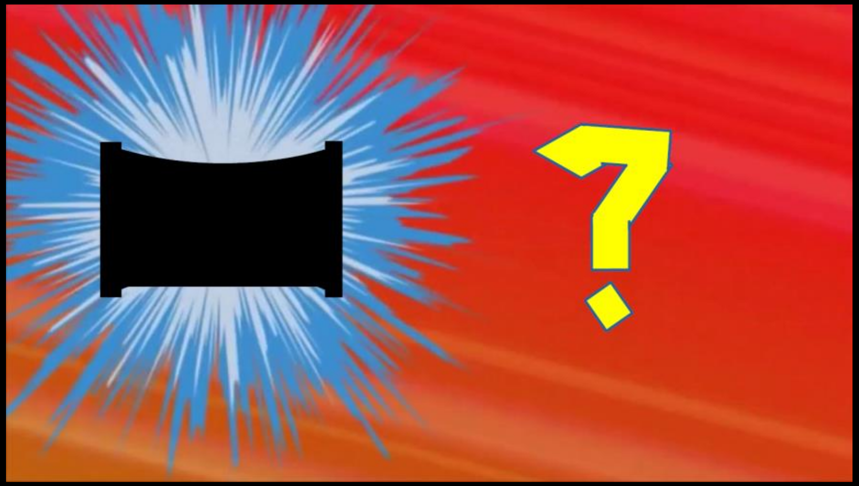


Alternative Design for Large-Scale Liquid Scintillator Detectors

Iwan Morton-Blake[a] , Steven Biller[b]

[a]Tsung-Dao Lee Institute / Shanghai Jiao Tong University

[b]University of Oxford

Outline

➢ MeV-scale neutrino physics

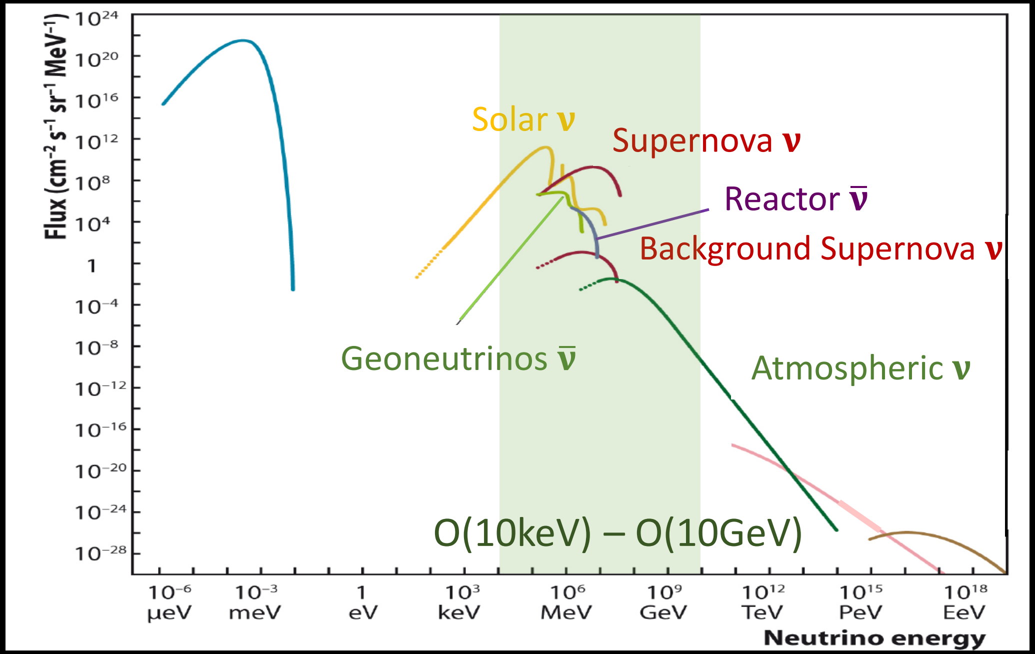


Fig. from [1]

Outline

- ➢ MeV-scale neutrino physics
- ➢ Liquid scintillator detector design

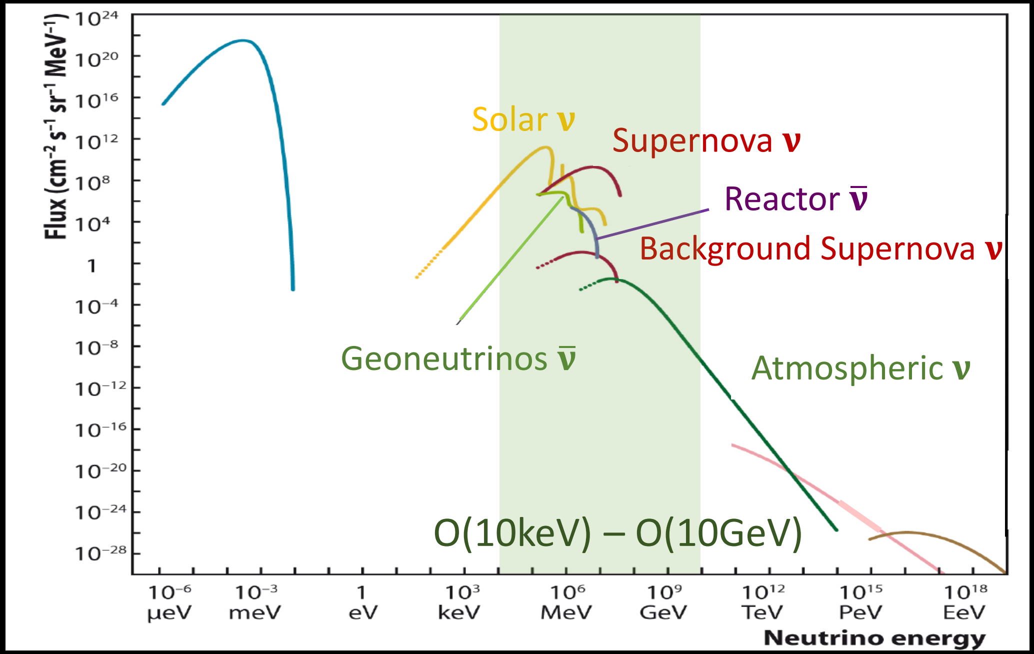
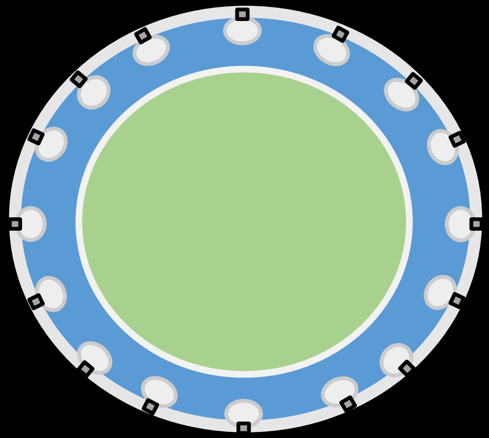


Fig. from [1]



Outline

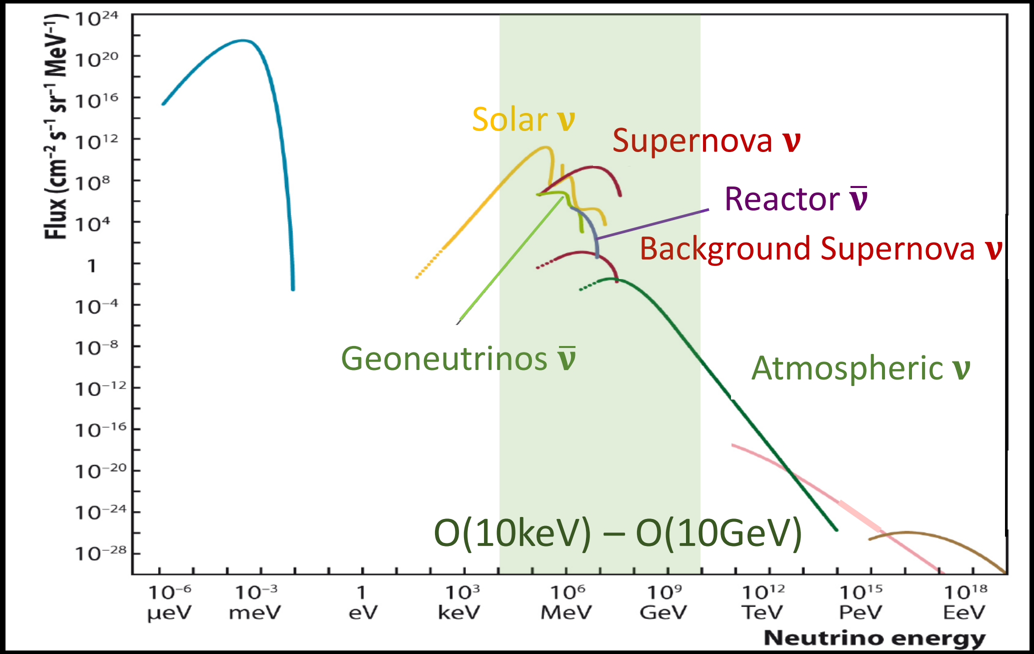
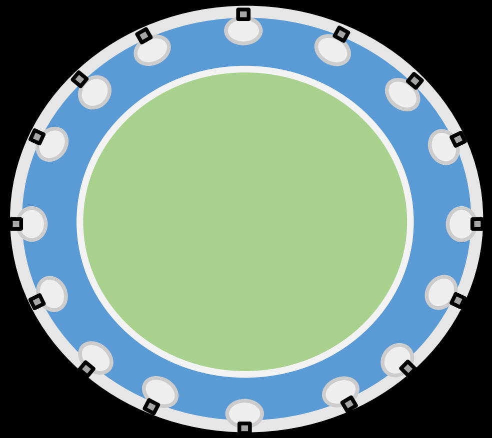


Fig. from [1]

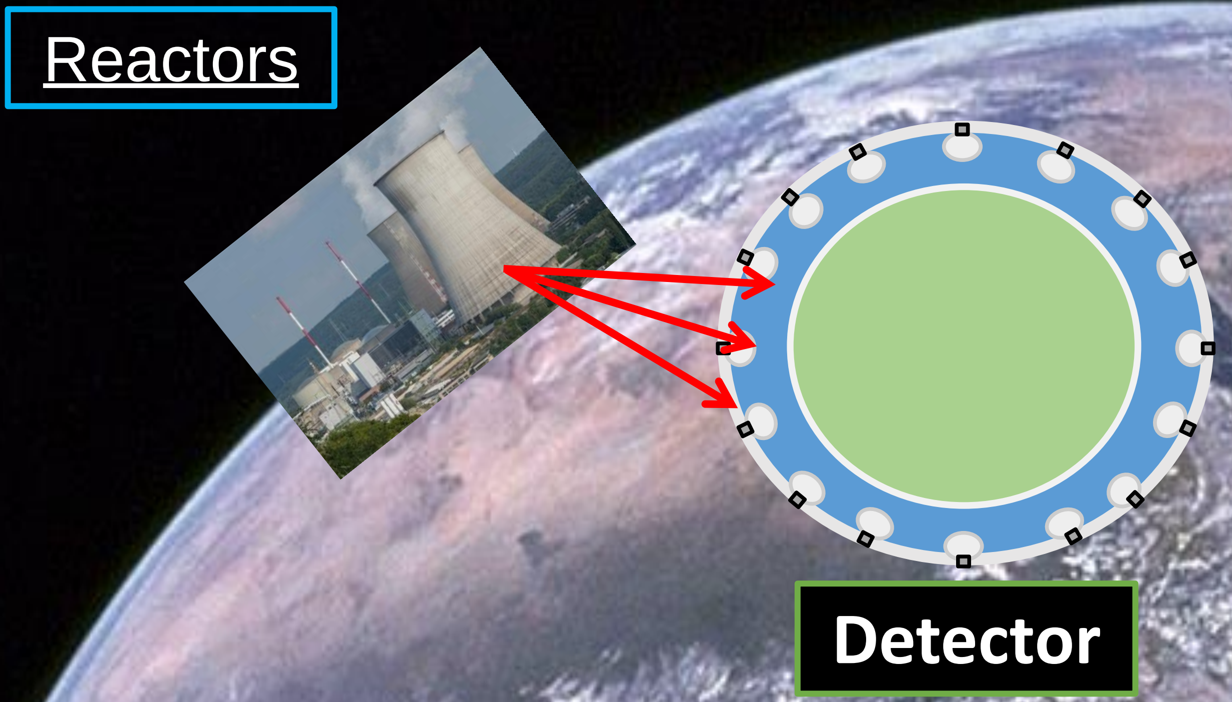
- ➢ MeV-scale neutrino physics
- ➢ Liquid scintillator detector design
- ➢ **Going larger : An alternative design?**



MeV-scale Neutrino Physics

Large Low Energy Neutrino Detectors

First neutrino measurement!
Reines & Cowan (1956)

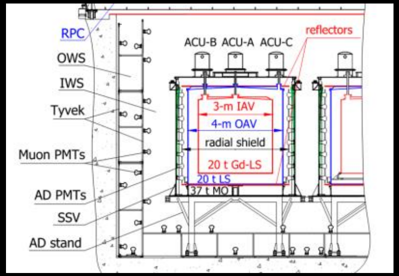


Large Low Energy Neutrino Detectors

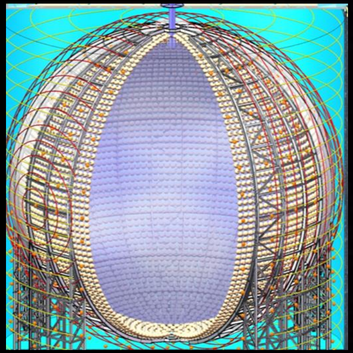
e.g.

Daya Bay (2001)
Liquid Scintillator 8x20 tons

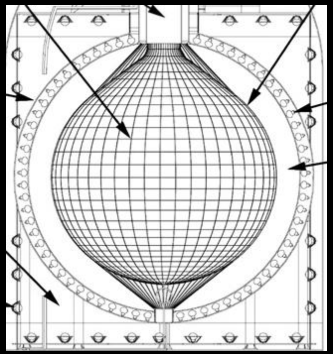
World-leading in θ_{13}



JUNO (Upcoming)
Liq. Scint. 20 kilotons

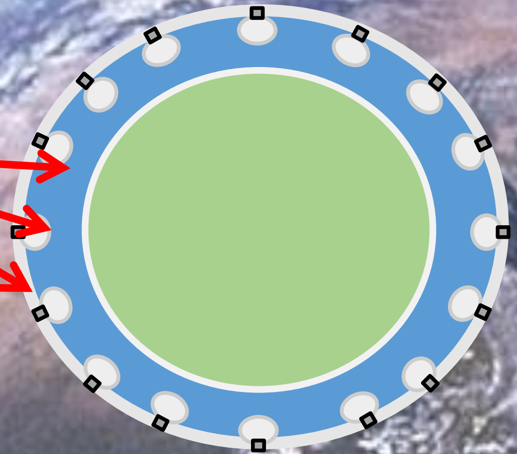


KamLAND (2002)
Liq. Scint. 1 kiloton



World-leading in Δm^2_{21}

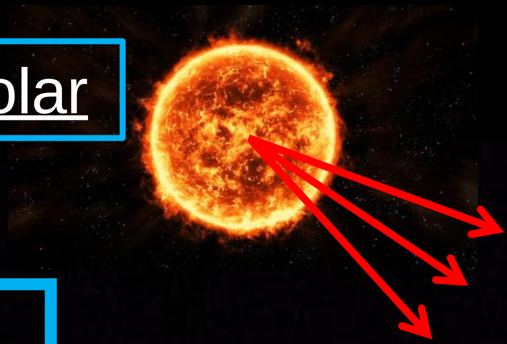
Reactors



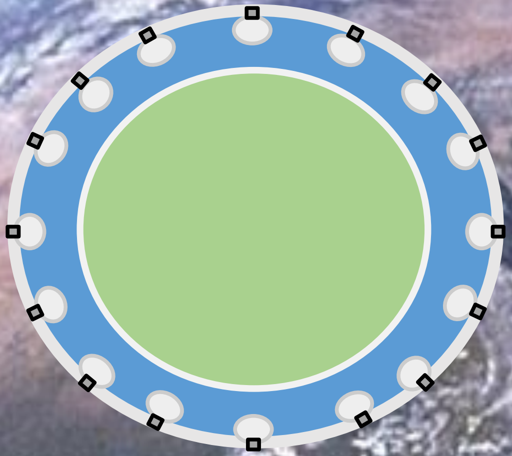
Detector

Large Low Energy Neutrino Detectors

Solar

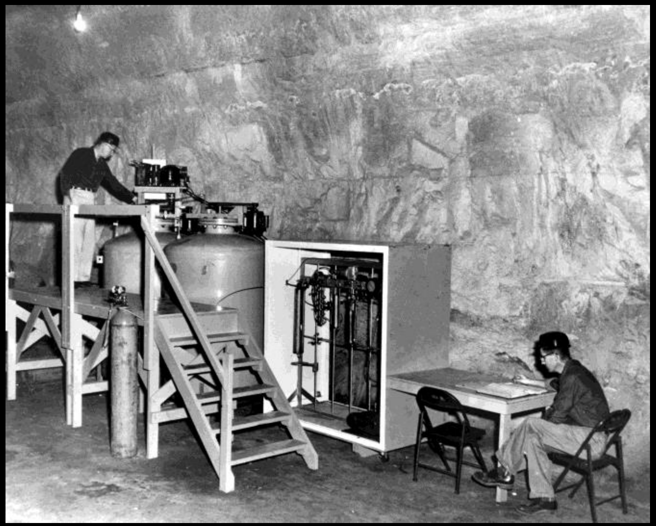


Reactors



Detector

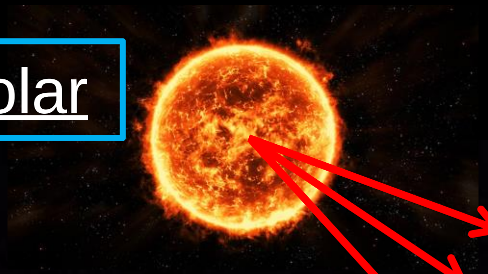
Homestake Experiment
R. Davis & J. Bahcall (1968)



First solar ν measurement!

