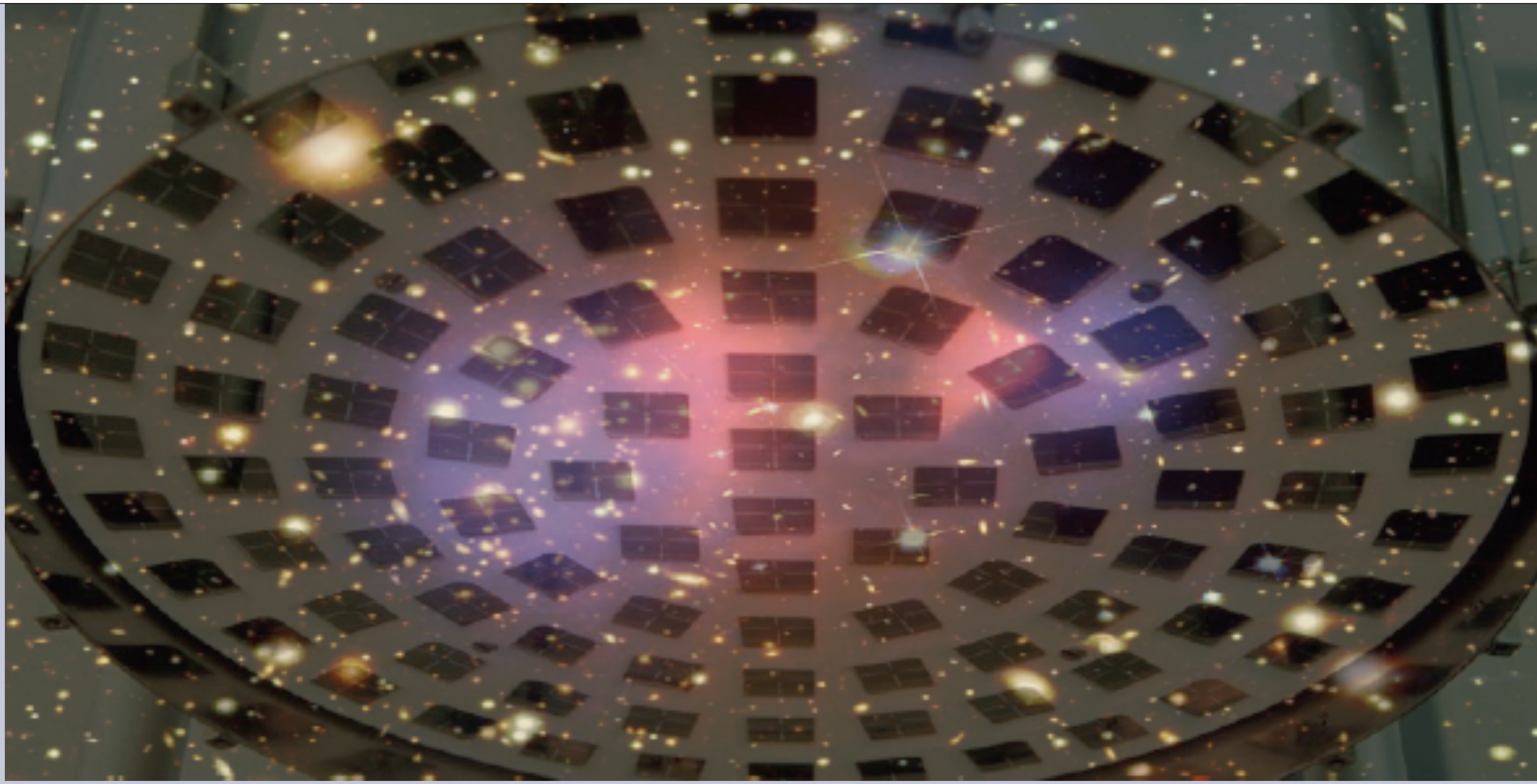


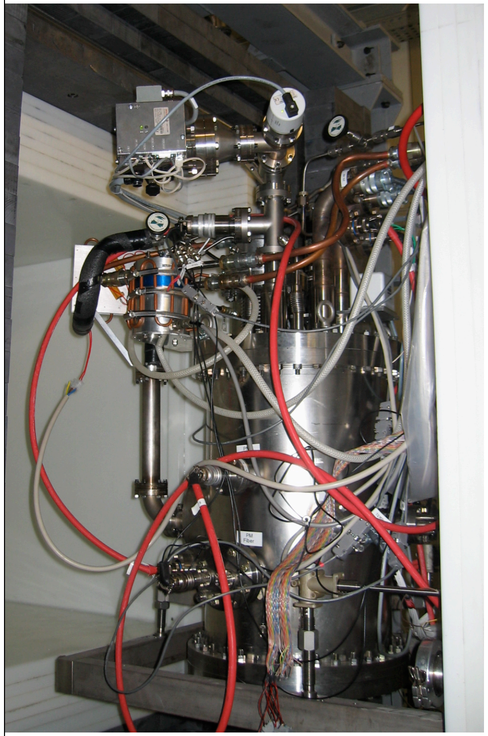
The XENON100 Dark Matter Experiment at LNGS: Status and Sensitivity

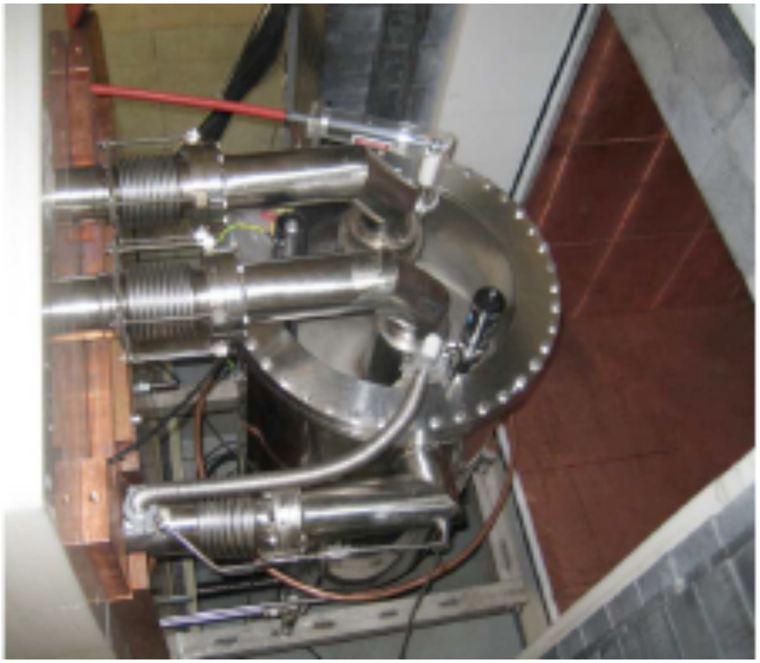
Elena Aprile
Columbia University

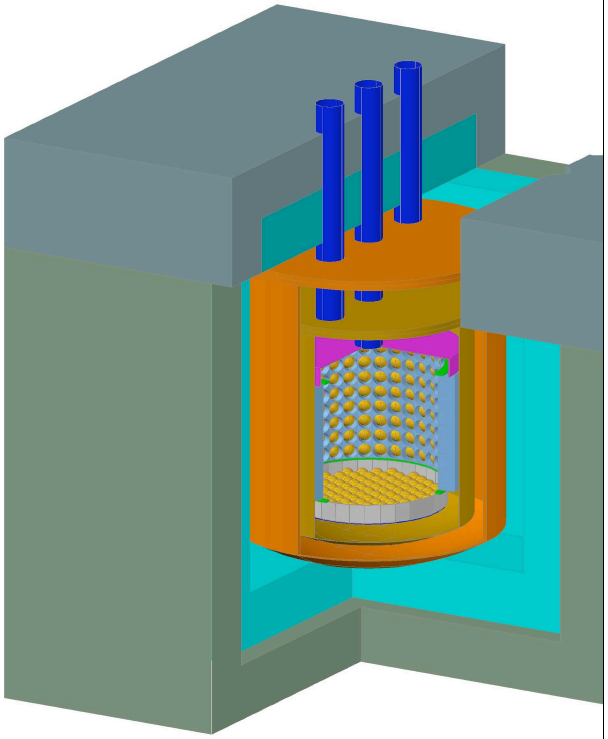
TAUP, Rome, July 2, 2009

The XENON program for Dark Matter Detection

past (2005 - 2007)	*current* (2008-2012)	*the future* (2013-2015)







XENON10

Achieved (2007) σ_{SI}*=8.8 x10*$^{-44}$ *cm*^{2}

XENON100 & 100+

Projected (2010) σ_{SI}~2x10^{-45} cm^2

Projected (20012) σ_{SI}~2x10^{-46} cm^2

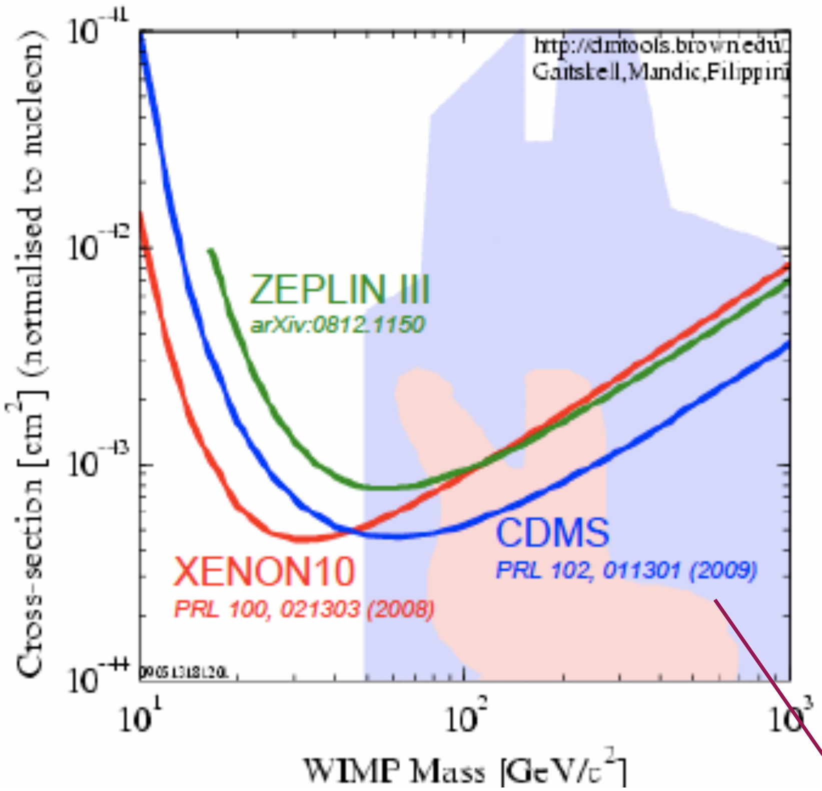
XENON1T

Projected (2015) σ_{SI} <10^{-47} cm^2

XENON10 Results

Spin-independent

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



(NO BKG SUBTRACTION)

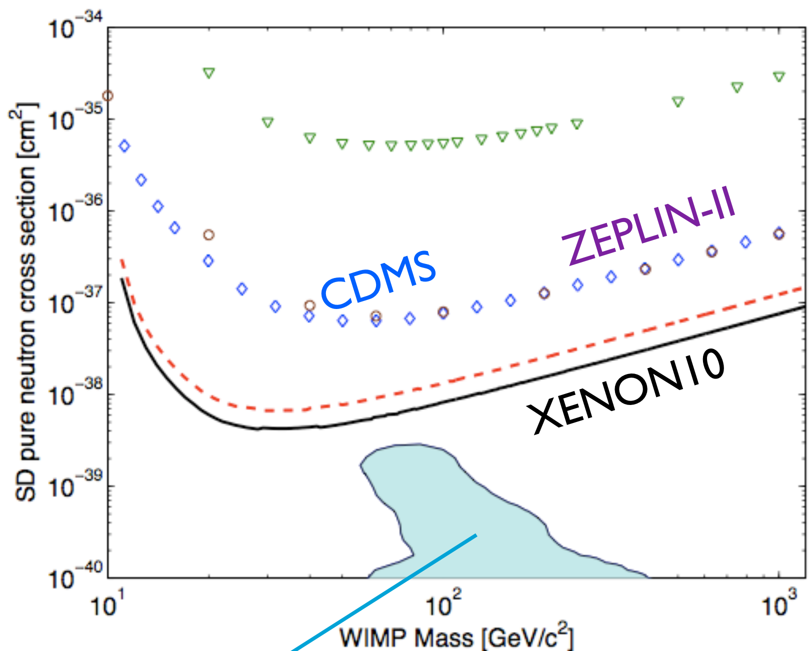
8.8 x 10^{-44} cm^2 at 100 GeV

4.5 x 10^{-44} cm^2 at 30 GeV

Constrained Minimal Supersymmetric Model

Spin-dependent

Phys. Rev. Lett. ***101****, 091301 (2008)*



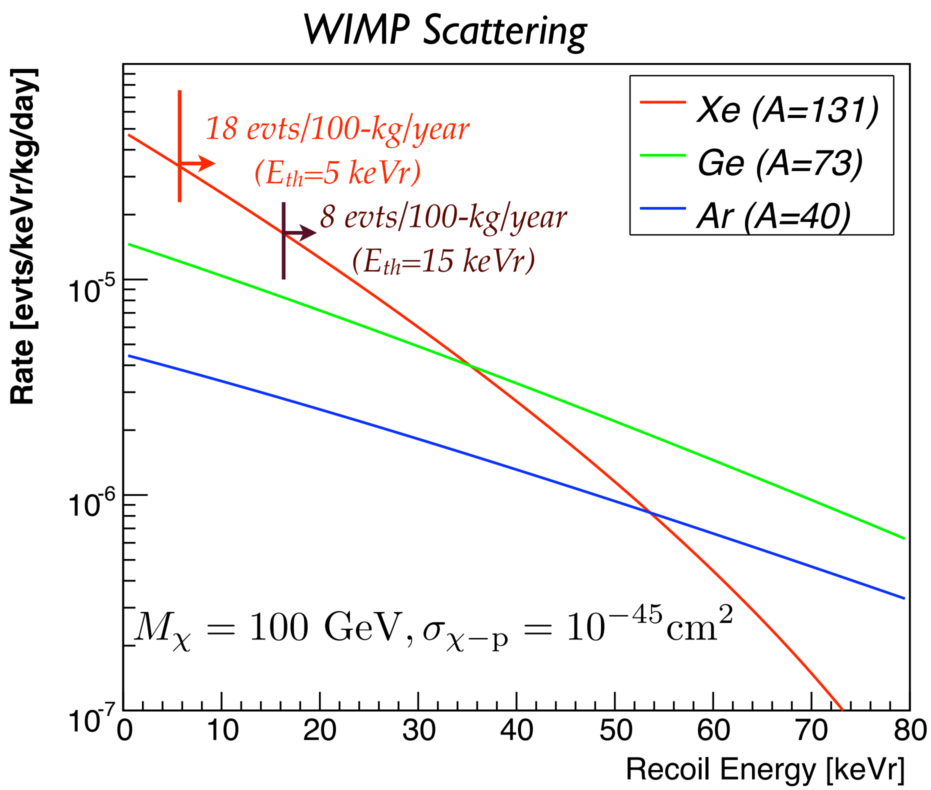
(NO BKG SUBTRACTION)

