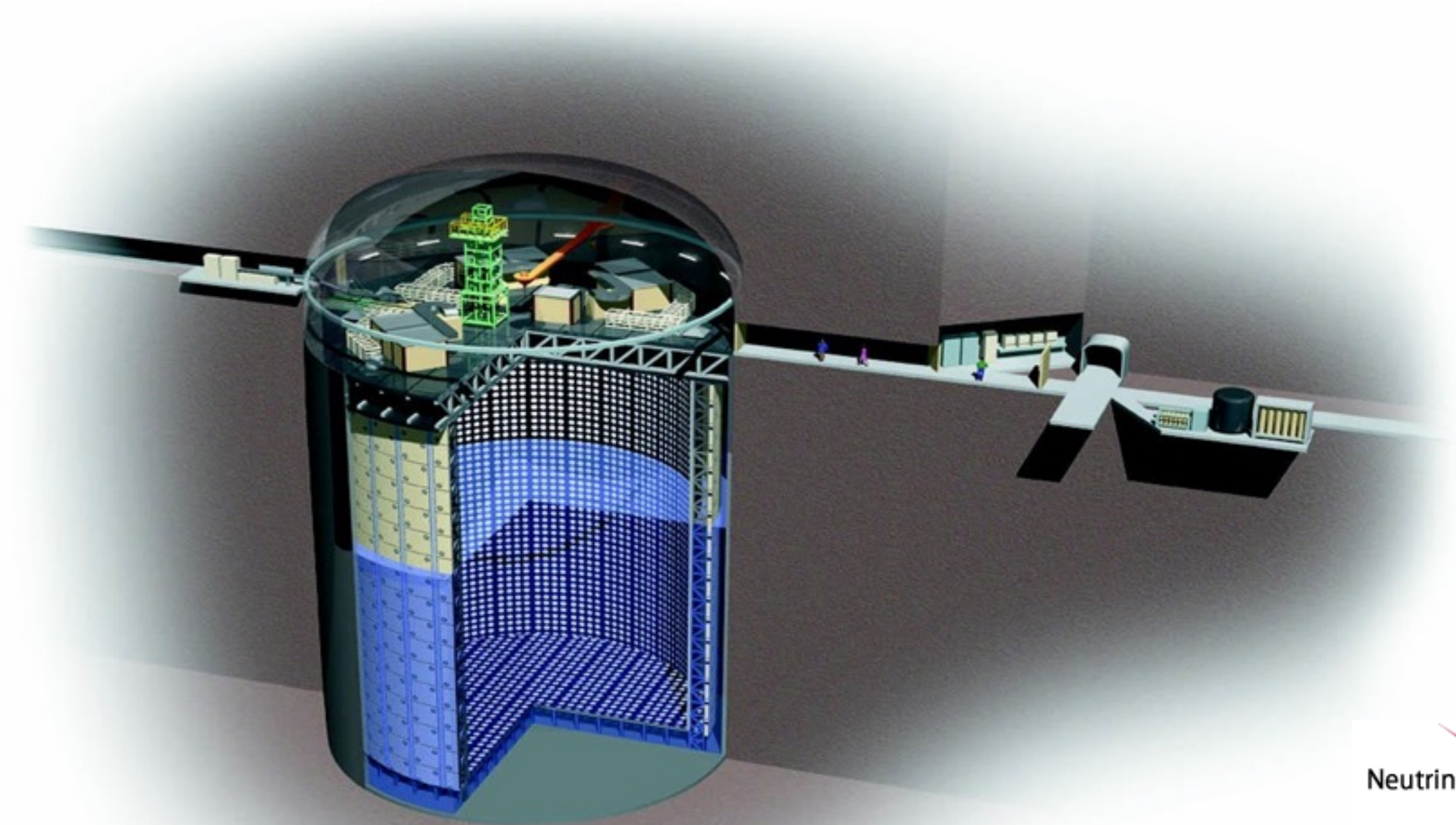
Gadolinium Doped Water Cherenkov Detectors

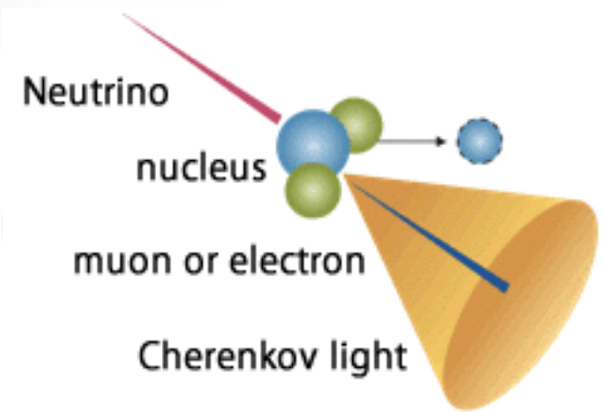
David Hadley
University of Warwick

NuInt-UK Workshop

20th July 2015

Water Cherenkov Detector





Super-Kamiokande
22.5 kt fiducial mass

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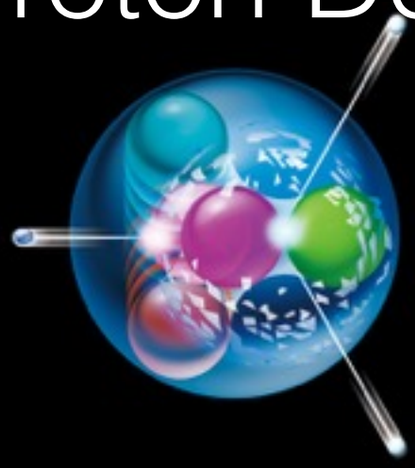
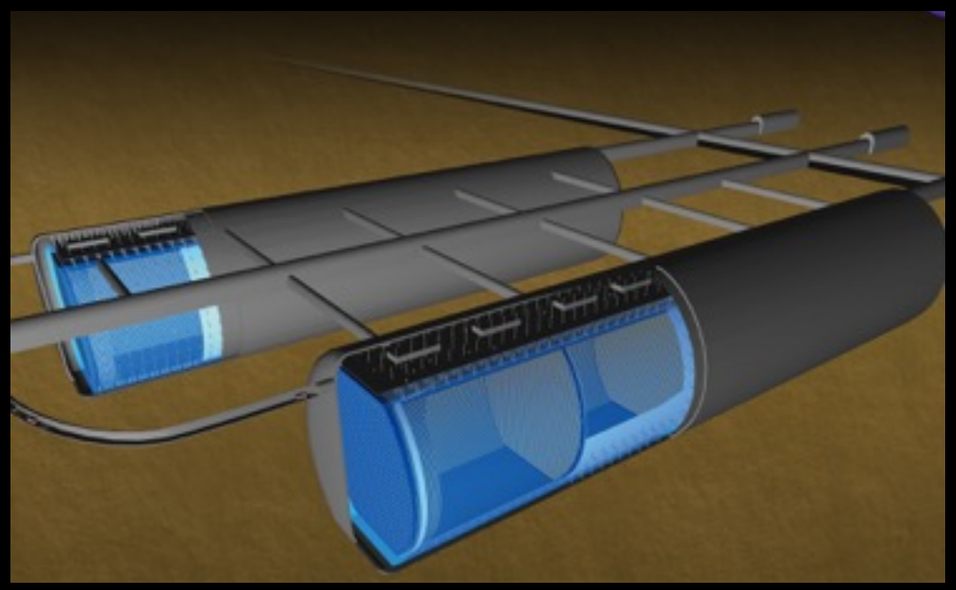
Physics with Large Scale WC

