

**Tokyo Axion Helioscope,
Hidden photon search
and
Anti-neutrino monitor of reactor
operations**

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and
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Solar axion detection – the principle

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17 OCTOBER 1983

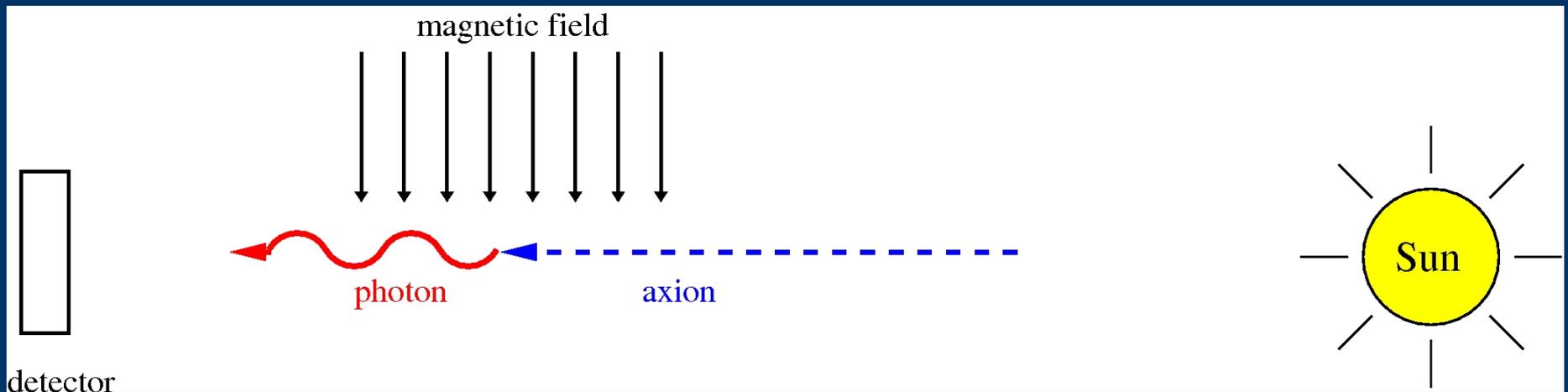
Experimental Tests of the “Invisible” Axion

P. Sikivie

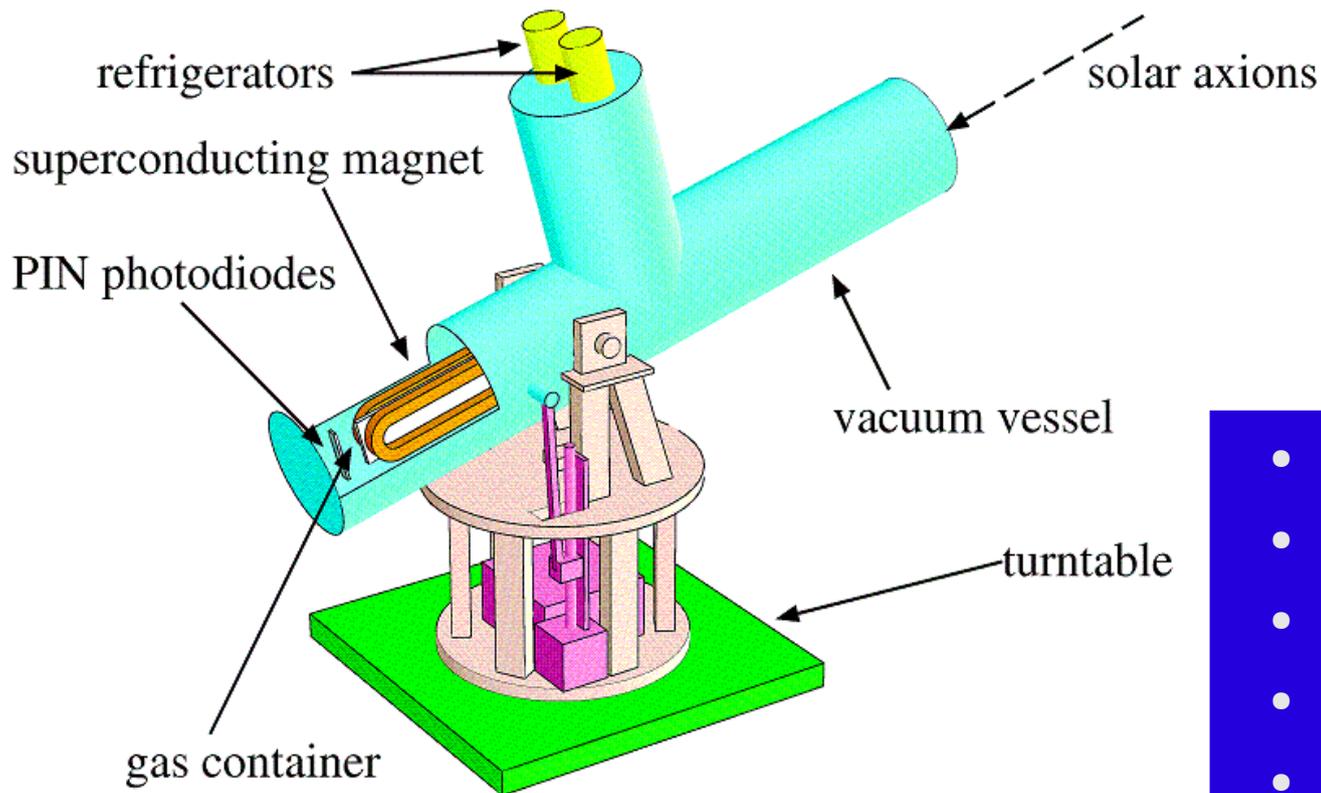
Physics Department, University of Florida, Gainesville, Florida 32611

(Received 13 July 1983)

The axion helioscope.—The idea here is the same as the previous one but now applied to the solar axion flux. In a strong magnetic field, solar axions convert to x rays. The change in three-momentum is



Tokyo Axion Helioscope aka **Sumico** first result in 1997



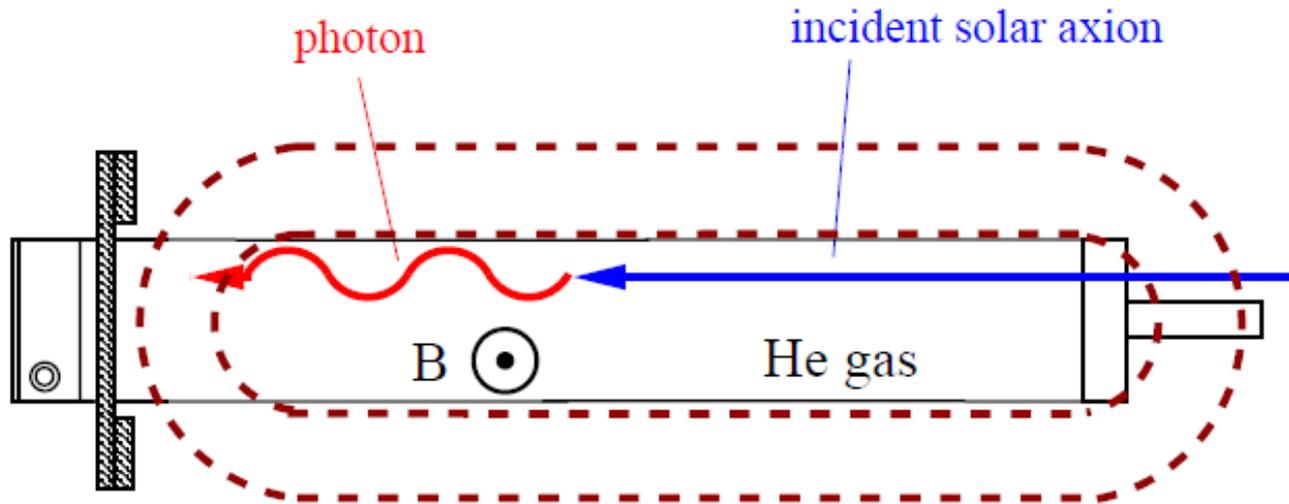
- No Liq. He
- $B=4T$, $L=2.3m$
- 268A persistent current
- 16 PIN photodiodes
- Altazimuth:
Horiz. 360° , vert. $\pm 28^\circ$

Tokyo axion helioscope - a start up

make it as simple as possible

- Dedicated superconducting dipole magnet
 - ✓ A. Ymamoto(KEK)
 - Computer controled altazimuth
 - ✓ no problem
 - Buffer gas for non-zero mass axions
 - Pressure-resistant X-ray window
 - X-ray detector in vacuum and low temperature
-
-

Buffer gas for non-zero mass axions



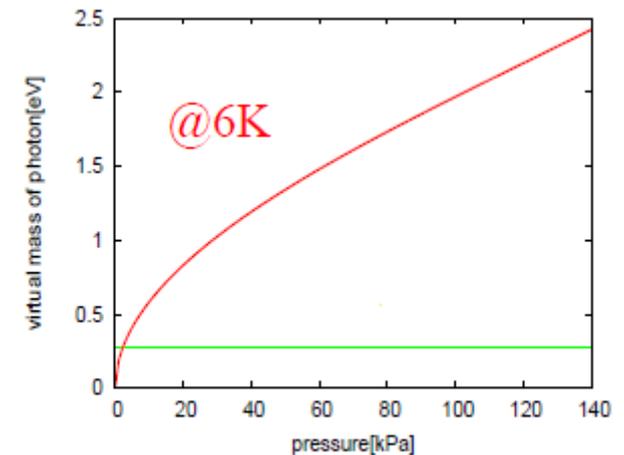
Helium-4 does not liquefy @1atm, 6K.

$$P_{a \rightarrow \gamma} = \left(\frac{g_{a\gamma\gamma} B}{q} \sin \frac{qL}{2} \right)^2$$

