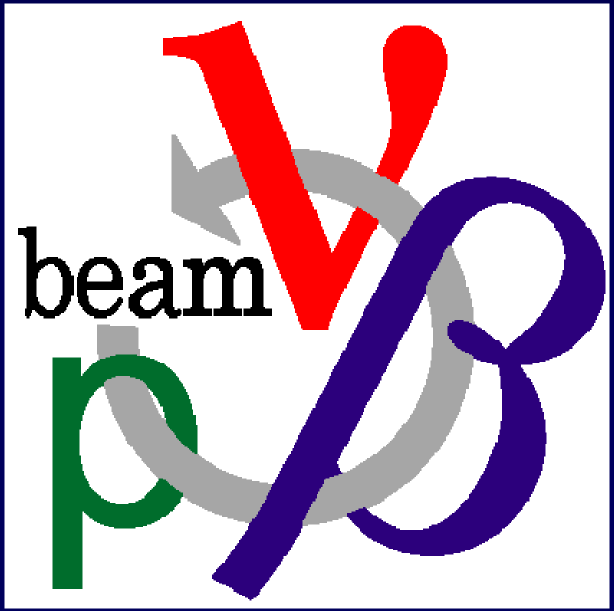
Beta-Beams



Accelerator Seminar --- DESY

Elena Wildner - CERN
Achim Stahl - RWTH Aachen

13.Jan.09

Outline

Part I: A European Neutrino Program
Scientific Motivation
- Achim Stahl -

Part II: R&D for beta-beams
- Elena Wildner -

Part III: Beta-beams at DESY ?
- Achim Stahl -

Part I

Scientific Motivation

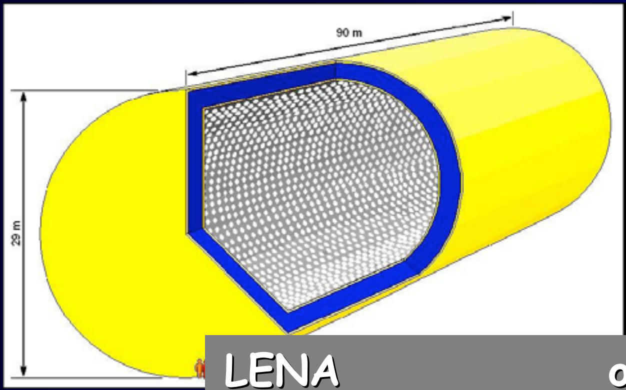
The Framework:
A European Neutrino Program

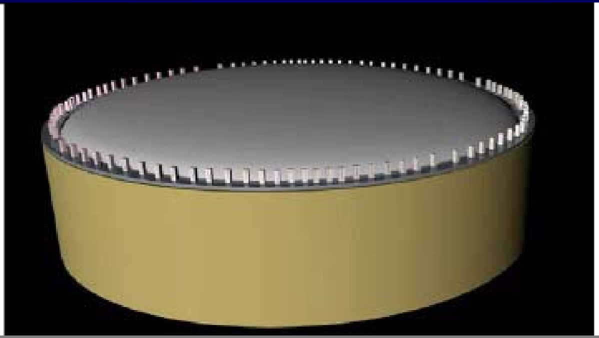
the core of the program is

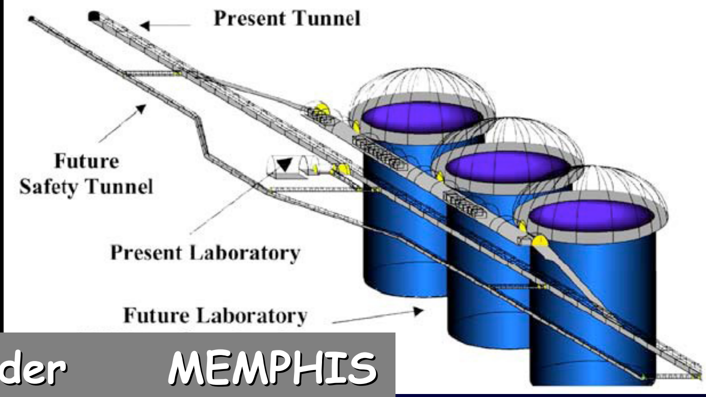
LAGUNA

Large Apparatus for Grand Unification and Neutrino Astrophysics

beta-beams are part of this program



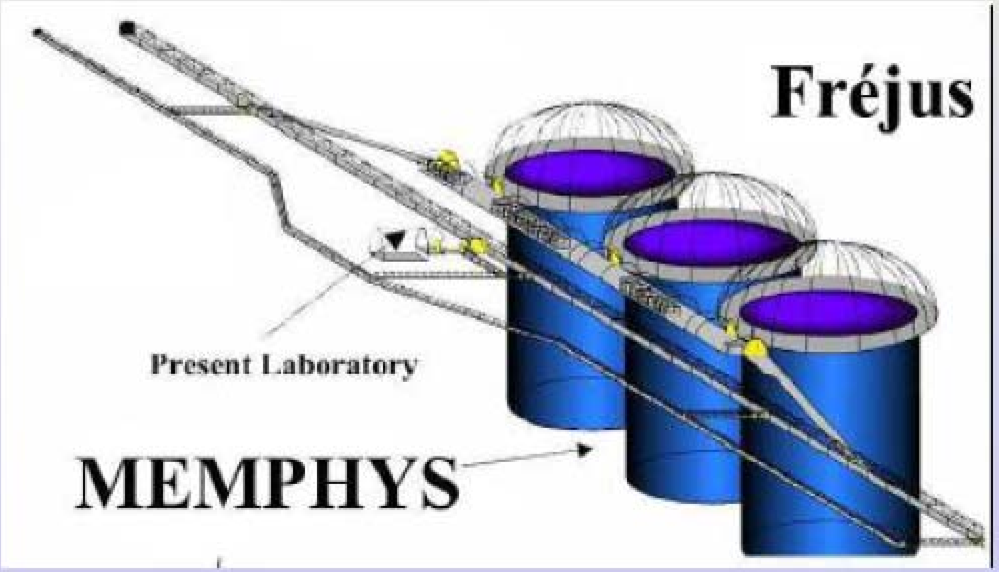




LENA oder **GLACIER** oder **MEMPHIS**

MEMPHYS - MEgaton Mass PHYSics

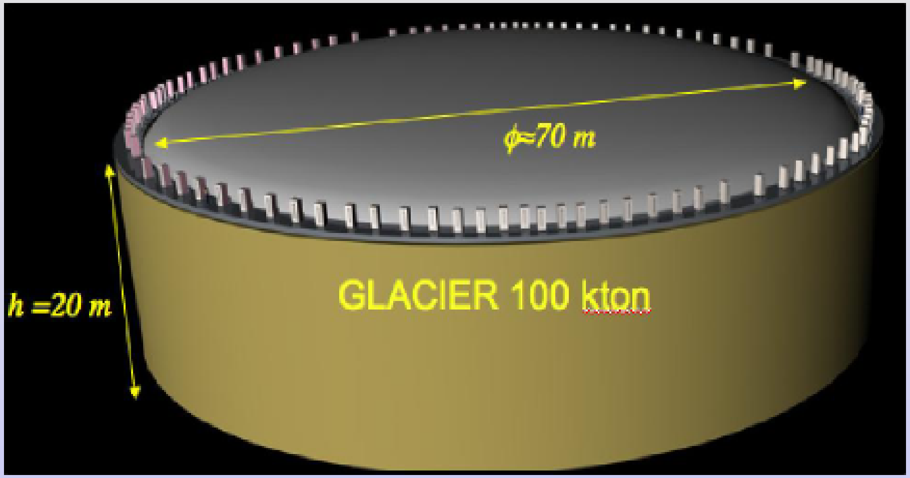
Detector scheme



- Size of each shaft
  - 80 m heigth
  - 65 m ∅
- Water Cherenkov Effect
  - ∼ 500 kton pure water
- Photomultipliers
  - 81 000 units per shaft
  - 30% coverage

GLACIER - Giant Liquid Argon Charge Imaging ExpeRiment

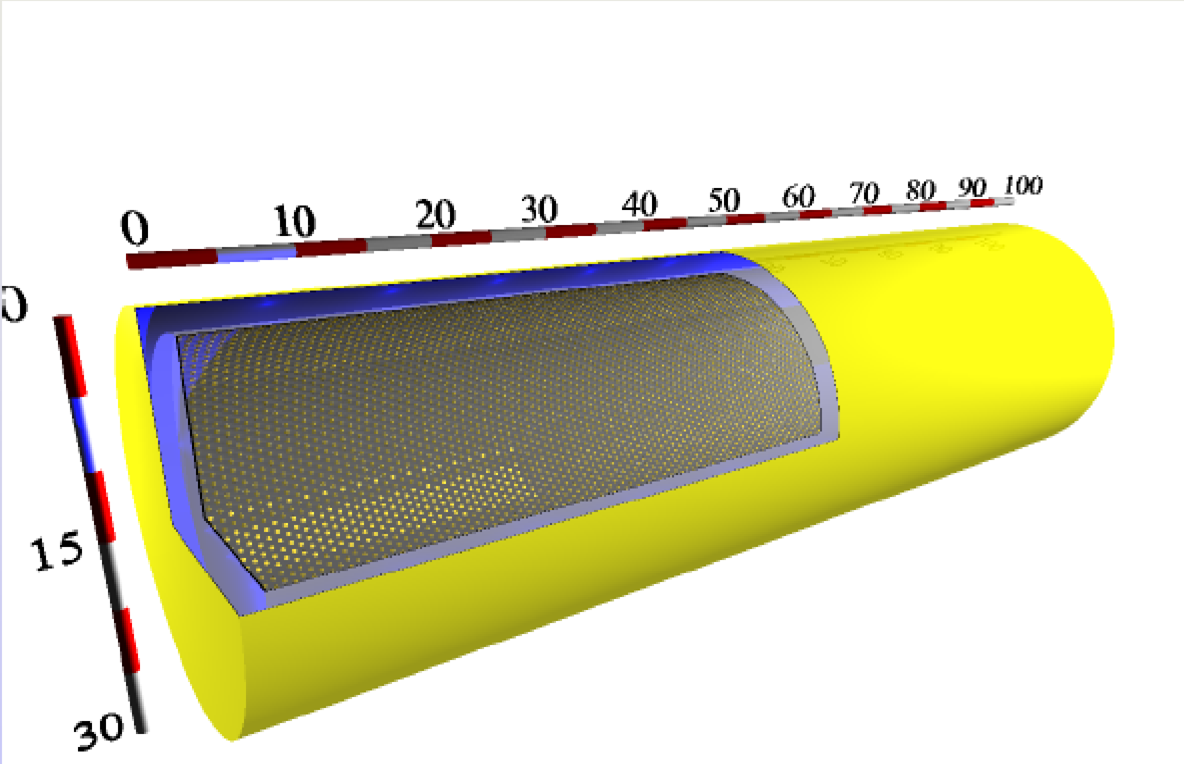
Detector scheme



- Size
  - 20 m heigth
  - 70 m ∅
- Liquid Argon TPC
  - $\sim$ 100 kton liquid argon
- Readout system
  - e^- drift: amplification with LEMs in the gas phase
  - Cherenkov Light: 27 000 PM 20% coverage
  - Scintillation Light: 1 000 PM

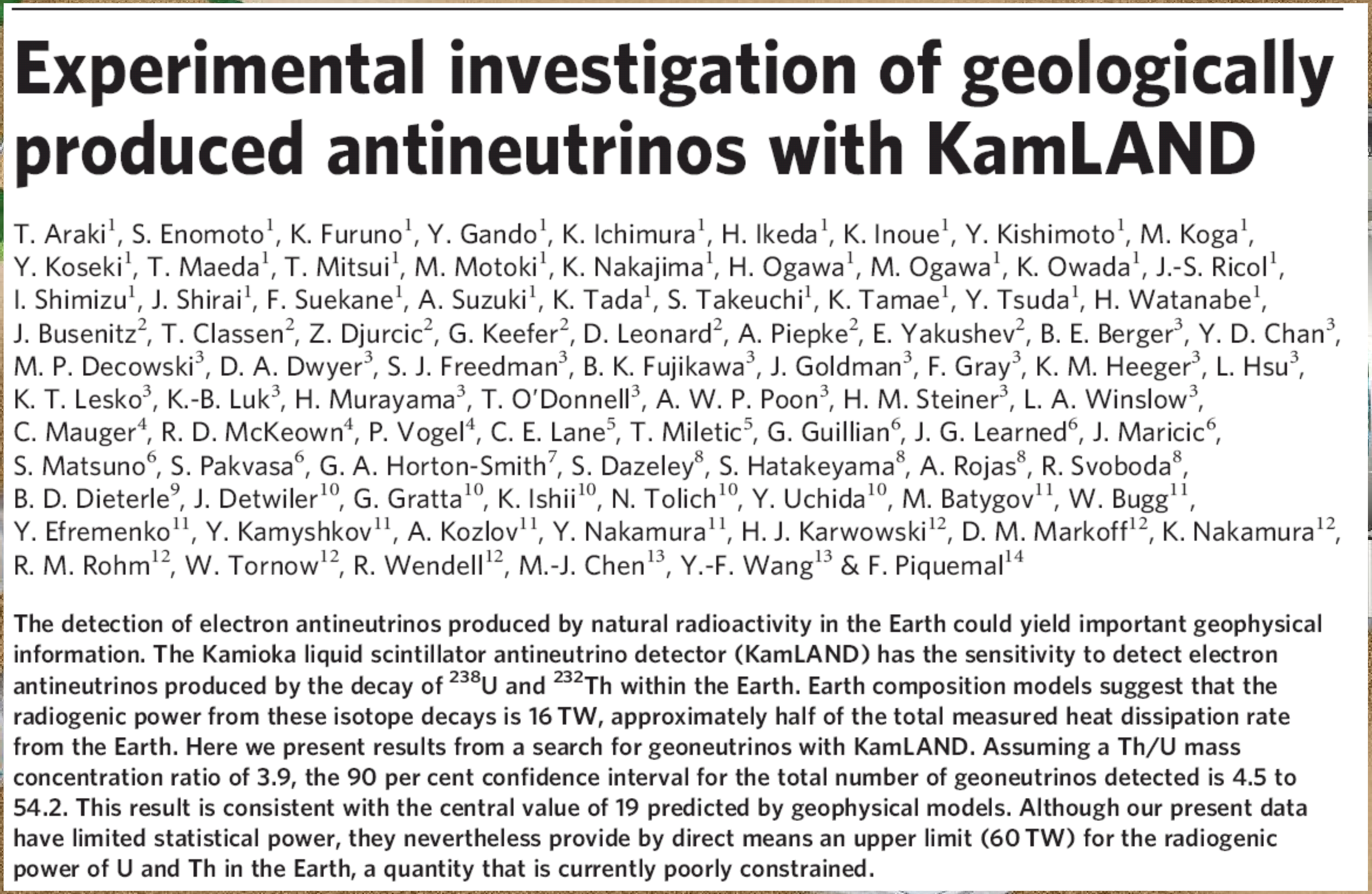
LENA - Low Energy Neutrino Astronomy

Detector scheme



- Size
  - 100 m length
  - 30 m ∅
- Liquid Scintillator
  - ~ 50 kton PXE
- Photomultipliers
  - 13 500 units
  - 30% coverage
- Photoelectron yield
  - 110 pe/MeV

Scientific Goals 1: GeoPhysics



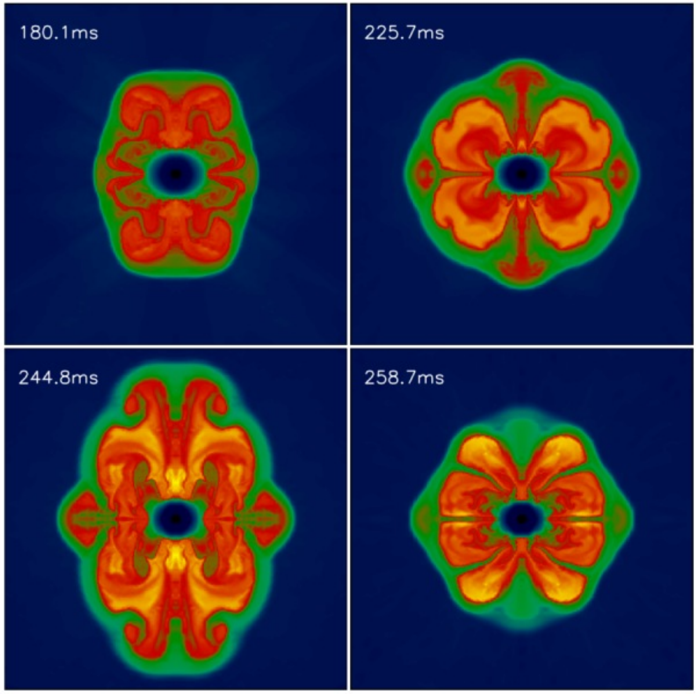
Experimental investigation of geologically produced antineutrinos with KamLAND

T. Araki[1], S. Enomoto[1], K. Furuno[1], Y. Gando[1], K. Ichimura[1], H. Ikeda[1], K. Inoue[1], Y. Kishimoto[1], M. Koga[1], Y. Koseki[1], T. Maeda[1], T. Mitsui[1], M. Motoki[1], K. Nakajima[1], H. Ogawa[1], M. Ogawa[1], K. Owada[1], J.-S. Ricol[1], I. Shimizu[1], J. Shirai[1], F. Suekane[1], A. Suzuki[1], K. Tada[1], S. Takeuchi[1], K. Tamae[1], Y. Tsuda[1], H. Watanabe[1], J. Busenitz[2], T. Classen[2], Z. Djurcic[2], G. Keefer[2], D. Leonard[2], A. Piepke[2], E. Yakushev[2], B. E. Berger[3], Y. D. Chan[3], M. P. Decowski[3], D. A. Dwyer[3], S. J. Freedman[3], B. K. Fujikawa[3], J. Goldman[3], F. Gray[3], K. M. Heeger[3], L. Hsu[3], K. T. Lesko[3], K.-B. Luk[3], H. Murayama[3], T. O'Donnell[3], A. W. P. Poon[3], H. M. Steiner[3], L. A. Winslow[3], C. Mauger[4], R. D. McKeown[4], P. Vogel[4], C. E. Lane[5], T. Miletic[5], G. Guillian[6], J. G. Learned[6], J. Maricic[6], S. Matsuno[6], S. Pakvasa[6], G. A. Horton-Smith[7], S. Dazeley[8], S. Hatakeyama[8], A. Rojas[8], R. Svoboda[8], B. D. Dieterle[9], J. Detwiler[10], G. Gratta[10], K. Ishii[10], N. Tolich[10], Y. Uchida[10], M. Batygov[11], W. Bugg[11], Y. Efremenko[11], Y. Kamyshkov[11], A. Kozlov[11], Y. Nakamura[11], H. J. Karwowski[12], D. M. Markoff[12], K. Nakamura[12], R. M. Rohm[12], W. Tornow[12], R. Wendell[12], M.-J. Chen[13], Y.-F. Wang[13] & F. Piquemal[14]

The detection of electron antineutrinos produced by natural radioactivity in the Earth could yield important geophysical information. The Kamioka liquid scintillator antineutrino detector (KamLAND) has the sensitivity to detect electron antineutrinos produced by the decay of ^{238}U and ^{232}Th within the Earth. Earth composition models suggest that the radiogenic power from these isotope decays is 16 TW, approximately half of the total measured heat dissipation rate from the Earth. Here we present results from a search for geoneutrinos with KamLAND. Assuming a Th/U mass concentration ratio of 3.9, the 90 per cent confidence interval for the total number of geoneutrinos detected is 4.5 to 54.2. This result is consistent with the central value of 19 predicted by geophysical models. Although our present data have limited statistical power, they nevertheless provide by direct means an upper limit (60 TW) for the radiogenic power of U and Th in the Earth, a quantity that is currently poorly constrained.

Scientific Goals 2: Super Novae

Observation & Simulation



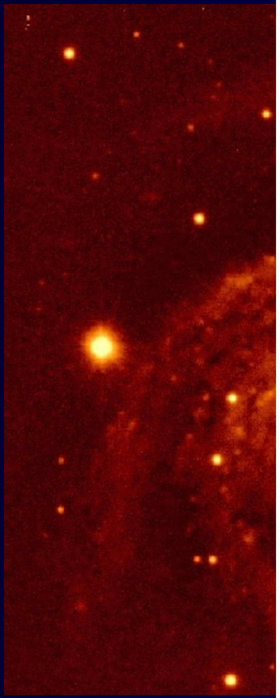
Today: 1 observed (SN1987a)
Expect: several 100 per year

Understand neutrino cooling
through cross section measurement

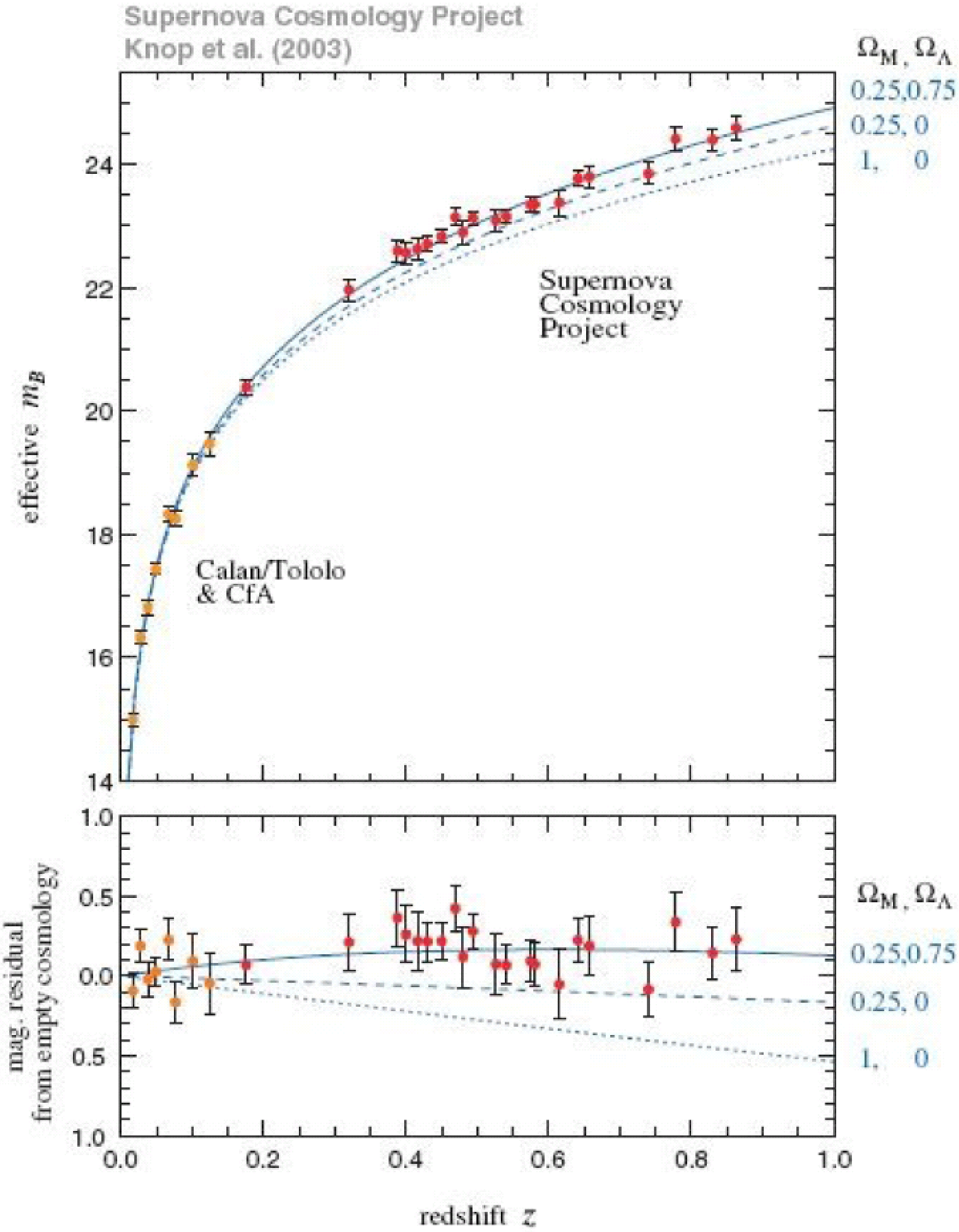
Super Nova explosions are one of our best sources of information on the development of the universe: Understand them better!

