Experimental Lecture New

D. Jason Koskinen

NBIA PhD School: Neutrinos Underground and in the Heavens
June 23-27, 2014

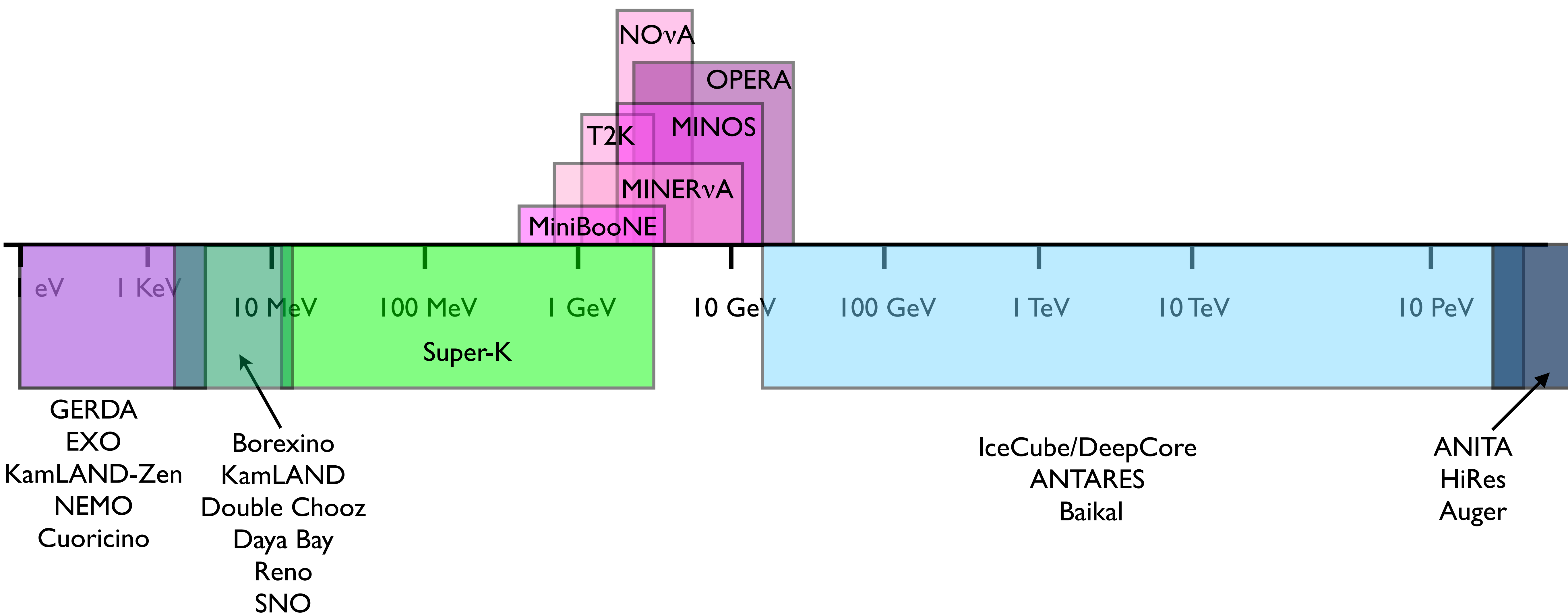
Niels Bohr Institutet

The Niels Bohr International Academy

centre for particle physics Discovery

Landscape

- Made it through neutrino physics experiments going from eV-PeV
- Today we'll cover some on-going, near future, and far future



Remaining Physics Issues

- Neutrino Mass Hierarchy
- Absolute Mass
- Charge-Parity Phase (δ_{cp})
- Majorana or Dirac
- Anomalies

Relic Neutrinos

Atmospheric Charm Production of Neutrinos

TeV Tau Neutrinos

GZK Neutrinos

Maximal Atmospheric Mixing

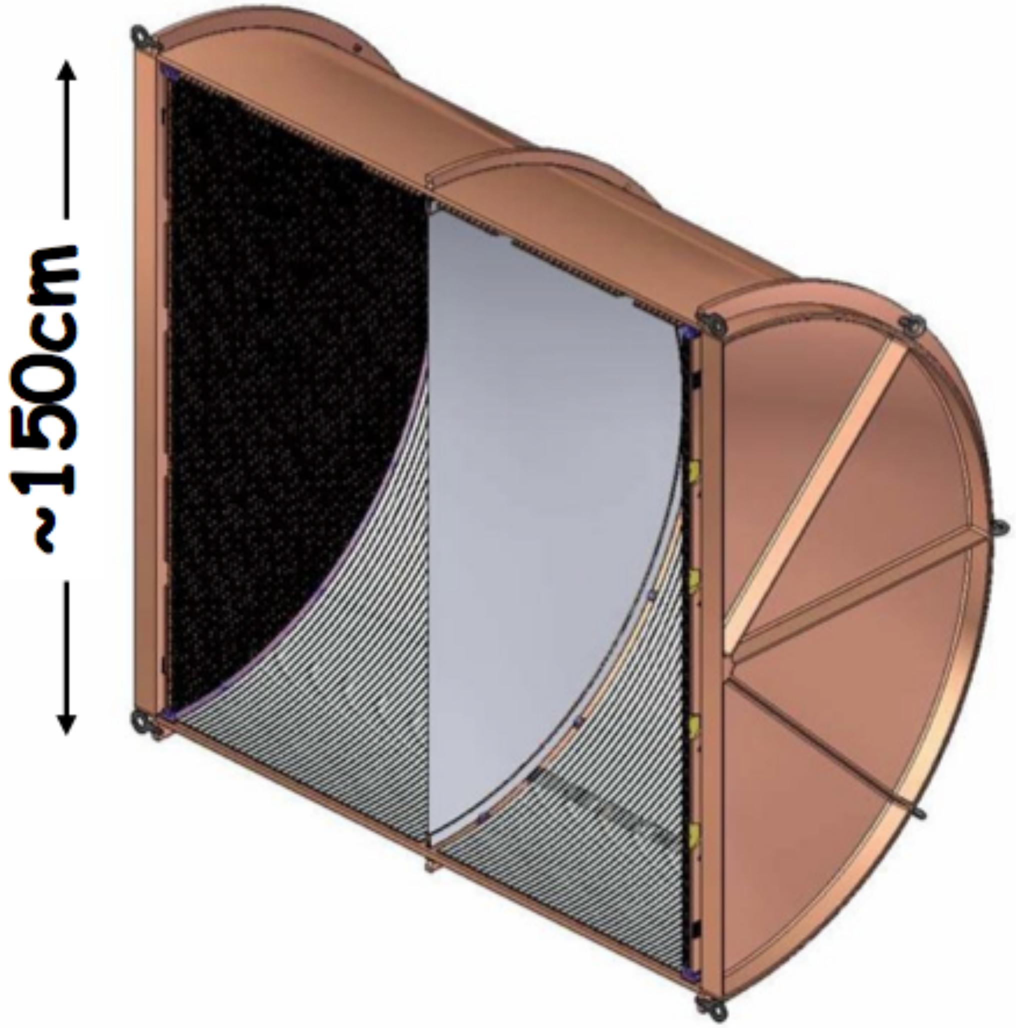
QE Pion Absorption

Astrophysical Point Source neutrino emitters

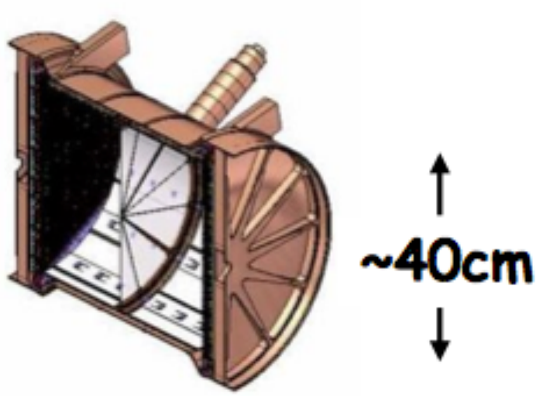
Majorana

nEXO

- 5 tonne: entirely cover inverted hierarchy
- LXe TPC "as similar to EXO-200 as possible"
- Provide access ports for a possible later upgrade to Ba tagging



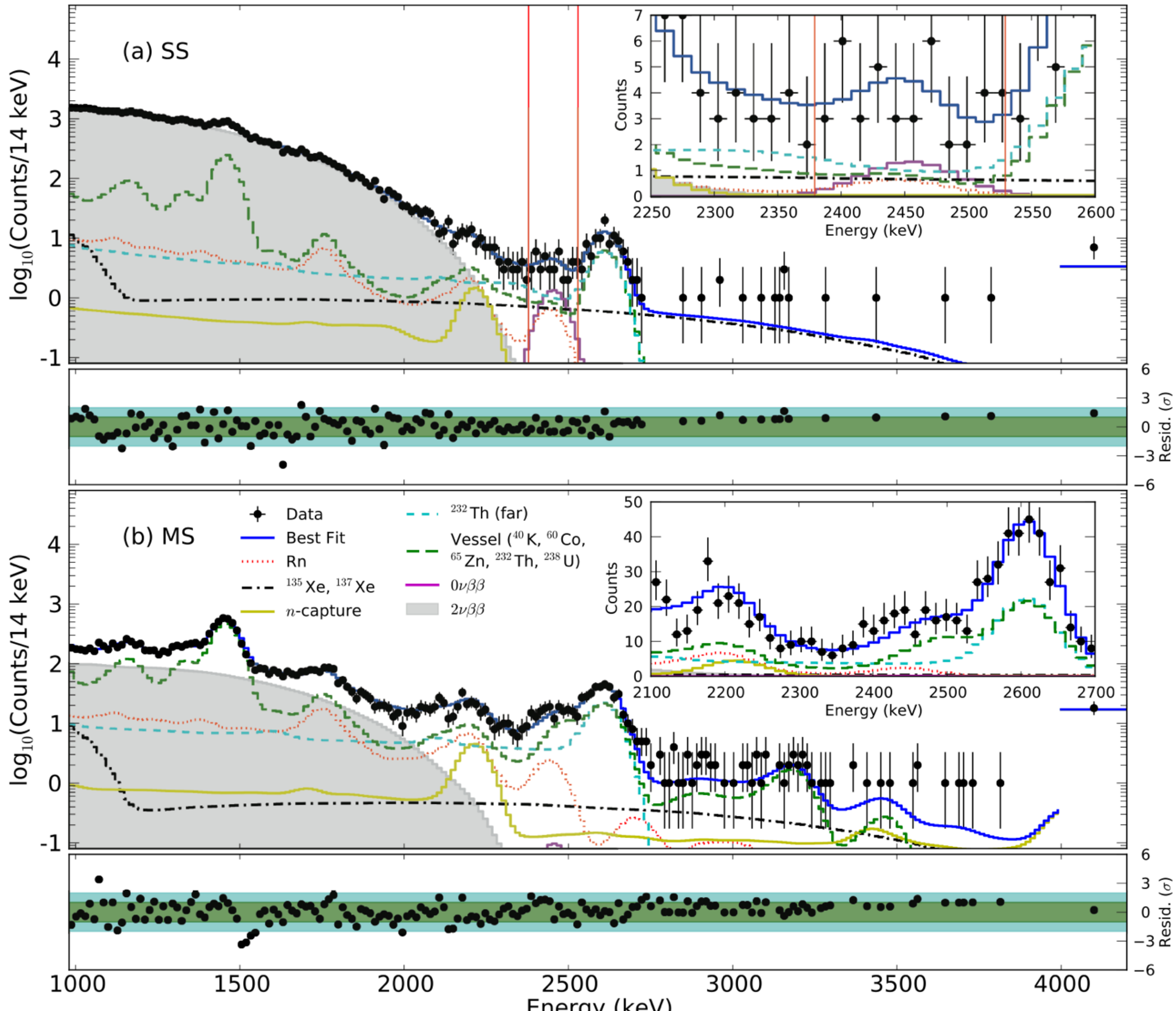
➔ *A unique combination of conservative and aggressive design with important upgrade paths as desirable for a large experiment*



*G. Gratta

EXO Result

*arXiv:1402.6956

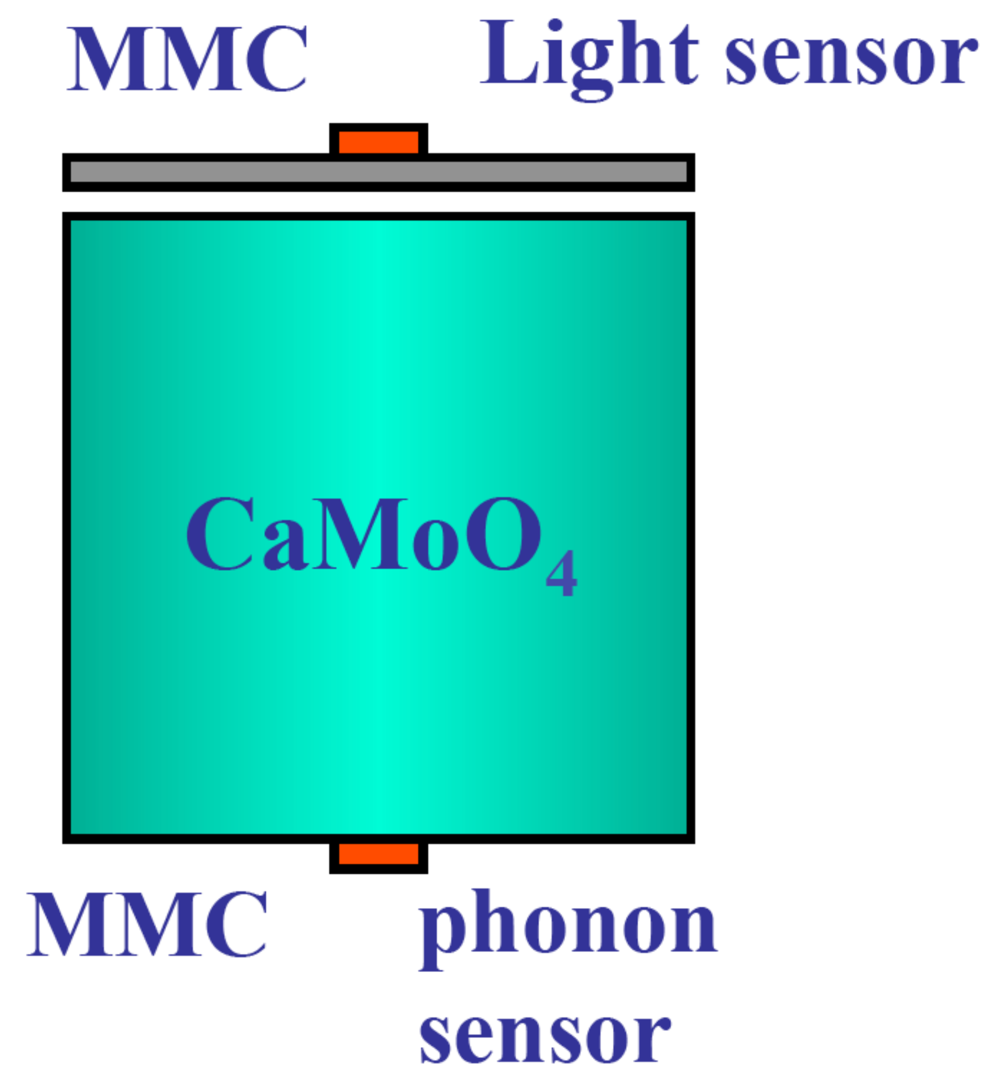


Majorana Heat

- Use calorimetry to get energy from electron capture
- Non-zero neutrino mass affects the de-excitation energy spectrum of the recoil atom
- Cryogenics

AMoRE

Low Temp. Detector
Source = Detector



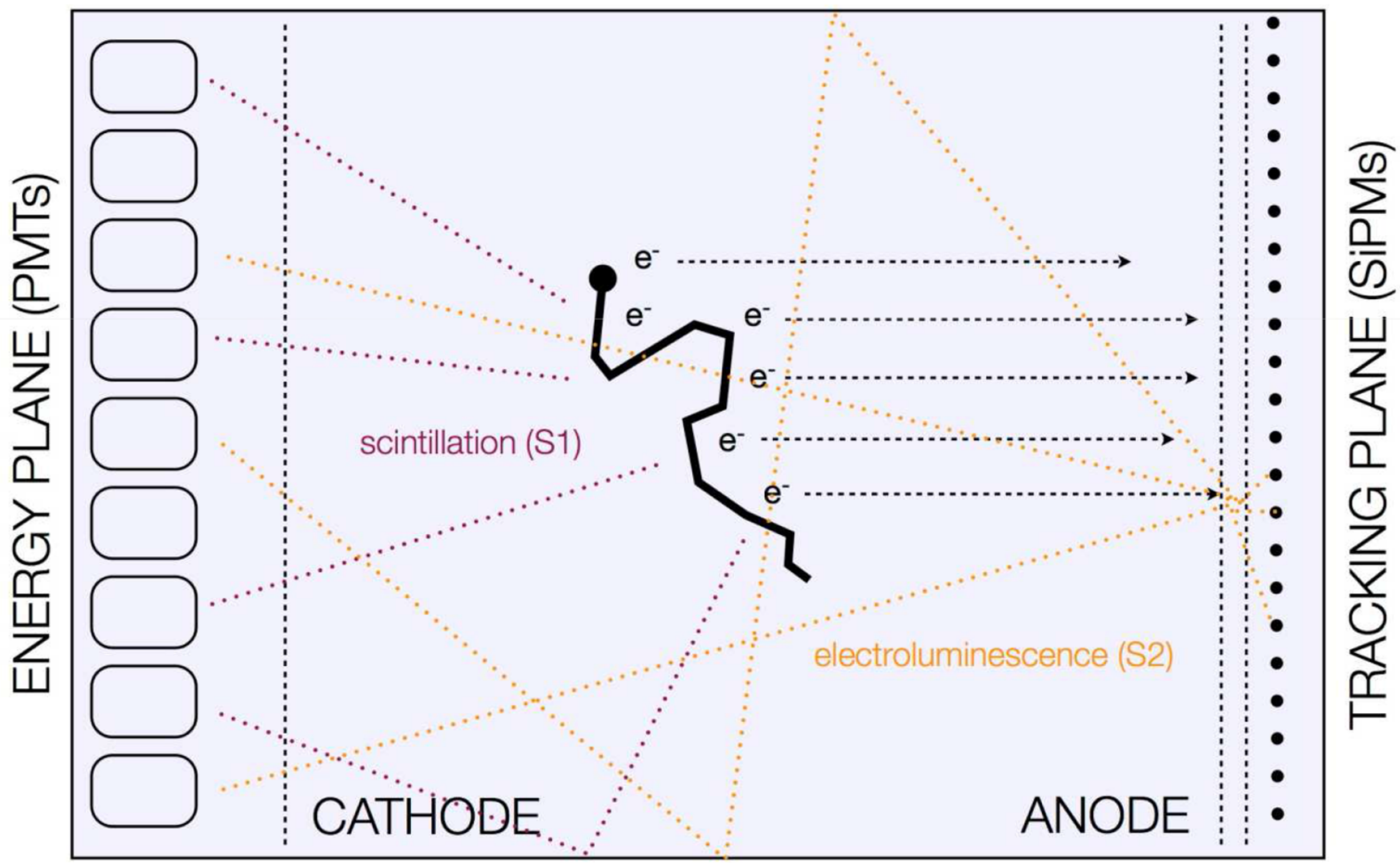
<10-50 mK>♪

*L. Windslow, Neutrino 2014

NEXT

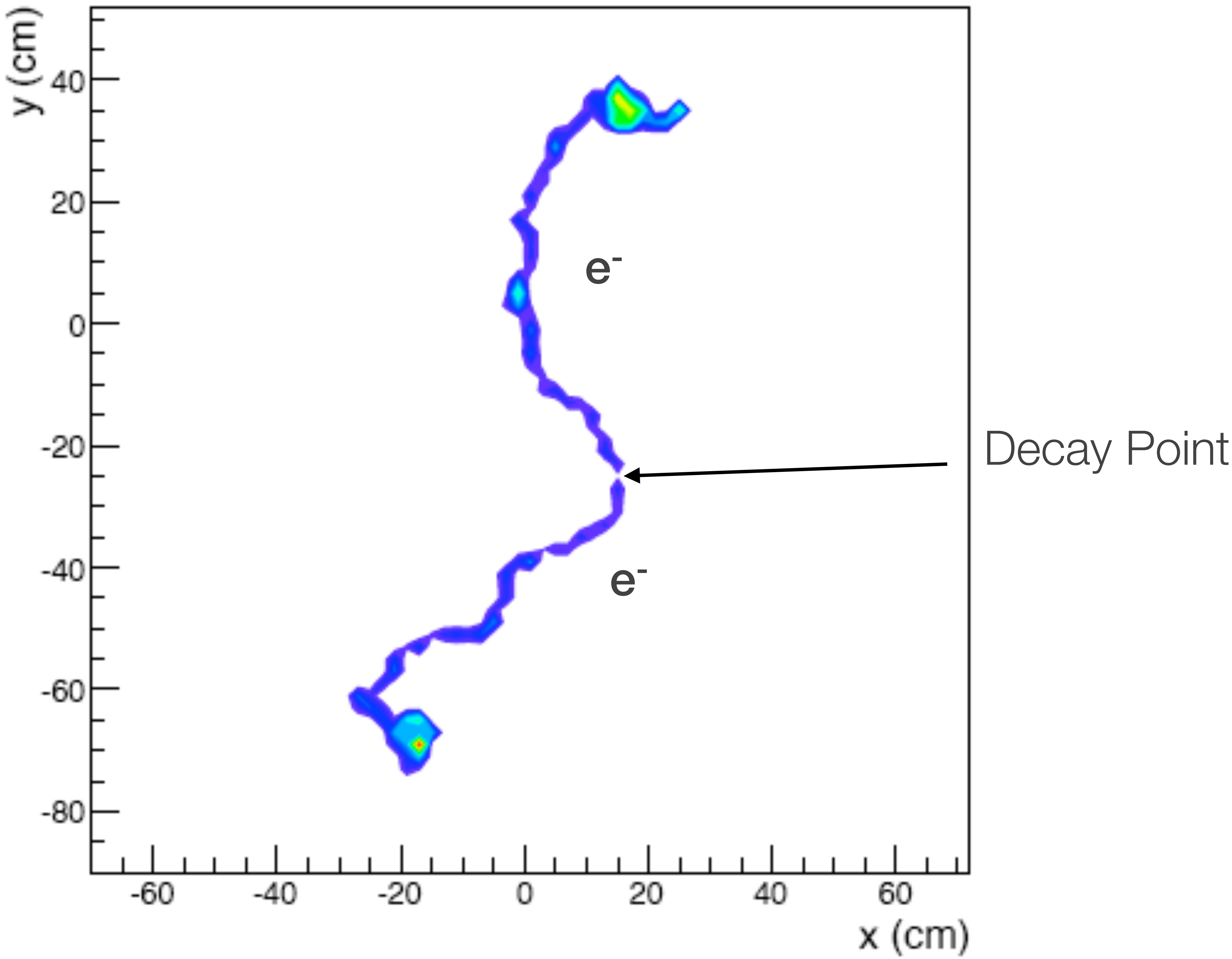
- High pressure xenon gas time projection chamber (TPC)
- Neutrinoless double-beta decay