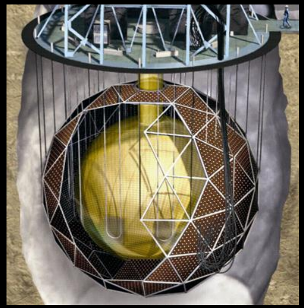
Large Low Energy Neutrino Detectors

Solar



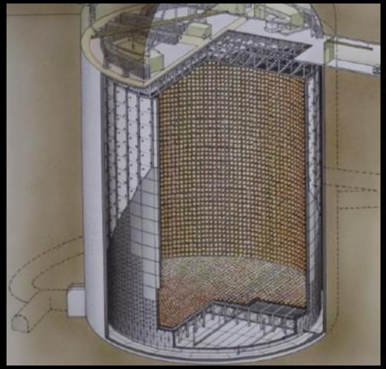
e.g.

SNO (1999)
Heavy Water 1 kiloton

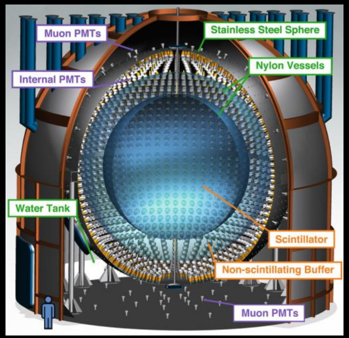


(w/ atmospheric ν)

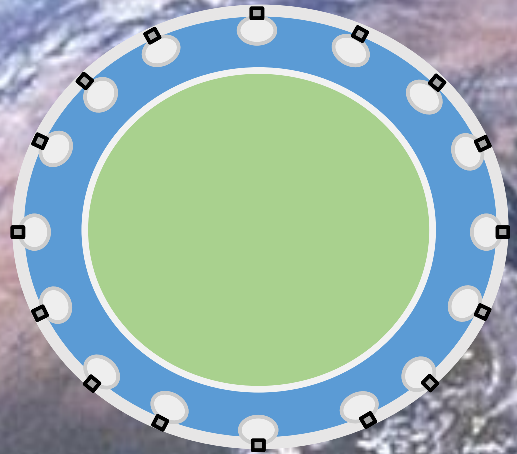
Super-K (1996)
Water 50 kilotons



Borexino (2007)
Liq. Scint. 300 tons



Reactors



Detector

Large Low Energy Neutrino Detectors

Supernovae

Solar

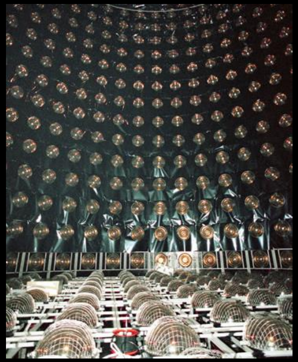
e.g.

Baksan
Liq. Scint. 5e4 m^2

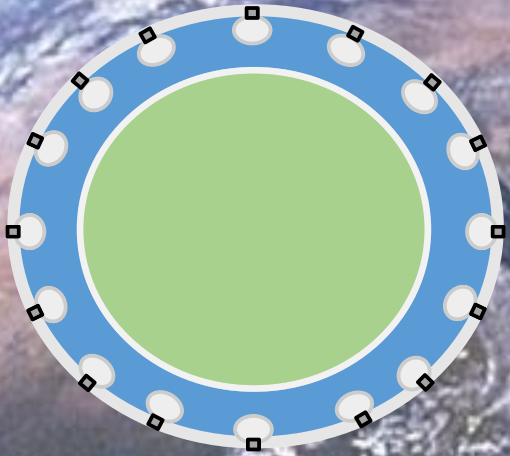
SN 1987A:
24 $\bar{\nu}_e$ candidates,
3 hrs before photons

IMB
Water 7 kt

Kamiokande-II
Water 3 ktons



Reactors



Detector

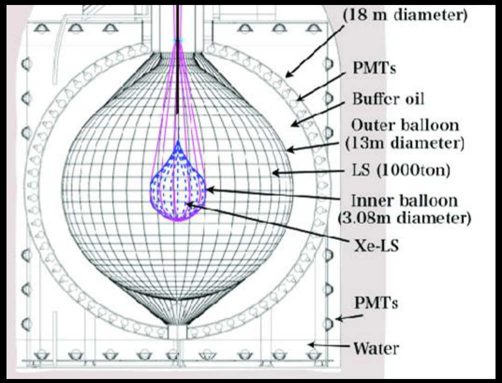
Large Low Energy Neutrino Detectors

Supernovae

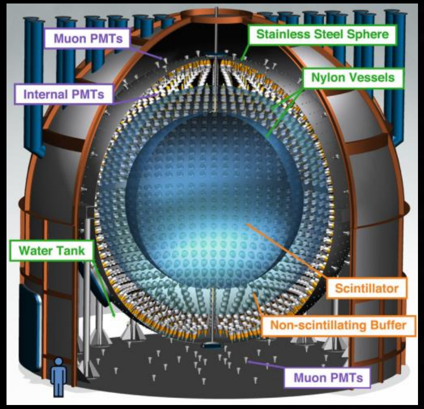
Solar

e.g.

KamLAND-Zen (2011)
Liq. Scint. 1 kt



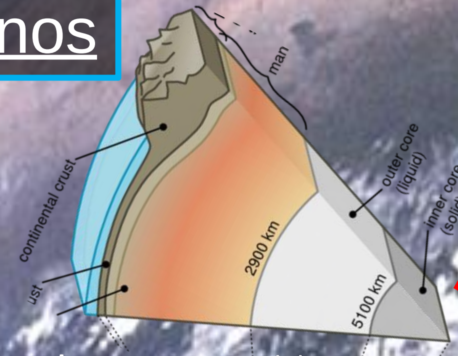
Borexino
Liq. Scint. 300 t

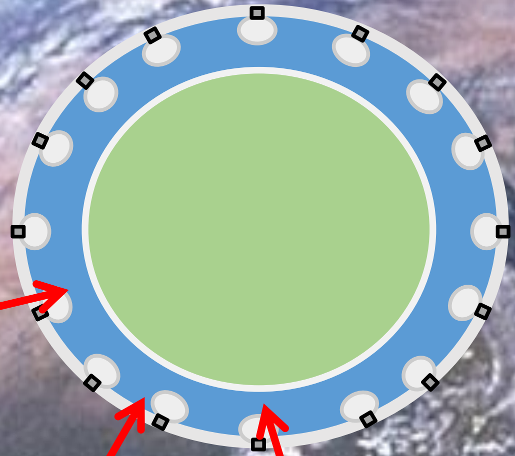


~200 candidate geo-$\bar{\nu}_e$ combined

Reactors

Geoneutrinos





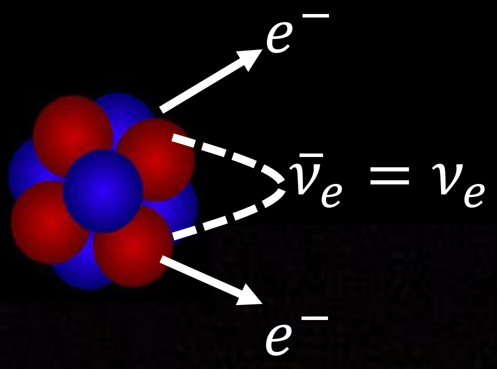
Detector

Large Low Energy Neutrino Detectors

Supernovae

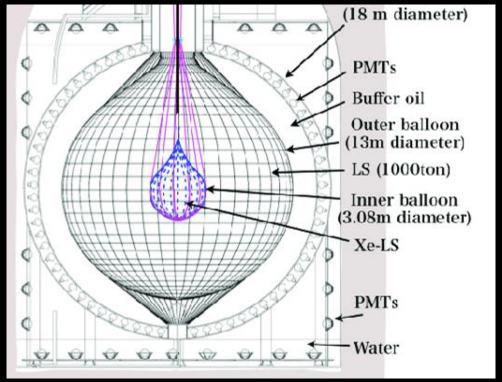
Solar

0νββ decay

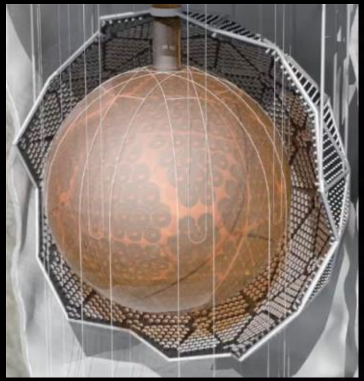


e.g.

KamLAND-Zen
Liq. Scint. 1 kt

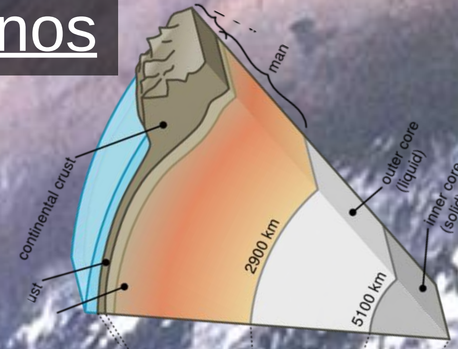


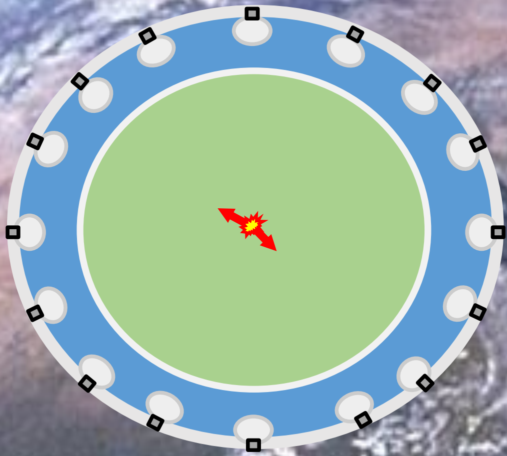
SNO+ (2021, Te-load upcoming)
Liq. Scint. 1 kton



Reactors

Geoneutrinos





Detector

Example : Search for 0νββ

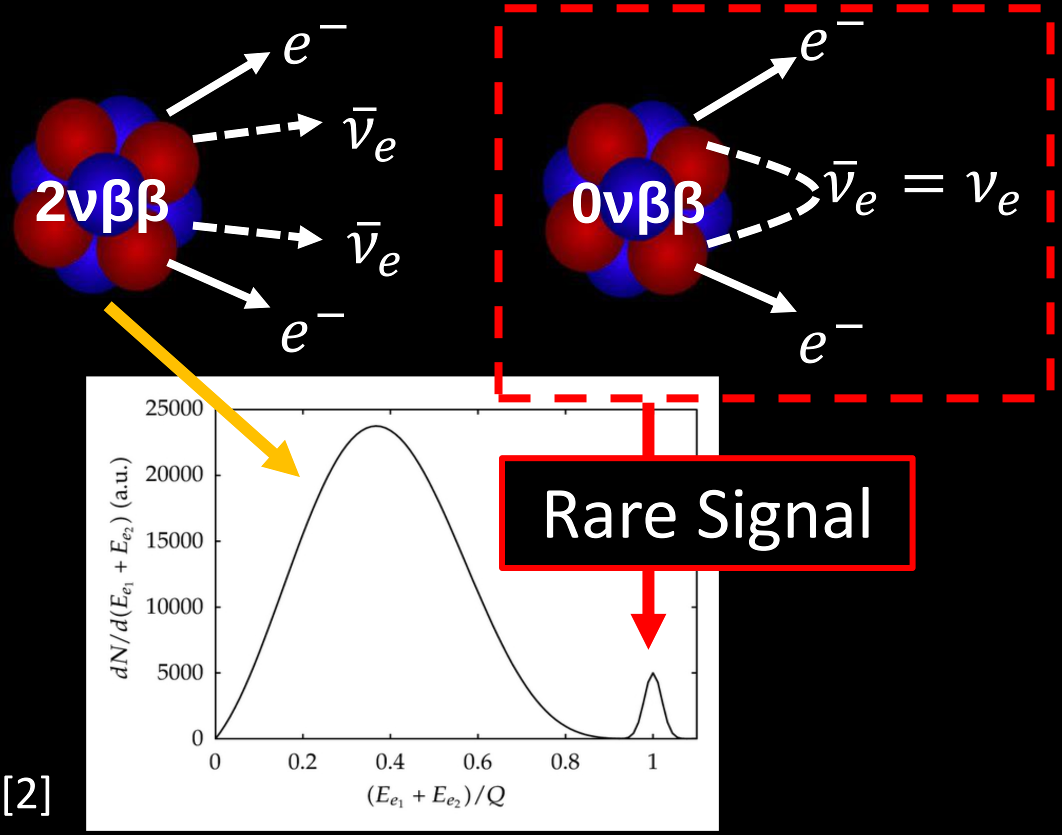
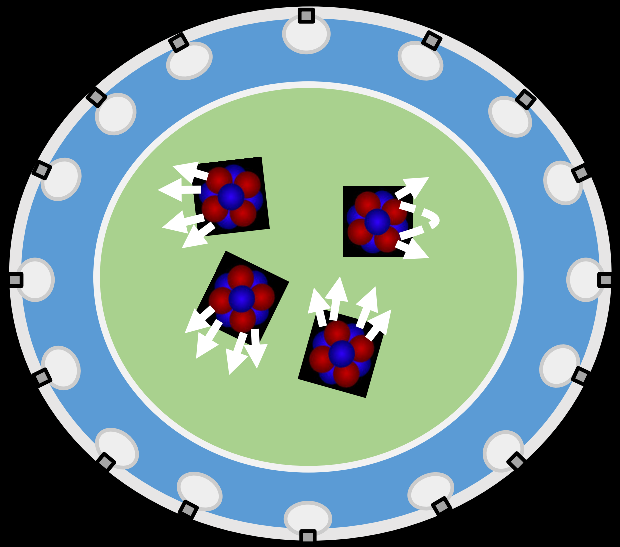


Fig from [2]



Observation of 0νββ
→ Neutrinos are Majorana particles

Black Box Theorem: Phys. Rev. D 25, 2951

Example : Search for 0νββ

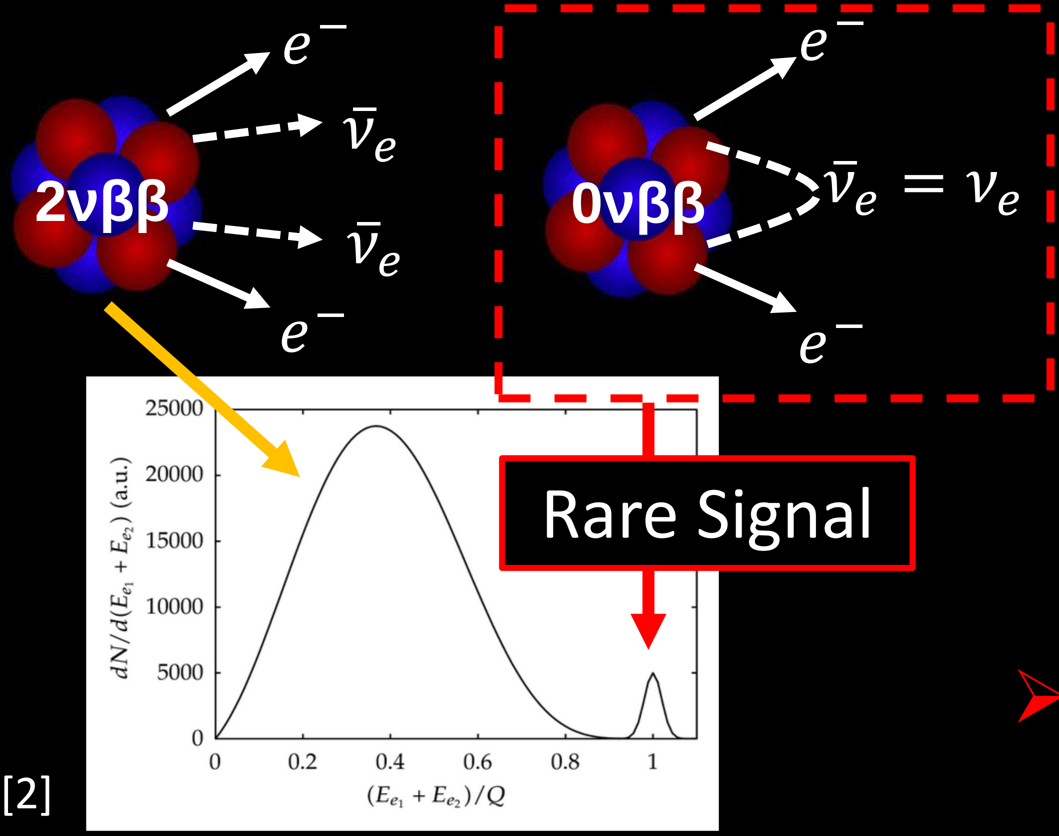
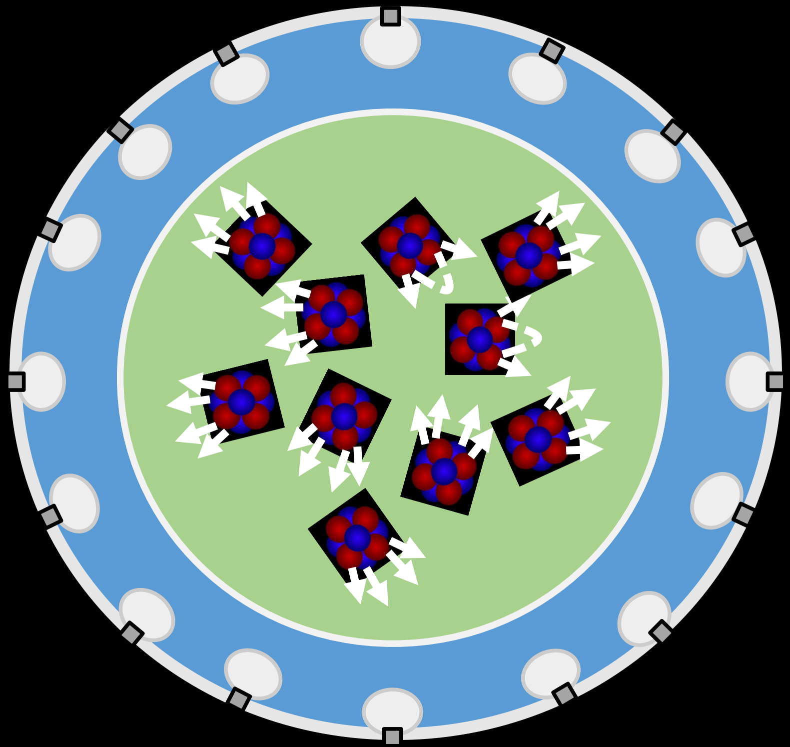


