First Result from XENON10 Dark Matter Experiment at Gran Sasso Laboratory

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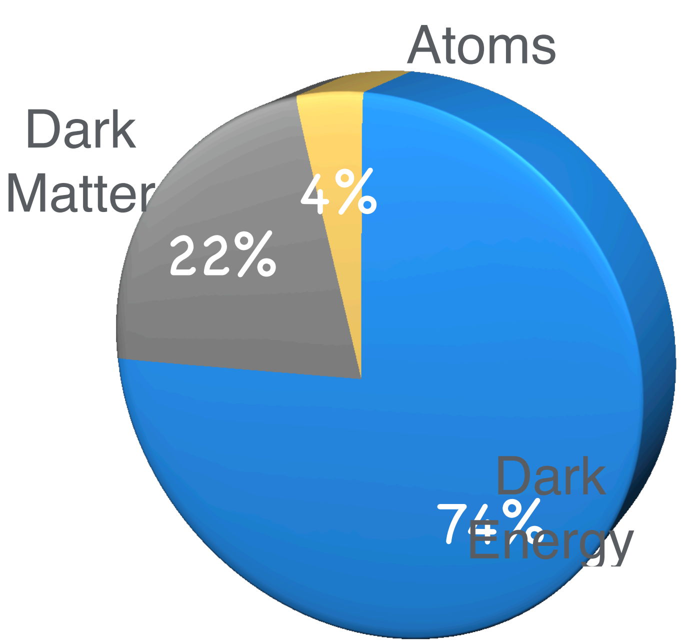
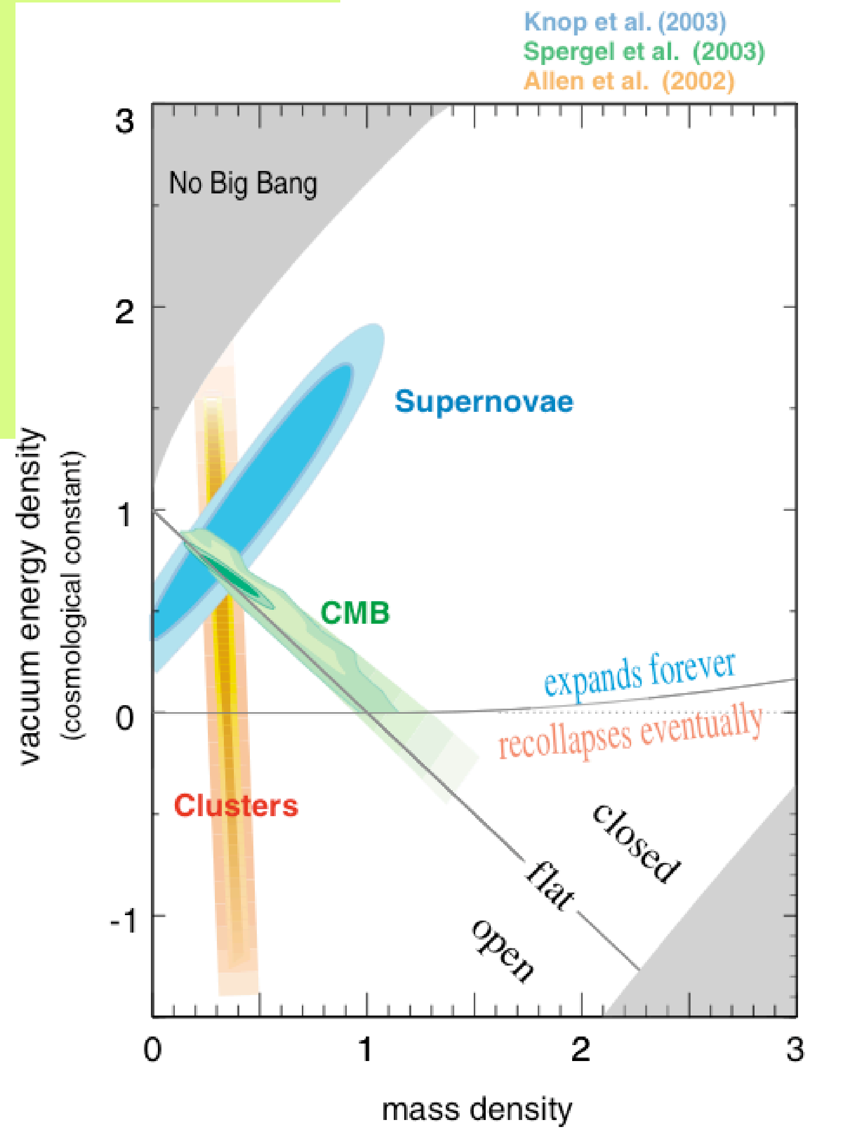
Dark Matter Problem

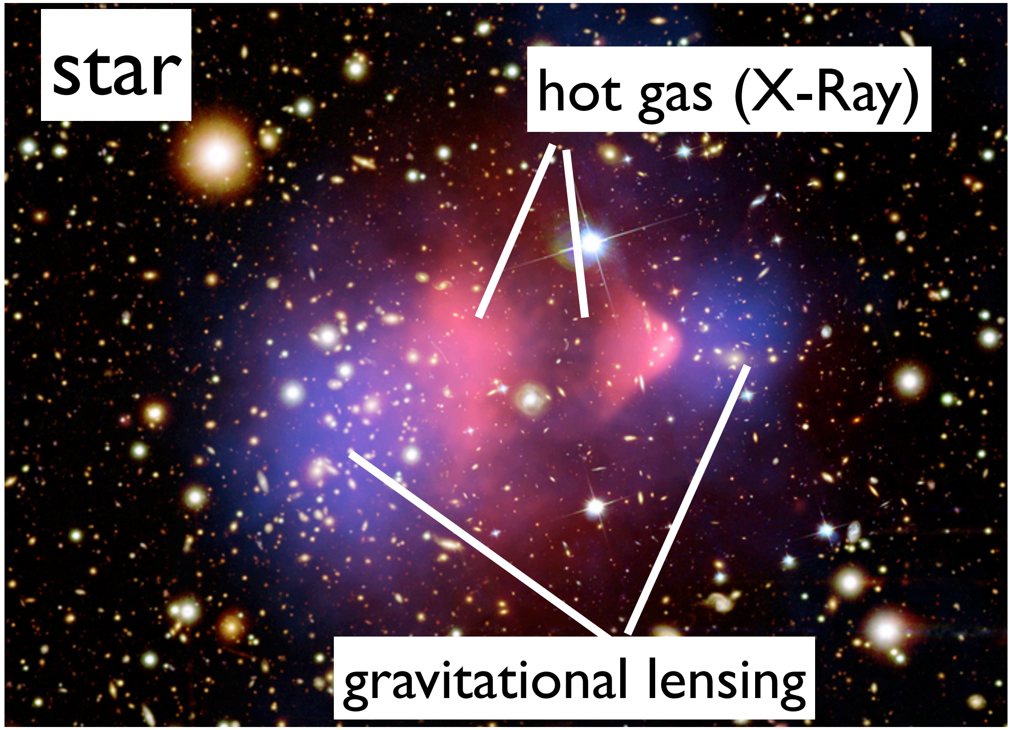
Existence of dark matter is required by a host of observational data:
galactic halos,
clusters of galaxies,
large scale structures,
CMB,
high-redshift SN_e Ia.

Baryonic Matter - Mostly known
Visible Matter (stars) only ~1% of the total.
Non-Baryonic Dark Matter
New Particle -SUSY

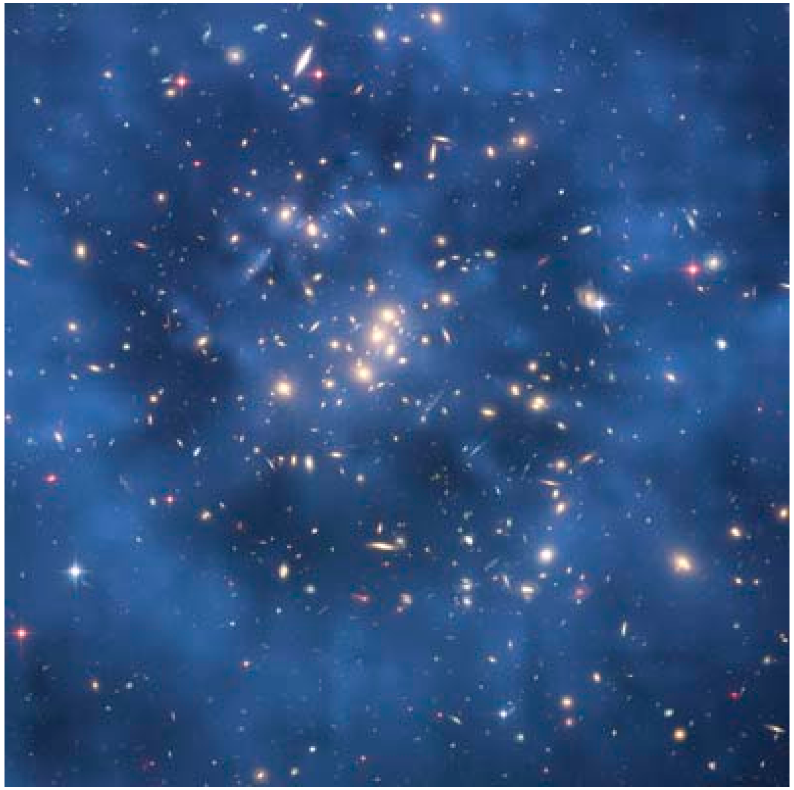




Observations(gravitational lensing)



D. Clowe et al.. 2006



M. J. Jee and H. Ford

Bullet Cluster
merger of two galaxy

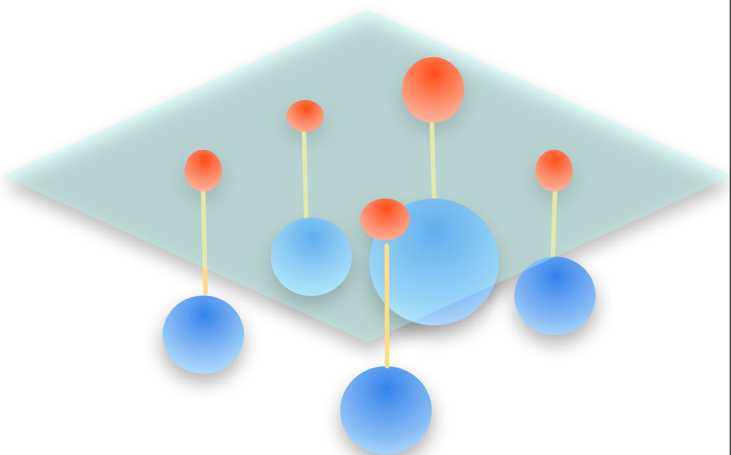
A titanic collision between two massive galaxy clusters

encourage Direct Dark Matter Detection.

Weakly Interacting Massive Particle

Dark Matter is required to be

- Neutral
  - ➡can not see ...
- Non-baryon
- Mass
  - ➡gravitational effect
- Cold (non-relativistic)
  - ➡structure formation



SUSY

- to prevent rapid proton decay **a discrete symmetry (R-parity)** is imposed

→ **$R = (-1)^{3B+L+2S}$**, B = baryon number, L = lepton number

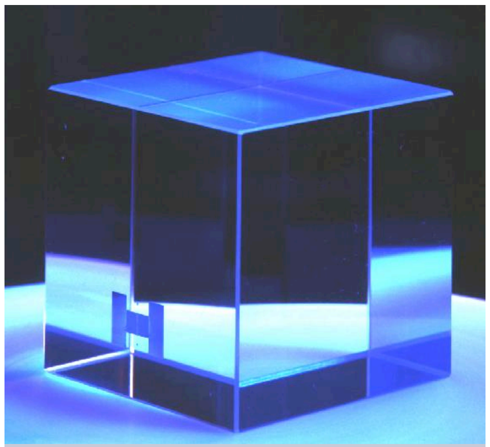
→ R = 1 for SM particles, R = -1 for SUSY

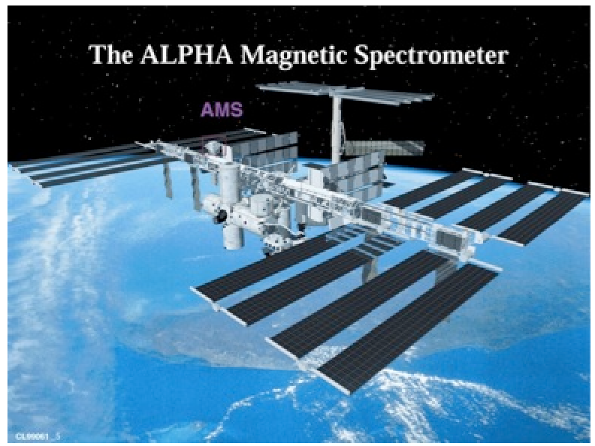
⇒ the **lightest SUSY particle is stable** and likely becomes a **dark matter candidate**

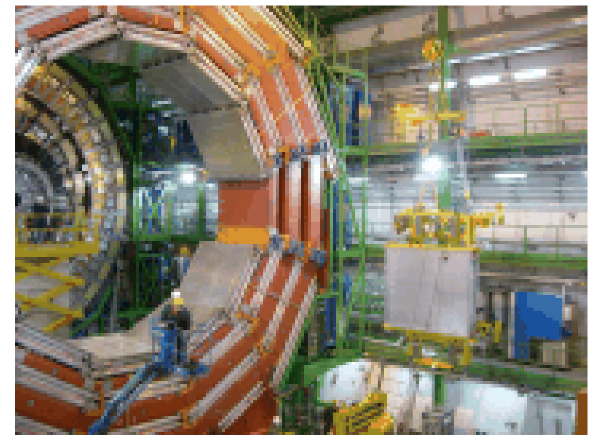
Linear combination of susy particles

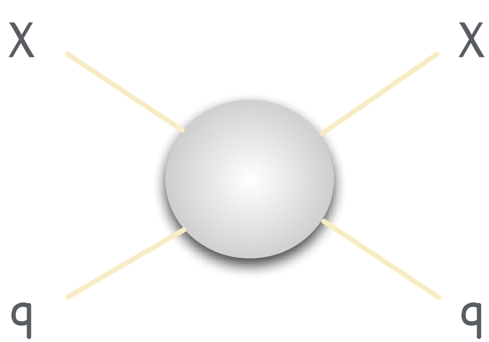
$$\chi_1^0 = \alpha_1 \tilde{B} + \alpha_2 \tilde{W} + \alpha_3 \tilde{H}_u^0 + \alpha_4 \tilde{H}_d^0$$

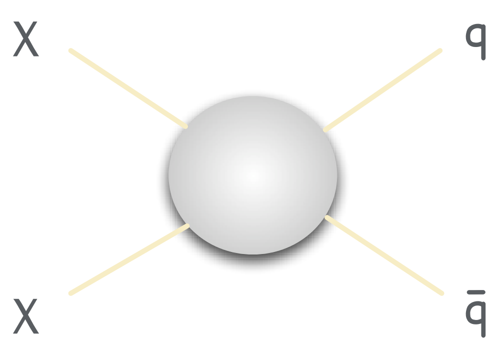
Approaches to Dark Matter Detection

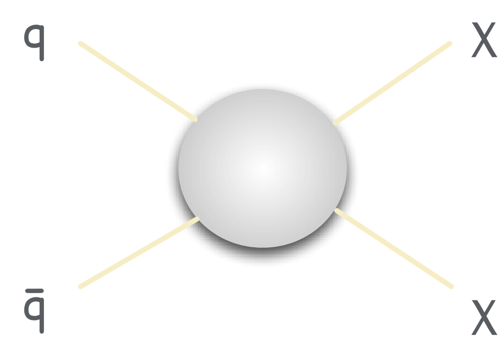












Direct

Indirect

Colliders

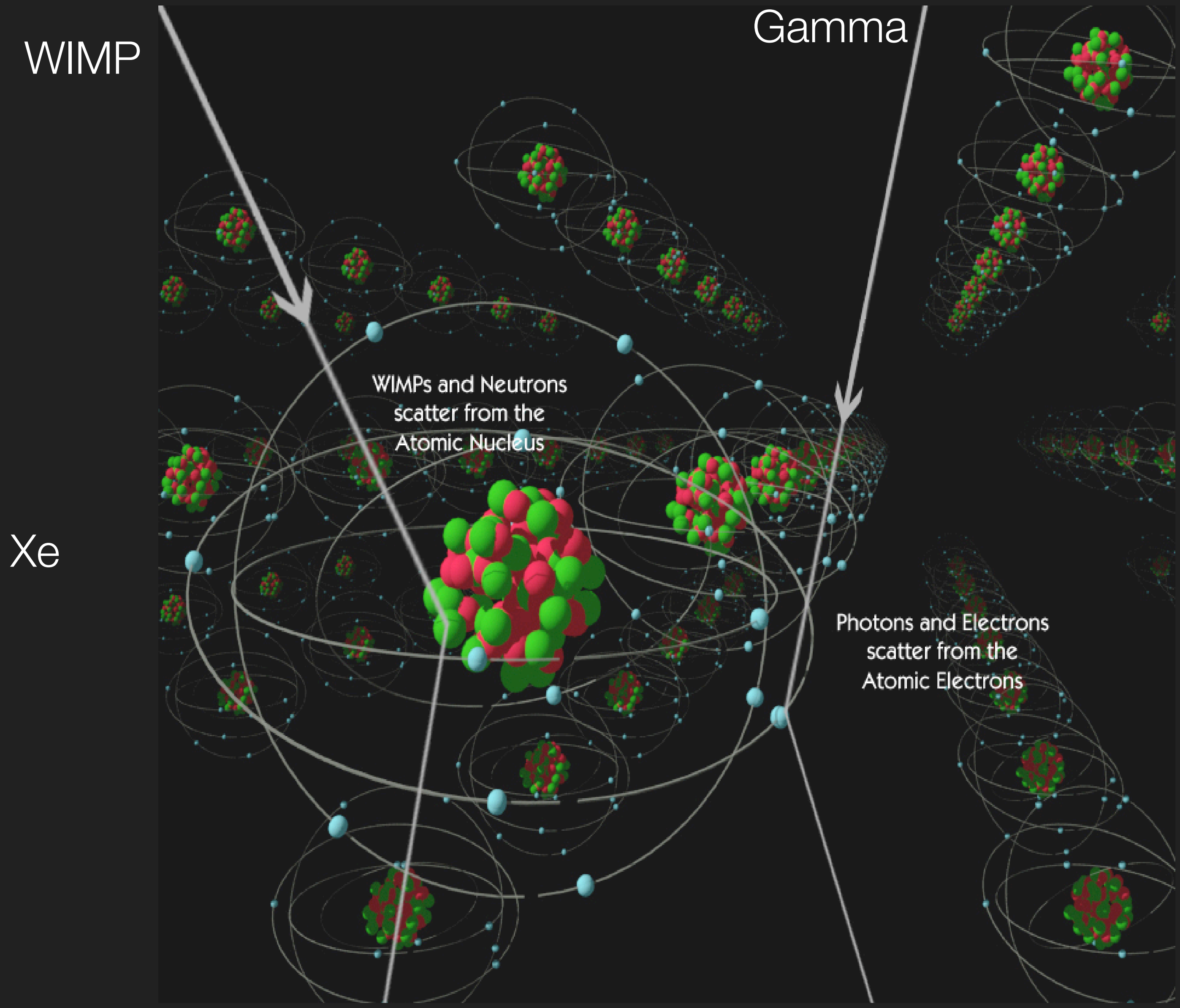
WIMPs:

10^6 per second through your thumb without being noticed!

10^{15} through a human body each day: only < 1 will interact, the rest is passing through unaffected!

If their interaction is so weak,
how can we detect them?

WIMP Detection: Scattering off Atoms



M. Attisha

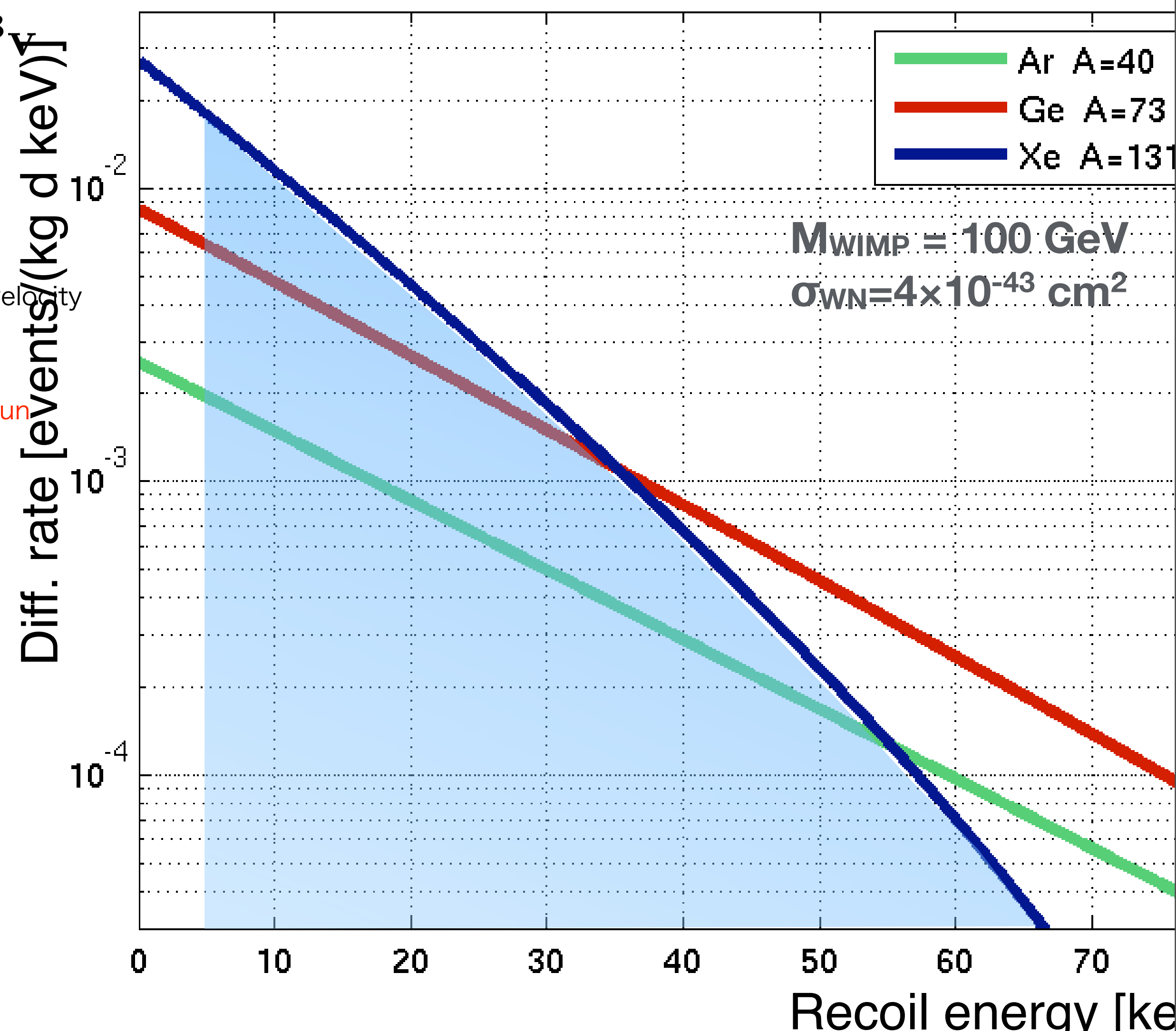
Direct Detection Principle

WIMPs elastically scatter off nuclei in targets, producing nuclear recoils.

$$\frac{dR}{dE_R} = \frac{R_0 F^2(E_R)}{E_0 r}\frac{k_0}{k}\frac{1}{2\pi v_0}\int_{v_{min}}^{v_{max}}\frac{1}{v}f(\mathbf{v},\mathbf{v_E})d^3\mathbf{v}$$

