Detector image product of RAT-PAC

The ASDC: ***A***dvanced ***S***cintillation ***D***etector ***C***oncept

Gabriel D. Orebi Gann

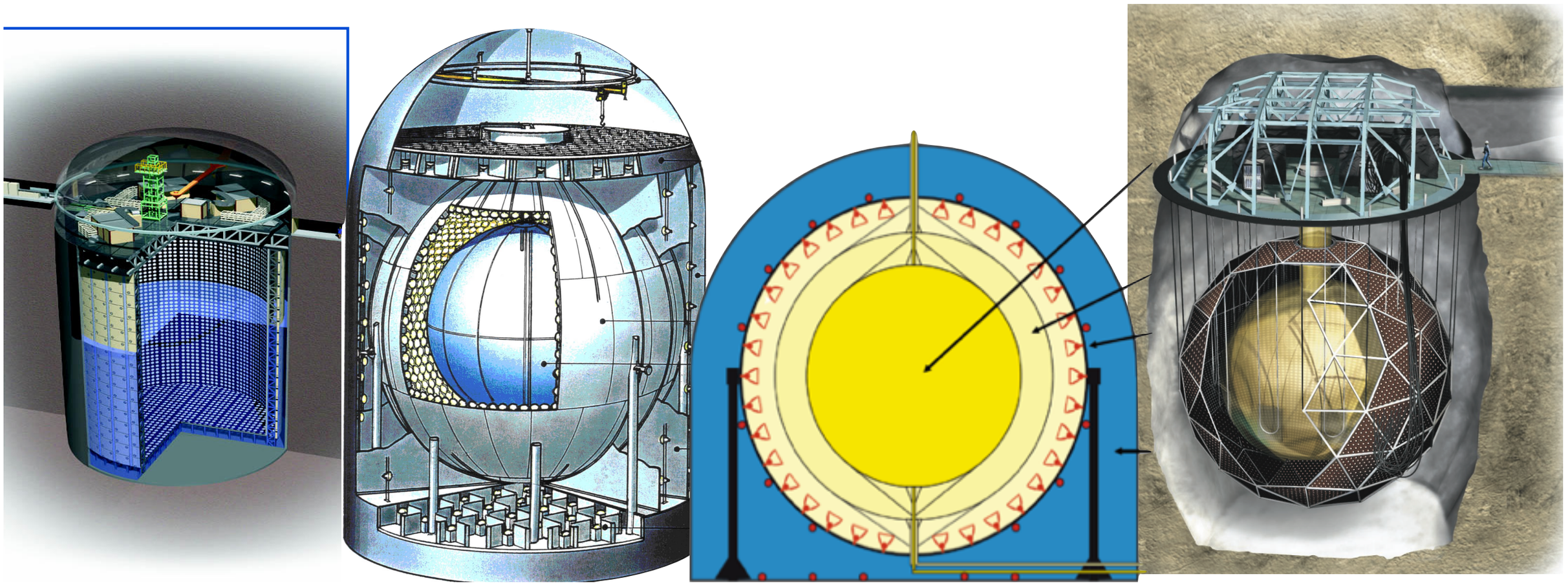
NNN '14, Paris

Nov 2014

UC Berkeley & LBNL

Advanced Scintillation Detector Concept (ASDC)

- **New technology with proven methodology**



House light-producing target inside large monolithic detector

Novel, breakthrough target medium

Having our  ...

- Simple mixture of oil and water (!)
  ⇒ **water-based liquid scintillator** (WbLS) -- Minfang Yeh, BNL

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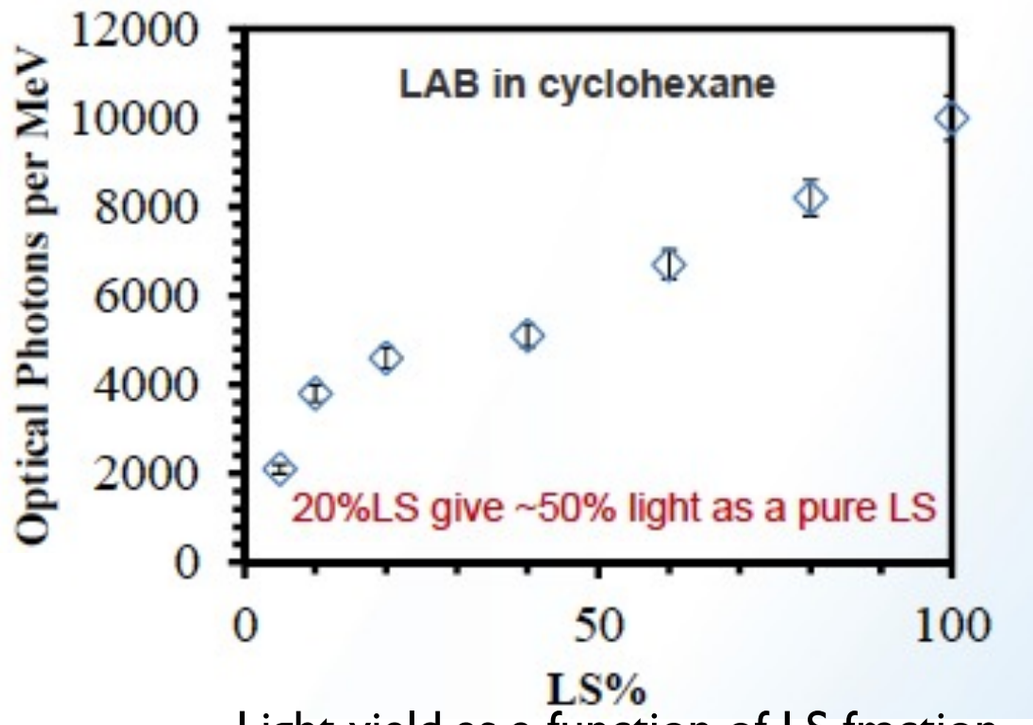
1. High light yield of organic scintillator
   a) Low energy threshold
   b) Good energy resolution

2. Predominantly water
   a) *Low absorption inc. light collection*
   b) *Directional information*

3. Tunable time profile
   ➡ improve particle ID, signal identification, bkg separation
   ➡ Cher / scint separation



Light yield as a function of LS fraction, M. Yeh et al., BNL

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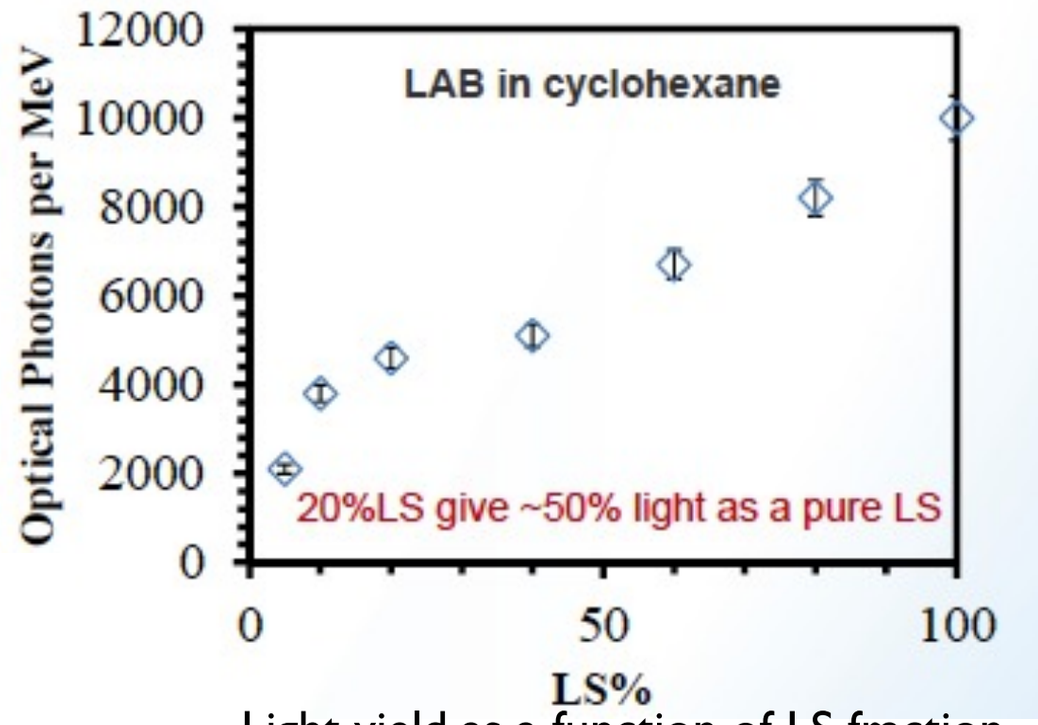

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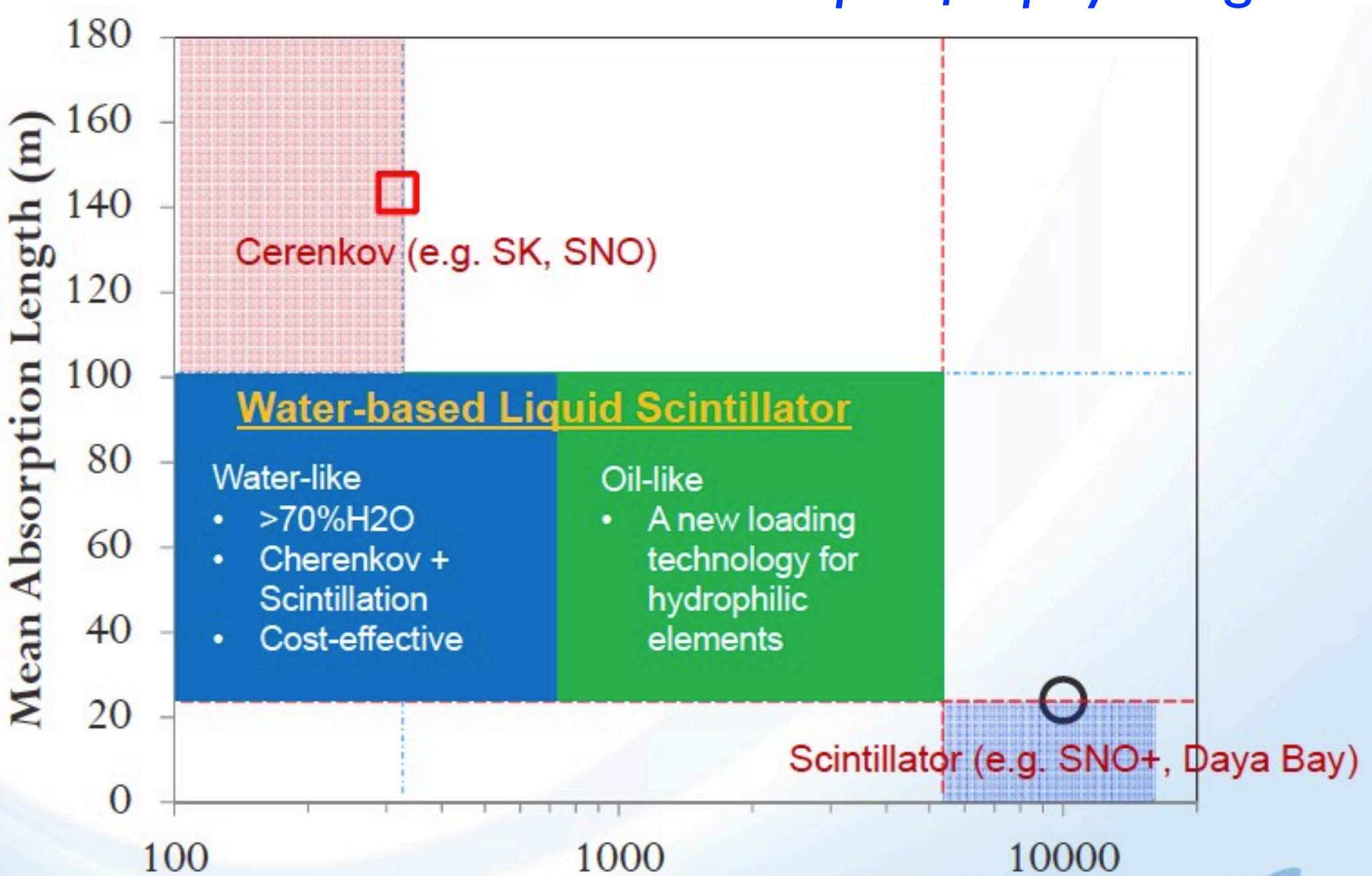
4. Loading of metallic ions
   ➡ broad physics applications

Powerful Target Medium

-- Tune to specific physics goals



The ASDC

- 50-100 kton WbLS target
- High coverage with ultra-fast, high efficiency photon sensors
- 4800 mwe underground (Homestake mine, SD)
- Comprehensive low-energy program
- In the LBNF beam: complementary program to proposed LAr detector at LBNF

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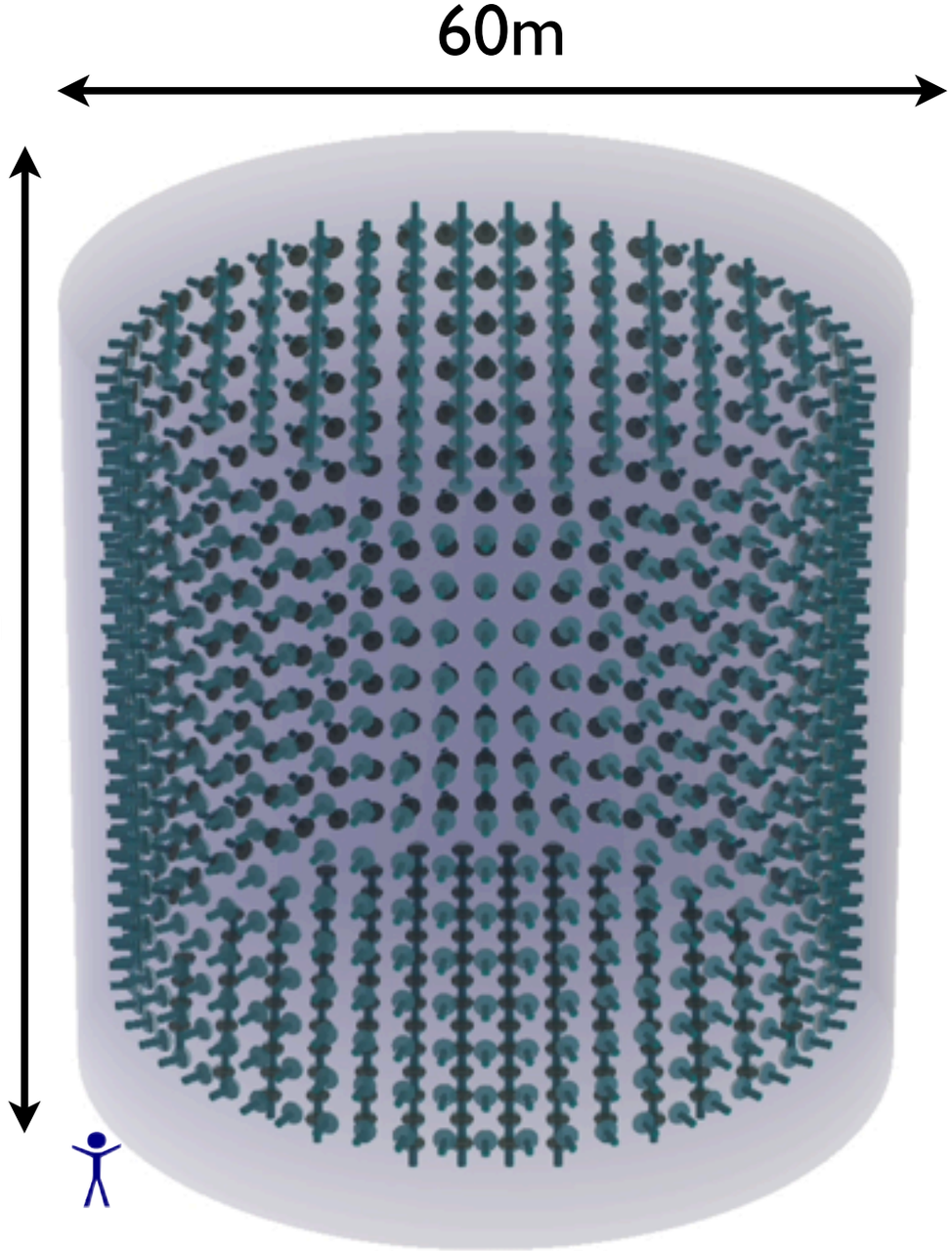

Detector simulation package under development

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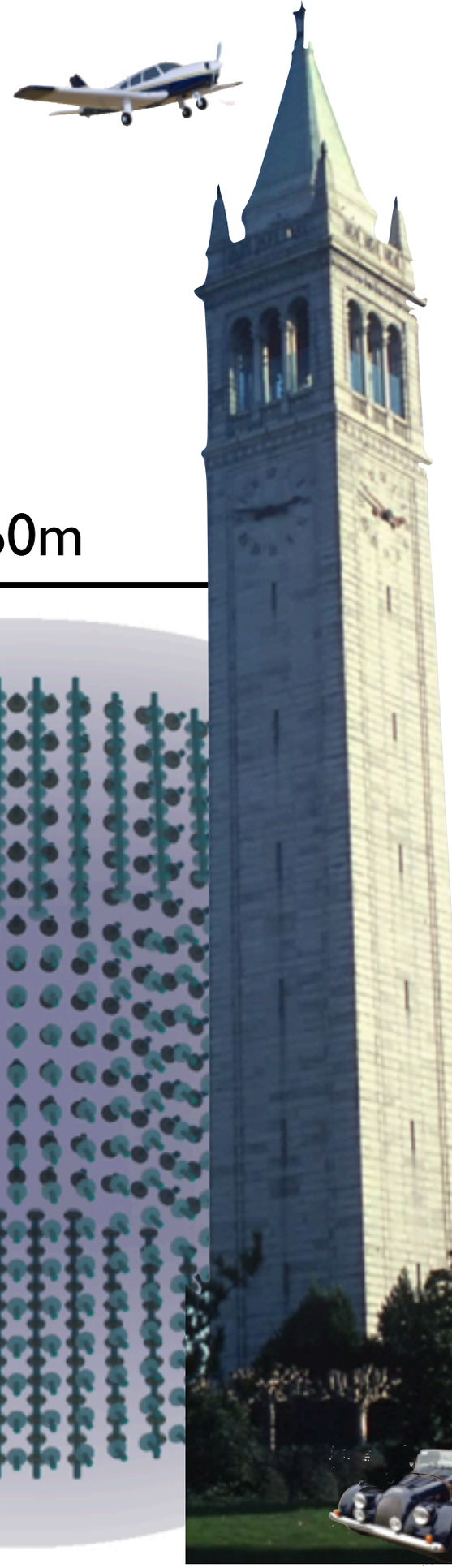

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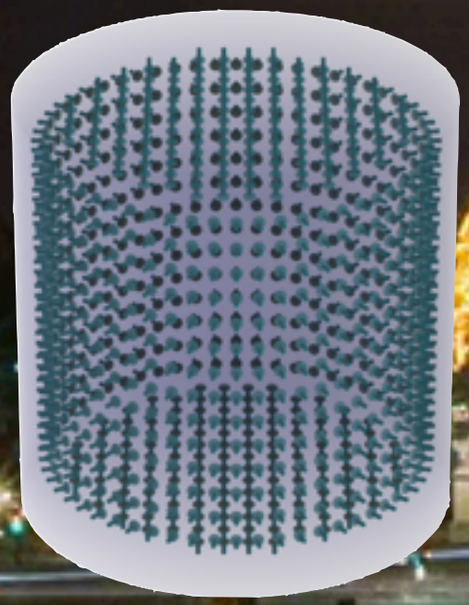
Ian Parker 2008



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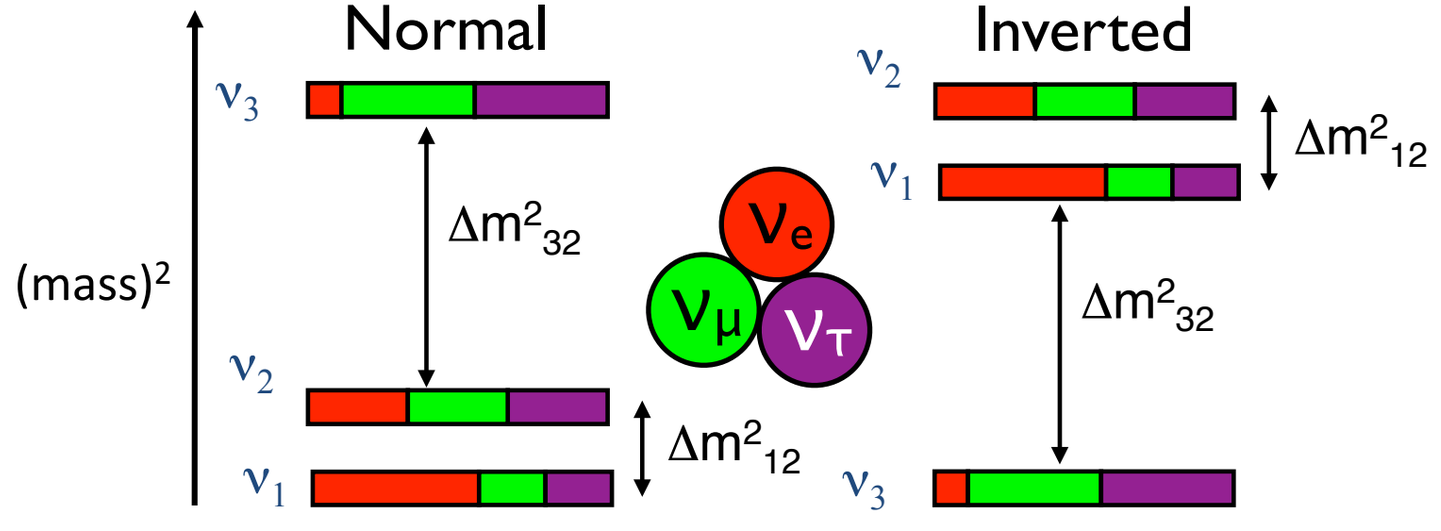

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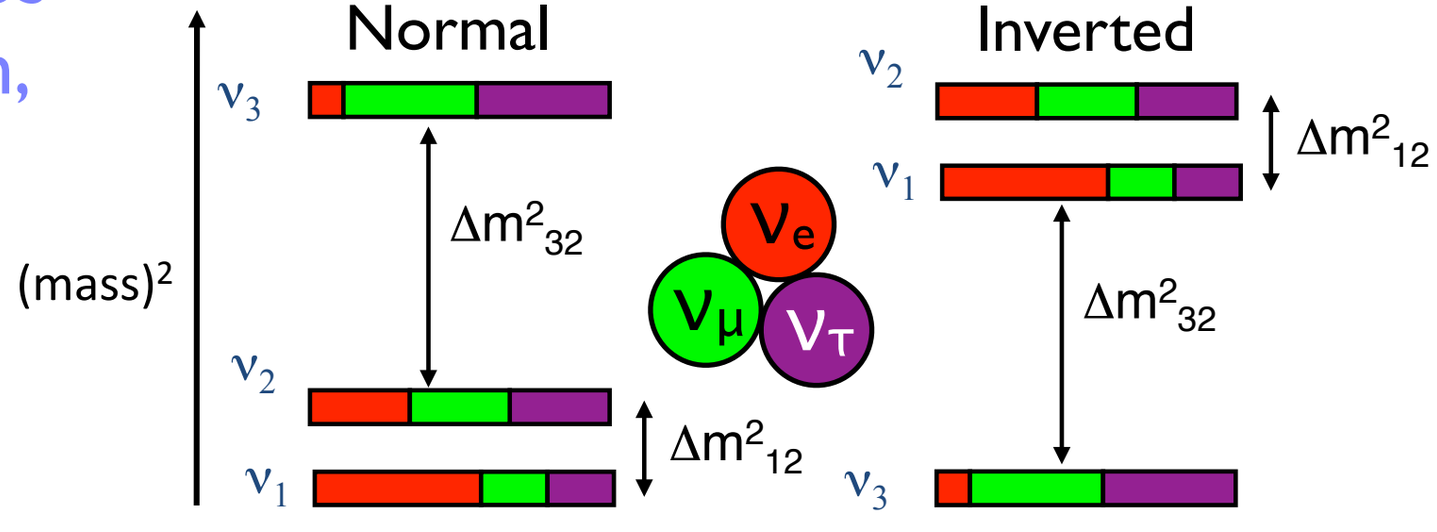

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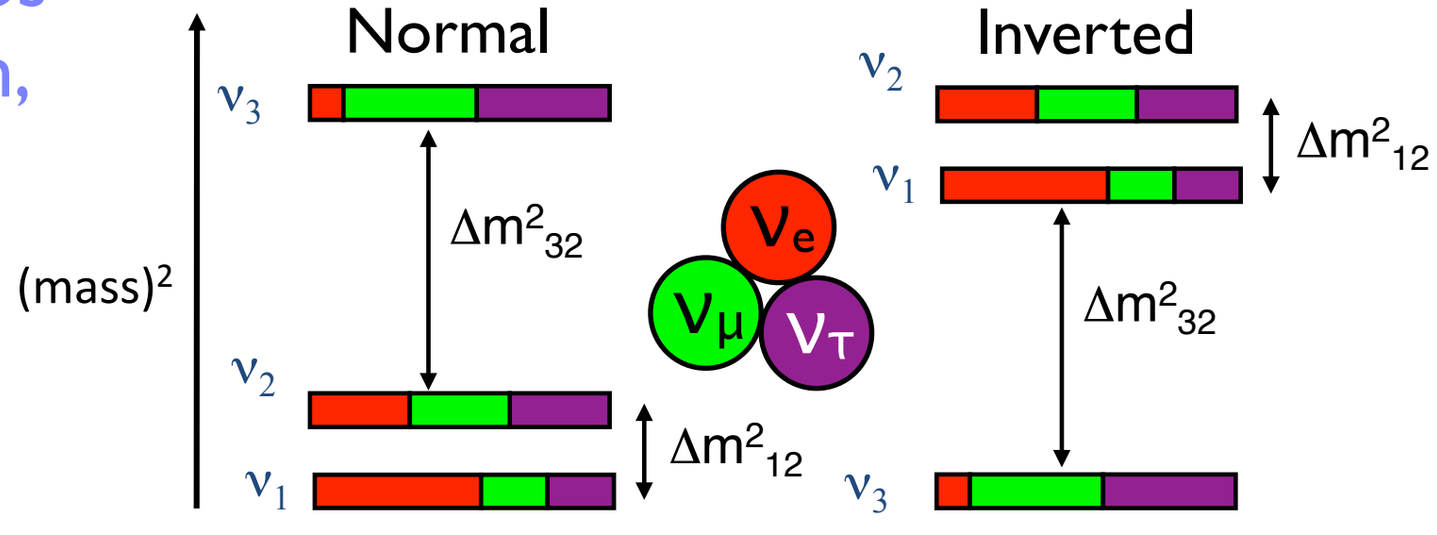
The ASDC can address all these questions



Physics Program

- Long-baseline physics (mass hierarchy, CP violation)
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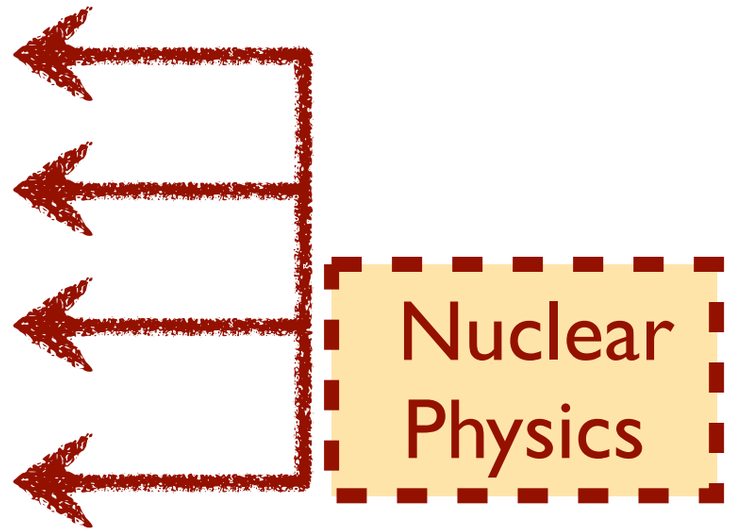

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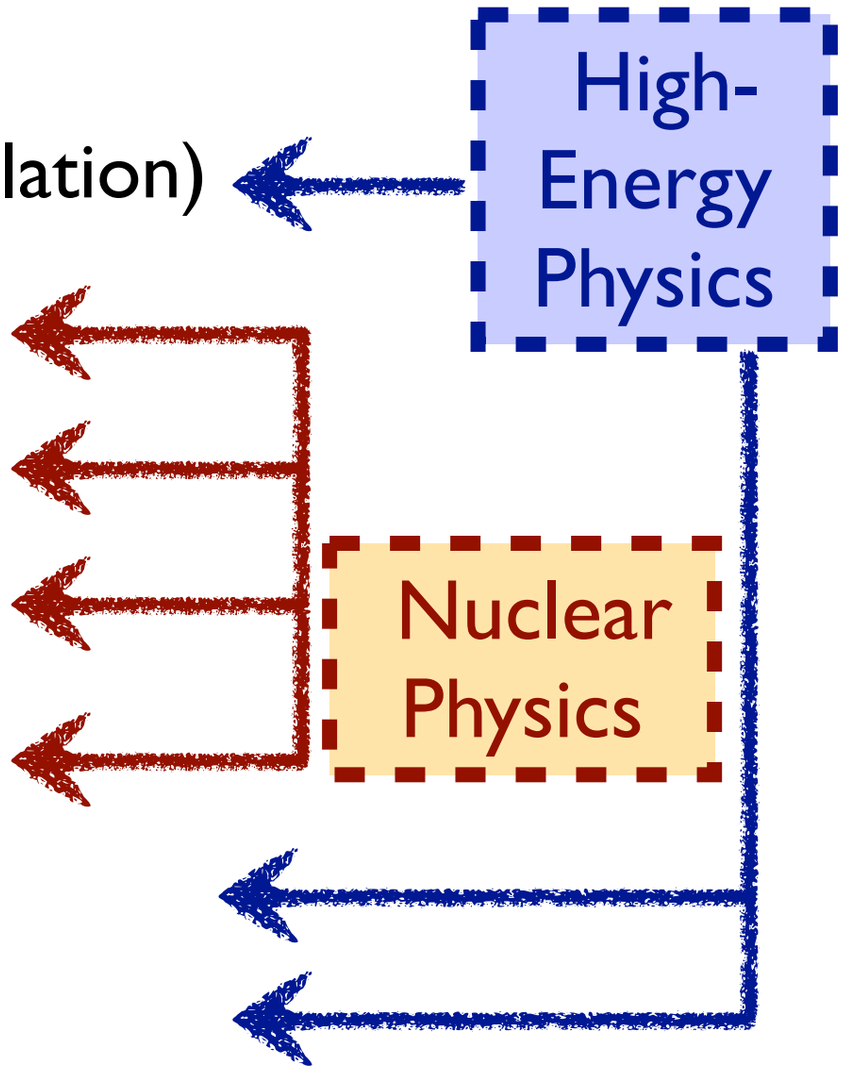

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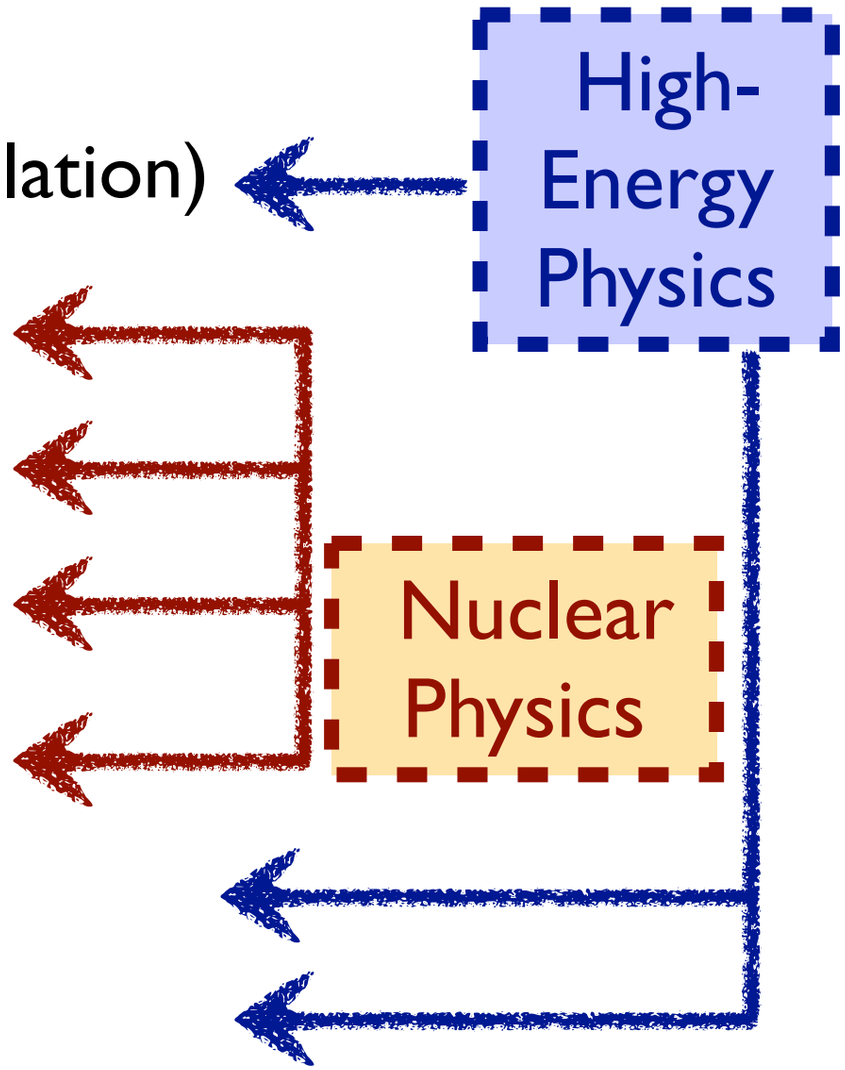

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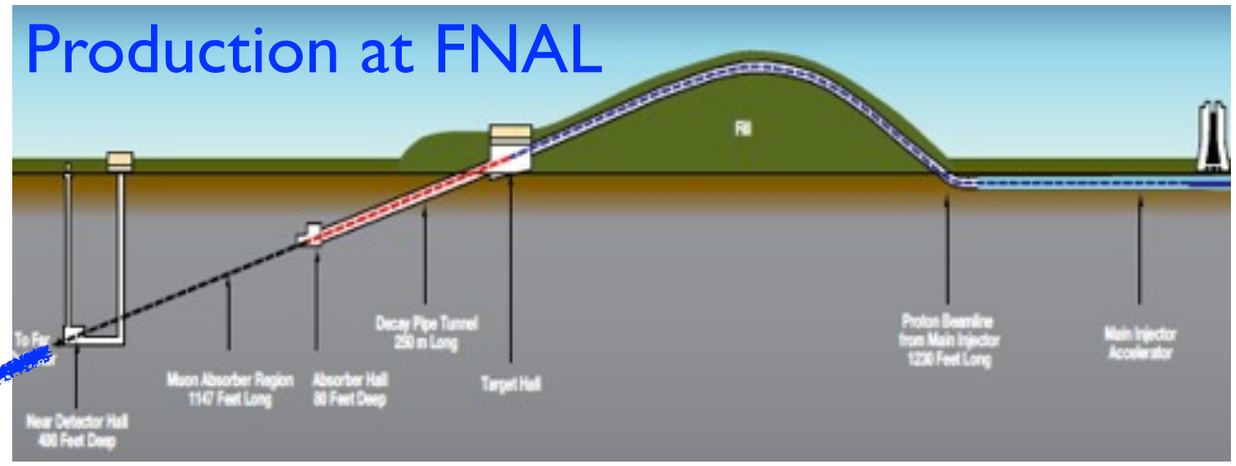
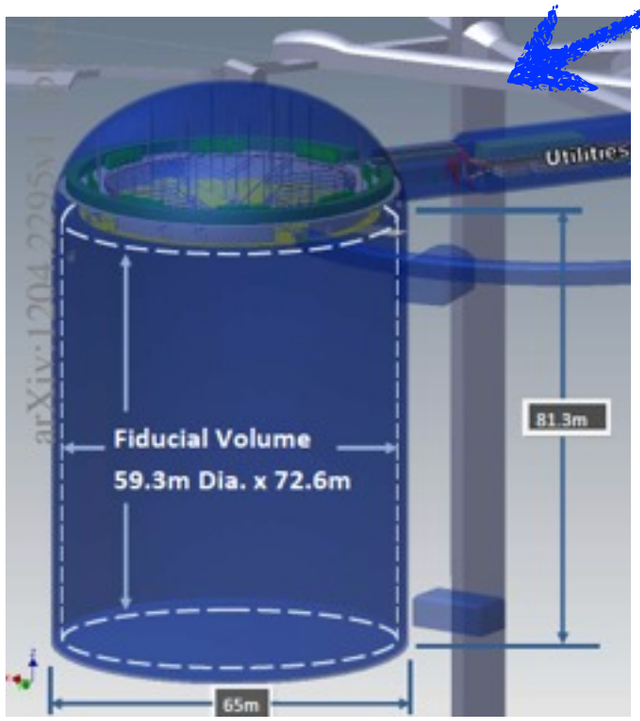
Physics over 5 orders of magnitude

ASDC Approach to LBL Physics

- Large-scale detector at Homestake, in the LBNF beam
- Complementary program to proposed LArTPC
- Build on WCD studies (arXiv:1204.2295)



1300km



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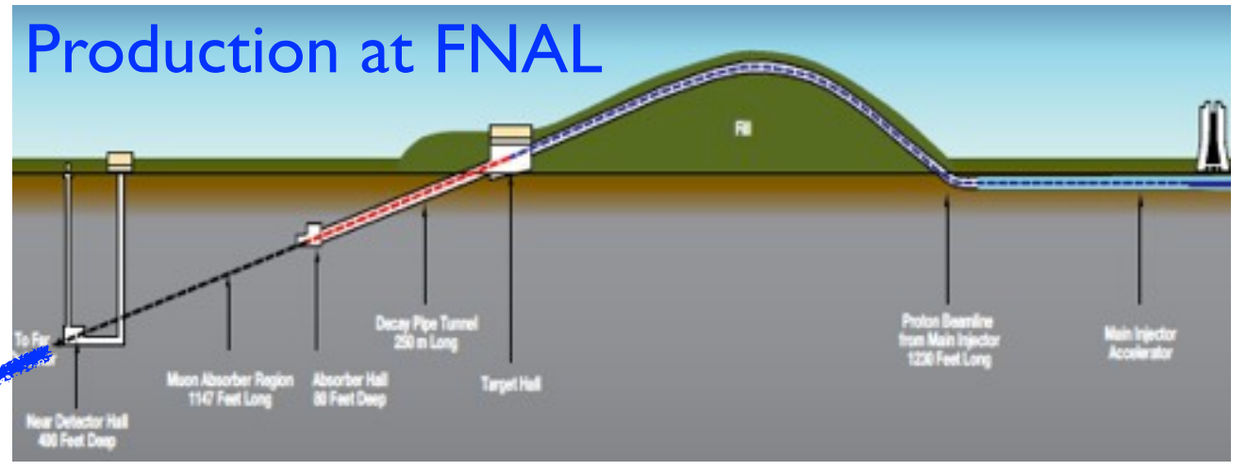