Proton Decay

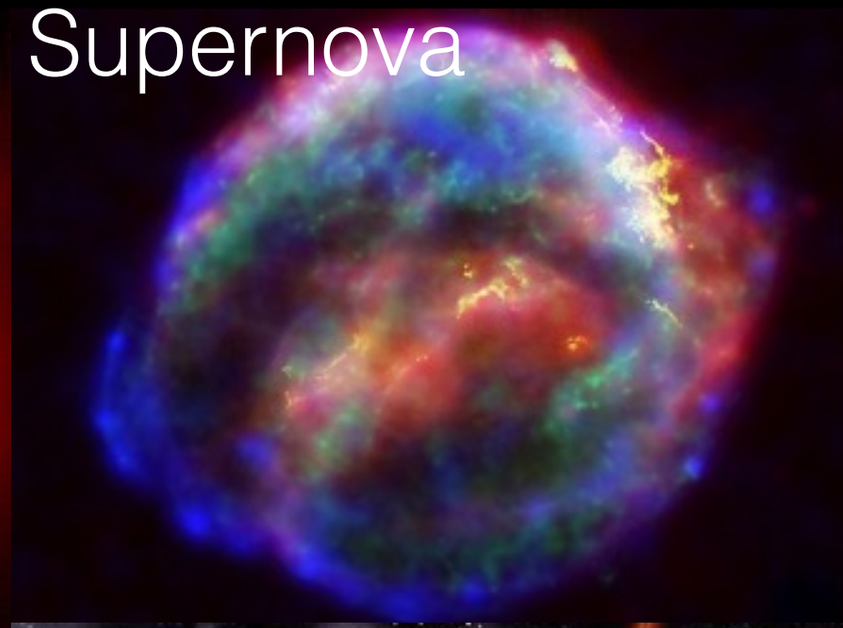




Neutrinos

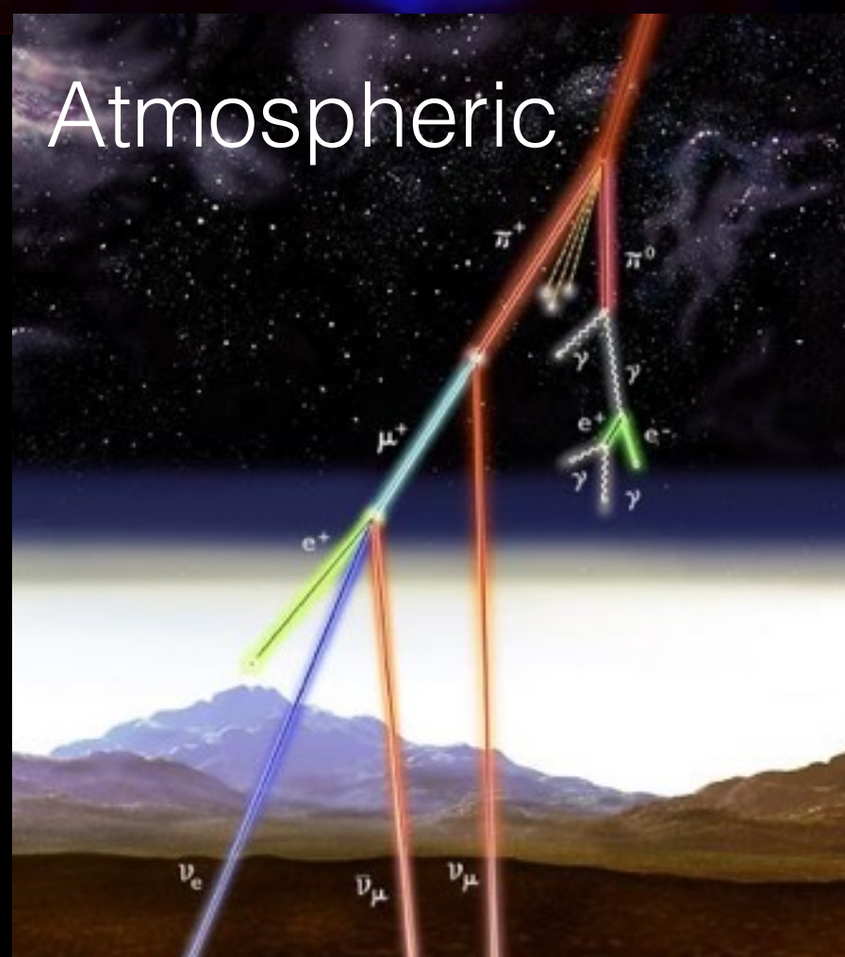
Solar

Supernova



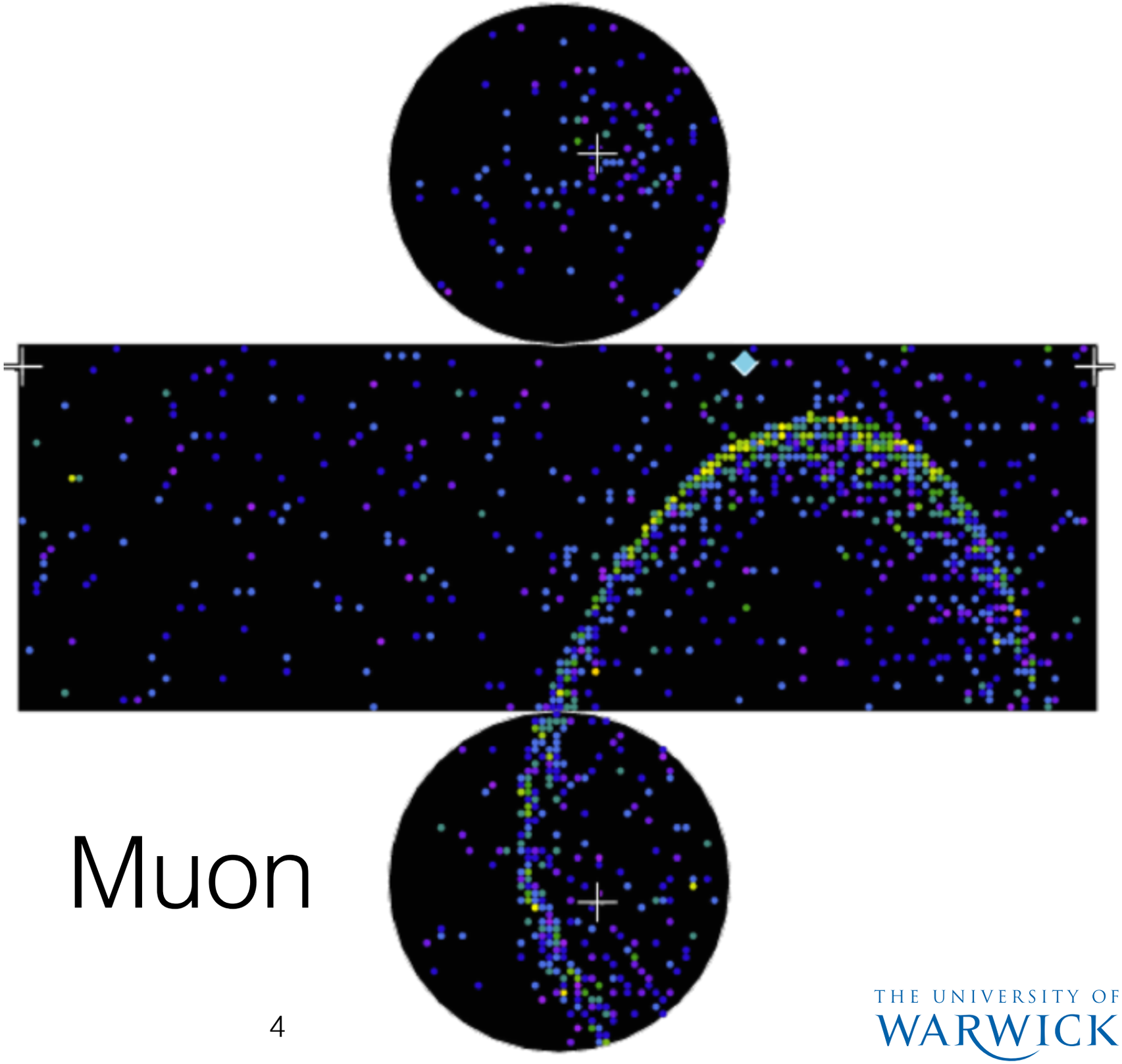
Accelerator

Atmospheric



Broad physics topics,
wide energy range

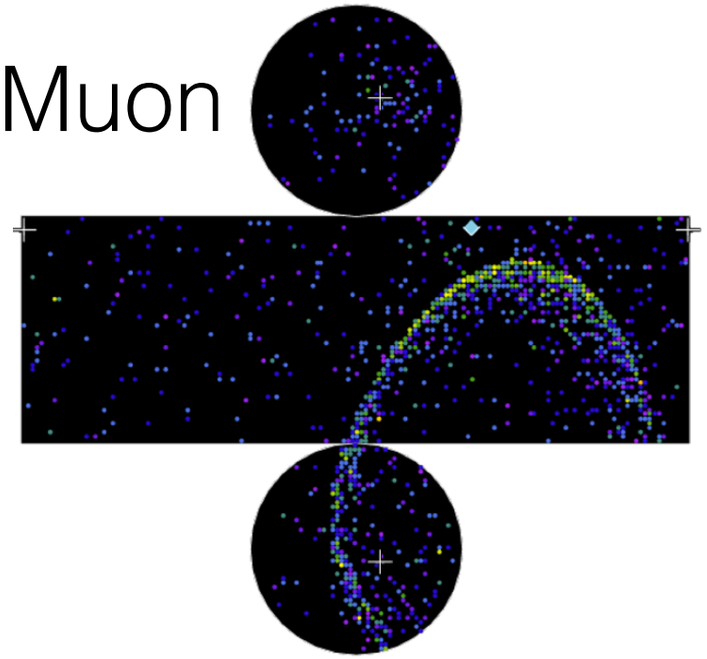
Water Cherenkov Technique

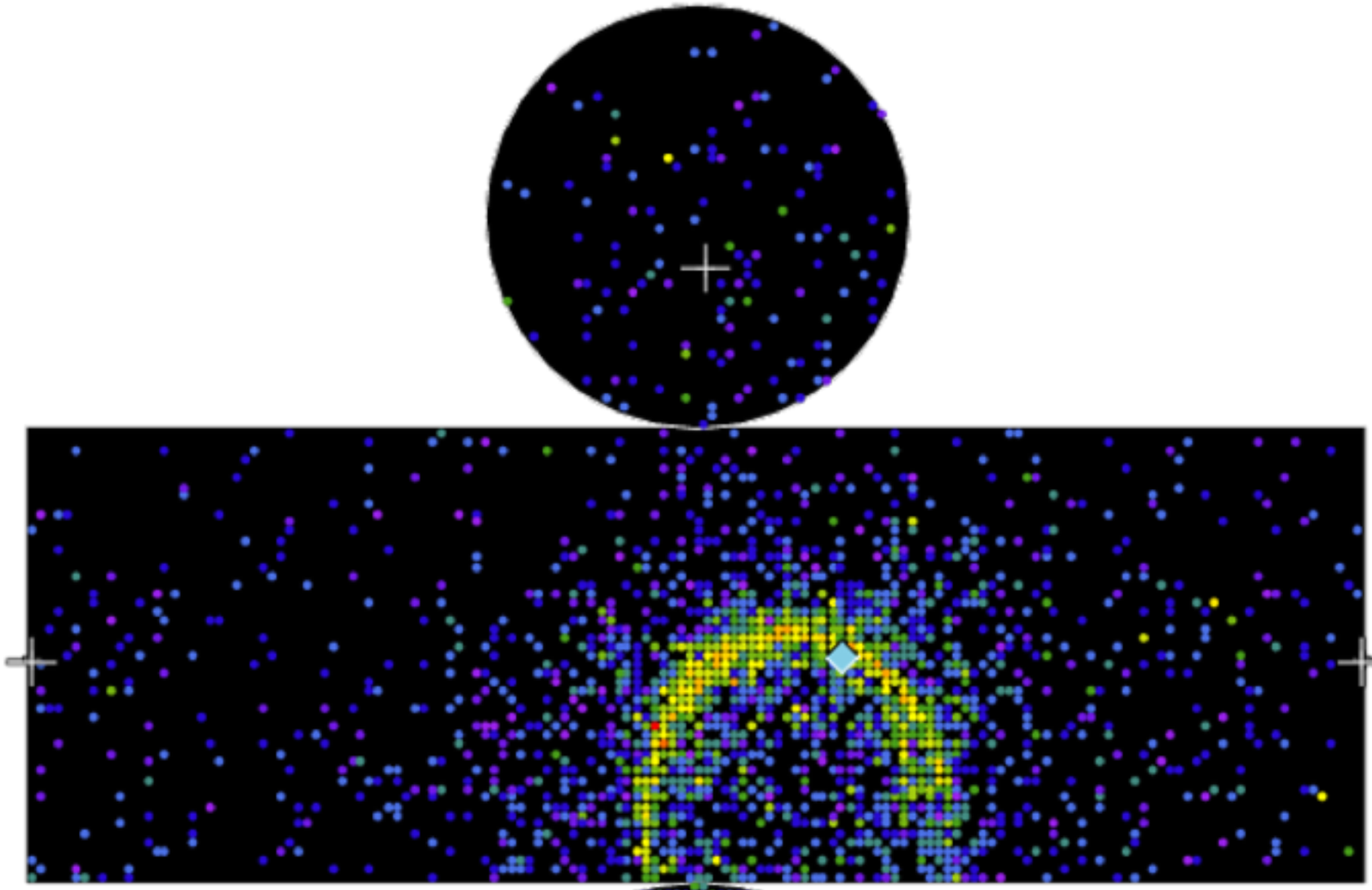


Muon

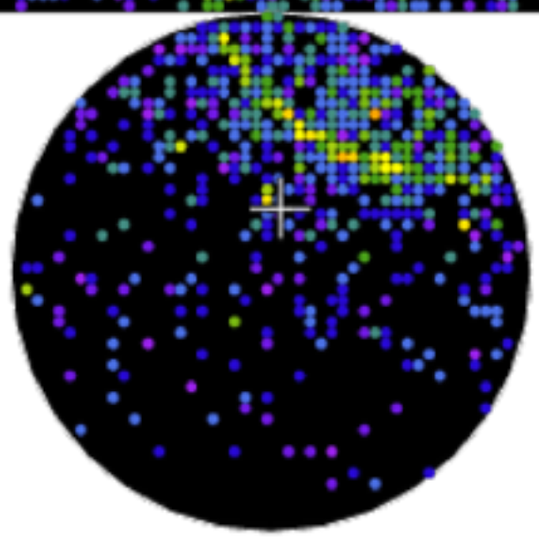
Water Cherenkov Technique

Muon



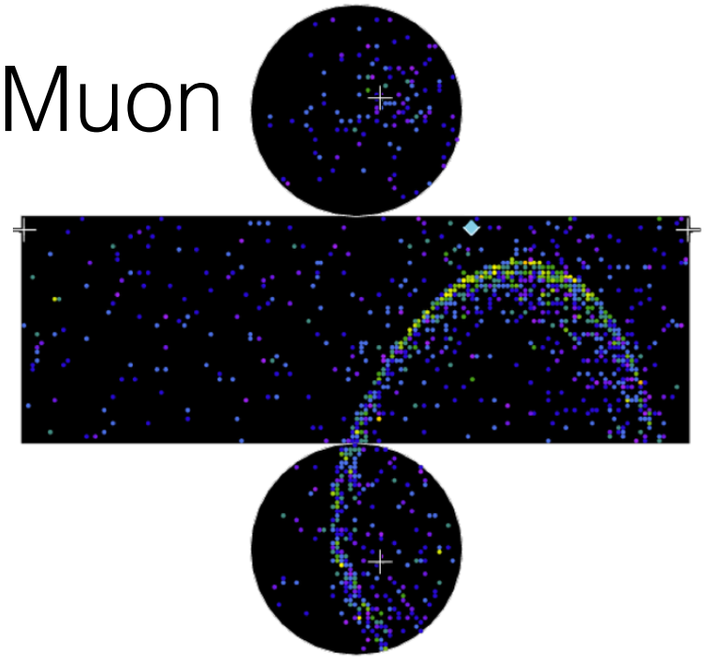


Electron

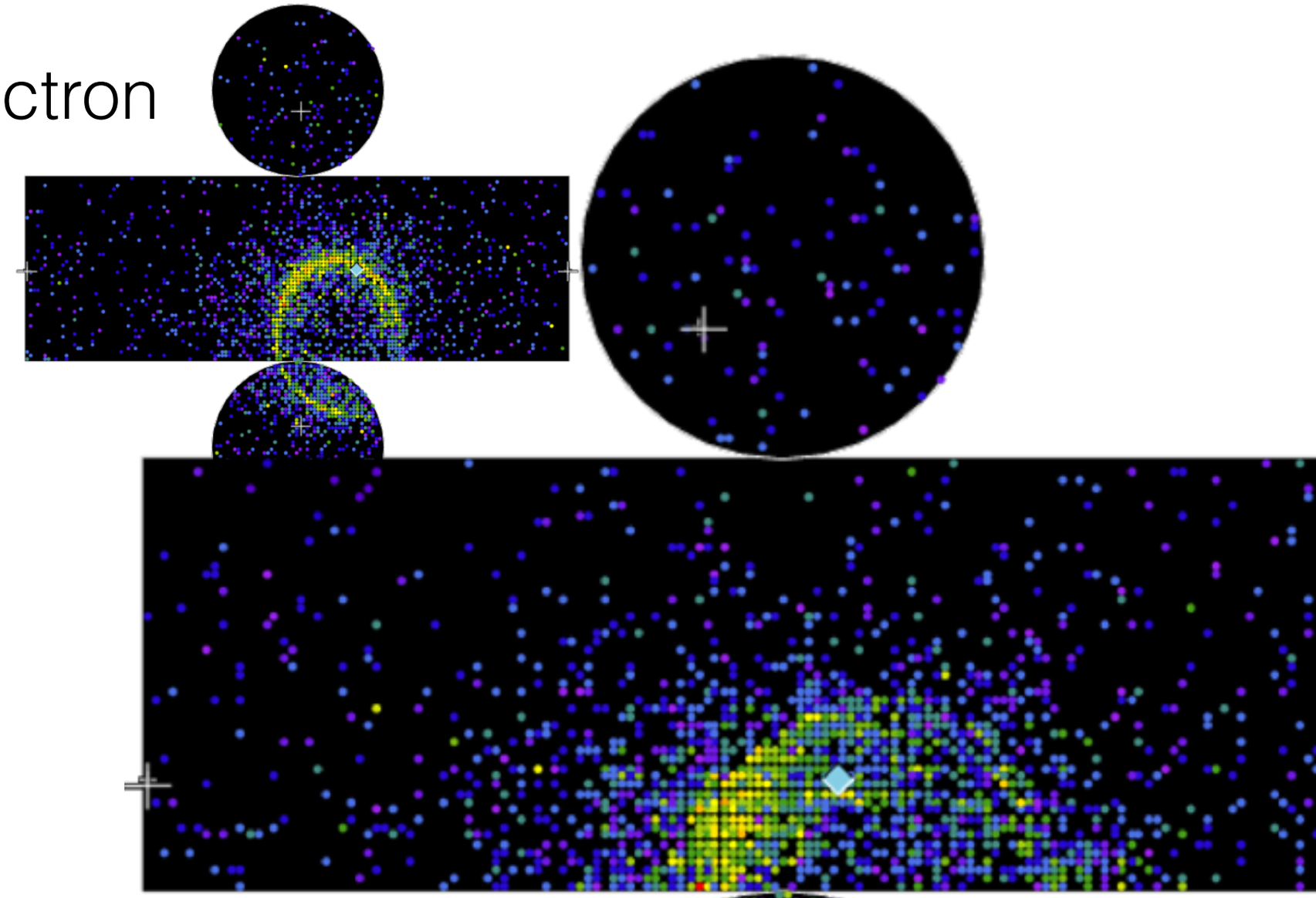


Water Cherenkov Technique

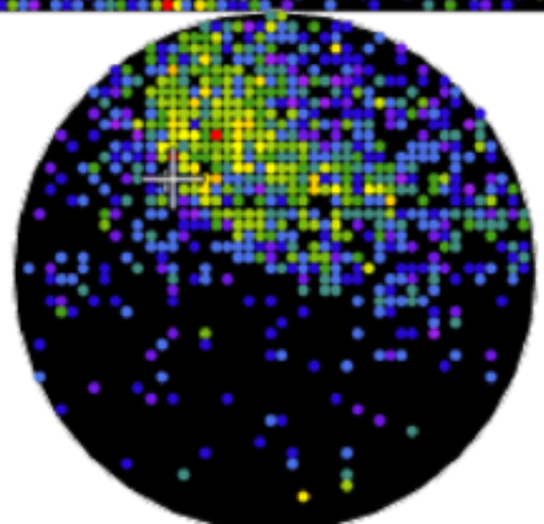
Muon



Electron

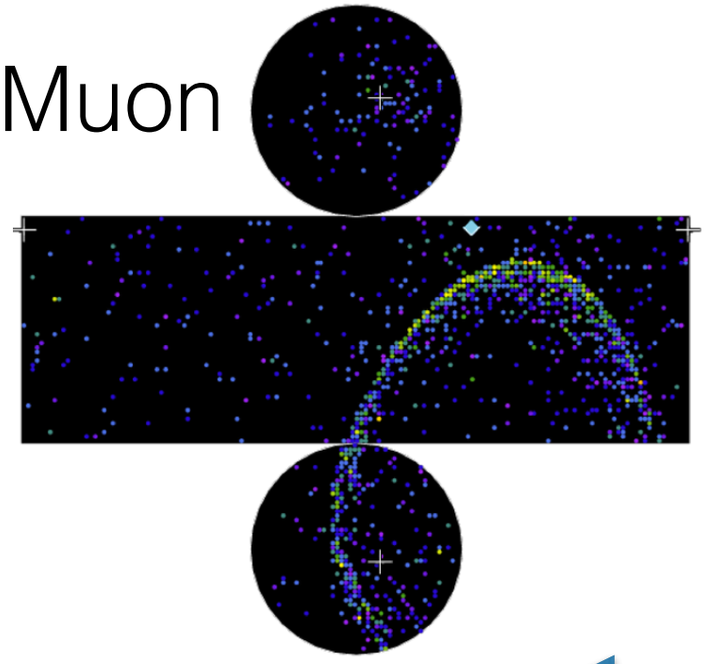


Neutral Pion

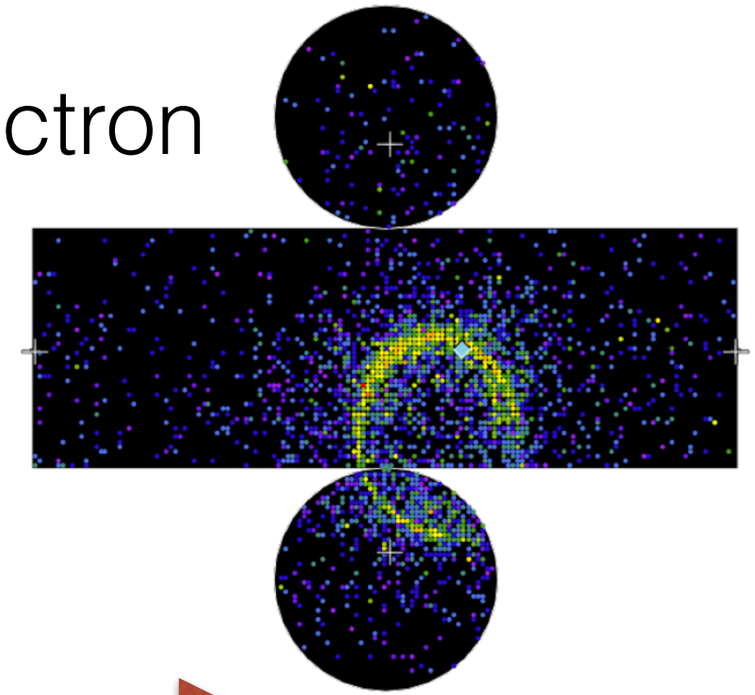


Water Cherenkov Technique

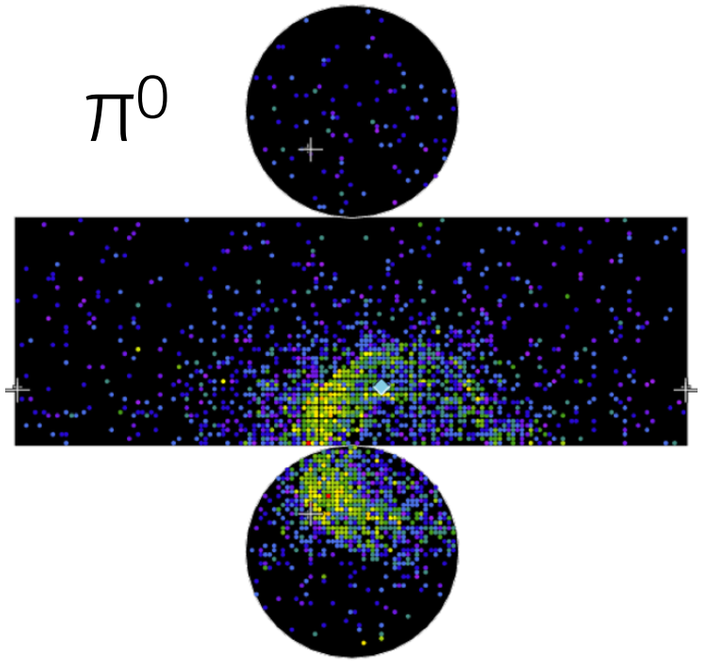
Muon

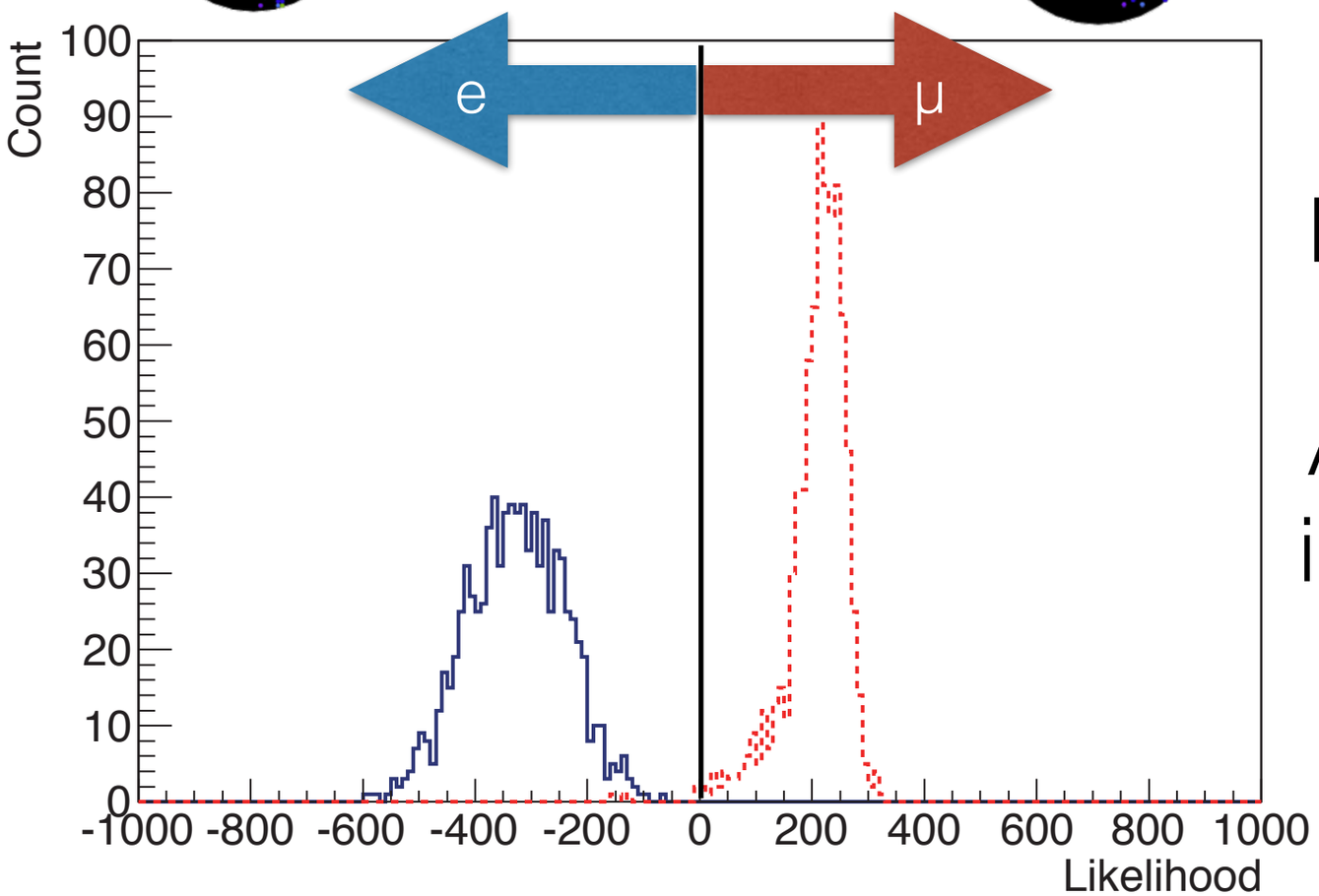


Electron



π^0





Excellent PID performance

Accelerator ν_e background is dominated by irreducible intrinsic ν_e.

