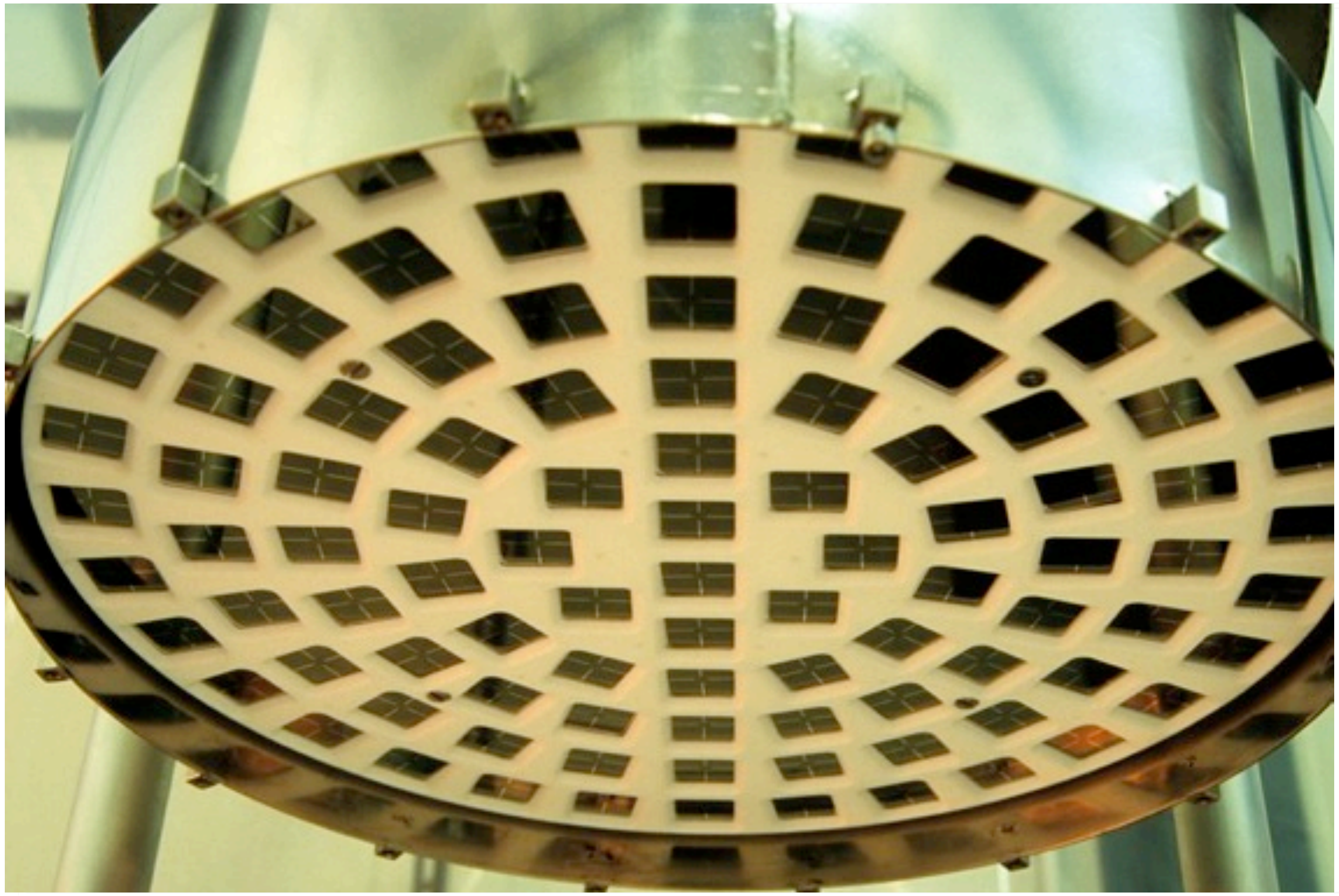
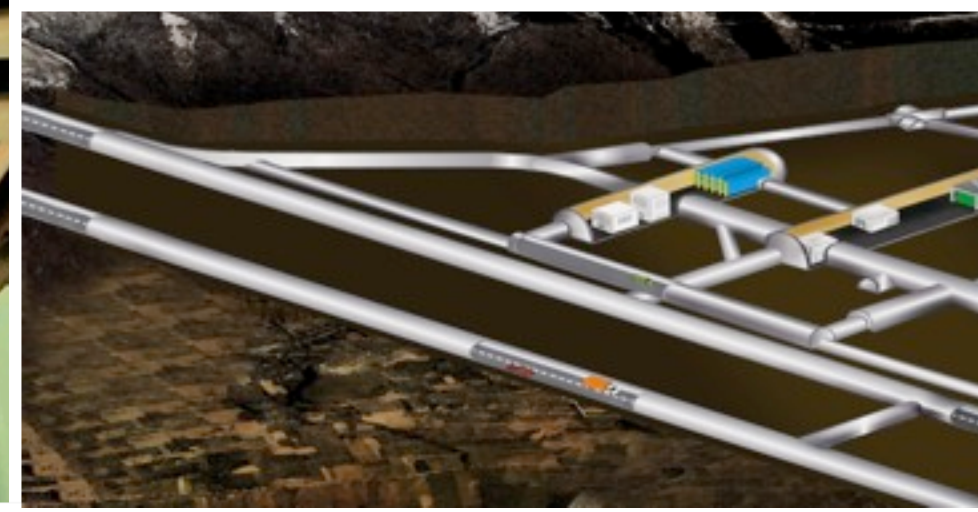
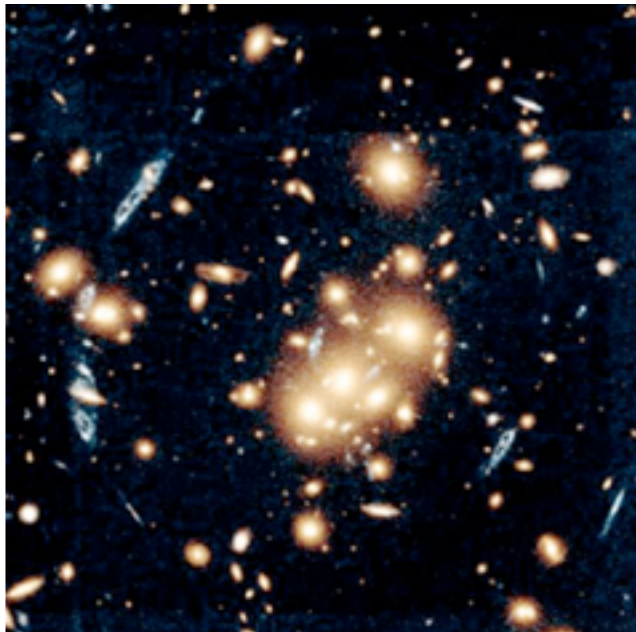


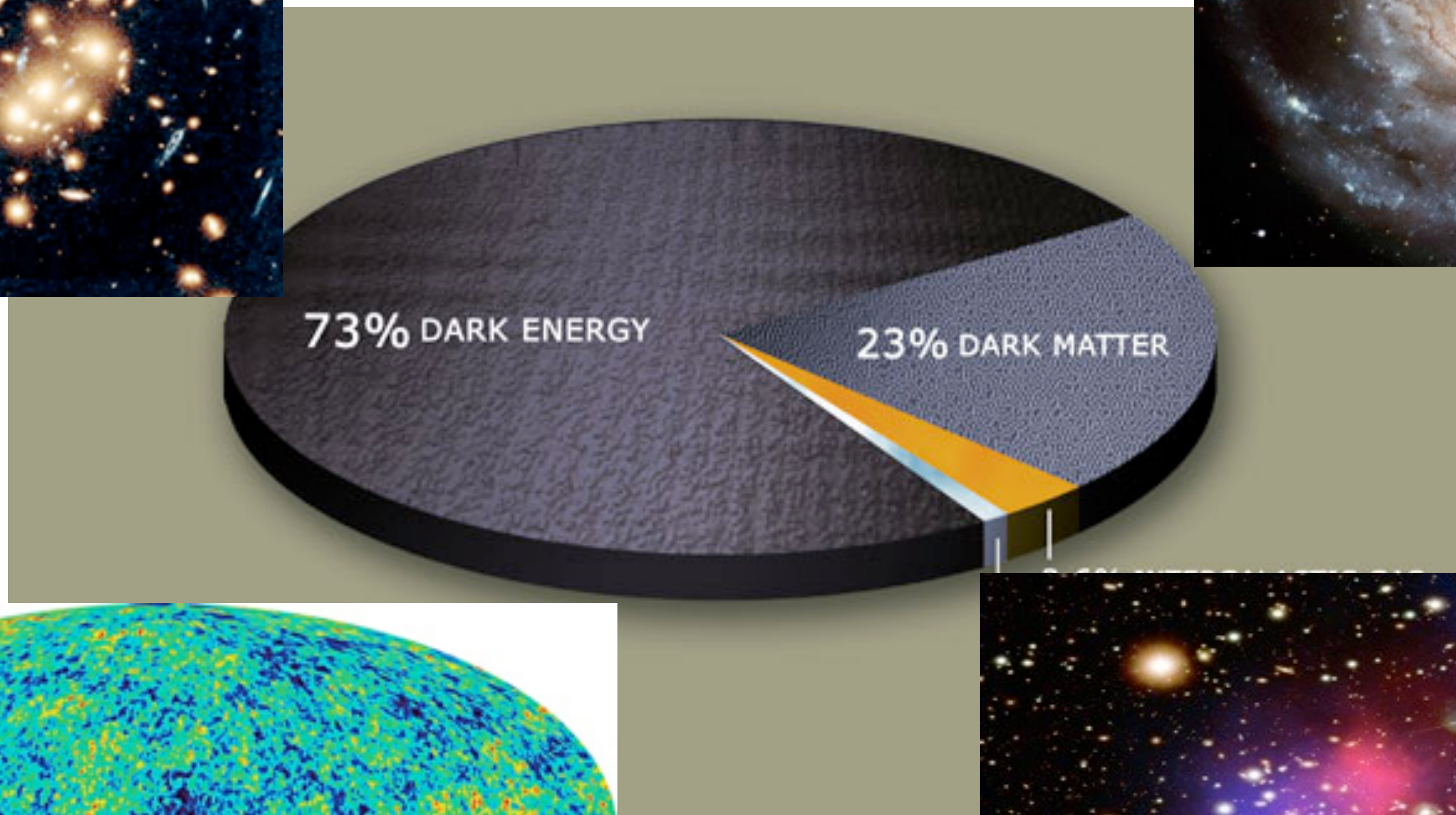


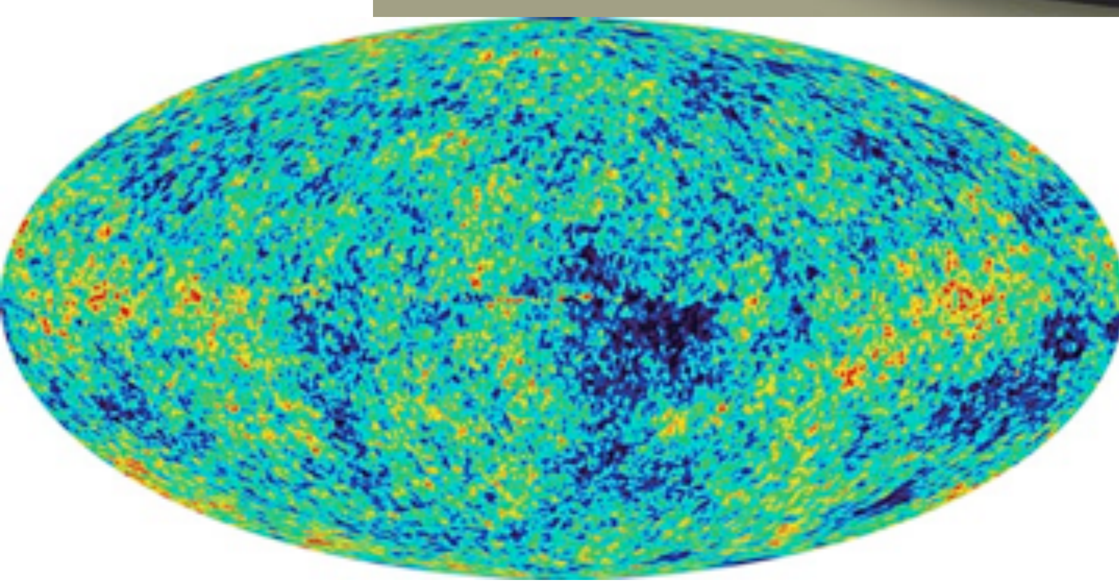
Direct Dark Matter Searches with Liquid Xenon

Kaixuan Ni
Shanghai Jiao Tong University
LHEP2010, Nanning, Nov.19th, 2010



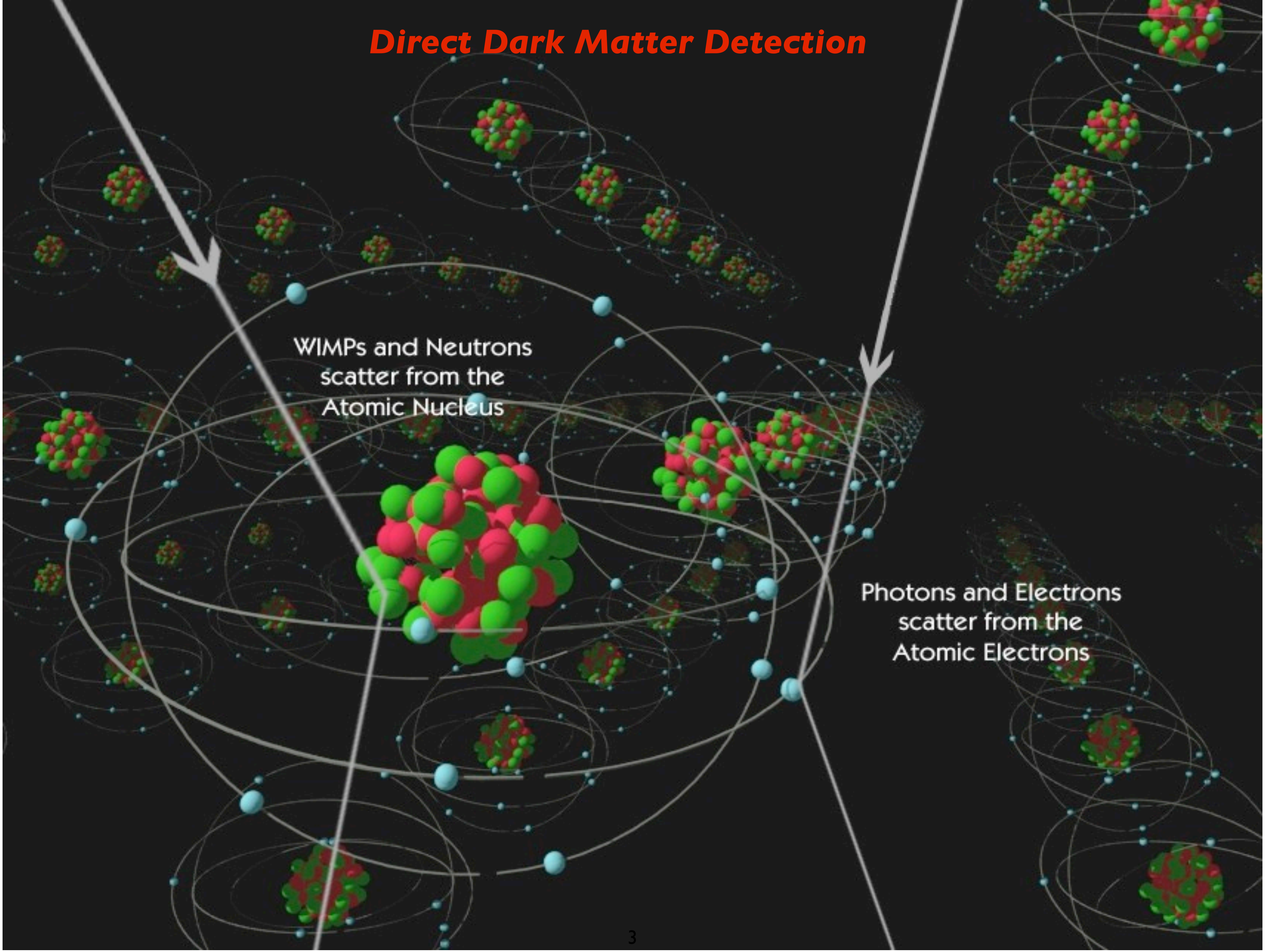
See Jin Li’s talk on Tuesday





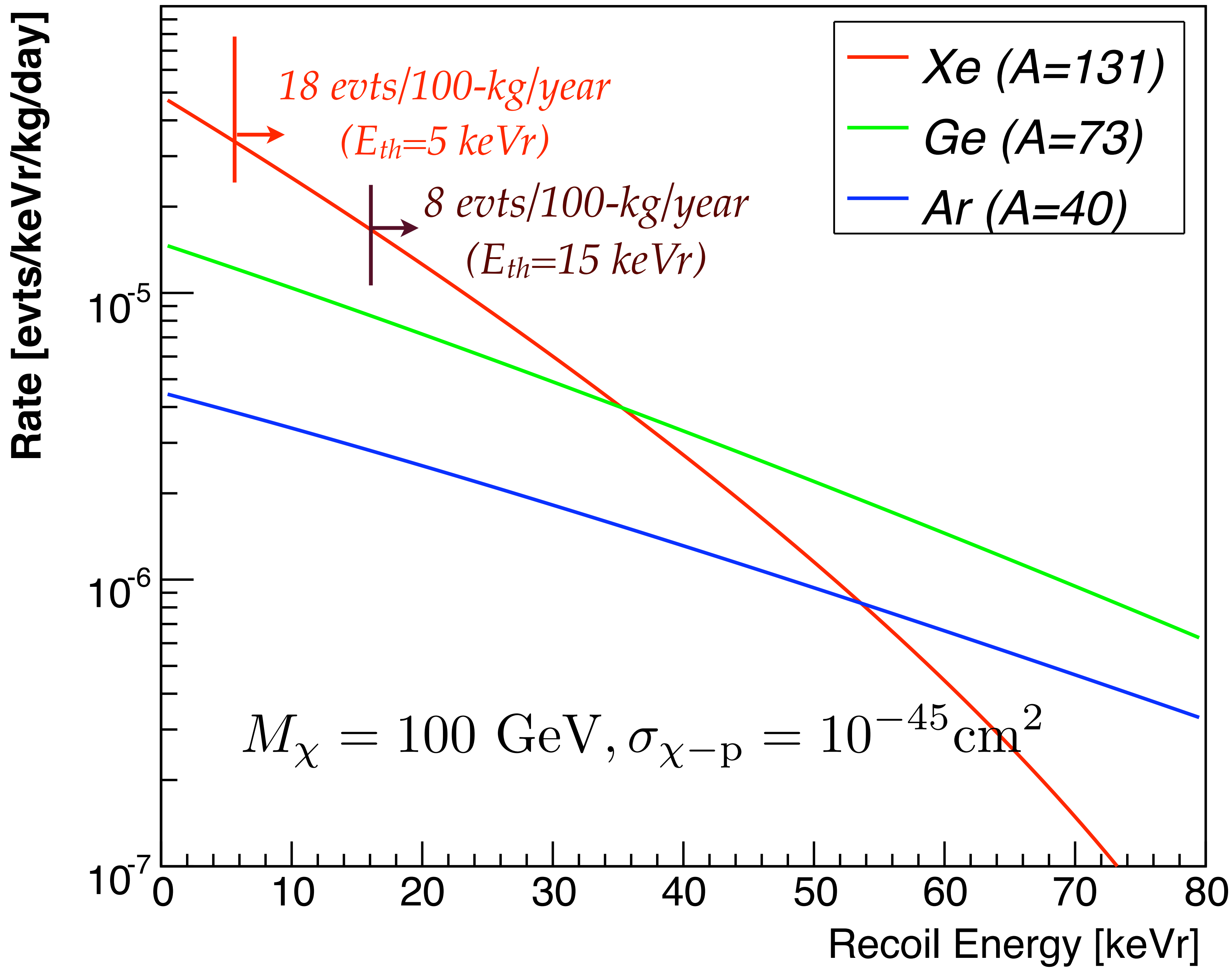
dark matter dominates the mass content in the universe!

Direct Dark Matter Detection



Dark Matter Detection Rates

dark matter may interact with us everyday,
but the rate is low and signal is small.



The challenge is to suppress the background!

