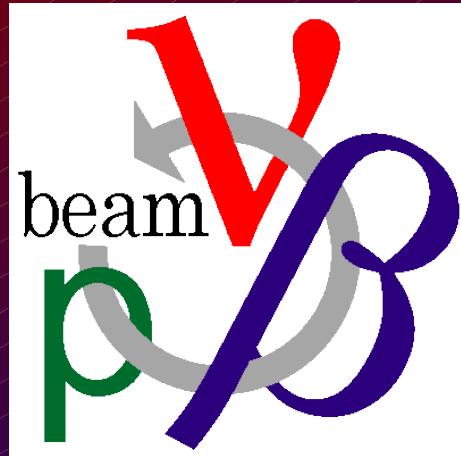


Beta-Beams



DESY – Fréjus

Achim Stahl
RWTH Aachen University

RHEINISCH-
WESTFÄLISCHE
TECHNISCHE
HOCHSCHULE
AACHEN

RWTH

CMS: Tracker / Computing / Physics
Neutrinos: DoubleChooz Trigger
T2K Magnet + TPC
BetaBeams

Contents

The European Framework
Neutrino-Oscillations
Future Concepts
A European BetaBeam Facility

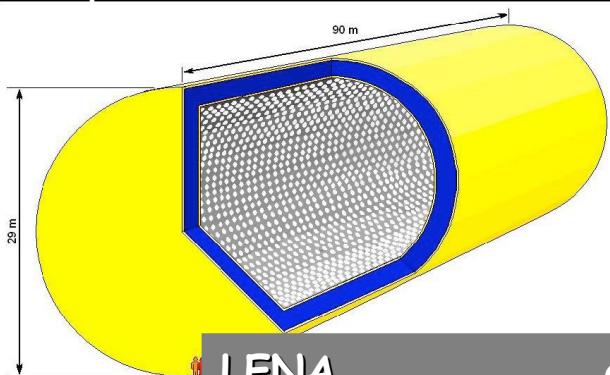
The European Framework

LAGUNA

Large Apparatus for Grand Unification and Neutrino Astrophysics

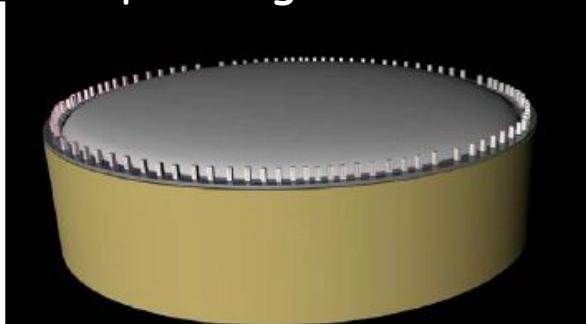
3 different technologies under discussion

liquid scintillator



LENA

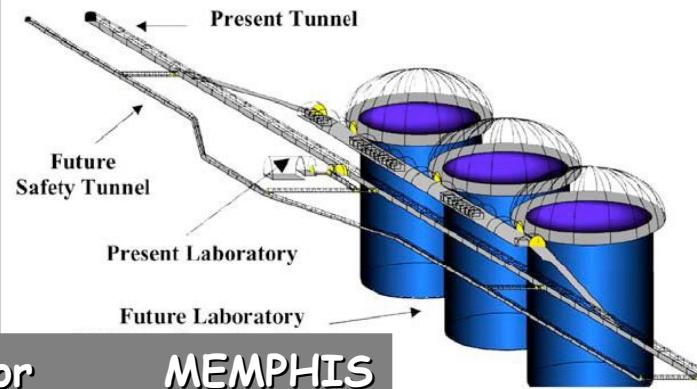
liquid Argon TPC



or

GLACIER

water cerenkov



or

MEMPHIS

Science Case: Multi-Disciplinary

Geo-Physics

Neutrinos from the core of the earth
Heat release, relevant to our climate

Astro-Physics

Observation of neutrinos from Super-Novae
Expect to observe several hundred

Nuclear Physics

Neutrino Nucleon Cross Sections
Study of Nucleons with axial vector current

Particle Physics

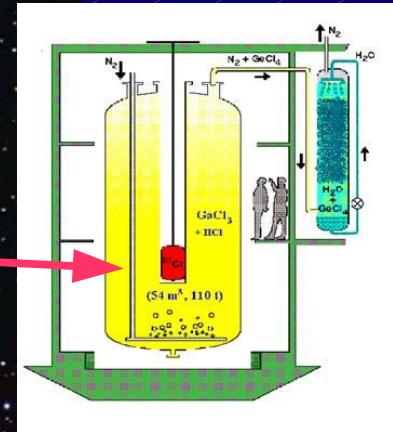
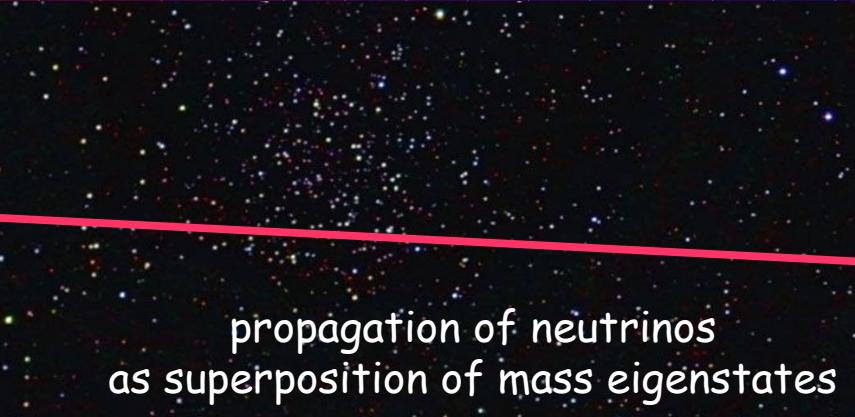
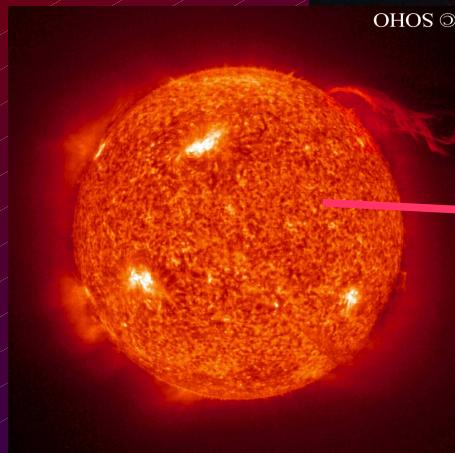
•

Search for proton decay, GUT

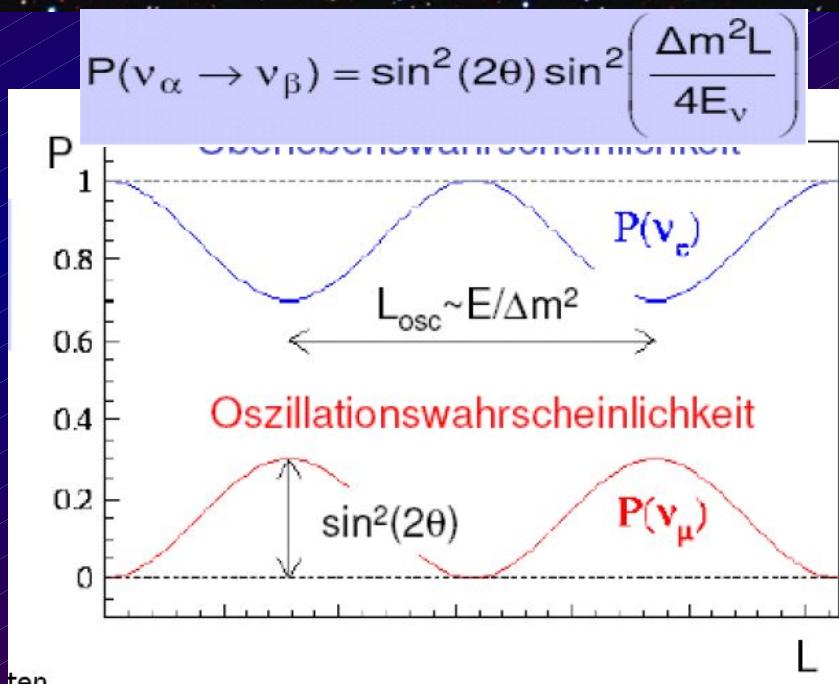
Neutrino oscillations:

- Reactor neutrinos (like KAMLAND)
- Atmospheric neutrinos (like Super-K)
- BetaBeams: CP-Violation