Fig from [2]



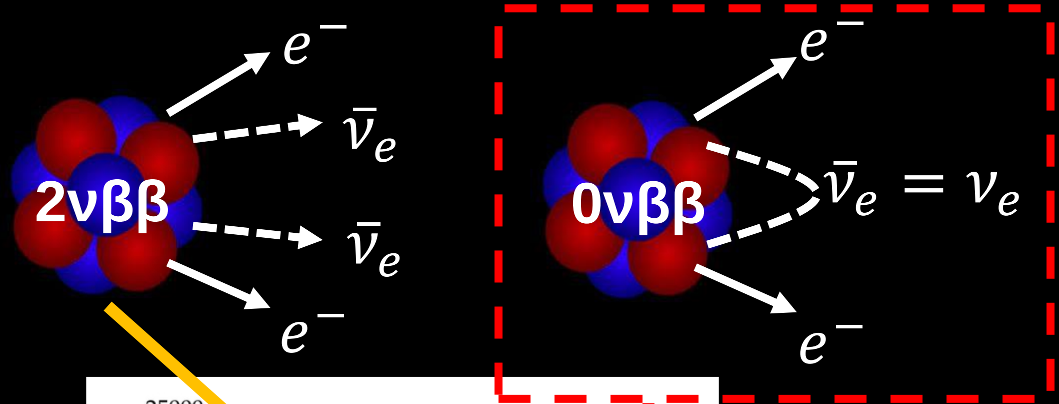
Ideal detector has:

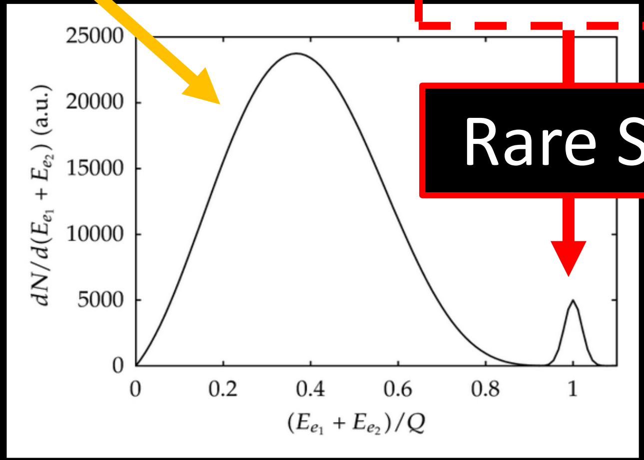
- Large mass of ββ-decay isotope

Observation of 0νββ
→ Neutrinos are Majorana particles

Black Box Theorem: Phys. Rev. D 25, 2951

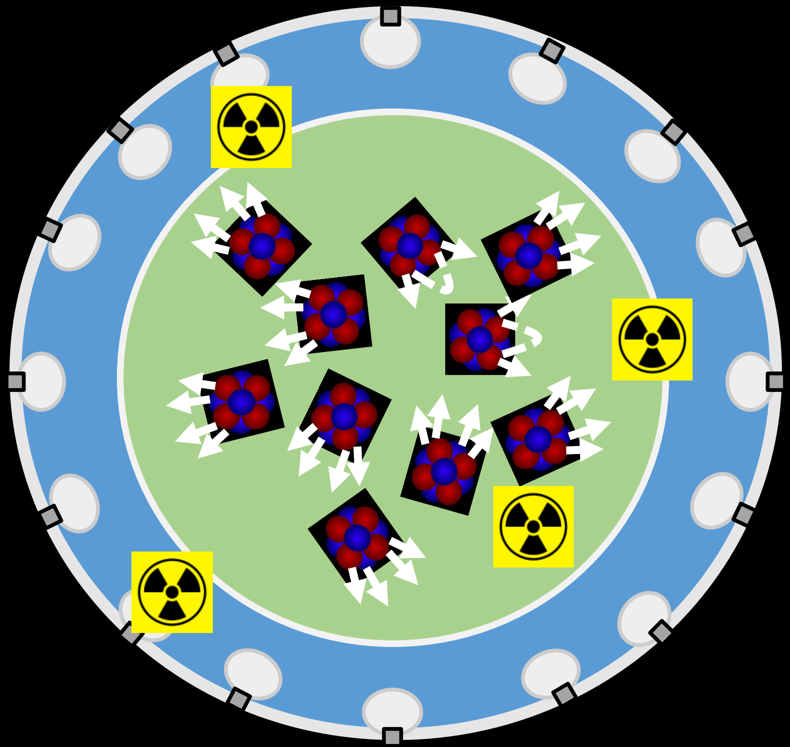
Example : Search for 0νββ





Rare Signal

Fig from [2]



Ideal detector has:

- Large mass of ββ-decay isotope
- Low Backgrounds → Rare event search

Observation of 0νββ
→ Neutrinos are Majorana particles

Black Box Theorem: Phys. Rev. D 25, 2951

Example : Search for 0νββ

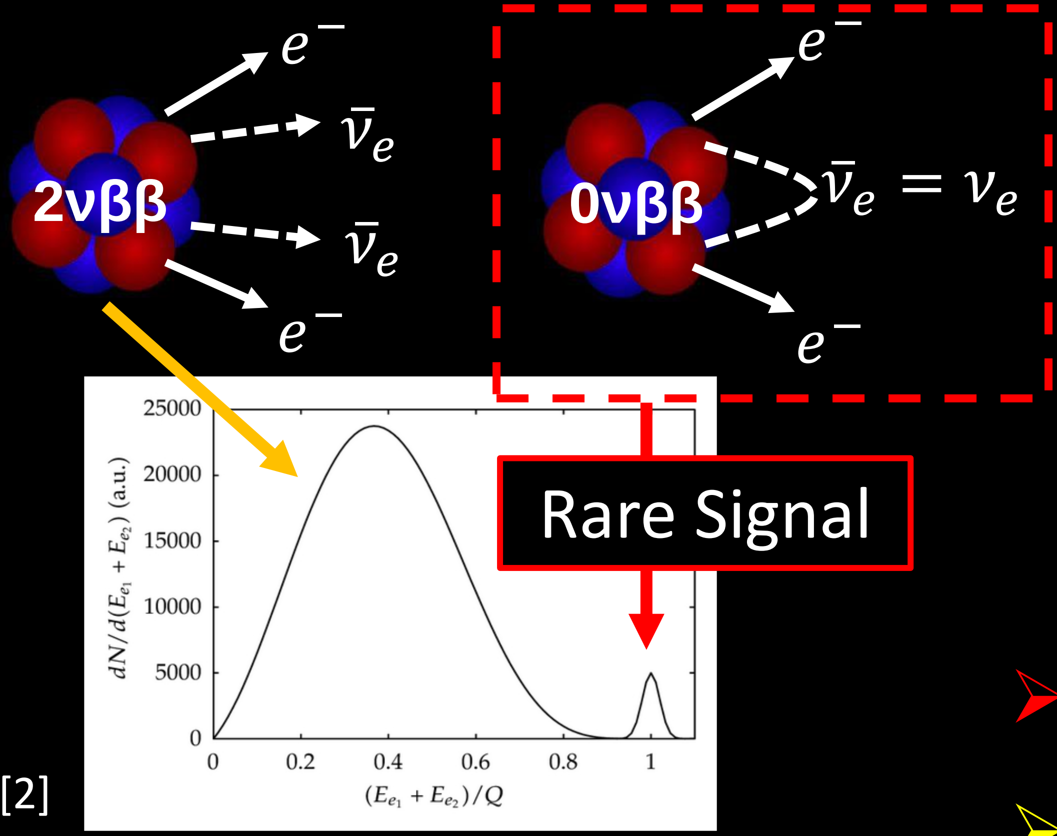


Fig from [2]

Observation of 0νββ
→ Neutrinos are Majorana particles

Ideal detector has:

- Large mass of ββ-decay isotope
- Low Backgrounds → Rare event search
- Fine Energy Resolution → lower BGs

Black Box Theorem: Phys. Rev. D 25, 2951

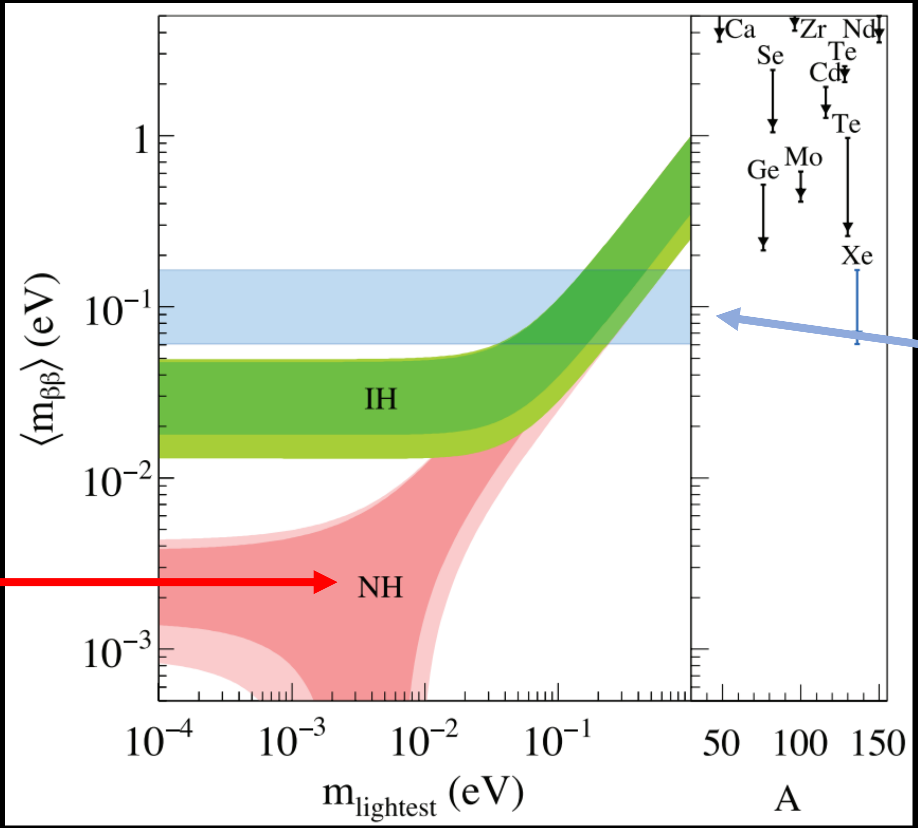
Example : Search for 0νββ

KamLAND-Zen

Liq. Scint. 1 kt

If neutrinos have Normal Ordering

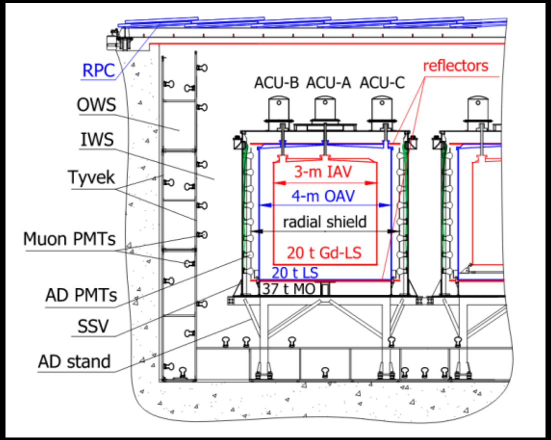
Need orders of magnitude improvement!



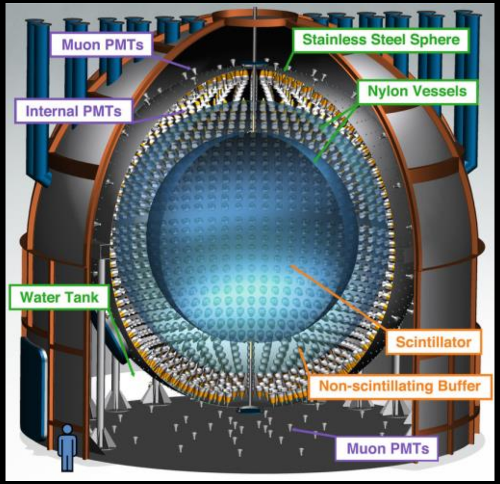
KL-Zen 2016 limits [3]

Fig. from [4]

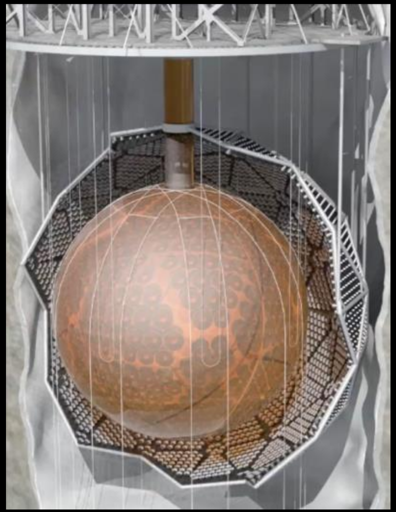
Liquid Scintillator Detectors
Getting larger and larger…