K. Ni (SJTU)

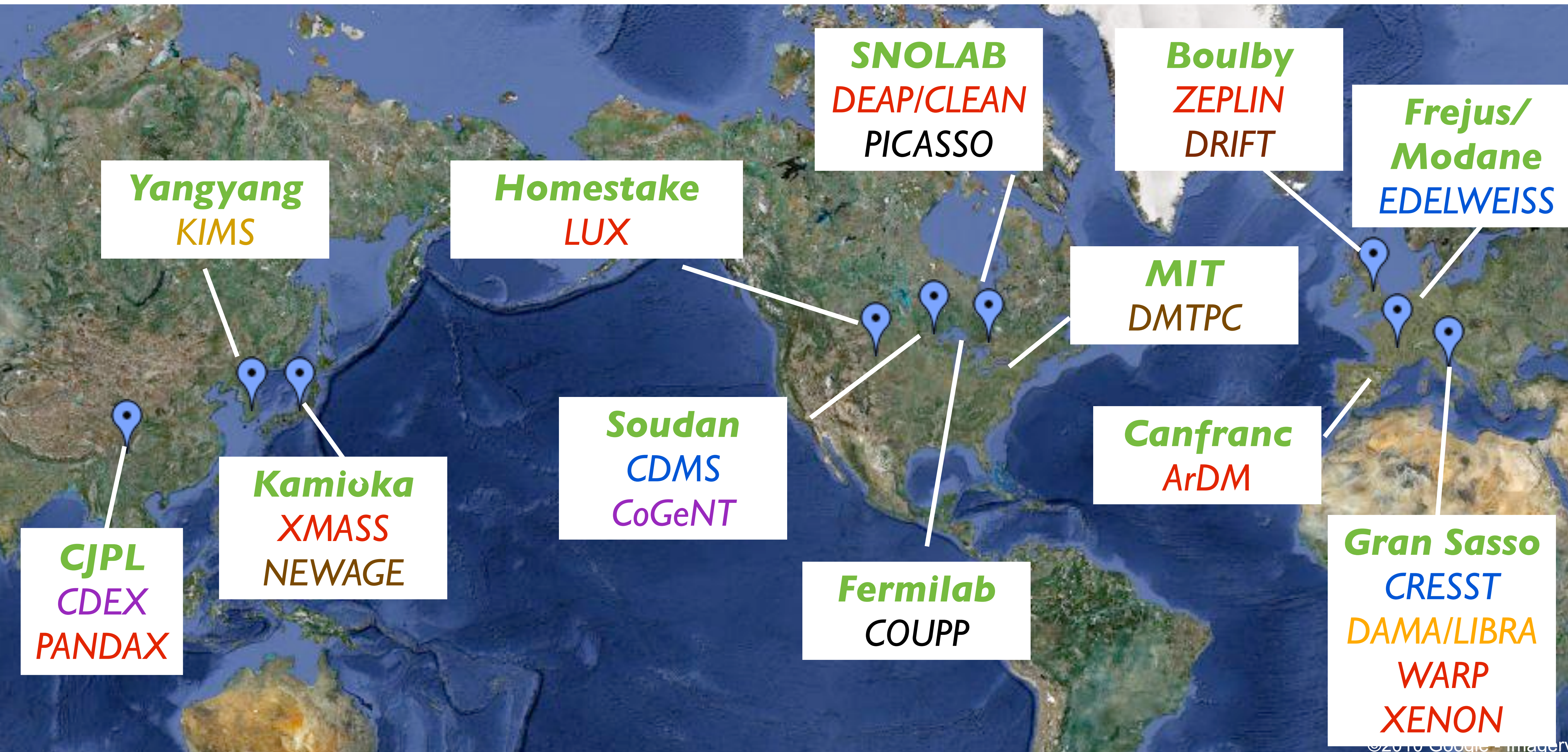
Despite the challenge, direct dark matter searches are not "so expensive" and there are many technologies...

World-Wide WIMP Searches

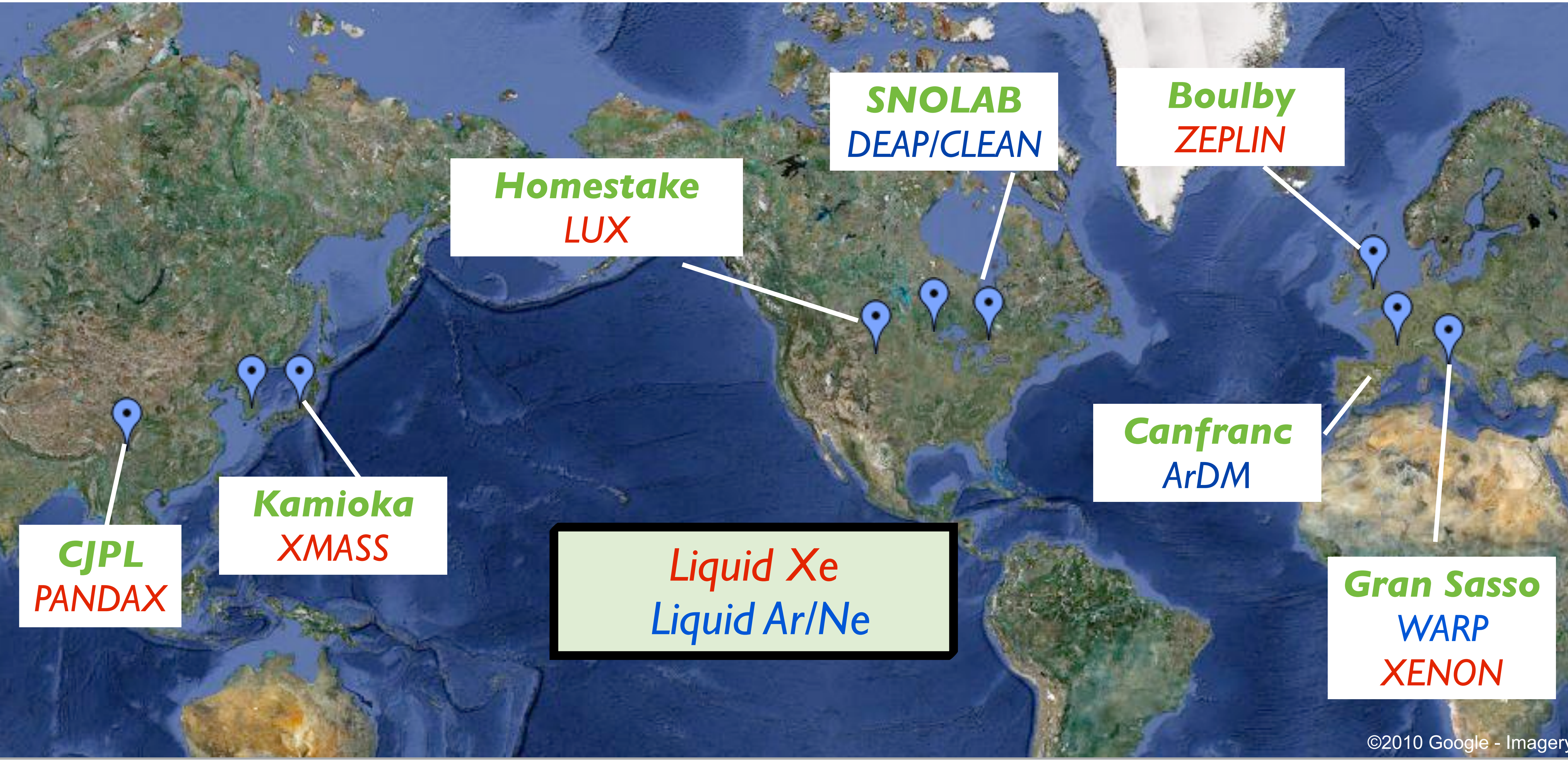
Technologies:

Cryogenic (Ge, Si etc.) Solid Scintillator (NaI, CsI) Noble Liquids (LXe, LAr)

Ultra-low threshold Directional Bubble chamber



Noble Liquids - a revolutionary technology for DM searches



after about 10 years of development, now Noble Liquids technology is mature.

Merits of Liquid Xenon for dark matter detection

✓ Optimized signal detection:

- Xe (large A~131): spin-independent rate $\propto A^2$
- Xe-129, Xe-131: sensitive to spin-dependent
- Low energy threshold achievable by high light yield and efficient photosensors

✓ Several techniques for background reduction:

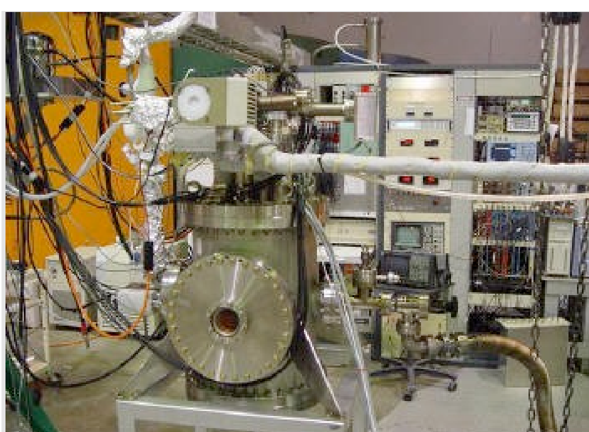
- 3D event localization - fiducial selection, event multiplicity
- Ionization/scintillation ratio - remove electron-type events

✓ Scalability:

- "Easy" cryogenics: 170 K (LXe)
- Relatively inexpensive for very large detector (today ~10000 RMB/kg)

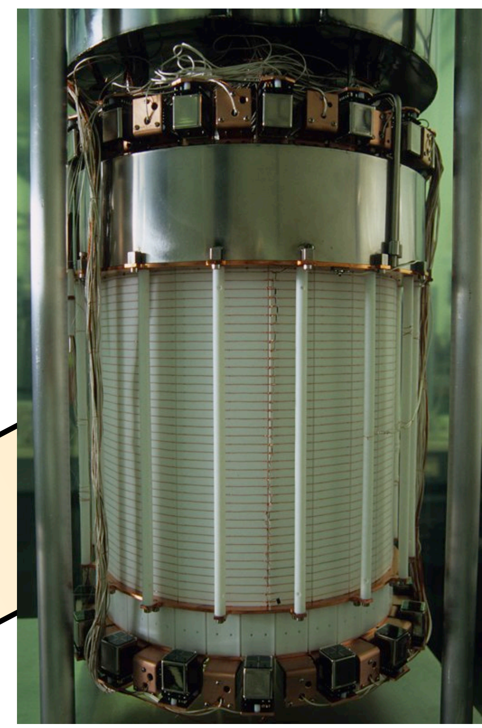
A historical evolution

earlier generations (<100 kg)



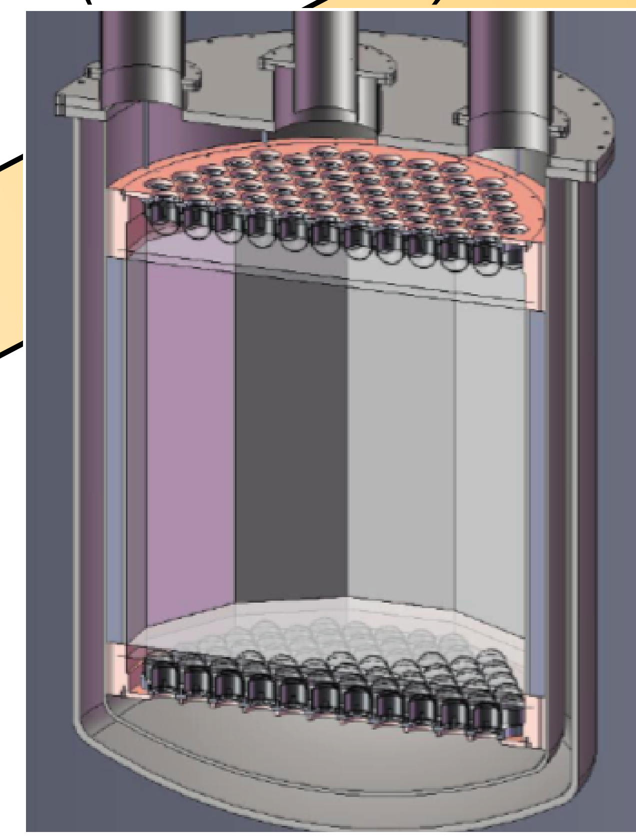
DAMA/LXe
ZEPLIN I
XENON10
ZEPLIN II
ZEPLIN III

current generation (100~1000 kg)



XENON100
XMASS
LUX
PandaX

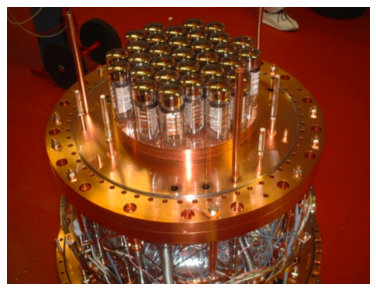
next generations (ton scale)

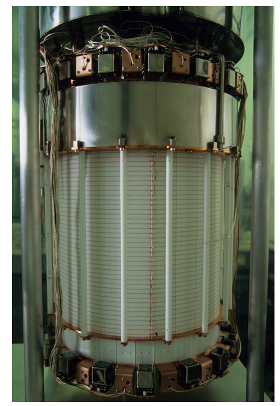


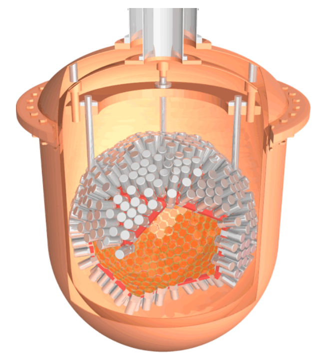
XENON1T
DARWIN
MAX
LZ20

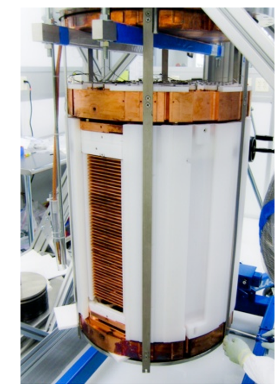
How these experiments suppress background?

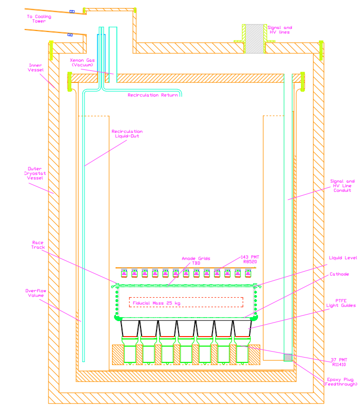
- Cosmic ray induced background: go to a deep underground lab (common to all experiments)









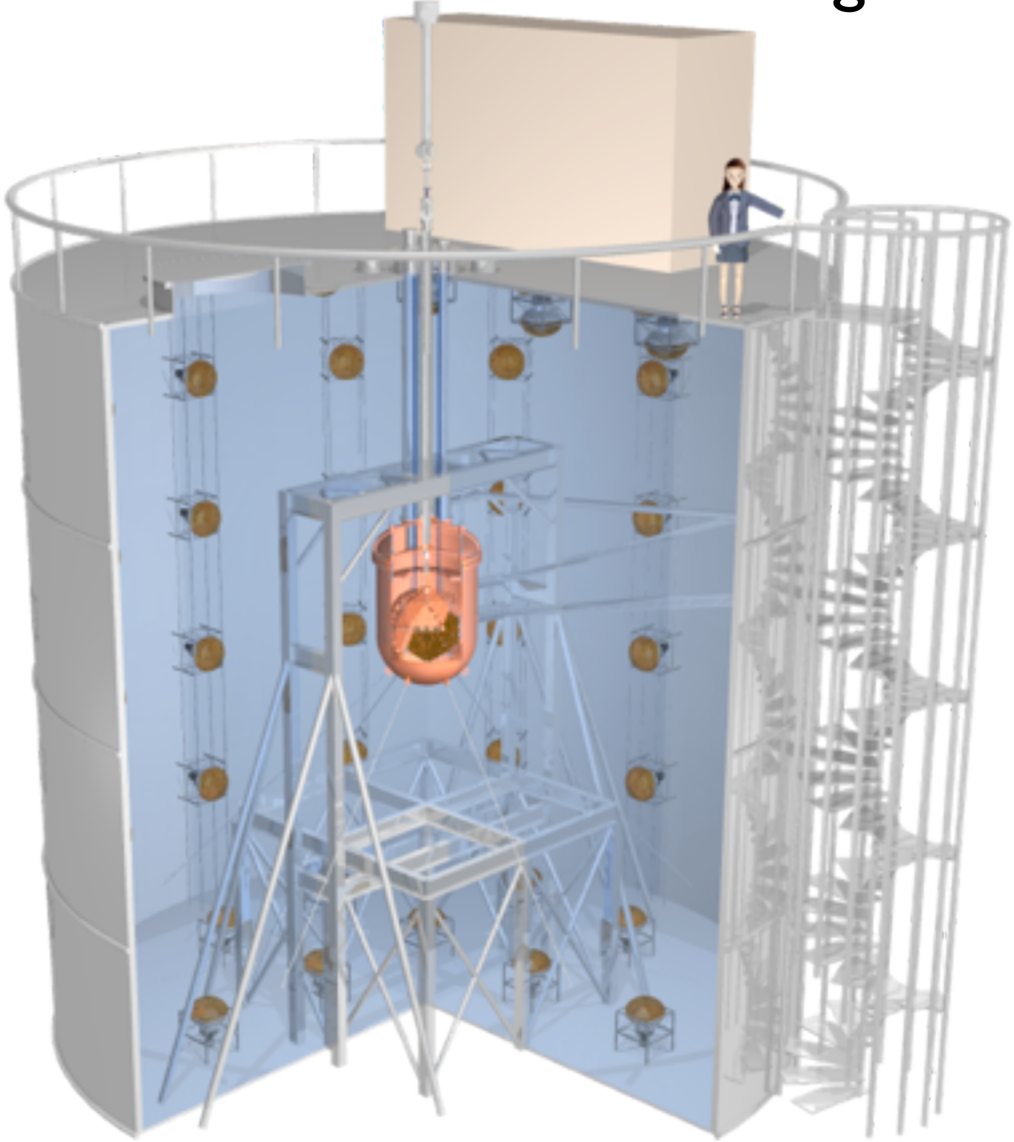


	ZEPLIN III	XENON100	XMASS	LUX	PandaX
location	Boulby/UK	LNGS/Italy	Kamioka/ Japan	Homestake/ USA	CJPL/China
depth (water equivalent)	2800 m	3500 m	2700 m	4500 m	>6000 m
muon flux ($/m^2/year$)	~10000	2000	~10000	~600	20

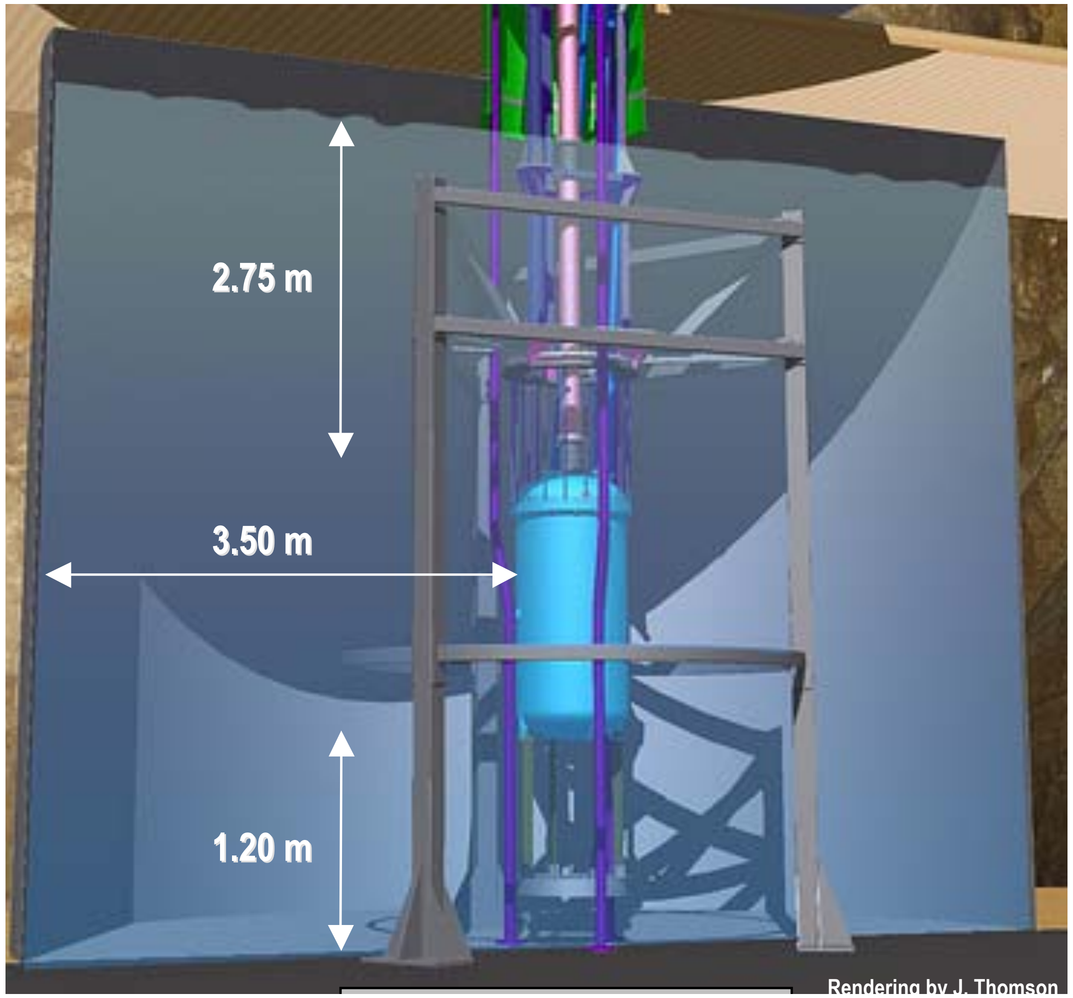
How these experiments suppress background?

