Imperial College London

K. Long, 18 April, 2007

The IDS and UK activities

Contents

- Motivation
- The International Scoping Study
- The International Design Study initiative
- The UKNF activity – highlights
- Conclusions

Motivation

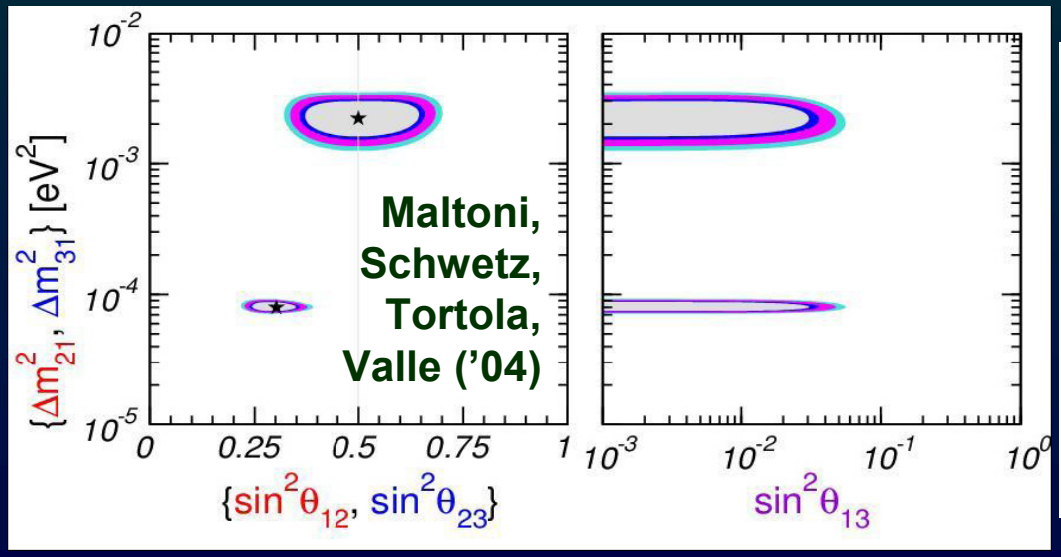
- Neutrinos in the Standard Model:
  - Neutrinos are massless
    - Helicity distinguishes neutrino and antineutrino
  - Lepton flavour is conserved
- Neutrino oscillations imply:
  - Neutrino mass is not zero
    - Neutrino is not an eigenstate of helicity
  - Lepton flavour is not conserved
  - Neutrino could be its own antiparticle

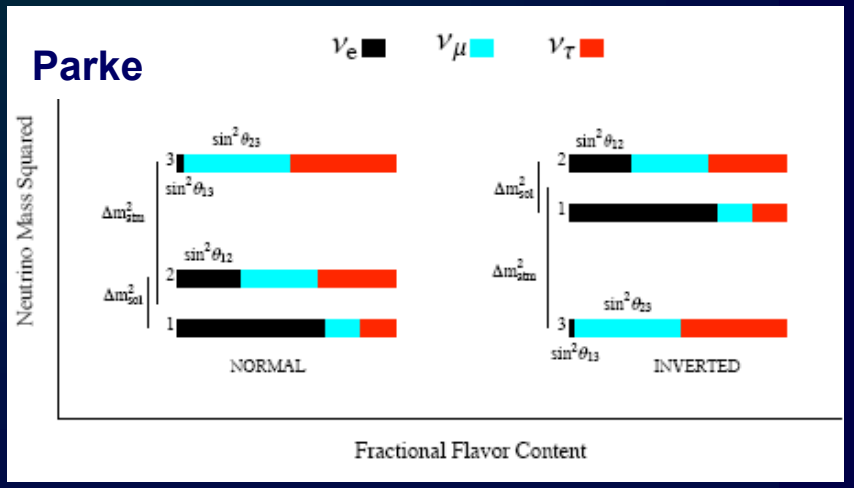
Extension of the Standard Model?
Fundamental breakthrough?

SM extension:

- **The Standard Neutrino Model (SvM):**
  - **Three neutrino mass eigenstates mix to produce three neutrino flavour eigenstates:**

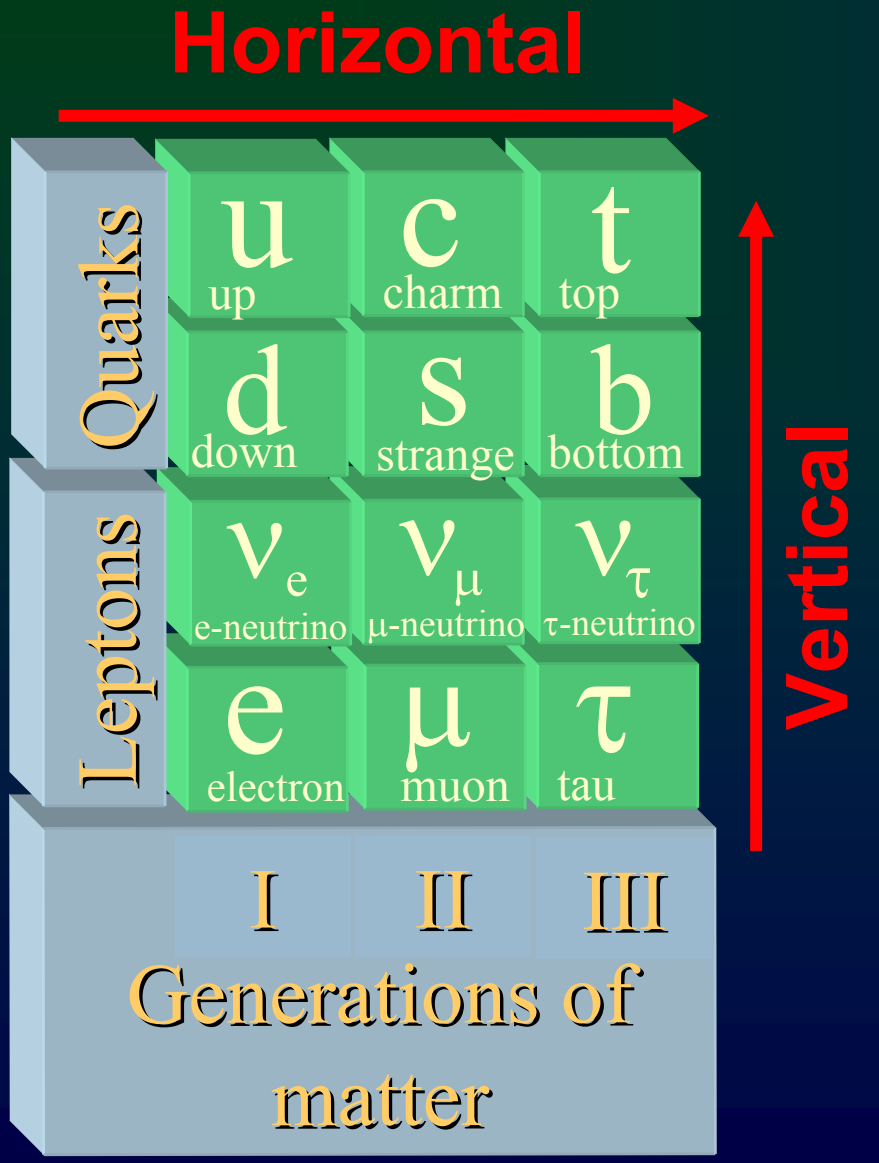
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12}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





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?

