Mauro Mezzetto,
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“ Beta Beams: Physics"

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Most of the material of this talk comes from M. Lindroos, M. Mezzetto "Artificial Neutrino Beams: Beta Beams", Imperial College Press, in preparation.

Ultimate neutrino beams will be very challenging . . .

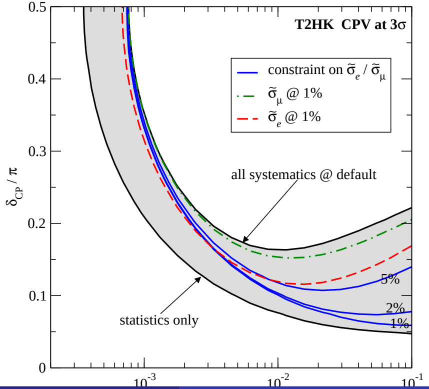
Searches for Leptonic CP Violation will require neutrino beams with:

- The highest possible intensity
- Very few or no intrinsic backgrounds
- Very good control of systematics

. . . and probably they will hit their intrinsic limitations

from Huber, Mezzetto and Schwetz, JHEP 0803:021,2008

- Neutrino come from the decay of SECONDARY particles
- Secondary particle production is known with not great precision.
- At least four neutrino flavours in any beam configuration



. . . these limitations are overcome if secondary particles become primary

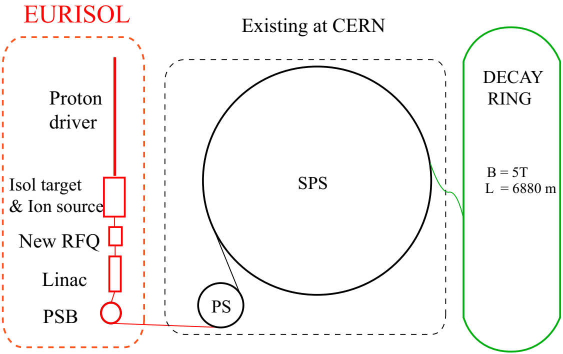
Collect, focus and accelerate the neutrino parents at a given energy. This is impossible within the pion lifetime, but can be tempted within the muon lifetime **(Neutrino Factories)** or within some radioactive ion lifetime **(Beta Beams)**:

- Just one neutrino flavor in the beam
- Energy shape defined by just two parameters: the endpoint energy of the beta decay and the Lorenz boost γ of the parent ion.
- Flux normalization given by the number of ions circulating in the decay ring.
- Beam divergence given by γ.

Beta Beams

(P. Zucchelli: Phys. Lett. B532:166, 2002)

see M. Lindroos et al., http://beta-beam.web.ch/beta-beam



- 1 ISOL target to produce He^6, 100 μA, $\Rightarrow 2.9 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \overline{\nu}_e$.
- 1 ISOL target to produce Ne^{18}, 100 μA, $\Rightarrow 1.1 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \nu_e$.

Some scaling laws in Beta Beams

β^+ emitters			β^- emitters		
Ion	Q_{eff} (MeV)	Z/A	Ion	Q_{eff} (MeV)	Z/A
$^{18}\mathrm{Ne}$	3.30	5/9	$^{6}\mathrm{He}$	3.508	1/3
$^{8}\mathrm{B}$	13.92	5/8	$^{8}\mathrm{Li}$	12.96	3/8

- Accelerators can accelerate ions up to Z/A $\times$ the proton energy.
- Lorentz boost: end point of neutrino energy $\Rightarrow 2\gamma Q$
- In the CM neutrinos are emitted isotropically $\Rightarrow$ neutrino beam from accelerated ions gets more collimated $\propto \gamma^2$. But $L \propto E_\nu/\Delta m^2 \propto \gamma Q$ and flux $\propto L^{-2} \Rightarrow \quad \Phi \propto Q^{-2}$. ν cross section $\propto E_\nu \propto \gamma Q$.
- Merit factor for an experiment at the atmospheric oscillation maximum: $\mathcal{M} = \frac{\gamma}{Q}$
- Ion lifetime must be:
    - As long as possible: to avoid ion decays during acceleration
    - As short as possible: to avoid to accumulate too many ions in the decay ring

  $\Rightarrow$ optimal window: lifetimes around 1 s.
- Decay ring length scales $\propto \gamma$.
- Two body decay kinematics : going off-axis the neutrino energy changes (feature used in some ECB setup and in the low energy setup)

A single $^{18}\mathrm{Ne}$ target is not enough

So far a single target is estimated to produce about $1/10$ of the needed $^{18}\mathrm{Ne}$ ions.
Possible wayouts:

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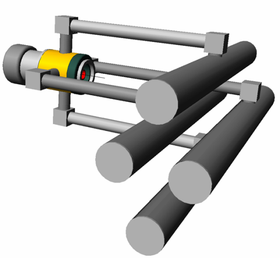
Build 7 targets in parallel $\rightarrow$ need 7 times more protons (1 MW proton beam at 1-2 GeV), proof of principle already tested at CERN.



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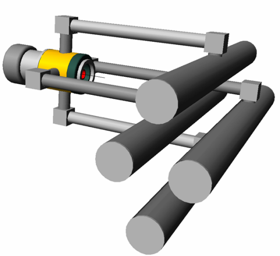


Isotope	Method	Rate within reach ions/second
^{18}Ne	ISOL at 1 GeV and 200 kW	$< 8 \times 10^{11}$
^{6}He	ISOL converter at 1 GeV and 200 kW	$< 5 \times 10^{13}$
^{18}Ne	Direct production (20 MeV, 2 MW) ^{16}O(^{3}He,n)^{18}Ne	$< 1 \times 10^{13}$
^{6}He	ISOL converter at 40 MeV Deuterons and 80 kW	$< 6 \times 10^{13}$
^{8}Li	Production ring through ^{7}Li(d,p)^{8}Li	$< 1 \times 10^{14}$

The merits of the "short baselines"

SPS can accelerate $^6\mathrm{He}$ up to $\gamma = 150$ $\Rightarrow$ baseline up to 300 km. Frejus is the only realistic possibility to accomodate a Megaton detector, 130 km away from CERN. The CERN-Frejus scenario, not necessarely the optimal one, is for $\gamma = 100$ and $L = 130$ km.

