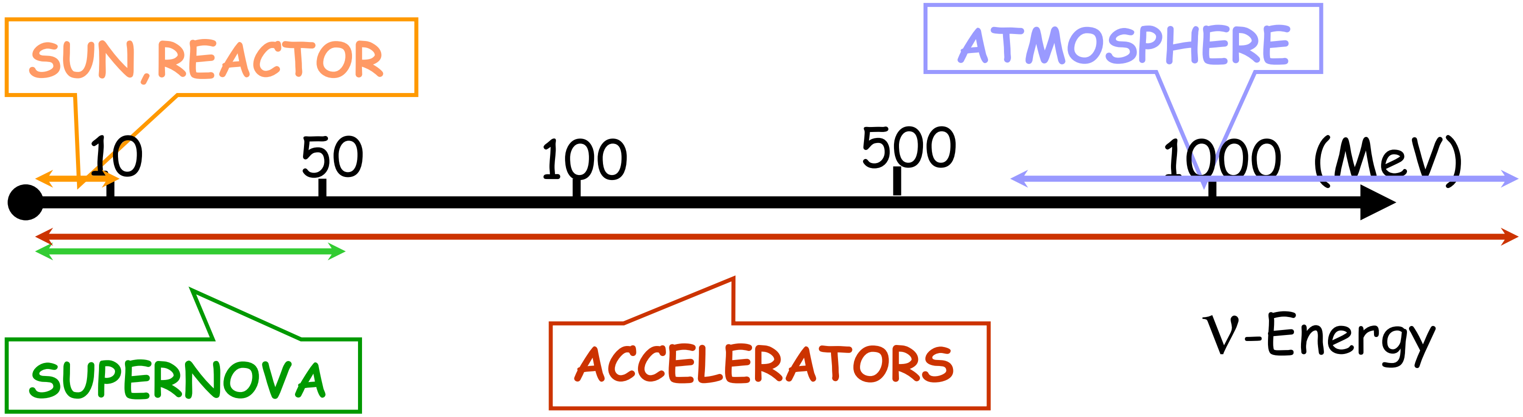
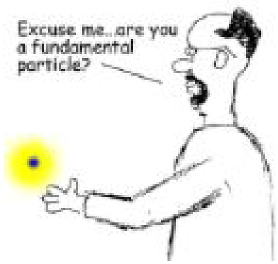
# Low energy beta-beams as a laboratory of neutrino interactions

## Neutrinos probe matter over a wide energy range



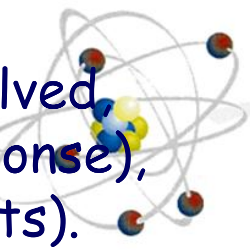

**1** ν-properties to learn:

- mass hierarchy
- mixing angle $\theta_{13}$
- Majorana or Dirac nature?
- CP violation (phase $\delta$)
- magnetic moment
- decay, ...




**2** ν-nucleus interaction studies, for:

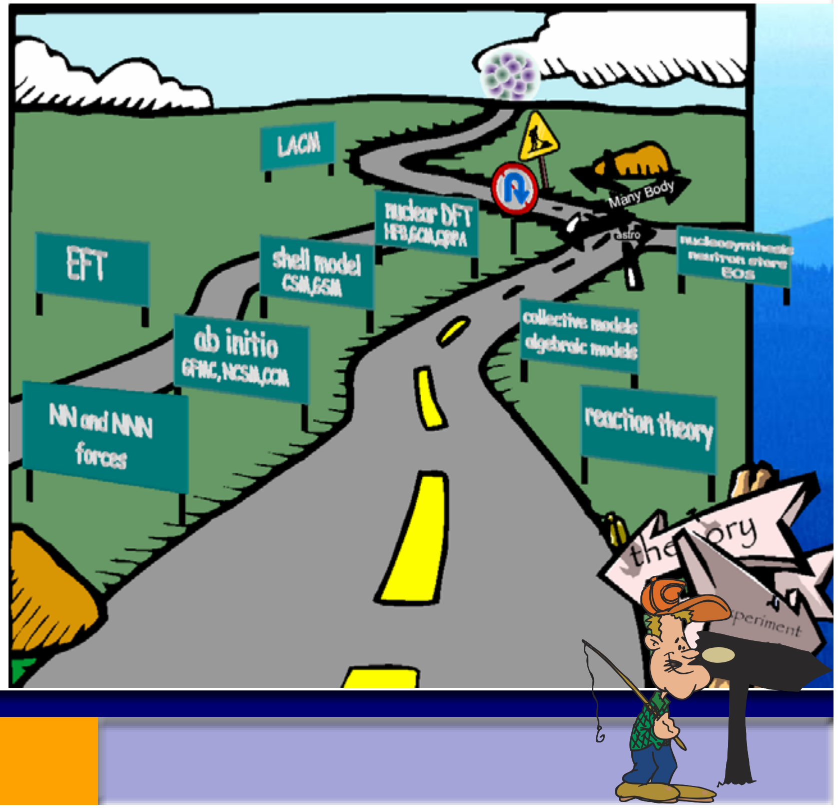
- a better understanding of the nuclear excitations involved,
- neutrino experiments (e.g. knowledge of detector response),
- nuclear astrophysics (nucleosynthesis of heavy elements).



R. Lazauskas, C. Volpe IPN, Orsay (France)

# Low energy beta-beams as a laboratory of neutrino interactions

- Experimental data is very scarce (D and $^{56}F$, $^{12}C$).
- Theory is complicated, needs control*. Getting precise predictions in the low-energy range (20-100 MeV) is a challenging task. As example the discrepancies (exp/th) for $\nu$-$^{12}C$ and (between calculations) for $\nu$-$^{208}Pb$.



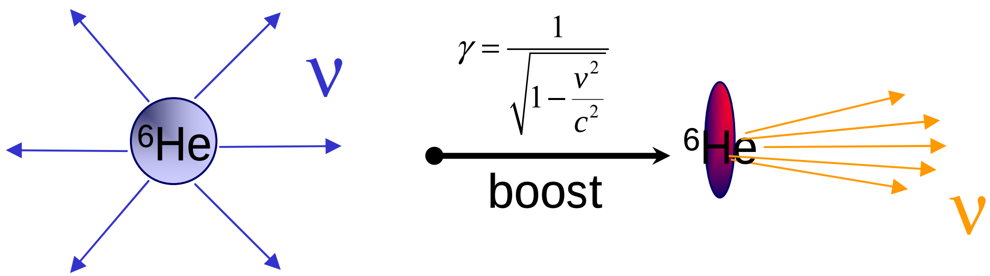

*see eg. Brown, Hayes, Kolbe, Fuller, Haxton, Jachowitz, Kubodera, Langanke, Martinez-Pinedo, Mintz, McLaughlin, Oset, Pourkaviani, Vogel, Volpe, Singh, Towner, etc..

