First Results from the XENON10 Dark Matter Search at Gran Sasso

Xe
XENON
Dark Matter Project

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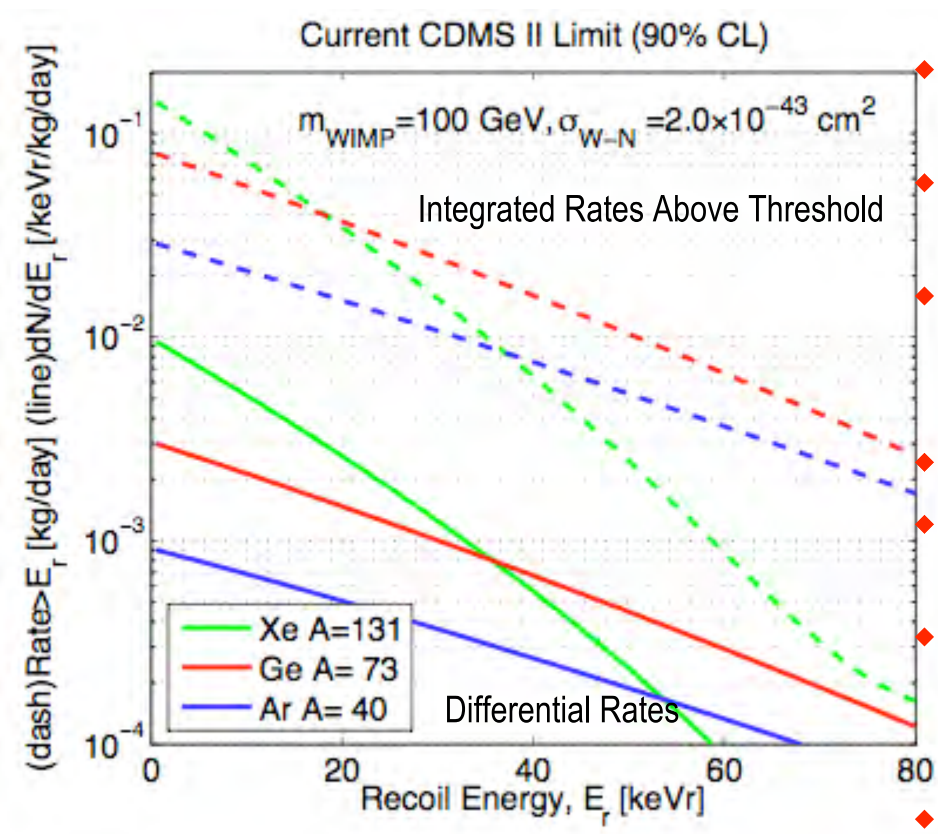
Why Liquid Xenon for Dark Matter Direct Detection



- Large A (~ 131): the best for SI ($\sigma \sim A^2$) if low NR threshold
- ~ 50% odd isotopes (^{129}Xe , ^{131}Xe) : very good for SD
- No long-lived radioisotopes. Kr85 to ppt level proven
- High stopping power for compact, self-shielding geometry
  - Fiducial Volume with very low activity
- 'Easy' cryogenics at -100 C
- Efficient scintillator (80% of NaI) with fast time response
- Nuclear vs Electron Recoil Discrimination:
  - Ionization/Scintillation Ratio
  - 3D Event Imaging in a TPC
- High Purity (<< 1ppb) for TPC Operation achieved
- Availability and Cost allow to reach the goal of a very large fiducial mass detector as required to reach $\sigma \sim 10^{-46}$ cm^2 or 1 event/100 kg/year

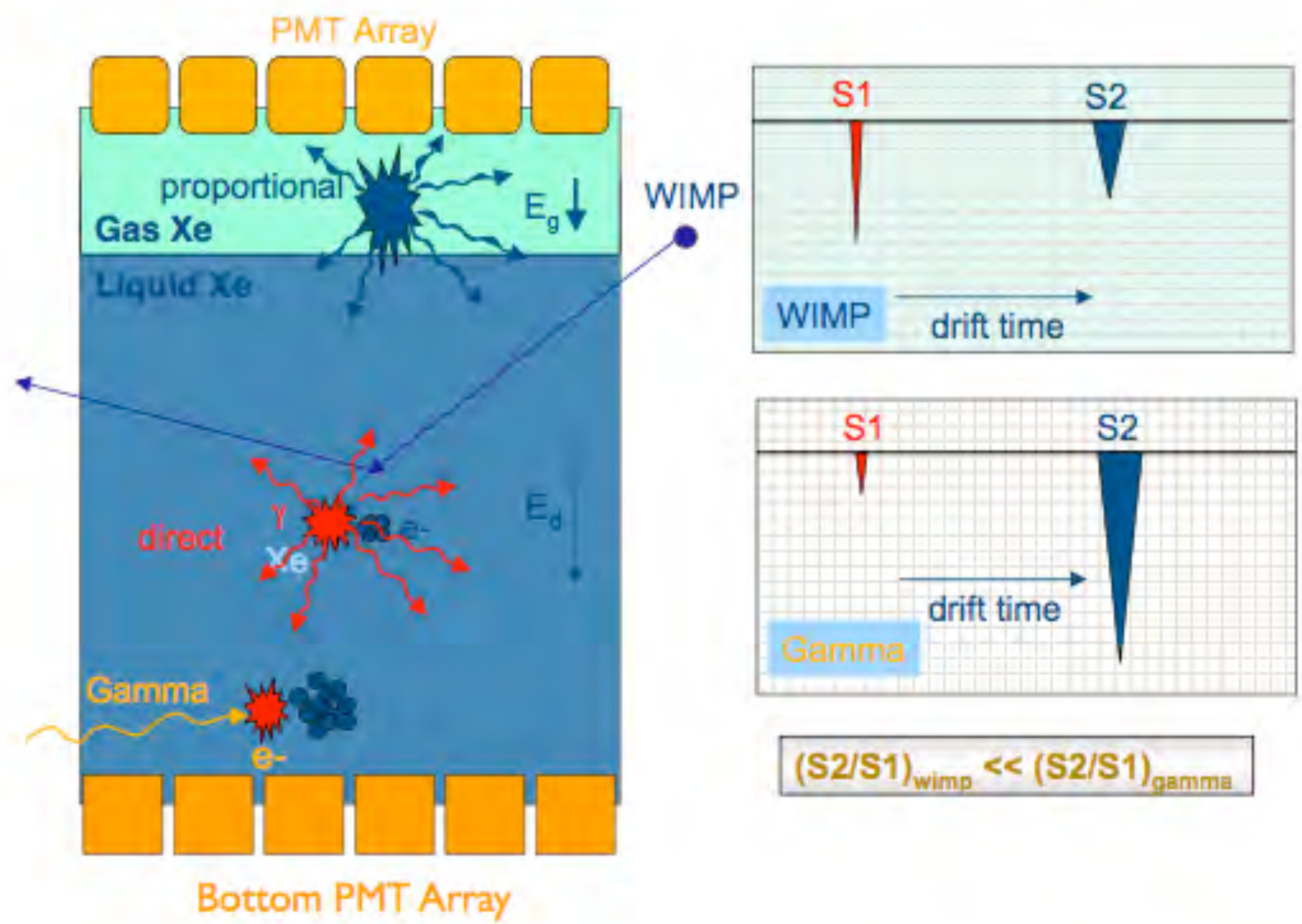
The XENON Project: Overview and Goals

- R&D for XENON was approved by NSF in 2002. The proposed experiment is to detect Galactic WIMPS through their interactions with Xe nuclei in a 1-ton scale liquid xenon detector (XENON1T) placed deep underground, with a sensitivity to spin independent WIMP-nucleon $\sigma \sim 10^{-46}$ cm^2
- The liquid target is distributed in 10 identical modules (XENON100), each a dual phase (liquid/gas) TPC with 100 kg active mass. Event-by-event discrimination (>99.5%) is provided by the simultaneous measurement of ionization and scintillation in the liquid, down to a threshold of 16 keVr. 3D event localization and appropriate γ and n-shielding are used to further reduce the background.
- Performance/ capabilities of dual phase TPC established with prototypes of ~ kg scale. A 15 kg detector (XENON10) was developed and installed underground at the LNGS in early 2006. Physics program started Sep 2006.
- Primary goal of the XENON10 experiment was to validate the low energy threshold and background rejection of the proposed concept, paving the way to the XENON100 module. Current plan is to have a 100kg LXe dark matter experiment taking data in 2009.

XENON is supported by NSF and DOE.

The XENON Detector Concept

A two-phase Time Projection Chamber with 3-D Event Imaging



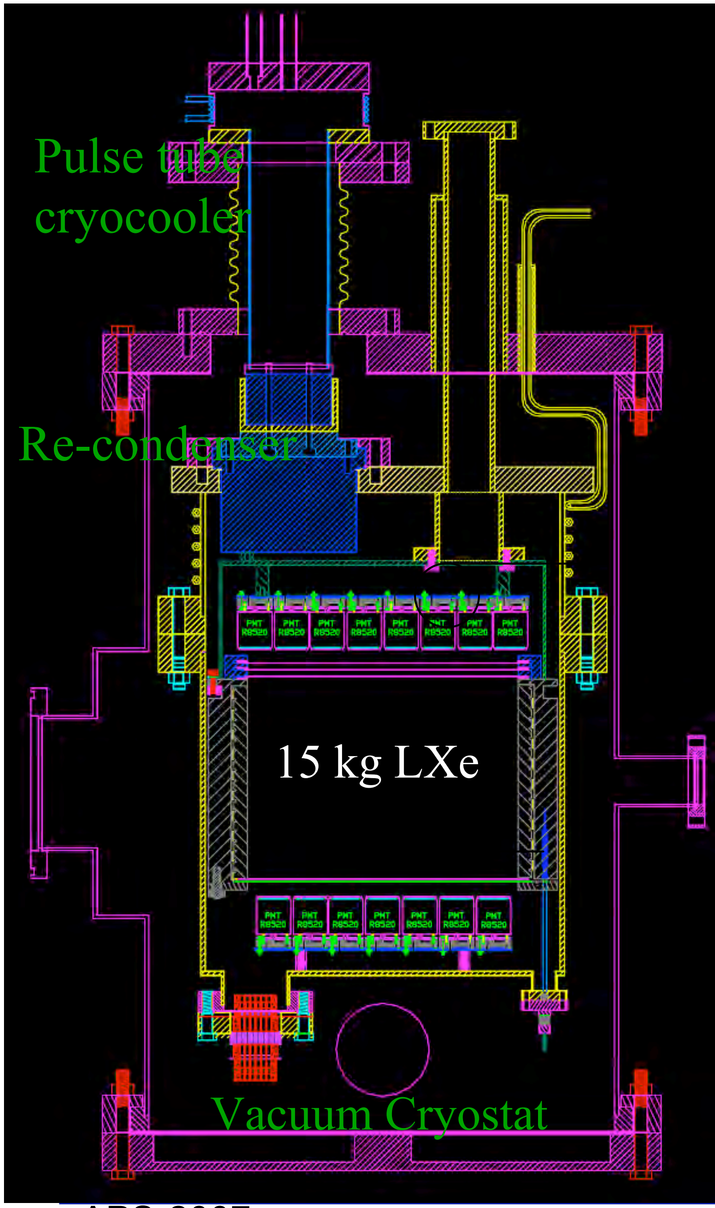
event-by-event discrimination (>99.5%) against dominant background (γ,e,α) by:

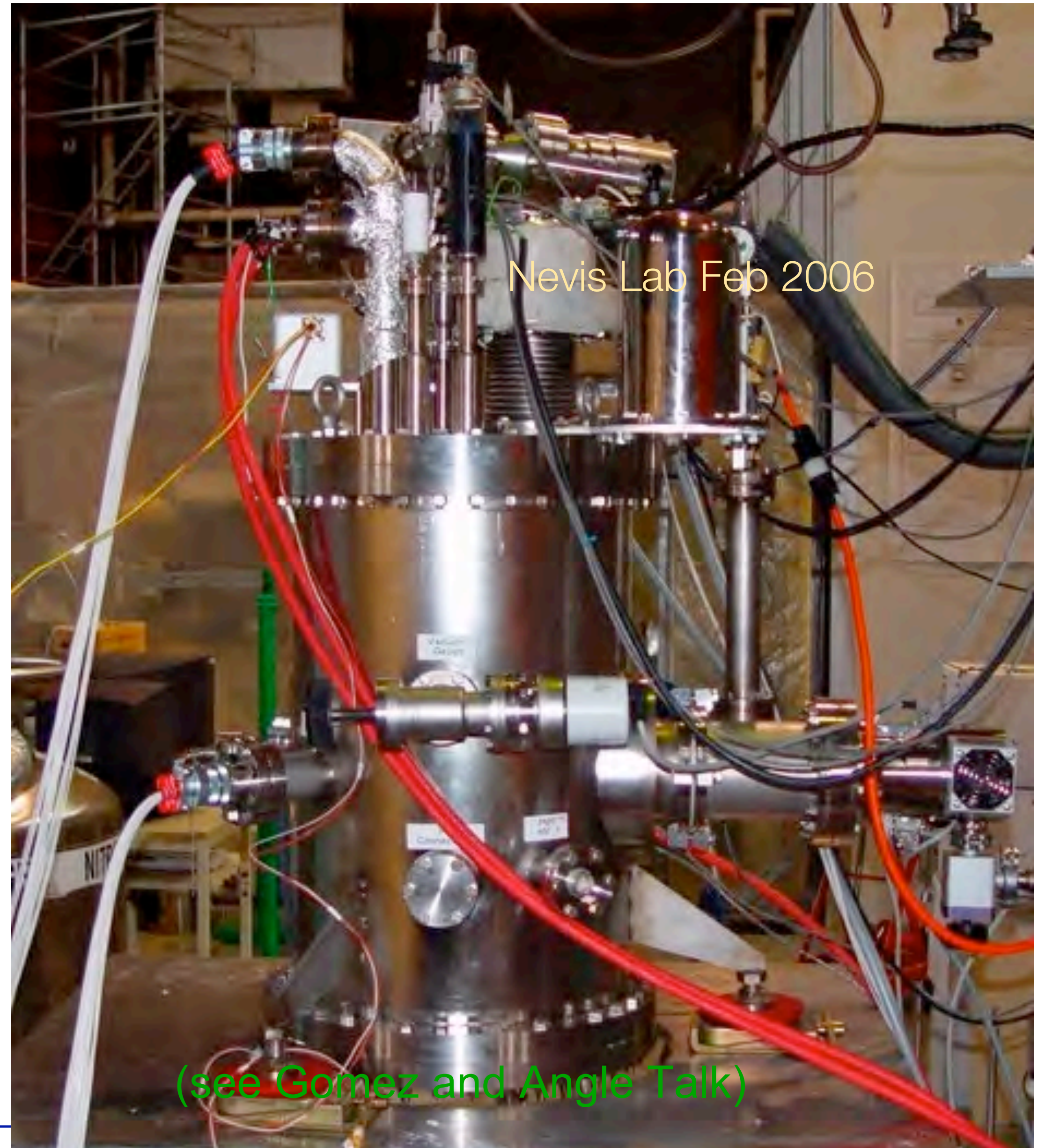
- Simultaneous Detection of scintillation (S1) and ionization (S2)
- 3D Event Localization

XENON10 Development: a very fast Timeline

- **December 05 - February 06**: detector assembled at Columbia Nevis Laboratory
- **March 2006**: XENON10 moved to LNGS and commissioned underground
- **April-July 2006**: test/optimize detector response with gamma sources
- **December 05 - July 06**: design/build Pb+Poly shield structure underground
- **July-August 2006**: commission XENON10 into shielded configuration
- **August 24, 2006 – Feb 14, 2007**: WIMP search runs plus periodic gamma calib
- **December 1, 2006**: in situ neutron calibration with AmBe source

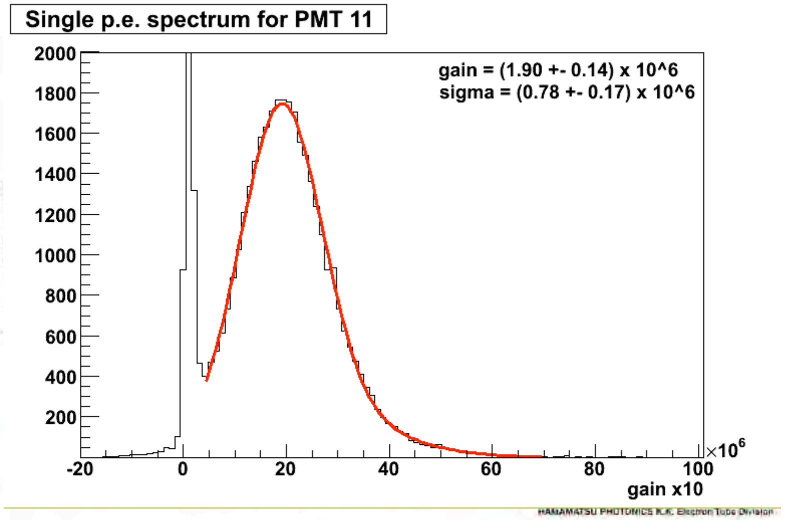
The XENON10 Detector



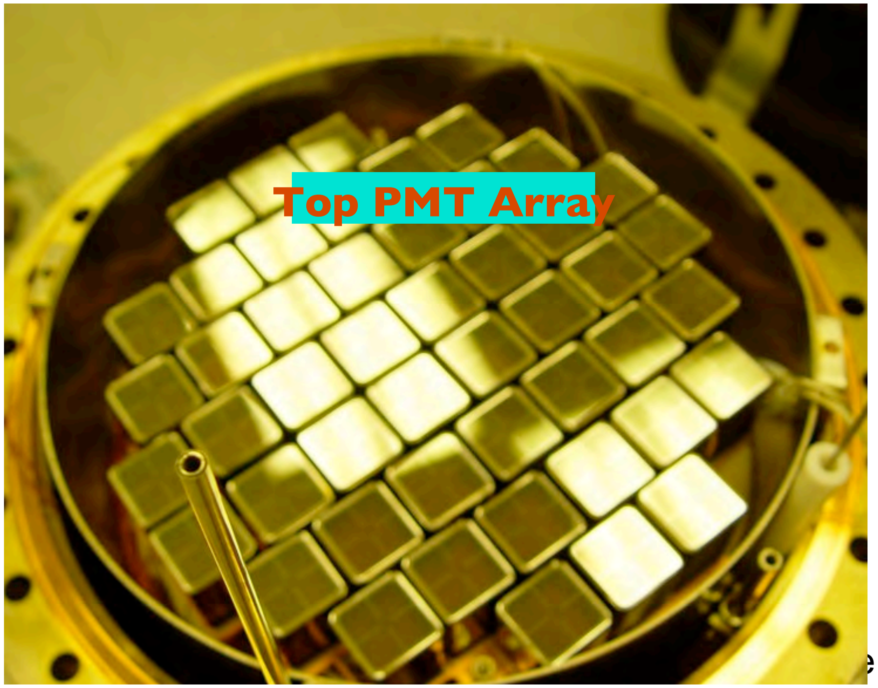


The XENON10 Photomultipliers

- **Hamamatsu R8520 1’’×3.5 cm**
- bialkali-photocathode Rb-Cs-Sb,
- Metal Channel; 10 dynodes
- Quartz window; at -100ºC and 5 bar



- Low Radioactivity: U/Th/K/Co measured as 0.17±0.04/0.20±0.09/10±1/0.56±0.05 mBq/PMT
- Quantum efficiency > 20% @ 178 nm



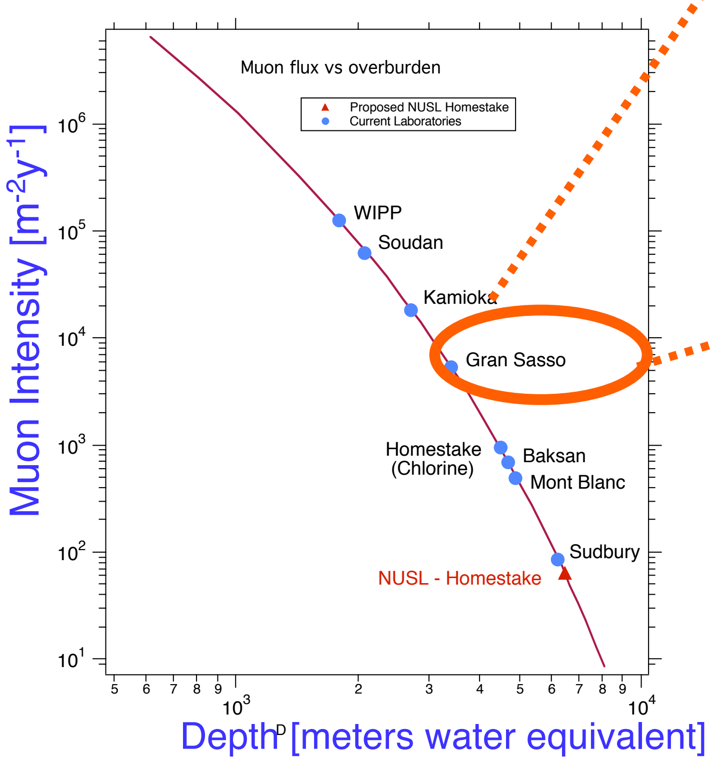
XENON10 at the Gran

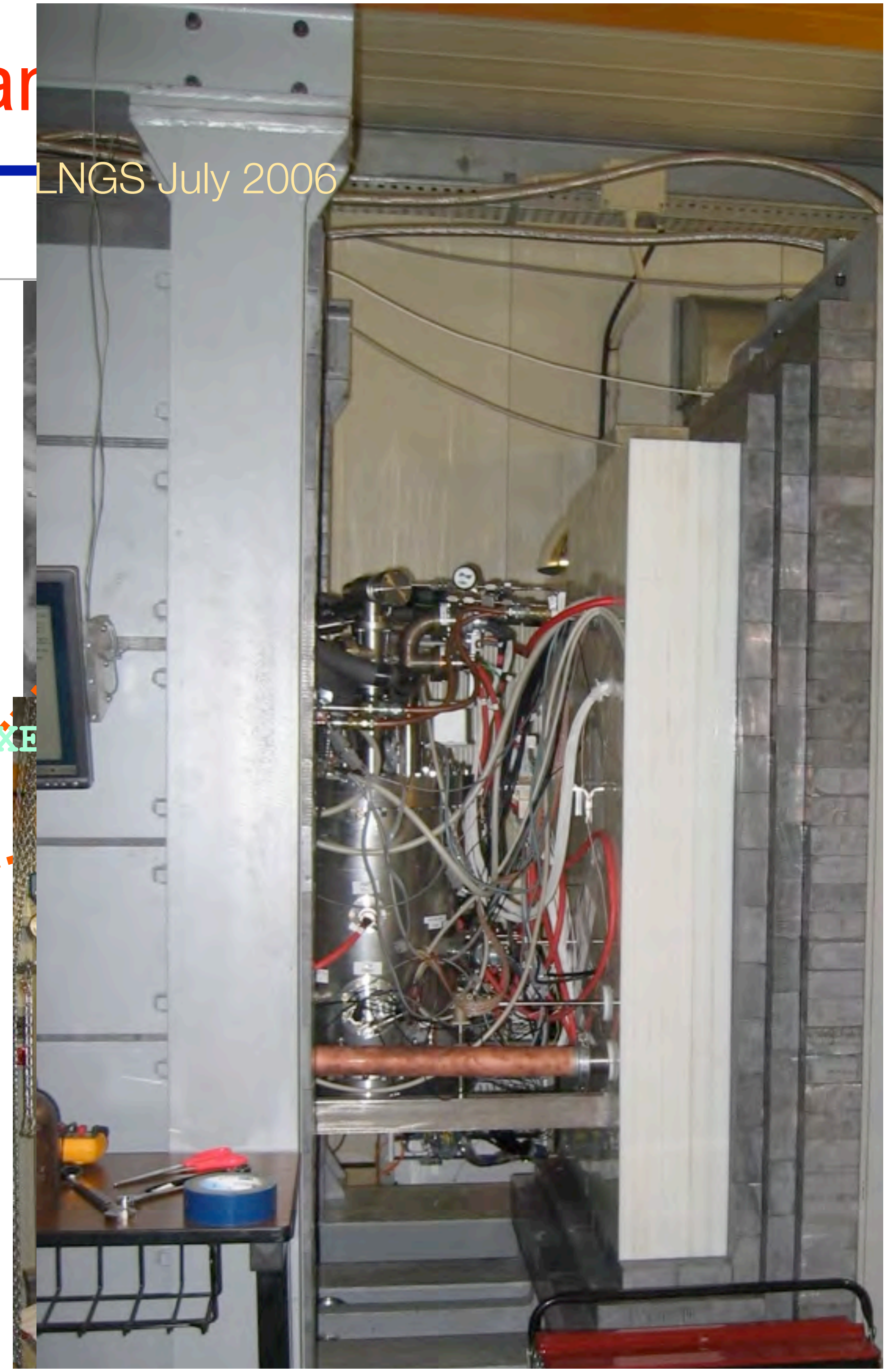
~3600 m.w.e; muon flux ≈ 1 m^{-2} h^{-1}

Shielding from γ and n backgrounds:

20 cm inner Poly and 20 cm outer Pb

No muon veto required





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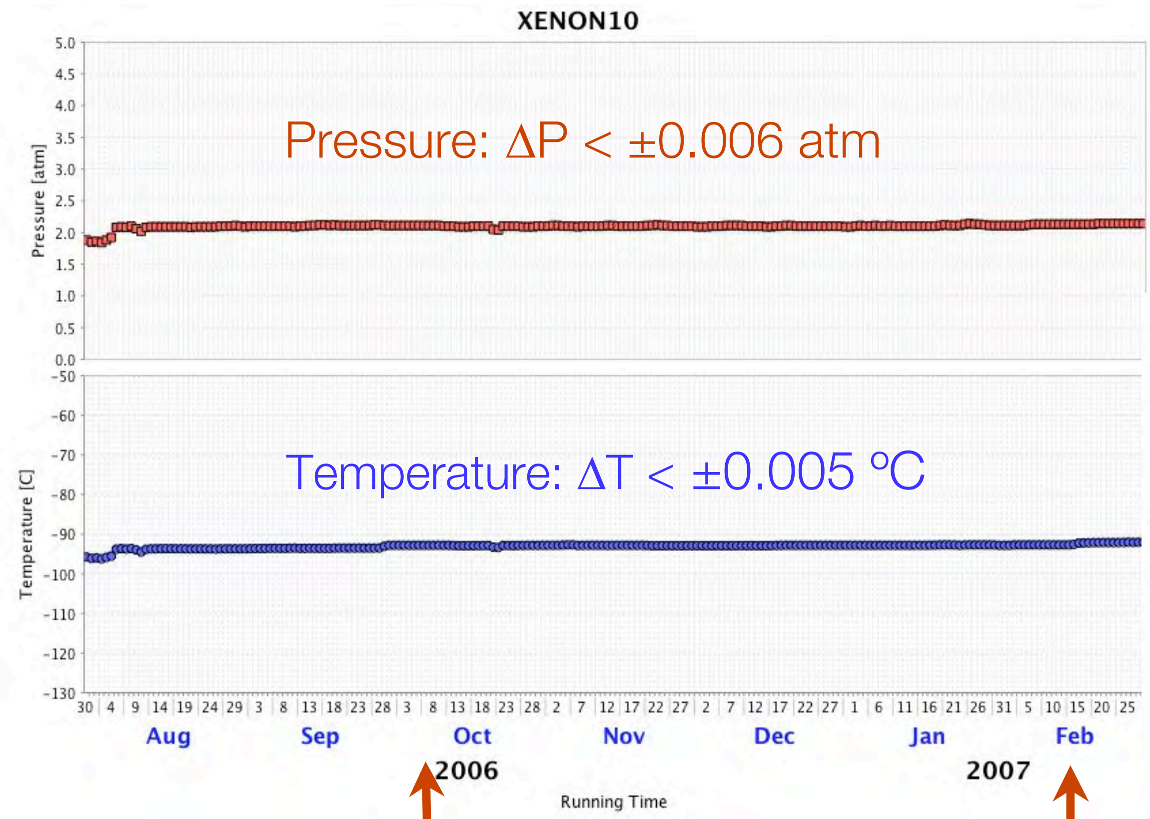
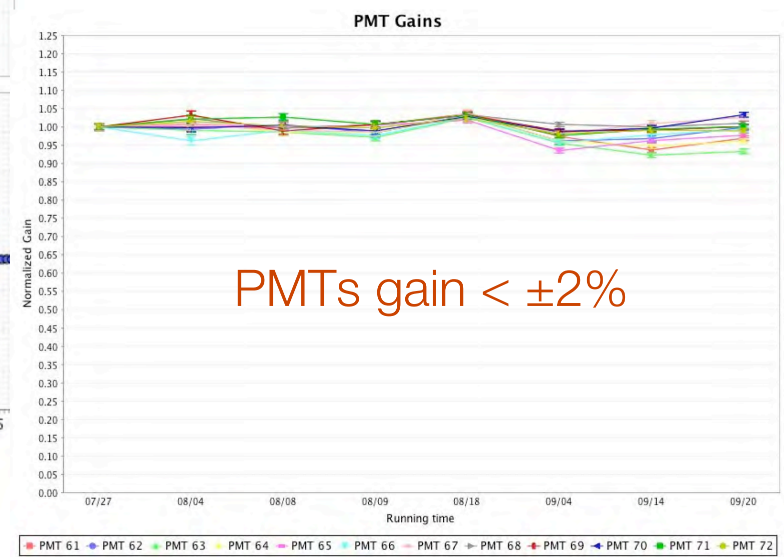
XENON10 Underground: Stability of Running

Detector operation and performance shows excellent stability over 9 months

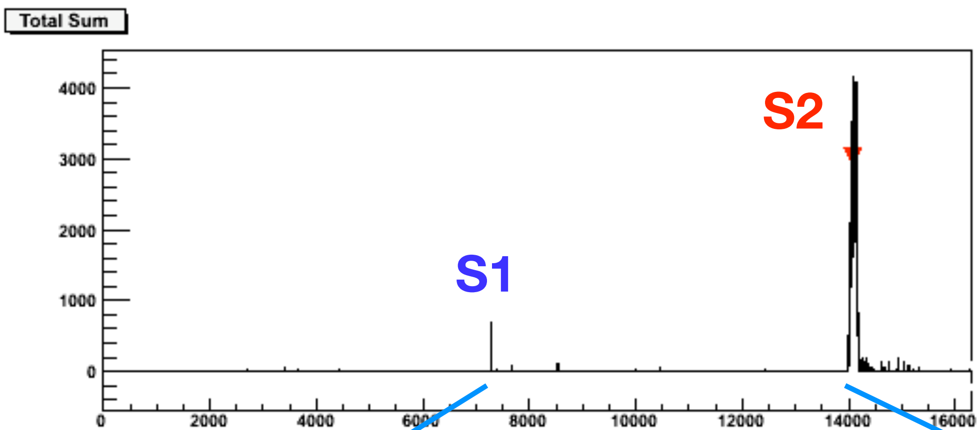




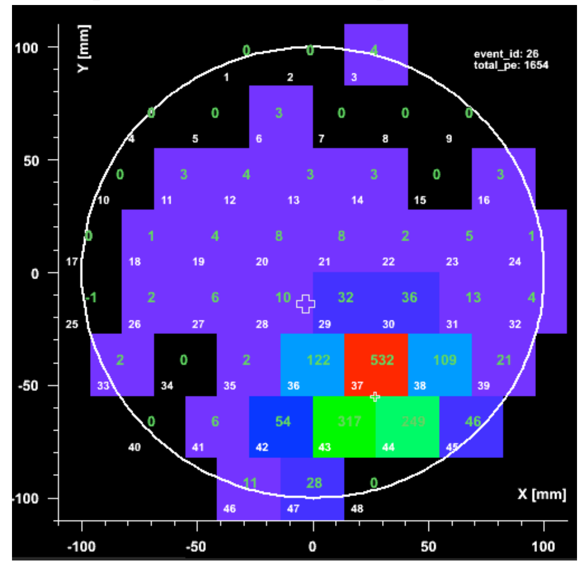
Start of Blind WIMP Search **End of Blind WIMP Search**