R0: Event rate
F: Form Factor
should be calculated

Maxwellian distribution for DM velocity is assumed.
V :velocity onto target,
VE: Earth's motion around the Sun



Spin independent case:

$$\sigma_0 = A^2\frac{\mu_T^2}{\mu_p^2}\sigma_{\chi-p}$$ → **Large A**

Spin dependent case:

$$\sigma_0 = \frac{(\lambda_{N,Z}^2 J(J+1))^{\mathrm{Nuclear}}}{(\lambda_{p,Z}^2 J(J+1))^{\mathrm{proton}}}\frac{\mu_T^2}{\mu_p^2}\sigma_{\chi-p}$$

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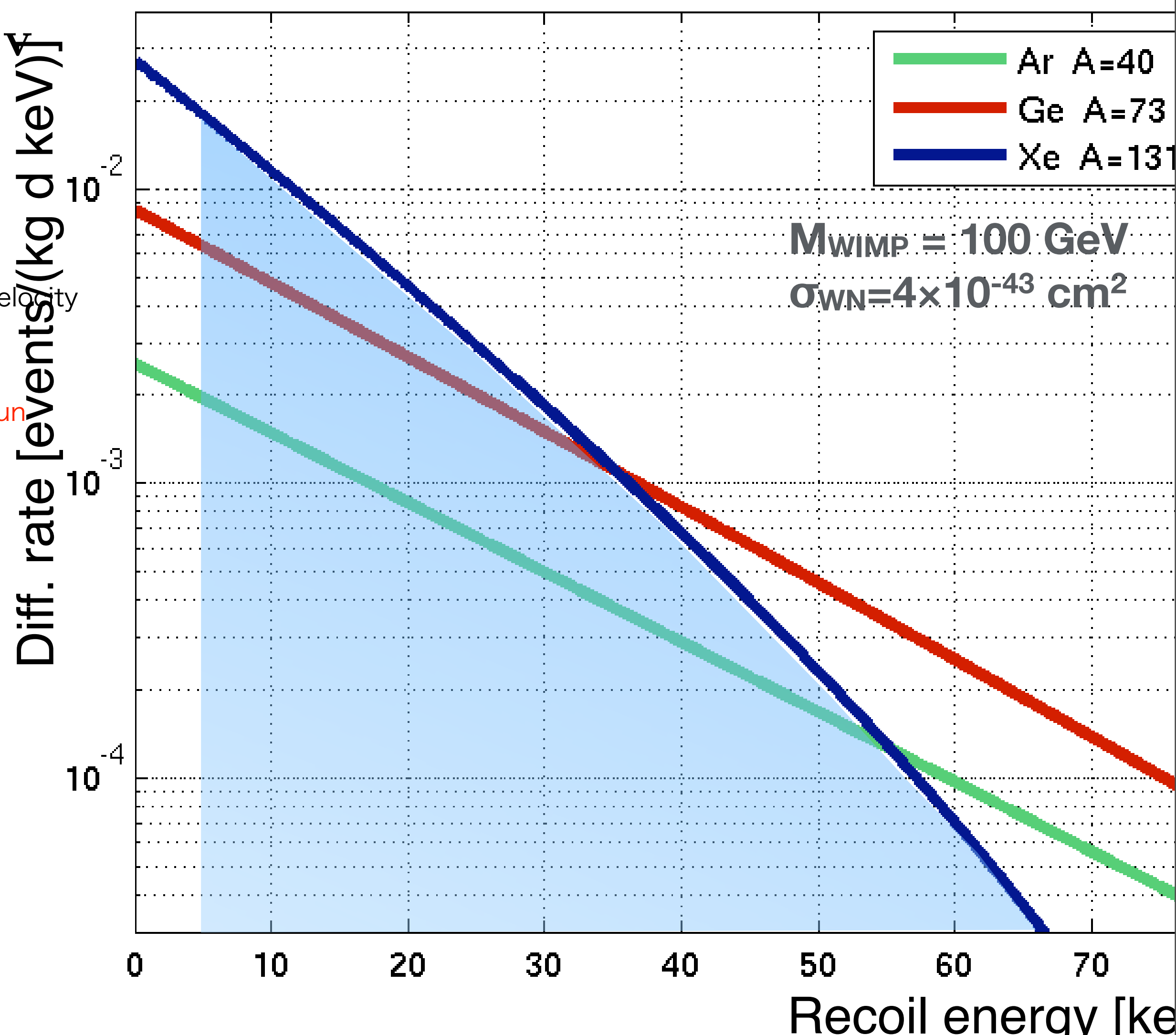

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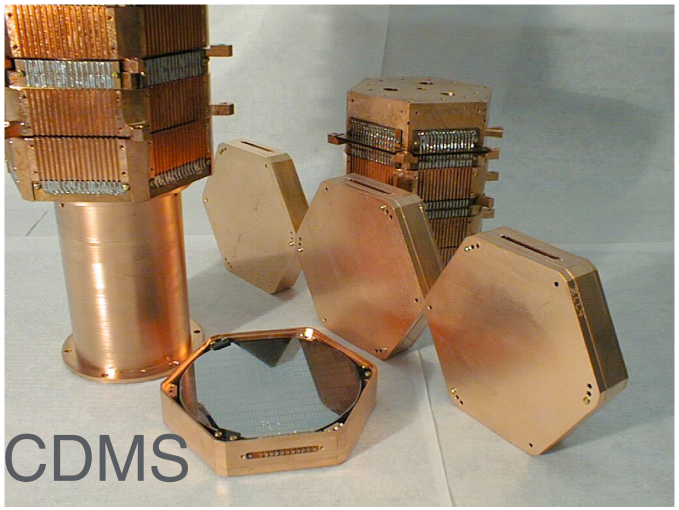
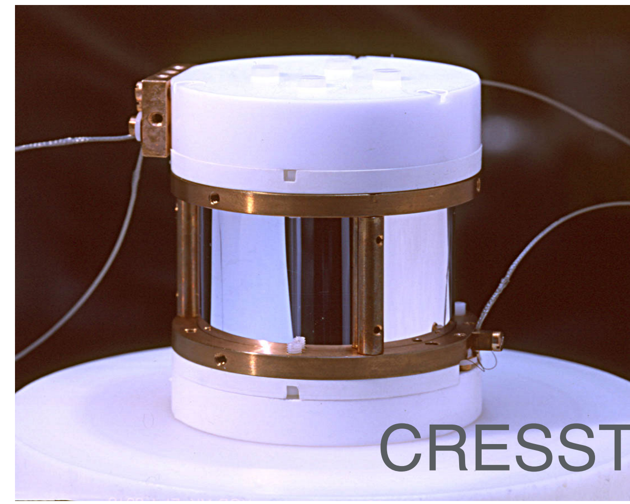
Xe (A=131) is one of the best target

Direct Detection Experiments (background rejection)



CDMS
EDELWEISS

Phonons

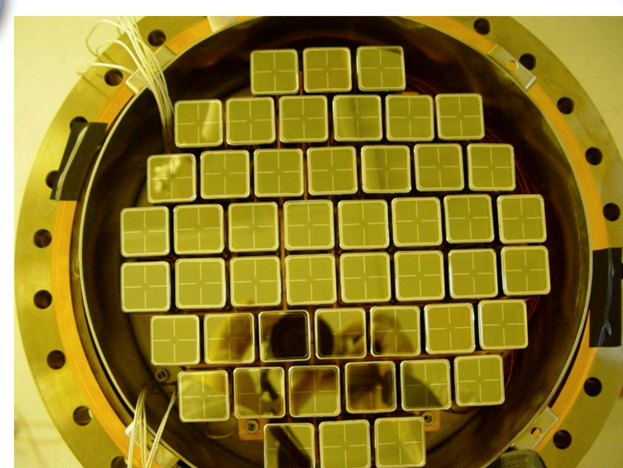


CRESST

E_R

Charge

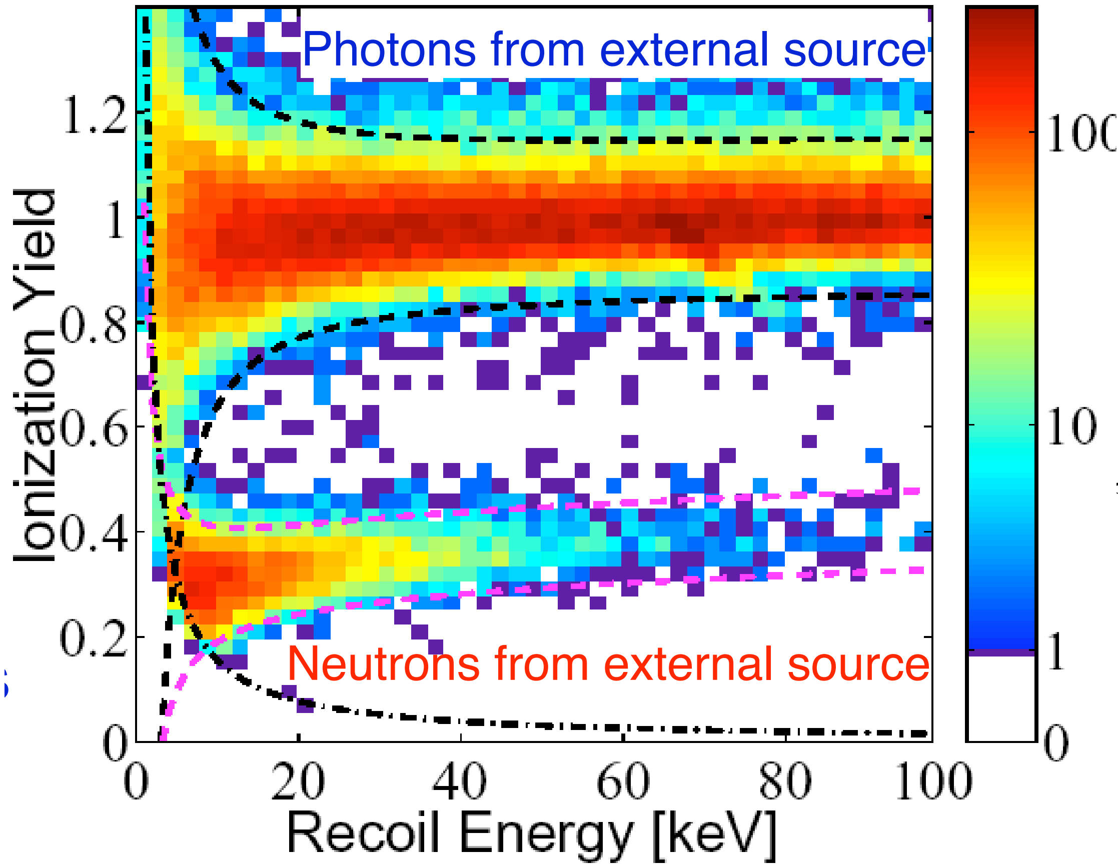
Light

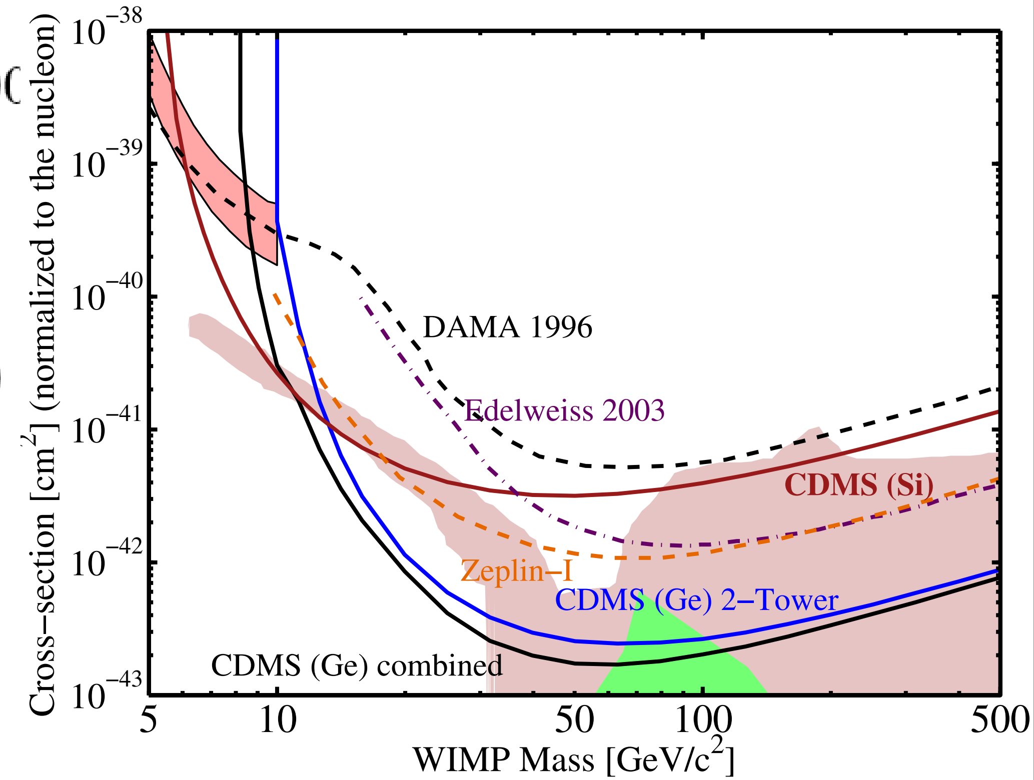


ZEPLIN, XENON
XMASS, WARP, ArDM

CDMS

- Spin-Independent WIMP upper limits (90% CL) and SUSY predictions:





Why Liquid Xenon ?

- High Atomic mass Xe (A~131) good for SI case (cross section ∝ A^2)
- Odd Isotope (Nat. abun: 48%, 129,131) with large SD enhancement factors
- High atomic number (Z~54) and density (ρ=3g/cc):
  - compact, flexible and large mass detector.
- High photon yield (~ 42000 UV photons/MeV at zero field) and high charge yield
- Easy to purify for both electro-negative and radioactive purity
  - by recirculating Xe with getter for electro-negative
  - Charcoal filter or distillation for Kr removal

The XENON Collaboration

Columbia University

Elena Aprile, Karl-Ludwig Giboni, Sharmila Kamat,
Maria Elena Monzani, Guillaume Plante*, Roberto Santorelli, Masaki Yamashita

Brown University

Richard Gaitskell, Simon Fiorucci, Peter Sorensen*, Luiz DeViveiros*

Aachen, University of Florida

Laura Baudis, Jesse Angle*, Joerg Orboeck, Aaron Manalaysay*

Lawrence Livermore National Laboratory

Adam Bernstein, Chris Hagmann, Norm Madden and Celeste Winant

Case Western Reserve University

Tom Shutt, Eric Dahl*, John Kwong* and Alexander Bolozdynya

Rice University

Uwe Oberlack , Roman Gomez* and Peter Shagin

Yale University

Daniel McKinsey, Richard Hasty, Angel Manzur*, Kaixuan Ni

LNGS

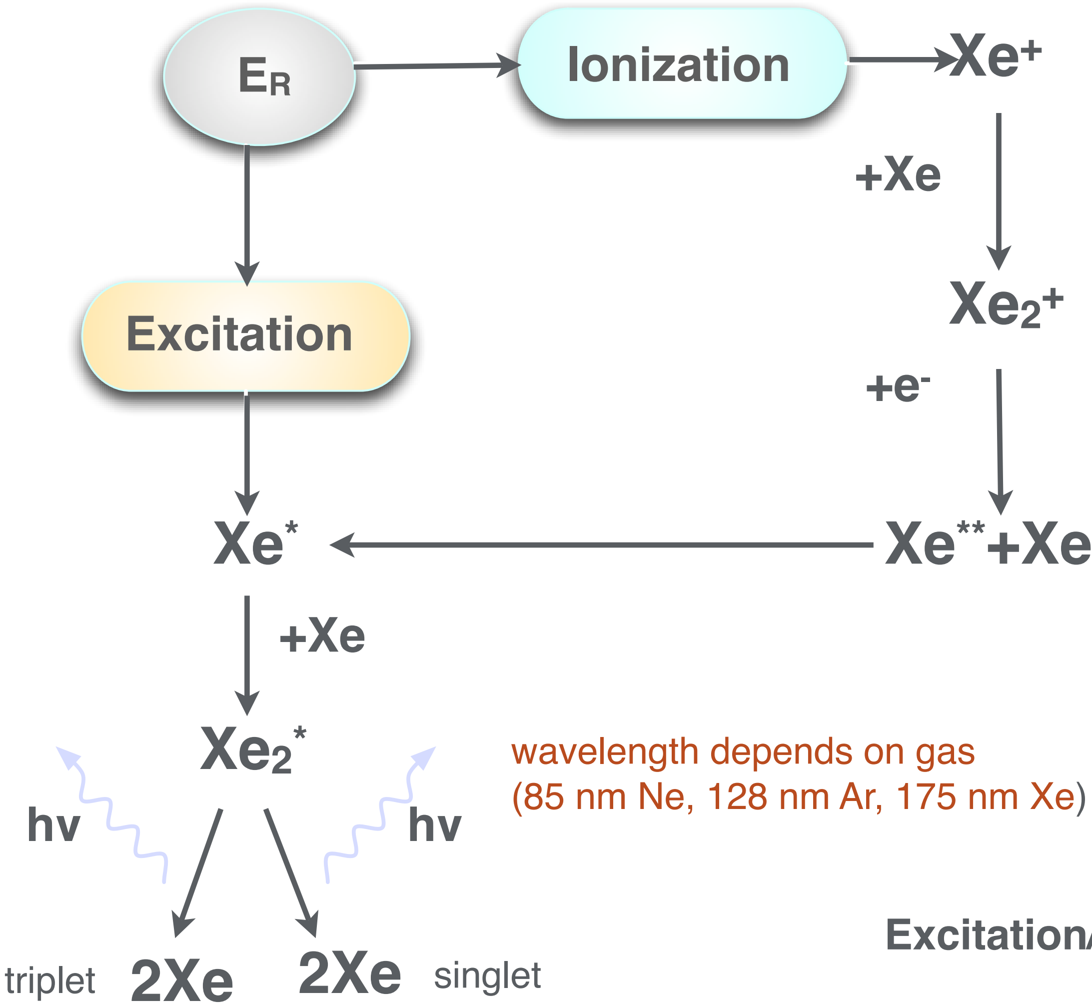
Francesco Arneodo, Alfredo Ferella*

Coimbra University

Jose Matias Lopes, Joaquin Santos, Luis Coelho*, Luis Fernandes

XENON consists of US and European institutes.

Charge and Light in Noble Liquids



wavelength depends on gas
(85 nm Ne, 128 nm Ar, 175 nm Xe)

time constants depend on gas
(few ns/15.4μs Ne, 10ns/1.5μs Ar, 3/27 ns Xe)

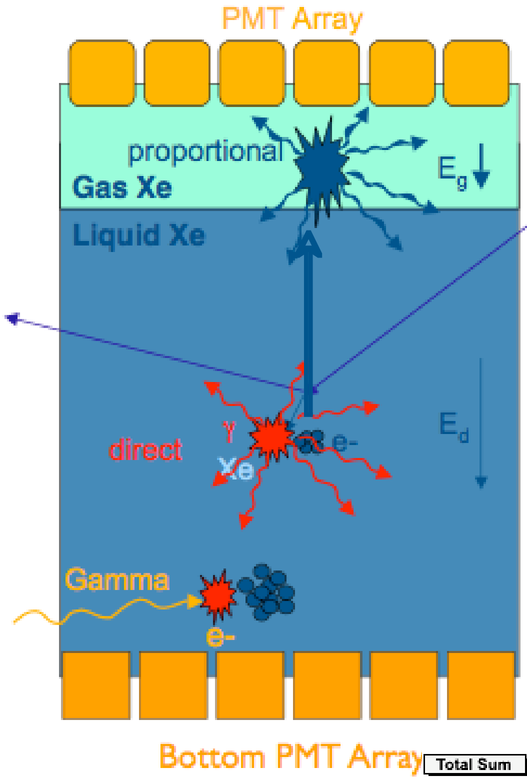
$$\begin{aligned} \mathrm{Xe}^* + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^* \\ \mathrm{Xe}_2^* &\rightarrow 2\mathrm{Xe} + h\nu \end{aligned}$$

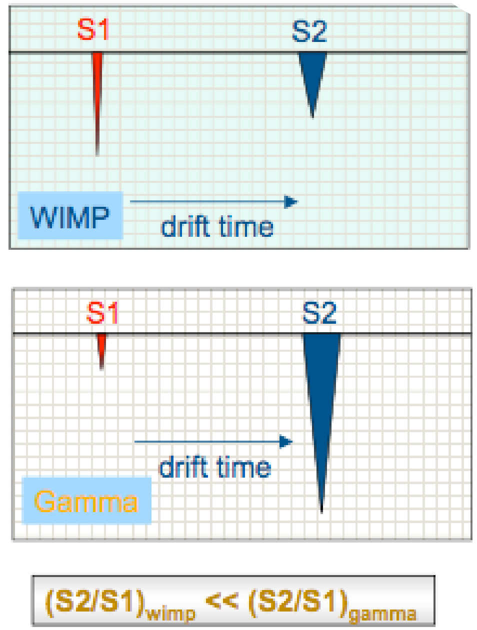
$$\begin{aligned} \mathrm{Xe}^+ + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^+ \\ \mathrm{Xe}_2^+ + e^- &\rightarrow \mathrm{Xe}^{**} + \mathrm{Xe} \\ \mathrm{Xe}^{**} &\rightarrow \mathrm{Xe}^* + \mathrm{heat} \\ \mathrm{Xe}^* + \mathrm{Xe} &\rightarrow \mathrm{Xe}_2^* \\ \mathrm{Xe}_2^* &\rightarrow 2\mathrm{Xe} + h\nu \end{aligned}$$

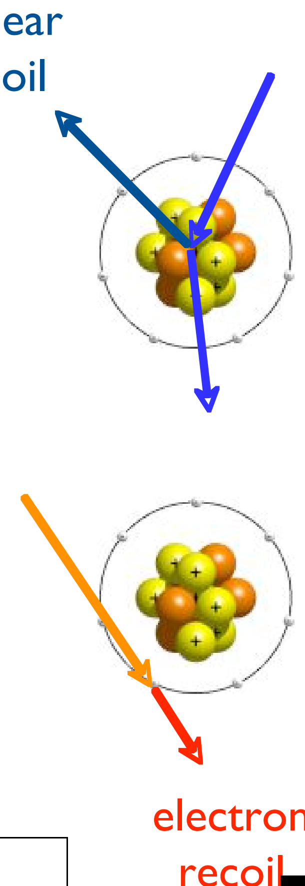
Excitation/Ionization depends on dE/dx!

=> discrimination of signal (**WIMPs=>NR**)
and (most of the) background (**gammas=>ER**)!

