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

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International Workshop on Fundamental Symmetries:
From Nuclei and Neutrinos to the Universe
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Outline

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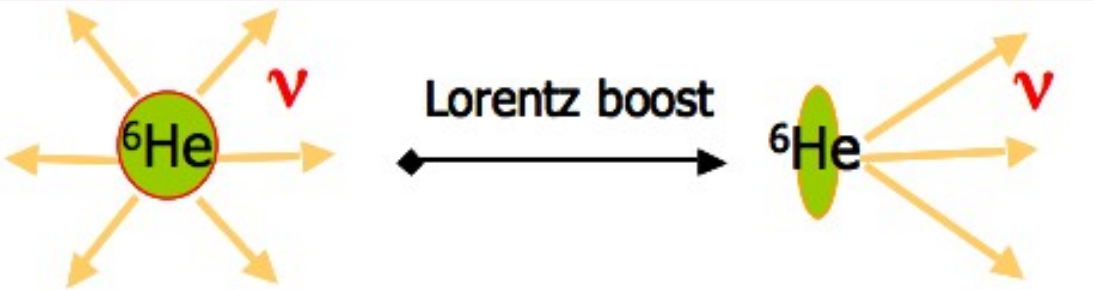
The beta-beam concept

Original idea by P. Zucchelli, Phys. Lett. B **532** (2002):
Pure, collimated, well-known neutrino fluxes can be obtained by boosted ions decaying through beta-decay



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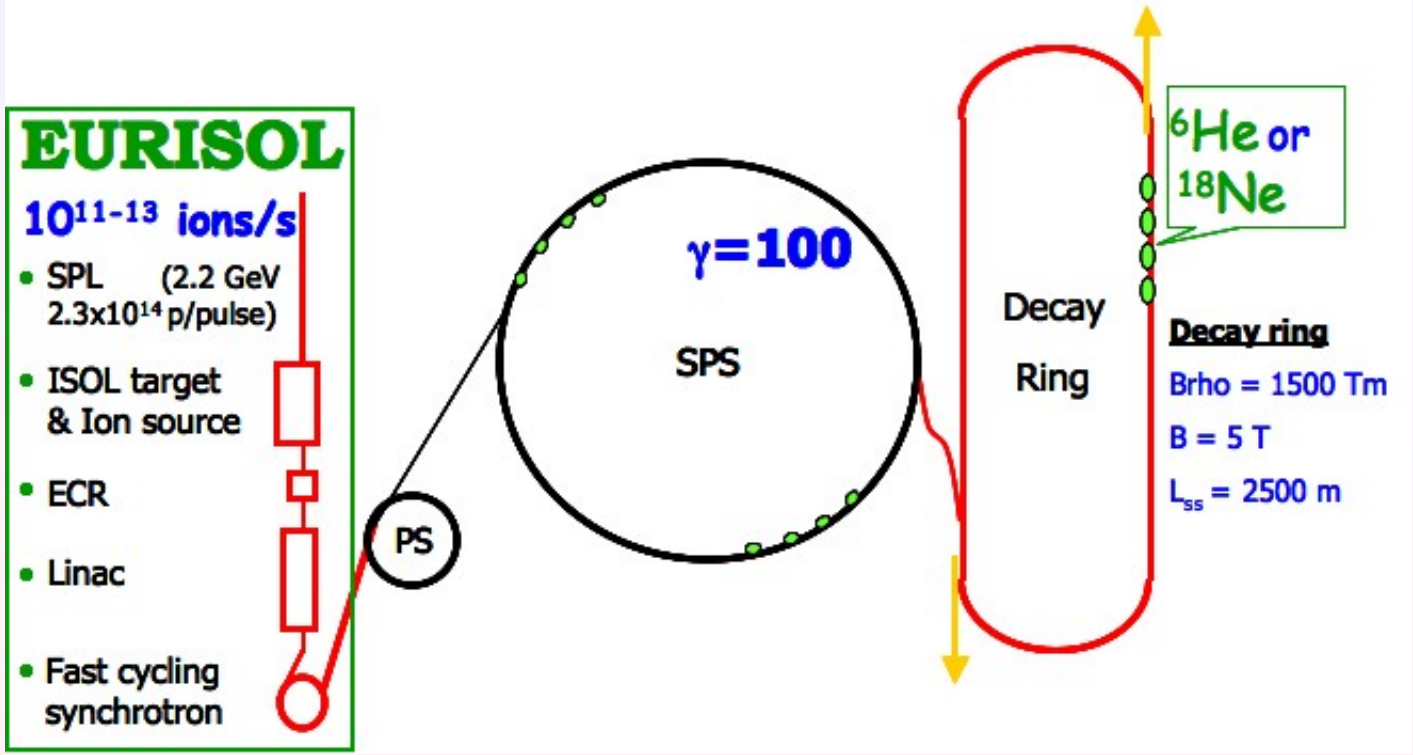

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Need for a decay ring

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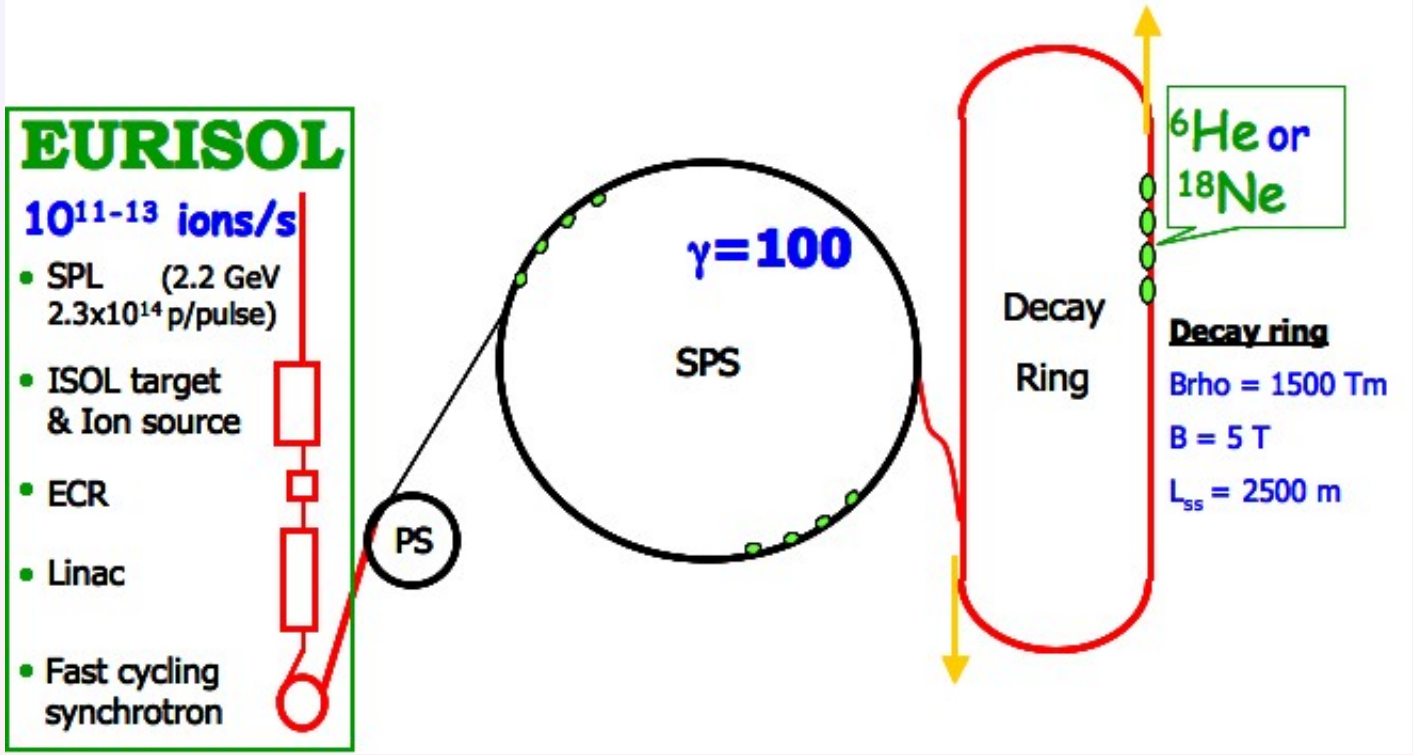

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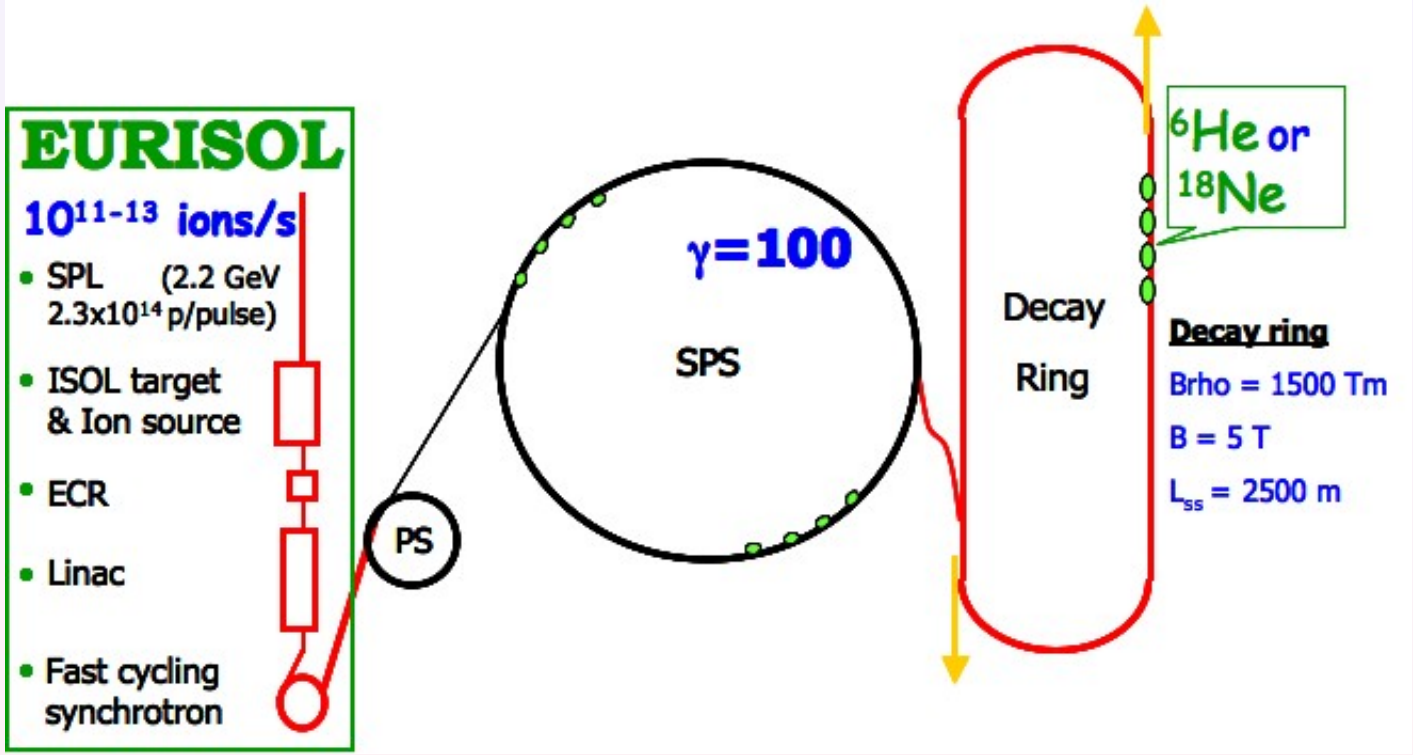

