Talk: choruswww.cern.ch/~pzucchel/files/betabeam/venice.ppt

Forewords:

A - newborn (few weeks)
- immature
- crawling
- trivial

But new concept
to produce neutrino beams

First Public Presentation

Therefore: Your feedback is the most important part of this talk.

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Reference: hep-ex/0107006 or CERN-EP/2001-056 (Subm. To PLB)

Legenda

0. neutrino beams from a different perspective

1. The "Beta-Beam" Concept

2. The Feasibility Questions

3. The EC Beta-Beam

4. The Possible Physics Impact

The evolution of neutrino physics demands new schemes to produce intense, collimated and pure neutrino beams. The current neutrino factory concept implies the production, collection, and storage of muons to produce beams of muon and electron neutrinos at equal intensities at the same time. Research and development addressing its feasibility are ongoing. In the current paper, a new neutrino factory concept is proposed, that could possibly achieve beams of similar intensity, perfectly known energy spectrum and a single neutrino flavour, electron anti-neutrino. The scheme relies on existing technology.

ν beam fundamentals

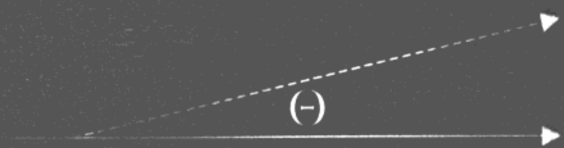
ν are produced by weak "decay" of a parent: μ,π,K,nucleus.
We assume the decay to be isotropic at rest and call E_0 the rest frame energy of the neutrino.

The focussing properties are given only by:

- the divergence of the parent "beam"
- the Lorentz transformations between different frames

$$P_T = p_T$$

$$P_L = \Gamma\,(p + p \times \cos\theta)$$



from which, on average

$\Theta \approx 1/\Gamma$ (it depends ONLY on parent speed!)

$E \approx \Gamma E_0$

and, in the forward direction,

$E \approx 2\Gamma E_0$ (same rest-frame spectrum shape multiplied by 2Γ)

ν beam fundamentals

“The Long Base-Line requirement”:
maximum neutrino flux for a given $\Delta m^2 \approx E/L \approx \Gamma E_0/L$.

The neutrino flux onto a “far” detector goes like $\Phi \approx \Gamma^2/L^2$
Trivially follows that

$$\Phi \approx (\Delta m^2)^2/E_0^2.$$

At a <u>given parent intensity</u>, decays which have a low energy in the rest frame are the most efficient in achieving the “LBL requirement”, independently of the Γ factor.

Of course, better the “signal” neutrinos interact!

$$N = \Phi \times \sigma$$

If we assume to be in the regime where $\sigma \propto E$ (>300 MeV for ν_e)

$$N \approx (\Delta m^2)^2 \, \Gamma/E_0$$

So acceleration enters into the game; the overall “Quality Factor” is Γ/E_0

ν beam func

$\Gamma/E_0 = E / mE_0$ **mE_0="parent quality factor"**

This description applies to a beam of collimated parents (so, not to conventional beams) as the muon beams, for example, are.

Why we should use muons? Are they magic?

In fact, these parameters do not say the obvious:

Up to now, we have accelerated ONLY stable particles.
All current accelerating schemes NEED time (beam cooling, power).

The short lifetime (2.2 μs) and the difficulty to collect muons into an accelerator are the major challenges of the neutrino factories.
Muon production is at high energy, very different from all existing accelerator sources.

A Worldwide Challenge.

The Beta-Bea[illegible]

1. Produce a Radioactive Ion with a beta-decay lifetime ~1s

2. Accelerate the ion in a conventional way (PS) to “high” energy

3. Store the ion in a storage ring with straight sections.

4. It will decay. $\bar{\nu}_e$ (ν_e) will be produced.

Muons:
$\Gamma \sim 500$
$E_0 \sim 34$ MeV
QF~15

- Pure SINGLE flavour
- Known spectrum
- Known intensity
- Focussed
- Low energy
- “Better” Beam of $\bar{\nu}_e$ (ν_e)

Beta:
$\Gamma \sim 100$
$E_0 \sim 1.7$ MeV
QF~57

The achievable “quality factor” QF=Γ/E_0 is bigger than in conventional neutrino factory. In addition, production & acceleration are simpler.

