Physics Reach of electron-capture Neutrino Beams

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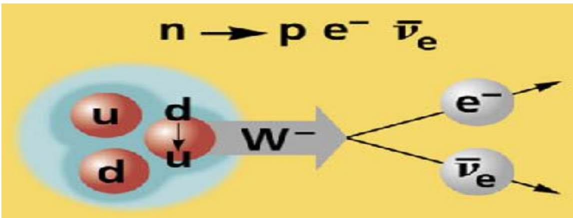
Physics Reach of electron-capture Neutrino Beams

- Introduction: neutrinos from electron capture
- Implementation
- Expectations
- Physics Reach
  - 2 energies of E.C. (main setup)
  - 1 energy and β^--beam
- Caveats
- Conclusions

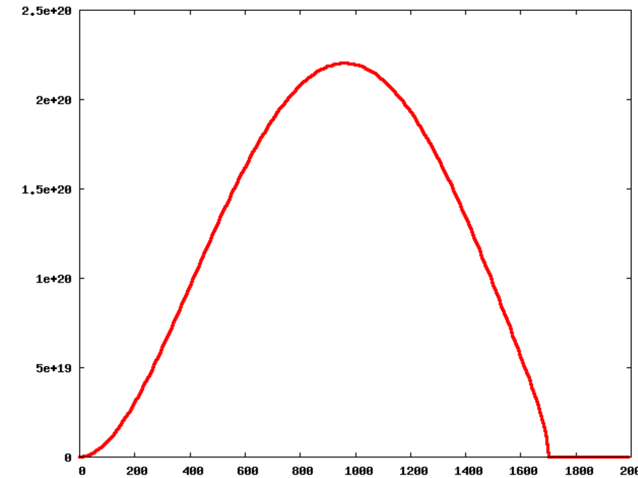
Introduction

β decay:



3 body decay

boost

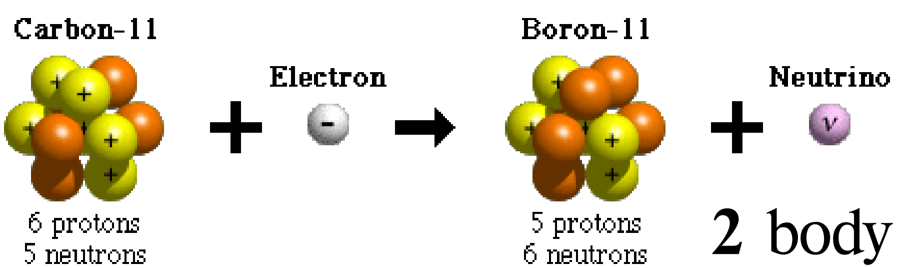


From the well-known β-decay neutrino spectrum, we can get a pure beam by accelerating β-unstable ions

$$\frac{d\phi}{dS\,dy}(\theta \simeq 0) \simeq \frac{N_\beta}{\pi L^2}\frac{\gamma^2}{g(y_e)}\,y^2(1-y)\sqrt{(1-y)^2-y_e^2}$$

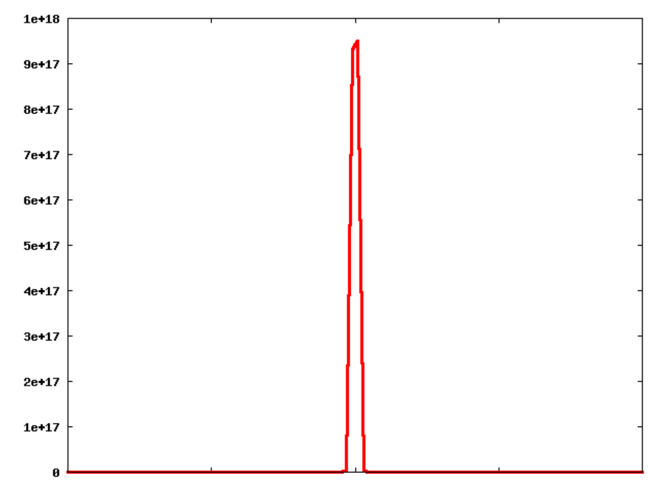
$$y=\frac{E}{2\gamma E_0},\; y_e = m_e / E_0$$

Electron capture:



2 body decay!

boost



From the single energy electron capture neutrino spectrum, we can get a pure and monochromatic beam by accelerating ec-unstable ions

$$\frac{d^2N_\nu}{dSdE} = \frac{\Gamma_{ec}}{\Gamma}\frac{N_{ions}}{\pi L^2}\gamma^2\delta(E-2\gamma E_0)$$

An idea whose time has arrived?

(My) First contact: β-beam studies at Benasque, July 2004.

Discussing with people, many had thought about using electron capture before (!), the idea seemed to be in the air... (for instance, J. Sato independently presented his development, *see his talk on Wednesday*).

The "breakthrough" came thanks to the discovery of isotopes with half-lives of a few minutes or less, which decay mainly through electron capture to Gamow-Teller resonances in super allowed transitions.
(more on that later)