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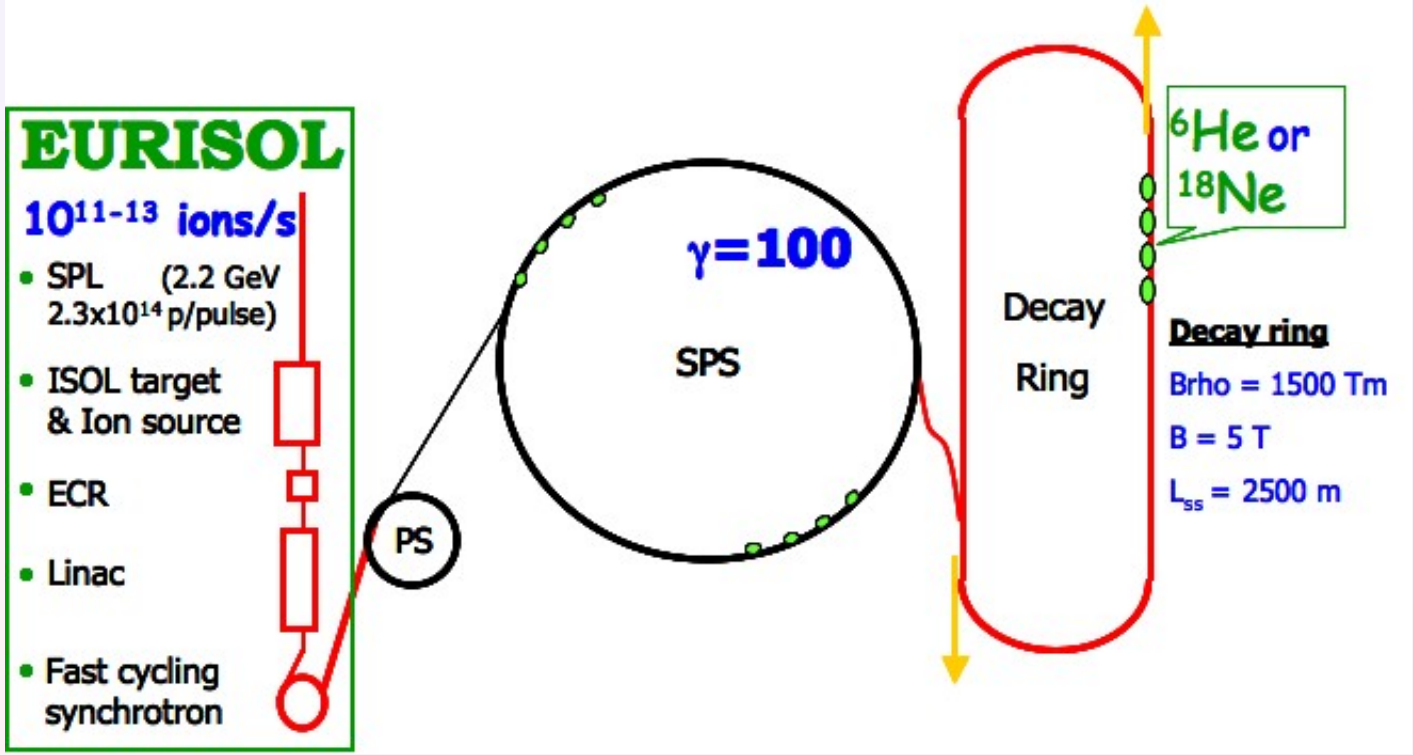

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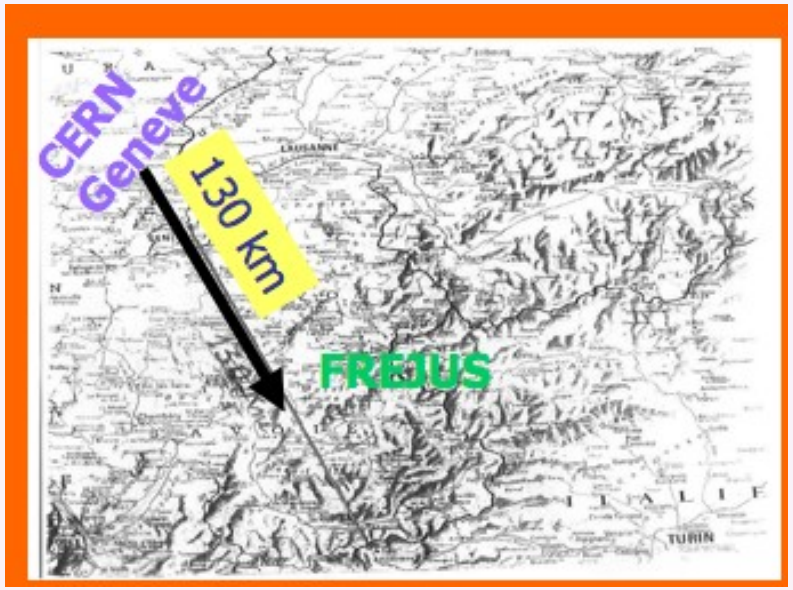

440 kton H_2O Čerenkov detector to study CP and T violation through ν oscillations...
... but also supernova neutrinos and proton decay.

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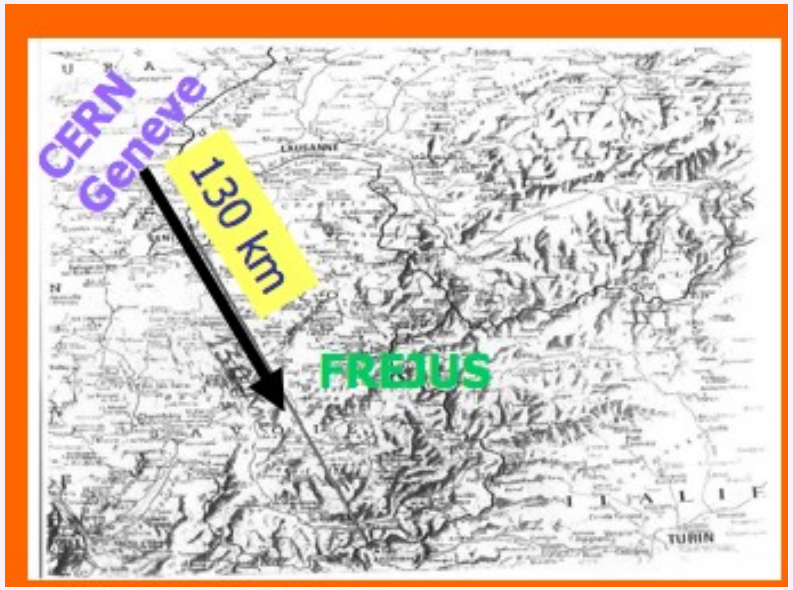

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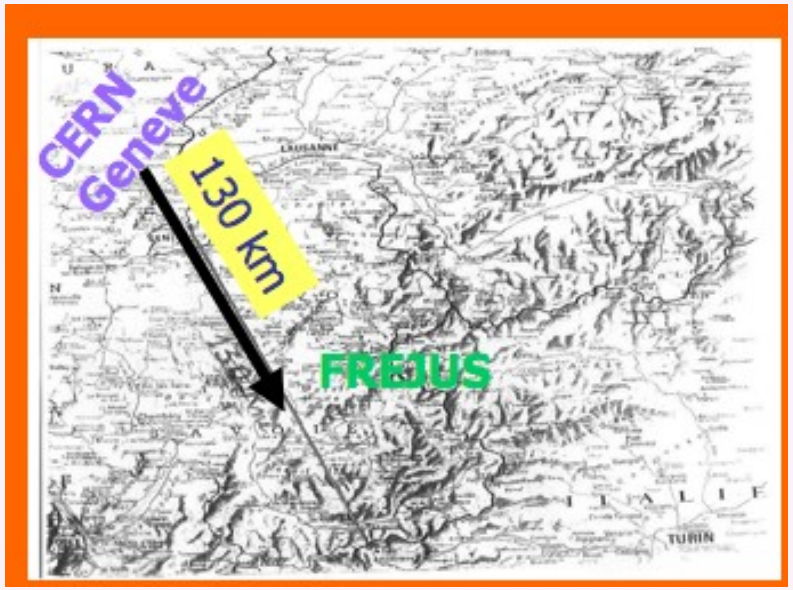

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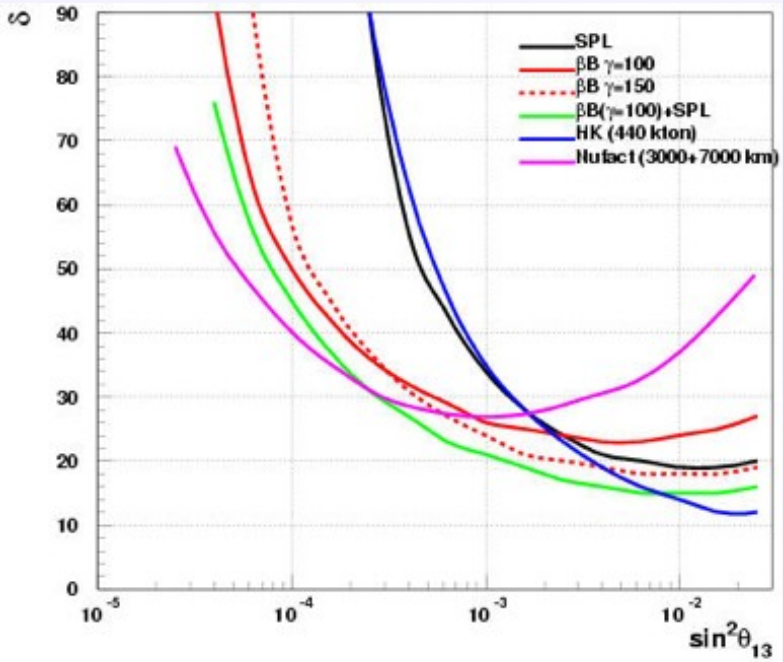

M. Mezzetto, Talk at NUFACT05, June 2005, Rome

CP-violation phase and θ_{13}

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

Different regimes

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

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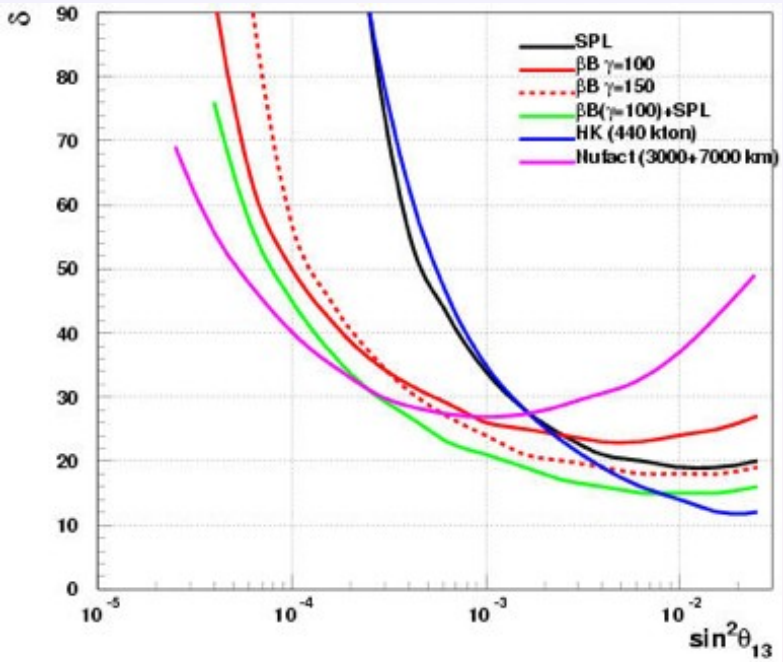

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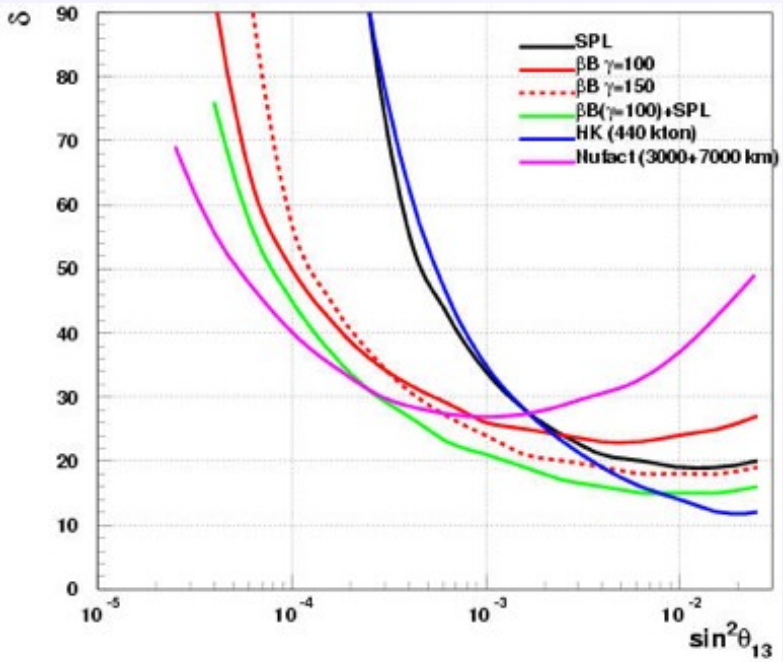