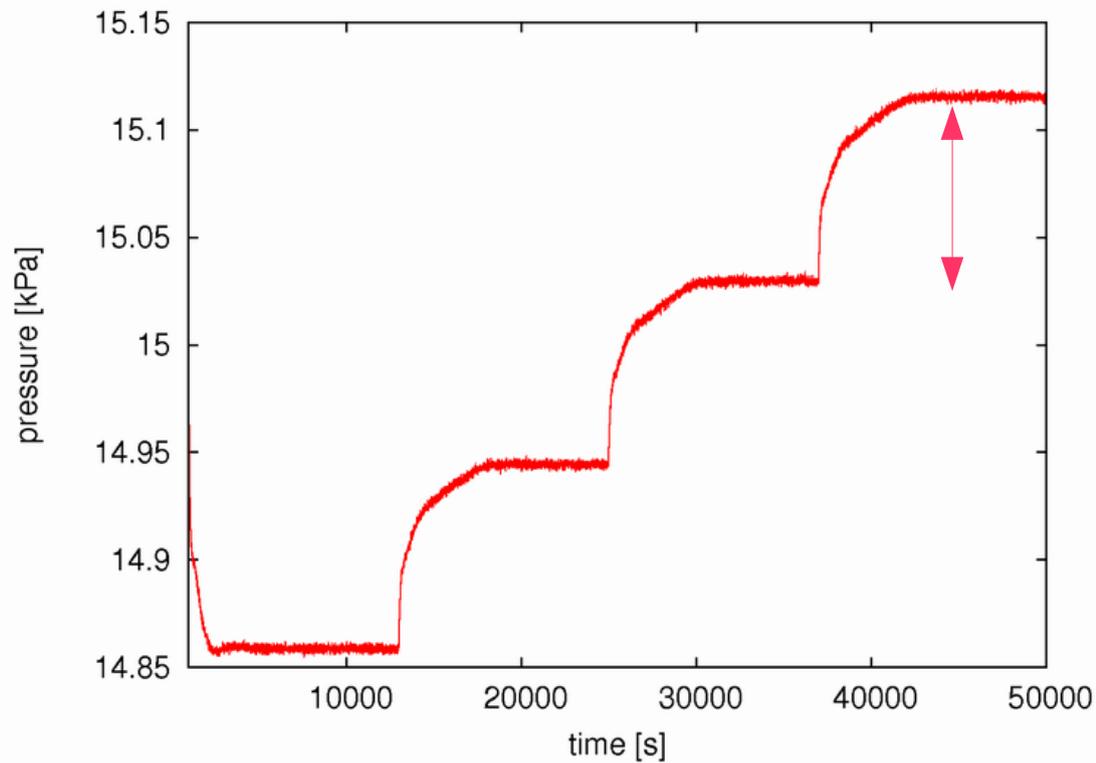
$$= \frac{g_{a\gamma\gamma}^2 B^2 L^2}{4}$$

$$q = \frac{|m_\gamma^2 - m_a^2|}{2\omega}$$

$$m_\gamma = \left(\frac{4\pi \alpha N_e(z)}{m_e} \right)^{1/2}$$



pressure setting with piezo valves



$T=5.75\text{K}$

$\Delta m_{\gamma} = 2 \text{ meV}$

X-ray detector in vacuum and low temperature

- 16 x Hamamatsu S3590-06-SPL
- High efficiency with 0.5 mm thickness
- Only $0.35\mu\text{m}$ inactive surface layer
- Cold operation at $T=60\text{K}$ anchored at the radiation shield

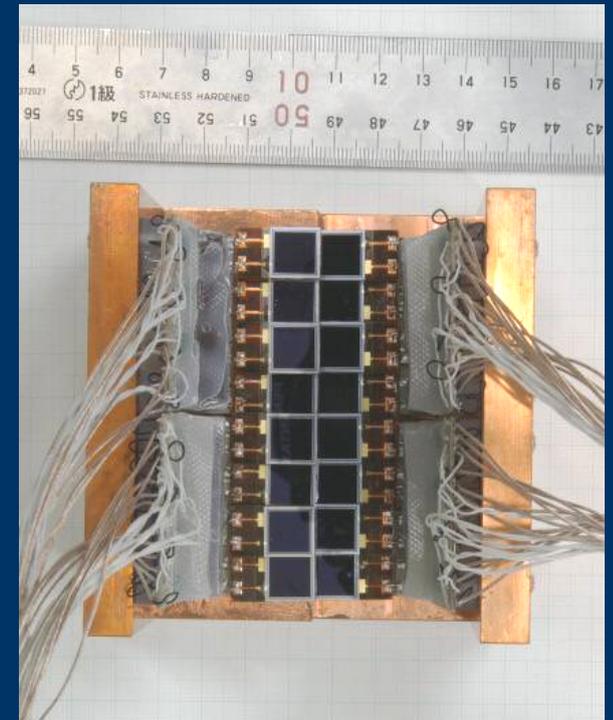
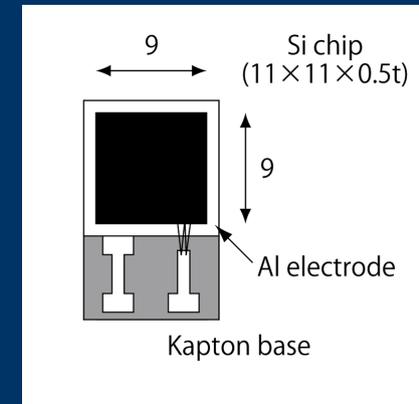
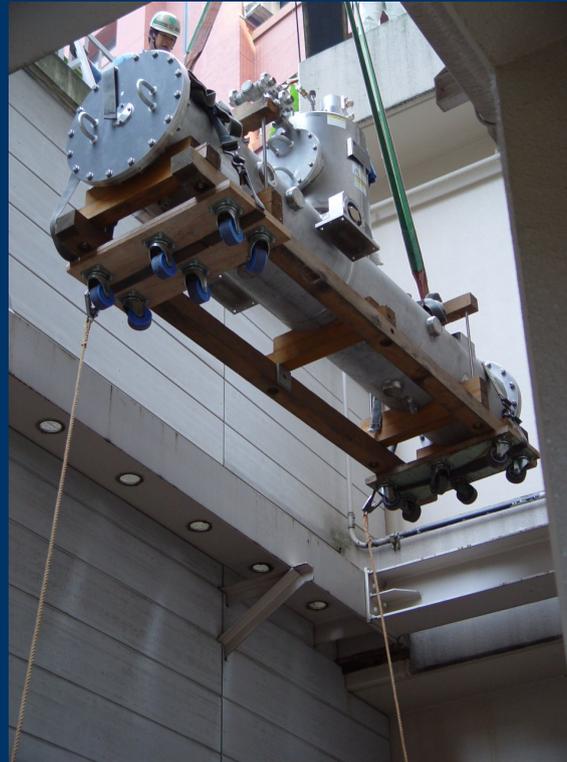
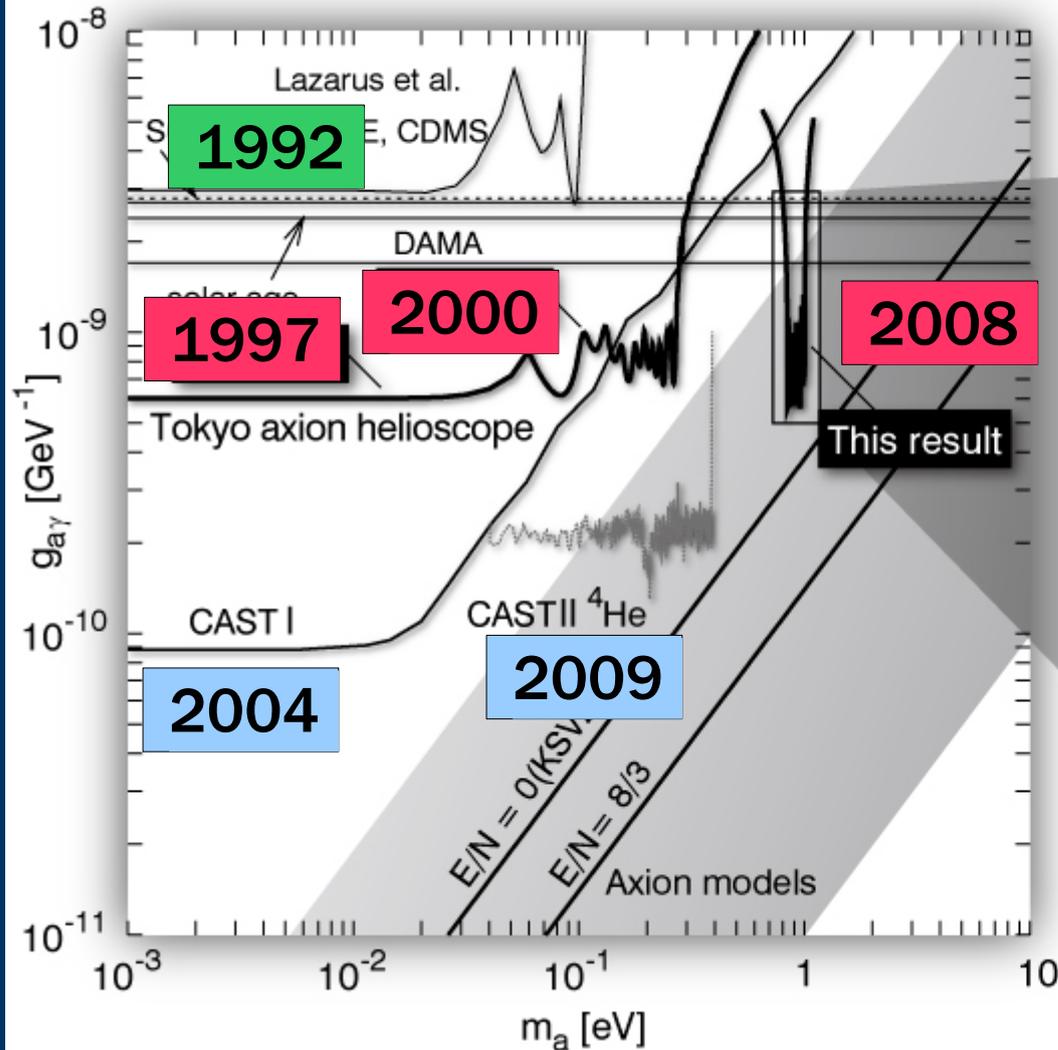


