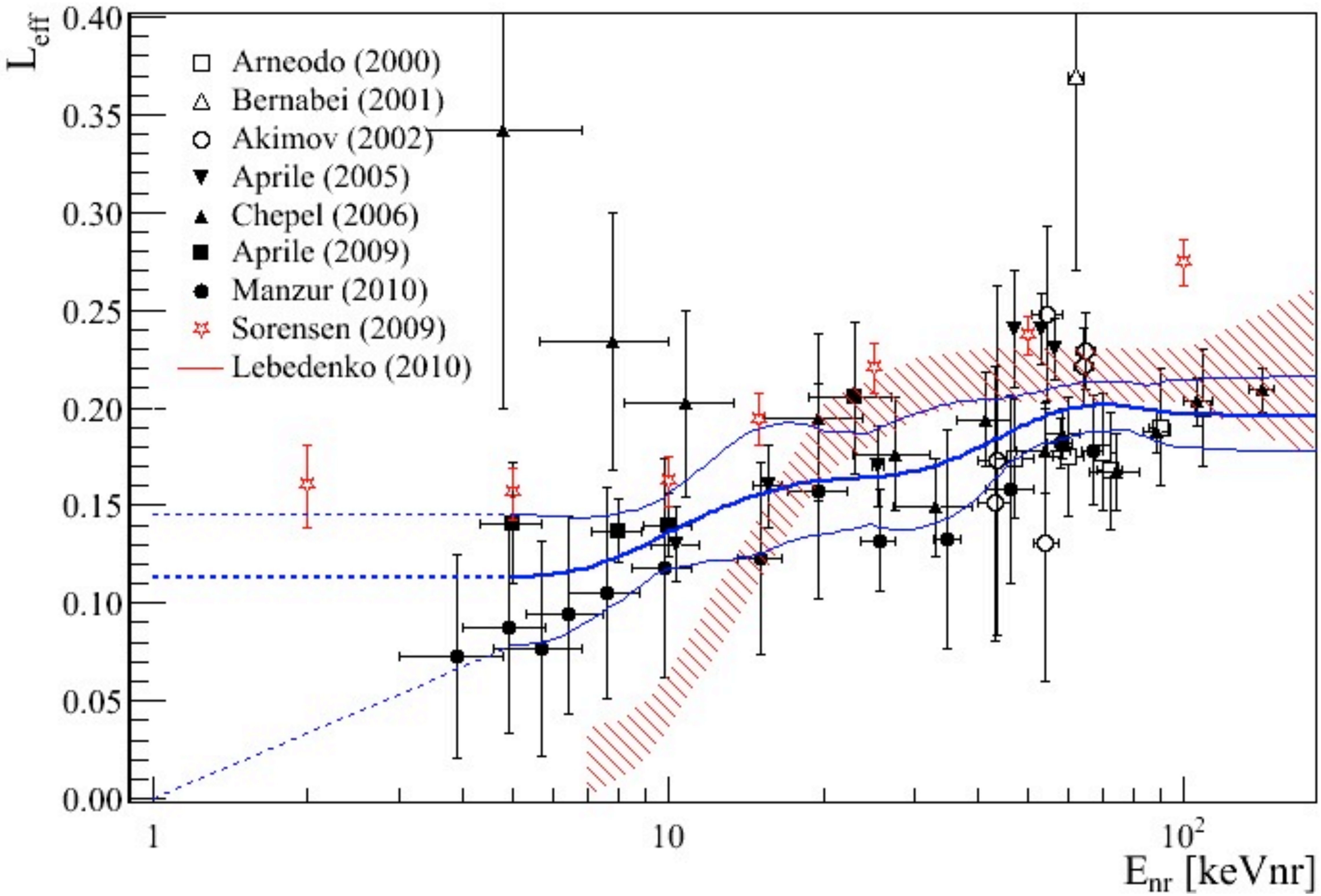
$L_y(122keV_{ee})$
$= (2.20\ \ 0.09)PE$

$S_{ee} = 0.58$
$S_{nr} = 0.95$



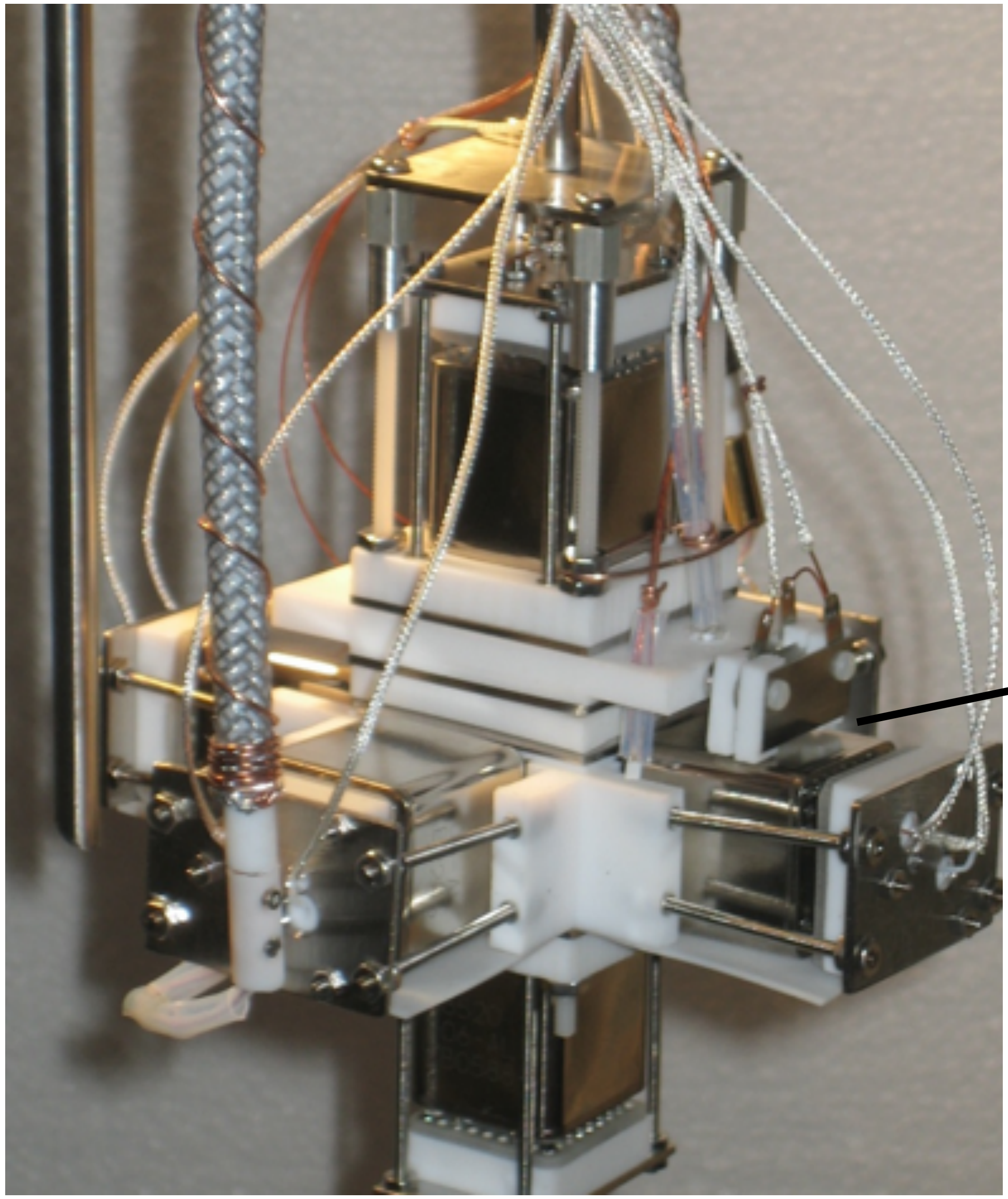
astro-ph/0601552

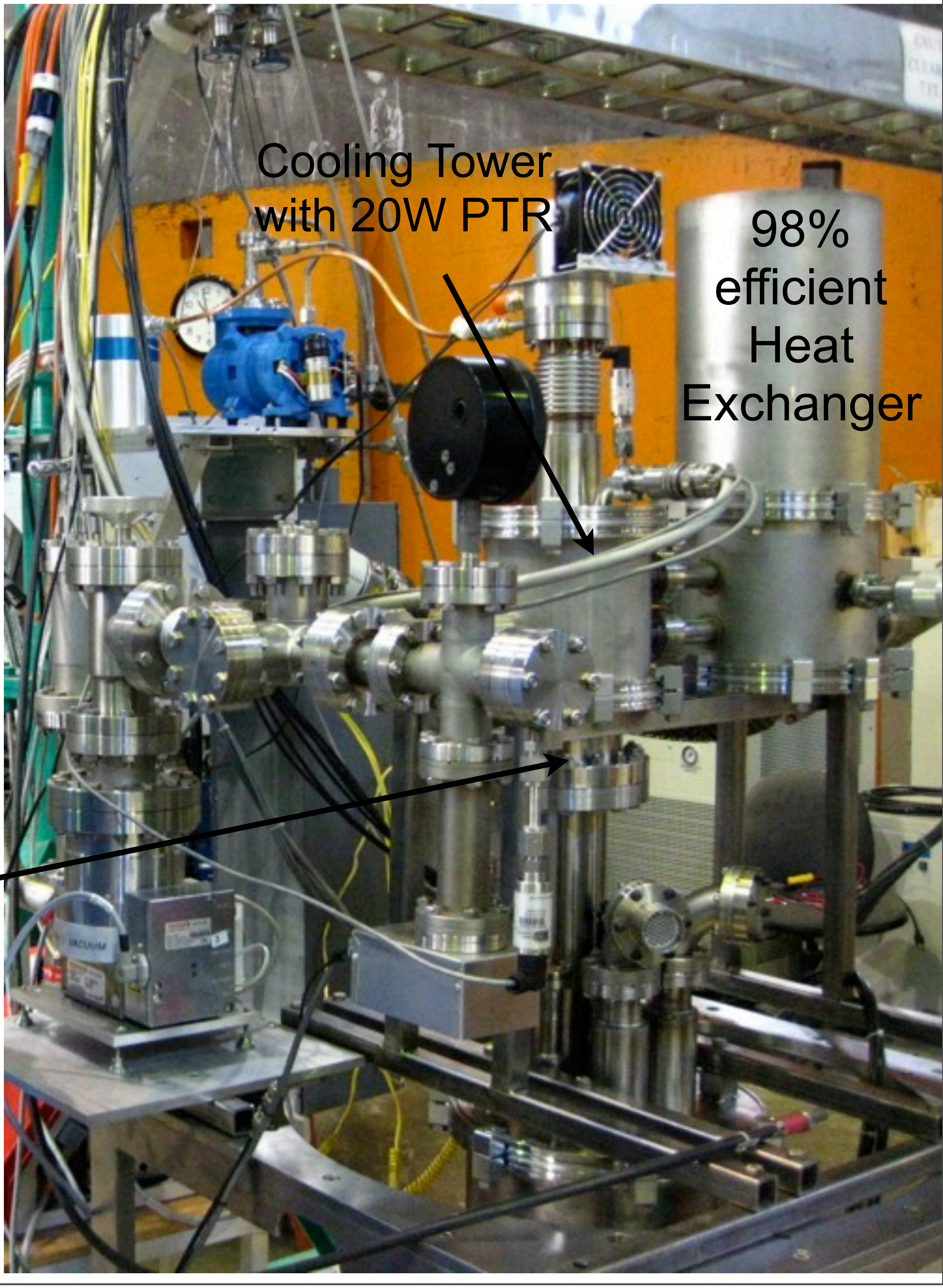
Current Leff Measurements in LXe



New Measurements of Leff in Liquid Xenon

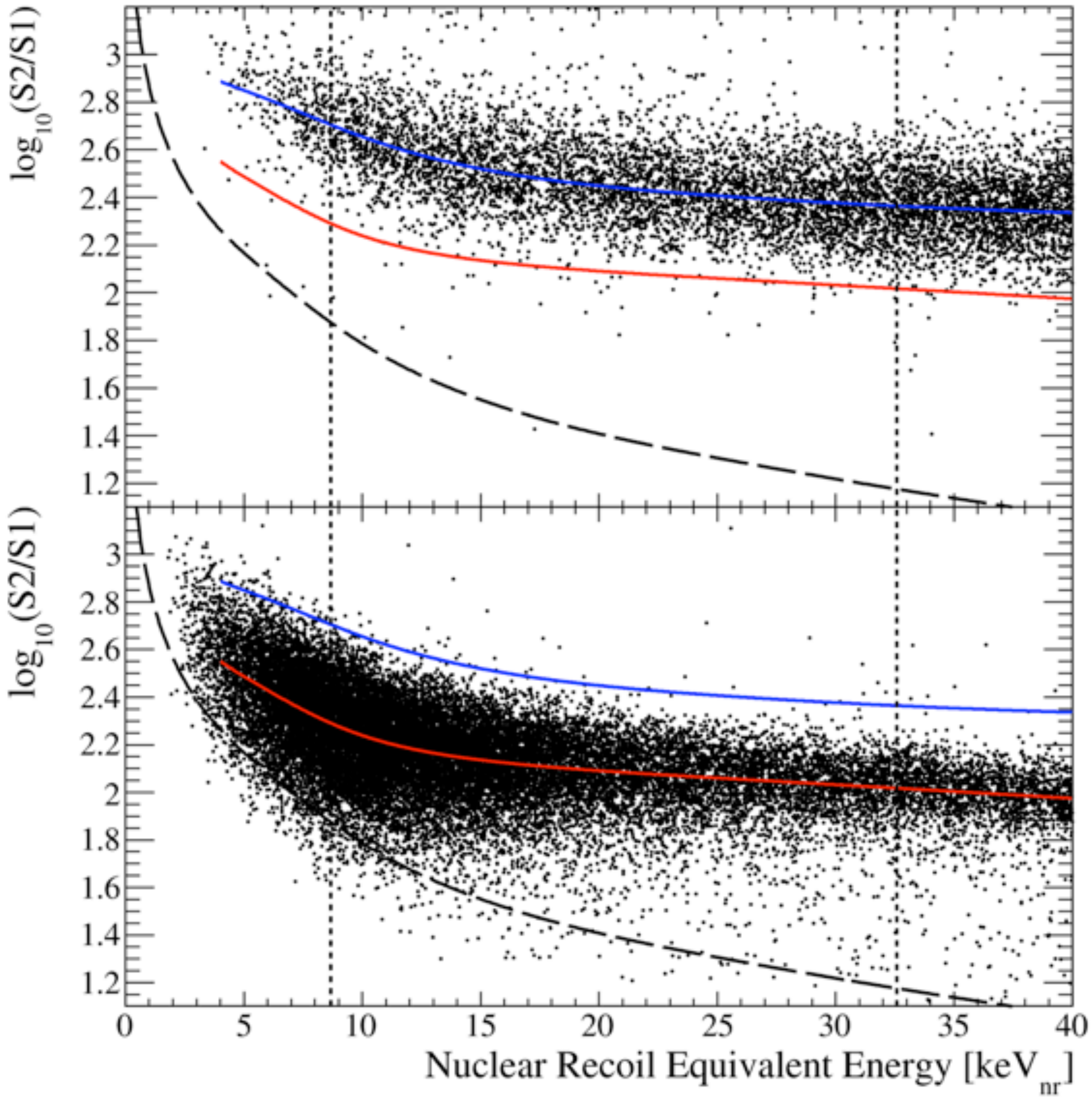
New experiment ongoing at the Columbia Nevis Lab, with a 2-phase miniTPC optimized for high light collection. Measure ionization and scintillation yield of very low energy ER and NR in LXe, as a function of field and energy.
DD- generator for neutrons
Additional set-up also at UZurich