6 x 10^{-39} cm^2 at 30 GeV

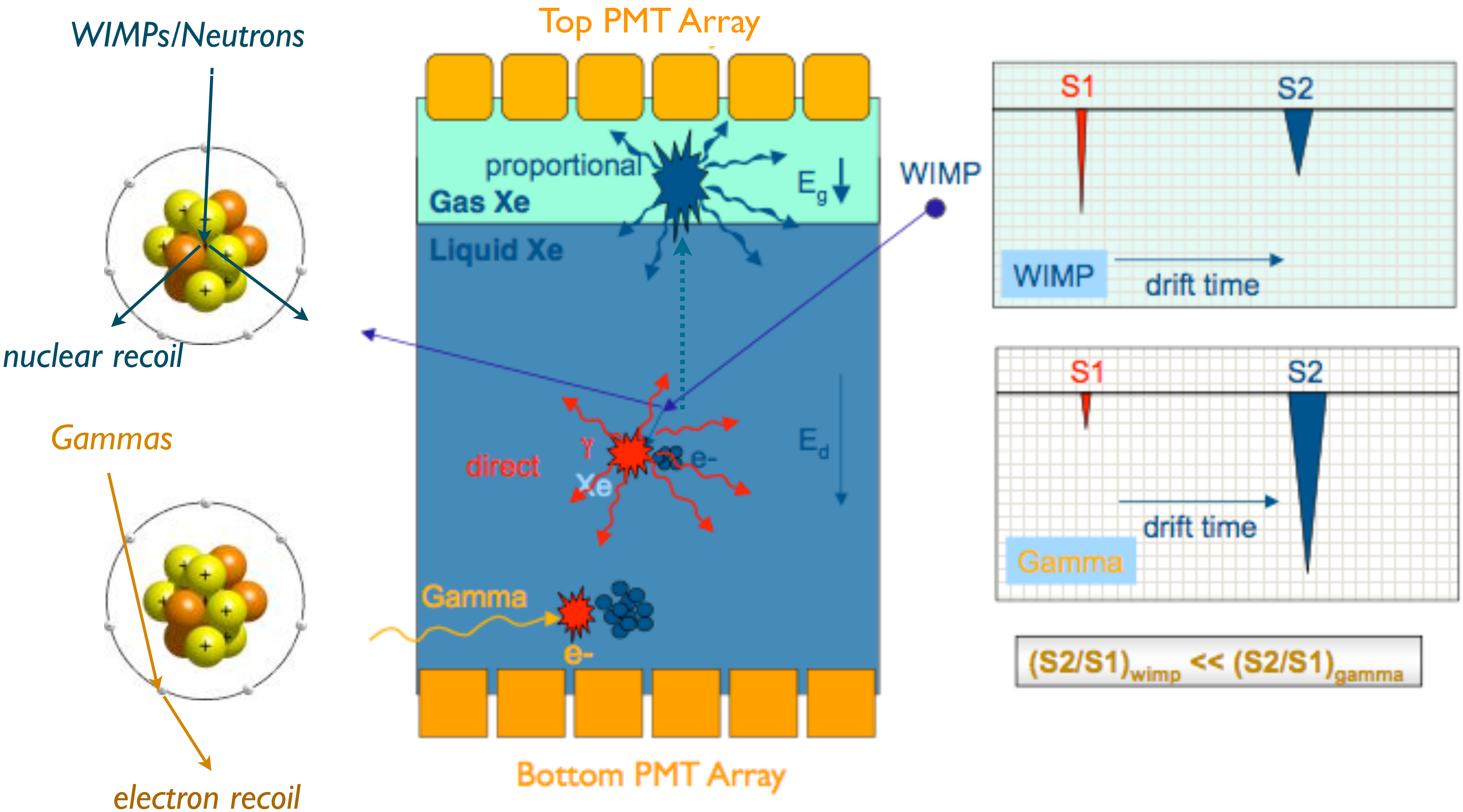
Liquid Xenon for Dark Matter

- *scalability: relatively inexpensive for very large detector (today ~$1300/kg)*
- *Xe nucleus (A~131): good for SI plus SD sensitivity (~50% odd isotopes)*
- *"easy" cryogenics: 170 K (LXe)*
- *Charge & Light: highest yield among noble liquids and best self-shielding*
- *low energy threshold: photosensors within liquid for efficient light detection*
- *background reduction: by charge-to-light ratio and 3D-event localization*
- *Intrinsically pure: no long-lived radioactive isotopes; Kr/Xe reduction to ppt level with established methods*

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

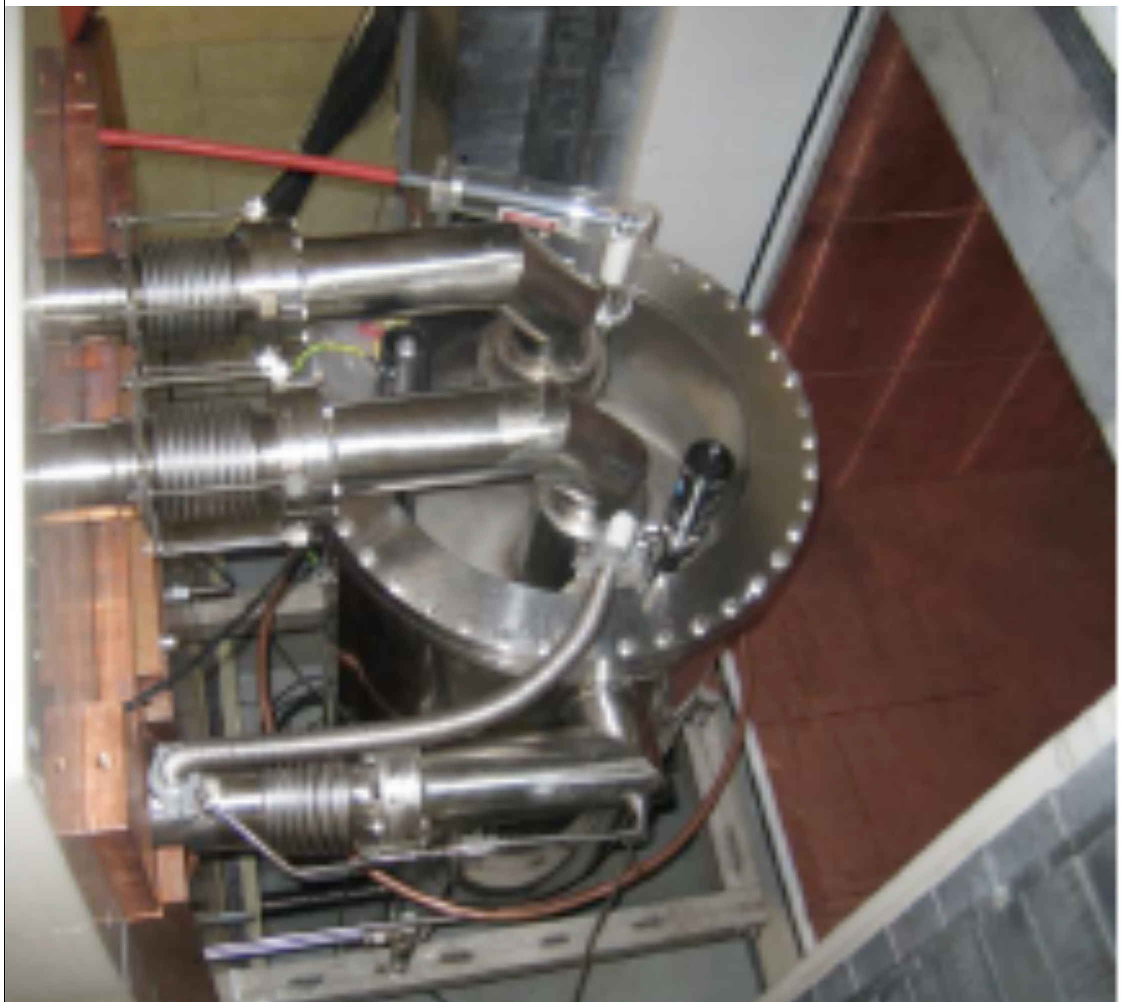


The XENON two-phase TPC



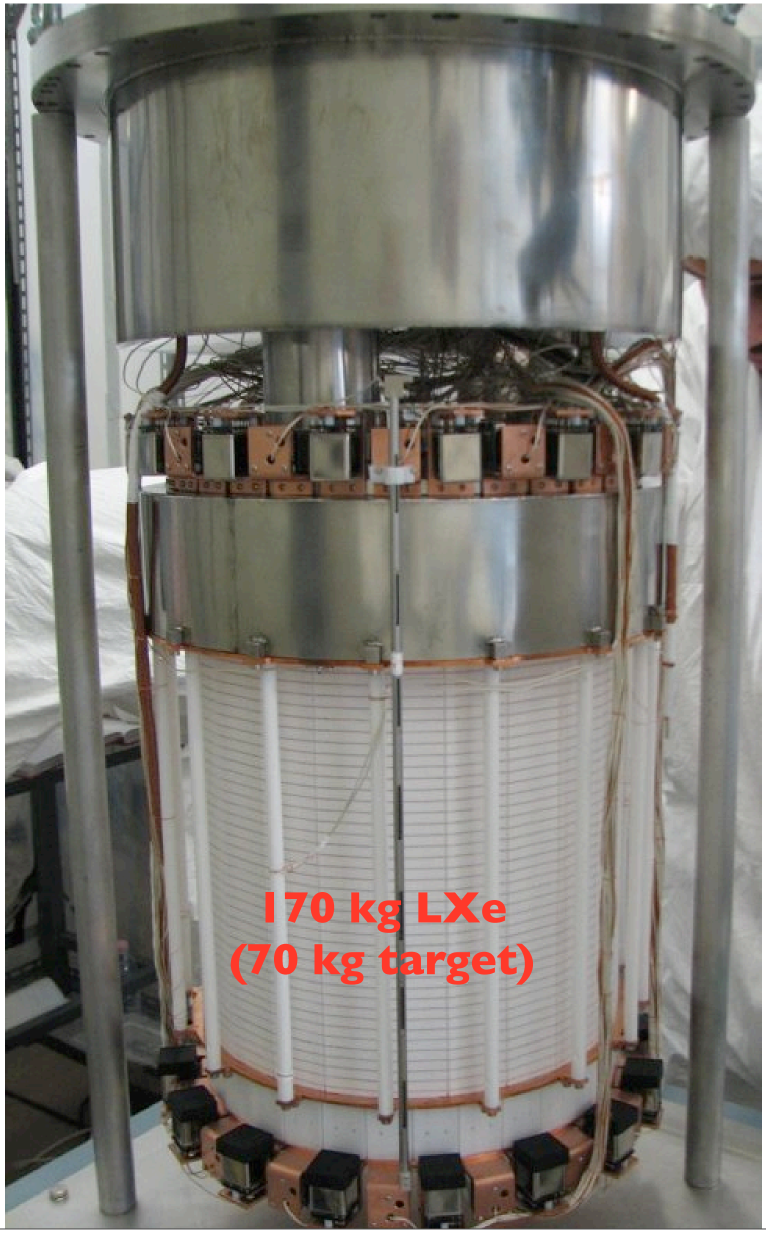
- Single electron and single photon measurement sensitivity
- > 99.5% ER rejection via Ionization/Scintillation ratio (S2/S1)
- 3D event-by-event imaging with millimeter spatial resolution

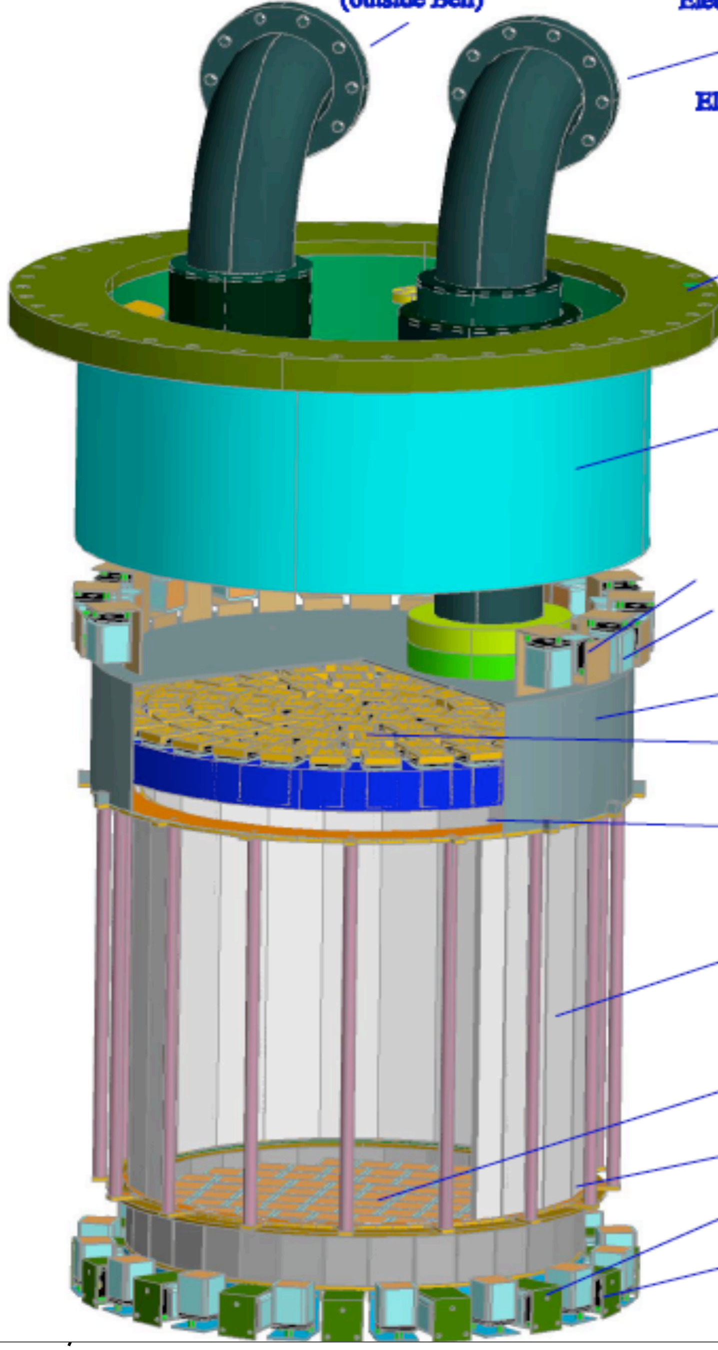
The XENON100 Experiment



- ~100 more sensitive than XENON10
- ~100 x less background and ~10 x more fiducial target than XENON10
- Target: 30 cm drift x 30 cm diameter TPC
- Cryocooler and FTs outside shield
- Materials screened for low radioactivity
- ~1 mBq (U/Th) and ~30% QE PMTs
- LXe veto around target on all sides
- 170 kg ultra pure LXe (target + veto)
- Improved passive shield (Cu,Poly, Pb)

