Status of the XENON100 Dark Matter Experiment

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on behalf of the XENON100 Collaboration

IDM08, Stockholm, August 19, 2008

The XENON Dark Matter Project

A phased program using LXe to probe both axial and scalar coupling of WIMPs with matter

Sensitivity goal σ_{SI}~10^{-47} cm^2 for 100 GeV WIMPs by 2013 with 1000 kg LXe (fiducial)

Detector: dual phase TPC - 3D position sensitive - self-shielded by a 4π active LXe veto

PMTs readout with ~5 pe/keV to achieve low energy threshold for nuclear recoils (~5 keV)

Simultaneous charge & light detection for event-by-event discrimination (>99.5%)

XENON10 Phase (2005-2007): first demonstration of the concept in underground laboratory (LNGS). Reached best sensitivity in 2007: σ_{SI}~10^{-43} cm^2 for 100 GeV WIMP

XENON100 Phase (2007-2009): currently operating at LNGS. 70 kg LXe target, shielded by 100 kg LXe active veto & passive shield. Predicted gamma background ~5 x10^{-5} cts/keV/kg/day after rejection (~100 x less than XENON10). Sensitivity goal by 2009: σ_{SI}~2x10^{-45} cm^2 for 100 GeV WIMP after 7 months of data (bkg free). Supported by NSF/DoE and foreign contributions

XENON1T Phase (2009-2012): under study by larger collaboration (US, EU, Japan). Advances in PMTs technology will enable a concept which will combine the advantages of single and dual phase LXe detectors with unprecedented physics reach (σ_{SI}~10^{-47} cm^2) for 100 GeV WIMP

The XENON100 Collaboration

LNGS Collaboration Meeting, July 15,2008

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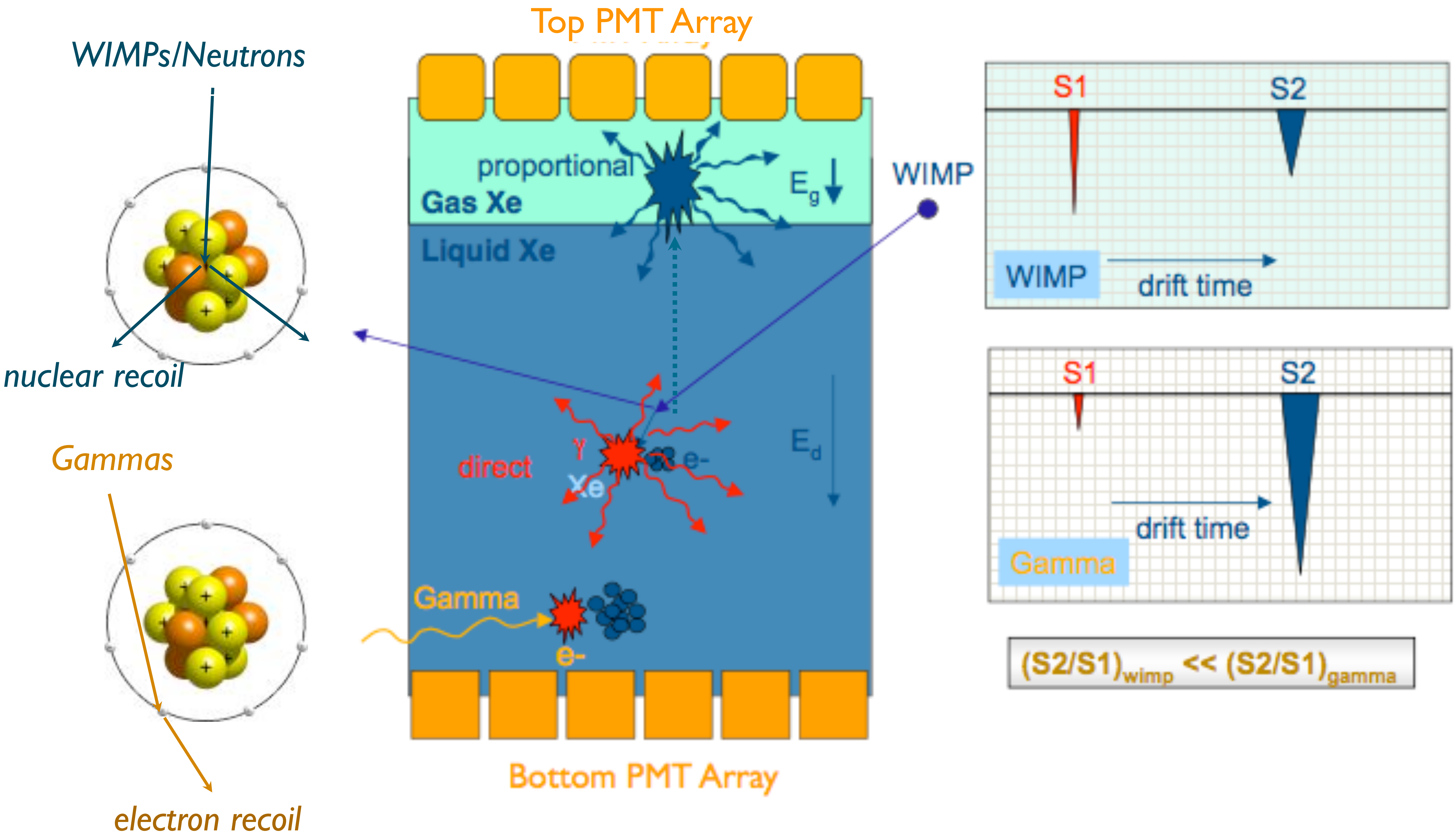
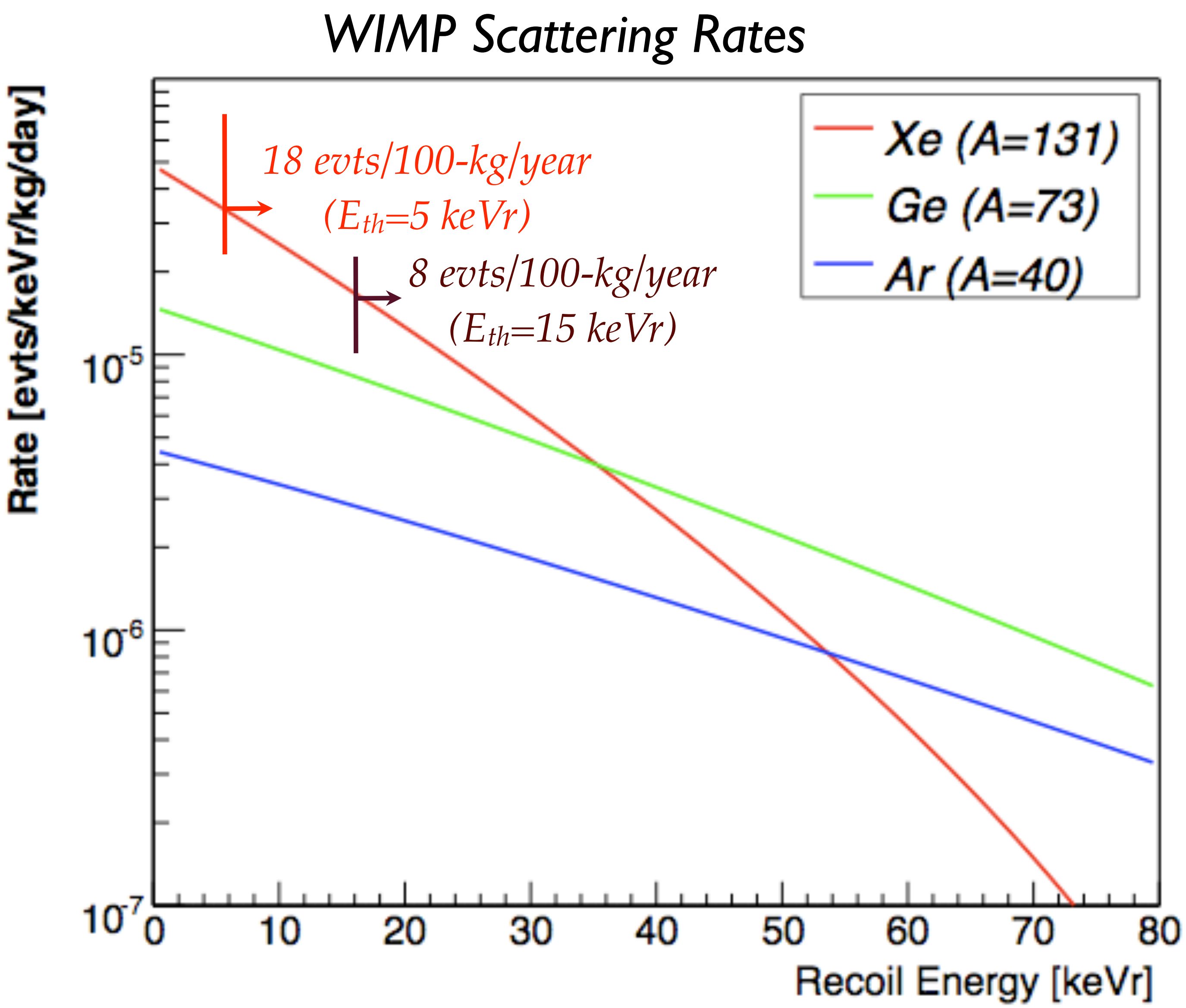
Principle of XENON dual phase time projection chamber



Merits of a dual phase XeTPC for Dark Matter

- *Xe sensitive to both SI and SD: large A (~131) and~50% odd isotopes*
- *bkg reduction: powerful self-shielding and 3D event localization*
- *intrinsic background free: Kr/Xe level can be reduced to a few ppt*
- *low threshold : high scintillation yield & good VUV PMTs directly coupled to LXe*
- *gamma rejection: simultaneous detection of ionization & scintillation*
- *Single vs Multiple scatters:WIMP vs Neutron event differentiation (the larger the detector the better)*
- *scalability: multi-tonne experiments relatively cheap compared to cryogenic crystals (even at current high Xe cost)*
- *Long term stability: "easy" cryogenics at 170 K maintained with cryocooler*

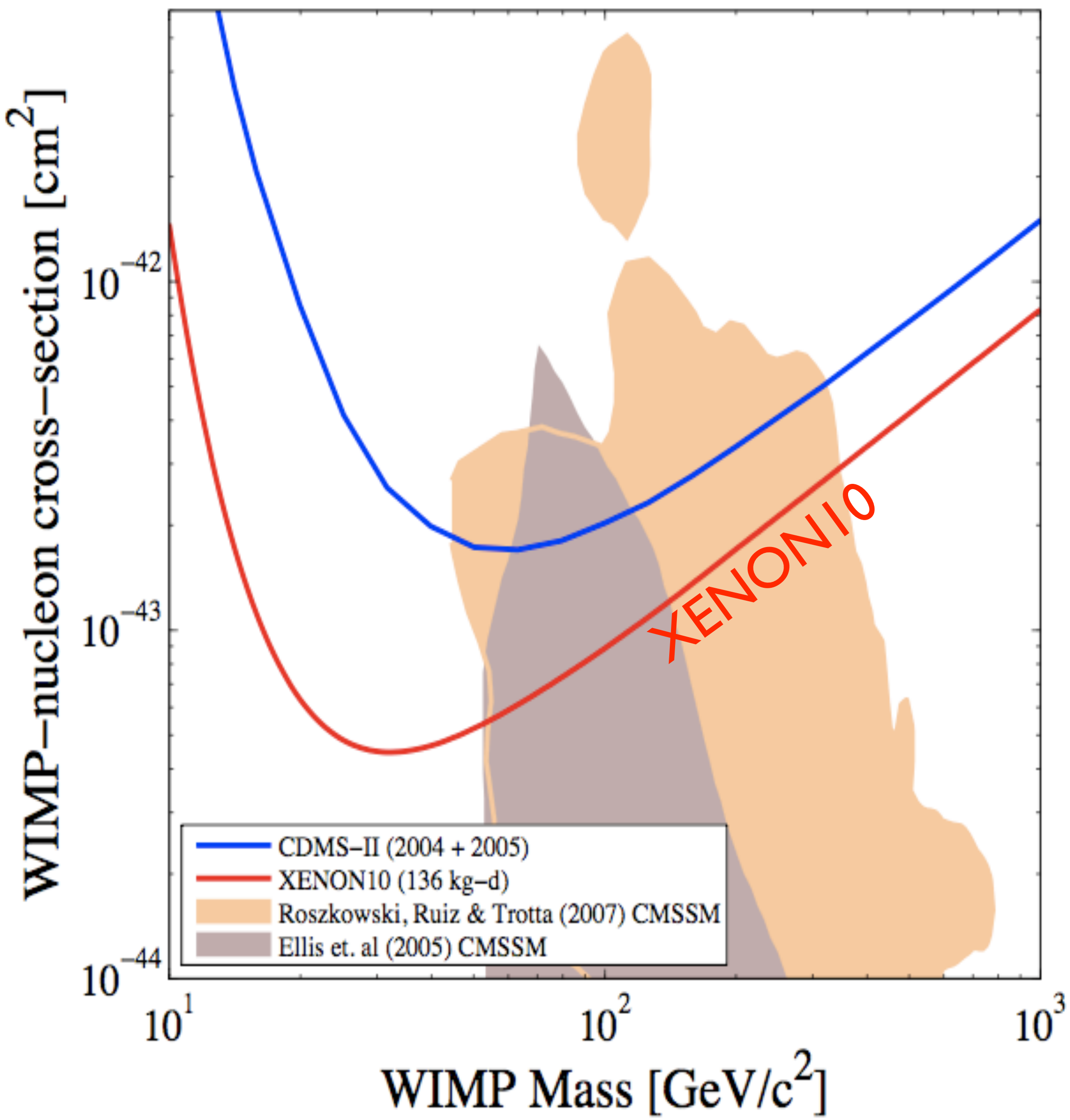
$$R \sim \frac{M_{det}}{M_\chi} \rho \sigma \langle v \rangle$$



XENON10: SI WIMP-Nucleon Cross-Section Upper Limits (90% CL)

136 kg-days Exposure= 58.6 live days x 5.4 kg x 086 (ε) x 0.50 (50% NR)

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



XENON10: SD WIMP-Nucleon Cross-Section Upper Limits (90% CL)

Natural Xe has non-zero nuclear spin isotopes: 129Xe (spin-1/2) @ 26.4% and 131Xe (spin-3/2)@ 21.2%

Both contain unpaired neutrons making XENON mostly sensitive to WIMP-neutron spin-dependent coupling

SD pure neutron cross section limit (90 % CL) by XENON10 is the most stringent to-date

