The XENON Dark Matter Search

Elena Aprile
on behalf of the XENON collaboration

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WONDER Workshop, LNGS, March 22, 2010

XENON Collaboration

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

COLUMBIA

RICE

UCLA

ZURICH

COIMBRA

LNGS

MPIK

BOLOGNA

SHANGHAI

MUENSTER

SUBATECH

NIKHEF

The XENON Roadmap

past (2005 - 2007)	current (2008-2010)	future (2011- 2015)

XENON10

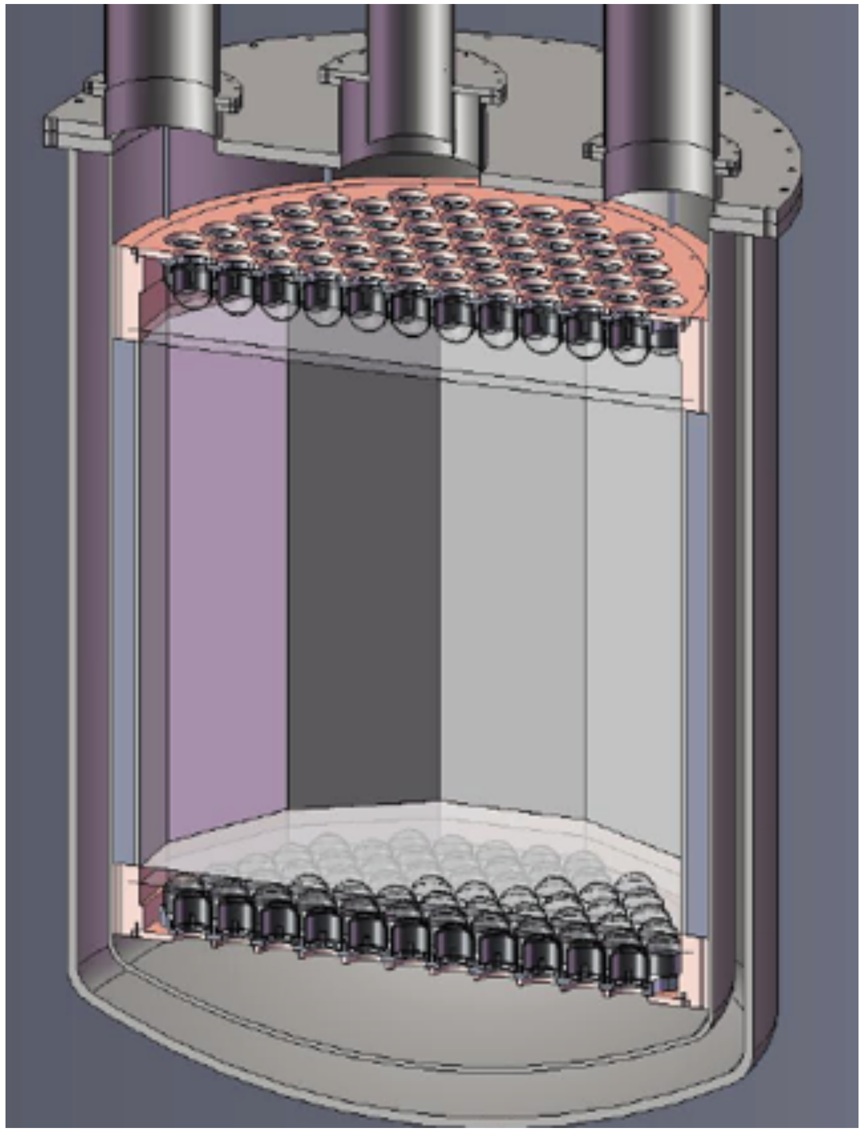
Achieved (2007) σ_{SI}=8.8 x10^{-44} cm^2

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

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

XENON100

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



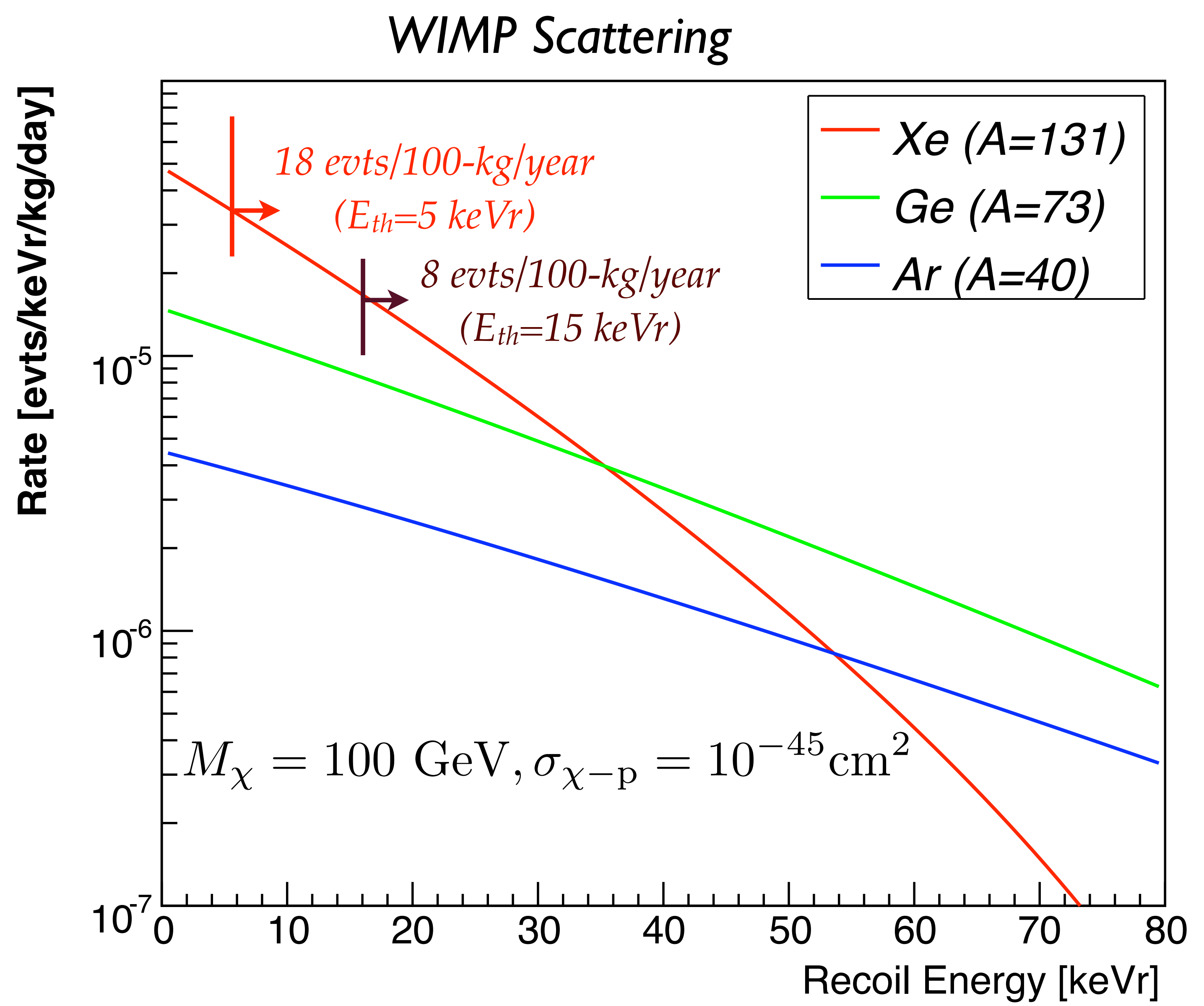
XENON1T

Goal: σ_{SI} <10^{-46} cm^2

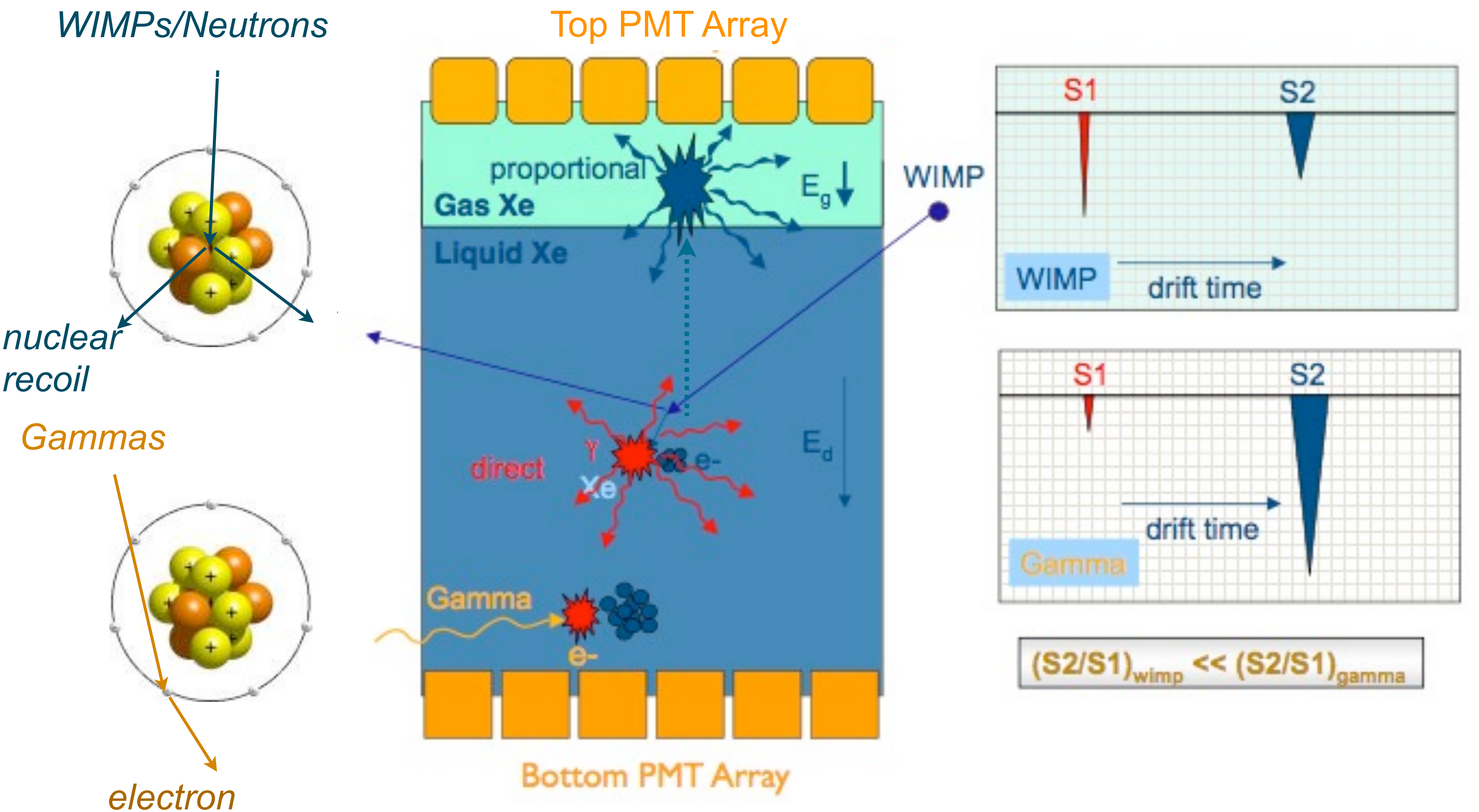
Liquid Xenon for Dark Matter

- *scalability: relatively inexpensive for very large detector (today < $800/kg)*
- *Large mass number (A~131): high rate for SI interactions if NR threshold is low*
- *~50% odd isotopes: SD interactions*
- *Excellent Stopping Power: active volume is shelf-shielding*
- *Excellent Scintillator and Ionizer: highest yield among noble liquids*
- *Intrinsically pure: no long-lived radioactive isotopes; Kr/Xe reduction to ppt level with established methods*
- *NR Discrimination: by simultaneous charge and light measurement*

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



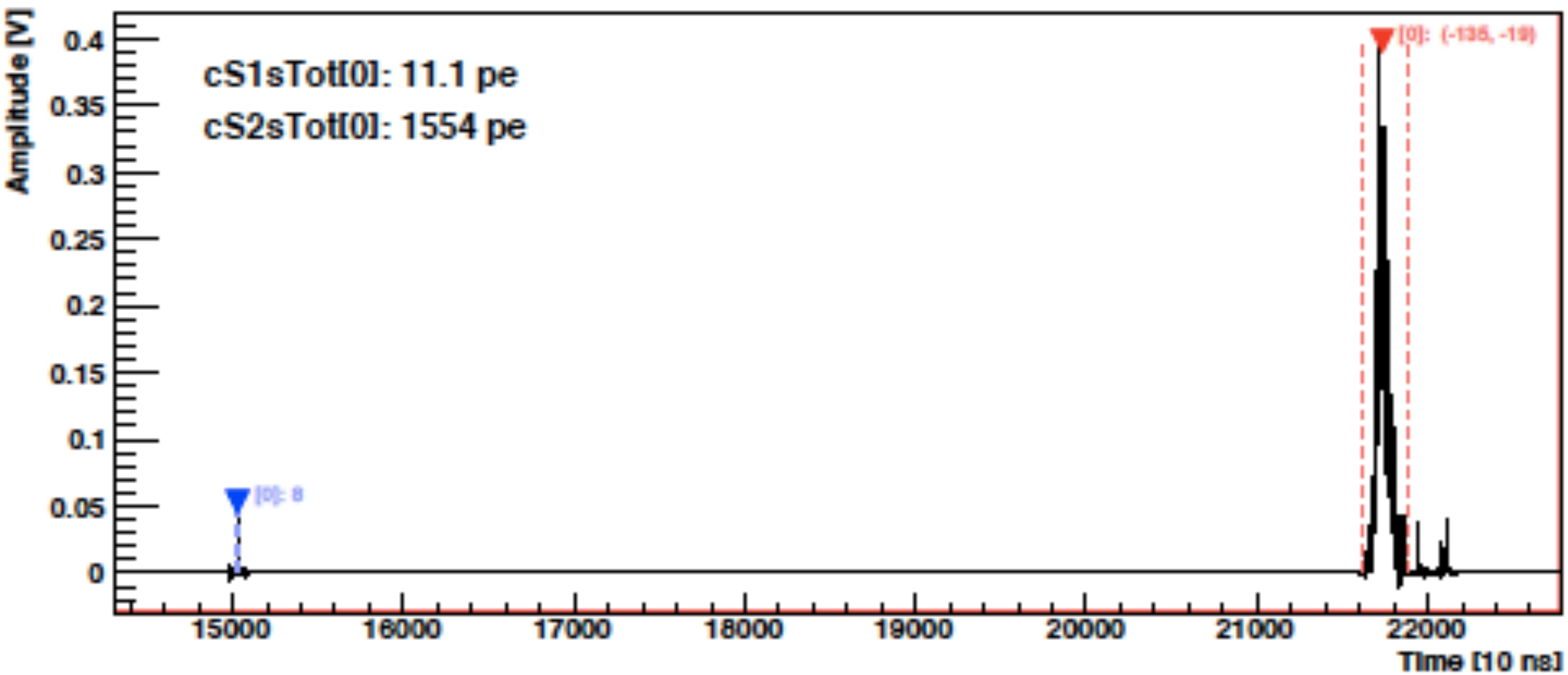
The XENON two-phase TPC



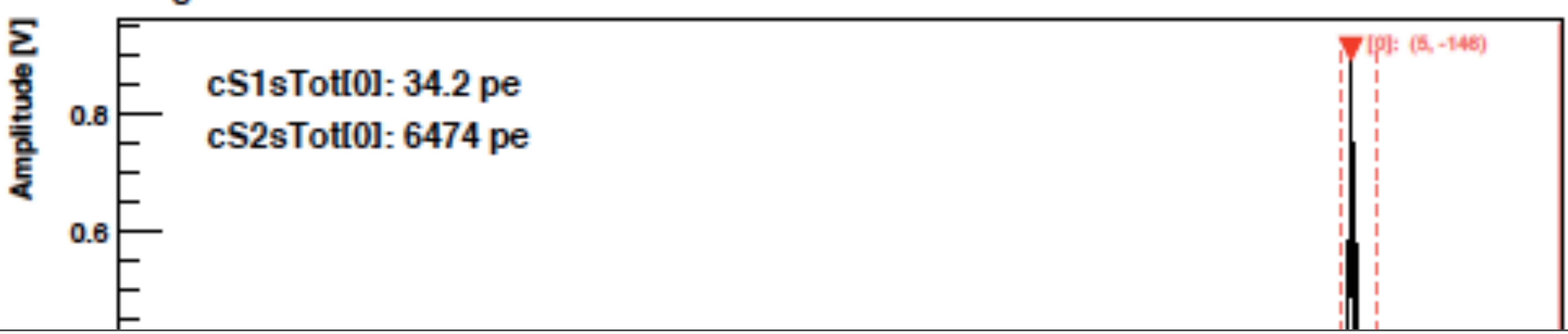
- XENON100 Events

➢ XENON100 Events

Single scatter NR



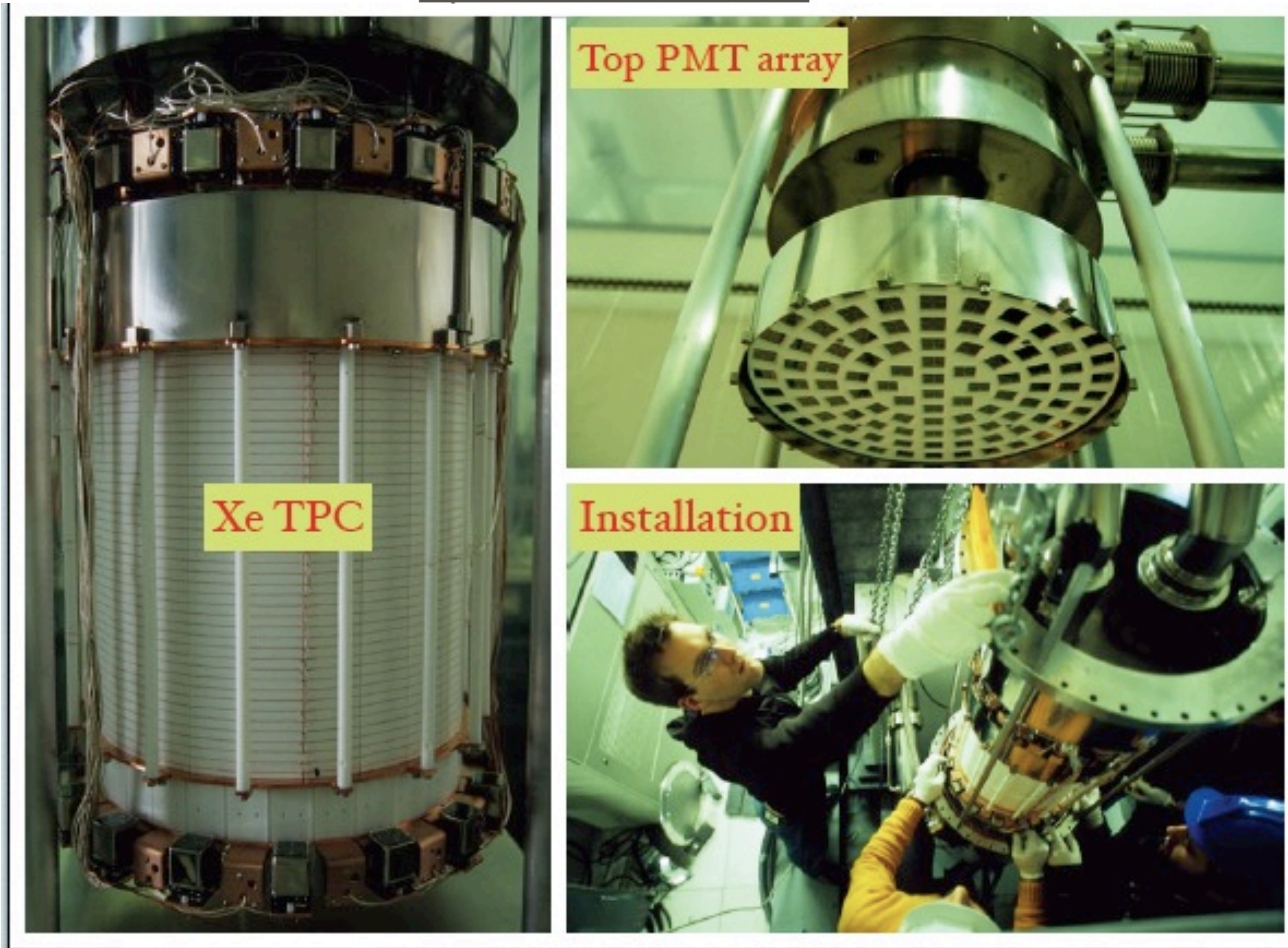
Single scatter ER



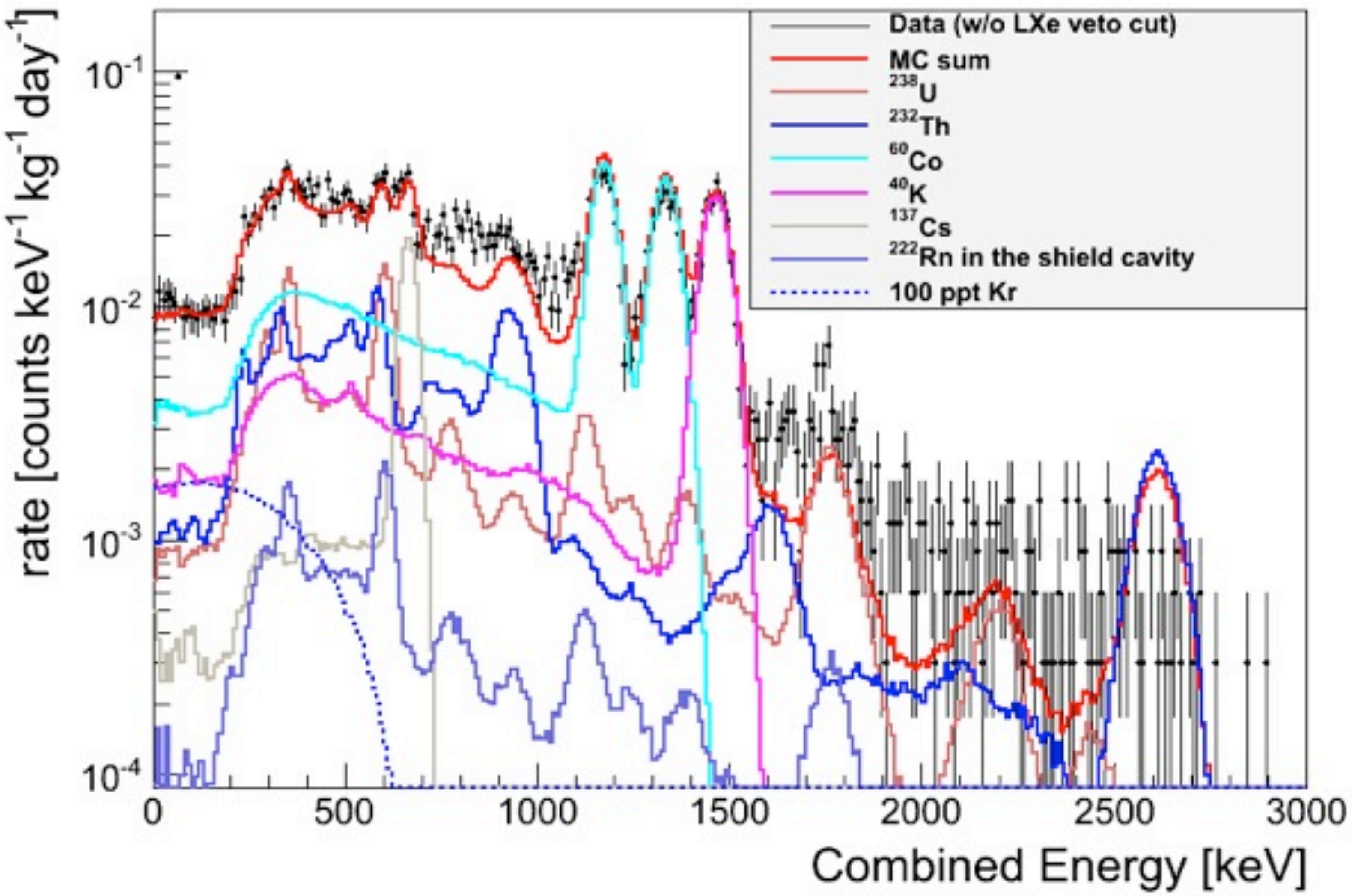
XENON100

- Use lessons/technologies from XENON10 to build a detector with x 10 more fiducial mass and x 100 less background
- 170 kg of LXe: the active target (65 kg) is surrounded on all sides by a 105 kg of LXe active veto
- TPC size: 30 cm drift x 30 cm diameter viewed by two arrays of PMTs with <1 mBq (U/Th) and ~30% QE (bottom array)
- Background from internal components reduced by: a) materials screening and selection; b) cryocooler and FTs outside shield; c) cryogenic distillation to reduce Kr/Xe contamination
- Background from external sources reduced by: a) active LXe veto; b) improved shield with 5 cm Cu lining of Poly and with water outside Pb

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

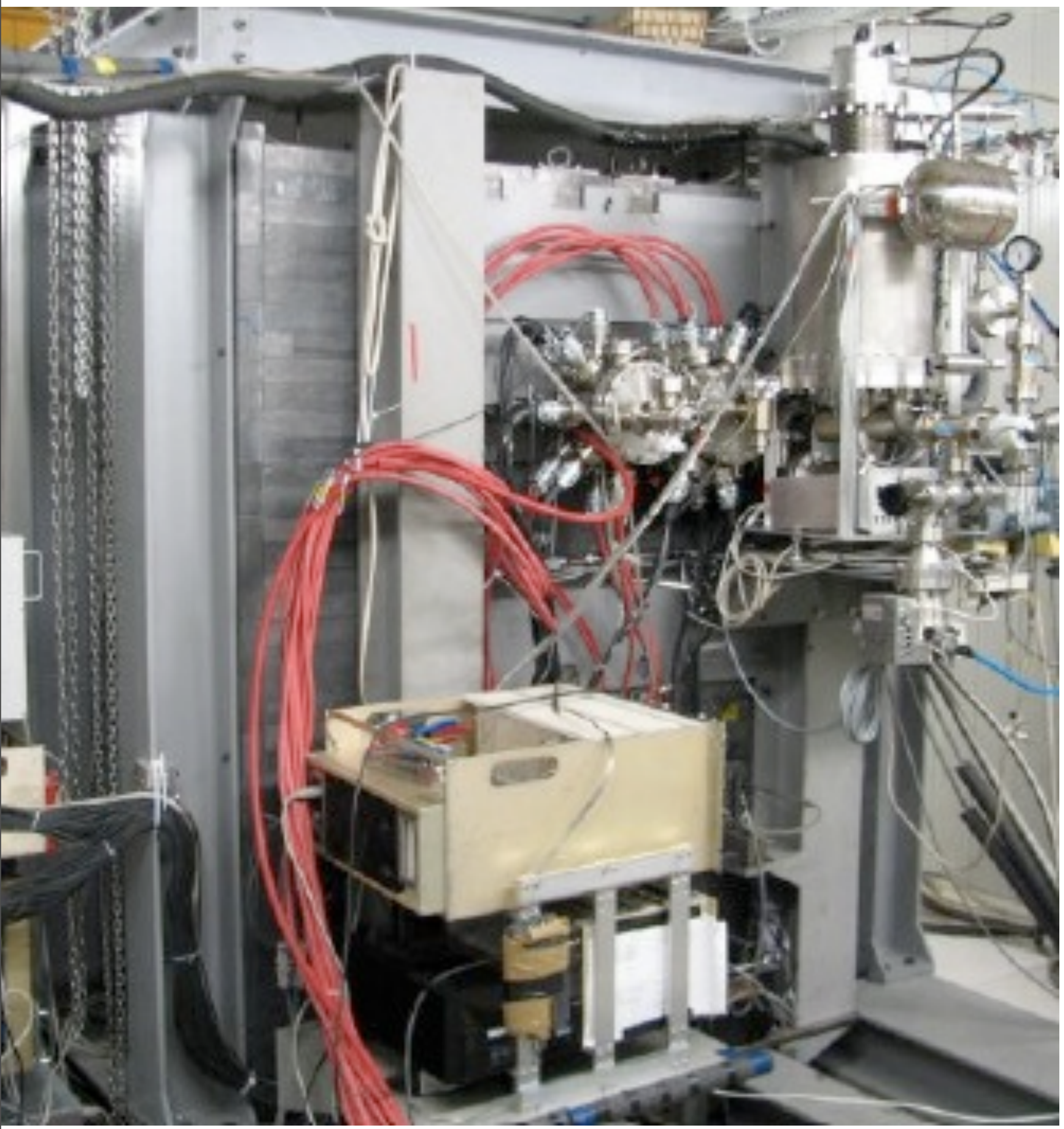


XENON100: Kr Distillation Column



- XENON100 goal requires ~100 ppt Kr/Xe contamination
- We start with Xe commercially cleaned to a Kr/Xe <10 ppb (verified by delayed coincidence events analysis)
- We use a dedicated cryogenic distillation tower to reduce this Kr/Xe contamination to the required level
- After distillation, delayed coincidence analysis gives a Kr/Xe contamination of ~150 ppt (limited by low statistics)

