Measurement of the Weinberg angle with low-energy beta-beams

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1. The beta-beam concept

2. Low-energy beta-beams

3. Measuring the Weinberg angle at low-energy beta-beams

4. Conclusions
Outline

1. The beta-beam concept
2. Low-energy beta-beams
3. Measuring the Weinberg angle at low-energy beta-beams
4. Conclusions
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The beta-beam concept


*Pure, collimated, well-known neutrino fluxes can be obtained by boosted ions decaying through beta-decay*
The beta-beam concept


Strong synergy with EURISOL Use CERN existing accelerator
Need for a decay ring

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Weinberg angle at low-energy beta-beams
The beta-beam concept


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440 kton $\text{H}_2\text{O}$ Čerenkov detector to study CP and T violation through $\nu$ oscillations...
... but also supernova neutrinos and proton decay.
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CP-violation phase and $\theta_{13}$

Explore $\theta_{13} \sim 1^\circ$ and $\delta \sim 20^\circ$.

Different regimes

- Standard $\gamma = 100$
- High-energy $\gamma \gg 100$
- Low-energy $\gamma = 5 - 14$

M. Mezzetto, Talk at NUFACT05, June 2005, Rome
The beta-beam concept

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Weinberg angle at low-energy beta-beams
Low-energy beta-beams


Ions accelerated in PS
($\gamma = 5 - 14$)

Small ($L_{SS} \sim 700$ m) storage ring

Near ($\sim 10$ m) 1 kton $\text{H}_2\text{O}$

Čerenkov detector

$^{18}\text{Ne} \rightarrow ^{18}\text{F} + e^+ + \nu_e$:
($\nu_e$, $e^-$) scattering
($\nu_e$, $^{16}\text{O}$) capture

$^{6}\text{He} \rightarrow ^{6}\text{Li} + e^- + \bar{\nu}_e$
($\bar{\nu}_e$, $e^-$) scattering
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\[
\begin{align*}
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& (\nu_e, e^-) \text{ scattering} \\
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\text{6He} & \rightarrow \text{6Li} + e^- + \bar{\nu}_e \\
& (\bar{\nu}_e, e^-) \text{ scattering} \\
& (\bar{\nu}_e, ^{16}O) \text{ capture} \\
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The concept | Low-energy \( \sin^2 \theta_W \) | Conclusions

Low-energy beta-beams


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João H. de Jesus | Weinberg angle at low-energy beta-beams

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Low-energy beta-beams

Rich physics program

- **Neutrino-nucleus interactions**: J. Serreau and C. Volpe, PRC 70 (2004); A. Bueno, M. C. Carmona, J. Lozano and S. Navas, PRD 74 (2006);
- **Neutrino magnetic moment**: G. C. McLaughlin and C. Volpe, PLB 591 (2004);
- **Electroweak tests** *(this talk)*: A. B. Balantekin, JHJ and C. Volpe, PLB 634 (2006);
- **CVC tests** *(next talk)*: A. B. Balantekin, JHJ, R. Lazauskas and C. Volpe, PRD 73 (2006);
- **Supernova neutrino spectra** *(tomorrow)*: N. Jachowicz and G. C. McLaughlin, PRL 96 (2006);
Measuring $\sin^2 \theta_W$ at low-energy beta-beams

- APV and Møller scattering consistent with SM prediction;
- NuTEV anomaly: NC/CC in $(\bar{\nu}_\mu, N)$ and $(\nu_\mu, N)$ DIS disagrees with the SM prediction by $3\sigma$;
- Probing $\sin^2 \theta_W$ through additional experiments would be very useful.
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Figure credits: K. Jungmann
The concept

Low-energy

$\sin^2 \theta_W$

Conclusions

Measuring $\sin^2 \theta_W$ at low-energy beta-beams

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Neutrino-electron scattering

\[ \frac{d\sigma_{(\nu,e)}}{dT_e} \sim (g_V^2 + g_A^2) + (g_V^2 - g_A^2) \left( 1 - \frac{T_e}{E_\nu} \right)^2 + \cdots \]

\[ g_V = \frac{1}{2} + 2 \sin^2 \theta_W + \cdots \quad g_A = \pm \frac{1}{2} + \cdots \]

Integrating over \( T_e \) and averaging over the neutrino flux \( \langle \phi_\nu \rangle \)

\[ \langle \sigma_{(\nu,e)} \rangle \sim -g_V (g_V + g_A) m_e \langle \phi_\nu \rangle + \frac{4}{3} \left( g_V^2 + g_A^2 + g_V g_A \right) \langle E_\nu \rangle \]

At low-energy beta-beams, the number of \((\nu, e)\) events is

\[ N_{(\nu,e)} \sim (\text{ions/s}) \Delta t \langle \sigma_{(\nu,e)} \rangle \]
Neutrino-electron scattering

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The concept

Low-energy $\sin^2 \theta_W$

Conclusions

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\[ N_{(\nu,e)} \sim (\text{ions/s}) \Delta t \langle \sigma_{(\nu,e)} \rangle \]
The slope tells us about $\sin^2 \theta_W$; 

