XENON10: Dark Matter Direct Detection

Peter Sorensen

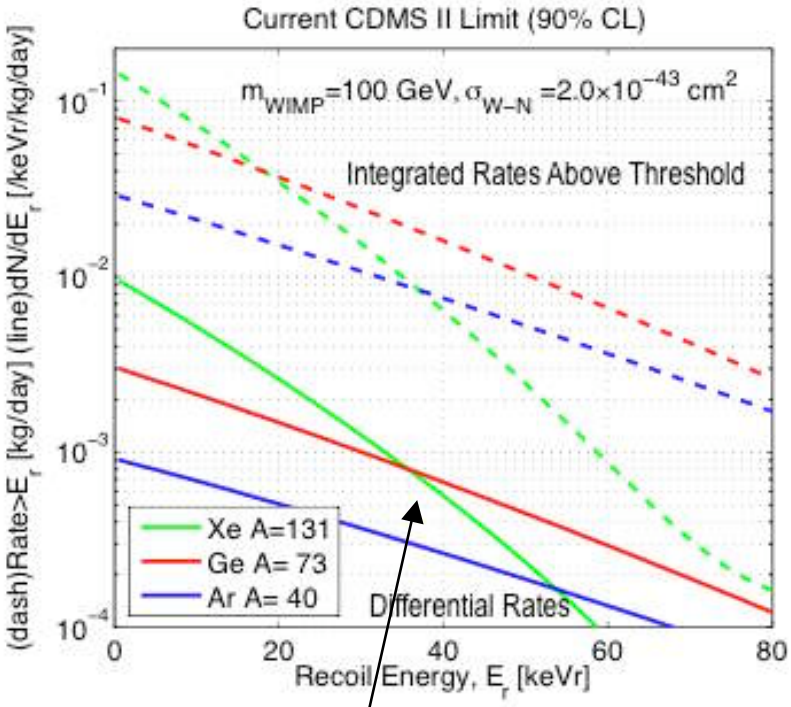
Brown University

On behalf of

~ XENON Collaboration ~

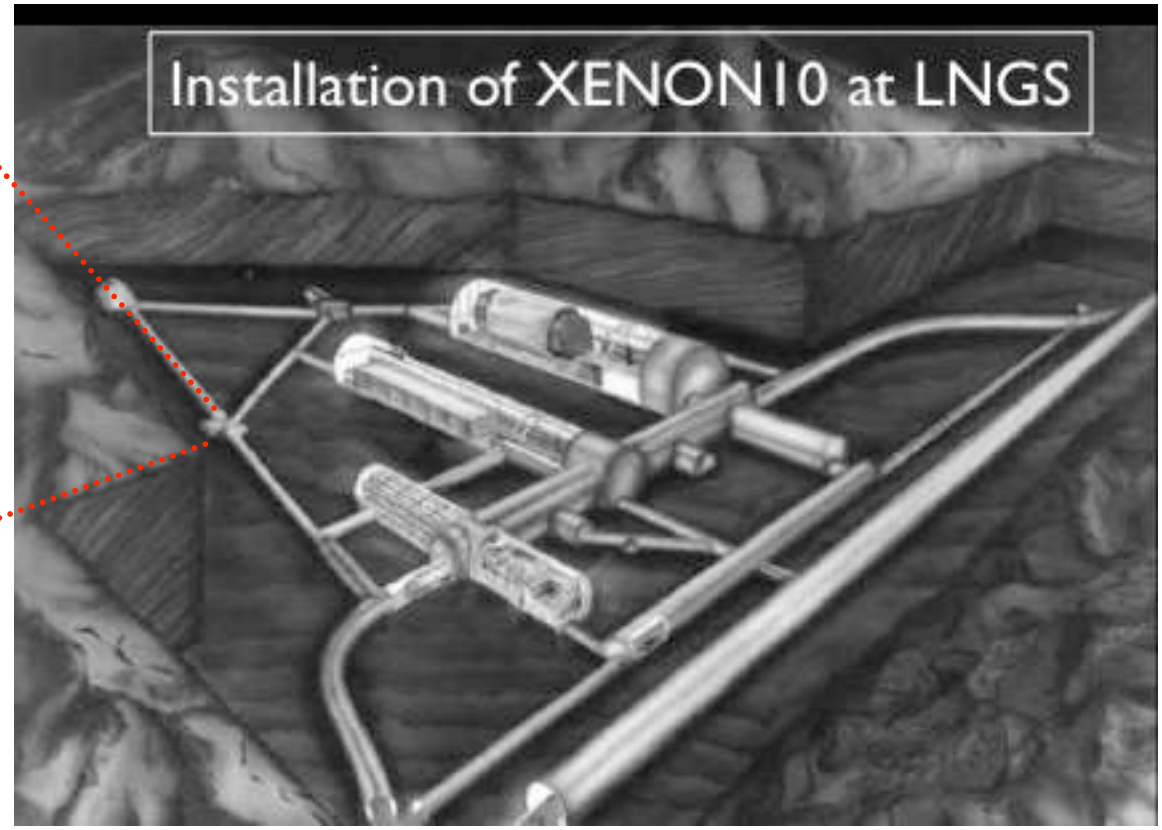
Scope of Talk: Some Challenges for WIMP Search

- Brief Overview of XENON10
  - Detector Response at Threshold (16 keVr nominal)
  - Reminder: predicted WIMP interaction rate in LXe
- Background Studies of Paramount Importance
  - n / γ : Sources / Contributions
  - M.C. Expected Event Rates v Actual Event Rates
- Trigger Threshold Studies (s1 & s2)
  - Initial goal was good trigger/analysis efficiency at 16 keVr, however…
  - Dark Matter sensitivity improves further with lower threshold
  - How much lower can we push it? (~ x2)



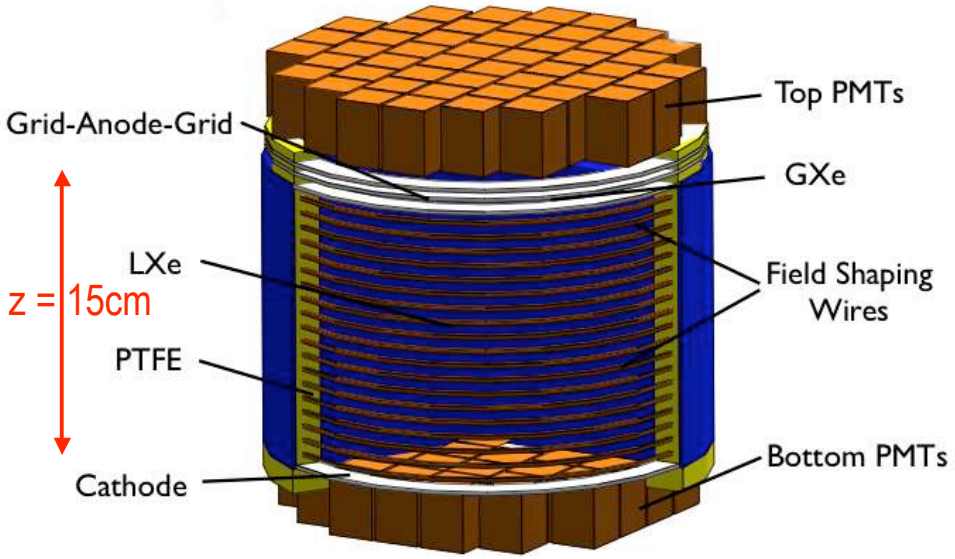
D.M. ROI : < 60 keVr
(effective: 10-40 keVr)

XENON10 Underground Installation

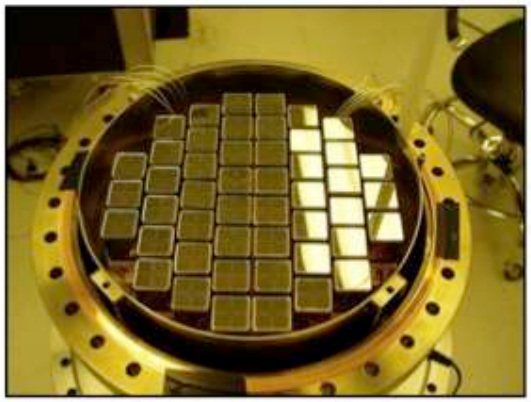


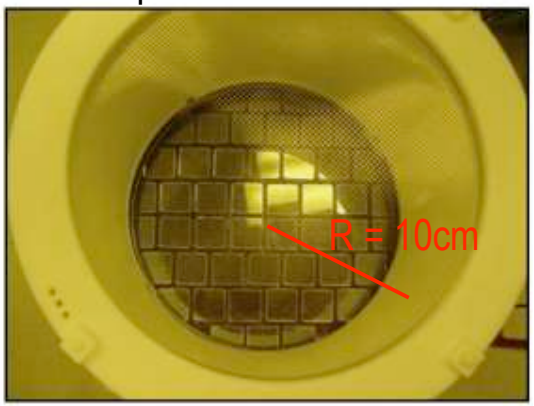
- Installed March 2006 @ LNGS (~3100 mwe)
- Muon flux ~ 24 μ/m^2/day (10^6 reduction from sea level)
- Began calibration end of March
- Shield completed July 2006
- Detector installed in shield Late July 2006 (bottom left) …