XENON100: Status

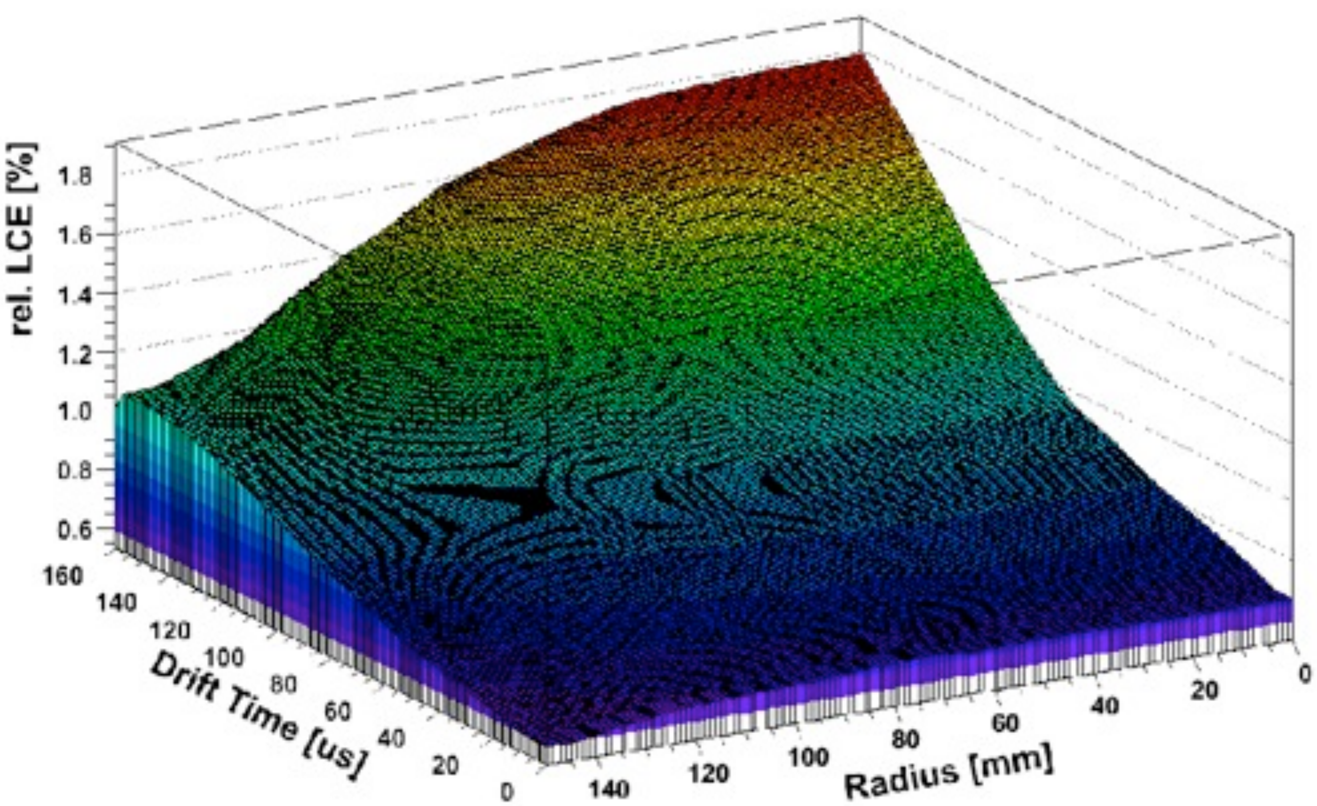


- In continuous operation underground for the past 6 months with high stability
- Neutron calibration performed in mid-December 2009
- Gamma calibrations are performed on regular basis (Cs137 for e-lifetime; Co60 for gamma band)
- Measured background level is consistent with design goal of 100 less than XENON10
- Dark Matter search run started on January 13, 2010: data in ROI “blinded”
- Event selection and cuts developed and optimized on calibration data

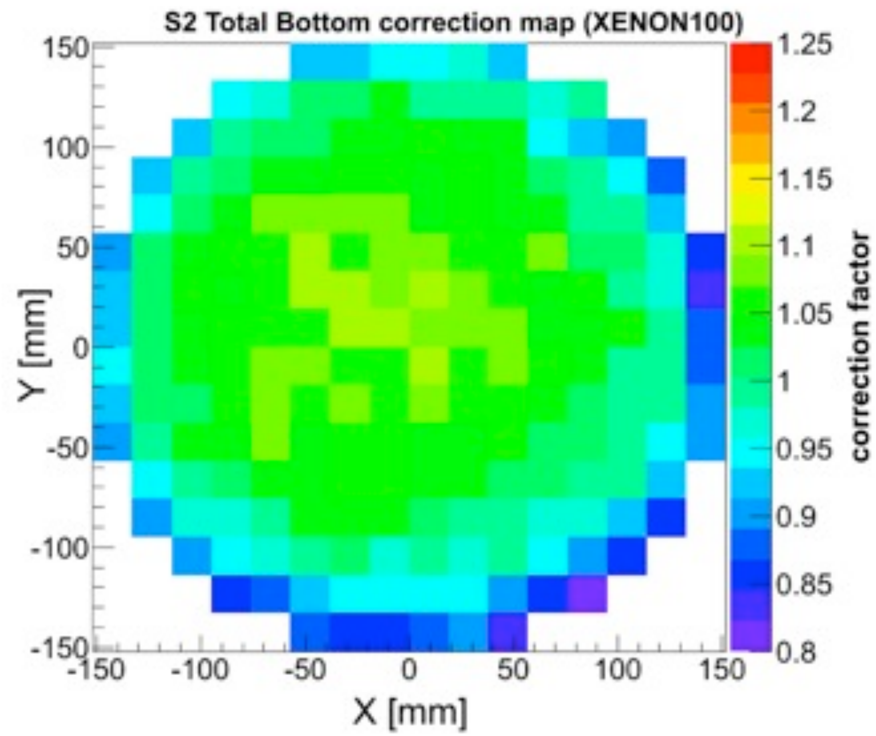
Position Dependence of Charge and Light Signals

- XENON100 is a 3D position sensitive TPC: for each event the XY information is extracted from from the light patten on PMTs and Z from measured drift time
- Three algorithms developed for XY positioning: tested with a collimated Co57 beam. Results consistent with a position resolution < 3 mm
- S1 and S2 signals are position dependent. The dependence is extracted from gamma and neutron calibration data

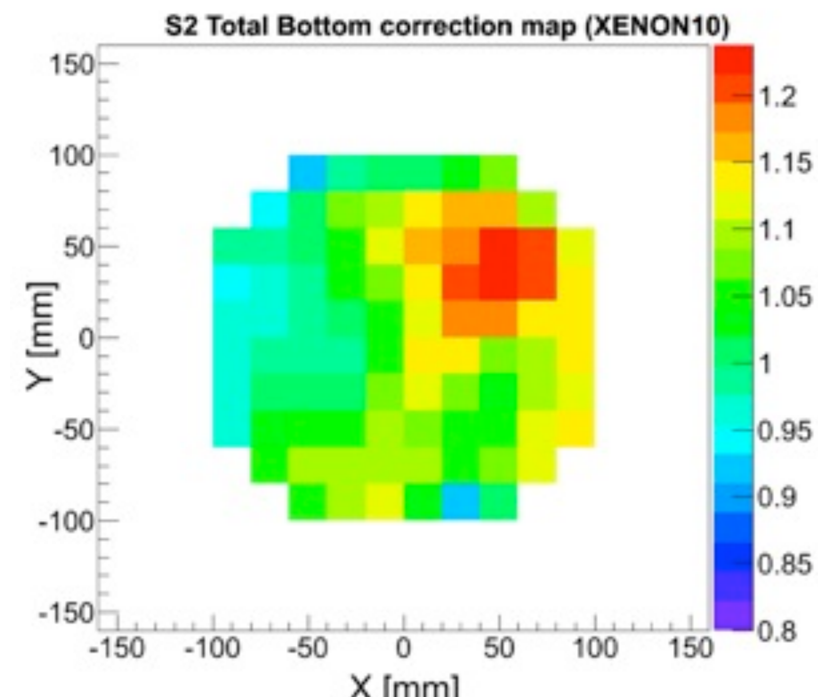
S1 Position (r, Z) Dependence



S2 Position (X,Y) Dependence



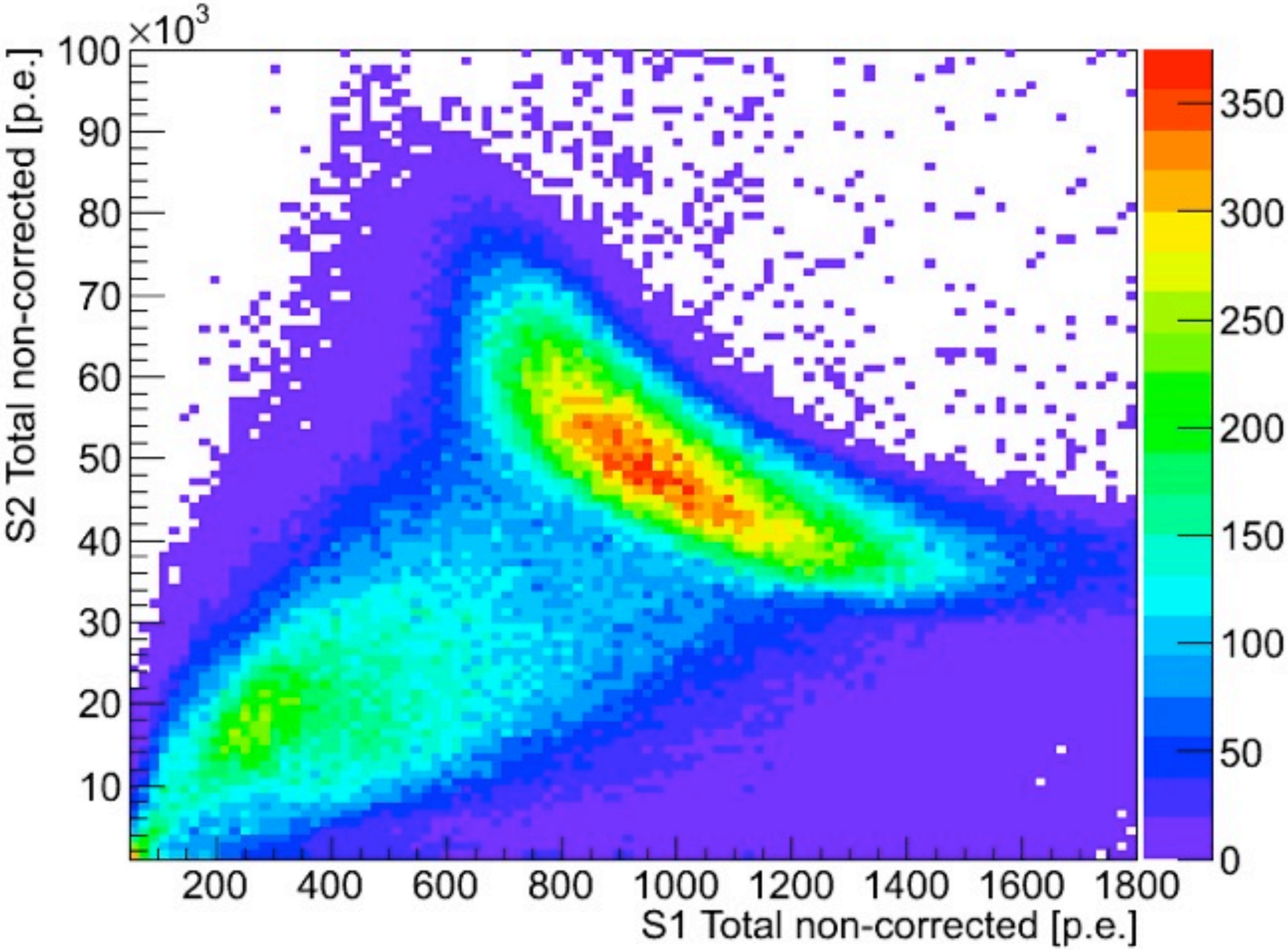
XENON100



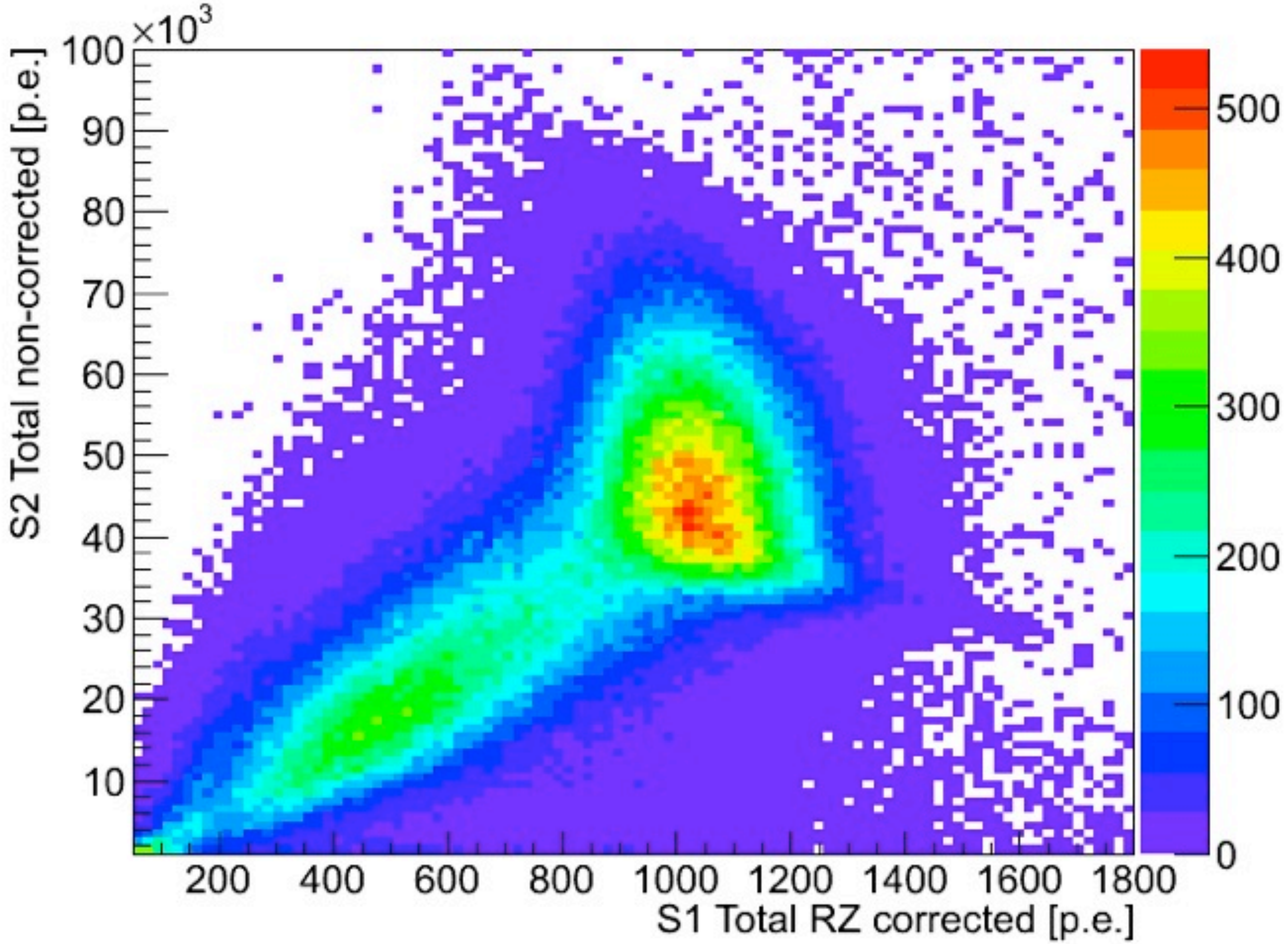
XENON10

Impact of Signals Position Dependence on Energy Resolution

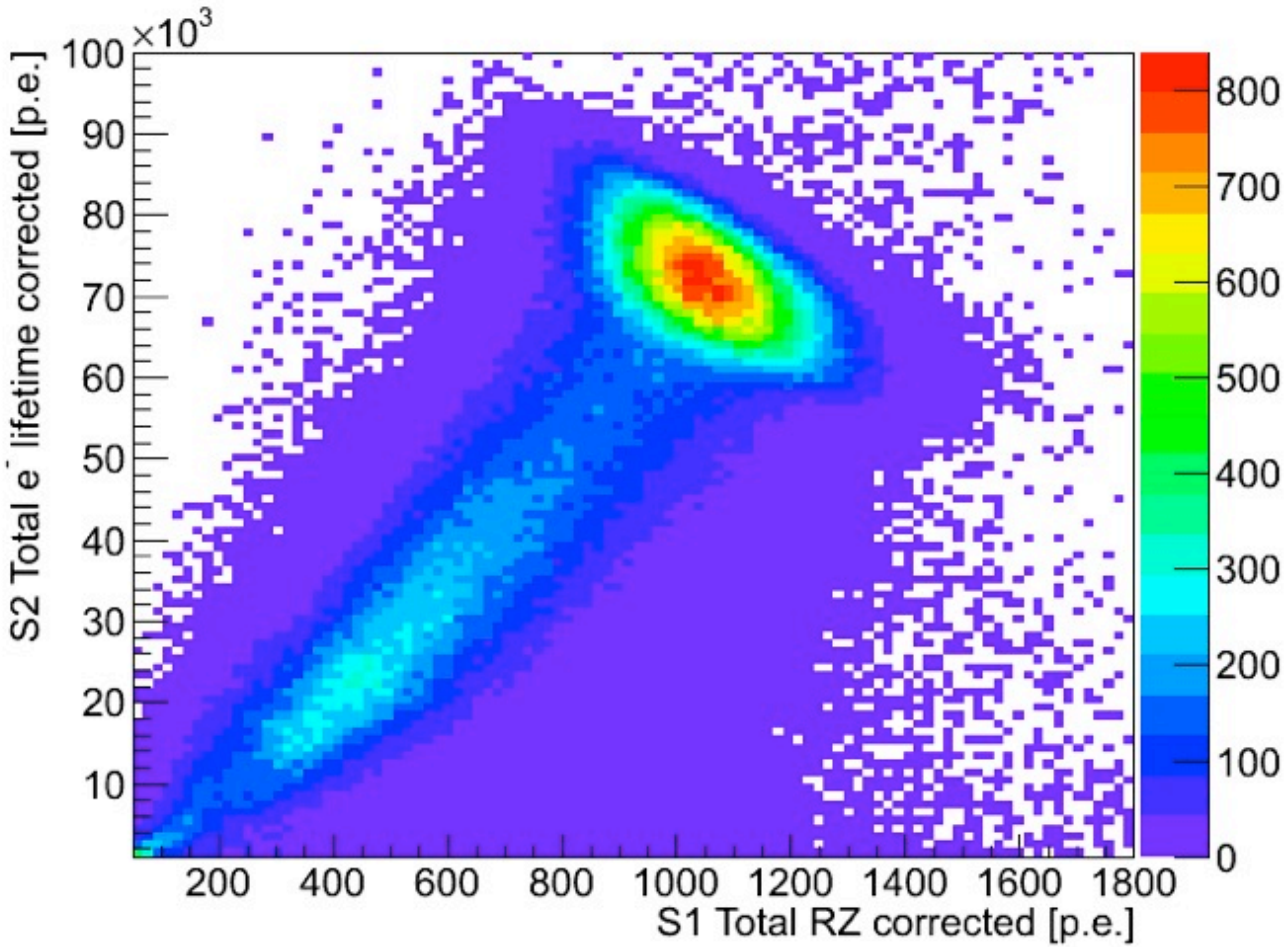
Impact of Signals Position Dependence on Energy Resolution



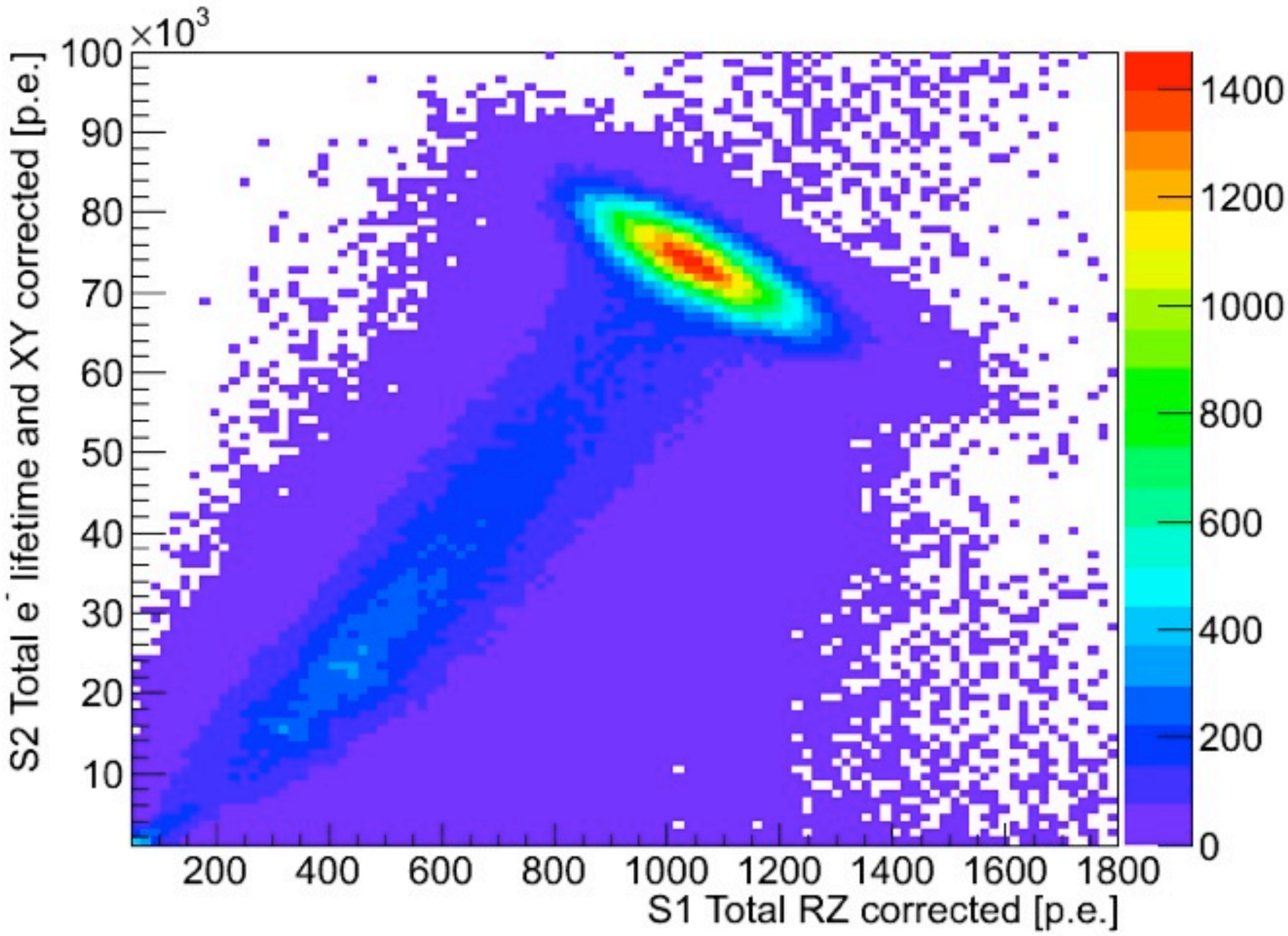
Impact of Signals Position Dependence on Energy Resolution



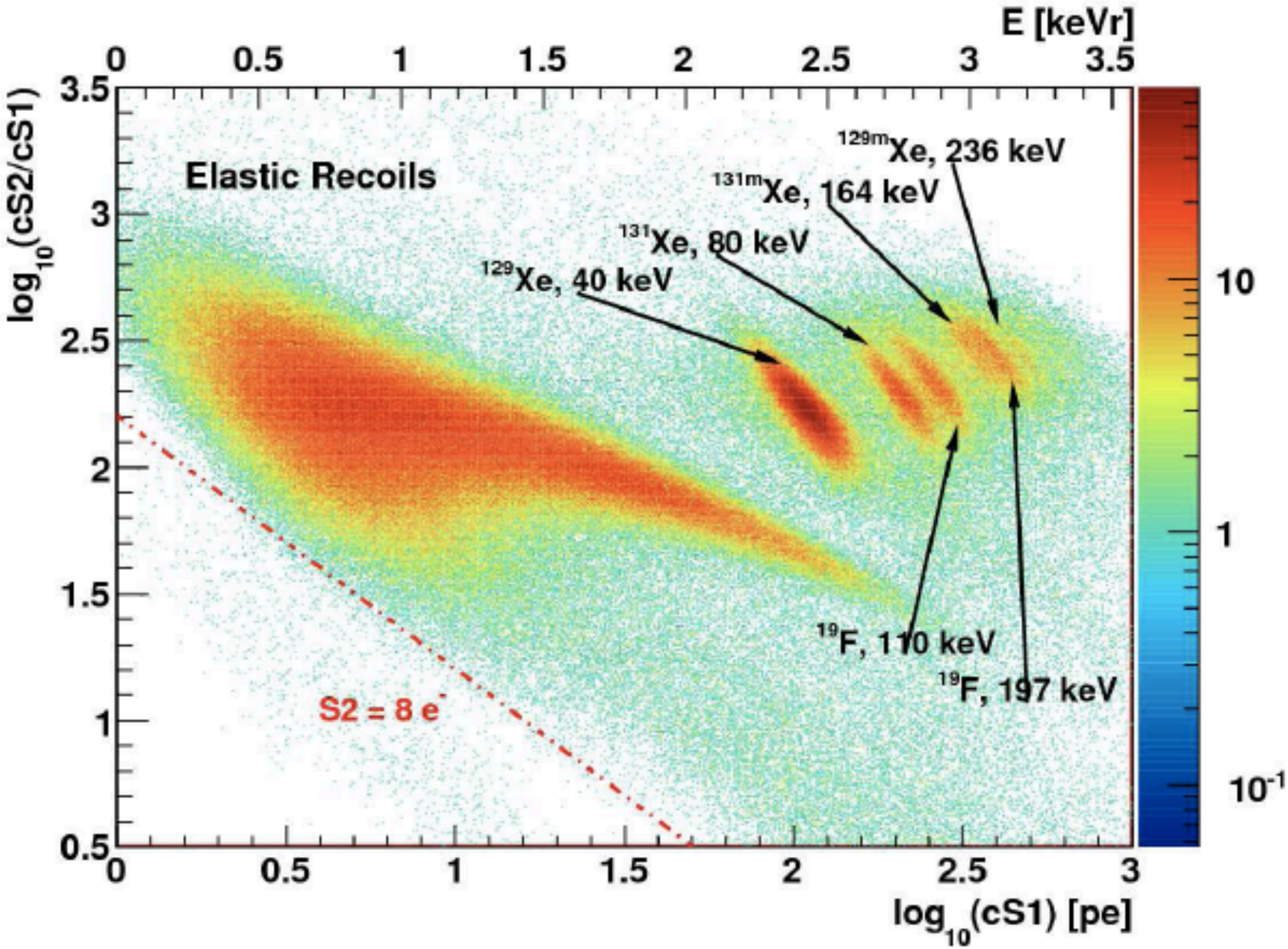
Impact of Signals Position Dependence on Energy Resolution



