XMASS

19th October 2006
ICRR external review meeting,
S. Moriyama, ICRR

1. XMASS: physics targets
2. 3kg FV prototype detector feasibility confirmation
3. 800kg liquid xenon detector Search for dark matter

XMASS collaboration (2000-)

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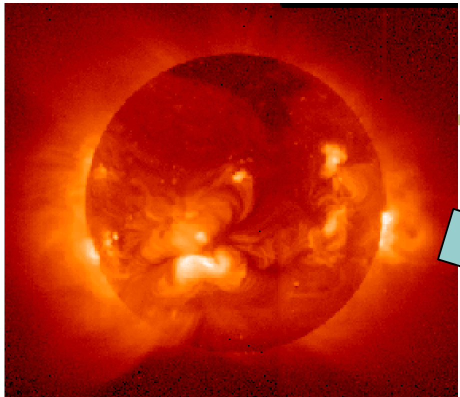
- Sejon University: Y.D.Kim, J.I.Lee, S.H.Moon

48 collaborators, 13 institutes

1. XMASS: physics targets

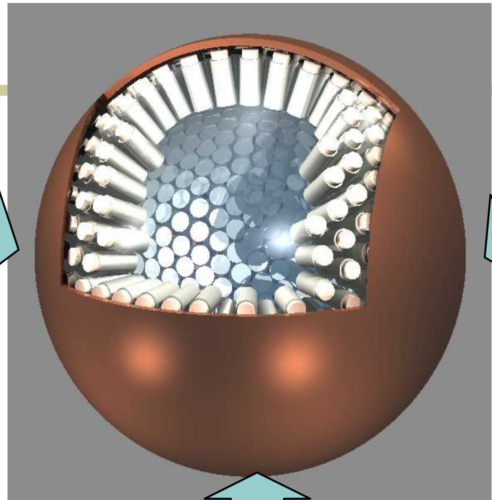
Goal: Multi purpose low-bg experiment with 10t LXe

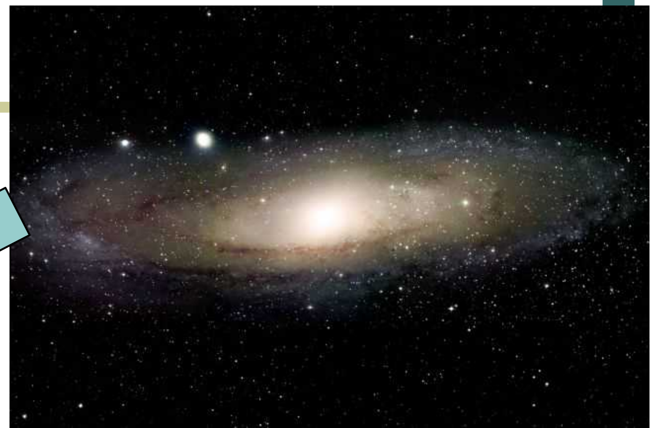
- Xenon MASSive detector for solar neutrino (pp/^{7}Be)
- Xenon neutrino MASS detector (ββ decay)
- Xenon detector for Weakly Interacting MASSive Particles (DM search)



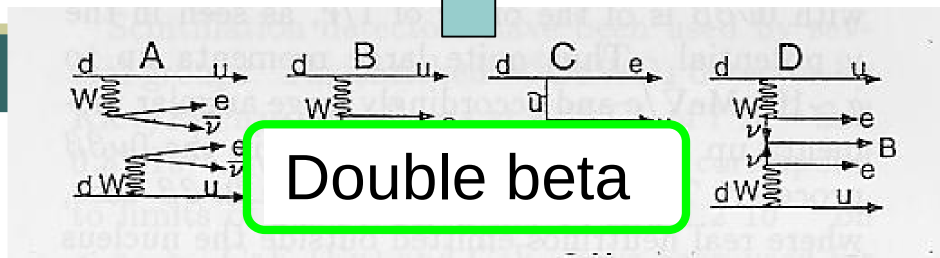
Solar neutrino

LXe scintillator



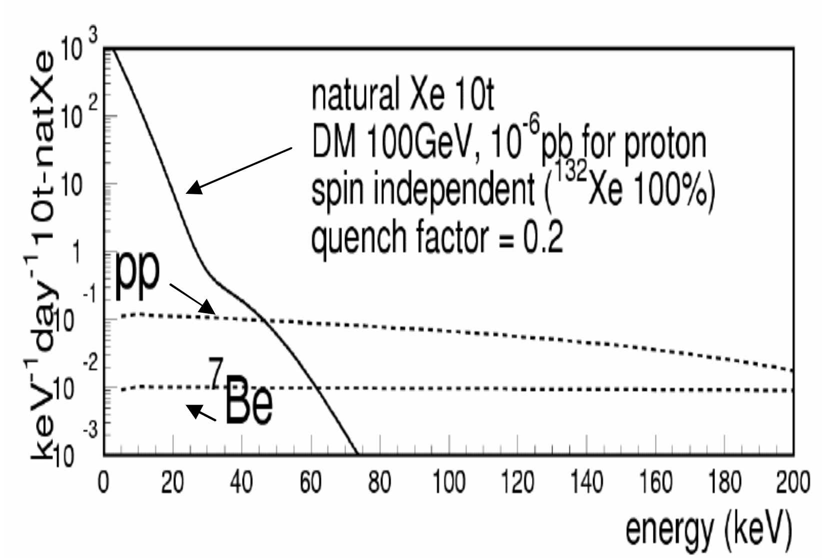


Dark matter



Double beta

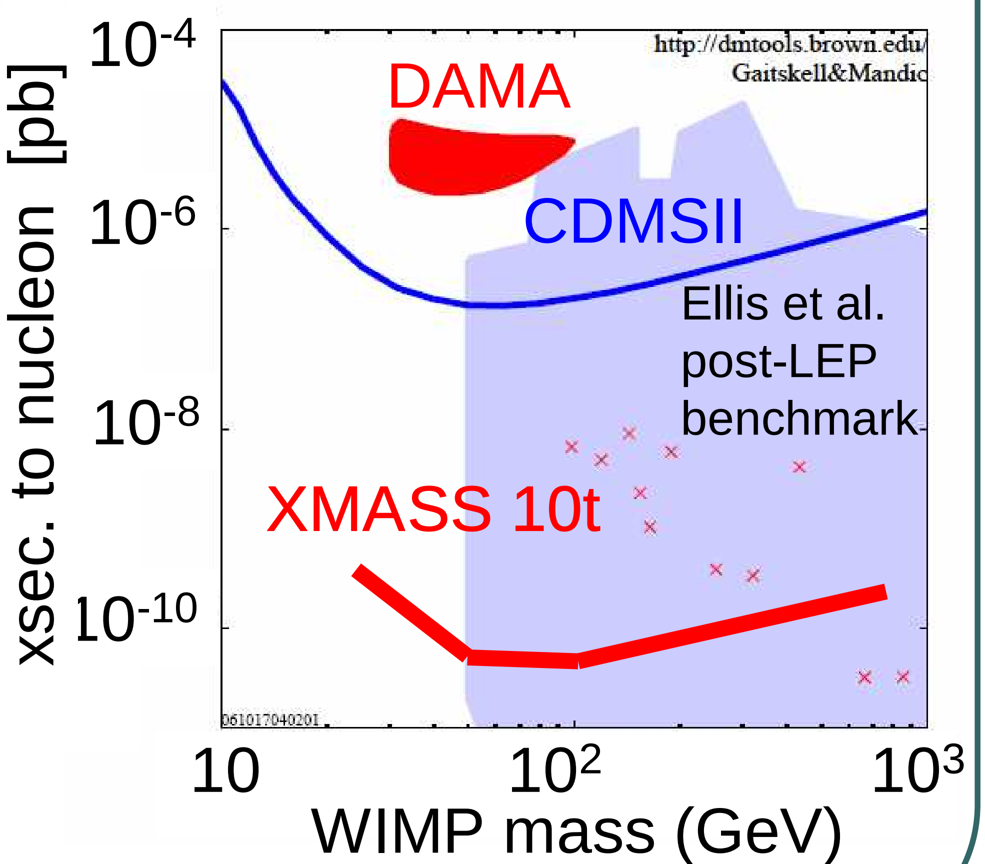
Ultimate sensitivity with 10t LXe: Direct detection of Dark Matter



E_{th} = 5keV: 2000 events/day

(Eth = 20keV: 30 events/day)

Large photosensitive area



Max.-sensitivity, $<10^{-10}$pb for spin independent xsec (5yr)

Why Liquid Xenon?

