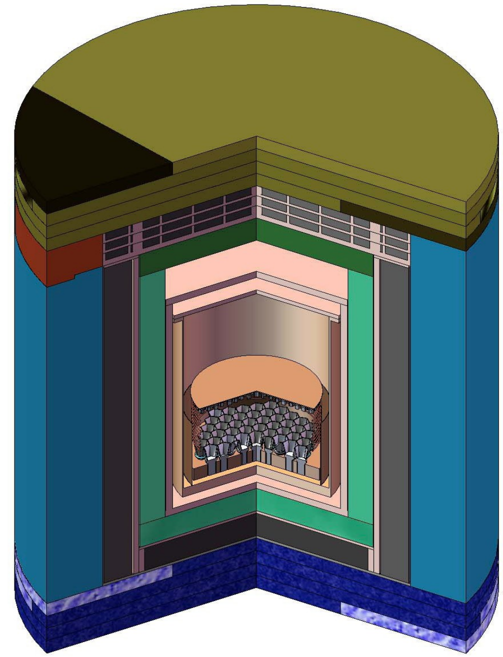
The PANDAX Experiment
Particle AND Astroparticle Xenon Observatory



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Shanghai Jiaotong Univeristy

Application of Germanium in Fundamental Physics
Tsinghua University
April 23-29, 2011

Outline

- Introduction to dark matter

- Direct detection

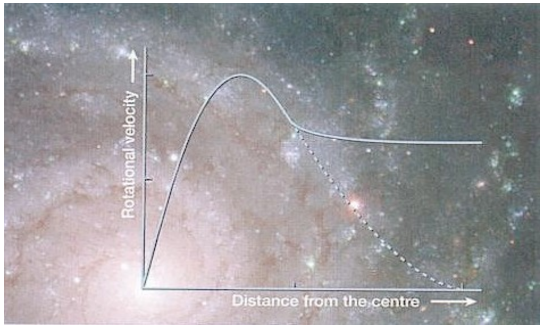
- Liquid Xenon advantages

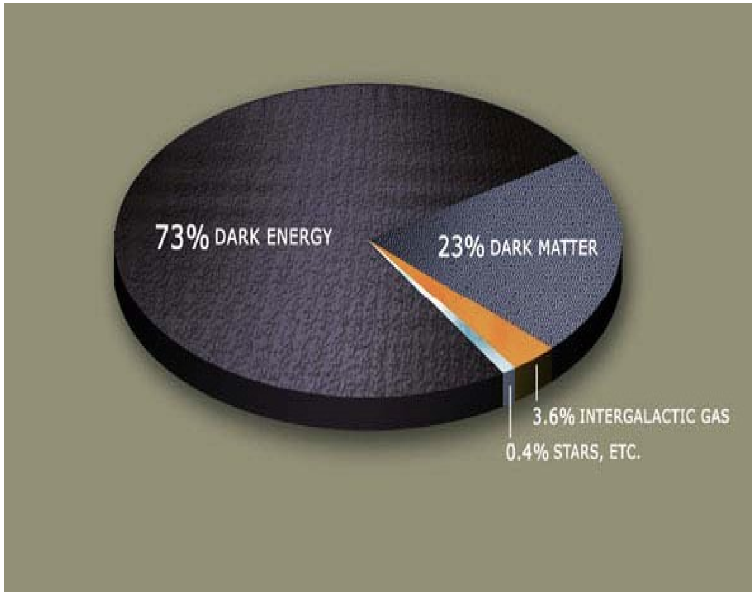
- Two Phase advantages

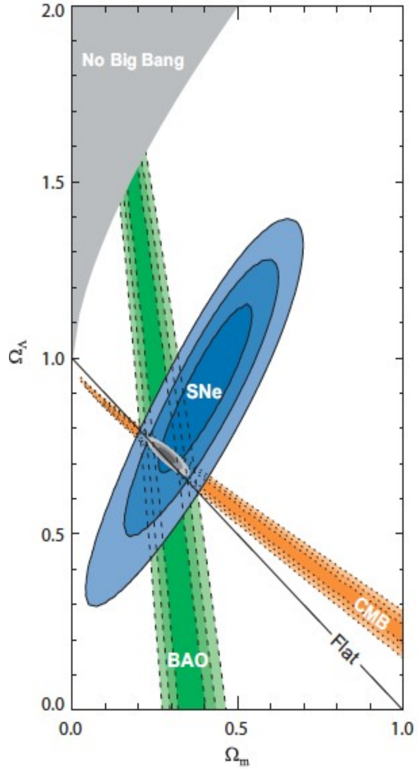
- PANDAX

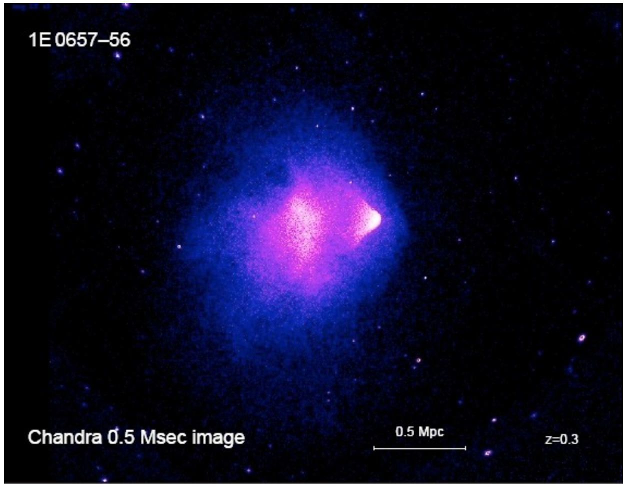
- Summary

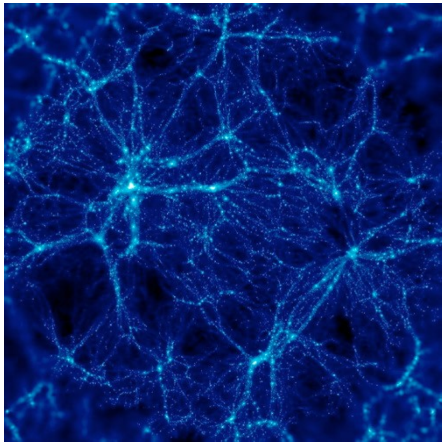
Existing evidence of dark matter

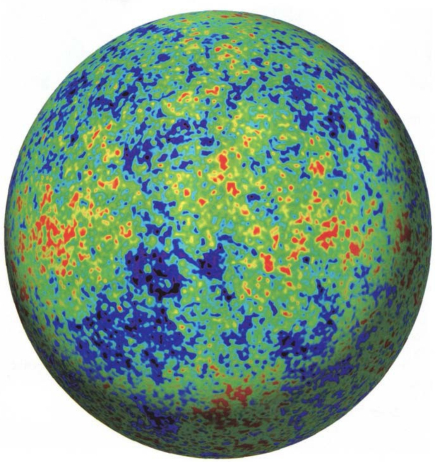


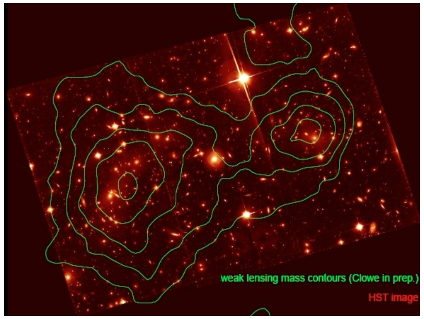






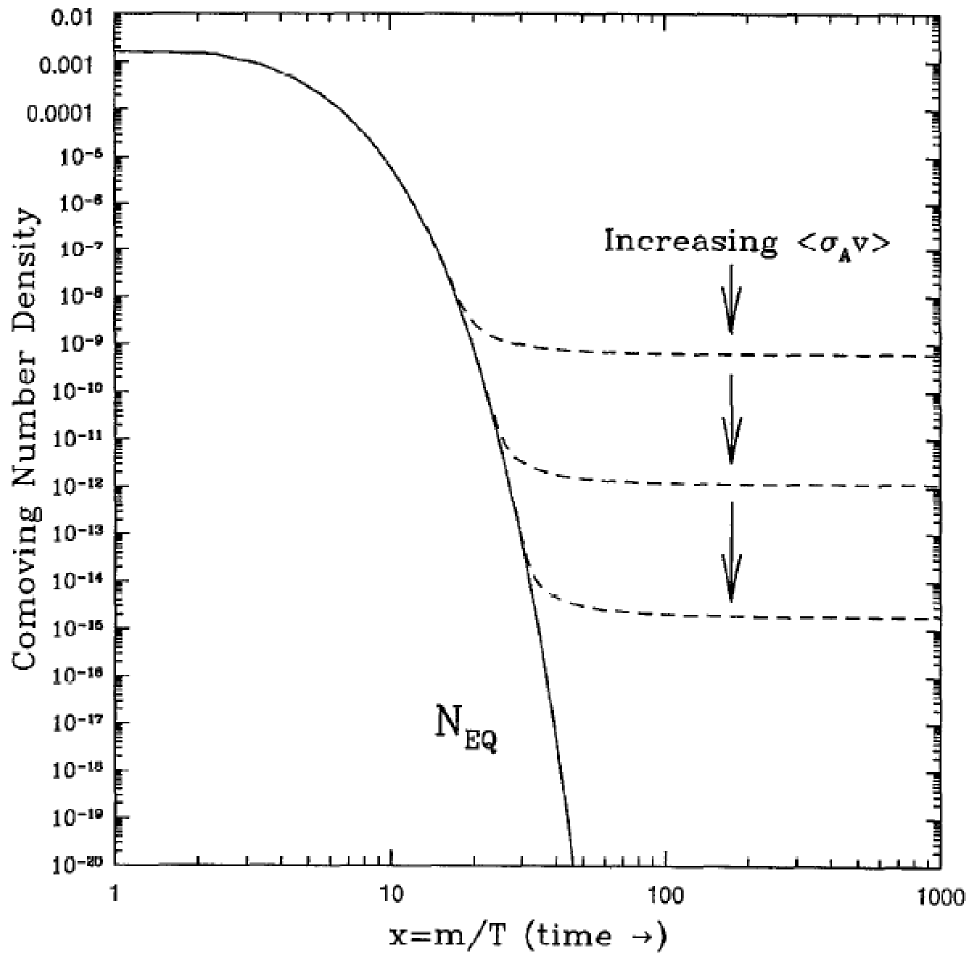






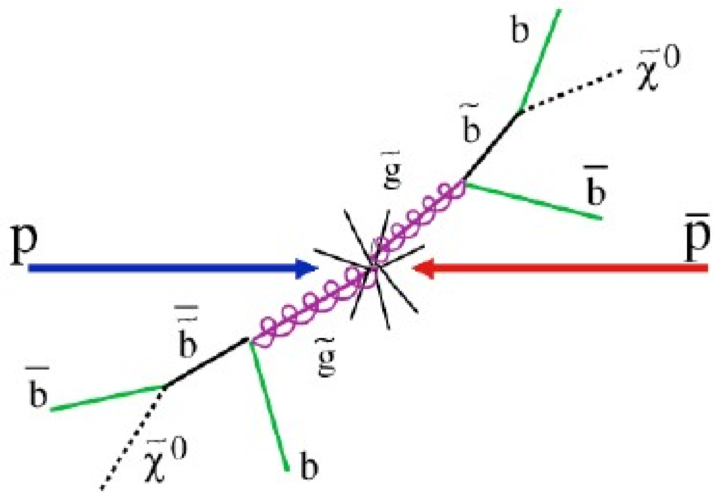
Favorite candidate: WIMP

Lightest SUSY Particle
Neutralino
with weak coupling
→ WIMP Miracle

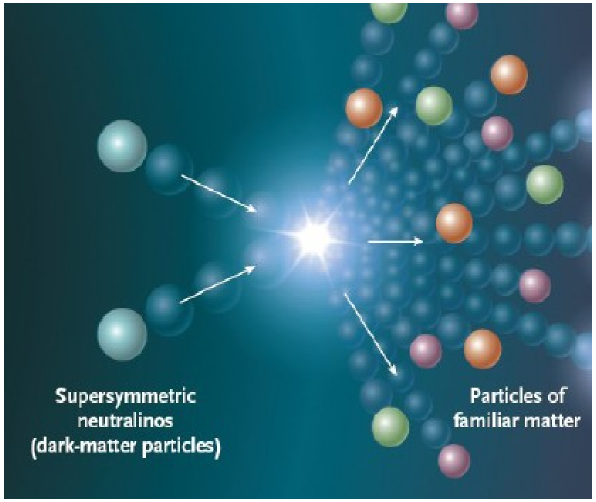


Phys. Rep. 267(1996) 195-273

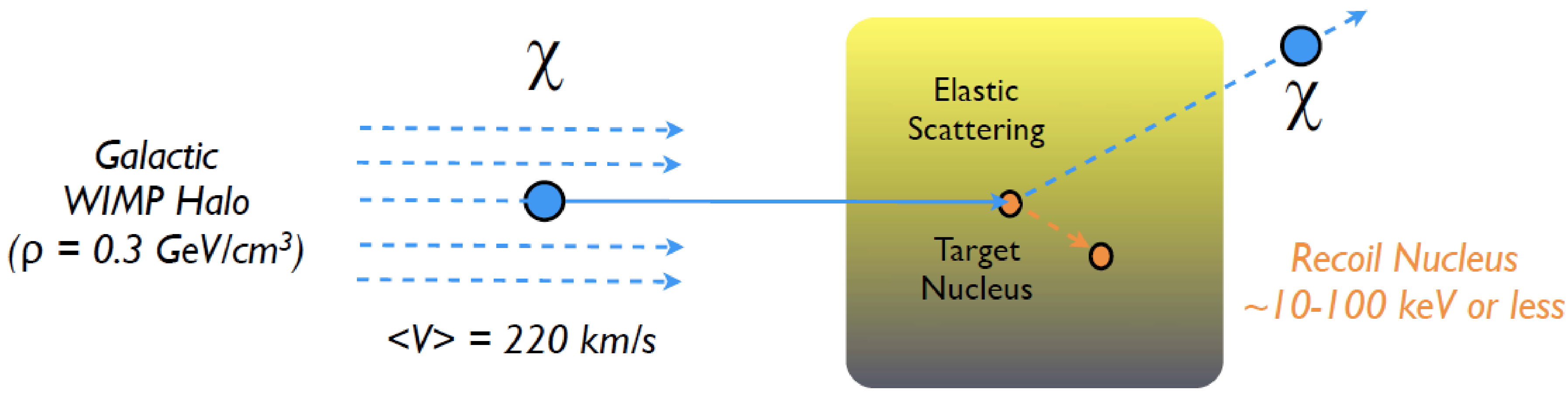
Methods to search LSP



production at collider

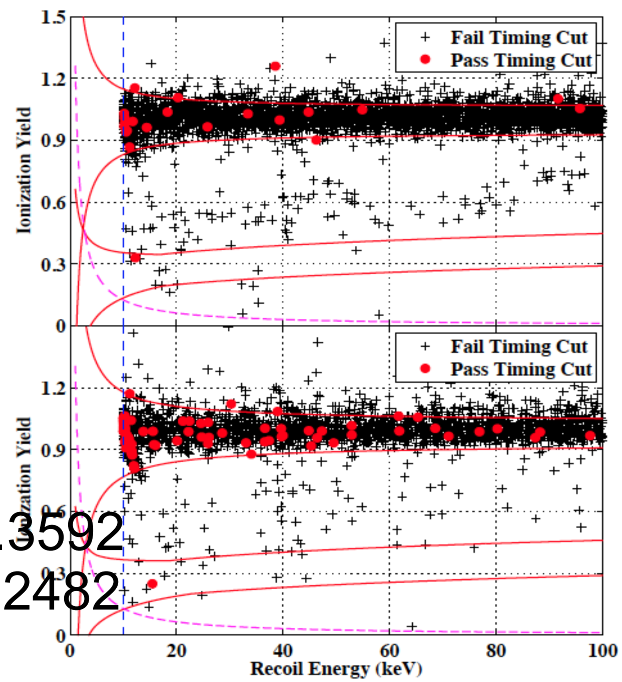


annihilation particle detection (indirect)



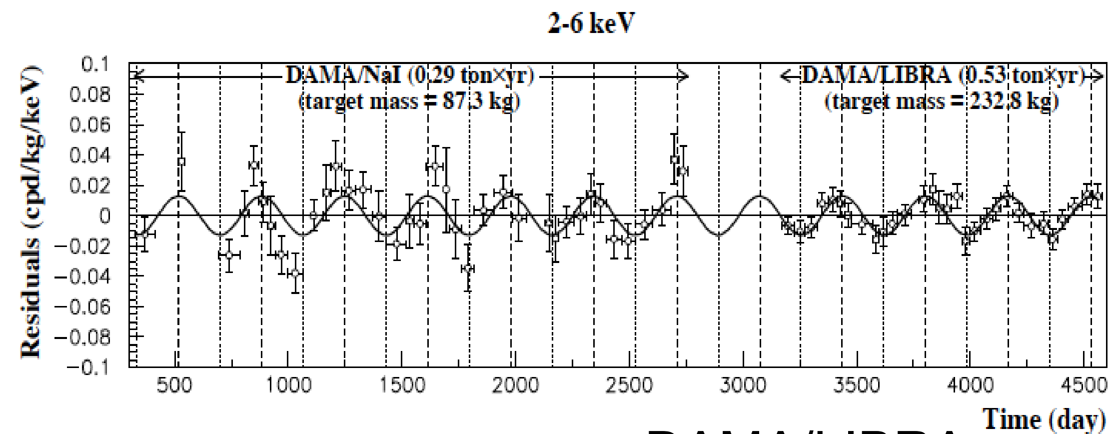
nuclear recoil (direct)