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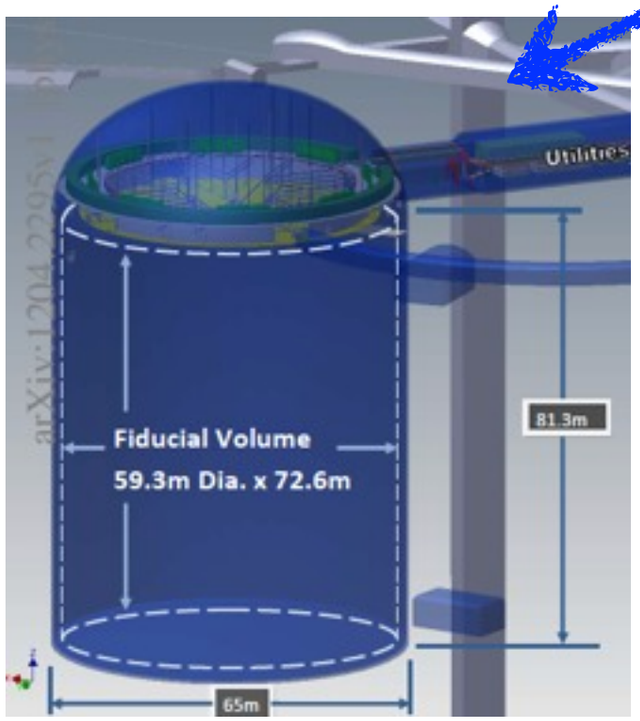

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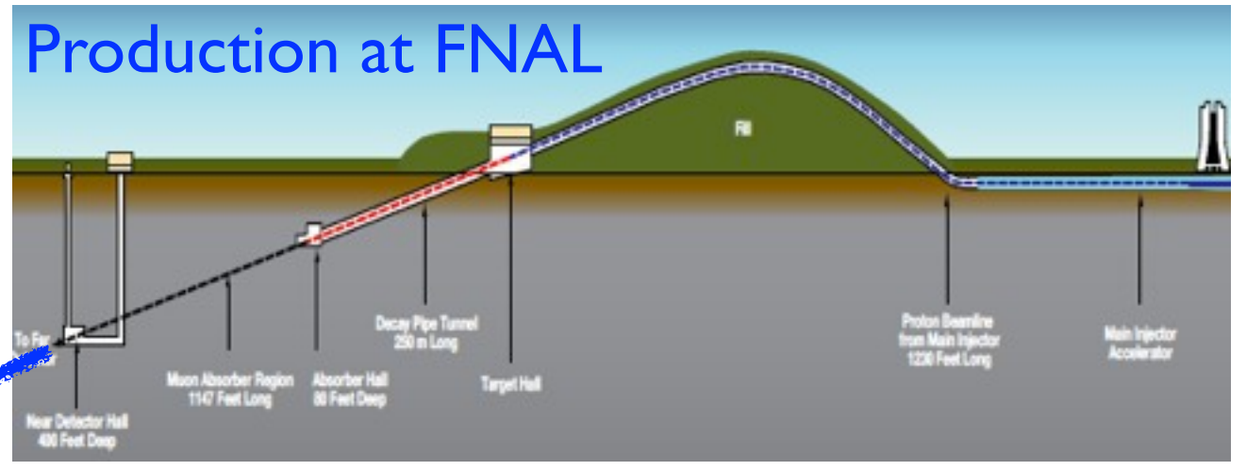

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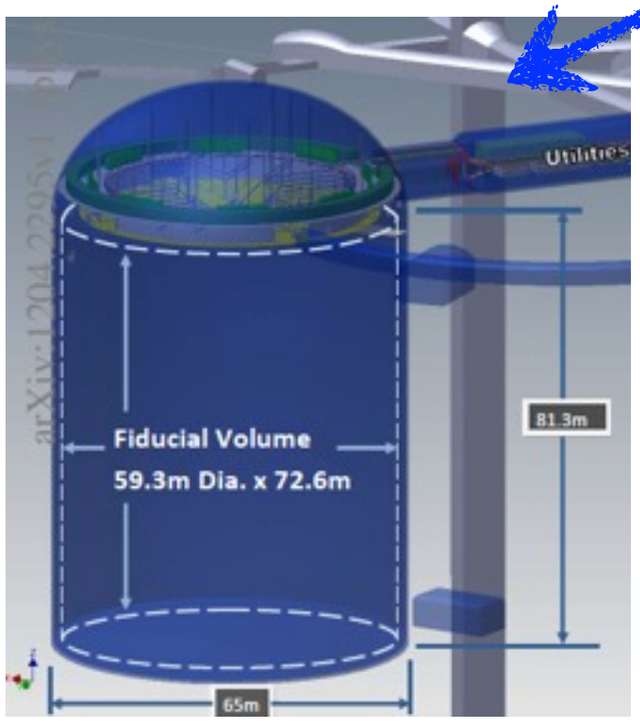

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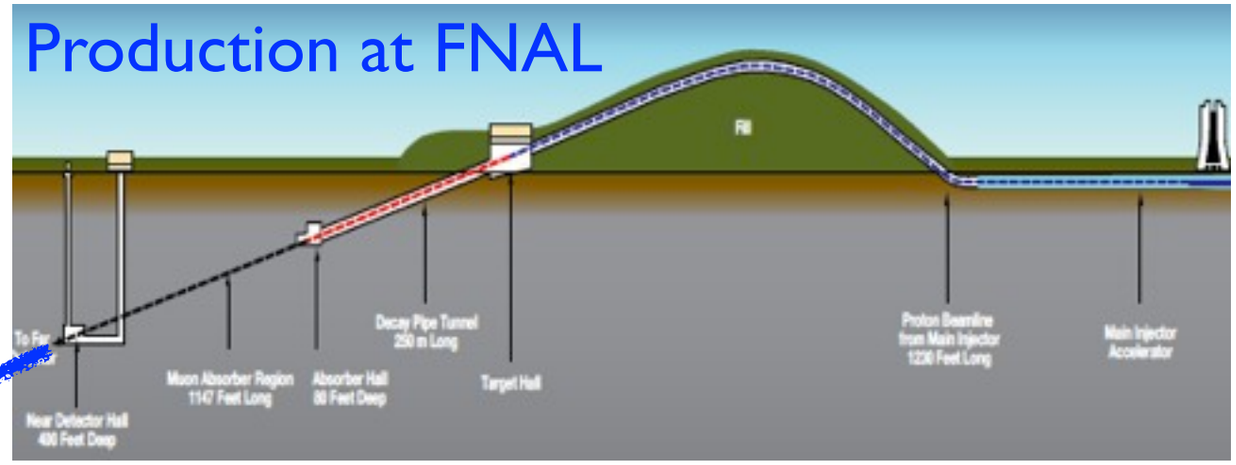

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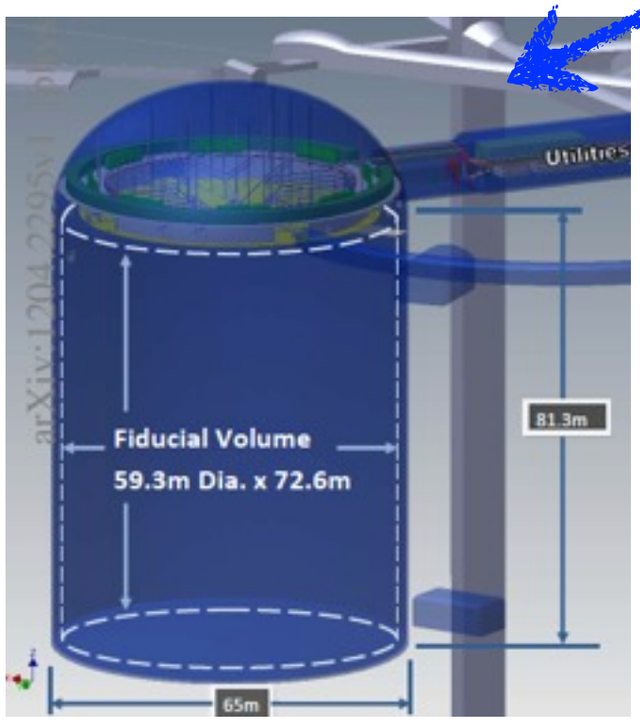

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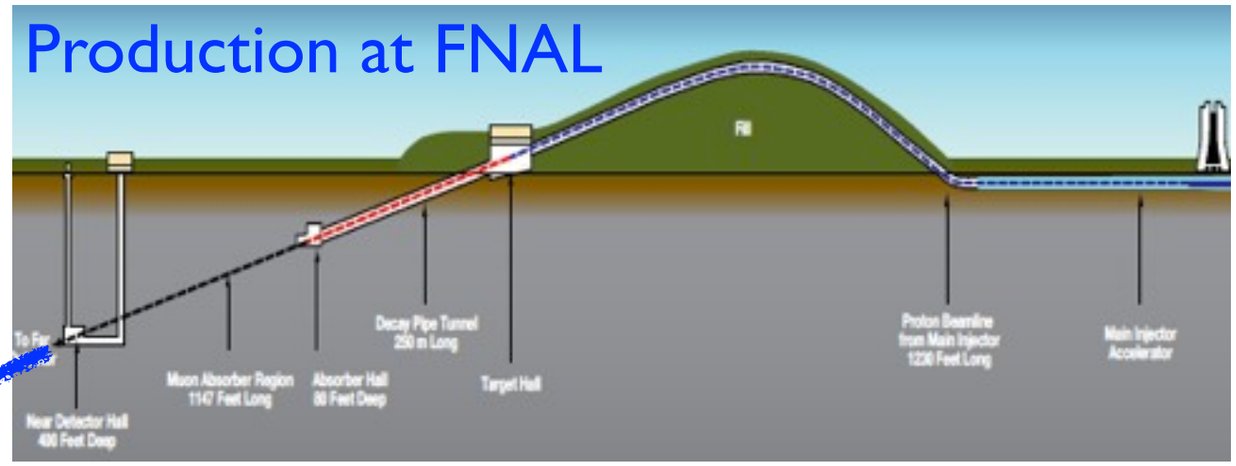

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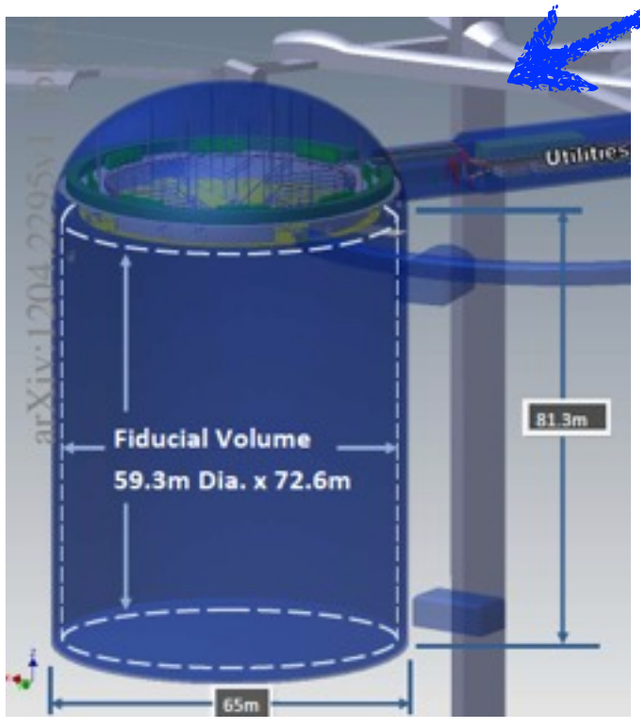

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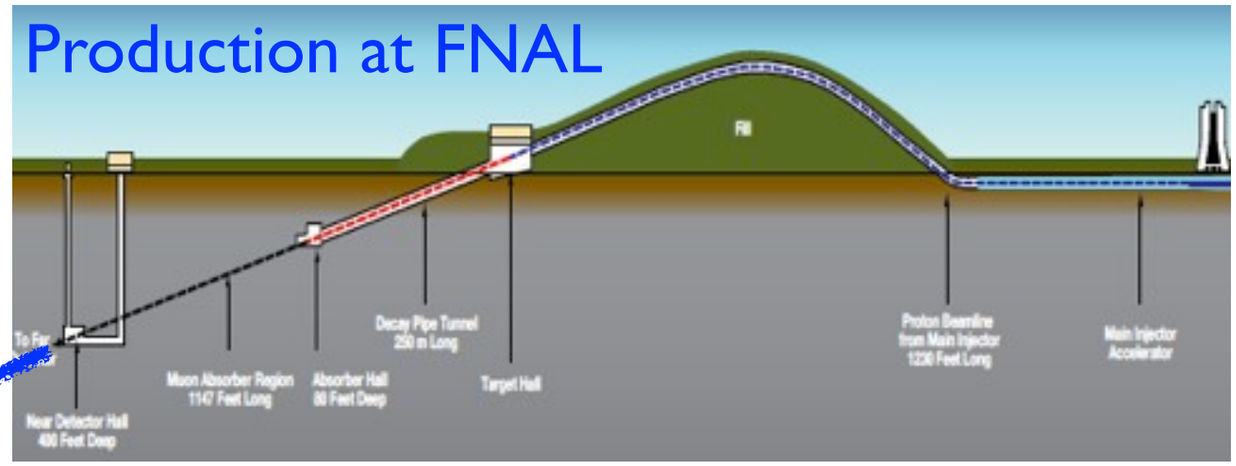

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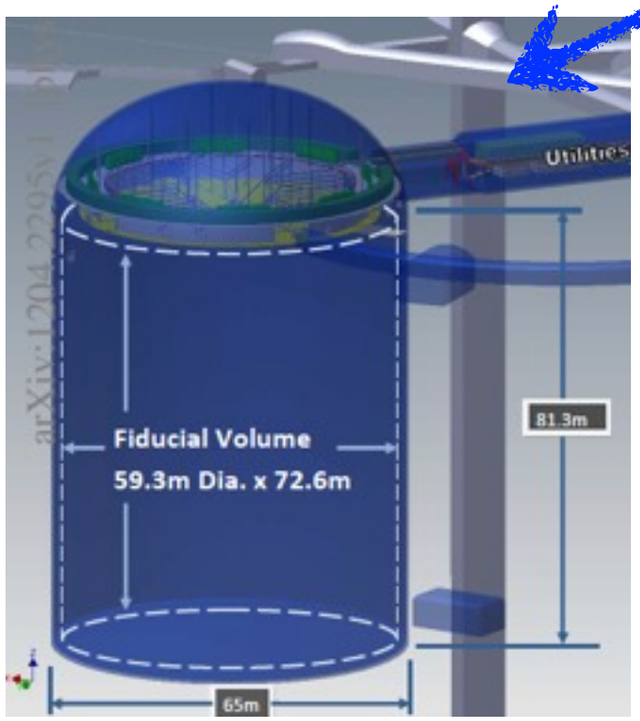

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➡ SKI vs SKII ⇒ no loss in beam physics sensitivity for x2 reduction in light yield

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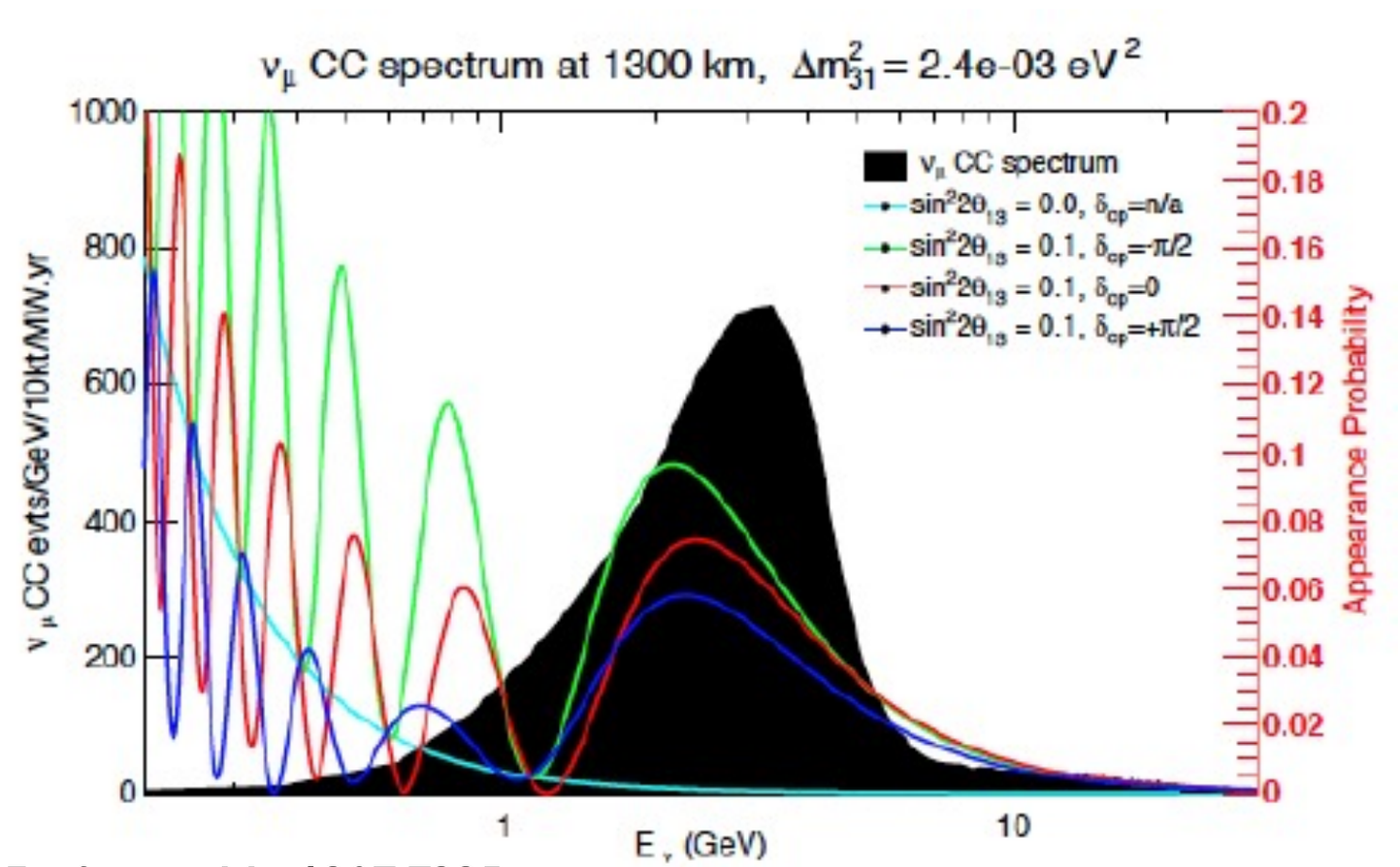

Fig from arXiv:1307.7335

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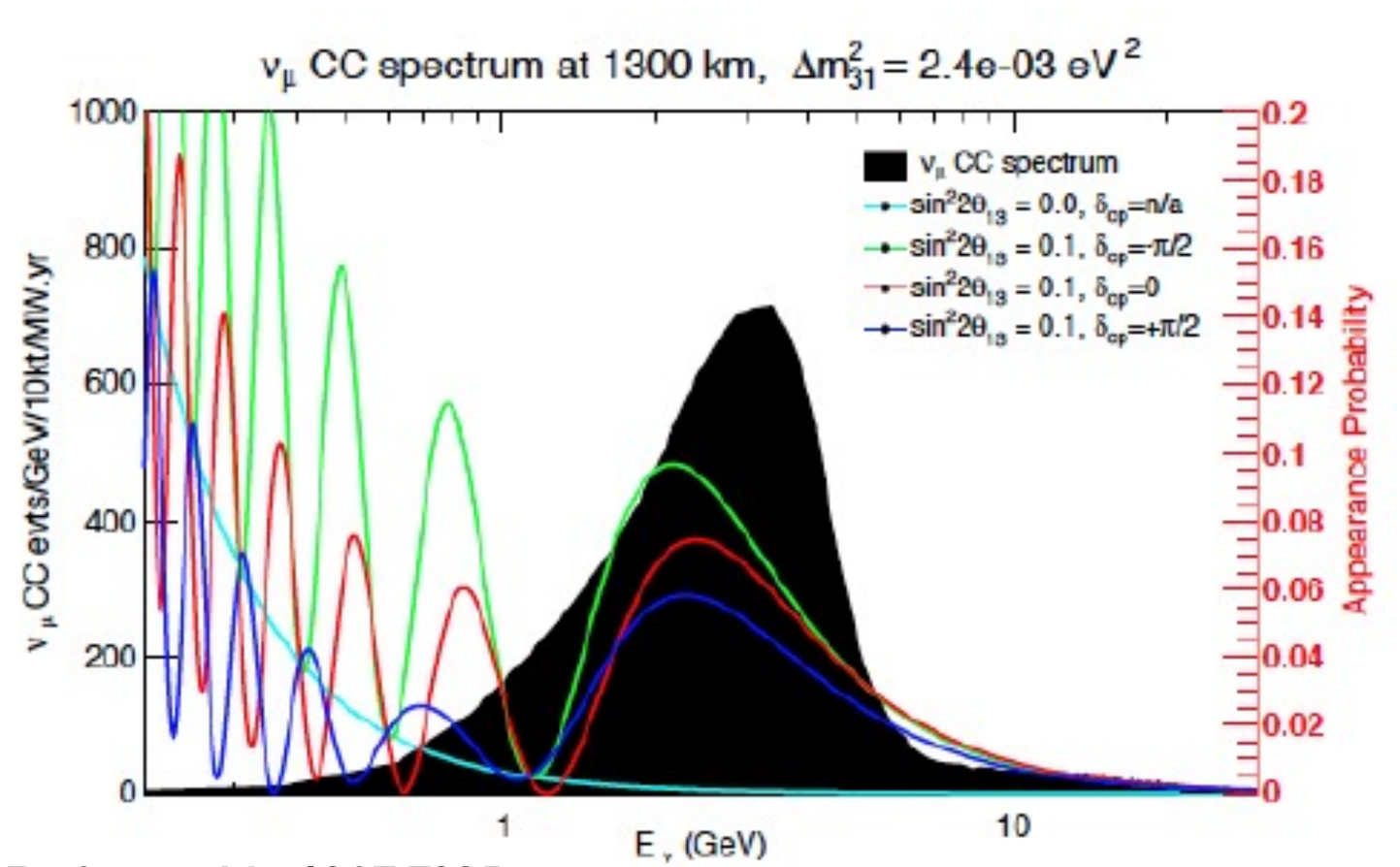

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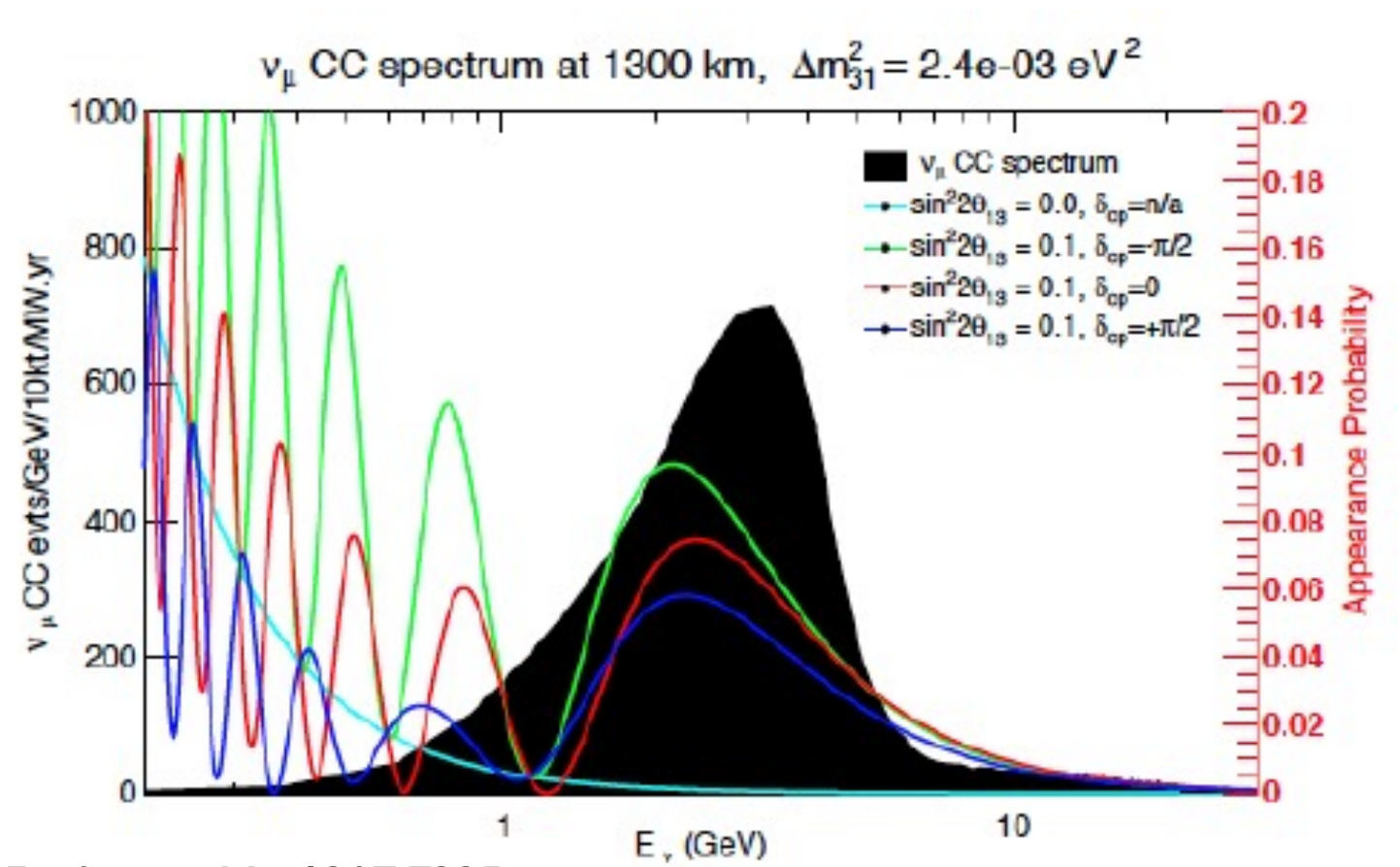

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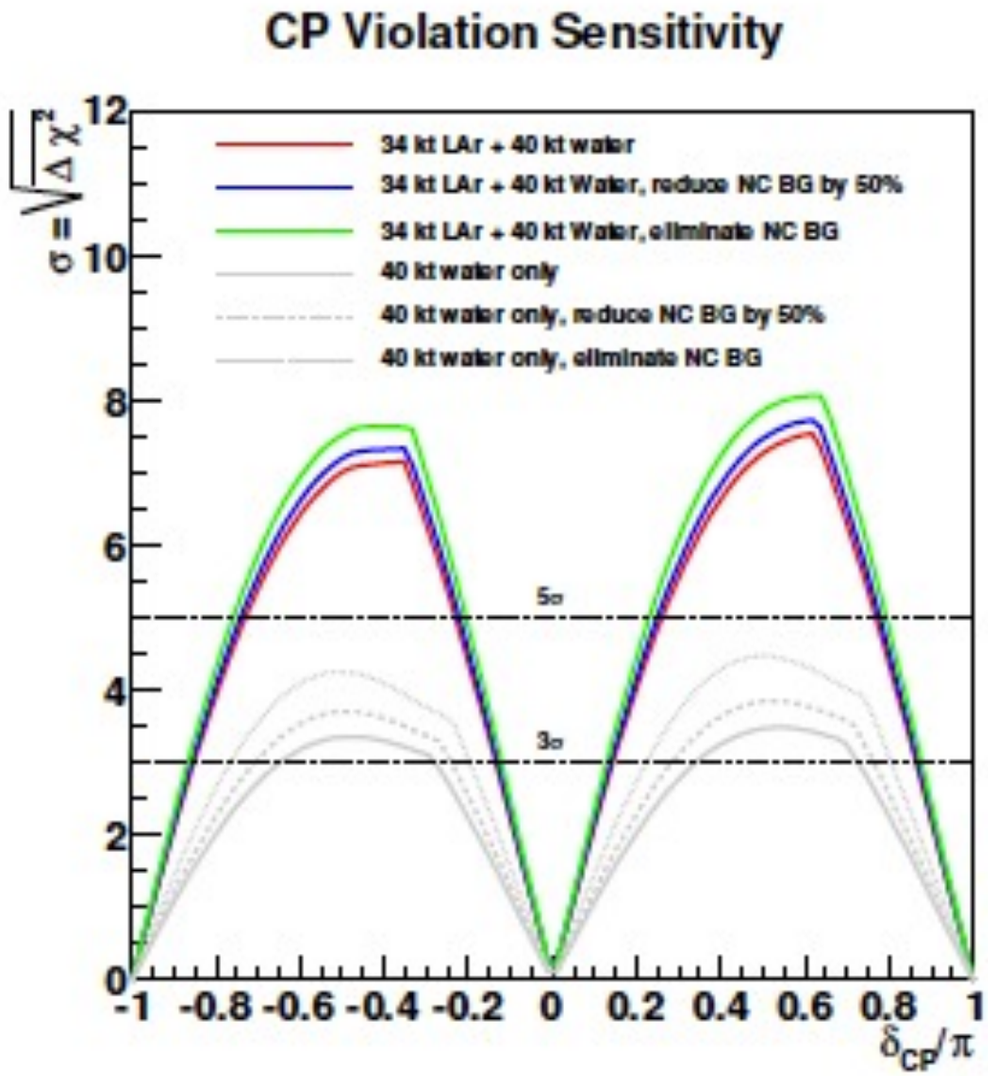
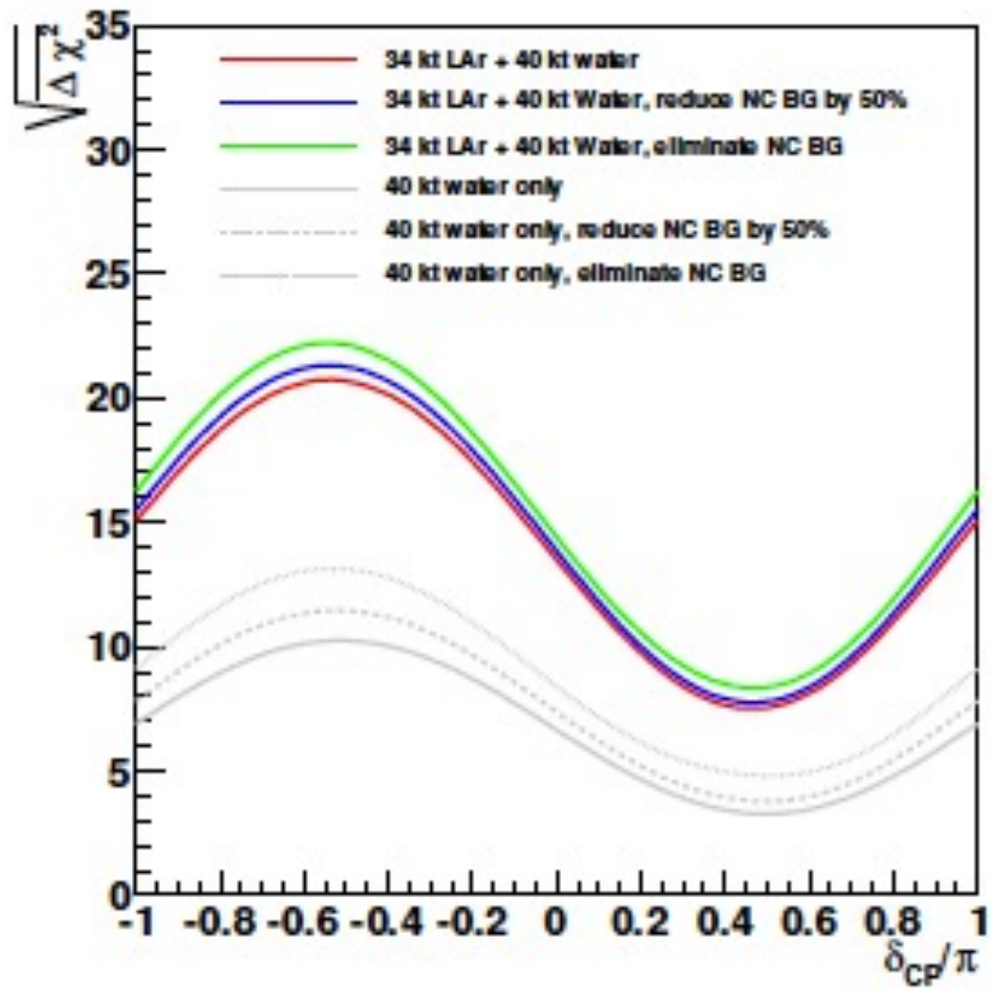
WbLS would do better!

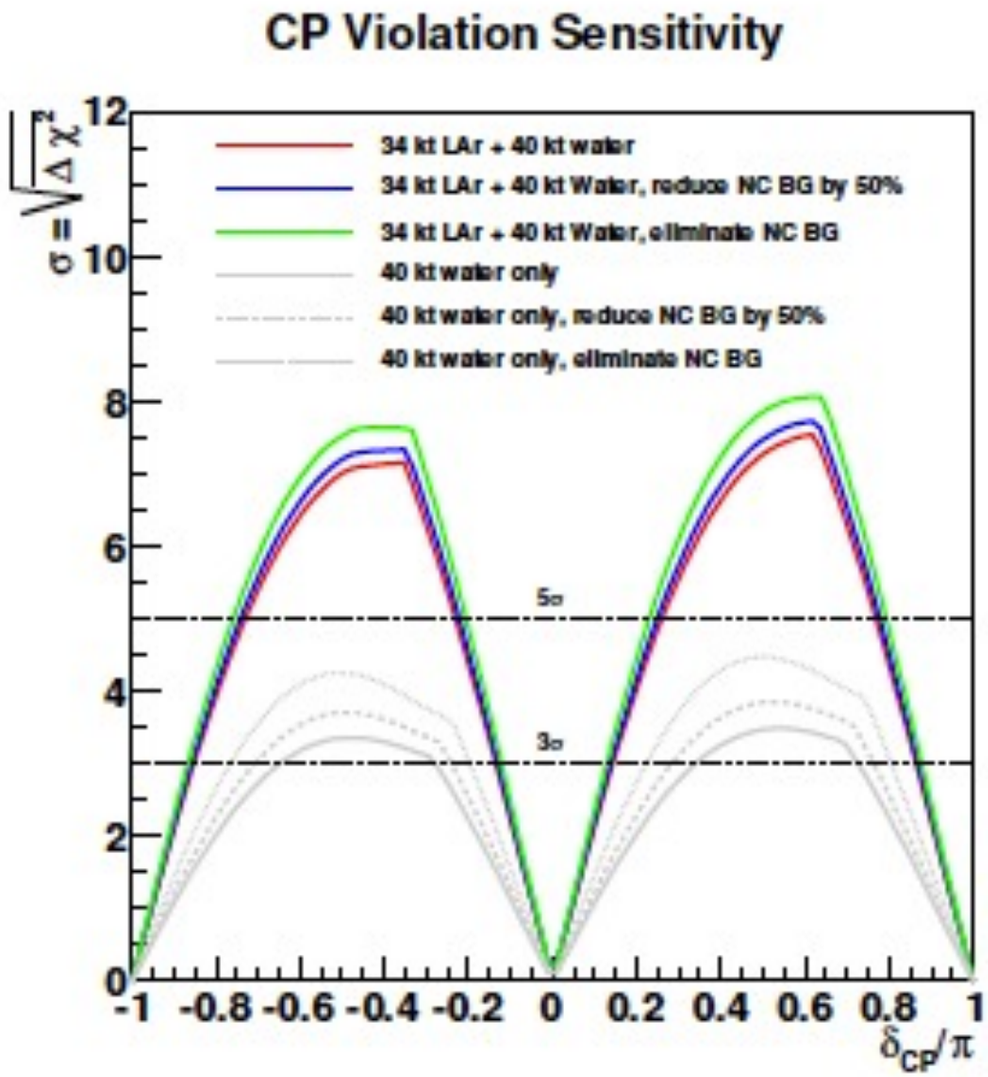
ASDC Sensitivity

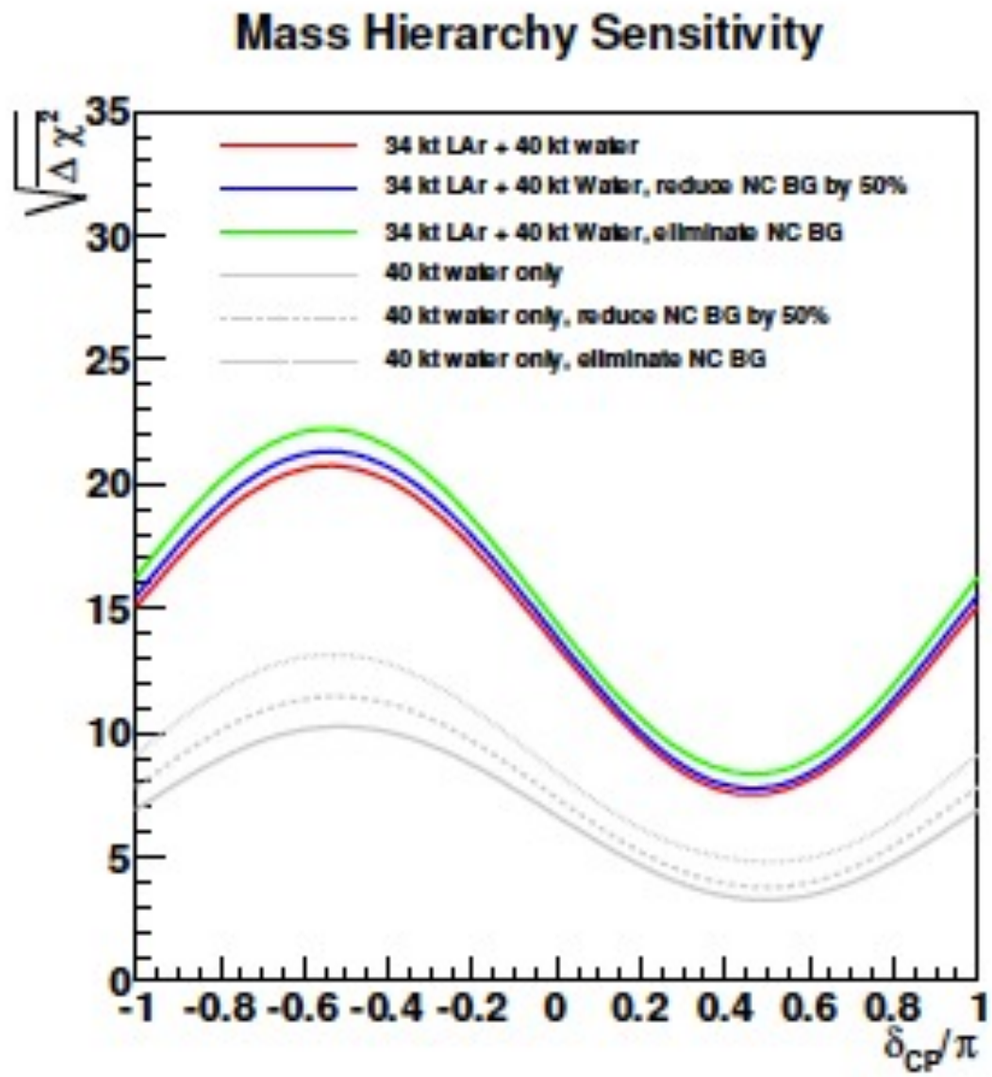




All figs from arXiv:1409.5864

ASDC Sensitivity



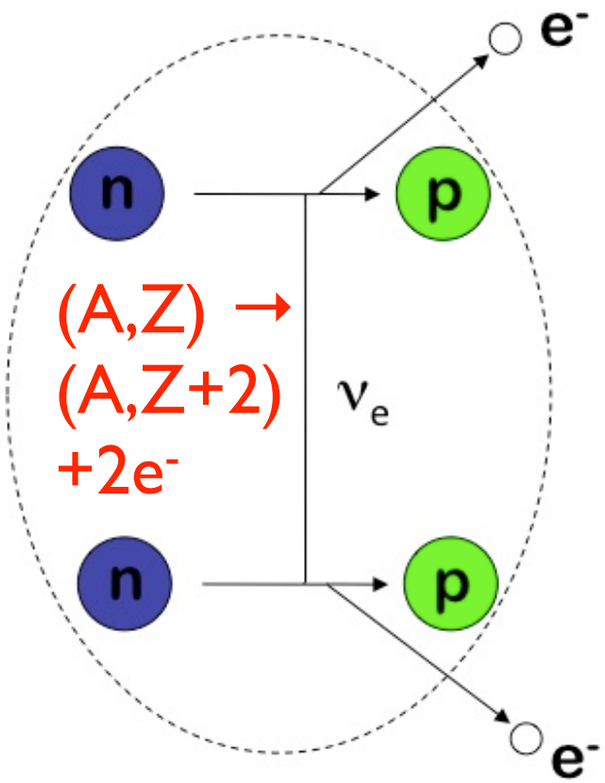


MH sensitivity for 40kT WbLS alone > 4.8 σ

All figs from arXiv:1409.5864

Equivalent to or better than 10kt LAr TPC

Neutrinoless Double Beta Decay



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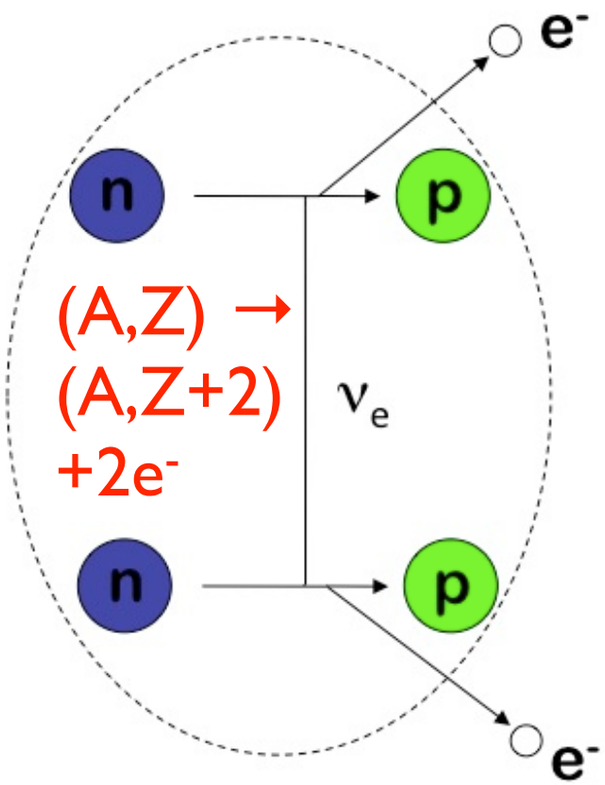

