ν

(VERY?) LOW ENERGY BETA-BEAMS

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- What is it?
- Where could it be ?
- What for ?

Low energy Beta-beams

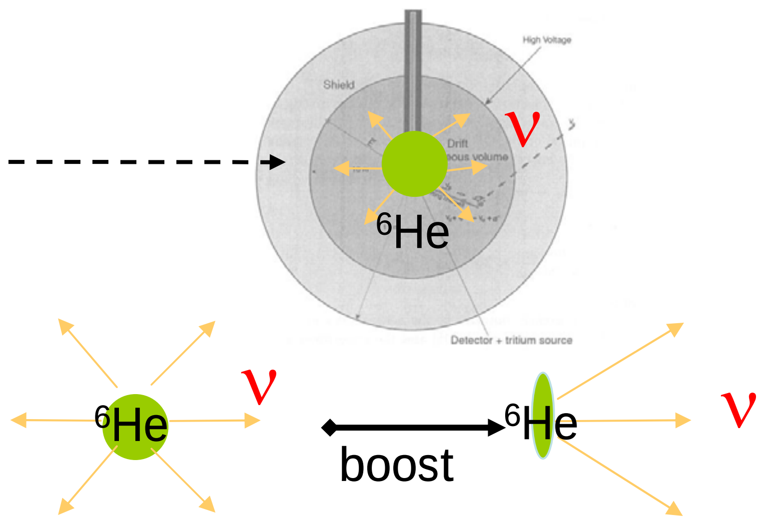
Volpe, Journ. Phys. G. 30 (2004).

THE PROPOSAL

To exploit the beta-beam concept to produce intense and pure low energy neutrino beams.

PHYSICS POTENTIAL

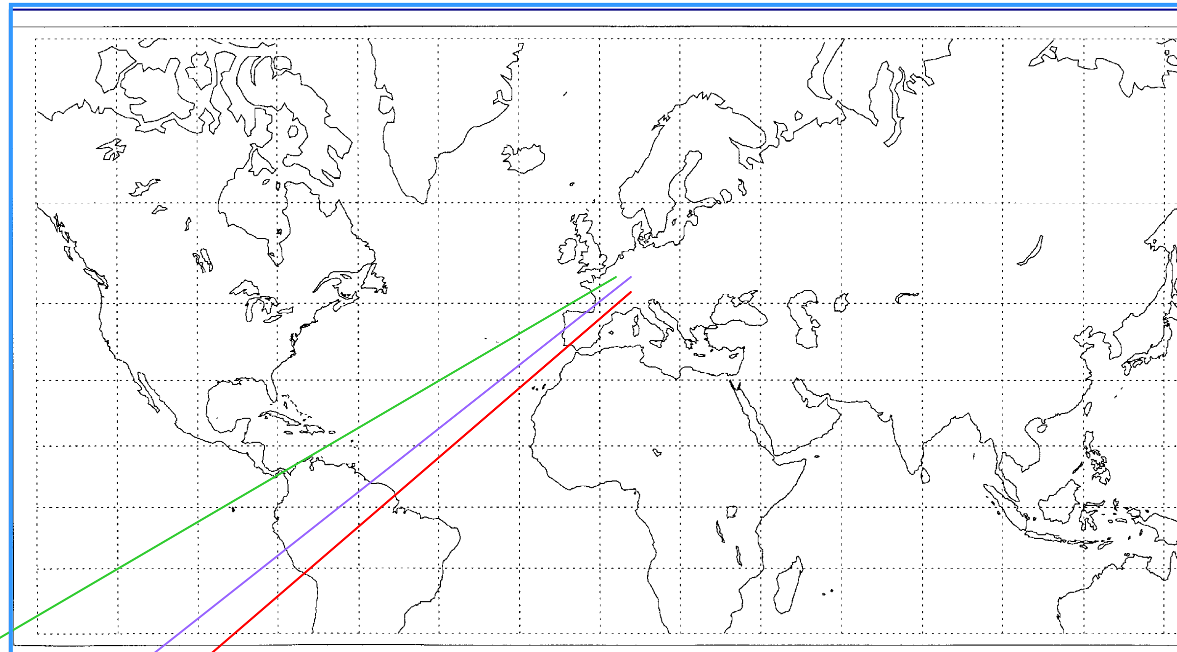
- Neutrino properties, like the ν magnetic moment.
- Neutrino-nucleus interaction studies.
- ...



A BETA-BEAM FACILITY FOR LOW ENERGY NEUTRINOS.

Possible sites for low energy β-beams

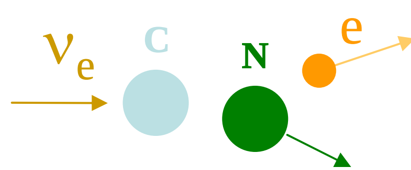
Many laboratories will produce intense exotic ion beams in the future.



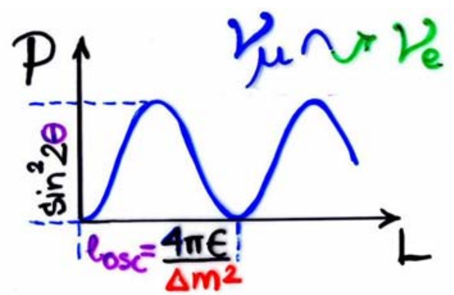
	Intensities	γ	Storage Ring	Detector
GANIL	10^{12} ν/s	1	✗	4π
GSI	10^{9} ν/s	1-10	✓	4π and Close detector
CERN	$10^{12\text{-}14}$ ν/s	1-100	✓	

Neutrino-nucleus interactions

NUCLEAR
PHYSICS

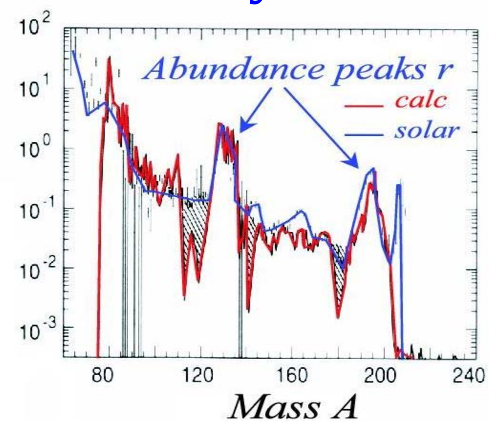


Neutrino
experiments



STANDARD MODEL
and BEYOND

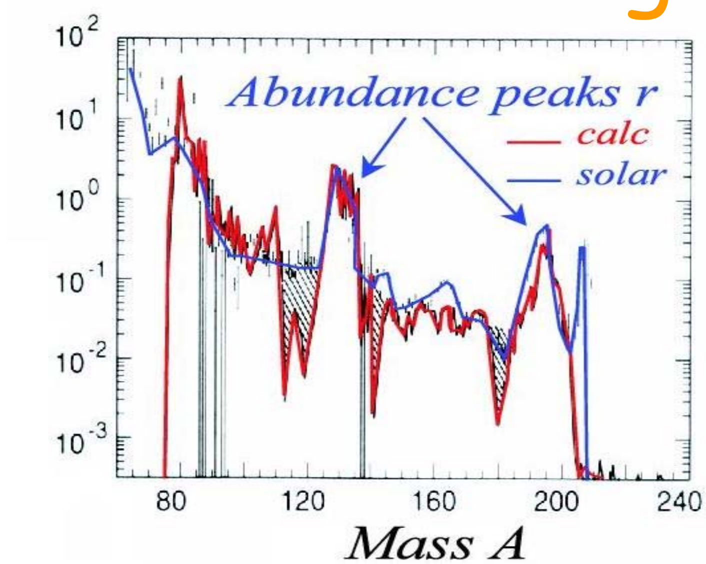
Supernovae,
Nucleosynthesis



ASTROPHYSICS

A TOPIC OF CURRENT GREAT INTEREST.