Angle et al. :arXiv 0805.2939, accepted in PRL

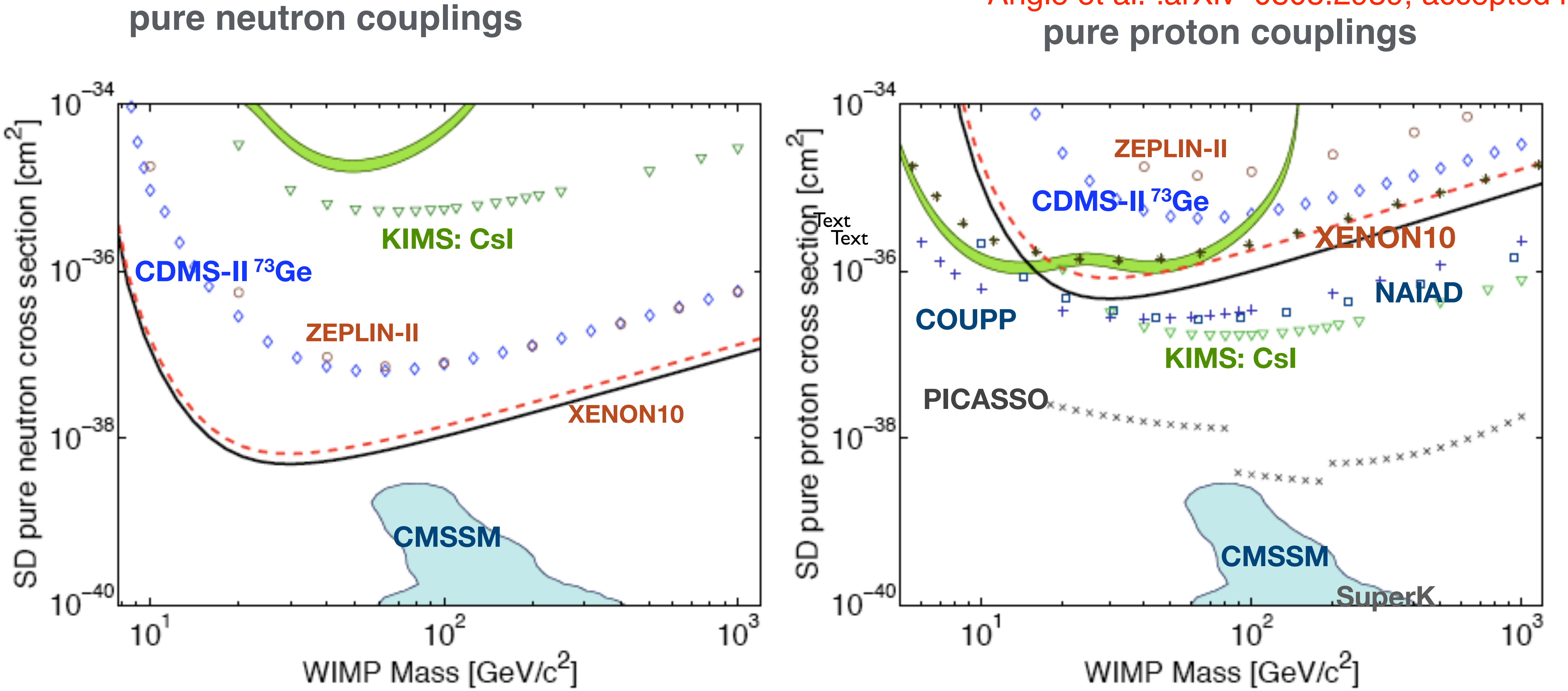


FIG. 1: XENON10 combined 90% CL exclusion limits for ^{129}Xe and ^{131}Xe for pure neutron (left) and pure proton (right) couplings (solid curves). The dashed curves show the combined Xe limits using the alternate form factor. Also shown are the results from the CDMS experiment [20] (diamonds), ZEPLIN-II [21] (circles), KIMS [22] (triangles), NAIAD [23] (squares), PICASSO [24] (stars), COUPP [25] (pluses), SuperK [31] (crosses), as well as the DAMA evidence region under the assumption of standard WIMP nuclear recoils and dark halo parameters (green filled region) [18]. The theoretical regions (blue filled) for

Systematic Uncertainty in XENON10 Limits from L_{eff}

Calibrating the Nuclear Recoil Energy Scale

energy of nuclear recoil (NR)

measured signal in p.e.

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

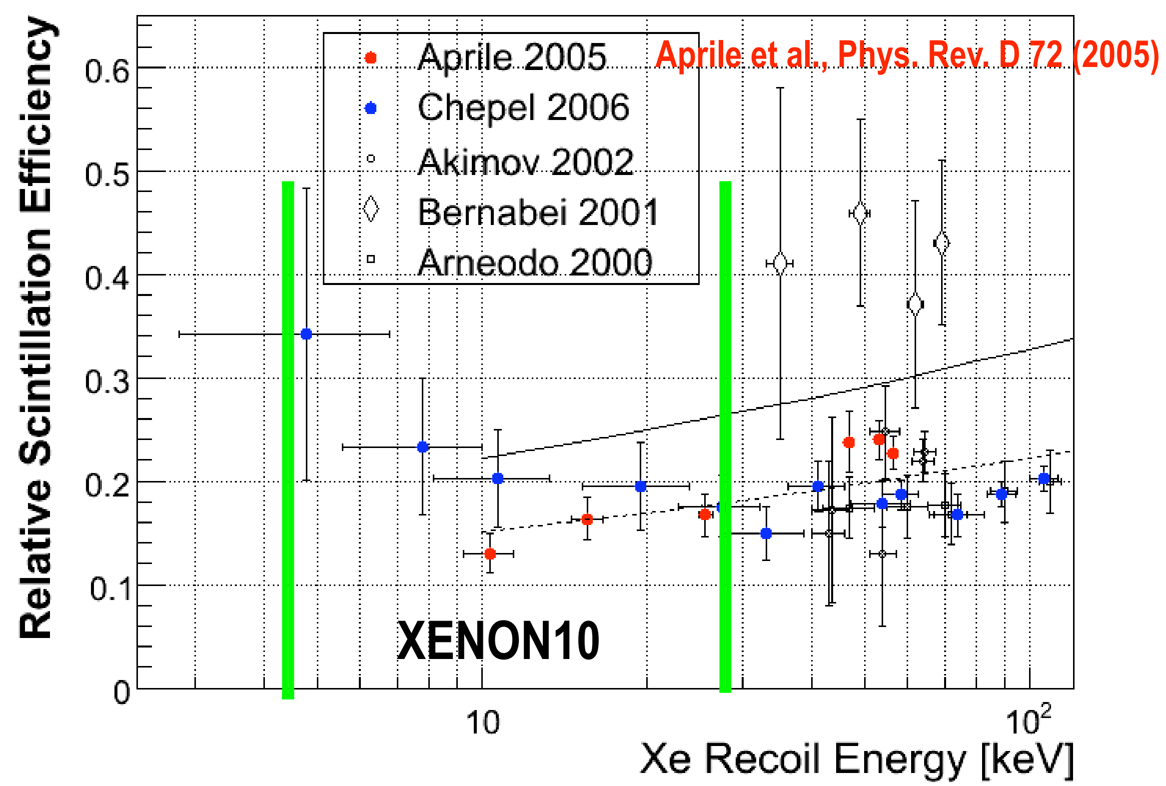
$$E_{nr} = \frac{S1}{L_y \mathcal{L}_{eff}} \times \frac{S_e}{S_r}$$

light yield for 122 keV γ in p.e./keV

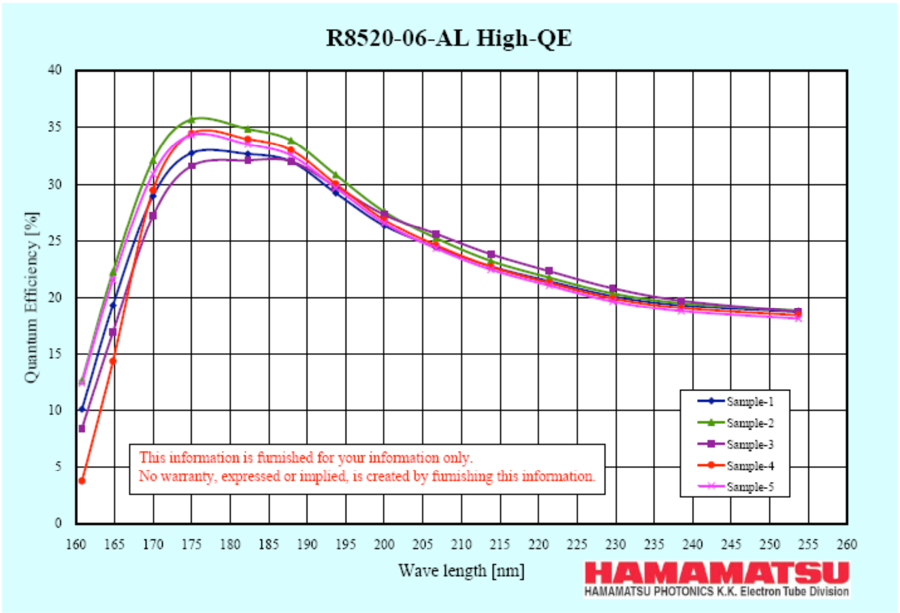
relative scintillation efficiency of NR to 122 keV γ at zero field

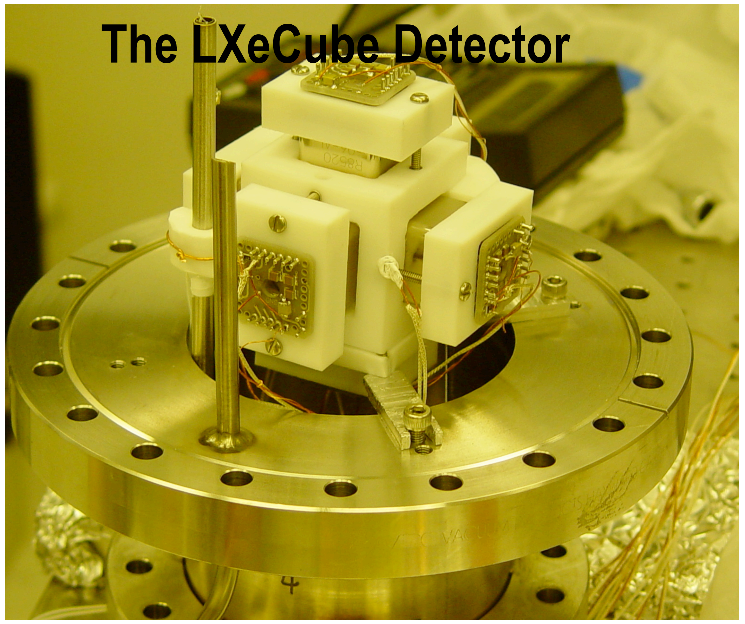
quenching of scintillation yield for NR due to drift field

Available L_{eff} Data prior to XENON10

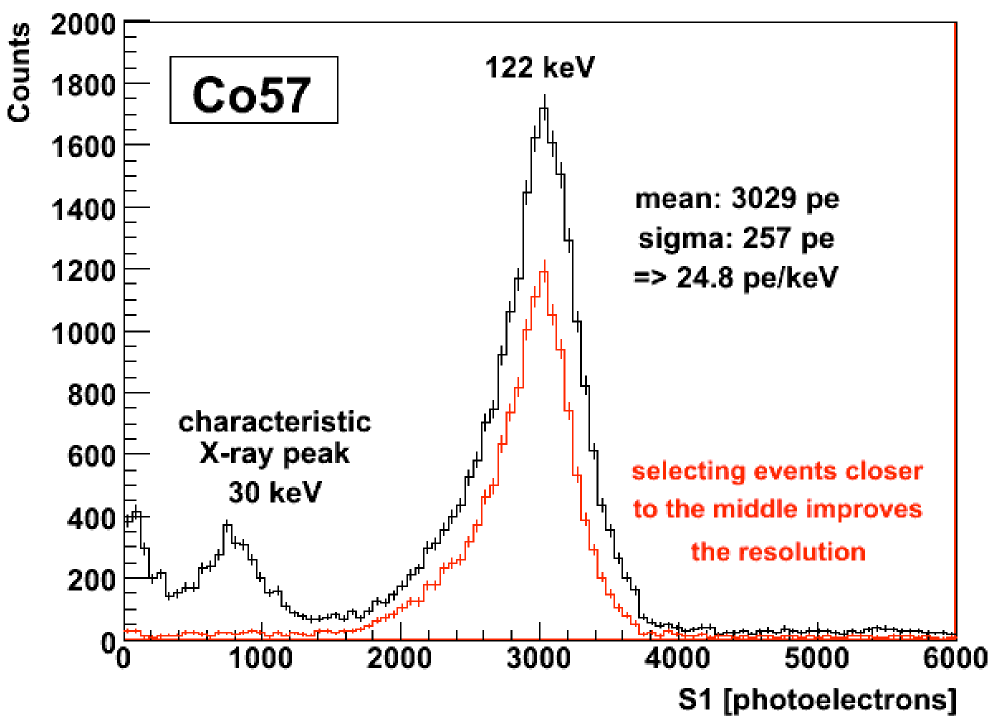


New Measurement of L_{eff} for Xe Recoils below 10 keV in LXe

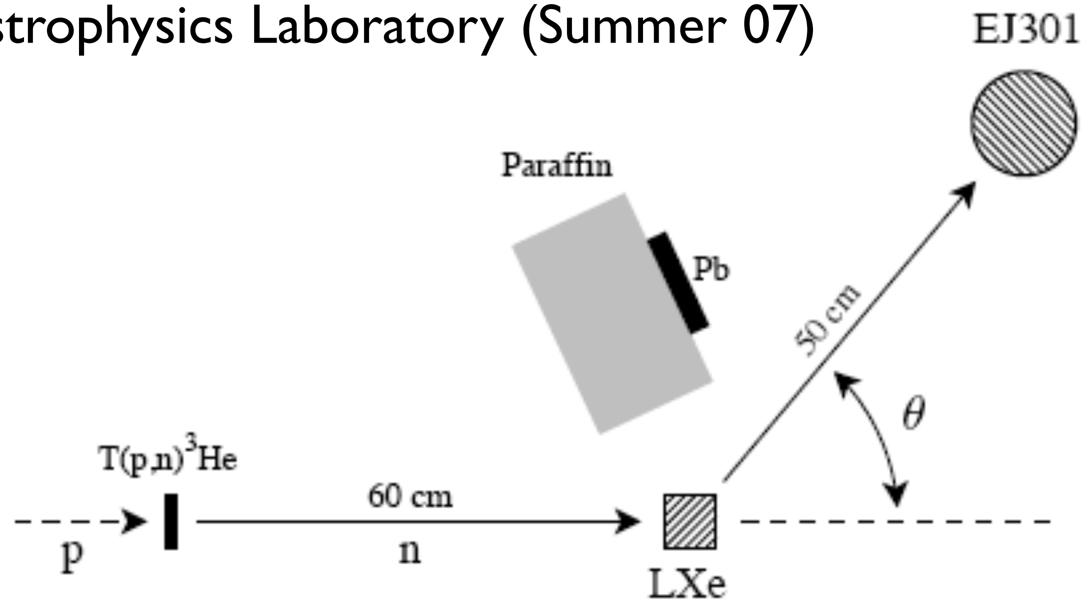




Single-phase LXe scintillation detector, optimized for maximum light collection (>95%): 6 square PMTs detect light from a cube of LXe: 25 pe / keV.



Low energy Xe-recoils produced with 1 MeV neutrons, in a tagged-neutron scattering experiment at the Columbia Astrophysics Laboratory (Summer 07)



Results

Results are consistent with previous measurements at energies >10 keV

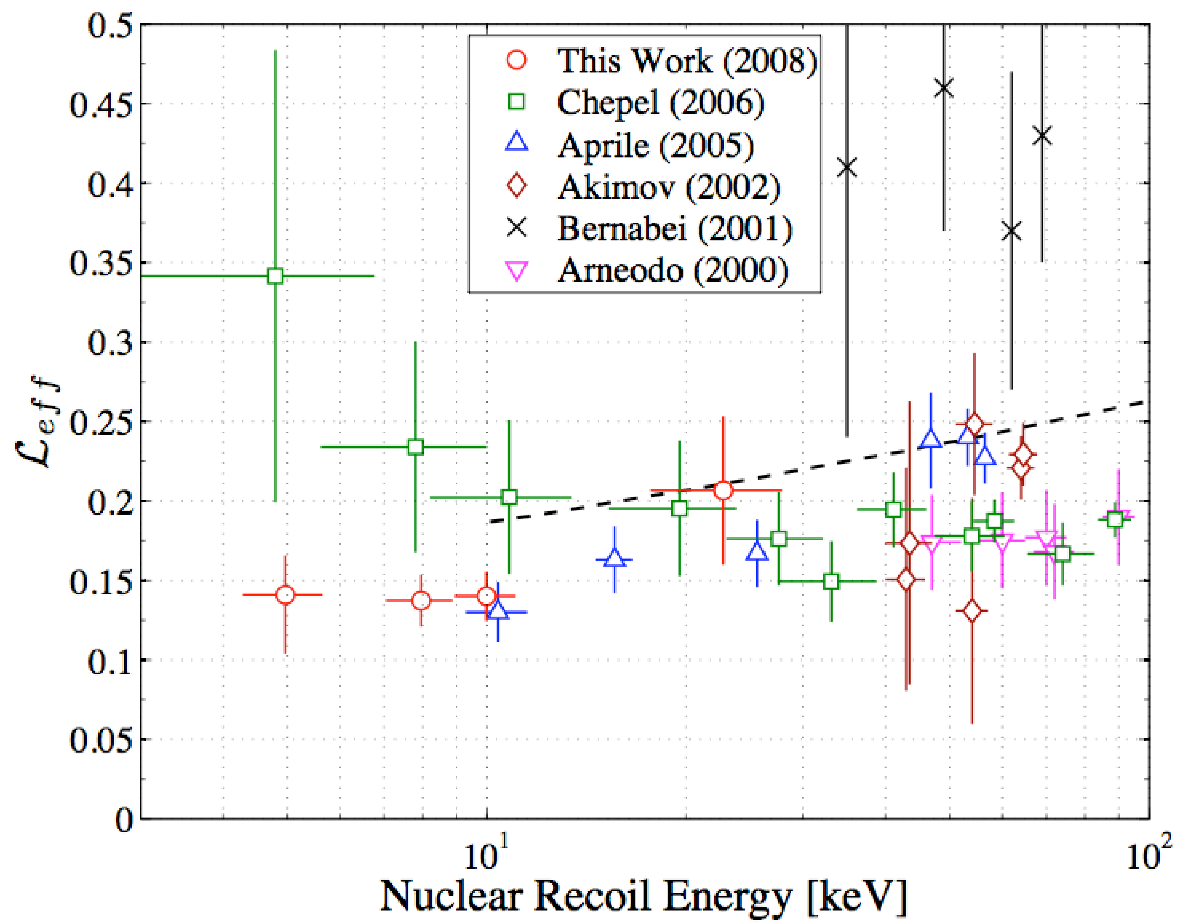
Below 10 keV, average value of Leff = 0.14, inconsistent with Chepel et al. data and consistent with a best fit of XENON10 Neutron Calibration data.