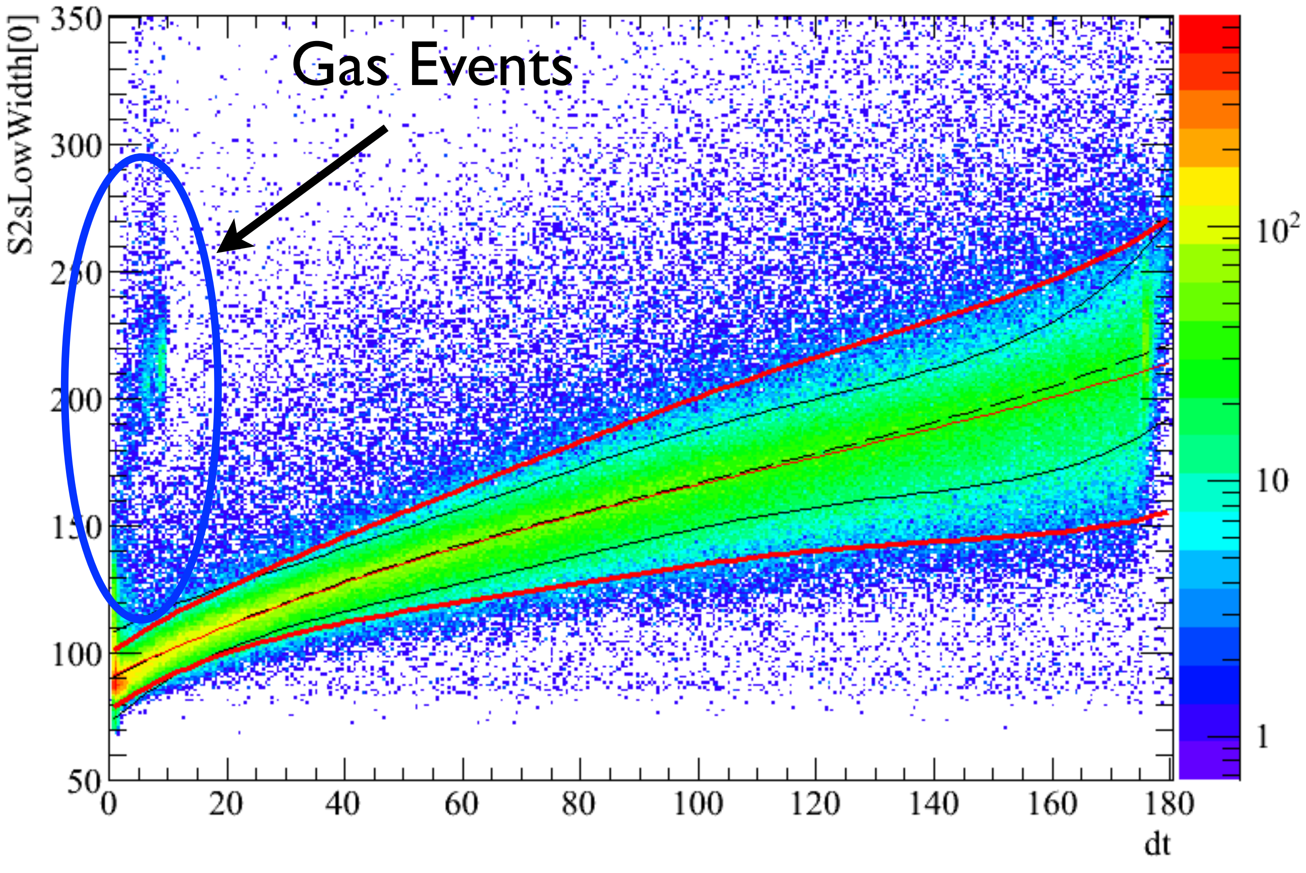
XENON100: arxiv-20100511

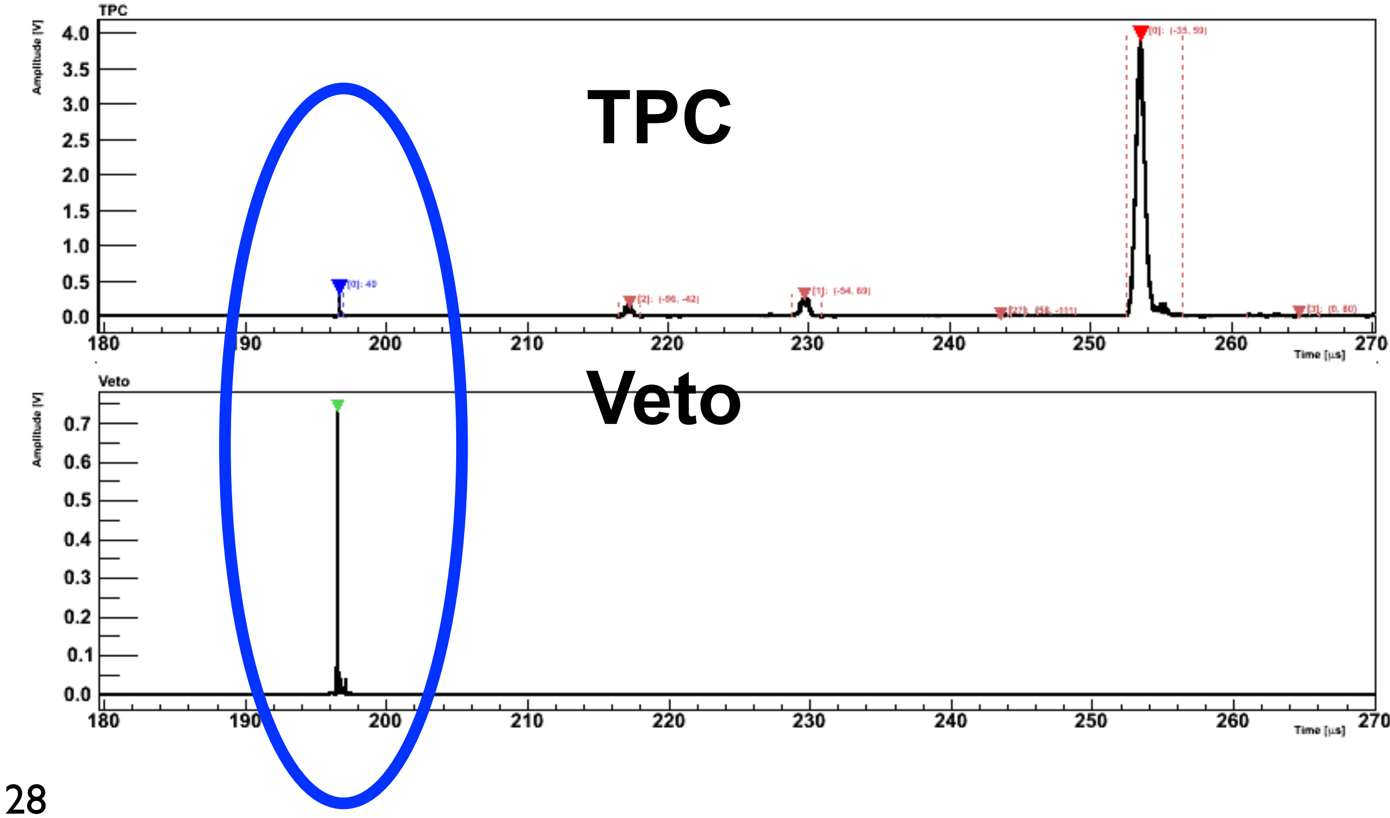
- WIMP search energy window: 4-20 PE or 8.7 - 32.6 keVr
- S2 software threshold: 300 PE



Analysis of XENON100 non-blinded data

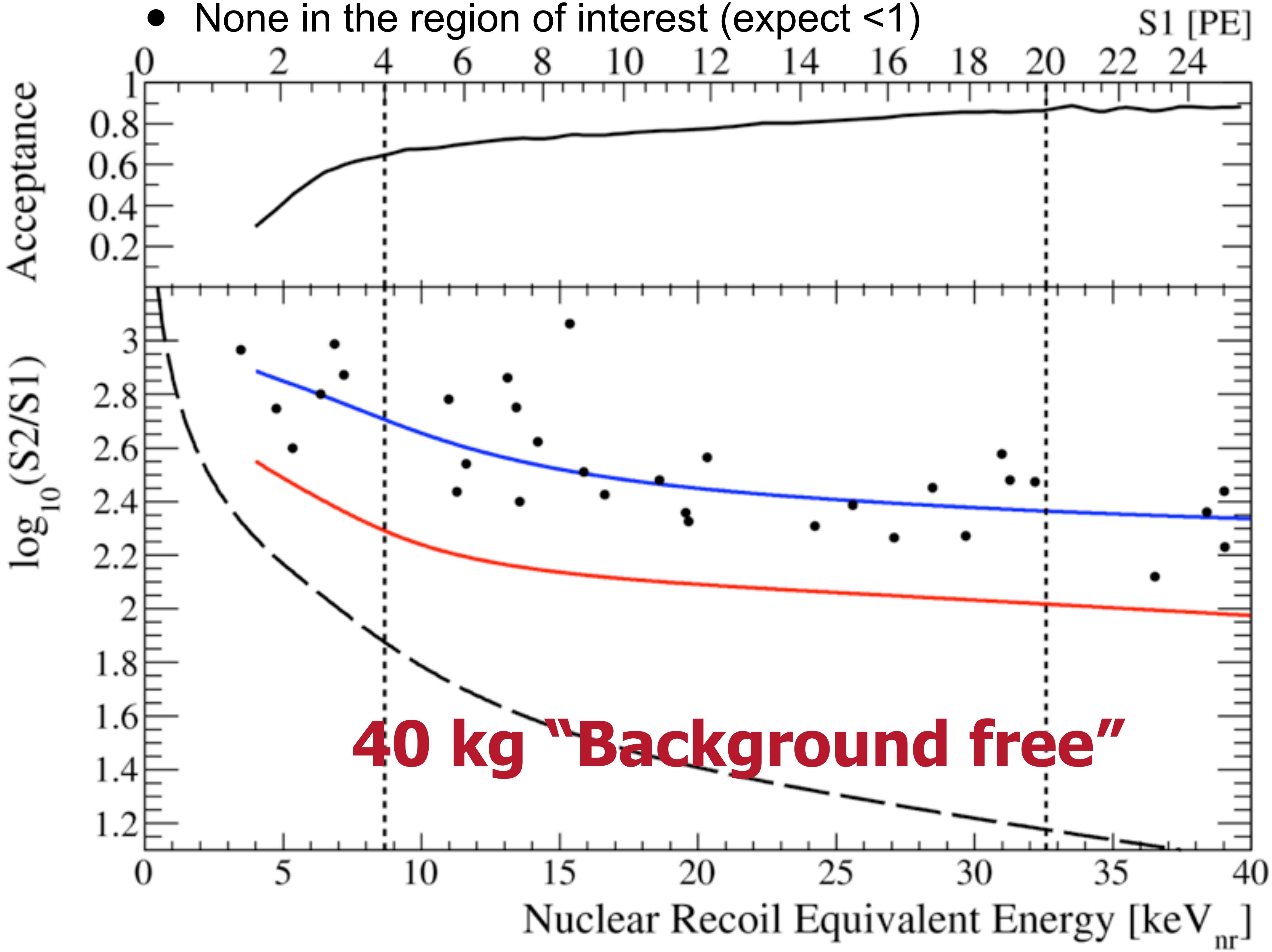
- 11.2 live days of background data from October-November 2009
- Non-blind analysis: but cuts optimized only on neutron and gamma calibration data
- Only very basic event selections are applied:
  - events with reasonable S/N ratio (TPC has high sensitivity to single electrons)
  - events with single S1 and single S2 peaks (remove delayed coincidence events and multiple Compton and neutron scatters)
  - events with the S2 pulse width compatible with drift time (remove gas events)
  - events with an S1 signal in active volume but no veto signal