Photo gallery

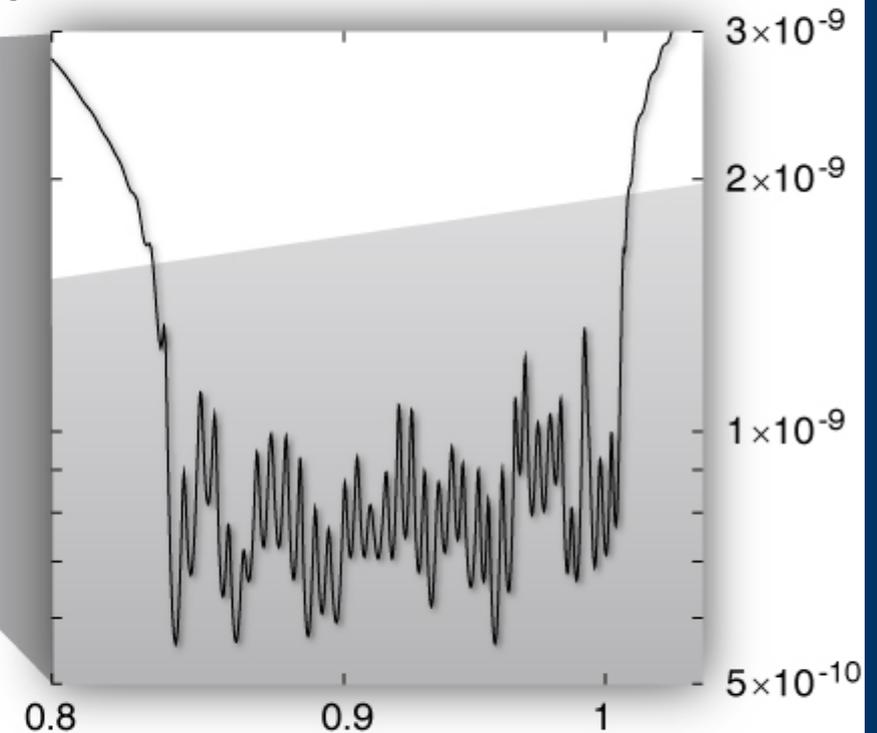


Sumico moved from an old building to a new one in 2002.

Search results – exclusion plots



Y. Inoue et al.,
Phys. Lett. B 668 (2008) 93



Sumico vs. CAST to scale



Sumico vs. CAST

<i>BL</i>	4T x 2.3m	9T x 9.26m
<i>T</i>	5 - 6 K	1.8 K
buffer gas	helium-4	helium-4 and -3
cooling	refrigerator	liq. helium
swing	(360°), ±28°	100°, ±8°
detectors	PIN photodiodes	many kinds
running cost	~20kW (¥10k/d)	don't know
# institutes	2	17
# collab.	6	61
size	\small	\Huge

Limitation and Hope

$$g_{a\gamma\gamma}^{\text{limit}} \propto N^{1/8} T^{-1/8} A^{-1/4} B^{-1/2} L^{-1/2}$$

N : background rate
 T : running time
 A : detector area

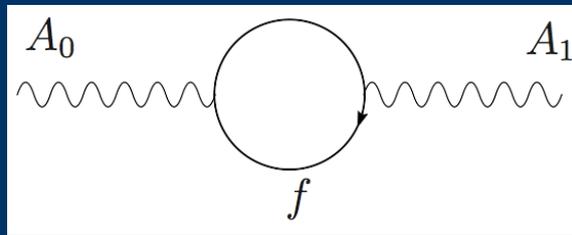
Smaller BL cannot be compensated by any other factors.

→ CAST wins

X-ray absorption and decoherence due to gravity are not fatal in helium-4 buffer gas even with $m_\gamma = 2 \text{ eV}$.

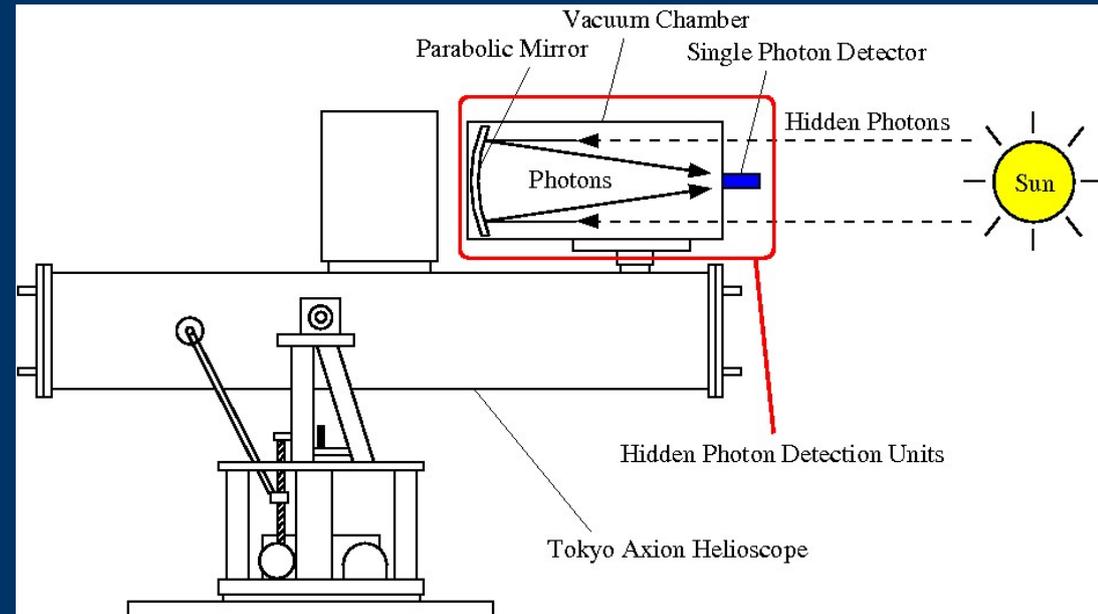
→ Sumico might survive in $1 < m_a < 2 \text{ eV}$.

Hidden photon search – a by-product



$$L_{\text{int}} = -\frac{1}{2} \chi F_{\mu\nu} B^{\mu\nu}$$

Ref: S. N. Gninenko et al., Phys. Lett.B 664 (2008) 180



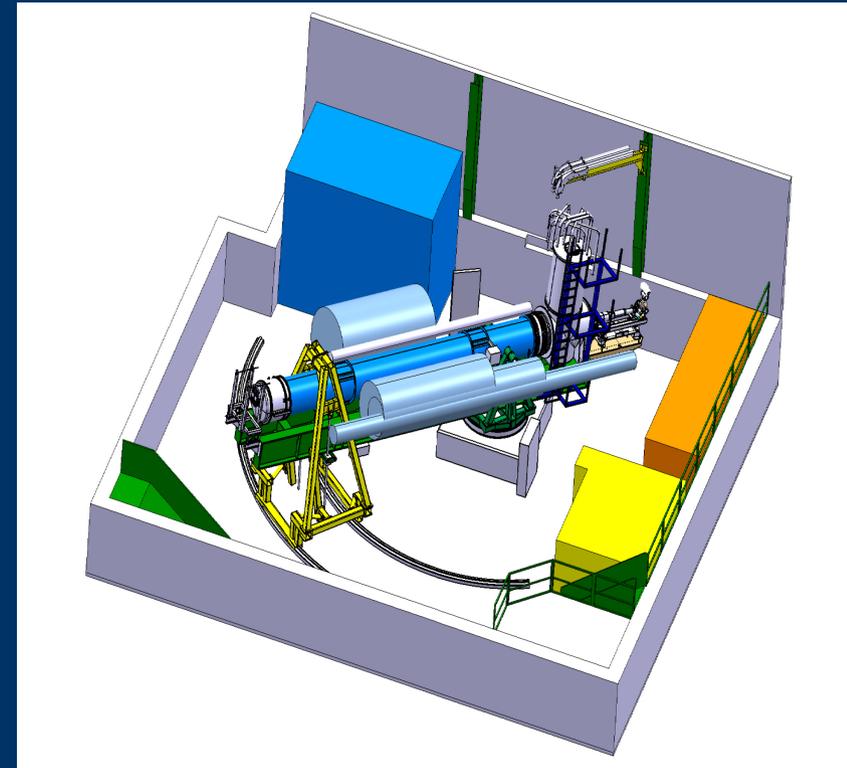
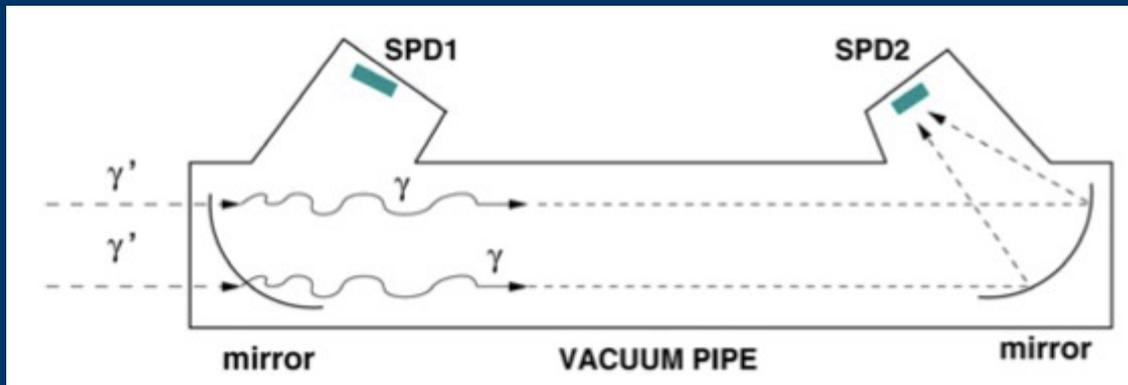
Projects around the world