- Absolutely negligible matter effects: the cleanest possible environment for direct leptonic CP violation and θ_{13} searches.
- Almost all the events are quasi elastics.
- Reasonable energy shape information.
- Degeneracies don't influence θ_{13} and LCPV discovery potential.

On the other hand

- Mass hierarchy cannot be directly measured. A not trivial sensitivity on $\mathrm{sign}(\Delta m^2_{13})$ can however been recovered combining accelerator neutrino signals with the atmospherics' (see the following).
- Small cross sections, loosely known and with important influence of nuclear effects.

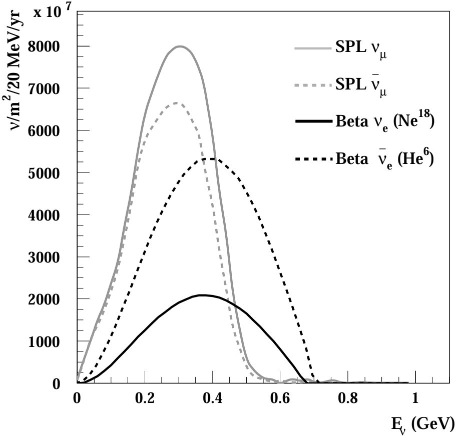
The synergy with SPL Super Beam

A Beta Beam has the same energy spectrum than the SPL SuperBeams and consumes 5% of the SPL protons.

The two beams could be fired to the same detector ⇒ LCPV searches through CP and T channels (with the possibility of using just neutrinos).

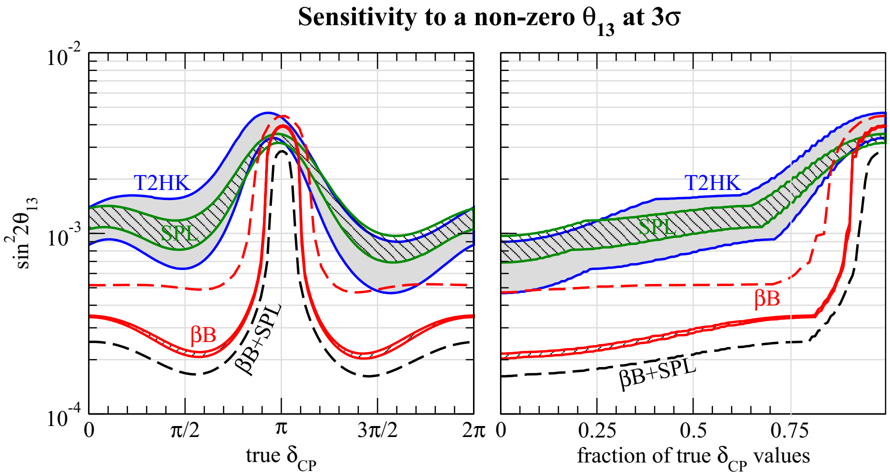
Access to CPTV direct searches.

Yearly Fluxes



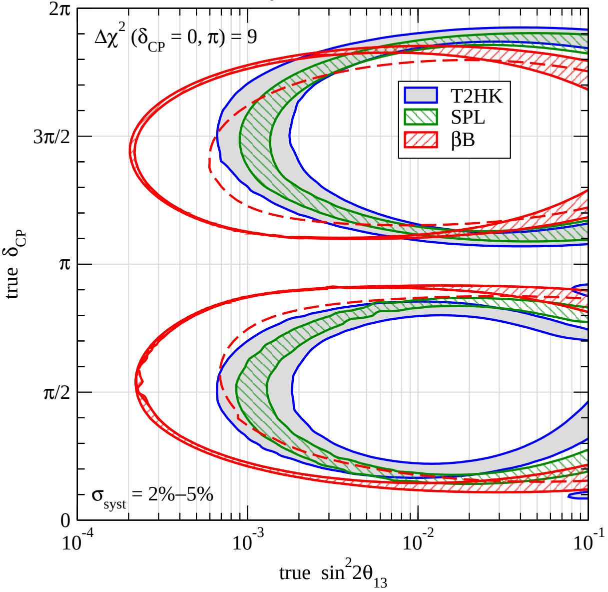
θ_{13} sensitivity at 3 σ

From Campagne, Maltoni, Mezzetto, Schwetz, JHEP **0704** (2007) 003



Line width: 2% and 5% systematic errors.

Sensitivity to CP violation at 3σ



The synergy with atmospheric neutrinos

Huber, Maltoni, Schwetz, Phys. Rev. D 71, 053006 (2005) Combining Long Baseline data with atmospheric neutrinos (that come for free in the megaton detector):

- Degeneracies can be canceled, allowing for better performances in θ_{13} and LCPV searches
- The neutrino mass hierarchy can be measured
- The θ_{23} octant can be determined.

The main reasons are:

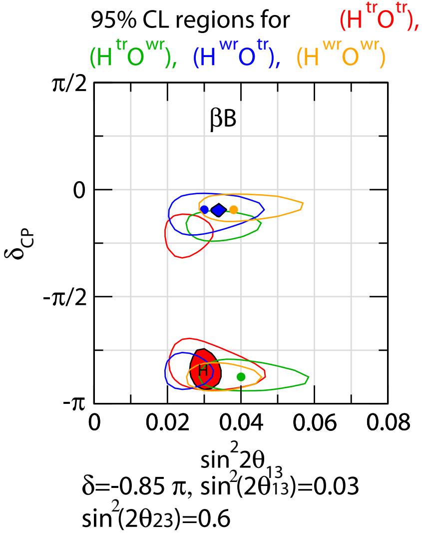
- **Octant** e-like events in the Sub-GeV data is $\propto \cos^2\theta_{23}$
- **Sign** e-like events in the Multi-GeV data, thanks to matter effects, especially for zenith angles corresponding to neutrino trajectories crossing the mantle and core where a resonantly enhancement occurs.