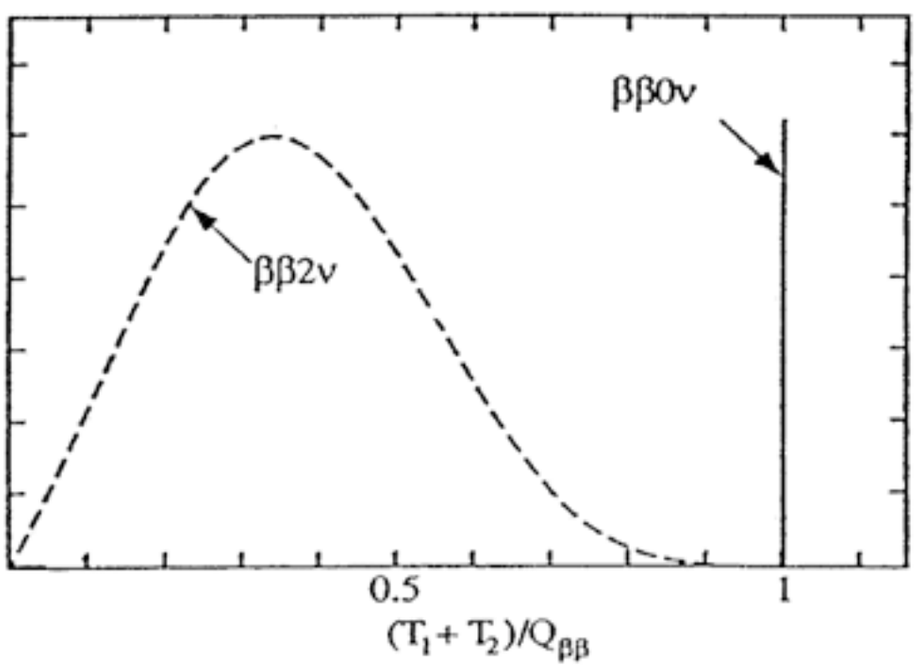

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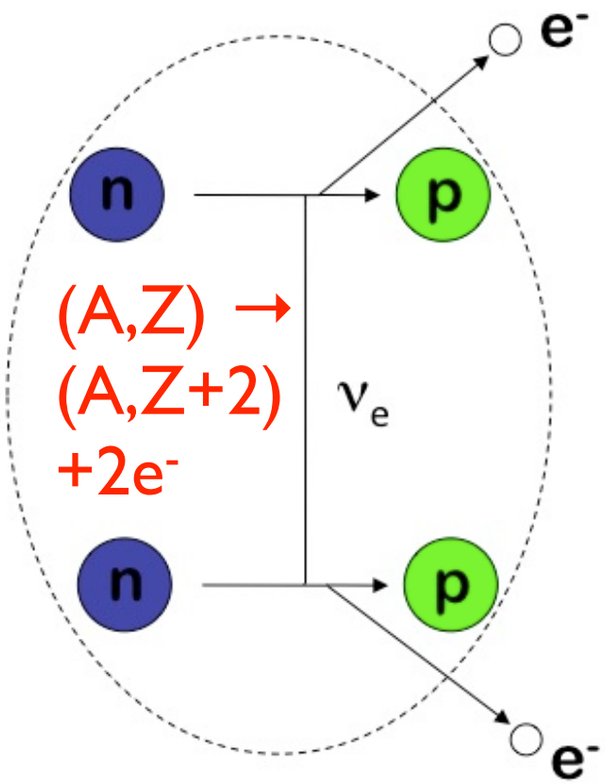
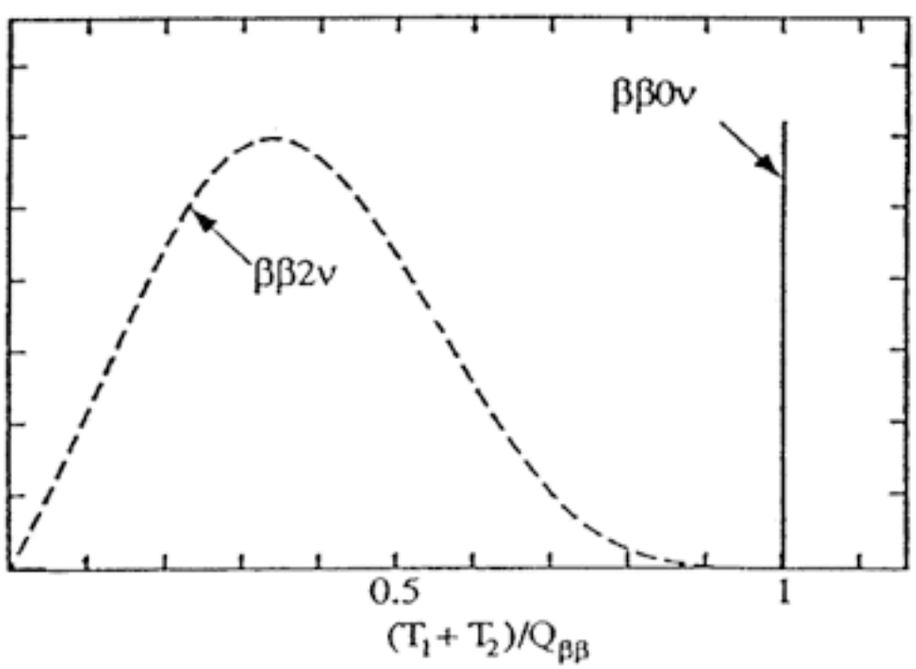
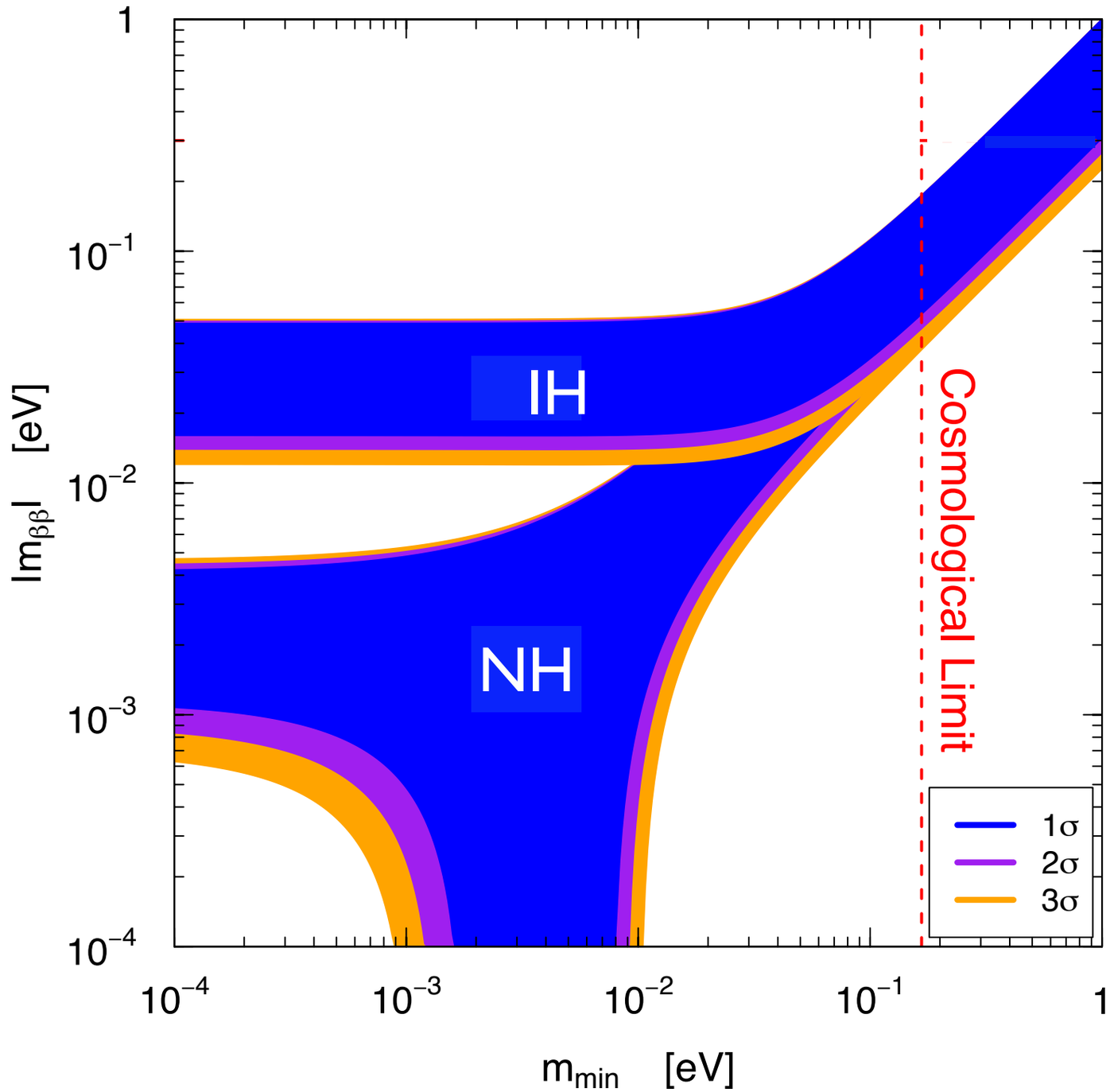
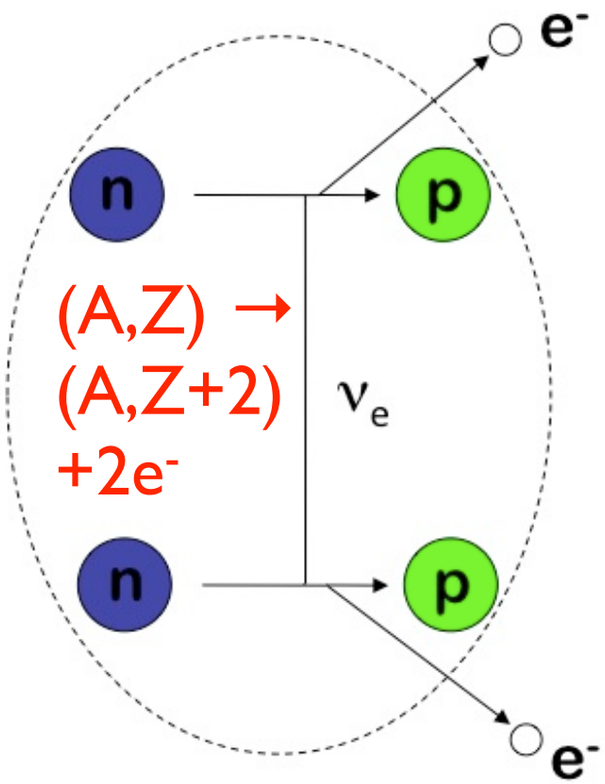


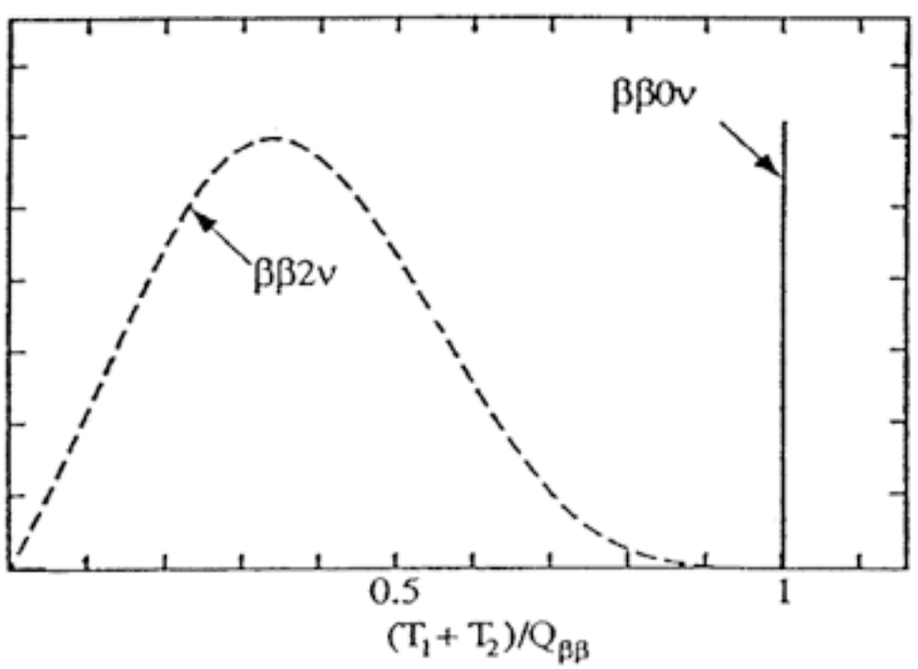


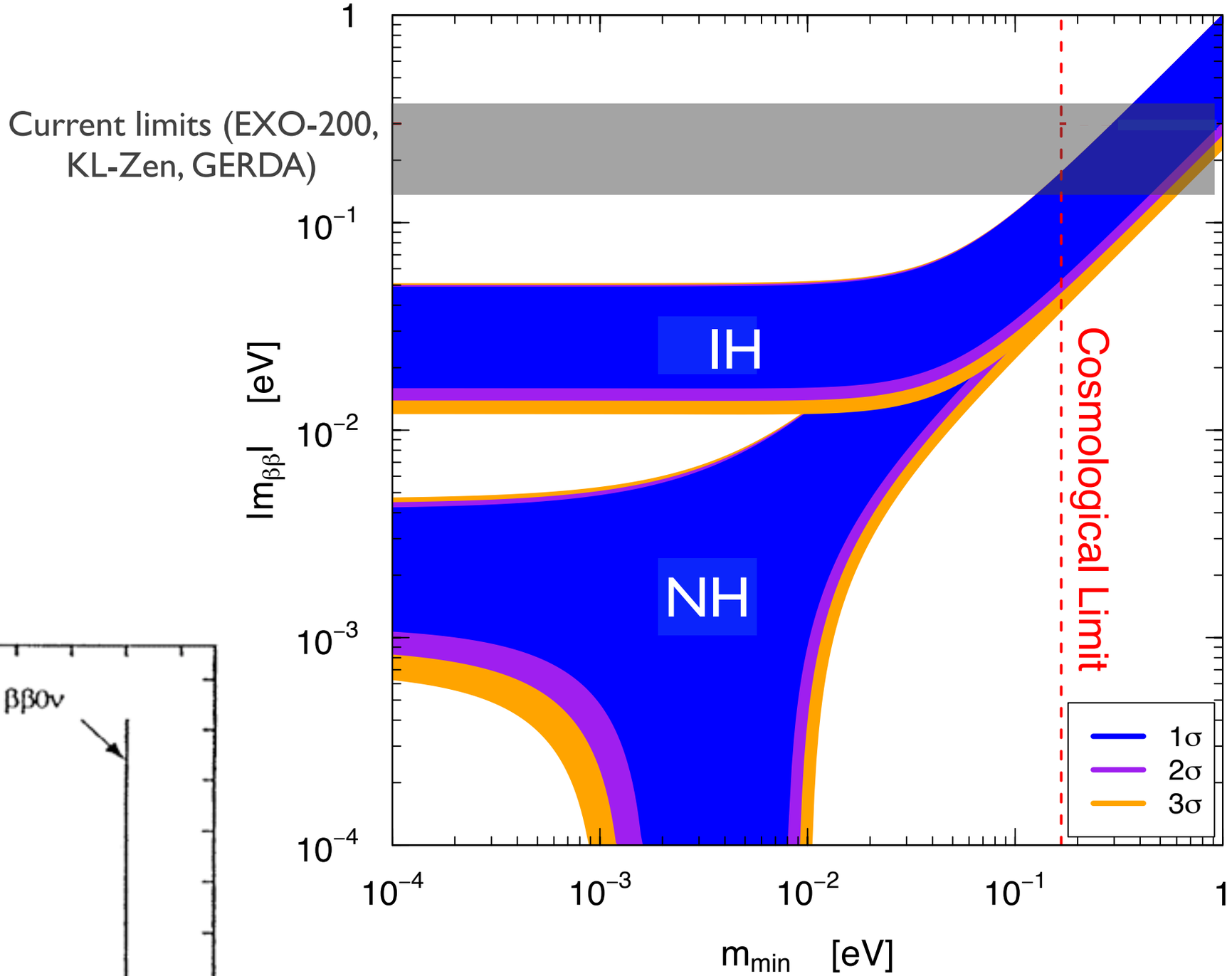


S. M. Bilenky & C. Giunti, Mod. Phys. Lett. A27, 1230015 (2012)

Neutrinoless Double Beta Decay







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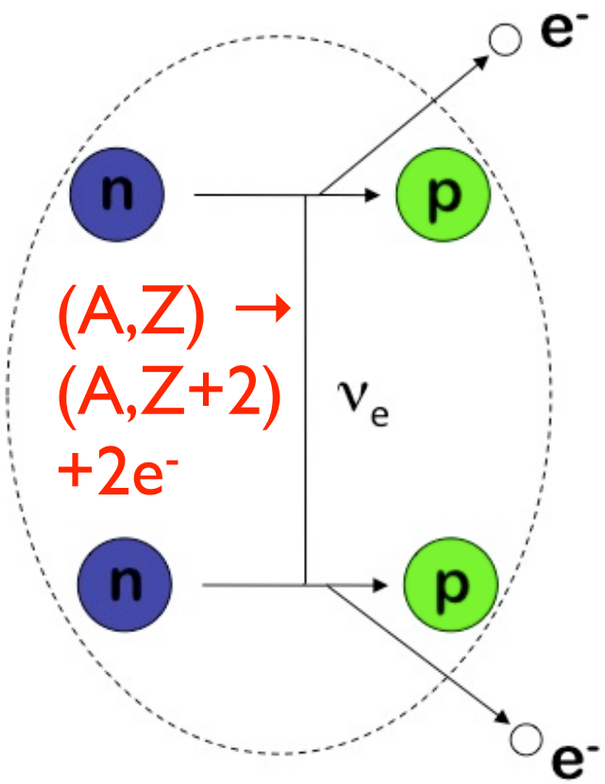

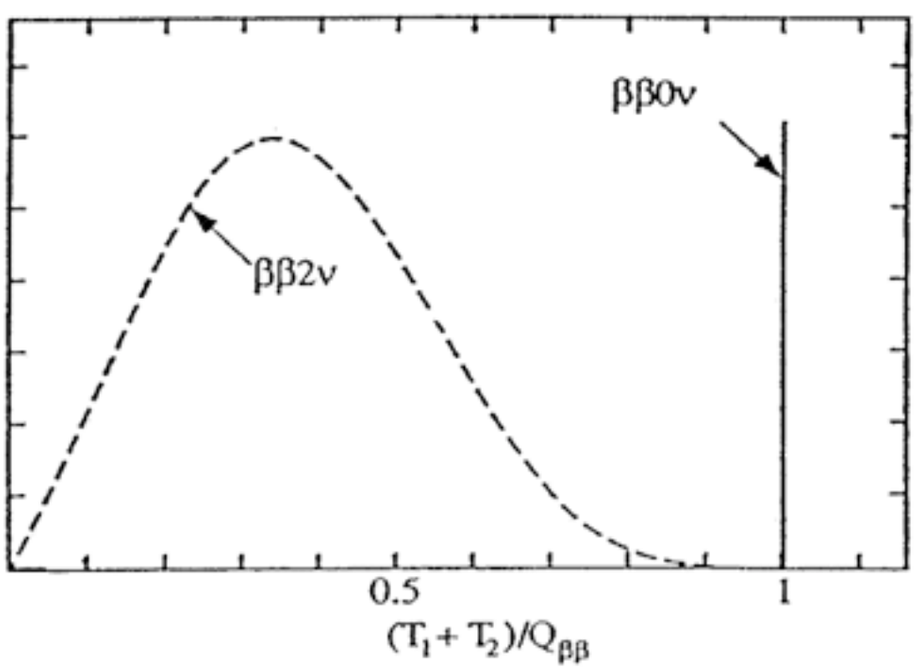

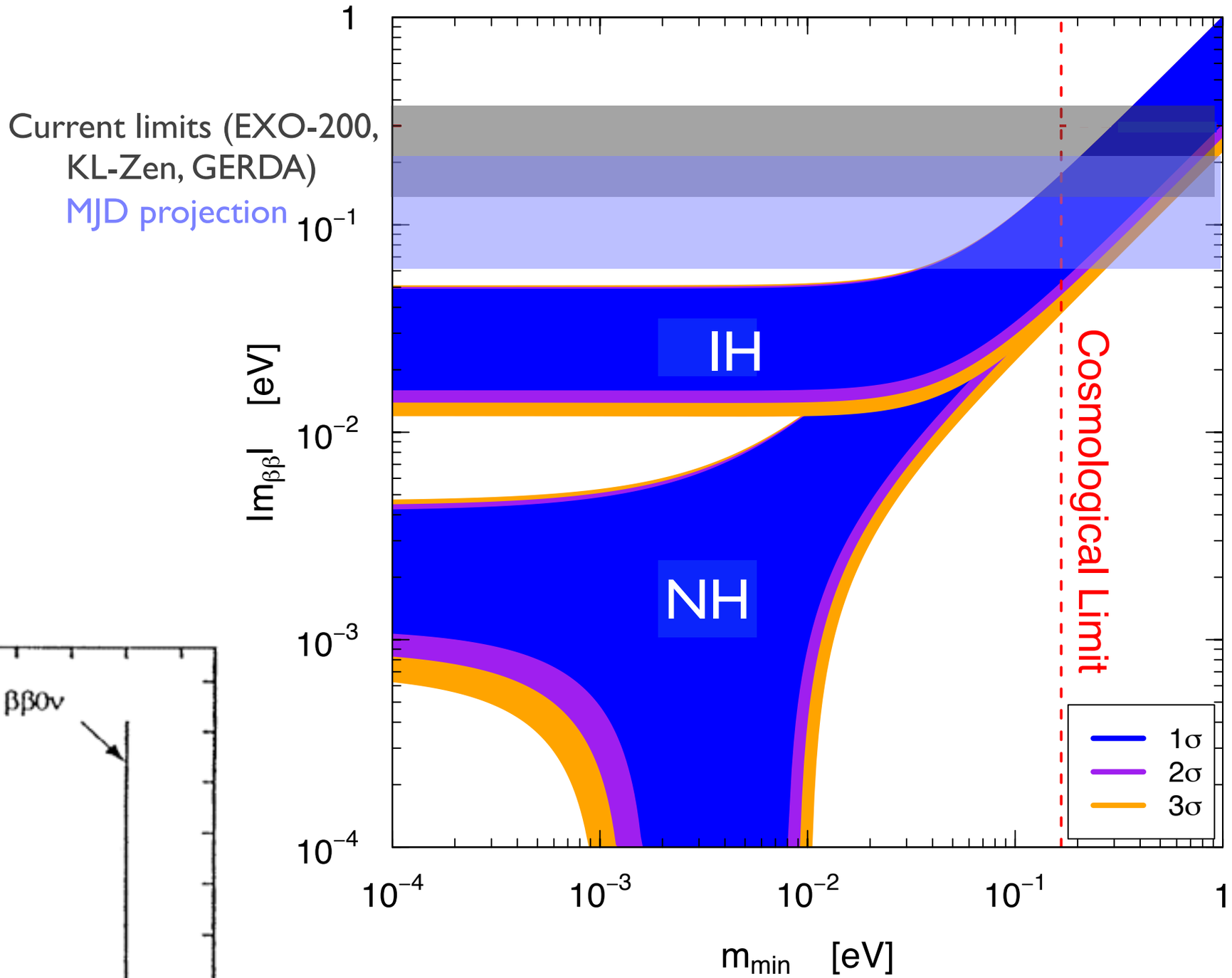

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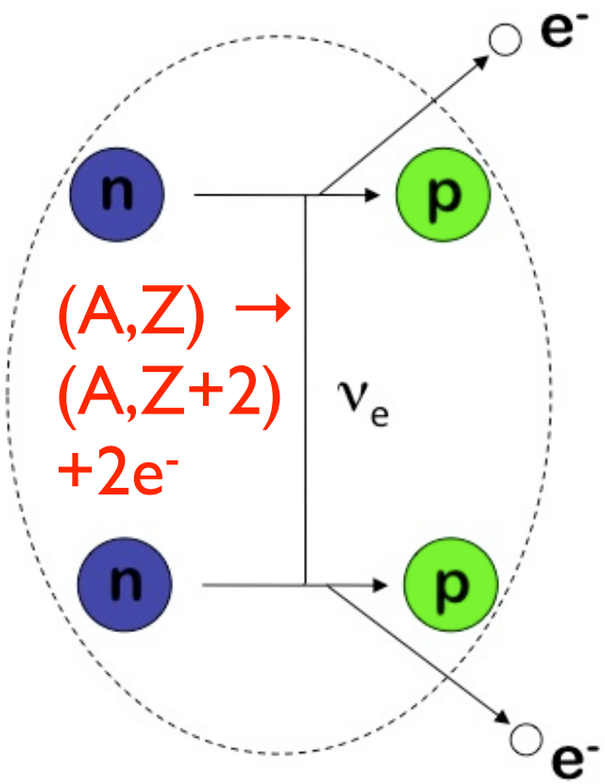

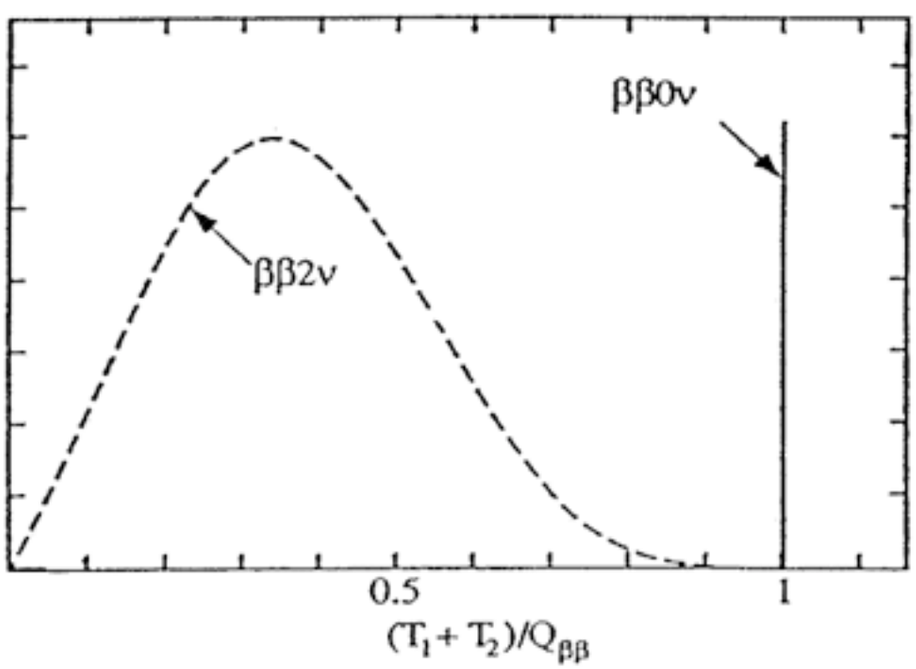

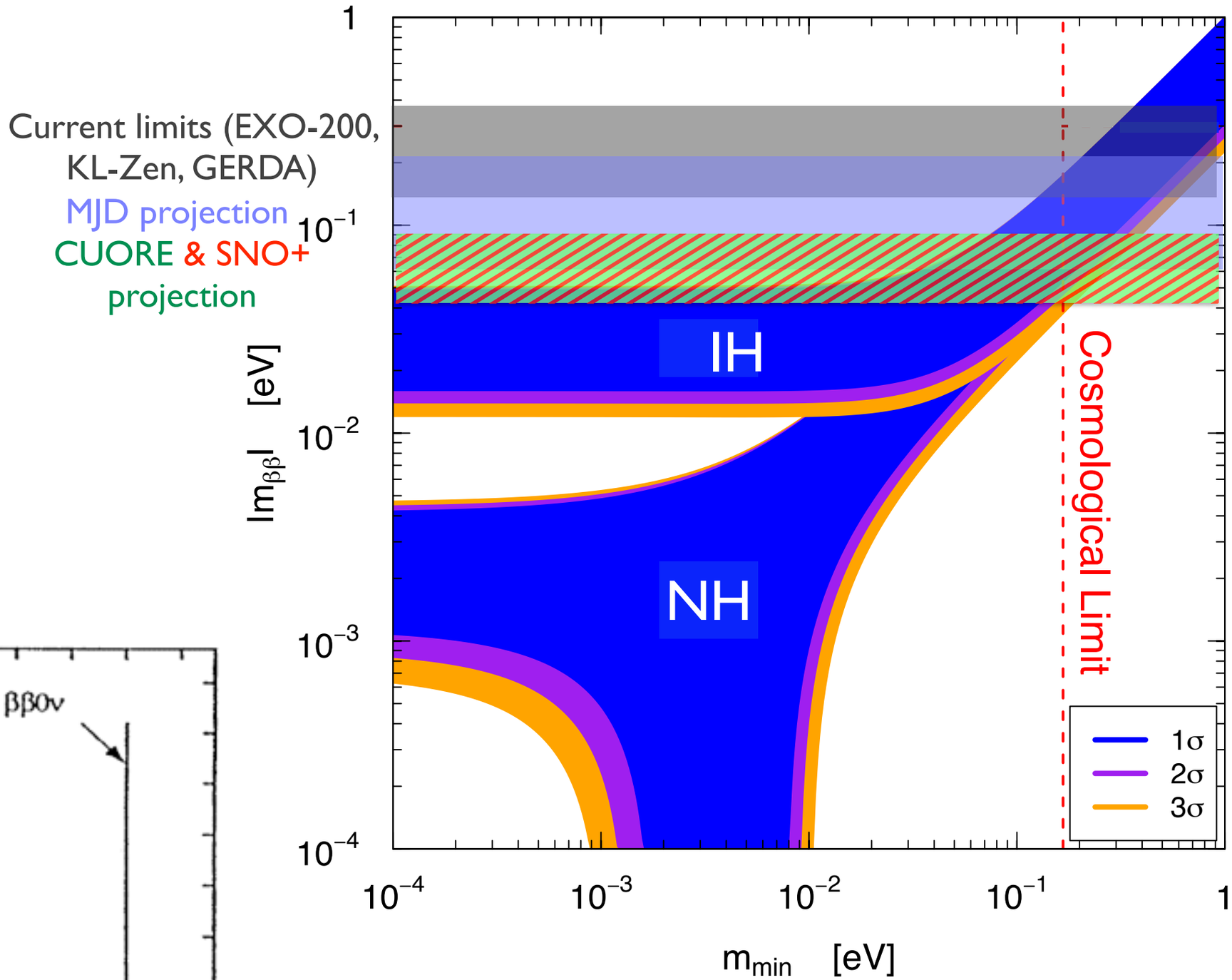

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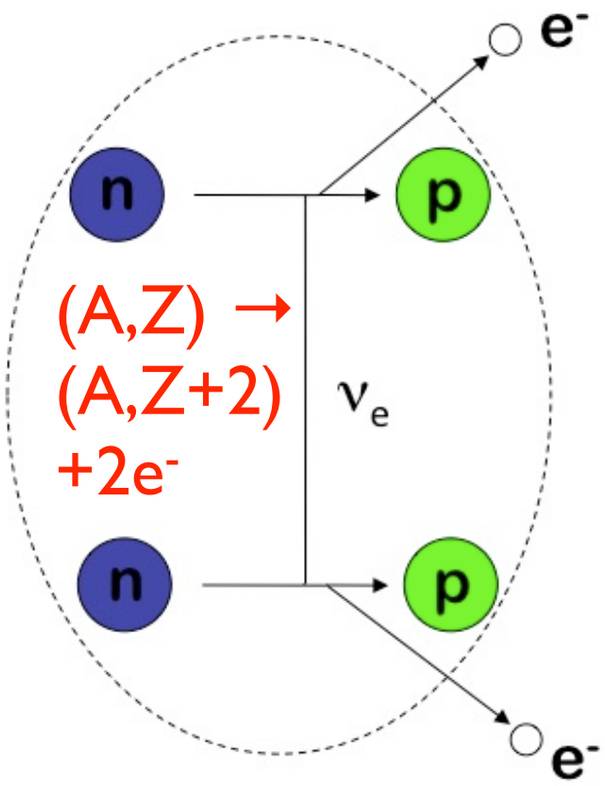

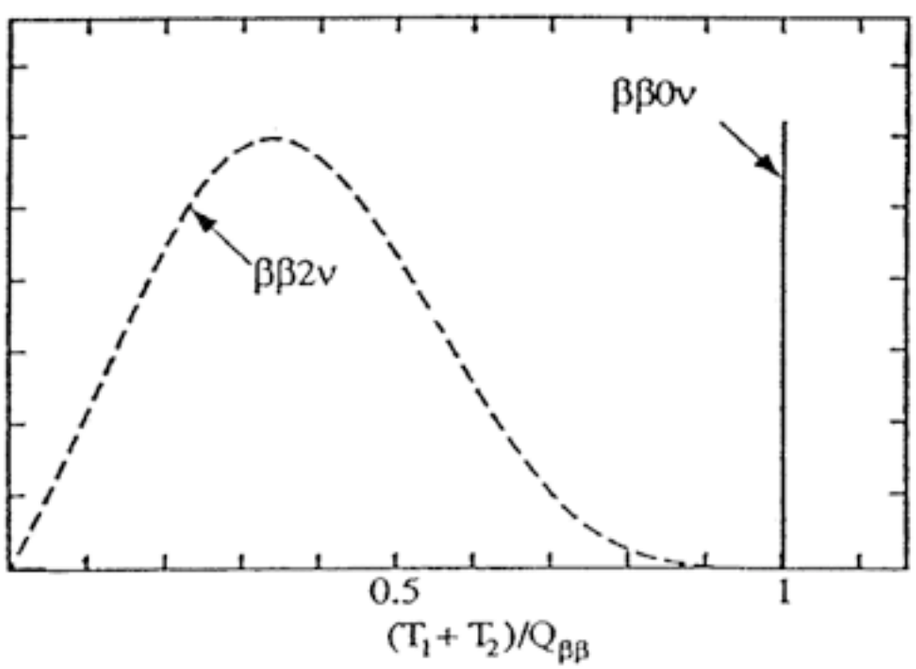

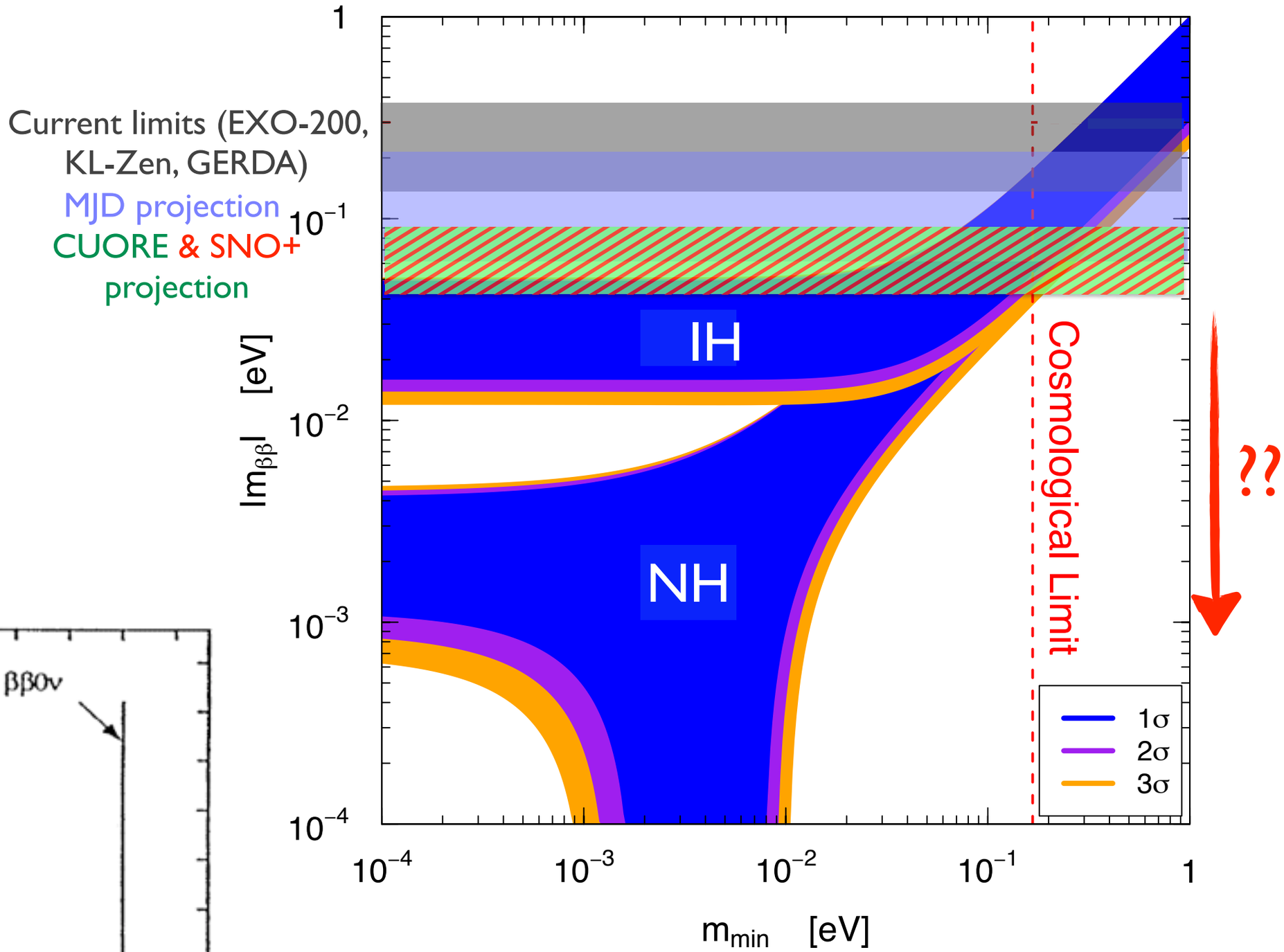

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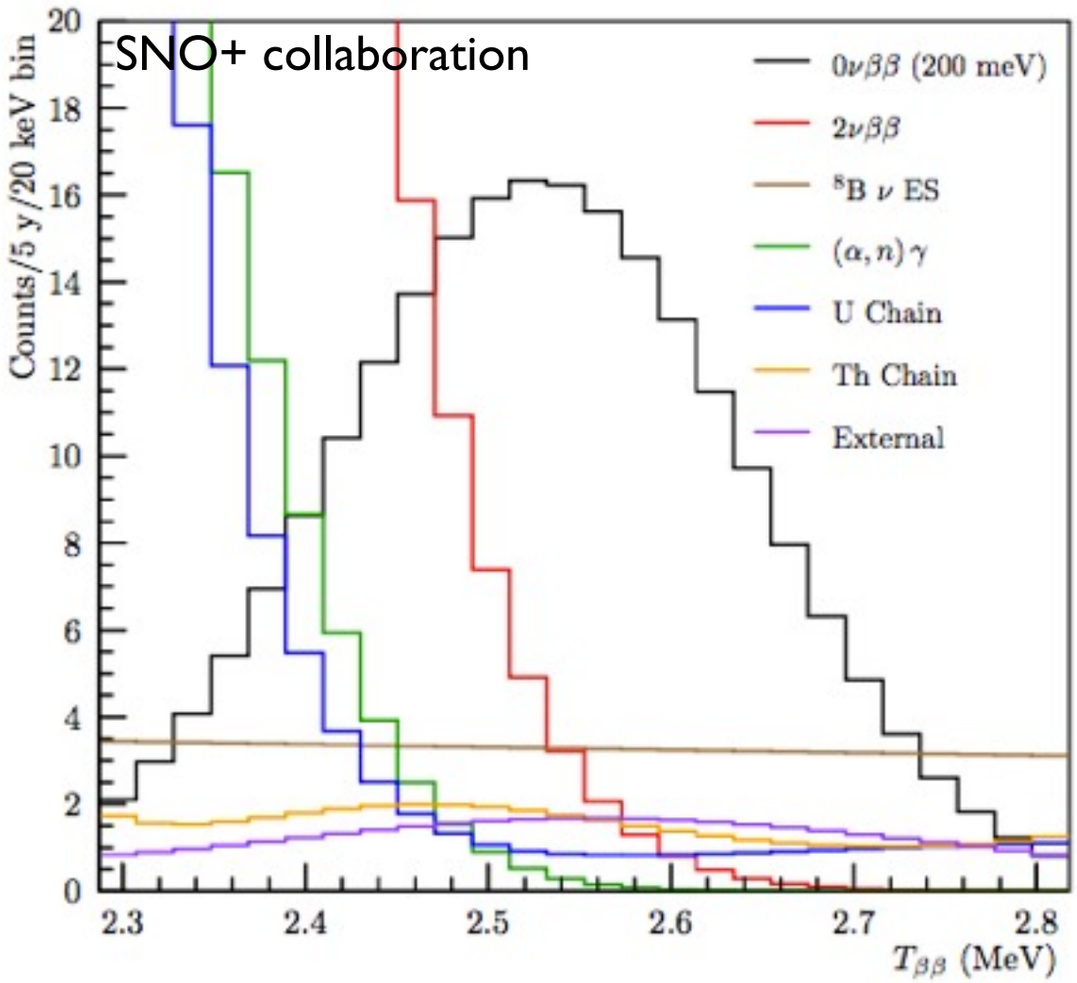
Liquid Scintillator Approach