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Why Water Cherenkov?

Scalability

Water is cheap, non-toxic, liquid at room temperature
long attenuation length achievable in pure water
(SK > 100m at 400nm)

Proven technology

many years of experience (eg Super-K 1996 to date)
low risk

Excellent performance

for charged particles above Cherenkov threshold

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long attenuation length achievable in pure water
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Proven technology

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low risk

Excellent performance

for charged particles above Cherenkov threshold

Why not Water Cherenkov?

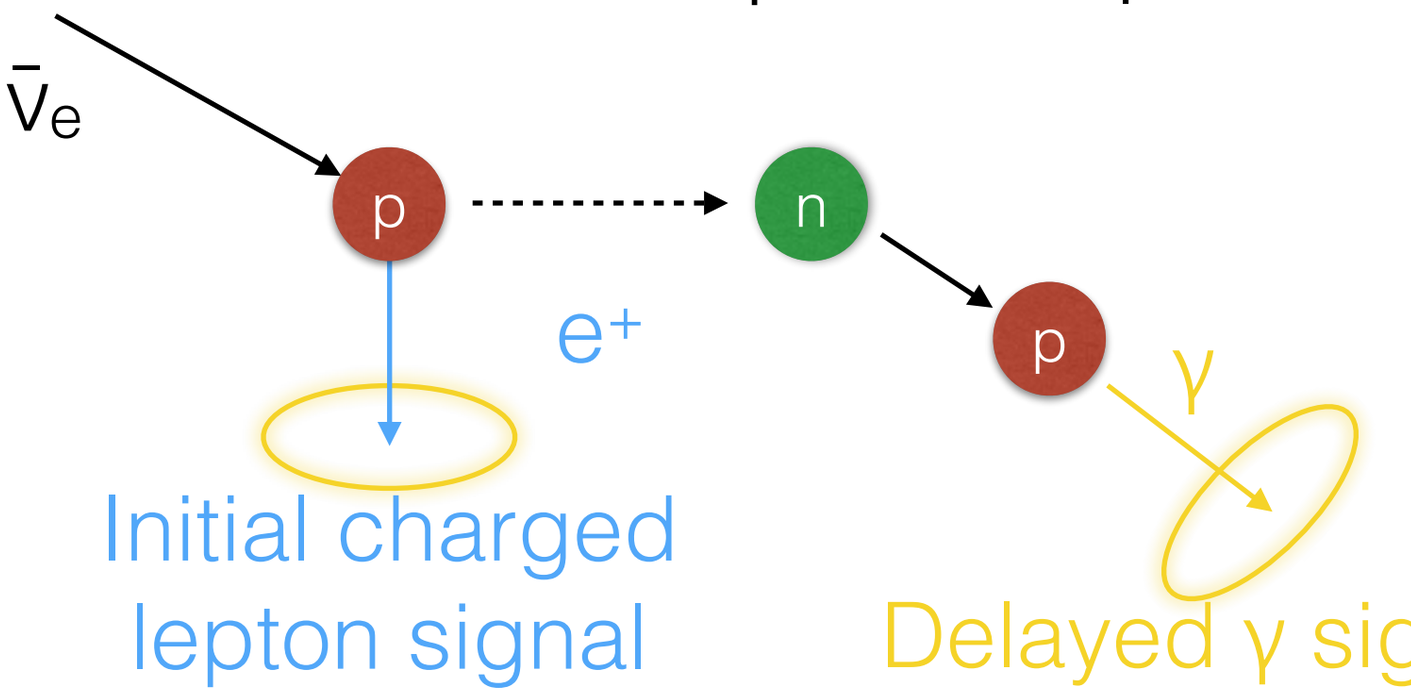
Blind to particles below Cherenkov threshold

for protons > 1.1 GeV/c.

Neutron Capture on Hydrogen

$\bar{\nu}_e + p \rightarrow e^+ + n$

$n + p \rightarrow d + \gamma$



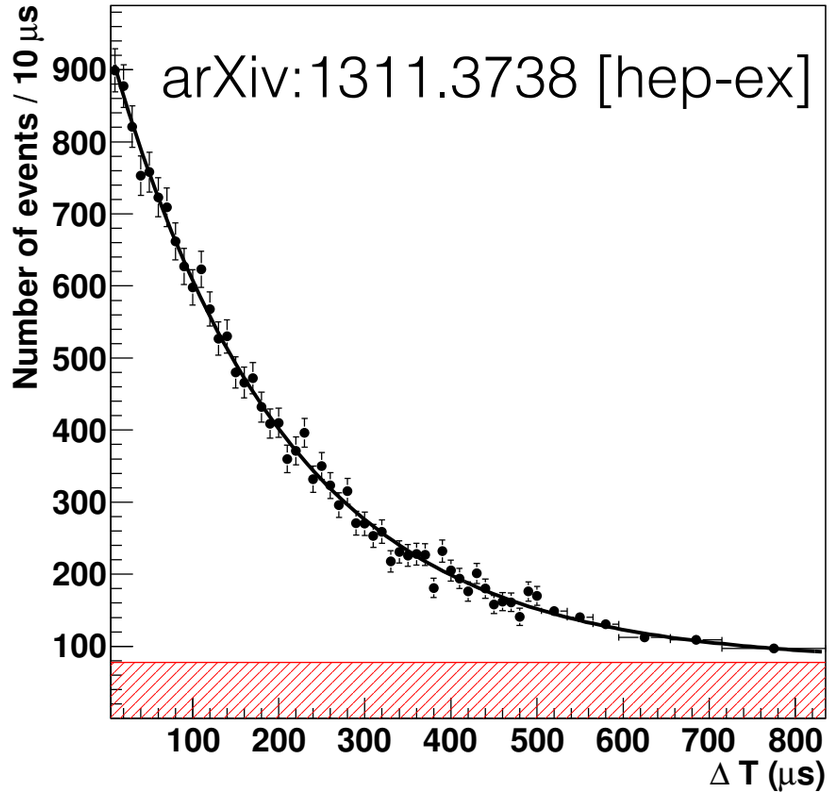
200 μs capture time

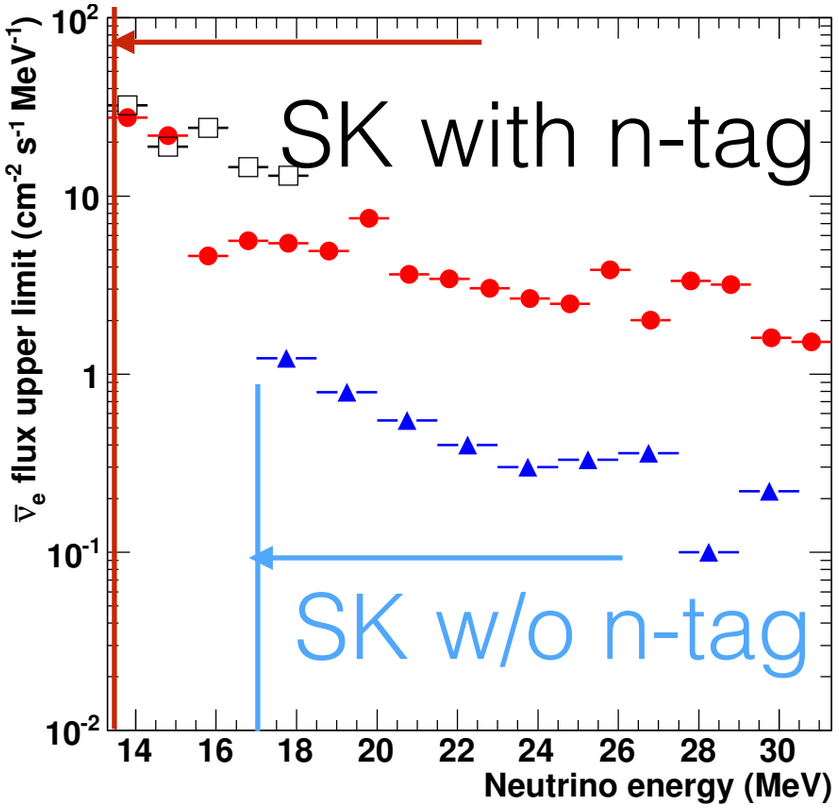
E_γ = 2.2 MeV

Low light yield

Close to or below trigger threshold

Low detection efficiency (~18%)

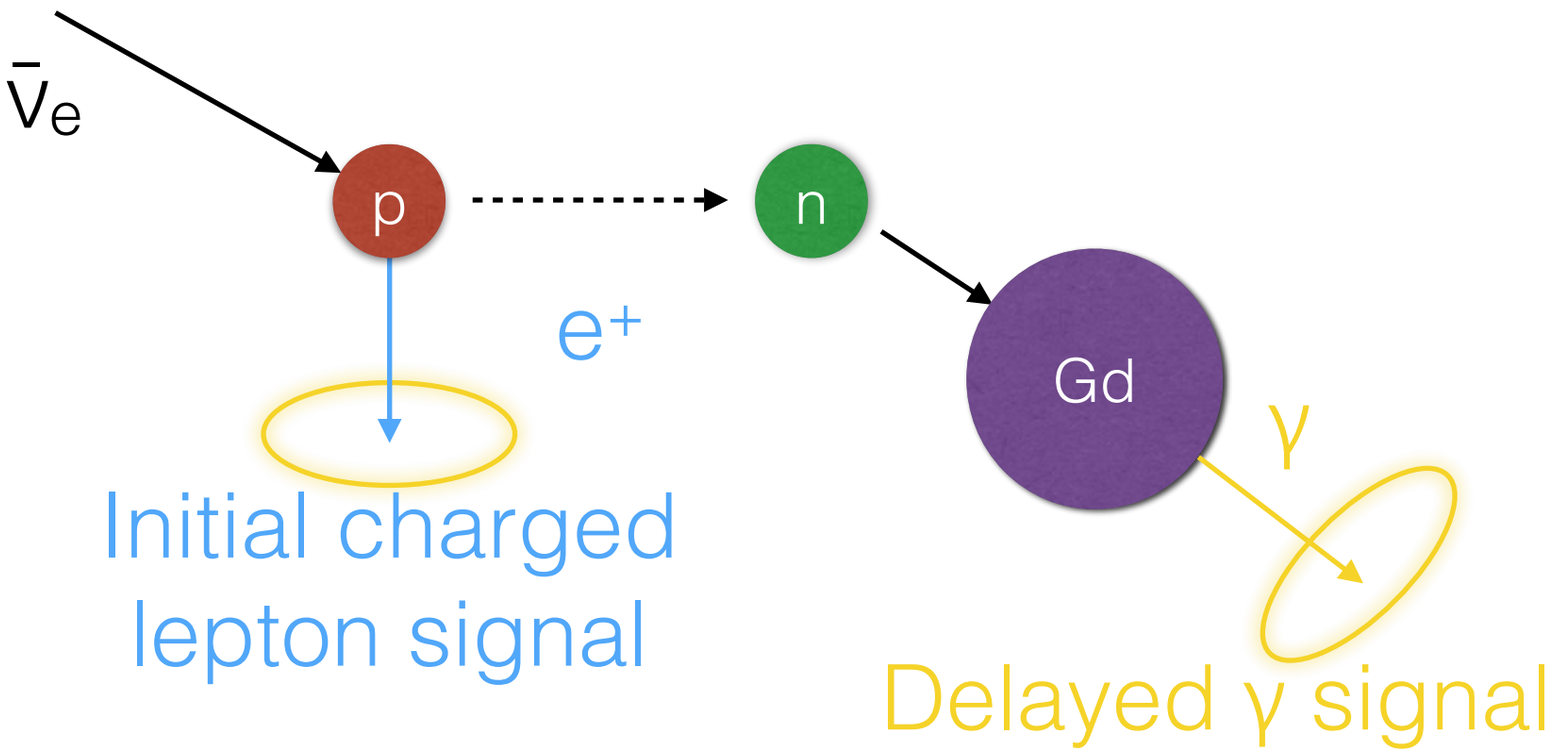


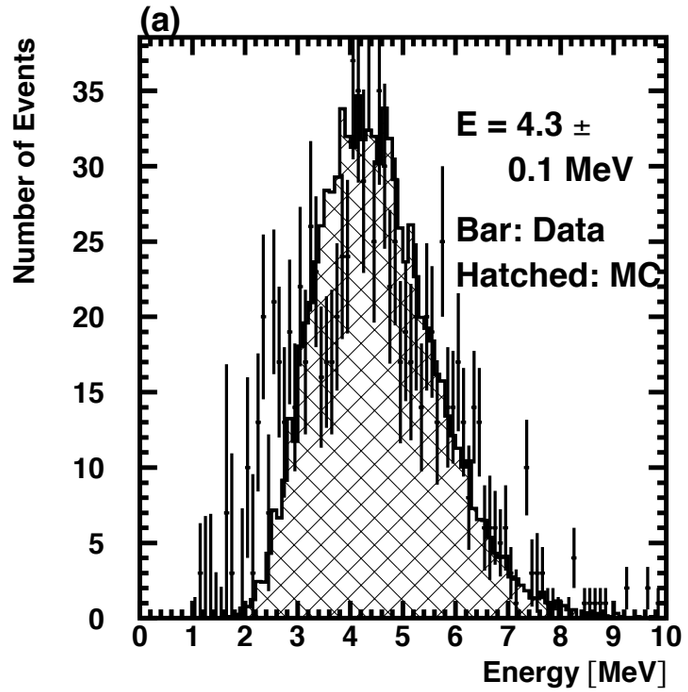


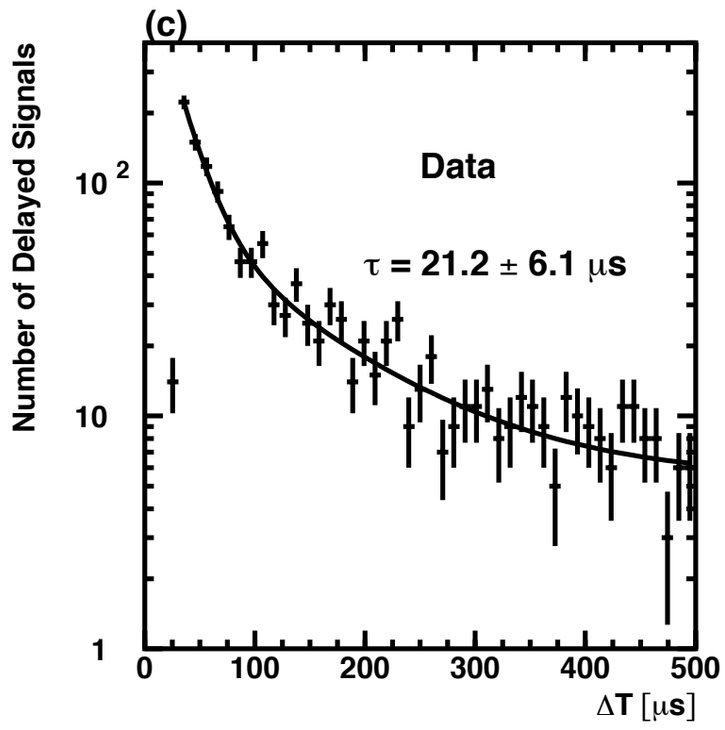
Neutron Capture on Gadolinium

arXiv:0811.0735 [hep-ex]

$\bar{\nu}_e + p \rightarrow e^+ + n$







20 μs capture time

E_γ ~ 8 MeV cascade (~4 MeV visible)

Fast capture time (small ΔT window)

Higher energy γ signal

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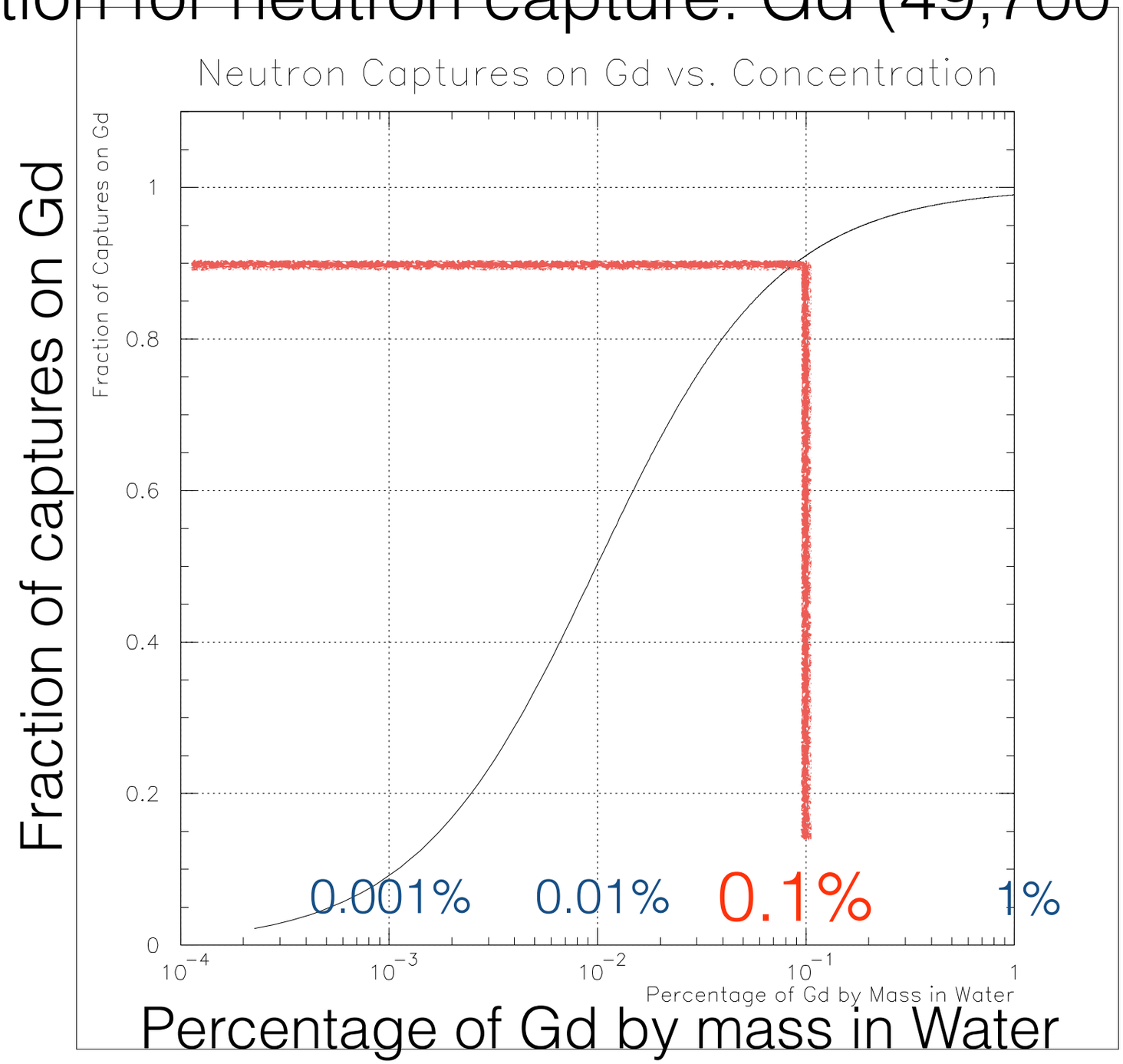
Neutron Capture on Gadolinium

Cross section for neutron capture: Gd (49,700 b), H (0.3 b)



0.1% Gd fraction gives 90% neutrons captured on Gd.