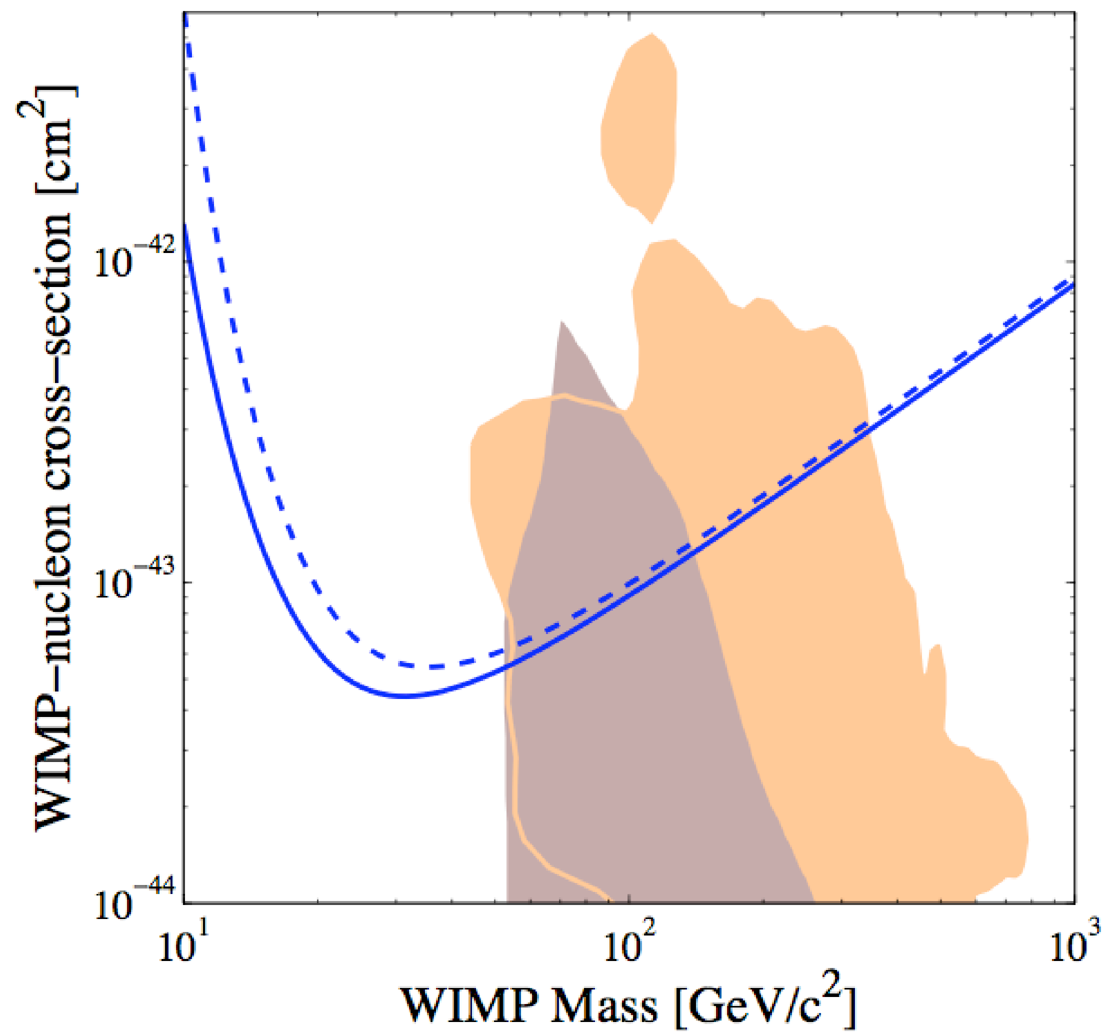
In light of this study, the published XENON10 SI limit (solid-blue) is shifted up by 12.5% for 100 GeV WIMPs, remaining relatively unchanged at higher masses (dashed-blue)

TABLE I: The values of $\mathcal{L}_{eff}$ obtained in this study and their energies. Error bars on the recoil energies are the spread of E_n as mentioned in section II A combined with the geometrical uncertainties. The uncertainties in $\mathcal{L}_{eff}$ are the combination of all statistical and systematic errors mentioned in the text.

θ	E_r (keV)	$\mathcal{L}_{eff}$
48°	5 ± 0.68	$0.141^{+0.025}_{-0.037}$
62°	8 ± 0.91	0.137 ± 0.016
70.5°	10 ± 1.06	0.140 ± 0.016
109.5°	22.94 ± 4.34	0.205 ± 0.039

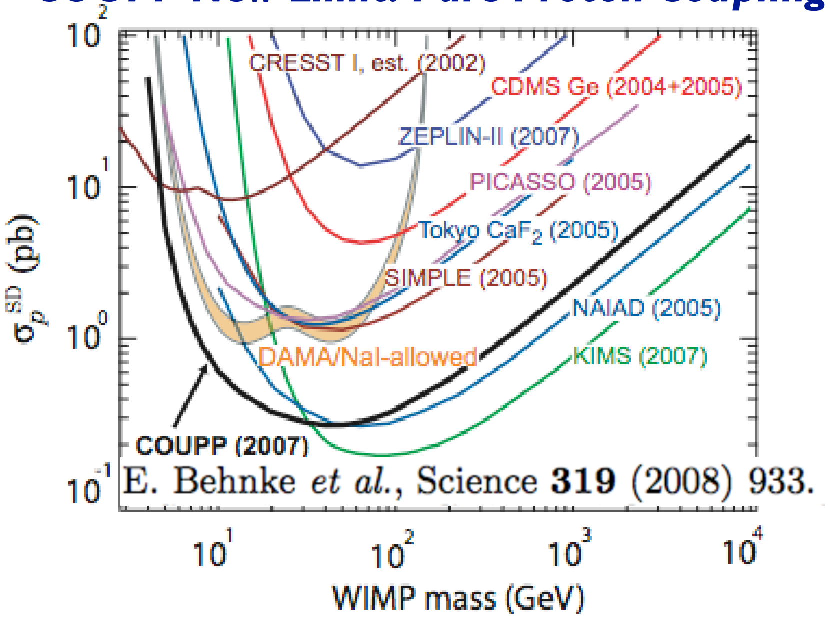
Paper ready for publication (PRD)



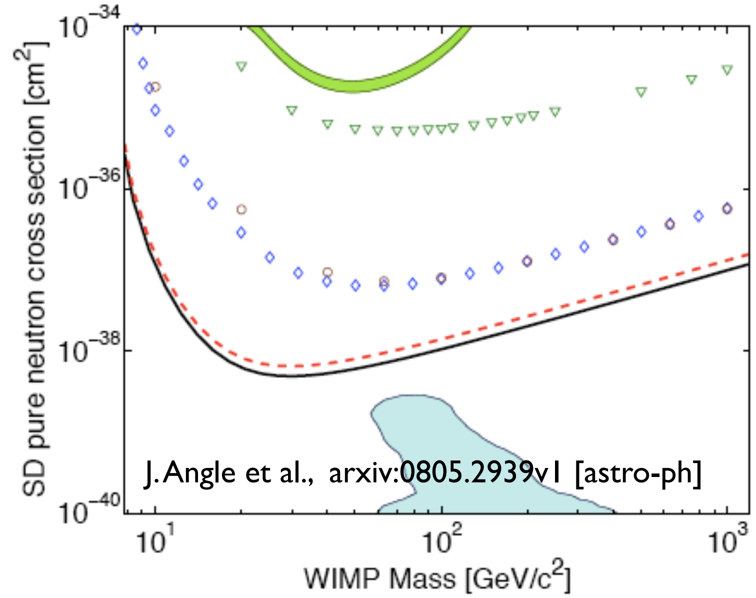


2008 : A very good year so far for the DM field!

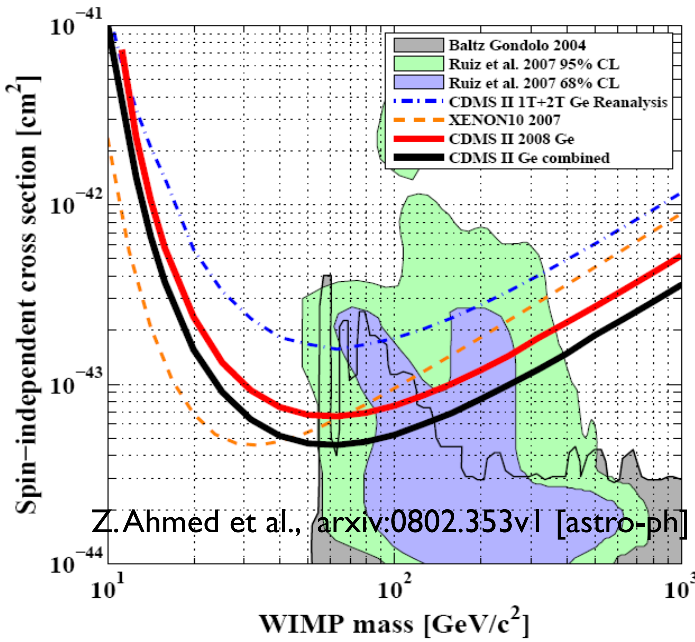
COUPP New Limit: Pure Proton Coupling



XENON New Limit: Pure Neutron Coupling



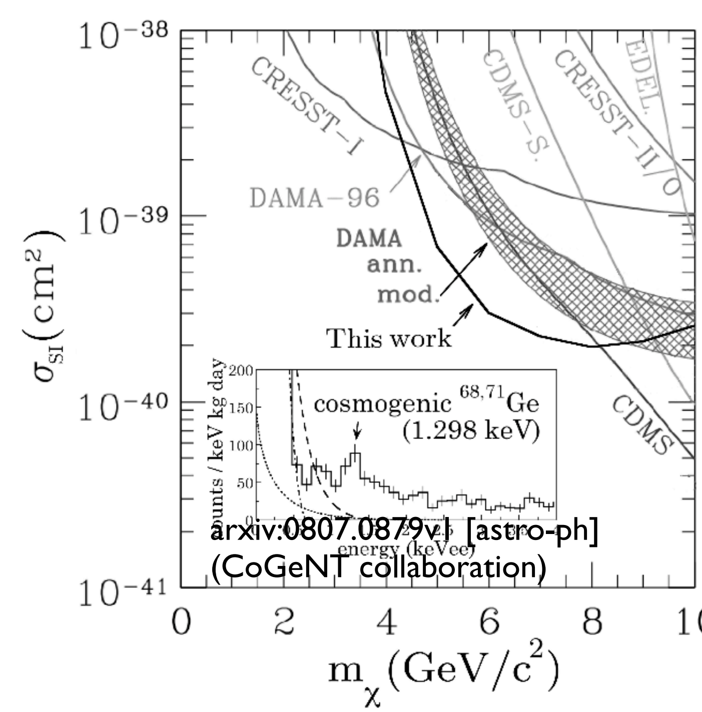
CDMS New Limit: Spin Independent Coupling



