Constraints on Sterile Neutrino Evidence, Light Neutralino and LSND with KARMEN1+2

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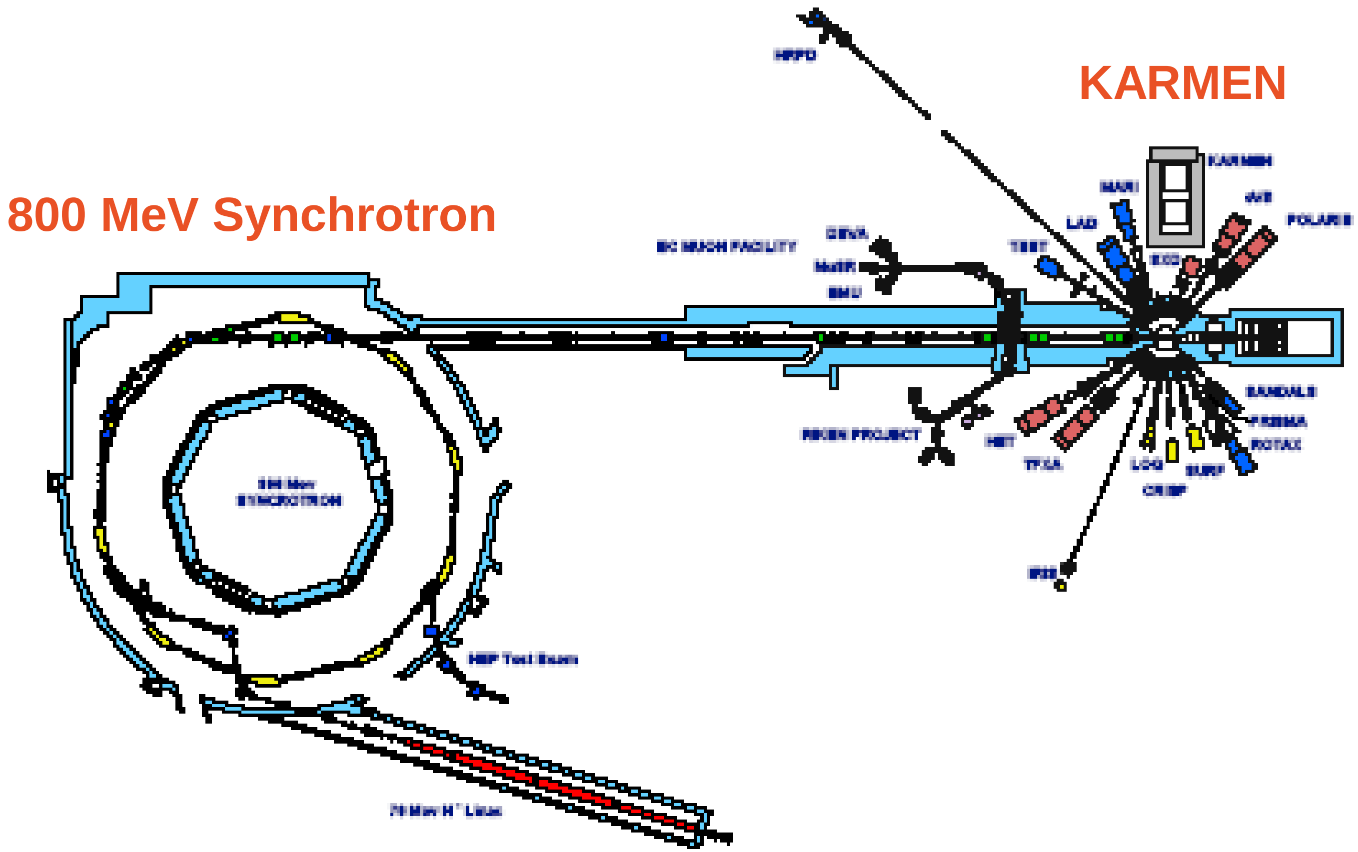
CETUP 2023
at Lead/Deadwood Middle School
THE INSTITUTE
For Underground Science at SURF
July 3, 2023

KARMEN at ISIS Neutron Spallation Source at Rutherford-Appleton-Laboratory in Oxford/UK



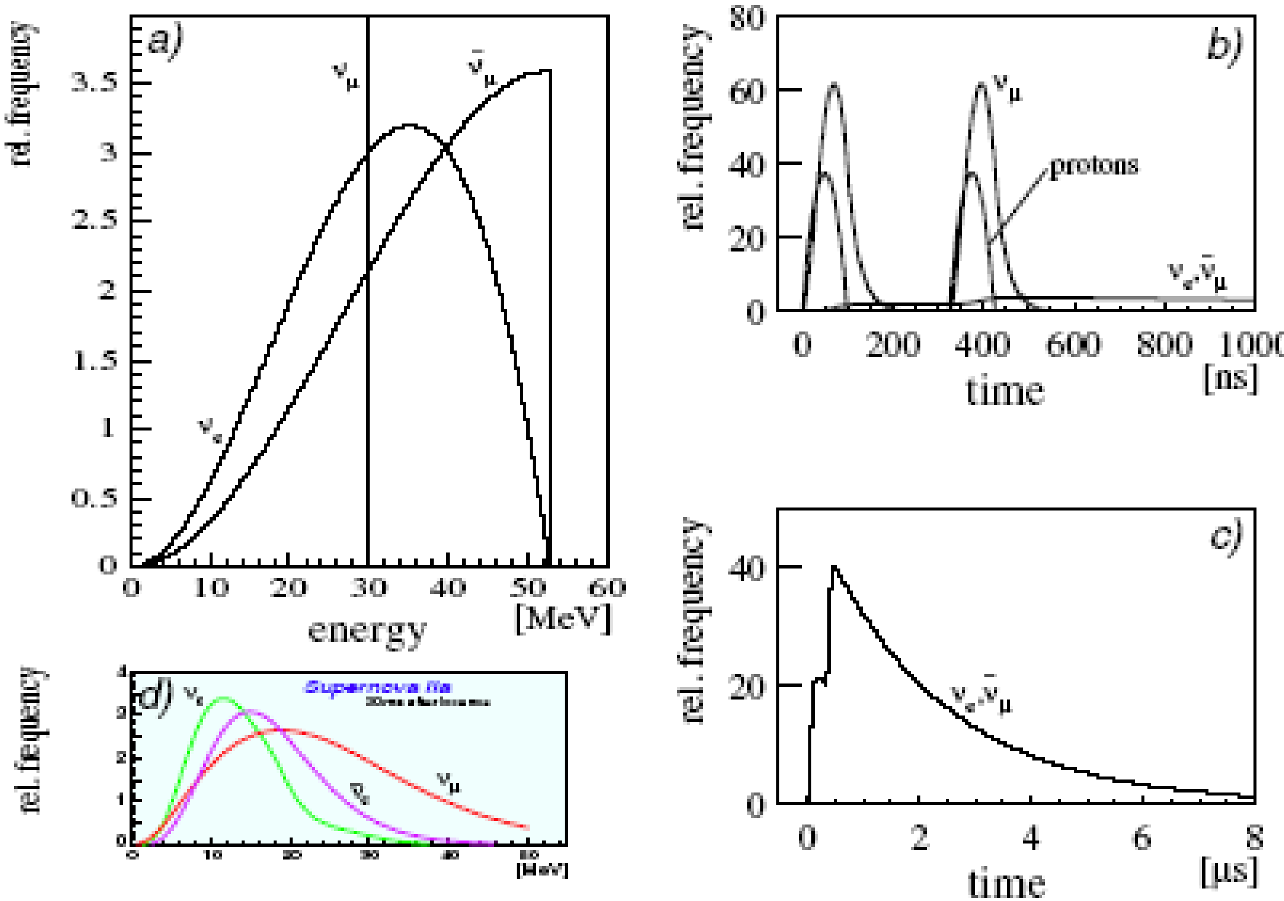
- **800 MeV protons with rapid cycling synchrotron (200 uA, 50 Hz, 20 ms beam periods)**

- **KARMEN detector was located at 17.5 m from main target (uranium/tantalum) at 90 degrees towards beamline**

Neutrinos from Well-Defined Decay at Rest

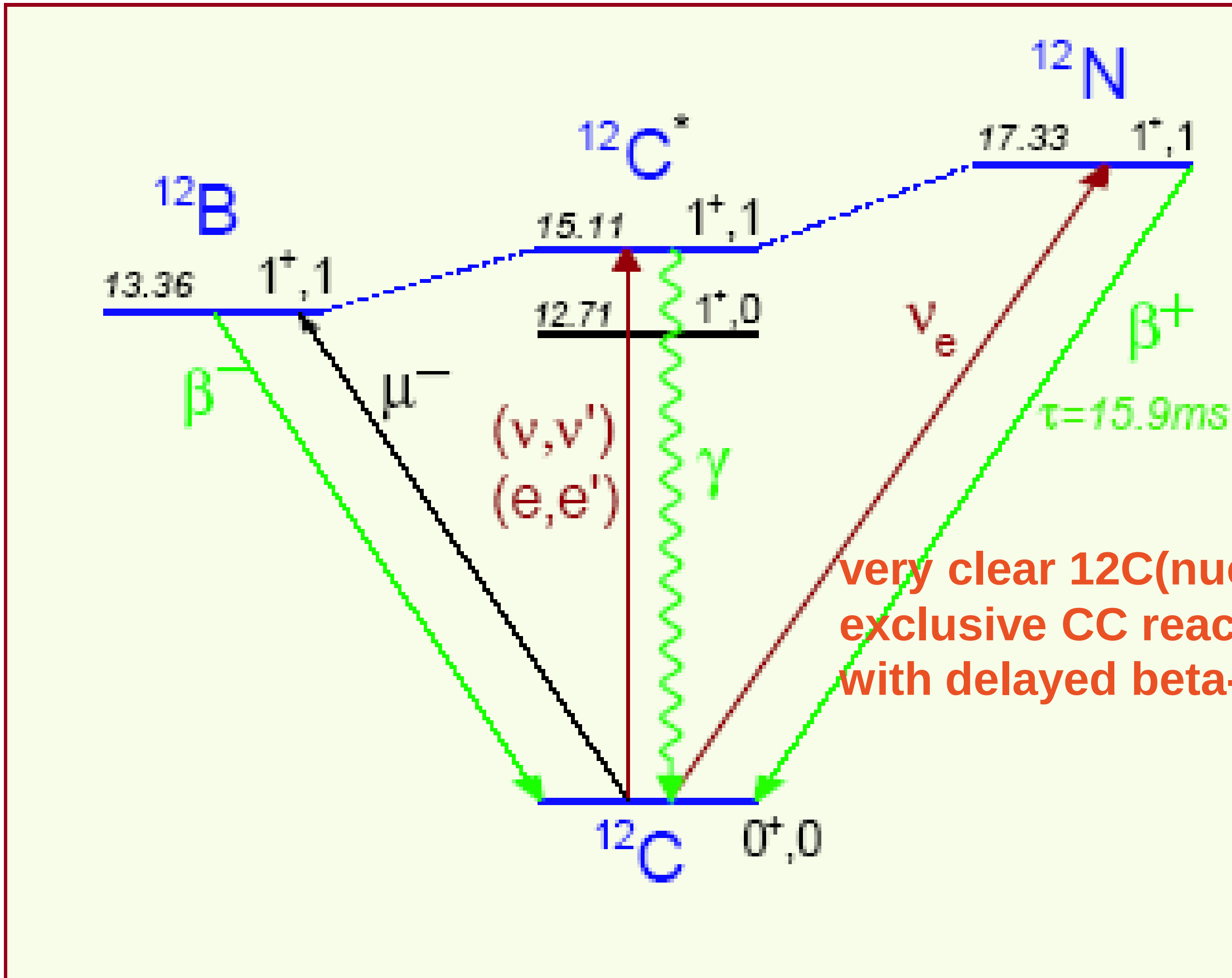
(negative pions undergo nuclear capture in high Z target;
contamination o(10^-4))

$$\pi^+ \longrightarrow \mu^+ + (\nu_\mu) \qquad \tau = 2.6 \cdot 10^{-8} s$$
$$\downarrow$$
$$e^+ + (\nu_e) + (\bar{\nu}_\mu) \qquad \tau = 2.2 \cdot 10^{-6} s$$