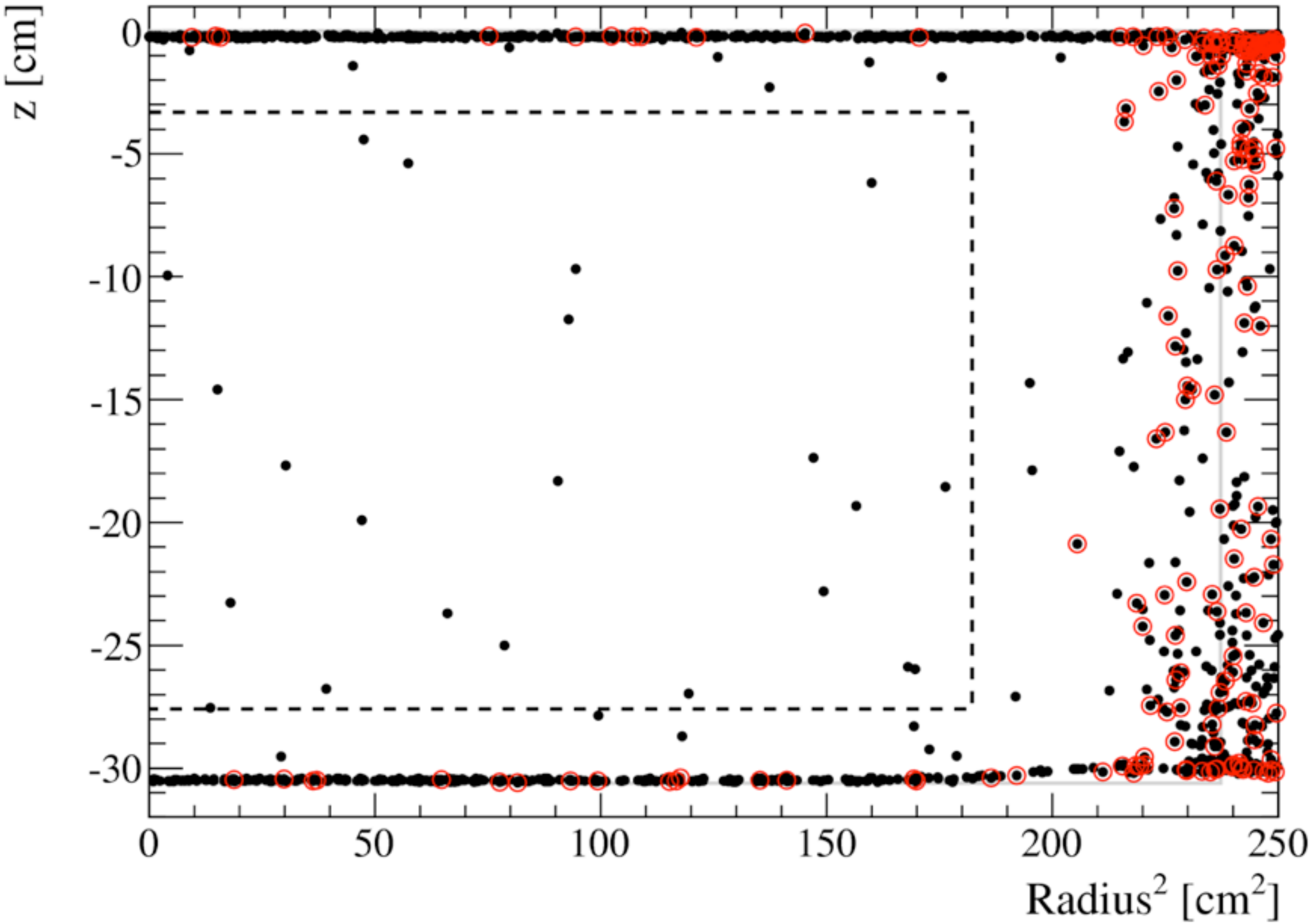


Results from the 11 days data

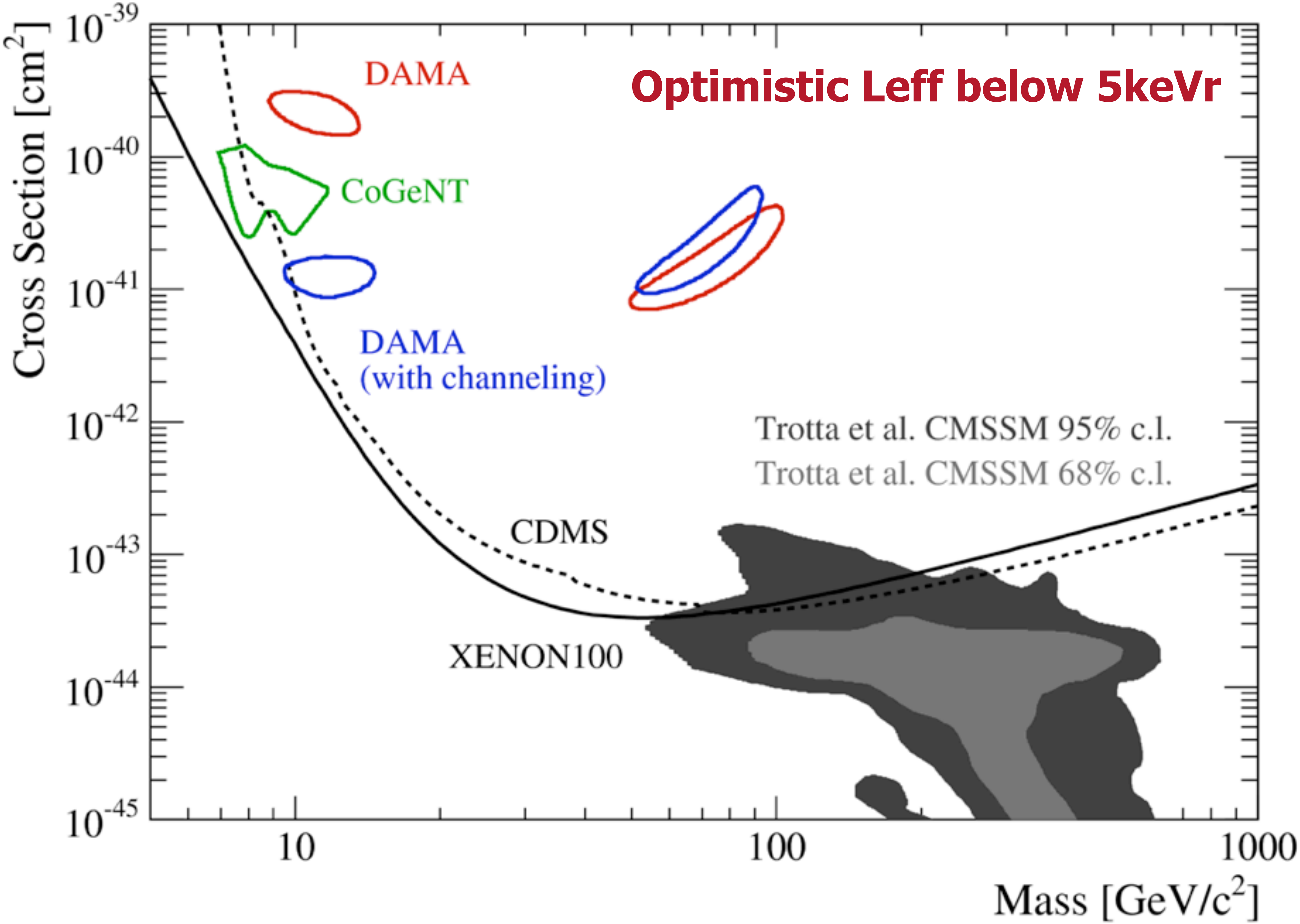
- 22 Events (8.7 - 32.6 keVr) after a 40 kg fiducial volume cut
- None in the region of interest (expect <1)