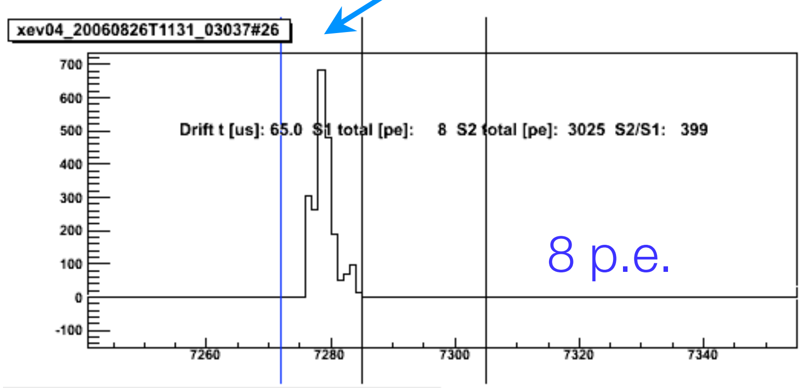
Typical XENON10 Low-Energy Event

4 keV_{ee} event; **S1: 8 p.e => 2 p.e./keV**

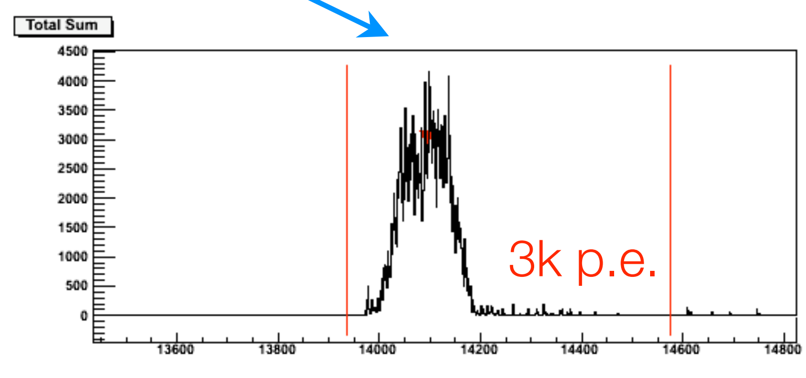


Hit pattern of top PMTs



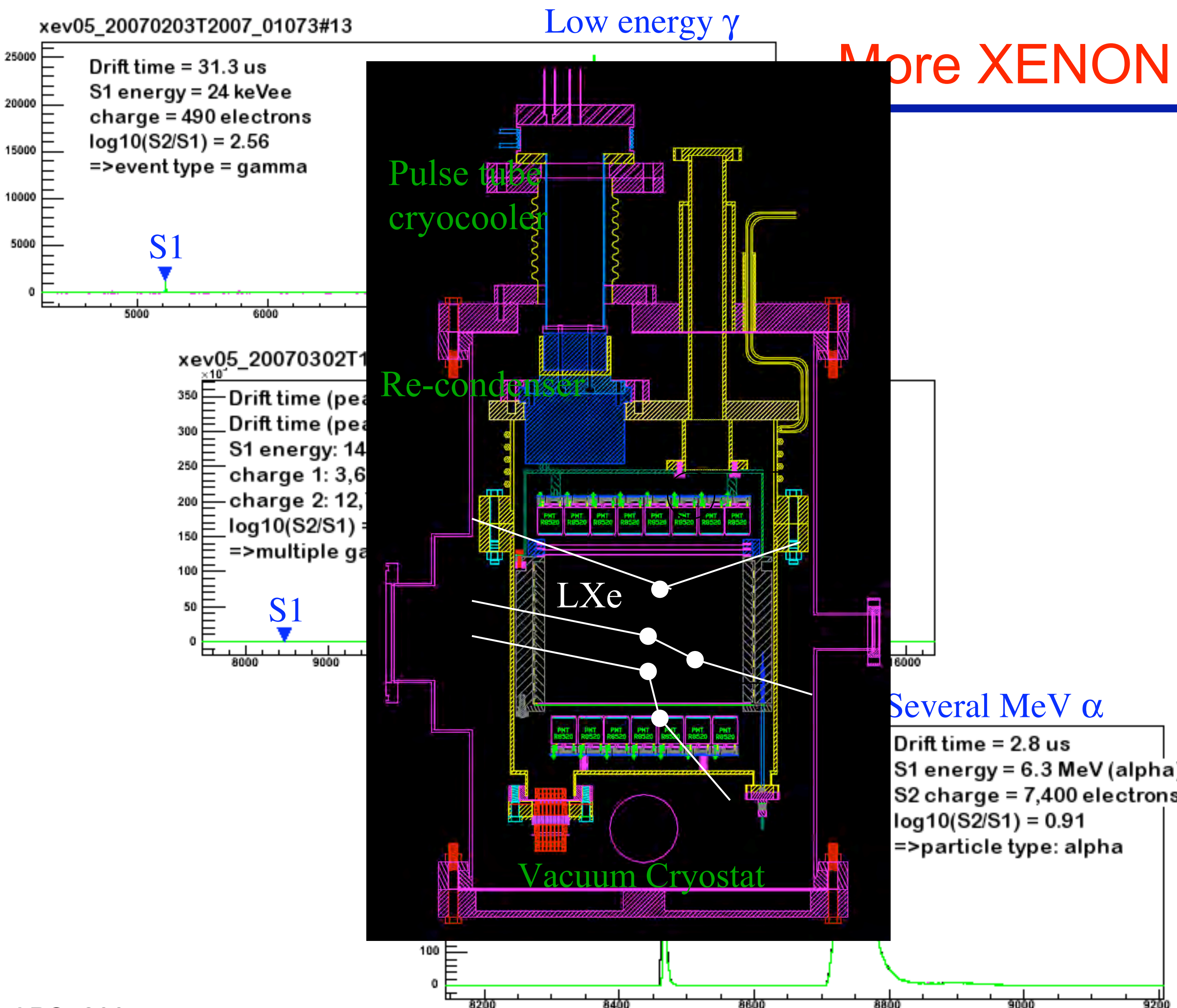


S1



S2

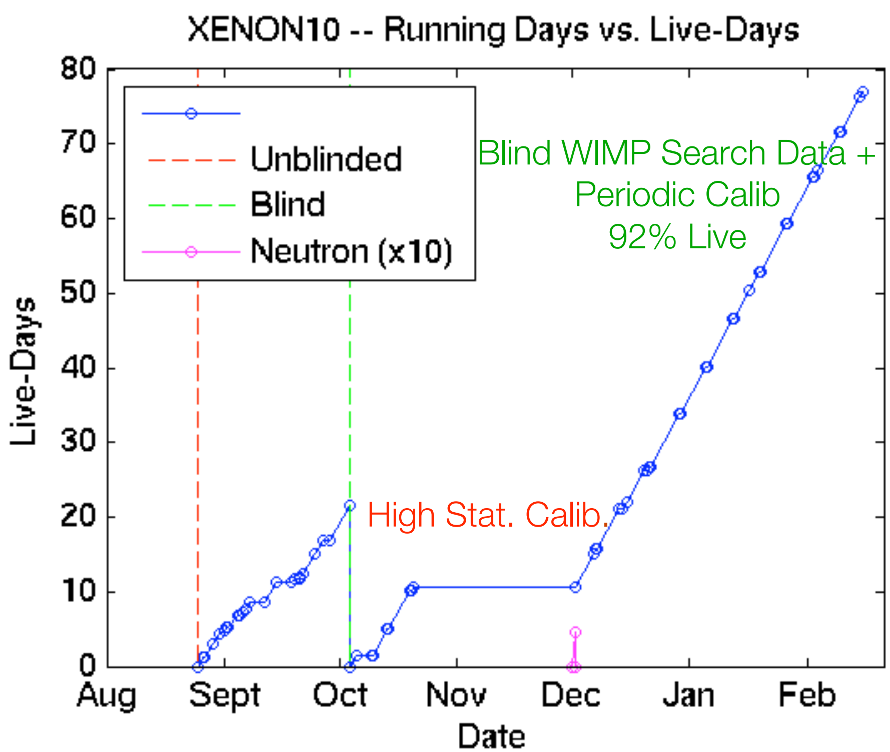
More XENON10 Event

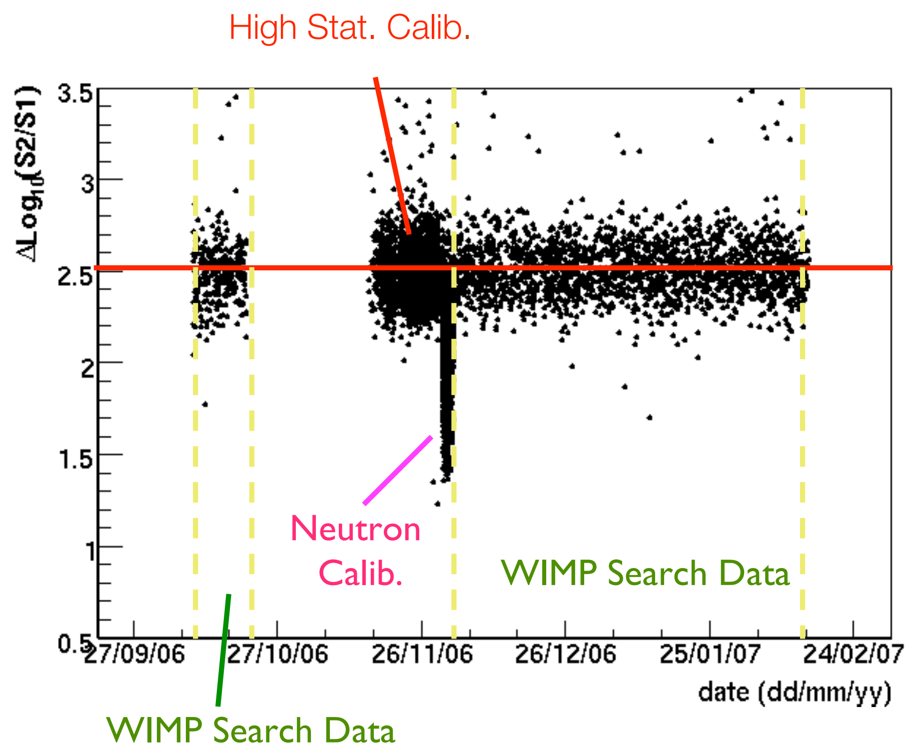


XENON10 WIMP Search

- XENON10 initial WIMP search results from data accumulated between October, 06 and February 07
- Blind analysis: data on low S2/S1 events from WIMP search run `in the box' until cut definitions completed. Cuts defined on data from calibration (gamma and neutron) and unblinded data
- Two independent analyses were performed. Both analyses aim at maximizing the signal efficiency and minimizing background in the the energy window of interest
- Analyses based on: different algorithms to extract the physical parameters from the digitized signal waveforms; different position reconstruction algorithms; and different selection & cuts
- The primary analysis was chosen based on: the more sophisticated pulse finding algorithm to reject multi-scatter events; the more accurate Neural Network position reconstruction algorithm; efficiency and simplicity of cuts to reject anomalous events while keeping high NR acceptance
- The box was opened box on April 8, 2007 . Results from primary analysis are presented

XENON10 Live-Time / Dark Matter Run Stability





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XENON10 Gamma Calibration with Radioactive Sources

^{57}Co, ^{137}Cs Gamma Sources introduced in shield

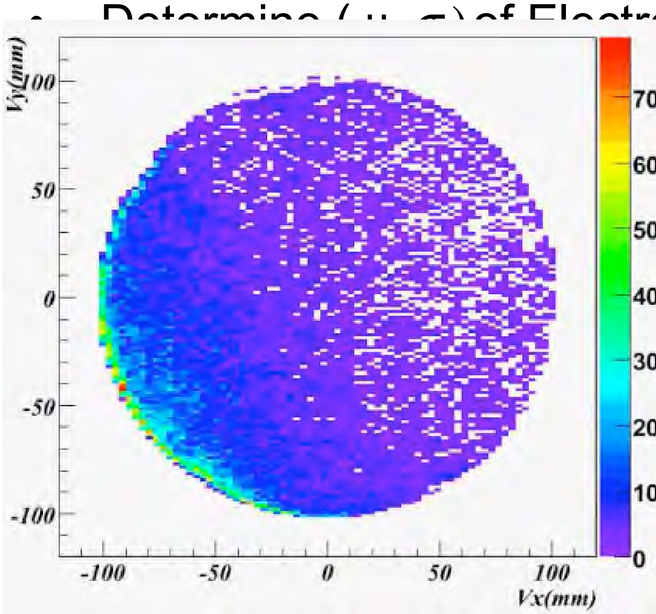
- Determine electron lifetime: (1.8±0.4) ms => << 1ppb (O_2 equiv.) purity
- Determine energy scale from primary light: 2.25 p.e./keV at 662 keV and 3.0 p.e./keV

(see K. Ni'talk)

- Test XY position reconstruction algorithms and vertex resolution:

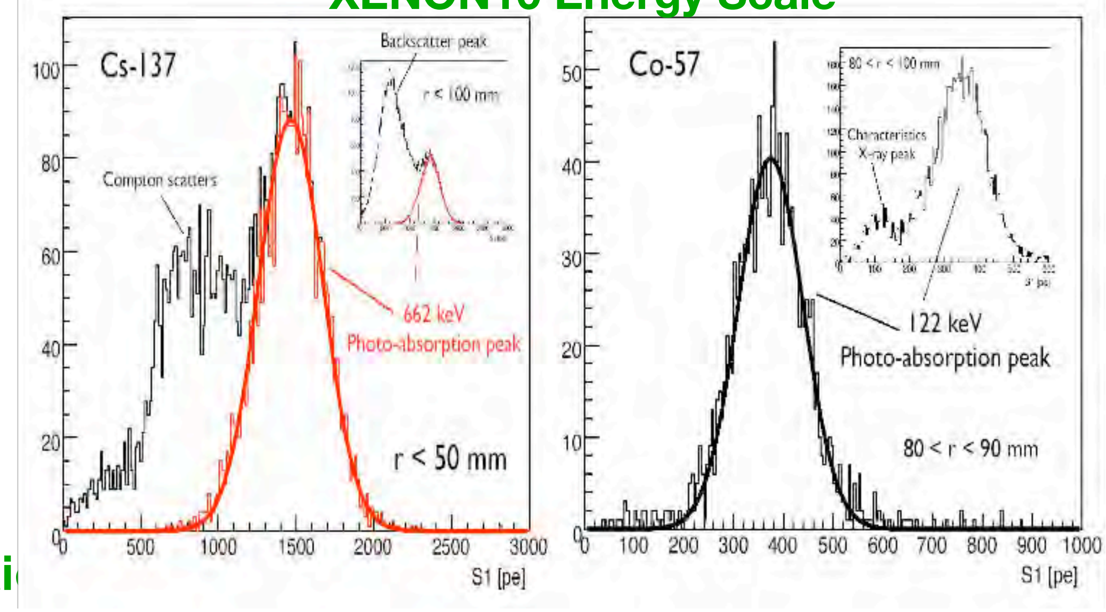
(see R. Santorelli'talk)

- Determine (μ, σ) of Electron Recoil band→ Background Rejection (see

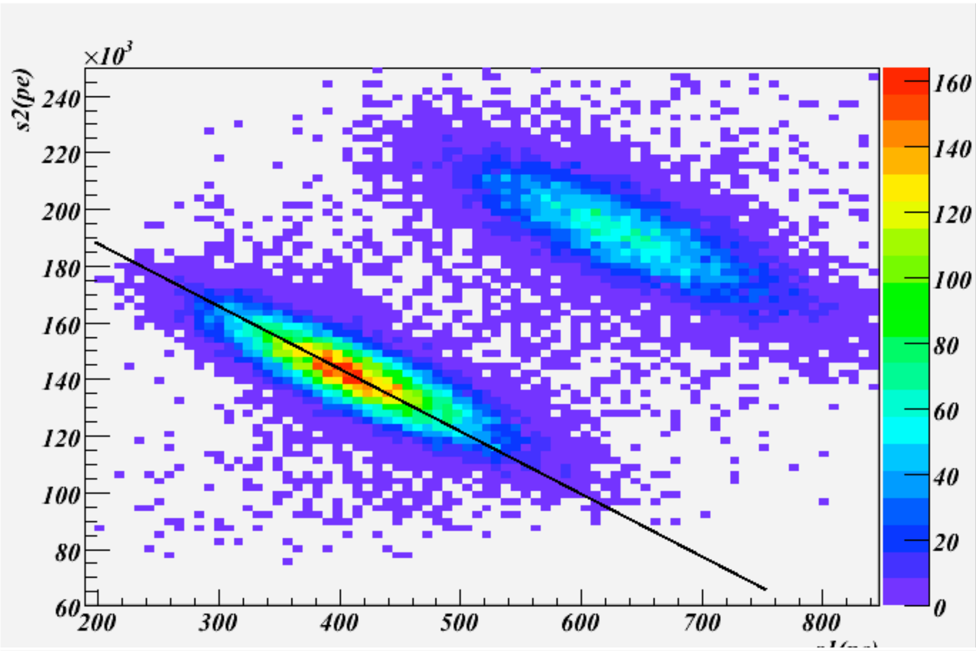


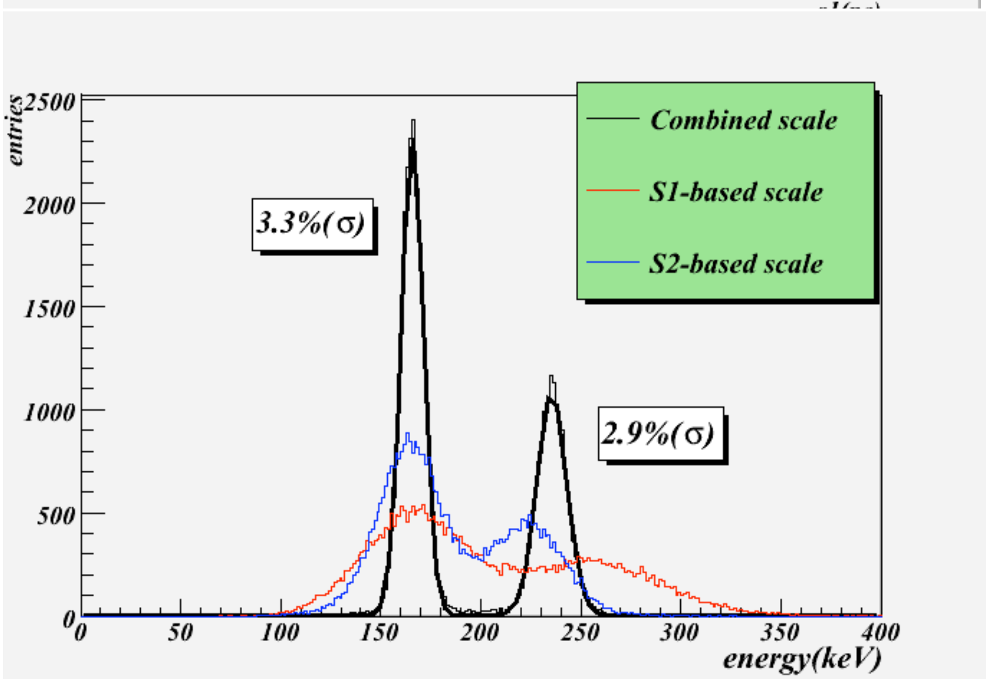
reconstructed source positi
(^{137}Cs)

