Light from

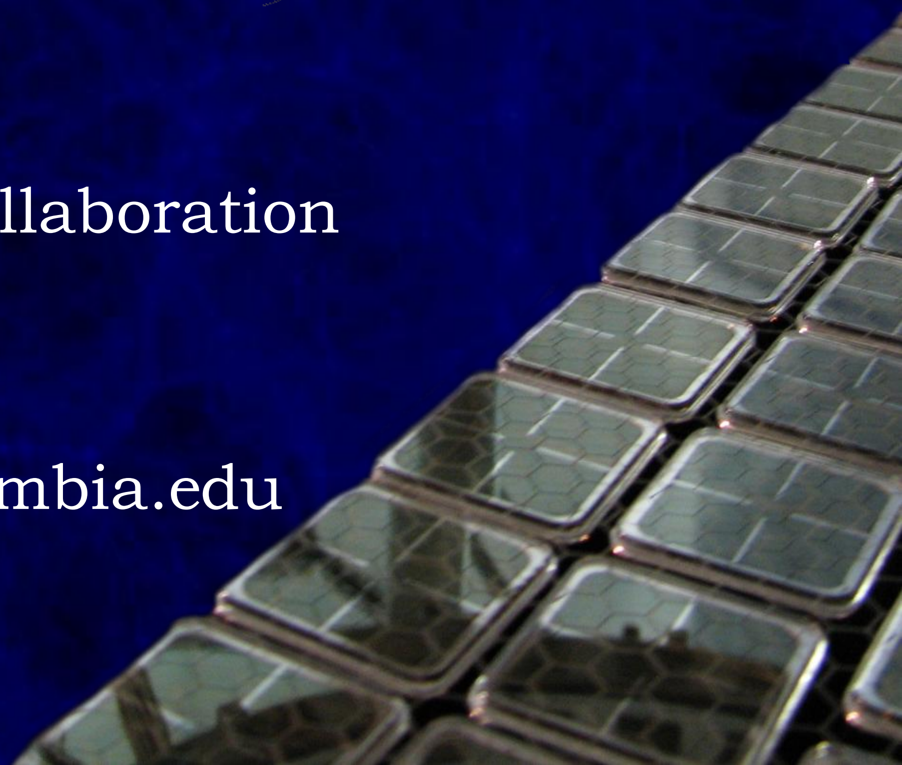
Light Dark Matter and XENON100

For the XENON100 Collaboration

Rafael F. Lang

Columbia University

rafael.lang@astro.columbia.edu

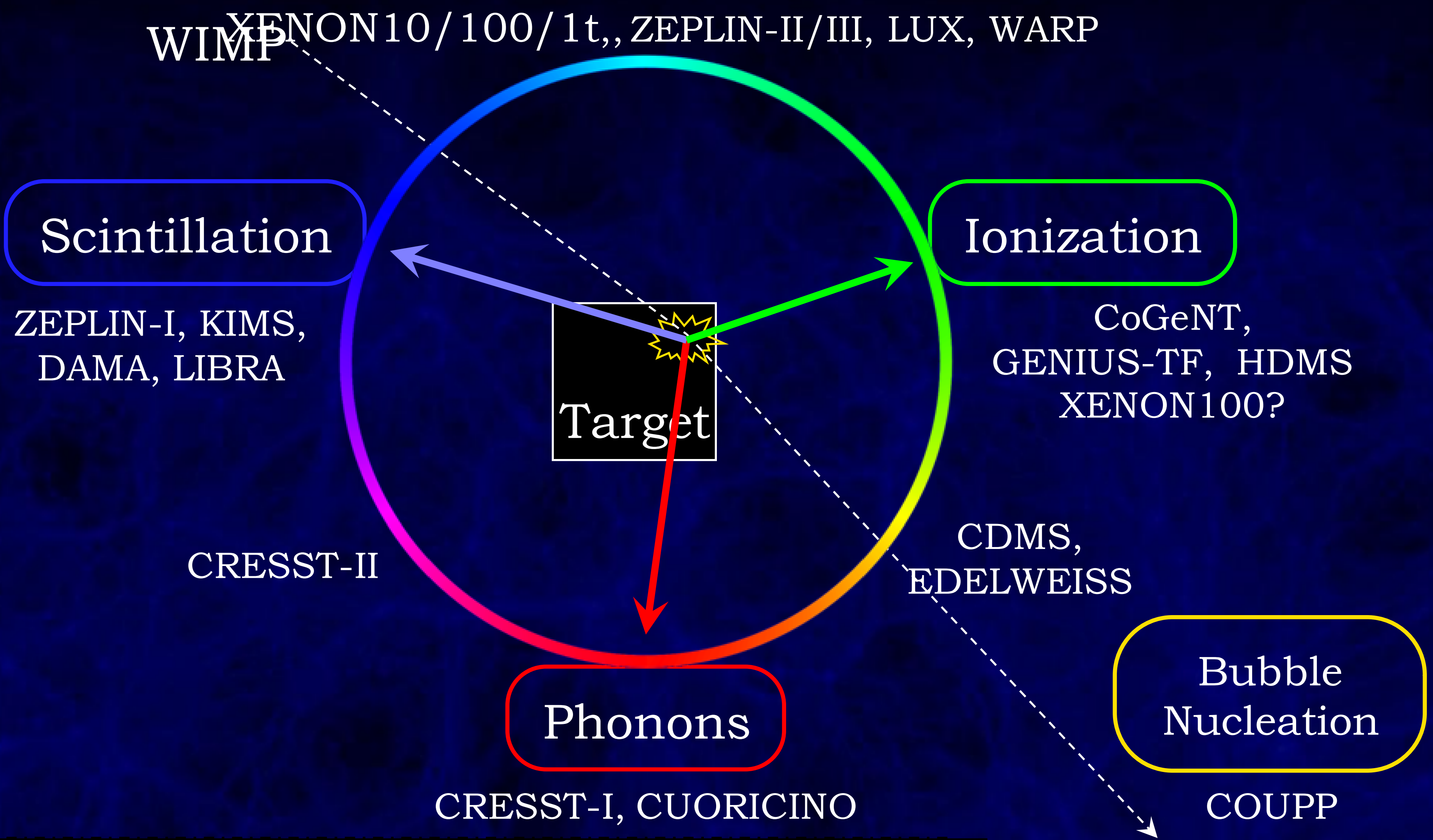


The XENON Collaboration

~60 scientists from 12 institutions:

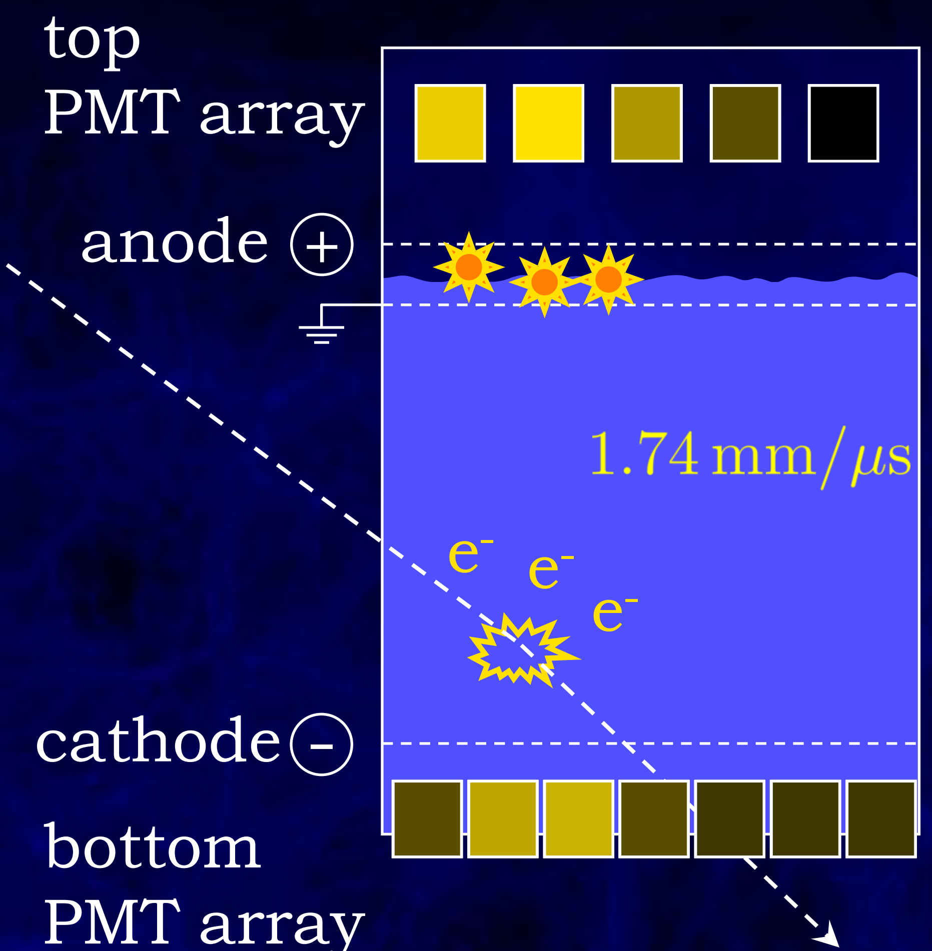
- University of California Los Angeles
- Rice University Houston
- Columbia University New York
- Universidade de Coimbra
- Subatech Nantes
- NIKHEF Amsterdam
- Willhelms Universität Münster
- Max-Planck-Institut Heidelberg
- Universität Zürich
- Laboratori Nazionali del Gran Sasso
- INFN e Università di Bologna
- Jiao Tong University Shanghai

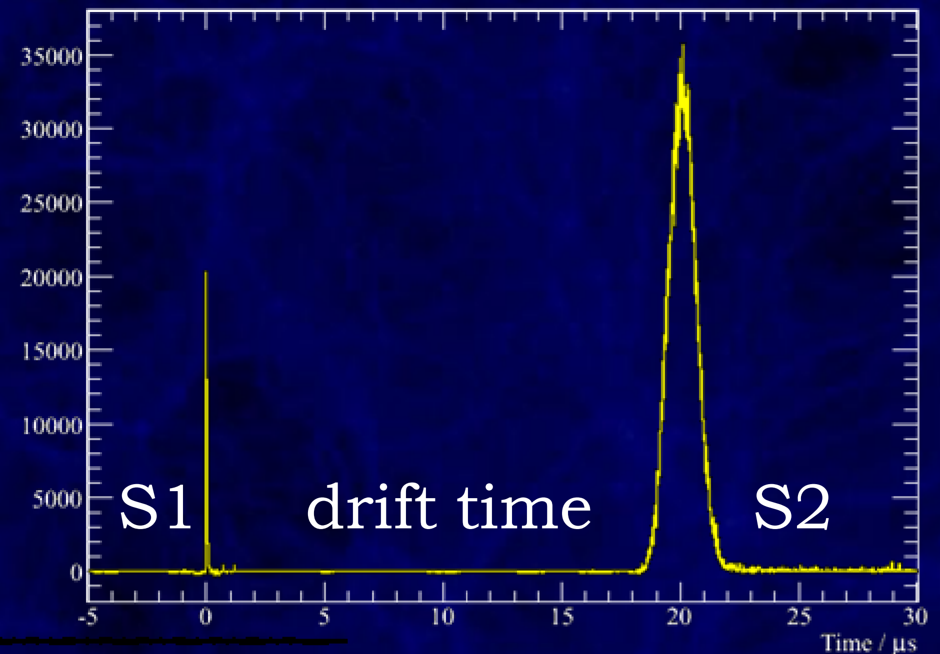
Particle Detection Channels



Dual-Phase Xenon TPC

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

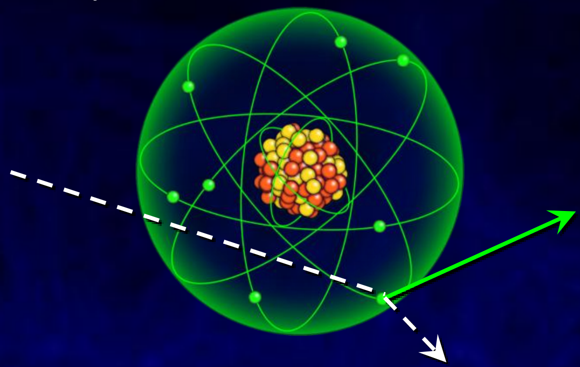


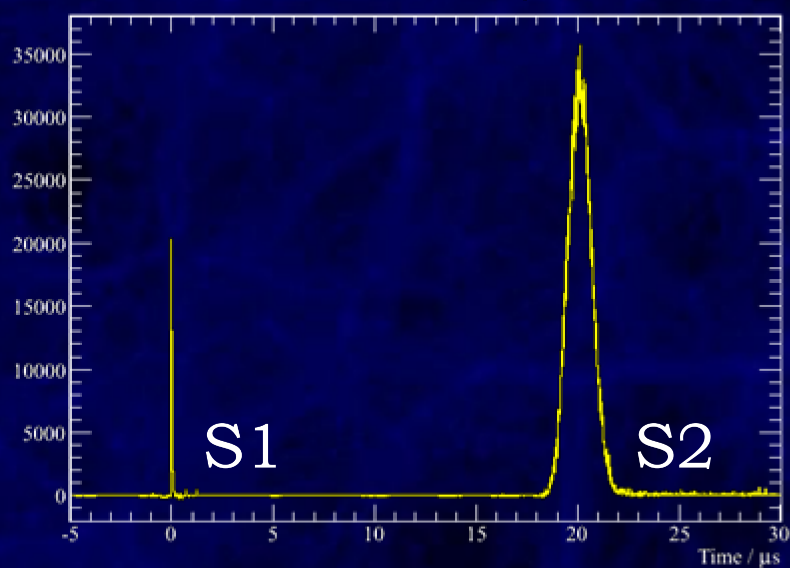


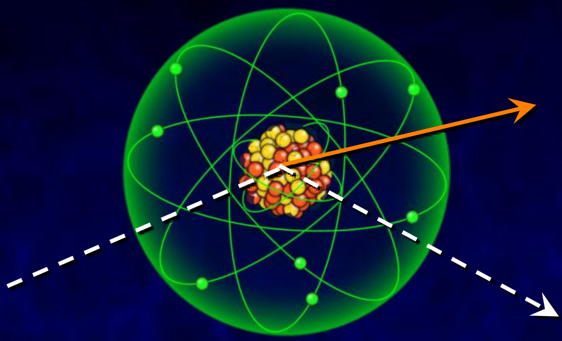
Recoil Discrimination > 99%

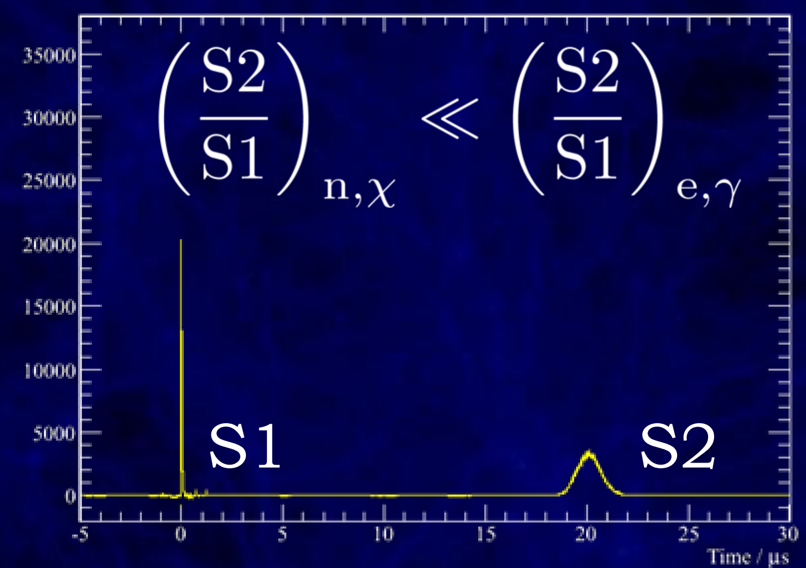
e^-/γ: electron recoil

n/WIMPs: nuclear recoil





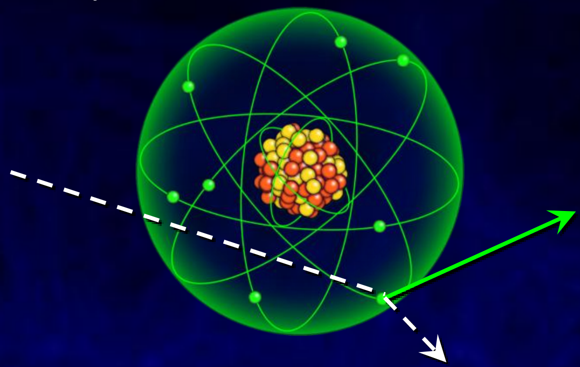




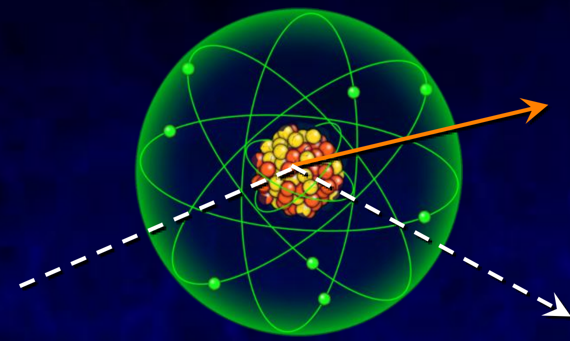
$\rightarrow$ lots of information for each event

Recoil Discrimination > 99%

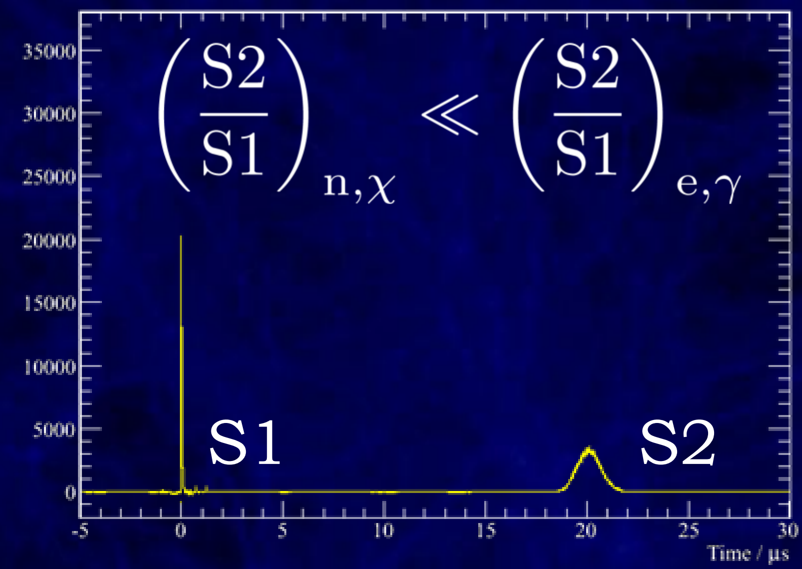
e^-/γ: electron recoil



n/WIMPs: nuclear recoil

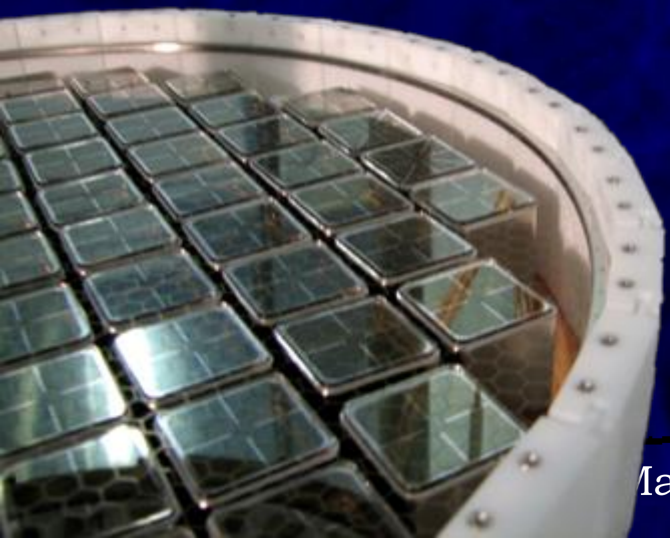


$10keV_{nr}$ WIMP yields
- ~160 S1 photons, detect ~10
- ~70 S2 electrons, generate ~10^4 photons, detect ~1750