Implementation

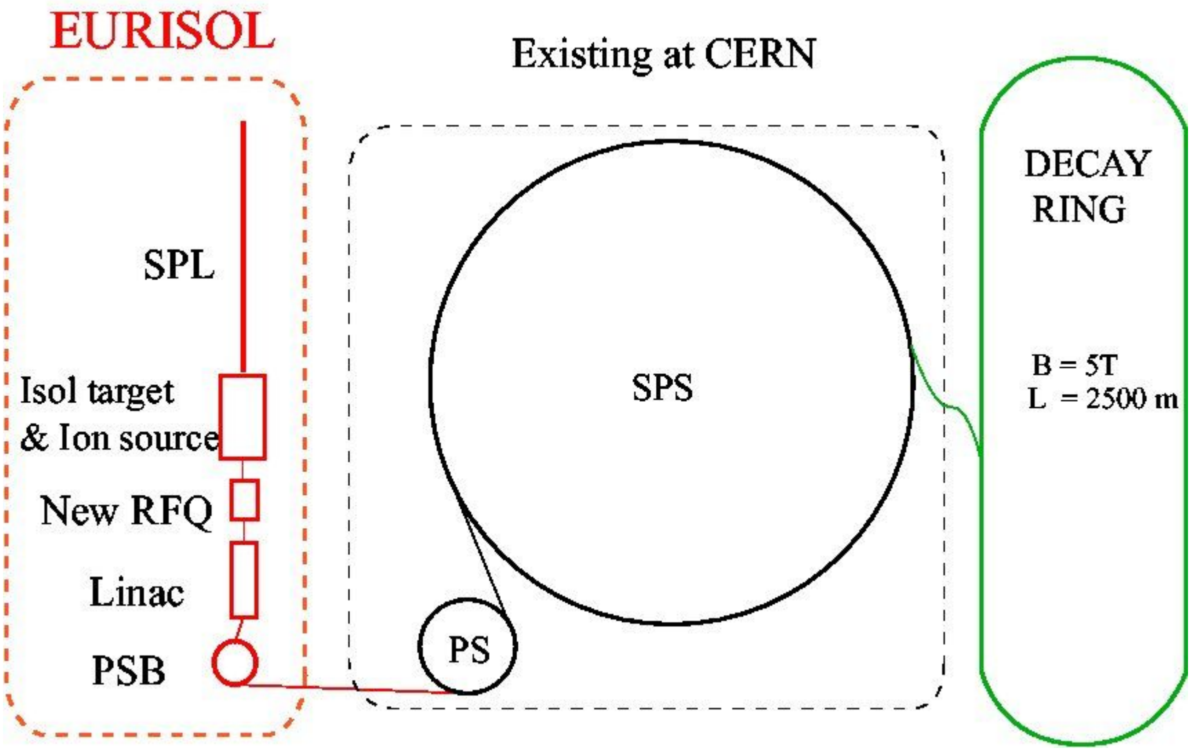
The facility would require a different approach to acceleration and storage of the ion beam compared to the standard beta-beam, as the ions cannot be fully stripped.

Partly charged ions have a short vacuum life-time. The isotopes we will discuss have a **half-life ≤ vacuum half-life**.

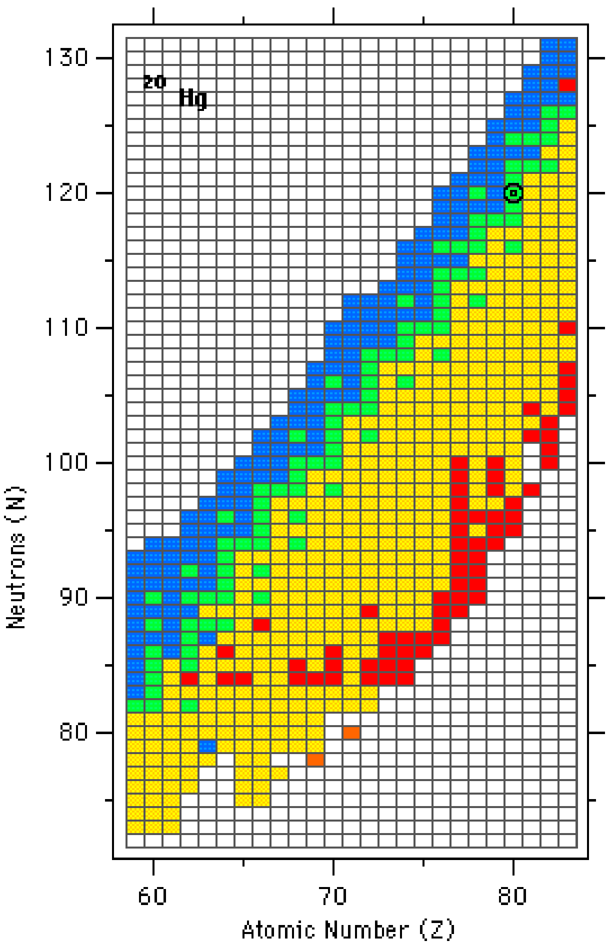
For the rest, setup similar to that of a beta-beam.

Brief recall:

- Ions produced at EURISOL
- Accelerated by the SPS
- Stored in a storage ring, straight sections point to detector



Ion Candidates



Ions must have a mean life short enough to allow them to decay in the storage ring before they lose its electron.

The recent discovery of nuclei that decay fast enough through electron capture opens a window for real experiments.

We want to have an initial neutrino energy E_0 low so that $E=2\gamma E_0$ is at the atmospheric peak (L/E) for a high γ ($\rightarrow$ higher fluxes).

Table 1: Beta decay properties of some rare-earth nuclei around ^{146}Gd

Decay	$T_{1/2}$	$I_{\beta GR}(\%)$	$B(GT)(g_A^2/4\pi)$	E_{GR}(keV)	Γ_{GR}(keV)	$E_\nu=Q_{EC}-E_{GR}$(keV)	ΔE_ν(keV)	$EC/\beta^+(\%)$	Comments
$^{148}Dy\rightarrow{}^{148}Tb$	3.1 m	96.2	0.46	620.2	—	2061.8	—	96/4	excellent!
$^{150}Dy\rightarrow{}^{150}Tb$	7.17 m	100	0.32	397.2	—	1396.8	—	99.9/0.1	36% goes α
$^{152}Tm\ 2^-\rightarrow{}^{152}Er$	8.0 s	≈50	0.48	≈4300	≈520	≈4400	≈520	45/55	
$^{150}Ho\ 2^-\rightarrow{}^{150}Dy$	72.0 s	≈56	0.25	≈4400	≈400	≈3000	≈400	77/33	

Setup

5 years $\gamma = 90$ (close to minimum energy above threshold)