Scien ae

Obs



Observation of dark energy



Today: 1 g

Expect: s ment

Super N on

the deve

Scientific Goals 3: Nuclear Physics

Structure of Nucleus

super-allowed Fermi-transistions (V_{ud})

Gamow-Teller transitions, 2nd Class Currents

Excitation of higher multipoles, axial-vector-cur.

low energy beta-beam

$\gamma = 5 \ldots 14$ / $E_\nu = 10 \ldots 100$ MeV

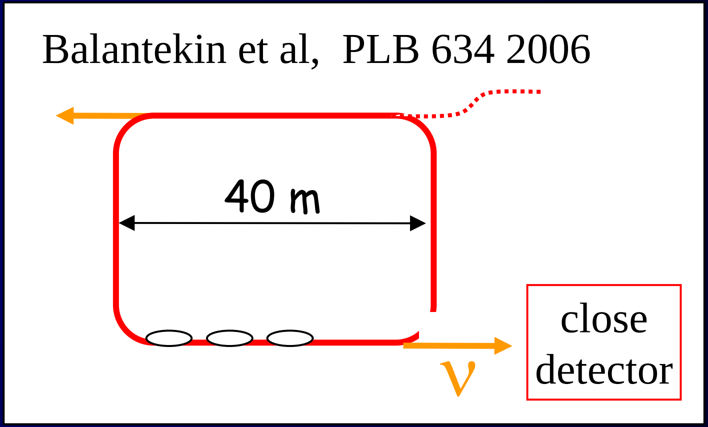
Cross Section Measurements

Xsec for neutrino-detectors

neutrino cooling in core-collapse Super Novae

breeding of heavy elements in Super Novae

prediction in neutrinoless 2-β-decay



Balantekin et al, PLB 634 2006

dedicated storage ring

parasitic use of the ion source

approx. 500 m circumference

Weak Interactions

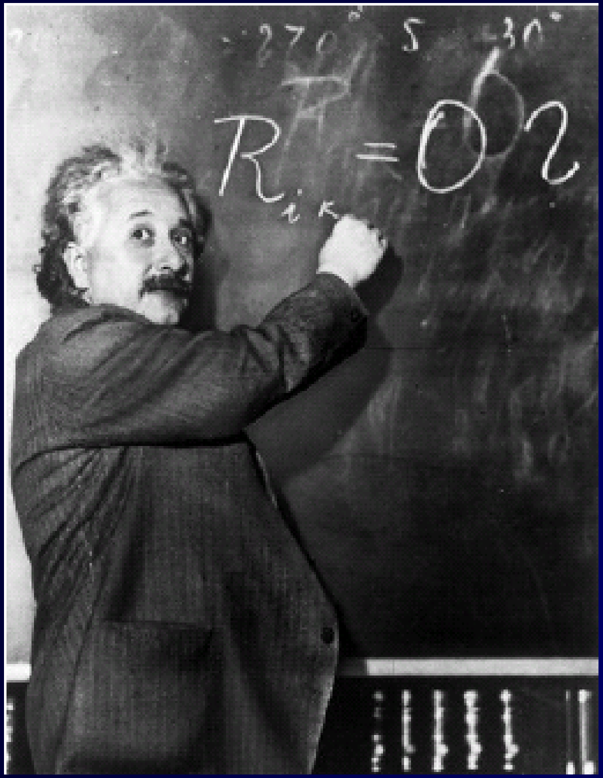
Weinbergangle at low Q^2 (running)

CVC tests

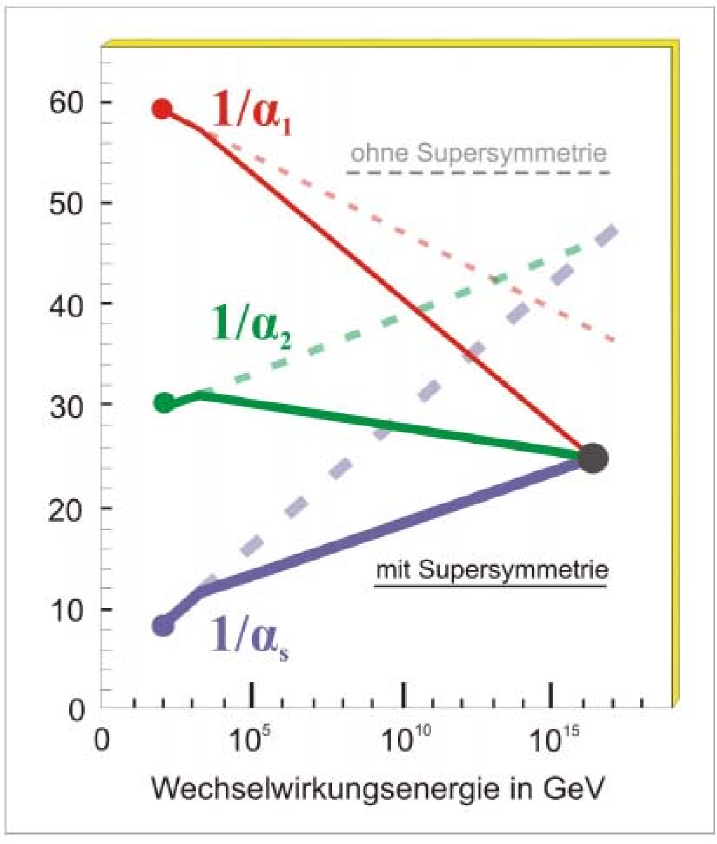
The magnetic moment of the neutrino

See Christina Volpe, Beta-beams, hep-ph/0605033v2, Nov. 2006 and references

Scientific Goals 4: Proton Decay

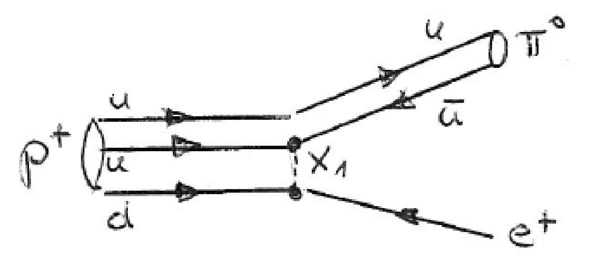


Einstein's dream of the
‚Weltformel'
Grand Unified Theories



Probably the only experimental chances:

1. Proton Decay
2. Magnetic Monopoles



Scientific Goal: Neutrino-Oscillations

Solar Neutrinos

electron-neutrino disappearance

$$\Delta m^2_{21} = \Delta m^2_{\mathrm{sol}} = 8.0^{+0.6}_{-0.4} \cdot 10^{-5}\mathrm{eV}^2$$

$$\theta_{12} = \theta_{\mathrm{sol}} = 33.9^{\circ}{}^{+2.4^{\circ}}_{-2.2^{\circ}}$$

Atmospheric Neutrinos

myon-neutrino disappearance

$$\Delta m^2_{32} = \Delta m^2_{\mathrm{atm}} = 2.4^{+0.6}_{-0.5} \cdot 10^{-3}\mathrm{eV}^2$$

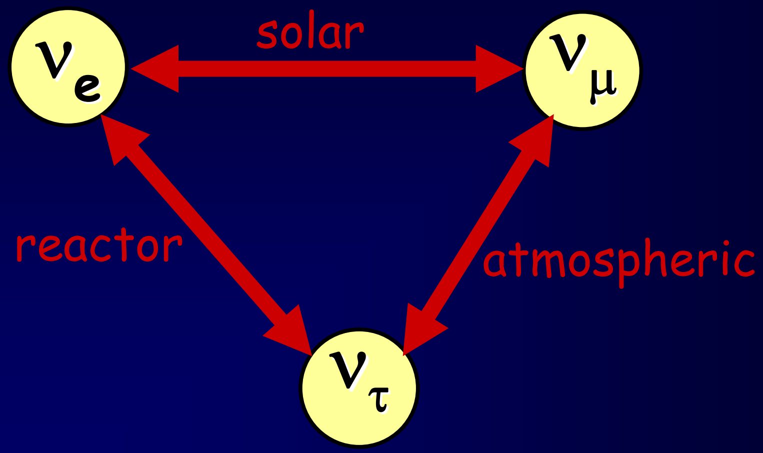
$$\theta_{23} = \theta_{\mathrm{atm}} = 45 \pm 7^{\circ}$$

Reactor Neutrinos

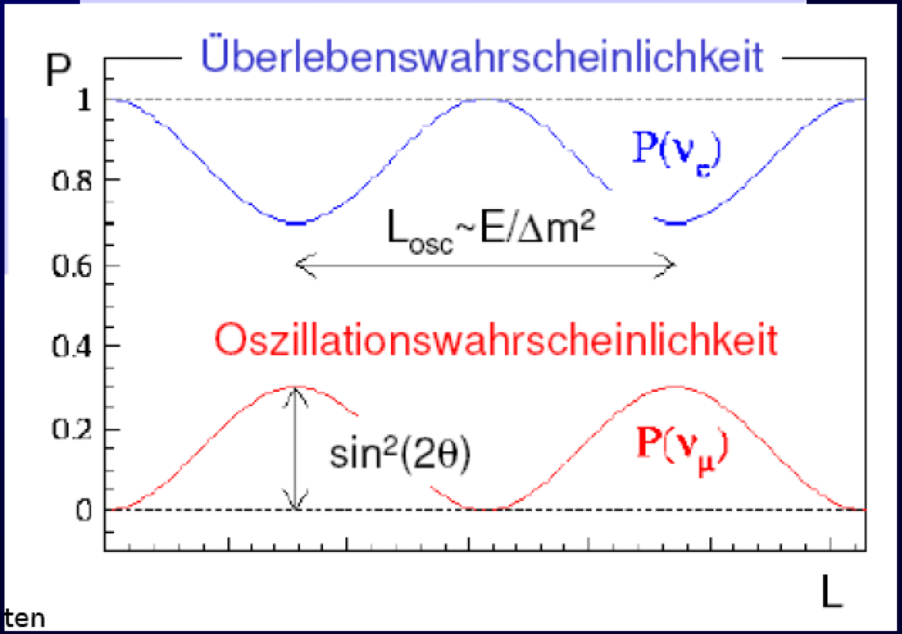
electron-neutrino disappearance
no signal

$$\theta_{13} < 13^{\circ}$$

systematic limited:
- neutrino flux from reactor
- Xsec for detection



$$P(\nu_\alpha \rightarrow \nu_\beta) = \sin^2(2\theta)\sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$



Scientific Goal: Neutrino-Oscillations

Solare Neutrinos

Elektron-Neutrino Disappearance

$$\Delta m^2_{21} = \Delta m^2_{\mathrm{sol}} = 8.0^{+0.6}_{-0.4} \cdot 10^{-5}\mathrm{eV}^2$$

$$\theta_{12} = \theta_{\mathrm{sol}} = 33.9^{\circ}{}^{+2.4^{\circ}}_{-2.2^{\circ}}$$

Atmosphärische Neutrinos

Müon-Neutrino Disappearance

$$\Delta m^2_{32} = \Delta m^2_{\mathrm{atm}} = 2.4^{+0.6}_{-0.5} \cdot 10^{-3}\mathrm{eV}^2$$

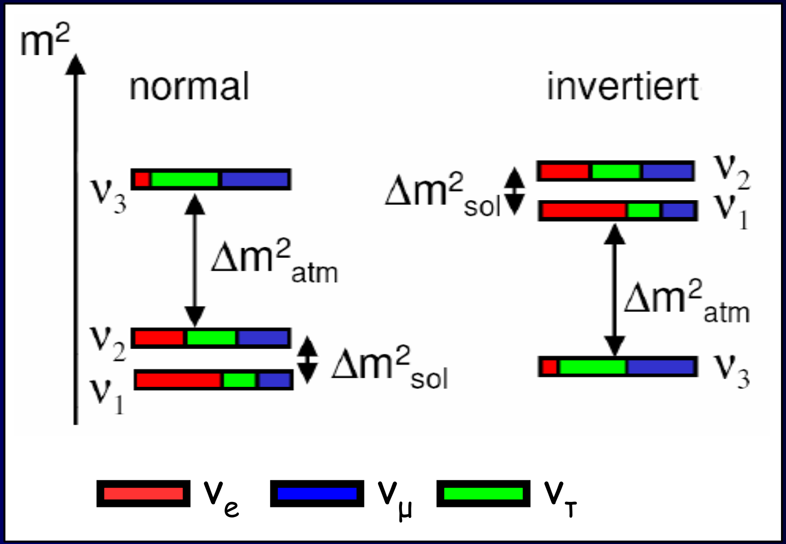
$$\theta_{23} = \theta_{\mathrm{atm}} = 45 \pm 7^{\circ}$$

Reaktorneutrinos

Elektron-Neutrino Disappearance
kein Signal

$$\theta_{13} < 13^{\circ}$$

systematisch limitiert:
- Neutrinofluß vom Reaktor
- WQ für Nachweisreaktion



Open Questions:

How large is θ_{13}?

Precision measurements (θ_{23} maximal ?)

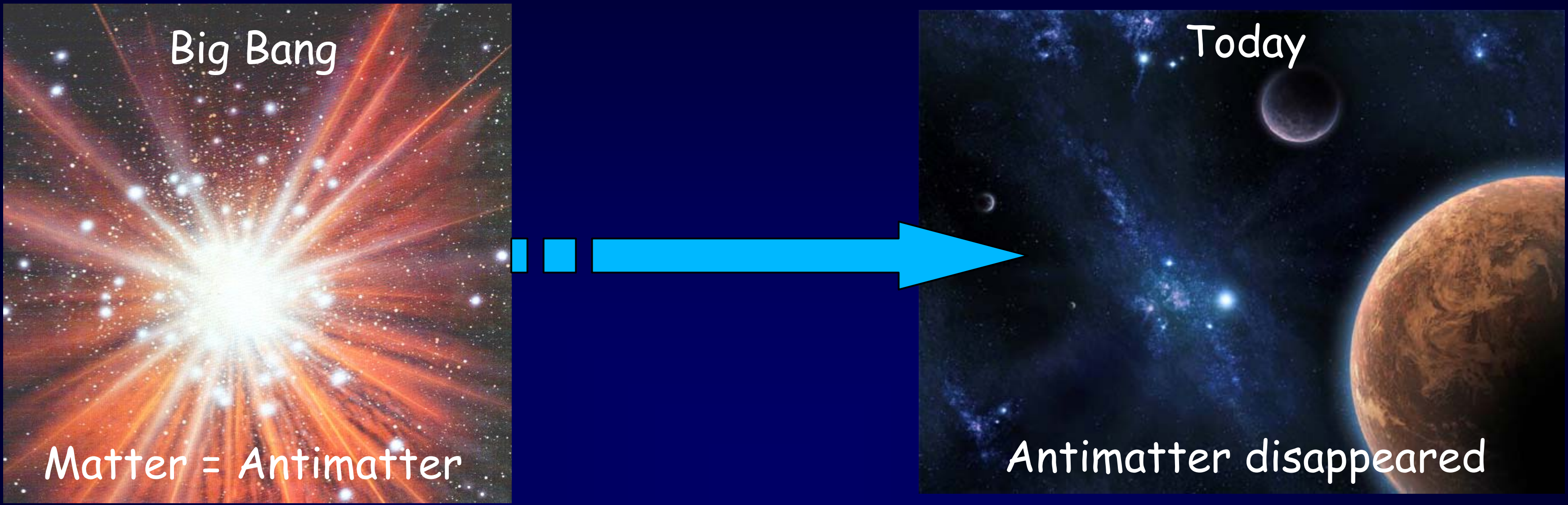
Absolute mass scale ?

Normal or inverted hierarchie ?

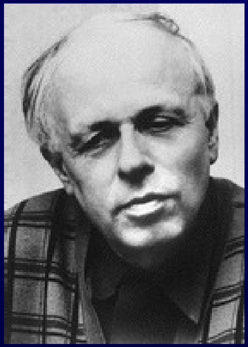
Majorana or Dirac-neutrinos ?

CP-violation ?

CP-Violation



Sakharov-Conditions



1.CP-Violation
2. Baryon-Number Violation
3. thermal non-equilibrium

Jarlskog's determinant

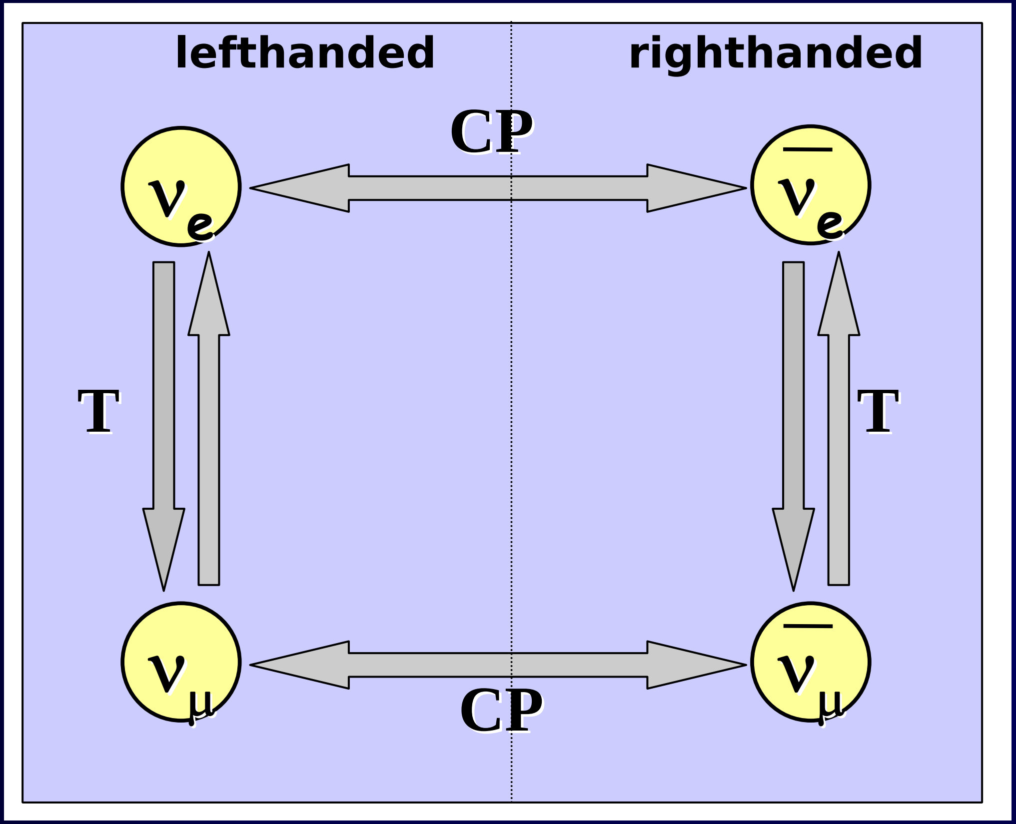
$$J = c_{12}s_{12}c_{23}s_{23}c_{13}^{2}s_{13}s_{\delta} = (1-s_{12}^{2})^{1/2}(1-s_{23}^{2})^{1/2}(1-s_{13}^{2})s_{12}s_{23}s_{13}s_{\delta}$$

Quarks: $4\ 10^{-5}$

Neutrinos: $0.028 \sin\delta$

CP-Violation

Testing the discrete symmetries with neutrinos



tau-neutrinos: no practical beam-source

Examples

CP-TEST:

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

T-TEST:

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

CPT-TEST:

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

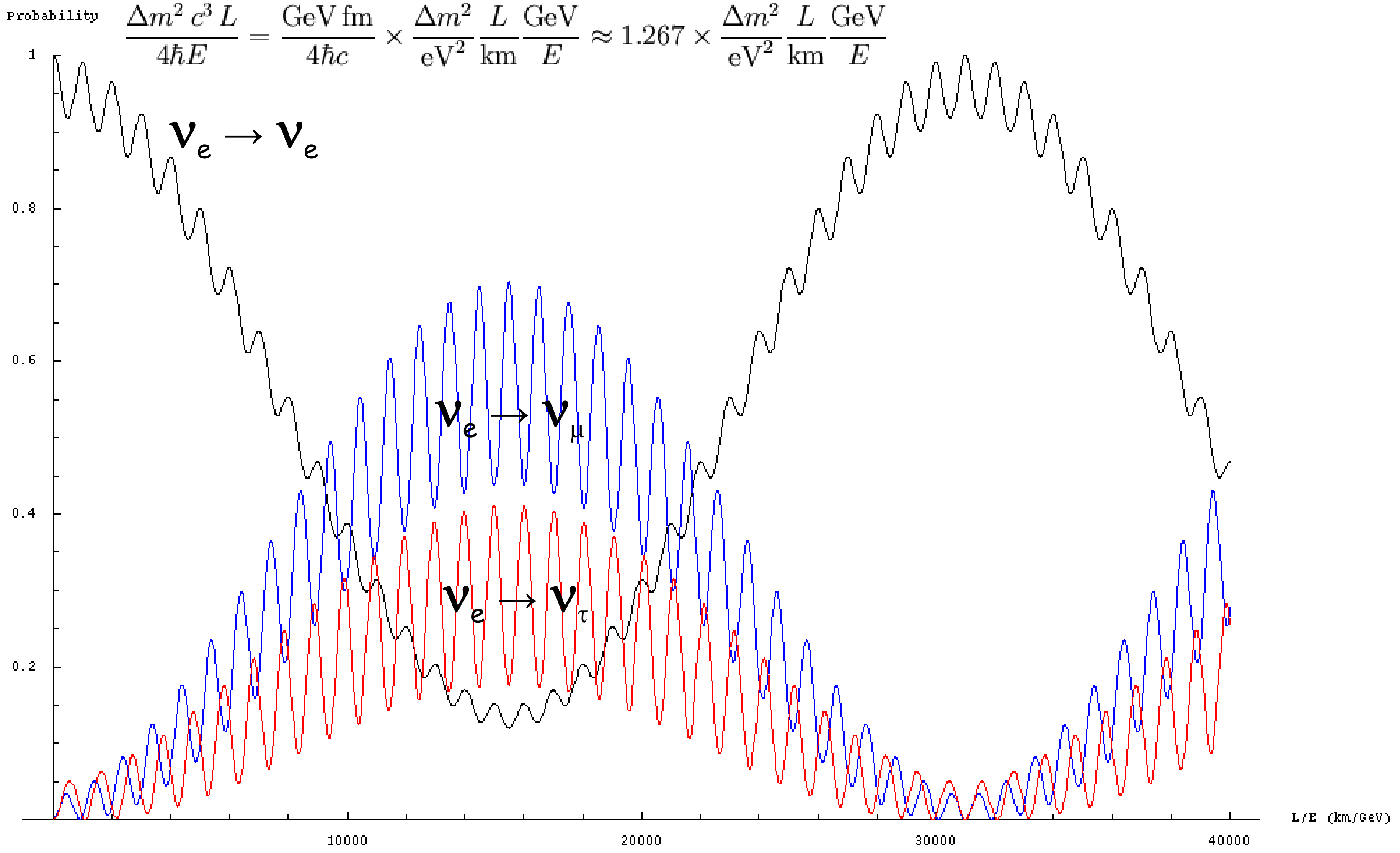
Vacuum-Oscillations

CP-violation is a genuin 3 generation effect

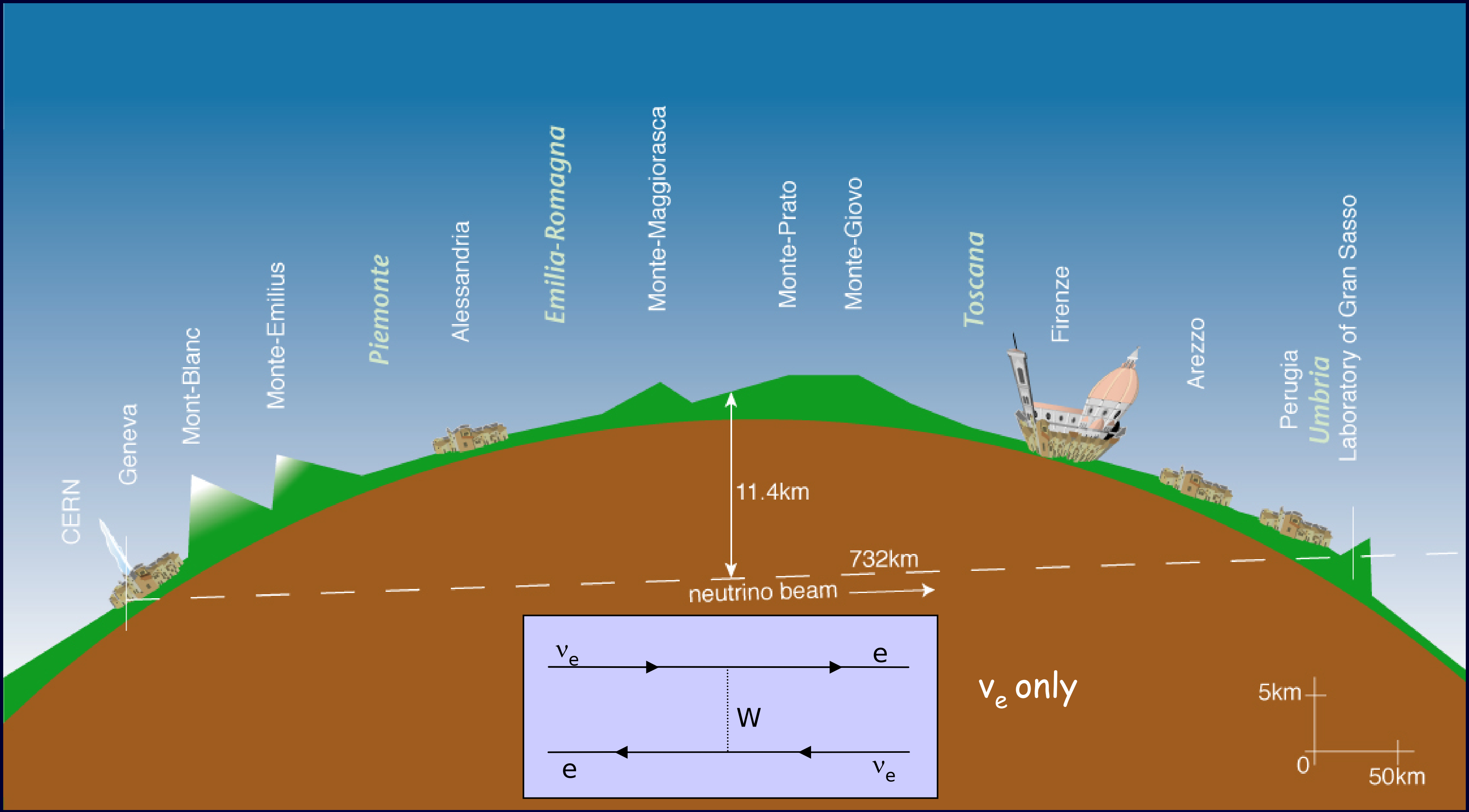
$$P_{\alpha\to\beta} = \delta_{\alpha\beta} - 4\sum_{i>j} Re(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j})\sin^2\left(\frac{\Delta m^2_{ij}L}{4E}\right) + 2\sum_{i>j} Im(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j})\sin\left(\frac{\Delta m^2_{ij}L}{2E}\right)$$

$$\Delta m^2_{ij} \equiv m^2_i - m^2_j$$

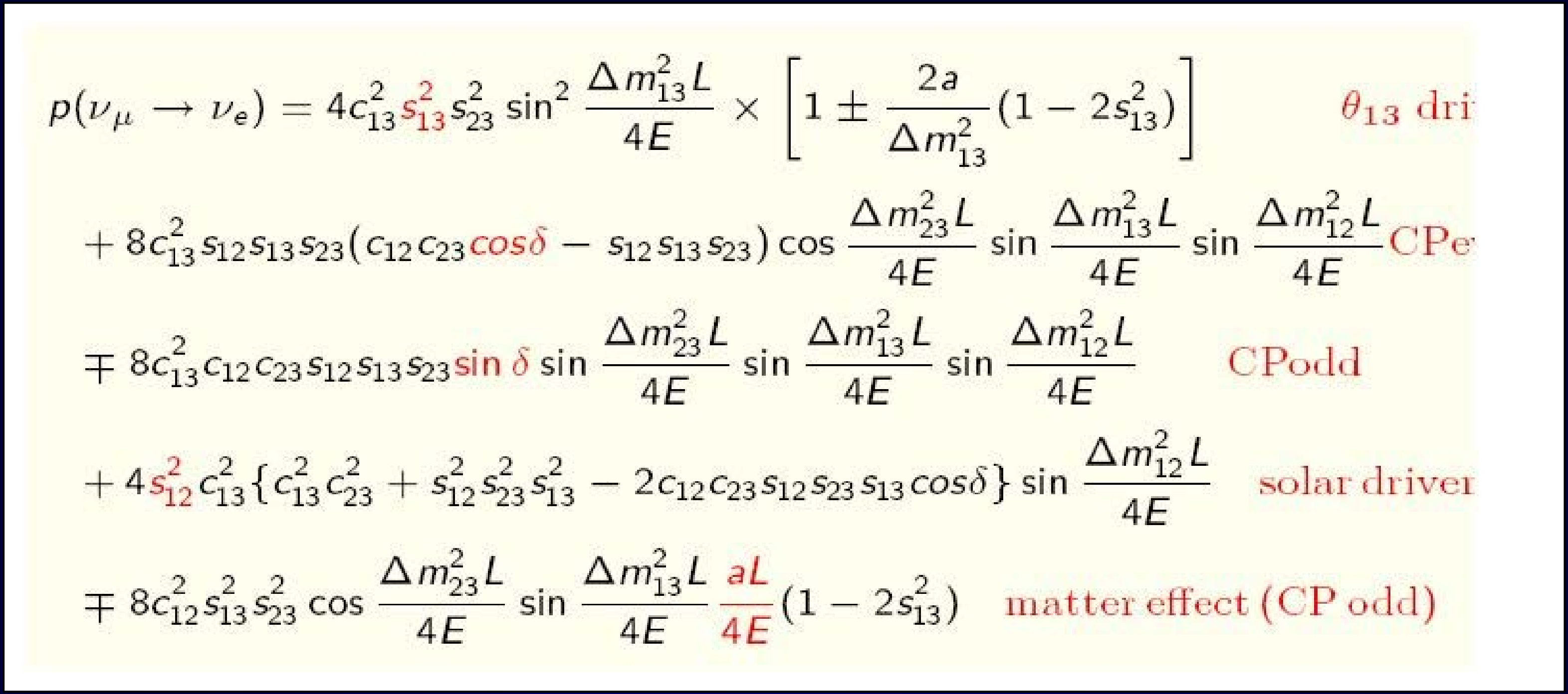
$$\frac{\Delta m^2\, c^3\, L}{4\hbar E} = \frac{\text{GeV fm}}{4\hbar c}\times\frac{\Delta m^2}{\text{eV}^2}\frac{L}{\text{km}}\frac{\text{GeV}}{E} \approx 1.267\times\frac{\Delta m^2}{\text{eV}^2}\frac{L}{\text{km}}\frac{\text{GeV}}{E}$$



Matter-Effect



Example: CERN-GranSasso (CNGS)



$$p(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2\frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1-2s_{13}^2)\right]$$

θ_{13} dri

$$+ 8c_{13}^2 s_{12}s_{13}s_{23}(c_{12}c_{23}\cos\delta - s_{12}s_{13}s_{23}) \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E}$$

CPe

$$\mp 8c_{13}^2 c_{12}c_{23}s_{12}s_{13}s_{23}\sin\delta \sin\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \sin\frac{\Delta m_{12}^2 L}{4E}$$

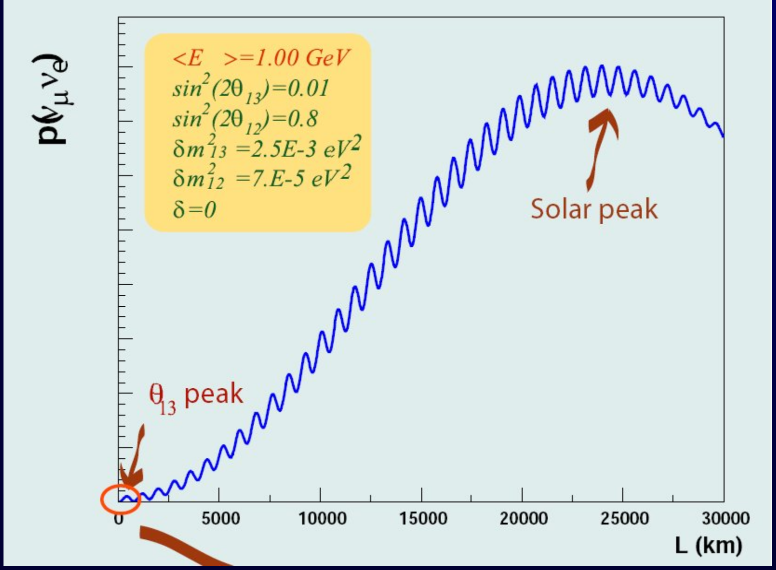
CPodd

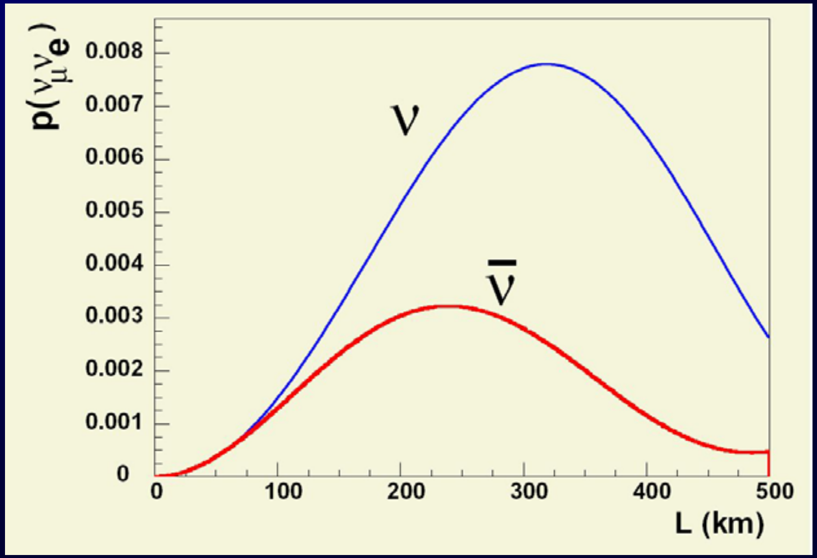
$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12}c_{23}s_{12}s_{23}s_{13}\cos\delta\} \sin\frac{\Delta m_{12}^2 L}{4E}$$

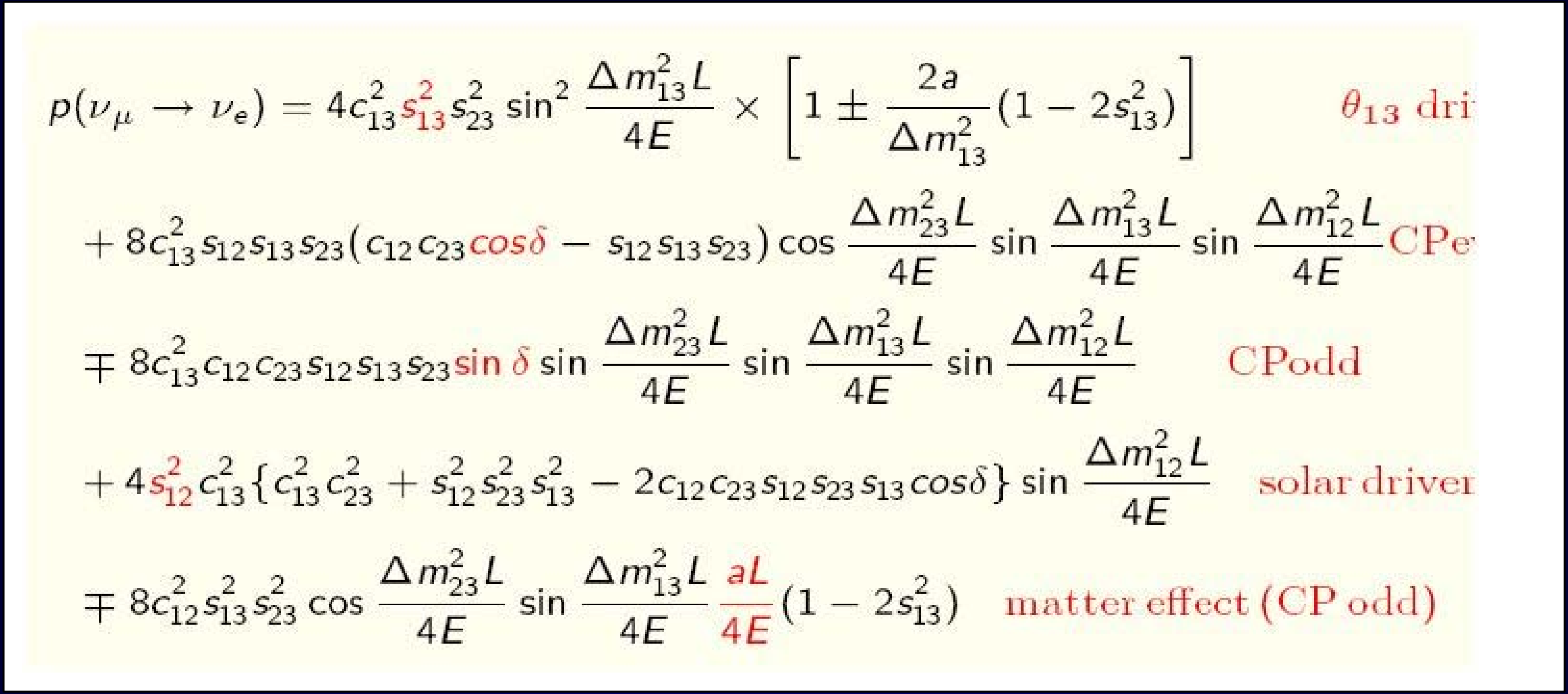
solar driver

$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos\frac{\Delta m_{23}^2 L}{4E} \sin\frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1-2s_{13}^2)$$

matter effect (CP odd)







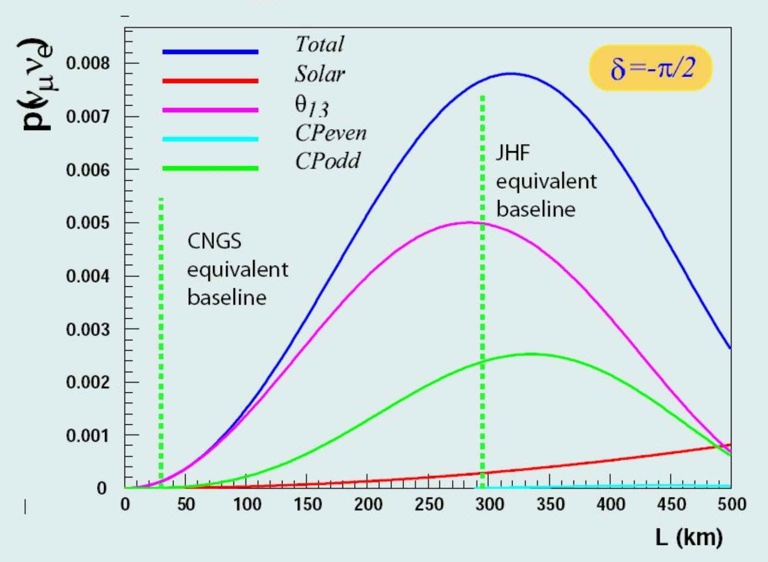
$$p(\nu_\mu \rightarrow \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \times \left[1 \pm \frac{2a}{\Delta m_{13}^2}(1 - 2s_{13}^2)\right] \qquad \theta_{13} \text{ dri}$$

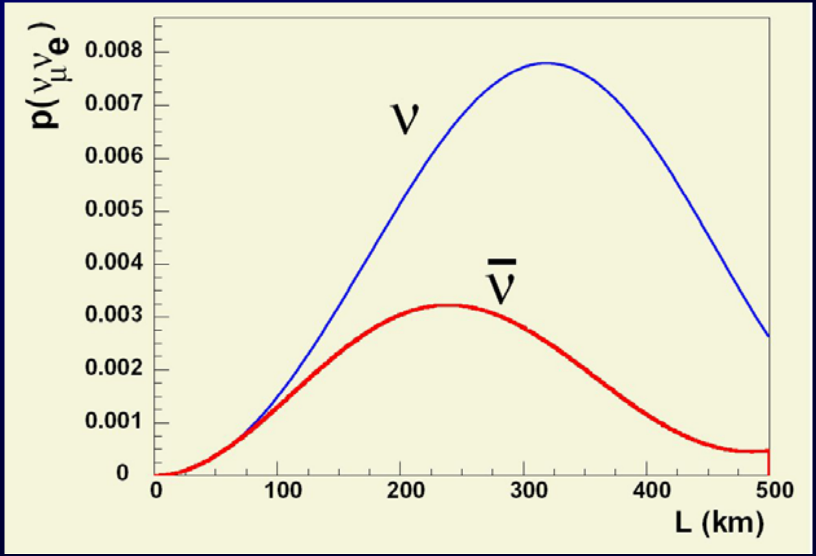
$$+ 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} \cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \text{CPe}$$

$$\mp 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \qquad \text{CPodd}$$

$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} \cos\delta\} \sin \frac{\Delta m_{12}^2 L}{4E} \qquad \text{solar driver}$$

$$\mp 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E}(1 - 2s_{13}^2) \qquad \text{matter effect (CP odd)}$$





Neutrino-Beams: Two Alternative Concepts

We need ν_e and ν_μ beam
with different baselines

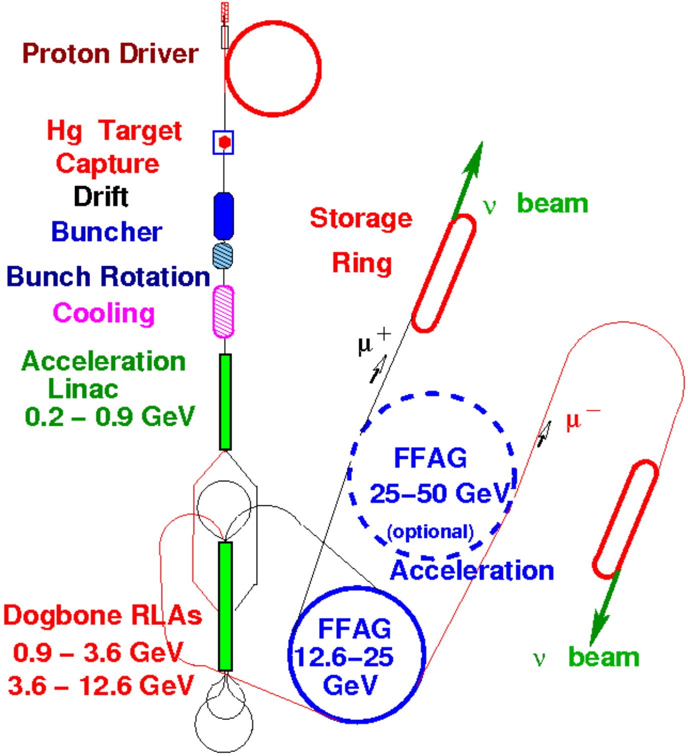
beta-beam

ν_e / $\bar{\nu}_e$ beam

&

conventional ν_μ beam

ν_μ / $\bar{\nu}_\mu$ beam

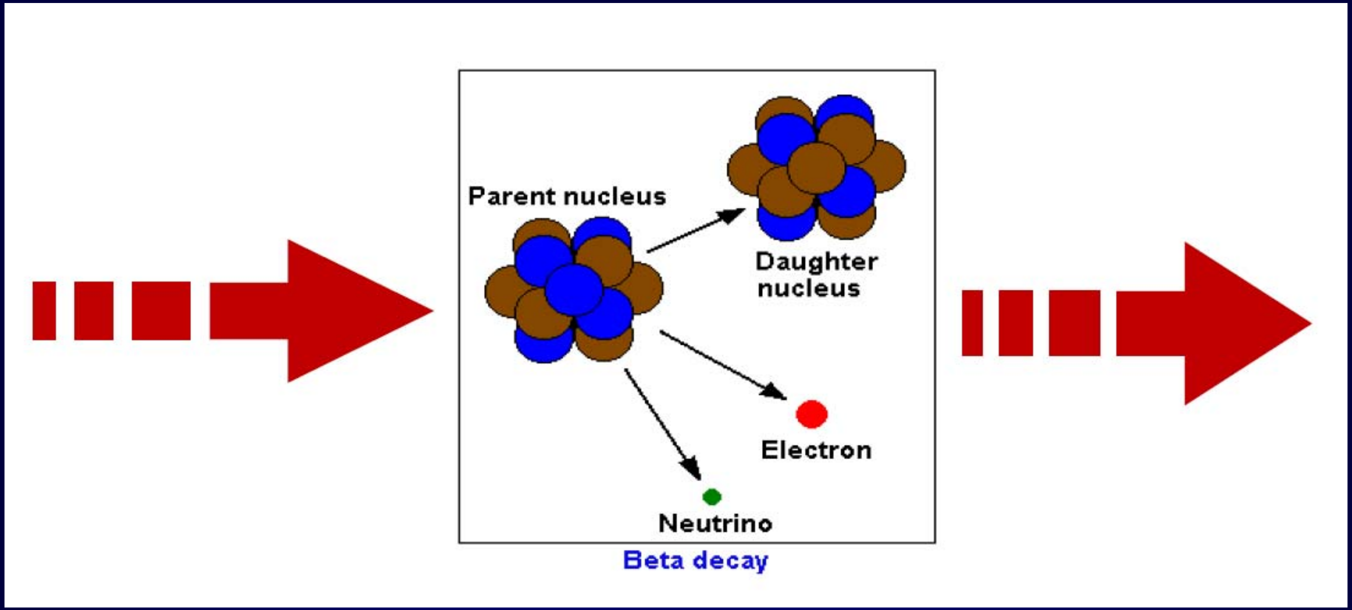


$\mu^+ \rightarrow e^+ \; \nu_e \, \bar{\nu}_\mu$ & $\mu^- \rightarrow e^- \; \bar{\nu}_e \, \nu_\mu$

magnetic detector for separation

New Idea: Beta-Beams

- Piero Zucchelli Phys.Lett. B532:166, 2002
- http://beta-beam.web.cern.ch/beta-beam



accelerate radioactive ions → beta-decay → neutrino beam

^{6}He

β^- emitter → anti-ν-beam

$^{6}He^{++} \rightarrow {}^{6}Li^{+++}\ \nu_e\ \overline{e}^-$

Lifetime: 0.8067 s
Q-Value: 3.5078 MeV
Ave. E_{υ}: 1.94 MeV

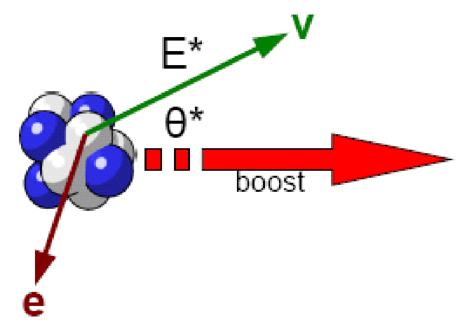
^{18}Ne

β^+ emitter → ν-beam

$^{18}Ne^{10+} \rightarrow {}^{18}F^{9+}\ \nu_e\ e^+$

Lifetime: 1.67 s
Q-Value: 3.4 MeV
Ave. E_{υ}: 1.86 MeV

Kinematics:



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

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

Event rate in your detector (fixed number of decays in the ring; detector at optimal baseline)

Dependance on γ

Opening angle ~ $1/\gamma$ → flux at fixed distance ~ γ^2
$E_{lab} \sim \gamma$ → optimal Baseline ~ γ → flux at detector ~ $1/\gamma^2$
$E_{lab} \sim \gamma$ → cross section ~ γ

~ γ

Dependance on E*

Opening angle independent of E*
$E_{lab} \sim E^*$ → optimal baseline ~ E* → flux at detector ~ $1/E^{*2}$
$E_{lab} \sim E^*$ → cross section ~ E*

~ $1/E^*$

Part II

R&D for Beta-Beams

R&D for beta-beams

Elena Wildner, CERN

Outline

- Options for Accelerators
- The EURISOL Beta Beam Scenario
- Ion Production
- Loss Management
- R&D

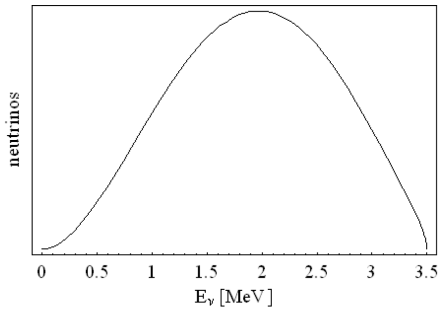
Outline

- Options for Accelerators
- The EURISOL Beta Beam Scenario
- Ion Production
- Loss Management
- R&D

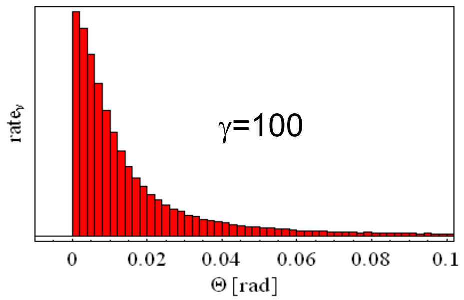
Crucial importance for physics

- Energy spectrum
- Flux
- Distance from production (neutrino oscillation)
- Neutrino and antineutrino pairs

Parameters for physics



- Energy spectrum
  - Reaction energy Q (a few MeV, ion dependent)
  - Relativistic boost factor γ
- Flux
  - Accelerator issues (apertures, intra beam scattering, space charge…)
  - Relativistic boost factor γ: forward focusing of neutrinos: $\theta \leq 1/\gamma$
  - Life-time of chosen ion
  - Decay losses in accelerator chain
  - Ion beam collimation



- Neutrino and anti-neutrino beams
  - Ion choice limited: life time, similar Q-value, β^+ & β^-, Z/A, chemistry…

Options

- Baselines, L (Distance from production to detector)
  - Short ≤ 300 km (Genuine CP asymmetry measurements)
  - Medium
  - Long ~ 7500 (Matter effects)
  - Magic (most optimal sensitivities for physics reach)
- Neutrino energy and angle (γ boost and Q value)
  - Sets optimal L and flux in detector
- Interacting ν_μ in detector
  - Merit factor M ~ γ / E_0 ;
- Long Baselines
  - Higher γ or higher ion Q, needs more decays

Not evident: physics, budget, existing infrastructures give boundaries

Ion Choice, β^+ emitters (ν_e)

Isotope	Z	A	A/Z	$T_{1/2}$	Q_β (gs>gs)	Q_β eff.	E_β av.	E_ν av.	<E_LAB> (MeV)
				s	MeV	MeV	MeV	MeV	(@450 GeV/p)
8B	5	8	1.6	0.77	17.0	13.9	6.55	7.37	4145
10C	6	10	1.7	19.3	2.6	1.9	0.81	1.08	585
14O	8	14	1.8	70.6	4.1	1.8	0.78	1.05	538
15O	8	15	1.9	122.2	1.7	1.7	0.74	1.00	479
18Ne	10	18	1.8	1.67	3.4	3.4	1.50	1.86	930
19Ne	10	19	1.9	17.34	2.2	2.2	0.96	1.25	594
21Na	11	21	1.9	22.49	2.5	2.5	1.10	1.41	662
33Ar	18	33	1.8	0.173	10.6	8.2	3.97	4.19	2058
34Ar	18	34	1.9	0.845	5.0	5.0	2.29	2.67	1270
35Ar	18	35	1.9	1.775	4.9	4.9	2.27	2.65	1227
37K	19	37	1.9	1.226	5.1	5.1	2.35	2.72	1259
80Rb	37	80	2.2	34	4.7	4.5	2.04	2.48	1031

Ion Choice, β^- emitters (ν_e)

Isotope	Z	A	A/Z	$T_{1/2}$	$Q_{\beta\ (gs>gs)}$	$Q_{\beta\ eff.}$	$E_{\beta\ av.}$	$E_{\nu\ av.}$	<E_LAB> (MeV)
				s	MeV	MeV	MeV	MeV	(@ 450 GeV/p)
6He	2	6	3.0	0.807	3.5	3.5	1.57	1.94	582
8He	2	8	4.0	0.119	10.7	9.1	4.35	4.80	1079
8Li	3	8	2.7	0.838	16.0	13.0	6.24	6.72	2268
9Li	3	9	3.0	0.178	13.6	11.9	5.73	6.20	1860
11Be	4	11	2.8	13.81	11.5	9.8	4.65	5.11	1671
15C	6	15	2.5	2.449	9.8	6.4	2.87	3.55	1279
16C	6	16	2.7	0.747	8.0	4.5	2.05	2.46	830
16N	7	16	2.3	7.13	10.4	5.9	4.59	1.33	525
17N	7	17	2.4	4.173	8.7	3.8	1.71	2.10	779
18N	7	18	2.6	0.624	13.9	8.0	5.33	2.67	933
23Ne	10	23	2.3	37.24	4.4	4.2	1.90	2.31	904
25Ne	10	25	2.5	0.602	7.3	6.9	3.18	3.73	1344
25Na	11	25	2.3	59.1	3.8	3.4	1.51	1.90	750
26Na	11	26	2.4	1.072	9.3	7.2	3.34	3.81	1450

Outline

- Options for Accelerators
- The EURISOL Beta Beam Scenario
- Ion Production
- Loss Management
- R&D

EURISOL design study

European Isotope Separation On-Line Radioactive Ion Beam Facility

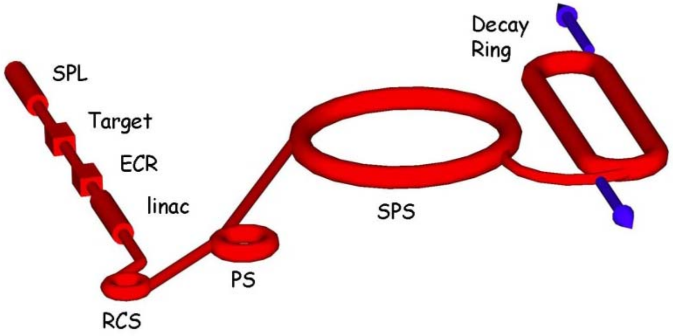
- Beta Beams is one task
- Related to the radioactive ion production
- Funding from FP6
- Design Report summer 2009

The EURISOL scenario (i)

- Based on CERN boundaries

- Based on existing technology and machine
    - Ion production through ISOL technique
    - Bunching and first acceleration: ECR, linac
    - Rapid cycling synchrotron
    - Use of existing machines: PS and SPS

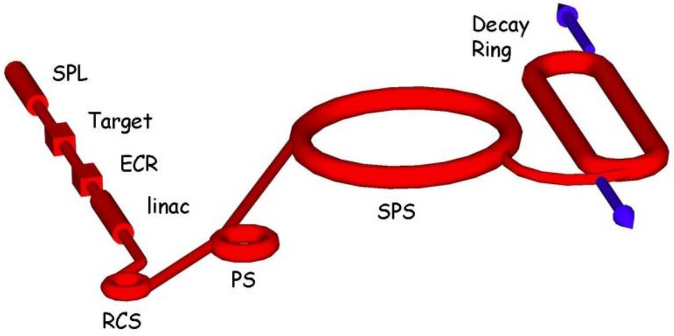
EURISOL scenario



- Opportunity to share a Mton Water Cerenkov detector with a CERN super-beam, proton decay studies and a neutrino observatory (Frejus)

- The EURISOL scenario will serve as reference for further studies and developments: See later for EUROnu

The EURISOL scenario (ii)



- Ion choice: ^{6}He and ^{18}Ne

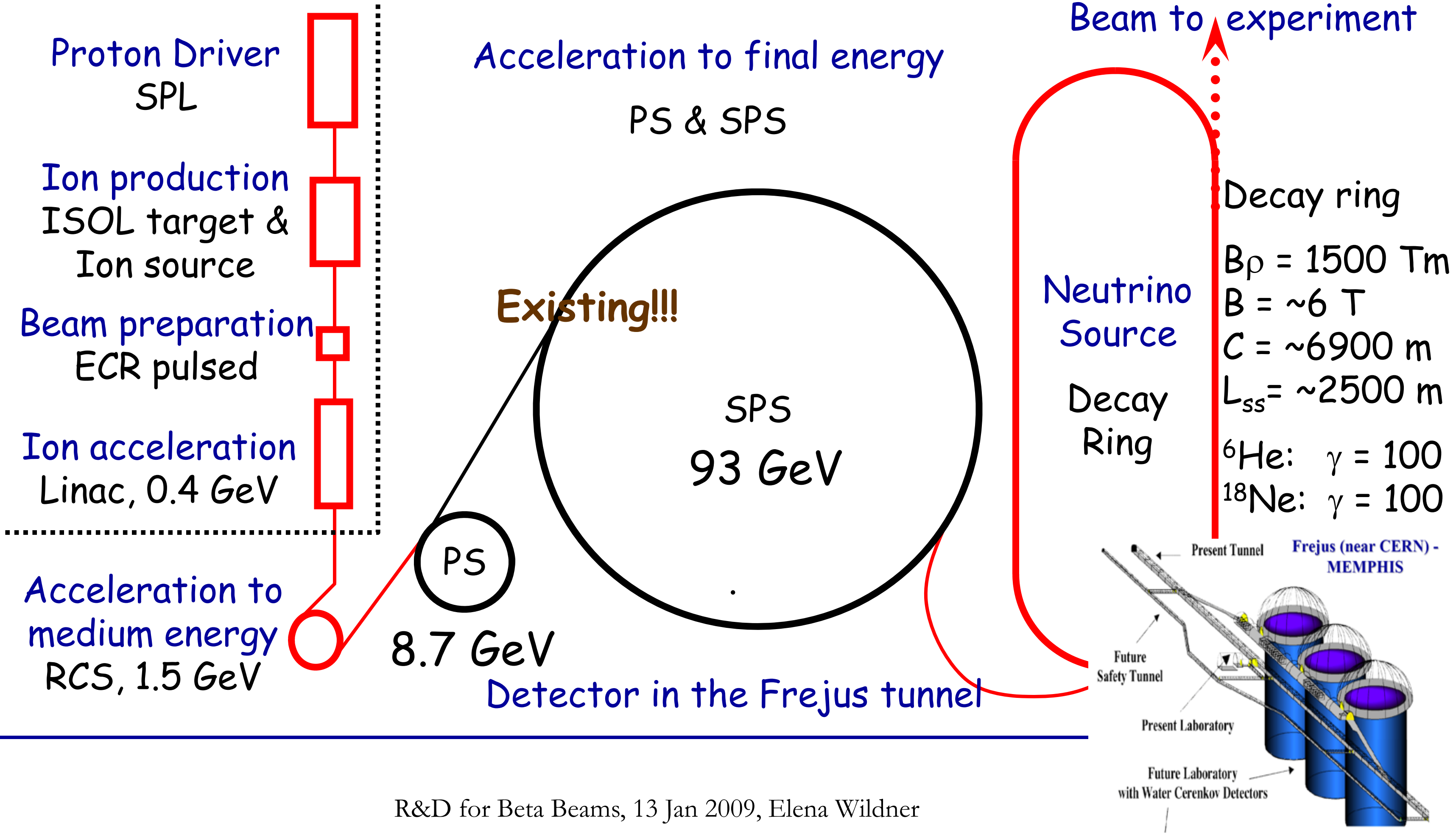
- Relativistic gamma=100 for both ions
  - SPS allows maximum of 150 (^{6}He) or 250 (^{18}Ne)
  - Gamma choice optimized for physics reach

- Opportunity to share a Mton Water Cerenkov detector with a CERN super-beam, proton decay studies and a neutrino observatory (Frejus)

- Achieve an annual neutrino rate of
  - 2.9*10^{18} anti-neutrinos from ^{6}He
  - 1.1 10^{18} neutrinos from ^{18}Ne

top-down approach

EURISOL Beta Beam complex



Low-energy part

Ion production

Proton Driver
SPL

Ion production
ISOL target &
Ion source

Beam preparation
ECR pulsed

Ion acceleration
Linac, 0.4 GeV

Acceleration to medium energy
RCS, 1.5 GeV

High-energy part

Acceleration

Acceleration to final energy

PS & SPS

Existing!!!

PS
8.7 GeV

SPS
93 GeV

Detector in the Frejus tunnel

Neutrino source

Beam to experiment

Neutrino Source

Decay Ring

Decay ring

$B\rho = 1500$ Tm
B = ~6 T
C = ~6900 m
L_{ss}= ~2500 m
^{6}He: $\gamma = 100$
^{18}Ne: $\gamma = 100$

Options for production

- ISOL method at 1-2 GeV (200 kW)
  - >1 10^{13} ^{6}He per second
  - <8 10^{11} ^{18}Ne per second
  - Studied within EURISOL
- Direct production
  - >1 10^{13} ^{6}He per second
  - 1 10^{13} ^{18}Ne per second
  - Studied at LLN, Soreq, WI and GANIL
- Production ring
  - 10^{14} (?) ^{8}Li
  - >10^{13} (?) ^{8}B
  - Will be studied within EUROν

Aimed:
He 2.9 10^{18} (2.0 10^{13}/s)
Ne 1.1 10^{18} (2.0 10^{13}/s)

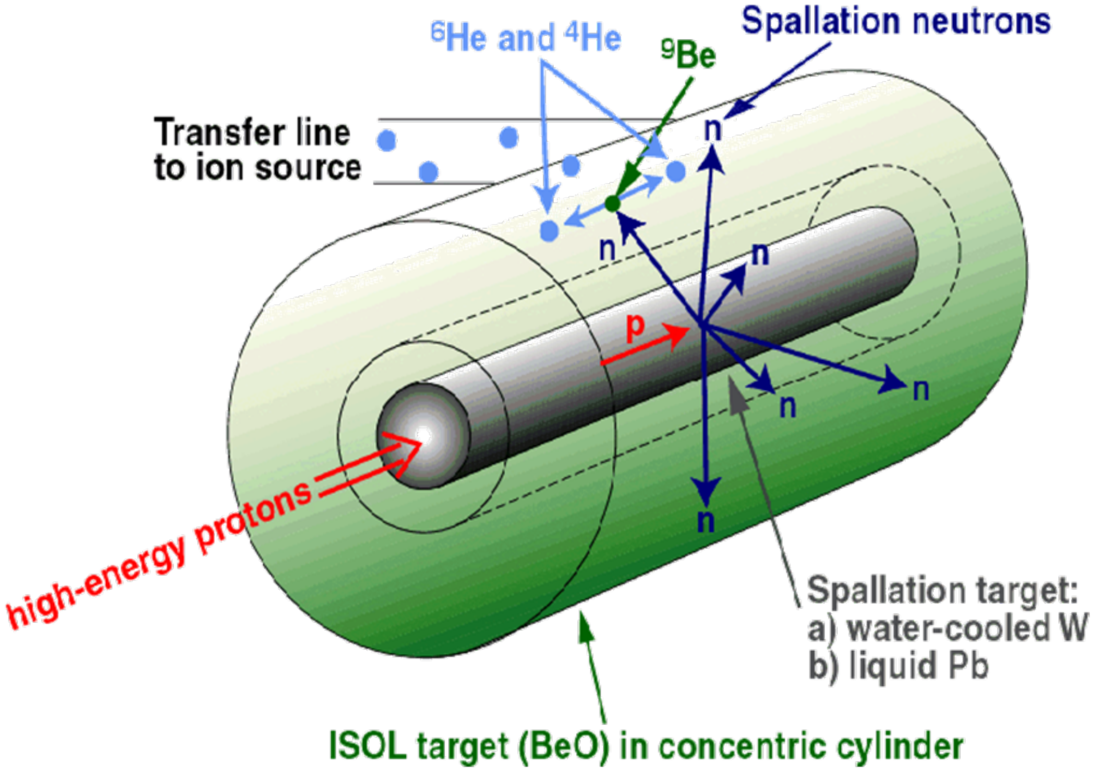
Courtesy M. Lindroos

N.B. Nuclear Physics has limited interest in those elements→ Production rates not pushed!

Outline

- Options for Accelerators
- The EURISOL Beta Beam Scenario
- Ion Production
- Loss Management
- R&D

^{6}He (ISOL)



Converter technology:
(*J. Nolen, NPA 701 (2002) 312c*)

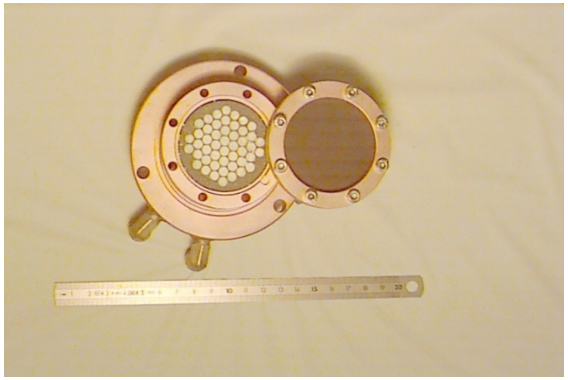
T. Stora, N. Thollieres, CERN

- Converter technology preferred to direct irradiation (heat transfer and efficient cooling allows higher power compared to insulating BeO).
- ^{6}He production rate is ~$2\text{x}10^{13}$ ions/s (dc) for ~200 kW on target.

Projected values, known x-sections!

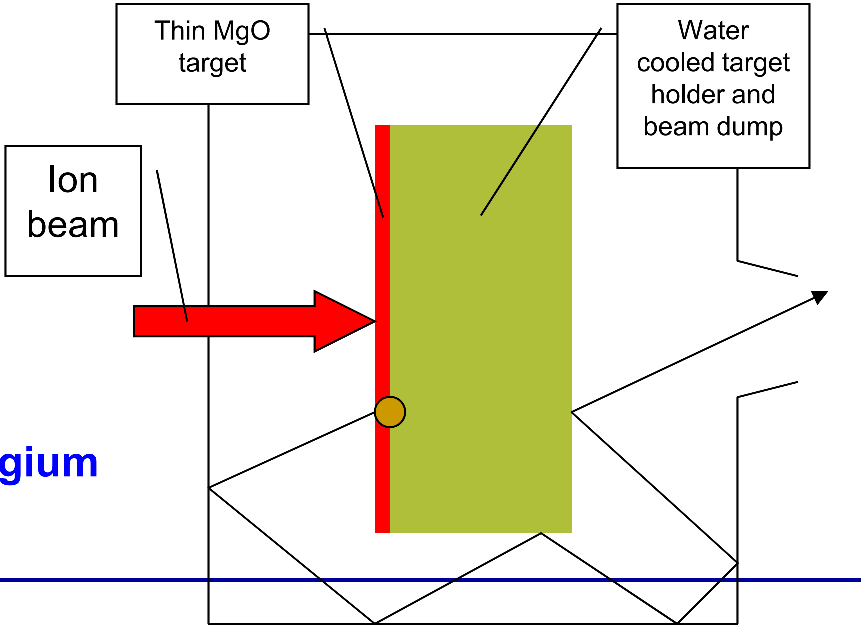
^{18}Ne (Direct Production)

Geometric scaling



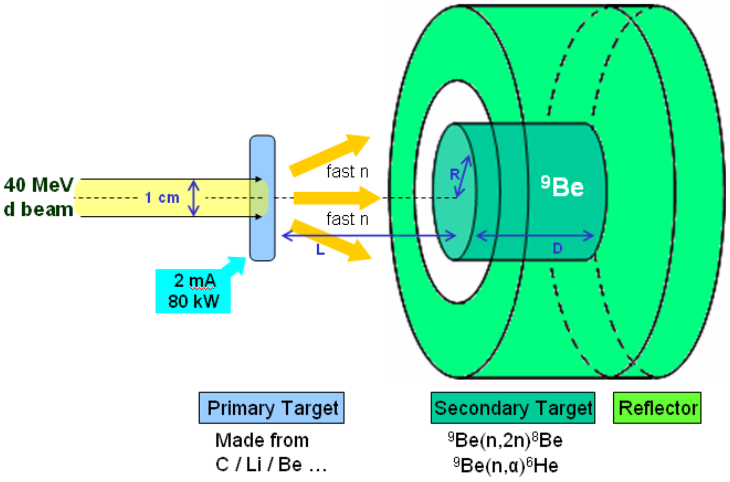
- Producing 10^{13} ^{18}Ne could be possible with a beam power (at low energy) of 2 MW (or some 130 mA ^{3}He beam on MgO).
- To keep the power density similar to LLN (today) the target has to be 60 cm in diameter.
- To be studied:
  - Extraction efficiency
  - Optimum energy
  - Cooling of target unit
  - High intensity and low energy ion linac
  - High intensity ion source

S. Mitrofanov and M. Loislet at CRC, Belgium



^{6}He (Two Stage ISOL)

- Studied ^{9}Be(n,α)^{6}He, ^{11}B(n,α)^{8}Li and ^{9}Be(n,2n)^{8}Be production
- For a 2 mA, 40 MeV deuteron beam, the upper limit for the ^{6}He production rate via the two stage targets setup is ~$6 \cdot 10^{13}$ atoms per second.



T.Y.Hirsh, D.Berkovits, M.Hass
(Soreq, Weizmann I.)