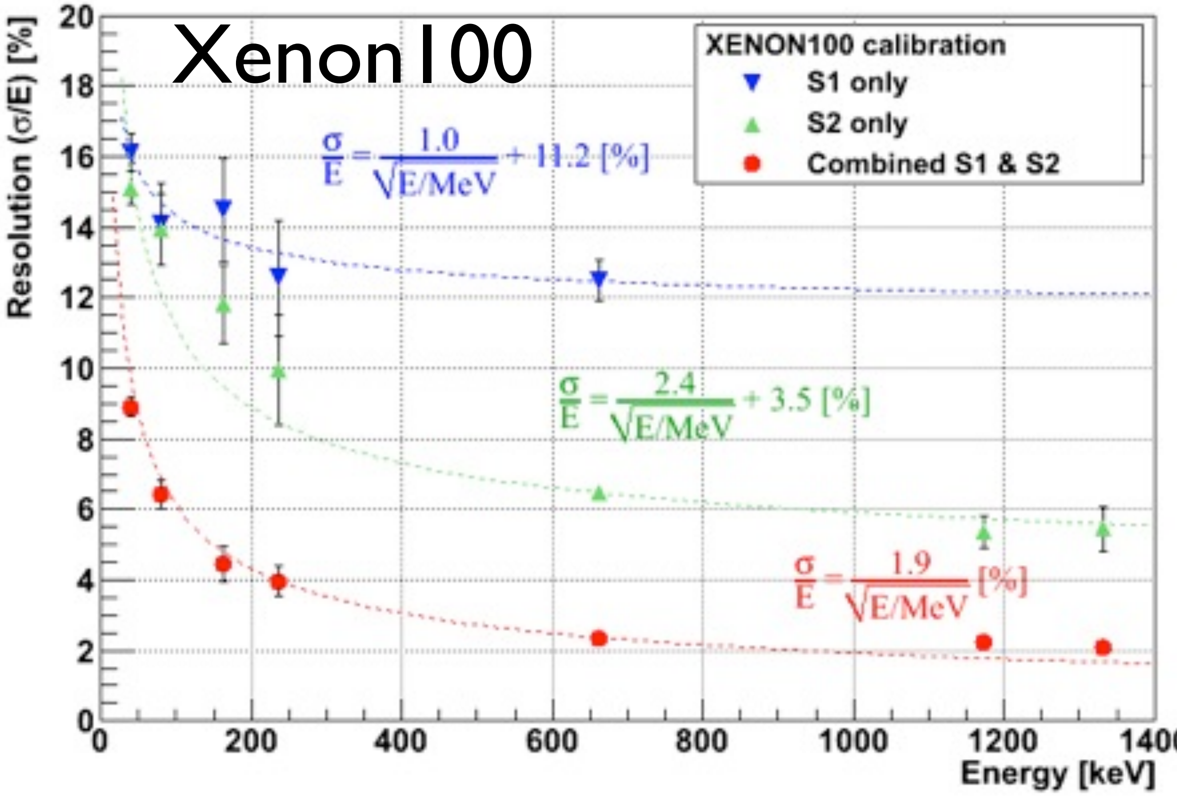
Impact of Signals Position Dependence on Energy Resolution

