# Mini-Time-Cube

## A Portable Directional Anti-Neutrino Detector

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National Geospatial Intelligence-Agency (NGA)

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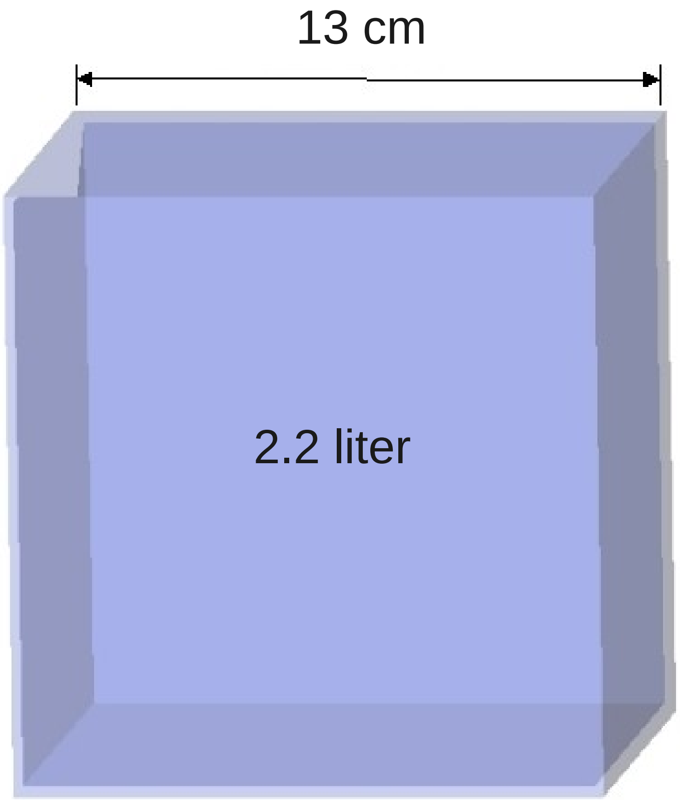
# Idea




Small portable 2.2 liter scintillating cube

24 MCP (64 pixels each) fast pixel detectors on surrounding faces

~10/day anti-neutrino interactions (inverse beta decay signature) from reactor

# Virtues

Small size avoids gammas which smear resolution.

Fast pixel timing (<100ps) and fast processing of waveforms rejects background in real time.

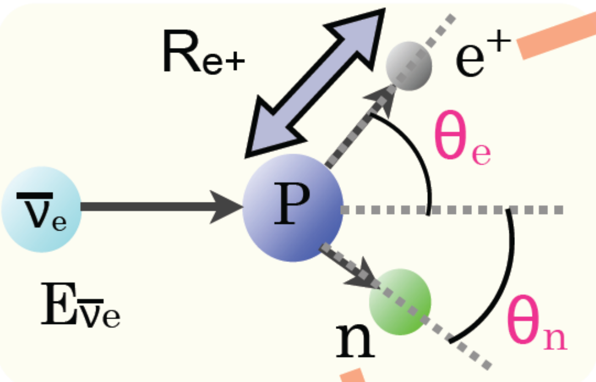
Feasible even in high noise environment.

No shielding needed.

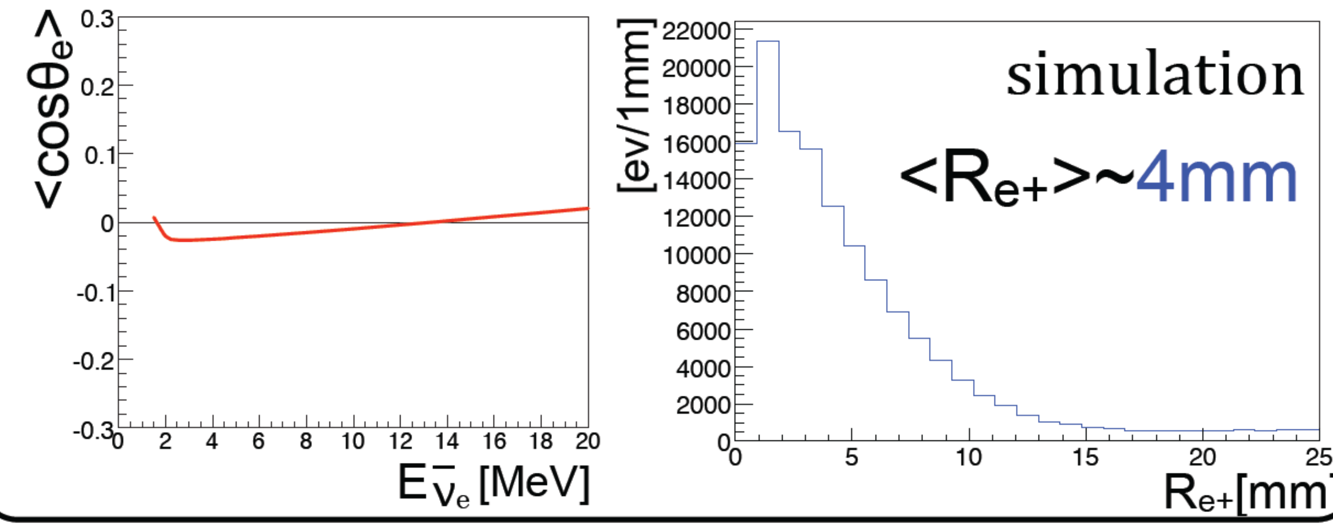
Neutrino directionality.

# Directional Measurement

- inverse β-decay : $\bar{\nu}_e + p \rightarrow e^+ + n$ (delayed coincidence)

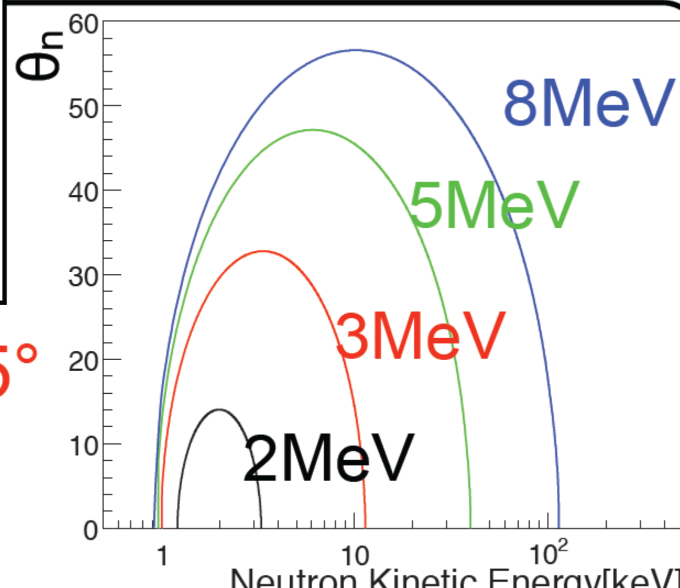


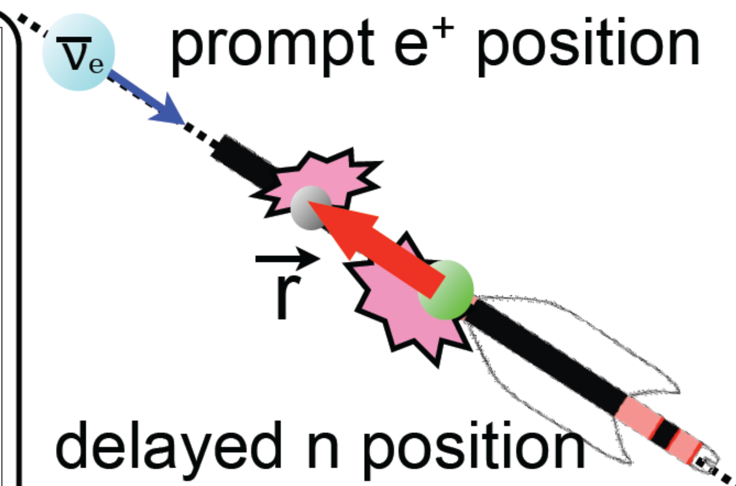

1. $e^+$ is emitted almost isotropically




2. the forward recoil neutron retains the information of the anti-neutrino direction