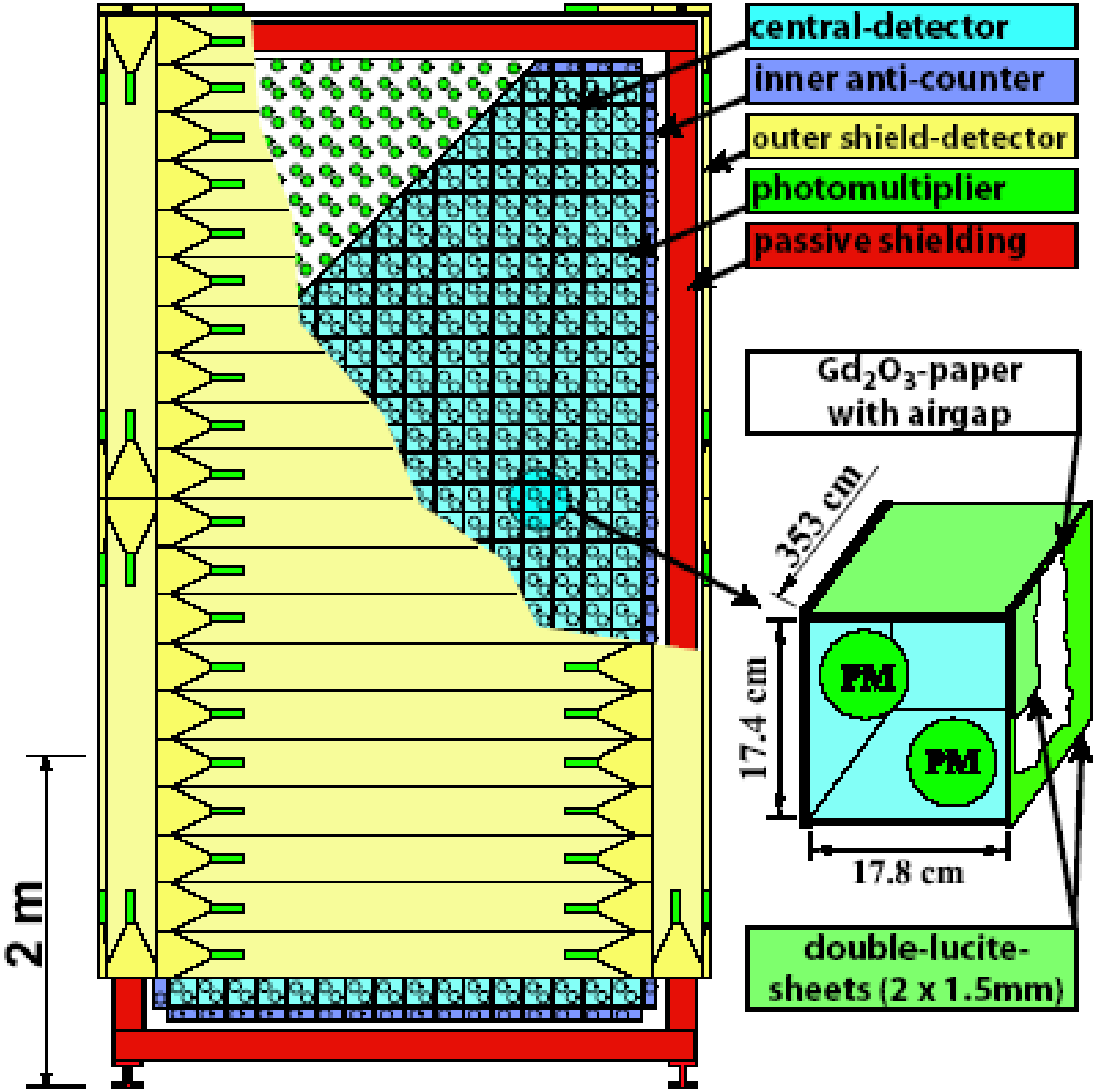
100ns wide proton pulses allow resolving muon and pion lifetimes

Isospin Triplet A=12

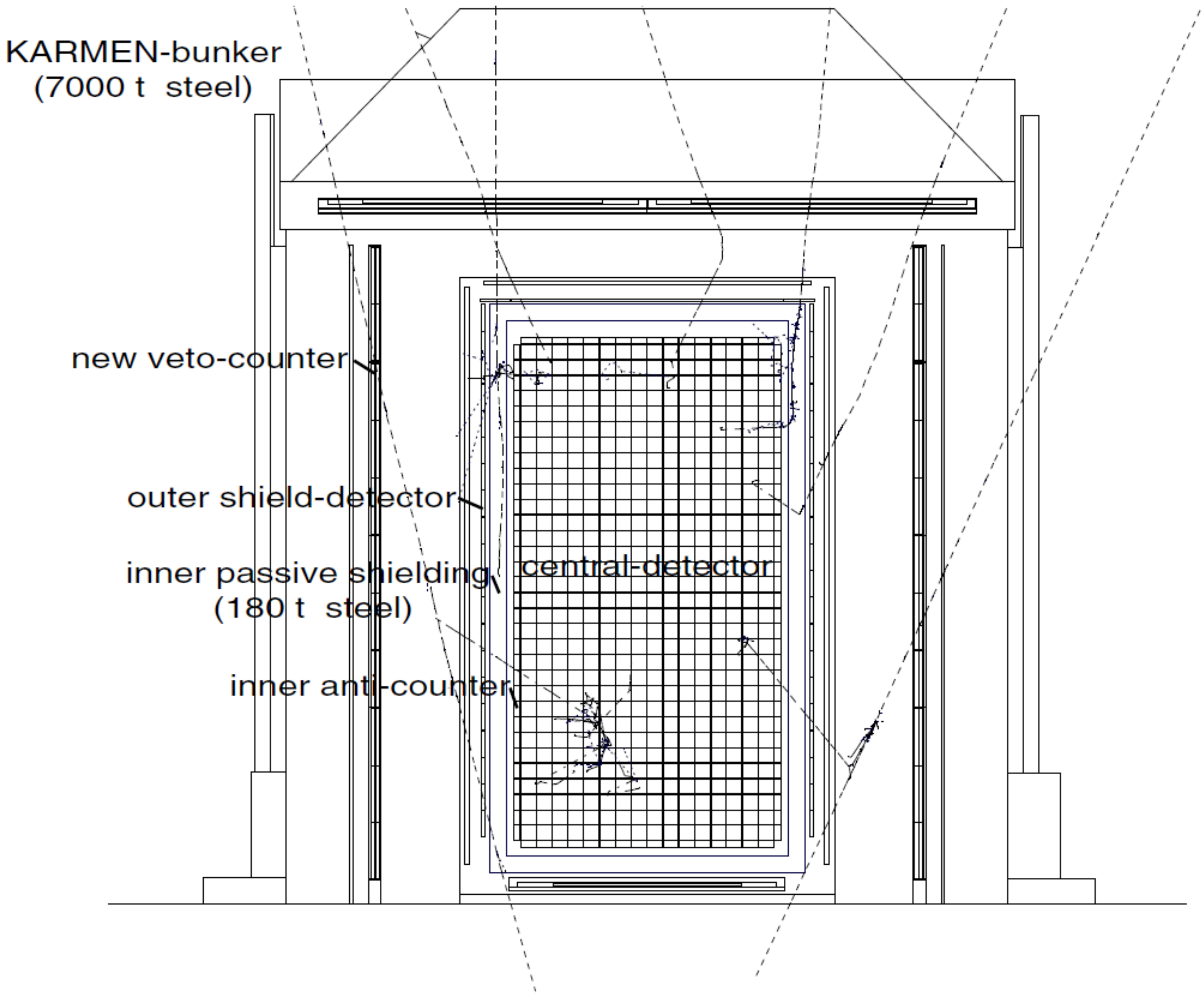


very clear 12C(nue, e-)12Ng.s. exclusive CC reaction signature with delayed beta-decay

KARMEN Detector (56t Liquid Scintillator) @ 17.5 m



KARMEN Outer Veto Upgrade (1995-1997) Marking Beginning of KARMEN2 (Ran until 2001)