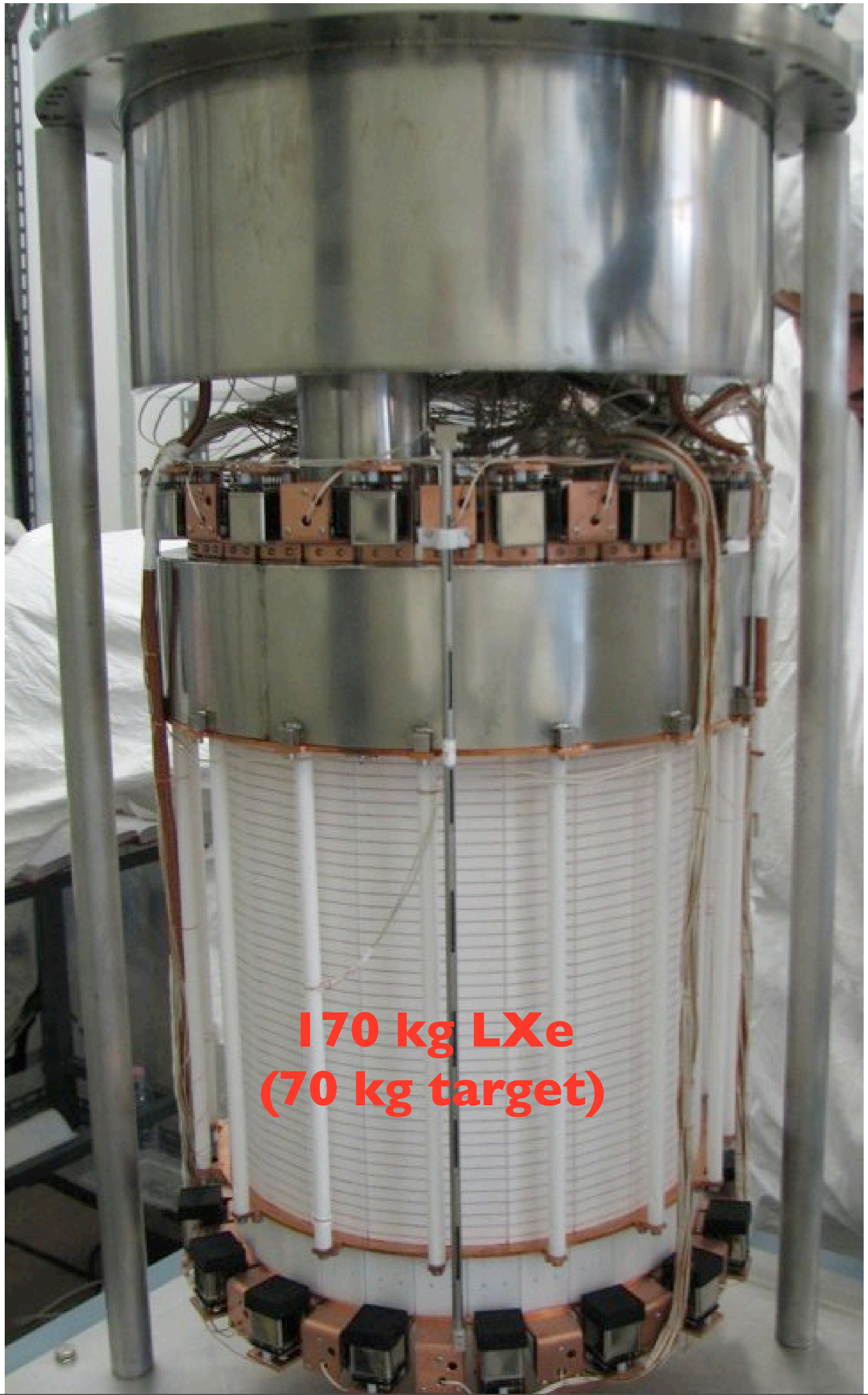
XENON kicks off XENON100

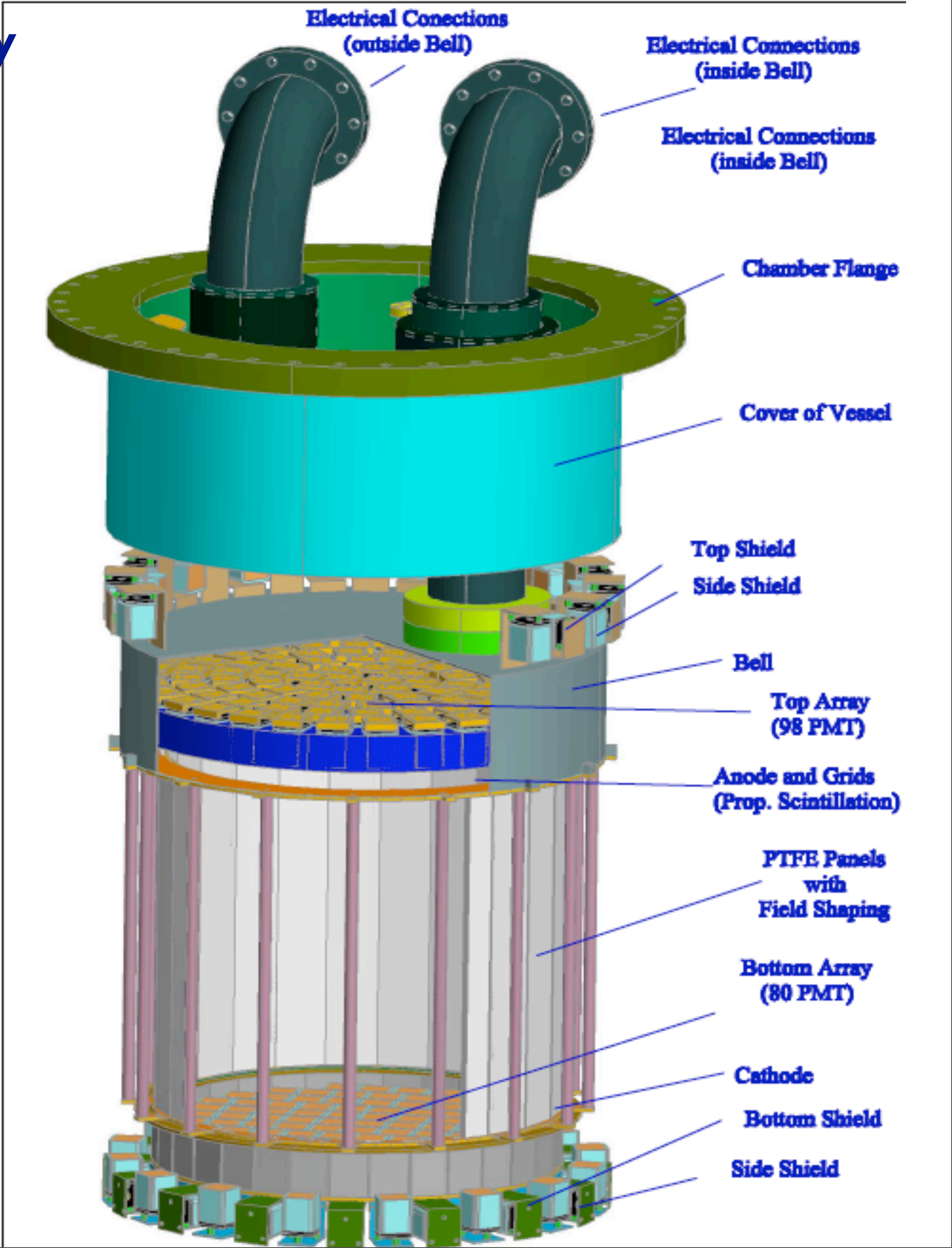
- *New TPC (170 kg LXe) assembly moved underground (LNGS) Feb 08*
- *New Cryogenics/Electronics/DAQ/Slow Control Systems tested*
- *Experiment designed for Low Background (~100 times less than XENON10)*
- *Gamma Calibration ongoing: Charge/Light Yield continue to increase*
- *1st Science Data Taking Run by Nov 08*

CoGeNT New Limit: Spin Independent Coupling



XENON100: The TPC Assembly



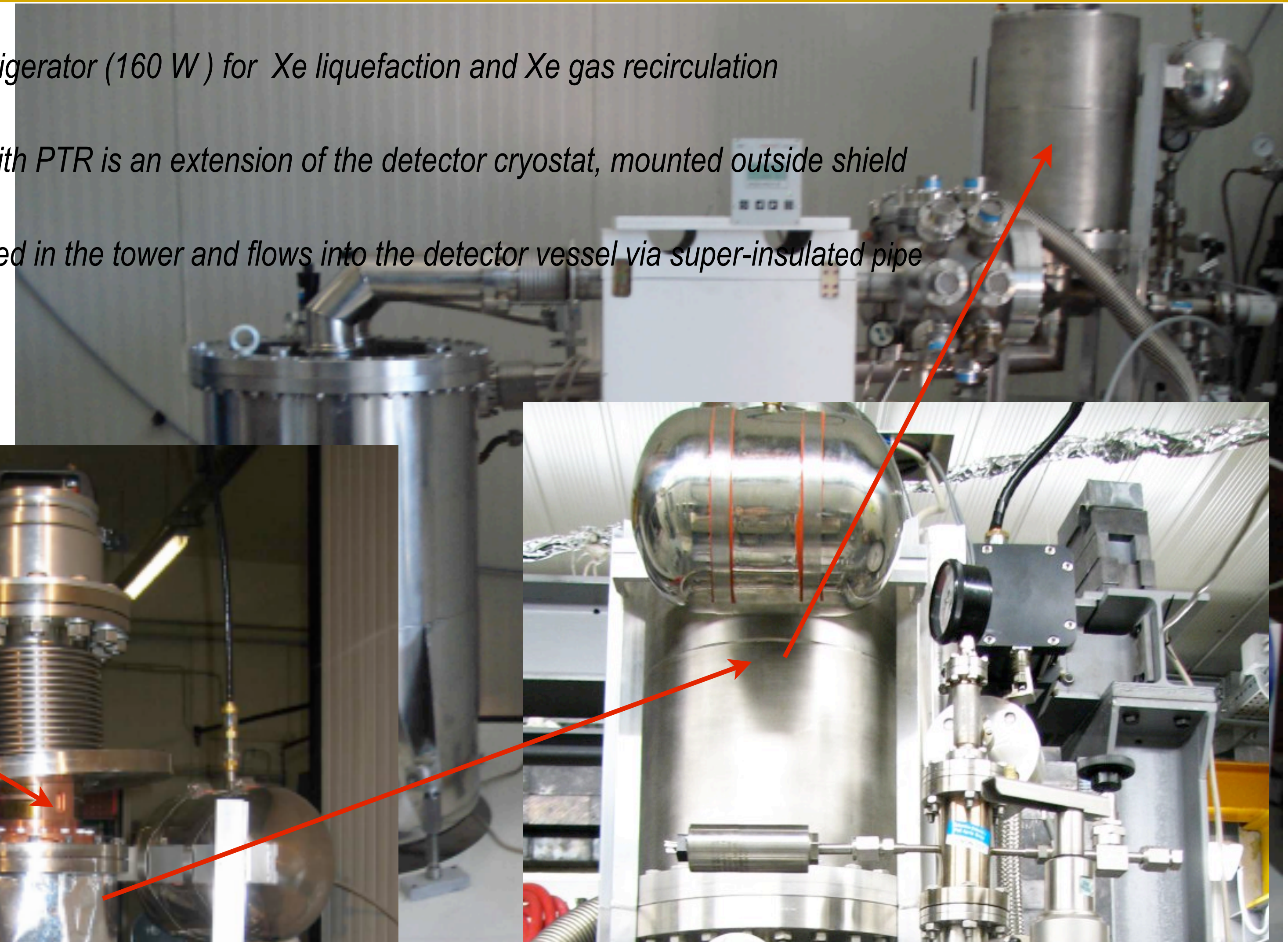


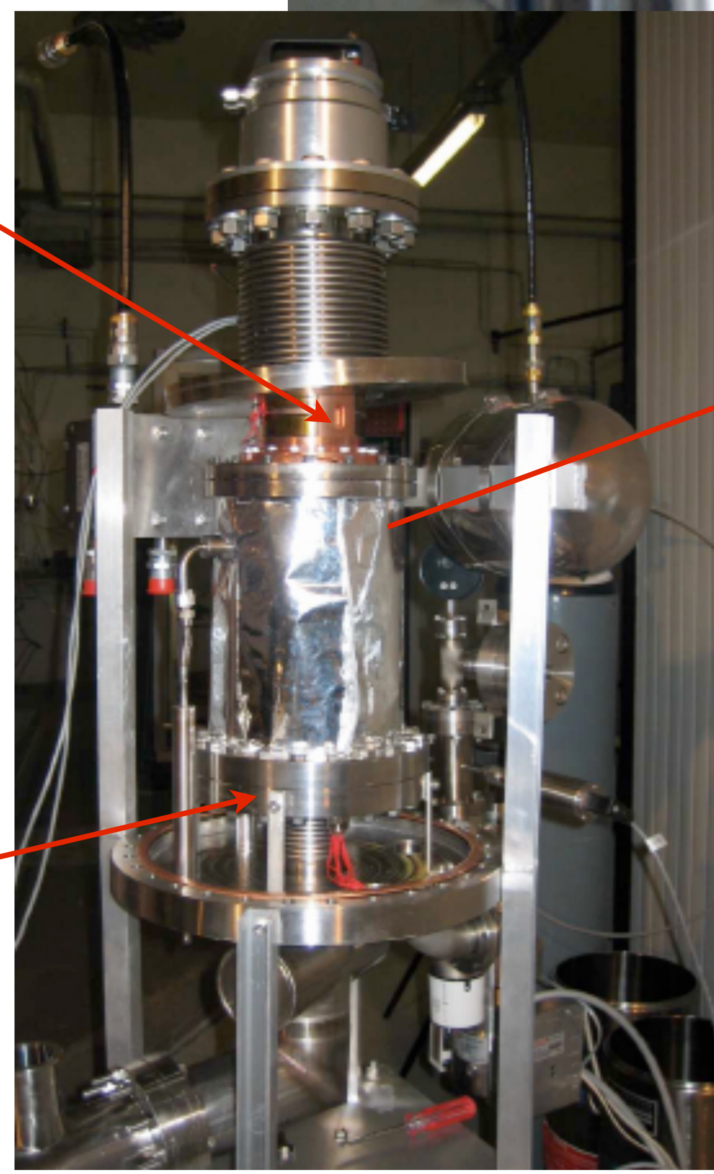
XENON100: Keeping it Cold! New Cryogenics System Design

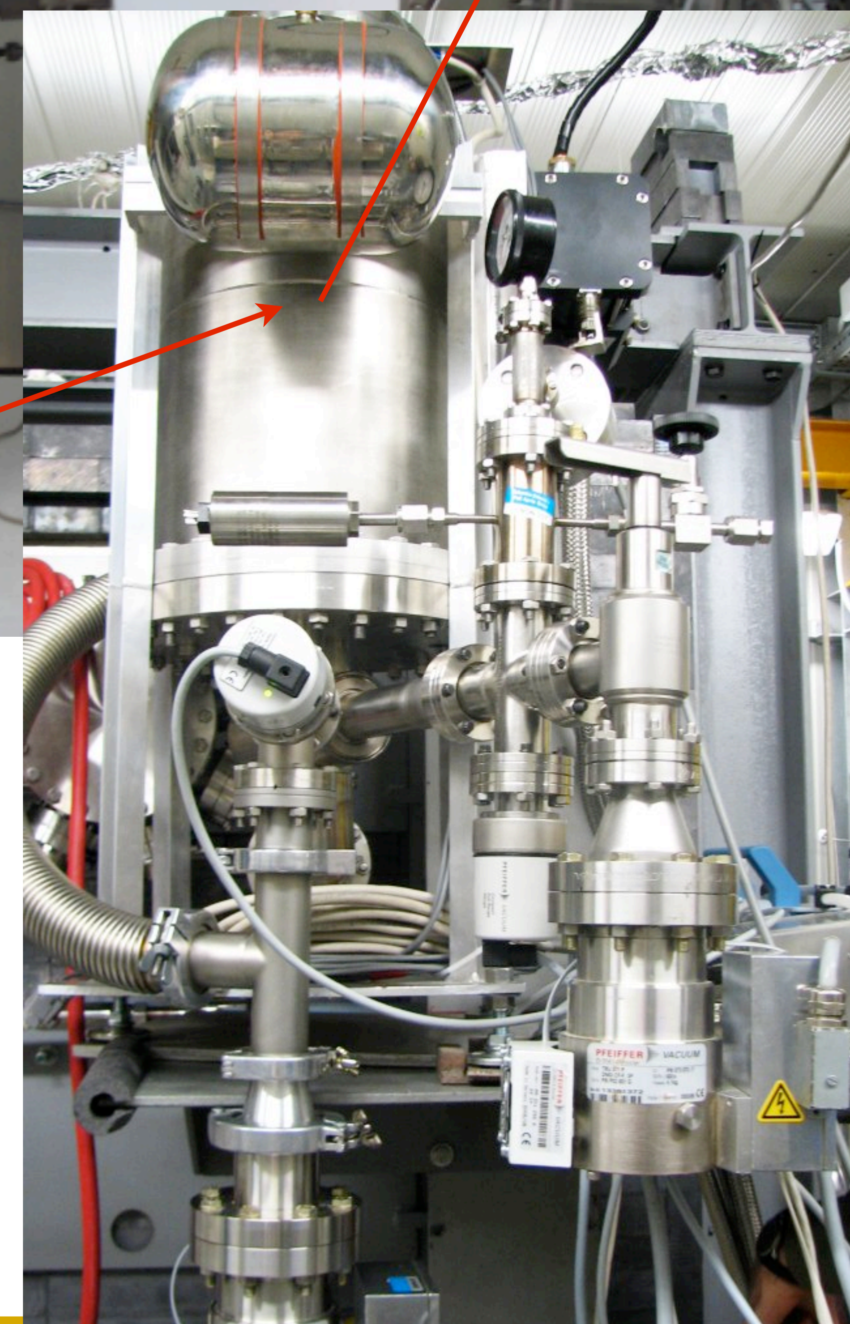
Pulse Tube Refrigerator (160 W) for Xe liquefaction and Xe gas recirculation

Cooling tower with PTR is an extension of the detector cryostat, mounted outside shield

Xe gas is liquefied in the tower and flows into the detector vessel via super-insulated pipe