CAST



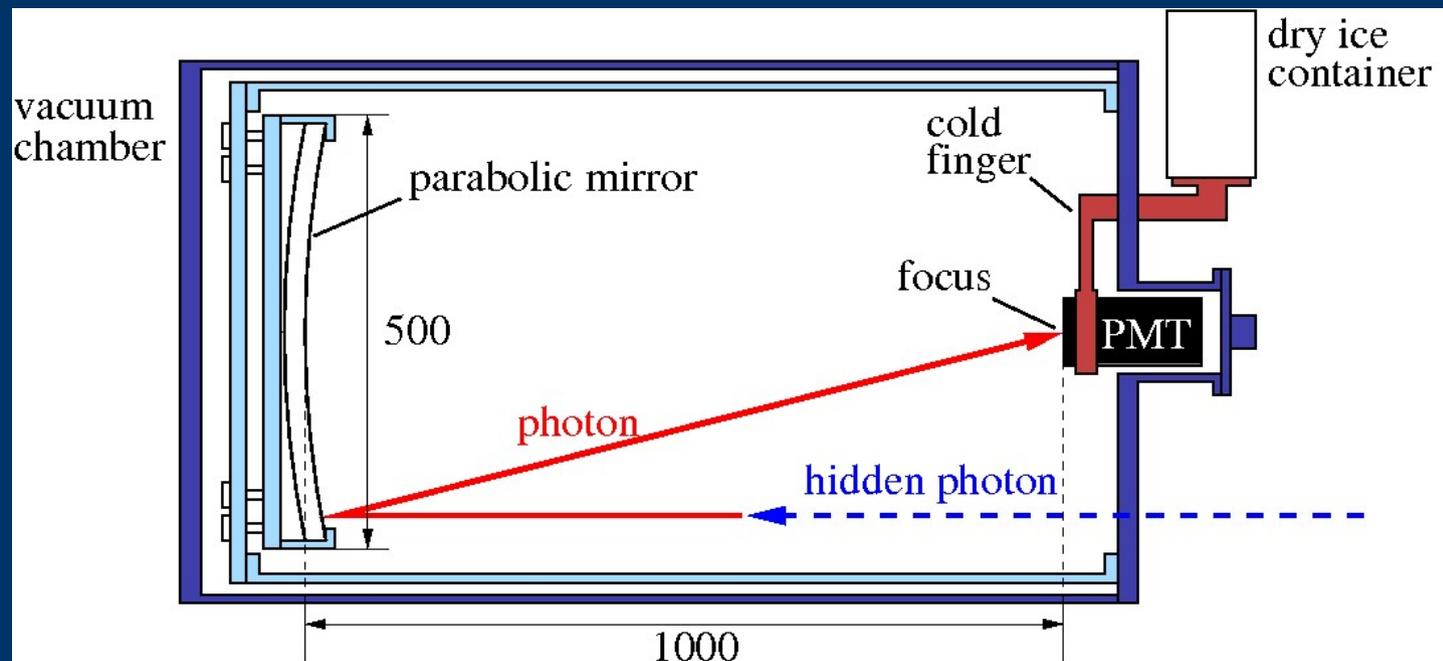
SH PS

(Solar Hidden Photon Search)

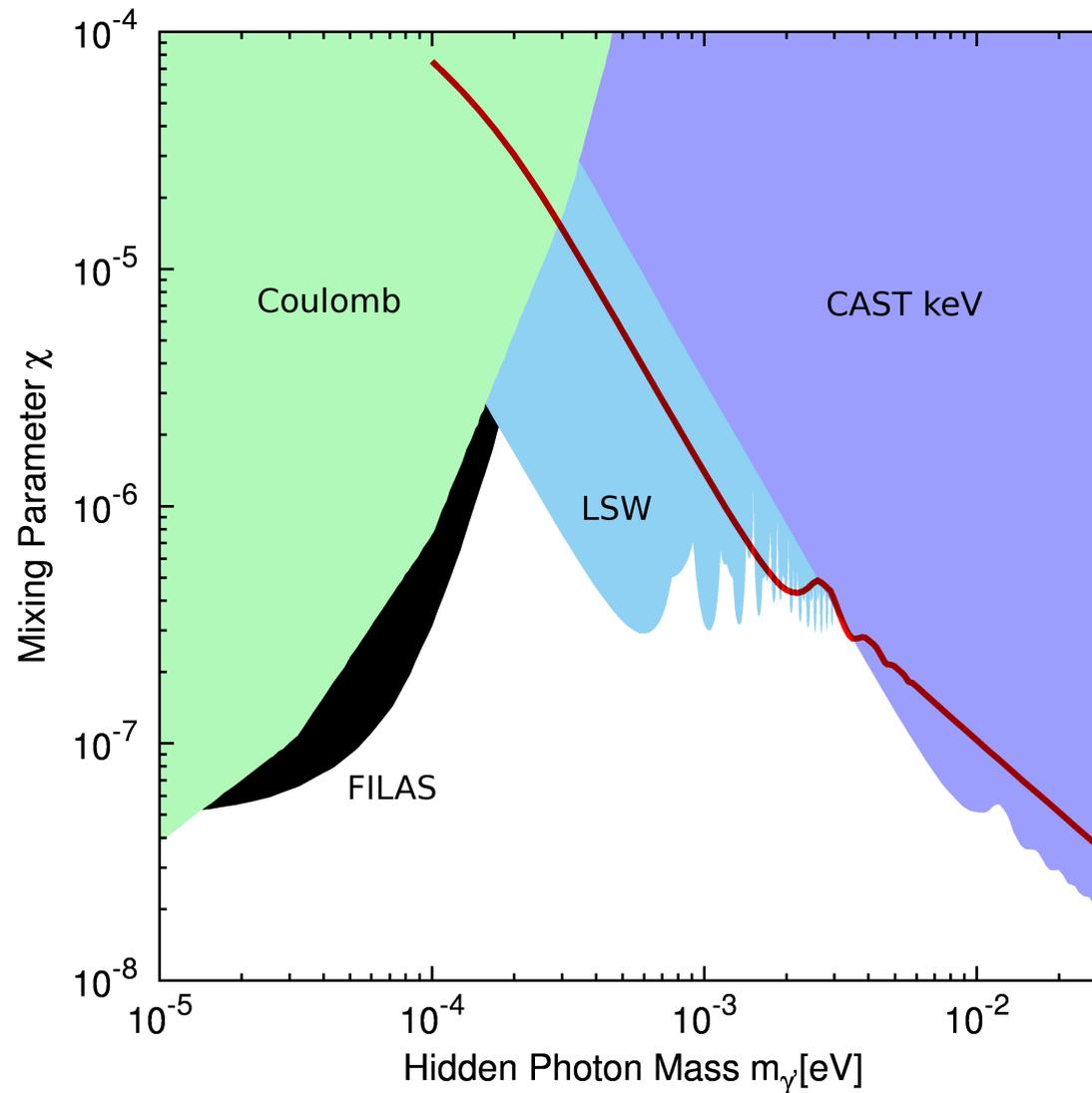


Hidden photon detection unit with Sumico

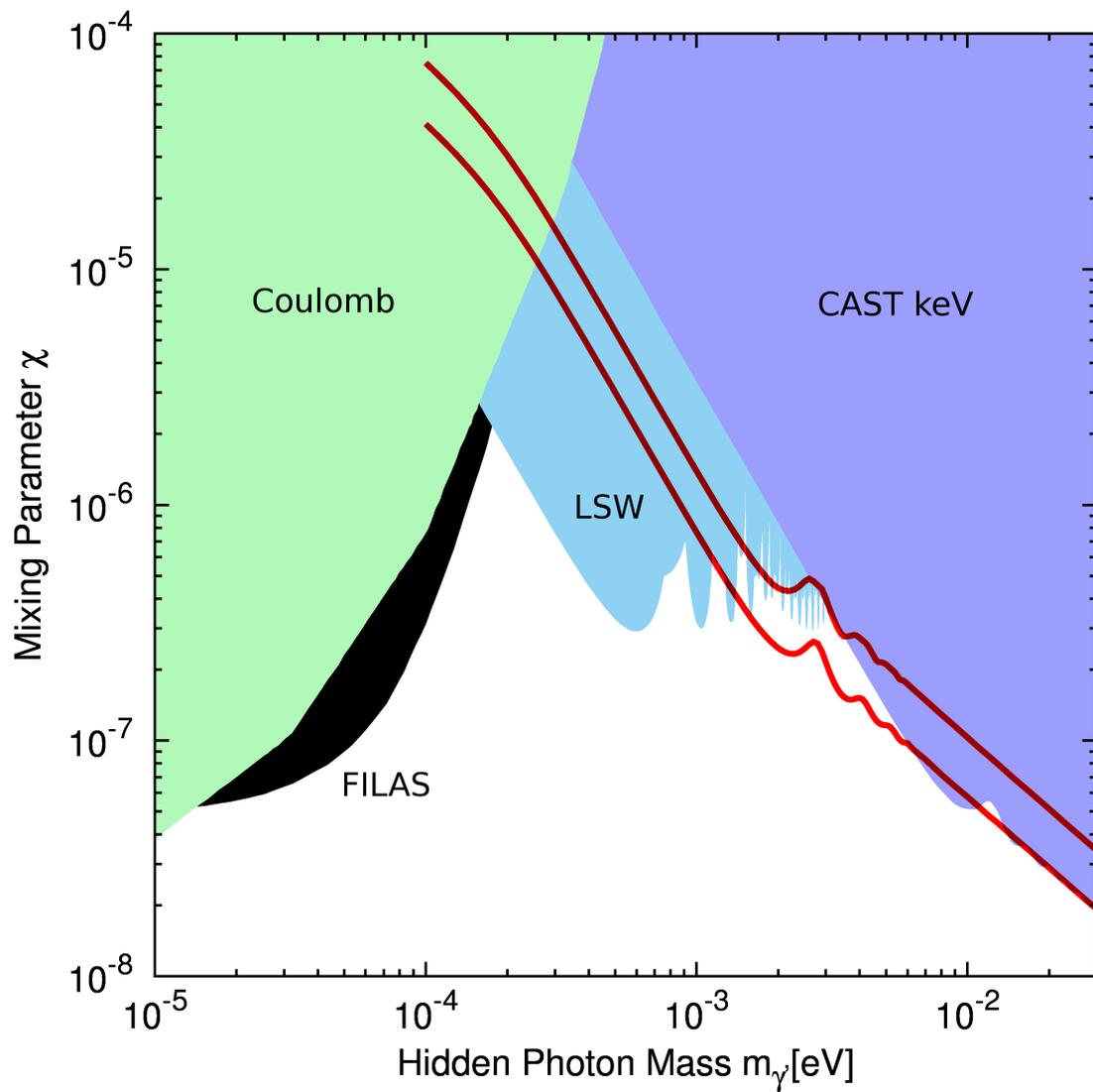
- PMT with Low-dark-noise $< 10\text{Hz}$
- Low-cost parabolic mirror for a searchlight