- Cosmic ray induced background: go to a deep underground lab (common to all experiments)
- Radiation from rock/lab environment: use passive/active shielding (common to all experiments)

XMASS water shielding



LUX water shielding

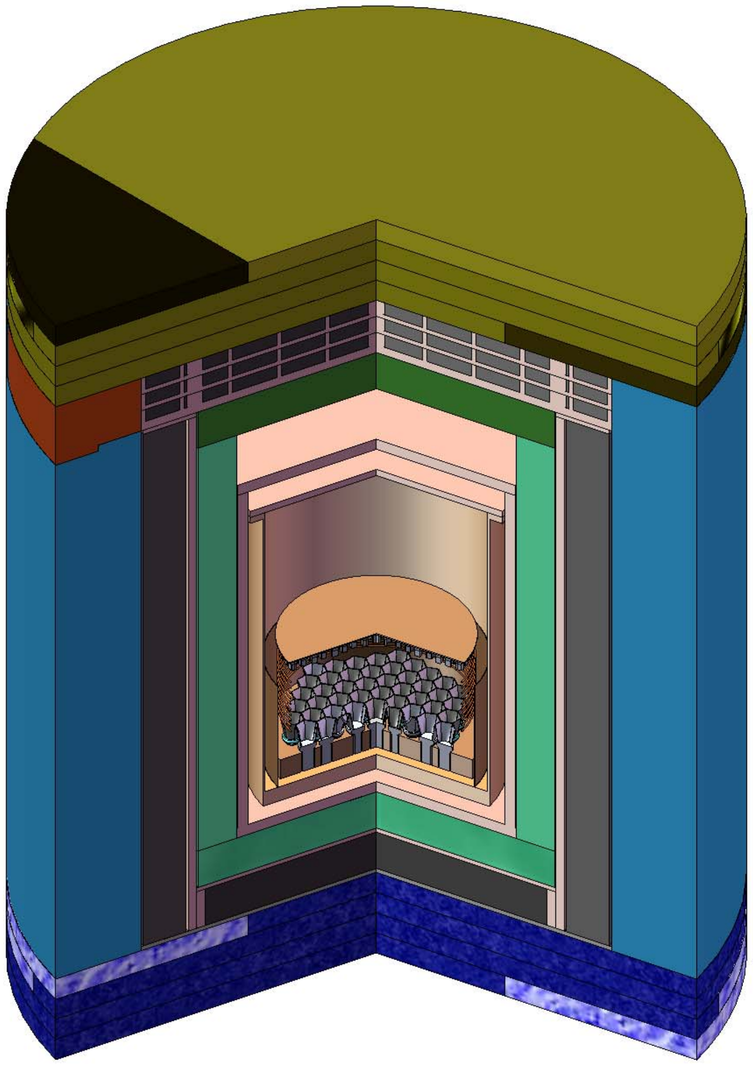


How these experiments suppress background?

- Cosmic ray induced background: go to a deep underground lab (common to all experiments)
- Radiation from rock/lab environment: use passive/active shielding (common to all experiments)

XENON100 in the passive shielding

PandaX lead/poly/Cu passive shielding

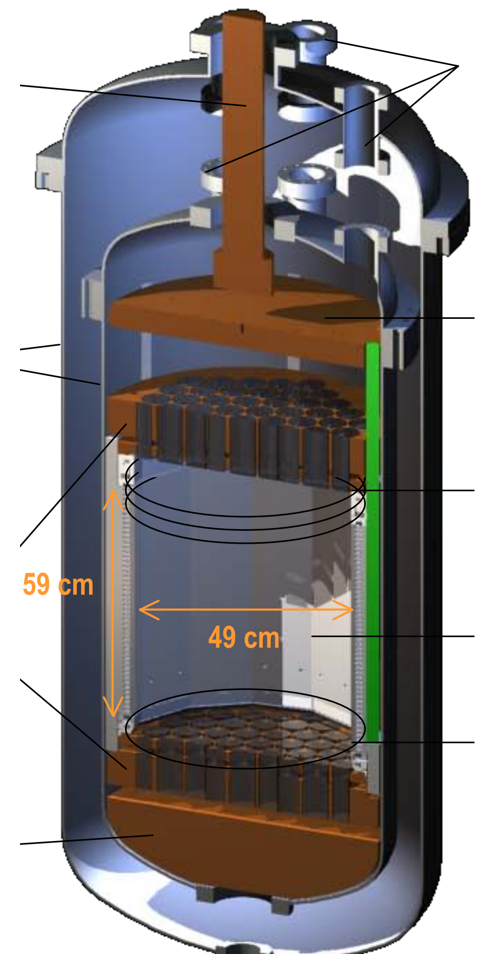


How these experiments suppress background?

- Cosmic ray induced background: go to a deep underground lab (common to all experiments)
- Radiation from rock/lab environment: use passive/active shielding (common to all experiments)
- Radiation from shield/detector itself: use low radioactive materials (common to all experiments)

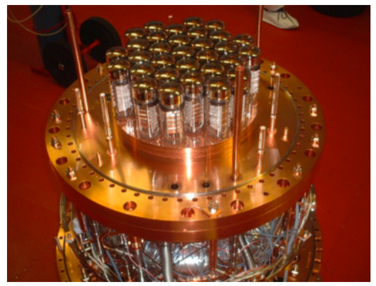
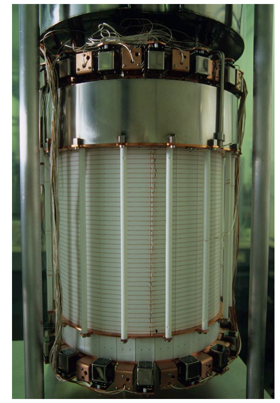
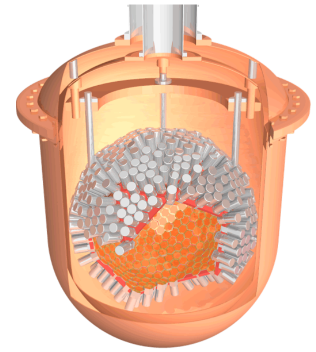
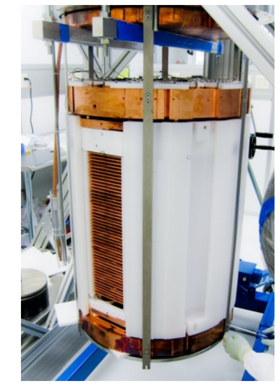
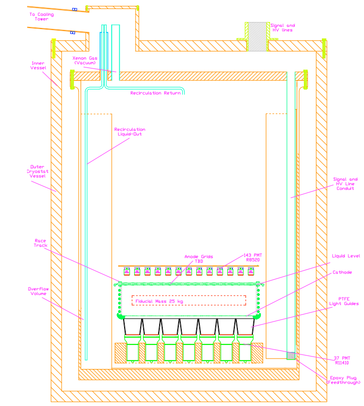
XE100 in low-activity stainless steel

XMASS in pure copper (OFHC)



LUX in pure titanium

low radioactive PMTs are used

	ZEPLIN III	XENON100	XMASS	LUX	PandaX
PMT	ETEL	R8520	R10789	R8778	R8520/ R11410*
U	-	0.15	0.7	10	0.15/-
Th	-	0.17	1.5	2	0.17/-
K	-	11	<5.1	-	11/-
Co	-	0.6	2.9	-	0.6/-

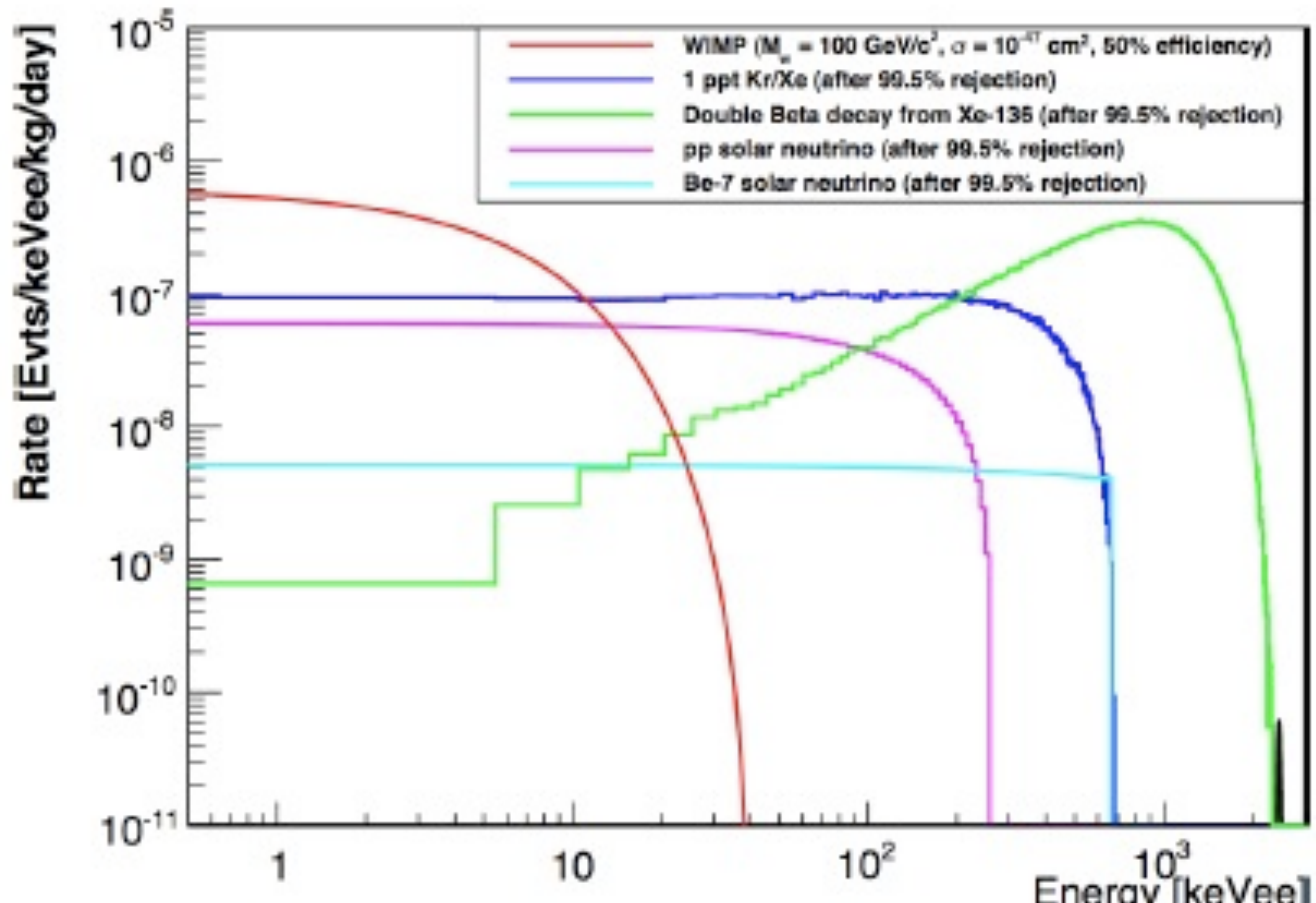
unit: mBq/PMT

* radioactivity being measured

Intrinsic Kr-85 background reduction

Xe has no long lived isotopes BUT has traces of radioactive Kr85 (Emax = 687 keV, t ~11 yr) is present in natural Kr at ~ 10^{-11}. Commercial Xe available with ~1 ppb Kr/Xe

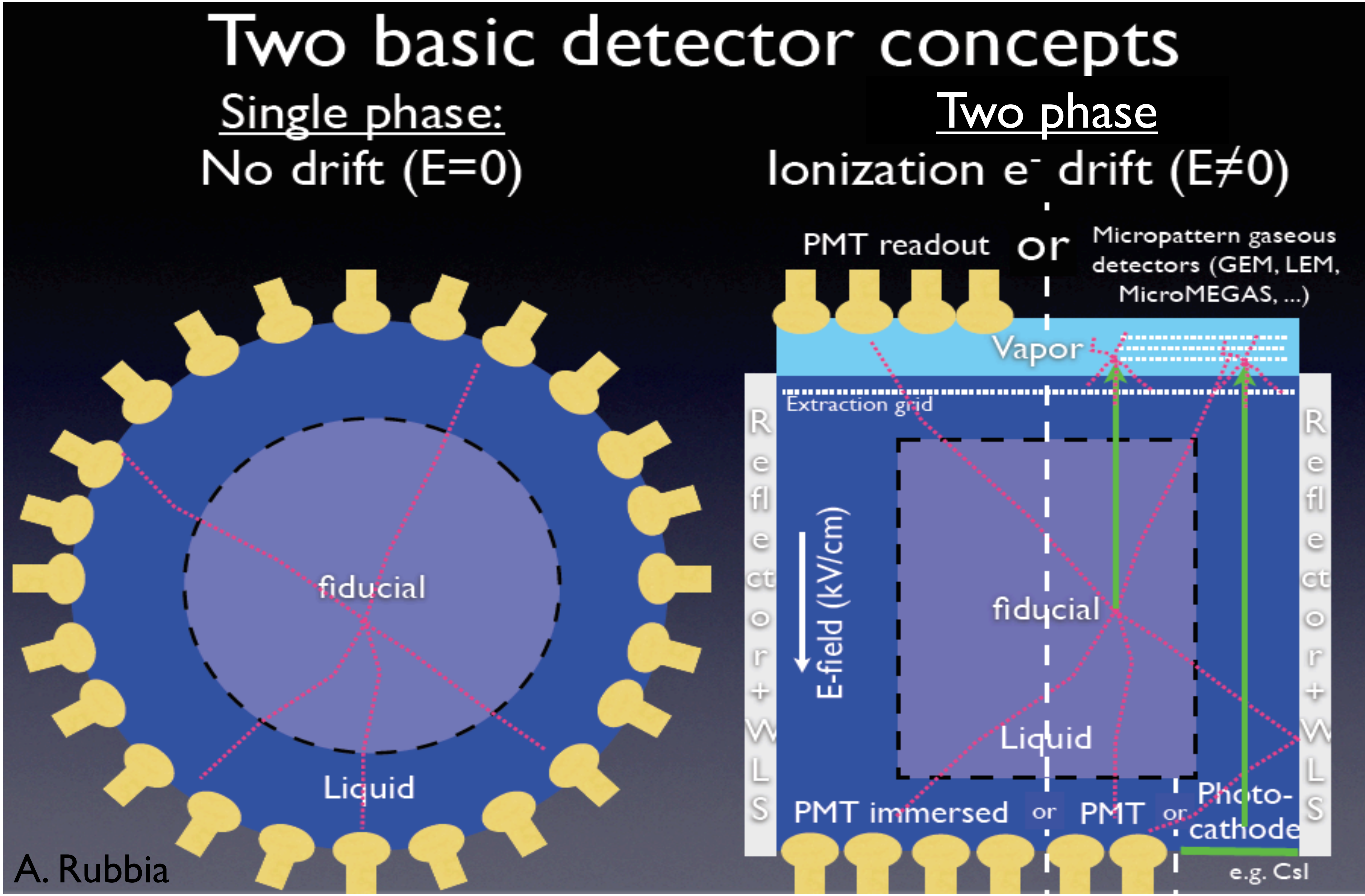
Cryogenic Distillation Tower (XENON100/XMASS/PandaX) or Charcoal adsorption technique (LUX) can be used to further reduce Kr too ~1ppt level, needed for the next generation experiments.



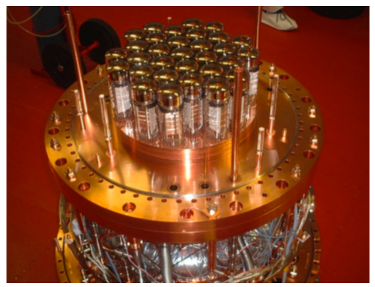
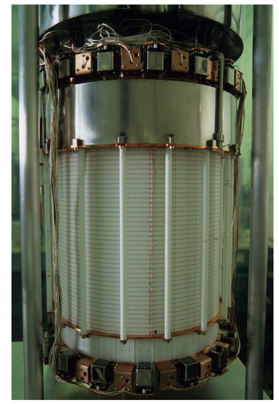
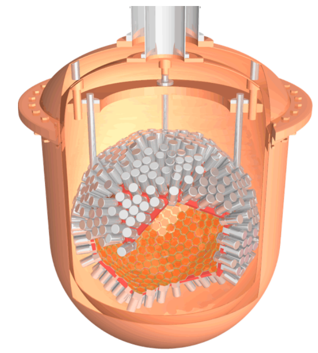
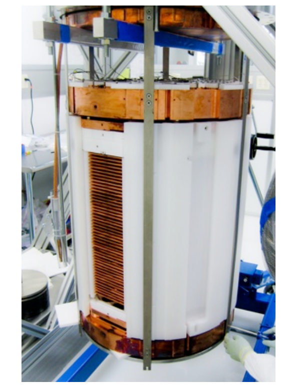
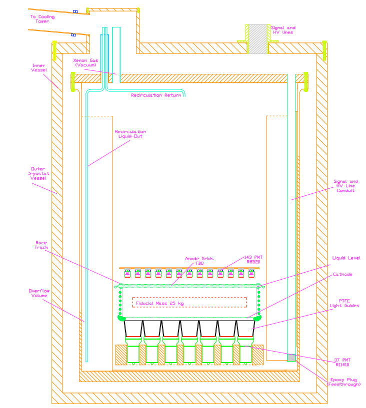
Kr distillation tower for XENON100

How these experiments suppress background?

