R&D on Xe136 0vββ search with Particle AND Astroparticle Xenon Observatory

Xiang Liu
Institute of Nuclear, Particle, Astronomy and Cosmology
Shanghai Jiaotong University

On behalf of the PandaX collaboration

International workshop on DBD and neutrino
Nov. 15-17, Osaka, Japan

A little bit MC
~~R&D~~ on Xe136 0νββ search with Particle AND Astroparticle Xenon Observatory

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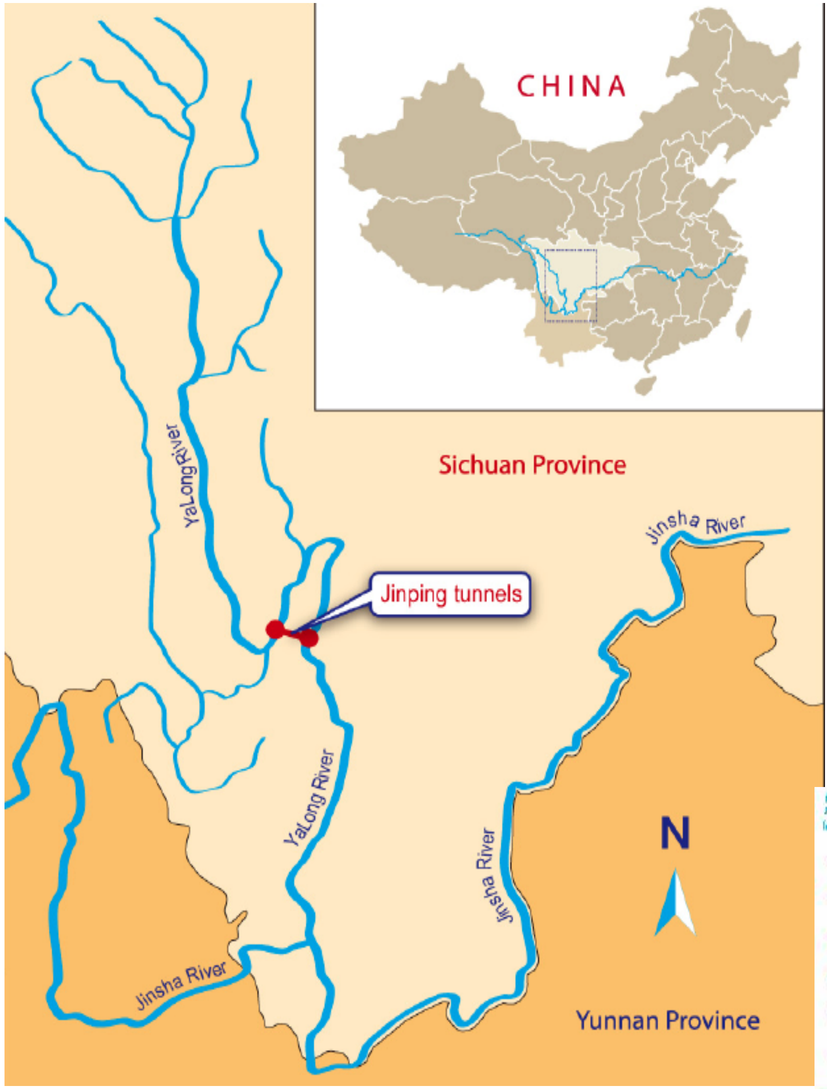
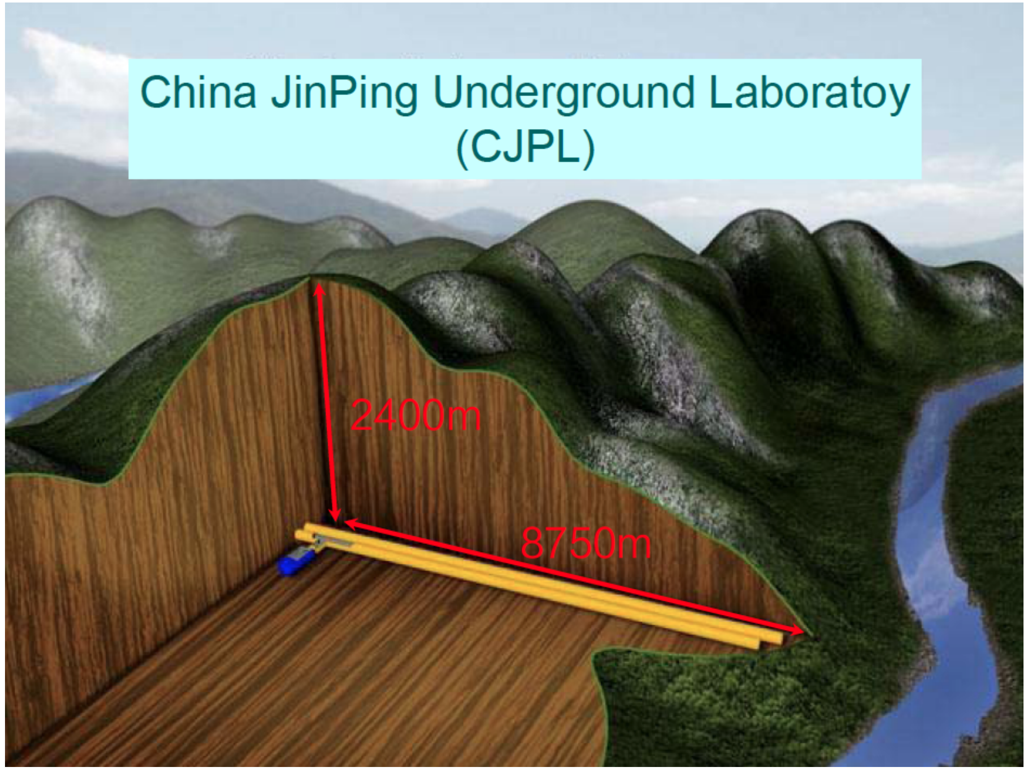
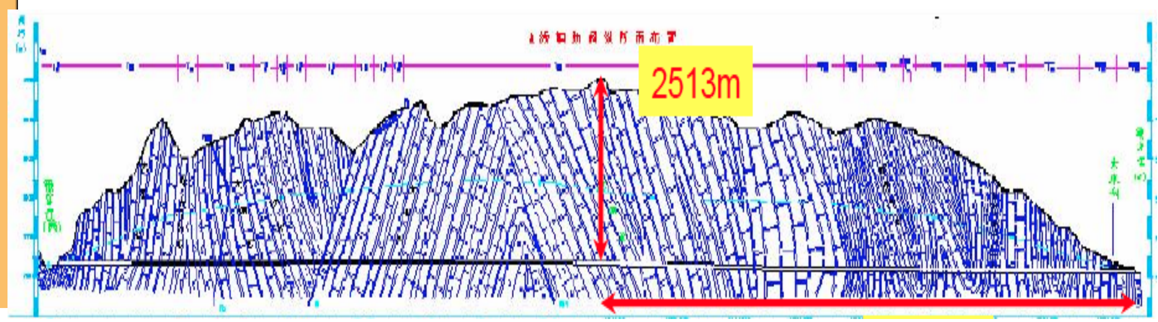
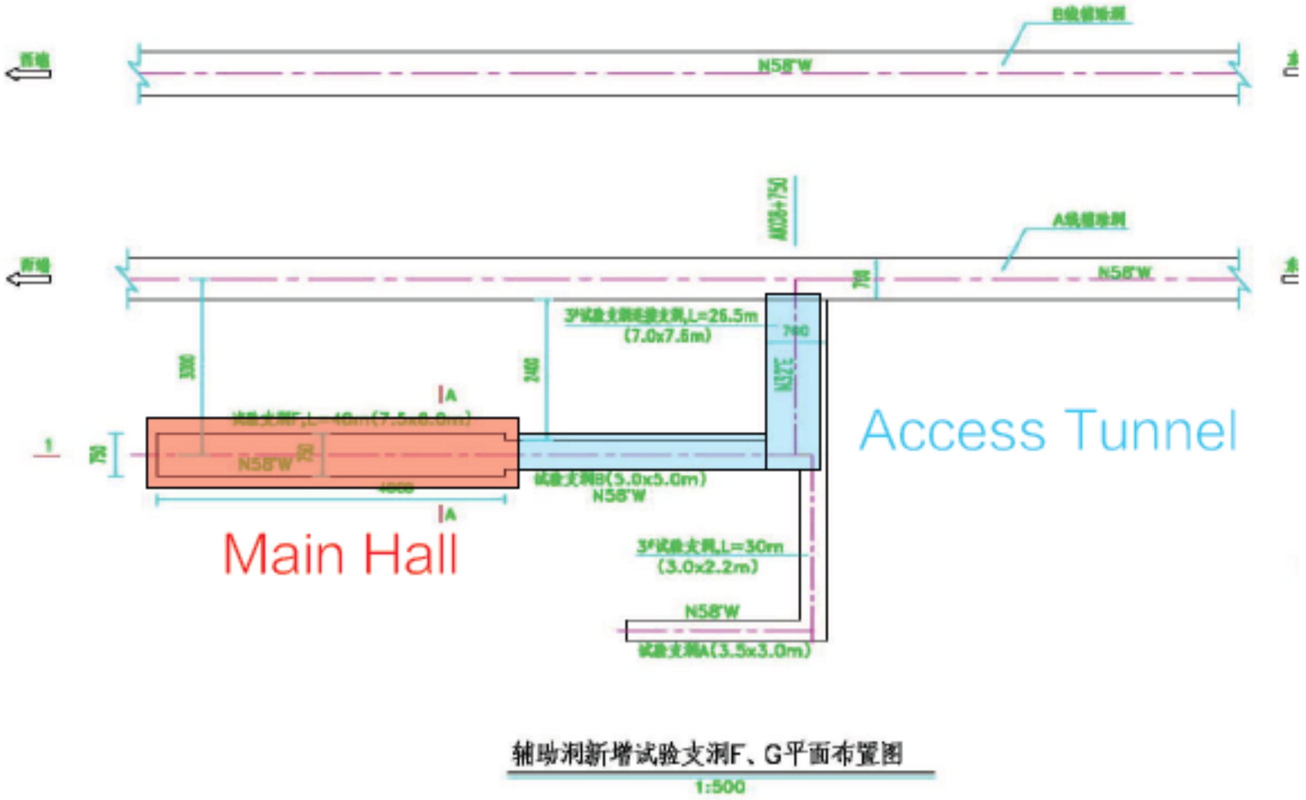
PANDAX at CJPL







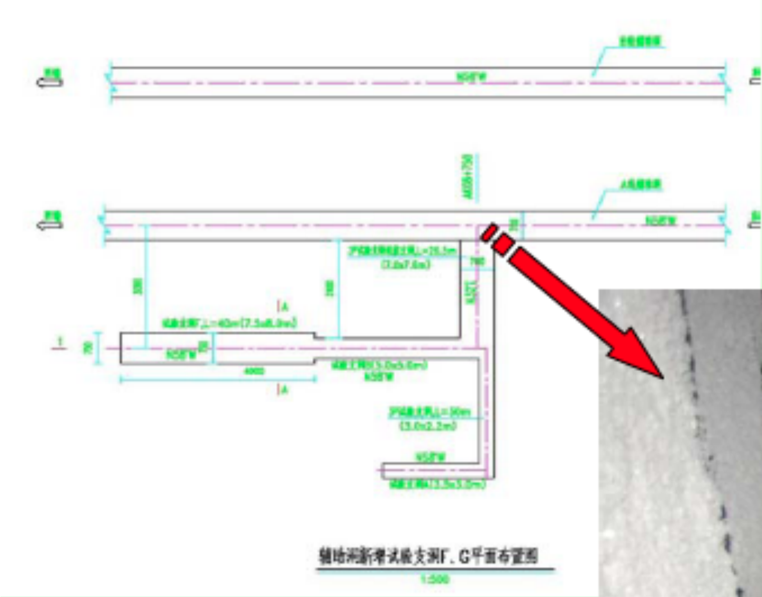
The Layout of CJPL-I

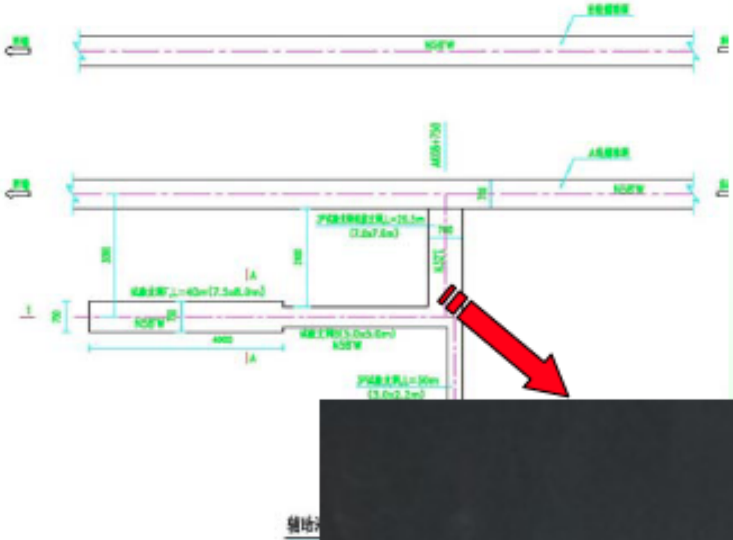


- **Main hall: 6.5*6.5*40m**
- **Total Volume: ~4000m^3**

From Qian Yue

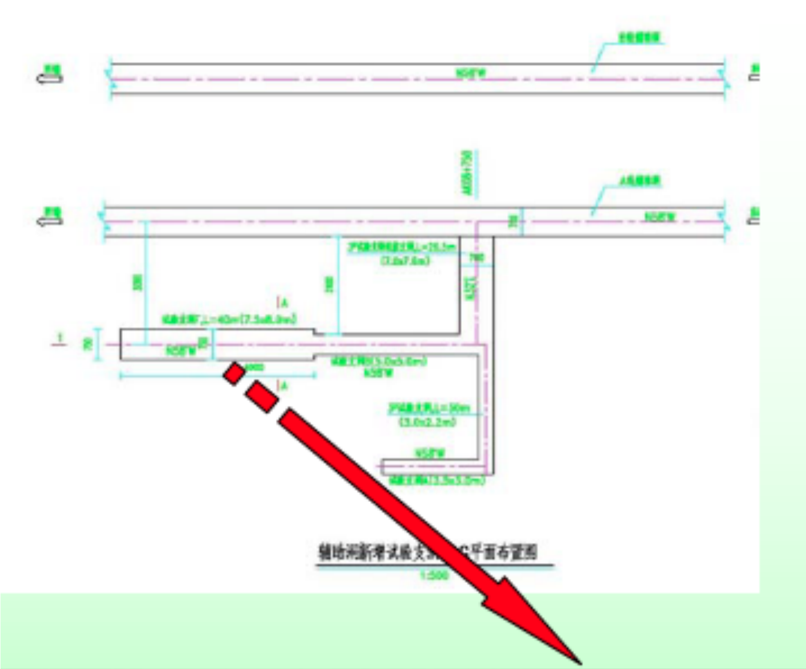
Dig the tunnel for CJPL in July,2009





Aug., 2009

2011-4-14



Jan., 2010


2010/01/27


2010.02.24


2010/04/24

2010/04/24

2010/04/27

2010/04/28

The main hall of CJPL in June 2010

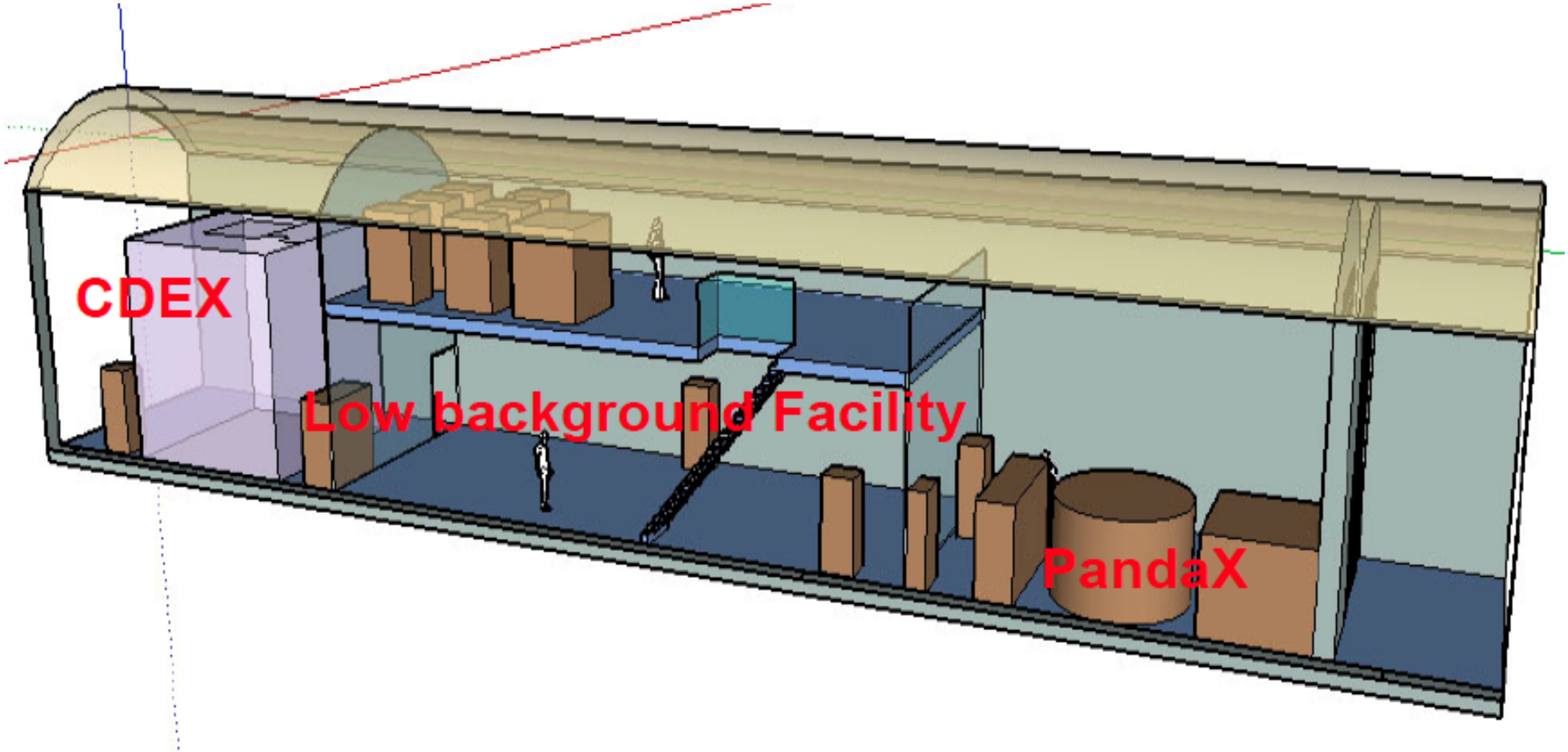
CJPL cosmic muon and rock

~7500 m.w.e.
cosmic muon <100/m^2 year

Bq/kg	Ra226 (U238)	Th232	K40
CJPL	1.8±0.2	<0.27	<1.1
LNGS*	5.4 - 84	0.25 – 8.9	

* E. Bellotti et al., INFN/TC-85/19, October 1985.