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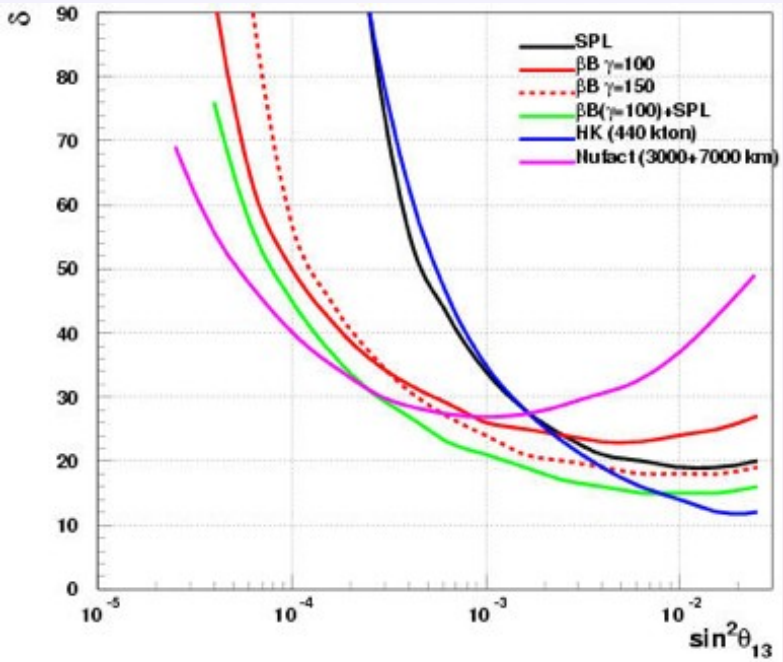

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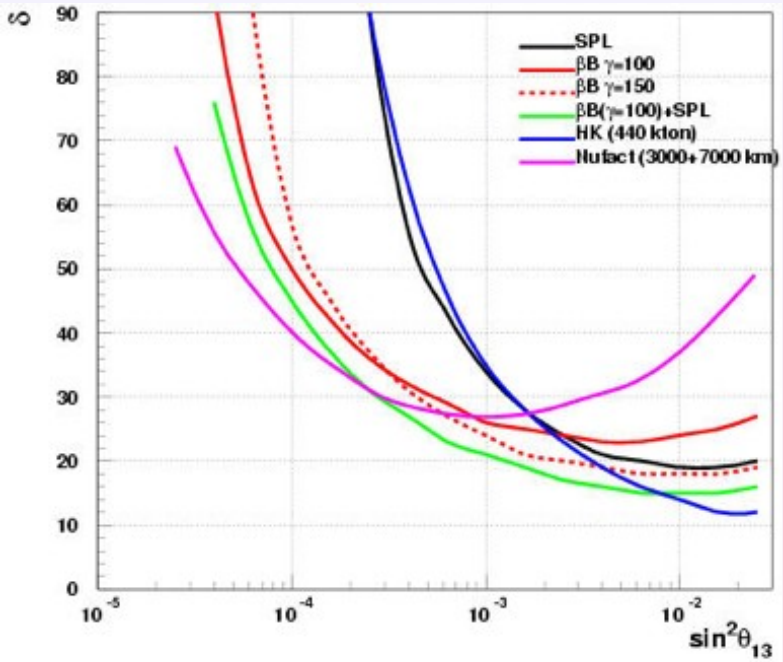

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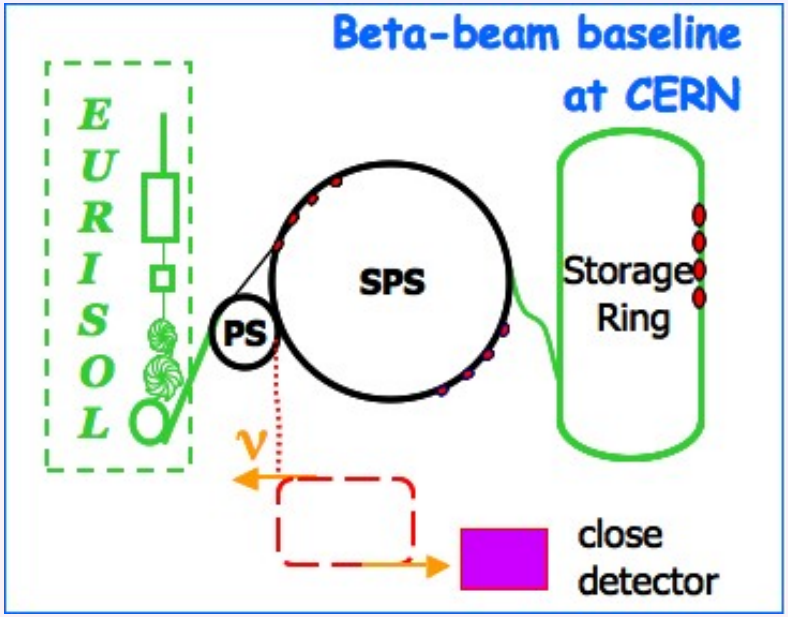

C. Volpe, J. Phys. G. **30** (2004)

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

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

Near ($\sim$10 m) 1 kton H_2O Čerenkov detector

$^{18}\mathrm{Ne} \rightarrow {}^{18}\mathrm{F} + e^+ + \nu_e$:

(ν_e, e^-) scattering

$(\nu_e, {}^{16}\mathrm{O})$ capture

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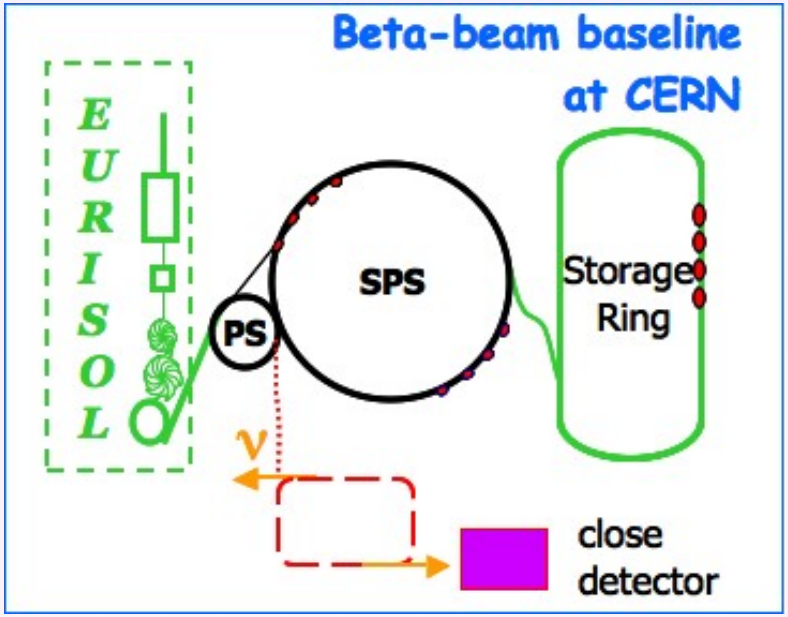

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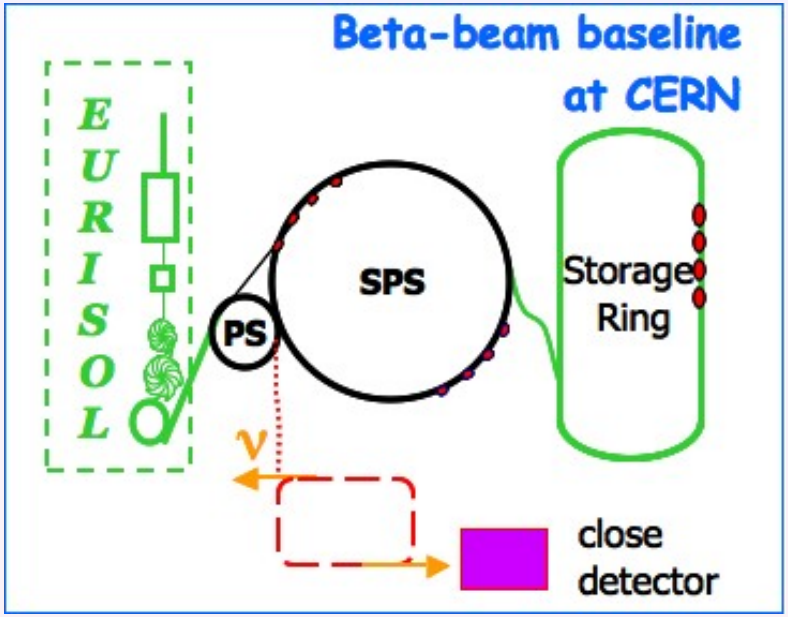

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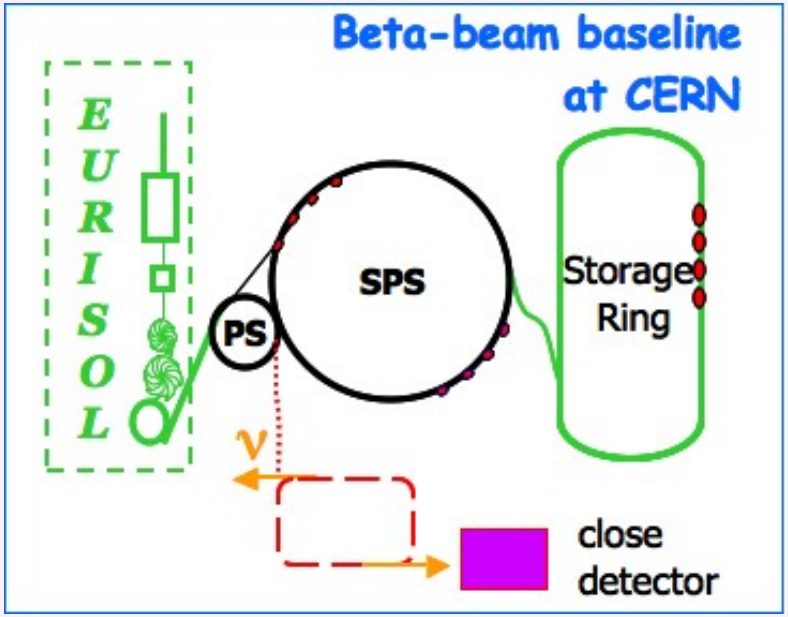

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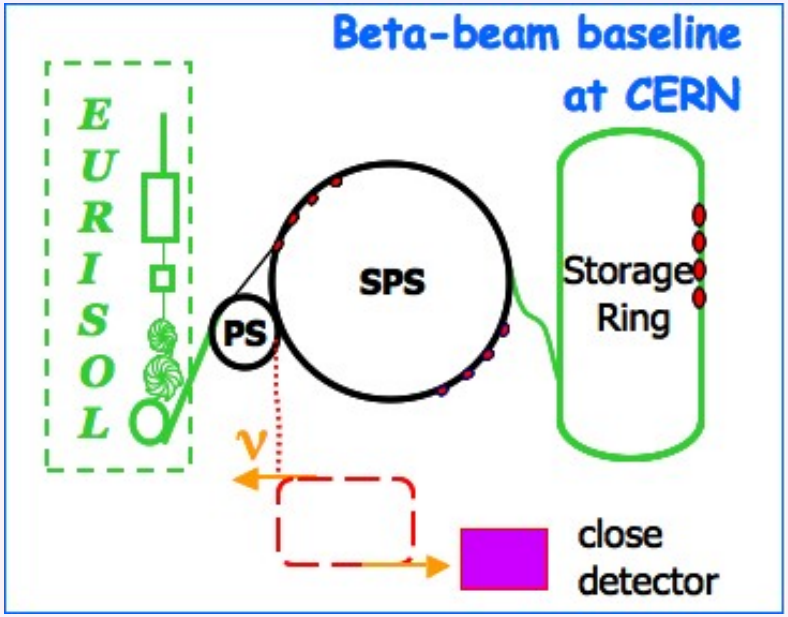