Projected spectrum in SNO+: 5 years, 0.3% ^{nat}Te



Asymmetric ROI (-0.5 - 1.5 σ):
2.1 0νββ events / yr
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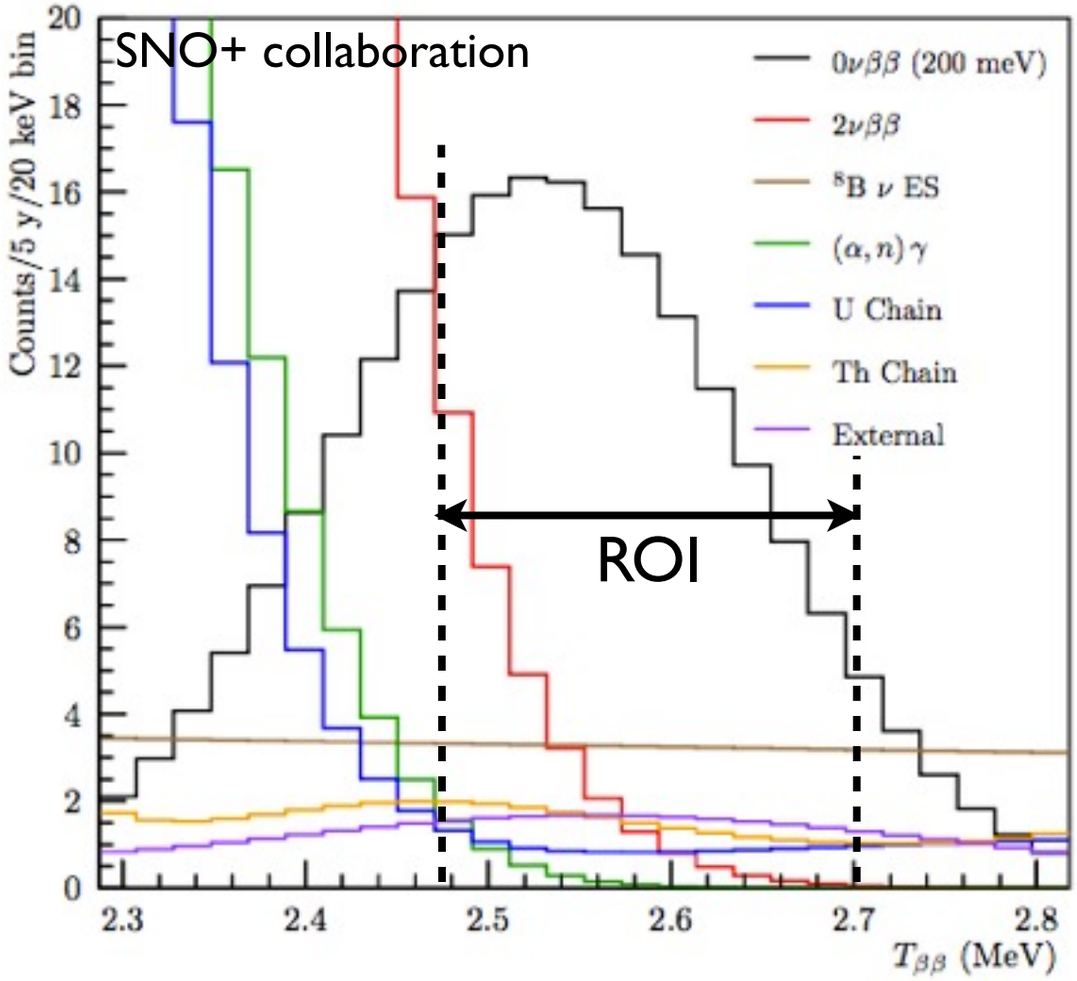

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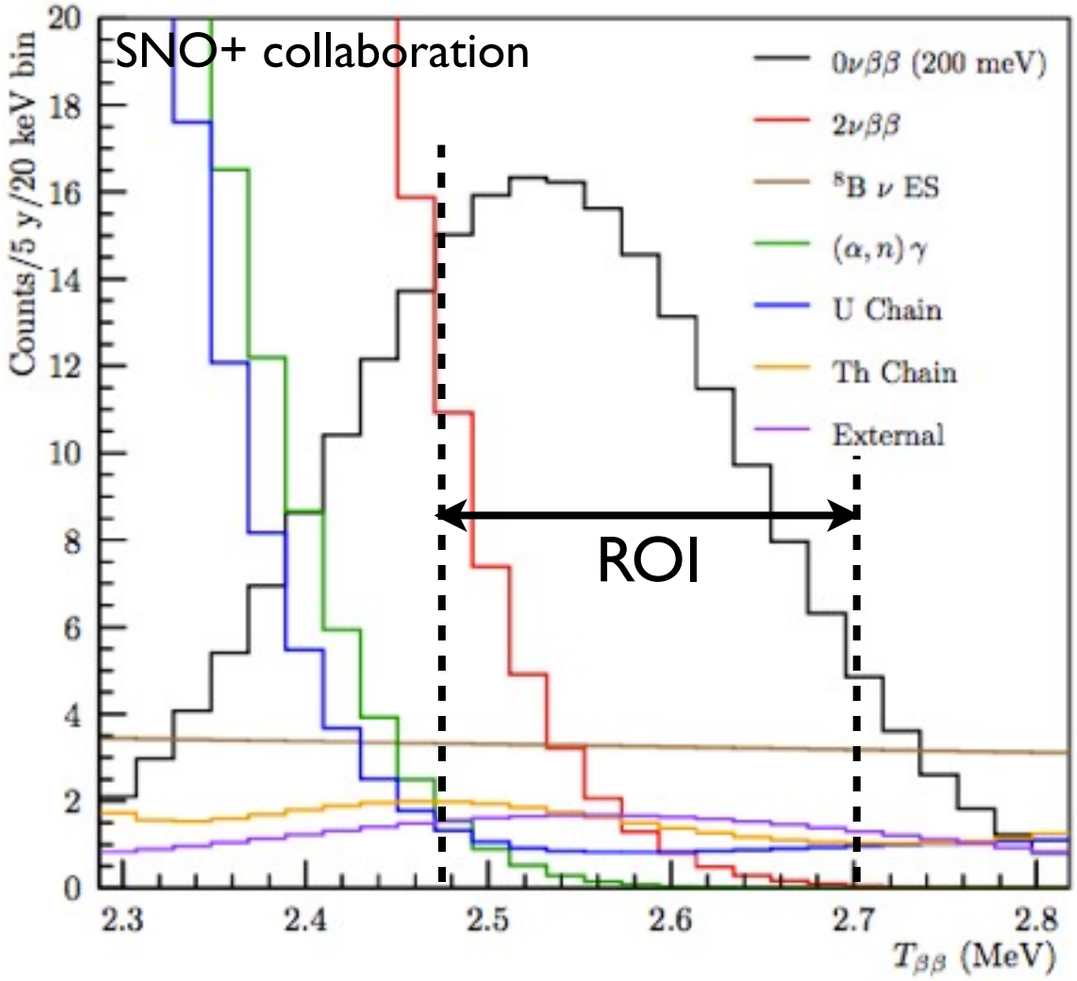

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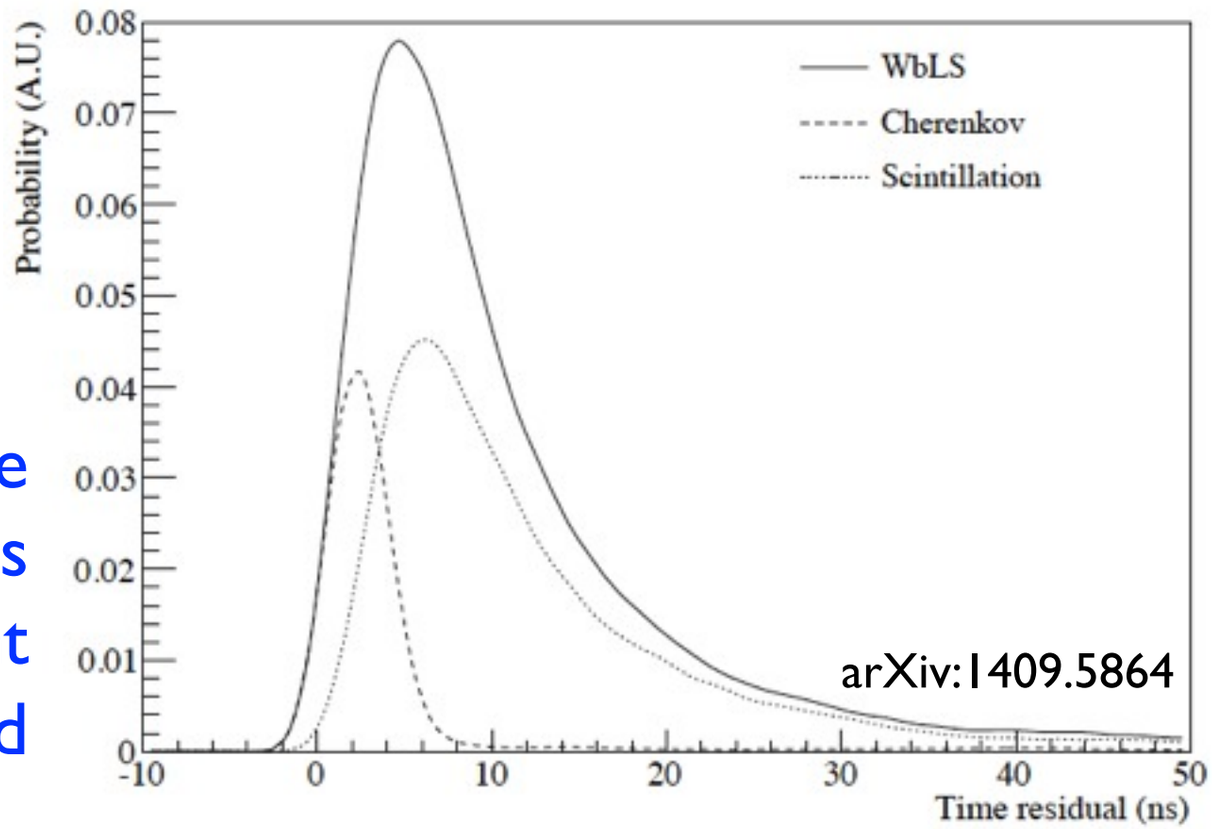
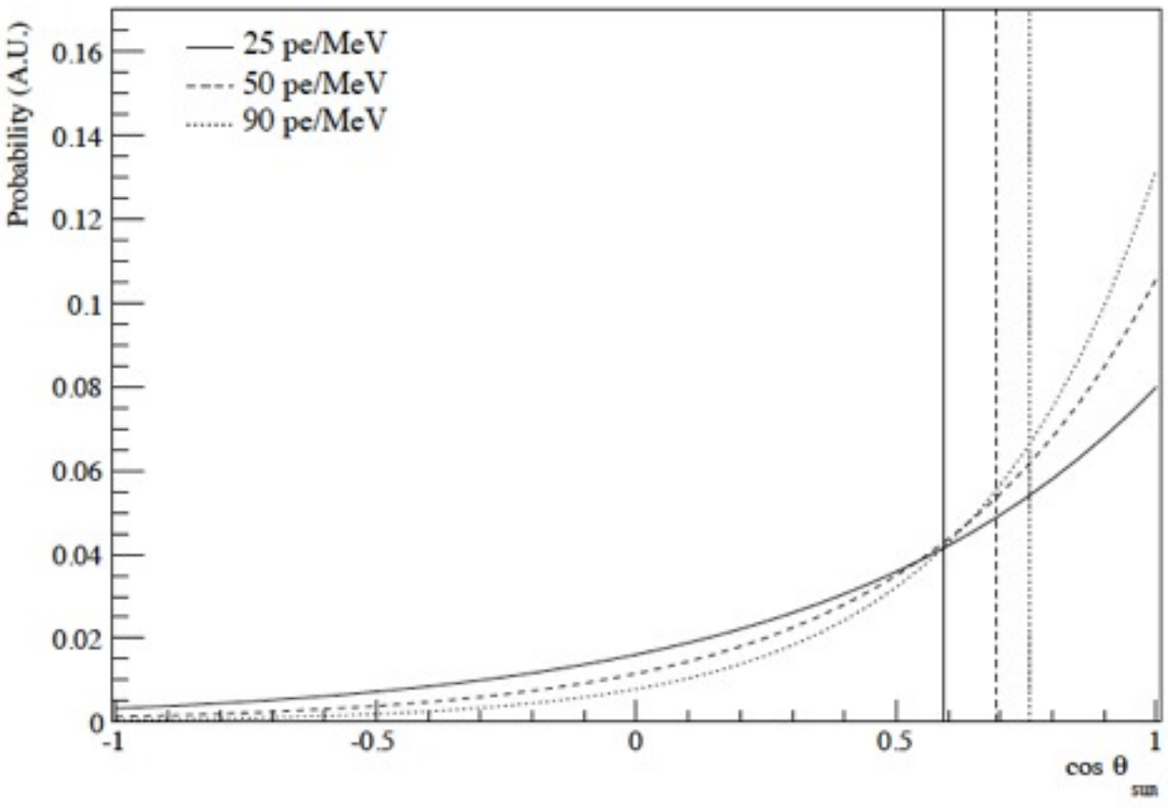
Use of precision timing to separate Chr / scint components allows directional cut to reject dominant ^{8}B solar ν background



ASDC Sensitivity

Directional resolution for different Cherenkov light yields



All figs from arXiv:1409.5864

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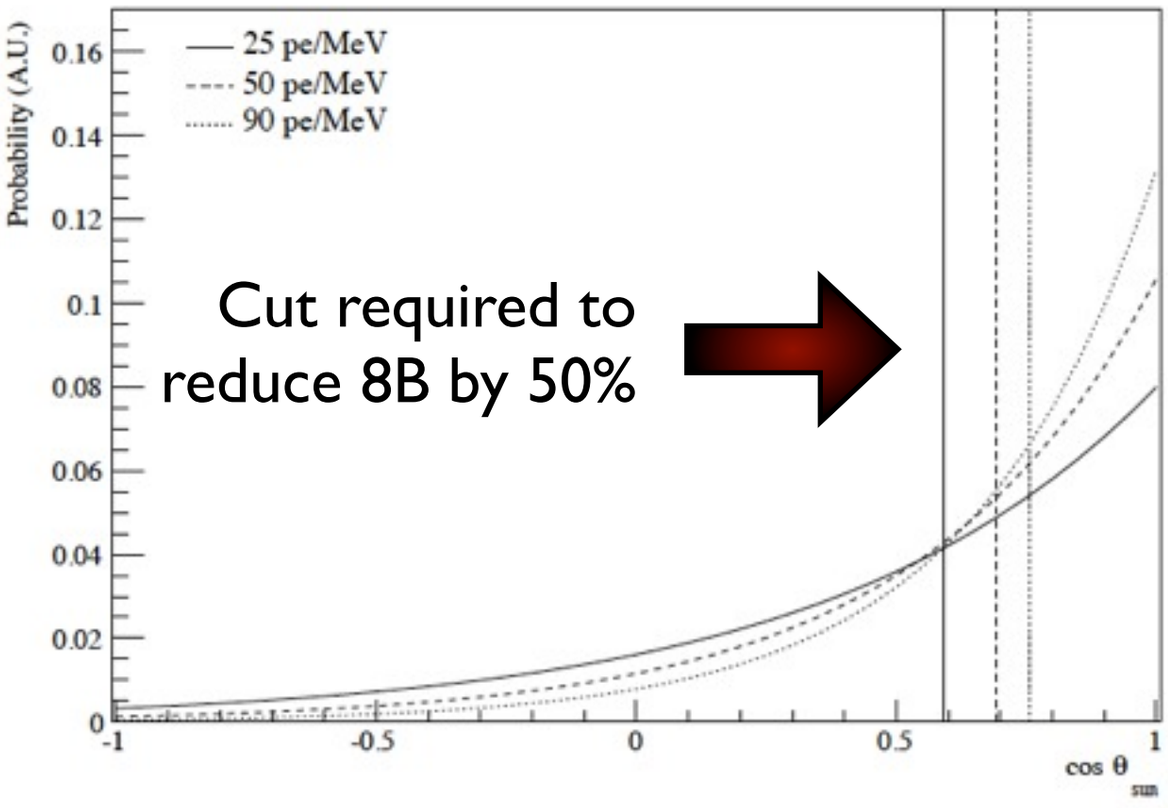

Cut required to reduce 8B by 50%

All figs from arXiv:1409.5864

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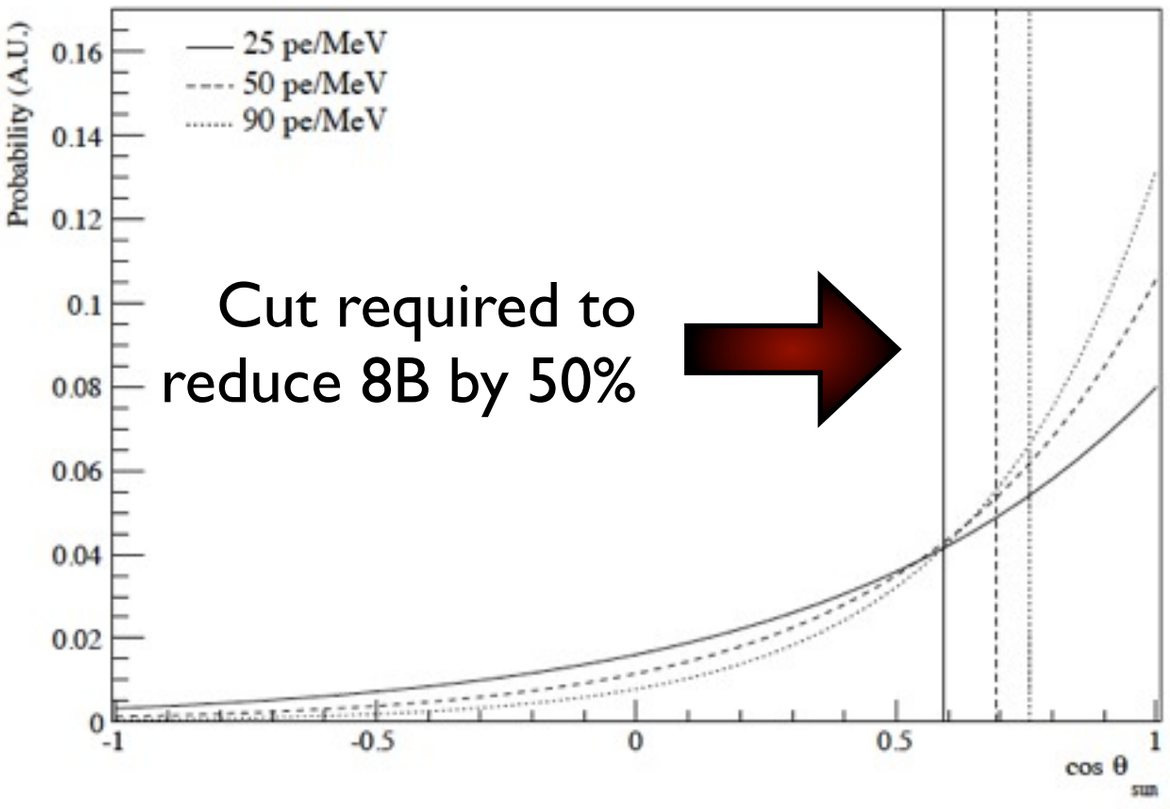

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50kt detector

50% reduction of ^{8}B

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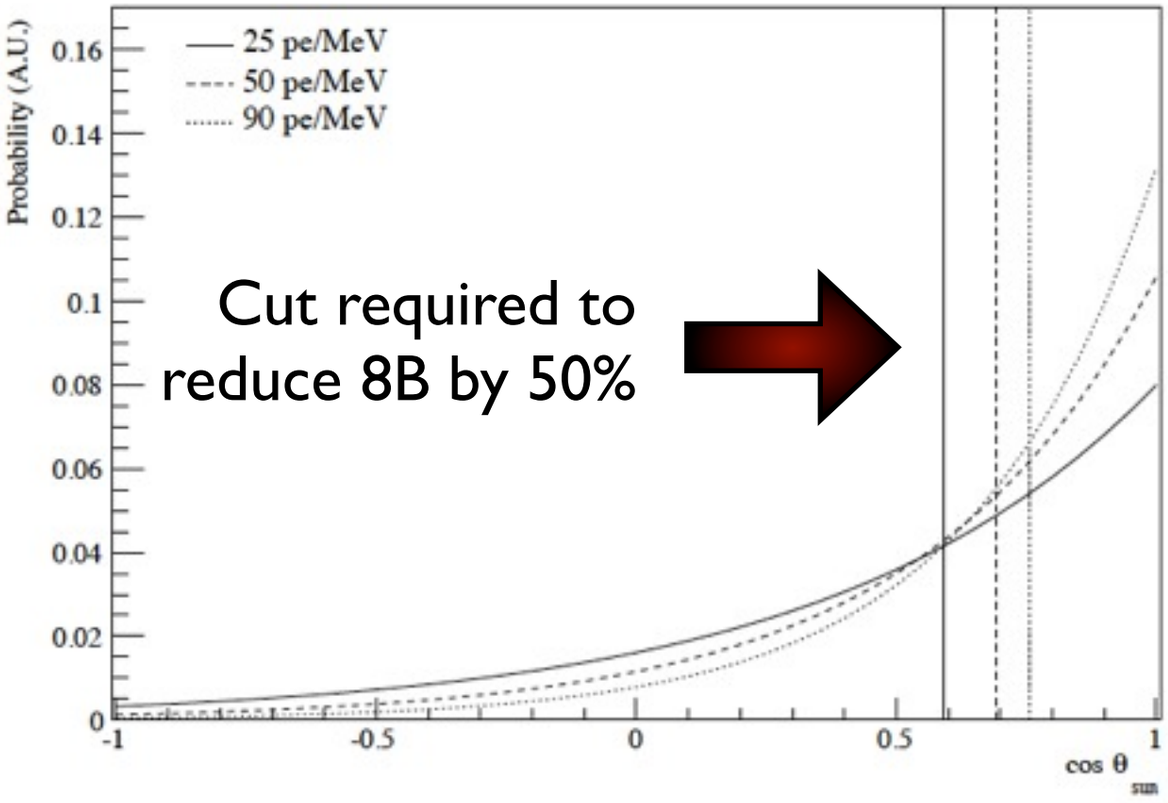

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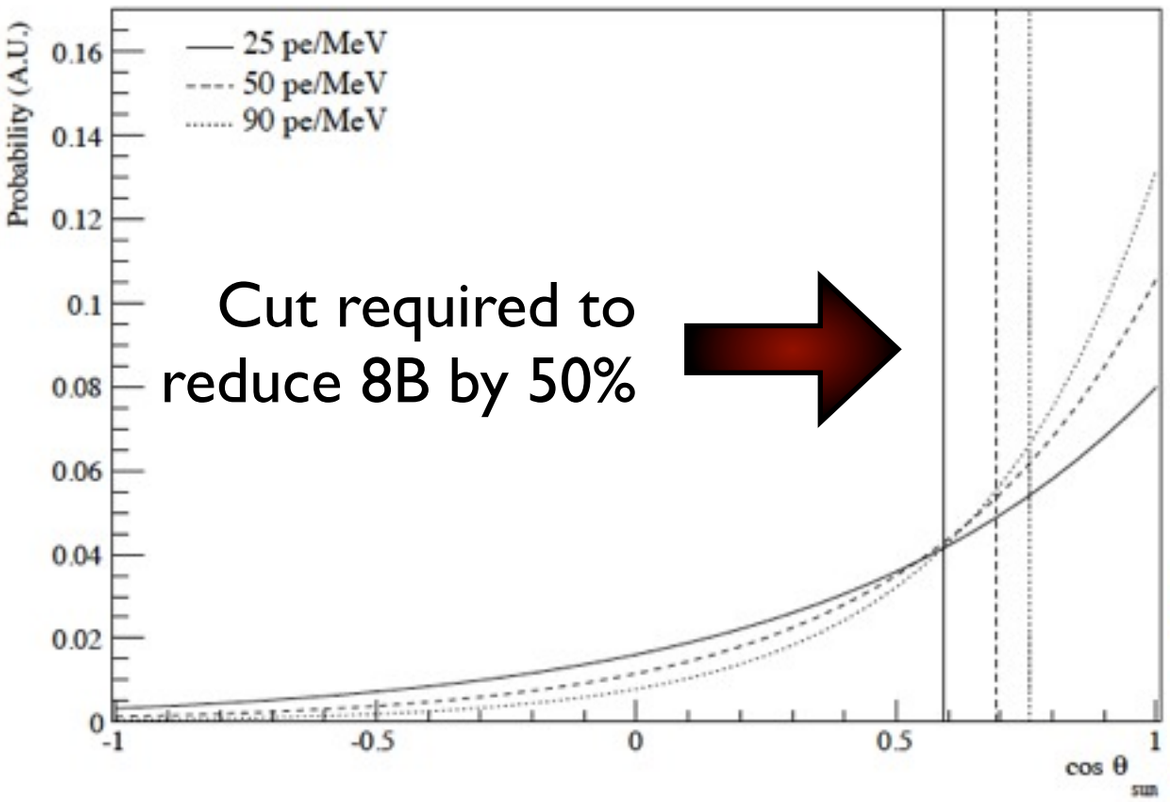

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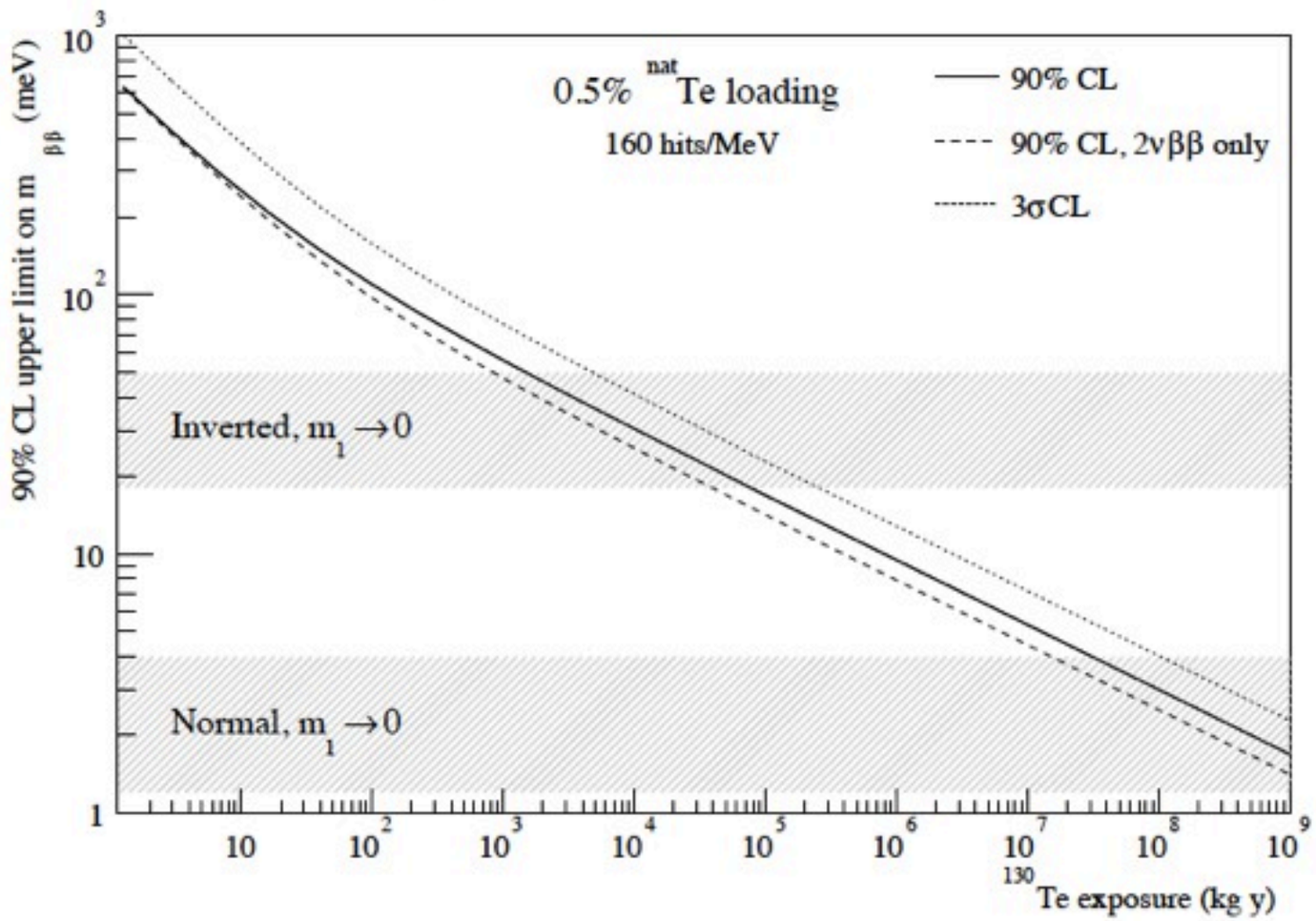

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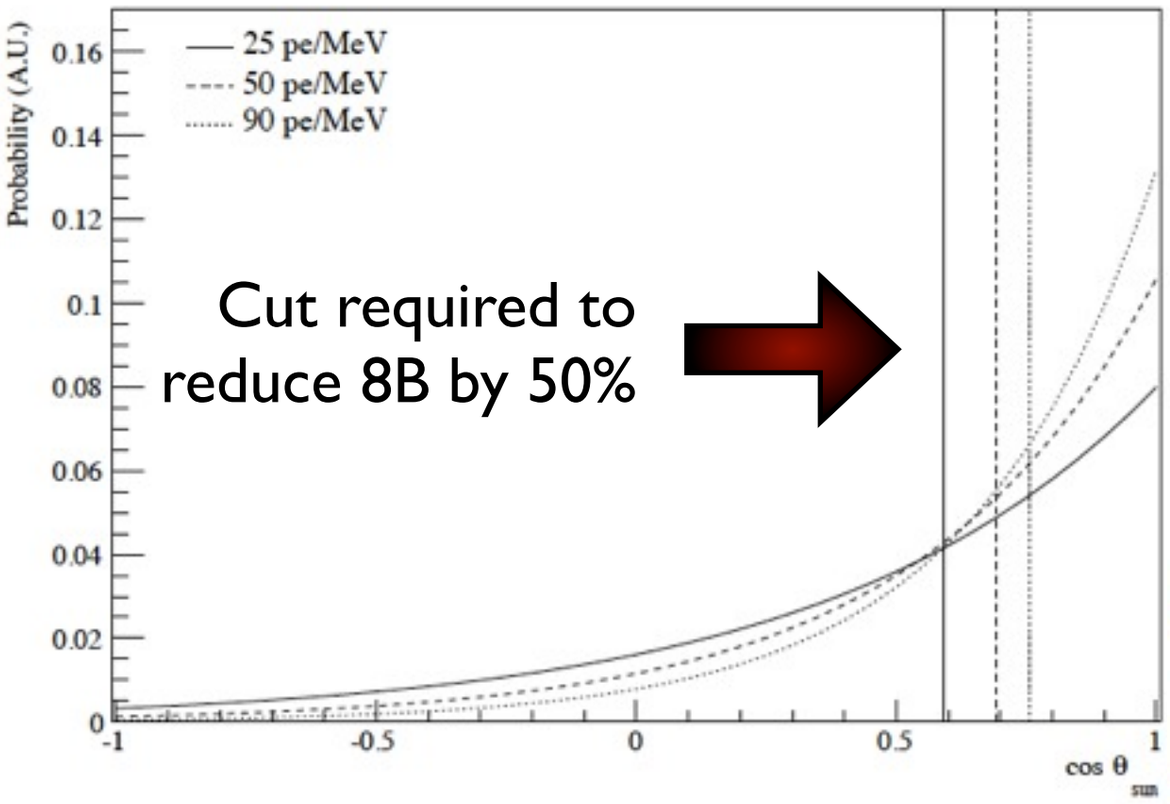

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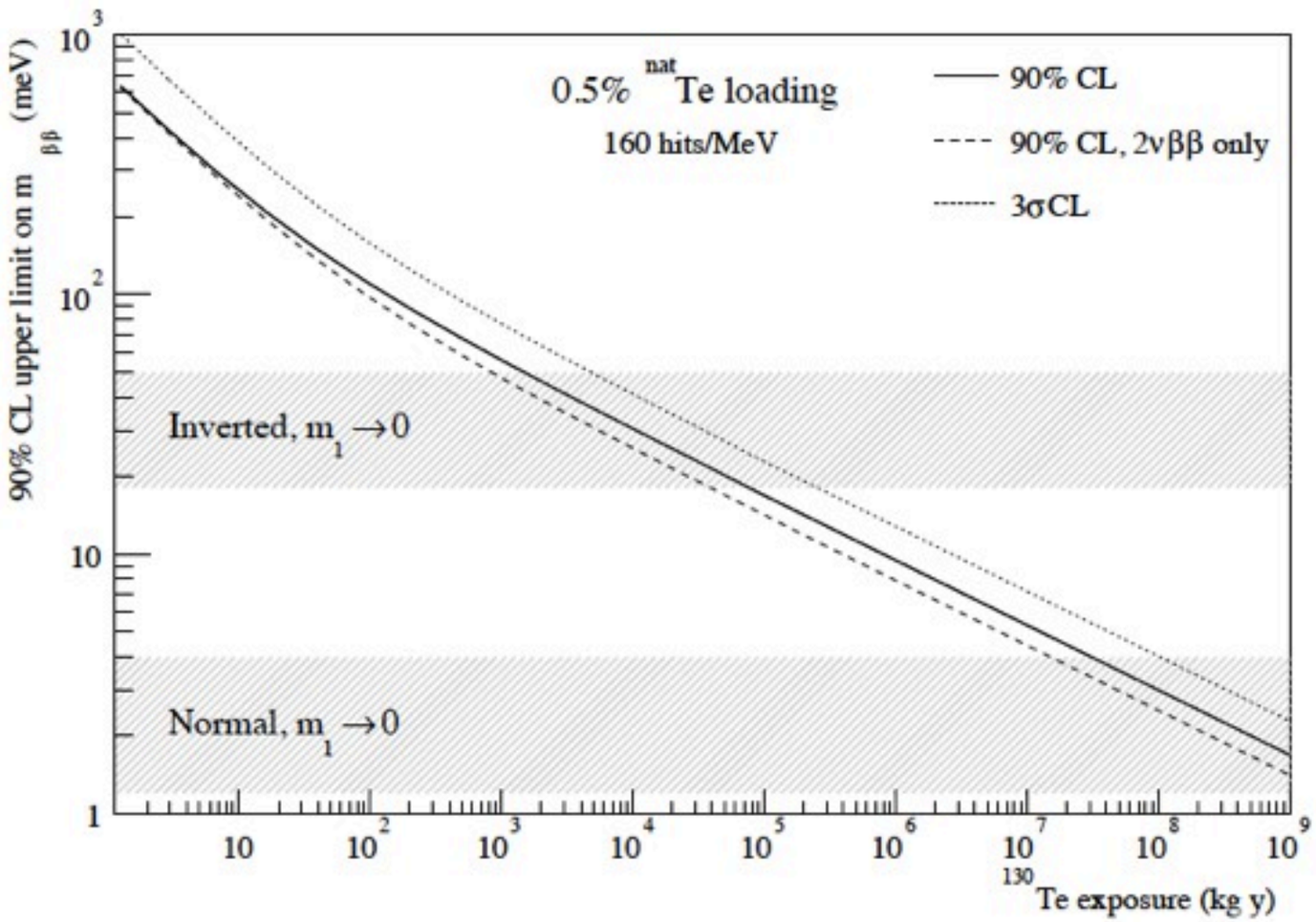

⇛ 3σ discovery for $m_{\beta\beta}$=15meV in 10 yrs

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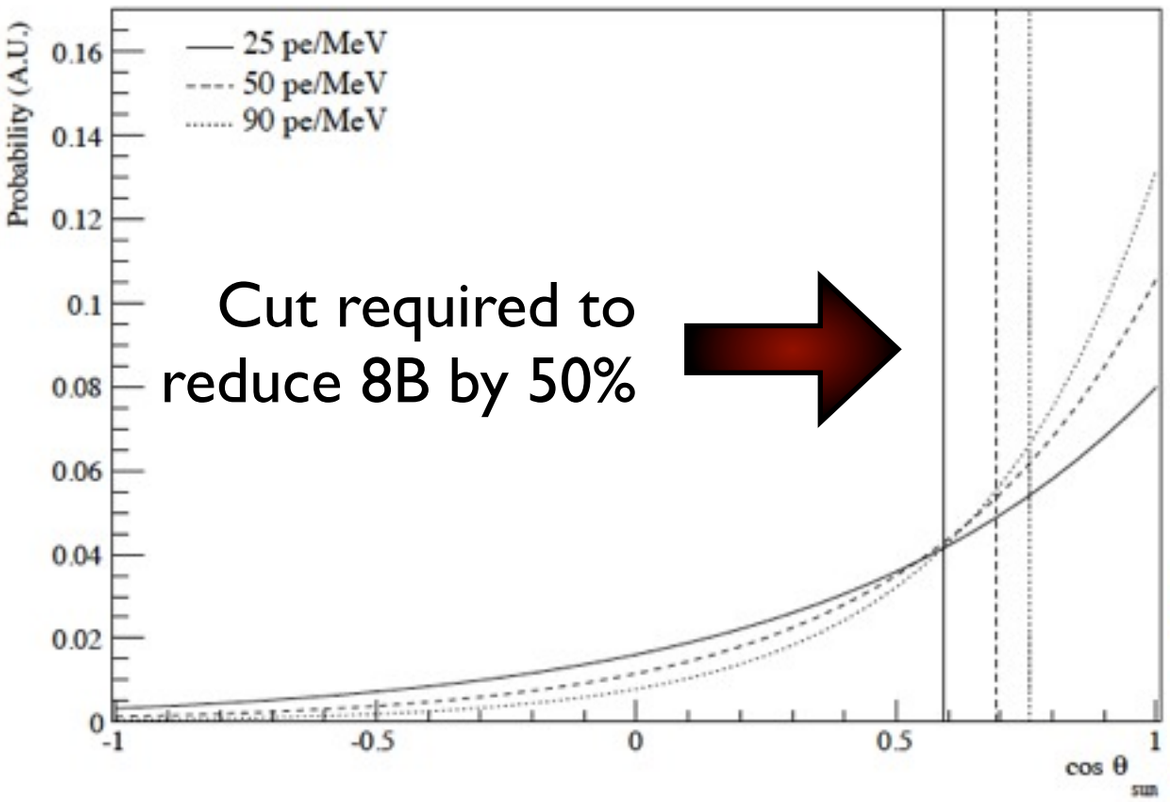

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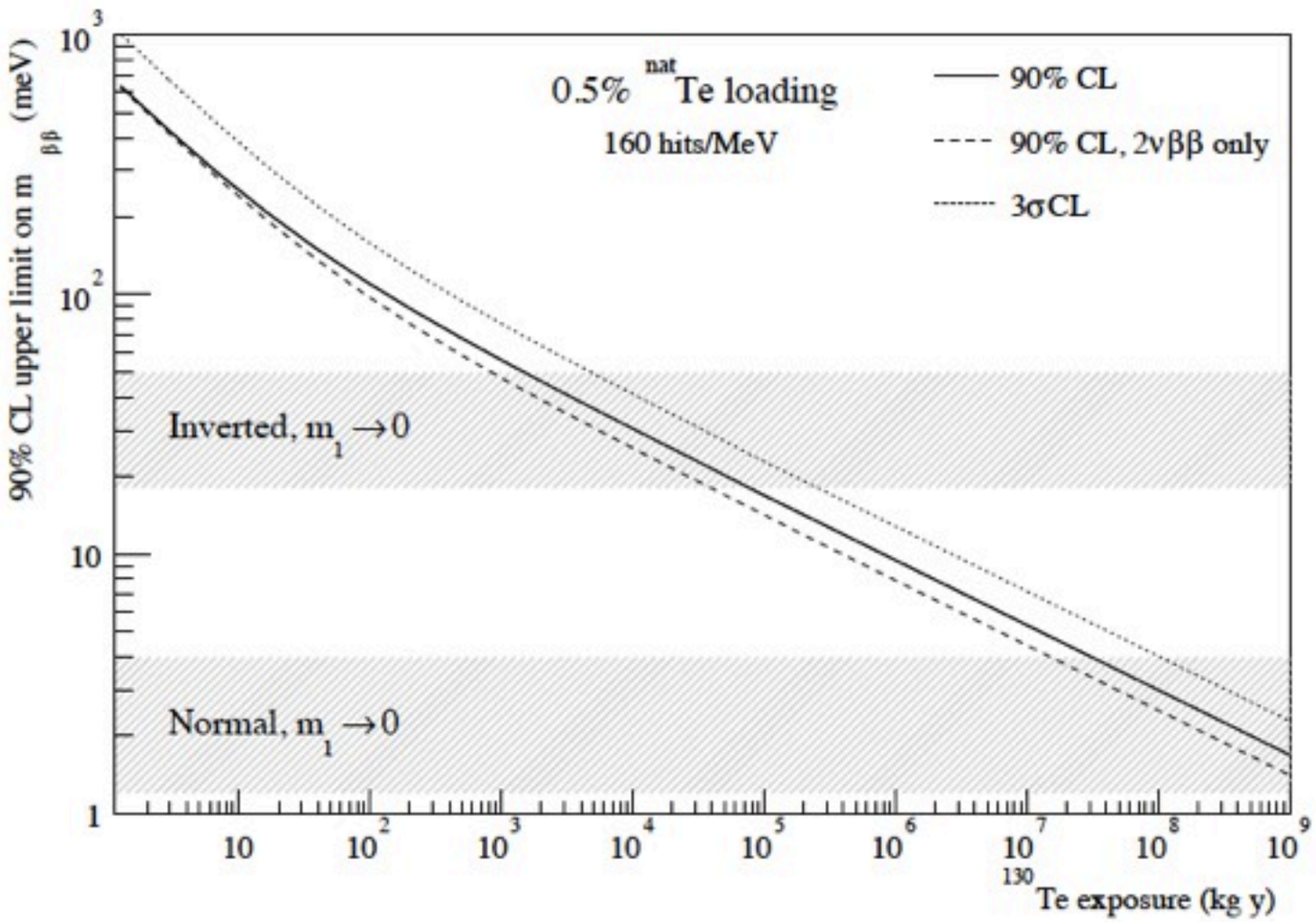

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Future sensitivity into NH region...