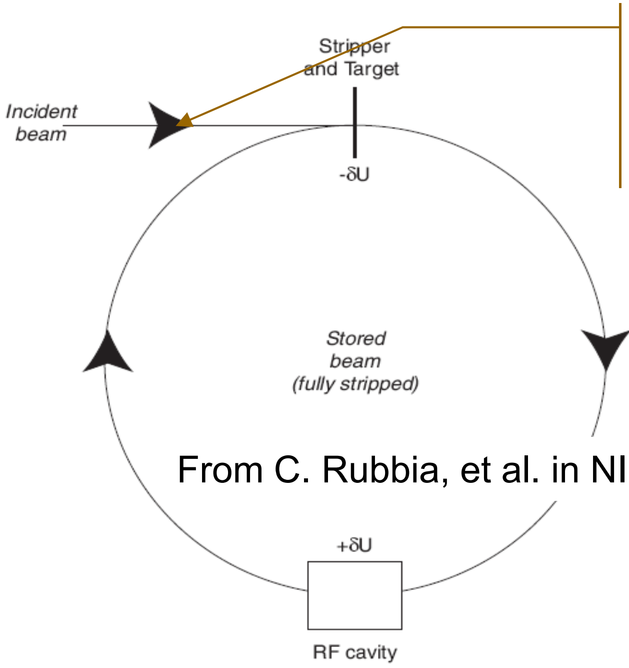
New approaches for ion production

“Beam cooling with ionisation losses” – C. Rubbia, A Ferrari, Y. Kadi and V. Vlachoudis in NIM A 568 (2006) 475–487

“Development of FFAG accelerators and their applications for intense secondary particle production”, Y. Mori, NIM A562(2006)591

^{7}Li

^{6}Li



^{7}Li(d,p)^{8}Li

^{6}Li(^{3}He,n)^{8}B

From C. Rubbia, et al. in NIM A 568 (2006) 475–487

Will be studied in Euroν FP7:

- Design of ring
- Cooling in ring
- Collection device
- ECR Source

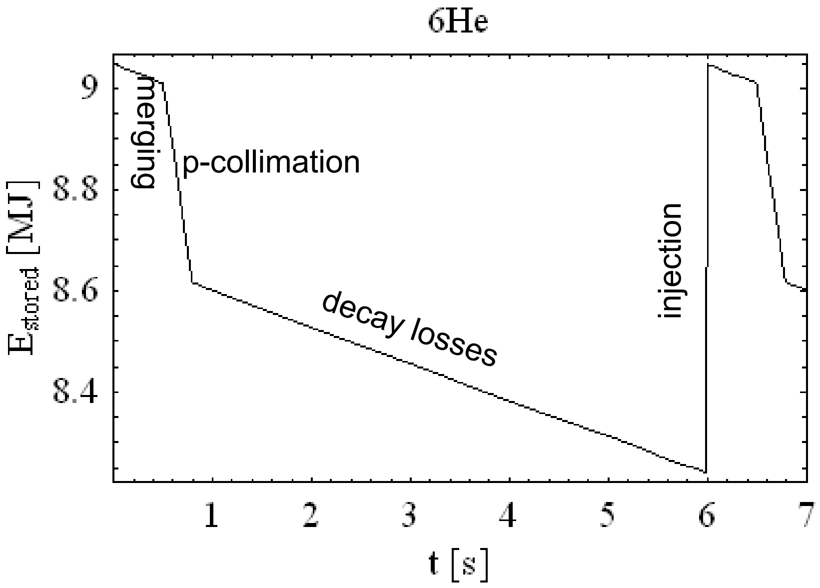
Outline

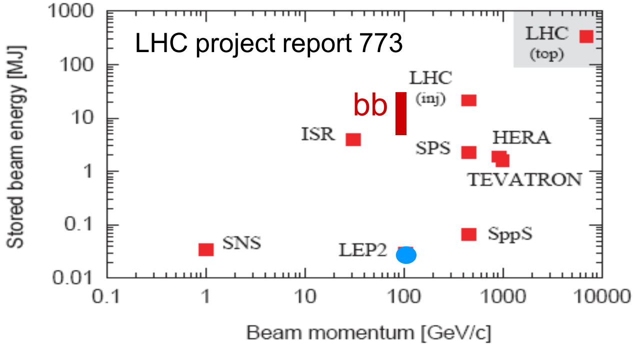
- Options for Accelerators
- The EURISOL Beta Beam Scenario
- Ion Production
- Loss Management
- R&D

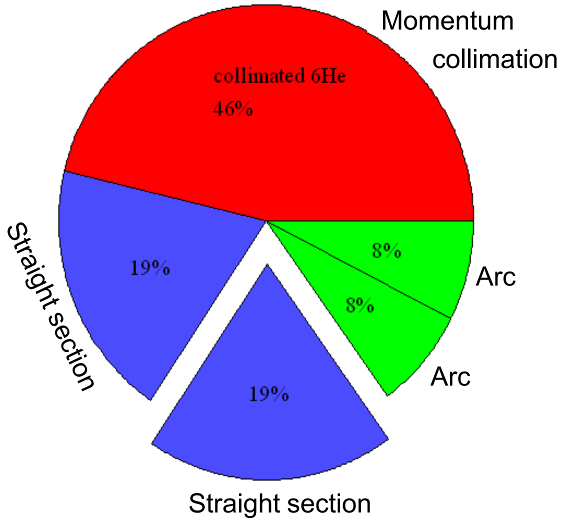
Radiation: Engineering issues

- Radiation safety
  - 88% of ^{18}Ne and 75% of ^{6}He ions are lost between source and injection into the Decay Ring
  - Detailed studies on RCS (manageable)
  - PS preliminary results available (heavily activated, 1 s flat bottom)
  - SPS and Decay Ring studies ongoing
- Safe collimation of ions during stacking, ongoing
  - ~1 MJ beam energy/cycle injected, equivalent ion number to be removed, ~25 W/m average
- Magnet protection (PS and Decay Ring manageable)
- Dynamic vacuum, studies ongoing
- Tritium and Sodium production in the ground water needs to be studied when site known (Magistris and Silari, 2002)

Particle turnover in Decay Ring





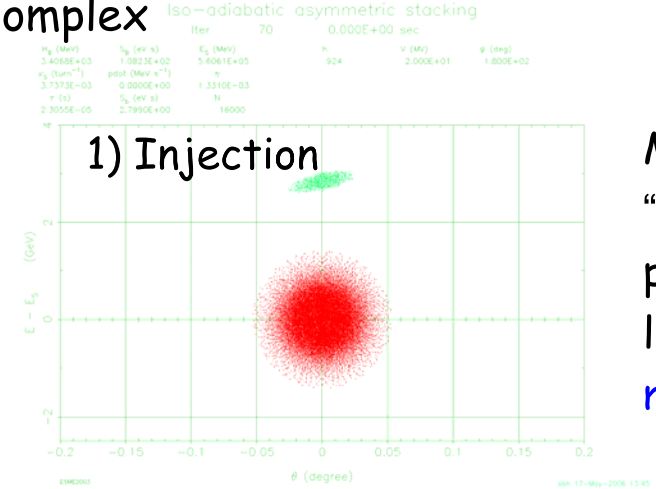


- Momentum collimation: ~$5*10^{12}$ ^{6}He ions to be collimated per cycle
- Decay: ~$5*10^{12}$ ^{6}Li ions to be removed per cycle per meter

Longitudinal Merging in DR

Mandatory for success of the $\gamma = 100$ beta-beam concept (need for duty cycle for background suppression)

Lifetime of ions (minutes) is much longer than cycle time (seconds) of a beta-beam complex



1) Injection

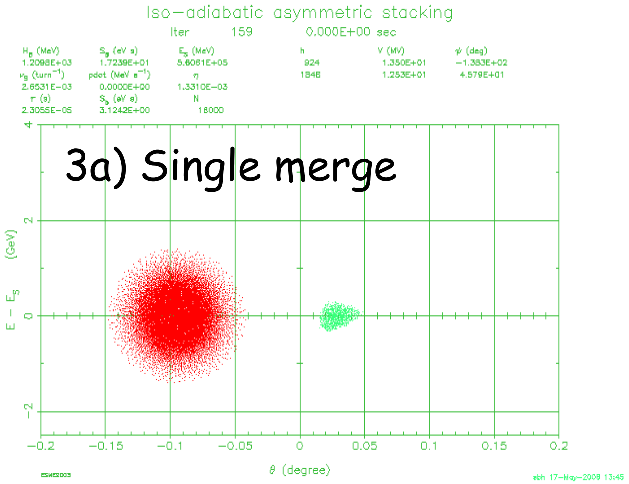
Merging:

"oldest" particles

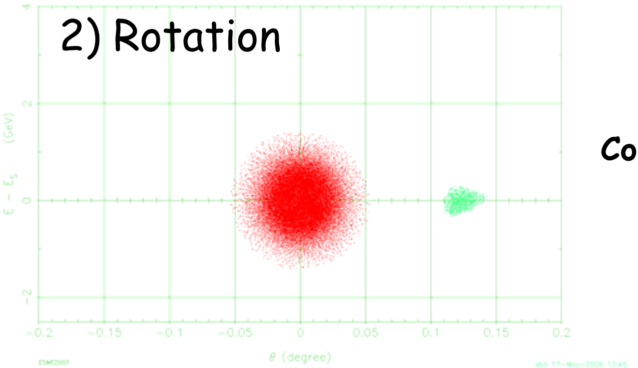
pushed outside

longitudinal acceptance →

momentum collimation

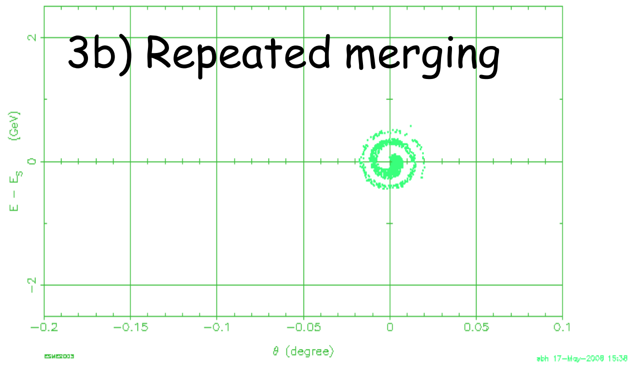


3a) Single merge



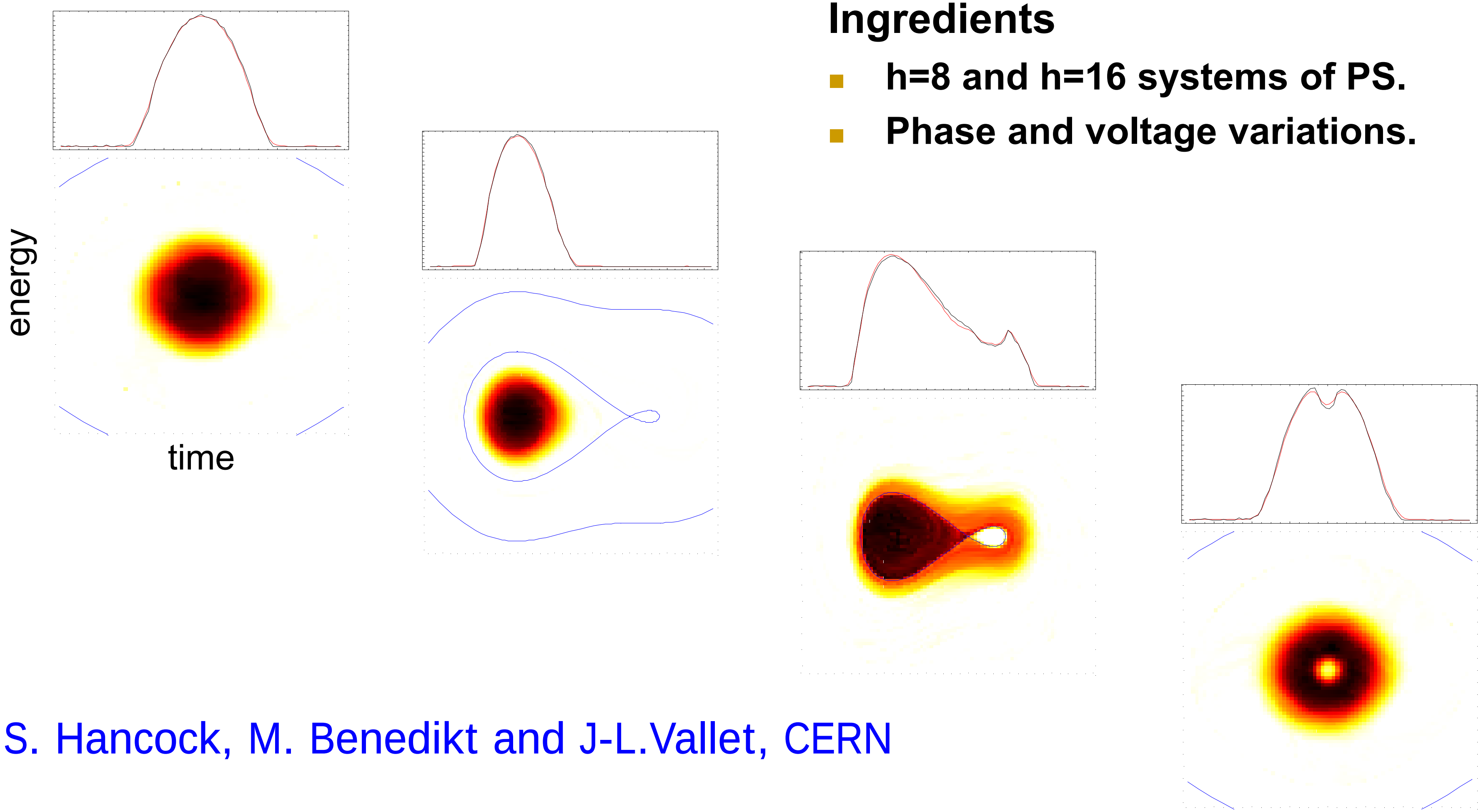
2) Rotation

Courtesy Steven Hancock, CERN



3b) Repeated merging

Decay Ring Stacking: experiment in CERN PS

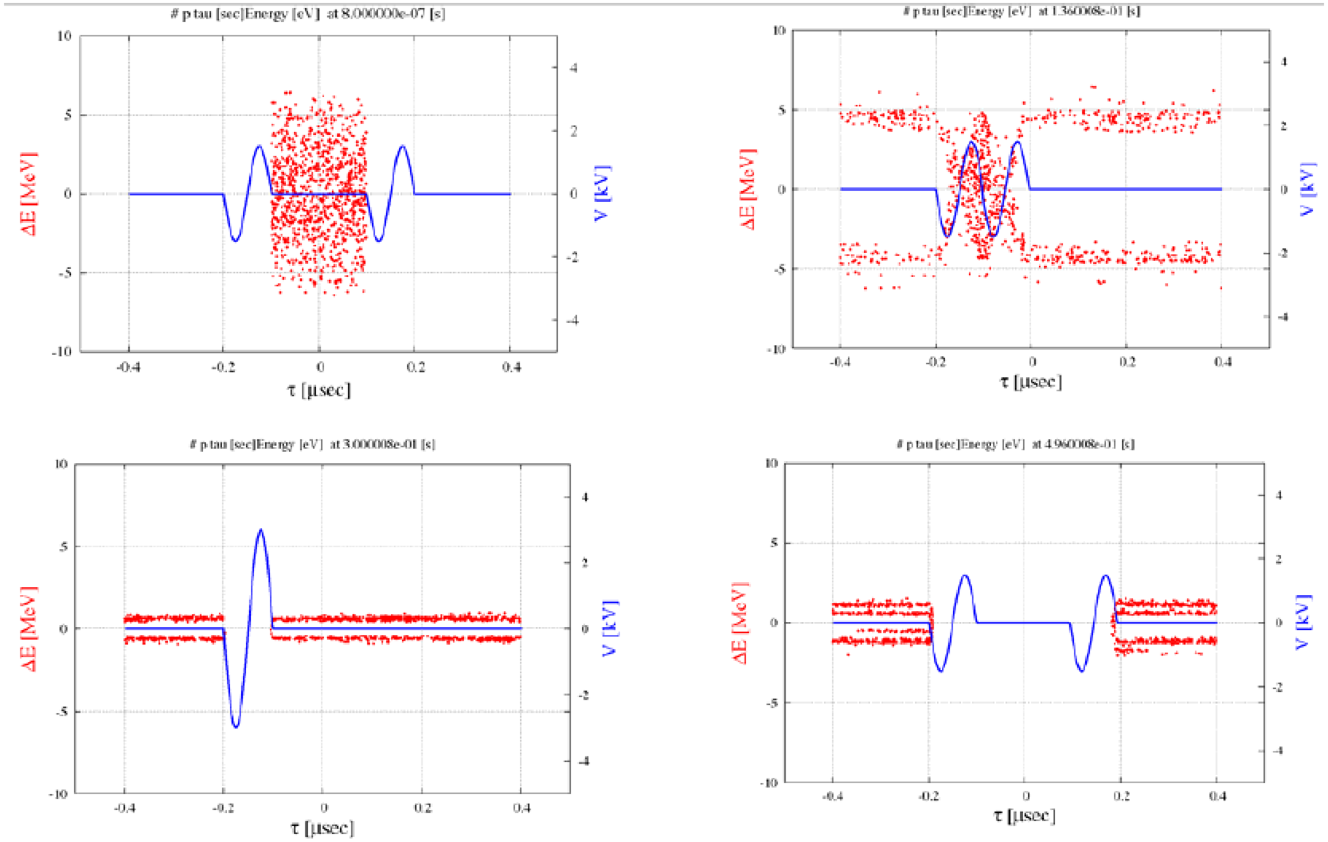


Ingredients

- h=8 and h=16 systems of PS.
- Phase and voltage variations.

S. Hancock, M. Benedikt and J-L.Vallet, CERN

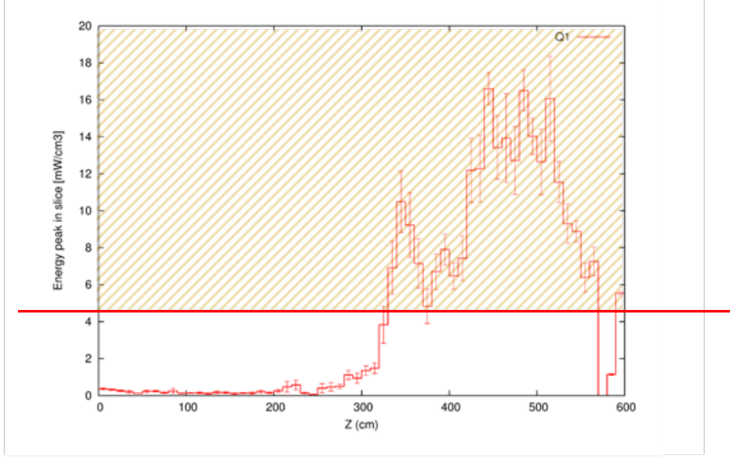
Barrier Buckets in the Decay Ring



Courtesy: P.Beller et al.

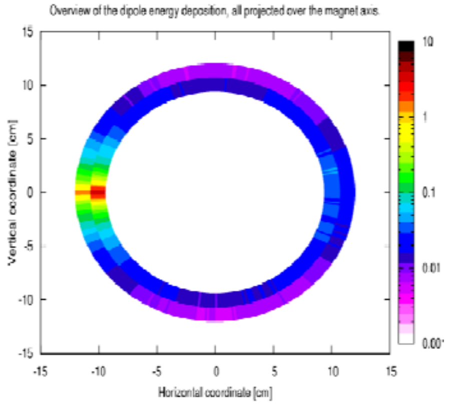
Heat Deposition study in Decay Ring

Peak Power Deposition in cable along magnet (FLUKA)



Decay Ring Lattice design with absorbers between dipoles: A. Chancé and J. Payet, CEA Saclay

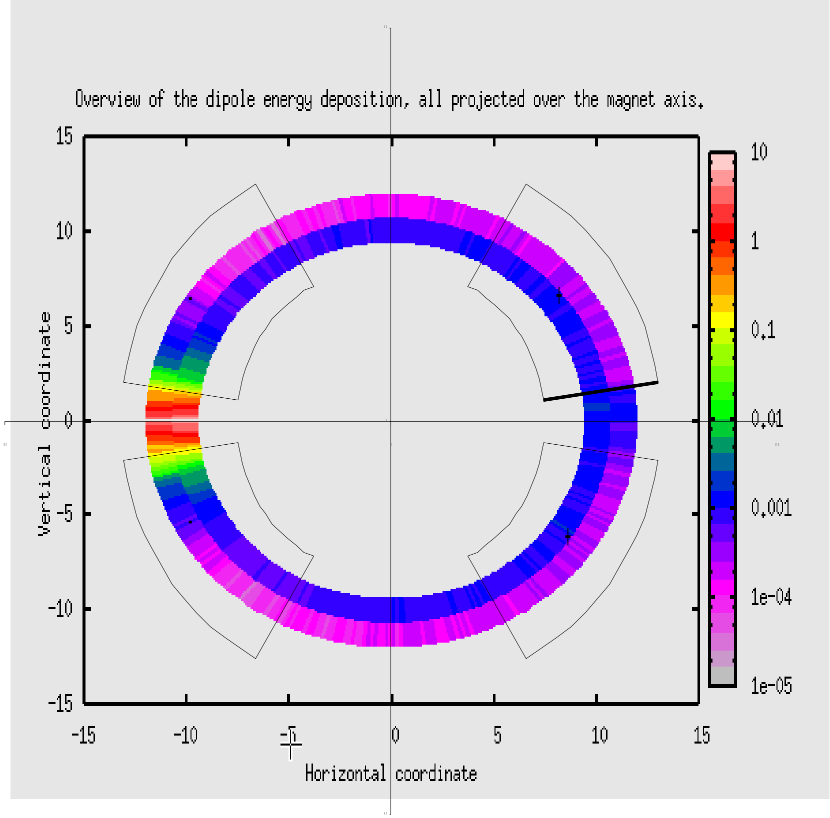
E. Wildner, CERN



- Need to reduce a factor 5 on midplane
  - Liners with cooling
  - Open Midplane magnets

Open Midplane Dipole for Decay Ring

Cosθ design open midplane magnet



J. Bruer, E. Todesco, CERN

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.