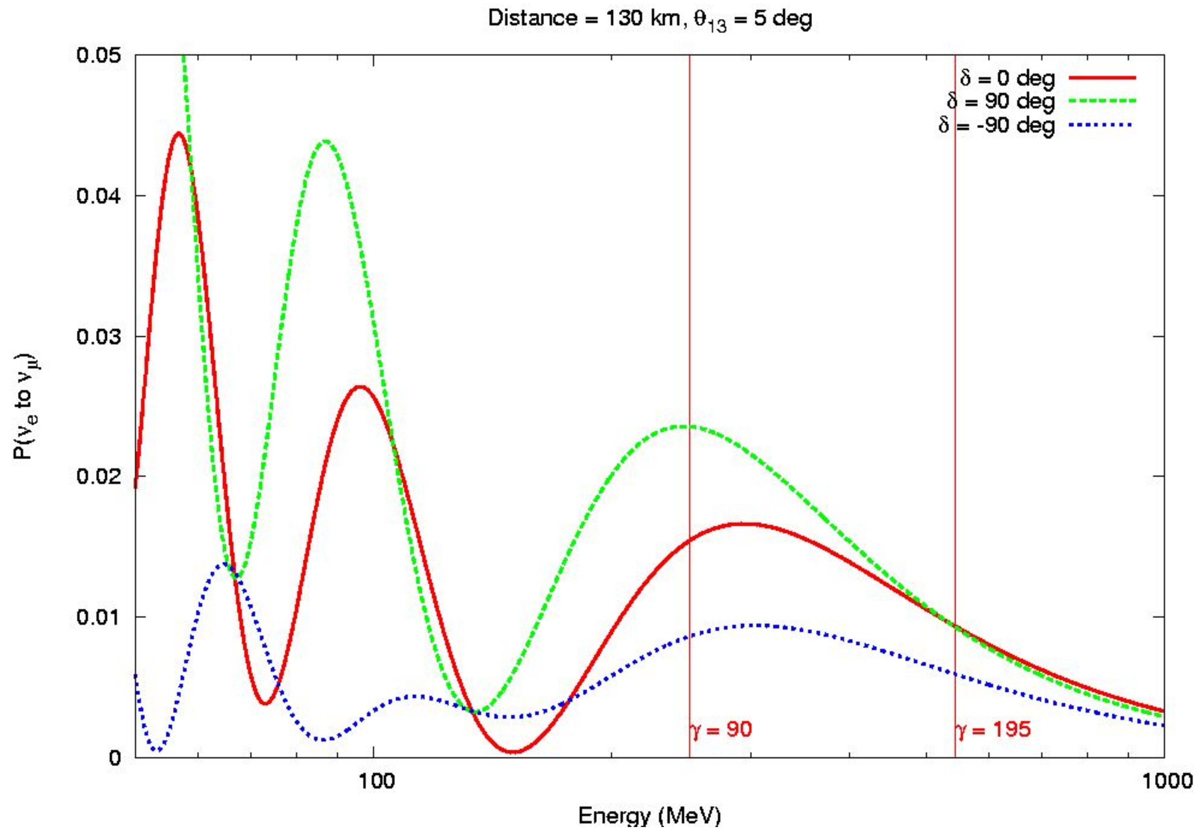
5 years $\gamma = 195$ (maximum achievable at SPS)

10^{18} ions/year (more on that later)

440 kton water ckov detector

Distance: 130 km
(CERN-Frejus)

Appearance &
Disappearance



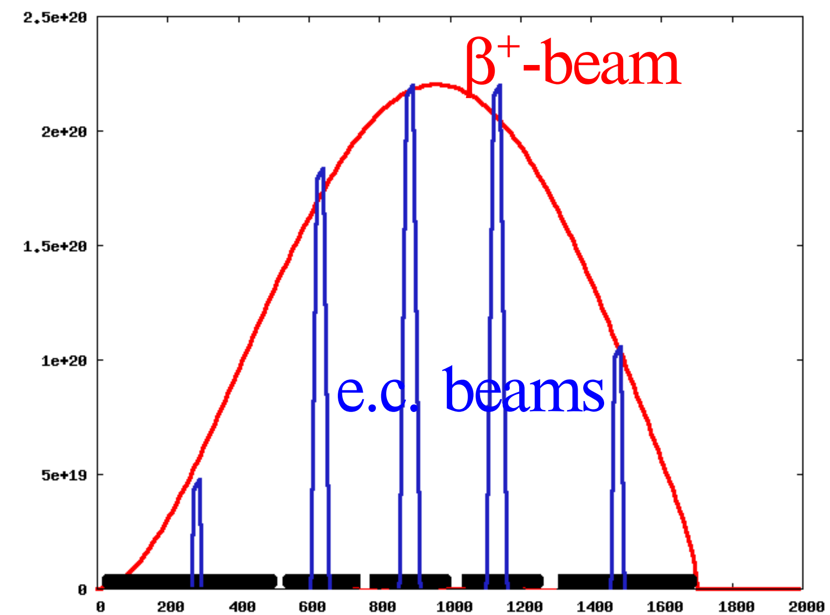
Expectations

- A big advantage over a β-beam is that all the neutrinos can be at the energy(ies) of interest (no spread on uninteresting energies).

- Also, no need for migration matrices (simpler analysis).

- It is not possible to do an antineutrino beam, though. But can combine energies and/or be combined with a β^--beam (^6He).