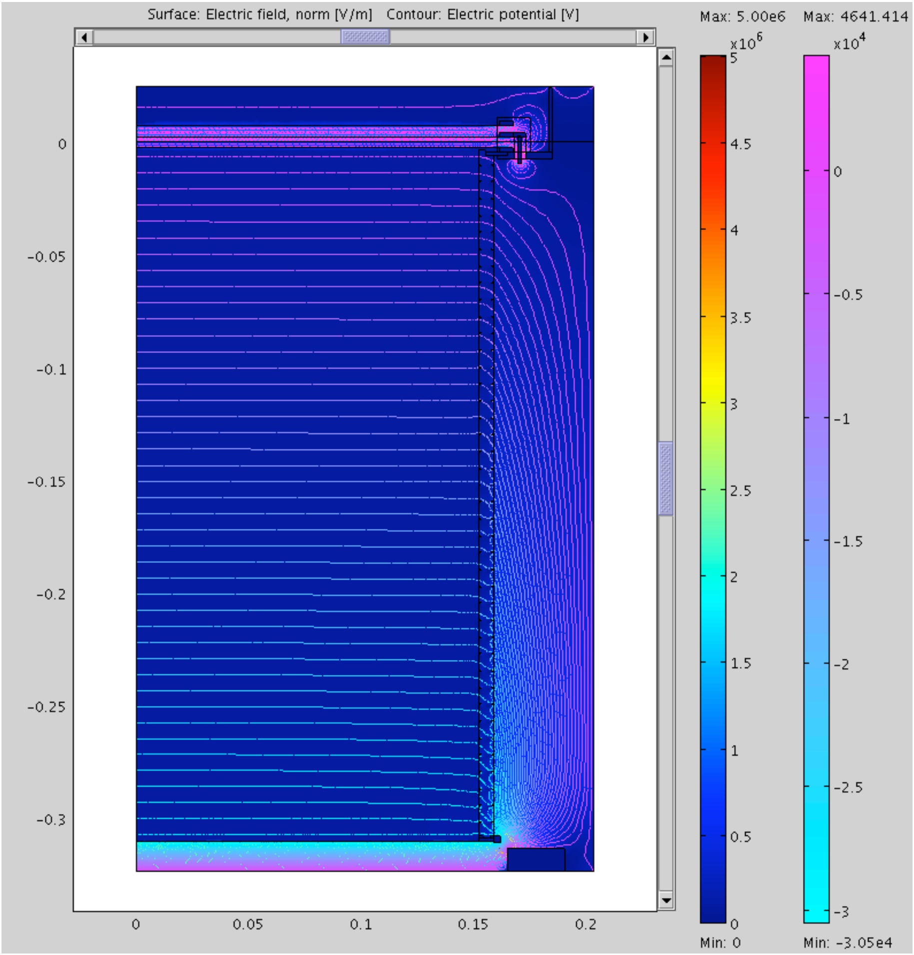


XENON100 Underground at the Laboratori Nazionali del Gran Sasso

LNGS: 1.4km rock (3100 mwe)

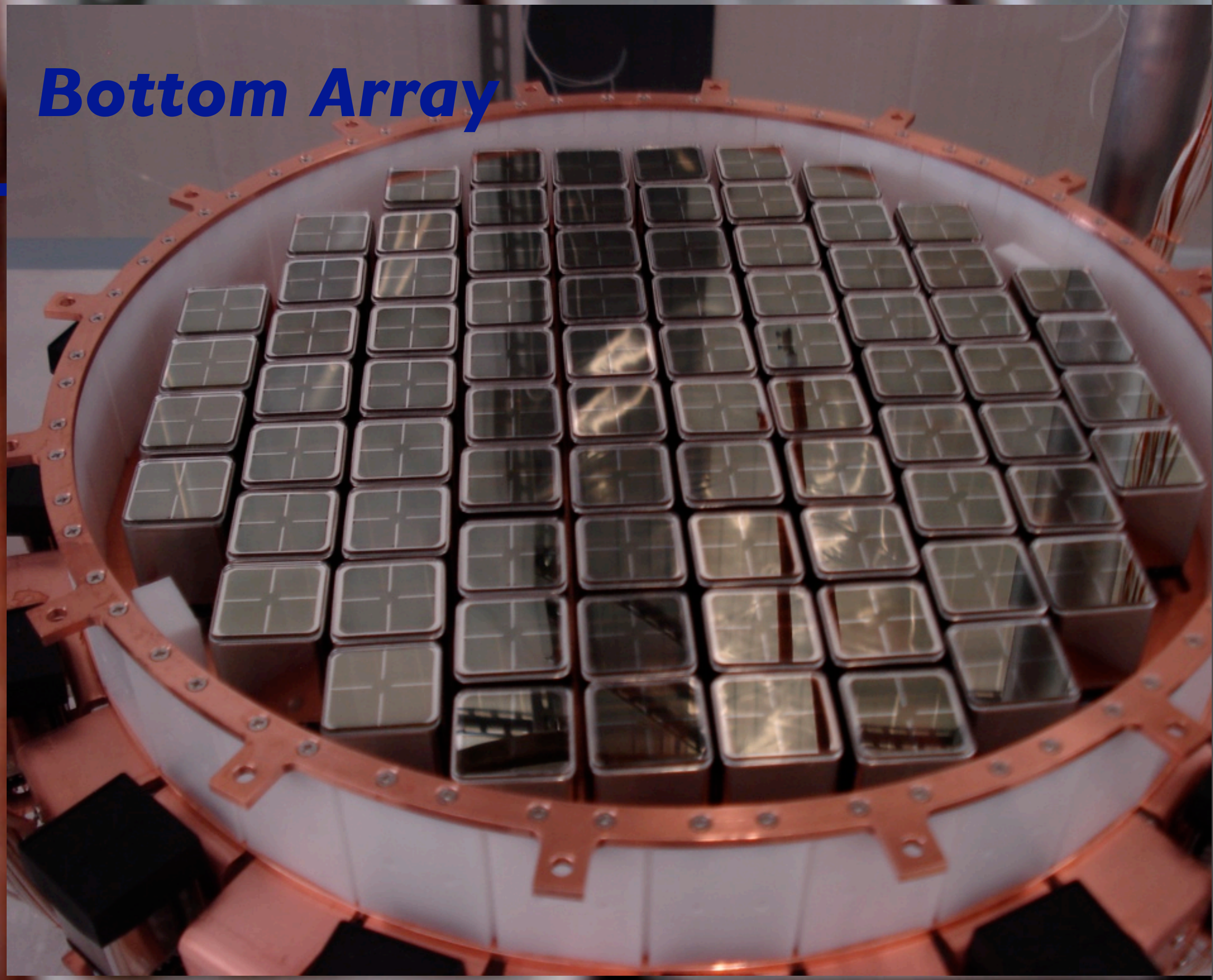
XENON100: Electric Field Cage and Grids

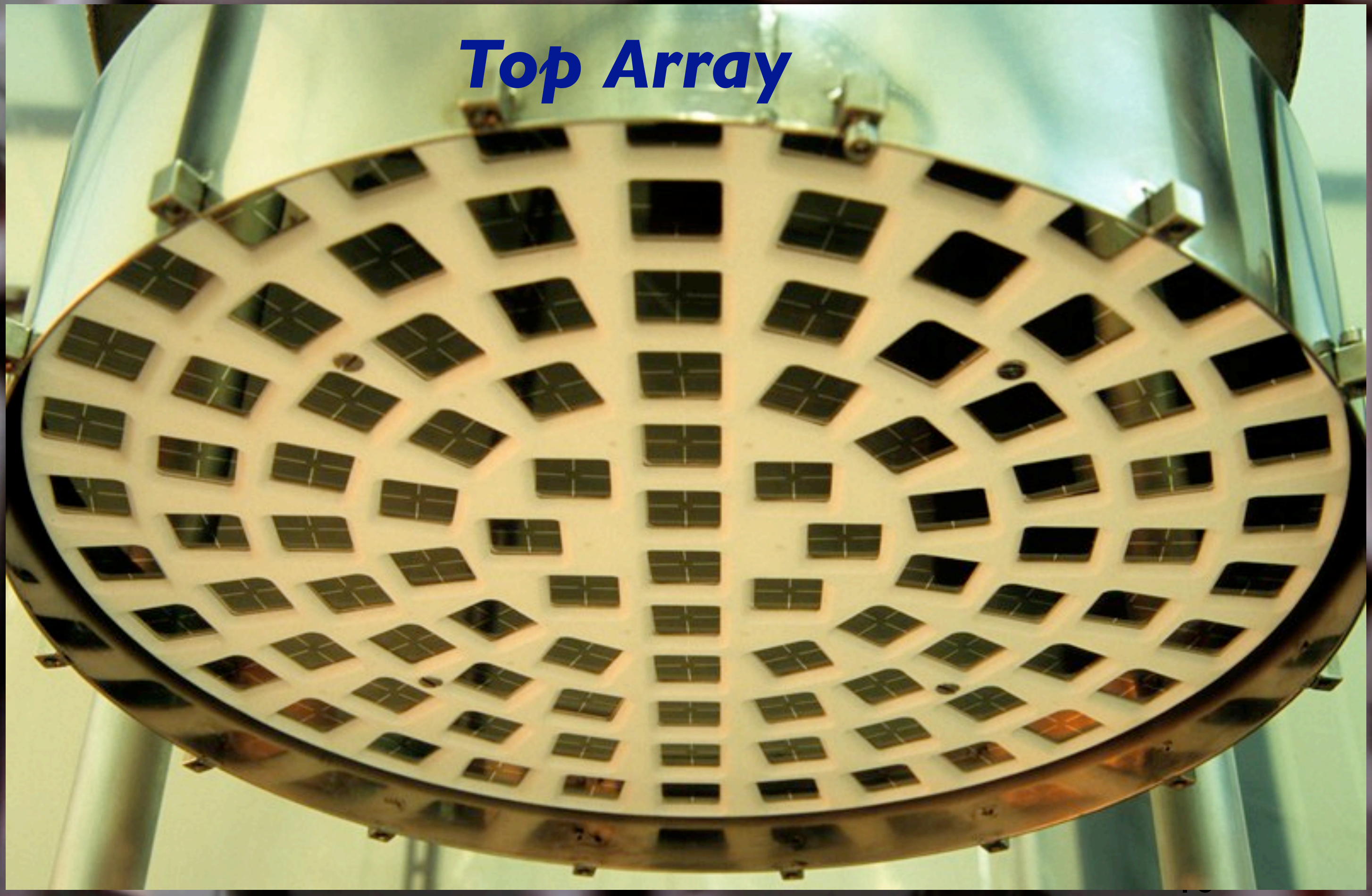
- Negative 30 kV on Cathode
- Positive 5 kV on Anode grid
- For both HV, custom-made low radioactivity feedthroughs
- 40 shaping Cu wires, inside and outside PTFE
- resistors for HV race-track mounted on shaping wires
- 1 kV/cm drift field homogeneity optimized with simulations
- hexagonal meshes with high optical transmission
- Low radioactivity frames and mounting materials



XENON100: The PMTs

- 242 PMTs (Hamamatsu R8520-06-Al)
- 1 “ square metal channel developed for XENON
- Low radioactivity (<1 mBq U/Th per PMT)
- 80 PMTs for bottom array (33% QE)
- 98 PMTs for top array (23% QE)
- 64 PMTs for top/bottom/side Veto (23% QE)