XENON10 Energy Scale



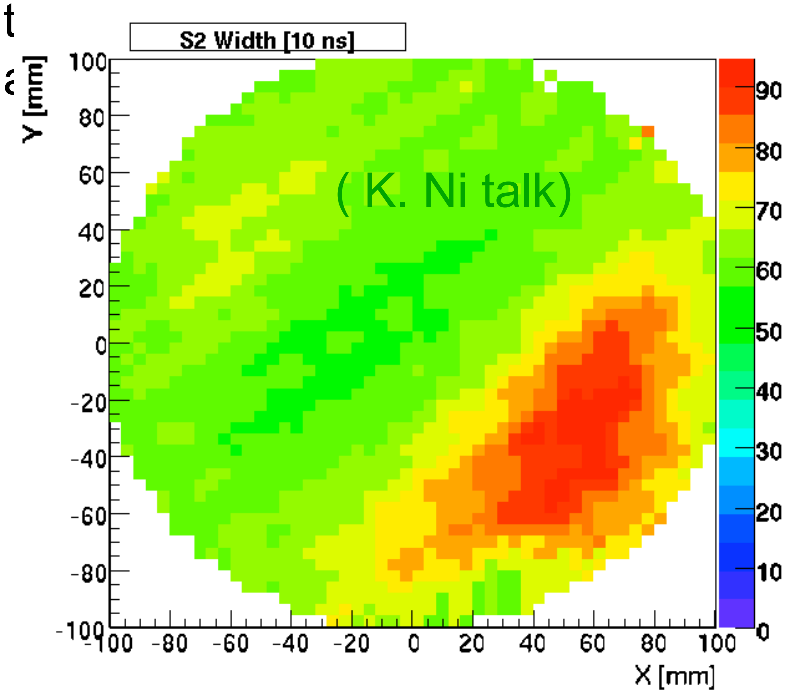
XENON10 Gamma Calibration with n-activated Xe





~200 g Xe gas irradiated with 2 weeks by $5\text{x}10^6$ n/s introduced to LXe volume

- Measure the energy scale from light yield of gammas uniformly distributed in volume
- Validate position reconstruction of events in full volume. Use data to infer position dependence for S1 and S2 signals.
- Position-dependent corrections improve t



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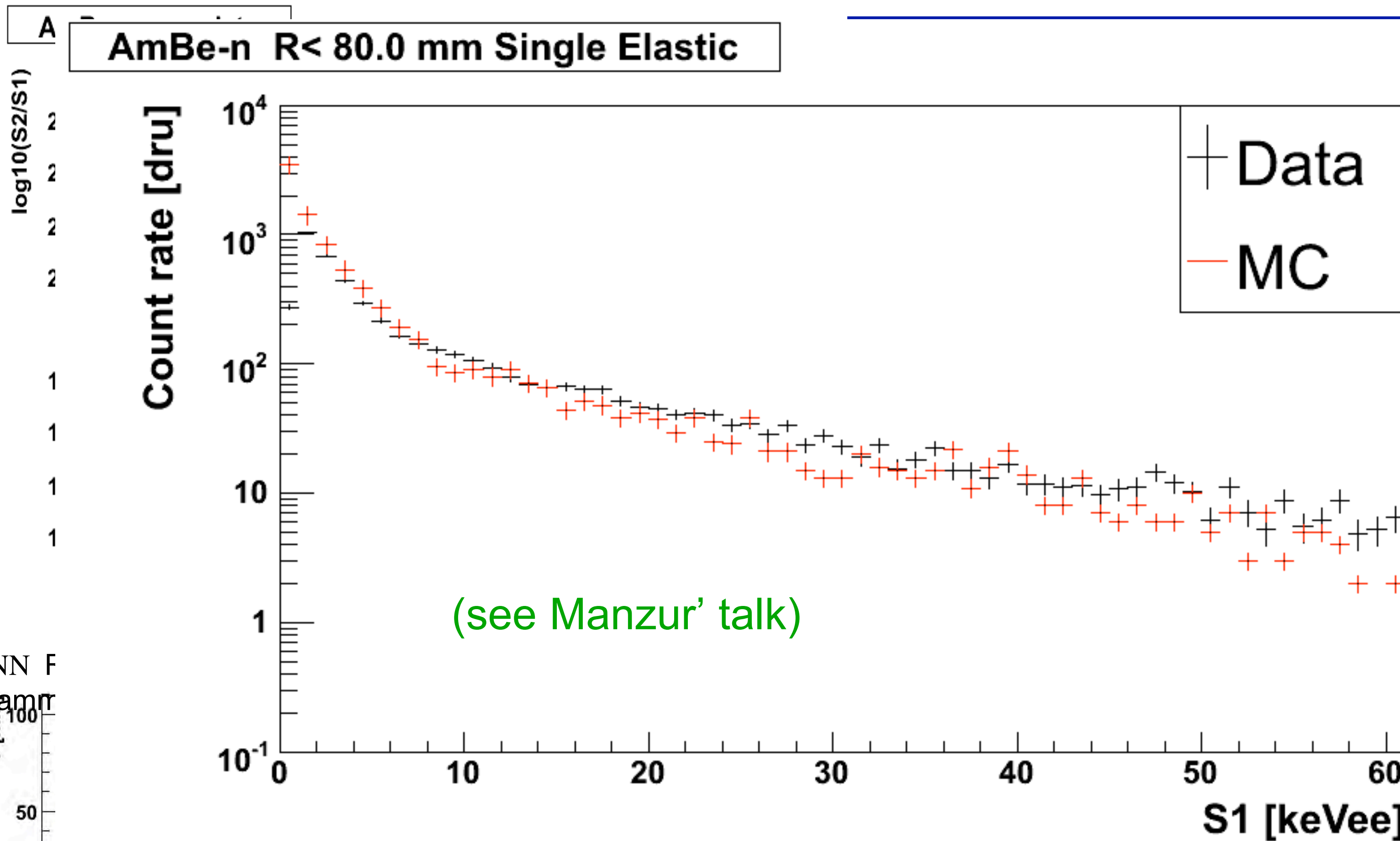
XENON10 Neutron Calibration



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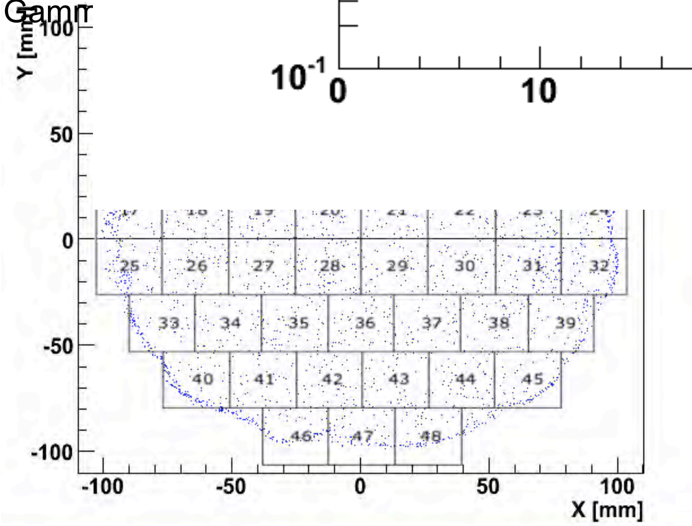
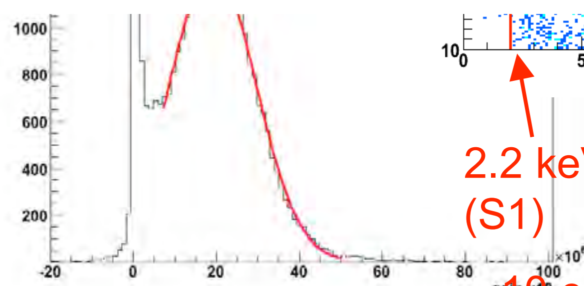
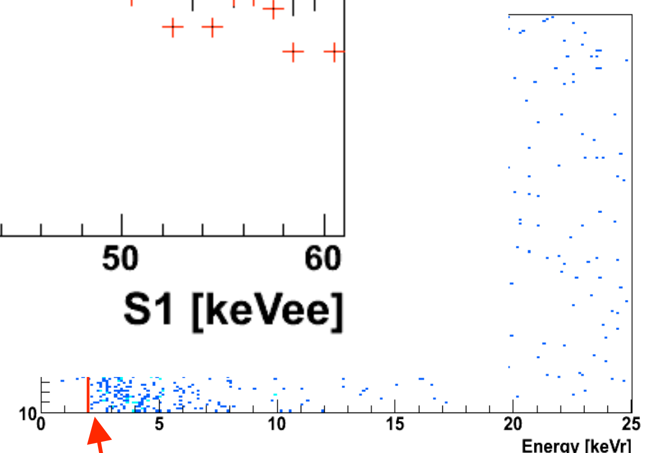
Gamm







2.2 keVr from primary light (S1)

~10 electrons signal

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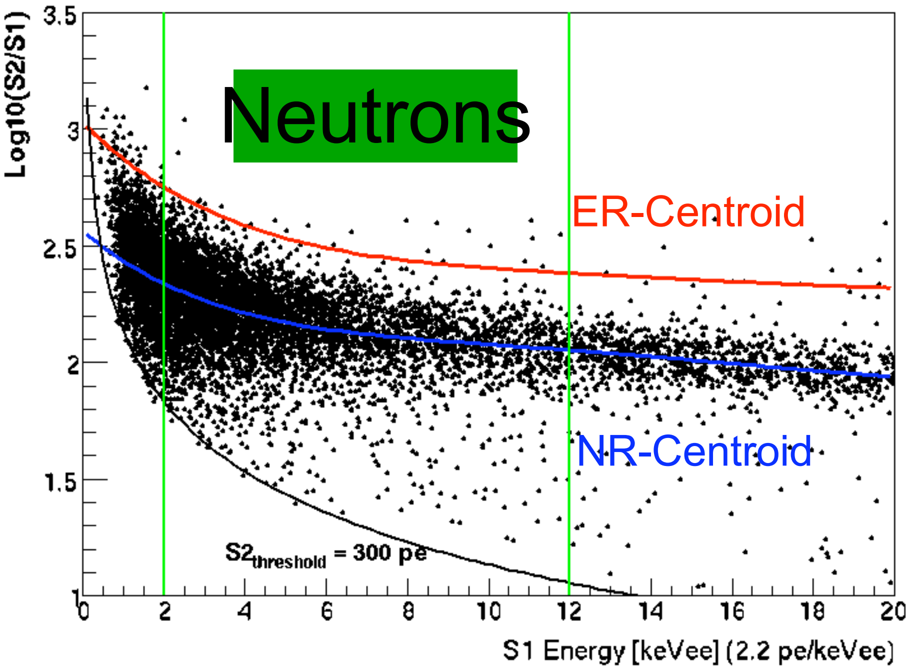
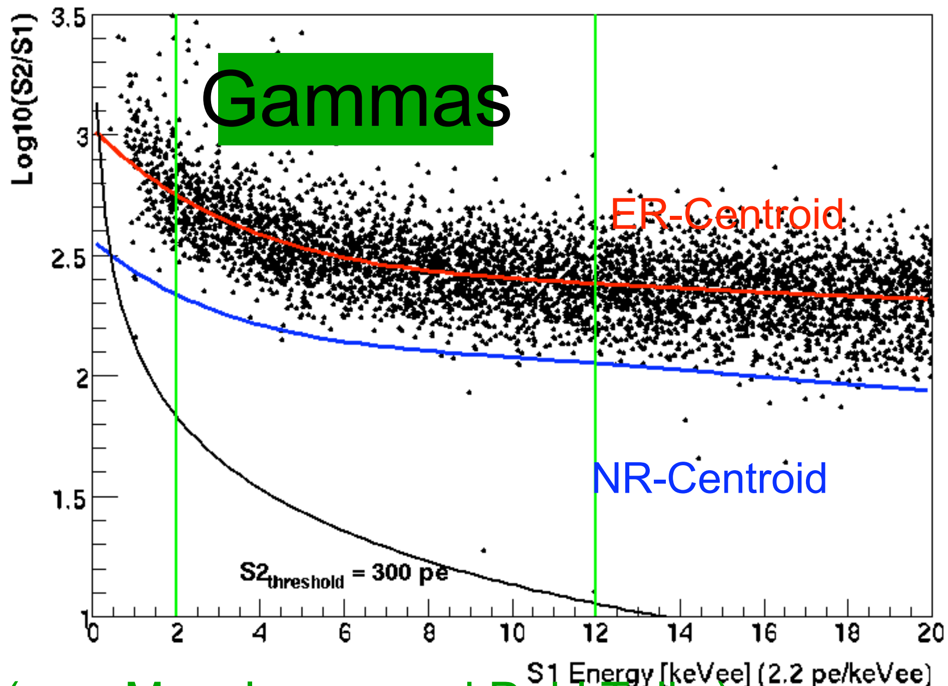
XENON10 Background Rejection Power



(see Plante Talk)



(see Manalaysay and Dahl Talks)

AmBe Neutron Calibration (NR-band)

In-situ Dec 1, 2006 (12 hours)

Source (~3.7MBq) in the shield

Cs-137 Gamma Calibration (ER-band)

In-situ Weekly calibration

Source (~1kBq) in the shield

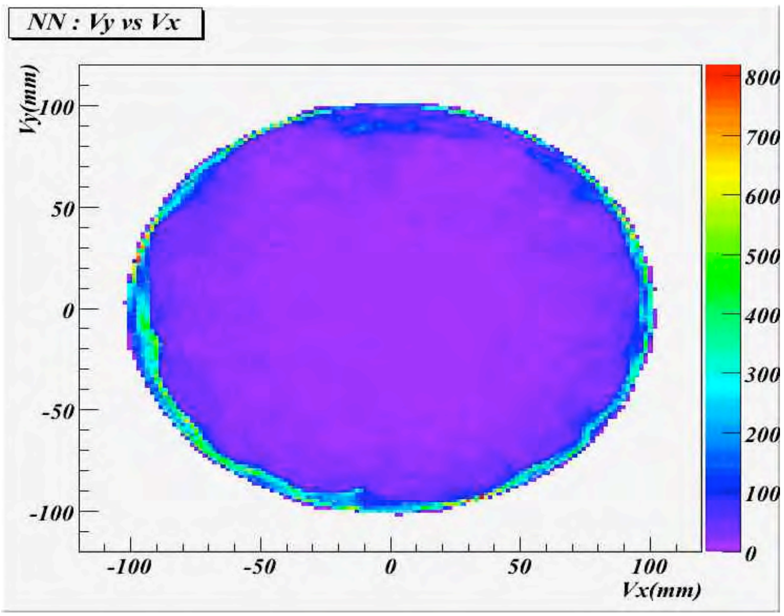
~99.5 % rejection power (improves to 99.9 % at low energy!!!)