XENON100: The TPC Assembly



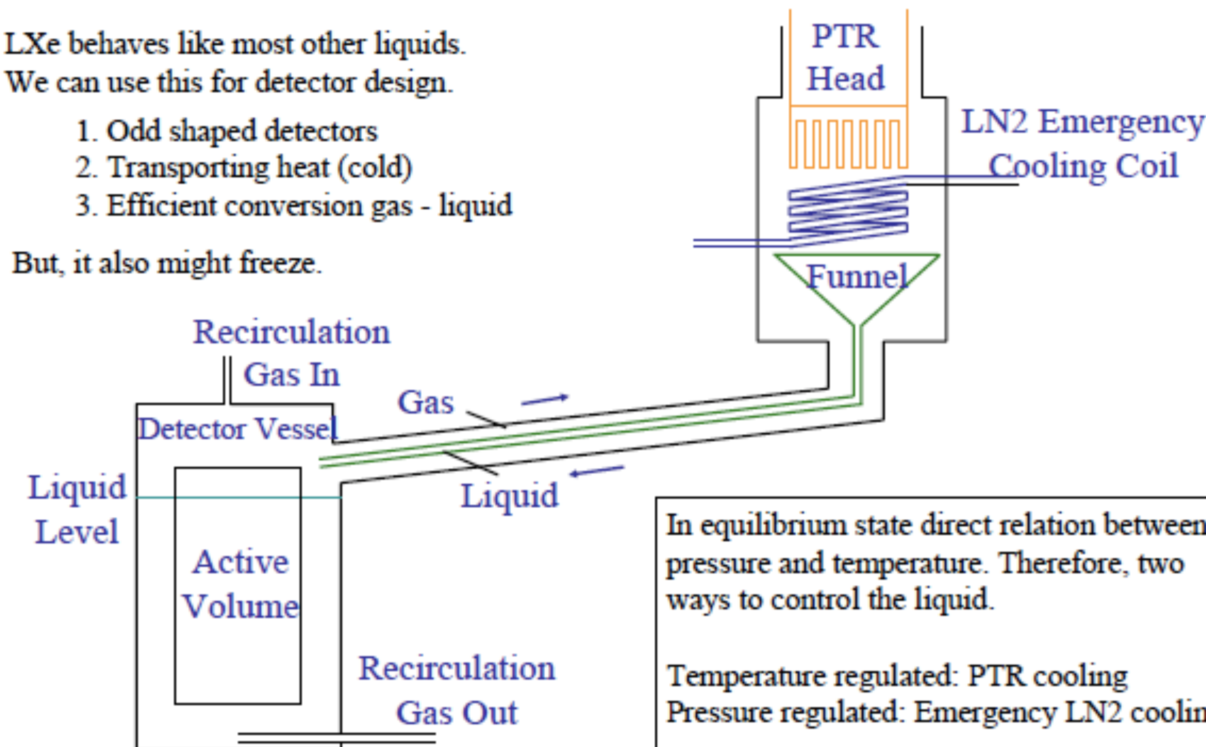


XENON100: New Cryogenics System Design

LXe behaves like most other liquids.
We can use this for detector design.

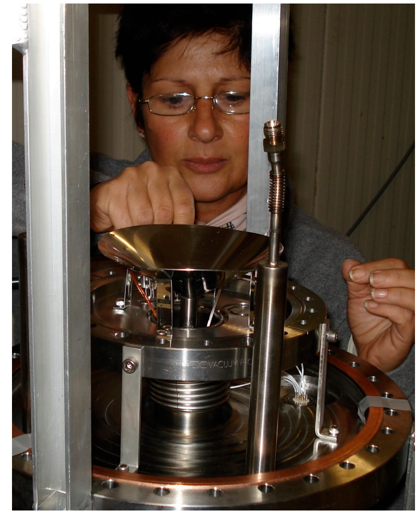
1. Odd shaped detectors
2. Transporting heat (cold)
3. Efficient conversion gas - liquid

But, it also might freeze.



In equilibrium state direct relation between pressure and temperature. Therefore, two ways to control the liquid.

Temperature regulated: PTR cooling
Pressure regulated: Emergency LN2 cooling



Feedthroughs and Cooling Tower outside Shield

Detector Vessel

Simulated Shield Door

Cooling Tower

The cooling tower supports all instrumentation

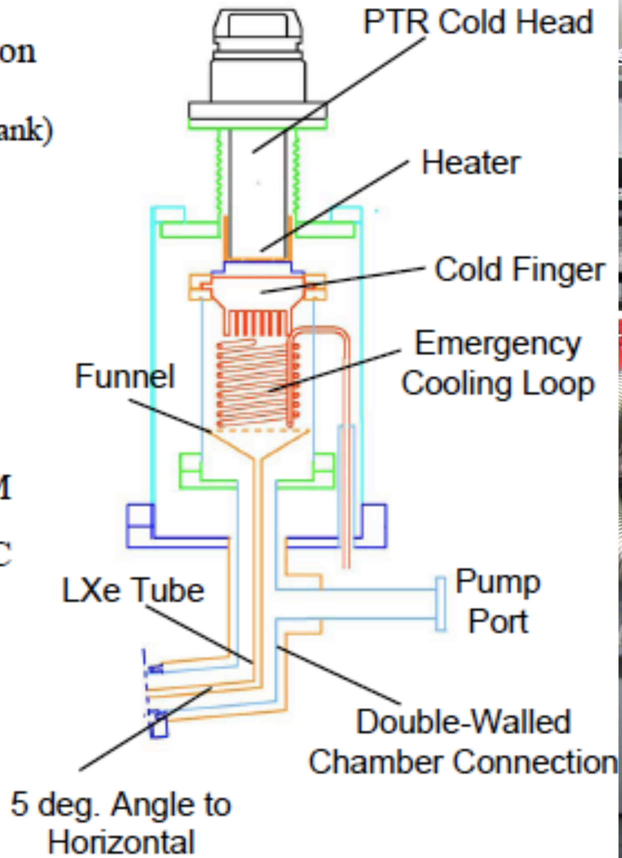
1. Refrigerator Head (incl. Motor Valve and Buffer Tank)
2. LN2 Emergency Cooling Coil
3. Vacuum Pumps for Chamber and Cryostat
4. Vacuum Gauges, Pressure Gauges, Rupture Disk
5. Feedhroughs for Control Circuits

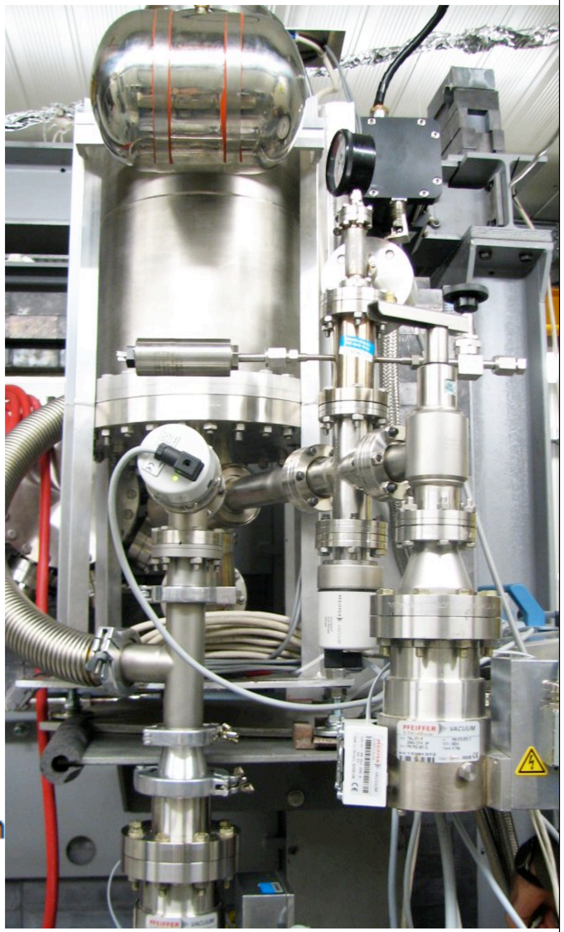
Iwatani PTR PC150, Cooling power 200 W
wih 6.5 kVA compressor

Sufficient to fill or re-circulate with 10 SLPM

PID Temperature Controller, Stability < 0.1 C

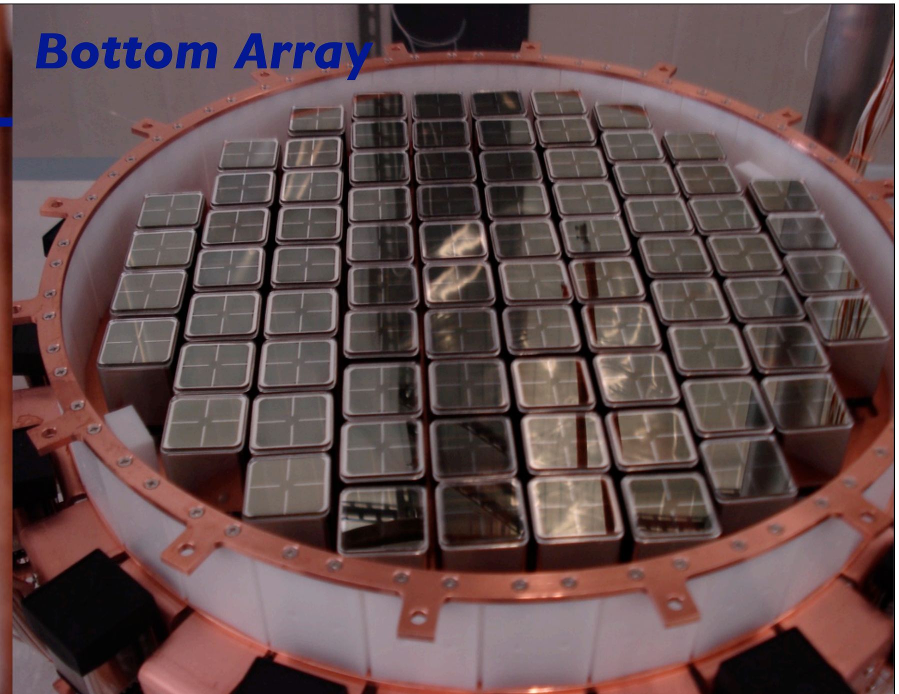
Emergency cooling with LN2 coil.
Regulated with pressure.
Two completely independent systems.

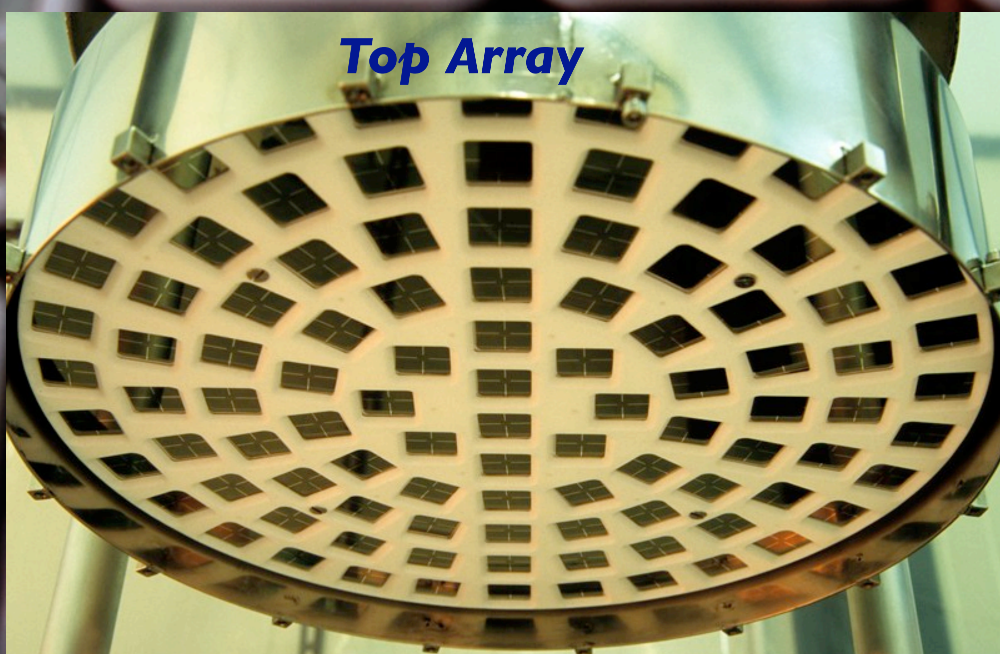


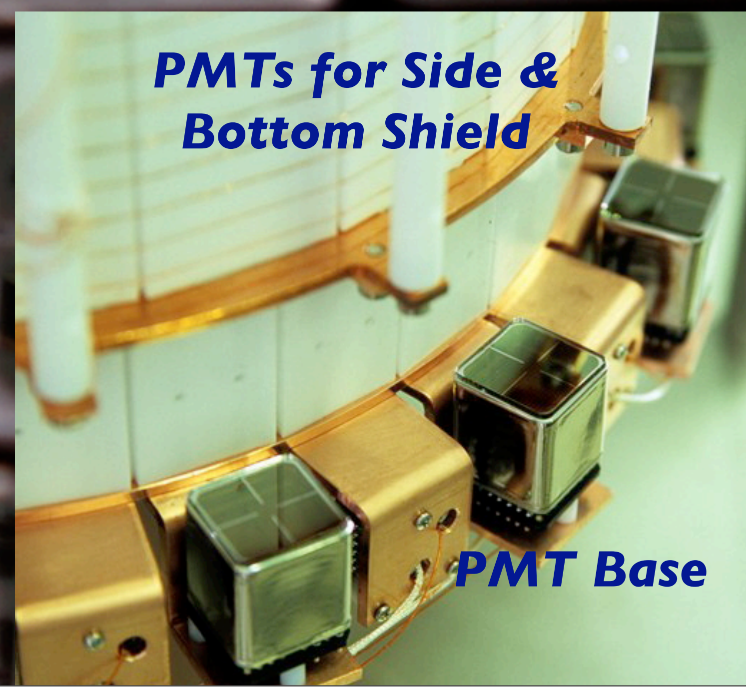


XENON100: The PMTs

- 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)