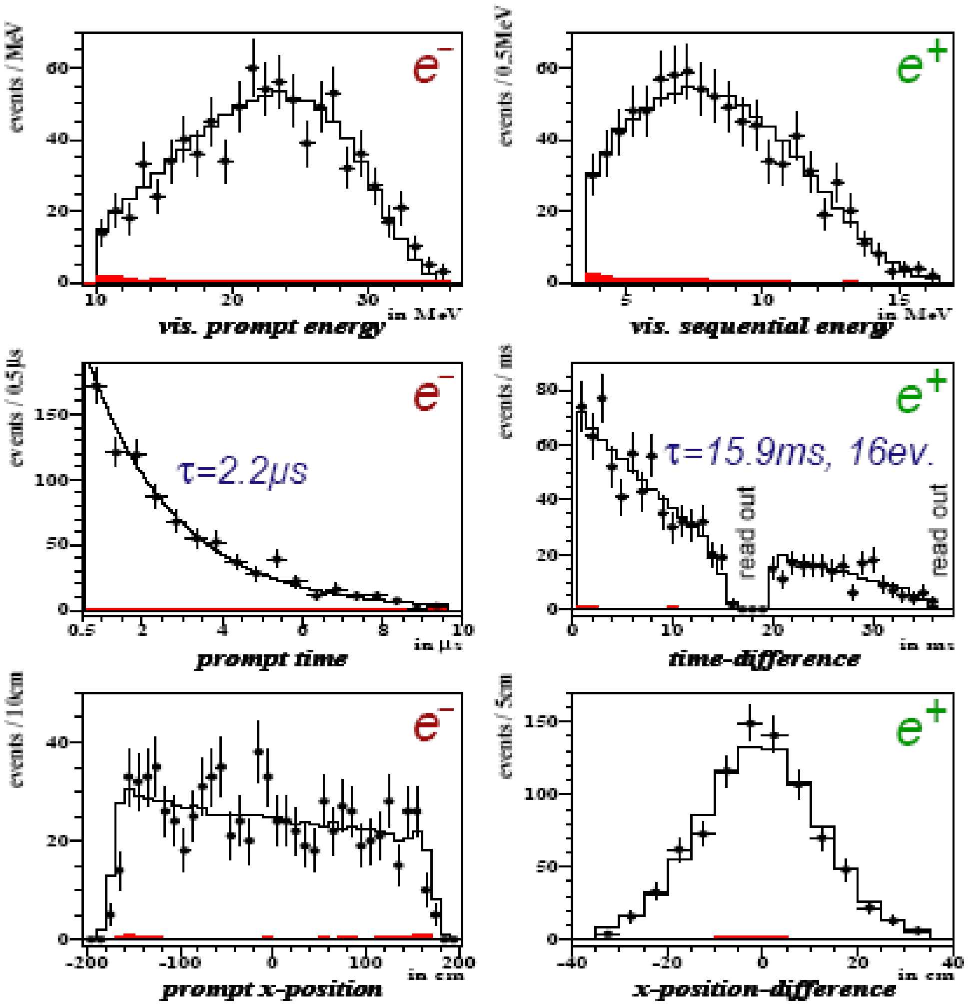


Measured Pure Electron-Neutrinos in Spectroscopic Quality via CC Sequence

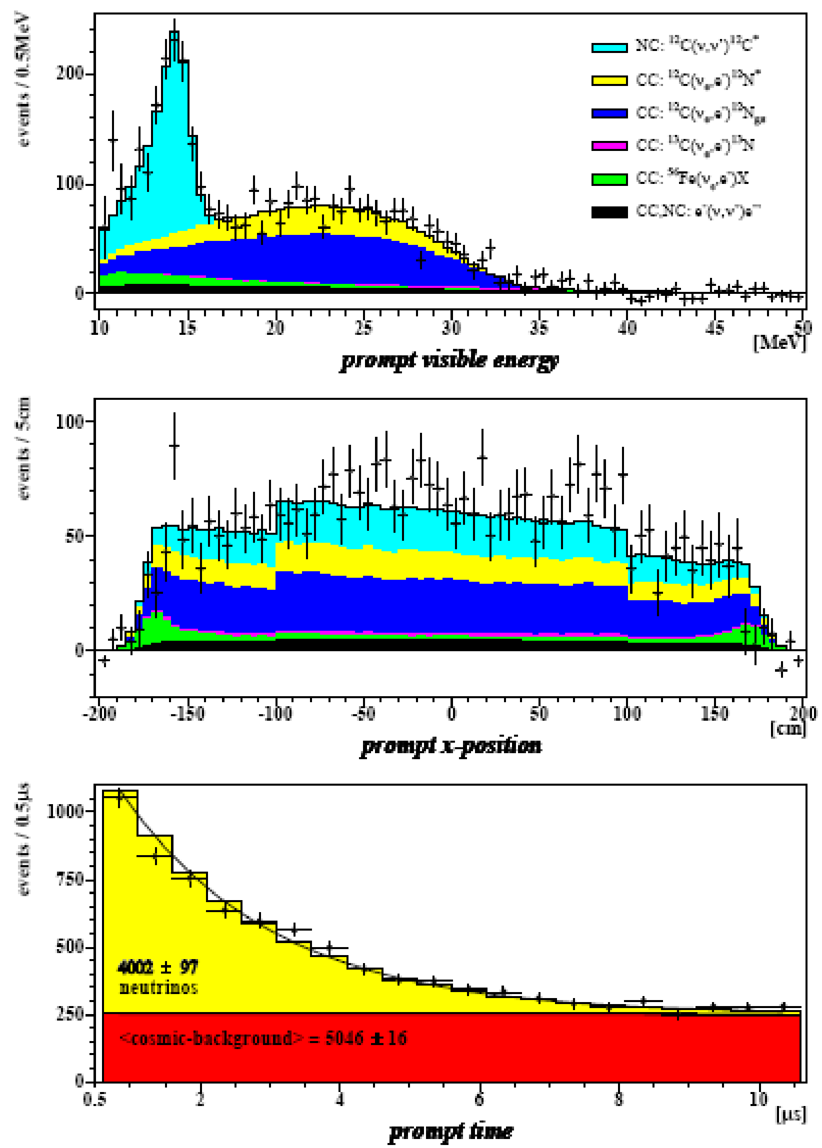
$\nu_e + {}^{12}C \rightarrow {}^{12}N_{g.s.} + e^-$ **(-17.33 MeV)**

${}^{12}N_{g.s.} \rightarrow {}^{12}C + e^+ + \nu_e$

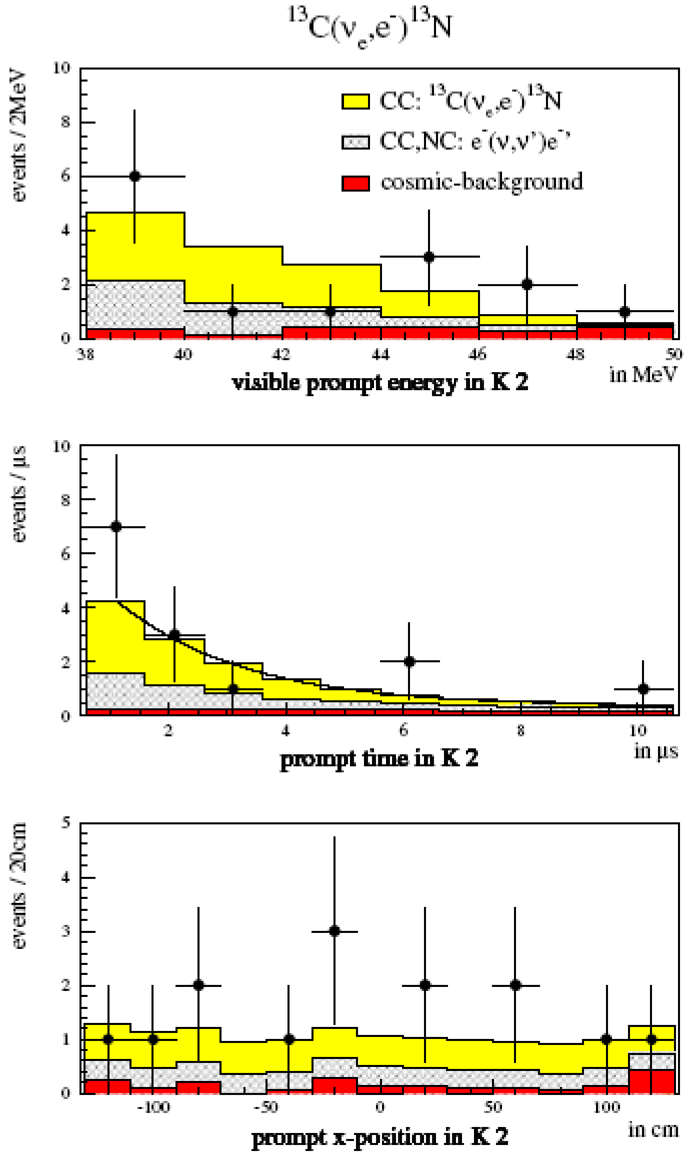
almost background free event by event based neutrino detection, reflecting 2.2us muon lifetime



Measured Neutrinos in Prompt Single-Events (NC+CC)



Measured Electron-Neutrinos in Prompt Single-Events (K2)



No excess above 38 MeV in single prompt events (only 2.2 MeV Q-value for inclusive CC on 13C)

$\Rightarrow$ No Hint for Appearance $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

2-flavor formalism: $\begin{pmatrix} |\nu_\alpha\rangle \\ |\nu_\beta\rangle \end{pmatrix} = \begin{pmatrix} \cos\Theta & \sin\Theta \\ -\sin\Theta & \cos\Theta \end{pmatrix} \cdot \begin{pmatrix} |\nu_1\rangle \\ |\nu_2\rangle \end{pmatrix}$

The probability $\mathcal{P}$ for the oscillation $\nu_\alpha \rightarrow \nu_\beta$ in vacuum is then given by:

$$\begin{aligned} \mathcal{P}(|\nu_\alpha\rangle \rightarrow |\nu_\beta\rangle) &= |\langle \nu_\beta | \nu_\alpha(x = L, t)\rangle|^2 \\ &= \sin^2(2\Theta) \cdot \sin^2\left(\frac{1.27 \cdot \Delta m^2[eV^2] \cdot L[m]}{E_\nu[MeV]}\right) \end{aligned}$$

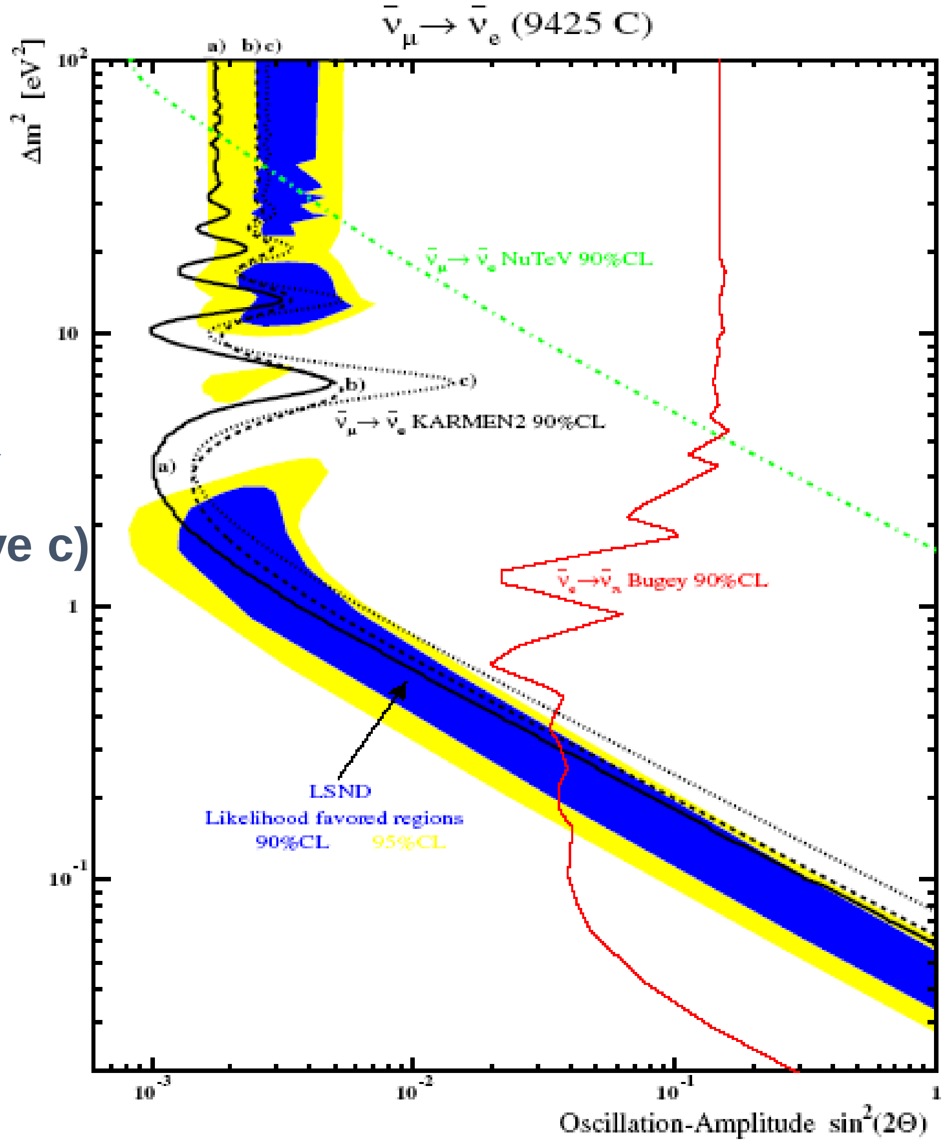
$$\textit{with} \quad \Delta m^2 = |{m_1}^2 - {m_2}^2|$$

