Imperial College London

K. Long, 1 February, 2007

# ISS summary and IDS

# Contents

- Motivation
- Facilities and timescales
- ISS summary
  - Physics summary
  - Neutrino Factory accelerator baseline
  - Detector baseline
- The IDS initiative
- Conclusions

# Motivation

- Neutrinos in the Standard Model:
  - Neutrinos are massless
    - Helicity distinguishes neutrino and antineutrino
  - Lepton flavour is conserved

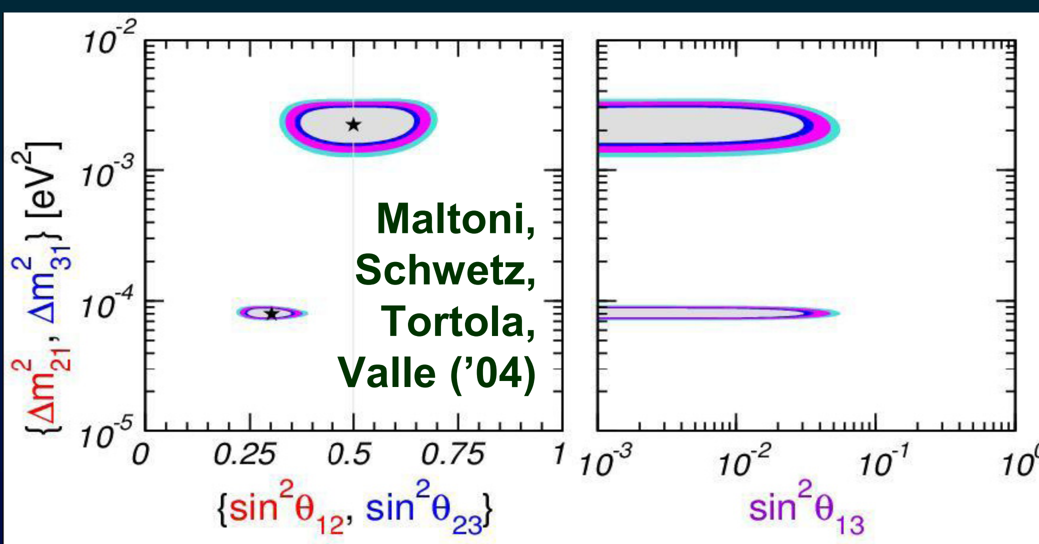
- Neutrino oscillations imply:
  - Neutrino mass is not zero
    - Neutrino is not an eigenstate of helicity
  - Lepton flavour is not conserved

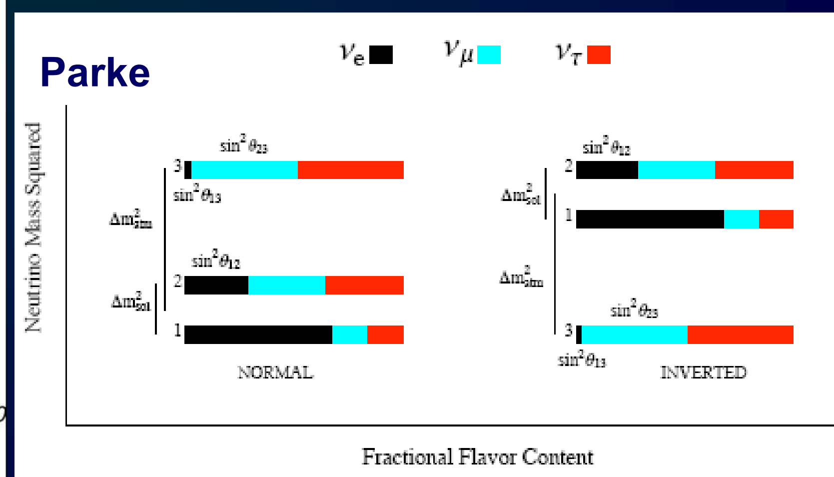
**Extension of the Standard Model?**
**Fundamental breakthrough?**

# SM extension:

- The Standard Neutrino Model (S$\nu$M):
  - Three neutrino mass eigenstates mix to produce three neutrino flavour eigenstates:

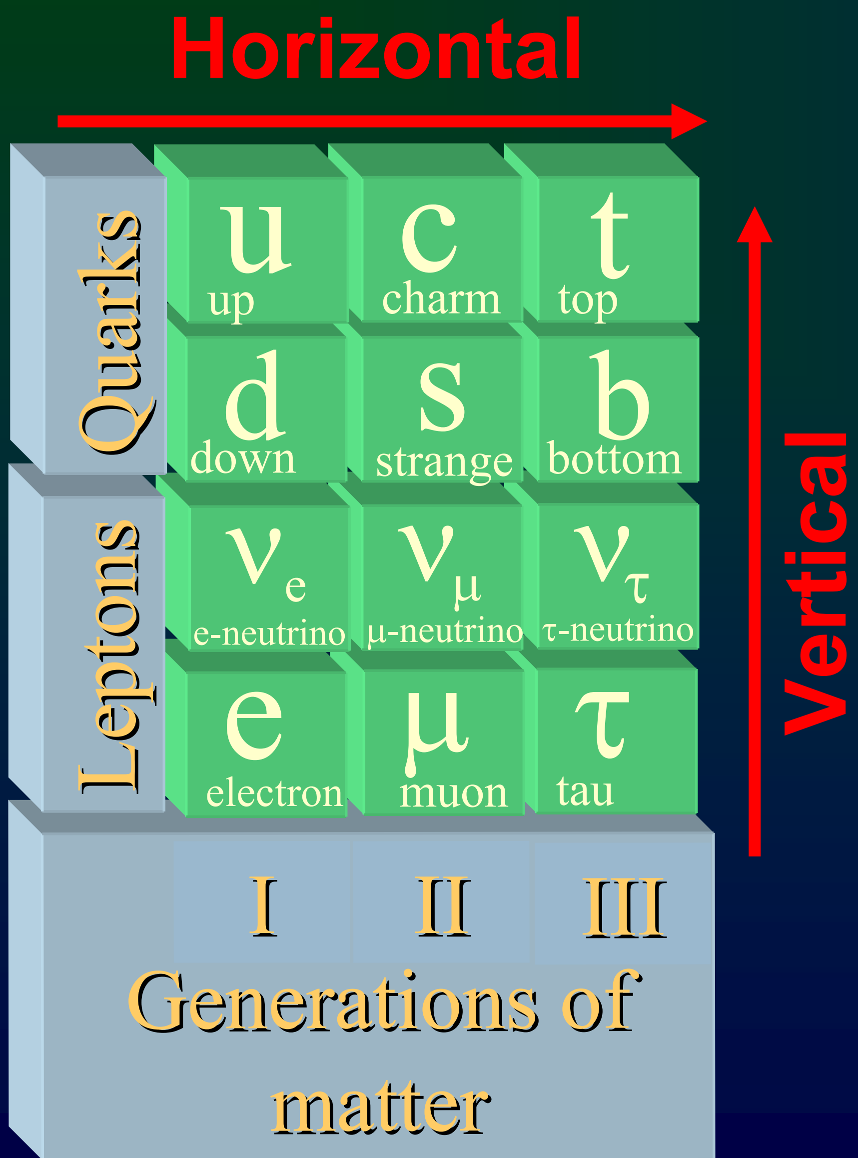
$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix}=\begin{pmatrix}1&0&0\\0&c_{23}&s_{23}\\0&-s_{23}&c_{23}\end{pmatrix}\begin{pmatrix}c_{13}&0&s_{13}e^{i\delta}\\0&1&0\\-s_{13}e^{-i\delta}&0&c_{13}\end{pmatrix}\begin{pmatrix}c_{12}&s_{12}&0\\-s_{12}&c_{12}&0\\0&0&1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$



# Fundamental breakthrough:

- Hierarchies and symmetries




- Properties repeat across generations
- Within generations properties exhibit patterns (e.g. $\Sigma q = 0$)
- Particle masses are hierarchical

**Why?**

# The physics of flavour:

- See-saw mechanism gives a 'natural' explanation of both:
  - Small neutrino mass
  - Large lepton mixing angles

  so neutrino probes physics at very high mass scales
- Create observed baryon asymmetry through heavy, Majorana, neutrinos?

**Detailed understanding of properties of neutrino is required to understand the physics of flavour.**

# Towards specification of required precision

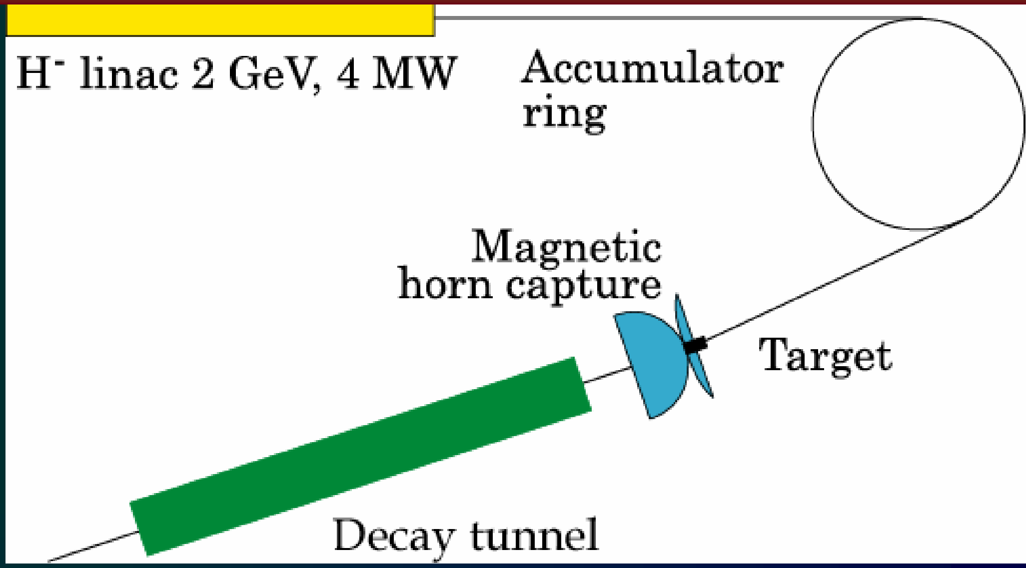
- If *physics of flavour* due to symmetry
  - GUT and/or family

then

- The quark- and lepton-mixing parameters must be related
- For the theory of flavour to be developed measurements must be sufficiently precise to remove the model-builders freedom
- Challenge to neutrino experimenters:
  - Measure neutrino-mixing parameters with a precision similar to the precision with which the quark-mixing parameters are known

# Facilities and timescales

- Second generation super-beam
  - CERN, FNAL, BNL, J-PARC II
    - MTon $H_2O$ Cherenkov



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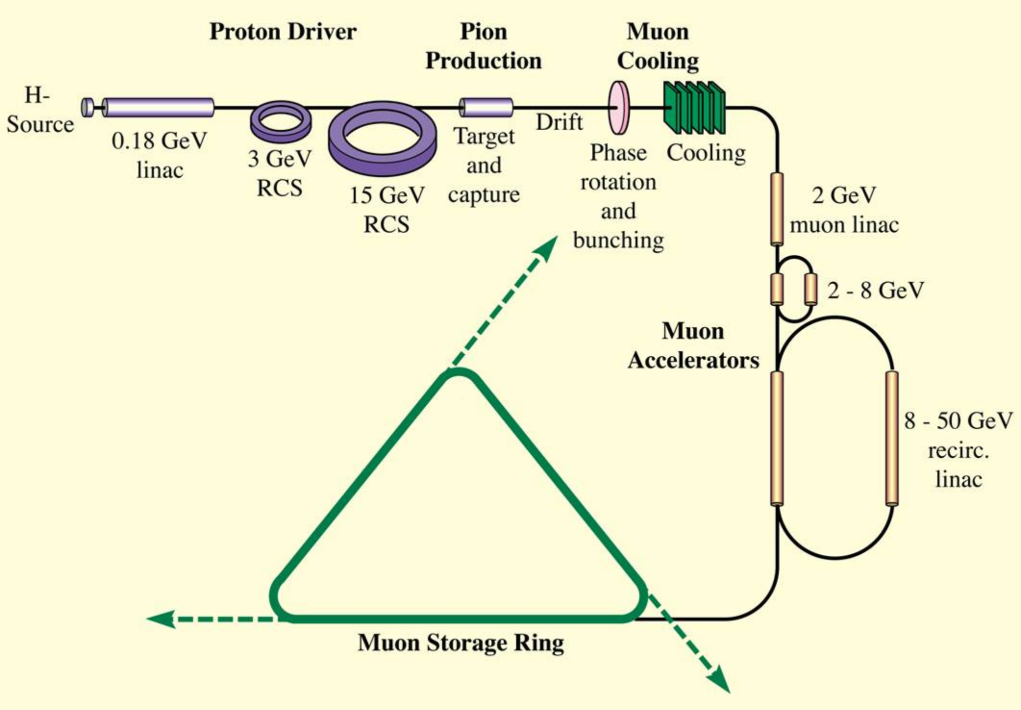
    - Magnetised detector



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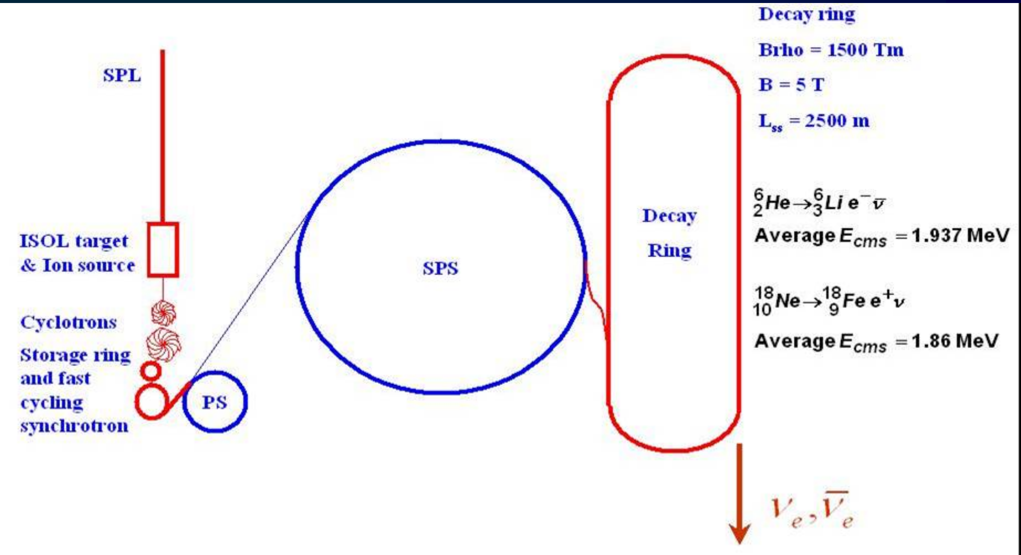
- Beta-beam
    - MTon $H_2O$ Cherenkov, liquid argon