$E_{\bar{\nu}e}<3MeV \rightarrow \theta_n<35°$

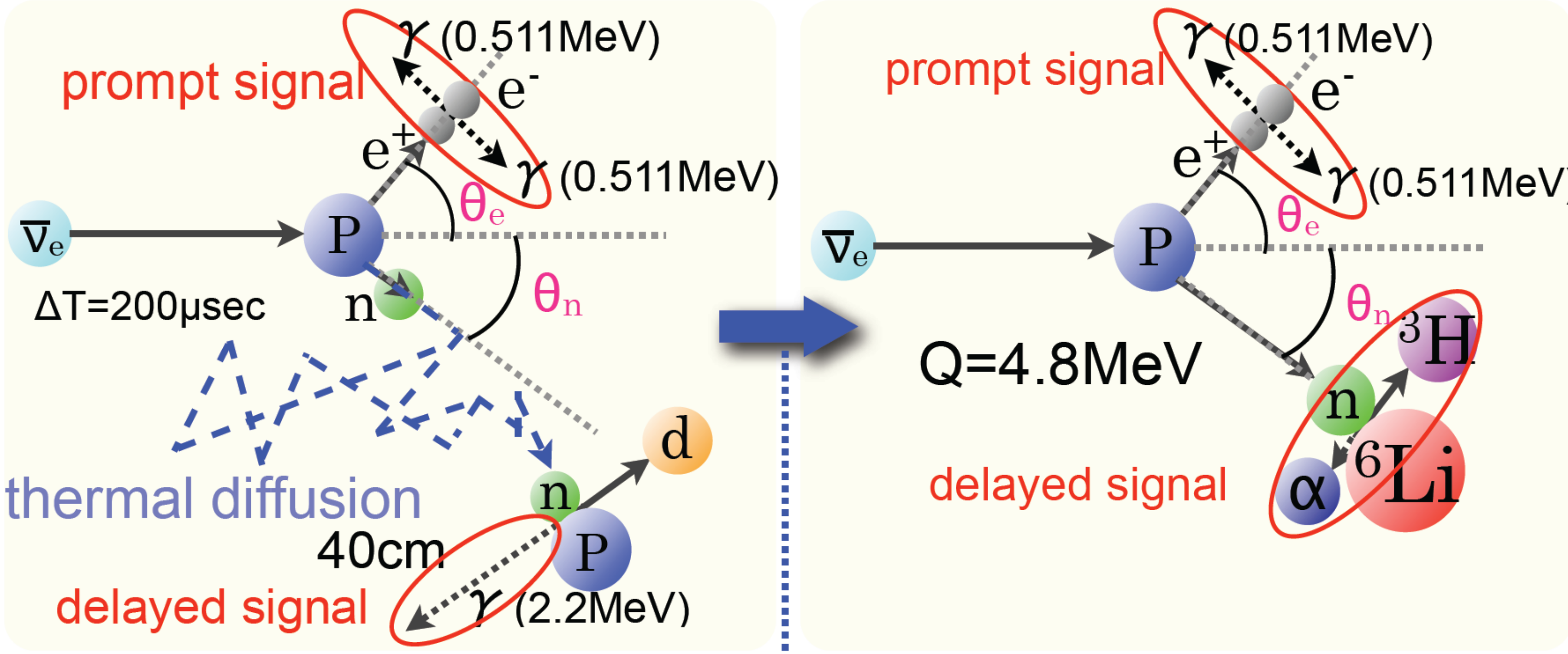



$\vec{r}$ : $\bar{\nu}_e$ direction

*Hiroko Watanabe (Workshop Towards Neutrino Technologies 2009)*

## ▸reaction in the LS




### Problems

1. directional data is lost due to the thermal diffusion.

2. 40 cm γ radiation length.

**introduction of neutron capture nucleus**

candidate: $^6$Li, $^{10}$B

✓large neutron capture cross section

✓(n,α)reaction

### Improvement

1. minimize the thermal diffusion

2. α & triton stop immediately.



*Hiroko Watanabe (Workshop Towards Neutrino Technologies 2009)*

# Neutron Capture Nucleus

- Candidate

① $^{10}B$ (3835barn)

$n + {}^{10}B \rightarrow {}^{7}Li^{*} + \alpha$ (BR=94%, Q=2.3MeV)

${}^{7}Li^{*} \rightarrow {}^{7}Li + \gamma$ ($E_\gamma$=0.48MeV)

$n + {}^{10}B \rightarrow {}^{7}Li + \alpha$ (BR=6%, Q=2.8MeV)

② $^{6}Li$ (940barn)

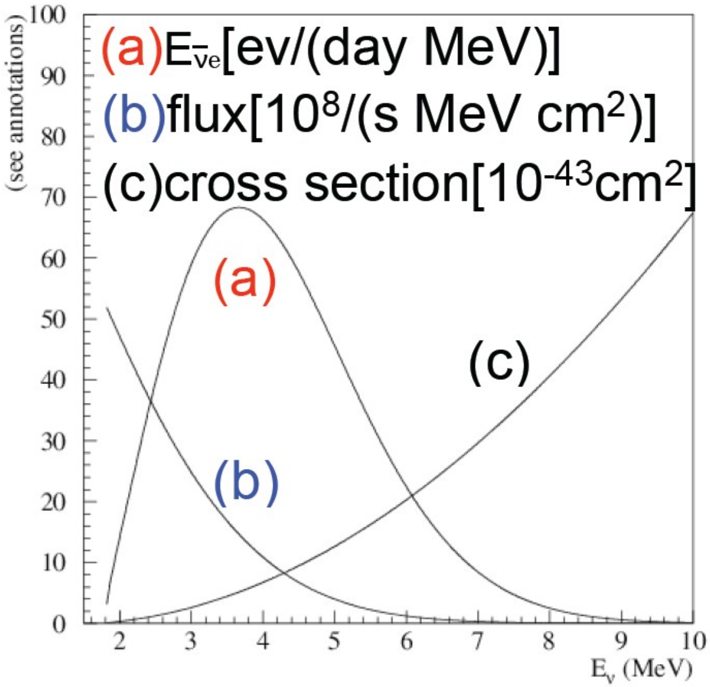
$n + {}^{6}Li \rightarrow \alpha + {}^{3}H$ (Q=4.8MeV)