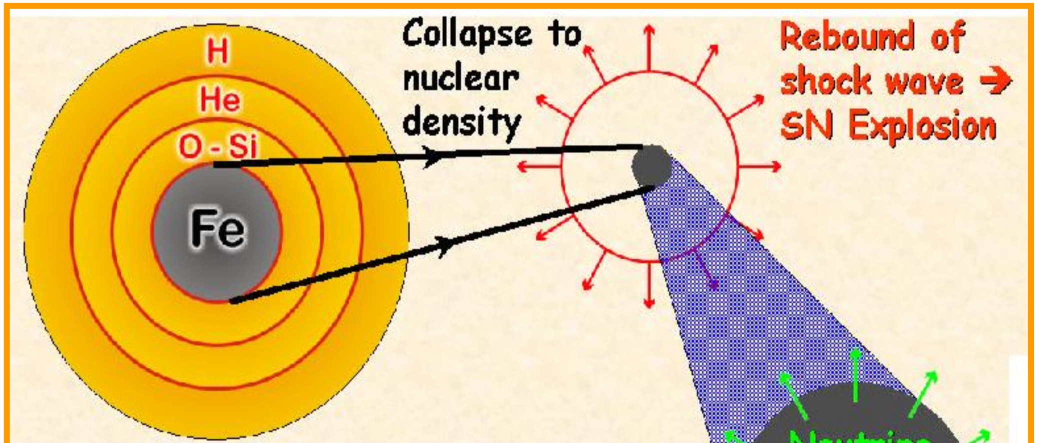
Understanding Nucleosynthesis

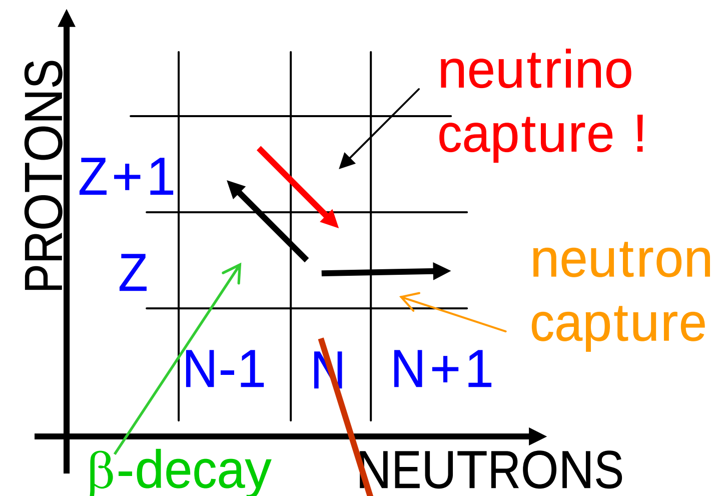


The site where the heavy elements are synthetized is not known.

Supernova type II explosions:

99 % of the energy is emitted as neutrinos.





Calculations of abundances.

neutron-rich (exotic) nuclei.

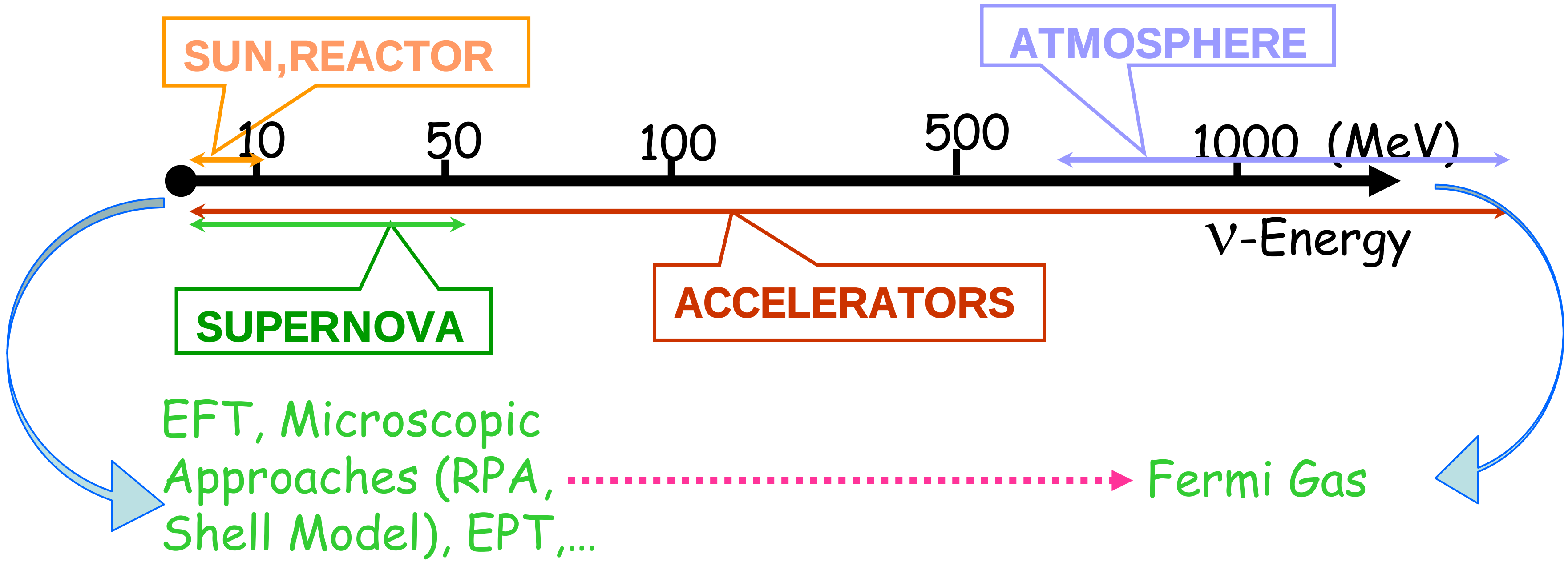
ν-NUCLEUS INTERACTIONS ARE NEEDED.

ν-Nucleus Interactions: Present status

Neutrinos probe nuclei over a wide energy range.

Nuclear Degrees of Freedom

Nucleon Degrees of Freedom



Experimental data are very scarce (deuteron and iron, carbon).

Theoretical predictions are absolutely necessary.

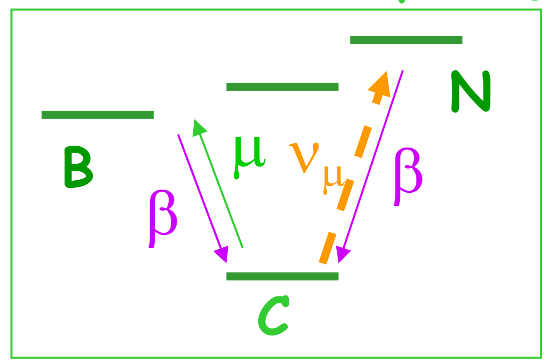
The interpolation between these two regimes as well as the extrapolation from stable to exotic nuclei are needed !