Neutrino Oscillations



production of neutrinos
as weak eigenstates



detection of neutrinos
as weak eigenstates

Experimental Status

Solar Neutrinos

oscillation observed

Davis
GALLEX
Super-K

confirmed
KAMLAND
SNO

disappearance of ν_e

Atmospheric ν

oscillation observed

Super-K
confirmed
K2K
MINOS

disappearance of ν_μ

Reactor ν , θ_{13}

no observation yet

intensive search
DoubleChooz
Daya Bay
RENO
T2K

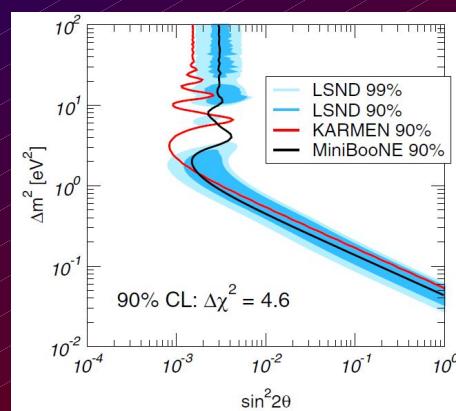
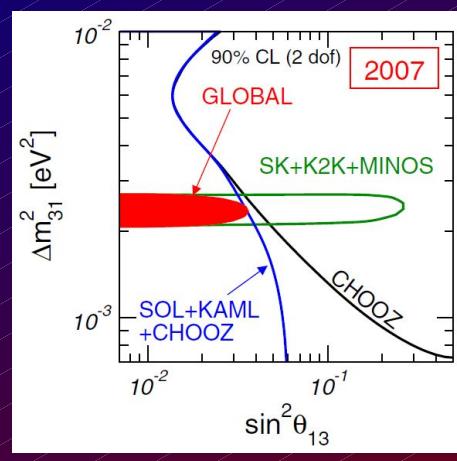
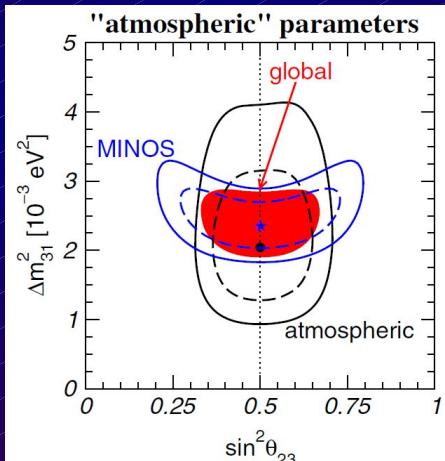
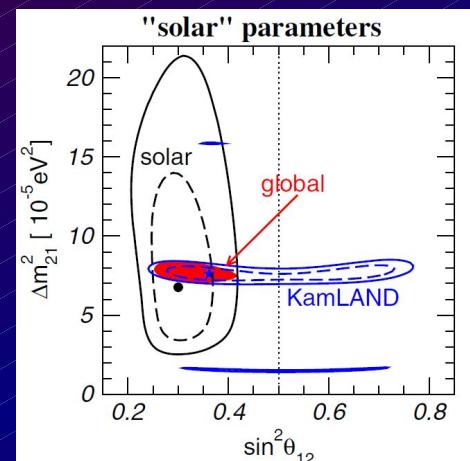
disappearance of ν_e

LSND effect

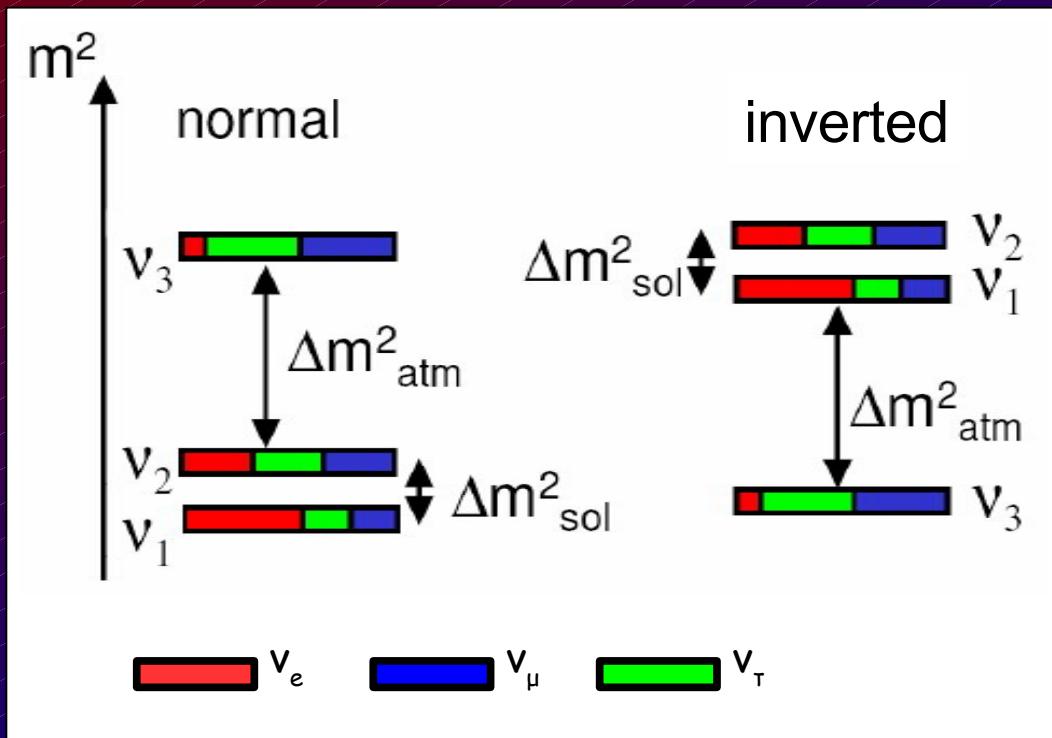
not confirmed

contradicted by
KARMEN
MiniBOONE

disappearance of ν_μ



Open Questions



How large is θ_{13} ?

Precision measurements (θ_{23} maximal?)

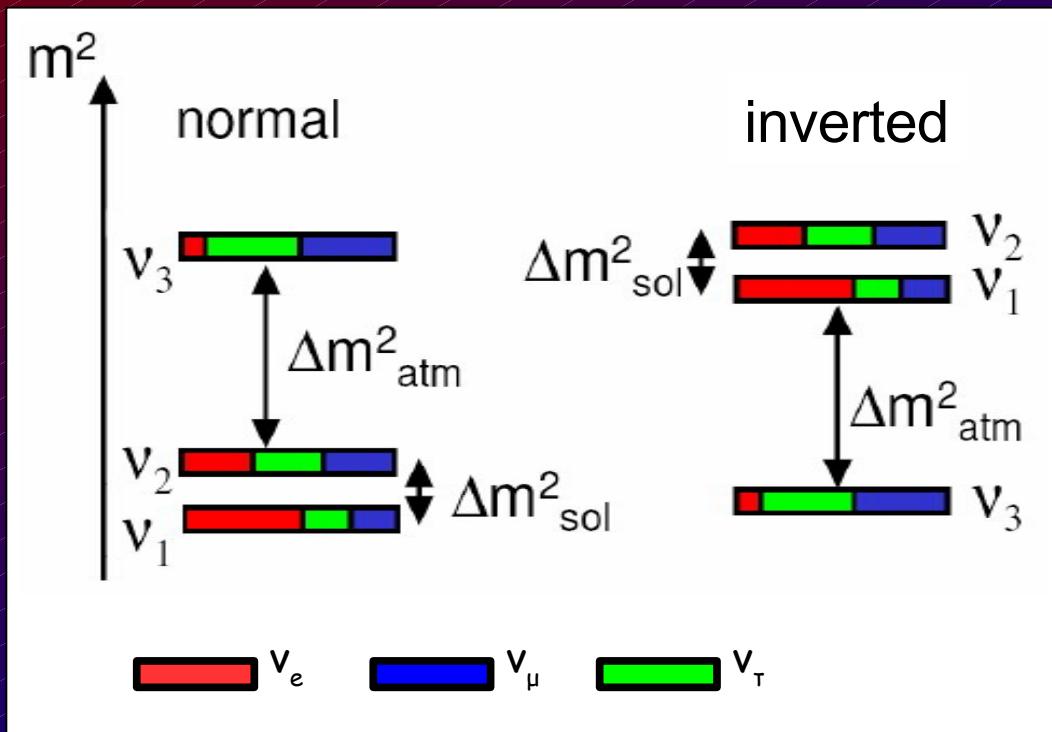
Absolute mass scale?

Normal or inverted hierarchie?

Majorana or Dirac-neutrinos?

CP-violation?

Open Questions



How large is θ_{13} ?

Precision measurements (θ_{23} maximal ?)

Absolute mass scale ?

Normal or inverted hierarchie ?

Majorana or Dirac-neutrinos ?

CP-violation ?

experiments just starting

→ next gen. oscillations exp.

nuclear physics exp. (KATRIN)

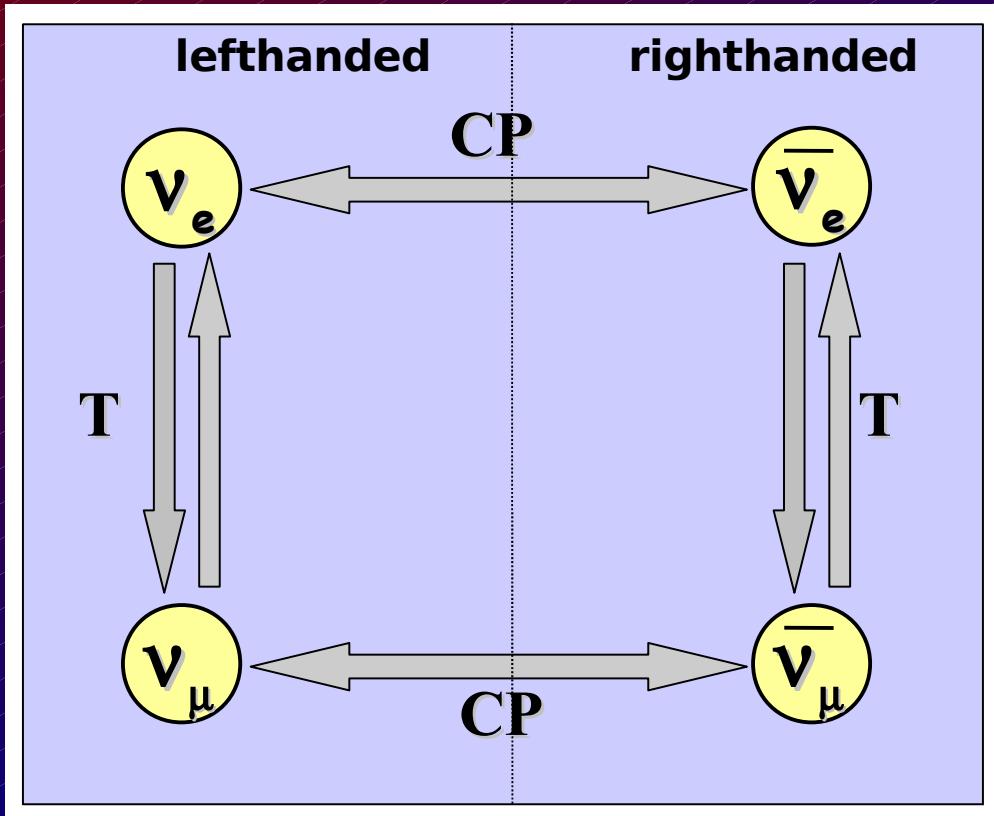
→ next gen. oscillations exp.

double beta decay

→ next gen. oscillations exp.