- Cosmic ray induced background: go to a deep underground lab (common to all experiments)
- Radiation from rock/lab environment: use passive/active shielding (common to all experiments)
- Radiation from shield/detector itself: use low radioactive materials (common to all experiments)
- Further background reduction techniques: (detector related)
  - fiducial volume selection (WIMP interacts uniformly, but background at edge/surface)
  - discriminate event type (in general, WIMP only produces nuclear recoils, unlike electron recoils)
  - event multiplicity (WIMP only scatters once)

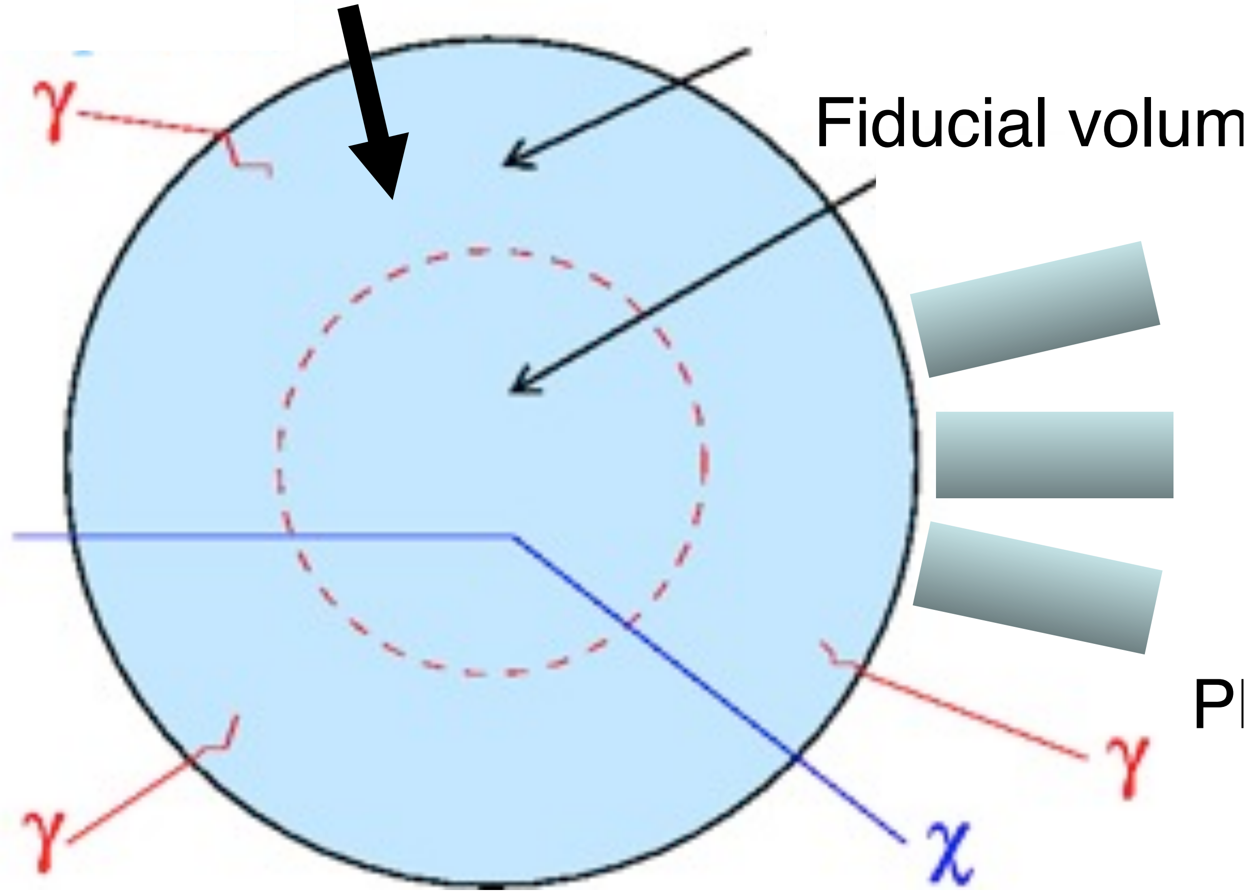

Two basic detector concepts
Single phase:
No drift (E=0)
Two phase
Ionization e- drift (E≠0)
PMT readout
or
Micropattern gaseous detectors (GEM, LEM, MicroMEGAS, ...)
Vapor
Extraction grid
Reflector + WLS
E-field (kV/cm)
fiducial
Liquid
fiducial
Liquid
PMT immersed
or
PMT
or
Photo-cathode
e.g. CsI
A. Rubbia

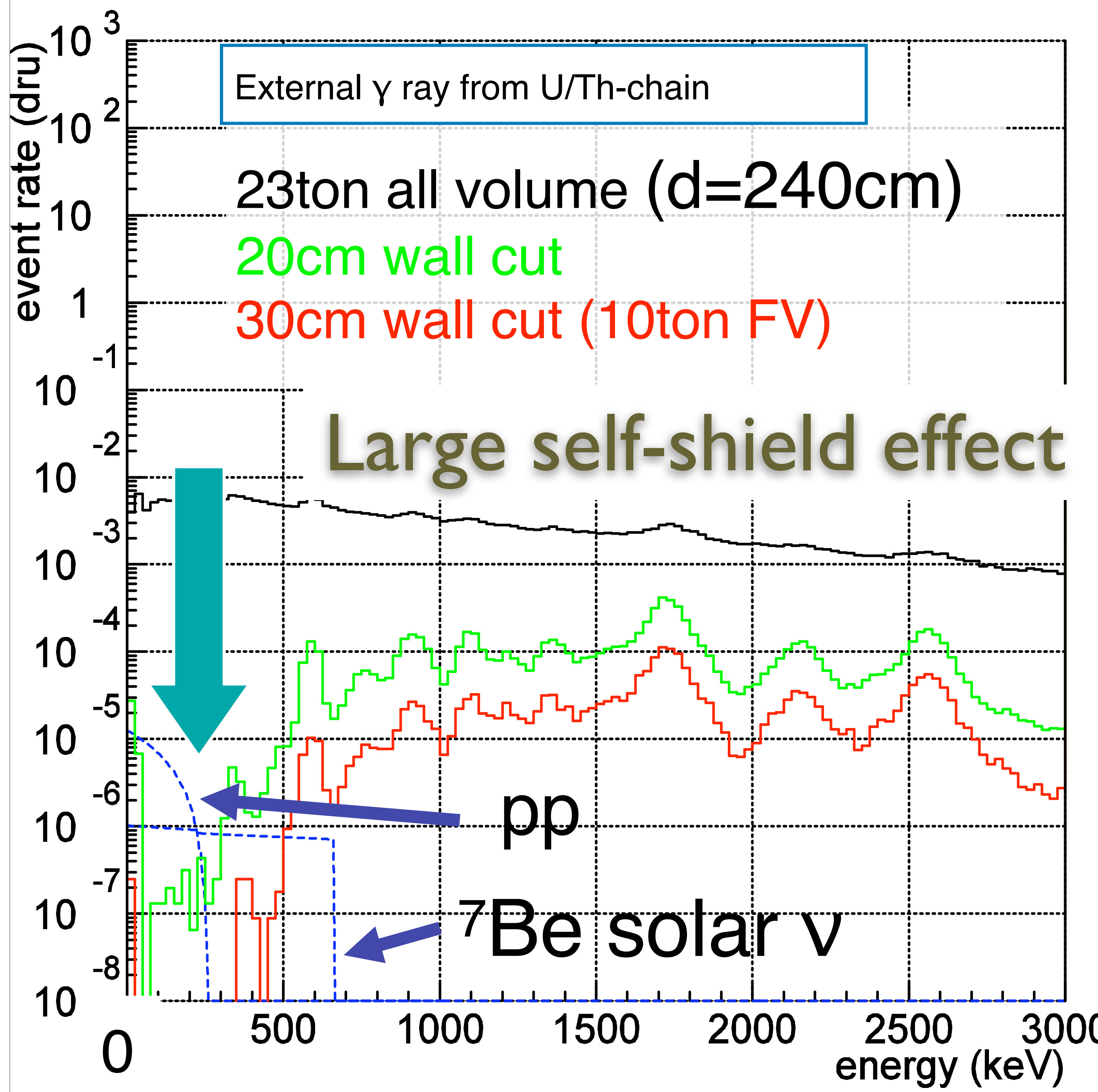
Liquid Xenon DM detectors

	ZEPLIN III	XENON100	XMASS	LUX	PandaX
technique	two-phase	two-phase	single-phase	two-phase	two-phase
active target mass (kg)	12	~60	~800 (100)	~300	~120

Concept of background reduction
Self-shielding (XMASS)

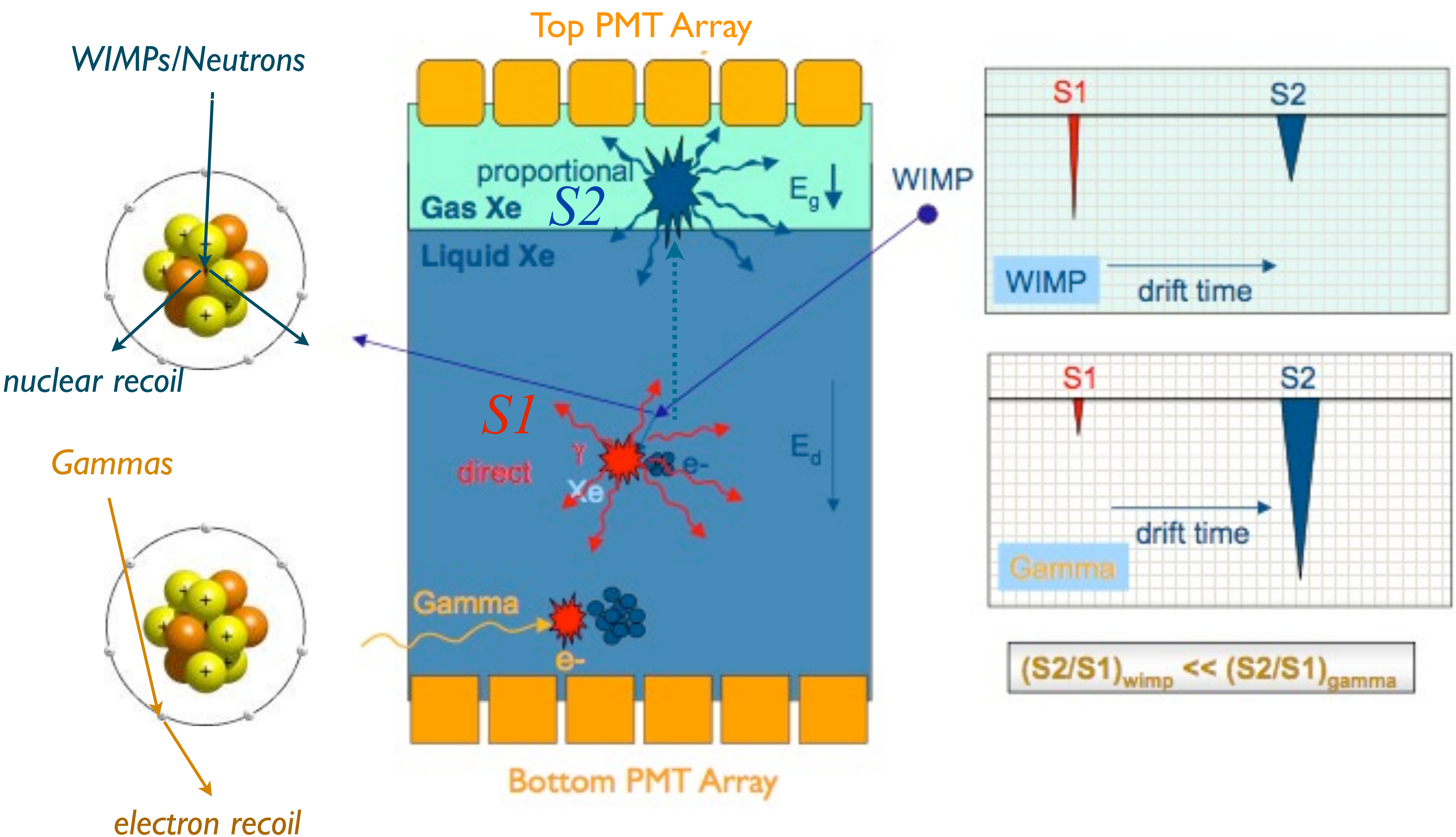




dru = event/day/kg/keV

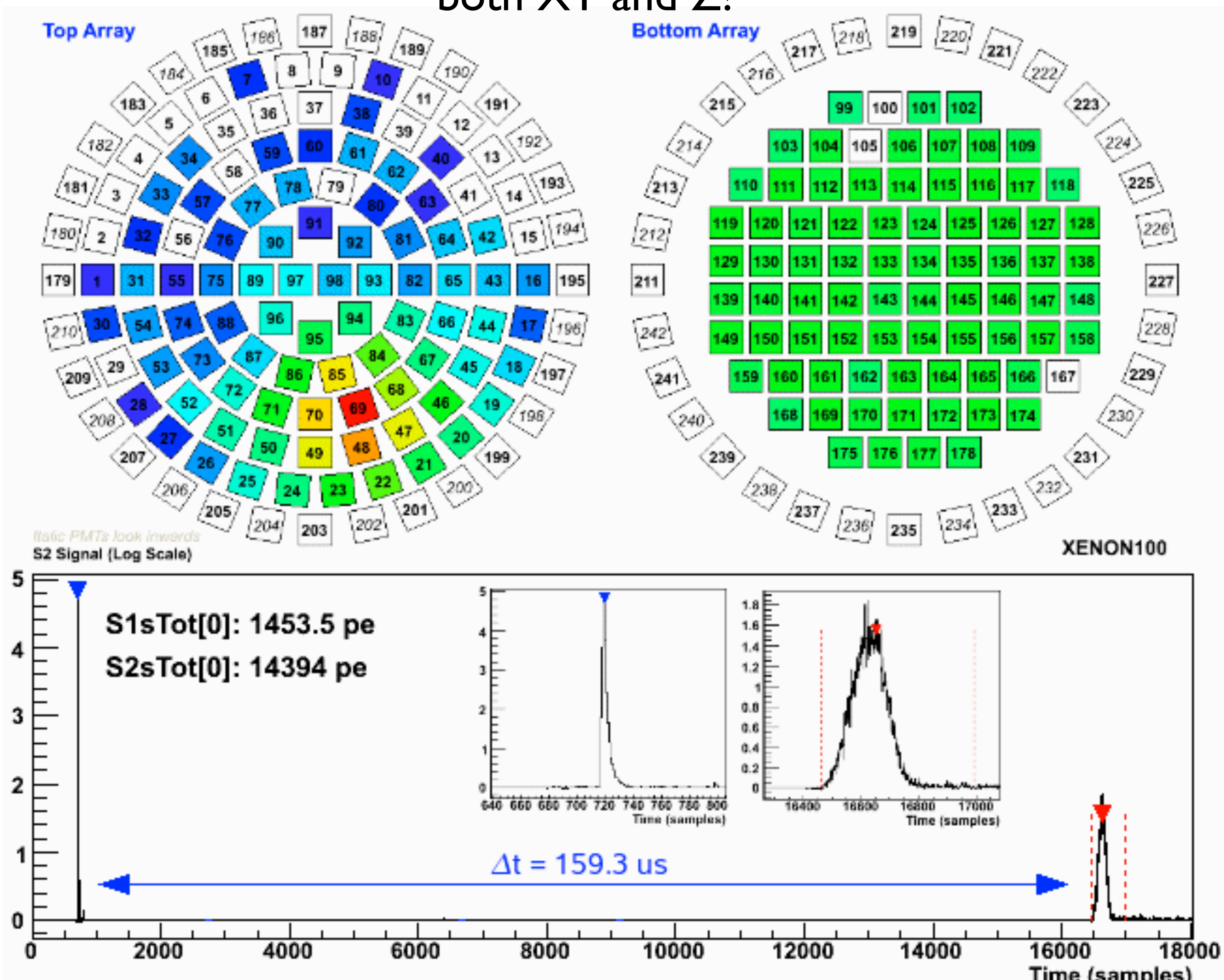
ne center of the fiducial volume

Two-phase Xenon for Dark Matter Detection

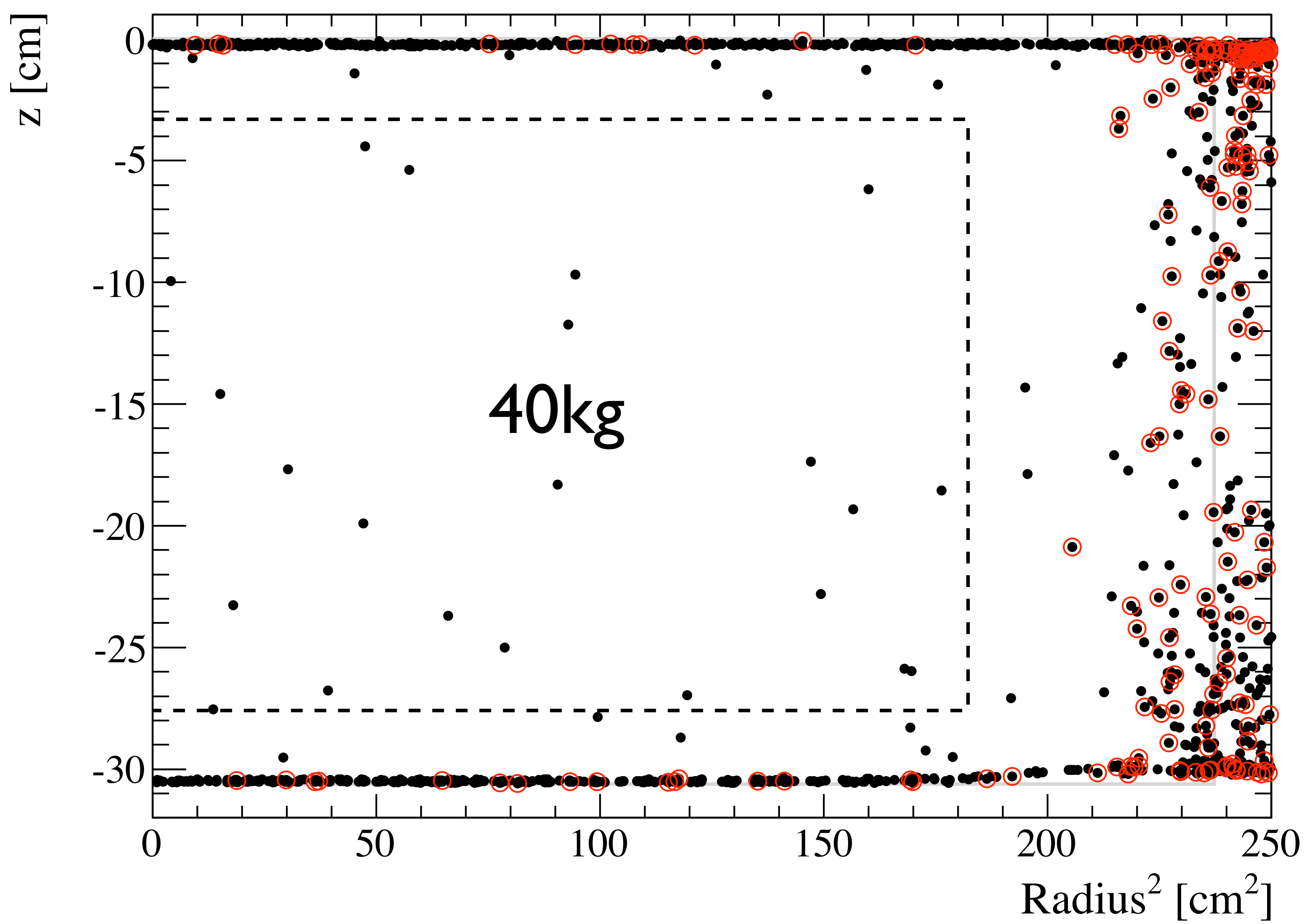


An event from XENON100

position resolution in a two-phase Xe detector is 2~3 mm in both XY and Z!

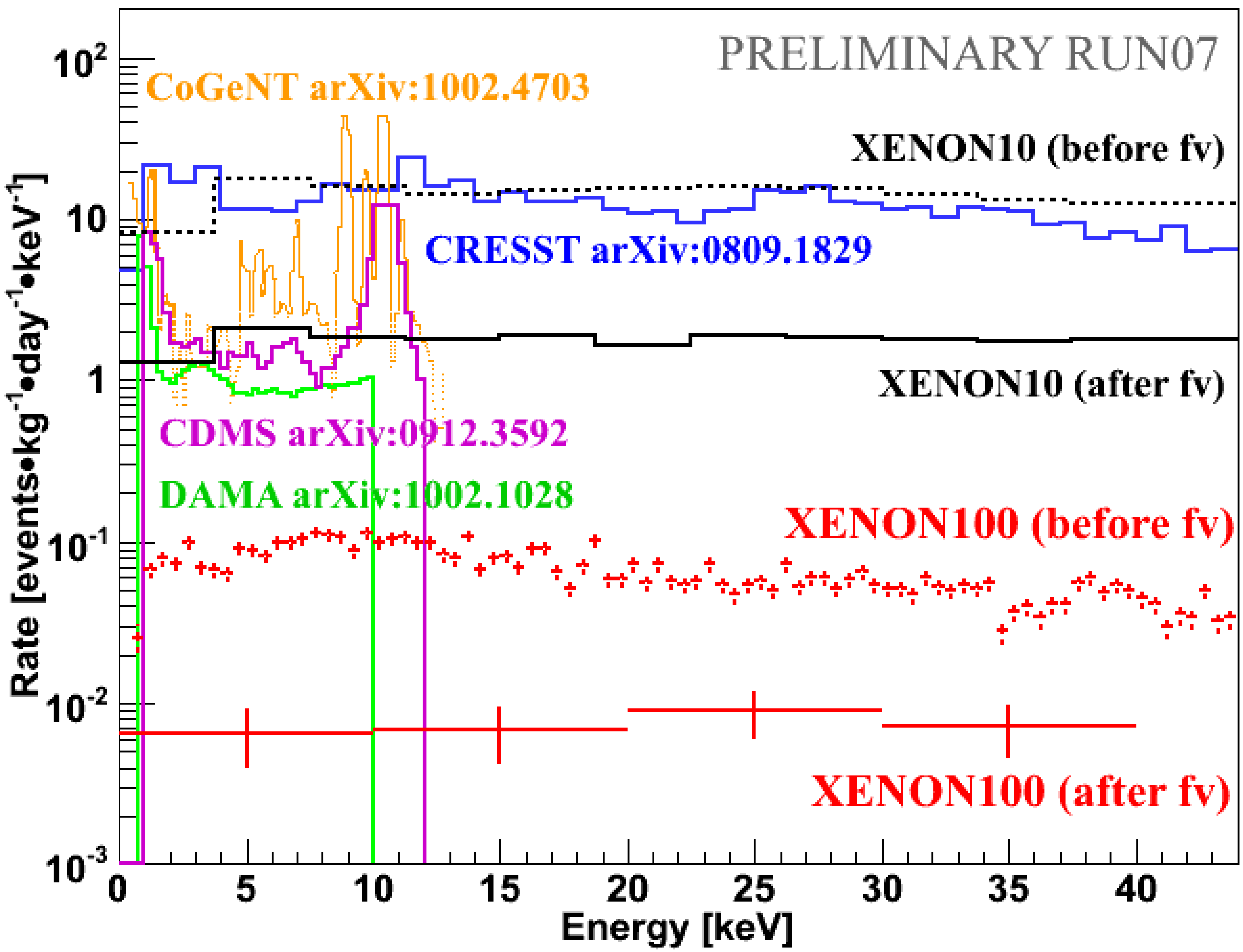


XENON100: 11.2 live-day background data (Oct-Nov,2009)