*C. Monteiro, TIPP 2014



NEXT

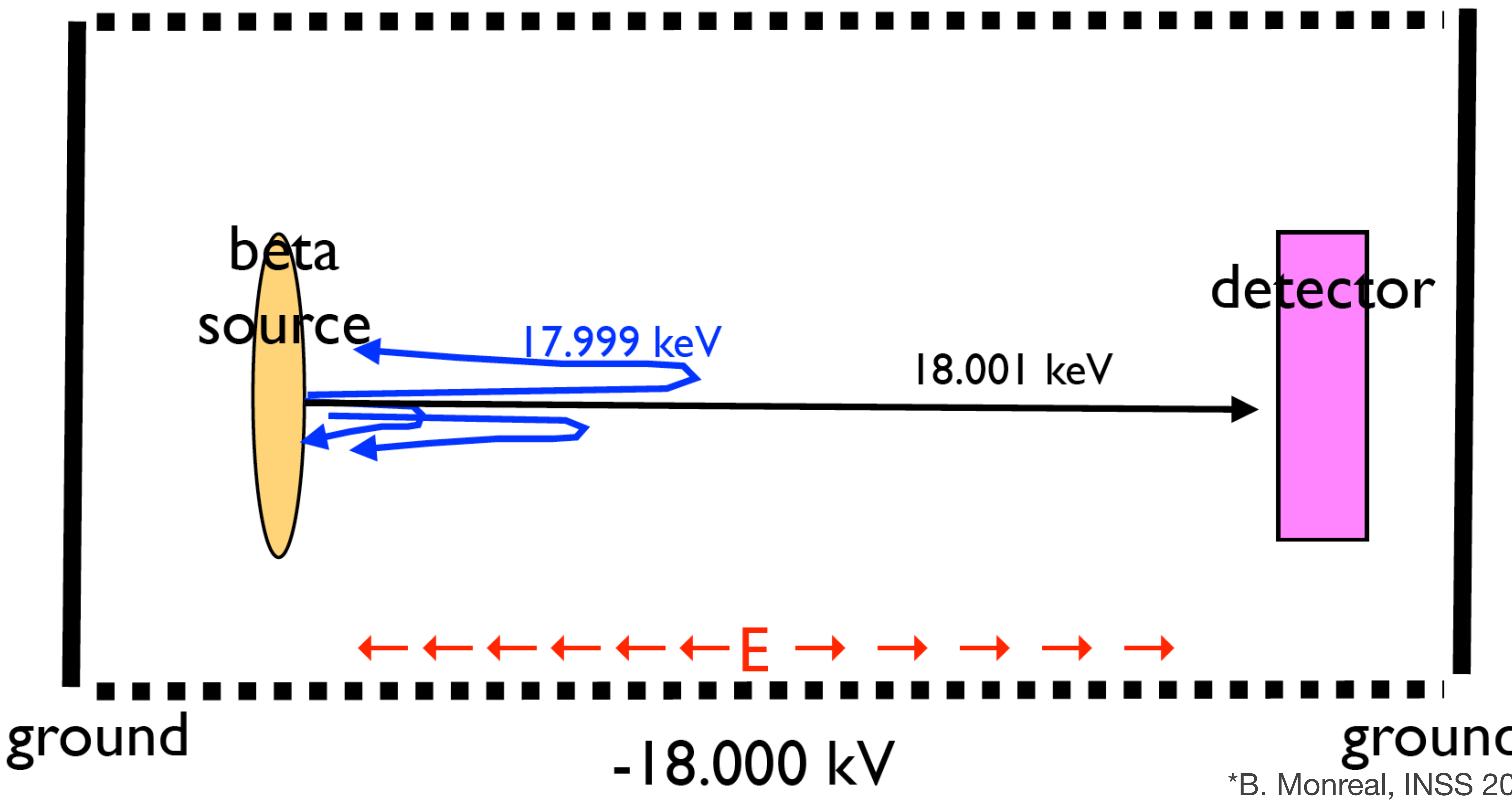
*D. Nygren, Erice 2009



Absolute Mass

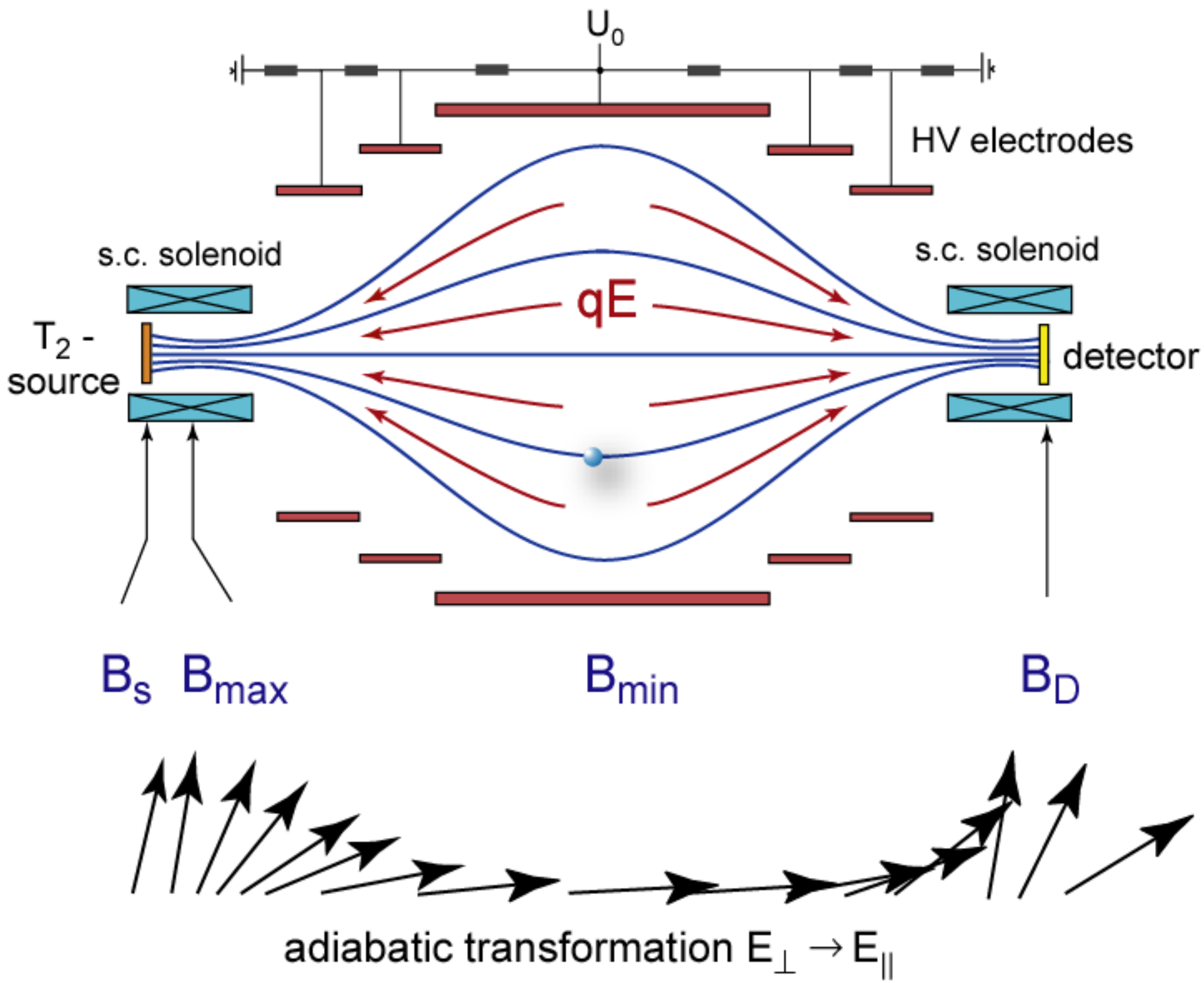
KATRIN

Electrostatic filter



*B. Monreal, INSS 2012

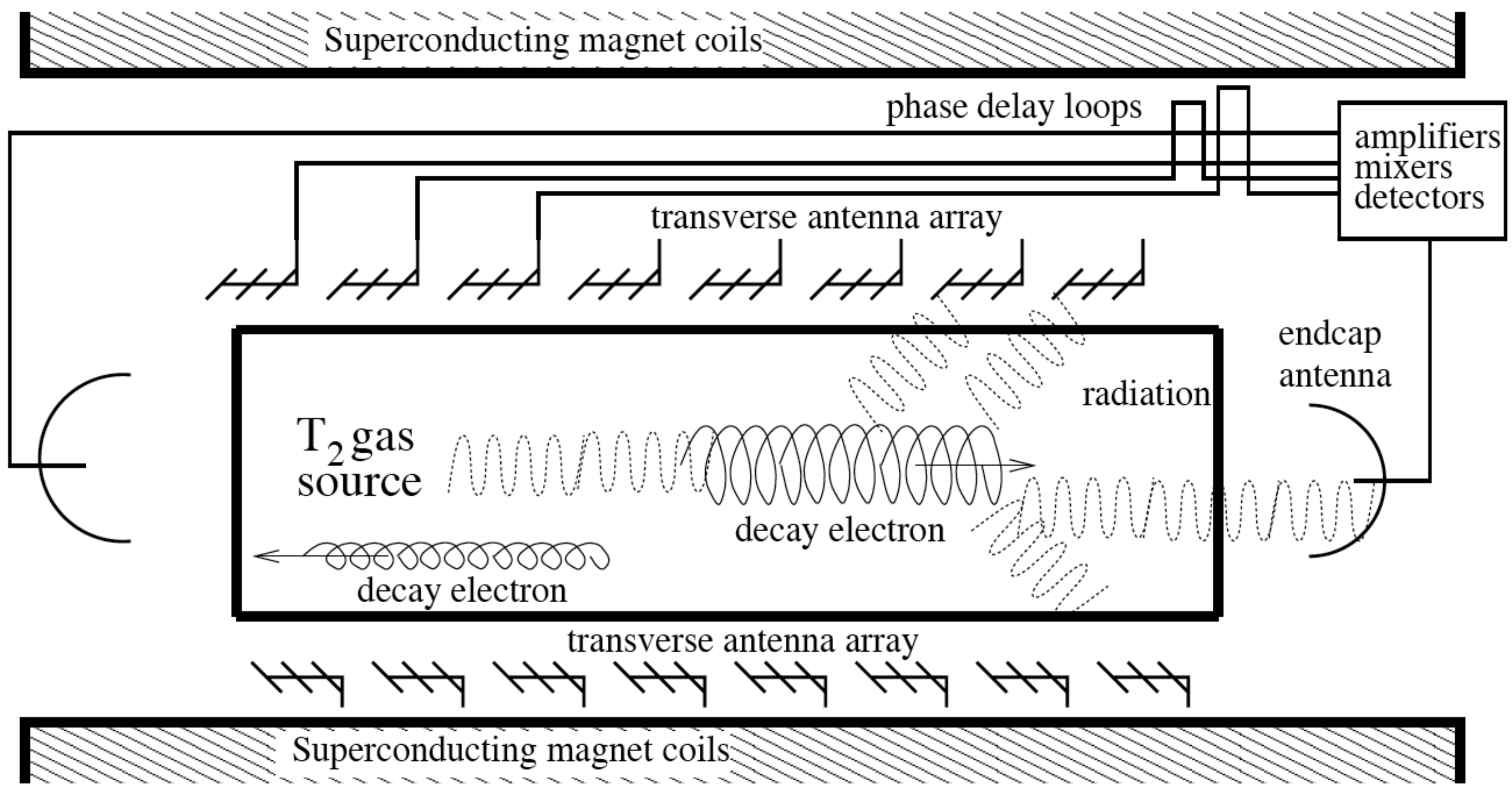
KATRIN Electron Filter



*J.F. Wilkerson, INSS 2009

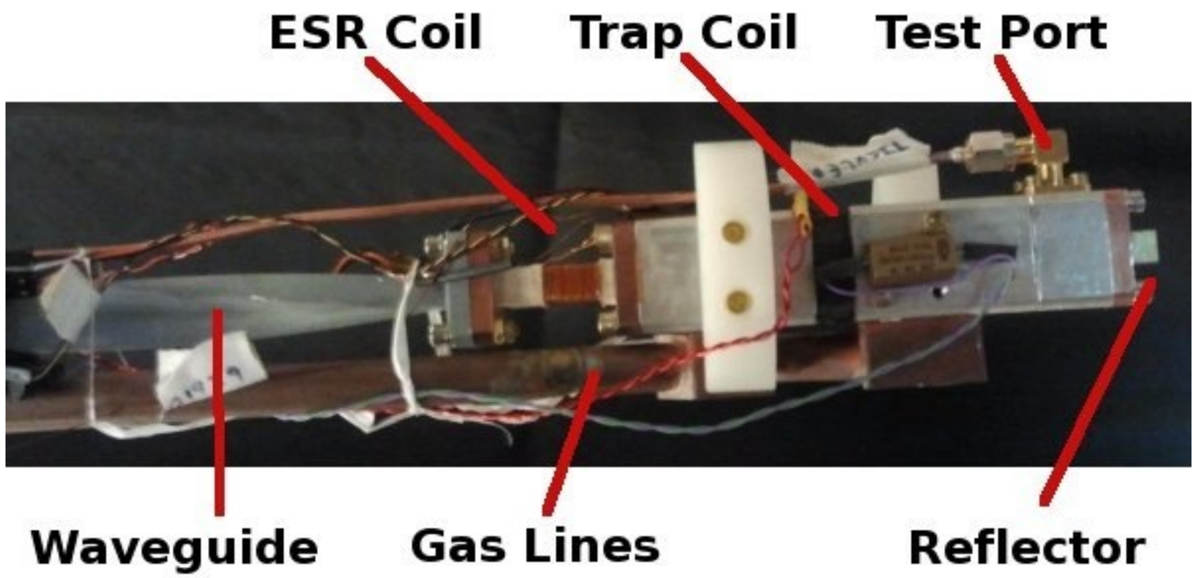
Project 8

- Measure frequency of cyclotron radiation from electron in beta-decay
- Surround with antennae

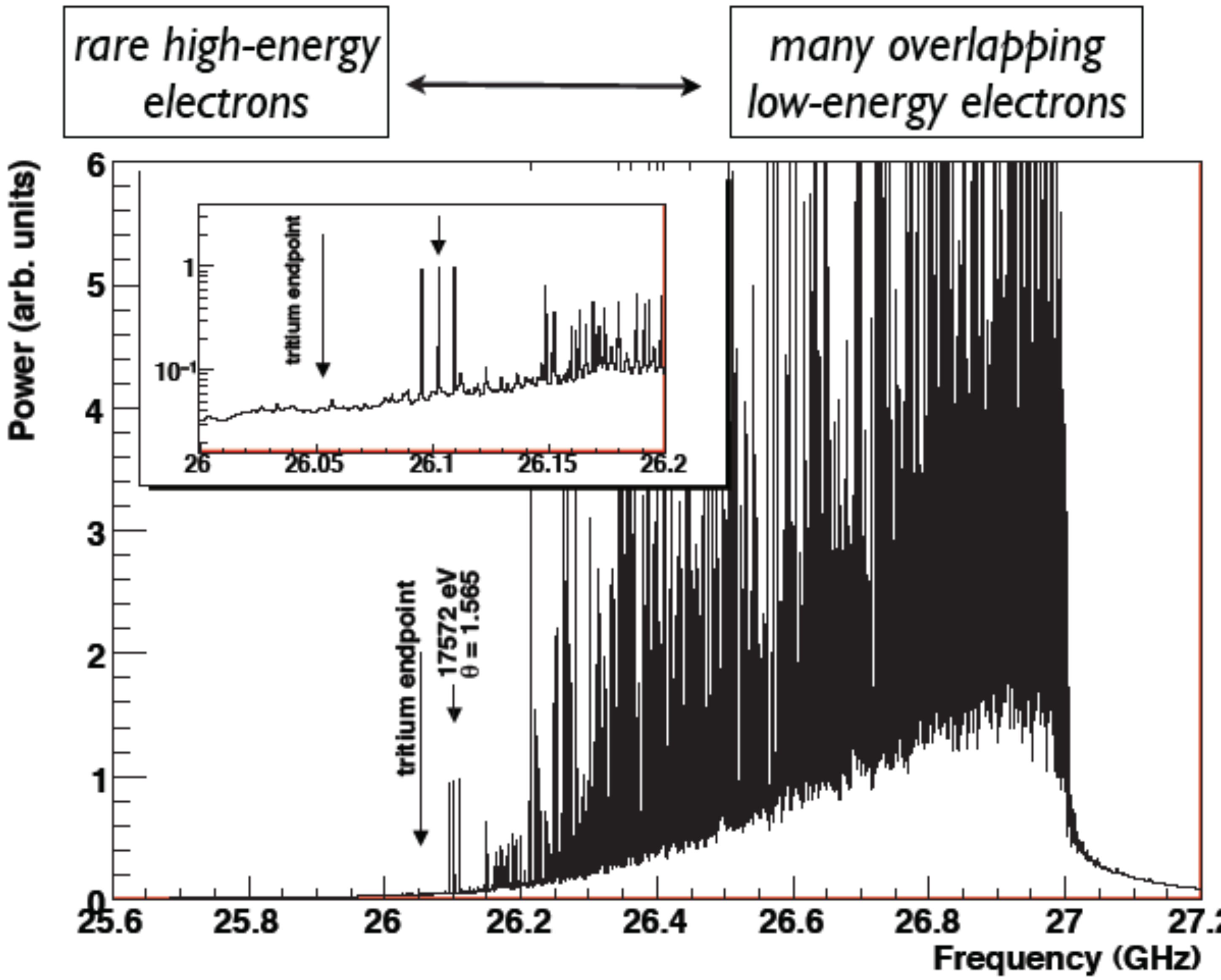


*arXiv:0904.2860

Project 8



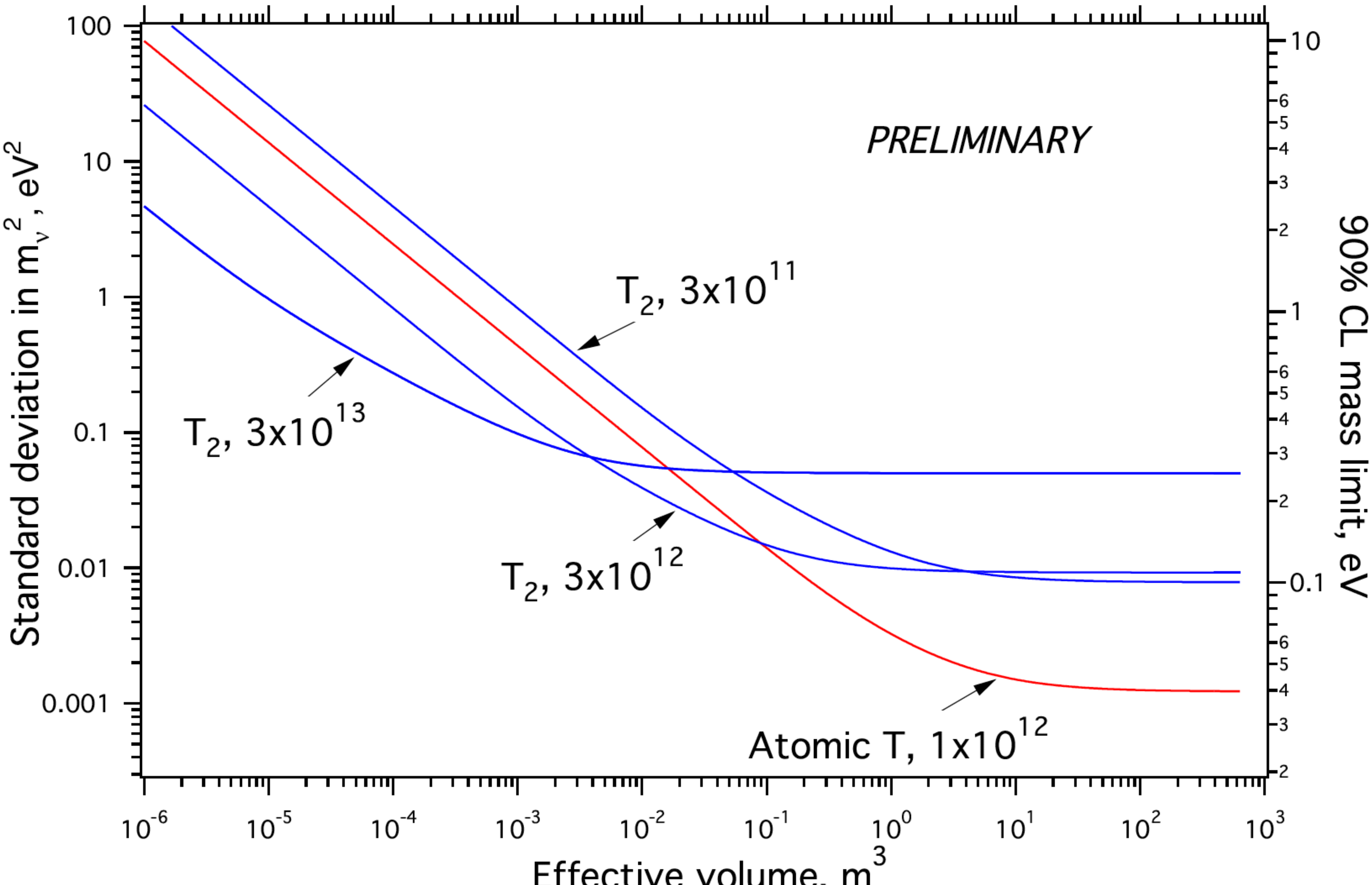
25.5-GHz waveguide cell



100,000 tritium decays in 30μs

*B. Monreal & R.G.H. Robertson, SNOMASS 2013

Project 8



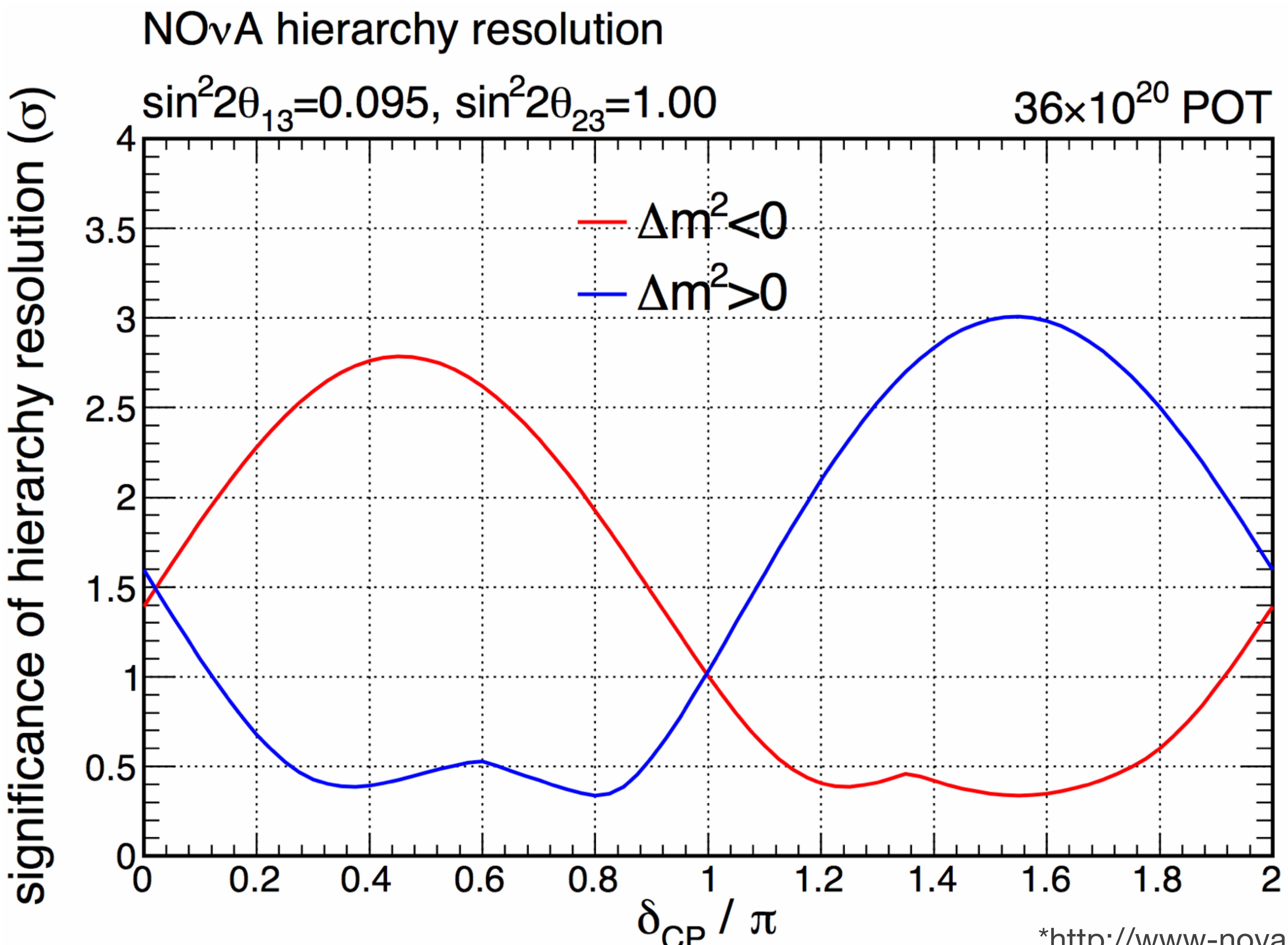
*B. Monreal & R.G.H. Robertson, SNOMASS 2013