Internal space



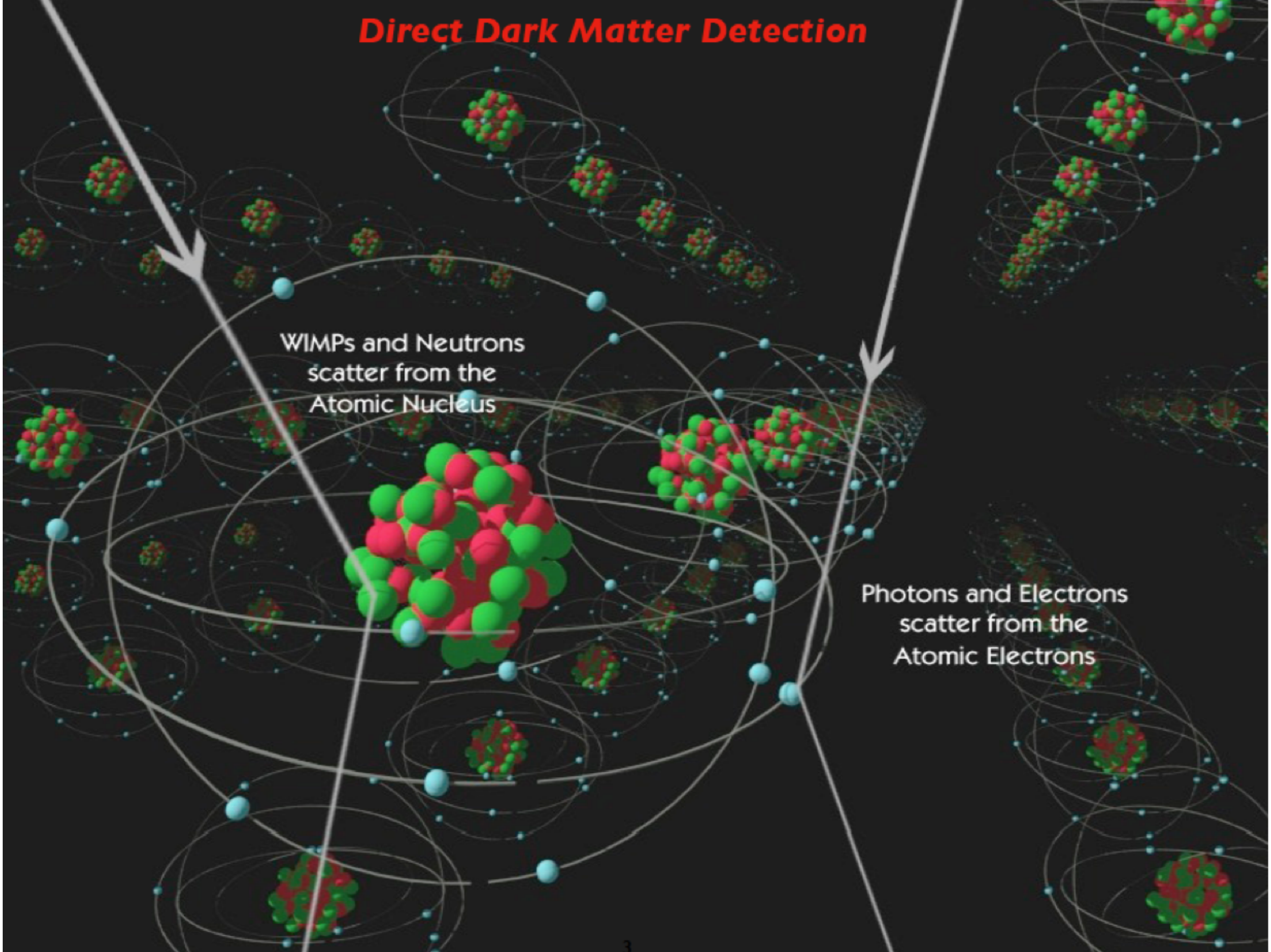
Inside the CJPL

PANDAX collaboration

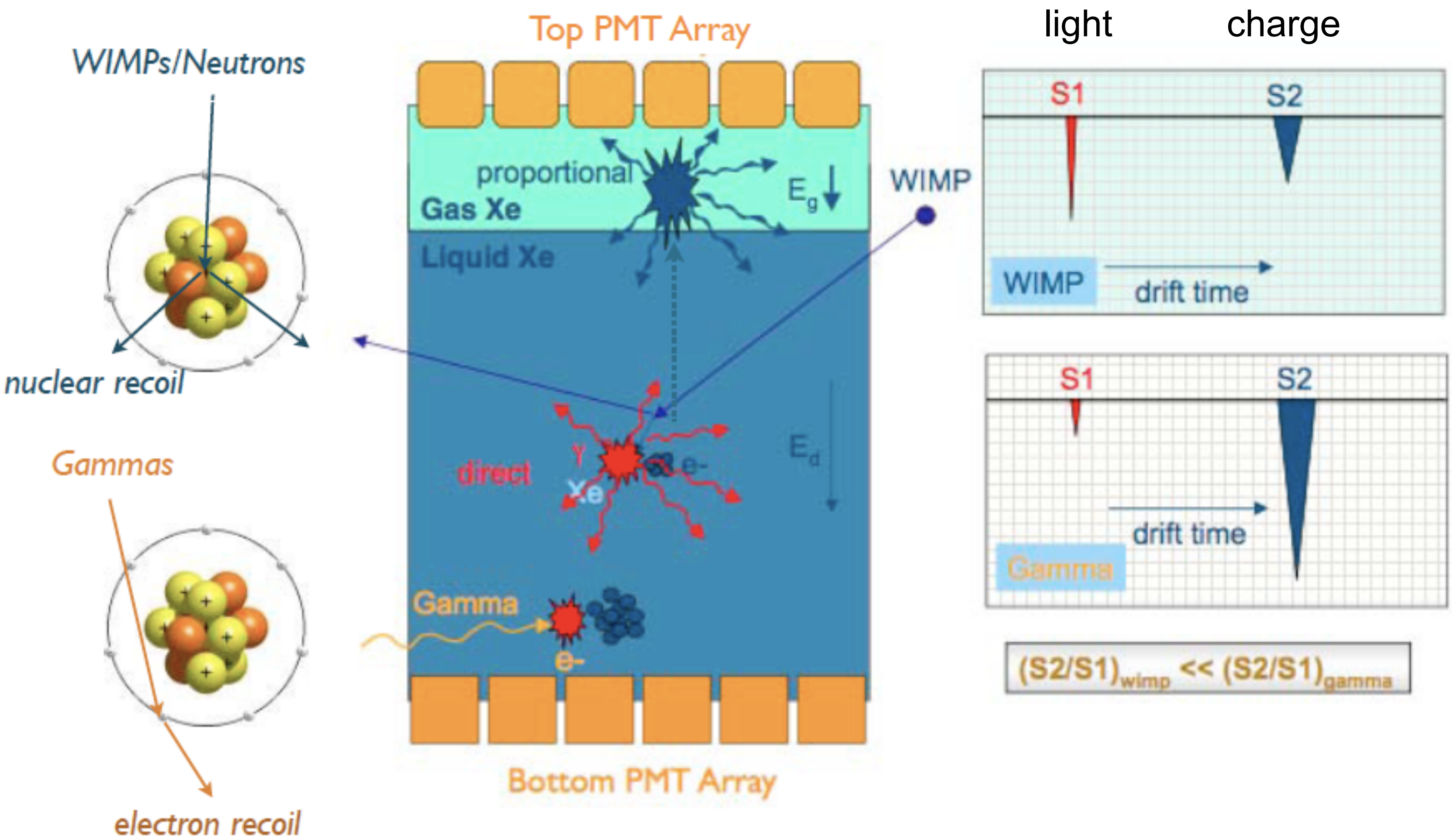
Shanghai Jiaotong University
Shanghai Institute of Applied Physics
Shandong University
Peking University
University of Michigan
University of Maryland

collaboration meeting May 8th, 2011

Direct Dark Matter Detection

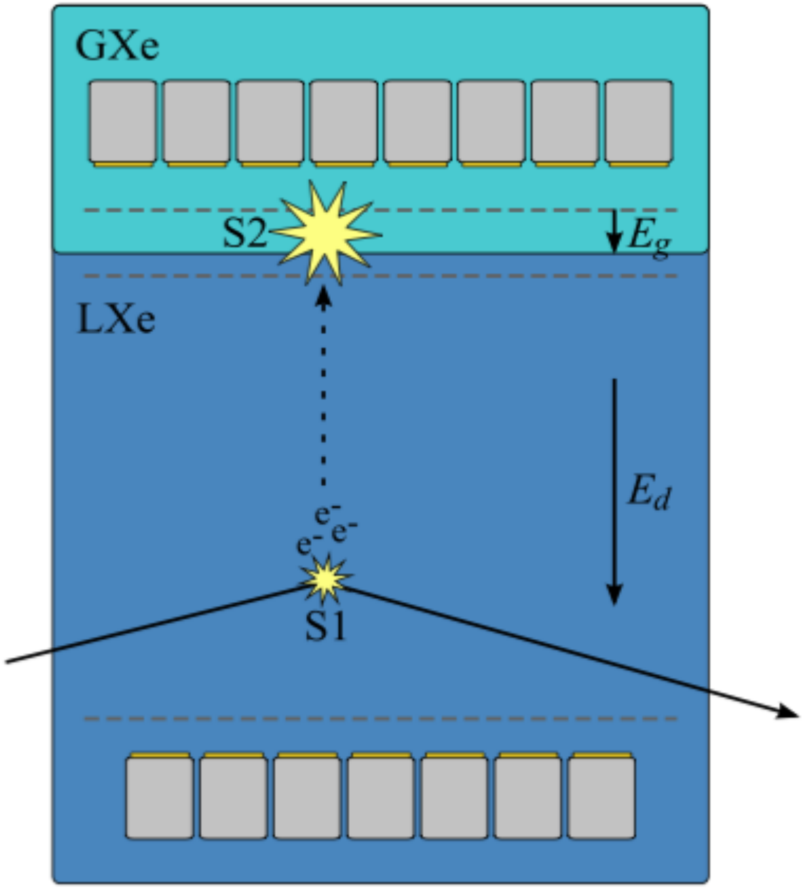


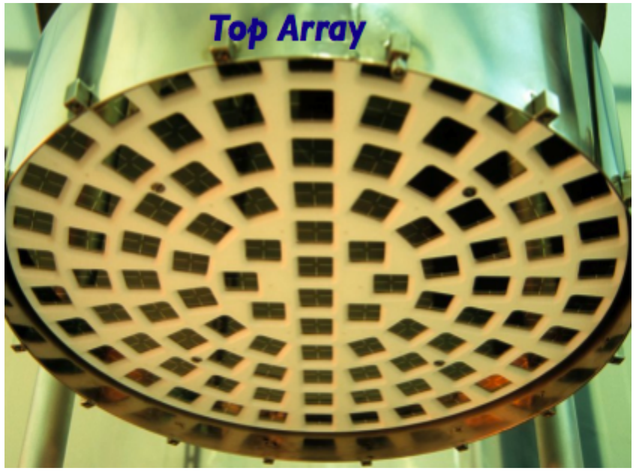
LXe dual-phase TPC



3D position reconstruction

position σ ~3mm
Fiducial volume, self-shielding



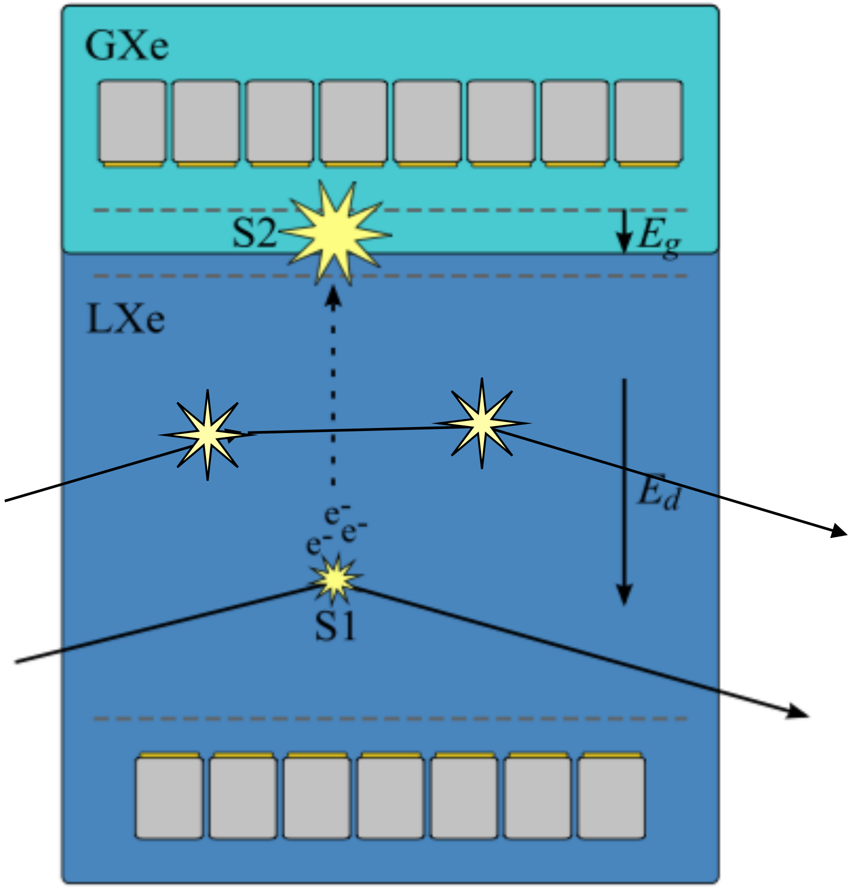


gamma event localized

Top PMT array

XENON100

Dual-phase TPC: single-/multi-site

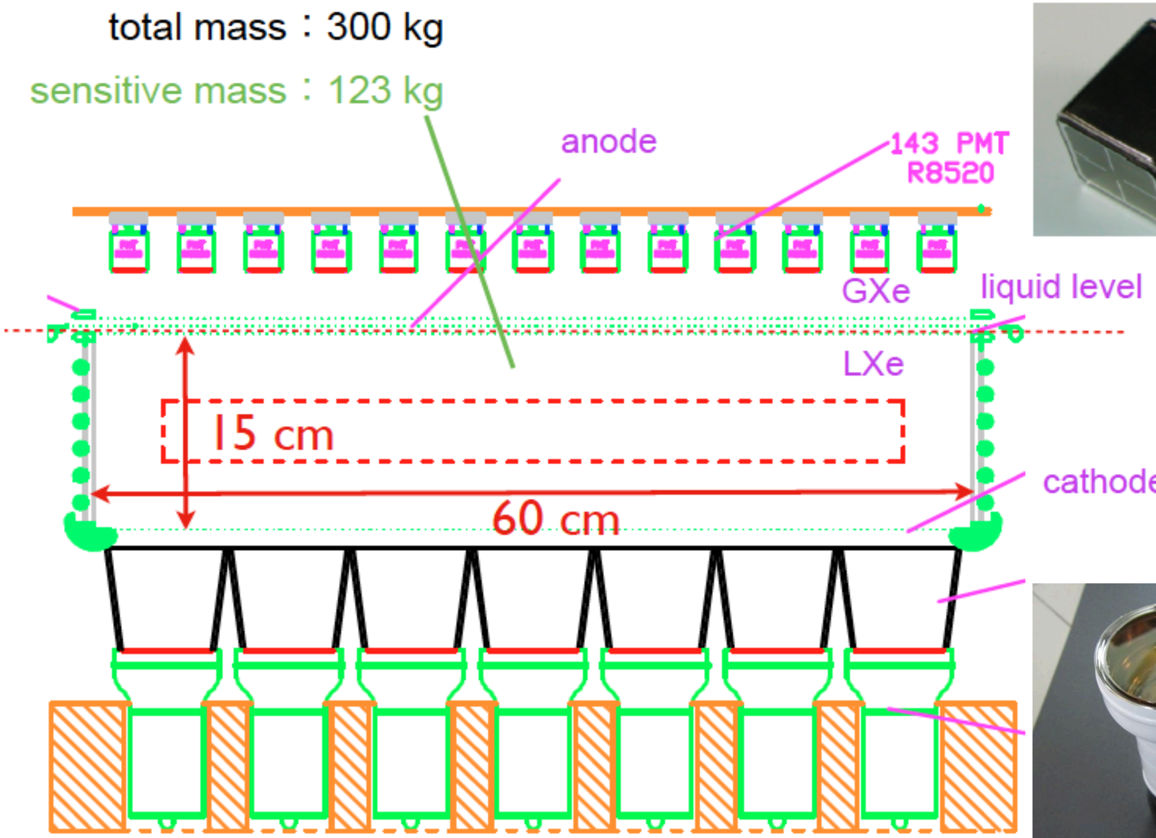


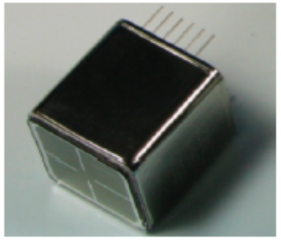
Mean-free-path
1 MeV gamma: ~5.5cm
1 MeV neutron: ~10 - 30cm