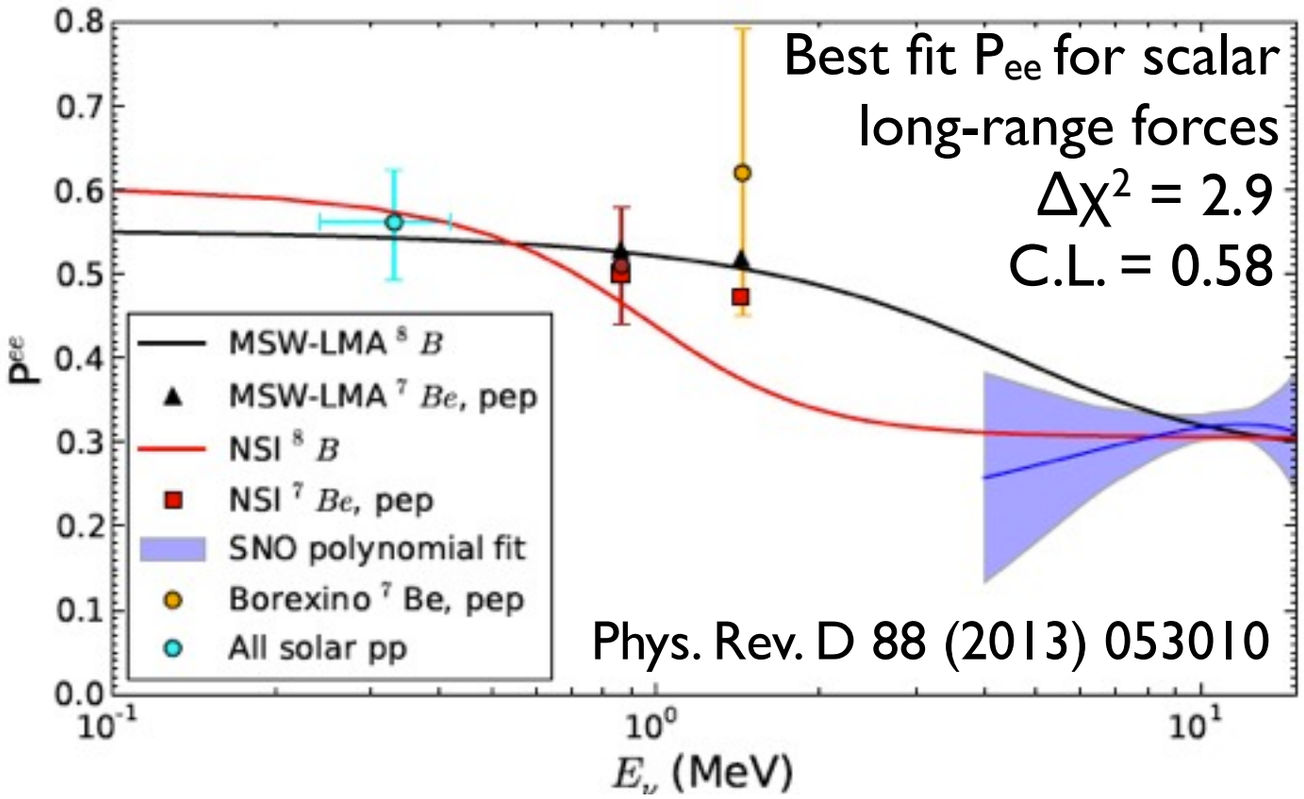
All figs from arXiv:1409.5864

Solar Neutrinos

1) Probe vacuum-matter transition via low-energy ^{8}B spectrum:

Confirm MSW

Sensitive search for new physics



Phys. Rev. D 88 (2013) 053010

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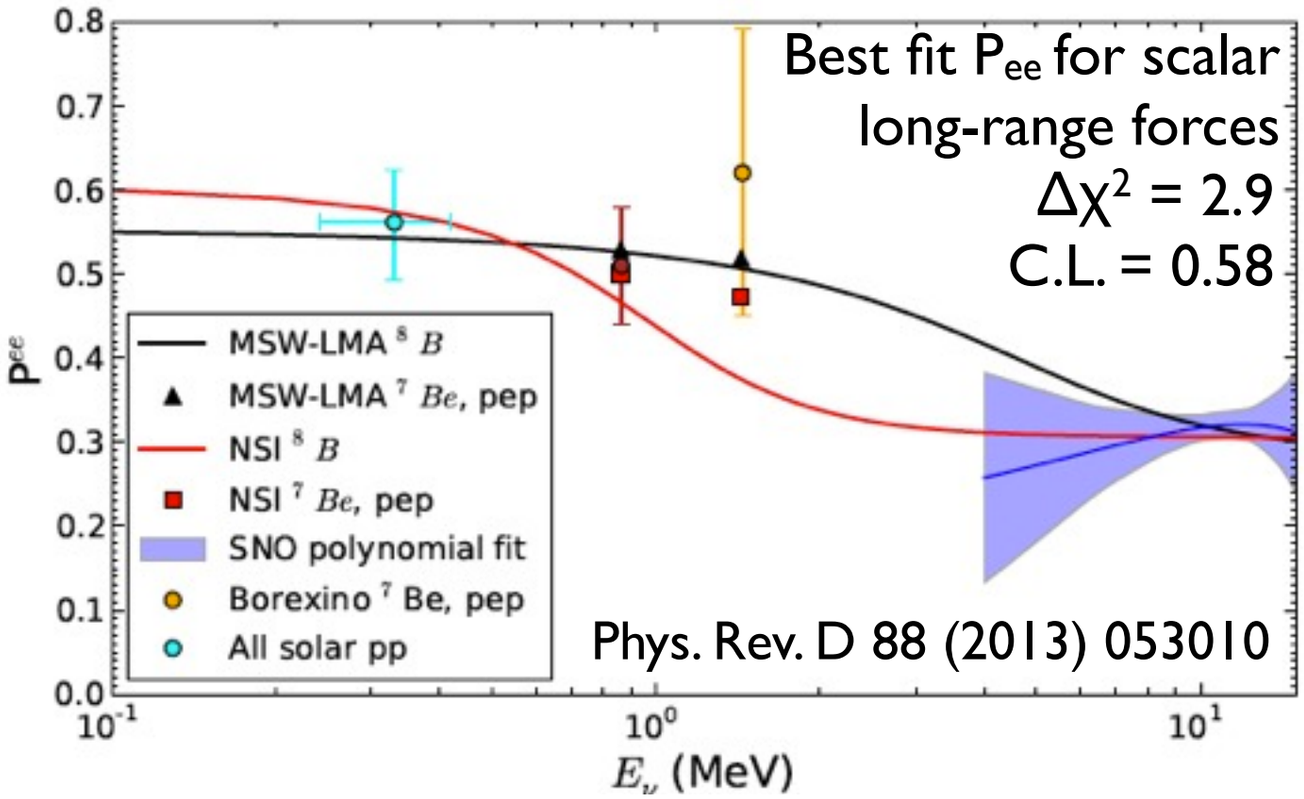

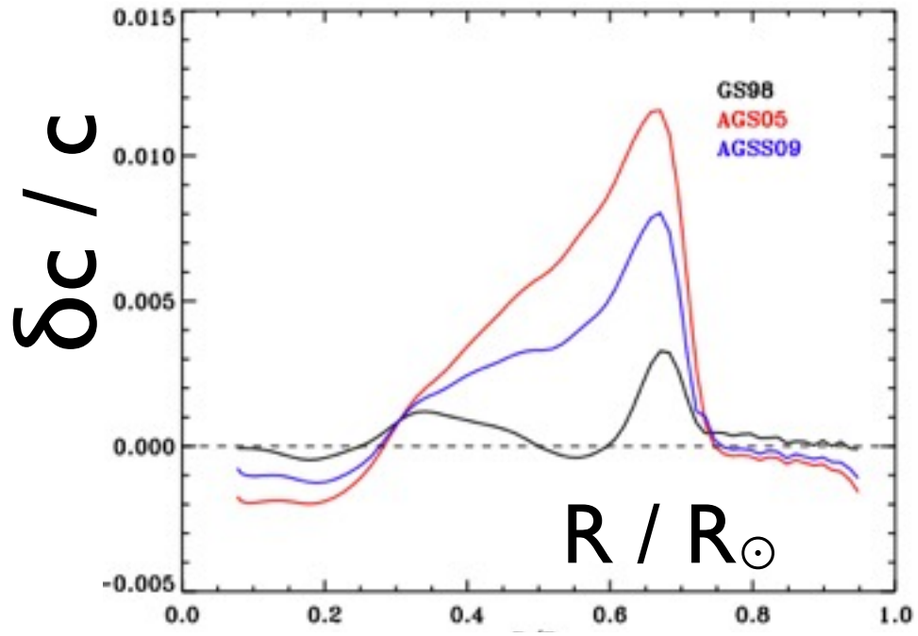

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Determine solar metalicity
Test understanding of heavier main-sequence stars
Test postulate of homog.T=0 Sun
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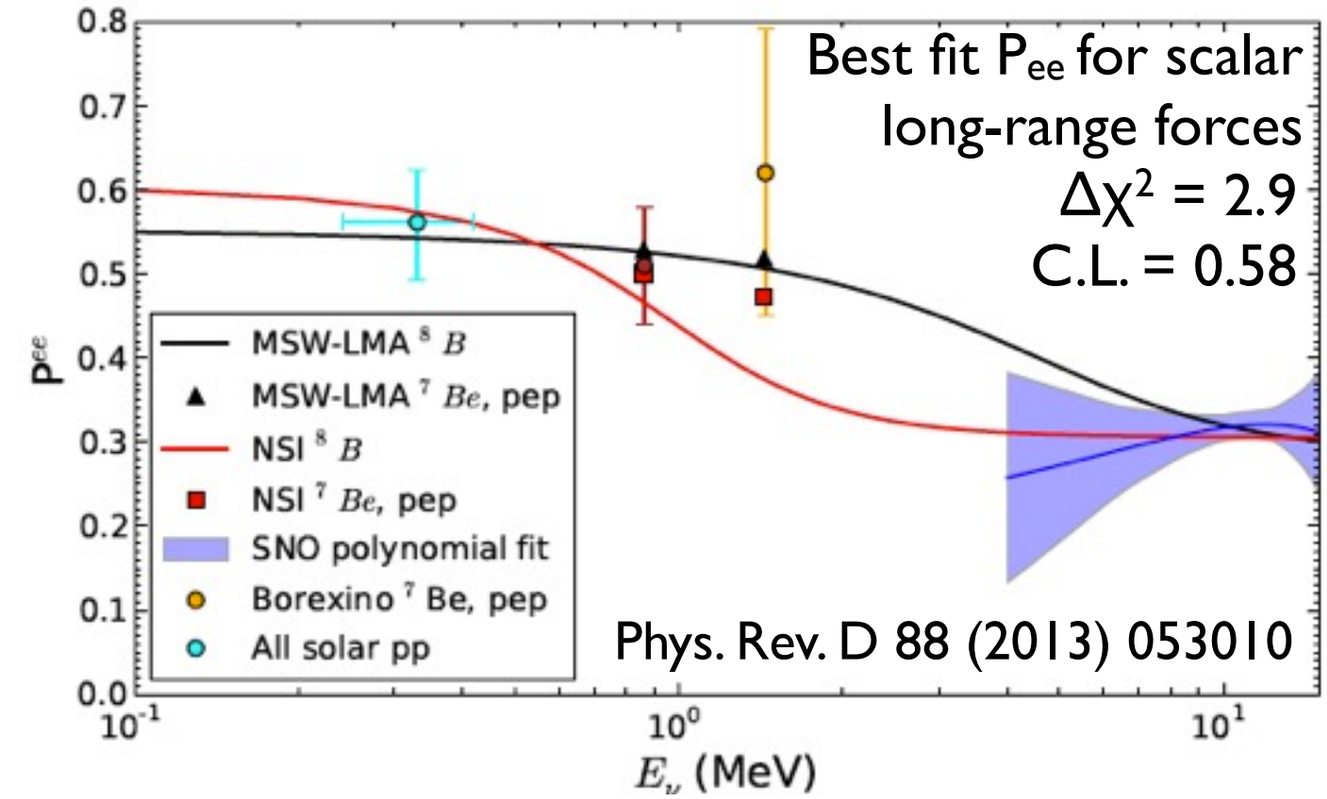

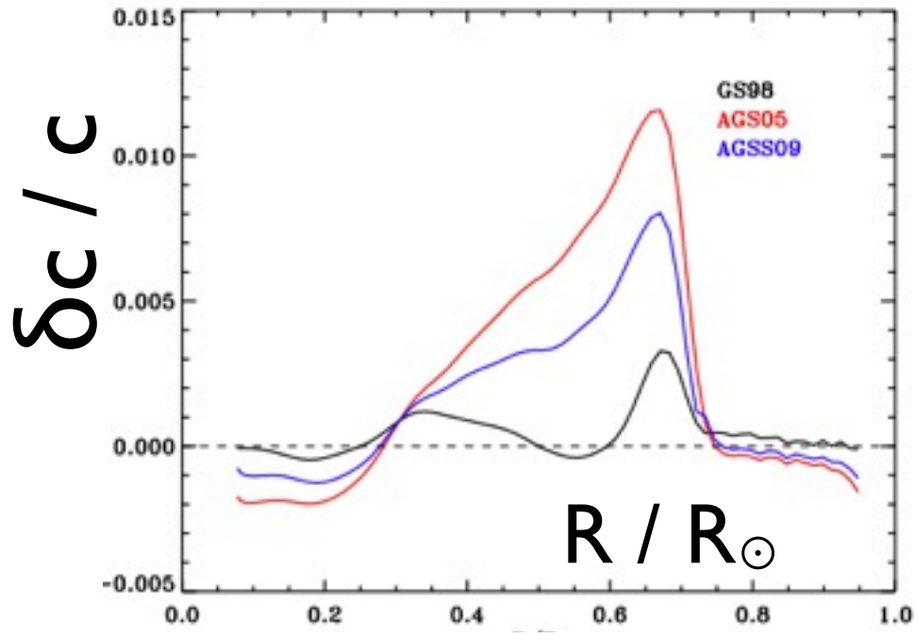

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3) Measure Day/Night asymmetry:
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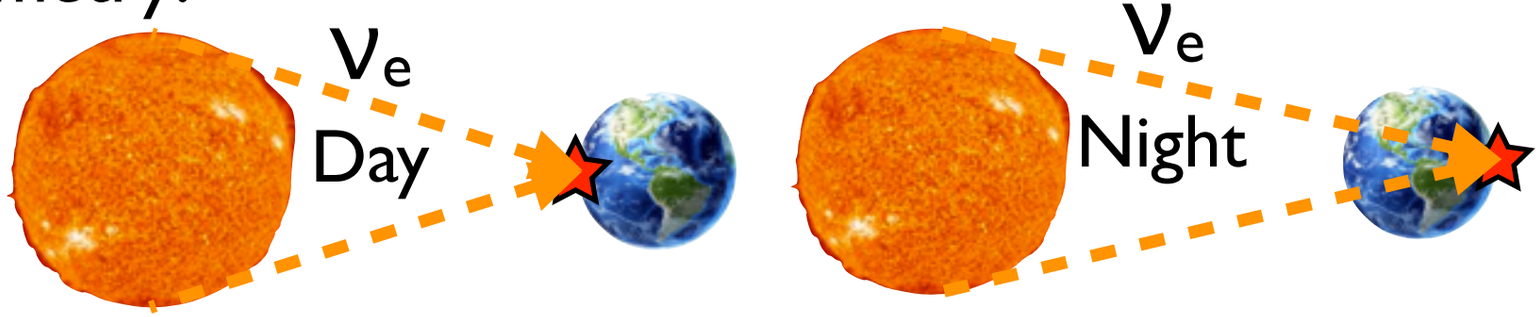

"Salty Water Detectors"

- Load large water Cherenkov detector with e.g. ^{7}Li for CC interaction

"Salty water Cherenkov detectors" W.C. Haxton PRL 76 (1996) 10

- Water Cherenkov ⇒ water-based LS

Nucl. Inst. & Meth. A660 51 (2011)

- Consider other isotopes?

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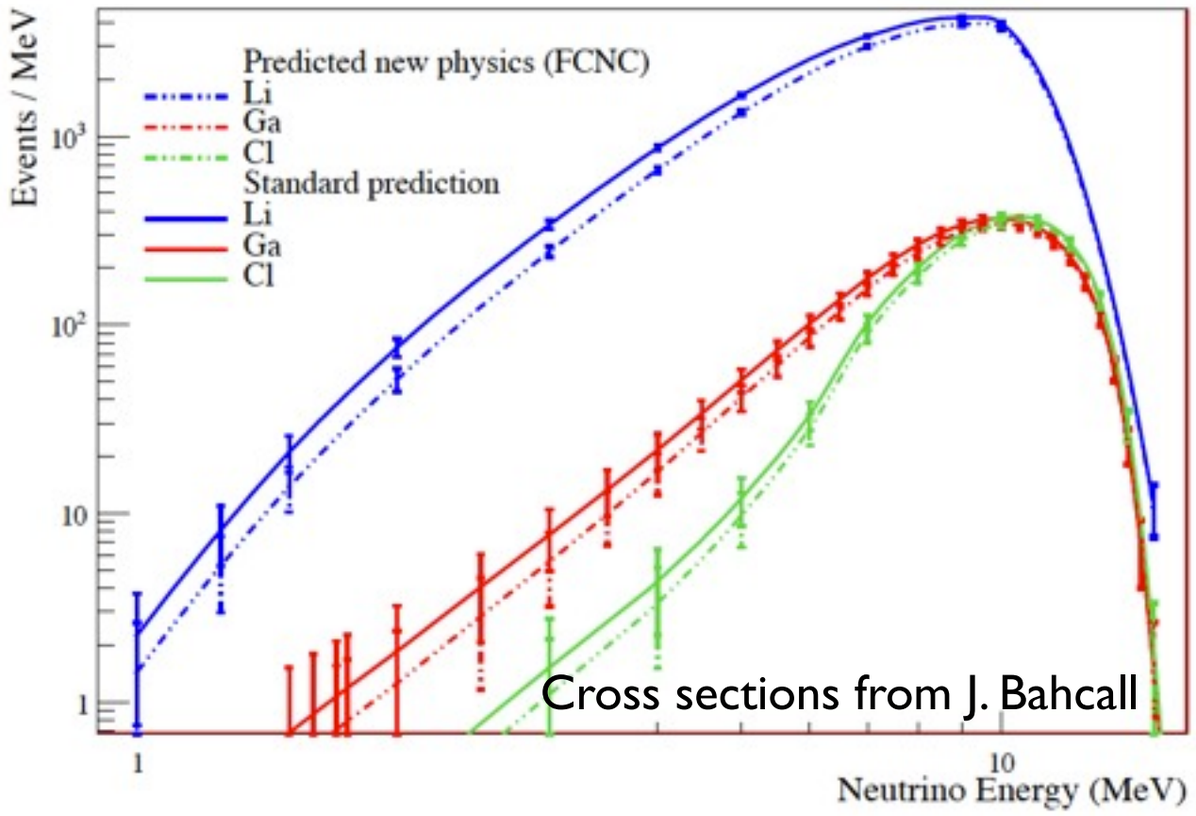

Cross sections from J. Bahcall

arXiv:1409.5864

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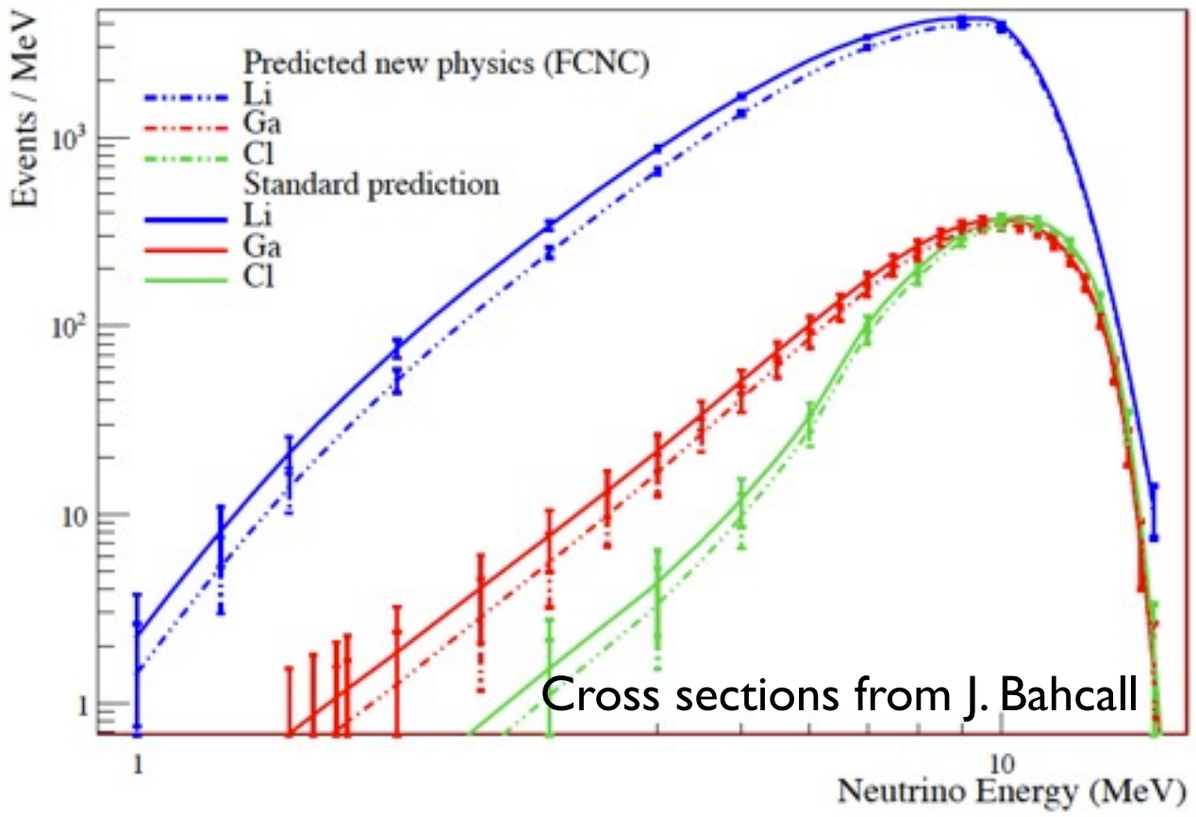

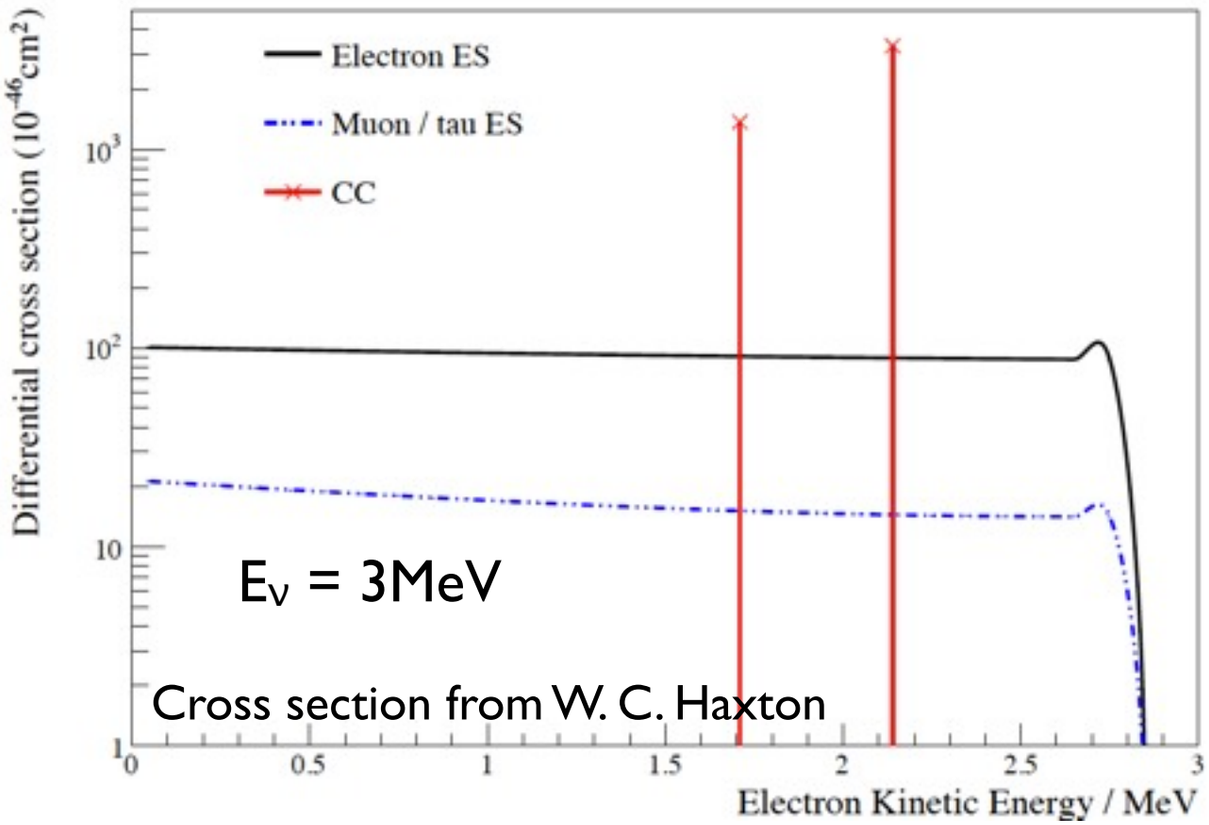

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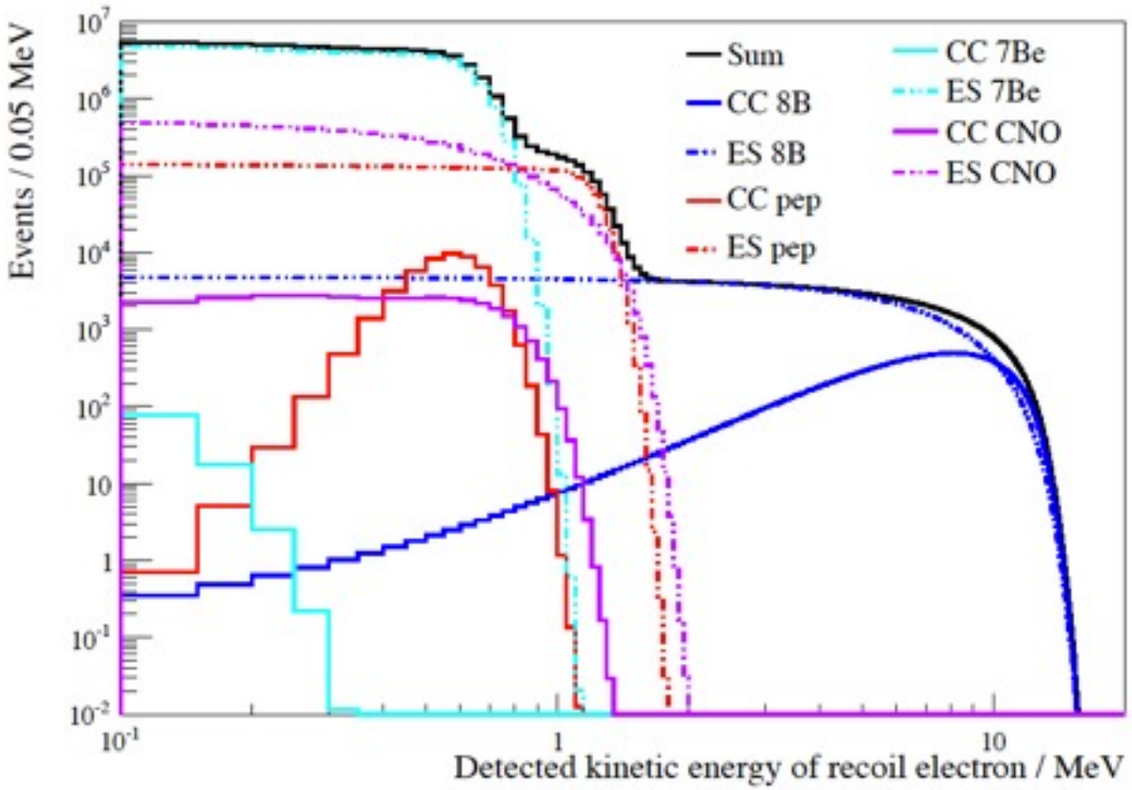
ASDC Sensitivity

Unprecedented low-energy statistics (ES)



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1% ^{7}Li by mass

Assumes 100 pe/MeV

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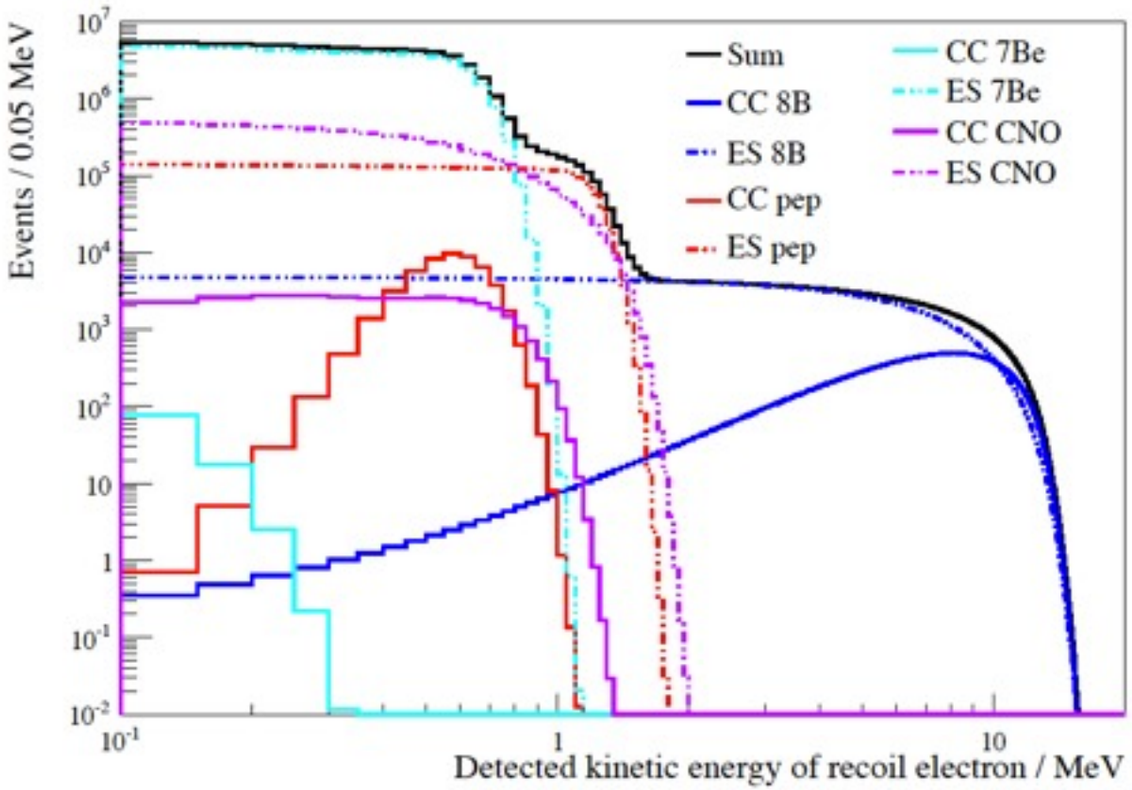

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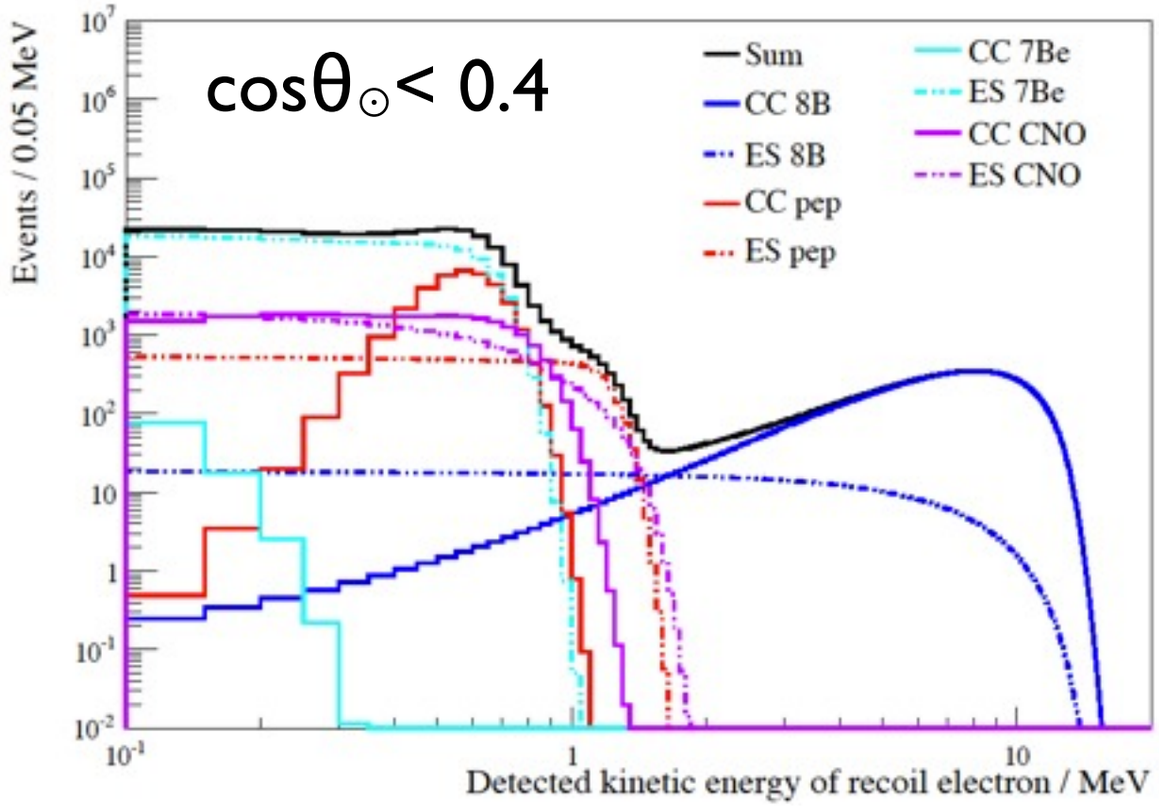