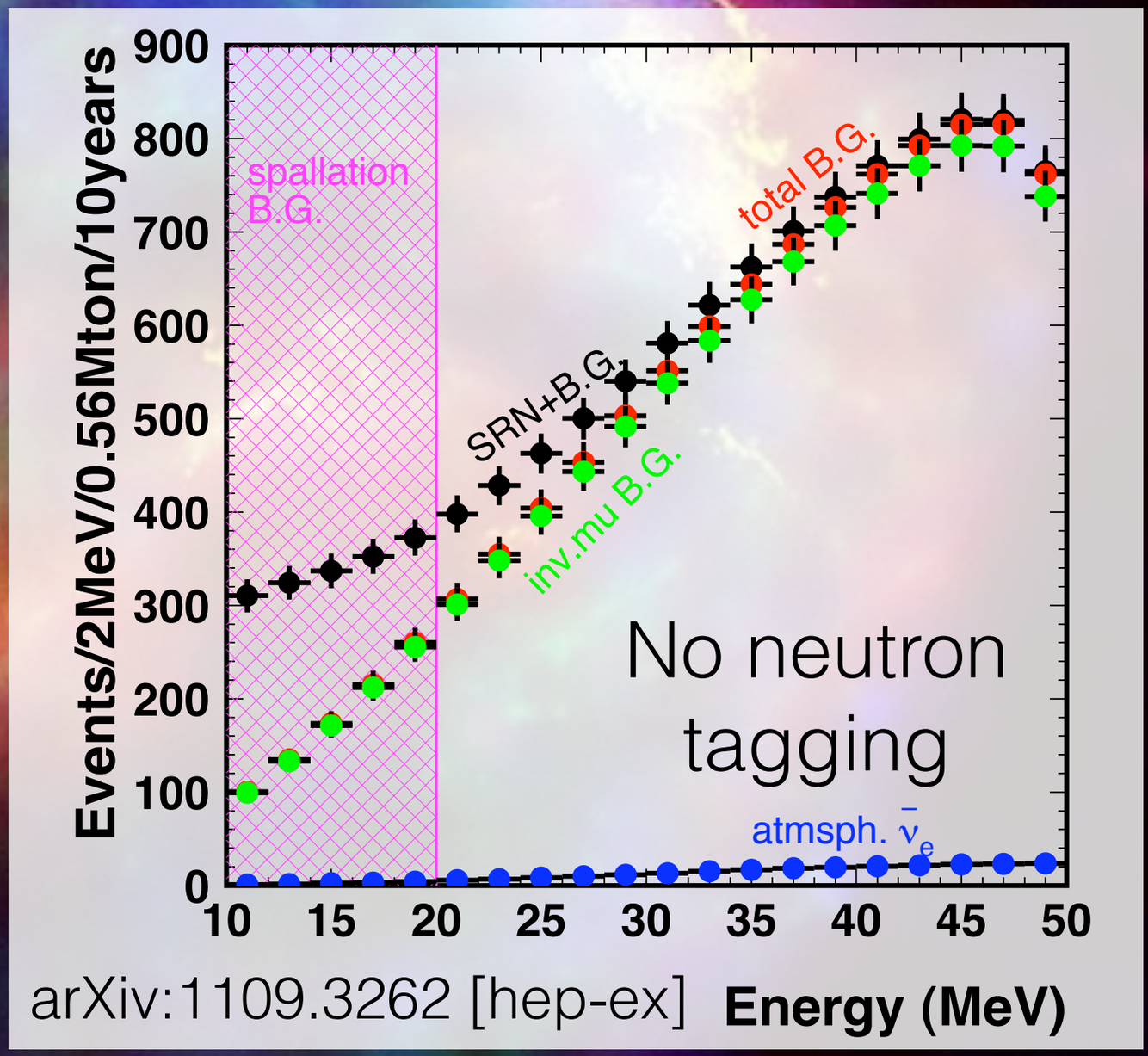
Applications: Supernova Relic Neutrinos

A low energy example

Directly observable local supernova are all too rare

Alternative is to measure diffuse supernova background DSNB/SRN

Very low rate
Large backgrounds



arXiv:1109.3262 [hep-ex]

Applications: Supernova Relic Neutrinos

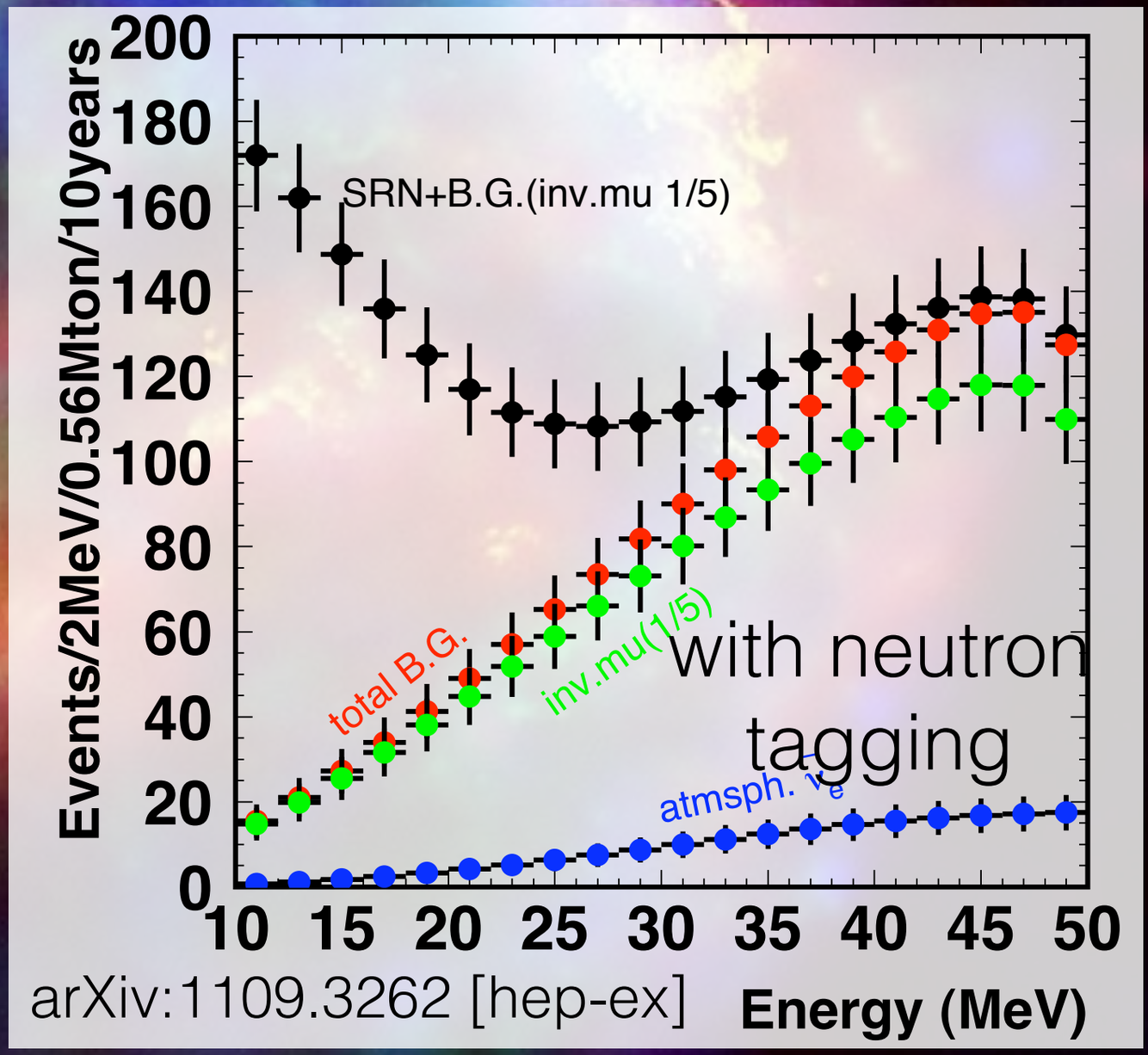
A low energy example

Directly observable local supernova are all too rare

Alternative is to measure diffuse supernova background DSNB/SRN

Very low rate
Large backgrounds

Removed by requiring coincidence with neutron



A few clean events per year in SK
~100s per year in HK

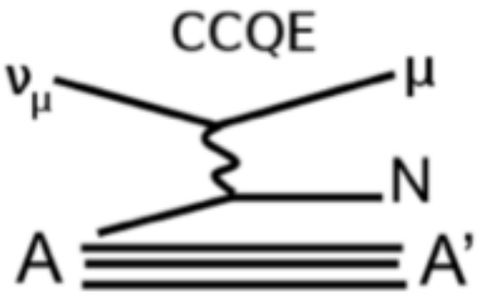
Applications: Accelerator based long baseline neutrino oscillations

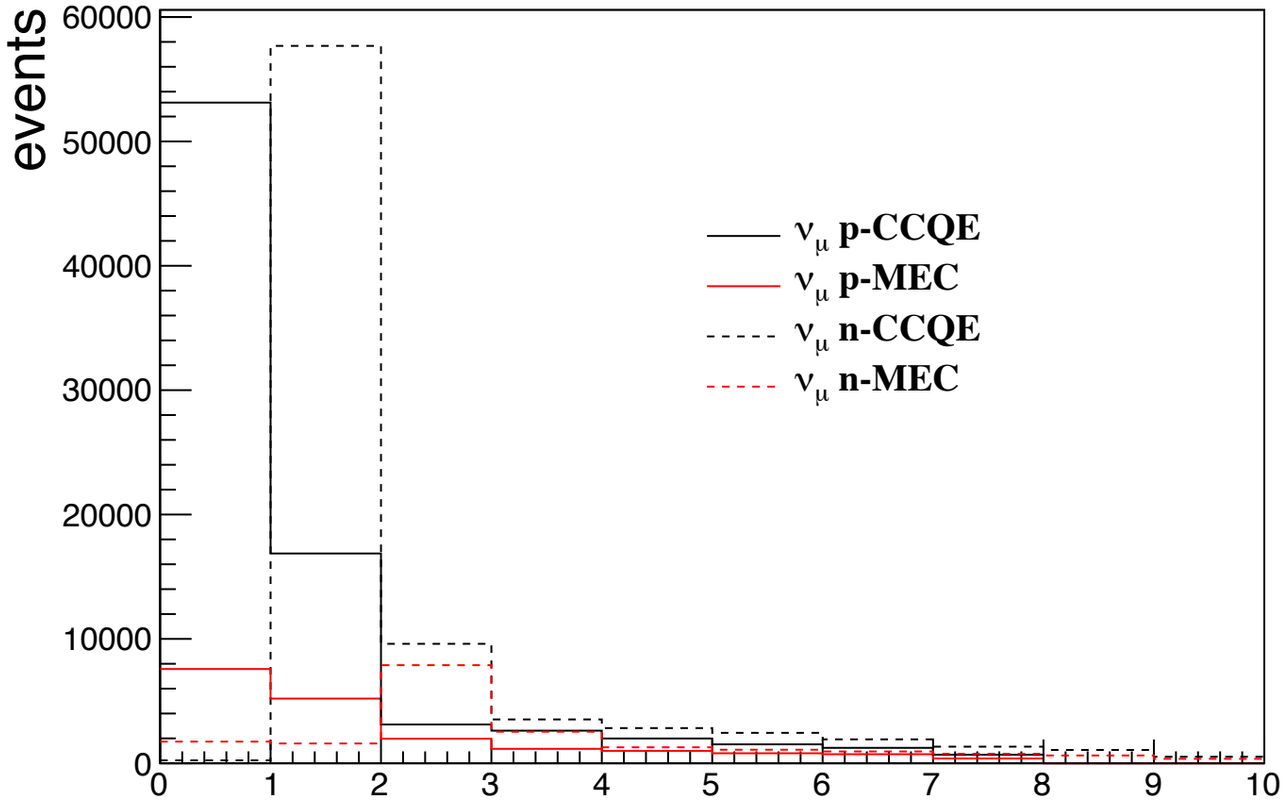
A high energy example

T2K / T2HK neutrino beam energy ~ 0.6 GeV

Signal: ν CCQE: $\nu + n \rightarrow l^- + p$

$\bar{\nu}$ CCQE: $\bar{\nu} + p \rightarrow l^+ + n$

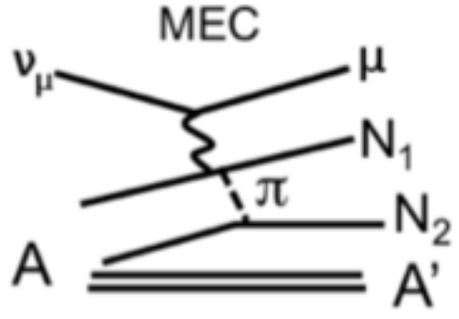




Multi-nucleon:

$\nu + (nn) \rightarrow l^- + p + n$

$\nu + (p\ p/n) \rightarrow l^+ + n + p/n$

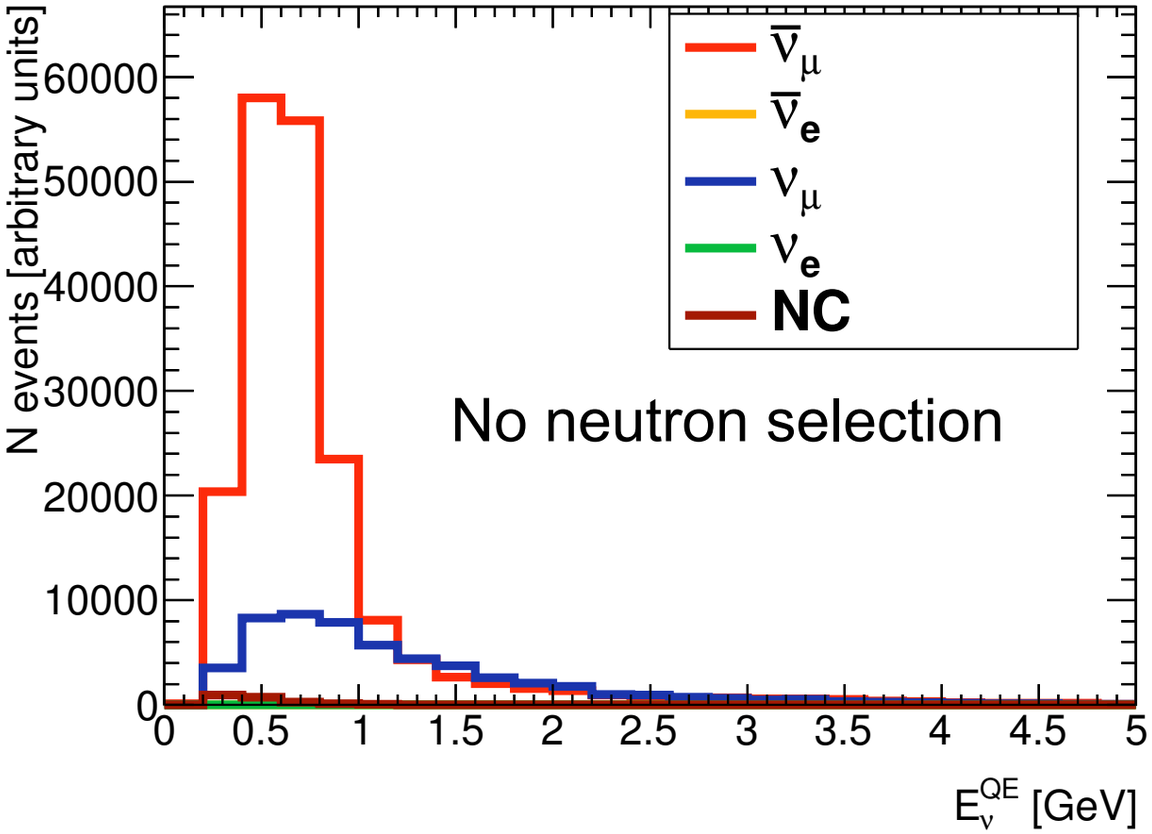


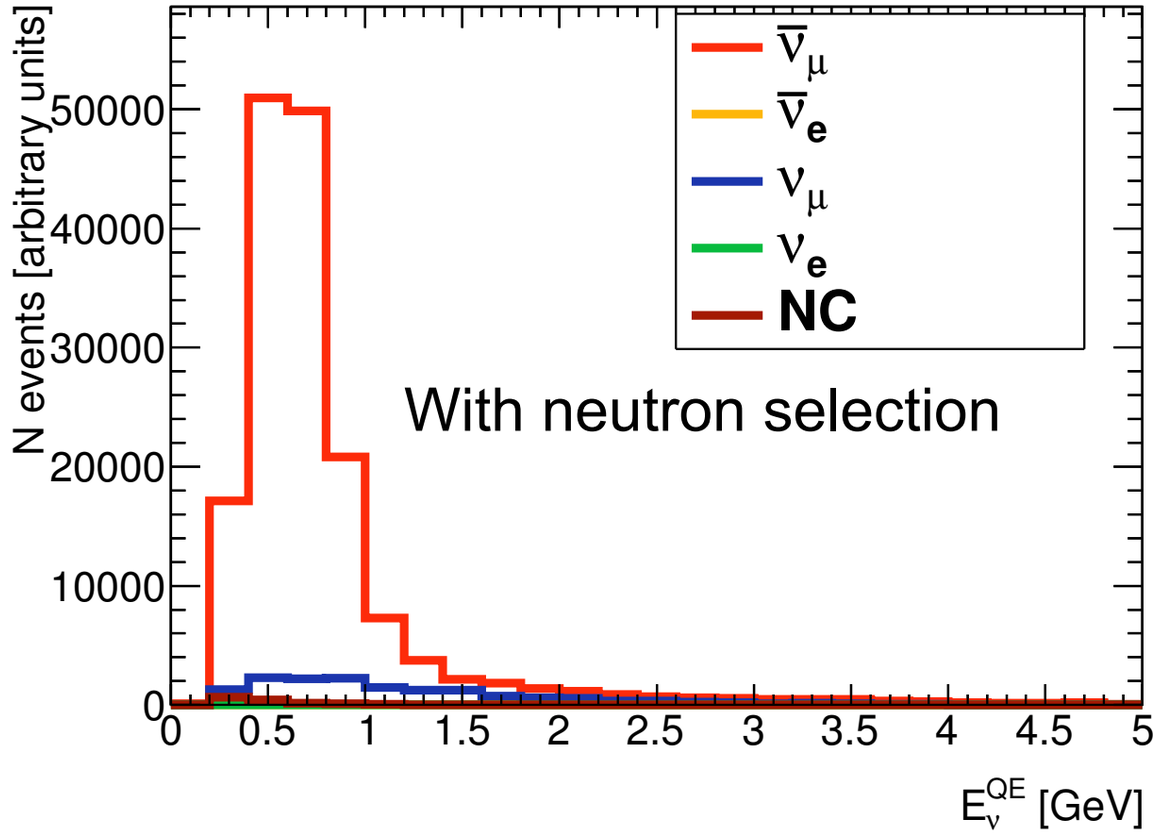
Neutron multiplicity gives an additional observable with which to isolate interaction modes.

Complimentary to LAr proton measurements

Applications: Accelerator based long baseline neutrino oscillations

Tagging neutron reduces wrong-sign background in anti-neutrino mode



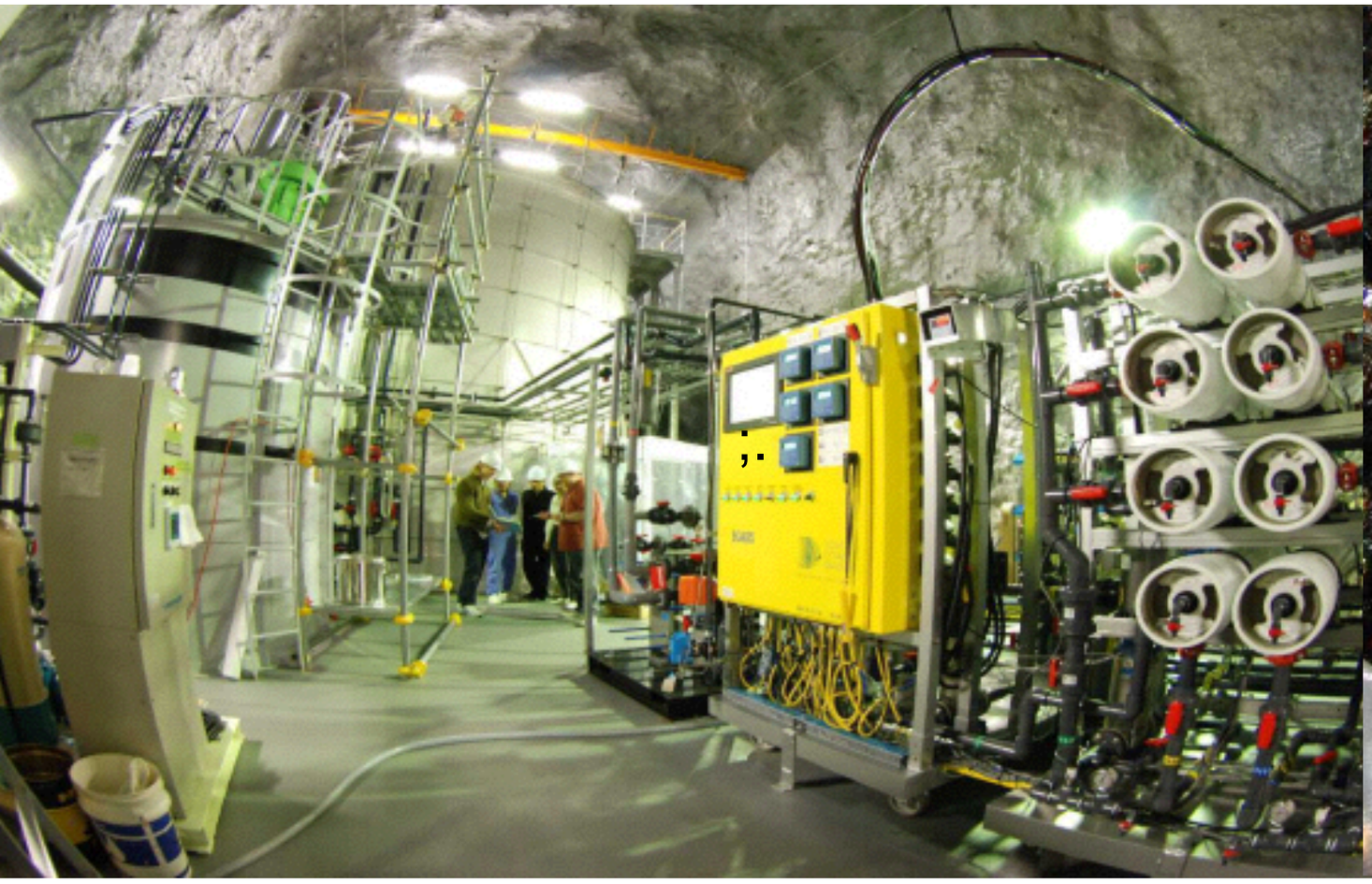


Impact on sensitivity being evaluated by Hyper-K Gd-doped Near Detector (TITUS) working group

EGADs

(Evaluating Gadolinium's Action on Detector Systems)

200 t instrumented Water Cherenkov detector to test introduction of a water soluble Gadolinium in a $Gd(SO_4)_3$

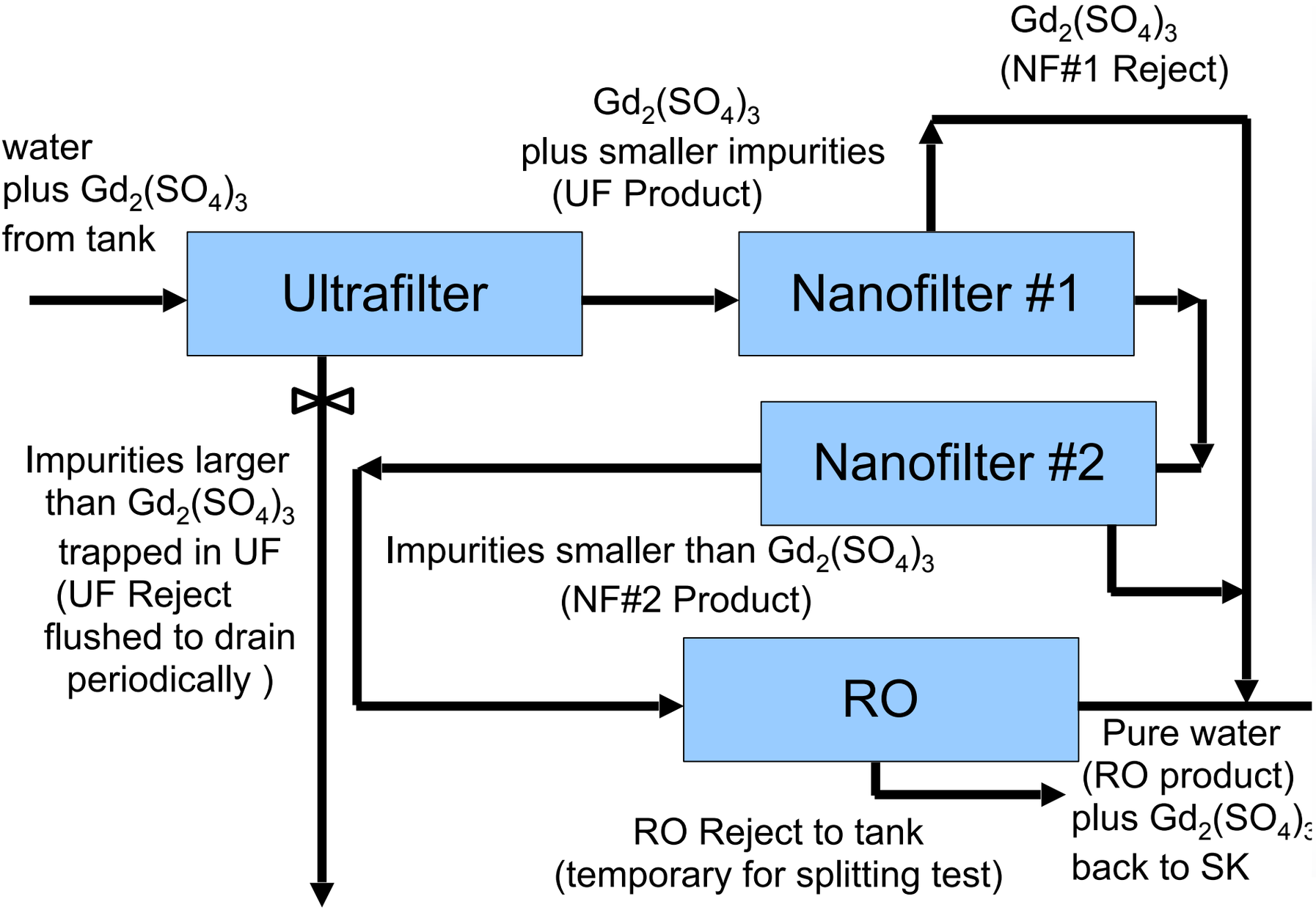


arXiv:1201.1017 [physics.ins-det]

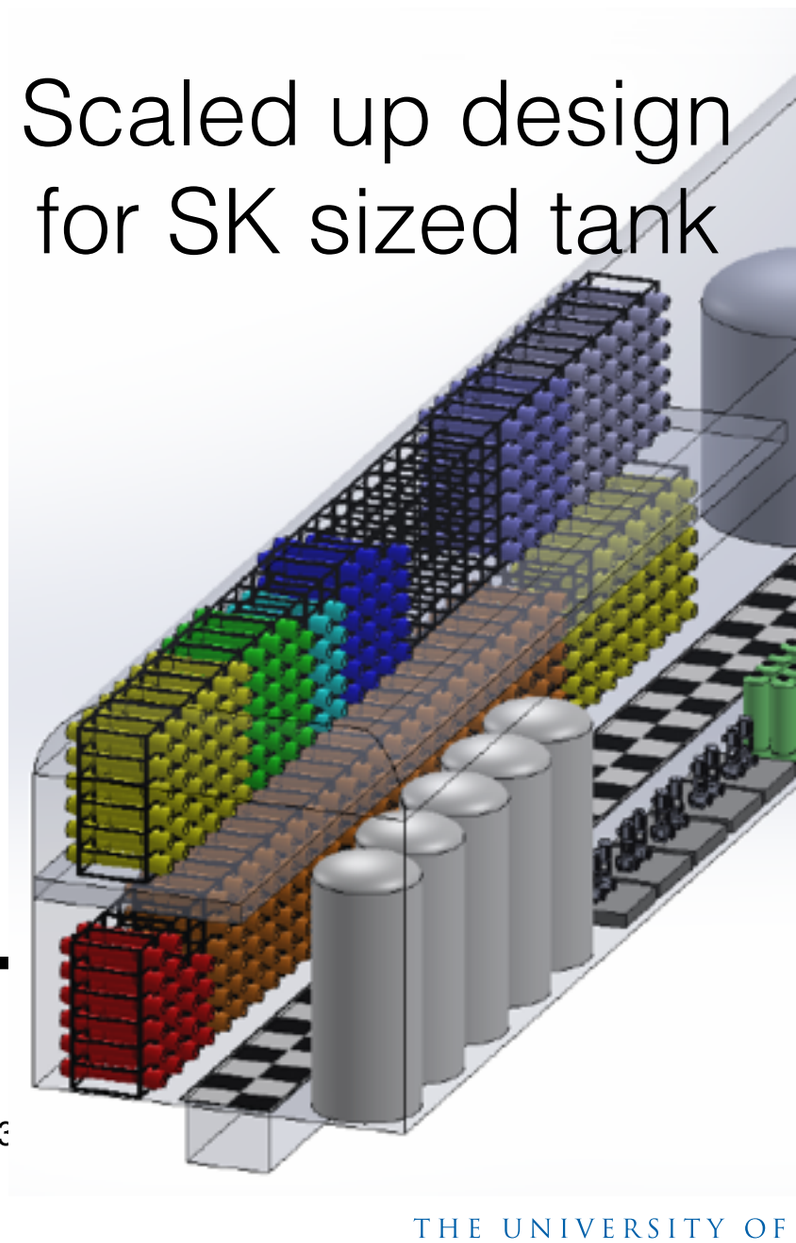
EGADs

(Evaluating Gadolinium's Action on Detector Systems)

Need a water filtration system that removes impurities but not $Gd(SO_4)_3$



Scaled up design for SK sized tank



arXiv:1201.1017 [physics.ins-det]

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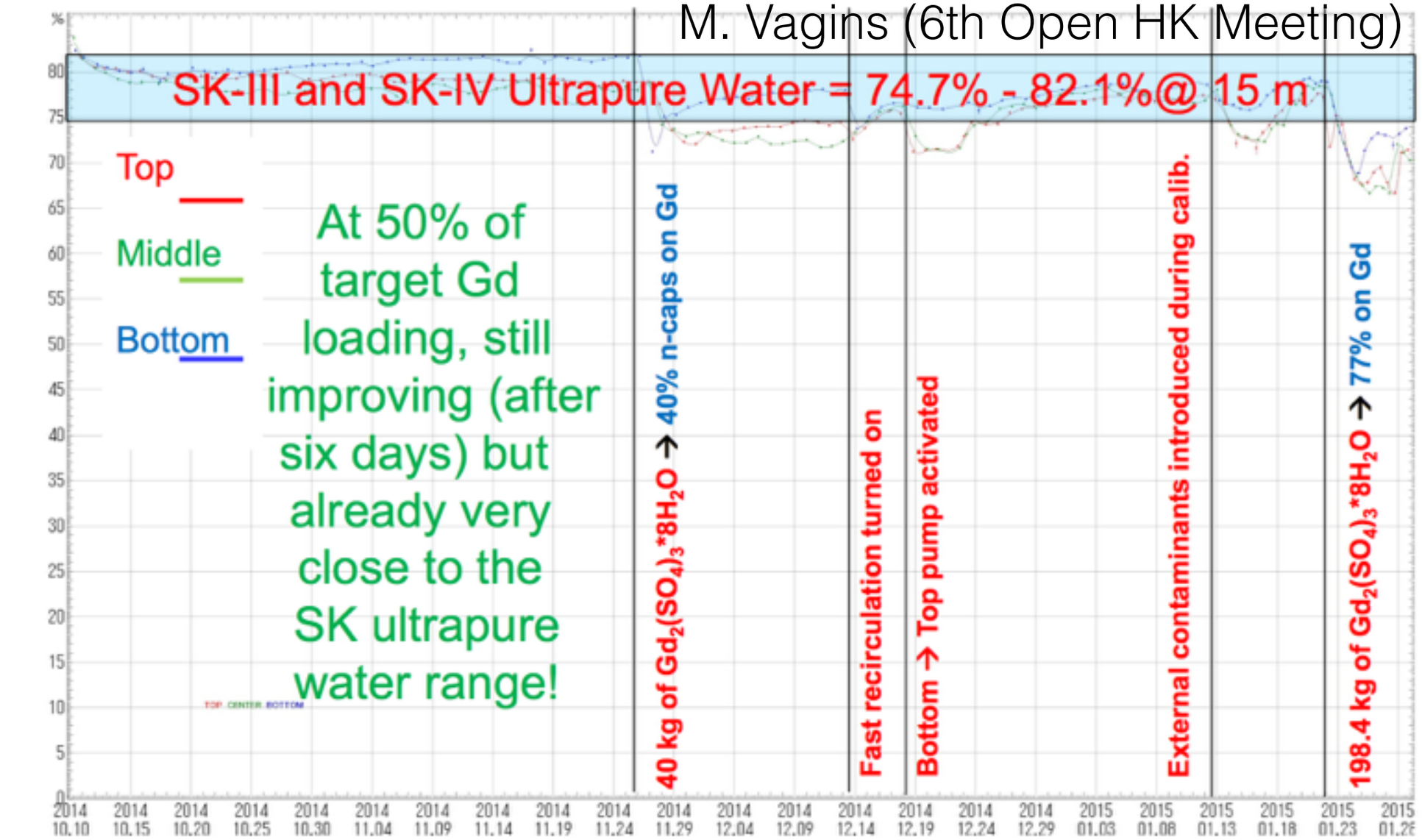
EGADs