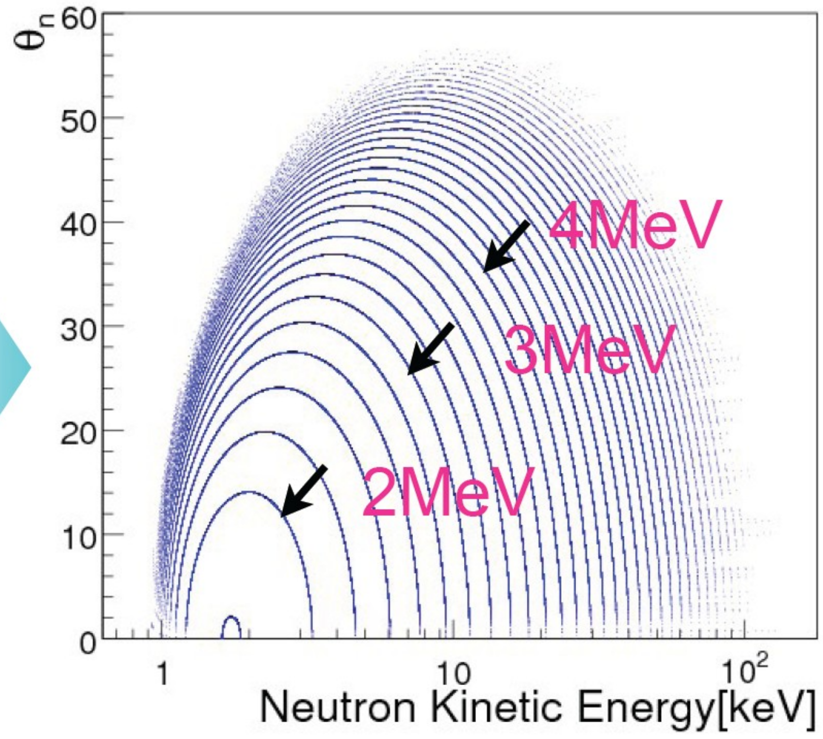
- Simulation

- reactor anti-neutrinos energy range

- neutron kinetic energy < 100keV

$\theta n$ < 55°



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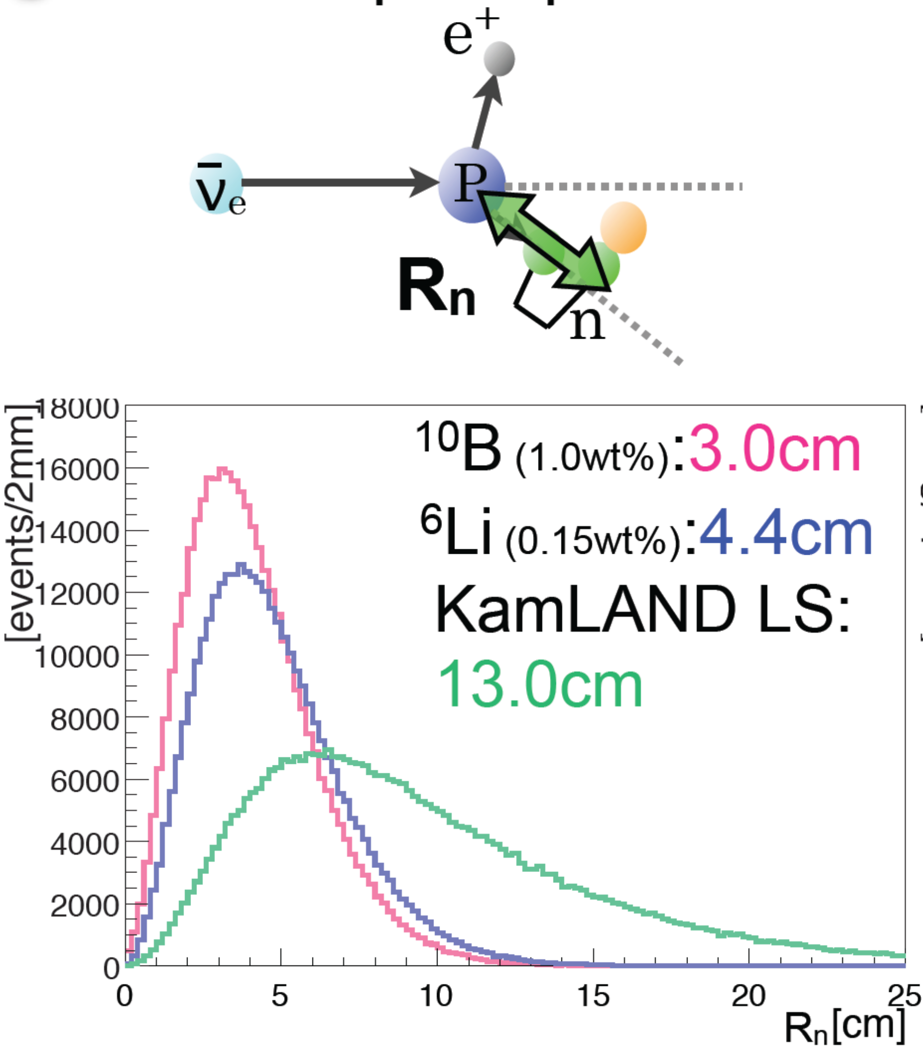
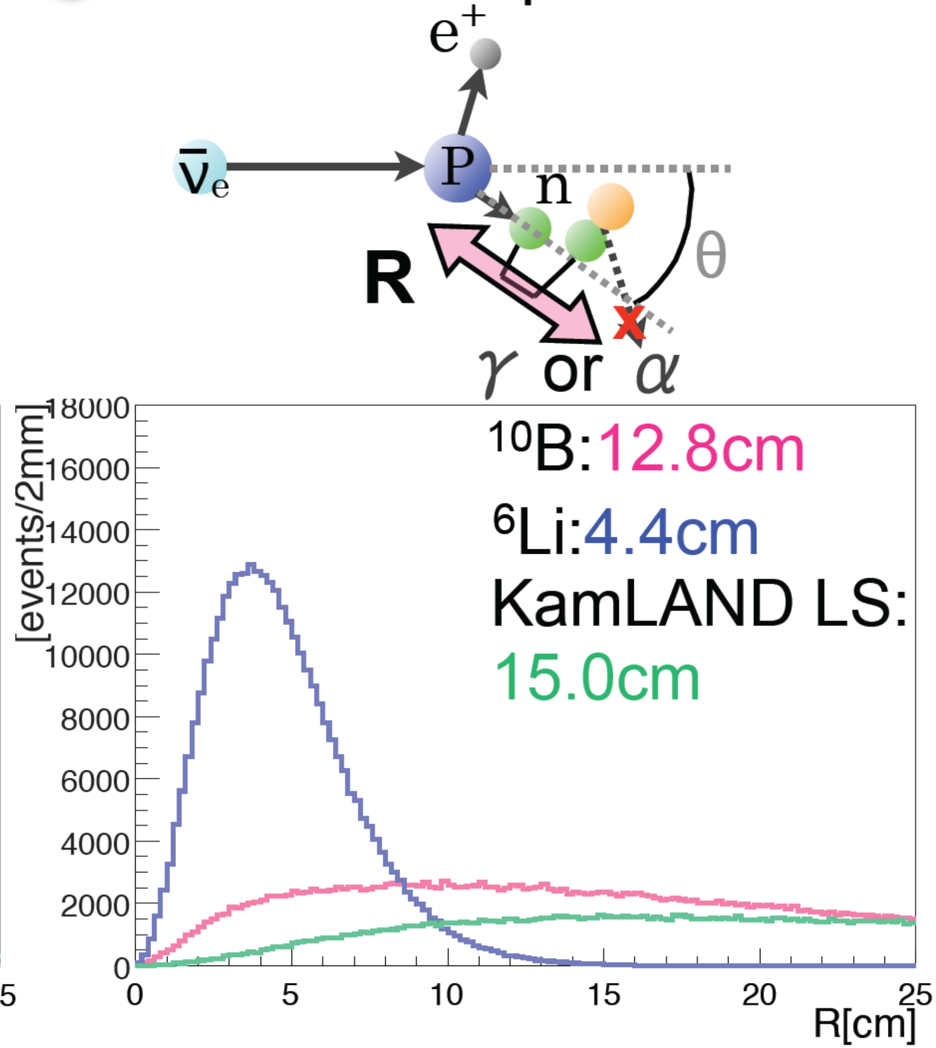
## $^6$Li or $^{10}$B

### neutron capture point




large neutron capture cross section is effective in minimizing the thermal diffusion