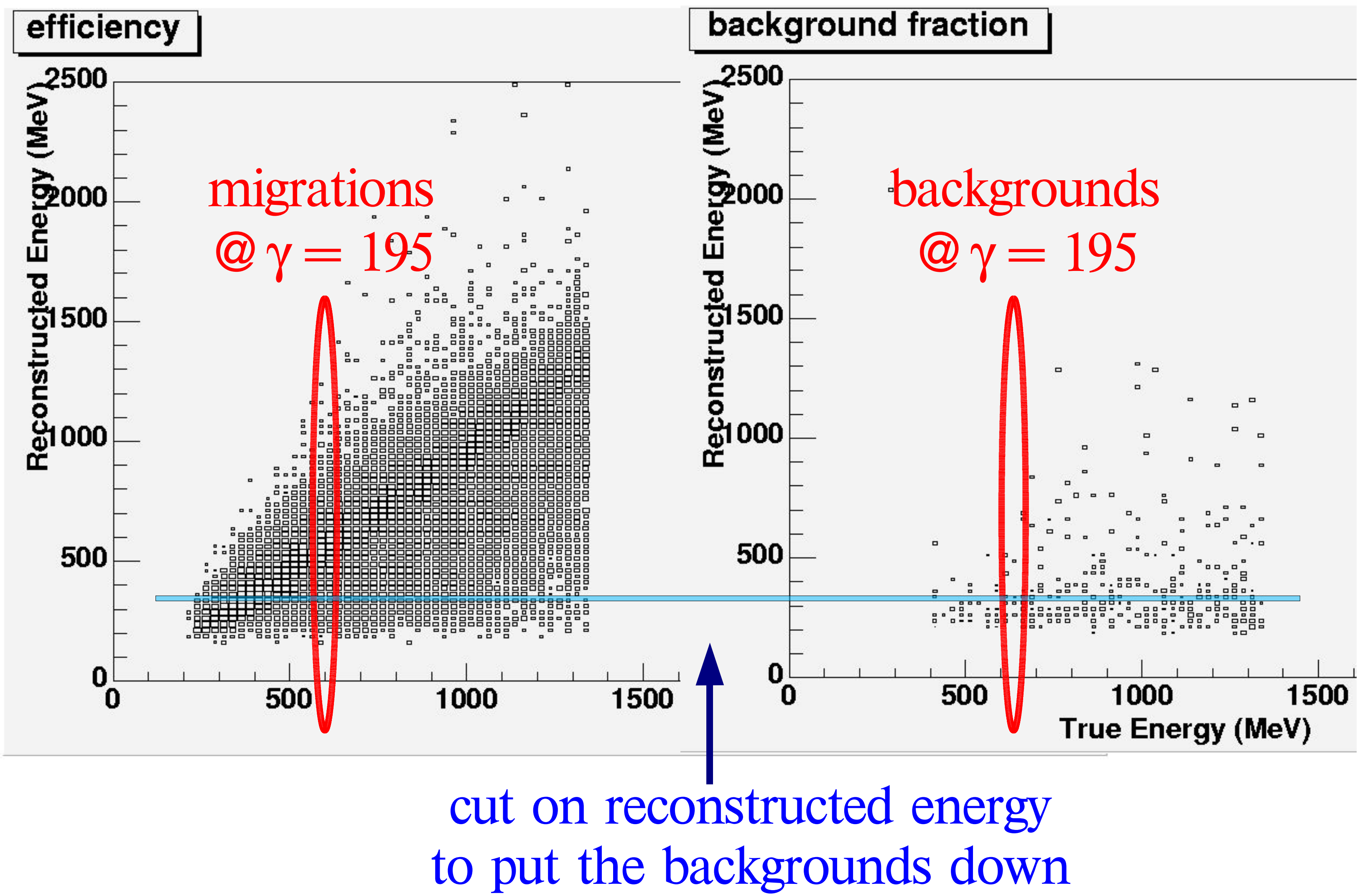
- It will have a real advantage over a β^+-beam depending on the achievable intensities.



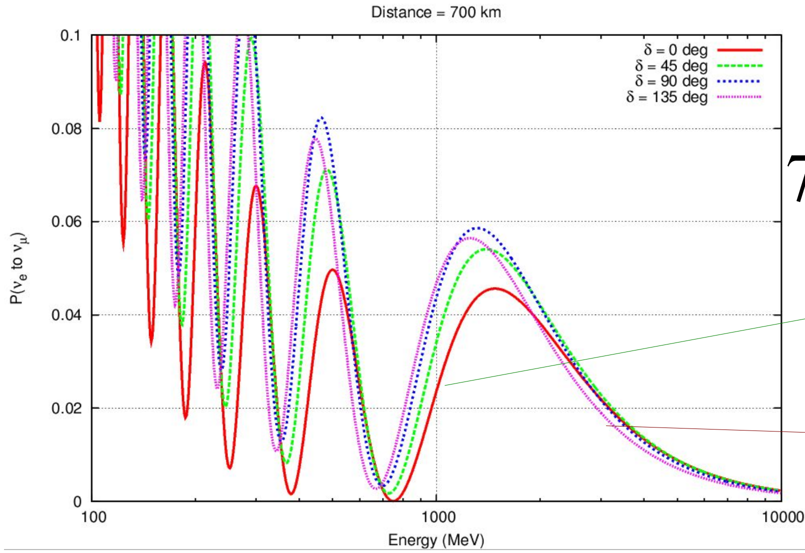
For the same initial intensity of ions, a β^+-beam can be "copied" by an electron capture beam (so it is *at least* as good)

Reconstructing energy?

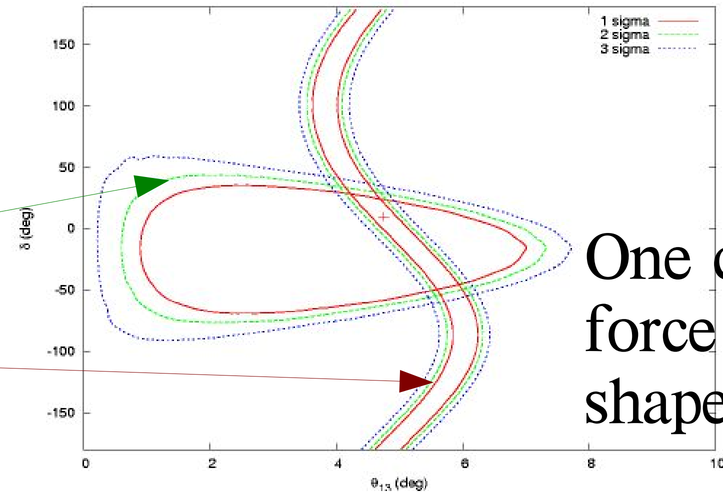
We *know* the neutrino energy, but by reconstructing it we can keep (detector) backgrounds really down!