(Evaluating Gadolinium's Action on Detector Systems)

Light @ 15 meters in the 200-ton tank (Gd water with PMT's)

M. Vagins (6th Open HK Meeting)



Oct. 10, 2014 **Dec. 4, 2014** **Jan. 29, 2015**

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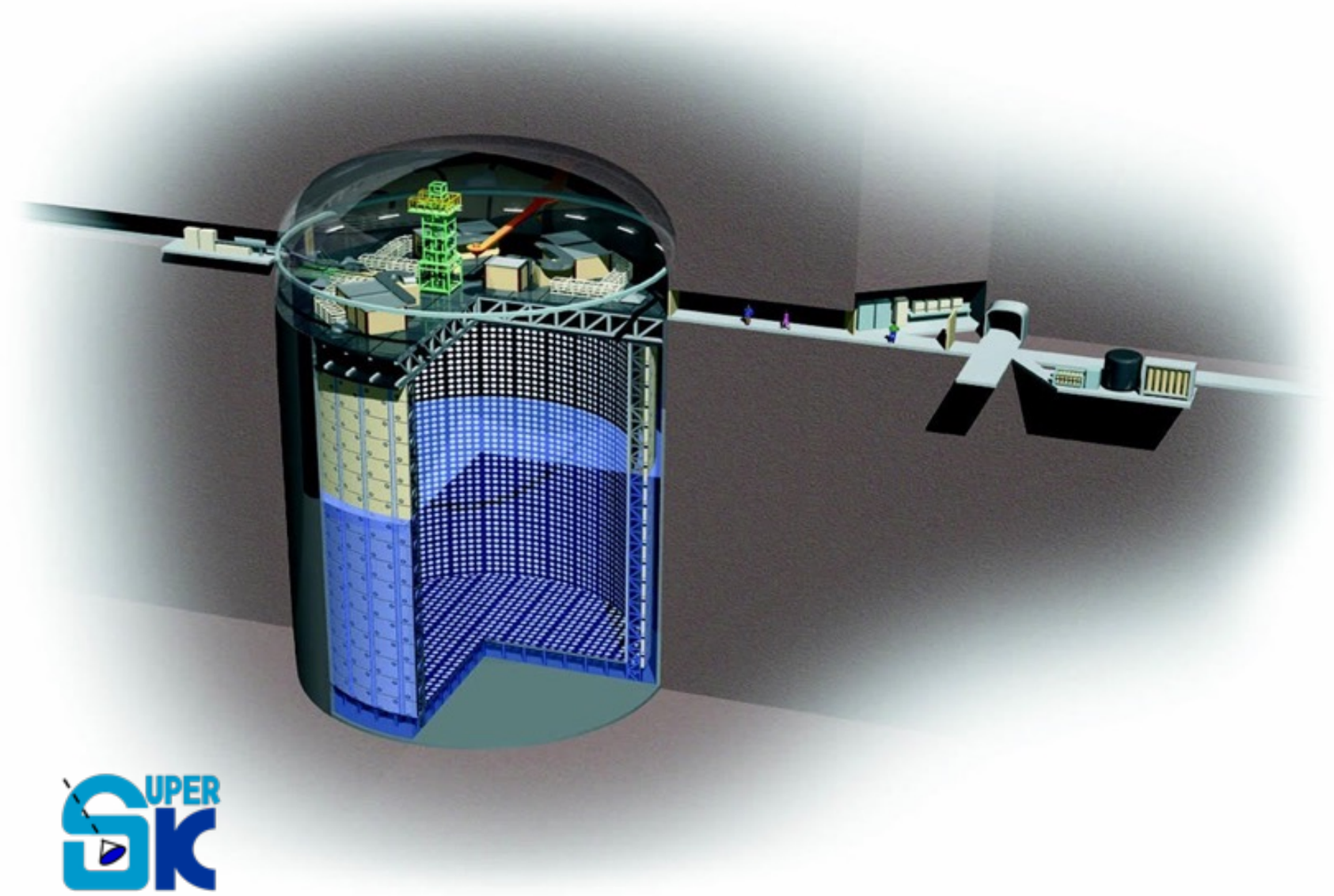
Super Kamiokande

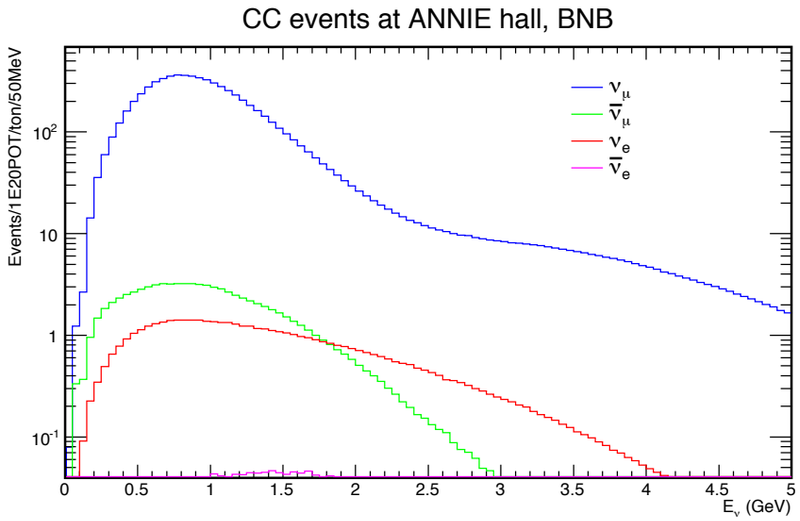


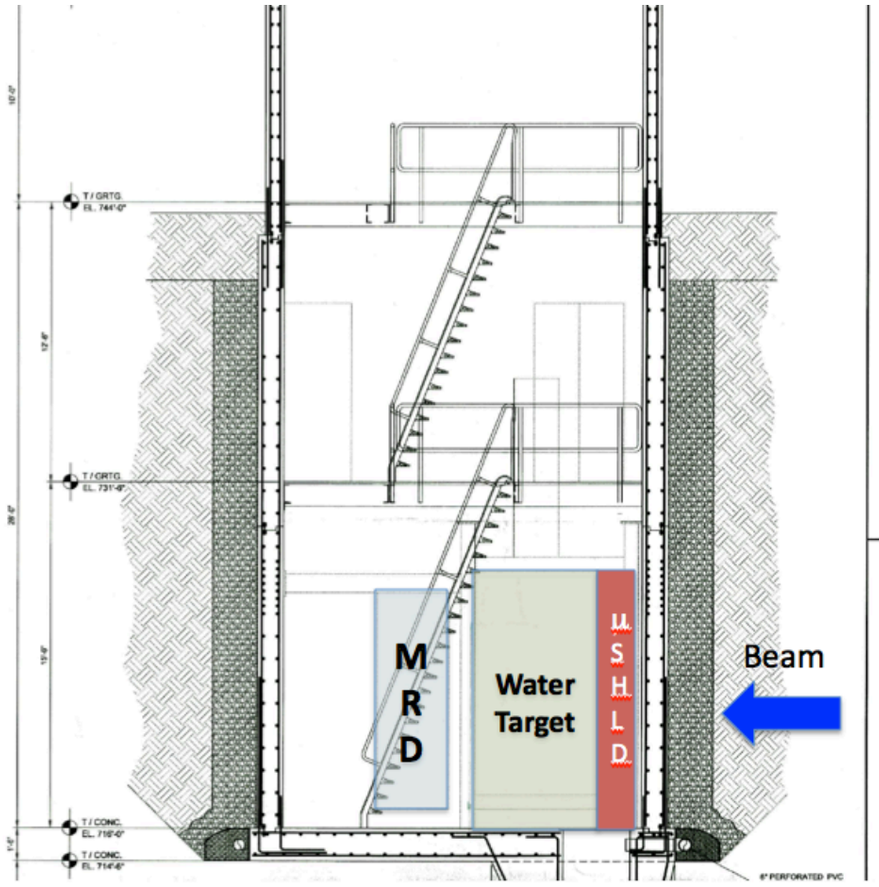
+ $Gd(SO_4)_3$

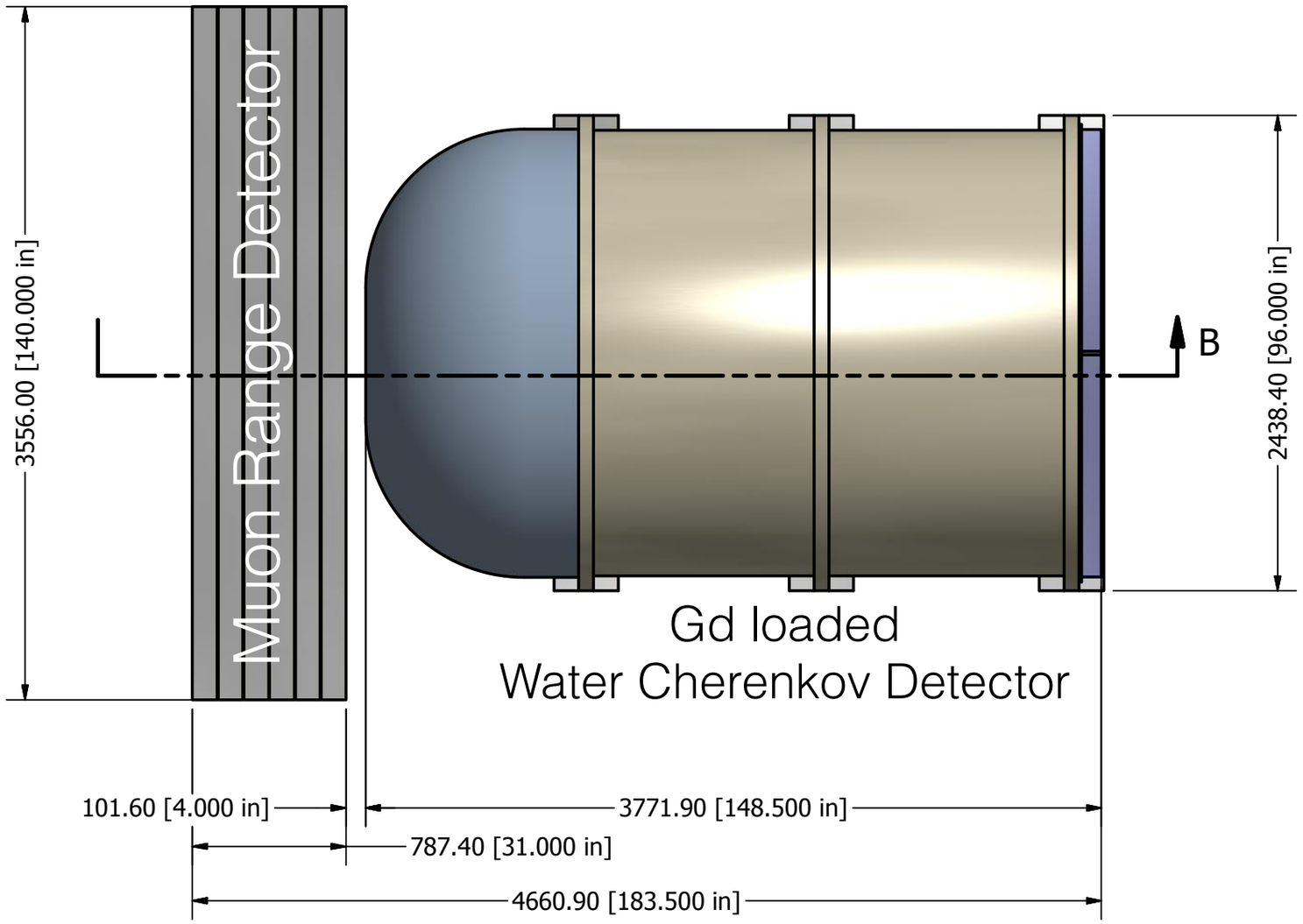
In June 2015 the Super-K collaboration approved Gd-loading.
Gd is also an option for Hyper-K.

ANNIE

(Accelerator Neutrino Neutron Interaction Experiment)







Aim to measure neutron multiplicities for neutrino interactions on Oxygen in the few GeV range

arXiv:1504.01480 [physics.ins-det]

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TITUS

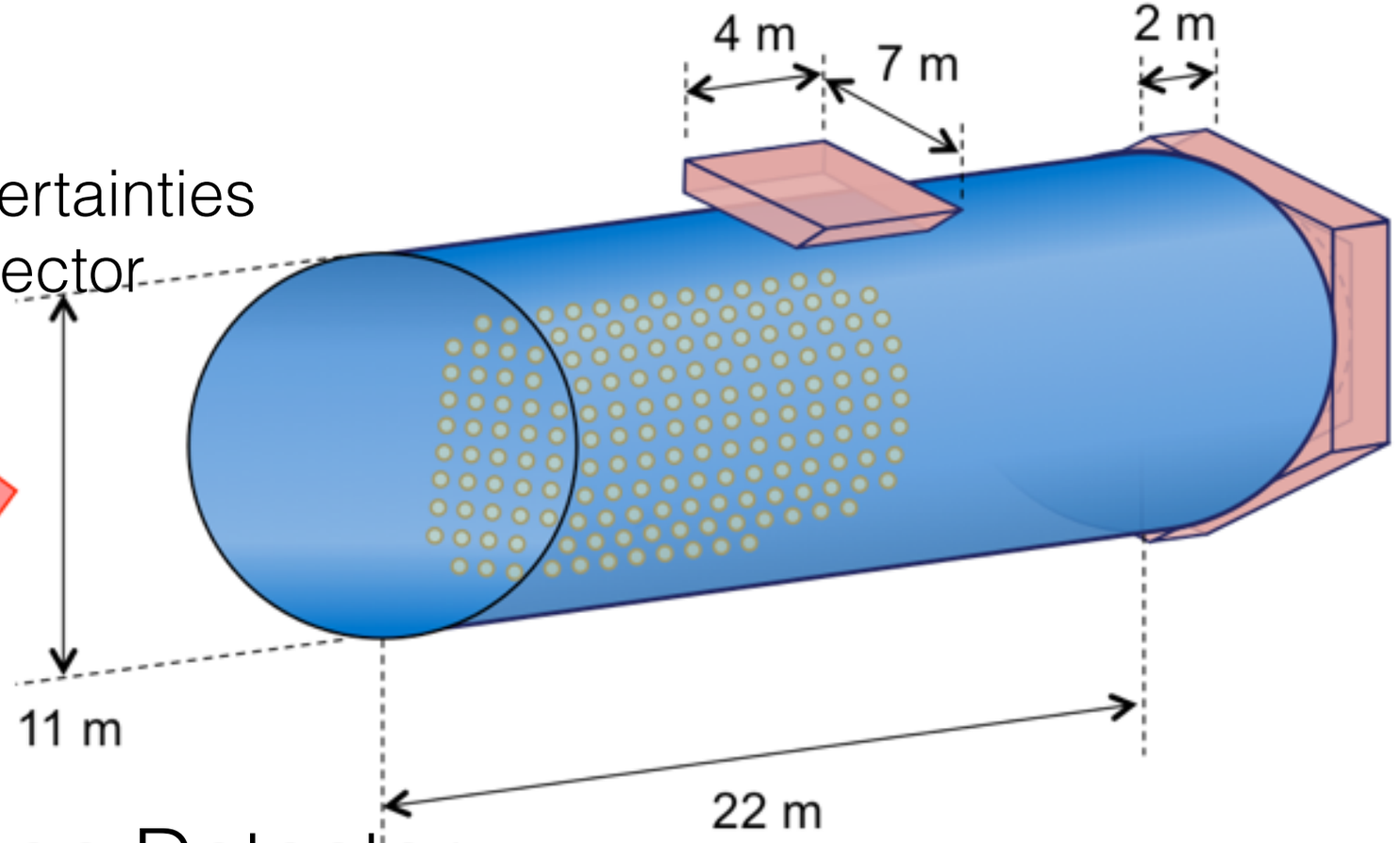
Proposed Intermediate Water Cherenkov Detector for T2HK

TITUS Detector

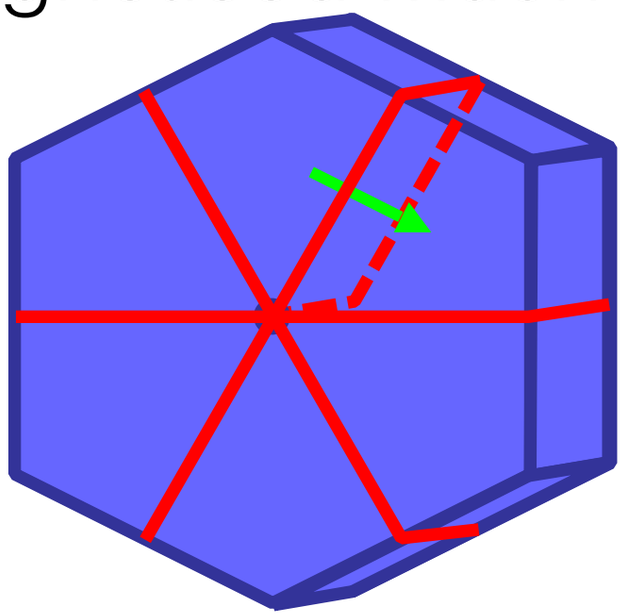
Maximise cancellation of uncertainties between near and far detector

Identical target nucleus and detector technologies

~2 km from beam source match the flux at the far detector

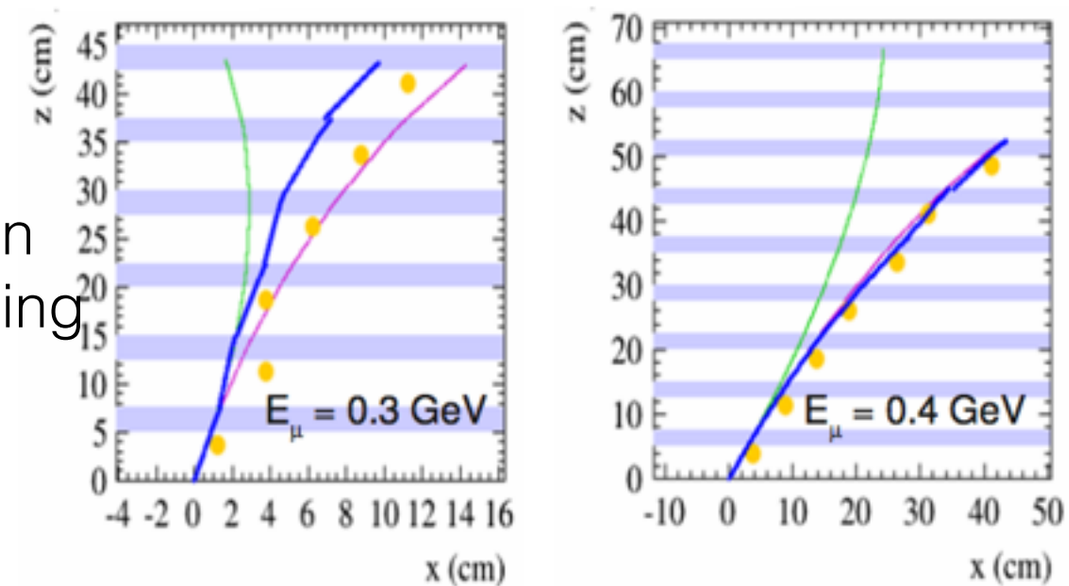


Magnetised Muon Range Detector



Measure momentum of escaping muons.