- Many theories, but, perhaps, some common features
- P*hysics of flavour* could be due to symmetry
  - GUT and/or family
- In this case, the quark- and lepton-mixing parameters must be related

- Furthermore, cosmological consequences:
  - Create observed baryon asymmetry through heavy, Majorana, neutrinos?
  - Significant neutrino contribution to dark matter (or dark energy)?

Clues to the physics of flavour:

- The neutrino's properties are unique, the key to the physics of flavour?

- The future neutrino programme must:
  - Determine of the mass scale:
    - End-point measurements
    - Cosmology
    - Neutrinoless double-beta decay
  - Determine whether the neutrino is its own anti-particle
    - Neutrinoless double-beta decay
  - Establish:
    - Whether there is CP violation in the lepton sector
    - Determine the neutrino-mixing parameters

The role of neutrino oscillations:

Neutrino oscillation must address:

- Mass hierarchy
- CP violation
- θ_{13}
- θ_{12}, θ_{23}, Δm_{31}^2, Δm_{21}^2
- More over:
  - Is θ_{23} maximal?
  - Is θ_{13} zero?
  - Beyond the SvM:
    - NSIs
    - MVNs
    - Sterile neutrinos

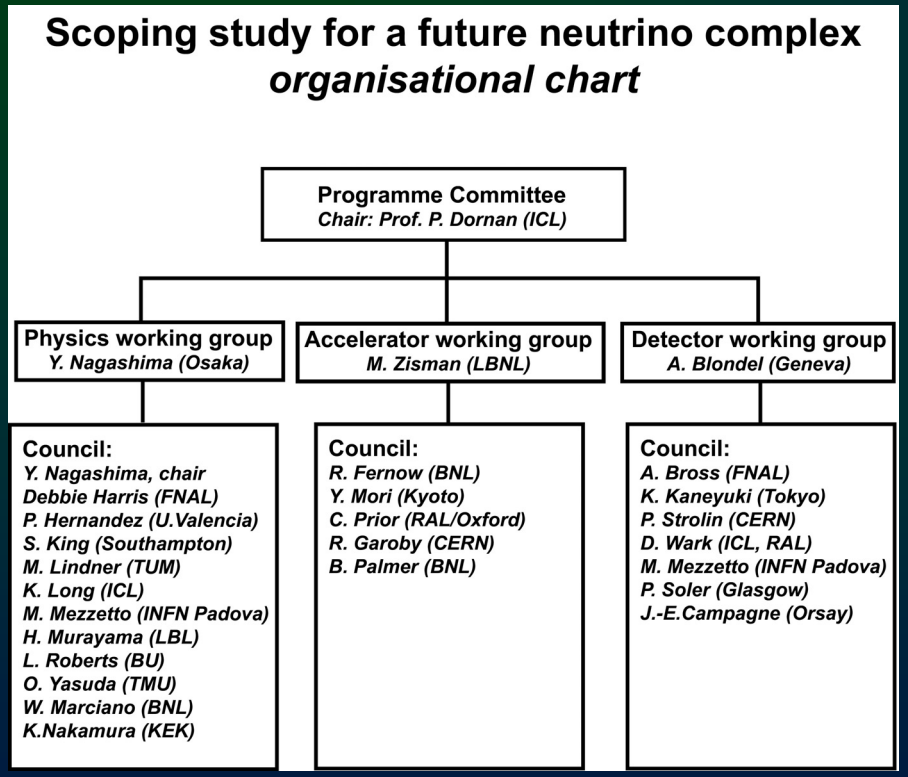
- Now:
  - MINOS, OPERA
- Soon:
  - T2K, NOvA, DChooz
    - Daya Bay, Angra
- The future:
  - Second-generation super beam
  - Beta beam
  - Neutrino Factory

Must determine best possible plan!

The International Scoping Study

- One-year study: NuFact05 – NuFact06 … a step on the way!
- Built on previous work:
  - Super beam:
    - CERN MW w/s, studies in US and Japan
  - Beta beam:
    - EU Study supported by EU under FP6
  - Neutrino Factory:
    - US Studies I, II, IIa
    - ECFA/CERN Study
    - NuFact-J Study
- Emphasis:
  - Incorporate progress made since previous studies
    - e.g. MERIT, MICE, MuCOOL, NSFFAG, …
  - Recognition of importance of holistic consideration of source and detector
  - Recognition of importance of an international approach

ISS organisation:



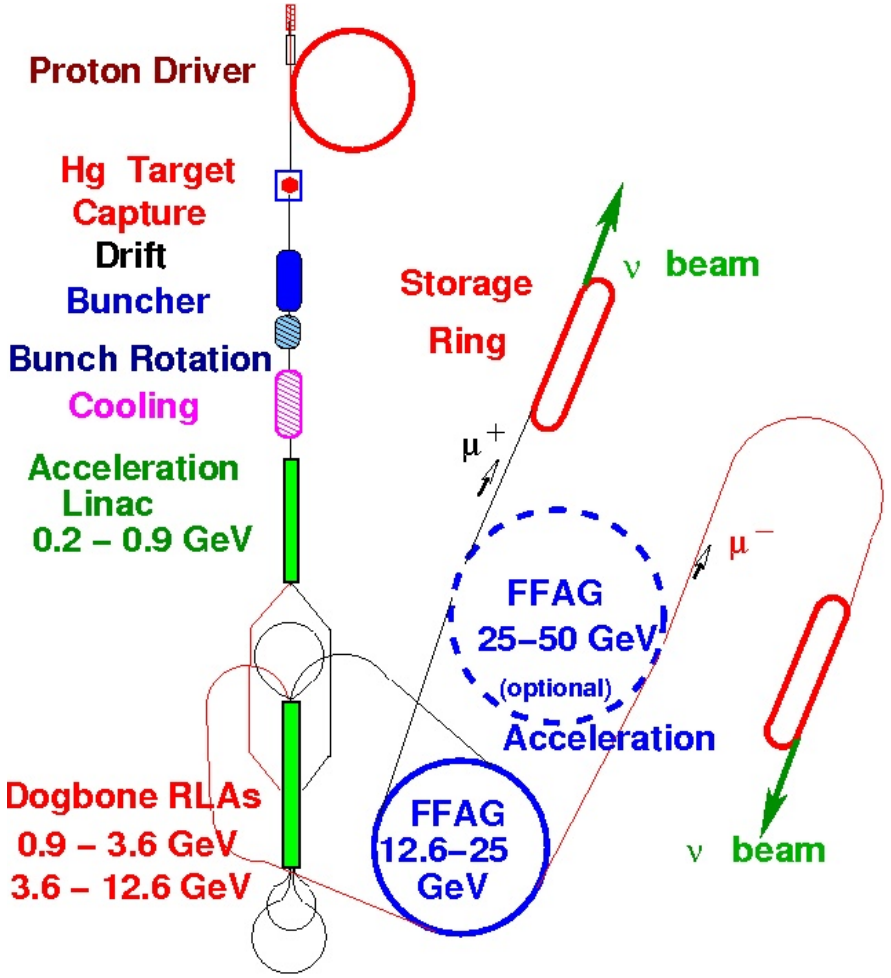
- Parallel study of:
  - Physics performance
  - Accelerator facility
  - Neutrino Detectors
- International participation
  - Programme committee and working groups