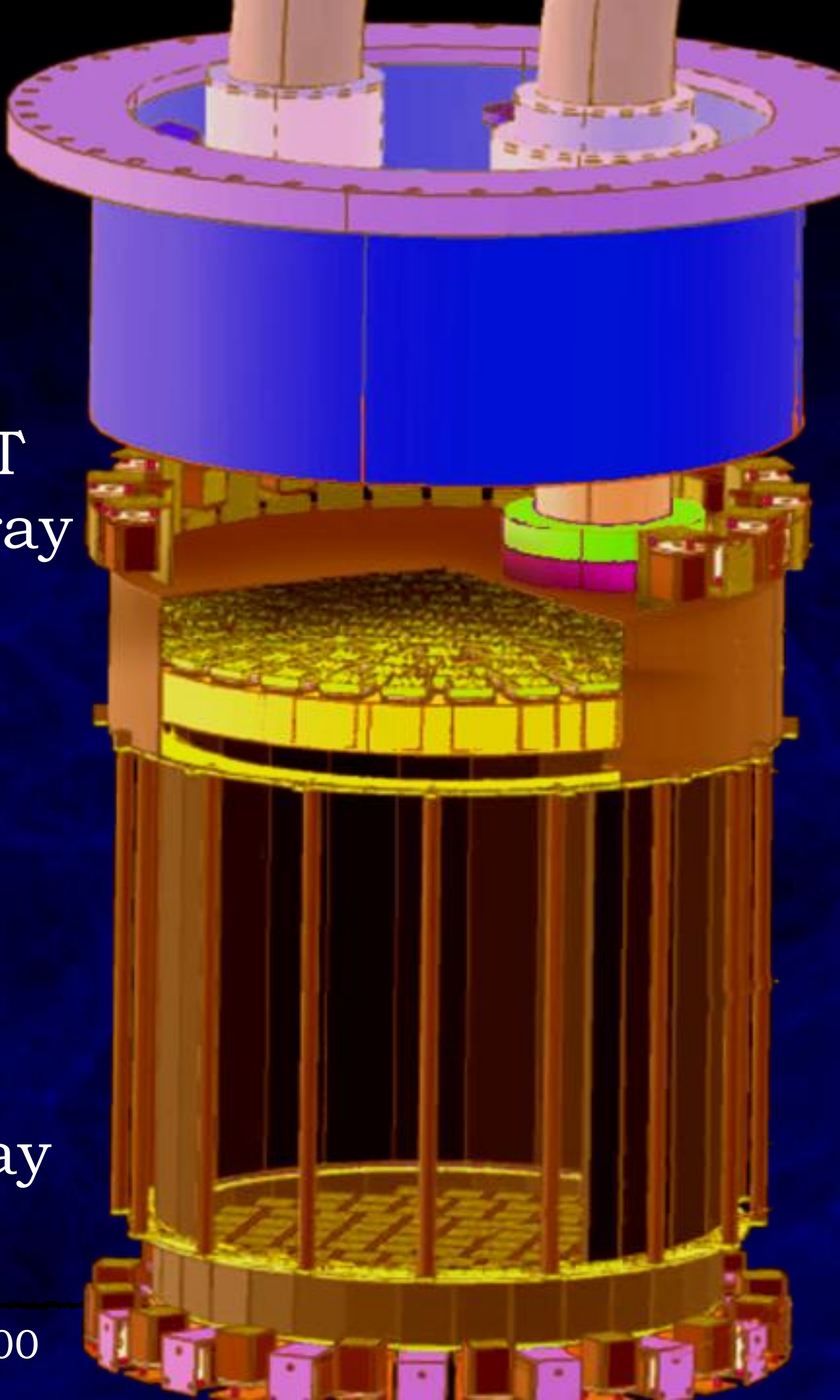


XENON100

98 PMT
top array



80 PMT
bottom array

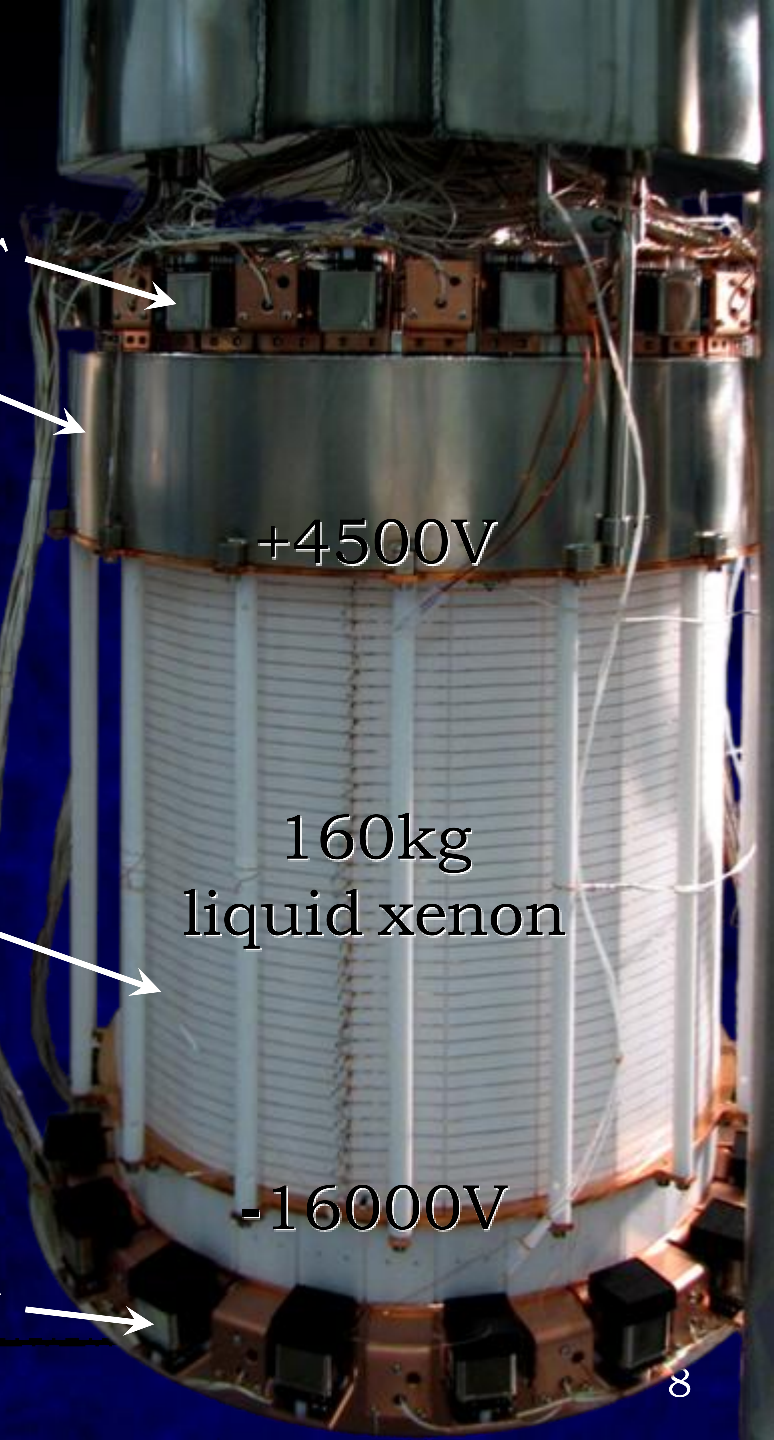


XENON100

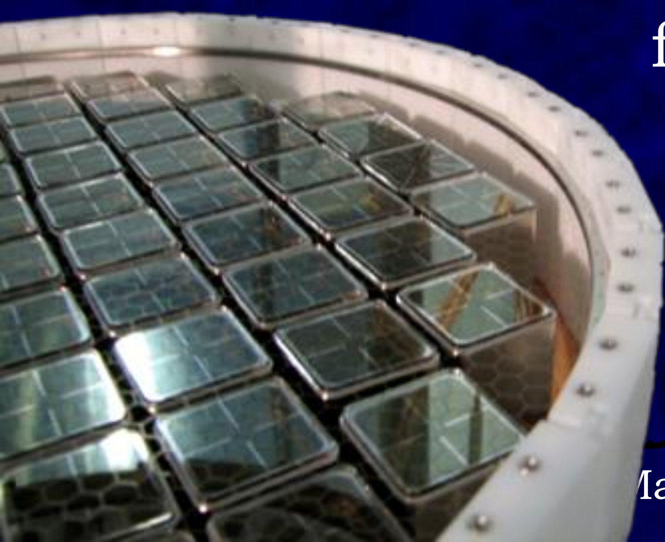
veto PMT

bell

98 PMT
top array



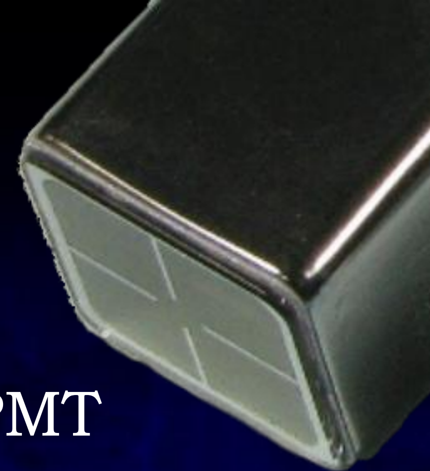
PTFE TPC,
field shaping



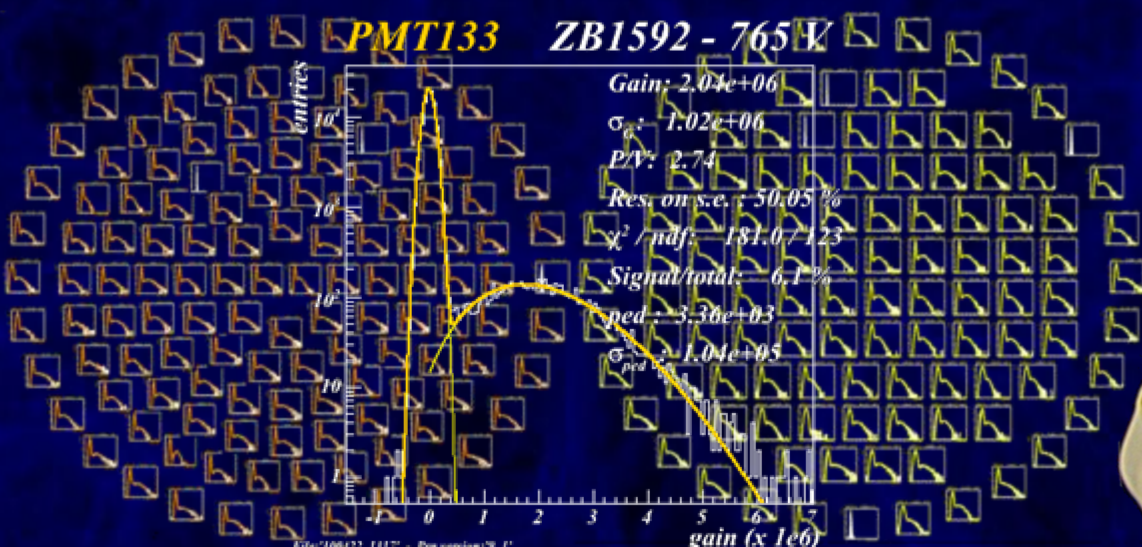
80 PMT
bottom array

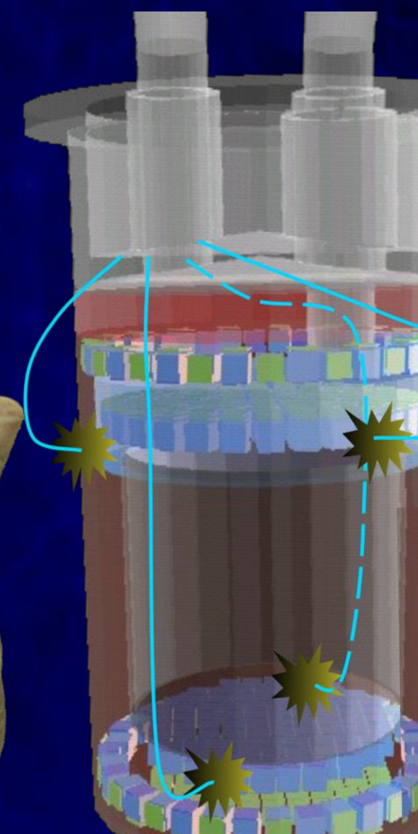
veto PMT

PMTs & Gain Calibration



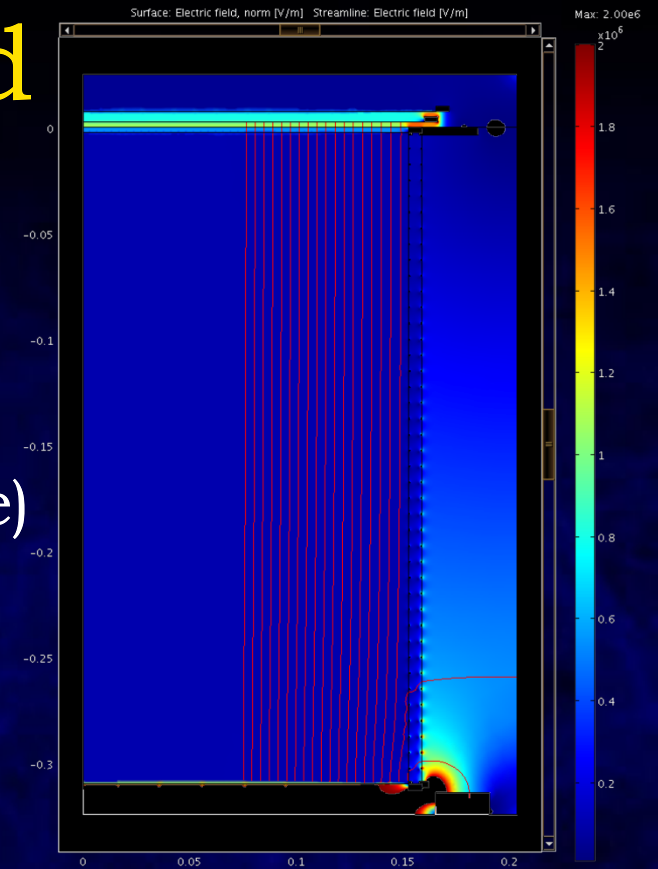
- 1” square metal-channel R8520-06-Al
- optimized for 178nm, low T, high p
- low radioactivity <1mBq in $^{238}U/^{232}Th$ per PMT
- 98 top PMTs, optimized for good r resolution
- 80 bottom PMTs, optimized for filling factor, QE ~33%
- 64 in veto looking up, down and inward
- regular gain monitoring

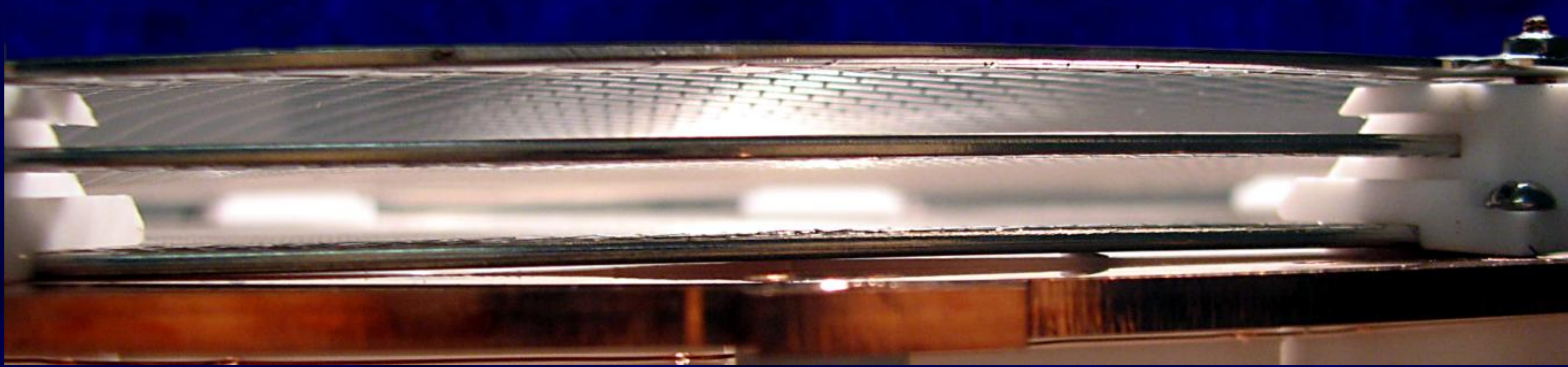




Design for Electric Field

- hexagonal electrode meshes
- cathode at -16kV
  drift field 0.53kV/cm
- anode at 4.5kV
  extraction field 6kV/cm (LXe)
  12kV/cm (GXe)
- 40 doubled field shaping rings



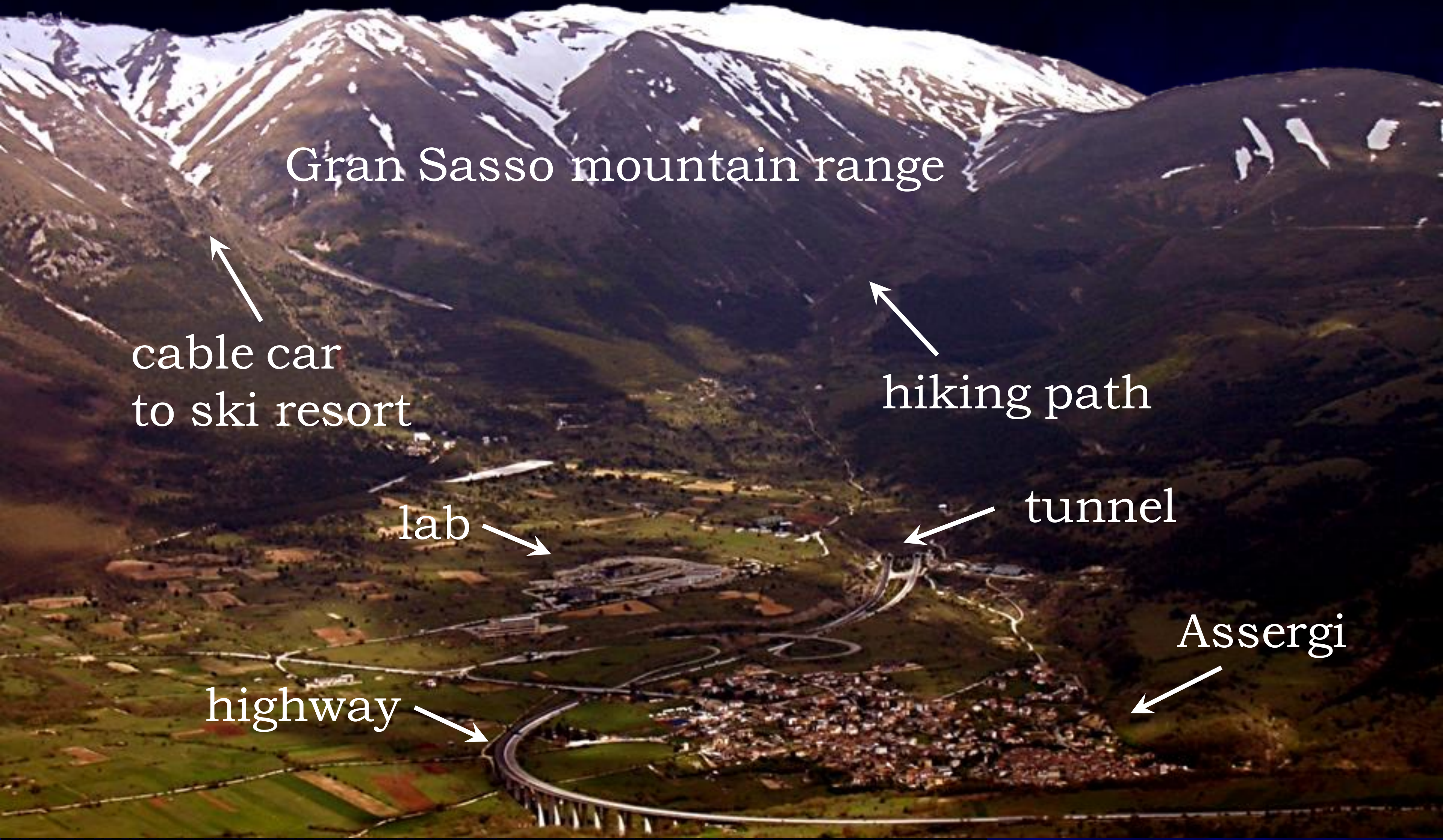


DAQ

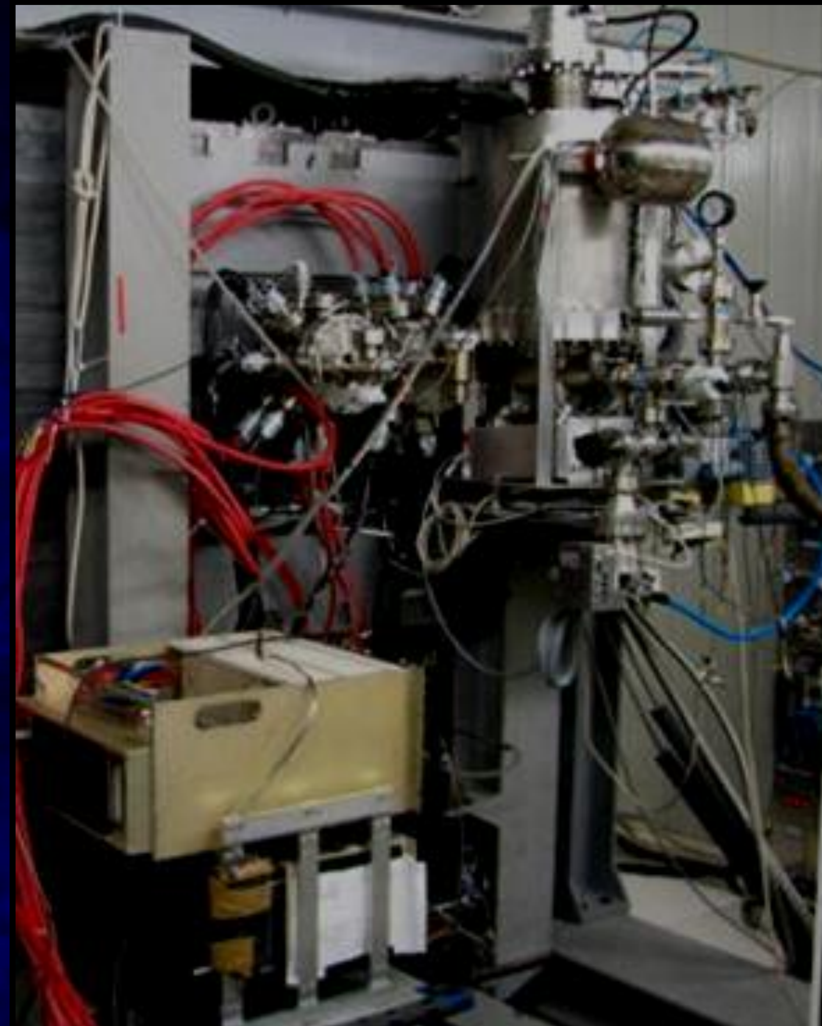
- 242 PMTs
- 400μs waveform
- 100MS/s, 14bit flash ADC
- zero-length-encoding (on-board FPGA)
- dead-time free during background data taking