NOTE: LBL and atmospherics are a true synergy. They add to each other much more that a simple gain in statistics. Atmospherics alone could not measure the hierarchy, the octant, θ_{13} and LCPV. While the Beta Beam at short baselines could not measure the hierarchy as well as the octant.

In the following sensitivities of the Beta Beam combined with the atmospherics are taken from J.E.Campagne, M.Maltoni, M.M., T.Schwetz, JHEP **0704** (2007) 003 (hep-ph/0603172)

βB plus atmospherics: degeneracy removal

From Campagne, Maltoni, Mezzetto, Schwetz, JHEP **0704** (2007) 003

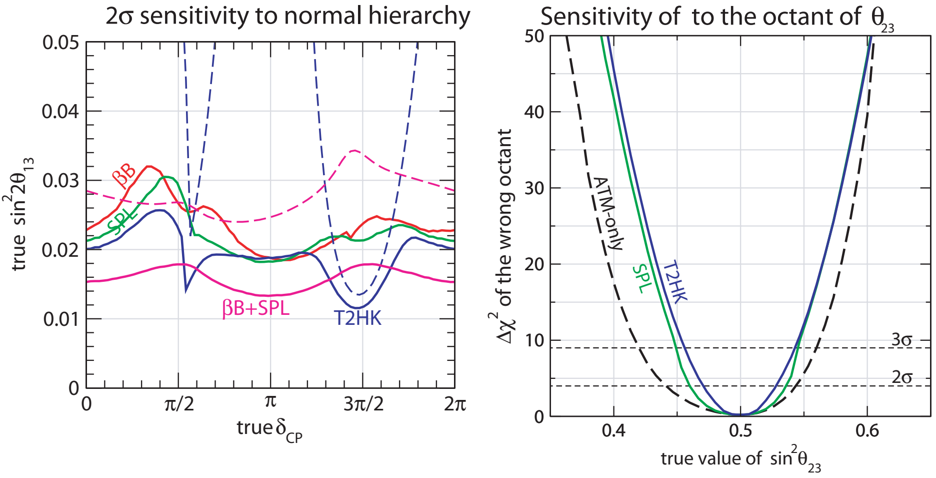


The red region is what is left after the atmospheric analysis.

Note how degeneracies were not influencing LCPV sensitivity too much.

βB plus atmospherics: mass hierarchy and octant

From Campagne, Maltoni, Mezzetto, Schwetz, JHEP **0704** (2007) 003.



Other Beta Beam options

Several different beta-beam setups have been proposed in literature.
Chronologically:

- High Energy Beta Beams
- Electron capture Beta Beams producing monochromatic neutrino beams
- Beta Beams based on $^{8}\mathrm{B}$ /$^{8}\mathrm{Li}$ ions
- High Energy $^{8}\mathrm{B}$ /$^{8}\mathrm{Li}$ Beta Beams

Ways to improve beta-beam performances

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- More neutrinos in the far detector

Ways to improve beta-beam performances

- More neutrinos in the far detector

- Longer baselines (higher γ or higher ion Q) to have improved sensitivities to mass hierarchy.

Ways to have more neutrinos in the far detector

Ways to have more neutrinos in the far detector

1. More ions

Ways to have more neutrinos in the far detector

1. More ions
2. Higher γ

Neutrino flux at a far detector placed at a distance L: $\Phi \propto \frac{\gamma^2}{L^2}$ (neutrino emission angle, in the laboratory frame, $\propto \gamma^{-1}$).

$\nu_e \to \nu_\mu \quad \propto \sin^2 2\theta \sin^2 \frac{\Delta m^2 L}{E_\nu} \Rightarrow$ optimal L: $L \propto E_\nu / \Delta m^2$, $E_\nu \propto \gamma E_0$

$$\Phi \propto \frac{(\Delta m^2)^2}{E_0^2} \quad \text{(no } \gamma \text{ dependence)}.$$

Interacting neutrinos at the far detector: $I = \sigma\Phi$, neutrino cross section $\sigma \propto E_\nu$

$$\text{Merit Factor} \quad \mathcal{M} \propto \frac{\gamma}{E_0}$$

Performances of a beta-beam scale as γ and are inversely proportional to the end-point energy E_0.
(End point energy of a muon decay = 68 MeV. End point energy of $^6\mathrm{He}$ =3.7 MeV Merit factor of a beta-beam about 20 times better than the merit factor of a Neutrino Factory.)

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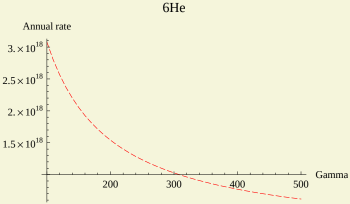
The high energy options

J. Burguet-Castell et al., Nucl. Phys. B **695**, 217 (2004), Nucl. Phys. B 725, 306 (2005)
F. Terranova et al., EPJC 38 (2004) 69. A. Donini et al., EPJC 48 (2006) 787.
P. Huber, M. Lindner, M. Rolinec and W. Winter, Phys. Rev. D 73,053002, 2006
S. Agarwalla, S. Choubey, A. Raychaudhuri, Nucl. Phys. B **771** (2007) 1
D. Meloni, O. Mena, C. Orme, S. Palomares-Ruiz and S. Pascoli, arXiv:0802.0255 [hep-ph].
W. Winter, arXiv:0804.4000 [hep-ph].

- Need a proton machine of 1 TeV energy (LHC cannot be used at such high fluxes), only possible candidate: SPS+: an upgrade of SPS studied in view of a possible energy upgrade of LHC.
- Assume the same ion decay rates of the SPS option. Requiring an improved decay ring configuration, otherwhile decay rates scale inversely to the ion γ



- The decay ring length rises linearly with $\gamma \rightarrow$ high energy Beta Beams require developments of high field, big aperture, radiation hard superconducting magnets to keep short the decay ring.