Outline

- Options for Accelerators
- The EURISOL Beta Beam Scenario
- Ion Production
- Loss Management
- R&D

EUROν DS (i)

- Comparison
  - Superbeam (ν–production on target)
  - ν–factory (decaying nuons in storage ring)
  - Beta Beams

https://espace.cern.ch/EURObeta/shared%20documents/EUROnu-proposal.doc

EUROν DS (i)

Work package No	Work package title	Type of activity	Lead participant No	Person-months	Start month	End month
1	Management and Knowledge Dissemination	MGT	1	92	1	48
2	Super-Beam	RTD	2	333	1	48
3	Neutrino Factory	RTD	5	282	1	48
4	Beta Beam	RTD	3	295	1	48
5	Detector Performance	RTD	4	199	1	48
6	Physics Reach	RTD	6	206	1	48
	TOTAL			1407		

3=CERN, coordinator: E. Wildner

The beta-beam in EUROν DS (ii)

- The study will focus on production issues for ^{8}Li and ^{8}B
  - ^{8}B is highly reactive and has never been produced as an ISOL beam
  - Production: enhanced direct production
    - Ring lattice design
    - Cooling
    - Collection of the produced ions (UCL, INFN, ANL), release efficiencies and cross sections for the reactions
    - Sources ECR (LPSC, GHMFL)
    - Supersonic Gas injector (PPPL)
- Parallel studies
  - Multiple Charge State Linacs (P Ostroumov, ANL)
  - Intensity limitations

https://espace.cern.ch/EURObeta/default.aspx

The beta-beam in EURONU DS (iii)

- Optimization of the Decay Ring (CERN, CEA,TRIUMF)
  - Lattice design for new ions
  - Open midplane superconducting magnets
  - R&D superconductors, higher field magnets
  - Field quality, beam dynamics
  - Injection process revised (merging, collimation)
- A new PS?
  - Magnet protection system
  - Intensity limitations?
- Overall radiation & radioprotection studies

The beta-beam in EURONU DS (iii)

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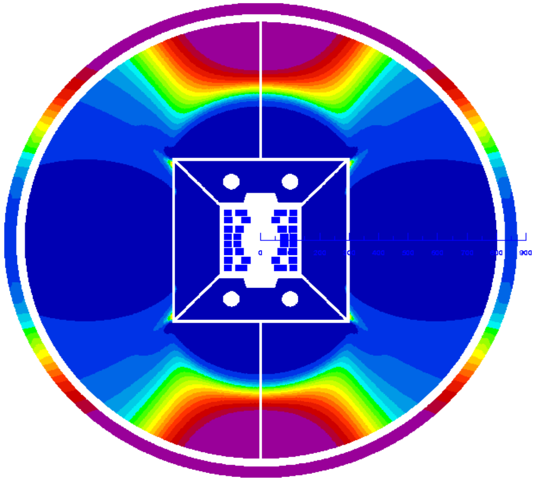
- Overall radiation & radioprotection studies

High field dipole model

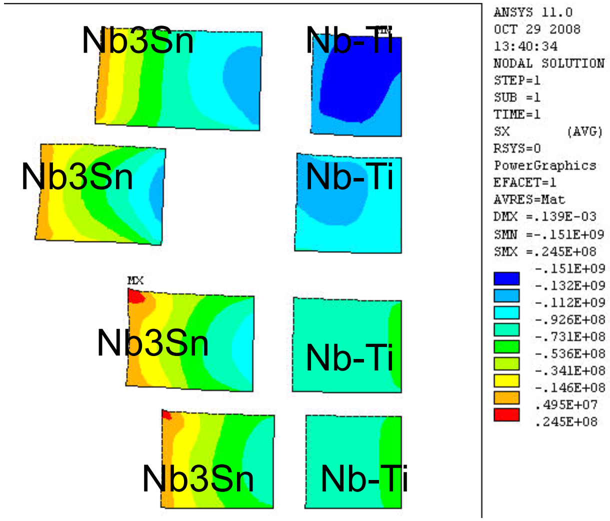
EUCARD Participants: CEA-DSM-Irfu, CERN, Wroclaw Technical University

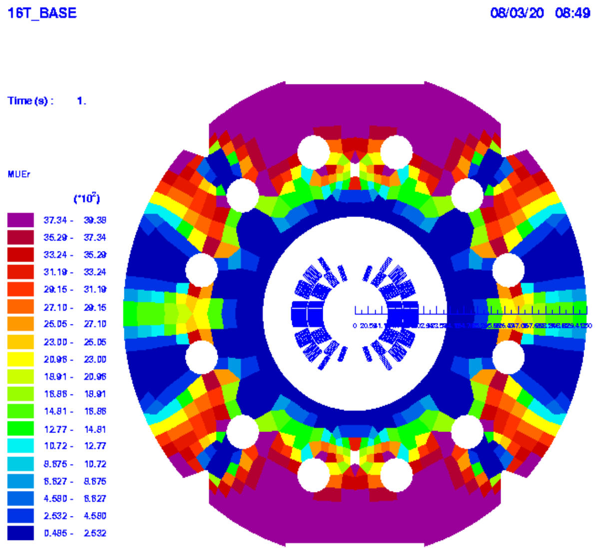
Aim: Design, build and test a 1.5 m long, 100 mm aperture dipole model with a design field of 13 T using Nb_3Sn high current Rutherford cables.

Several concepts' are being studied already



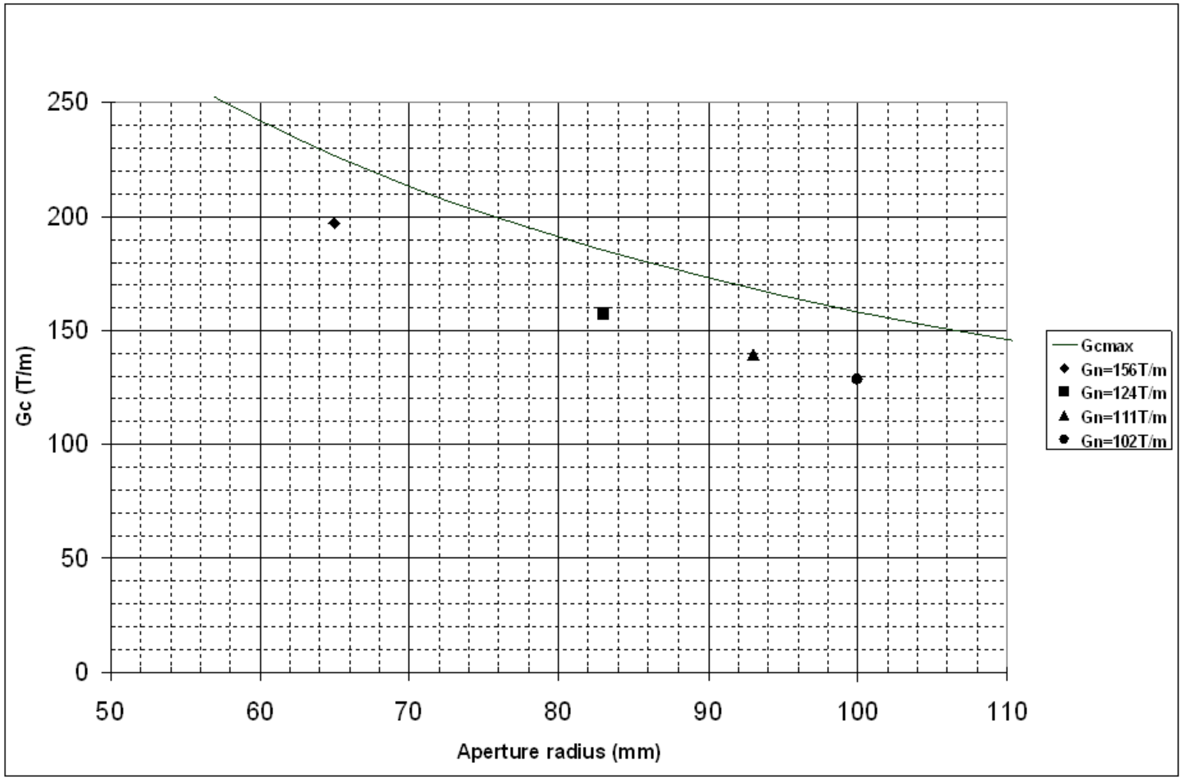
Block coil design





CosΘ design

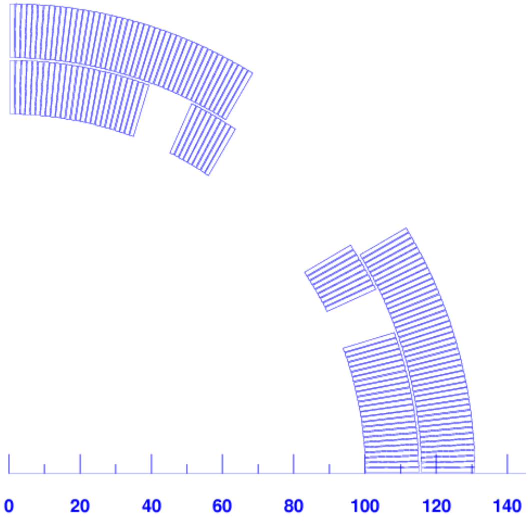
Cos2θ Quadrupoles for LHC upgrade phaseII



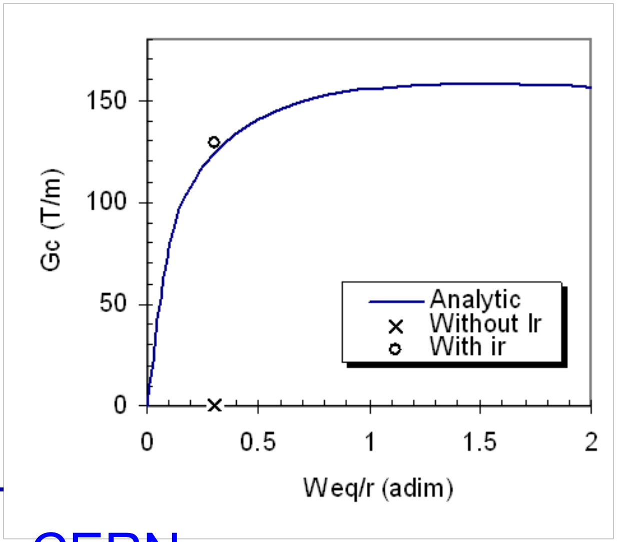
F. Borgnolutti, E. Todesco, CERN

102 T/m Quadrupole

coil parameters							
Block Nº	Nb Cond	r (mm)	φ (º)	α (º)	cable type	current (A)	grading
1	25	100.000	0.143	0.000	TQ15MM	13000	1.000
2	9	100.000	26.013	24.209	TQ15MM	13000	1.000
3	45	115.750	0.124	0.000	TQ15MM	13000	1.000



- Aperture diameter
  - 200 mm
- Gradient
  - ssG = 129 T/m
  - Gn = 102 T/m ⟹ margin of 20%
- Current
  - Ss current =14950 A
  - In = 11960 A



F. Borgnolutti, E. Todesco, CERN

The beta-beam in EURONU DS (iii)

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- A new PS?
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Greenfield Studies

- EUROν framework concentrates on production
  - EURISOL Scenario still valid
- BUT is this the best way
  - Budget
  - Do we get what physicists want
- Greenfield studies for comparison
- Upgrades of CERN

Greenfield Studies: gamma

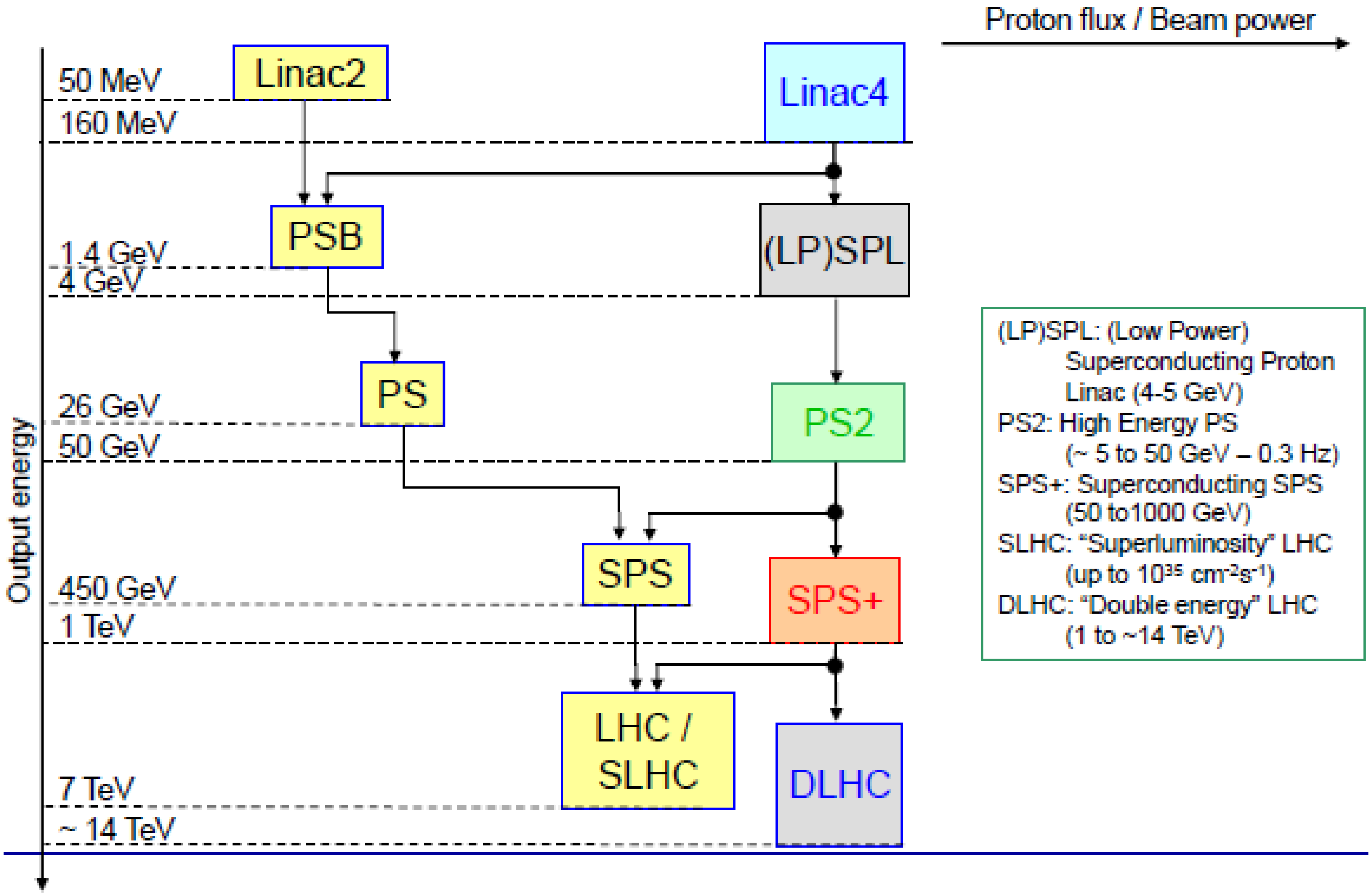
Gamma	Rigidity [Tm]	Ring length T=5 T f=0.36	Dipole Field rho=300 m Length=6885m
100	935	4197	3.1
150	1403	6296	4.7
200	1870	8395	6.2
350	3273	14691	10.9
500	4676	20987	15.6

New SPS

Civil engineering

Magnet R&D

CERN Upgrades



Proton flux / Beam power

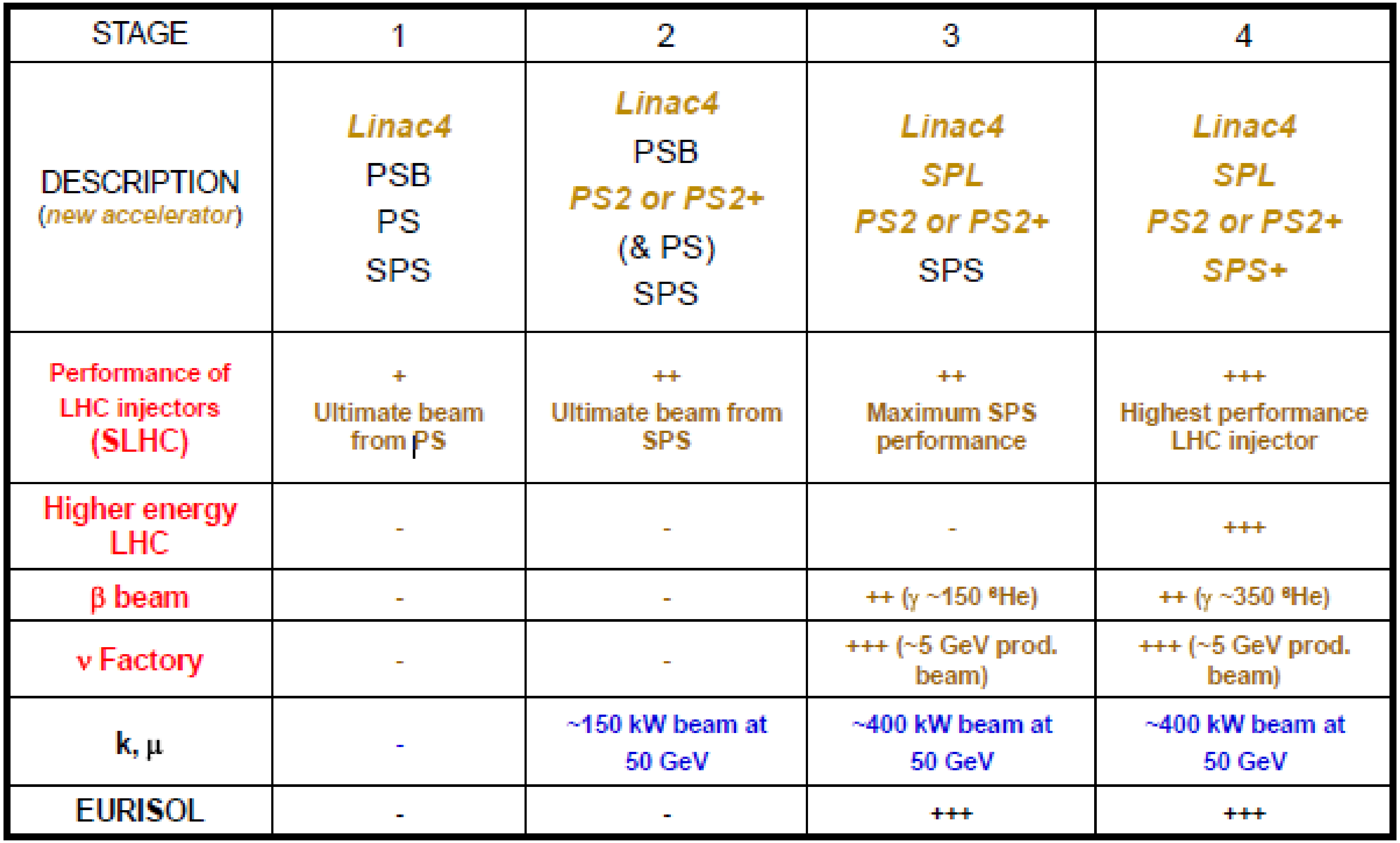
Output energy

50 MeV
160 MeV
1.4 GeV
4 GeV
26 GeV
50 GeV
450 GeV
1 TeV
7 TeV
~ 14 TeV

Linac2
Linac4
PSB
(LP)SPL
PS
PS2
SPS
SPS+
LHC / SLHC
DLHC

(LP)SPL: (Low Power) Superconducting Proton Linac (4-5 GeV)
PS2: High Energy PS (~ 5 to 50 GeV – 0.3 Hz)
SPS+: Superconducting SPS (50 to1000 GeV)
SLHC: "Superluminosity" LHC (up to 10^{35} $cm^{-2}s^{-1}$)
DLHC: "Double energy" LHC (1 to ~14 TeV)

CERN Upgrades: benefits for Physics



STAGE	1	2	3	4
DESCRIPTION *(new accelerator)*	*Linac4* PSB PS SPS	*Linac4* PSB *PS2 or PS2+* (& PS) SPS	*Linac4* *SPL* *PS2 or PS2+* SPS	*Linac4* *SPL* *PS2 or PS2+* *SPS+*
Performance of LHC injectors (SLHC)	+ Ultimate beam from PS	++ Ultimate beam from SPS	++ Maximum SPS performance	+++ Highest performance LHC injector
Higher energy LHC	-	-	-	+++
β beam	-	-	++ (γ ~150 ^{6}He)	++ (γ ~350 ^{6}He)
ν Factory	-	-	+++ (~5 GeV prod. beam)	+++ (~5 GeV prod. beam)
k, μ	-	~150 kW beam at 50 GeV	~400 kW beam at 50 GeV	~400 kW beam at 50 GeV
EURISOL	-	-	+++	+++

Summary

- The EURISOL beta-beam conceptual design report will be presented in second half of 2009
  - First coherent study of a beta-beam facility
- Continuation of the work: a beta-beam facility using ^{8}Li and ^{8}B
  - Experience from EURISOL
  - First results will come from Euroν DS

    beta beam WP started 1 Sept. 2008 (4 year study)

Acknowledgements

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Particular thanks to
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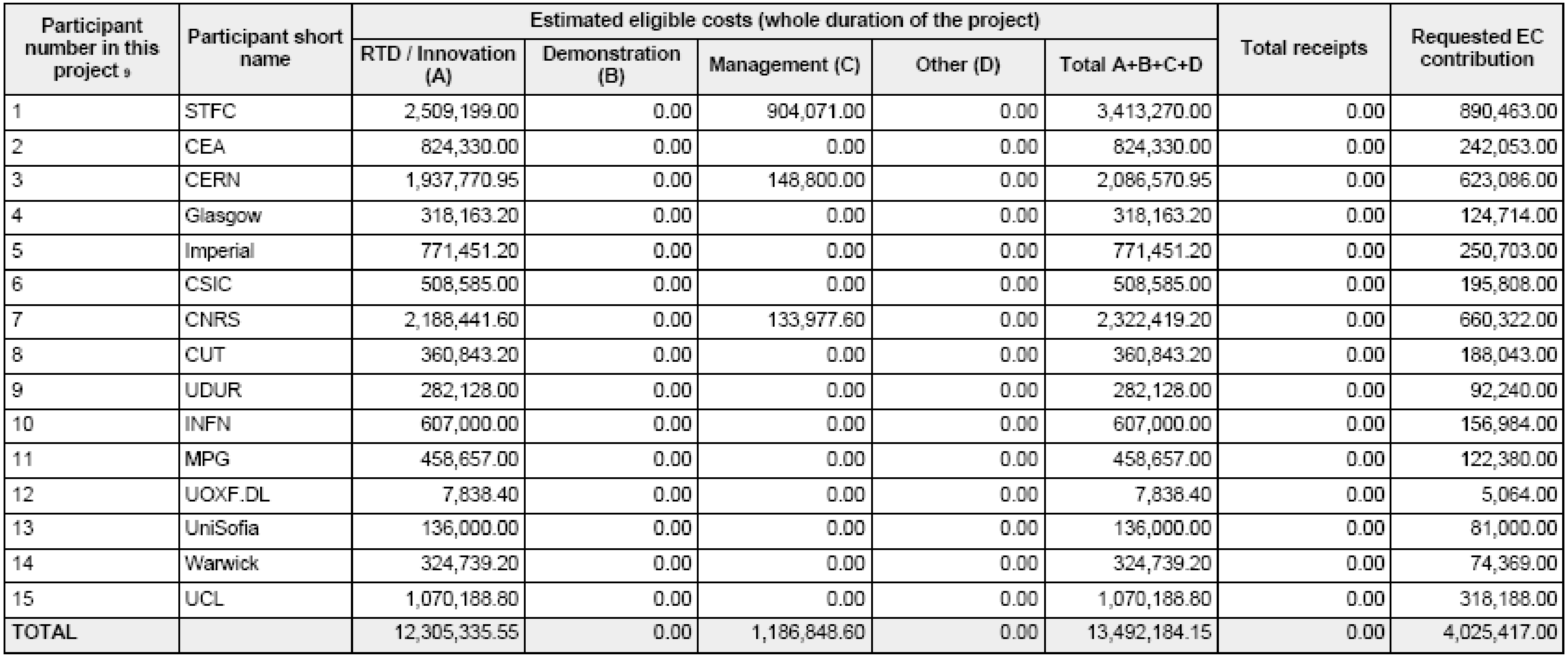
M. Benedikt,
A. Fabich,
for contributions to the material presented.

EUROv DS budget



Participant number in this project[9]	Participant short name	Estimated eligible costs (whole duration of the project)					Total receipts	Requested EC contribution
		RTD / Innovation (A)	Demonstration (B)	Management (C)	Other (D)	Total A+B+C+D		
1	STFC	2,509,199.00	0.00	904,071.00	0.00	3,413,270.00	0.00	890,463.00
2	CEA	824,330.00	0.00	0.00	0.00	824,330.00	0.00	242,053.00
3	CERN	1,937,770.95	0.00	148,800.00	0.00	2,086,570.95	0.00	623,086.00
4	Glasgow	318,163.20	0.00	0.00	0.00	318,163.20	0.00	124,714.00
5	Imperial	771,451.20	0.00	0.00	0.00	771,451.20	0.00	250,703.00
6	CSIC	508,585.00	0.00	0.00	0.00	508,585.00	0.00	195,808.00
7	CNRS	2,188,441.60	0.00	133,977.60	0.00	2,322,419.20	0.00	660,322.00
8	CUT	360,843.20	0.00	0.00	0.00	360,843.20	0.00	188,043.00
9	UDUR	282,128.00	0.00	0.00	0.00	282,128.00	0.00	92,240.00
10	INFN	607,000.00	0.00	0.00	0.00	607,000.00	0.00	156,984.00
11	MPG	458,657.00	0.00	0.00	0.00	458,657.00	0.00	122,380.00
12	UOXF.DL	7,838.40	0.00	0.00	0.00	7,838.40	0.00	5,064.00
13	UniSofia	136,000.00	0.00	0.00	0.00	136,000.00	0.00	81,000.00
14	Warwick	324,739.20	0.00	0.00	0.00	324,739.20	0.00	74,369.00
15	UCL	1,070,188.80	0.00	0.00	0.00	1,070,188.80	0.00	318,188.00
TOTAL		12,305,335.55	0.00	1,186,848.60	0.00	13,492,184.15	0.00	4,025,417.00

Part III

Beta-Beams @ DESY ?