New KARMEN2 Result from Single Prompt Events

⇒ No Other Hint for Heavy Sterile ν_s at large Δm^2 (~eV²) from KARMEN

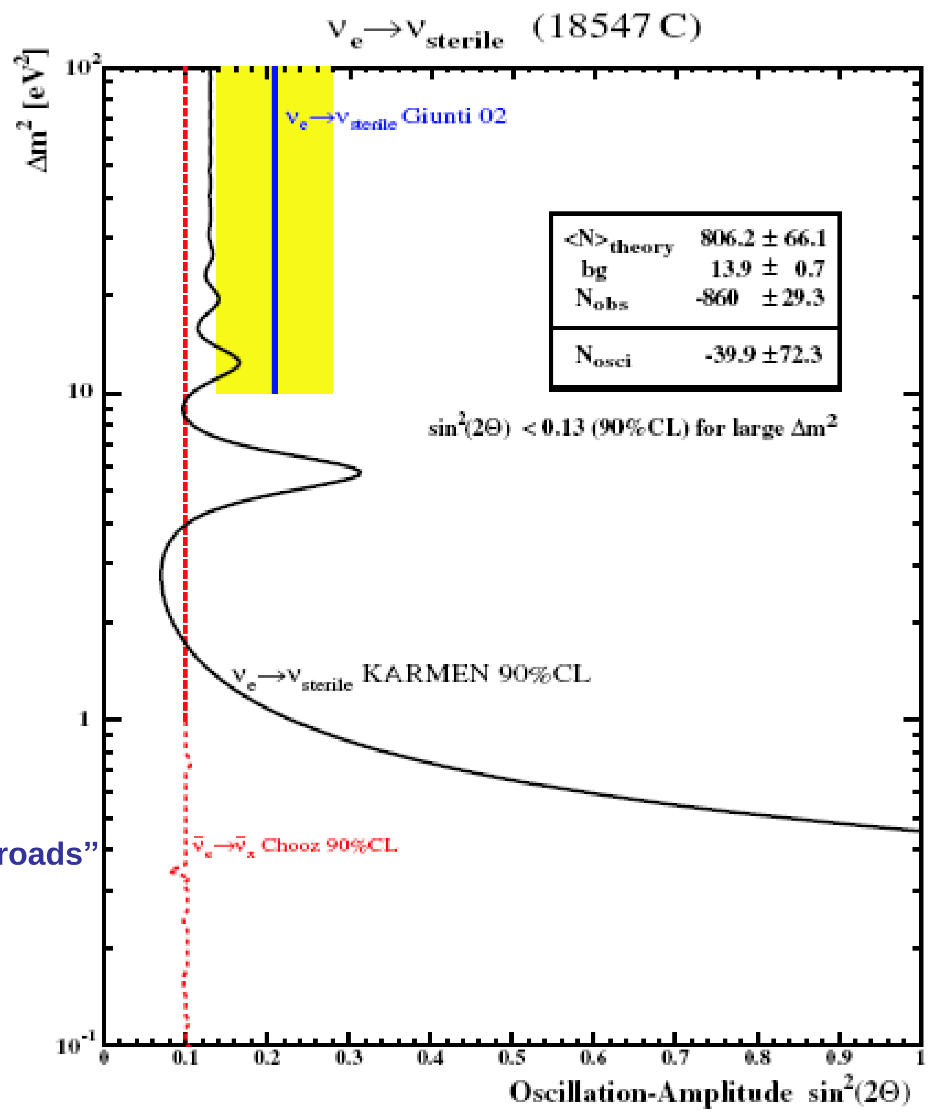
⇒ No other hint for Appearance $\nu_\mu \rightarrow \nu_e$

c.f. new exclusion curve c) vs. published limit a)



Phys.Rev.D65:112001,2002
Reichenbacher PhD Thesis, FZKA Report 7093

Good Agreement with Predictions!
Limit on Sterile Neutrinos from nue->nus

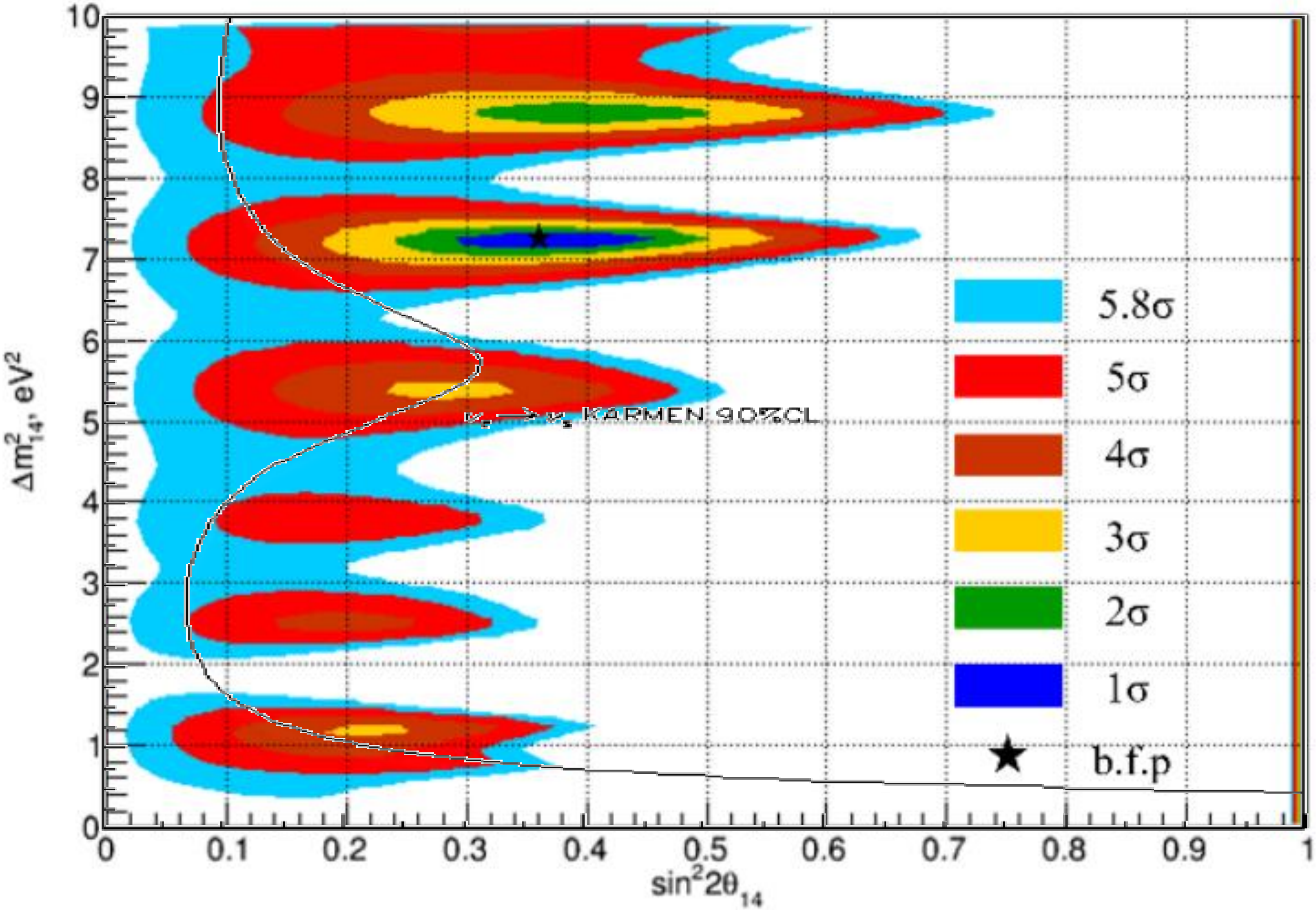


measured more 12C(nue,e-)12Ng.s. sequences than expected
⇒ No hint for disappearance

Conference "Sterile Neutrinos at the Crossroads" Sept. 25-28, 2011, Virginia Tech

KARMEN1+2 Can Exclude Global Fit Evidence Regions for Sterile Neutrinos at More than 2sigma !

[2306.09962.pdf (arxiv.org)](https://arxiv.org/pdf/2306.09962.pdf)

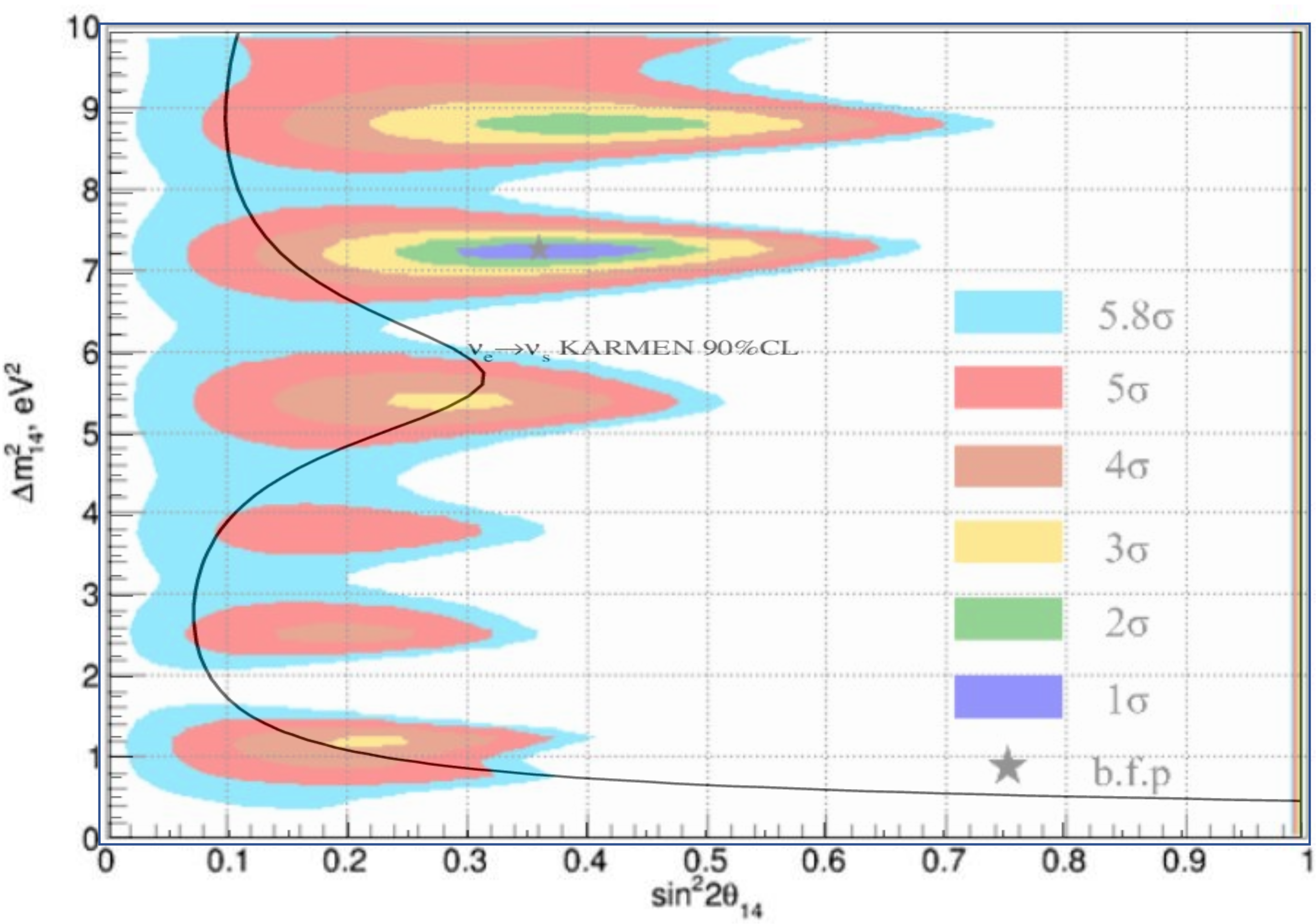


(Done at CETUP 2023 workshop!)

assuming CPT conservation

KARMEN1+2 Can Exclude Global Fit Evidence Regions for Sterile Neutrinos at More than 2sigma !

2306.09962.pdf (arxiv.org)



assuming CPT conservation

KARMEN1+2 Can Exclude Global Fit Evidence Regions for Sterile Neutrinos at More than 2sigma !