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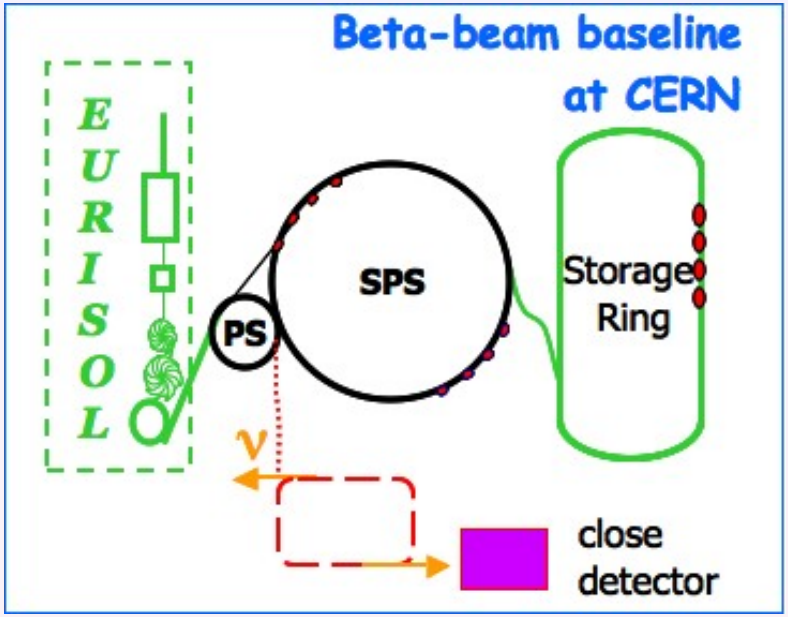

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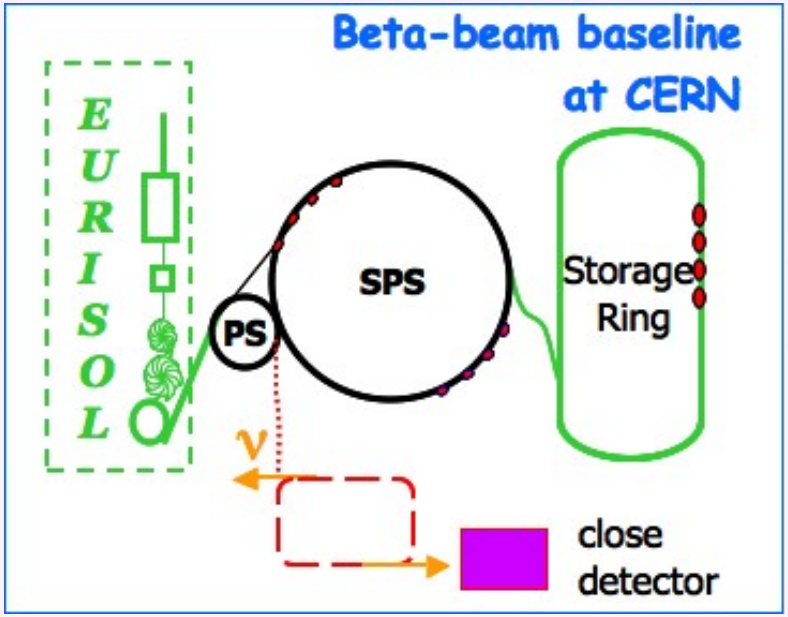

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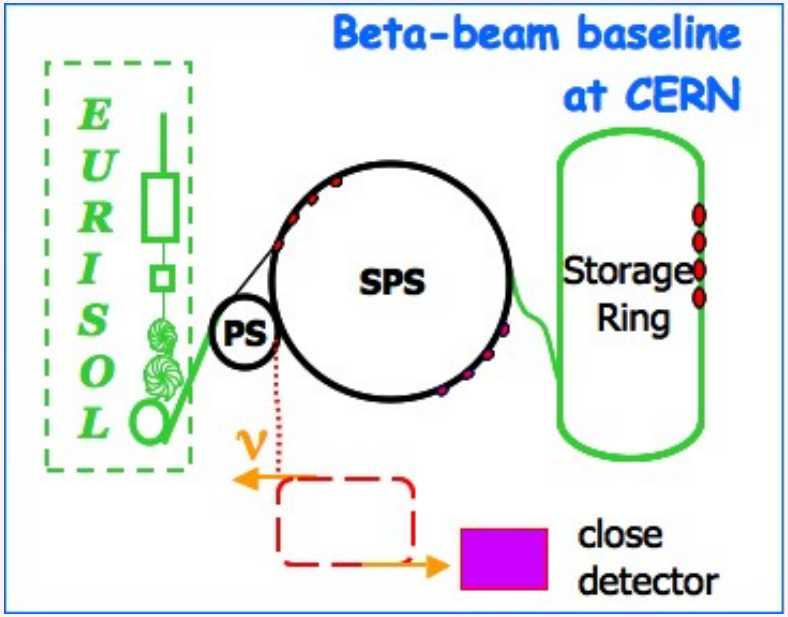

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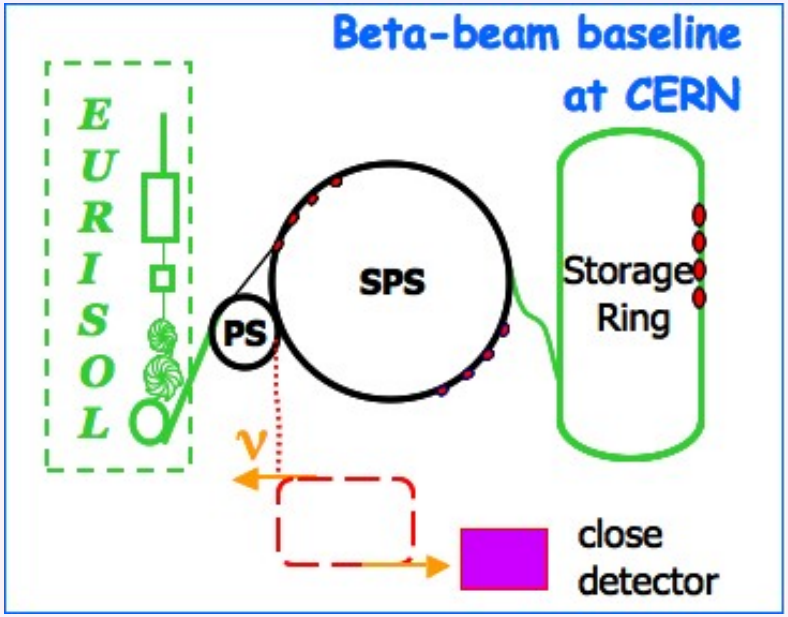

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Low-energy beta-beams

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);
- **Off-axis neutrinos** (next talk): R. Lazauskas, A.B. Balantekin, JHJ and C. Volpe, hep-ph/0703063.

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

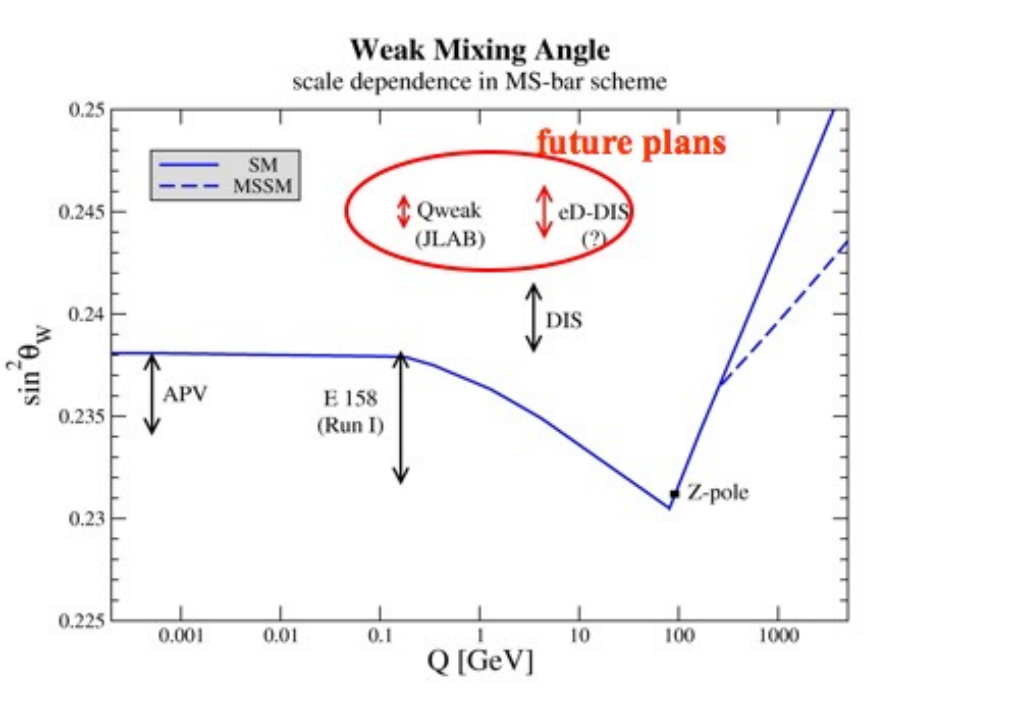

Figure credits: K. Jungmann

- APV and Møller scattering consistent with SM prediction;
- NuTEV anomaly: NC/CC in $(\overline{\nu}_\mu, \mathrm{N})$ and (ν_μ, N) DIS disagrees with the SM prediction by 3σ;
- Probing $\sin^2\theta_W$ through additional experiments would be very useful.

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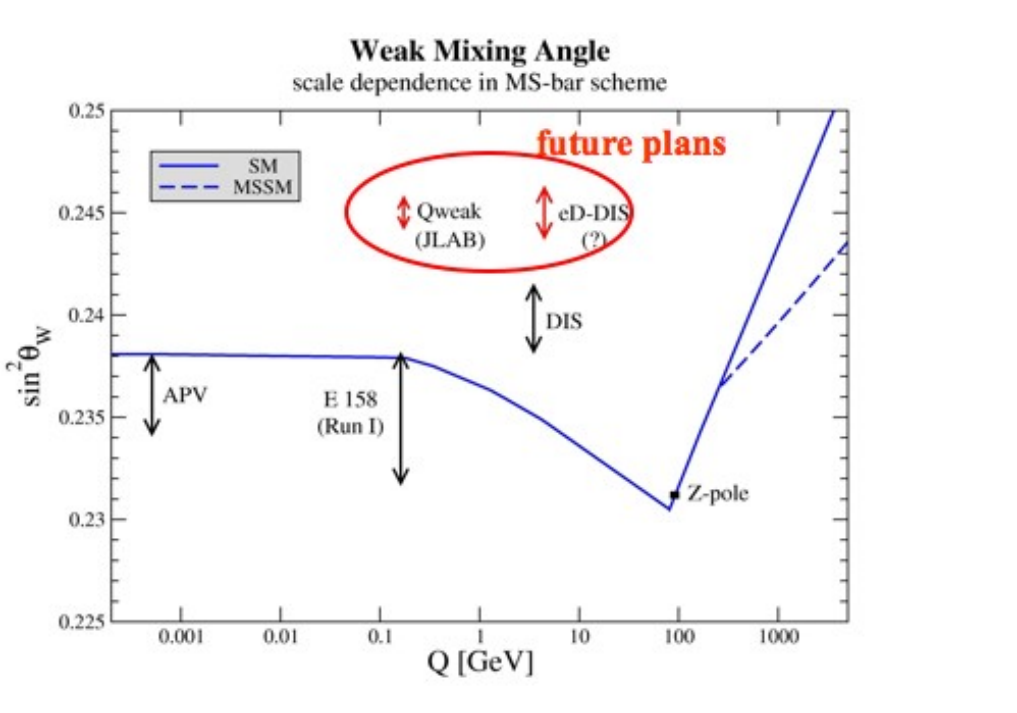