Recent direct detection results

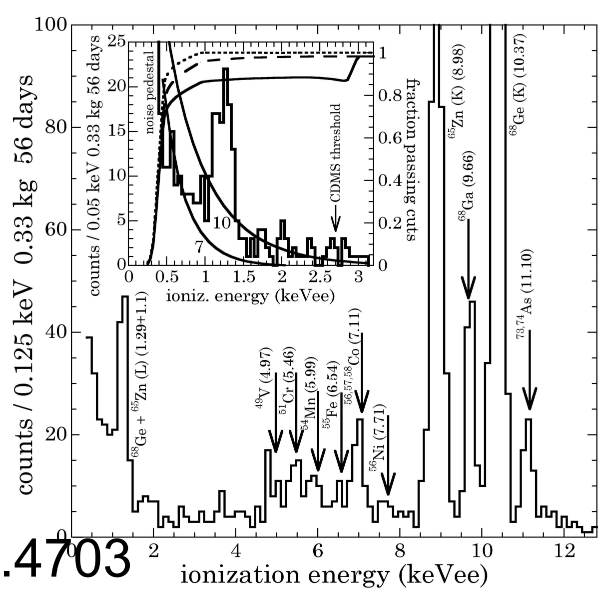


CDMS

arXiv:0912.3592
arXiv:1011.2482

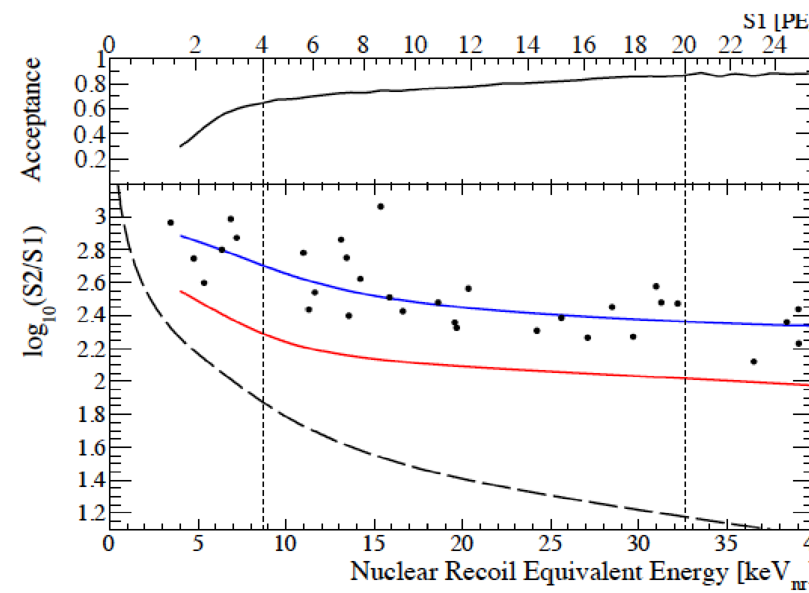


DAMA/LIBRA



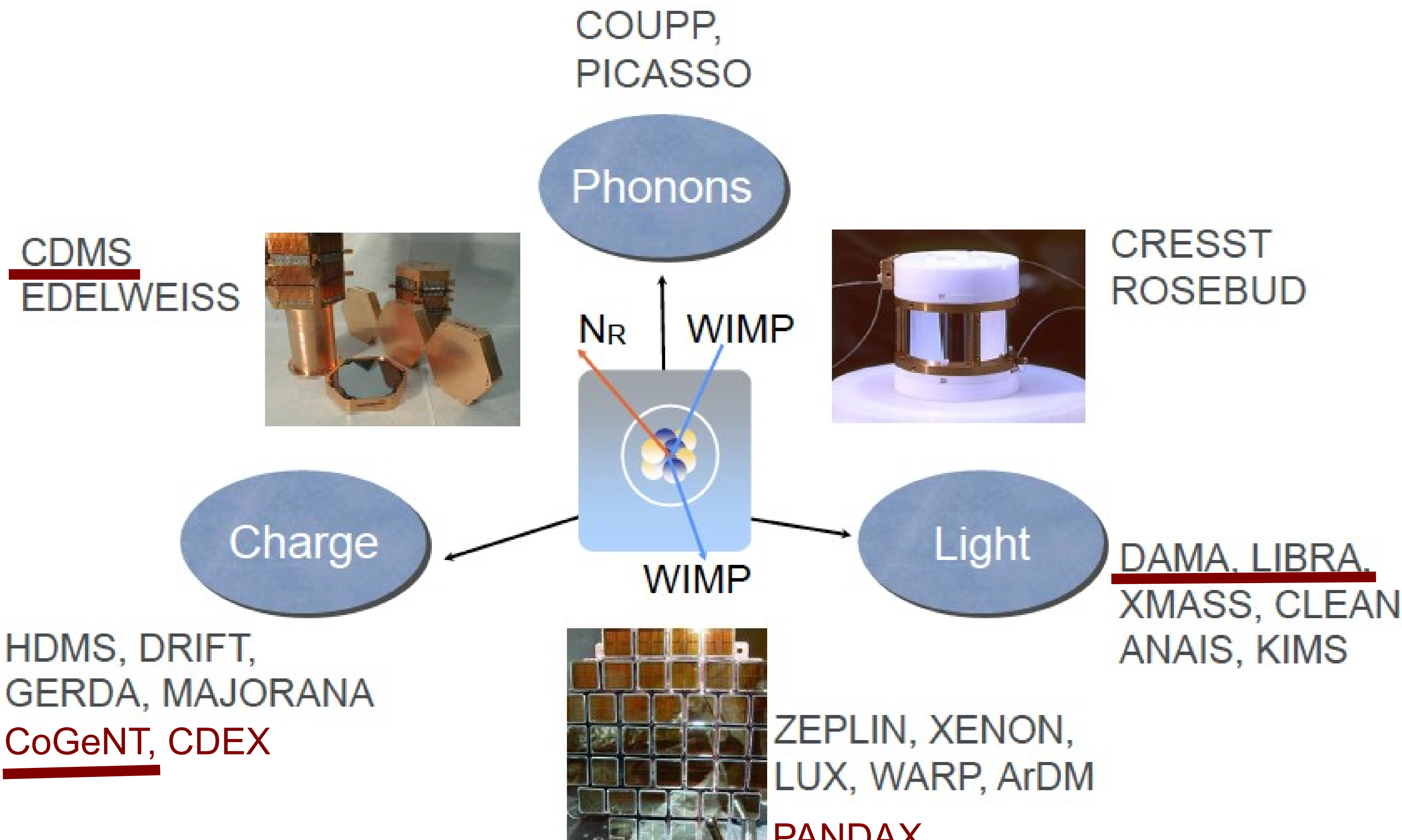
CoGeNT

arXiv:1002.4703



XENON100 arXiv:1005.0380

Direct detection technique

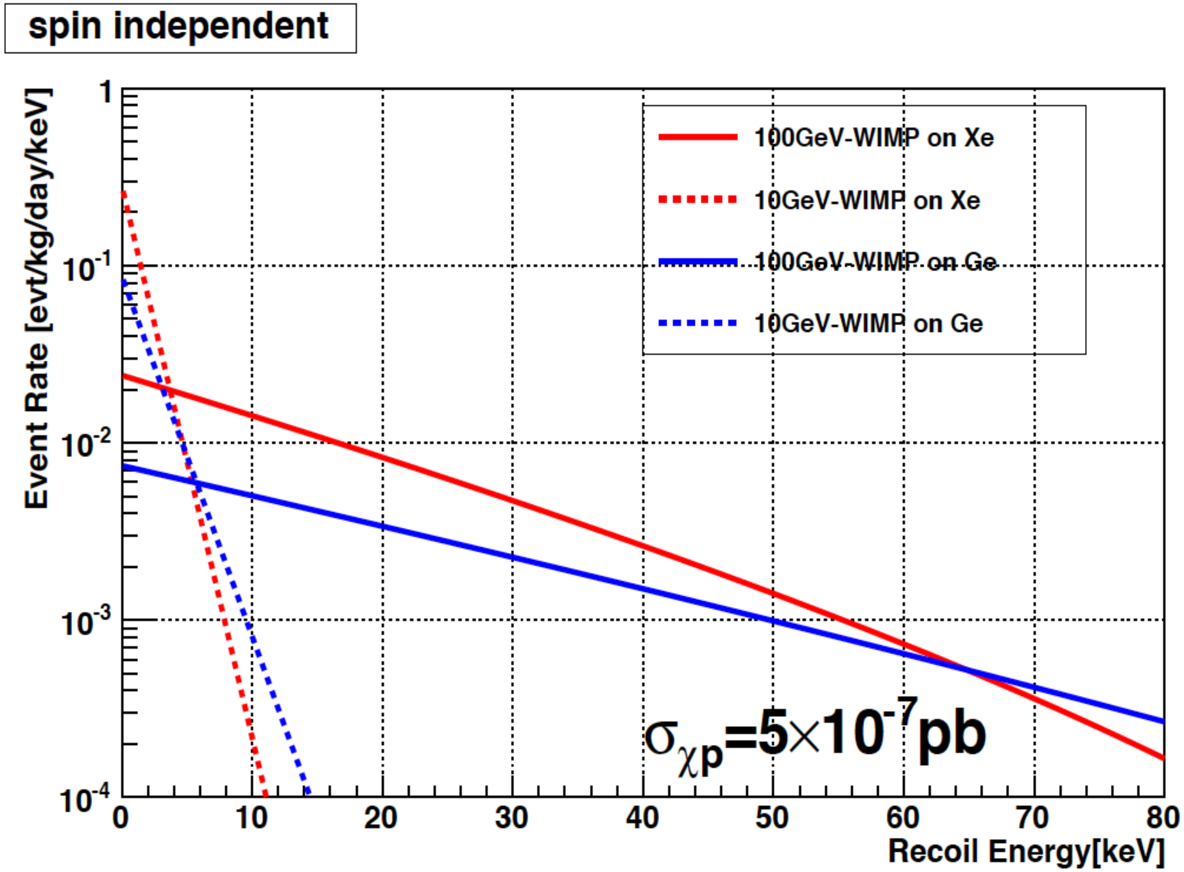


Direct detection challenge

WIMP signal: <0.1/kg day
<100keV
no feature

Signal collection

Background rejection



Xenon advantage

Signal collection

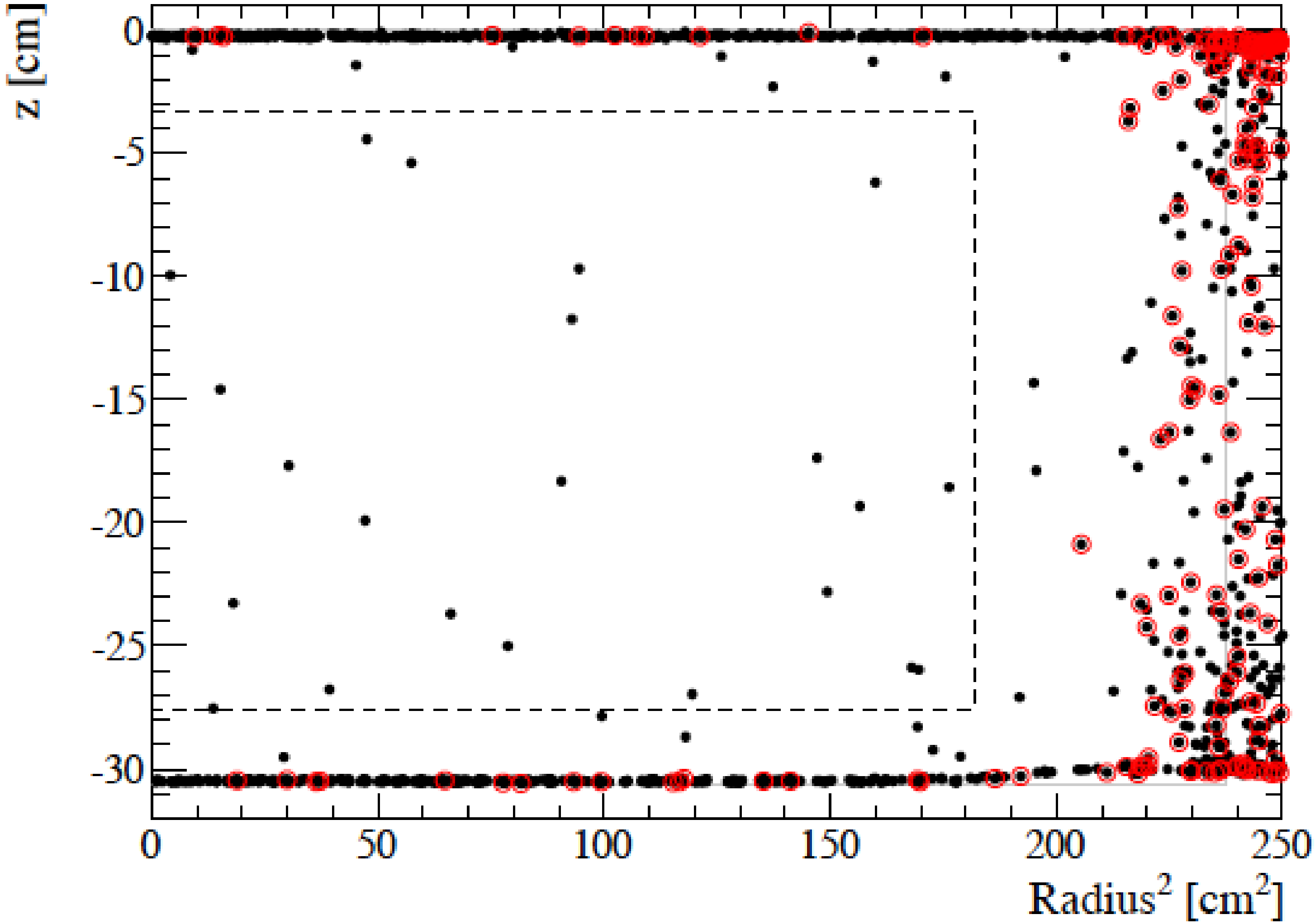
- large A: $\sigma_{SI} \sim A^2$
- easy scale-up, larger mass
- efficient scintillation (80% of NaI), 178nm, no WS
- Xe131 sensitive to spin-dependent

Background rejection

- self-shielding, 3g/cm^3
- no long-life radioactive isotopes
- easy to remove Kr (distillation)
- dual phase

