Future sensitivity of Cevns to a weak mixing angle

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Outline

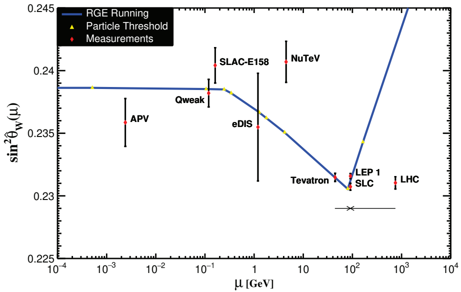
1. Motivation
2. neutrino electron scattering
3. Coherent Elastic Neutrino-Nucleus Scattering
4. Conclusions

Motivation

Motivation

→ The weak mixing angle is a fundamental parameter of the Standard Model and it has been measured with great precision at high energies.

→ At low energies its measurement has been a difficult task, especially in the neutrino sector. On one hand, the interaction of neutrinos with quarks at low energies gave measurements that appeared to be in disagreement with the SM, although a recent evaluation of the sea quark contributions reports coincidence with the standard model (R. D. Ball et al., Nucl. Phys B823 (2009) 195; W. Bentz et al., Phys. Lett B 693 (2010) 462).

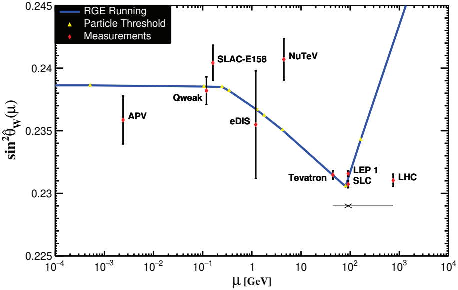


PDG M. Tanabashi et al. PRD 98 (2018) 030001

Motivation

- → From the current measurement of Cevns (Akimov et al. Science 357 (2017) 6356, 1123-1126) we can have a first measurement of the weak mixing angle, although with a large error: $0.117 < \sin^2\theta_W < 0.315$ at 90 % CL (Papoulias, Kosmas, PRD 97 (2018) 033003)
- → The evaluation of the neutron rms radius from COHERENT could shift the APV value to $\sin^2\theta_W = 0.239^{+0.006}_{-0.007}$ (Cadeddu, Dorde, arXiv:1808.10202)

PDG M. Tanabashi et al. PRD 98 (2018) 030001



$$\sin^2\widehat{\theta}_W(\mu) = \widehat{\kappa}(\mu)\sin^2\widehat{\theta}_W(M_Z)$$

A. Czarnecki and W. J. Marciano, Phys. Rev. D **53**, 1066 (1996).

$$\bar{\nu}_e + e^- \rightarrow \bar{\nu}_e + e^-$$

Reactor and accelerator experiments

Experiment	E_ν(MeV)	T(MeV)	Published cross-section	$\sin^2\theta_W$
Reactor $\bar{\nu}_e$:				
Krasnoyarsk	$3.2-8.0$	$3.3-5.2$	$[4.5\pm2.4]\times10^{-46}\text{cm}^2/\text{fision}$	$0.22^{+0.7}_{-0.8}$
Rovno	$0.6-8.0$	$0.6-2.0$	$[1.26\pm0.62]\times10^{-44}\text{cm}^2/\text{fision}$	$\dots$
MUNU	$0.7-8.0$	$0.7-2.0$	$[1.07\pm0.34]$events/day	$\dots$
Texono	$3.0-8.0$	$3.0-8.0$	$[1.08\pm0.21\pm0.16]\cdot\sigma_{SM}]$	$0.251\pm0.031\pm0.024$
Accelerator ν_e:				
LAMPF	$7-50$	$7-50$	$[10.0\pm1.5\pm0.9].\ 10^{-45}\text{cm}^2$	0.249 ± 0.063
LSND	$20-50$	$20-50$	$[10.1\pm1.1\pm1.0].\ 10^{-45}\text{cm}^2$	0.248 ± 0.051