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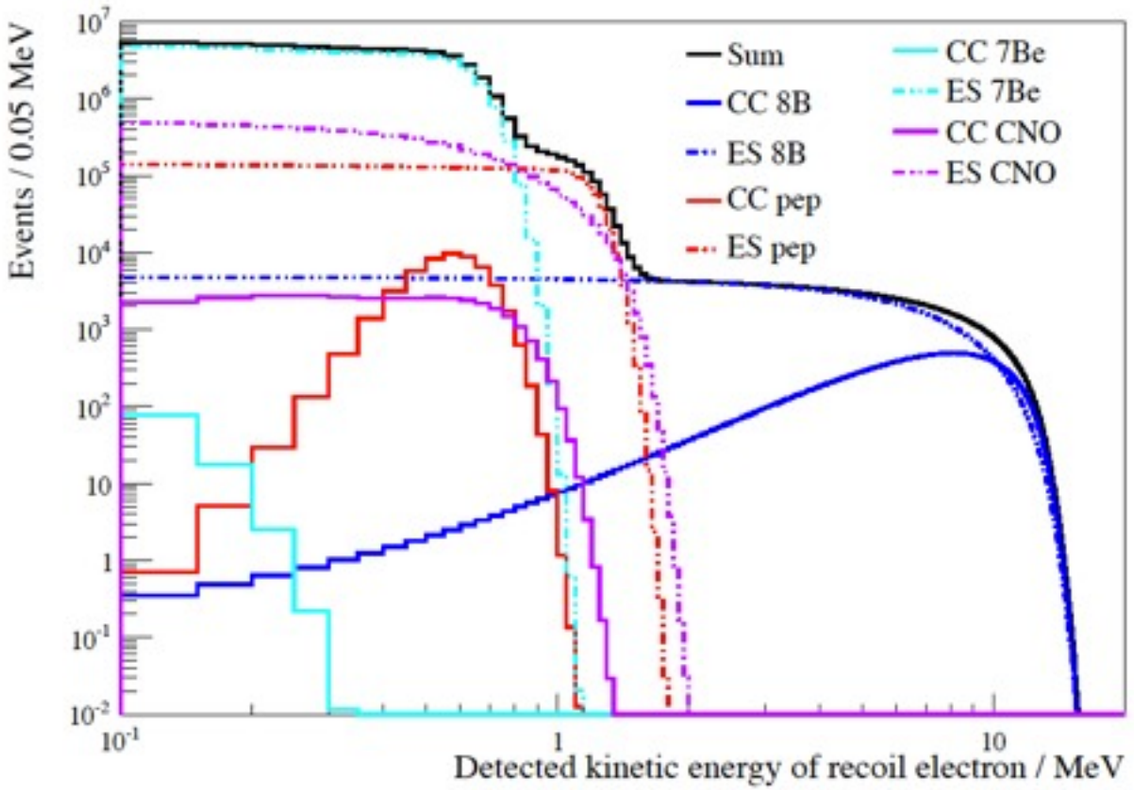

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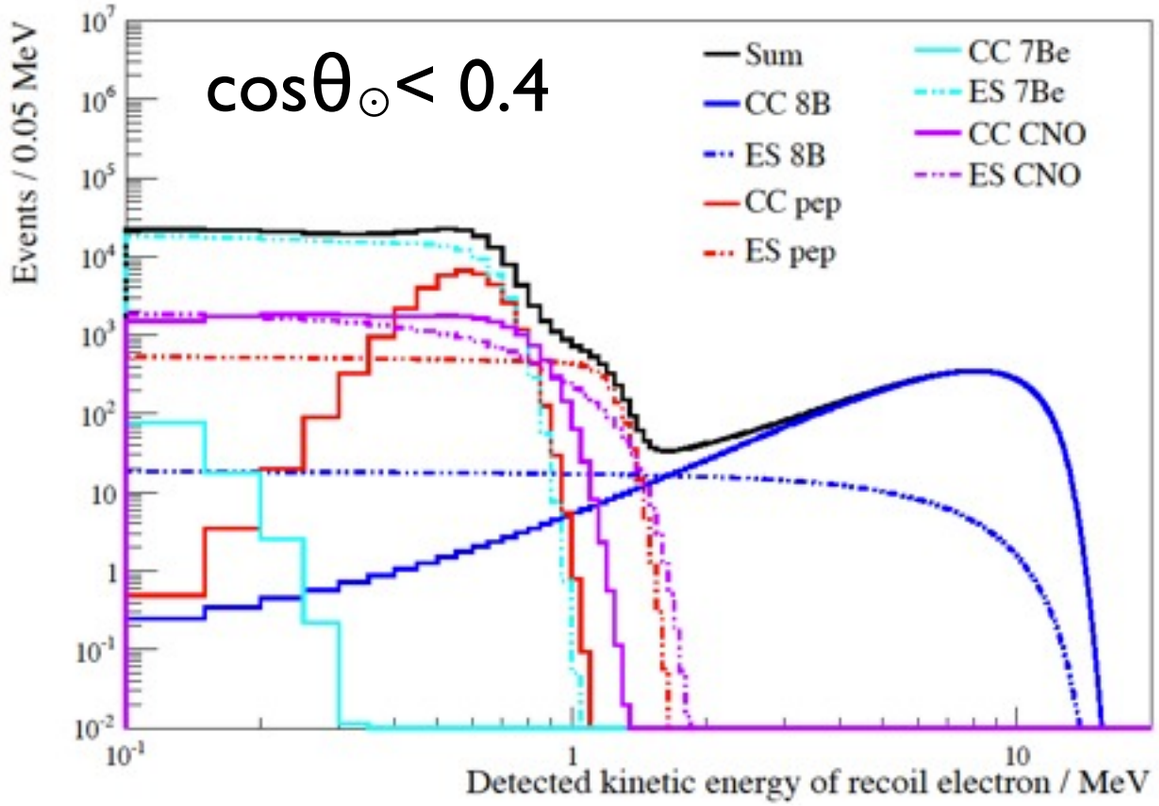
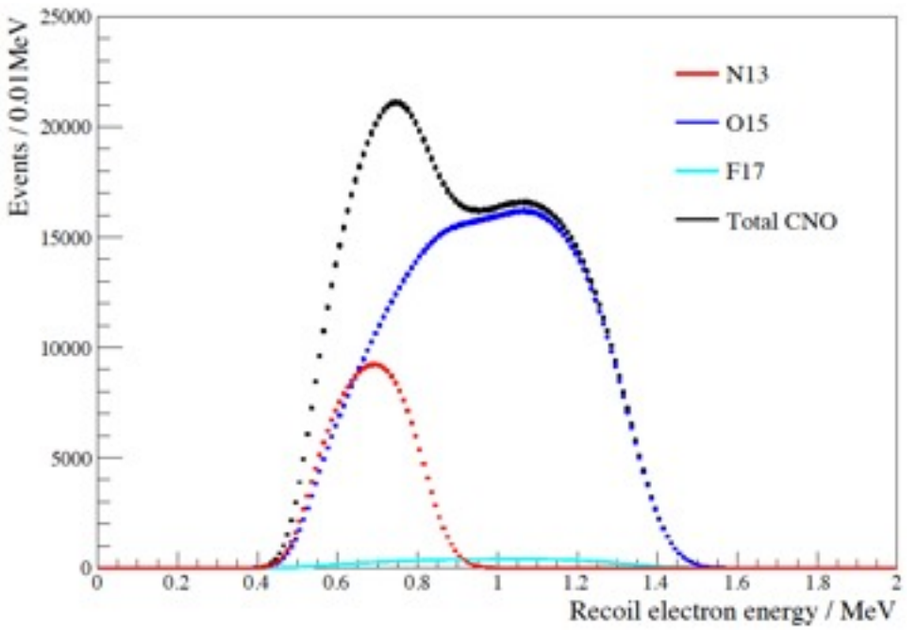
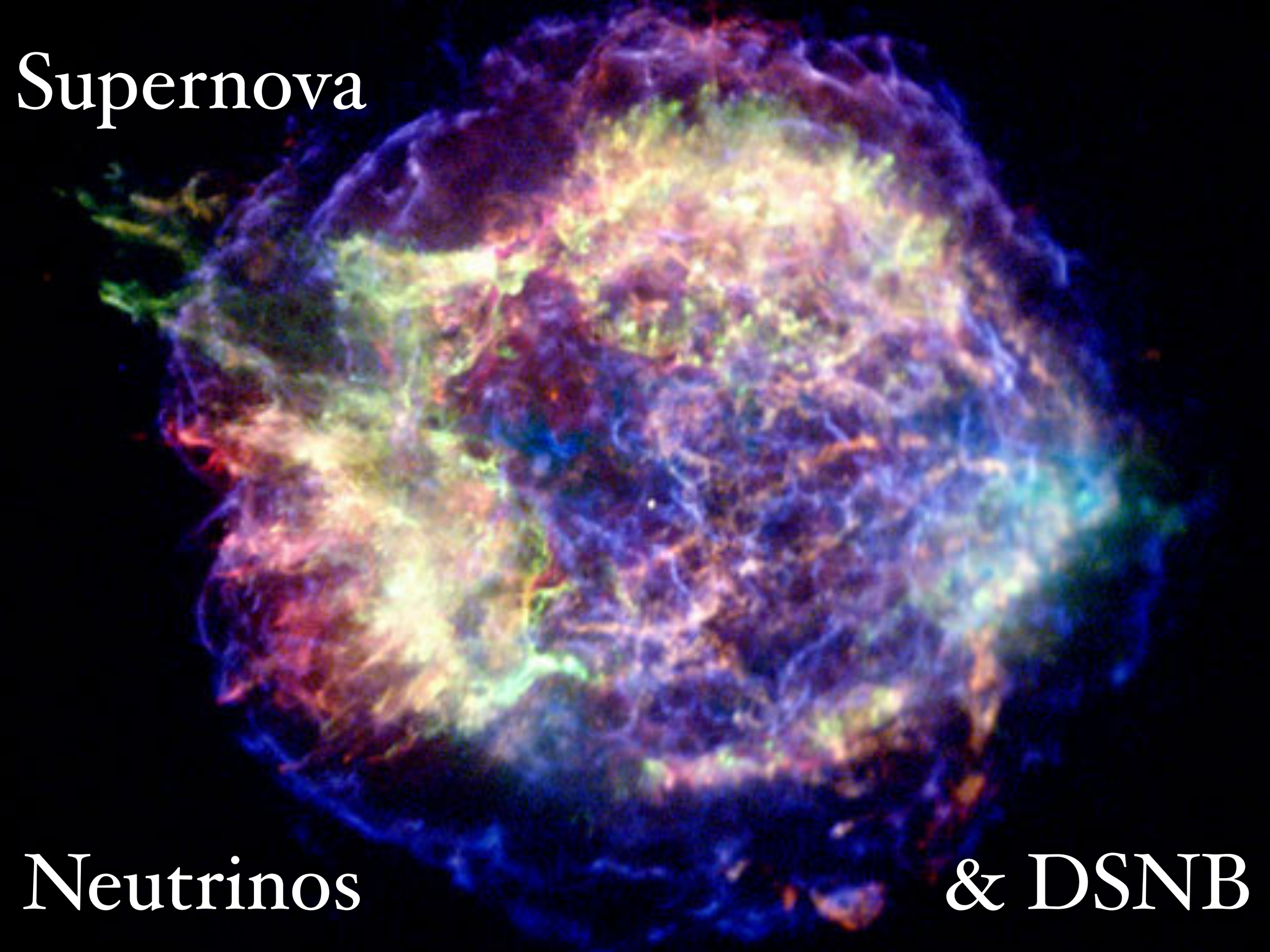




Separation of CNO constituent components via shape analysis..?

All figs from arXiv:1409.5864

Supernova



Neutrinos & DSNB

Supernova Burst ν in ASDC

Neutrino Reaction	Percentage of Total Events	Type of Interaction
$\overline{\nu}_e + p \rightarrow n + e^+$	88%	Inverse Beta
$\nu_e + e^- \rightarrow \nu_e + e^-$	1.5%	Elastic Scattering
$\overline{\nu}_e + e^- \rightarrow \overline{\nu}_e + e^-$	<1%	Elastic Scattering
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$\nu_e + {}^{16}O \rightarrow e^- + {}^{16}F$	2.5%	Charged Current
$\overline{\nu}_e + {}^{16}O \rightarrow e^+ + {}^{16}N$	1.5%	Charged Current
$\nu_x + {}^{16}O \rightarrow \nu_x + O^*/N^* + \gamma$	5%	Neutral Current

Supernova Burst ν in ASDC

- ~12k events for 10kpc SN (50kt volume)

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Supernova Burst ν in ASDC

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- ~90% events are IBD

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- ES of ν on p (requires high light yield)
  - Scint. differentiates from primary 14C bkg

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- High light yield allows n tag : 2.2 MeV γ from ^{1}H
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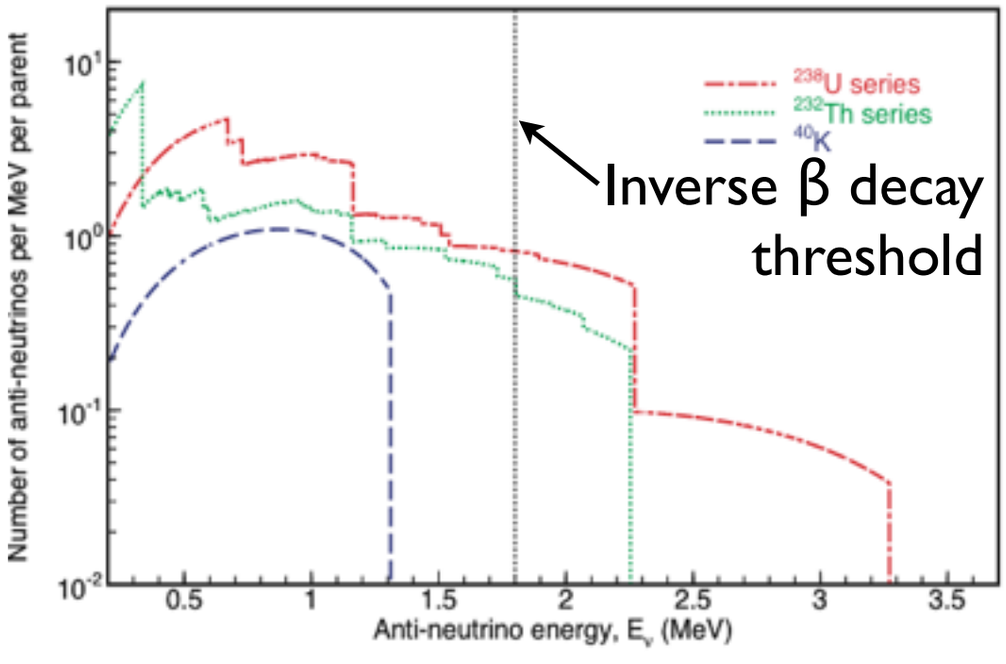
- Higher detection efficiency than Gd-H_2O due to high scint. yield
- Low NC background
  - Atmos. ν + C → n + fragments
  - Prompt recoil + delayed n capture mimics signal
  - WbLS allows separation of nuc/e recoil using Cherenkov signal
  - Plus distinct Cherenkov hit patten (single e+ vs multiple γs)

Geo Neutrinos

Electron antineutrinos from U, Th, K decay in the Earth

Assay the Earth by
looking at the
"antineutrino glow"



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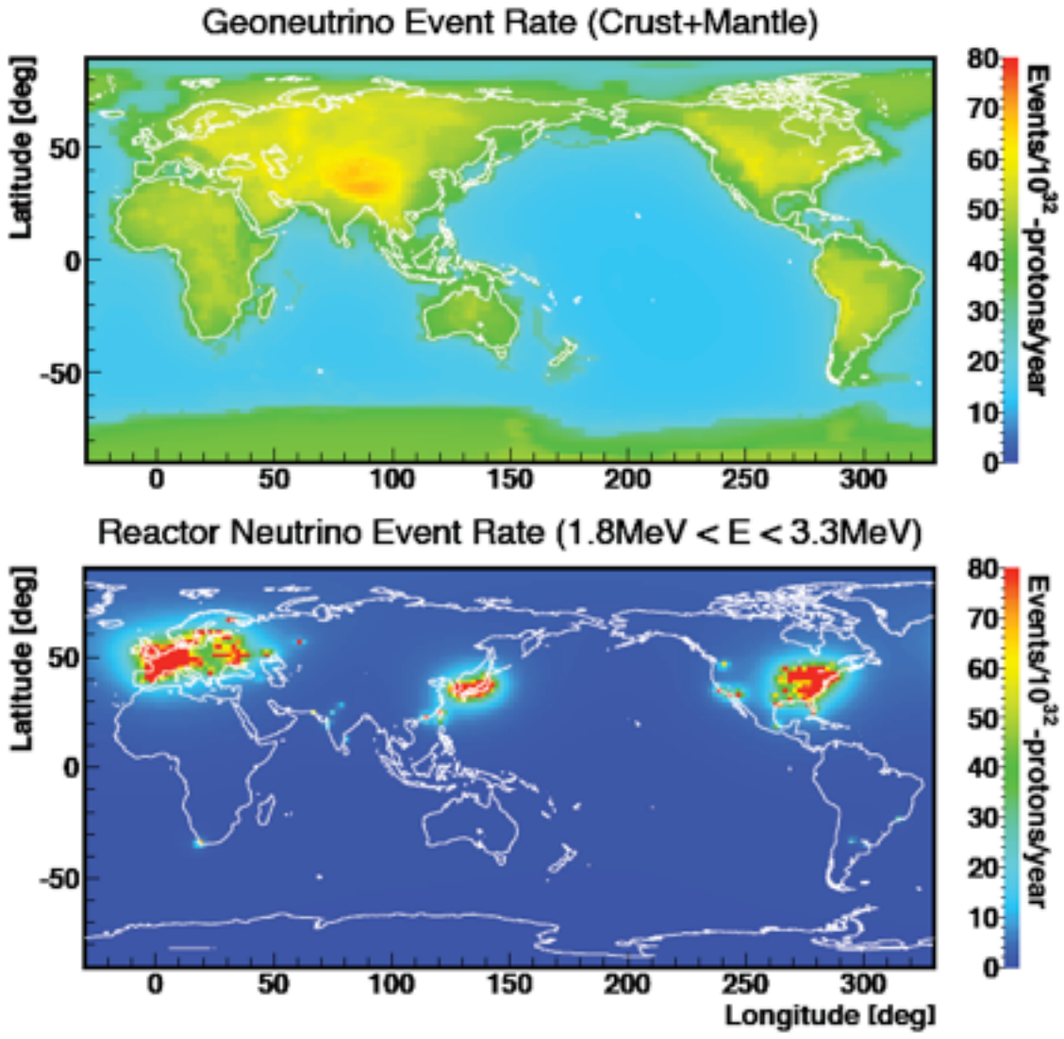
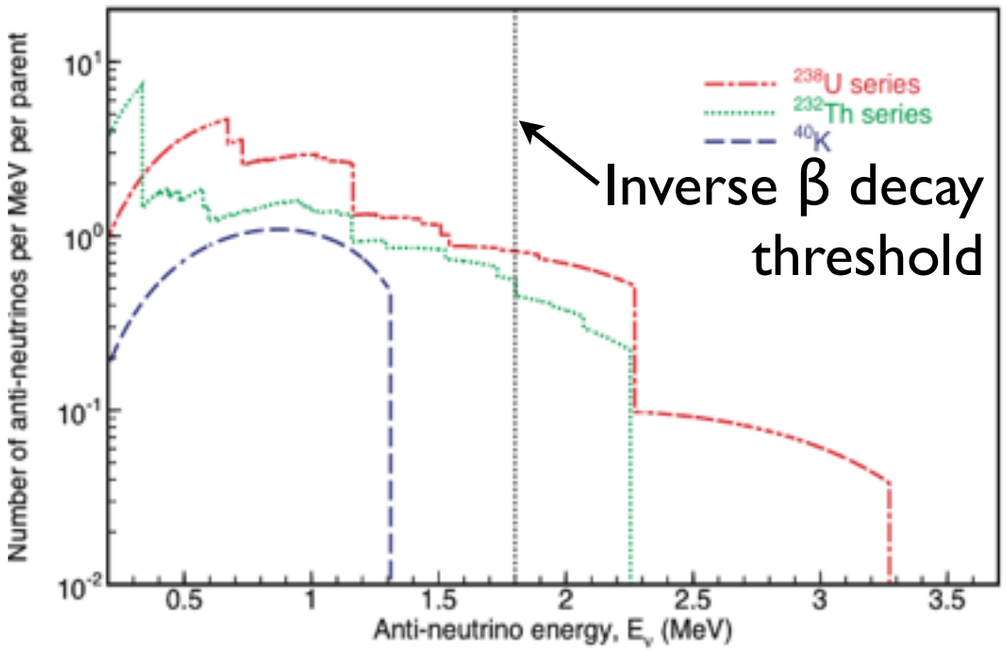


Image: S. Enomoto



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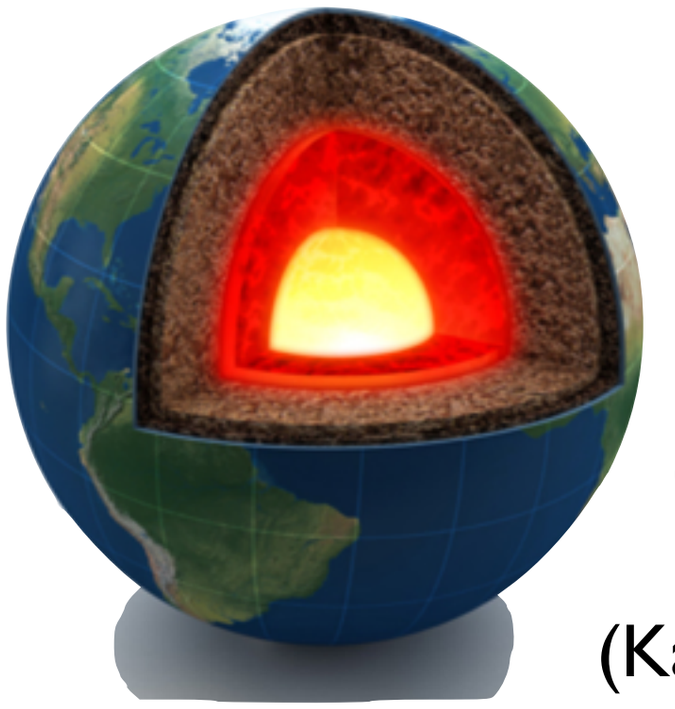

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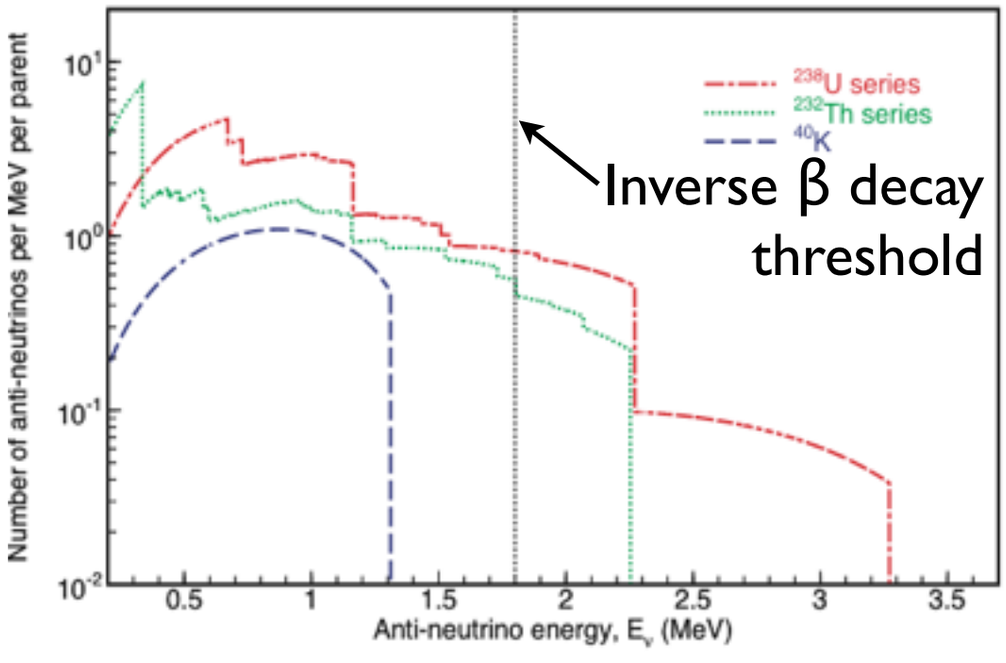

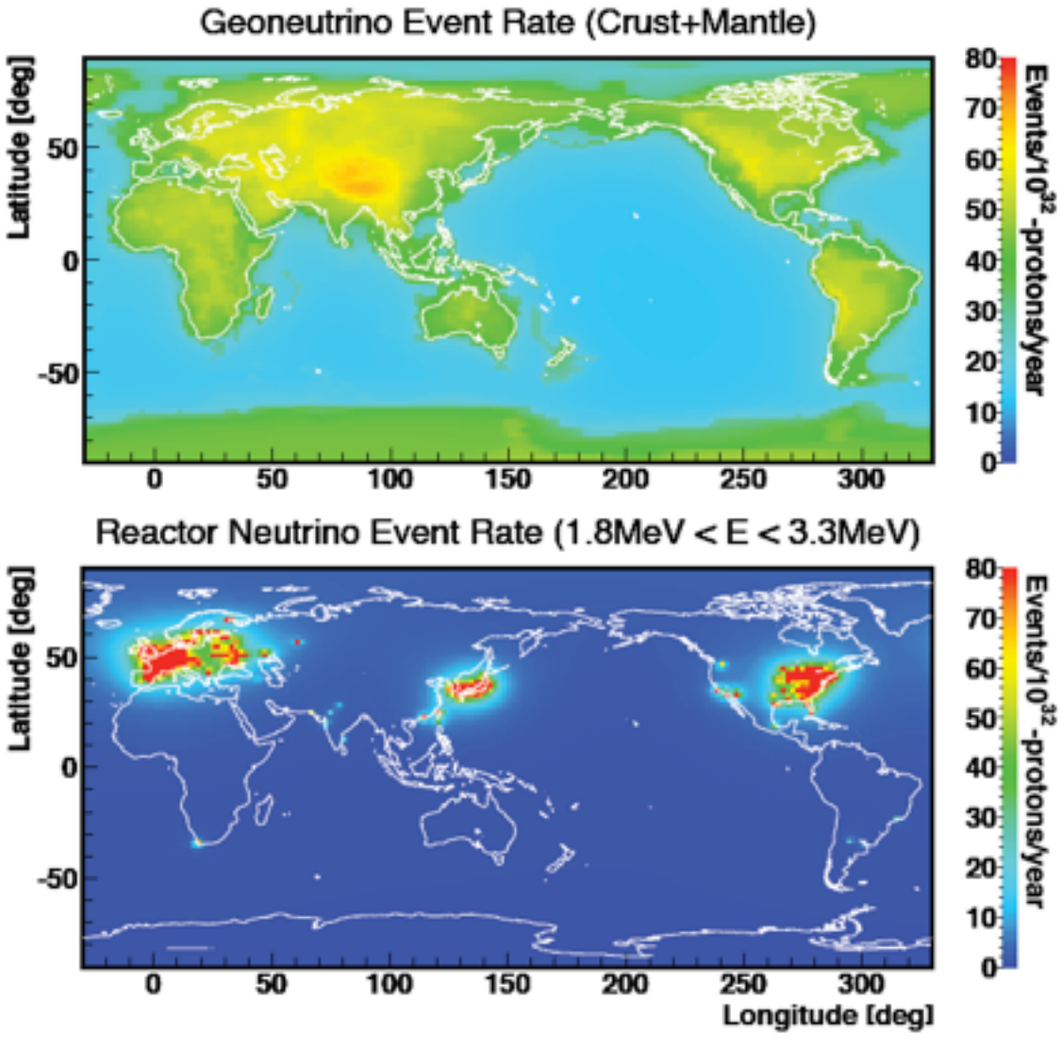

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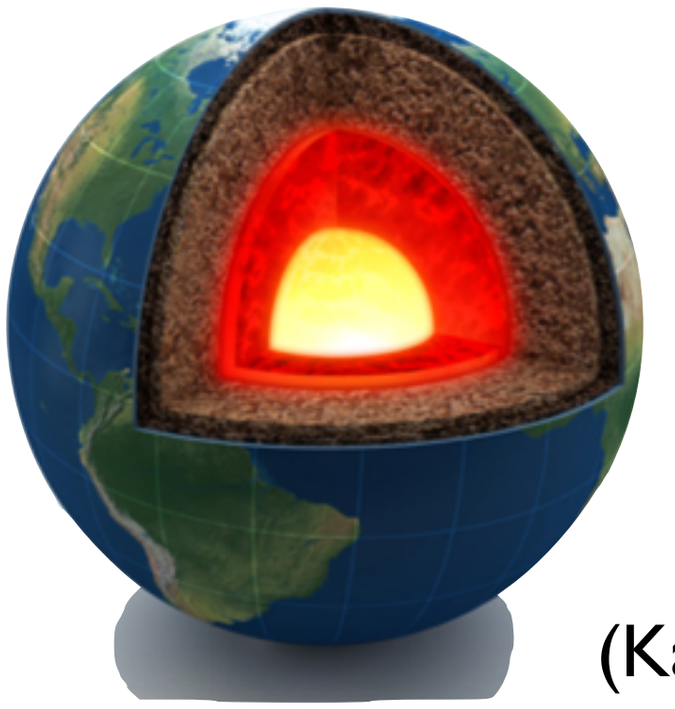

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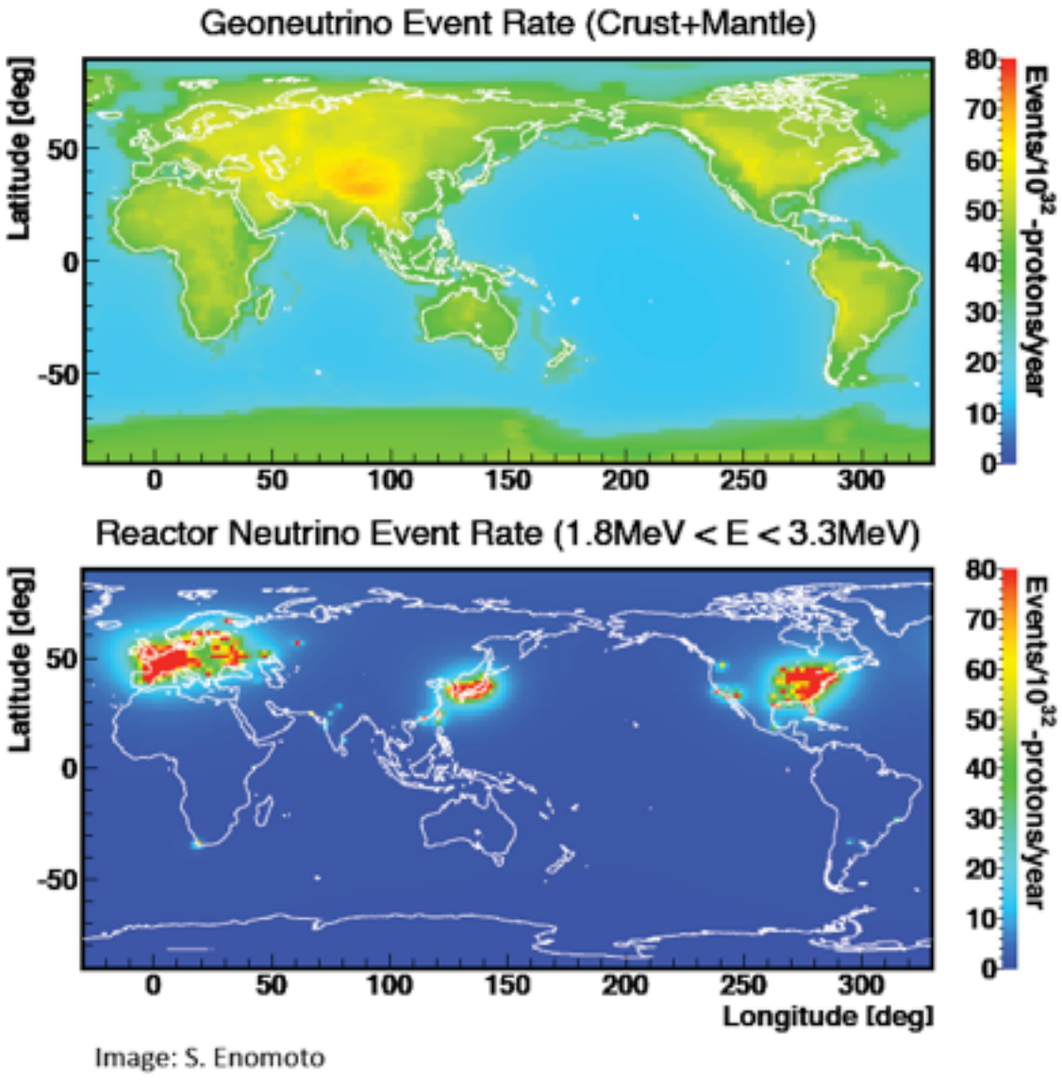

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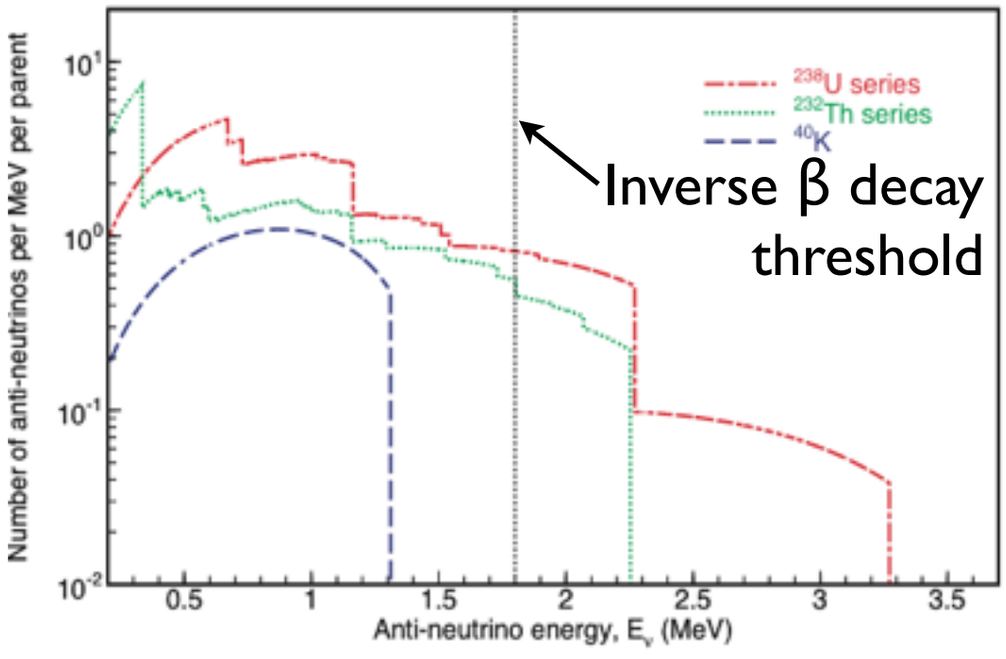


ASDC:

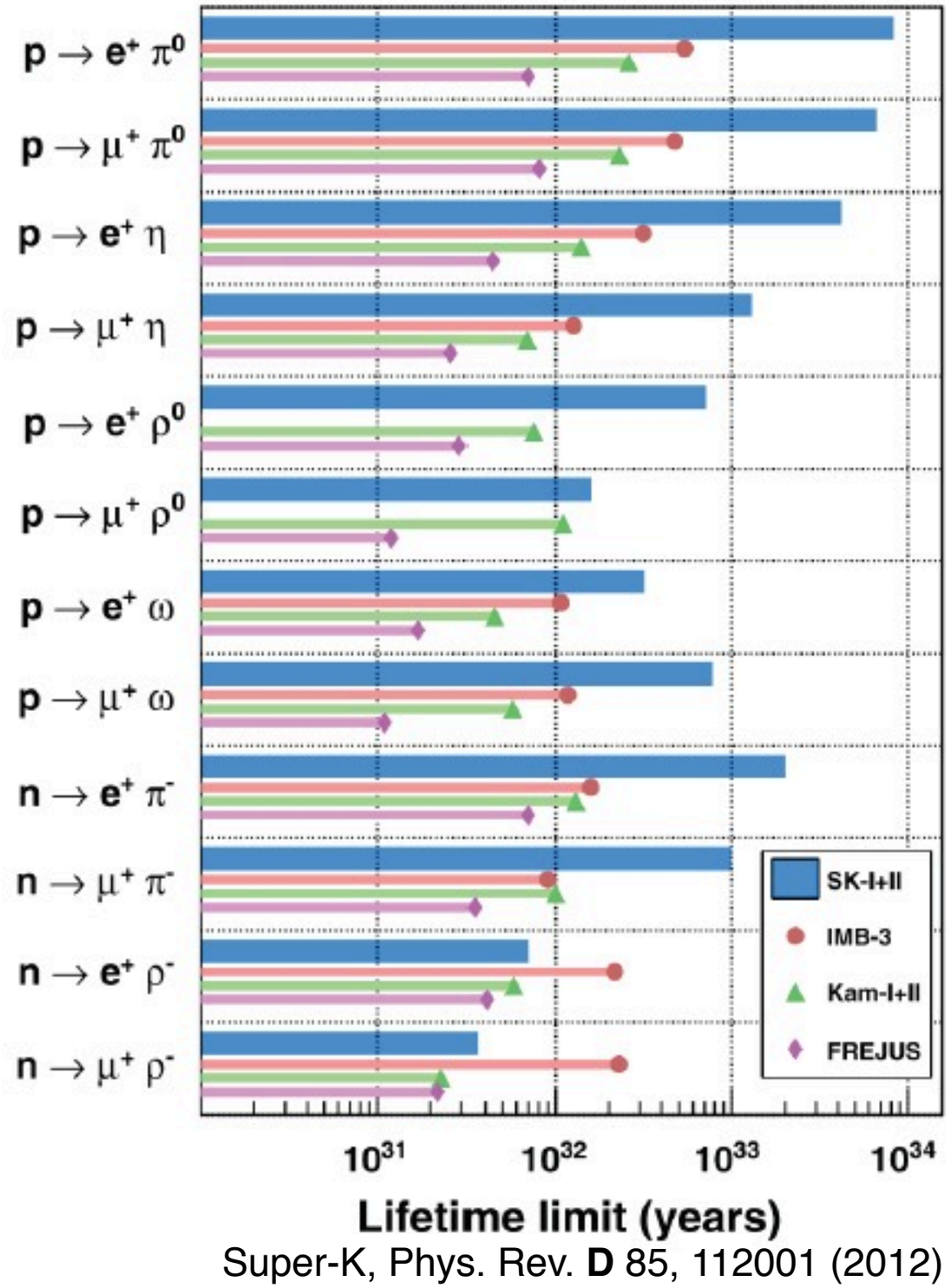
Large statistics

Options for isotopes loading: Gd, 6Li, B

Fast timing ⇒ directionality

Nucleon Decay

Limits on lepton+meson modes



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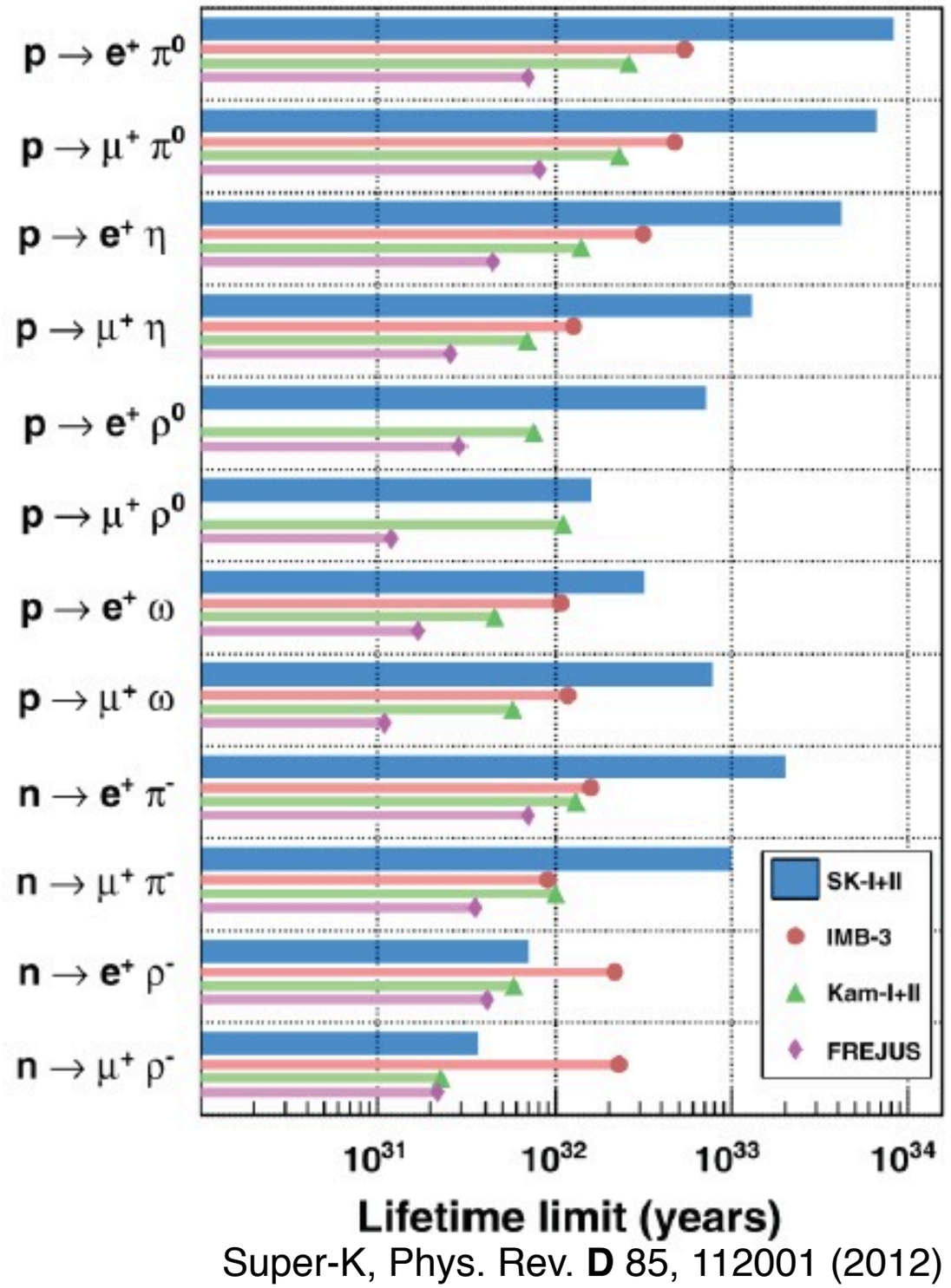