XENON10 Detector



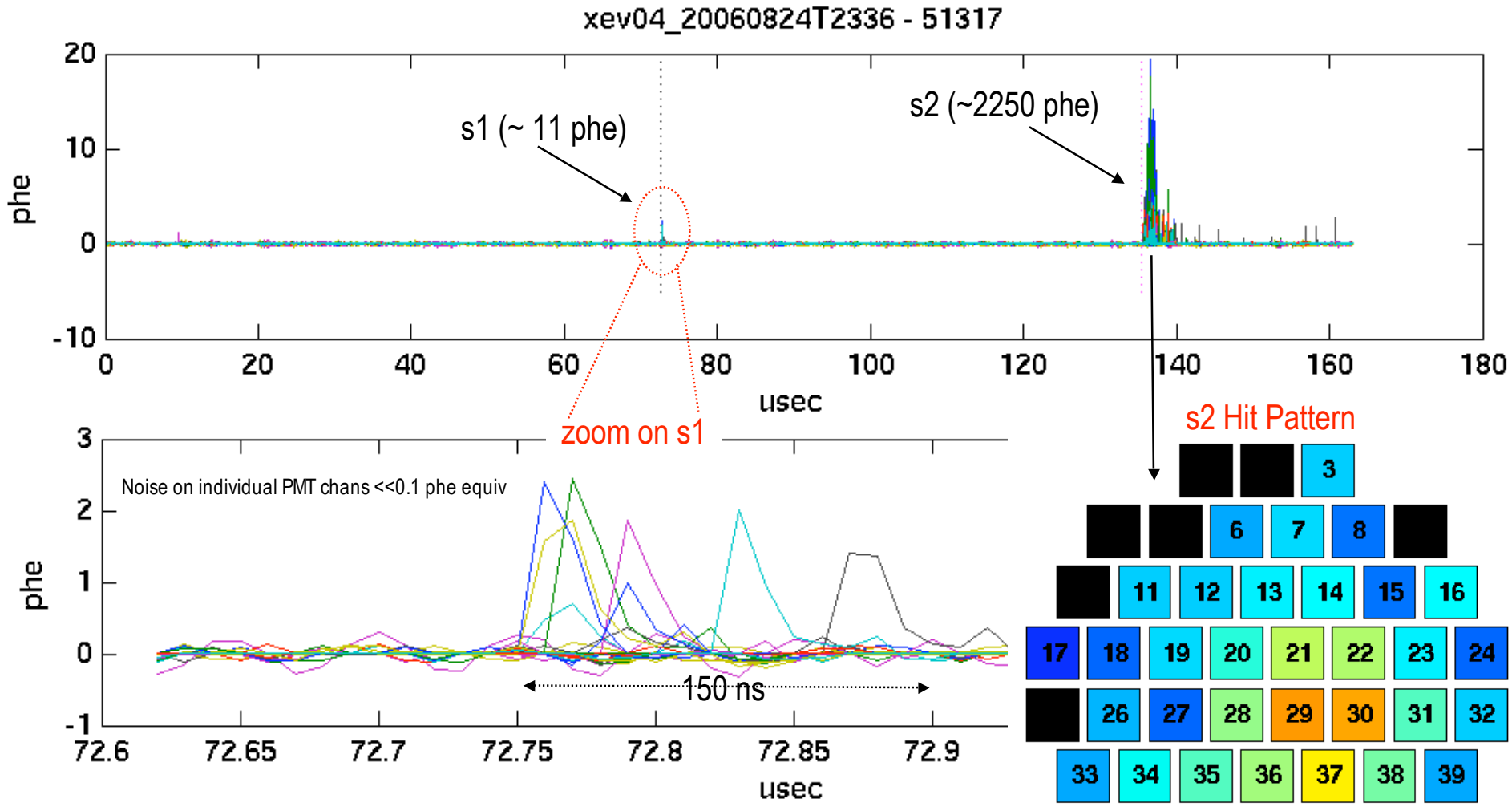
89 PMTs: Hamamatsu R8520-AL 2.5 cm square





- see also talk by M. Yamashita -

XENON10 Typical Low-Energy Gamma Event

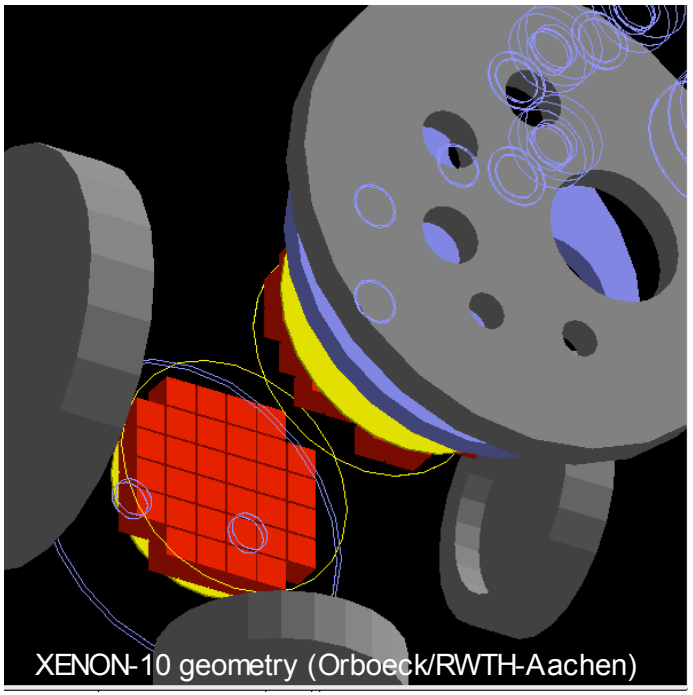


Expect > 99% rejection efficiency of γ/n Recoils…

Reduction of Backgrounds => Reduction of Leakage Events

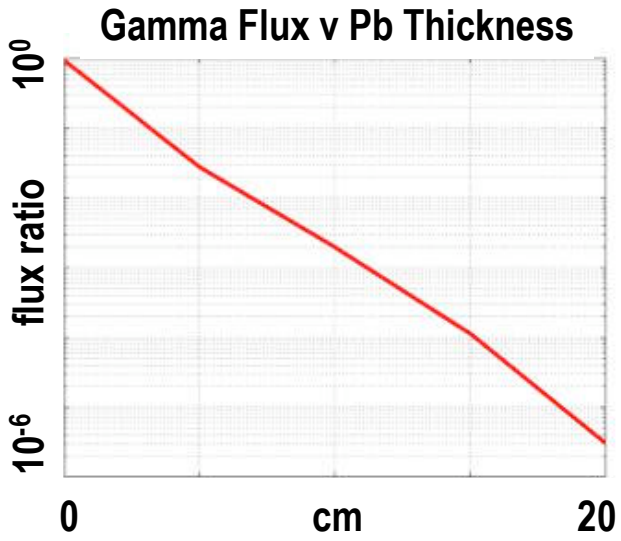
XENON10 Background Studies

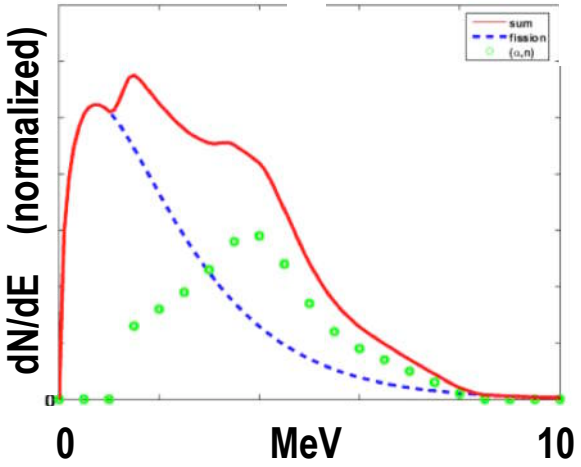
- Gamma / Electron (External Gammas ~ 10^4 dru)
  - PMT (U/Th/K/Co)
  - Vessel: Stainless Steel (Co)
  - Other Components, e.g. Feed-Throughs
  - ^{222}Rn in cavity (removed by N2 purge)
  - ^{85}Kr contamination in LXe (ppm --> ppb --> ppt)
  - Pb Shield (25 Bq/kg ^{210}Pb)
- Neutron Backgrounds
  - Internal: PMT (α,n)
  - External: Rock (α,n) & fission / Muons in Shield
  - Punch-through neutrons: Generated by muons in rock
- Detector Performance/Design
  - Use of xyz position reconstruction to make fiducial cuts
- Active Muon Veto Not Required for XENON10 @ LNGS
  - Neutron flux from muon interaction in Pb shield << Target Level