CP-Violation

Testing the discrete symmetries with neutrinos



tau-neutrinos: no practical beam-source

Examples

CP-TEST:

$$\nu_e \rightarrow \nu_\mu \quad / \quad \bar{\nu}_e \rightarrow \bar{\nu}_\mu$$

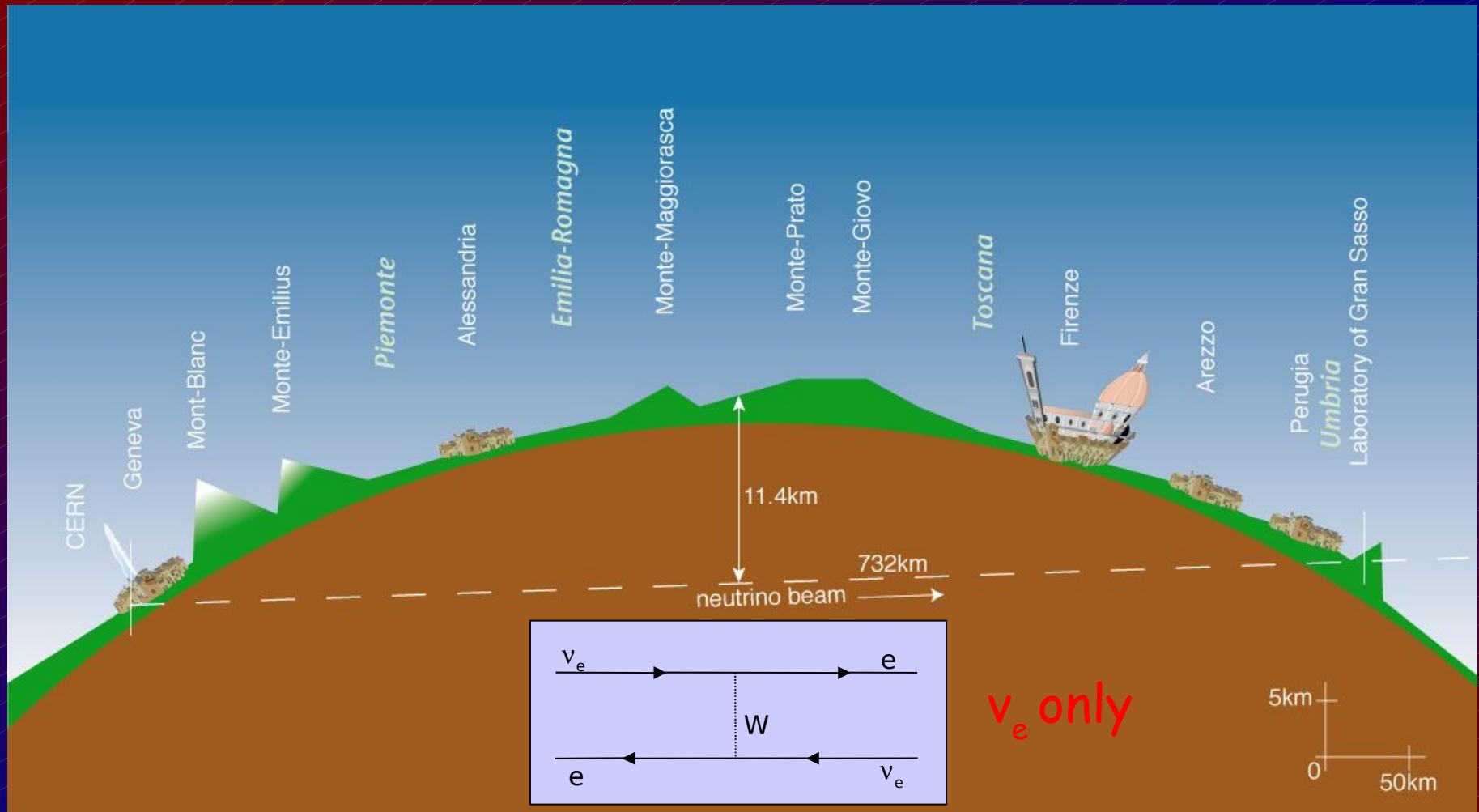
T-TEST:

$$\nu_e \rightarrow \nu_\mu \quad / \quad \nu_\mu \rightarrow \nu_e$$

CPT-TEST:

$$\nu_e \rightarrow \nu_\mu \quad / \quad \bar{\nu}_\mu \rightarrow \bar{\nu}_e$$

Matter Effect



Example: CERN-GranSasso (CNGS)

matter parameter: $a \sim \rho$

Neutrino Oscillations

3-flavour oscillation (including matter effect)
numerically relevant terms only

$$\begin{aligned} p(\nu_\mu \rightarrow \nu_e) = & 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2} (1 - 2s_{13}^2) \right] & \theta_{13} \text{ dri} \\ & + 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos \delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \text{ CPe} \\ & \mp 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin \delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} & \text{CPodd} \\ & + 4s_{12}^2 c_{13}^2 \{ c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos \delta \} \sin \frac{\Delta m_{12}^2 L}{4E} & \text{solar driver} \\ & \mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2) & \text{matter effect (CP odd)} \end{aligned}$$

Need two different baselines to disentangle
matter effect from CP-violation !

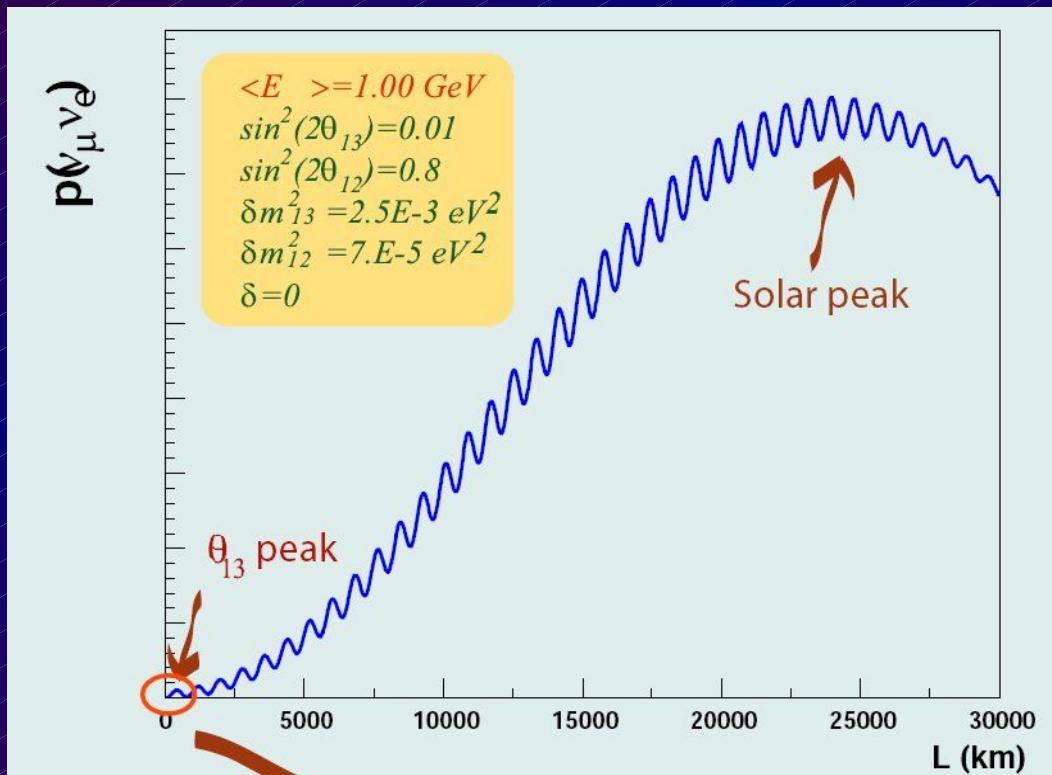
Neutrino Oscillations

$$\begin{aligned}
 p(\nu_\mu \rightarrow \nu_e) = & 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2\alpha}{\Delta m_{13}^2} (1 - 2s_{13}^2) \right] \quad \theta_{13} \text{ dri} \\
 & + 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \text{ CPe} \\
 & \mp 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin \delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{CPodd} \\
 & + 4s_{12}^2 c_{13}^2 \{ c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta \} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{solar driver} \\
 & \mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{\alpha L}{4E} (1 - 2s_{13}^2) \quad \text{matter effect (CP odd)}
 \end{aligned}$$

Two frequencies:

$$\Delta m_{12} \rightarrow L_0/E \approx 31000 \text{ km}$$

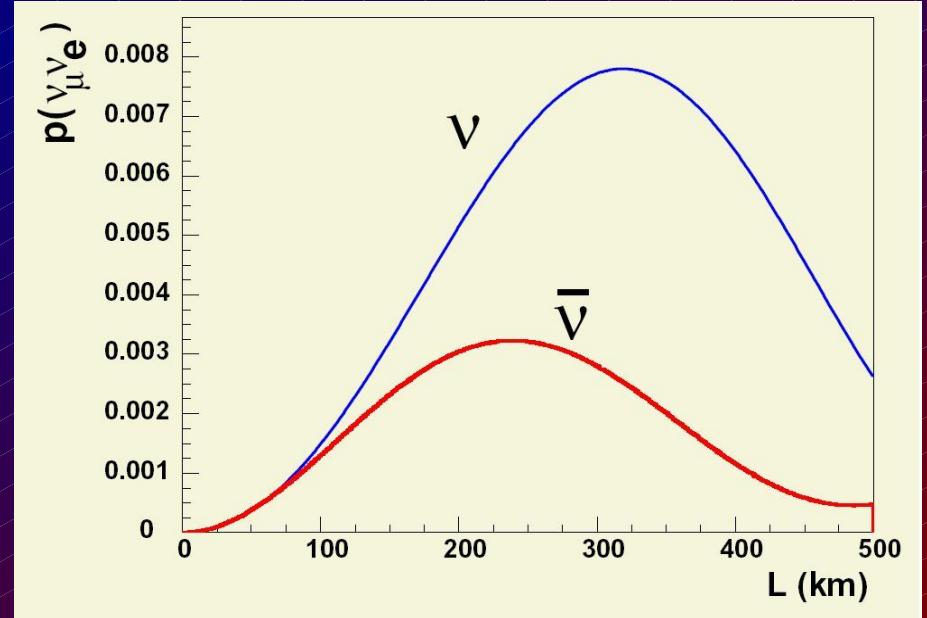
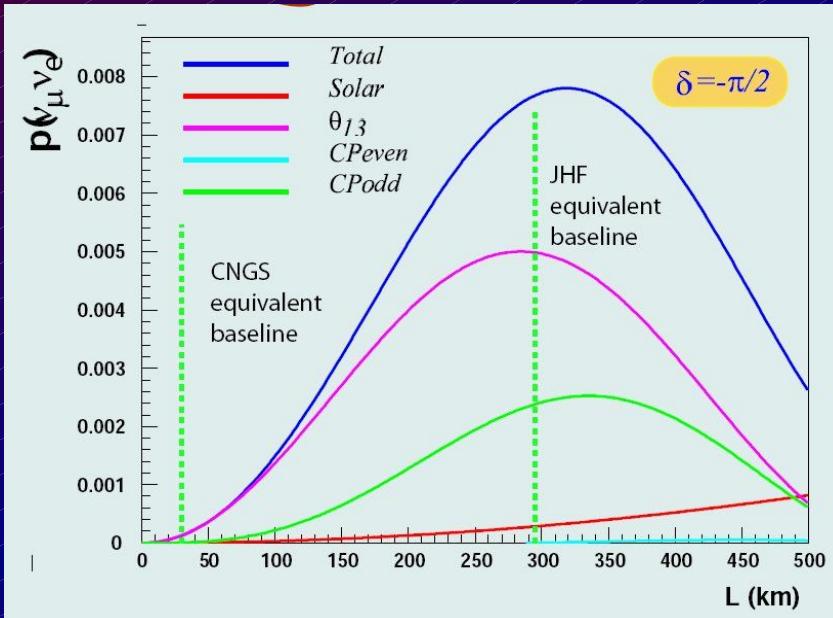
$$\Delta m_{13} \approx \Delta m_{23} \rightarrow L_0/E \approx 1000 \text{ km}$$