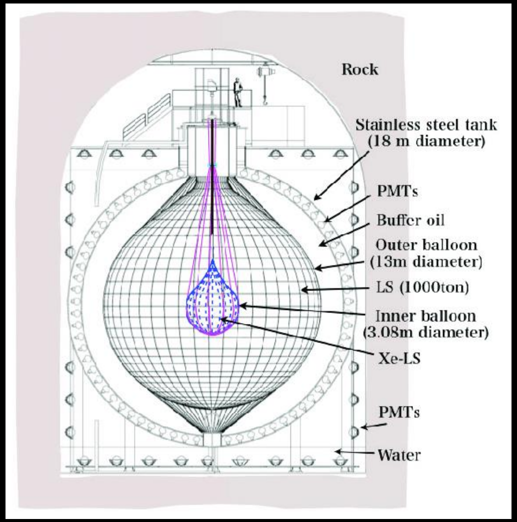
Daya Bay 8 x 20 tonnes



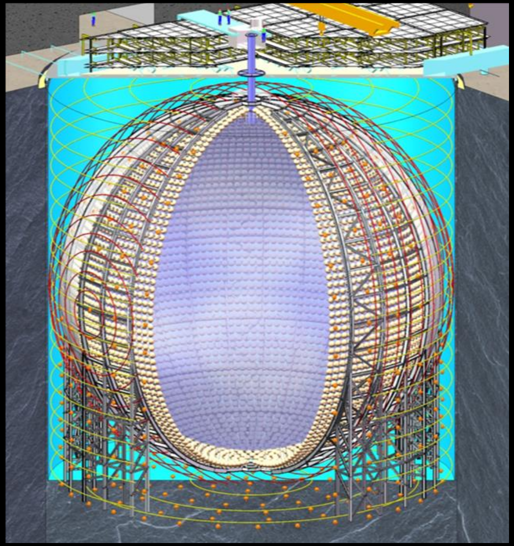
Borexino 300 t



SNO+ 800 t



KamLAND 1000 t

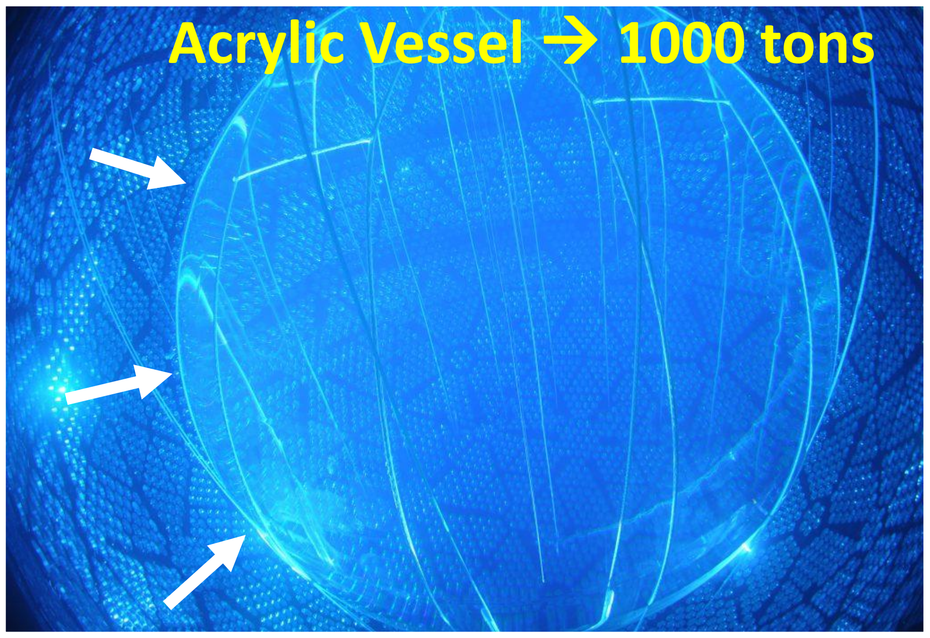


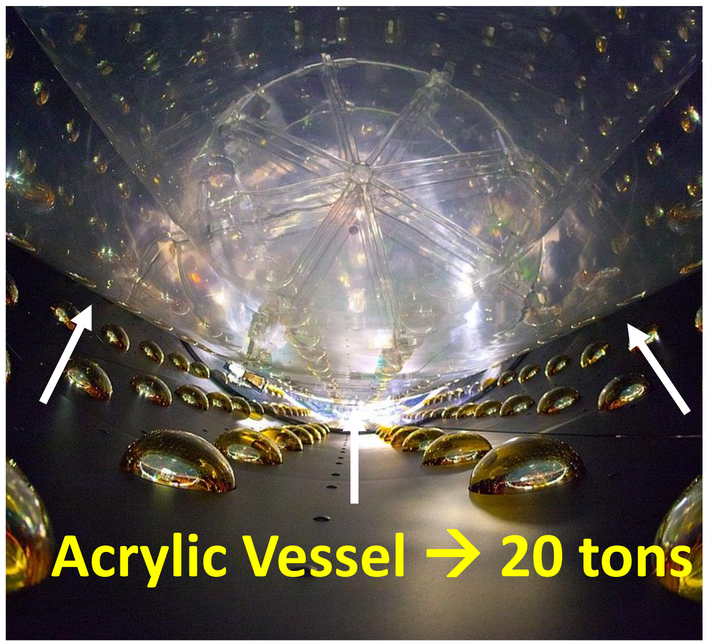
JUNO 20,000 t

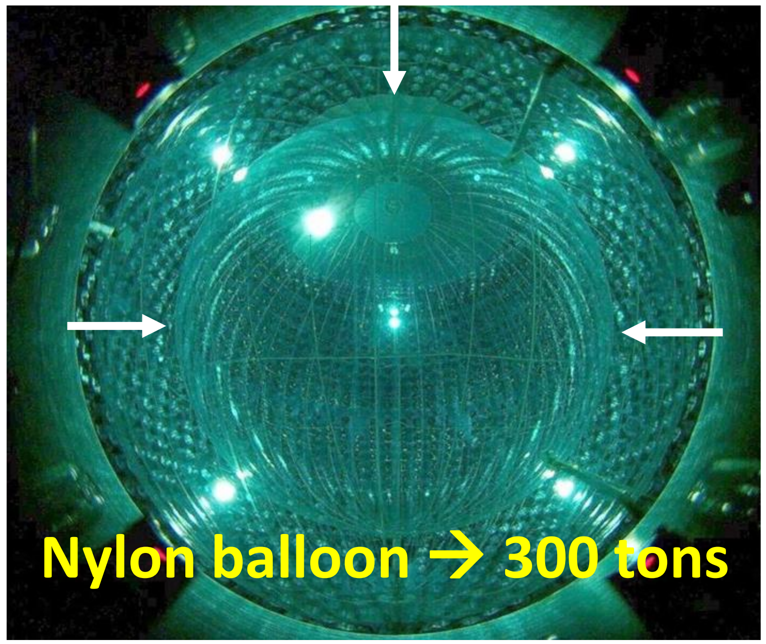
Liquid Scintillator Detectors
Getting larger and larger…

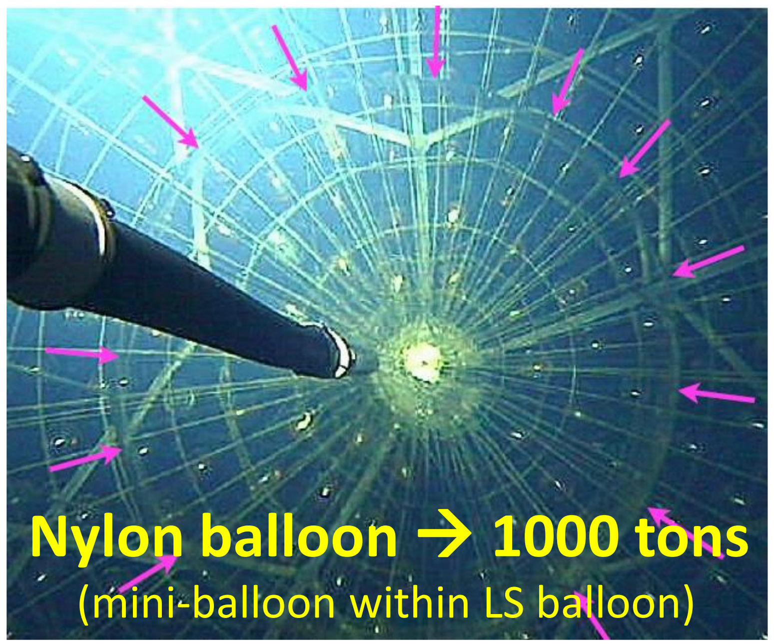
<u>Common to all</u>:

<u>Huge</u> & <u>transparent</u> barrier containing the scintillator





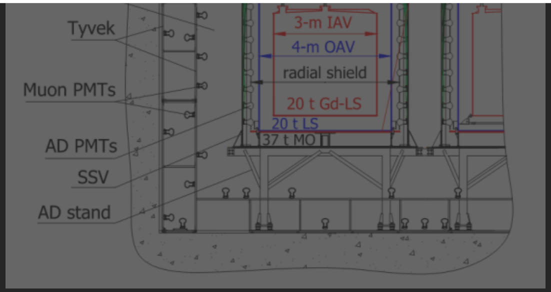




Liquid Scintillator Detectors
Getting larger and larger

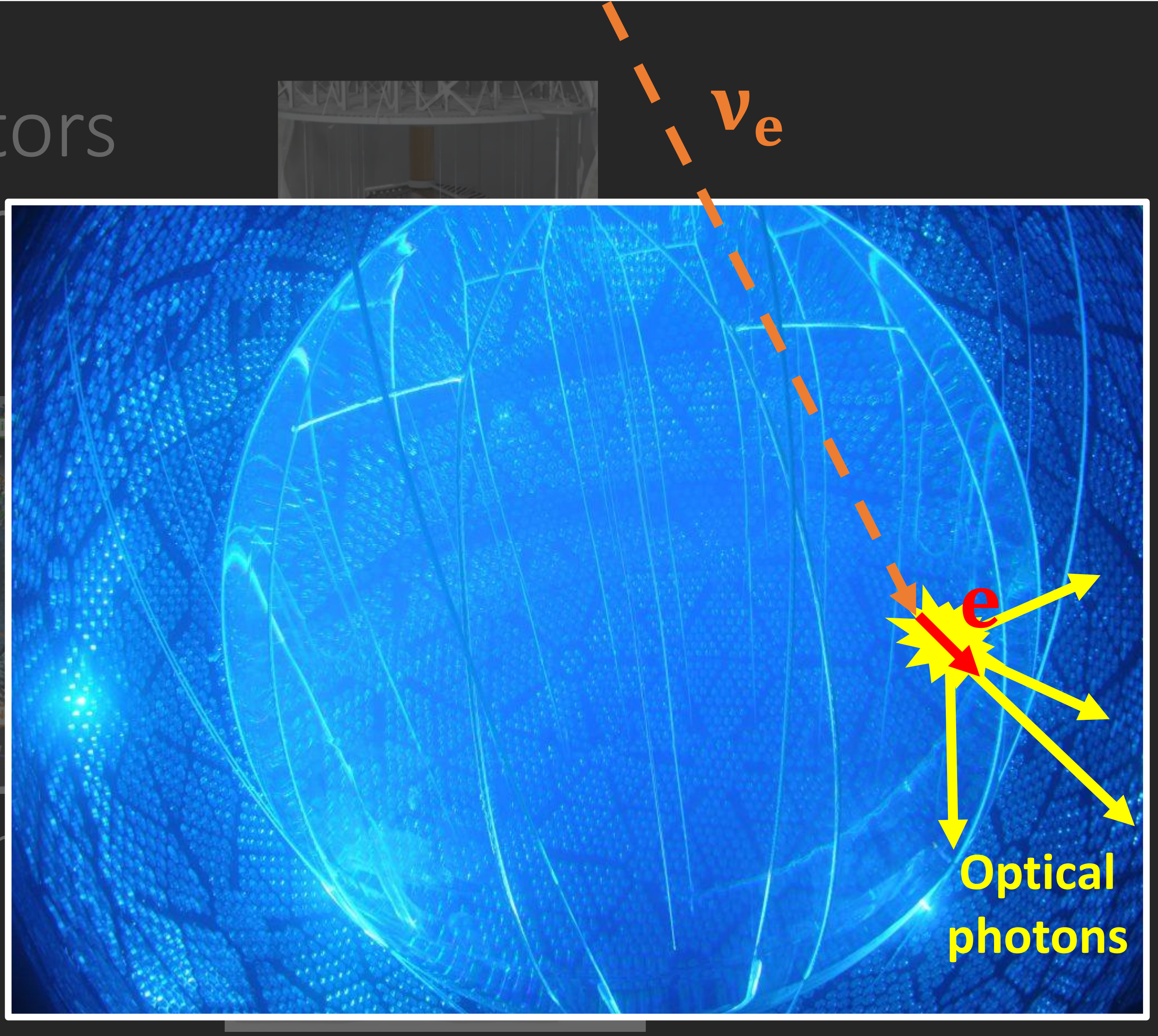
<u>Common to all</u>:

<u>Huge</u> & <u>transparent</u> barrier containing the scintillator



Daya Bay 8 x 20 tonnes

Borexino



KamLAND ~1000 t

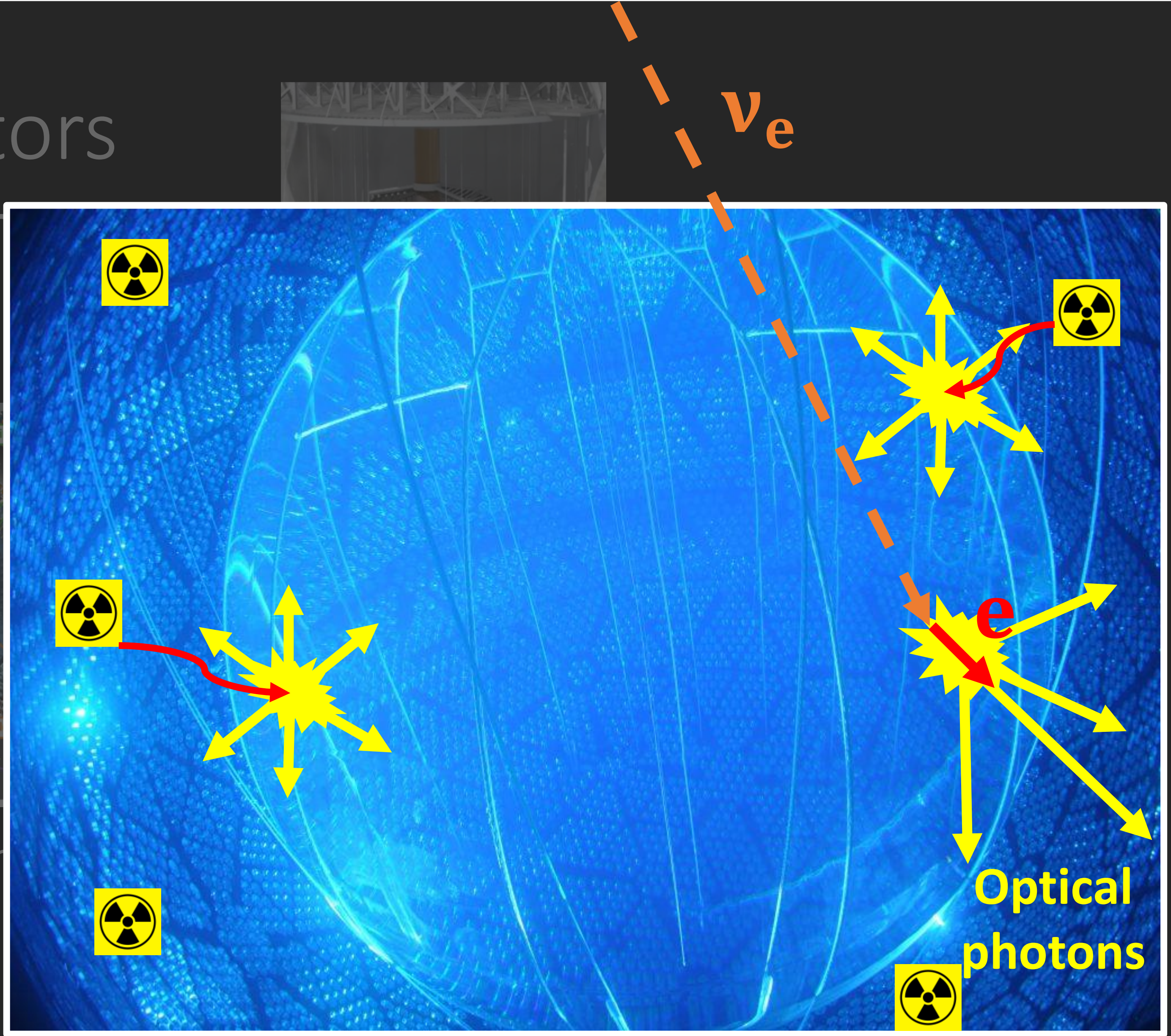
Liquid Scintillator Detectors
Getting larger and larger

<u>Common to all</u>:

<u>Huge</u> & <u>transparent</u> barrier containing the scintillator

<u>Transparent Barriers</u>:

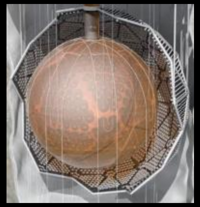
+ Separates scintillator from PMTs
- Contributes contamination
- Difficult to build



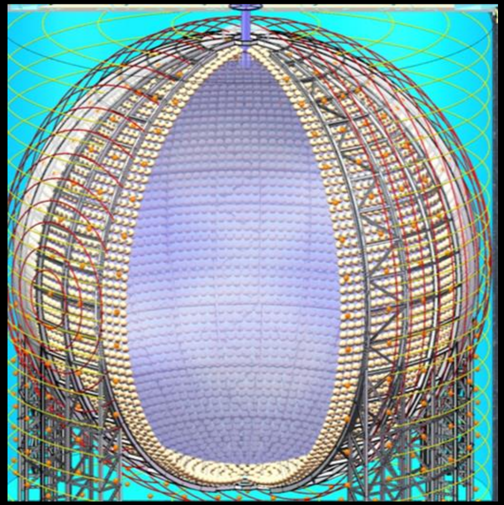
KamLAND ~1000 t

Increasing size : JUNO

SNO+ 1kt



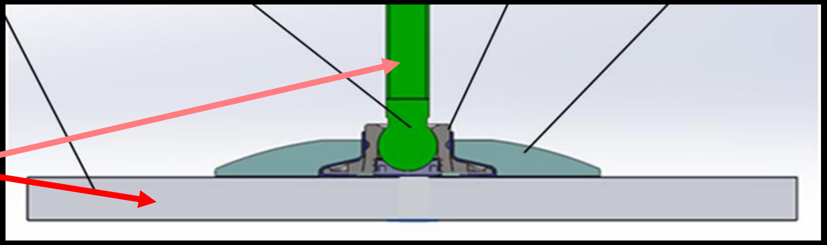
JUNO 20 kt

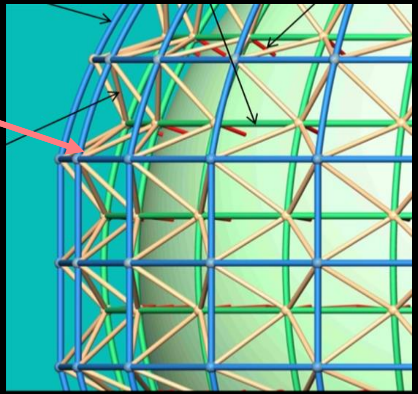


- 1 kt → 20kT, cannot simply scale up!