Constraints and Challenges

- From other weak processes :

  Very low momentum transfer (a few MeVs) ← β-decay

  Low momentum transfer (about 100 MeV) ← μ-capture

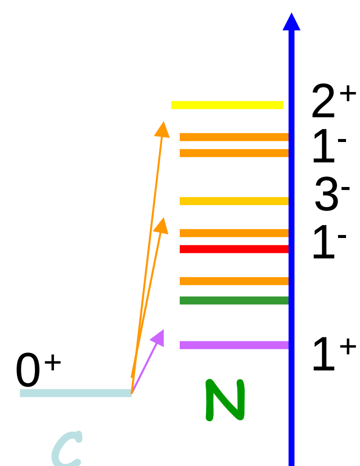


EXAMPLE

- From model-independent sum-rules, for some states.

BUT... Neutrinos can transfer a lot of energy to a nucleus.

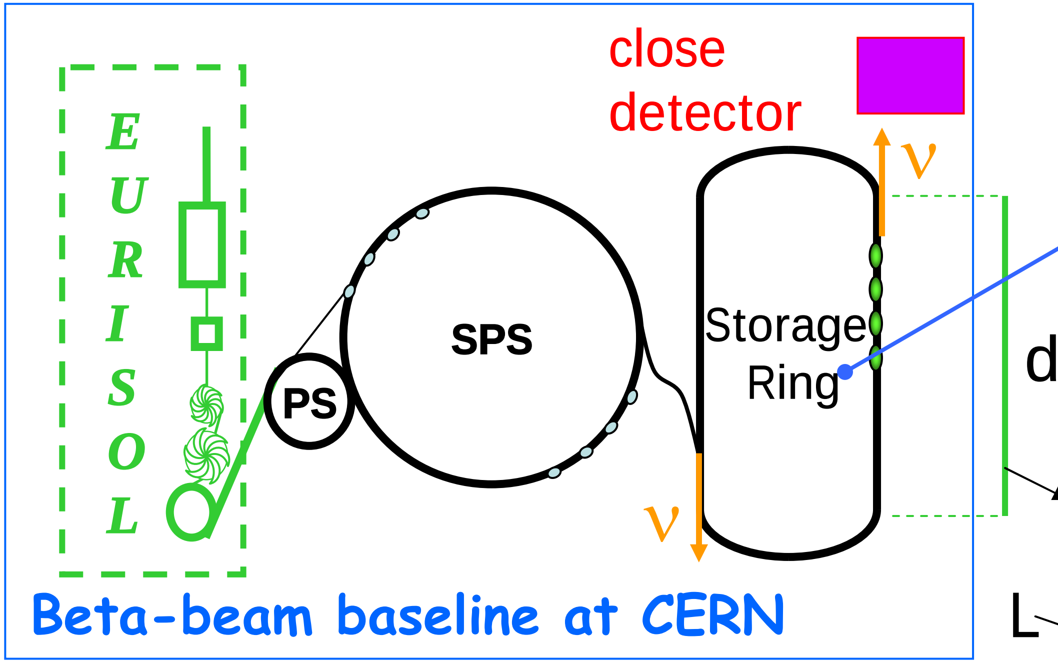
$$\nu_\mu + {}^{12}C \longrightarrow {}^{12}N + \mu^-$$



GETTING PRECISE PREDICTIONS IS A CHALLENGING TASK.

Neutrino-nucleus measurements

Serreau and Volpe, hep-ph/0403293, PRC70 (2004).



Two options studied :
- Large ring
- Small Ring

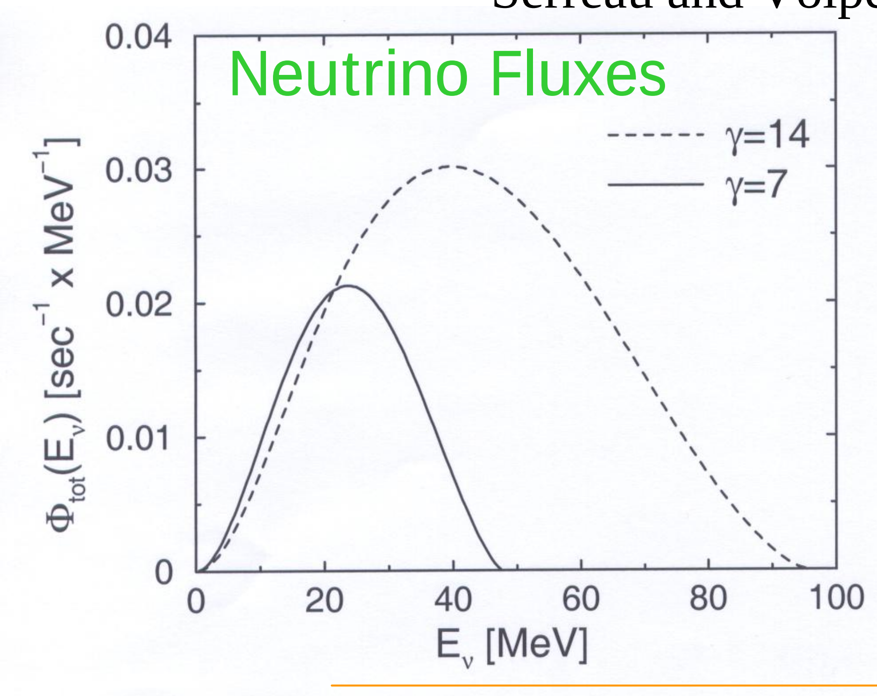
length of the straight sections

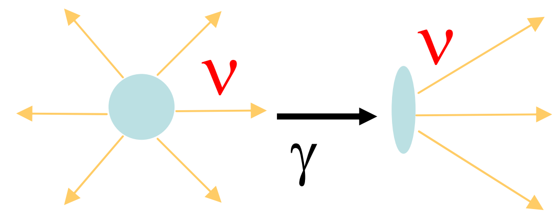
total length

...or at one of the laboratories that will produce intense radioactive beams in the future (need of ion acceleration to GeV energy and of a storage ring).

ν-Nucleus Interaction Rates

Serreau and Volpe, hep-ph/0403293, PRC70 (2004).





$<E\nu>\sim 2\gamma Q_\beta/2$

The unique feature that the ν-energy can be easily varied.