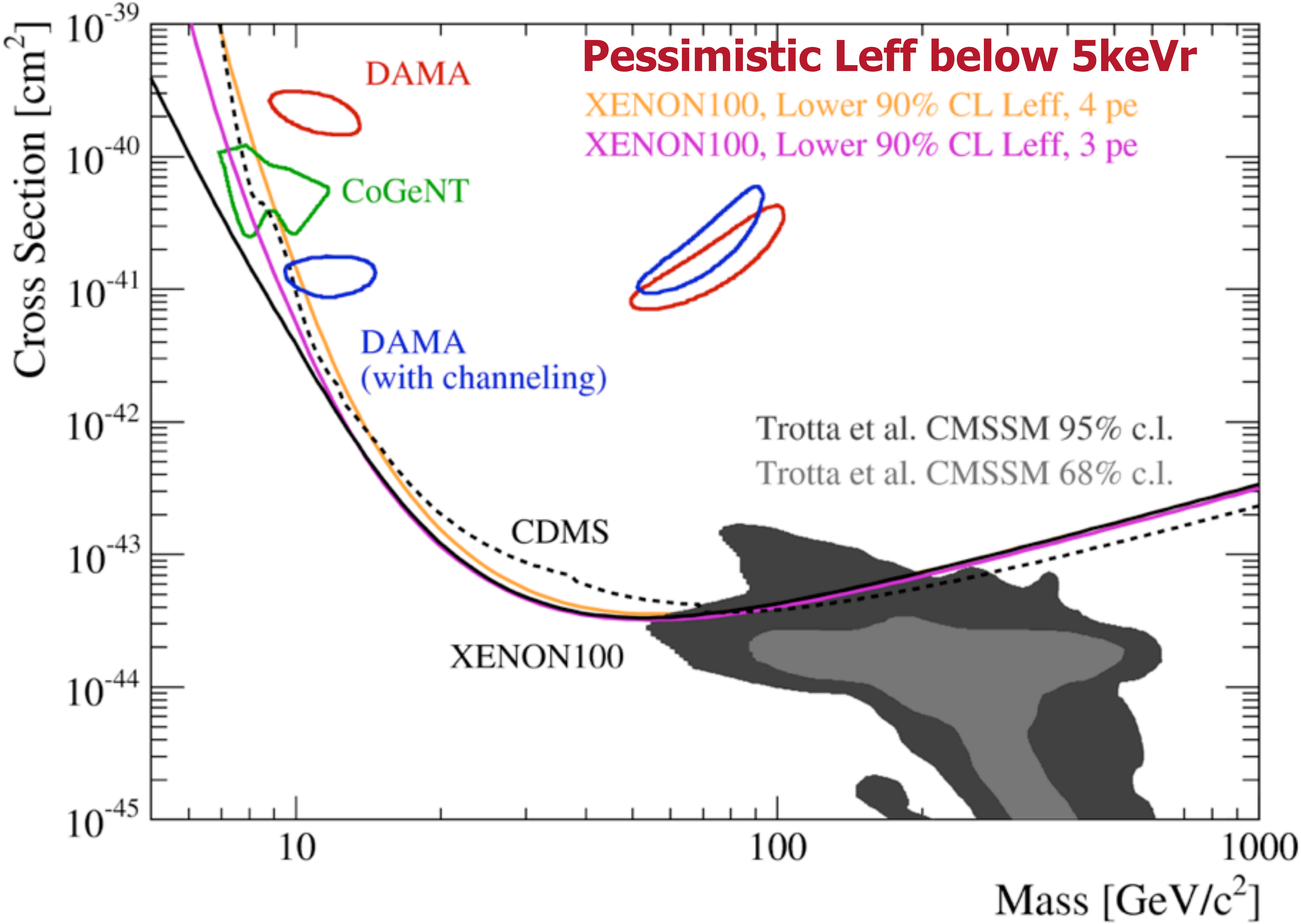
Results from the 11 days data



XENON100: First Spin Independent Limit



XENON100: First Spin Independent Limit



expect 4 evt above 3PE for pessimistic Leff

obeserve 0 evt->90%CL exclusion

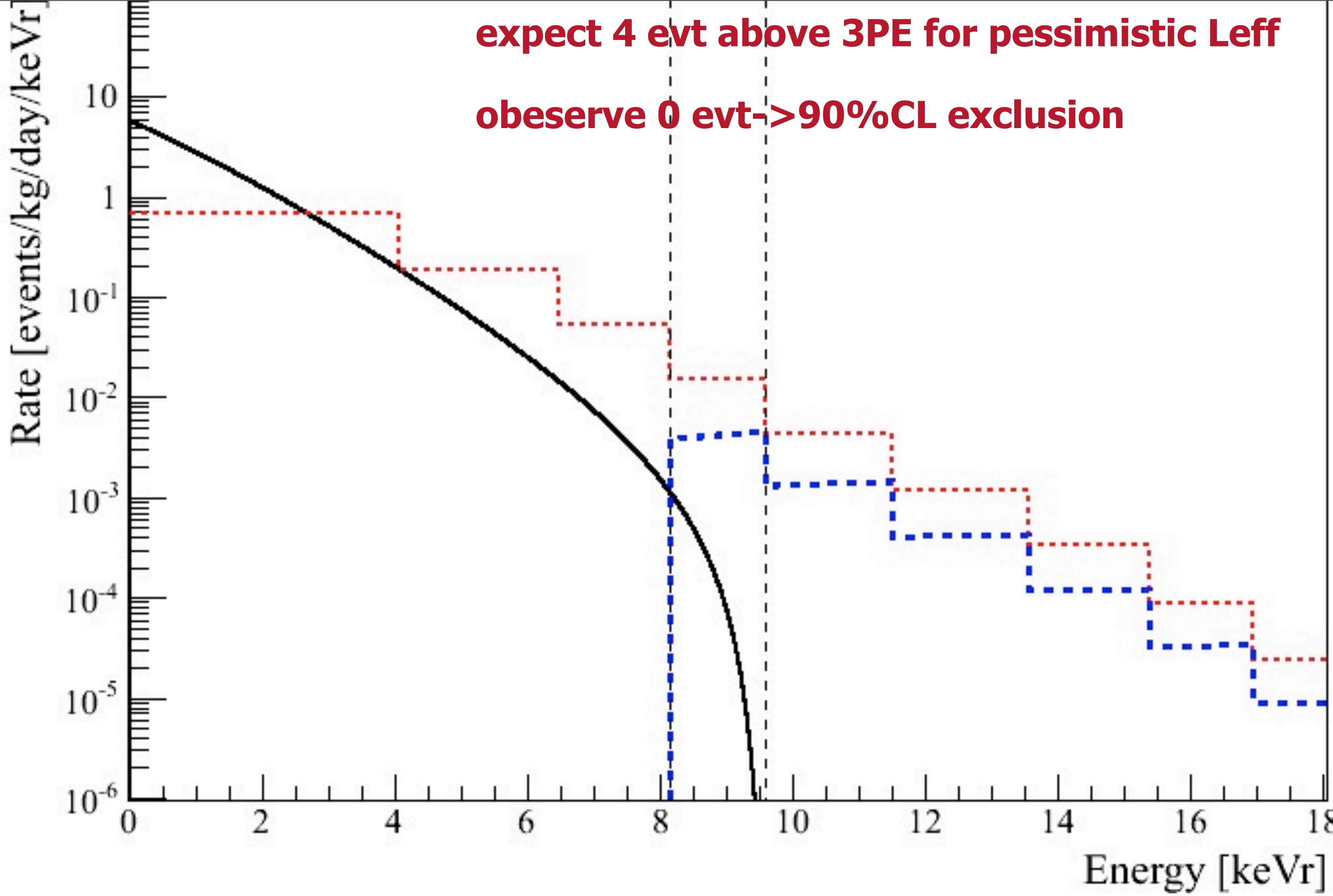
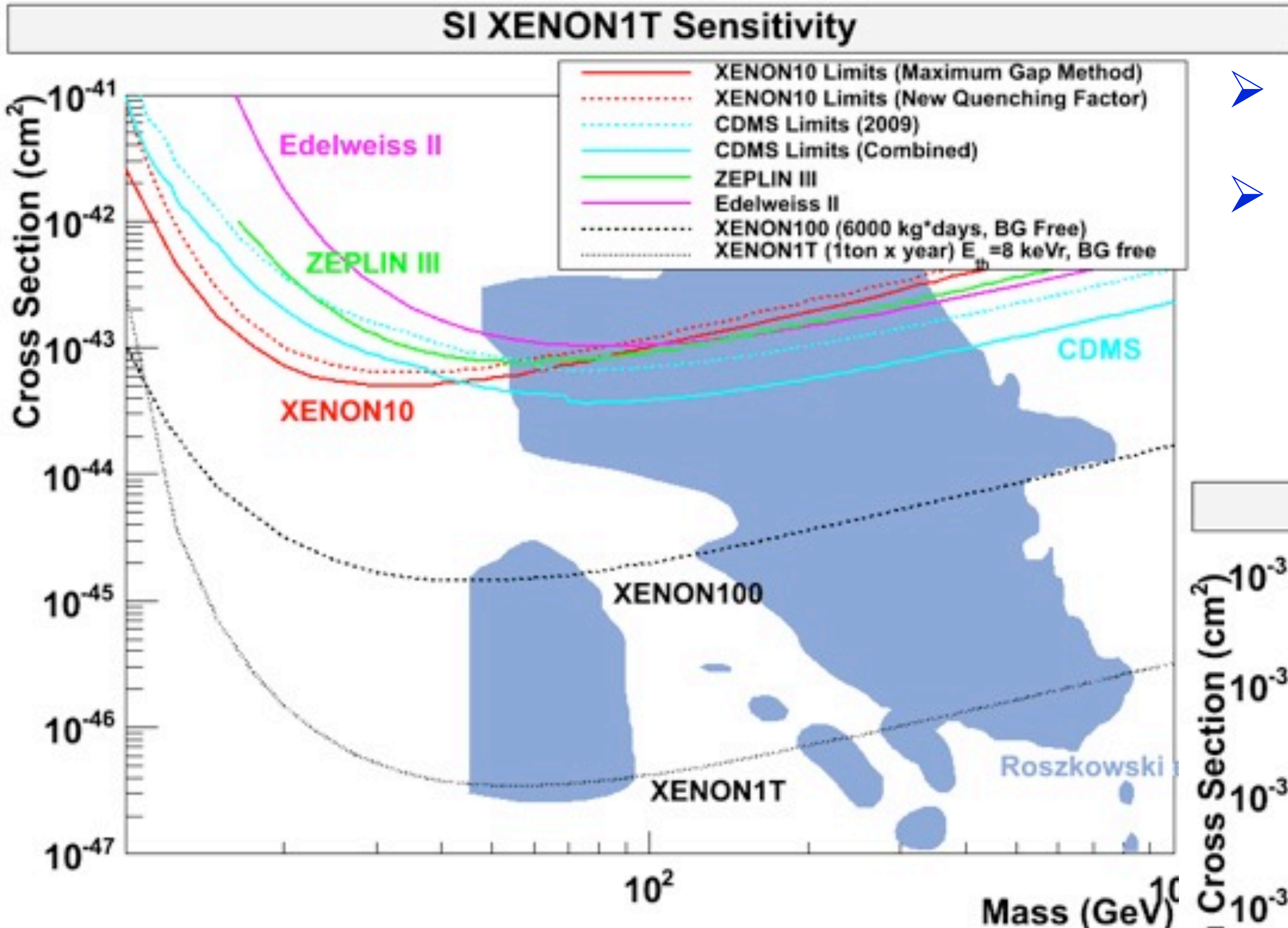


FIG. 2: Expected spectrum of a 10 GeV/c^2 WIMP with a cross section of 1×10^{-41} cm^2 (black, solid), a benchmark case at the lower edge of the DAMA region. The red (dashed) lines show the spectrum after a convolution with a Poisson distribution, the blue (thick dashed) line is corrected for the XENON100 efficiency. The straight lines are the 3 PE and 4 PE thresholds using the lower 90% CL $\mathcal{L}_{\text{eff}}$ contour of the global fit as explained in the text.

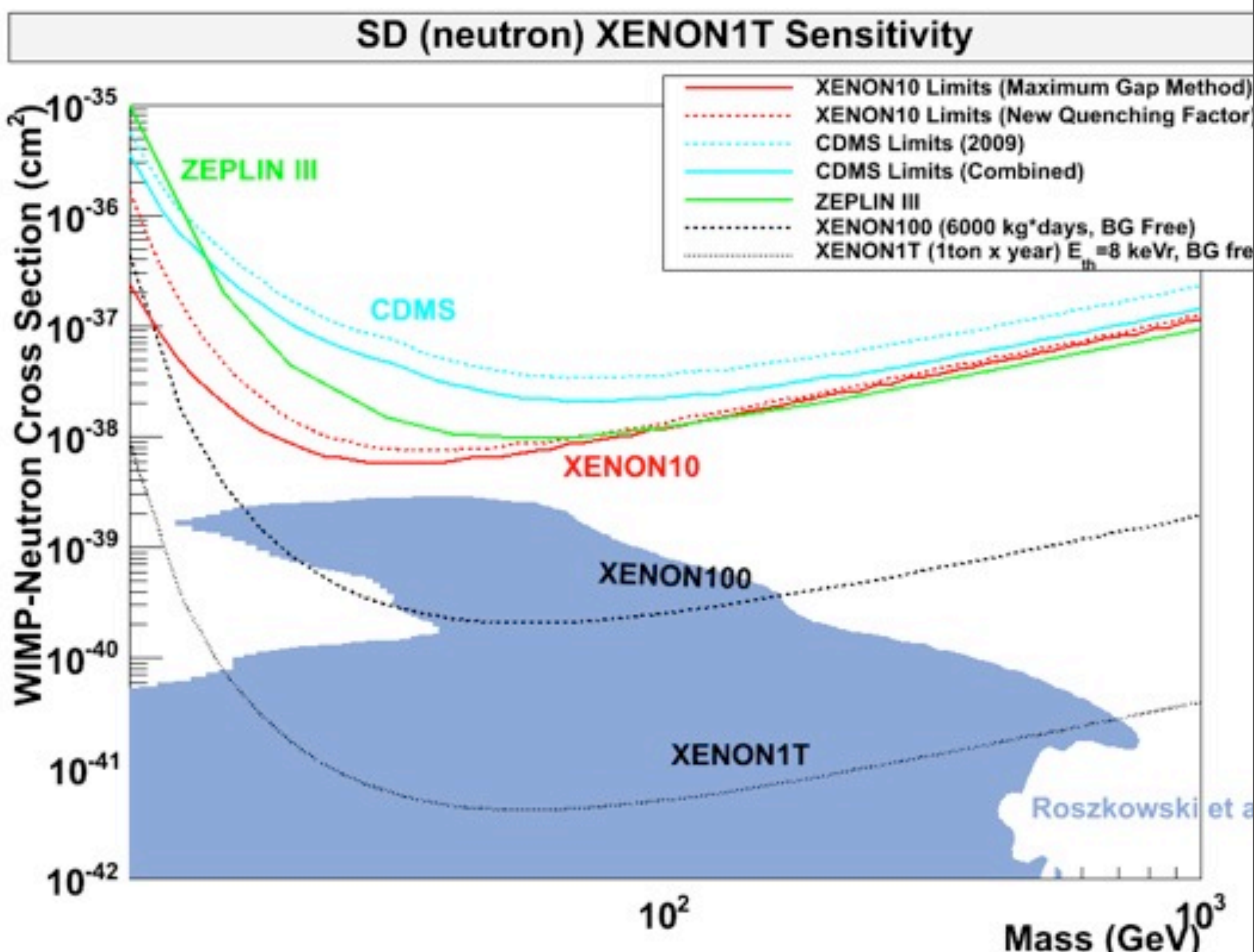
The case for XENON1T

- XENON100 is working very well. It is the largest mass and lowest background DM experiment in operation underground and with a large exposure ready to be unveiled.
- Within 2010 XENON100 will a) either see a signal or b) will significantly constraint WIMP models for both SI and SD cross-section.
- Larger scale experiments with even lower background are needed in both cases.
- Critical technologies developed within the XENON10/100 programs can be directly applied to the next scale. Risks and the costs are fully understood.
- A strong international collaboration, with valuable expertise and resources, is in place.
- A technical design proposal for a XENON1T is in preparation. With 50 - 50 share of resources between US and other groups, we plan to realize the experiment before 2015.