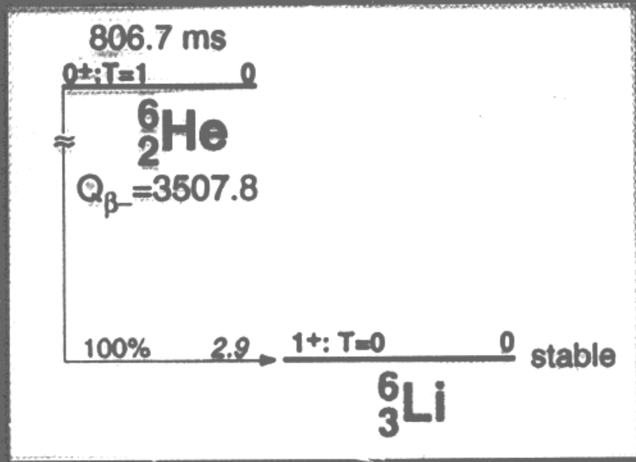
The Beta-Beam

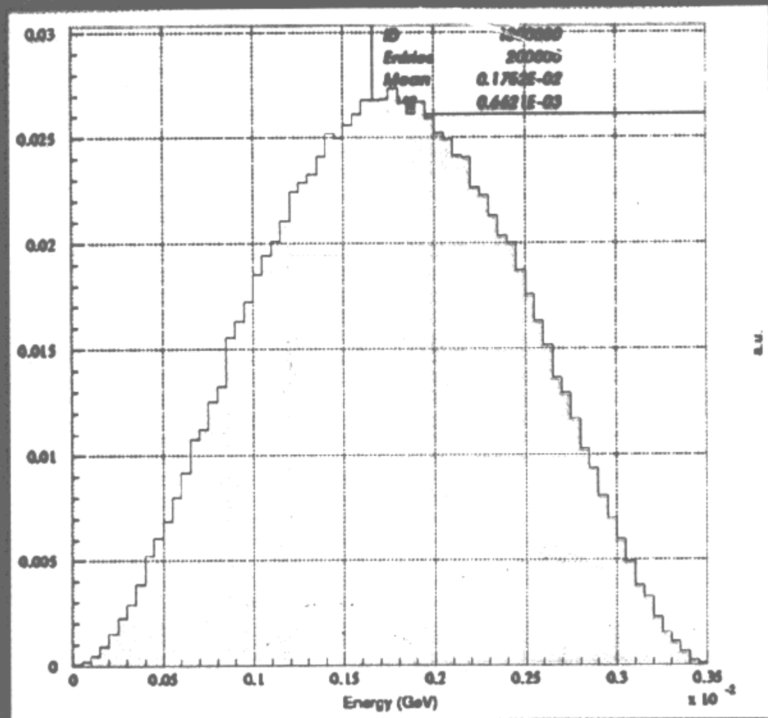
Consider $^6He^{++} \rightarrow {}^6Li^{+++}\, e\, \overline{\nu}_e$

$E_0 \approx 3.5$ MeV $T/2 \approx 0.8$ s

This radioisotope can be produced and separated, <u>today</u>, at CERN ISOLDE, at a rate of 10^8 $^6He/s$ with 4 μA and 1.4 GeV p beam. Without specific optimization.

Needless to say, the $\overline{\nu}_e$ energy spectrum is perfectly known on the basis of existing electron measurements.