Event Discrimination: Electron or Nuclear Recoil

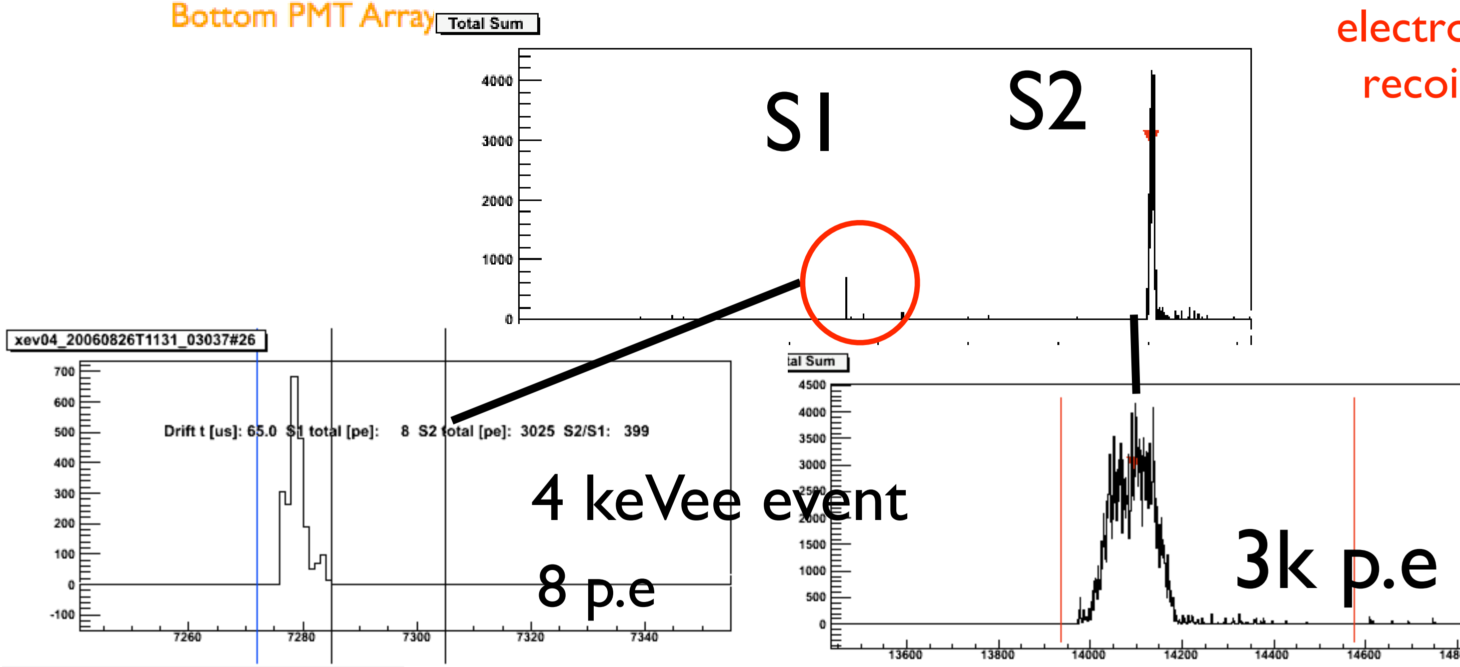




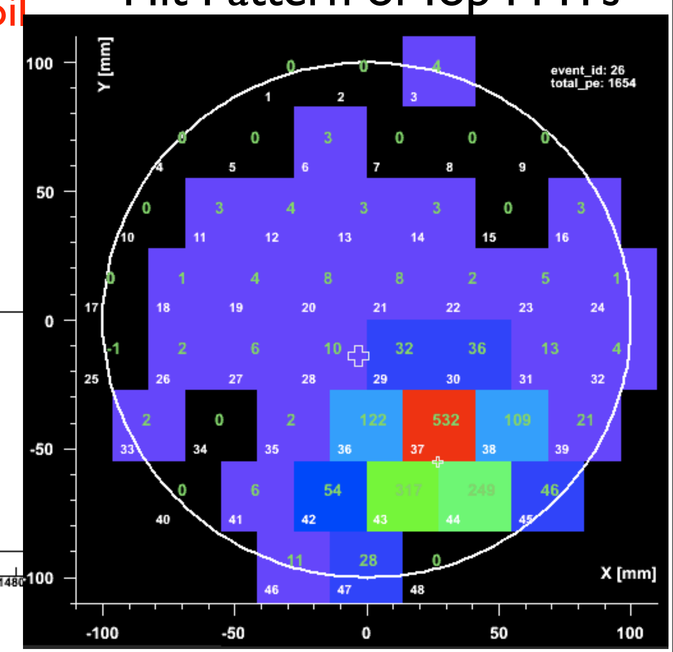


nuclear
recoil

electron
recoil



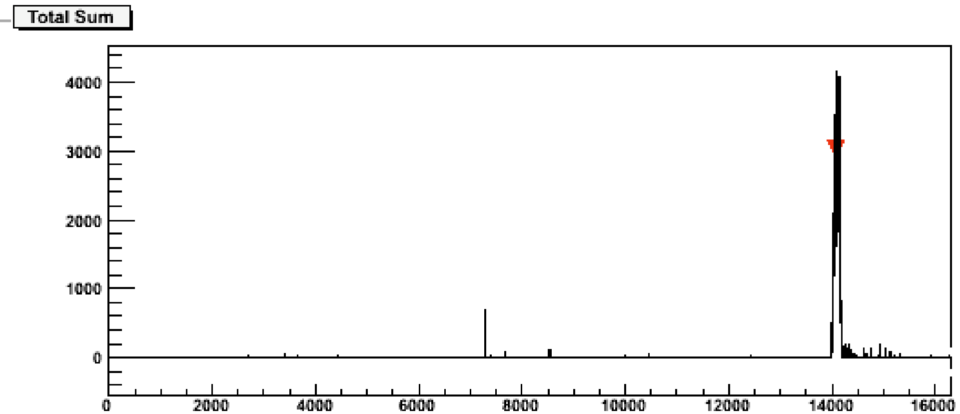
Hit Pattern of Top PMTs



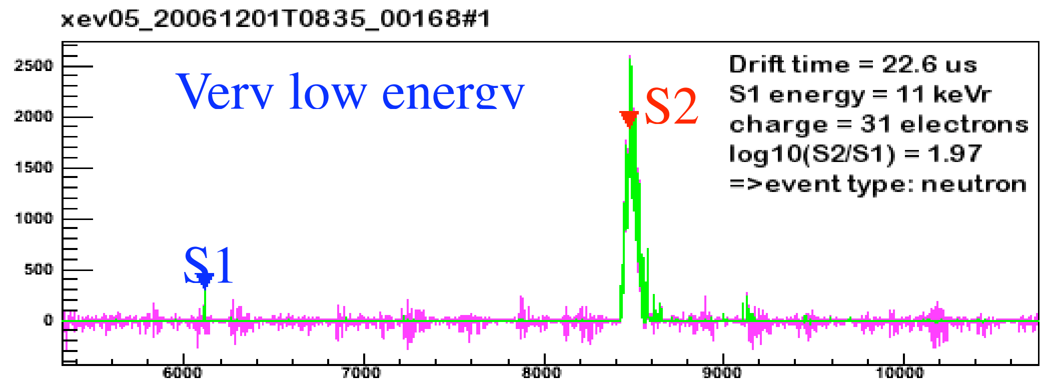
UCLA 2007/06/06

Particle ID

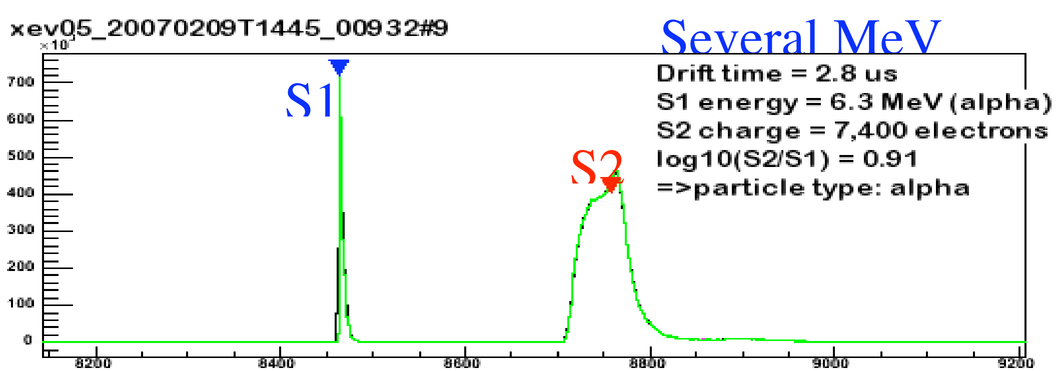
gamma



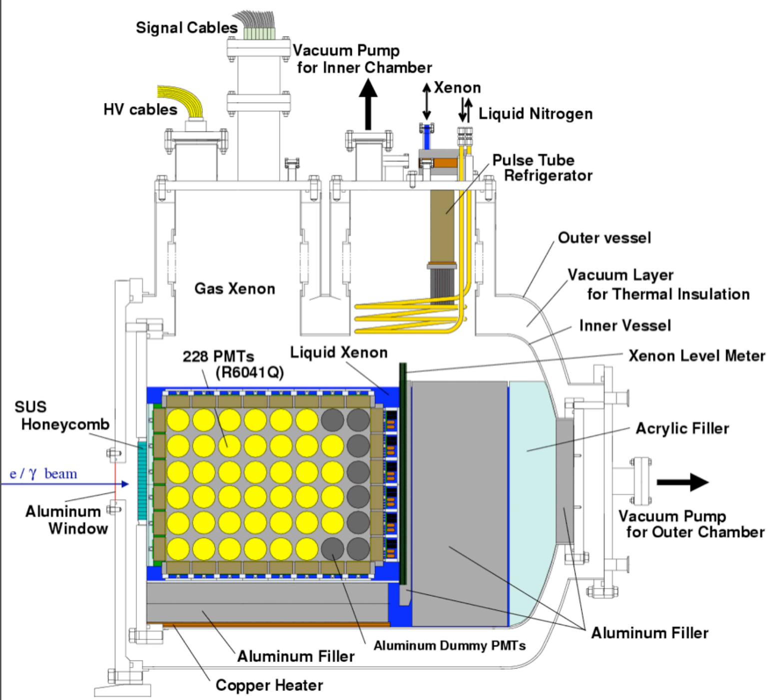
Neutron

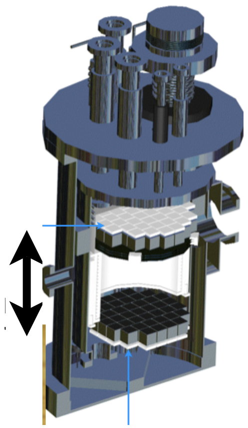


Alpha



ICEPP 向け

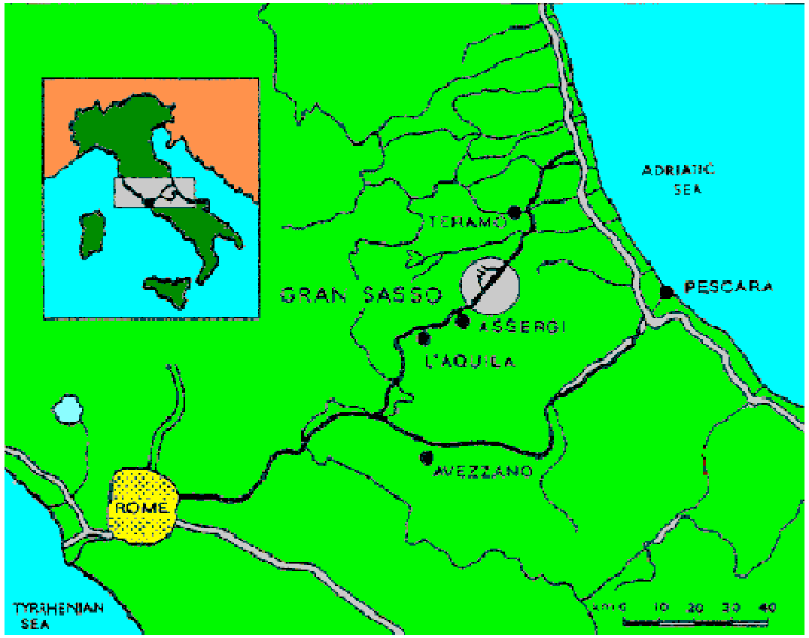




	MEG	XENON
rate[Hz]	10^5-10^6	~3
signal	S	S+Q
size	300 kg, 2.4 ton	15kg, 1 ton, 10 ton
PMT	2 inch	1 inch

XENON10 at LNGS

The Gran Sasso underground Lab



- 3 experimental halls: 100 m long, 20 m wide, 18 m high (total underground area: 18,000 m^2)
- Natural temperature: 6° C
- Relative humidity: 100%
- Location: 963 m over sea level

Main research lines:
- Neutrino physics
- Dark matter
- Nuclear astrophysics
- Gravitational waves
- Geophysics
- Biology

ta

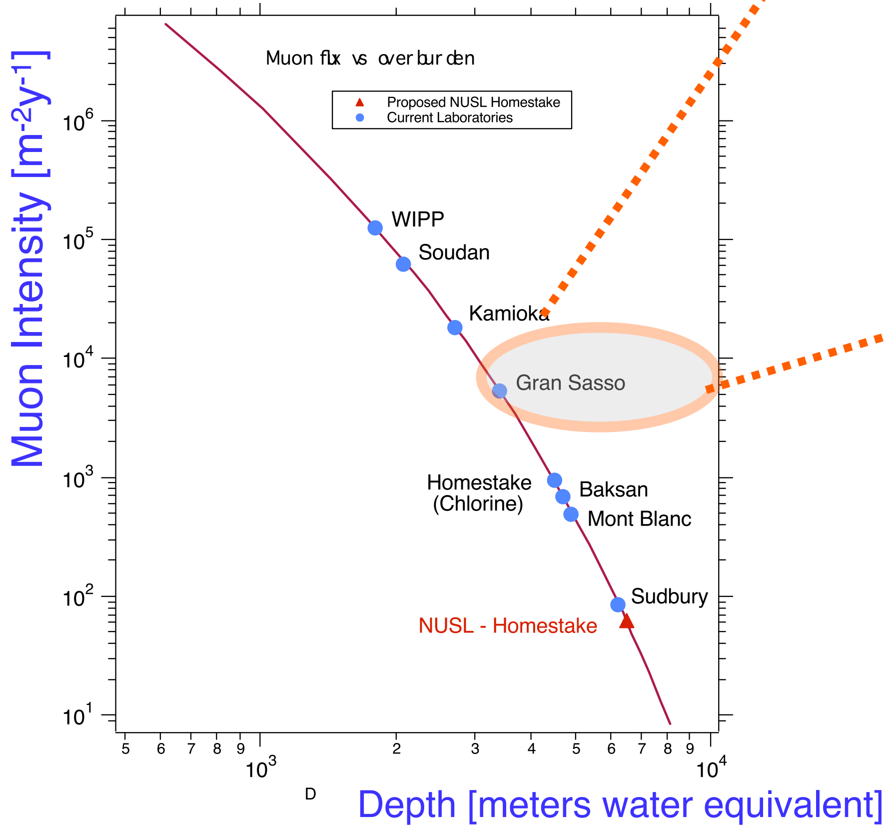
XENON10 at the Gran Sasso Laboratory

~3800 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



XENON10 at the Gran Sasso Laboratory

LNGS July 2006

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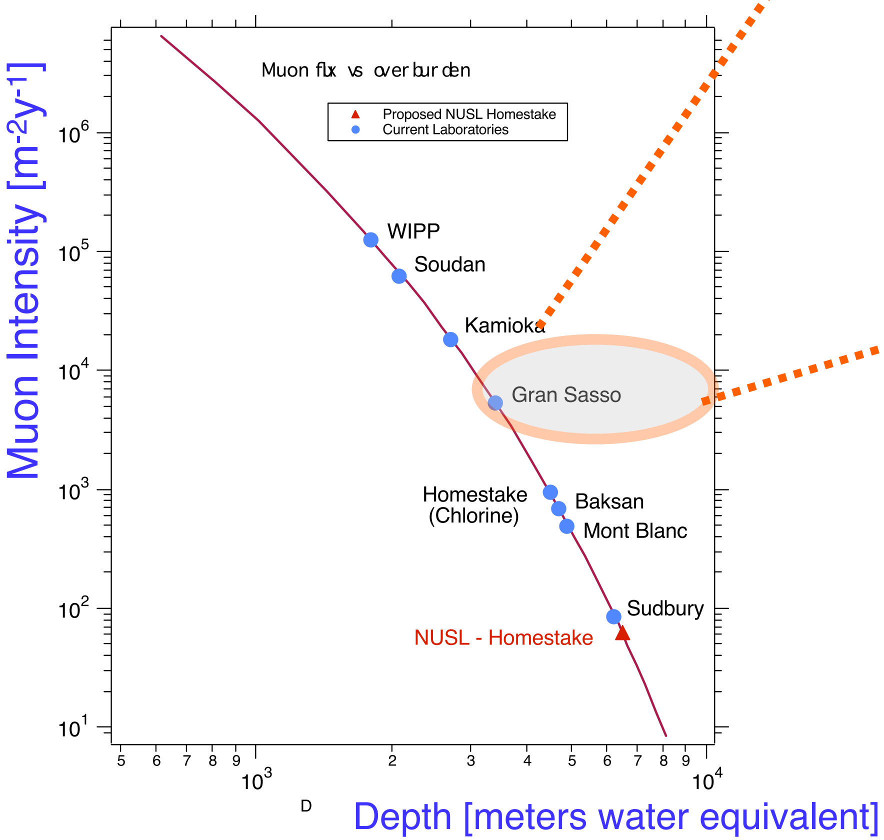
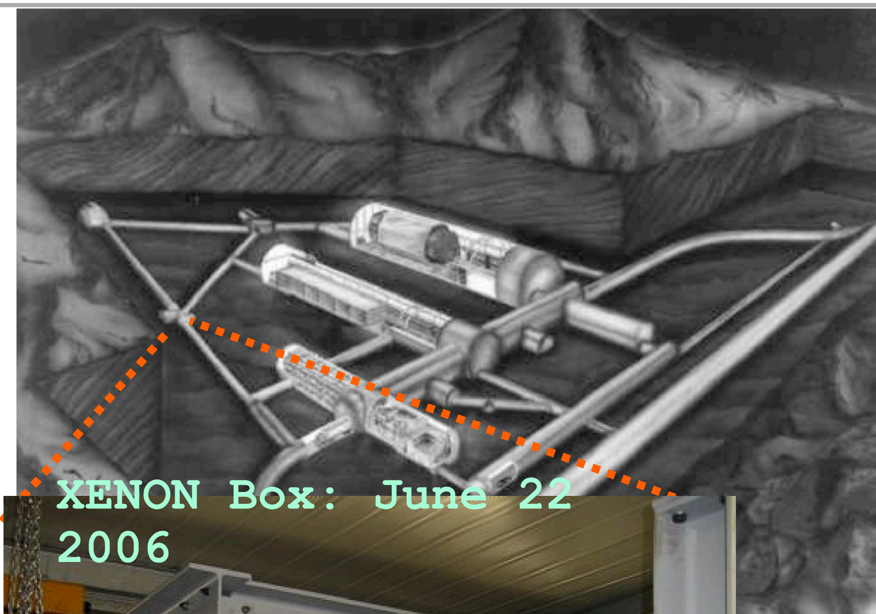
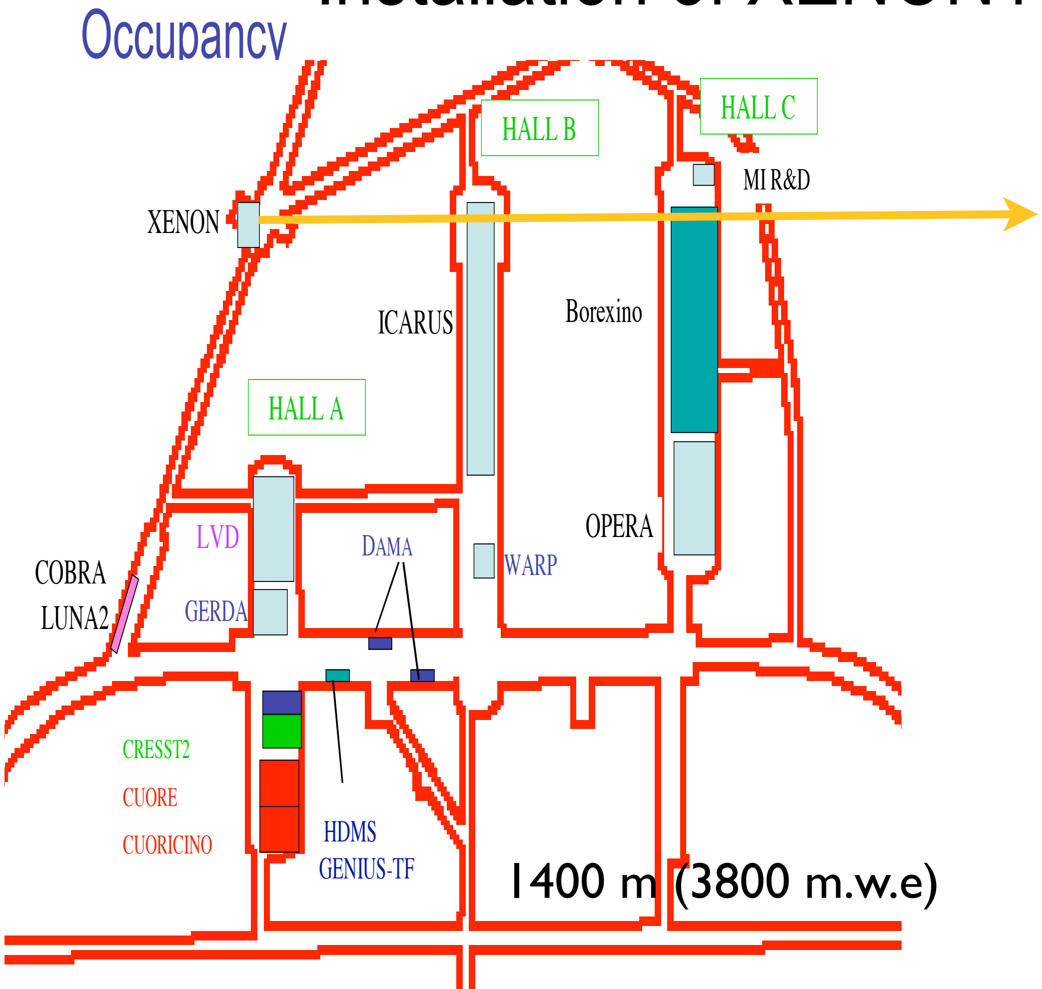
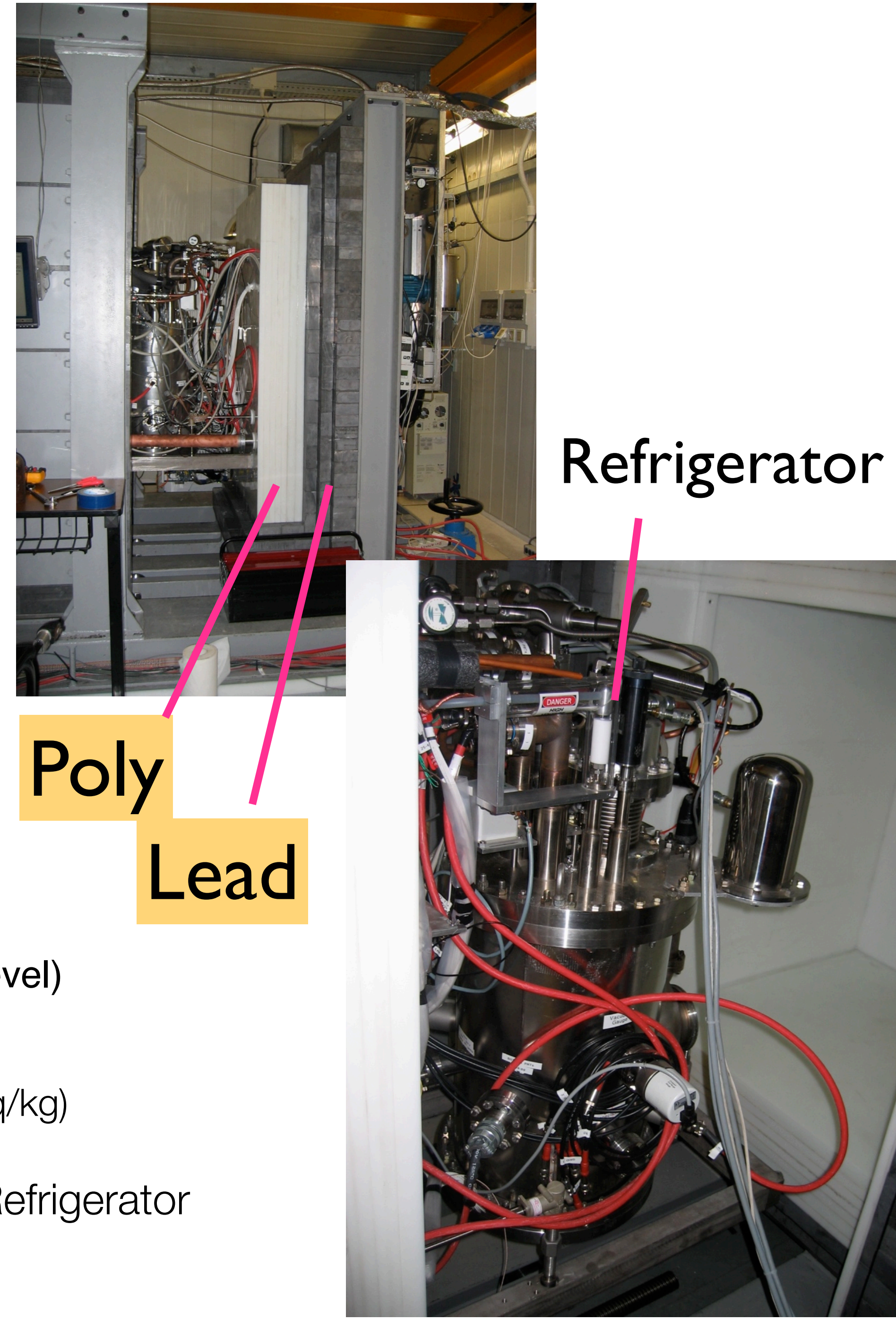