(1km of cables inside the detector, 3km outside)

Gran Sasso Underground Lab



XENON100 Shield



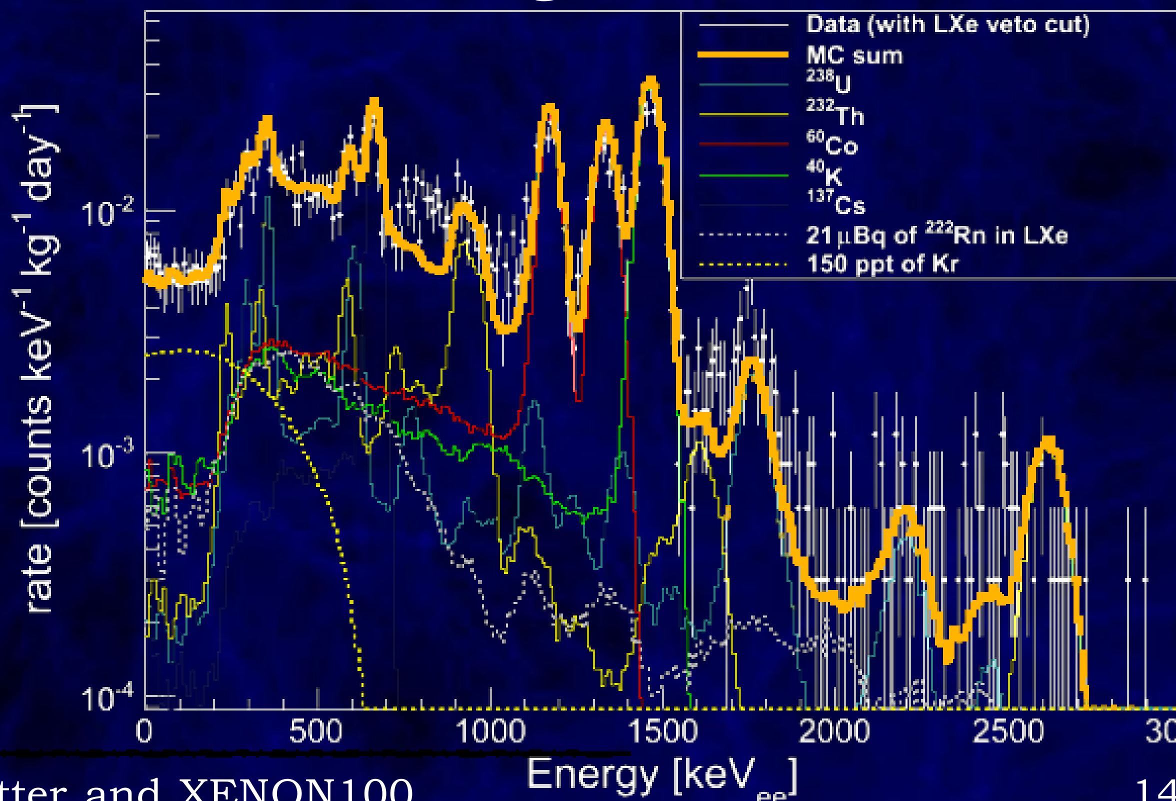
20cm H_2O, 15cm Pb, 5cm French Pb, 20cm PE, 5cm Cu

Screening & Simulation

dedicated HPGe setup @ LNGS

MATERIAL	UNIT	^{238}U	^{232}Th	^{60}Co	^{40}K
Stainless steel	mBq/kg	< 1.7	< 1.9	5.5±0.6	< 9.0
PTFE	mBq/kg	< 0.31	< 0.16	< 0.11	< 2.25
PMTs	mBq/piece	0.15±0.02	0.17±0.04	0.6±0.1	11±2
PMT bases (cirlex)	mBq/piece	0.16±0.02	0.07±0.02	< 0.01	< 0.16
Support bars (steel)	mBq/kg	< 1.3	2.9±0.7	1.4±0.3	< 7.1
Copper (inside)	mBq/kg	< 0.22	< 0.16	0.20±0.08	< 1.34
Resistor chain	µBq/piece	27±4	14±3	< 3	0.19±0.03
Cathode support ring	mBq/kg	3.6±0.8	1.8±0.5	7.3±1.3	< 4.92
Top grids support rings	mBq/kg	< 2.7	< 1.5	13±1	< 12
IT signal cables	mBq/kg	< 1.6	3.7±1.8	< 0.69	35±13
pper shield	µBq/kg	83±22	12±5	39±5.5	3.2±1
lyethylene shield	mBq/kg	0.23±0.05	< 0.094	-	0.7±0.4

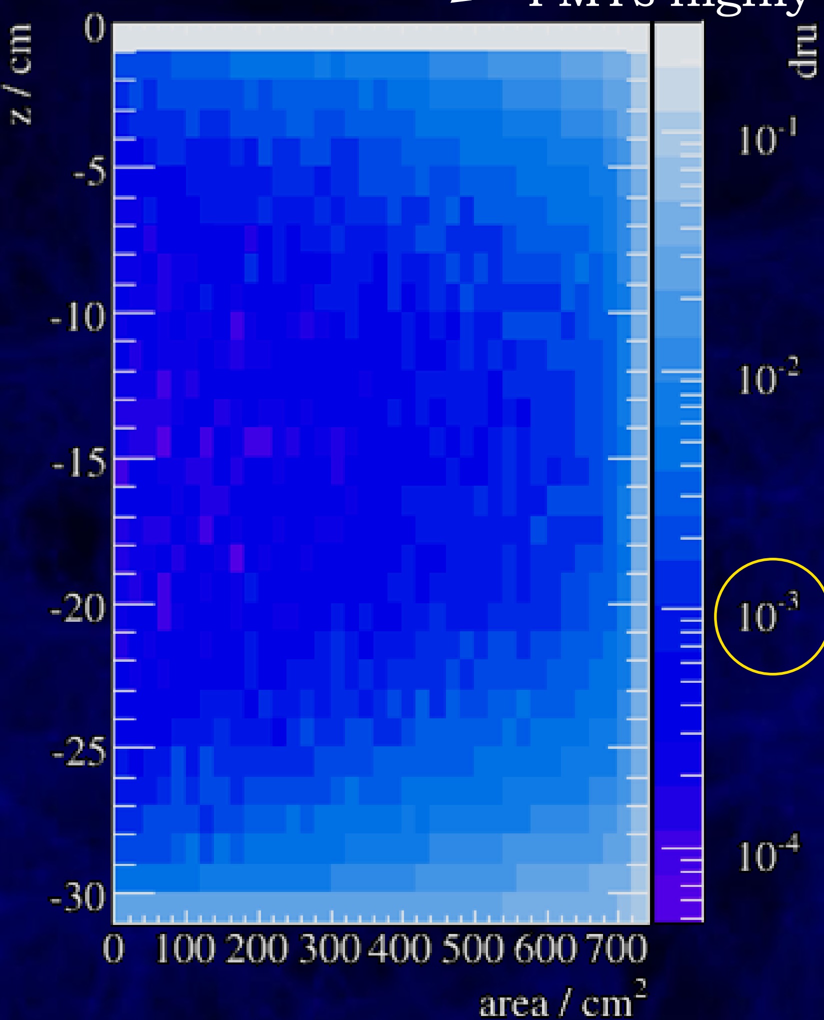
simulation agrees with data



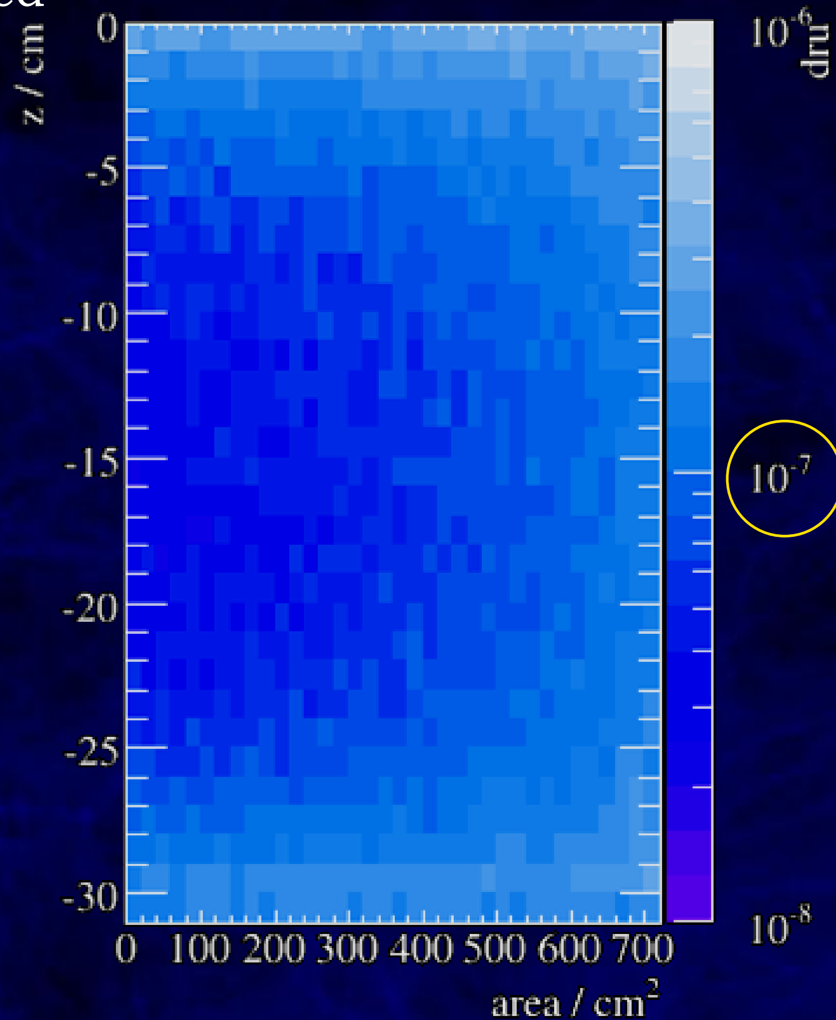
Spatial Distribution

gammas:

main contribution from PMTs highly localized



neutrons:



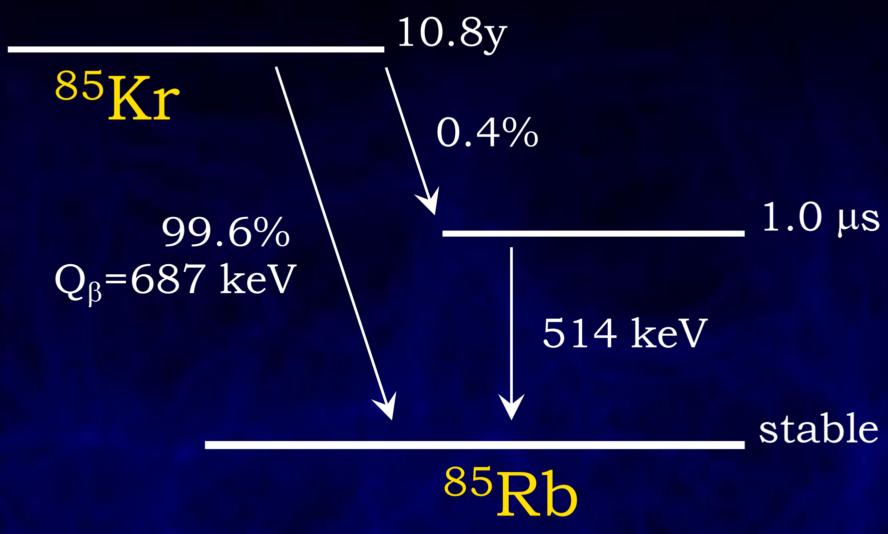
The Other Noble Gas in Xenon

Firestone

Rb78 17.66 m 0(+) EC	Rb79 22.9 m 5/2+ EC	Rb80 34 s 1+ EC	Rb81 4.576 h 3/2- EC	Rb82 1.273 m 1+ EC	Rb83 86.2 d 5/2- EC	Rb84 32.77 d 2- EC,β-	Rb85 5/2- 72.165	Rb86 18.631 d 2- EC,β-	Rb87 4.75E10 y 3/2- β- 27.835	Rb88 17.78 m 2- β-
Kr77 74.4 m 5/2+ EC	Kr78 0+ 0.35	Kr79 35.04 h 1/2- EC	Kr80 0+ 2.25	Kr81 2.29E+5 y 7/2+ EC	Kr82 0+ 11.6	Kr83 9/2+ 11.5	Kr84 0+ 57.0	Kr85 10.756 y 9/2+ β-	Kr86 0+ 17.3	Kr87 76.3 m 5/2+ β-
Br76 16.2 h 1- EC	Br77 57.036 h 3/2- EC	Br78 6.46 m 1+ EC,β-	Br79 3/2- 50.69	Br80 17.68 m 1+ EC,β-	Br81 3/2- 49.31	Br82 35.30 h 5- β-	Br83 2.40 h 3/2- β-	Br84 31.80 m 2- β-	Br85 2.90 m 3/2- β-	Br86 55.1 s (2-) β-

- ^{81}Kr: 281keV electron capture, long decay, abundance ^{81}Kr/Kr ~ 10^{-13} → irrelevant
- but ^{85}Kr beta decays (687keV), natural abundance ^{85}Kr/Kr ~ 10^{-11}
- use dedicated distillation column to get Kr to ~100ppt level

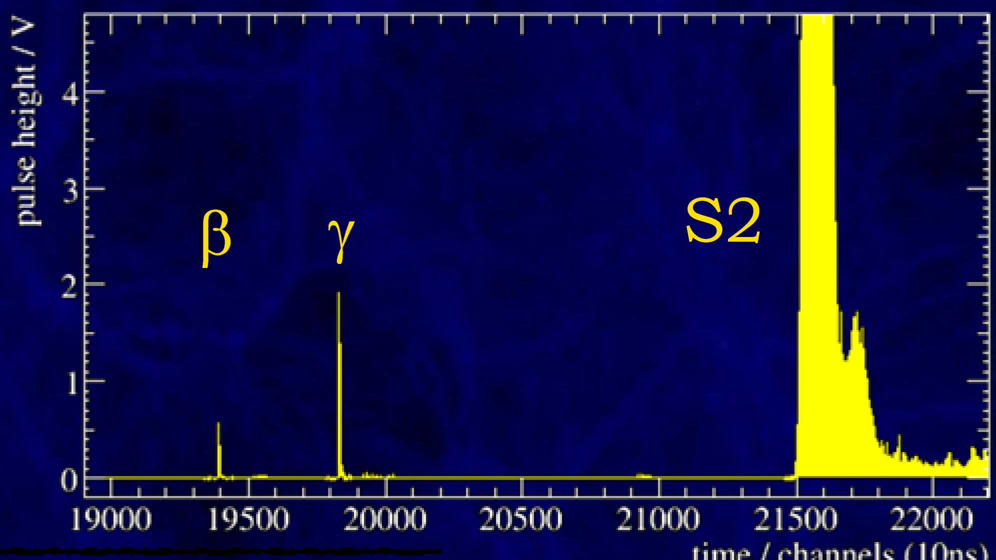
How to Ensure Kr at That Level?