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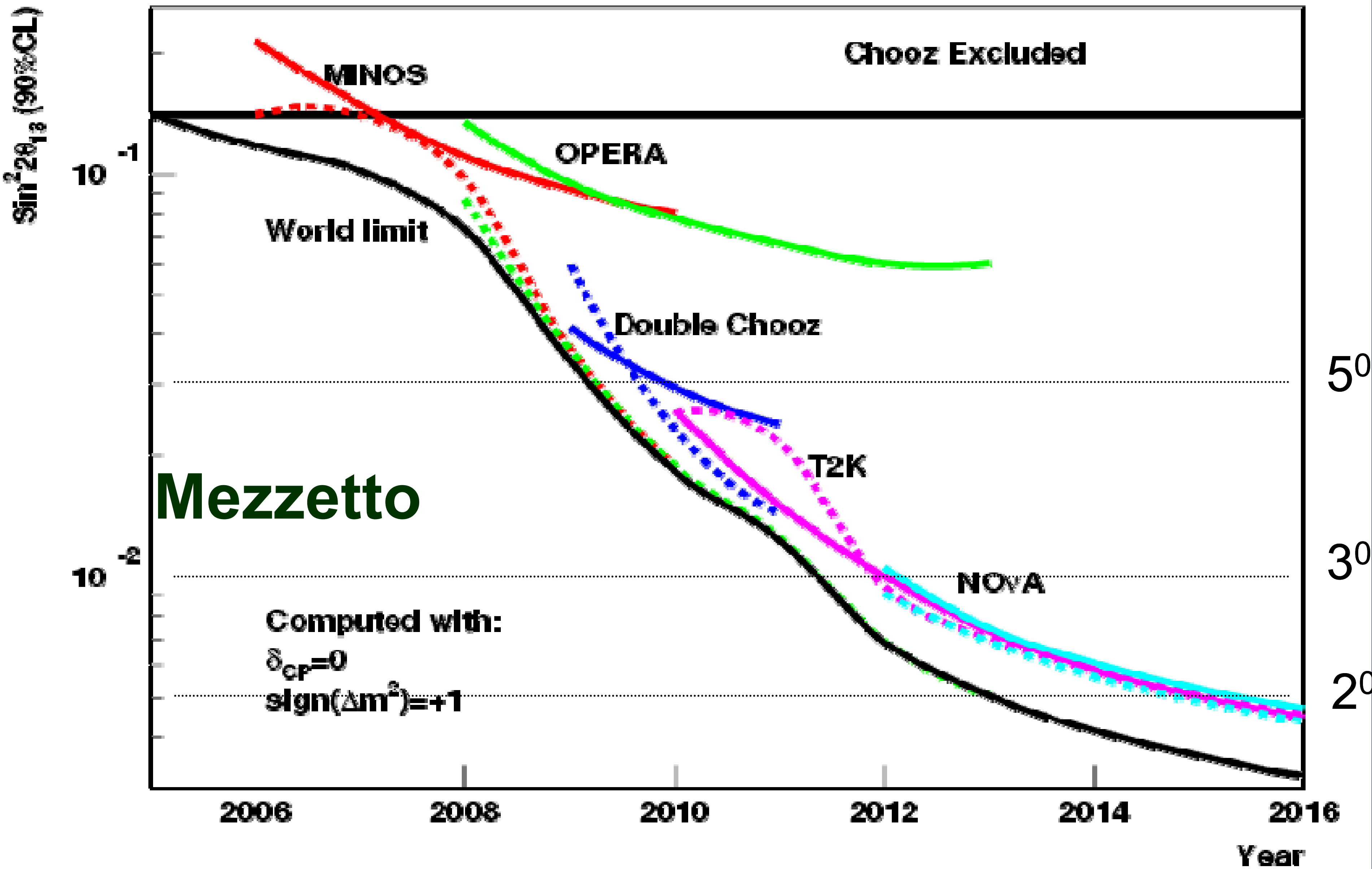
    - MTon $H_2O$ Cherenkov, liquid argon

**Precision-era facility must address:**

- Mass hierarchy
- CP violation
- $\theta_{13}$
- $\theta_{12}$, $\theta_{23}$, $\Delta m_{31}^2$, $\Delta m_{21}^2$
- More over:
  - Is $\theta_{23}$ maximal?
  - Is $\theta_{13}$ zero?
  - Beyond the SνM:
    - NSIs
    - MVNs
    - Sterile neutrinos

# Science-driven timescale:



# Timescale drivers:

- By around 2012 – 2016:
  - MINOS, OPERA, T2K, NOvA, D-Chooz, etc.:
    - Better measurement of $\theta_{12}$, $\theta_{23}$, $\Delta m_{31}^2$, $\Delta m_{21}^2$
    - Measurement of, or improved limit on, $\theta_{13}$
    - Perhaps determination of mass hierarchy

  Time to prepare 'ultimate' neutrino programme
- Ultimate programme likely to require significant *and novel* new facility
- Timely definition of the ultimate programme – the responsibility of the neutrino-physics community
- Hence, the 'International Design Study' initiative:
  - The one-year 'International Scoping Study of a future Neutrino Factory and super-beam facility' (the ISS) was the first step on this road

# The ISS:

- Initiated at NuFact05, concluded at NuFact06:
  - Report now in preparation
- Goals:
  - Critical comparison of the performance of the three options
  - Establish a baseline for the accelerator and detector systems required

  i.e. lay the foundations for a detailed International Design study leading to conceptual design report(s)
- Work of ISS carried out in three working groups:
  - Physics (convener Y. Nagashima, Osaka)
  - Accelerator (convener M. Zisman, LBNL)
  - Detector (convener A. Blondel, Geneva)
  - Overall coordination via Programme Committee chaired by P. Dornan, Imperial

# Performance comparison

- Second-generation super-beam
  - Options considered:
    - SPL → Frejus: 10 year exposure, on-axis beam
      - Proton beam energy: 2.2/3.5 GeV; neutrino energy: ~0.3 GeV
      - Baseline ~130 km
    - J-PARC → HyperKamiokande: 10 year exposure off-axis beam
      - Proton beam energy: 50 GeV; neutrino energy: ~0.6 GeV
      - Baseline ~295 km
      - T2KK — one detector in Japan, second in Korea

E. Fernandez
J.E. Champagne
T. Schwetz

- Beta beam
  - Options considered:
    - Gamma 100; baseline 130 km
    - Gamma 350; baseline 730 km
    - Fluxes:
      - He — $2.9 \times 10^{18}$ decays per year
      - Ne — $1.1 \times 10^{18}$ decays per year

E. Couce
P. Hernandez
M. Mezzetto
T. Schwetz

- Neutrino Factory

# Neutrino Factory performance:

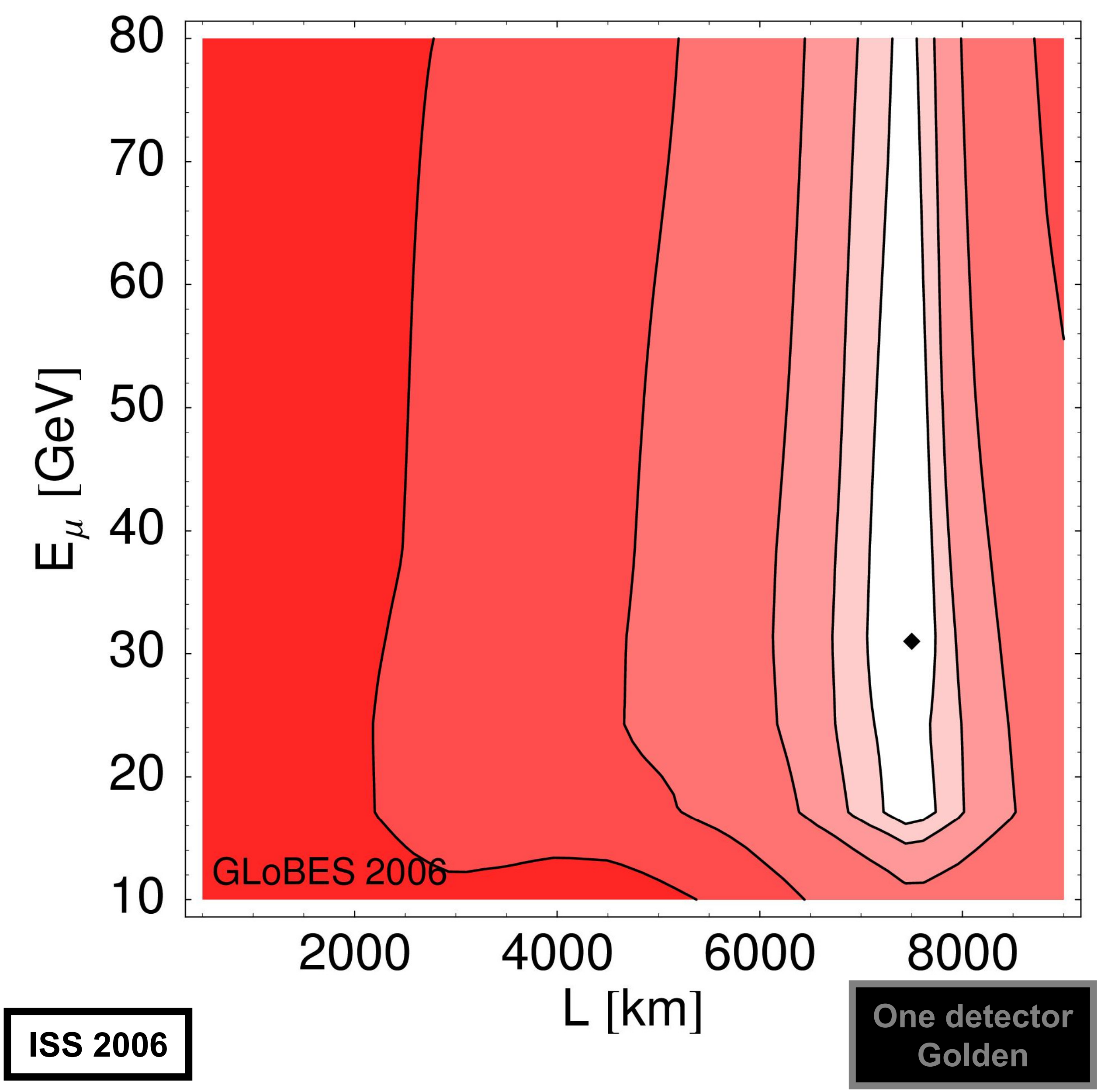
| $\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$ | $\mu^- \rightarrow e^- \overline{\nu}_e$ | |
|---|---|---|
| $\overline{\nu}_\mu \rightarrow \bar{\nu}_\mu$ | $\nu_\mu \rightarrow \nu_\mu$ | disappearance |
| $\overline{\nu}_\mu \rightarrow \bar{\nu}_e$ | $\nu_\mu \rightarrow \nu_e$ | appearance (challenging **"platinum"** |
| $\overline{\nu}_\mu \rightarrow \bar{\nu}_\tau$ | $\nu_\mu \rightarrow \nu_\tau$ | appearance (atm. oscillation) |
| $\nu_e \rightarrow \nu_e$ | $\bar{\nu}_e \rightarrow \bar{\nu}_e$ | disappearance |
| $\nu_e \rightarrow \nu_\mu$ | $\bar{\nu}_e \rightarrow \bar{\nu}_\mu$ | appearance: "golden" channel |
| $\nu_e \rightarrow \nu_\tau$ | $\bar{\nu}_e \rightarrow \bar{\nu}_\tau$ | appearance: "silver" channel |

**"Golden"**

- **Reference Neutrino Factory:**
  - $10^{21}$ useful decays/yr; exposure '5 plus 5' years
  - 50kTonne magnetised iron detector (MID) with MINOS performance
  - Backgrounds (for golden channel):
    - Right-sign muons
    - Charm decays
  - $E_{res} \sim 0.15 * E_\nu$
  - variable $E_\nu$ bins, efficiency and migration matrices

**P. Huber, M. Lindner M. Rolinec W. Winter, A. Donini, et al.**

# NF: Golden channel optimisation




ISS 2006

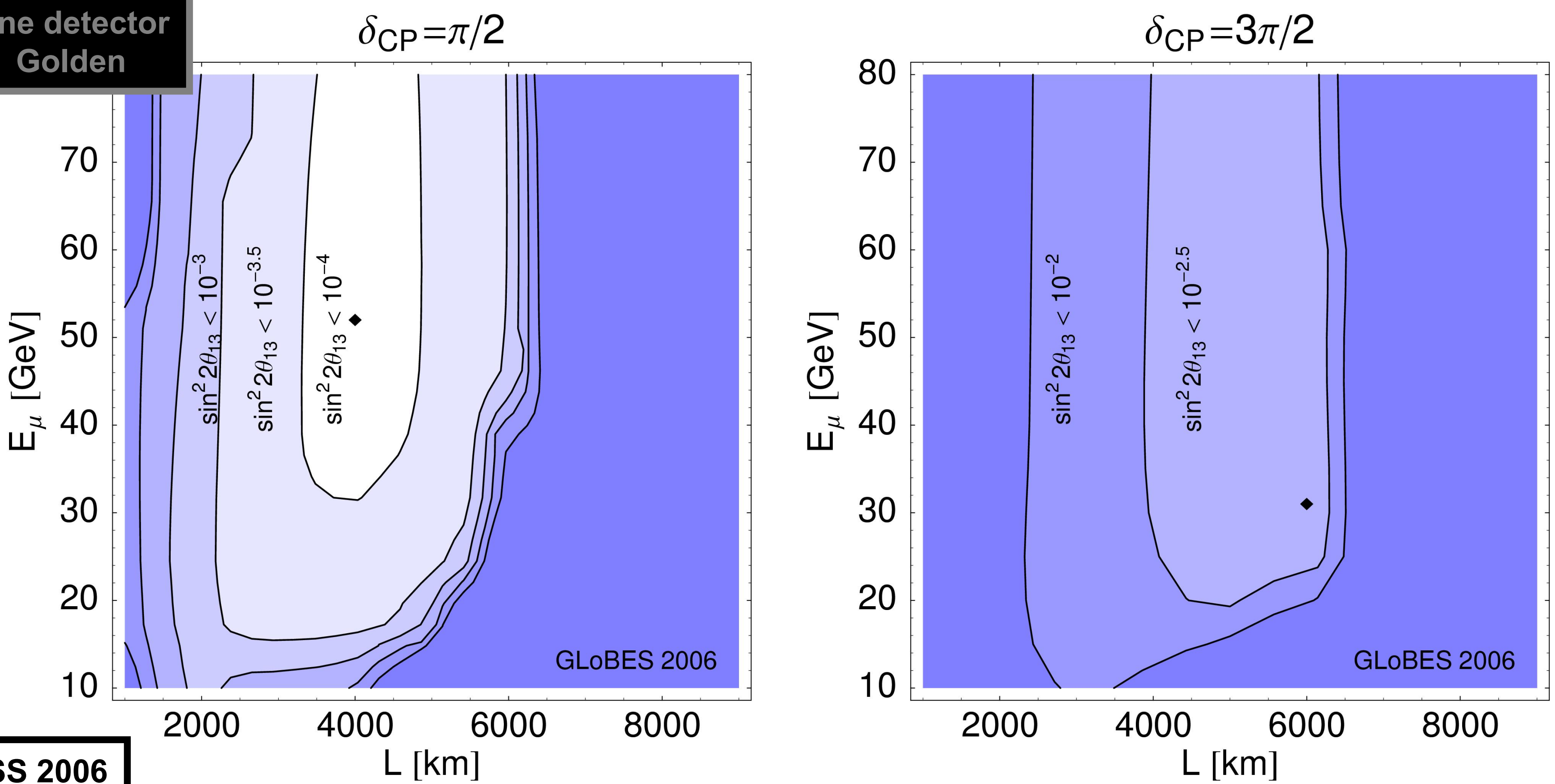
**$\sin^2 2\theta_{13}$: 5σ sensitivity**