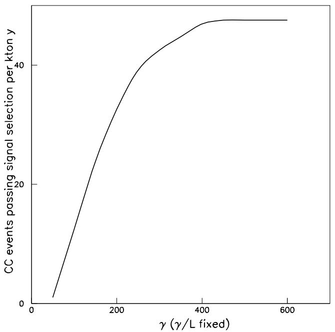
The high energy options (cont.)

Greater γ for the same ion decay rate/yr $\rightarrow$ increase ν rates $\propto \gamma$. (Merit factor: $\mathcal{M} = \frac{\gamma}{Q}$)

from J. Burguet-Castell et al., Nucl. Phys. B 725, 306 (2005)

A water Čerenkov detector properly reconstructs the energy only for QE events $\rightarrow$ the fraction of badly reconstructed events scales with energy $\rightarrow$ kind of saturation of performances at high γs.

Other detector technologies as iron magnetized detectors, totally active scintillators and liquid argon have been considered in literature for high energy beta beams.



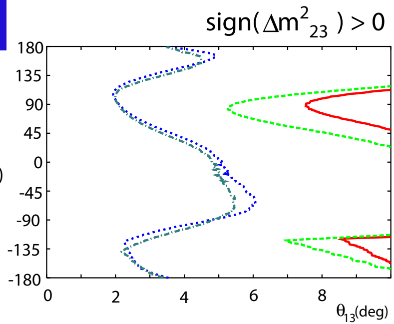
High Energy vs Standard βB (99% CL, 4.4 Mton yr)

From Burguet Castell et al. 2006

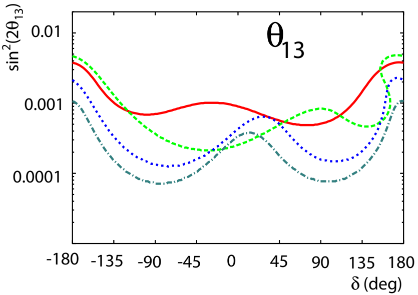
The chosen binning penalizes low energy βB (just one bin from 0 to 500 MeV)

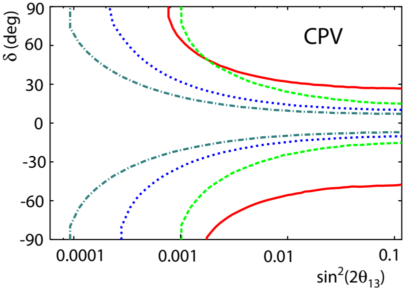
Optimal SPS (γ=150) not that far from optimal HE (γ=350)

Atmospherics not included



- γ = 60,100 and L = 130 km
- γ = 120,120 and L = 130 km
- γ = 150,150 and L = 300 km
- γ = 350,350 and L = 730 km





Another high energy option

"High" energy ν_μ events can be efficiently detected by an iron-RPC detector.

A. Donini et al., EPJC 48 (2006) 787 (see also, F. Terranova, A. Marotta, P. Migliozzi and M. Spinetti, Eur. Phys. J. C **38** (2004) 69.) studied the case of a 40 kton iron detector (4 cm thick iron slabs interleaved with glass RPCs) to be placed at 732 km from a $\gamma = 350$ Beta Beam.

This detector can be hosted inside an existing LNGS hall.

A full detector simulation shows that the main limiting factor of this setup are backgrounds from NC events. Fraction of NC backgrounds: $5.6 \cdot 10^{-3}$ @ $\gamma = 350$. $8.8 \cdot 10^{-3}$ @ $\gamma = 580$. CERN-Frejus has $2 \cdot 10^{-3}$, other studies on magnetic detectors assume NC background at 10^{-4} for $\gamma \geq 350$.

Overall performances (slightly) worse than the CERN-Frejus scenario (but better $\mathrm{sign}(\Delta m^2_{13})$ sensitivity) (N.B. An iron detector have opposite problems than water Čerenkov : high threshold to detect muons (around 1 GeV))

Electron capture beams

Radioactive ions can produce neutrinos also through electron capture.
Monochromatic, single flavor neutrino beams!

J. Bernabeu, J. Burguet-Castell, C. Espinoza and M. Lindroos, JHEP **0512**, 014 (2005) [arXiv:hep-ph/0505054]. J. Bernabeu and C. Espinoza, arXiv:0712.1034 [hep-ph]. J. Sato, Phys. Rev. Lett. 95(2005)131804. M. Rolinec and J. Sato, JHEP **0708**, 079 (2007) [arXiv:hep-ph/0612148].

- The same complex could run either beta or electron capture beams.
- No way to have $\overline{\nu}_e$ beams (possible wayout: bound state β decays, see A. Fukumi et al. arXiv:hep-ex/0612047)
- Ions should be partially (and not fully) stripped. Technologically challenging.
- Ion candidates are much heavier than beta candidates and have longer lifetimes (far more difficult to stack them in the decay ring)

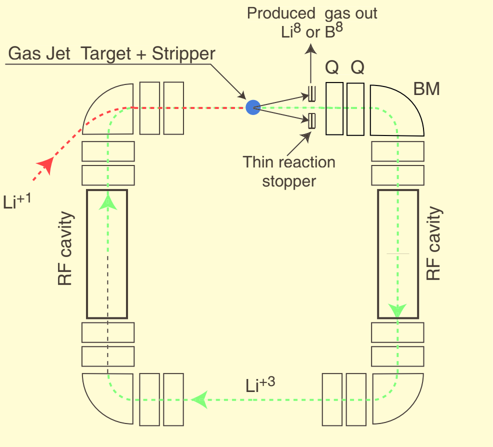
^8B /^8Li Beta Beams

C. Rubbia et al., NIM A568 (2006) 475

Y. Mori,NIM A562 (2006) 591

C. Rubbia hep-ph/0609235

D. Neuffer, FNAL NFMCC-doc-516 (2007)



- It could deliver up to two order of magnitudes more radioactive ions than the Eurisol targets.
- If realistic, this production method could bring to a completely different Beta Beam optimization scheme.
- Specific aspects of this innovative technology will be studied within the EuroNu design study, funded by EU and by the European funding agencies.

^8B /^8Li Beta Beams (cont.)