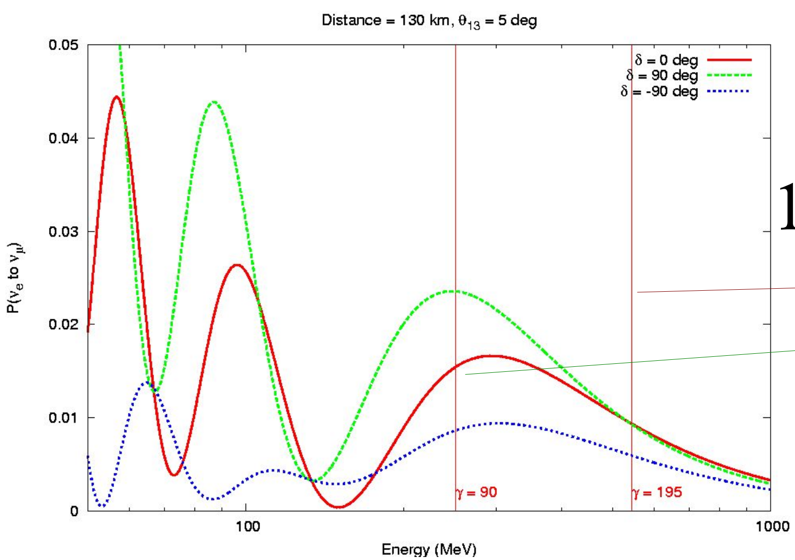
Fits with a 2nd energy



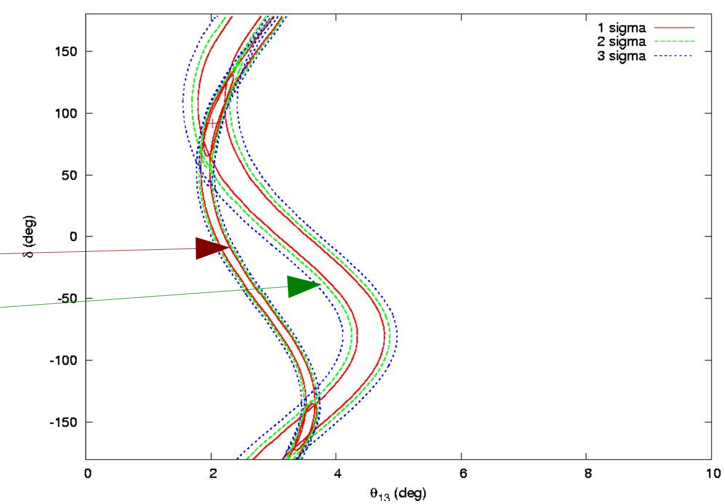
700 km



One can only force the "S" shape so much...



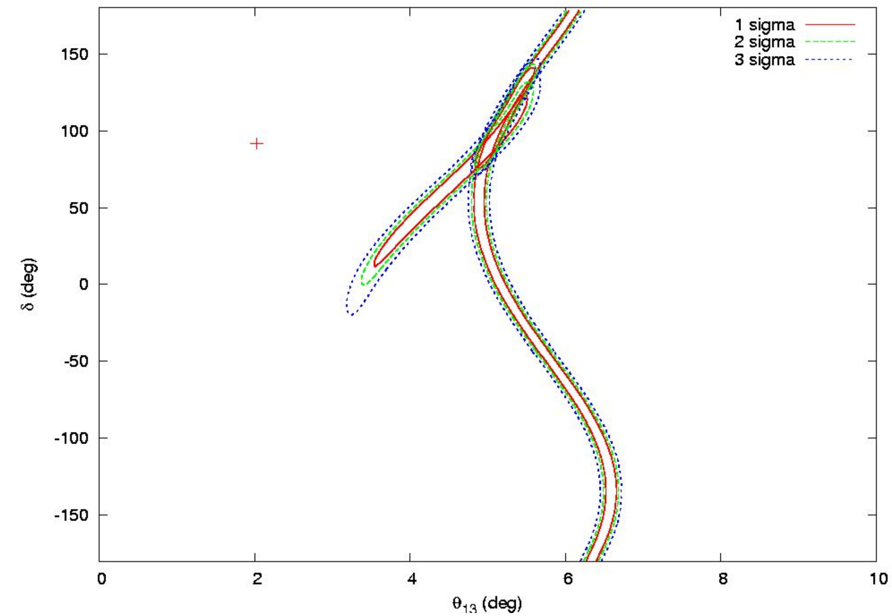
130 km



For a combination of energies to be of interest fluxes must be very high.
(probably necessary for degenerations too, but not considered here!)

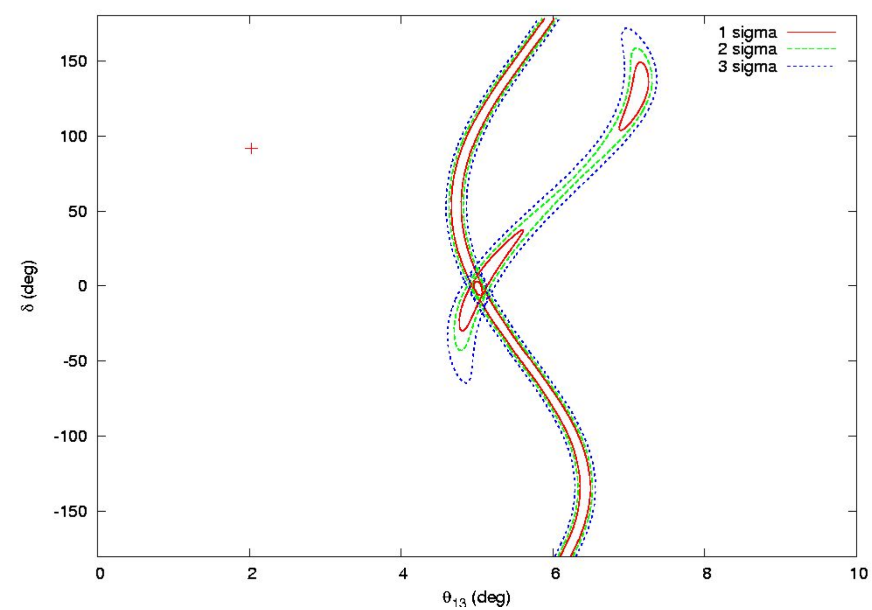
Fits with a β^--beam

The shape of the allowed region for β^- antineutrinos complements very well the E.C. neutrinos shape (of course, like in betabeams)

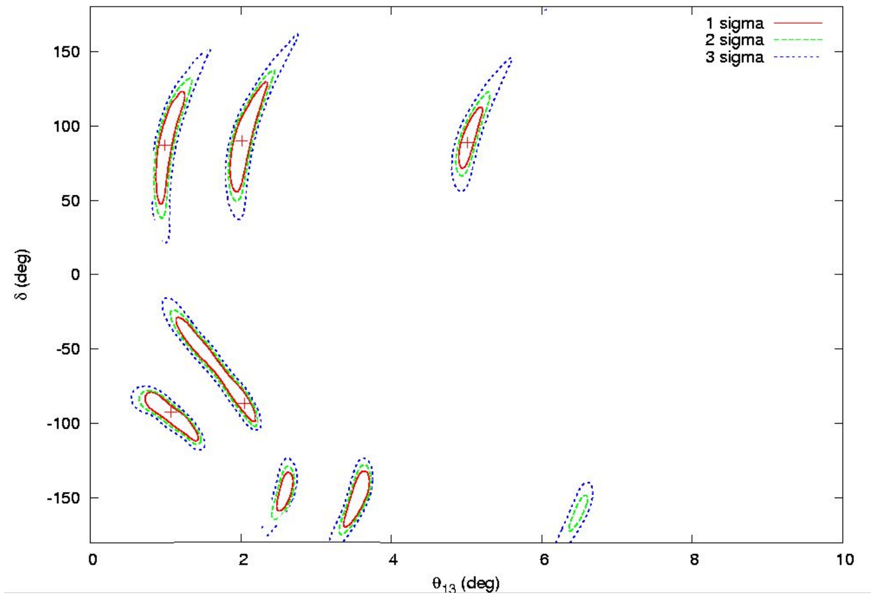


And their complementarity is especially good close to $\delta = 0, 180$

→ hints for an *extremely* good sensitivity to CP violation!