In-situ cross-check of sign selection with neutron tagging method.



Gadolinium Doped Water Cherenkov Detectors

Neutron tagging with Gd-doped WC significantly extends the physics reach of large scale Water Cherenkov detectors.

Technical implementation has been successfully demonstrated (EGADs etc).
Gd-doping is the future for Super-K (and Hyper-K?).

To fully exploit this new technology, we need to make measurements of neutron multiplicity for ν-Oxygen interactions and build models that reproduce them.

Thank you for listening

David Hadley
University of Warwick
29th May 2015

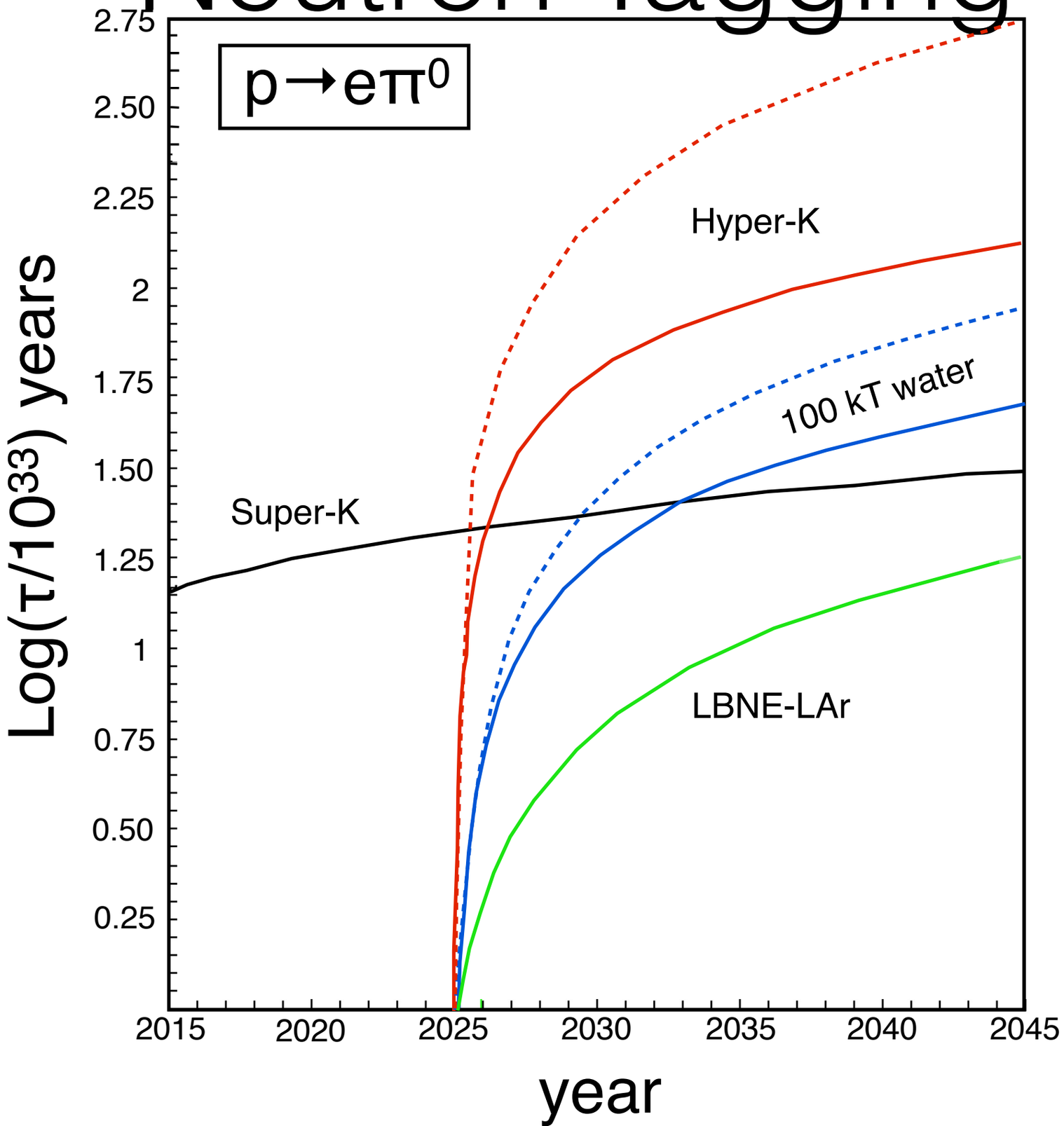
References

sk.icrr.u-tokyo.ac.jp
hyperk.org
t2k-experiment.org

arXiv:hep-ph/0309300
arXiv:1311.3738
arXiv:0811.0735
arXiv:1109.3262
arXiv:1201.1017
arXiv:1504.01480

Backup

Proton Decay Limits with Neutron Tagging



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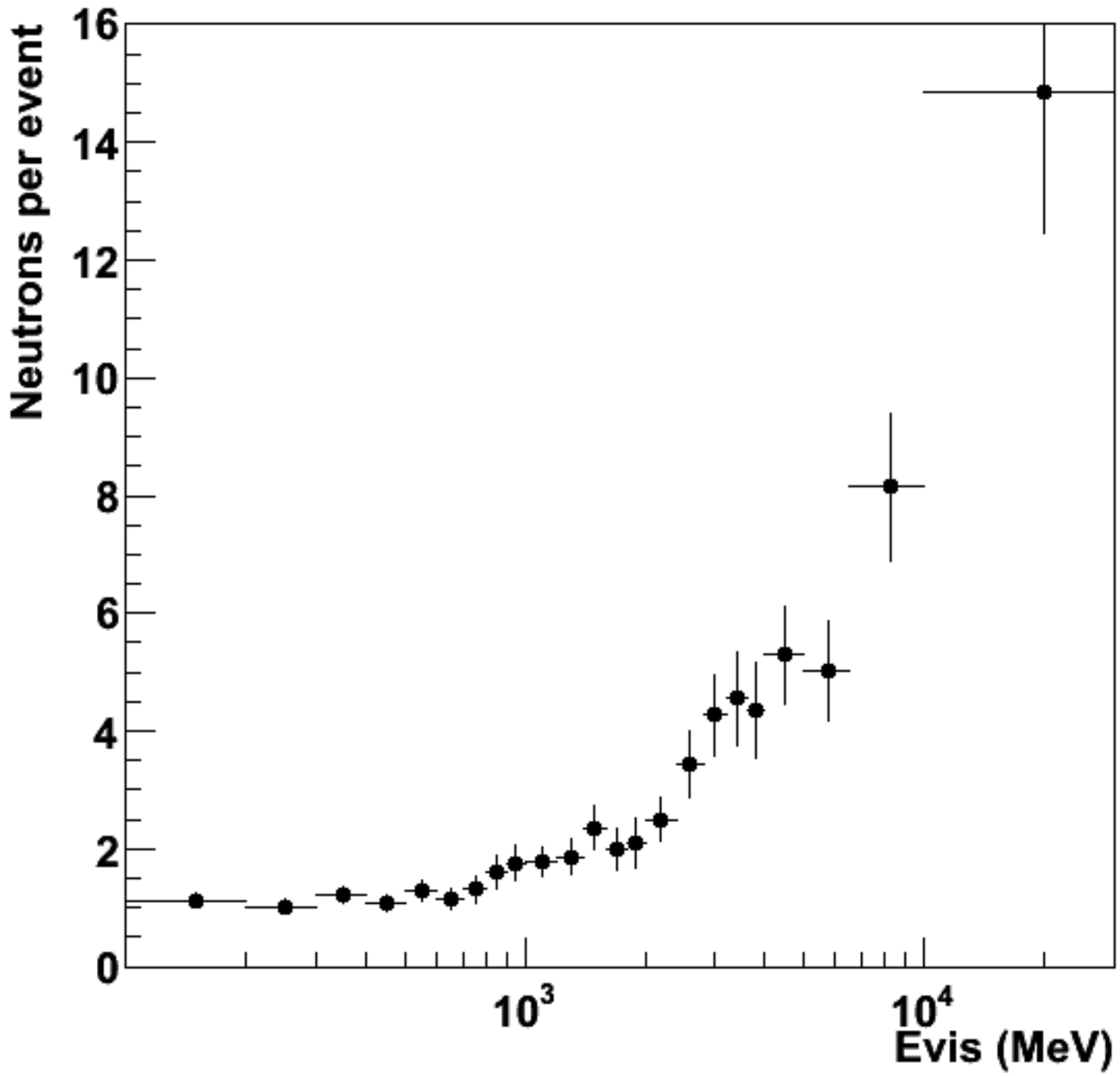
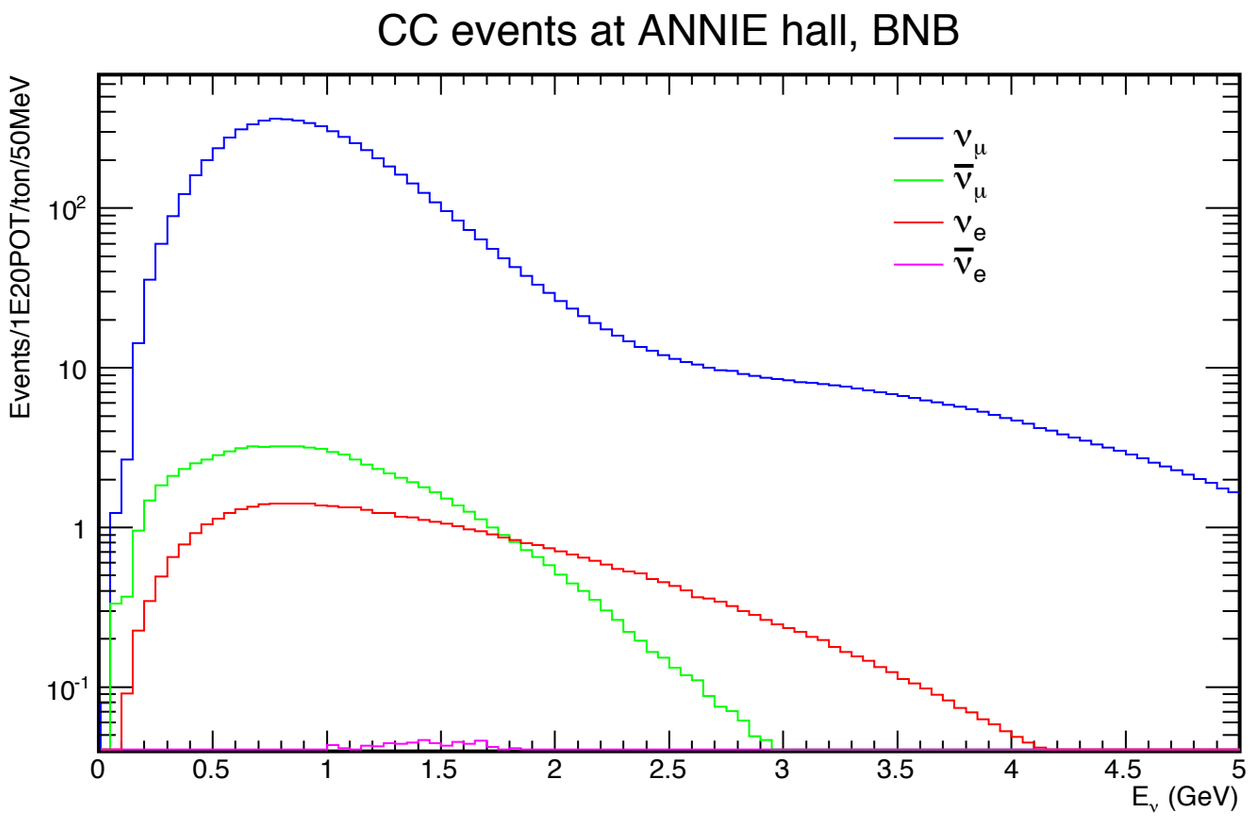
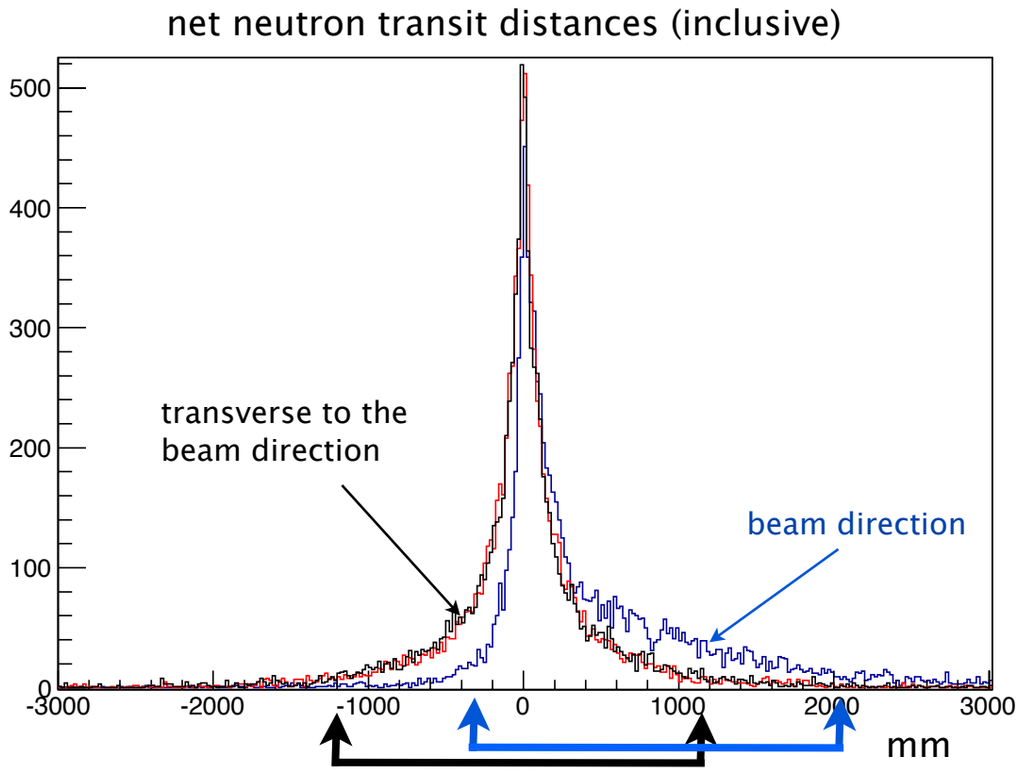
Super-K Measurements of Neutron Multiplicity