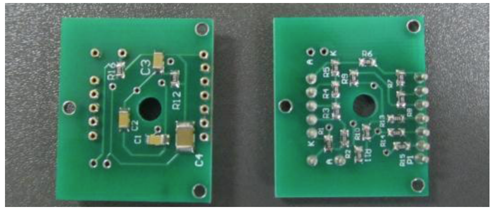
gamma/neutron , multiple hits
(neutron reduction factor 2)

WIMP, single hit

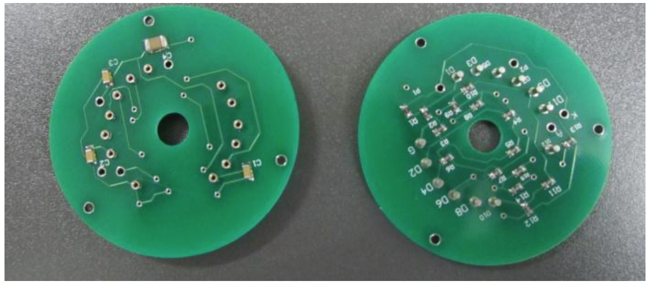
PMT & base



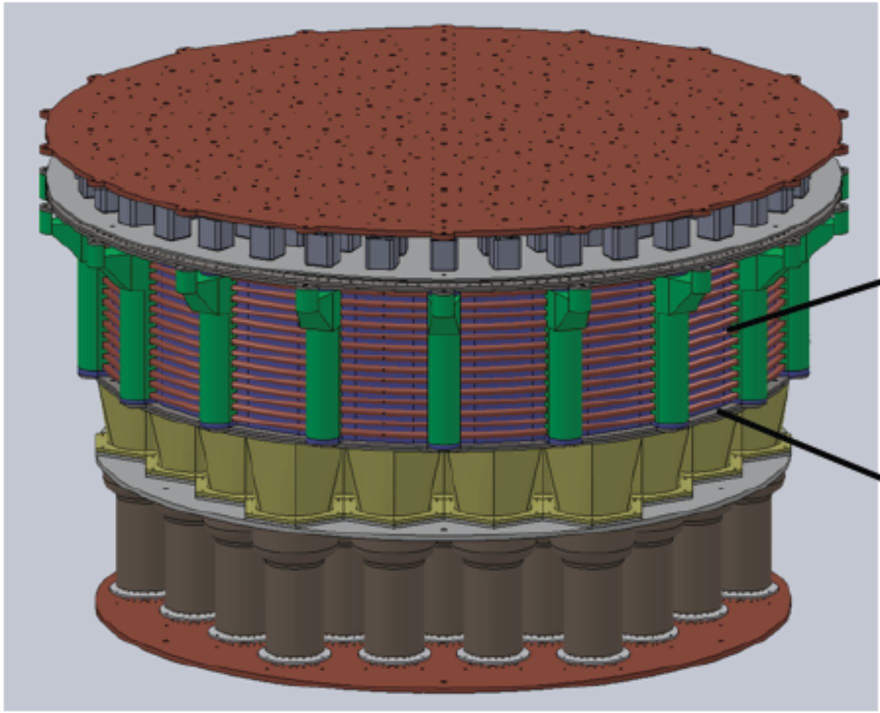


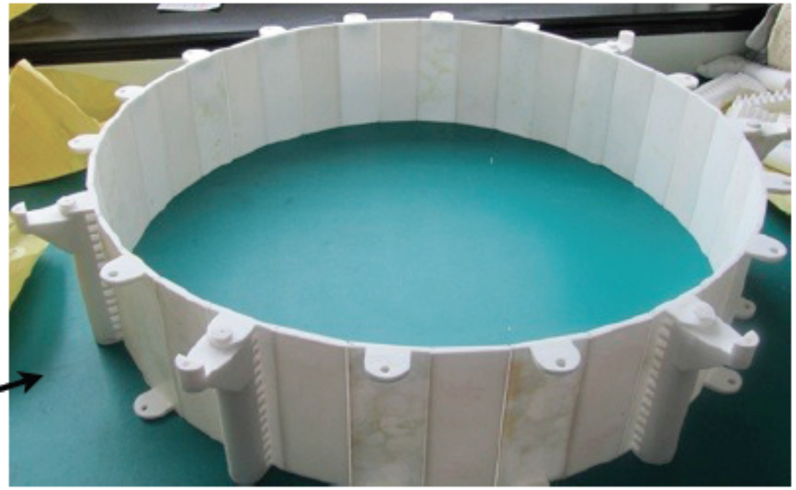


37 R11410 PMT



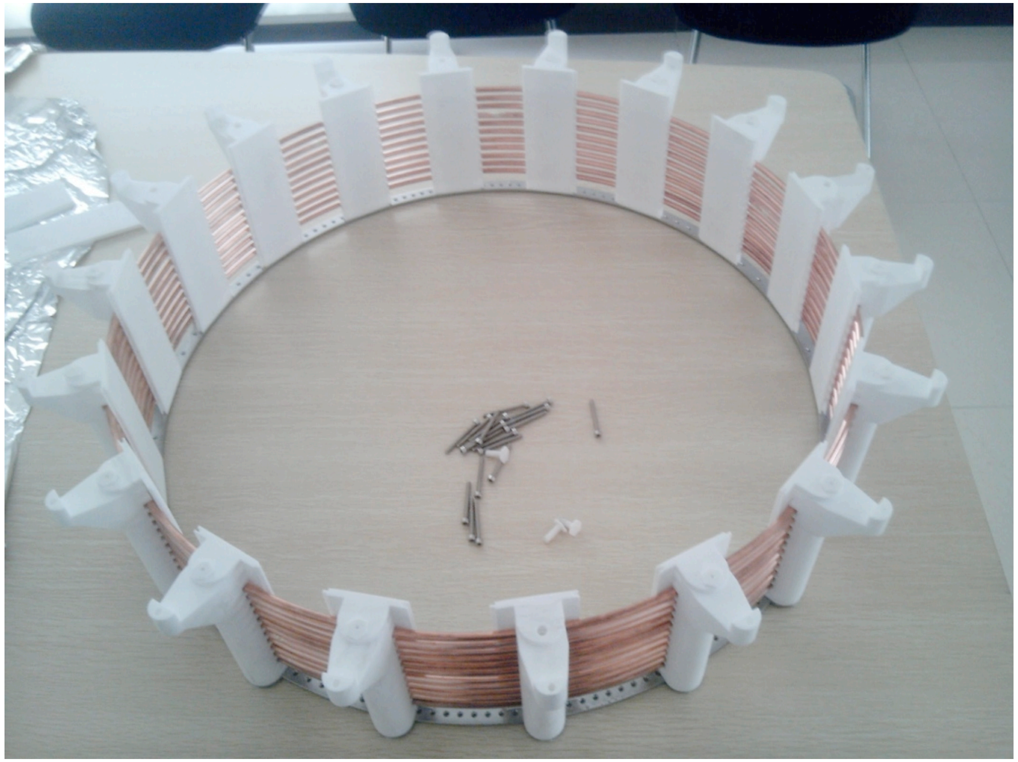
Inner TPC



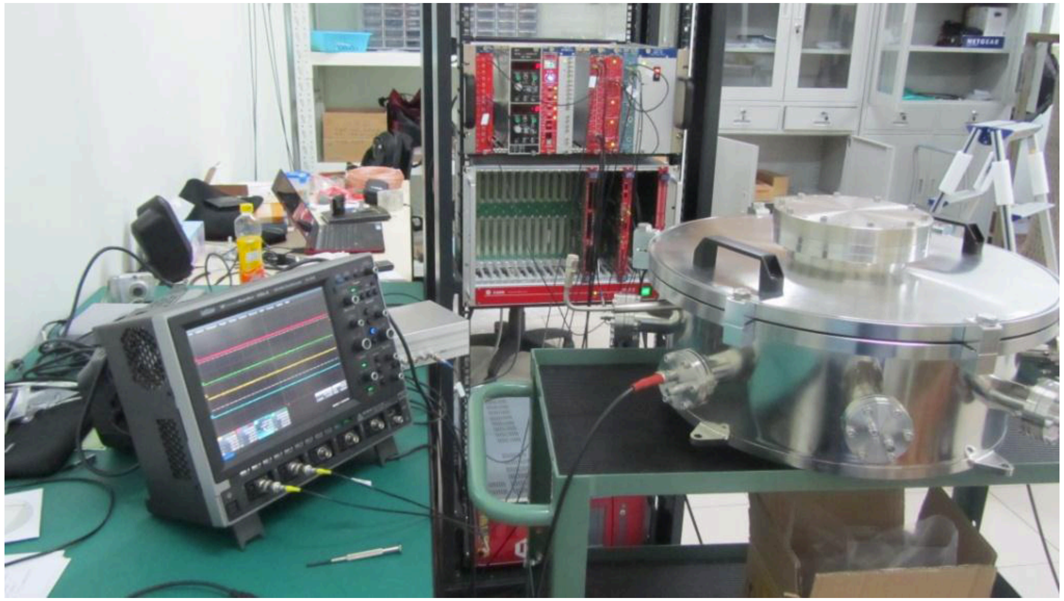


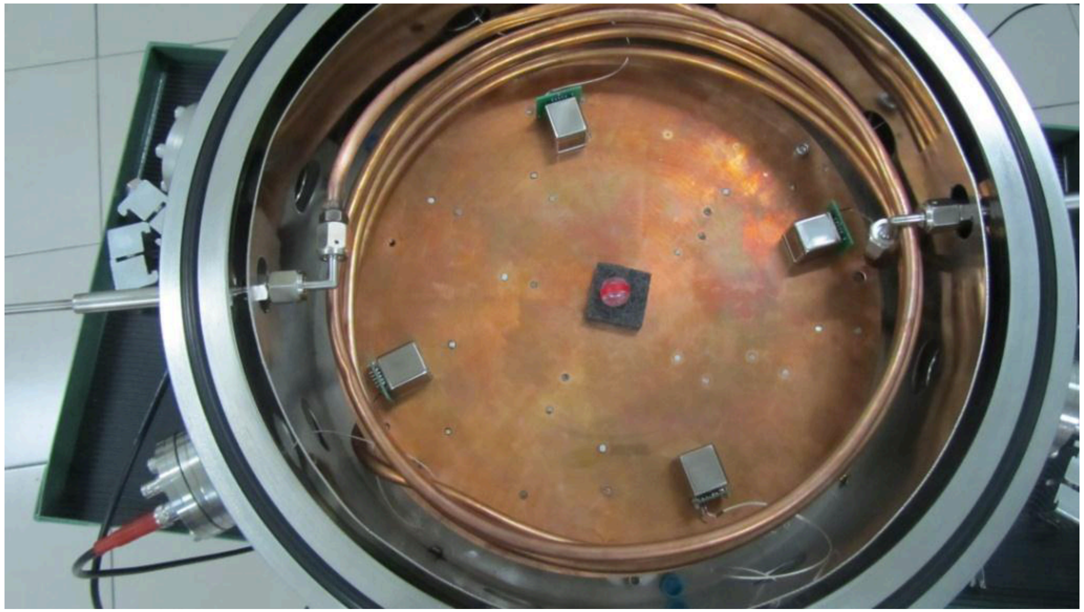
60cm in diameter

Inner TPC



PMT under test



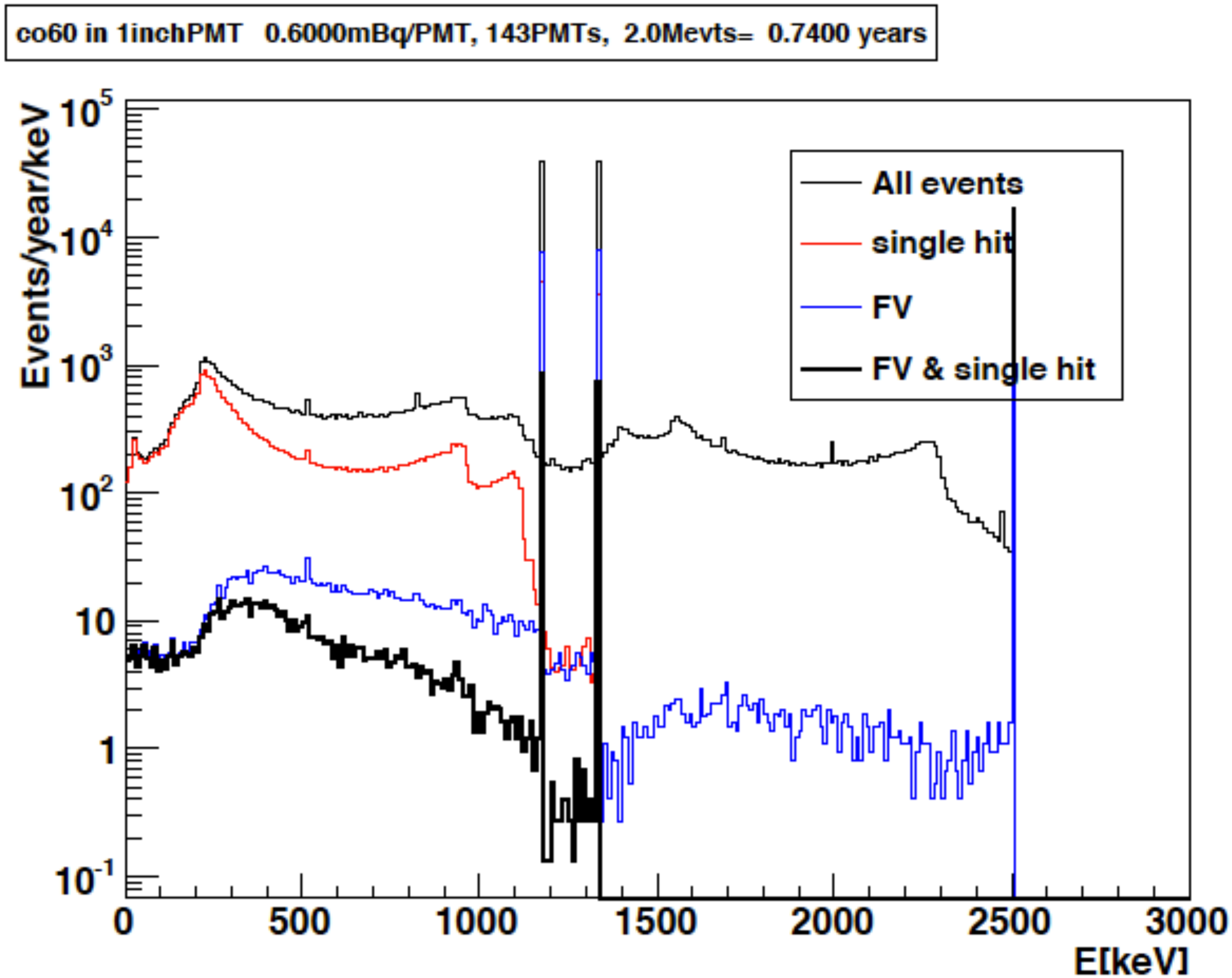


Test
- PMT performance at liquid Xenon temperature.
- Electronics and signal processing.