General properties:

Large scintillation yield (~42000photons/MeV ~NaI(Tl))
Scintillation wavelength (175nm, direct read out by PMTs)
Higher operation temperature (~165K, LNe~27K, LHe~4K)
Compact (ρ=2.9g, 10t detector ~ 1.5m cubic)
Not so expensive
Well-known EW xsec for solar ν, 136Xe $\beta\beta$, large A (SI)

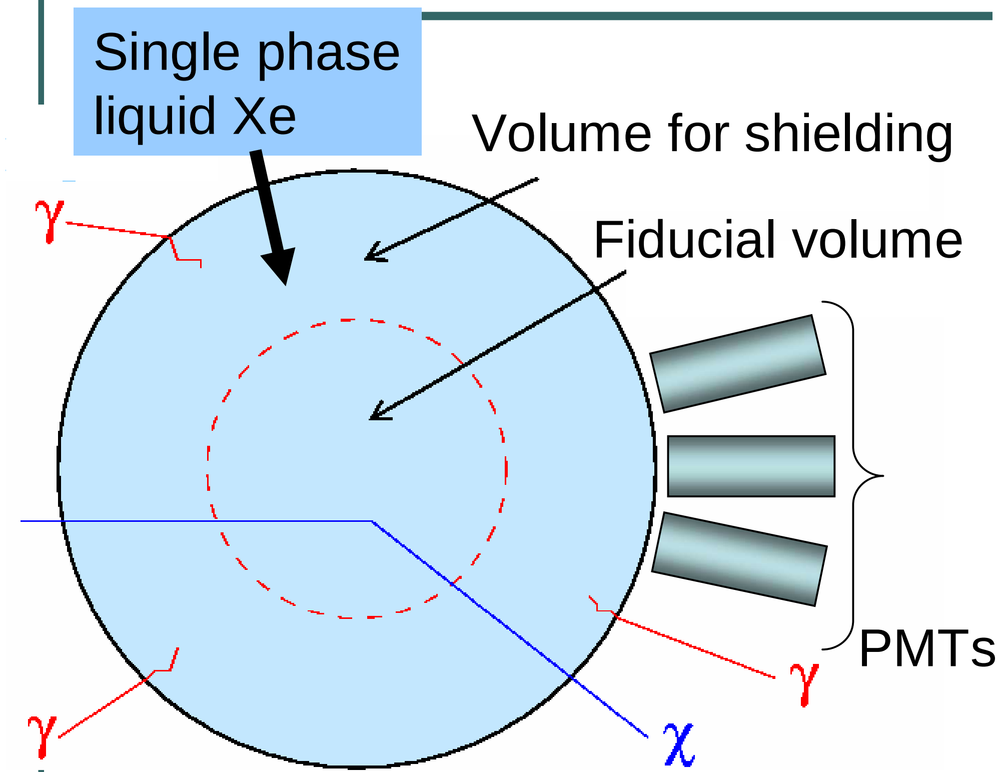
External gamma ray background:

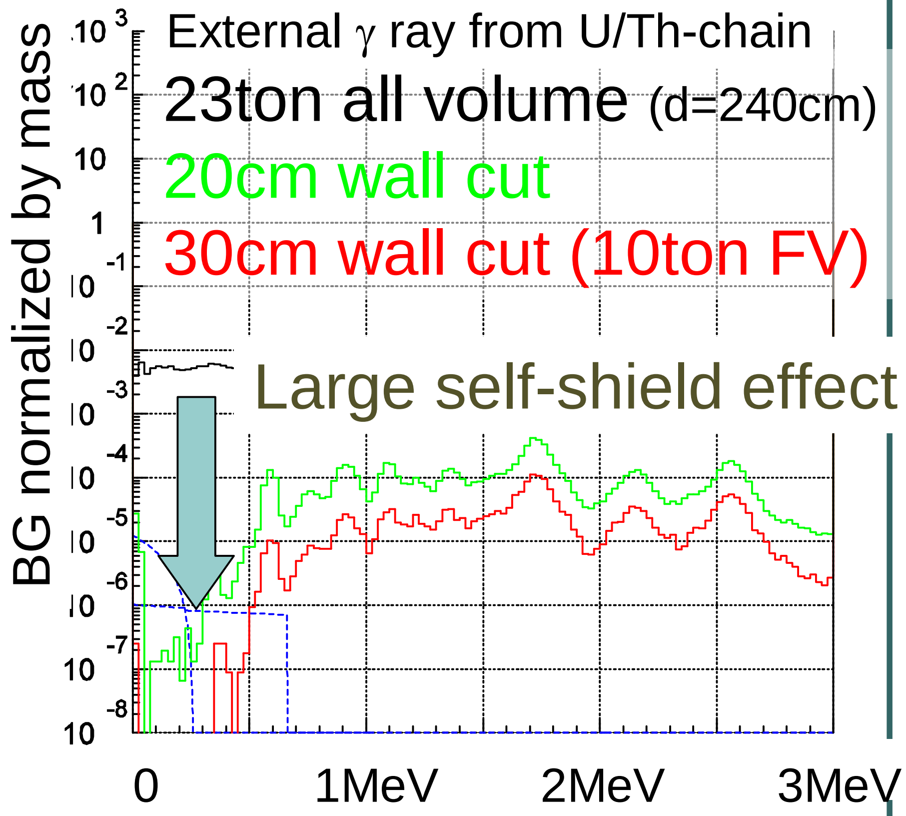
Self shielding (large Z=54)

Internal background:

Purification (distillation, etc) Circulation
No long-life radio isotopes
Isotope separation is relatively easy
No ^{14}C contamination (can measure low energy)

Key idea: self shielding effect for low energy signals

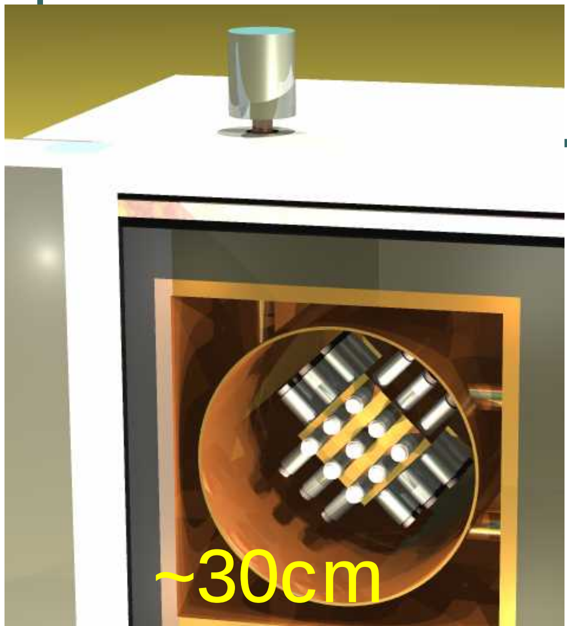




- Large Z makes detectors very compact
- Large photon yield (42 photon/keV ~ NaI(Tl))

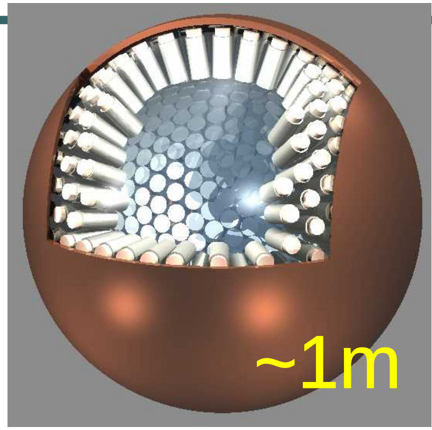
Liquid Xe is the most promising material.