ISS outcomes:

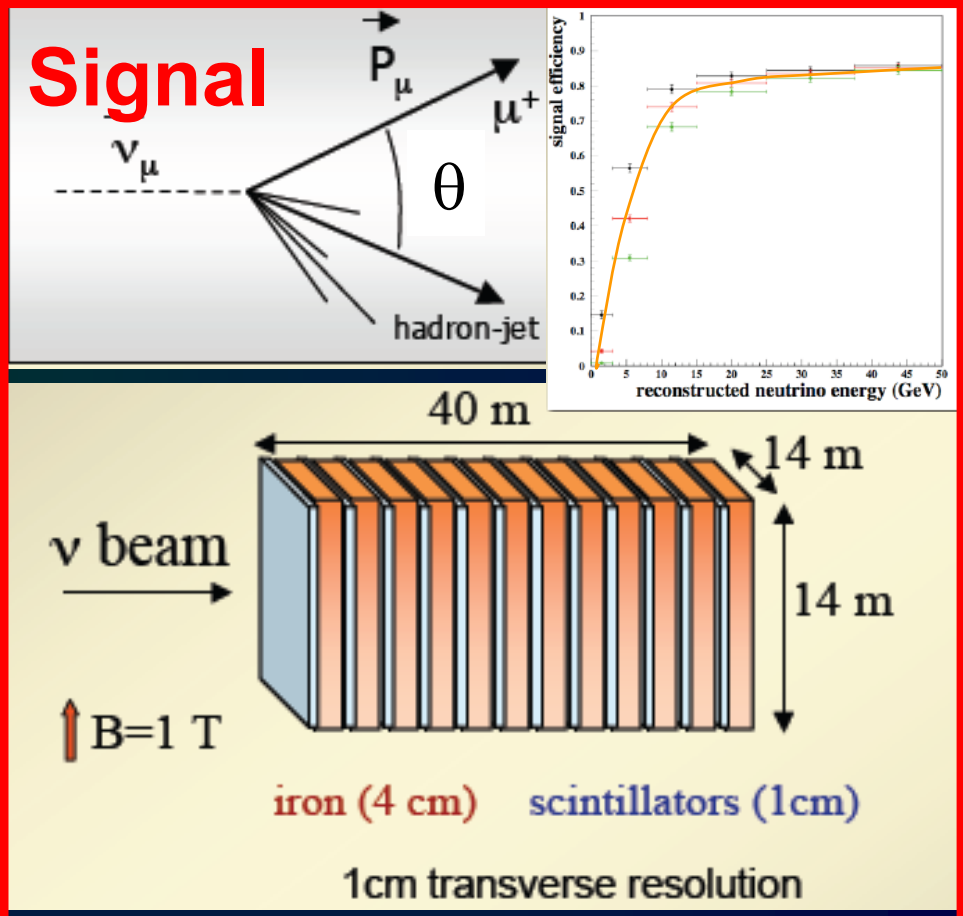
- Principal outcomes:
  - Defined baselines for Neutrino Factory accelerator and detector systems
  - Established importance of:
    - Low muon-detection threshold for $\nu_e \rightarrow \nu_\mu$ ('golden') channel
      - New analysis of magnetised-iron calorimeter gives good performance
    - $\nu_e \rightarrow \nu_\tau$ ('silver') and $\nu_\mu \rightarrow \nu_e$ ('platinum') channels essential to search for 'non-SvM' processes
      - e.g. non-unitarity of MNS matrix
  - Comparison of sensitivity of various options