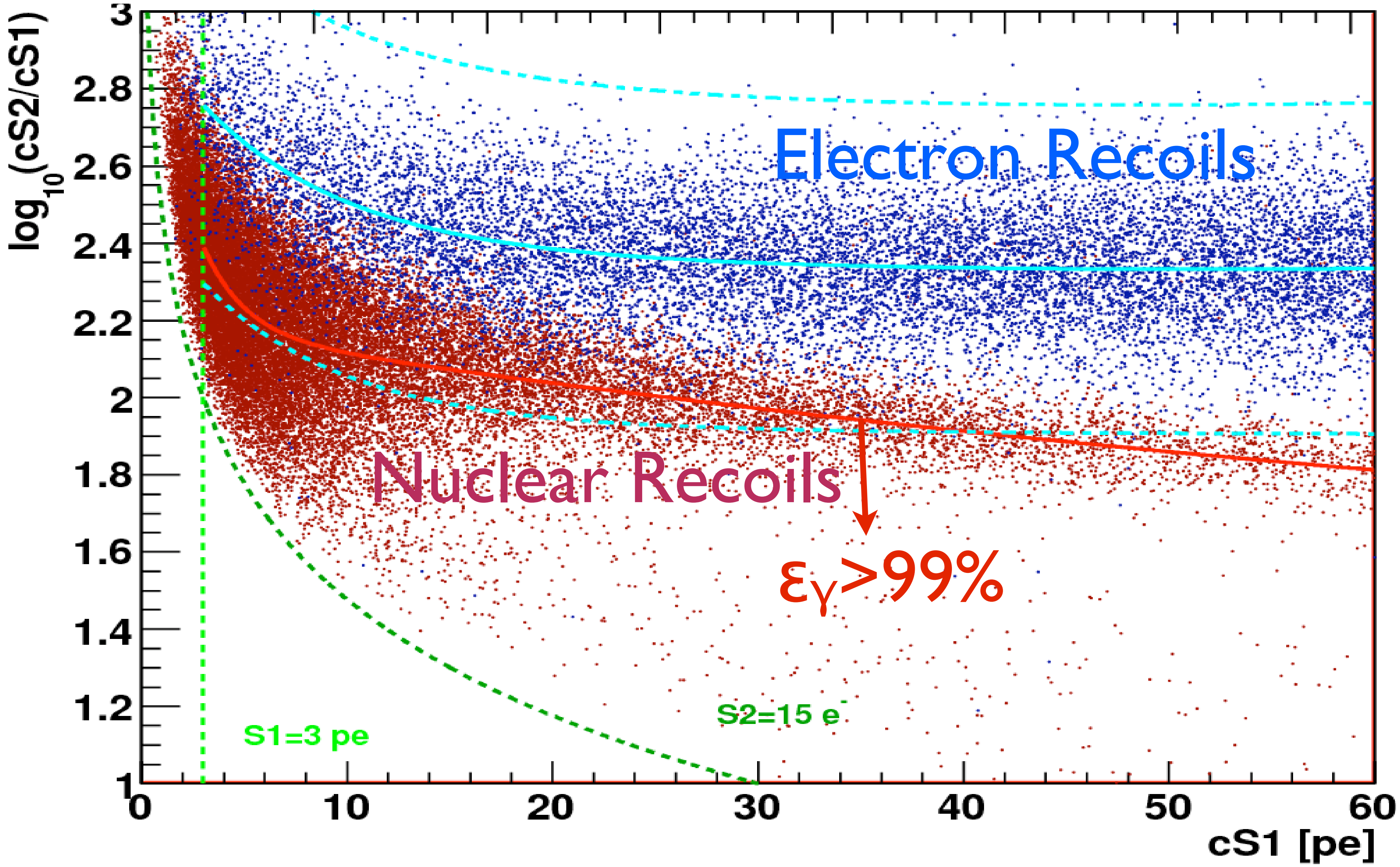


Phys.Rev.Lett.105, 131302 (2010)

Measured background rate in XENON100



electron recoil background rejection by S2/S1

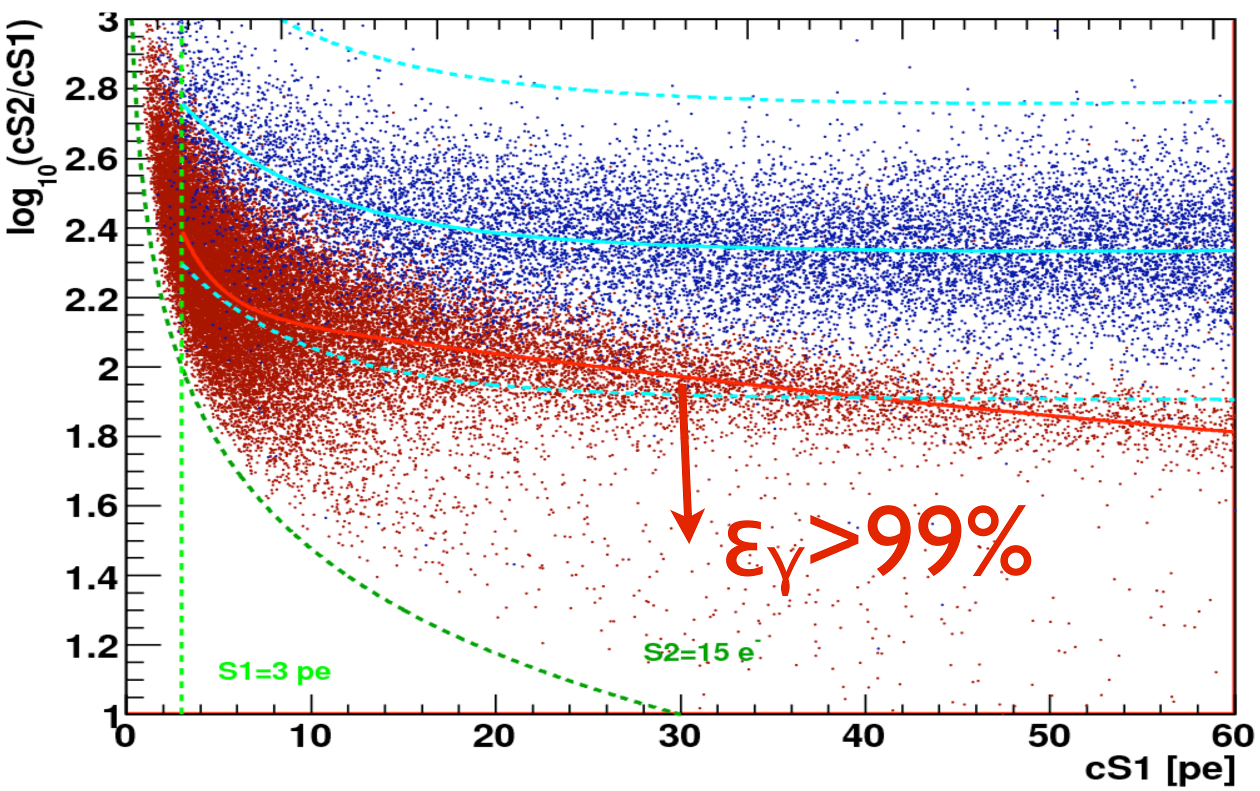


more than 99% electron recoil events are rejected with 50% acceptance of nuclear recoil events

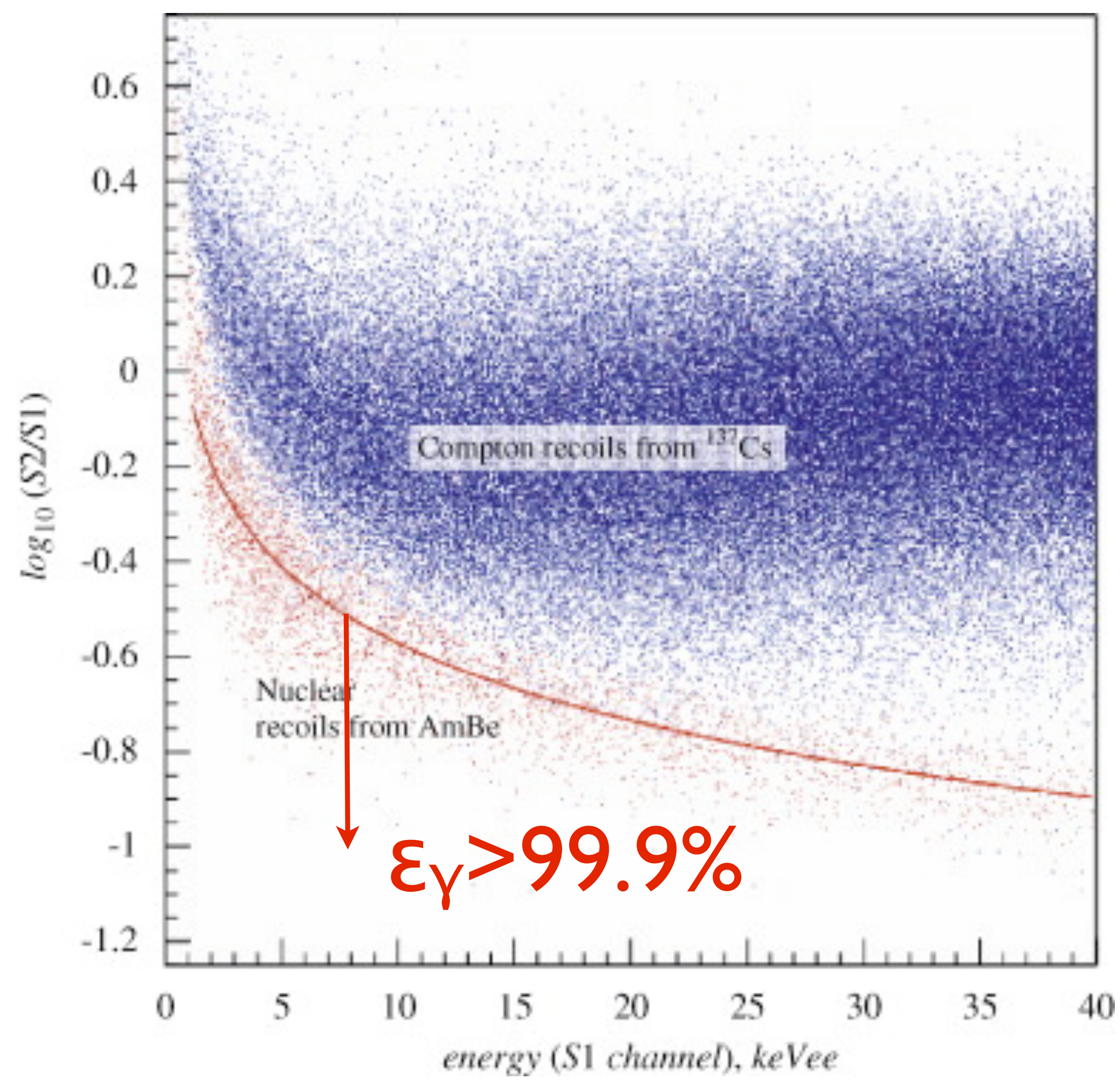
K. Ni (SJTU)

higher drift field, higher electron recoil rejection

XENON100: E = 0.5 kV/cm

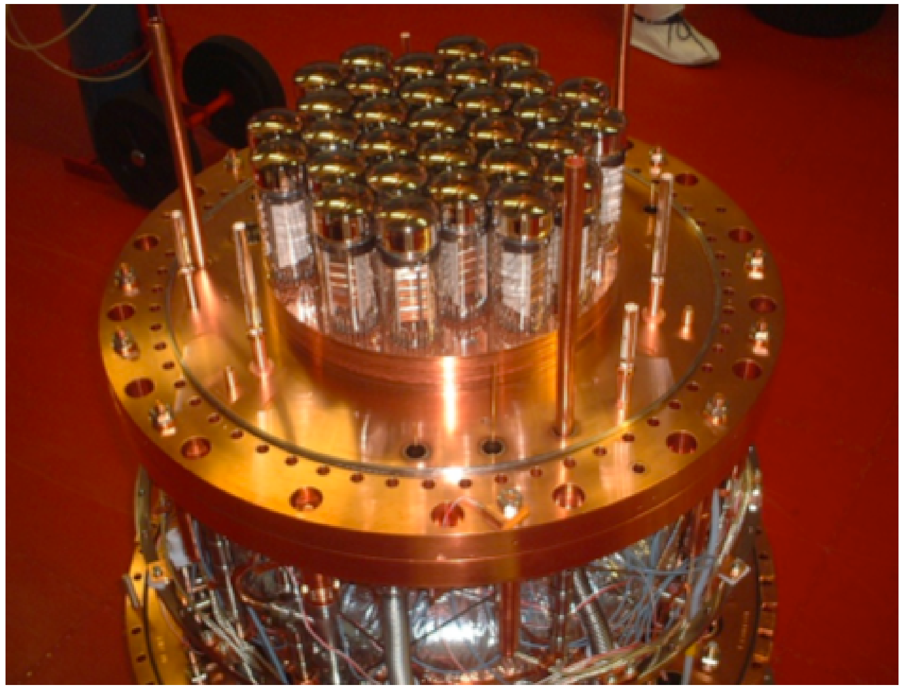


ZEPLIN III: E = 3.9 kV/cm



Current Experimental Status

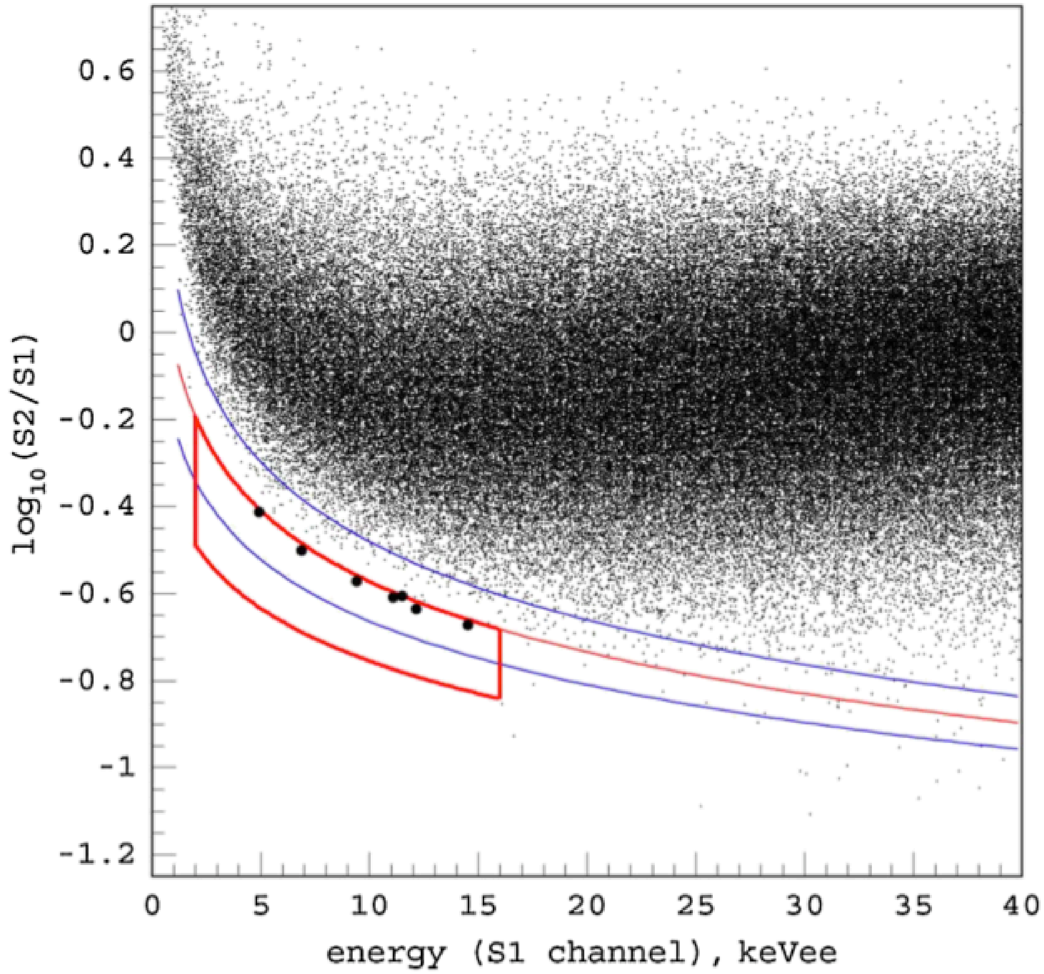
ZEPLIN III: *first science run results*



- $\sim$30 cm $\varnothing$ and 3.6 cm drift depth

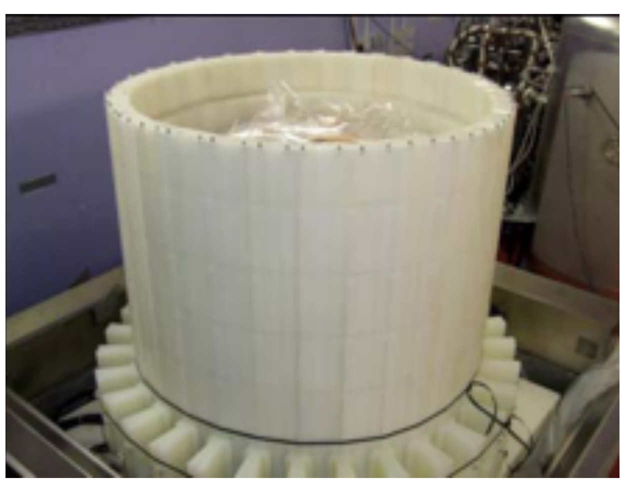
$\rightarrow$ high E-field 3.9 kV per cm

- 0.5 cm electroluminescent gap
- 31 $\times$ 2 inch PMTs
- 12 kg active target mass



- 83 d operation with 84% livetime @ **Boulby**
- 267.9 kg d effective fiducial exposure
- 7 events in the box with 11$\pm$3 events expected bg

ZEPLIN III: second science run with upgraded detector



- *31 new ultra-low background PMTs from ETEL, bkg reduction by 1/20*
- *upgraded calibration system*
- *new anti-coincidence veto system installed*

800 kg-day raw data has accumulated for the second science run.