Long Baseline


NOvA
810 km
NOvA Far Detector
MINOS Far Detector
Ontario
Minnesota
Wisconsin
Iowa
Milwaukee
Michigan
Fermilab
Chicago
© 2007 Europa Technologies
Image © 2007 TerraMetrics
Image © 2007 NASA
168 km
43°34'32.84" N 89°04'55.60" W elev 271 m
Streaming 100%
Eye alt 545.86 km


T2K
Super-K
J-PARC
295km
E133°
E135°
E137°
E139°
E141°
N35°
N37°
Kanazawa
Kanazawa
Kobe
Kyoto
Osaka
Tsu
Nagoya
Gifu
Gifu
Nagano
Nagano
Japan
Sado
Niigata
Kofu
Shizuoka
Maebashi
Hachioji
Saitama
Honshu
Kanagawa
Tokyo
Yokohama
Kawasaki
Tokyo
Funabashi
Chiba
Chiba
Mito
Fukushi
shima
Image NASA
© 2007 Europa Technologies
Image © 2007 TerraMetrics
© 2007 ZENRIN
Pointer 36° 23'41.59" N 139° 11'54.71" E elev 665 m
Streaming 100%

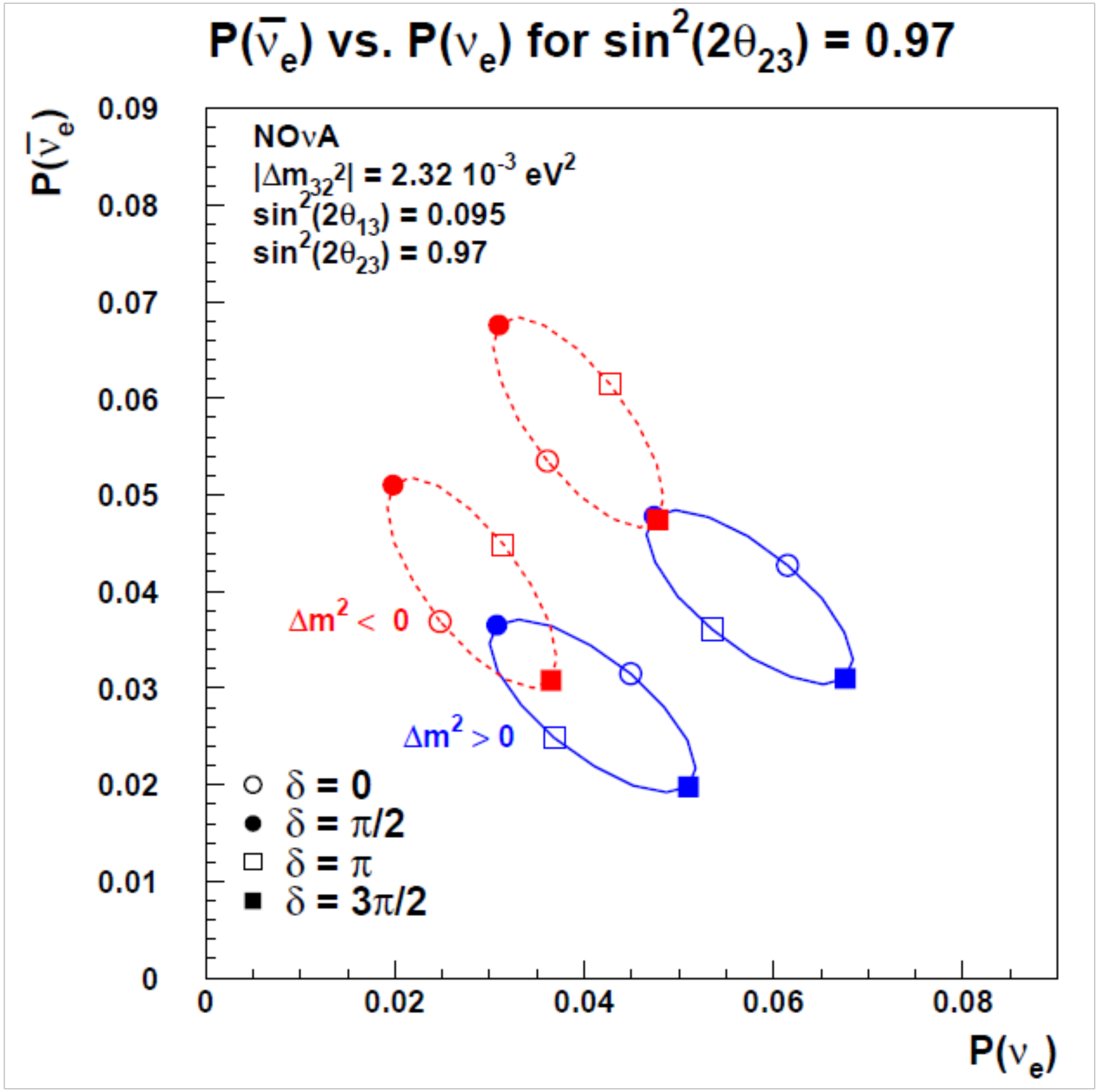
NOvA Hierarchy Sensitivity



*http://www-nova.fnal.gov

How?

- Neutrino and anti-neutrino operation
- Because T2K has a shorter baseline (less matter) a combined fit will help break any oscillation versus mass hierarchy-matter effect degeneracies or issues



*http://www-nova.fnal.gov


super-kamiokande


Hyper-K
(8 km south of SK)
T2K
Super-K
295km
J-PARC
Kanazawa
Nagano
Japan
Niigata
Kofu
Shizuoka
Maebashi
Hachioji
Saitama
Kanagawa
Tokyo
Yokohama
Kawasaki
Tokyo
Funabashi
Chiba
Chiba
Mito
Honshu
Fukushi
N37°
N35°
E139°
E137°
E135°
E141°
Kobe
Osaka
Kyoto
Tsu
Nagoya
Gifu
Gifu
Sado
Image NASA
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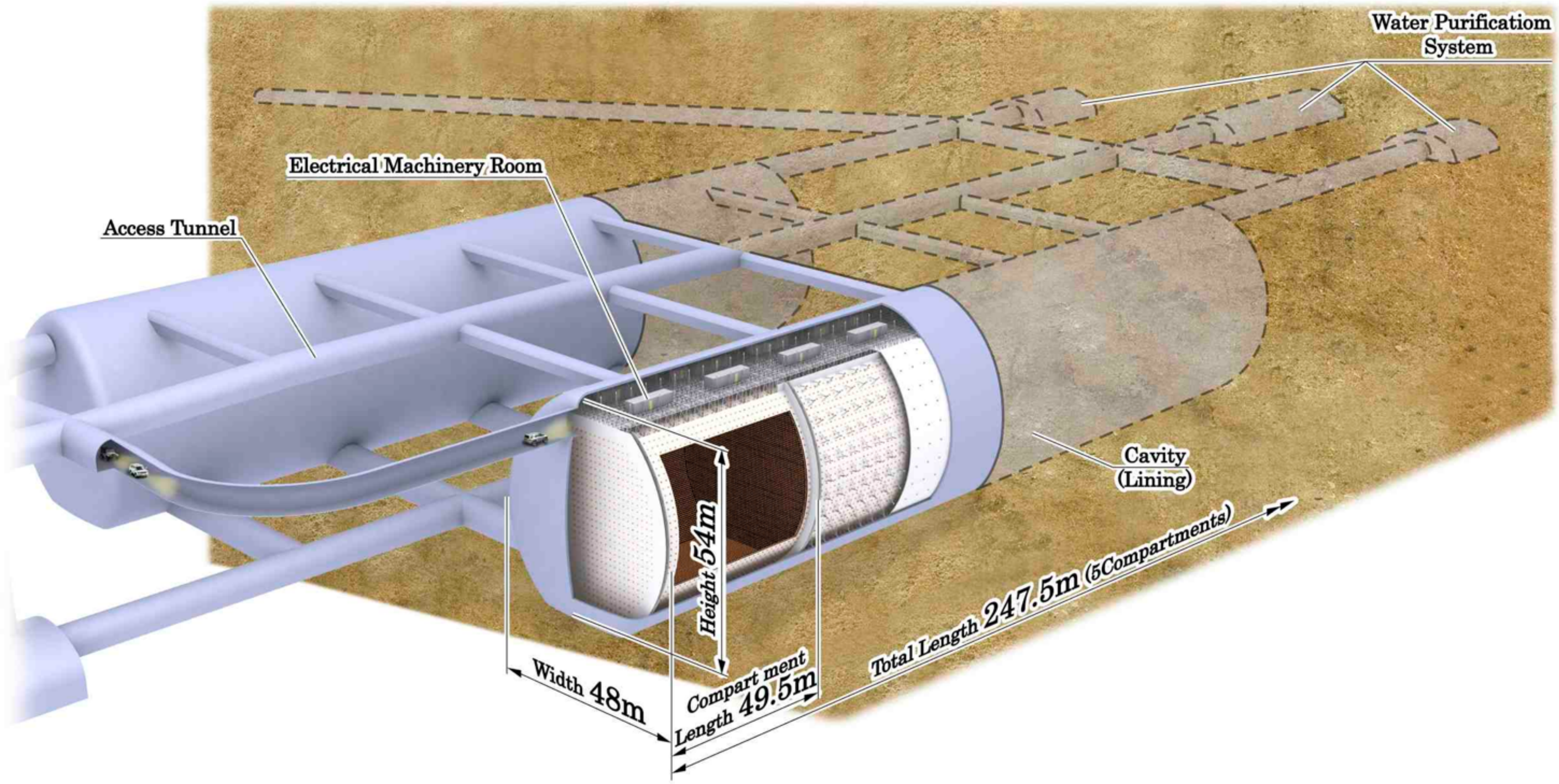
Pointer 36° 23'41.59" N 139° 11'54.71" E elev 665 m
Streaming 100%

Hyper-Kamiokande

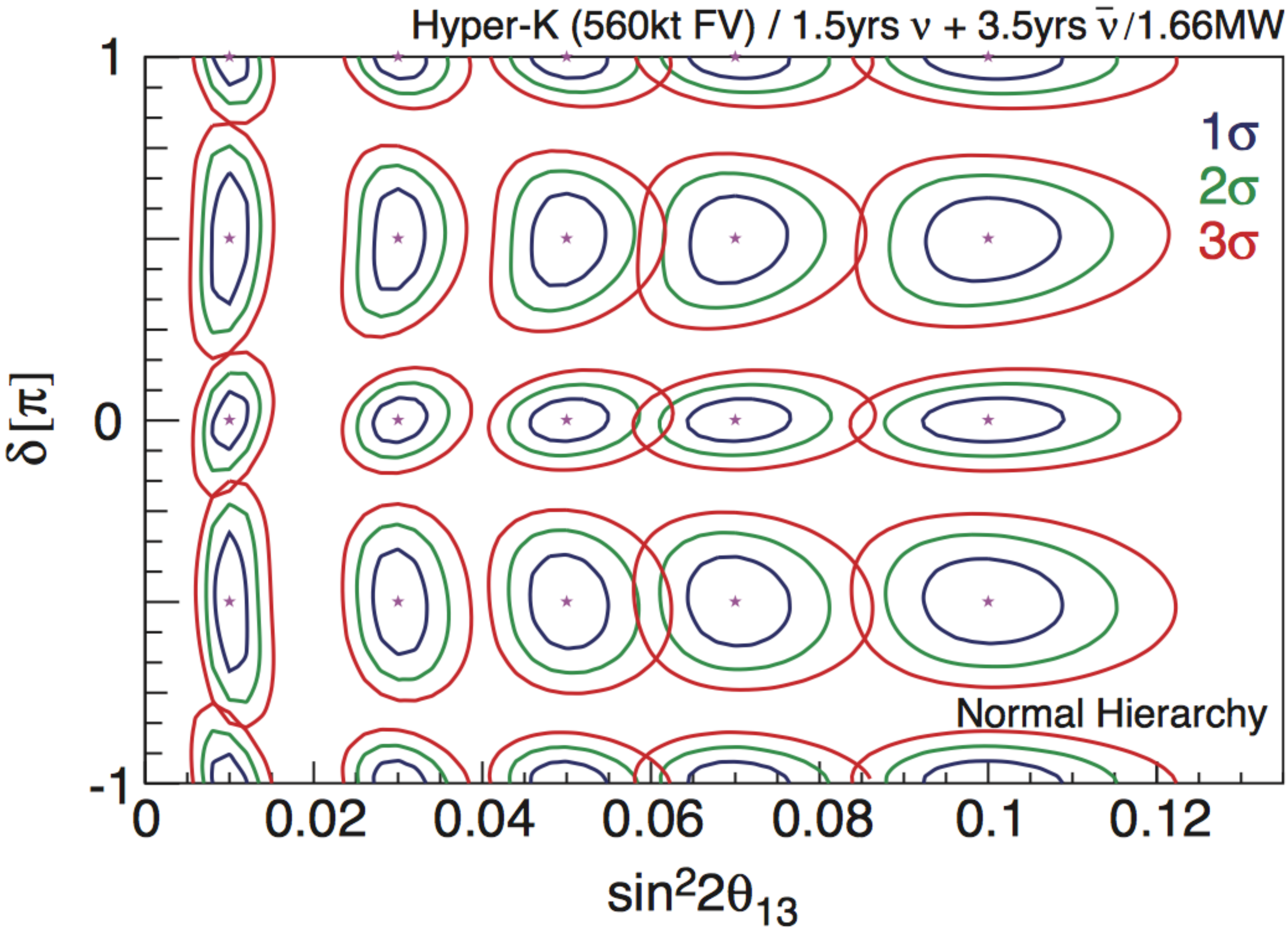
*arXiv:1109.3262



- 99,000 PMTs 20 inch w/ 20% photocathode coverage (50% the PMT coverage of Super-Kamiokande)
- 0.99 megaton total, w/ 0.56 mton fiducial

CP-Phase

*arXiv:1109.3262



Proton Decay

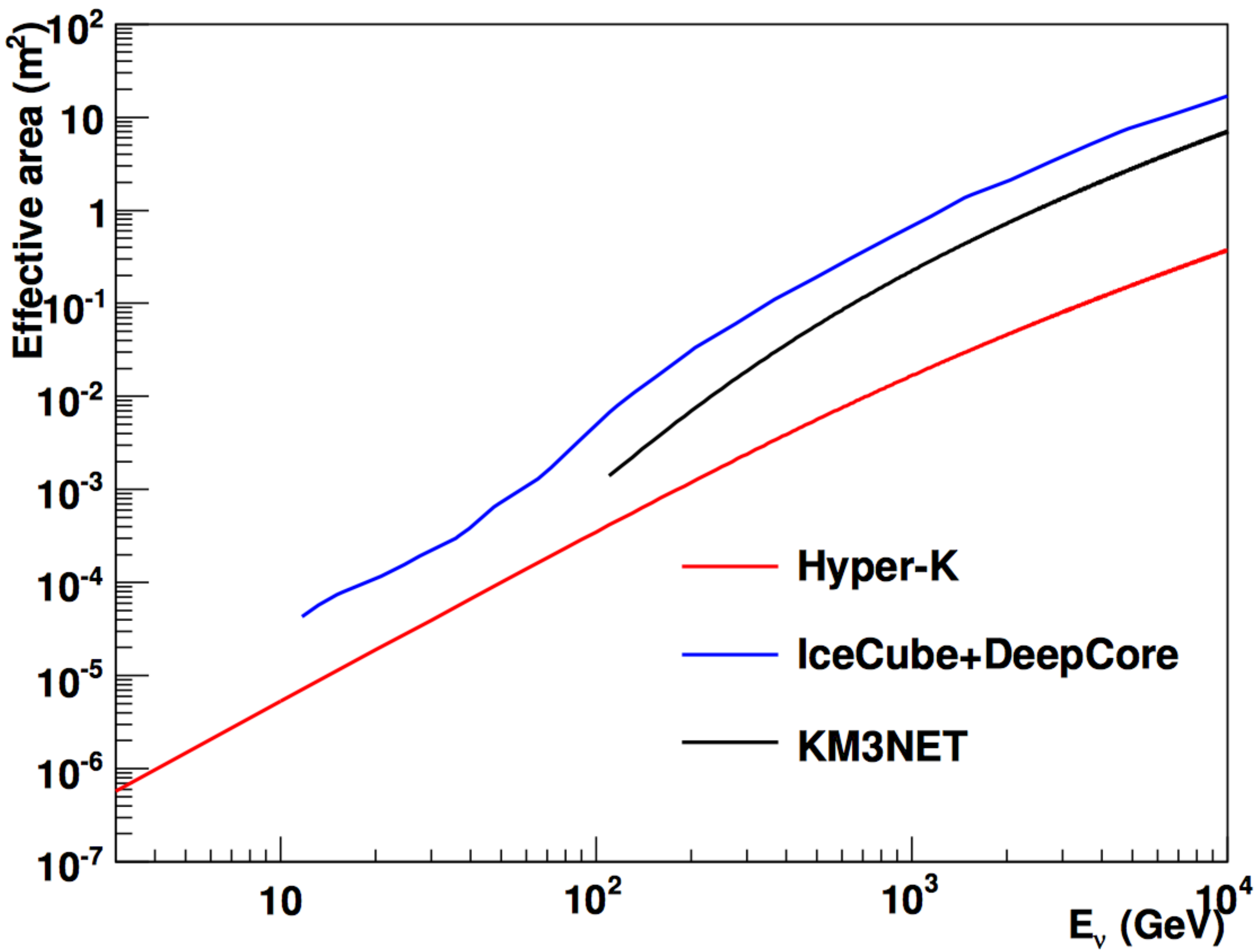
*arXiv:1109.3262

Mode	Sensitivity (90% CL)	Current limit
$p \to e^+\pi^0$	13×10^{34} years	1.3×10^{34} years
$p \to \mu^+\pi^0$	9.0×10^{34}	1.1×10^{34}
$p \to e^+\eta^0$	5.0×10^{34}	0.42×10^{34}
$p \to \mu^+\eta^0$	3.0×10^{34}	0.13×10^{34}
$p \to e^+\rho^0$	1.0×10^{34}	0.07×10^{34}
$p \to \mu^+\rho^0$	0.37×10^{34}	0.02×10^{34}
$p \to e^+\omega^0$	0.84×10^{34}	0.03×10^{34}
$p \to \mu^+\omega^0$	0.88×10^{34}	0.08×10^{34}
$n \to e^+\pi^-$	3.8×10^{34}	0.20×10^{34}
$n \to \mu^+\pi^-$	2.9×10^{34}	0.10×10^{34}
$p \to \overline{\nu}K^+$	2.5×10^{34}	0.40×10^{34}

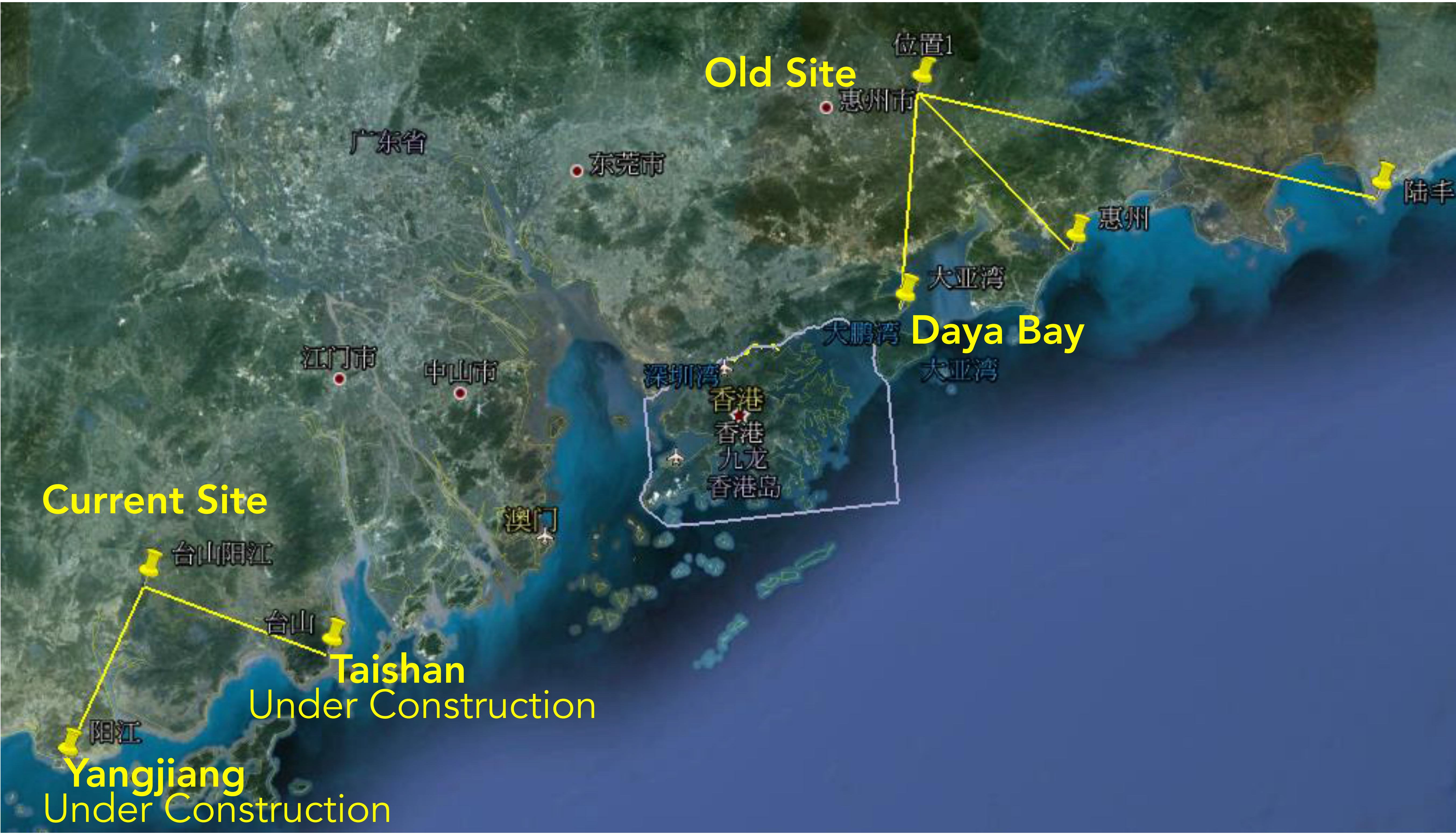
Comparison

- Size for up-going muon, i.e. from neutrino

*arXiv:1109.3262



JUNO



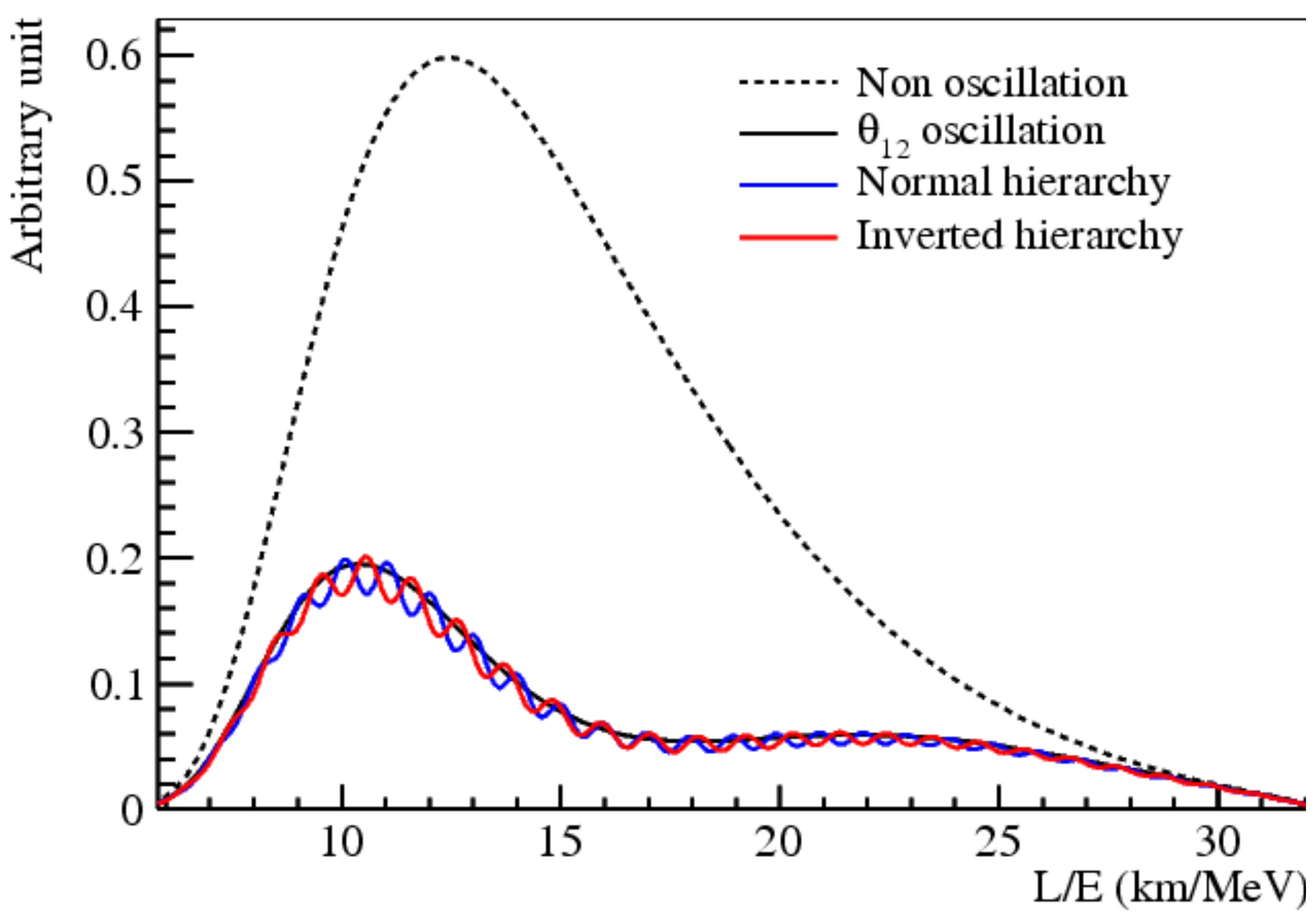
Old Site
位置1
惠州市
广东省
东莞市
陆丰
惠州
大亚湾
Daya Bay
大鹏湾
大亚湾
深圳湾
香港
香港
九龙
香港岛
江门市
中山市
澳门
Current Site
台山阳江
台山
Taishan
Under Construction
阳江
Yangjiang
Under Construction