R. Lazauskas, C. Volpe IPN, Orsay (France)

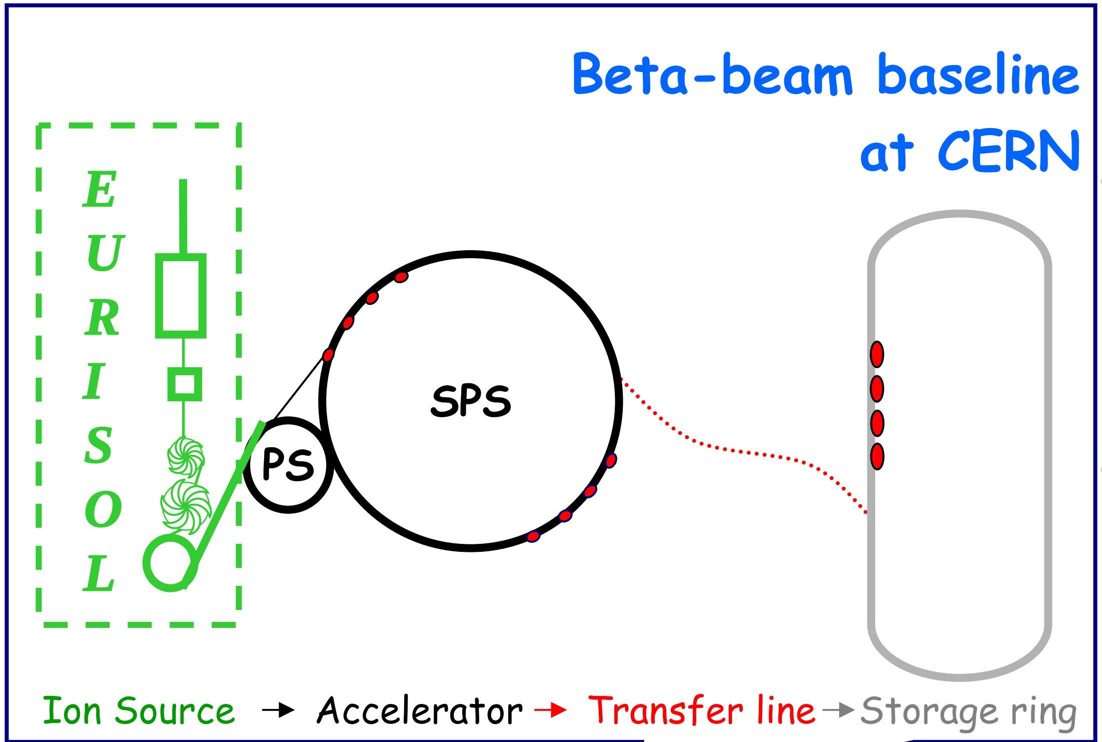
# Can one dispose of ν–source?

- Superbeam
- ν- factory
- Beta Beam (P. Zucchelli, Phys. Lett. **B 532** (2002) 166)

  Production of $\nu_e$ Purity in flavor Energy tuning Well known flux



# Low energy beta-beams as a laboratory of neutrino interactions




- **Original beta-beam** 1
  (High energies >60 GeV/N)

  1st Goal: ν CP violation

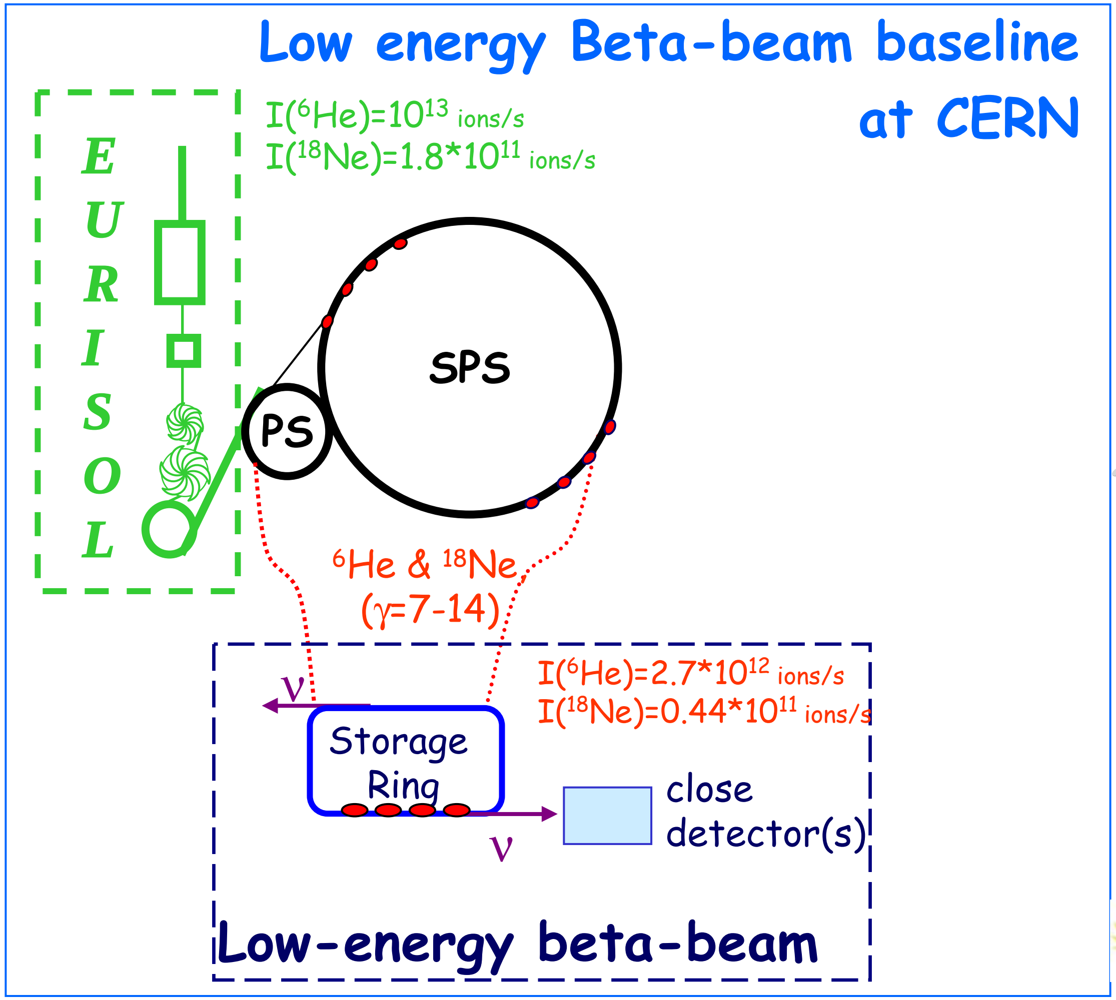
- **Low energy beta-beam** 2
  (energies ~10 GeV/N)