### reconstructed point

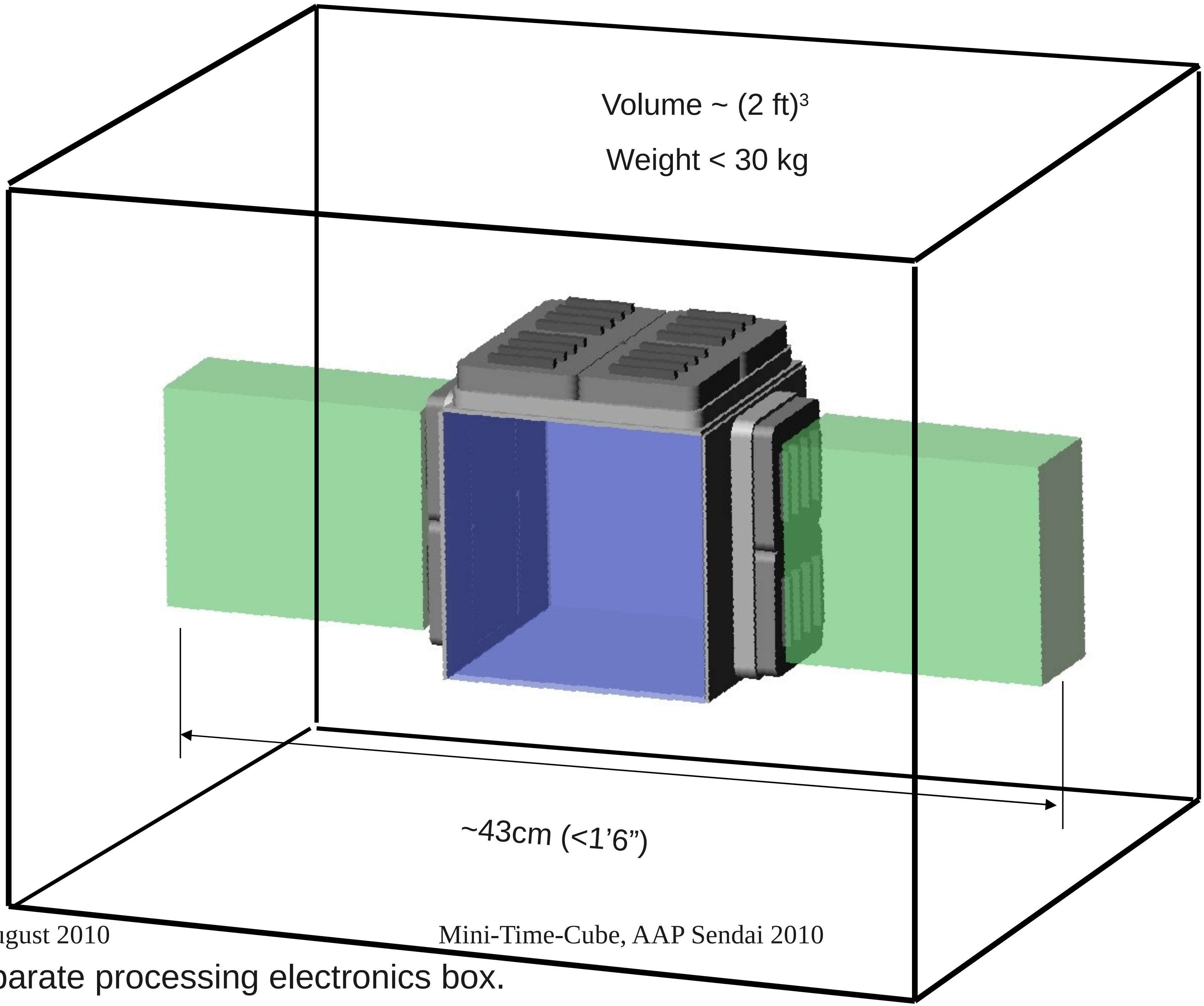



(n,α) reaction is effective in holding the neutron capture position information



*Hiroko Watanabe (Workshop Towards Neutrino Technologies 2009)*

# Mini-TimeCube + PMTs and Readout Electronics (Portable)





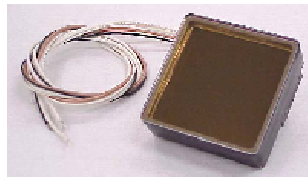

Plus separate processing electronics box.

# The Photo-Sensor: Photonis XP85012 (64 channel MCP)

## Photon Detector *Preliminary* XP85012

**PLANACON**

**25µm MCP-PMT**
**8x8 Anode**
**53 mm Square**

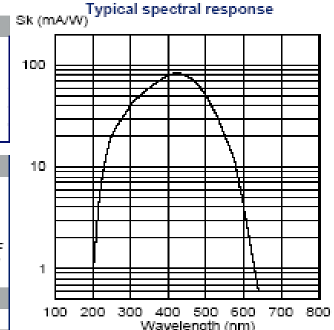


**Applications**
- ✓ Specialized Medical Imaging
- ✓ Ring Imaging Cherenkov
- ✓ High Energy Physics Detectors

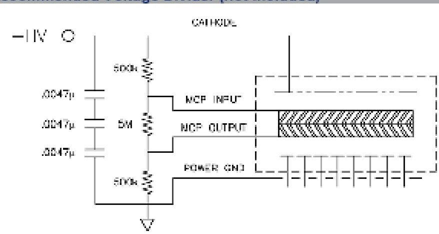
| Description | |
|---|---|
| Window material | UV-Glass, Schott 8337B or equivalent |
| Photocathode | Bialkali |
| Multiplier structure | MCP chevron (2), 25 µm pore, 40:1 L:D ratio |
| Anode structure | 8×8 array, 5.9 / 6.5 mm (size / pitch) |
| Active area | 53×53 mm |
| Open-area-ratio | 80% |

| Photocathode characteristics | Min | Typ | Max | Unit |
|---|---|---|---|---|
| Spectral range: | 200 | | 650 | nm |
| Maximum sensitivity at | | 400 | | nm |
| Sensitivity: | | | | |
| Luminous * | 50 | 60 | | µA/lm |
| Blue * | 7.5 | 8.5 | | µA/lmF |
| Radiant, at peak | | 76 | | mA/W |
| Quantum Efficiency | | 24 | | % |
| **Characteristics** | **Min** | **Typ** | **Max** | **Unit** |
| Gain * | $1\times10^5$ | $6\times10^5$ | | - |
| Total anode dark current @ $10^6$ gain * | | 1 | 5 | nA |
| Rise time | | 0.6 | | ns |
| Pulse width | | 1.8 | | ns |
| Anode uniformity | | 1 : 1.5 | 1 : 2.5 | |

Typical spectral response

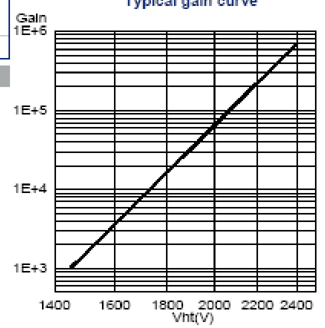



**Recommended Voltage Divider (not included)**




CAUTION: POWER GROUND CONNECTION AND UNUSED ANODES MUST BE CONNECTED TO GROUND FOR SAFETY AND PROPER TUBE OPERATION

Typical gain curve




** Characteristic measured and recorded on the test ticket of each tube*

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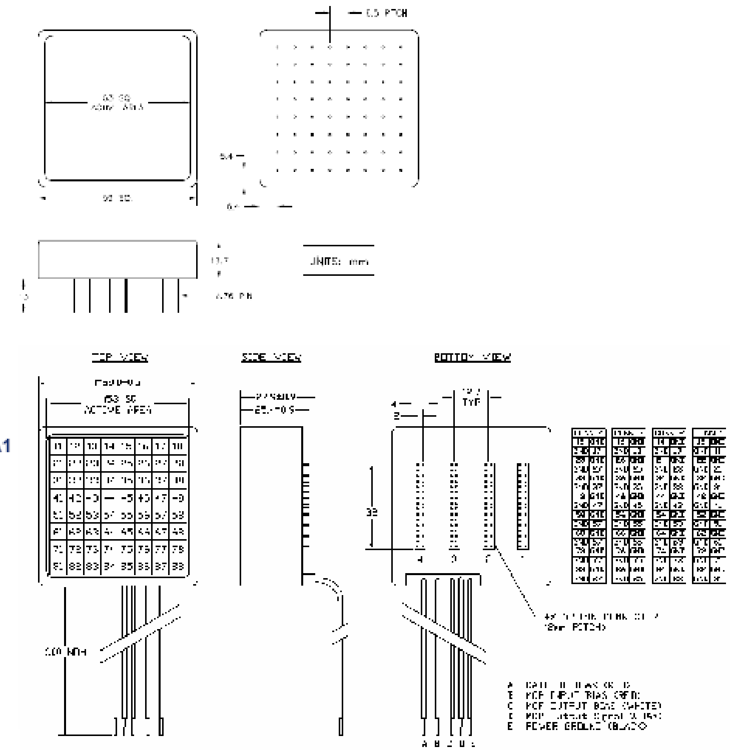
## Photon Detector XP85012