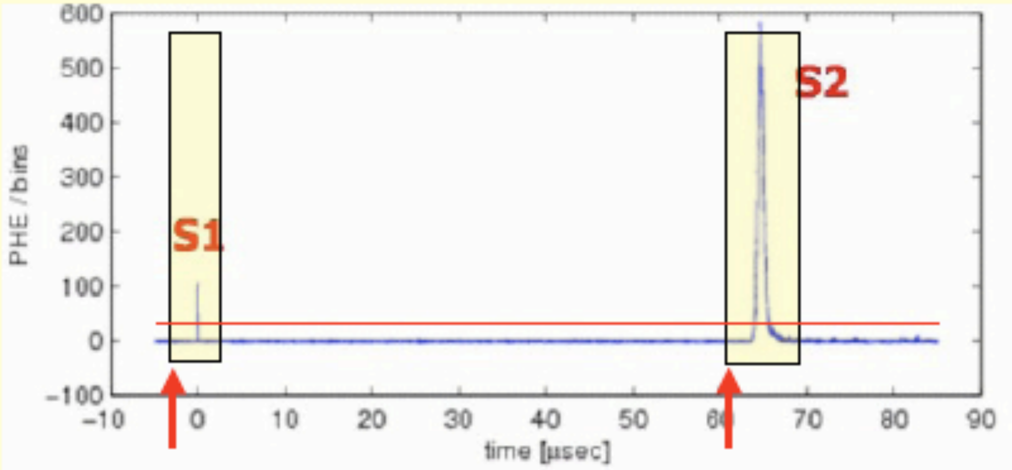
XENON100: Data Acqusition System

Requirements:

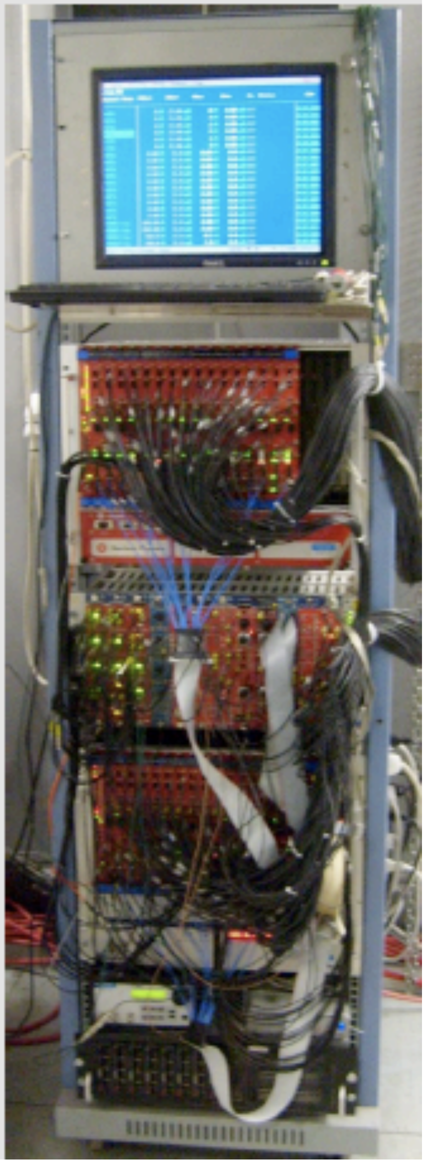
- digitize full waveform (320μs) of 242 PMTs
- no deadtime
- high rate capability for calibration

CAEN V1724 Flash ADC: 14bit, 100MHz

- circular buffer → no deadtime
- on board FPGA: *Zero Length Encoding*

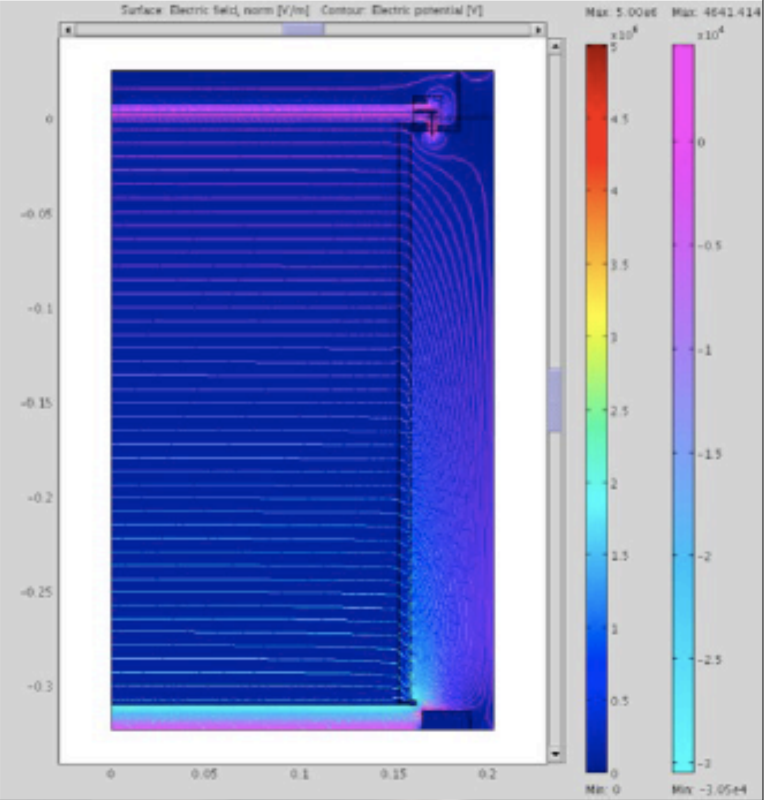


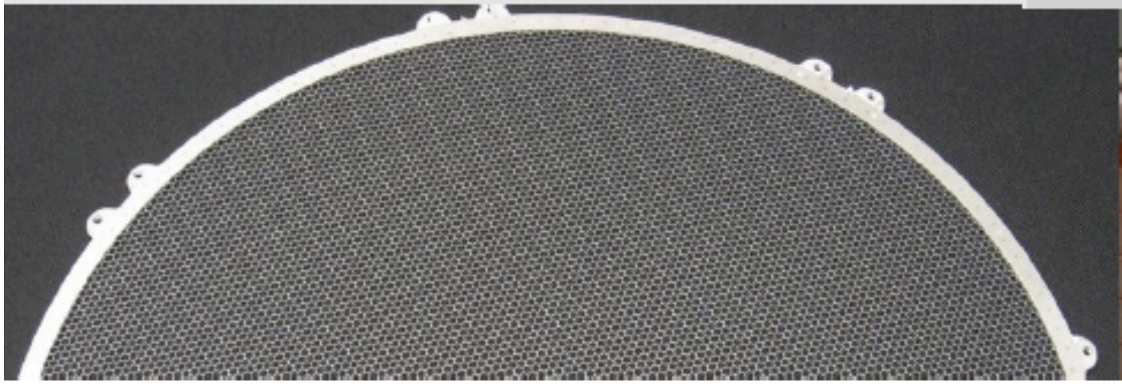
⇒ calibration rates >50 Hz possible

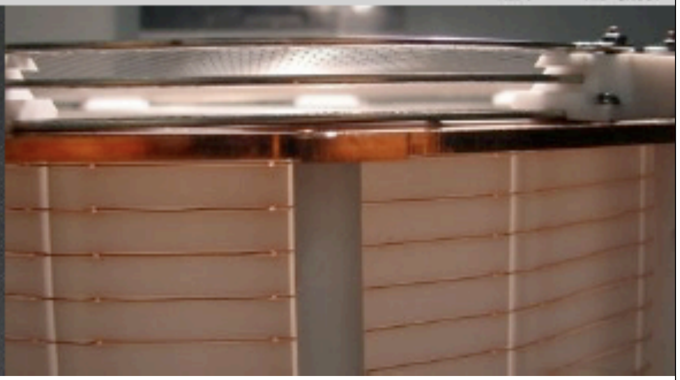


XENON100 TPC: Electric Fields

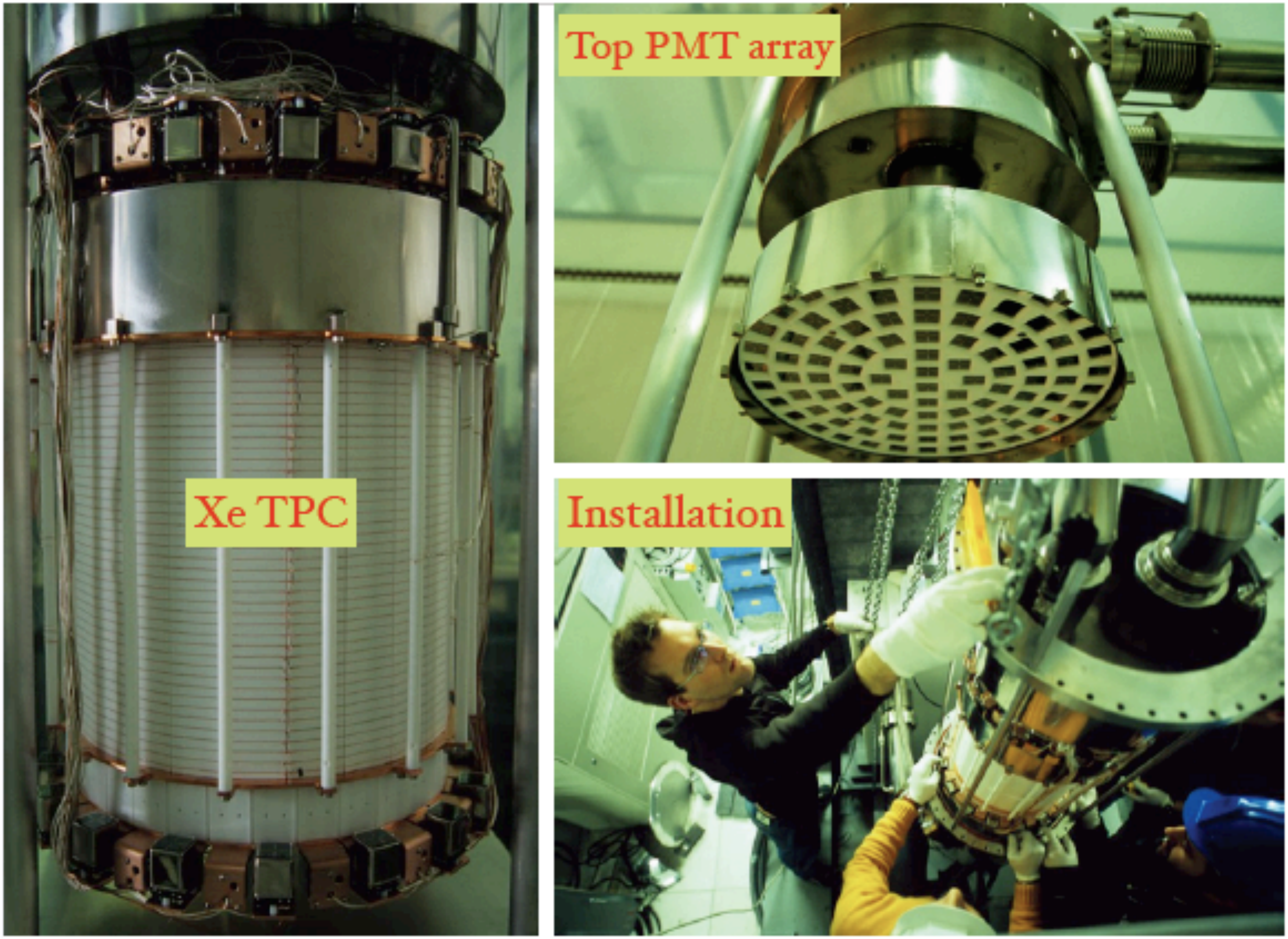
- cathode: -30kV → drift field 1kV/cm
- anode: extraction field ~5kV
- field inside TPC was optimized in simulations for field homogeneity
  → 40 double field shaping rings
- anode stack optimized for
  - optical transparancy
  - S2 energy resolution (+4%)
- hexagonal mesh structures, pitch cathode 5mm, anode 2.5mm







more detector photos at:
http://xenon.astro.columbia.edu/



XENON100: Purification System

- Gas purification with continuous re-circulation of the 170 kg of Xe gas through hot getter (SAES)
- re-circulation speed 10 slpm (5 slpm in XENON10)
- Impurities in LXe affect both charge and light
- Source of Impurities: 1) leaks, 2) materials outgassing and 3) Xe gas contamination.
- Light is strongly absorbed by H_2O. Charge is strongly reduced by electronegative substances
- We have succeeded to reduce the H_2O level to < 1ppb as measured with dedicated IR detector
- We have succeeded in drifting electrons through entire 30 cm gap as measured directly with S2