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

  1st Goal: ν cross sections


Detector(s)

# Low energy beta-beams as a laboratory of neutrino interactions




## Feasibility Study within EURISOL Design Study (2006-2009)

- Acceleration issues
  M. Benedikt and
  M. Lindroos, CERN
- Storage Ring
  - Size (D~700 m or D~900 m)
  - Space-charge effects
  - Duty cycle
  - Intensities

  J. Payet and
  A. Chancé,
  CEA Saclay, France

Small Storage ring-detector:
*J. Serreau, C. Volpe,* ***PRC70*** *(2004) 055502*

# Low energy beta-beams as a laboratory of neutrino interactions

## PHYSICS POTENTIAL

→ Neutrino-nucleus interaction studies
*C. Volpe: Eurisol proposal; R. Lazauskas , C.Volpe: in preparation; A. Bueno et al.: Phys. Rev. D74 (2006) 033010*

→ Fundamental tests: Weinberg angle, CVC test
*A.B. Balantekin, J.H. de Jesus, C. Volpe: Phys.Lett. B634 (2006) 180*
*A.B. Balantekin et al.:, Phys.Rev. D73 (2006) 073011*

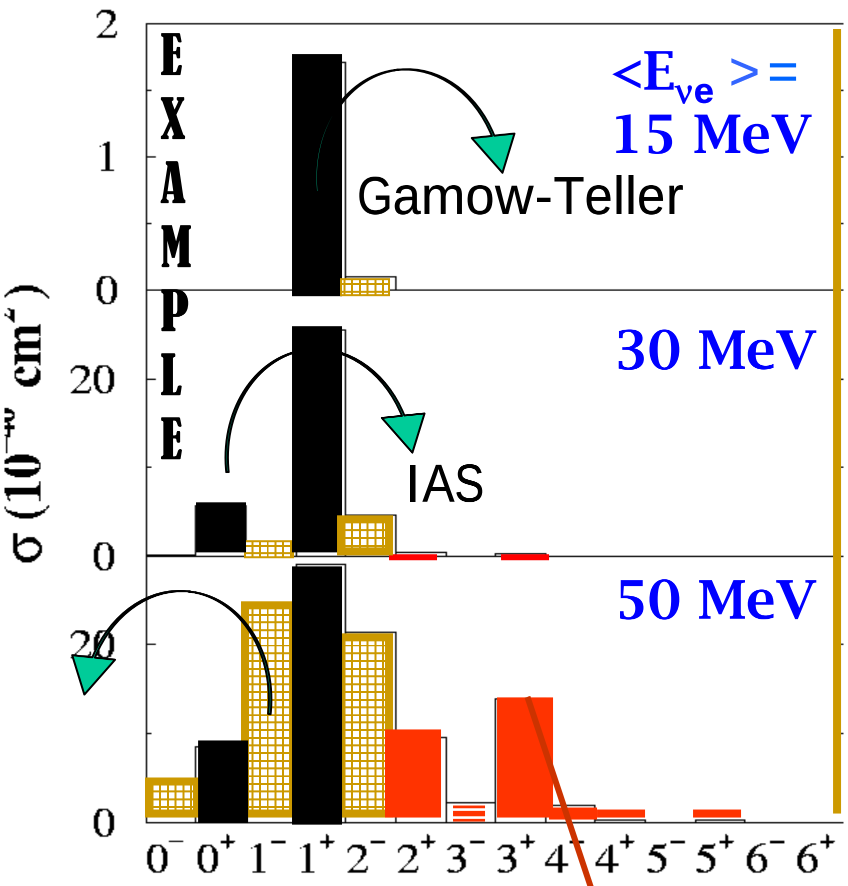
→ Neutrino properties, like the $\nu$ magnetic moment
*G.C. McLaughlin, C. Volpe, Phys.Lett.B591 (2004) 229*

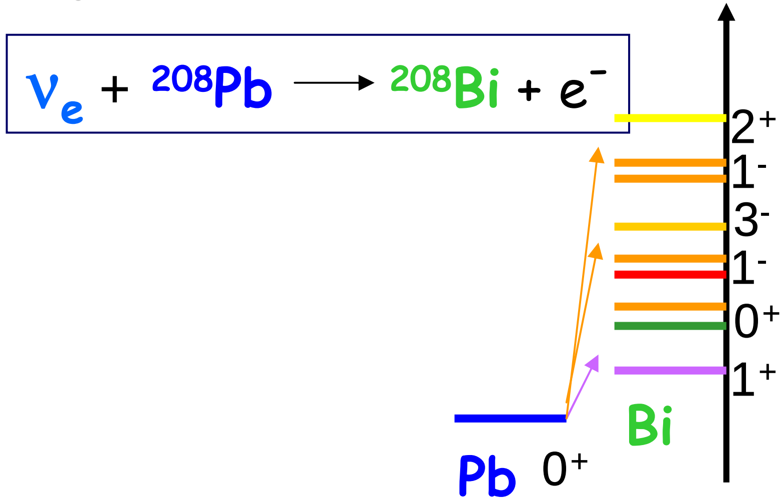
→ Aspects related with astrophysics:
Supernova-neutrino spectra *N. Jachowicz, G.C. McLaughlin: Phys.Rev.Lett. 96 (2006) 172301*

→ ....