Preliminary exclusion limit for live time=5,200s



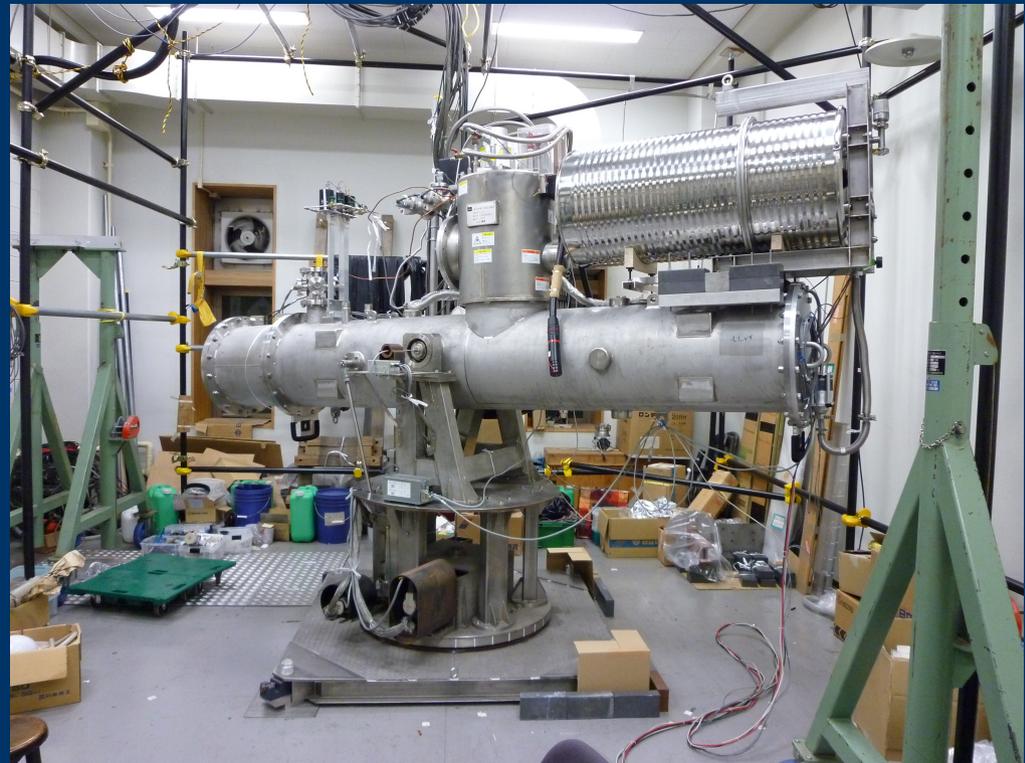
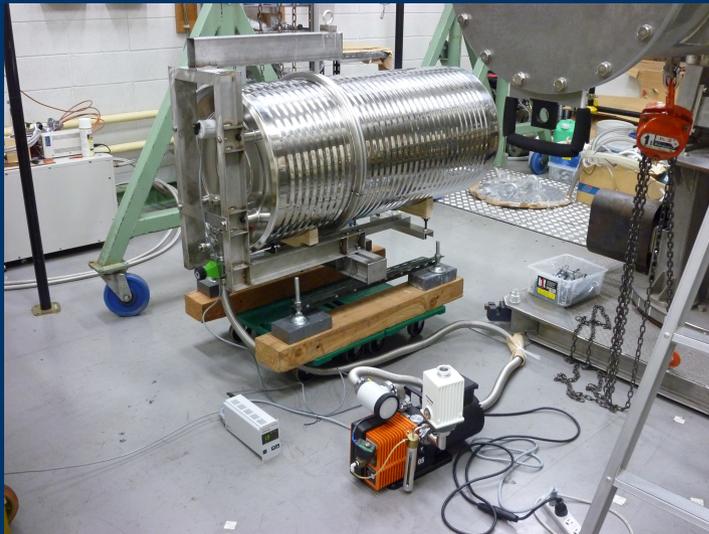
Tentative goal



Hidden photon detection unit



Piggyback on Sumico



Anti-neutrino monitor of reactor operations

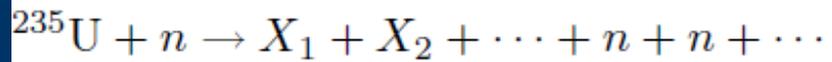
(原子炉ニュートリノモニター)



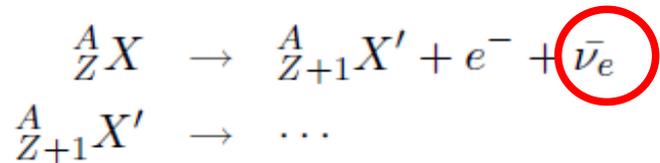
原子炉ニュートリノモニタ

- ▶ IAEAは核不拡散・保障措置の新手法として原子炉ニュートリノモニタリングのfeasibility studyを提案
 - ▶ 発展途上国等における原子力発電所の新設増加
-
-

原子炉での 反電子ニュートリノの発生



核分裂



生成物のベータ崩壊

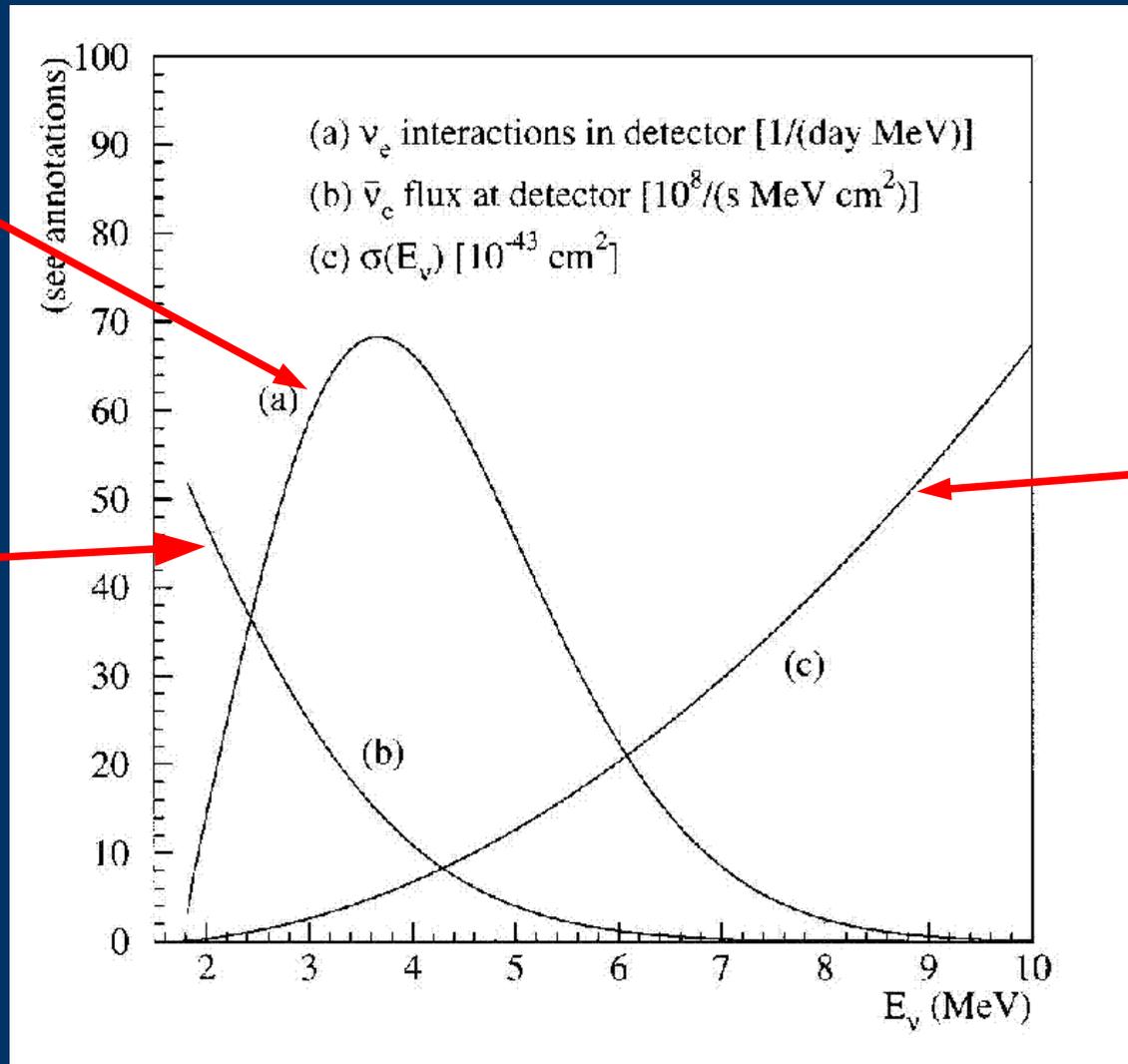
熱出力 3GW の原子炉の出す
反電子ニュートリノは

約 2×10^{20} 個 / 秒 (2MeV 以上で)