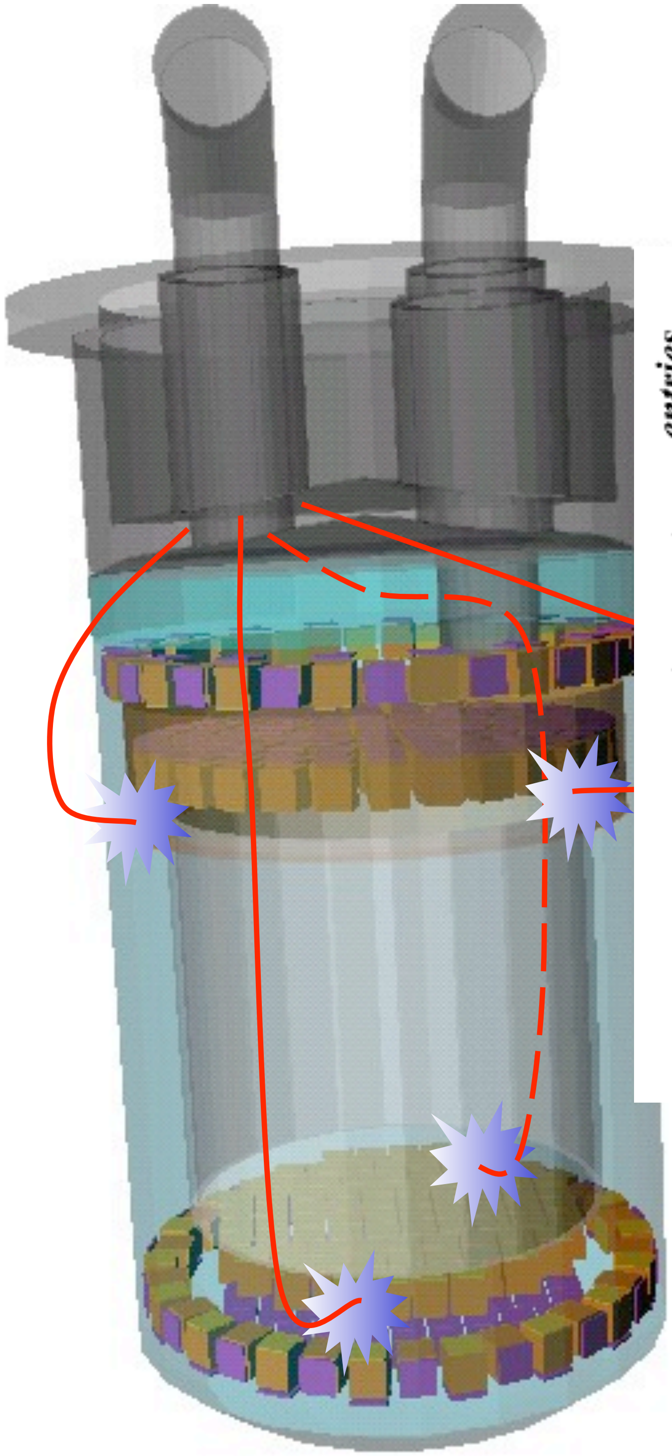




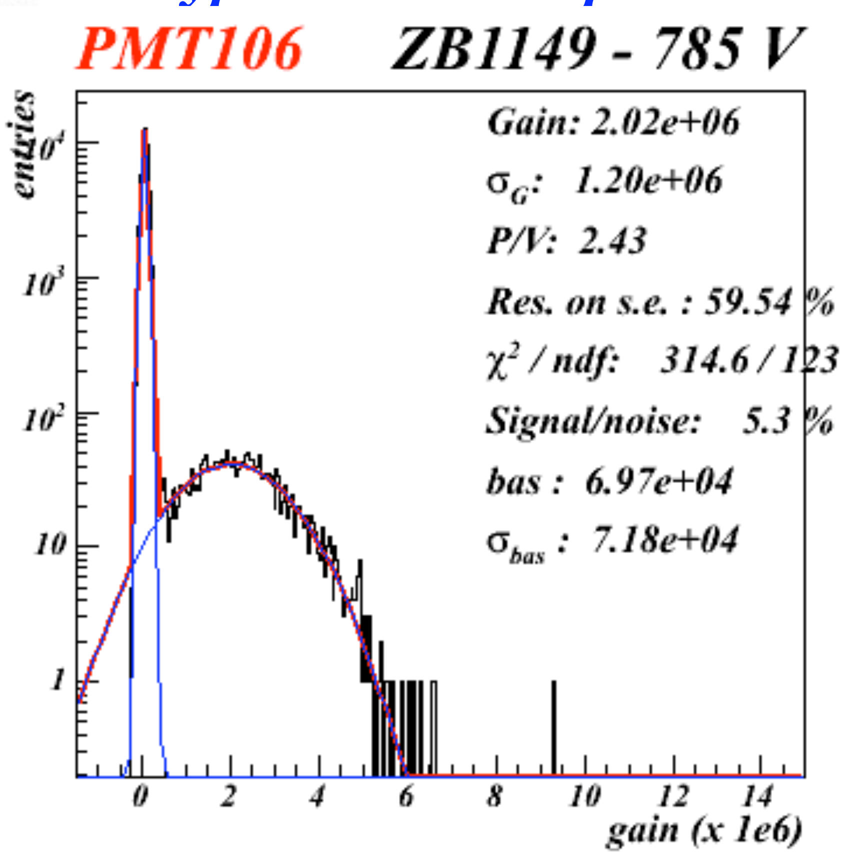
XENON100: Putting it all together

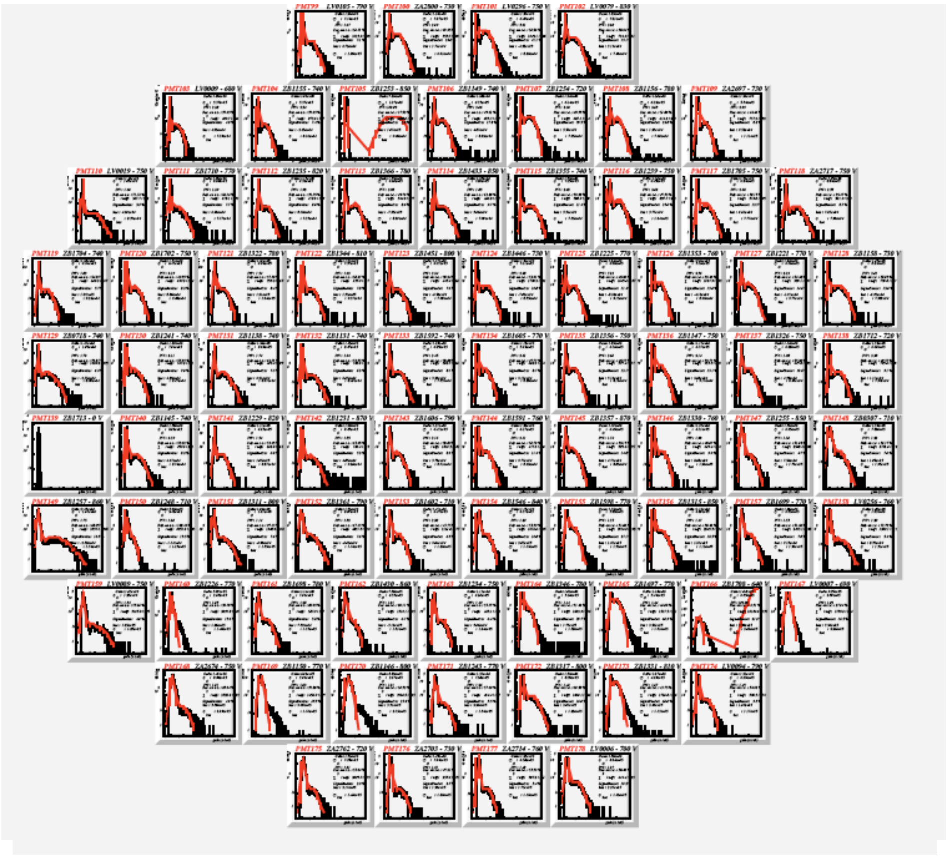
XENON100: PMTs Calibration

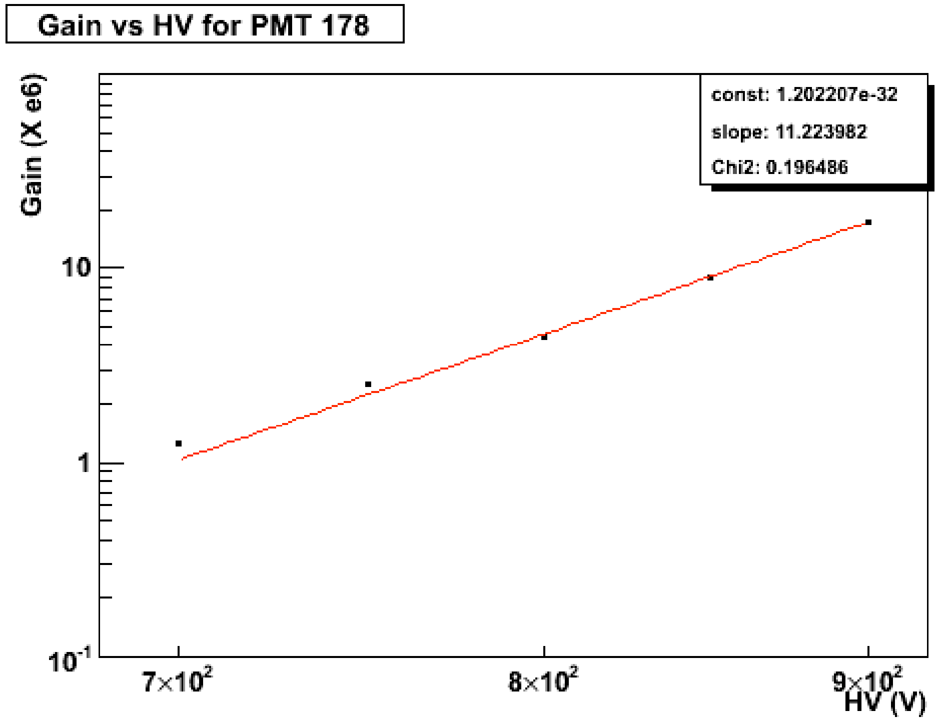
Scintillation fibers + LEDs to calibrate Gain of PMTs for Inner Target and Veto Region



Typical SPE Response



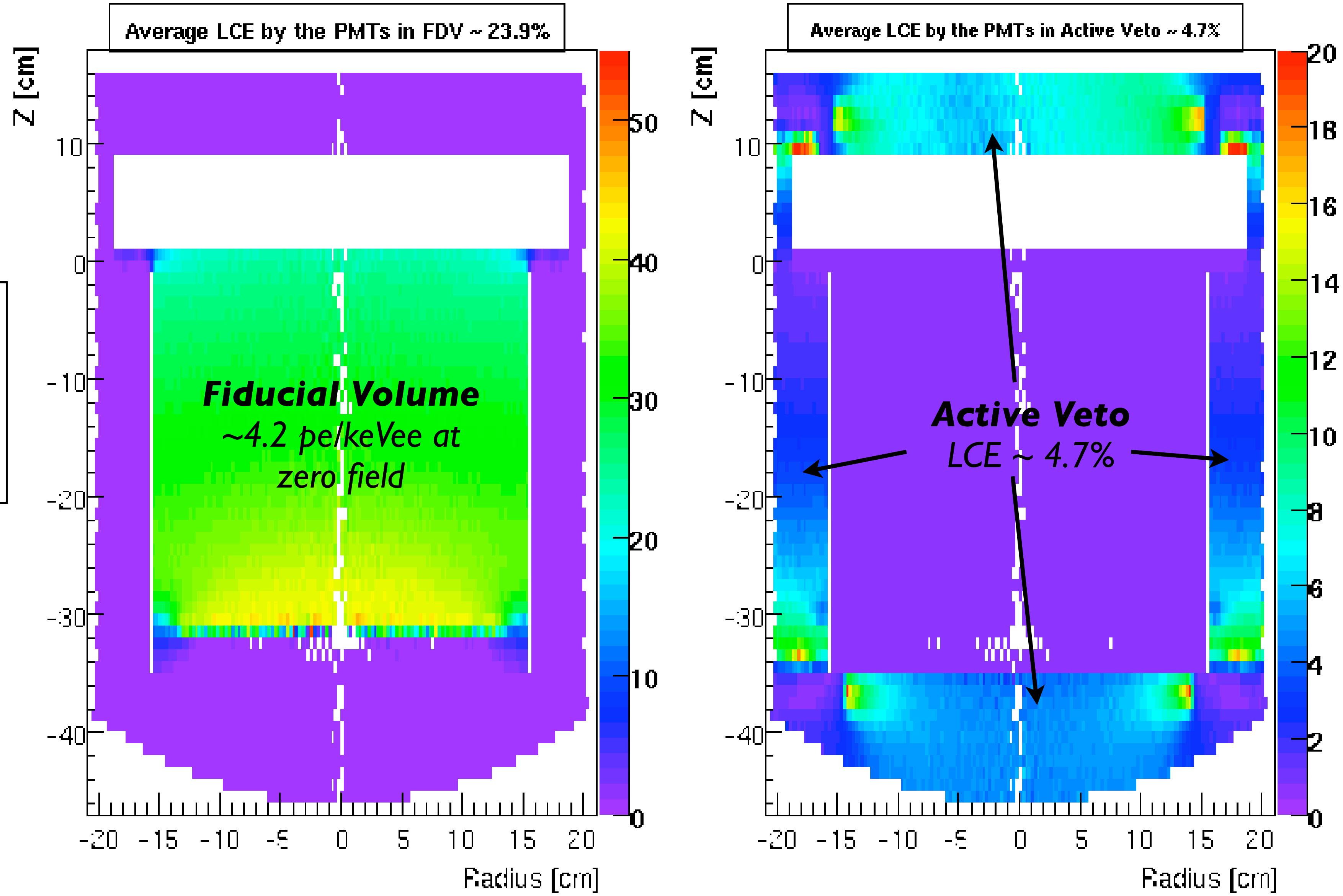




XE100: light collection efficiency

Light Simulation Assumptions

Absorption length: 1.5 m
Rayleigh scatter: 50 cm
PTFE reflectivity: 95%



- *Average LCE in fiducial volume: 24% ➙ 4.2 pe/keVee at zero field (with 35% PMT effective QEs)* *➙ Nuclear recoil detection efficiency ~100% at 5 keVr*
- *Average LCE in the active veto: 4.7% ➙ trigger efficiency in veto ~90% at 50 keVee*

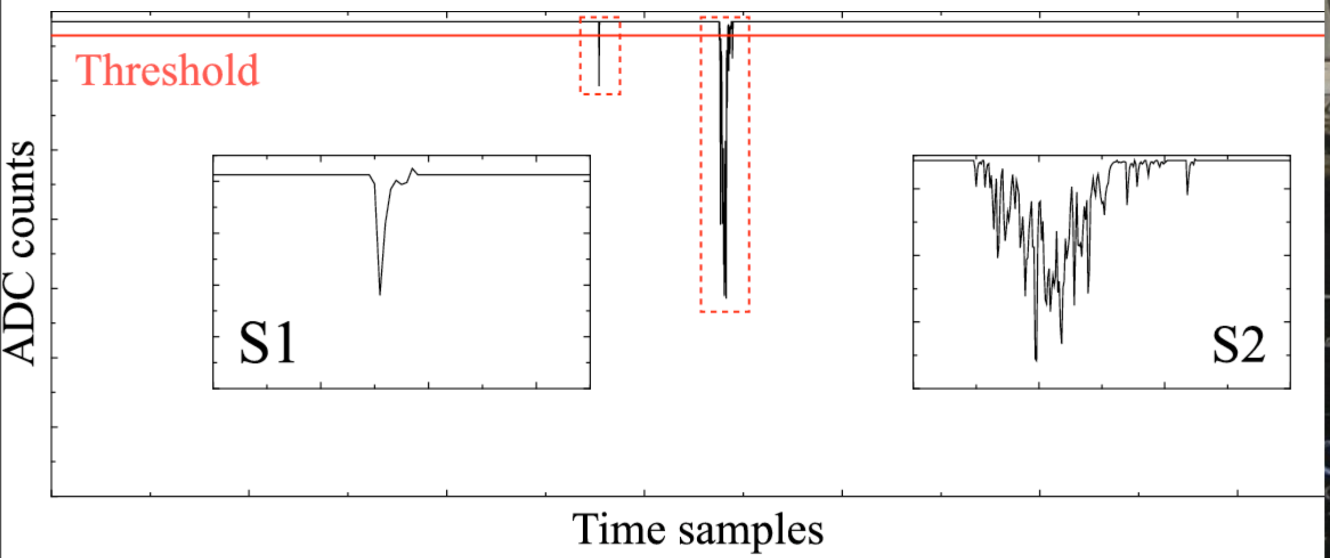
XENON100: Data Acqusition System

Requirements:

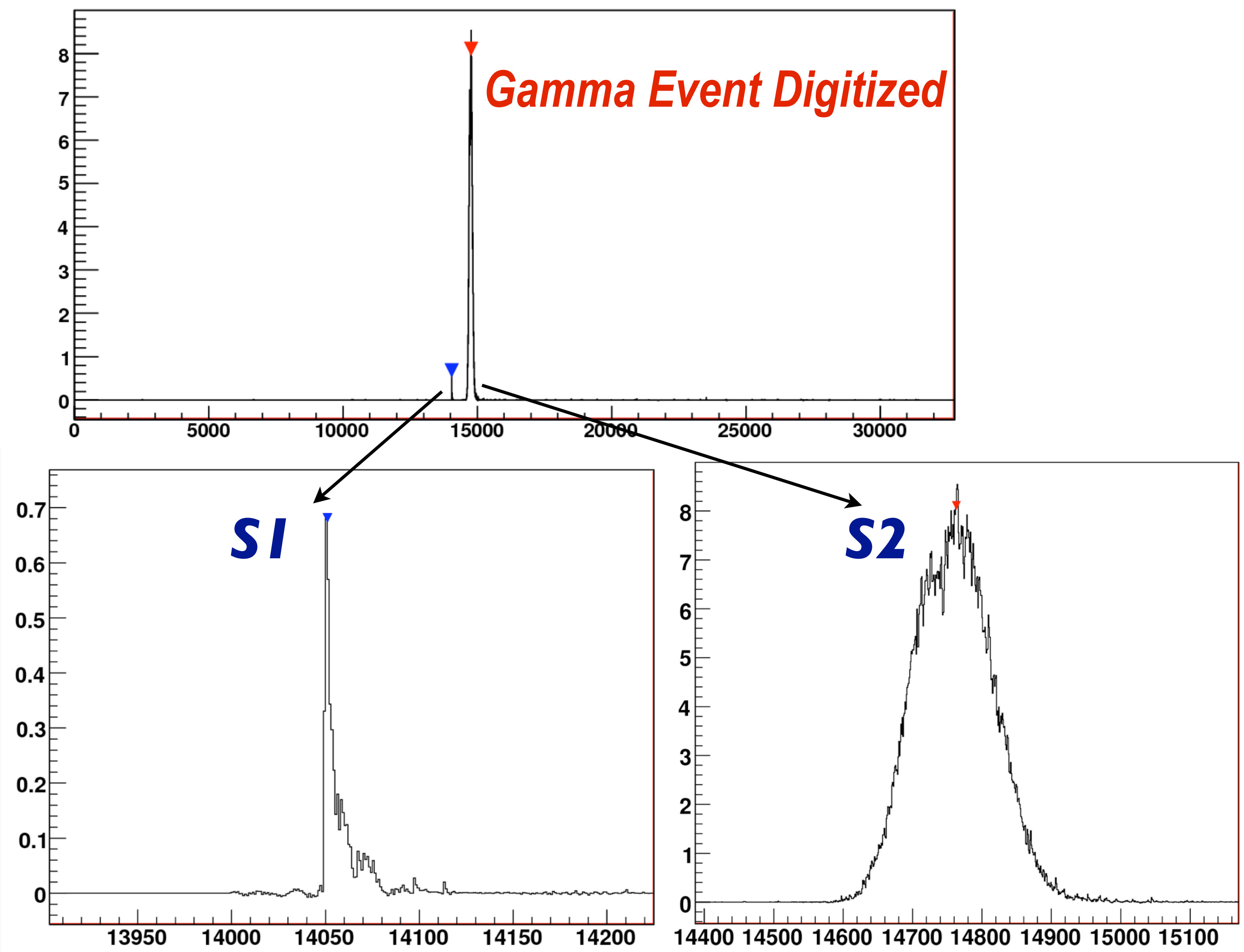
digitize full waveform (320µs) of 242 PMTs
with no deadtime and with
high rate capability for calibration

CAEN V1724 Flash ADC: 14bit, 100MHz

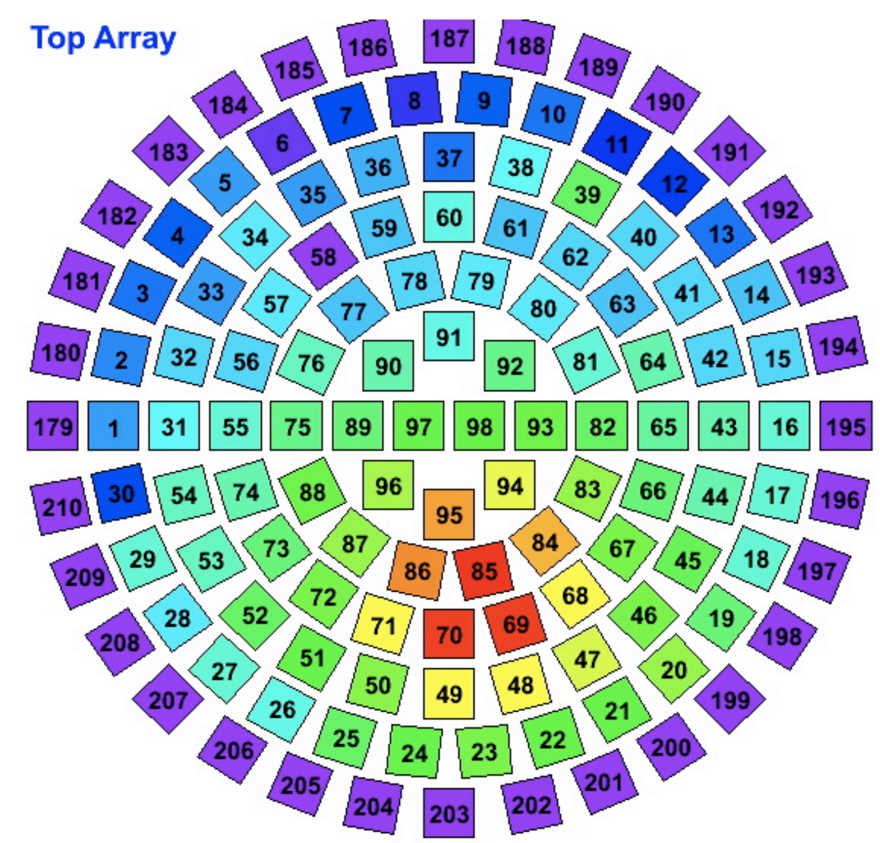
circular buffer: no deadtime
on board FPGA: *Zero Length Encoding*
only relevant signal portion transferred from ADC
to DAQ computer to allow faster event transfer rates
>60 Hz in calibration mode



XENON100: First Charge & Light Signals (Cs137 Source)



Gamma Event Localized



XENON100: Kr Removal

Kr85 (Beta, Emax = 687 keV, t = 10.8 y, br = 99.563%) -> Rb85

Kr85 (Beta, Emax = 173 keV, t = 10.8 y, br = 0.434%) -> Rb85m (Gamma, E = 514 keV, t = 2.43 us) -> Rb85

XENON100 gas purified by Spectra Gases Industry to a Kr concentration < 10 ppb.