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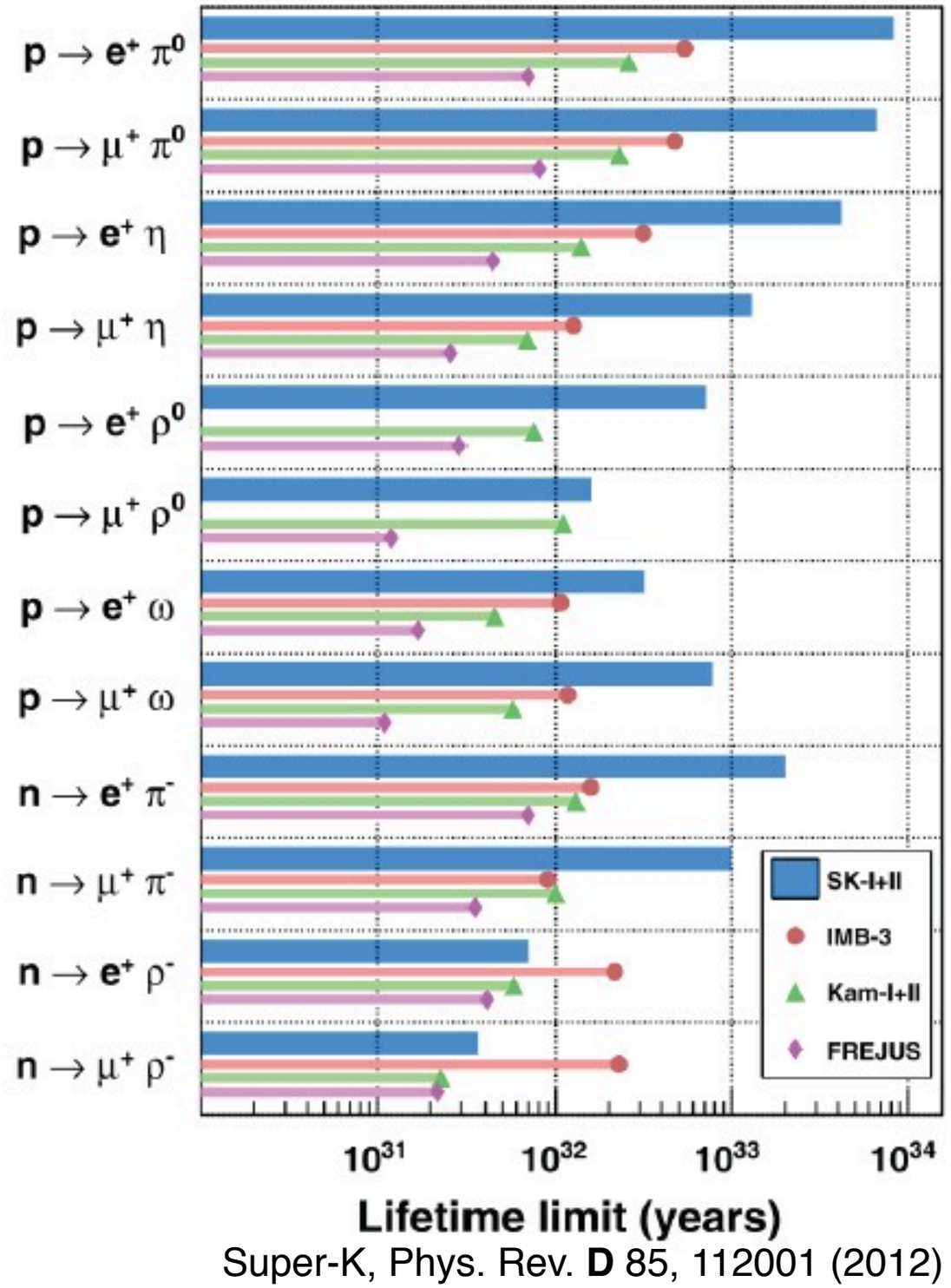

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- Plus other theories e.g. extra Ds predict $n \to 3\nu$
  Look for daughter de-excitation

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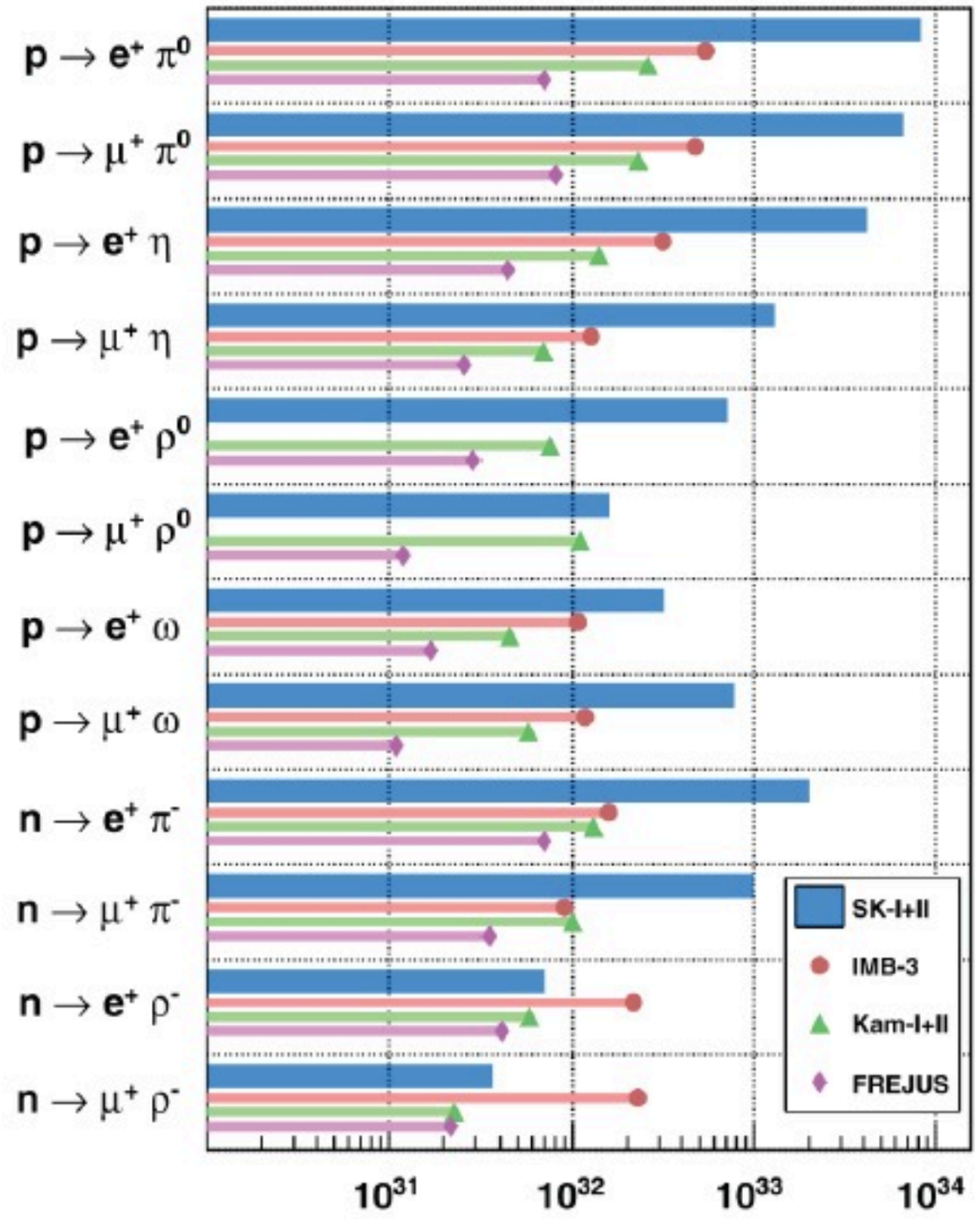

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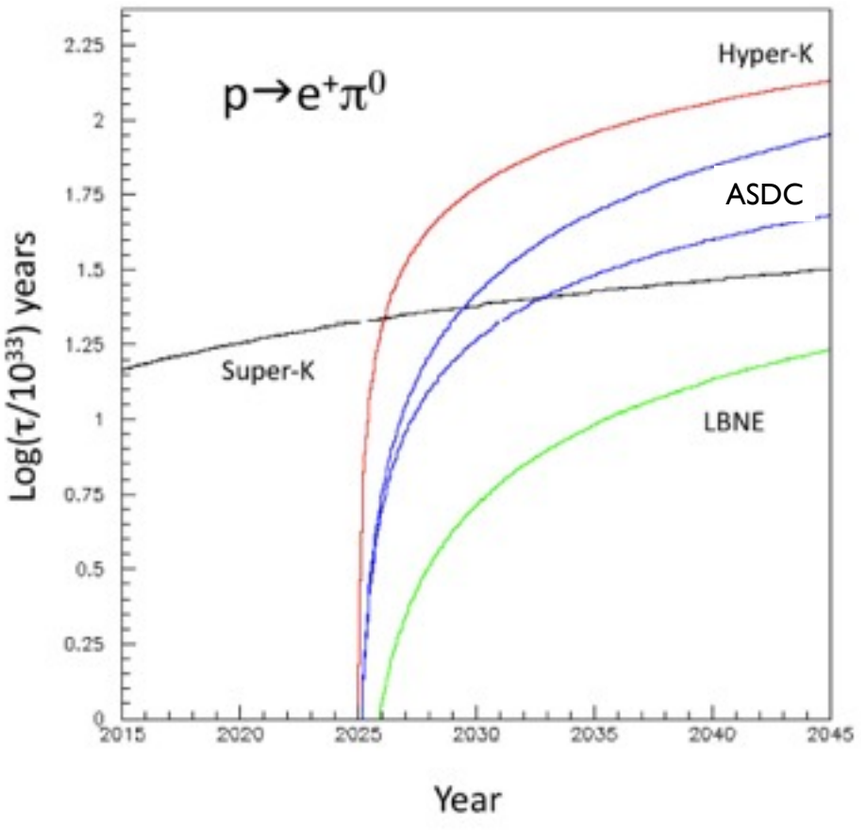

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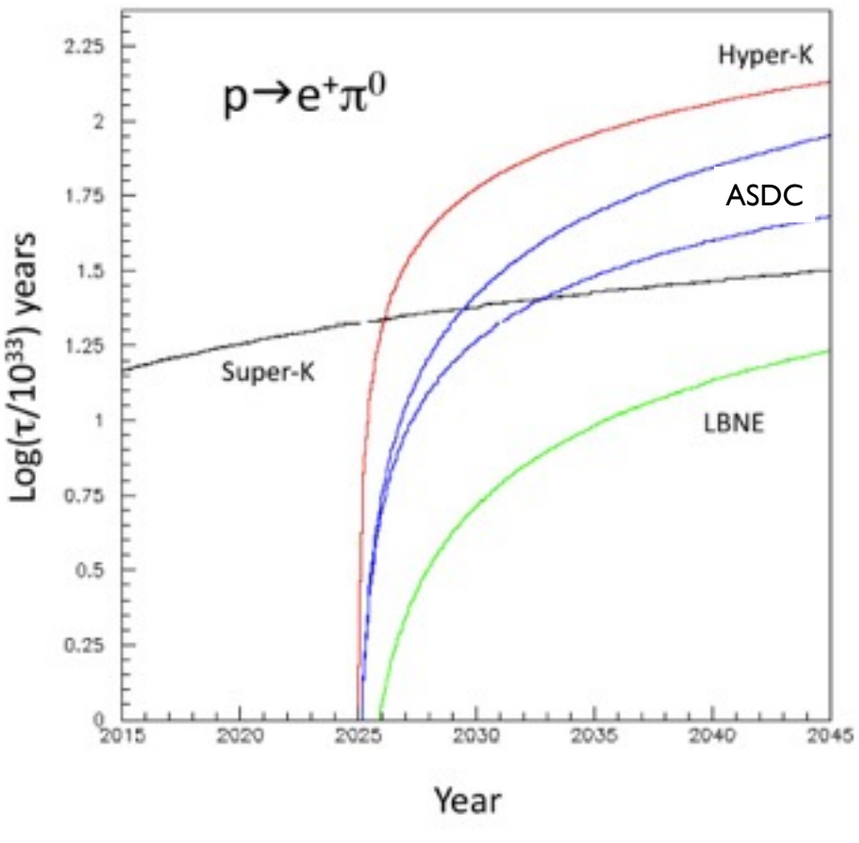

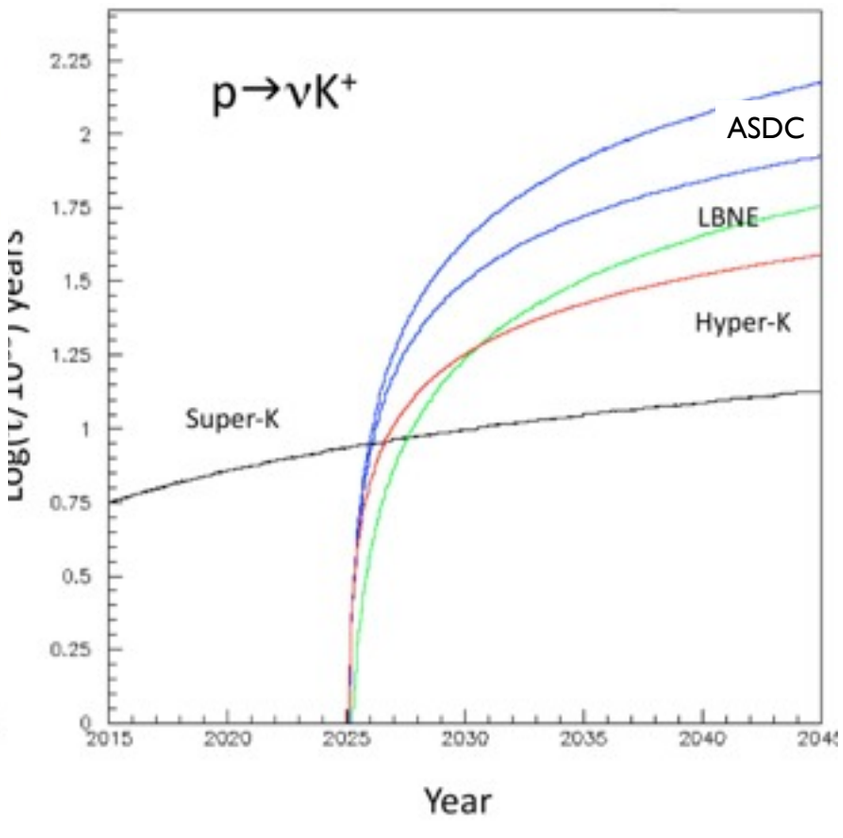

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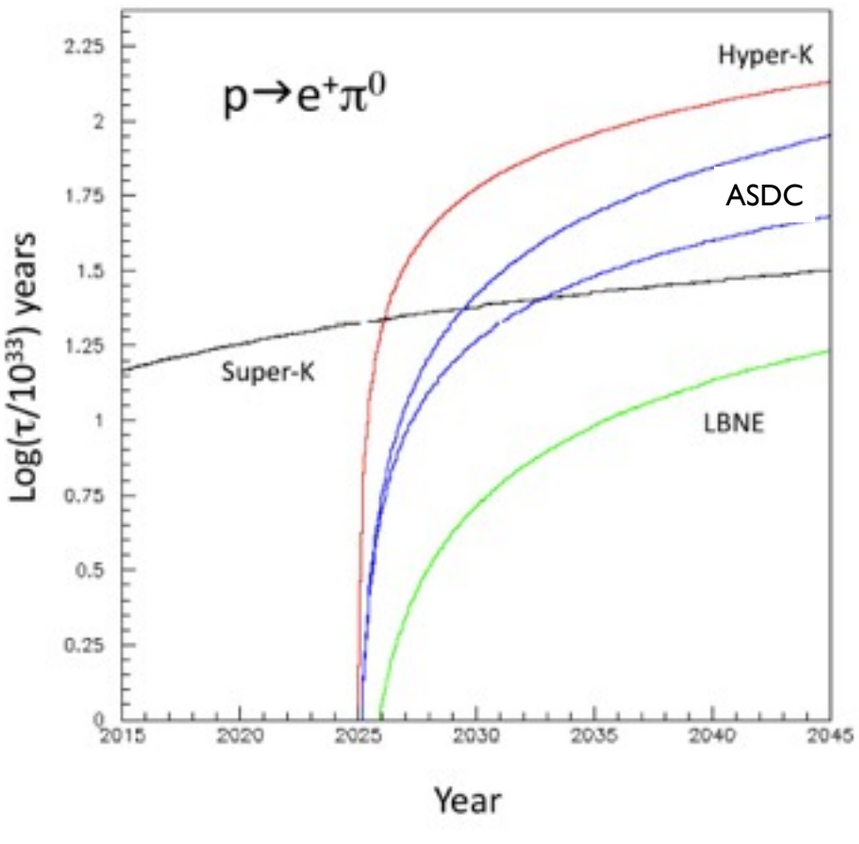

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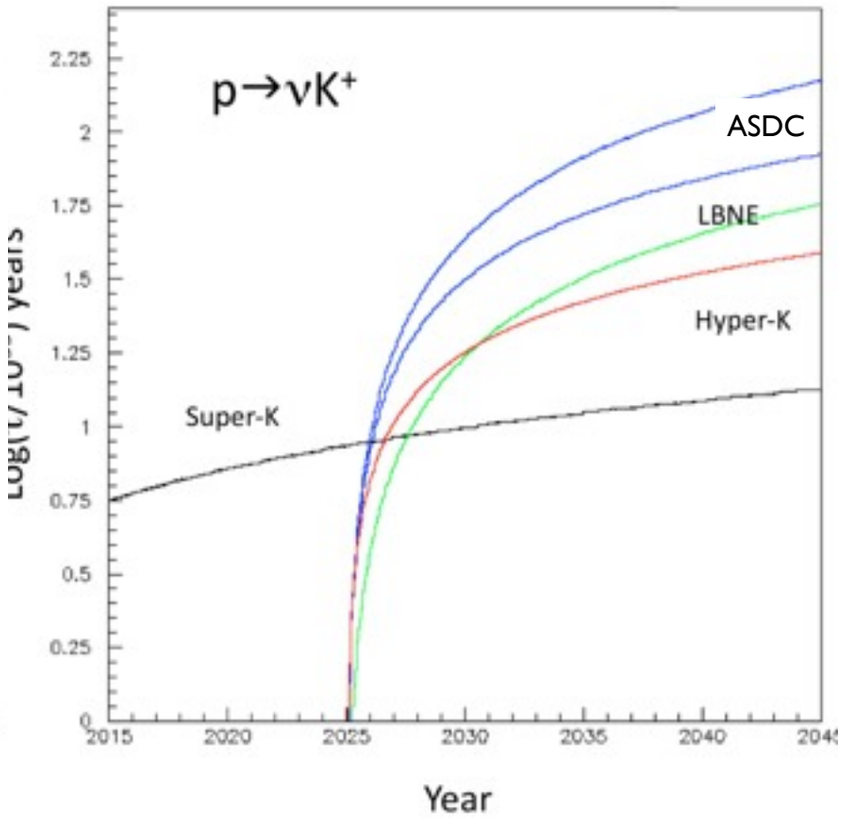

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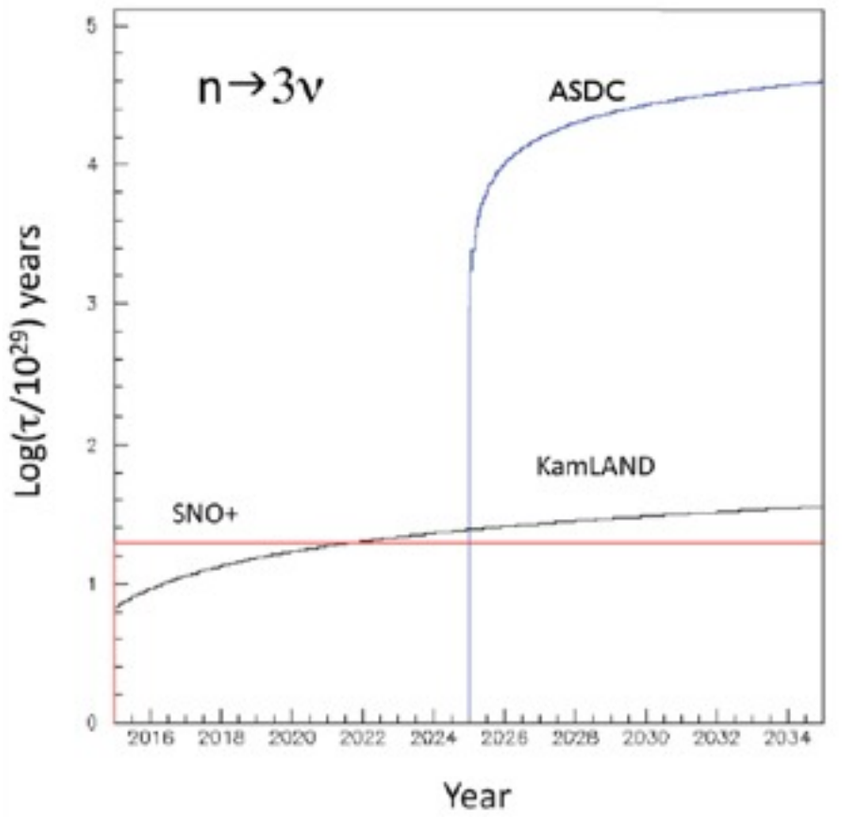

Deep, low threshold
Directionality : solar
n tag : reactor

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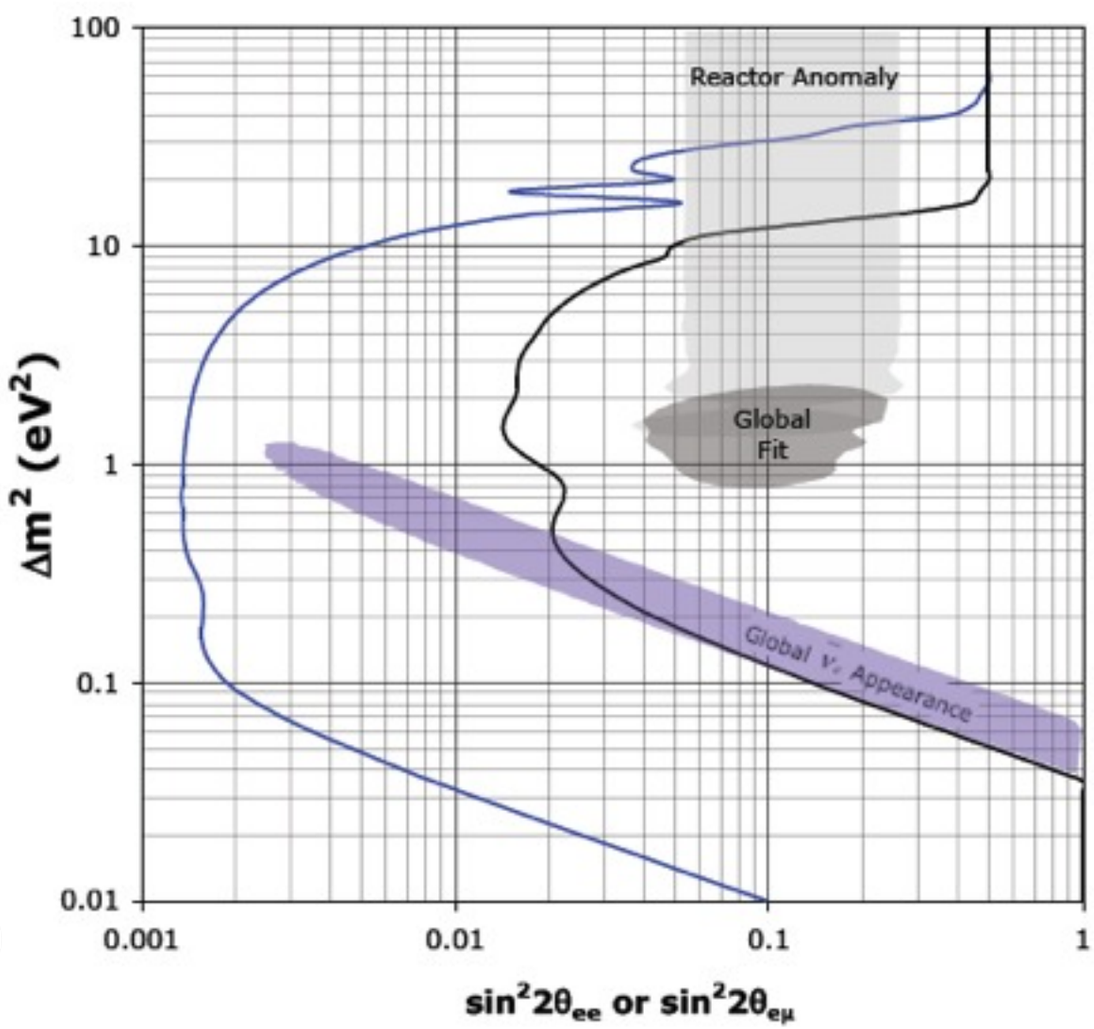

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6. Isotope loading — *0νββ, solar, n tagging etc*

Planned Demonstrations

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LBNL	bench top	WbLS	1, 2a, 2b, 3, 6	Winter 2014
BNL	1 ton	WbLS	1, 2b, 3, 4, 6	Summer 2015
WATCHMAN-II	1 kton	WbLS	1, 2a, 2b, 3, 4, 5, 6	2019?

ASDC "Interest Group"

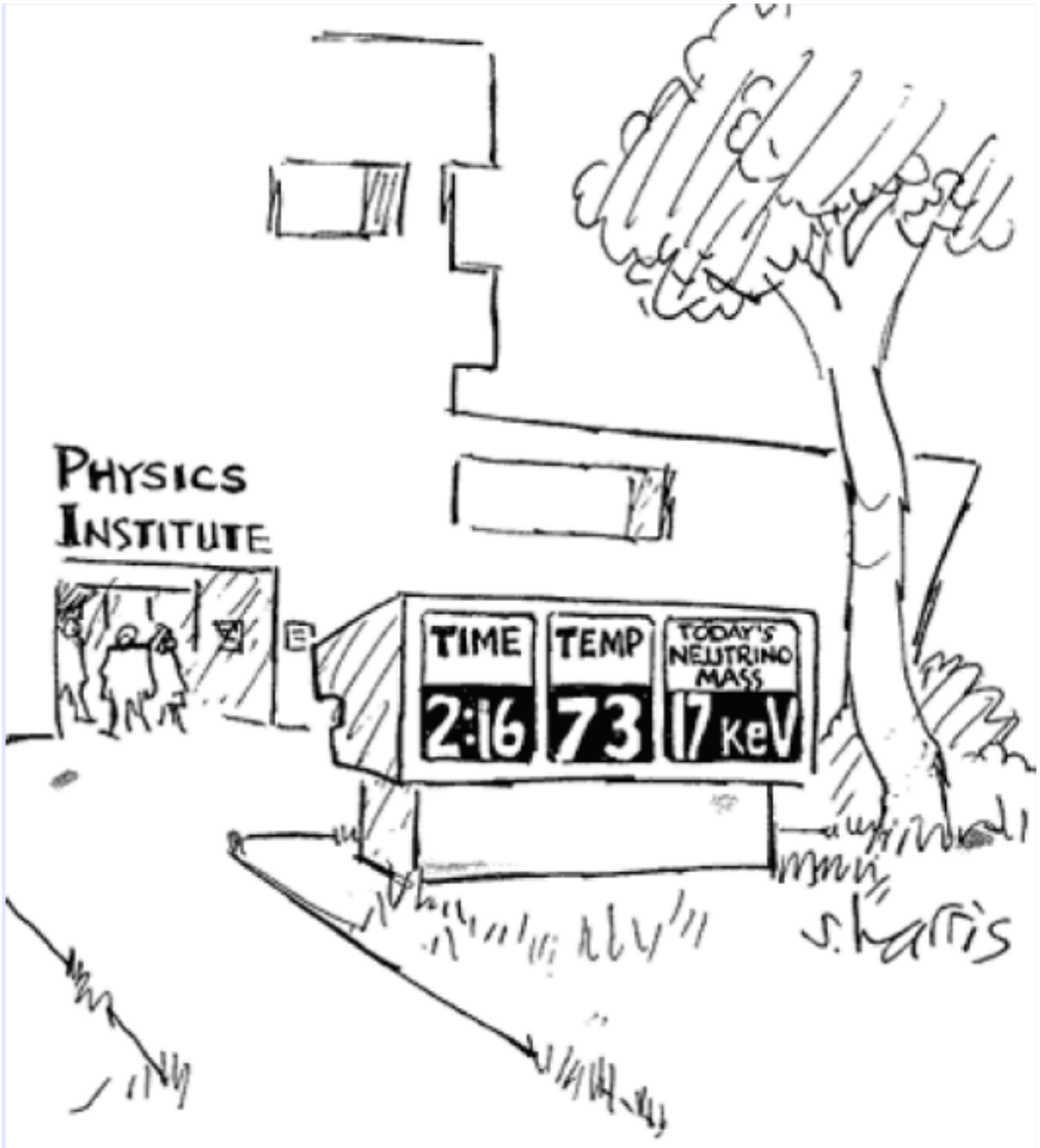
- Workshop - May 17/18 (LBNL): 27 participants, 17 talks
- Concept paper - arXiv:1409.5864
- 50 authors (potential PIs), 23 institutions (US and Germany)
  Borexino, LBNE, KamLAND, SNO, Double CHOOZ, SNO+, Daya Bay, LENA, KamLAND-Zen, MiniBOONE, Super-Kamiokande, WATCHMAN, ANNIE, T2K....
- Large international community with interest and experience
- New participation welcome contact G. D. Orebi Gann, B. Svoboda, E. Blucher, J. R. Klein

Advanced Scintillator Detector Concept (ASDC):
A Concept Paper on the Physics Potential of Water-Based Liquid Scintillator

J. R. Alonso,[1] N. Barros,[2] M. Bergevin,[3] A. Bernstein,[4] L. Bignell,[5] E. Blucher,[6] F. Calaprice,[7] J. M. Conrad,[1] F. B. Descamps,[8] M. V. Diwan,[5] D. A. Dwyer,[8] S. T. Dye,[9] A. Elagin,[6] P. Feng,[10] C. Grant,[3] S. Grullon,[2] S. Hans,[5] D. E. Jaffe,[5] S. H. Kettell,[5] J. R. Klein,[2] K. Lande,[2] J. G. Learned,[11] K. B. Luk,[8,12] J. Maricic,[11] P. Marleau,[10] A. Mastbaum,[2] W. F. McDonough,[13] L. Oberauer,[14] G. D. Orebi Gann*,[8,12,†] R. Rosero,[5] S. D. Rountree,[15] M. C. Sanchez,[16] M. H. Shaevitz,[17] T. M. Shokair,[18] M. B. Smy,[19] A. Stahl,[20] M. Strait,[6] R. Svoboda,[3] N. Tolich,[21] M. R. Vagins,[19] K. A. van Bibber,[18] B. Viren,[5] R. B. Vogelaar,[15] M. J. Wetstein,[6] L. Winslow,[1] B. Wonsak,[22] E. T. Worcester,[5] M. Wurm,[23] M. Yeh,[5] and C. Zhang[5]

The ASDC

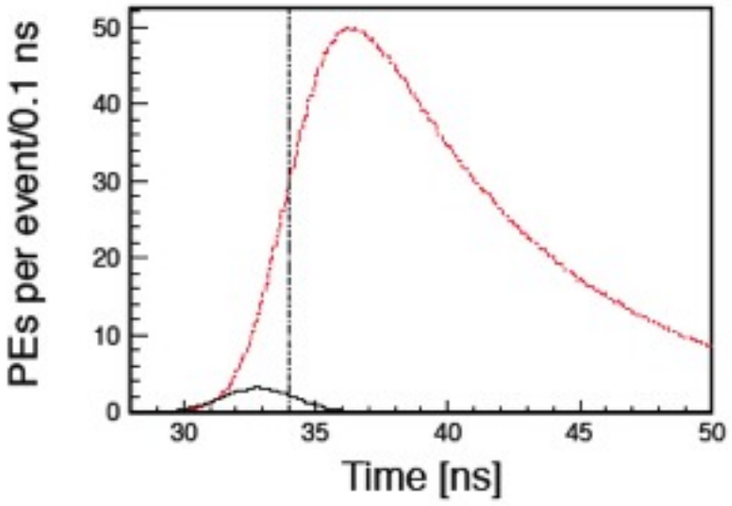
- **Broad program of compelling science**
- **Unique opportunity to combine conventional neutrino physics with rare-event searches in a single, large-scale detector**
- **Flexibility to adapt to new directions in the scientific program as the field evolves**
- **Unique instrument of discovery**



Thank you for your attention

Back up

Photon detection



Simulation with
1.3 ns timing of
standard PMT

Cherenkov (prompt, scarce)

Scintillation (delayed, abundant, tunable)

C. Aberle et al, JINST 9 P06012 (2014)

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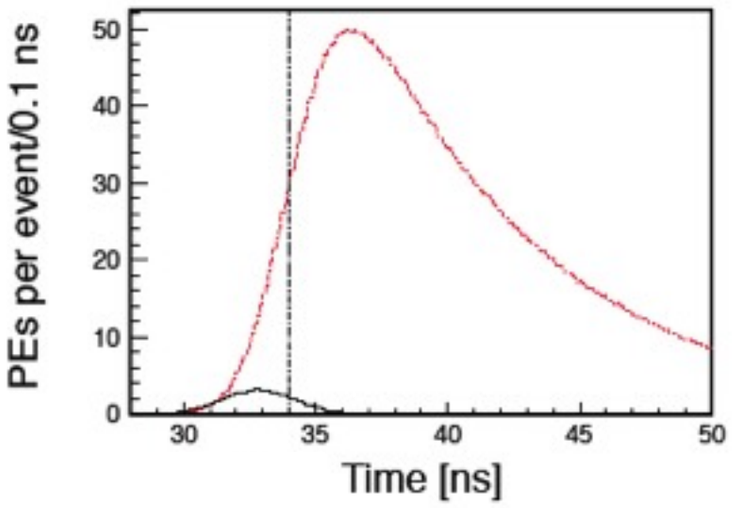

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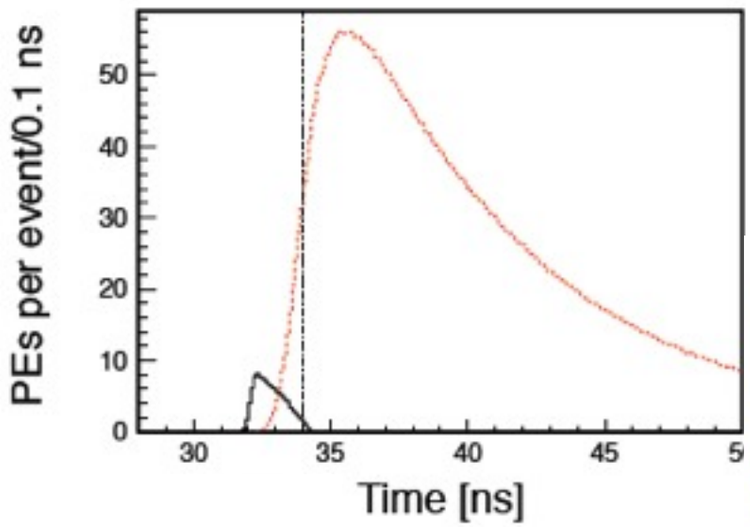
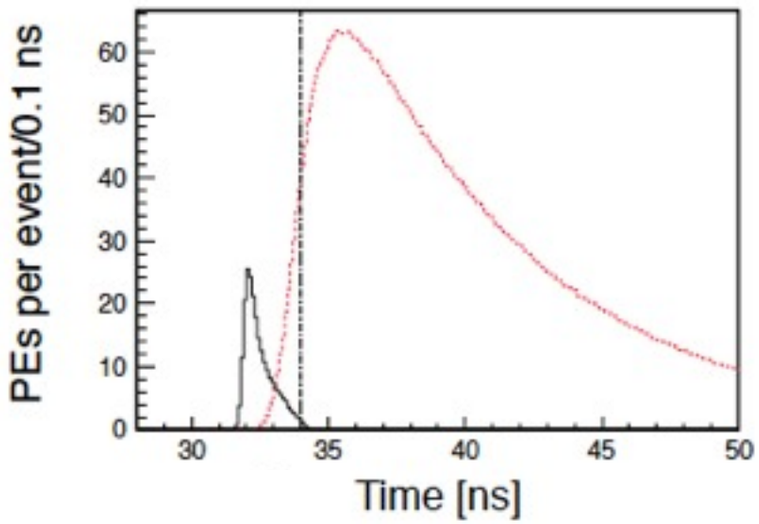