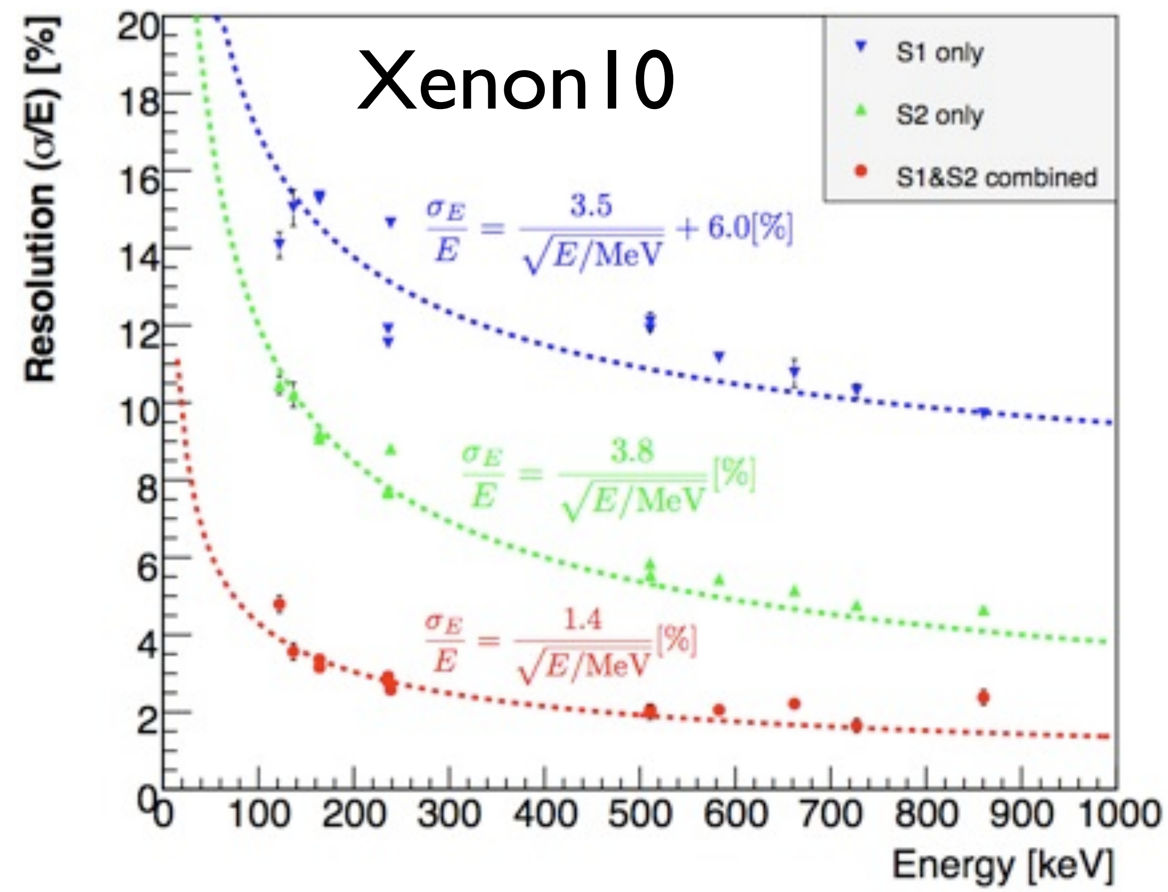


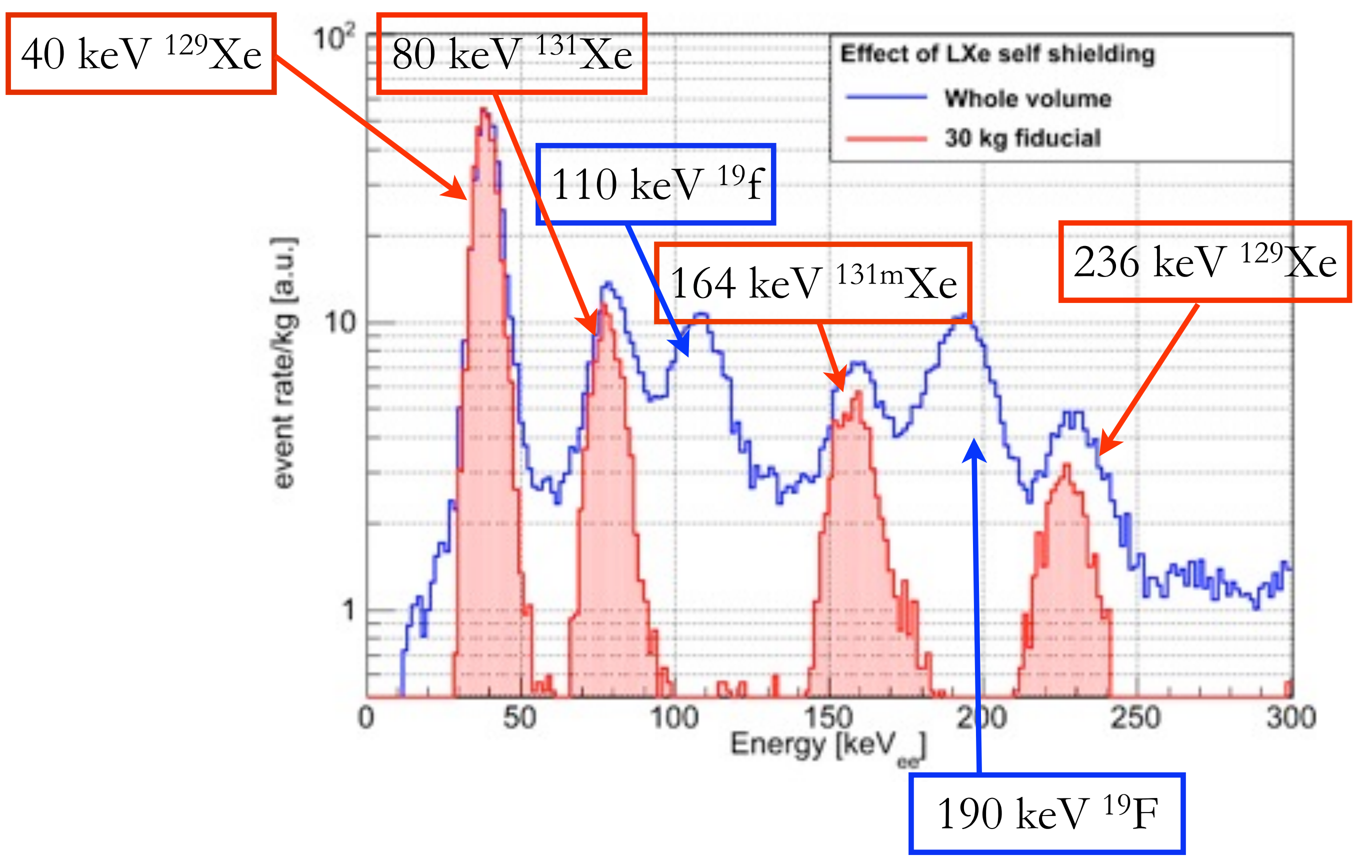
XENON100: Neutron Calibration

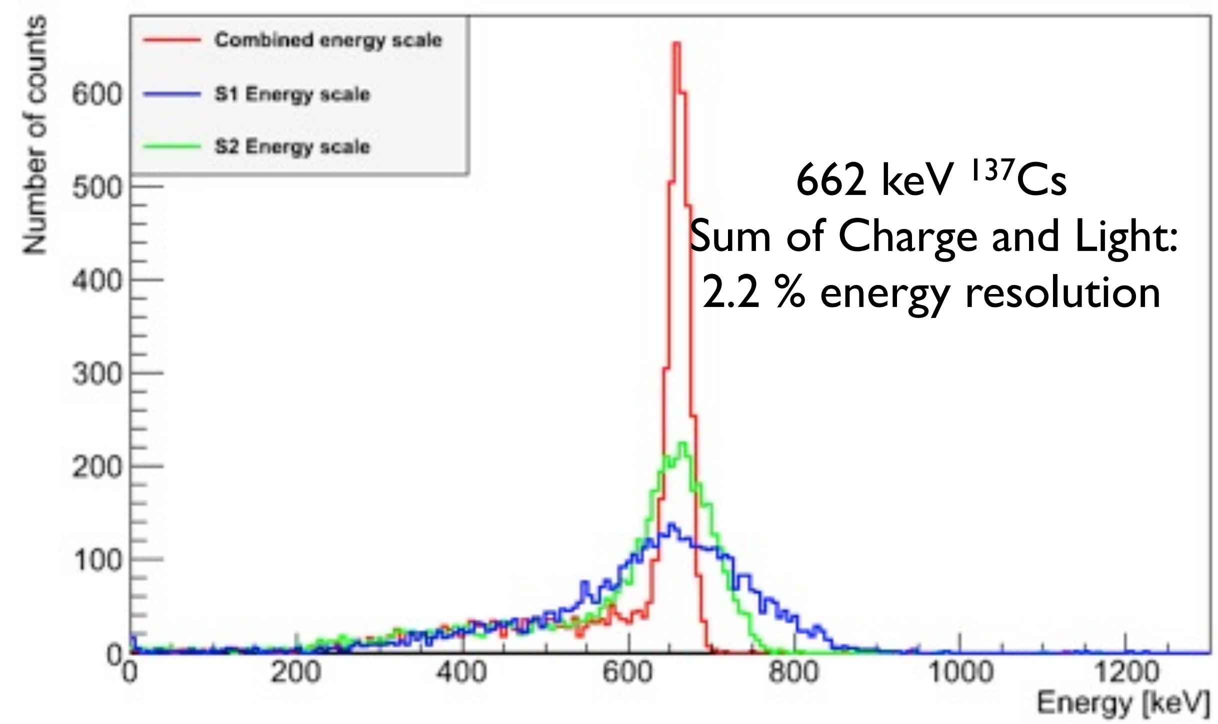


XENON100: Energy Resolution

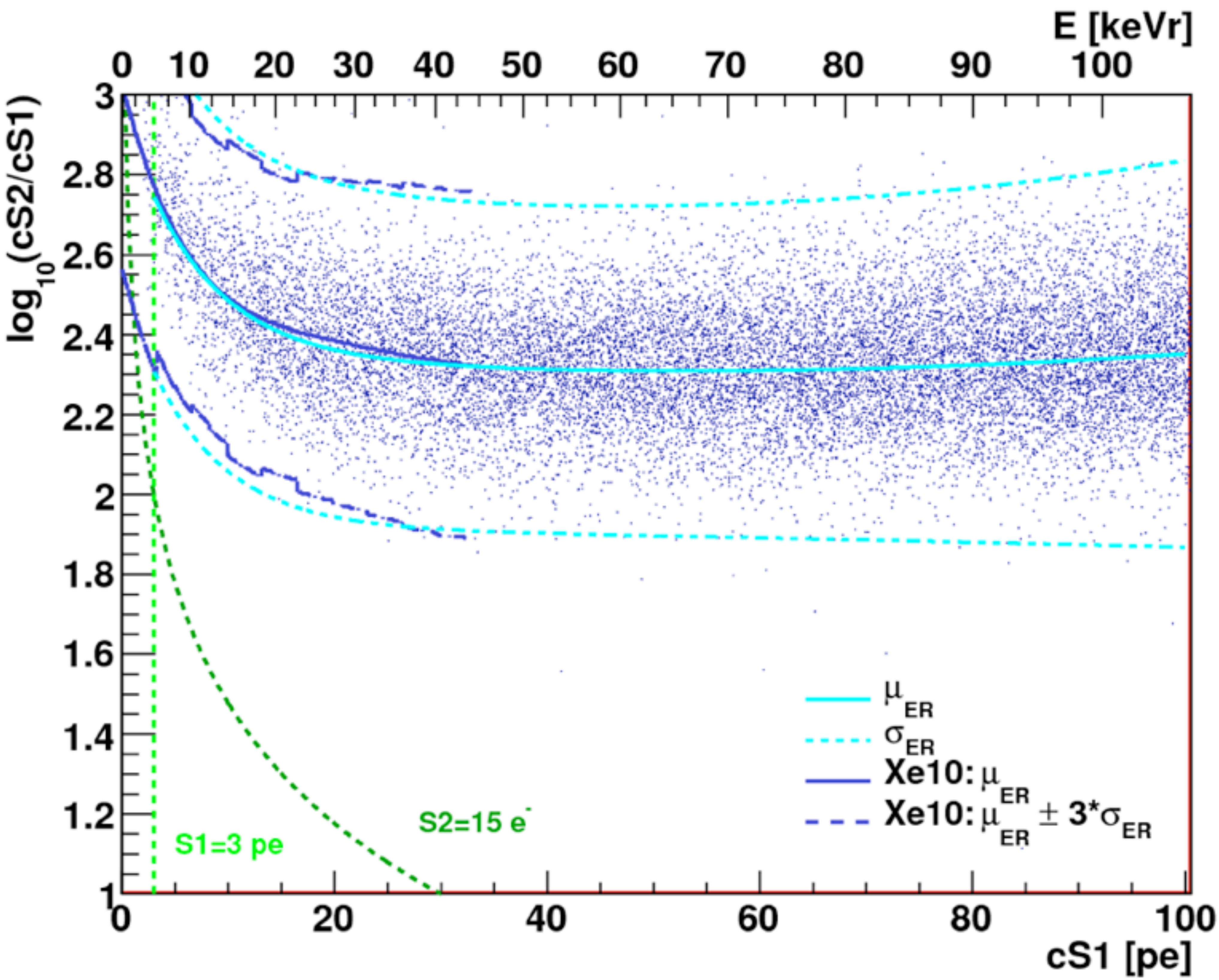




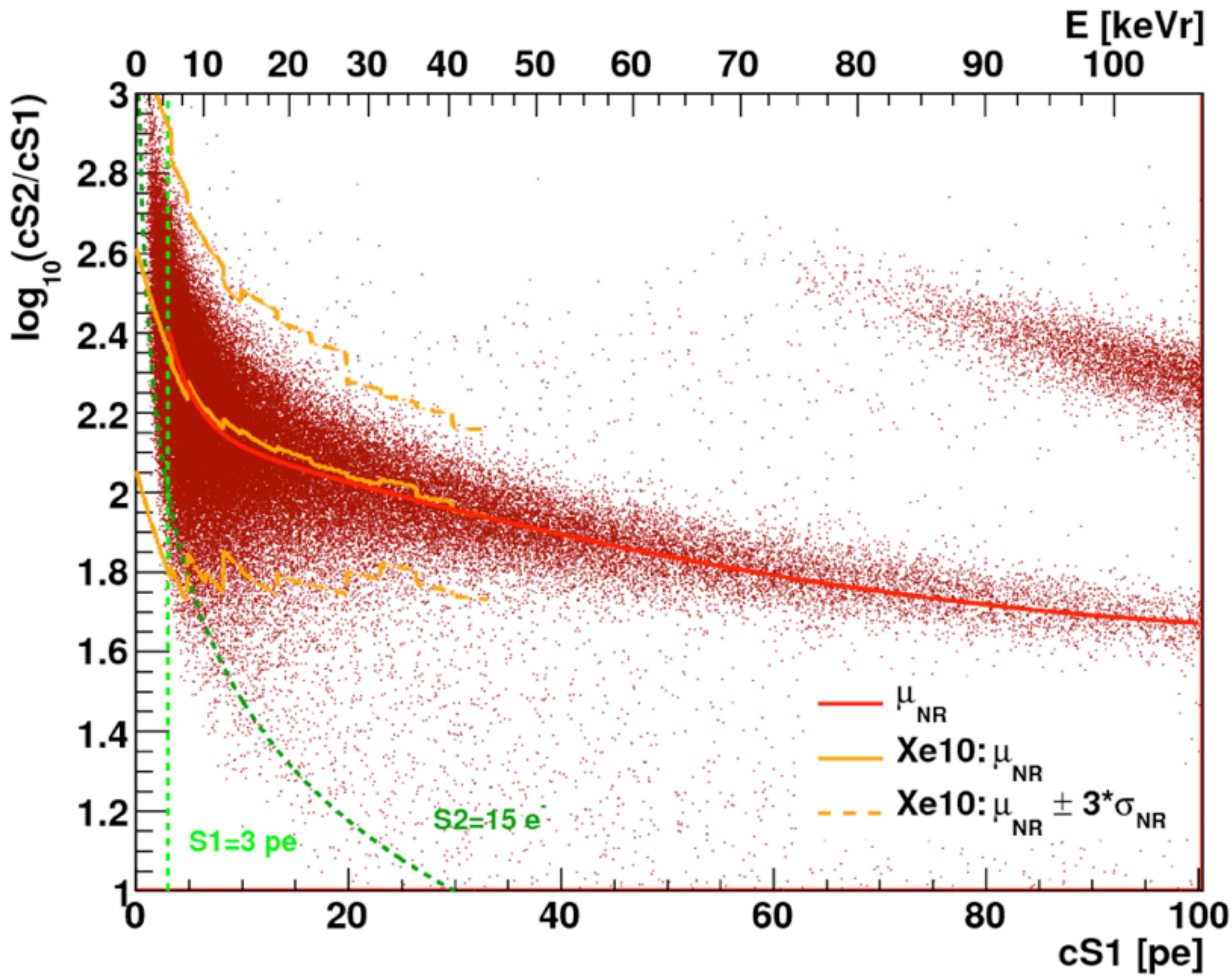




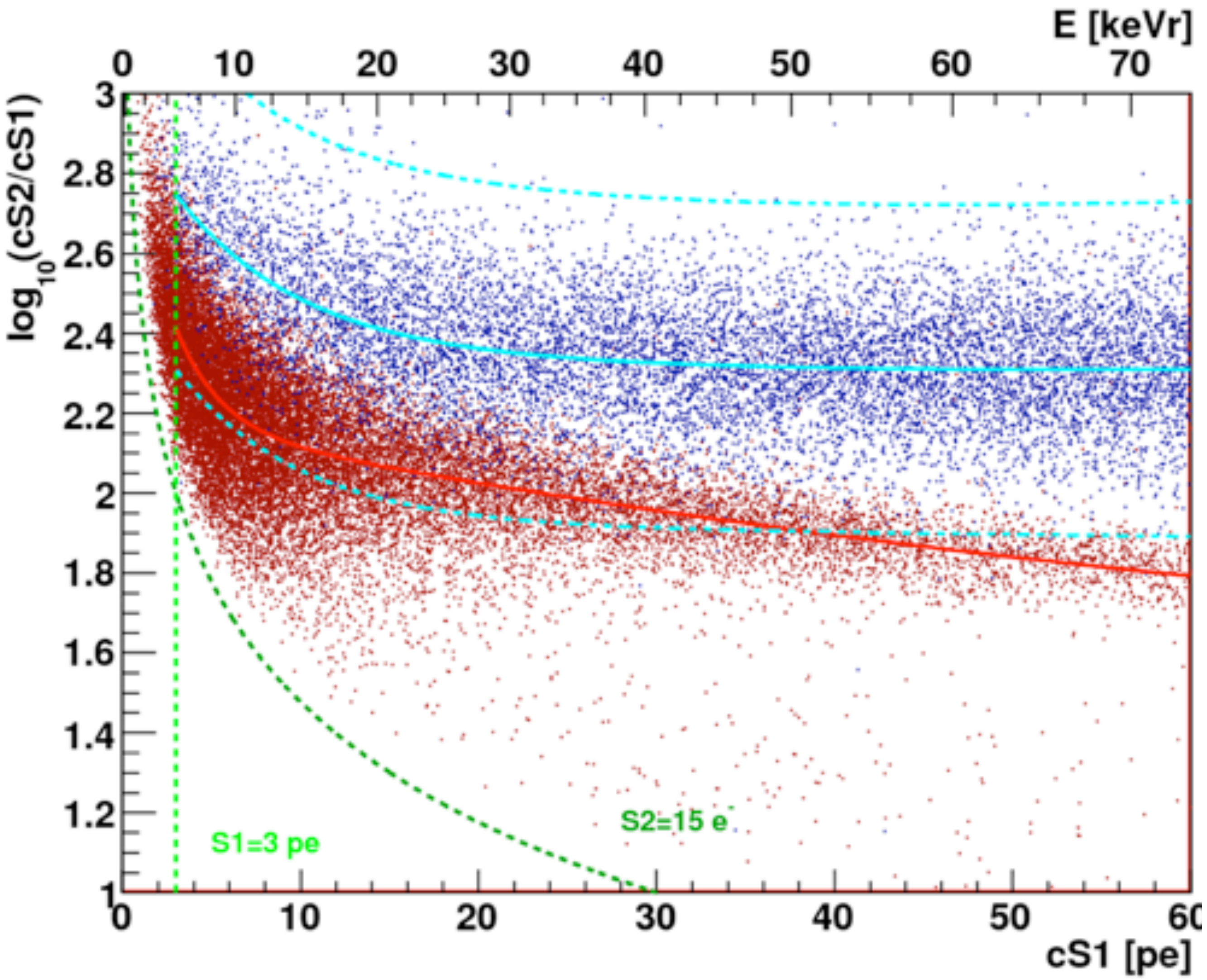
XENON100: Gamma Recoil Band

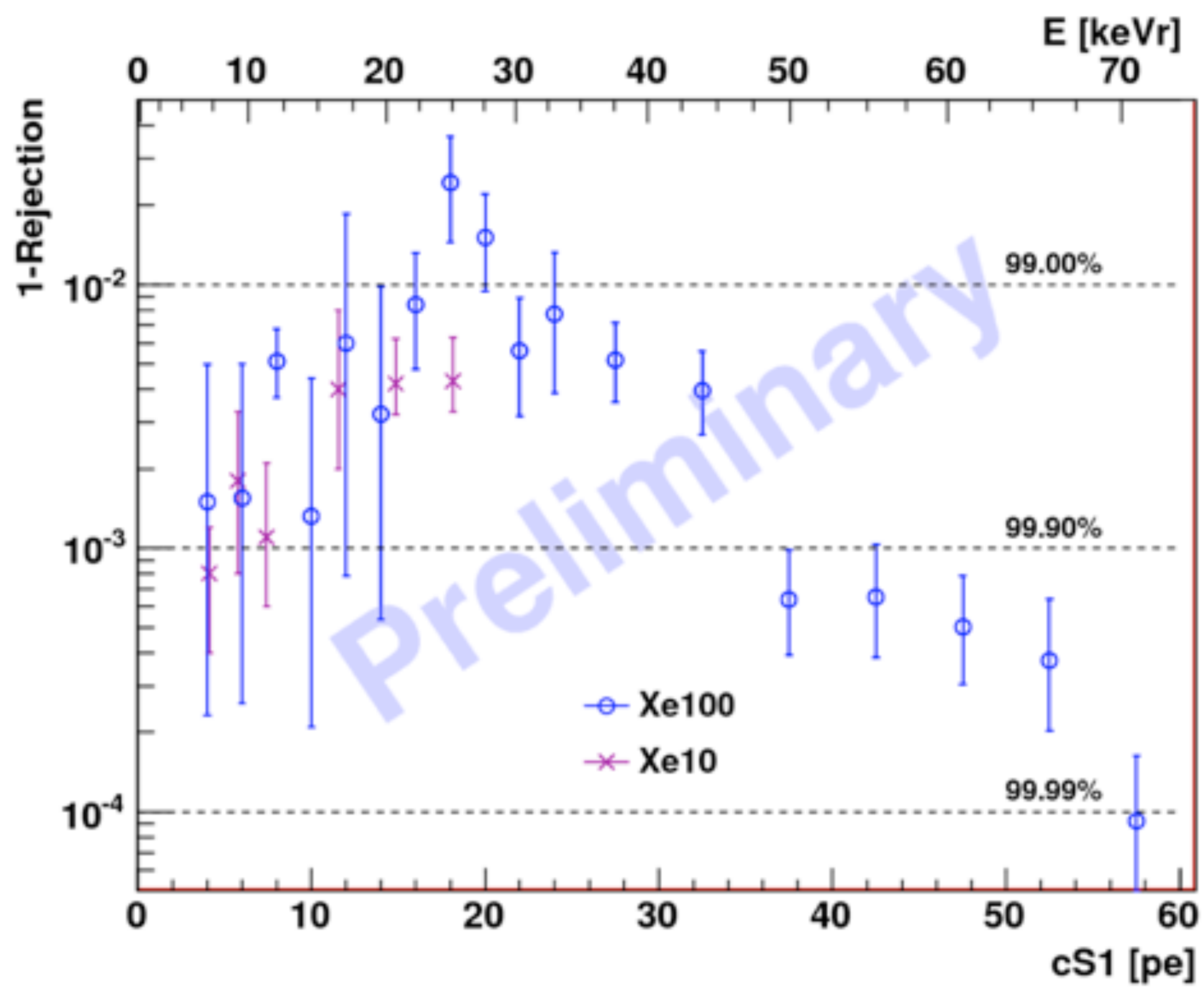


XENON100: Neutron Recoil Band

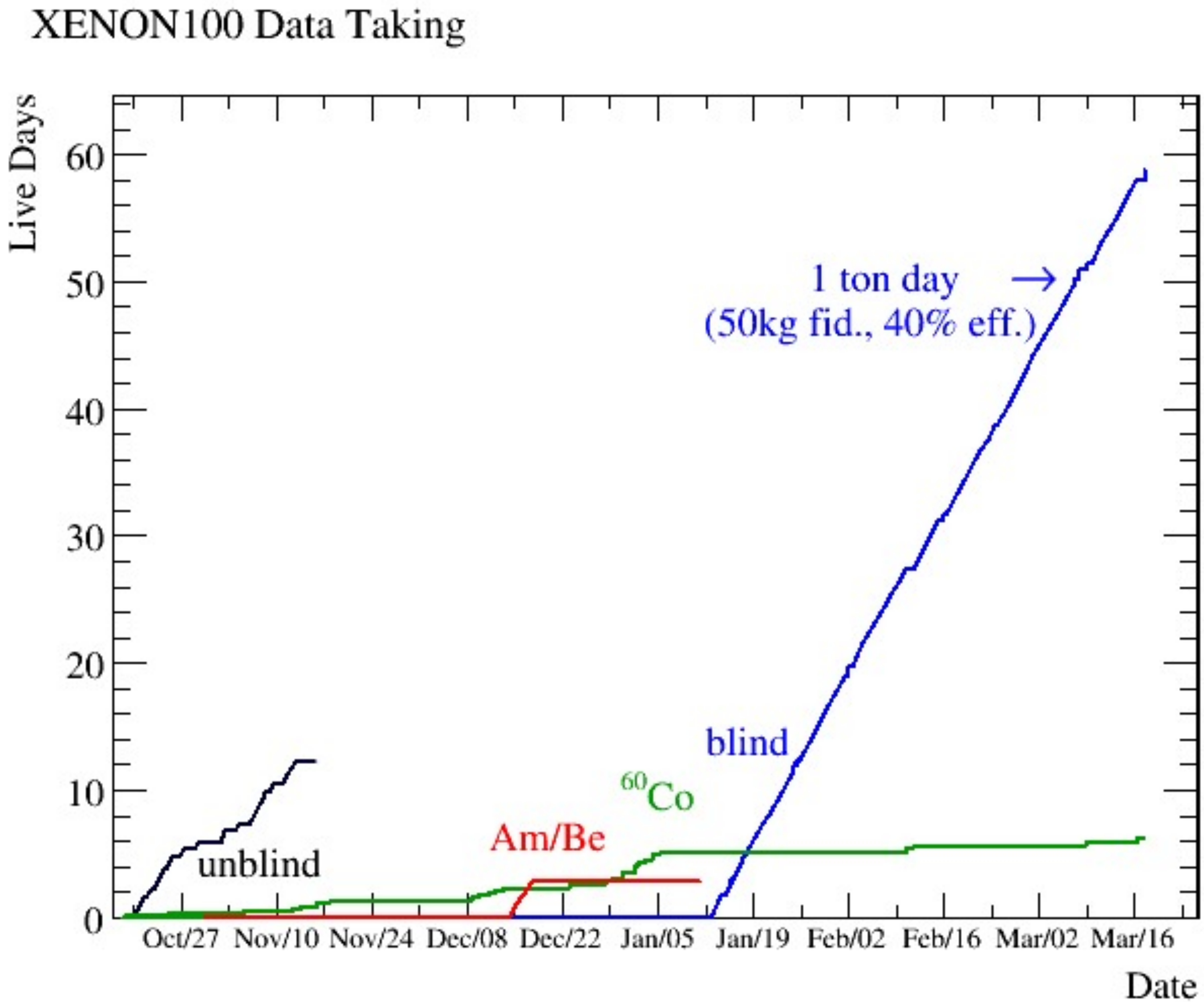


XENON100: Rejection Power



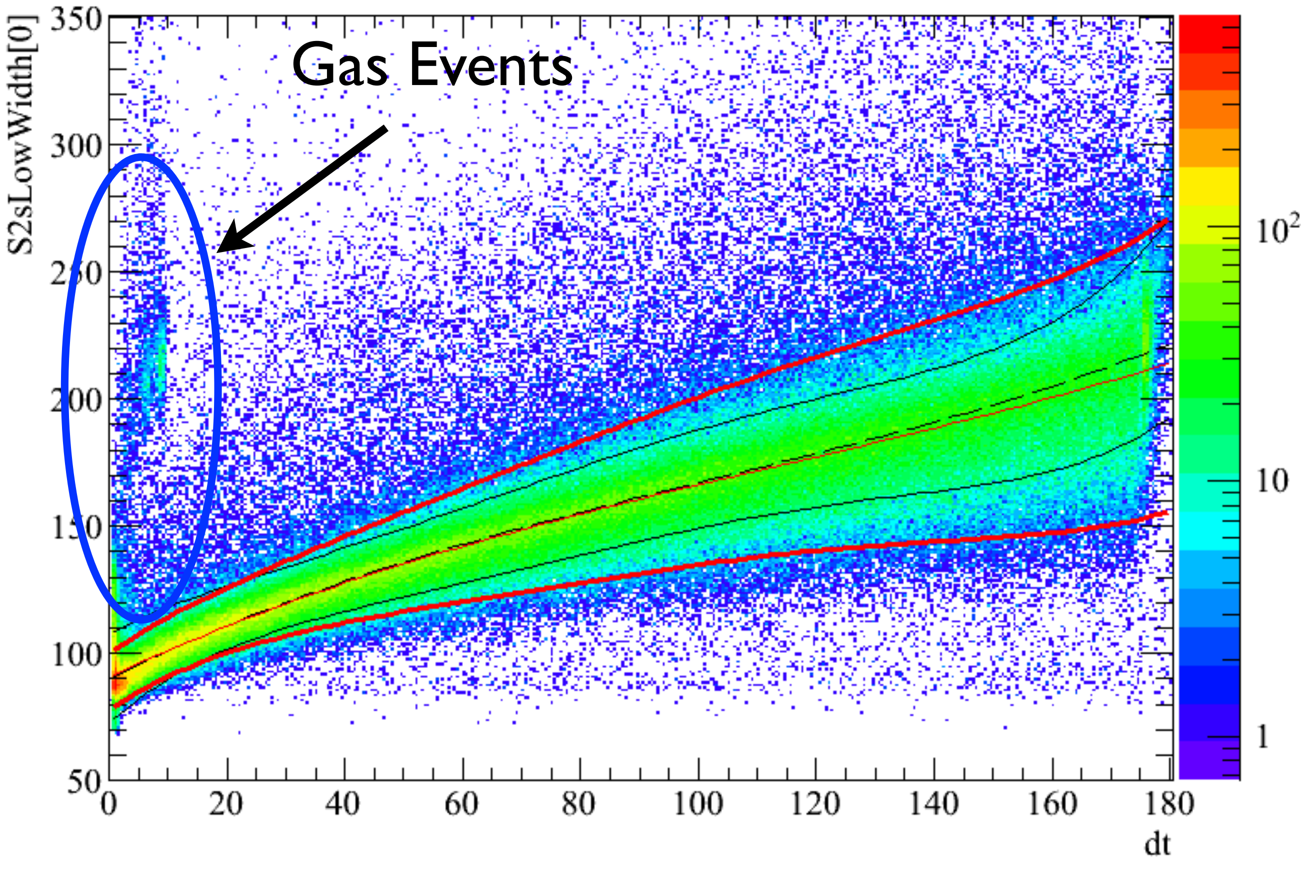


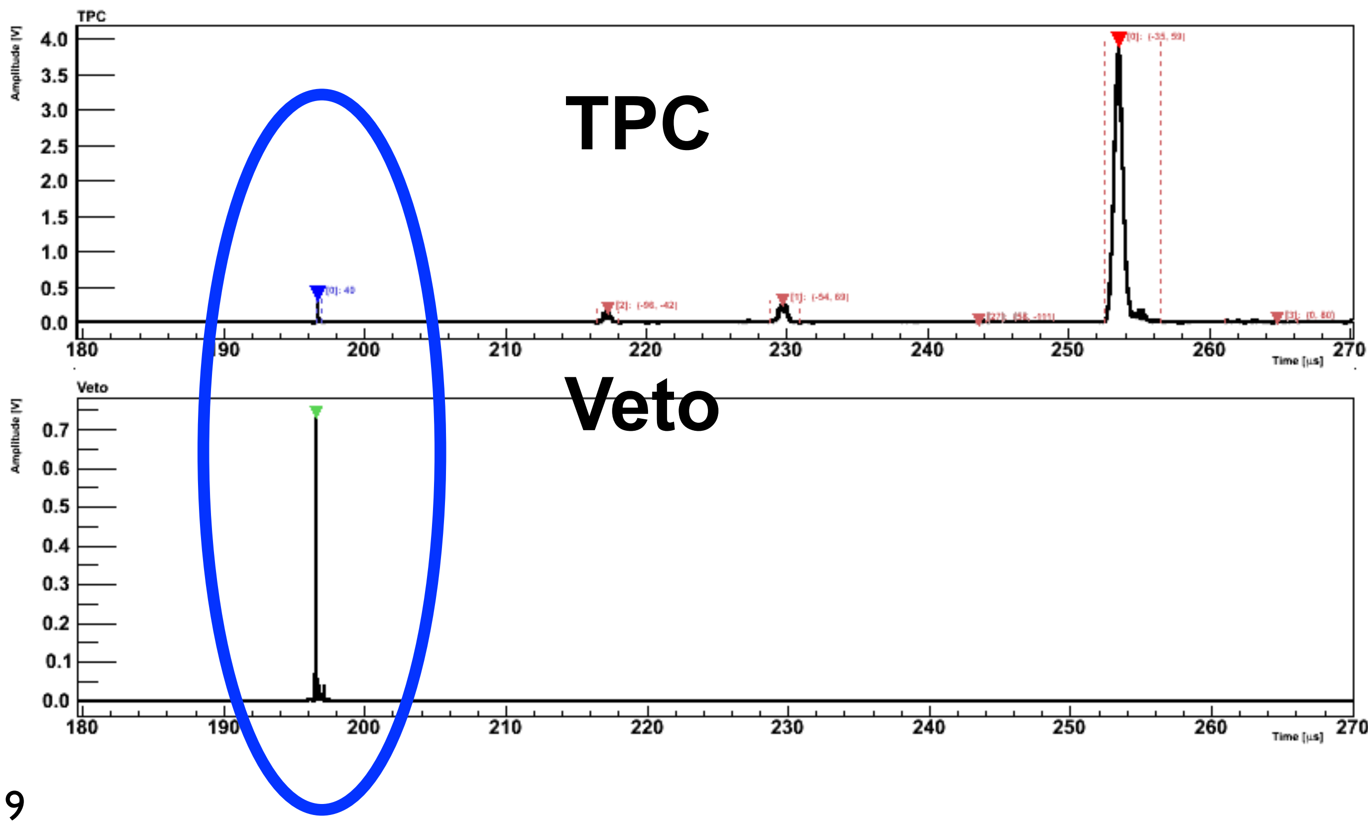
XENON100 Dark Matter Data to-date



Analysis of XENON100 non-blinded data

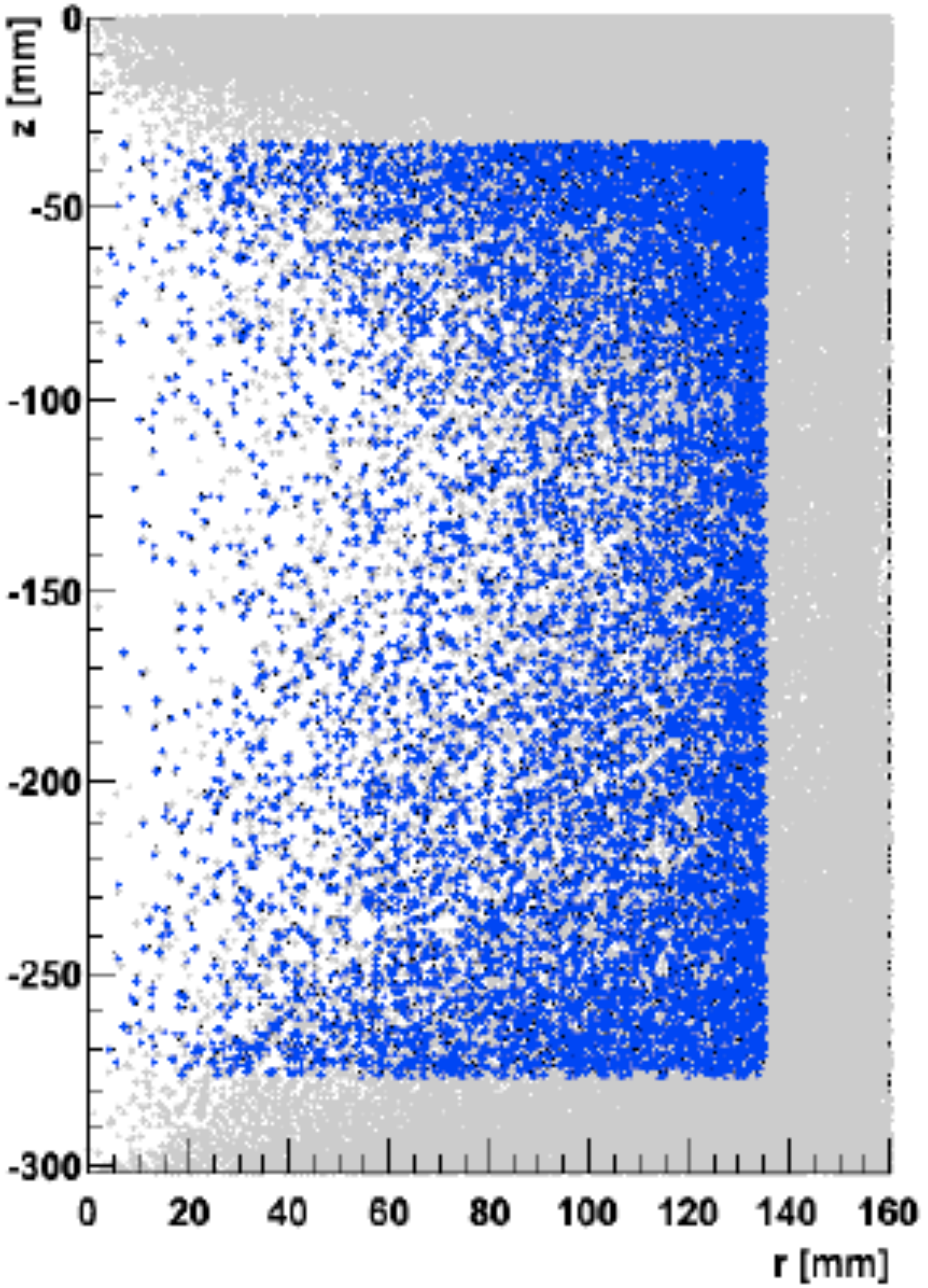
- 11. 2 live days of background data from October-November 2009
- Non-blind analysis: but cuts optimized only on neutron and gamma calibration data
- Only very basic event selections are applied:
  - events with reasonable S/N ratio (TPC has high sensitivity to single electrons)
  - events with single S1 and single S2 peaks (remove delayed coincidence events and multiple Compton and neutron scatters)
  - events with the S2 pulse width compatible with drift time (remove gas events)
  - events with an S1 signal in active volume but no veto signal



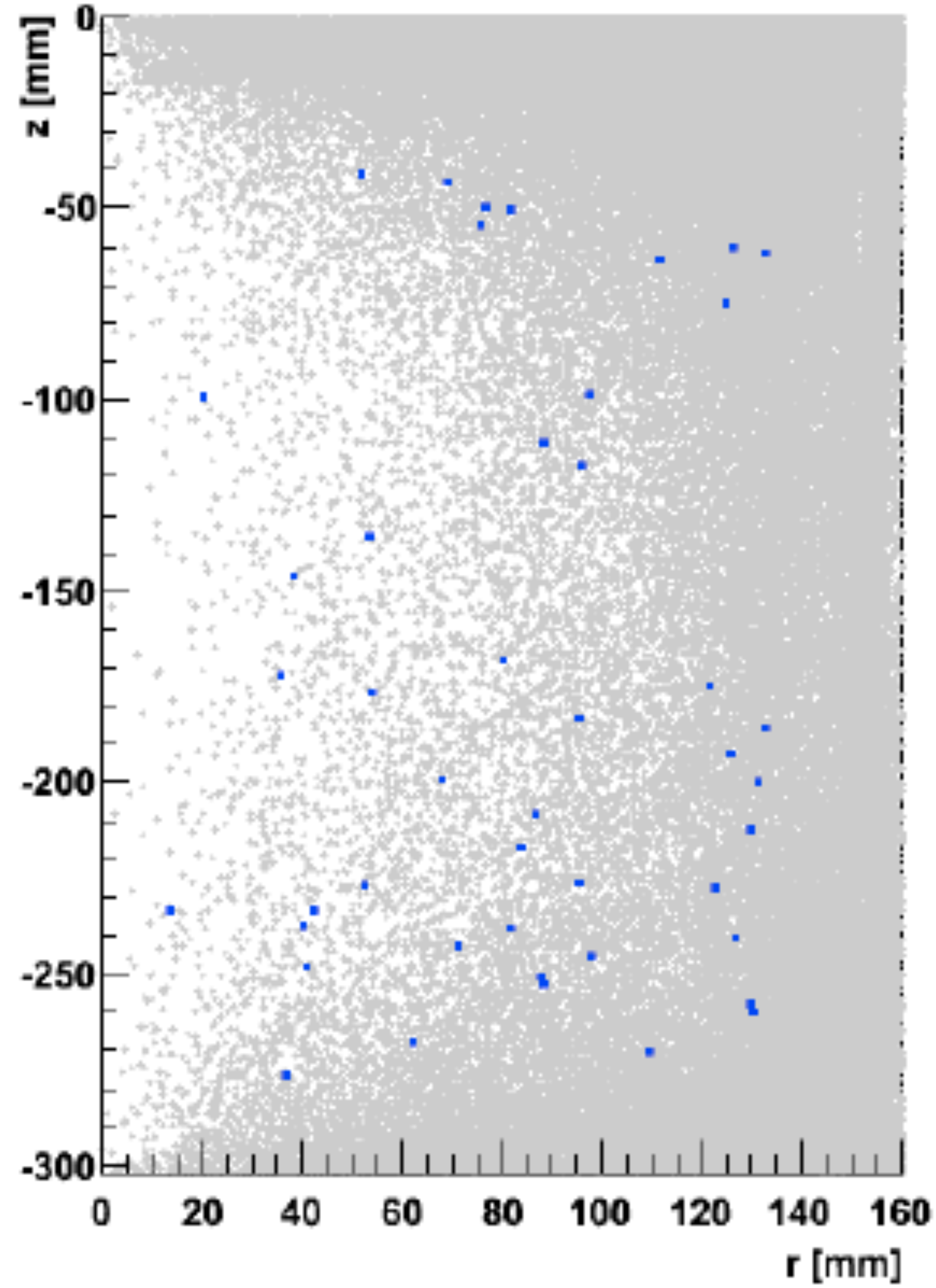


Select Fiducial Volume and Event Energy

11.2 days: Select Fiducial Volume
40 kg mass (further optimization ongoing)



11.2 days: Select Event Energy
< 28 keVr (~XENON10 WIMP search range)



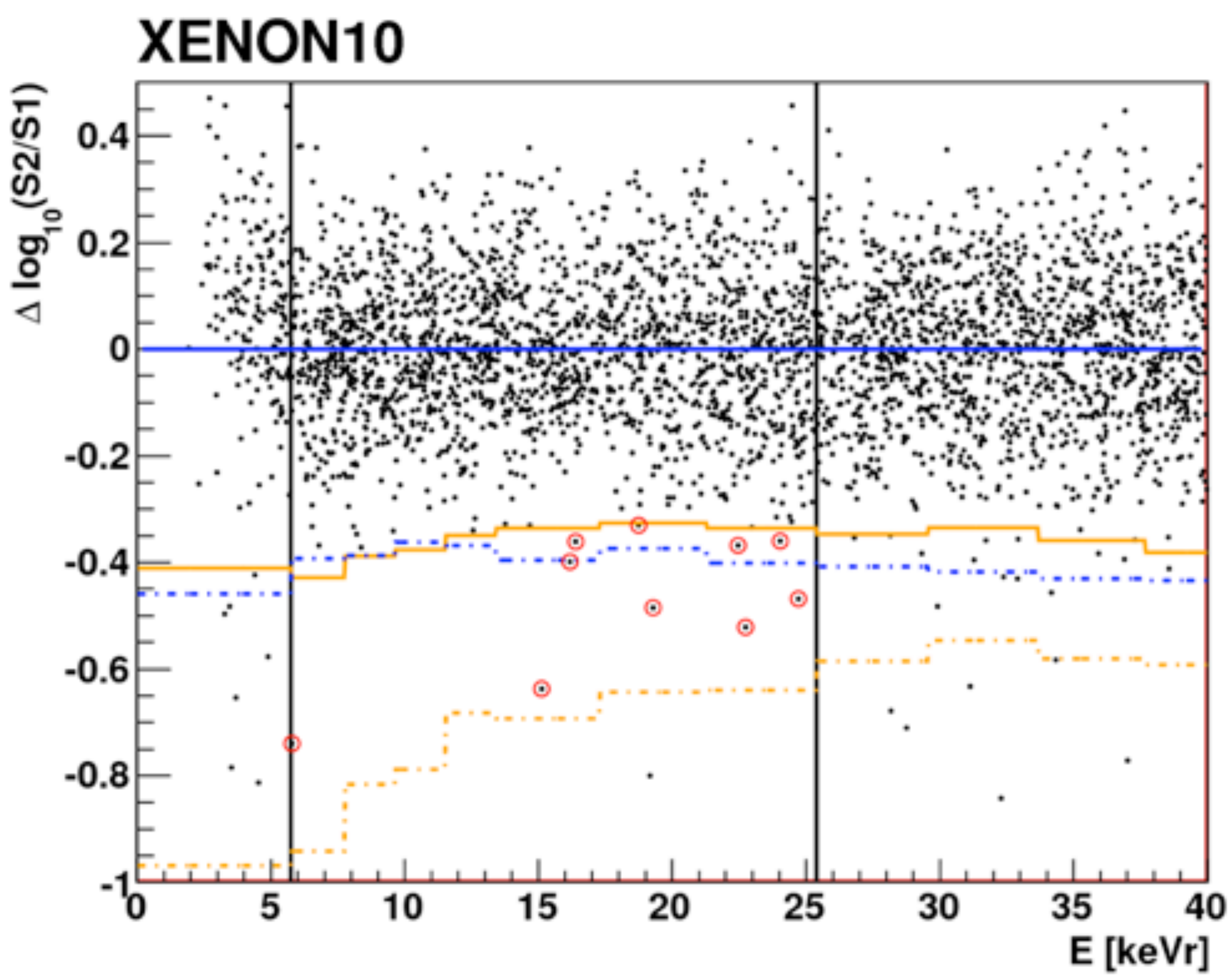
XENON100: the power of LXe self-shielding!

and apply S2/S1 Discrimination..