The Accelerator

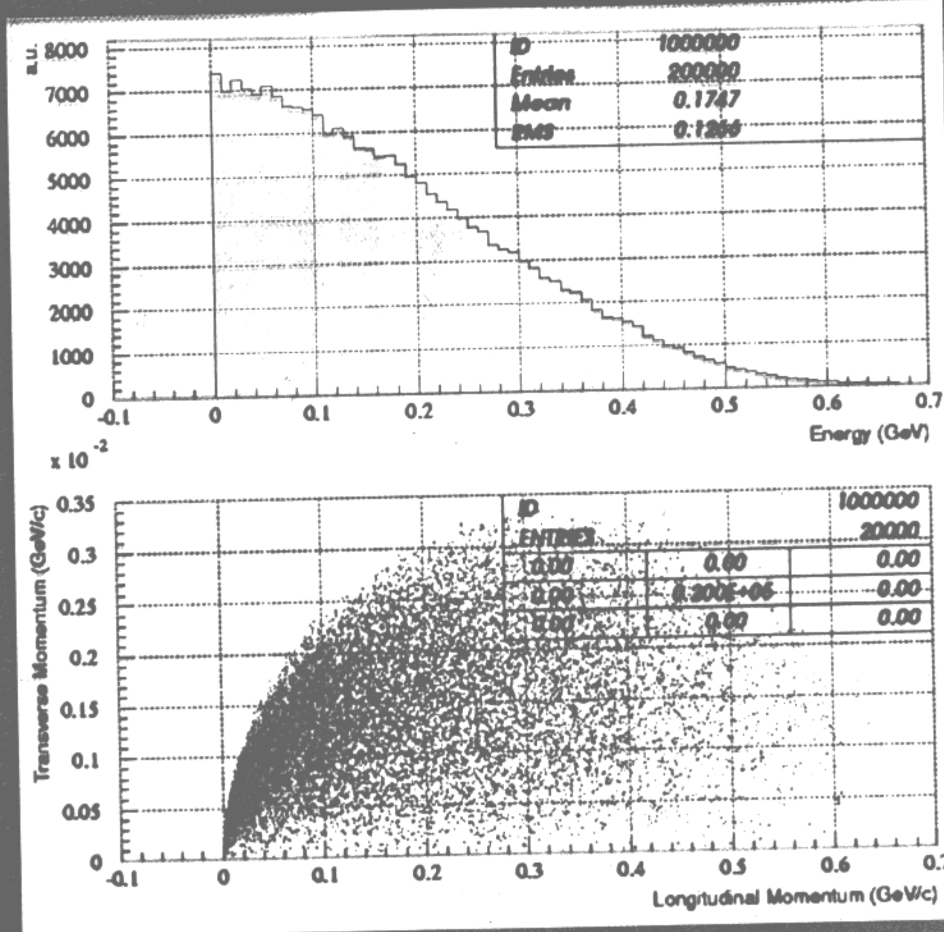
2. the Ion can be accelerated in a conventional way.

The radioisotope acceleration is a conventional technique in nuclear physics studies (e.g. REX-ISOLDE).

A large variety of RIBs (Radioactive Ion Beams) is existing, and new facilities are expected (see CERN COURIER, July/August 2001).

CERN PS+SPS are (today) accelerating heavy ions up to $\Gamma=150$.

The complexity of the FAST muon acceleration is absent (4×10^5 more time).