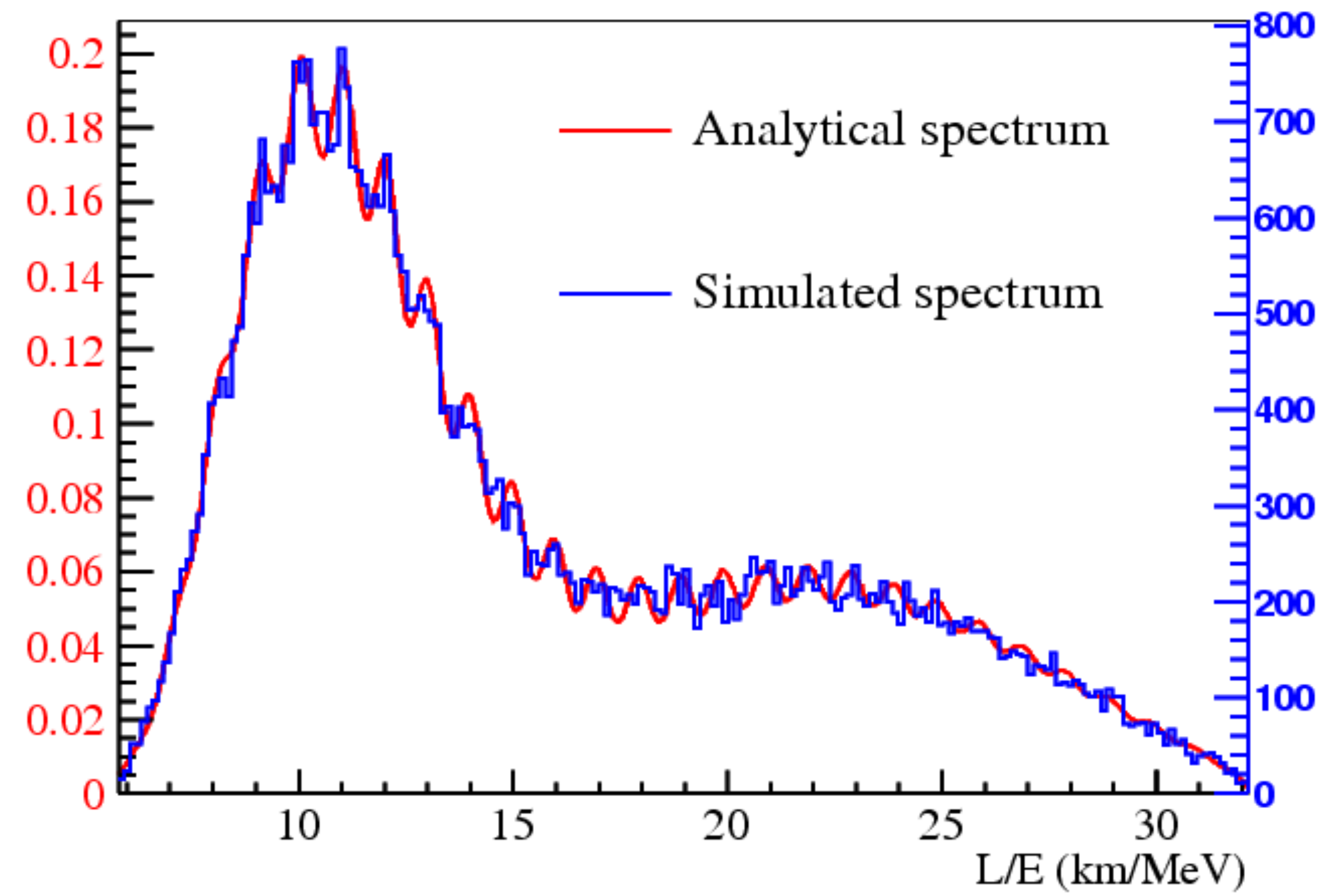
JUNO


Previous Site
Huizhou
Guangzhou
Dongguan
Zhaoqing
CNS
Daya Bay
Jiangmen
Zhongshan
Hong Kong
Zhujiang River Estuary
Current Site
Macau
Taishan
Under Construction
Yangjiang
Under Construction

JUNO

- Modulation of solar oscillation parameters in reactor long-baseline





*X. Li, Windows on the Universe 2013

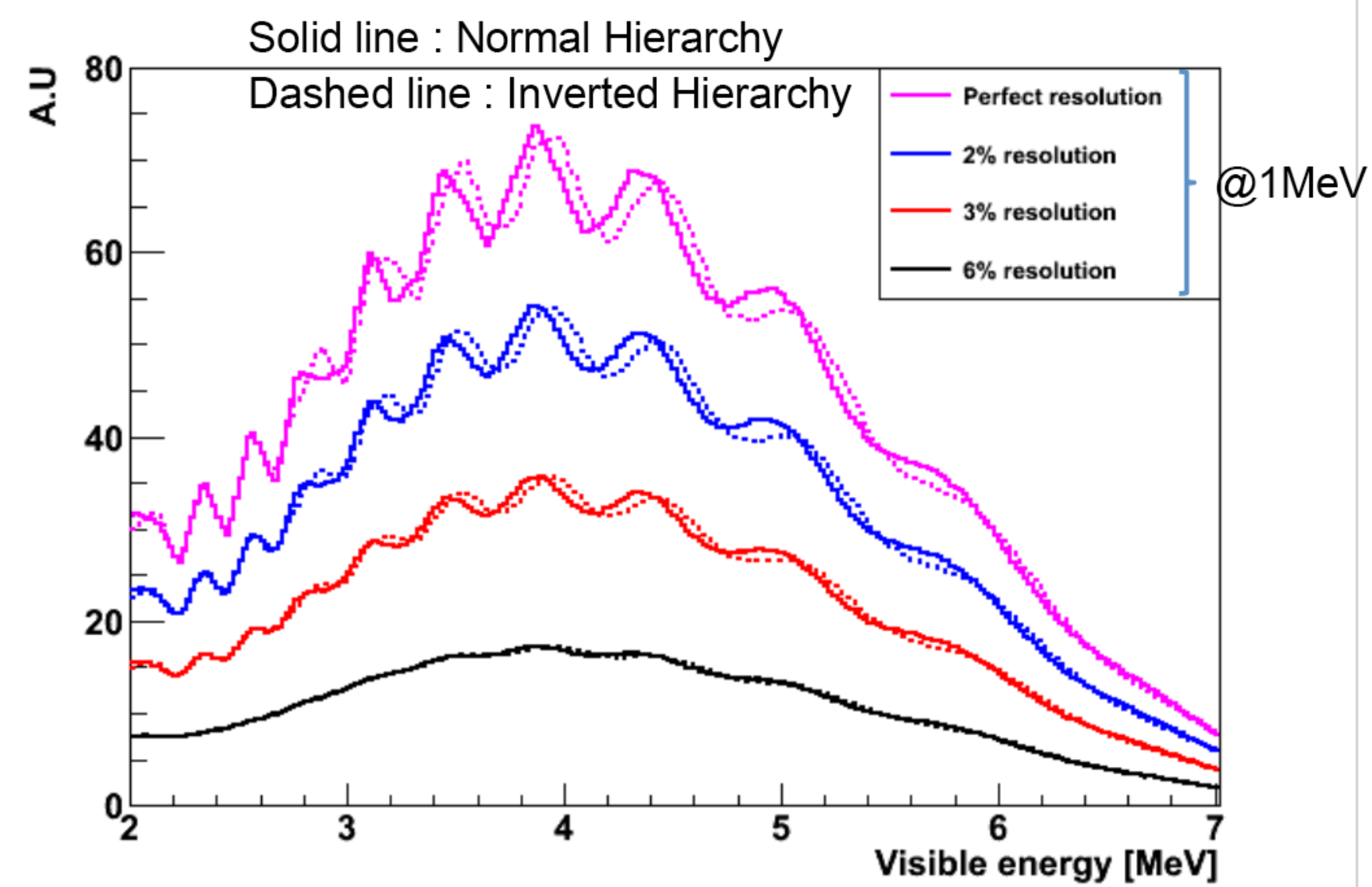
Requirements

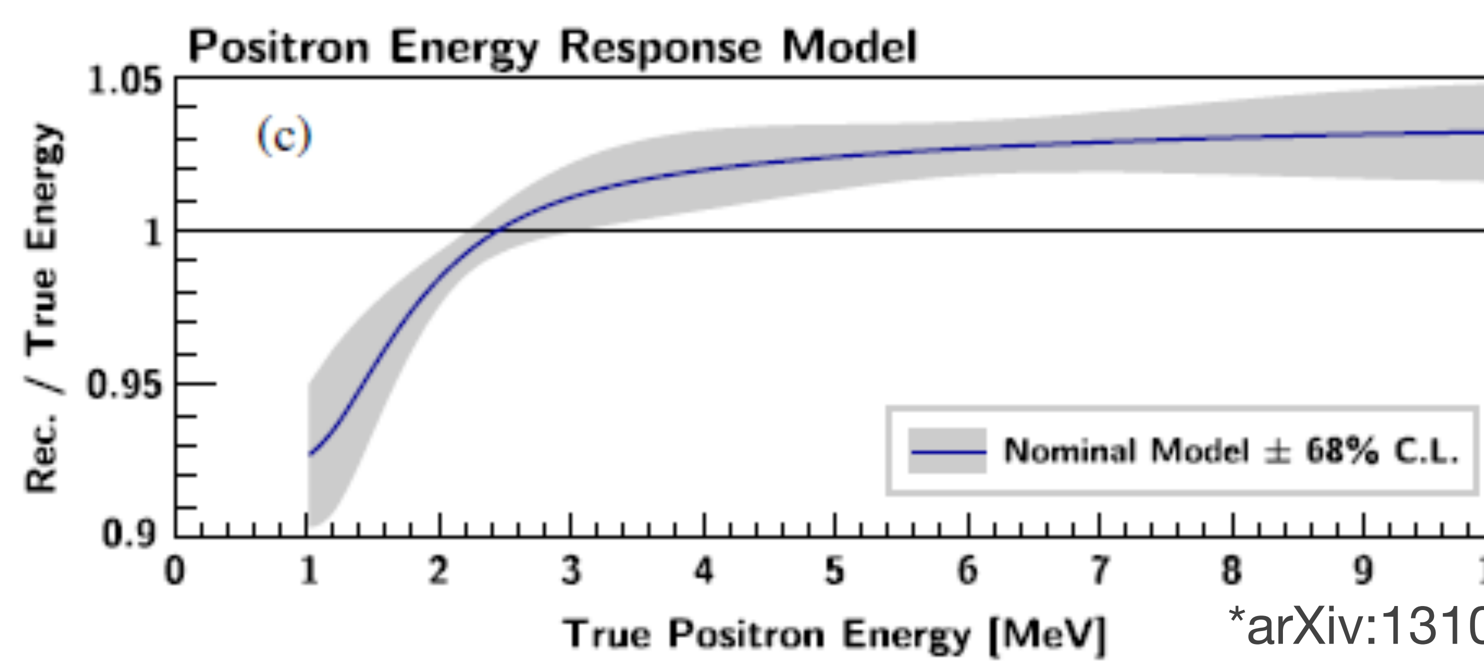
- Photo-cathode coverage of ~80% w/ 50,000 PMTs
- Energy
  - Resolution of $3\%/\sqrt{E(MeV)}$
  - Absolute of $< 1\%$
- High quantum Efficiency PMT (>35%)
- ~100,000 inverse beta-decay events
  - 55km baseline
  - >35 GW_{th} from reactor(s)
- 20 kilotons liquid scintillator
  - 30m attenuation
  - Light yield 1.5x better than KamLAND

Energy

- Non-linear energy regime for liquid scintillator
- Resolution, resolution, resolution

*J.S. Park, International Workshop on "RENO-50" 2013

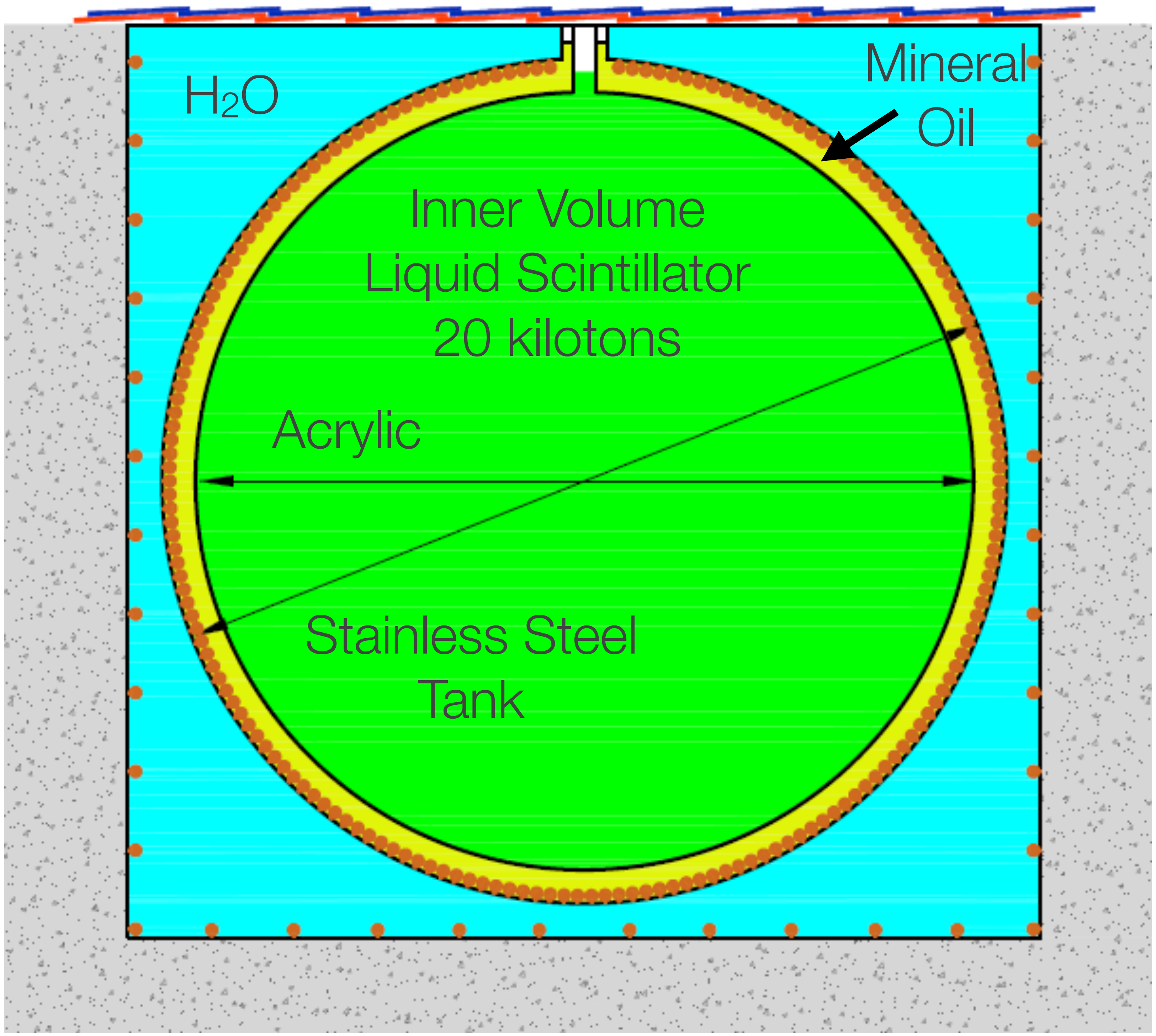




*arXiv:1310.6732

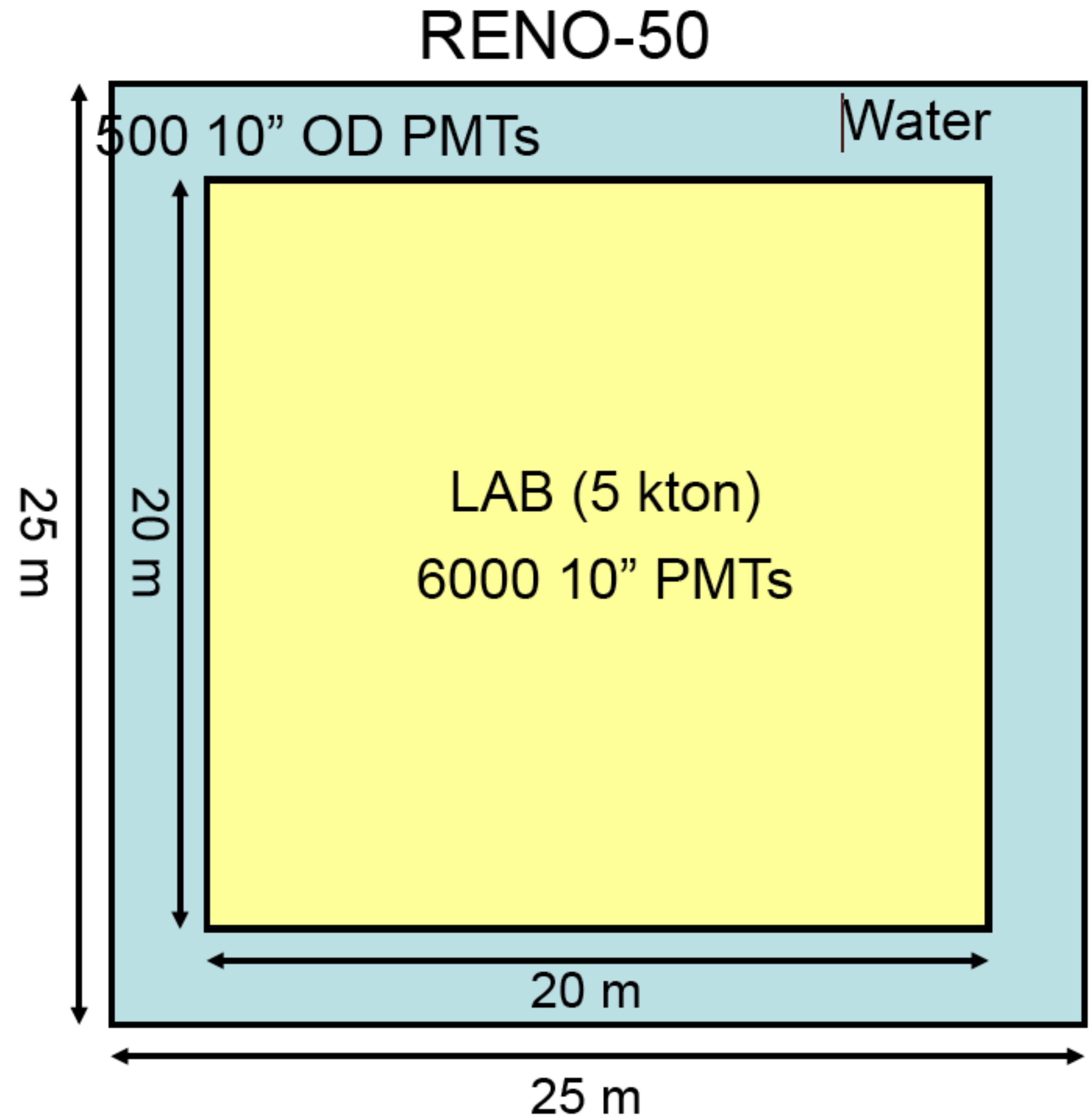
Possible Volume

- Ambitious
- Examining how to separate inner LS volume from veto region and PMT glass (radioactivity)
  - Acrylic sphere
  - Acrylic box
  - Balloon