- **Magic baseline (7500 km) good degeneracy solver**
- **Stored muon energy > 20 GeV**

# NF: Golden channel optimisation

## CP violation: 3σ sensitivity

One detector
Golden

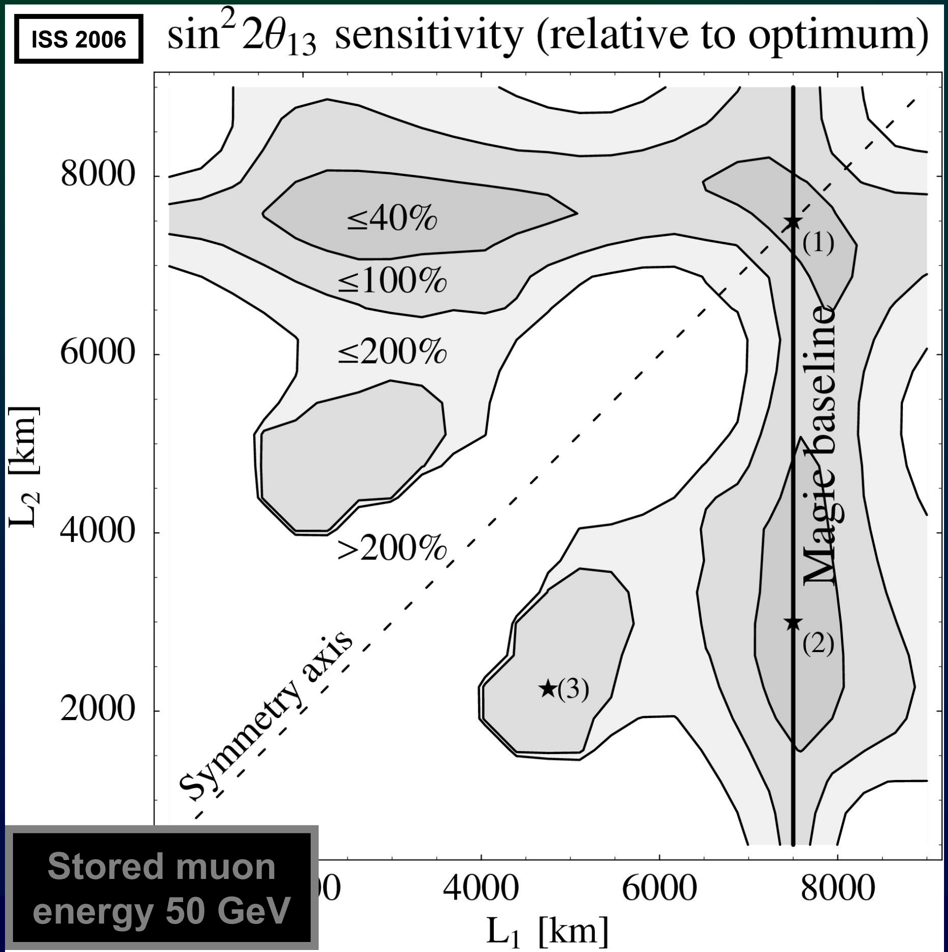



ISS 2006

- **Baseline: 3000 – 5000 km**
- **Stored-muon energy > 30 GeV**

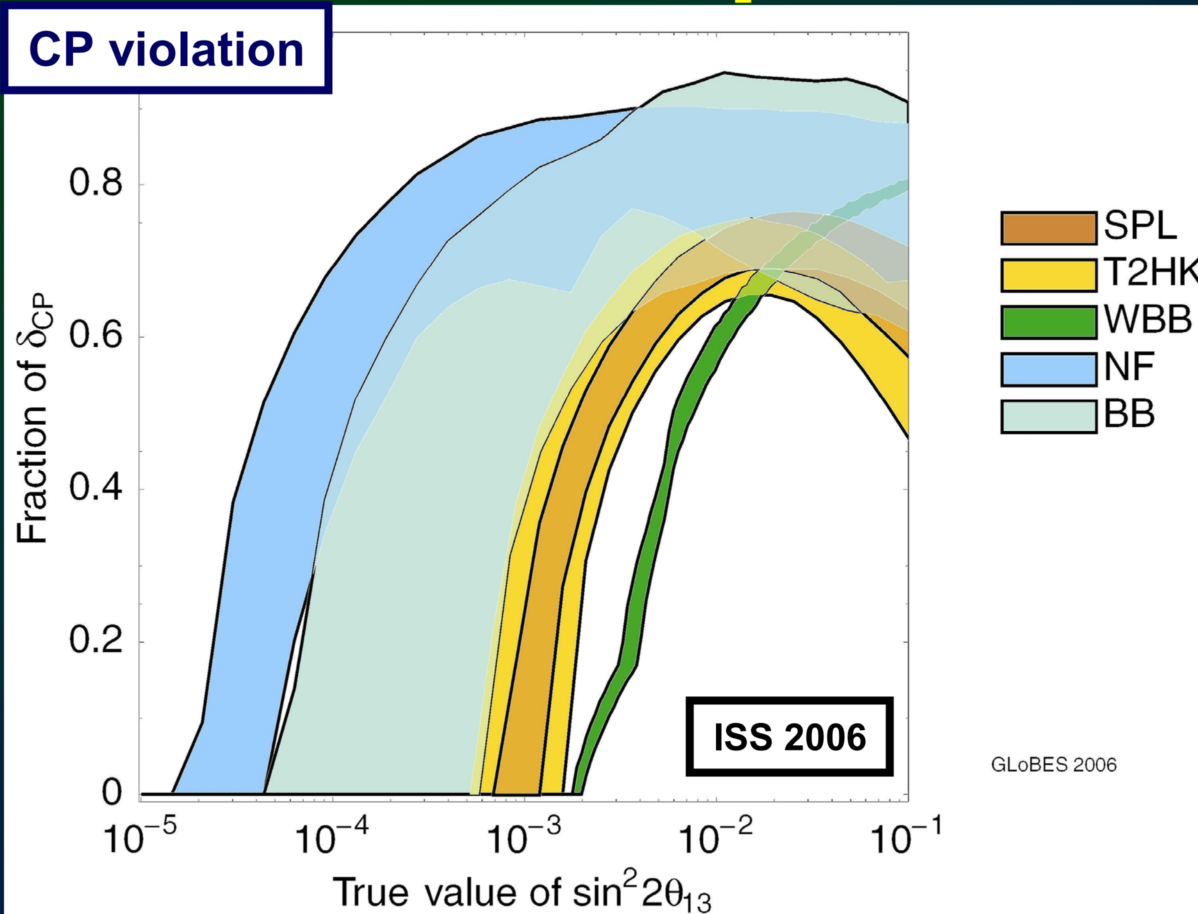
# NF: Multiple baselines:

- Plot performance for two 25kT detectors relative to the performance for one 50 kT detector at the magic baseline




**Second detector at ~3000 km preferred as it has sensitivity to CP violation**

# Comparison: CP violation




**SPL**
Systematics: 2% – 5%

**T2HK**
Systematics: 2% – 5%

**WBB**
Systematics from proposal

**Beta beam**

$\gamma$ = 100
500 kT $H_2O$ Ç (130 km)

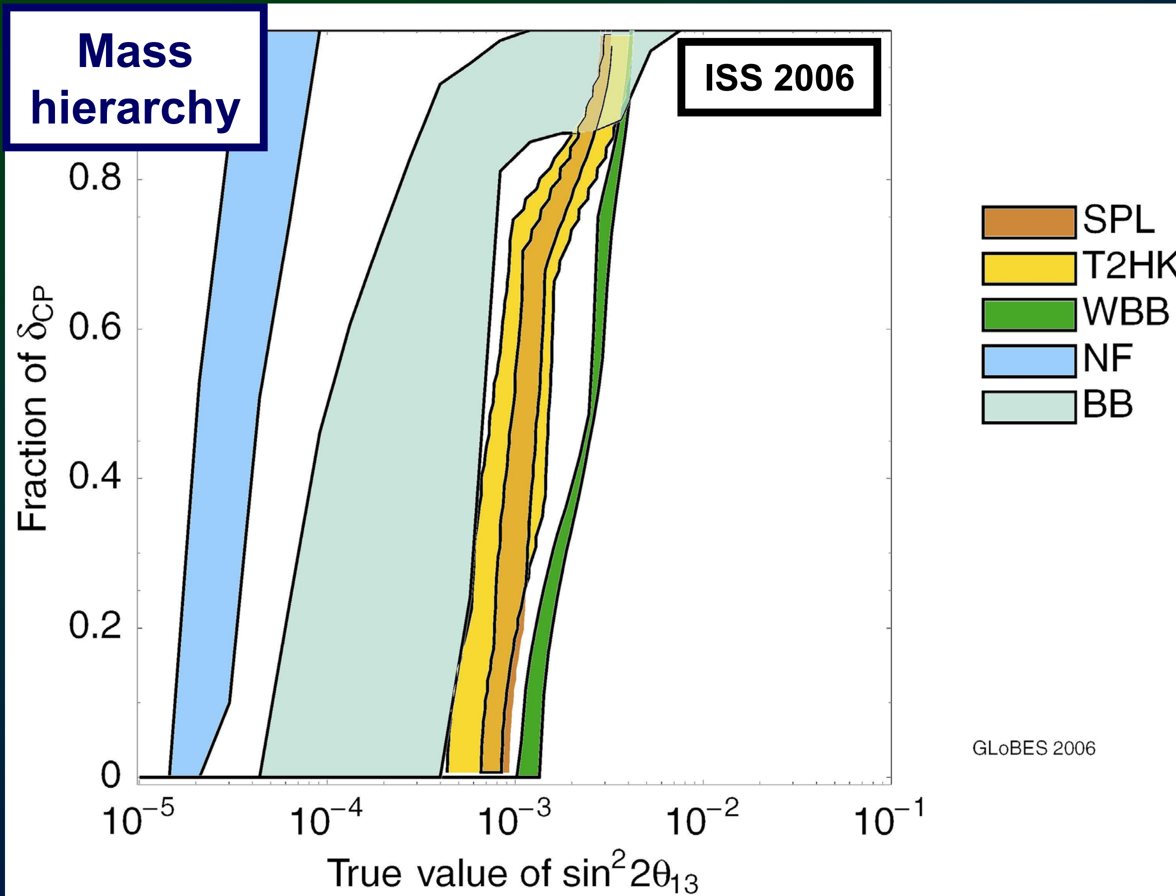
$\gamma$ = 350
500 kT $H_2O$ Ç (730 km)

**Neutrino Factory**

Golden, 4000,
$E_\mu$ = 50 GeV

Golden* (4000 km), Golden* (7500 km)
$E_\mu$ = 20 GeV

# Comparison: mass hierarchy

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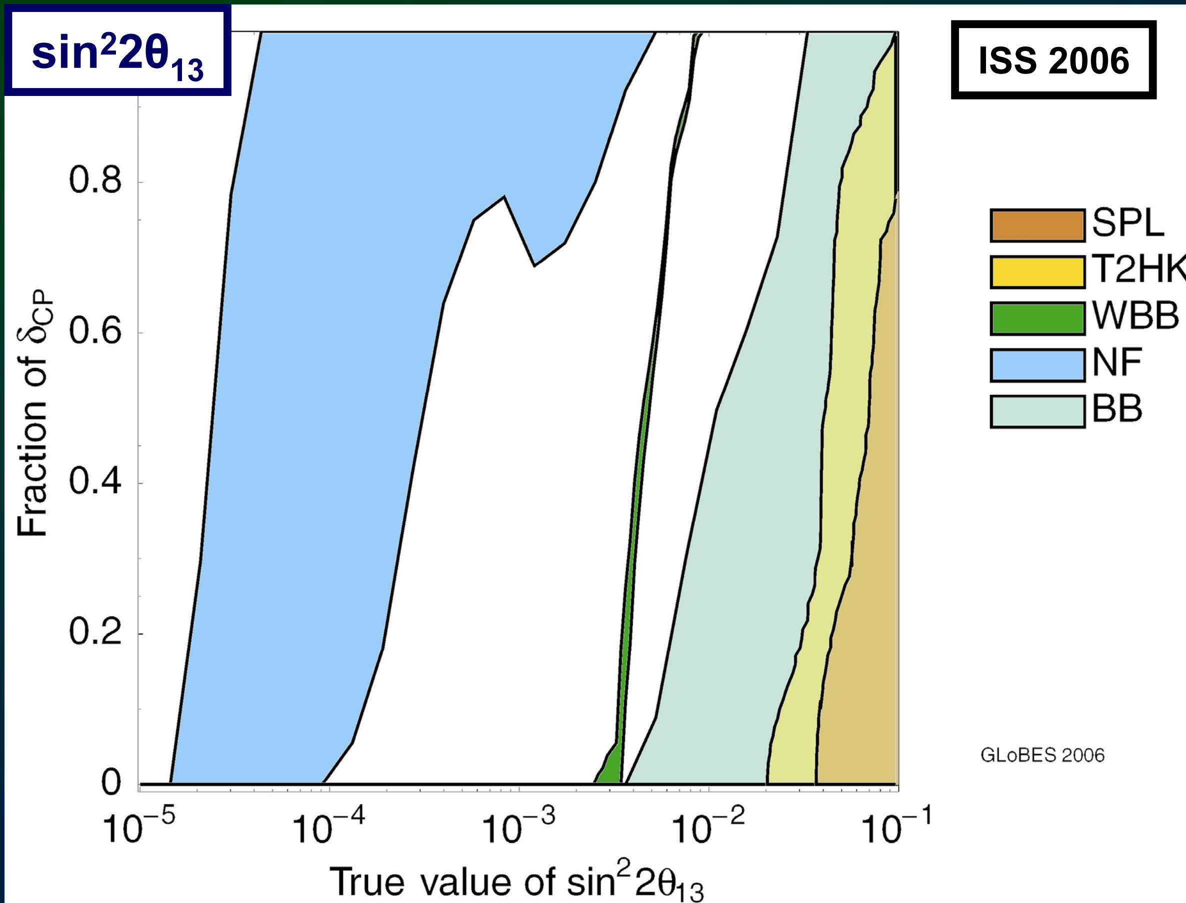
**$E_\mu$ = 20 GeV**