Higher stresses/tensions:

- Need thicker acrylic segments
- Need stainless steel support structure
  - Possible extra backgrounds
  - Possible complicated reflections
- Cost of creating large spherical underground cavity





Figs from [5]

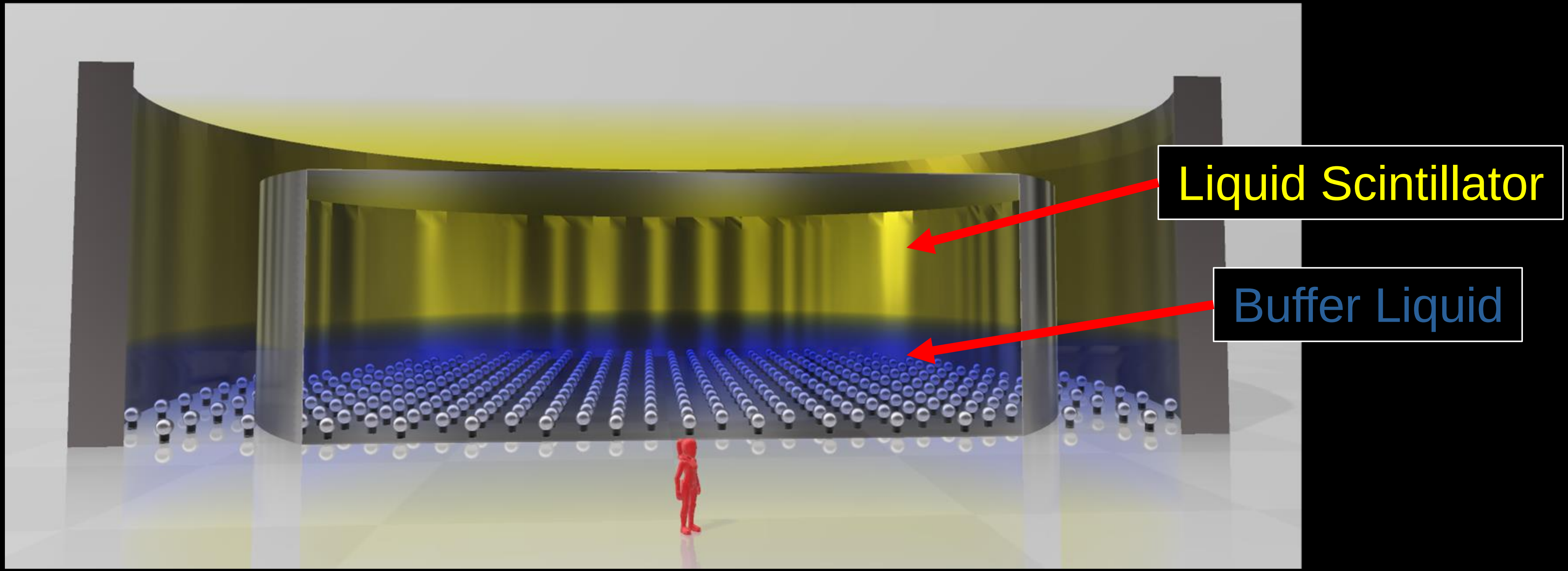
An Alternative Design?

Stratified LIquid Plane Scintillator : **SLIPS**

Float liquid scintillator on top of a buffer liquid

- No transparent vessel/barriers required

Phys. Rev. D **105**, 072003

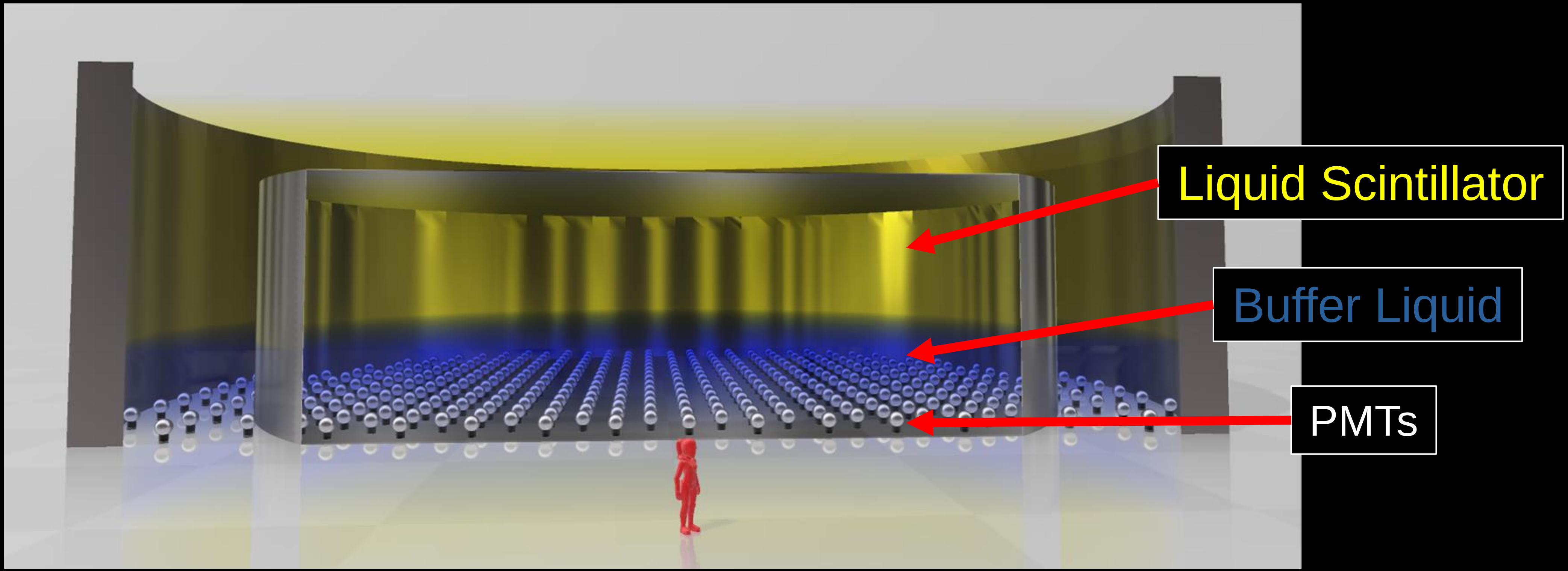


Stratified LIquid Plane Scintillator : **SLIPS**

Float liquid scintillator on top of a buffer liquid

- ➢ No transparent vessel/barriers required

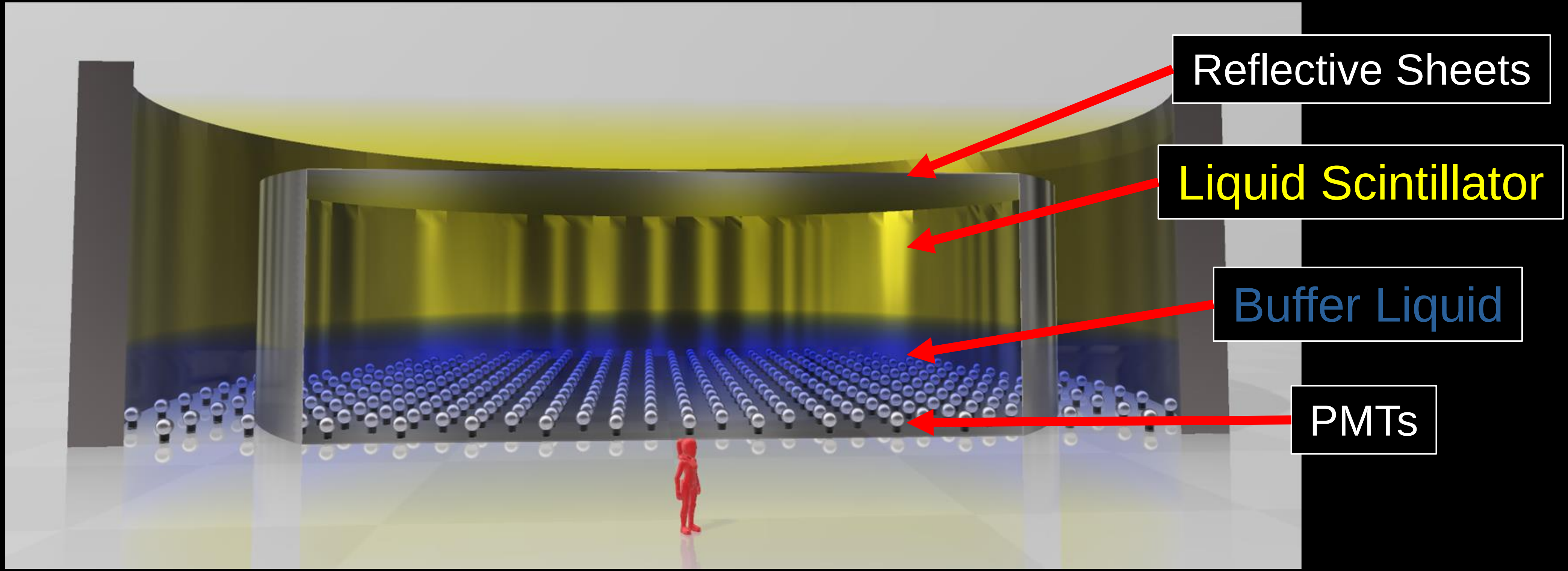
Phys. Rev. D **105**, 072003



Stratified LIquid Plane Scintillator : **SLIPS**

Float liquid scintillator on top of a buffer liquid
- ➢ No transparent vessel/barriers required

Phys. Rev. D **105**, 072003



Stratified LIquid Plane Scintillator : **SLIPS**

Float liquid scintillator on top of a buffer liquid
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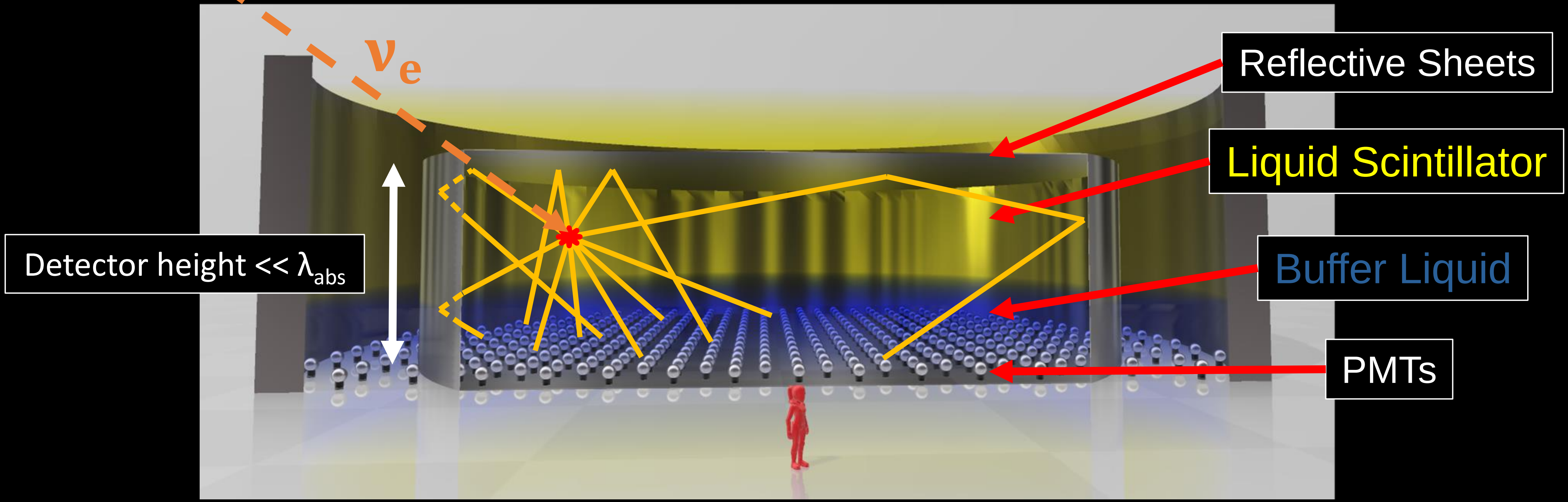
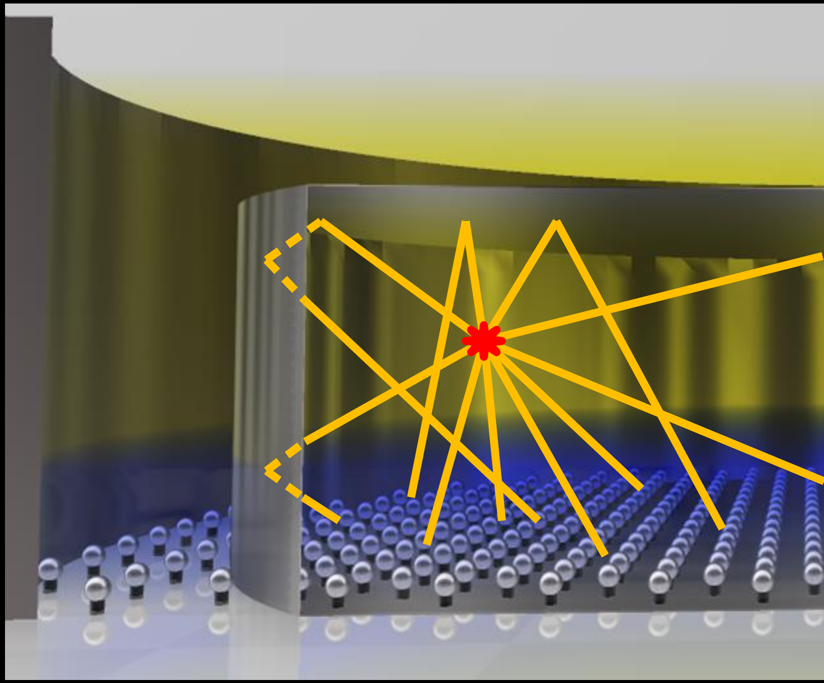
[Phys. Rev. D **105**, 072003]



Performance Testing : Geant4

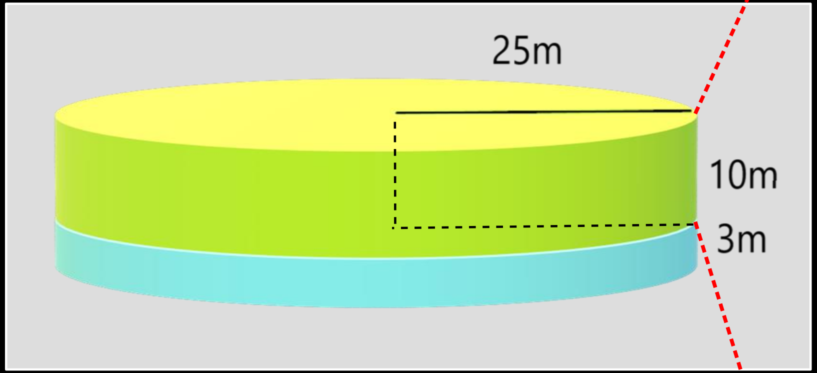
Scintillator : LAB + 2g/L PPO + 15mg/L bisMSB
Shielding : Ethylene Glycol
PMTs : 20” R12860 Hamamatsu



Light Collection

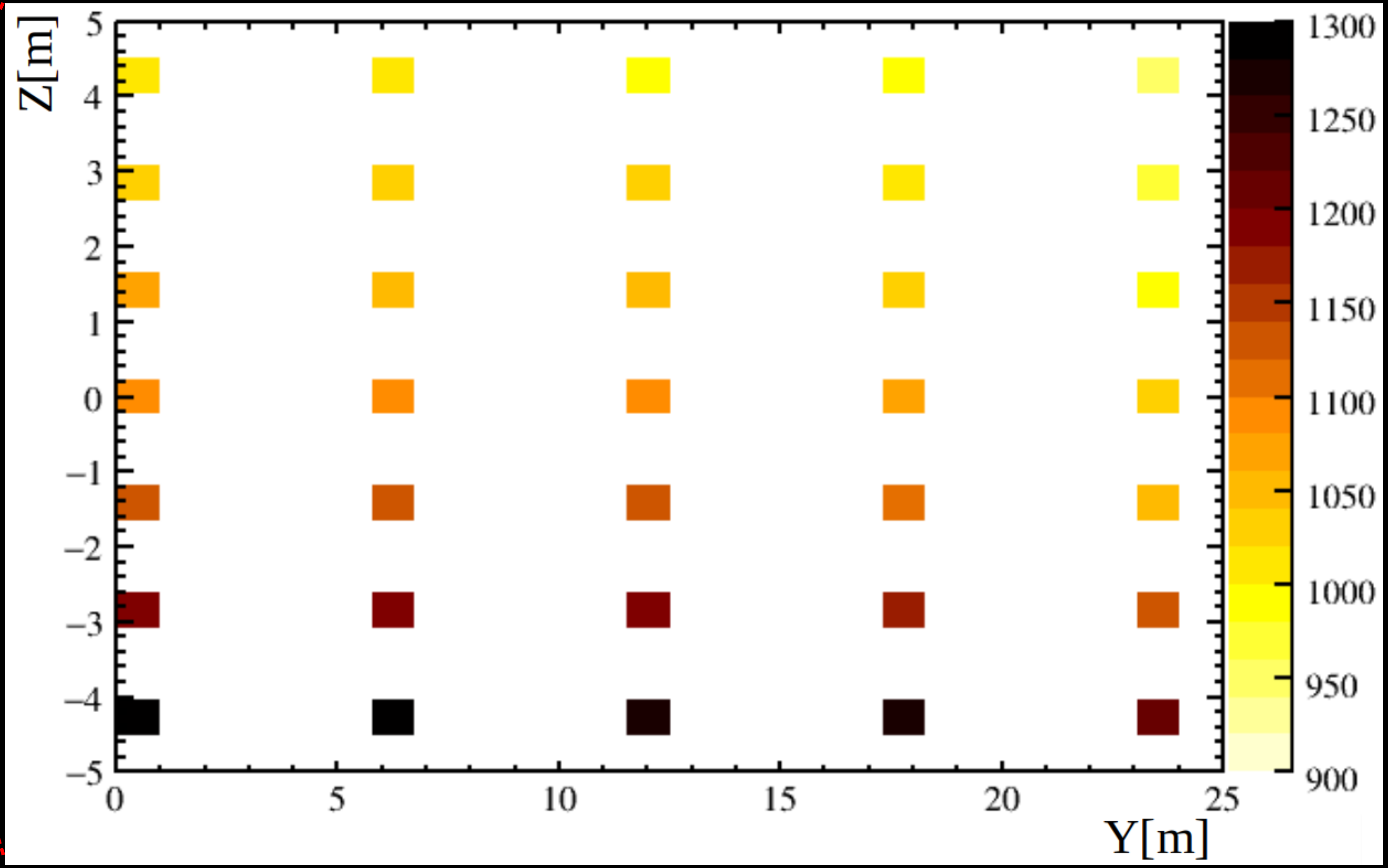
↓

Energy/Position Resolution

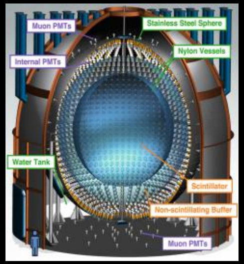


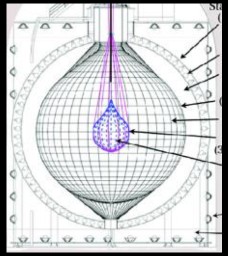
~1100 p.e. / MeV

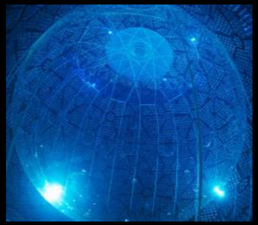
Num. of photoelectrons per MeV
vs position within in SLIPS