Strategy of the XMASS project

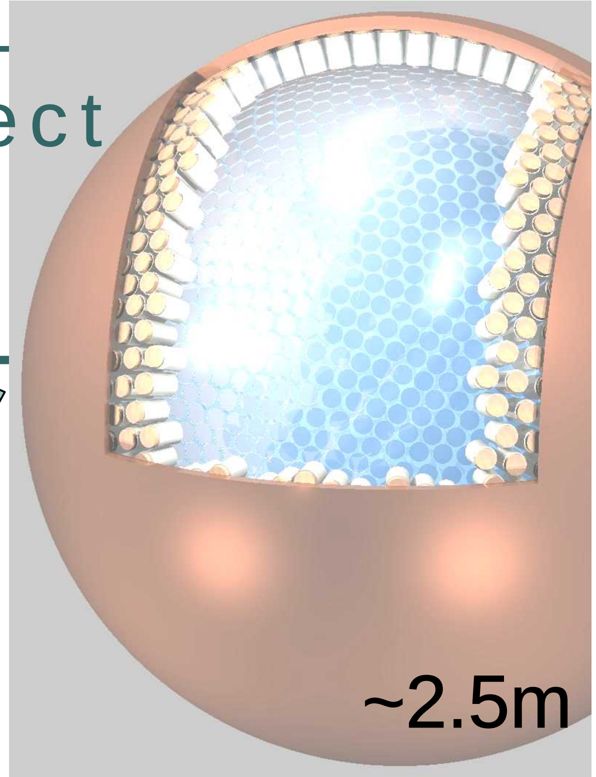


Prototype detector
(FV 3kg) R&D

Confirmation of feasibility of the ~1ton detector



800kg detector
(FV 100kg)
Dark matter search

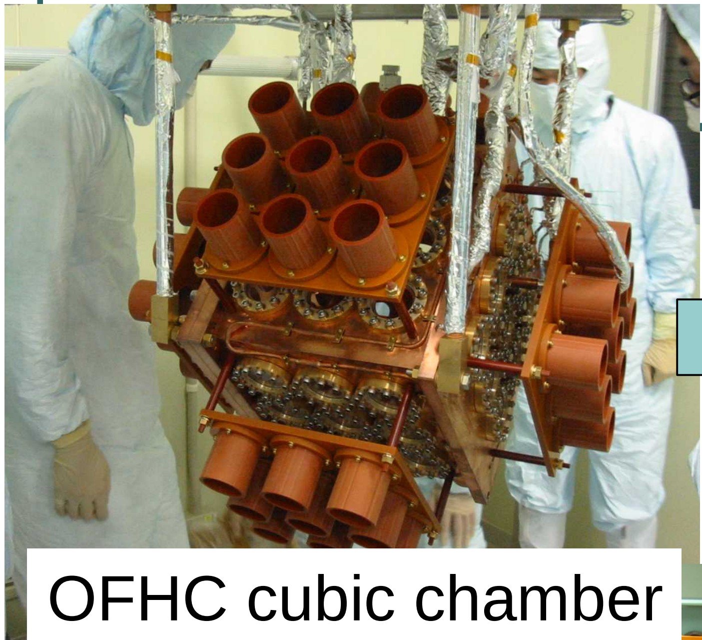


~20 ton detector
(FV 10ton)
Solar neutrinos
Dark matter search

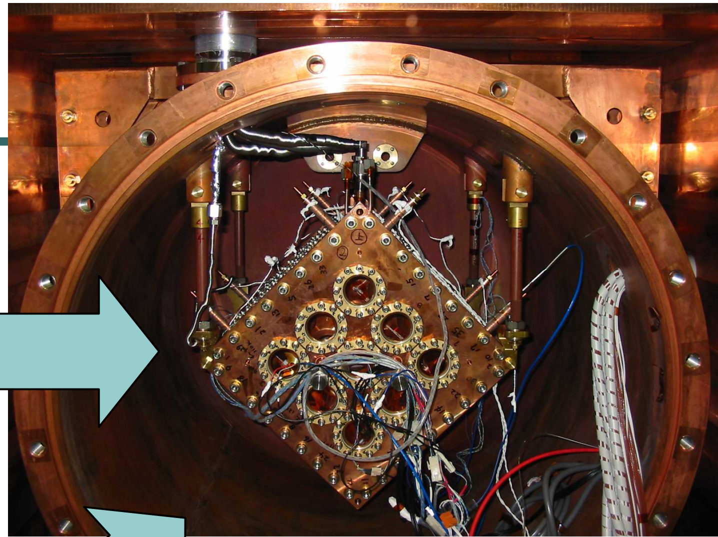
Double beta decay option?

Feasibility confirmed

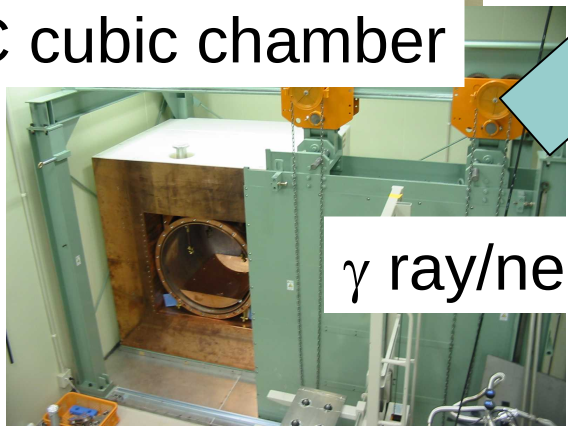
2. 3kg FV prototype detector



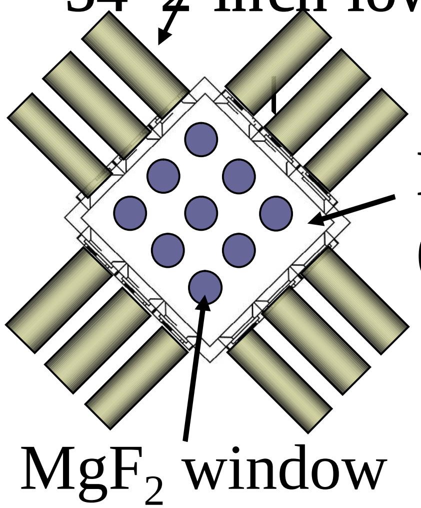
OFHC cubic chamber



In the Kamioka Mine (near the Super-K)



γ ray/neutron shield



16% photo-coverage

- Demonstration of reconstruction, self shielding effect, and low background properties.