To Fix ideas, $\Gamma=100$

The Storage Ring

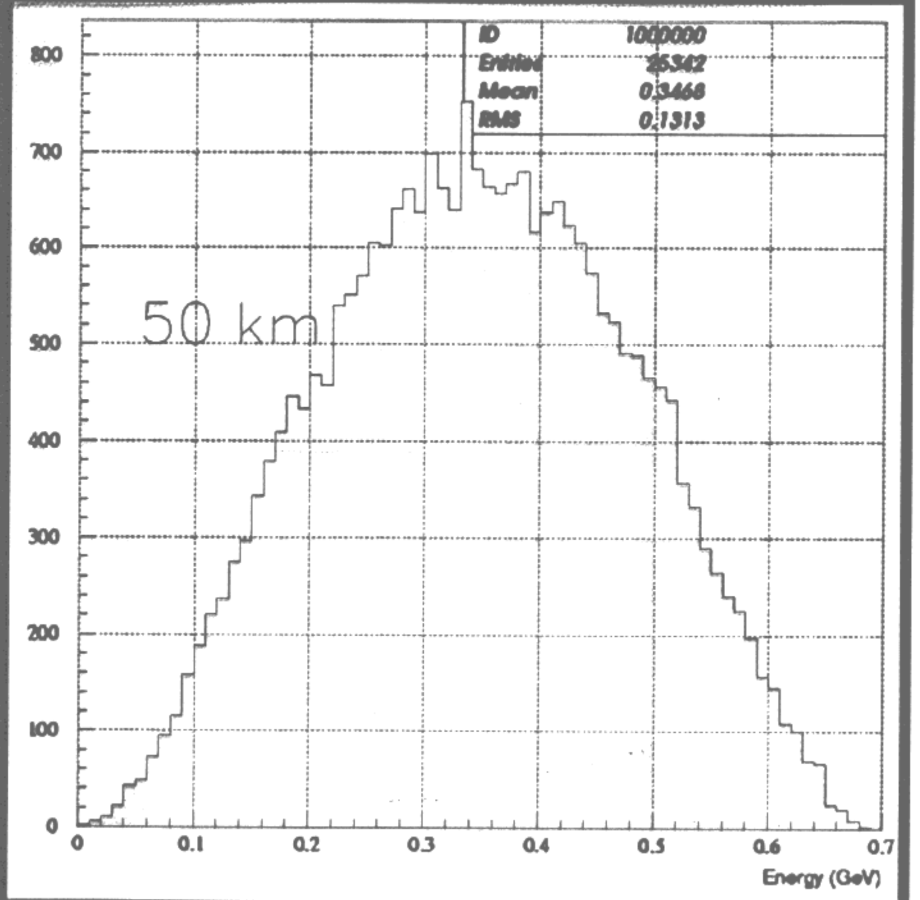
Conceptually like in a "conventional" neutrino factory, but for a larger time (140 s) and larger momenta (100 GeV/nucleon).

Some numbers:

$\Theta \approx 1/\Gamma \approx 10$ mrad
$\langle E \rangle \approx 350$ MeV

Beta-beam @100 km:
$\langle E \rangle/L = 3.5 \times 10^{-3}$ GeV/km (Atmo)
$\Phi \approx 3.8 \times 10^{-7}$ /m²/ ^{6}He

Conventional muon beam @3000 km:
$\langle E \rangle/L = 1.1 \times 10^{-2}$ GeV/km
$\Phi \approx 8 \times 10^{-9}$ /m²/ μ



Γ=100, 350 MeV@50 Km.

The Feasibility Question

1. How many Ions can be produced?

T. Nilsson, CERN-ISOLDE, is evaluating improvement factors on current ^{6}He rates:

- low Z target
- p energy (1.0 to 2.2 GeV)
- target thickness
- ionization source
- target degrader (neutron yield)

+ SPL (high intensity linac) 2.5 mA

currently: 6.8×10^{13} ^{6}He/s collected!!!

In the paper, the same number was 10^{12}.

The facility to produce ions for neutrino beta-beams is essentially the same facility already advocated by the nuclear physics community.

The Feasibility Questions

2. Can a "conventional" machine stand the decays during acceleration?

The decay, on average, comes from a relatively low energy parent: the average $^6He^{++}$ ion produces:

- a negative electron with ~40 MeV;
- a harmless neutrino ~ 100 MeV;
- a triple charged $^6Li^{+++}$ ion, with 25 GeV/nucleon.

? Is a relative $^6Li^{+++}$ loss rate ~5% tolerable ?