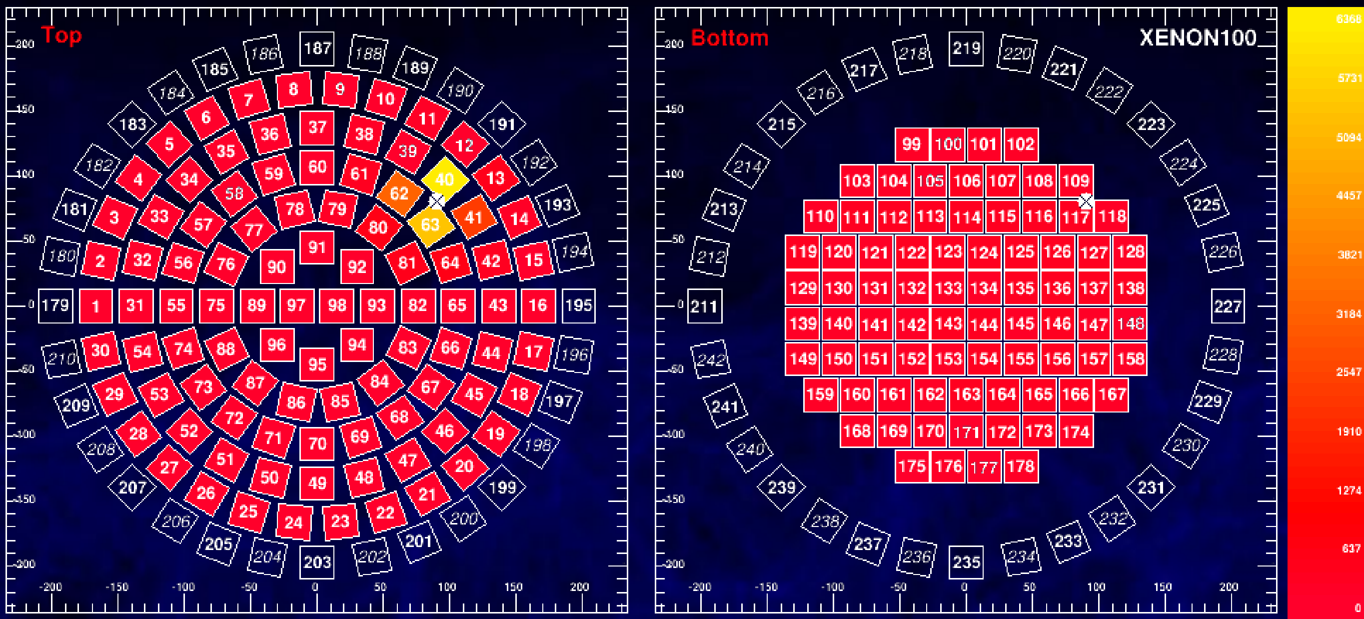
- use delayed β-γ-coincidence to tag events *in situ*
- only 0.4% branching

XENON100:

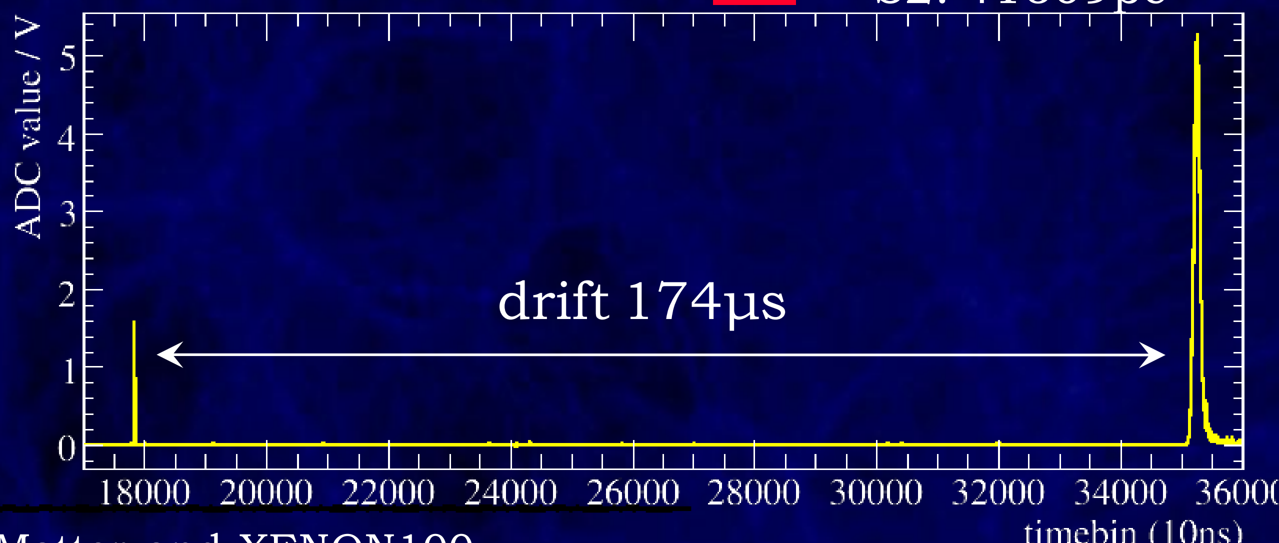
- tagged 6 events in 60.6 live days
  $\hat{=} 143^{+140}_{-81}$ ppt



Example with Full 30cm Drift



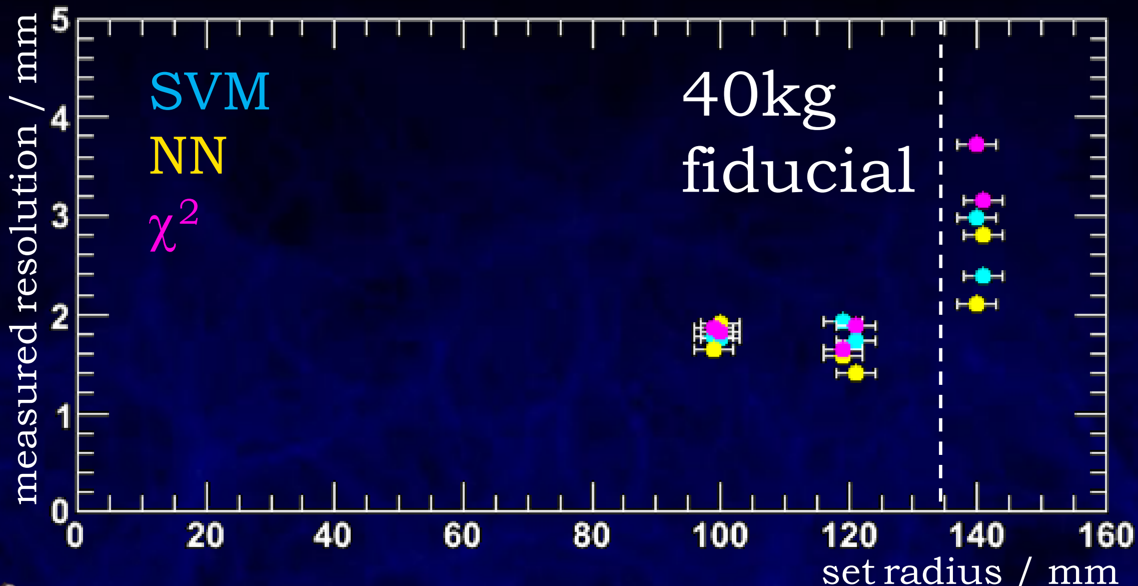
S1: 498pe
S2: 41609pe

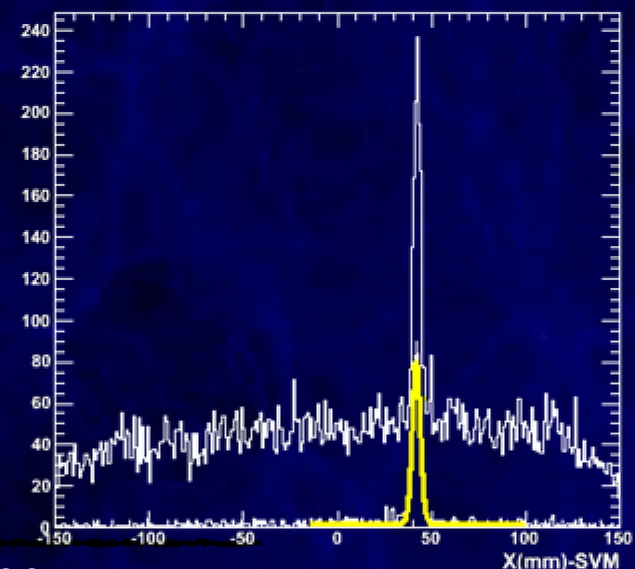


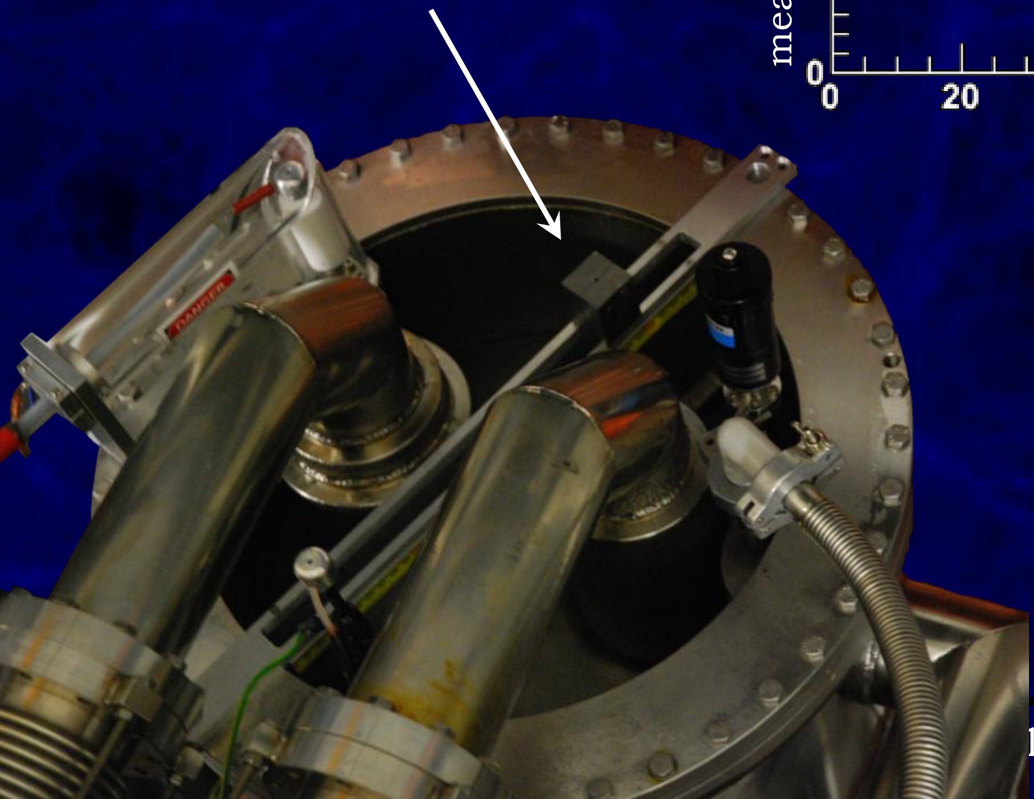
electron lifetime during background data taking 154μs to 192μs

Position Reconstruction

test with collimator:
resolution < 3mm
(~anode mesh pitch)