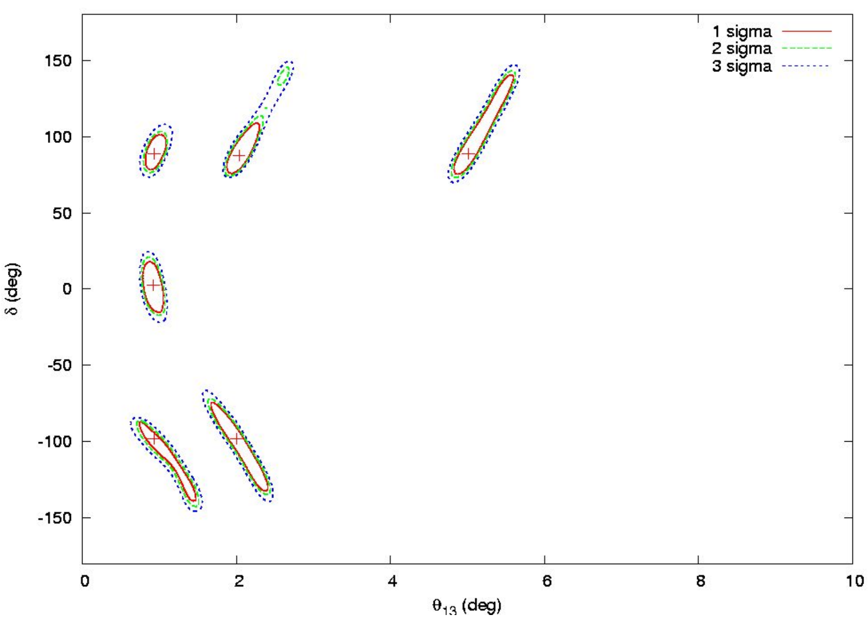


$EC_{\gamma=195} + EC_{\gamma=90}$ vs. $EC_{\gamma=195} + \beta^-$



EC+EC

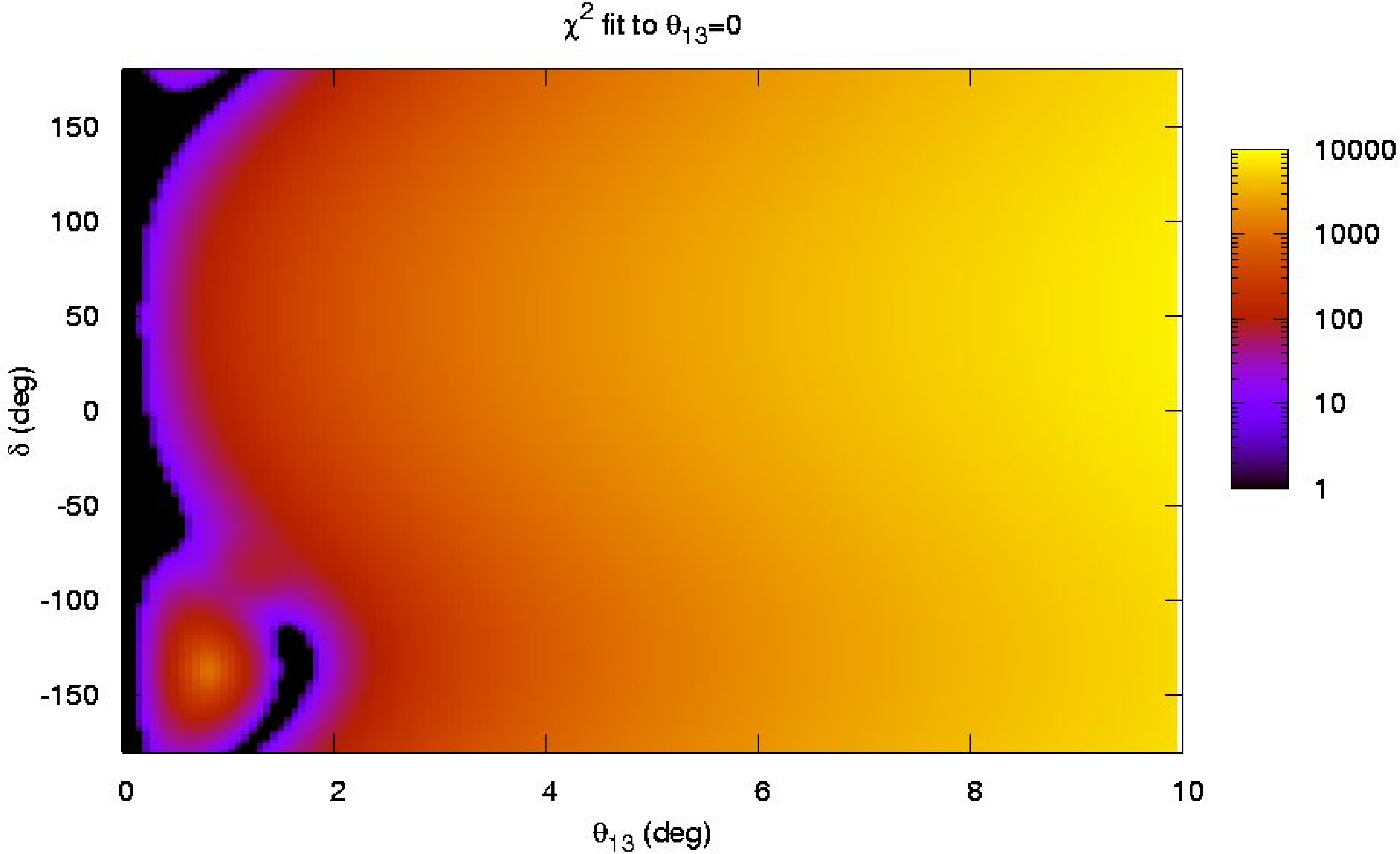
(intrinsic degeneracies would be corrected if systematics in disappearance were low enough, and they could)