Vertex and energy reconstruction

Reconstruction is performed by
PMT charge pattern (not timing)

Calculate PMT acceptances from various vertices by Monte Carlo.
Vtx.: compare acceptance map F(x,y,z,i)
Ene.: calc. from obs. p.e. & total accept.

$$\mathrm{Log(L)} = \sum_{\mathrm{PMT}} \mathrm{Log}\left(\frac{\exp(-\mu)\mu^{n}}{n!}\right)$$

L: likelihood

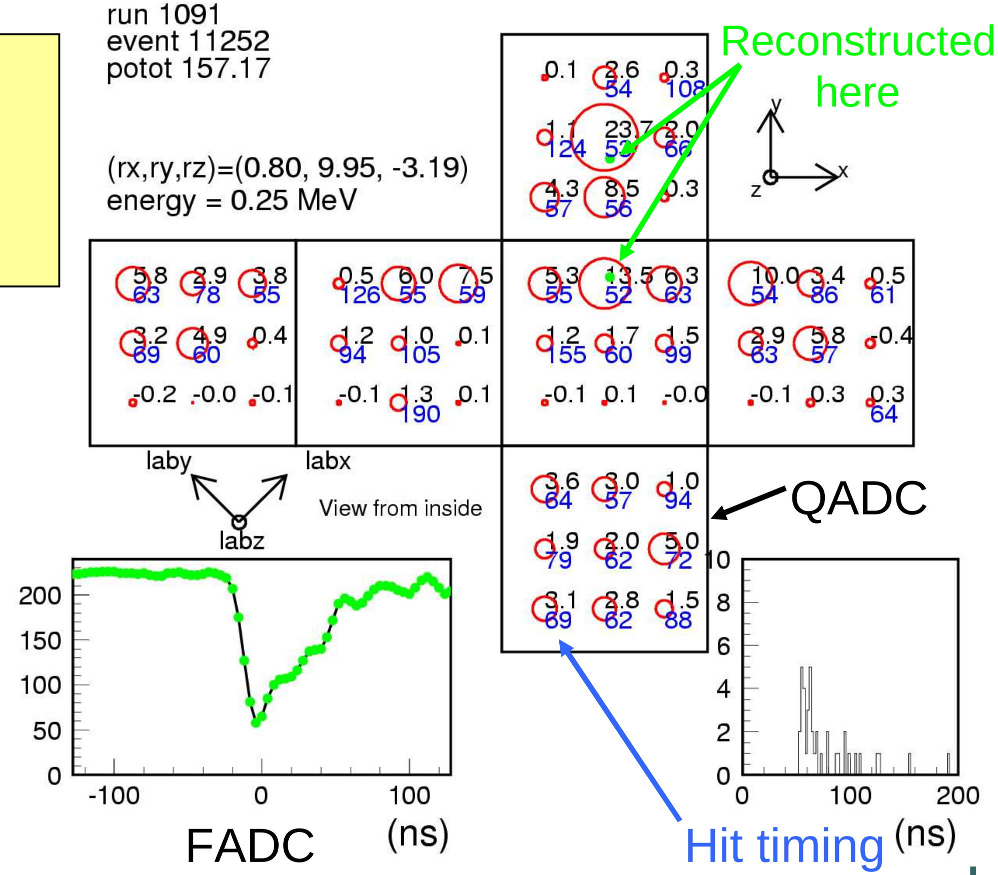
$$\mu : \frac{F(x,y,z,i)}{\Sigma F(x,y,z,i)} \text{ x total p.e.}$$

n: observed number of p.e.

F(x,y,z,i): acceptance for i-th PMT (MC)
VUV photon characteristics:

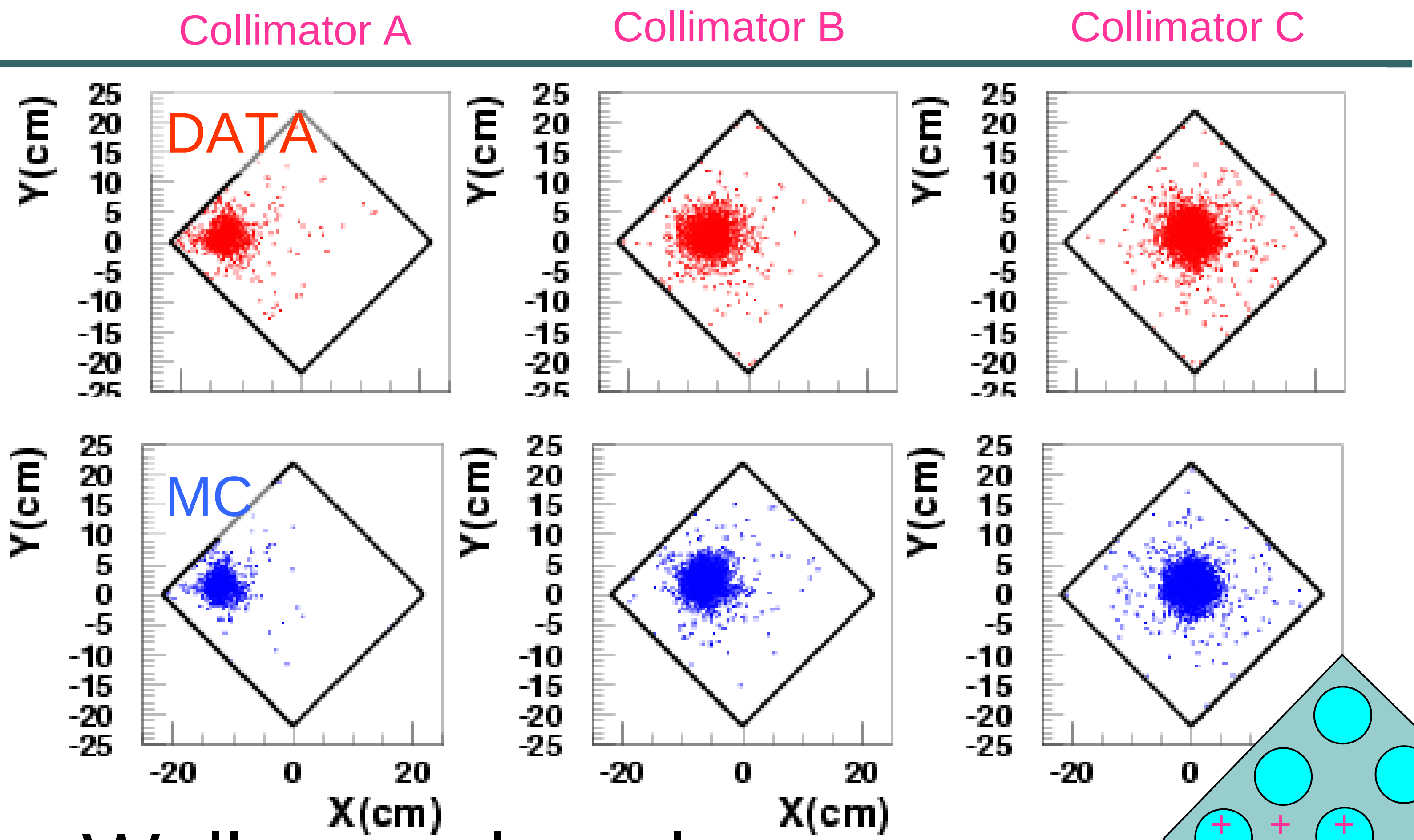
L_{emit}=42ph/keV
τ_{abs}=100cm
τ_{scat}=30cm

