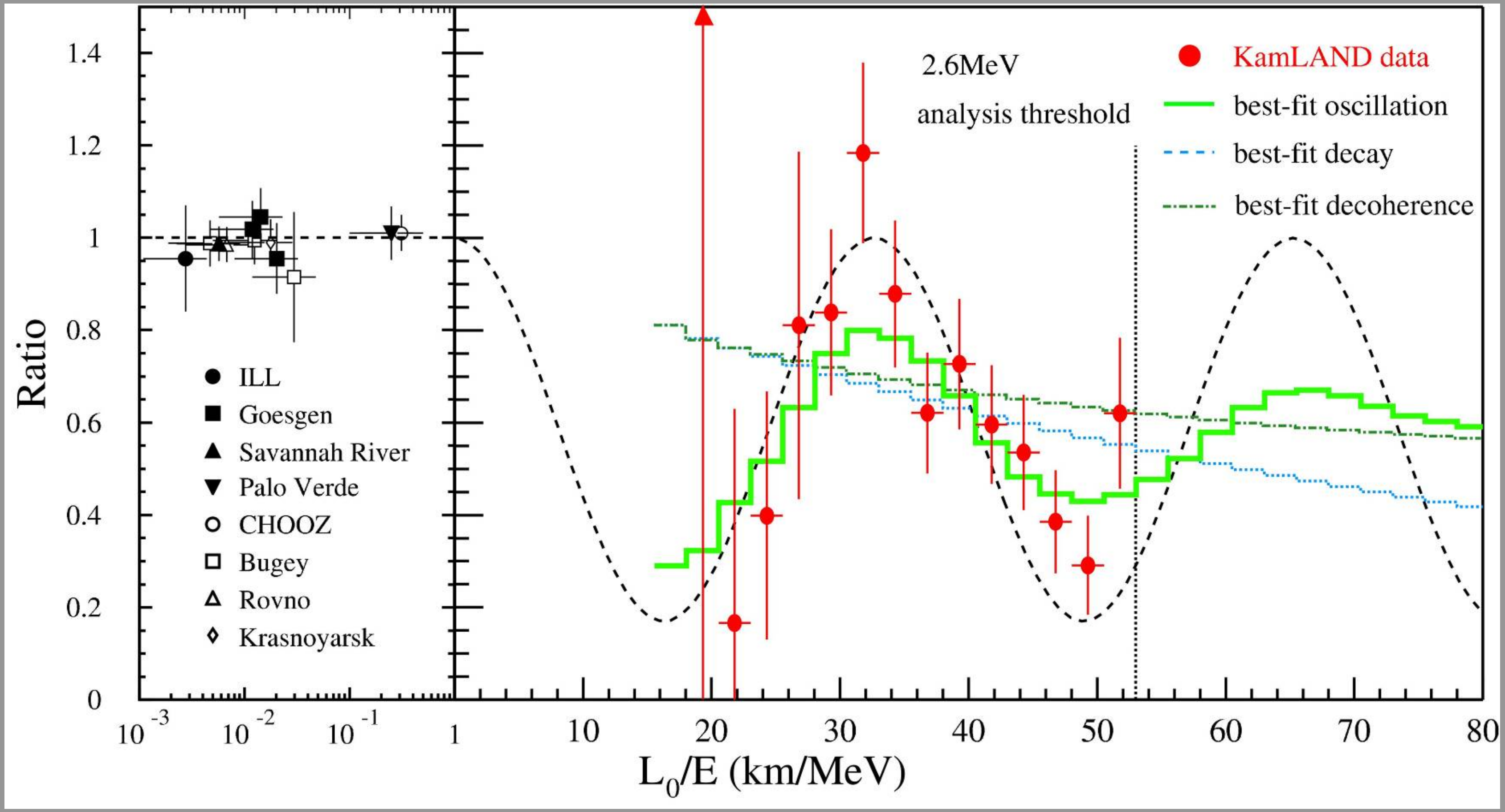
Imperial College London

K. Long, 22 February, 2008

The Neutrino Factory and MICE

Motivation

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



Ratio
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10^-3
10^-2
10^-1
1
10
20
30
40
50
60
70
80
L_0/E (km/MeV)
ILL
Goesgen
Savannah River
Palo Verde
CHOOZ
Bugey
Rovno
Krasnoyarsk
2.6MeV
analysis threshold
KamLAND data
best-fit oscillation
best-fit decay
best-fit decoherence

Motivation

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

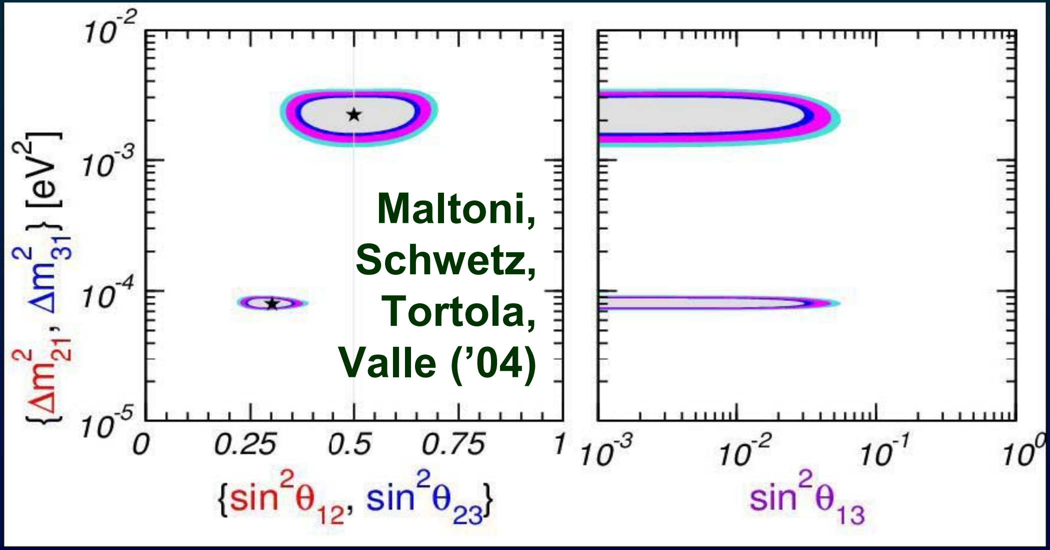
- Neutrino oscillations imply:
  - Neutrinos mix and neutrino mass is not zero
    - Neutrino is not an eigenstate of helicity
  - Lepton flavour is not conserved

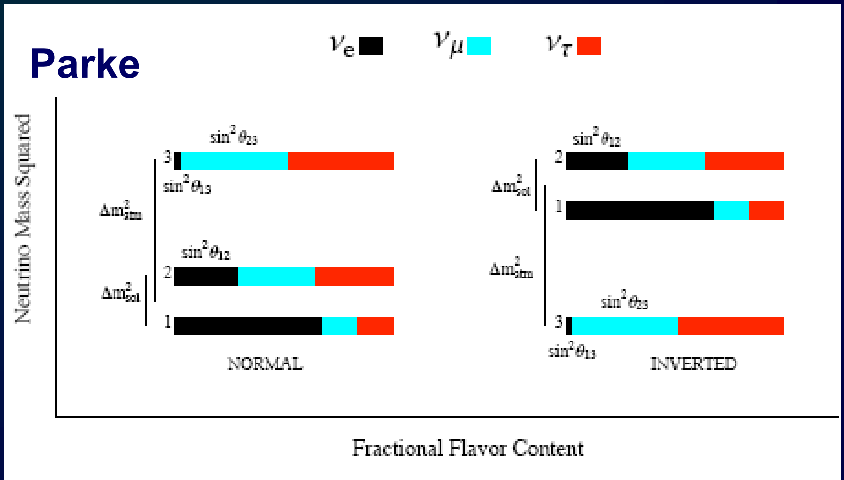
Extension of the Standard Model?
Fundamental breakthrough?

SM extension:

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

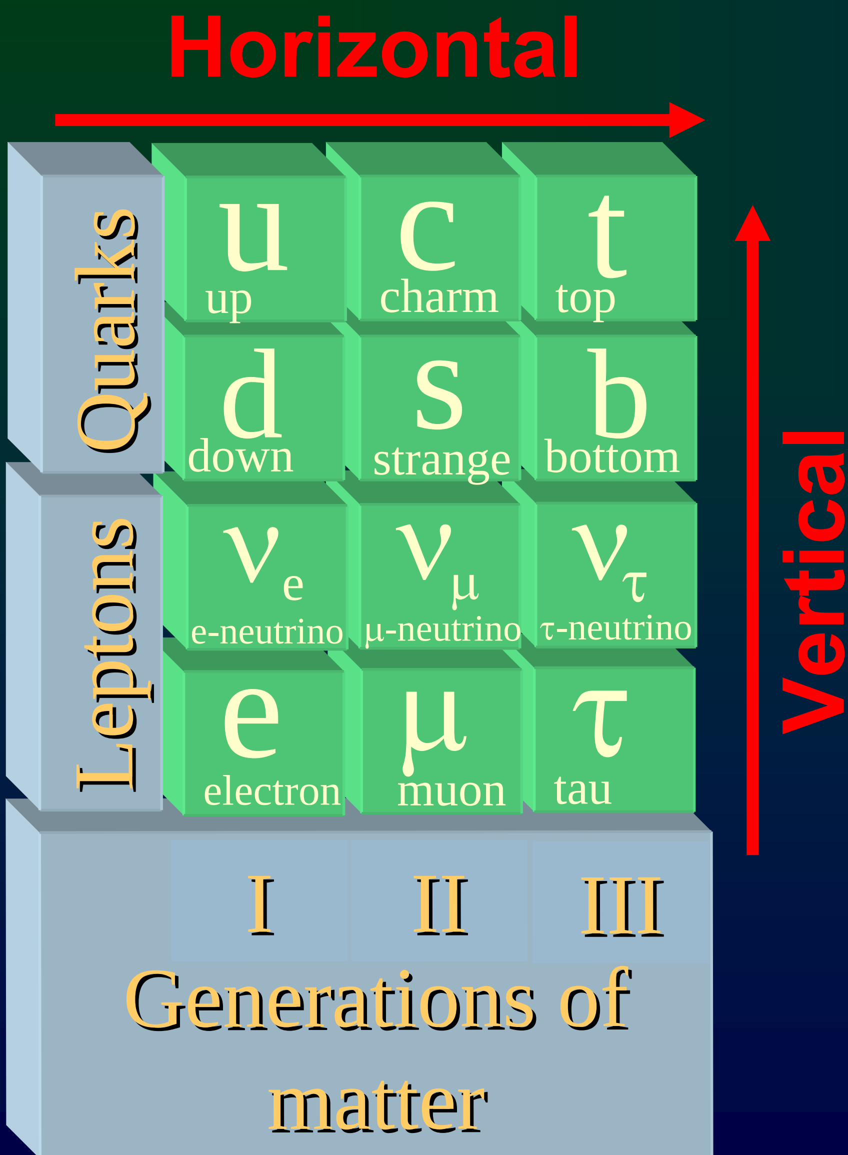
$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12}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





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:

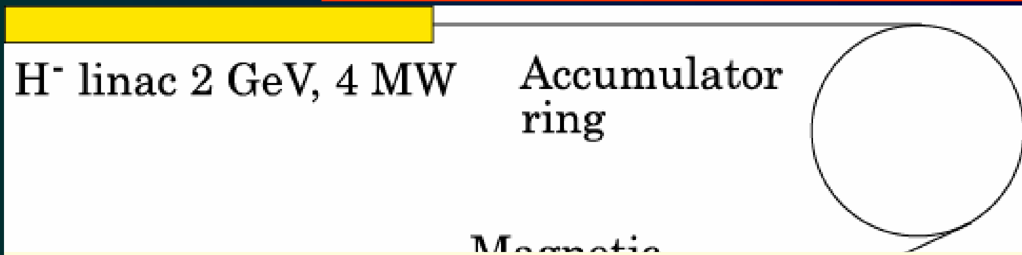
- See-saw mechanism gives a ‘natural’ explanation of both:
  - Small neutrino mass
  - Large lepton mixing angles

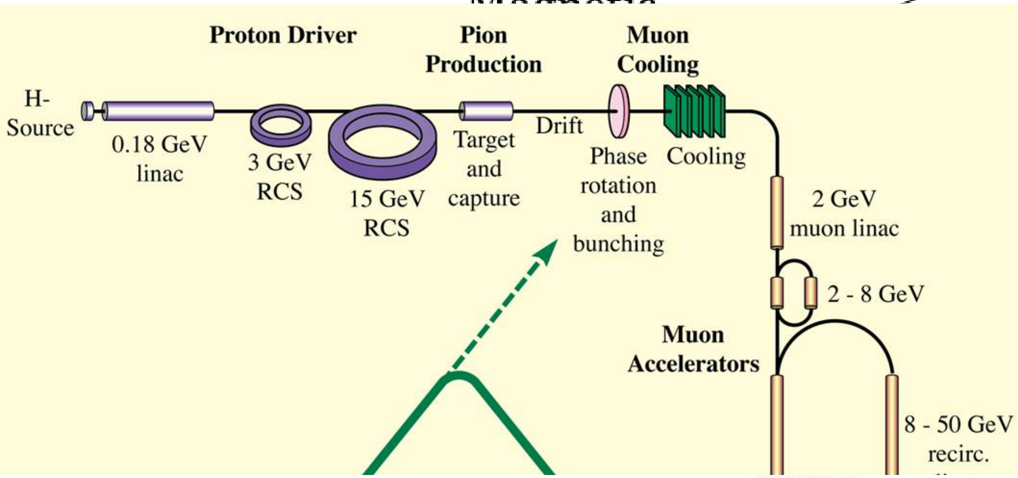
  so neutrino probes physics at very high mass scales
- Create observed baryon asymmetry through heavy, Majorana, neutrinos?

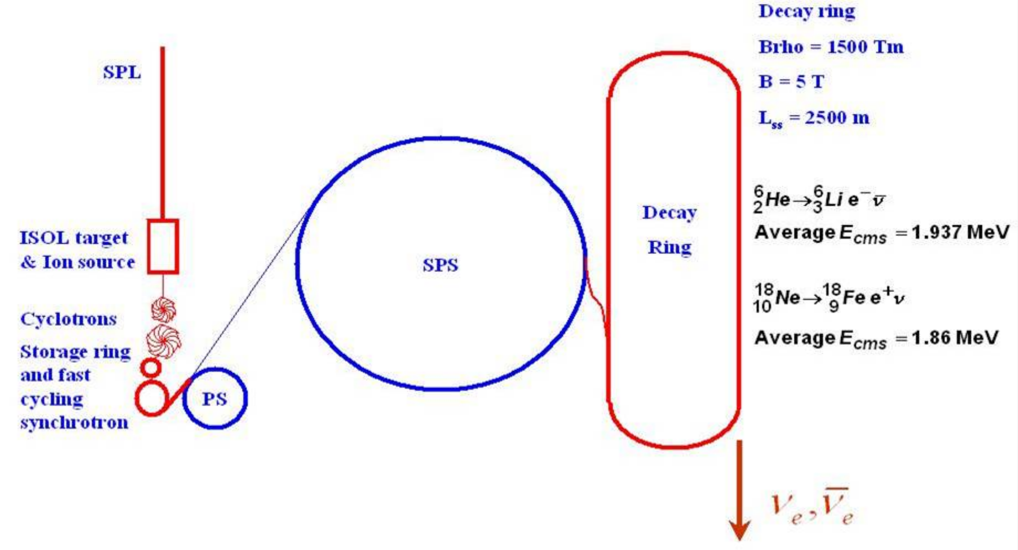
Detailed understanding of properties of neutrino is required to understand the physics of flavour.

Facilities for precision era:

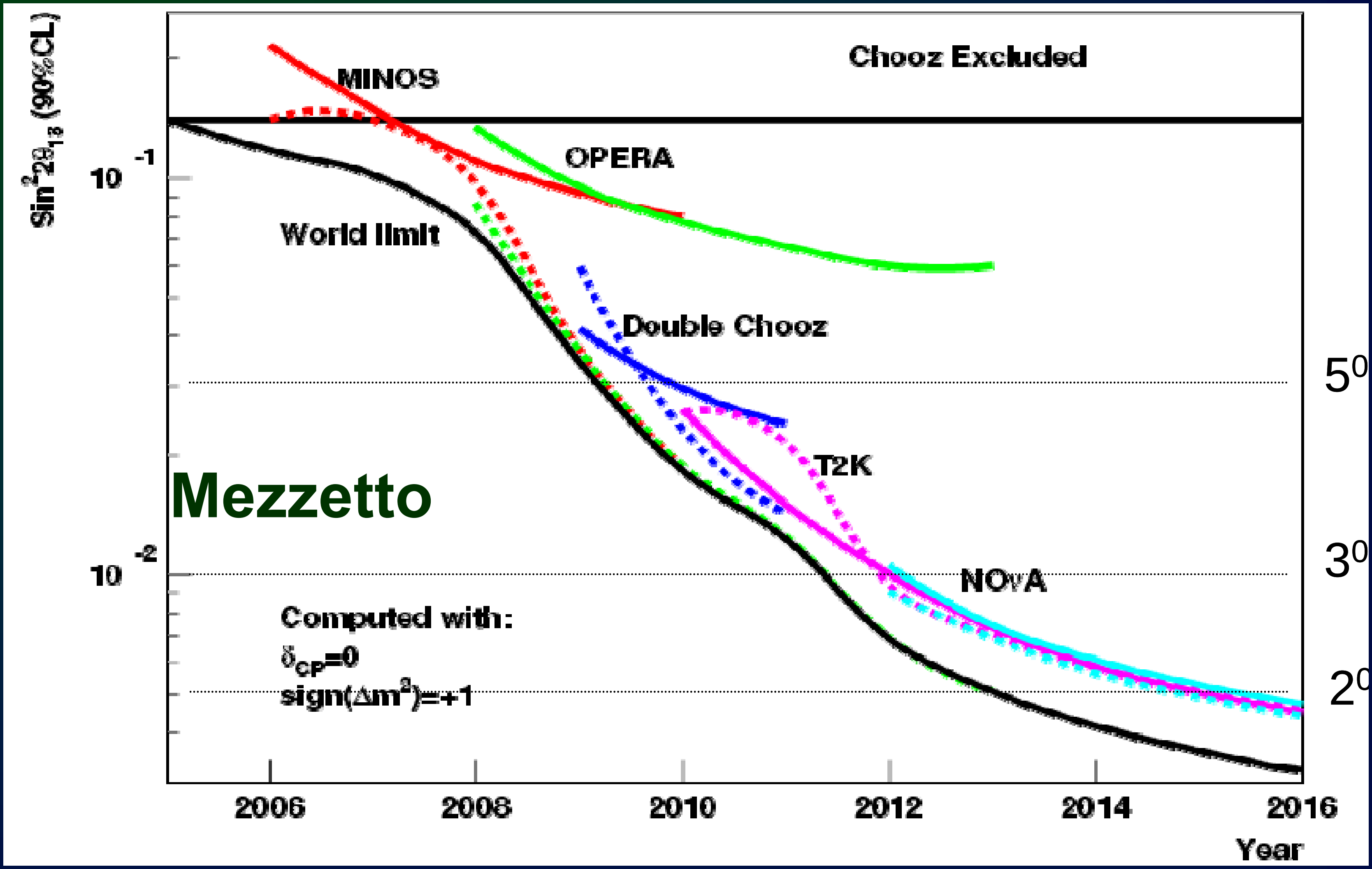
- Second generation super-beam
  - CERN, FNAL, BNL, J-PARC II
    - MTon H_2O Cherenkov
- Neutrino Factory
    - Magnetised detector
- Beta-beam
    - MTon H_2O Cherenkov, liquid argon