XENON1T: A tremendous scientific reach

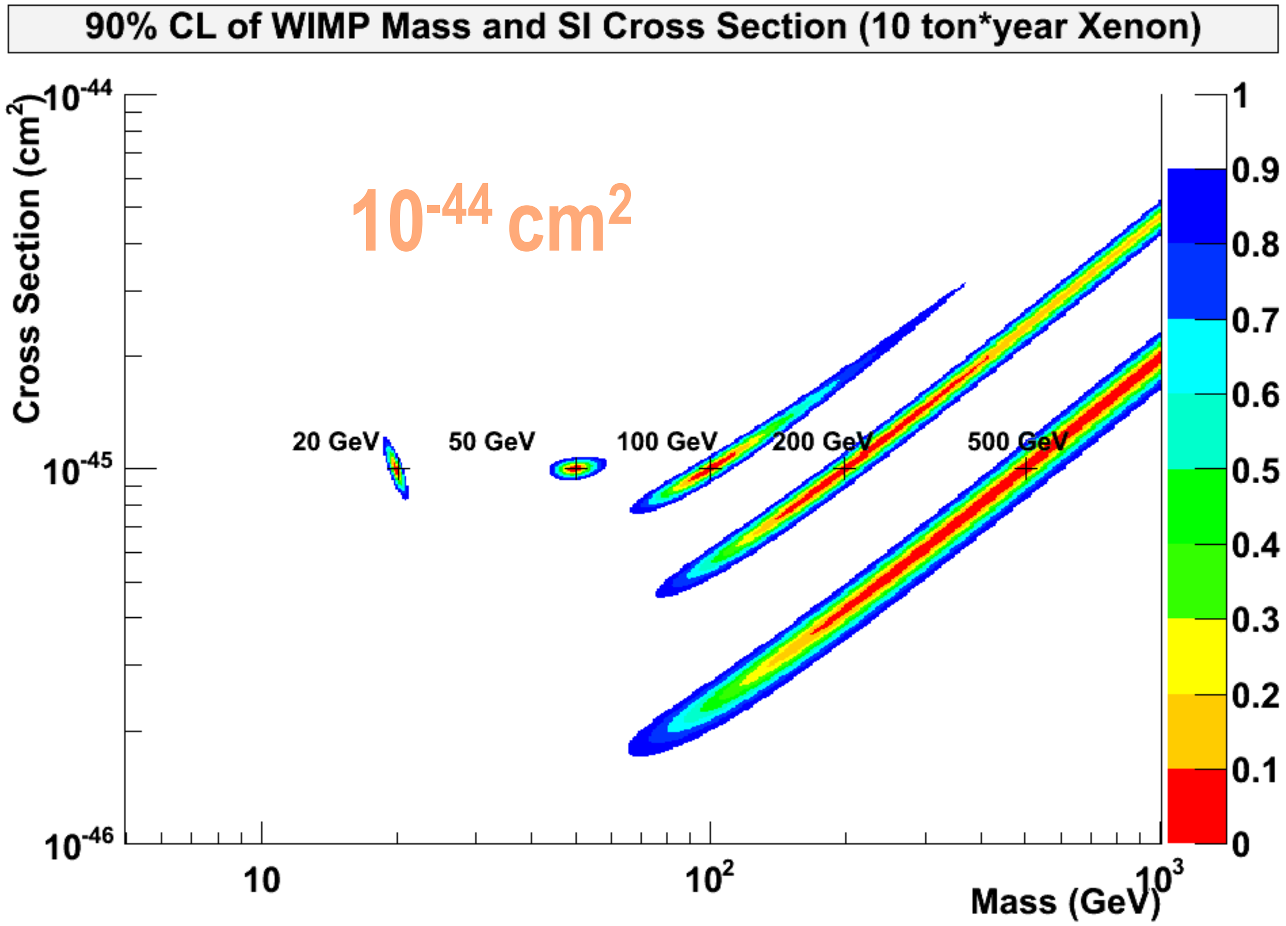


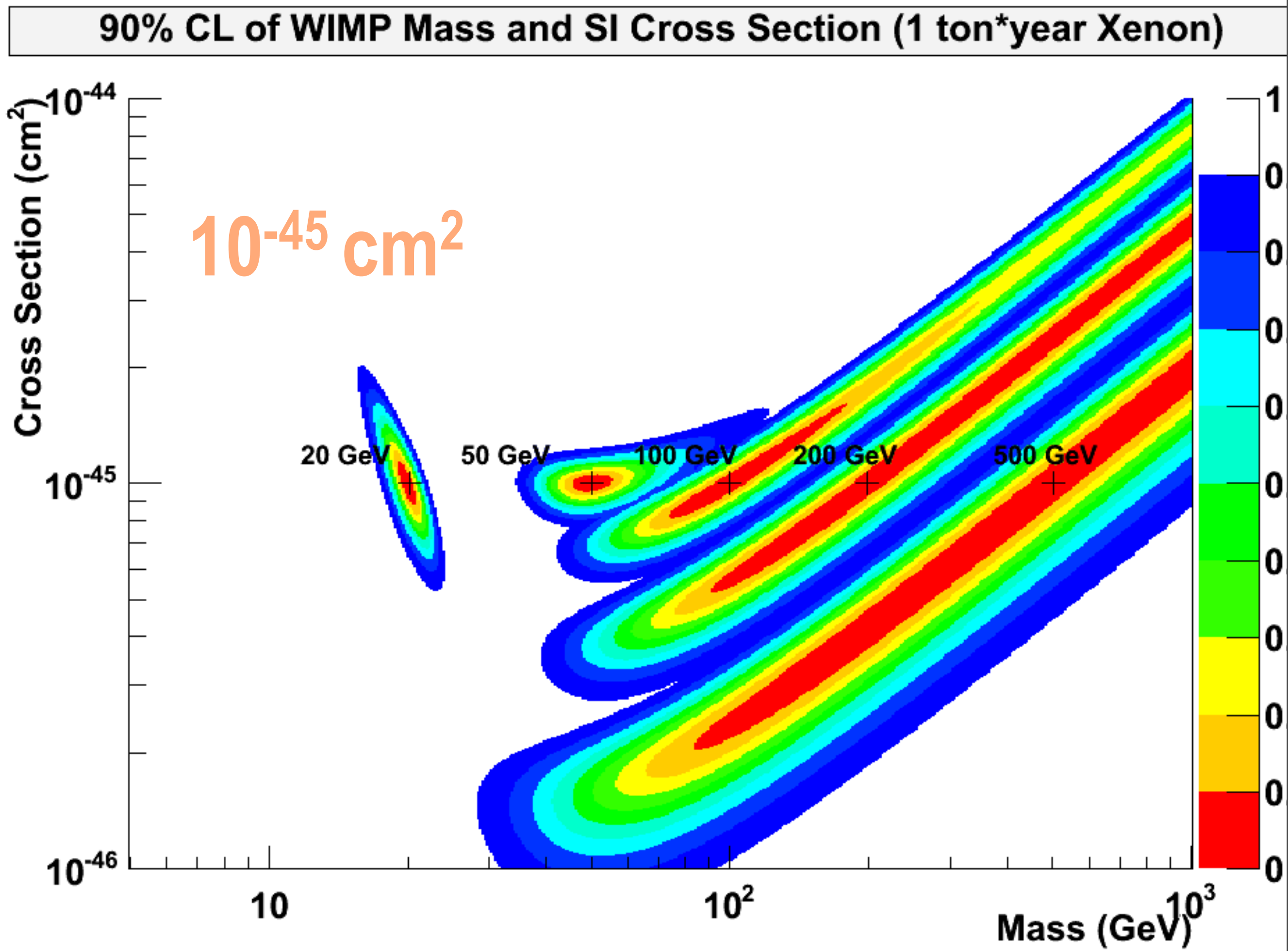
- ➢ probe simultaneously SI and SD channels
- ➢ explore the entire MSSM parameter space