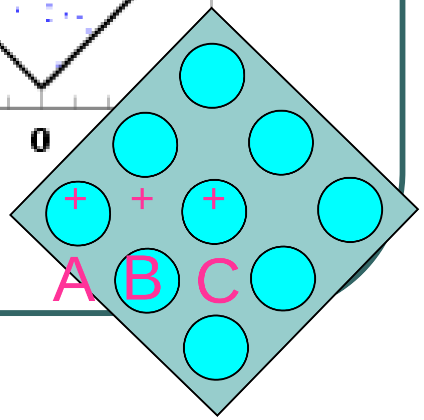
XMASS prototype detector



=== Background event sample ===
QADC, FADC, and hit timing information are available for analysis

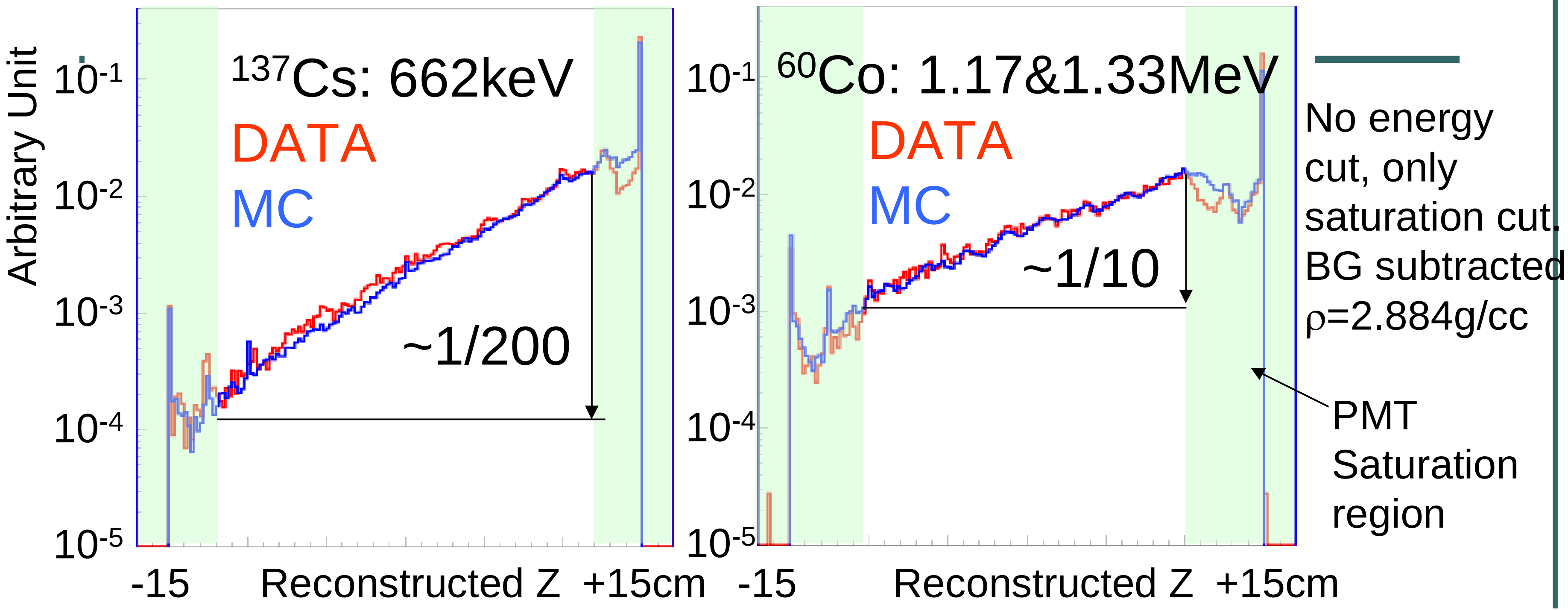
Source run
(γ ray injection from collimators) I

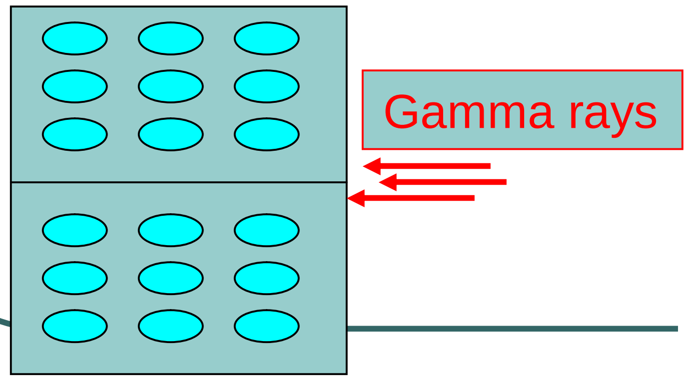




- Well reproduced.

Source run
(γ ray injection from collimators) II

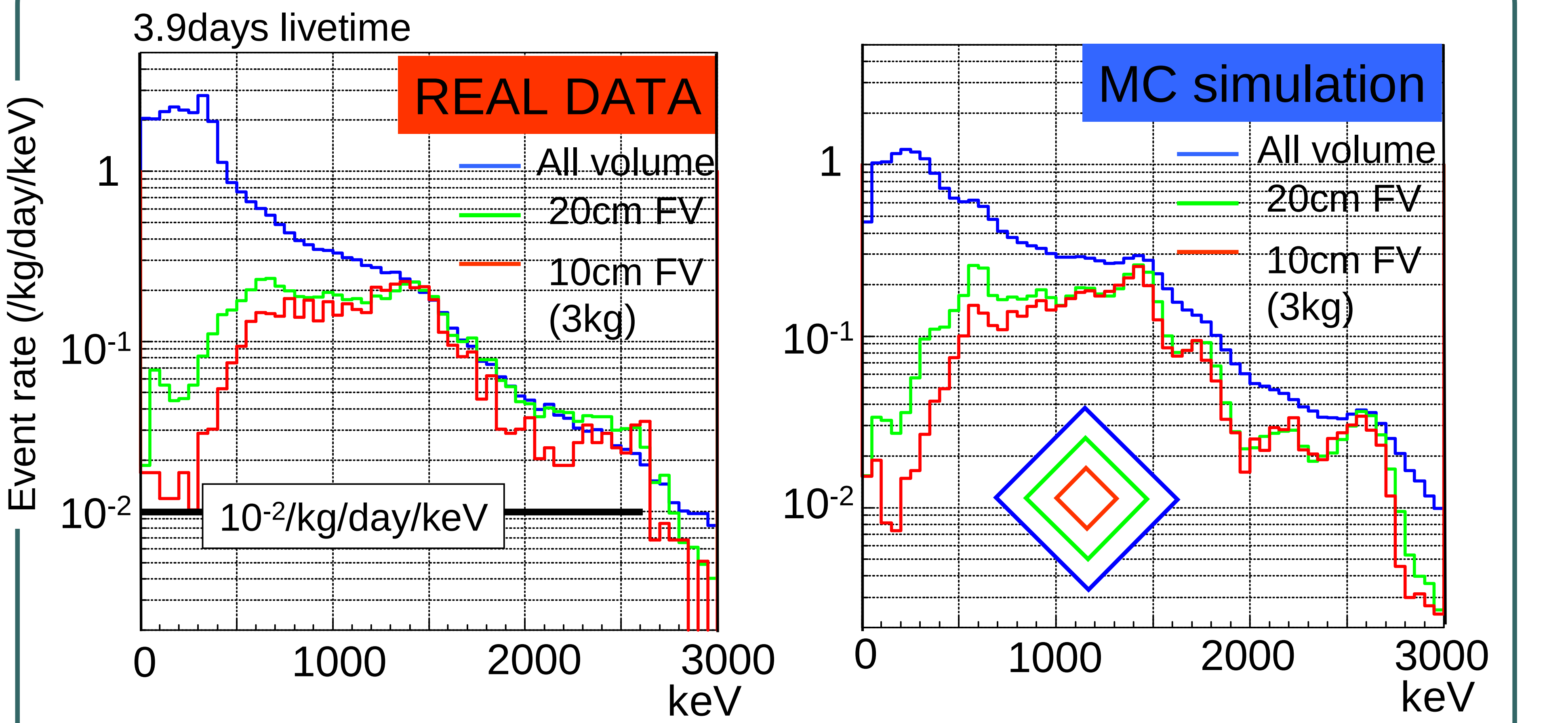




Z= -15 Z= +15

- Self shield works as expected.
- Photo electron yield ~ 0.8p.e./keV for all volume