Events per year for γ=14

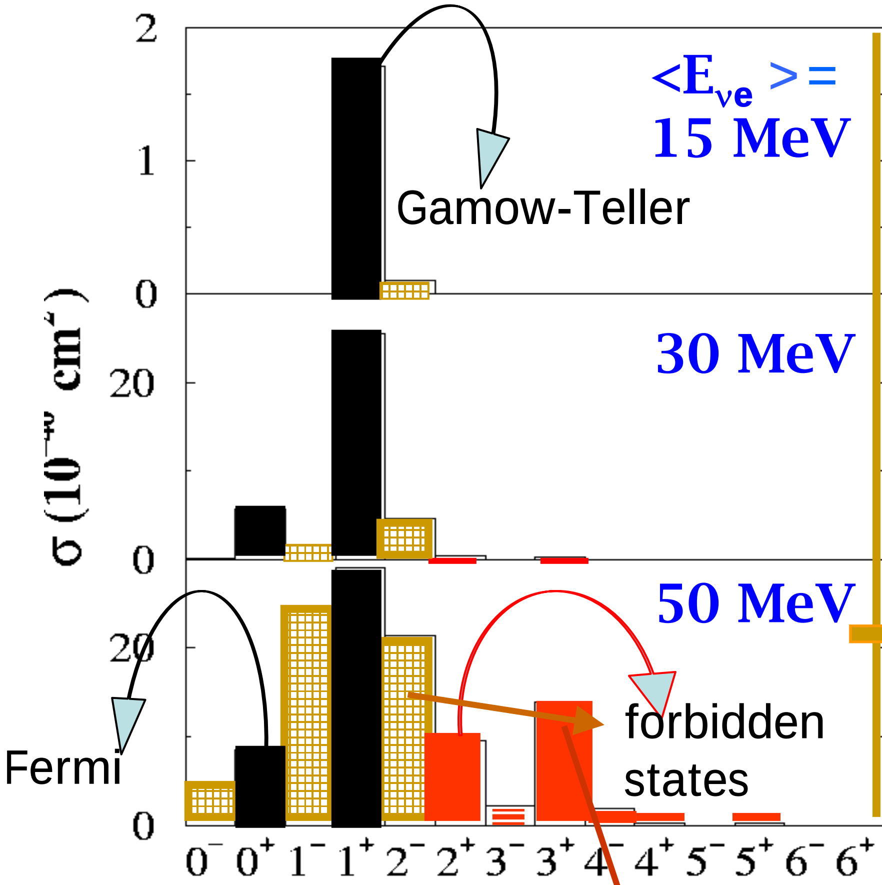
	Mass (tons)	Small Ring	Large Ring
$\bar{\nu}_e$ + D	35	25779	1956
$\bar{\nu}_e$ + ^{16}O	952	82645	9453
ν_e + ^{208}Pb	360	103707	7922

Small Ring : d = 150 m, L= 450m Large Ring :d = 2.5 km, L =7.5 km

INTERESTING INTERACTION RATES CAN BE OBTAINED.

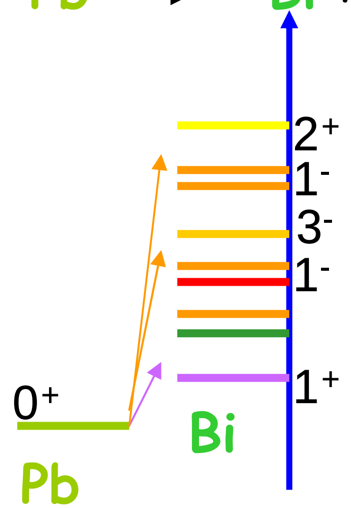
NEUTRINOS AS a PROBE for NUCLEAR STRUCTURE STUDIES.

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



EXAMPLE

$\nu_e + {}^{208}Pb \longrightarrow {}^{208}Bi + e^-$



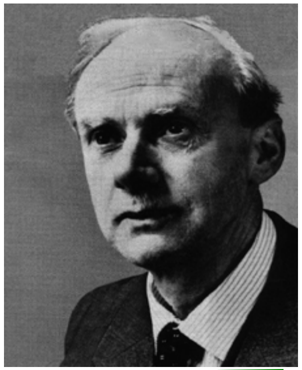
The contribution of forbidden states to the total cross section increases for increasing impinging neutrino energy.

no experimental information is available.

LEARN ABOUT FORBIDDEN STATES.

ν: Majorana or Dirac particles?

ν Dirac



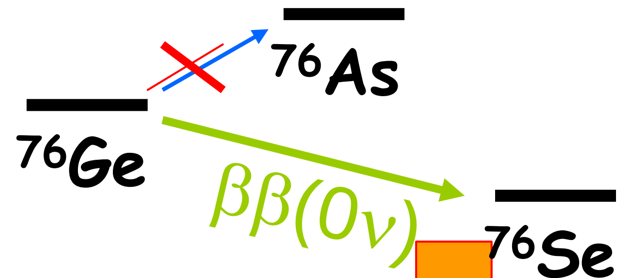
$\nu \neq \bar{\nu}$

?

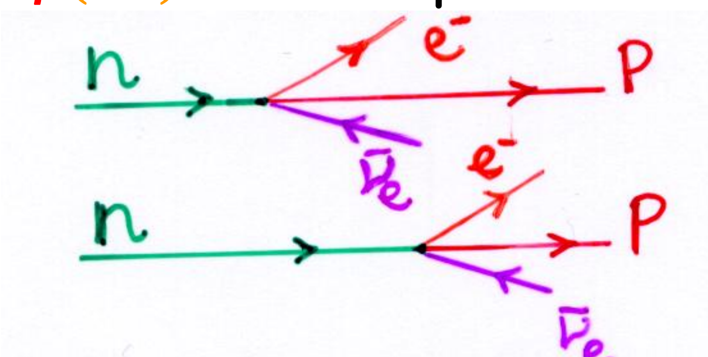
ν Majorana

$\nu = \bar{\nu}$

How do we search for the ν-nature?



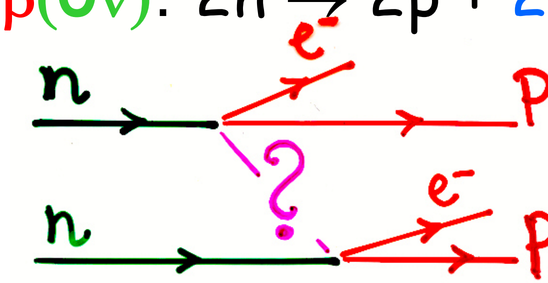
$2\beta(2\nu)$: $2n \rightarrow 2p + 2e^- + 2\bar{\nu}_e$



Within the Standard Model
(V-A theory)

Observed in various nuclei.

$2\beta(0\nu)$: $2n \rightarrow 2p + 2e^-$

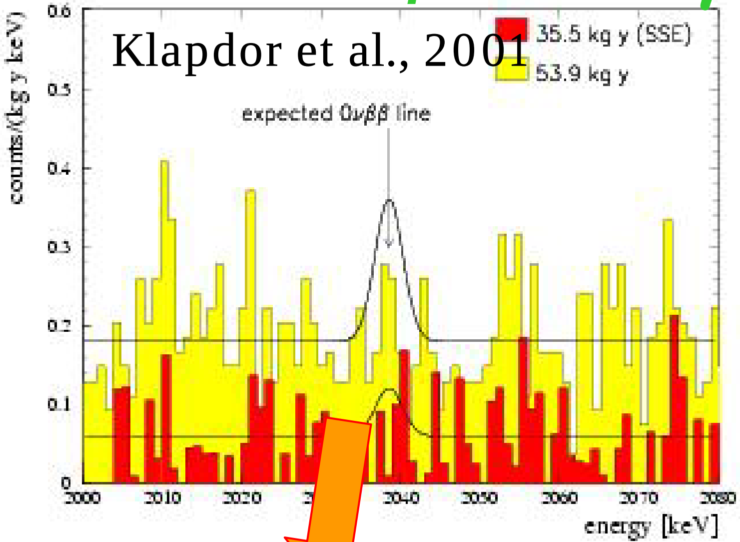


Lepton-violating process

Beyond the Standard Model
(e.g. exchange of massive Majorana neutrinos)

Never observed.