# Comparison: $\theta_{13}$

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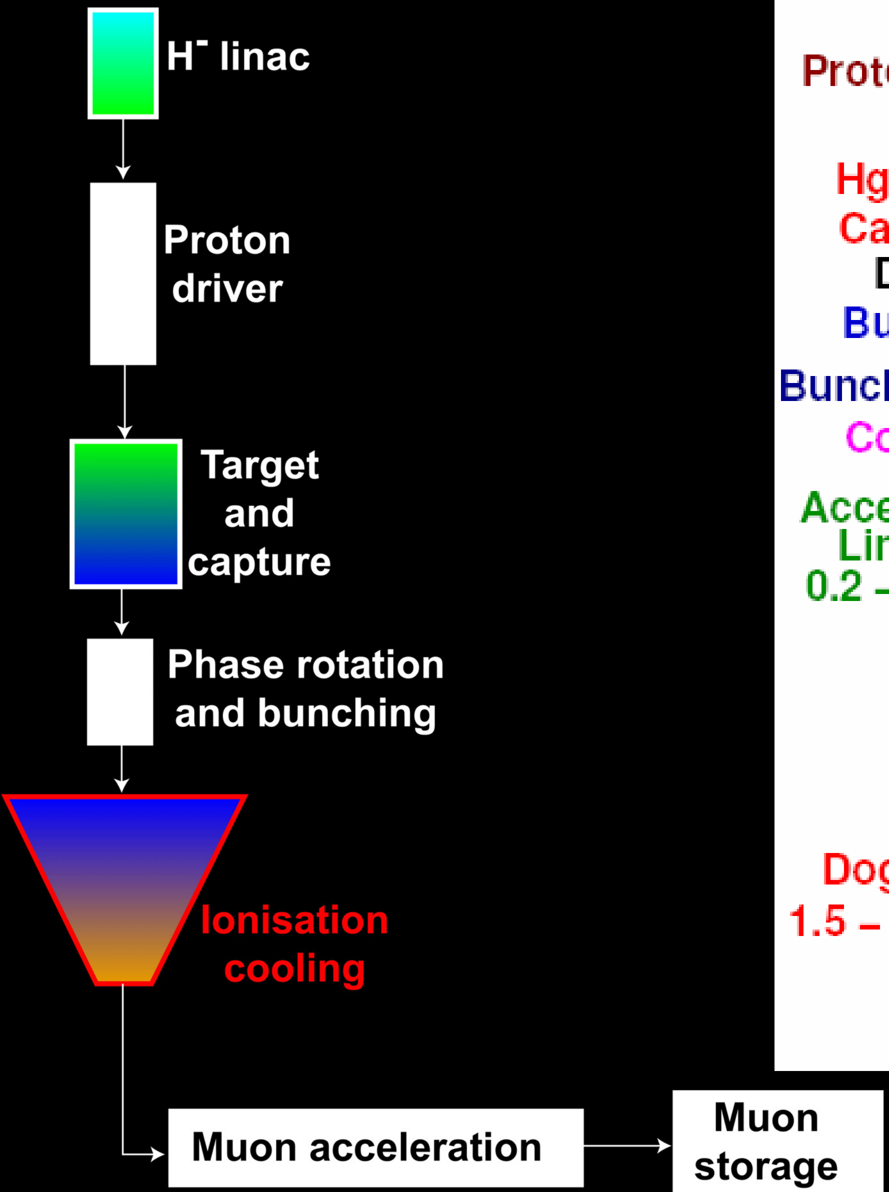
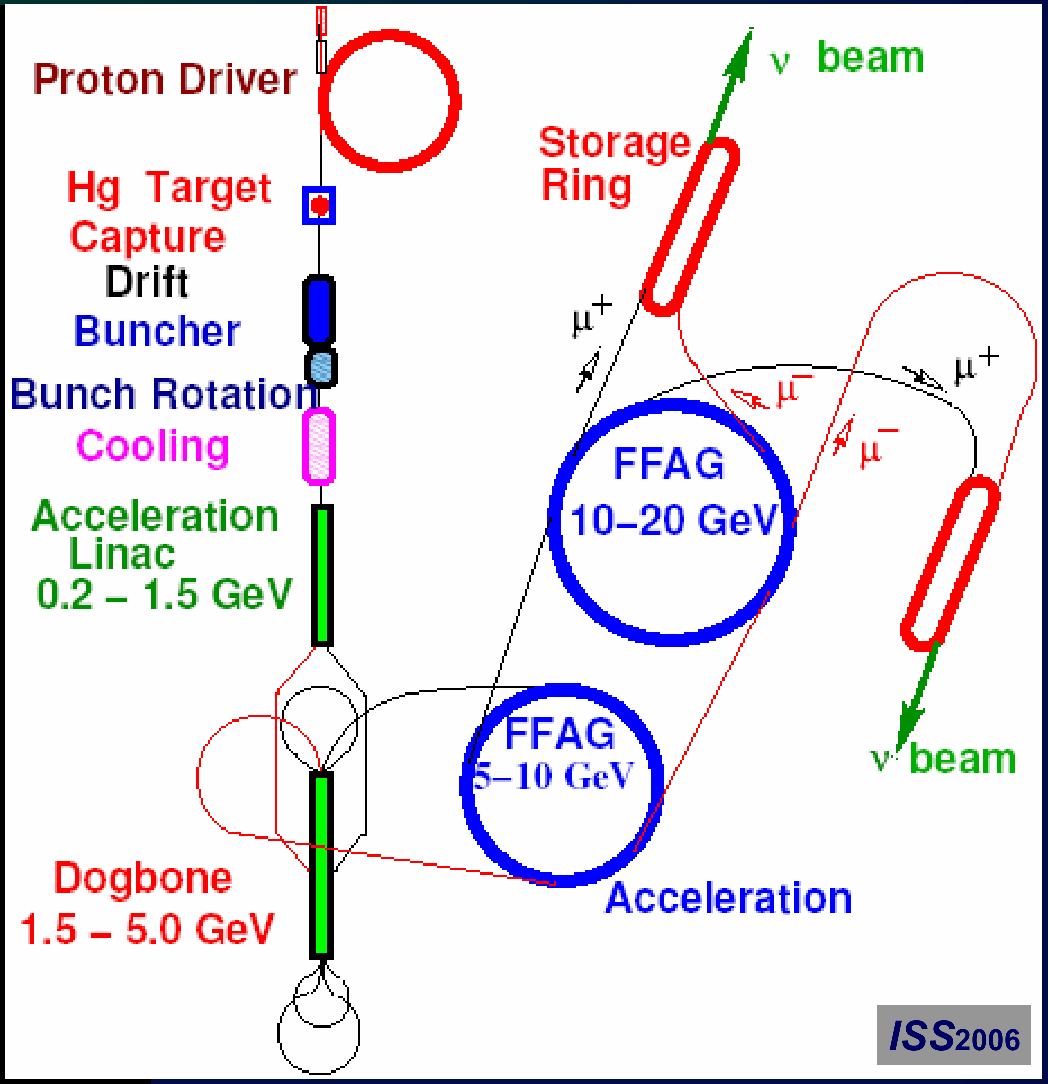
# Comparison conclusions

- Compelling case for precision neutrino programme
  - Develop and evaluate methods to discriminate between theories describing the Physics of Flavour
  - Evaluate contribution a muon-physics programme can make
- Extensive performance evaluation of super-beam, beta-beam, and Neutrino Factory options:
  - Large $\theta_{13}$: $\sin^2 2\theta_{13} > 10^{-2}$
    - Comparable sensitivity
      - $\Rightarrow$ need to include cost and schedule considerations in evaluating optimum
  - Intermediate $\theta_{13}$: $5 \times 10^{-4} < \sin^2 2\theta_{13} < 10^{-2}$
    - Neutrino Factory better, beta beam competitive
      - $\Rightarrow$ need to include cost and schedule considerations in evaluating optimum
  - Low $\theta_{13}$: $\sin^2 2\theta_{13} < 5 \times 10^{-4}$
    - With present assumptions Neutrino Factory out-performs other options
      - $\Rightarrow$ need to include cost and schedule considerations in evaluating optimum