XENON100: Kr Removal System

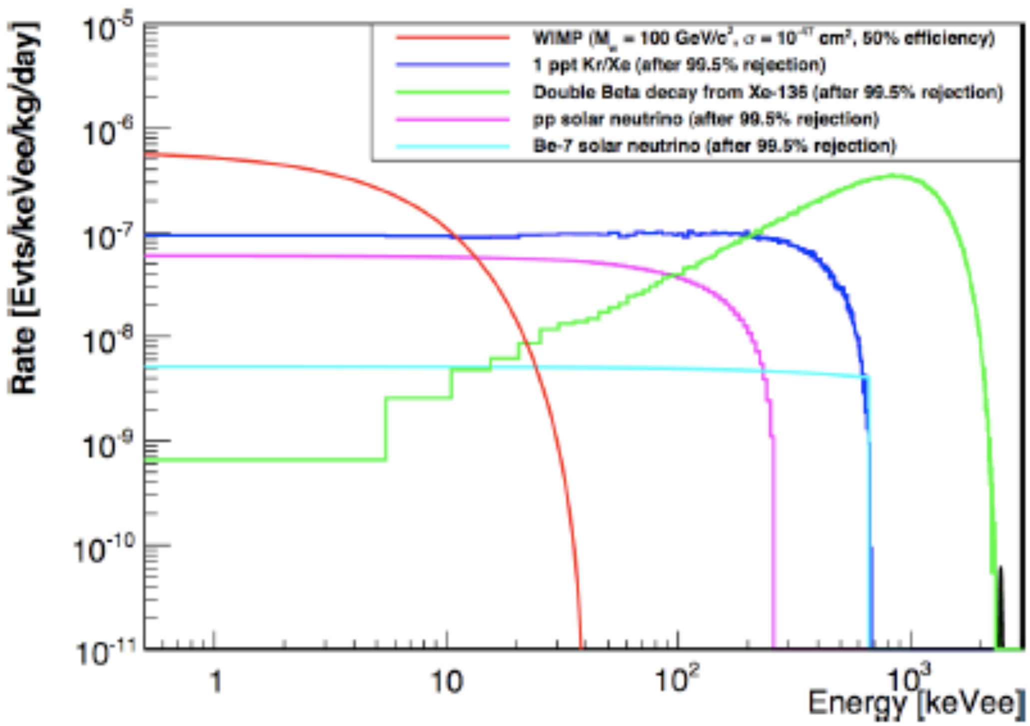
Xe has no long lived isotopes BUT has traces of radioactive Kr85

Kr85 (Emax = 687 keV, t ~11 yr) is present in natural Kr at ~ 10^{-11}

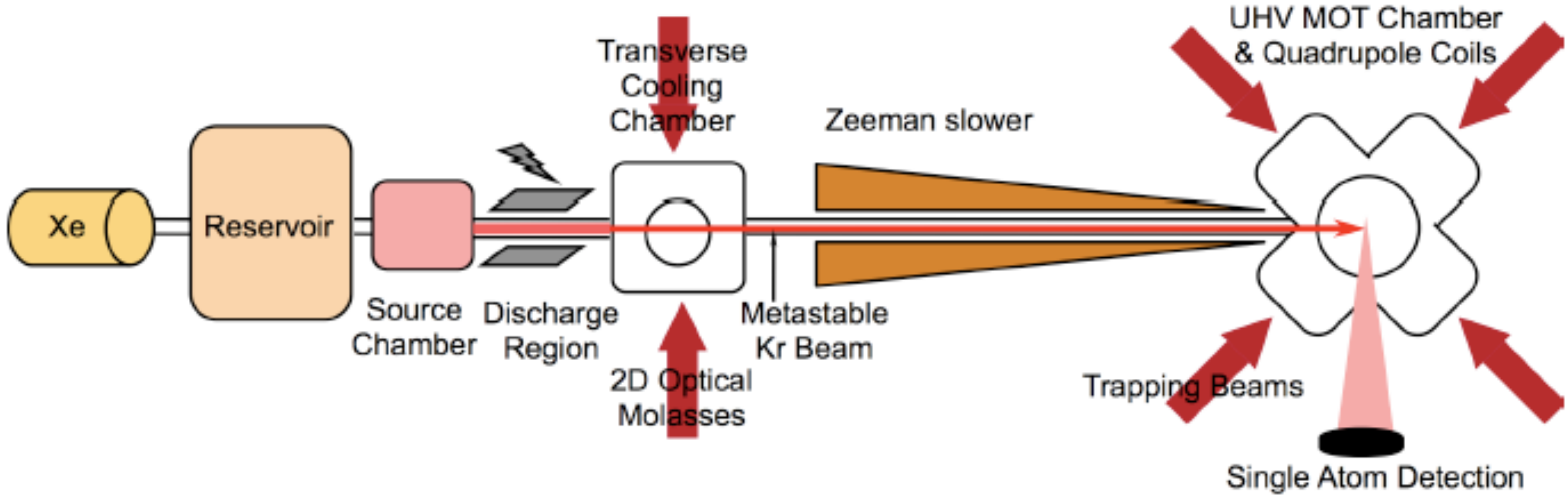
The Kr level in the XENON100 fill gas is currently at ~1 ppb level as measured with delayed coincidence events

A dedicated Cryogenic Distillation Tower designed for Kr reduction by 10^3 has been commissioned and installed next to XENON100: purification run scheduled for July 2009

XENON100 science goal requires ~ 50 ppt of Kr (<1 ev / 0.5 yr)

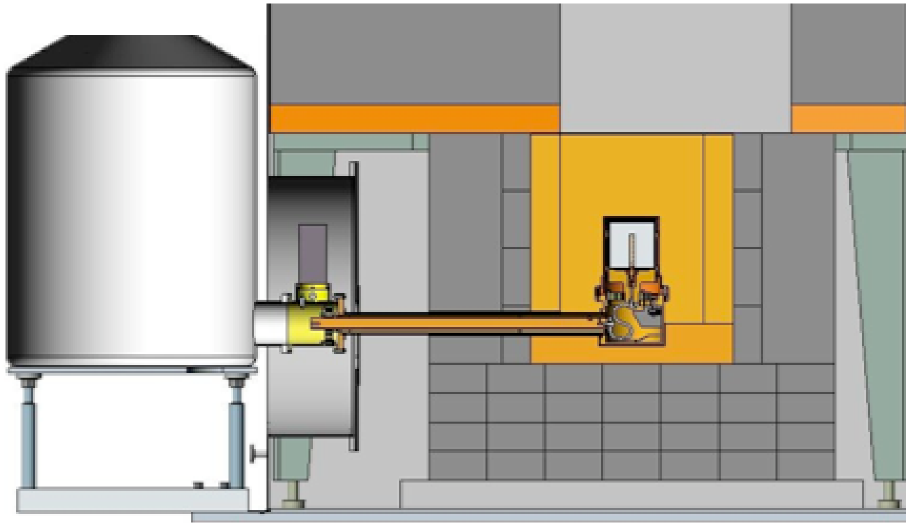


A new facility for XENON: an Atom Trap Trace Analysis System



- Major Research Infrastructure proposal by Columbia University to the National Science Foundation
- Proposal submitted January 2009 and now approved for funding - 3 Years Development Effort
- System based on laser cooling, slowing and trapping of single Kr atoms from Xe purified sample
- Single atoms counted by detection of their fluorescence with high S/N photodetector

XENON100: Materials Screening Facility

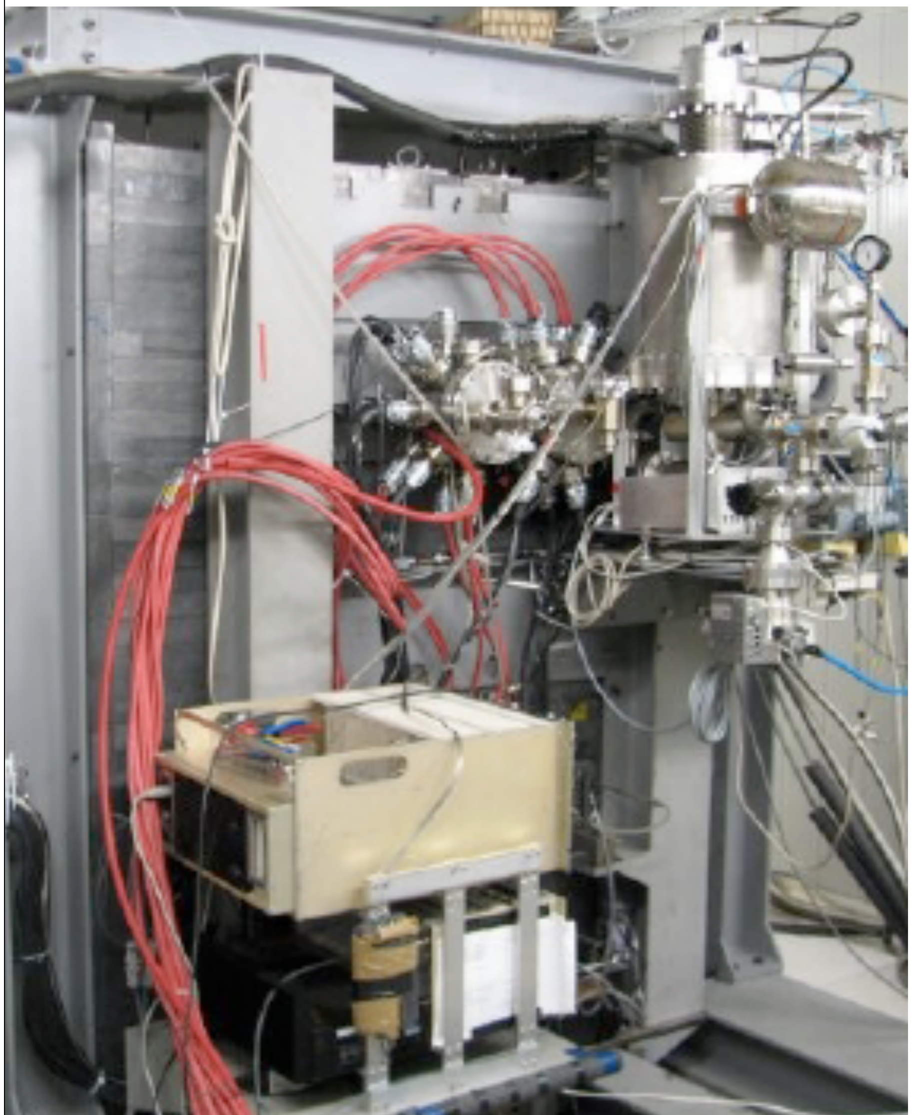


Radioactivity of all materials used in XENON100 measured with a dedicated 2.2 kg HPGe counter at LNGS

TPC Material	Unit	Quantity used	^{238}U [mBq/unit]	^{232}Th [mBq/unit]	^{40}K [mBq/unit]	^{60}Co [mBq/unit]	^{210}Pb [Bq/unit]
R8520 PMTs	PMT	242	0.15 ± 0.02	0.17 ± 0.04	9.15 ± 1.18	1.00 ± 0.08	
PMT bases	base	242	0.16 ± 0.02	0.07 ± 0.02	< 0.16	< 0.01	
Stainless steel	kg	70	< 1.7	< 1.9	< 9.0	5.5 ± 0.6	
PTFE	kg	10	< 0.31	< 0.16	< 2.2	< 0.11	
QUPID	QUPID	-	<0.49	<0.40	<2.4	<0.21	
Shield Material							
Copper	kg	1600	< 0.07	< 0.03	<0.06	<0.0045	
Polyethylene	kg	1600	< 3.54	< 2.69	< 5.9	< 0.9	
Inner Pb (5 cm)	kg	6300	< 6.8	< 3.9	< 28	< 0.19	17 ± 5
Outer Pb (15 cm)	kg	27200	< 5.7	< 1.6	14 ± 6	< 1.1	516 ± 90

Table 1: Radioactivity of XENON100 materials: Average values are given if different activities were obtained for different material samples, such as different batches of PMTs and stainless steel. Upper limits are given if no activity above background was found. Radioactivity from other components, such as screws and cables, are negligible (at least a factor of 10 lower compared to those in the table).