Installation of XENON10 at LNGS on July

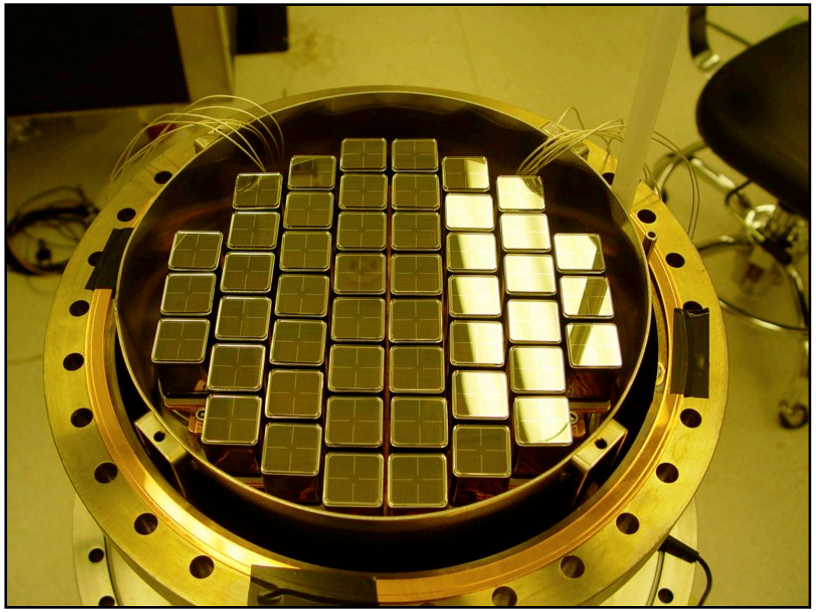


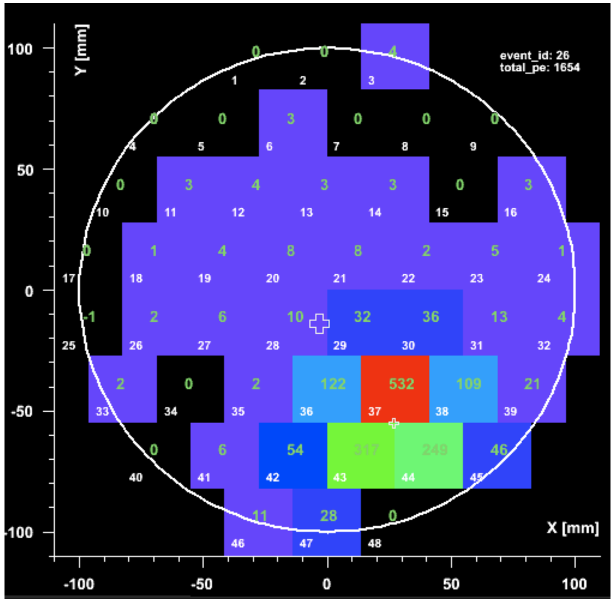


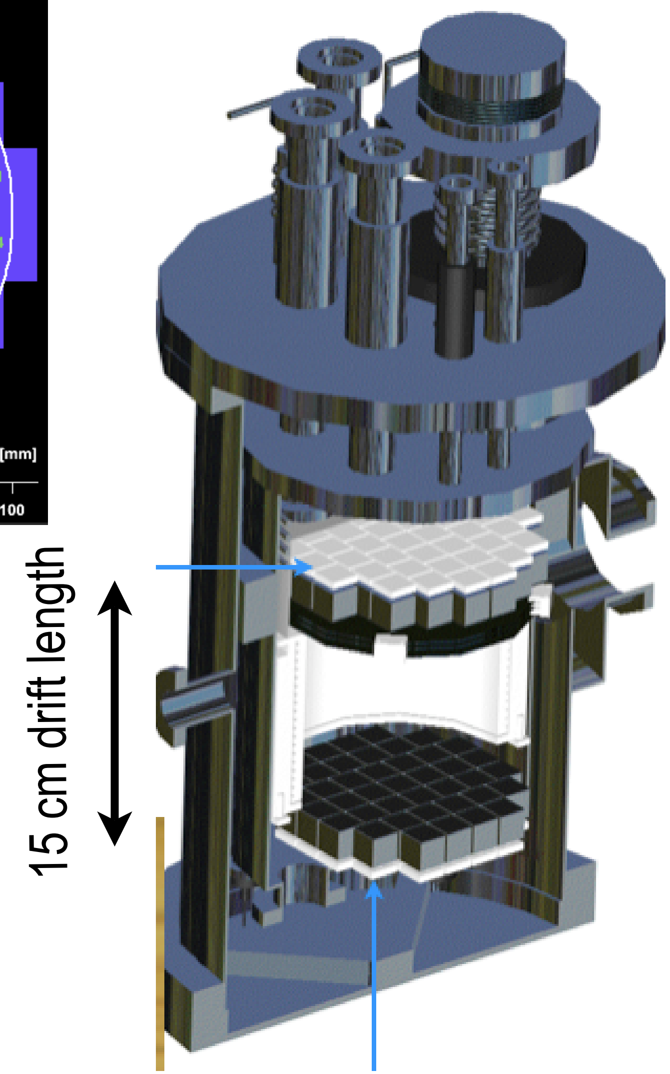
- March, 2006 From Columbia Univ. in NY to LNGS
- Muon flux ~ 24 μ/m²/day (10^6 reduction from sea level)
- Neutron Flux ~ 10^{-6} n/cm^{-2}/sec
- Shield
  - 20 cm Lead (15cm-700Bq/kg ^{210}Pb, 5cm-15Bq/kg)
  - 20 cm Polyethylene
- Full checkout of cryogenics with Pulse Tube Refrigerator
  - 10 months operation with stable condition

XENON10 Detector

48 PMTs on top



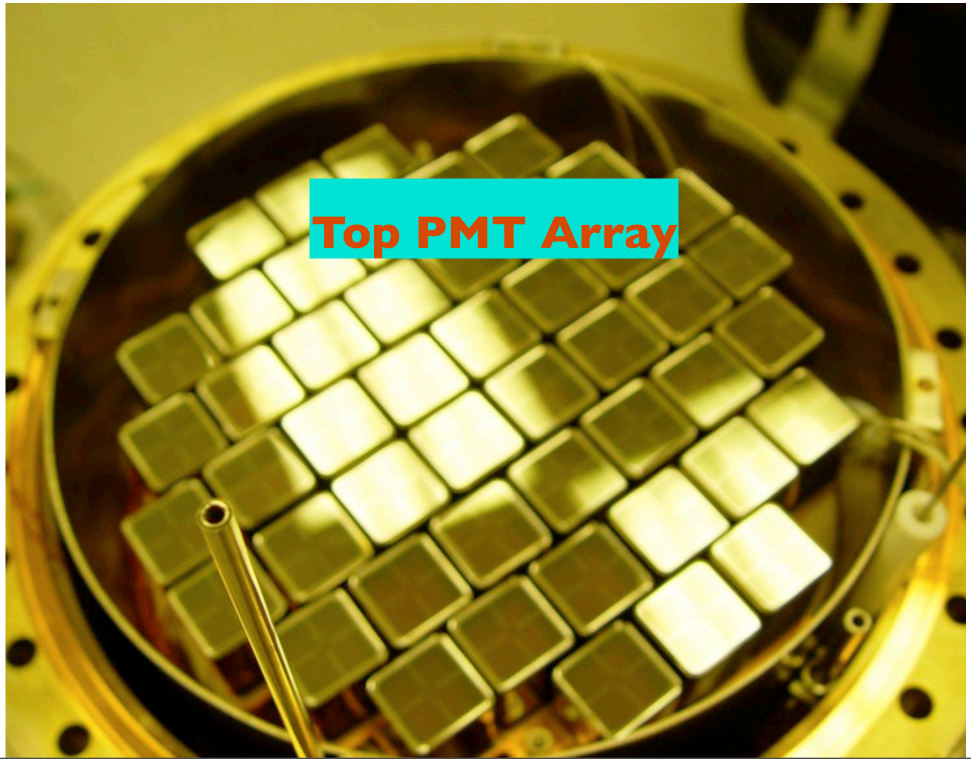




- 48 PMTs on top, 41 on bottom,
    - Hamamatsu R8520 PMT:Compact metal channel:
    - 1 inch square x 3.5 cm
    - Quantum Efficiency: >20% @ 178 nm
- 20 cm diameter, 15 cm drift length
- 22 kg needed to fill the TPC. Active volume 15 kg.
- 3D position sensitive TPC
    - Z-position: Drift Time, X-Y position: Top array of PMTs (neural network)

The XENON10 Photomultipliers

- **Hamamatsu R8520 1”×3.5 cm**
- bialkali-photocathode Rb-Cs-Sb,
- Metal Channel; 10 dynodes
- Quartz window; at -100°C and 5 bar
- Quantum efficiency > 20% @ 178 nm
- Low Radioactivity: U/Th/K/Co measured as 0.17±0.04/0.20±0.09/10±1/0.56±0.05 mBq/PMT



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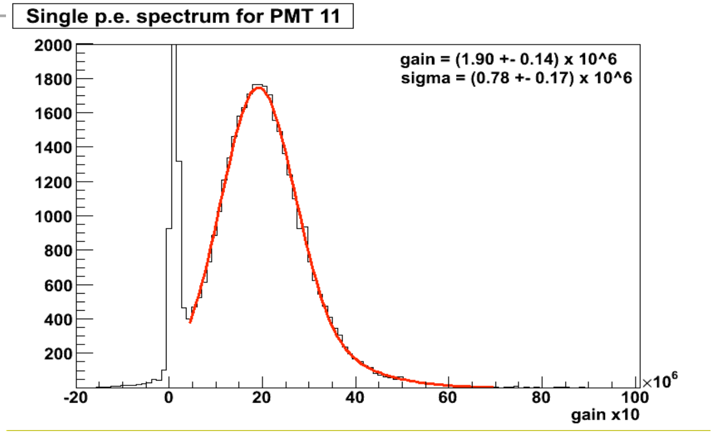

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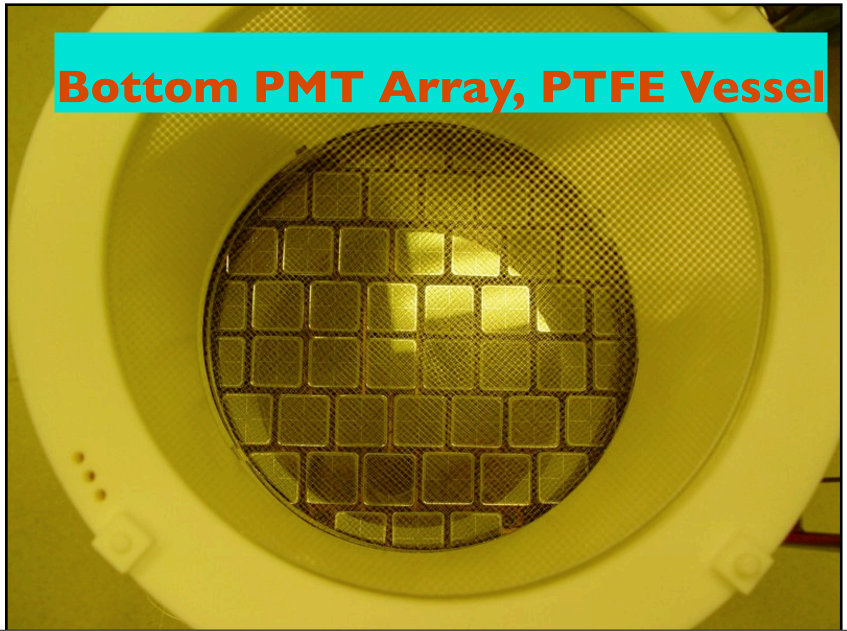

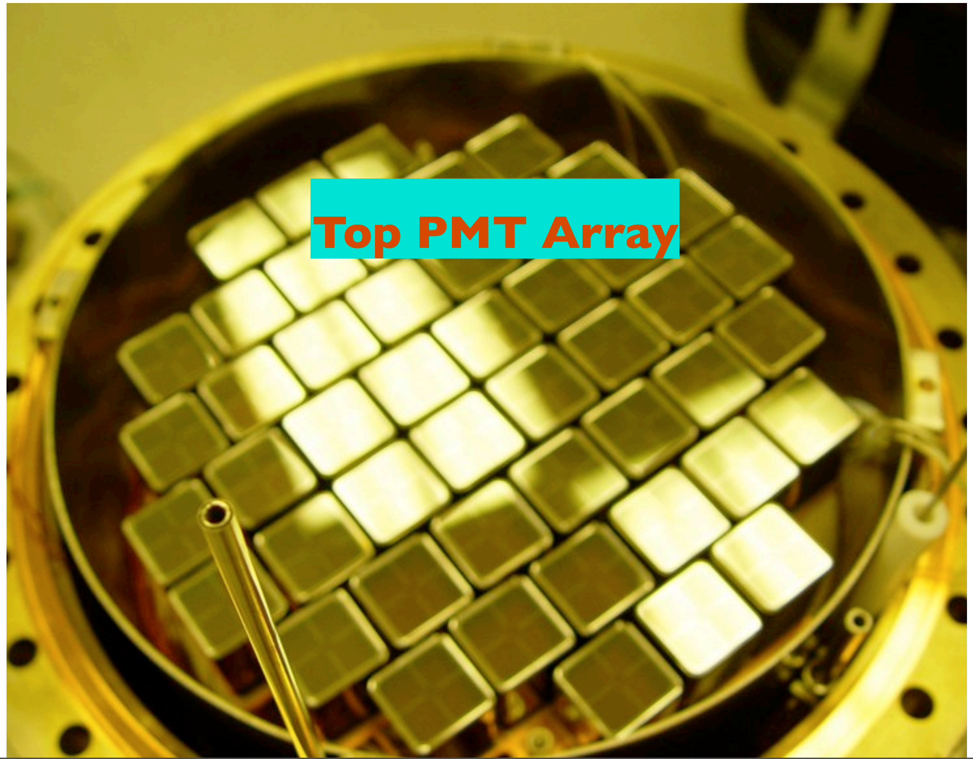

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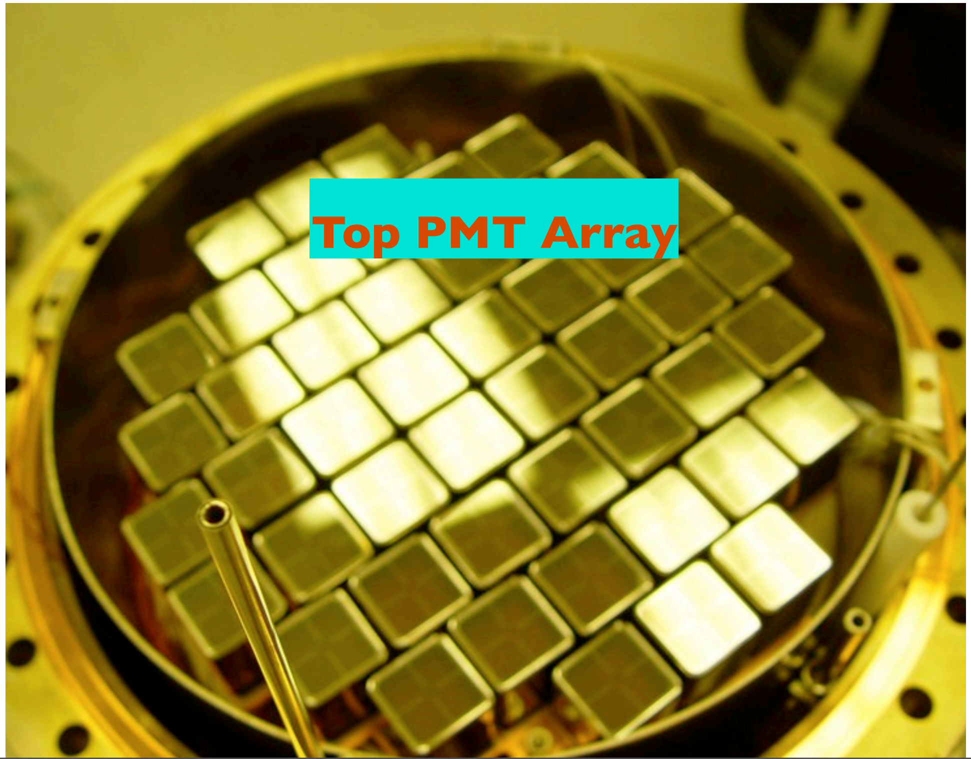

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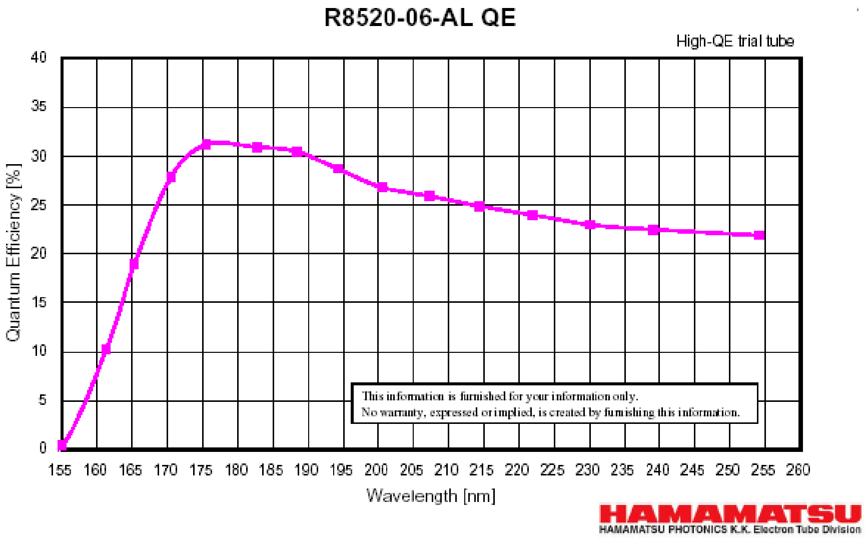