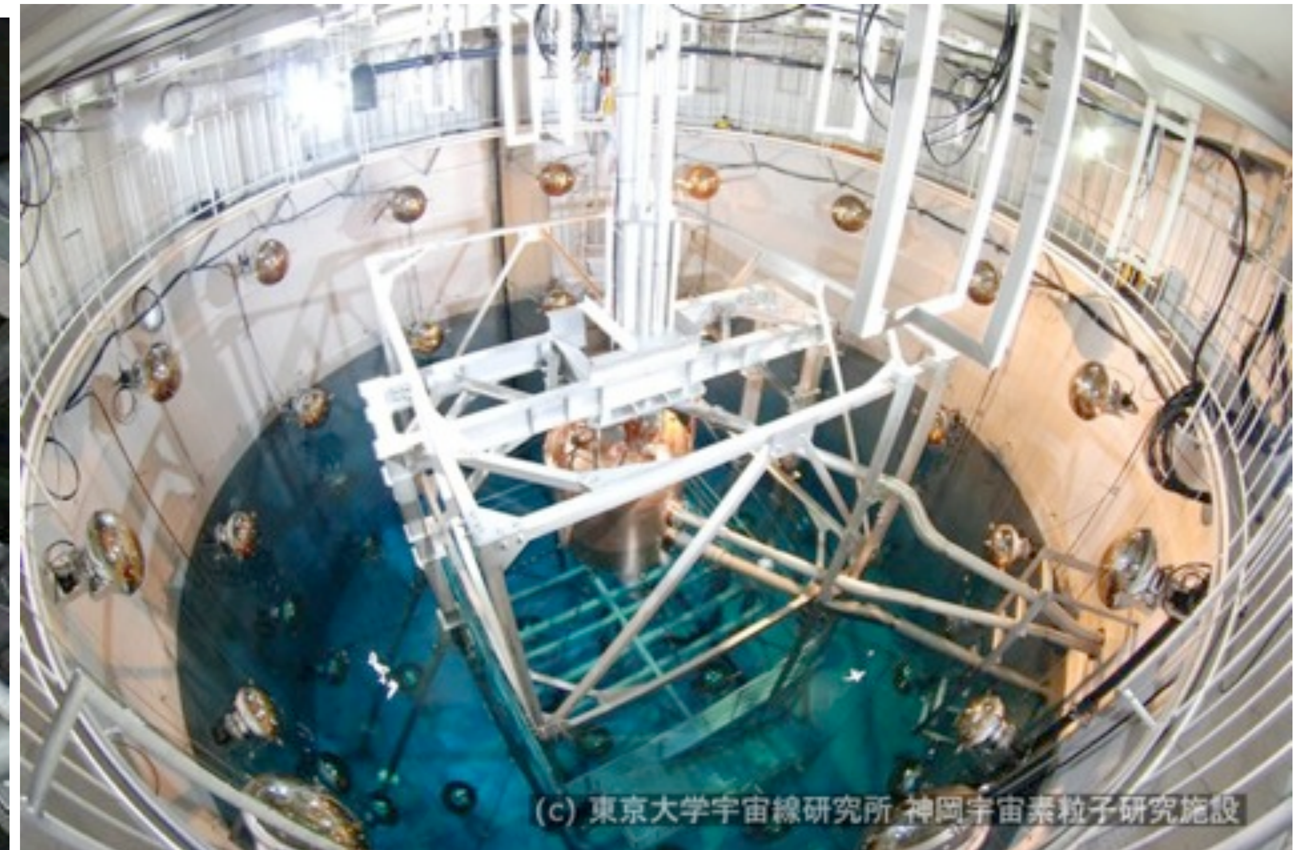
XMASS: ready to take science data soon

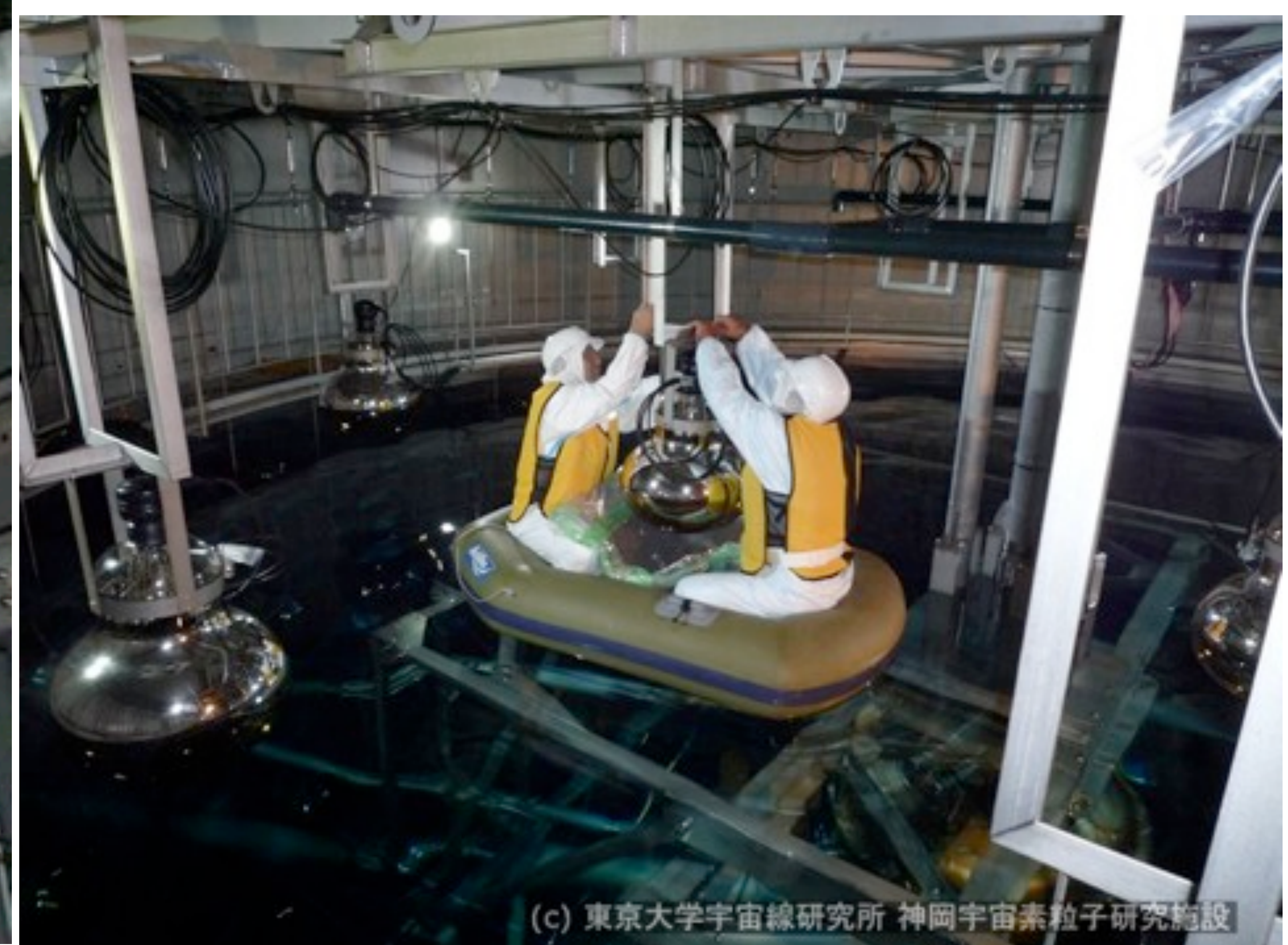
PMT Holder

OFHC Filler

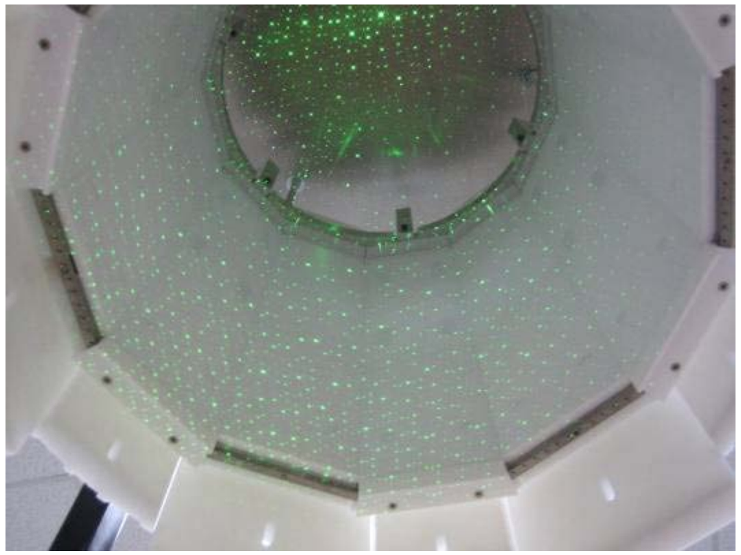
Masaki Yamashita


(c) 東京大学宇宙線研究所 神岡宇宙素粒子研究施設

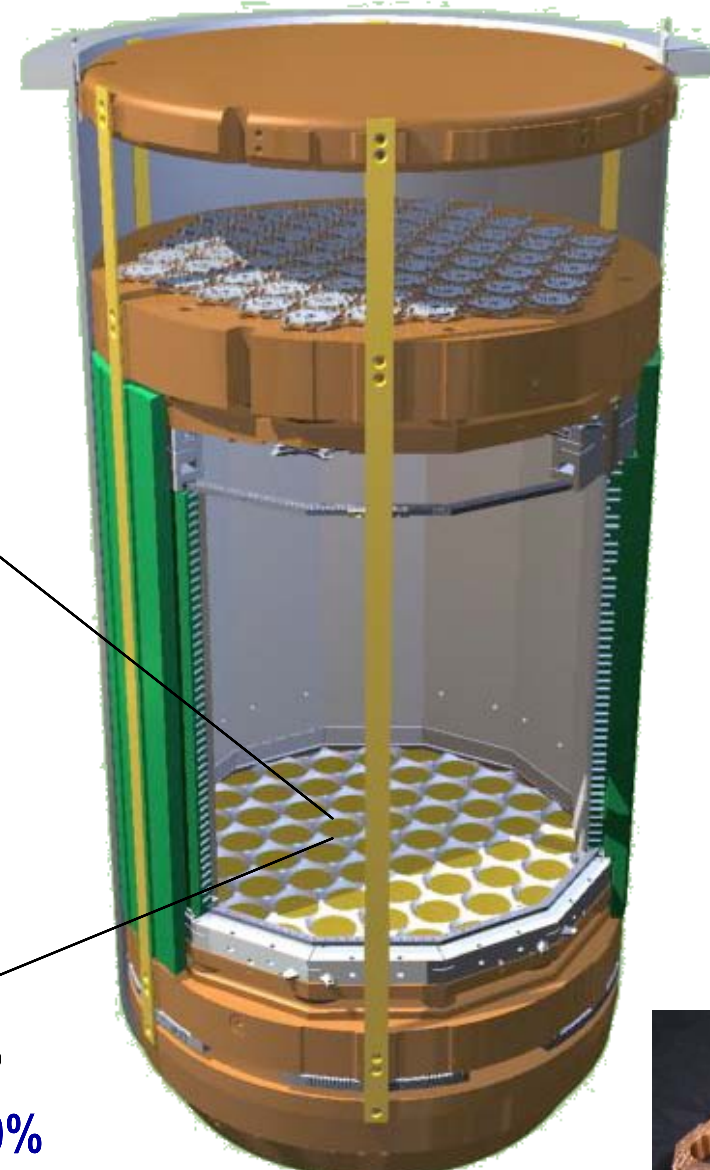

(c) 東京大学宇宙線研究所 神岡宇宙素粒子研究施設


(c) 東京大学宇宙線研究所 神岡宇宙素粒子研究施設

LUX: detector assembled



- HV Grids in place and tested



- 122 2" PMT R8778
  - 175 nm, QE > ~30%
  - U/Th ~10/2 mBq/PMT
  - All tested in LUX 0.1 program

- Dodecagonal field cage + PTFE reflector panels

- Copper PMT holding plate

Assembly taking place at Sanford Surface Lab since Spring 2010

LUX: detector operation at surface facility

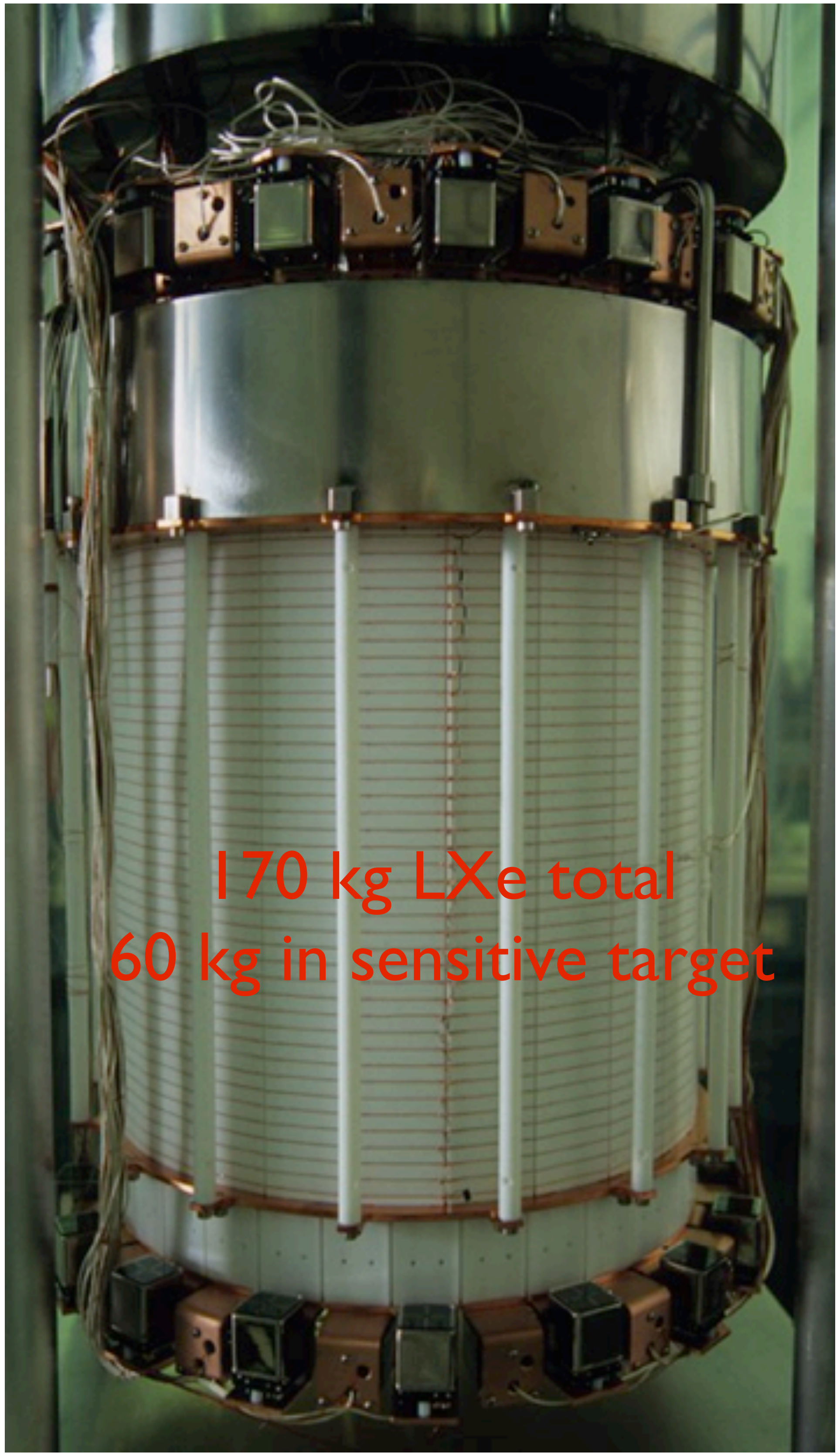
LUX: underground lab ready in 2011

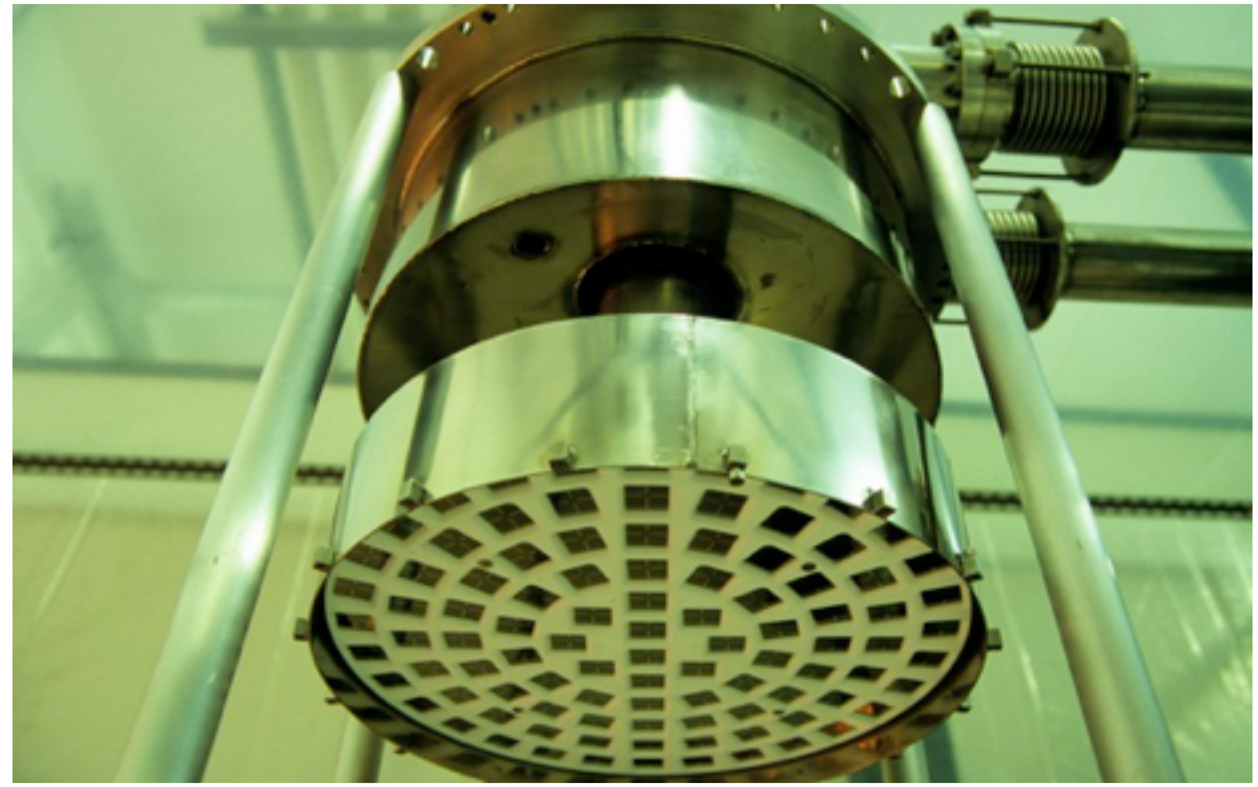
- Aug 24 2009: Equipment commissioning complete
- Aug 31 2009: Began excavation of new drift
- Sep 10 2009: Steel structures removal complete
- Nov 15 2009: Detailed Construction Docs 95% complete
- Jul 2010: Excavation complete

now

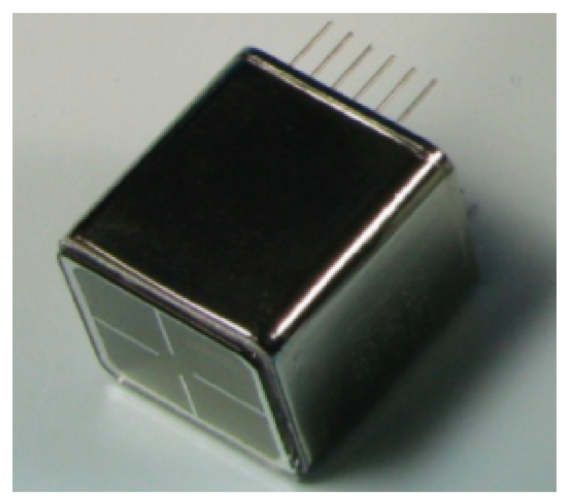
- Sep 2010: Rock support & wall finish complete
- Oct 2010: Begin Lab outfitting
- Jul-Oct 2011: Lab ready