Cooling & purification system

Under construction

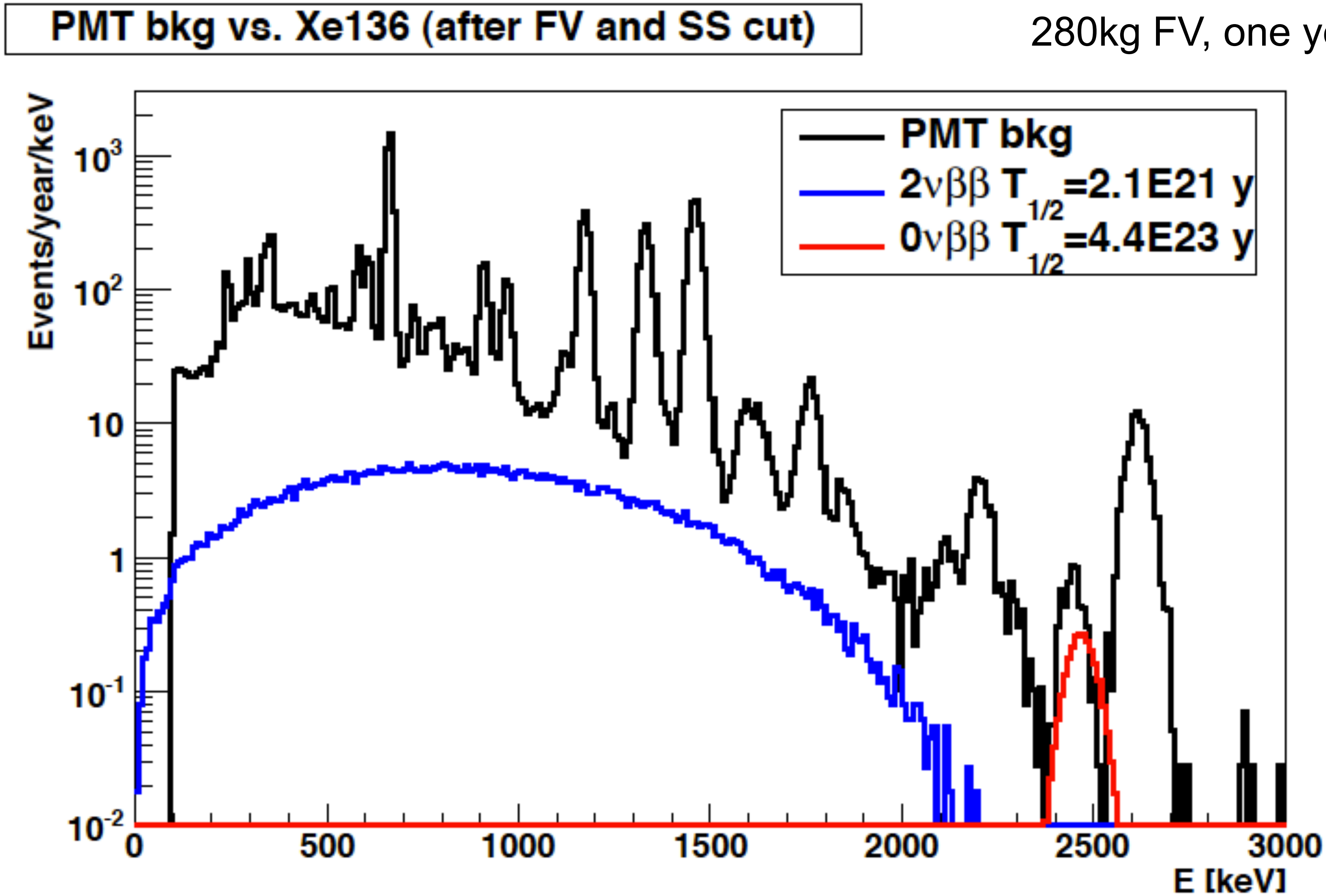
Background simulation



PMT Co60 induced background

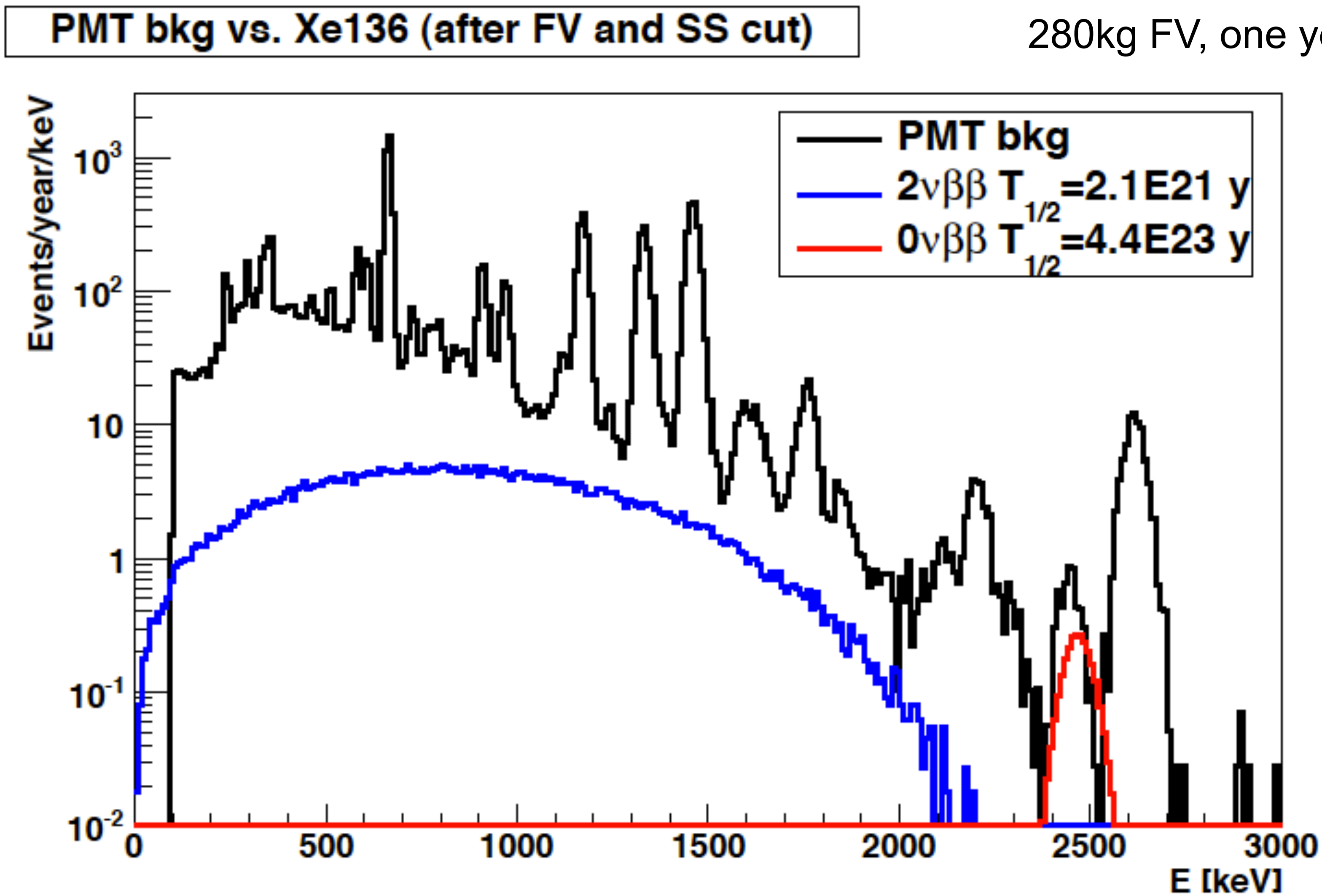
MC simulation

280kg FV, one year



MC simulation

280kg FV, one year



stay tuned……

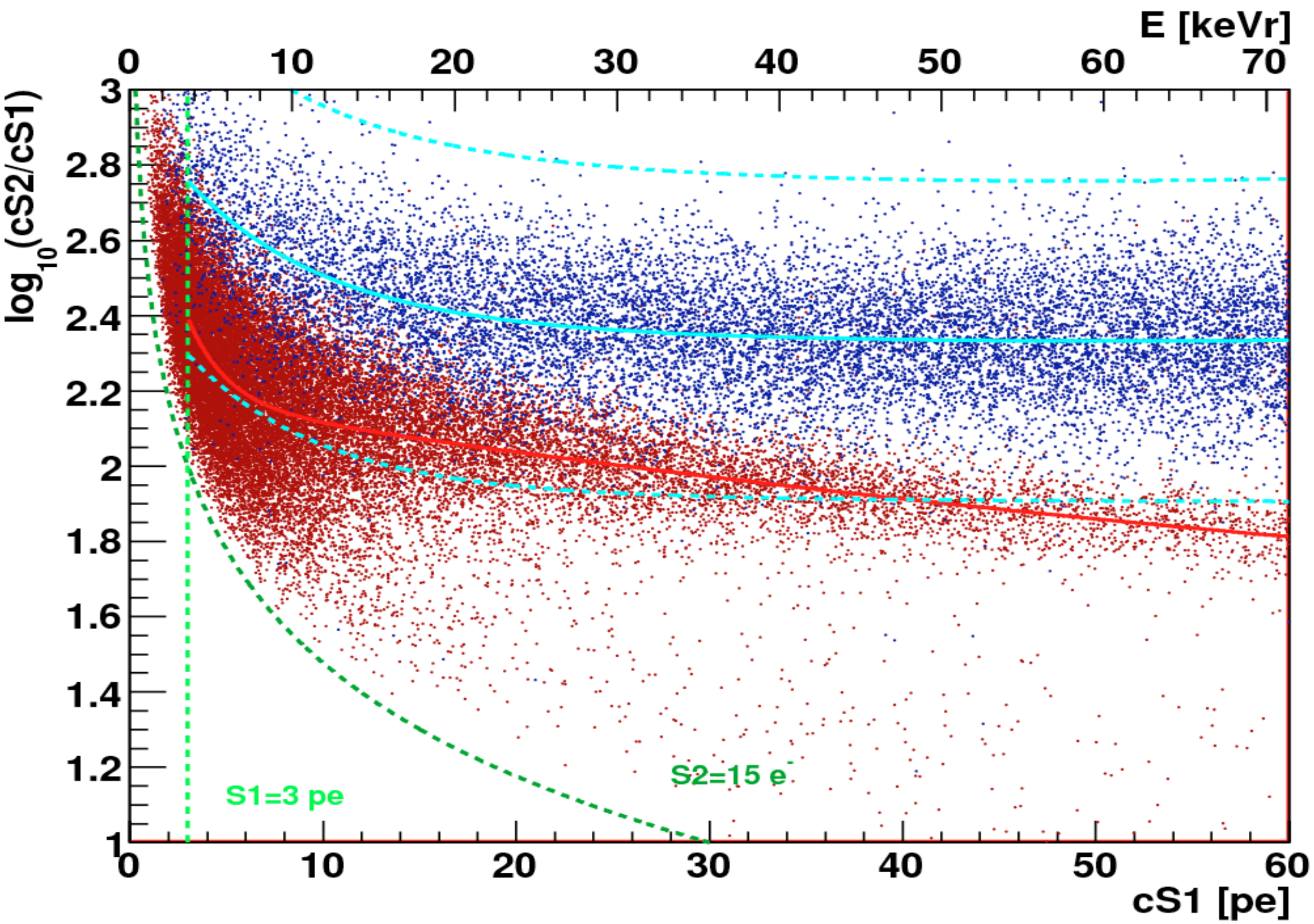
Backup

MC simulation

isotope [mBq/PMT]	1inch	Xenon100 MC	3inch (MOD/Normal)
Th234 (U238)	<1.4 - <75	0.25	<95 / 50
Ra226 (U238)	0.12 - 0.6		<2.4 / 6.1
Ac228 (Th232)	0.087 - 0.5	0.46	<3.8 / <2.7
Th228 (Th232)	0.11 - 1.9		<2.6 / 3.0
U235	0.04 - 0.10		<4.3 / 3.1
K40	6 - 120	8.15	13 / 50
Co60	0.46 - 4.5	0.75	3.5 / 8.4
Cs137	0.027 - 17	0.17	<1.3 / <0.38

arXiv:1101.5831, 1101.3866

Dual-phase TPC: charge/light



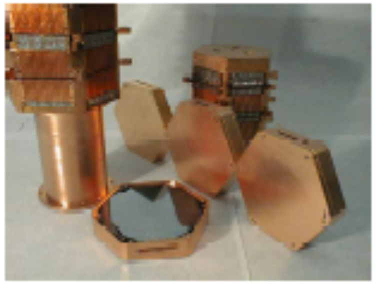
XENON100 Courtesy

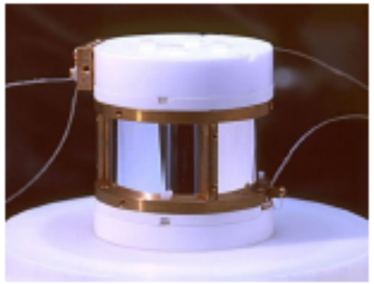
WIMP direct detection methods

COUPP,
PICASSO

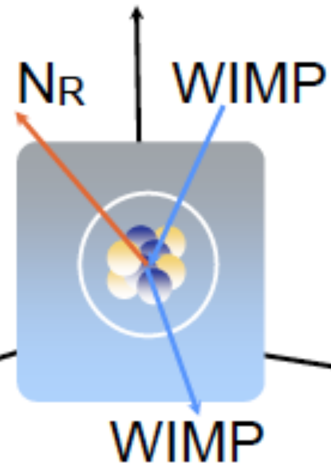
Phonons

CDMS
EDELWEISS





CRESST
ROSEBUD

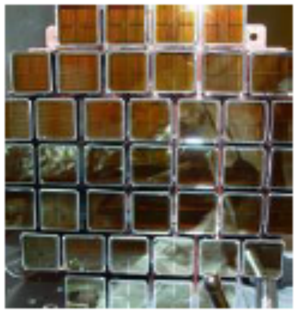


Charge

Light

DAMA, LIBRA,
XMASS, CLEAN,
ANAIS, KIMS

HDMS, DRIFT,
GERDA, MAJORANA
CoGeNT, CDEX

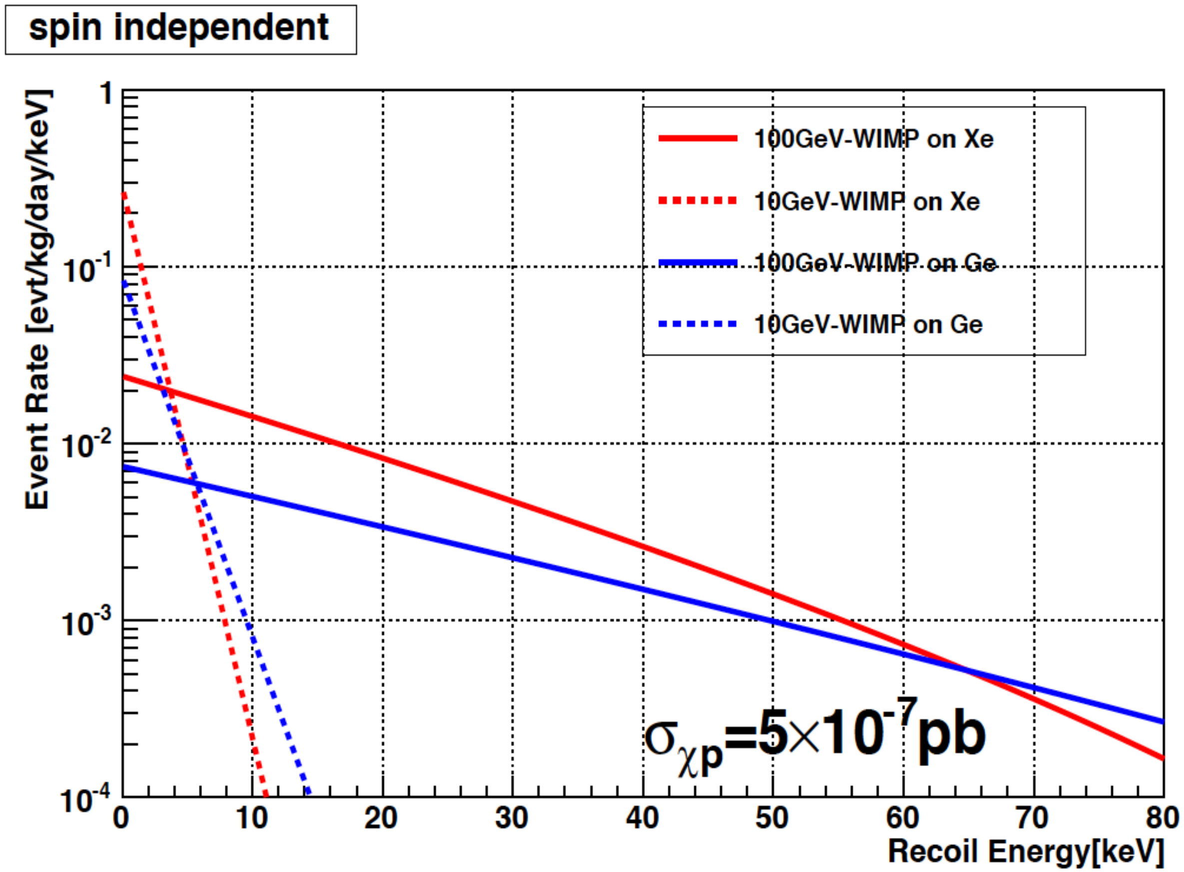


ZEPLIN, XENON,
LUX, WARP, ArDM
PANDAX

Direct detection challenges

Signal collection

Background rejection



WIMP signal rare, small, no feature

Xenon advantage

Signal collection

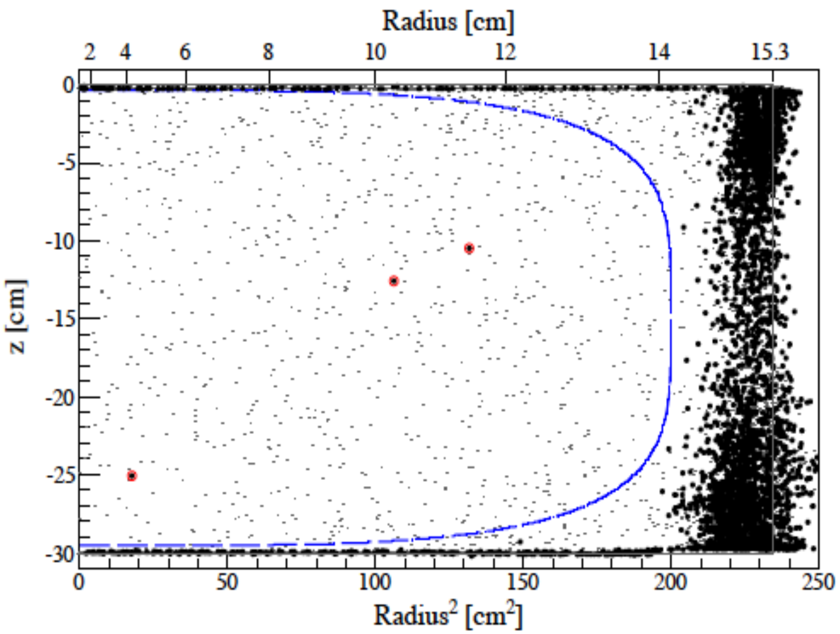
- large A: $\sigma_{SI} \sim A^2$
- easily scale-up to ton-scale
- efficient scintillation (80% of NaI), 178nm, no WS
- Xe131 sensitive to spin-dependent interaction

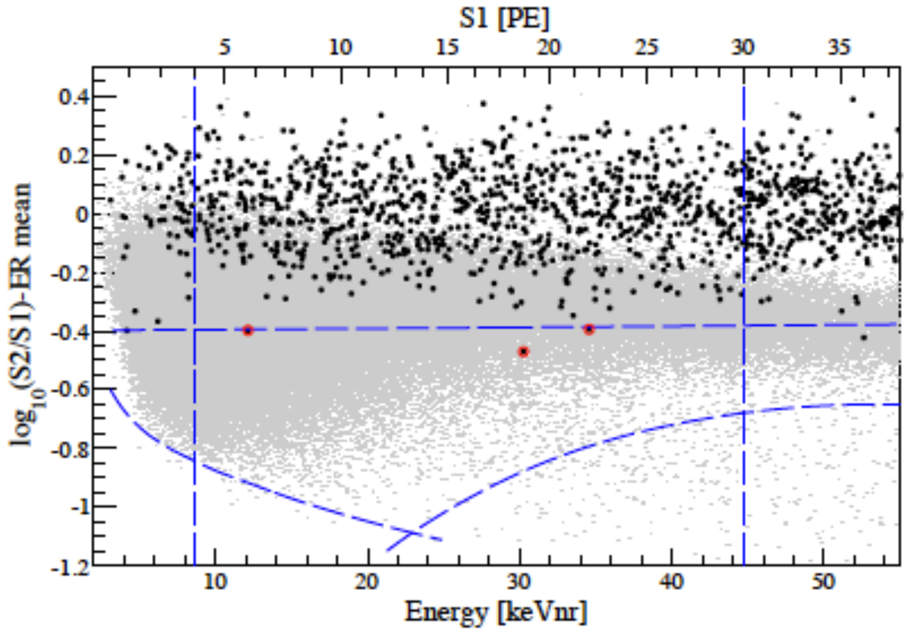
Background rejection

- dual phase: charge/light, single-site/multi-site
- self-shielding, $3 g/cm^3$
- no long-life radioactive isotopes
- Kr removal (distillation)