Assume 0.1 ns time resolution
e.g. LAPPDs
OR red-sensitive PMT



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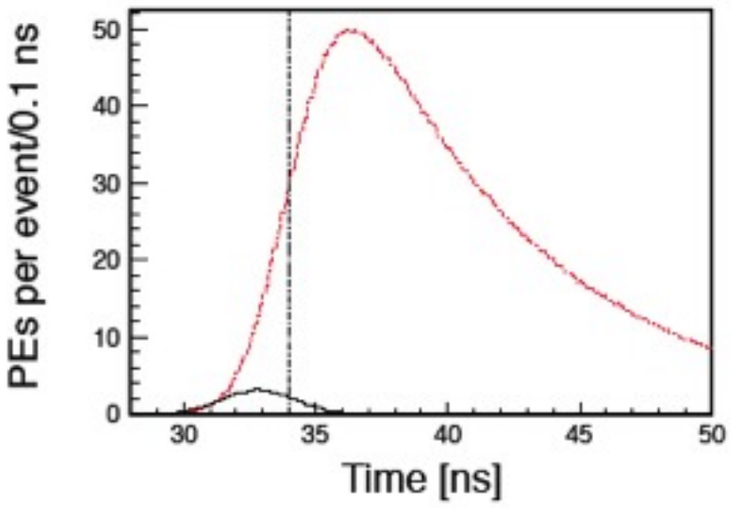

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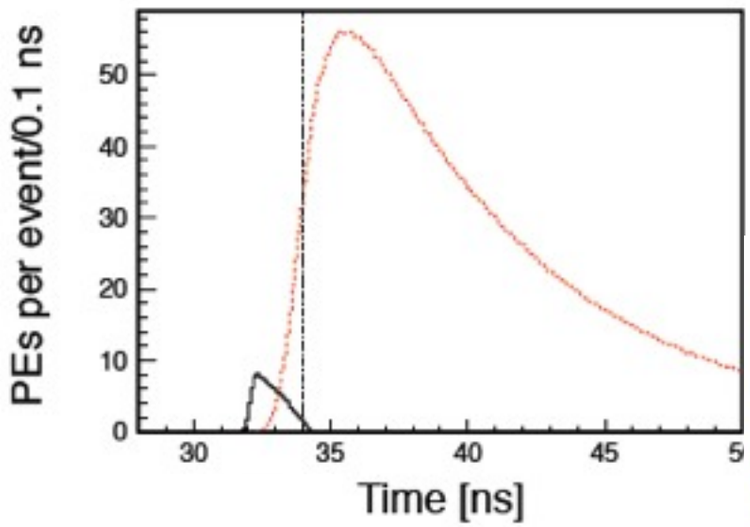

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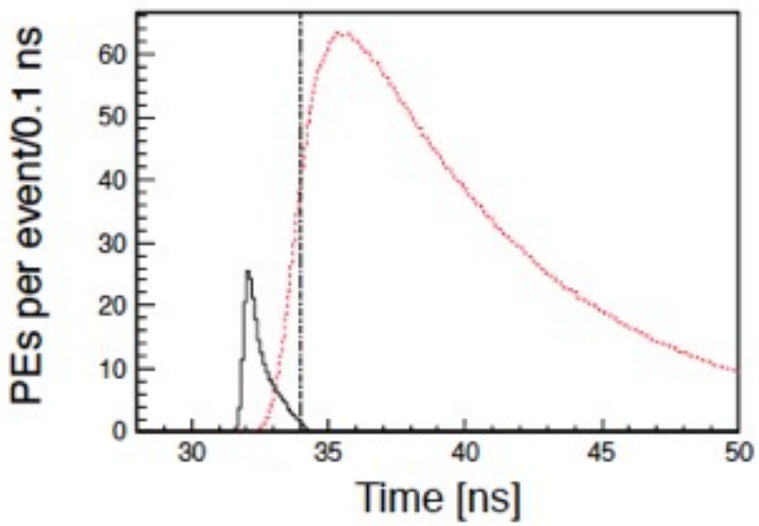
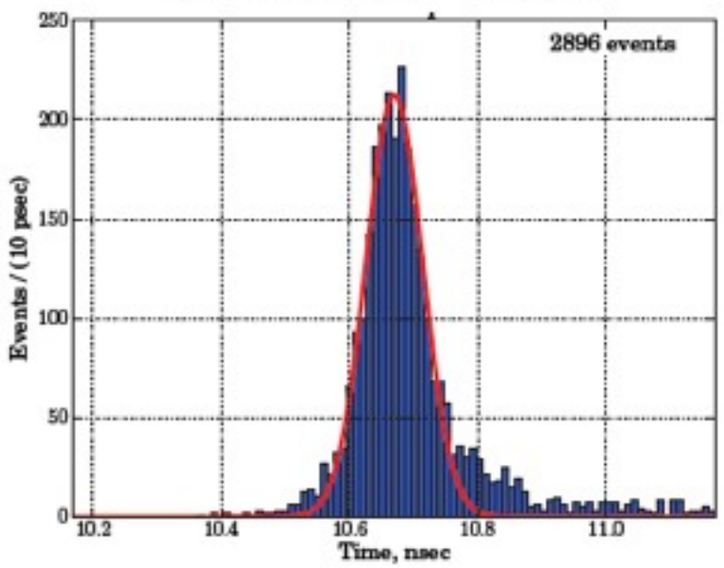


LAPPD Development



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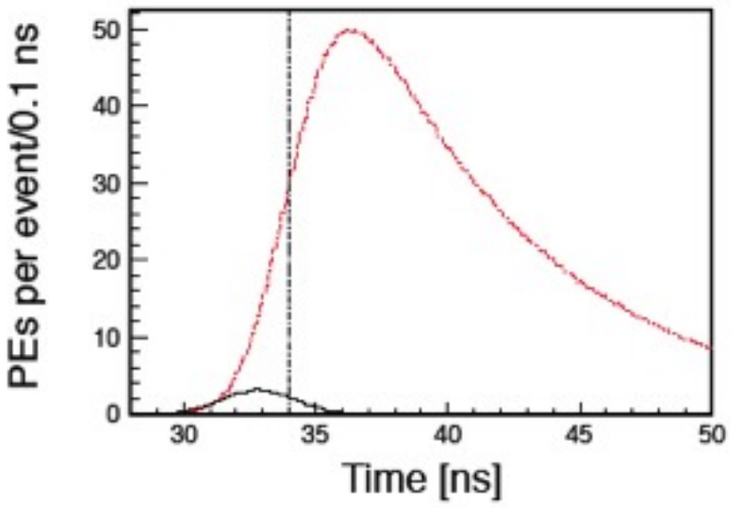

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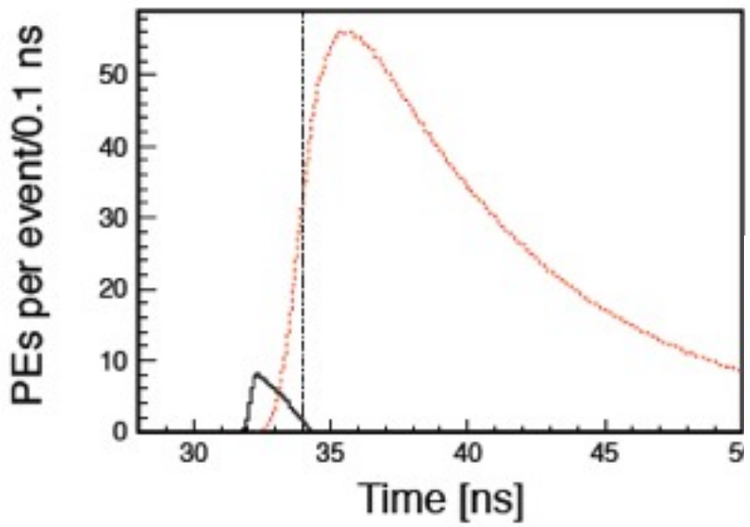

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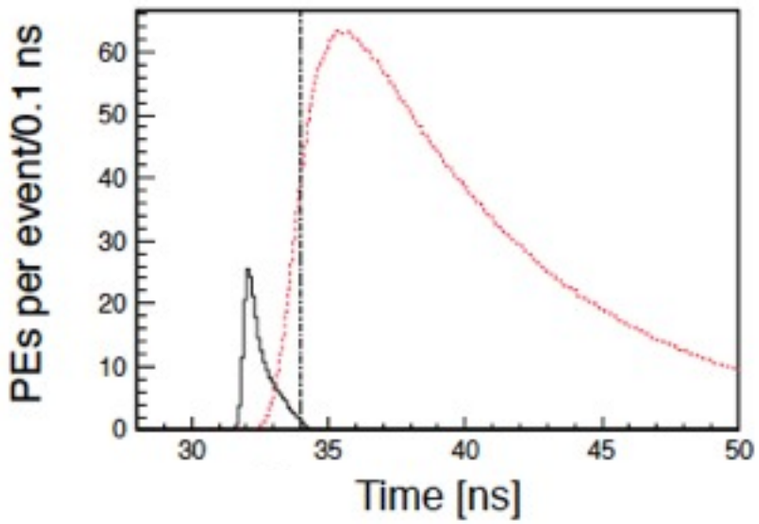

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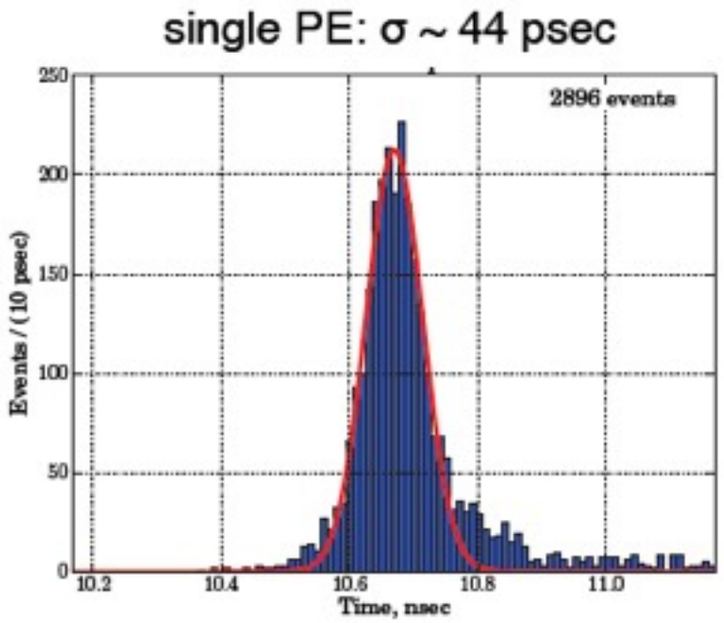
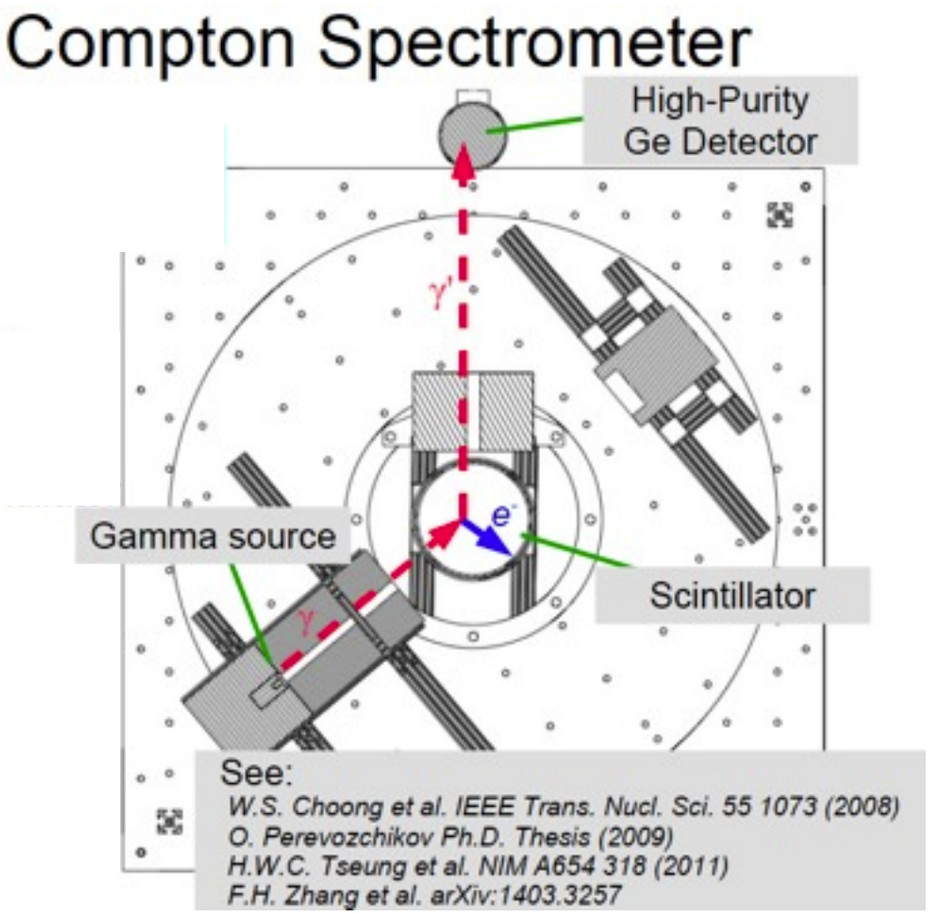


Cherenkov/scintillation separation ⇒ particle ID,

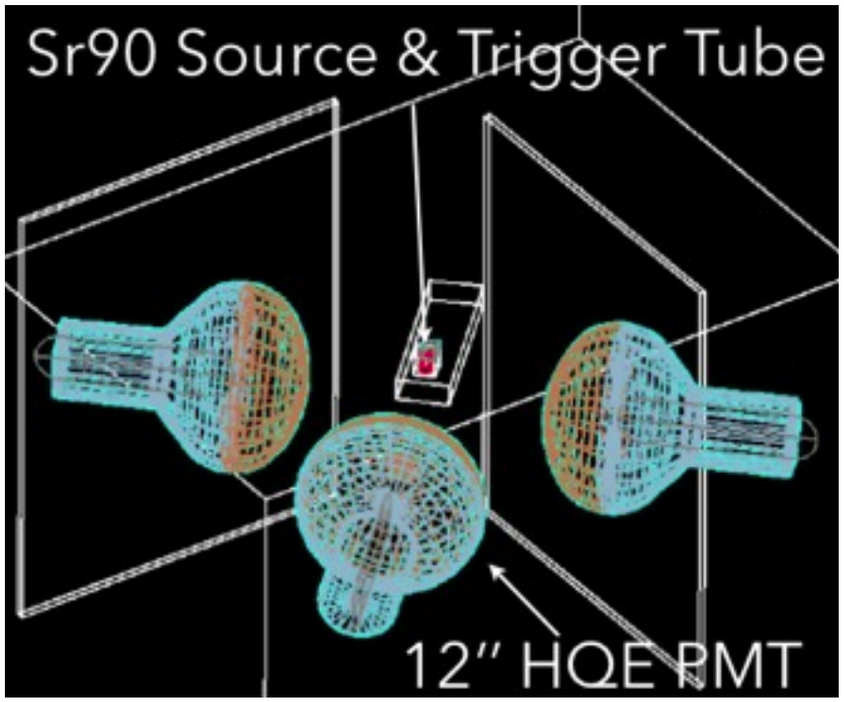
background rejection

ASDC @ LBNL

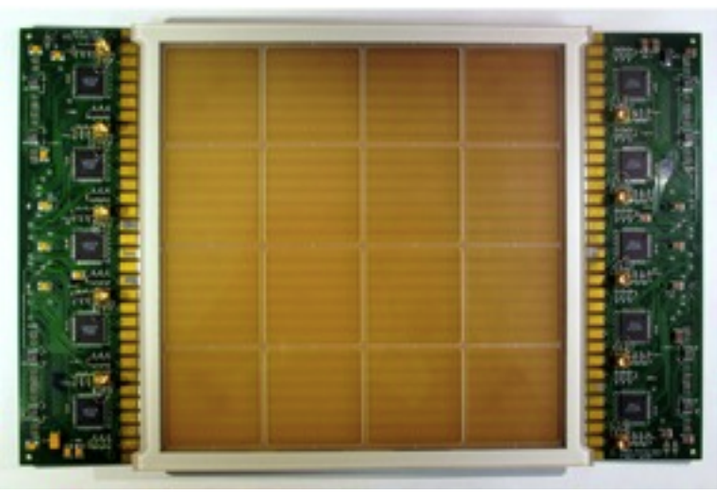
Compton scattering => nonlinearity



Absolute light yield



Cherenkov ring imaging



Heading up software development
(ASDC + WATCHMAN)

Forging a New Path

- Initiate US-based working group
- "Socialise" idea with funding agencies
- Foster international collaboration
  (NNN'14, dedicated meetings)
- Develop full detector model (simulation) to optimize detector configuration for maximal physics output
  (size, coverage, cocktail, loading)
- Critical R&D for proof of concept:
  a) Demonstrate sufficient light yield
  b) Separate prompt Cherenkov from delayed scintillation light
  c) Measure light loss over long distances
  (BNL, WATCHMAN)

Forging a New Path

Timeline

- Initiate US-based working group — *Done!*
- "Socialise" idea with funding agencies — *Ongoing*
- Foster international collaboration (NNN'14, dedicated meetings) — *Strong beginning in Europe, reaching out to Canada, Japan*
- Develop full detector model (simulation) to optimize detector configuration for maximal physics output (size, coverage, cocktail, loading) — *2014 - 2016*
- Critical R&D for proof of concept:
  a) Demonstrate sufficient light yield — *2014 - 2015*
  b) Separate prompt Cherenkov from delayed scintillation light — *2015 - 2017*
  c) Measure light loss over long distances (BNL, WATCHMAN) — *2015 - 2018*

Prospects

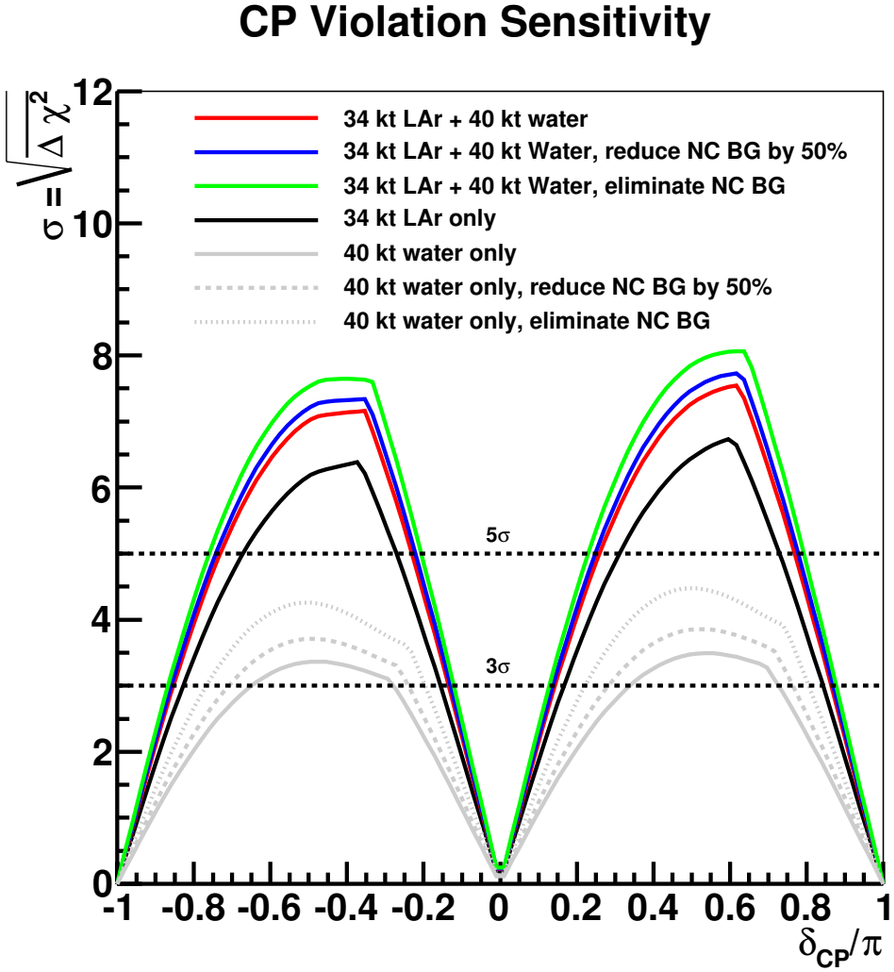
EXPERIMENT	WbLS	Doping	Other
SNO+	90% +	0.3-3% ^{130}Te	
Prospect	70% +	0.1% Gd or ^{6}Li	
WATCHMAN	1%	0.1% Gd	LAPPDs
T2K	10%	--	
ANNIE	1%	0.1% Gd	LAPPDs
Medical apps	1-5%	high Z for TOF-PET	

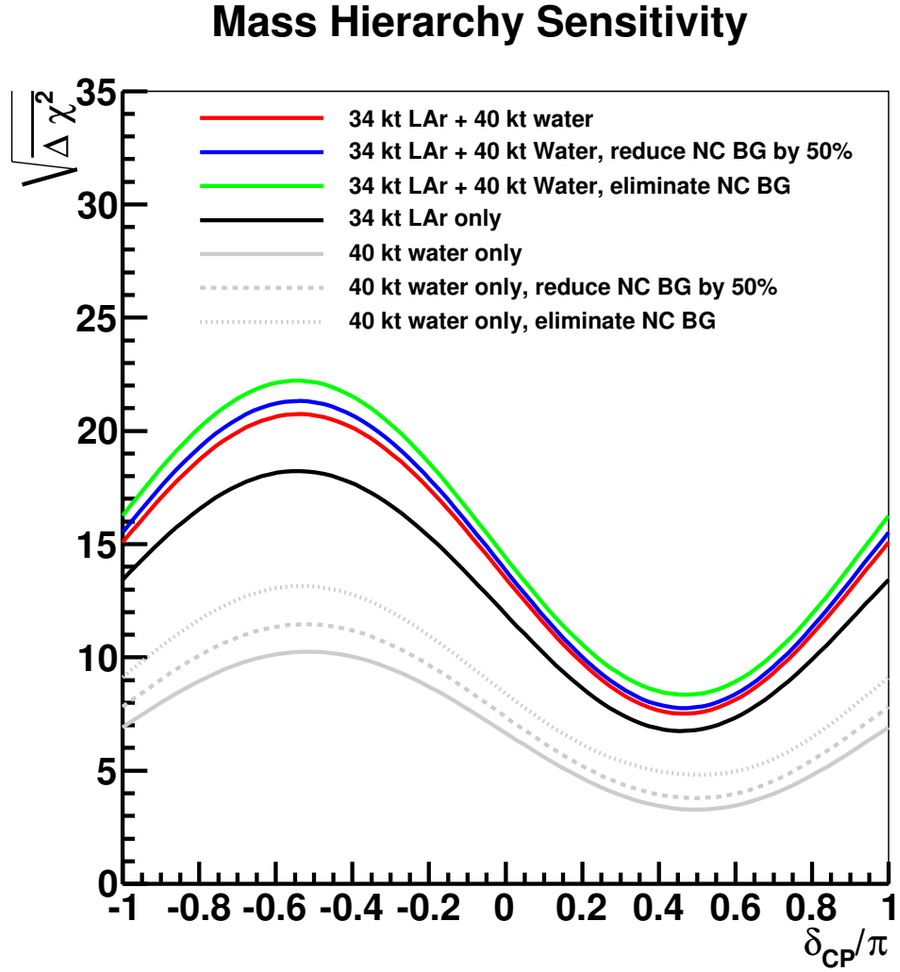
Oil-like

Water-like

Long-baseline

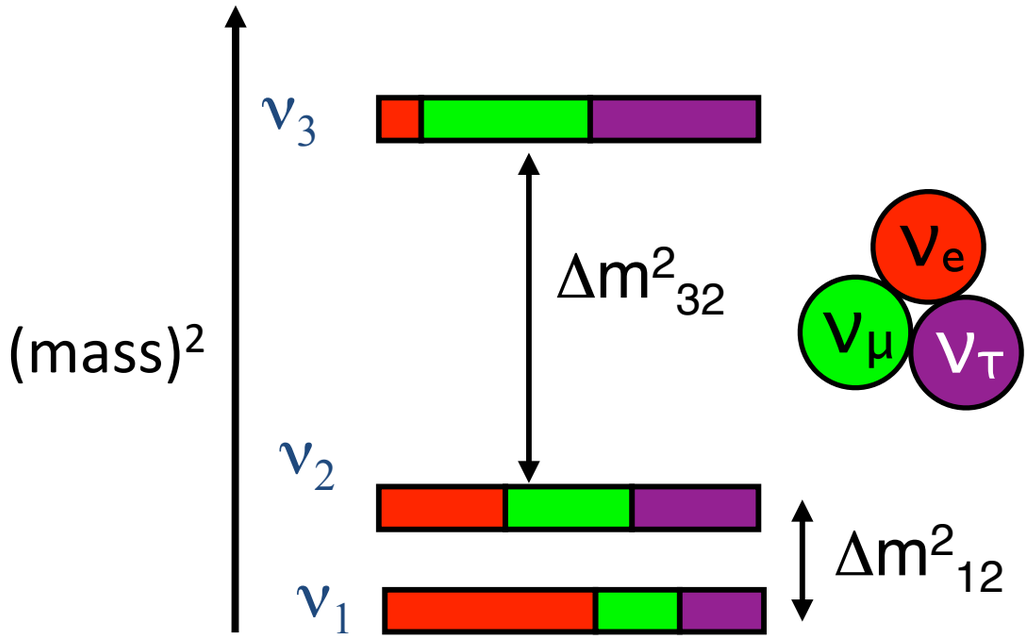
- Ring-imaging water Cherenkov detector
- + particle ID from Chr/scint comparison
- + NC-bkg reduction with high-precision timing & resolution





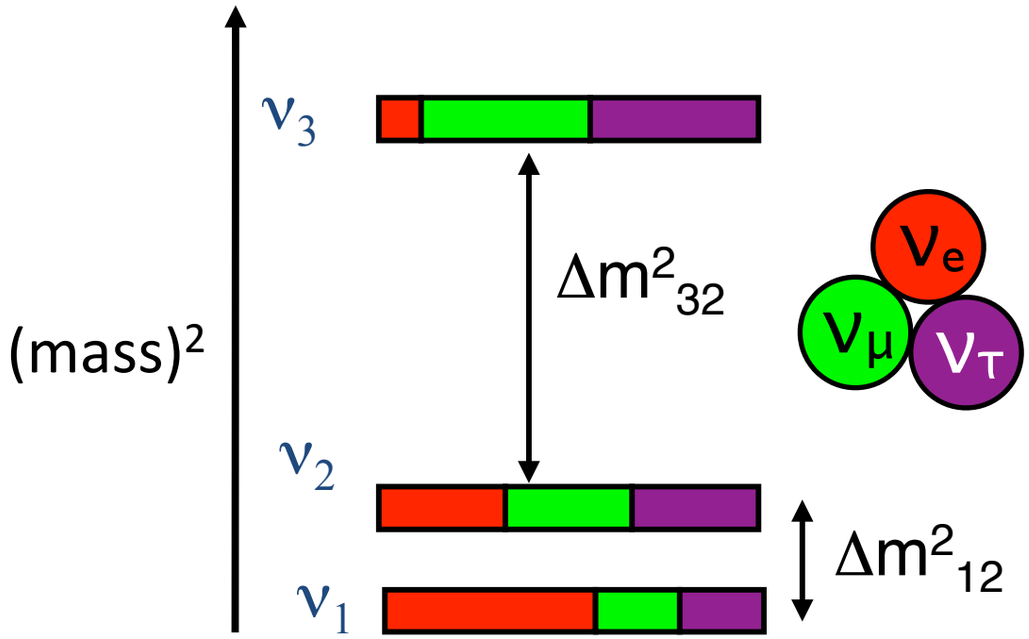
MH sensitivity for 40kT WbLS alone > 4.8 σ

Neutrino Mixing



Parameters:
3 mixing angles
2 mass differences
1 phase

Neutrino Mixing



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$$U_{\text{PMNS}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{\text{CP}}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{-i\delta_{\text{CP}}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix} \times \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times U^{\text{diag}}_{\text{Maj}}$$

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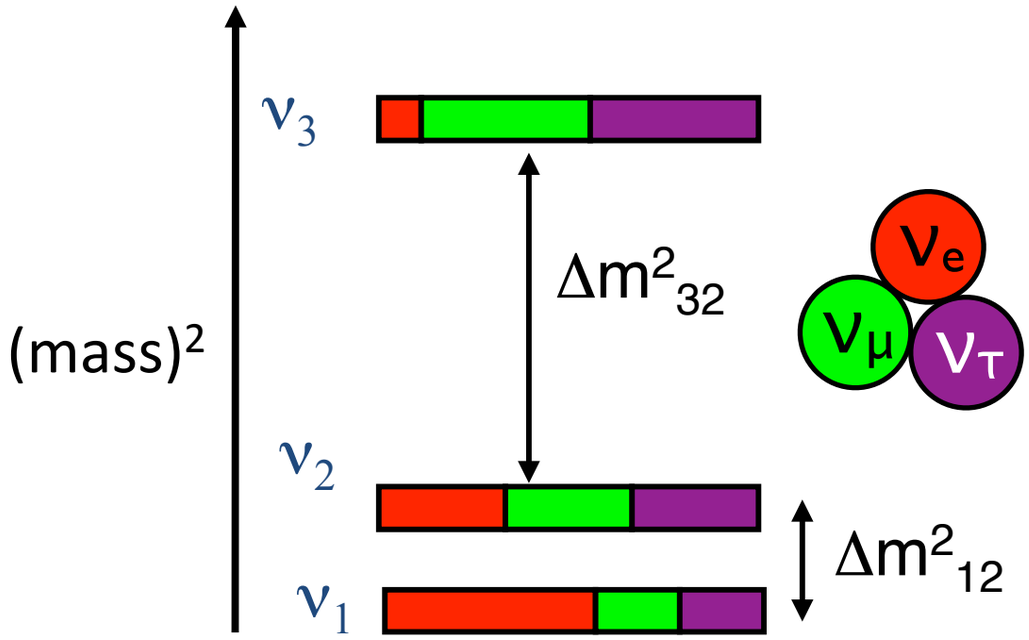

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Atmospheric
well measured

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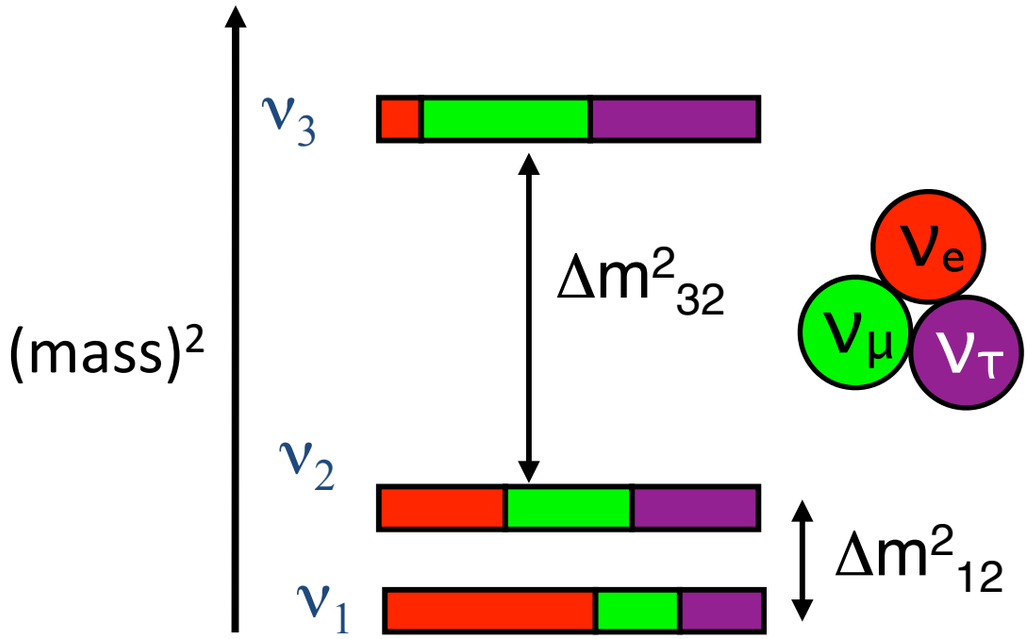

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Atmospheric well measured

θ_{13} measured as of Mar 2012!

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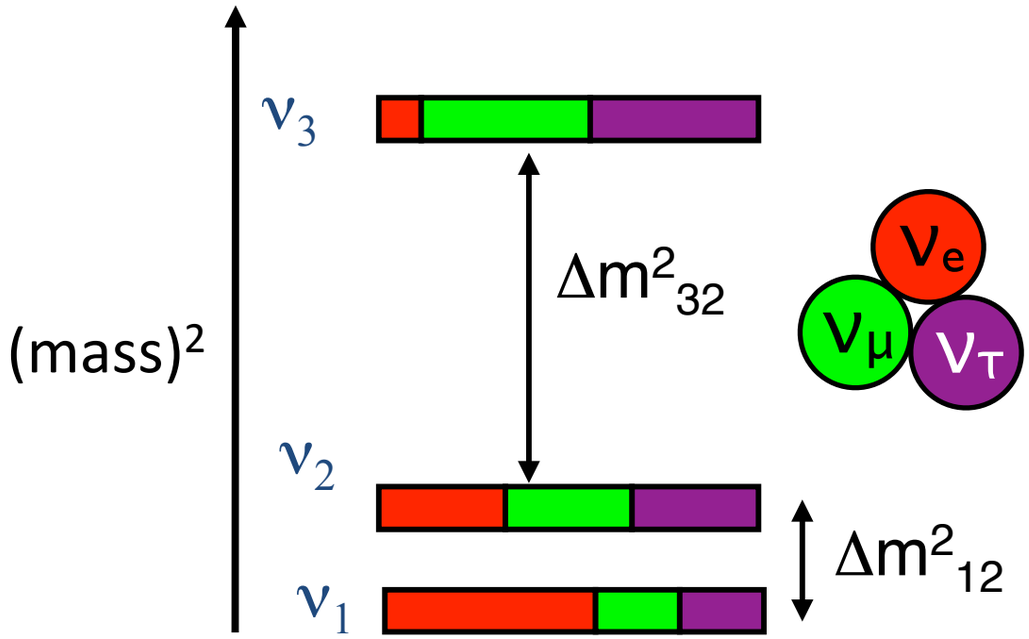

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Solar well measured

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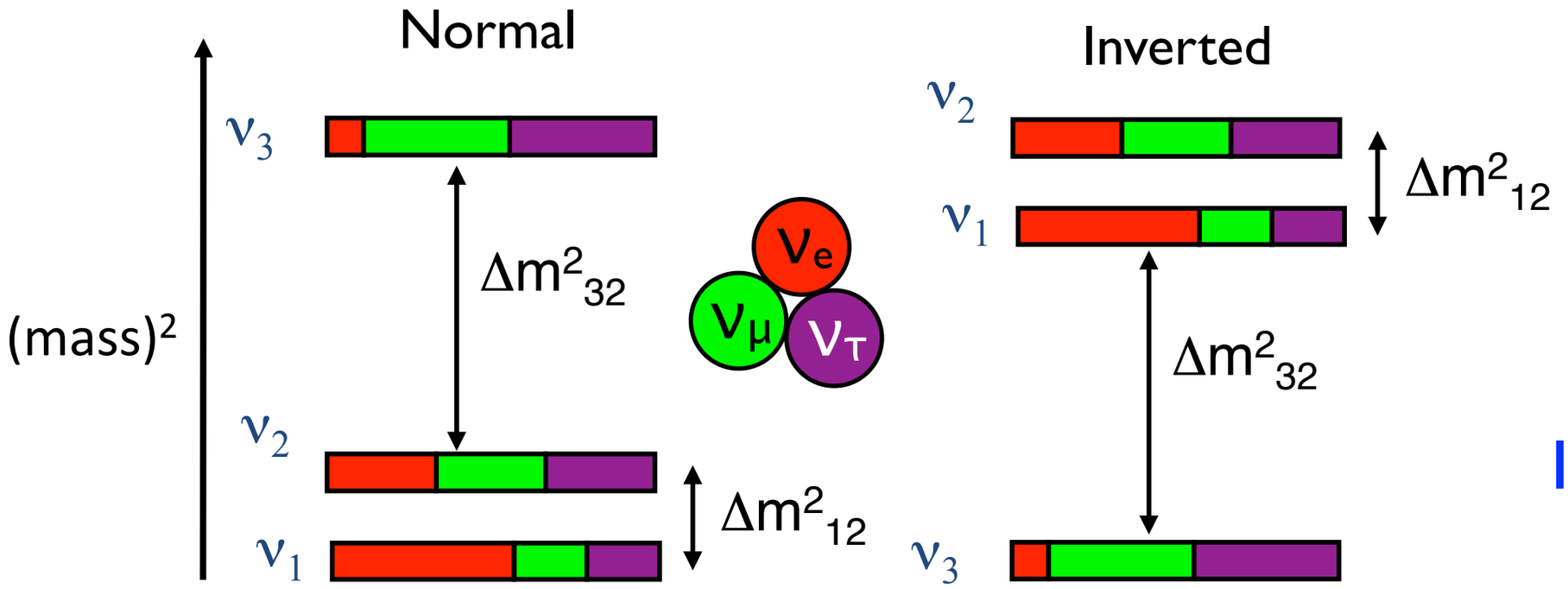

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1. Mass hierarchy??

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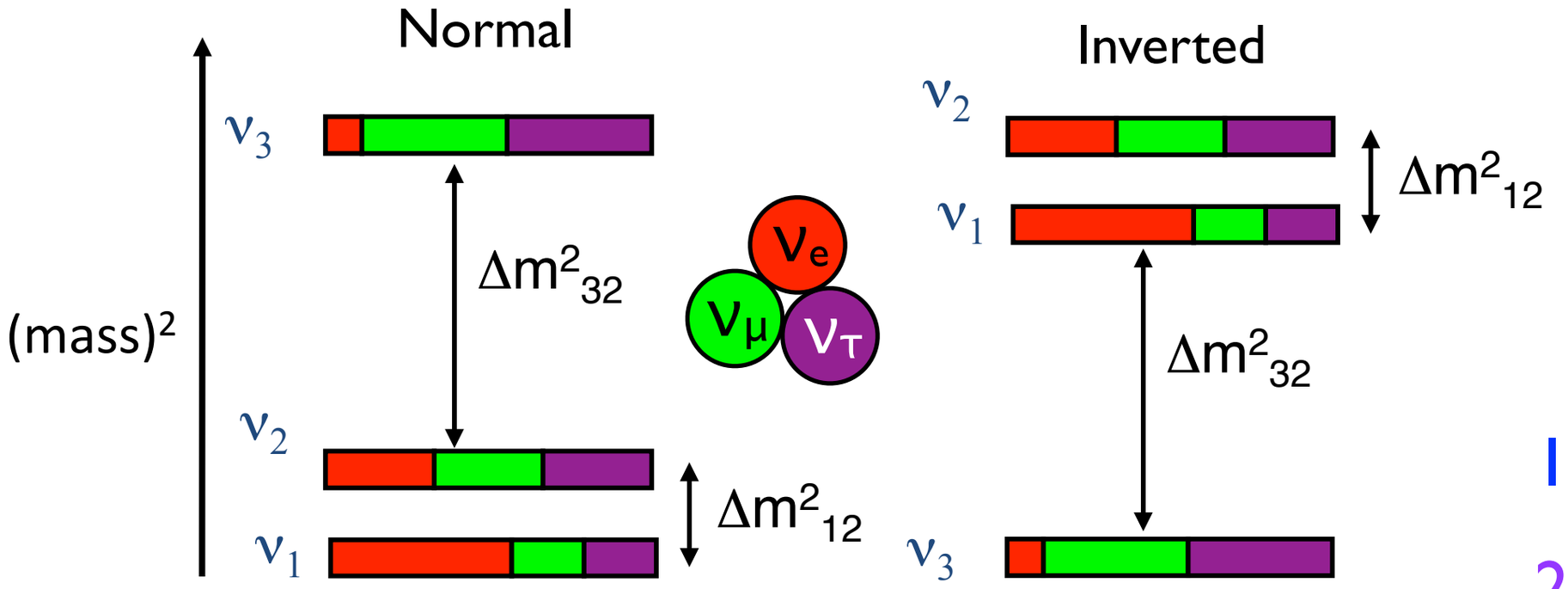

Parameters:
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1. Mass hierarchy??

2. CP violation??

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Solar
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