XENON100 Operating Underground @ LNGS



XENON100 Collaboration

USA, Switzerland, Portugal, Italy, Germany, France, Japan, China

45 people: 15 GRA, 10 postdocs

COLUMBIA
E. Aprile

RICE
U. Oberlack

UCLA
K. Arisaka
H. Wang

ZURICH
L. Baudis

COIMBRA
J.A.M Lopez

LNGS
F. Arneodo

MUENSTER
C. Weinheimer

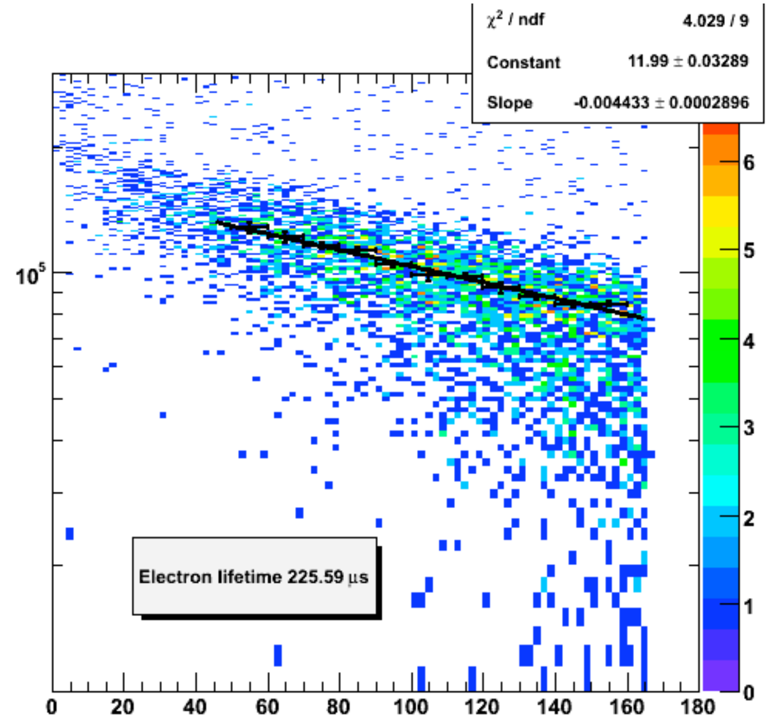
SUBATECH
D. Thers

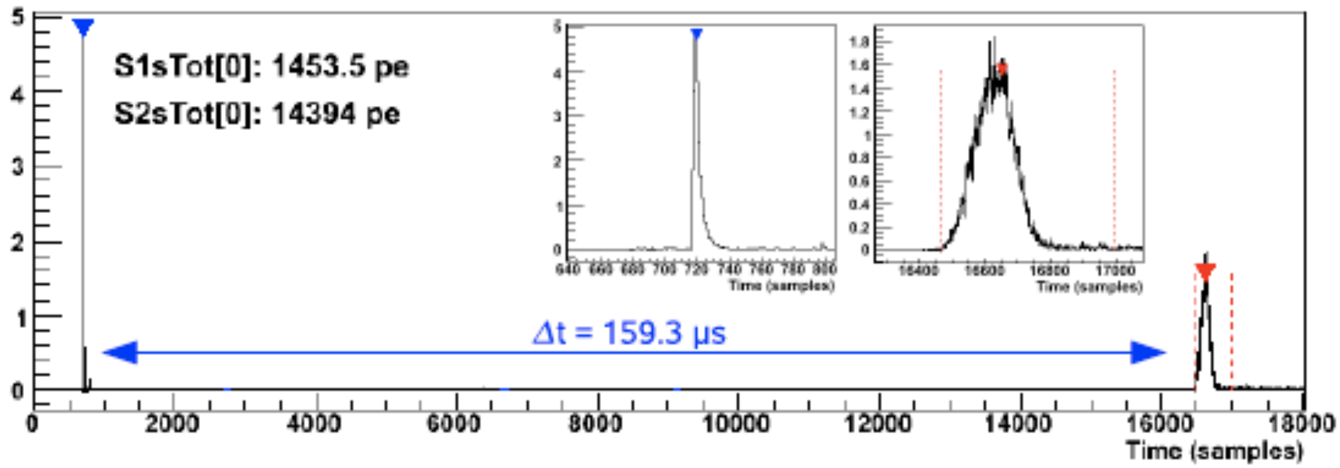
WASEDA
N. Hasebe

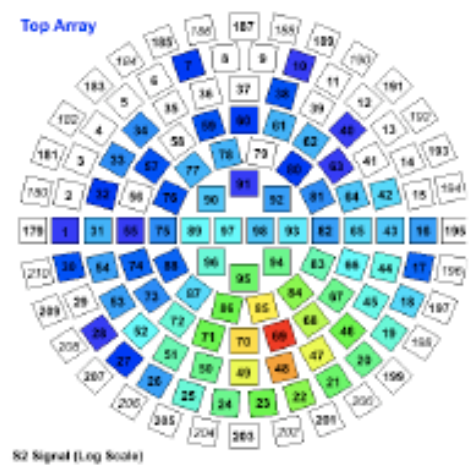
SJTU
K. Ni

XENON100 Status and Preliminary Results

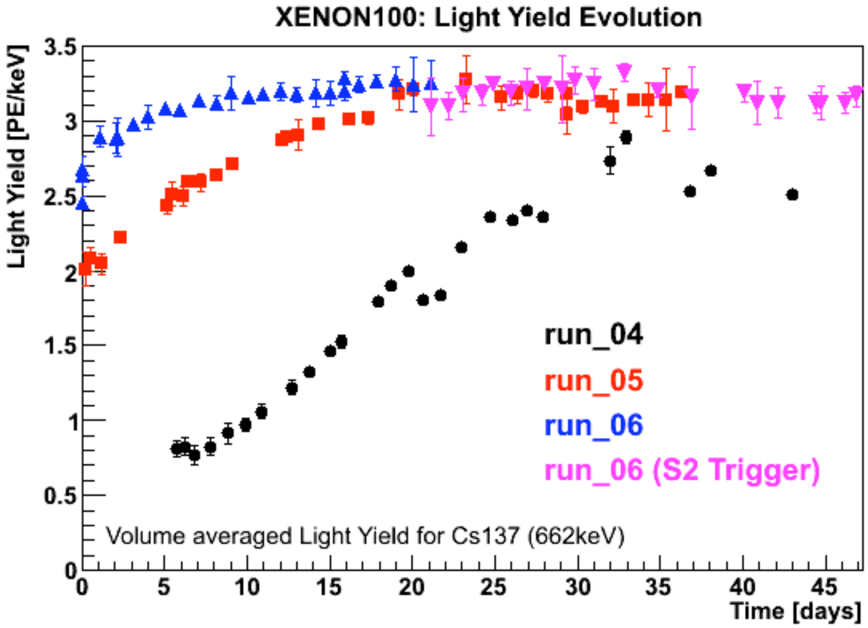
- Detector fully functional and taking gamma calibration data underground at LNGS
- Both Charge and Light signals detected
- Optimizing trigger level, threshold, overall response
- Light Yield is maximum and Electron Lifetime currently 225 microsec and keeps increasing
- Initial background run shows a background level consistent with level predicted by MC simulations
- Following Neutron Calibration with AmBe in Fall 09 the 1st DM search run will start before end of the year



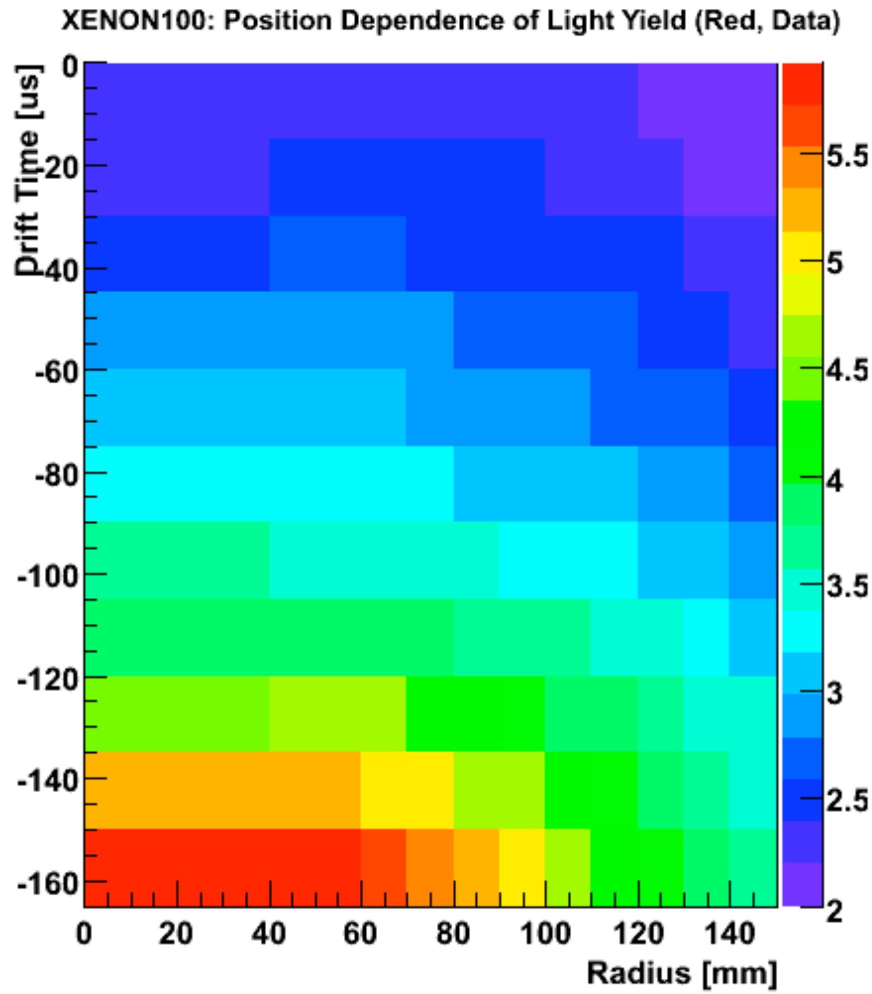




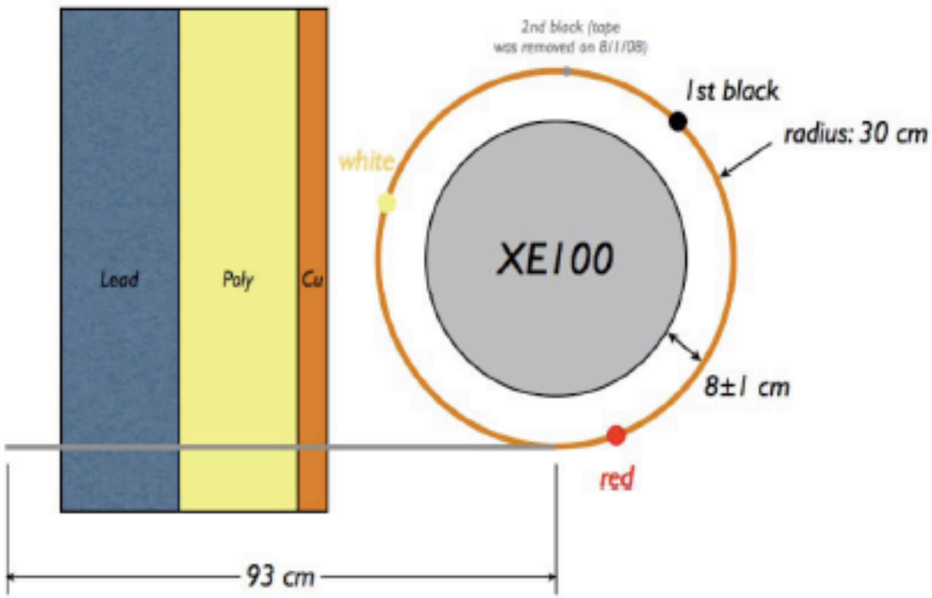
XENON100 Status: Light Yield

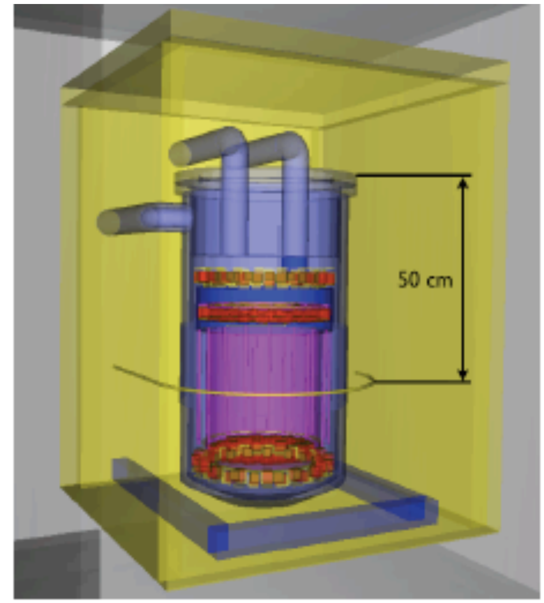


- In April 09 we replaced a vacuum seal and reduced further detector outgas with bake-out and hot gas re-circulation
- In May 09 we filled TPC again (current run-06): Light Yield 3.2 pe/keV for 662keV
- Equivalent to 4.5 pe/keV for 122 keV
- With event position reconstruction we can now measure the S1 position dependence



Calibration Sources for XENON100



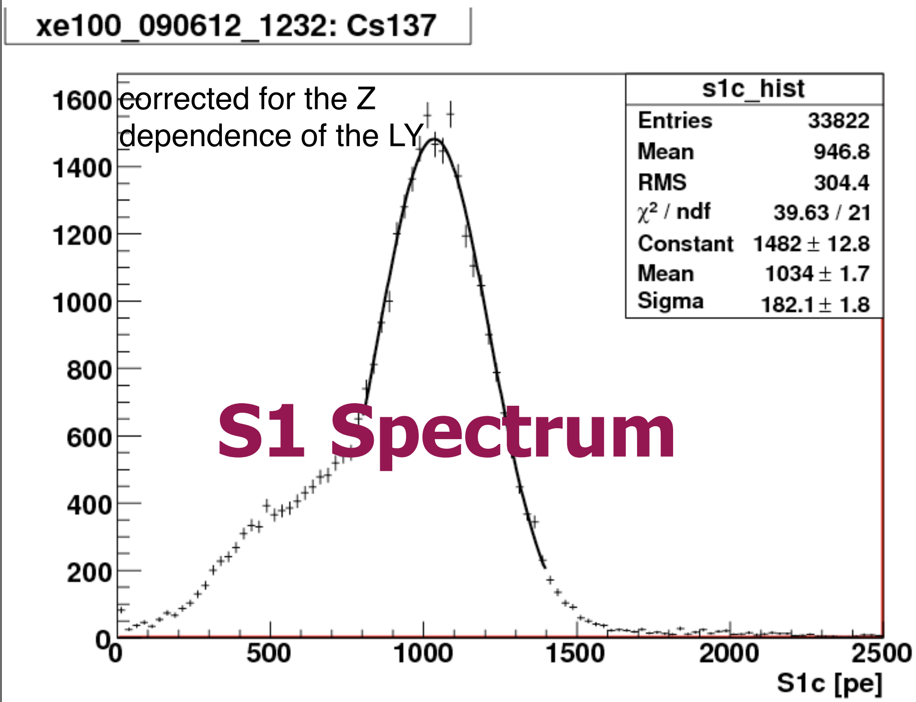


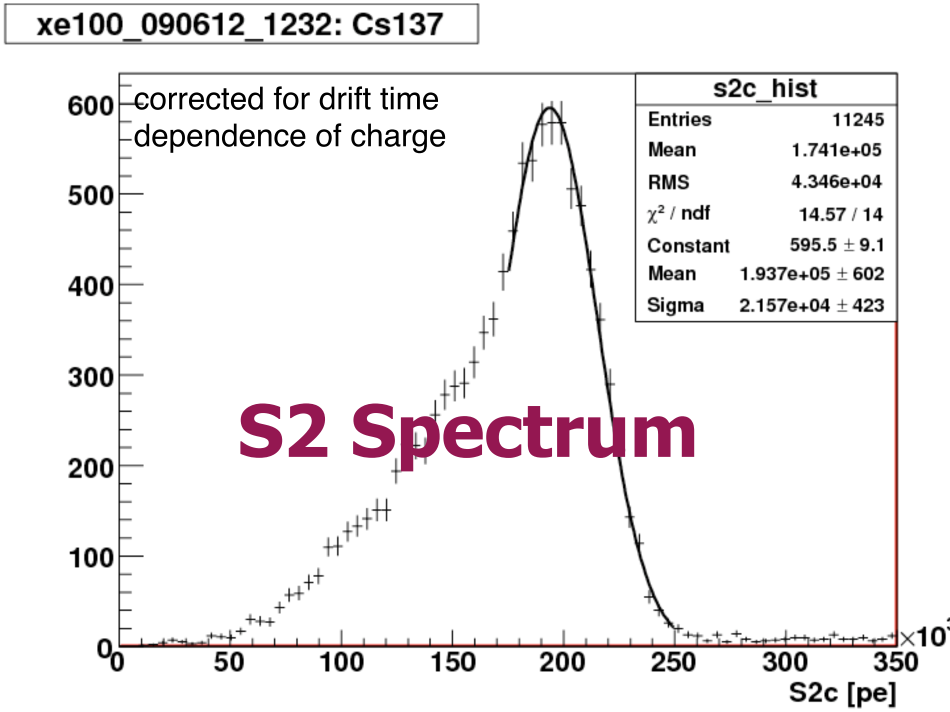
1) External Sources: Cs-137 (662 keV), Co-57 (122 keV), Co-60 (1173, 1332 keV), Th-228 (2600 keV), AmBe (~ MeV)