- noble gas, -100°C, relatively easy to handle

XENON100 results



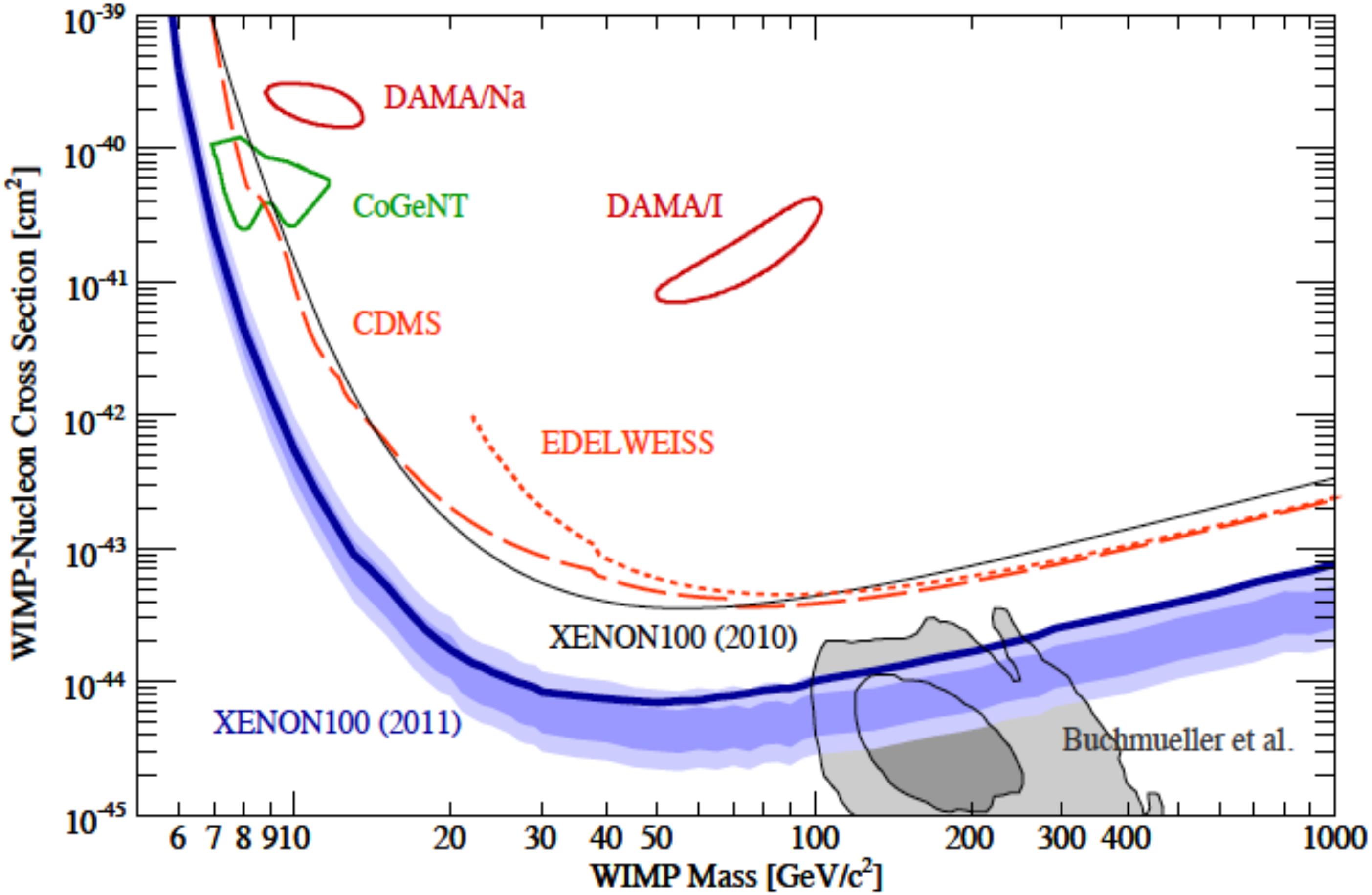


Self-shielding

S2/S1

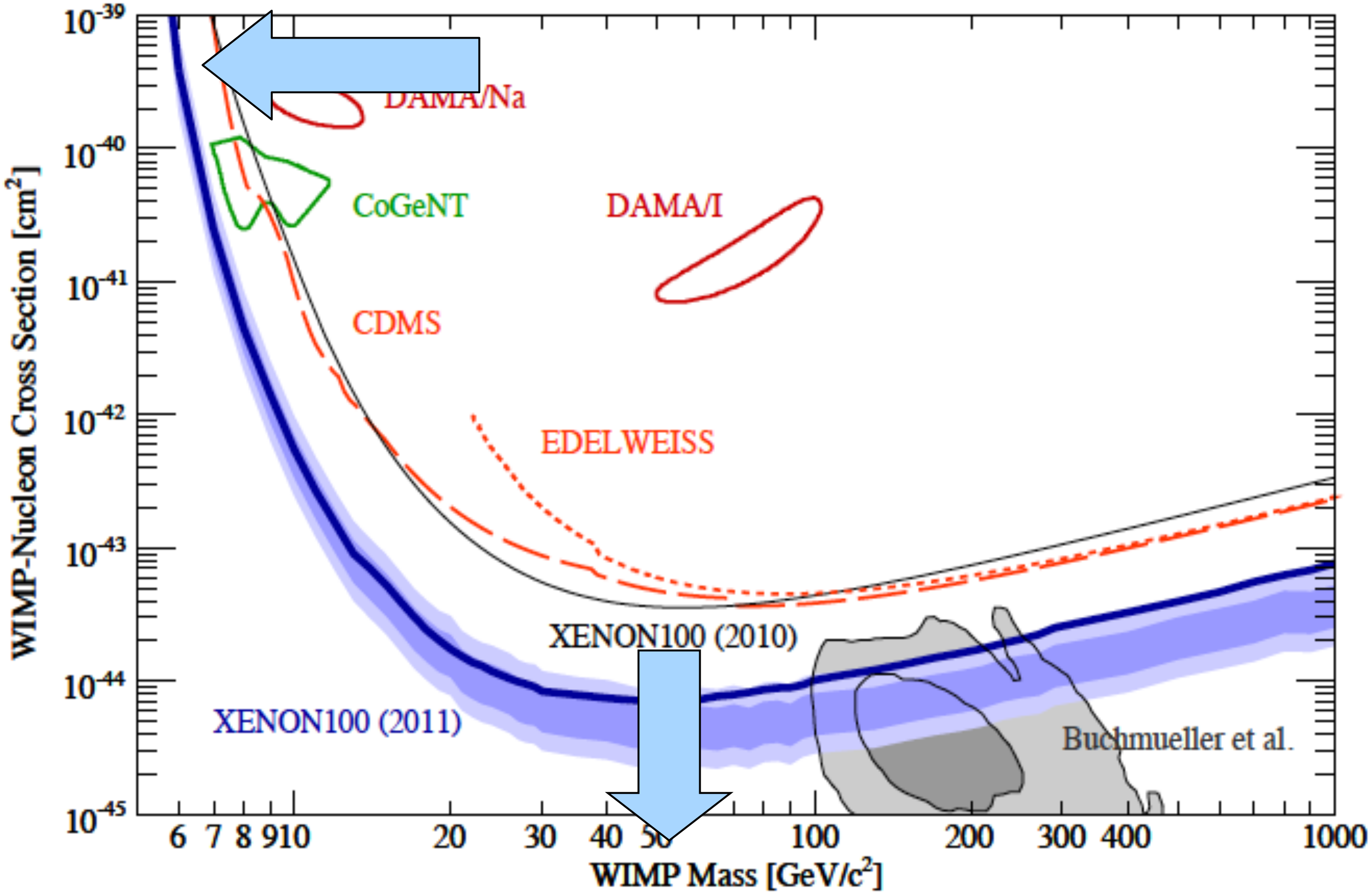
arXiv:1104.2549

Direct detection status



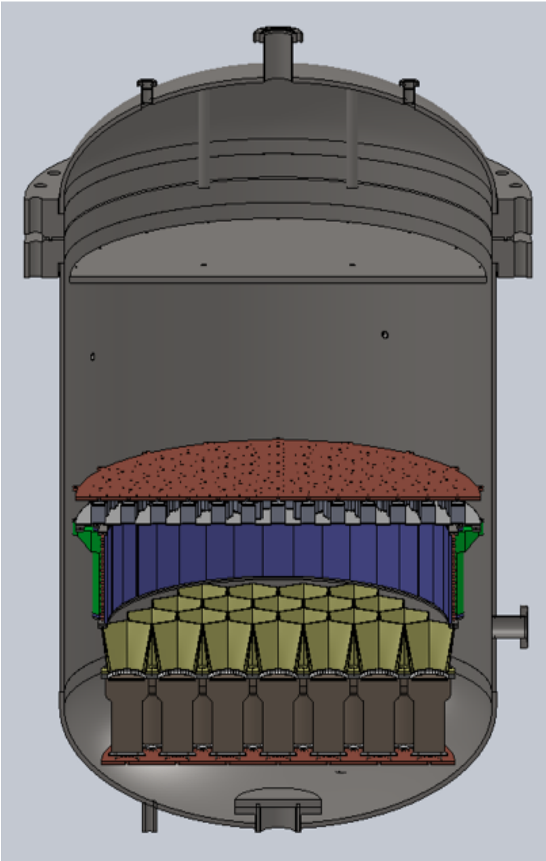
Direct detection status

Smaller WIMP mass, smaller energy threshold



Smaller σ, larger detector mass, lower bg rate.

Plan



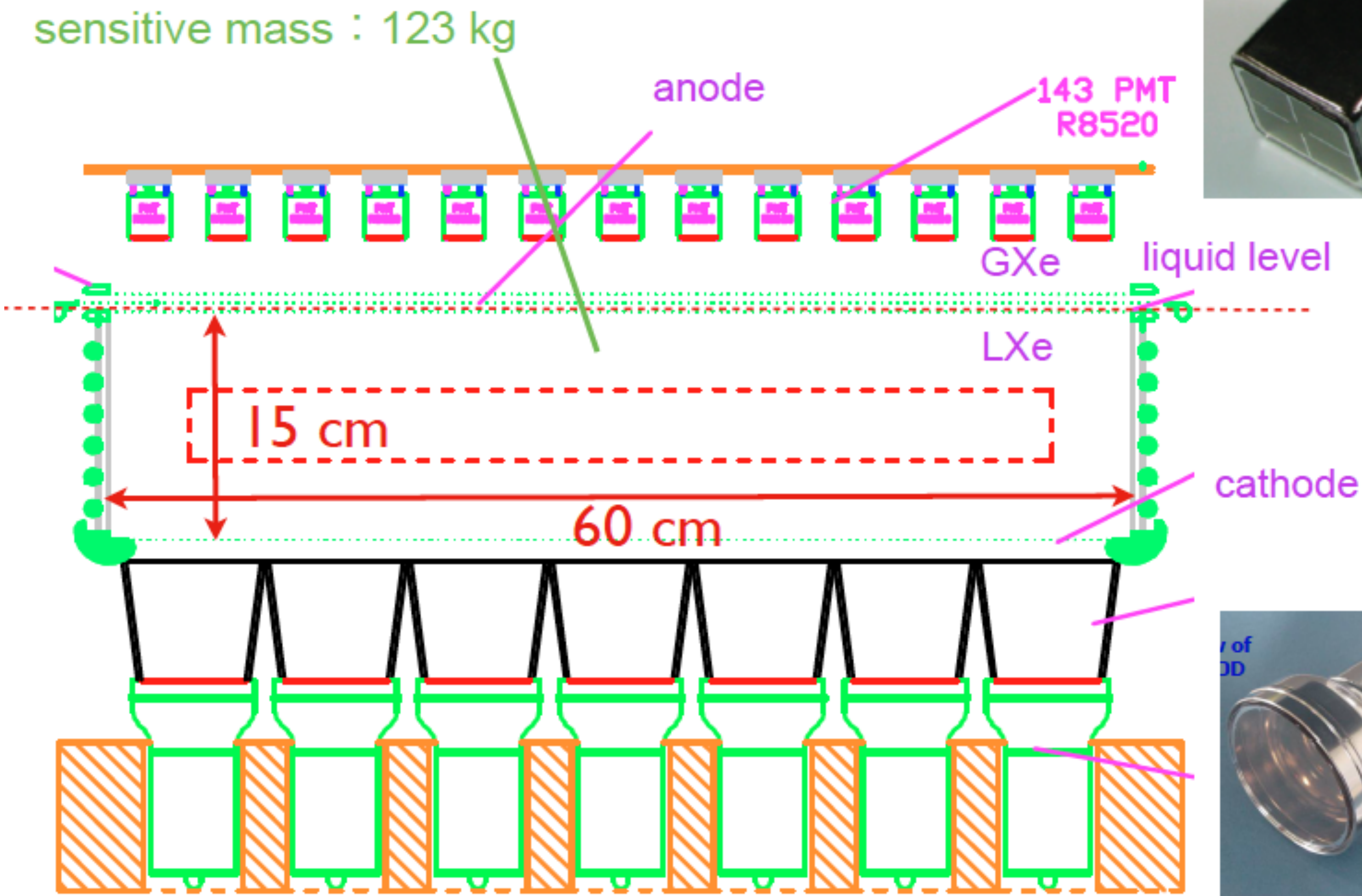
TPC inside inner vessel

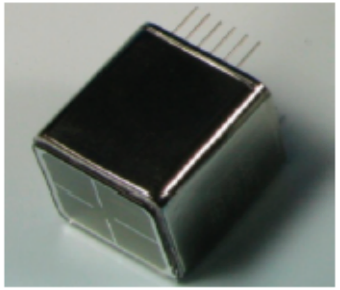
Support systems for ton-scale, allowing for fast upgrade
- Cooling and purification
- Shielding
- DAQ and slow control…

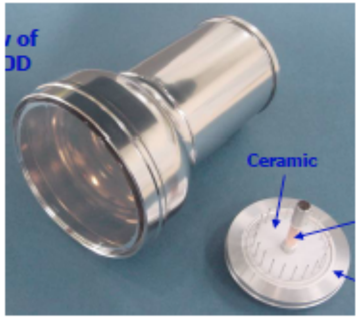
Phase approach:

Phase	I	II	III
Total LXe [kg]	300	1300	2500
Target LXe [kg]	120	600	1500

Pancake TPC with high light yield







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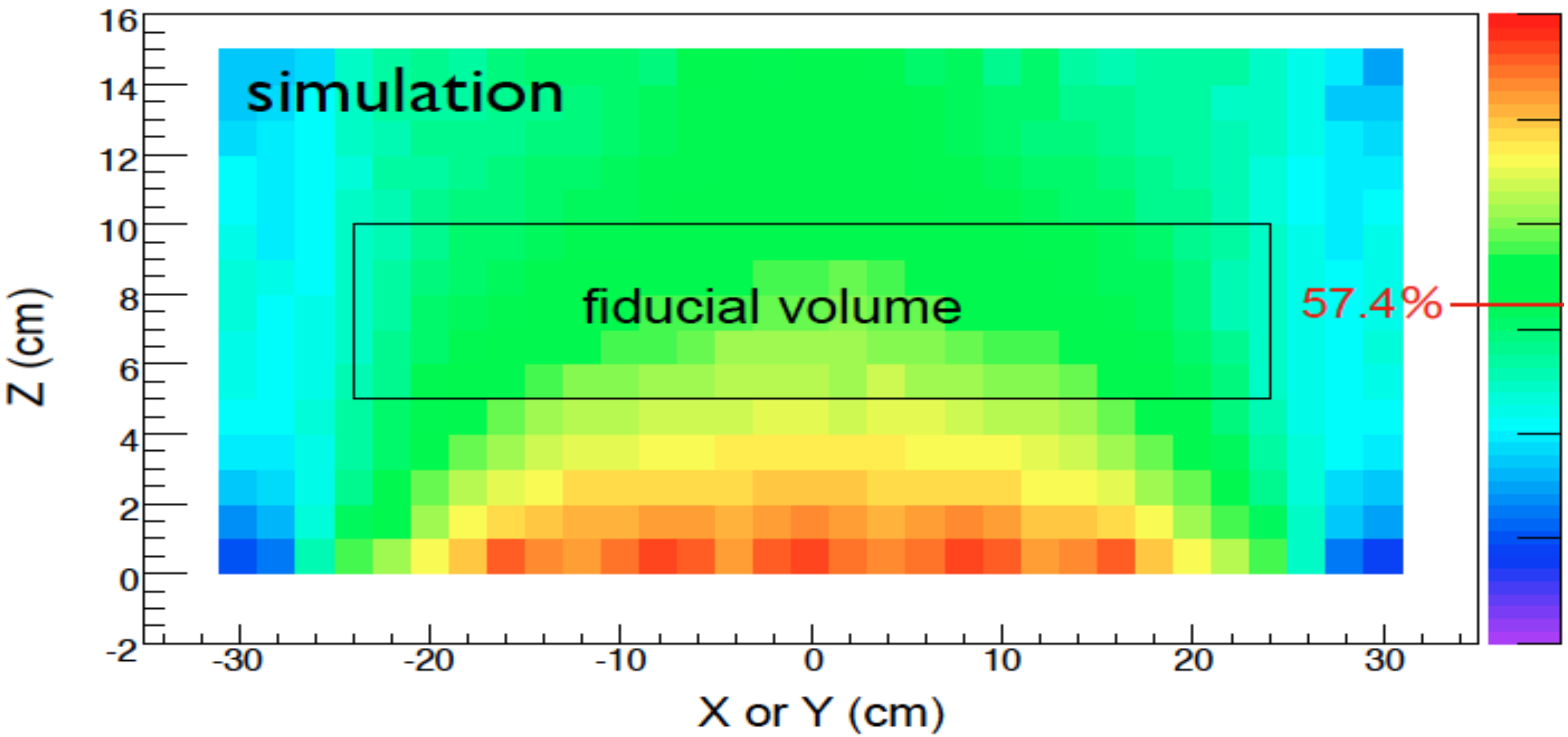
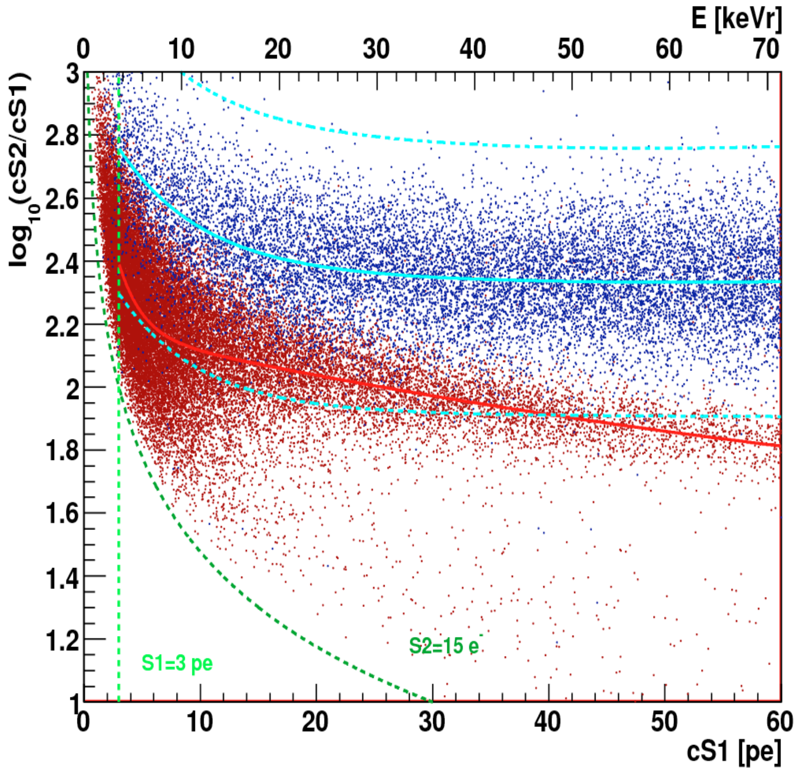
Pancake advantage (I)