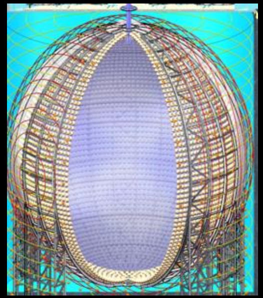


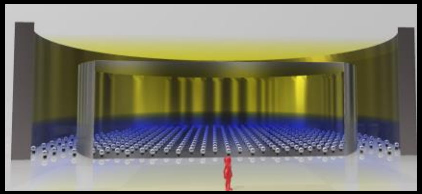
Light Collection







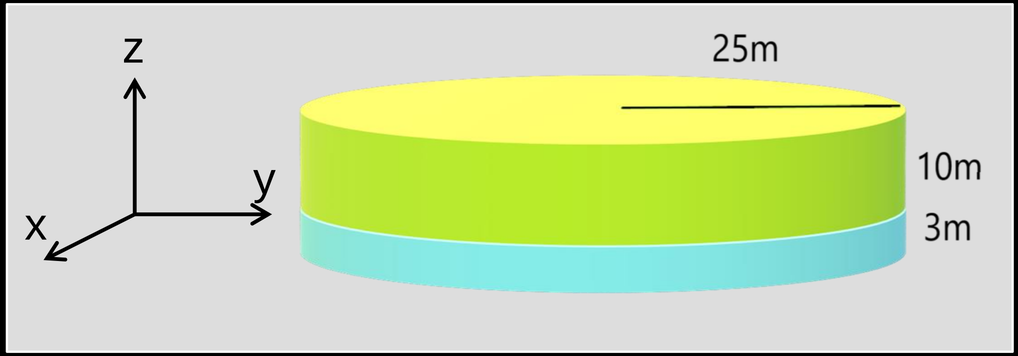




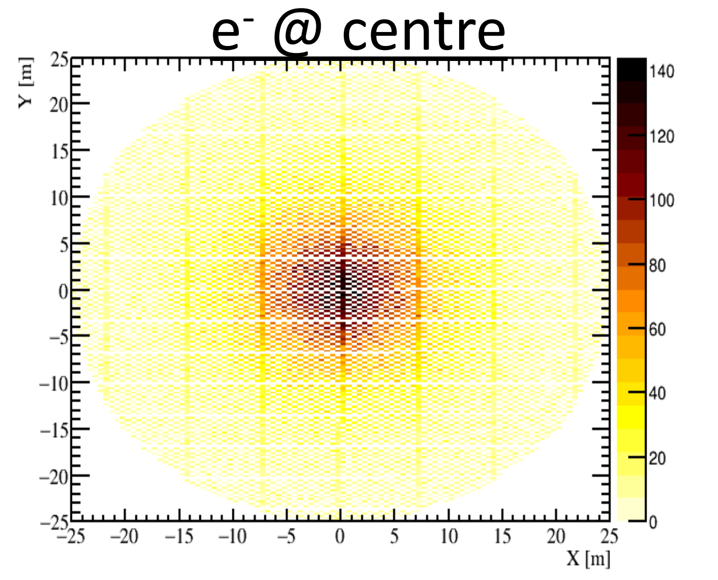
	Borexino [6][7]	KamLAND [8][9]	SNO+ [10]	JUNO [11][12]	SLIPS
Target Mass	300t	1kt	780t	**20kt**	**20kt**
PMT Coverage	~30%	~34%	~50%	**~80%**	**~30%**
Light Collection [photoelectrons/MeV]	~450	~200	~520	**>1200**	**~1100**
Light Coll./ Coverage	15%	6%	10%	**15%**	**37%**

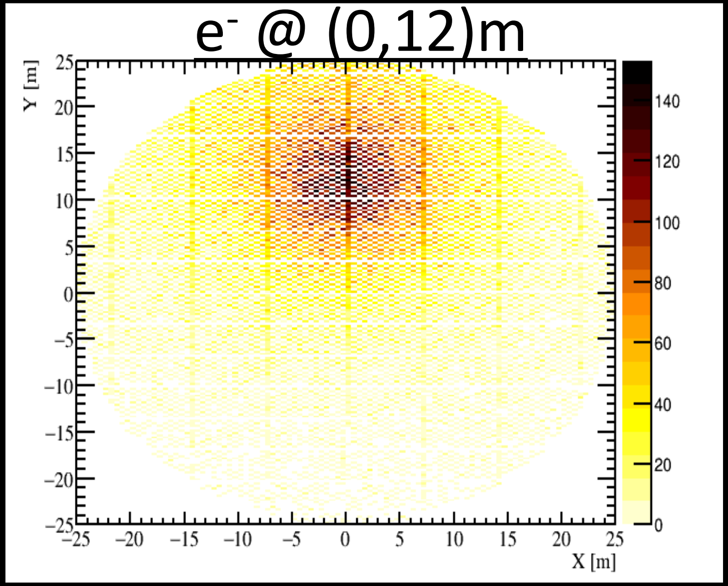
Would be world-leading!

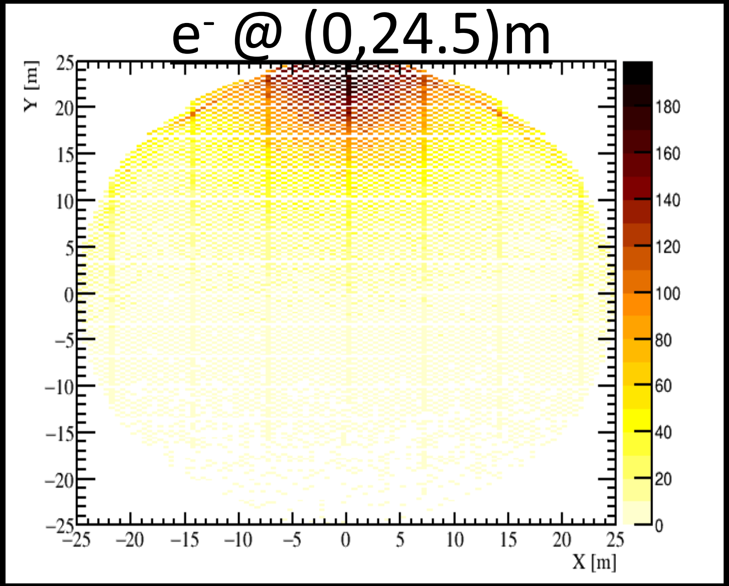
Horizontal Position Resolution



PMT hit density vs X,Y







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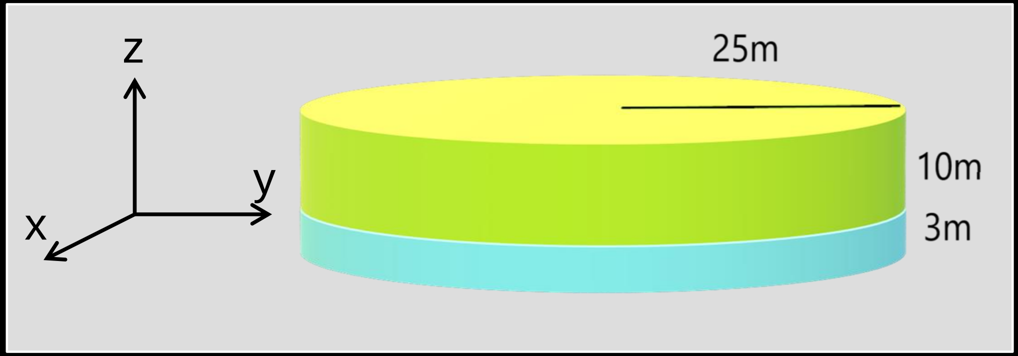

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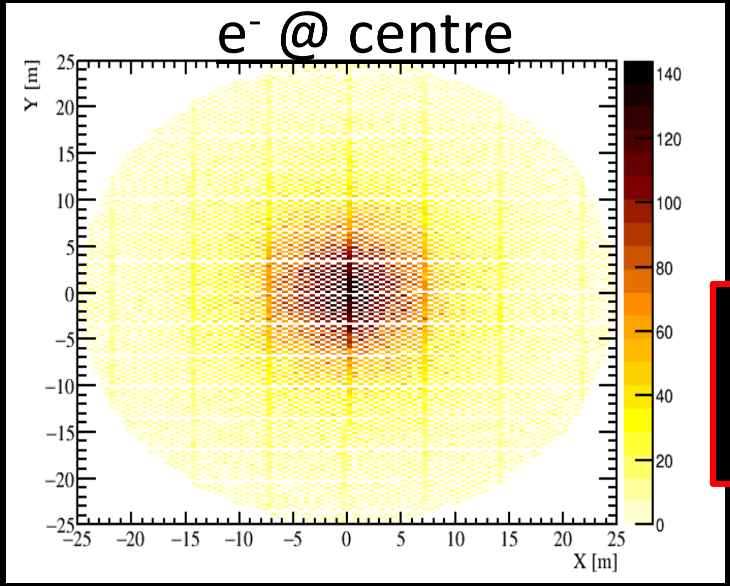
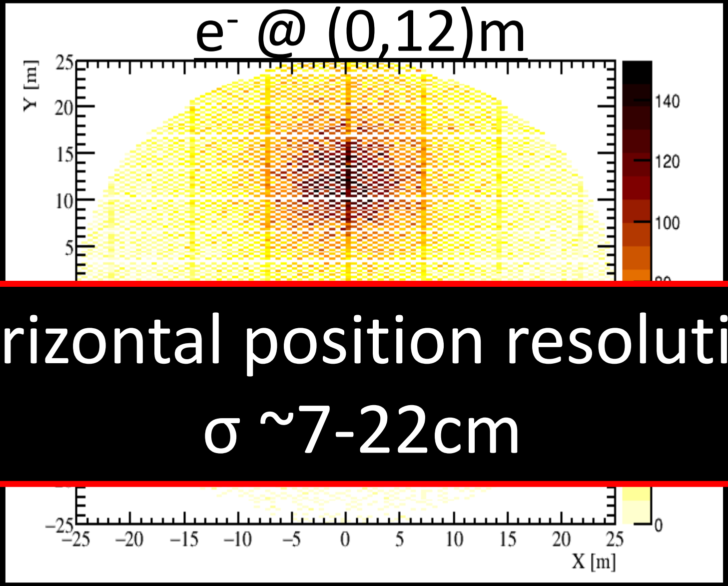
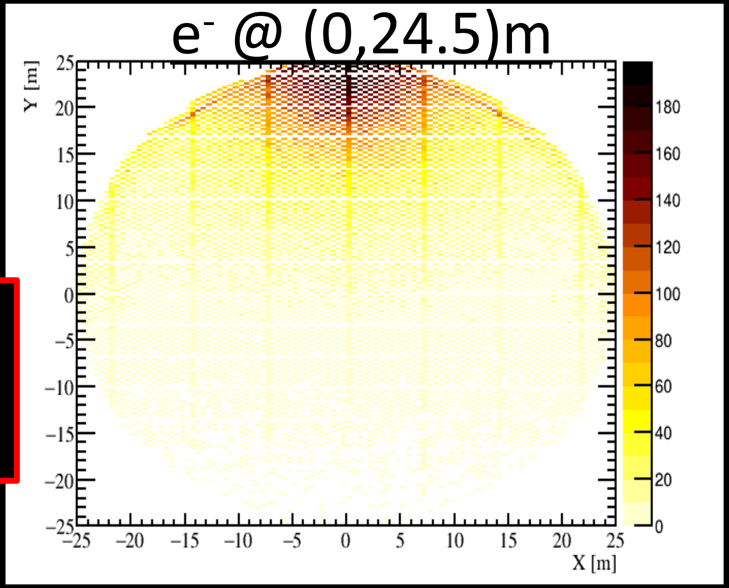