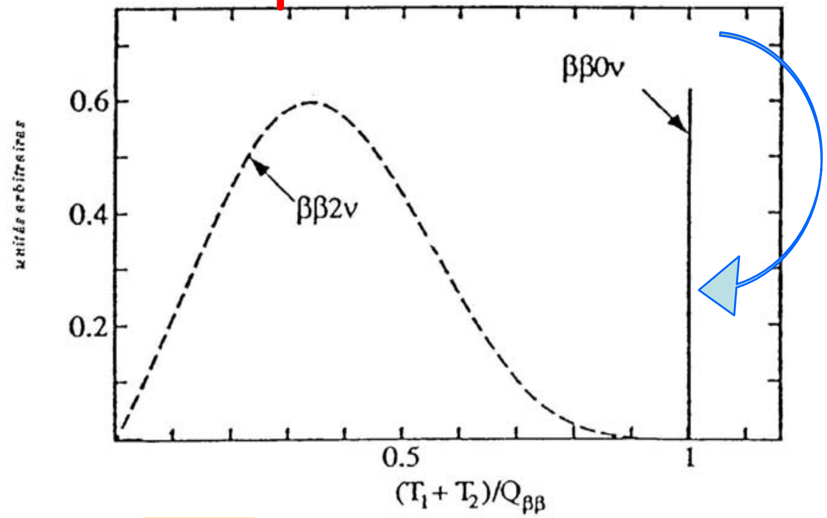
2β decay: Present Status

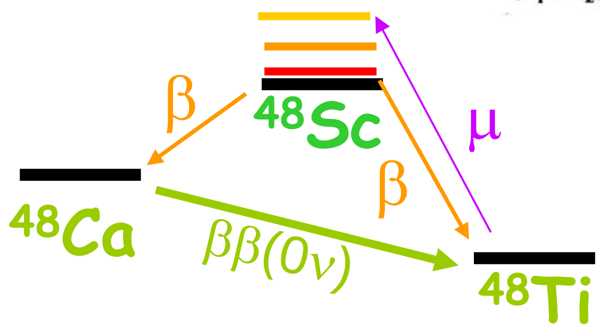


$T^{0\nu}_{1/2} > 1.9\ 10^{25}$ y (90% C.L.)

$< m_\nu > \; < 0.3 - 1.0$ eV

The experimental search





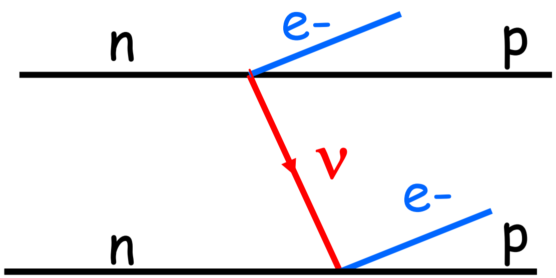
The theoretical situation

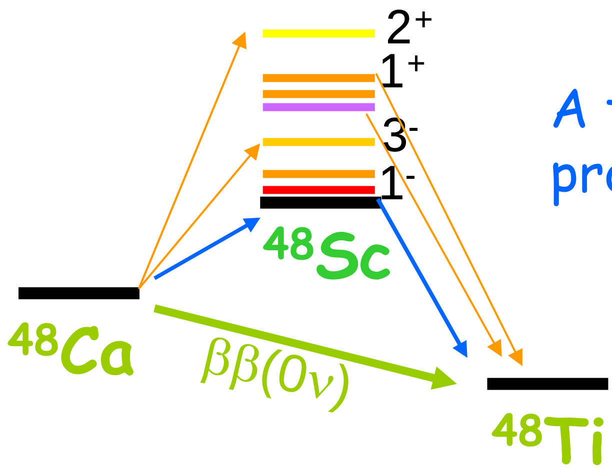
- Theoretical predictions on the half-lives exhibit important variations for the same candidate emitter.

- Several processes have been considered to constrain the nuclear matrix elements, in particular beta-decay, muon capture, 2β(2ν), charge-exchange reactions.

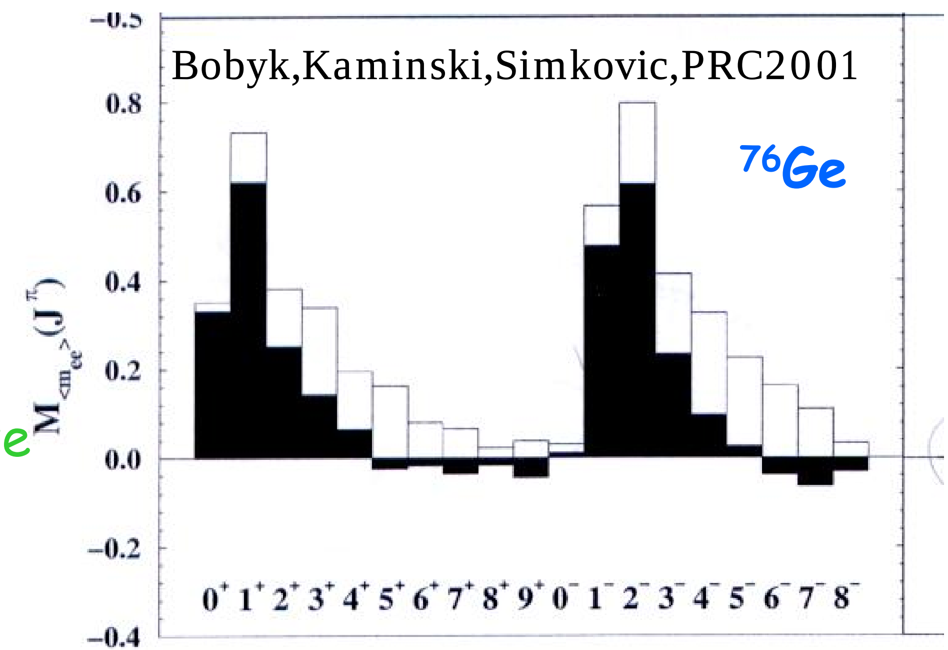
The 2β(0ν) half-life

2β(0ν): 2n → 2p + 2e⁻





A two-step process

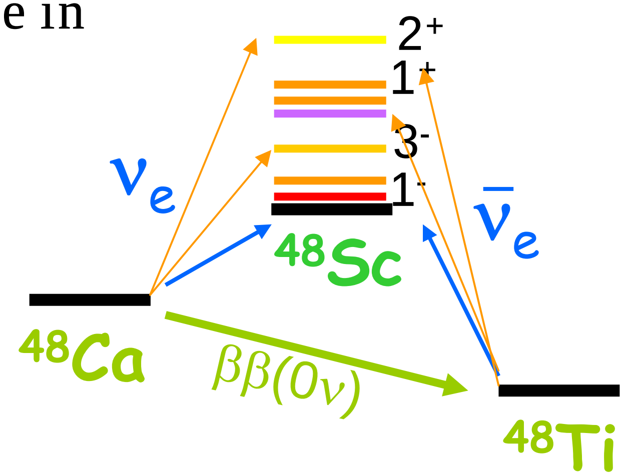


Because of the massive Majorana neutrino propagator, many nuclear states between the initial (final) nucleus and the intermediate one can be excited.

MANY STATES ARE INVOLVED.