- Report in preparation

ISS: baselines

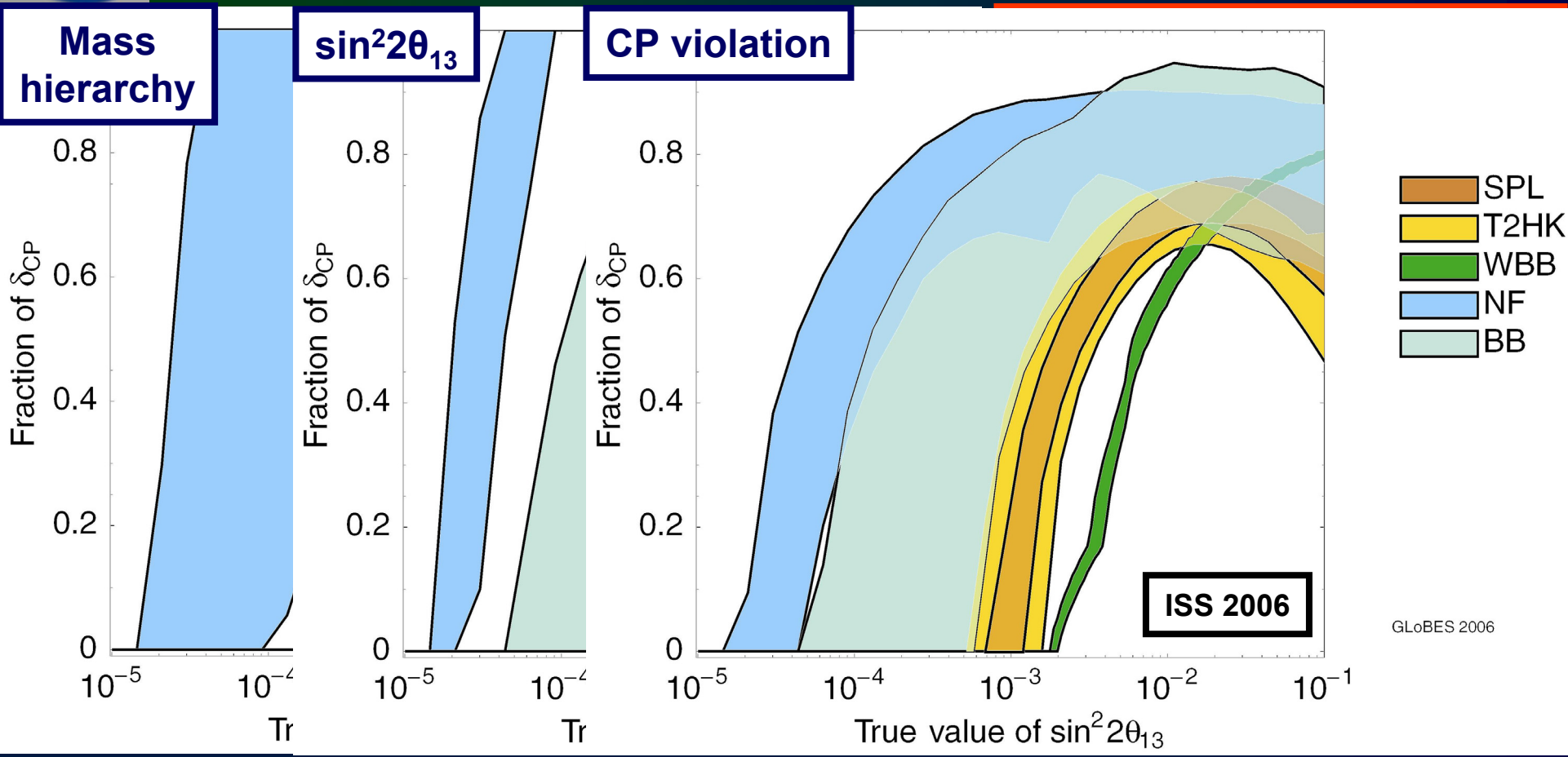


- Store μ^+ & μ^- simultaneously
  - 10^{21} muon decays/yr
  - E_μ ~ 25 GeV



- 100 (50) kT magnetised iron detector
- Two baselines:
  - 3000 – 5000 km
  - 7000 – 8000 km

ISS conclusion: physics



- **ISS sensitivity comparison:**
  - Neutrino Factory offers best performance over most of the parameter space;
  - High-gamma beta beam: comparable CP sensitivity for $5\times10^{-4} < \sin^2 2\theta_{13} < 10^{-2}$
  - For $\sin^2 2\theta_{13} > 10^{-2}$ Neutrino Factory, beta-beam, and super-beam performance comparable

The International Design Study

- **NuFact06: … initiative**

ISS-2006-02 28th August 2006

Towards a future high-intensity neutrino programme

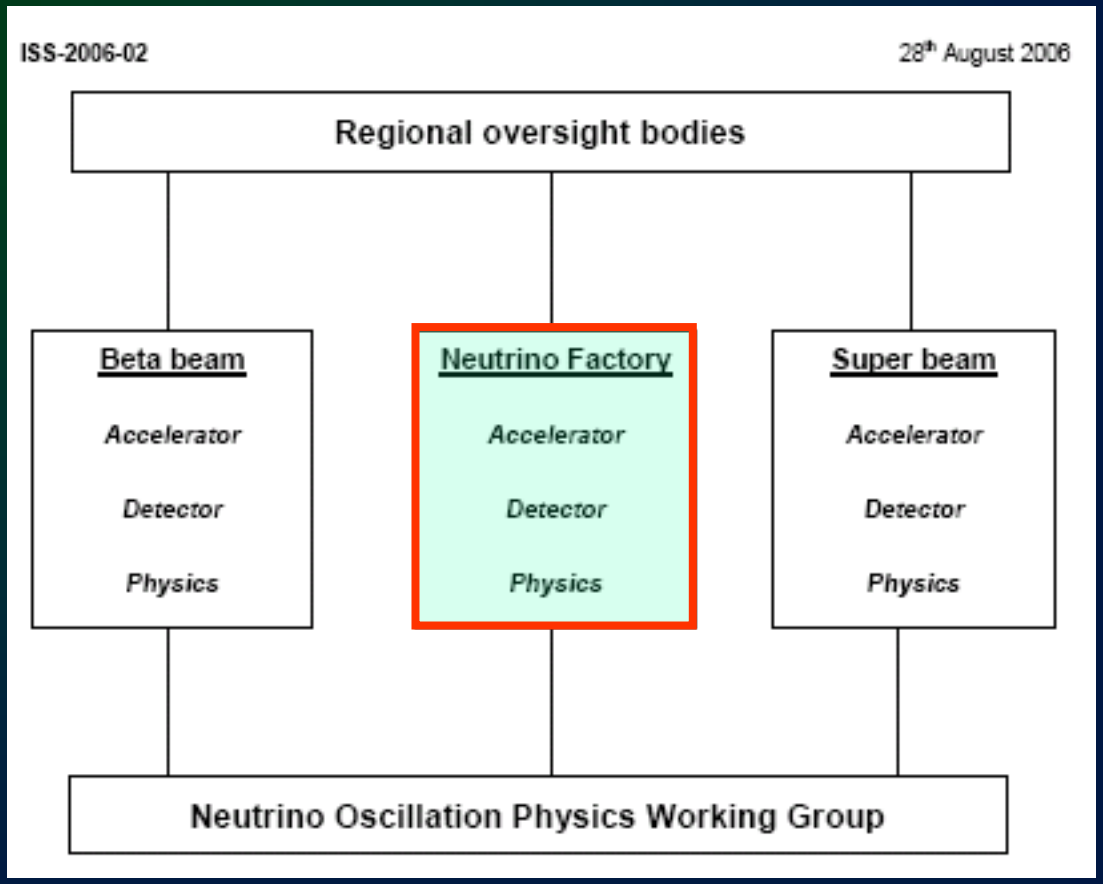
The ISS Programme Committee

- **Made the case for high-sensitivity neutrino-oscillation programme for second half of next decade and concluded:**

Timescale

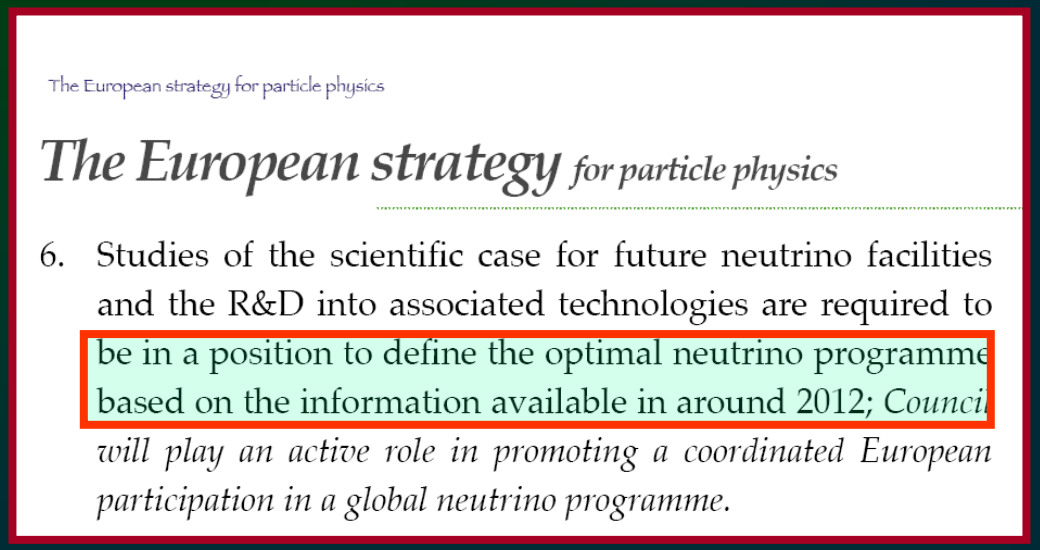
The decision on the precision accelerator-based neutrino-oscillation programme should be possible soon after the reactor and long-baseline neutrino oscillation experiments which are presently being implemented, have provided information on the key parameter θ_{13}. Meeting this timescale requires that 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