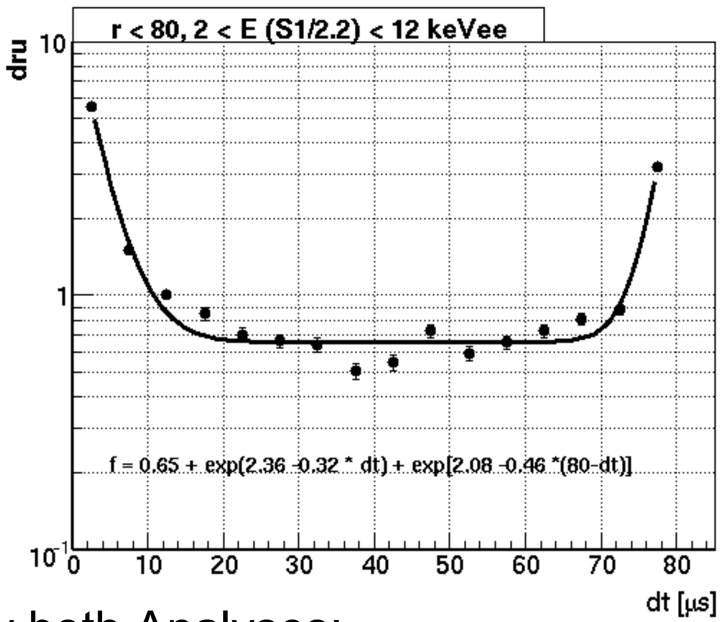
at 50% Nuclear Recoil Acceptance

XENON10 Blind Analysis Cuts

Energy Window: 2-12 keVee (based on 2.2 pe/keVee)

- Basic Quality Cuts (QC0): remove noisy and uninteresting events
- Fiducial Volume Cuts (QC1): capitalize on LXe self-shielding (see Plante Talk)
- High Level Cuts (QC2): remove anomalous events (S1 light pattern)





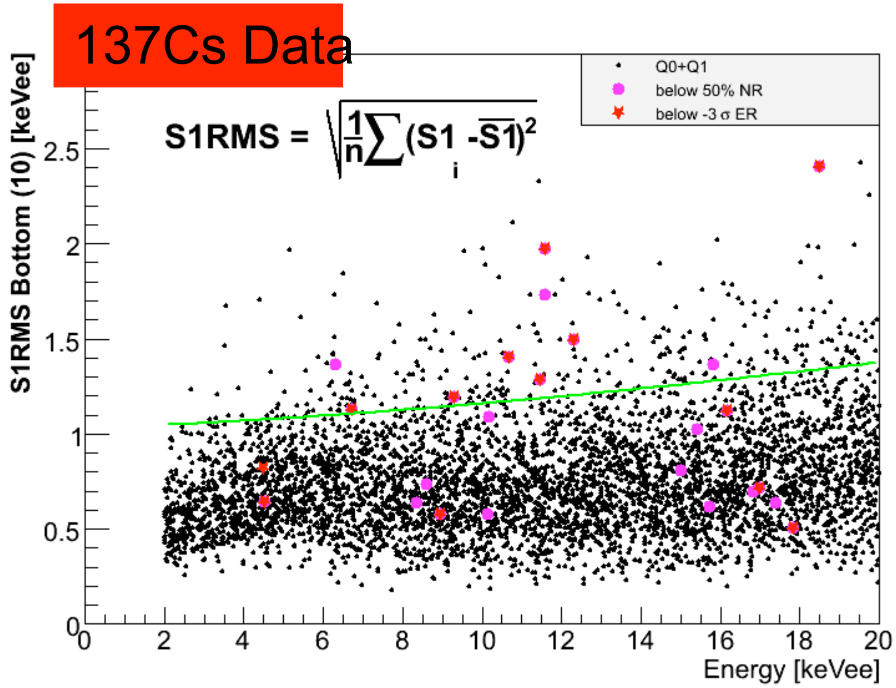
Fiducial Volume chosen by both Analyses:

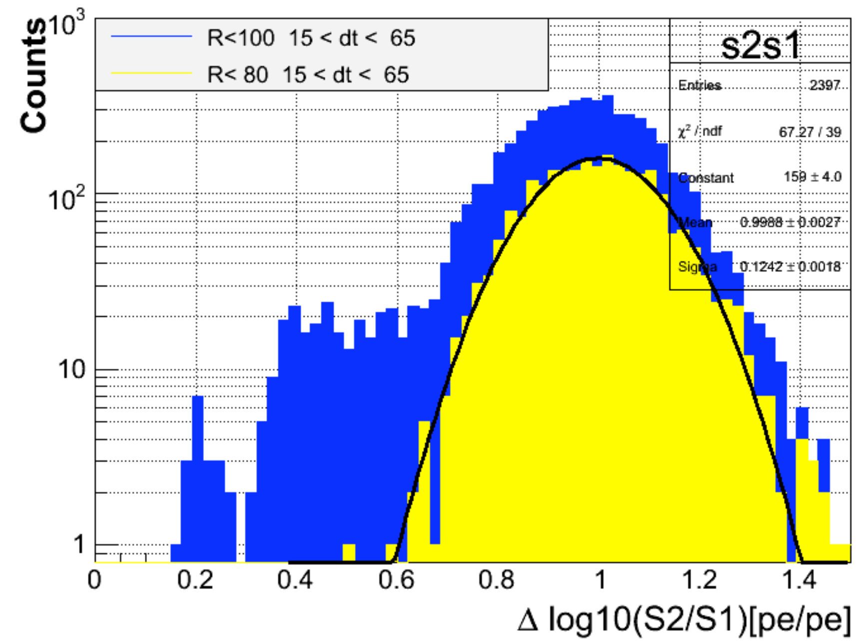
15 < dt < 65 us, r < 80 mm

Fiducial Mass= 5.4 kg (reconstructed radius is algorithm dependent)

Overall Background in Fiducial Volume ~0.6 event/(kg d keVee)

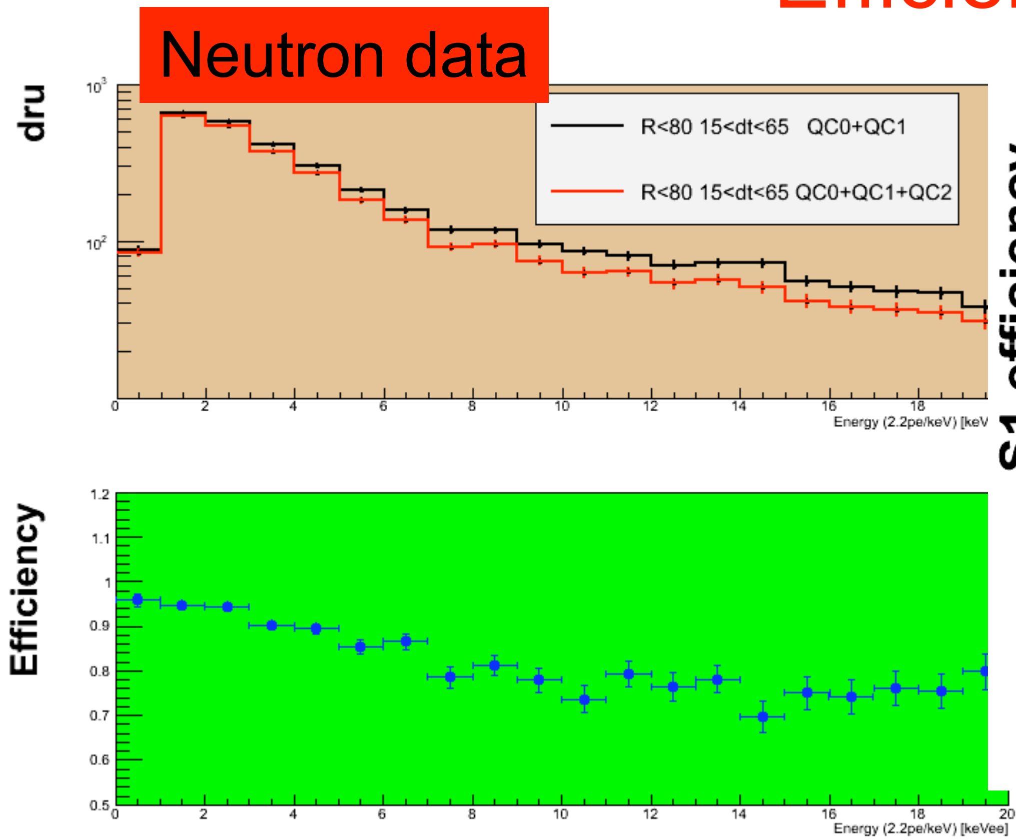
Performance of QC2 Cut (S1 RMS Cut) on Cs Data

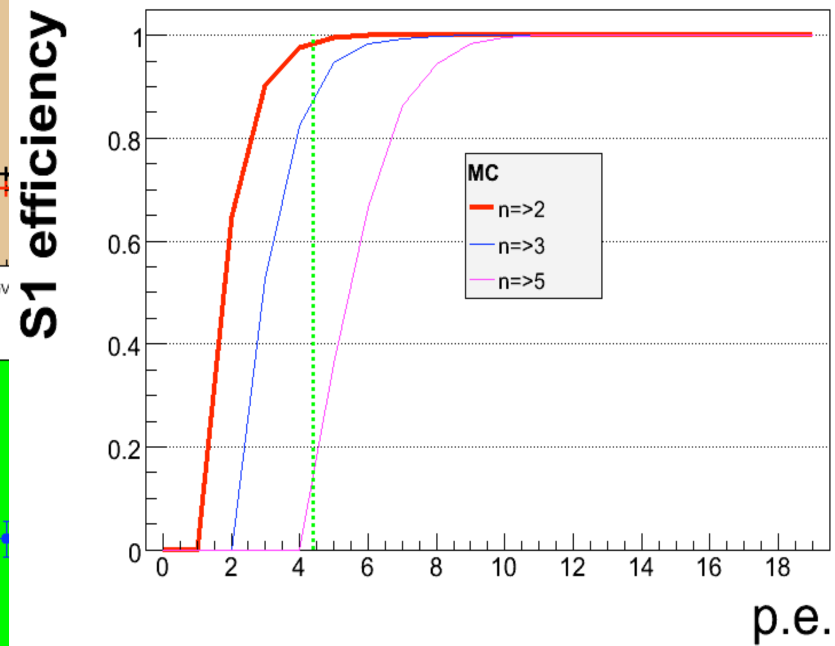




- 137Cs data (1.3 x WIMP search data) + Not Blind WIMP search data used to optimize QC2cuts.
- Define S1-RMS parameter to reject “Events with Anomalous S1 light pattern” : events with most S1 signal localized in a few adjacent bottom PMTs are likely to have scattered first in the LXe layer above bottom PMTs and below cathode grids, or other “dead” LXe regions.
- S1-RMS for bottom PMTs array: events with high S1-RMS parameter coincide with the non-Gaussian events from the ER-band distribution.
- Lowest delta log10(S2/S1) for Cs data shows one event with a 12% probability of being consistent with Gaussian distribution of ER background events