β^+ emitters			β^- emitters		
Ion	Q_{eff} (MeV)	Z/A	Ion	Q_{eff} (MeV)	Z/A
^{18}Ne	3.30	5/9	^6He	3.508	1/3
^8B	13.92	5/8	^8Li	12.96	3/8

Can produce a neutrino beam 4.7 times more energetic than ^6He /^{18}Ne, with a shorter decay ring. $\Rightarrow$ cover longer baselines with the same accelerator.
For a given baseline, they provide a smaller flux $\propto 1/Q^2$ (since $\mathcal{M} = \frac{\gamma}{Q}$)
For a given accelerator, optimal baseline, a smaller flux $\propto (Z/A)/Q$

C. Rubbia, 2006: ^8B /^8Li βB based on the Fermilab Main Injector, ($\gamma(^8B) = 80$ and $\gamma(^8Li) = 48$) and a 50-100 kton liquid argon detector at Soudan (732 km baseline)

A. Donini, E. Fernandez-Martinez Phys.Lett. B641, 432 (2006): possibility of mixing ^6He /^{18}Ne ions to ^8B /^8Li ions $\Rightarrow$ neutrinos at the first and at the second oscillation maximum in the same detector $\Rightarrow$ not competitive with ^6He /^{18}Ne high energy beta-beam.

High Energy ^{8}B /^{8}Li Beta Beams

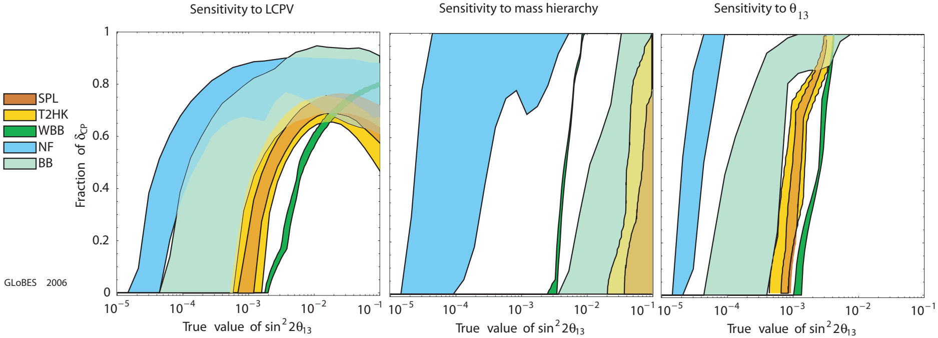
S. K. Agarwalla, S. Choubey and A. Raychaudhuri, Nucl. Phys. B **771**, 1 (2007), Nucl. Phys. B **771**, 1 (2007) and arXiv:0711.1459 [hep-ph].
S. K. Agarwalla, S. Choubey, A. Raychaudhuri and W. Winter, JHEP **0806** (2008) 090
P. Coloma et al. arXiv:0712.0796 [hep-ph].
For $L = \sqrt{2}\pi/G_F Y_e$ any $\delta_{\rm CP}$ dependence disappears from $P_{e\mu}$ allowing to measure $\mathrm{sign}(\Delta m^2_{13})$ effects without any degenerate solution.
$L_{\rm magic} \simeq 7690$ km. The resonance energy for matter effects is:

$$E_{\rm res} \equiv \frac{|\Delta m^2_{31}| \cos 2\theta_{13}}{2\sqrt{2} G_F N_e} \simeq 7 \ \mathrm{GeV}$$

($|\Delta m^2_{31}| = 2.4 \cdot 10^{-3}\ \mathrm{eV}^2$, $\sin^2 2\theta_{13} = 0.1$).
In this regime flux of oscillated events scales as $1/L$ and not $1/L^2$, merit factor to be revised in favor of high Q ions.
Proposed by the India-based Neutrino Observatory (INO), where a 50 kton iron magnetized calorimeter (ICAL) is set to come up (S. Goswami talk) CERN-INO baseline: 7152 km.

Beta Beams vs Neutrino Factory

Comparison made within the International Scoping Study (ISS) framework, arXiv:0710.4947 [hep-ph]. (Not including $^8\mathrm{B}\,/^8\mathrm{Li}\,\beta\mathrm{B}$)
See K. Long talk.
Line widths reflect different possible assumptions about machin configurations, neutrino fluxes, detector performances, systematic errors.



Other comparisons

The following two tables compare beta-beams with neutrino factories under the following hypothesis

- Green field beta beam with two iron detectors at the oscillation maximum and at the magic baseline compared with the optimized Neutrino Factory set-up with two improved golden detectors (50 kton each) placed at 4000 km & 7500 km respectively. $E_\mu = 20$ GeV & total 5×10^{21} decays for μ^- & μ^+ each. Computed at the nominal beta beam ion decay rate and at 10 times the nominal fluxes.
  From S. K. Agarwalla, S. Choubey and A. Raychaudhuri, arXiv:0711.1459 [hep-ph].
- "Minimal" beta beam configuration in case of large θ_{13} (in the reach of Double Chooz capable of measuring i) $\sin^2 2\theta_{13} > 0$ at 5σ, ii) mass hierarchy at 3σ for any value of $\delta_{\rm CP}$ and iii) LCPV at 3σ for 80% of the allowed values of $\delta_{\rm CP}$.
  From W. Winter, arXiv:0804.4000 [hep-ph].