**Outline (dimensions in mm)**

XP85012

XP85012/A1




Mass: ~128g

| Limiting values | Min | Max | Unit |
|---|---|---|---|
| Cathode to $MCP_{in}$ voltage | | 500 | V |
| $MCP_{in}$ to $MCP_{out}$ voltage | | 2000 | V |
| $MCP_{out}$ to Anode voltage | | 500 | V |
| Average total anode current | | 3 | µA |
| Ambient temperature: | | | |
| Operating Temperature | 0 | +50 | °C |
| Storage Temperature (for extended periods) | -15 | +50 | °C |

* Warning: Continuous operation at maximum ratings may result in shorter product life or unreliable performance.



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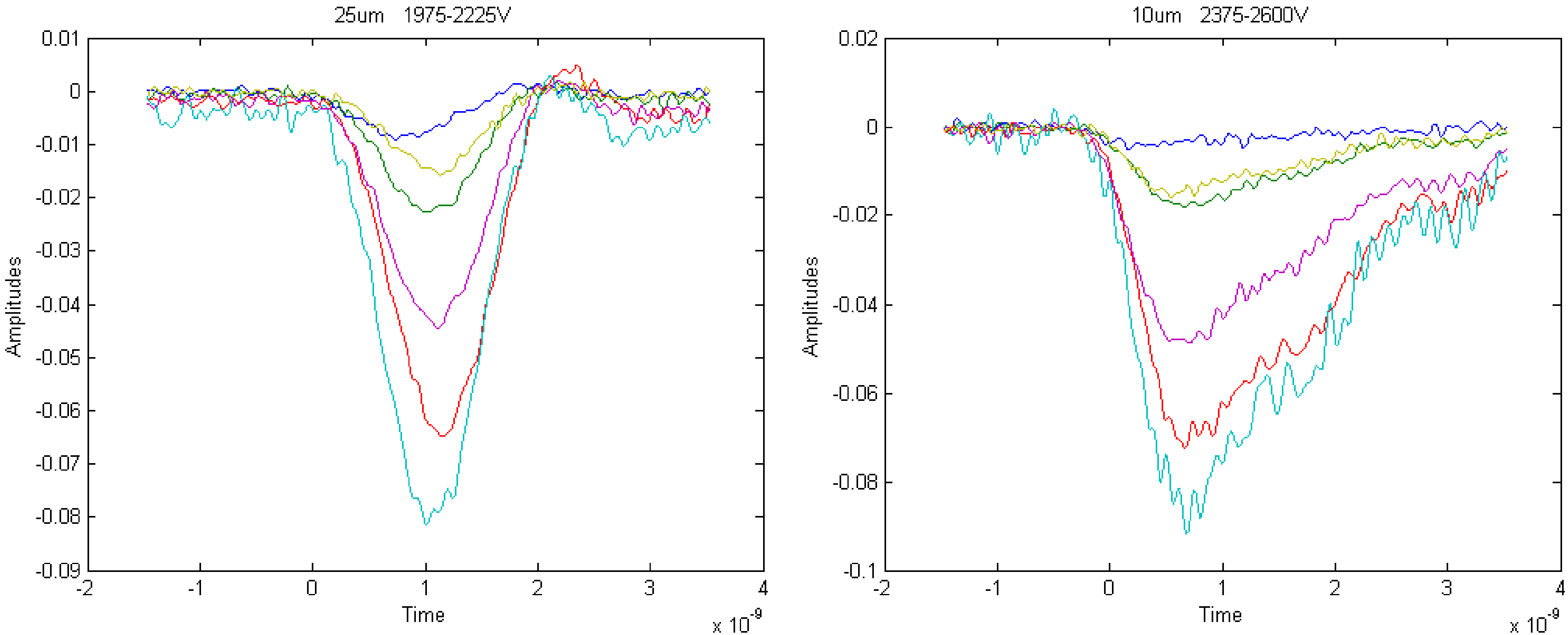
# Evaluation MCP Signal

408nm laser, 100 Photo-Electrons

Jean-Francois Genat, ANT Workshop, August 13, 2009




Conclusion:

Gain: 40mV/100PE ~ 0.4mV/PE (25µm) at 2100 V

5mV/100PE ~ 50 µV/PE (10µm) at 2500V

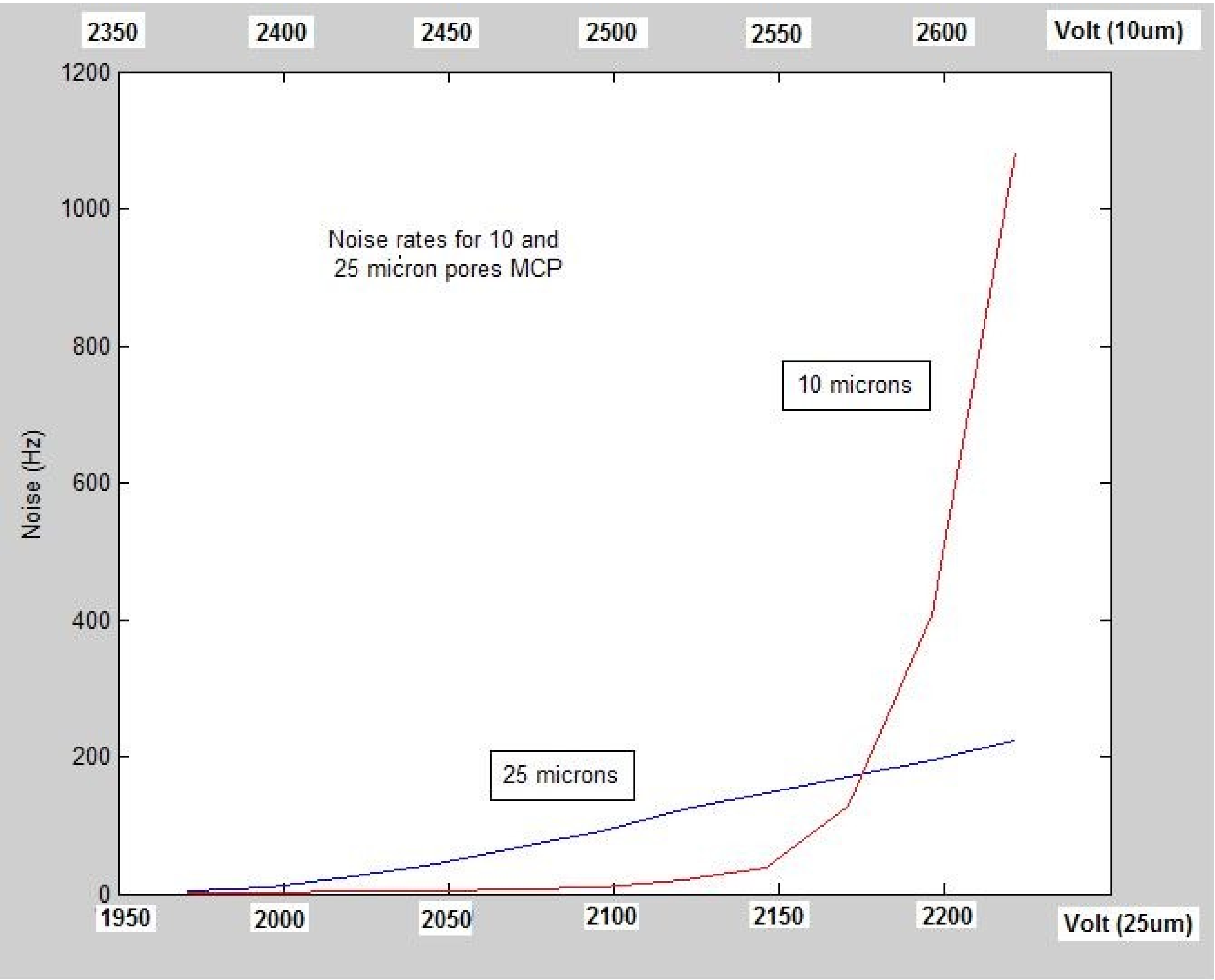
10µm longer trailing edge

Seems that rise time does NOT depend upon the amplitude

**=> We choose 25µm pore size**

Under development

# Impulse Dark Noise vs HV




Conclusion: At optimum efficiency (25μm 2000V, 10μm 2400V), dark counts rates are: <u>**25Hz (25μm), 20Hz (10μm) per pixel**</u>

# Mini-TimeCube Sensitivity

(13 cm^3 cube with 24 MCP's)

Rough cost => **$300K** (includes electronics)

Rate => ~**10 anti-neutrino events/day** (25m from 3.3GW reactor)

Photo sensitive Area => 75% coverage

Pixel count => 1536

All pixels get several PE for reactor anti-neutrino (~2MeV).

100ps MCP time resolution => 20mm spatial resolution.

**1 ns** scintillator **decay constant** => **120 PE/MeV** in first 100ps.

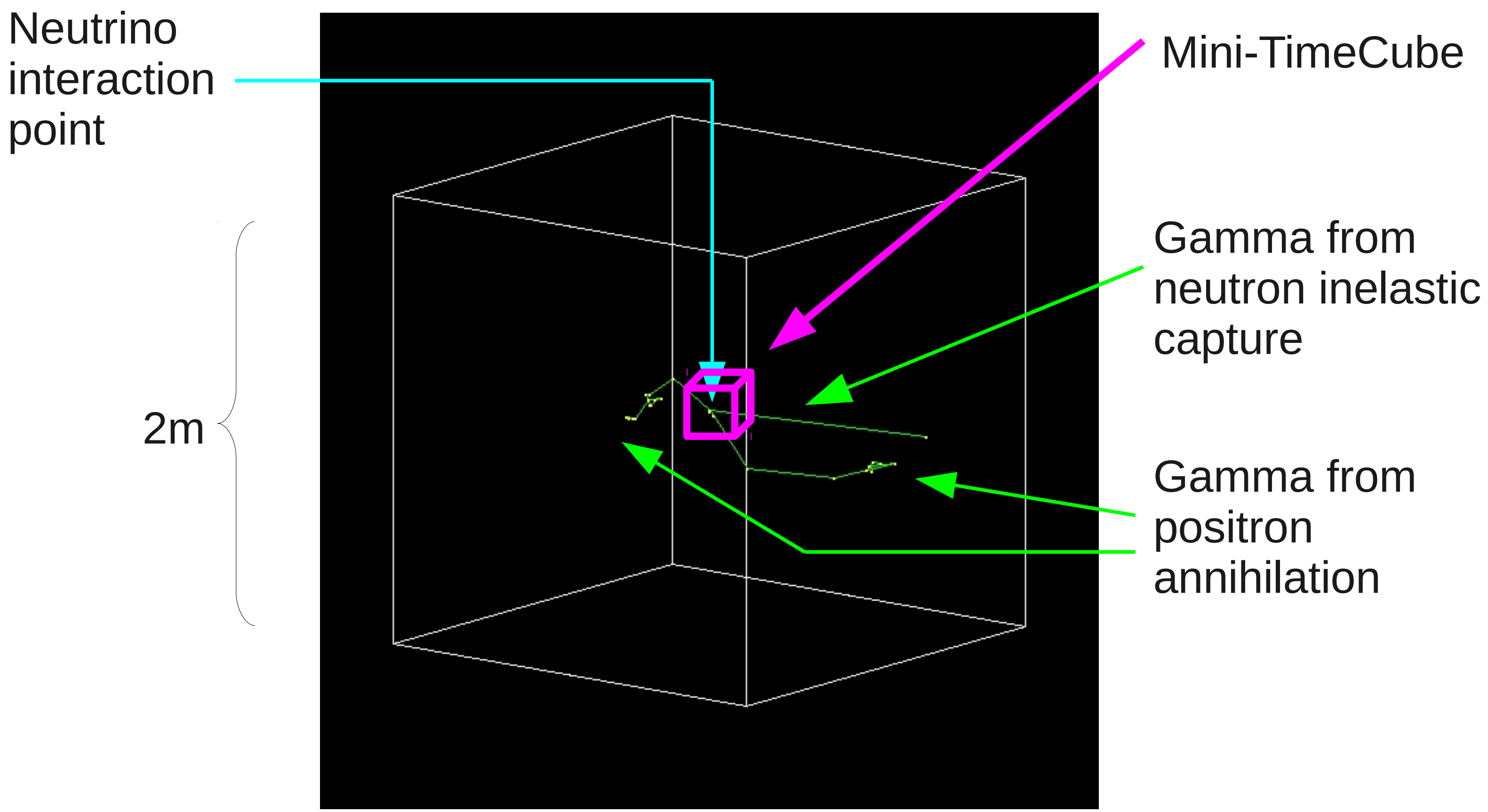
How well can we do vertex reconstruction from 1st photon hits? => TBD

"John Learned" arXive:0902.4009v1

# Neutrino Vertex Resolution

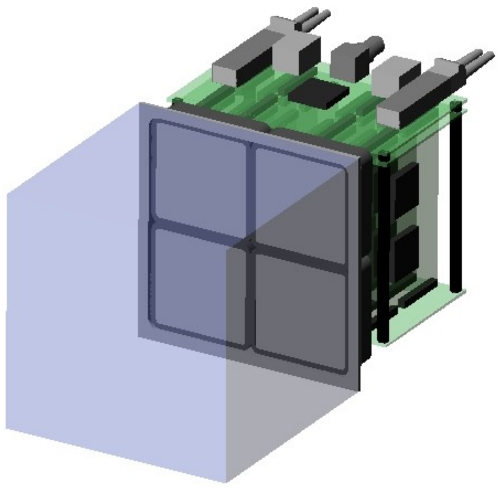
| | |
|---|---|
| 120 PE/MeV on Fermat surface | => ~20mm/sqrt(120*E/MeV) = 1.3 mm (2 MeV anti-neutrino). |
| Neutrino Vertex Resolution | => **Several mm & directionality** |

# Geant4: Radiation Length in LS

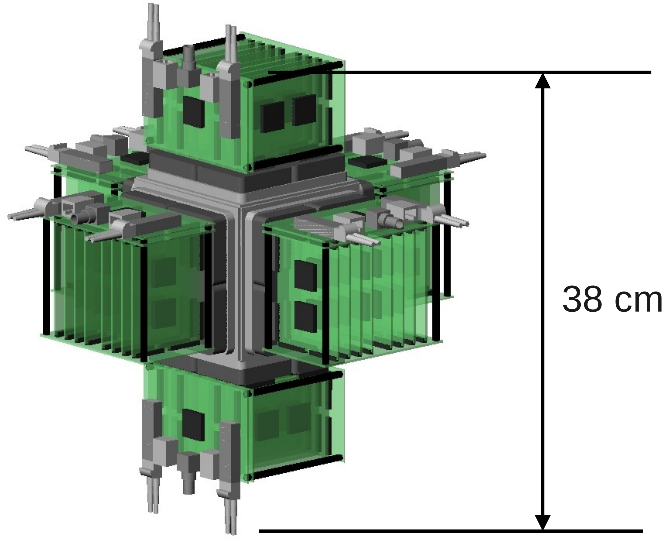



Conclusion:
Gamma from positron annihilation
leaves detector without interaction.