Science-driven timescale:



- Source for high-sensitivity/high-precision era required **‘second half of next decade’**

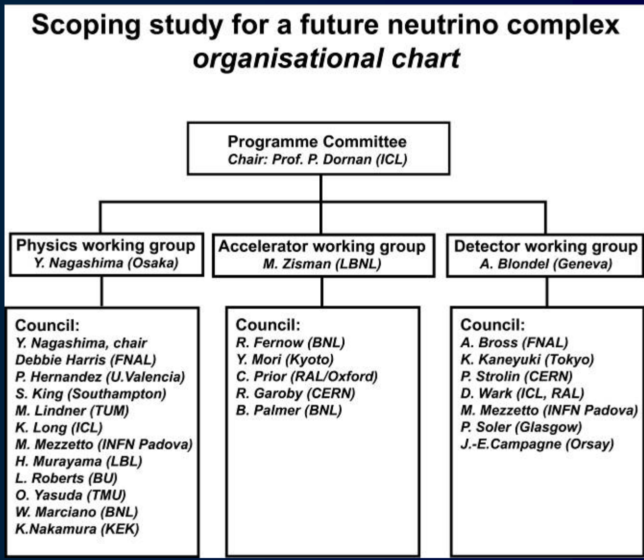
Objectives for the precision programme:

- Within the standard three-neutrino mixing model (the Standard Neutrino Model) require to:
  - Search for non-zero δ – Discovery
  - Determine the sign of Δm^2_{23} – Discovery
  - Exquisite sensitivity to non-standard physics – Discovery
  - Precisely measure θ_{13} – precision
- As important as study of CKM matrix …

The International Scoping Study:

… a step on the way!

- One-year study: NuFact05 – NuFact06
- 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, SFFAG, NSFFAG, …
  - Recognition of importance of holistic consideration of source and detector
  - Recognition of importance of an international approach

Contents:

- The conclusions of the ISS:
  - Physics
  - Accelerator
  - Detector
- Towards the RDR for the Neutrino Factory
  - The IDS-NF
- Status of Neutrino Factory accelerator R&D
  - MERIT
  - MICE
  - MuCOOL
  - EMMA
- Conclusions

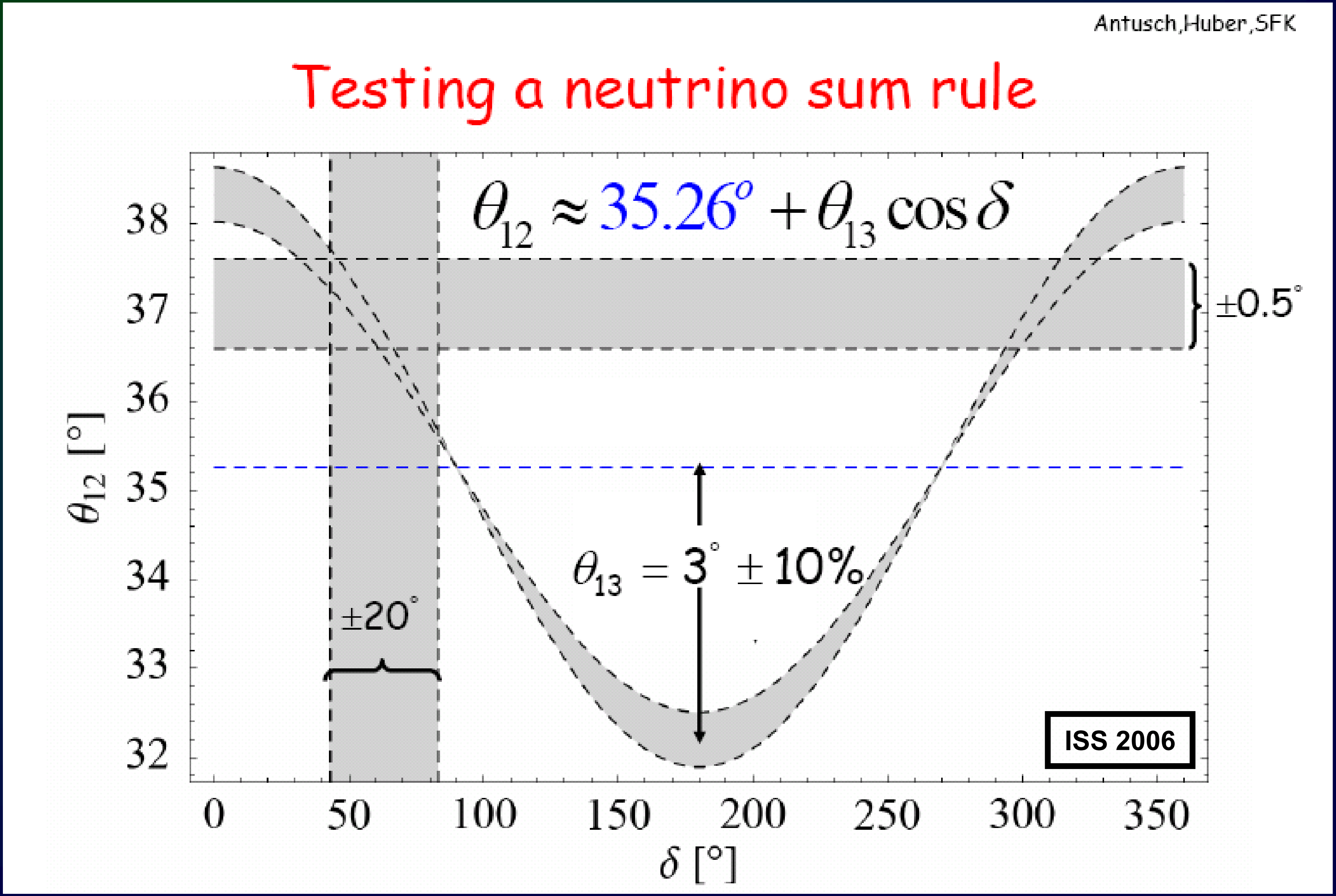
The physics case:

- If *physics of flavour* is 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

Quark-lepton relationship – example



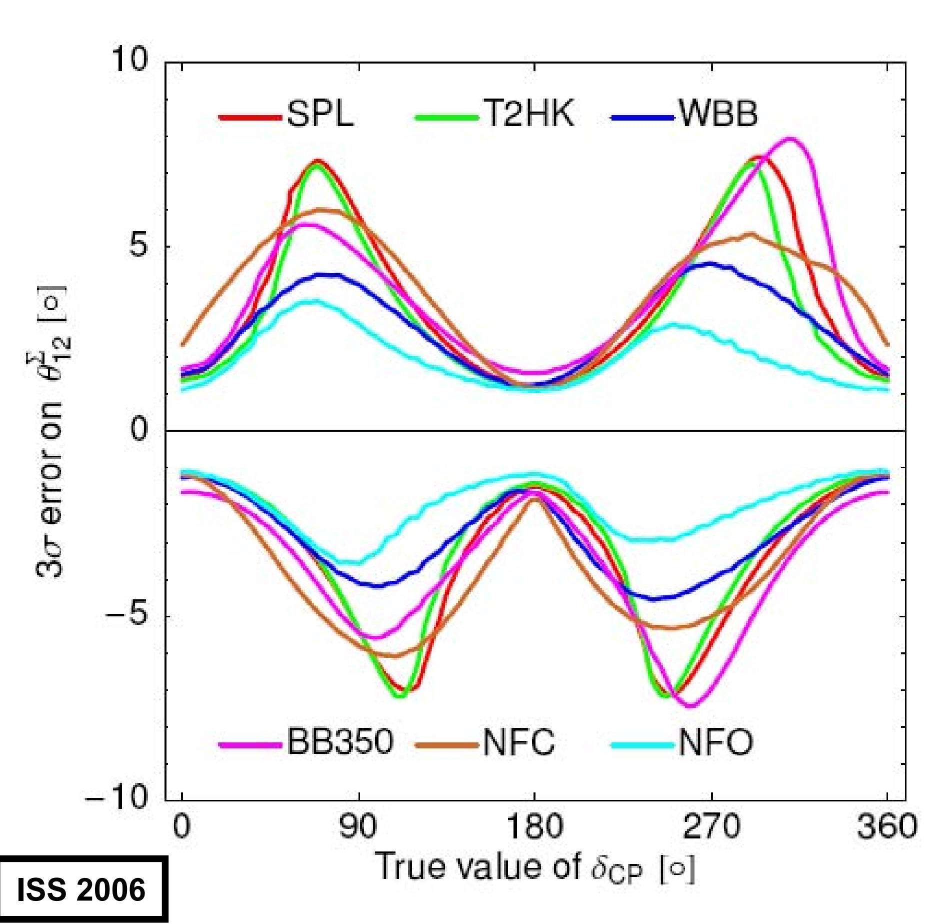
Quark-lepton relationship – example

- Define:

$$\theta_{12}^{\Sigma} = \theta_{12} - \theta_{13} \cos\delta$$

- Precision evaluated assuming:

$$\theta_{12} = 33.12^\circ \quad \theta_{13} = 9^\circ$$



ISS 2006

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
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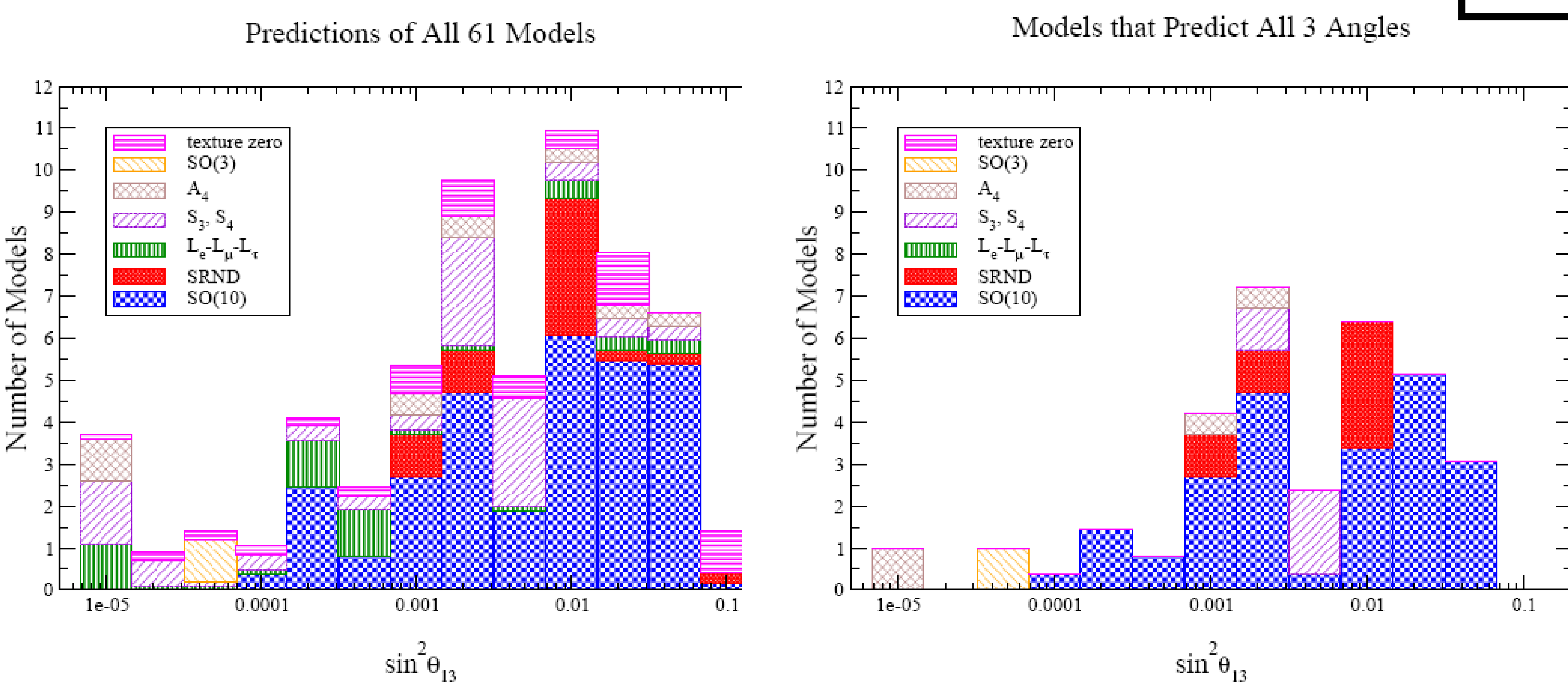
Identifying the correct theory:

- **Precise knowledge of neutrino mixing parameters can discriminate:**

ISS 2006



Chen et al., hep-ph/0608137

Towards specification of required precision:

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  - GUT and/or family

then

- The quark- and lepton-mixing parameters must be related
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- Challenge to neutrino experimenters:
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Neutrino Factory performance:

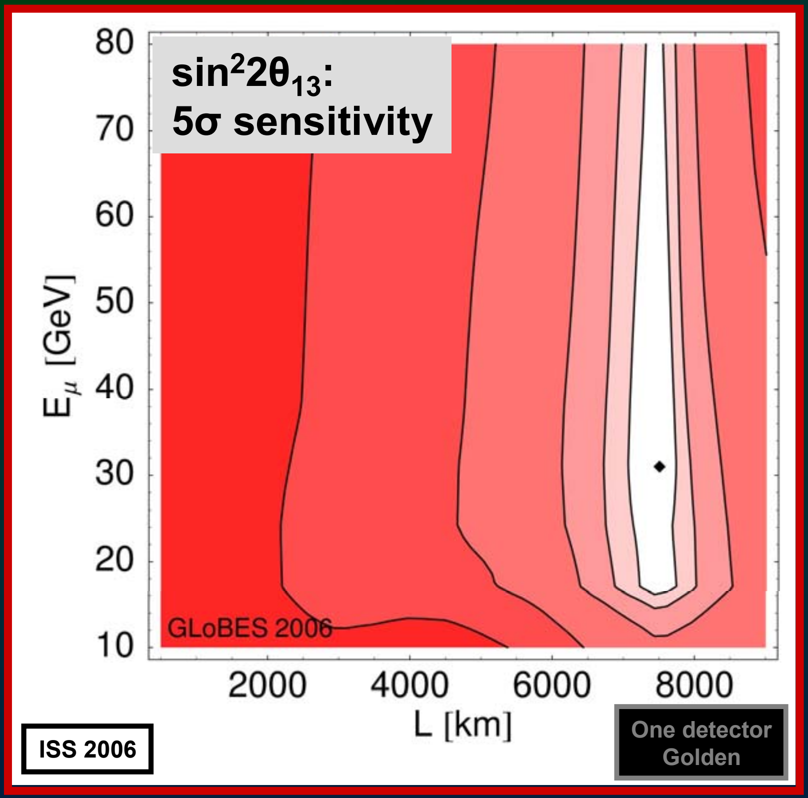
$\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu$	$\mu^- \rightarrow e^- \overline{\nu}_e$	
$\overline{\nu}_\mu \rightarrow \bar{\nu}_\mu$	$\nu_\mu \rightarrow \nu_\mu$	disappearance
$\overline{\nu}_\mu \rightarrow \bar{\nu}_e$	$\nu_\mu \rightarrow \nu_e$	appearance (challenging "platinum"
$\overline{\nu}_\mu \rightarrow \bar{\nu}_\tau$	$\nu_\mu \rightarrow \nu_\tau$	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

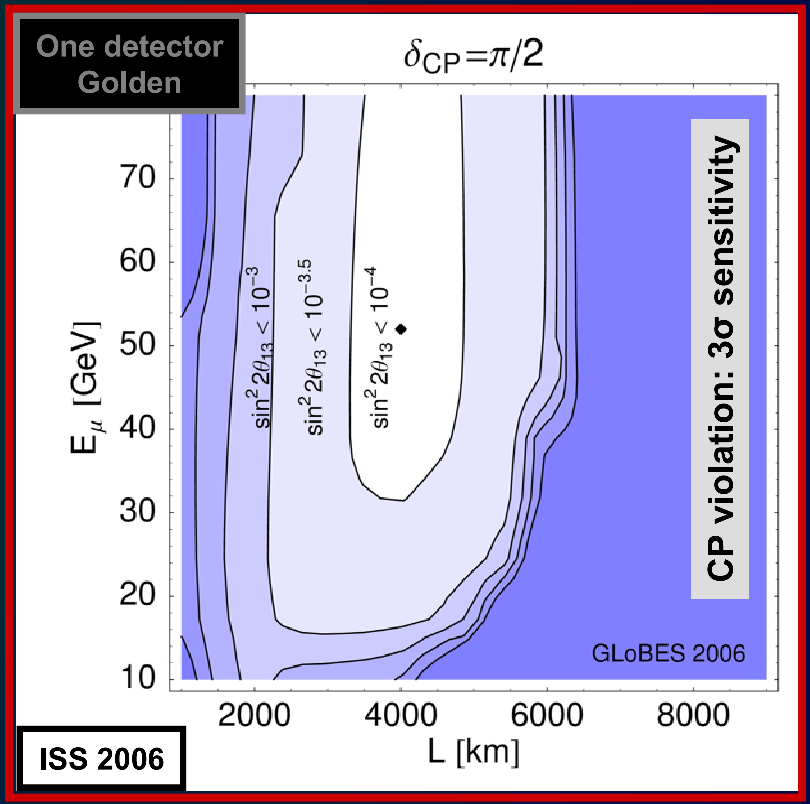
"Golden"