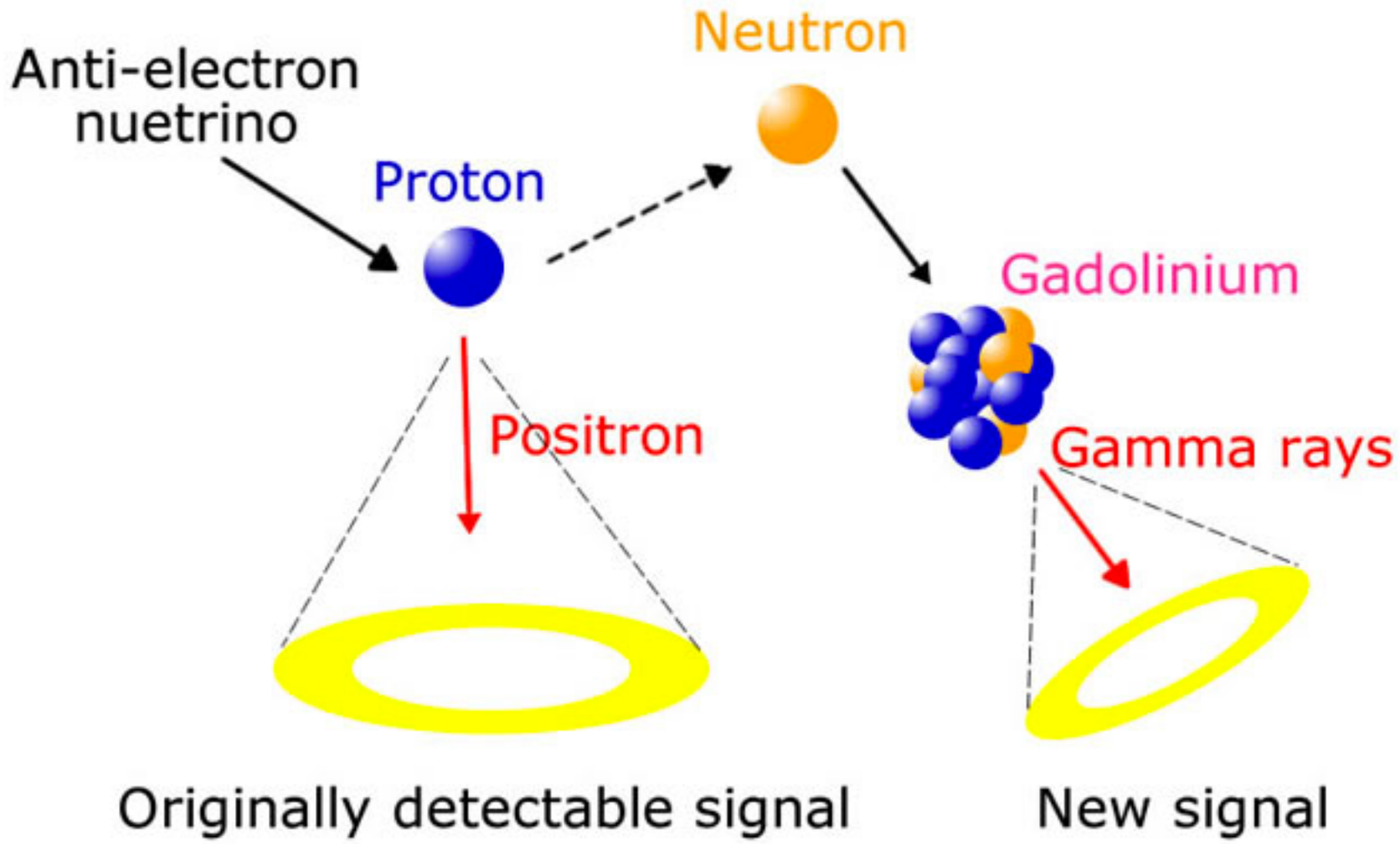
ANNIE Events



ANNIE Neutron Transit

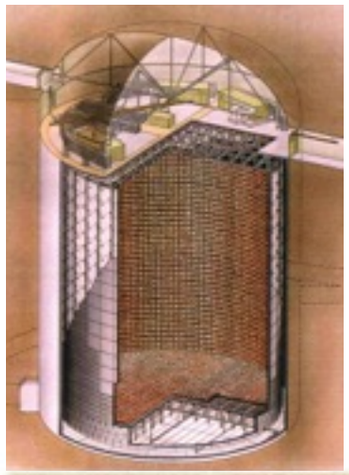


Neutron Capture on Gd

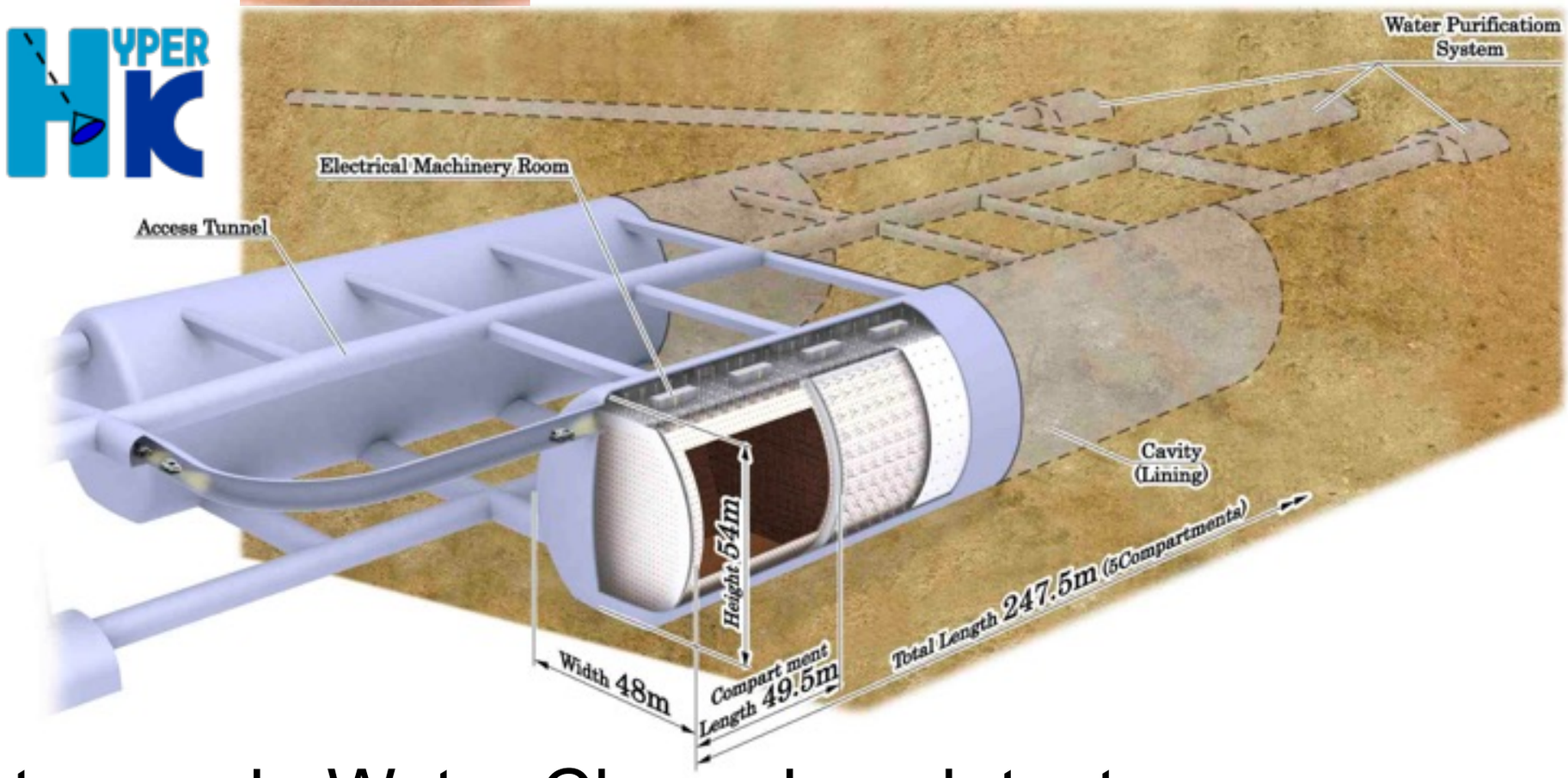


Kamiokande Detectors

Kamiokande
680 tonne
fiducial mass
(1983)



Super-Kamiokande
22.5kt fiducial mass
(33x Kamiokande)



Megaton scale Water Cherenkov detector
x25 larger fiducial volume than Super-K.
(202X)

Physics with Large Scale WC

Proton Decay

$p \rightarrow e^+ + \pi^0$

$>1.3 \times 10^{35}$ years 90% CL

$p \rightarrow \bar{\nu} + K^+$

$>3.2 \times 10^{34}$ years 90% CL

Neutrinos

Solar

200 solar ν per day

Indirect dark matter search

Supernova

SN ~200,000 @ 10kPC

SN ~30-50 @ M31

Accelerator

Leptonic CP violation

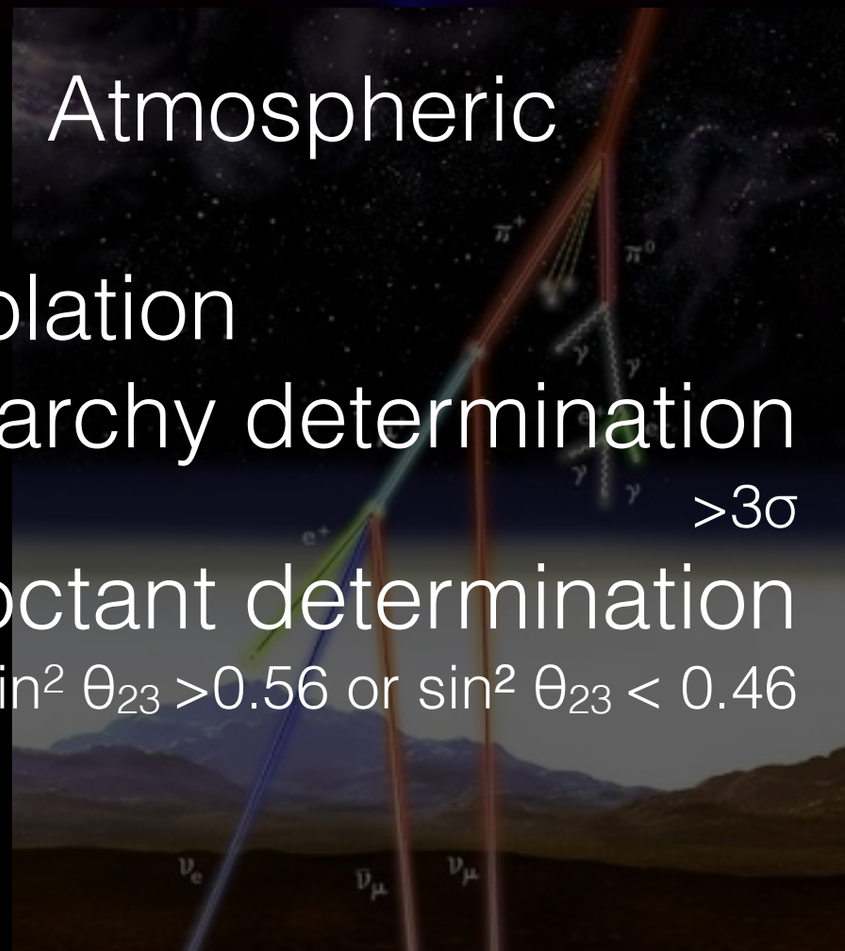
Mass Hierarchy determination

>3σ

θ_{23} octant determination

3σ for $\sin^2 \theta_{23} > 0.56$ or $\sin^2 \theta_{23} < 0.46$

Atmospheric



Broad physics programme.

Near Detector Development

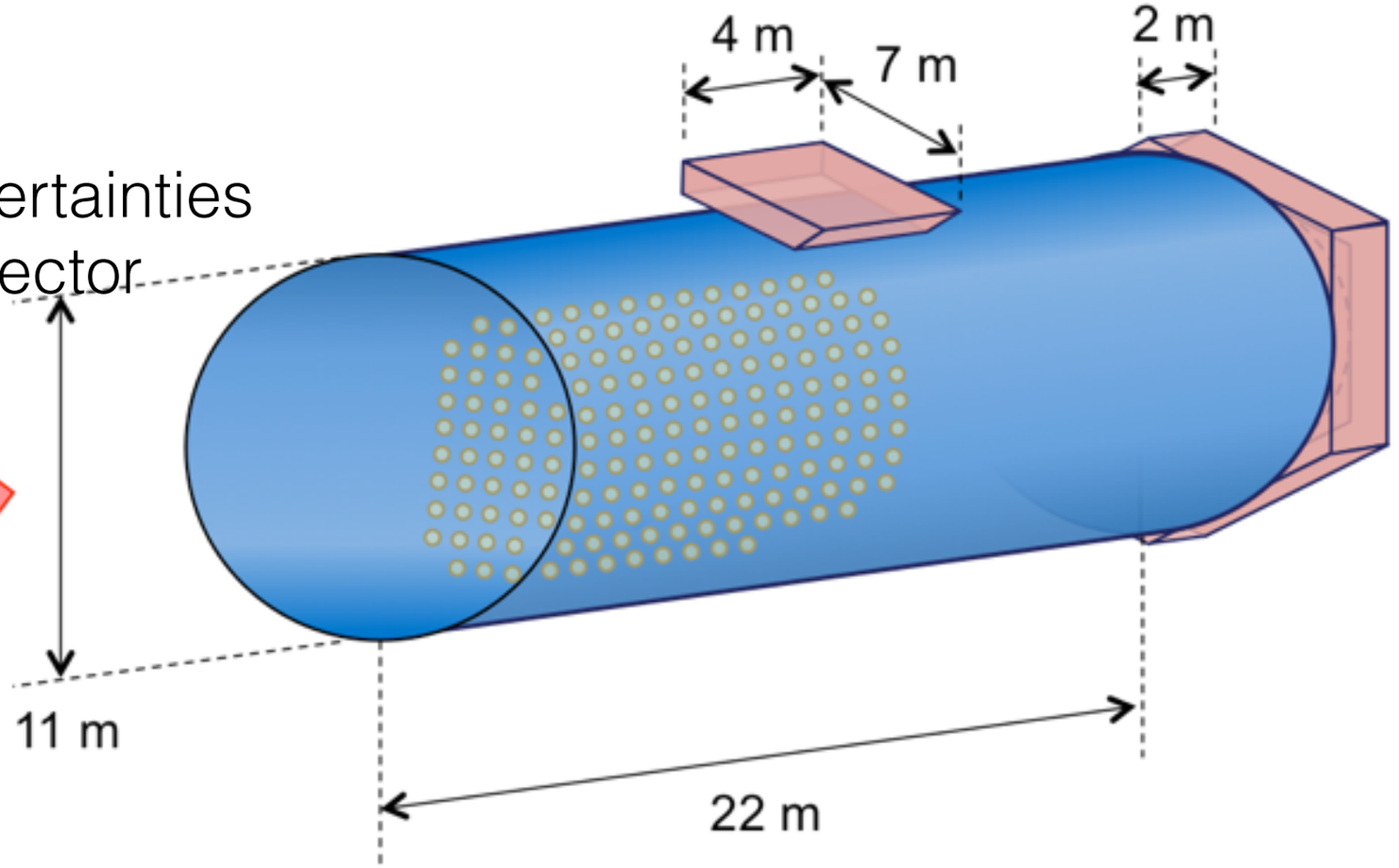
New Intermediate Water Cherenkov Detectors

TITUS Detector

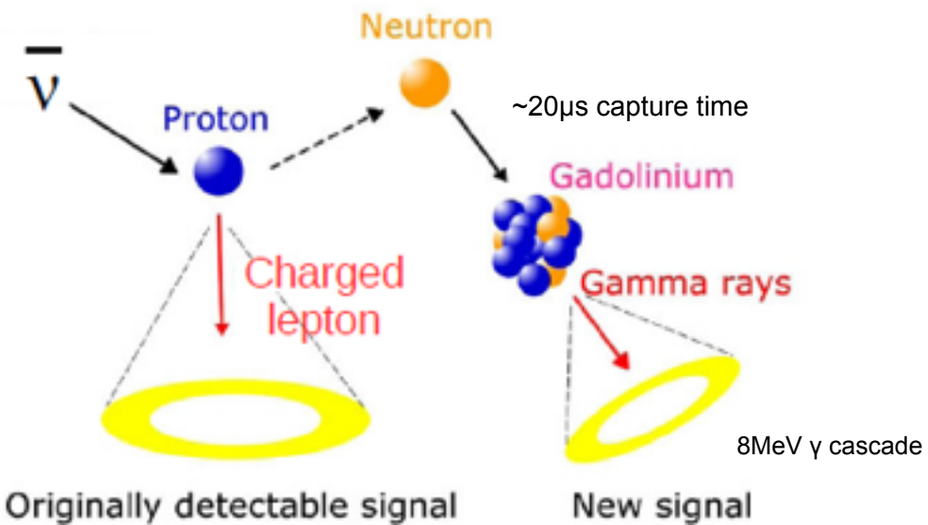
Maximise cancellation of uncertainties between near and far detector

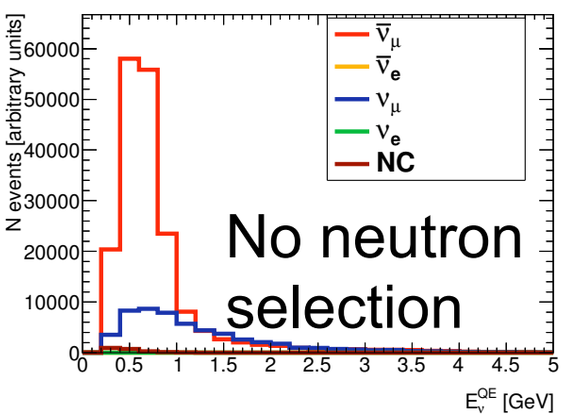
Identical target nucleus and detector technologies

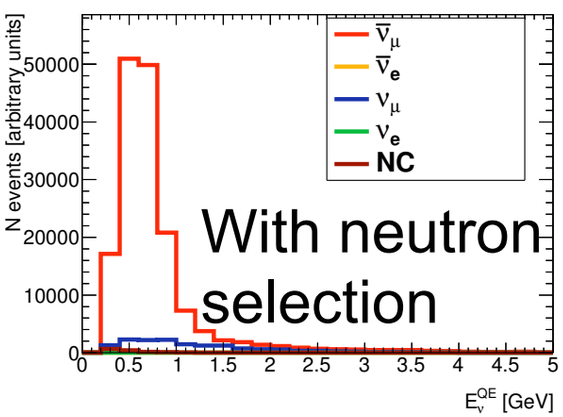
~2 km from beam source match the flux at the far detector



Neutron Capture on Gd







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