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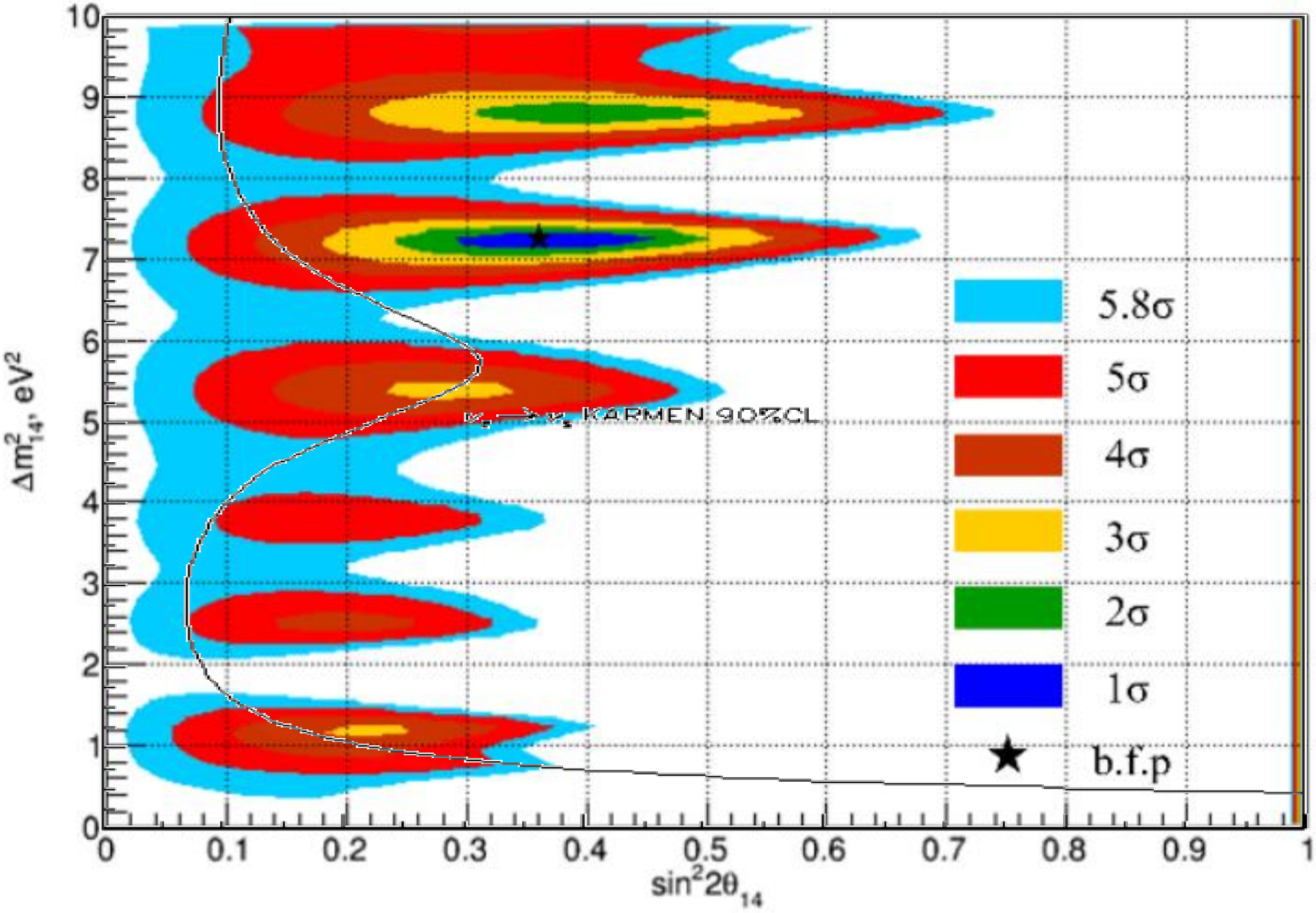
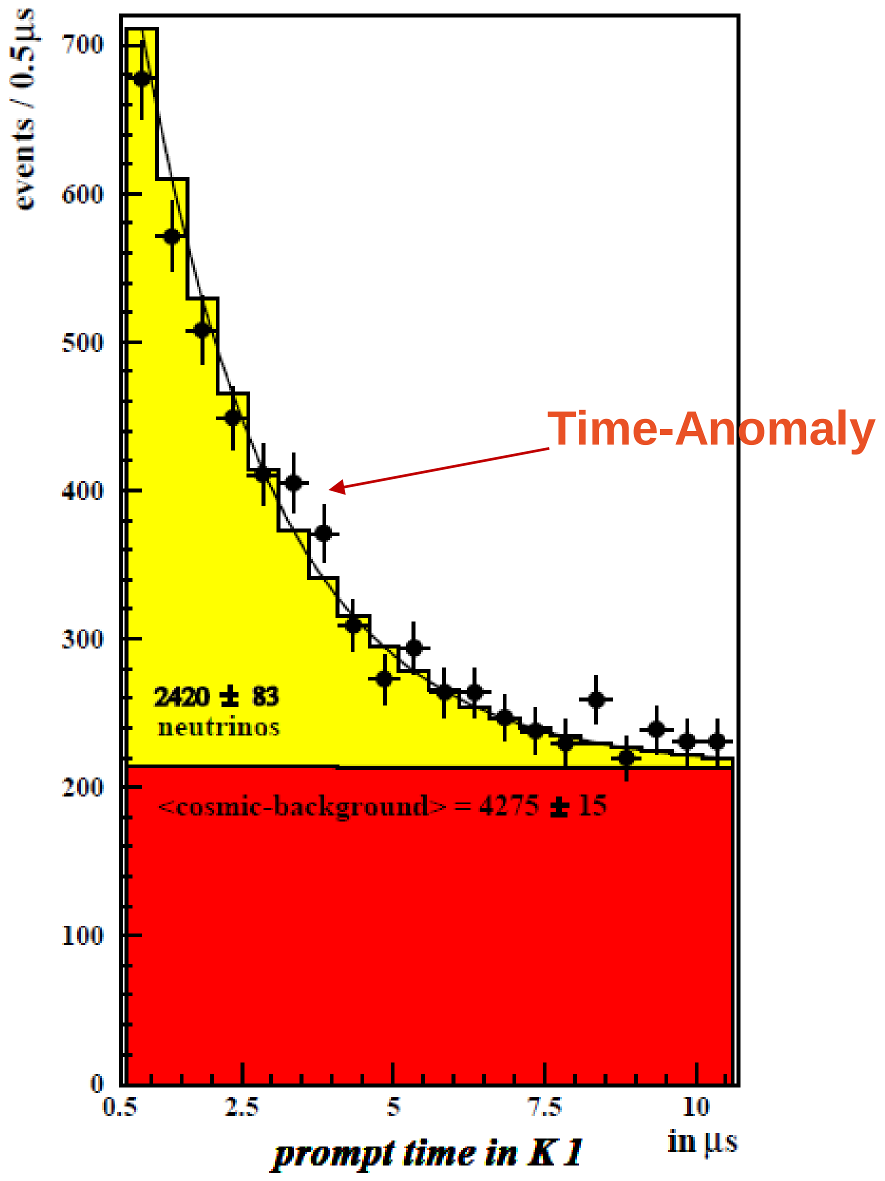
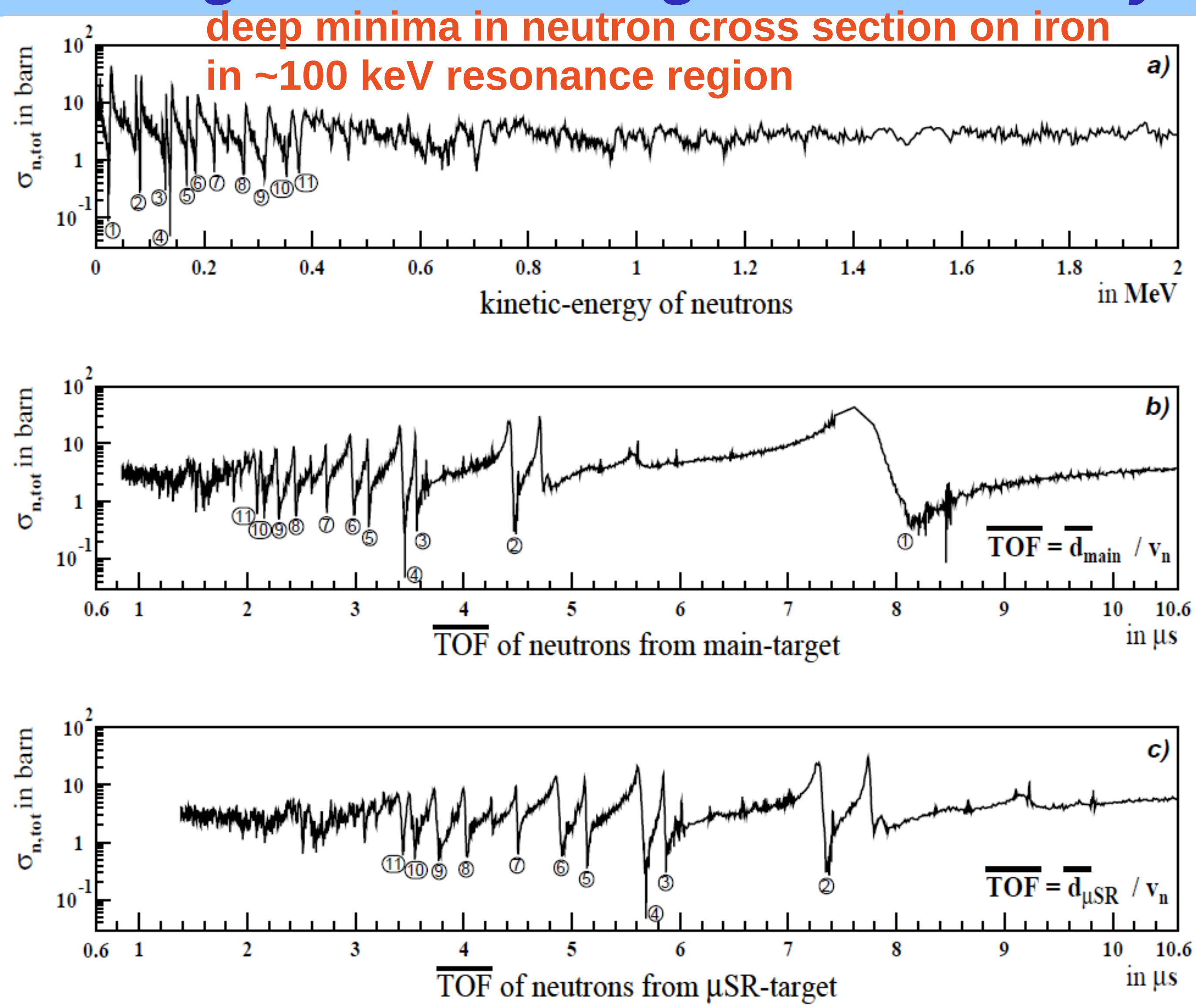