- 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_ν bins, efficiency and migration matrices

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

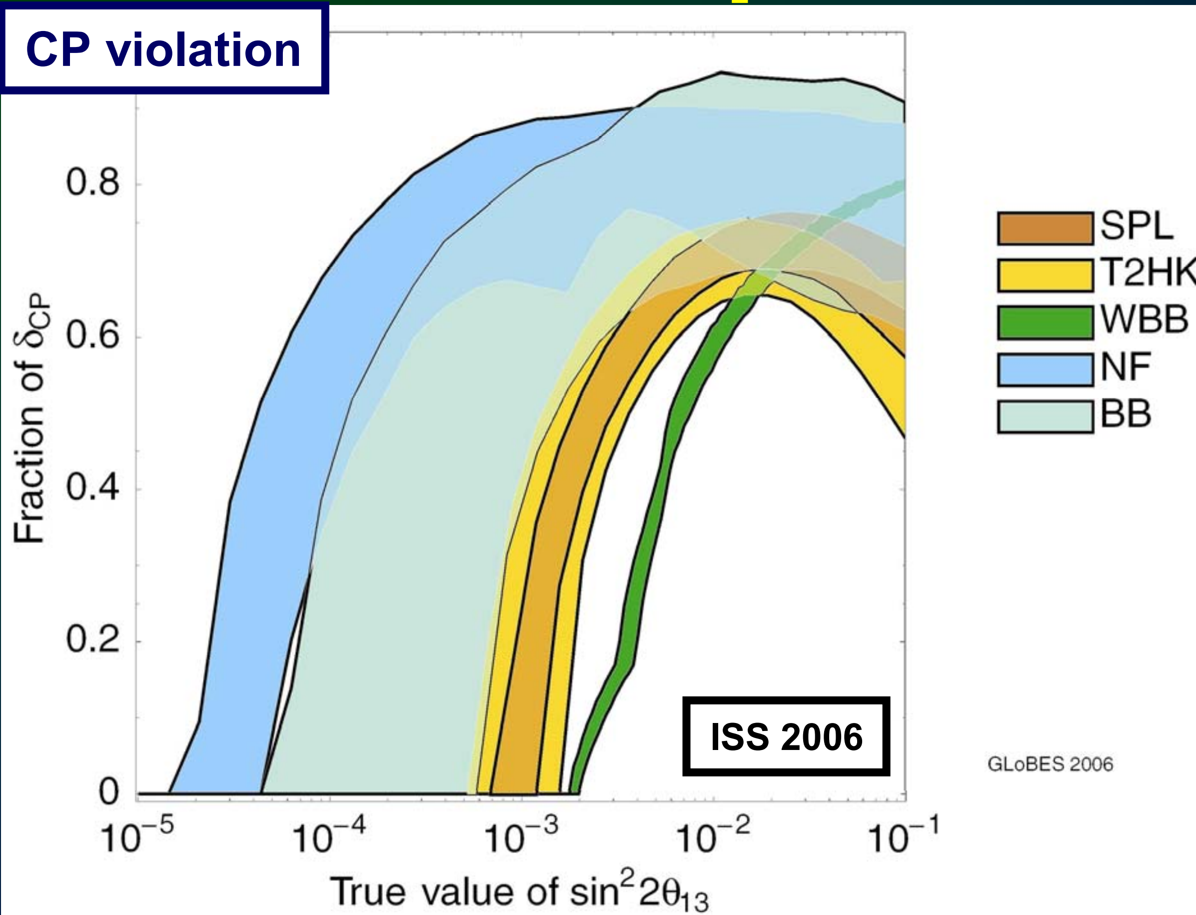
NF: Golden channel optimisation





- Magic baseline (7500 km) good degeneracy solver
- Best sensitivity to CP requires baseline ~4000 km
- Stored muon energy: baseline 25 GeV

Comparison: CP violation



SPL
Systematics: 2% – 5%

T2HK
Systematics: 2% – 5%

WBB
Systematics from proposal

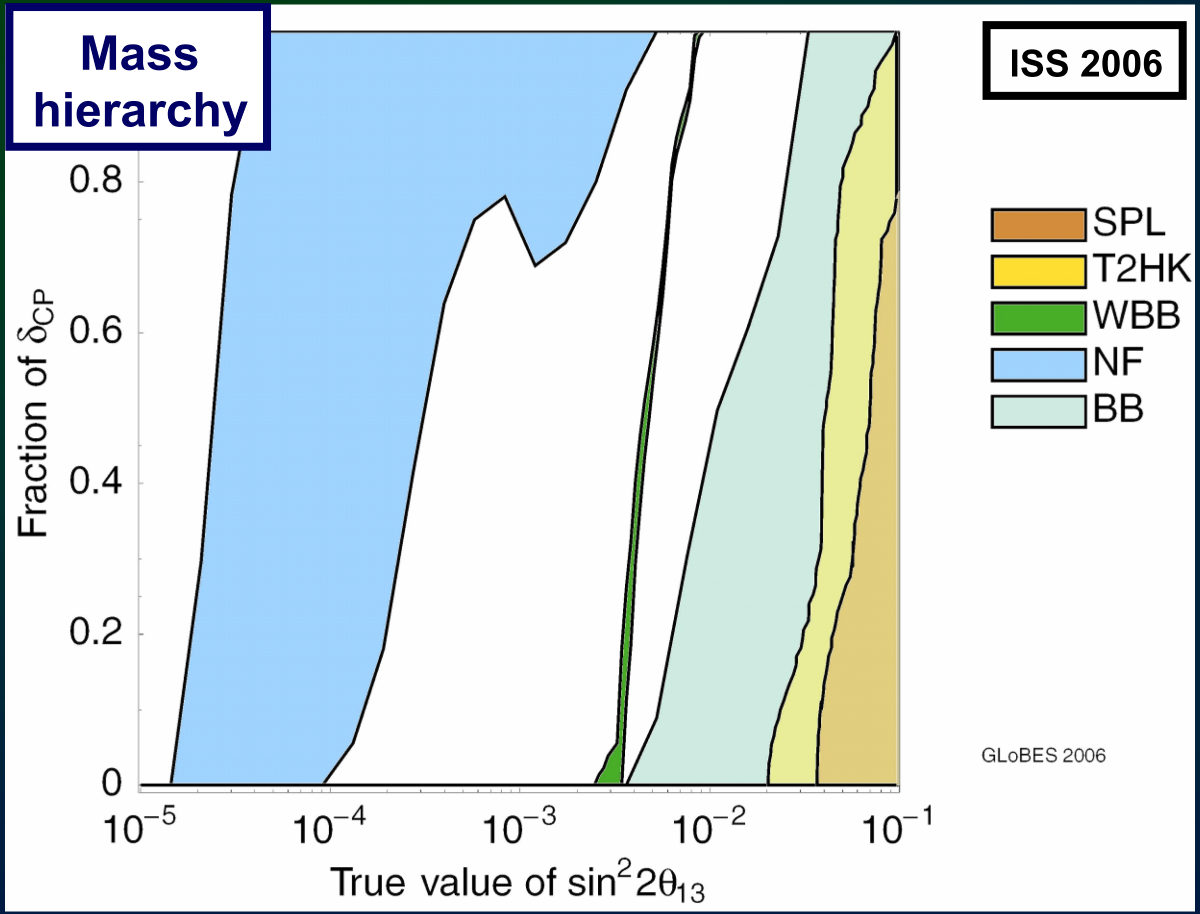
Beta beam
γ = 100
500 kT H_2O Ç (130 km)

γ = 350
500 kT H_2O Ç (730 km)