XENON10 *PRL 100, 021303 (2008)*

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

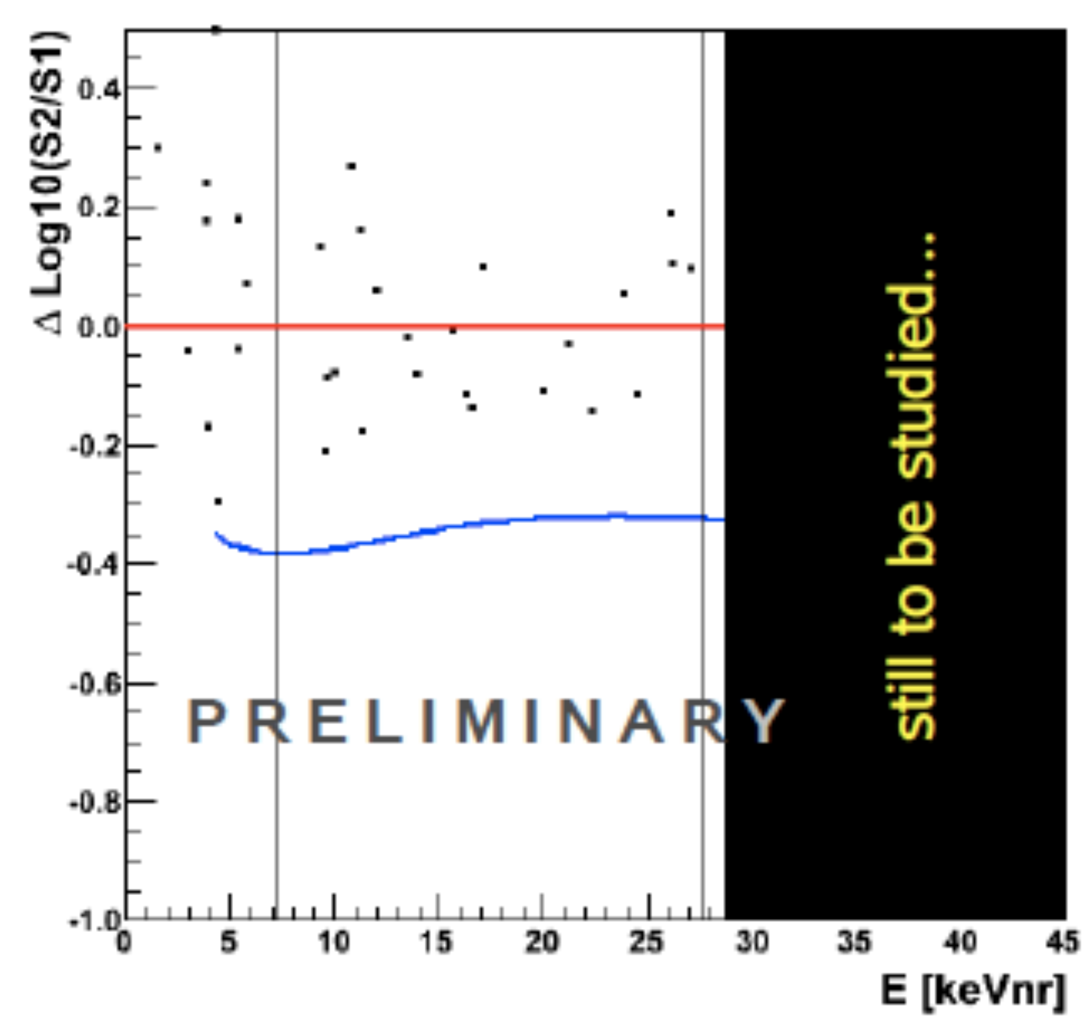
(data collected between Oct.2006 and Feb.2007)



XENON100 *PRL in preparation*

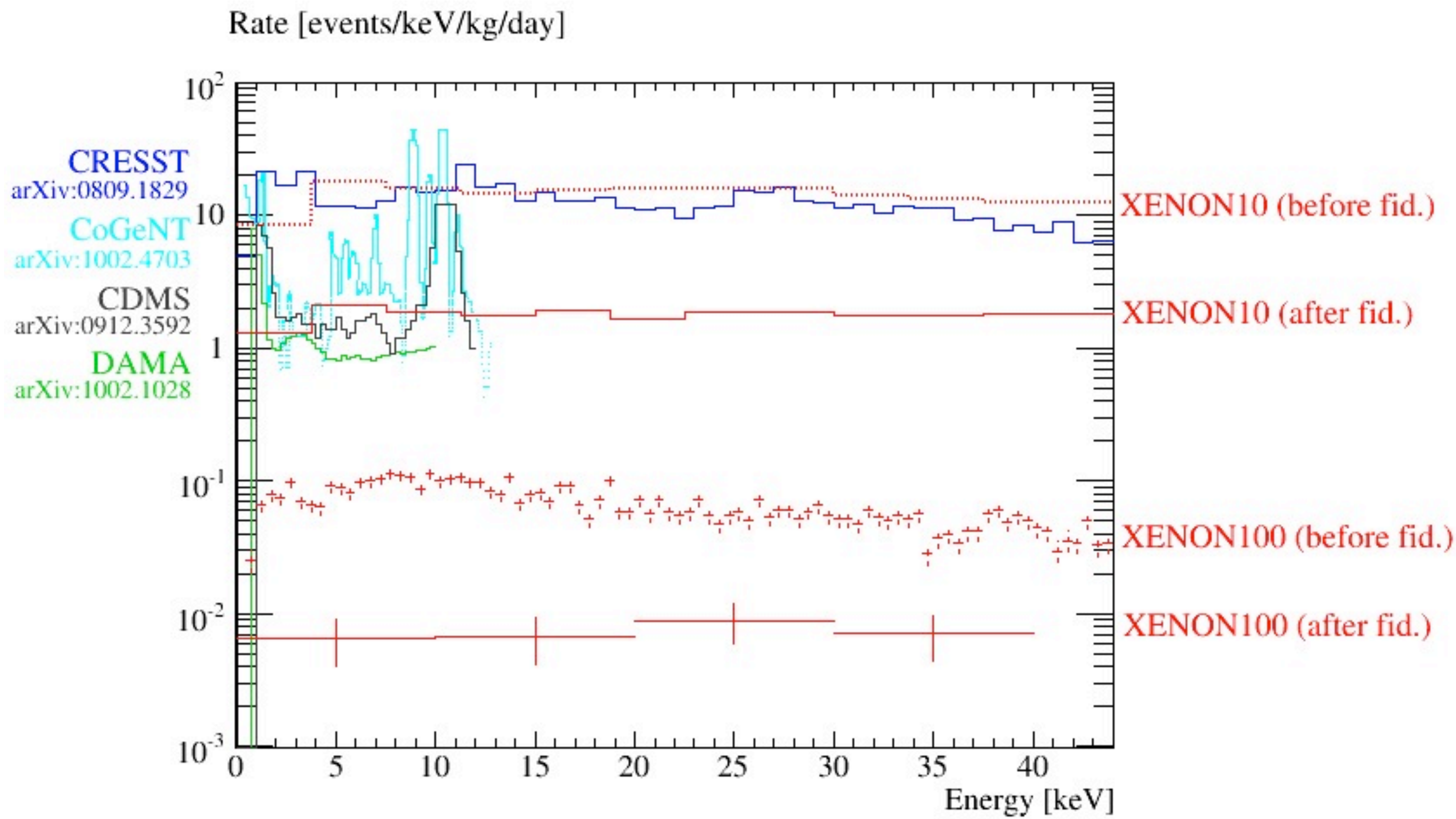
190.4 kg-days Exposure= 11.2 live days x 40 kg x 0.85 (ε) x 0.50 (50% NR)

(data collected between Oct.and Nov.2009)

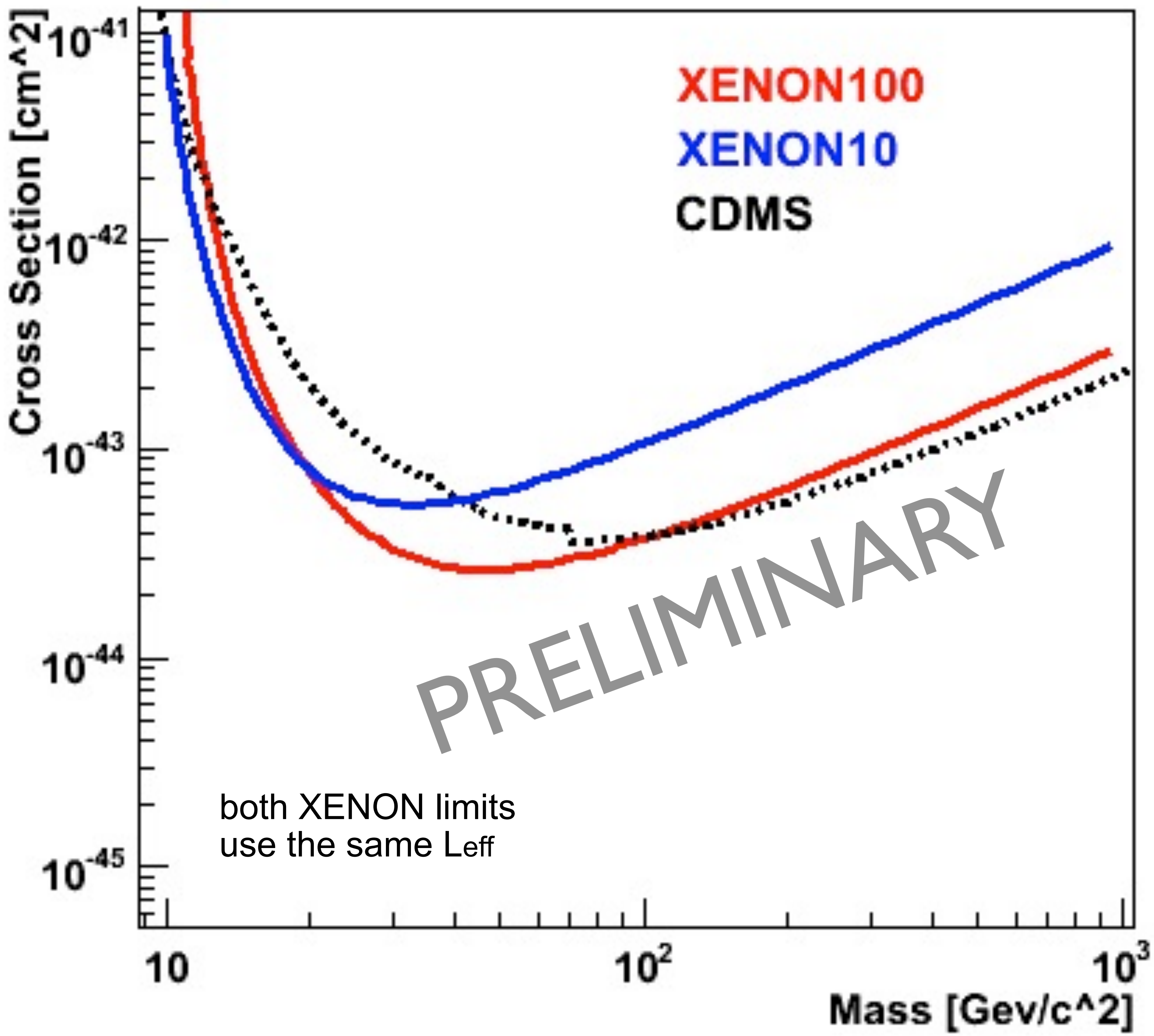


XENON100: 40 kg "Background free"

XENON100: the lowest background of all DM detectors



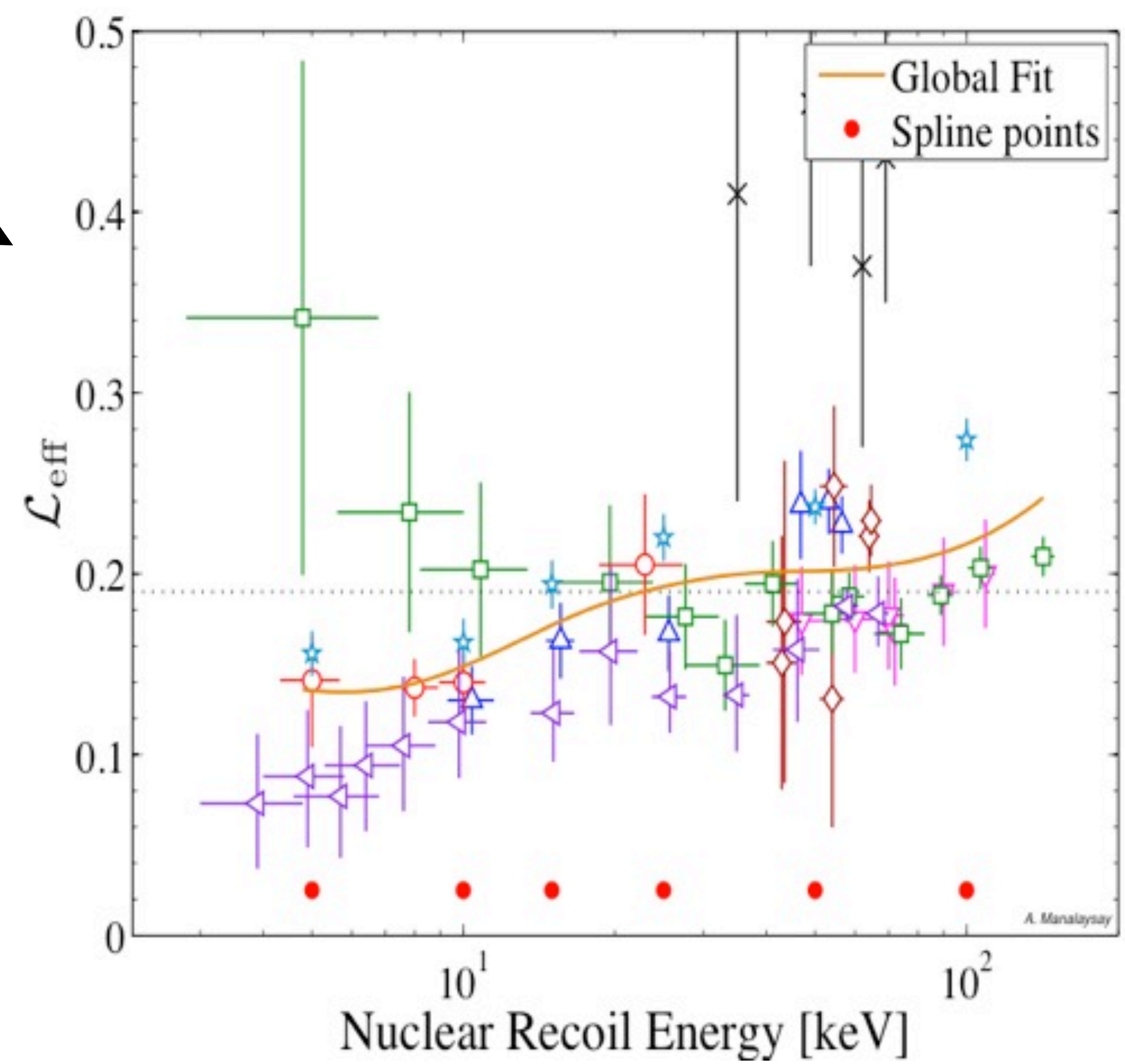
XENON100: First Spin Independent Limit



Nuclear Recoil Energy Scale from Leff in LXe

Global fit of all L_{eff} data

Arneodo 2000
Bernabei 2001
Akimov 2002
Aprile 2005
Aprile 2009
Sorensen 2009
Manzur 2010



Energy of nuclear recoil (NR)

measured signal in p.e.

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

$$E_{nr} = \frac{S1}{L_y L_{eff}} \times \frac{S_e}{S_r}$$

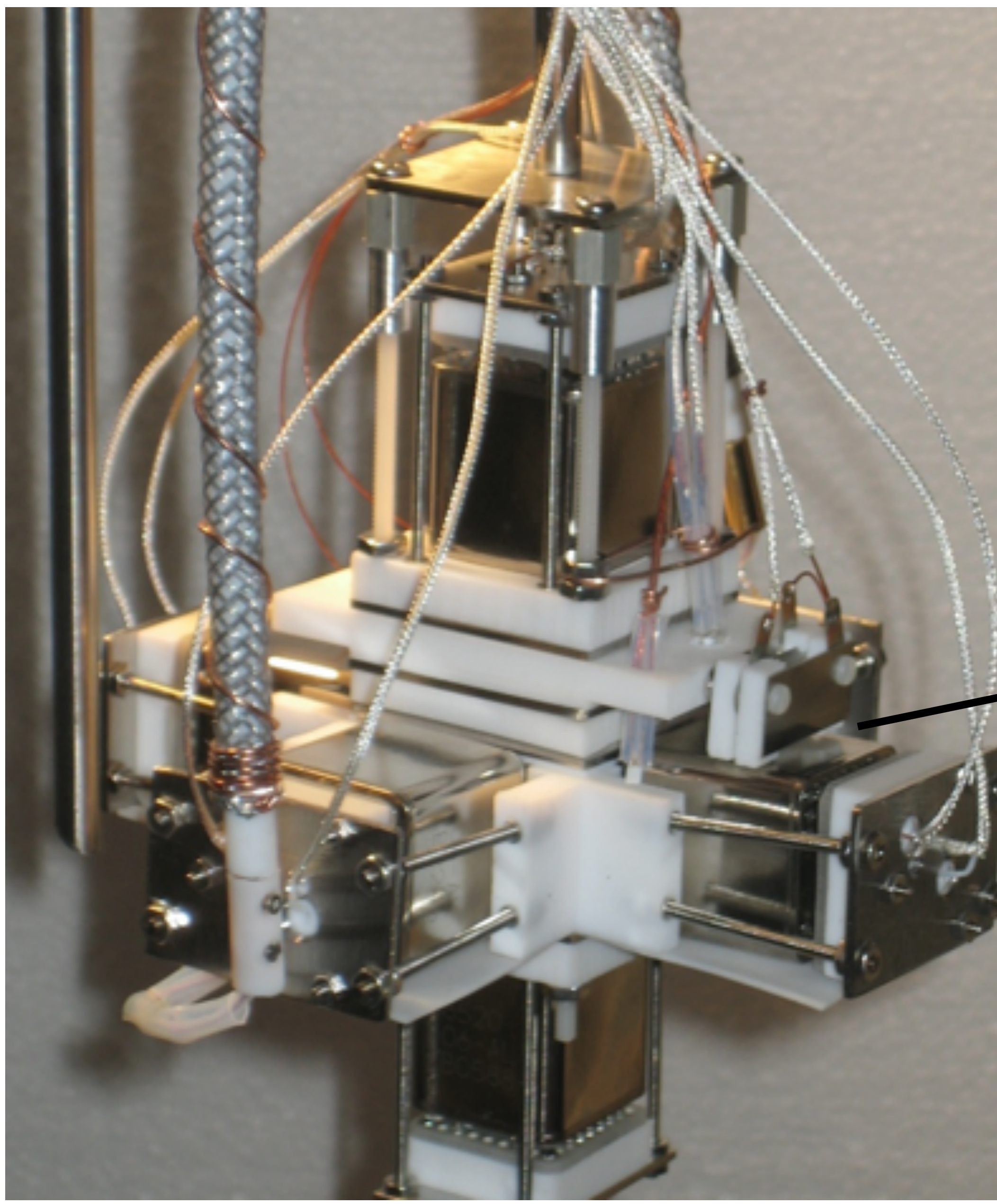
light yield for 122 keV in p.e./keV

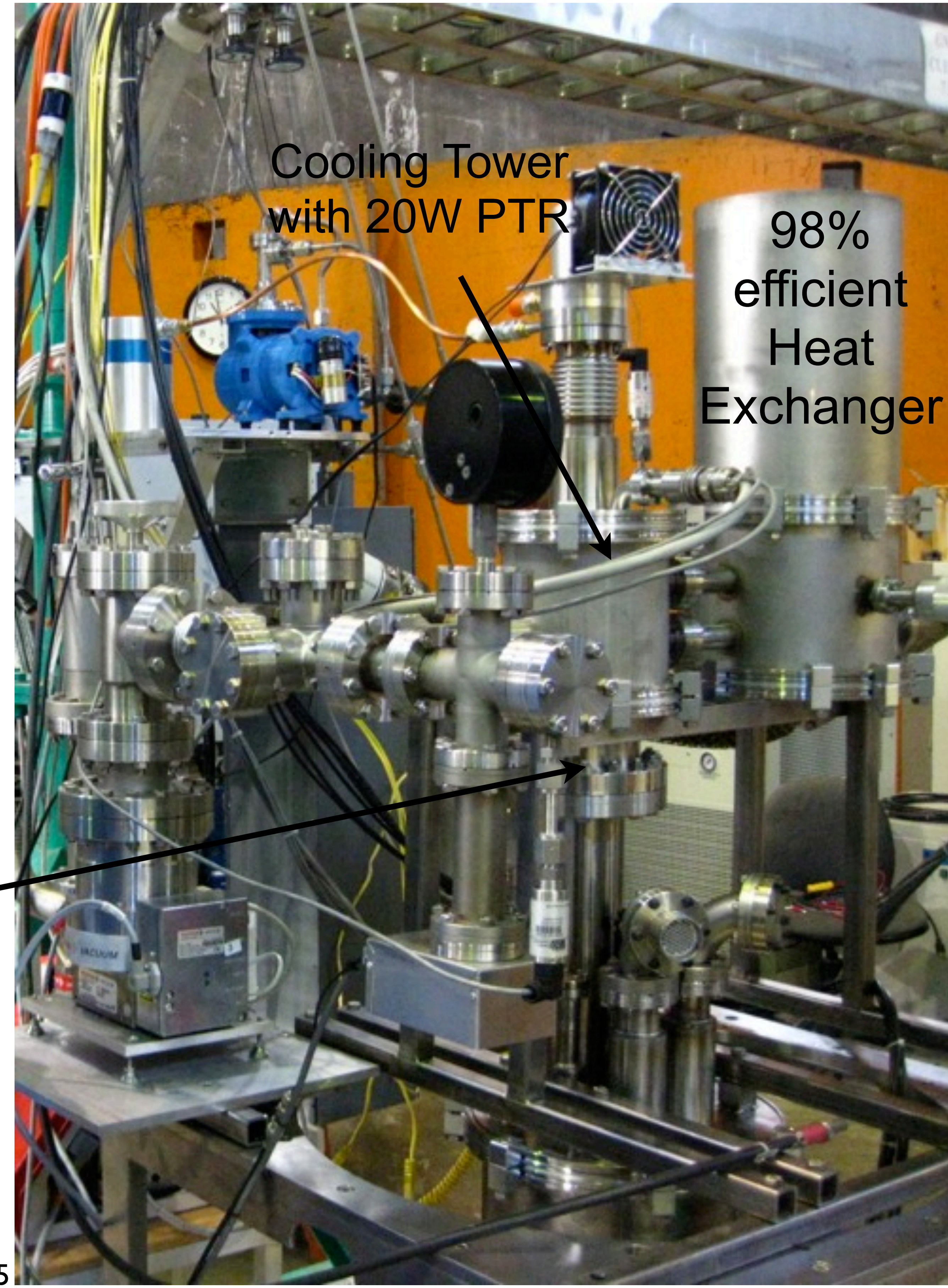
scintillation efficiency of NR relative to 122 keV γ at zero field

quenching of scintillation yield for NR due to drift field

New Measurements of Leff in Liquid Xenon

New experiment ongoing at the Columbia Nevis Lab, with a 2-phase miniTPC optimized for high light collection. Measure ionization and scintillation yield of very low energy ER and NR in LXe, as a function of field and energy.
DD- generator for neutrons
Additional set-up also at UZurich





The case for XENON1T

- XENON100 is working very well. It is the largest mass and lowest background DM experiment in operation underground and with a large exposure ready to be unveiled.
- Within 2010 XENON100 will a) either see a signal or b) will significantly constraint WIMP models for both SI and SD cross-section.
- Larger scale experiments with even lower background are needed in both cases.
- Critical technologies developed within the XENON10/100 programs can be directly applied to the next scale. Risks and the costs are fully understood.
- A strong international collaboration, with valuable expertise and resources, is in place.
- A technical design proposal for a XENON1T is in preparation. With 50 - 50 share of resources between US and other groups, we plan to realize the experiment before 2015.

XENON1T Funding Sources

DOE

NSF

FNSNF
SWISS NATIONAL SCIENCE FOUNDATION

FCT
Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

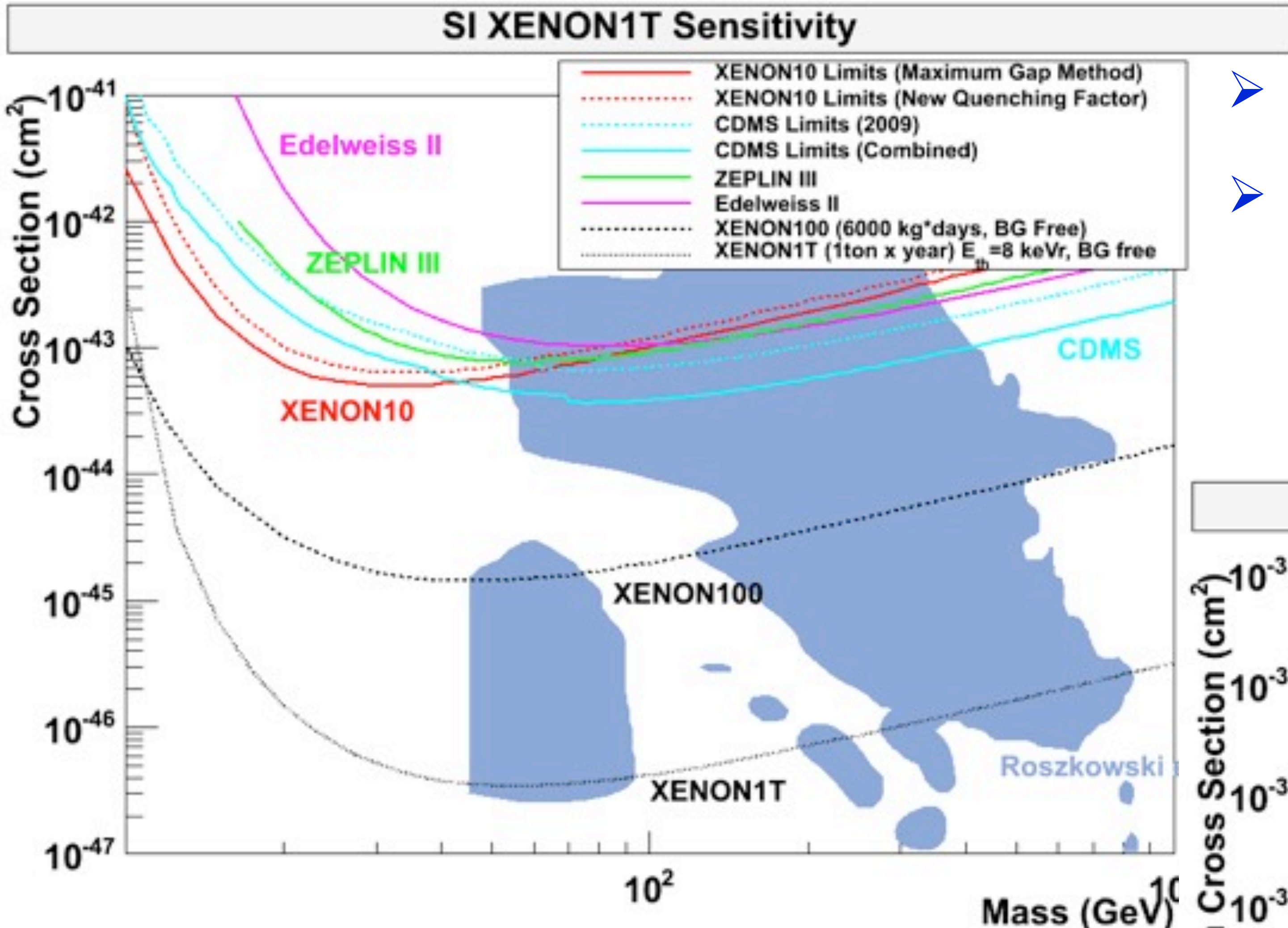
INFN
Istituto Nazionale
di Fisica Nucleare