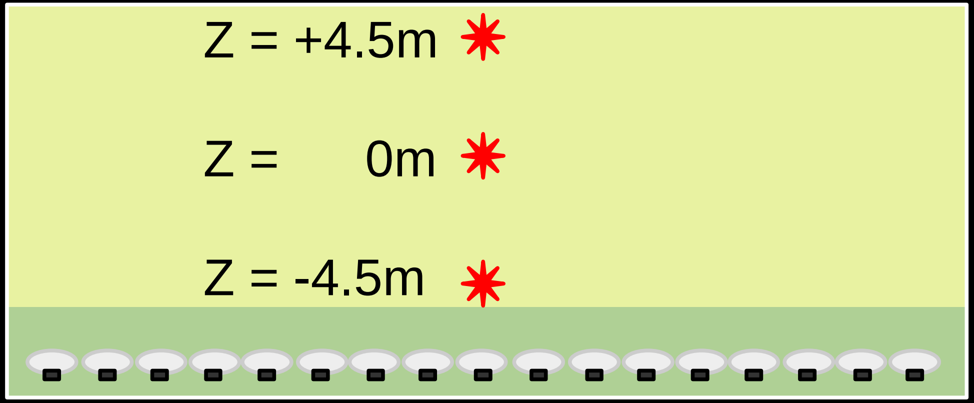




Horizontal position resolution
σ ~7-22cm

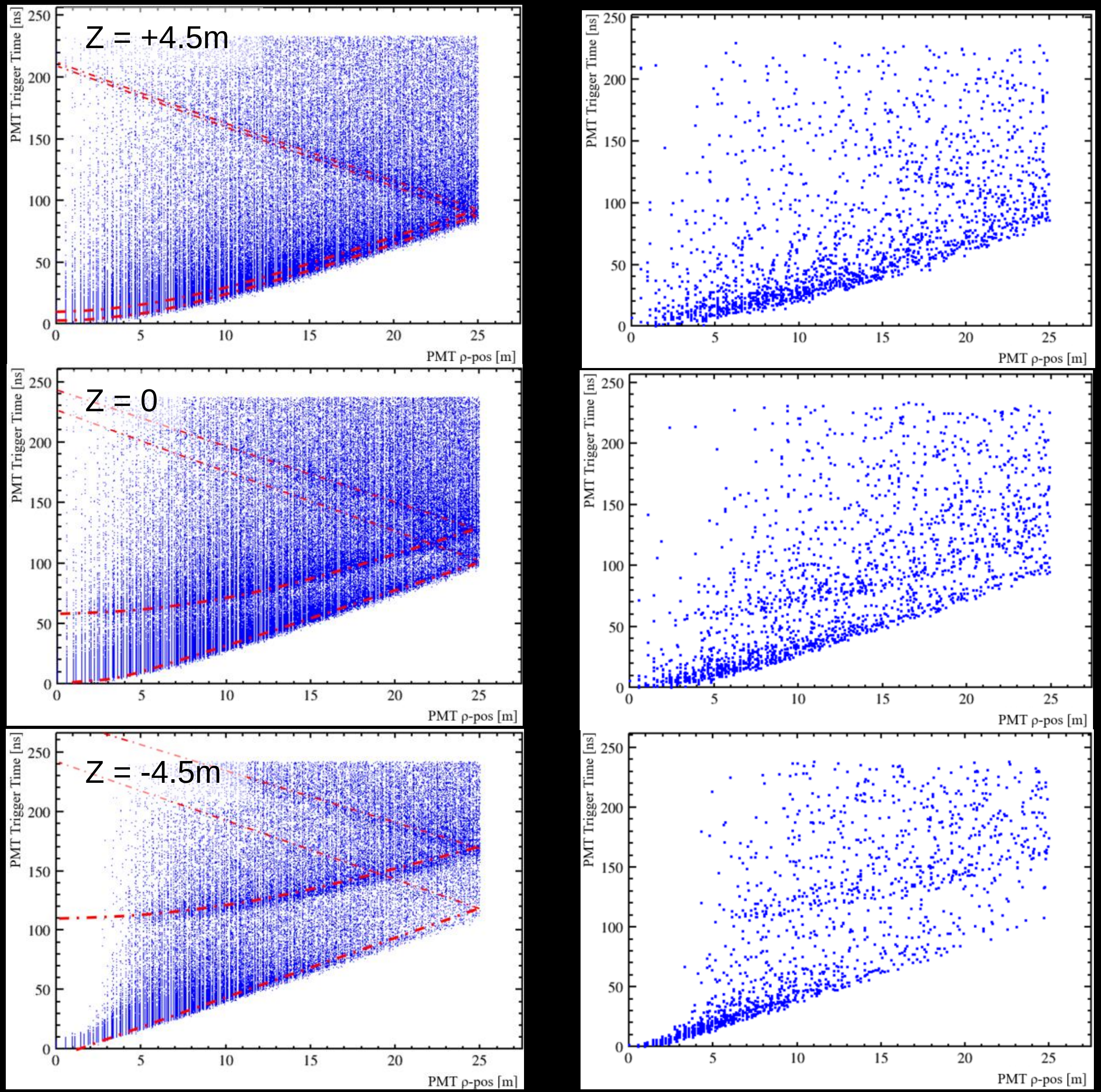
Vertical Resolution

PMT hit times vs PMT radius



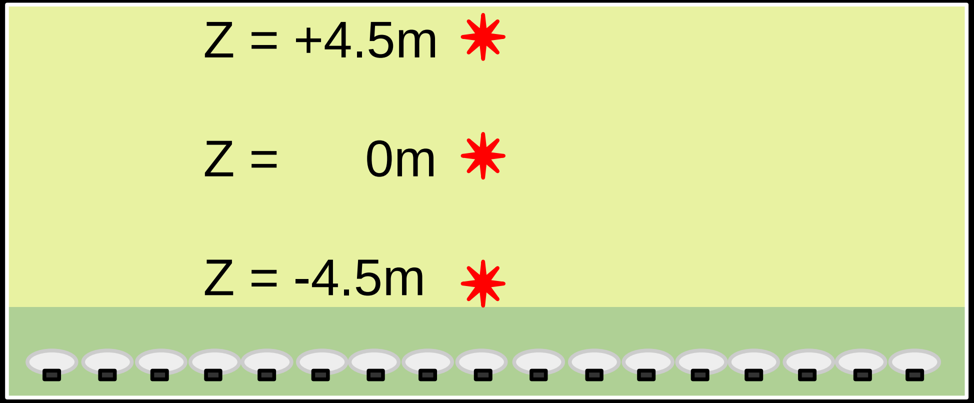
Many e⁻ events

Single 3MeV event



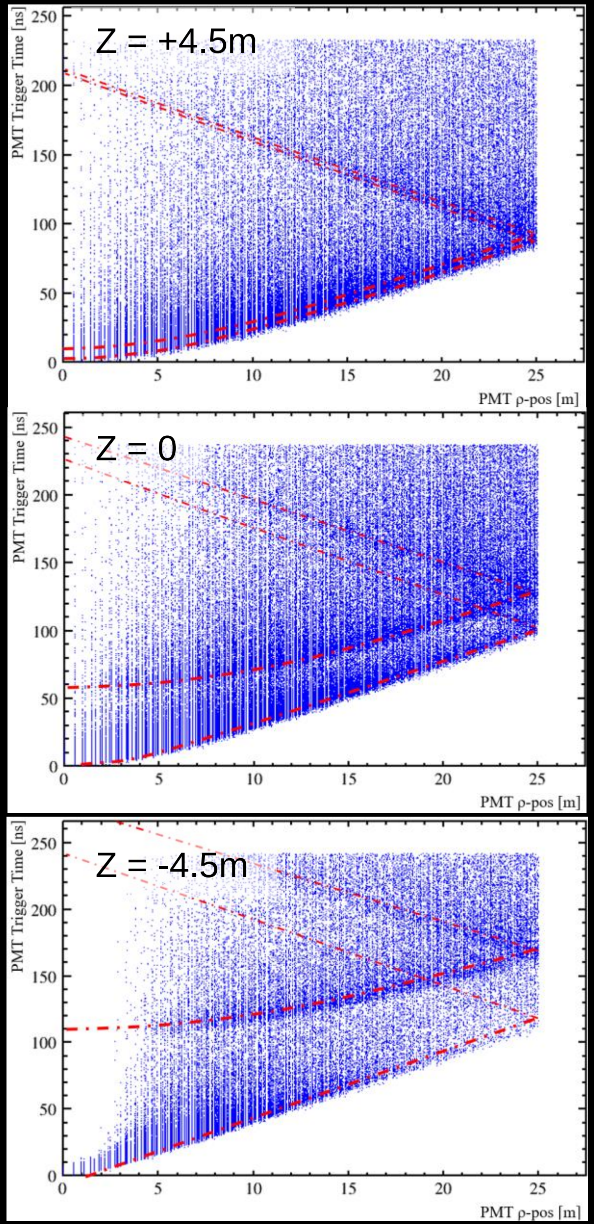
Vertical Resolution

PMT hit times vs PMT radius

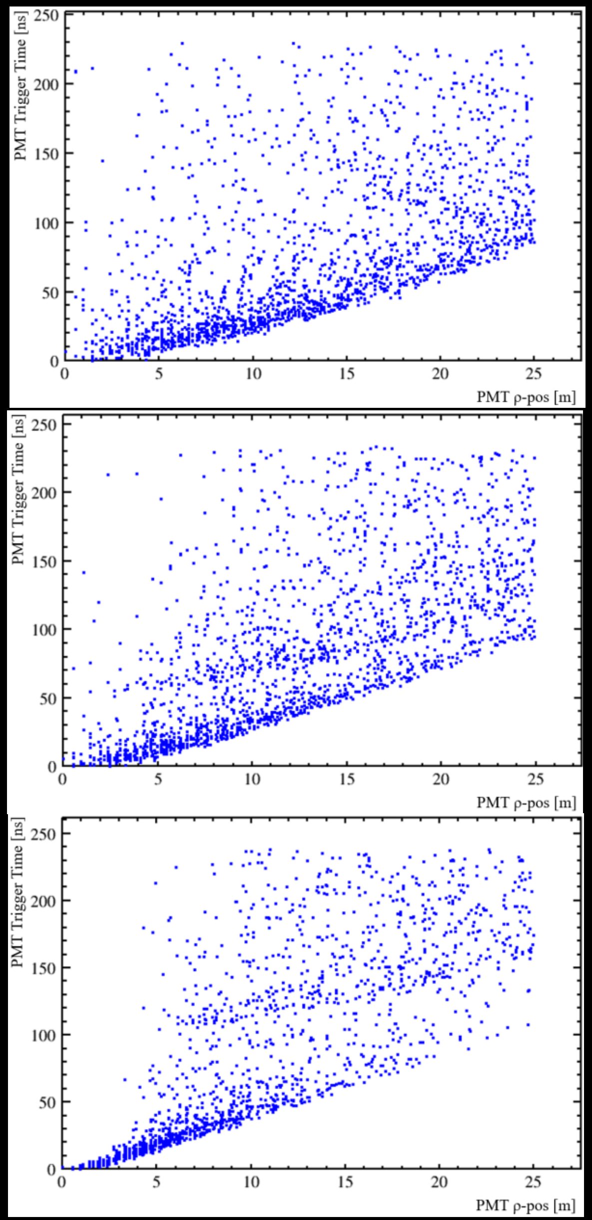


Fitting PMT hit times z-position resolution: $\sigma_Z \sim 8cm$

Many e⁻ events

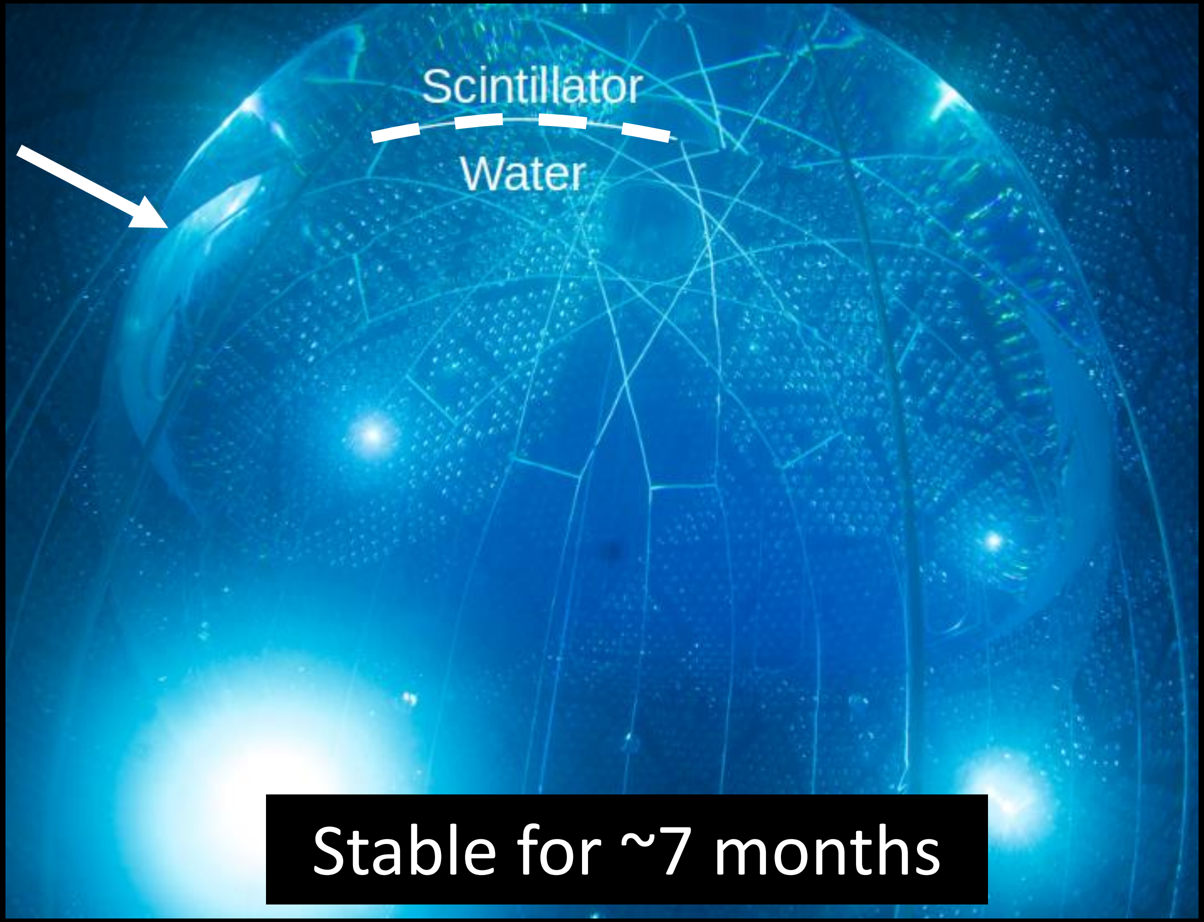


Single 3MeV event

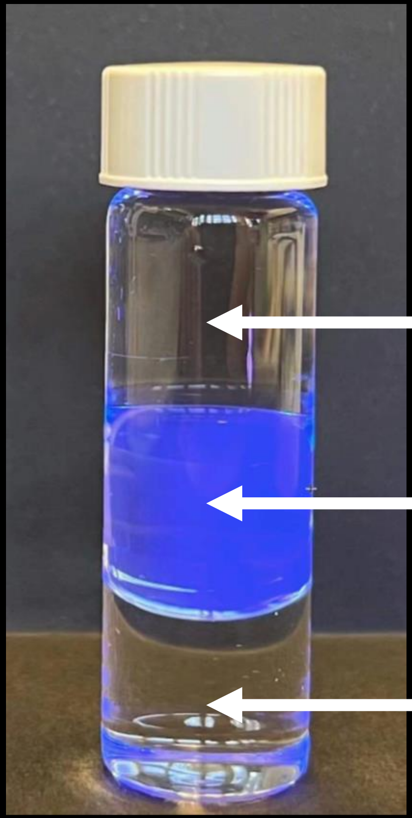


Working “Prototype”

SNO+ detector
Partially filled with
~400 tons of LAB and water



Working “Prototype”



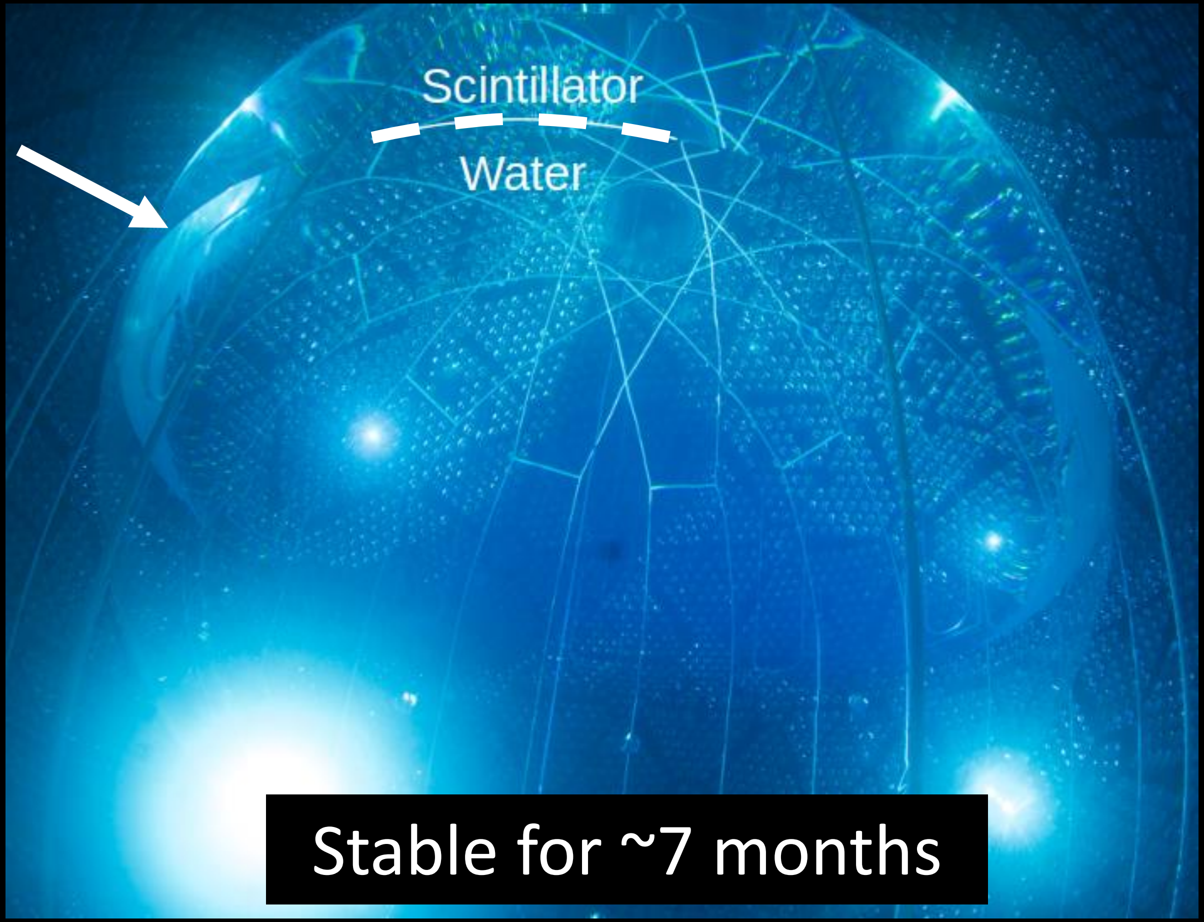
Example:
Propylene glycol

DPE-based scintillator

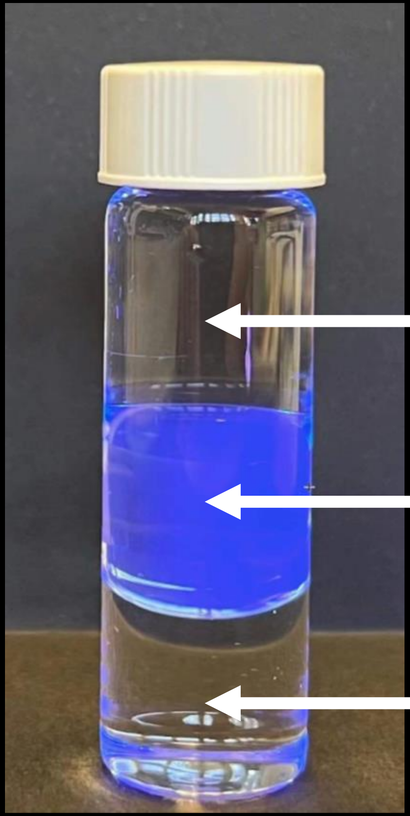
Ethylene glycol

No flour transfers observed

SNO+ detector
Partially filled with
~400 tons of LAB and water

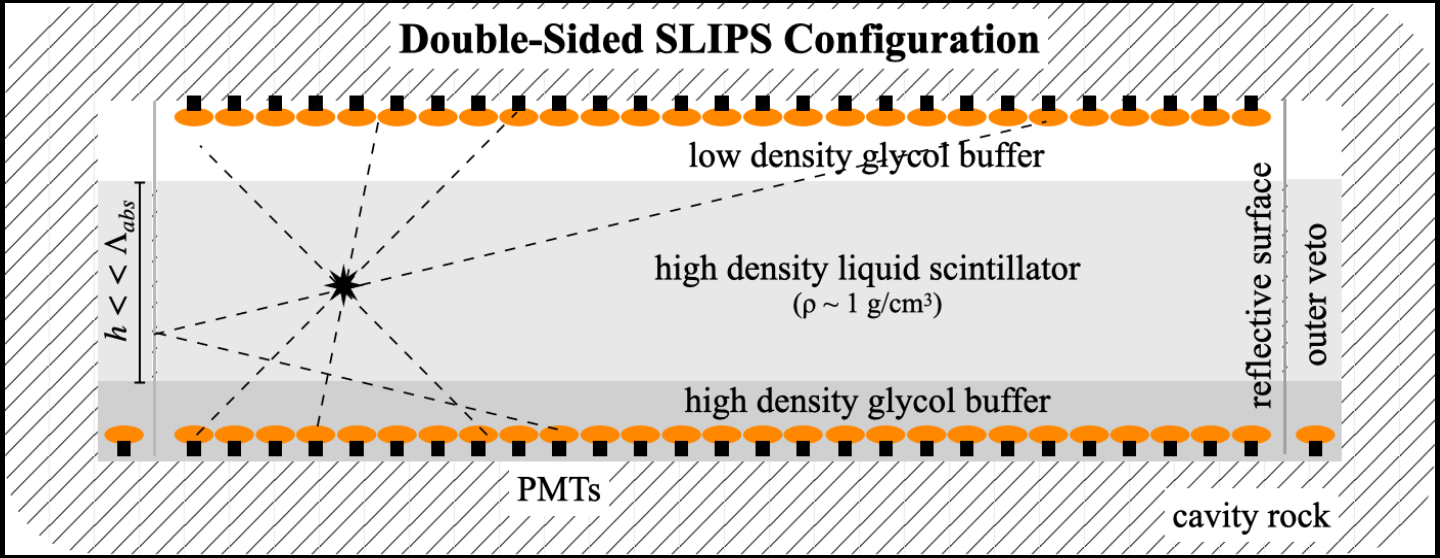


Working “Prototype”