Texono

- The neutrino laboratory is located at the Kuo-Sheng Nuclear Power Plant a distance of 28 m from the reactor core with 2.9 GW of thermal power, having a total flux of about $6.4\times10^{12}cm^{-2}s^{-1}$.
- Fuel proportions: ^{235}U-55%, ^{239}Pu-32%, ^{238}U-7%, ^{241}Pu-6%.
- Original neutrino flux used: $\lambda(E_\nu)=\exp\left\{a_0+a_1E_\nu+a_2E_\nu^2\right\}$.
- Resolution function: $R(T,T')=\frac{1}{\sqrt{2\pi}\sigma}\exp\left\{-\frac{(T-T')^2}{2\sigma^2}\right\}$; $\sigma=\sigma(T)=0.0325\sqrt{T/MeV}$.

M. Deniz, et al., Phys. Rev. D 81 (2010) 072001.

Neutrino data analysis

The number of events (in the $i-$th bin) is given by

$$N_i^{\mathrm{theo}}(\sin^2\hat{\theta}_W) = \kappa \int\int\int_{T'_i}^{T'_{i+1}} \lambda(E_\nu)\frac{d\sigma(E_\nu, T, \sin^2\hat{\theta}_W)}{dT}R(T,T')dT'dTdE_\nu,$$

- $\lambda(E_\nu) = \sum_k f_k\,\lambda_k(E_\nu) = \sum_k f_k\,\exp\left[\sum_{p=1}^{6}\alpha_{pk}E_\nu^{p-1}\right]$,
- $R(T,T') = \frac{1}{\sqrt{4\pi}\sigma}\exp\left(\frac{-(T-T')^2}{2\sigma^2}\right)$,
- $$\frac{d\sigma}{dT} = \frac{2G_F^2 m_e}{\pi}\left\{g_L^2(T)\left[1+\frac{\alpha}{\pi}f_-(z)\right] + g_R^2(T)(1-z)^2\left[1+\frac{\alpha}{\pi}f_+(z)\right] - g_R(T)g_L(T)\frac{m_e}{E_\nu}z\left[1+\frac{\alpha}{\pi}f_{+-}(z)\right]\right\},$$

Taking into account the new phenomenological parametrization of the spectrum [1]

$$\lambda_k(E_\nu) = \exp\left[\sum_{p=1}^{6} \alpha_{pk}\, E_\nu^{p-1}\right] ,$$

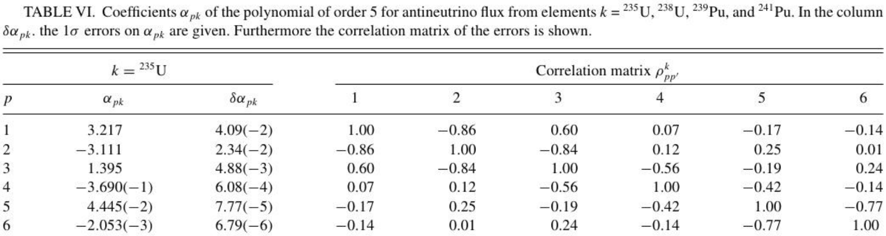


TABLE VI. Coefficients α_{pk} of the polynomial of order 5 for antineutrino flux from elements $k = {}^{235}\mathrm{U}, {}^{238}\mathrm{U}, {}^{239}\mathrm{Pu}$, and ${}^{241}\mathrm{Pu}$. In the column $\delta\alpha_{pk}$. the 1σ errors on α_{pk} are given. Furthermore the correlation matrix of the errors is shown.