XENON100: the most advanced Xe dark matter experiment

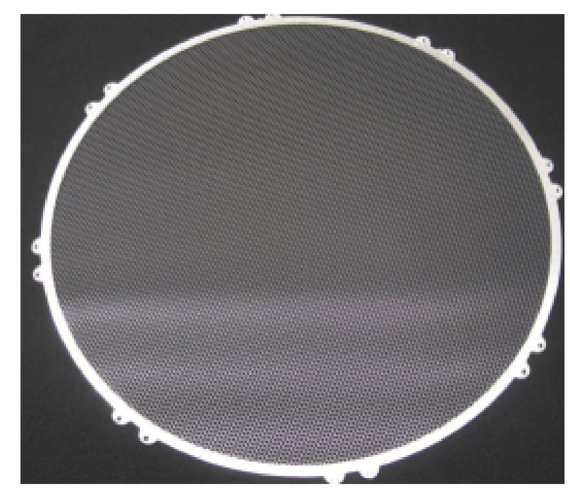




242 low activity PMTs



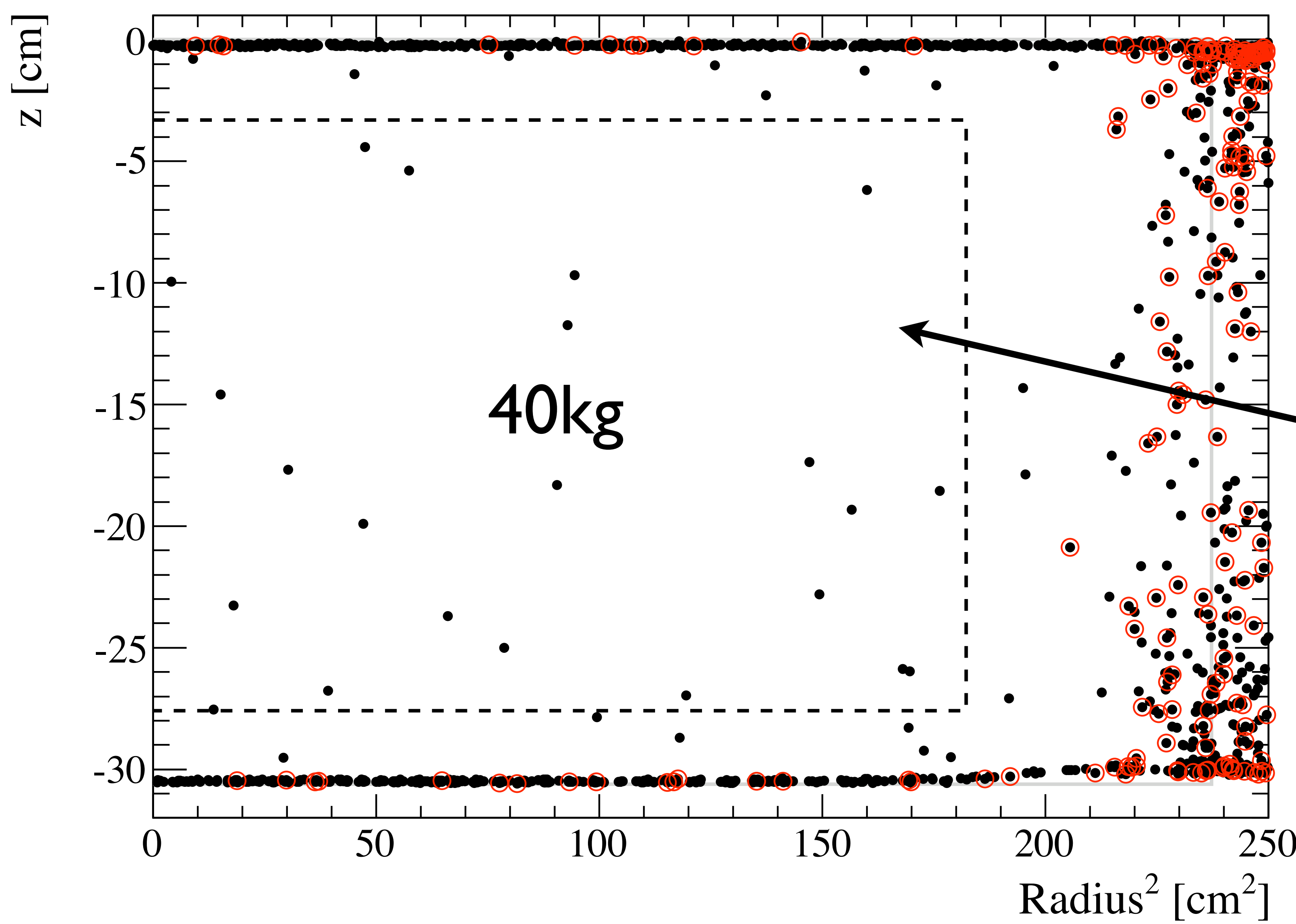
1 inch PMTs

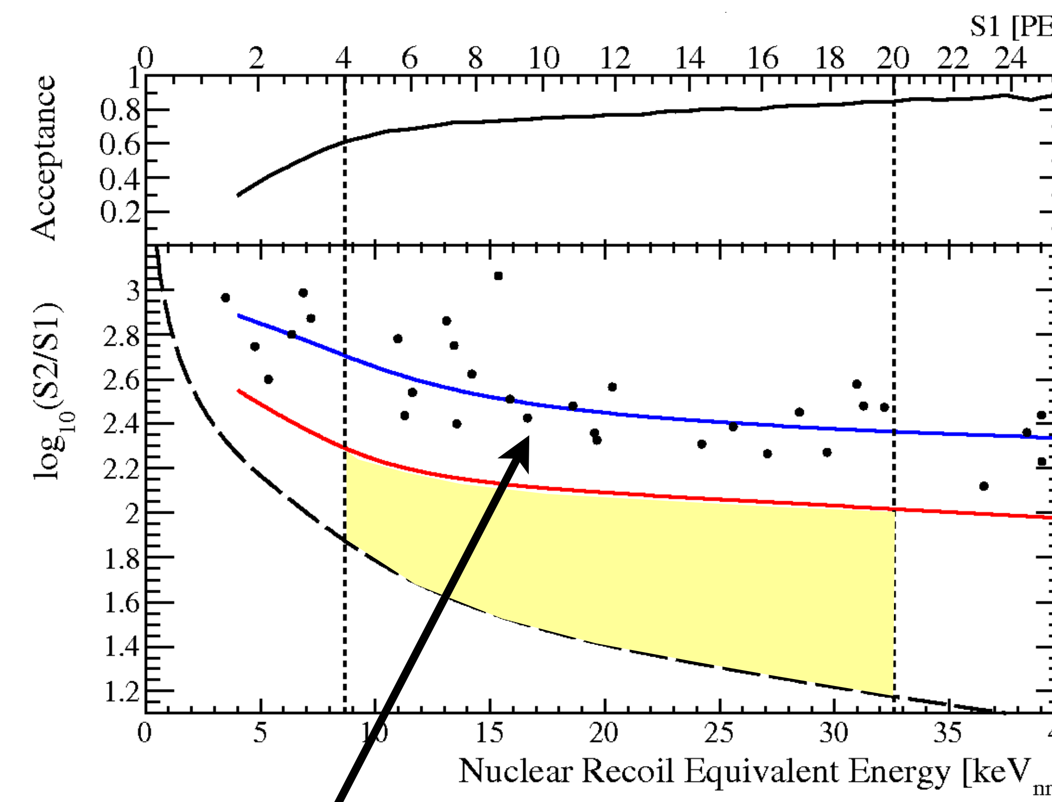


30 cm ⌀ meshes

background reduction by fiducial volume selection

11.2 live-day background data
(Oct-Nov,2009)





22 events in the fiducial volume are all electron recoil events, no WIMP candidate observed

K. Ni (SJTU)

Achieved upper limits

“hot” low-mass wimps and debates:
1002.4703, 1005.0838,1005.2615
1005.3723,1006.0972, 1006.2031
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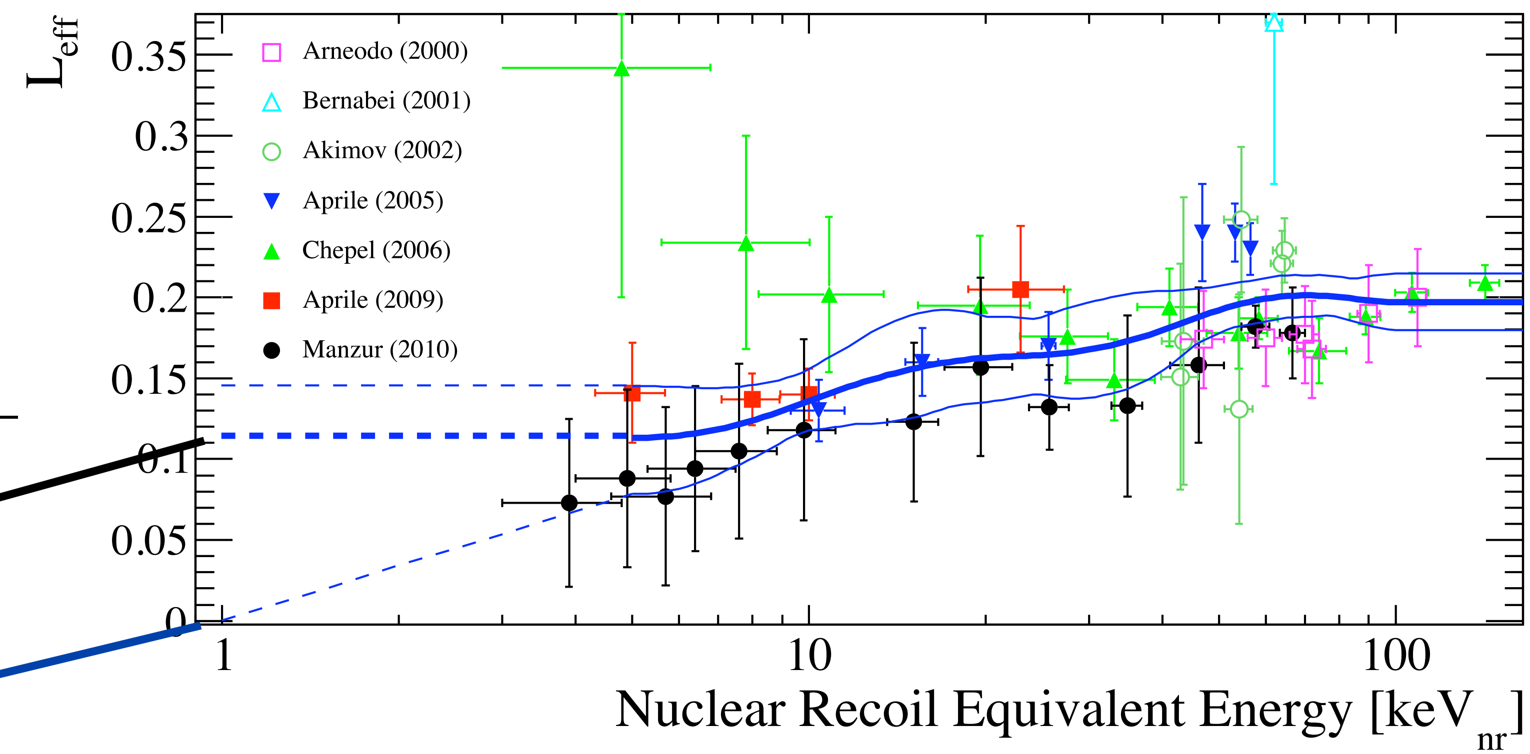
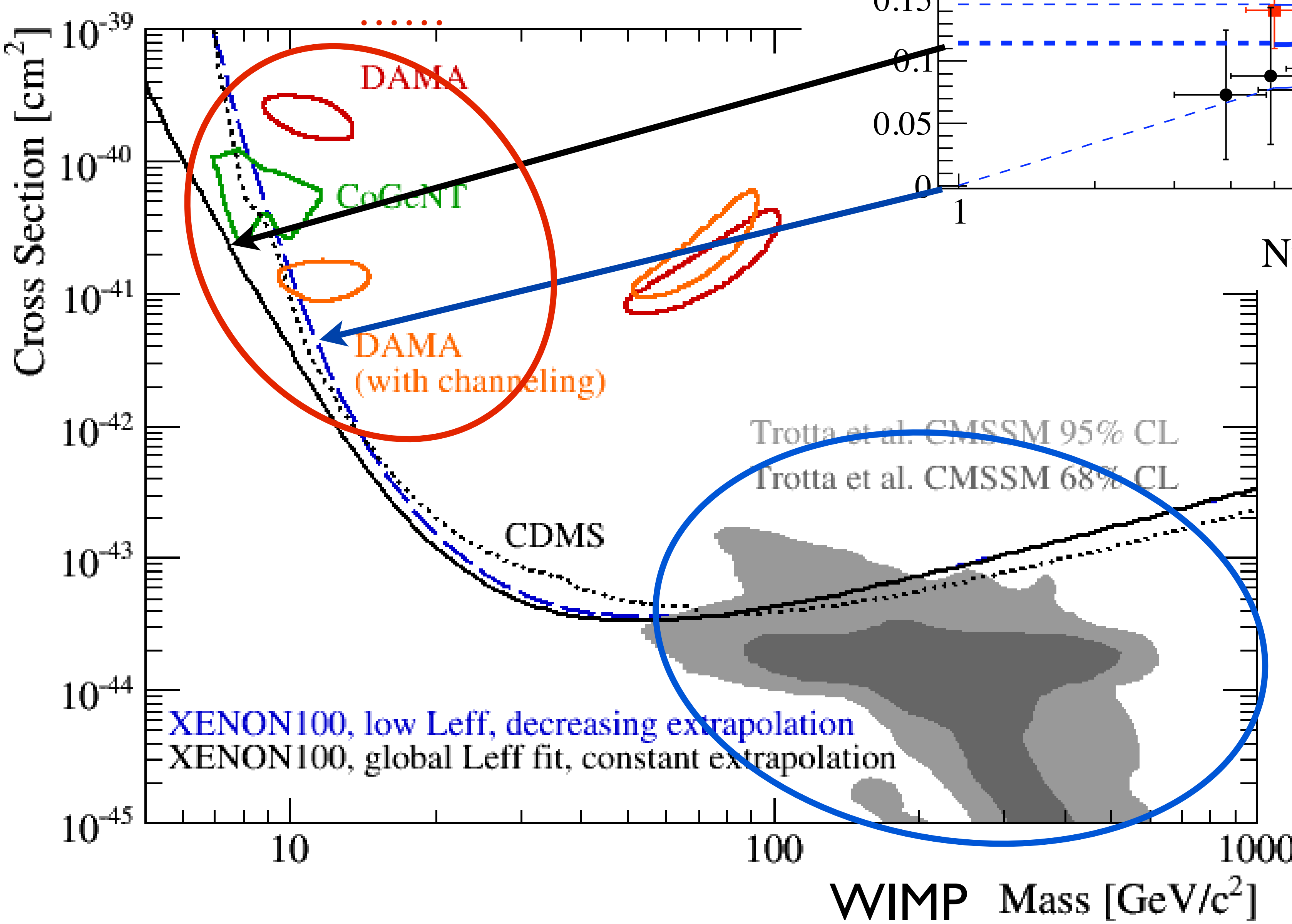




achieved competing sensitivity for “normal” mass WIMPs

Phys.Rev.Lett.105, 131302 (2010)

Energy Calibration: determine the energy of nuclear recoils

energy of nuclear recoils (NRs)

measured signal in # of pe

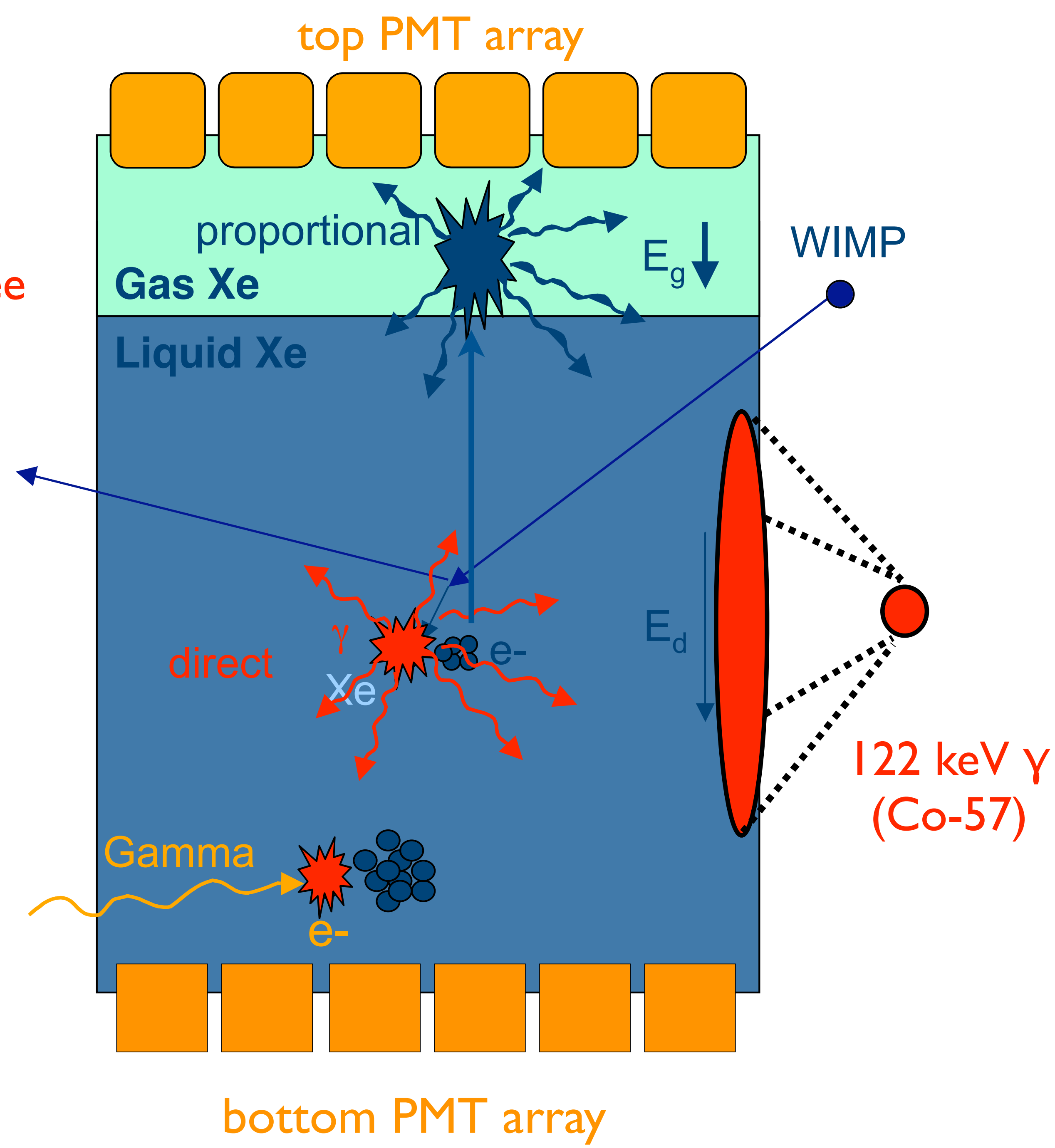
light yield for 122 keV γ in pe/keVee
(detector dependent)

$$E_{nr} = S1/L_y/\mathcal{L}_{eff} \cdot S_{er}/S_{nr}$$

relative scintillation efficiency of NRs to 122 keV γ's at zero field (large uncertainty at low energy)

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

quenching of scintillation yield for NRs due to drift field



K. Ni (SJTU)

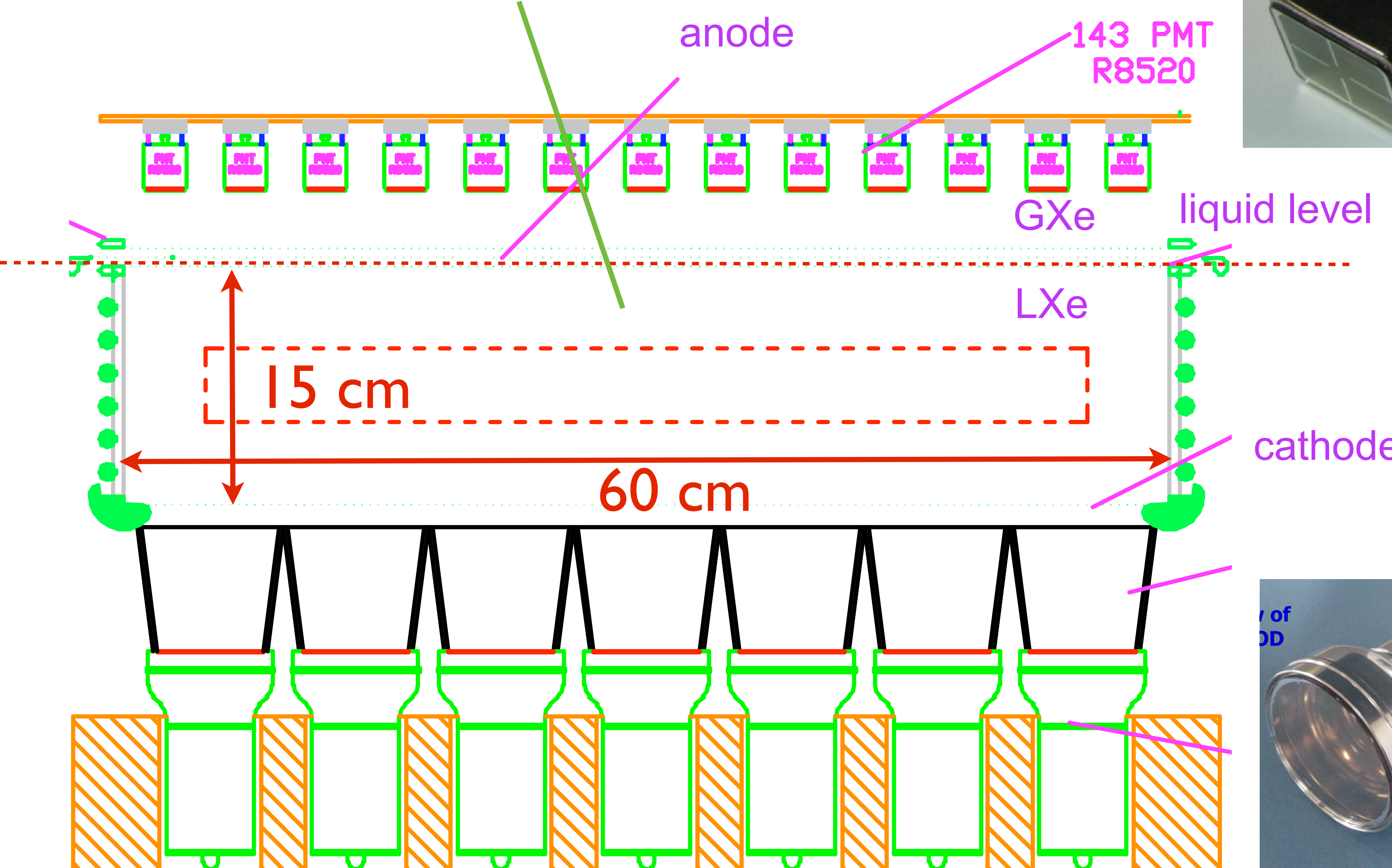
How to improve our knowledge of low-mass WIMPs with liquid xenon experiments?