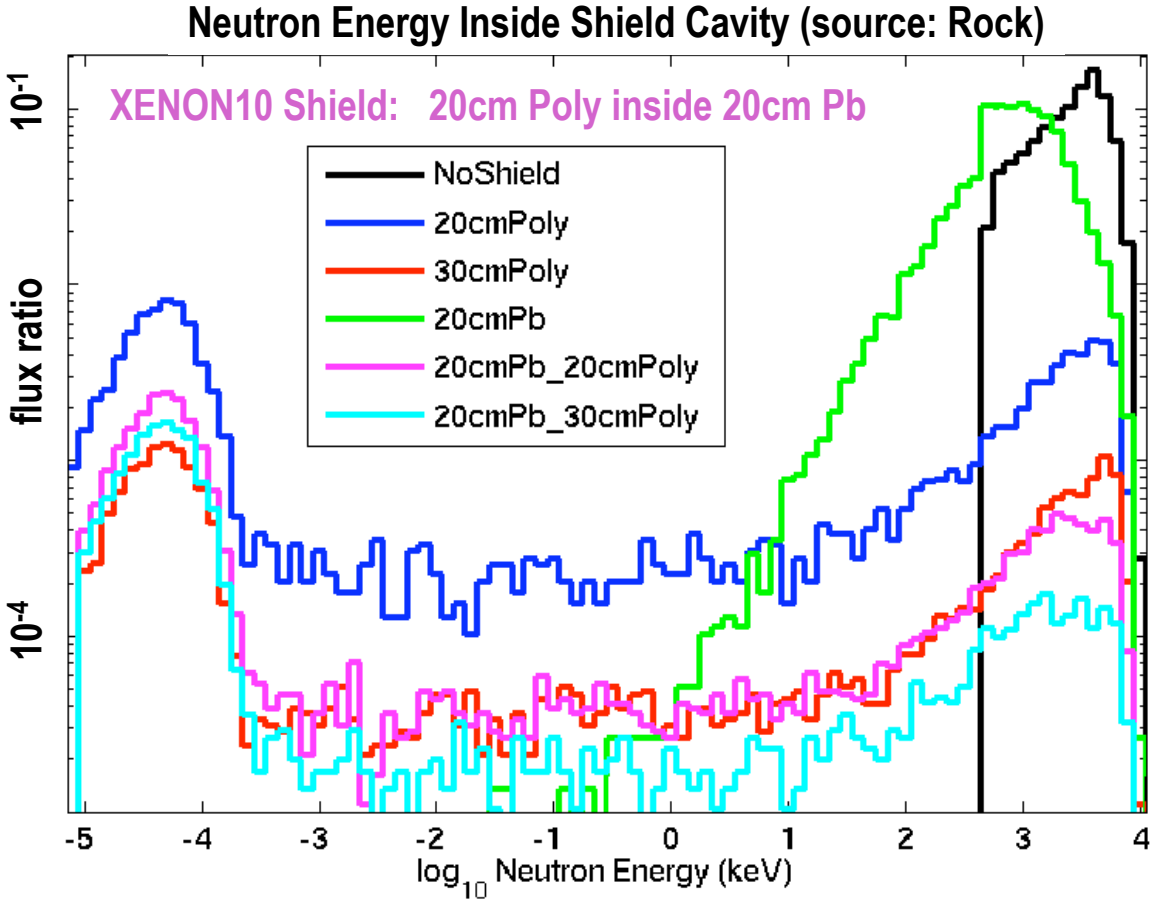


June 2006: shield under construction

XENON10 Background Flux MC



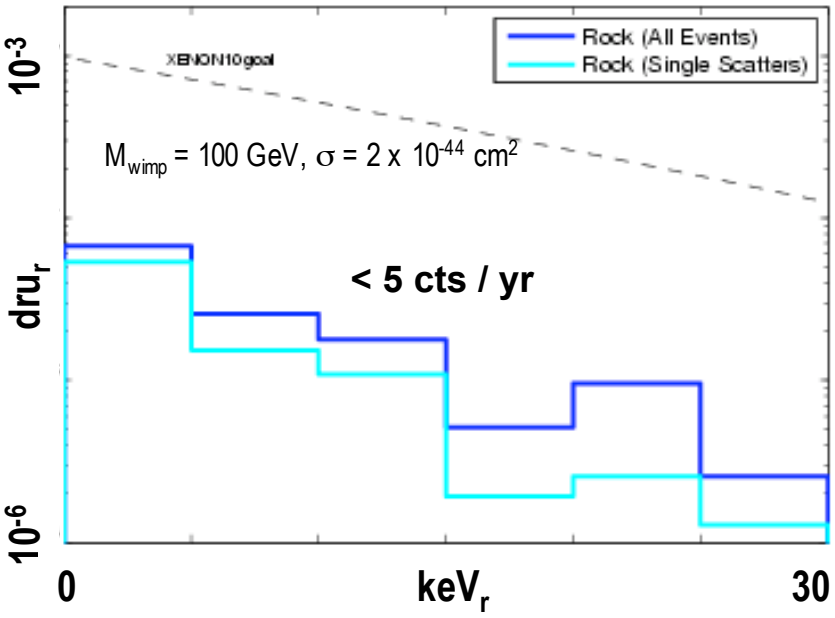




- Gamma Flux reduced by > 10^5 (top left)
- Neutron Energy Spectrum used for MC sim. (bot. left)
- Neutron Flux reduced by > 10^2 (above)
- Event Rate in XENON10…

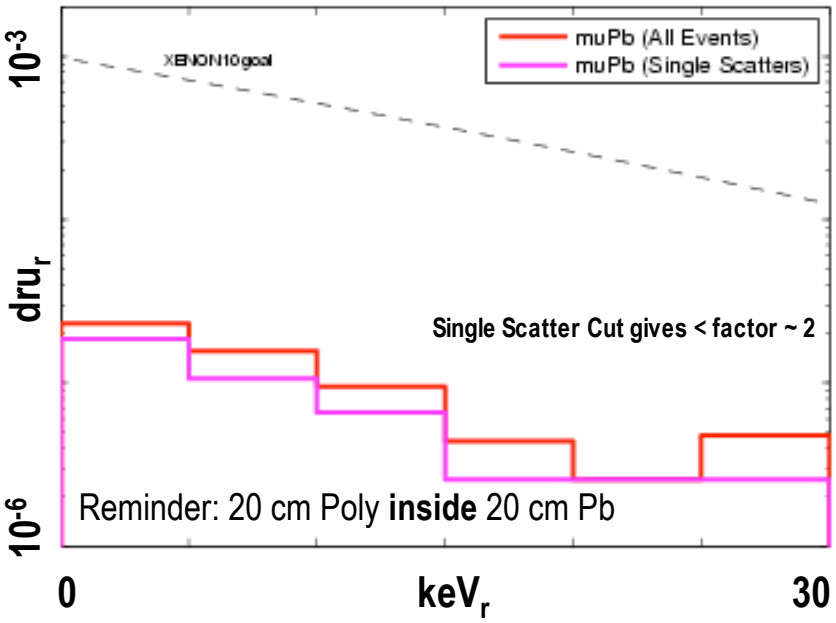
XENON10 Neutron Background: Rate Below Goal

NR Event Rate from Rock (α,n) & fission



Assuming flux from Cavern Rock ~ 2x10^{-6} n/cm^2/s

NR Event Rate from Muons on Pb



n Yield in Pb = 4e-3 neutrons / (muon*g*cm^{-2})
(in Poly ~ 18x < Pb (ρ ~ 12x less) so **x200/cm** lower)

other neutron sources

Internal n Sources:

- (α,n) from PMTs calculated. Assuming 20 mBq U/Th tubes & dominant contribution from silica ~0.05 n / 10^6 alphas: ~ 0.2 n / yr / PMT
- ^{238}U fission (5x10^{-7} BR) : ~ 7.2 MeV prompt γ's

Punch-Through n:

- **RAW** rate ~ x60 below goal

(~ 10^3 < raw rate from radioactivity in rock, see also Carson et. al. 2004)

- shield < 20% effective; depth is best solution
- Homestake (4300 mwe) ~ x300 below goal