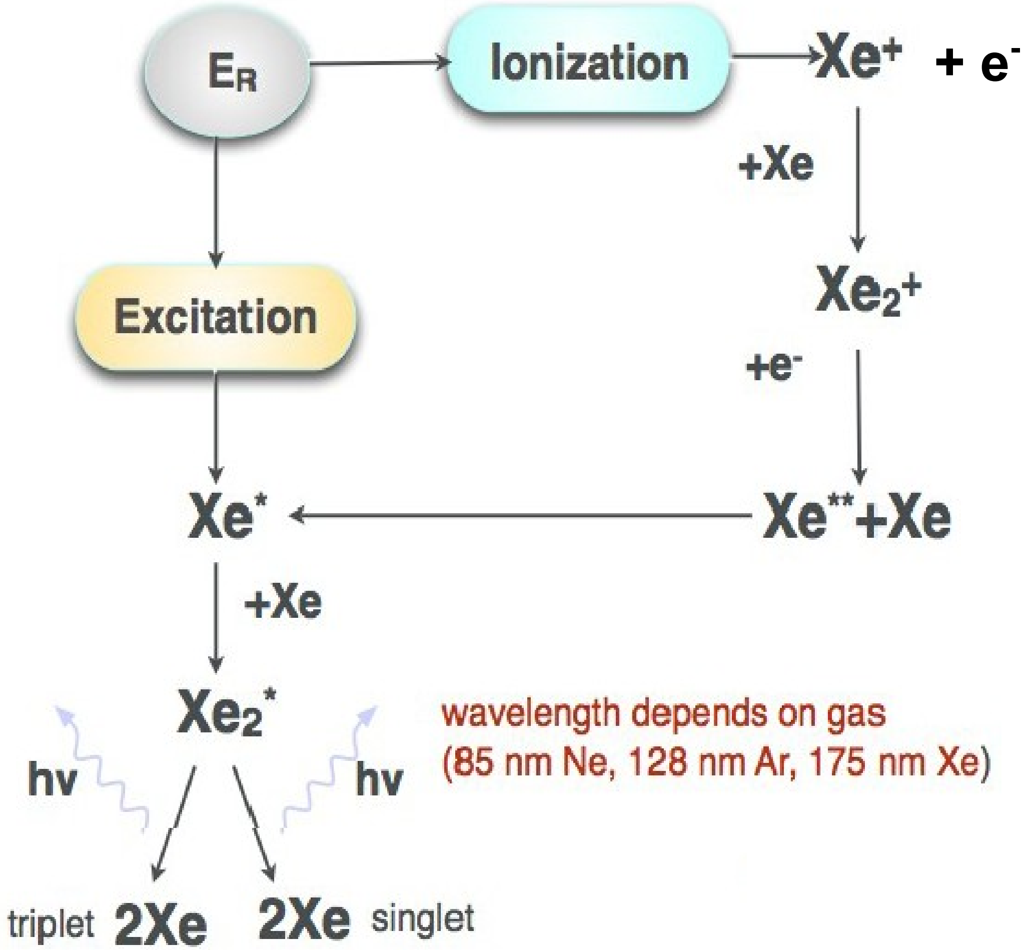
- noble gas, -100°C, easy to handle

Xenon self-shielding



XENON100 arXiv1005.0380

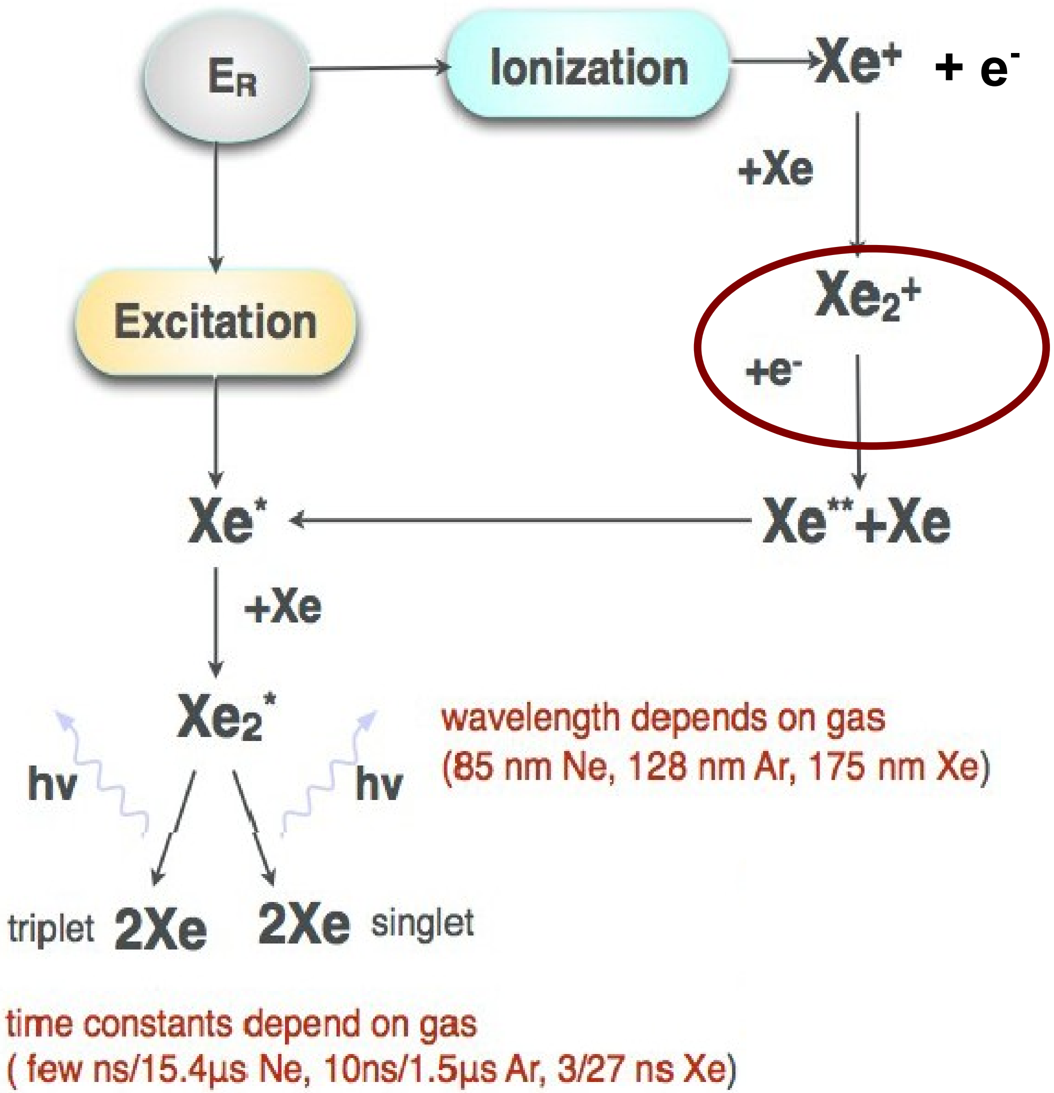
Xenon light & charge



wavelength depends on gas
(85 nm Ne, 128 nm Ar, 175 nm Xe)

time constants depend on gas
(few ns/15.4μs Ne, 10ns/1.5μs Ar, 3/27 ns Xe)

Xenon light & charge

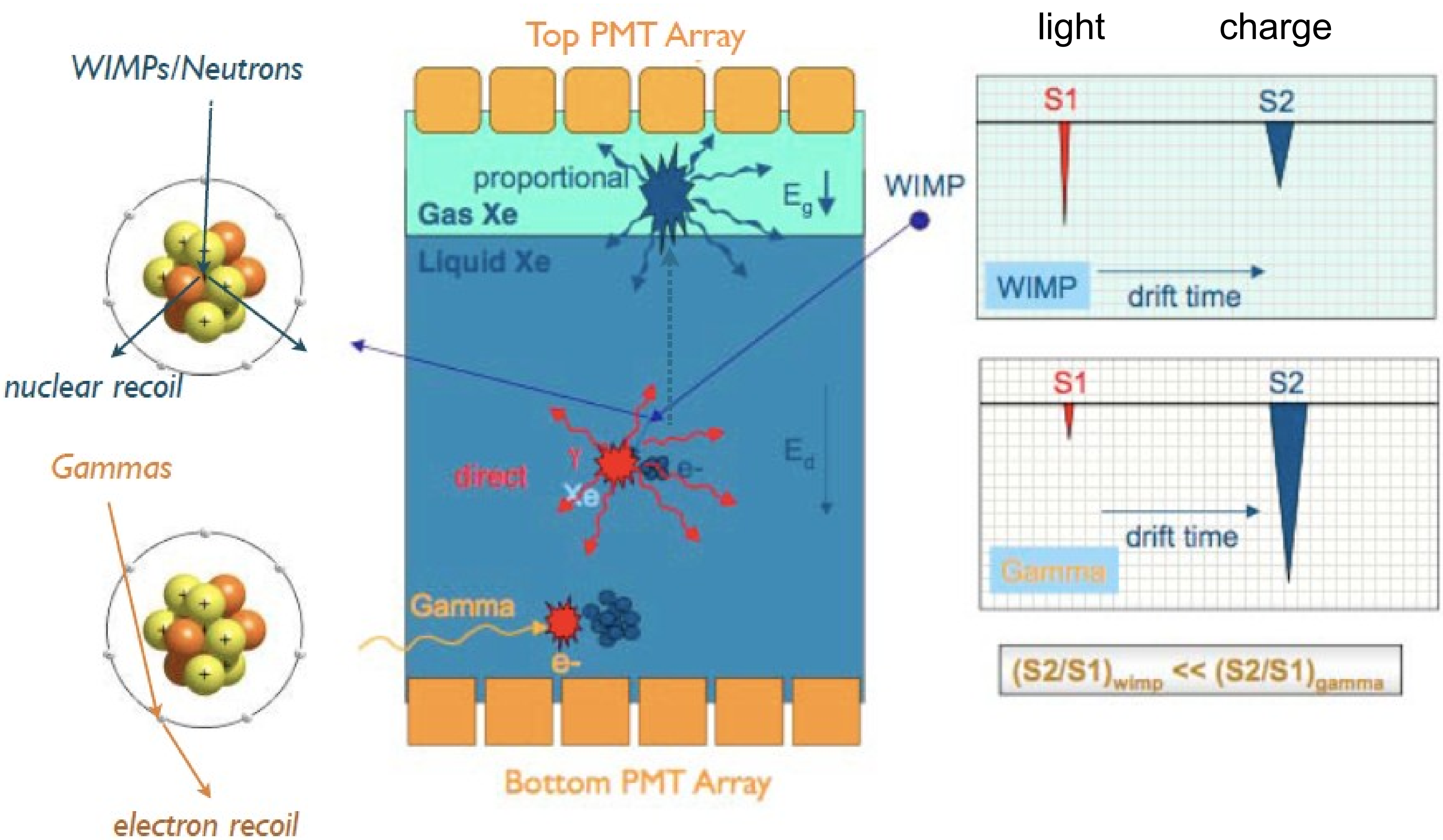


Recombination:
Nuclear Recoil >> Elec. Recoil

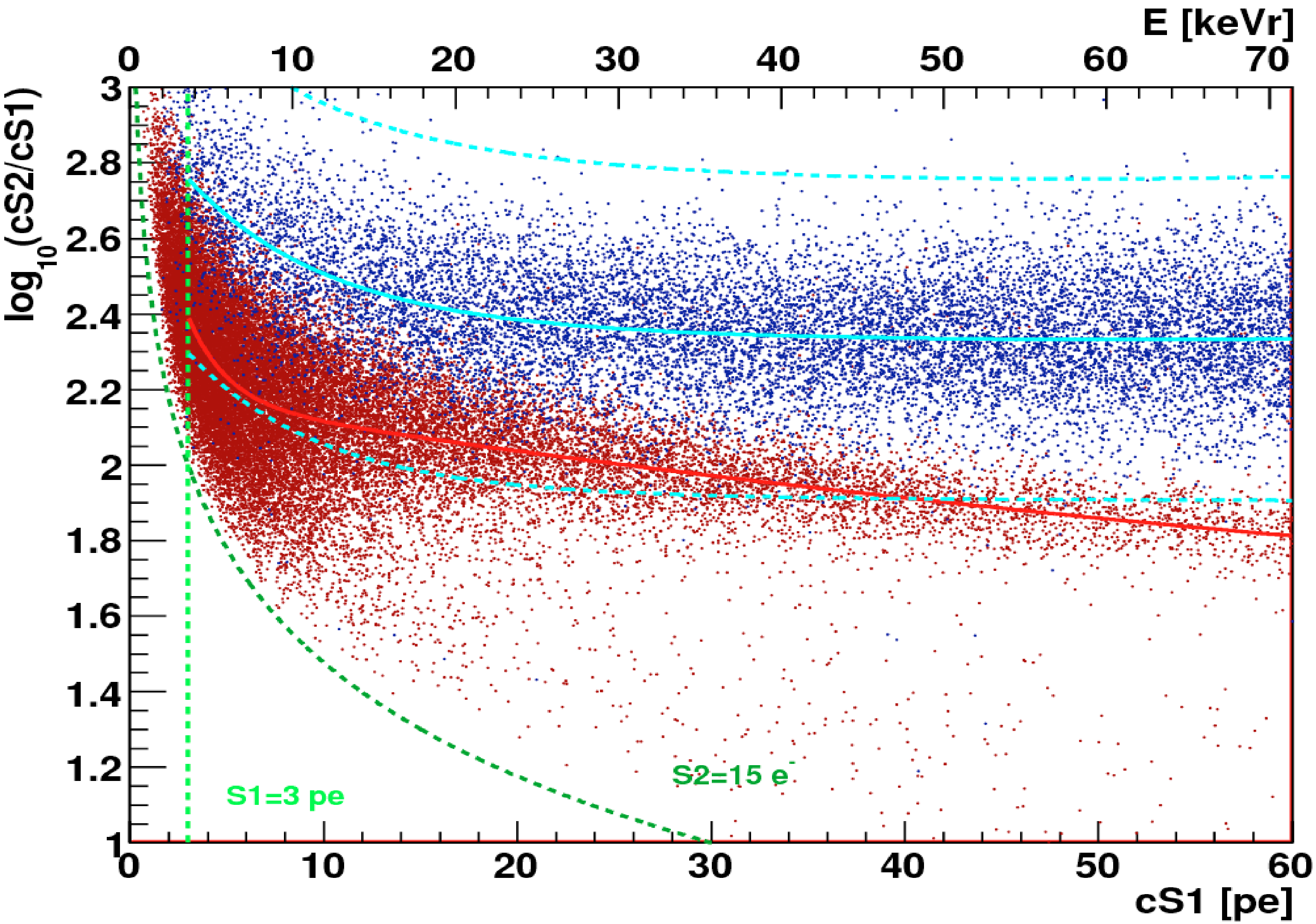
Nuclear Recoil	Electron Recoil
More light	More charge

two-phase detector

Advantage of two-phase TPC (I)



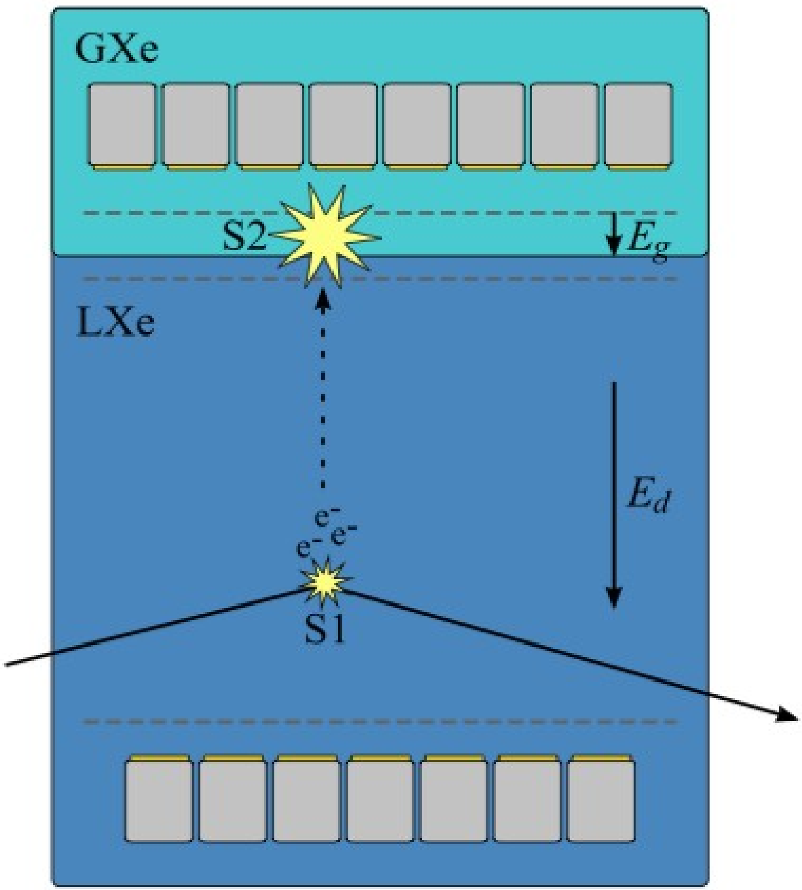
Advantage of two-phase TPC (I)



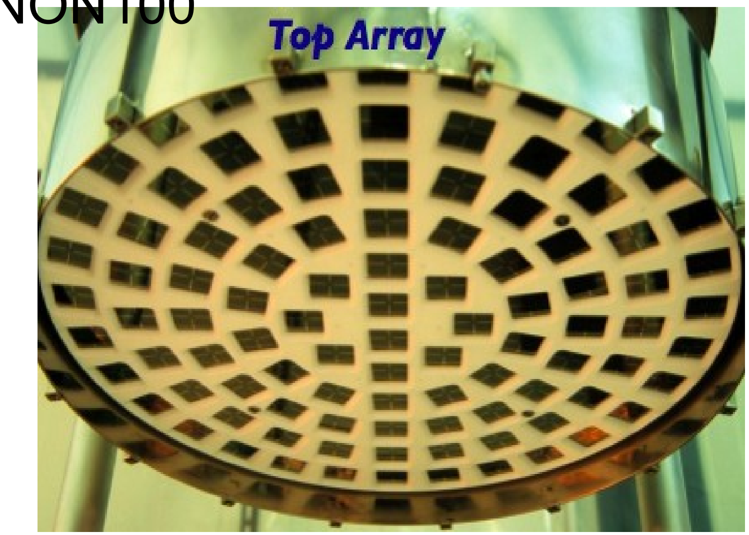
XENON100

Advantage of two-phase TPC (II)