EC+β^-

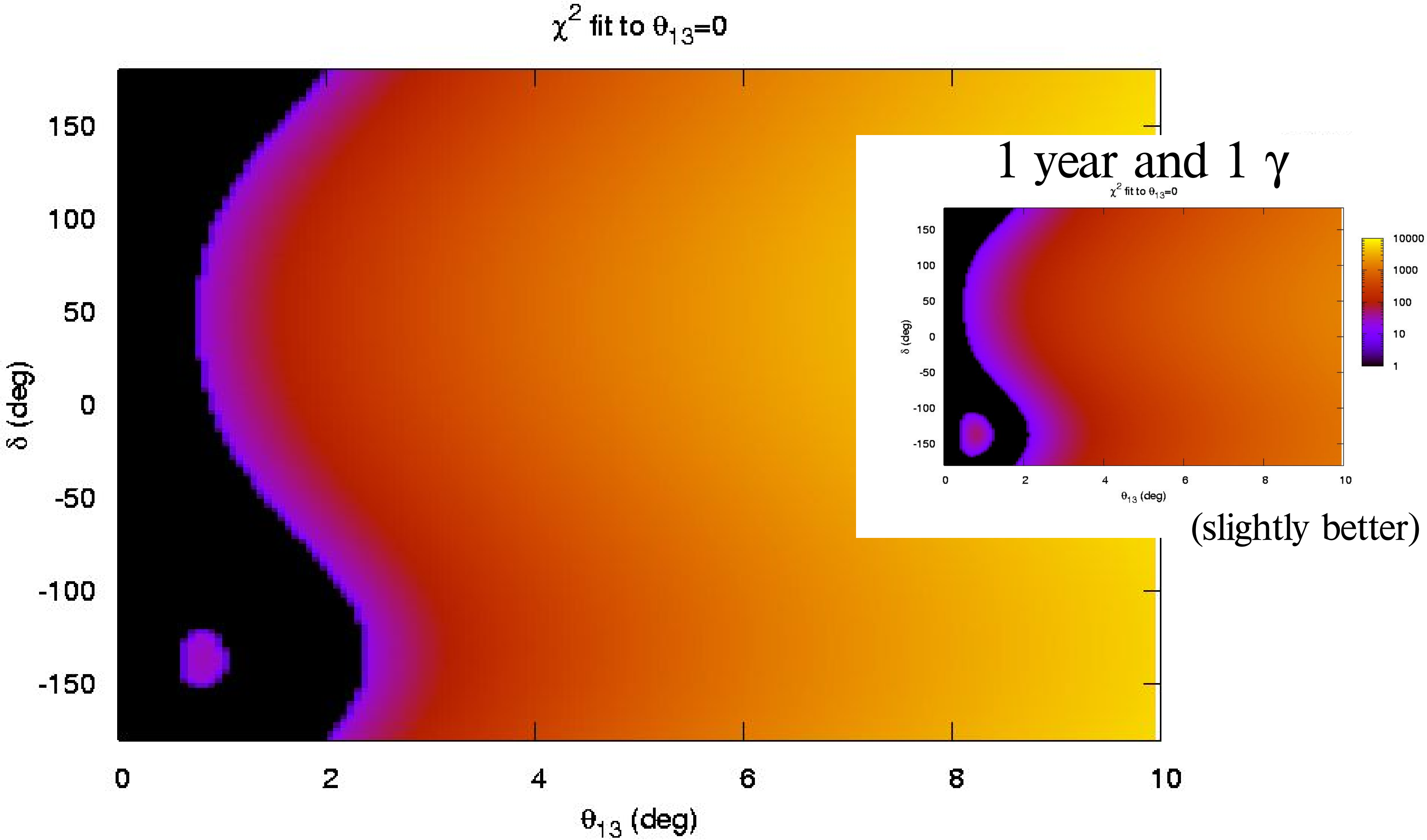
Enjoy: potatoes get straightened when approaching both $\theta_{13} = 0$ or $\delta = 0$