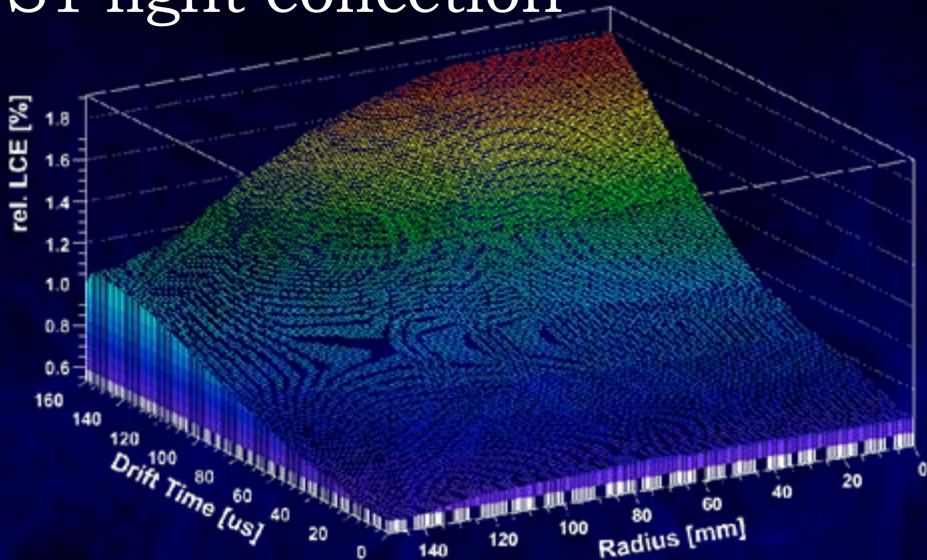




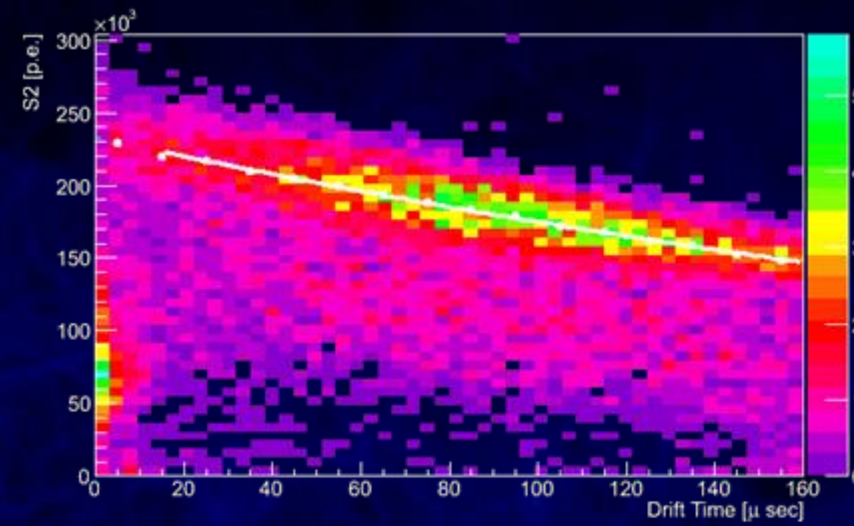
100

Position Dependent Corrections

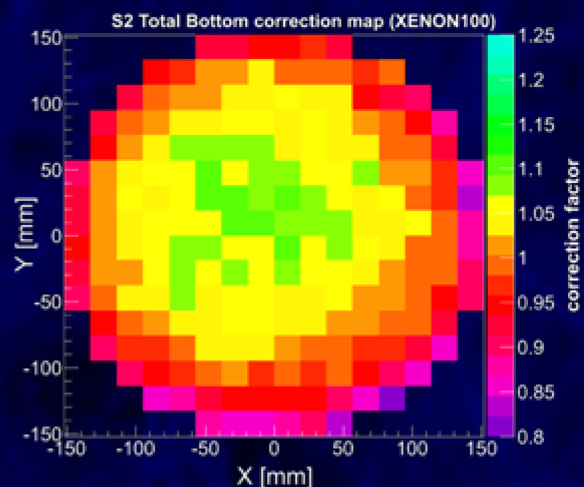
S1 light collection

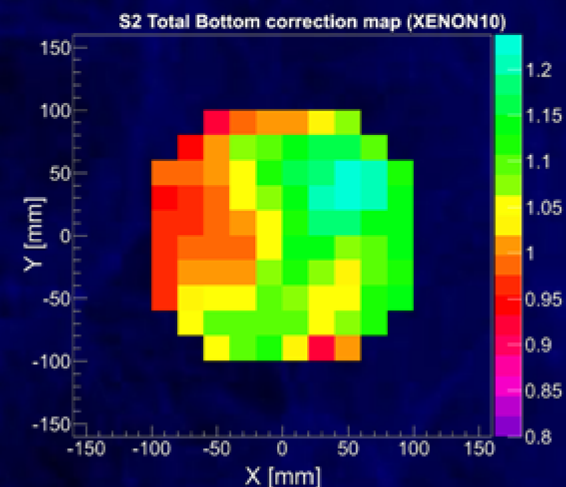


S2 electron lifetime

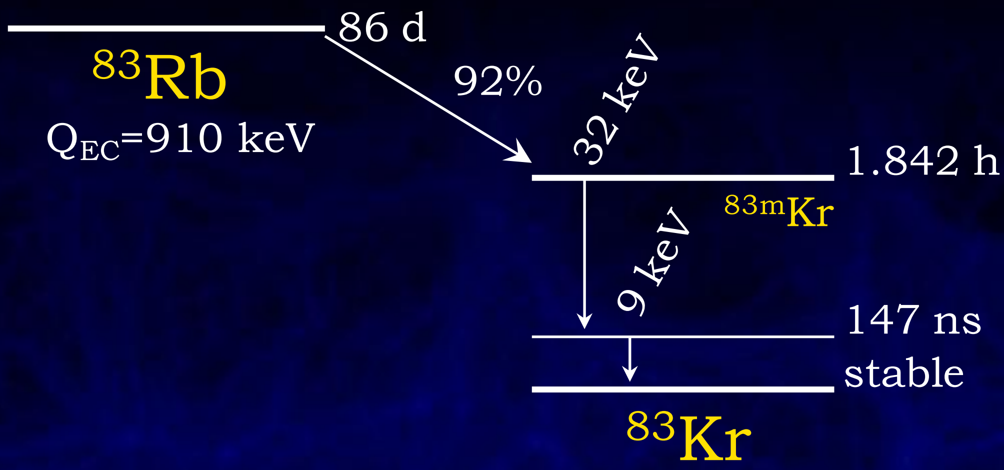


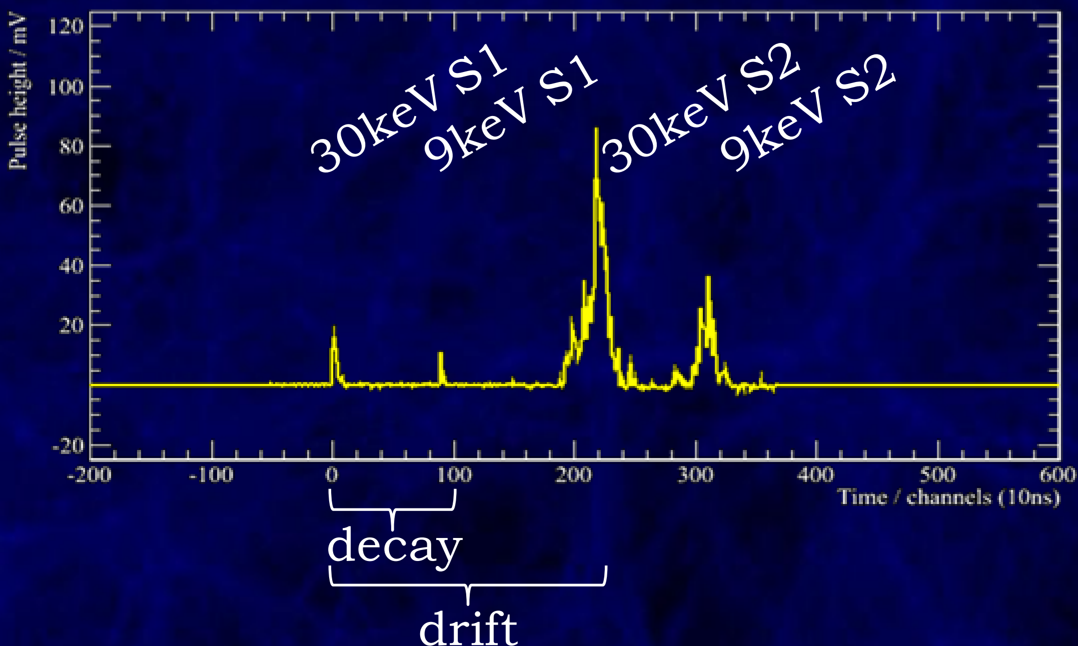
S2 x-y-dependence



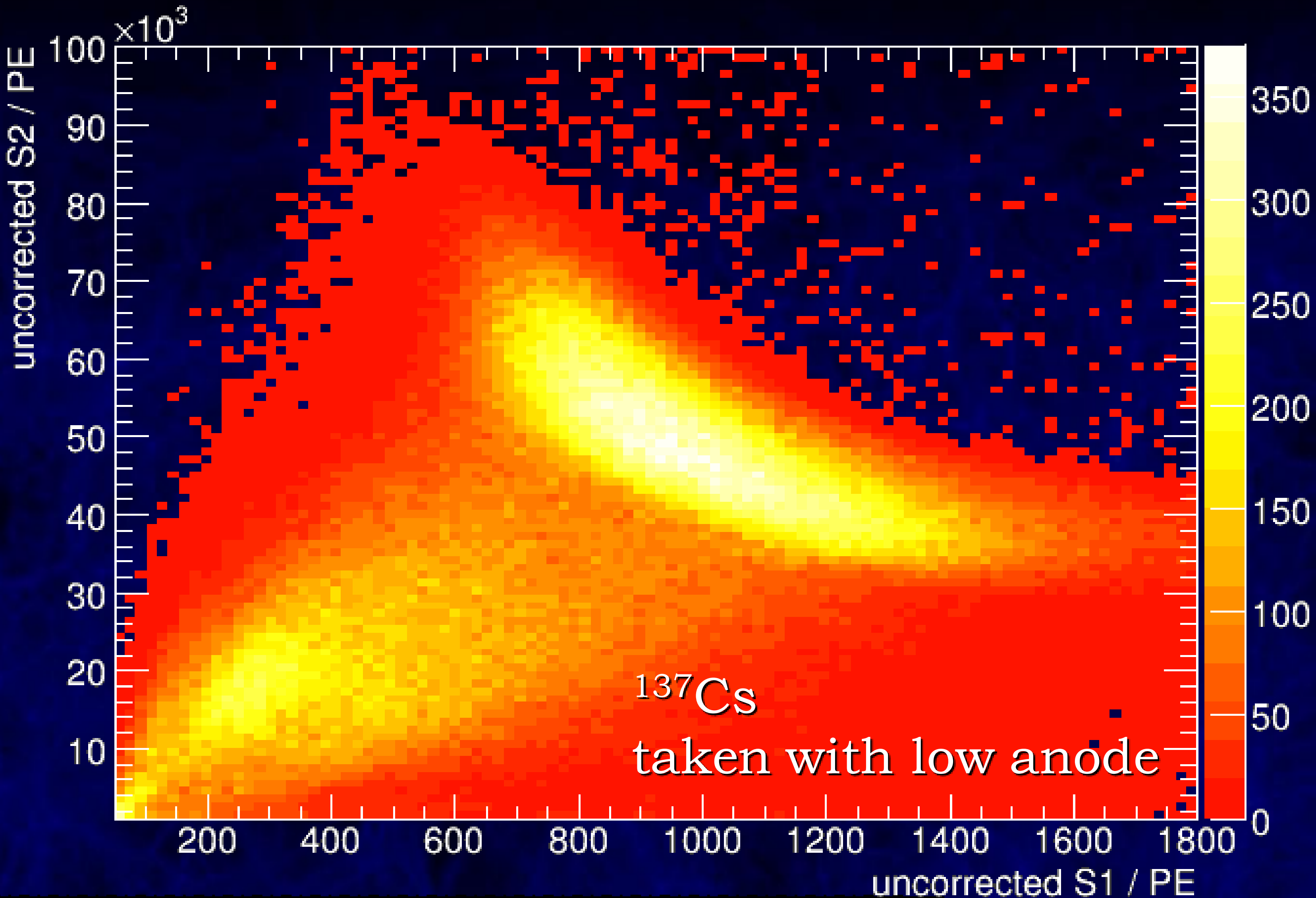


Calibration with ^{83m}Kr

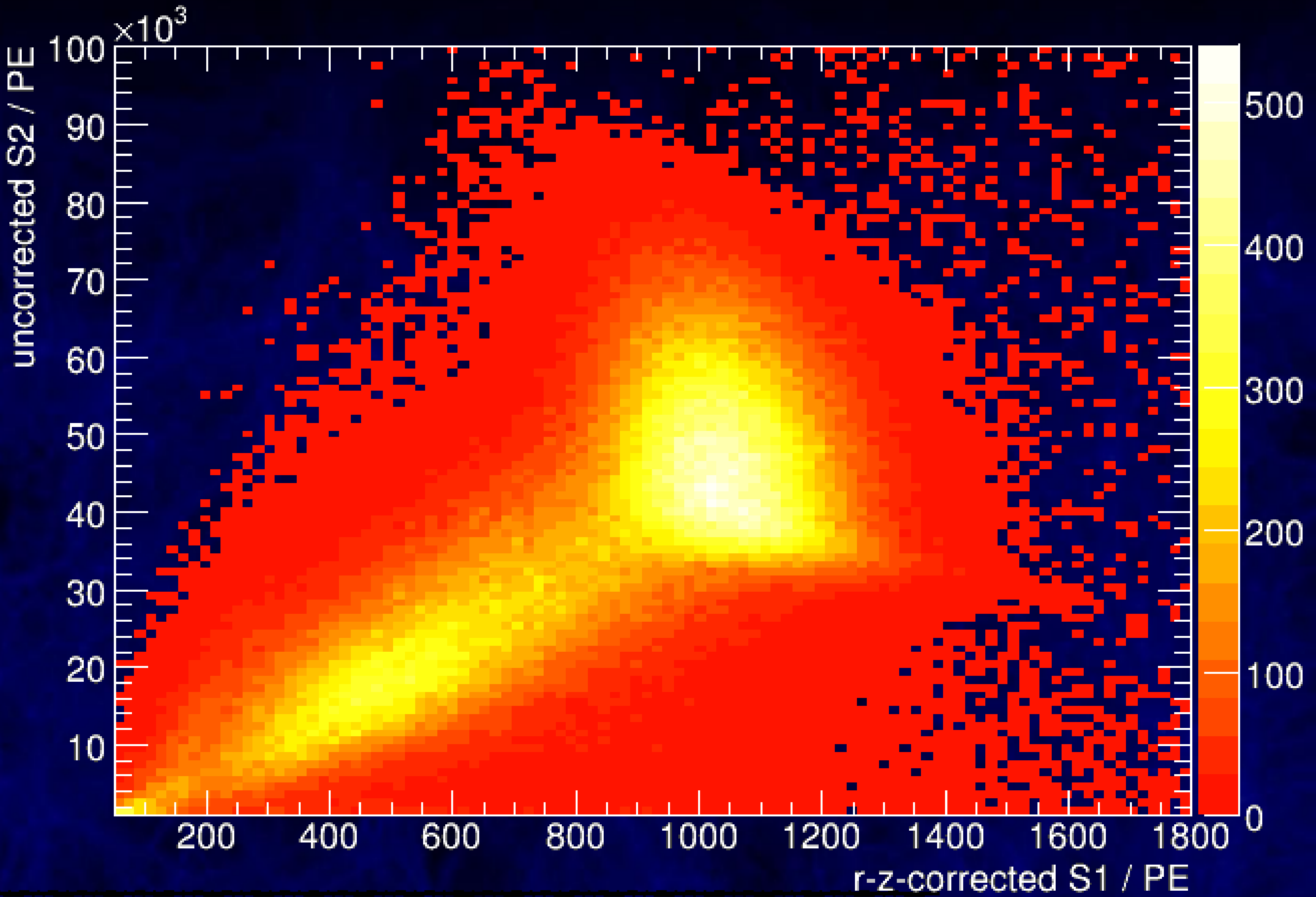




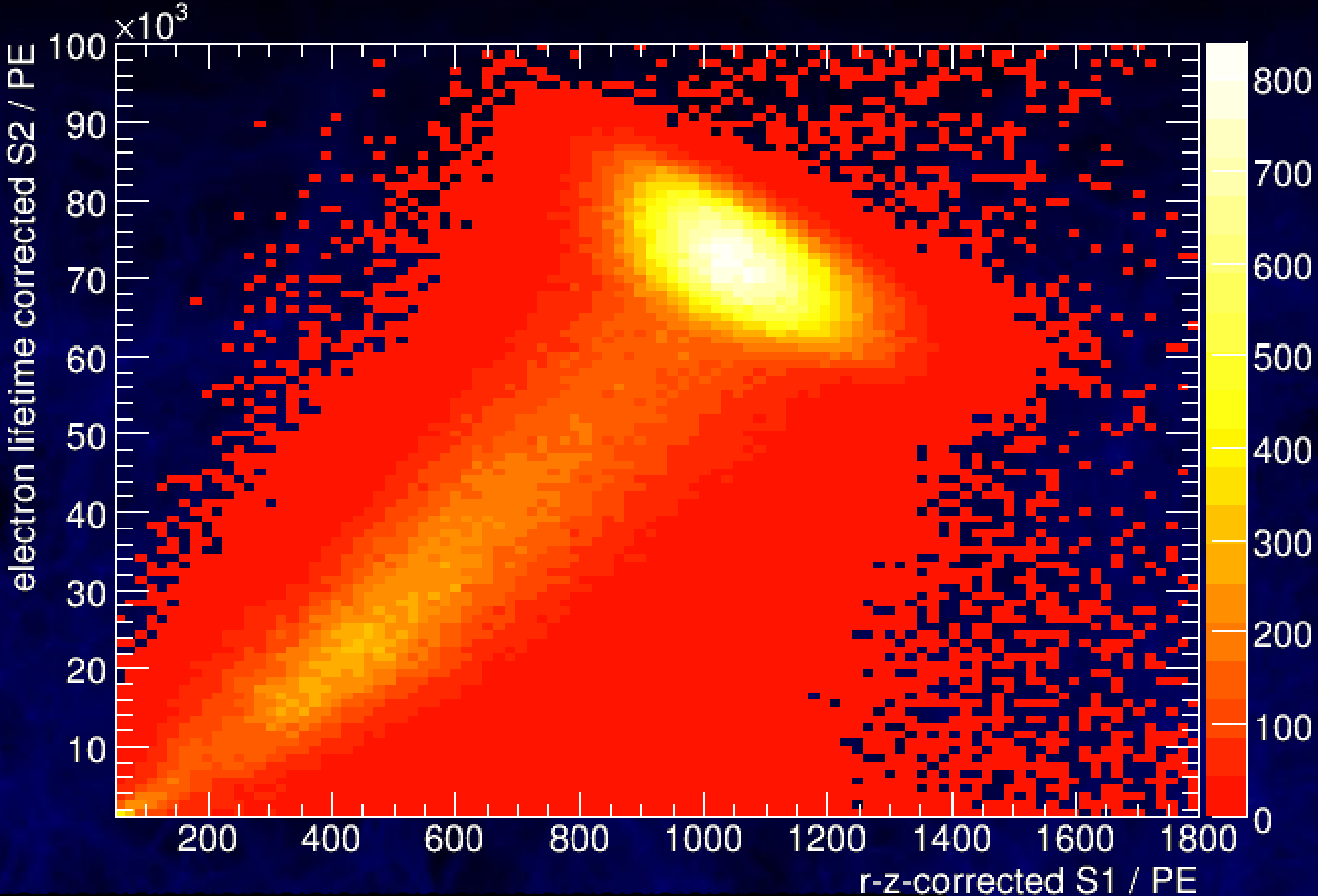
Position Dependent Corrections



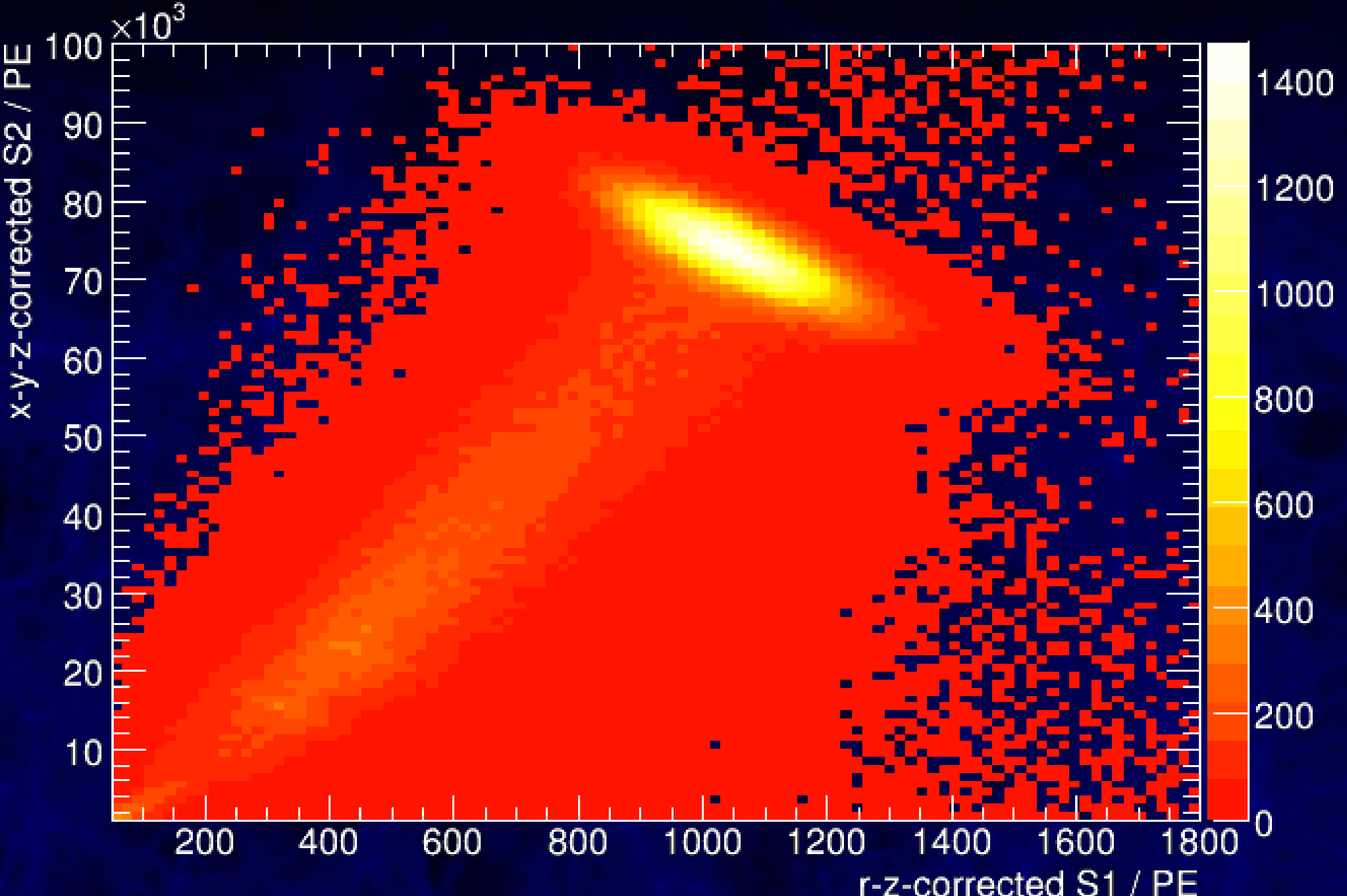
S1 r-z-Correction



S2 *z*-Correction (electron lifetime)

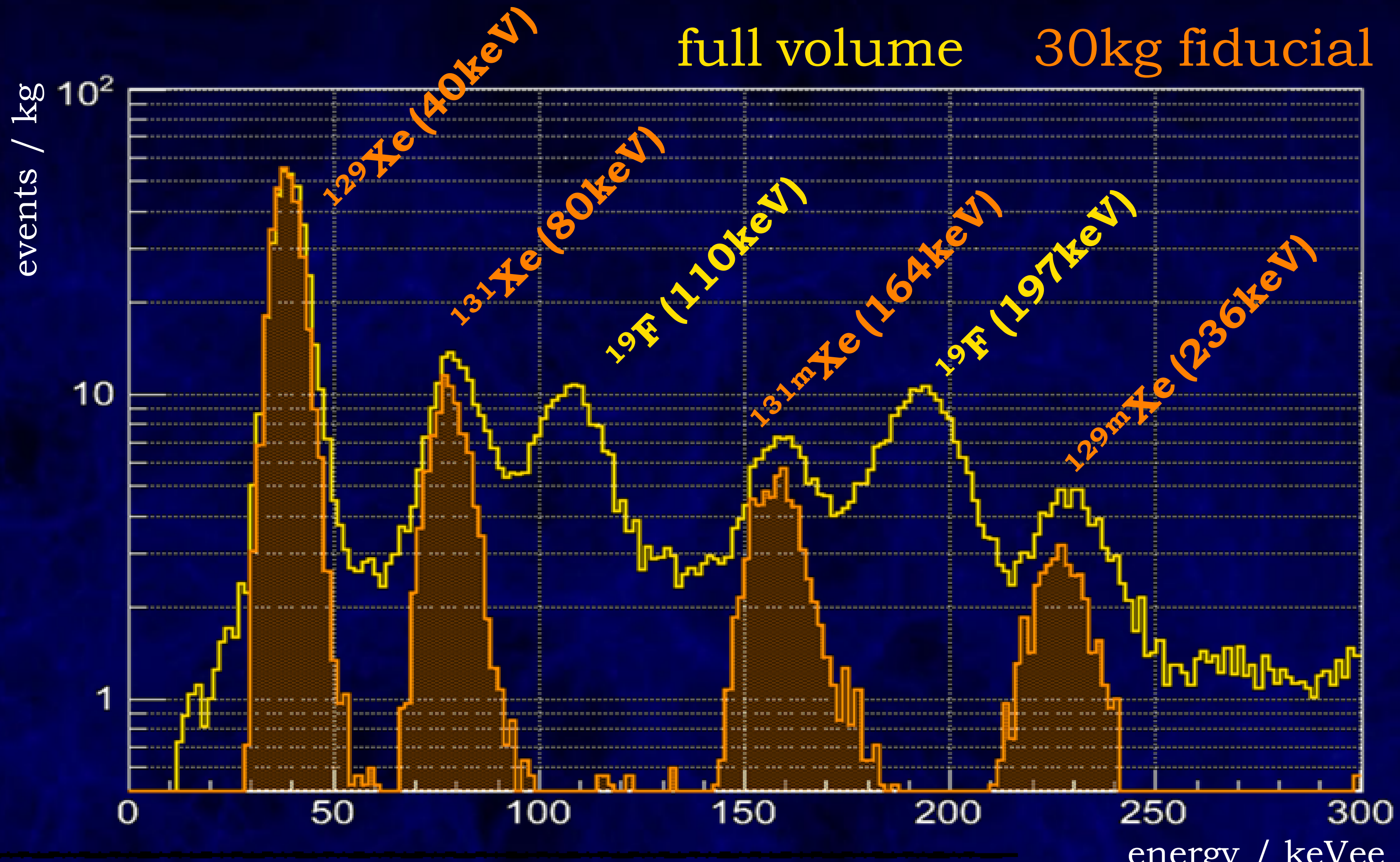


S2 x-y-z-Correction



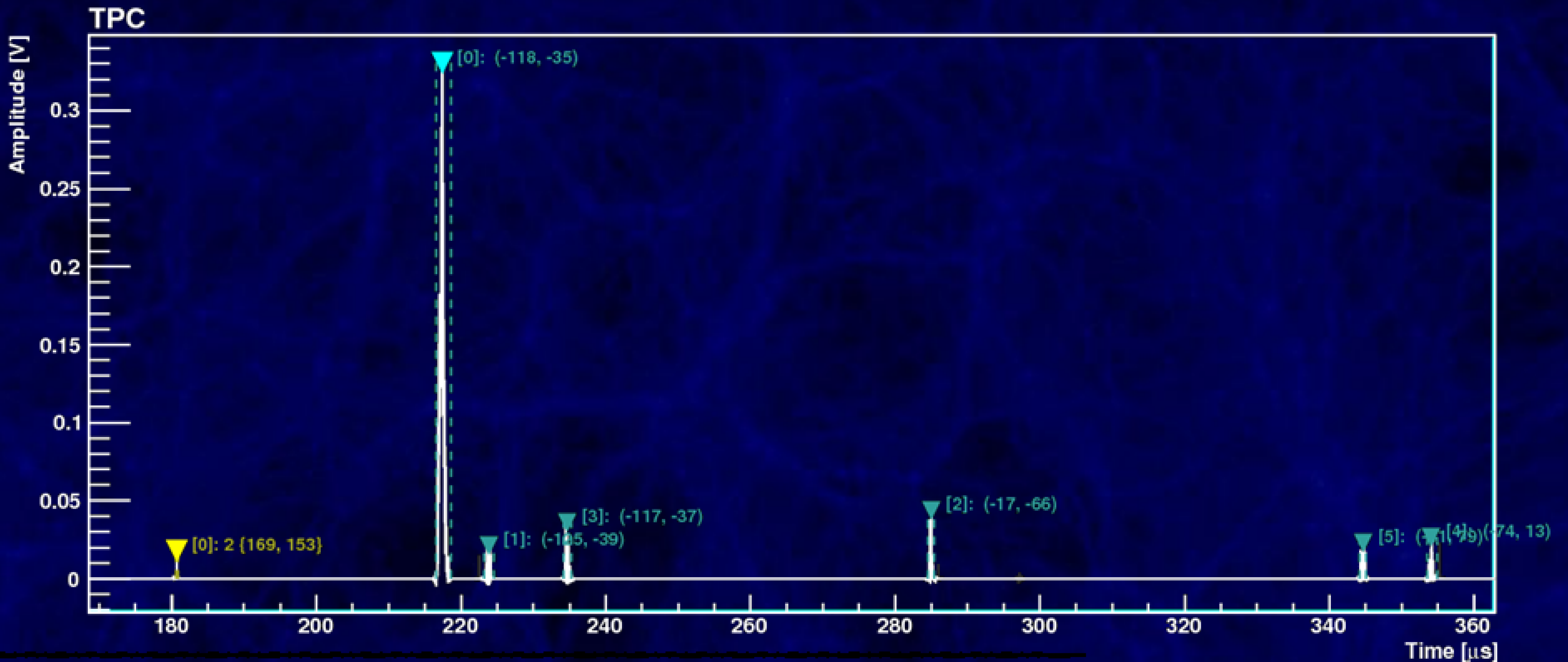
Inelastic Scatters & Fiducialization

Electronic recoils during ^{241}AmBe calibration:



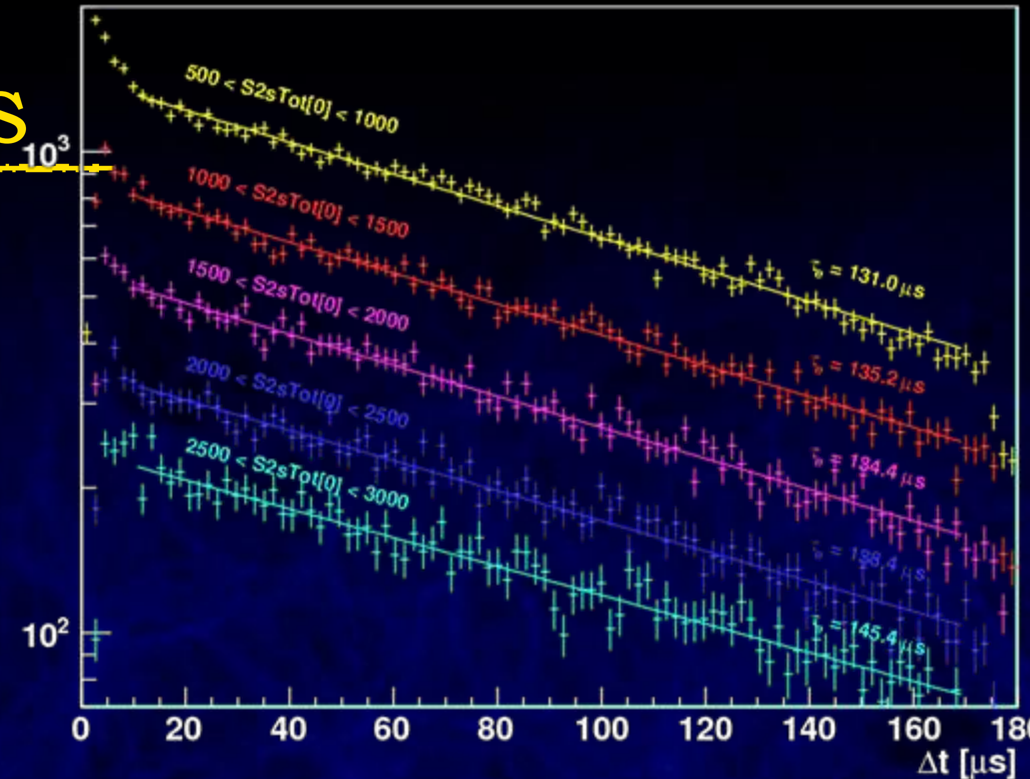
Single Electrons

typical waveform:

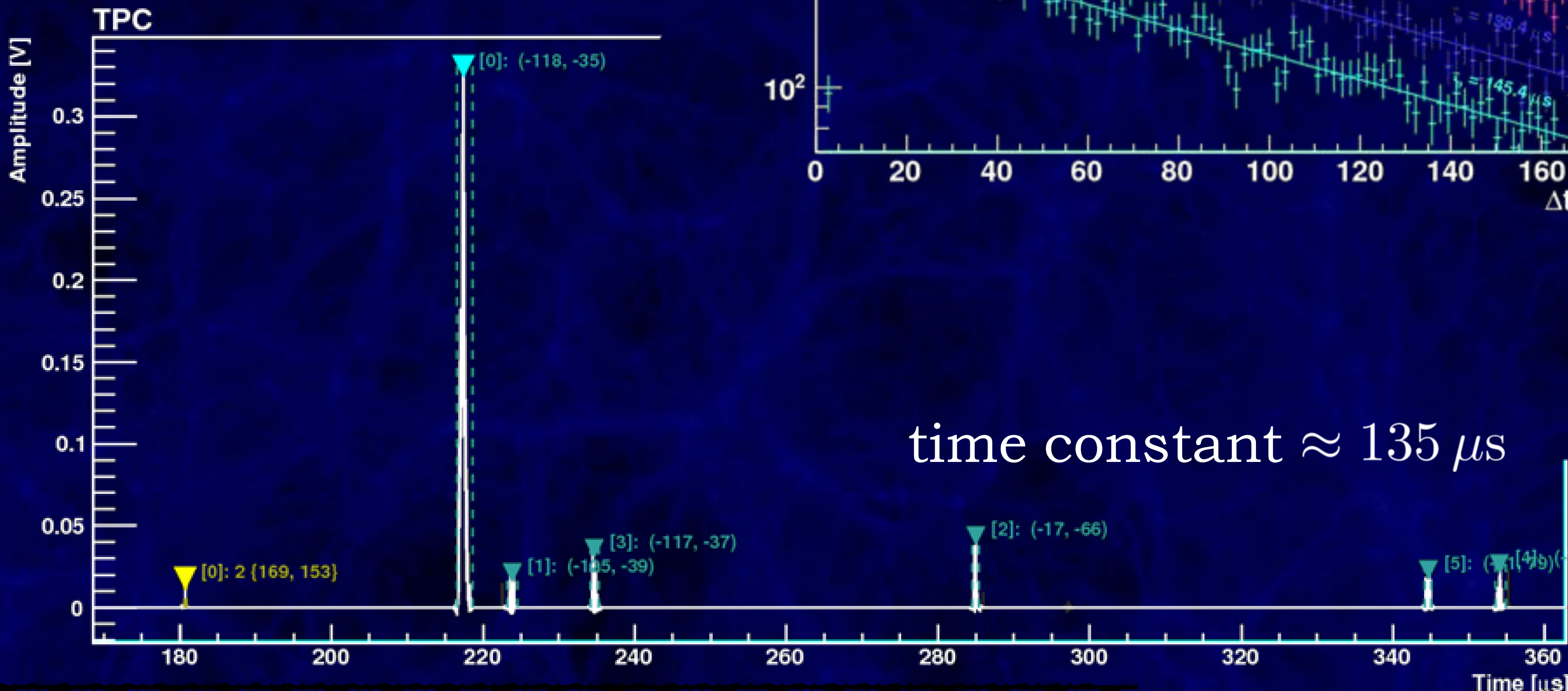


Single Electrons

time correlation:



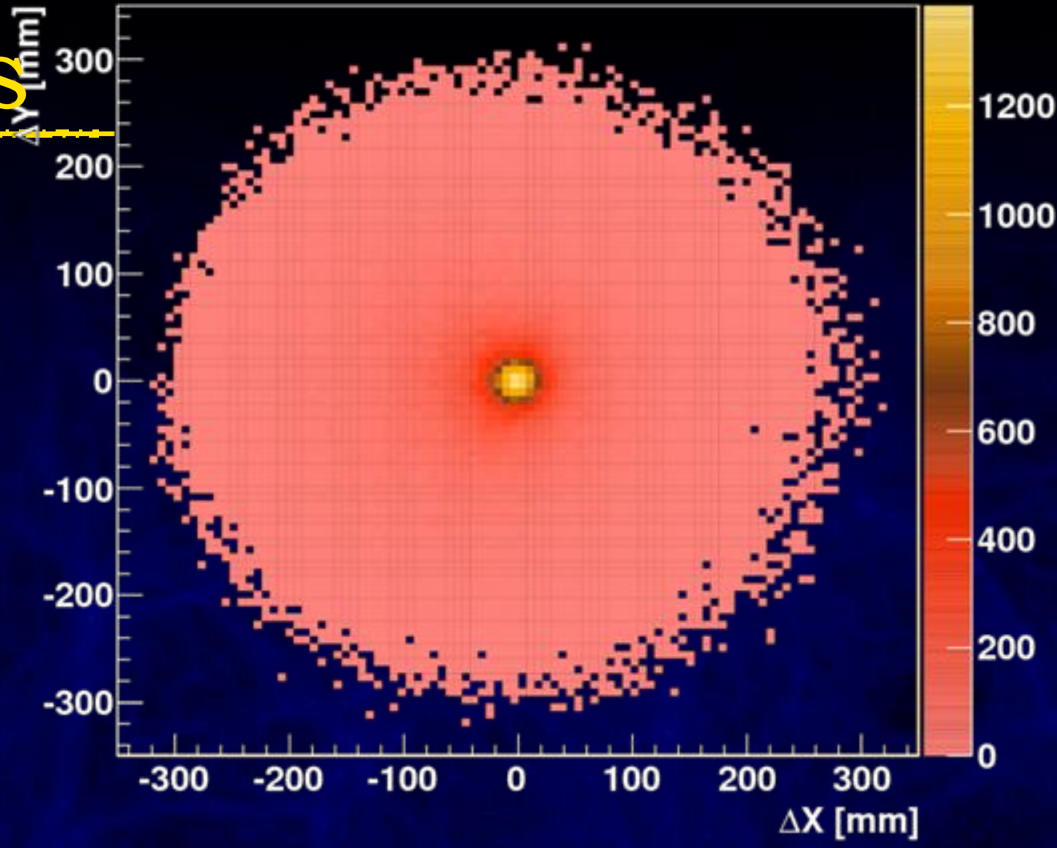
typical waveform:



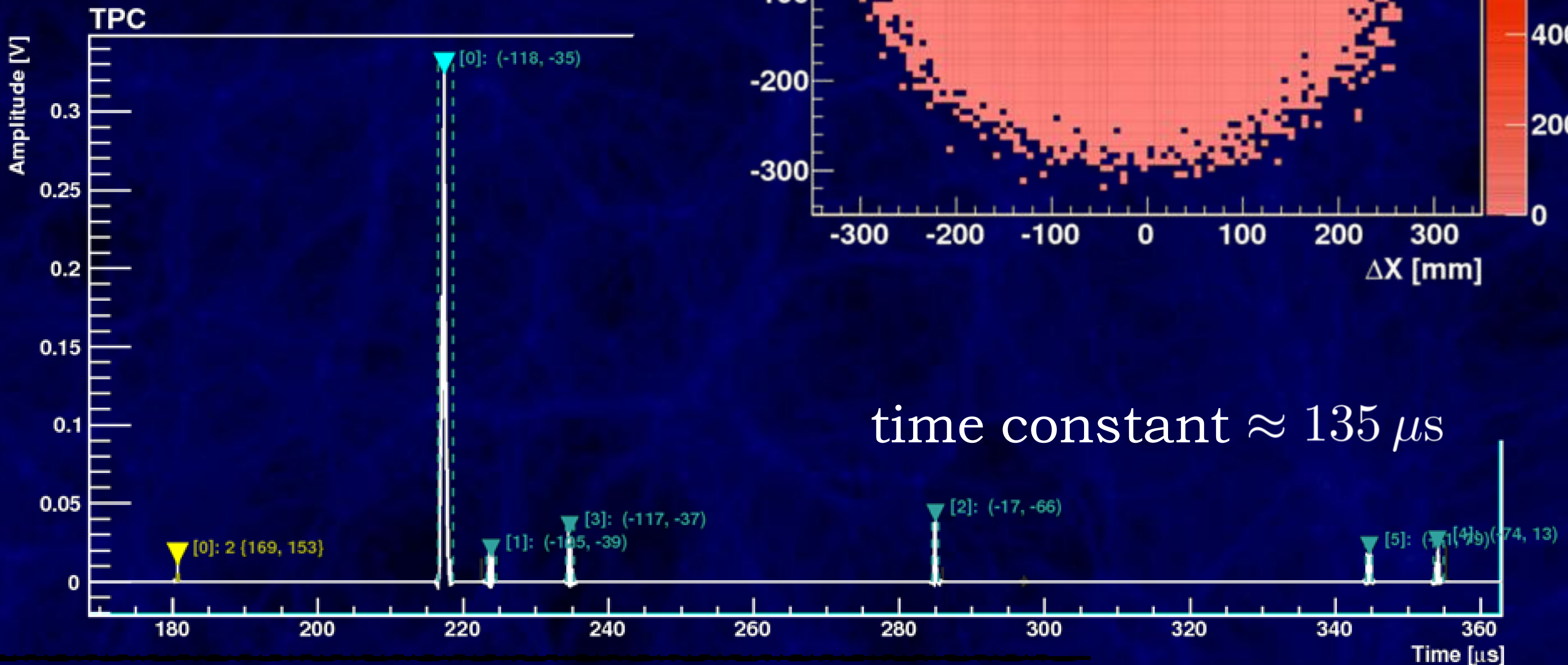
time constant ≈ 135 μs

Single Electrons

position correlation:



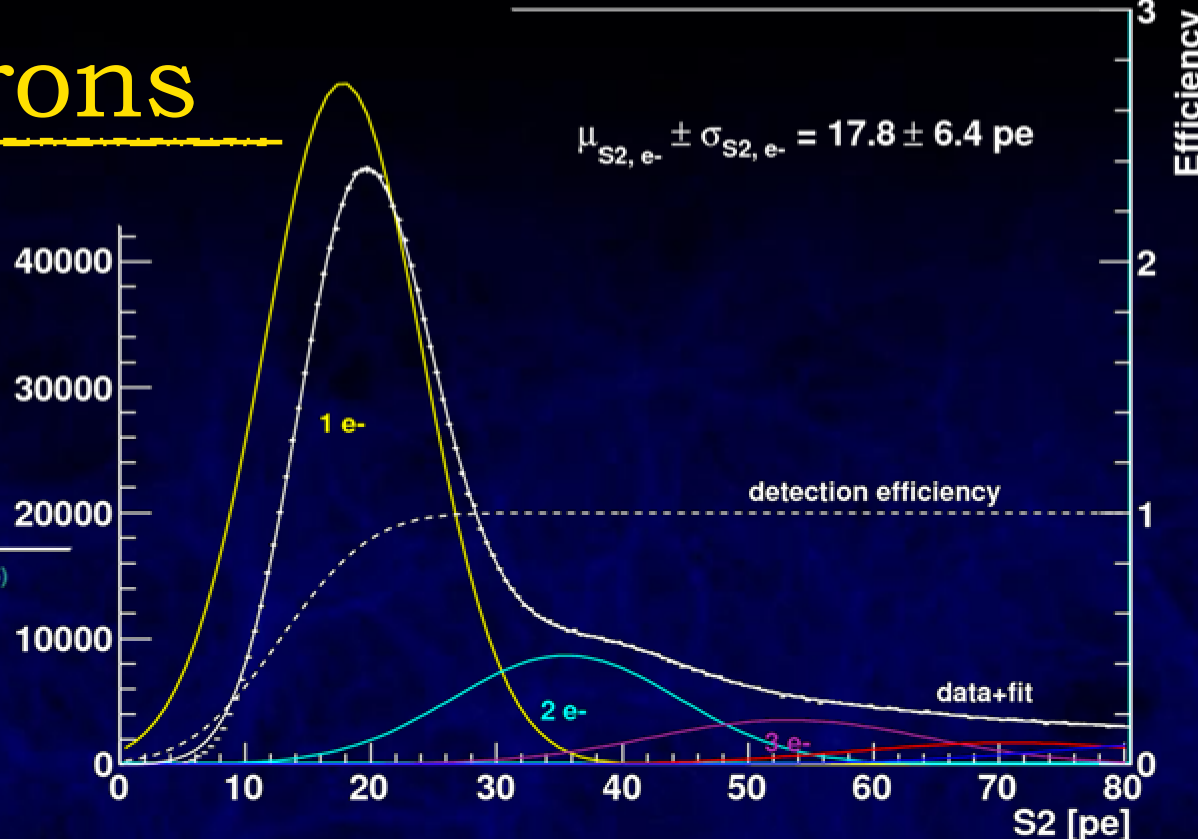
typical waveform:



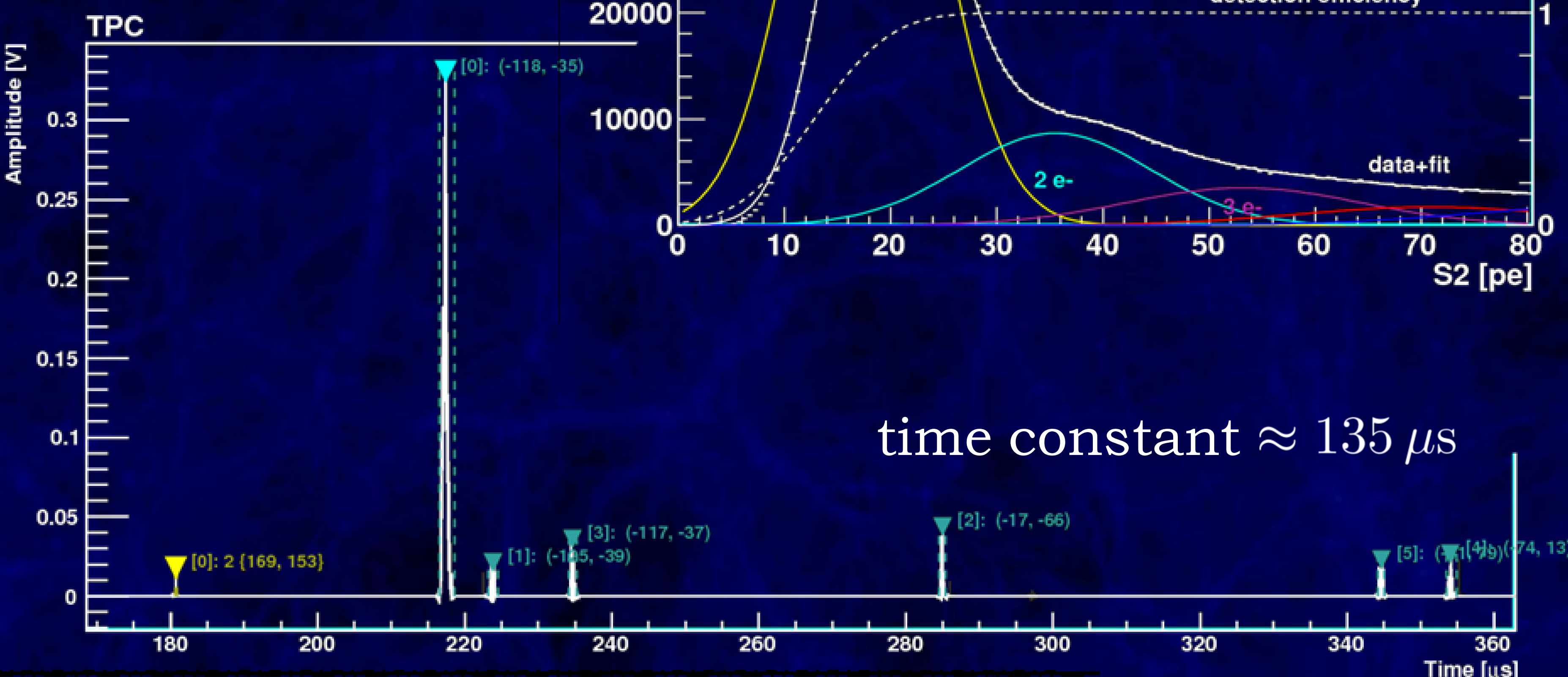
time constant $\approx 135\,\mu s$

Single Electrons

low S2 spectrum:



typical waveform:



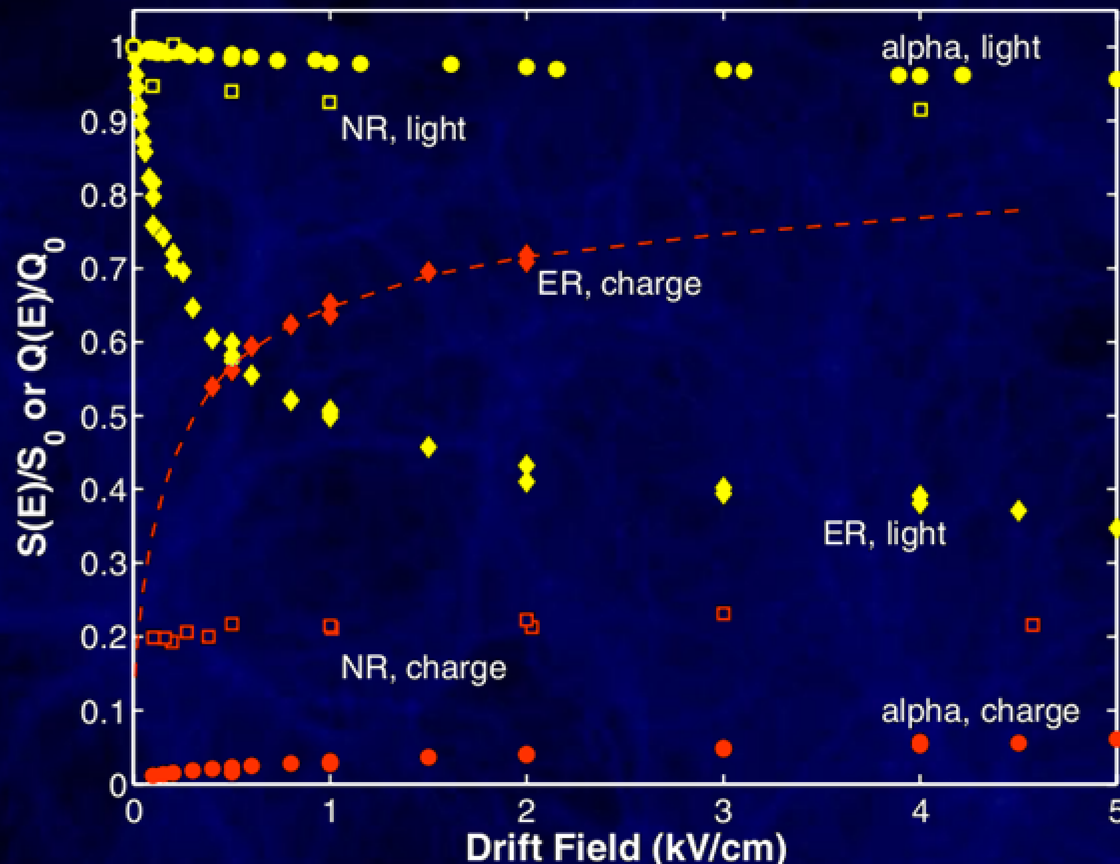
time constant ≈ 135 μs

Nuclear Recoil Equivalent Energy

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

$L_y(122\mathrm{keV}_{ee})$
= (2.20 0.09)PE

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



astro-ph/0601552

Nuclear Recoil Equivalent Energy

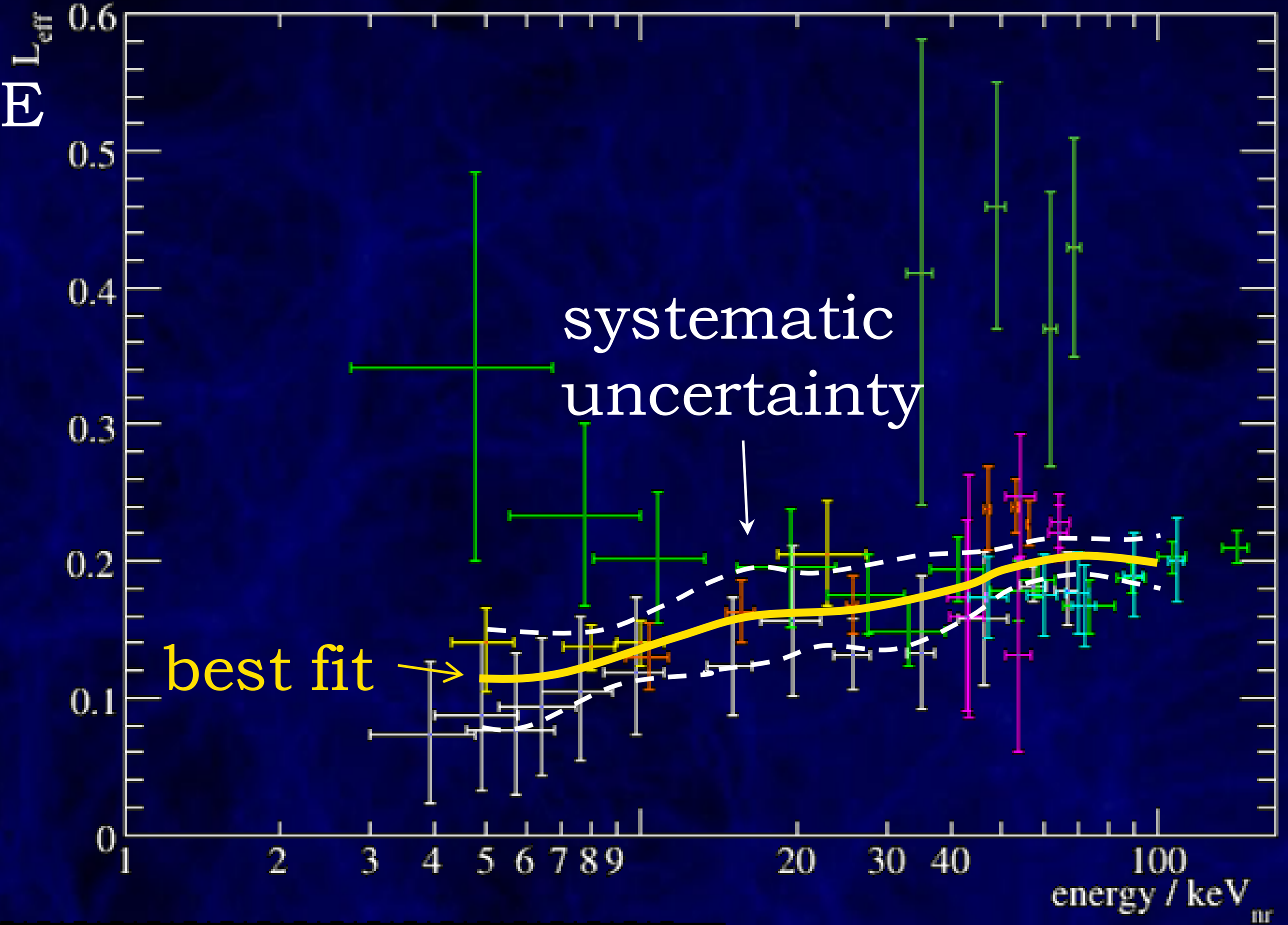
Nuclear Recoil Energy: $E_{\mathrm{nr}} = \frac{S1}{L_y} \cdot \frac{S_{\mathrm{ee}}}{S_{\mathrm{nr}}} \cdot \frac{1}{\mathcal{L}_{\mathrm{eff}}}$

$L_y(122\mathrm{keV}_{ee})$
= (2.20 0.09)PE

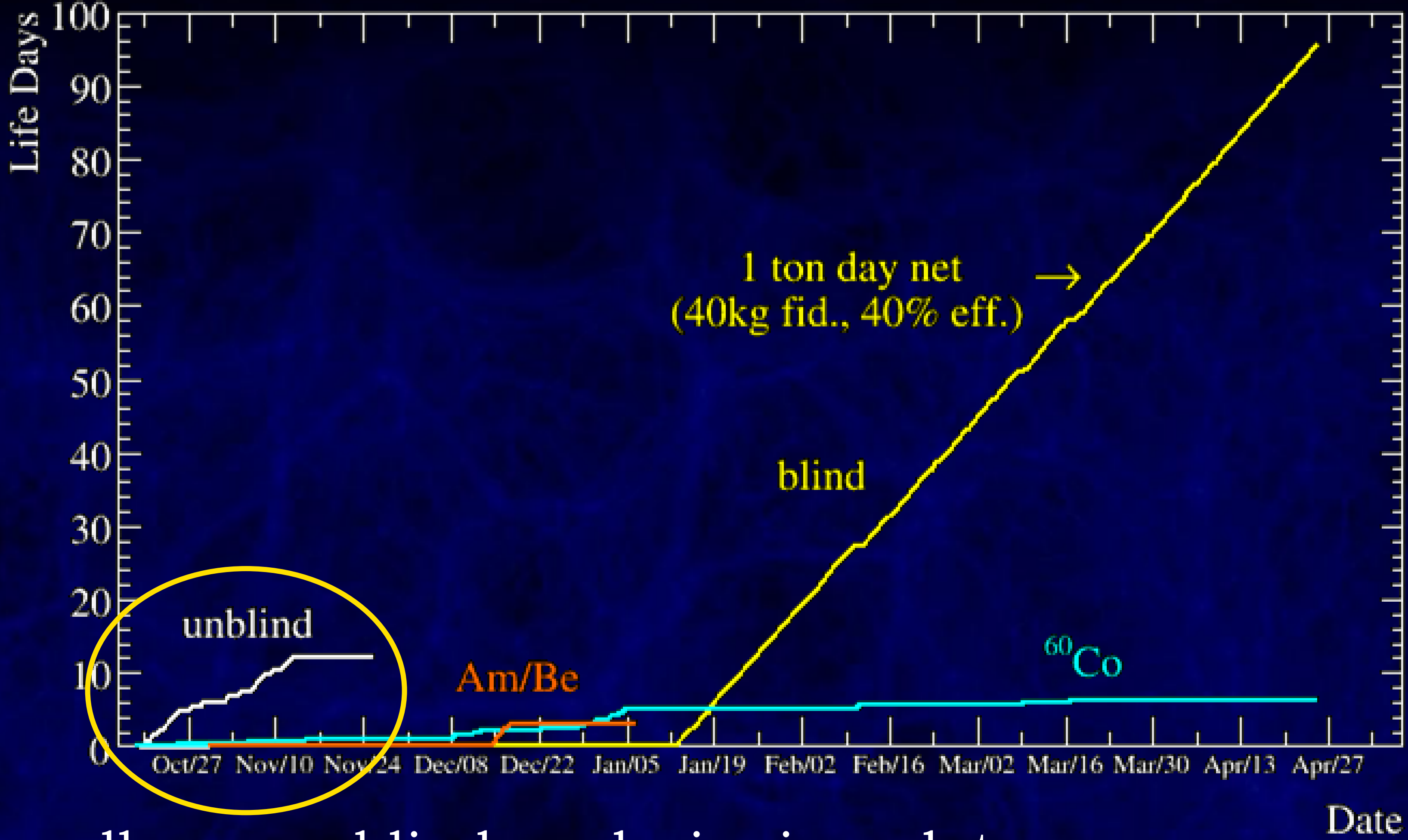
S_{ee}= 0.58
S_{nr}= 0.95

$\mathcal{L}_{\mathrm{eff}}$ best fit

Manzur et al. 2010
Aprile et al. 2009
Chepel et al. 2006
Aprile et al. 2005
Akimov et al. 2002
Bernabei et al. 2001
Arneodo et al. 2000



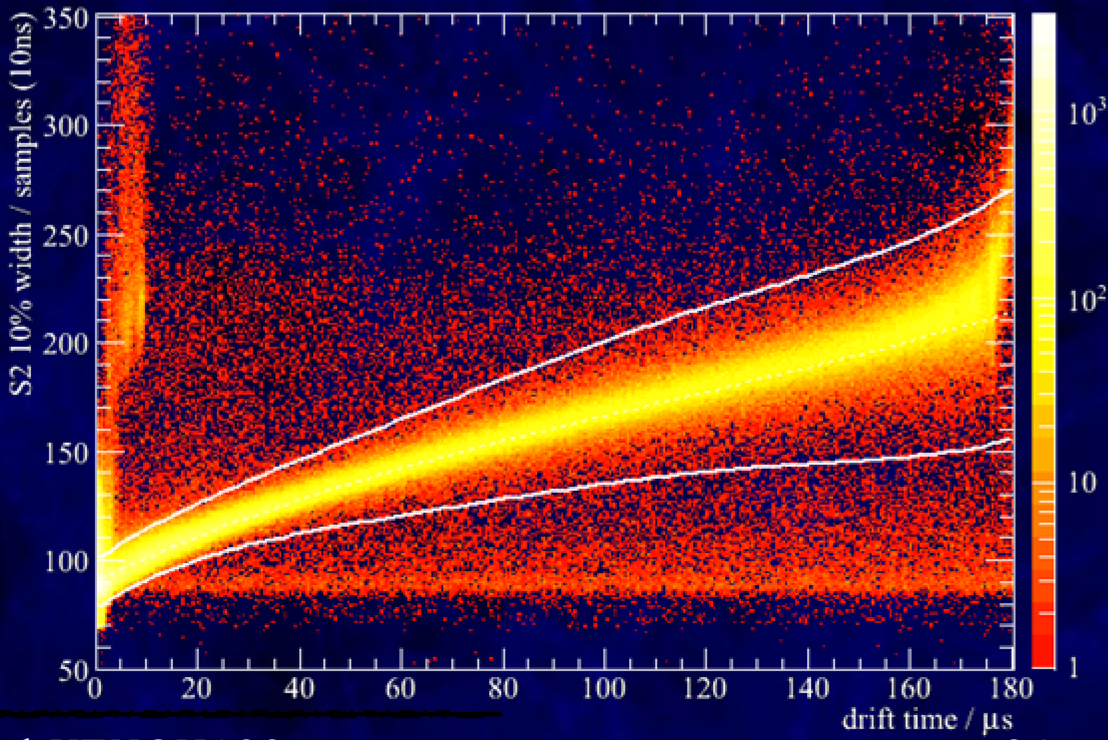
XENON100 Data Taking



formally a non-blind analysis since data was open,
in reality analysis developed on calibration data only

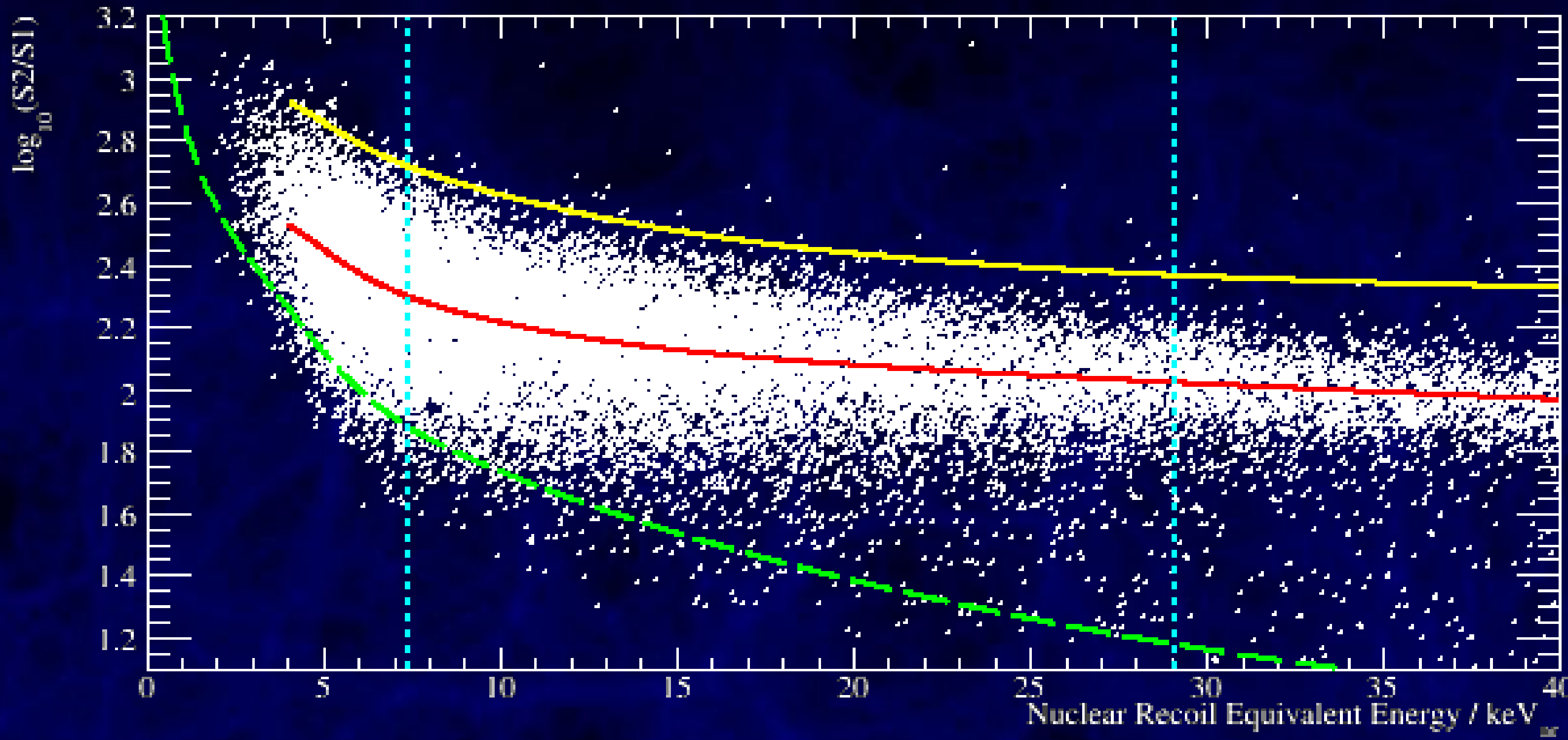
Quality Cuts from Calibration

- reject PMT single PE: require one two-fold coincident S1 pulse in the waveform
- reject double scatters: require one S2>300PE and no signal in veto during 20ns around the S1 pulse
- reject electronic artifacts: no obvious noise
- reject events not from fiducial volume: S2 width consistent with drift time



Nuclear Recoil Band

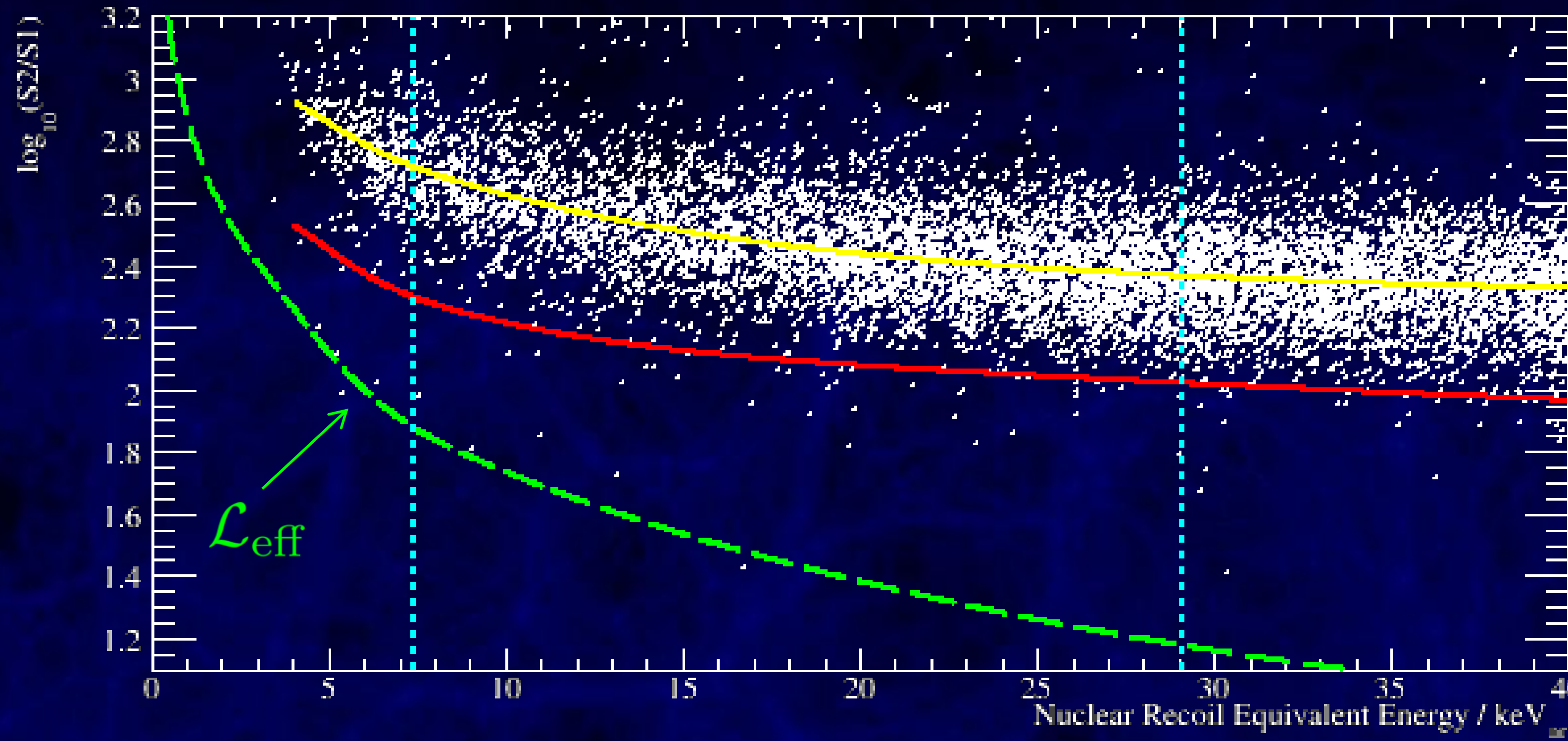
Neutrons from ^{241}AmBe



energy range 7.4-29.1 keV$_r$
(4-20 PE, S1 coincidence with >90% efficiency above 4PE)
and below nuclear recoil median