# Low energy beta-beams as a laboratory of neutrino interactions

## NEUTRINOS AS a PROBE of NUCLEAR STRUCTURE



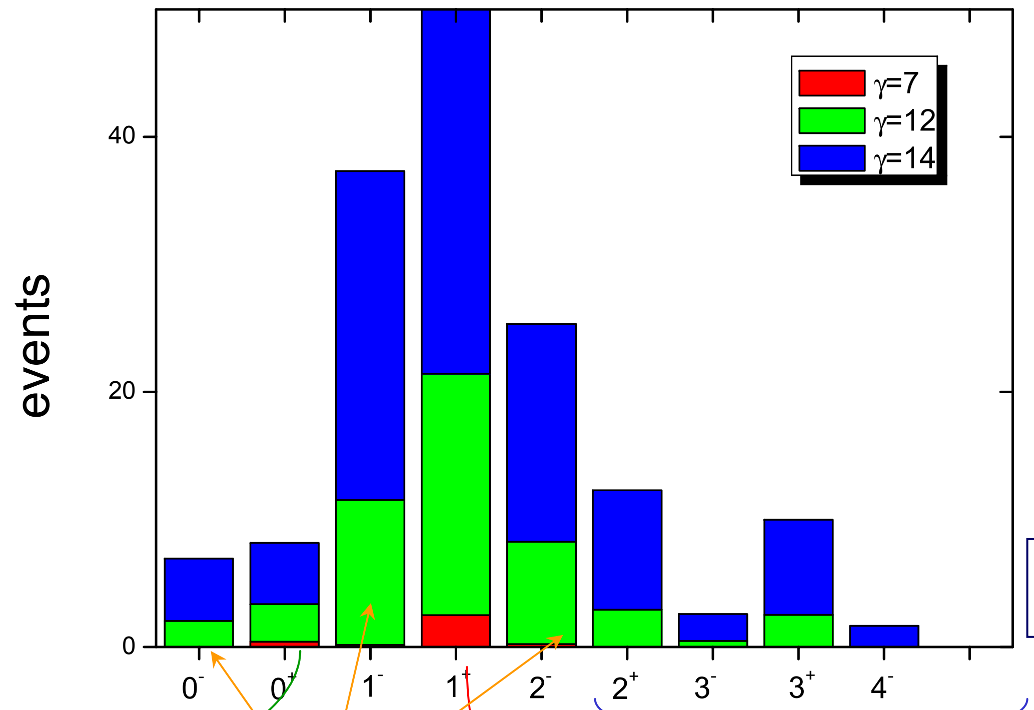

A BETTER KNOWLEDGE OF « SPIN-ISOSPIN AND ISOSPIN » NUCLEAR RESPONSE.

The contribution to the total cross section increases for increasing impinging neutrino energy.

little or no experimental information is available.