Neutrino flux dependence on $\gamma$; 

$N(\gamma)E_0(\gamma)$ independent of intensity of ions and duration of measurement... $\sigma_{NE_0}$ depends on those; 

$$\Delta \chi^2(f, \Delta t) \sim \sum \gamma \left[ \frac{N_{\text{data}}(\gamma) - N_{\text{exp}}(\gamma)}{\sigma_{\text{data}}(\gamma)} \right]^2$$

$\Delta t = 3 \times 10^7$ s (a.k.a one year)

$\bar{\nu} (\text{He}) : f = 2.7 \times 10^{12}$ ions/s  \hspace{1cm} $\nu (\text{Ne}) : f = 0.5 \times 10^{11}$ ions/s
The concept: Low-energy sin$^2 \theta_W$

Conclusions

The Weinberg angle at beta-beams

$$N(\gamma)E_0(\gamma) - g_A^2 m_e = \frac{4}{3} \left( g_A^2 + g_V^2 + g_V g_A \right) \left[ \frac{\langle E(\gamma) \rangle}{\langle \phi(\gamma) \rangle} - \frac{3}{4} m_e \right]$$

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Low-energy

$\sin^2 \theta_W$

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$\langle E_\nu(\gamma) \rangle / \langle \Phi_{tot}(\gamma) \rangle - (3/4)m_e$ [MeV]

$N(\gamma)E_0(\gamma) - g_A$ $m_e$ [MeV]

slope $\sim g_V^2 + g_A^2 + g_V g_A$

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Weinberg angle at low-energy beta-beams
The concept

The Weinberg angle at beta-beams

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$\phi_{\text{tot}}(E_\nu) [\text{MeV}^{-1}\text{s}^{-1}]$

$\gamma = 12$

$\gamma = 7$

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\[ f (\text{He}) : \quad f = 2.7 \times 10^{12} \text{ ions/s} \quad \sigma (\text{He}) : \quad f = 0.5 \times 10^{11} \text{ ions/s} \]
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Short measurement duration
Low intensity of ions

\[ \frac{N(\gamma)E_0(\gamma)}{\Phi_{\text{tot}}(\gamma)} - \frac{3}{4}m_e \text{ [MeV]} \]
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$<E_{\nu}(\gamma)/<\Phi_{tot}(\gamma)> - (3/4)m_e \text{ [MeV]}$

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Low-energy $\sin^2 \theta_W$

Conclusions

$0.15 \quad 0.18 \quad 0.21 \quad 0.24 \quad 0.27 \quad 0.3$

$\sin^2 \theta_W$

$\Delta \chi^2$

$\gamma = 7.12$

antineutrinos

neutrinos

$1\sigma = 12.3\%$

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Weinberg angle at low-energy beta-beams
The concept

Low-energy $\sin^2 \theta_W$

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$\Delta \chi^2 = 7, 8, 9, 10, 11, 12$

$\gamma = 7, 12$

$\gamma = 12$

$12.3\%$

$15.2\%$

$7.1\%$

João H. de Jesus

Weinberg angle at low-energy beta-beams
The concept

Low-energy $\sin^2 \theta_W$

Conclusions

$0.15 \ 0.18 \ 0.21 \ 0.24 \ 0.27 \ 0.3$

$\sin^2 \theta_W$

$\Delta \chi^2 = 7, 8, 9, 10, 11, 12$

$\chi^2 = 7, 12$

$\chi^2 = 12$

$12.3\%$

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$0.15 \ 0.18 \ 0.21 \ 0.24 \ 0.27 \ 0.3$

$\sin \ 2 \ \theta \ W$

$\Delta \chi^2$

$\gamma=7, 8, 9, 10, 11, 12$

$\gamma=7, 12$

$\gamma=12$

12.3\%

15.2\%

7.1\%
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Conclusions

1e+12 3e+12 5e+12 7e+12 9e+12

6

\( ^6 \text{He}^{2+} \) intensity at the storage ring [ions/s]

3

18

\( \sigma \) uncertainty in \( \sin^2 \theta_W \) [%]

1 year

2.7x10^{12} ions/s

Measurement duration for each \( \gamma \) [s]

2e+07 4e+07 6e+07 8e+07 1e+08

one \( \gamma \)
two \( \gamma \)'s

two \( \gamma \)'s

six \( \gamma \)'s

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Systematic error at each $\gamma$ [%]

$1\sigma$ uncertainty in $\sin^2 \theta_W$ [%]

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Weinberg angle at low-energy beta-beams
Low-energy beta-beams provide *clean* single type neutrino fluxes plus a range of $\langle E_\nu \rangle$.

They can be used to measure the Weinberg angle at $Q \sim 10^{-2}$ GeV to a better precision than LSND.

A factor of three increase in the intensity of the ions (plus controlled systematics) can bring the $1\sigma$ uncertainty in the Weinberg angle down to $7\% - 10\%$. 
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