If "conventional"="existing" (JHF,SPS,Tevatron), the answer, I guess, is probably NO*.
(A correct answer should come from experts)

*Then, an idea by K. Niwa on the usage of K-shell electron capture (EC)

The feasibility issue in “existing” accelerators has triggered the following, simple, consideration:

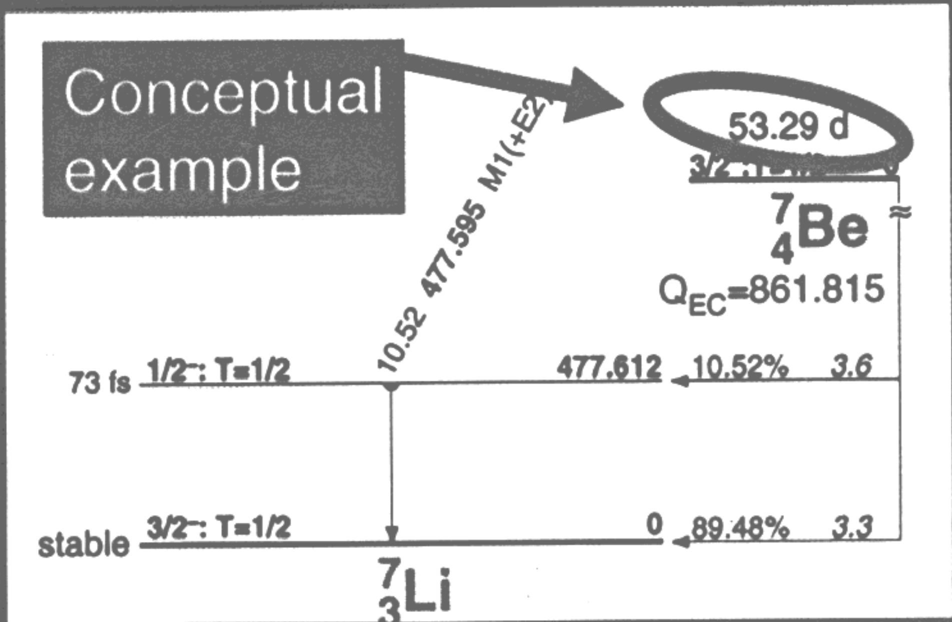
“Pollution occurs <u>only</u> since the charge/mass ratio in beta decay varies from parent to daughter ion”

Therefore:

1. Accelerate an Electron Capture (EC) radioisotope;

2. Strip the electrons with the exception of the K-shell ones

3. Further Acceleration in an <u>EXISTING</u> machine (SPS).



The EC beta-beam

The DECAY OCCURS...

...But

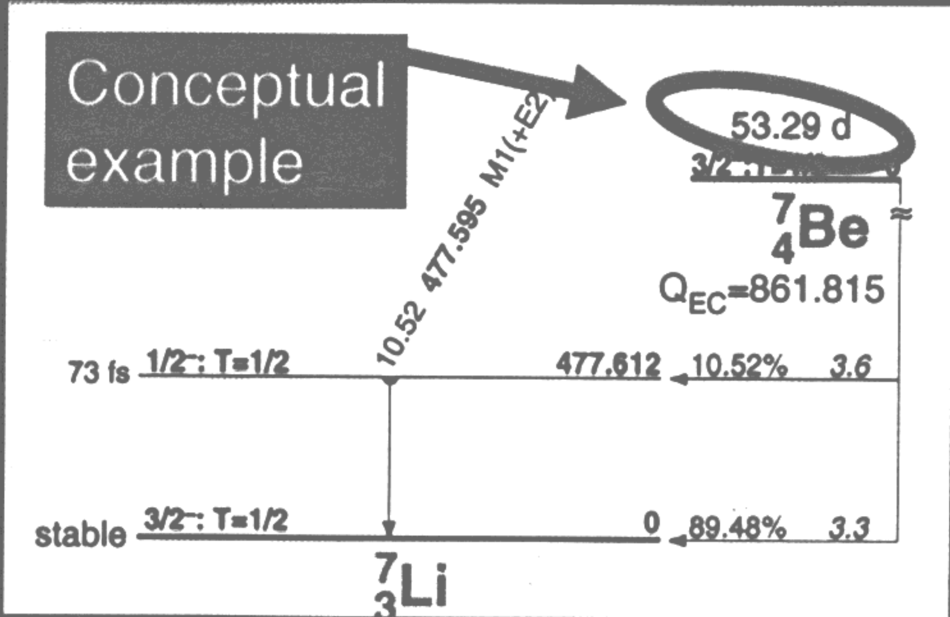
1. **The atomic charge doesn't change! And the beam transmutes.**
2. **Only a HARMLESS nue is emitted!**

A

NON POLLUTING

<u>MONOCHROMATIC</u>

NUE BETA-BEAM!