$k = {}^{235}\mathrm{U}$			Correlation matrix $\rho^k_{pp'}$					
p	α_{pk}	$\delta\alpha_{pk}$	1	2	3	4	5	6
1	3.217	4.09(−2)	1.00	−0.86	0.60	0.07	−0.17	−0.14
2	−3.111	2.34(−2)	−0.86	1.00	−0.84	0.12	0.25	0.01
3	1.395	4.88(−3)	0.60	−0.84	1.00	−0.56	−0.19	0.24
4	−3.690(−1)	6.08(−4)	0.07	0.12	−0.56	1.00	−0.42	−0.14
5	4.445(−2)	7.77(−5)	−0.17	0.25	−0.19	−0.42	1.00	−0.77
6	−2.053(−3)	6.79(−6)	−0.14	0.01	0.24	−0.14	−0.77	1.00

The covariance matrix is given by

$$V^k_{pp'} = \delta\alpha_{pk}\,\delta\alpha_{p'k}\,\rho^k_{pp'} \;\rightarrow (\delta N^k_i)^2 = \sum_{pp'} \frac{\partial N^k_i}{\partial\alpha_{pk}}\frac{\partial N^k_i}{\partial\alpha_{p'k}} V^k_{pp'} .$$

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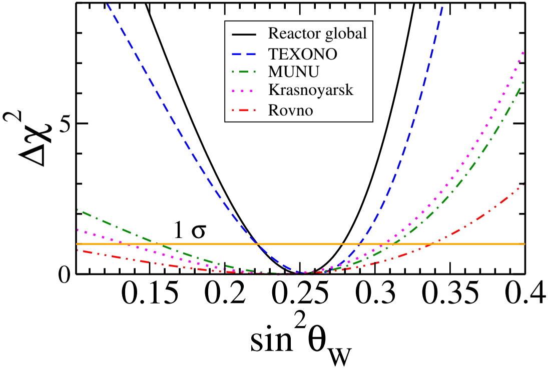
[1] T. Mueller, et al., Phys. Rev. C 83 (2011) 0.54615.

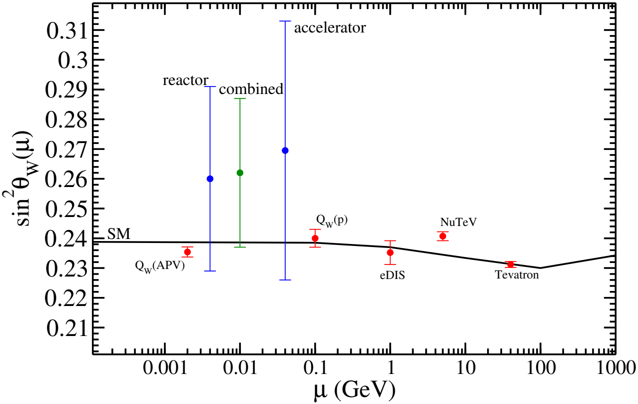
Limits on the weak mixing angle



$$\boxed{\sin^2\theta_W = 0.252 \pm 0.030.}$$

B. C. Canas, et al., Phys. Lett. B **761**, 450 (2016).

Limits on the weak mixing angle



$$\boxed{\sin^2\theta_W = 0.254 \pm 0.024.}$$

B. C. Canas, et al., Phys. Lett. B **761**, 450 (2016).

Coherent Elastic Neutrino-Nucleus Scattering

Future experiments to measure CENNS at reactors

- TEXONO: 1kg of germanium Nucl.Instrum.Meth. A836 (2016) 67-82
- CONUS: 4-100 kg of germanium JHEP 1703 (2017) 097
- Connie: Si detector at Angra Reactor in Brasil JINST 11 (2016) P07024
- RED100: Xe detector at Kalinin Reactor JINST 8 (2013) P10023
- MINER: GeSi at a Reactor in Texas Nucl.Instrum.Meth. A853 (2017) 53

Future experiments to measure CENNS at reactors

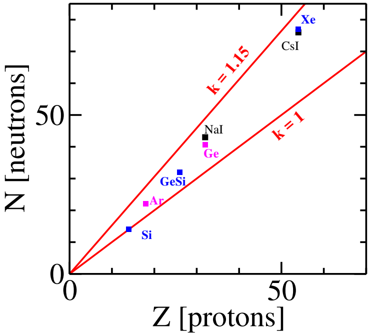
	T_{thres}	Baseline	Z/N	Det. Tec.	Fid. Mass
CONNIE	28 eV	30 m	1.0	CCD (Si)	1 kg
RED100	500 eV	19 m	0.70	Lq.Xe	100 kg
MINER	10 eV	1 m	0.81	^{72}Ge:^{28}Si (2:1)	30 kg
TEXONO	100 eV	28 m	0.79	HPGe	1 kg
CONUS	100 eV	10 m	0.79	HPGe	100 kg