Green Field Beta Beams vs Neutrino Factory

Set-up	Mass Ordering (3σ) NH (True)		CP Sensitivity (3σ) NH (True)		$\sin^2 2\theta_{13}$ Sensitivity (3σ)	
	1.1×10^{18} & 2.9×10^{18}	1.1×10^{19} & 2.9×10^{19}	1.1×10^{18} & 2.9×10^{18}	1.1×10^{19} & 2.9×10^{19}	1.1×10^{18} & 2.9×10^{18}	1.1×10^{19} & 2.9×10^{19}
CERN-INO $\gamma = 650$, 7152 Km	4.7×10^{-4} (4.9×10^{-4})	9.4×10^{-5} (1.2×10^{-4})	Not possible	Not possible	1.14×10^{-3}	1.76×10^{-4}
CERN-LNGS $\gamma = 575$, 730 Km	3.89×10^{-3} (9.23×10^{-3})	1.58×10^{-3} (4.48×10^{-3})	1.6×10^{-4} (1.8×10^{-4})	1.97×10^{-5} (2.03×10^{-5})	1.78×10^{-3}	8.59×10^{-5}
CERN-BOULBY $\gamma = 575$, 1050 Km	2.49×10^{-3} (7.87×10^{-3})	2.19×10^{-4} (4.1×10^{-3})	1.85×10^{-4} (2.02×10^{-4})	1.99×10^{-5} (2.04×10^{-5})	1.41×10^{-3}	1.45×10^{-4}
CERN-LNGS $\gamma = 575$, 730 Km + CERN-INO $\gamma = 650$, 7152 Km	2.7×10^{-4} (3.58×10^{-4})	4.64×10^{-5} (5.45×10^{-5})	1.42×10^{-4} (1.49×10^{-4})	1.78×10^{-5} (1.88×10^{-5})	5.46×10^{-4}	5.26×10^{-5}
CERN-BOULBY $\gamma = 575$, 1050 Km + CERN-INO $\gamma = 650$, 7152 Km	2.67×10^{-4} (3.37×10^{-4})	4.57×10^{-5} (5.17×10^{-5})	1.63×10^{-4} (1.76×10^{-4})	1.8×10^{-5} (1.87×10^{-5})	6.1×10^{-4}	6.69×10^{-5}

Optimized Neutrino Factory	4.5×10^{-5} (100% of δ_{CP} (true) coverage)	1.5×10^{-5}	4.5×10^{-5}

Minimum wish list

- Assume that
  Double Chooz finds θ_{13} →

$\sin^2 2\theta_{13}$ best-fit	90% CL range	3σ range	Zero excl. at
0.04	0.019 - 0.063	0.002 - 0.082	3.2σ
0.08	0.060 - 0.102	0.043 - 0.121	6.4σ
0.12	0.100 - 0.142	$\geq$ 0.084	9.7σ

(Sim. from hep-ph/0601266;
1.5 yr far det. + 1.5 yr both det.)

- Minimum wish list
  easy to define:
  - 5σ independent confirmation of $\theta_{13} > 0$
  - 3σ mass hierarchy determination for any (true) δ_{CP}
  - 3σ CP violation determination for 80% (true) δ_{CP}

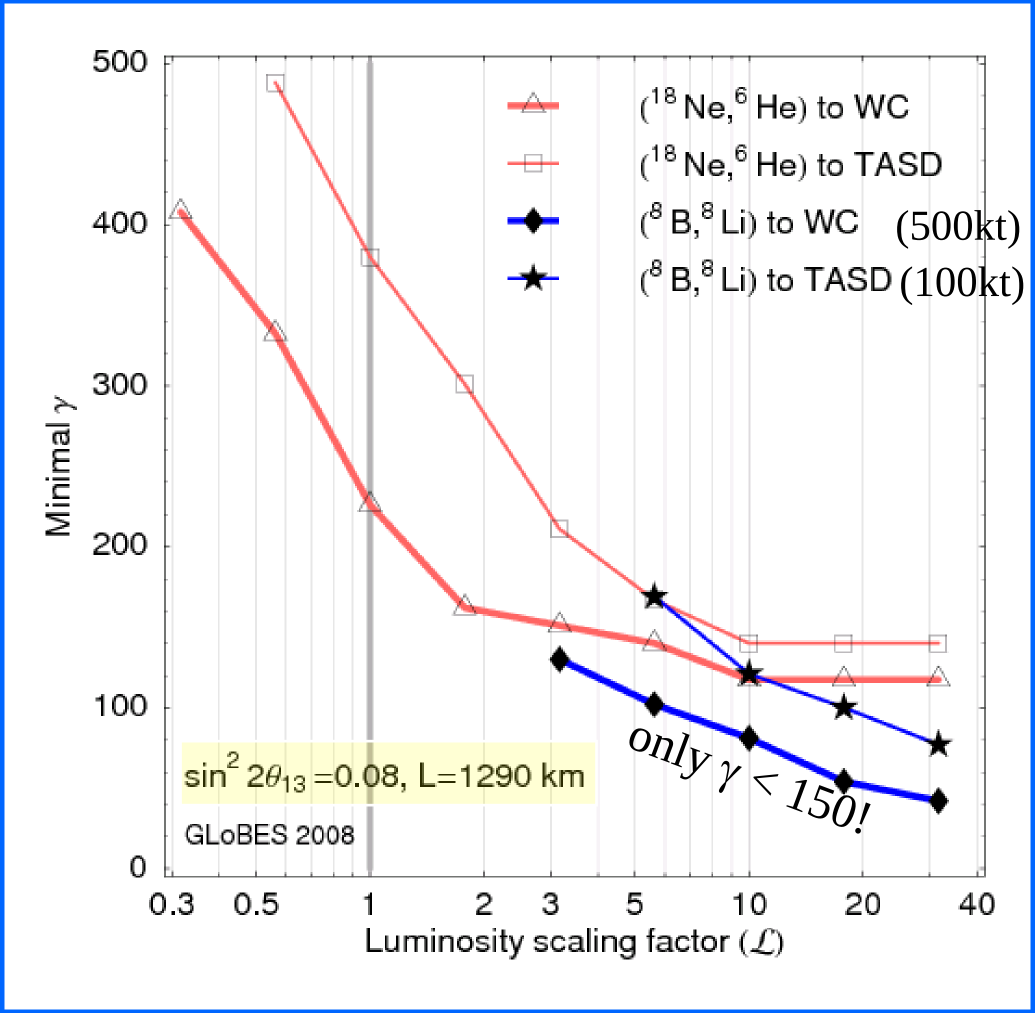
  For any (true) θ_{13} in 90% CL D-Chooz allowed range!

➢ What is the minimal (effort) beta beam for that?

- NB: Such a minimum wish list is non-trivial for small θ_{13}
- NB: CP fraction 80% comes from comparison with IDS-NF baseline etc.