cnrs
IN2P3
Les deux infinis

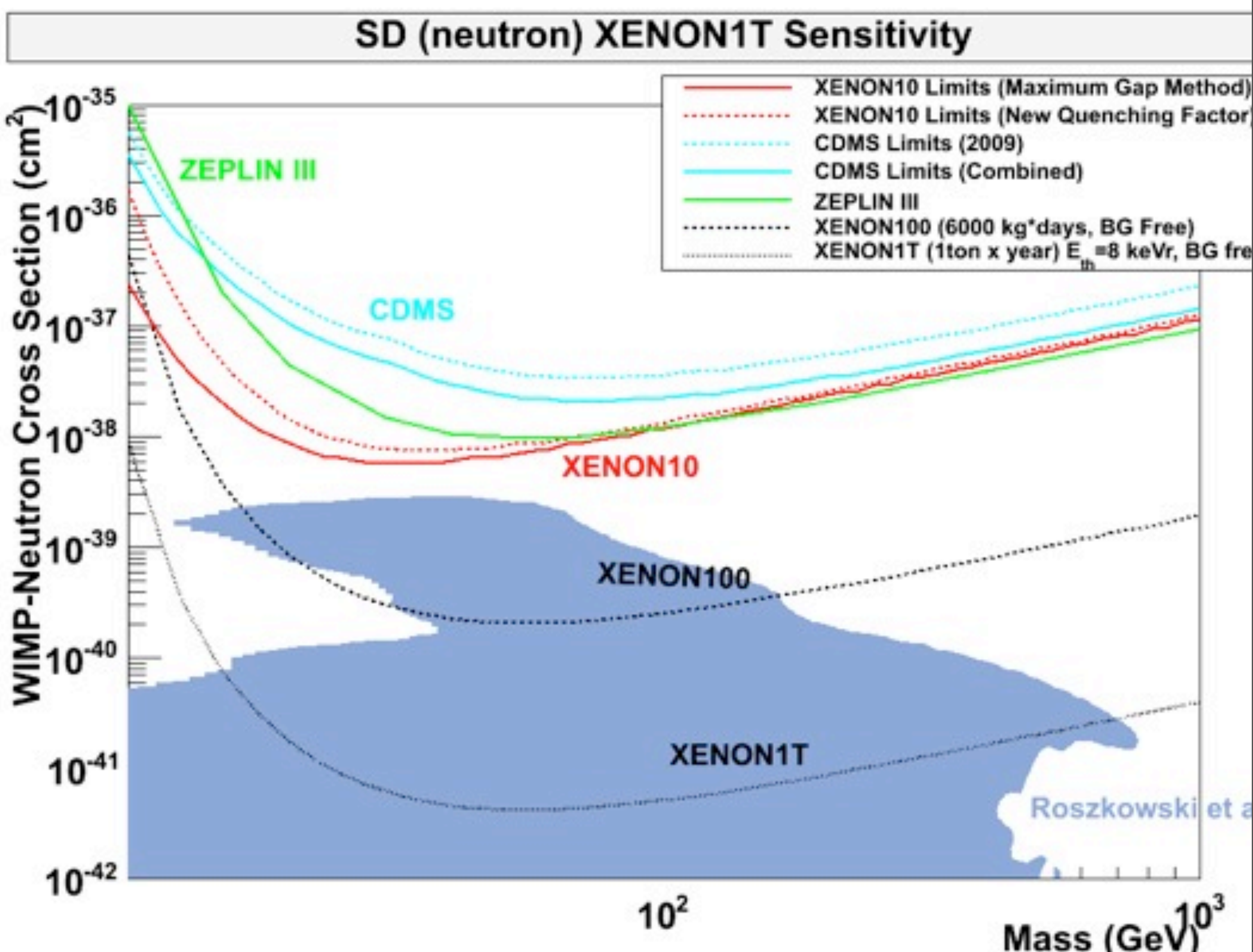
DFG Deutsche Forschungsgemeinschaft

NIKHEF

XENON1T: A tremendous scientific reach

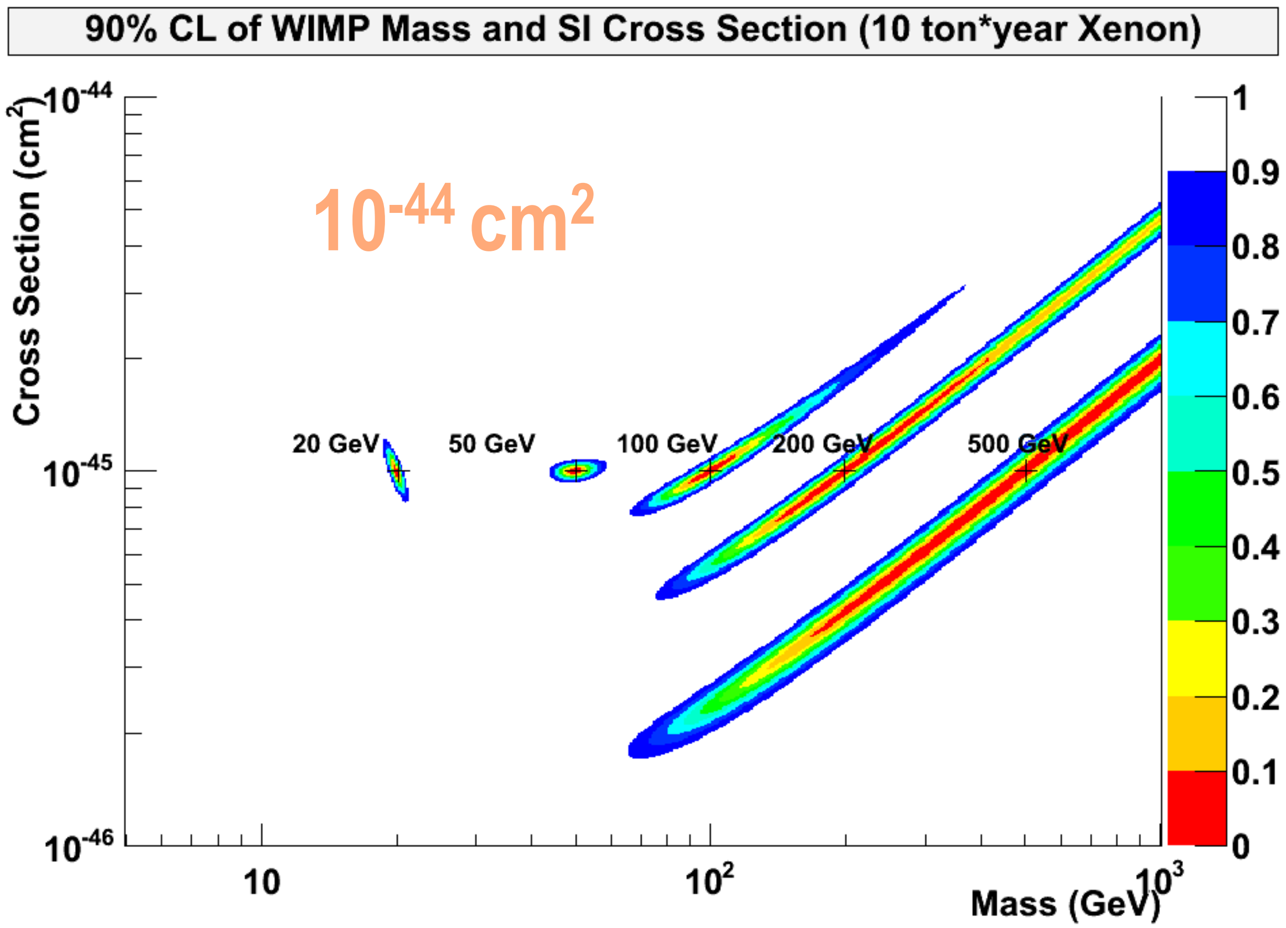


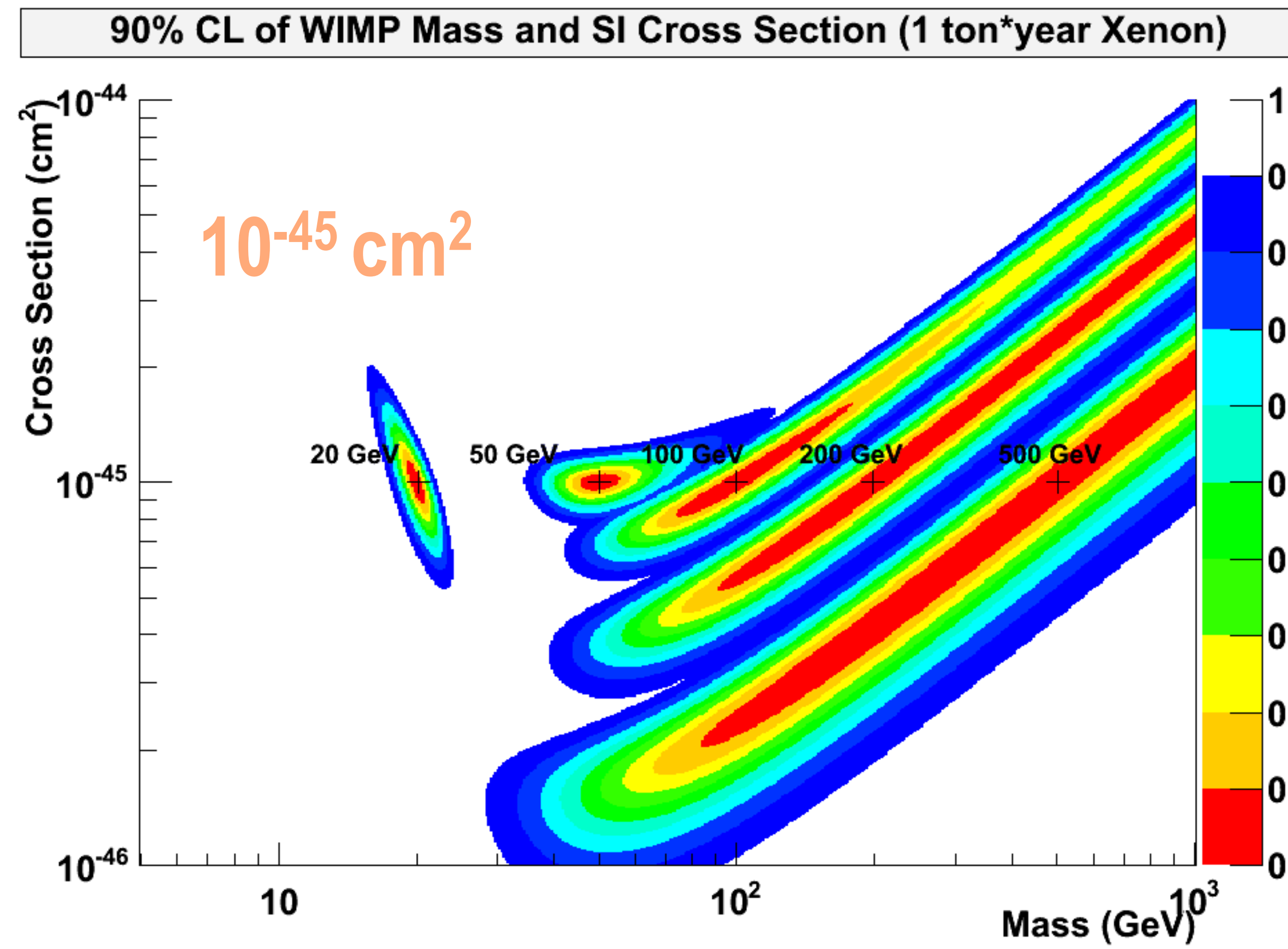
- probe simultaneously SI and SD channels
- explore the entire MSSM parameter space



XENON1T: constraints on WIMP mass

Number of events		Mass (GeV)				
		20	50	100	200	500
Cross Section	10^{-44} cm^2	230	710	560	330	140
	10^{-45} cm^2	23	71	56	33	14





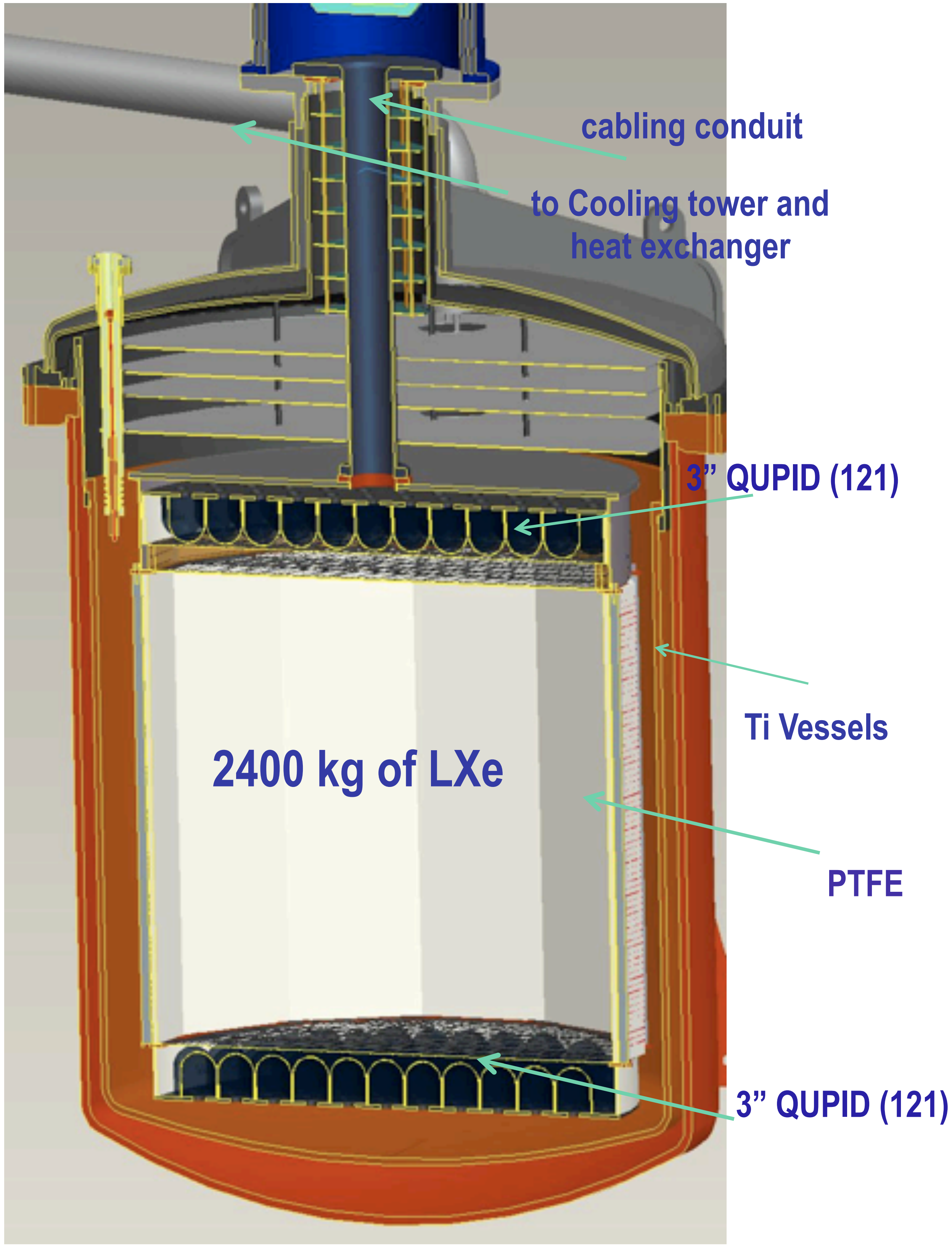
XENON1T: Detector Overview

- Baseline design similar to XENON100 with improvements in different areas

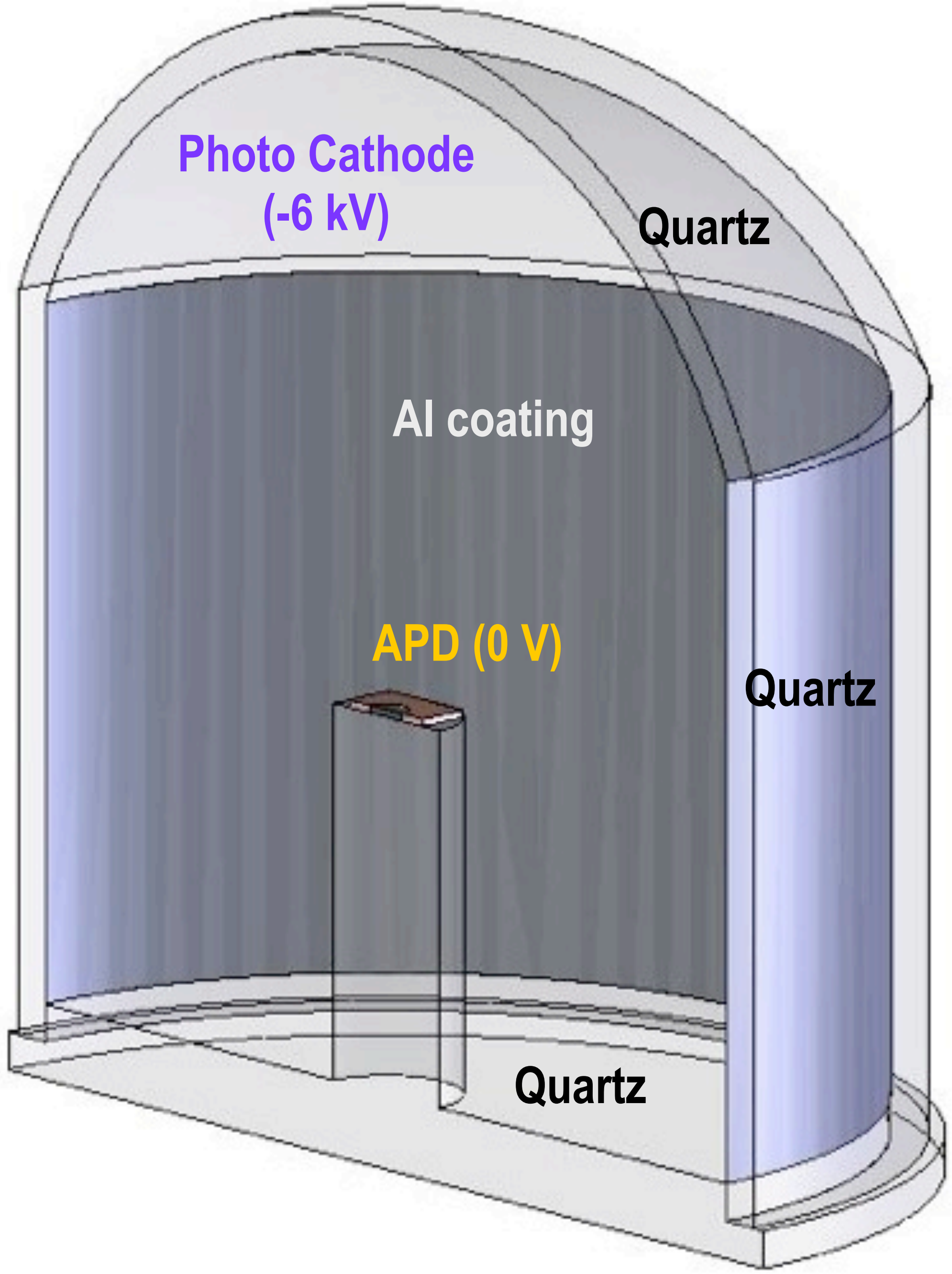
- lower radioactivity cryostat (Ti and Cu)
- lower radioactivity PMTs (QUPIDs)
- high efficiency heat exchanger: >98% achieved with Columbia setup
- filling & recovery in liquid phase

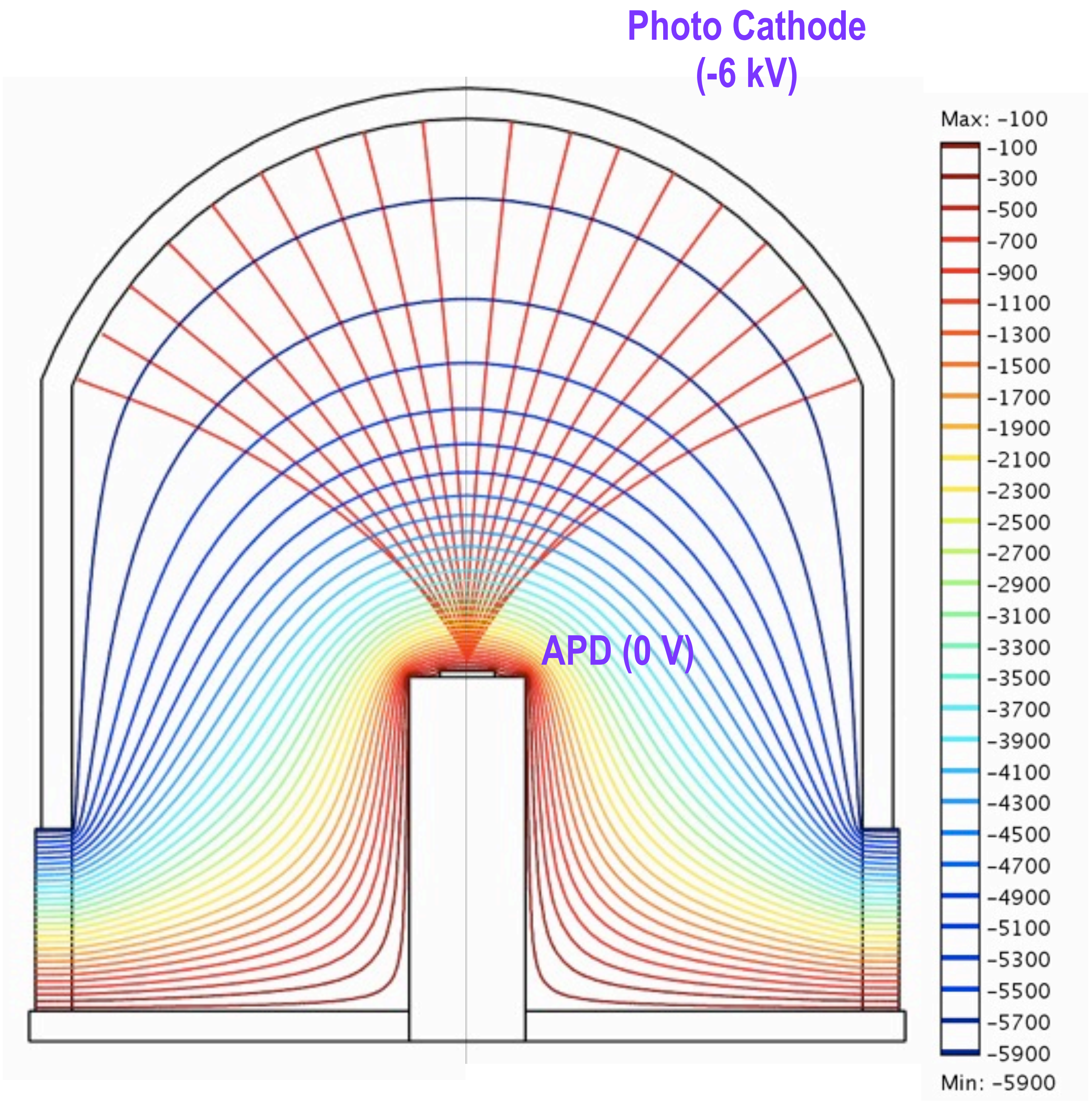
- Design has been validated with detailed MC studies of internal/external background sources

- Capital cost ~ 8M$ shared equally between US and foreign groups



QUPID (QUartz Photon Intensifying Detector)



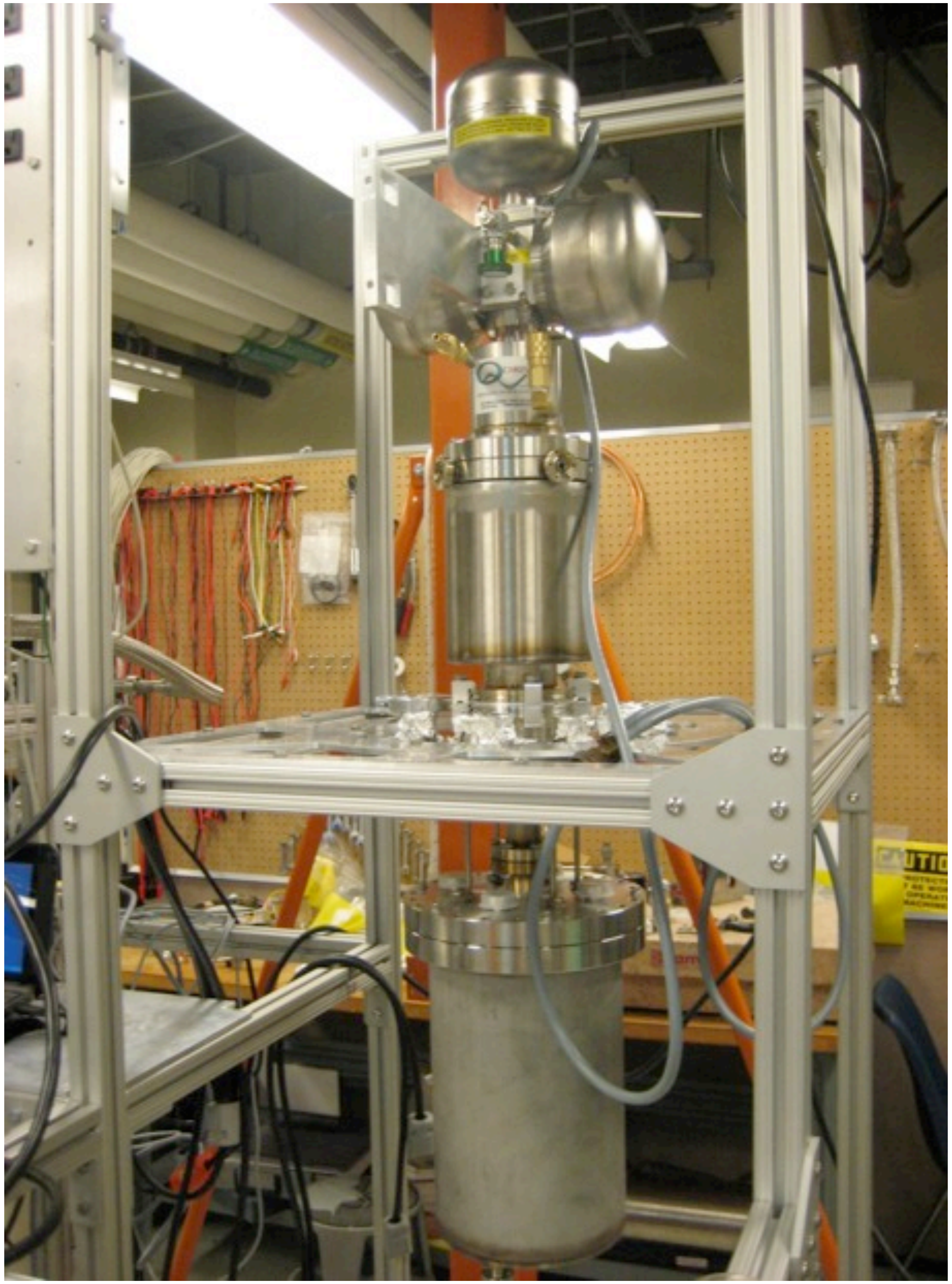


QUPID (QUartz Photon Intensifying Detector)

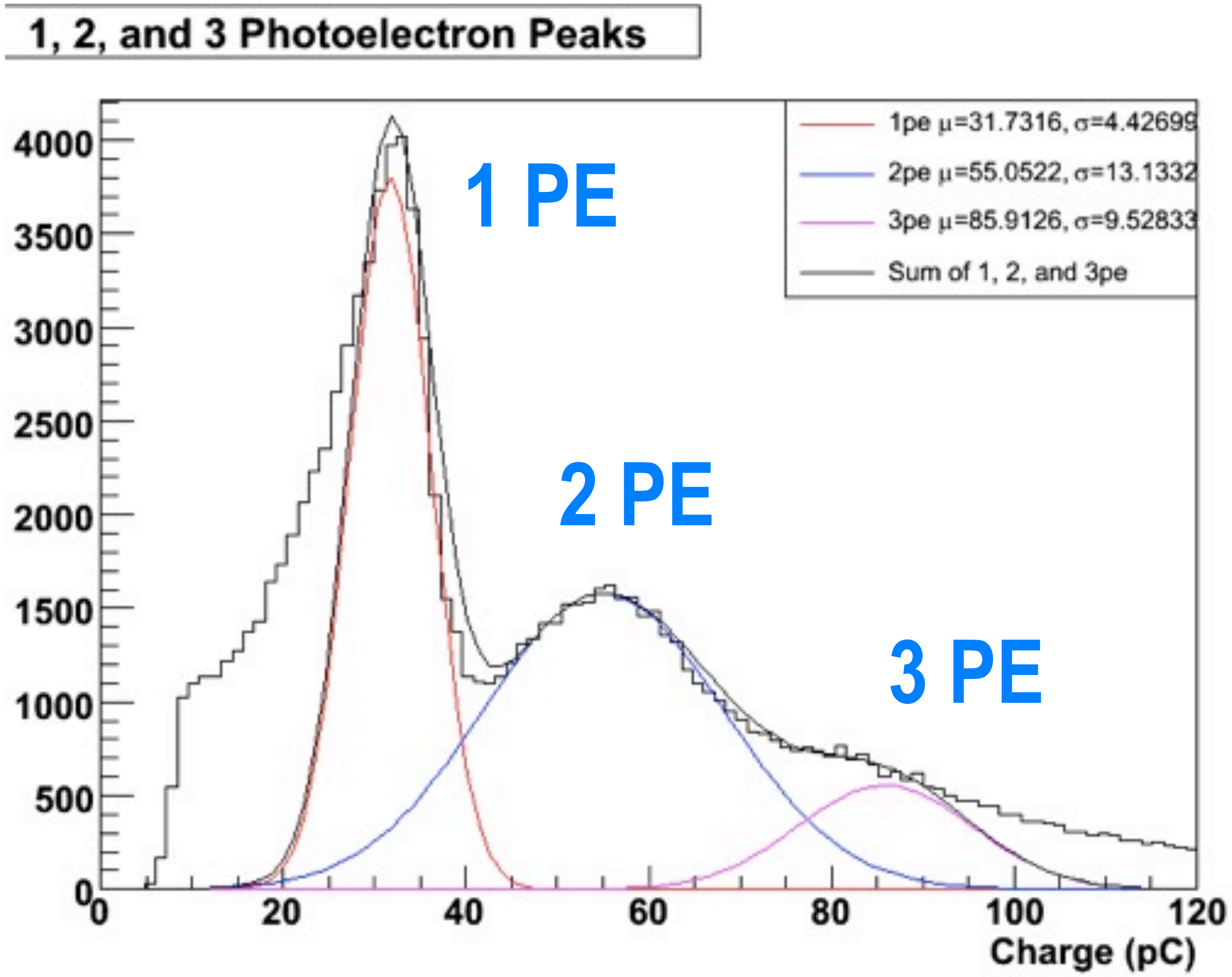
QUPID Characteristics

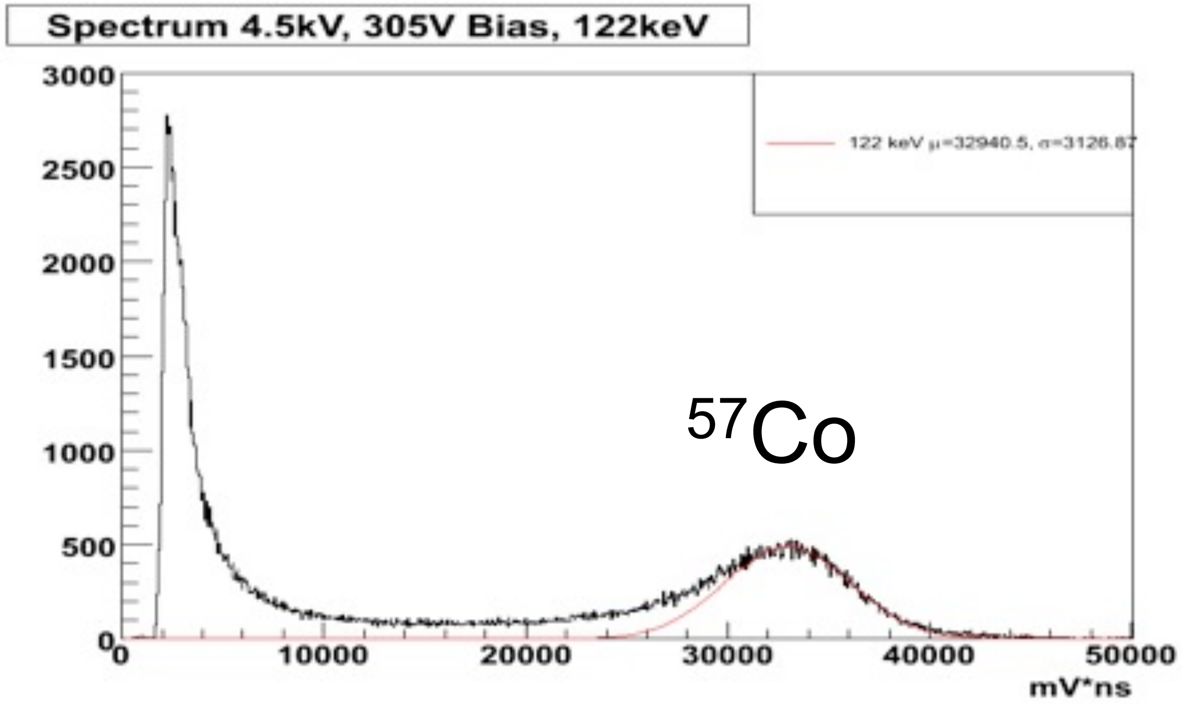
- **Extremely low radioactivity:** < 1 mBq
  - < 0.1 neutron / year
  - << 10 times lower than conventional low radioactive PMTs.
- **Large diameter:** 3 inch
  - 6 inch is also under investigation.
- **Special Photocathode:** Bialkali LT
  - > 30 % QE at 170 – 450 nm
  - Low resistivity even at Liquid Ar temperature (- 185 ^{o}C)
- **True photon counting.**
  - 1, 2, 3… photoelectron peaks clearly visible.
  - 100% collection efficiency.
- **Simple HV supply.**
  - Common HV (-6 kV) for all QUPIDs
  - Resistor chain not necessary
- **First successful operation in Liquid Xenon at UCLA**