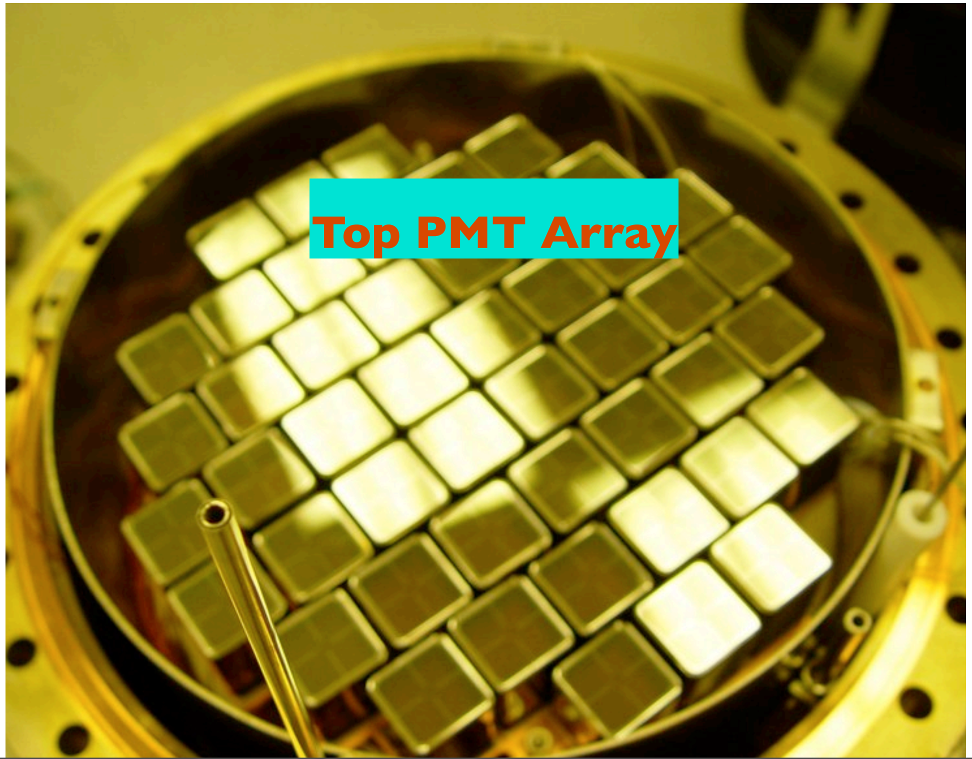

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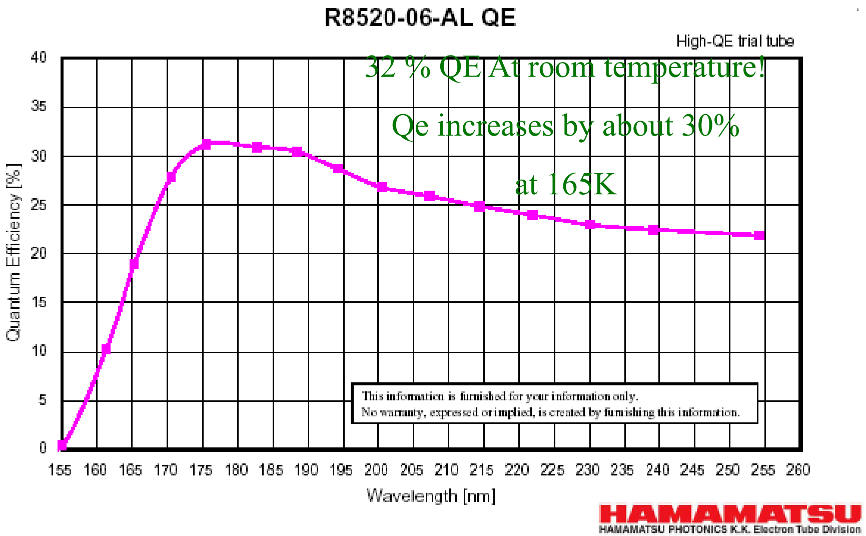
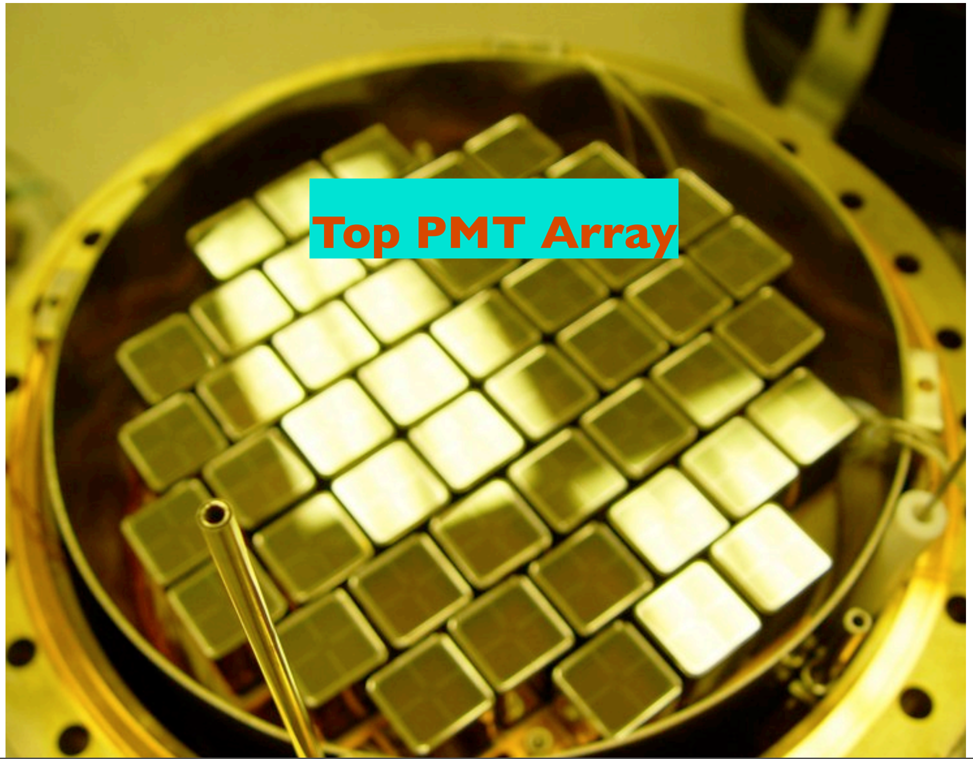
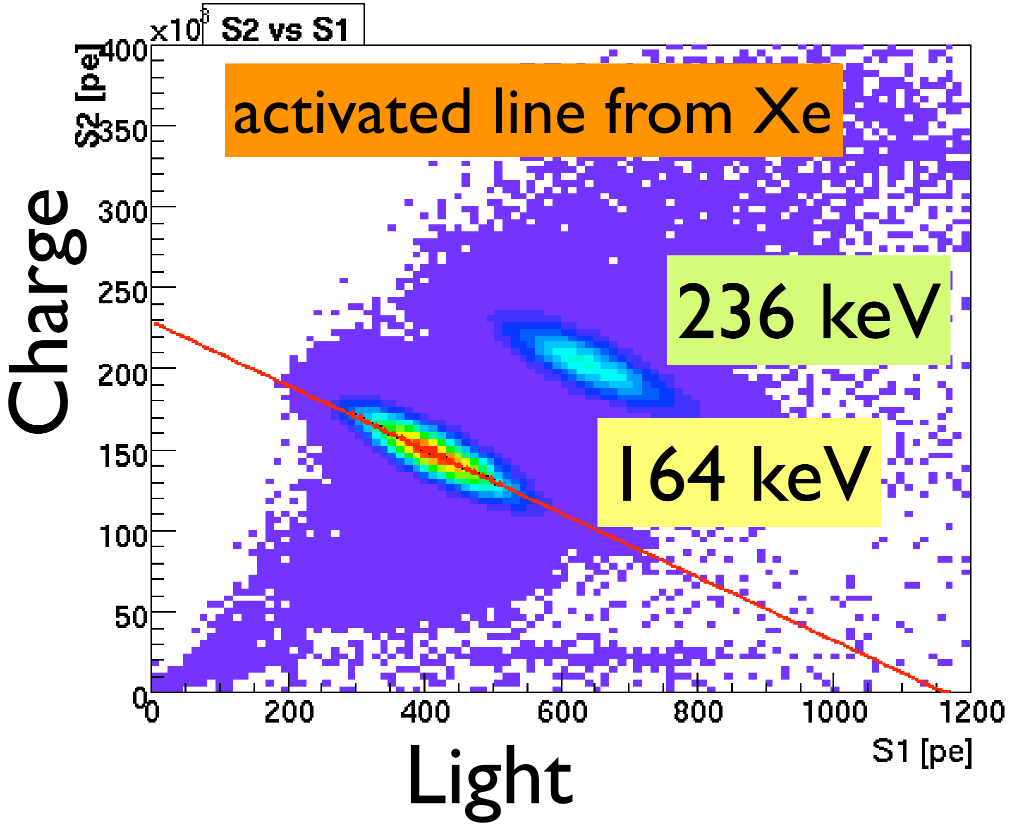
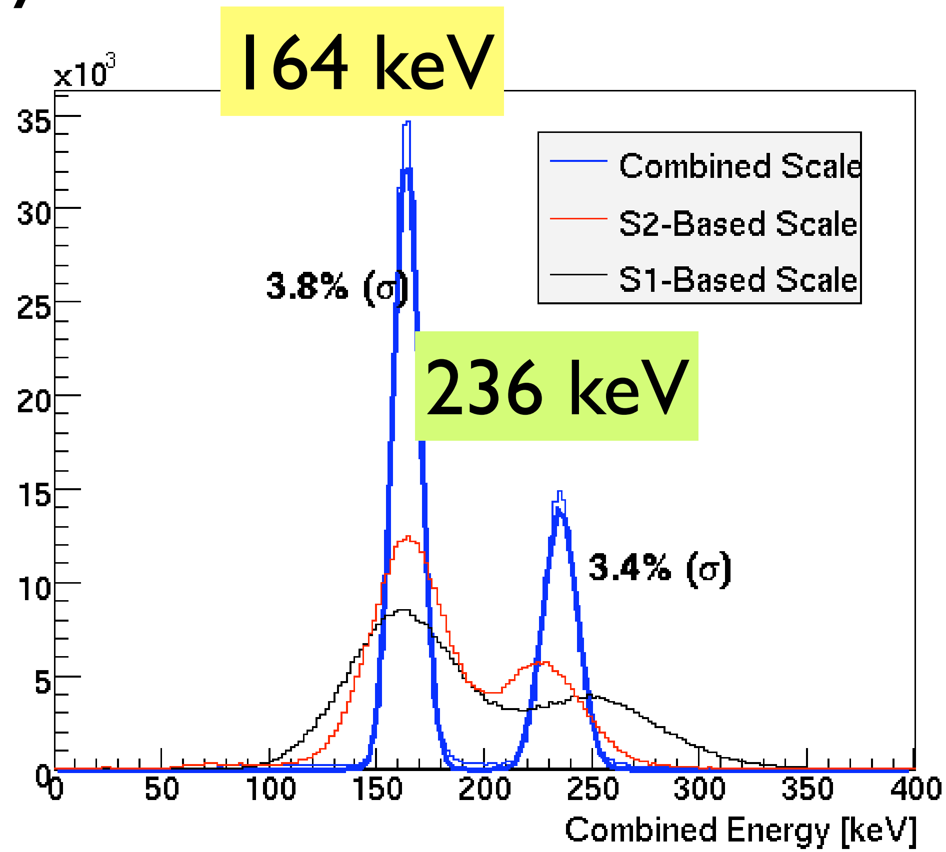
- Low Radioactivity: U/Th/K/Co measured as 0.17±0.04/0.20±0.09/10±1/0.56±0.05 mBq/PMT





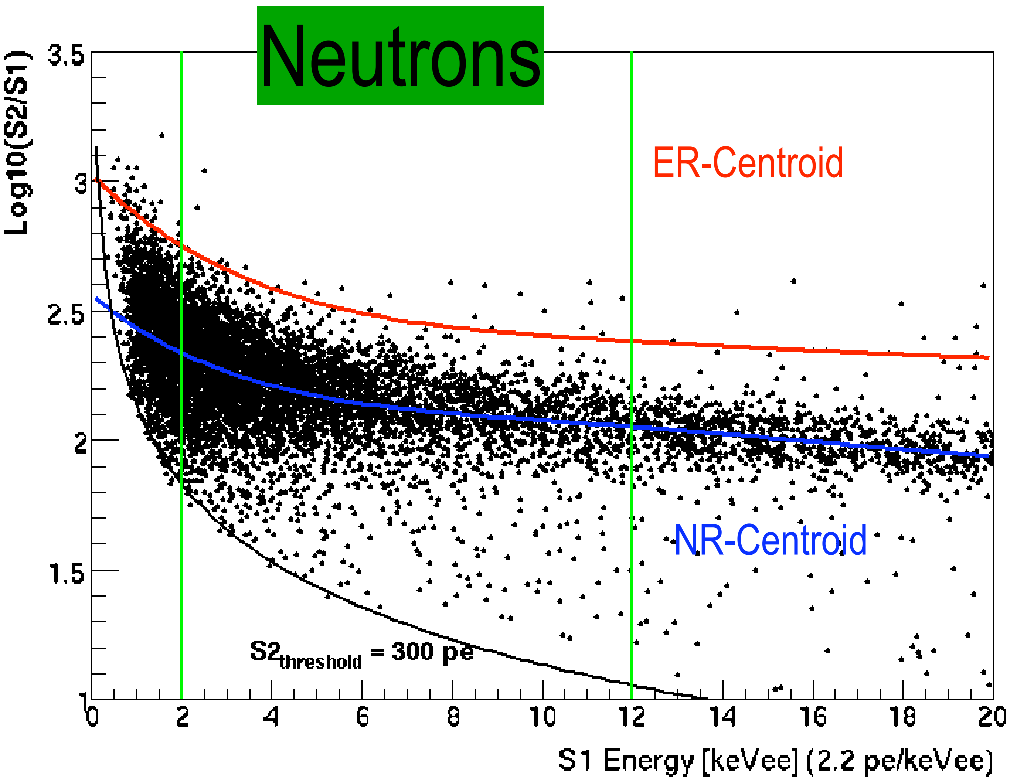
XENON10 Calibration by Activated Xe

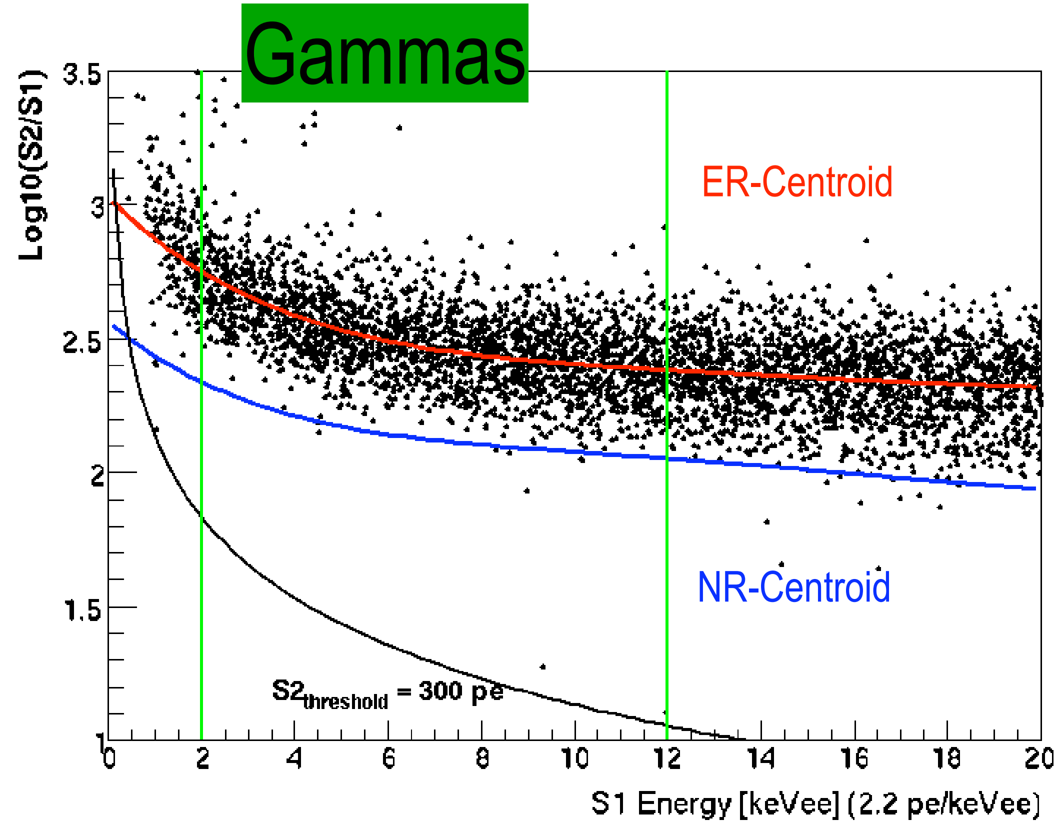




- Position dependency correction by looking at activated line.
  - Uniform source in the whole detector
- Activated Xe (5×10^6 n/s Cf, ~ 2 weeks)
- 164 keV Xe131-m, 236 keV Xe129-m (half life ~ 10 days)
- Injected ~ 200 g activated Xe gas into detector

XENON10 nuclear and electron recoil band calibration





AmBe Neutron Calibration (NR-band)

In-situ Dec 1, 2006 (12 hours)

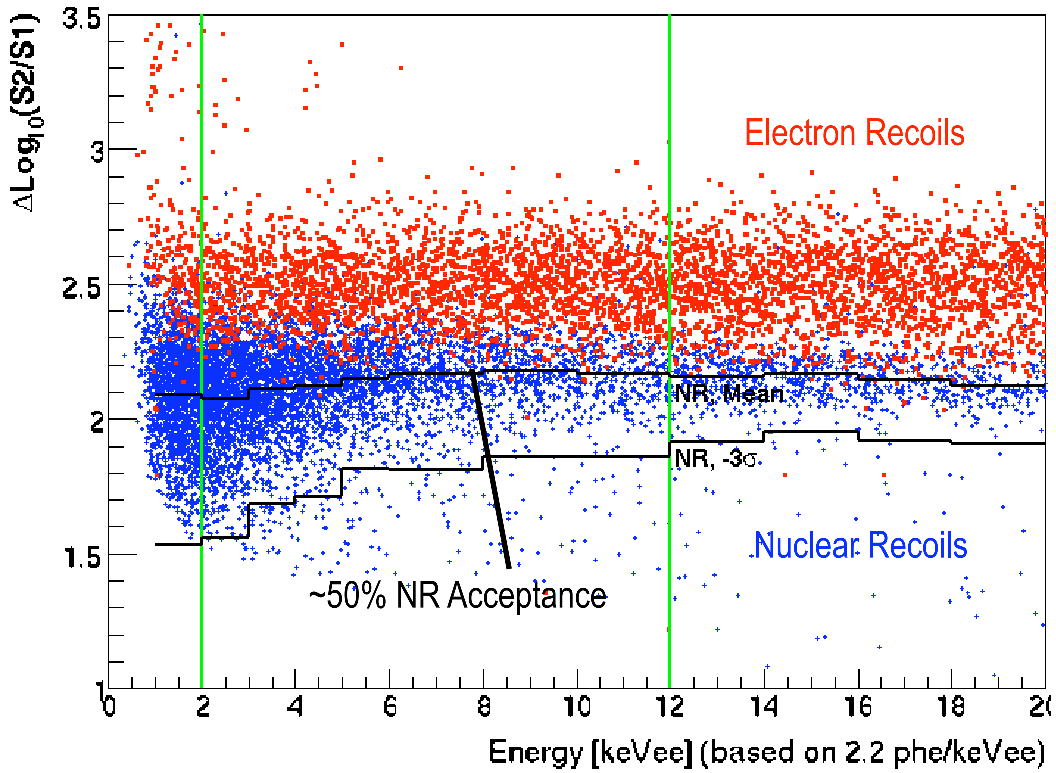
Source (~3.7MBq) in the shield

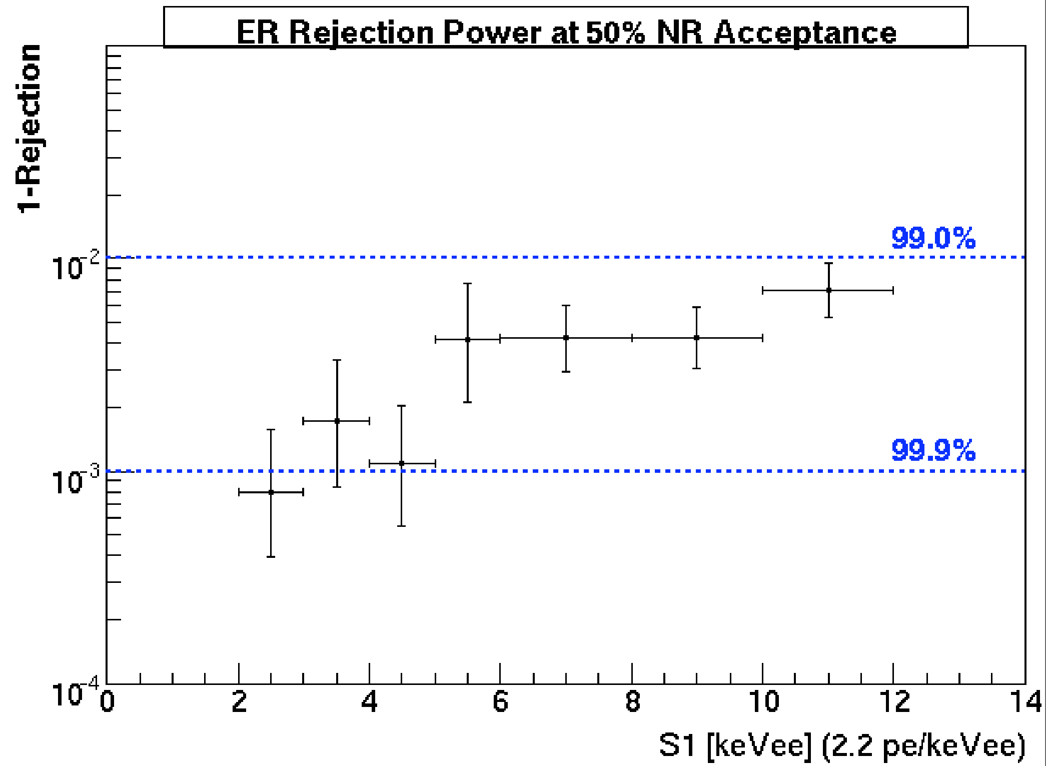
Cs-137 Gamma Calibration (ER-band)

In-situ Weekly calibration

Source (~1kBq) in the shield

XENON10 Background Rejection Power





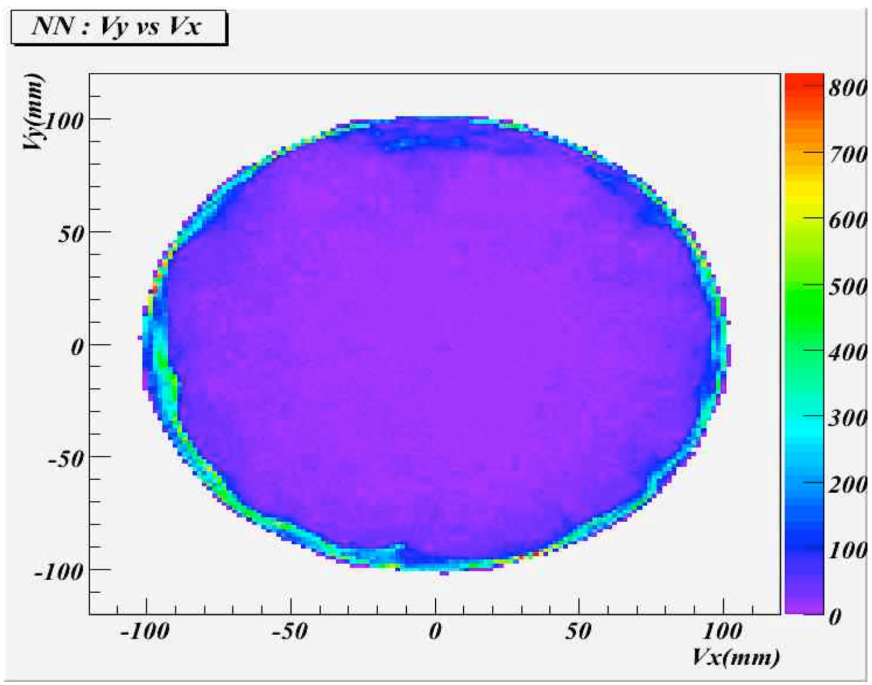
~ 99.5 % rejection power

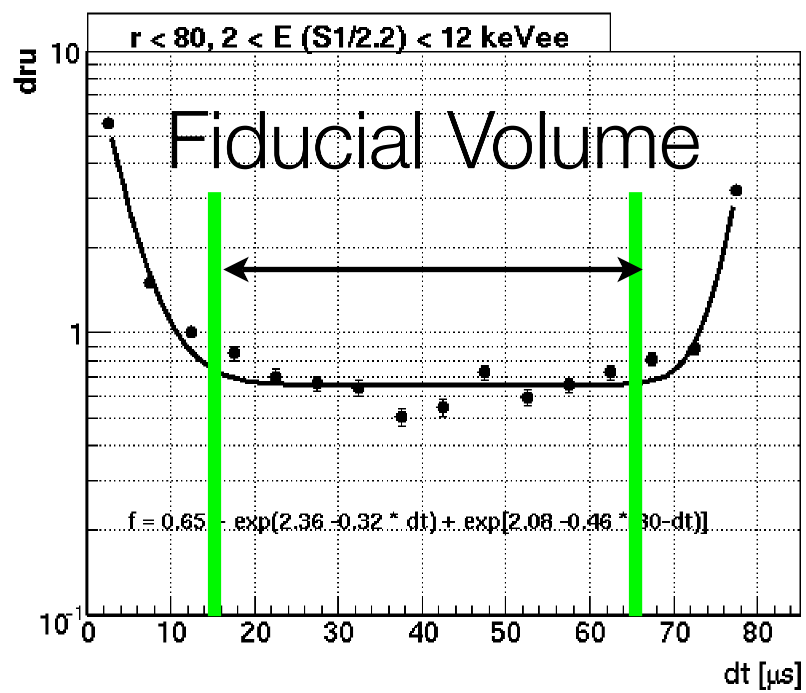
For 50% Nuclear Recoil Acceptance

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
- High Level Cuts (QC2): remove anomalous events (S1 light pattern)





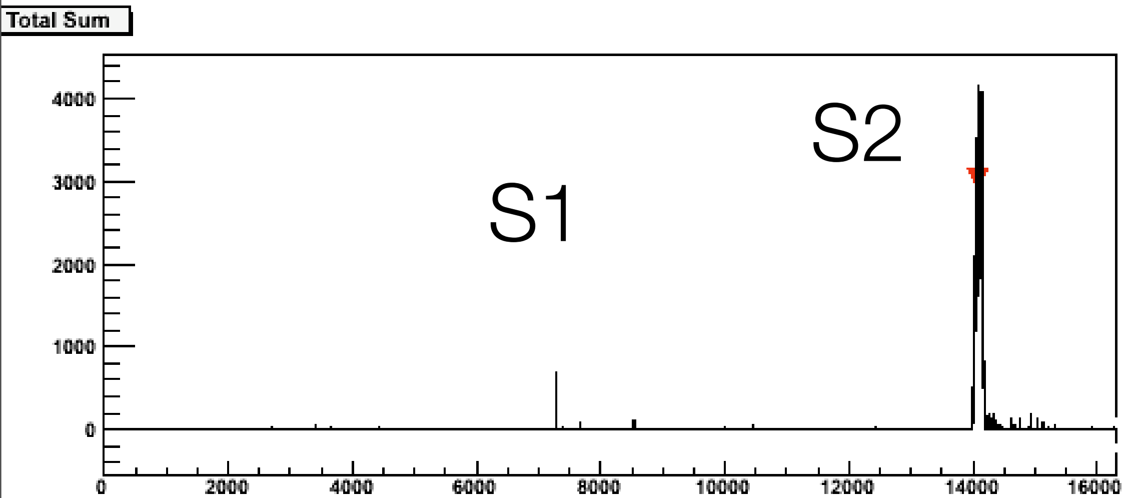
Fiducial Volume chosen by both Analyses:

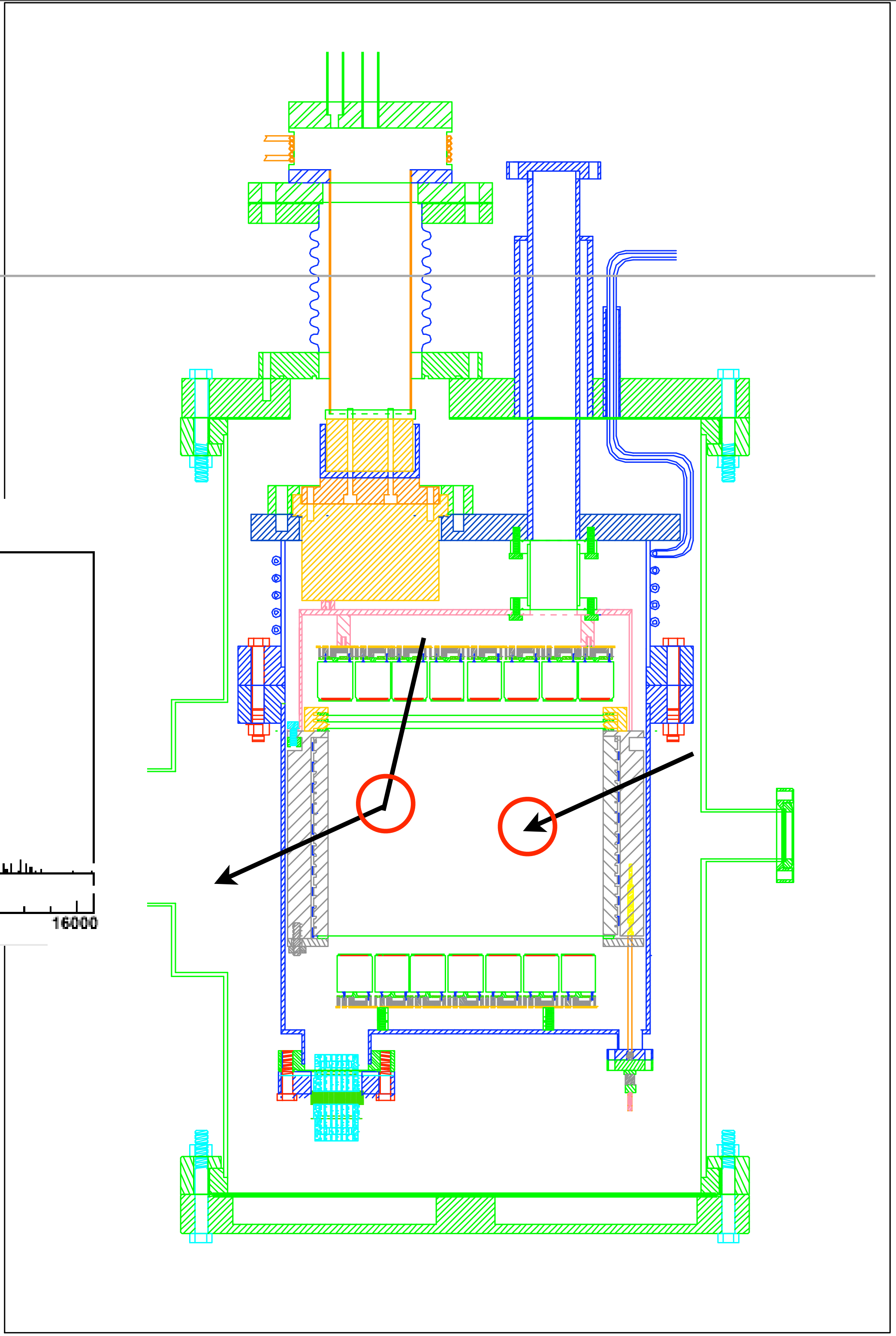
15 < dt < 65 us, r < 80 mm

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

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

Multiple Scatter Cut

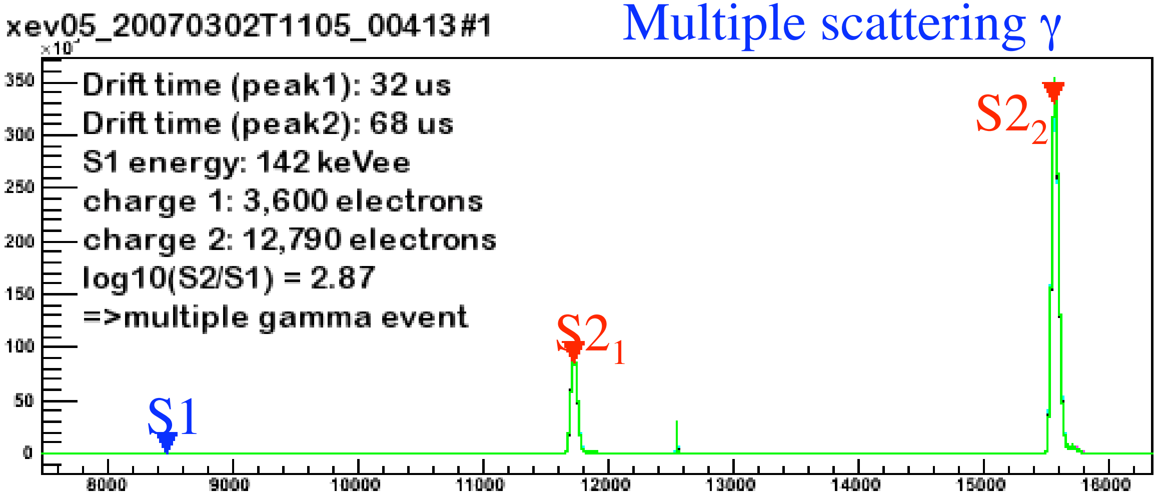


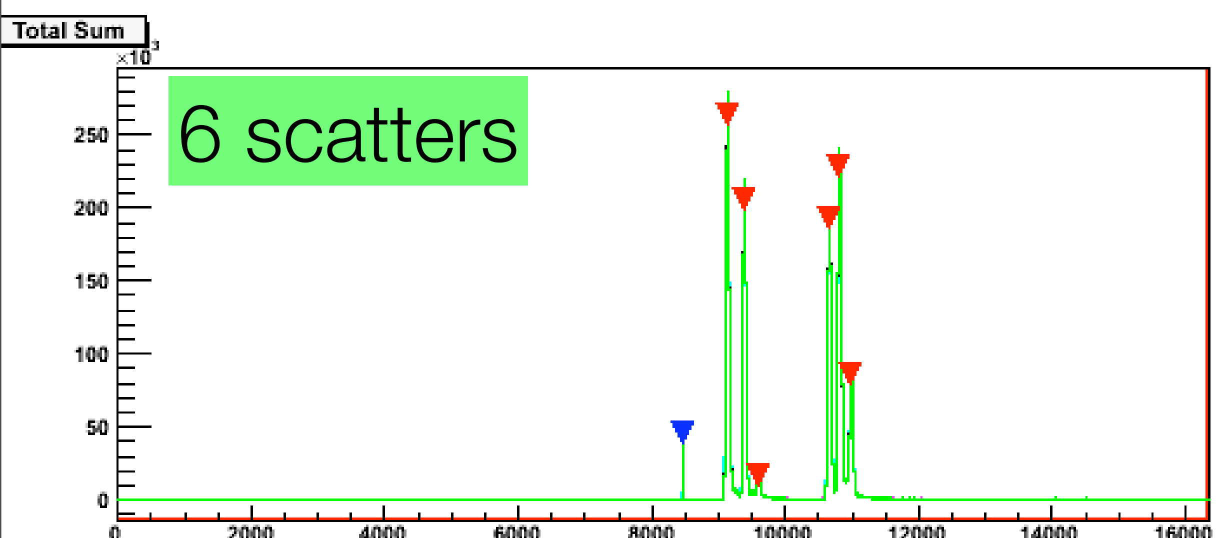


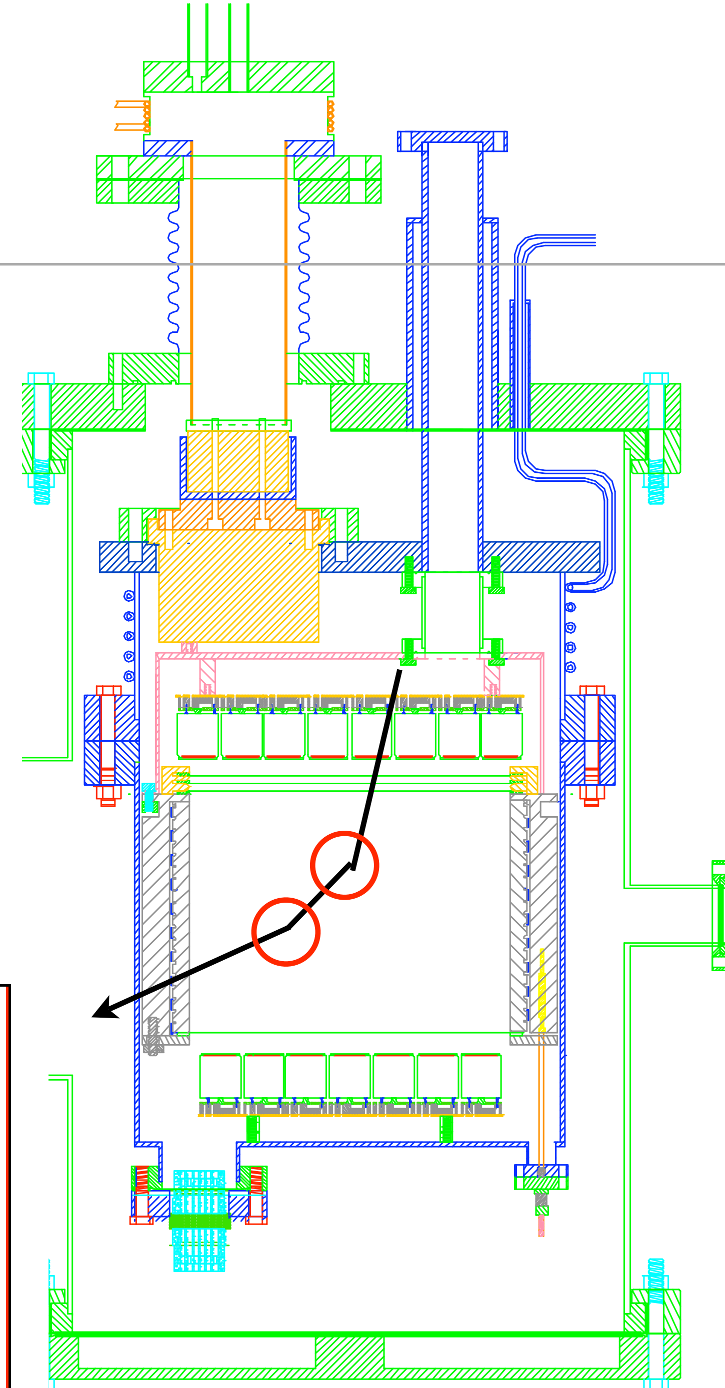
More XENON10 Events

Multiple scattering γ

Multiple scattering γ

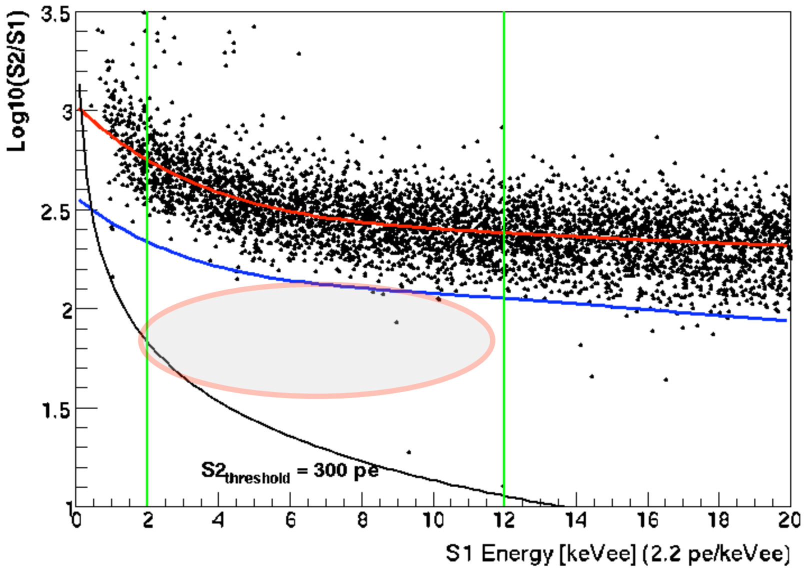


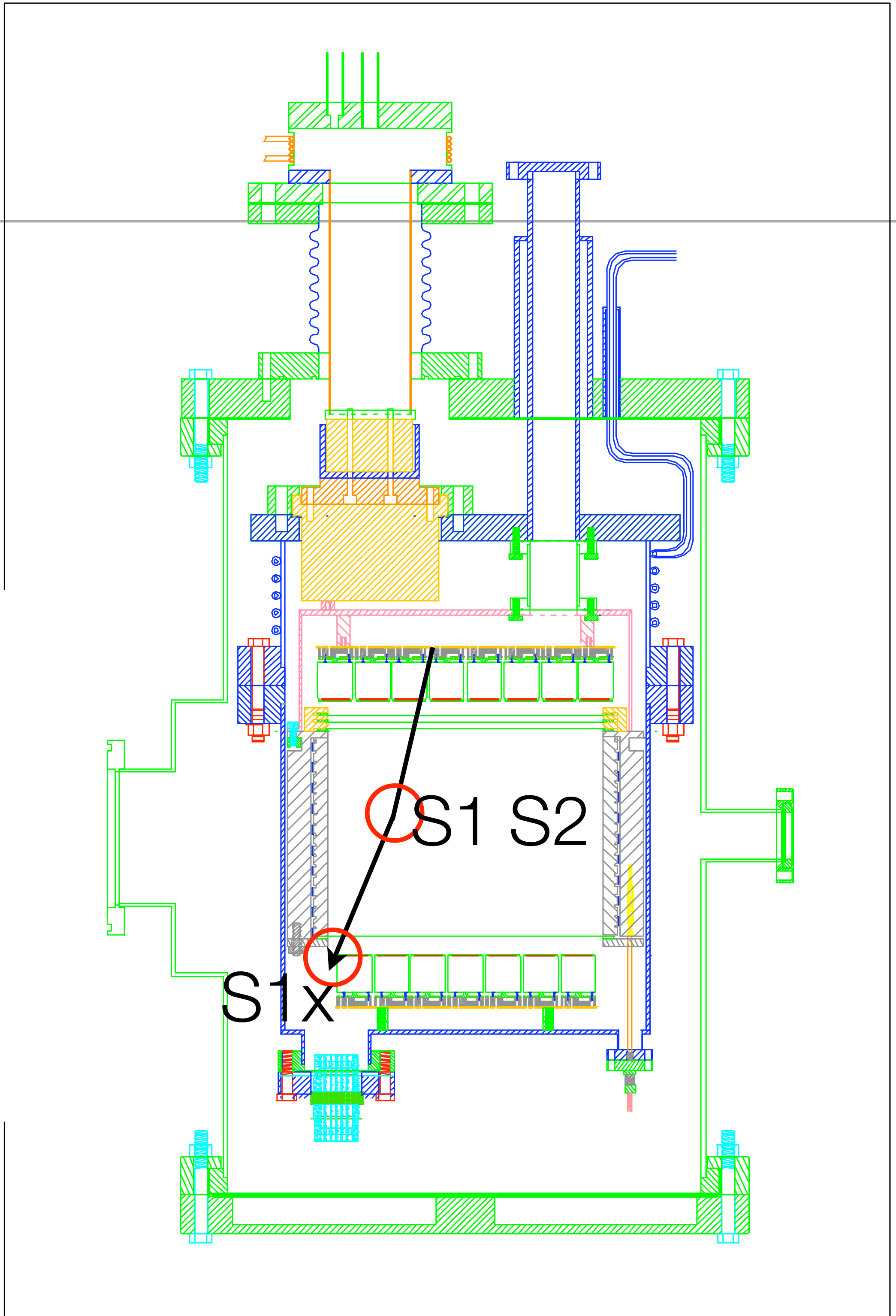




QC2 Cut

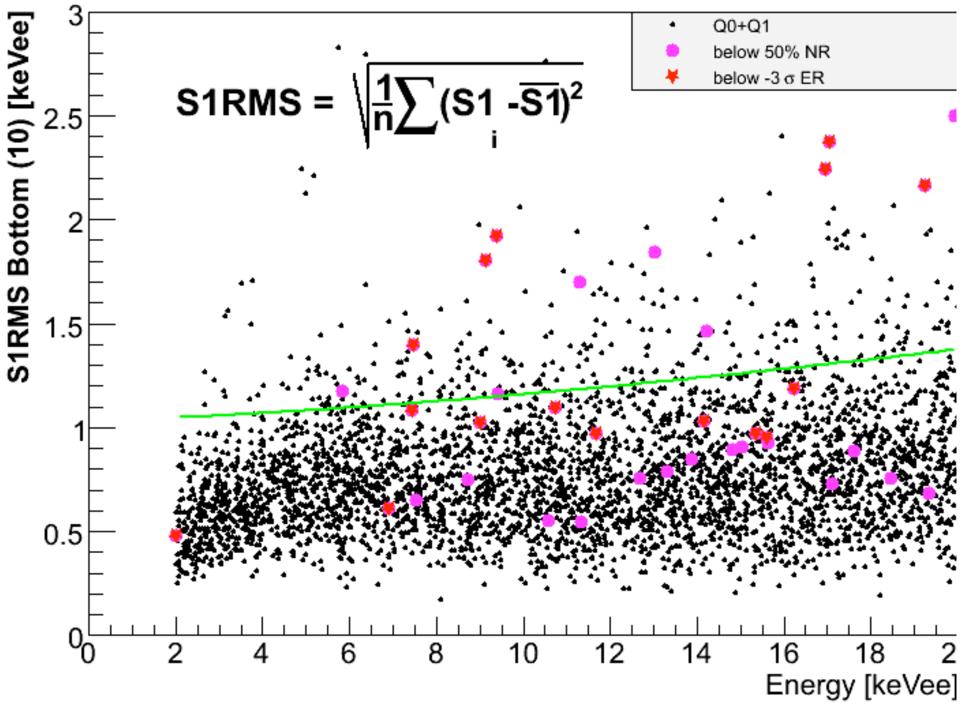
$$\frac{S2}{S1} > \frac{S2}{S1 + S1x}$$

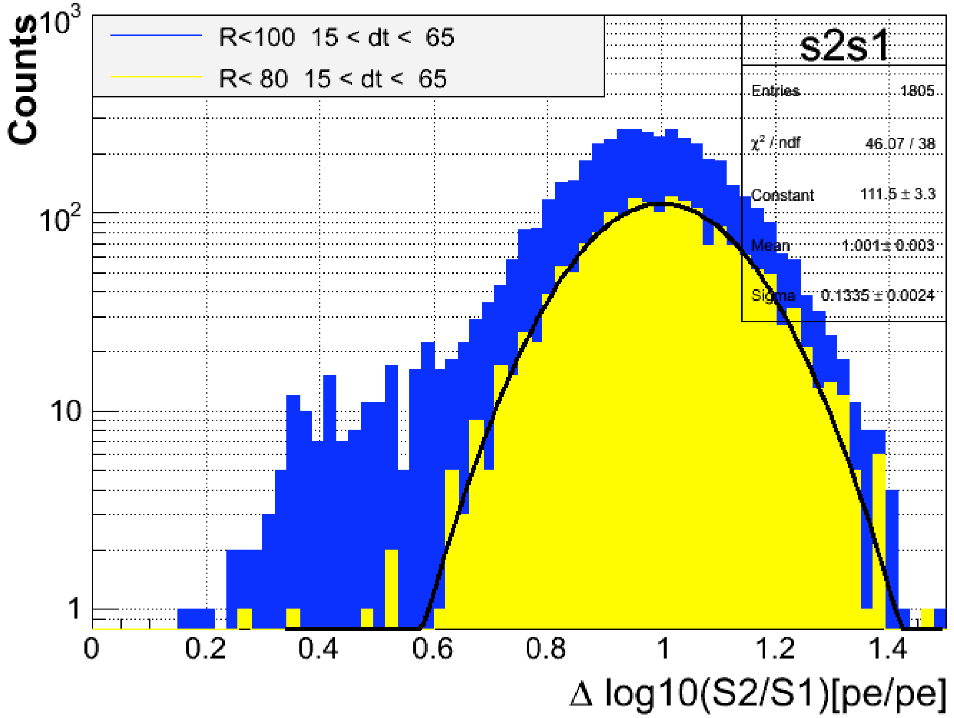




Performance of QC2 Cut (S1 RMS Cut) on Search Data

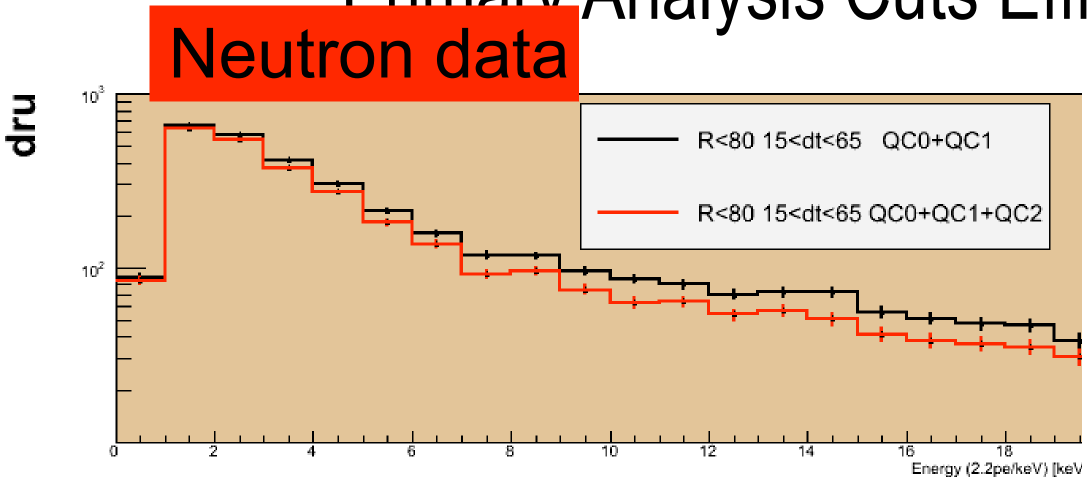
WS003+WS004 (58days)

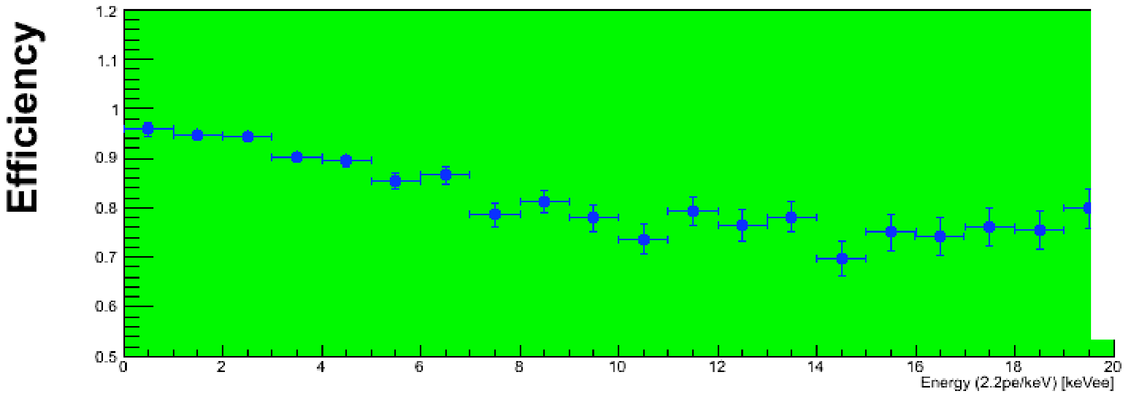


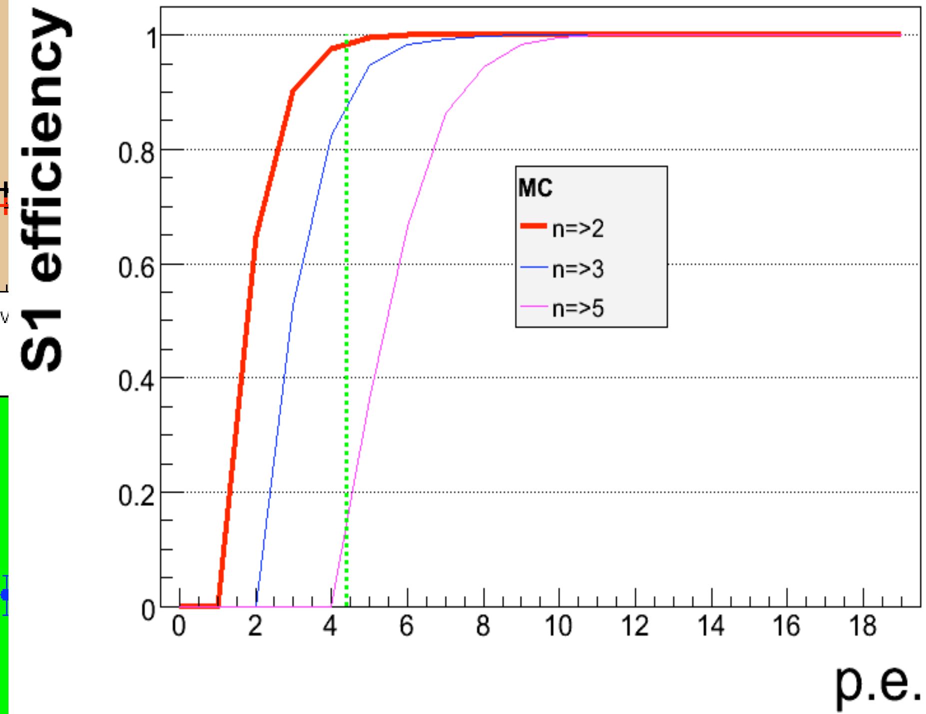


- 5 "non-Gaussian" events remain after all QC2 cuts on the WIMP search data.
- The sigma of delta log10(S2/S1) shows higher number (+0.09, 2-12 keVee)→ the "gaussian leakage" events estimated from 137Cs data appear to be too conservative before opening the box.
- These non-Gaussian events will be studied by modifying the detector to remove a large fraction of dead LXe layers. We note that these events appear mostly at higher energies. 4 of these have been cut by the Secondary Analysis QC2 cuts.
- "Blind" analysis has provided a good sample to study these evens since the origin is different from 137Cs.