NuFact06: recommendation



- **Neutrino Factory IDS:**
  - **Continue holistic approach of ISS**
  - **Goal: deliver Neutrino Factory 'CDR' by ~2012**

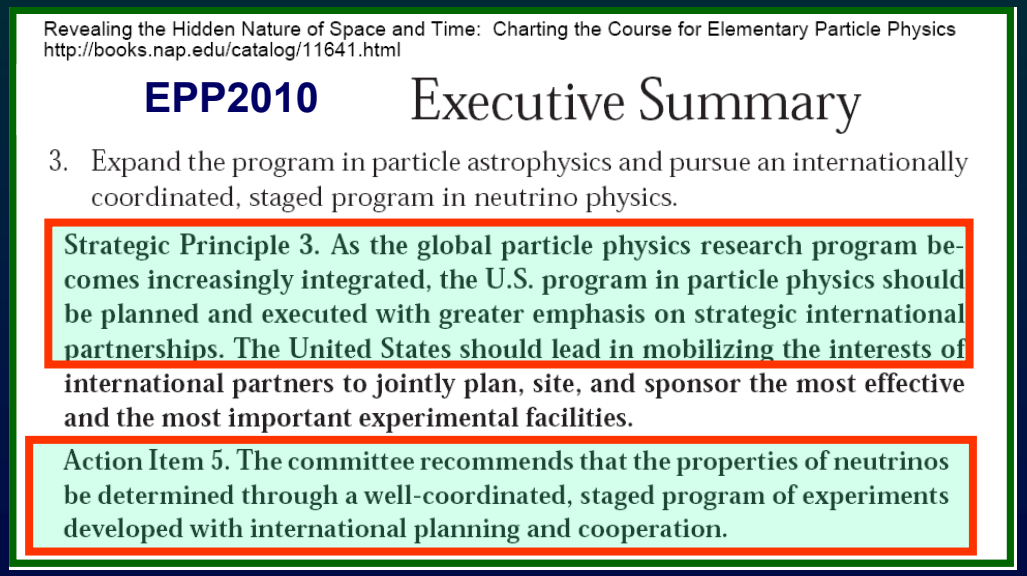
Strategic review conclusions:



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.*



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.

- **Reviews of particle-physics strategy in Europe and the US concluded that:**
  - **Future neutrino programme be developed as an internationally coordinated programme**
  - **Goal to define the '*optimal*' programme around 2012**
- **NuFact community aspiration matches this**

IDS initiative: status

- IDS ad hoc Steering Group (IDSahSG) formed
  - See `http://www.hep.ph.ic.ac.uk/ids`
  - Representation:
    - K.Long (Co-ordinator), A.Blondel, A.Bross, P.Dornan, M.Dracos, R.Edgecock, P.Huber, H.Kirk. Y.Kuno, Y.Mori, M.Lindner, M.Lindroos, N.Mondal, Y.Nagashima, V.Palladino, S.Pascoli, P.Soler, M.Zisman
      - Representation from Betabeam and Superbeam Community
  - Actions taken to date:
    - Defined over-arching objectives of IDS:
      - Neutrino Factory RDR (~2012):
        - Engineering designs for most components
      - Neutrino Factory IDR (~2010):
        - Marks transition from:
        - Concept development/R&D with engineering support … to …
        - Significant engineering effort with concept-development/R&D programmes to mitigate risks
    - Organised a plenary ISS→IDS transition meeting:
      - CERN, 29/30Mar07

ISS→IDS meeting, CERN

	Thursday		29/03/2007
Plenary session 1		**Chair: P.Dornan (Imperial)**	
		International Scoping Study summary and perspectives	
09:30	Welcome	R.Aymar (CERN)	00:10
09:40	ISS Physics Group Sum		
10:10	ISS Accelerator Group S		
10:40	ISS Detector Group Sum		
11:10	Coffee		
11:30	MW class proton beams		
12:00	Report from POFPA		
12:30	Lunch		
Plenary session 2			
	I		
14:00	Open issues: accelerato		
14:30	Discussion		
15:30	Coffee		
16:00	Open issues: detector		
16:30	Discussion		
17:30	Next steps, organisation		
18:00	Adjourn		

	Friday		30-Mar-07
Plenary session 3		**Chair: M.Lindner (MPI)**	
		Neutrino Oscillation Physics Group	
09:00	Low-energy Neutrino Factory	S.Pascoli (IPPP)	00:20
09:20	The merits of the silver channel	A.Donini (UAM)	00:20
09:40	New results on performance comparison	P.Huber (UW)	00:20
10:00	Very long baseline Neutrino Factory	W.Winter (UW)	00:20
10:20	Coffee		00:20
10:40	The U.S. Long Baseline Neutrino Experiment Study:		
	Contribution 1	M.Bishai (BNL)	00:25
	Contribution 2	N.Saoulidou (FNAL)	
11:05	Magic baseline beta beam	N.Mondal (TIFR)	00:20
11:25	Neutrino oscilations: issues	M.Lindner (MPI)	00:35
12:00	Discussion		01:00
13:00	Lunch		
Plenary session 4		**Chair: Y. Kuno (Osaka)**	
		Summary and plans	
14:00	Beta-beam DS status and plans	M.Lindroos (CERN)	00:30
14:30	Super-beam DS status and plans	M.Zito (Dapnia-Saclay)	00:30
15:00	The way forward, discussion	P.Dornan (Imperial)	01:00
16:00	Coffee and adjourn		00:30
Building 1 1-025		**IDS Ad hoc steering group**	
17:00	IDSahSG meeting		01:30
18:30	Adjourn		

Palmer

Accelerator issues:

	Issues	R&D	Comment
Proton driver	Optimum energy Multiple bunches Technology	Delivery of 4 MW of beam power	Under development at proton laboratories around the world
Target	Mercury vs. Pb-Bi Liquid vs. solid (e.g. carbon)	Pion-production rates MERIT (with Pb-Bi) Solids	MERIT Solid target studies at various laboratores
Phase rotation and cooling	200 MHz cavity @ 15 MV/m in 3T field Closed versus open cavities Degree of cooling	MICE Breakdown studies: Closed cell Open cell In magnetic field Encapsulation of LiH	Being addressed by MICE and MuCOOL collaborations
Acceleration	201 MHz SC RF Transfer lines and injection Comparison to 'all RLA' scheme	SC cavity development EMMA Combined function magnets	Cavity development programmes in various labs. EMMA approved and funded.
Storage ring	Cost savings from fewer bunches 4 GeV option	Simulation	Studied through ISS

- Internationally coordinated accelerator R&D programme addressing principal hardware issues
- IDS required to complete conceptual design and to produce single consistent RDR