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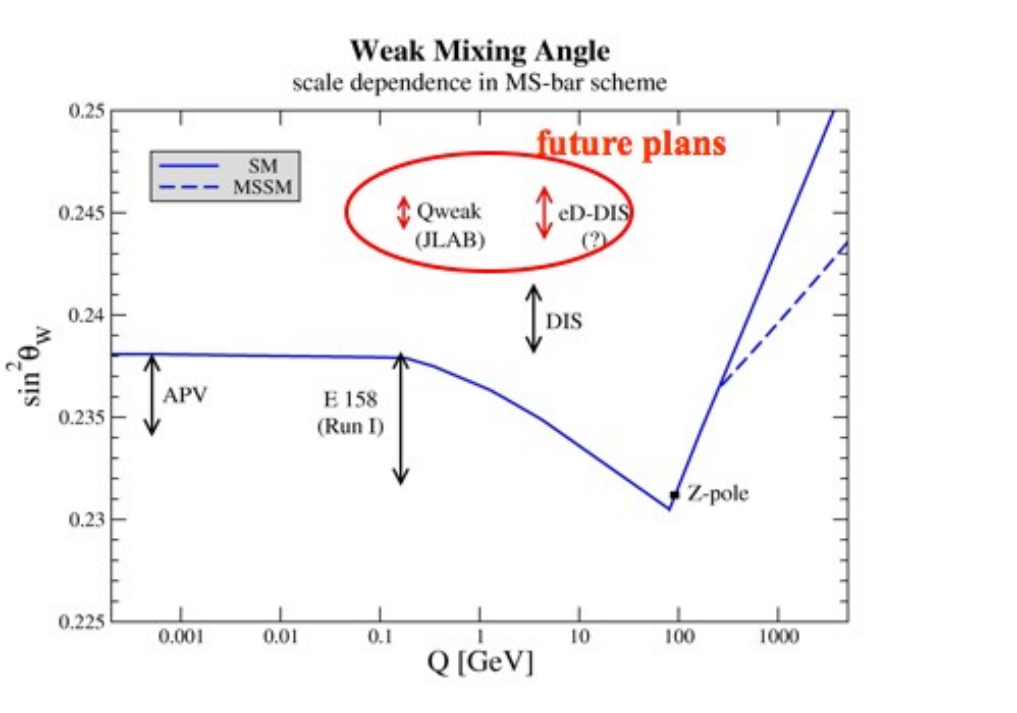

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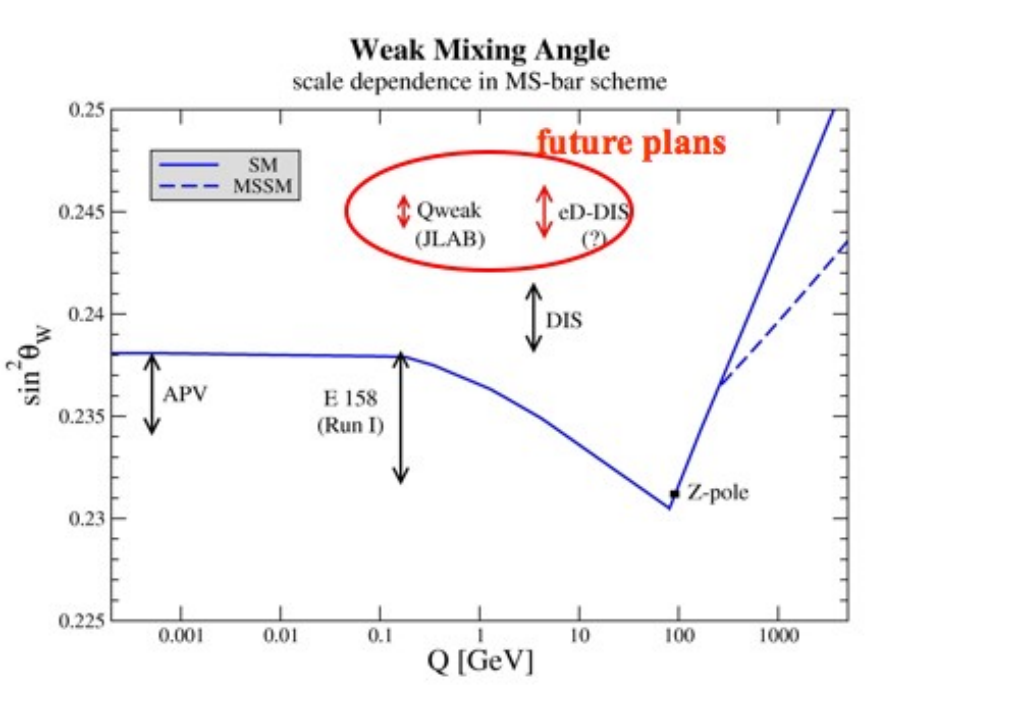

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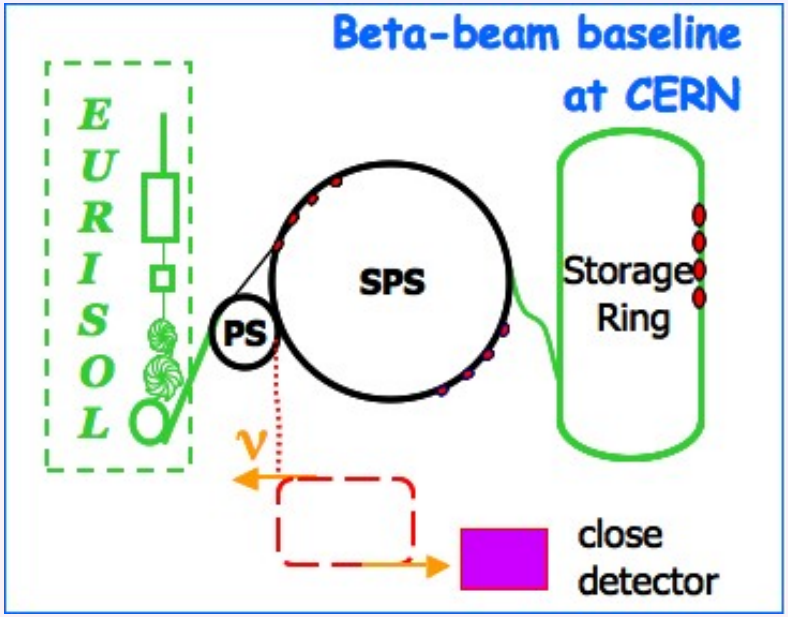

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Neutrino-electron scattering

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

$$g_V = 1/2 + 2\sin^2\theta_W + \cdots \qquad g_A = \pm 1/2 + \cdots$$

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

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$$N_{(\nu,e)} \sim (\mathrm{ions/s})\Delta t\,\langle\sigma_{(\nu,e)}\rangle$$

Neutrino-electron scattering

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

$$g_V = 1/2 + 2\sin^2\theta_W + \cdots \qquad g_A = \pm 1/2 + \cdots$$

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

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

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

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

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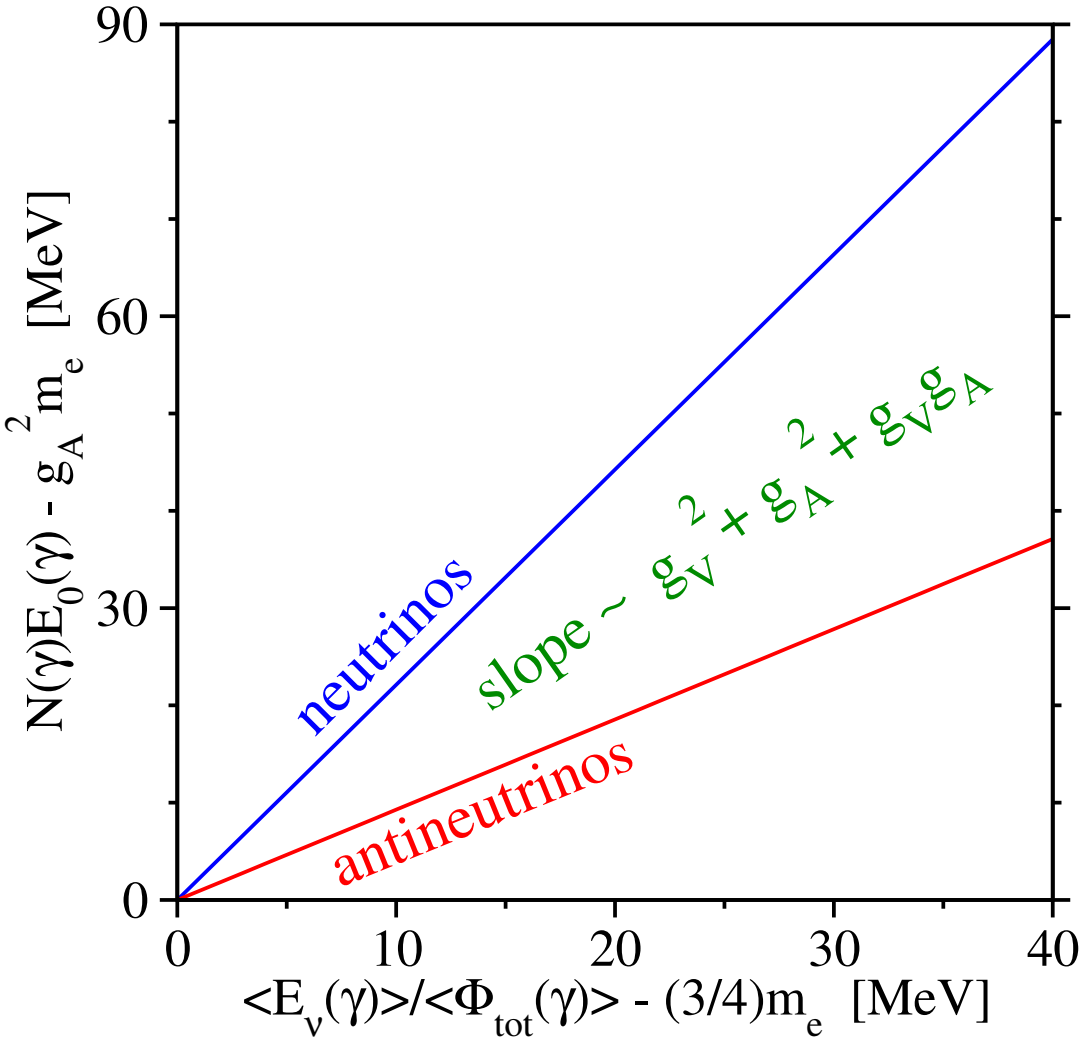
90
60
30
0
0
10
20
30
40
N(γ)E0(γ) - gA2me [MeV]
<Eν(γ)>/<Φtot(γ)> - (3/4)me [MeV]
neutrinos
antineutrinos
slope ~ gV2 + gA2 + gVgA