The EC beta-beam

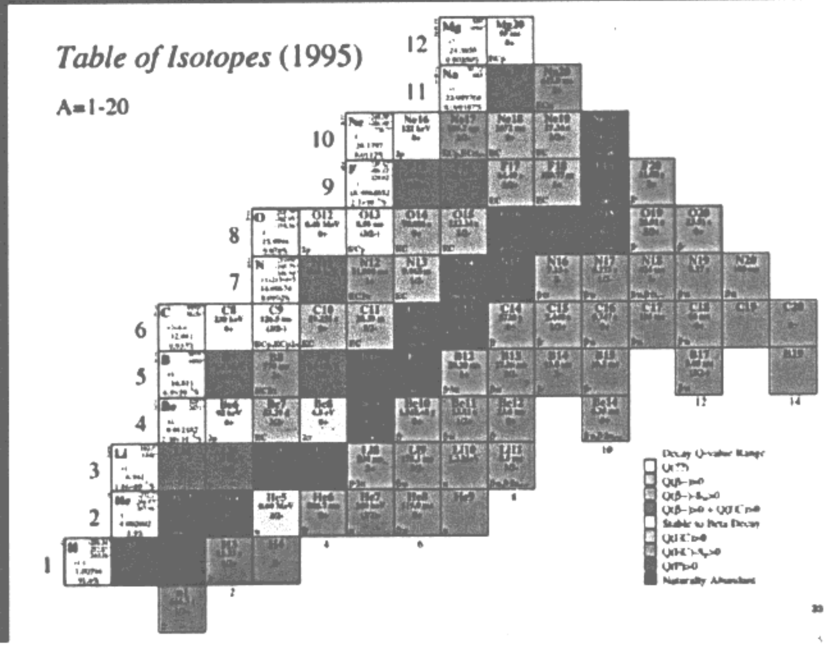
The BIG Question: Do we have a valid EC capture nucleus?

Problem:
An EC capture nucleus ALSO has a β^+ decay (e^+ emission),
Unless it is forbidden because:
- $Q<2m_e$
- "other" conservation laws.

A low Q beta decay, however, has a long lifetime ($\sim Q^{-5}$)!

- ^{7}Be, for example, has 52 days.

- ^{46}Mn has a 26 ms decay, but it's followed by 2α emission. It's anyway interesting for the monochromatic properties.



The Impact

Recent estimates:70X Larger!!!

Table 2: Summary of possible performances and characteristics of a beta-beam.

^{6}He ions production	10^{12}/s	
^{6}He accelerator efficiency	50%	
^{6}He final energy	100 GeV/nucleon	
Storage ring bunches	140	
Straight section relative length	28.7 %	
Storage time	140 s	
Running time/year	10^7 s	
Neutrino flux at 1 km	$3 \times 10^{15}/m^2/year$	$\langle E \rangle /L = 0.3$ GeV/km (LSND)
Neutrino flux at 12.5 km	$1.7 \times 10^{13}/m^2/year$	$\langle E \rangle /L = 2.8 \times 10^{-2}$ GeV/km (CNGS)
Neutrino flux at 25 km	$5.2 \times 10^{12}/m^2/year$	$\langle E \rangle /L = 1.4 \times 10^{-2}$ GeV/km (NuFact)
Neutrino flux at 50 km	$1.4 \times 10^{12}/m^2/year$	$\langle E \rangle /L = 7.0 \times 10^{-3}$ GeV/km (Super-beam)
Neutrino flux at 100 km	$3.8 \times 10^{11}/m^2/year$	$\langle E \rangle /L = 3.5 \times 10^{-3}$ GeV/km (SuperK Atm)