XENON10 EM Background: MC Summary

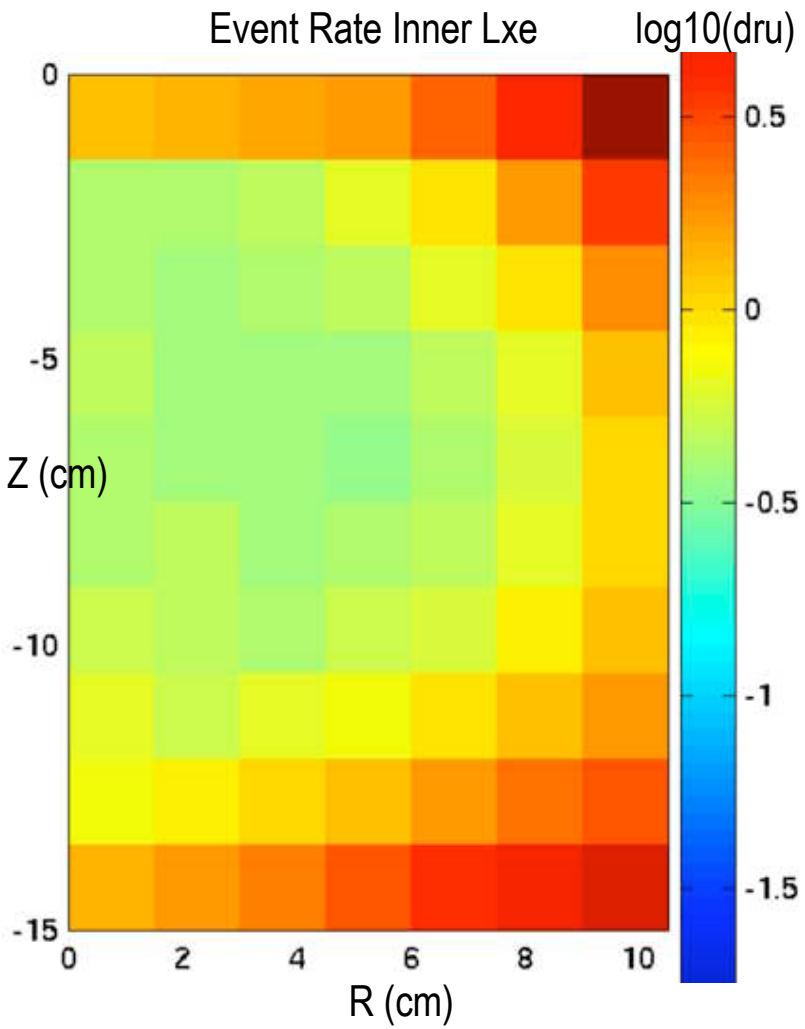
- Gamma Background Event Rates (8< E < 32 keVee) for XENON10
- Goal: 140 mdruee (gammas) before electron recoil rejection (x200) -- This was based on less PMTs. 89 PMTs => must modify BG Evt. Rate Goal

Source	Inner Event Rate [mdruee] 2 cm Fid. Cut	Radio-Impurities [mBq/kg] ^{238}U / ^{232}Th / ^{40}K / ^{60}Co
89 Inner PMTs	400	17.2 / 3.5 / 12.7 / 3.9
HV Shaping Ring Resistors	1.6	
SS Inner Cryostat	120 **	21 / 61 / 12 / 101
SS Outer Cryostat	50 **	21 / 61 / 12 / 25
Polyethylene Shield	< 9	
External/Pb shield Gammas	< 5	
Teflon Walls	< 1	0.4 / 0.2 / 40 / 0
^{85}Kr (< 0.1 ppb)	< 6	
^{210}Pb Brem.	< 10	[25 Bq/kg ^{210}Pb]
Tritium	(removed by gas purification)	
Total	~ 600 mdru	

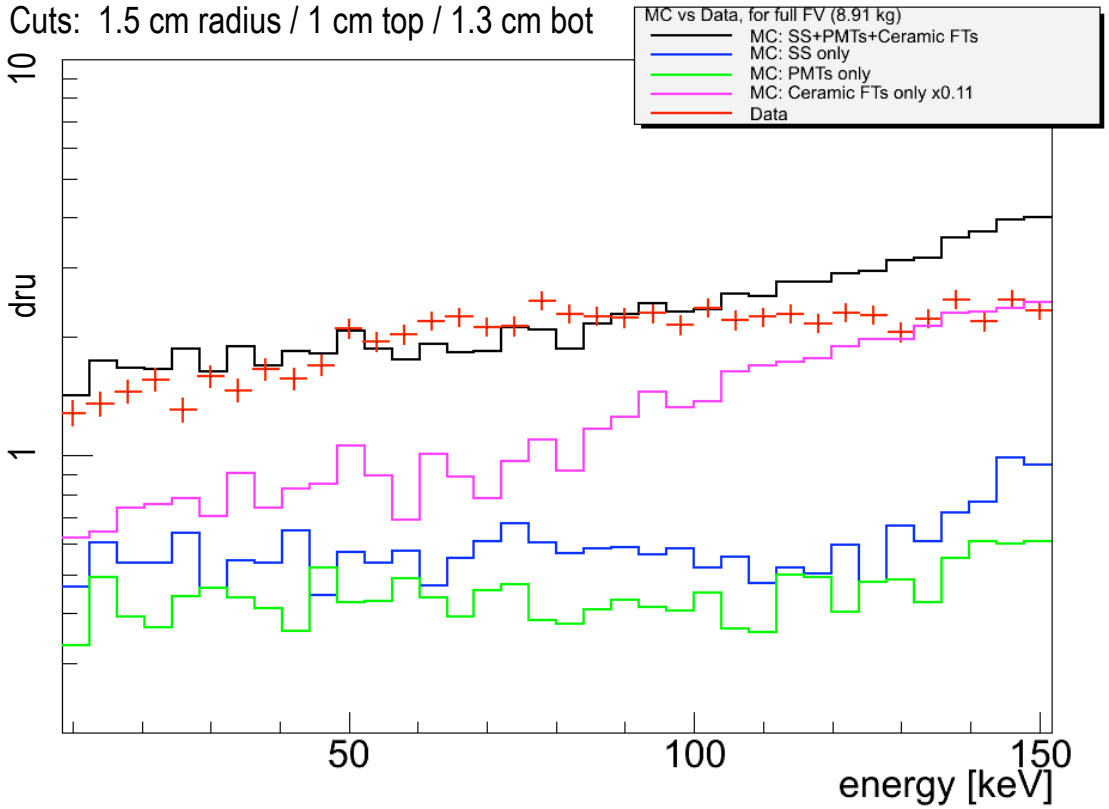
mdruee = 10^{-3} evts/keVee/kg/day

** approximate based on counting 2 ss samples

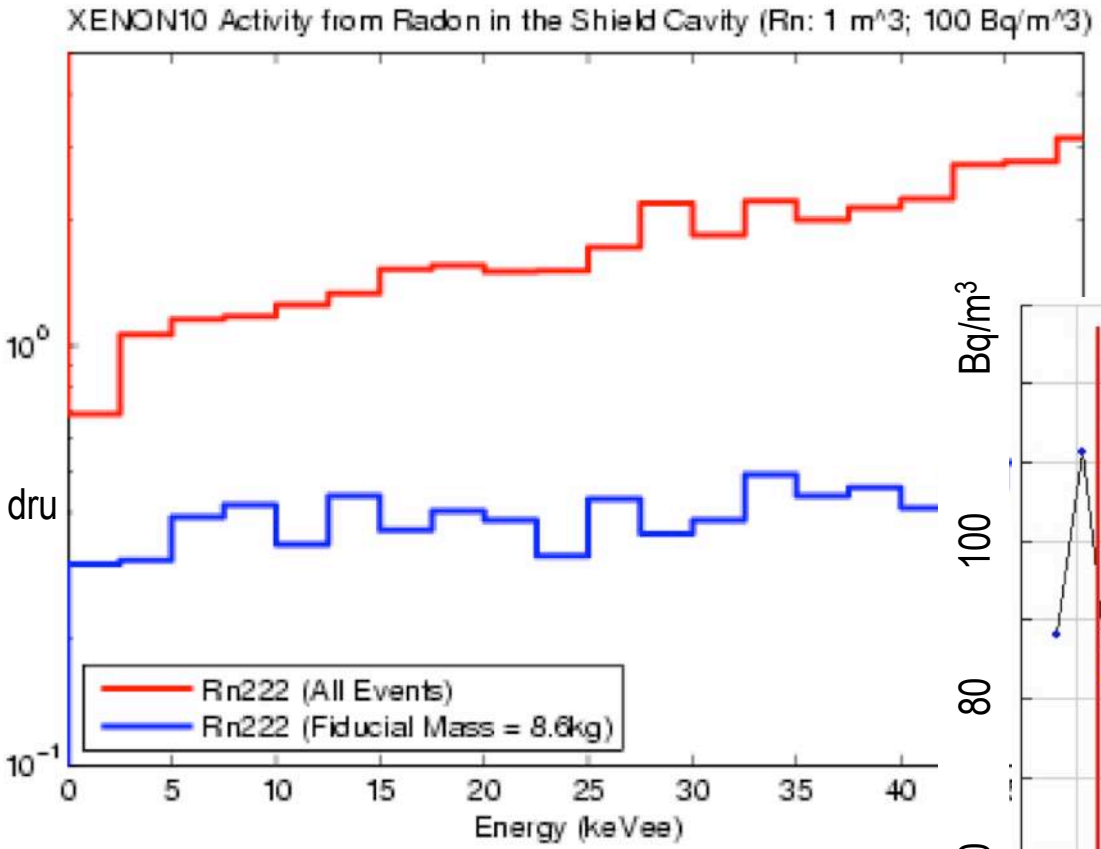
XENON10 EM Background : Event Rate Fiducial LXe