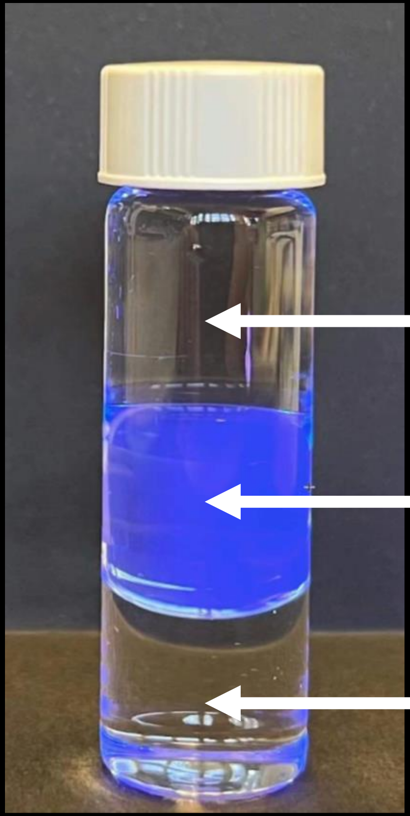
Example:
- Propylene glycol
- DPE-based scintillator
- Ethylene glycol

3-layer configuration : Avoids reflections



No flour transfers observed

Working "Prototype"



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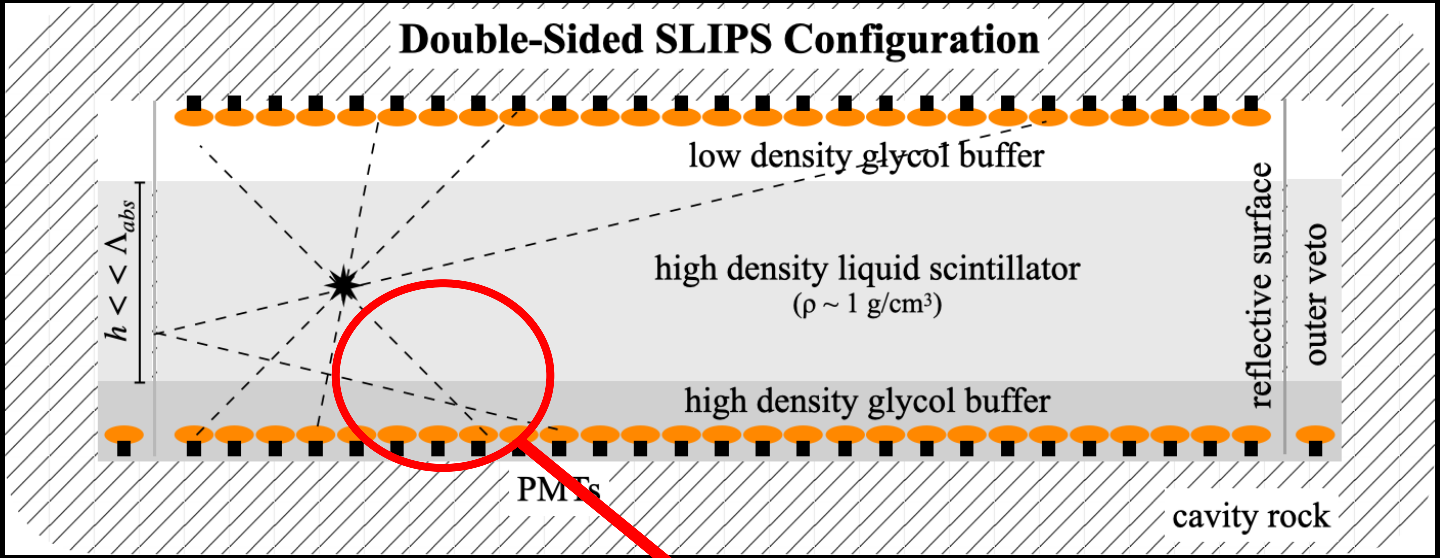


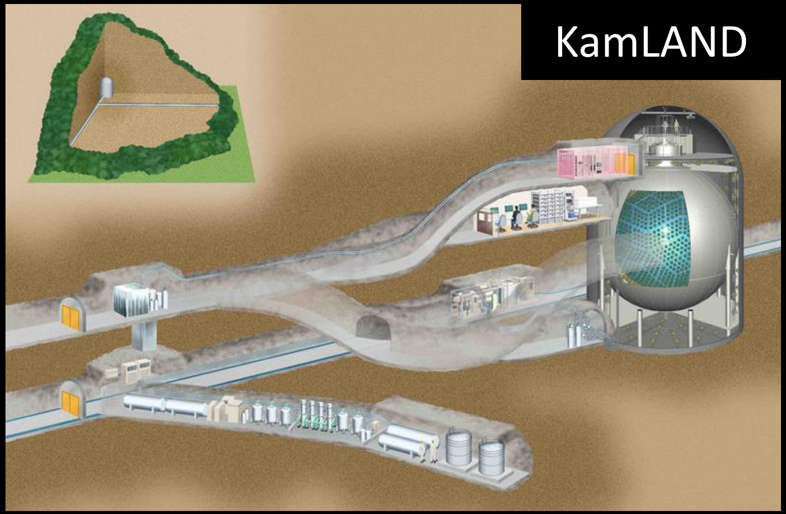
Want matching refractive indices
Minimise light reflections & bending!

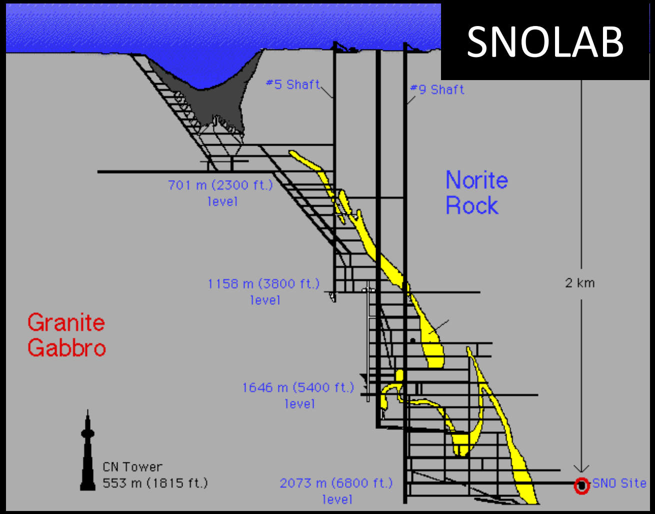
Underground Excavation : Cost Reduction

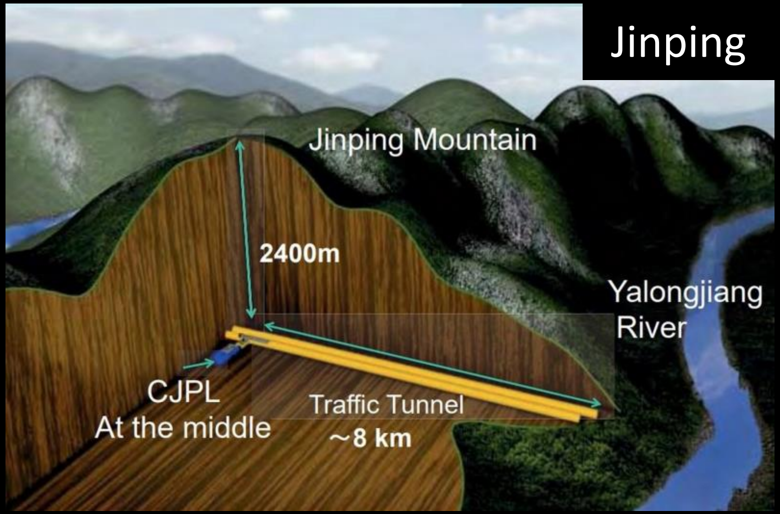
Fig from [CAS]

Costly to excavate large, tall cavities!

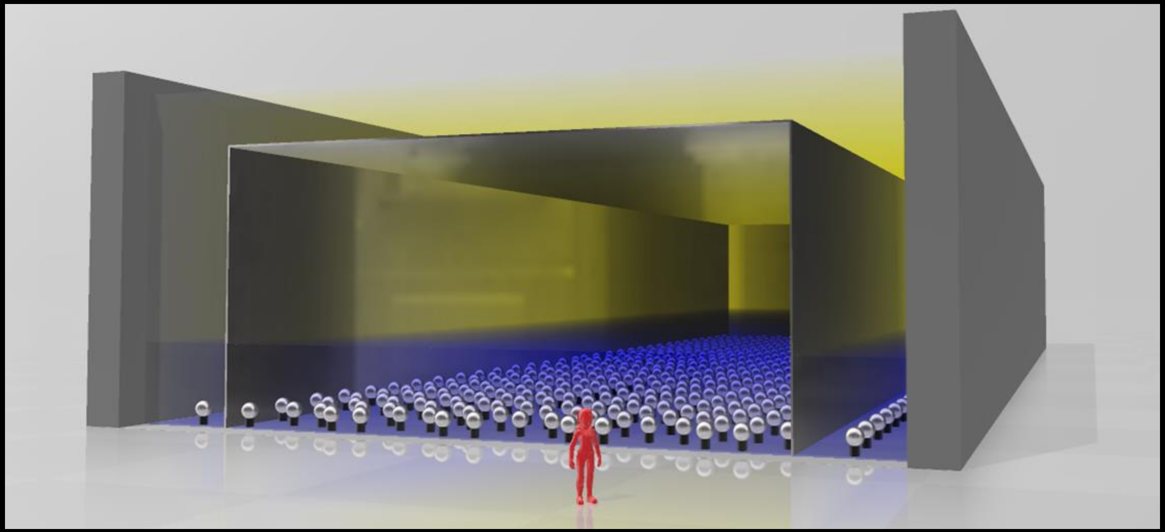
Underground Excavation : Cost Reduction





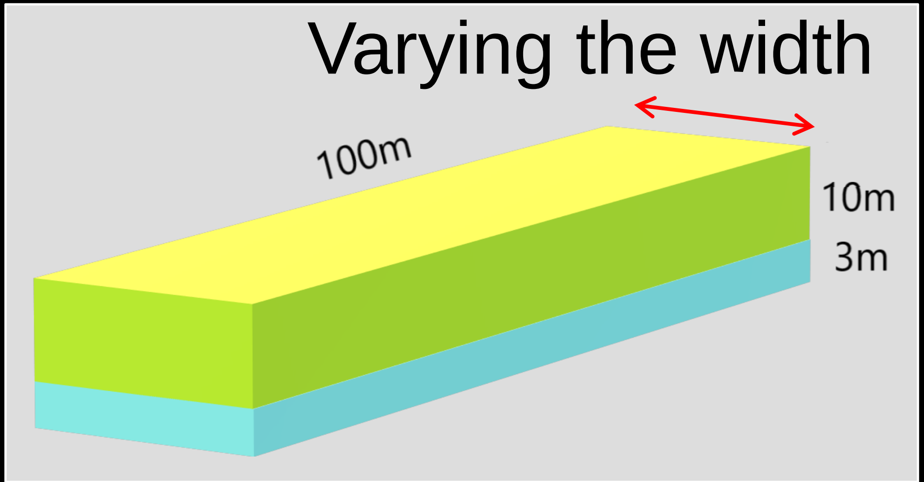


Long & narrow tunnels are cheaper
Can construct a cuboid SLIPS design

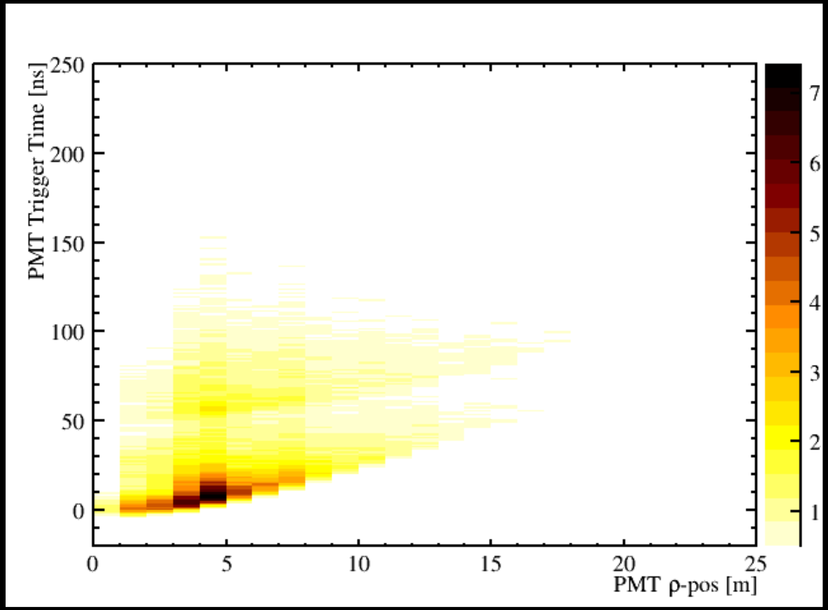


How Narrow?

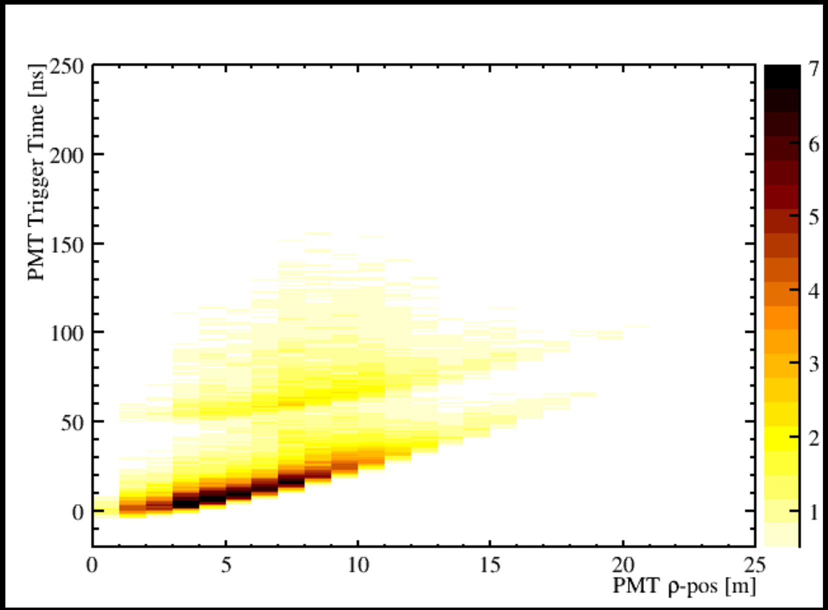
Narrower cuboid design:
More reflections → Harder reconstruction



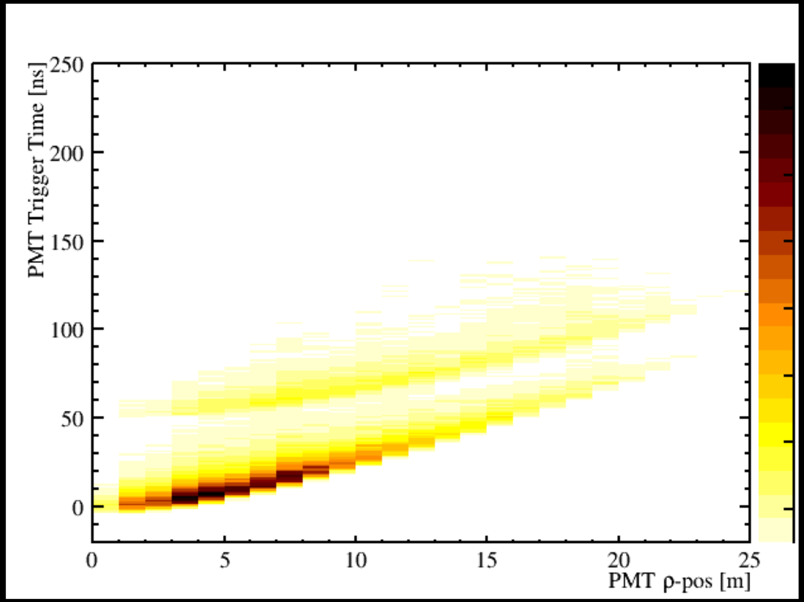
Width : 10 metres



Width : 20 metres



Width : 30 metres



Conclusion

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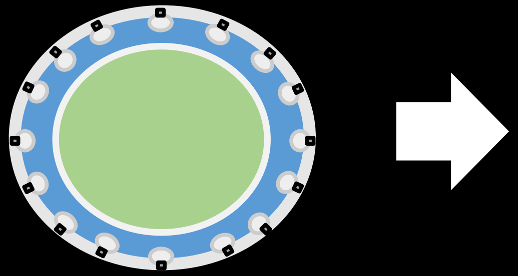

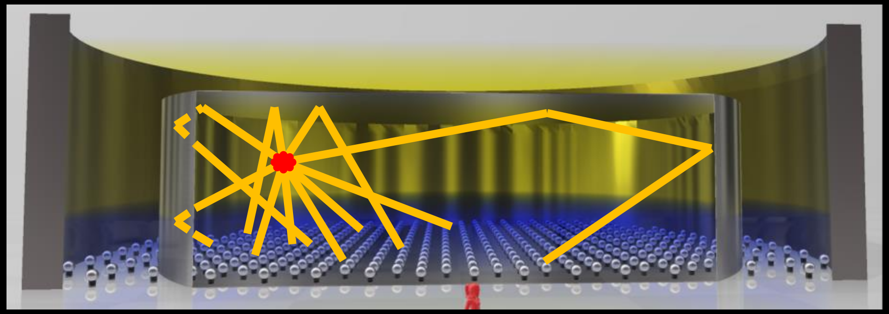

SLIPS is a cheaper and easier-to-build detectors for MeV-scale ν physics:

- Size – More cheaply increase volume
- Low backgrounds – Highly purifiable minimal materials
- Energy resolution – High light yield with good position resolution