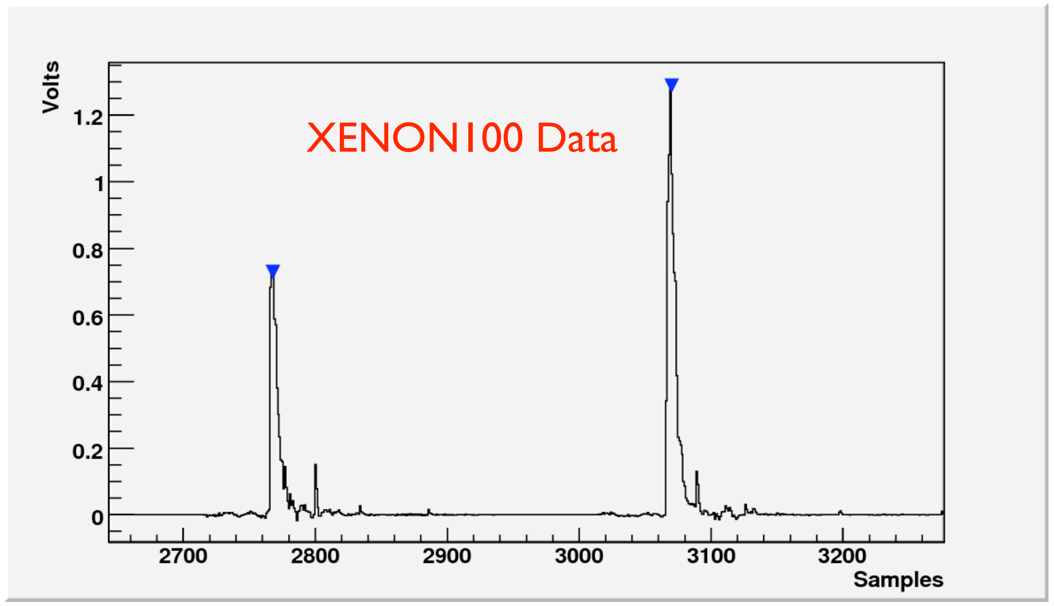
Concentration verified by delayed coincidences analysis: in 1.83 days we observed 13 events or
Measured Kr contamination = 7+-2 ppb

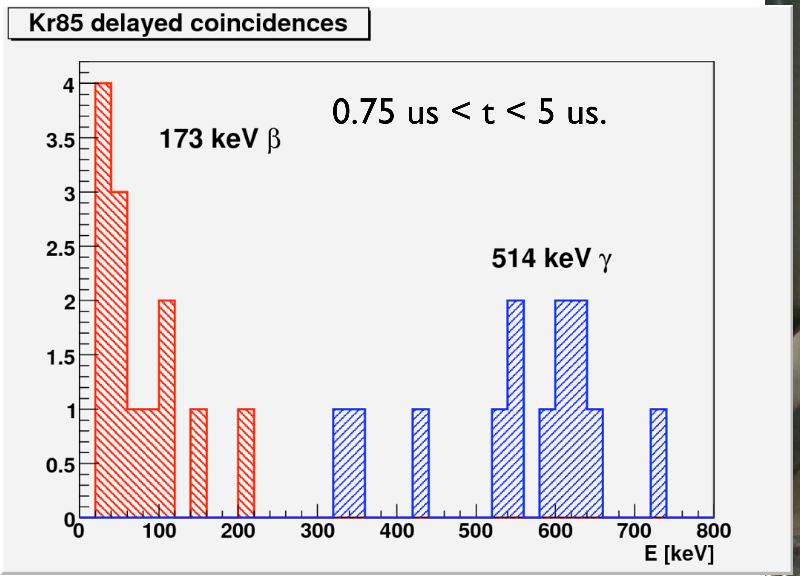
XENON100 science goal requires Kr contamination ~ 50 ppt

A Cryogenic Distillation Tower for XENON100
was commissioned from the same company used by XMASS for 100 kg detector

Column is designed to reduce Kr by factor 10^3 at a rate of 0.6 kg/hr

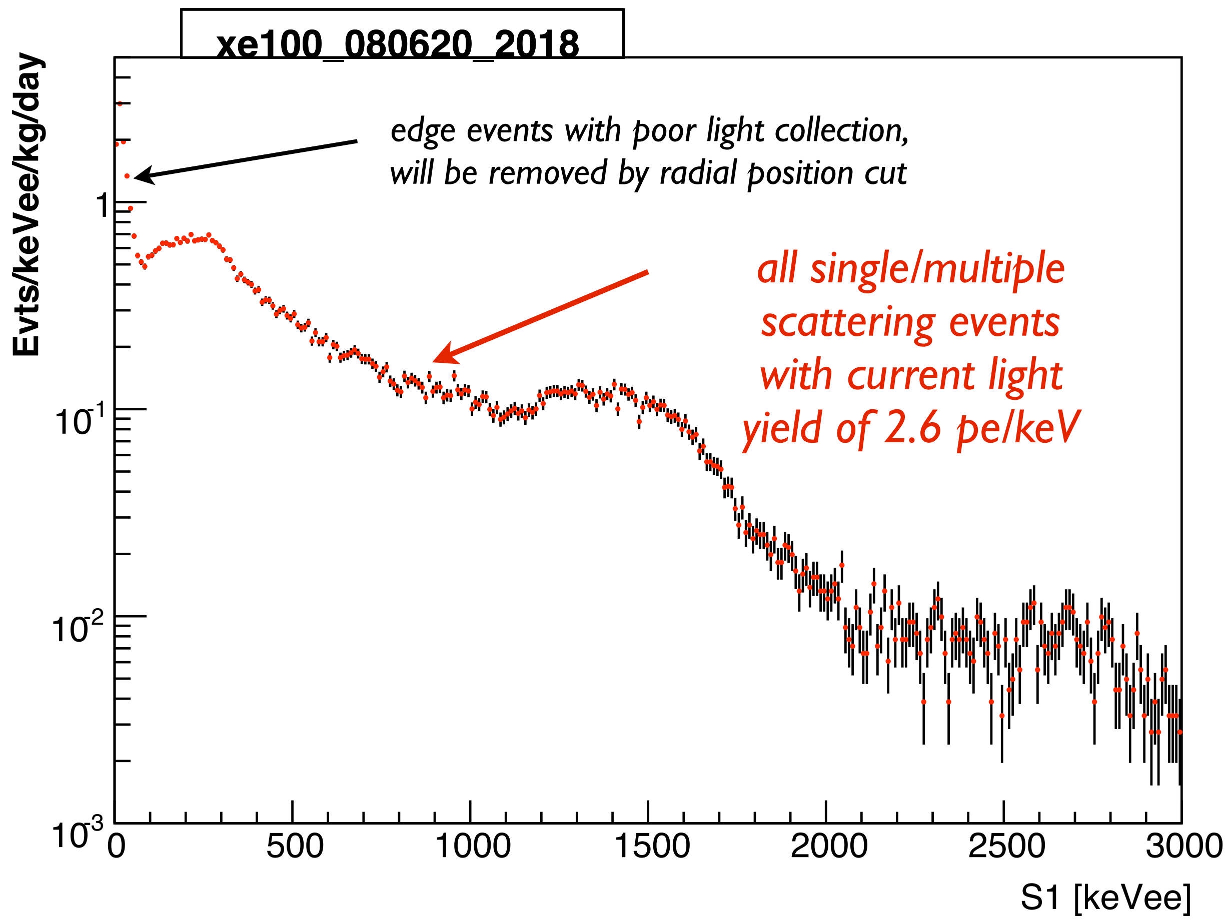
We expect to reach 50 ppt level in < 3 weeks during Sep 08