2) Internal Sources:

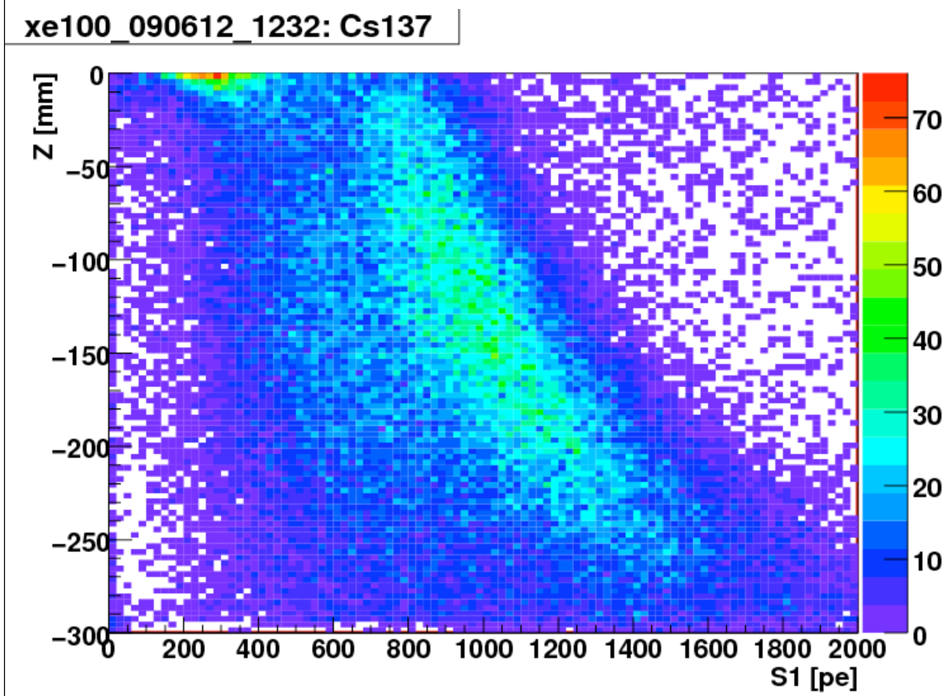
- Xe-131m (164 keV, 11.84 d), Xe-129m (236 keV, 8.88 d) from neutron activation of Xe
- Kr-83m (32 keV, 9 keV) from Rb-83, studied as calibration tool for the KATRIN neutrino mass experiment (Applied Radiation and Isotopes 63 (2005) 323-327)

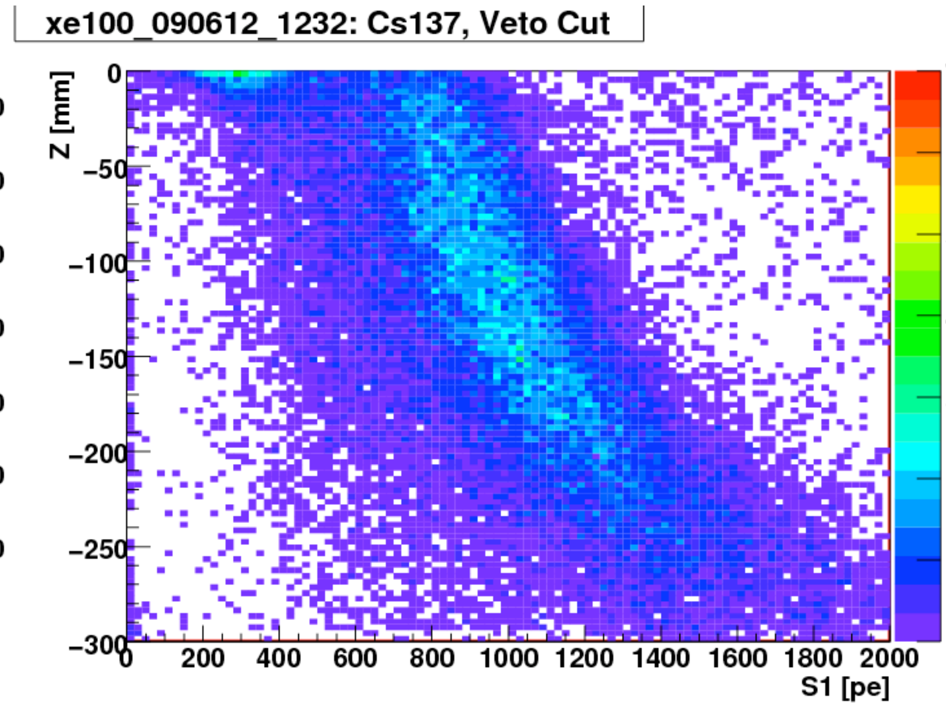
Initial Results from Cs-137 Gamma Calibration





XENON100 Data: Background Reduction by LXe Veto





Left plot: the right band is the 662 keV full absorption peak and the left band is the energy deposited by gammas that backscatter in the sensitive volume.

Right plot: when we apply a cut for events with a 2 fold coincidence in the veto the left band disappears (and the overall rate is also lower) --> Gammas that backscatter (depositing 478 keV) in the LXe of target, interact in the veto and are removed by cut

XENON100 MonteCarlo: Background Reduction by LXe Veto

- The LXe Veto (embedding the target on all sides) decreases the background rate in the target by more than 50% even with a 200 keV veto threshold

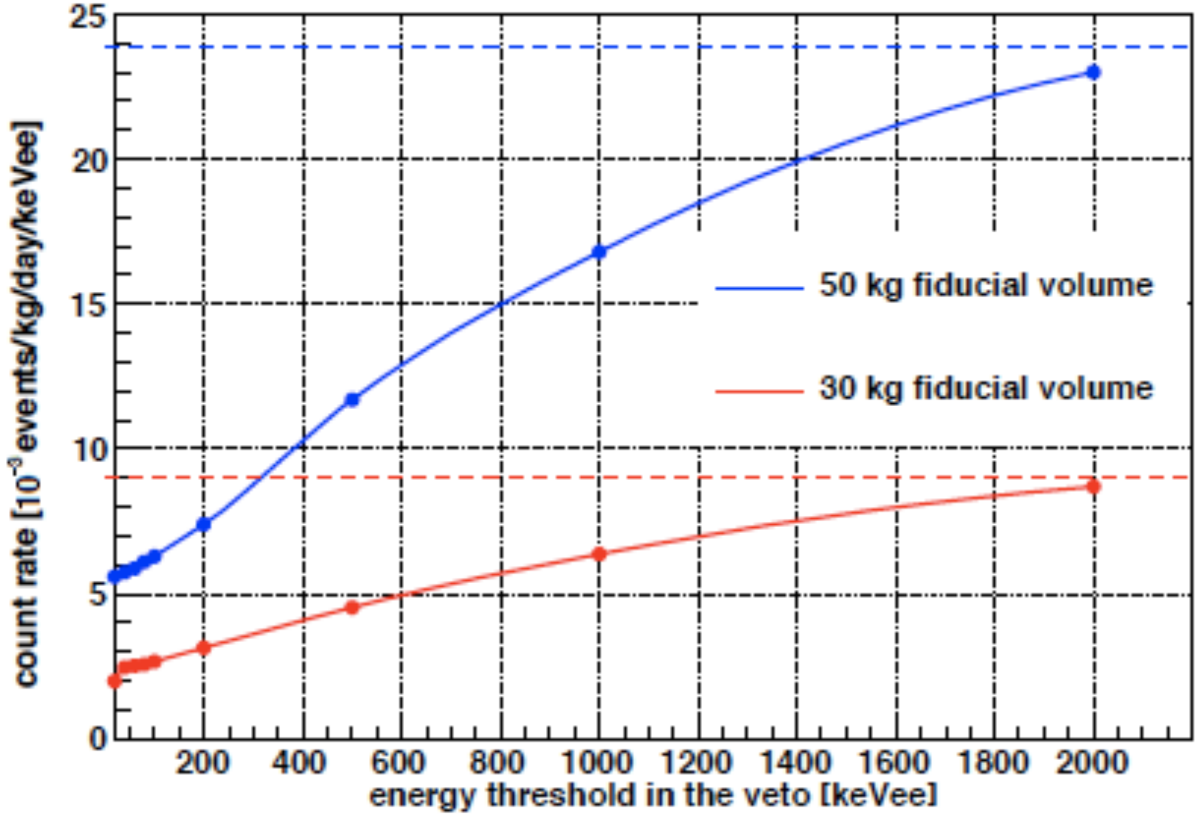
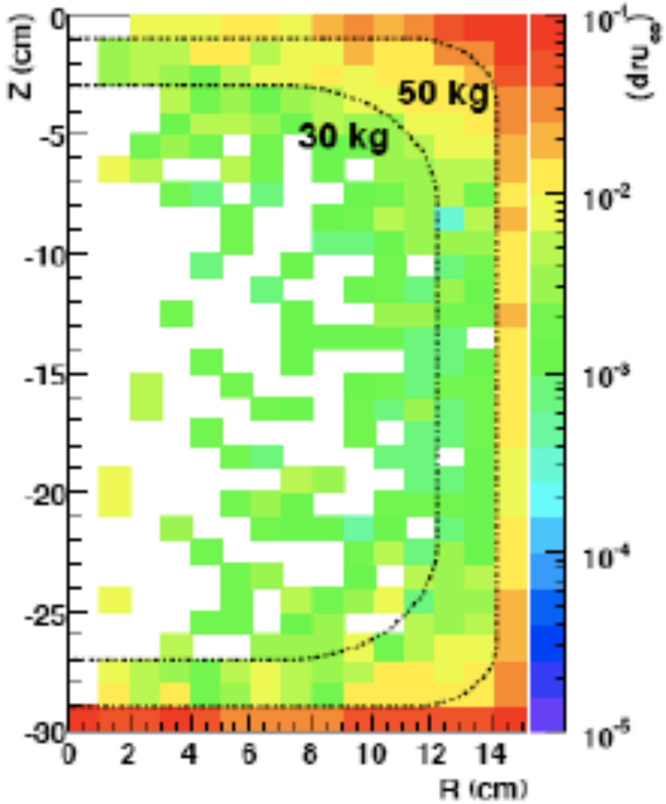
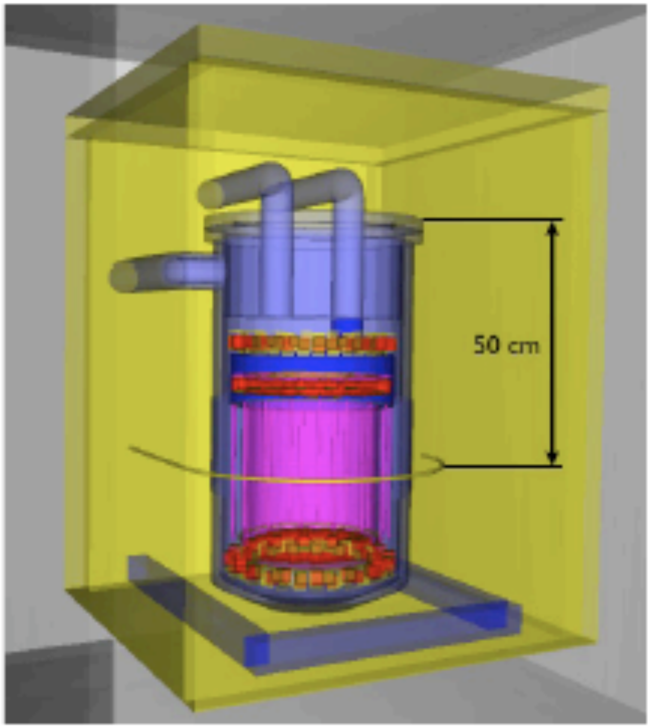


Figure 5: Background rate reduction with fiducial volume cuts and active veto cuts. Dashed Lines show the background rate with the passive veto.