Excellent 3D position σ, 2mm



XENON100

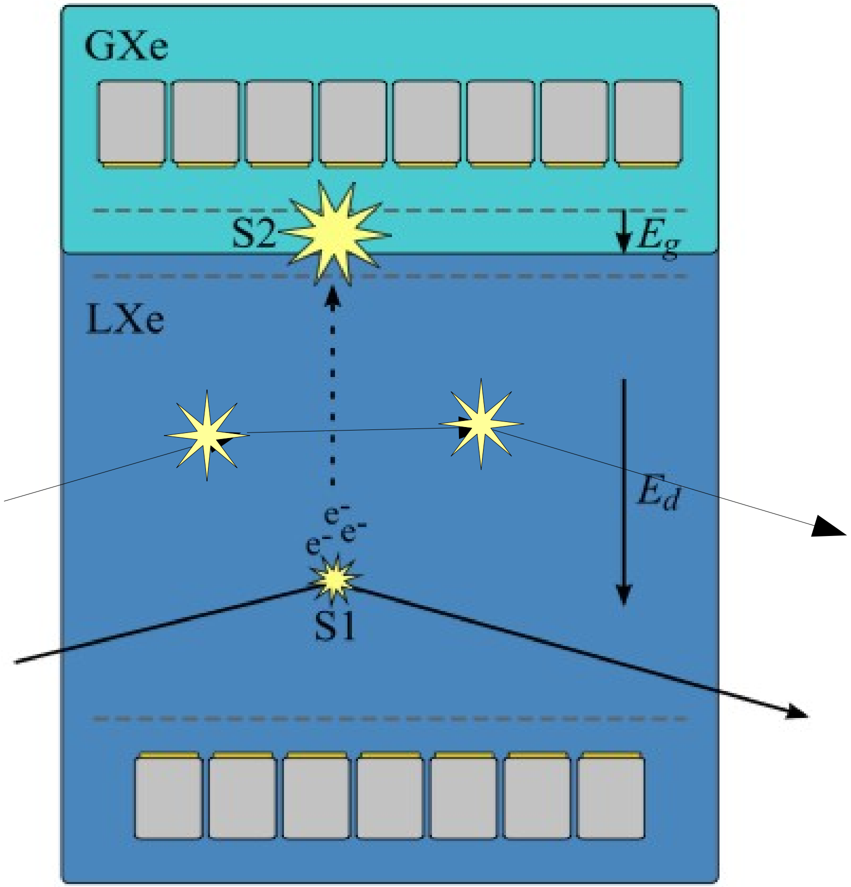


gamma event localized

Top PMT array

Advantage of two-phase TPC (II)

Excellent 3D position σ, 2mm

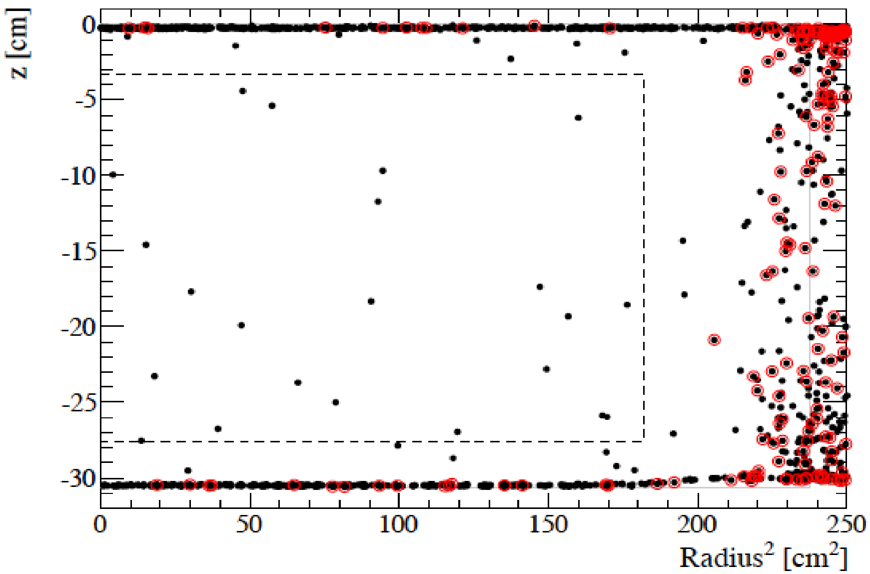


Mean-free-path
MeV gamma: ~3cm
MeV neutron: ~30cm

gamma/neutron , multiple hits

WIMP, single hit

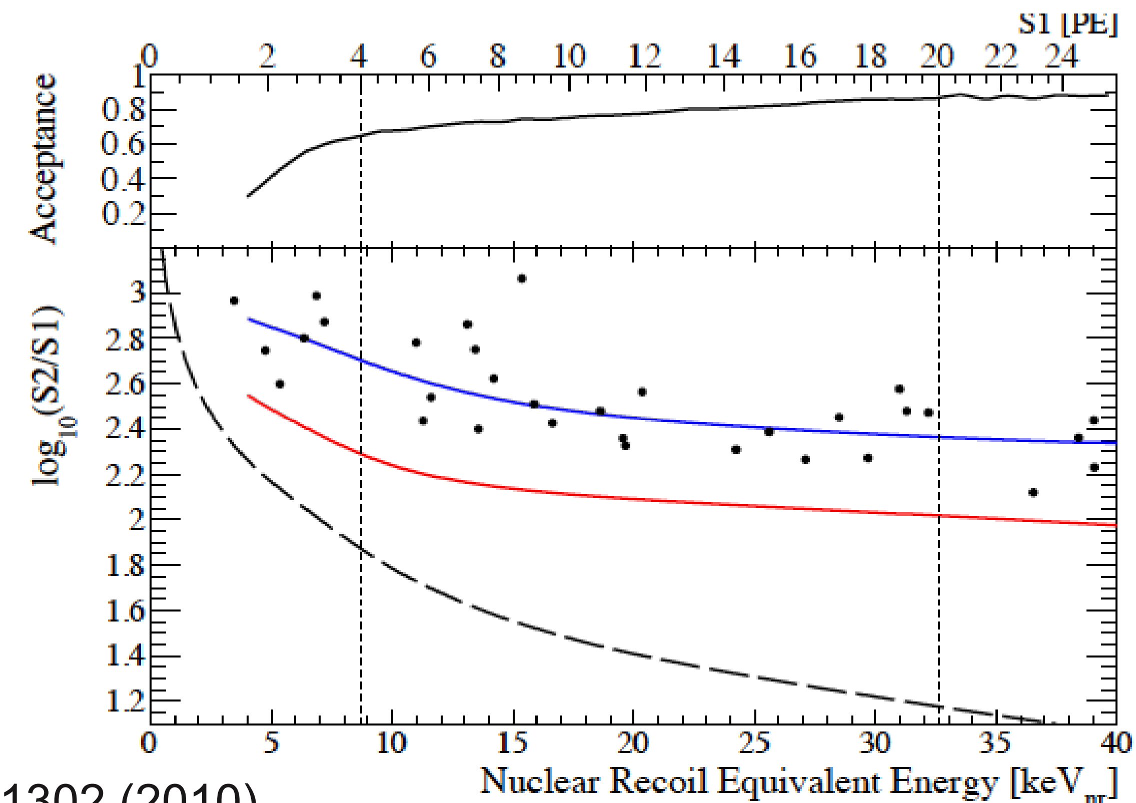
Latest XENON100 results



all 22 events in fiducial volume failed S2/S1 and single-hit cut

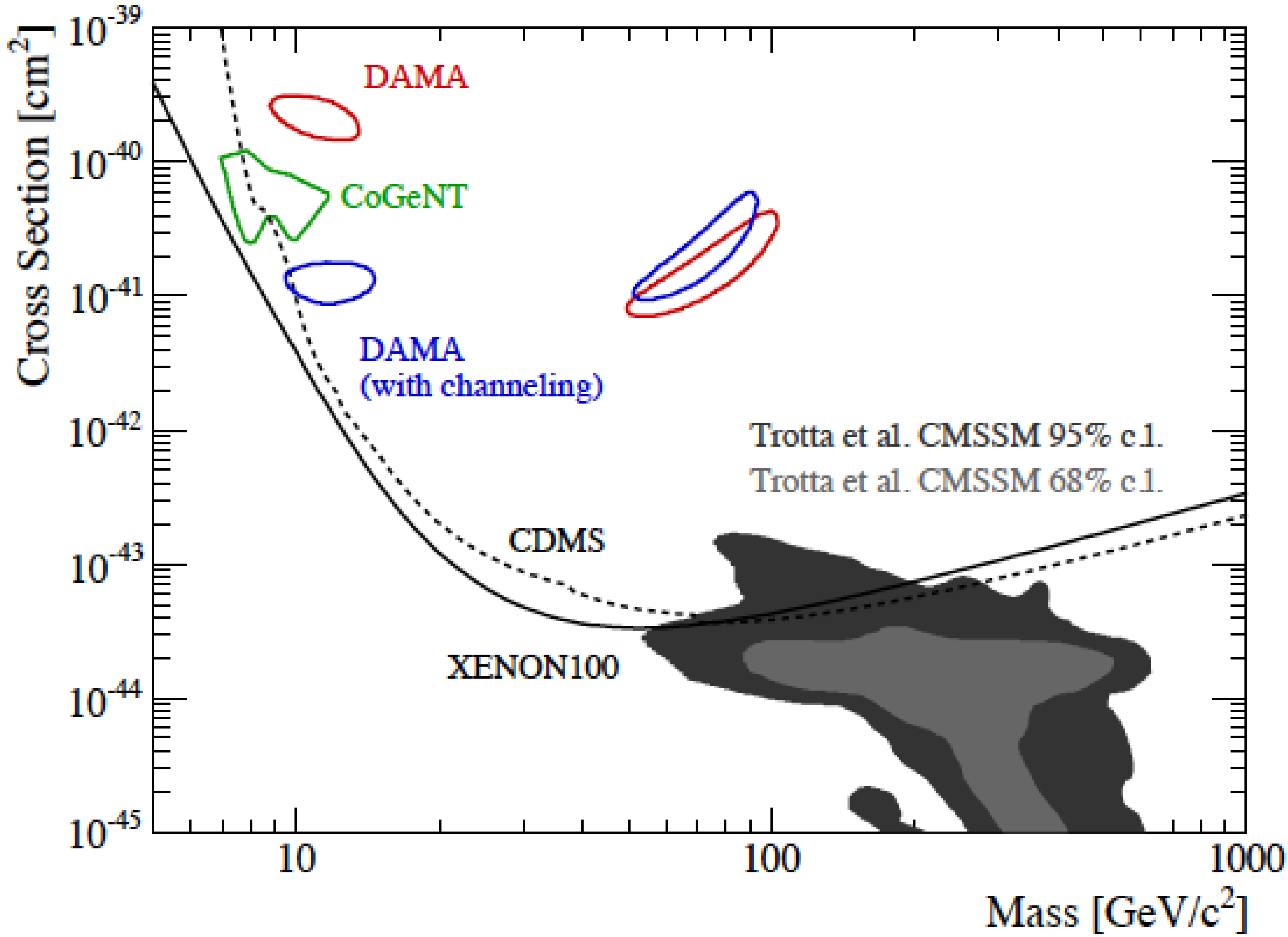
→

Zero background achieved



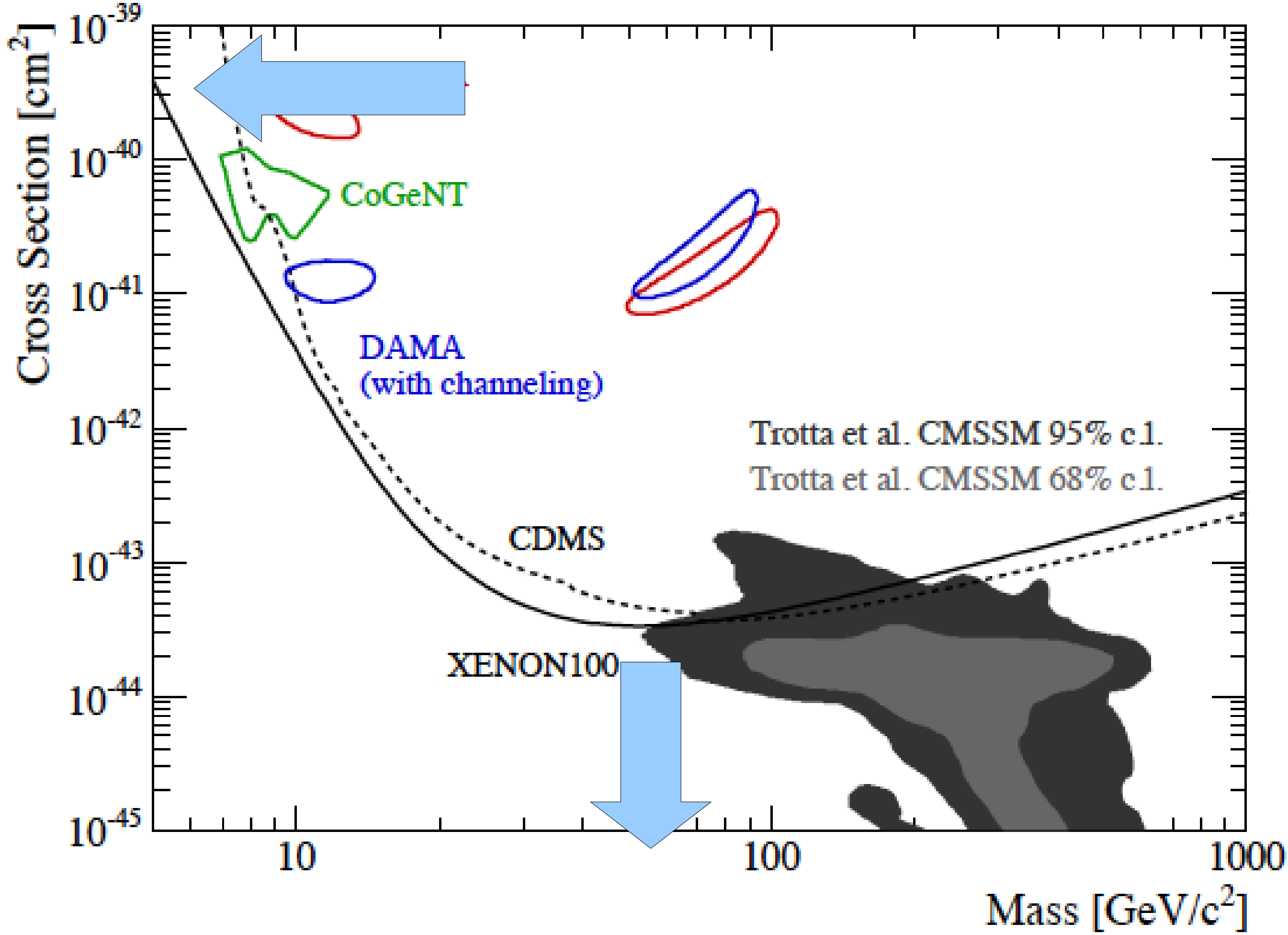
XENON100, PRL 105, 131302 (2010)

Direct detection status



Direct detection status

Smaller WIMP mass, smaller energy threshold



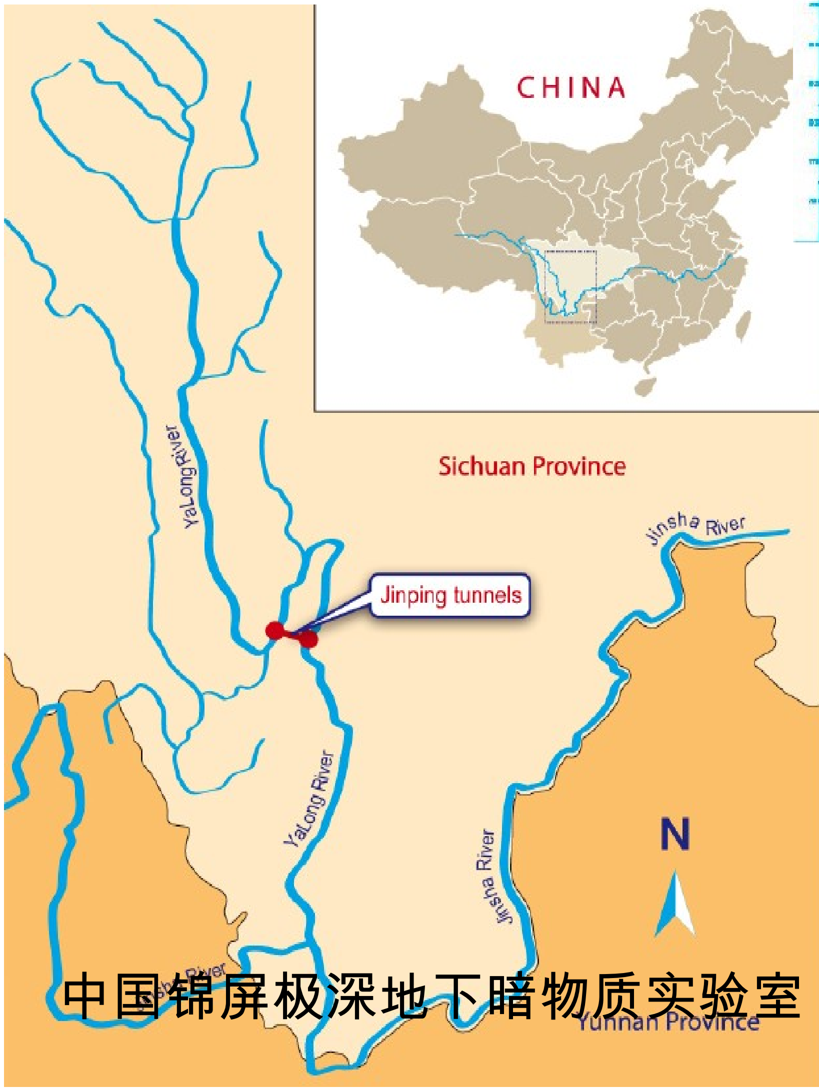
Smaller σ, larger detector mass, lower bg rate.