First Liquid Xenon Light Detected by QUPID



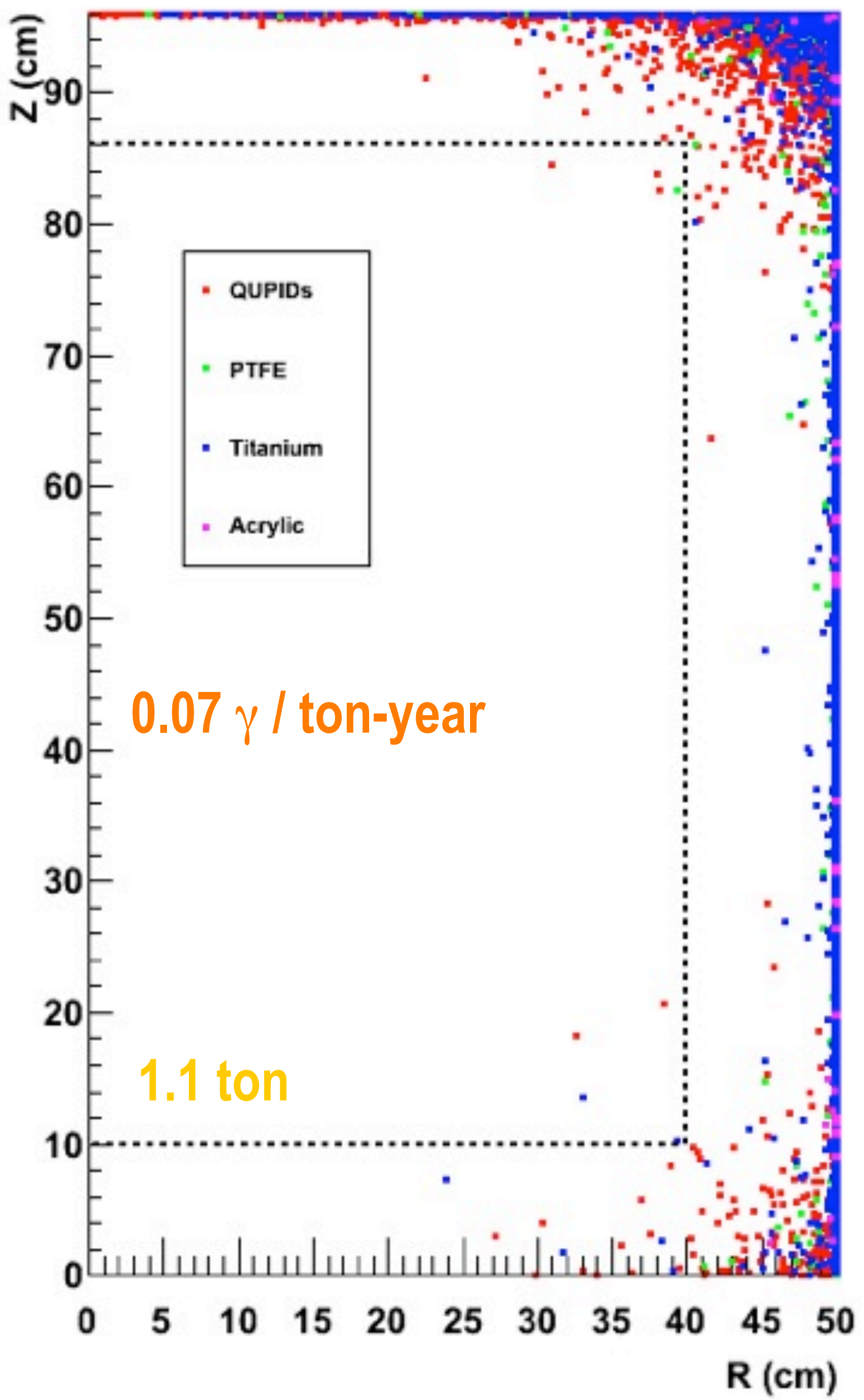
QUPID Test in Liquid Xenon



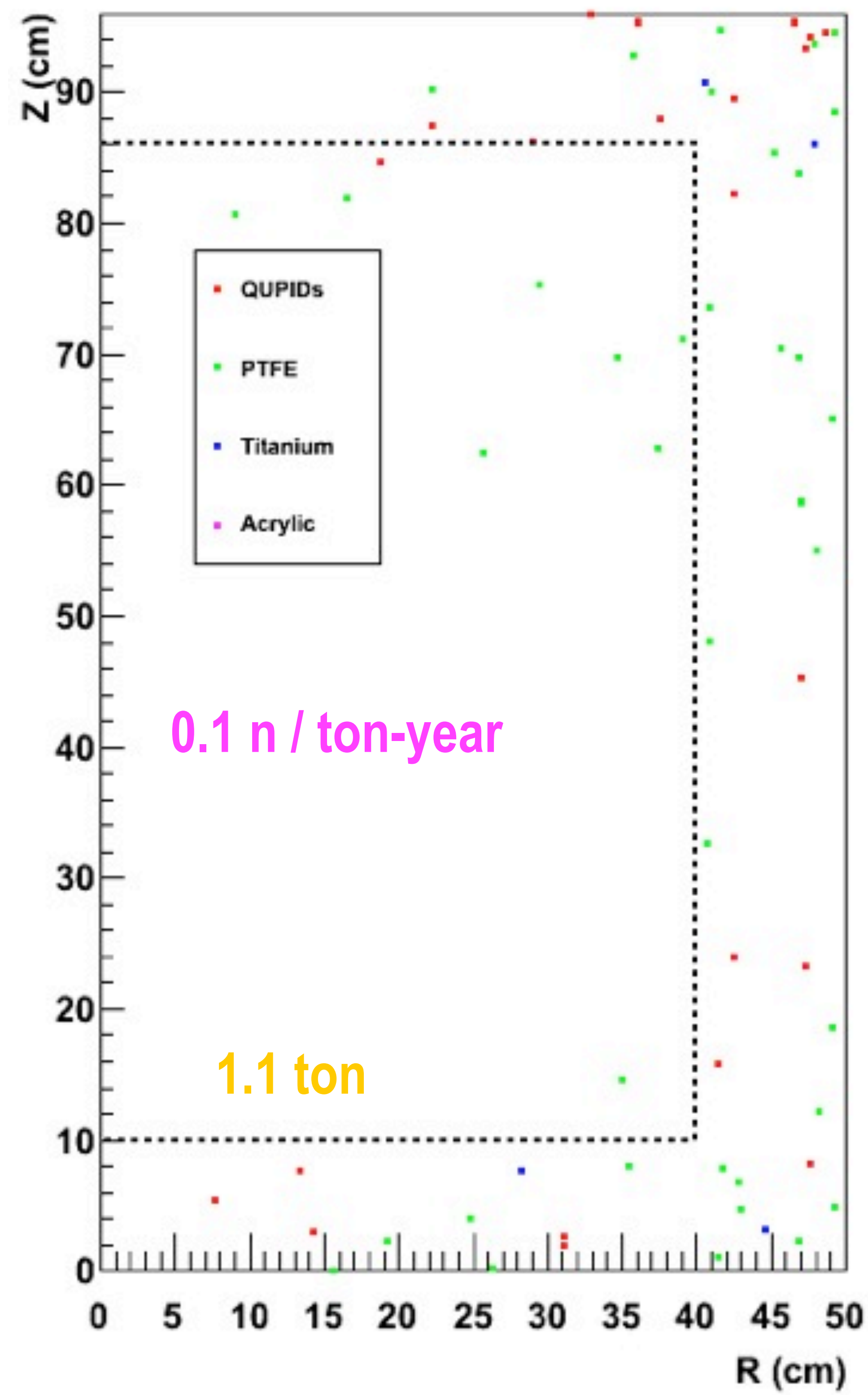


Expected Backgrounds from Detector Materials

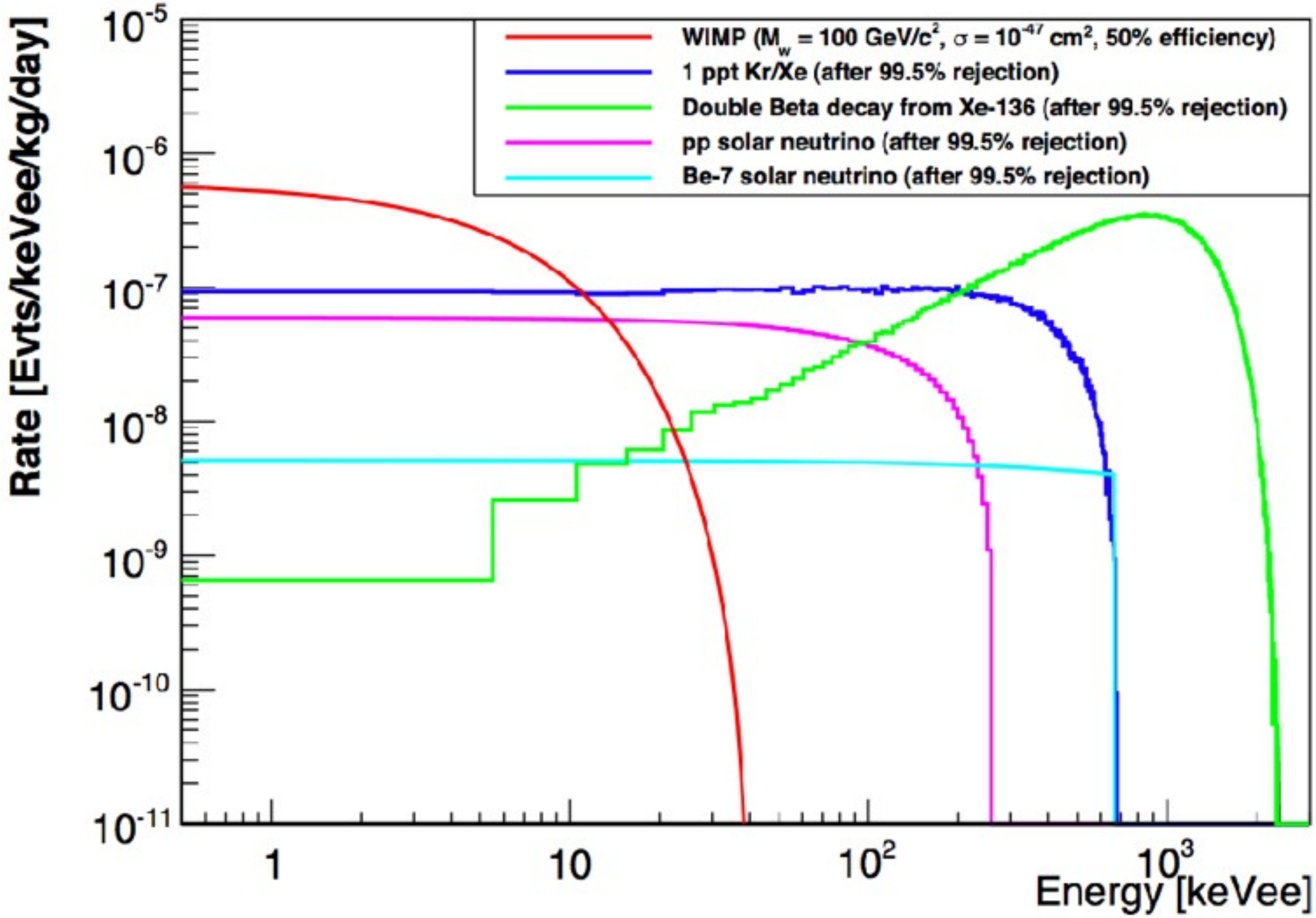
Gamma Rays



Neutrons



WIMP Signal and Gamma Background

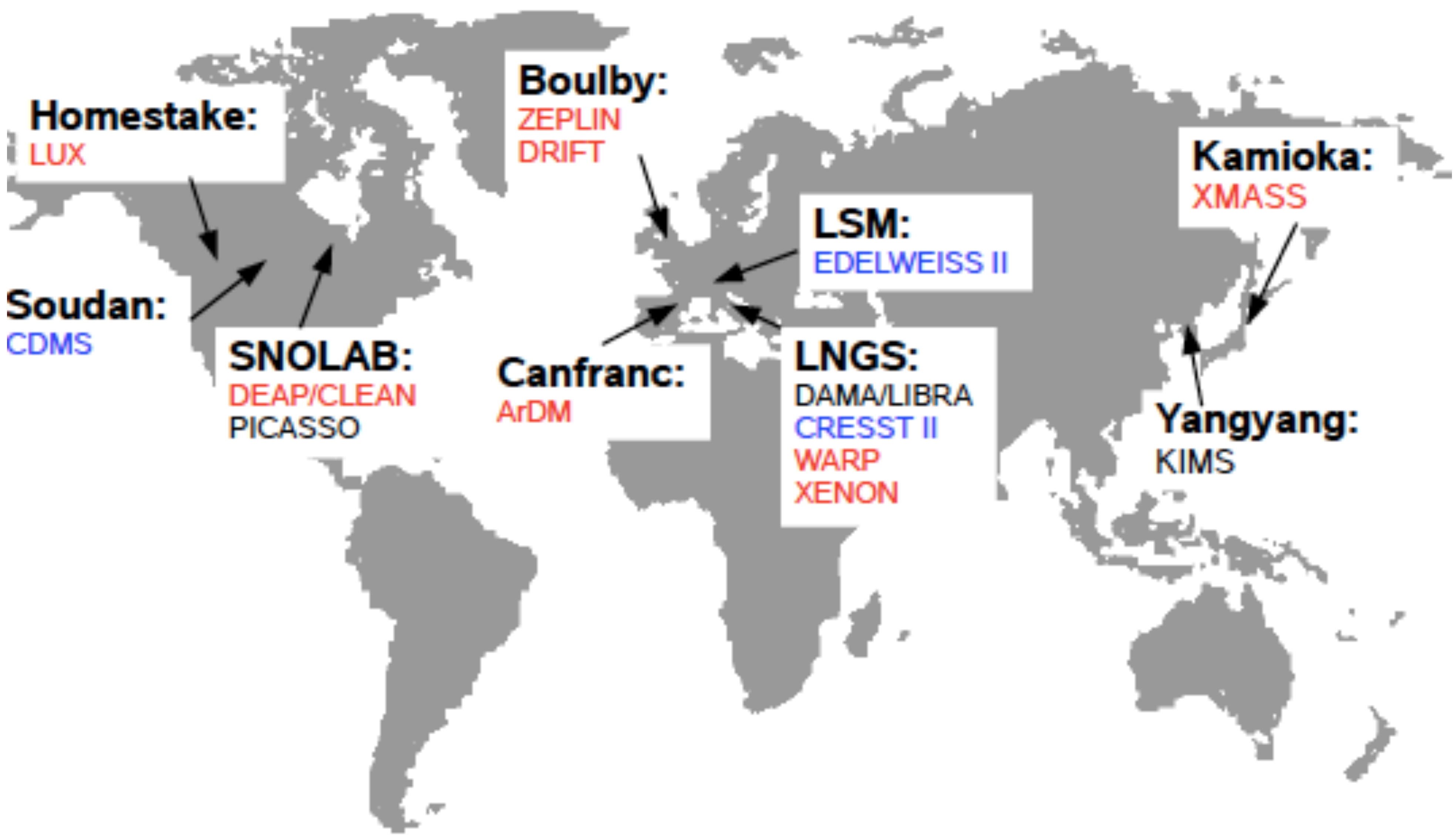


- pp solar neutrino rate: ~ 0.5 ev/ton-year
- Kr85 rate: < 1 ev/ton-year if Kr/Xe ~ 1ppt

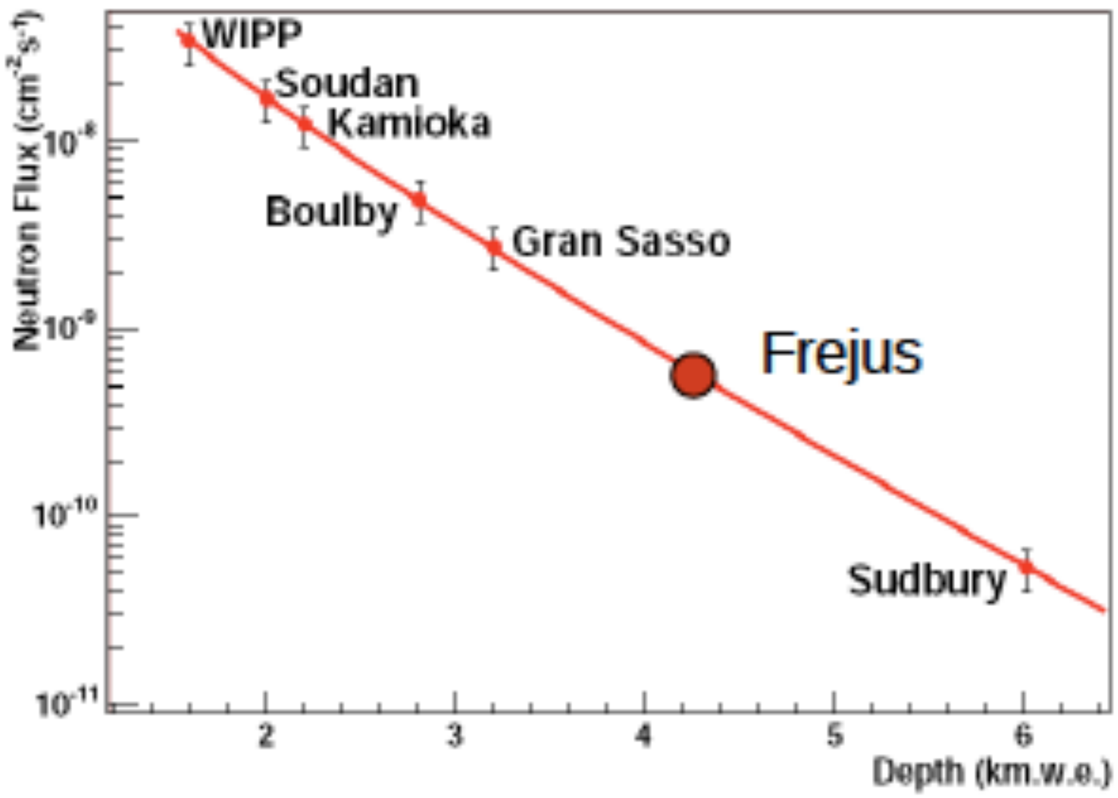
Location for XENON1T

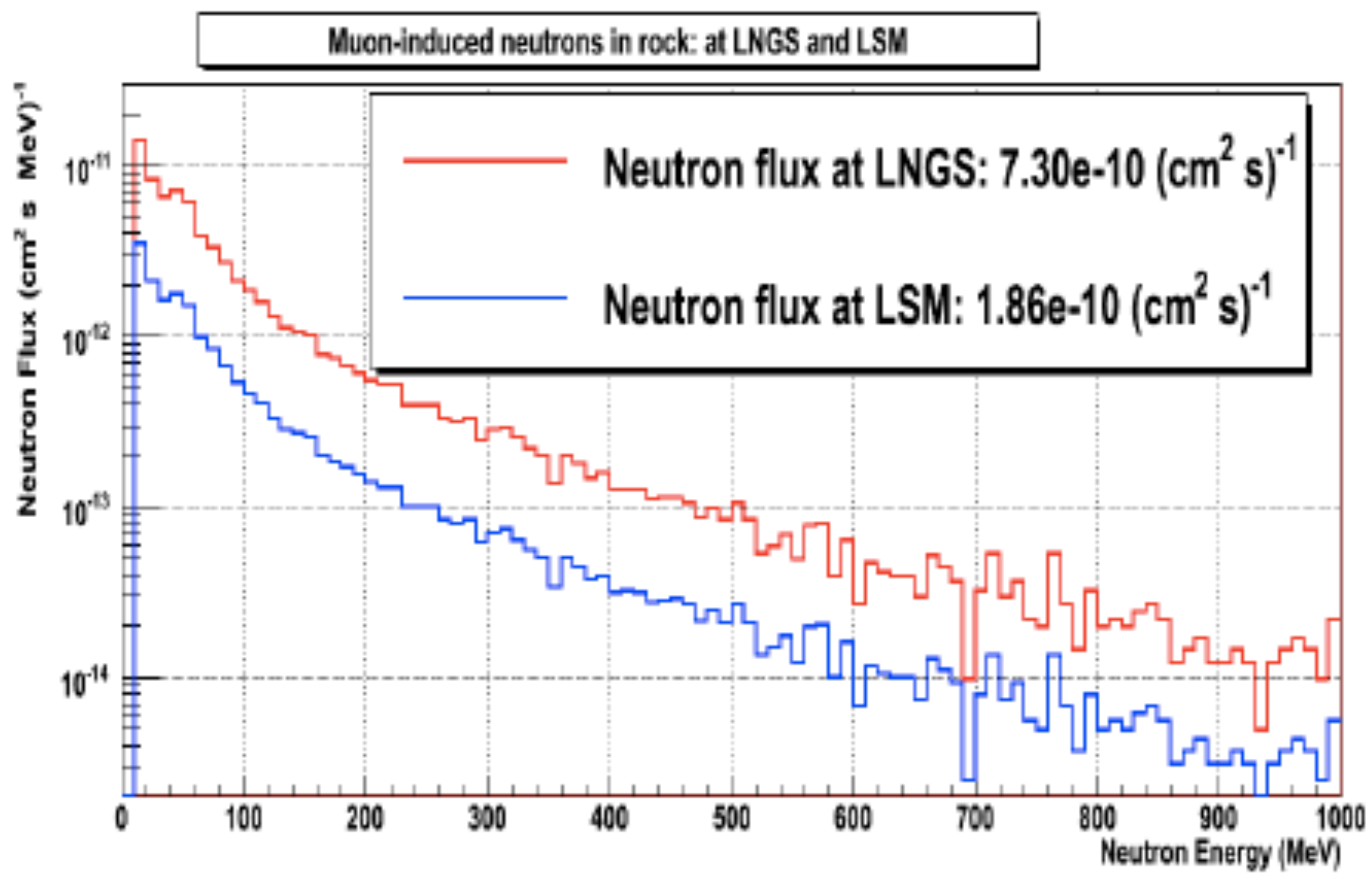
Collaboration is studying two options for site and shield

- LNGS with a water tank acting as shield and muon veto
- LSM with a Polyethylene-Lead shield and plastic scintillators for muon veto