**Clear motivation to move from ISS phase to full 'International Design Study' phase**

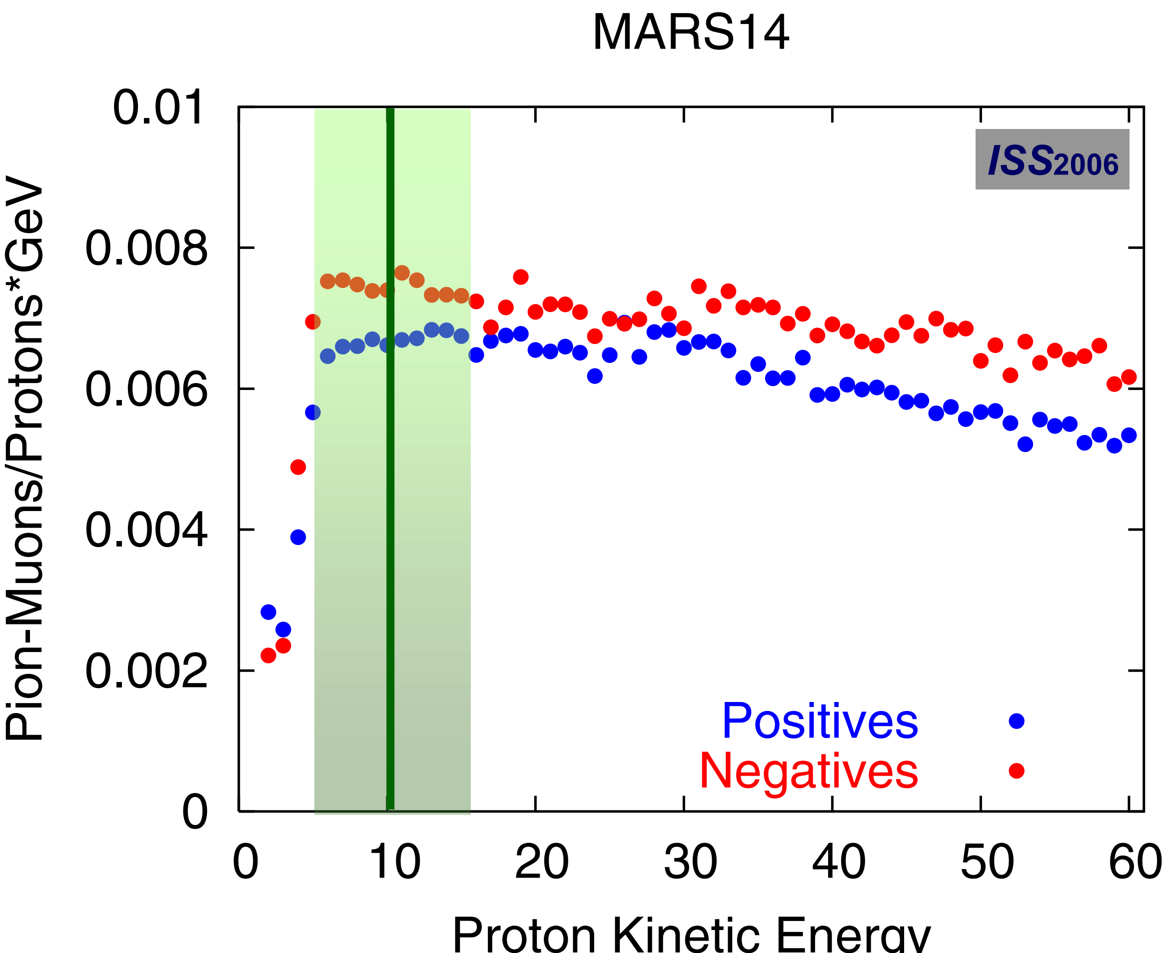
# Neutrino Factory: ISS baseline



# Proton-driver baseline: energy

- Optimum energy for high-*Z* targets is broad, but drops at low-energy

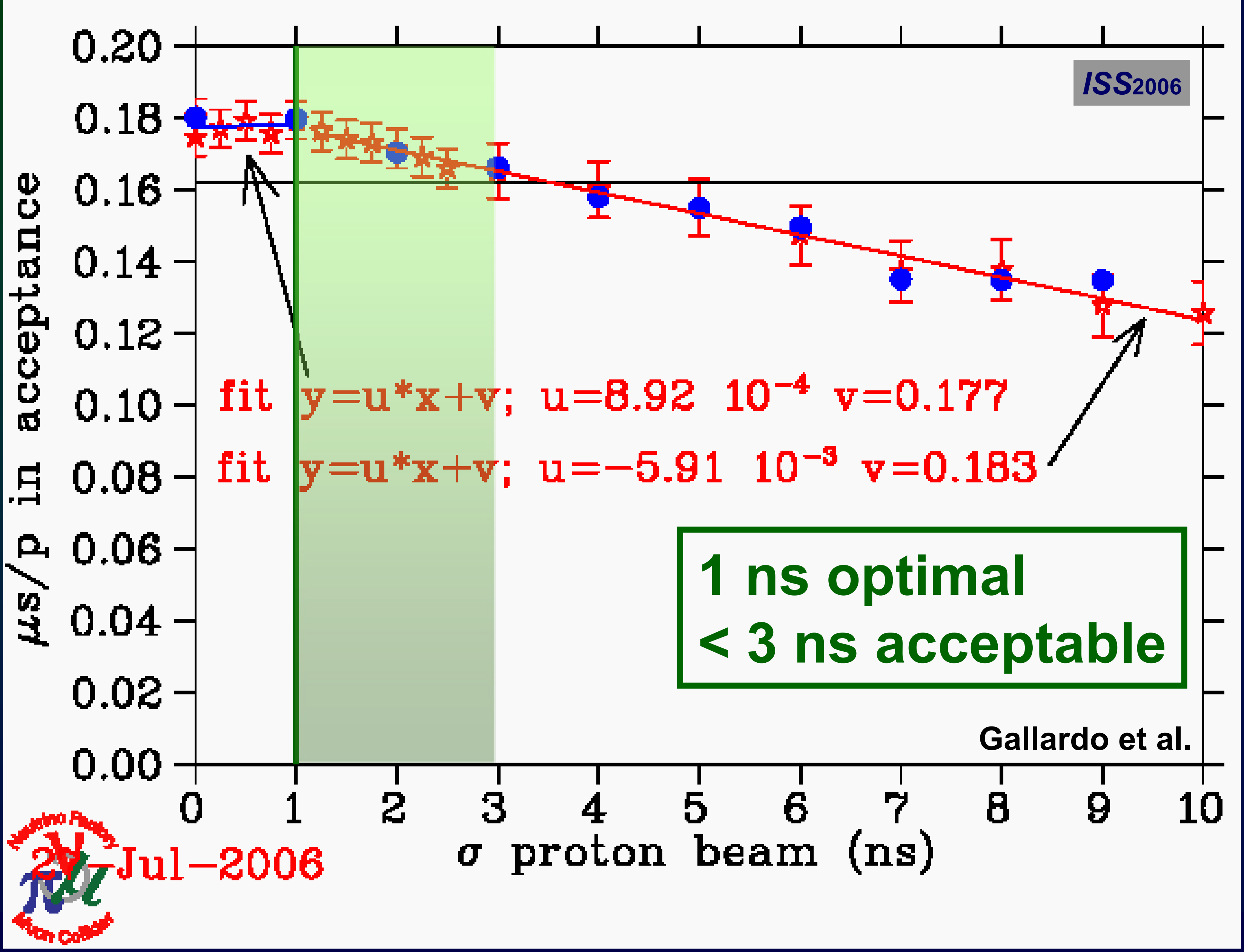



$\mu^-$: 6 – 11 GeV

$\mu^+$: 9 – 19 GeV

We adopted 10 ± 5 GeV as representative range

# Proton-driver baseline: bunch length



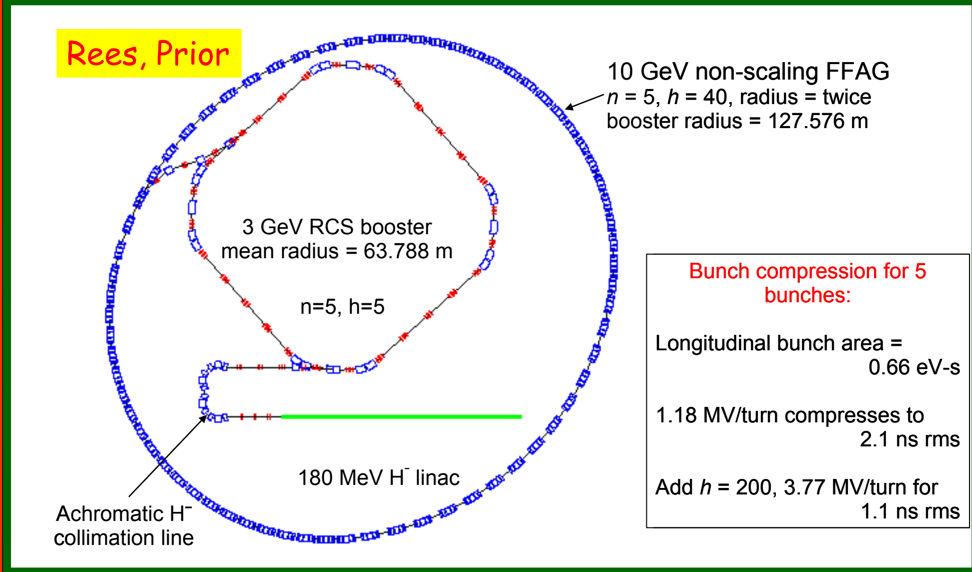
# Proton-driver baseline:

- Proton Driver
  - specify parameters, not design
    - implicitly assumes liquid-metal target

| Parameter | Value |
|---|---|
| Energy (GeV) | 10 ± 5 |
| Beam power (MW) | 4 |
| Repetition rate (Hz) | ≈50 |
| No. of bunch trains | 3,5[a)] |
| Bunch length, rms (ns) | 2 ± 1 |
| Beam duration[b)] (μs) | ≈40 |

[a)] Values ranging from 1–5 possibly acceptable.
[b)] Maximum spill duration for liquid-metal target.

- Options:
  - FFAG
  - RCS
  - Linac



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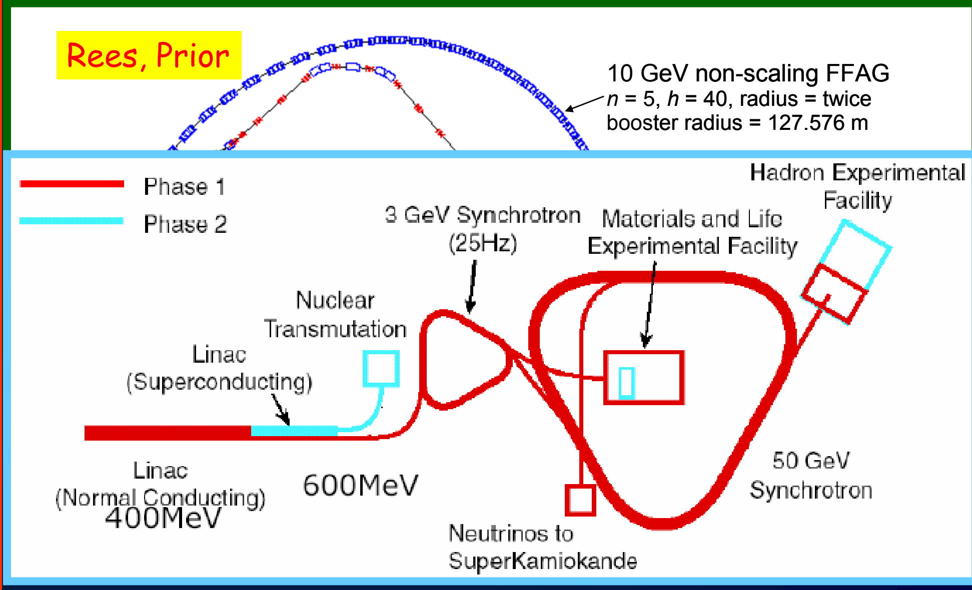

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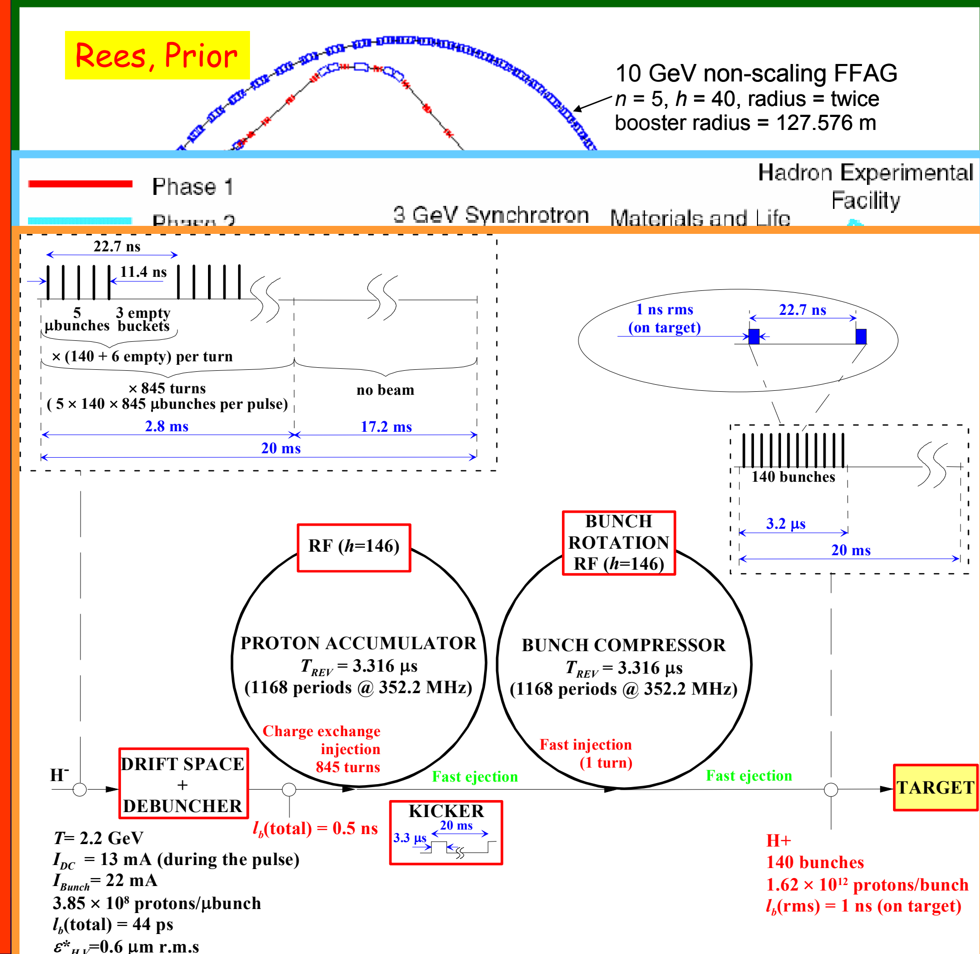
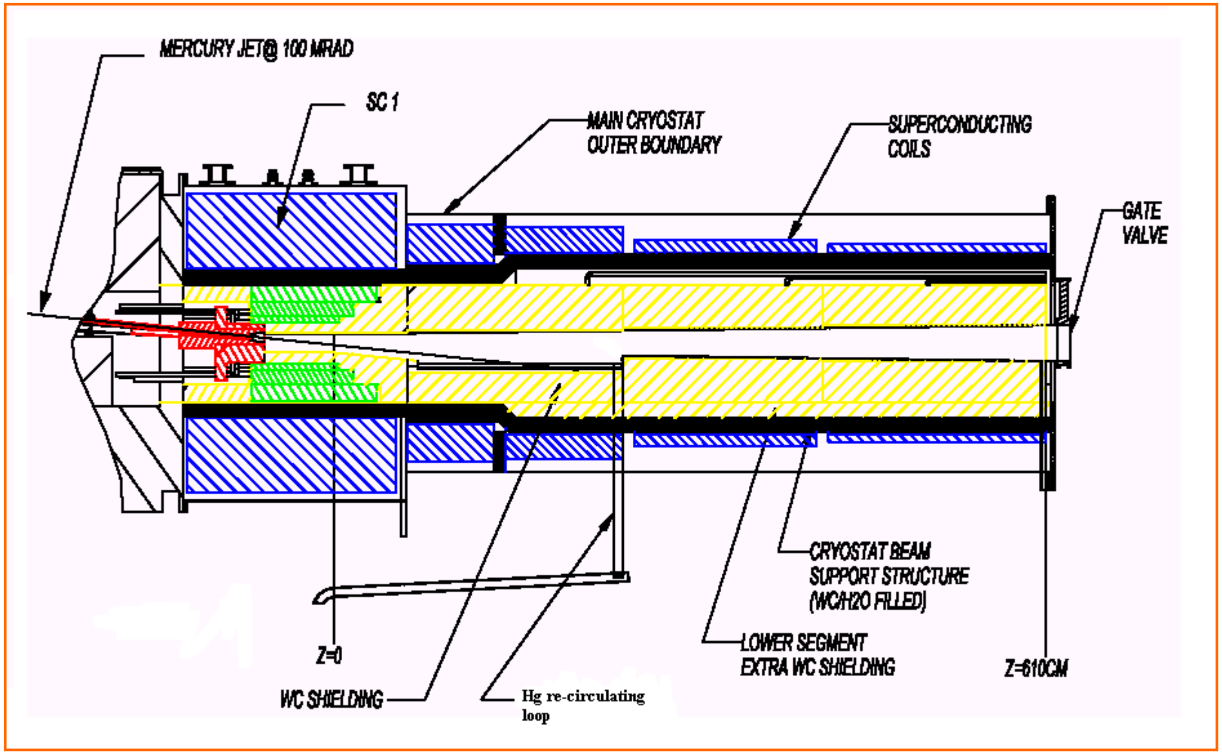