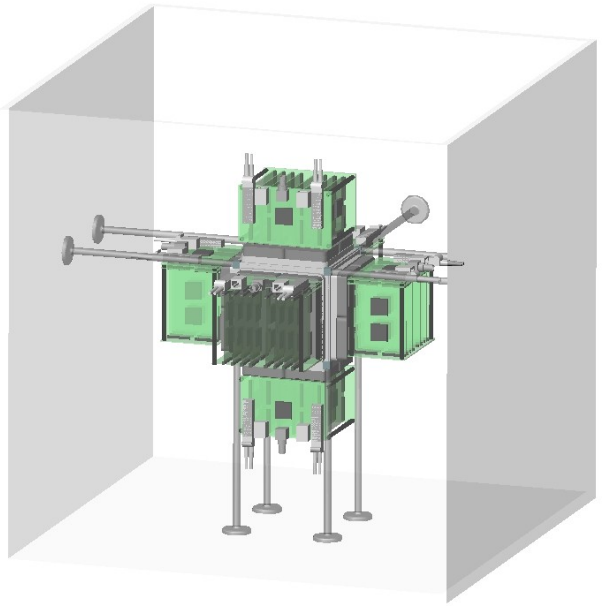
# Mini Time Cube Based On 13cm³ Boron Loaded Plastic Scintillator



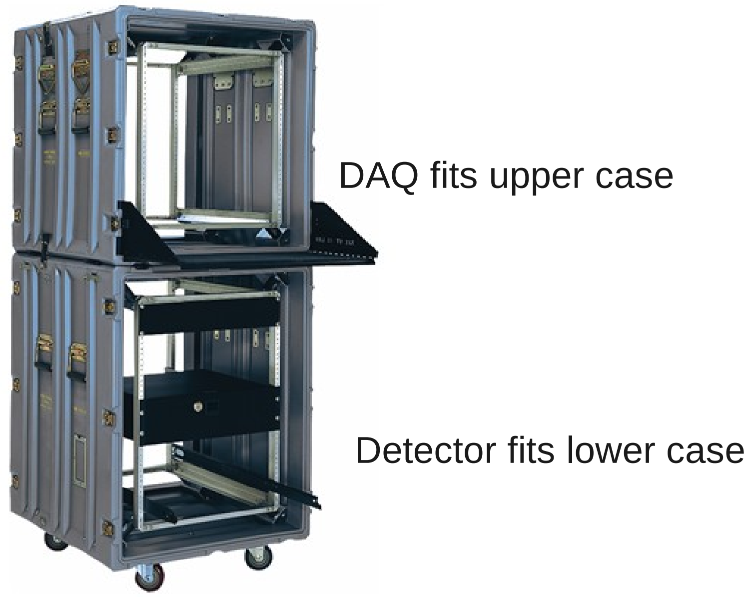
MTC with read-out electronics on one face