Efficiency

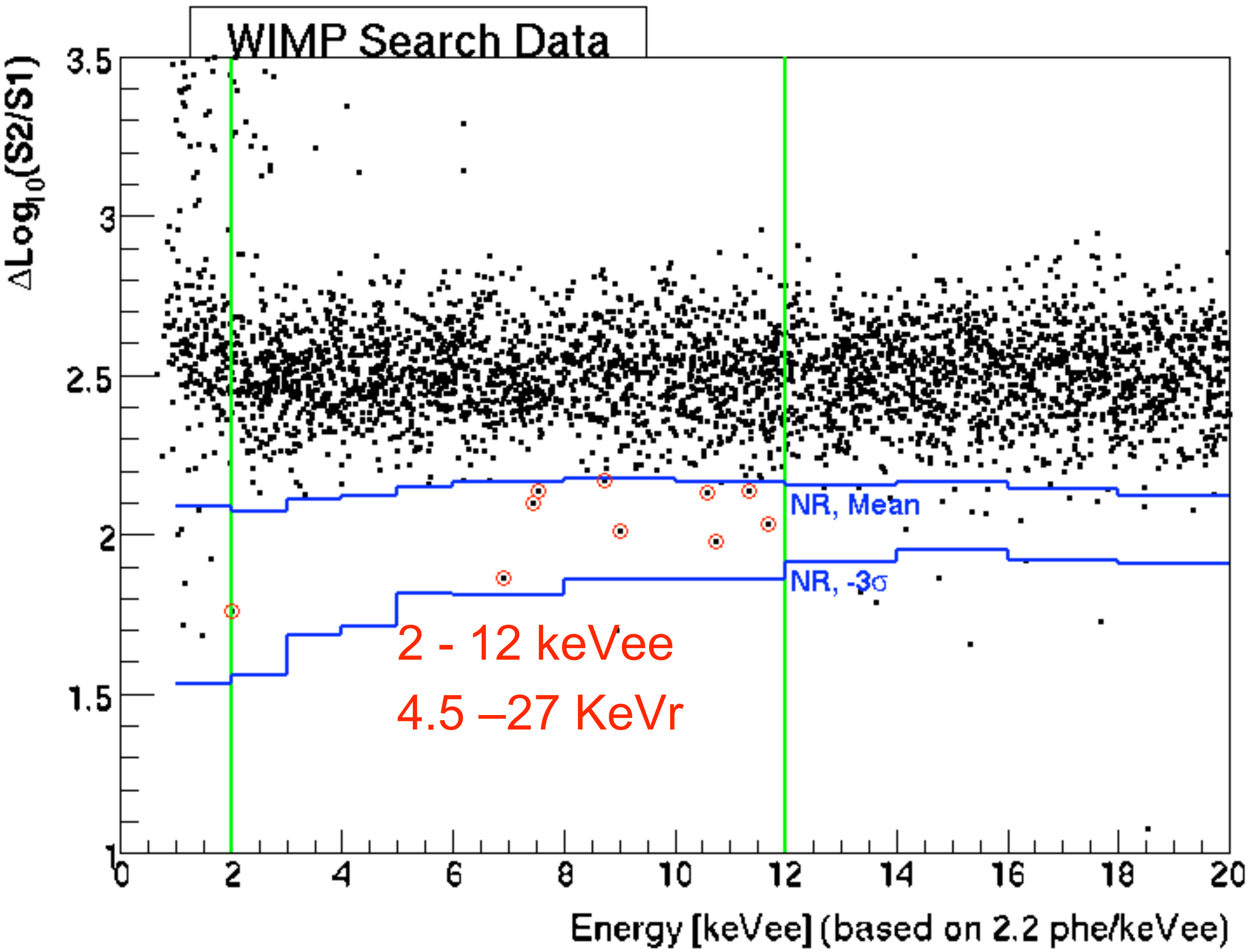




- WIMP Search Data: Trigger by Sum of S2 signal from Top PMTs
- S2 threshold is 300 photoelectron (~ 20 ionization electrons)
- A gas gain of a few hundred allows 100% S2 trigger efficiency
- The S1 signal associated with an S2 signal is searched for in the off-line analysis
- The coincidence of 2 PMT hits is used in Primary Analysis and the S1 energy threshold is set to 4.4 photoelectrons. Its efficiency is ~ 100% at 2keVee
- The QC2 cuts efficiency varies between 95% and 80% in the 2-12 keVee energy window

XENON10 WIMP Search Data with Blind Cut

136 kg-days Exposure= 58.6 live days x 5.4 kg x 0.86 (ε) x 0.50 (50% NR)

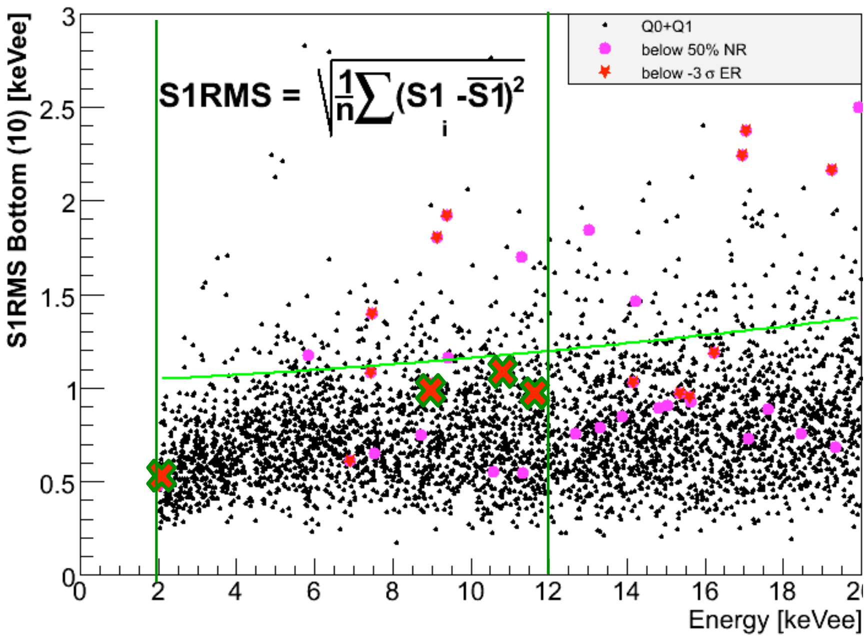


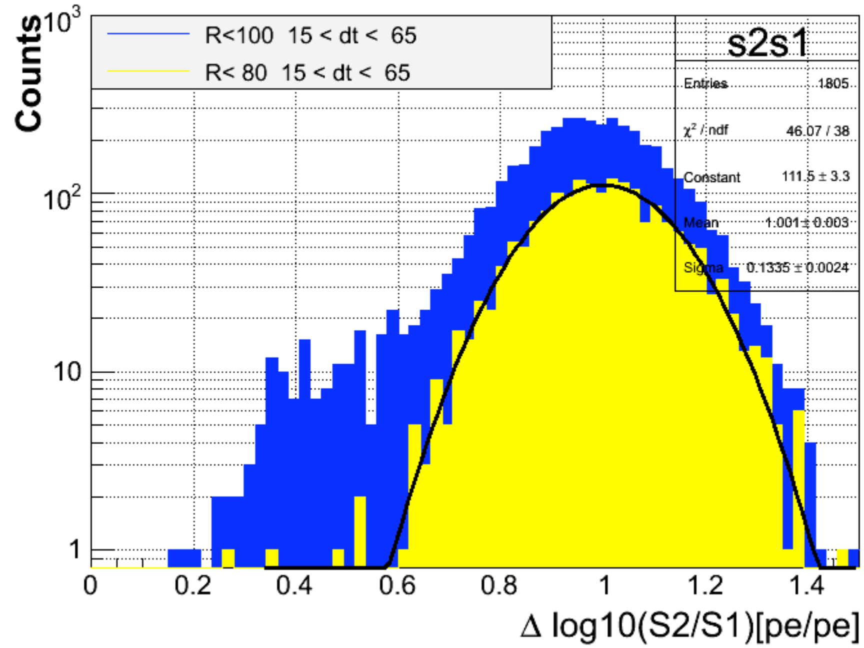
- WIMP "Box" defined at ~50% acceptance of Nuclear Recoils (blue lines): [Mean, -3σ]
- 10 events in the "box" after all cuts in Primary Analysis
- 6.9 events expected from γCalibration
- NR energy scale based on 19% constant QF

(see Manzur Talk)

Performance of QC2 Cut (S1 RMS Cut) on Search Data

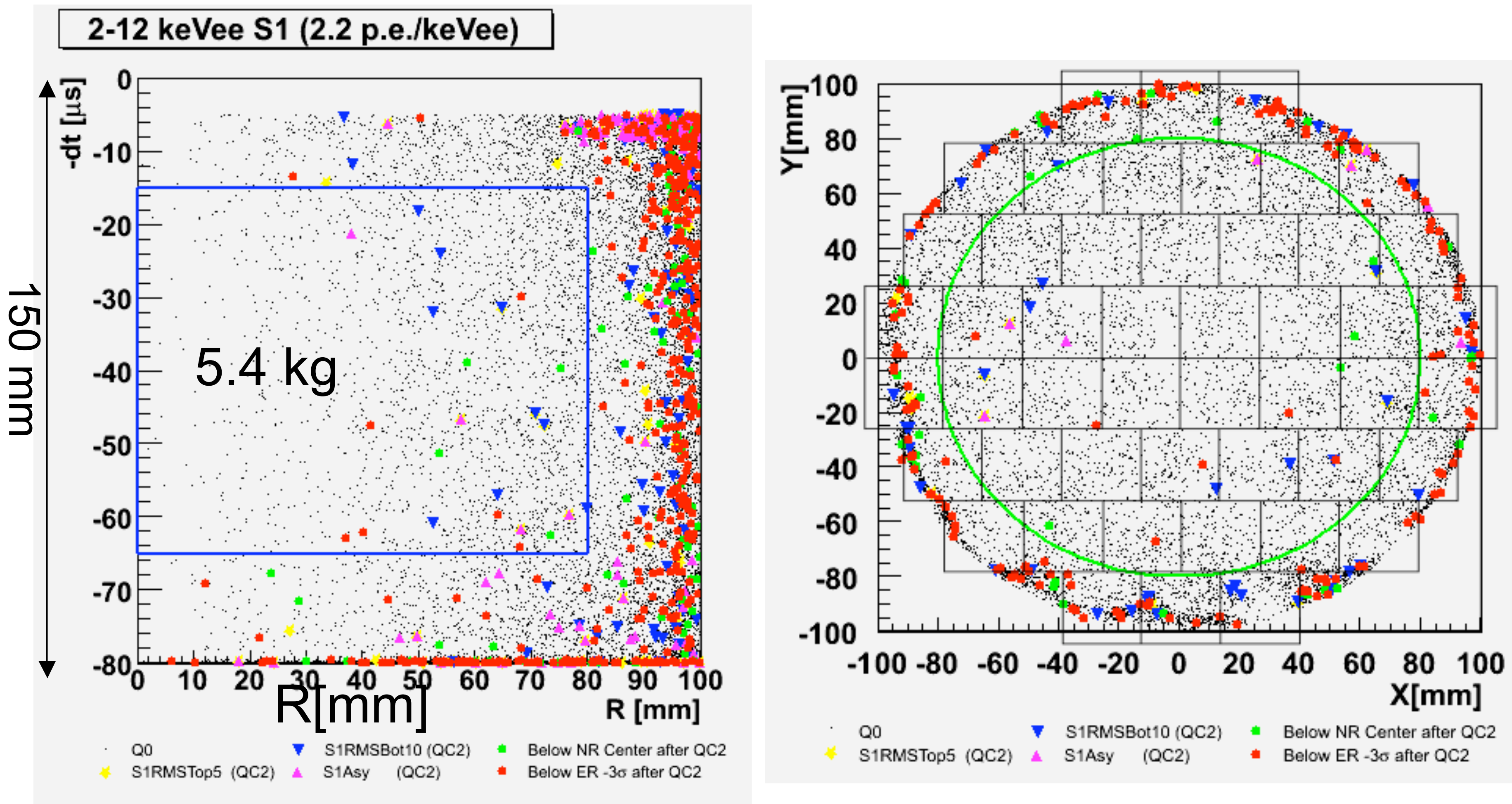
WS003+WS004 (58days)