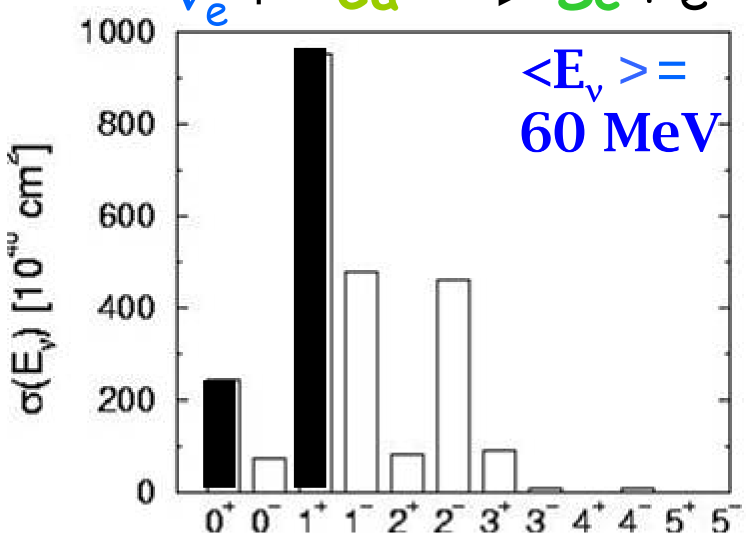
$2\beta(0\nu)$: Link to ν-nucleus

C. Volpe, article in preparation.

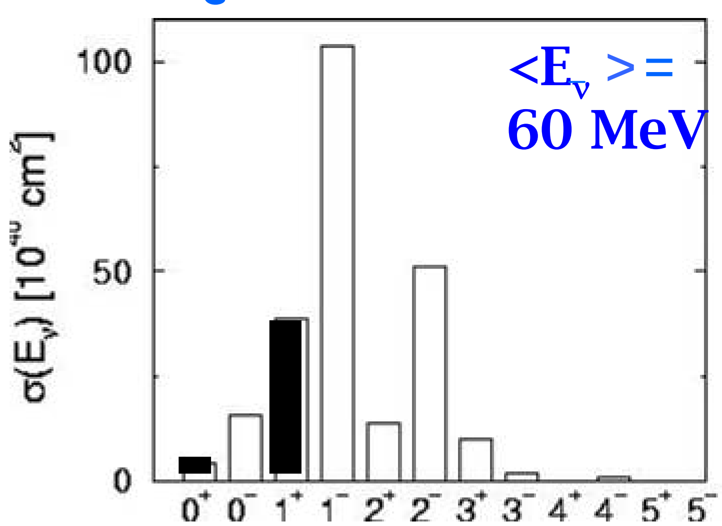


The forbidden Fermi and Gamow-Teller states involved are the same as those excited in neutrinoless double-beta decay due, e.g. to a massive neutrino exchange.

$\nu_e + {}^{48}Ca \longrightarrow {}^{48}Sc + e^-$



$\bar{\nu}_e + {}^{48}Ti \longrightarrow {}^{48}Sc + e^+$



THESE STUDIES COULD GIVE A SUPPLEMENTARY CONSTRAIN TO $2\beta(0\nu)$ DECAY PREDICTIONS.

Low energy Beta-beams

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

THE PROPOSAL

To exploit the beta-beam concept to produce intense and pure low energy neutrino beams.

PHYSICS POTENTIAL

- Neutrino properties, like the ν magnetic moment.
- Neutrino-nucleus interaction studies.
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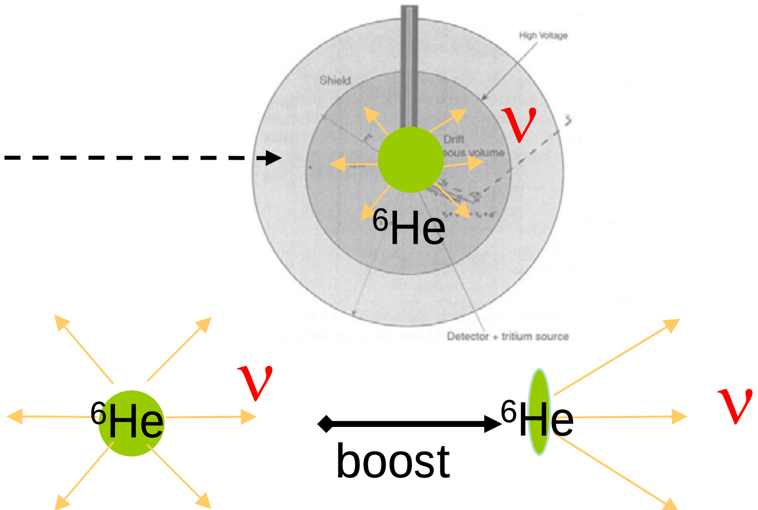


A BETA-BEAM FACILITY FOR LOW ENERGY NEUTRINOS.

Conclusions and Perspectives

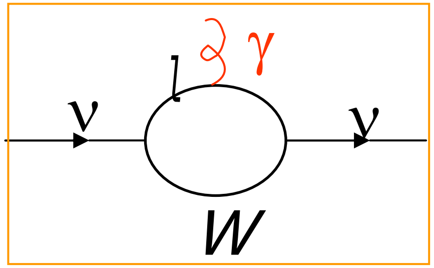
Low energy Beta-beams

- A facility producing low energy neutrinos.
- CERN appears as a unique site, but there could be other possibilities.
- A rich physics program can be performed.
- The feasibility study :
  A close look at the feasibility of the small storage ring?

More to come…

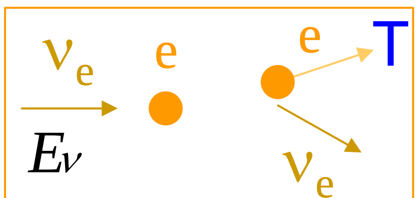
IT'S A UNIQUE OPPORTUNITY !

The ν-Magnetic Moment: Prospects

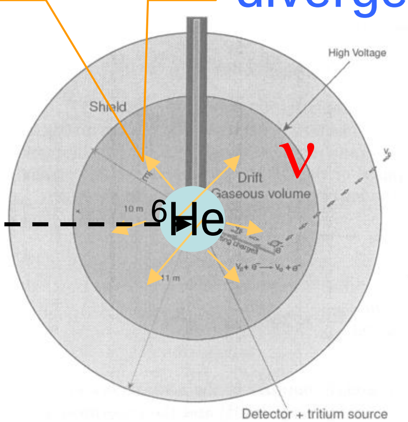


PRESENT DIRECT LIMIT:

$\mu_\nu < 1.0 \times 10^{-10}\ \mu_B$.