RENO-50

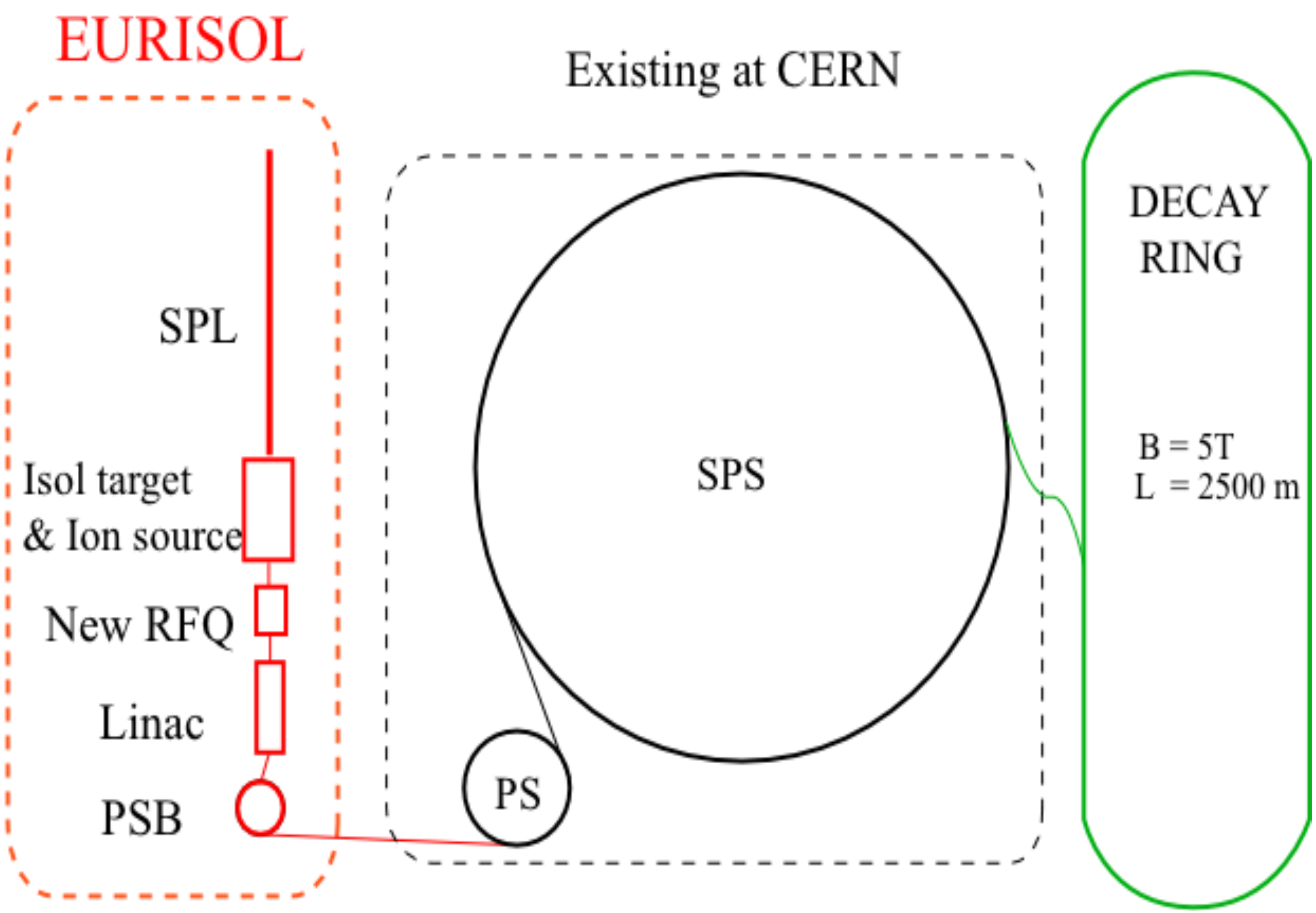
- S. Korea experiment to measure the NMH using the Yonggwang Nuclear Power Plant



Future Beams

Beta-Beam

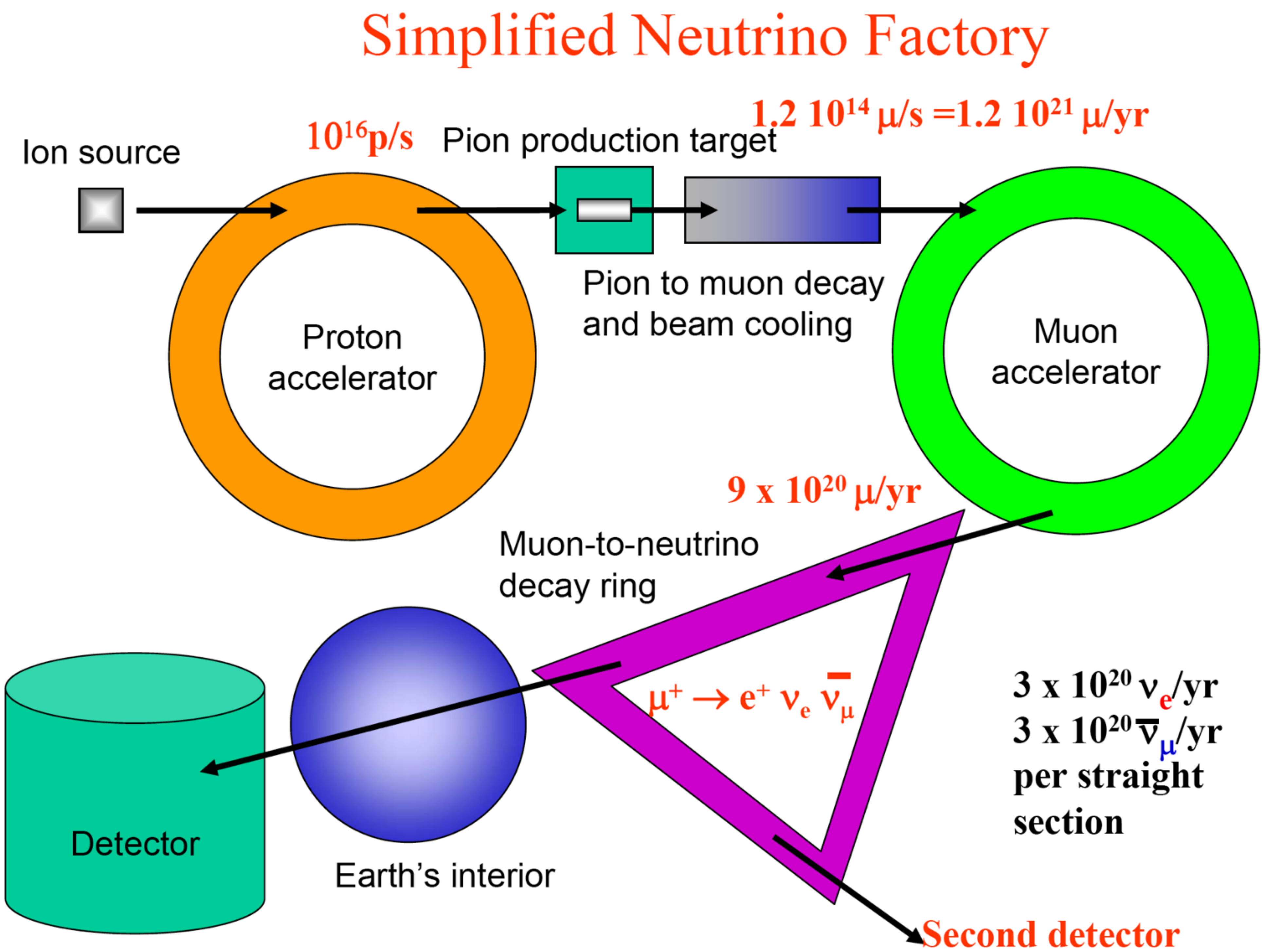
- Instead of accelerating protons, accelerate radioactive ions
- Ions undergo beta-decay producing extremely pure $\overline{\nu}_e/\nu_e$



*L. Camilleri, Neutrino 2006

Neutrino Factory

*L. Camilleri, Neutrino 2006

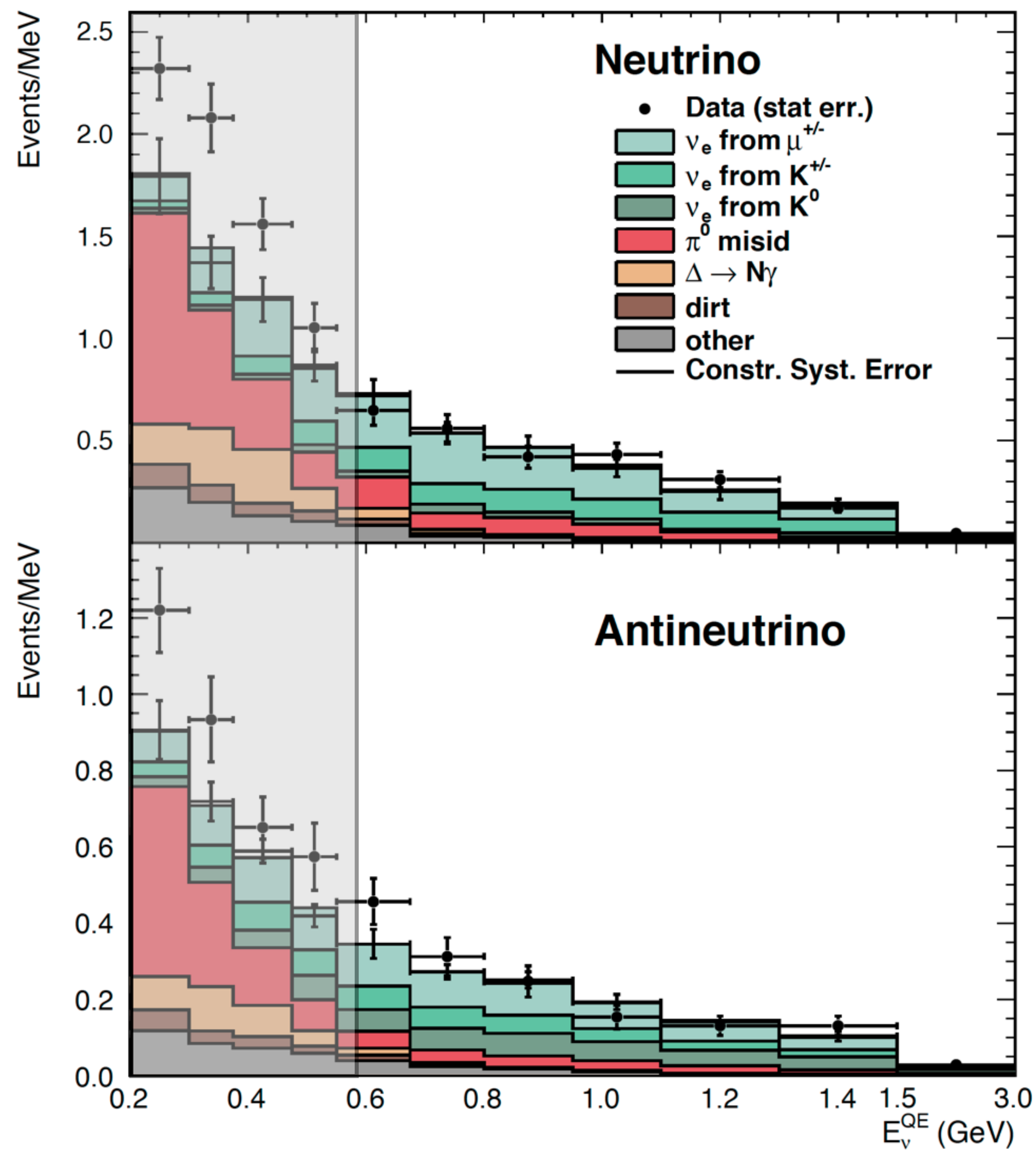


Anomalies

Anomalies

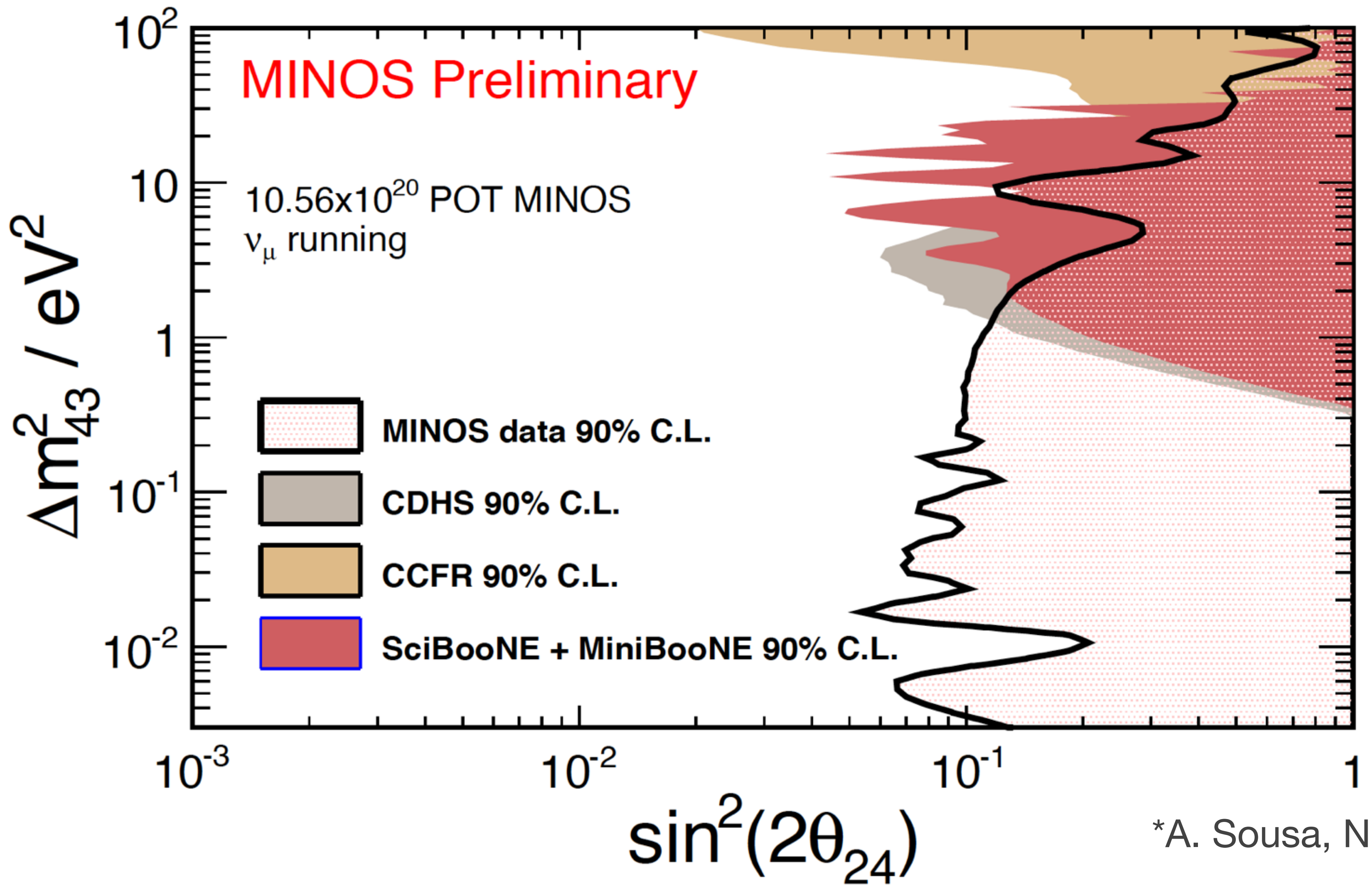
- Certainly exist in data
- Reactors
- Short-baseline

arXiv:1303.2588



Anomalies

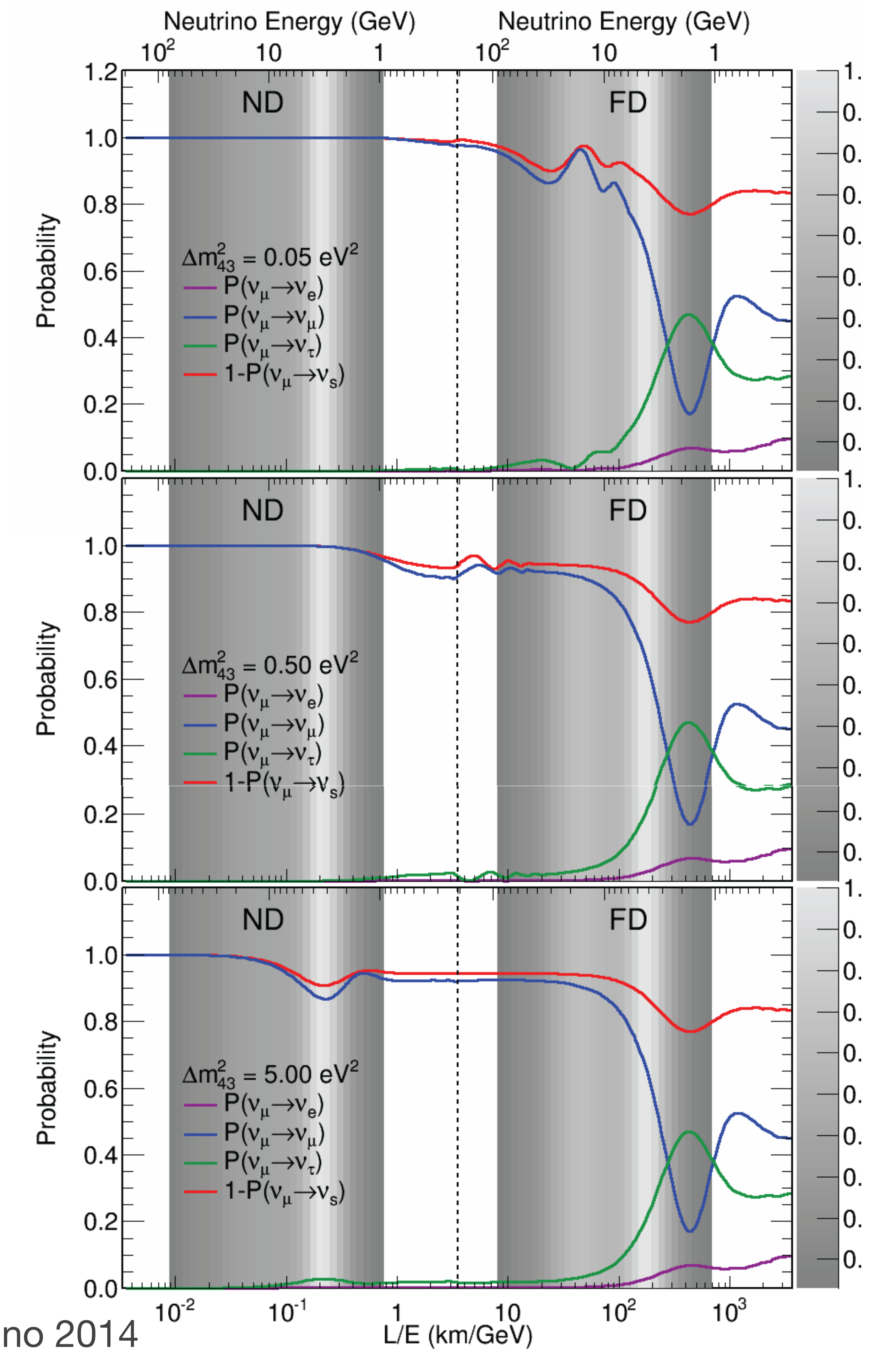
- Disappearance experiments have strong limits on sterile mixing in the < 1 eV



*A. Sousa, Neutrino 2014

Probabilities

- Can be thought of in terms of L/E (baseline/energy) for comparison
  - Different energy regions
  - Different neutrino flavors
  - Different detection methods

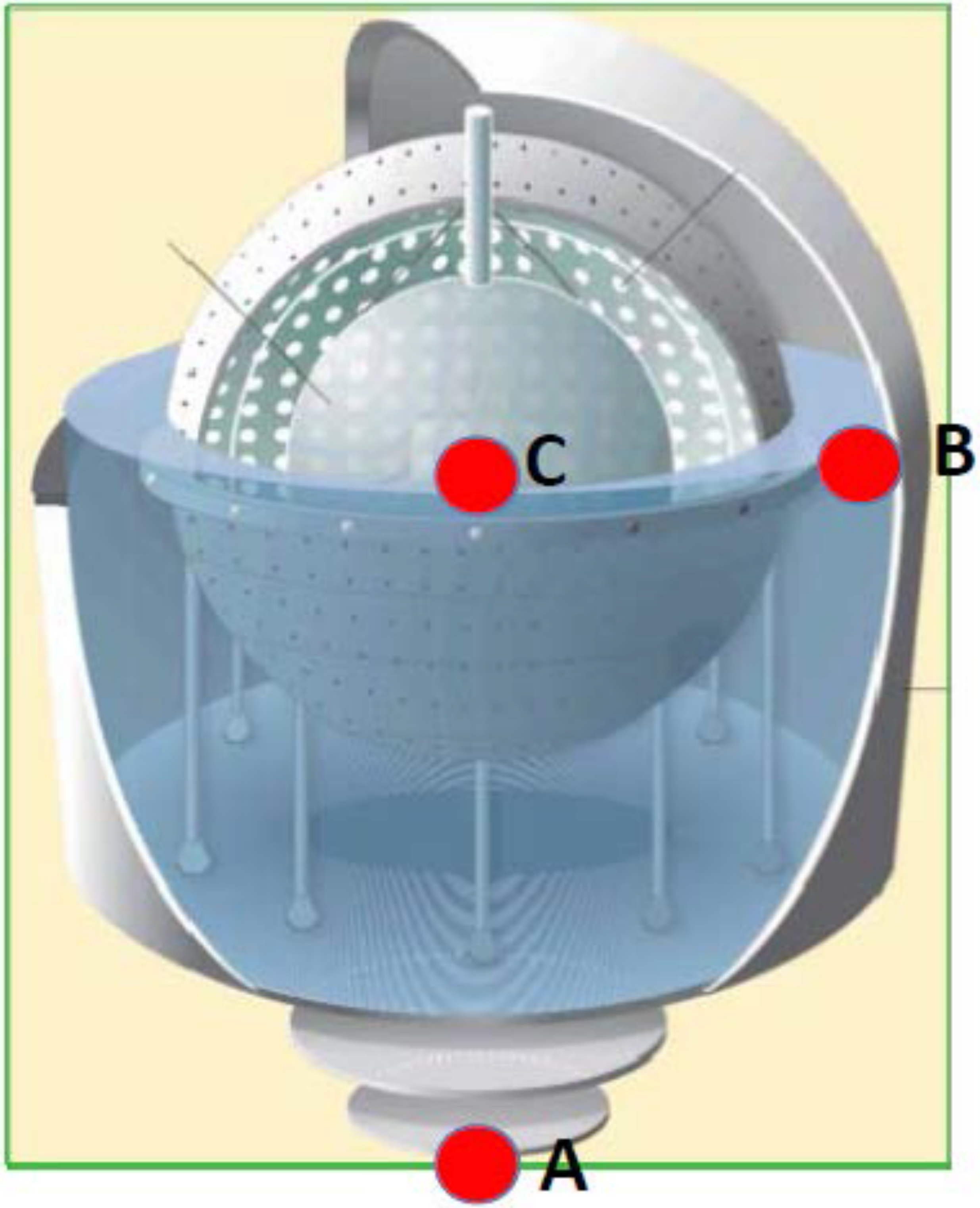


*A. Sousa, Neutrino 2014

New Experiments

- Put a high-power radioactive source next to an anti-neutrino detector
  - Borexino, KamLAND, JUNO, …
  - Source transport is a logistics issue
- CeLAND, SOX (Cr, Ce) are options