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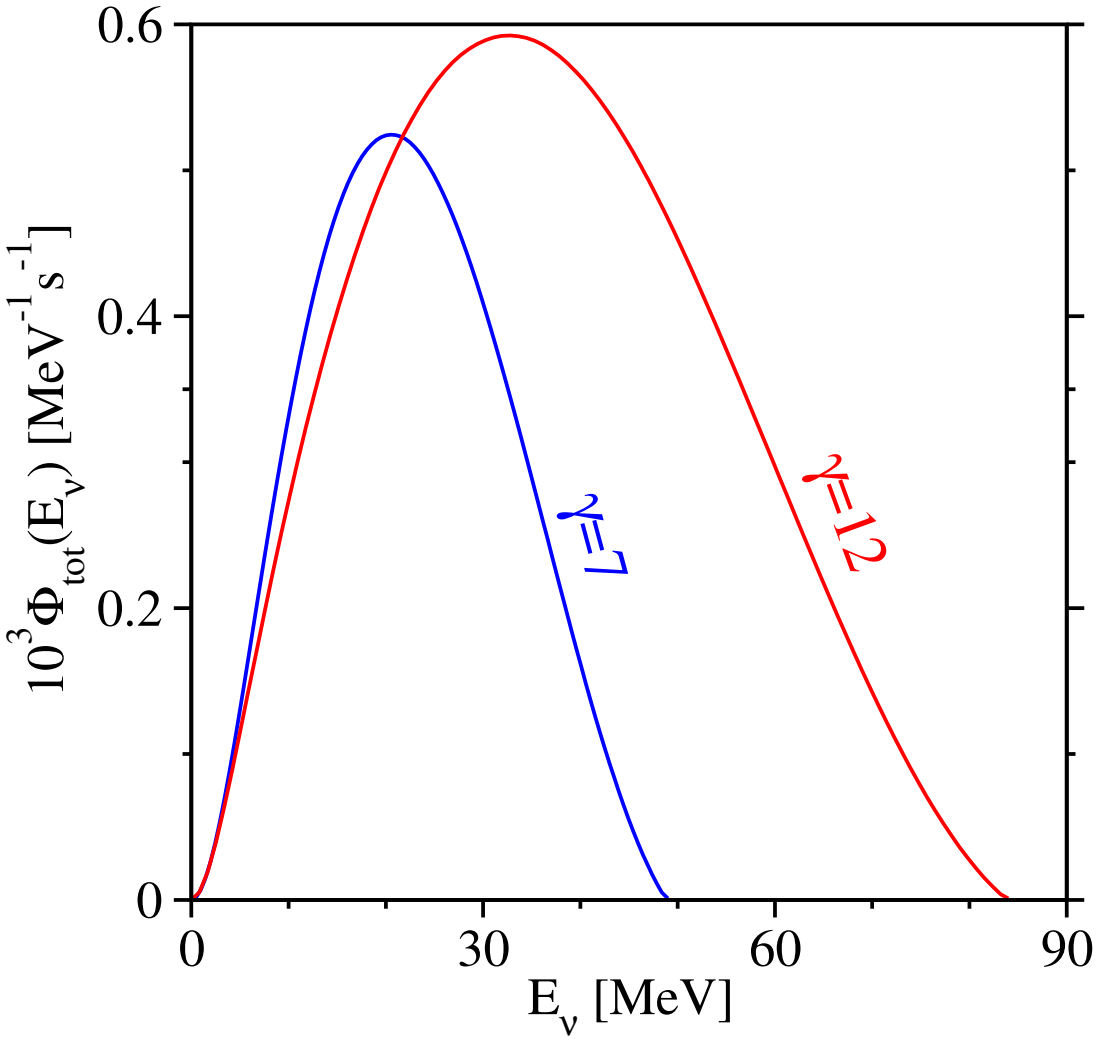
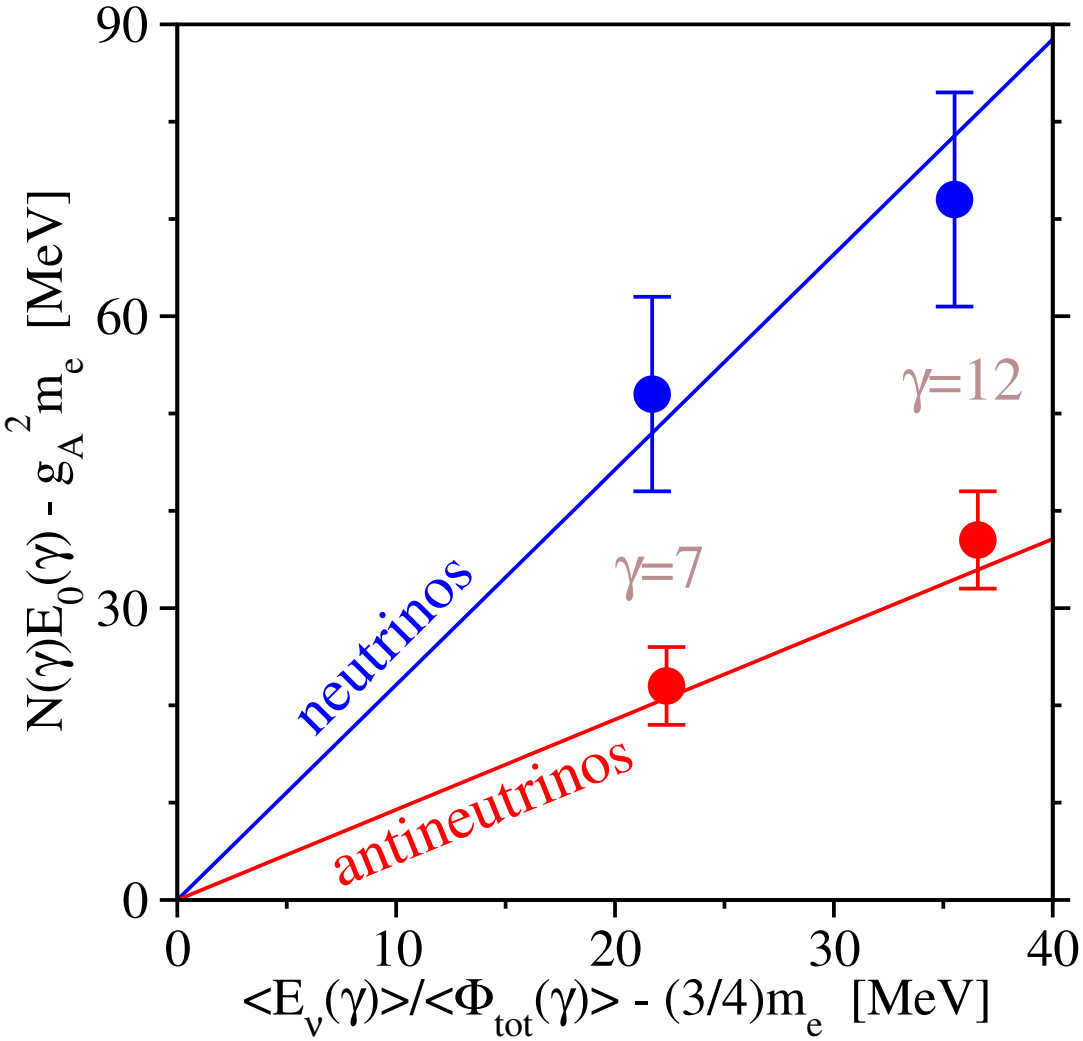

0.6
0.4
0.2
0
0
30
60
90
$10^3\Phi_{tot}(E_\nu)$ [MeV^{-1}s^{-1}]
E_ν [MeV]
γ=7
γ=12


90
60
30
0
0
10
20
30
40
N(γ)E0(γ) - gA2me [MeV]
<Eν(γ)>/<Φtot(γ)> - (3/4)me [MeV]
neutrinos
antineutrinos
γ=7
γ=12

The Weinberg angle at beta-beams

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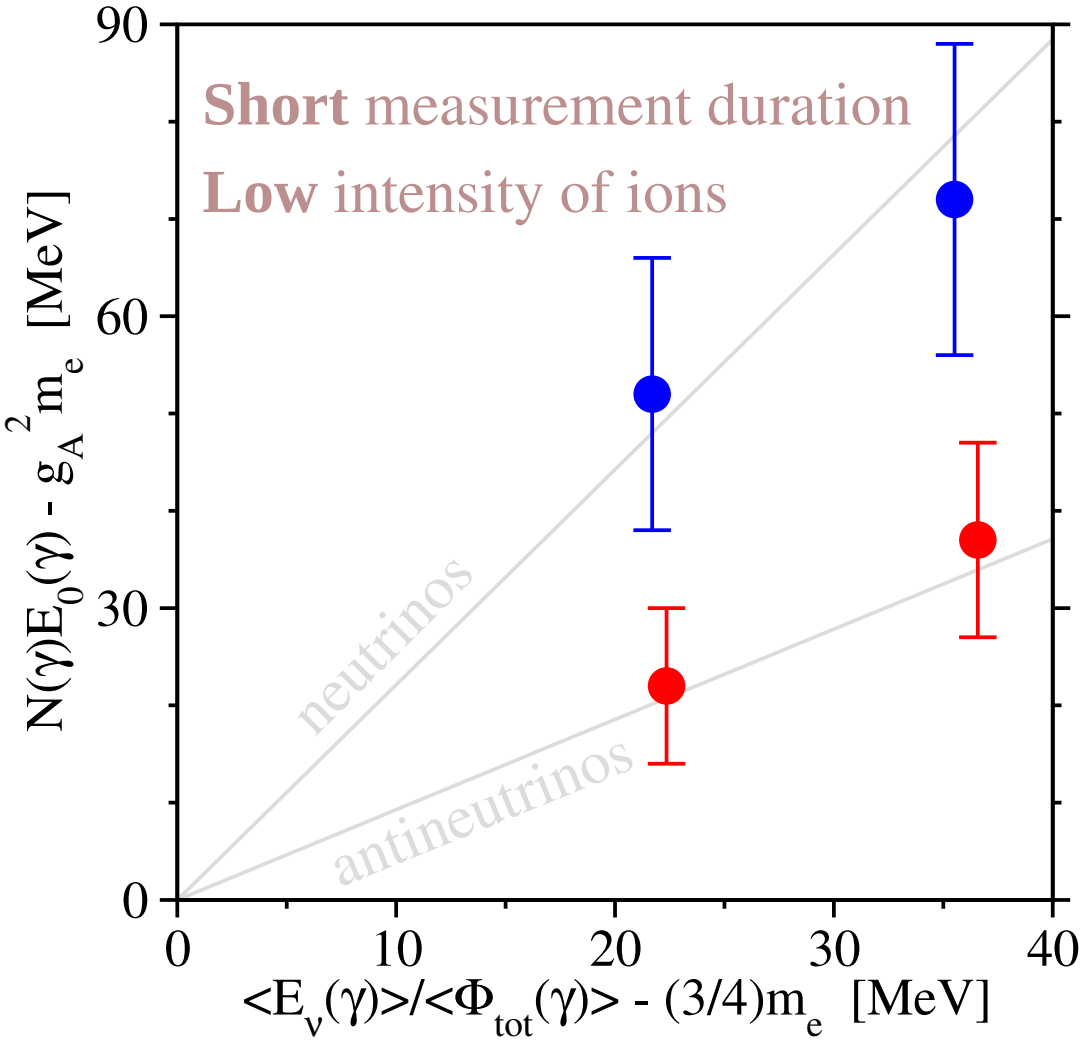
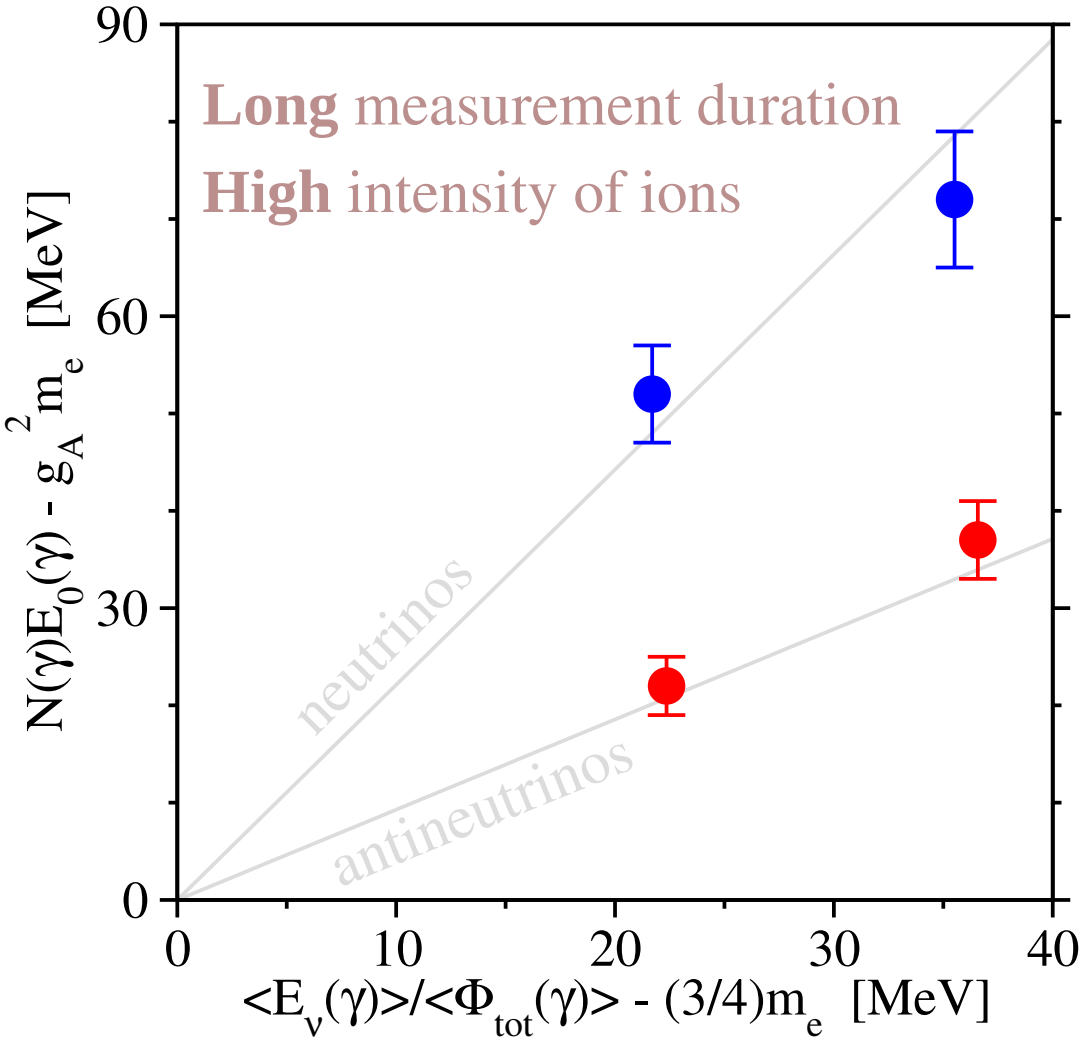