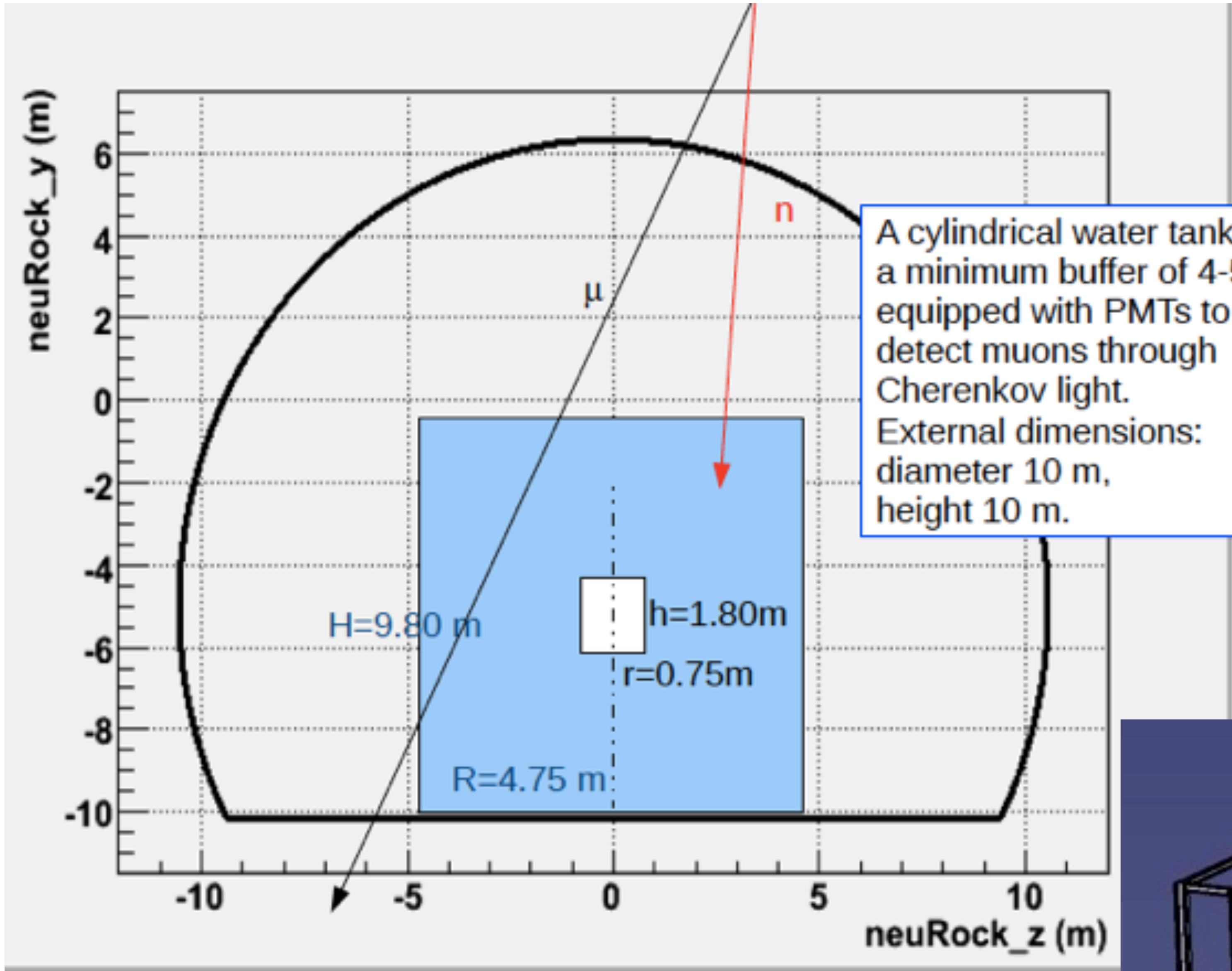


Advantage of depth for Muon-induced Neutrons

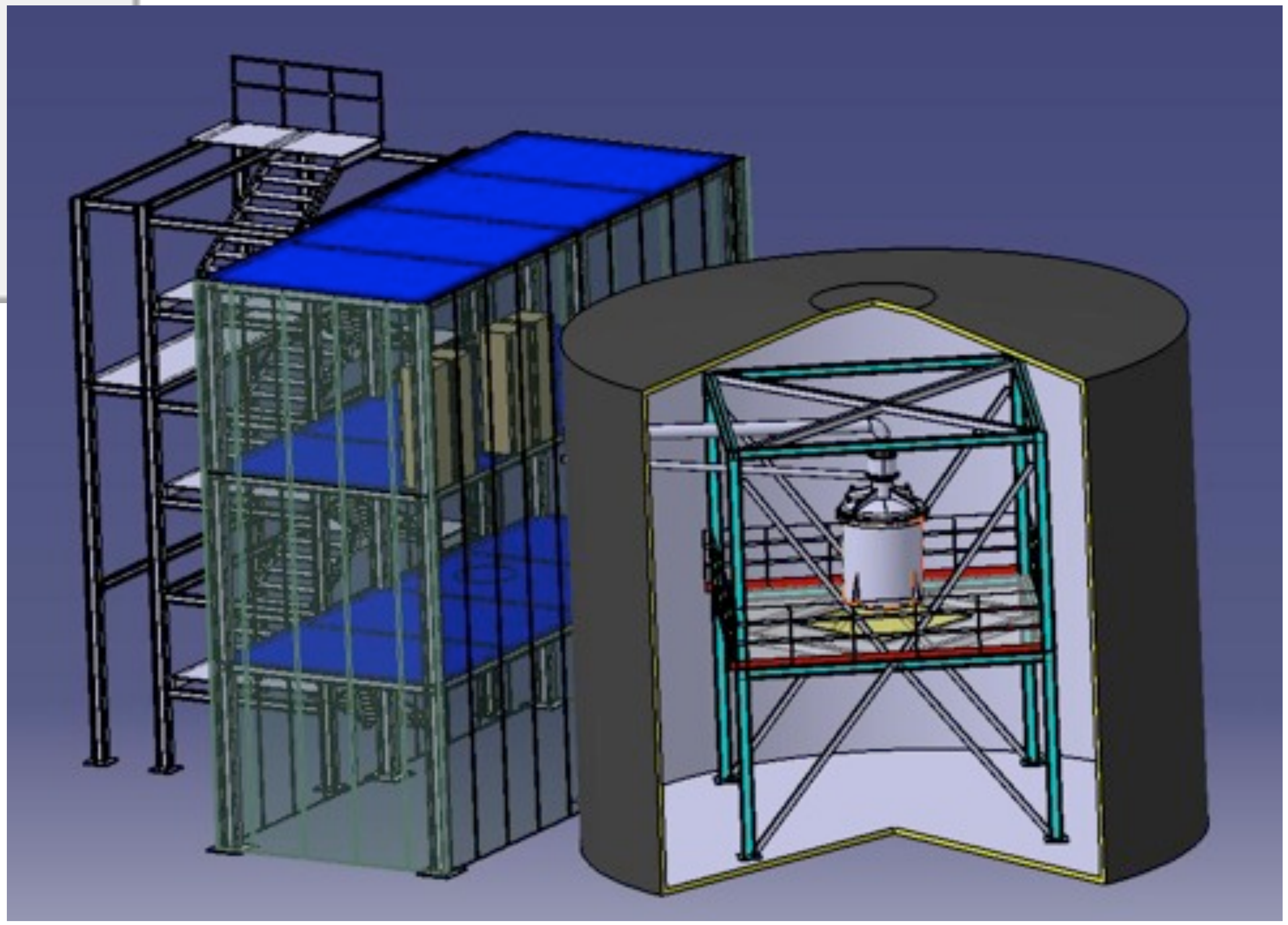




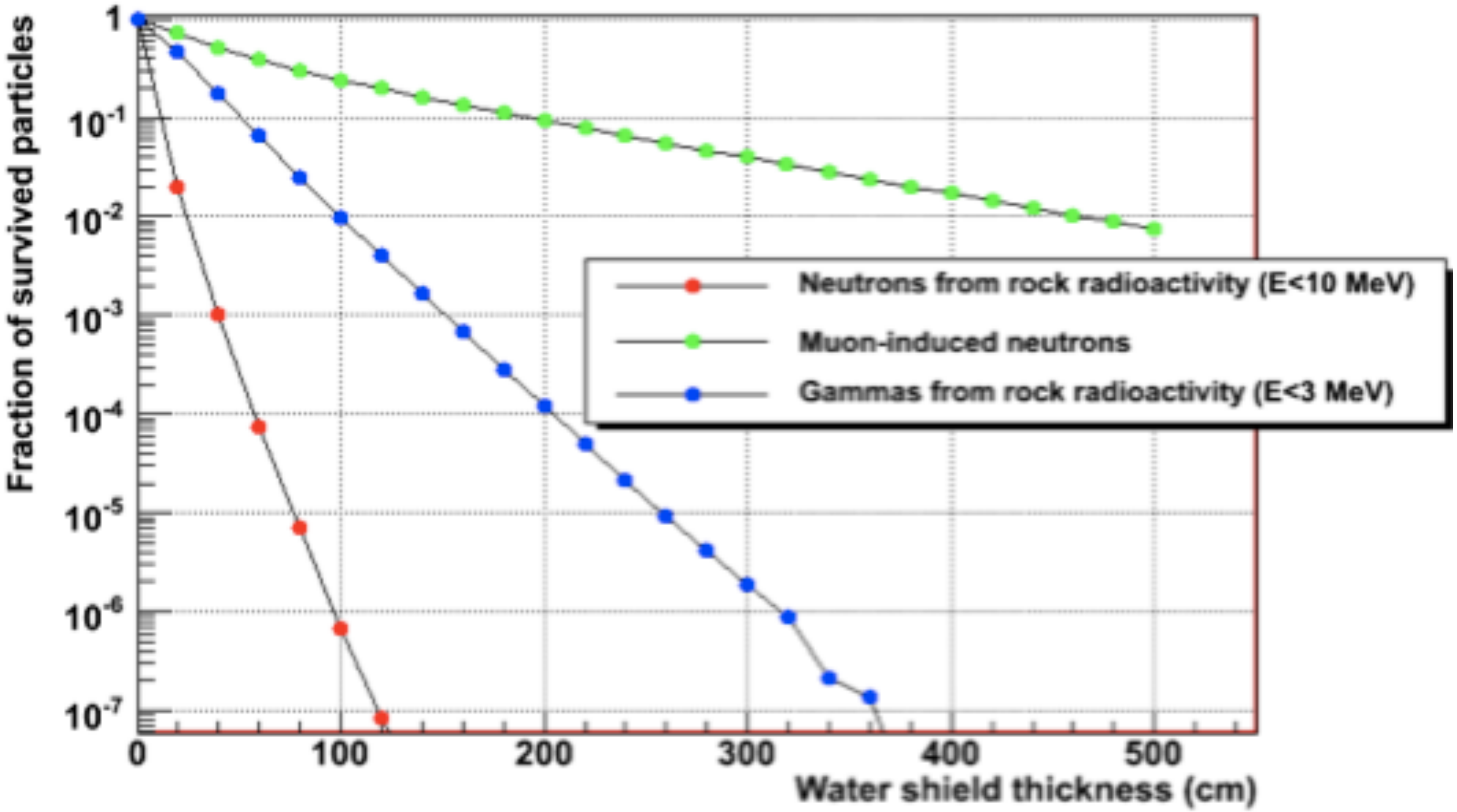
Water Shield Study for LNGS



A cylindrical water tank with a minimum buffer of 4-5 m, equipped with PMTs to detect muons through Cherenkov light.
External dimensions:
diameter 10 m,
height 10 m.



Neutrons and Gamma from Rock Radioactivity



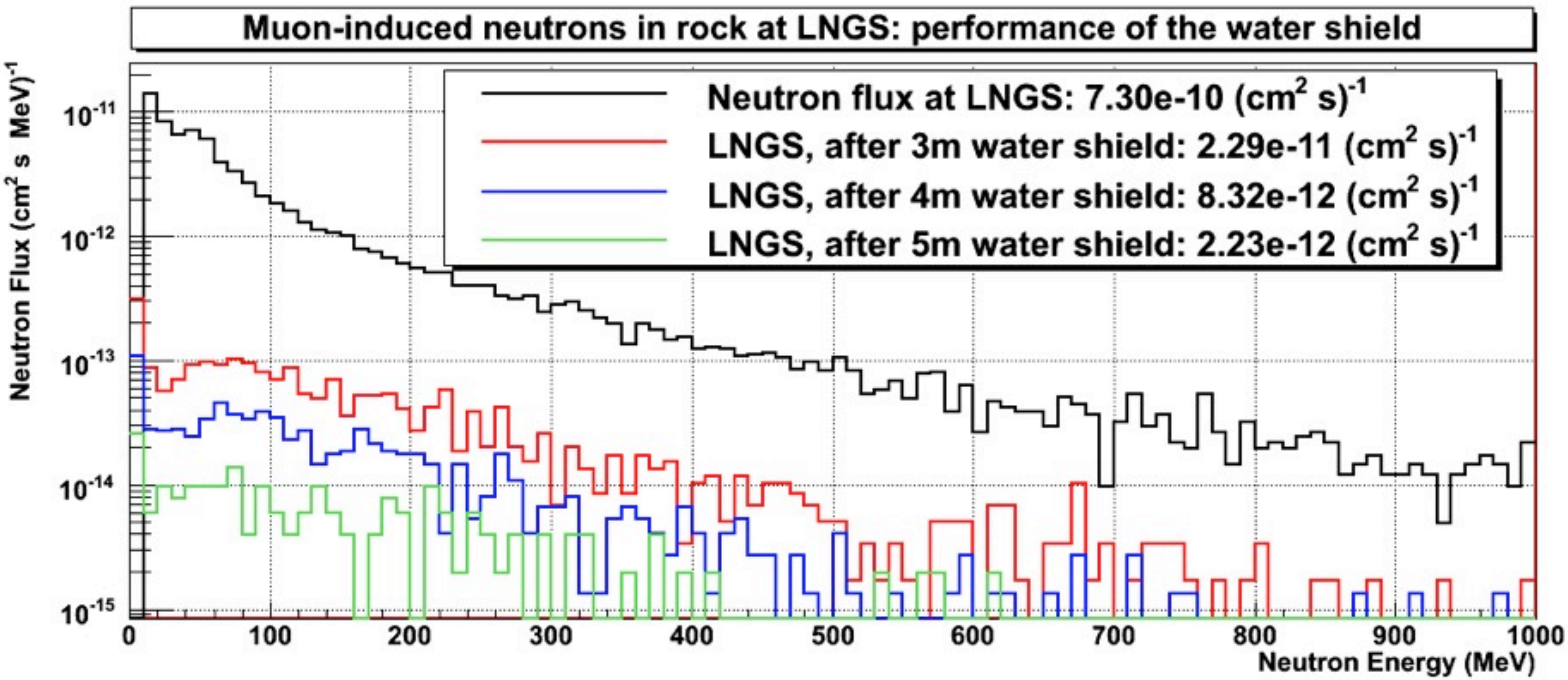
Gammas from U/Th/K in rock (γ flux in Hall B ~ 0.5 / cm^2 / s) reduced by ~10^6 by 3m of water: after ER discrimination, rate below 0.0001 evt / keVee / ton / year in the fiducial volume.

Fission and (α, n) neutrons from U/Th/K in rock and concrete (neutron flux in Hall B ~ 9 10^{-7} n / cm^2 / s) reduced to a completely negligible level with 3m of water.

Muon-induced Neutrons in Rock

Tagging muons with the active veto (water Cerenkov) with a water buffer of 3, 4, 5 m allows to remove respectively about 20, 30, 40% of the neutrons produced in rock.

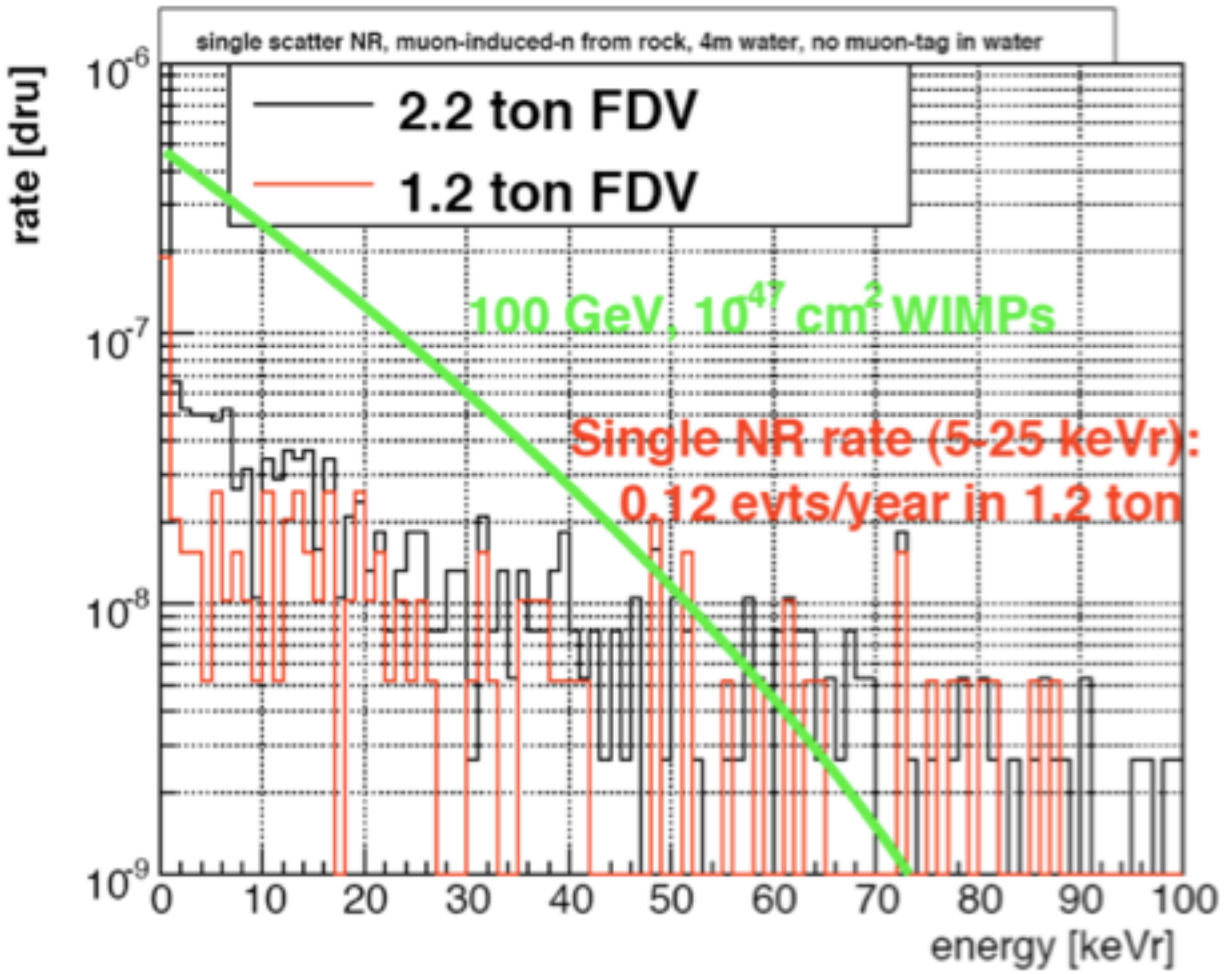
A further reduction of 96, 98, 99.5% of the neutrons is given by the moderation in the water shield itself.



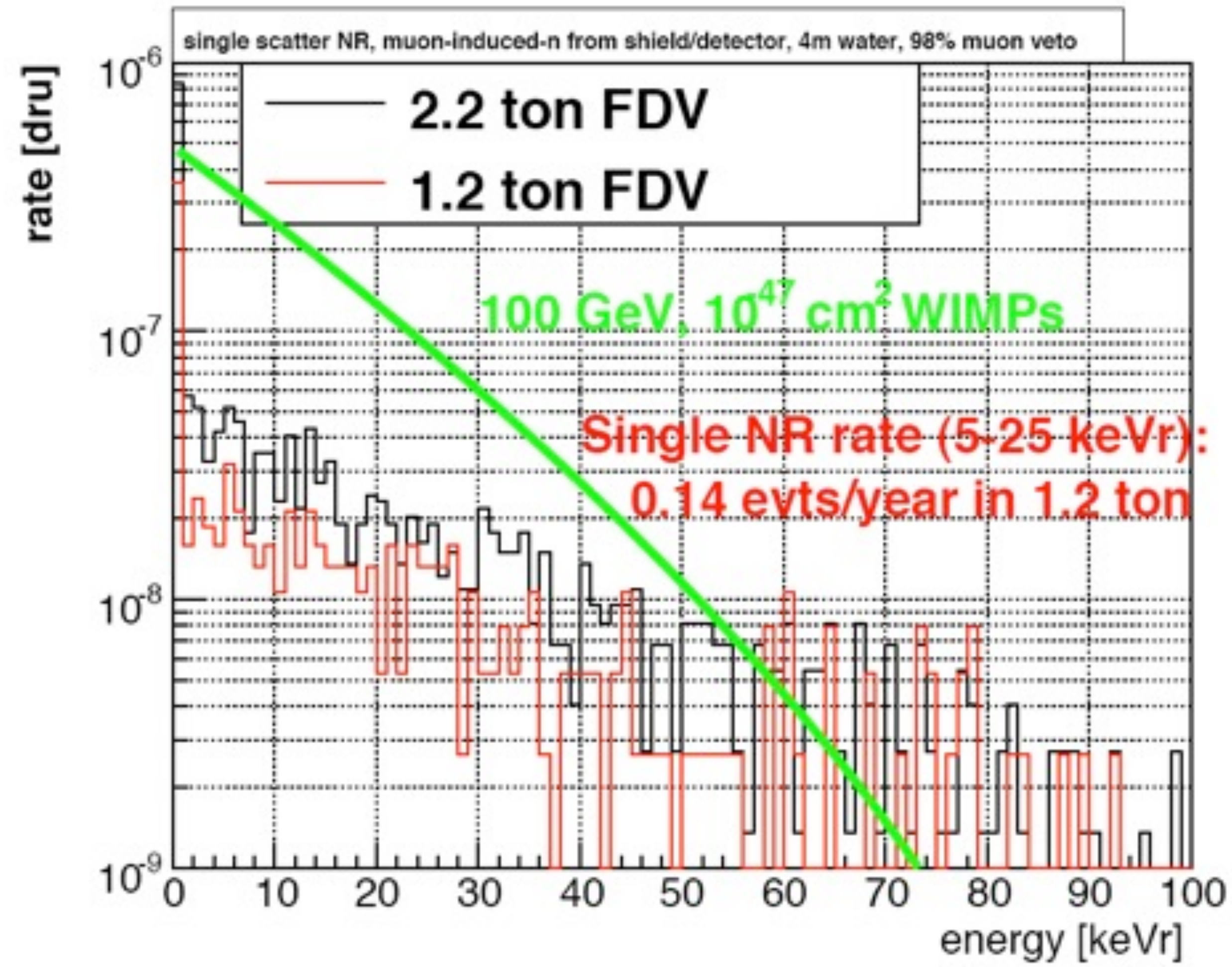
Single Scatter Neutrons in Rock and Water

Recoils in the liquid Xenon due to muon-induced neutron produced:

in rock

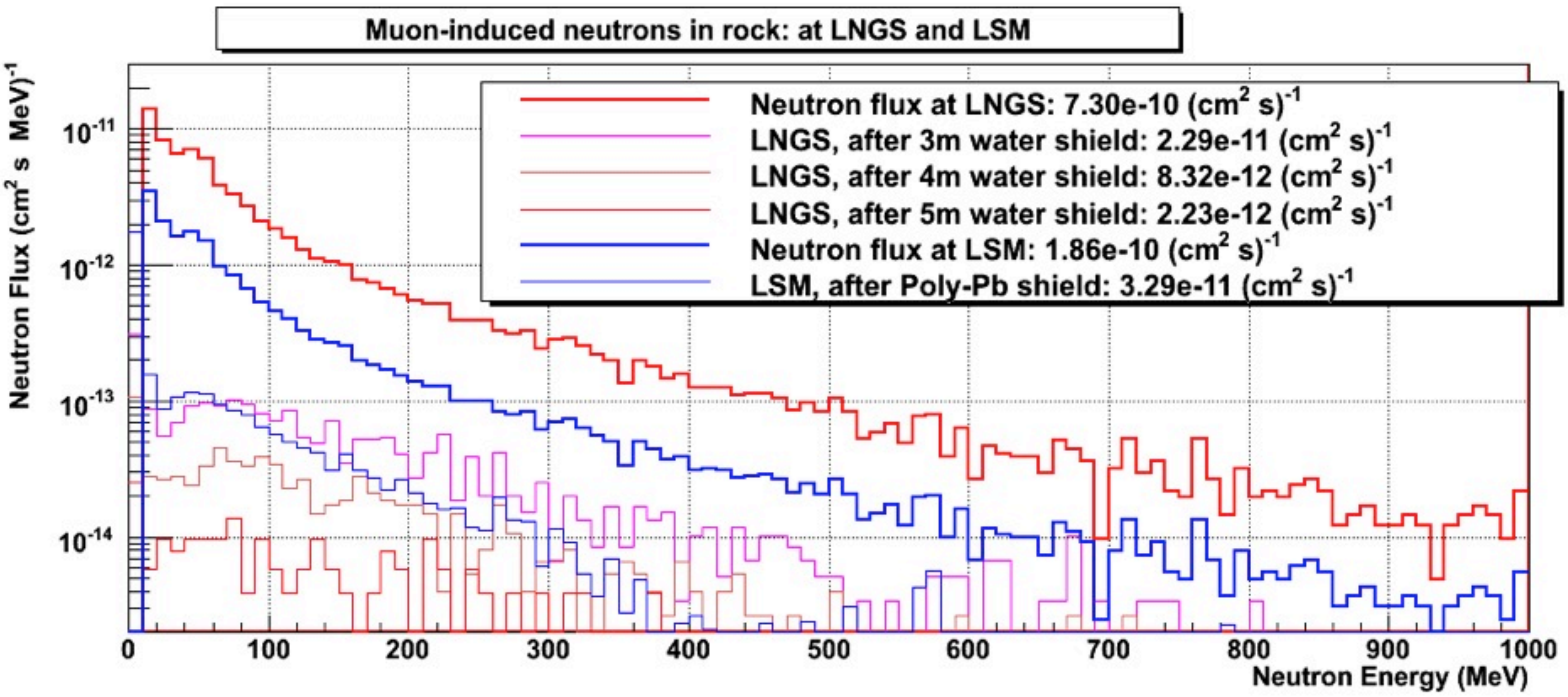


in water shield and cryostat



Less than 1 event/ ton / year with 4 m thick water shield and 98% muon veto efficiency

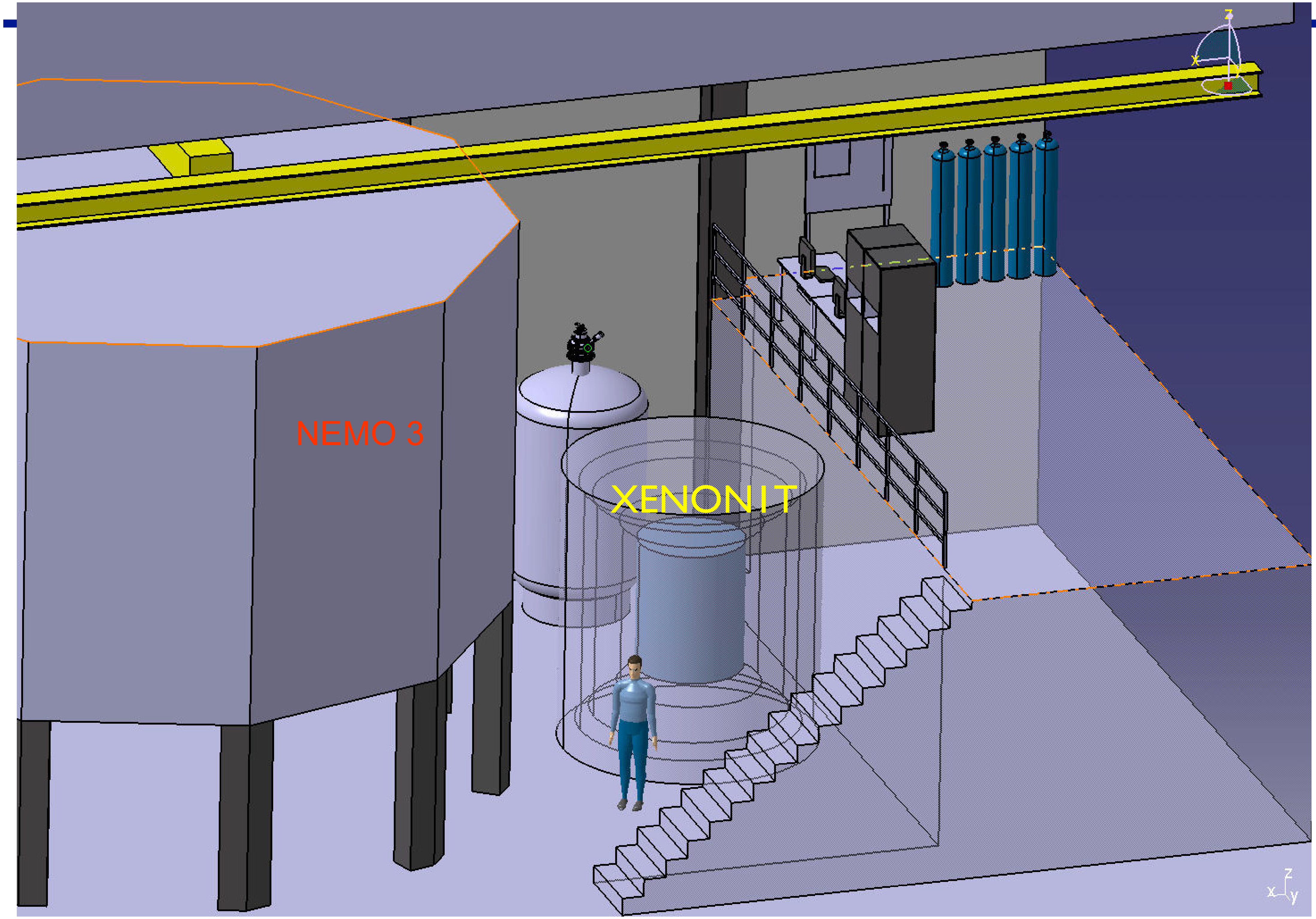
Muon-induced Neutrons: LNGS vs LSM



The neutron flux inside the Poly-Pb shield @ LSM is of the same order of magnitude as the one inside a 3m thick water shield @ LNGS.

With 5 m-thick water shield one gains an order of magnitude reduction, making such a shield ready also for the next generation LXe experiment (i.e. DARWIN).

XENON1T @ LSM



Solid shield (55 cm Poly, 20 cm Pb, 15 cm Poly, 2 cm ancient Pb) plus >99 % muon veto

XENON1T at LNGS