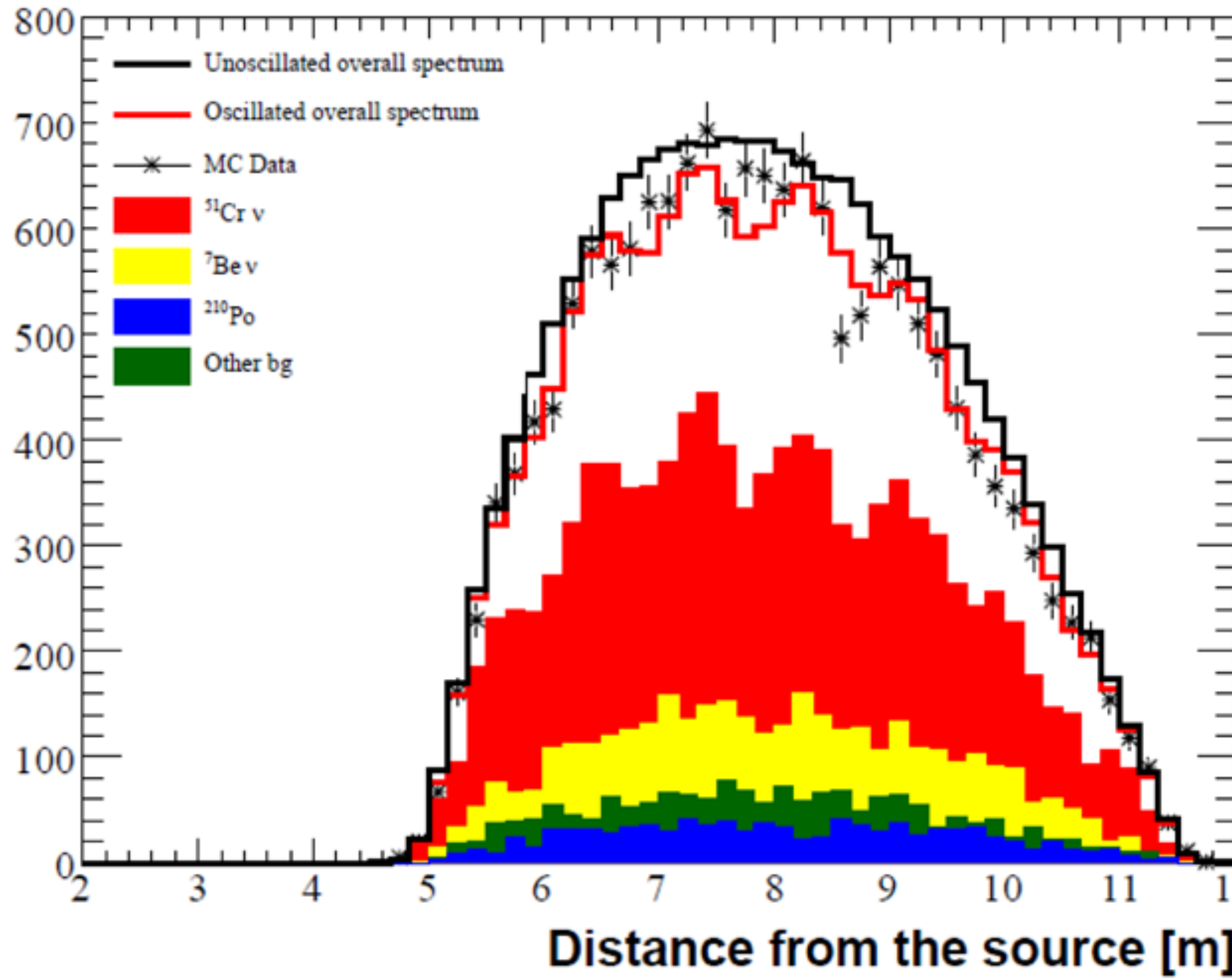
Borexino



Near/Medium/Far Detector in One

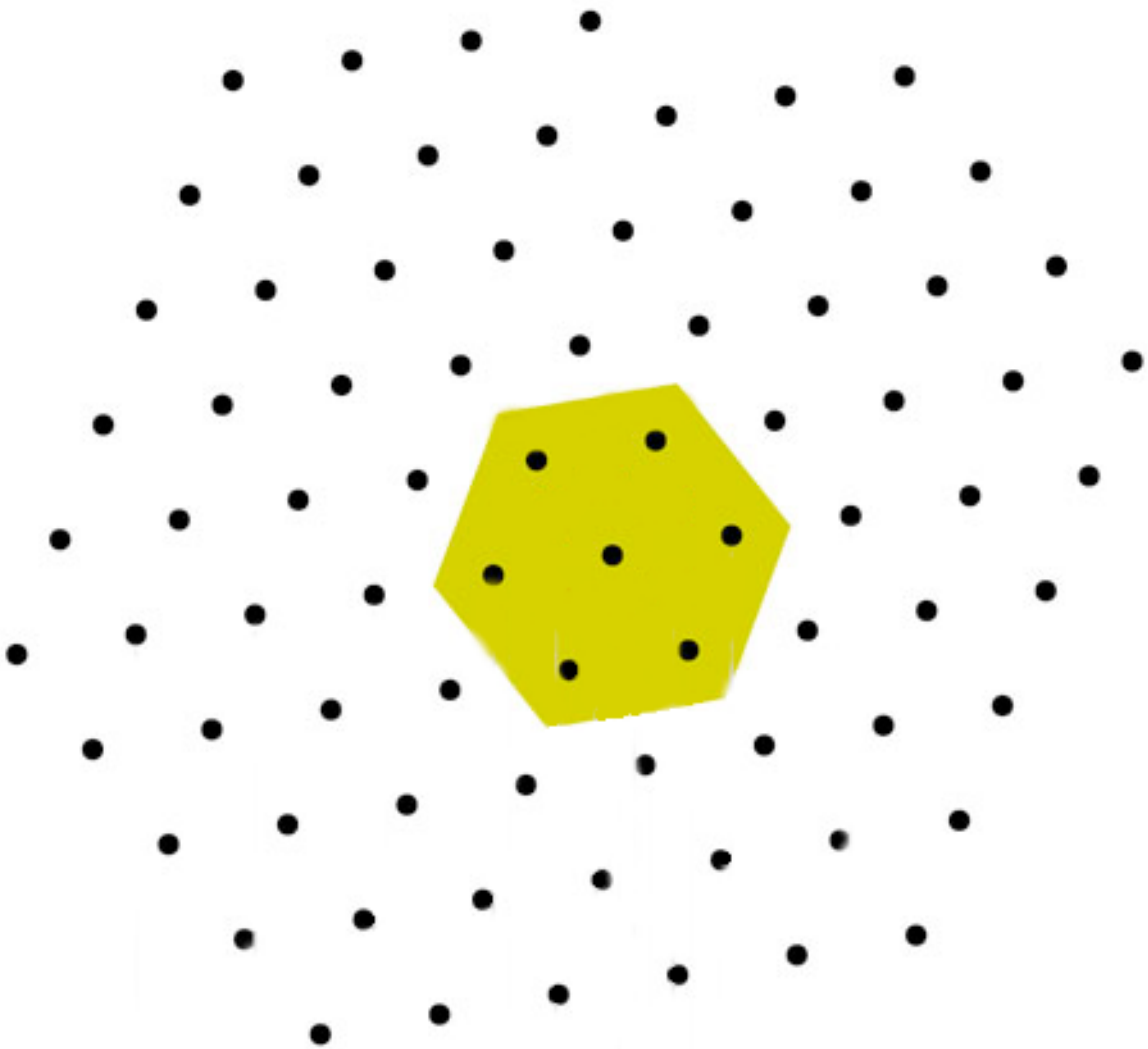
- Oscillation effect can be seen across the detector
- Signal changes as source strength decreases, but most backgrounds remain constant in time

arXiv:1304.7721



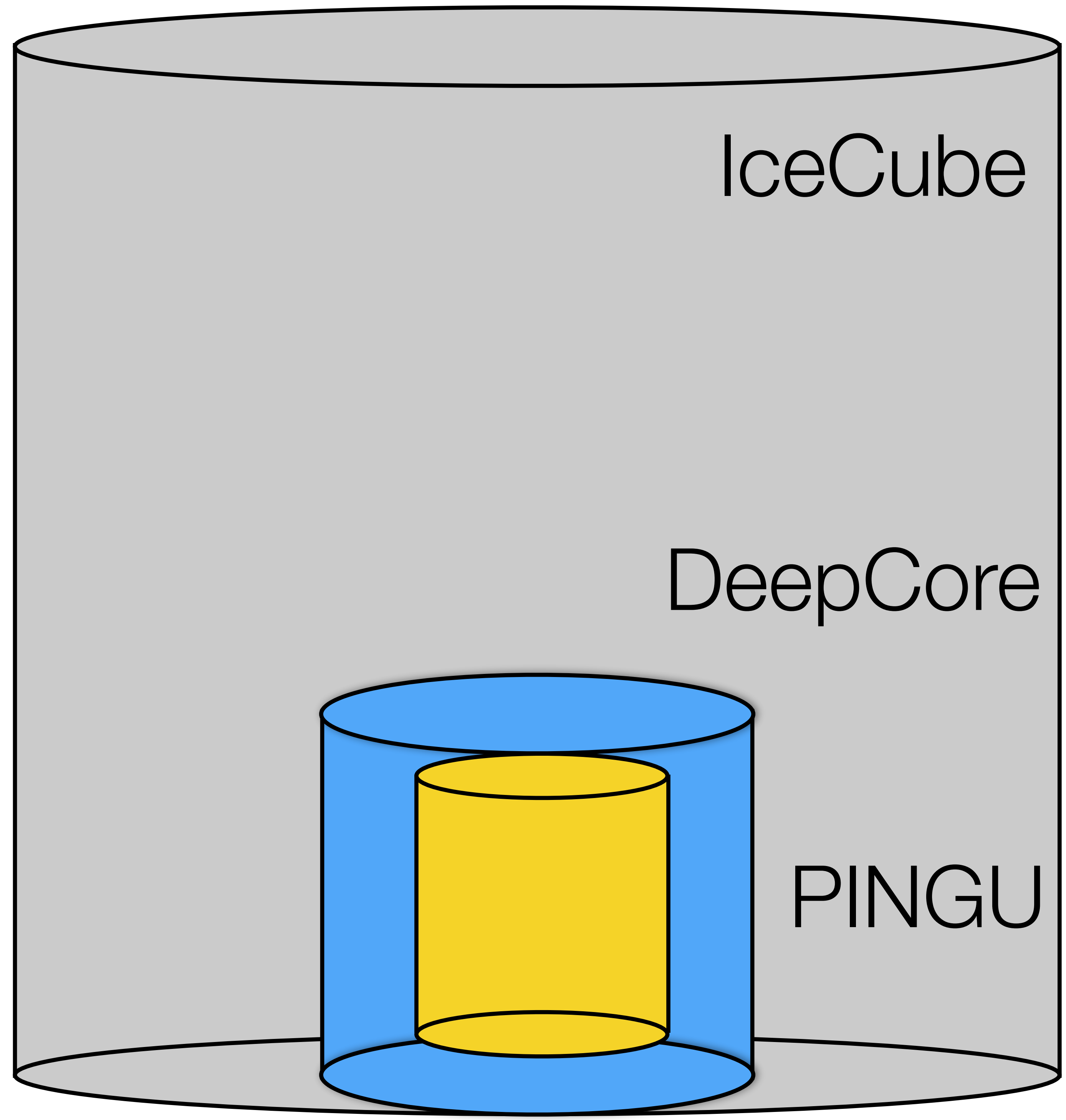
South Pole

Top View



Precision IceCube Next Generation Upgrade

- Use existing and familiar technology to infill DeepCore
- Improve rejection of cosmic ray muon background
- Primary physics goal is resolving neutrino mass hierarchy

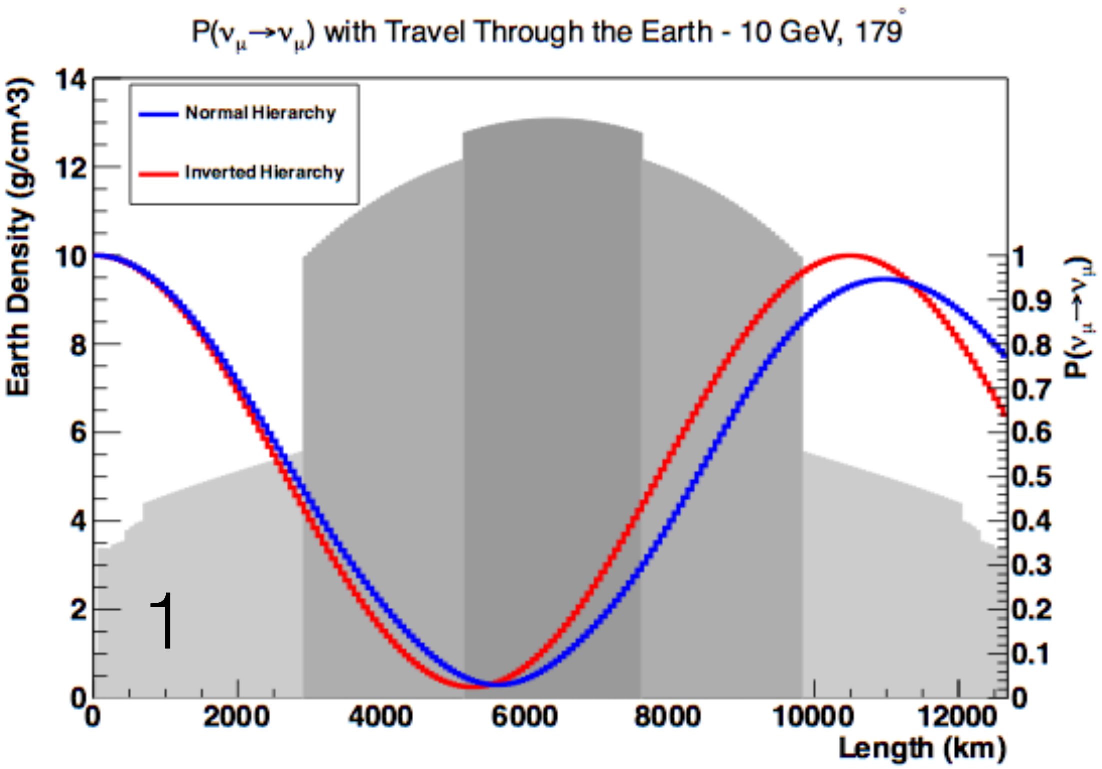


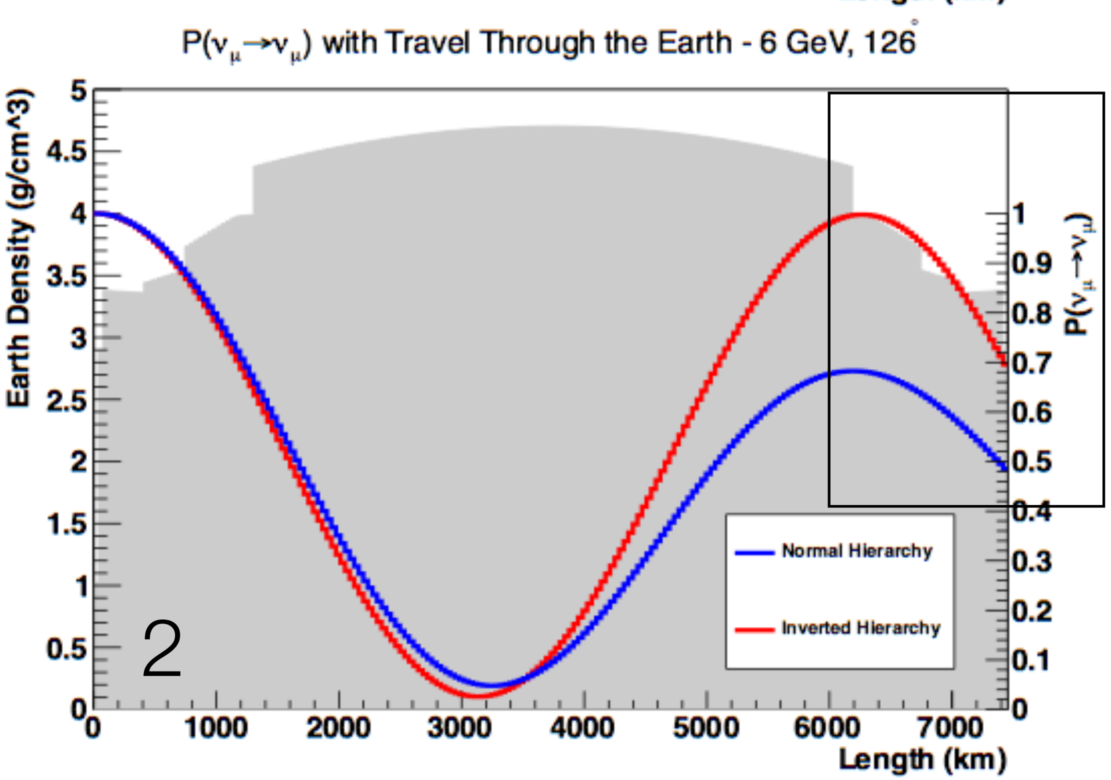
PINGU Simulation Event

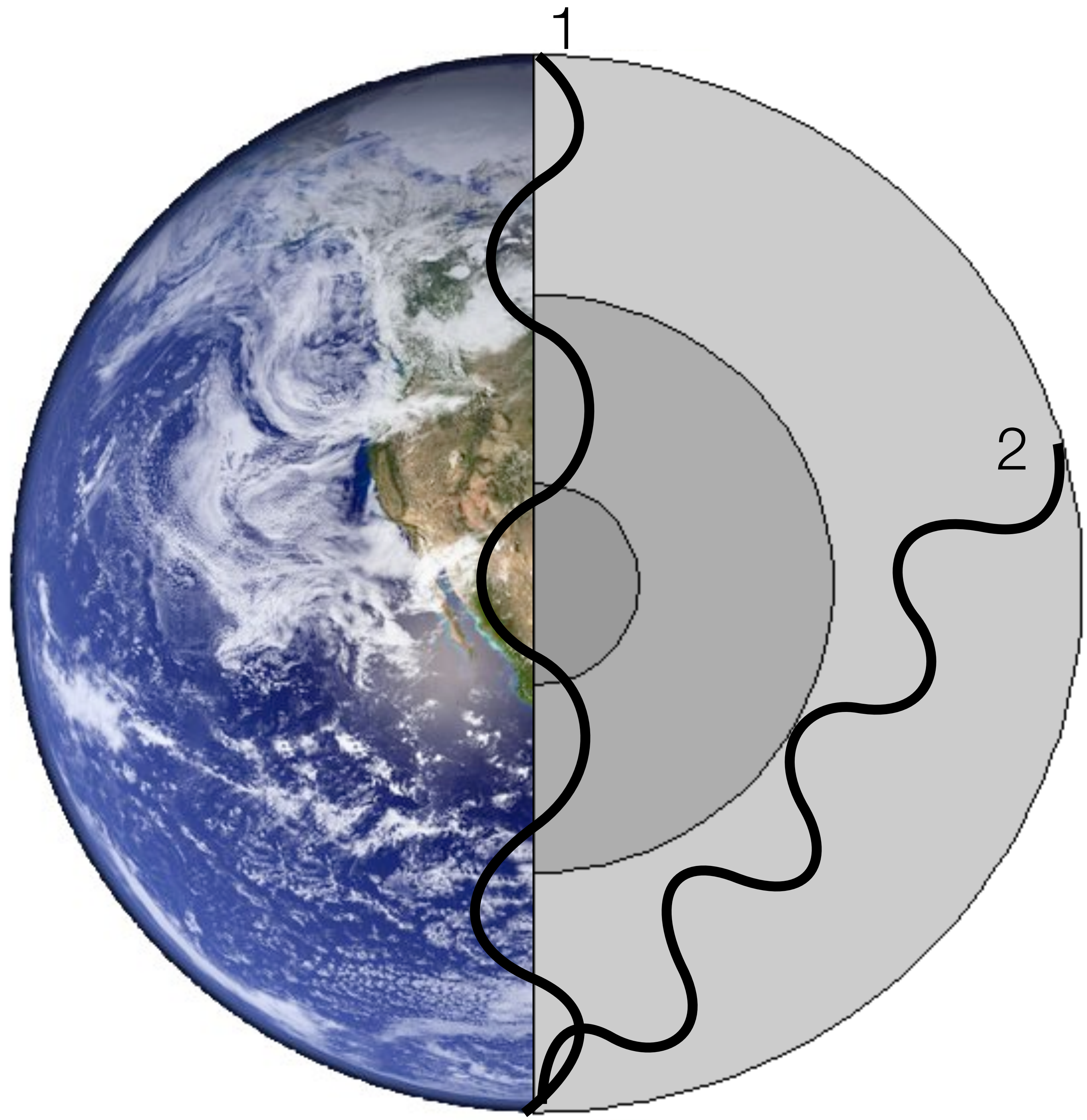
- 9.28 GeV Neutrino, 4.9 GeV

- ~20 vs. ~50 Hit Modules

Matter Effect and NMH



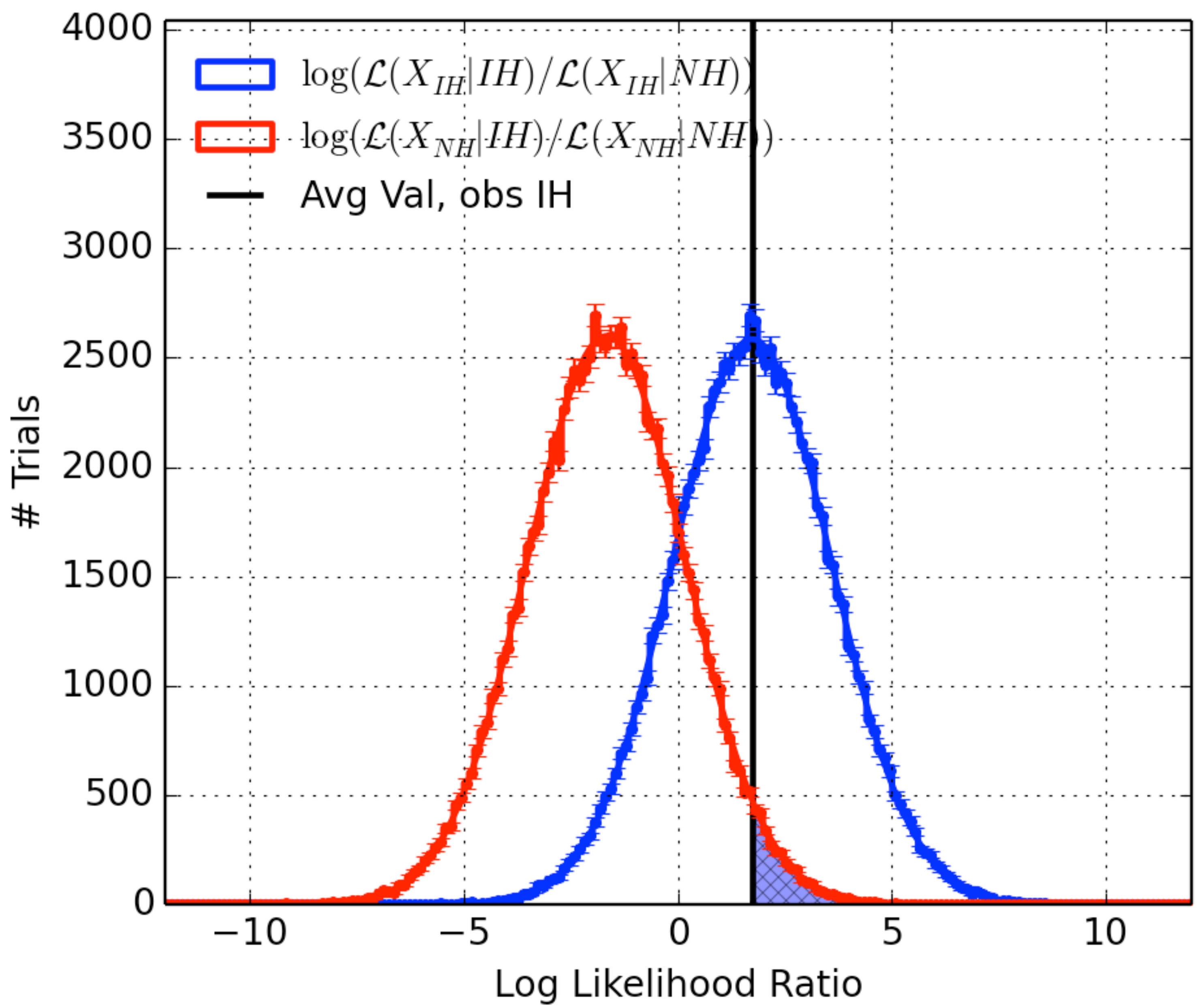




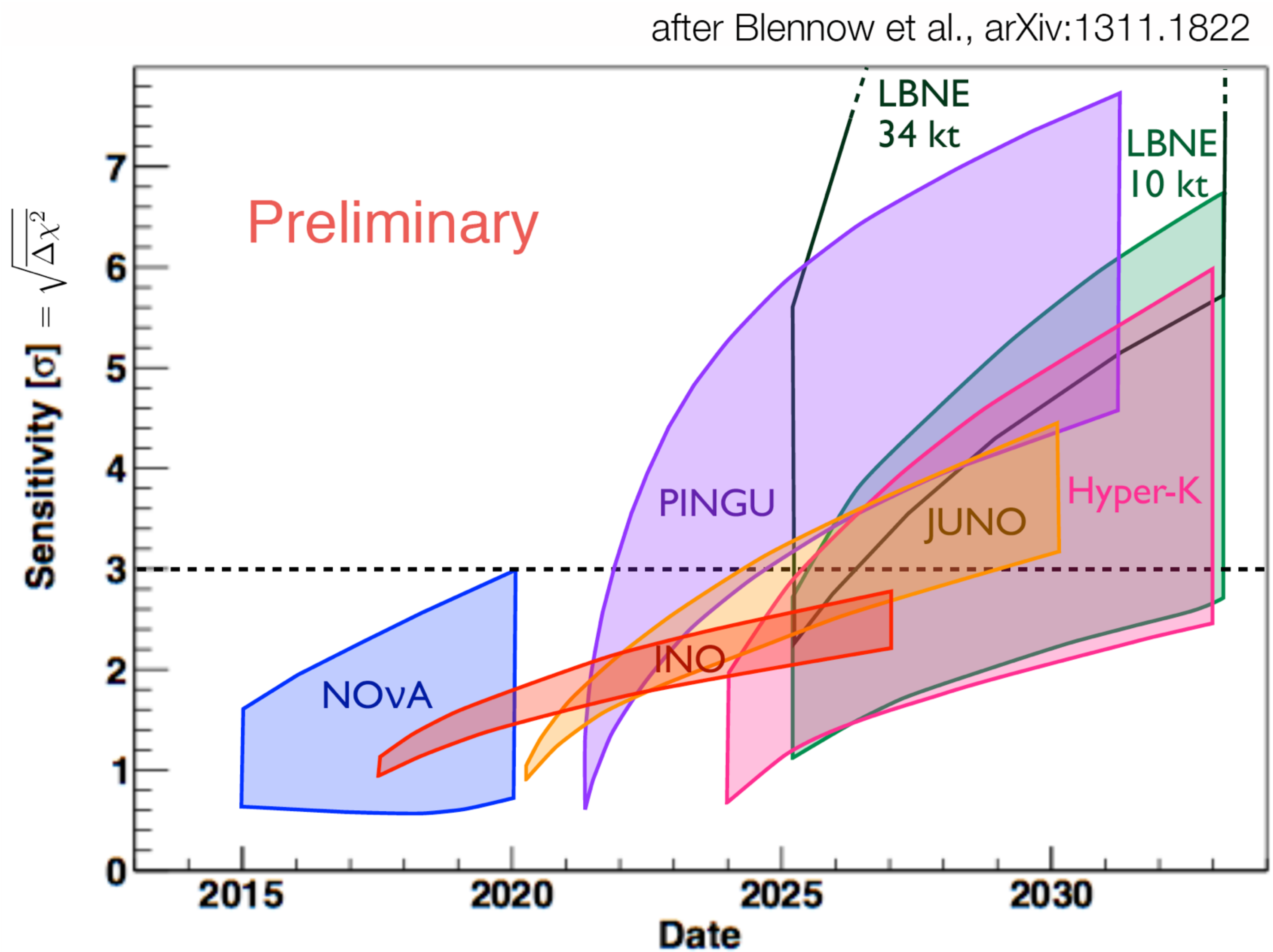
- Inverted/Normal hierarchy has up to a 20% difference in oscillation probability for specific energies and zenith angles (baselines)