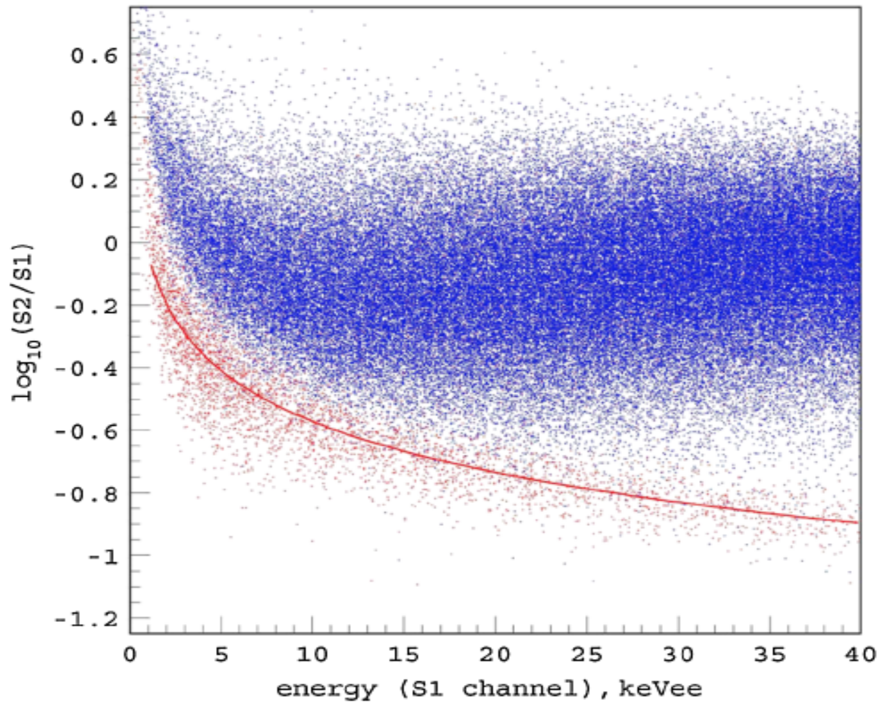
S1 light collection efficiency



XENON100 energy threshold: 8.7keVnr
PANDAX expected : 3.6keVnr

Pancake advantage (II)





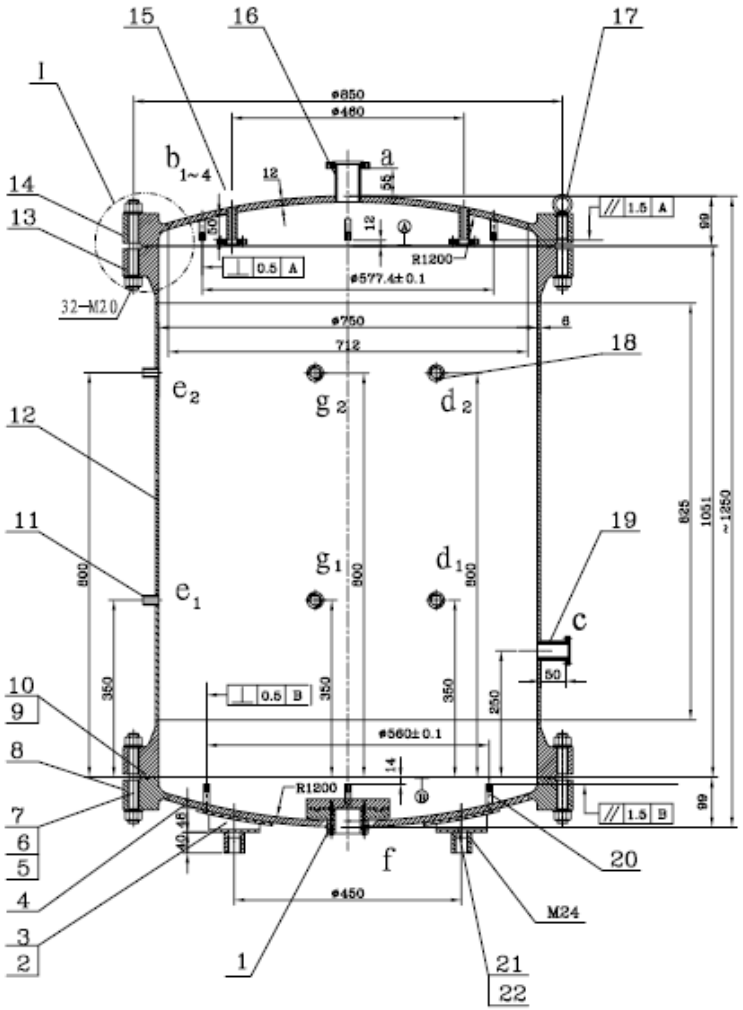
XENON100 E_{drift}=0.5kV/cm
99% gamma rejected
(at 50% WIMP efficiency)

PRL 105, 131302 (2010)

ZEPLIN-III E_{drift}=3.9kV/cm
99.9% gamma rejected

PRD 80, 052010 (2009)

Inner vessel (prototype)



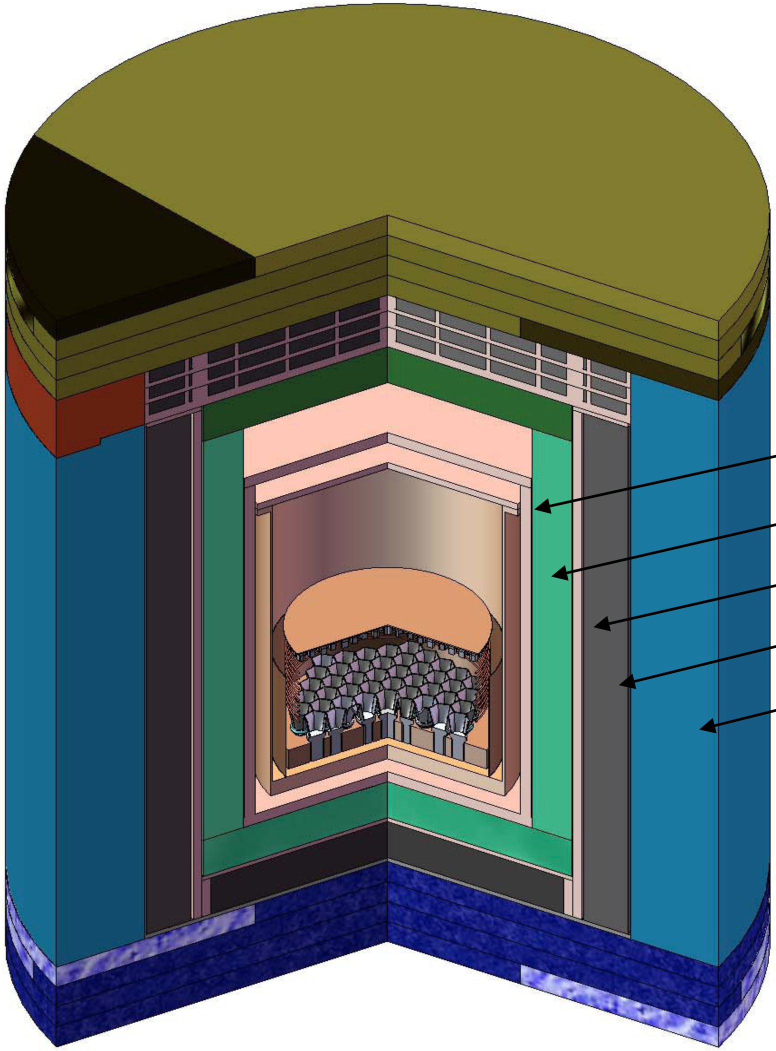
Outer vessel

- OFHC, 1.85m high, 1.34m in diameter, 5cm thick, 4.4ton
- Ready for leak test.

Many test/construction

Many more items under test/construction:
- HV feedthrough
- Signal feedthrough
- Small cooling and purification system
- Kr distiller
- Storage tank and recover system
- DAQ and slow control
- …

PANDAX Shielding



Diameter 3m, Height 3.6m

5cm Cu (outer vessel)
20cm PE
5cm Cu
20cm Pb
40cm PE

Inner Vaccum
Height 160cm
Diameter 120cm

Goal: <1 external bg event in 5-15keV per year

External Background Simulation

Require 1t FV, single-site, 99.5% S2/S1

events in 5-15keV per year:

	neutron	gamma
Rock+concrete	<0.0005	0.5
Cosmic muon	<0.02 (30% from Cu shielding)	
Shielding	0.03 (60% from Cu shielding)	0.6 (80% from Cu shielding)
Rn		0.01 (assume 1Bq/m3)

Goal: <1 external bg event in 5-15keV per year
MC simulation: ~1.1

Cu radioactive levels

Radioactive elements:

isotope	PANDAX [mBq/kg]	Xenon100 [mBq/kg] [2]
Ra228 (Th232)	<0.36	0.021
Th228 (Th232)	<0.51	
Ra226 (U238)	<0.38	0.070
Pa234m (U238)	<9.0	
U235	<0.86	0.0034
K40	4±1	0.023
Cs137	<0.16	

surface?

Cosmogenic activation at sea level:

isotope	T1/2	measured [mBq/kg]	activation rate [#/day·kg]	saturation [mBq/kg]
Co60	5.27y	0.20±0.09	97.4 / 55.4	1.13
Co58	71.3d	1.2 ±0.2	159.6 / 123.0	1.85
Co56	78.76d	0.20±0.07	22.9 / 20.0	0.27
Mn54	312.3d	0.19±0.08	32.5 / 27.7	0.38

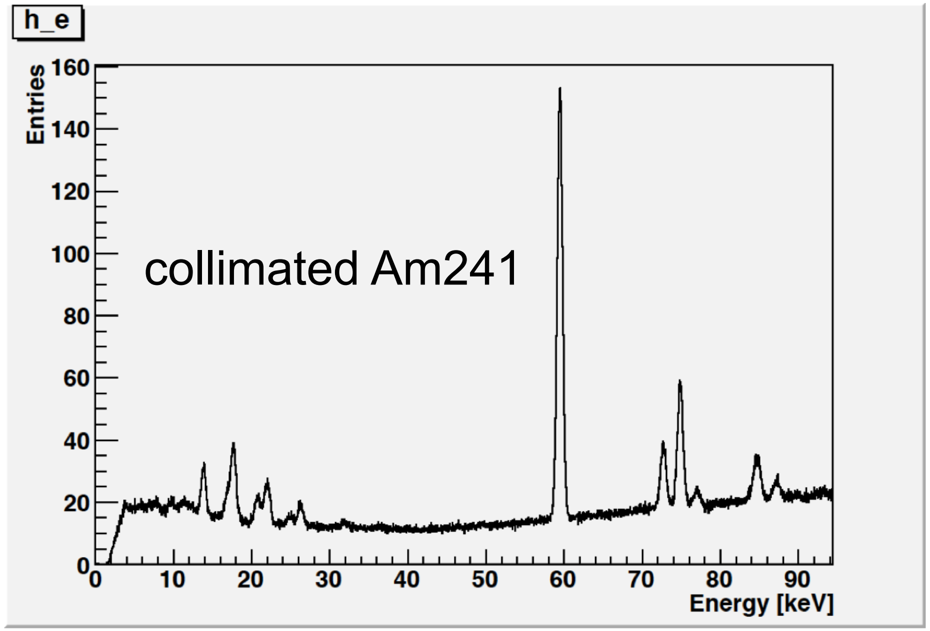
BEGe for counting facility

Canberra BEGe3830

energy threshold 3keV

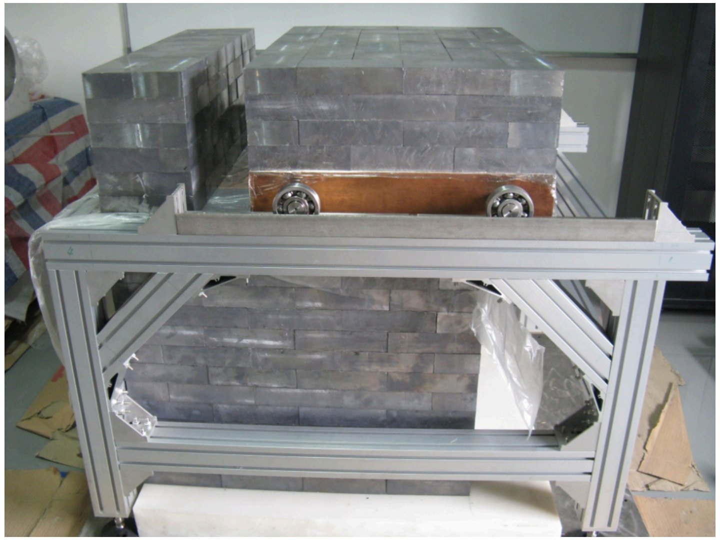
relative efficiency 34%

Energy [keV]	FWHM [keV]
59.4	0.99
661.5	1.46
1173	1.88
1332.5	1.91
40.2 [pulser]	0.93
630.0 [pulser]	0.95
1237 [pulser]	1.02