# Low energy beta-beams as a laboratory of neutrino interactions

## NEUTRINOS AS a PROBE of NUCLEAR STRUCTURE



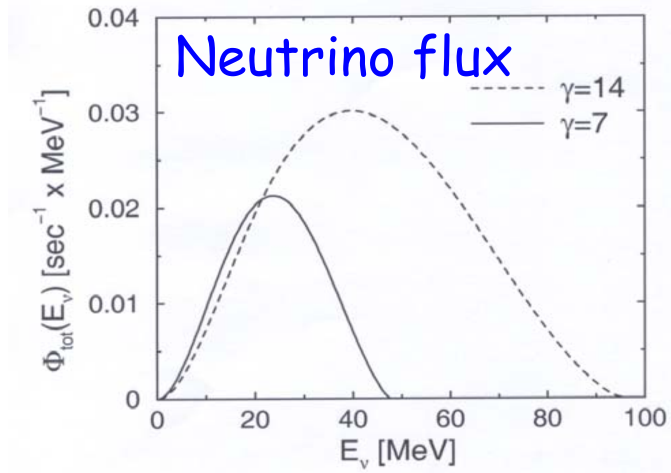

IAS

A better knowledge is needed

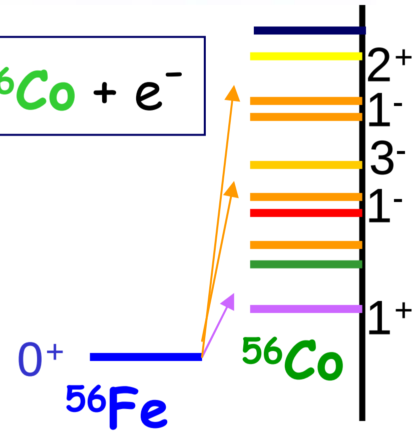
No exp. info

Gamow-Teller

R. Lazauskas, C. Volpe, work in progress.

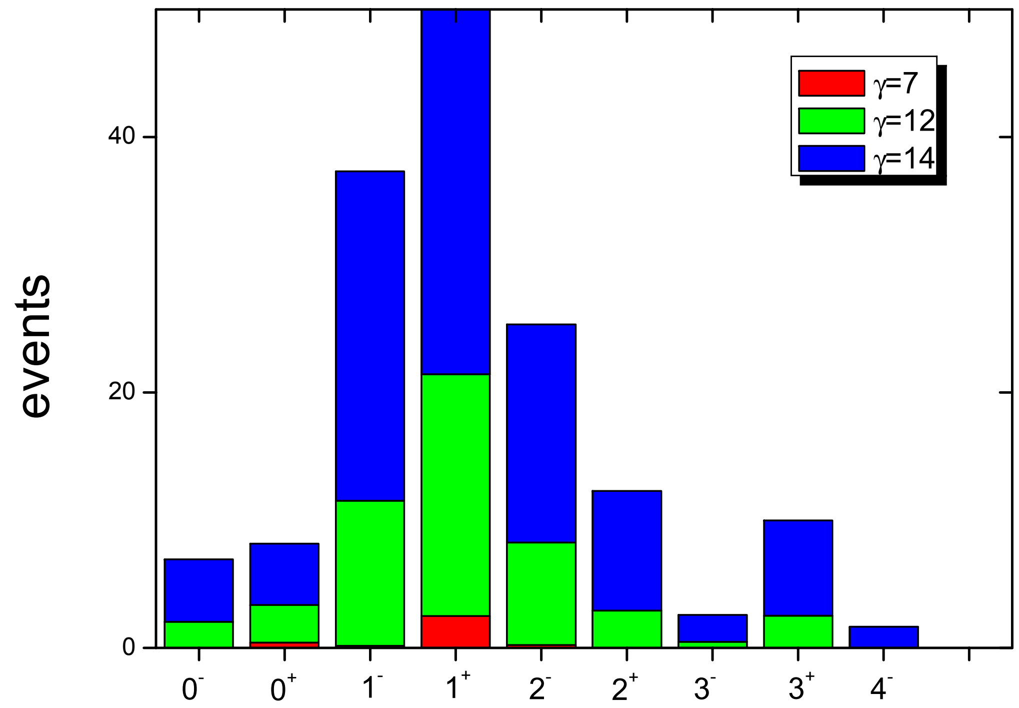


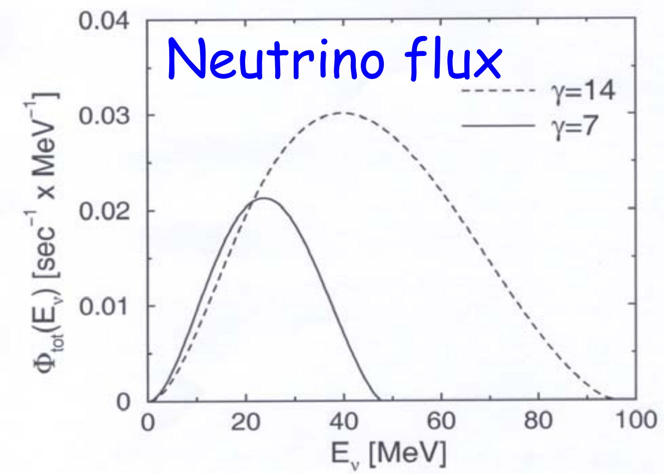

$\nu_e + {}^{56}Fe \rightarrow {}^{56}Co + e^-$



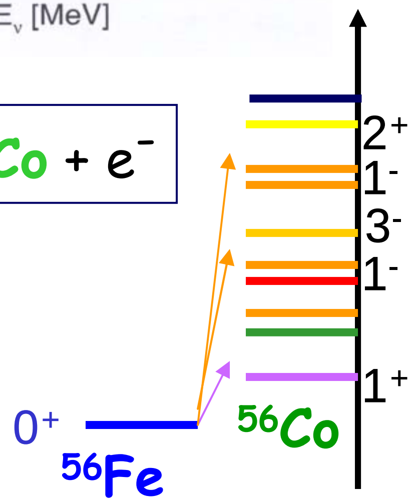
# Low energy beta-beams as a laboratory of neutrino interactions

## NEUTRINOS AS a PROBE of NUCLEAR STRUCTURE




$\nu_e + {}^{56}Fe \rightarrow {}^{56}Co + e^-$




**Low energy beta-beams as a tool to study nuclear spin-isospin excitations**

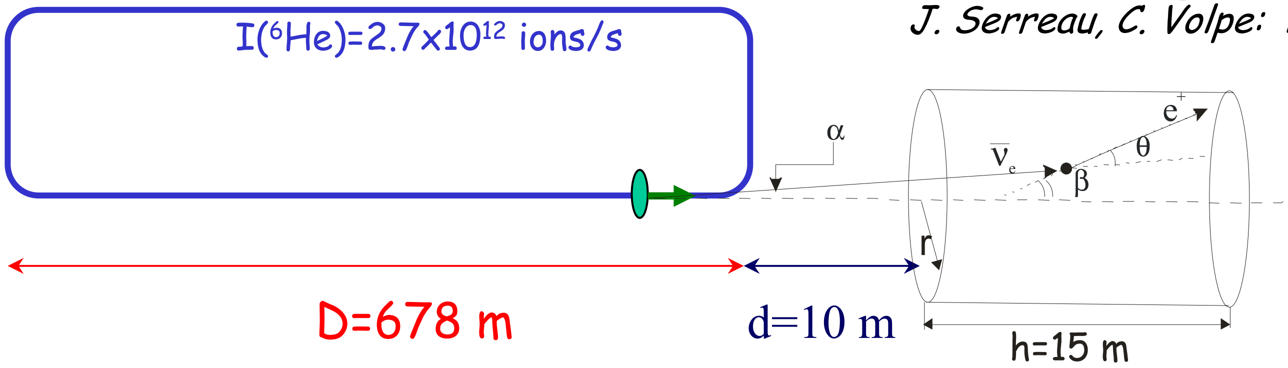
R. Lazauskas, C. Volpe, work in progress.

# Low energy beta-beams as a laboratory of neutrino interactions

## Fundamental tests using water Čerenkov detector:

Small Storage ring-detector:

*J. Serreau, C. Volpe: **PRC70** (2004) 055502*



# Low energy beta-beams as a laboratory of neutrino interactions

The most general form for $\bar{\nu} + p \rightarrow n + e^-$

$$\mathcal{M} = \frac{G_F \cos\theta_C}{\sqrt{2}} \{\bar{u}_n [\gamma_\alpha (f_1 + g_1 \gamma_5) + \sigma_{\alpha\beta} k^\beta (f_2 + g_2 \gamma_5) + k_\alpha (f_3 + g_3 \gamma_5)] u_p\} \{\bar{\nu}_\nu \gamma^\alpha (1 - \gamma_5) \nu_e\}$$