Differentiation Between Hierarchies

- Use a likelihood ratio



Timelines



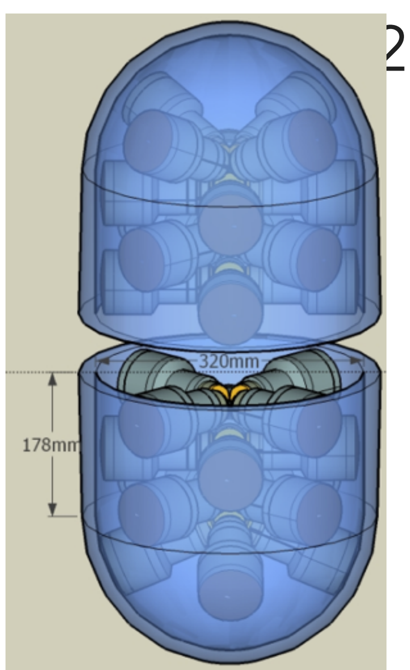
after Blennow et al., arXiv:1311.1822
Preliminary
LBNE
34 kt
LBNE
10 kt
PINGU
JUNO
Hyper-K
INO
NOvA
Sensitivity [σ] = $\sqrt{\Delta\chi^2}$
0
1
2
3
4
5
6
7
2015
2020
2025
2030
Date

Going Very Low

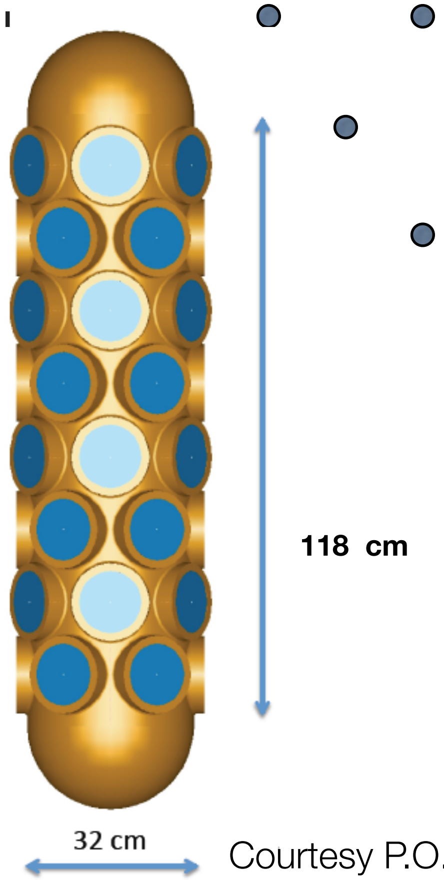
- South Pole Infrastructure
  - No excavation
  - Deployment is a now a precision process
- Unchanging, low-background medium
- Move from GeV to tens of MeV
  - Cerenkov Ring Imaging
  - Single PMT Module is no longer feasible
- Multi-megaton Ice Cherenkov Array (MICA)

Detector Modules

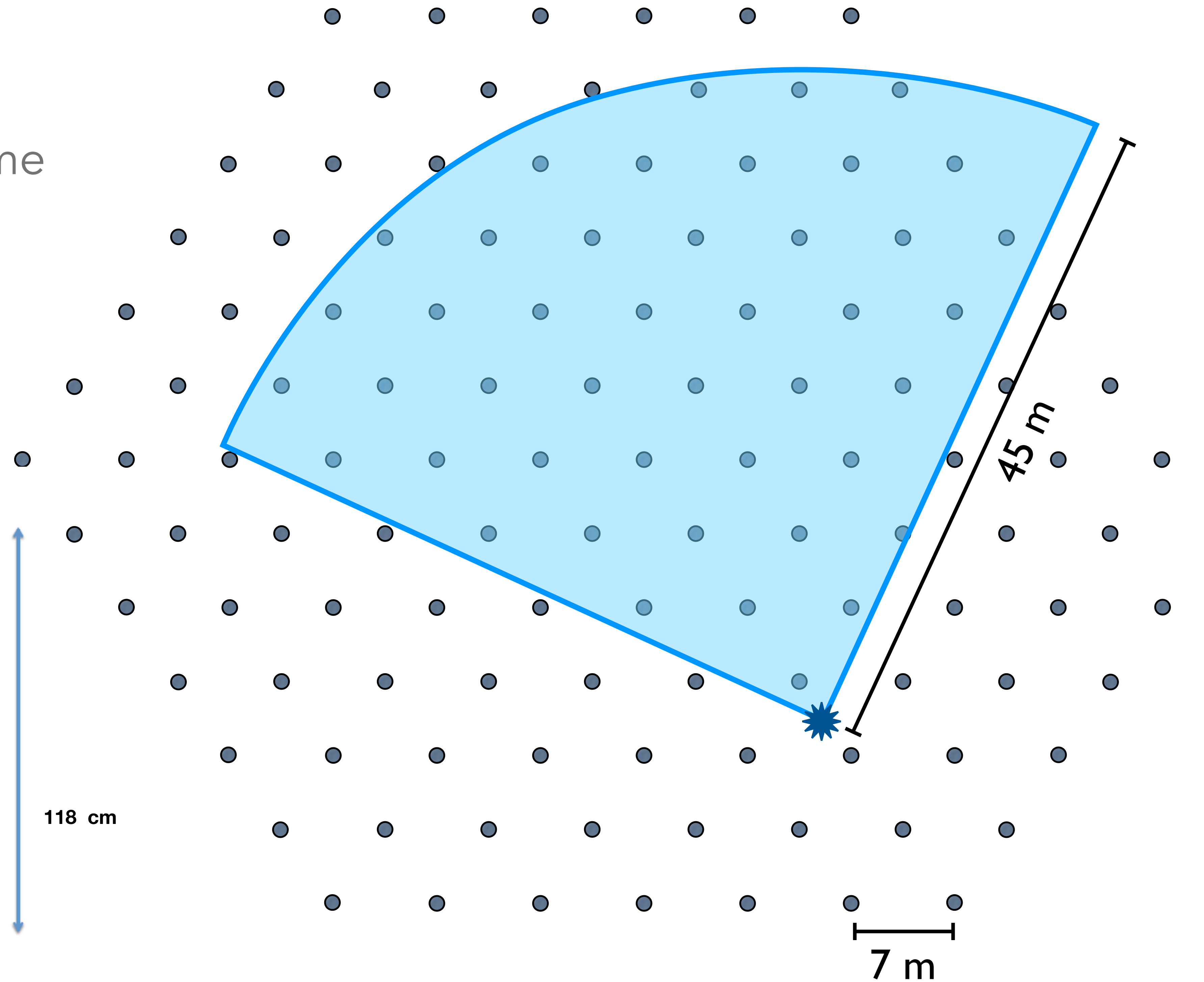
- 120 strings of 125 composite DOMs each
  - Instrumented volume of 250 m height, ~40 m radius
- 1 MegaTon fiducial volume, at dep
  2450 r

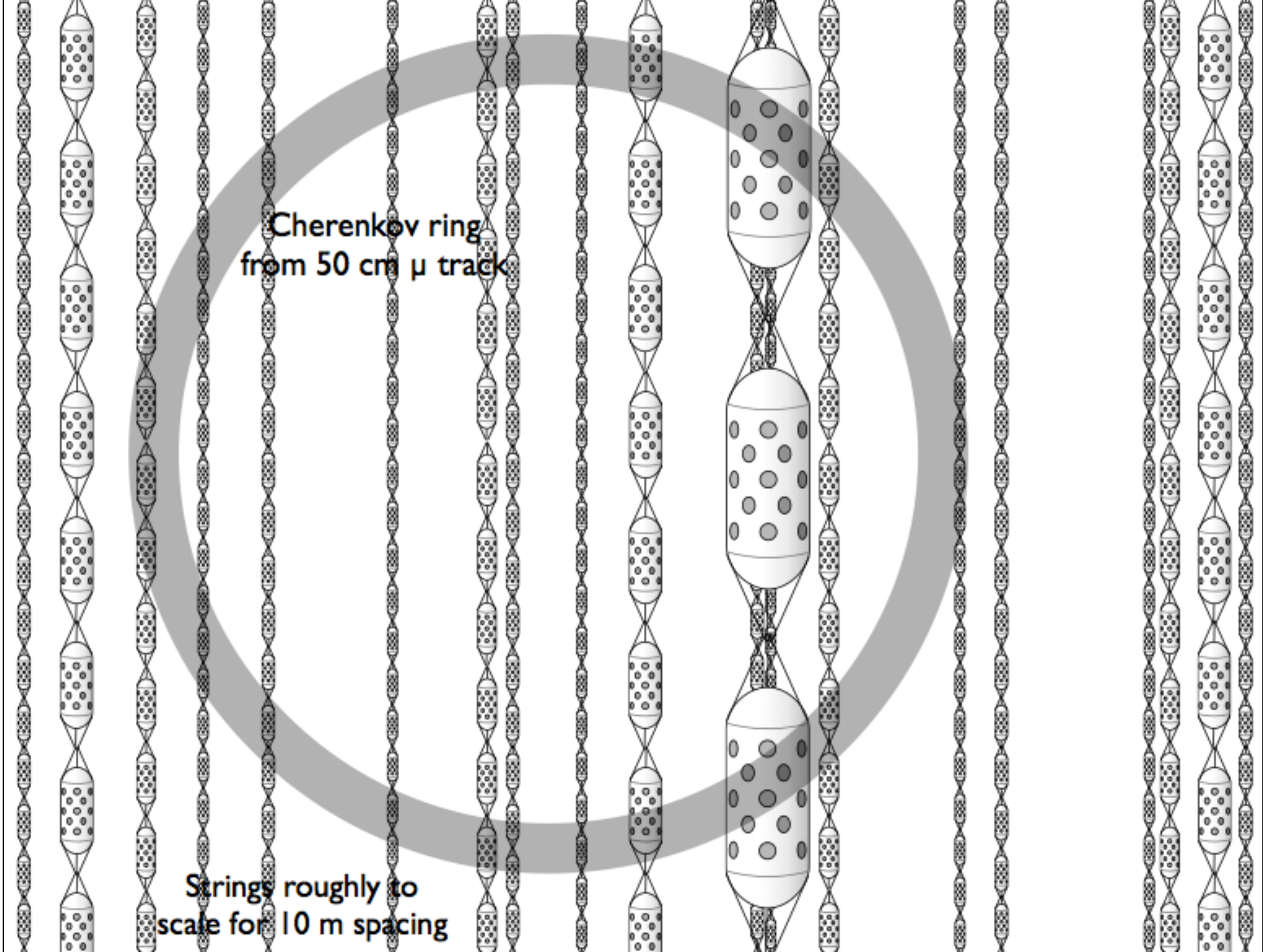


Courtesy P. Kooijman



Courtesy P.O. Hulth

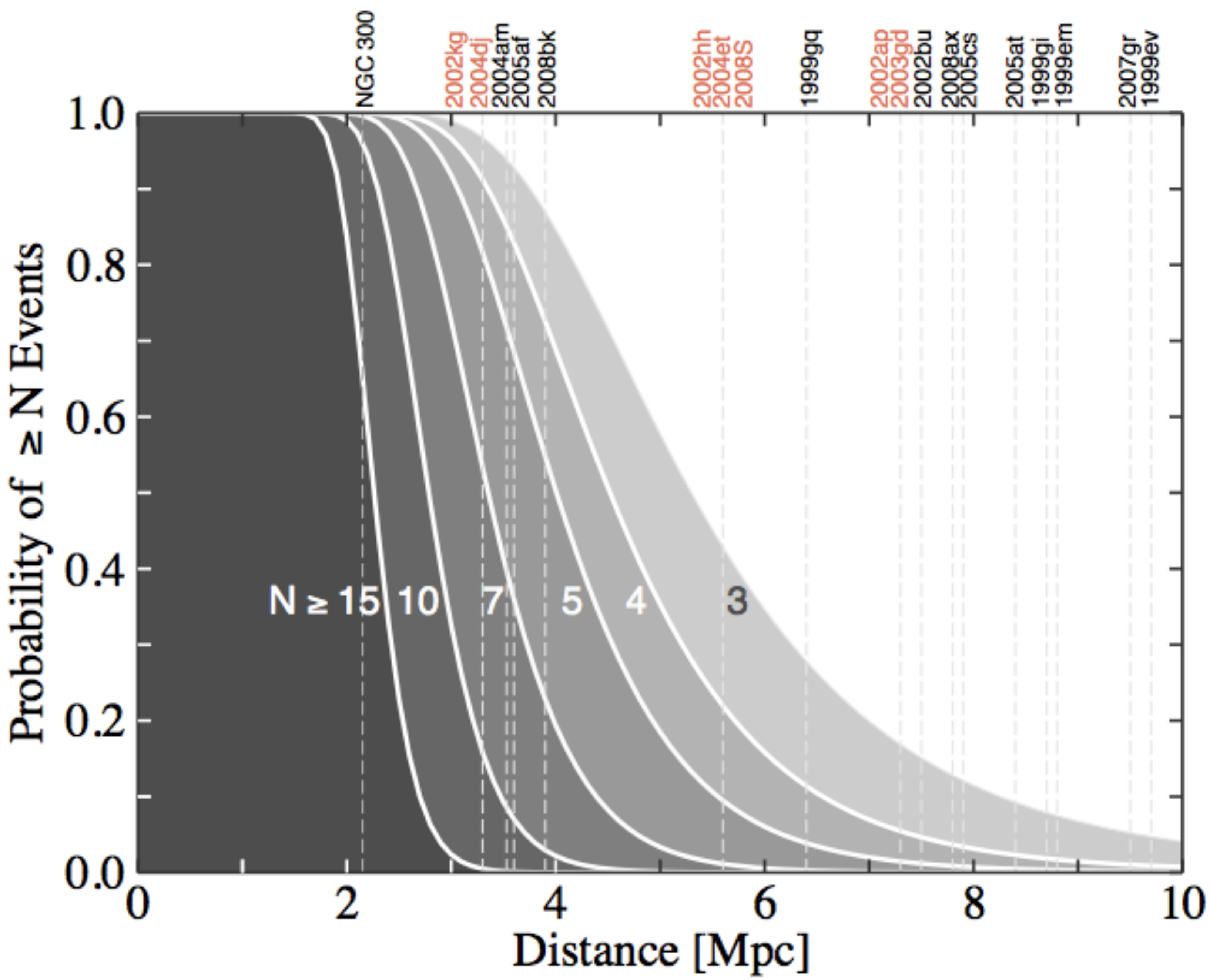




Cherenkov ring
from 50 cm μ track
Strings roughly to
scale for 10 m spacing

SuperNova

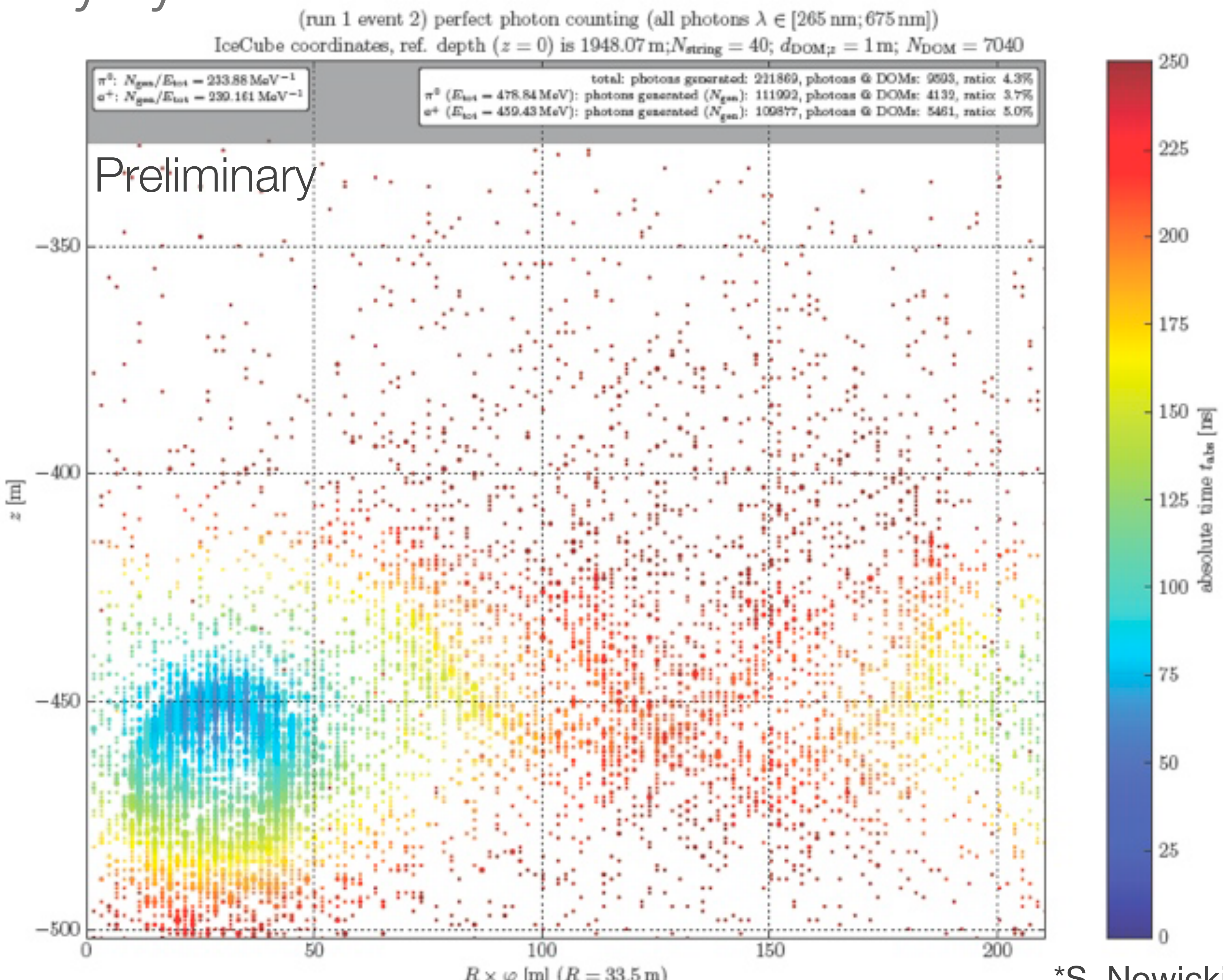
- A detector with a megaton(s) sensitive volume to bursts of MeV neutrinos could extend neutrino observation of SN to beyond our galaxy



Kistler et. al.
arXiv:0810.1959

Proton Decay

- For an idealized detector, the rings from $p \rightarrow \pi^0 + e^+$ are visible by eye



*S. Nowicki, U of Alberta

Beam to South Pole

- PINGU and MICA physics portfolio makes us of natural neutrino sources. Adding a beam will strengthen the diversity.

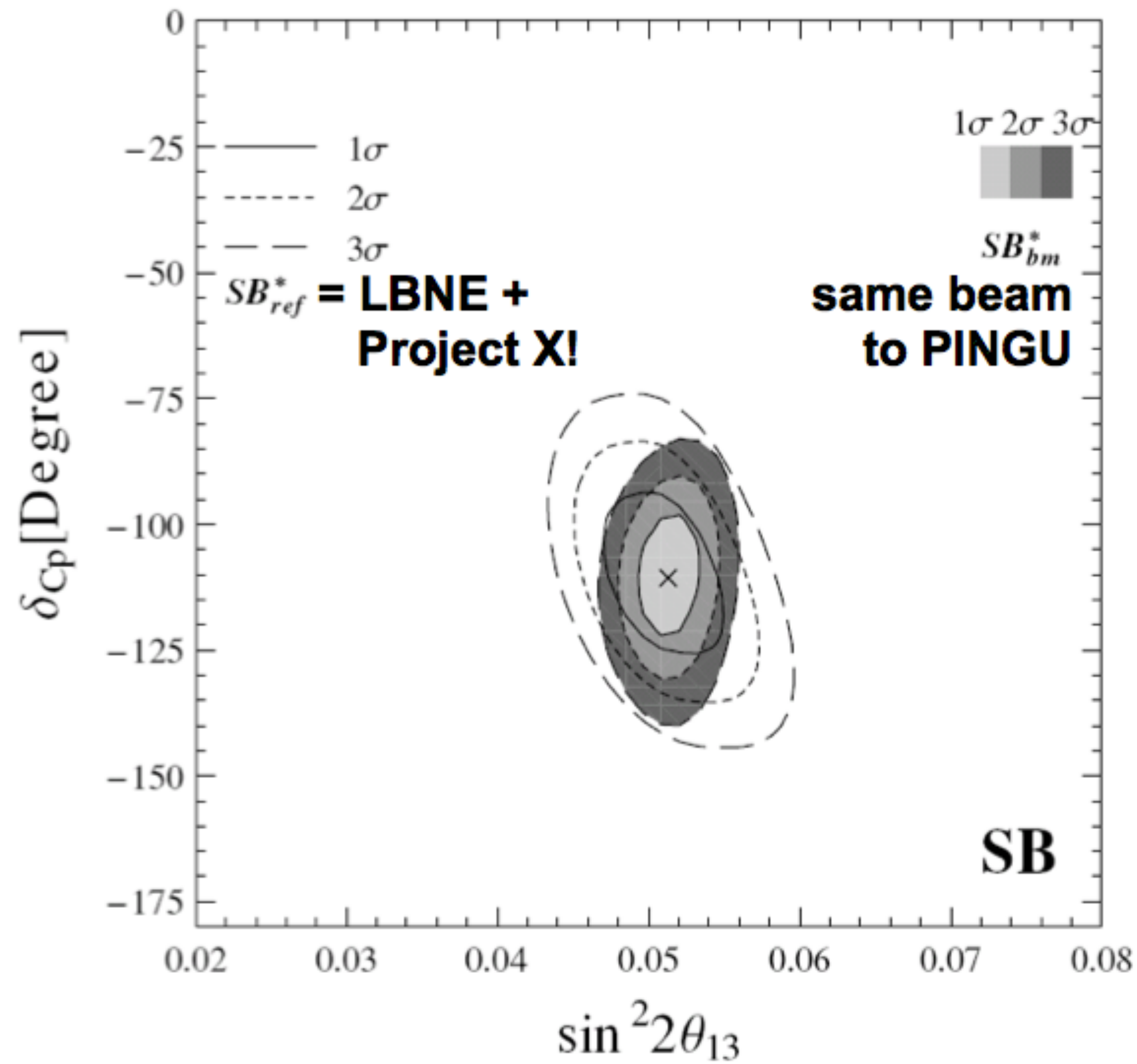
- 11620 baseline has a tilt angle of 65.8^{o} from FNAL (similar for CERN)

“Superbeam FNAL-PINGU?”, W. Winter

Julius-Maximilians-
UNIVERSITÄT WÜRZBURG

Upgrade path towards δ_{CP}?