CEvNS

$$G_V = \left[F_Z^V(q^2) g_V^p Z + F_N^V(q^2) g_V^n N \right]$$

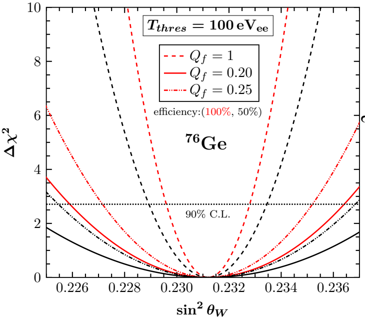
$$\begin{aligned} g_V^p &= \rho_{\nu N}^{\mathrm{NC}} \left(\frac{1}{2} - 2\hat{\kappa}_{\nu N} \hat{s}_Z^2 \right) \\ g_V^n &= -\frac{1}{2} \rho_{\nu N}^{\mathrm{NC}} \end{aligned}$$

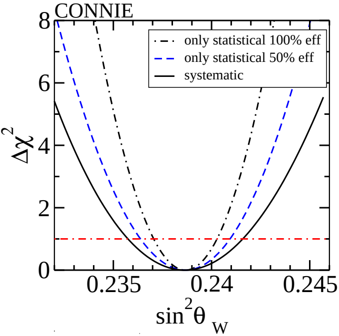
Target for CEνNS



updated from J. Barranco, OGM, T.I. Rashba JHEP 0512:021 (2005)

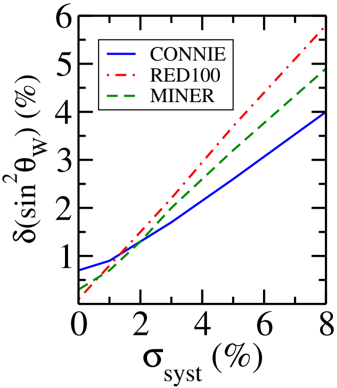
Texono and CONNIE





T.S. Kosmas, OGM, D.K. Papoulias, M. Tortola, J.W.F. Valle, PLB **750** 459 (2015)

Canas et al. Phys. Lett. B **784**, 159 (2018)

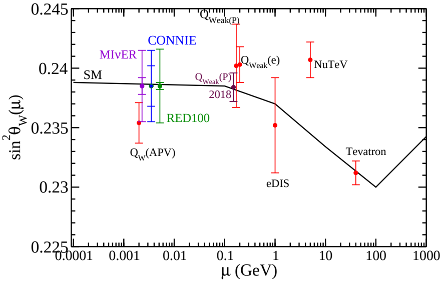


Canas et al. Phys. Lett. B **784**, 159 (2018)

Future experiments to measure CENNS at reactors

	50 %	eff.	100 %	eff.	including	systematics
experiment	$\delta_{\sin^2\theta_W}$	%	$\delta_{\sin^2\theta_W}$	%	$\delta_{\sin^2\theta_W}$	%
TEXONO	0.0015	0.6	0.0011	0.5	0.0028	1.2
RED100	0.0004	0.2	0.0003	0.1	0.0031	1.3
MINER	0.0010	0.4	0.0007	0.3	0.003	1.3
CONNIE	0.0023	1.0	0.0017	0.7	0.003	1.3
CONUS	0.0003	0.1	0.0002	0.1	0.0023	1.0

expectations for $\sin^2\theta_W$



Canas et al. Phys. Lett. B **784**, 159 (2018)