Short measurement duration
Low intensity of ions
neutrinos
antineutrinos
N(γ)E0(γ) - gA2me [MeV]
<Eν(γ)>/<Φtot(γ)> - (3/4)me [MeV]
0
30
60
90
0
10
20
30
40


Long measurement duration
High intensity of ions
neutrinos
antineutrinos
N(γ)E0(γ) - gA2me [MeV]
<Eν(γ)>/<Φtot(γ)> - (3/4)me [MeV]
0
30
60
90
0
10
20
30
40

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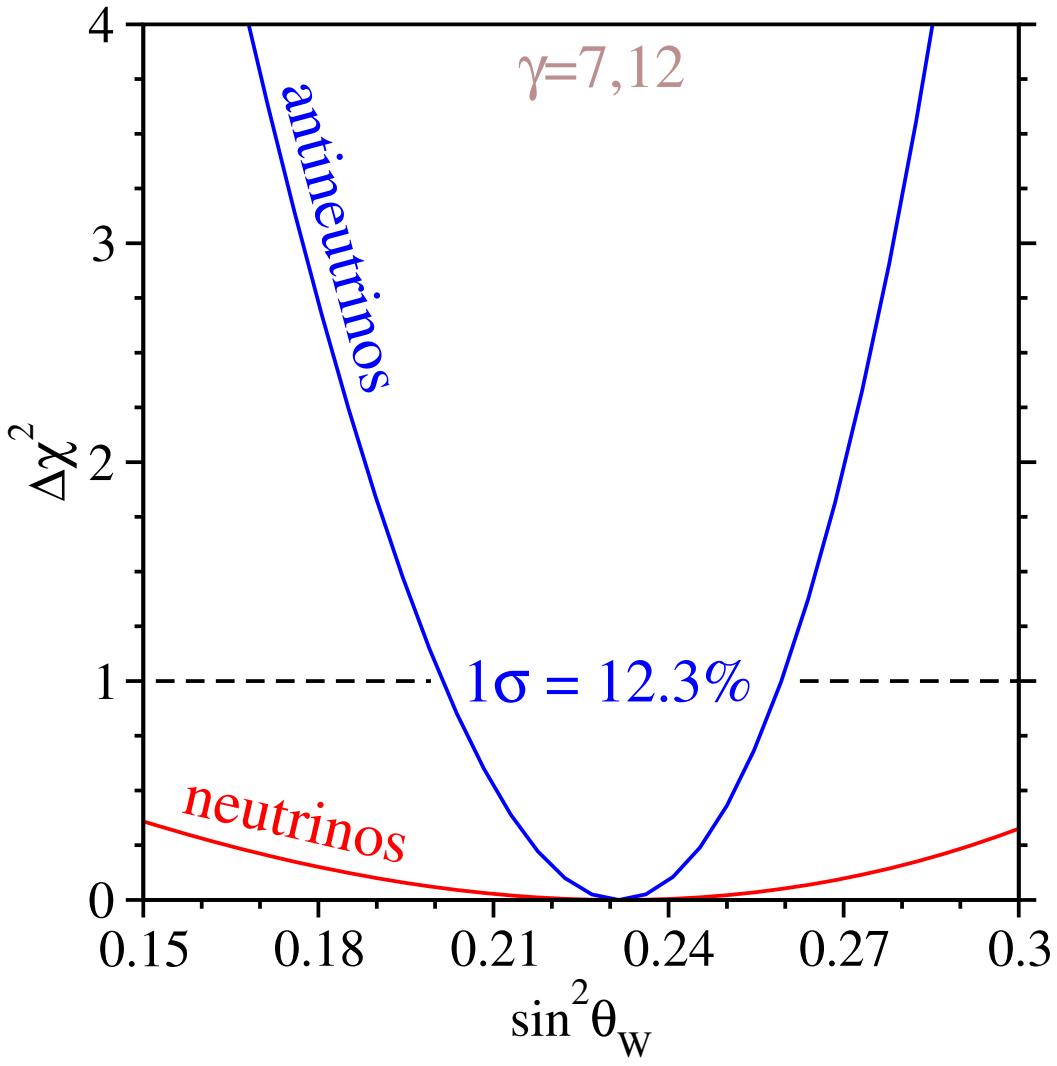
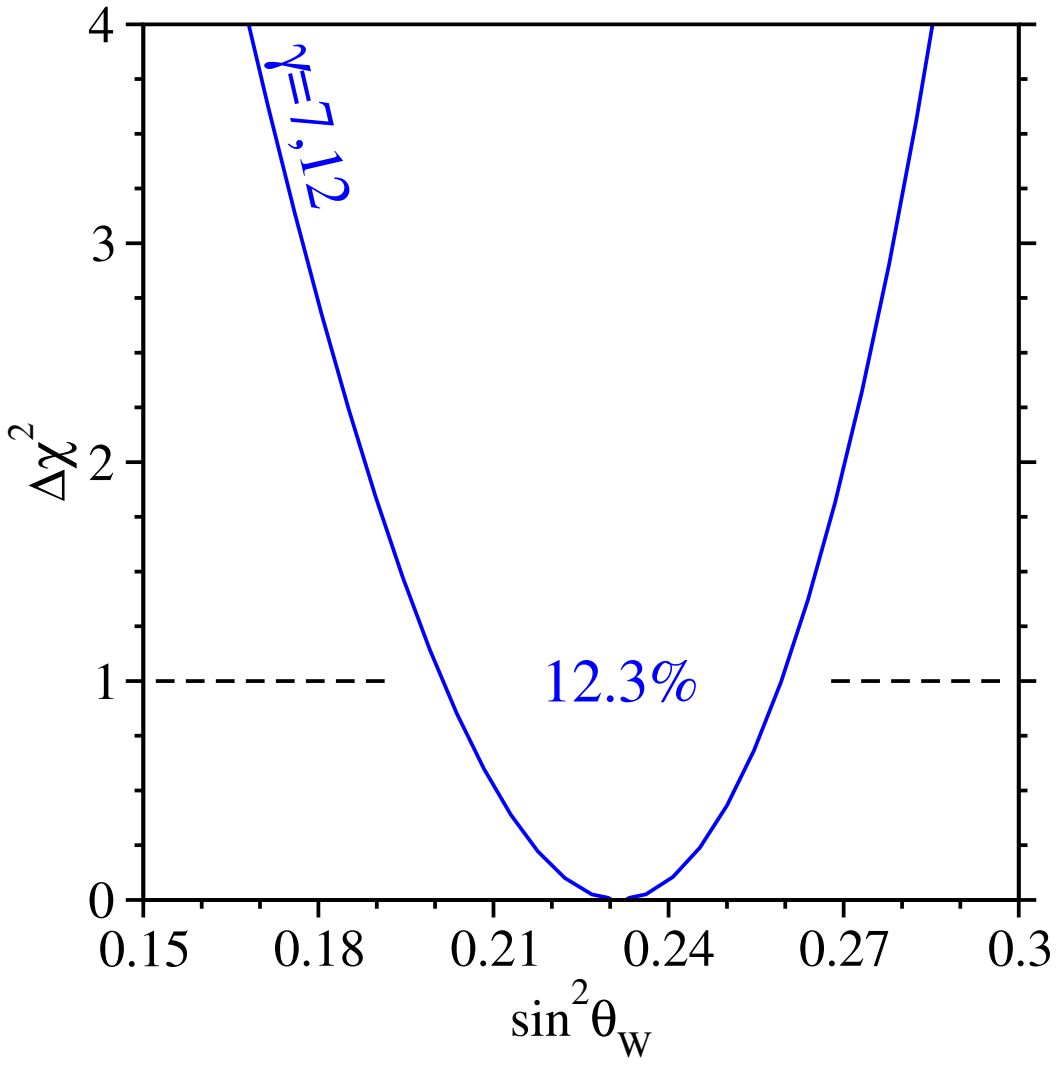
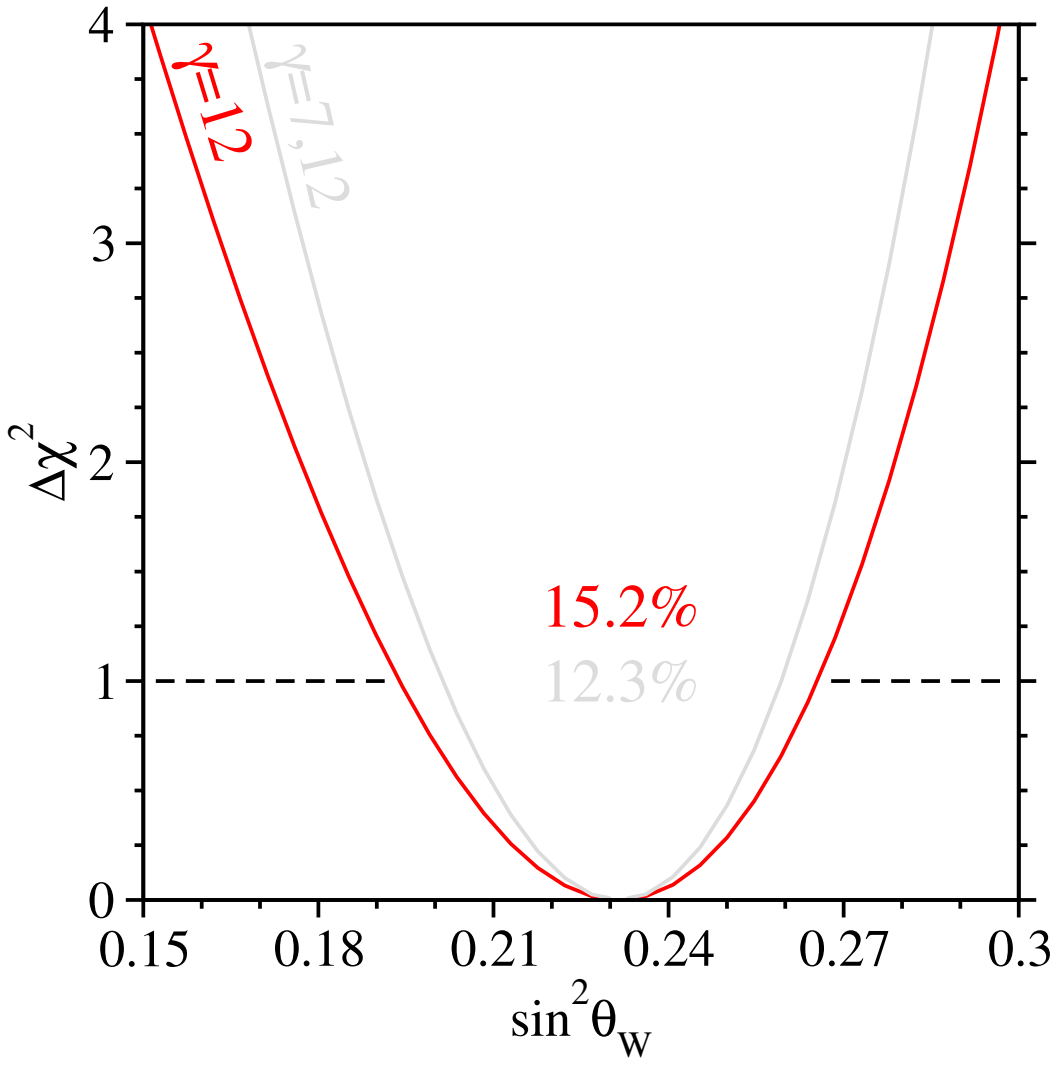
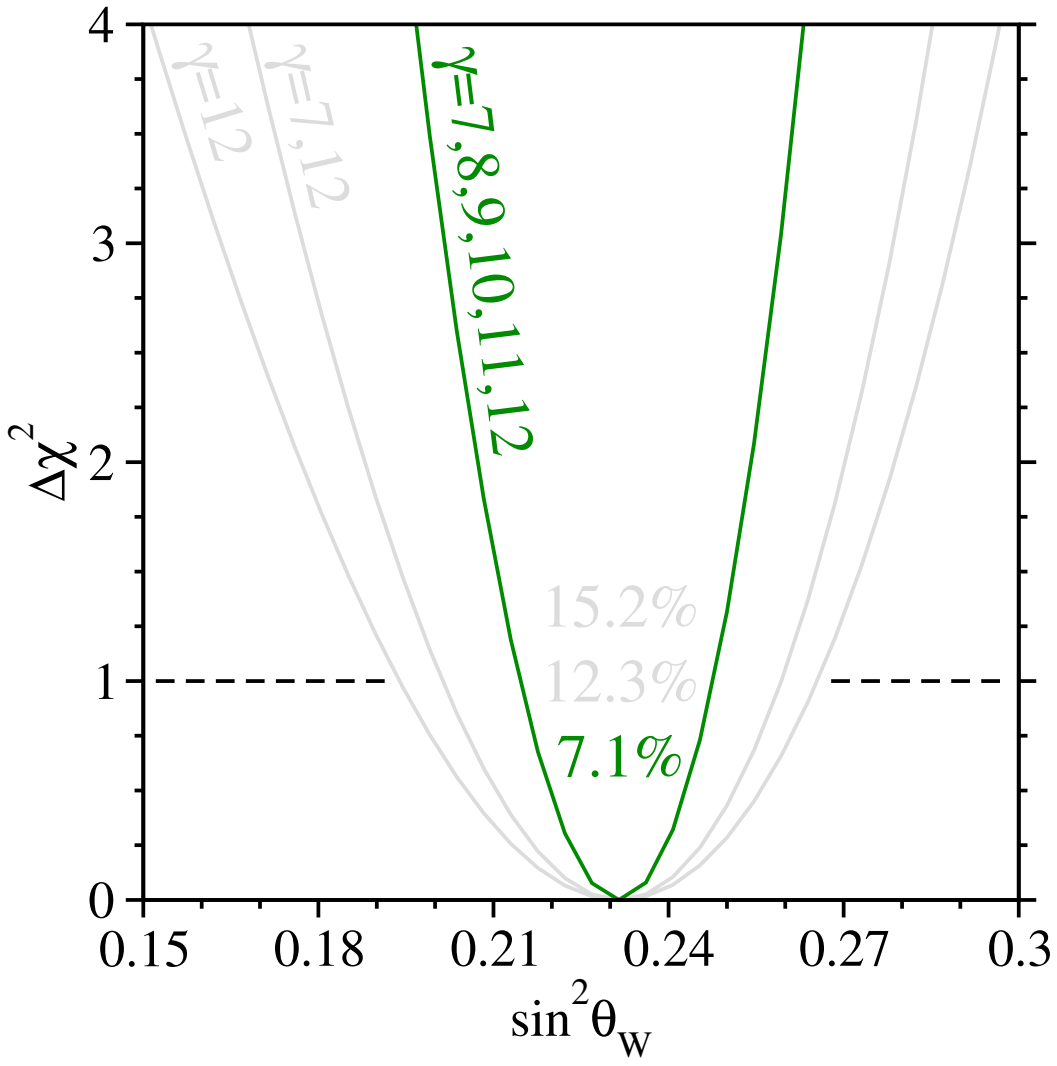
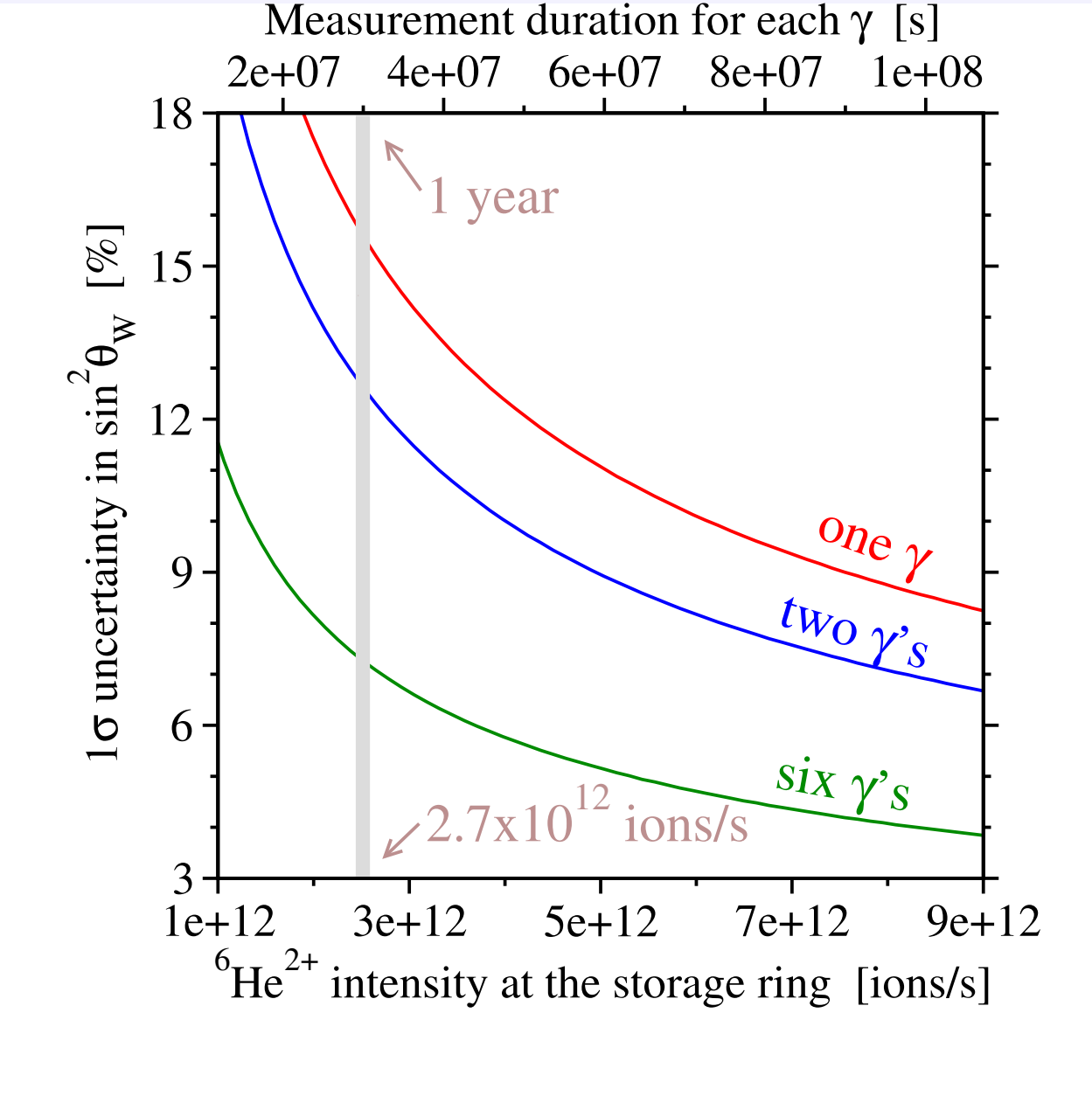
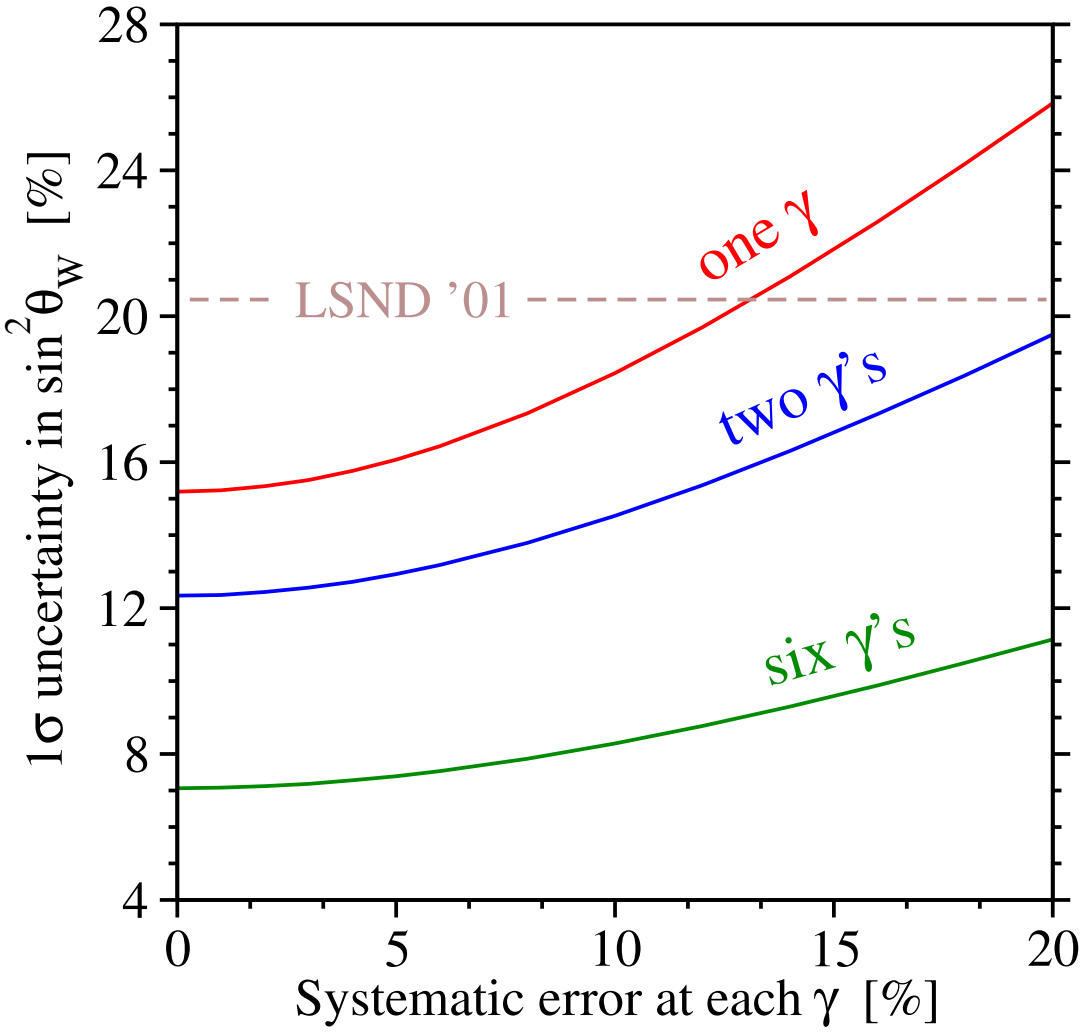