assuming CPT conservation

KARMEN Time-Anomaly between 3us and 4us

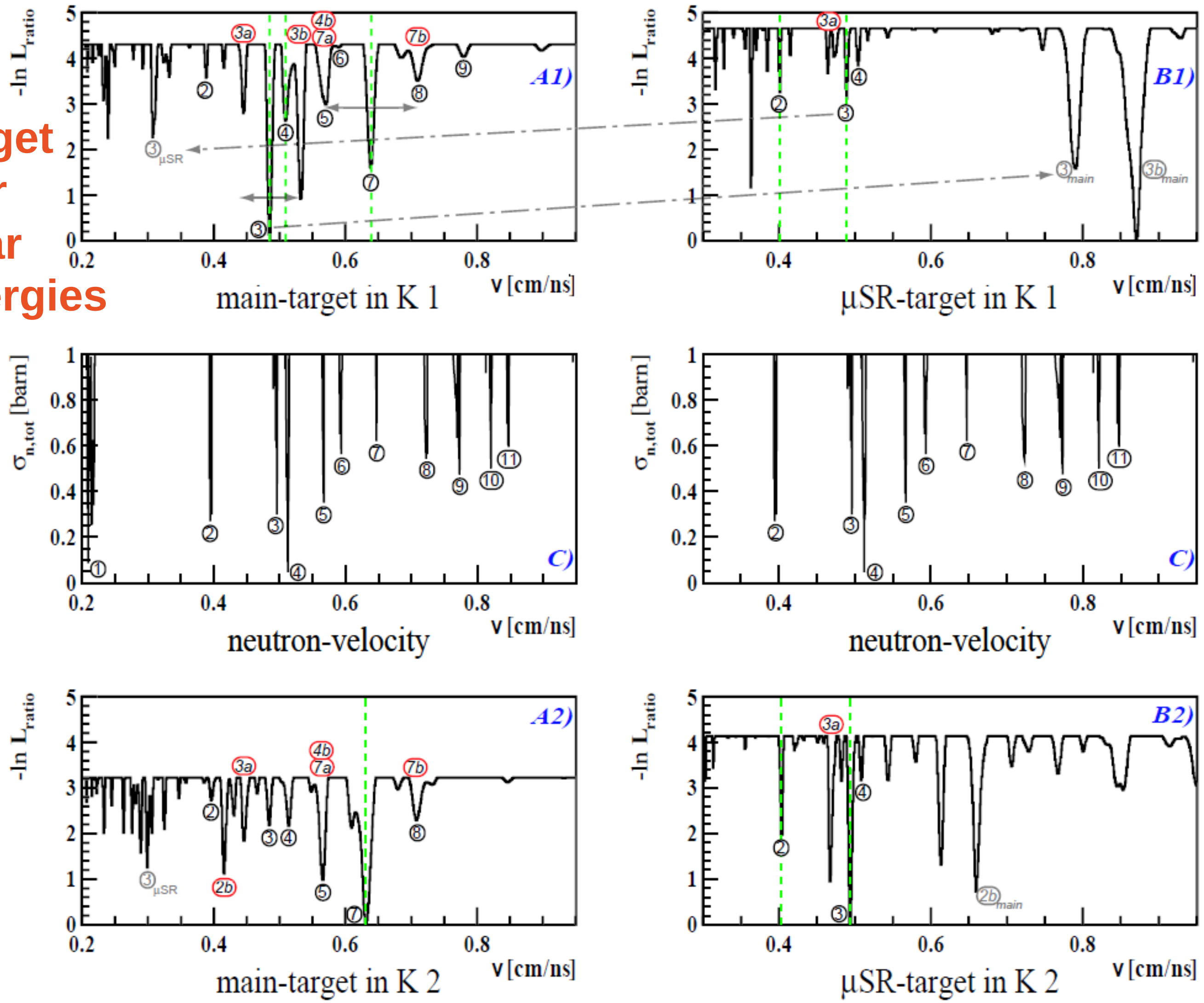


Hypothesis of Beam-Correlated Neutron Background Causing Time-Anomaly

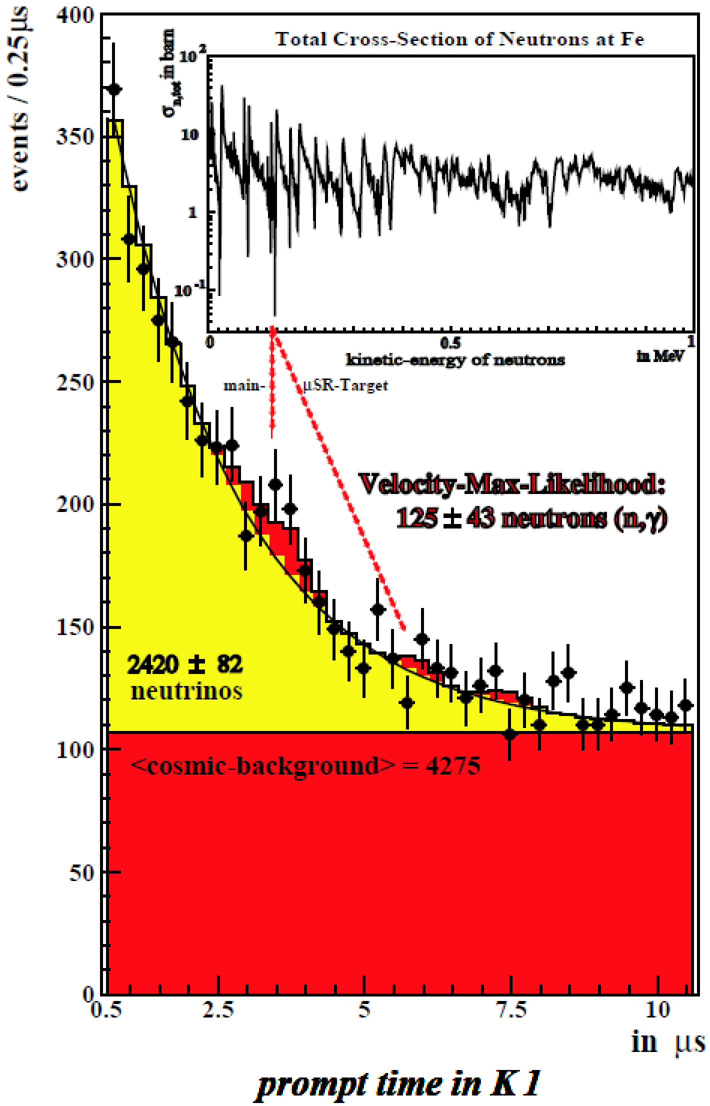


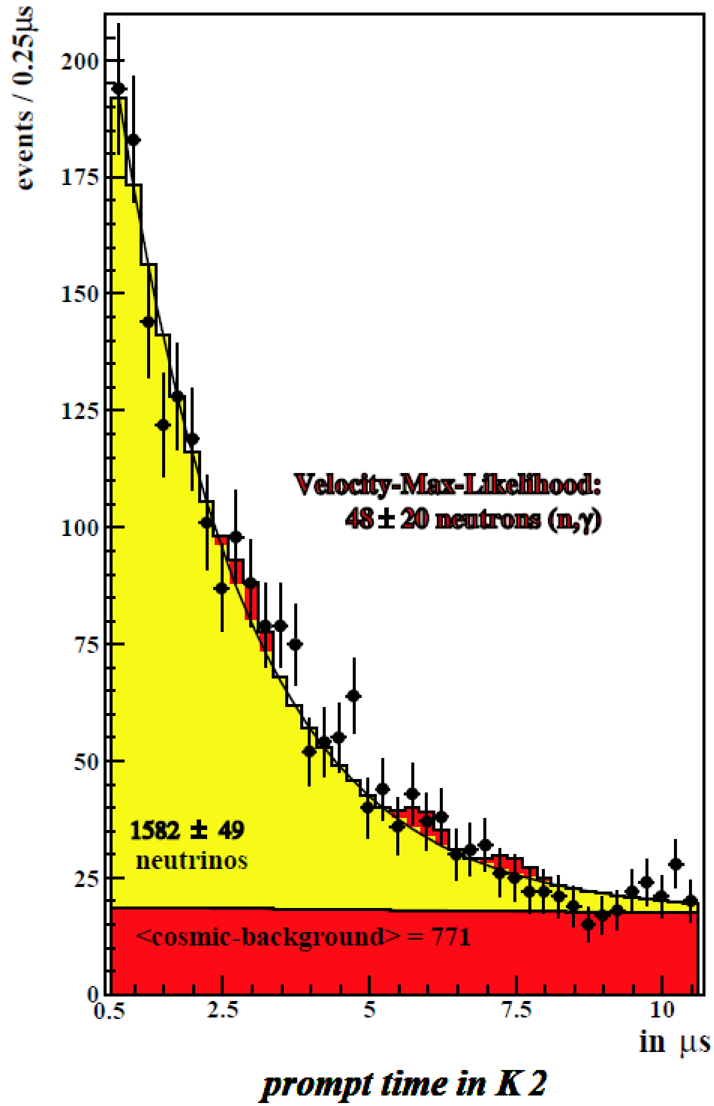
Matched Neutron Cross Section Minima in Iron with Neutron Velocities from Main and Pre-Targets!

7 m steel shielding towards target acts as filter for particular neutron energies

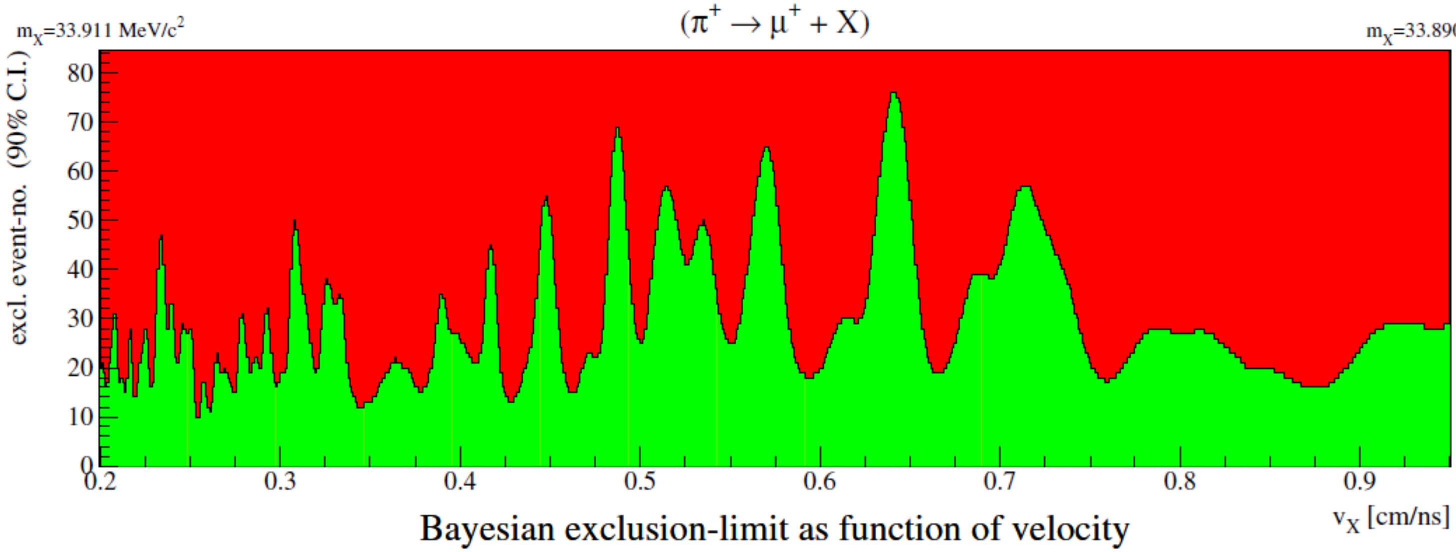


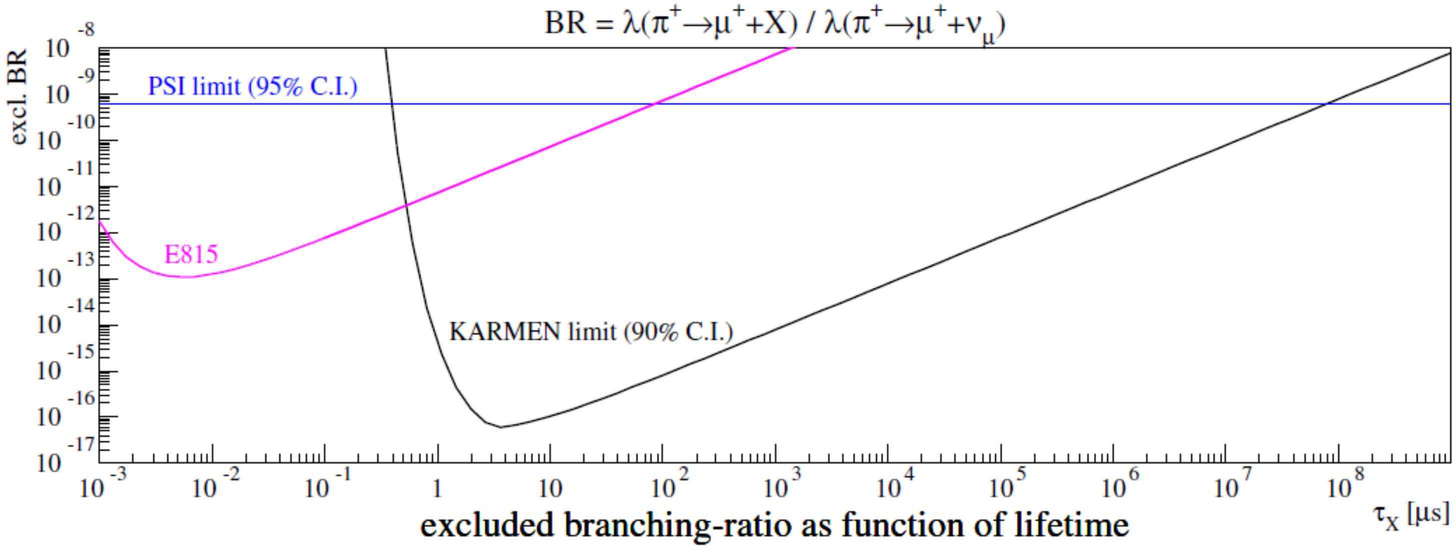
Fitted Beam-Correlated Neutron Background in KARMEN1 and KARMEN2 (After Veto Upgrade)