原子炉（反電子）ニュートリノ

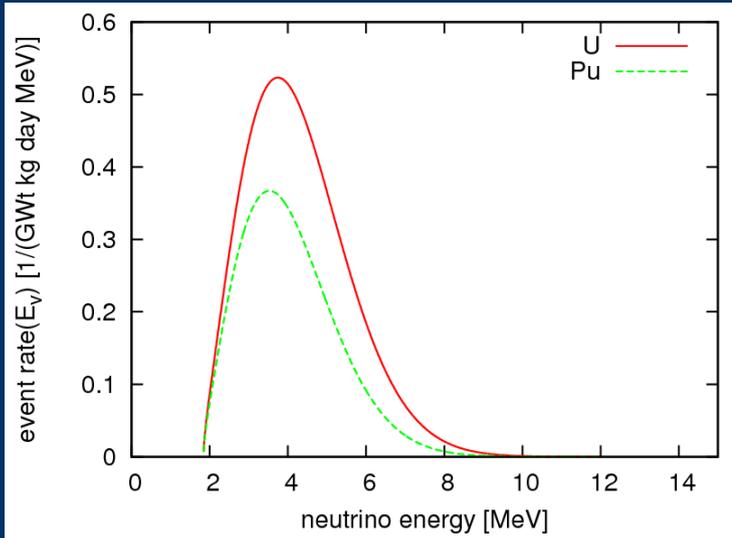
検出器での
反応率

フラックス



断面積

核燃料の燃焼度とニュートリノ



²³⁵U

²³⁹Pu

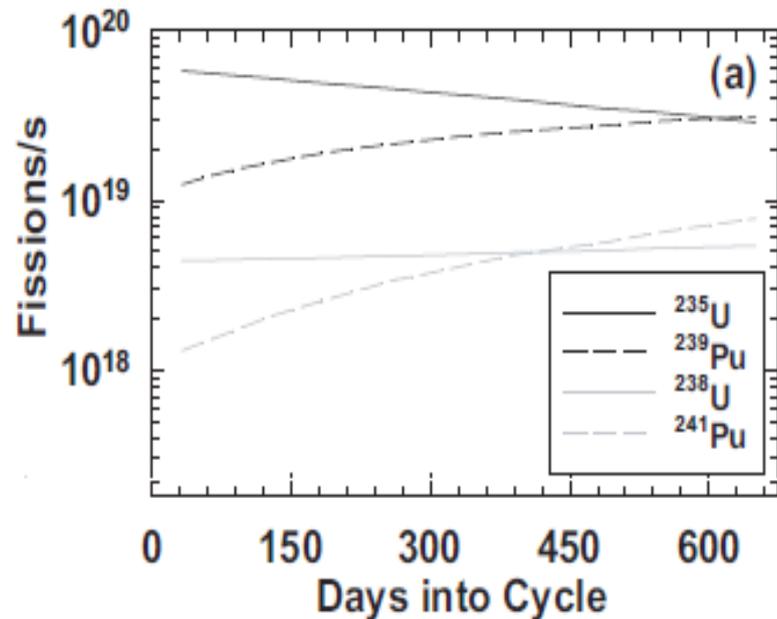
E_{fis} 201.7MeV 210.0MeV

\bar{E}_v 2.94MeV 2.84MeV

N_v/fis 1.92 1.45

σ 3.2 : 2.76

$N_{\text{det}}/E_{\text{fis}}$ 1.6 : 1.0



われわれの提案

Plastic Anti-Neutrino Detector Array

PANDA

検出器の特徴

▶ 安全性

(可燃性液体ではなく、プラスチックシンチレータ)

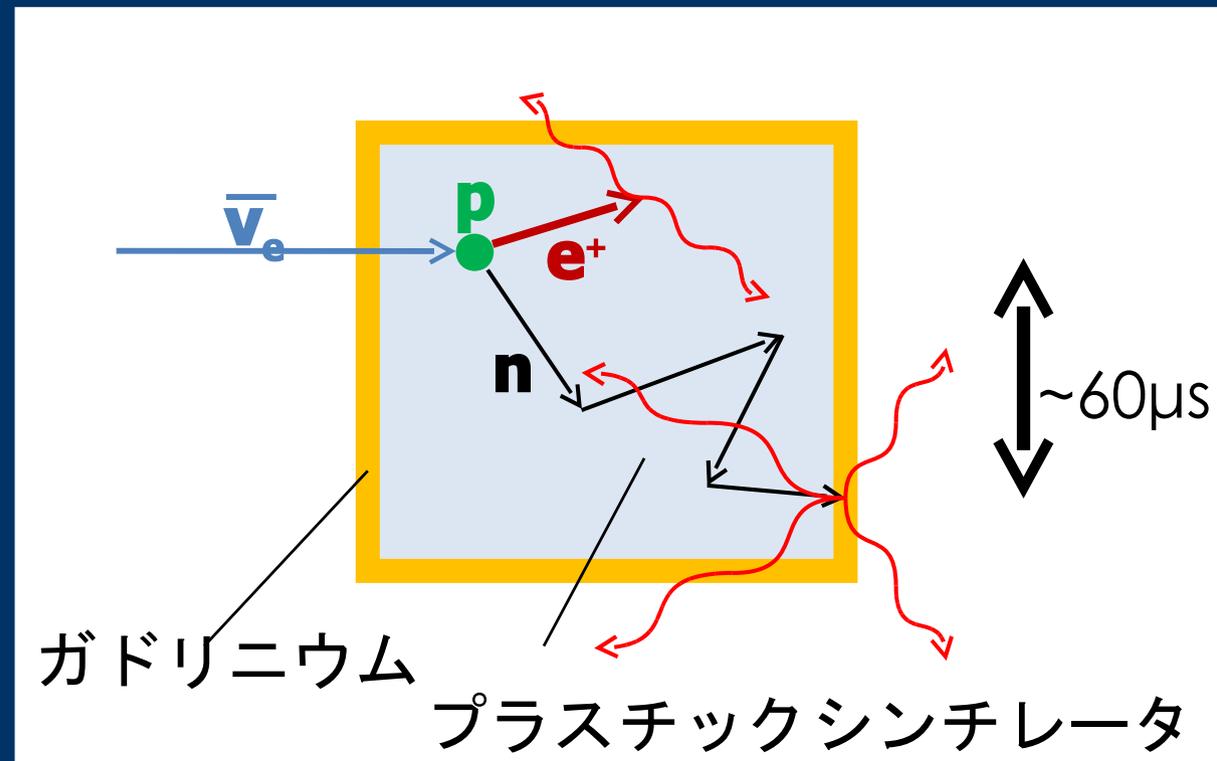
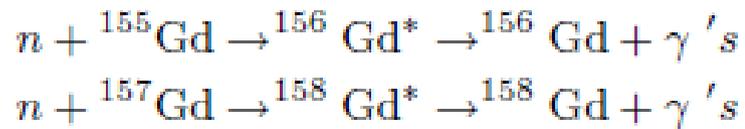
▶ 可搬性

(有効検出器質量約1トン)

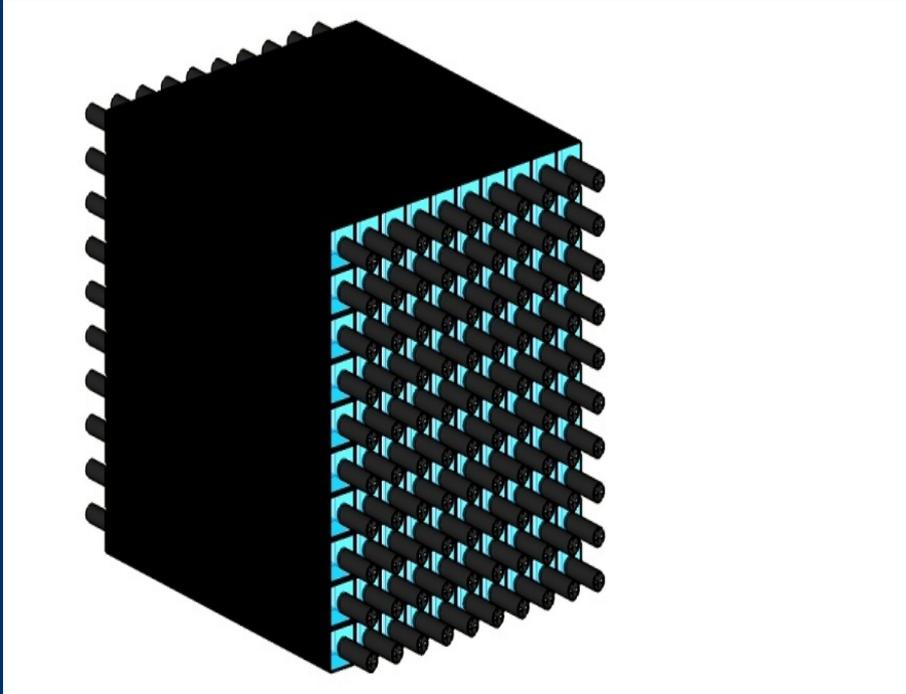
(商用電源 100V 1kW以下)