Neutrino-Beams: Two Alternative Concepts

We need ν_e and ν_μ beam
with different baselines

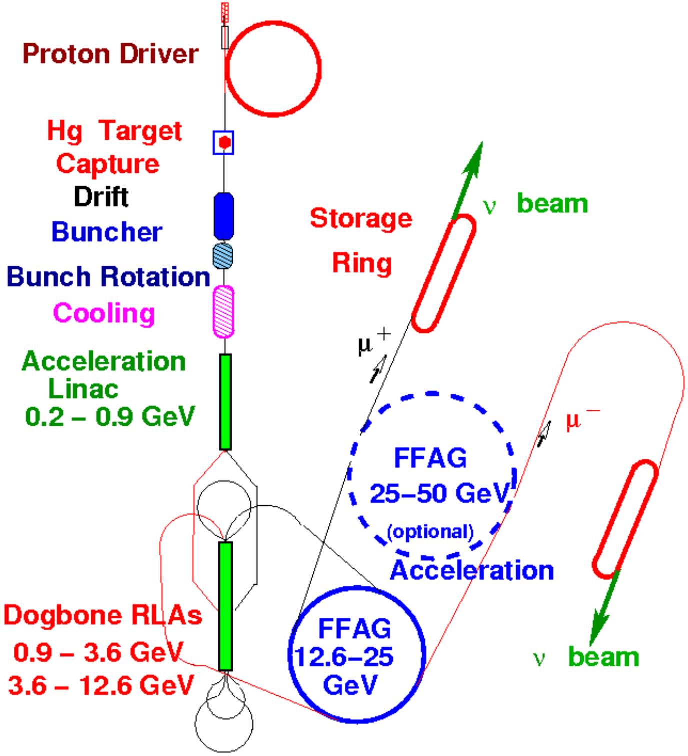
beta-beam

ν_e / $\bar{\nu}_e$ beam

&

conventional ν_μ beam

ν_μ / $\bar{\nu}_\mu$ beam



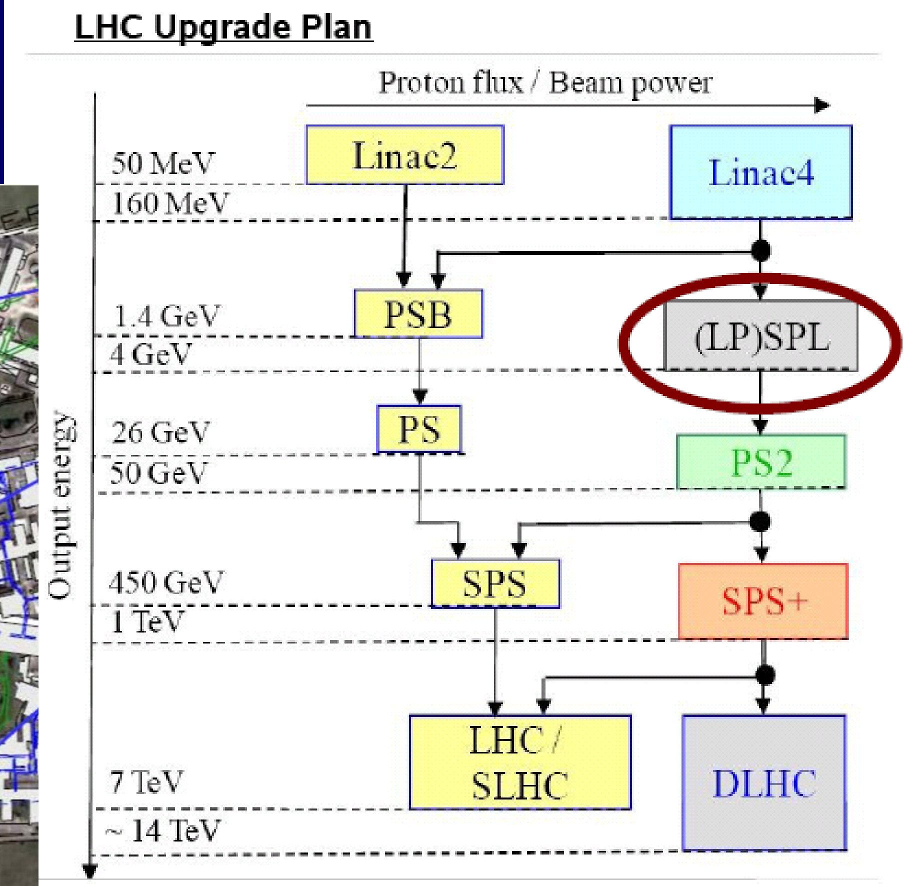
$\mu^+ \rightarrow e^+ \ \nu_e \ \bar{\nu}_\mu$ & $\mu^- \rightarrow e^- \ \bar{\nu}_e \ \nu_\mu$

magnetic detector for separation

Conventional Neutrino-Beam from SPL

Protonbeam: part of the LHC-upgrade
2.2 GeV / 4 MW - 10^{16} p+/sec
$\langle E_\nu \rangle$ = 260 MeV

10% of this intensity is sufficient


LHC Upgrade Plan

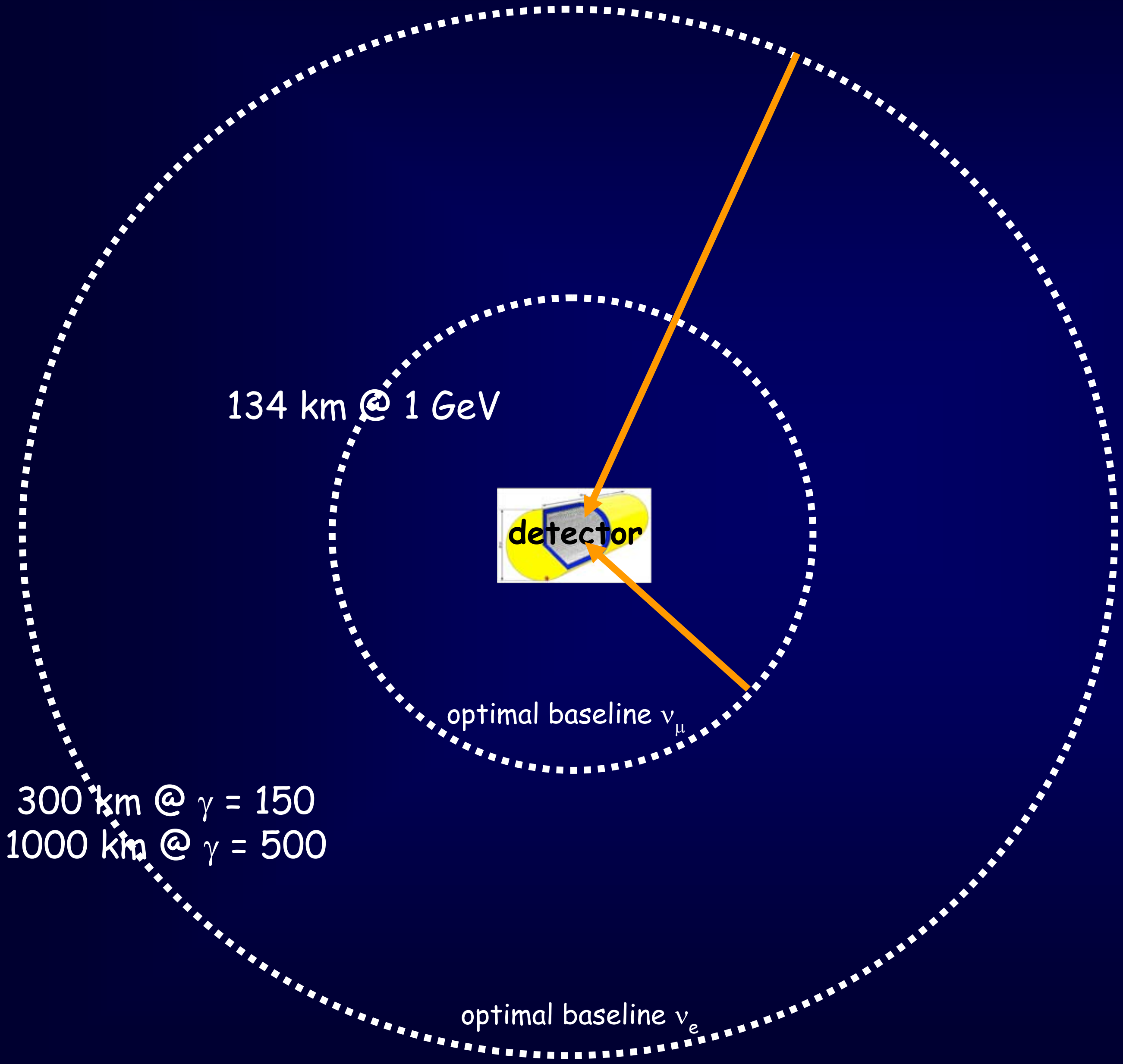
Proton flux / Beam power

Output energy

50 MeV
160 MeV
1.4 GeV
4 GeV
26 GeV
50 GeV
450 GeV
1 TeV
7 TeV
~ 14 TeV

Linac2
Linac4
PSB
(LP)SPL
PS
PS2
SPS
SPS+
LHC / SLHC
DLHC

Why DESY ?



134 km @ 1 GeV

optimal baseline ν_μ

300 km @ γ = 150
1000 km @ γ = 500

optimal baseline ν_e

1 Detector only (price!)

ν_μ - beam

SPL, $\langle E_\nu \rangle$ = 260 MeV
L_{opt} = 134 km

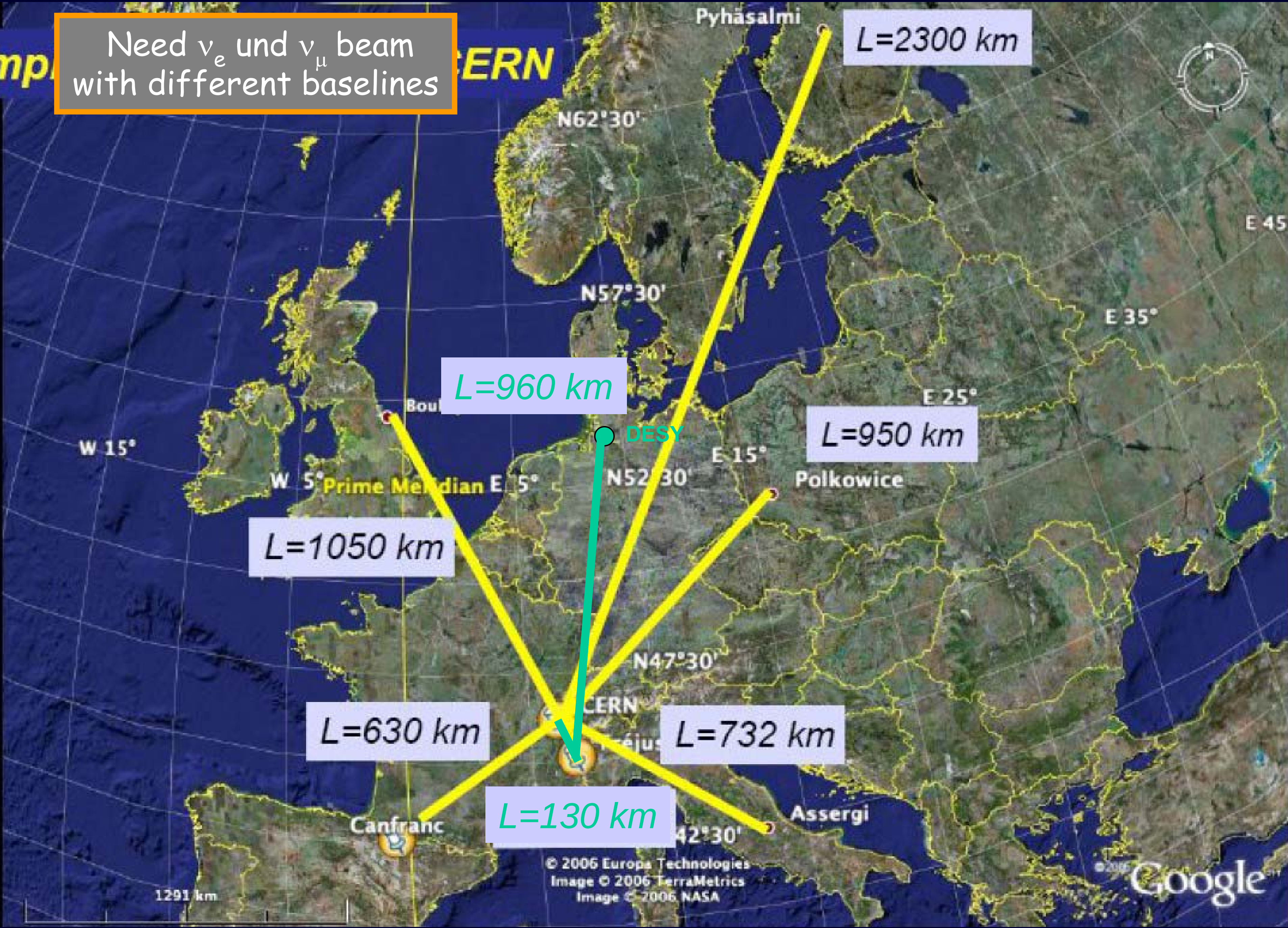
CERN – Frejus: 130 km

ν_e - beam

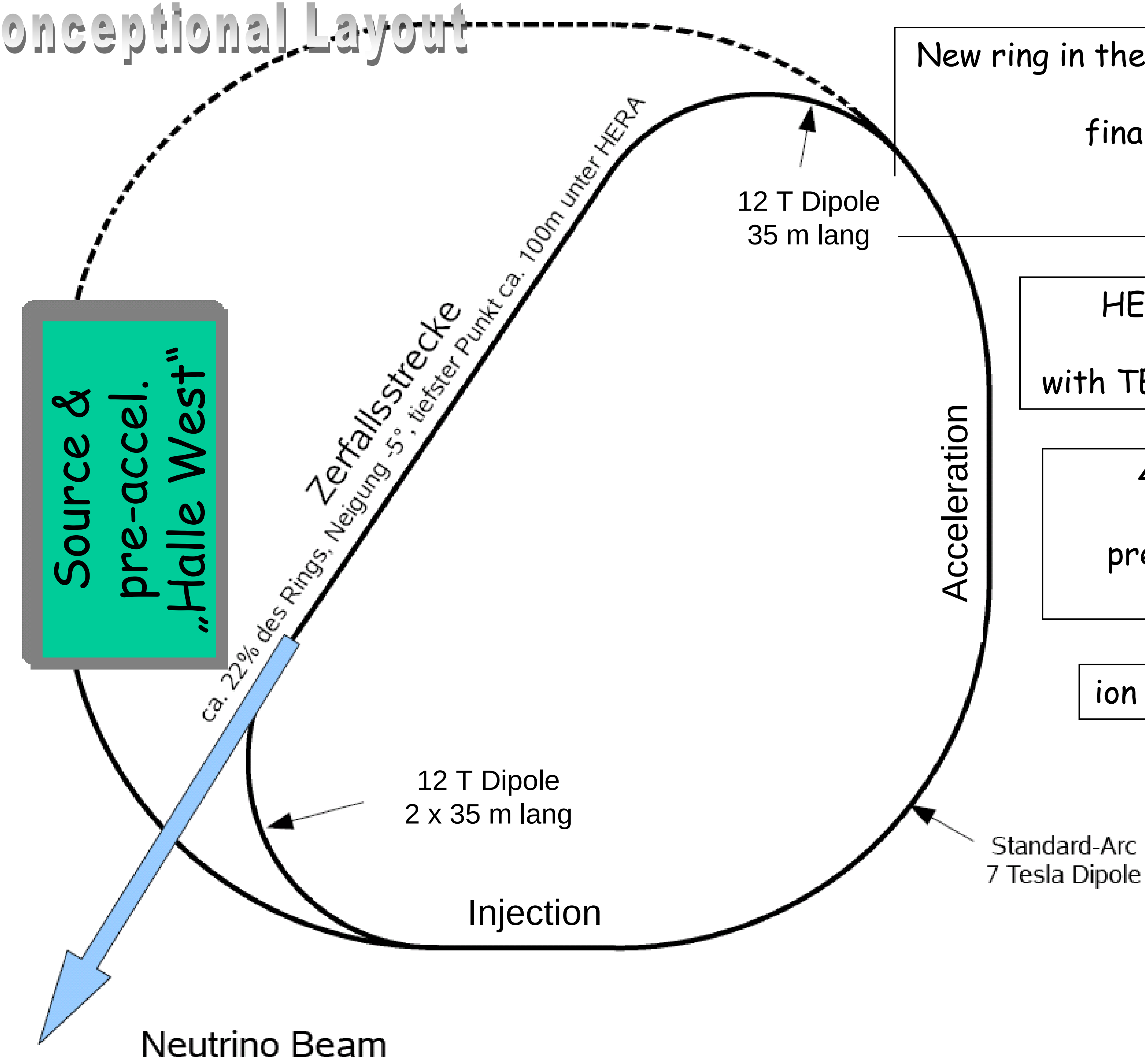
γ = 150 L_{opt} = 300 km
γ = 500 L_{opt} = 1000 km

CERN – Frejus: 130 km
DESY – Frejus: 960 km

Need ν_e und ν_μ beam with different baselines



Conceptional Layout



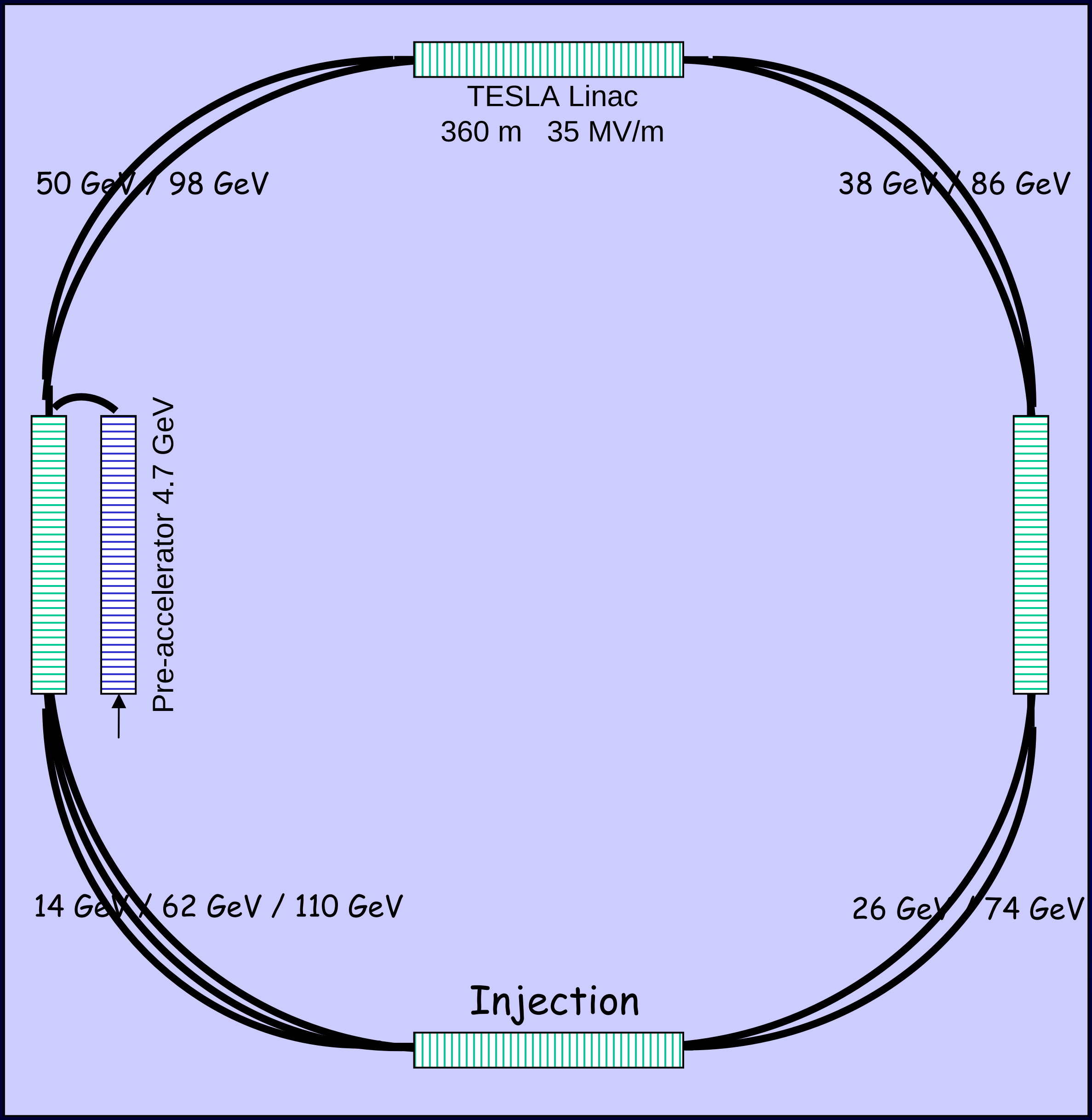
New ring in the HERA tunnel
for
final acceleration
and as
decay ring

HERA rebuild as
RCL
with TESLA cavities

4.7 GeV Linac
for
preacceleration
(new)

ion source (new)

Conceptional Layout: Preacceleration



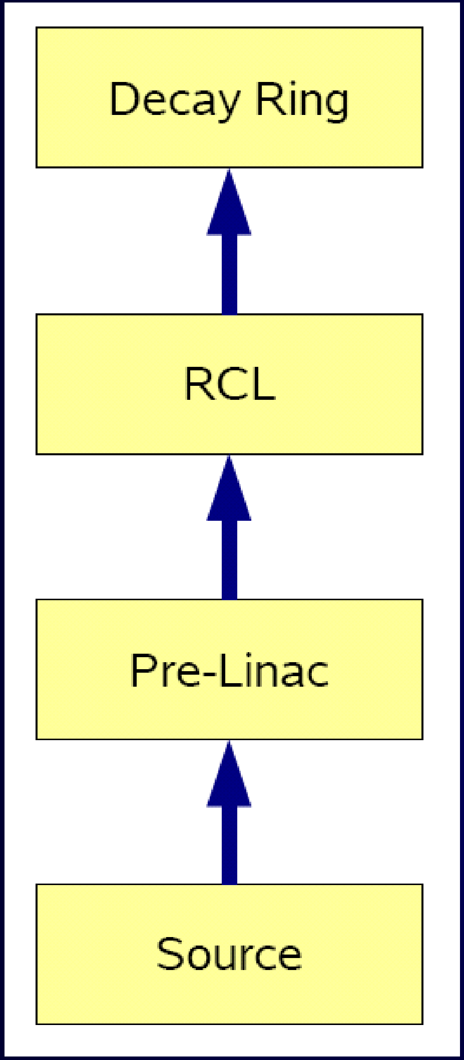
Energies

Preaccelerator
4.7 GeV $\beta = 0{,}8$

Injektion into RCL
14 GeV
26 GeV
38 GeV
50 GeV
HERA e-ring
62 GeV new
74 GeV
86 GeV
98 GeV
110 GeV
HERA p-ring

Injection into decay ring
ramp @ 0,5 T/s
to 1,4 TeV
$\gamma = 500$

Conceptual Design: Intensities & Time Structure



Work in cycles:

Production of ions:	1 sec	
Preacceleration:	50 μsec	
Ramp main ring:	20 sec	→ < 20% loss
active decays:	400 sec	→ ~ 22% in straight section
Decelerate + dump:	20 sec	
total:	~ 500 sec	

Intensities (100% effizieny !):

$2.1\ 10^{10}$ Ionen pro Bunch — 1.3 GHz (TESLA)

3100 m long bunch train

3500 bunches per train — every 4th bucket filled

1 train

$2.7\ 10^{13}$ usefull ν per cycle

$5.8\ 10^{17}$ ν per year

Source

$1.8\ 10^{14}$ ν per cycle

10^{-3} to 10^{-4} ^{6}He per ^{2}H

2 mA DC for ~ 10 msec

Technological Challenges

Very first analysis:

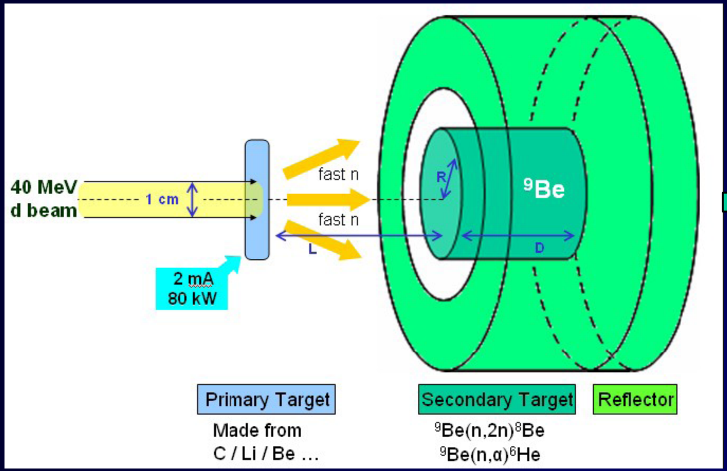
- **Ion Source**
- **Dipoles into straight section (12 T)**
- **Higher Order Modes in the cavities**

? RF peak power ?