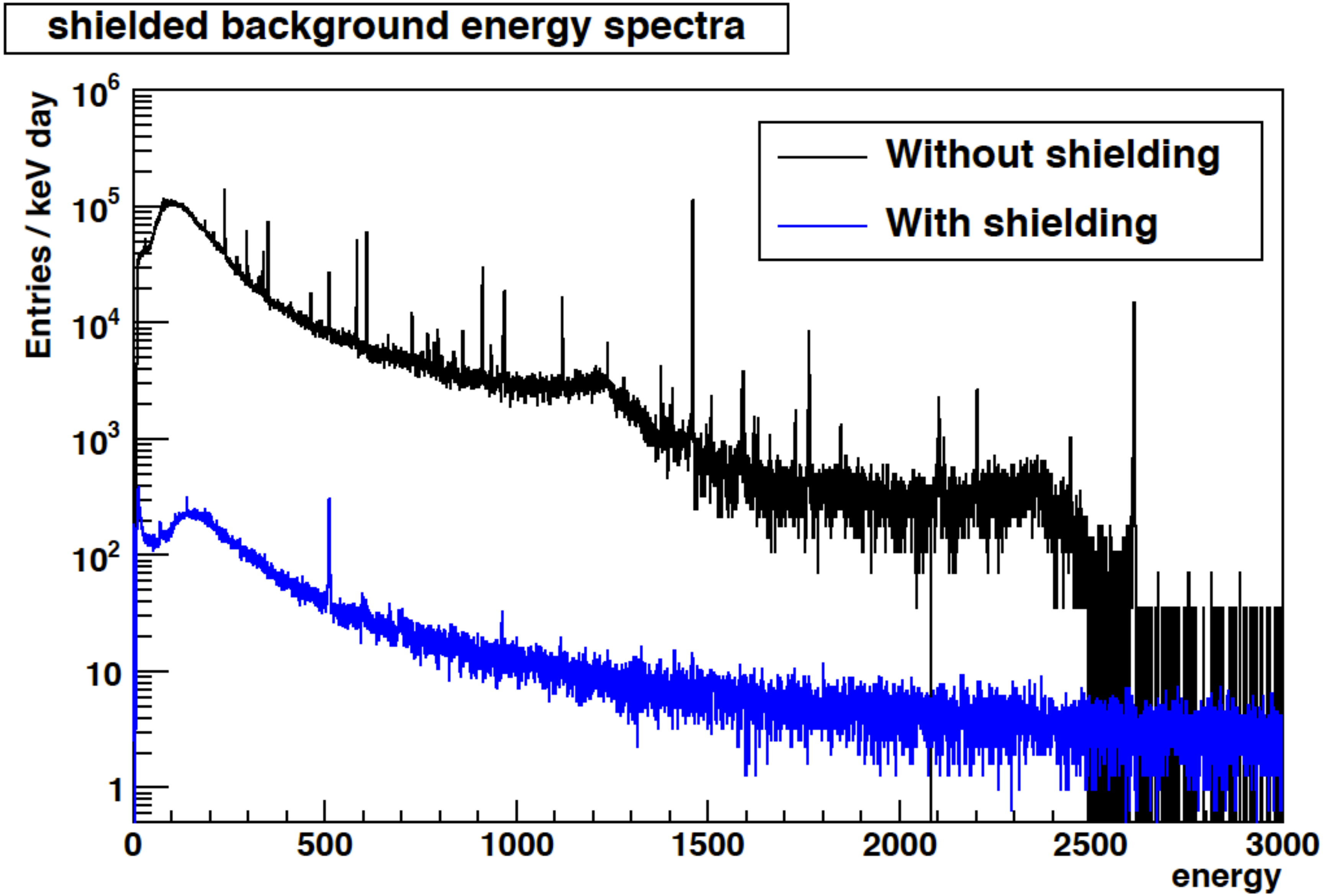


Counting Facility

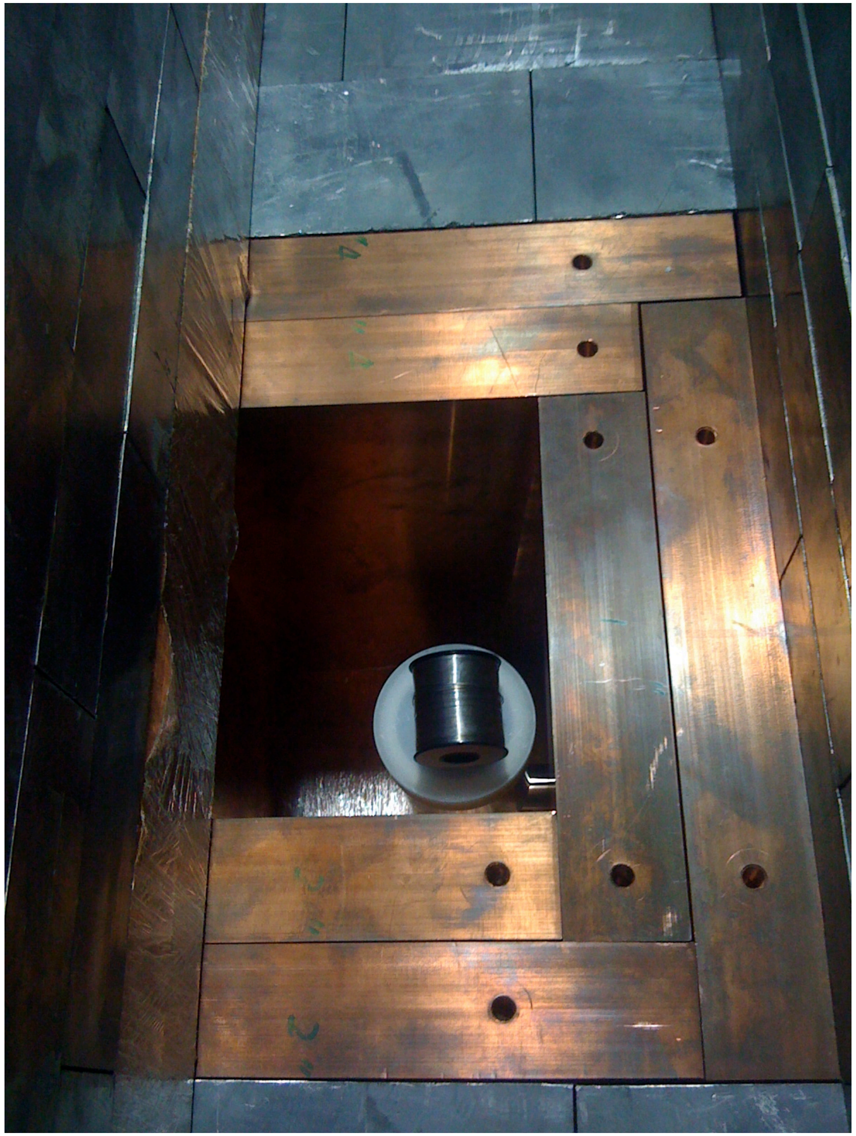
- Shielded by 10cm OFHC Cu, 20cm Pb and 10cm PE
- Background count rate 1.5-2Hz
- Sensitivity ~10mBq (isotope-dependent)



Counting Facility



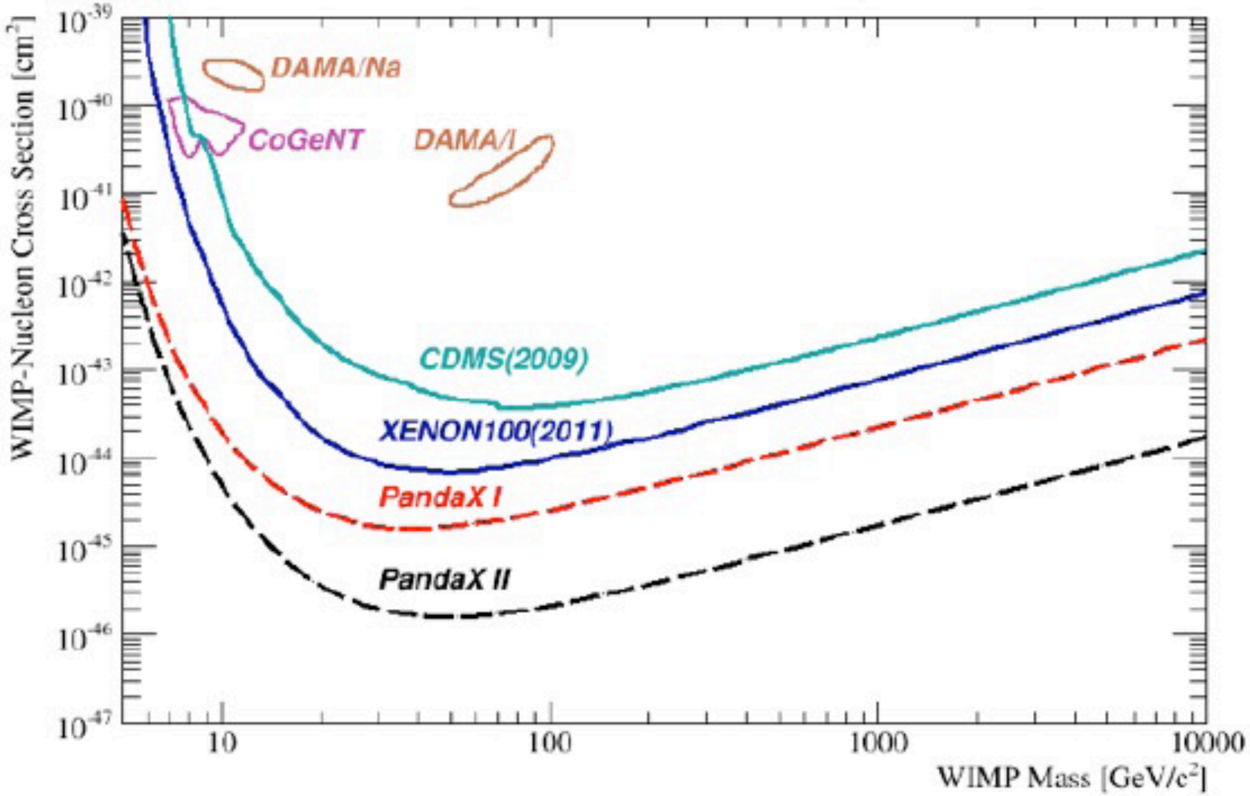
Start Counting



soldering tin

- Add air-tight glove-box
- Move to shallow underground
- Move to Jinping eventually.

PANDAX Expected Sensitivity



PandaX I:

- light yield: 5.0 pe/keVee (w/ field)
- S1 energy range: 3-30 pe
- exposure: 25 kg x 300 days
- NR acceptance: 0.35
- estimated bkg events: 0.3

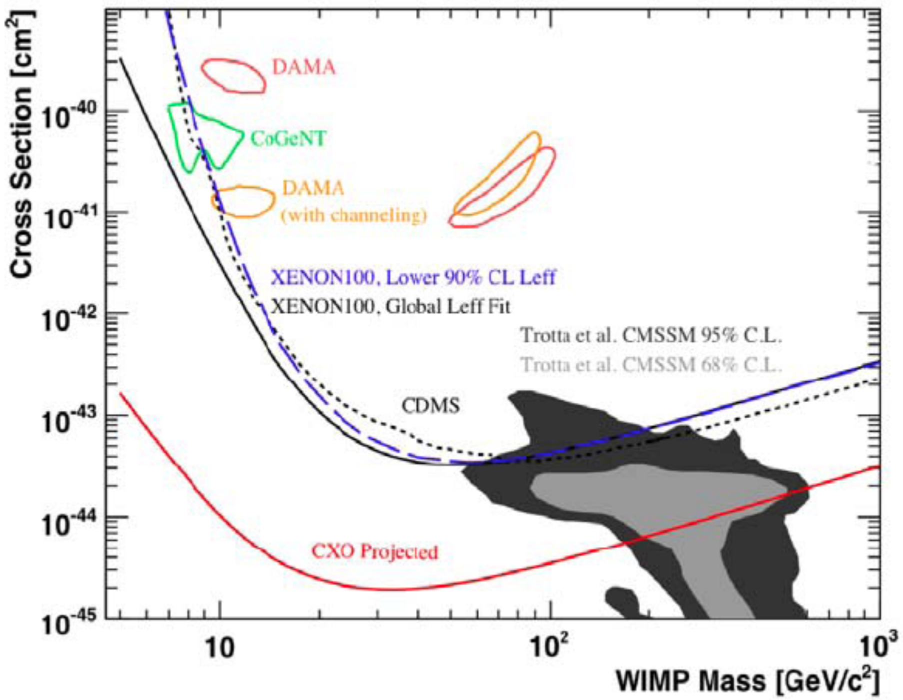
PandaX II:

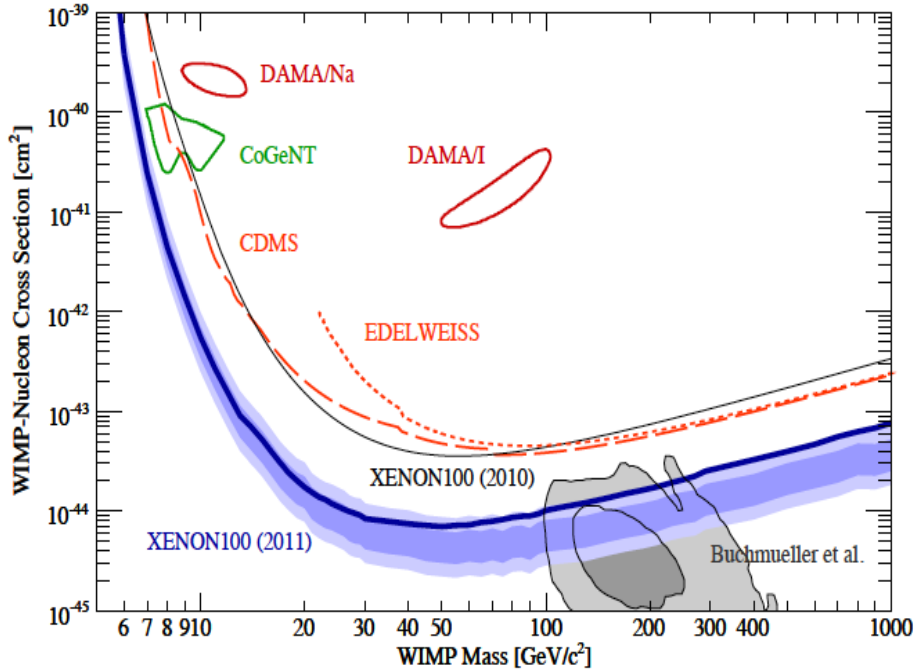
- light yield: 2.5 pe/keVee (w/ field)
- S1 energy range: 3-30 pe
- exposure: 300 kg x 300 days
- NR acceptance: 0.35
- estimated bkg events: 0.5

backup

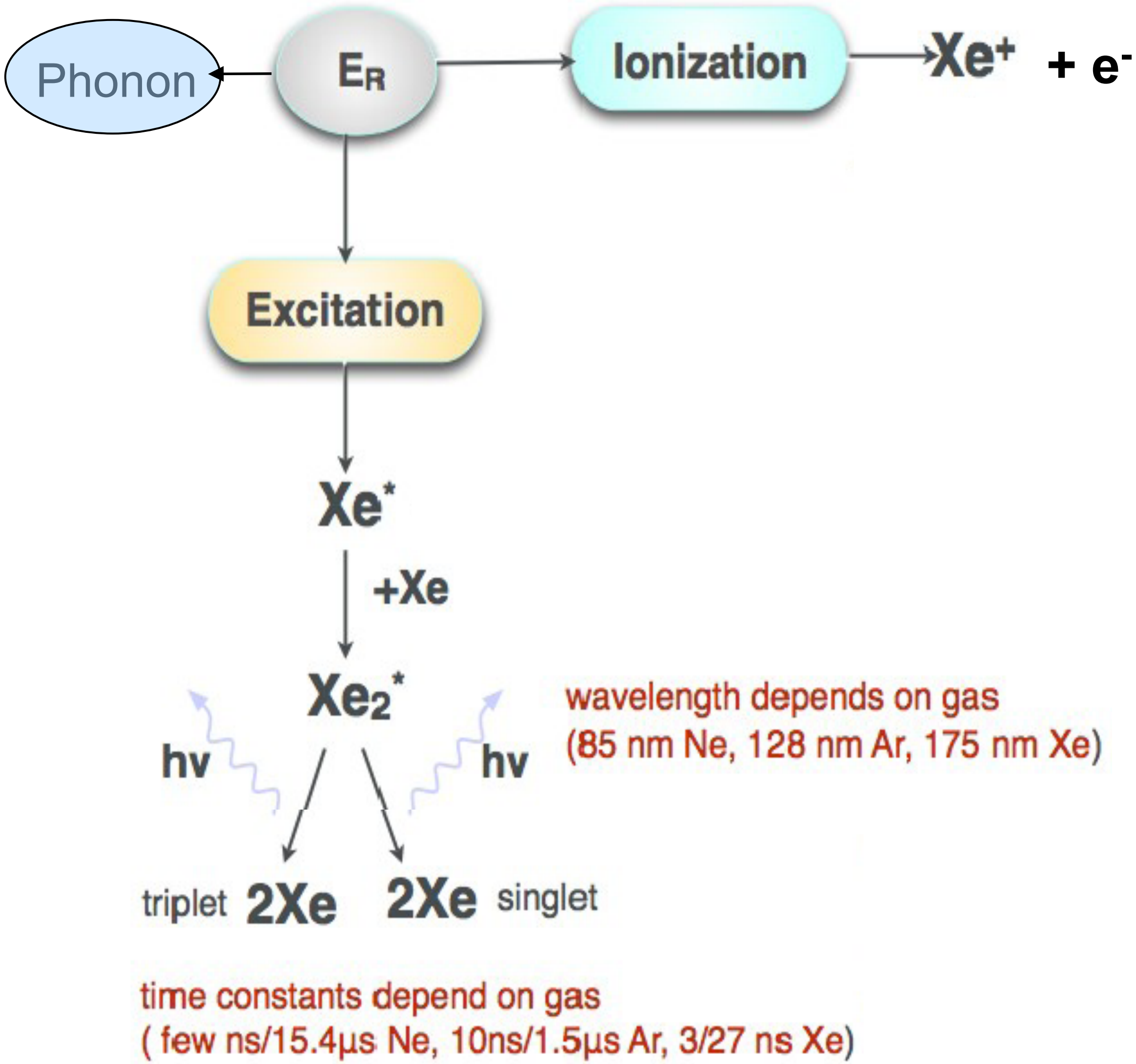
Summary

- Exciting physics on dark matter direct detection.
- Liquid Xenon Dual-Phase a promising technique.
- Very strong competition.