PANDAX collaboration

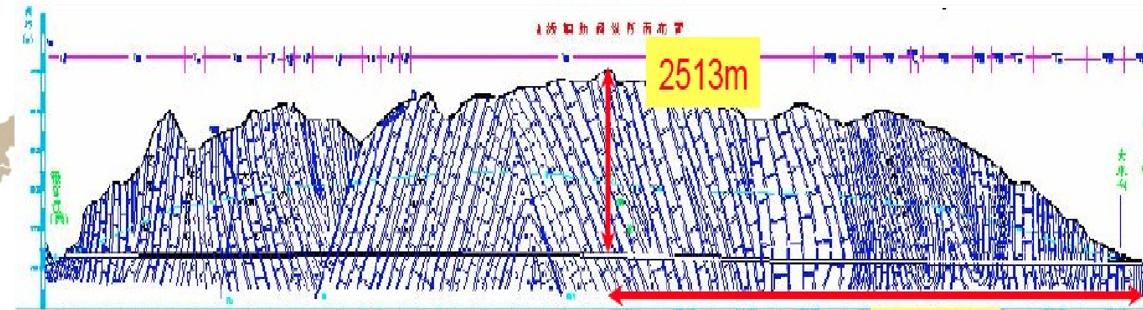
Particle AND Astro-particle Xenon Observatory

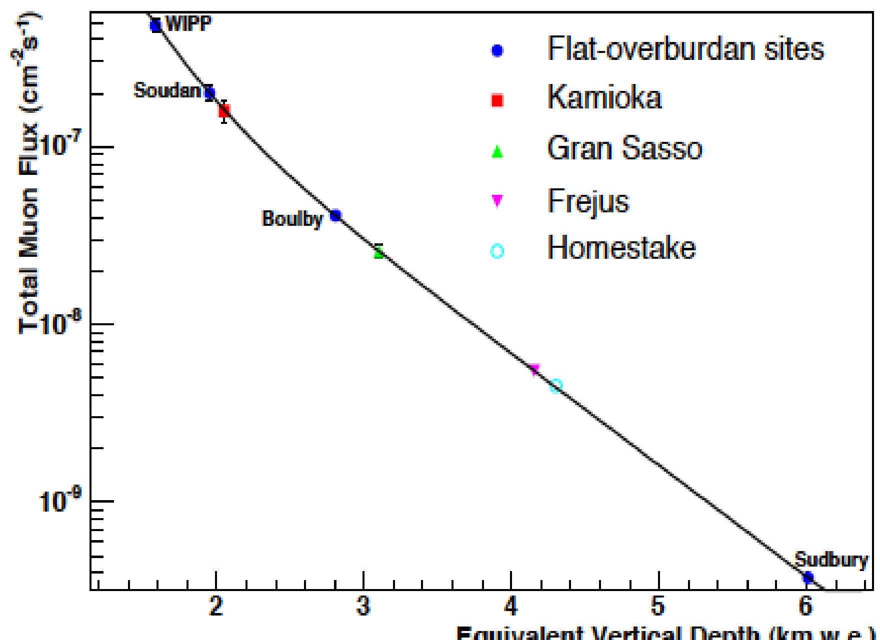
Shanghai Jiaotong University
Shanghai Institute of Applied Physics
Shandong University
Peking University, Center for High Energy physics

PANDAX in Sichuan



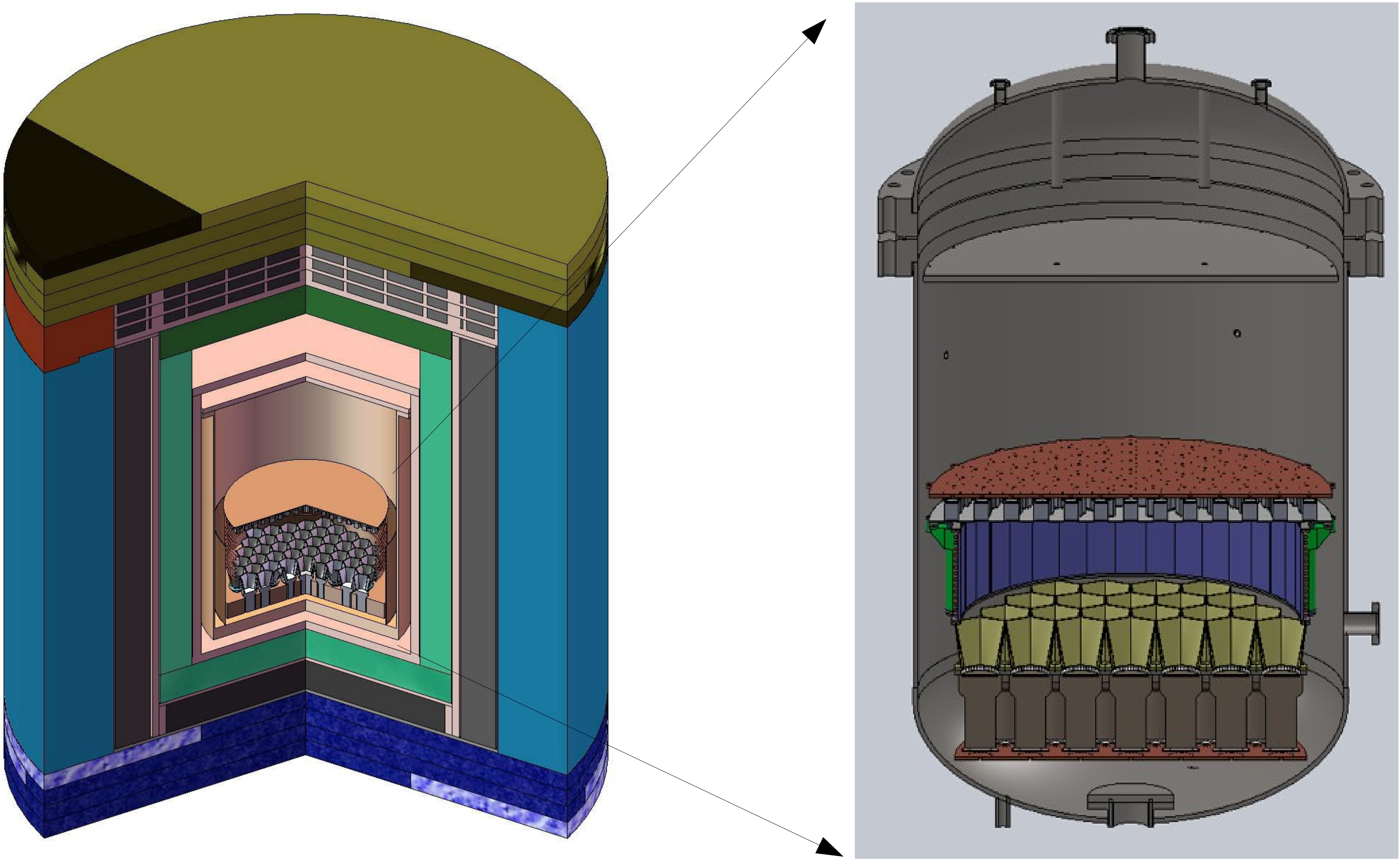
中国锦屏极深地下暗物质实验室





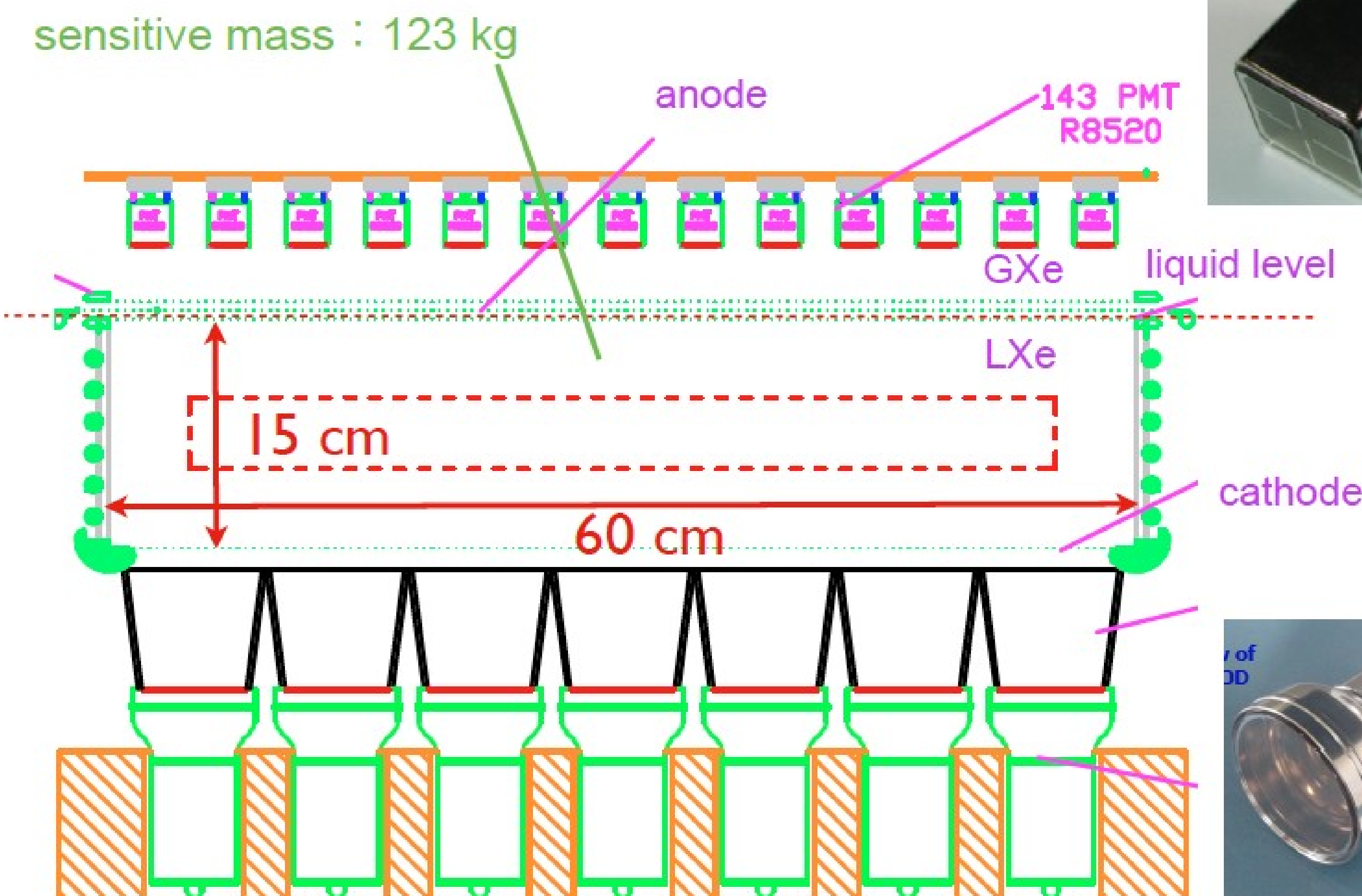
Cosmic muon 25-50/m^2 year

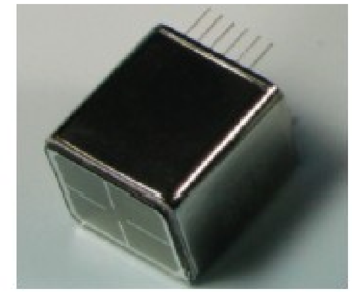
PANDAX shield and inner vessel



Passive shielding with Cu, Pb and PE

PANDAX: Pancake TPC with high light yield





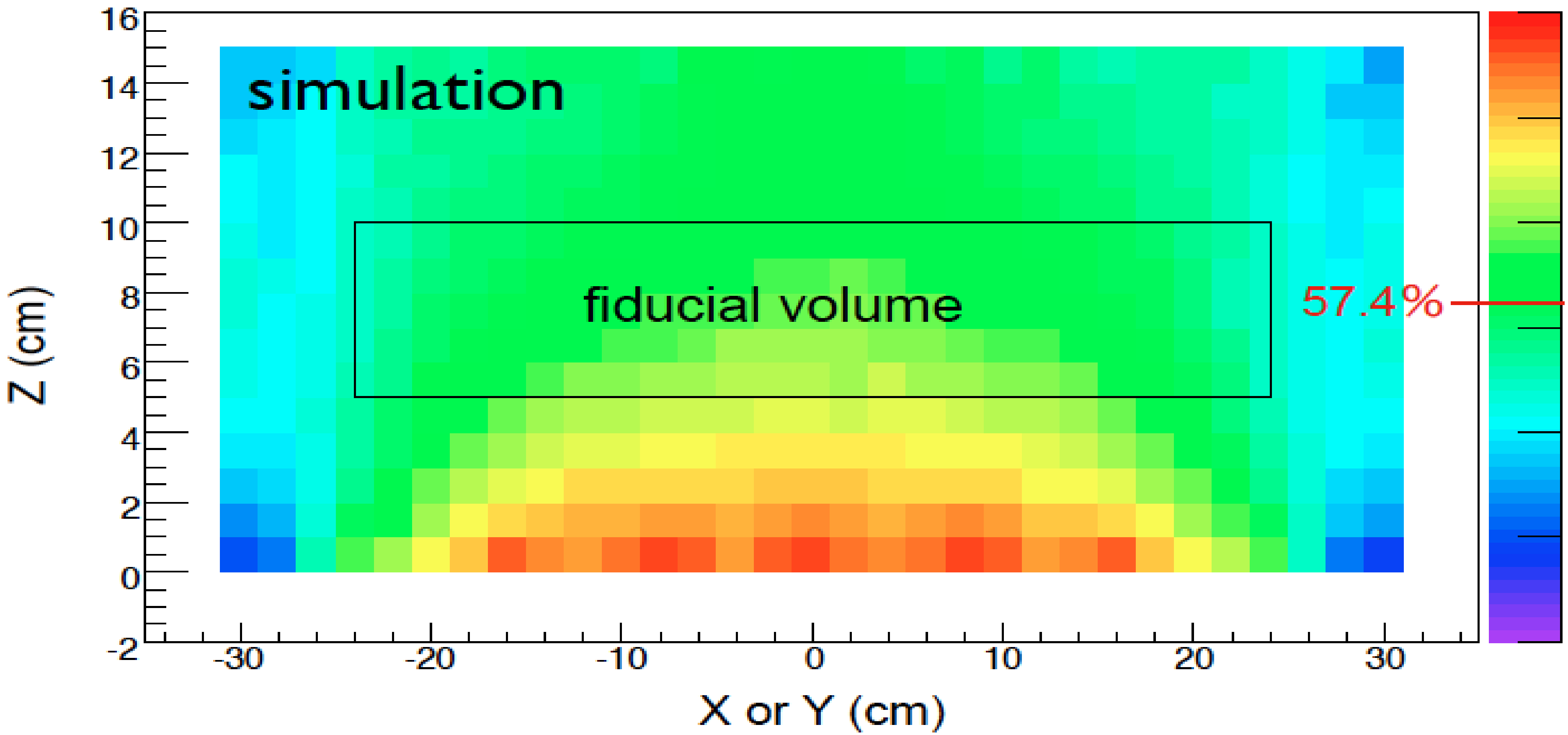
37 R11410 PMT

PANDAX 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)

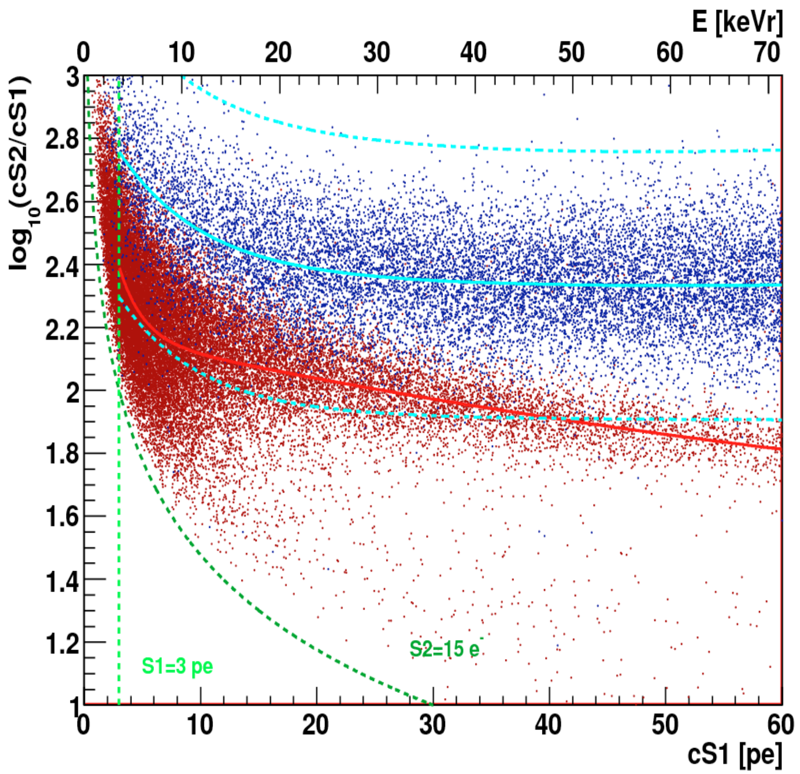
Pancake advantage (I)