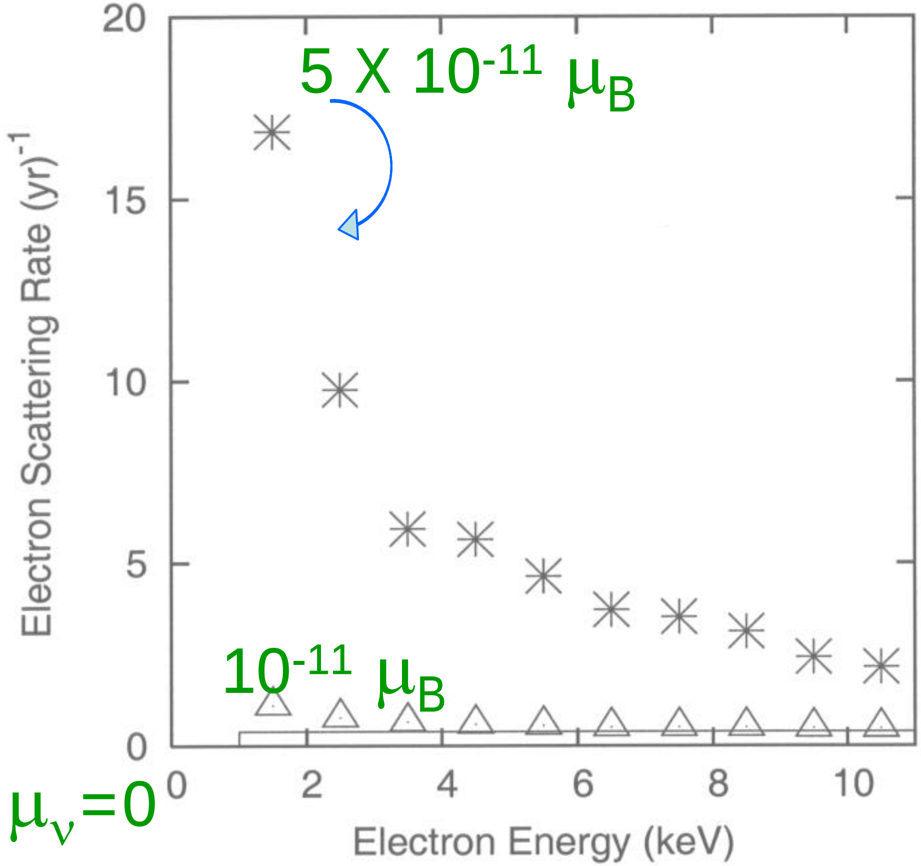


μ_ν introduces a 1/T-like divergence.



Q_β=4. MeV

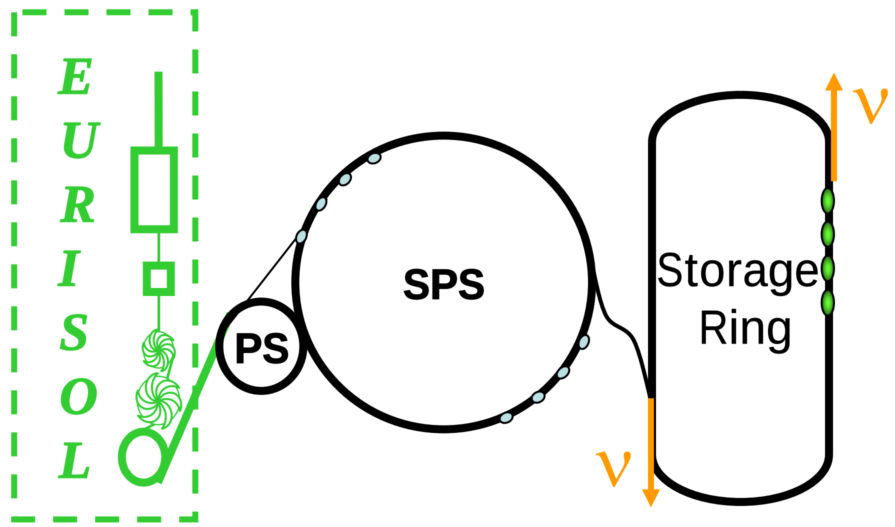
ν_e-e **events with low-energy beta-beams** (10^{15} ν/s) and a 4π low threshold detector.



THE LIMIT CAN BE IMPROVED BY ONE ORDER of MAGNITUDE .

G.C. McLaughlin and C. Volpe, Phys. Lett. B 591 (2004).

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



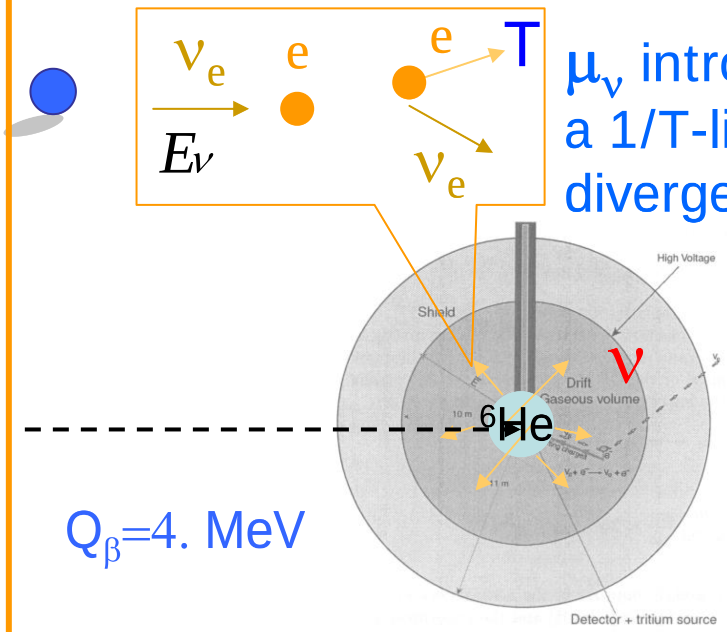
Beta-beam baseline at CERN

...or at one of the laboratories that will produce intense radioactive beams in the future (need of ion acceleration to GeV energy and of a storage ring).

TWO POSSIBLE SCENARIOS.

Prospects with low energy beta-beams

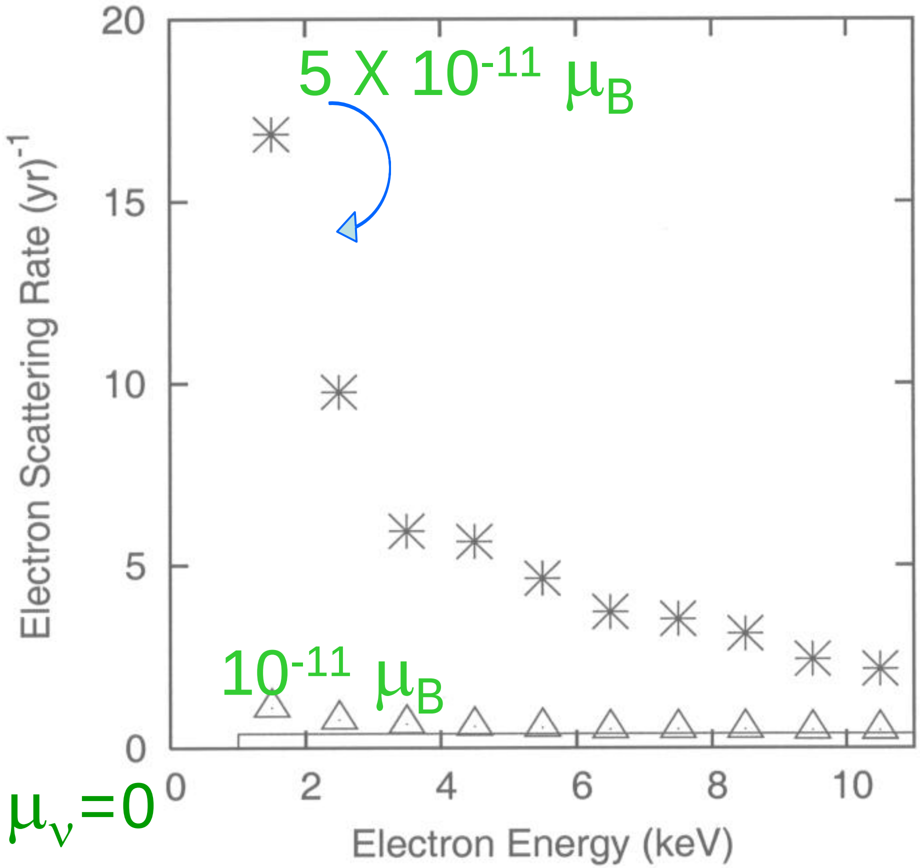
McLaughlin and Volpe, Phys. Lett. B 591 (2004).