Luminosity scaling for fixed L

- What is the minimal LSF x γ?
- (Ne,He): LSF = 1 possible (B,Li): LSF = 1 not sufficient
- But: If LSF >= 5: γ can be lower for (B,Li) than for (Ne,He), because MH measurement dominates there (requires energy!)

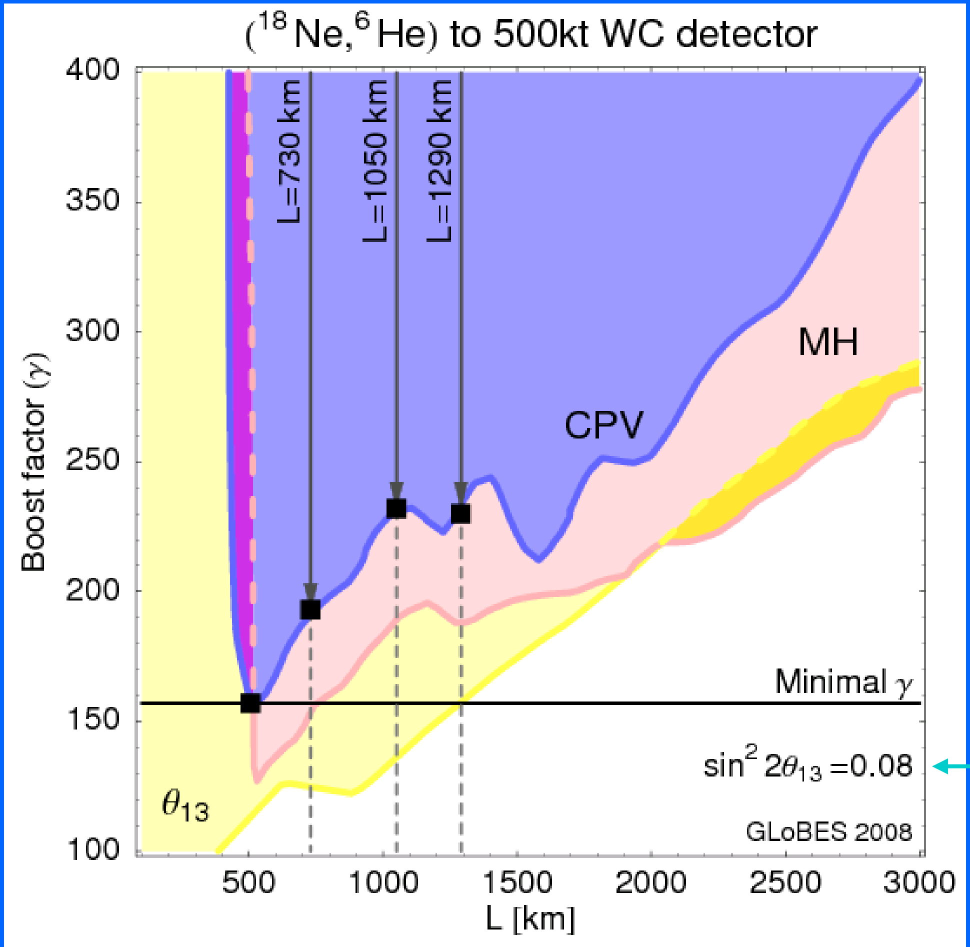


(Winter, arXiv:0804.4000)

Minimal effort beta beam

- Minimal effort =
  - One baseline only
  - Minimal γ
  - Minimal LSF
  - Any L (green-field!)
- Example: Fix LSF and optimize L-γ →
  - ➢ Sharp cutoff by MH from left, from CPV from bottom
  - ➢ Use fixed L >= 730 km to avoid fine-tuning

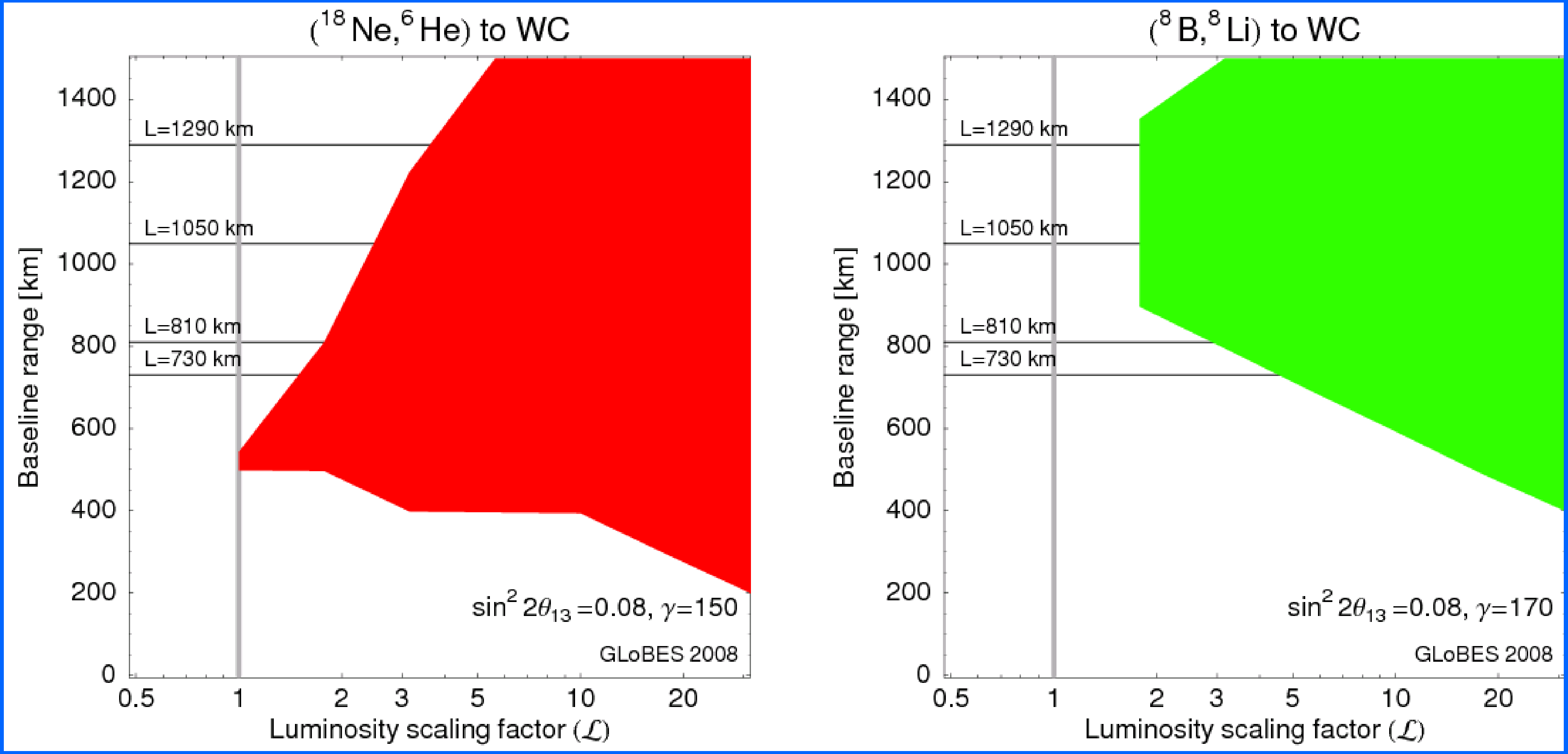
LSF=1 (Winter, arXiv:0804.4000)