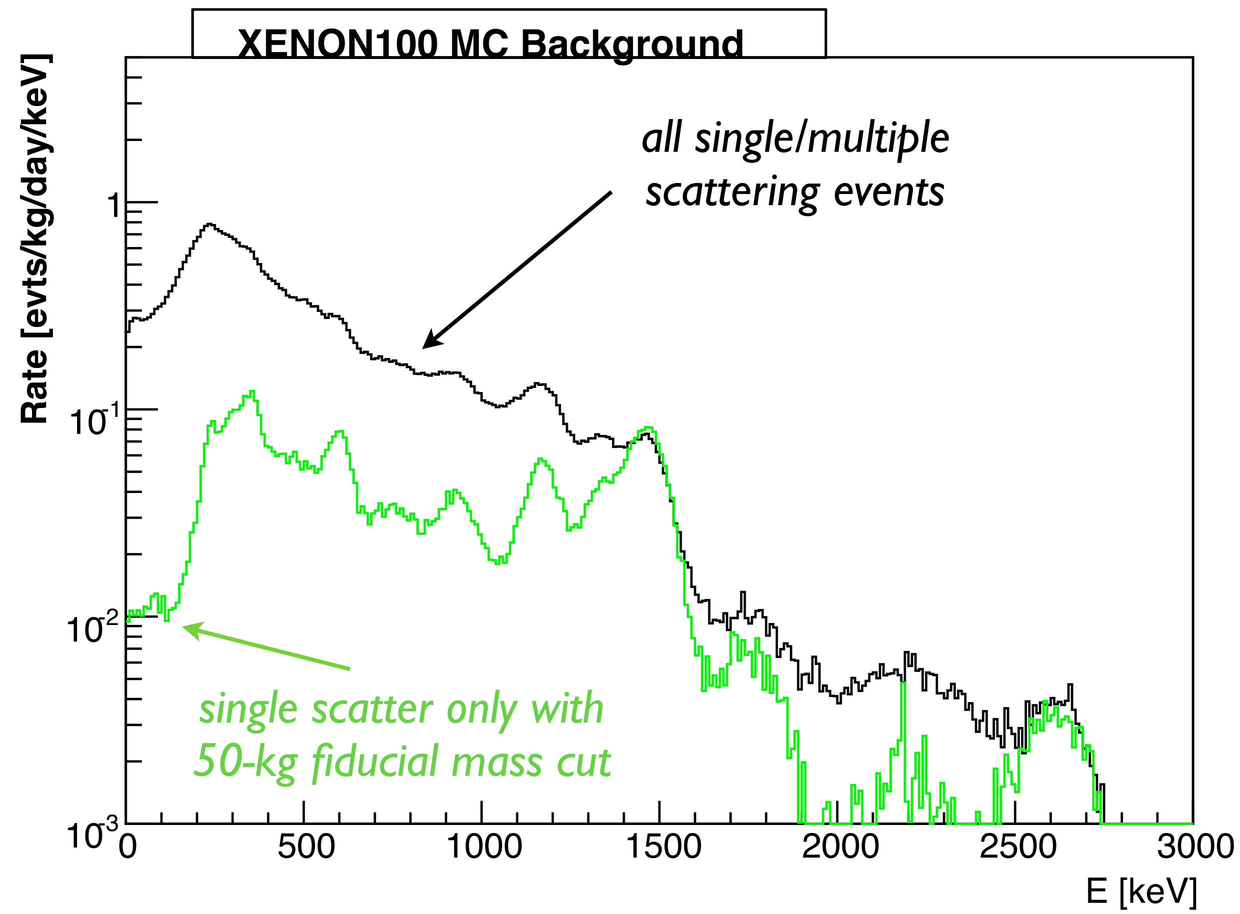


Understanding the background in XENON100

Data

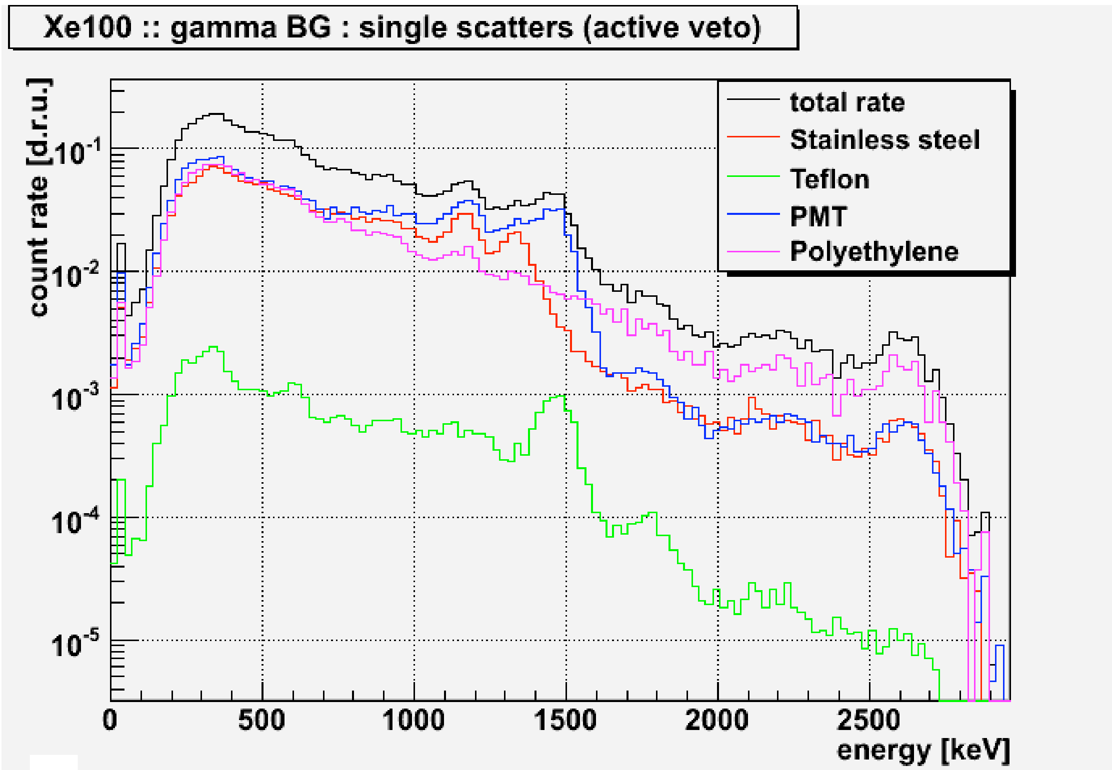


MC

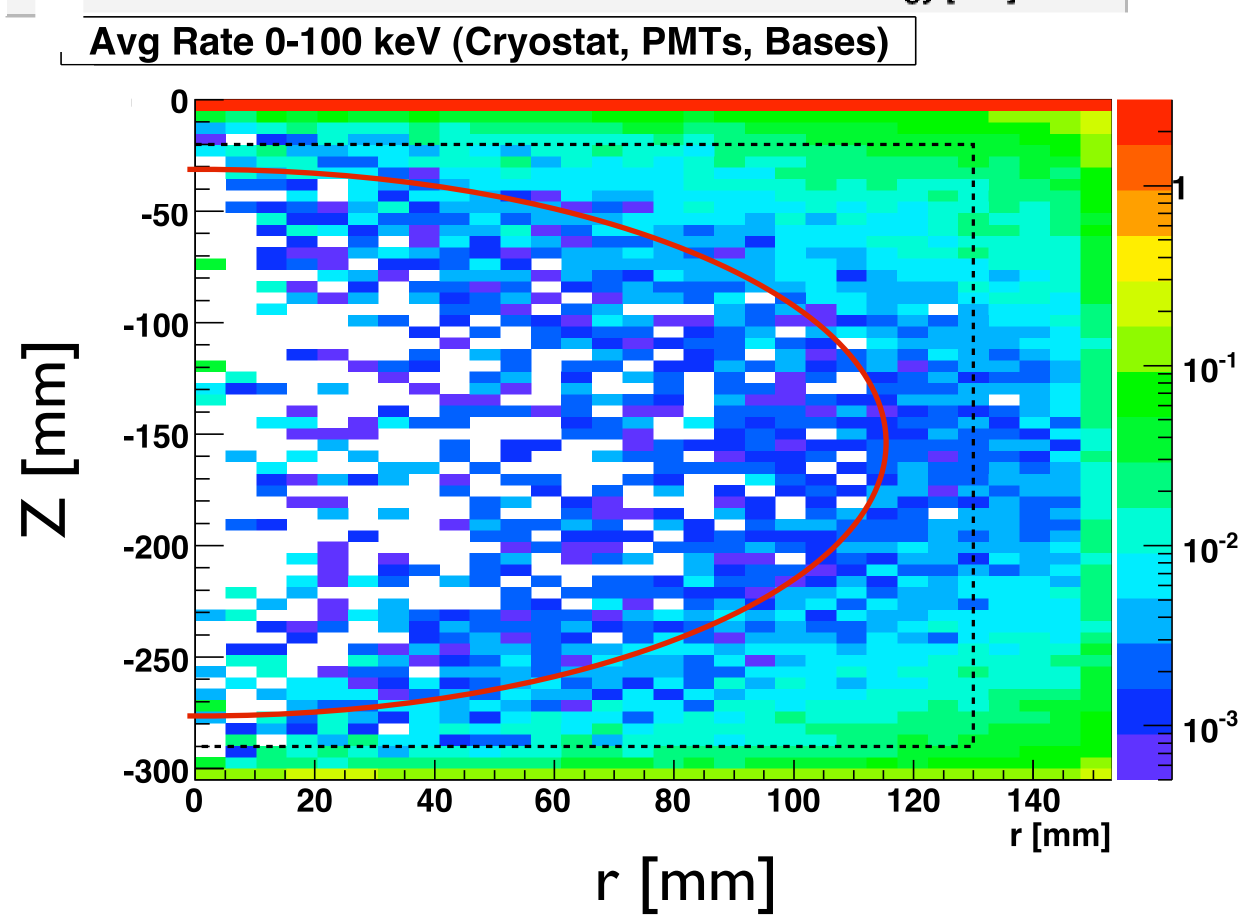


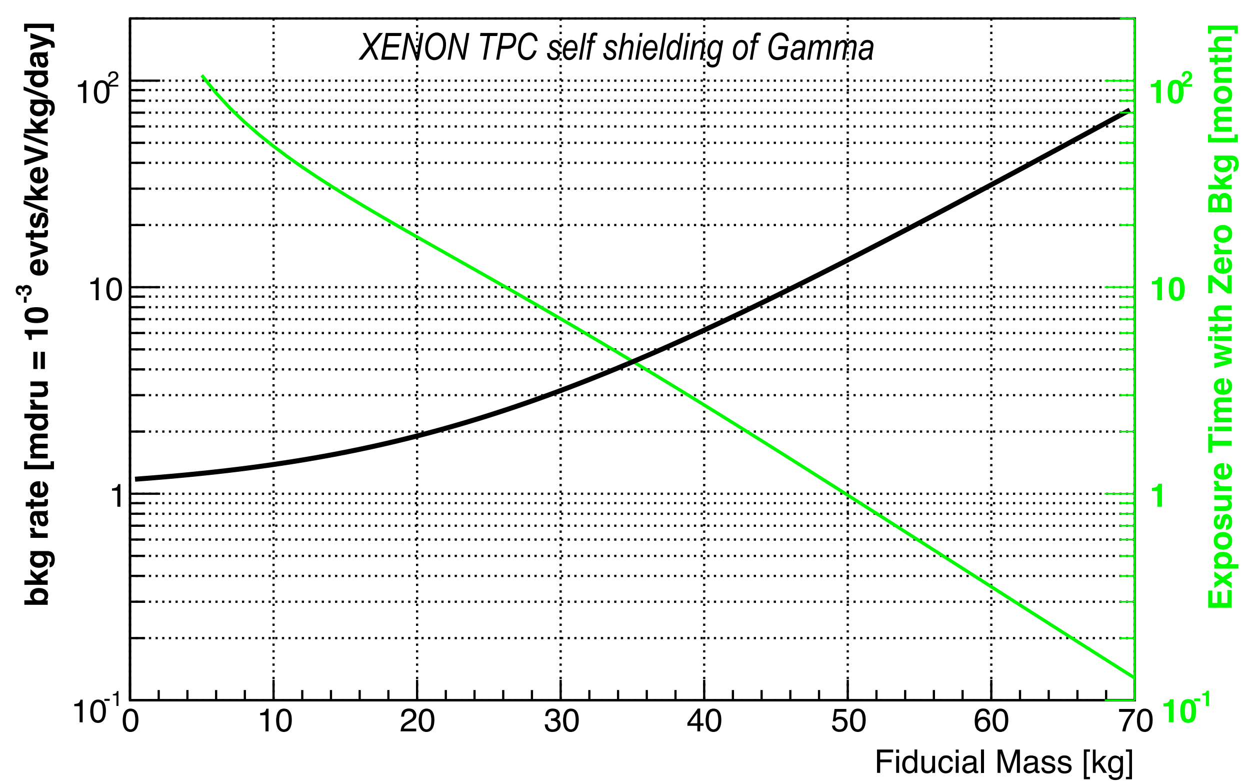
Measured background in good agreement with MC prediction!

XENON100: Summary of Expected Backgrounds & Sensitivity

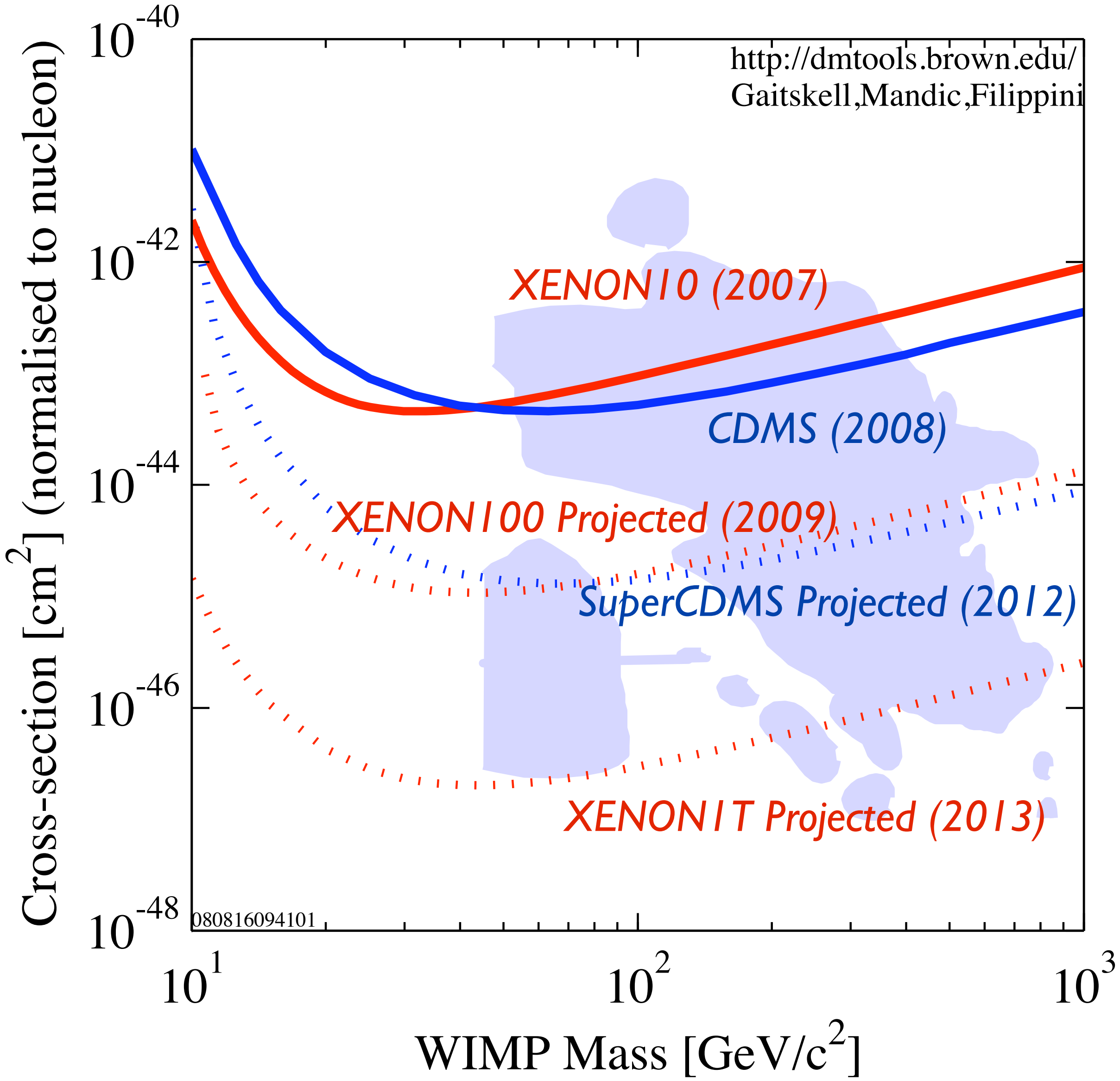


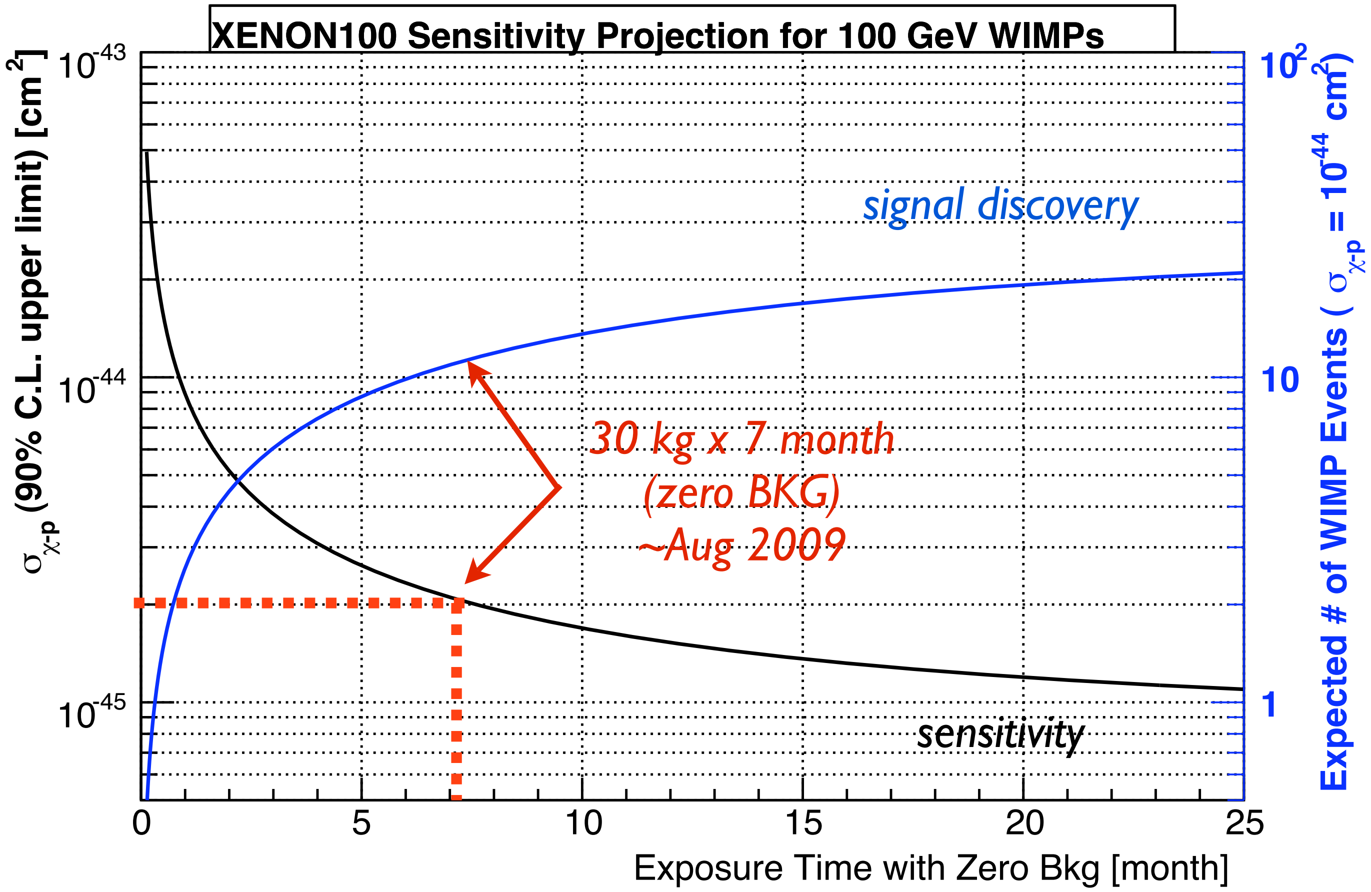
- *different fiducial volume cuts (spherical vs cylindrical) to achieve the best bkg rate vs fiducial mass*
- *~6 mdru (100 x less than XENON10) for a fiducial mass of 40 kg (no gamma background for 3 months)*
- *~2 mdru for a fiducial mass of 20 kg (no gamma background for 1.5 year)*
- *total neutron bkg from detector's materials and shield <0.6 n/yr.* **See L. Baudis's Talk**





XENON100: Projected Sensitivity





- *XENON100 dark matter search run expected to start in Nov 2008.*
- *XENON100 experiment can probe down to* σ_{SI}~10^{-45} cm^2 *..but has also great discovery potential!*

Summary

The XENON Project is moving fast towards the discovery of Dark Matter Particles

The XENON100 experiment is **operational** underground at LNGS

The new TPC designed to have 100 x less background than XENON10

Much effort has gone in materials screening for low radioactivity

Amazing PMTs (thanks Hamamatsu!) working in LXe give us ~5 pe/keV

Initial XENON100 measured total BGK rate is in good agreement with MC

Expect 1st Dark Matter Search data taking to start Nov 08

Sensitivity reach is $\sigma_{SI}\sim 2\times10^{-45}$ cm^2 after 7 months data with zero BKG

Two years of data would give ~20 WIMPs event if $\sigma_{SI}\sim 2\times10^{-44}$ cm^2 for 100 GeV

We thank the NSF, the DoE, the SNF and European agencies for continued support!