γ=7,12
antineutrinos
1σ = 12.3%
neutrinos
Δχ²
sin²θw
0
1
2
3
4
0.15
0.18
0.21
0.24
0.27
0.3


4
3
2
1
0
$\Delta\chi^2$
χ=7.12
12.3%
0.15
0.18
0.21
0.24
0.27
0.3
$\sin^2\theta_W$


4
3
2
1
0
$\Delta\chi^2$
γ=12
γ=7,12
15.2%
12.3%
0.15
0.18
0.21
0.24
0.27
0.3
$\sin^2\theta_W$


γ=12
γ=7,12
γ=7,8,9,10,11,12
15.2%
12.3%
7.1%
Δχ²
sin²θw
0
1
2
3
4
0.15
0.18
0.21
0.24
0.27
0.3


Measurement duration for each γ [s]
2e+07
4e+07
6e+07
8e+07
1e+08
18
15
12
9
6
3
1σ uncertainty in sin²θ_W [%]
1 year
one γ
two γ's
six γ's
2.7x10¹² ions/s
1e+12
3e+12
5e+12
7e+12
9e+12
⁶He²⁺ intensity at the storage ring [ions/s]


28
24
20
16
12
8
4
0
5
10
15
20
1σ uncertainty in sin²θ_W [%]
Systematic error at each γ [%]
one γ
LSND '01
two γ's
six γ's

Conclusions

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.

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... THE END!