Neutrino Factory
Golden, 4000,
E_μ = 50 GeV

Golden* (4000 km), Golden* (7500 km)
E_μ = 20 GeV

Comparison: mass hierarchy



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Golden, 4000, E_μ = 50 GeV
Golden* (4000 km), Golden* (7500 km)
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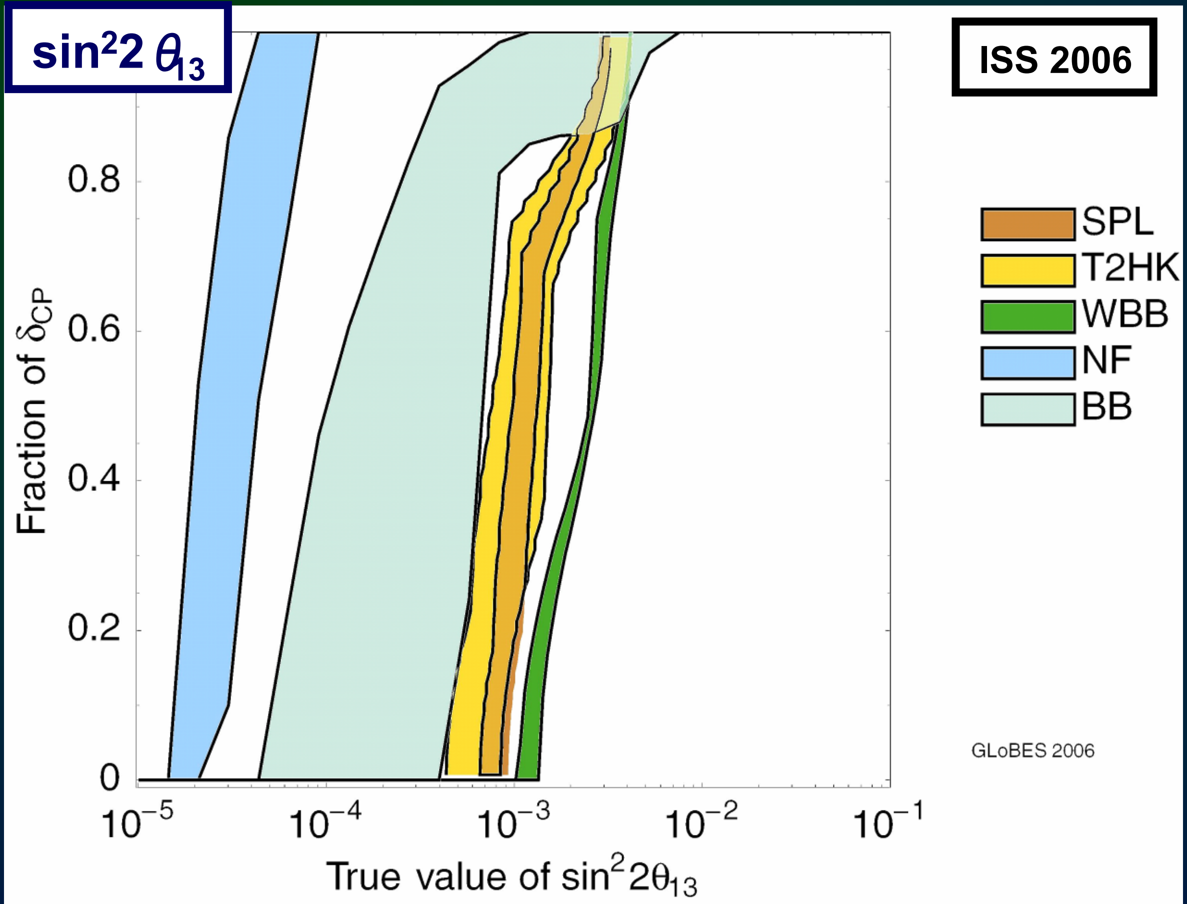
γ = 350
500 kT H_2O Ç (730 km)

Comparison: θ_{13}



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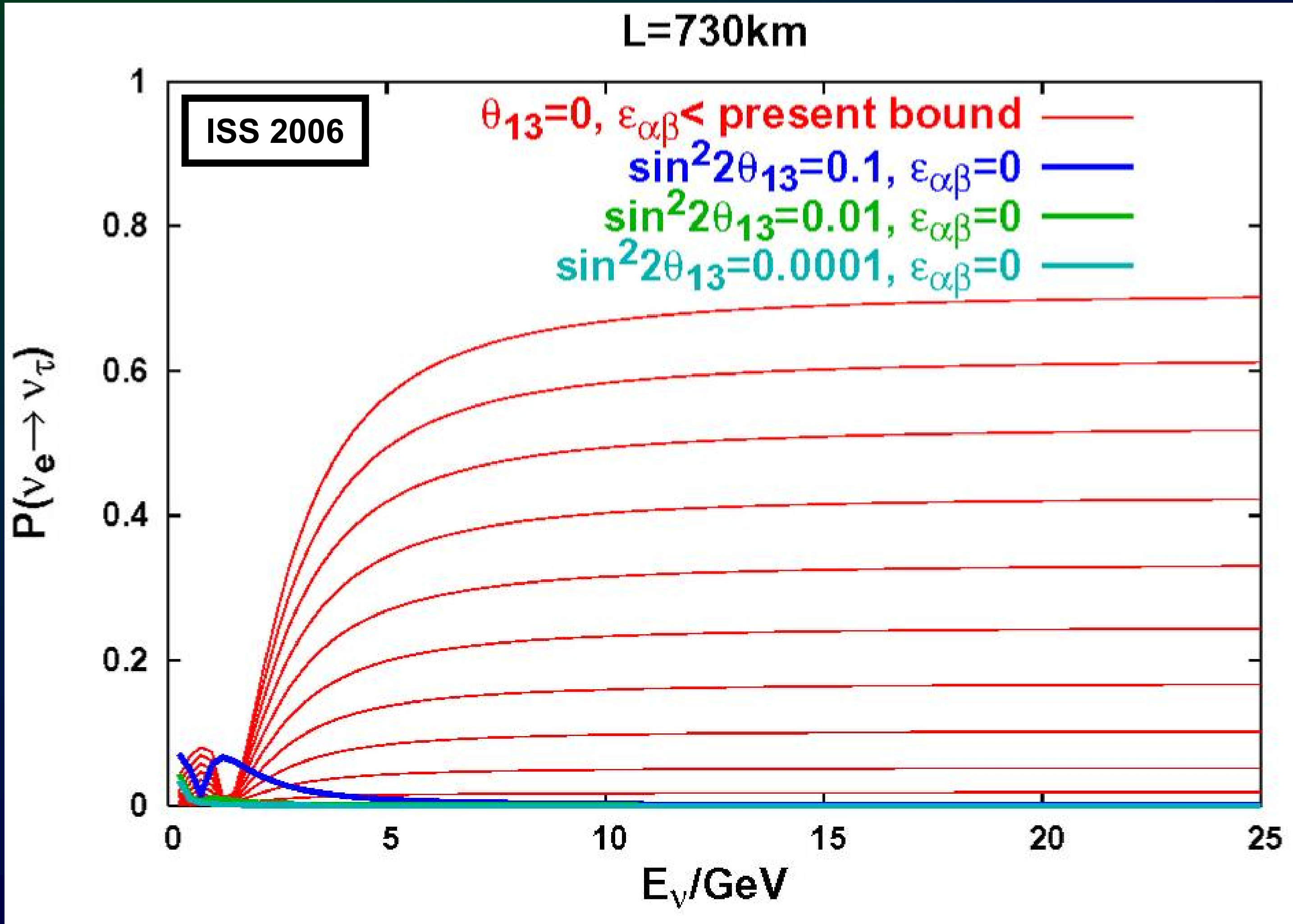
Neutrino Factory

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

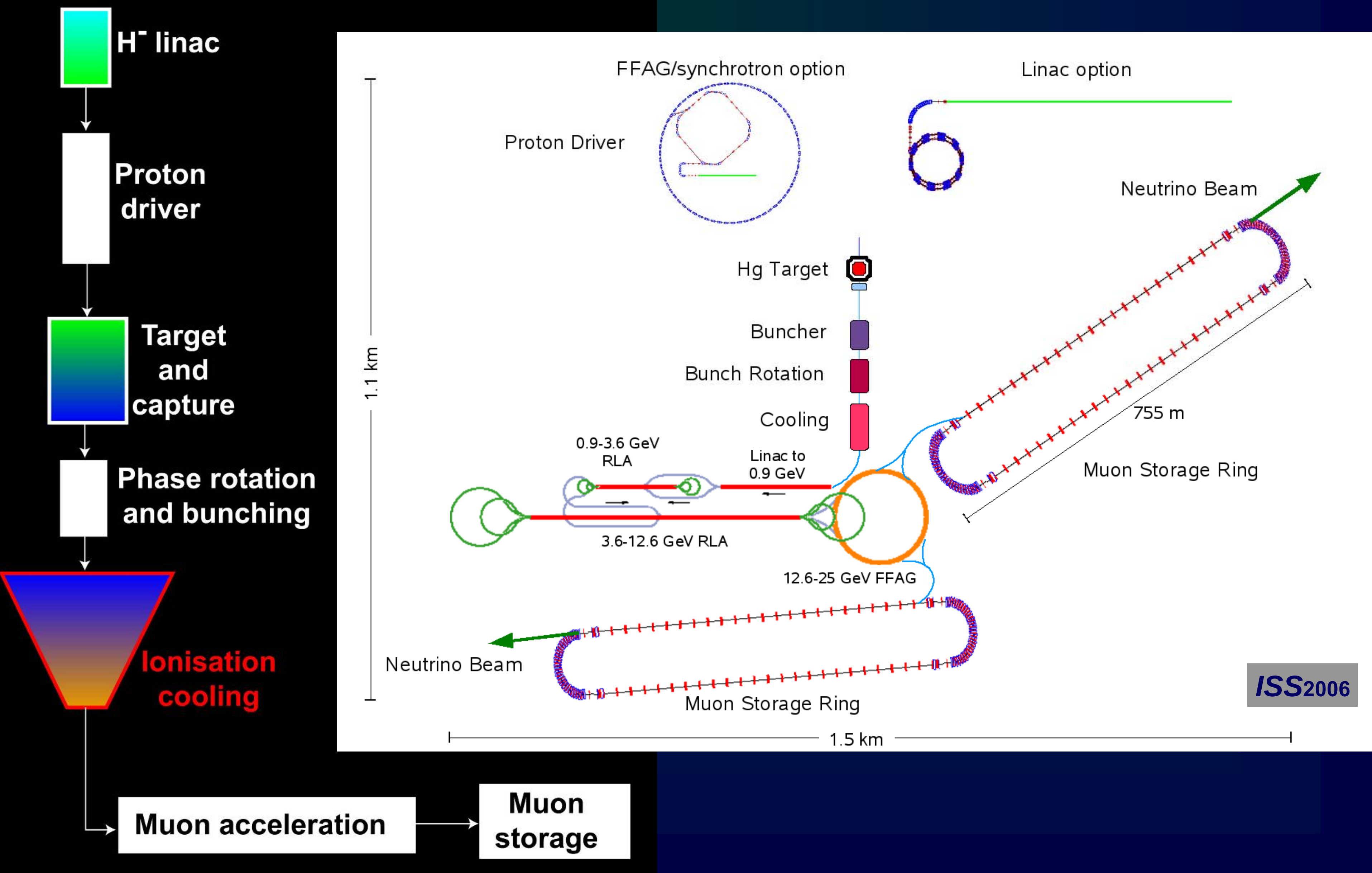
Golden* (4000 km), Golden* (7500 km)
$E_\mu = 20$ GeV