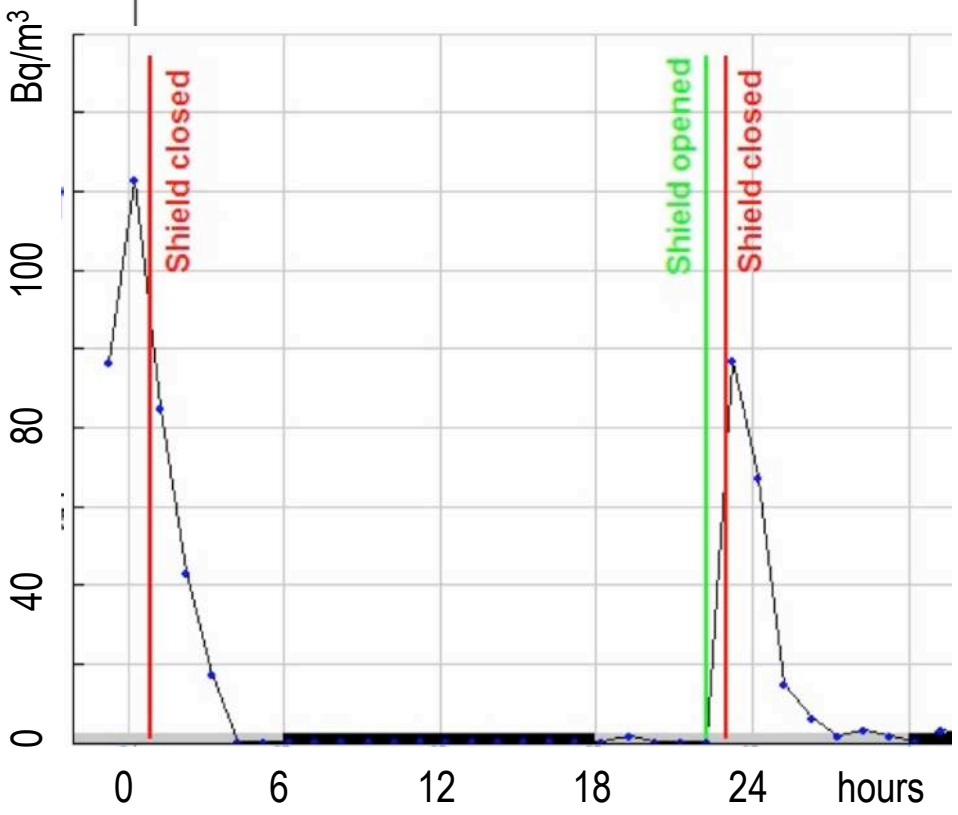
(left) M.C. of Event Rate with Position
(below) Comparison: M.C. (black line) & data (red cross)



XENON10 EM Background: ^{222}Rn



Effect of Radon Purge:



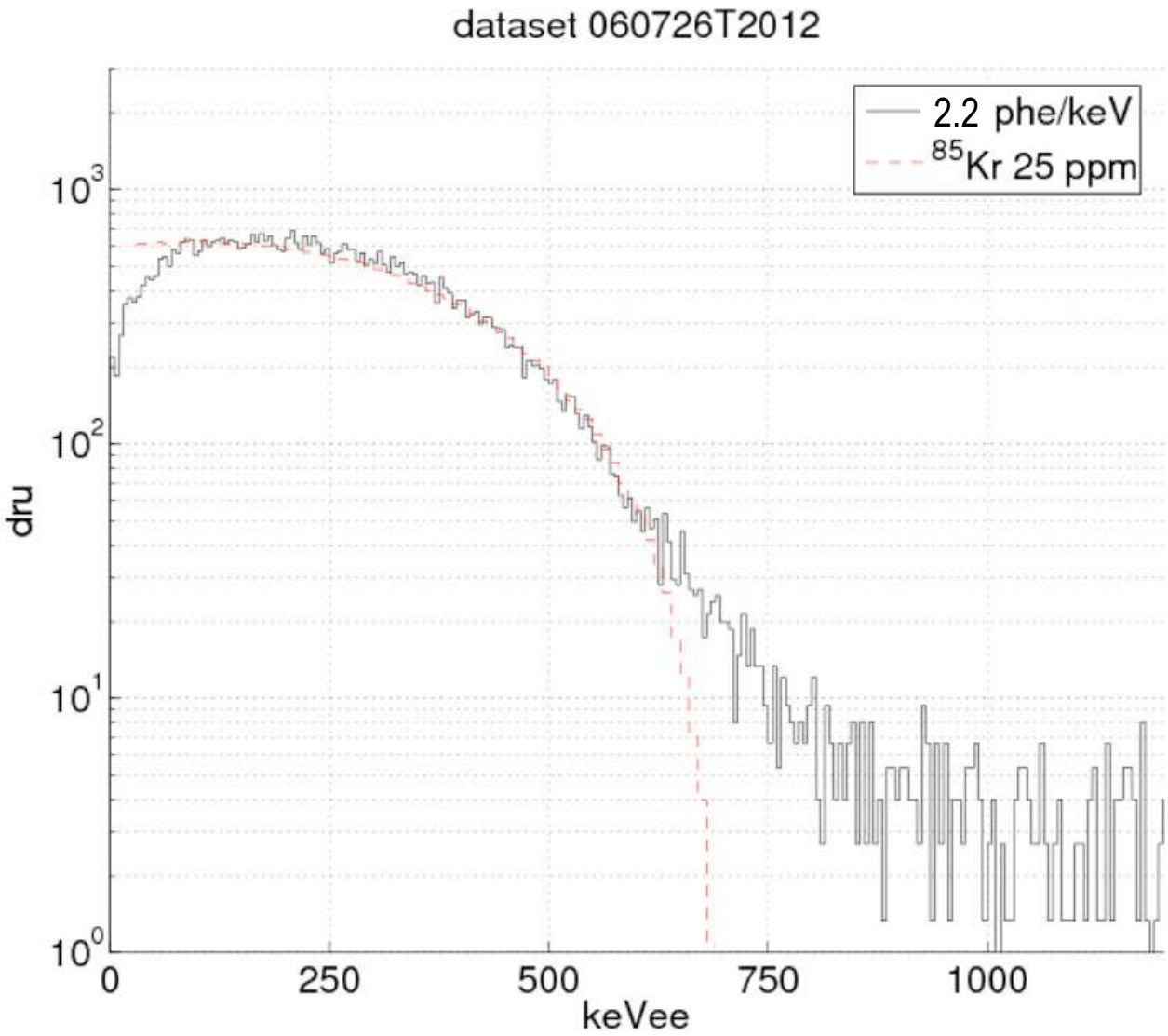
- Note: activity from ^{210}Pb (25 Bq/kg) is ~ x2 lower than 100 Bq/m^3 ^{222}Rn

XENON10 Internal Background: ^{85}Kr

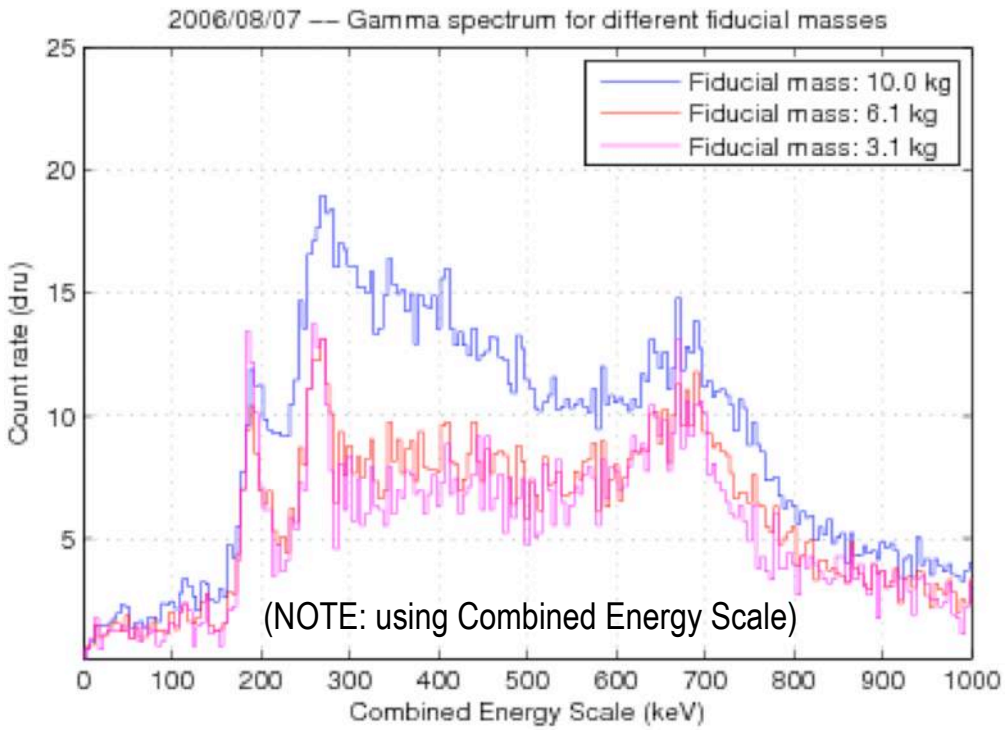
First dataset in shield: before switching to low-^{85}Kr Xenon!