PANDA- 検出原理

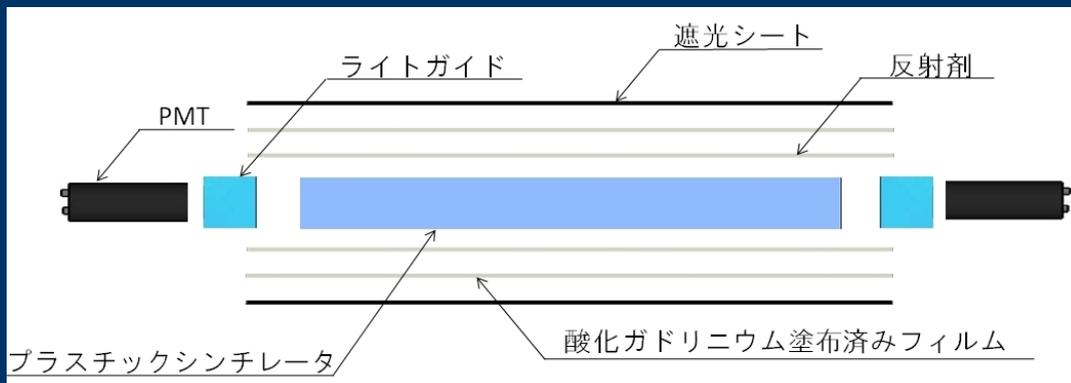
Reines-Cowanや
KamLANDと同じ
遅延同時計数



PANDA- 検出器の構成



10cm×10cm×100cm
の
プラスチックシンチレー
タを
100本使用



原子炉ニュートリノ検出率

実機（有効検出器質量 1トン）

熱出力 3 GW $L = 20\text{m}$ で 約 5×10^6 イベント/d

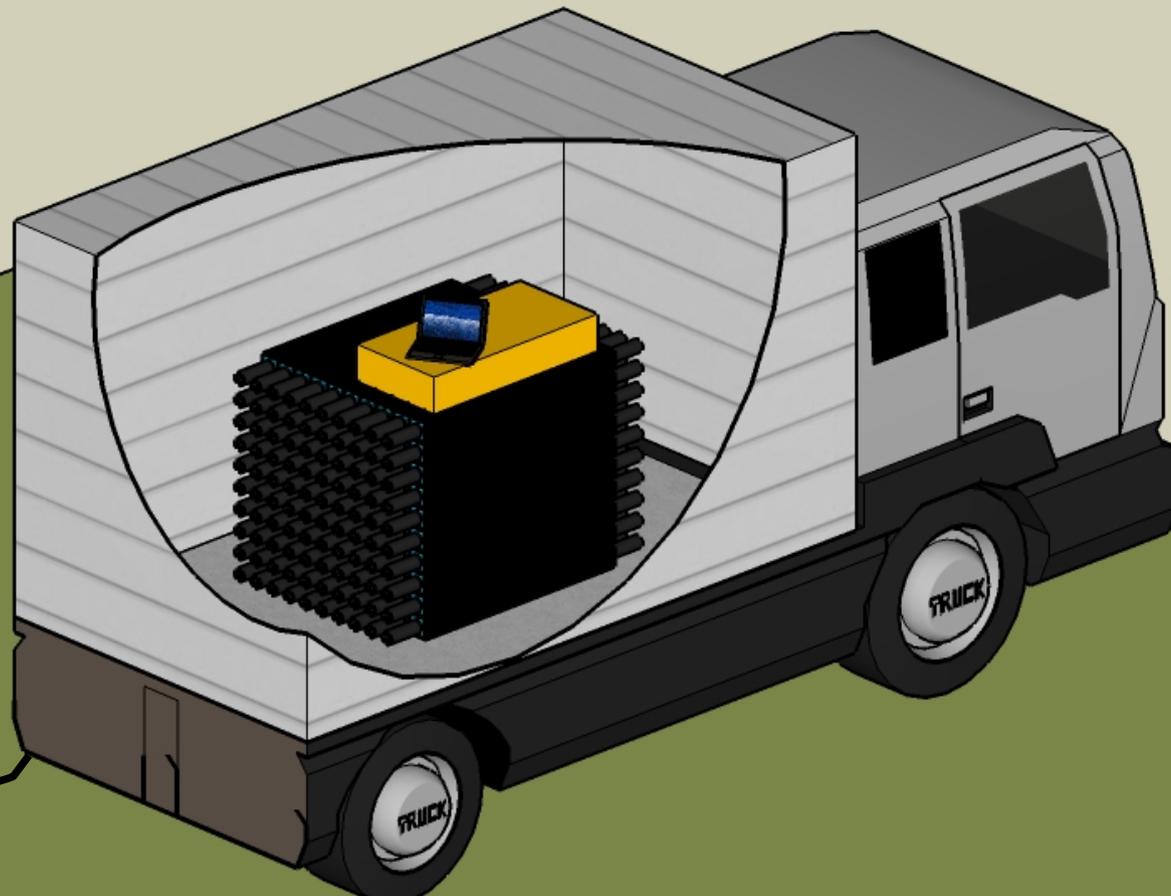
（検出効率 10%として）

検出効率 = （検出数） / （検出機内での反応数）

PANDA 完成予想図

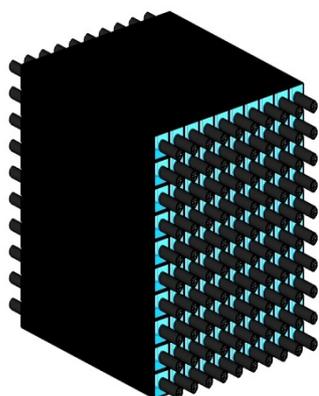
2トントラックで移動・測定

100V 1kW 以下



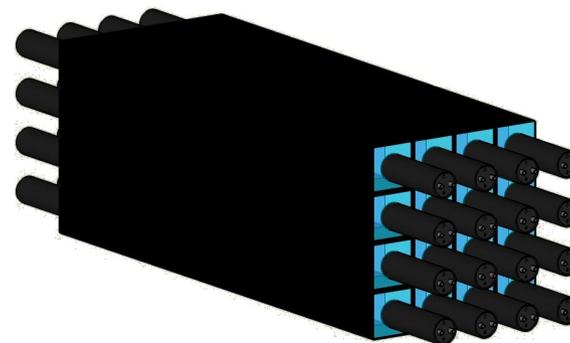
小型試作機は完成済み - 試験配備可能

実機



$10 \times 10 = 100$ 本
1 トン

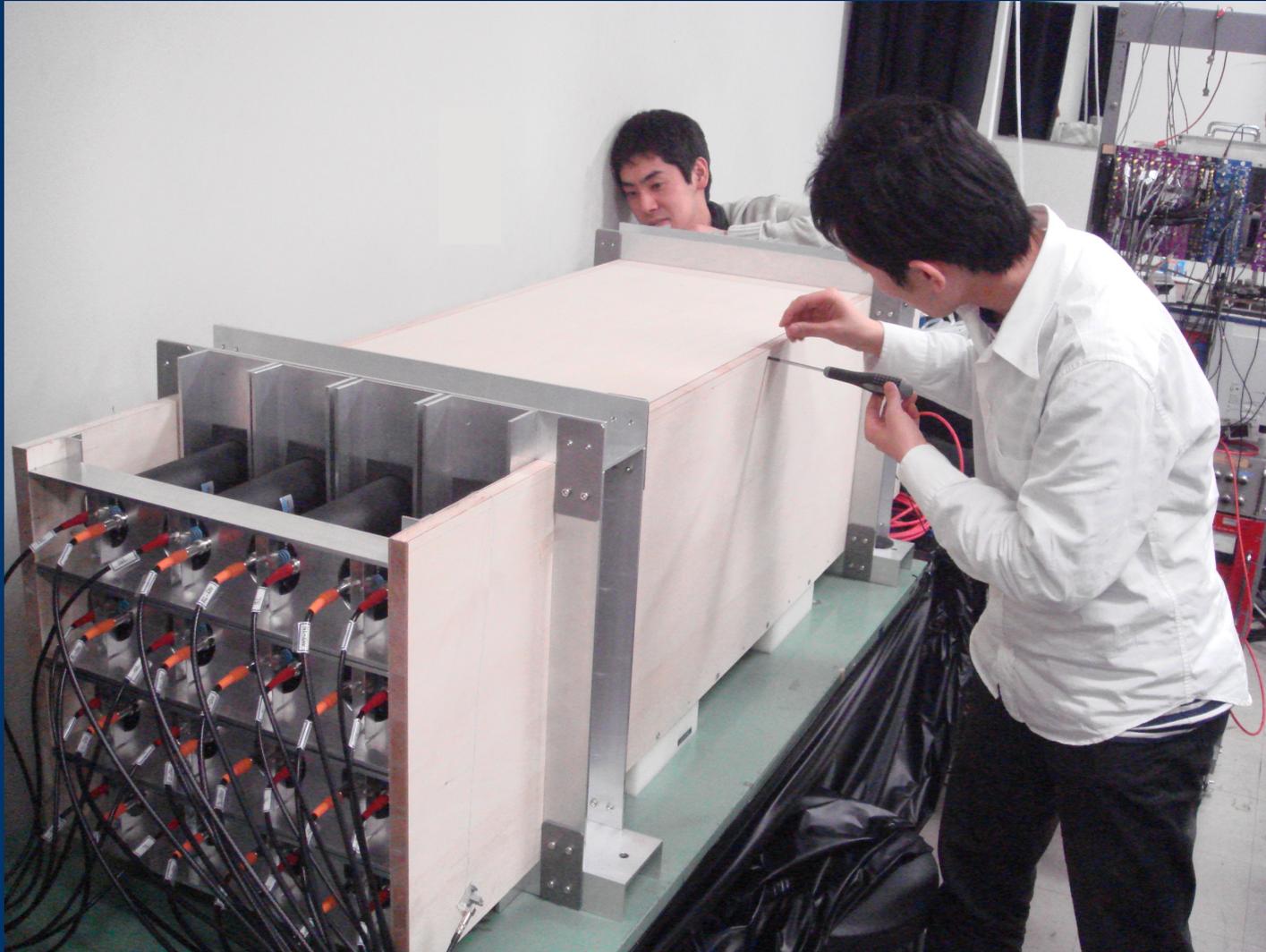
試作機



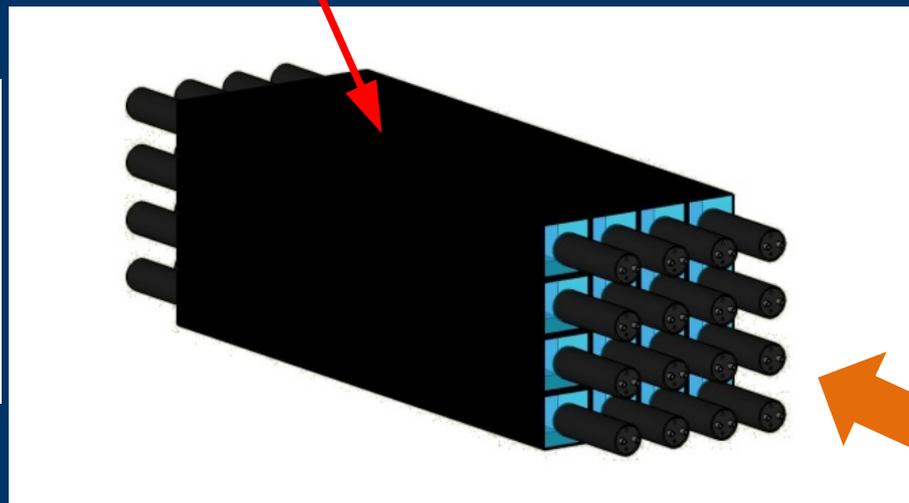
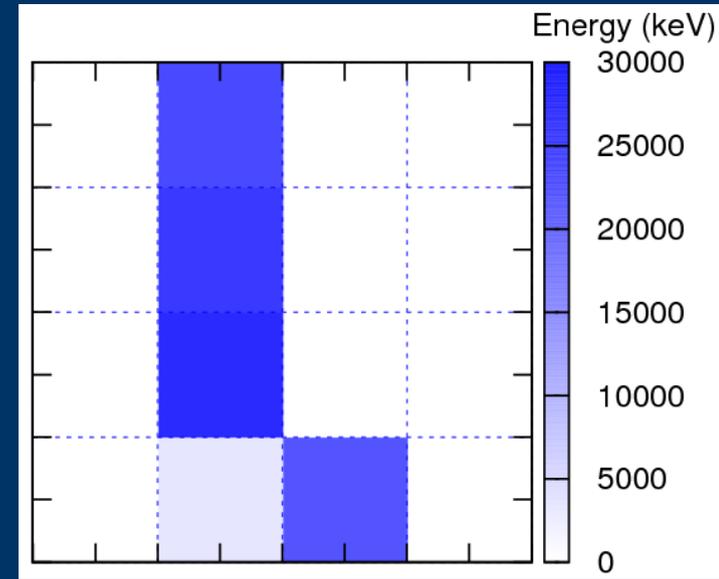
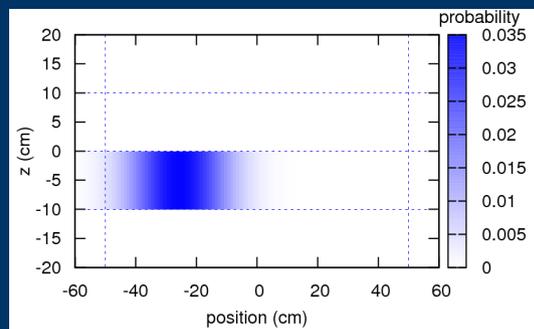