Cervera

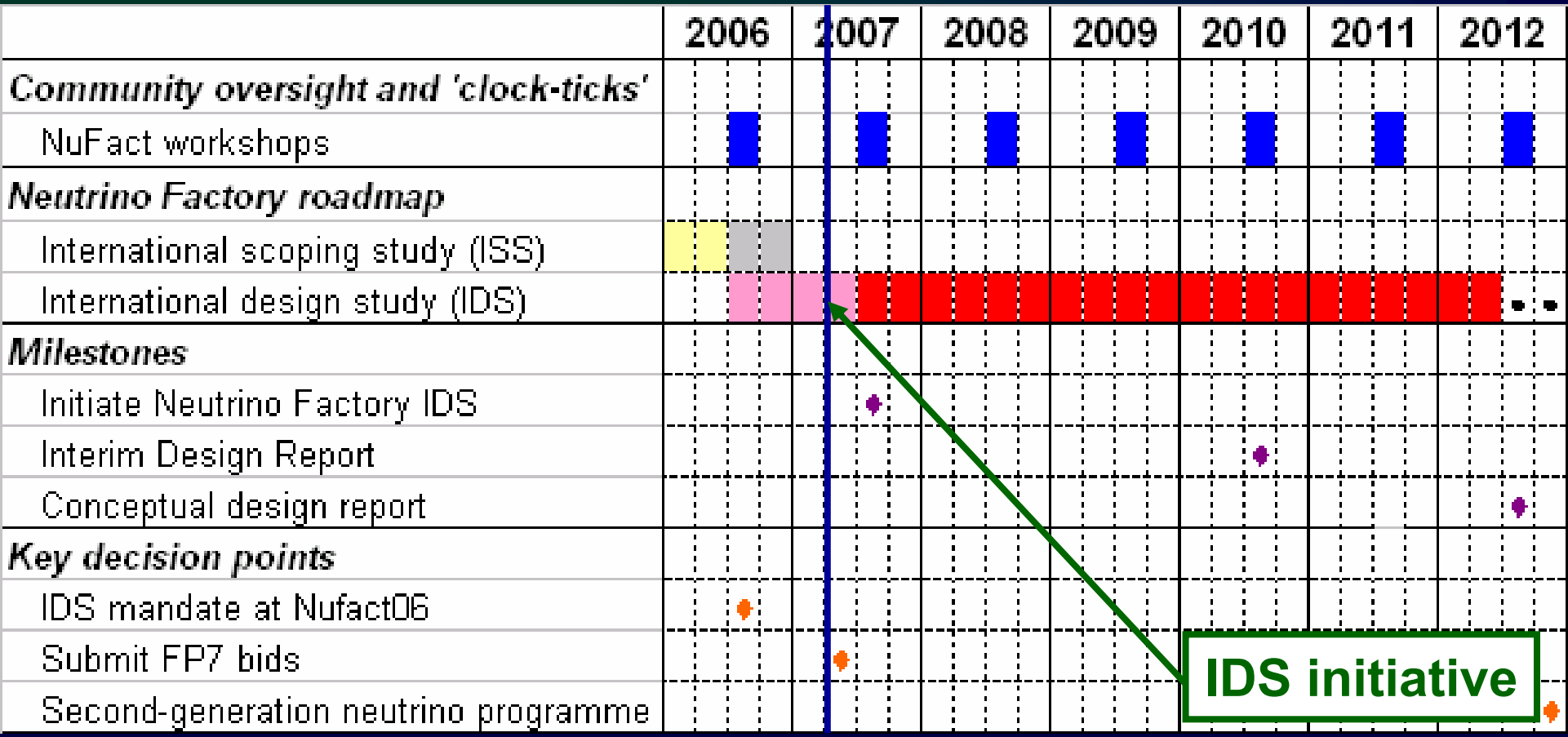
Detector issues:

	Issues	R&D	Comments
Magnetised iron neutrino detector	Consider use of RPCs Full simulation Construction/test of prototypes	Scintillator extrusions with fibre readout R&D on photon counters	Golden07 w/s Valencia, 27—30 June 2007
Totally active scintillator detector	Magnetization Bg rejection at low and high energy Performance for silver and platinum channel	Scintillator extrusions with fibre readout R&D on photon counters Conductor development (e.g. STL)	
Liquid argon detector	Magnetization Safety and logistics in u/g lab Simulation	Charge collection, long drift Conductor development (e.g. STL)	Established efforts in Europe and US
Magnetised emulsion cloud chamber	Maximum mass (cost, scanning) Magnetization	Conductor development (e.g. STL)	
Near detector	Development of conceptual scheme		
Beam instrumentation	Divergence measurement Luminosity measurement Polarisation measurement	Low pressure Cherenkov? BPC, exploit decays? Develop polarimeter scheme	

- Required programme of concept development, R&D, and prototyping identified
- Need to develop internationally-coordinated approach similar to that on the accelerator
- IDS provides a mechanism for this coordination

IDS initiative: the next steps

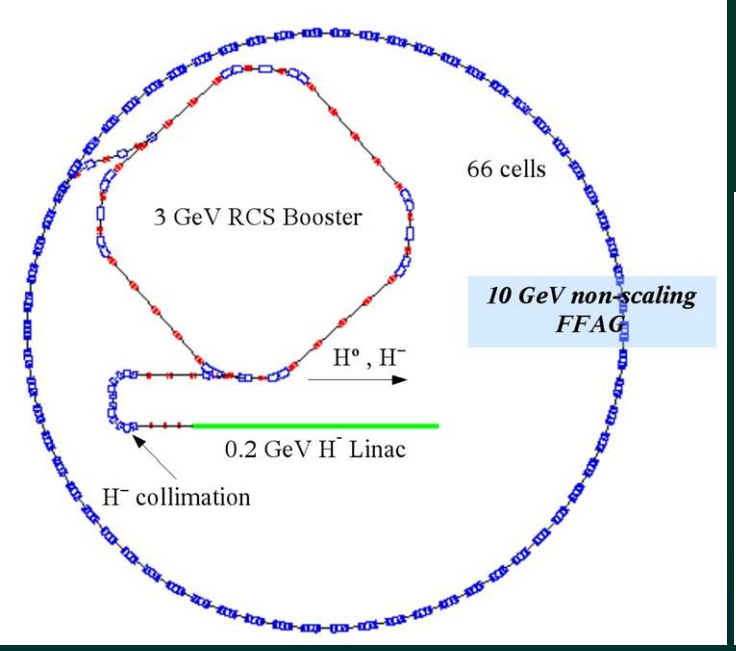
- IDSahSG working to develop a 'straw-man' plan in time for launch at NuFact07
  - Physics: Huber, Pascoli, …
  - Detectors: Bross, Cervera, Soler, …
  - Accelerator: Zisman, …