Electron Recoil Band

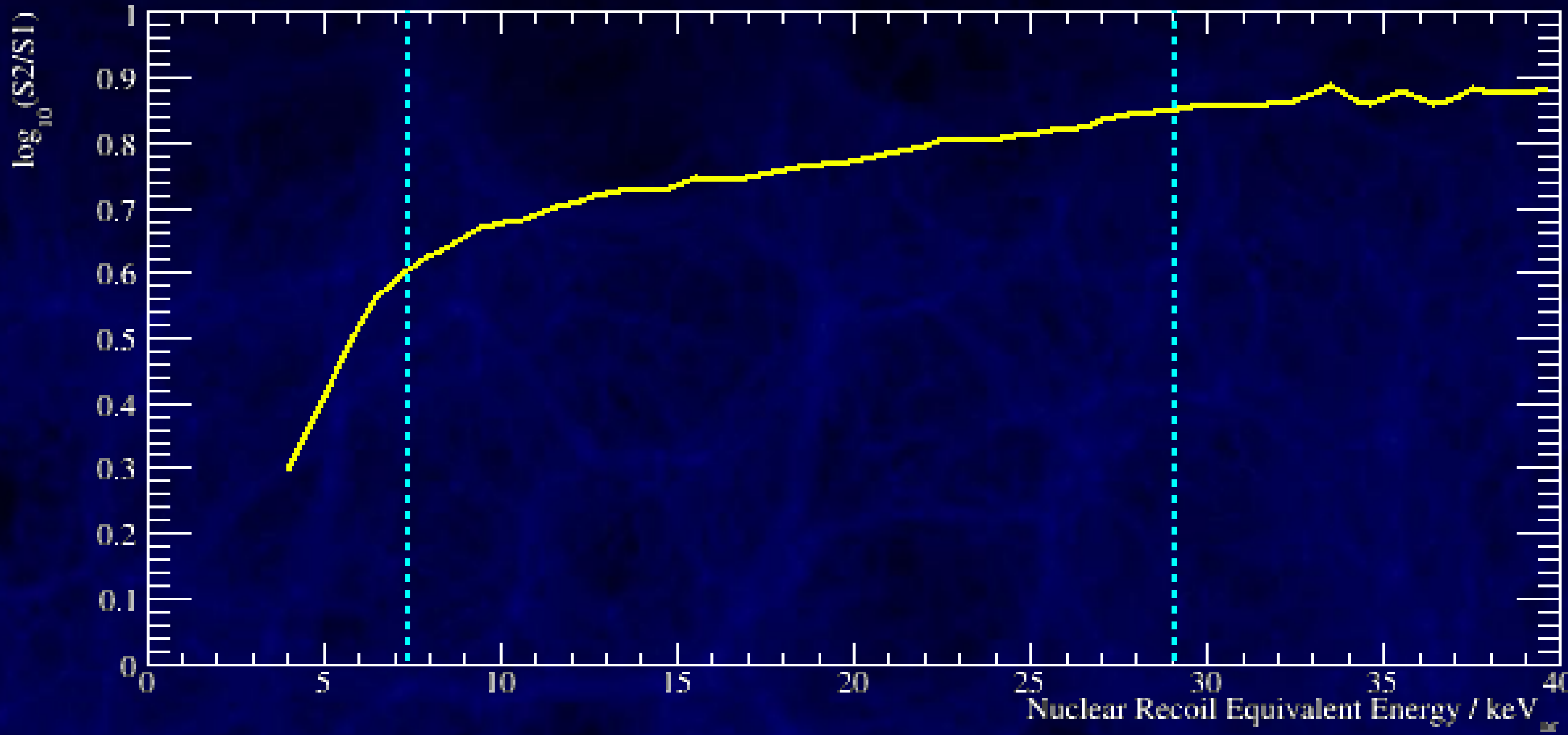
Compton scatters from ^{60}Co



50% nuclear recoil acceptance gives
>99% discrimination at low energies

Cut Acceptance

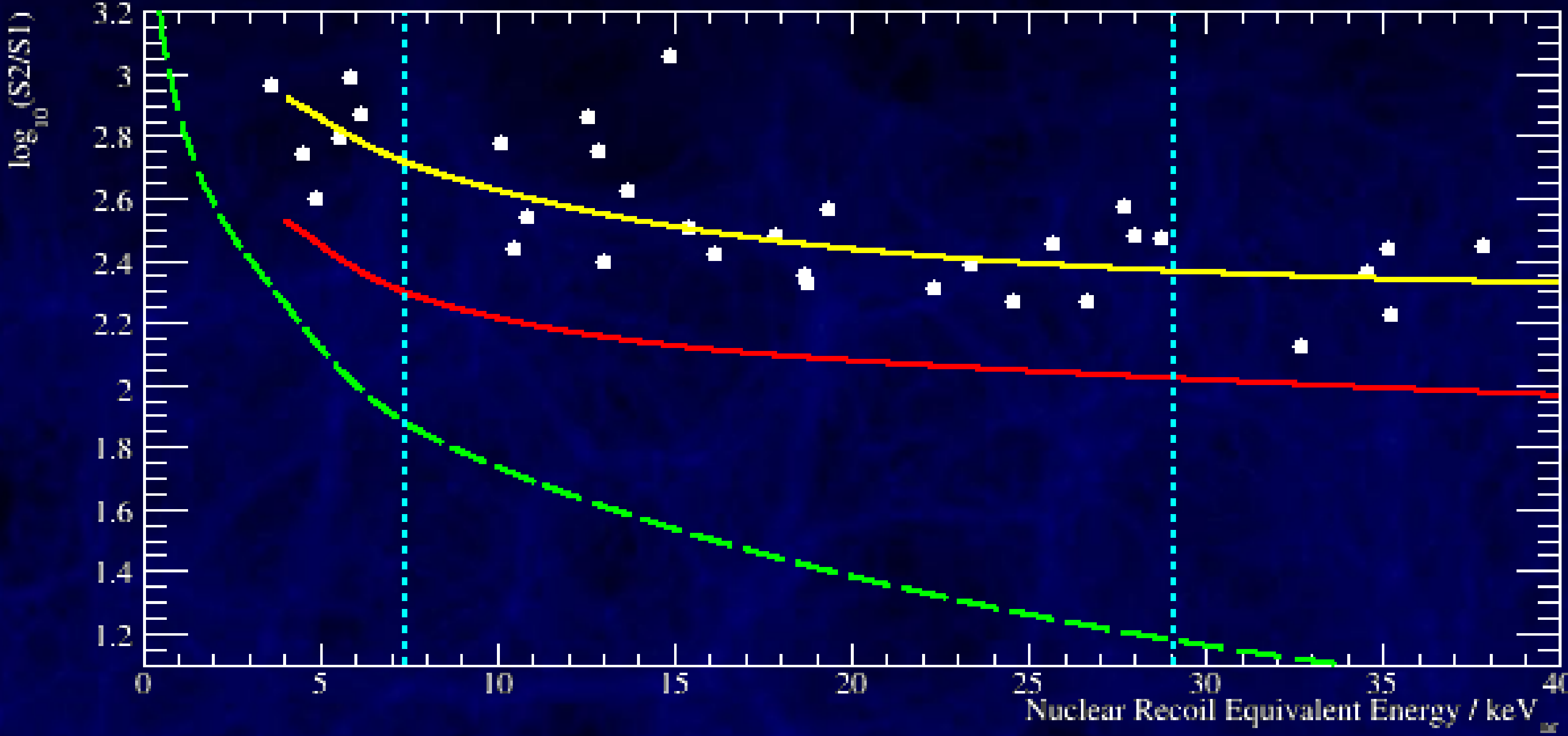
consider every event cut by only one cut as valid event



expect improvements of cuts in the future

Discrimination

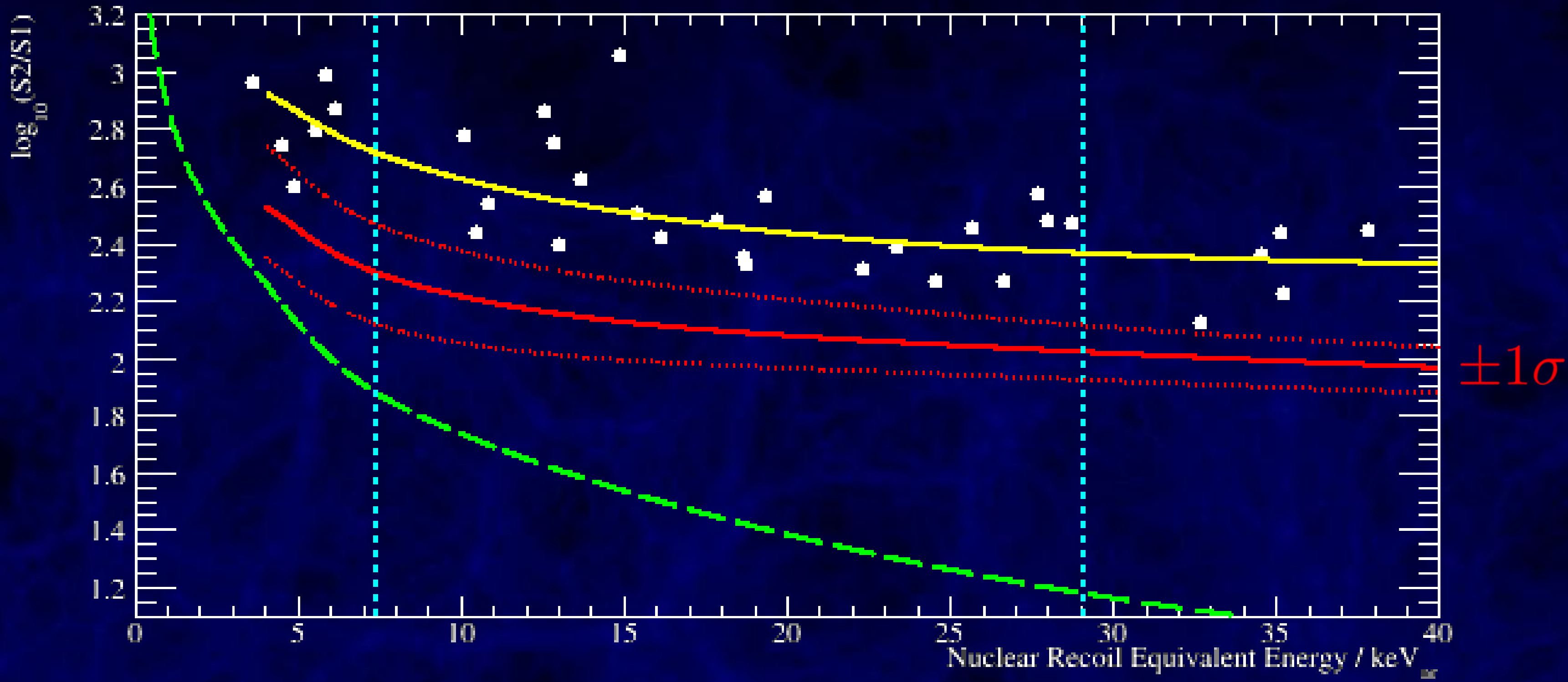
11.17 days, 40kg fiducial, 30%-40% efficiency



no events close to or below the nuclear recoil median even below 4PE

Discrimination

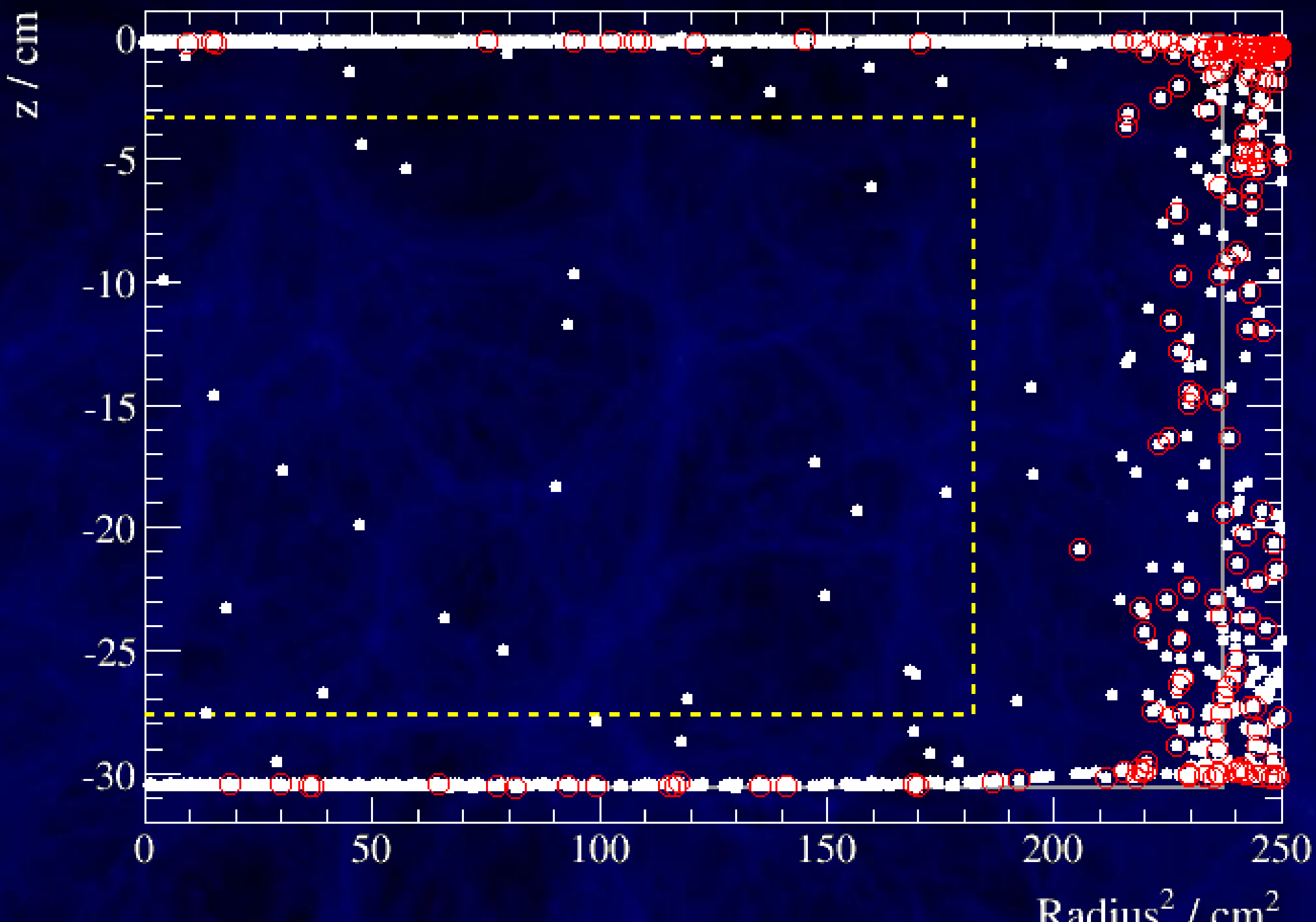
11.17 days, 40kg fiducial:



(no events even at 84% acceptance)

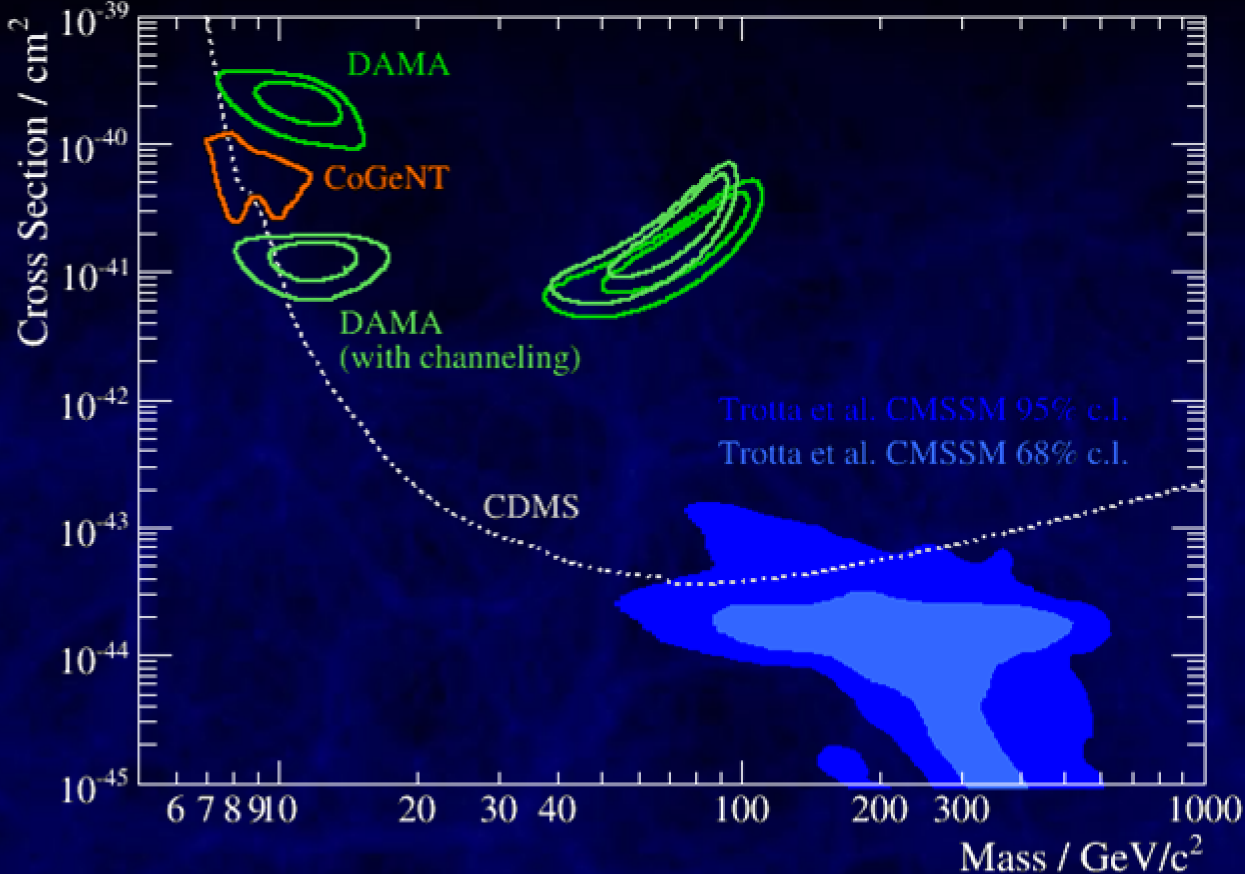
Fiducialization

11.17 days, 40kg fiducial, 30%-40% efficiency



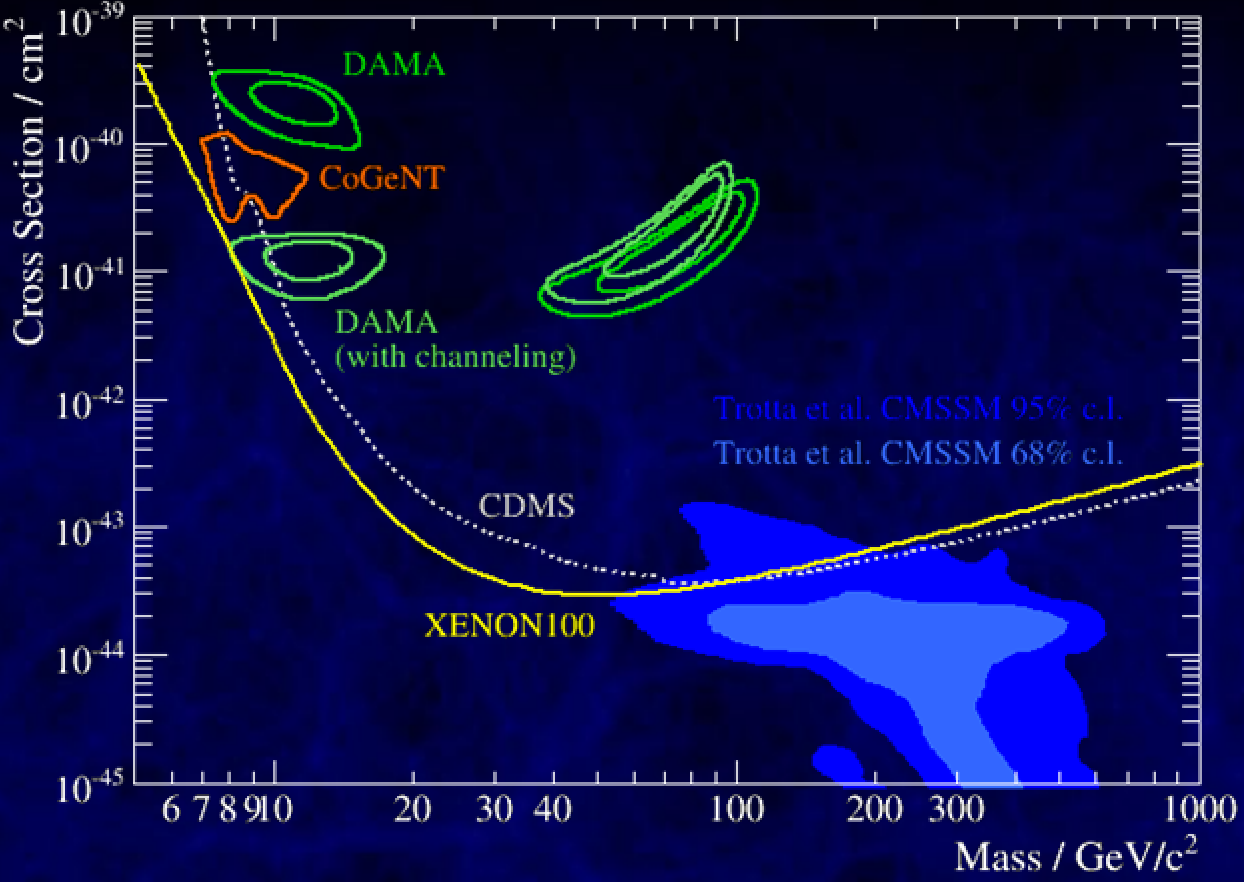
no nuclear recoils anywhere near the fiducial volume

Resulting Limit



characteristic velocity 220km/s, Earth velocity 232km/s, escape velocity 544km/s, local density 0.3GeV/cm^2, Helm Formfactor, Poisson dominated energy resolution

Resulting Limit



excludes CoGeNT and DAMA favored regions at 90% c.l.
robust: fiducial volume, discrimination, cut acceptance, energy threshold all very conservative!

on the arXiv tomorrow