MTC fully populated with read-out electronics

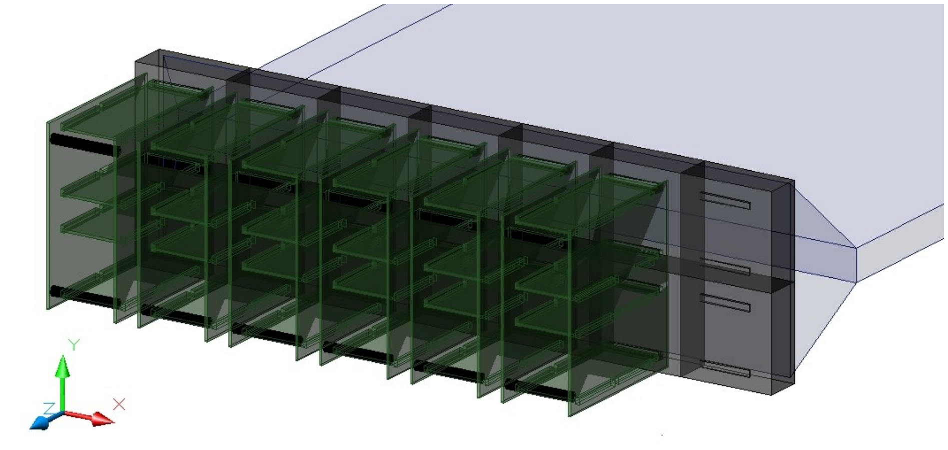


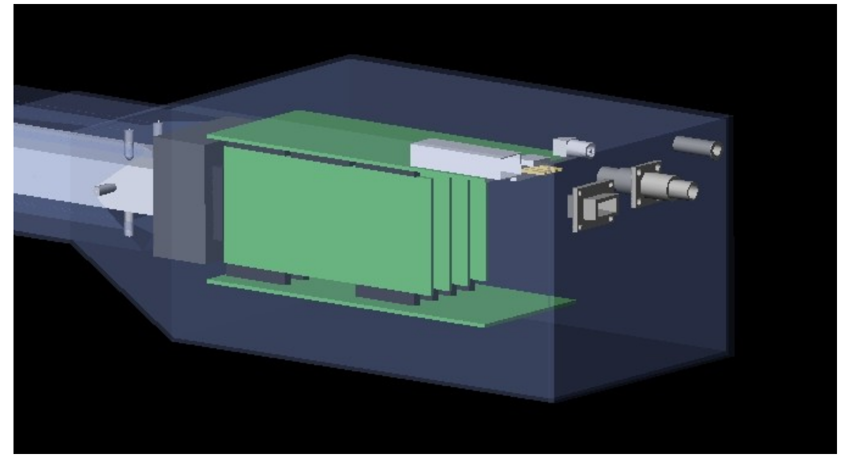
MTC within 2ft³ honeycomb enclosure

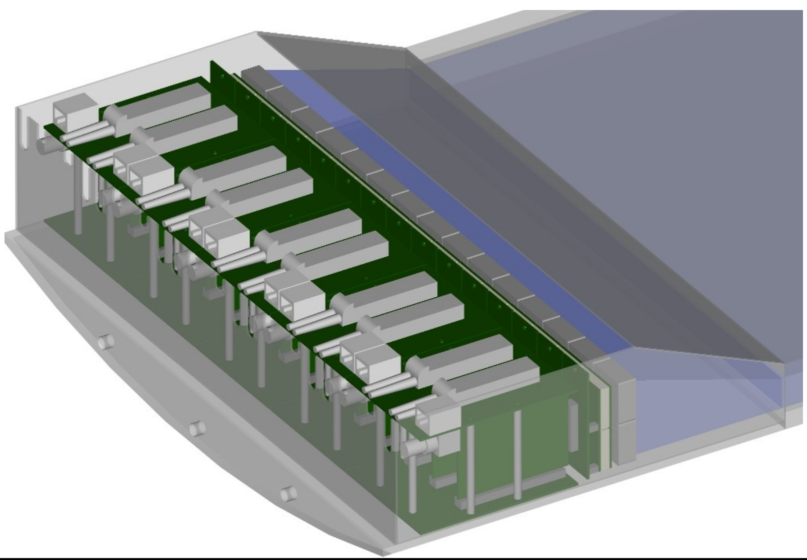


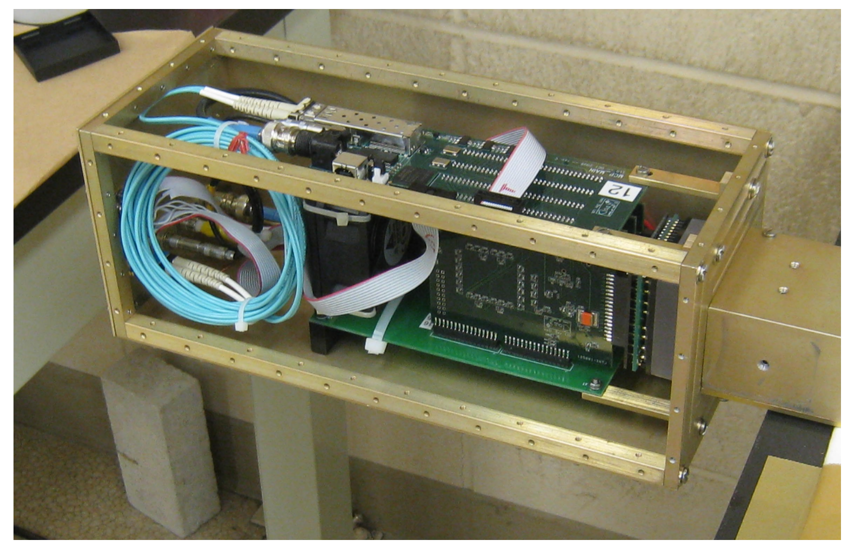

Stackable transportt cases

# Examples of PMT Read-outs Developed by IDL, Hawaii (Gary Varner)









Fast waveform digitizer for the Photonis MCP is currently under development evolving from existing technology used in BELLE, BESS, ANITA. Length beyond photo-sensor will be ~125mm. One module per MCP.

# Data Acquisition System (DAQ) Based on cPCI Format

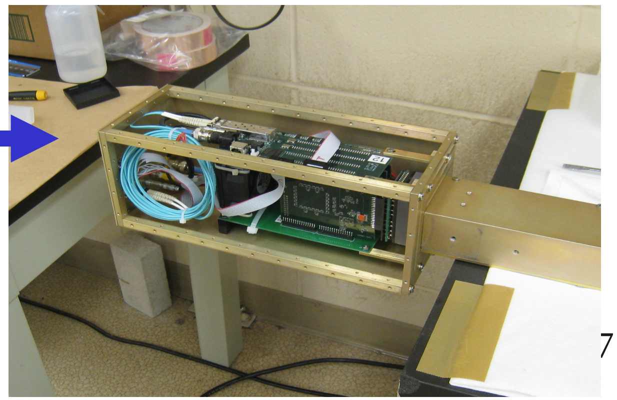
cPCI CPU

x1

cPCI crate

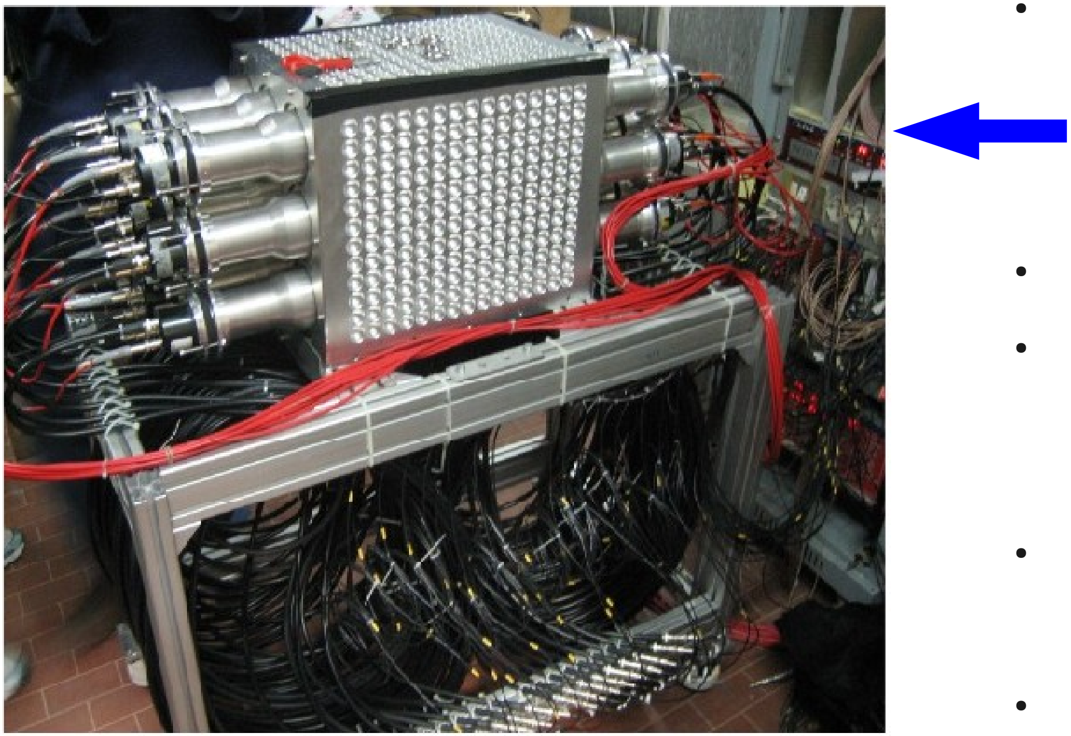
Data processing card


x3 (= 24 PMTs)



3Gbs fiber link

# Noise Rate



”A proposal for a high segmented power reactor antineutrino detector”, Marco Battaglieri, July 13~17, 2009, Workshop Towards Neutrino Technologies”

- Refer to CORMORAD talk given by Marco Battaglieri at Trieste.

Prototype segmented detector of square logs of NE110 plastic scintillator, 3 inch PMTs on ends, 40x30x30 cm^3 total volume.

- No shielding (similar to MTC) => big background

- CORMORAD noise rate:
  => R = ~120 Hz (single)
  => 2 x R^2 x tau = ~10 Hz (two hits in time window tau = 330us)

- MTC noise rate = 1/(30 x 10) x CORMORAD rate
  => good enough for real-time background analysis

- We will have to use GEANT to figure out how much rejection we can get

# Items for Further Study

- Backgrounds => stopping muon, decay processes, random internal/external gamma (from reactor), thermal neutron...
- Liquid scintillators => find shortest n capture time, optimum Li loading.
- Solid scintillators => boron loaded plastic from Eljen Technology.
- Pulse shape discrimination for neutron capture?
- Can we do anything with neutron elastic scattering?
- GEANT Simulation of Mini-Time Cube in progress.
- More….

# Backup

# Noise Rates

Talk that was given in Trieste last summer by Battaglieri from Genoa.  Their idea is to build a segmented detector of square logs of scintillator with 3 inch PMTs on the ends, eventually aiming at a detector around 1m3 but they operated a smaller prototype.  In this attached report are some nice measurements of various scintillators they evaluated.  They chose NE110 plastic.

In their prototype measurements they had troubles at the (apparently not so well shielded old Romanian reactor) reactor they visited, which had a huge difference between reactor on and off in backgrounds (unlike San Onofre).  Their idea was to use no shielding, so this is directly applicable to our case.

They did not do so well in rate because their time window was tau = 330 microsec, and singles rates with reactor on were R1 = 120/s.  With a dumb trigger of two hits in this window the net trigger rate of R12*tau = 4.75/s

So, this is most encouraging, that even with their much larger mass and sensitive volume of 40x30x30 cm3 (not initially sure how to scale this... by volume I suppose, so something like 18 times our volume.  If we scale by surface area it would be more like 10x.  If we take the more modest 10x factor in singles rates, and we take a more reasonable loaded scintillator capture time, let us say 1/10 th of theirs, our raw two fold random rate would be down by 1000 from theirs,  and hence totally trivial. (Of course this is not trivial compared to the neutrino rate of a few per day, but it is trivial compared to what we can easily harvest and chew upon in our leisure.) In any event, this looks very nice for us.  I have a hard time believing it could be so good....

Next we will have to use GEANT to figure out how much rejection we can get.