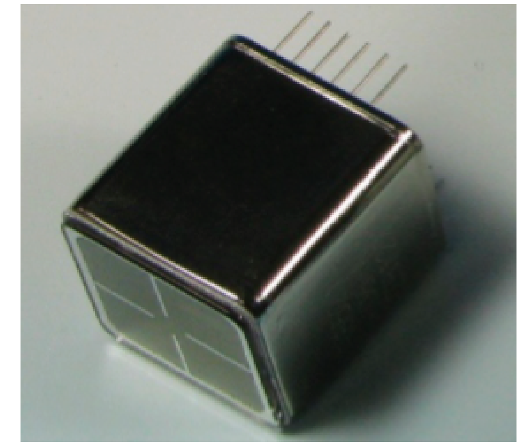
- Increase dark matter search exposure
  - XE100 has accumulated more than 100 live-days new data (new release soon)
- Precise measurement of L_{eff} at low energy
  - efforts ongoing at Columbia and Zurich universities
- Improve L_y of the detector
  - initiative of the PandaX experiment

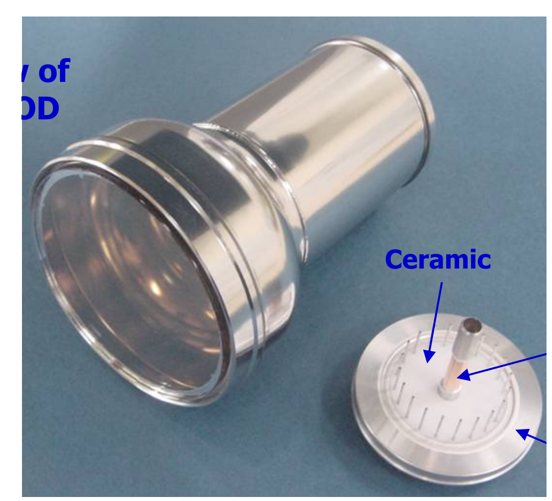
PandaX: a liquid xenon detector with high light yield

total mass：300 kg

sensitive mass：123 kg

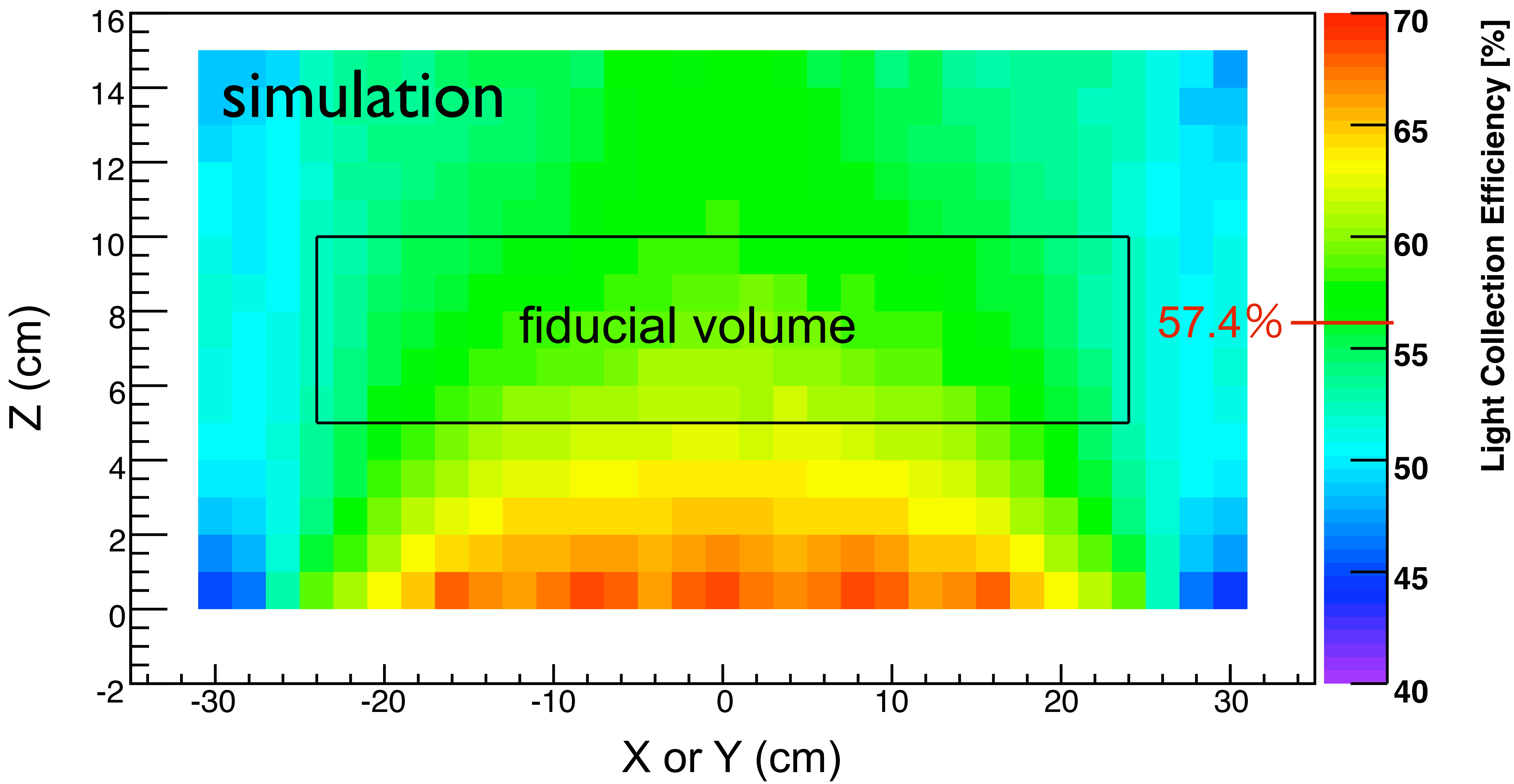






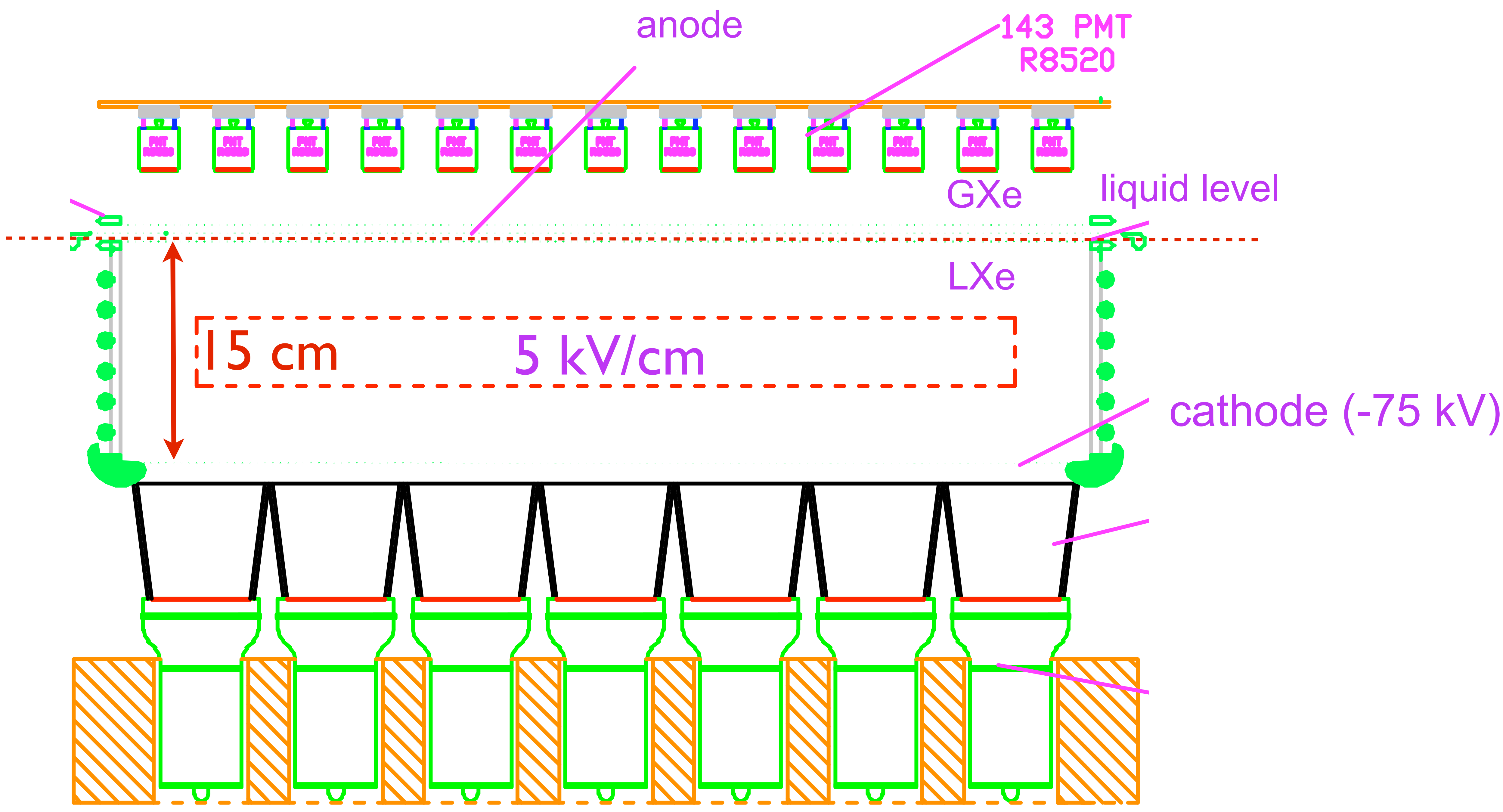
37 R11410 PMT

Pancake design improves the L_y significantly



The light yield in the fiducial volume is 57%, about 2.4 times of that for XE100

a liquid xenon detector with high drift field



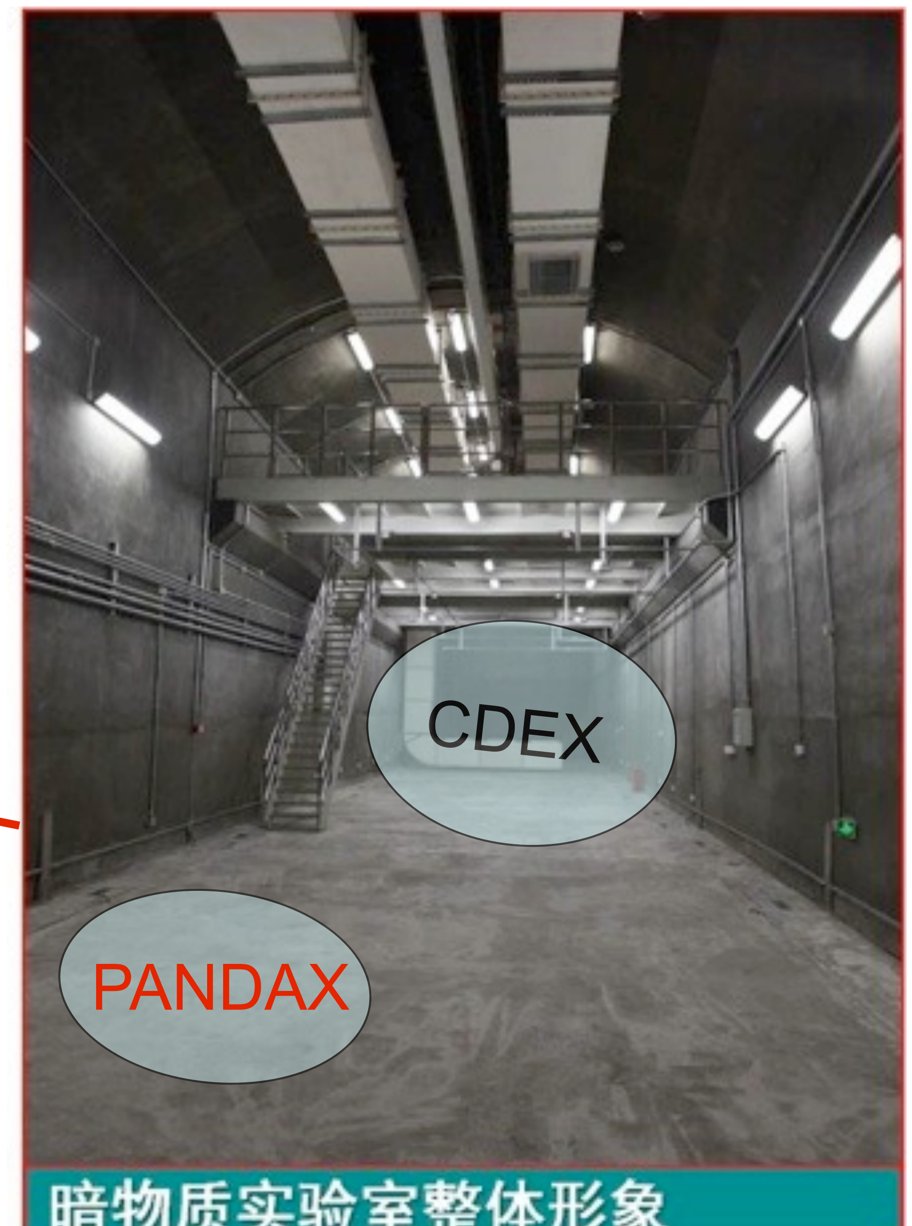
Like ZEPLIN III, PandaX will use high field operation.
Expected electron-type background rejection >99.9%

The PANDAX experiment at CJPL

PandaX

Particle and Astrophysics Xenon Observatory

- *Shanghai Jiao Tong University*
- *Shanghai Institute of Applied Physics, CAS*
- *Shandong University*

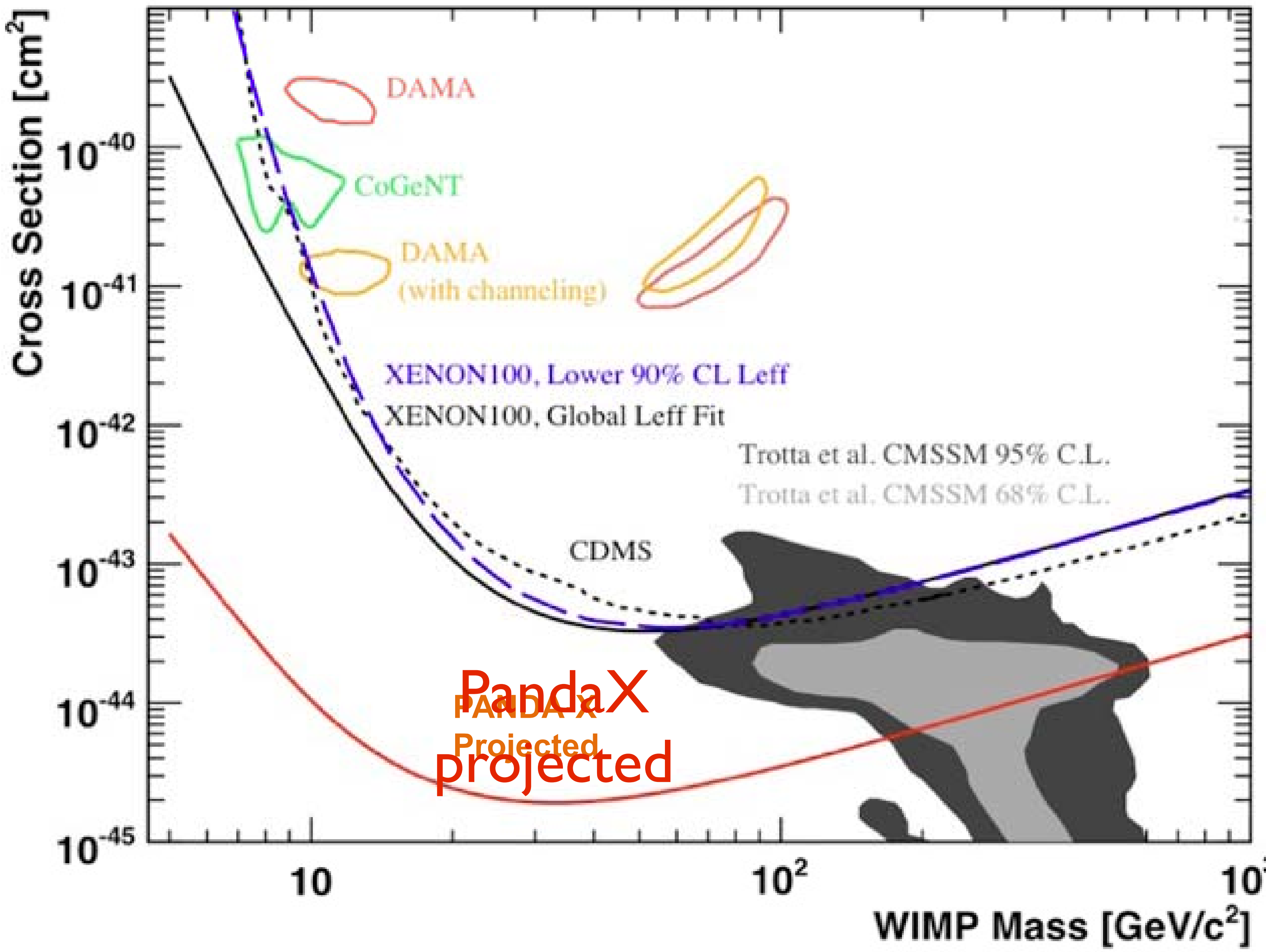


CJPL (China Jin-Ping Laboratory) is located in Sichuan province. It has 2500 m rock overburden, developed by Tsinghua University and Ertan Hydropower company.

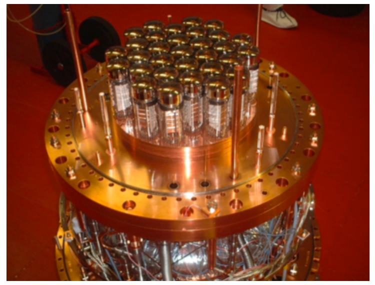
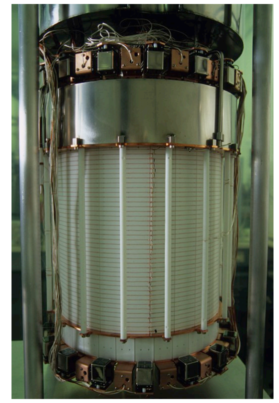
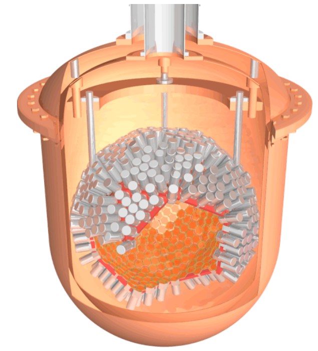
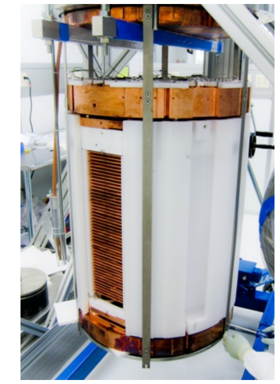
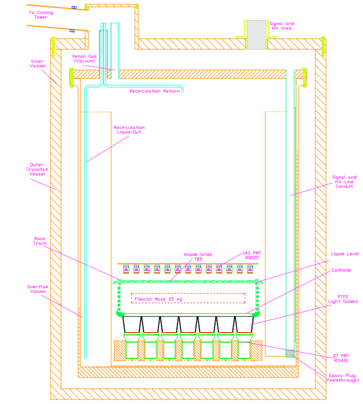
PandaX: Expected sensitivity

Assumptions:
- 5.5 PE/keV
- Energy range: 3-30 PE
- 200 day × 25 kg exposure

zero background



Summary of the experiments

	ZEPLIN III	XENON100	XMASS	LUX	PandaX
active target mass (kg)	12	~60	~800 (100)	~300	~120
electron recoil rejection	99.9%	99%	0	99%	99.9%
energy threshold (keVr)	10	9	20	10	5
sensitivity at 100 GeV (cm^2)	$\sim 10^{-44}$	2×10^{-45}	1×10^{-45}	3×10^{-46}	4×10^{-45}
sensitivity at 10 GeV (cm^2)	$>10^{-42}$	3×10^{-43}	$> 10^{-42}$	4×10^{-44}	1×10^{-44}
status	science run	science run	operation	surface testing	construction

Conclusion

Liquid Xenon is a mature technology for dark matter search.

With new science data coming from ZEPLIN III and XENON100, and new experiments (XMASS, LUX, PandaX) joining the effort, we may uncover the nature of dark matter soon!