μ_ν introduces a 1/T-like divergence.

Q_β=4. MeV

ν_e-e events with 10^{15} ν/s from ^{6}He and a 4π low threshold detector.



AN IMPROVEMENT BY ONE ORDER of MAGNITUDE .

Present limits and strategies

- PRESENT DIRECT LIMITS: $\mu_\nu < 1.0 \times 10^{-10}\ \mu_B$ (95 % C.L.)
  from reactor experiments (MUNU, Kuo-Sheng, Rovno,...)

  INDIRECT LIMITS : $\mu_\nu < 10^{-10} - 10^{-12}\ \mu_B$ model-dependent !
  from astrophysical considerations (star cooling, SN1987A, ...)

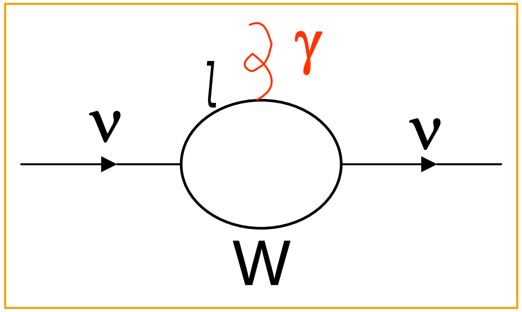
- To improve direct limits one needs :

SOURCE	DETECTORS
well known ν-fluxes high ν-intensities	low-threshold detectors

STRATEGIES → reactors
STRATEGIES → static sources
STRATEGIES → beta-beams

McLaughlin and Volpe, Phys. Lett. B 591 (2004).

The neutrino magnetic moment

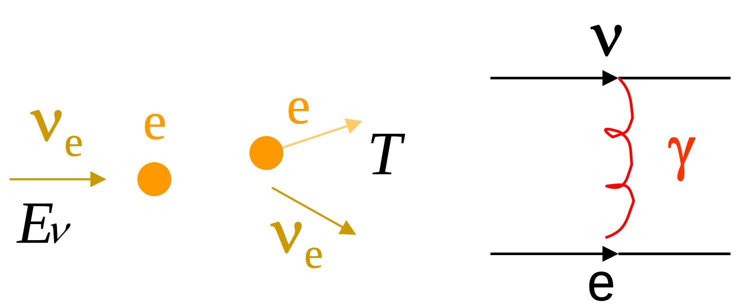


Since $m_\nu \neq 0$, at the one-loop level :

$$\mu_\nu = 3.2 \times 10^{-19} \, (m_\nu/1 \text{ eV}) \, \mu_B$$

This neutrino property has important implications in astrophysics, e.g. for core-collapse Supernovae.

A large ν magnetic moment points to new physics.



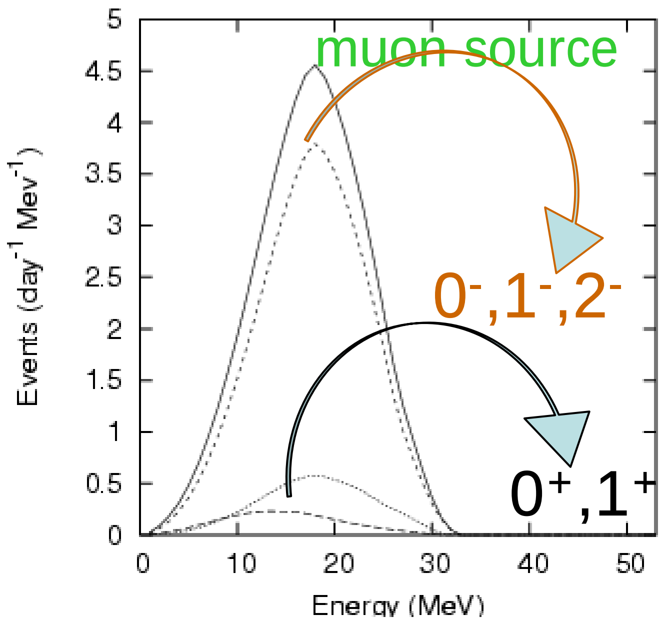
Neutrino-electron scattering

How can one measure μ_ν?

The presence of a magnetic moment introduces in the ν_e-e cross section, a 1/T-like divergence, where T is the electron recoil energy.

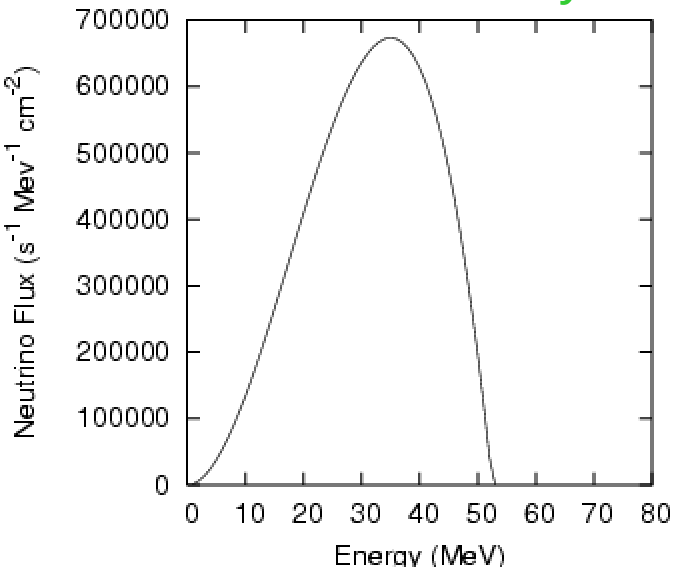
$\nu_e + {}^{208}Pb \longrightarrow {}^{208}Bi + e^- + 2n$

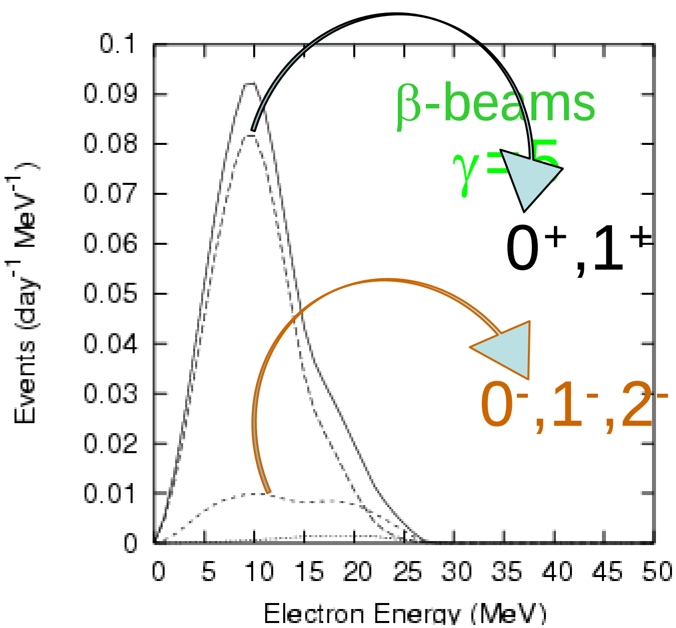
A comparison with conventional beams



McLaughlin, nucl-th/0404002.

Neutrino flux from the decay of muons





COMPLEMENTARY INFORMATION CAN BE OBTAINED.