Estimation of ppm from observed dru:

- Expect ~ 0.18 Bq / kg / ppm
- Have 15 kg inner Lxe, so ~ 2.8 Hz / ppm
- Global Trigger Rate was 115 Hz (estimate 65% ^{85}Kr triggers)



XENON10 Gamma Lines from Activation

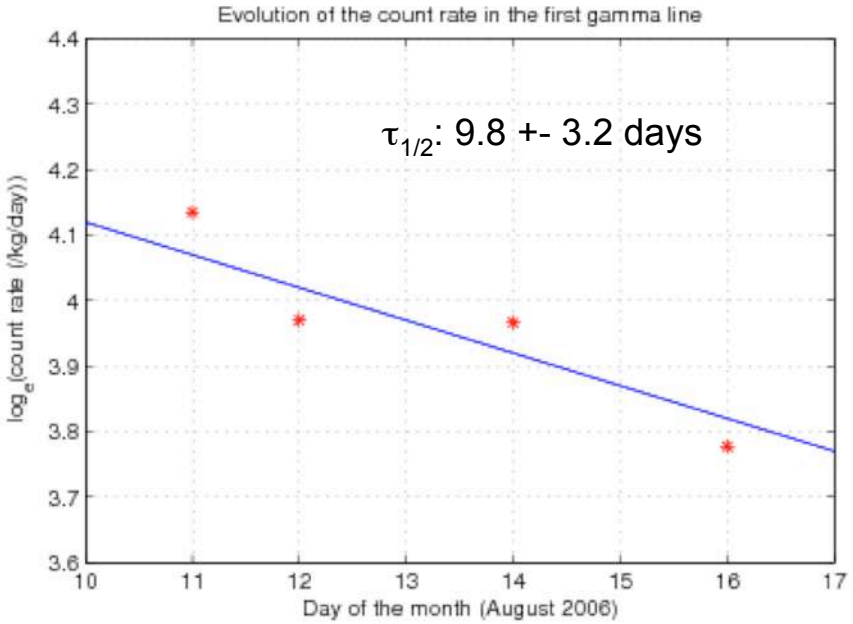


Background Data: Lines (!?)

- Energies: 188, 267 (narrow) and 672 keV (wide)
- Previous results show higher light yield for low-E γ's (Yamashita et al, NIM A 535 (2004) 692)

Within 14% on E-Calib. Compatible with activation of Xenon (Cosmics during flight and/or thermal neutrons -- still studying). Expected lines:

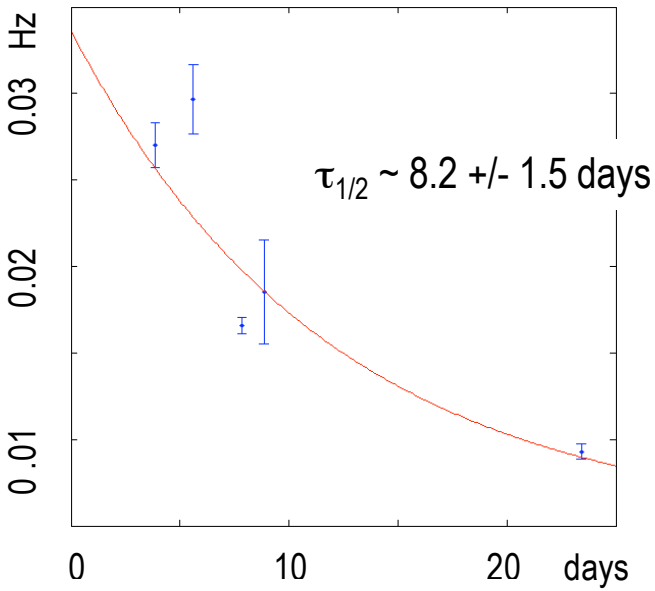
- 164 keV from ^{131}Xe ($\tau_{1/2}$ =12 days)
- 237 keV from ^{129}Xe ($\tau_{1/2}$ = 9 days)

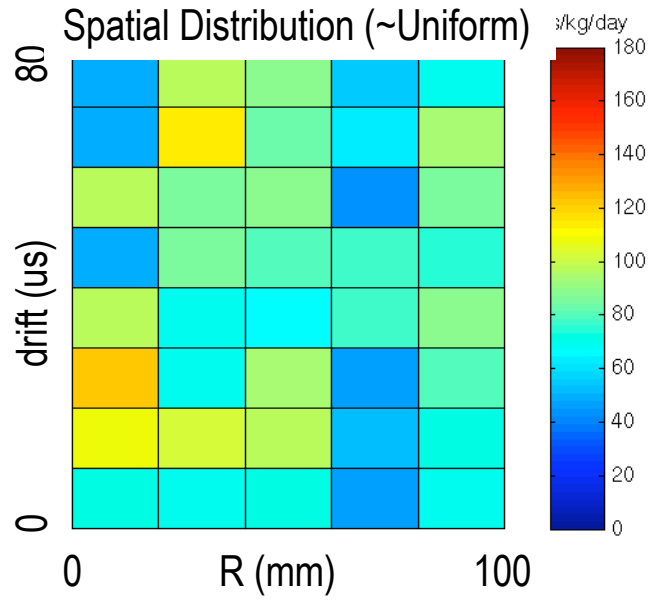


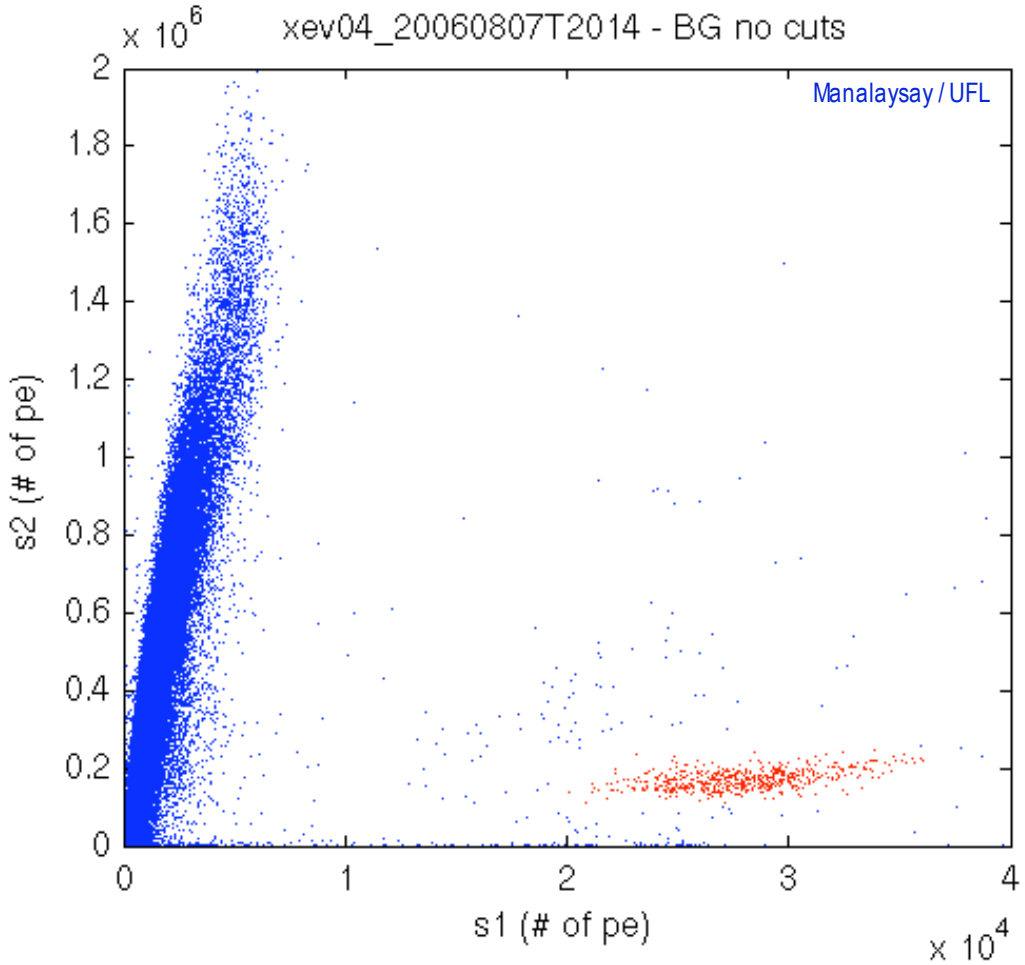
Further study using the first line only, because high-energy veto in place > 200 keV to reduce trigger rate

- Homogeneous rate in all the volume of the detector
- Rate decreases with a half-life compatible with 12 days