XENON100 Background: Monte Carlo Prediction

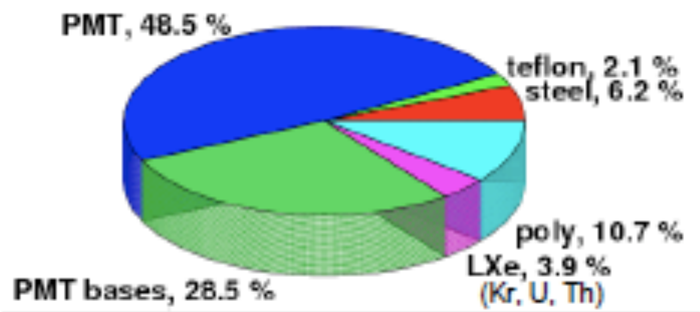
GEANT4 Simulations of full experiment: detector + shield + cavern





50 kg: <1x10^{-2} evts/kg/keV/day
(2000 kg-day, background free)

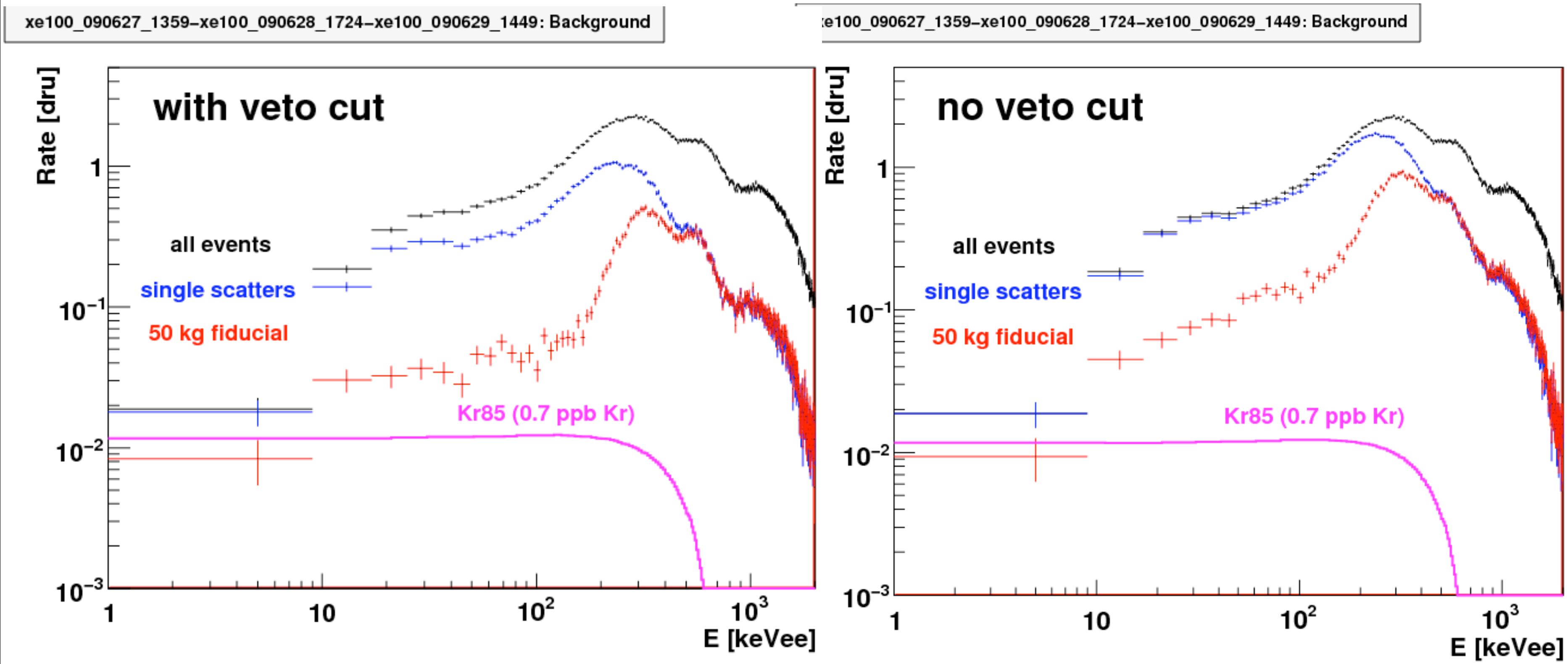
30kg: <3x10^{-3} evts/kg/keV/day
(6000 kg-day, background free)



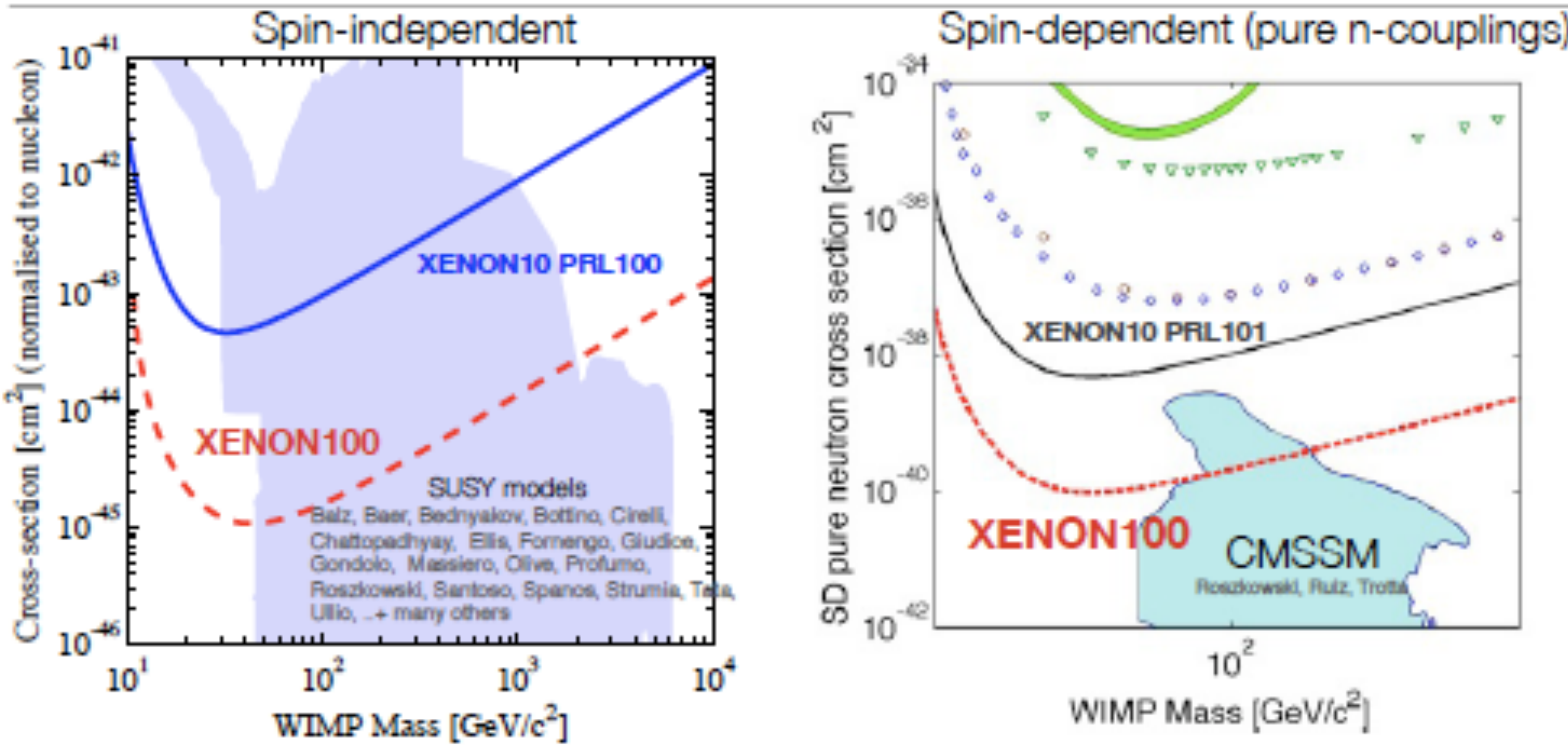
- rate before S2/S1 discrimination!

XENON100 Background: preliminary data

- we are very pleased at what we see in this first peek!



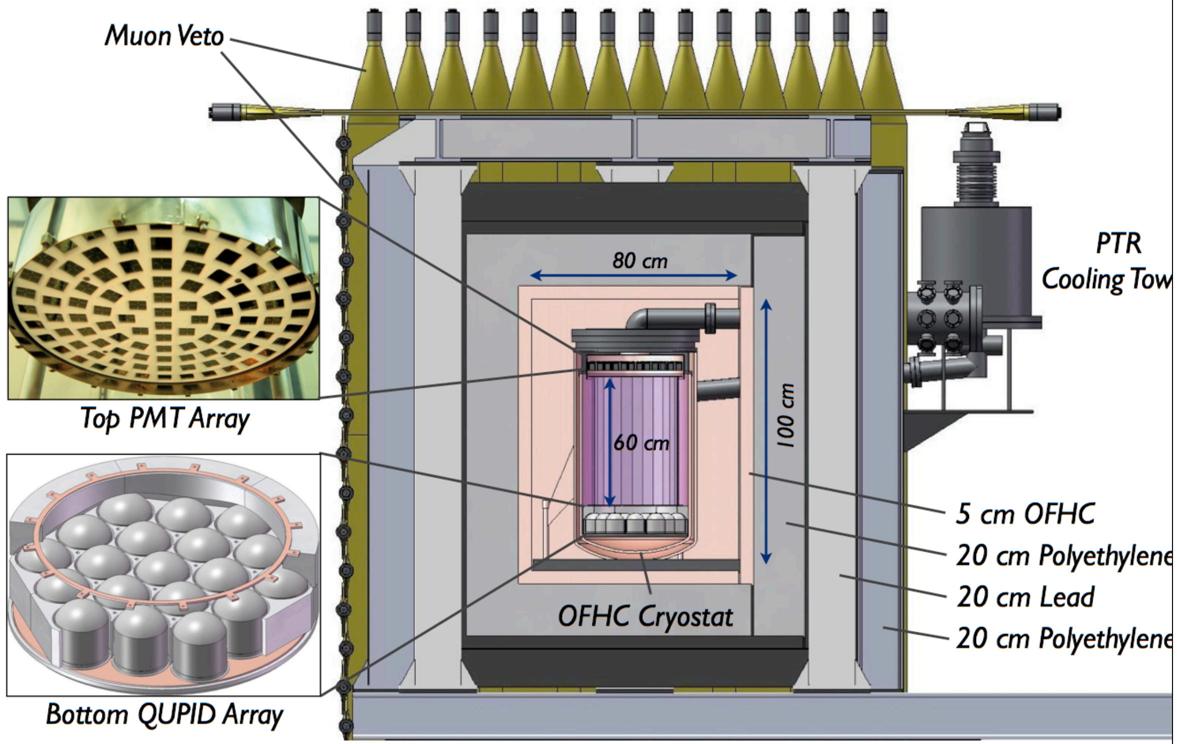
XENON100 Sensitivity

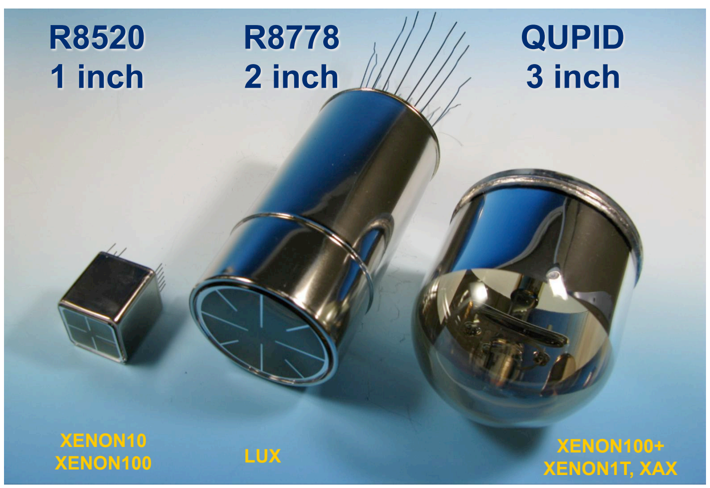


50 kg target, 40 days:	$\sigma = 6 \times 10^{-45}$ cm² (at M_W =100 GeV)
30 kg target, 200 days:	$\sigma = 2 \times 10^{-45}$ cm² (at M_W =100 GeV)

XENON100+ (2010-12)

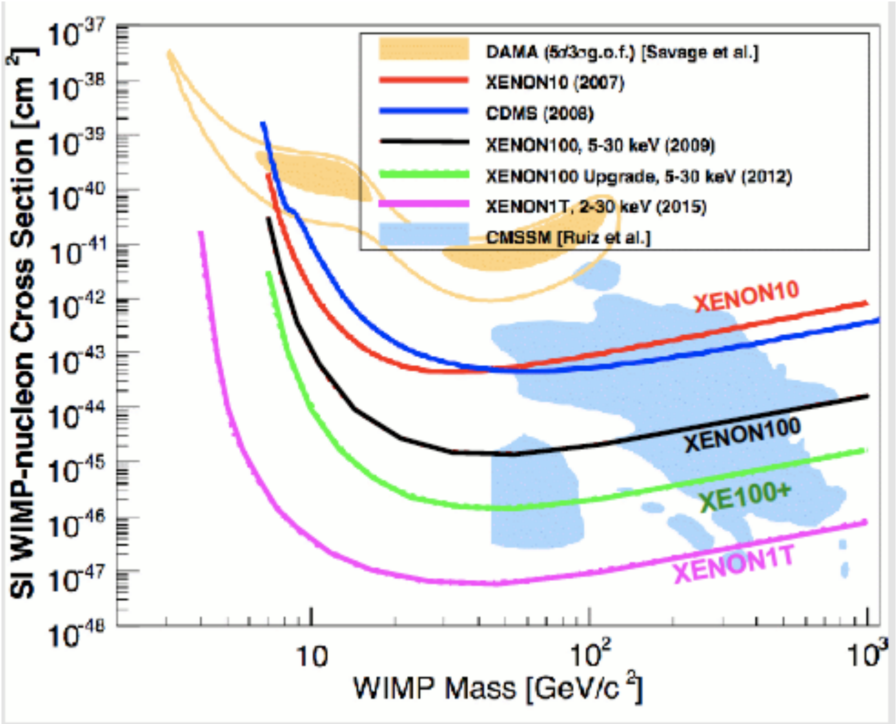
- increase fiducial target to >100 kg
- decrease background by factor 10
- increase sensitivity by factor 10
- pathfinder for XENON1T
- funded in the US by the NSF
- strong non- US support





Extremely low radioactivity: << 1mBq
Large area: ~ 3 inch
Single photon detection capability
High QE: > 30 %
Low temperature operation
Liquid Xenon: -108 °C
Liquid Argon: -186 °C

Summary



- **XENON100: 1st 100 kg scale LXe dark matter experiment operating underground**
- **Two-phase TPC works as designed: currently optimizing response with sources**
- **Neutron Calibration by Fall 09 and 1st dark matter search before end of 2009**
- **XENON100+ :funded and moving ahead with design and tests of key technologies**
-

Discovery Potential of XENON100 Program