Background data



- MC uses U/Th/K activity from PMTs, etc (meas. by HPGe).
- Self shield effect can be clearly seen.
- Very low background (10^{-2} /kg/day/keV@50-300 keV)

Internal background activities

Goal to look for DM by 800kg detector

- Current results
  - ^{238}U(Bi/Po): = $(33+-7)\times10^{-14}$ g/g ← 1×10^{-14} g/g x33

    Factor ~30, but may decay out further
  - ^{232}Th(Bi/Po): < 23×10^{-14} g/g ← 2×10^{-14} g/g x12

    Factor ~10 (under further study)
  - Kr: = 3.3±1.1ppt ← 1 ppt x3

    Achieved by distillation

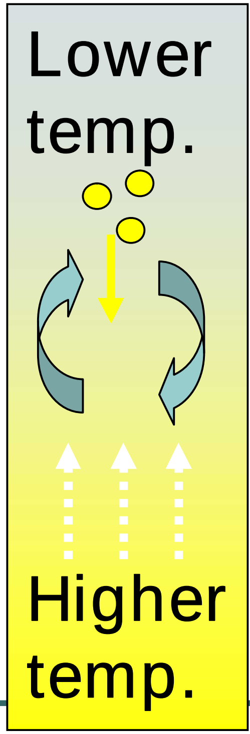
Very near to the target level of U, Th Radon and Kr contamination.

Distillation to reduce Kr (1/1000 by 1 pass)

- Very effective to reduce internal impurities (^{85}Kr, etc.)
- We have processed our Xe before the measurement.

	Boiling point (@1 atm)
Xe	165K
Kr	120K

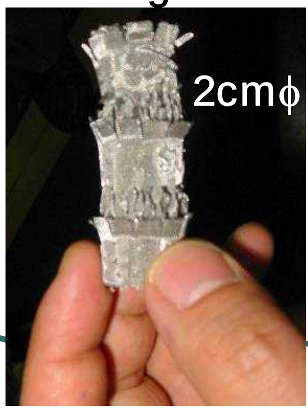
Original Xe:
~3 ppb Kr



~1%

Off gas Xe:
330±100 ppb Kr
(measured)

13 stage of



Operation: 2 atm
Processing speed: 0.6 kg / hour
Design factor: 1/1000 Kr / 1 pass

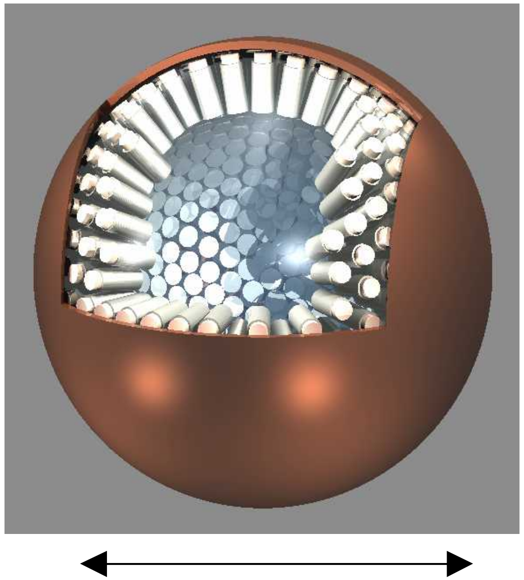
~99%

Purified Xe:
=3.3±1.1ppt Kr
(measured after Kr-enrichment)

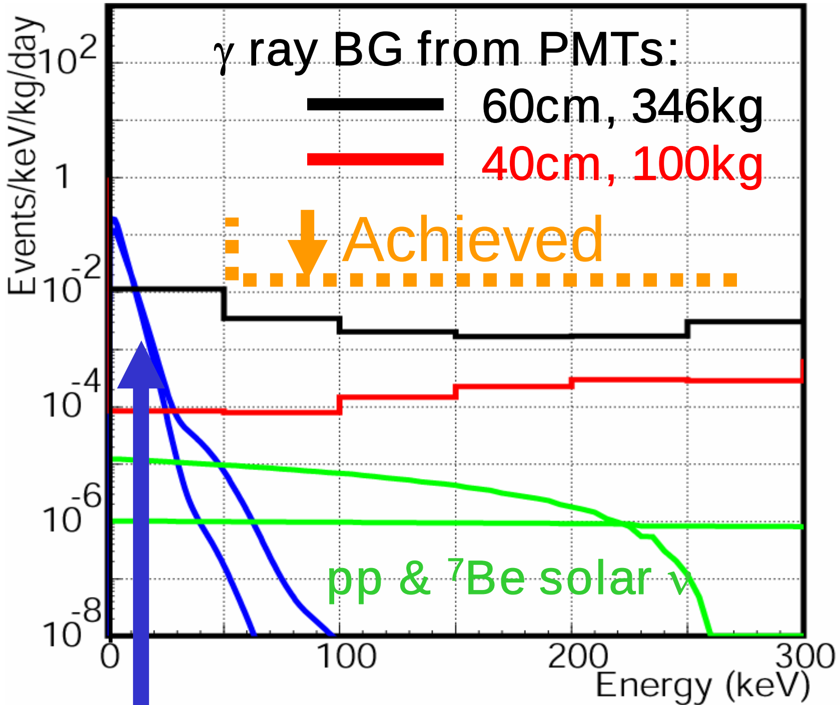
3. 800kg(100kg FV) detector for DM search

- Improve Energy threshold ➔ immerse PMTs into LXe
- Ext. γ BG: from PMT's ➔ Self-shield effect demonstrated
- Int. BG: Kr (distillation), Radon ➔ Almost achieved