XENON1T: constraints on WIMP mass

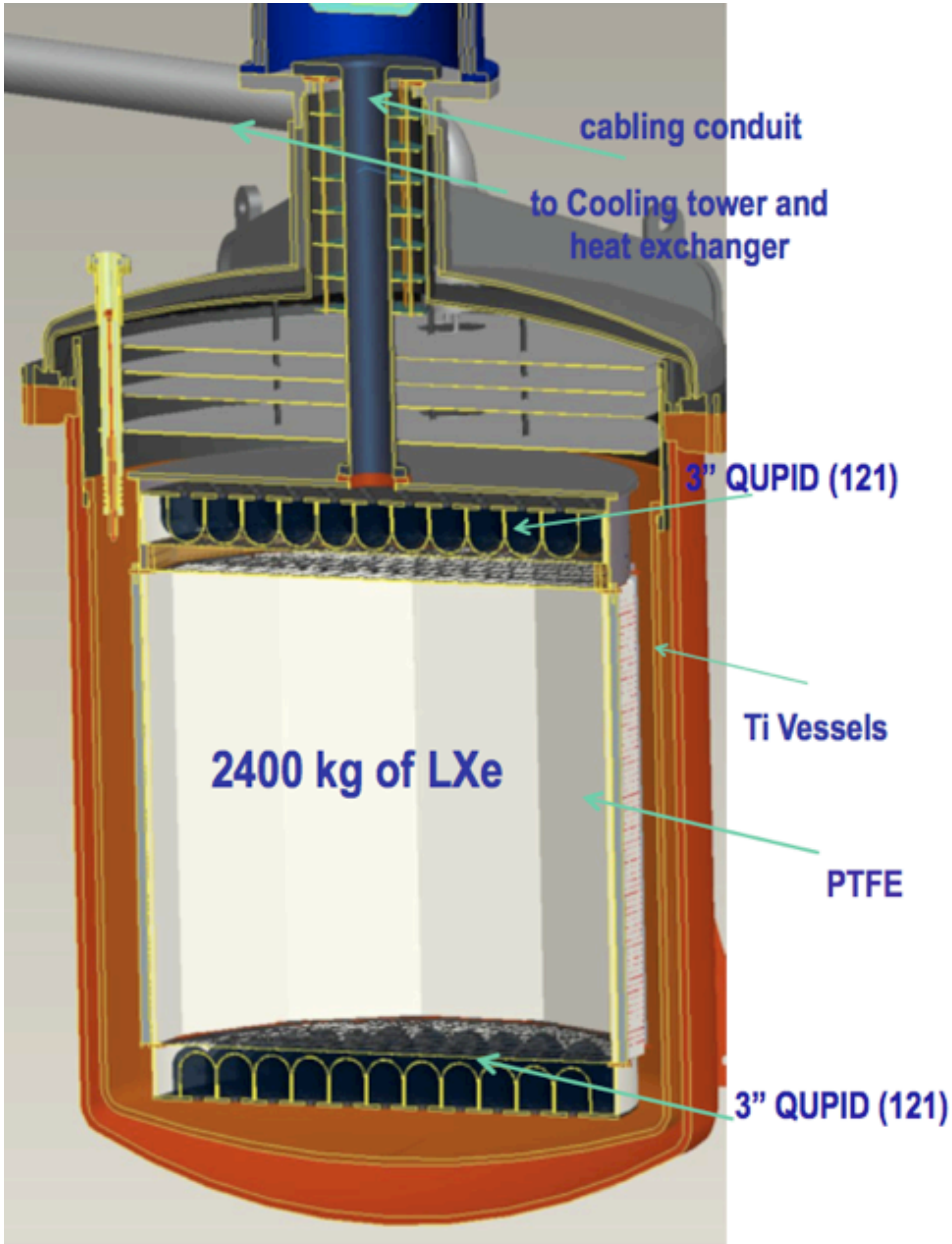
Number of events		Mass (GeV)				
		20	50	100	200	500
Cross Section	10^{-44} cm^2	230	710	560	330	140
	10^{-45} cm^2	23	71	56	33	14





XENON1T: Detector Overview

- **Baseline design similar to XENON100 with improvements in different areas**
  - ➡ lower radioactivity cryostat (Ti and Cu)
  - ➡ lower radioactivity PMTs (QUPIDs)
  - ➡ high efficiency heat exchanger: >98%
  - ➡ filling & recovery in liquid phase
- **Design has been validated with detailed MC studies of internal/external background sources**
- **Capital cost ~ 8M$ shared equally between US and foreign groups**

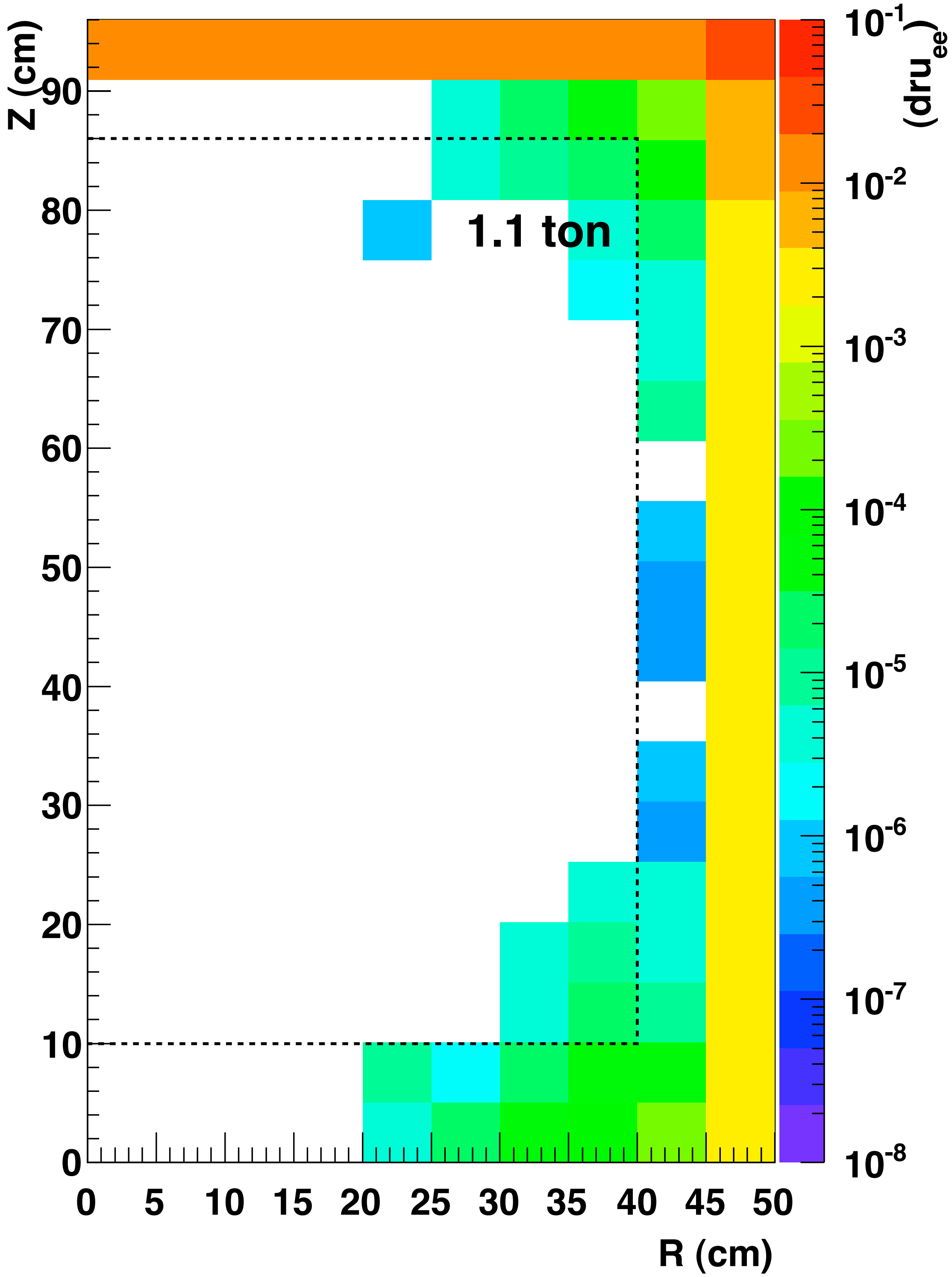


QUPID Characteristics

- **Extremely low radioactivity: < 1 mBq**
  - ✓ < 0.1 neutron / year
  - ✓ << 10 times lower than conventional low radioactive PMTs.
- **Large diameter: 3 inch**
  - ✓ 6 inch is also under investigation.
- **Special Photocathode: Bialkali LT**
  - ✓ > 30 % QE at 170 – 450 nm
  - ✓ Low resistivity even at Liquid Ar temperature (- 185 $_{o}$C)
- **True photon counting**
  - ✓ 1, 2, 3… photoelectron peaks clearly visible.
  - ✓ 100% collection efficiency.
- **Simple HV supply.**
  - ✓ Common HV (-6 kV) for all QUPIDs
  - ✓ Resistor chain not necessary
- **Successful test at UCLA in LXe with >33% QE.**