- Measurement of δ_{CP} in principle possible, but challenging
- Requires:
  - Electromagnetic shower ID (here: 1% mis-ID)
  - Energy resolution (here: 20% x E)
  - Maybe: volume upgrade (here: ~ factor two)
  - Project X
- Performance and optimization of PINGU, and possible upgrades (MICA, …) require further study

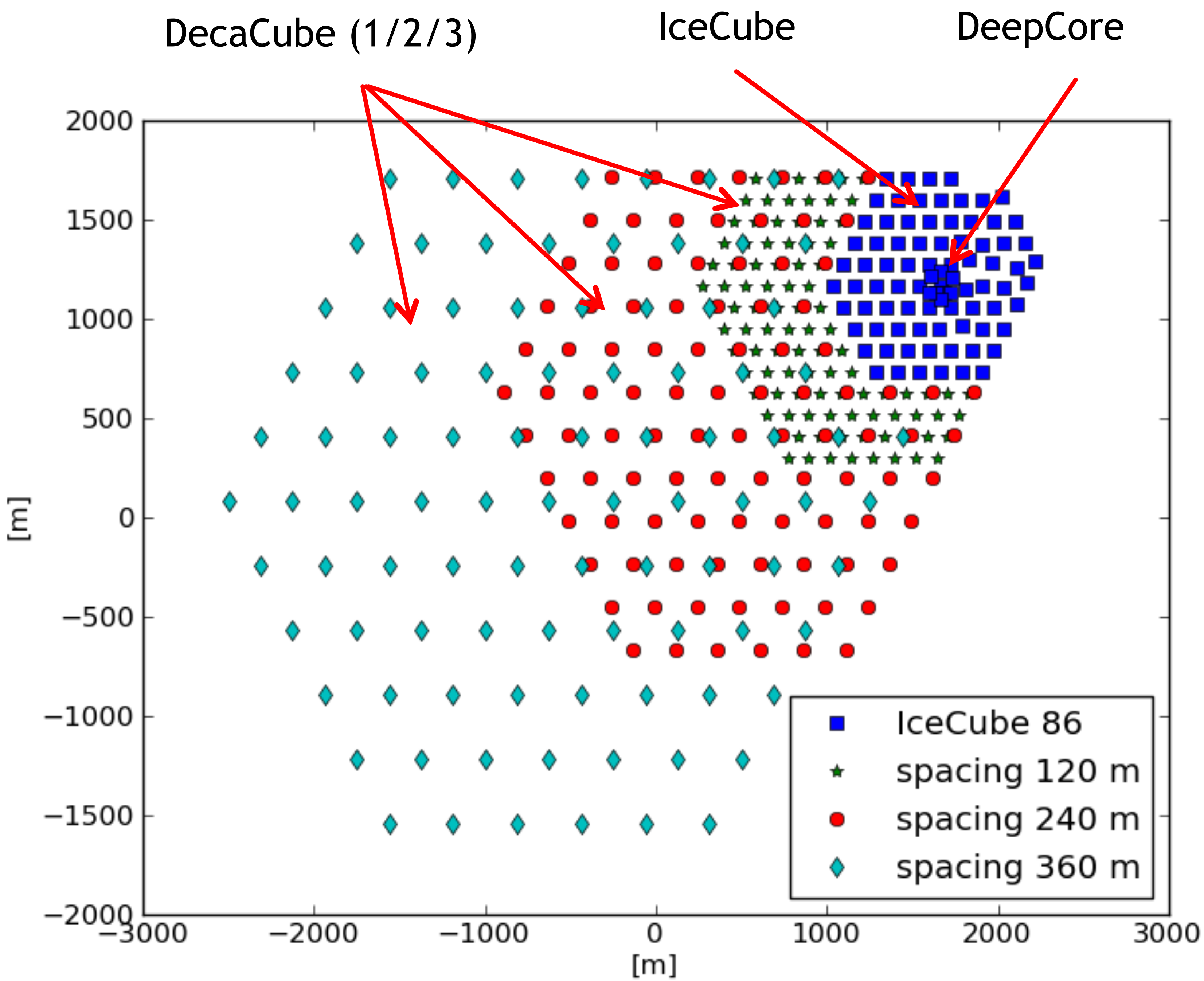


(Tang, Winter, JHEP 1202 (2012) 028)

15

Astro

Potential High Energy



Spacing 1 (120m): IceCube (1 km^3)
+ 98 strings (1,3 km^3)
= 2,3 km^3

Spacing 2 (240m):
IceCube (1 km^3)
+ 99 strings (5,3 km^3)
= 6,3 km^3

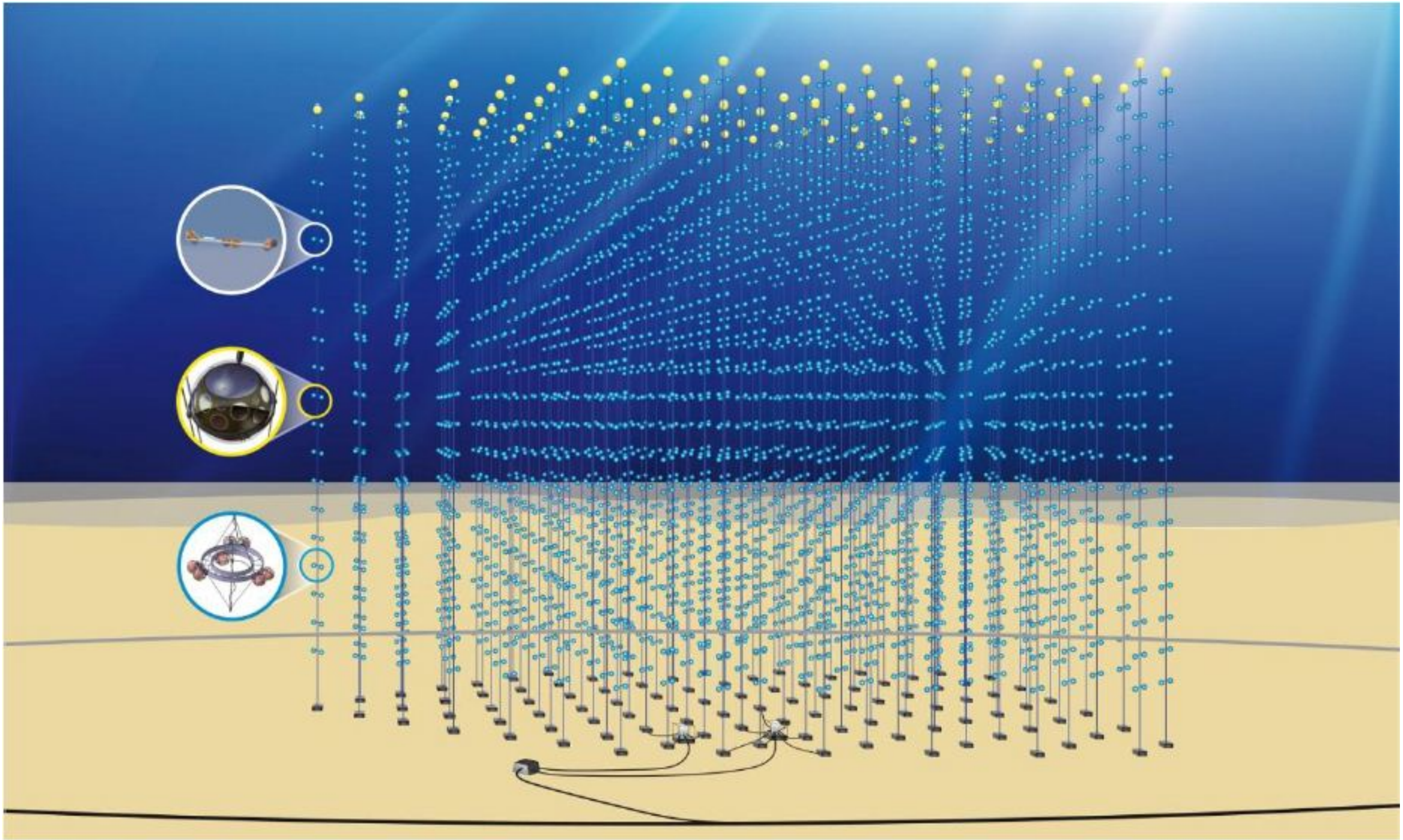
Spacing 3 (360m):
IceCube (1 km^3)
+ 95 strings (11,6 km^3)
= 12,6 km^3

Chosen geometry not optimum (i.e. for HESE)

… historically chosen to demonstrate that we do respect boundary conditions

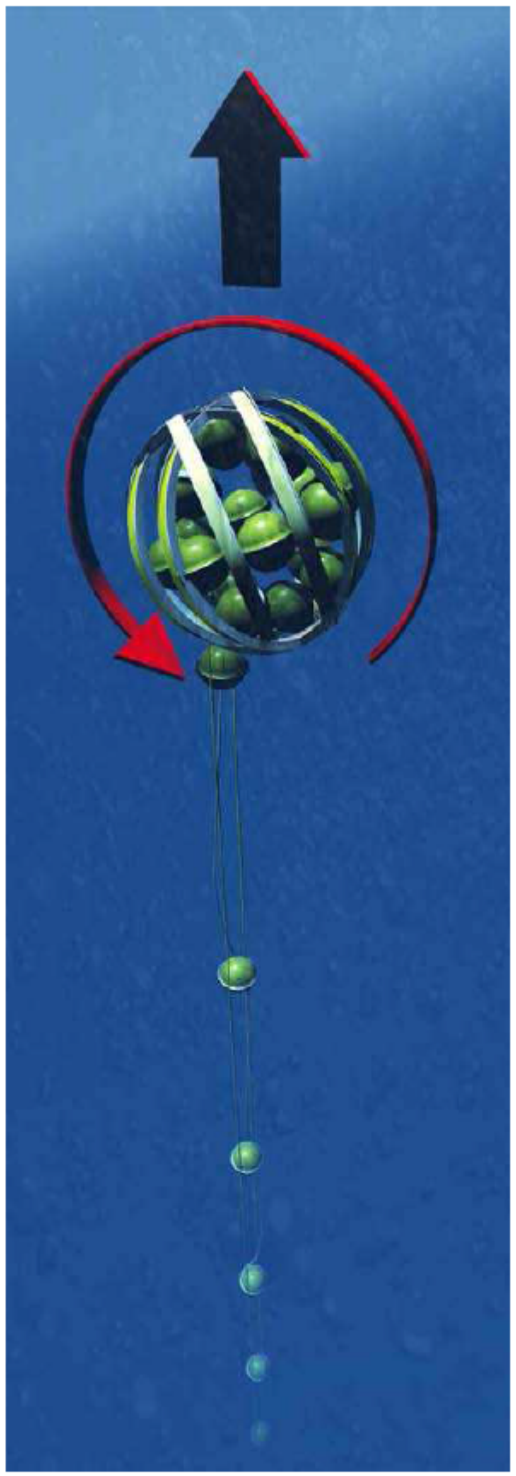
*courtesy of C. Wiebusch (RTWH Aachen)

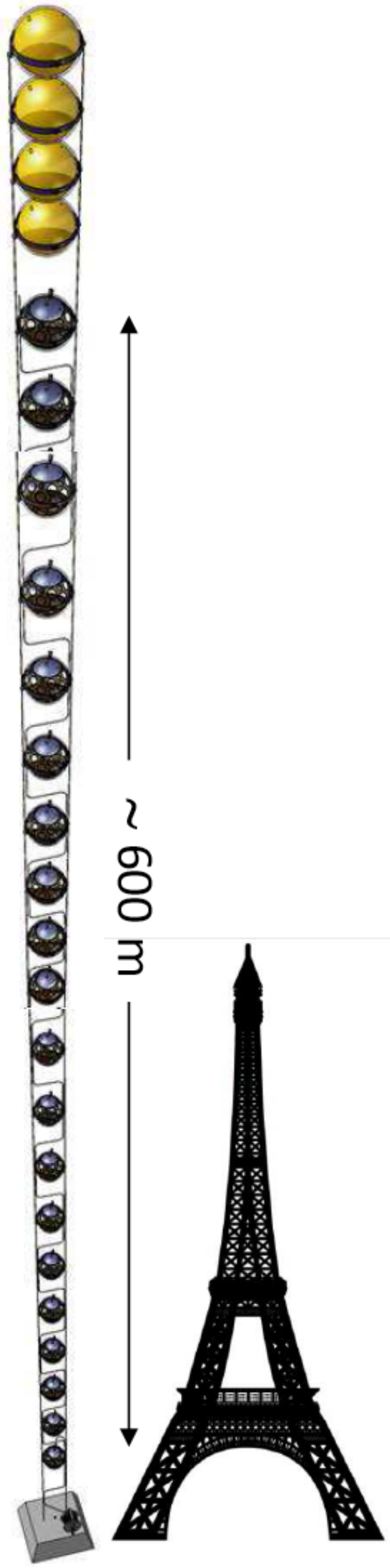
KM3NeT



Deployment

*P. Coyle, Asterics 2014

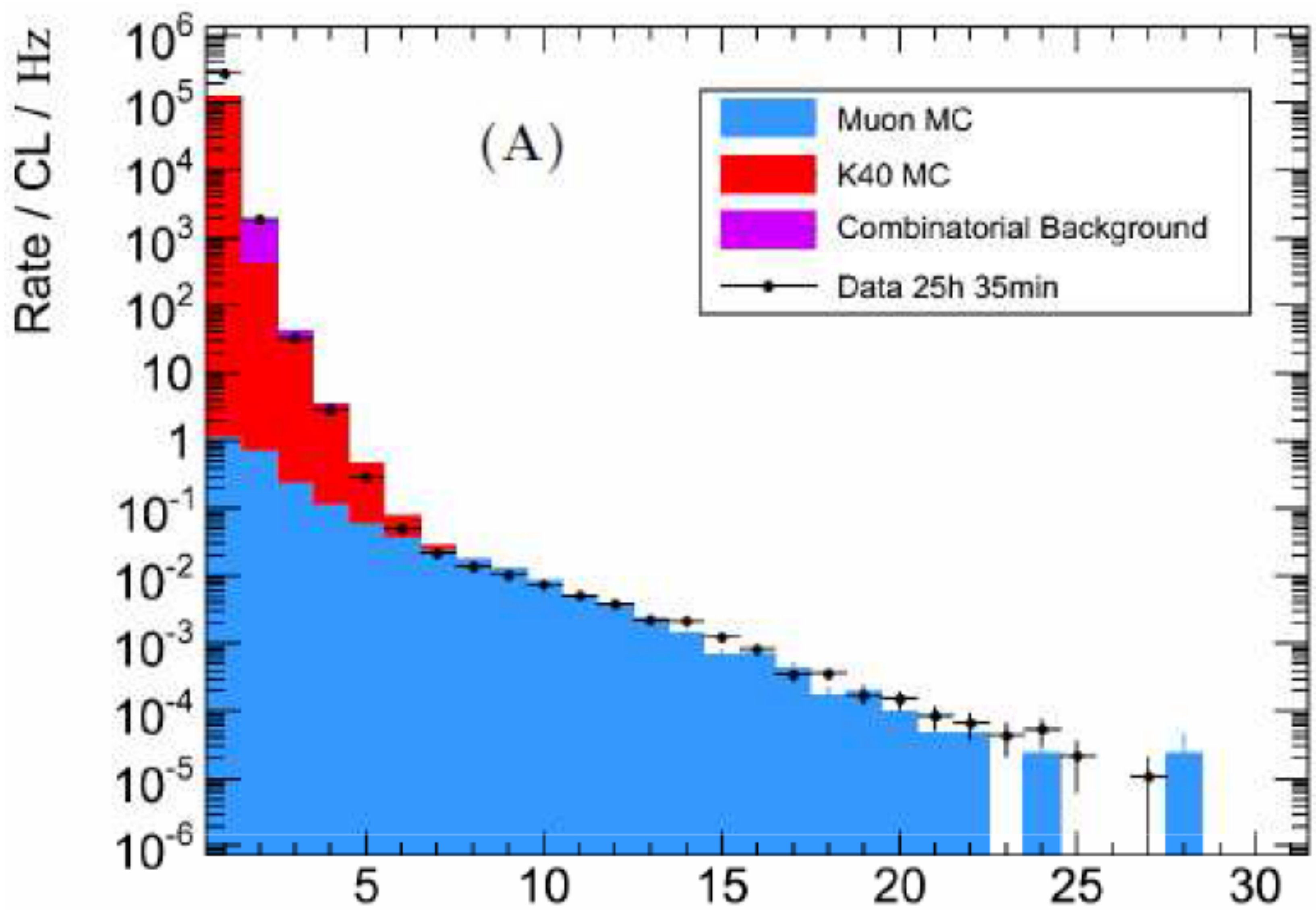




KM3NeT

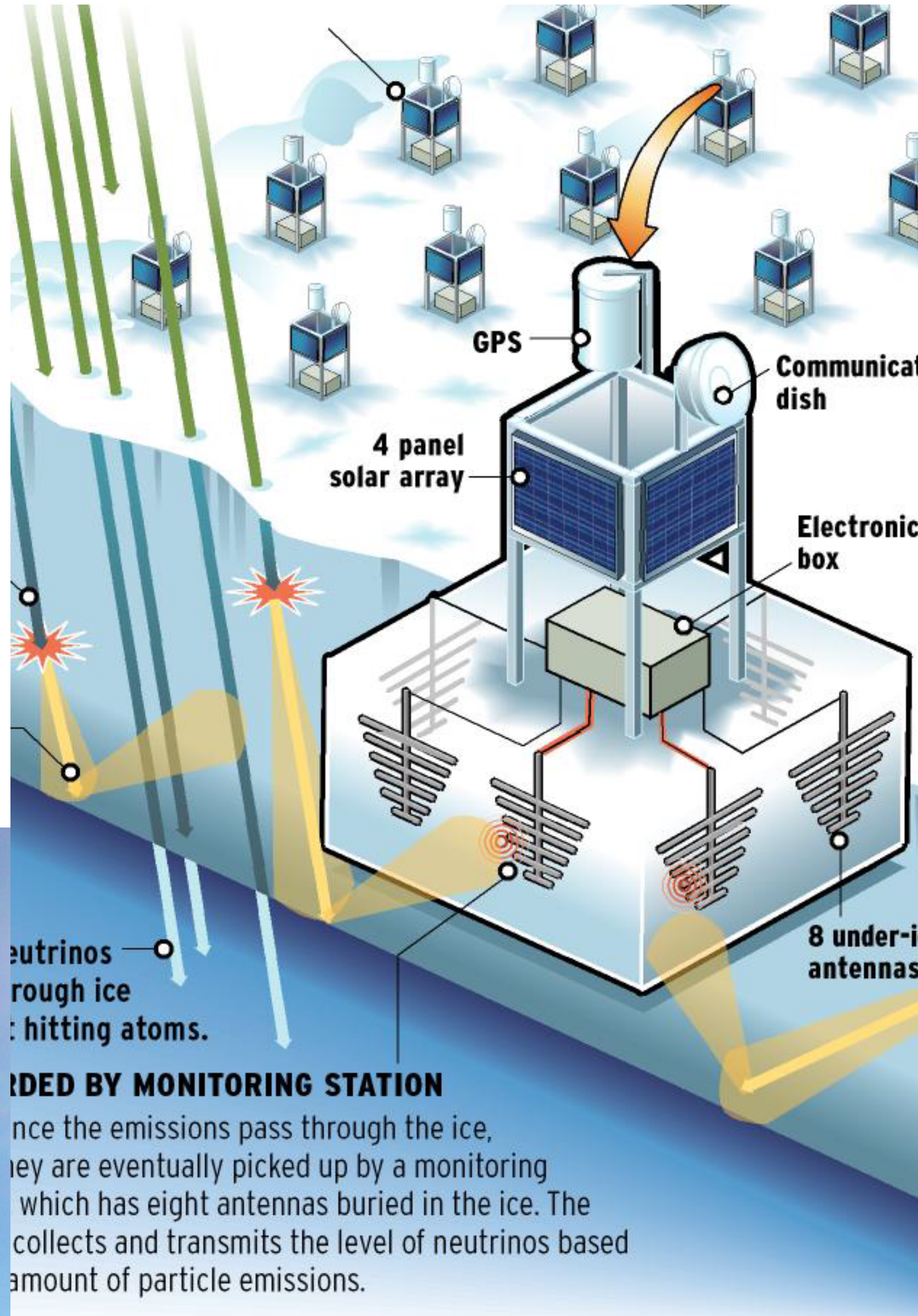
- Sea water has natural potassium background (K40)

*P. Coyle, Asterics 2014

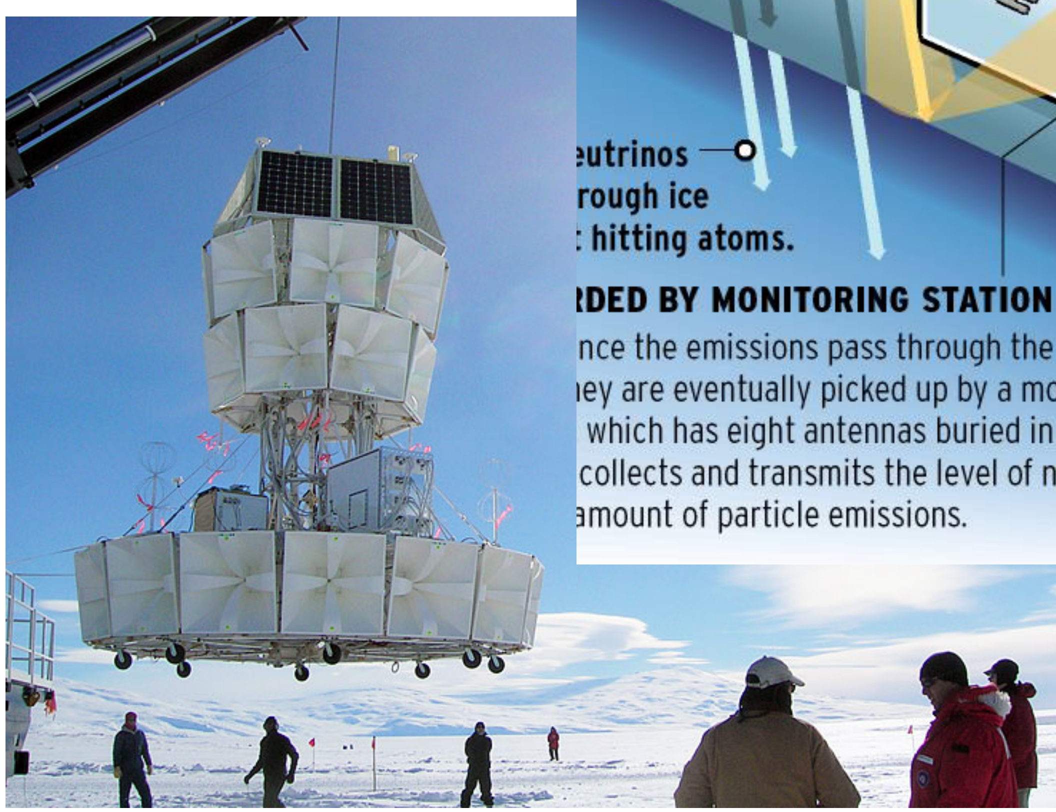


Radio

ARIANNA



ANITA



Lots of New Experiments

- What will the landscape look like in 2, 5, 10 years?