S1 light collection efficiency



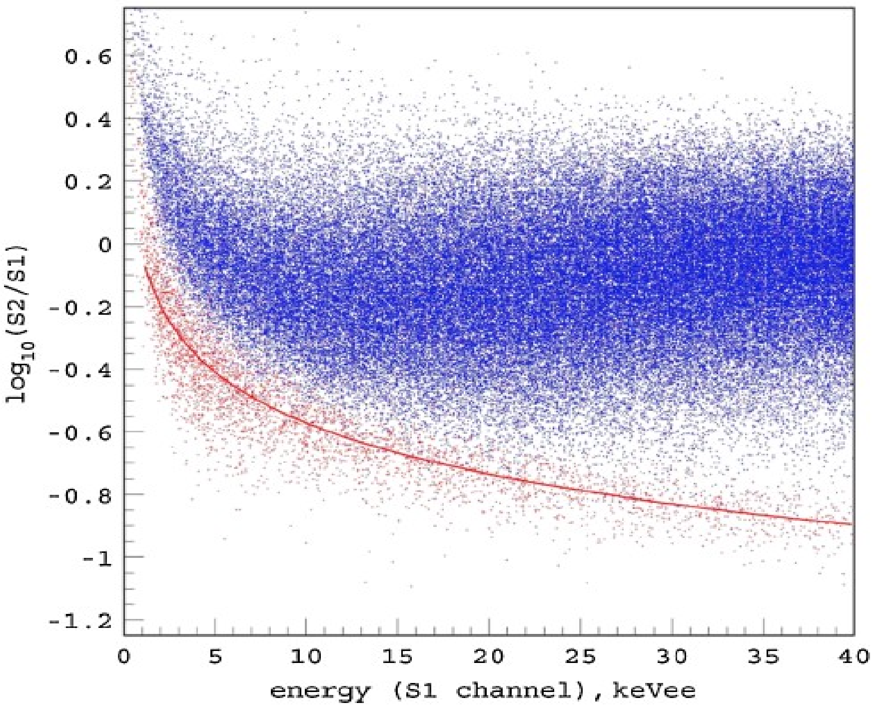
XENON100 energy threshold: 8.7keVnr
PANDAX expected : 3.6keVnr

Pancake advantage (II)



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

PRL 105, 131302 (2010)



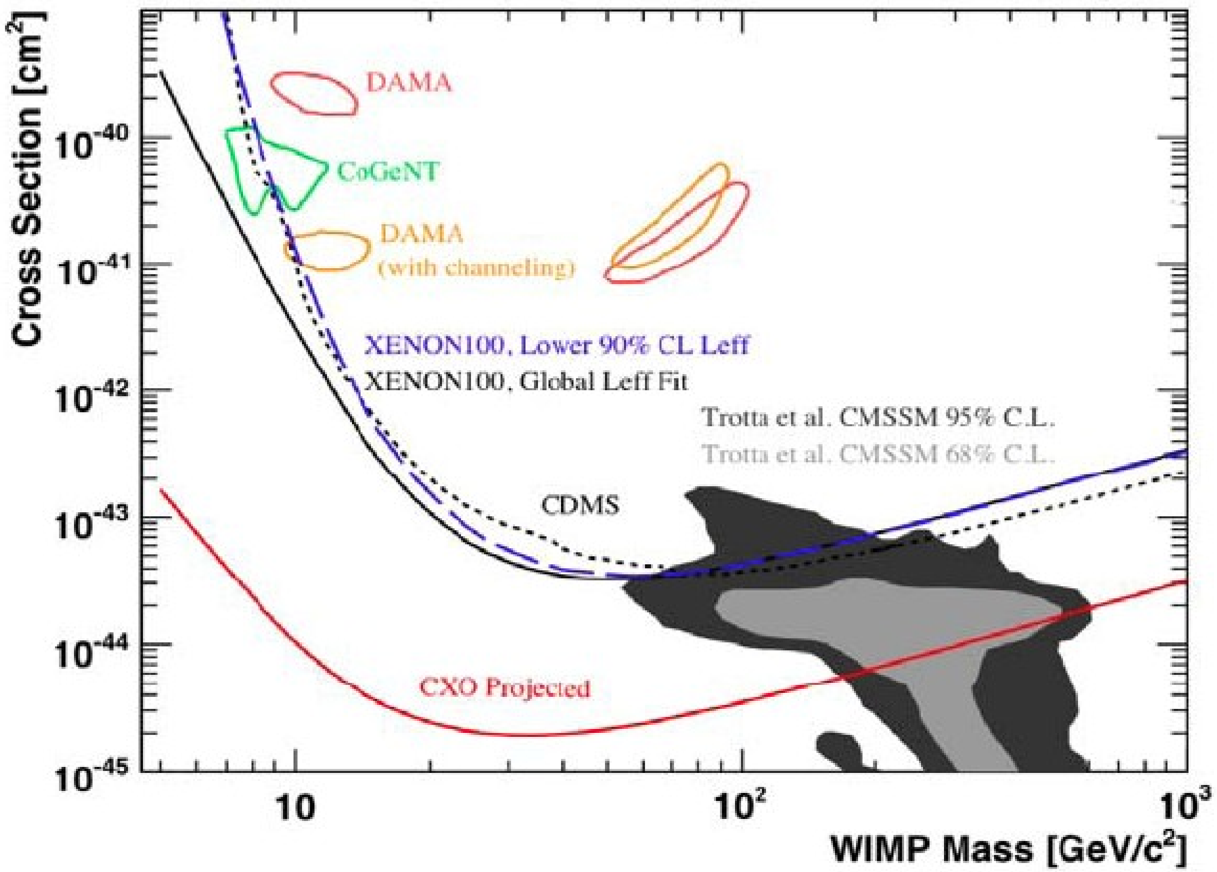
ZEPLIN-III E_{drift}=3.9kV/cm
99.9% gamma rejected

PRD 80, 052010 (2009)

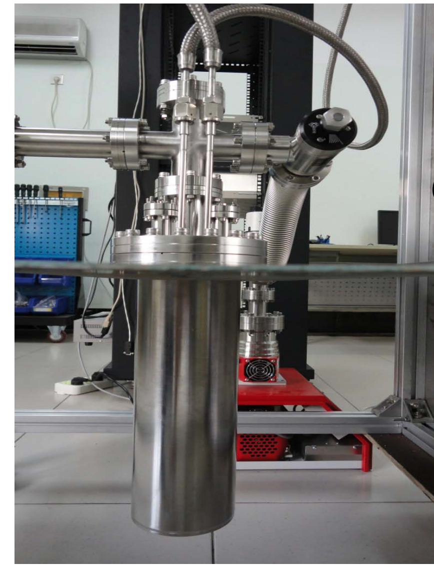
PANDAX projected sensitivity

assume:
- light yield 5.5 p.e./keV
- energy range 3-30 p.e.
- 25kg x 200 days exposure