KARMEN Exclusion Limit on Light Neutralino (pi+ -> mu+ + X)





LSND Detector Location wrt. Target at LANSCE

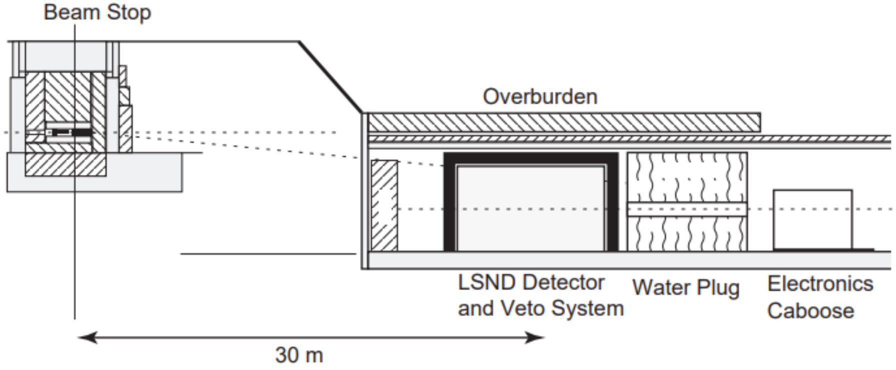


FIG. 1: The layout of the LSND detector and the A6 beam stop area.

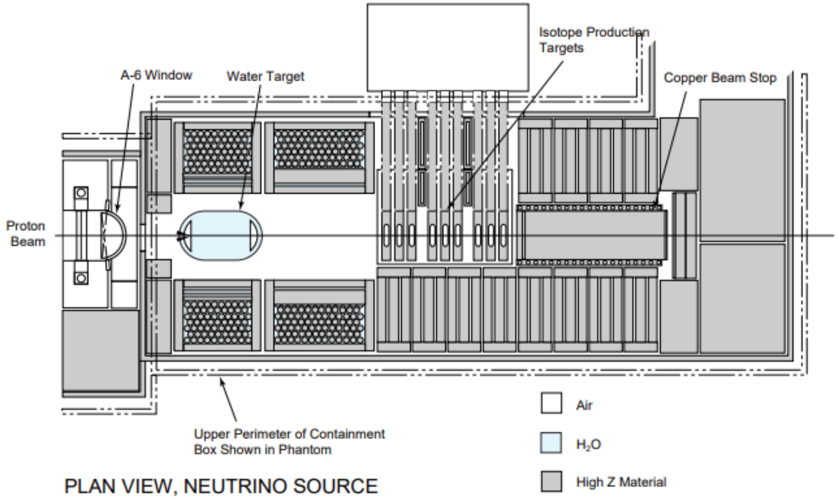


FIG. 2: The layout of the A6 beam stop, as it was configured for the 1993-1995 data taking.

LSND detector has comparable shielding,
neutrons could cause increase in random background for neutron sequence search

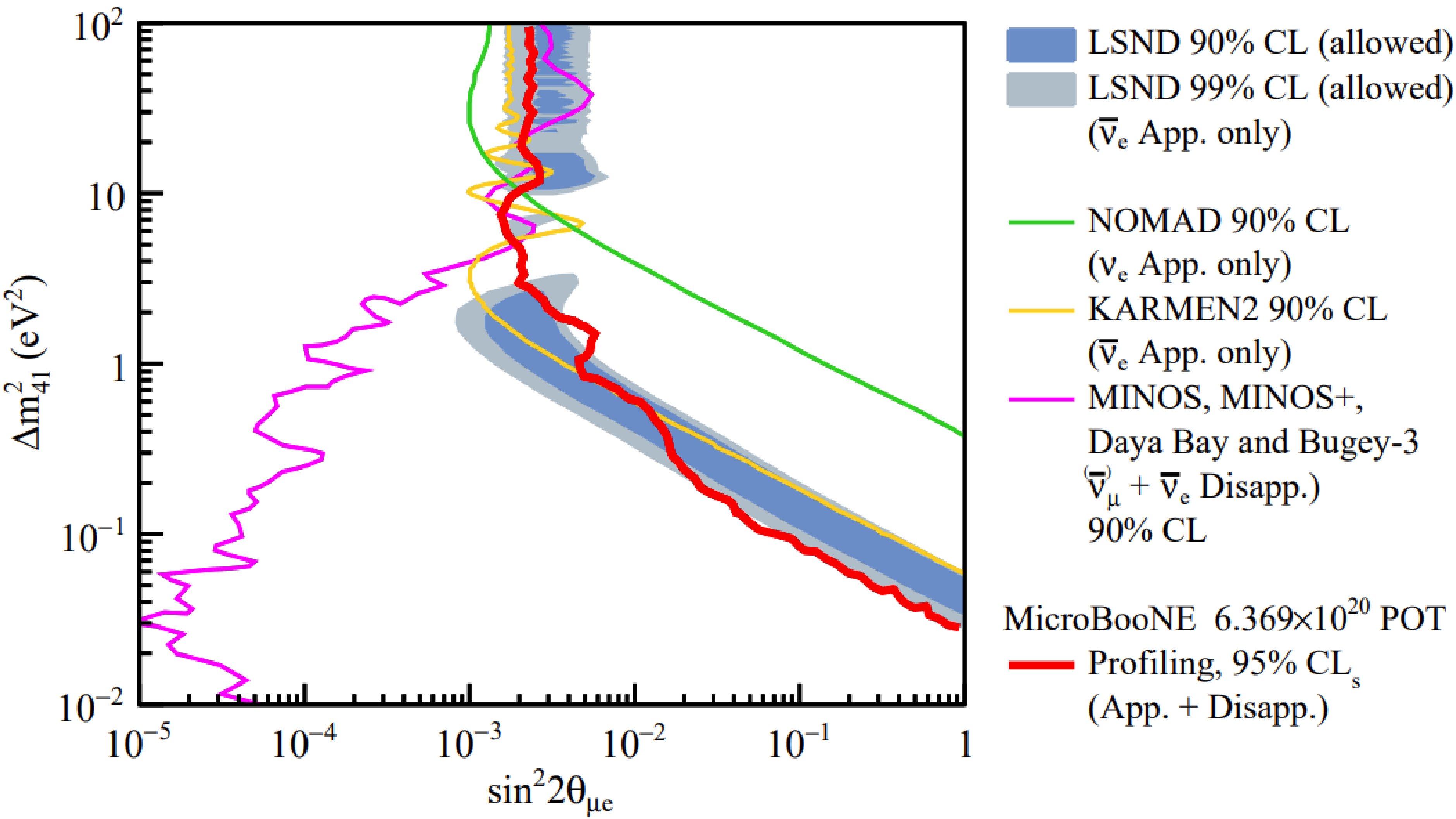
600us wide proton pulses do not allow for muon lifetime resolution (no "time-anomaly" detectable)

ascertained random background from mostly beam off data
⇒ underestimated beam-correlated neutron background?
⇒ or is nuebar contamination underestimated?

arXiv:hep-ex/0104049v3 10 Aug 2001

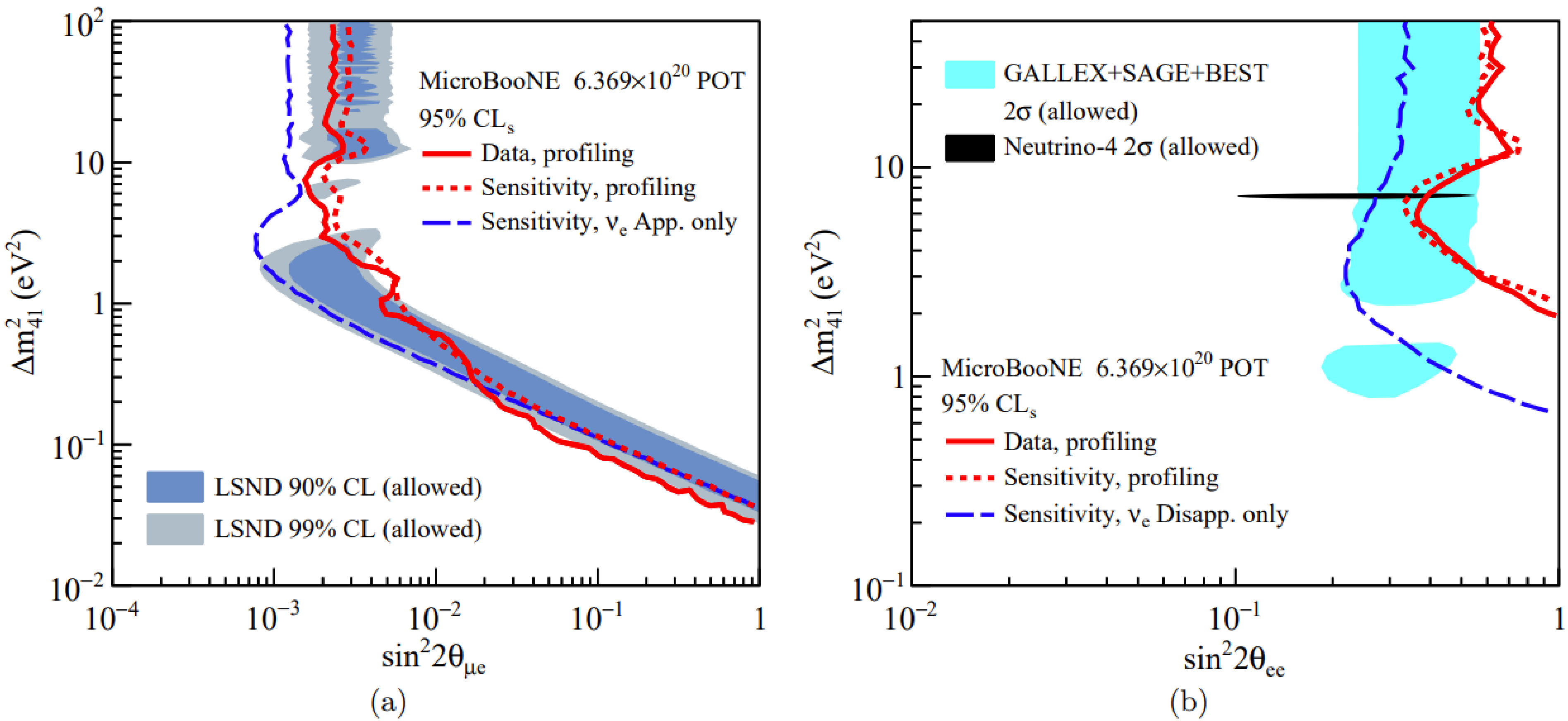
MicroBooNE Result vs. LSND w/ KARMEN2

2210.10216.pdf (arxiv.org)



Degeneracy of MicroBooNE Result

2210.10216.pdf (arxiv.org)



=> New stringent KARMEN1+2 limit on nue disappearance (CPT conservation) could rule out LSND regions together with MicroBooNE!