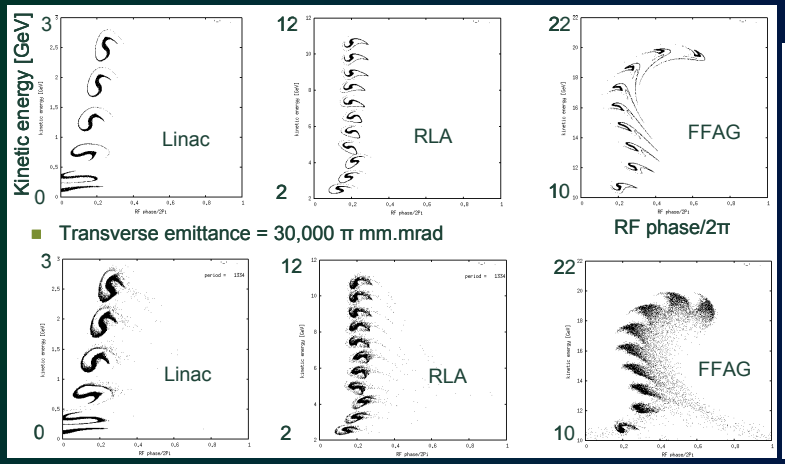


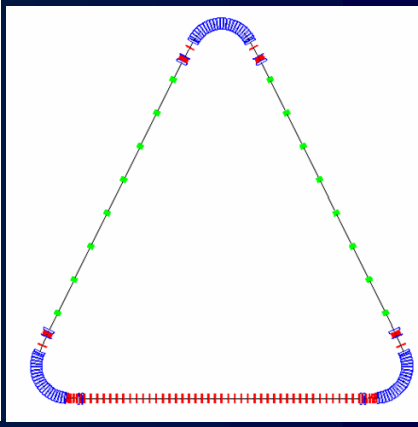
UKNF activity – highlights

- UKNF activity (and recent proposal) conceived as UK's contributions to IDS
  - Presently in 'reconciliation' negotiation with the Science and Technology Facilities Council
    - STFC $\supset$ CCLRC $\oplus$ PPARC
    - Expect one-year continuation *"… with the expectation that the future level of support for these programmes beyond March 2008 will be established following a programmatic review across STFC during 2007."*
- Programme classified according to:
  - Neutrino Factory specific:
    - Conceptual design
    - IDS support and management
    - MICE – expect Phase II funding – See A.Blondel's talk
    - EMMA – approved and construction funded – See S.Berg's talk
  - Generic underpinning accelerator R&D
    - Develops capability
      - Proton-driver Front End Test Stand
      - Target studies (incl. contribution to MERIT)
      - Development of manufacturing process for high-gradient cavities

Conceptual design:



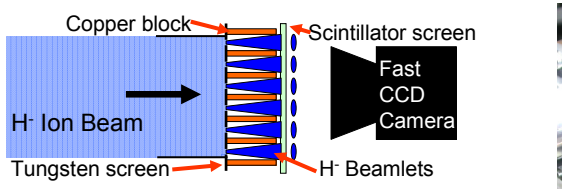


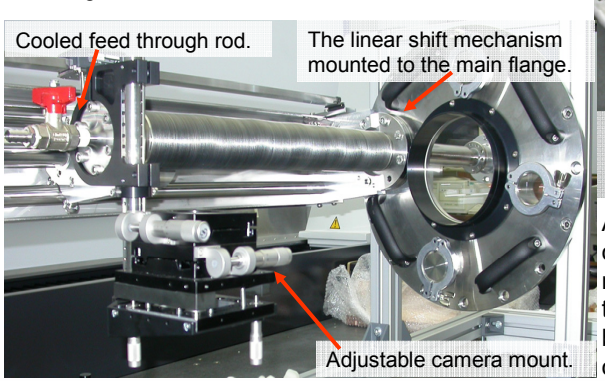


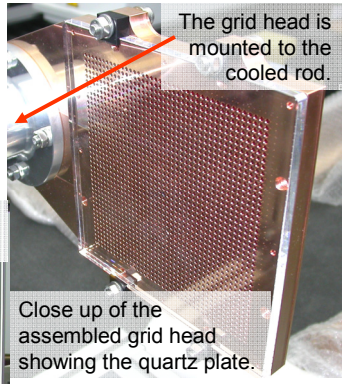
- Future programme based on core of 5 people in Chris Prior's Intense Beams Group in ASTeC
- University contributions (also training students)
- Basis of contribution to IDS

Front End Test Stand:

Pepper pot emittance measuring device



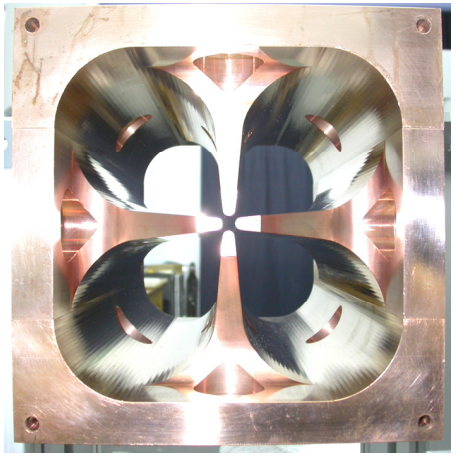


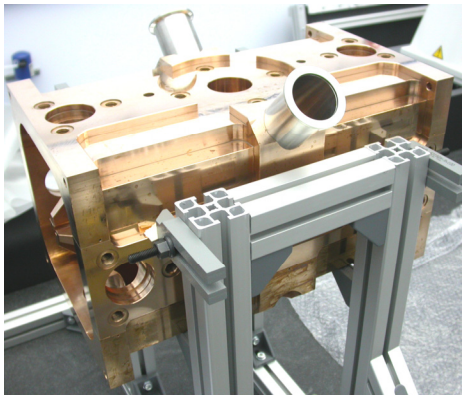


A pepper pot device mounted on a linear stage for correlated measurements of the transversal phase space along beam propagation is installed on the ion source test stand.

RFQ cold model

The 4 quadrants of the 4 vane RFQ cold model (l=0.5 m) are machined.



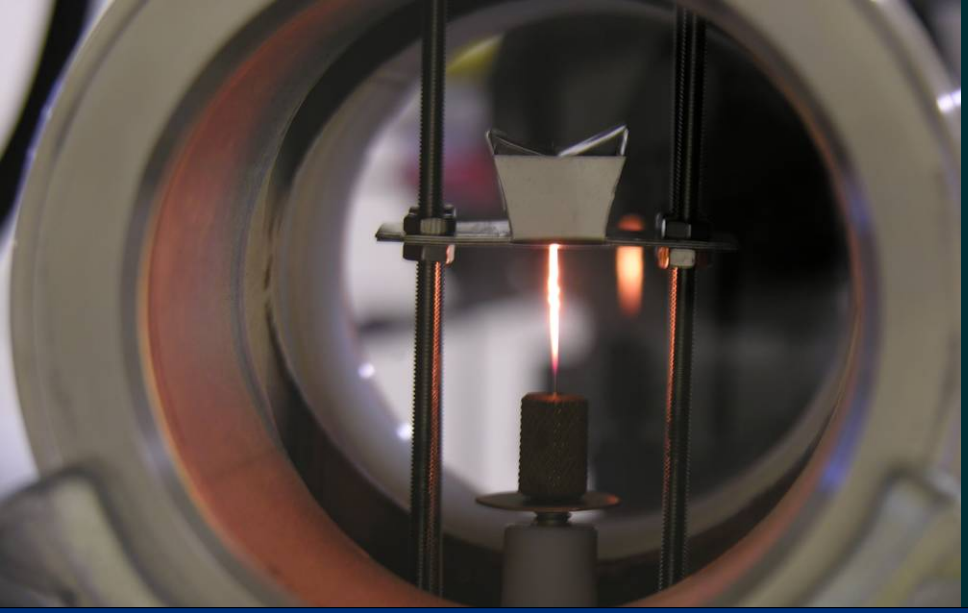


The quality of the quadrants will be measured by using a CMM and bead pull measurements will be performed before and after brazing.