θ_{13} sensitivity



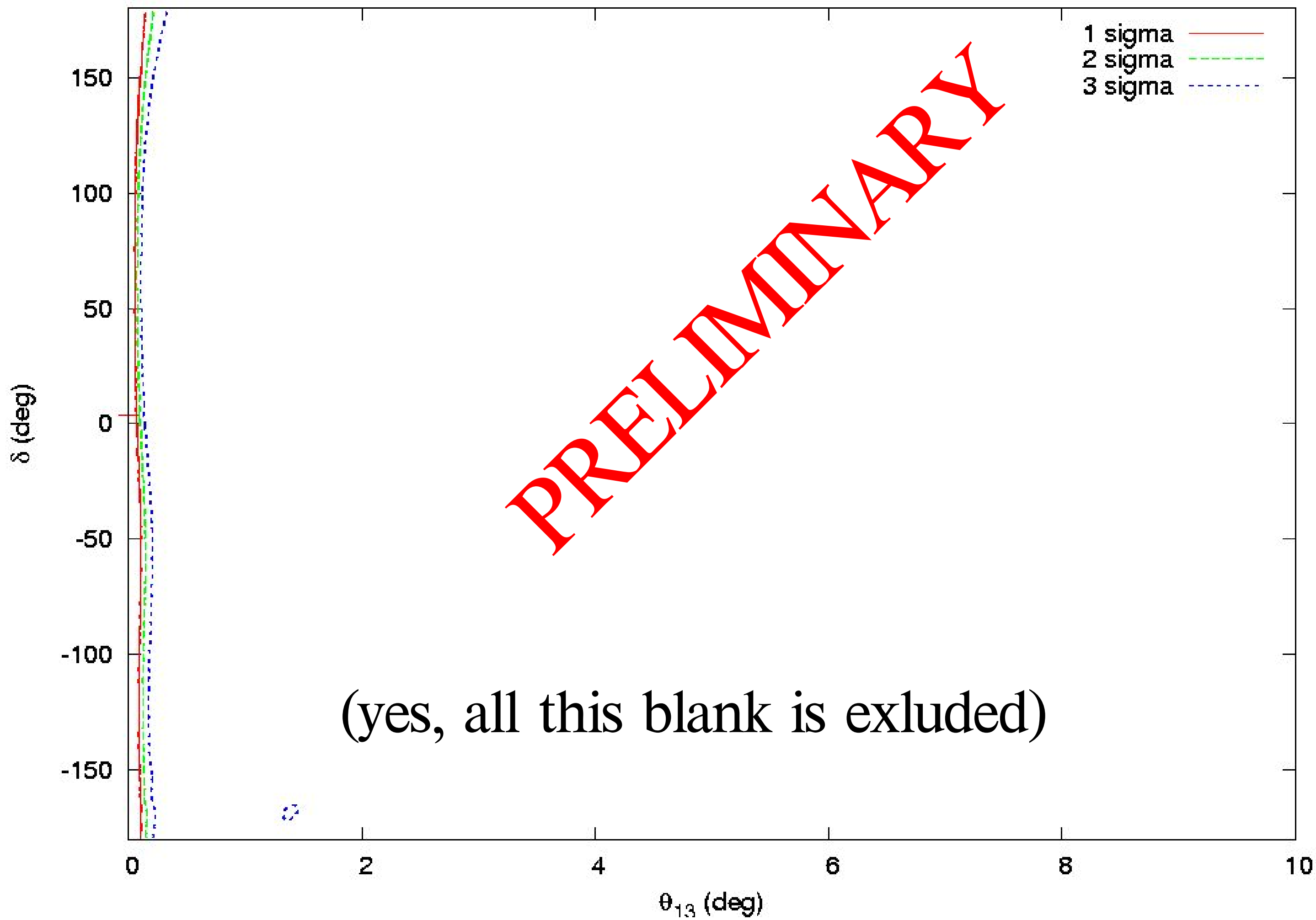
Total running time: **10 years**... not bad?

θ_{13} sensitivity



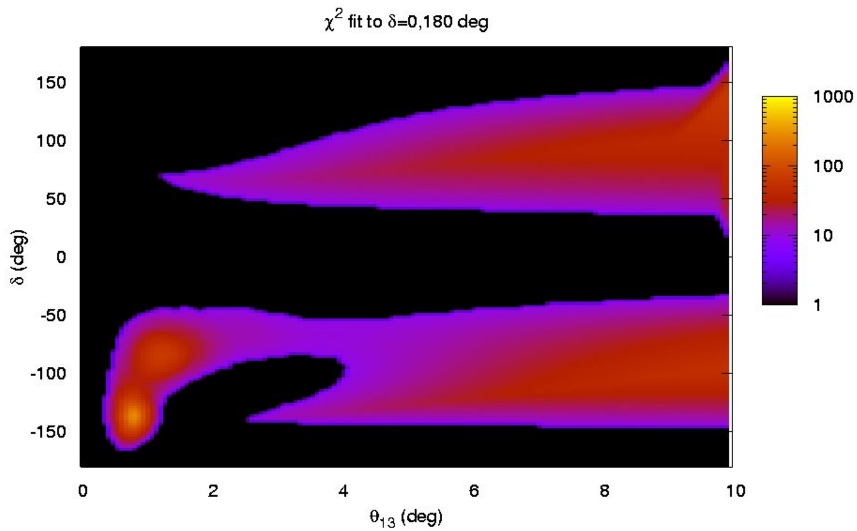
Total running time: **1 year**

θ_{13} sensitivity, with a β^- beam

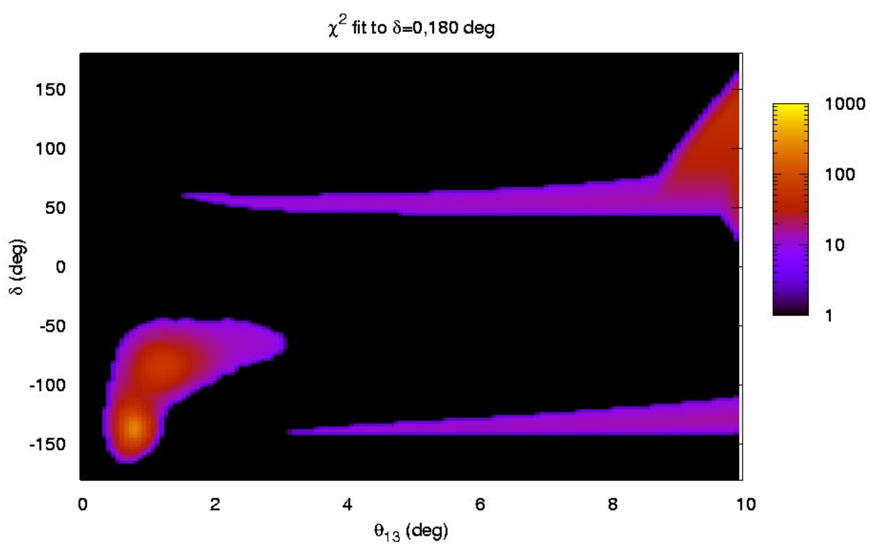


sorry for the inappropriate scale!

δ sensitivity



Appearance + Disappearance
(no systematics)



Appearance + Disappearance
(1% systematics)

Well, we didn‘t expect it
to be good for δ indeed...

Caveats

- A detailed study of production cross-section, target and ion source designs, ion cooling and accumulation schemes, possible vacuum improvements and stacking schemes is required in order to reach a definitive answer on the achievable flux.

- Full analysis with degeneracies may change things quite a bit.

Non-oscillation physics

The EC beam can be useful for other kind of physics:

- High precision ν cross section measurement?
- Probing the nucleus structure?
- Ideas?

Conclusions

- An electron-capture neutrino beam is feasible, thanks to the recent discovery of nuclei that *decay fast enough* through e-capture.
- An *e*.c.beam can be competitive with a β-beam in its physics reach measuring θ_{13}.
- Combination with a β^{-}-beam is very promising.
- The concept needs/deserves further exploration!