Neutrino Oscillations

$$\begin{aligned}
 p(\nu_\mu \rightarrow \nu_e) = & 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2} (1 - 2s_{13}^2) \right] \quad \theta_{13} \text{ dri} \\
 & + 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos \delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \text{ CPe} \\
 \mp & 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin \delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{CPodd} \\
 & + 4s_{12}^2 c_{13}^2 \{ c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos \delta \} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{solar driver} \\
 \mp & 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2) \quad \text{matter effect (CP odd)}
 \end{aligned}$$

disentangle CP-odd and matter effect through different baselines.



Future Concepts

What we want to know:

Mixing angles: θ_{12} , θ_{23} (maximal?), θ_{13} ($\neq 0$?)

Mass hierarchie: $\Delta m_{\text{atm.}} < \text{or} > 0$

CP-violation: Phase $\delta \neq 0$?

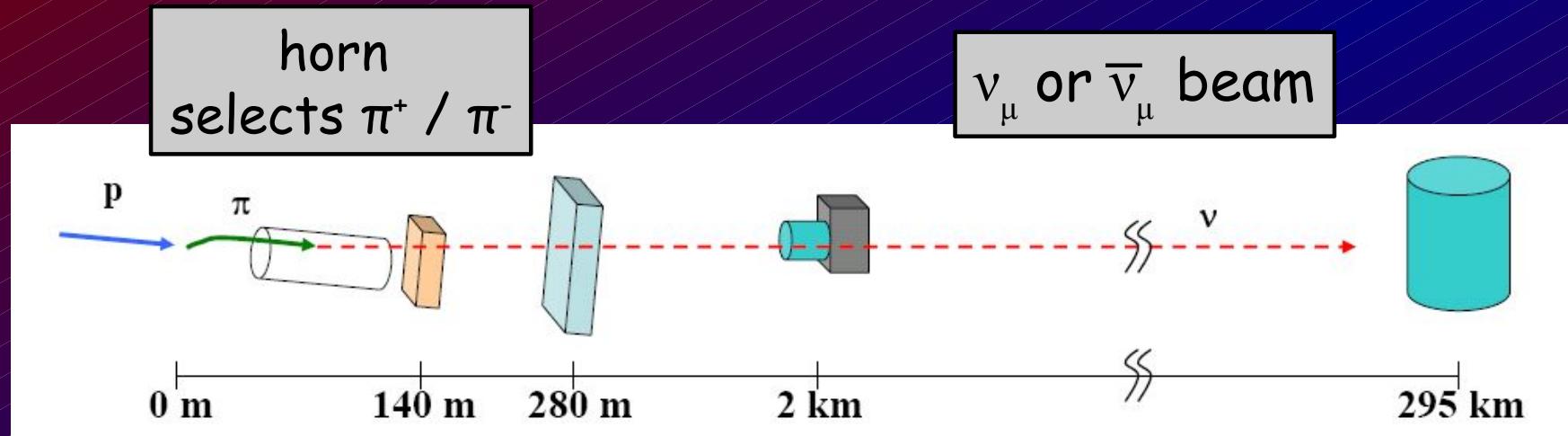
What we need:

ν_e and ν_μ beams to test T-invariance

(ν_e and $\bar{\nu}_e$) or (ν_μ and $\bar{\nu}_\mu$) beams to test CP

two different baselines to control matter effect

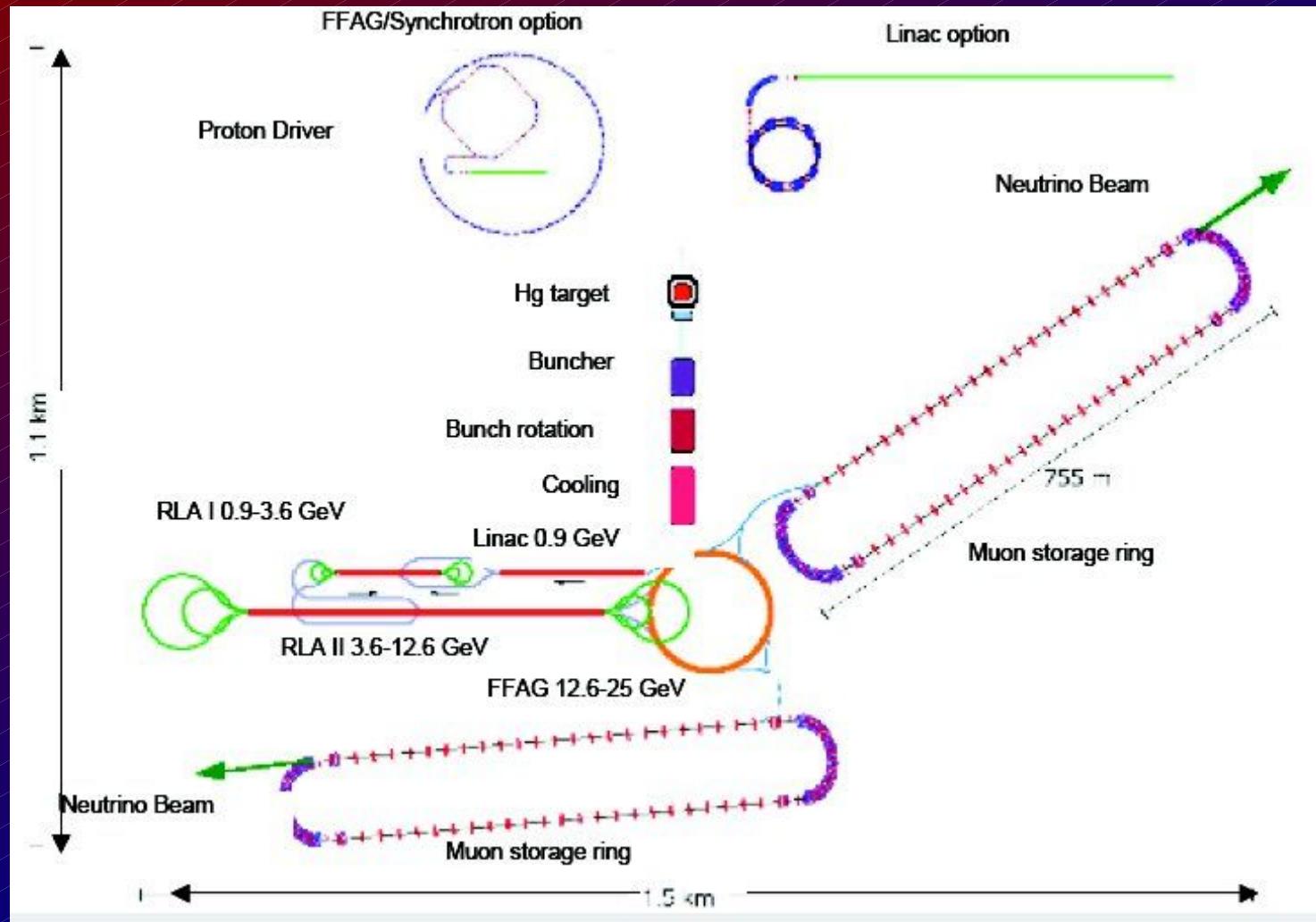
Conventional Neutrino Beam



Example T2K

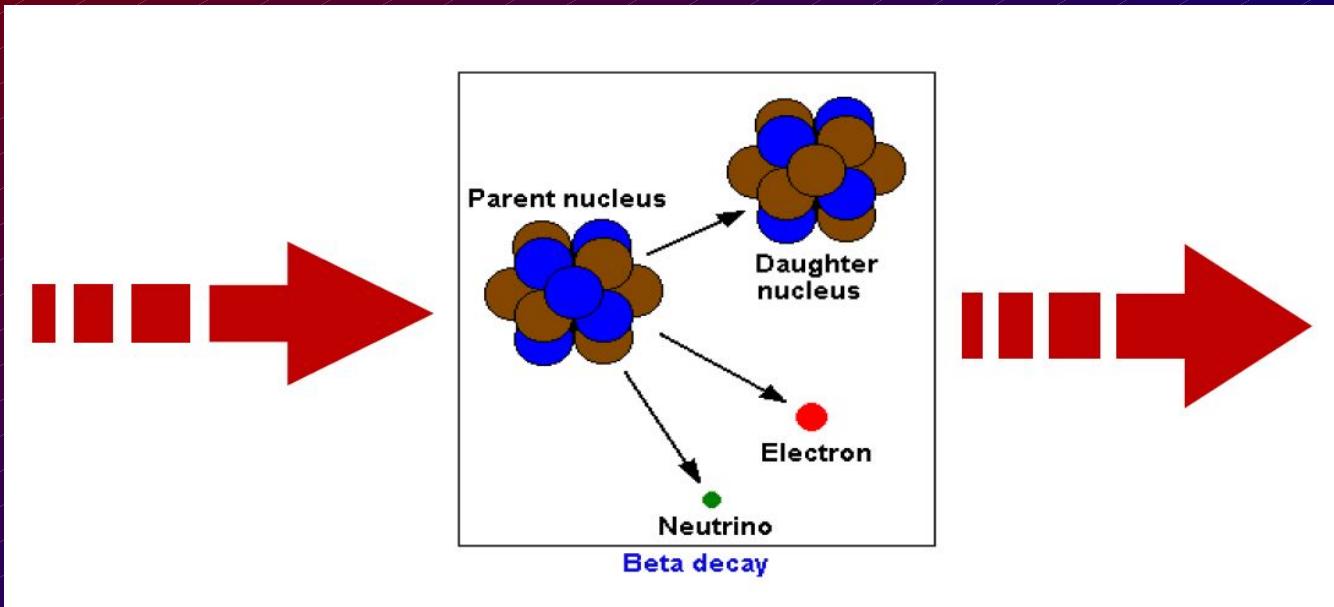
some background of ν_e

Neutrino Factory



$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu \quad \& \quad \mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