- **Also, progress on:**
  - Ion source
  - LEBT
  - High-speed beam chopper
  - Laser diagnostics

- **Collaboration with Spain**
- **Initial contact with FNAL (R.Webber)**
  - Possible collaboration e.g. on diagnostics

- **Continuation as part of ‘generic’ programme**



Target studies:

- Electrical pulse excitation of samples of wire
- Extended running
- Encouraging results from tantalum
- Future programme:
  - Visar to measure surface movement
  - Comparison to LS-DYNA
  - Development of solid target concept and initial engineering

Some Results: 0.5 mm diameter Tungsten Wires

Target Number	Pulse Current A	Temp Jump K	Peak Temp K	Number of Pulses to Failure	Comments	Equivalent Power, MW, in Target Diameter	
						2 cm	3 cm
W03	4900 7200	90 200	2000 2200	>3.4x10^6 16,500	Broke	2.3	4.8
W08	6400	150	1900	>1.6x10^6	Wire stuck to top connection (cu blocks)	3.9	8.4
W09	5560 5840	120 130	1900 2050	4.2x10^6 9x10^6	Top connector failed	3 3.3	6.4 7.0
W15	6400	180	1950	1.3x10^6	Wire stuck to top connection (cu blocks)	3.9	8.4
W26	6200 7520-8000	140 ~230	2000 ~1800	10x10^6 3x10^6	Broke	3.6 ~6	7.8 ~12
W28	6560	180	1900	>19x10^6	Still running	4.1	8.8

"Equivalent Target": This shows the equivalent beam power (MW) and target radius (cm) in a real target for the same stress in the test wire. Assumes a parabolic beam distribution and 3 micro-pulses per macro-pulse of 20 micro-s.

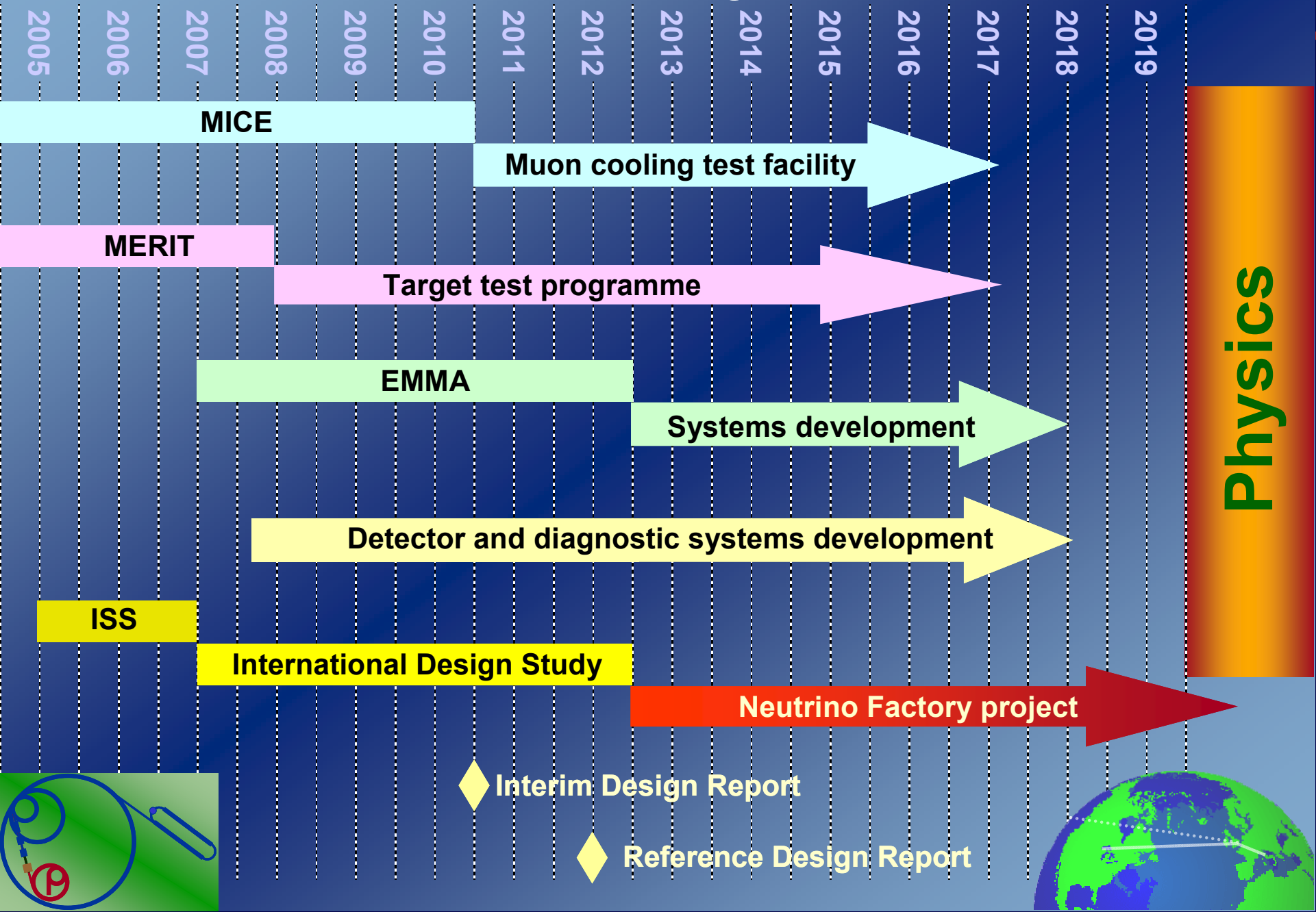
Cavity development:

- Present team:
  - Cockcroft/Lancaster: Seviour (WPM), Stables
  - Imperial Mech. Eng.: Ristic, Zarrabini
    - Some support from ASTeC, Brunel, Imperial Physics (Kurup, FNAL/IC fellow)
- Scope of work for 2007/08 being discussed:
  - Seek to work alongside MuCool programme, perhaps contributing to the 'button tests'
  - Perhaps seek to support MICE-US in RF cavity manufacture
- In parallel, some development of connection with industrial partner(s) for the study and evaluation of the manufacturing processes

Conclusions

- The ISS succeeded in establishing an internationally-agreed baseline for the Neutrino Factory accelerator and long-baseline detectors
- Clear need, and momentum, to work towards a Neutrino Factory RDR by ~2012
  - Clear need for this to be an *international* endeavour
  - The International Design Study initiative is in place and must bring a proposal to NuFact07
    - IDS must recognise and exploit synergies
      - The Neutrino Factory/Muon Collider synergies are significant
      - STFC (Centre for Fundamental Physics) wishes to host a 2/3 day workshop focused on the Neutrino Factory and Muon Collider R&D programmes in September or October

Neutrino Factory roadmap



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