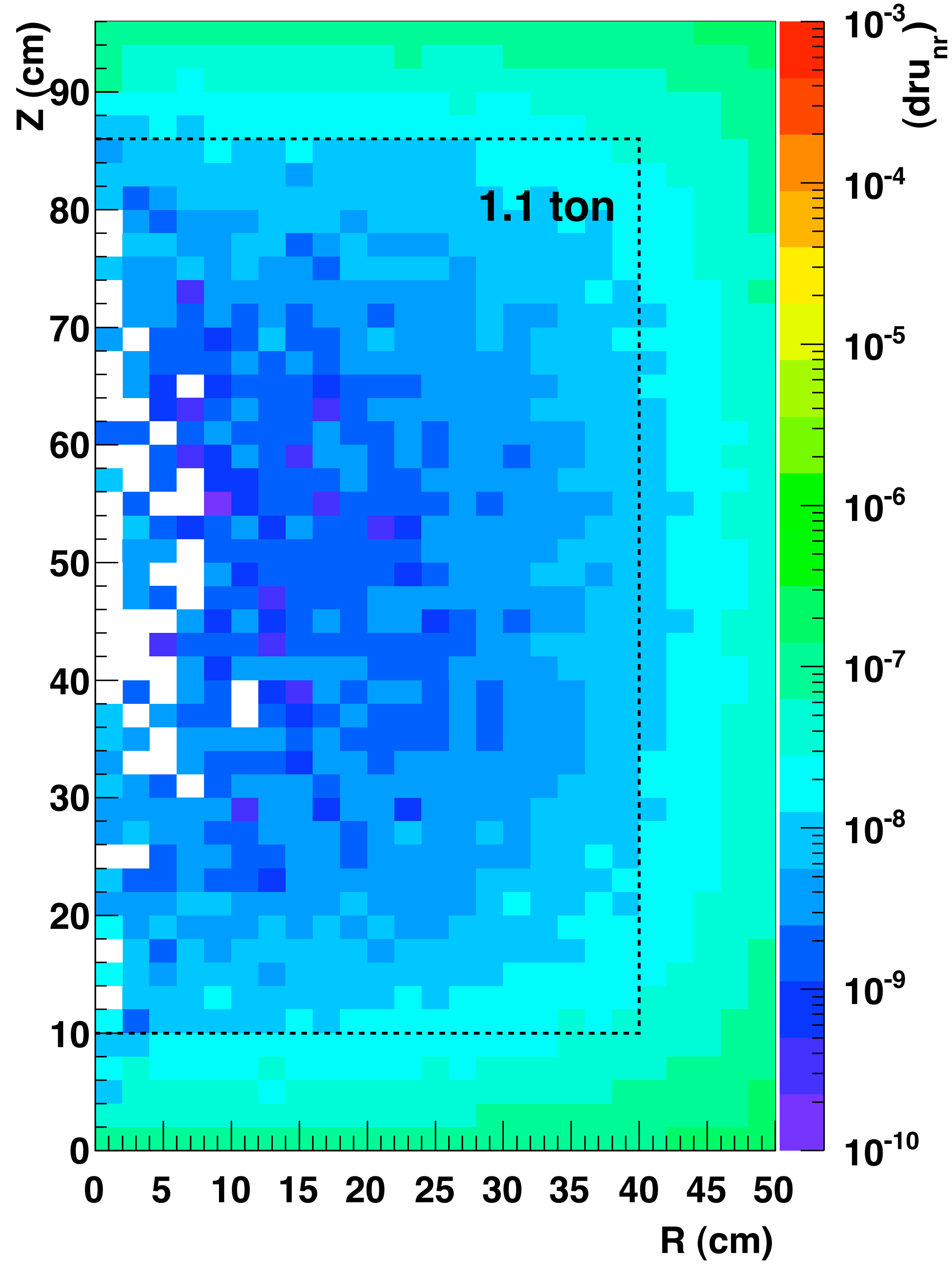
Expected Backgrounds from Detector Materials

Gamma Rays



0.07 γ / ton-year

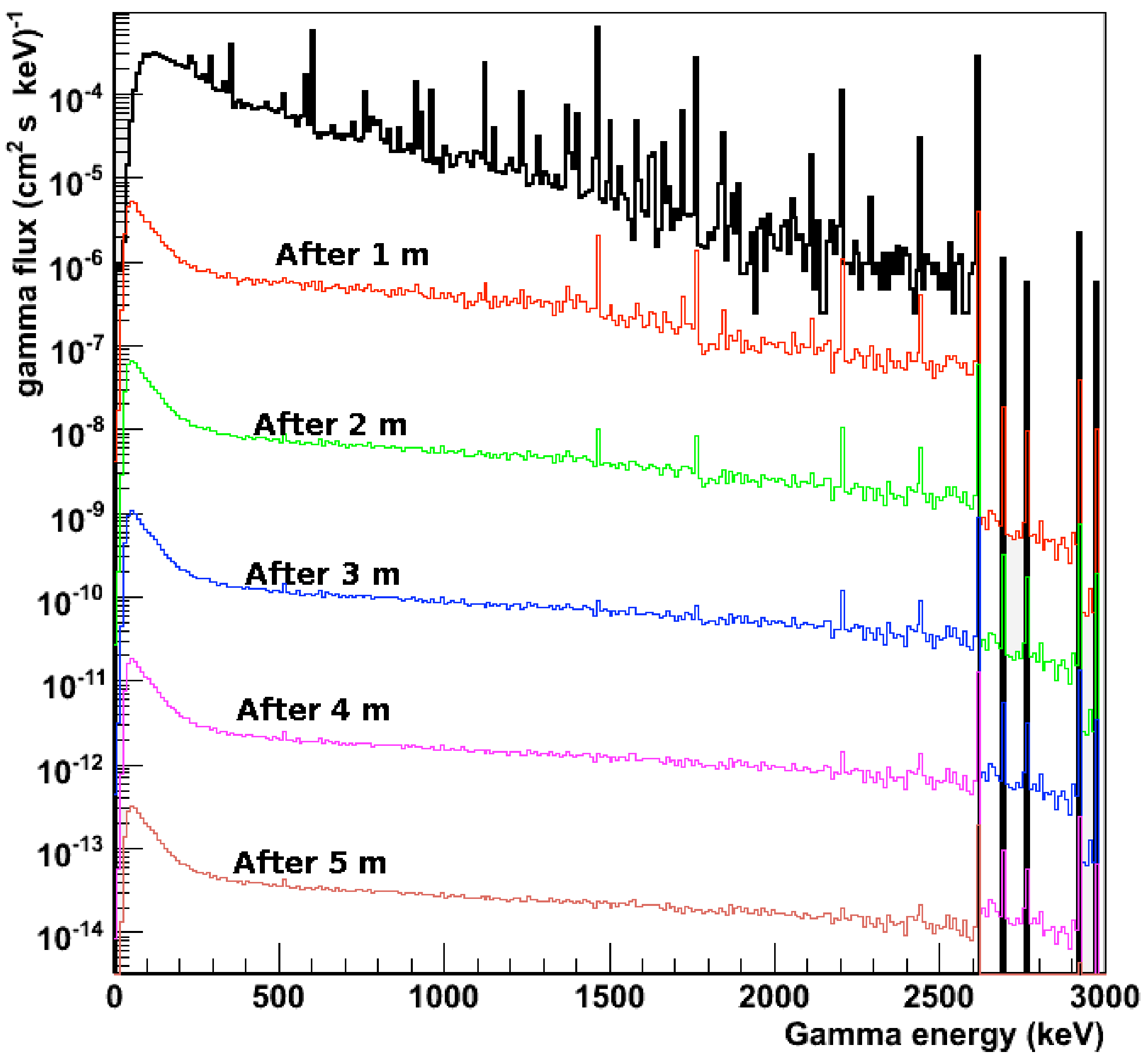
Neutrons



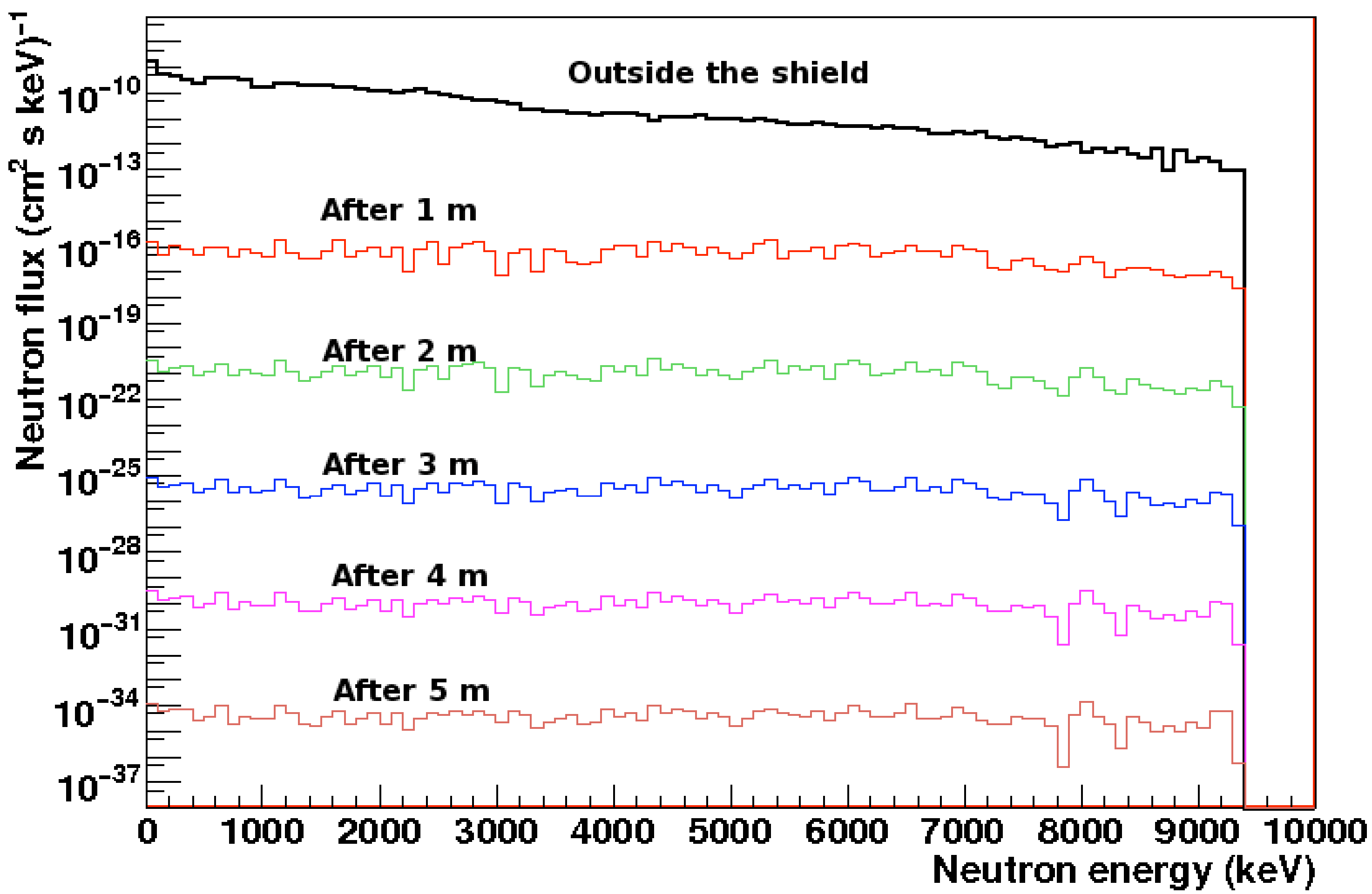
0.1 n / ton-year

External background at LNGS:

gamma



neutrons



Residual gamma and neutron flux after different thicknesses of **water shield**

XENON1T Baseline at LNGS

A 4-π active water muon veto and shield