ZERO background

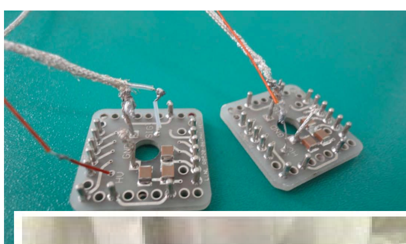


PANDAX status



prototype detector

cryogenic testing

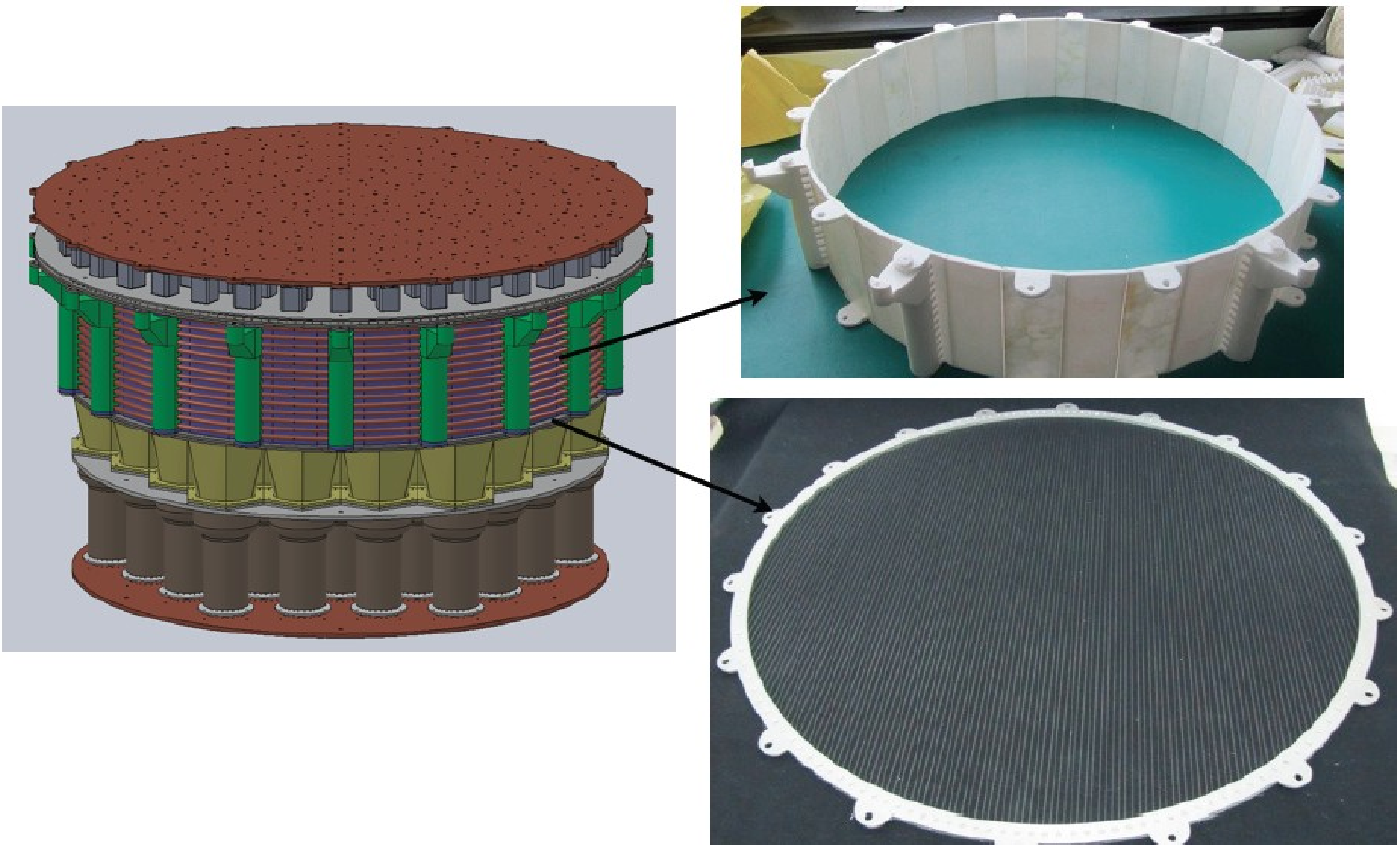


PMT base

测量低本底材料放射性的探测器

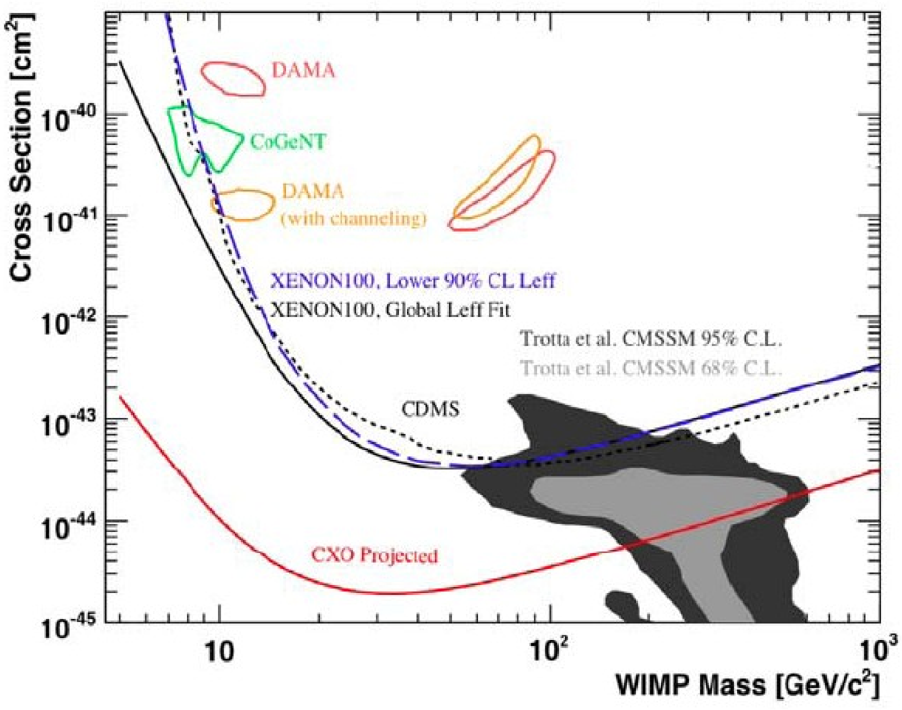
PMT testing facility

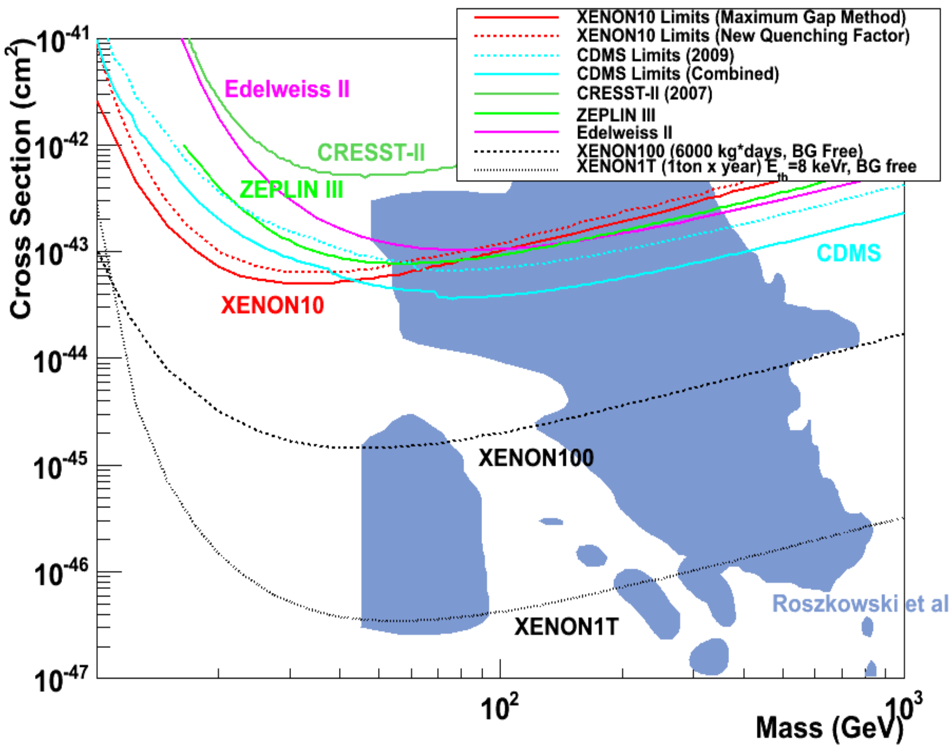
PANDAX status



Summary

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

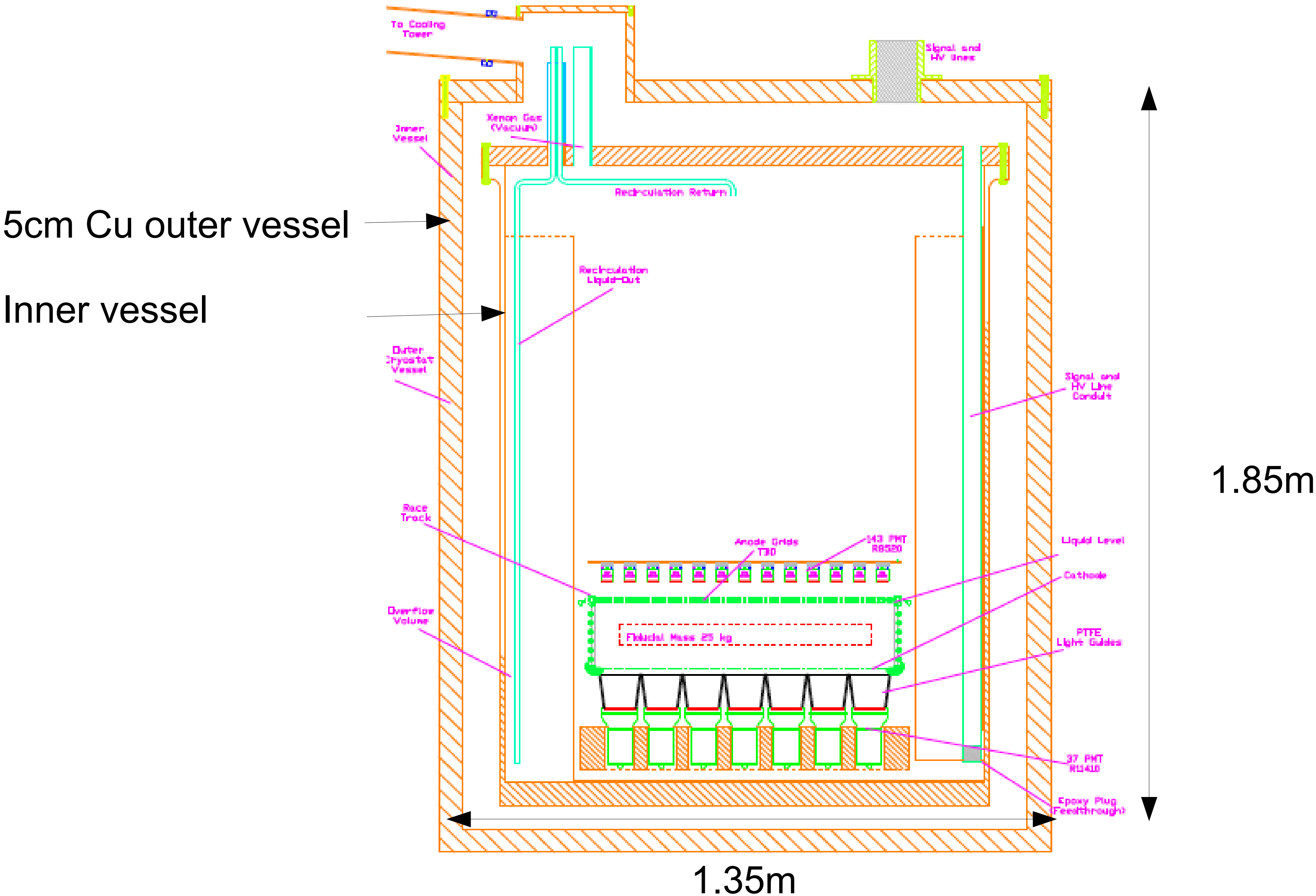




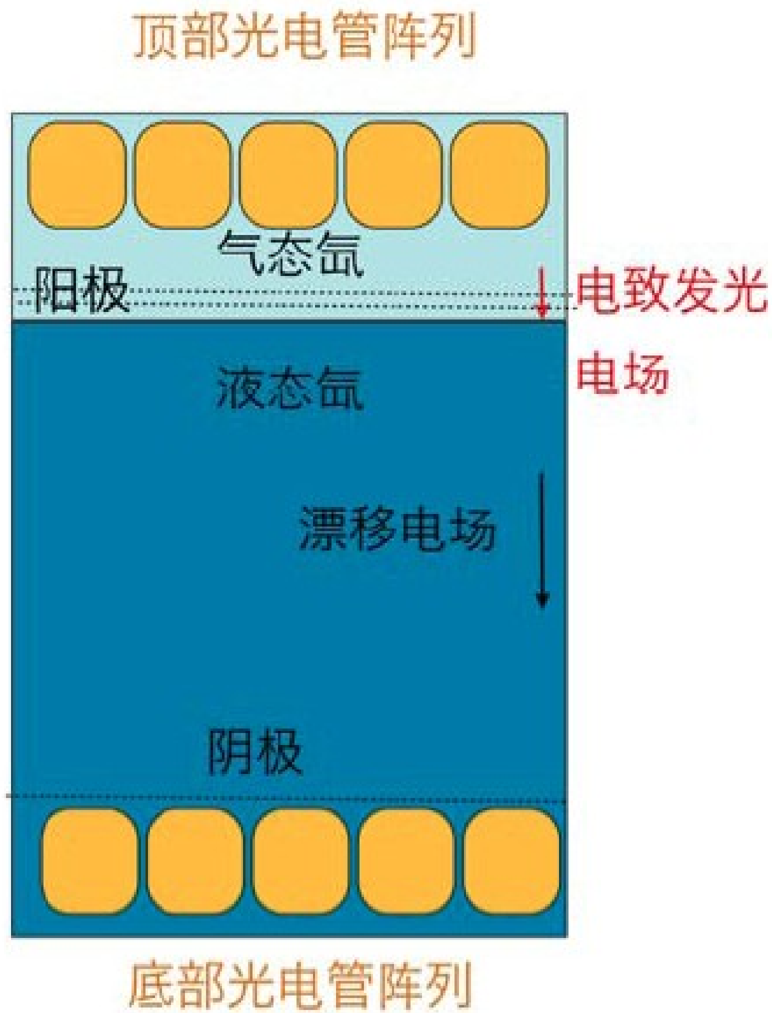
Thank you!

backup

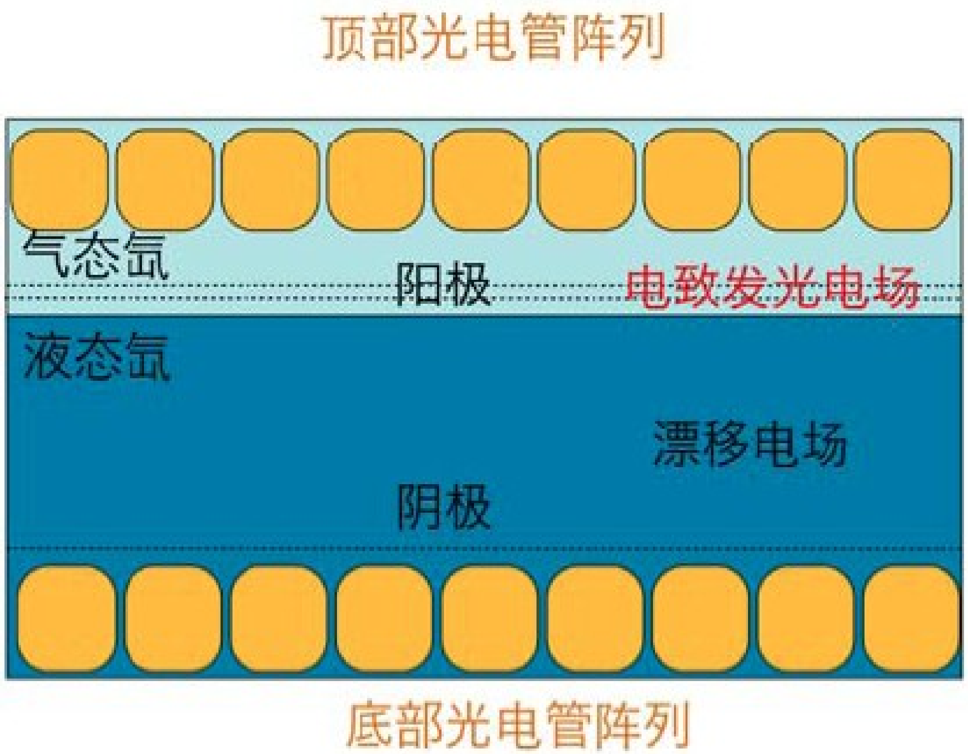
Detector overview



Disk-like Xenon TPC

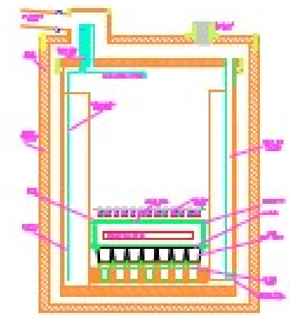


XENON10/100



PANDAX

Comparison with other Xe-based exp.



	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

Energy Calibration: determine the energy of nuclear recoils

energy of nuclear recoils (NRs)

measured signal in # of pe

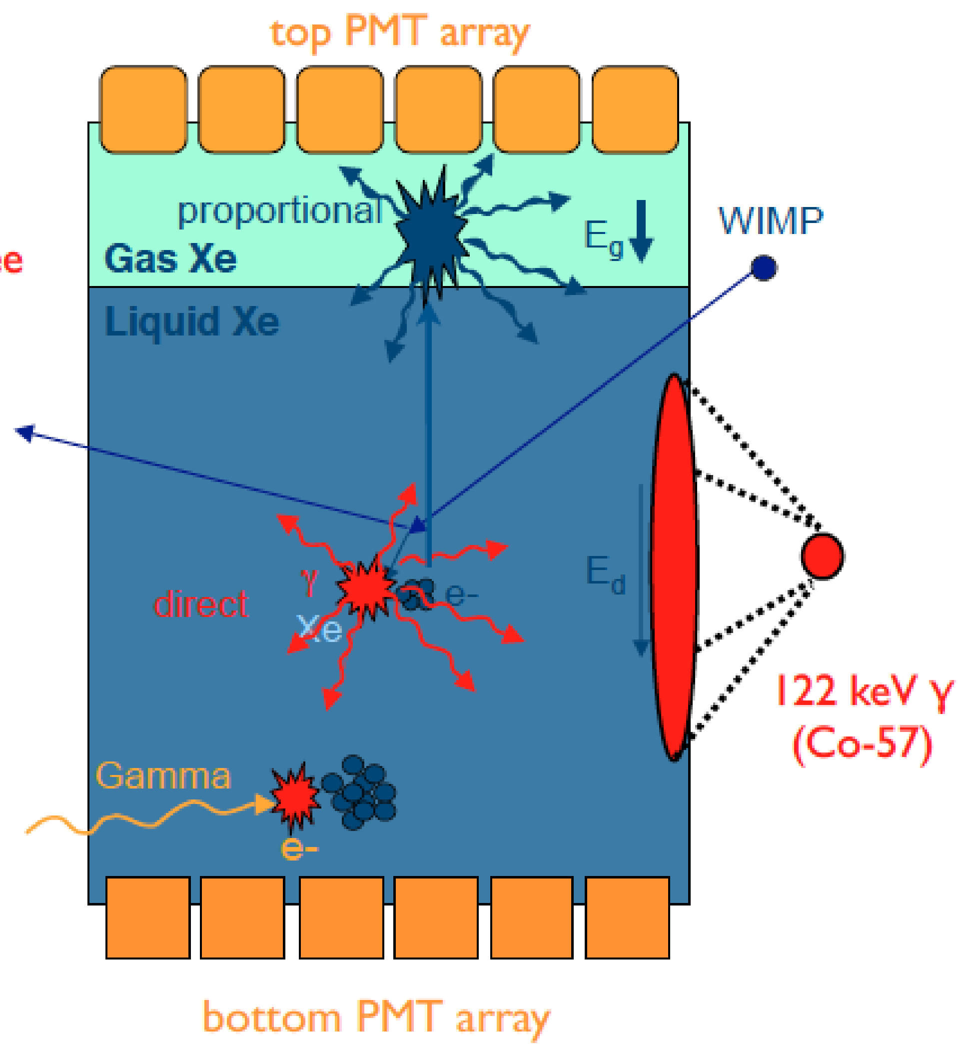
light yield for 122 keV γ in pe/keVee (detector dependent)

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

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

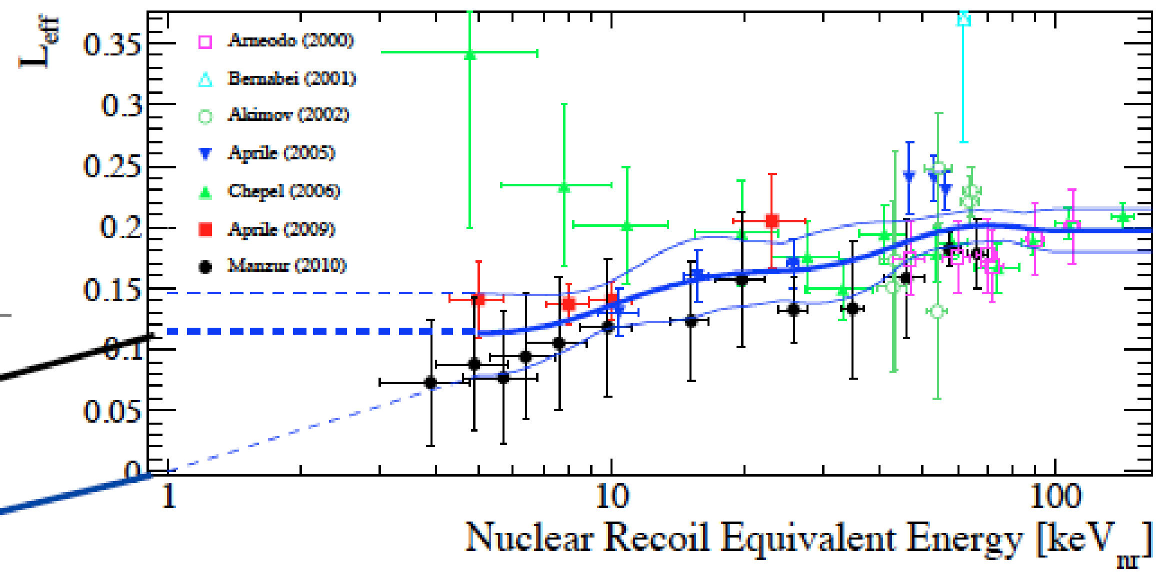
quenching of scintillation yield for 122 keV γ's due to drift field

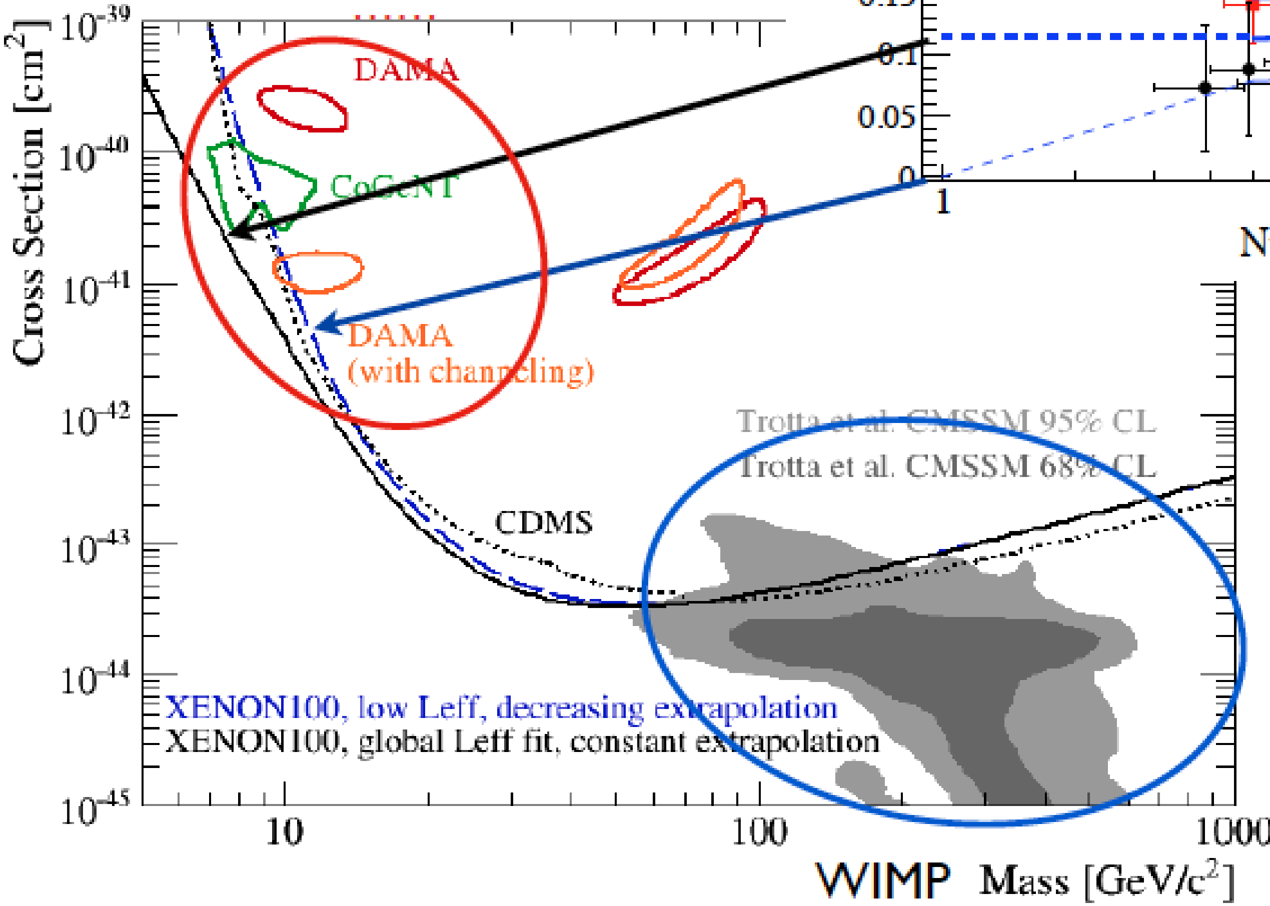
quenching of scintillation yield for NRs due to drift field



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
......