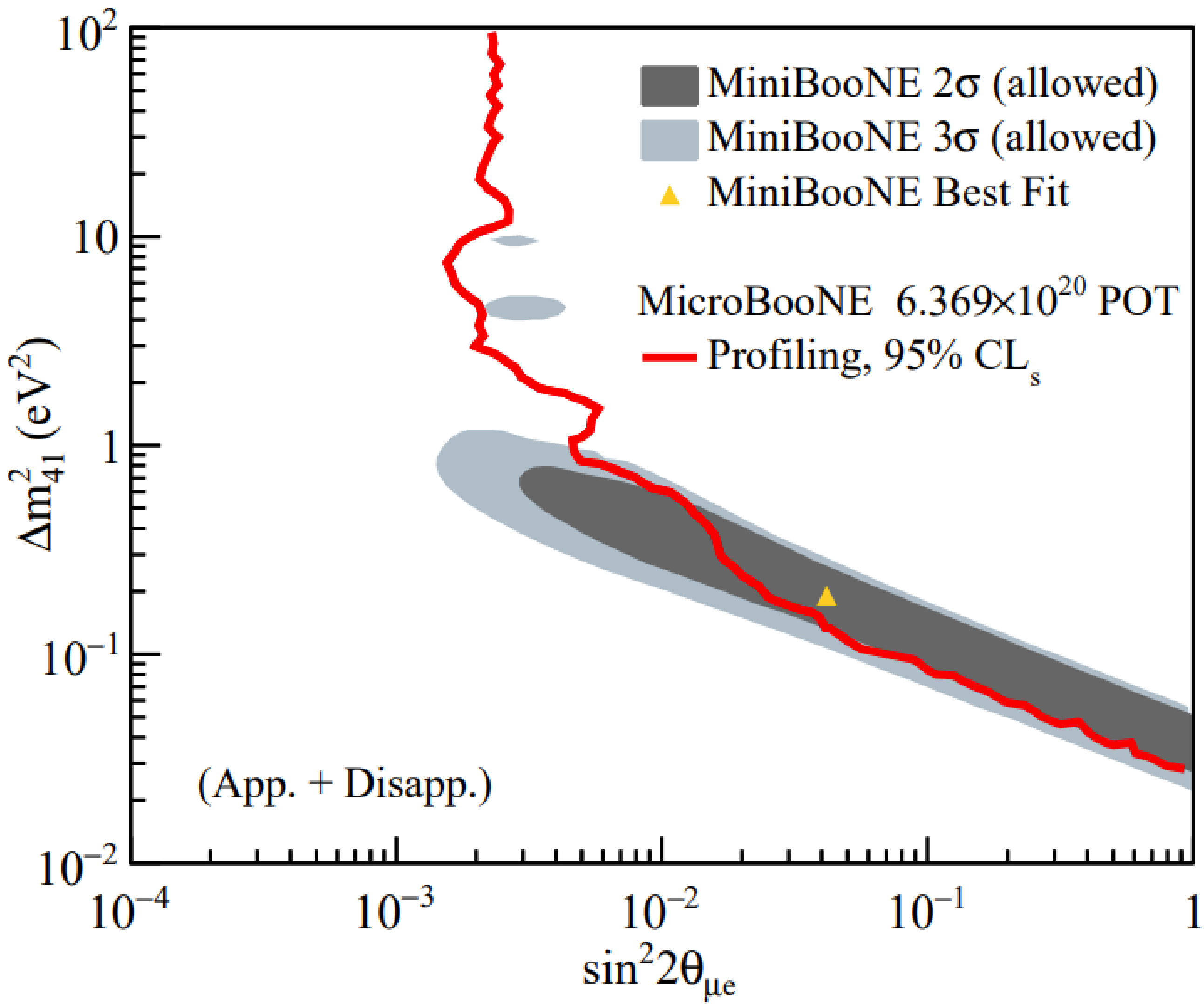
Acknowledgements

CETUP 2023 organizers Barbara and Jaret

Backup Slides

MicroBooNE vs MiniBooNE

2210.10216.pdf (arxiv.org)



Theoretical Cross Section Calculations

Author		*Type of Model*	$\langle\sigma(^{12}C\,(\nu_e\,,e^-\,)\,^{12}N_{g.s.})\rangle$ $[10^{-42}\ cm^2]$
Kolbe	[Kol99]	CRPA	8.9
Auerbach(SIII)	[Aue97]	RPA	10.1
Vogel	[Vog96]	SM	9.1
Volpe	[Vol01]	SM	8.1
Hayes	[Hay00]	SM	7.9
Donnelly	[Don91]	SM	9.4
Fukugita	[Fuk88]	EPT	9.1(9)
Mintz	[Min93]	EPT	8.0

Table 3.4: Comparison of theoretical calculations of the cross section $\langle\sigma\rangle$ for the exclusive CC-reaction $^{12}C\,(\nu_e\,,e^-\,)\,^{12}N_{g.s.}$.

Theoretical Cross Section Calculations
Ratio NC/CC and mu – e – Universality Validation

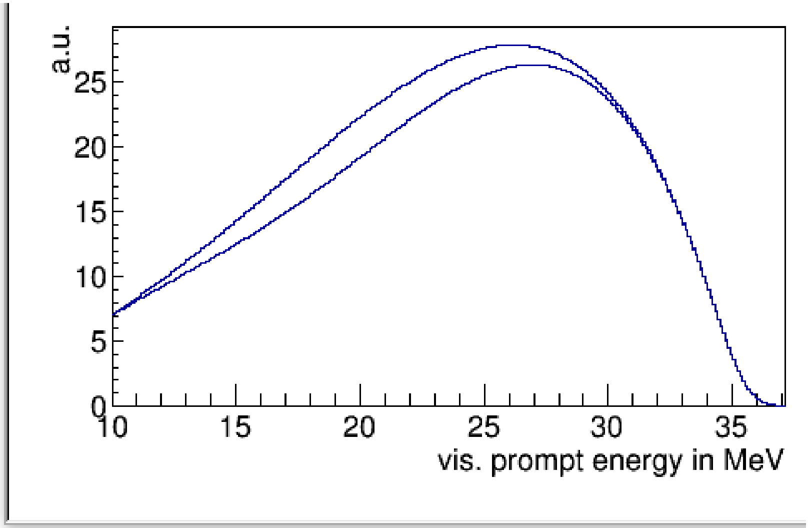
	Cut	K1	K2	K1 + K2
$\langle\sigma(^{12}\mathrm{C}\,(\,\nu\,,\nu'\,)\,^{12}\mathrm{C}^*)\rangle$ $[10^{-42}\,cm^2]$	standard	10.4 ± 0.4	10.0 ± 0.8	10.2 ± 0.4
$\langle\sigma(^{12}\mathrm{C}\,(\,\nu\,,\nu'\,)\,^{12}\mathrm{C}^*)\rangle$ $[10^{-42}\,cm^2]$	full fid.	11.1 ± 0.4	10.7 ± 0.4	10.9 ± 0.3
$\langle\sigma(^{12}\mathrm{C}\,(\,\nu_e\,,\mathrm{e}^-\,)\,^{12}\mathrm{N}_{\mathrm{g.s.}})\rangle$ $[10^{-42}\,cm^2]$	standard	9.9 ± 0.5	9.1 ± 0.5	9.6 ± 0.3
$\langle\sigma(^{12}\mathrm{C}\,(\,\nu_e\,,\mathrm{e}^-\,)\,^{12}\mathrm{N}_{\mathrm{g.s.}})\rangle$ $[10^{-42}\,cm^2]$	full fid.	10.8 ± 0.6	9.9 ± 0.6	10.4 ± 0.4
$R = \langle\sigma^{NC}\rangle/\langle\sigma^{CC}_{gs}\rangle$	standard	1.05 ± 0.06	1.09 ± 0.10	1.07 ± 0.06
$R = \langle\sigma^{NC}\rangle/\langle\sigma^{CC}_{gs}\rangle$	full fid.	1.04 ± 0.07	1.08 ± 0.08	1.05 ± 0.05

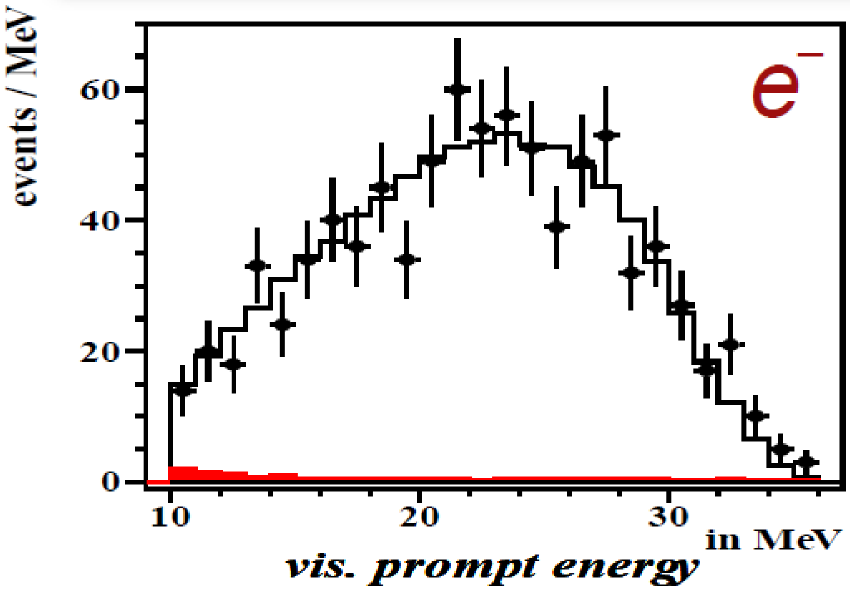
Table 3.13: Measured values of the cross sections for the inclusive NC-reaction $^{12}\mathrm{C}\,(\,\nu\,,\nu'\,)\,^{12}\mathrm{C}^*$, the exclusive CC-reaction $^{12}\mathrm{C}\,(\,\nu_e\,,\mathrm{e}^-\,)\,^{12}\mathrm{N}_{\mathrm{g.s.}}$ and the corresponding ratio $R = \langle\sigma^{NC}\rangle/\langle\sigma^{CC}_{gs}\rangle$ in dependence of the applied cuts (standard cuts for each of the two reactions as introduced in this thesis and moreover a full fiducial cut with $|X_{pr}| < 150\,cm$, $1.5 < ROW_{pr} \leq 31.5$, $1.5 < COL_{pr} \leq 15.5$ and only good modules if $|X_{pr}| > 100\,\mathrm{cm}$). The values for K1 and K2 are always added flux- and efficiency-weighted in order to derive the corresponding global value for KARMEN (K1 + K2).

Author		*Type of Model*	$R = \langle\sigma^{NC}\rangle/\langle\sigma^{CC}_{gs}\rangle$
Kolbe	[Kol99]	CRPA	1.18
Vogel	[Vog96]	SM	1.08
Donnelly	[Don91]	SM	1.27
Fukugita	[Fuk88]	EPT	1.07
Mintz	[Min93]	EPT	1.23

Table 3.14: Comparison of theoretical calculations for the flux-independent ratio $R = \langle\sigma^{NC}\rangle/\langle\sigma^{CC}_{gs}\rangle$ of the cross sections for the NC-reaction $^{12}\mathrm{C}\,(\,\nu\,,\nu'\,)\,^{12}\mathrm{C}^*$ and the exclusive CC-reaction $^{12}\mathrm{C}\,(\,\nu_e\,,\mathrm{e}^-\,)\,^{12}\mathrm{N}_{\mathrm{g.s.}}$.

Good Agreement with Predictions!
7.3 eV^2 Visual Check





7.3 eV^2 Visual Check at Different Baselines