XENON10 Alpha Background: ~ 0.01 Hz



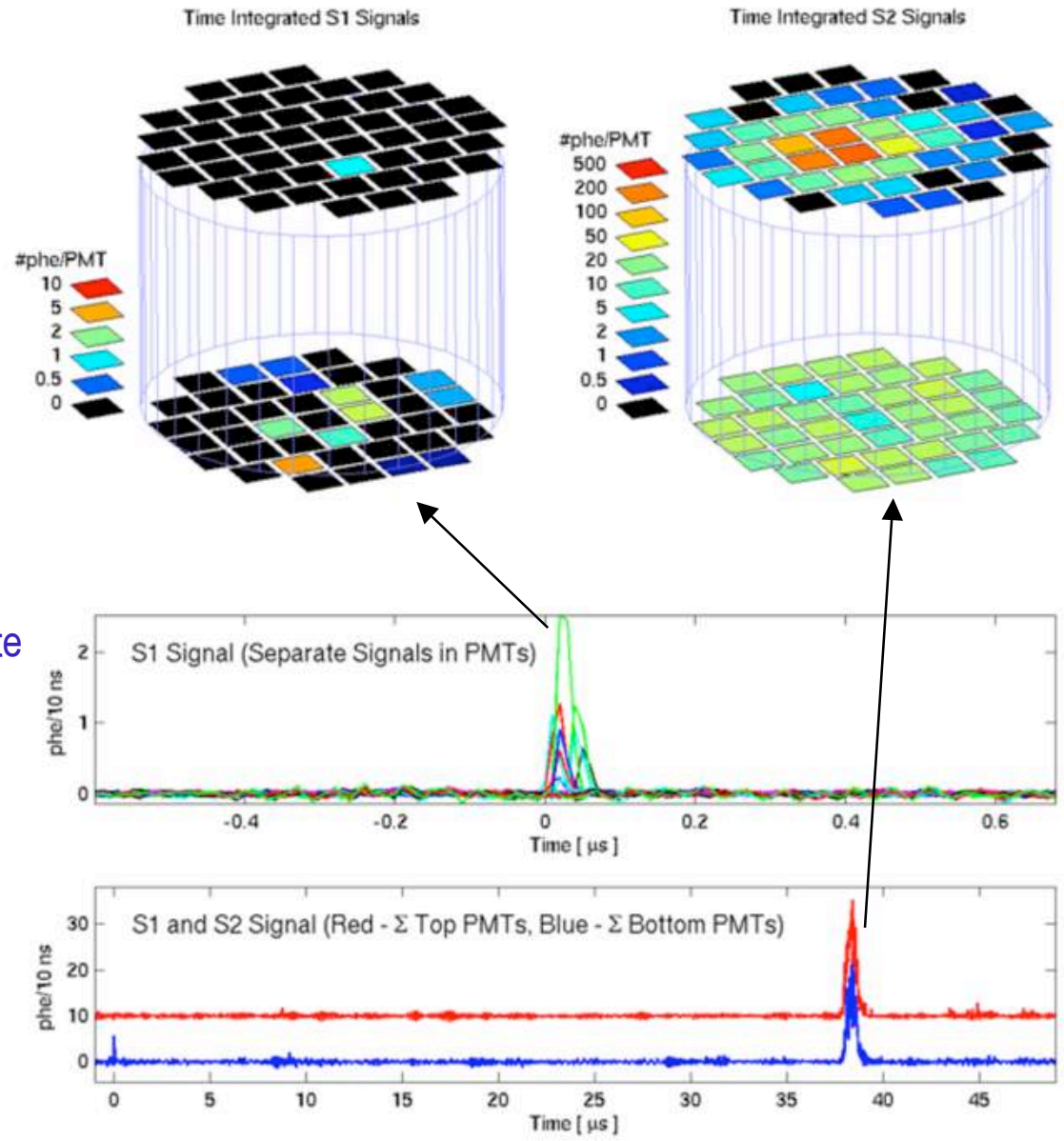




- (Above) Alpha's Easily Distinguishable from s2 v s1 (also E)
- (Top Left) Alpha Rate in fiducial volume in early August
  (don't yet know if rate is decreasing further)
- (Bot. Left) Event Rate ~ uniform in bulk

XENON10 s1 Trigger & s2 "catch-all"

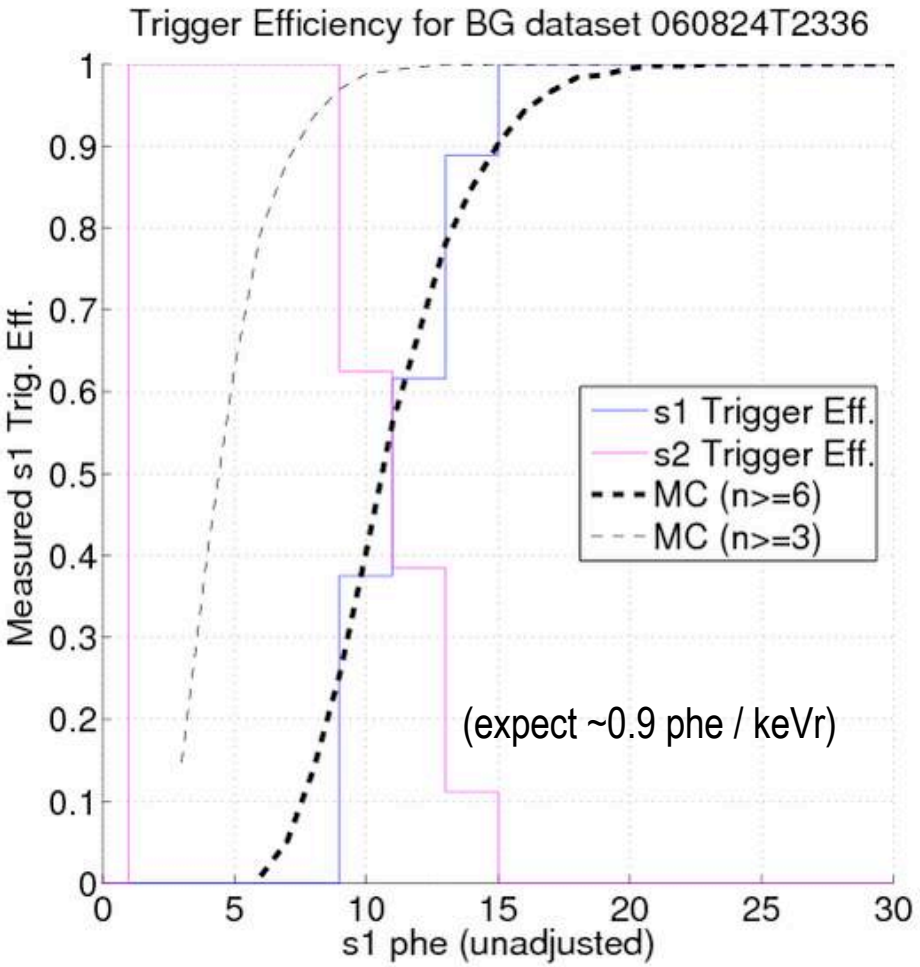
Example: Low Energy Compton Scatter
- S1=15.4 phe ~ 6 keVee
- Drift Time ~38 μs => 76 mm

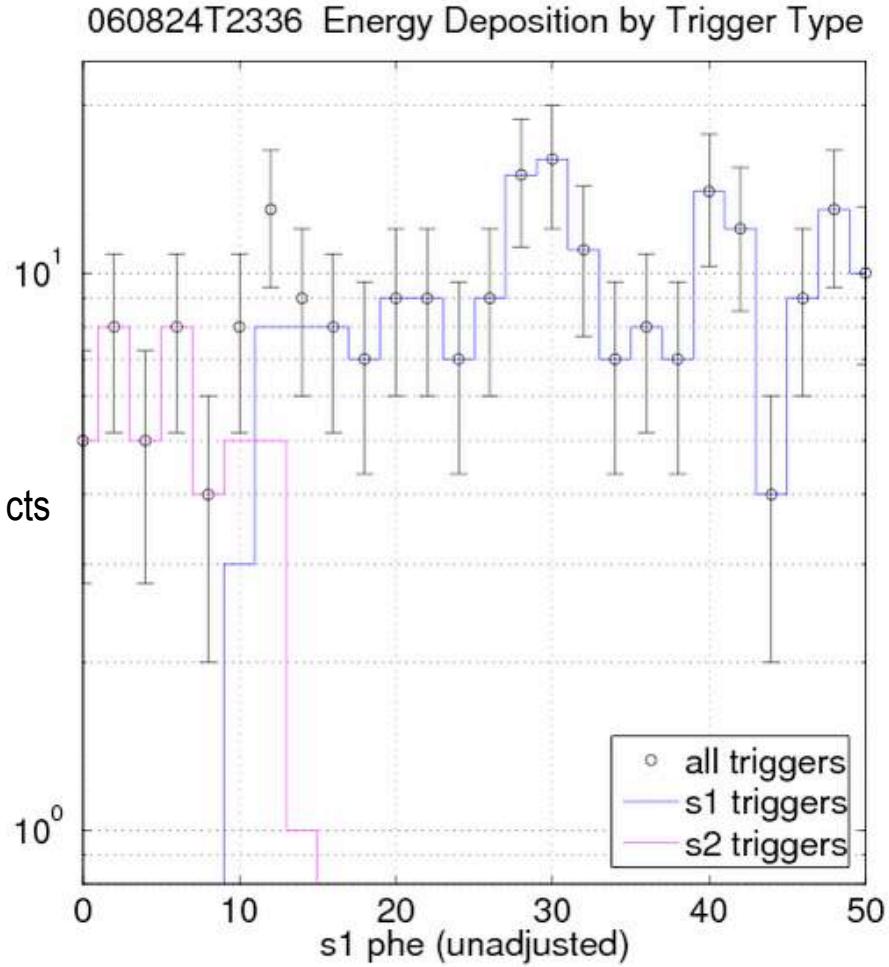


s1 Trigger (plan A):
- n>=6 on bottom PMT in 80 ns window
- Threshold set for each PMT based on Rate Sweep (~ 80% efficient)
- 41 bottom PMTs (~80% efficient)

s2 Trigger "catch-all":
- 1 μs RC of ∑34 Center-Top PMTs
- requires look-back for s1