Beta Beams



accelerate radioactive ions → beta-decay → neutrino beam

^6He

β^- emitter → anti- ν -beam



Lifetime: 0.8067 s
Q-Value: 3.5078 MeV
Ave. E_u : 1.94 MeV

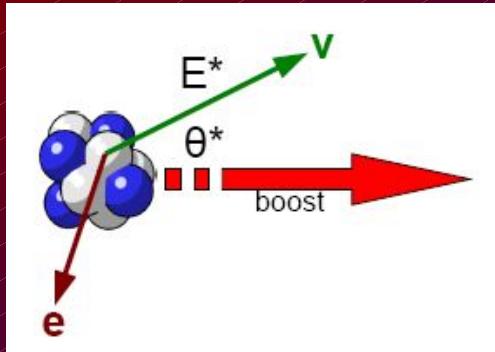
^{18}Ne

β^+ emitter → ν -beam



Lifetime: 1.67 s
Q-Value: 3.4 MeV
Ave. E_u : 1.86 MeV

Kinematics



$$E_{\text{lab}} = \gamma E^*$$

$$\theta_{\text{lab}} = 1/\gamma \sin \theta^* / (1 + \cos \theta^*)$$

Q-values:

Nu-Factory: 105 MeV

Beta-Beam: typ. 3 MeV

Dependance on γ

Opening angle $\sim 1/\gamma$ \rightarrow flux at fixed distance $\sim \gamma^2$

$E_{\text{lab}} \sim \gamma$ \rightarrow optimal Baseline $\sim \gamma$ \rightarrow flux at detector $\sim 1/\gamma^2$

$E_{\text{lab}} \sim \gamma$ \rightarrow cross section $\sim \gamma$

$\sim \gamma$

Dependance on E^*

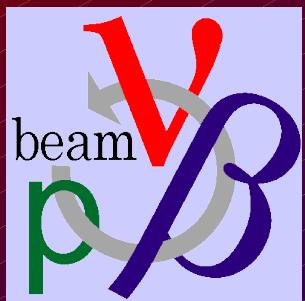
Opening angle independent of E^*

$E_{\text{lab}} \sim E^*$ \rightarrow optimal baseline $\sim E^*$ \rightarrow flux at detector $\sim 1/E^{*2}$

$E_{\text{lab}} \sim E^*$ \rightarrow cross section $\sim E^*$

$\sim 1/E^*$

Two Alternative Concepts



beta-beam
 $\nu_e / \bar{\nu}_e$ beam

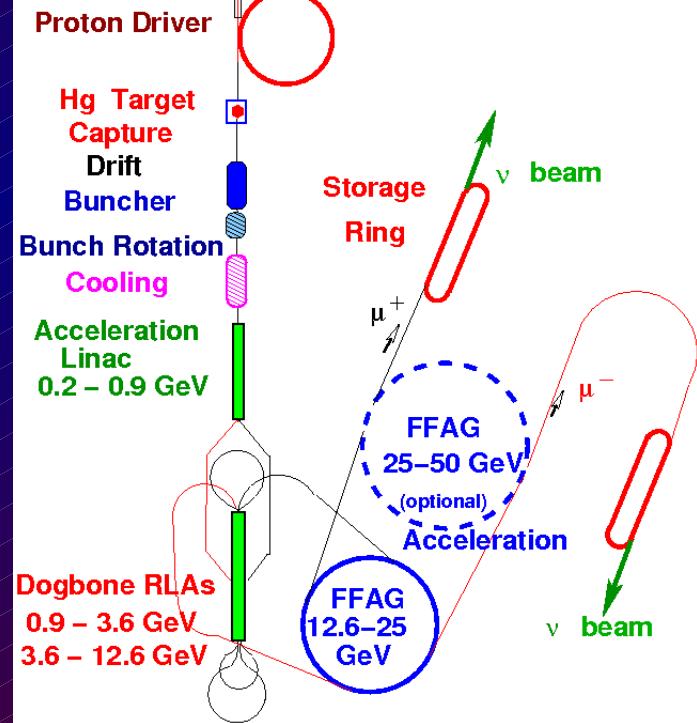
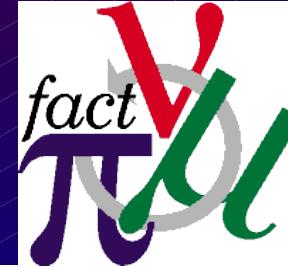
&

conventional ν_μ beam



$\nu_\mu / \bar{\nu}_\mu$ beam

We need ν_e and ν_μ beam
with different baselines

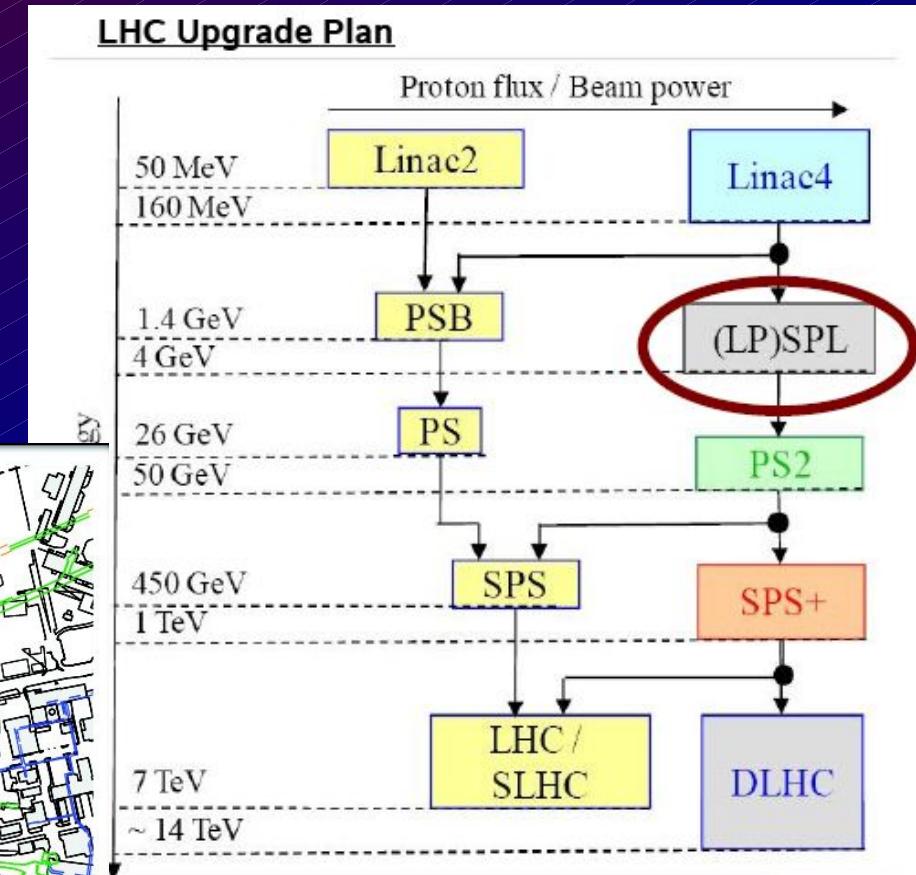
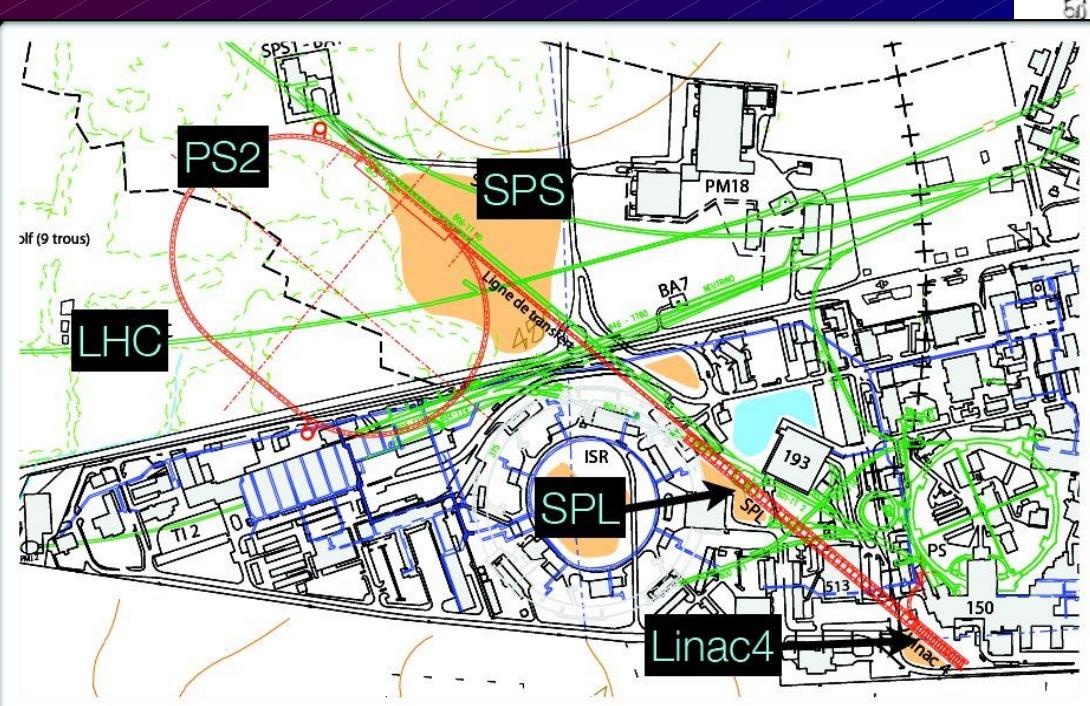


$$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu \quad \& \quad \mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