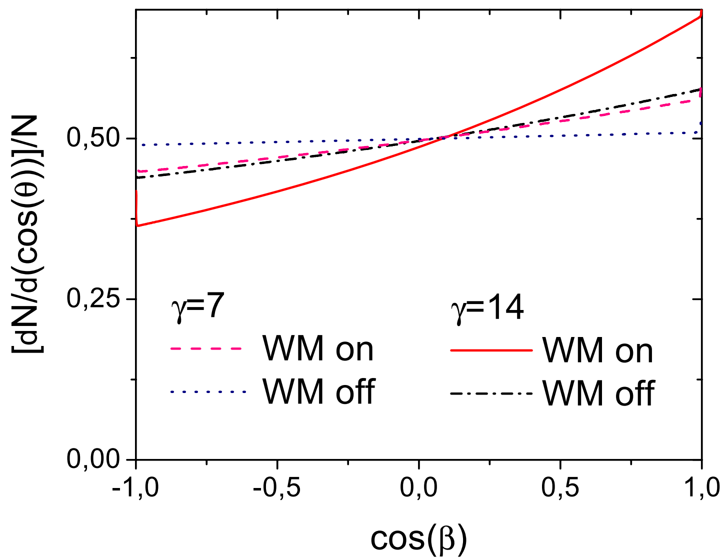
? Negligible

**CVC hypothesis:**

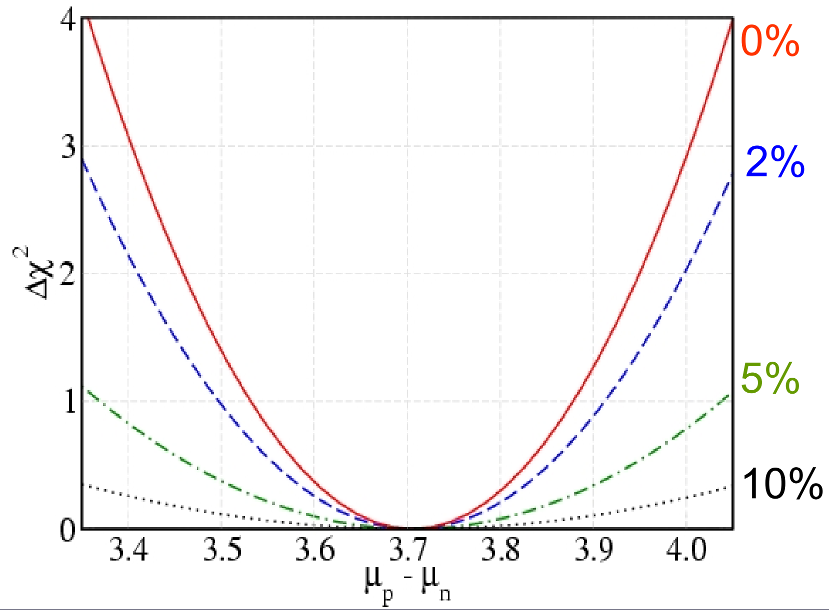
$$\lim_{q^2 \to 0} f_1(q^2) = 1 \, ; \qquad \lim_{q^2 \to 0} f_2(q^2) = \frac{\mu_p - \mu_n}{2 m_N} \, ; \qquad f_3(q^2) = 0$$

Weak magnetism

S




*A.B. Balantekin et al., **PRD73** (2006) 073011*



# Low energy beta-beams as a laboratory of neutrino interactions

The most general form for $\bar{\nu} + p \rightarrow n + e^-$

$$\mathcal{M} = \frac{G_F \cos\theta_C}{\sqrt{2}} \{\overline{u}_n [\gamma_\alpha (f_1 + g_1 \gamma_5) + \sigma_{\alpha\beta} k^\beta (f_2 + g_2 \gamma_5) + k_\alpha (f_3 + g_3 \gamma_5)] u_p\} \{\overline{\nu}_\nu \gamma^\alpha (1 - \gamma_5) \nu_e\}$$

Negligible

?

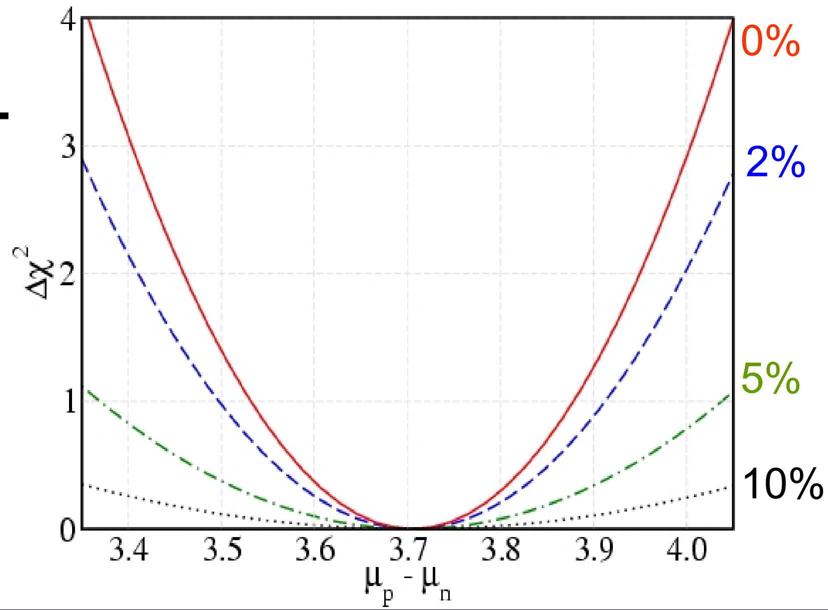
## CVC hypothesis:

$$\lim_{q^2 \to 0} f_1(q^2) = 1 \; ; \quad \lim_{q^2 \to 0} f_2(q^2) = \frac{\mu_p - \mu_n}{2 m_N} \; ; \quad f_3(q^2) = 0$$

Superallowed β-decay

Weak magnetism

Accurate and model independent CVC hypothesis test is possible




*A.B. Balantekin et al., **PRD73** (2006) 073011*

# Low energy beta-beams as a laboratory of neutrino interactions

Pure leptonic scattering can be used to measure $\sin^2\theta_W$ at low momentum transfer (t' Hooft 71)

NuTEV disagrees within 3σ with SM!!!

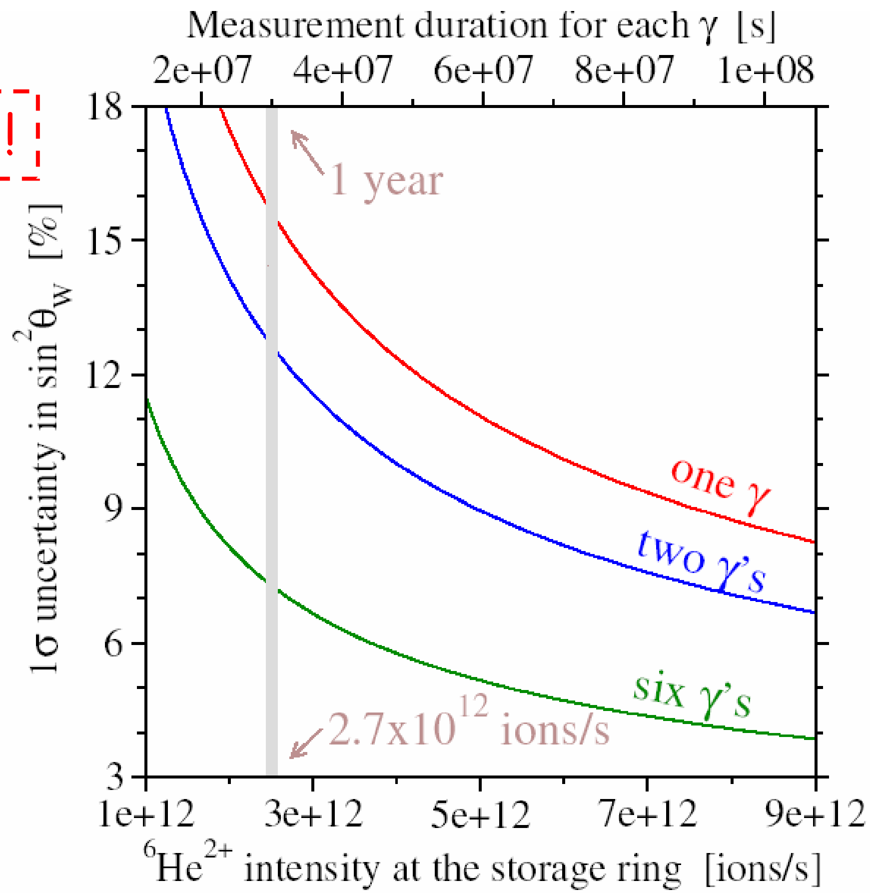
Consider, ν+e elastic scattering:

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

$$g_V=\frac{1}{2}+\sin^2\theta_W \quad g_A=\pm\frac{1}{2}$$

Integrating over $T_e$ and averaging over neutrino flux $\phi(\gamma)$

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

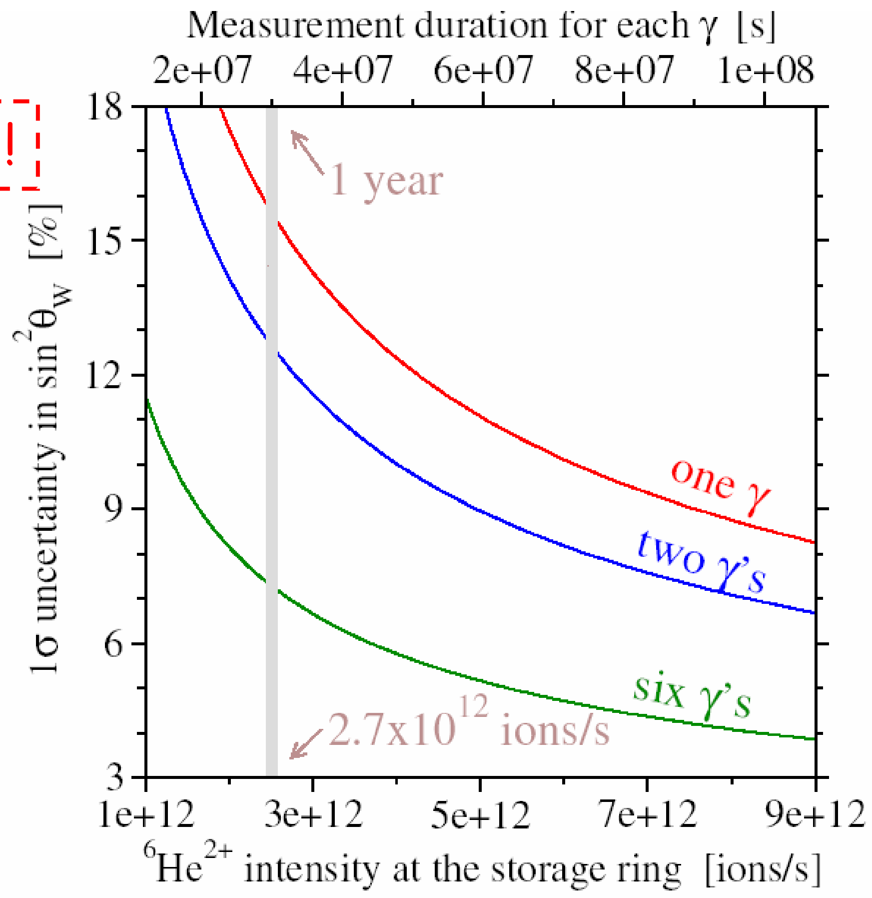



A.B. Balantekin et al, *Phys.Lett.* **B634** (2006) 180

# Low energy beta-beams as a laboratory of neutrino interactions

Pure leptonic scattering can be used to measure $\sin^2\theta_W$ at low momentum transfer (t' Hooft 71)

NuTEV disagrees within 3σ with SM!!!




Weinberg angle measurement with an accuracy of ~13% is within reach by combining two γ's

A.B. Balantekin et al, *Phys.Lett.* **B634** (2006) 180

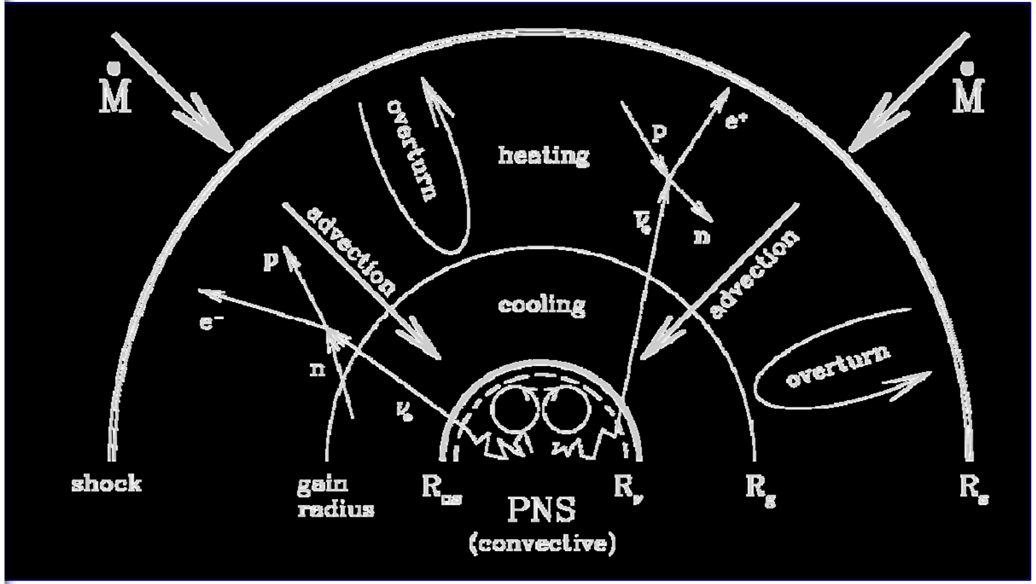
# Low energy beta-beams as a laboratory of neutrino interactions

## Supernova process:

• neutrinos are produced in the neutronization processes characterizing the gravitational collapse

• neutrinos are responsible for the cooling of the proto-neutron star

• neutrinos might reheat the stalled shock wave and cause a delayed explosion




**Observing the neutrinos from a future (Galactic) supernova explosion might tell a lot about the processes going on in the center of the star and the dynamics of the supernova explosion**