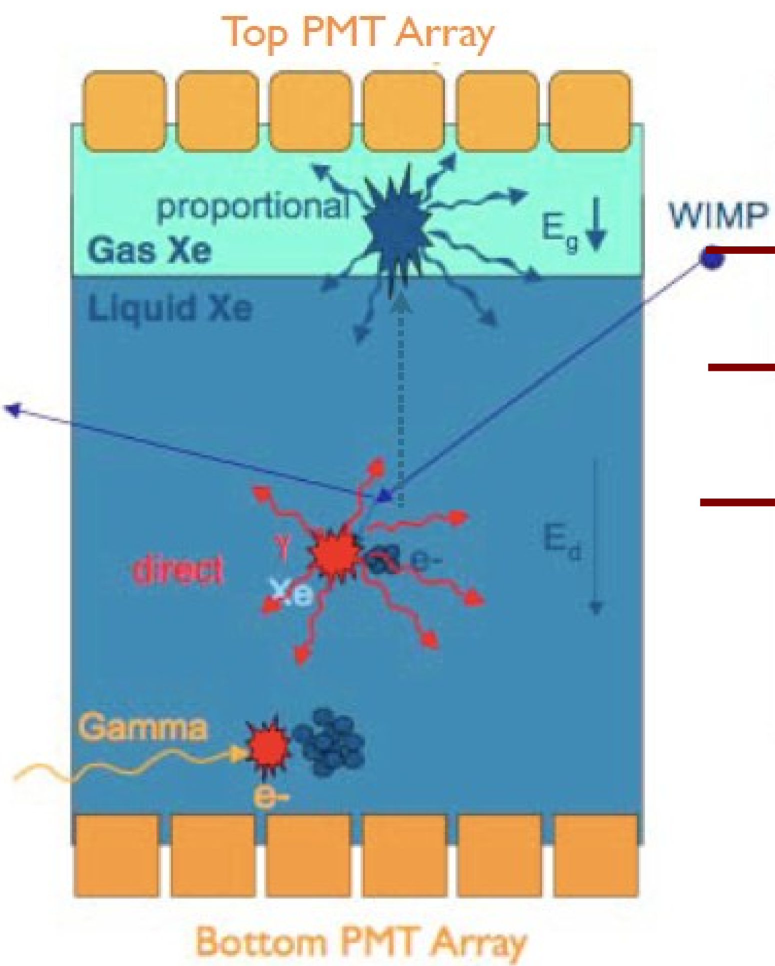


achieved competing sensitivity for "normal" mass WIMPs

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

Two-Phase Xenon TPC

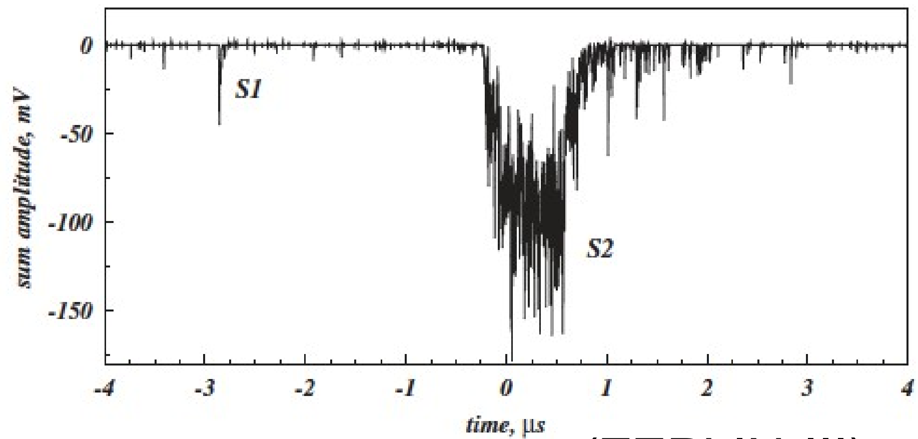
10keV



x100, 400K gamma (S2=charge)

4000 electrons drift

400 gamma (S1=photon)

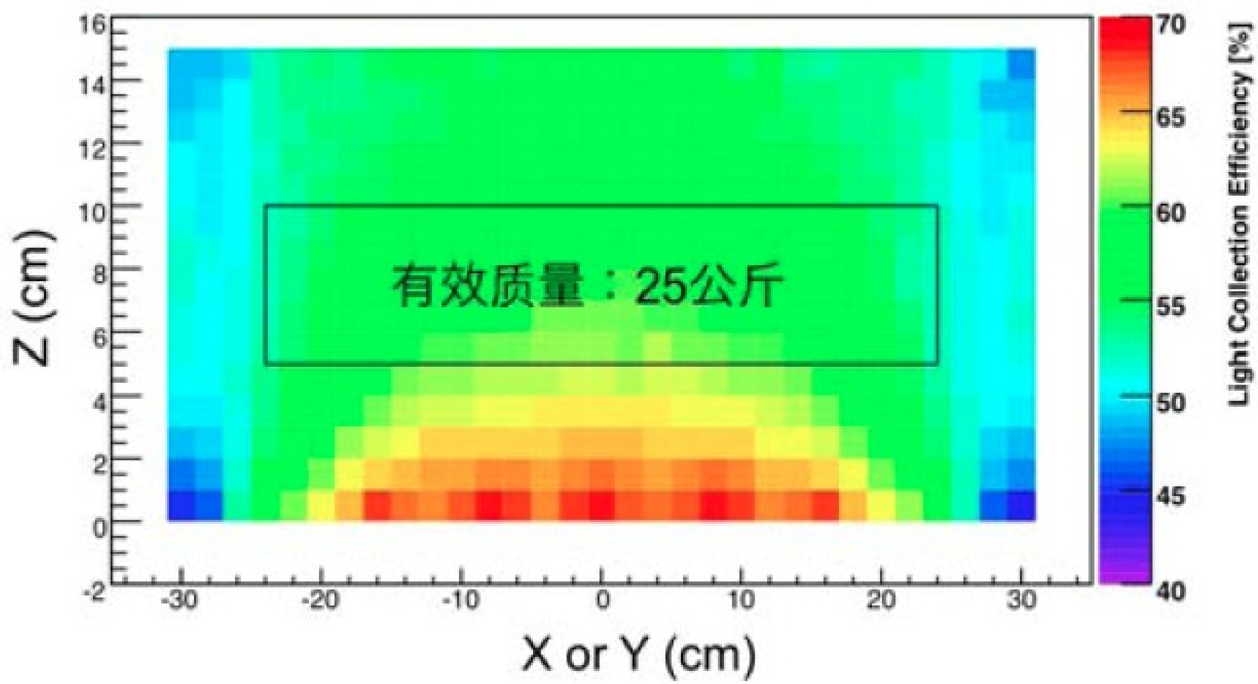


(ZEPLIN-III)

σ_E (S1+S2) can reach5%

Disk-like advantage (I)

S1 light collection efficiency ε



E_{NR} = S1 / ε / Fraction_E_in_scintillation

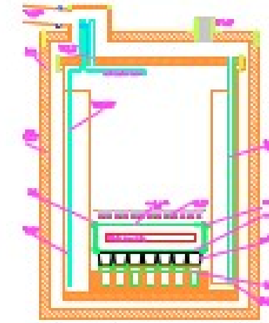
ε↑, E threshold ↓, { WIMP event rate ↑
low-mass WIMP sensitivity ↑

Xenon100, 4-20p.e. S1 signal, 8.7-32.6keV E_{NR}
PANDAX, 5keV E_{ER}

Comparison with other Xe-based DM exp.

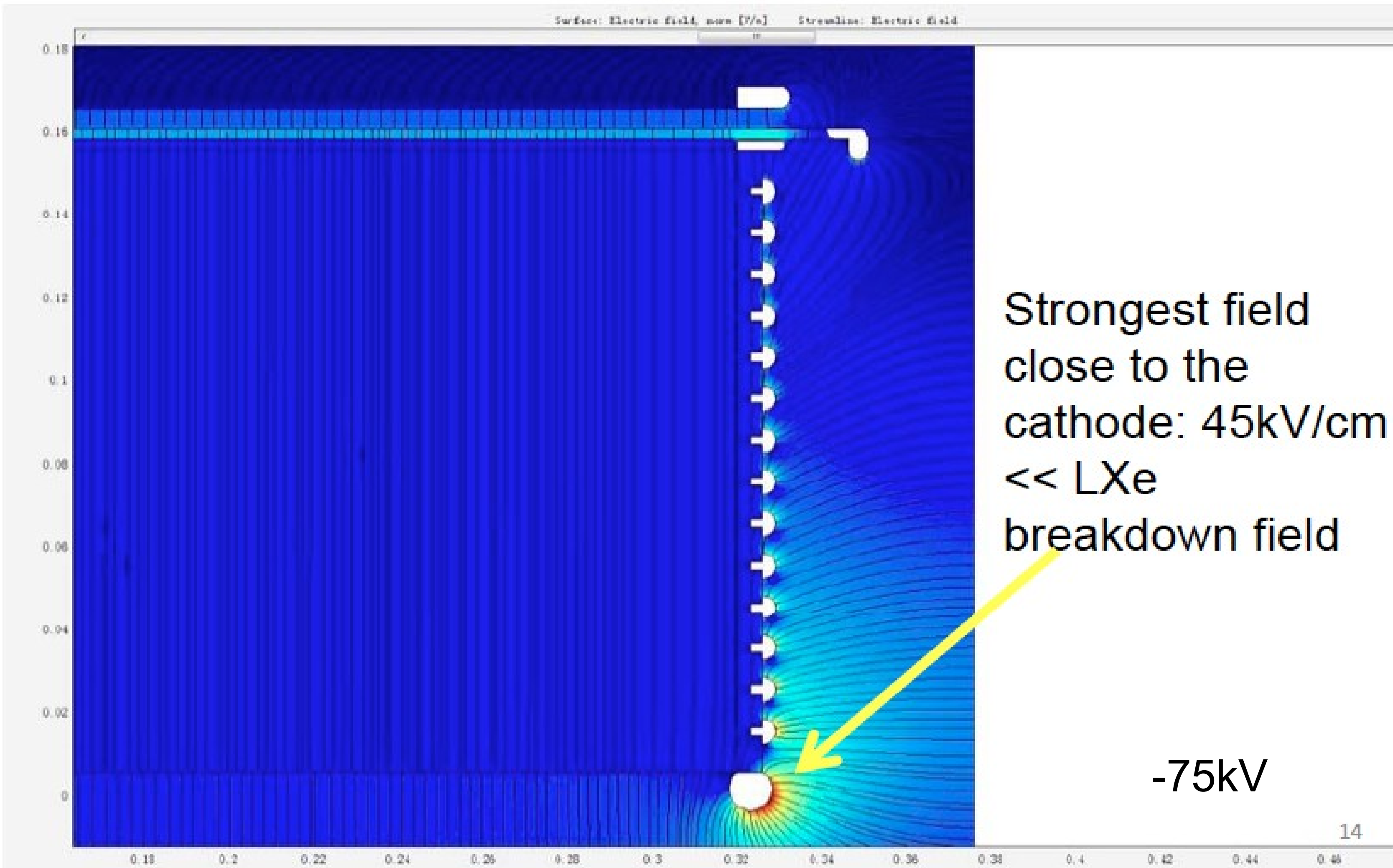




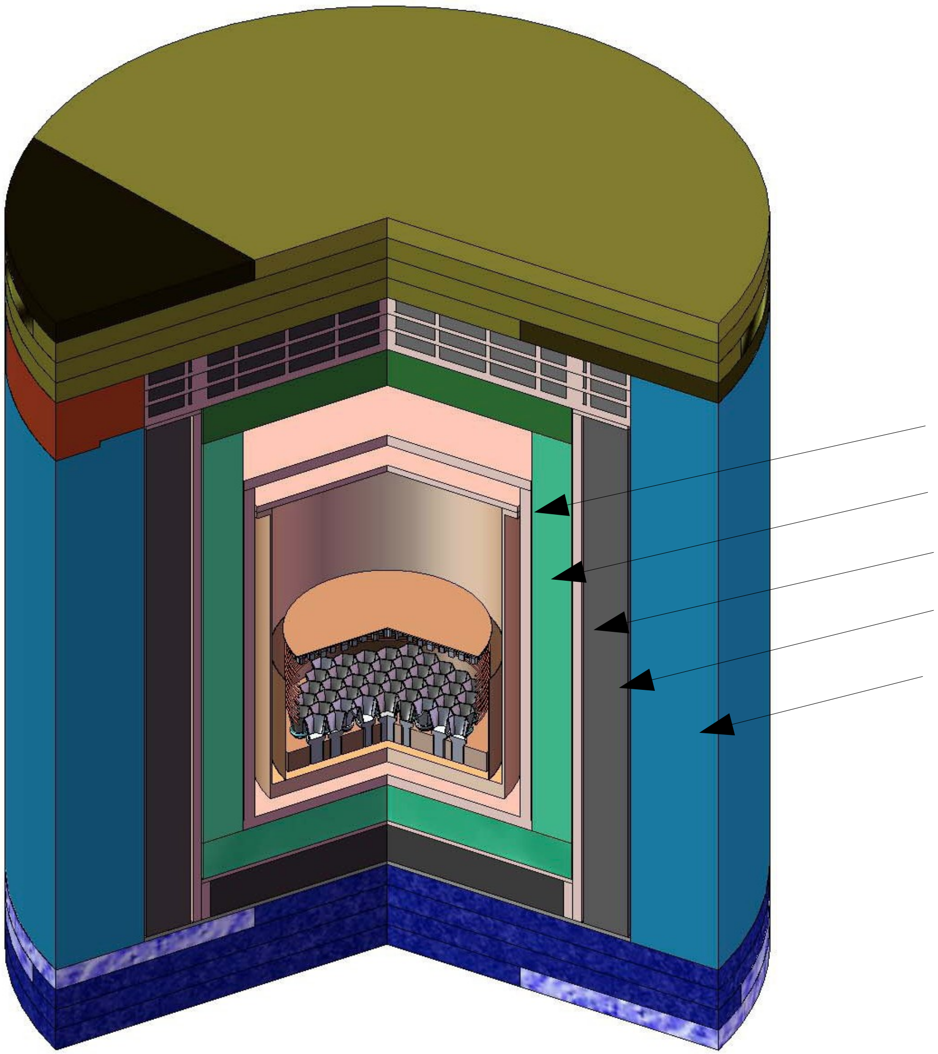


	ZEPLIN III	XENON100	XMASS	LUX	PandaX
active target mass (kg)	12	~60	~800 (100)	~300	~120
electron recoil rejection	99.9%	99%	0	99%	99.9%
energy threshold (keVr)	10	9	20	10	5
sensitivity at 100 GeV (cm^2)	$\sim 10^{-44}$	2×10^{-45}	1×10^{-45}	3×10^{-46}	4×10^{-45}
sensitivity at 10 GeV (cm^2)	$>10^{-42}$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

Strong E field achievable



PANDAX Shielding



Diameter 3m, Height 3.6m

5cm Cu
20cm PE
5cm Cu
20cm Pb
40cm PE

Inner Vaccum
Height 160cm
Diameter 120cm

Goal set for ton-scale: external bg event in 5-15keV, ~1.1/ton year

External background

1, n/gamma from rock & concrete

材料	放射性元素含量[Bq/kg]		
	Ra226	Th232	K40
岩石	1.8 ± 0.2	< 0.27	< 1.1
水泥骨料	≈ 2	≈ 0.7	低于探测极限
水泥	≈ 60	≈ 25	≈ 130

2, cosmic muon and induced neutron

3, n/gamma from shielding material

表 2，XENON100 实验屏蔽体材料的放射性元素含量，单位 mBq/kg。

材料	U238	Th232	Co60	K40	Pb210
铜	<0.07	<0.03	<0.0045	<0.06	
内层聚乙烯	0.23±0.05	<0.094	<0.89	0.7±0.4	
铅	<0.92	<0.72	<0.12	14±3	530±70

4, Radon

Shielding simulation results

Simulation based on Gean4.9.3
~1.1 event in 5-15keV / ton year
  0.5 from rock+concrete gamma
  0.6 from Cu gamma

实验	所在地下实验室/探测器材料	铜（厘米）	铅（厘米）	聚乙烯（厘米）	屏蔽体内本底事例率（mdru）	内部容积（立方米）
XMASS	Kamioka / Xe	-	-	2 米水	0.1*** [6]	0.27
XENON100	LNGS / Xe	5	20	20	0.006**** [7]	0.67
LUX	DUSEL / Xe	-	-	3 米水	0.0005**** [8]	0.12
PANDAX	CJPL / Xe	>10	20	20+40	0.0002****	1.9