# Target baseline:

• Neutrino Factory solenoid capture system

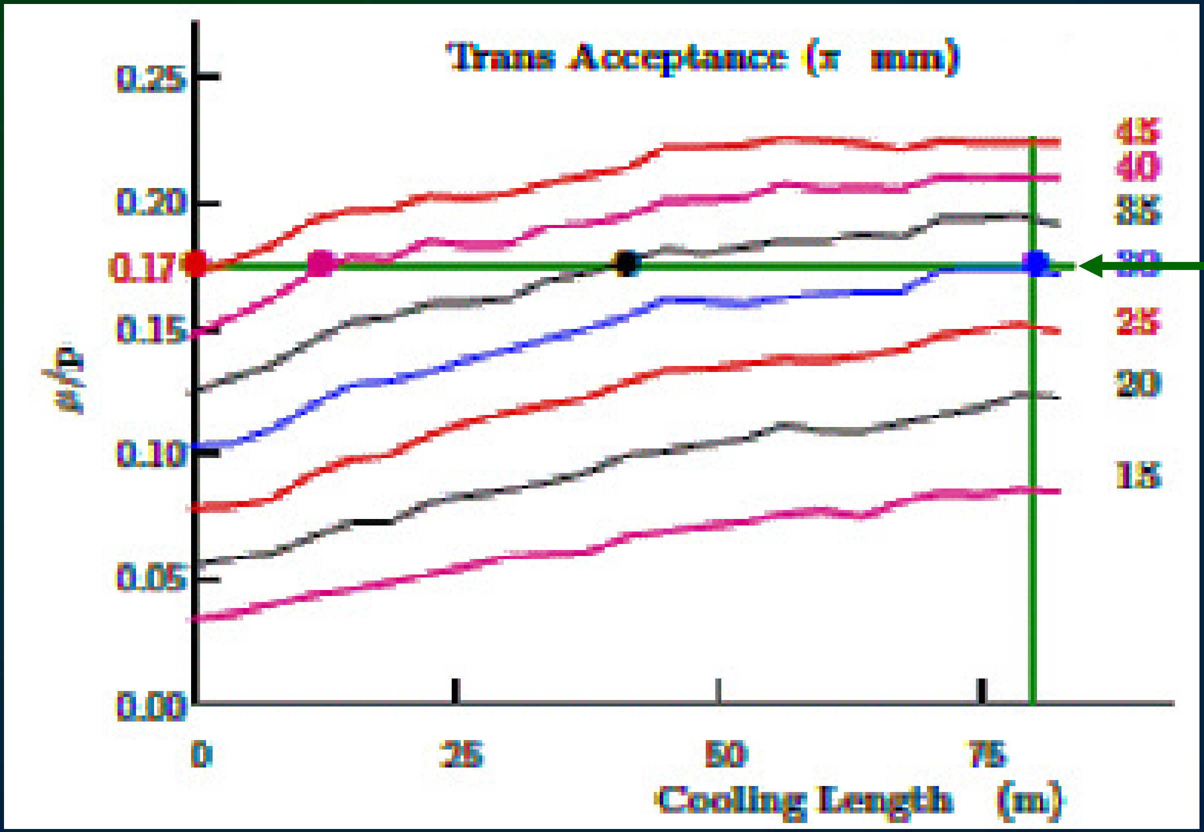



Tapers from 20 T, 15 cm to 1.75 T, 60 cm over 20 m

**Solenoid: captures both signs**

- Optimum material study performed:
  - Liquid mercury, baseline (consider PbBi)
- Operation at 4 MW:
  - Limitation from target or from beam dump …

# Cooling vs acceptance



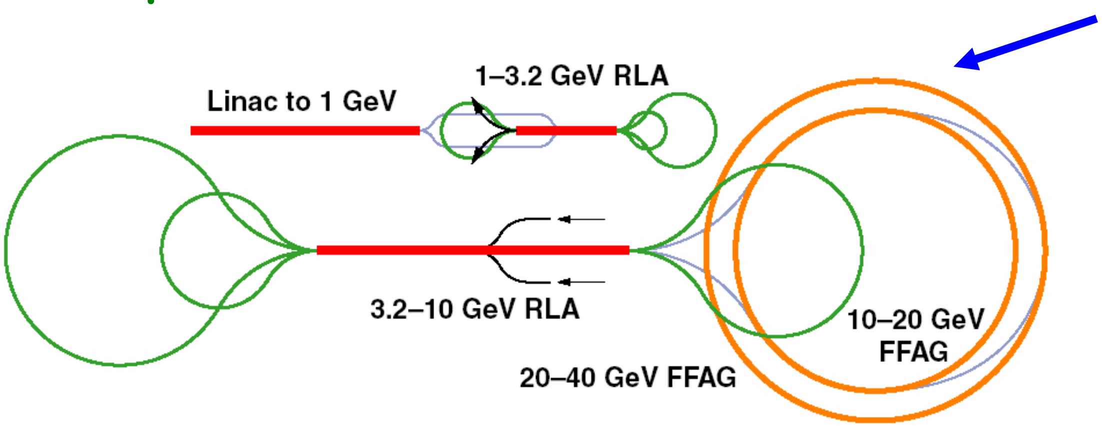

30 π mm

- Specification: μ/p = 0.17 implies require:
  - 45 π mm acceptance in downstream accelerator if no cooling – not clear this can be achieved
- Baseline:
  - Cooling channel (FS2a) to deliver 30 π mm beam
  - Challenging specification for accelerator (and cooling channel)

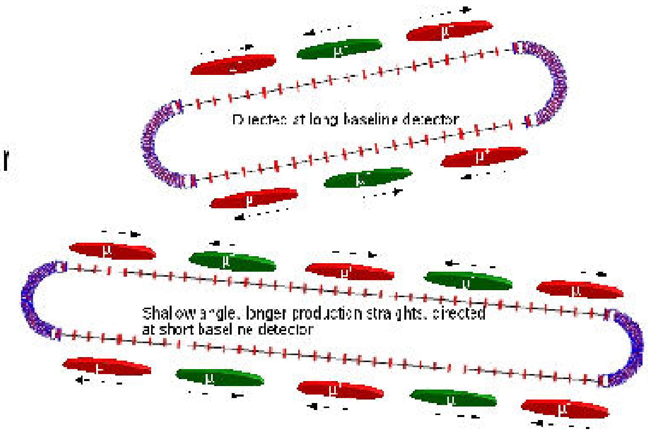
# Acceleration

- **Compare different schemes *on an even footing***
  - RLA, scaling FFAG, non-scaling FFAG
    - consider implications of keeping both sign muons
    - consider not only performance but relative costs
  - bring scaling FFAG design to same level as non-scaling design

- **Look at implications of increasing acceptance**
  - transverse and longitudinal
    - acceptance issues have arisen in non-scaling case
      - leading to exploration of a revised acceleration scenario



# DECAY RINGS

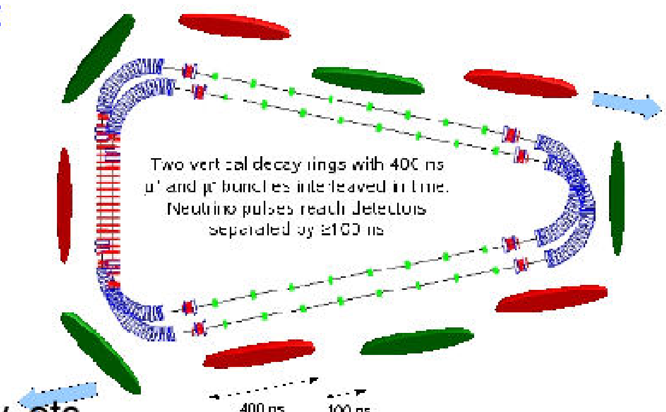



Working hypothesis :

- Compare alternatives and trade-offs, racetrack and triangular
- Implications of final energy (20 GeV, 50 GeV) on design
- Allow 3 $\pi$ cm stored emittance
- Assume both signs muons $\rightarrow$ one or two rings.
- Consider double baseline
- Radiation issues at $10^{21}\mu/10^{7}$s

Goal : decide on racetrack versus triangle

Some fundamental criteria considered at the present stage :




- Efficiency
- Number of rings, number of tunnels, for two detectors
- Constraint of geometry on baseline angles.
  Flexibility in choice of site
- Construction - 10-15 degs. to horizontal / near vertical
- Total depth ($\approx 0.25 - 0.3\mathcal{C}$ )
- Muon bunch structure - impact on efficiency, ring geometry, etc.
- RF requirements
- Apertures and fields needed

# Detectors and instrumentation

***Information from ISS Detector group***

- **Detector options and subgroups**
  - **Large water Cherenkov**
    - **ISS activity focuses on consideration of R&D required:**
      - **Photo tubes**
      - **Front-end electronics**
    - **Omit further comment**
  - **Liquid argon**
  - **Emulsion**
  - **Magnetic sampling calorimeter**
  - **Near detector**
- **Further instrumentation issues:**
  - **Flux, muon-polarisation measurement**

# Detector technology: summary

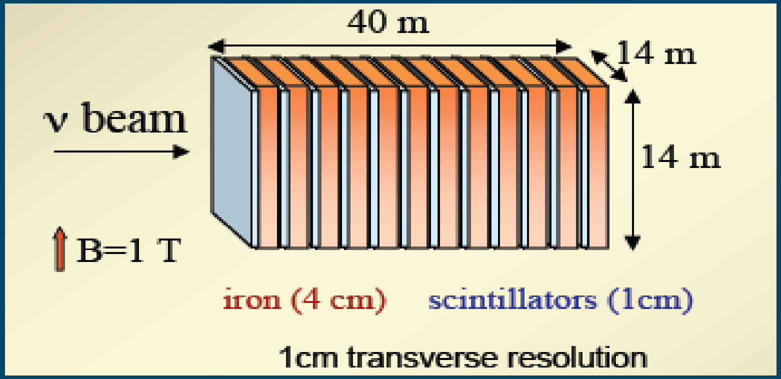
| Detector | Mass kt | Solar | SN | Atm | Nucleon decay | Superbeam, $\beta$-beam subGeV | GeV | 10's GeV | $\nu$-factory 10's GeV |
|---|---|---|---|---|---|---|---|---|---|
| WC | $\simeq 1000$ | $\approx$ | yes | yes | yes | yes | $\approx$ | no | no |
| LAr | $\simeq 100$ | yes | yes | yes | yes | yes | yes | yes | yes ($\mu$-catcher) |
| Magnetized LAr | $\simeq 25$ | yes | yes | yes | yes | yes | yes | yes | $e^\pm$, $\mu^\pm$, $\tau^\pm$ |
| Magnetized sampling Cal. | $\simeq 50$ | no | no | $\mu^\pm$ | no | $\approx$ | yes | yes | $\mu^\pm$ |
| Non-magnetized sampling Cal. | $\simeq 50$ | no | no | $\mu$'s | no | $\approx$ | yes | yes | no |
| Emulsion hybrid | $\simeq 1$ | no | no | no | no | no | $\approx$ | yes | $\tau^\pm$ |

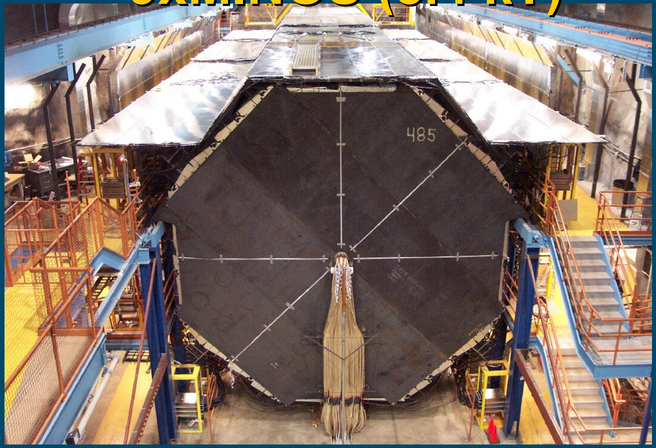
- Magnetised liquid argon:
  - Golden, platinum, and silver channels accessible
- Magnetised sampling calorimeter:
  - Golden channel accessible
    - Sampling fraction:
      - Can totally active 'get' some silver or platinum sensitivity
- Hybrid detector system?

# Magnetised Segmented Detectors

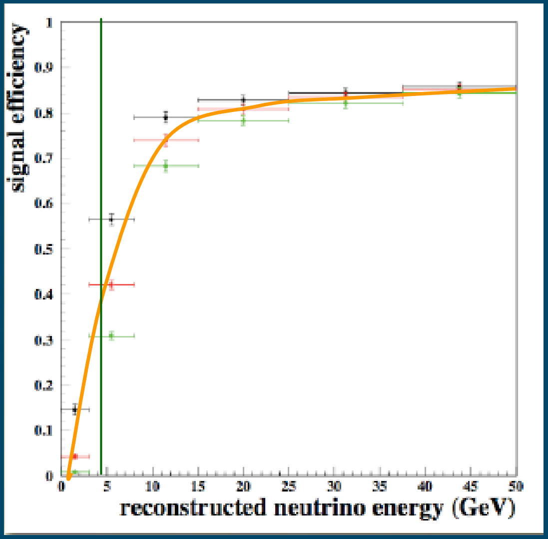
- Golden channel signature: "wrong-sign" muons in magnetised calorimeter

9xMINOS (5.4 kT)




- Baseline technology for a NuFact far detector
- Issues: segmentation, electron ID, readout technology (RPC or scintillator?), muon threshold – need R&D to resolve these
- A ~100 kton detector with a B-field of 1.4 T is considered feasible

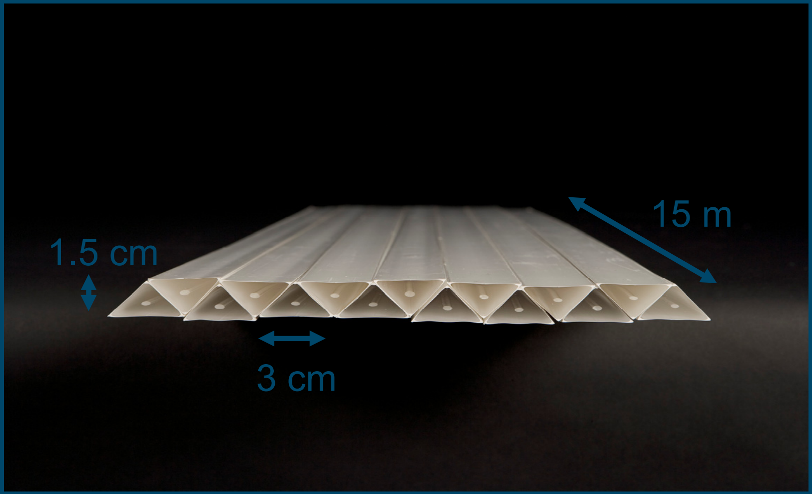


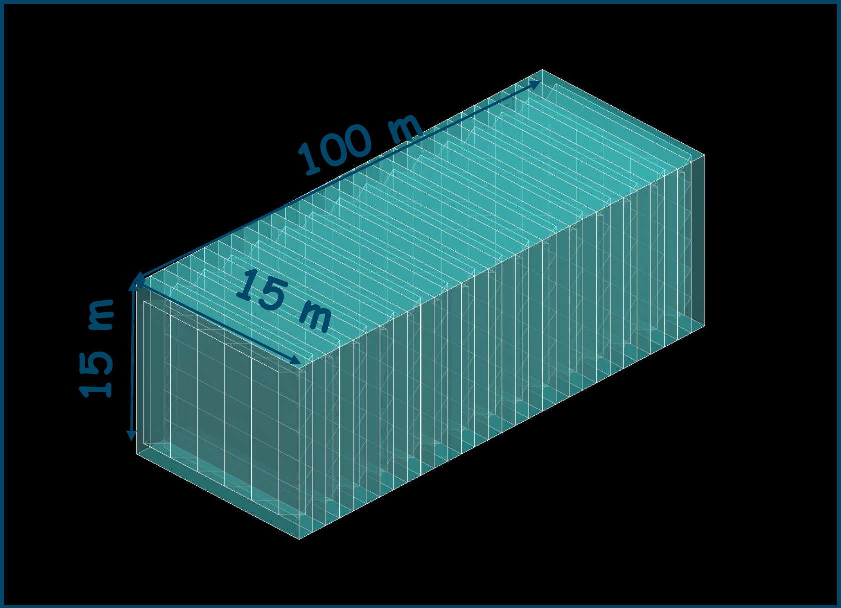
# Totally Active Scintillating Detector

Simulation of a Totally Active Scintillating Detector (TASD) using Nova and Minerva concepts with Geant4