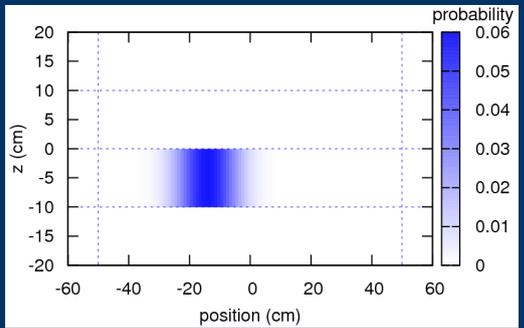
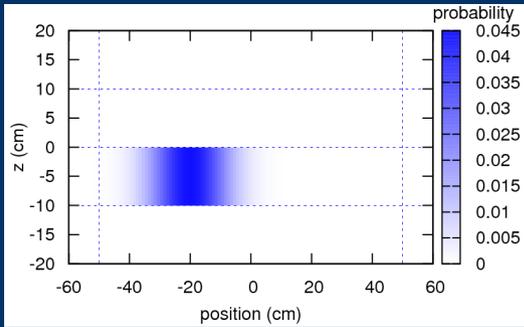
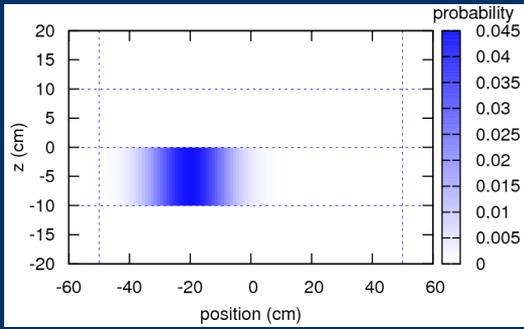
$4 \times 4 = 16$ 本
160kg

- 組み立てに関するノウハウ
- バックグラウンドの見積もり

4×4 小型試作機

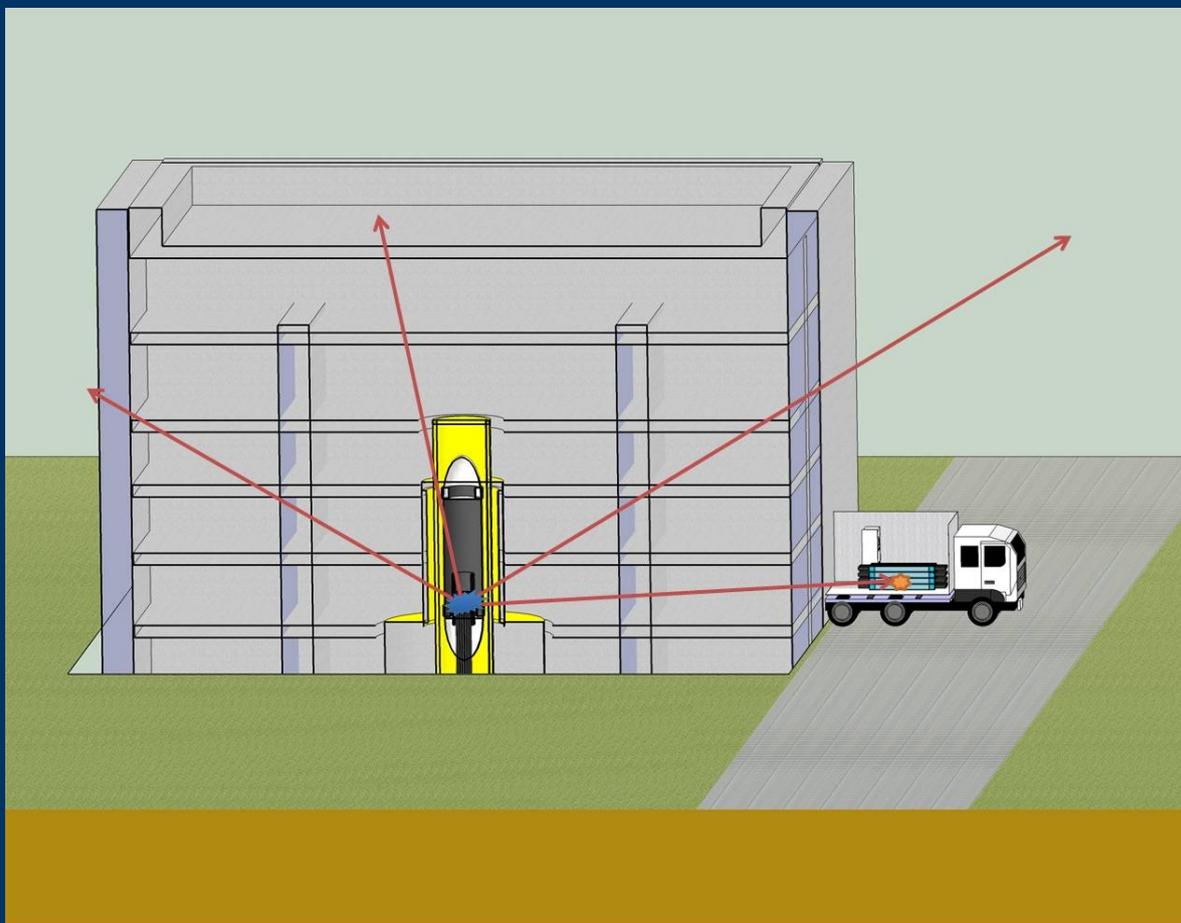


宇宙線 μ 粒子 バックグラウンド - 実測データ -



実際の測定時の想像図

発電所の運転には何ら干渉せず
に原子炉ニュートリノ計測により
原子炉の運転状況をモニターできる



モンテカルロシミュレーションで
検出効率を見積り
→ 5% - 10%

バックグラウンドの排除との
兼ね合い

→ 原子炉からのニュートリノ発生
の有無が検出可能

PANDAの特徴

- ▶ 可燃性液体を不使用—原子炉敷地内への安全な立ち入りが可能
 - ▶ 原子炉建屋の外側から測定—非侵襲的
 - ▶ トラックに積載した可搬型—配備と撤収が簡便
 - ▶ 無人運用が可能—保障措置に関する費用低減
 - ▶ 原子力発電所への試験設置を交渉中
-
-

まとめ

Tokyo axion helioscope, Sumico

Hidden photon search on Sumico

Anti-neutrino monitor of reactor operations