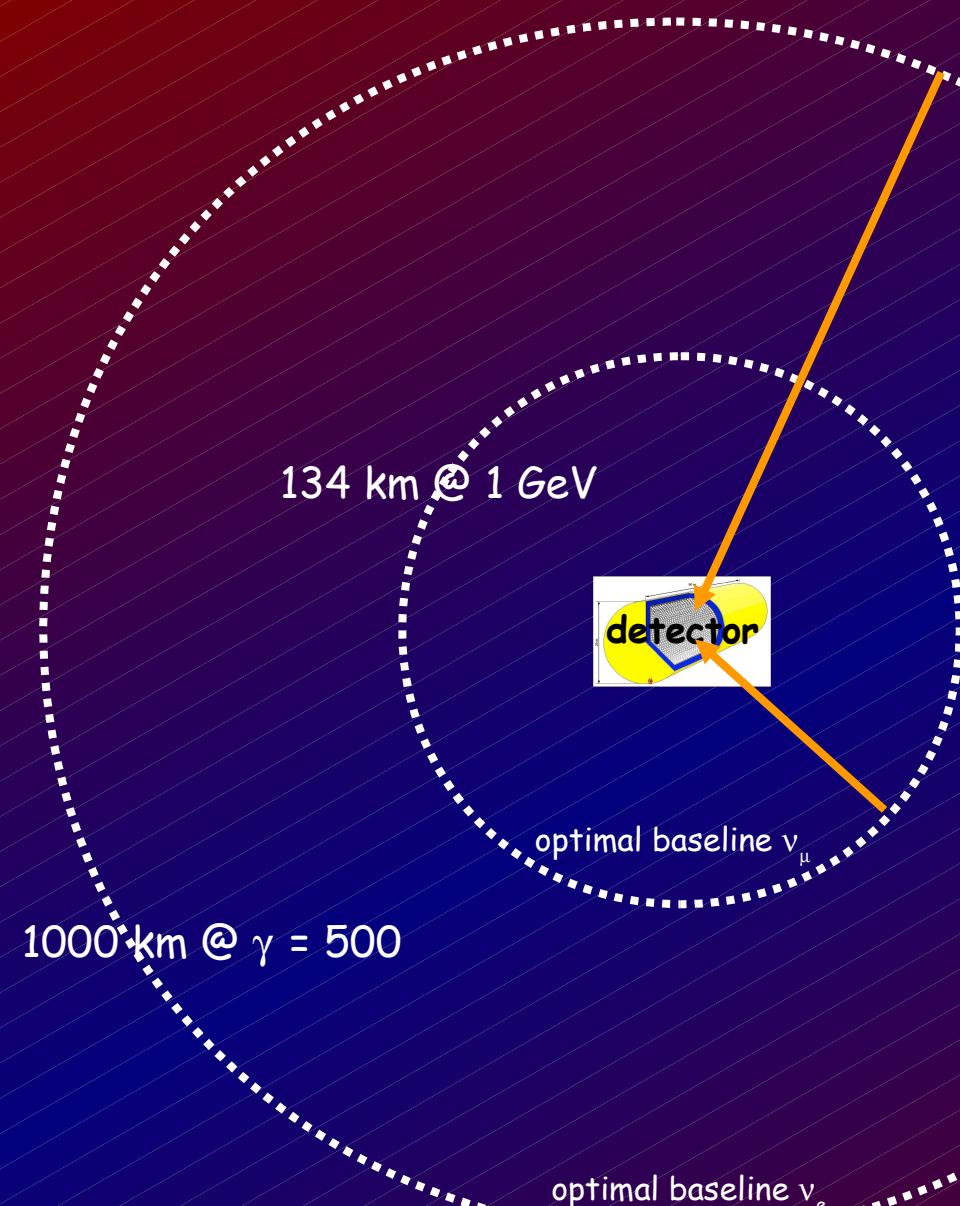
magnetic detector for separation

A European BetaBeam Facility

conventional neutrino beam
from CERN SPL
need 10% of its intensity



Why DESY – Fréjus



1 Detector only (price!)

ν_μ - beam

SPL, $\langle E_\nu \rangle = 260$ MeV

$L_{\text{opt}} = 134$ km

CERN – Fréjus: 130 km

ν_e - beam

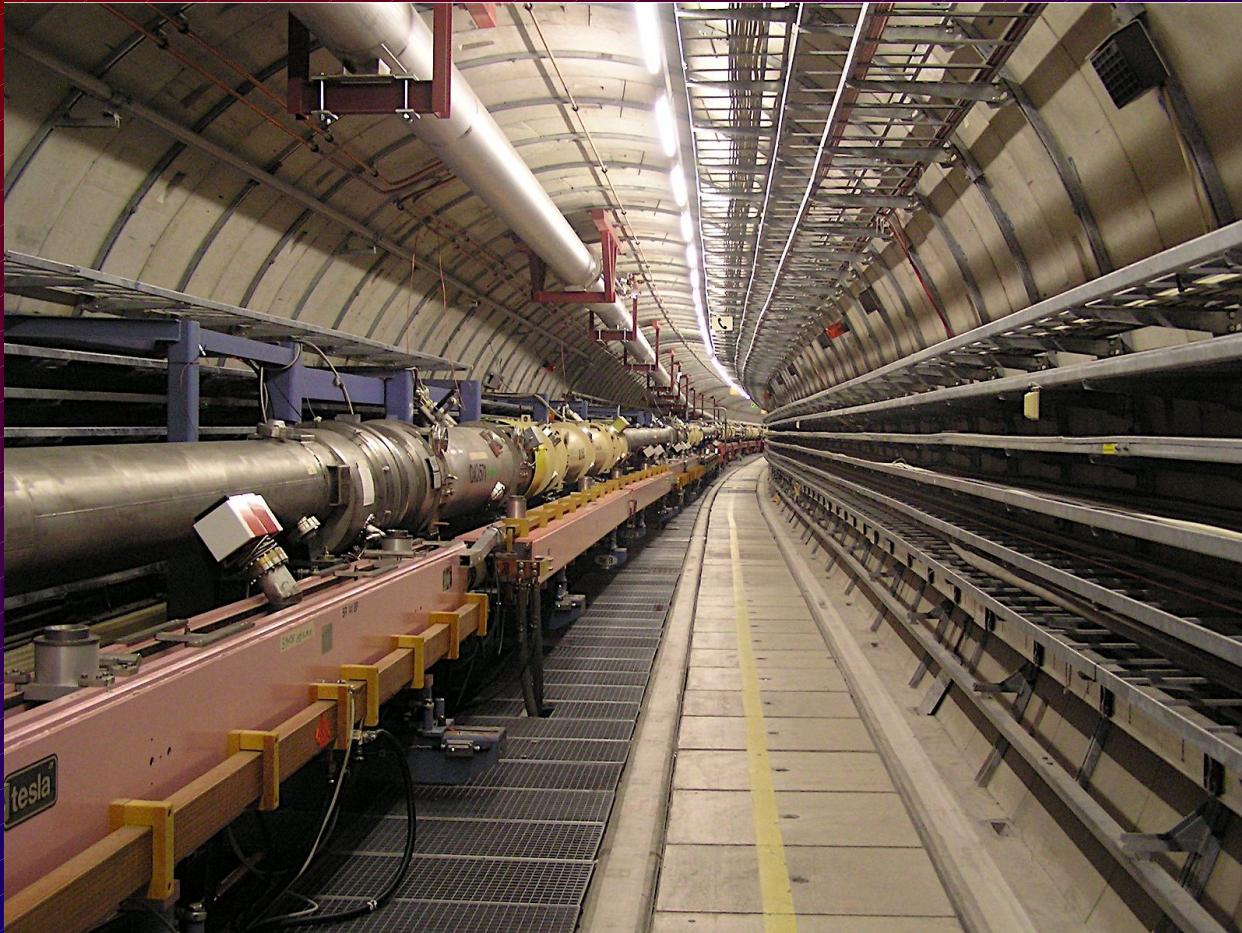
$\gamma = 500$ $L_{\text{opt}} = 1000$ km

DESY – Fréjus: 960 km

Need ν_e und ν_μ beam
with different baselines



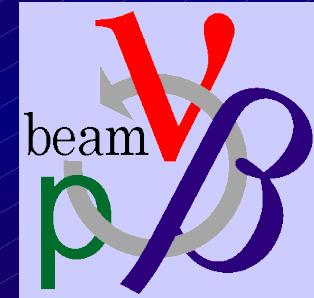
BetaBeam from HERA



Comment from the summer studenten, who took the picture:

Inside the long HERA tunnel which was just shutdown before we came to DESY. The experiments (like ZEUS in the previous photo) are being dismantled. Asking the CEO of DESY what they will do with HERA after they have dismantled the experiments he just shrugged and said that they currently have no idea?!?