"Full" photo-sensitive, "Spherical" geometry detector



80cm diameter

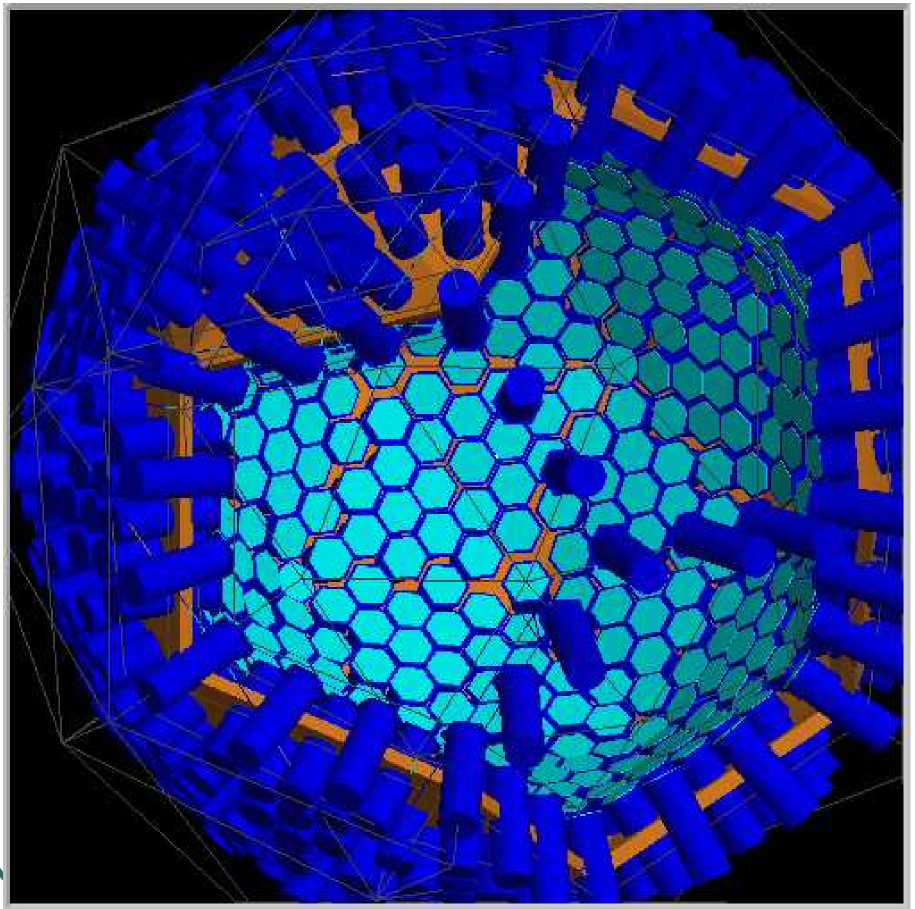


812-hex PMTs (1/10 Low BG)
70% photo-coverage ~5p.e./keVee

Expected dark matter signal
(assuming 10^{-42} cm^2, Q.F.=0.2 50,100GeV)

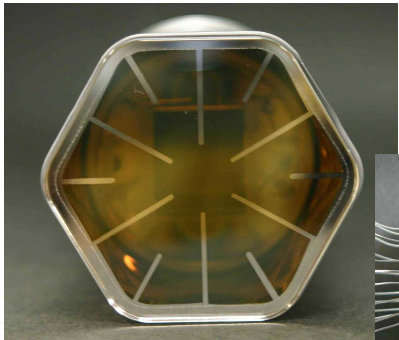
More detailed geometrical design

- A tentative design (not final one)



12 pentagons /
pentakisdodecahedron

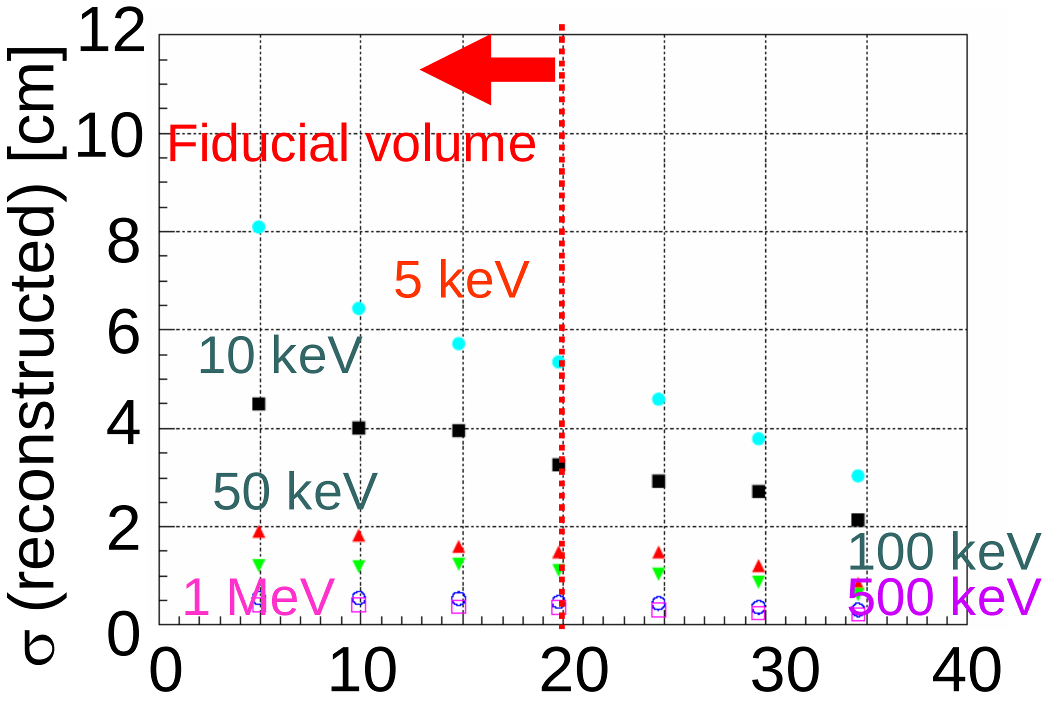
Hexagonal PMT
~50mm diameter

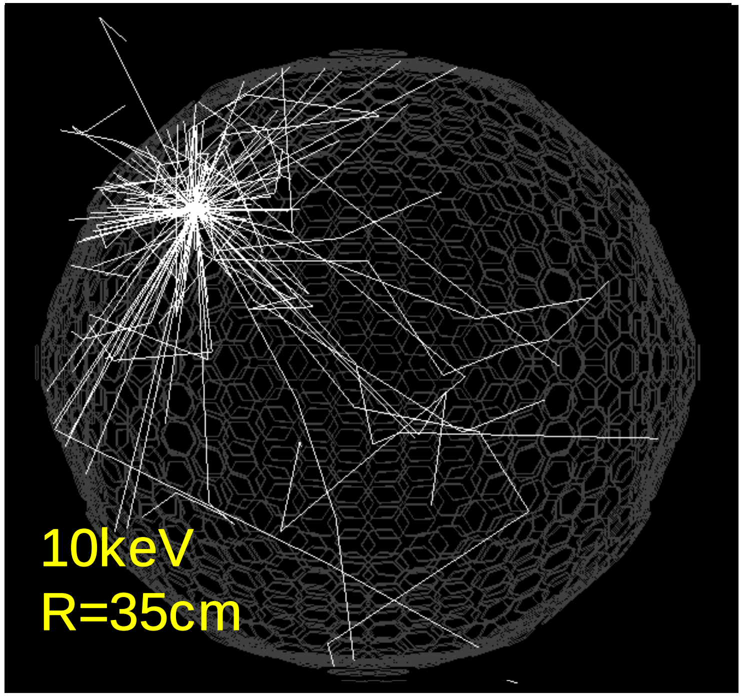


Aiming for 1/10 lower BG than R8778
R8778: U $1.8 \pm 0.2 \times 10^{-2}$ Bq
Th $6.9 \pm 1.3 \times 10^{-3}$ Bq
^{40}K $1.4 \pm 0.2 \times 10^{-1}$ Bq

▲ This geometry has been coded in a Geant 4 based simulator

800kg reconstruction and BG study energy threshold: 5keV (~25p.e.)