Ellis, Bross

- 3333 Modules (X and Y plane)
- Each plane contains 1000 slabs
- Total: 6.7M channels




- Momenta between 100 MeV/c to 15 GeV/c
- Magnetic field considered: 0.5 T
- Reconstructed position resolution ~ 4.5 mm

# Detector Baseline

| beam | Far detector | R&D needed |
|---|---|---|
| sub-GeV<br>BB and SB<br>(MEMPHYS, T2K) | Megaton WC | photosensors!<br>cavern and infrastructure |
| few GeV<br>BB and SB<br>(off axis NUMI, high $\gamma$ BB, WBB) | no established baseline<br>TASD (NOvA-like)<br>or<br>Liquid Argon TPC<br>or Megaton WC | photosensors and detectors<br>long drifts,<br>long wires, LEMs |
| Neutrino Factory<br>(20-50 GeV,<br>2500-7000km) | ~100kton magnetized iron calorimeter (golden)<br>+ ~10 kton<br>non-magnetic ECC (silver) | straight forward from MINOS<br>simulation+physics studies<br>ibid vs OPERA |

# The IDS initiative

**Improved knowledge of $\theta_{13}$**

**Double CHOOZ, T2K, NOvA, …**

**High-sensitivity ν-oscillation facility second half of next decade**

**J-PARC, SNS, …**

**Decision point 2012**

The European strategy for particle physics

## *The European strategy for particle physics*

6. Studies of the scientific case for future neutrino facilities and the R&D into associated technologies are required to be in a position to define the optimal neutrino programme based on the information available in around 2012; *Council will play an active role in promoting a coordinated European participation in a global neutrino programme.*

# The IDS initiative

**Improved knowledge of $\theta_{13}$**

Double CHOOZ, T2K, NOvA, …

**High-sensitivity ν-oscillation facility second half of next decade**

J-PARC, SNS, …

**Decision point 2012**

**Scientific imperative: Neutrino Factory must be an option**

The European strategy for particle physics

*The European strategy f*

6. Studies of the scientific case fo
and the R&D into associated te
be in a position to define the op
based on the information availa
*will play an active role in promo*
*participation in a global neutrino p*

Revealing the Hidden Nature of Space and Time: Charting the Course for Elementary Particle Physics
http://books.nap.edu/catalog/11641.html

**EPP2010** Executive Summary

3. Expand the program in particle astrophysics and pursue an internationally coordinated, staged program in neutrino physics.

Strategic Principle 3. As the global particle physics research program becomes increasingly integrated, the U.S. program in particle physics should be planned and executed with greater emphasis on strategic international partnerships. The United States should lead in mobilizing the interests of international partners to jointly plan, site, and sponsor the most effective and the most important experimental facilities.

Action Item 5. The committee recommends that the properties of neutrinos be determined through a well-coordinated, staged program of experiments developed with international planning and cooperation.

# NuFact06 mandate

ISS-2006-02 28th August 2006

## Towards a future high-intensity neutrino programme

*The ISS Programme Committee*

**High-precision measurements of neutrino oscillations are required**

It is widely recognised that a precise and detailed knowledge of the properties of the neutrino is of the highest scientific importance. High-precision accelerator-based measurements of neutrino oscillations are an essential part of the programme required to determine these properties.

Three classes of facility have been proposed to serve the high-precision era: second-generation super-beam experiments; beta-beam facilities; and the neutrino factory. The cost of each of these options is significant making it likely that the particle-physics community will eventually have to make choices. The criteria upon which these choices will be made include: the measured values of the oscillation parameters, in particular the value of $\theta_{13}$; the physics reach and the cost of each of the proposed facilities; and the schedule on which each facility can be implemented. It is important that the best possible information be available at the time the decisions are needed. For each option, significant investment in hardware R&D and engineering design is required for a Conceptual Design Report (CDR) to be produced.

The International Scoping Study of a future Neutrino Factory and super-beam facility (the ISS), which presented its conclusions at NuFact06 (24 – 30 August, 2006, Irvine, California) studied the physics case for high-precision measurements of the properties of the neutrino, compared the performance of the different options on an equal footing, and outlined a number of accelerator and detector baseline scenarios for a neutrino factory that now need to be carried forward in a design study.

**Timescale**

The decision on the precision accelerator-based neutrino-oscillation programme should be possible soon after the reactor and long-baseline neutrino oscillation experiments which are presently being implemented, have provided information on the key parameter $\theta_{13}$. Meeting this timescale requires that CDRs for the considered facilities be available by ~2012. In addition, it is important that interim design reports (IDRs) containing reliable estimates of performance and cost are available by ~2010. It is anticipated that at this time, LHC results being available, decisions on the infrastructure needed for the high-energy-frontier exploration will be made. For substantial neutrino infrastructures to be included in plans for the future of the field appropriate IDRs will need to be available.

**The International Design Study initiative**

In order to provide the information required, full design studies of the super-beam, beta-beam, and neutrino factory options are needed. To support the instigation of the various studies, and to provide a degree of oversight during the design-study period, it is proposed that an organisation such as that shown in figure 1 be put in place. The three separate design studies would each be initiated by those seeking to propose a particular option, and would be carried out in parallel.

The teams carrying out the studies would be strongly encouraged to work together on areas of common interest. The detector requirements for beta-beams and super-beams are very similar as are the multi-Megawatt proton driver and target for the neutrino factory and super-beam. The over-arching synergy, the neutrino-oscillation science driver, is recognised in the form of the Neutrino Oscillation Physics Working Group, which is envisioned to continue the work of performance evaluation and comparison that was initiated through the ISS. The regional oversight bodies could provide a degree of coordination.

To facilitate the initiation of the various design studies, the ISS Programme Committee seeks to produce a short document, to be published alongside the ISS report, that will summarise the R&D roadmap to the decision point in ~2012.

ISS-2006-02 28th August 2006

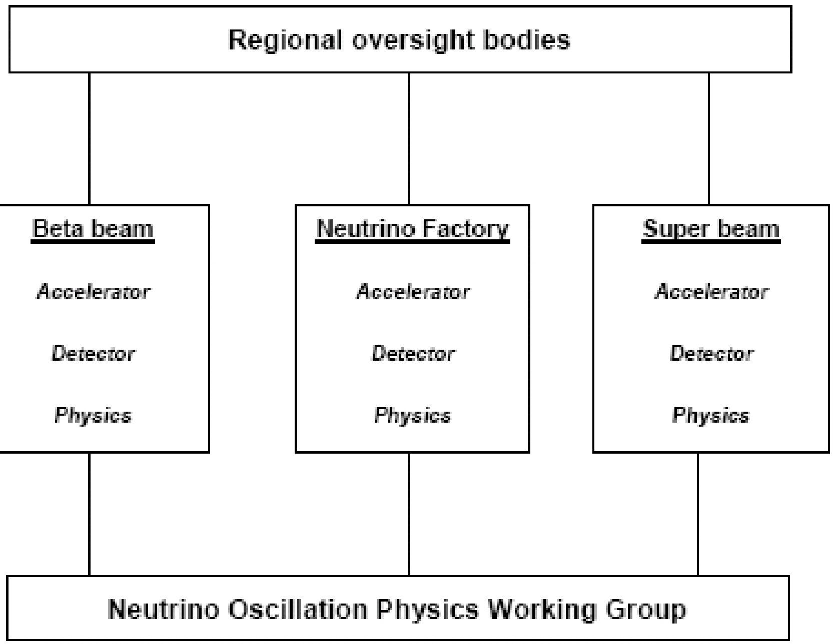
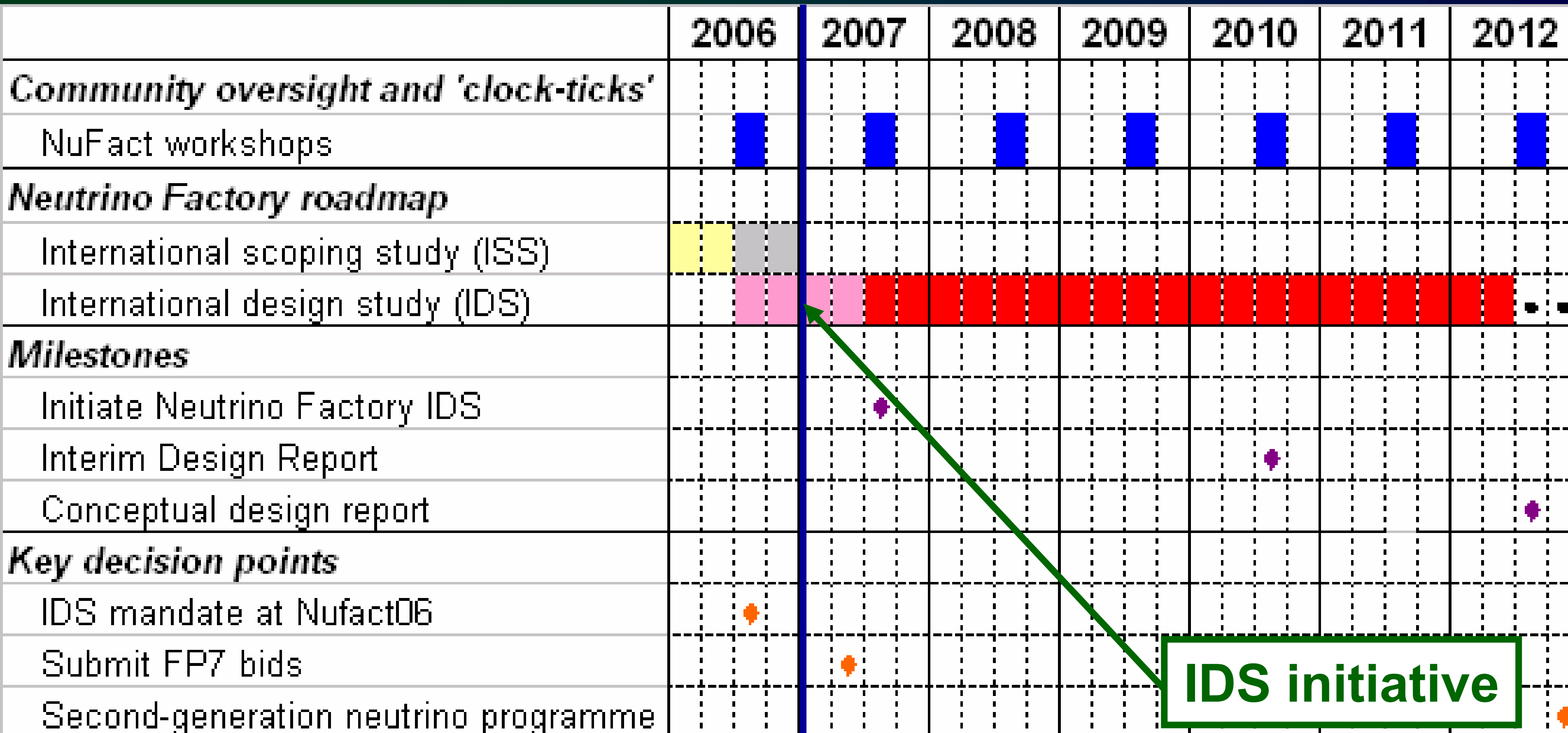



*Figure 1: Organisation for the design-study programme.*

**Timescale**

The decision on the precision accelerator-based neutrino-oscillation programme should be possible soon after the reactor and long-baseline neutrino oscillation experiments which are presently being implemented, have provided information on the key parameter $\theta_{13}$. Meeting this timescale requires that CDRs for the considered facilities be available by ~2012. In addition, it is important that interim design reports (IDRs) containing reliable estimates of performance and cost are available by ~2010. It is

# Timescale: overview



# Components:

**Neutrino Factory International Design Study**

**Accelerator** | **Detector**

**SvM … and BSvM**

**Physics**

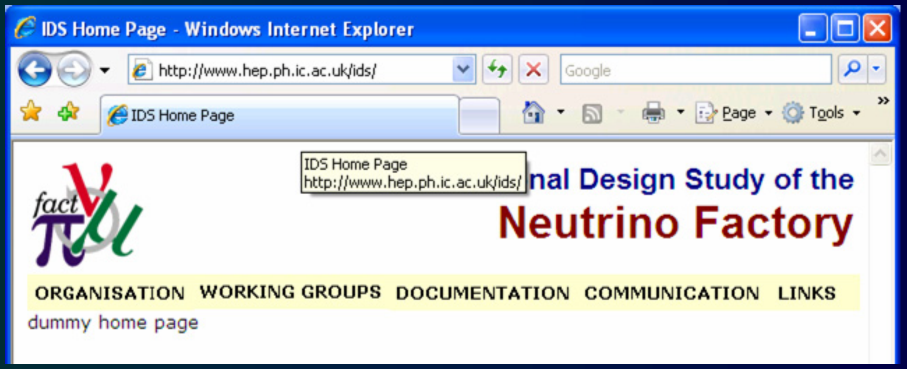
**DIS**

**Muon physics**

Neutrino oscillation physics working group

# IDS initiative: status

- AhSG: two meetings:
  - 08Dec06, 05Jan07
- IDS www page:
  - http://www.hep.ph.ic.ac.uk/ids




- IDS mailing lists being set up
  - Morphed from ISS mailing lists
- Next meetings:
  - 19-21 February, CERN: ISS report editorial meeting
  - 29-31 March, CERN: ISS→IDS meeting

# IDS initiative: status

- Ad hoc steering group:

Steering Group - Windows Internet Explorer

http://www.hep.ph.ic.ac.uk/ids/organisation/steering.html

International Design Study of the **Neutrino Factory**

ORGANISATION WORKING GROUPS DOCUMENTATION COMMUNI

## Ad-hoc Steering Group

### Meetings

| *Meeting* | *Date/time* | *Agenda* |
|---|---|---|
| 3 | 09Feb07, 14:00 GMT | Agenda |
| 2 | 05Jan07, 22:00 GMT | Agenda |
| 1 | 08Dec06, 14:00 GMT | Agenda |