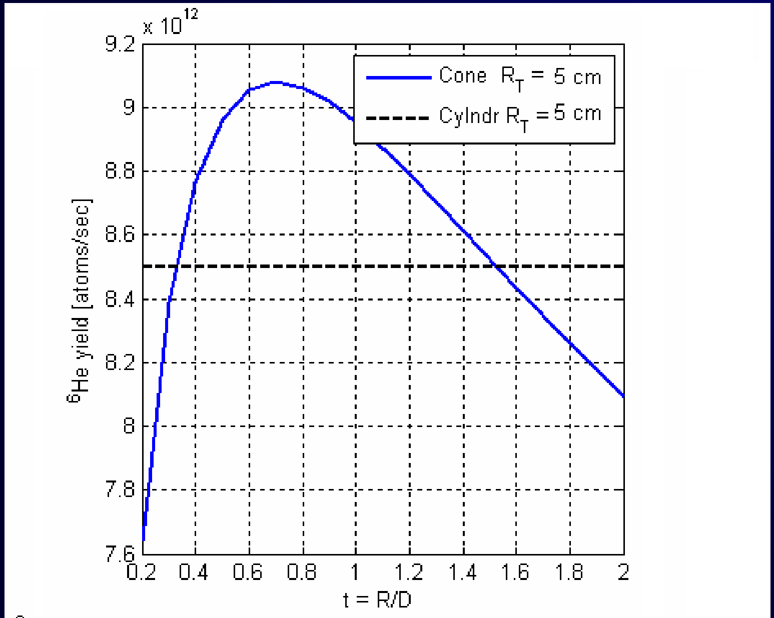
Ion Source

Copy of EURISOL @ DESY much too expensive

Idee von T. Hirsch/M. Hass Weizmann



Ionisation → Bunching → Linac

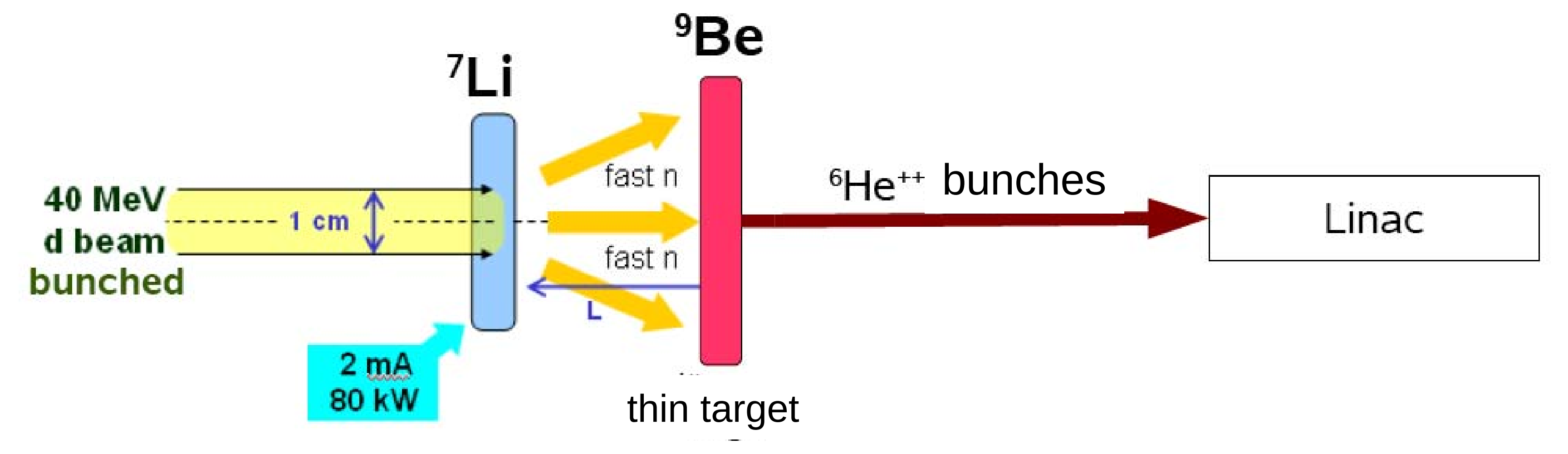


^{6}He production yields for a constant target volume and for different R to D ratios
These results are for a 785.4 cm^3 cone target and for R_T = 5 cm

SARAF @ Soreq NRC: 40 MeV d-Beam 2 mA

Ion Source

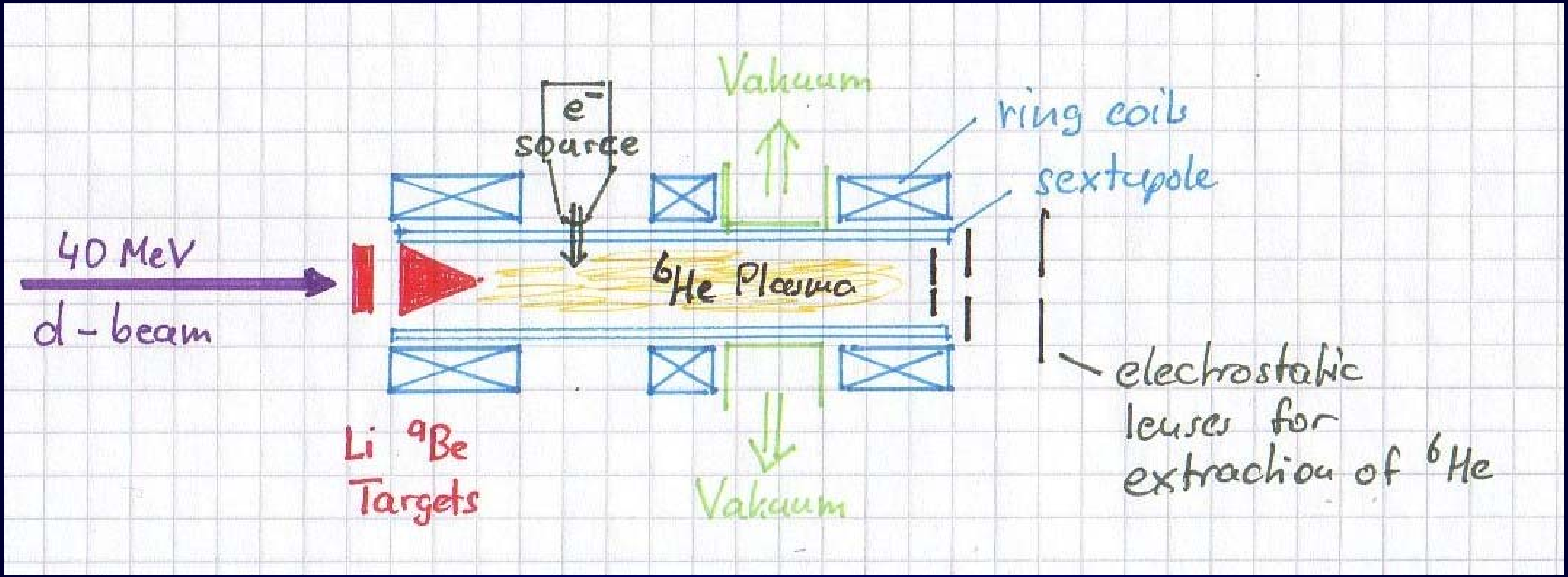
a dream ?



Problem: Puls charge of deuteron beam is too large

Ion Source

A more realistic Idea ?



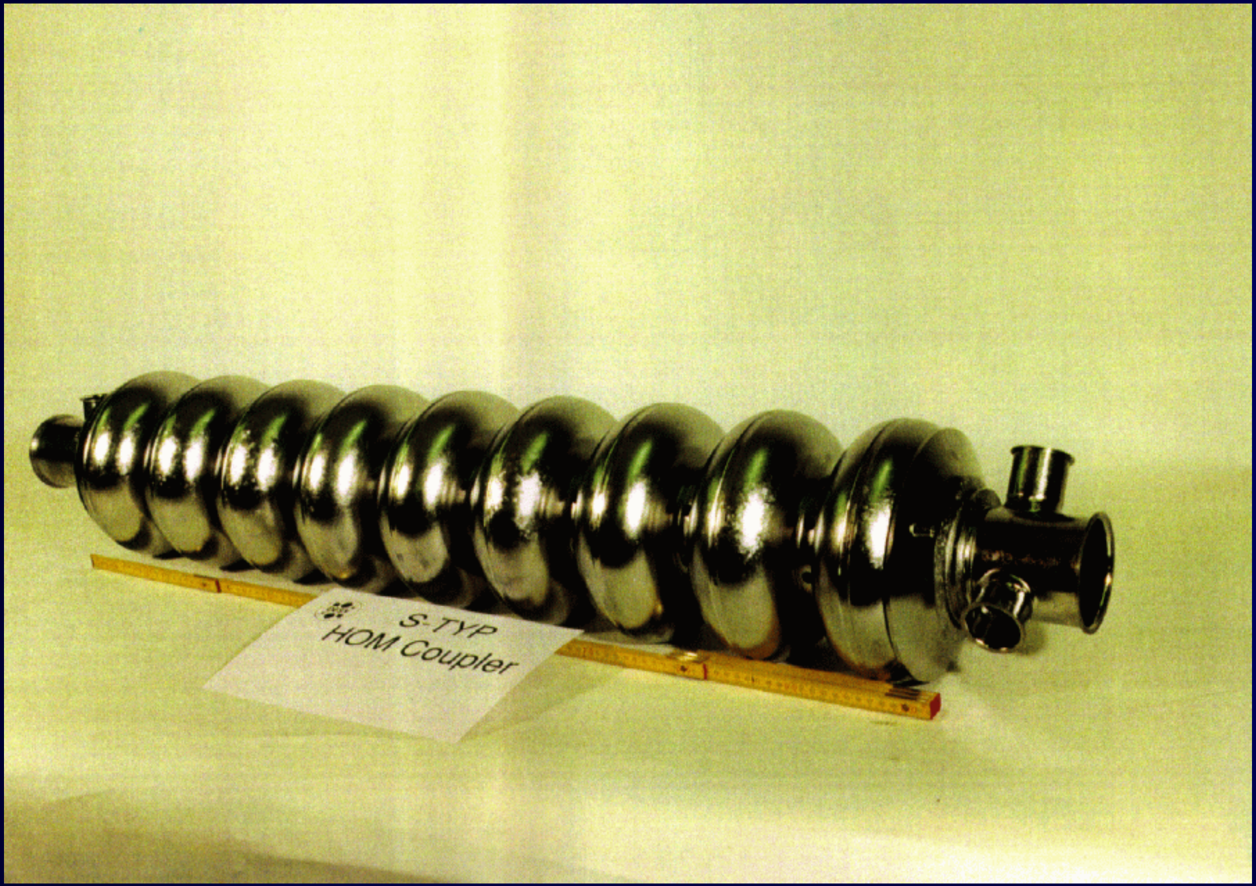
Production of ions at start of the cycle

Ionize and store in the plasma-cell of an ECR-source

Extract bunches with electrostatic lenses as a bunch train

Cavities

TESLA Technology suited ?



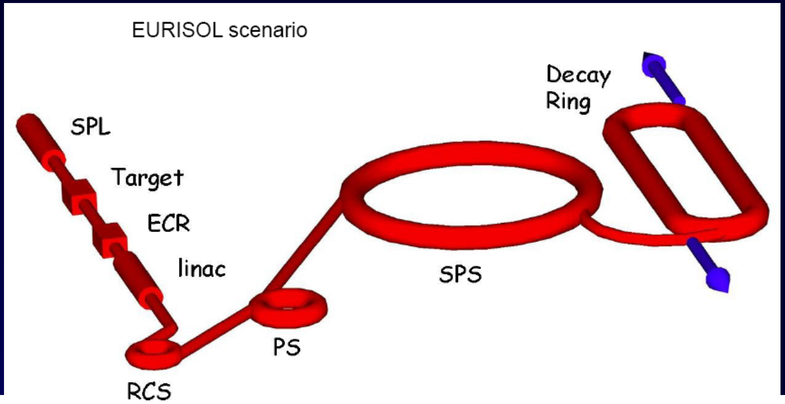
bunch-train similar to
TESLA trains
except
bunch spacing !

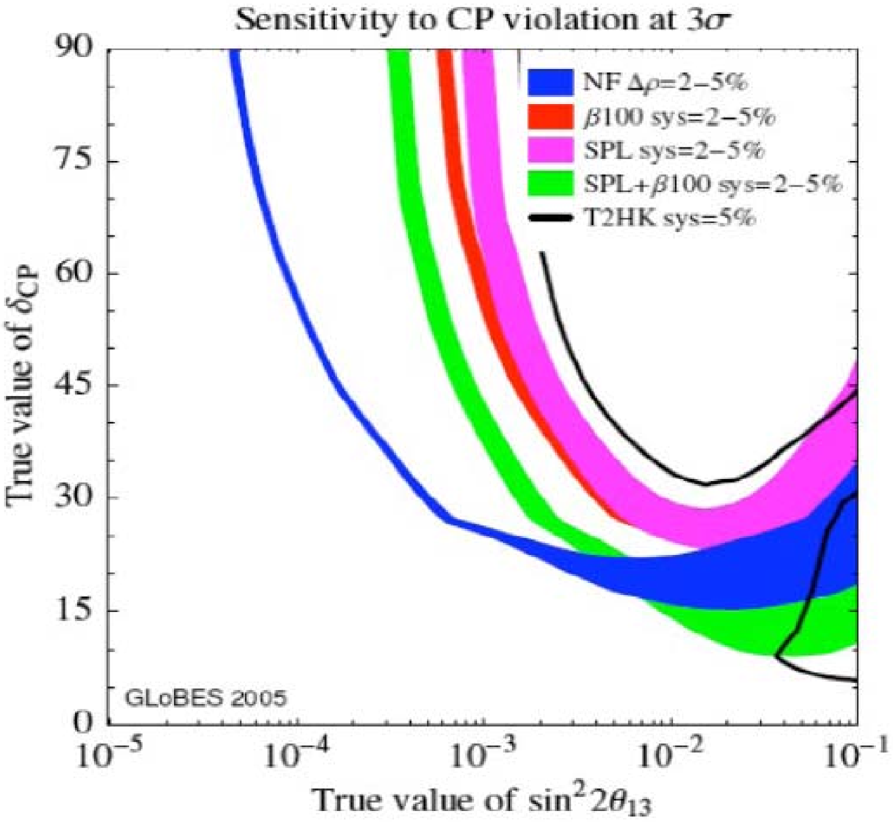
TESLA: 100 m
beta-beam: 92 cm
→ 2.2 A

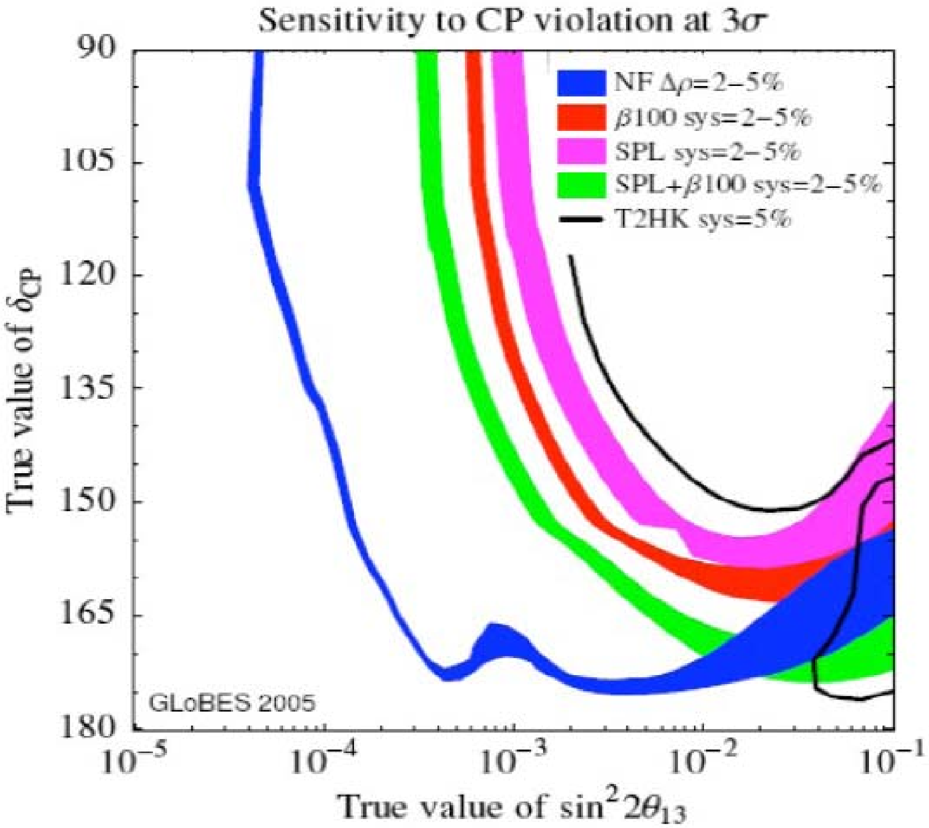
Problem:
Higher Order Modes

Physics Potential

FP6 scenario



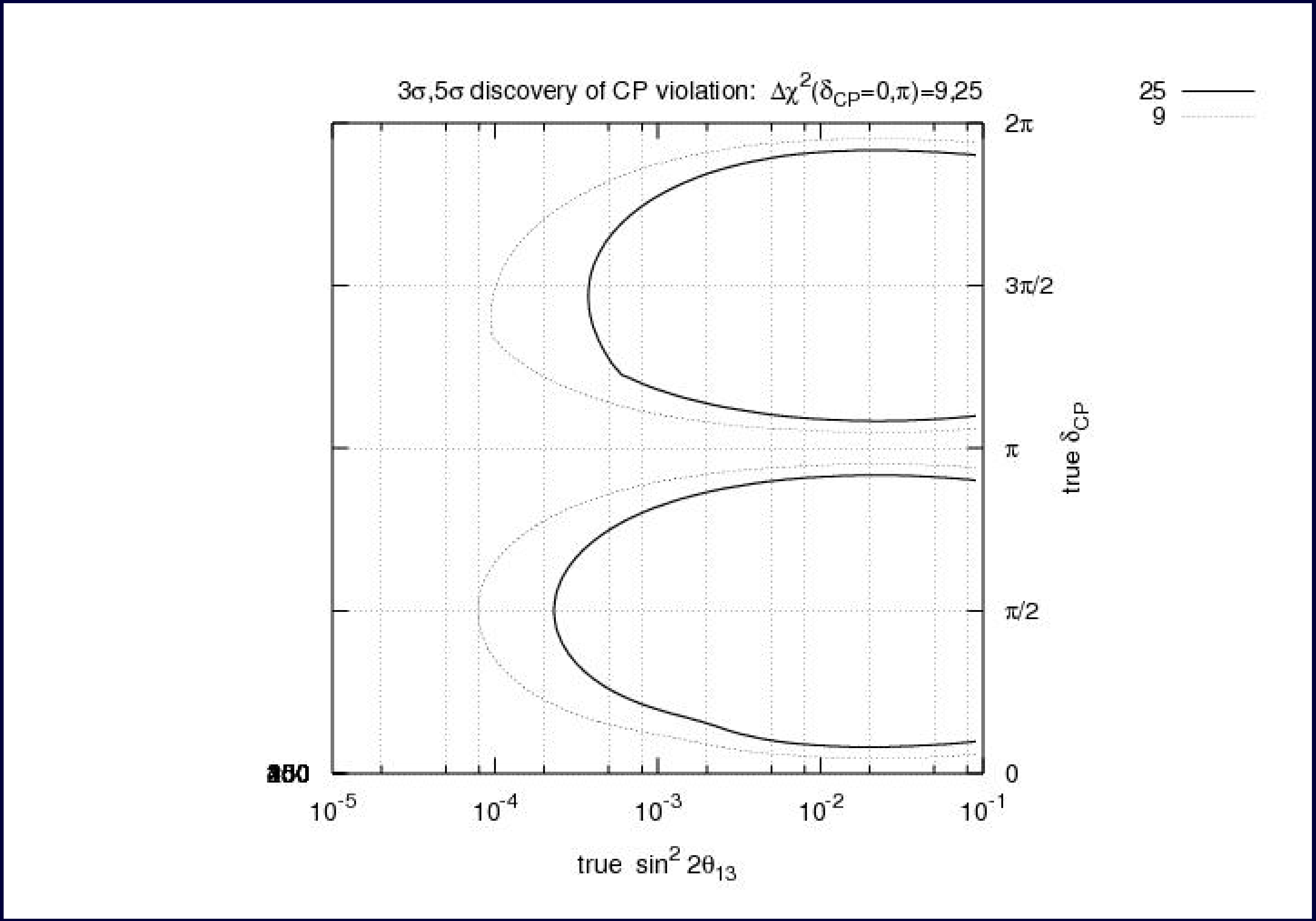




Plots from Walter Winter / Patrick Huber

Physik Potentzial

beta-beam @ DESY
Super-beam from SPL
Water-Cerenkov Det @ Frejus



very similar sensitivity

Status

- FP7 EUROnu Projekt (CERN): WP beta-beams
- Cooperation with Weizmann-Institute on ^{6}He production
  - May 2009: First measurements on ^{6}He production (SARAF ?)
- Compare Physics potential: CERN-Frejus / DESY-Frejus
- Submitted funding request to BMBF:
  - Physics simulation: Verification of Potential (ν-Oscillations)
  - Accelerator: conceptional Layout

Thanks