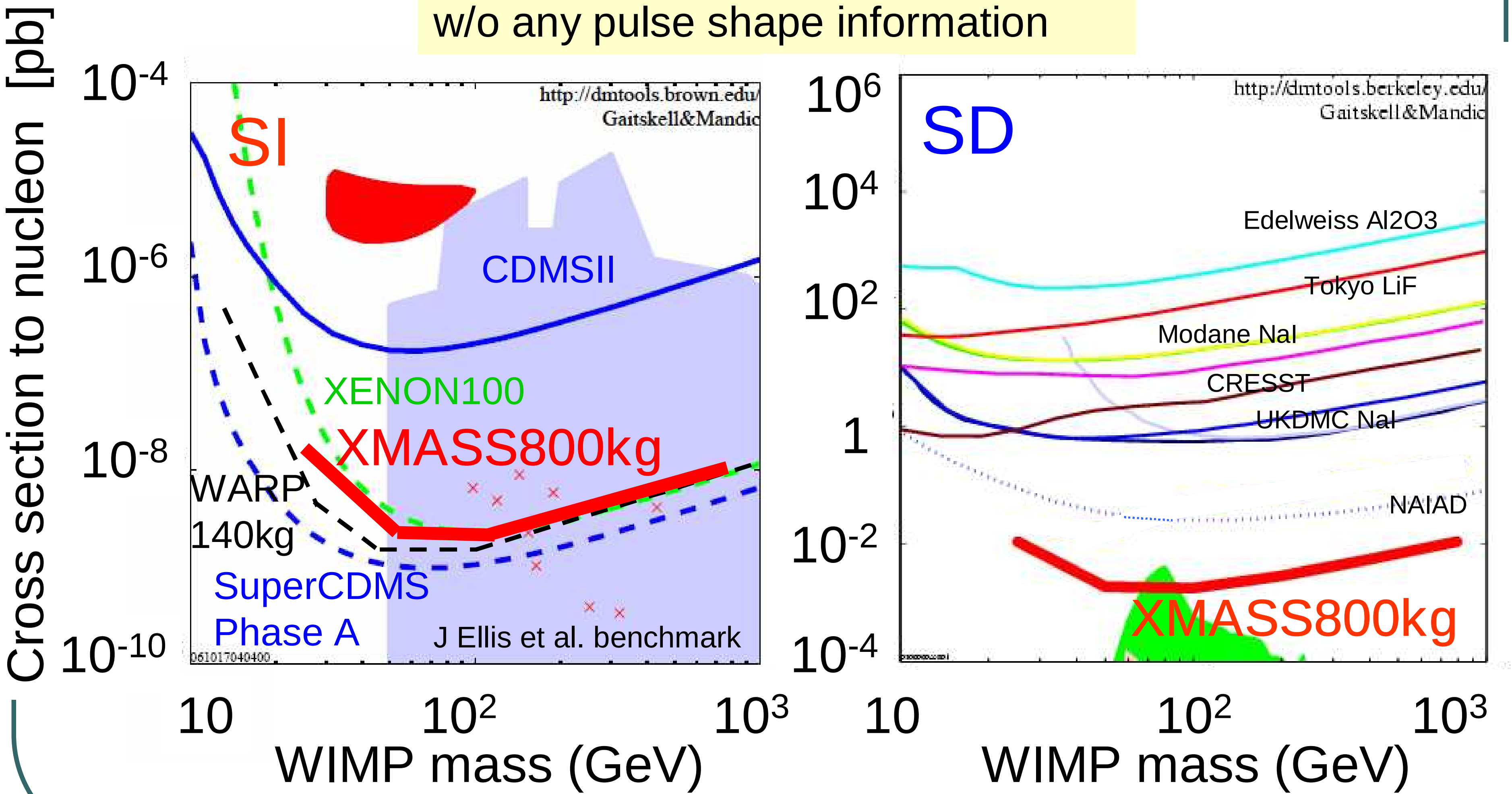


Photon tracking: absorption, scattering, and reflection

Extensive study to optimize the detector ongoing

Expected sensitivity

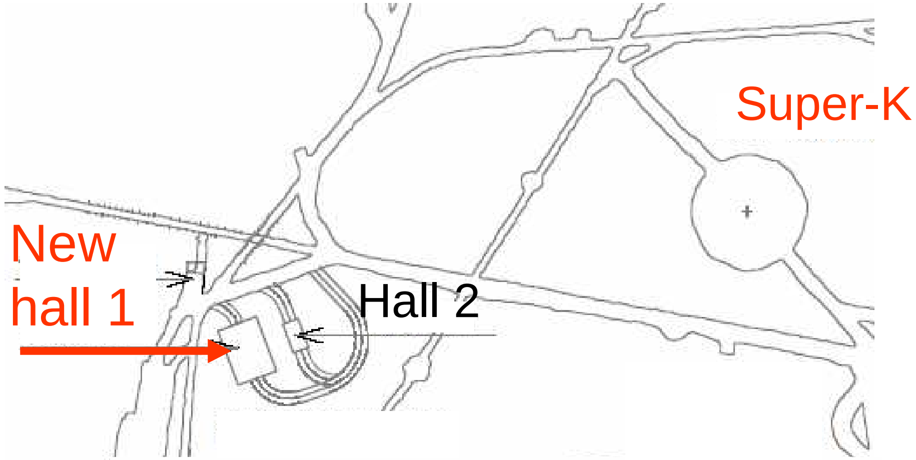
XMASS FV 0.5ton year (100kg, 5yr)
3σ discovery
w/o any pulse shape information

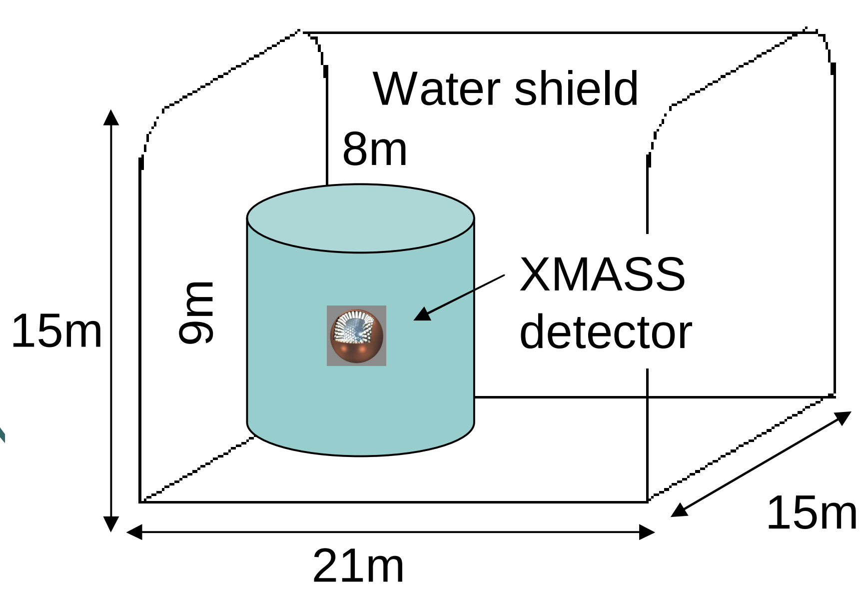


Large improvements ~10^2 expected.

Plots except for XMASS:
http://dmtools.berkeley.edu
Gaitskell & Mandic

New experimental hall





- New two halls will be excavated by the next summer.
- One of them accommodates the xmass detector including a large water shield which protects it from gamma rays and neutrons.
- 250cm water

  γ ~10^{-4}

  Fast neutron ~ 10^{-5}

Summary

- XMASS aims to detect

  Low energy solar ν, $0\nu\beta\beta$ decay, and Dark Matter
- Feasibility for 800kg liquid xenon detector was confirmed with the prototype detector.

  Reconstruction, self shielding, and purification tech. have been demonstrated.
- 800kg detector is under designing.

  10^2 improvement of sensitivity (~10^{-9}pb) above existing experiments is expected.