N. Jachowicz, G.C. McLaughlin: ***PRL 96** (2006) 172301*

# Low energy beta-beams as a laboratory of neutrino interactions

## Reconstructing supernova ν-spectra

1) Measure detector response
with several $\gamma_i$

2) Fit detector response
to measured supernova neutrino signal

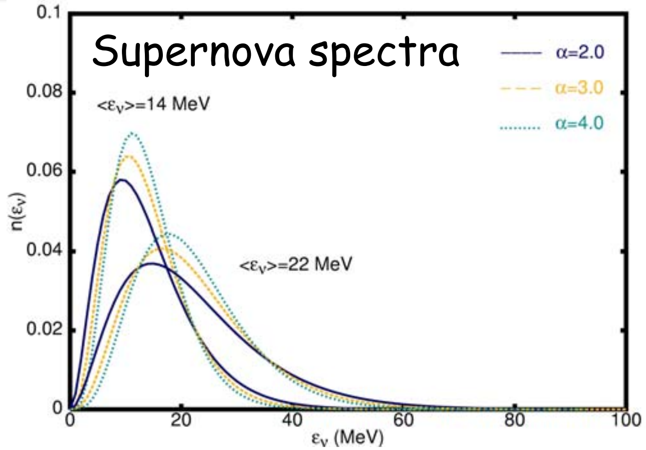
$$\sigma_{fit}^{fold}(\omega) = \sum_{i=1}^{N} a^{\gamma_i} \int d\varepsilon_\nu \, \sigma(\varepsilon_\nu, \omega) \, n^{\gamma_i}(\varepsilon_\nu).$$

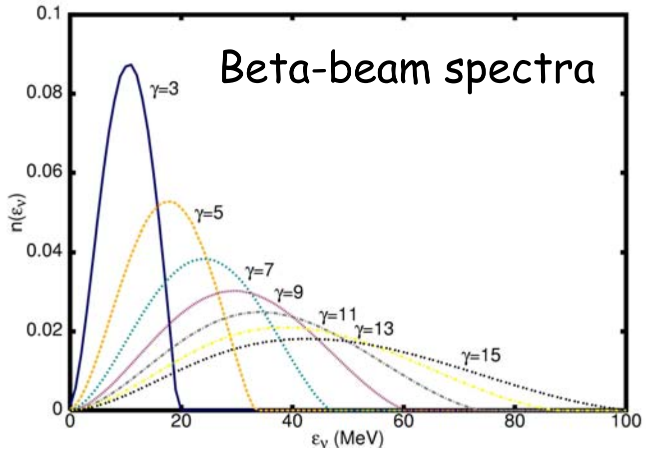
3) One gets supernova neutrino flux by:

$$n_{fit}(\varepsilon_\nu) = \sum_{i=1}^{N} a^{\gamma_i} n^{\gamma_i}(\varepsilon_\nu).$$

---

**Low energy beta-beams as a 'direct' way to measure the nuclear response to a supernova neutrino signal and obtain information about the supernova neutrino spectrum**



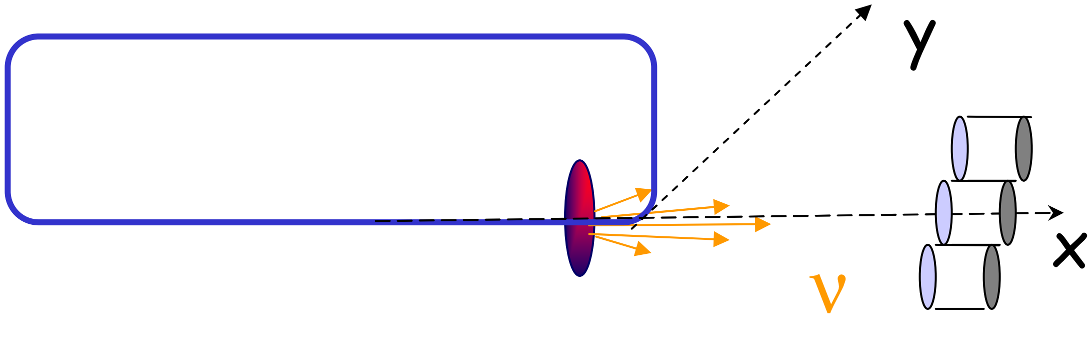



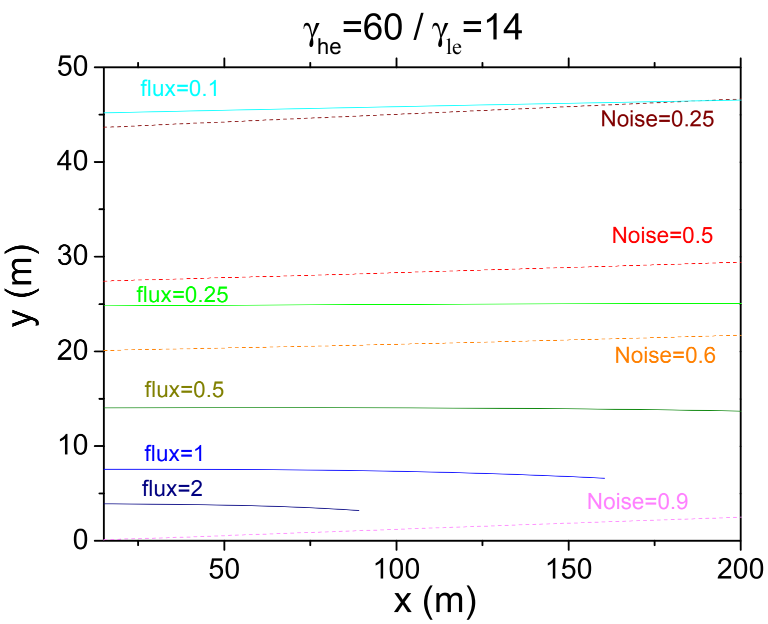

N. Jachowicz, G.C. McLaughlin: *PRL 96 (2006) 172301*

# Low energy beta-beams as a laboratory of neutrino interactions

✓ Can one use the original beta-beam for low energy neutrino experiments?

Place detector out of the large storage ring axis




Compromise to be done:
flux vs high-energy neutrino noise

R. Lazauskas, C. Volpe, work in progress.

# Low energy beta-beams as a laboratory of neutrino interactions

Low energy beta-beams:

✓ is rich and unique laboratory for neutrino interaction as well as fundamental studies

✓ presents interest for research in several domains of physics

✓ represents an interesting extension of EURISOL

Acknowledgements: I acknowledge the financial support of the EC under the FP6 "Research Infrastructure Action-Structuring the European Research Area" EURISOL DS Project; Contract No. 515768 RIDS. The EC is not liable for any use that can be made of the information contained herein.

# Low energy beta-beams as a laboratory of neutrino interactions

Neutrino-nucleus cross section measurements

Better understanding of neutrino physics
nuclear physics
astrophysics
...