Recycling für
beta-beams:

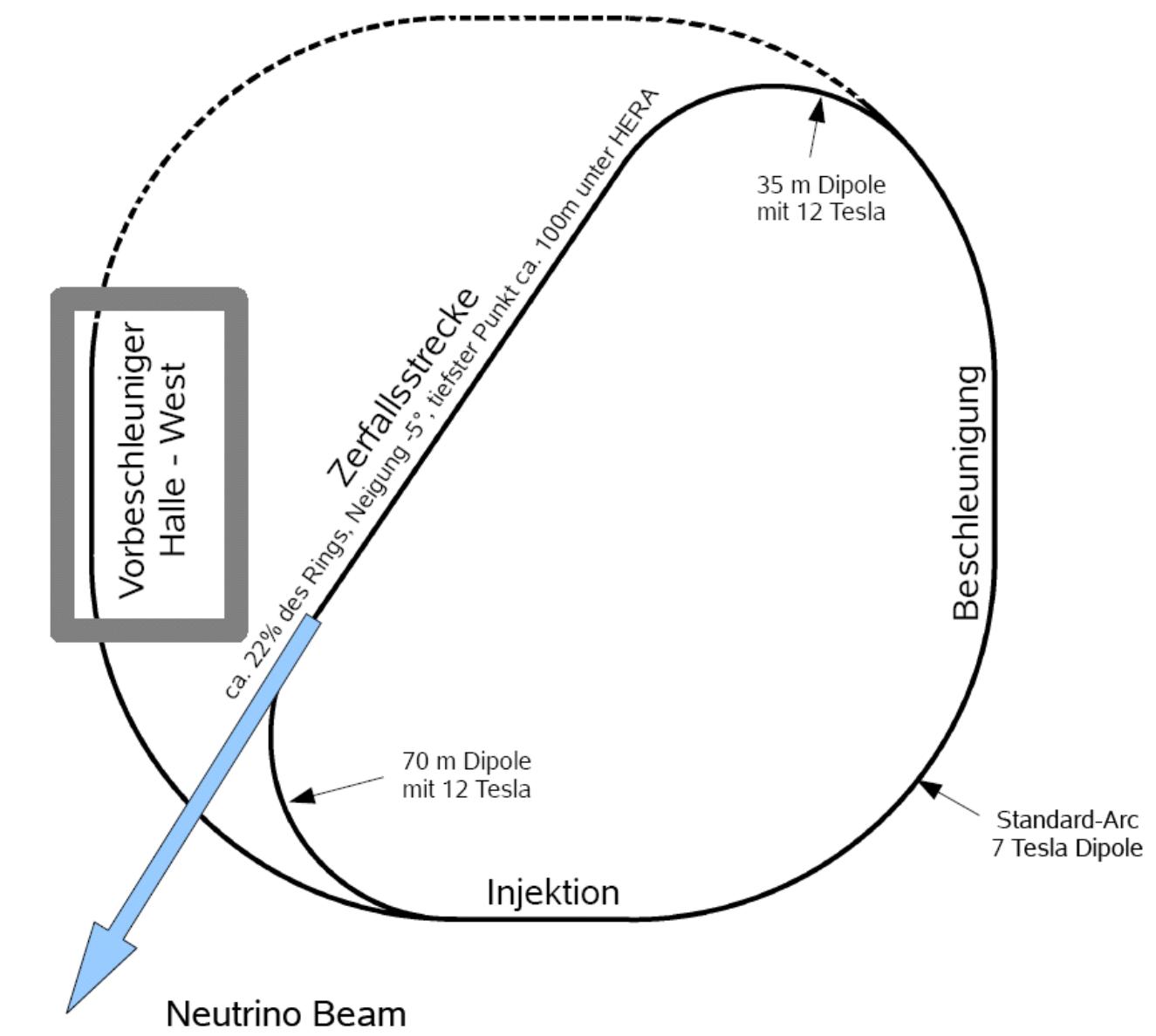


use HERA tunnel
dipoles unsuited for
decay ring
e- and p-Ring as
pre-accelerator

- cryo plant
- power supplies
- vacuum equipment
- ...

Conceptional Layout

New ring in the HERA tunnel
for final acceleration
and as decay ring

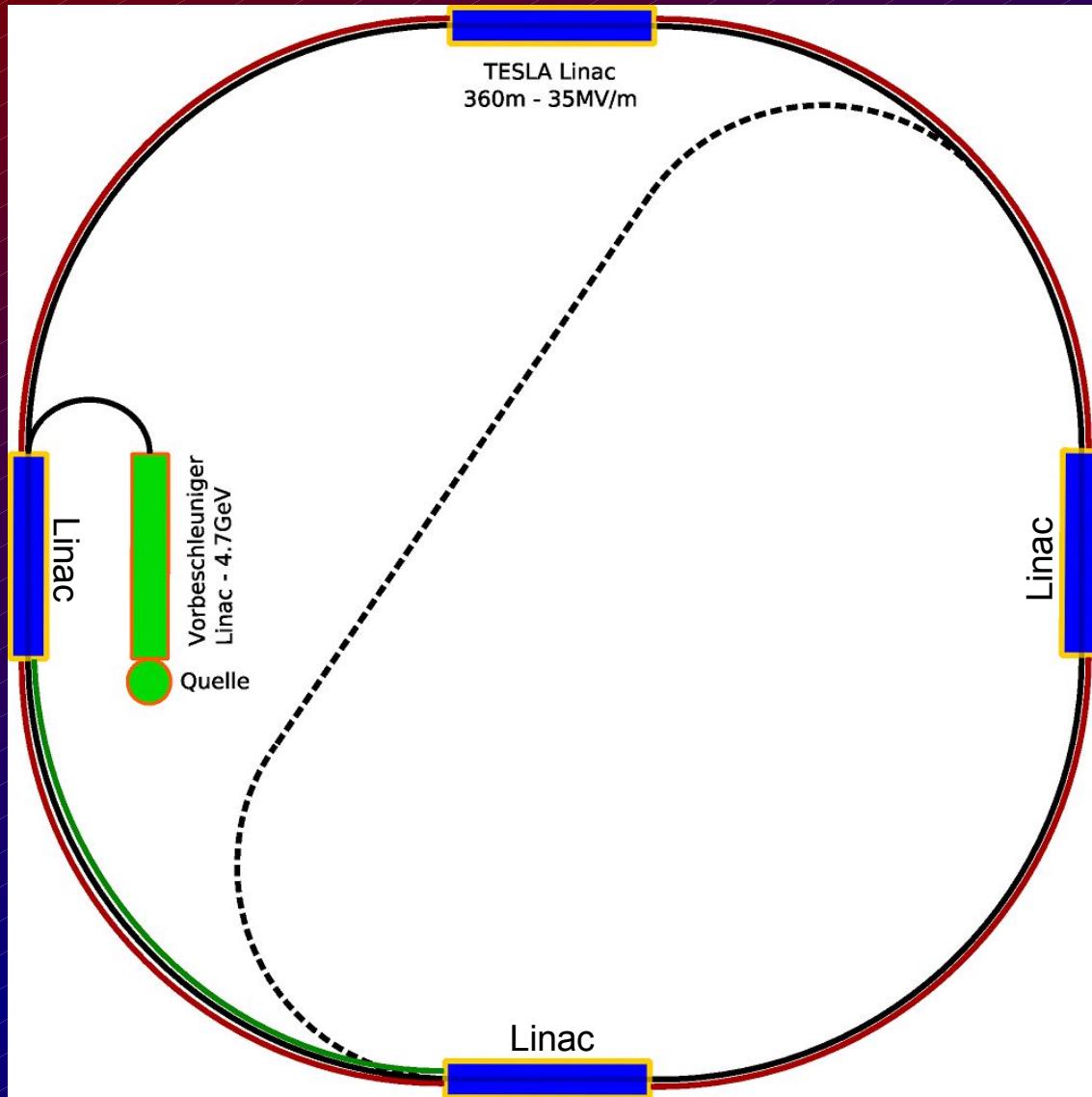


HERA rebuild as RCL
with TESLA cavities

4.7 GeV
preacceleration
(new)

ion source (new)

HERA as Recycling Linac



$2 \frac{1}{4}$ turns
 $2 \frac{1}{4}$

Energy gain per section:
360m x 35 MeV/m + 12 GeV

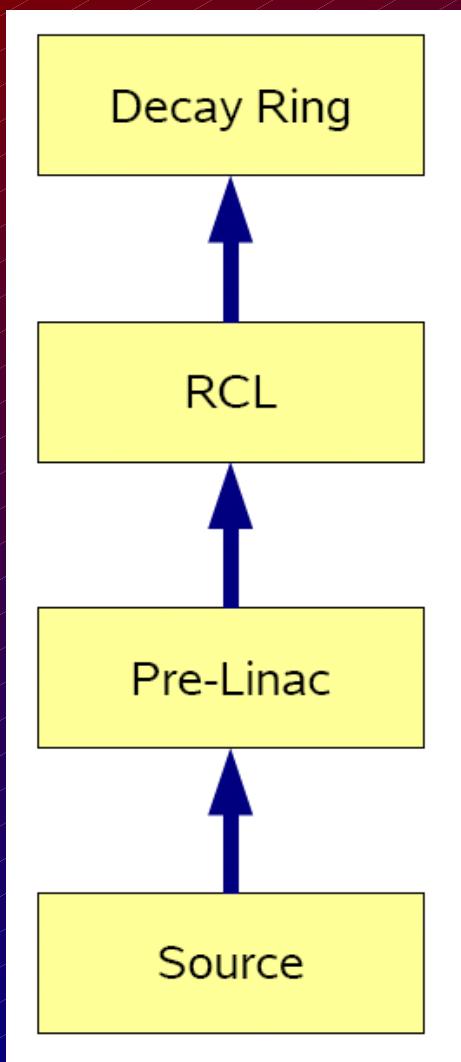
Inject @ $\beta = 0.8$ (4.7 GeV)

Transfer to decay ring
@ 110 GeV

Ramp decay ring to 1.4 TeV
at 0.5 T per second

$$\rightarrow \gamma = 500$$

Conceptual Design: Intensities & Time Structure



Work in cycles:

Production of ions:	1 sec
Preacceleration:	50 μ sec
Ramp main ring:	20 sec
active decays:	400 sec
Decelerate + dump:	<u>20 sec</u>
total:	\sim 500 sec

\rightarrow < 20% loss
 \rightarrow \sim 22% in straight section

Intensities (100% effizieny !):

2.1 10^{10} Ionen pro Bunch
3100 m long bunch train
3500 bunched per train
1 train
2.7 10^{13} usefull v per cycle
5.8 10^{17} v per year