Sensitivity for entire Double Chooz allowed range!

Minimal beta beam at the CERN-SPS?

(γ fixed to maximum at SPS)



In case of large θ_{13}

Setup ↓ Baseline [km] →	$\sin^2 2\theta_{13} = 0.04$ 730	810	1050	1290	$\sin^2 2\theta_{13} = 0.08$ 730	810	1050	1290
Beta beams								
(^{18}Ne, ^{6}He) to WC, $\mathcal{L} = 1$	**220**	230	290	350	**200**	210	240	230
(^{18}Ne, ^{6}He) to TASD, $\mathcal{L} = 1$	-	**300**	370	430	**300**	310	340	380
(^{18}Ne, ^{6}He) to WC, $\mathcal{L} = 5$	**190**	**190**	**190**	230	**140**	**140**	**140**	**140**
(^{18}Ne, ^{6}He) to TASD, $\mathcal{L} = 5$	**200**	**200**	220	230	180	180	**170**	180
(^{8}B,^{8}Li) to WC, $\mathcal{L} = 5$	-	-	**100**	130	**80**	**80**	100	110
(^{8}B,^{8}Li) to TASD, $\mathcal{L} = 5$	-	-	**150**	190	-	-	**190**	**190**
(^{8}B,^{8}Li) to WC, $\mathcal{L} = 10$	**70**	**70**	90	110	**60**	70	80	90
(^{8}B,^{8}Li) to TASD, $\mathcal{L} = 10$	-	**100**	130	140	**110**	**110**	120	130
Superbeam upgrades								
T2KK	-				$\surd$			
NOνA*	-				-			
WBB-120$_S$	-				$\surd$			
Neutrino factories								
IDS-NF 1.0	$\surd$				-			
Low-E NF	-				$\surd$			
Hybrids								
NF-SB	$\surd$				$\surd$			

Conclusions

- The CERN-Frejus scenario is already a very good player in the context of future neutrino oscillation experiments
- An increase of neutrino fluxes would be highly beneficial for the beta-beam discovery potential. Duty cycle can be sacrified to have higher neutrino fluxes.
- In case of “high” θ_{13} values an upgraded CERN-Frejus configuration could represent the ultimate neutrino oscillation set-up.
- In case of small θ_{13} values higher γ are needed
- For very small θ_{13} a setup including a magic baseline experiment and a “short” baseline experiment is the only competitor to neutrino factories.

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- 21.5 kton of Liquid Argon in 4 modules "600 ton" like.
- At shallow depth, 7 or 10 km off-axis from CNGS.
- Modified CNGS optics and target to lower the mean $\nu_\mu$energy.
- Assume $1.2 \cdot 10^{20}$ pot/yr (CNGS-1, 0.5 MW) or $4.4 \cdot 10^{20}$ pot/yr (CNGS-2, 1.6 MW). At present, CNGS: $4.5 \cdot 10^{19}$ pot/yr.

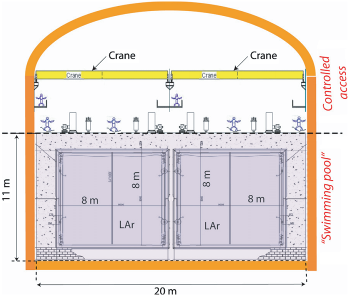
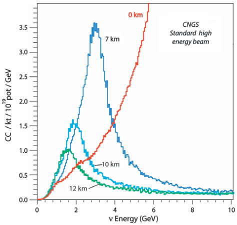
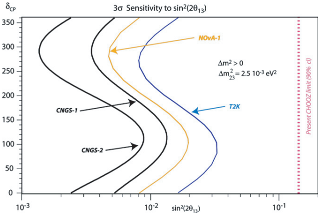


Fig. 1. Indicative cross-section of the T600 "clone " in the dedicated "swimming pool like" underground hall. The lower part is made of two twin separate LAr containers made of aluminum extruded structures, thermally stabilized with forced N2 circulation. Outside the structure an about 1.5 m thick per wall provides spontaneous, passive heat insulation. The region on top of the "swimming pool" is accessible to auxiliary equipments. Personnel access is strictly controlled.





Thanks to A. Guglielmi

- Place the detector **on surface**, at the LNGS Assergi site, 7 km off-axis.
- CNGS neutrinos are detectable on surface:
  - Full drift time, 2.7 ms, less than one crossing muon every 2 m^2.
  - The PMTs allow to reduce the window to the 10.5 μs SPS time window, 0.5 cosmic events per spill per semi-module.
  - Additional reduction of a factor 2 by splitting the PMTs upstream and downstream the semimodule.