Signal: phonon, scintillation & charge

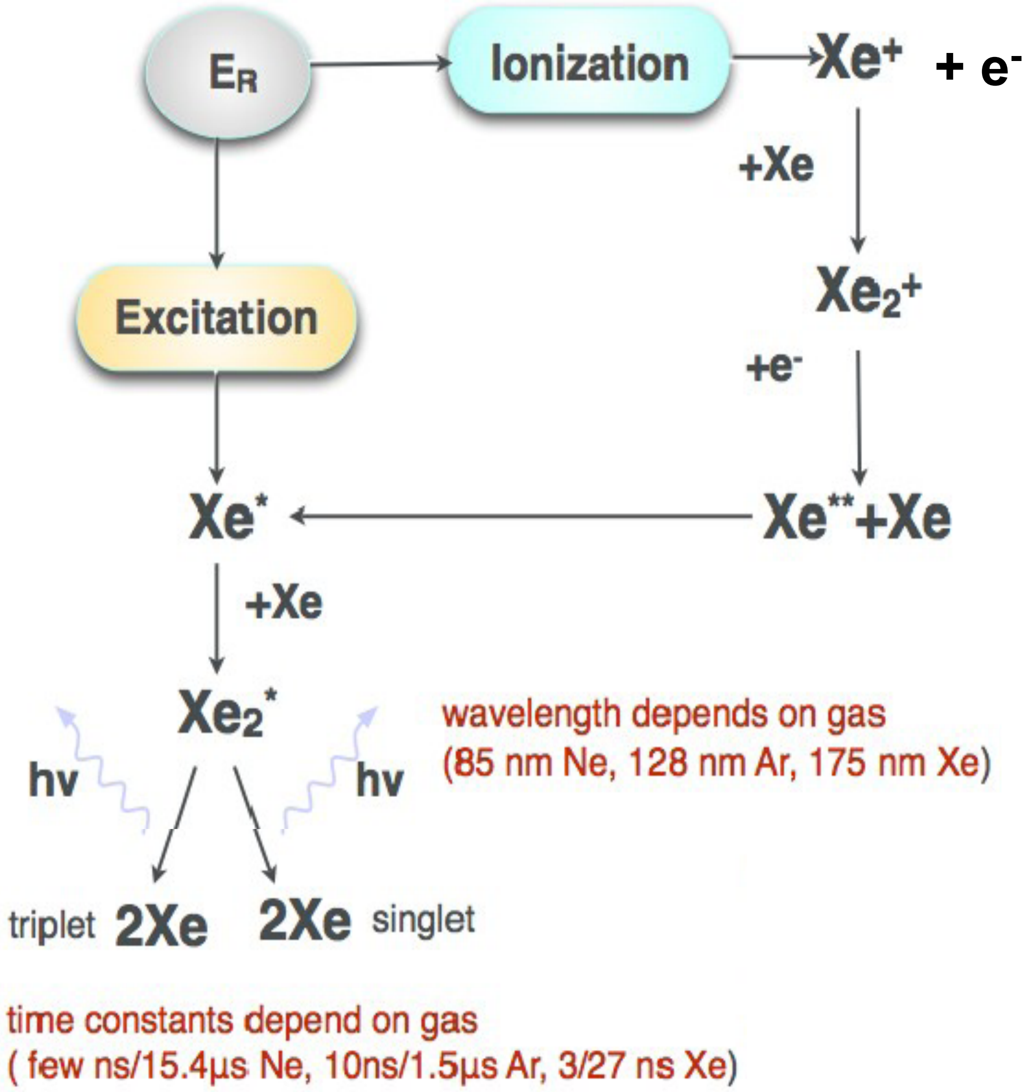


$E_{er} = (n\gamma + ne) \cdot W$
$W \sim 14eV$

$E_{nr} = (n\gamma + ne) \cdot W / L$

Lindhard factor L
(quenching factor):
$L \sim 25\%$

scintillation & charge



Recombination:
depends on dE/dx

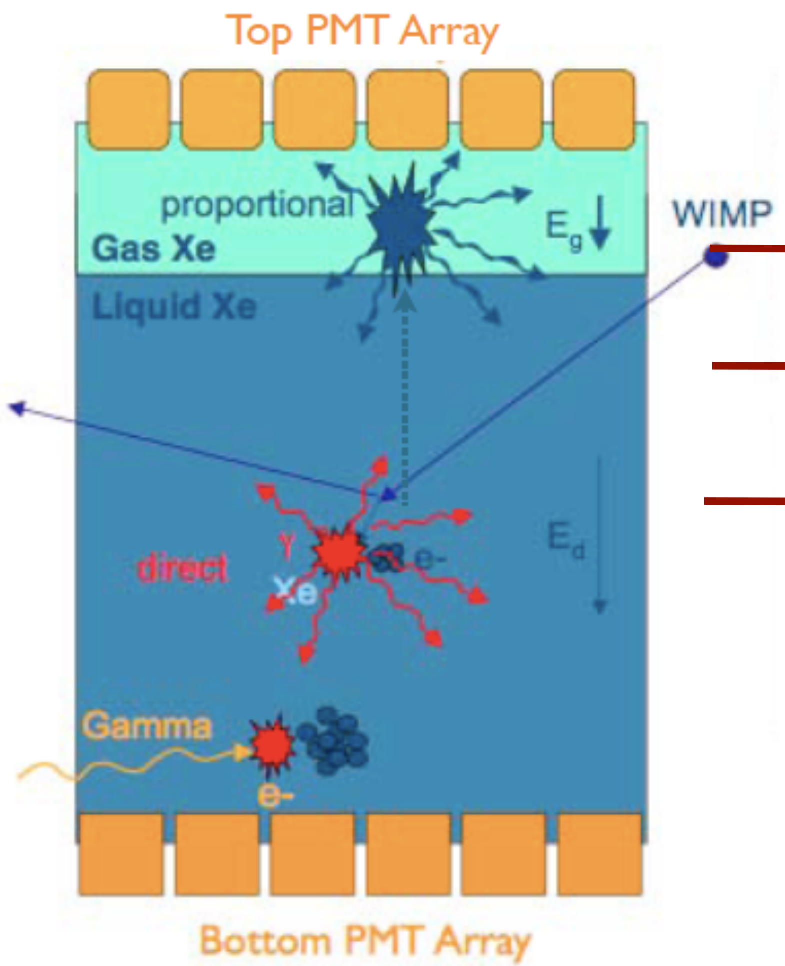
→

Nuclear Recoil	Electron Recoil
More light	More charge

→ detect both

Two-Phase Xenon TPC

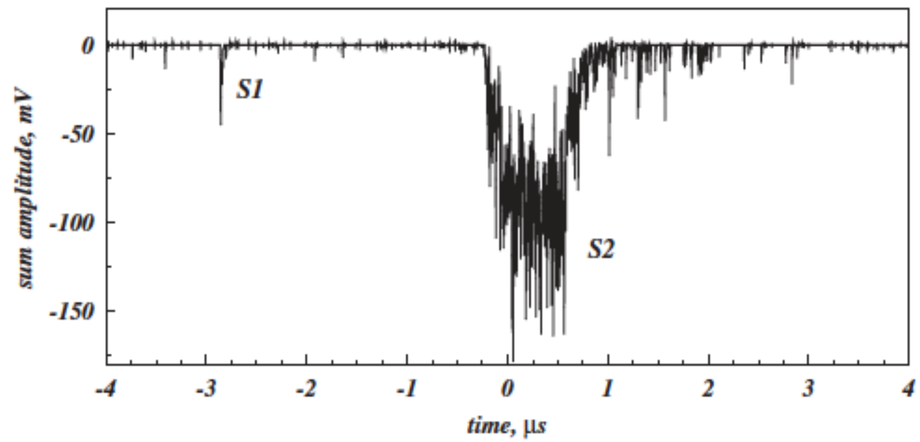
10keV



x300, 50K gamma (S2=charge)

170 electrons drift

550 gamma (S1=photon)

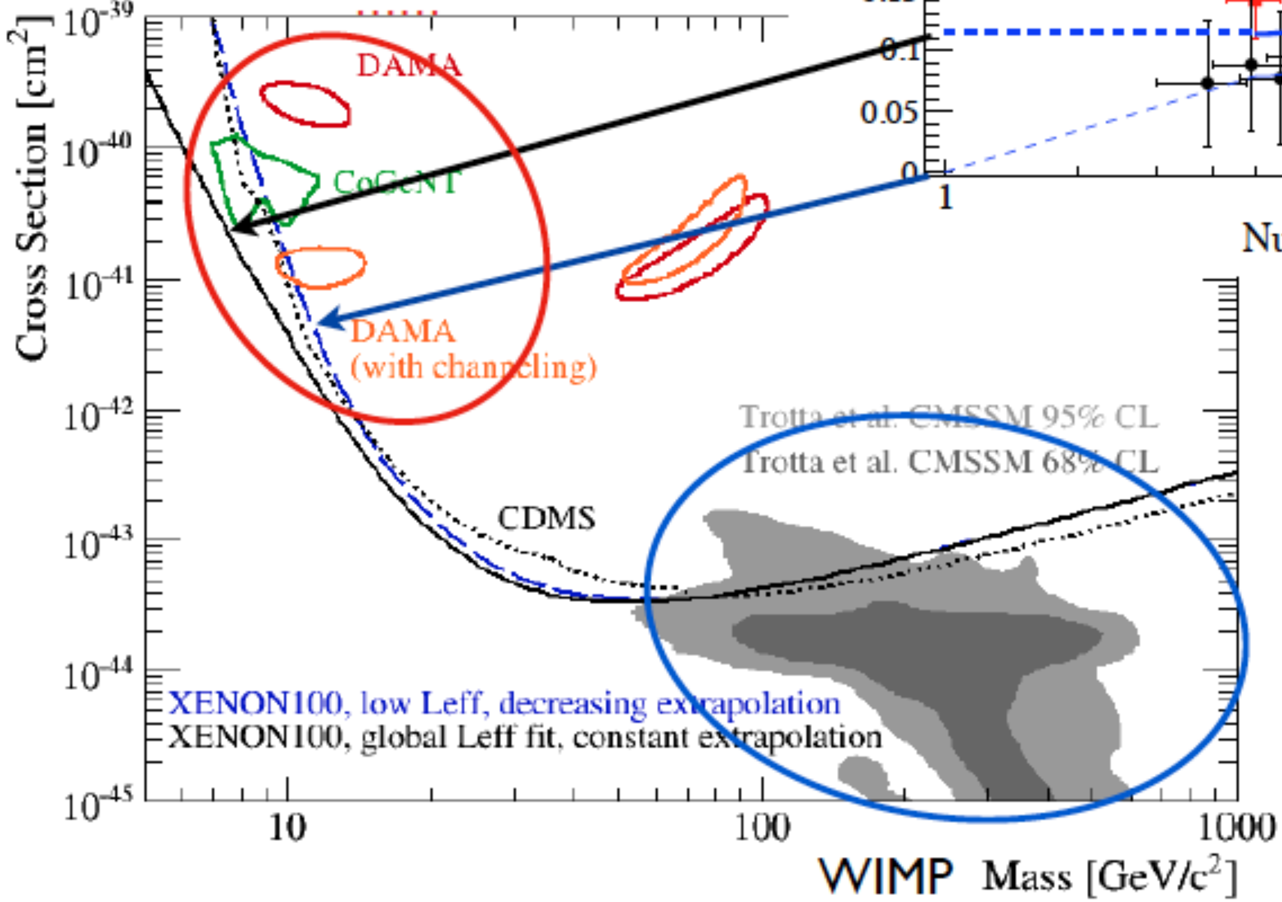


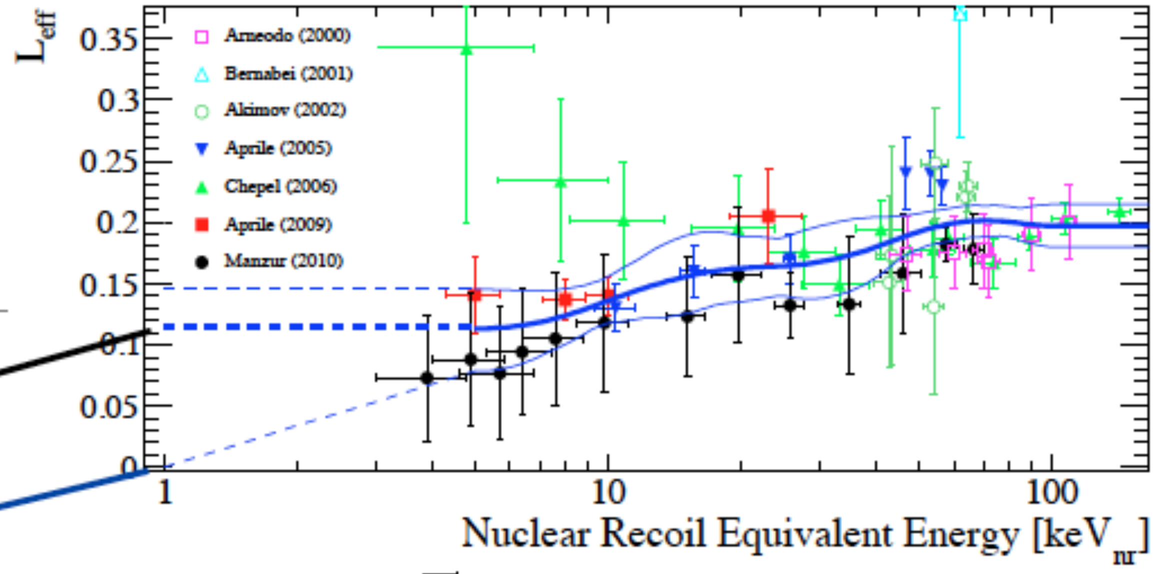
ZEPLIN-III, PHYSICAL REVIEW D 80, 052010 (2009)

Achieved upper limits

“hot” low-mass wimps and debates:

1002.4703, 1005.0838, 1005.2615
1005.3723, 1006.0972, 1006.2031
1007.1005, 1009.0549, 1010.5187
......

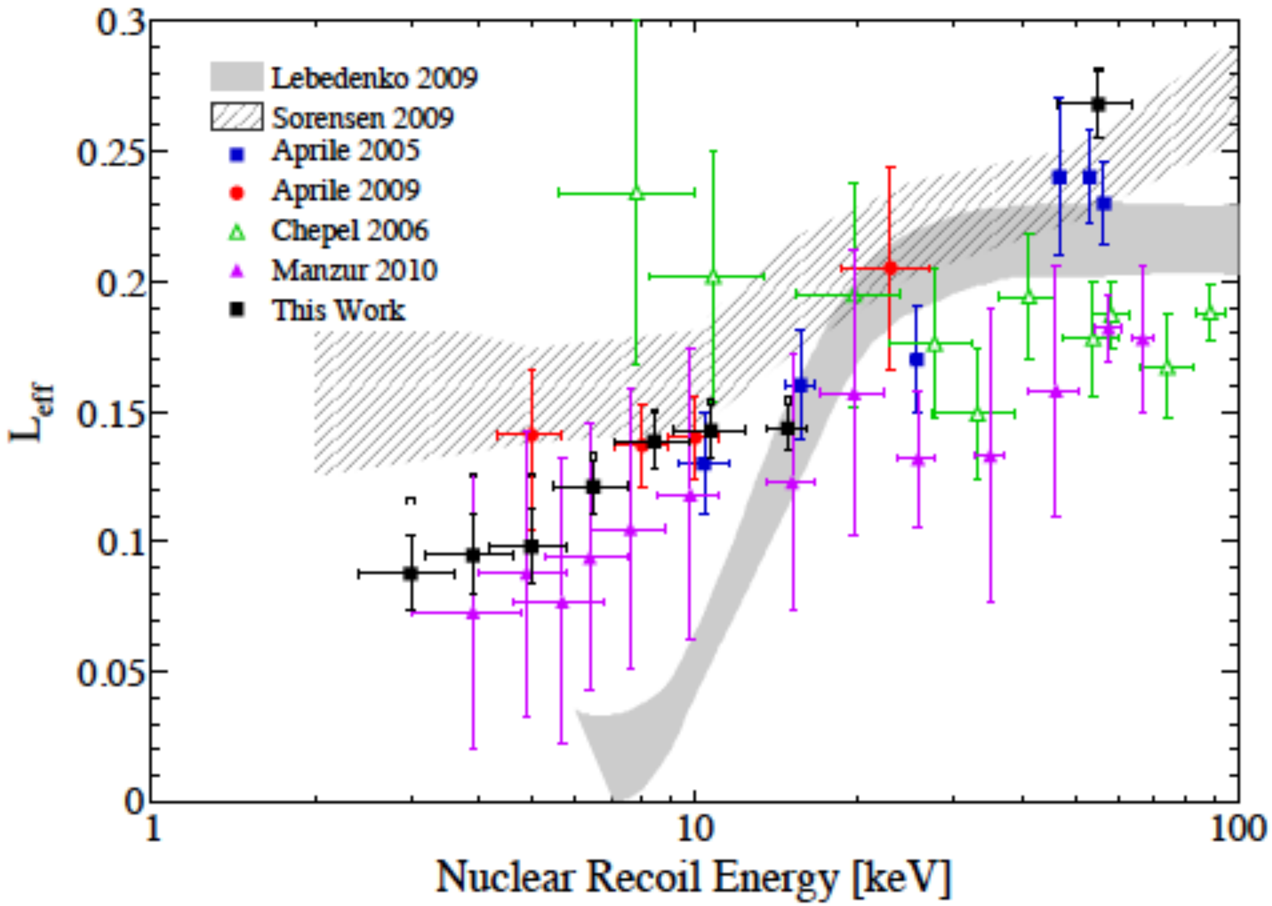




achieved competing sensitivity for “normal” mass WIMPs

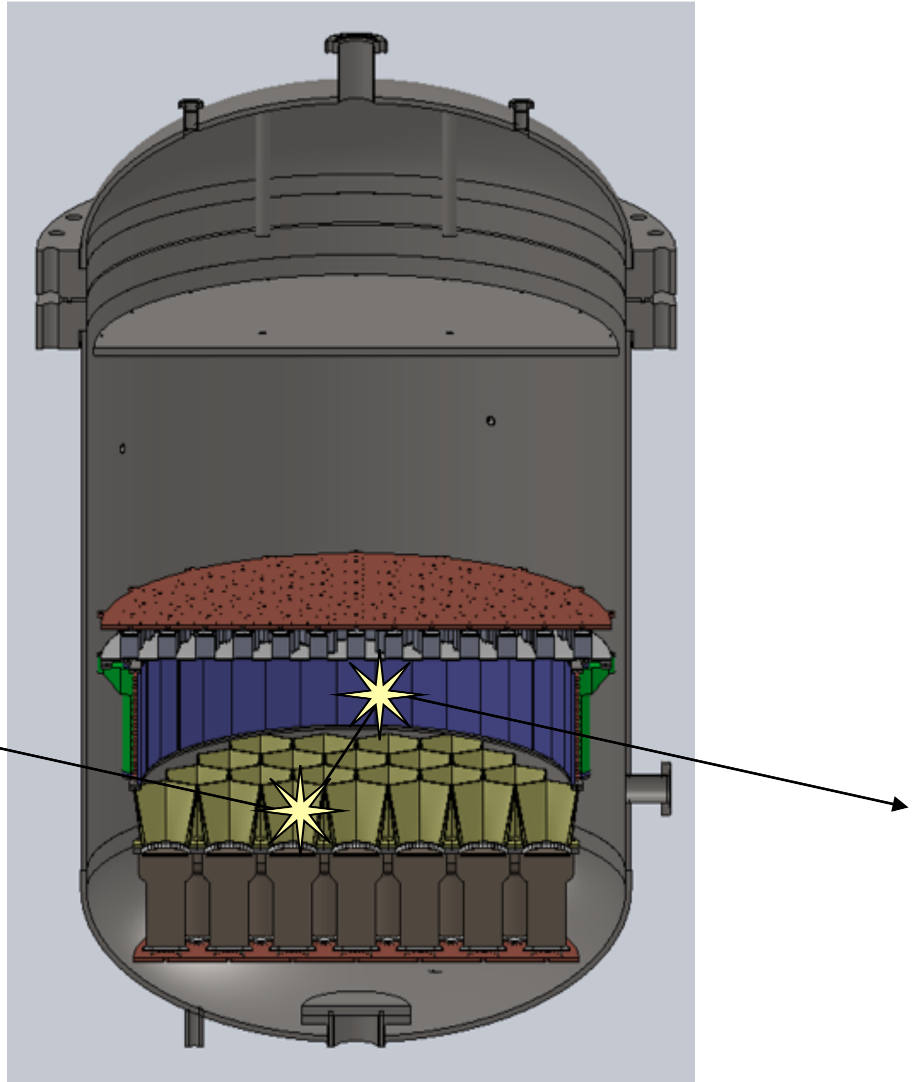
Phys.Rev.Lett.105, 131302 (2010)

Leff



arXiv:1104.2587

Remove “leakage events”



PTFE reflector

PANDAX Phase I vs. Xenon100

	Xenon100	PANDAX
LXe Diameter [cm]	30	60
LXe Height [cm]	30	15
Cathode Voltage [kV]	-16	-75
Drift field [kV/cm]	0.53	5.0
Fiducial mass [kg]	40	30
S1 collection efficiency	24%(average)	57% (average)
Gamma S2/S1 rejection	99%	99.9% (expected)