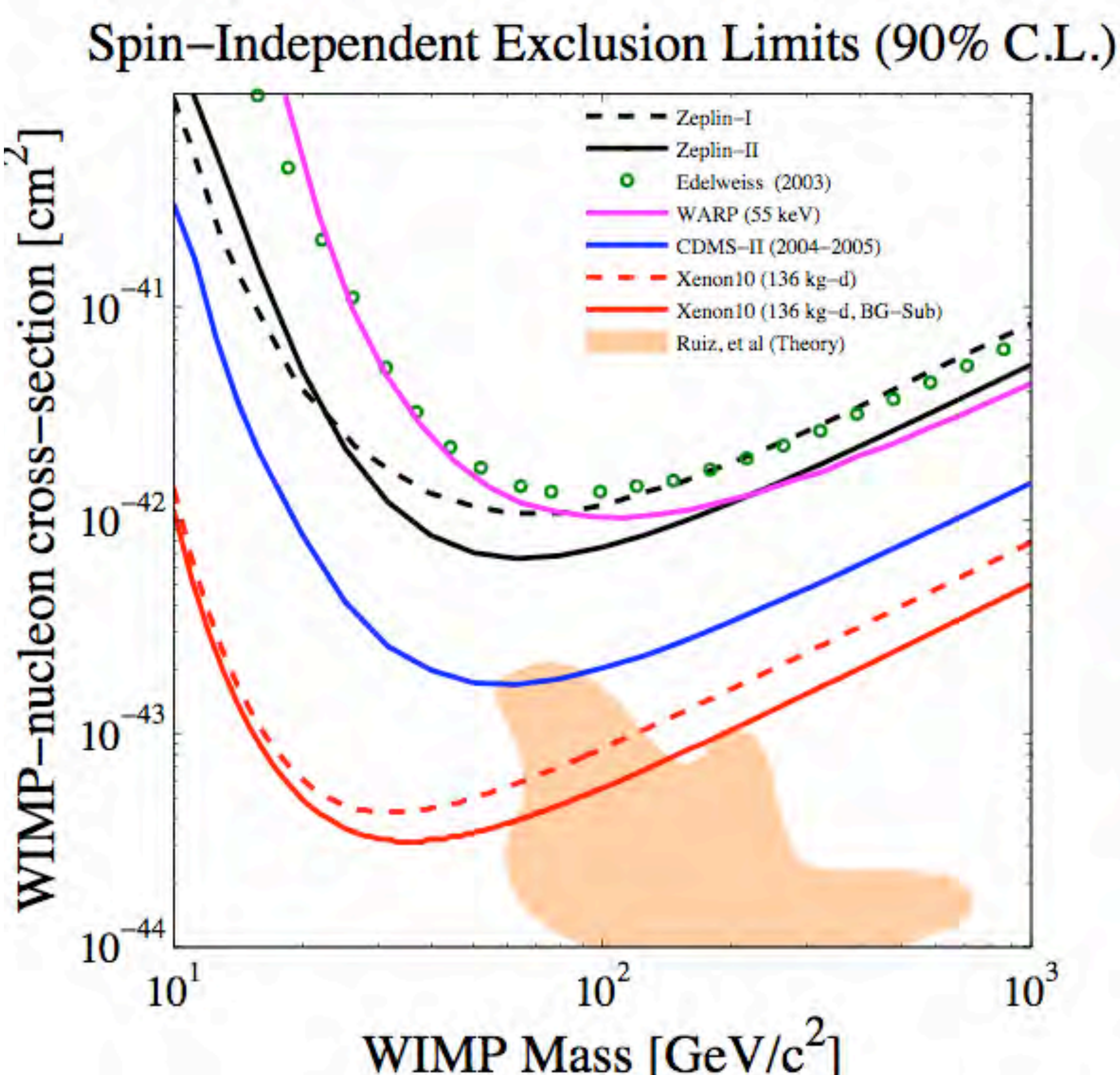
- *5 "non-Gaussian" events remain after all QC2 cuts on the WIMP search data.*
- 3 of these non-Gaussian events are removed by the more sophisticated QC2 GammaX cut of the Secondary Analysis. The very low energy event at edge of energy window and is also cut by Secondary Analysis (see De ViveirosTalk)
- *1 of the 5 "non-Gaussian" events survives both analyses cuts (>15 keVr, S2/S1 far from NR centroid). Event S1RMS parameter is typical of "good events" and event location is in the center of FD. In secondary analysis is very marginal (close to cut)*

Spatial Distribution of Events from Blind Analysis



In total 13 events are removed from box by Primary Analysis QC2 Cuts (

XENON10 Experimental Upper Limits



- Upper limits on the WIMP-nucleon cross section derived with Yellin Maximal Gap Method (PRD 66 (2002))
- For a WIMP of mass 100 GeV/c^2

  9.0 $\times 10^{-44}$ cm^2 Max Gap (4.5-15.5keVr)

  5.5 $\times 10^{-44}$ cm^2 including known Back
- Factor of 6 below best previous limit
- XENON10 is testing SUSY models. With a phased approach towards ton scale, XENON aims at maximizing discovery potential at every phase

(see Gaitskell Talk)

On behalf of the entire XENON10 Collaboration

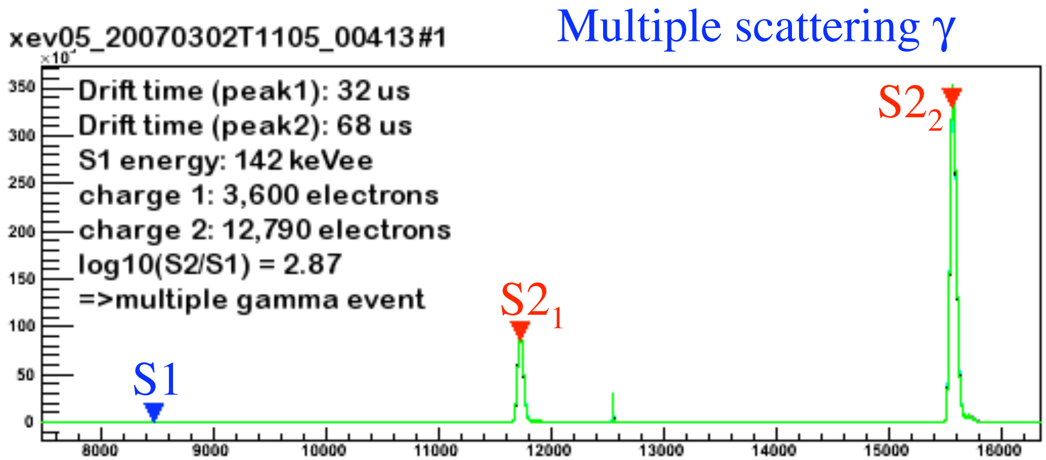
We thank

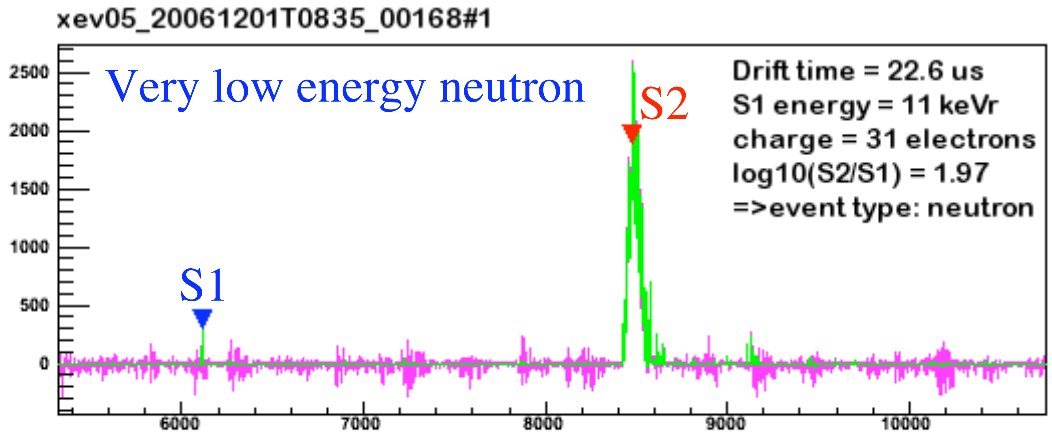
NSF and DOE

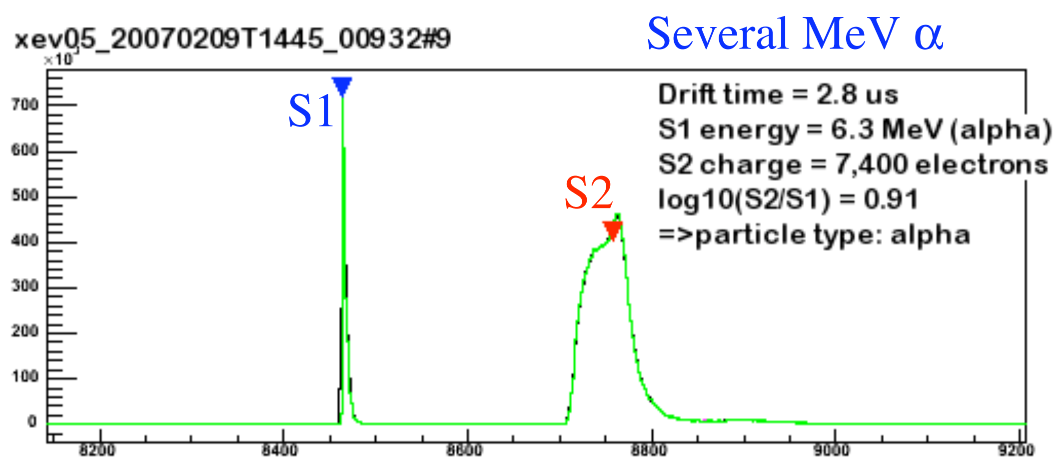
and

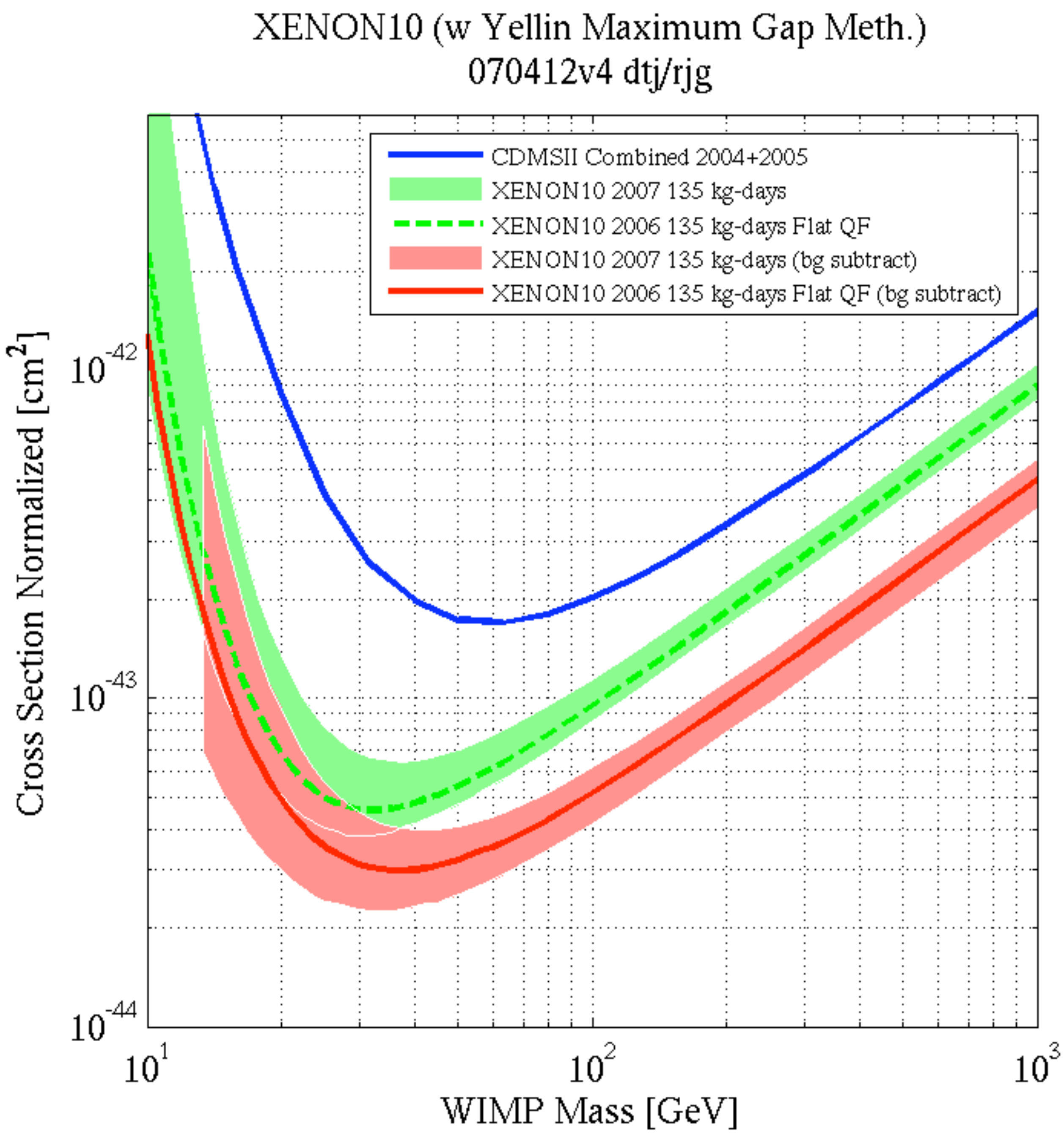
Laboratori Nazionali del Gran Sasso and its Staff

More XENON10 Events








XENON10 (w Yellin Maximum Gap Meth.)
070412v4 dtj/rjg
CDMSII Combined 2004+2005
XENON10 2007 135 kg-days
XENON10 2006 135 kg-days Flat QF
XENON10 2007 135 kg-days (bg subtract)
XENON10 2006 135 kg-days Flat QF (bg subtract)
Cross Section Normalized [cm^2]
10^{-42}
10^{-43}
10^{-44}
10^1
10^2
10^3
WIMP Mass [GeV]