Primary Analysis Cuts Efficiency

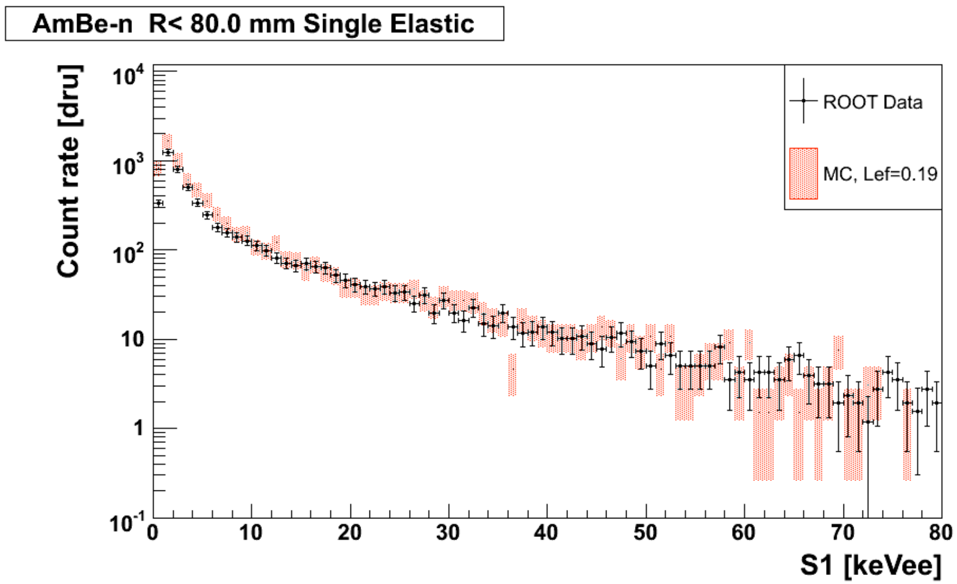


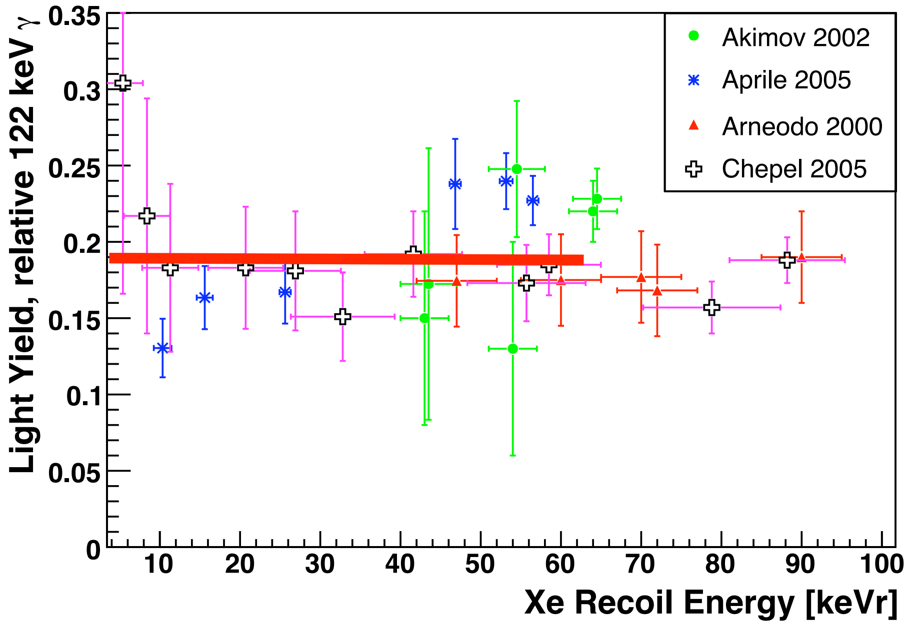




- Sum of S2 signal from Top PMTs was used for trigger.
- The threshold for S2 is 300 photoelectron (~ 10 ionization electrons) .
- A gas gain of a few hundred allows 100% S2 trigger efficiency.
- The S1 signal associated with an S2 signal was searched for in the off-line analysis.
- The coincidence of 2 PMT Hits is used in the analysis and the S1 energy threshold is set to 4.4 photoelectrons. Its efficiency is ~ 100%. (2keVee)
- The QC2 cuts efficiency varies between 95% and 80% in the 2-12 keVee energy window.

Neutron MC Simulations



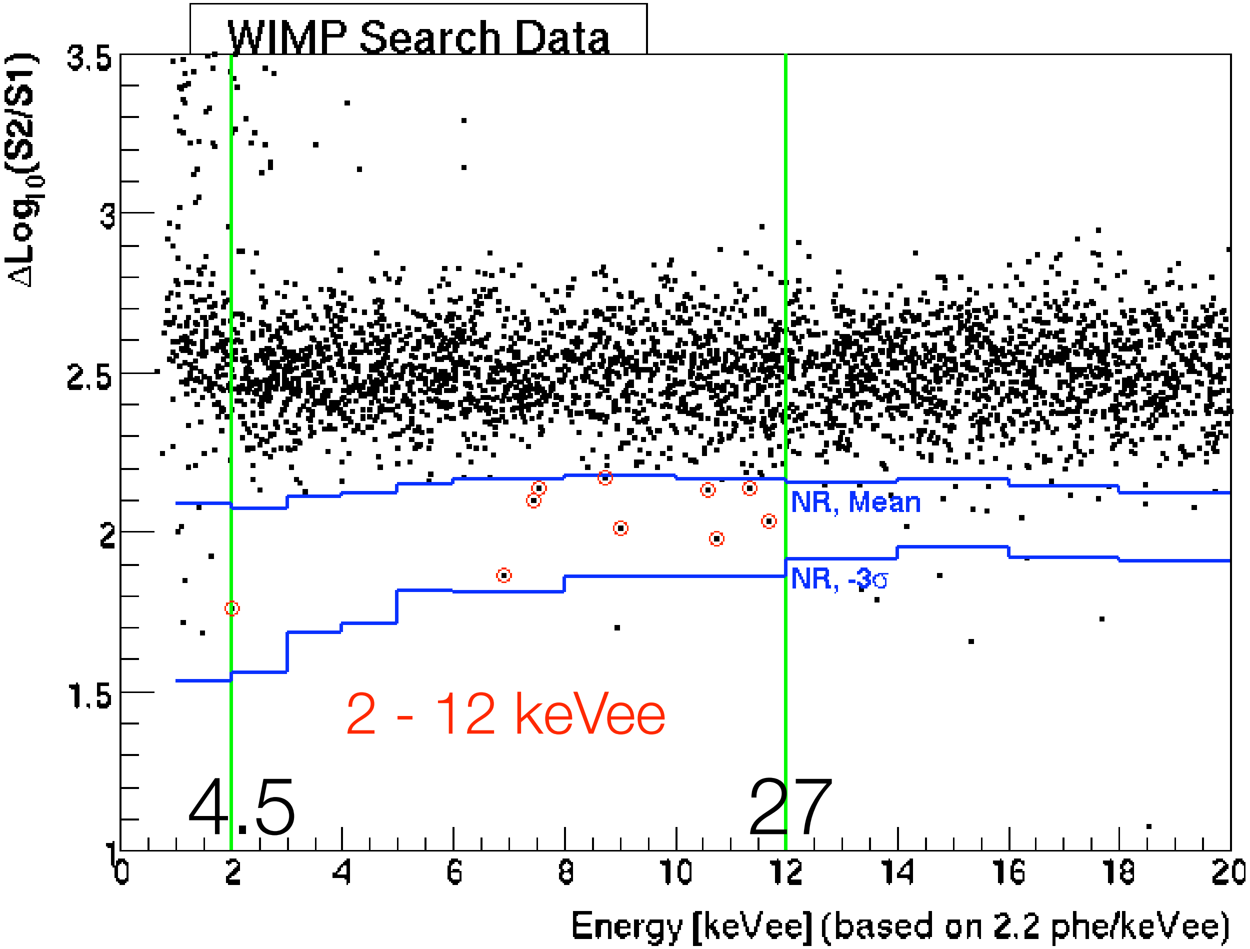


$$\text{Scintillation Efficiency} = \frac{\text{nuclear recoil}}{\text{electron recoil}}$$

- Very low threshold achieved
- Very good agreement with MC in over all range
- It is true that some uncertainty at low energy (20-35% error in sensitivity curve)
- We take average 19% but new measurement is planned for <5 keVr.

XENON10 WIMP Search Data with Blind Cuts

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



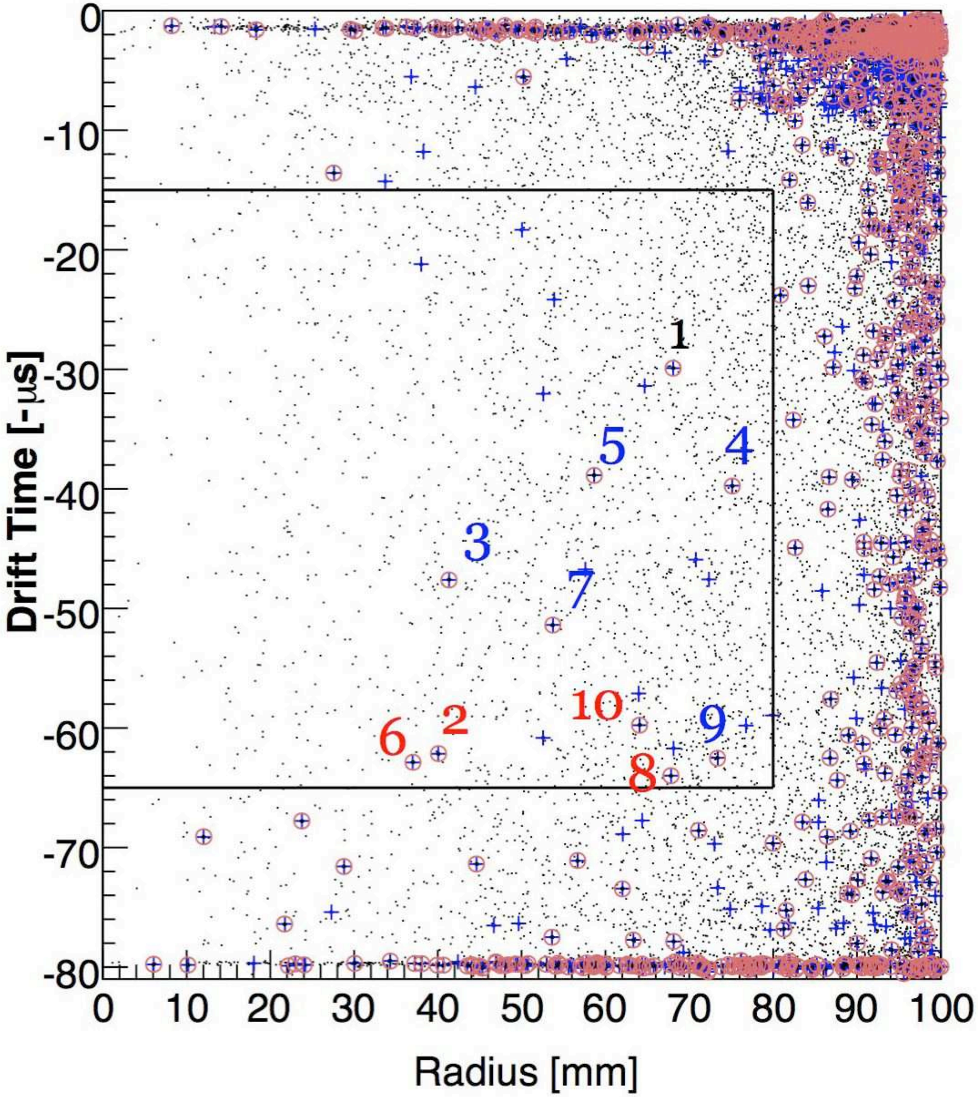
- WIMP "Box" defined at ~50% acceptance of Nuclear Recoils (blue lines): [Mean, -3σ]
- 10 events (o) in the "box" after all cuts in Primary Analysis
- 6.9 events expected from γ Calibration
- 5 of them *not consistent* with Gaussian distribution of ER Background
- 4 of the 5 non-Gaussian events (1 of lowest energy and 3 near upper energy band) are removed by cuts developed in the Secondary Analysis
- Only 1 non-Gaussian event survives both Primary and Secondary cuts (>15keVr, S2/S1 = 2.7σ away from NR centroid)

NR Energy scale: use a constant 19% Quenching Factor

Er = Ee/Leff · Se/Sr = S1tot (pe)/3.0 pe/keV/0.19*0.54*0.93

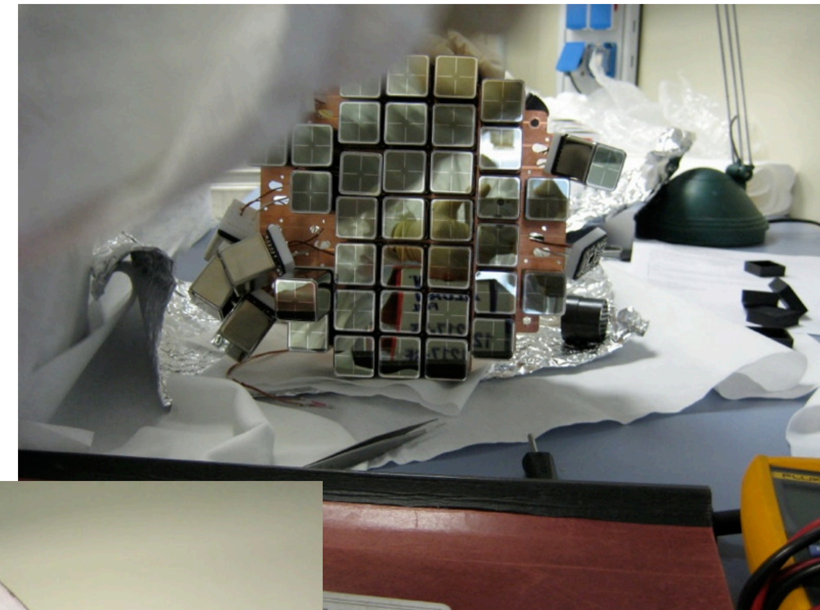
2 – 12 KeVee → 4.5 –27 KeVr

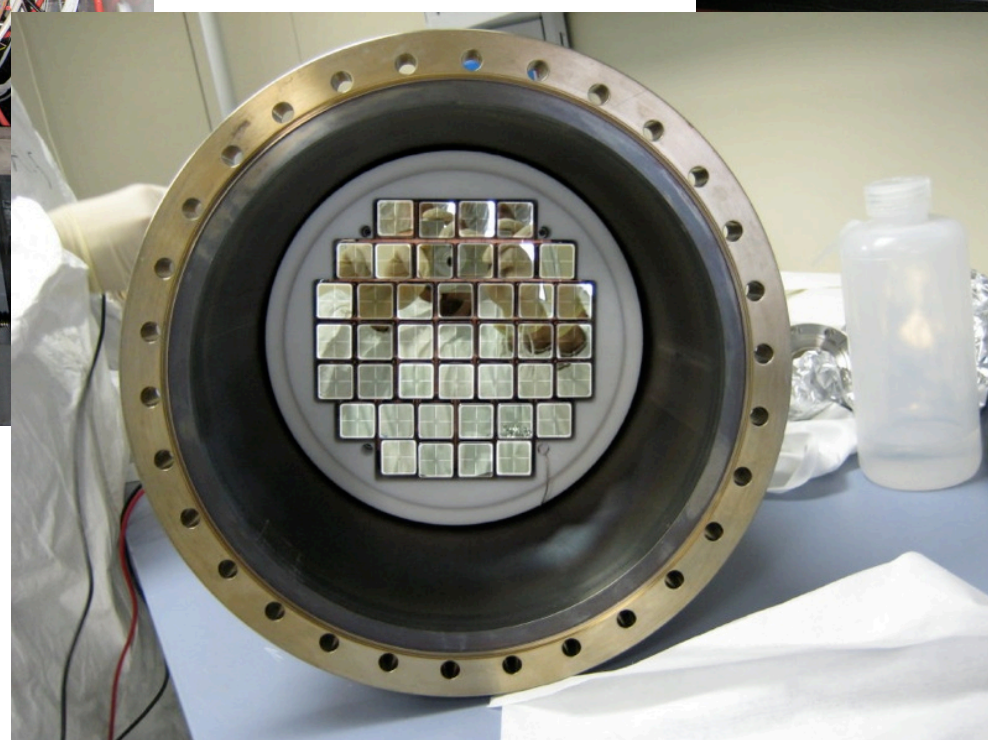
The events in the WIMP search box



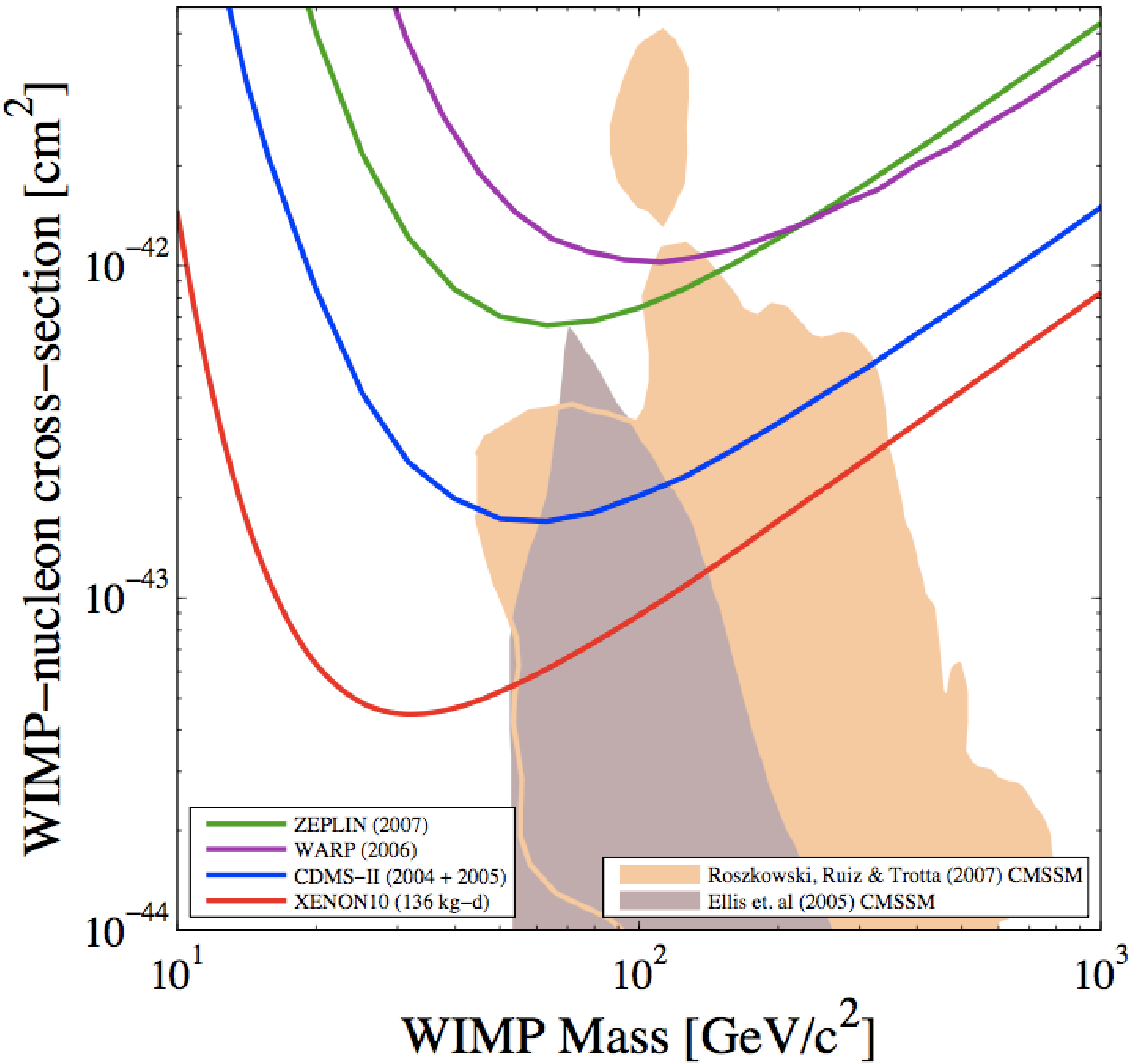
- We think the 5 non-gaussian events are not likely WIMP events
  - ➡No1 noise glitch
  - ➡No 2, 6, 8, 10
    - clustered in lower part
    - The expected nuclear recoil spectrum for both neutron and WIMP falls exponentially where as not in this case.