## Representation on ad-hoc steering group

| | | | |
|---|---|---|---|
| ***ISS Programme Committee*** | | | |
| P. Dornan | P.Dornan@imperial.ac.uk | ISS Programme Committee Chair | |
| A. Blondel | Alain.Blondel@cern.ch | ECFA study group leader<br>ISS Programme Committee | |
| M. Zisman | mszisman@lbl.gov | ISS Programme Committee<br>NFMCC Project Manager | |
| Y. Nagashima | nagashimayori@ybb.ne.jp | ISS Programme Committee | |
| ***International partners*** | | | |
| V. Palladino | Vittorio.Palladino@na.infn.it | BENE coordinator | Europe |
| R.Edgecock@rl.ac.uk | R.Edgecock@rl.ac.uk | NF coordinator on FP7 DS proposal | Europe |
| N. Mondal | nkm@tifr.res.in | INO spokesman | India |
| Y. Mori | yoshiharu.mori@kek.jp | NuFact-J spokesman | Japan |
| Y. Kuno | kuno@phys.sci.osaka-u.ac.jp | NuFact-J spokesman | Japan |
| A. Bross | bross@fnal.gov | NFMCC spokesman | US |
| H. Kirk | hkirk@bnl.gov | NFMCC spokesman | US |
| K. Long | K.Long@Imperial.AC.UK | UKNF spokesman | UK |
| P. Soler | p.soler@physics.gla.ac.uk | Detector/instrumentation | UK |
| ***Observers – making the link with other design-study activities in Europe*** | | | |
| M. Dracos | marcos.dracos@ires.in2p3.fr | SB coordinator on FP7 DS proposal | |
| M. Lindroos | Mats.Lindroos@cern.ch | BB coordinator in FP6 Eurisol DS<br>Acting coordinator BB for FP7 DS | |

# AhSG: o/p

Draft V2

International Design Study of the
**Neutrino Factory**

17 January 2007

## Principal objectives

The principal objective of the International Design Study of the Neutrino Factory (the IDS) is to deliver a design report in which:

- The physics performance of the Neutrino Factory is detailed and the specification of each of the accelerator, diagnostic, and detector systems that make up the facility is defined;
- The schedule for the implementation of the Neutrino Factory facility is presented;
- The cost of the Neutrino Factory accelerator, the diagnostics, and the detector systems are presented at a level of accuracy appropriate for the report to inform a decision to initiate the Neutrino Factory project; and
- The outstanding technical and financial uncertainties are documented and an appropriate uncertainty-mitigation plan is presented.

This report, the Reference Design Report (RDR), is required in 2012/13. As a step on the way, an Interim Design Report (IDR) is required in 2010/11. The purpose of this note is to define the terms RDR and IDR.

### *The Interim Design Report*

The Interim Design Report has three functions: it marks the point in the IDS at which the focus turns to the engineering studies required to deliver the RDR; it documents the baseline for the accelerator complex, the neutrino detectors, and the instrumentation systems. It also defines example sites to be taken forward in the RDR; and it forms the basis of the proposals required to deliver the RDR. The IDR must therefore contain engineering designs of each of the accelerator, diagnostic, and detector systems that make up the facility together with estimates of the cost and schedule accurate at the 50% level. In addition, the IDR must contain a detailed, precisely-costed, plan of the work required to deliver the RDR. This plan must include a description of the hardware R&D work required to address any outstanding technological or systems-integration issues that must be addressed before the RDR can be completed. To avoid the additional cost incurred unnecessary engineering multiple designs, the transition from IDR phase to the RDR phase implies the implementation of an appropriate change-control procedure.

### *The Reference Design Report*

The Reference Design Report is conceived as the basis on which a request for the resources to carry out the first phase of the Neutrino Factory project can be made. The Neutrino Factory project necessarily encompasses detailed design work, a continuing R&D programme by which the technical and cost uncertainties are managed, and the initial stages of the construction of the facility itself.

For the RDR to be used to support such a proposal requires that the cost and schedule estimates must be robust, accurate at the 30% level, and that an appropriate evaluation of contingency has been carried out. The RDR must therefore contain sufficient engineering detail on each subsystem to demonstrate that the cost and schedule estimates are robust at this level.

# Neutrino Factory IDS

- Goal of NF IDS:
  - Neutrino Factory RDR (~2012):
    - Engineering designs for most components
  - Neutrino Factory IDR (~2010):
    - Marks transition from:
      - Concept development and R&D with engineering support to:
      - Significant engineering effort with concept-development and R&D programmes to mitigate risks, begin to address site-specific issues

# Tasks:

- Indicative only!
- Clearly a ‘big job’
  - Require international collaboration
- Hardest task:
  - Initiate the activity

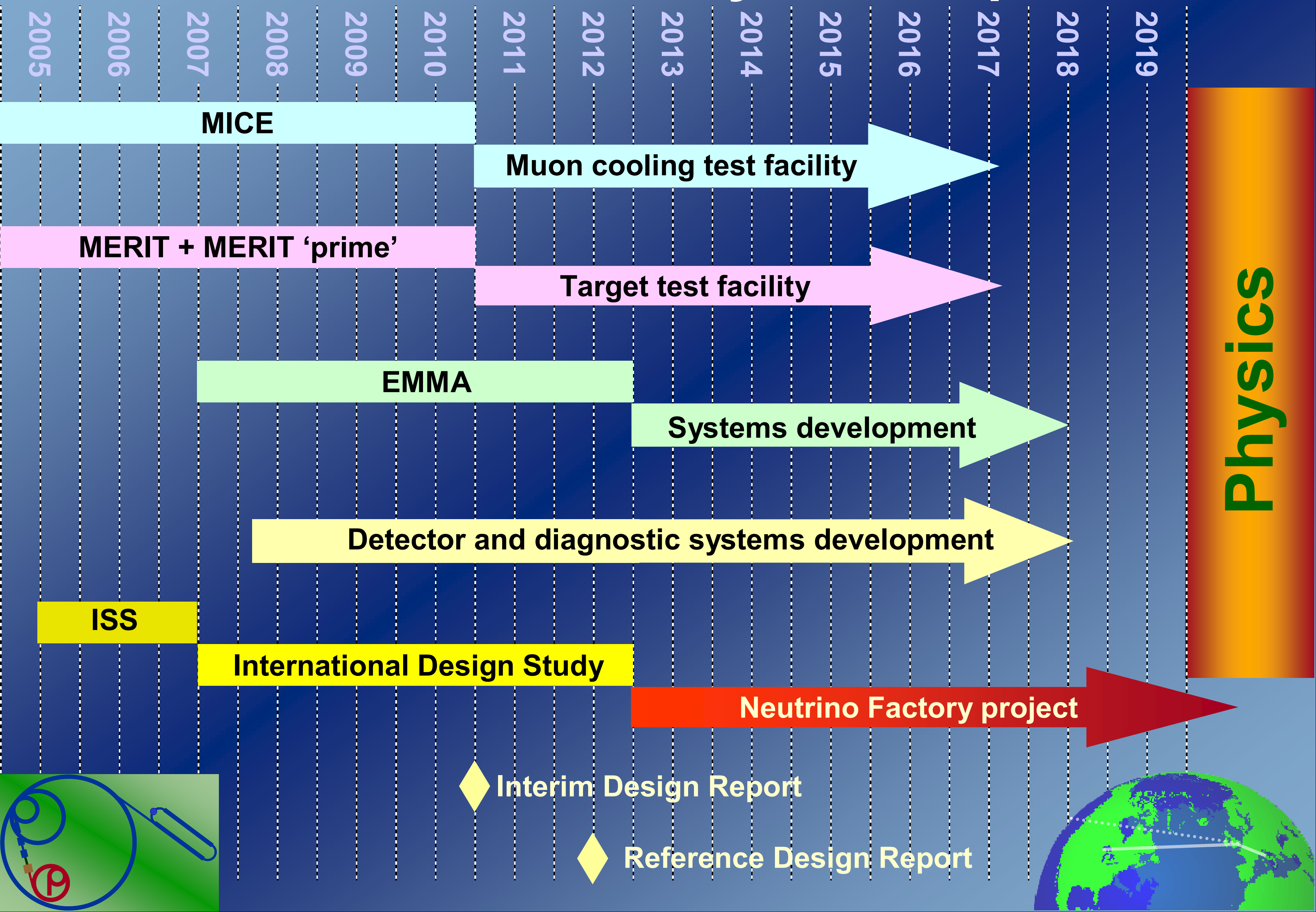
| | 2007/08 | 2008/09 | 2009/10 | 2010/11 | 2011/12 |
|---|---|---|---|---|---|
| ***IDS*** | | | | | |
| *Conceptual design phase* | | | | | |
| *Technical design phase* | | | | | |
| *Mangement and coordination* | | | | | |
| ***Development of key accelerator systems*** | | | | | |
| *Proton driver* | | | | | |
| Proton driver front end | | | | | |
| Proton-injector linac prototypes | | | | | |
| *Target and capture* | | | | | |
| Proof-of-principle experiment: MERIT | | | | | |
| Engineering demonstrators | | | | | |
| *Bunch-rotation and cooling* | | | | | |
| Engineering demonstration: MICE | | | | | |
| Demonstration of components: MuCool | | | | | |
| Second phase ionisation cooling development | | | | | |
| *Rapid acceleration* | | | | | |
| Non-scaling FFAG proof of of principle: EMMA | | | | | |
| *Storage ring* | | | | | |
| Component R&D and site investigations | | | | | |
| *Generic technology development* | | | | | |
| RF | | | | | |
| Power sources | | | | | |
| Accelerating structures | | | | | |
| Magnets | | | | | |
| Large apperture, high field | | | | | |
| High-current, rapid rise-time power supplies | | | | | |
| High-$T_C$ conductor development | | | | | |
| ***Development of instrumentation systems*** | | | | | |
| *High-resolution/high-granularity option* | | | | | |
| Development of liquid argon or other techniques | | | | | |
| *High-mass, large volume option* | | | | | |
| Development of tracking calorimeter option | | | | | |
| *Large volume magnetisation* | | | | | |
| High critical temperature, novel magnets | | | | | |
| *Near detector* | | | | | |
| Development of elements of spectrometer | | | | | |
| Detectors for cross section measurement etc. | | | | | |
| *Generic technology development* | | | | | |
| Photo sensors | | | | | |
| Long drift in nobel gases | | | | | |
| TASD: electronics | | | | | |
| *Accelerator-complex instrumention* | | | | | |
| Polarimeter for luminosity monitoring | | | | | |
| Beam divergence monitor | | | | | |

# Synergy:

- Technologies and systems have application in a number of facilities
- Planning of IDS must recognise, and seek to benefit from, these synergies

| | Super beam | Beta beam | Neutrino Factory | Muon Collider | European Spallation Source | Inertial Fusion Material Irradiation Facility | LHC luminosity upgrade | International Linear Collider |
|---|---|---|---|---|---|---|---|---|
| ***Development of key accelerator systems*** | | | | | | | | |
| *Proton driver* | | | | | | | | |
| Proton driver front end | | | | | | | | |
| Proton-injector linac prototypes | | | | | | | | |
| Proton acceleration (linac & rings) | | | | | | | | |
| *Target and capture* | | | | | | | | |
| Proof-of-principle experiment: MERIT | | | | | | | | |
| Engineering demonstrators | | | | | | | | |
| *Bunch-rotation and cooling* | | | | | | | | |
| Engineering demonstration: MICE | | | | | | | | |
| Demonstration of components: MuCool | | | | | | | | |
| Second phase ionisation cooling development | | | | | | | | |
| *Rapid acceleration* | | | | | | | | |
| Non-scaling FFAG proof of of principle: EMMA | | | | | | | | |
| *Storage ring* | | | | | | | | |
| Component R&D and site investigations | | | | | | | | |
| ***Generic technology development*** | | | | | | | | |
| RF | | | | | | | | |
| Power sources | | | | | | | | |
| Accelerating structures | | | | | | | | |
| Magnets | | | | | | | | |
| Large apperture, high field | | | | | | | | |
| High-current, rapid rise-time power supplies | | | | | | | | |
| High-$T_C$ conductor development | | | | | | | | |
| ***Development of instrumentation systems*** | | | | | | | | |
| *High-resolution/high-granularity option* | | | | | | | | |
| Development of liquid argon or other techniques | | | | | | | | |
| *High-mass, large volume option* | | | | | | | | |
| Development of tracking calorimeter option | | | | | | | | |
| *Large volume magnetisation* | | | | | | | | |
| High critical temperature, novel magnets | | | | | | | | |
| *Near detector* | | | | | | | | |
| Development of elements of spectrometer | | | | | | | | |
| Detectors for cross section measurement etc. | | | | | | | | |
| *Generic technology development* | | | | | | | | |
| Photo sensors | | | | | | | | |
| Long drift in nobel gases | | | | | | | | |
| TASD: electronics | | | | | | | | |
| *Accelerator-complex instrumention* | | | | | | | | |
| Polarimeter for luminosity monitoring | | | | | | | | |
| Beam divergence monitor | | | | | | | | |

# Neutrino Factory roadmap



# Conclusions

- Opportunity:
  - Outstanding case for the development of high-precision neutrino-oscillation facility
- Vibrant *international* concept-development and R&D programme *in place*
  - The ISS
  - MICE
  - MERIT
  - EMMA
- Clear motivation and mandate for the next step:

The International Design Study

Imperative: establish partnership that can carry out the IDS

… make the Neutrino Factory a realistic proposition

# Contributions from the UK

- **Physics:**
  - Discussions between experimenters and theorists/phenomenologists in hand to define joint proposal (S.Pascoli, Durham)
    - First meeting 26Feb07 @ Imperial
- **Detector:**
  - Discussion of ‘seed-corn’ proposal starting (P.Soler, Glasgow)
    - First meeting 26Feb07 @ Imperial
- **Accelerator:**
  - Proton driver:
    - CCLRC, Imperial, Warwick
  - Target/capture:
    - Brunel, CCLRC, Glasgow, Sheffield, Warwick
  - Muon front-end:
    - Brunel, CCLRC, Cockcroft, Glasgow, Imperial, Liverpool, Oxford, Sheffield
  - Acceleration:
    - CCLC, Imperial, Oxford
  - Storage ring:
    - CCLRC

# EU FP7 Design Study proposal

- DS proposal in preparation;
  - deadline 5pm 2nd May!
- Limited resources:
  - 5MEUR from EU; 5M from EU partners
- Duration: 4 years; main objective: CDRs
- Includes SB, NF and BB
- Focus on certain “key questions” only
- Fine for IDS
- More difficult to deliver CDRs
- Goals and partners currently being defined