D. Androic et al., Nature **557** 207 (2018)

C. Patrignani et al., Chin. Phys. C **40** 100001 (2016)

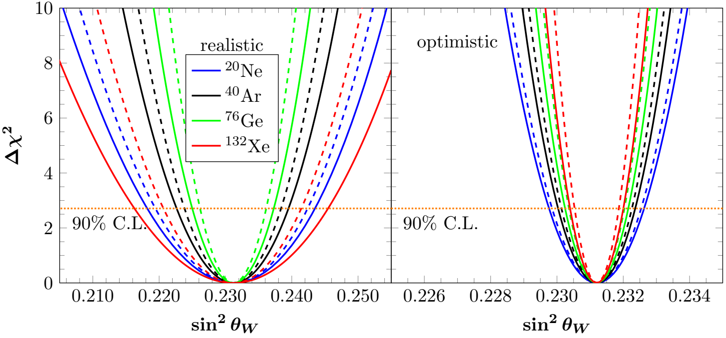
For the current constraint from COHERENT see D. K. Papoulias and T. Kosmas Phys.Rev. D97 (2018) no.3, 033003

COHERENT CENNS

COHERENT experiment					
		^{20}Ne	^{40}Ar	^{76}Ge	^{132}Xe
Realistic	Mass	391 kg	456 kg	100 kg	100 kg
	Distance	46 m	46 m	20 m	40 m
	Efficiency	50%	50%	67%	50%
	Recoil window	30-160 keV	20-120 keV	10-78 keV	8-46 keV
Optimistic	mass	1 ton	1 ton	1 ton	1 ton
	Distance	20 m	20 m	20 m	20 m
	Efficiency	100%	100%	100%	100%
	Recoil window	1keV – $T_{\rm max}$	1keV – $T_{\rm max}$	1keV – $T_{\rm max}$	1keV – $T_{\rm max}$

T.S. Kosmas, OGM, D.K. Papoulias, M. Tortola, J.W.F. Valle, PRD **92** 013011 (2015)

COHERENT CENNS



T.S. Kosmas, OGM, D.K. Papoulias, M. Tortola, J.W.F. Valle, PRD **92** 013011 (2015)

COHERENT CENNS

Nucleus	^{20}Ne	^{40}Ar	^{76}Ge	^{132}Xe
$\delta s_W^2(\nu_\mu)$	0.0052 [0.0007]	0.0042 [0.0006]	0.0031 [0.0005]	0.0073 [0.0004]
Uncer. (%)	2.23 [0.30]	1.82 [0.26]	1.34 [0.22]	3.14 [0.17]

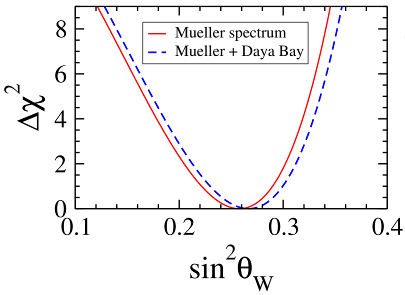
T.S. Kosmas, OGM, D.K. Papoulias, M. Tortola, J.W.F. Valle, PRD **92** 013011 (2015)

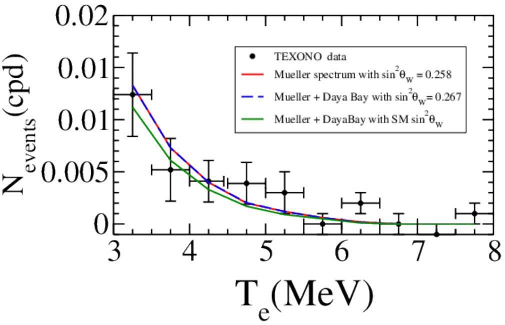
Conclusions

- ✓ After the first measurement of Cevns, a new window for testing new physics is open.
- ✓ The weak mixing angle can be measured with precision in the low energy region.
- ✓ A deviation from the Standard Model prediction would be a clear hint of new physics

Thanks

Limits on the weak mixing angle





$$\boxed{\sin^2\theta_W = 0.267 \pm 0.033 \quad \text{(Mueller + DayaBay spectrum).}}$$

B. C. Canas, et al., Phys. Lett. B **761**, 450 (2016).