Last Week ... Now data taking started





XENON10 Experimental Upper Limits
Spin Independent case

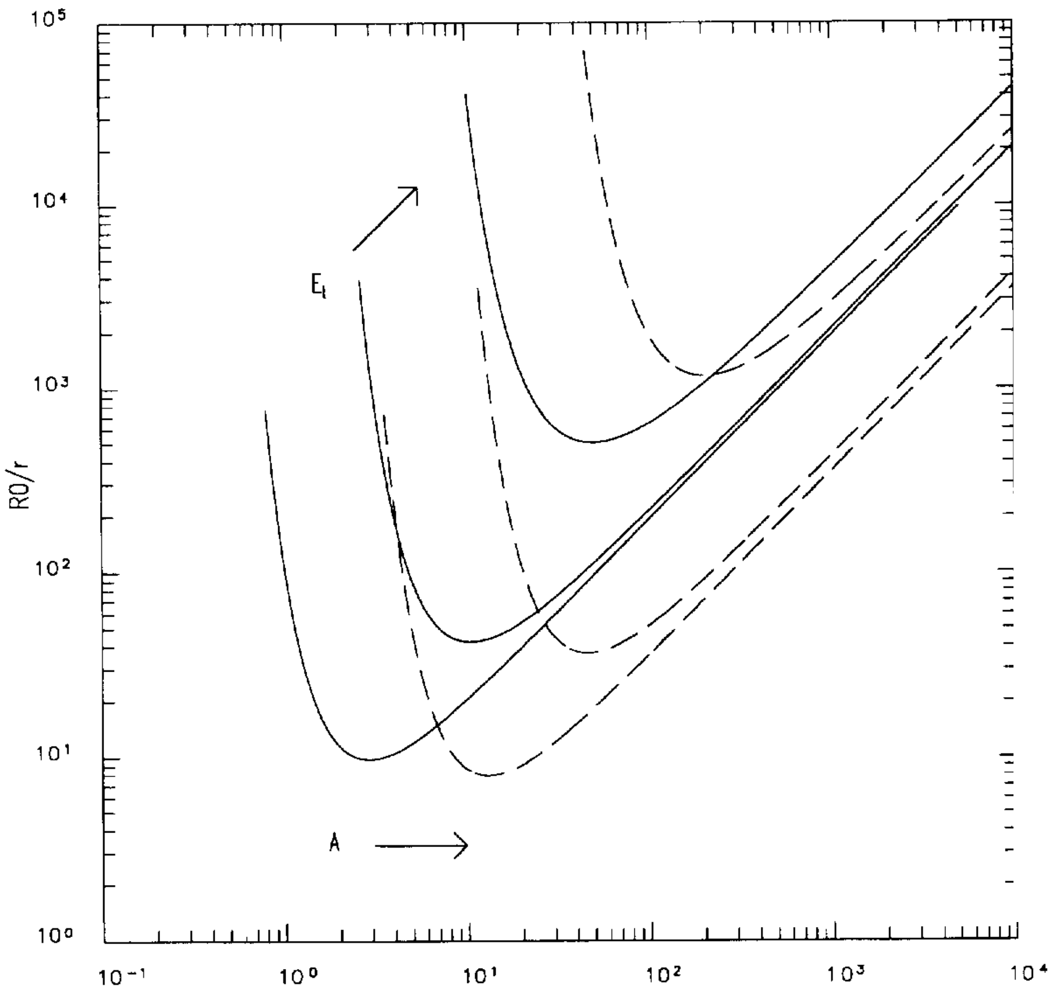


- Upper limits on the WIMP-nucleon cross section derived with Yellin Method (PRD 66 (2002))
- No bg subraction
- 8.8×10^{-44} cm^2 Max Gap (4.5-15.5keVr)

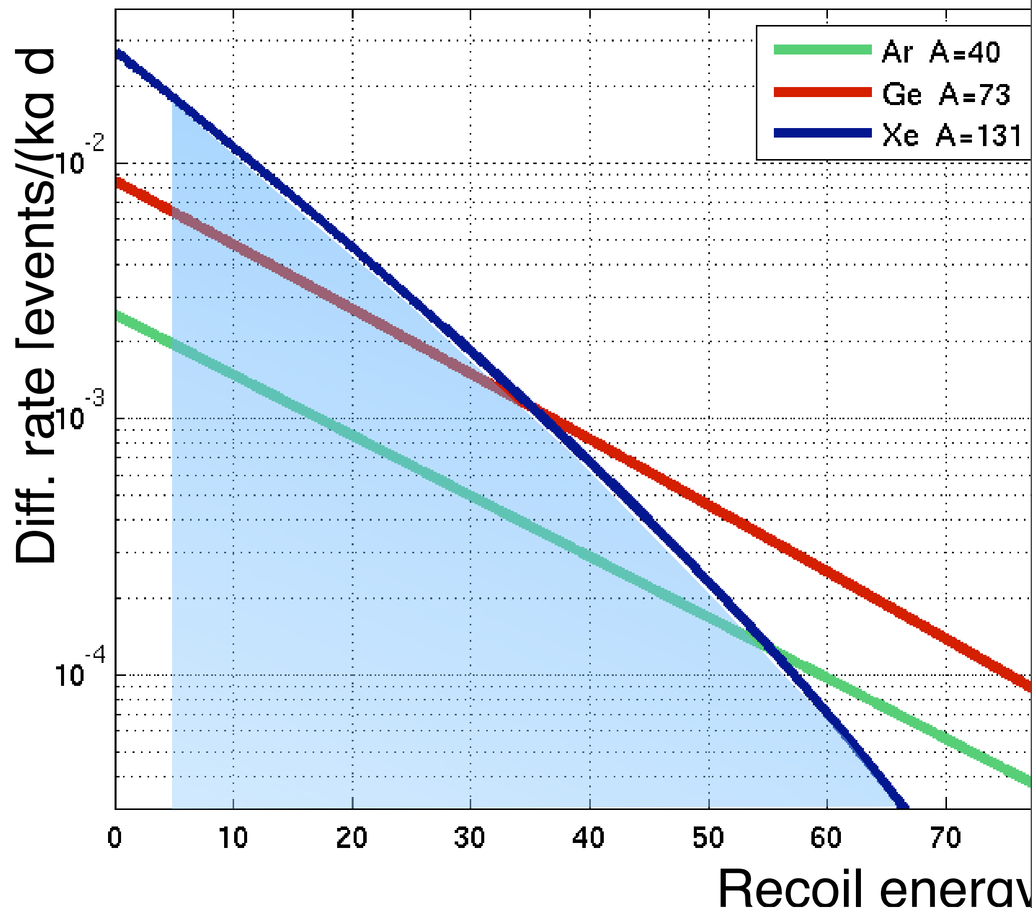
for a WIMP of mass 100 GeV/c^2

Factor of 6 below best previous limit (CDMSII)

For lower WIMP mass (35 GeV)→ $3.1\ (4.3) \times 10^{-44}$ cm^2
Factor of 10 lower than best limit



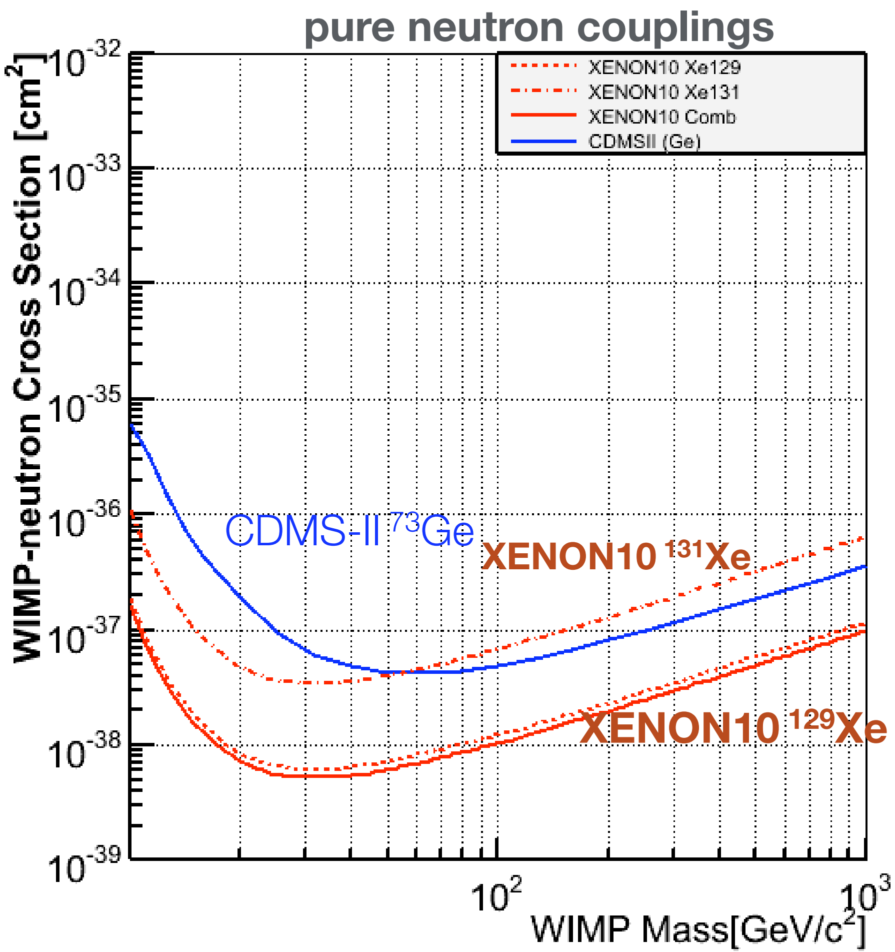
R0/r
E_t
A

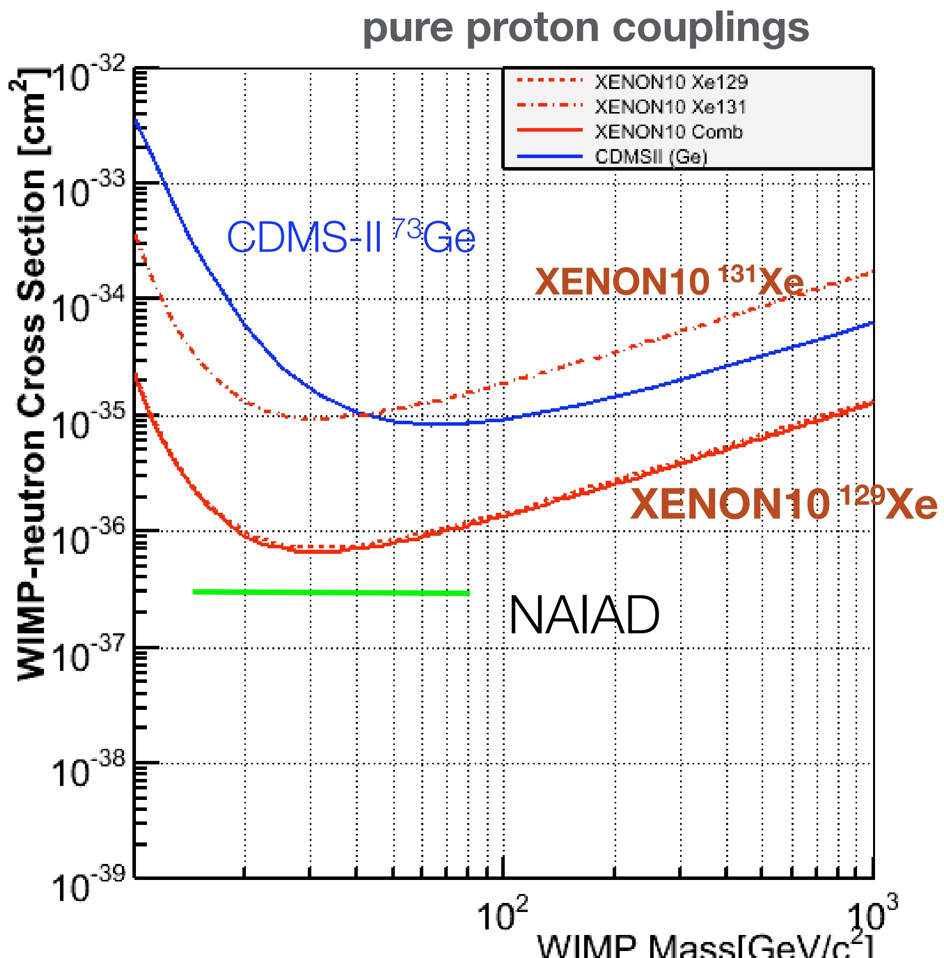


Ar A=40
Ge A=73
Xe A=131
Diff. rate [events/(kg d
Recoil energy

XENON10 WIMP Search Results for SD Interactions

- natural Xe: ^{129}Xe, 26.4 %, spin 1/2, ^{131}Xe, 21.2%, spin 3/2
- use shell-model calculations by Ressel and Dean [PRC 56, 1997] for <S_n>, <S_p>
- upper limits: Yellin Maximal Gap method, **no background subtraction**





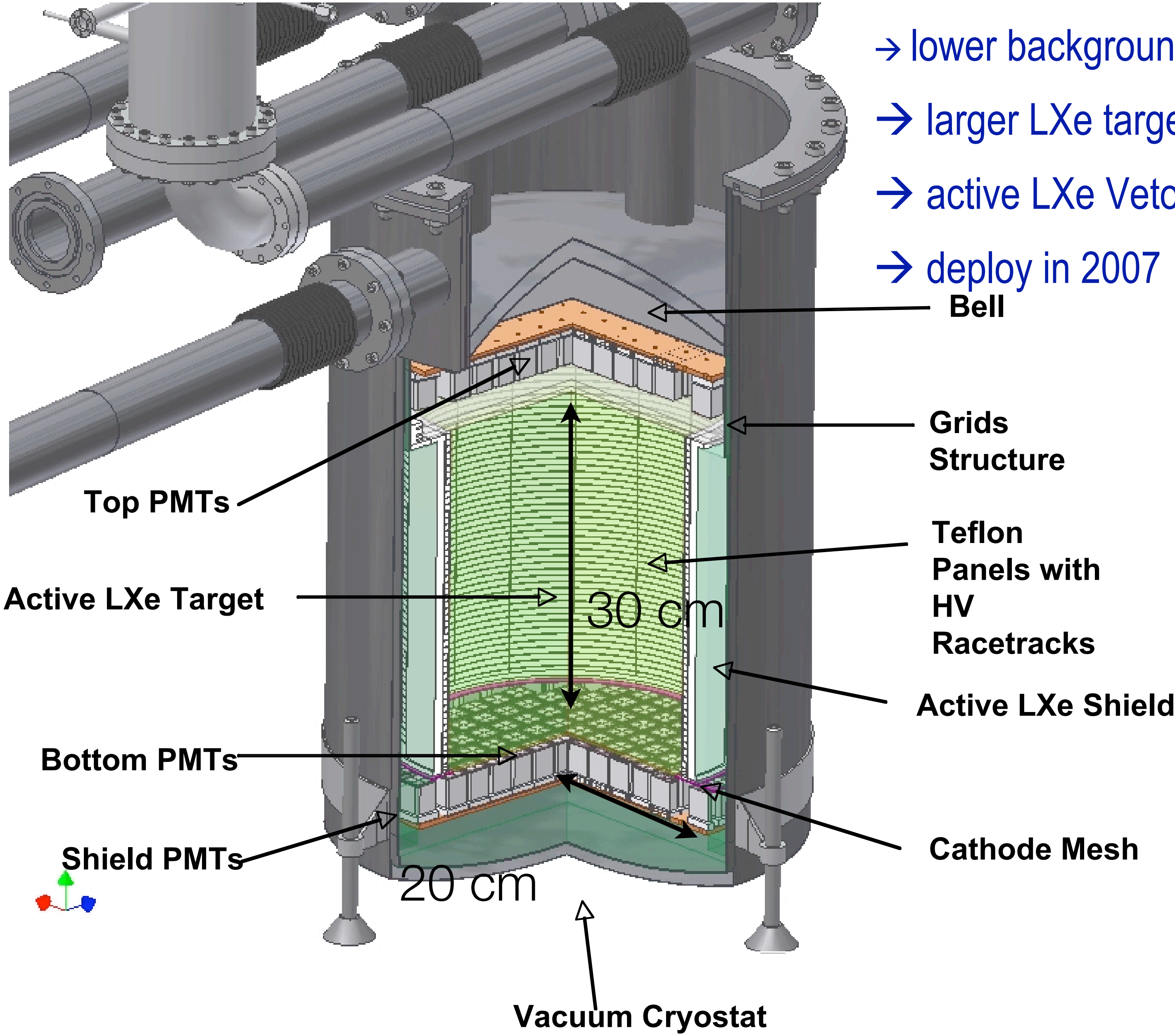
Dark Matter
XENON10+

No R&D is needed !

Detector will be ready in this 2007.

XENON10+ Detector

Columbia-Rice-Zurich-Coimbra-LNGS



→ lower background

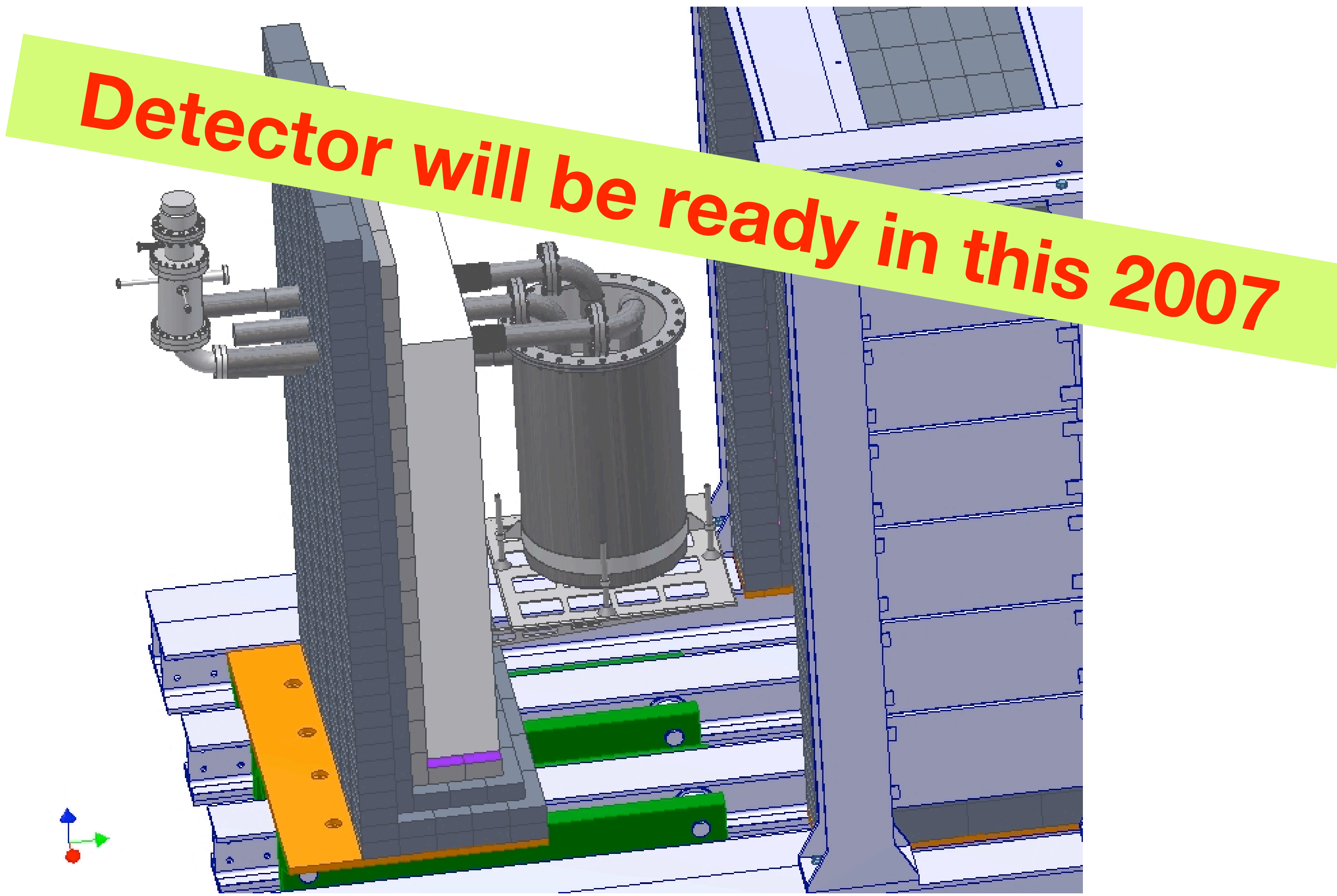
→ larger LXe target mass

→ active LXe Veto

→ deploy in 2007

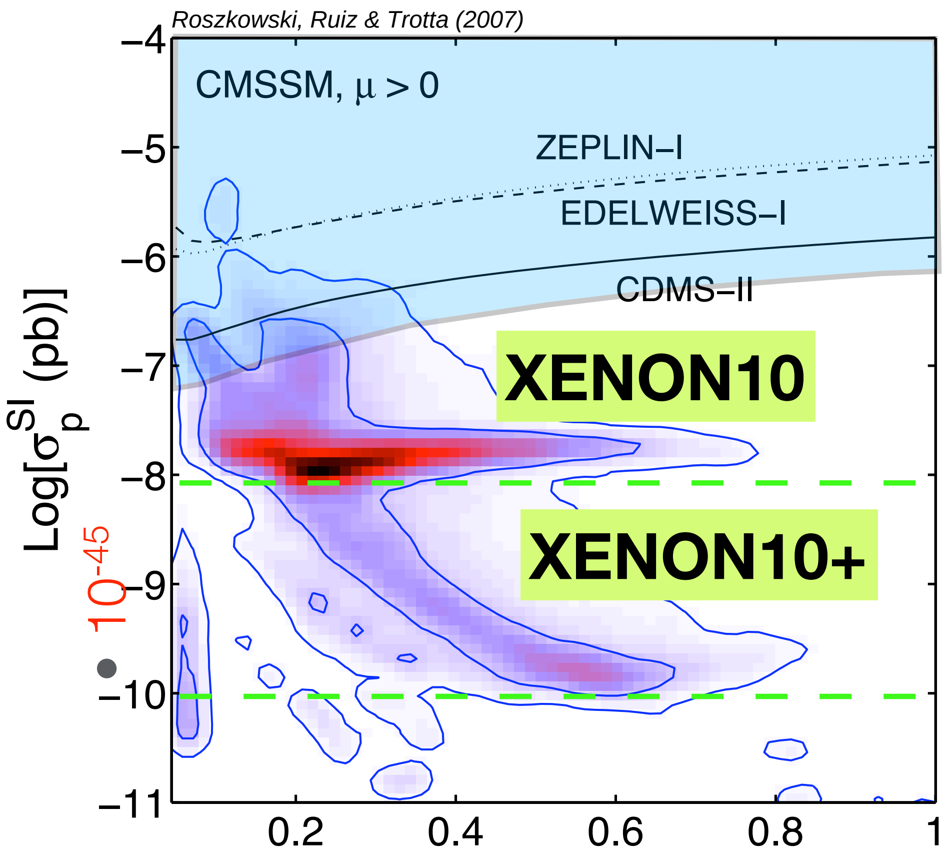
110 kg of LXe
40 kg of fiducial

Dark Matter
XENON10+



Summary

- **XENON10**: First Result http://arxiv.org/abs/0706.0039, submitted to PRL
  - ➡upper limit to Spin Independent WIMP-nucleus cross section
    - 4.5×10^{-44} cm^2 at 35 GeV
  - ➡upper limit to Spin Dependent WIMP-n cross section
    - 5.2×10^{-39} cm^2 at 35 GeV



CMSSM in 2007
hep-ph 0705.2012v1

Roszkowski et al.

1 event/kg/
2008~
CDMS-II, XENON10+, COUPP, CRESST-II, EDELWEISS-II, ZEPLIN-III,...

1 event/t/
2010~
SuperCDMS1t, WARP1t, ArDM XENON1t. EURECA. ELIXIR.

Single Phase VS Double Phase

Multi Purpose Experiment
have been proposed by
XMASS (Xe), CLEAN (Ne) ...

Single phase detector is simple detector but ...

LXe	Single (S1 only)	Double (S1+S2)
Particle Id	not good	very good
Position Resolution	a few cm	a few mm
Energy Resolution	~3 %	~ 1 %
Multiple Scatter Cut	not good	very good