1.3 GHz (TESLA)
every 4th bucket filled

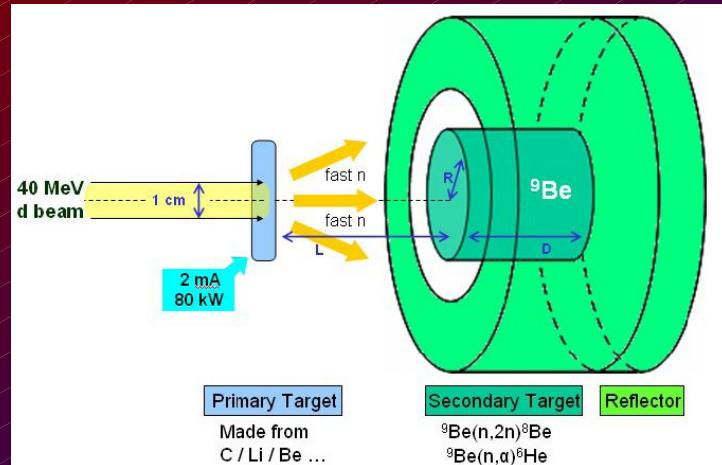
Source

$1.8 \cdot 10^{14}$ v per cycle
 10^{-3} to 10^{-4} ^6He per ^2H
2 mA DC for \sim 10 msec

Ion Source

Copy of EURISOL @ DESY much too expensive

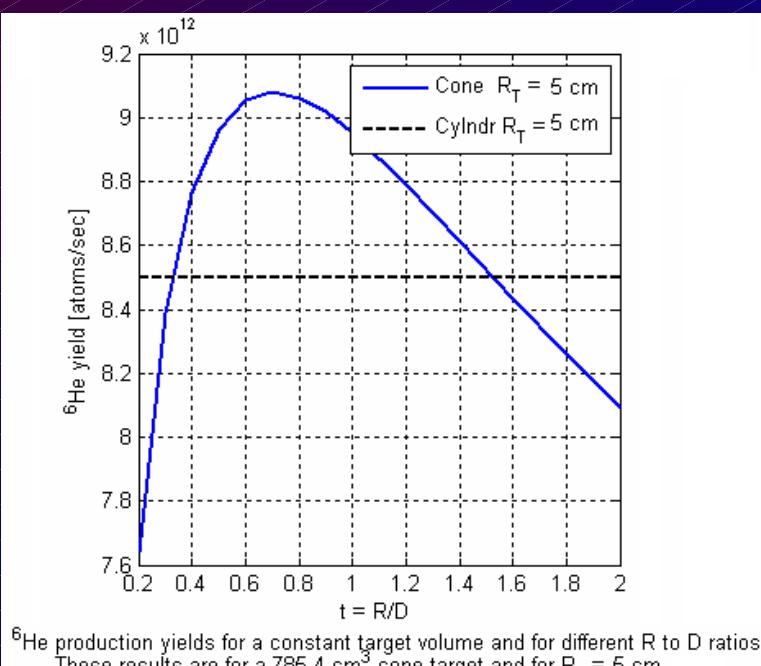
Idea from T. Hirsch/M. Hass Weizmann



Ionisation
LPSC Grenoble

Bunching

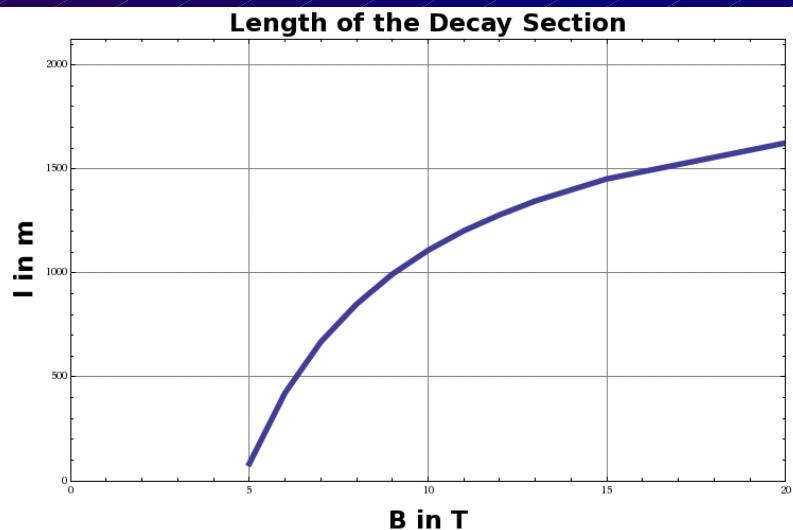
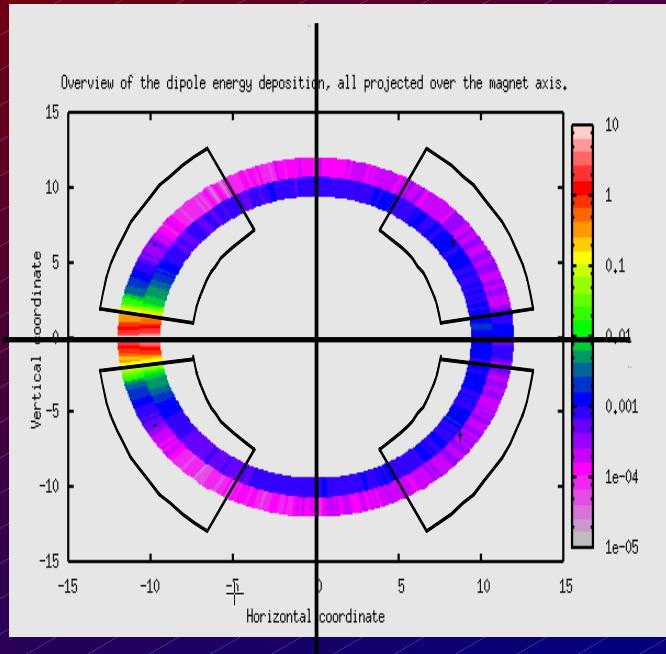
Linac



^{6}He production yields for a constant target volume and for different R to D ratios
These results are for a 785.4 cm^3 cone target and for $R_T = 5\text{ cm}$



Dipole Magnets



Open Midplane Magnets

Manageable (7 T operational) with Nb -Ti at 1.9 K

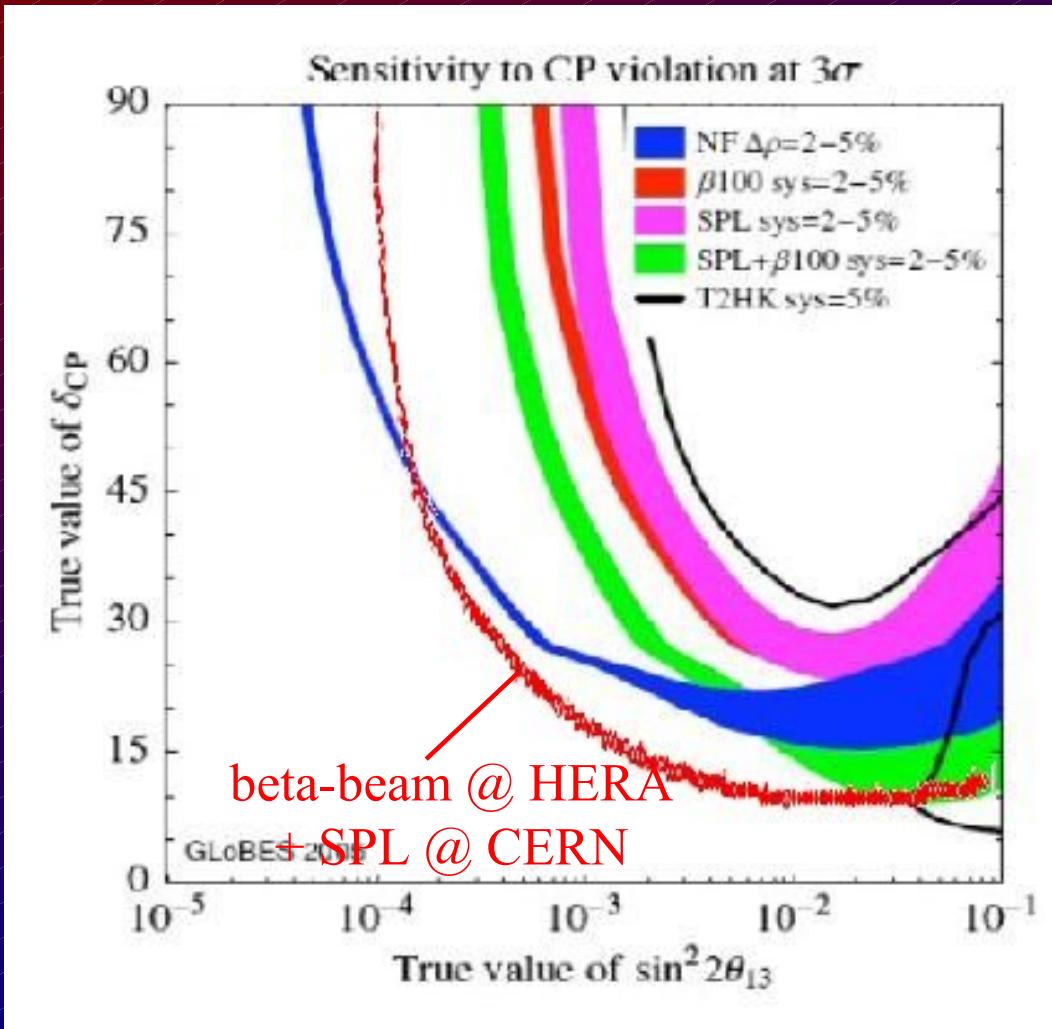
Aluminum spacers possible on midplane to retain forces: gives transparency to the decay products

Special cooling and radiation dumps may be needed inside yoke.

Need higher fields ~ 12 T

profit from D-LHC R&D on NbSn super conductor

Physics Reach: CP-Violation



Globes simulation shows statistical power to discover CP-violation as good as v -factory (no systematics studied, yet)

precision measurement of θ_{13}

determination of mass hierarchy

Conclusion

BetaBeams are an interesting alternative to a NuFactory
(Not as well studied as NuFactory)

CERN (SPL) - Fréjus (detector) - DESY (BetaBeam)
would fullfil the physics requirements

BetaBeam in the HERA tunnel might be feasable with minimum effort
No real studies done, yet

Major technical issues:

- ion source
- dipole magnets
- RF for RCL

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Thanks