XENON10 Trigger Efficiency

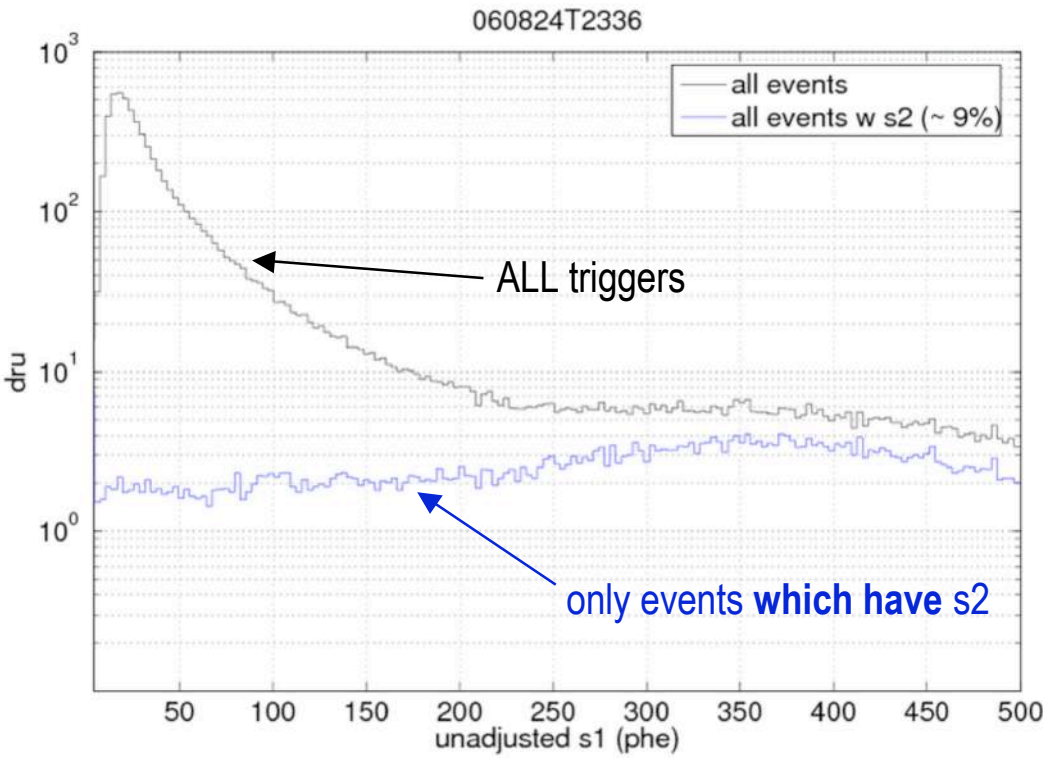


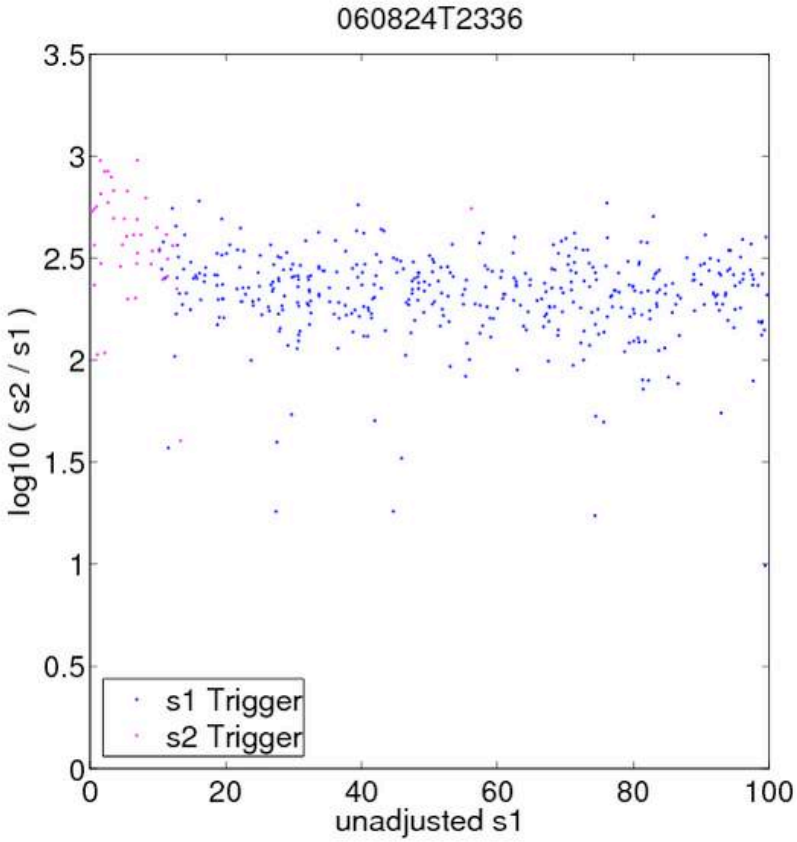


> 95% efficient @ 16 keVr (XENON10 Target Threshold)
~ 50% efficient @ 12 keVr

Plan to move to n>=3 Trigger…

XENON10 Trigger Rate



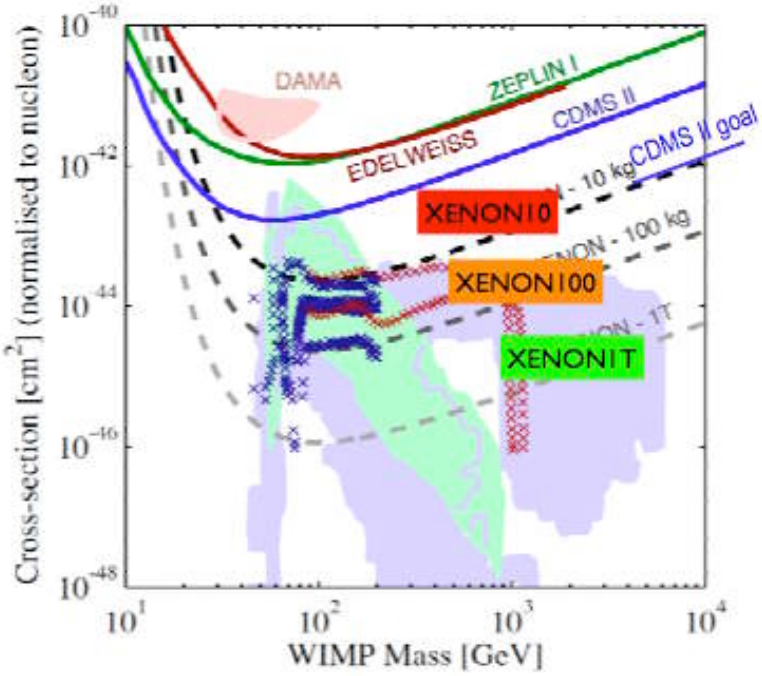


- Presently using n>=6 bc of high s1-only event rate.
- Easily Vetoed in DAQ, but for now want to keep all events (to fully understand & characterize detector)
- Principle Cause: "dead" LXe regions

- Gamma Band (same cuts as for Trig. Eff.)
- **Minimal Cuts Shown** : Leakage vanishes with Fiducial Cuts (by cutting Edge Events)

Conclusions

- XENON10 Running in Shield @ LNGS
  - Taking preliminary WIMP-Search Data
  - Imminent Neutron Calibration to establish NR band in s2/s1
  - Currently studying ER rejection performance (expect > 99% 10-40 keVr)



- Background Status
  - SS & PMTs give dominant γ contribution (~0.8 DRU in 6 kg FV)
  - (XENON10 built as proof-of-principle step toward larger instruments)
  - Shield contributions appear sub-dominant (as projected)
  - Studying contribution from other components - e.g. Feed-throughs
  - ^{85}Kr sub-dominant. Using Xe with ~ ppb Kr (CWRU Xe has achieved < 10 ppt Kr)
  - M.C.'s project background rate of neutrons ~ x10 below XENON10 Sensitivity Goal ($\sigma \sim 2 \times 10^{-44}$ cm^2)

- Trigger: presently operating s1 n>=6 + s2 "catch-all"
  - s1 > 95% efficient @ 16 keVr
  - studying s2 trigger threshold
  - Overall: expect to achieve > 95 % Efficient @ 10 keVr