CERN CNGS: **3.5×10^{11} ν/m^2/year @17.7 GeV**

SuperBeam: **2.4×10^{12} ν/m^2/year @ 260 MeV**

NuFact: **2.4×10^{12} ν/m^2/year @ 34 GeV**

BEWARE: pure ν fluxes, NOT INTERACTION RATE. σ NOT included

The Physics Impact

Possible neutrino physics scopes:

1. ν_e cross sections (astrophysics)

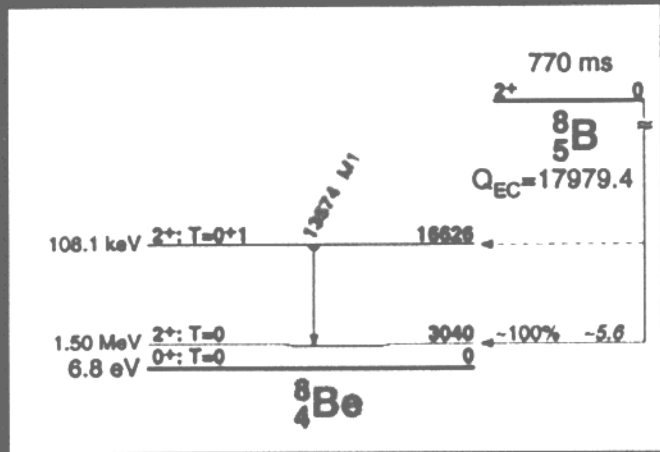
2. Short baseline oscillations (LSND)

3. LBL: θ_{13} (disappearance and appearance)

4. CP violation.

Reminder: 350 MeV is NOT a magic number. Apart from the Γ tuning, the atom choice plays a crucial role:

In the same machine, ${}^{8}_{5}B$ could make a 2.7 GeV ν_e beam with the same focussing properties!



The Physics Imp

On θ_{13}

BEWARE of the comparison based on "expected number of signal events". An experiment sitting at the <E>/L value corresponding to the Δm^2 value of interest has more information than an experiment at a smaller distance and the same signal. A visible energy modulation is an important signature.
Γ can be modulated for precision measurements!

A ν_e beam, allows to measure θ_{13} in two different ways:

- disappearance. Limited θ_{13} sensitivity, but model independent.

- ν_μ appearance. "SuperK" θ_{23} AND the three families mixing model to be used.

The Physics Imp

On CP violation

ν_e beam: β^+ decays, easy. Maximum intensity could be lower (as in the conventional neutrino factory with μ^-) if production rate is lower.

The matter effects are less important than in the conventional ν factory case (higher energy therefore longer distances), and consequently the S/N conditions should be more favourable.

The Physics Impact

General comment:
Is a "detector independent" comparison correct?

<u>No.</u> **A conventional neutrino factory detector has a background of wrong sign ν which is 1:1. Therefore a magnetic detector is always needed.**

In the beta-beam case, the only requirements are:

1- Electro-magnetic energy measurement (disappearance)
2- μ identification (appearance)

Large (~50 kton) and Very large (~Mton) detector are possible, anyway much simpler and cheaper than magnetic options.

The Physics Impa

(My) last word on EC beta-beams:

What you would do with a (tunable) monochromatic neutrino beam?

- CC/NC separation on global energy
- Above ground detectors
- Oscillation pattern map
- Nucleus studies by E conservation and neutral probe
- ???

Summary

1. Focussed, low energy neutrino beams appear to be possible by radioisotope acceleration (beta-beam).

2. The beta-beams appear to have also additional properties:

- unprecedented purity (single flavour)
- new ν_e or $\bar{\nu}_e$ flavour
- large intensity (^6He)

and - maybe - simpler than a conventional neutrino factory.
NO EVIDENCE, TODAY, THEY ARE NOT POSSIBLE!

3. The EC beta-beams could be monochromatic sources of neutrinos. They would be possible in the short term with existing machines *if* there's a short lifetime, and clean, EC decay (not identified yet).
NO EVIDENCE, TODAY, THEY ARE POSSIBLE!

4. We should really address in better details:

- "Realistic" physics impact studies.
- Short/Medium/Long term feasibility