New physics in neutrino oscillations

- **Example:**
  - **Silver channel at the Neutrino Factory** $\nu_e \to \nu_\tau$

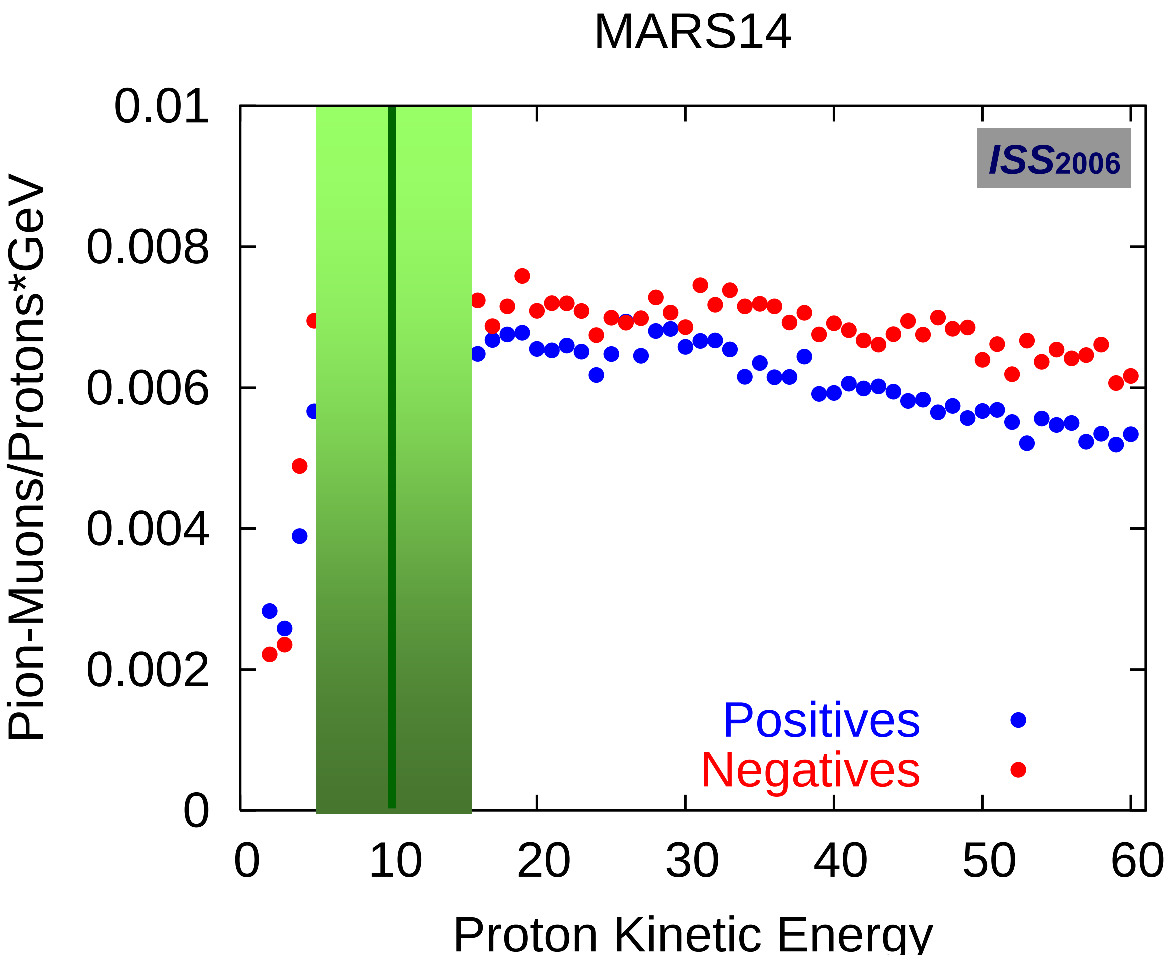


ISS baseline Neutrino Factory



Proton-driver baseline: energy

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

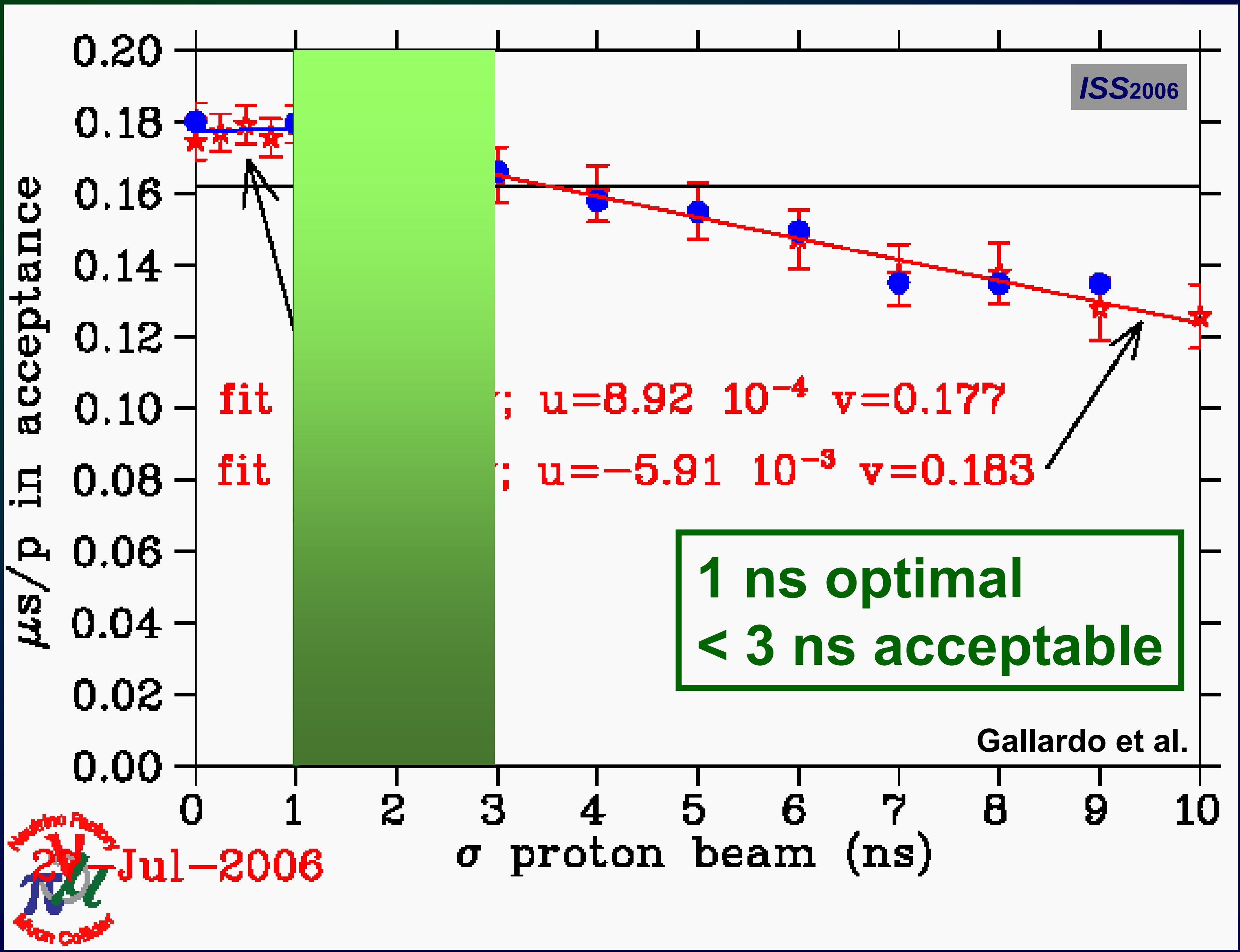


μ^-: 6 – 11 GeV

μ^+: 9 – 19 GeV

We adopted 10 ± 5 GeV as representative range

Proton-driver baseline: bunch length



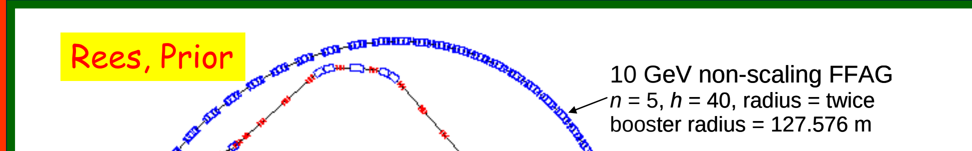
Proton-driver baseline:

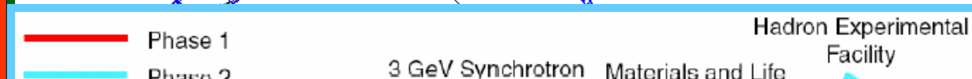
- Proton Driver
  - specify parameters, not design
    - implicitly assumes liquid-metal target

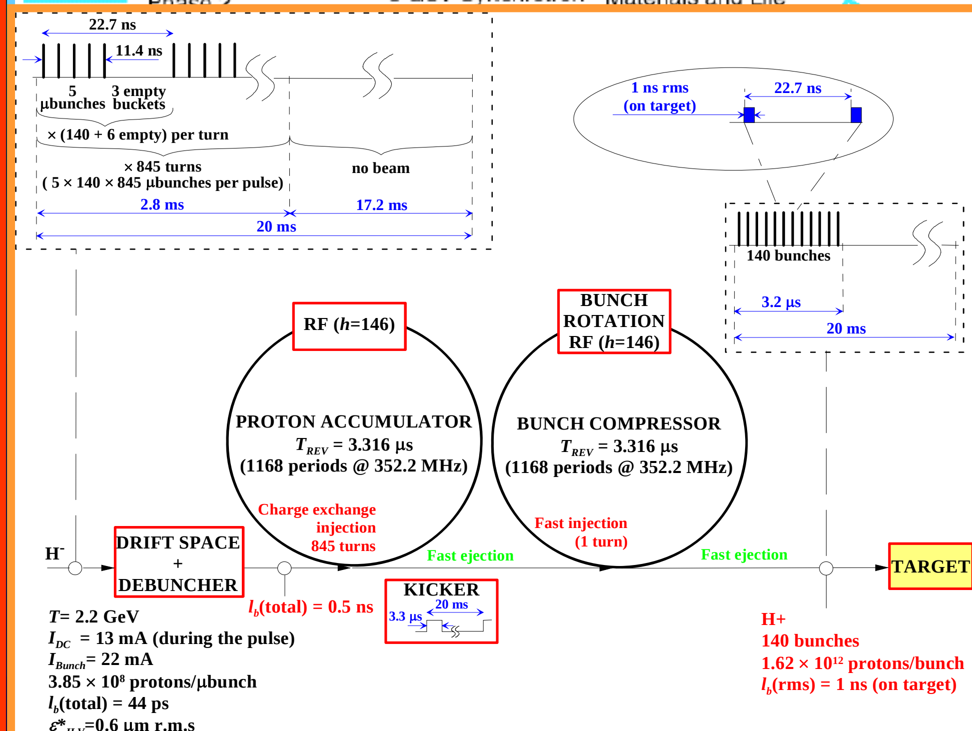
Parameter	Value
Energy (GeV)	10 ± 5
Beam power (MW)	4
Repetition rate (Hz)	≈50
No. of bunch trains	3,5[a)]
Bunch length, rms (ns)	2 ± 1
Beam duration[b)] (μs)	≈40

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

- Options:
  - FFAG
  - RCS
  - Linac

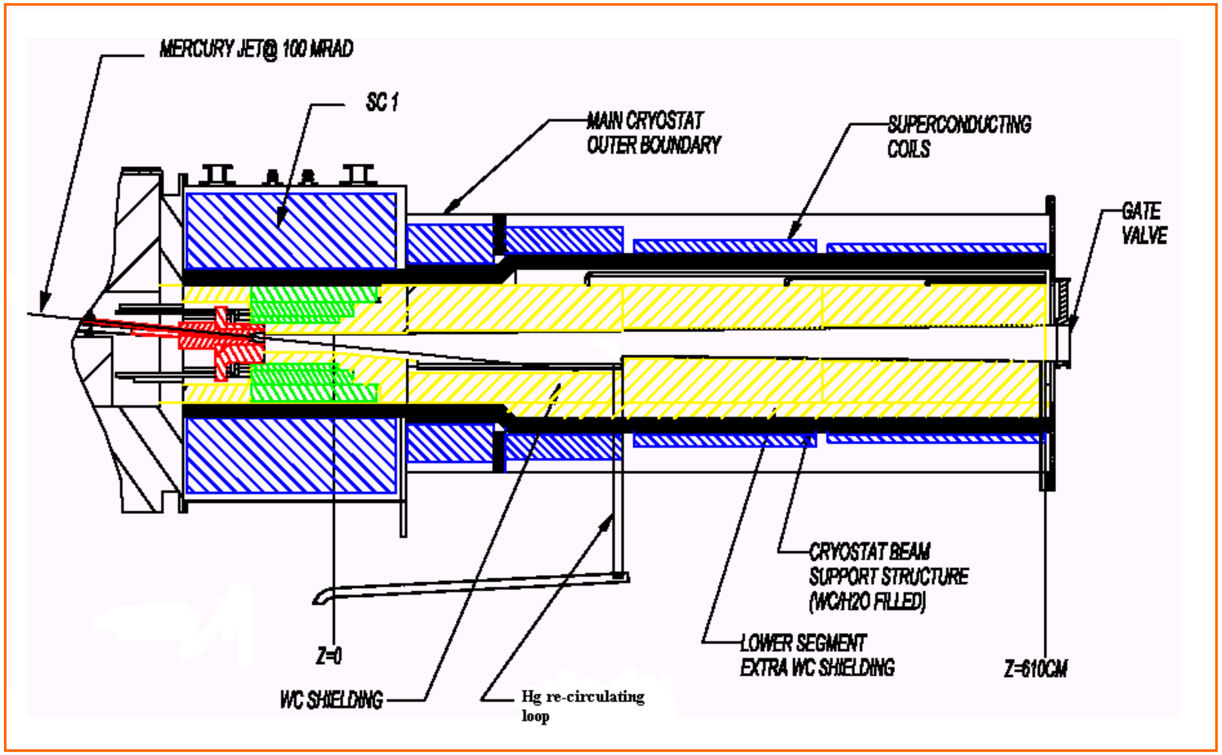






Target baseline:

• 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 …**

Ionisation cooling:

- **Muons beam is a tertiary beam:**
  - **Phase space very large, needs to be reduced (cooled) before acceleration**
- **Short muon lifetime implies:**
  - **Ionisation cooling the only technique that is fast enough**

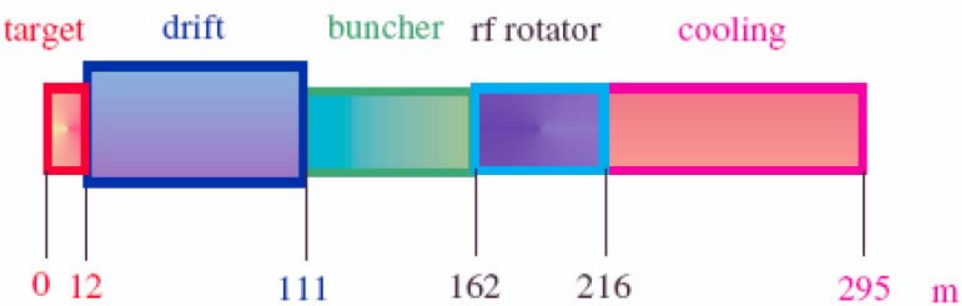
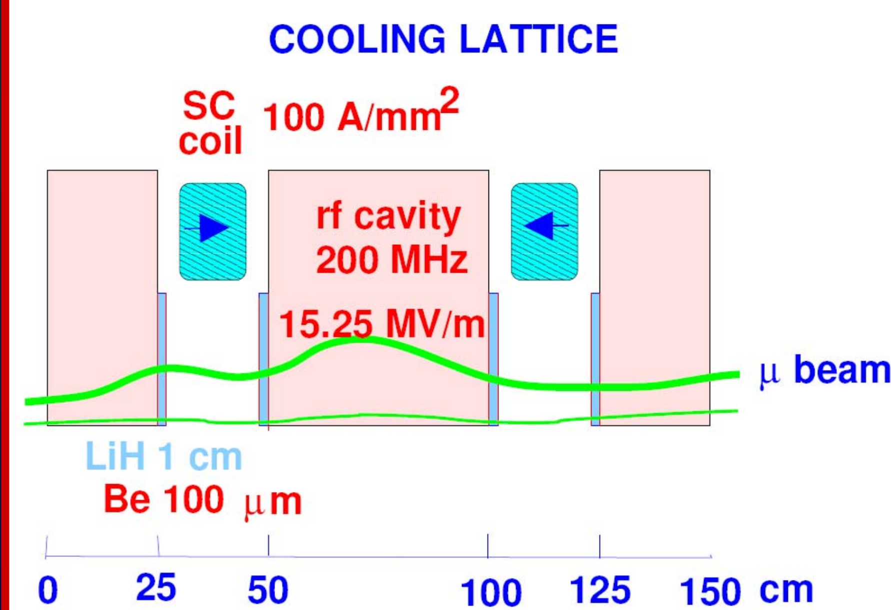


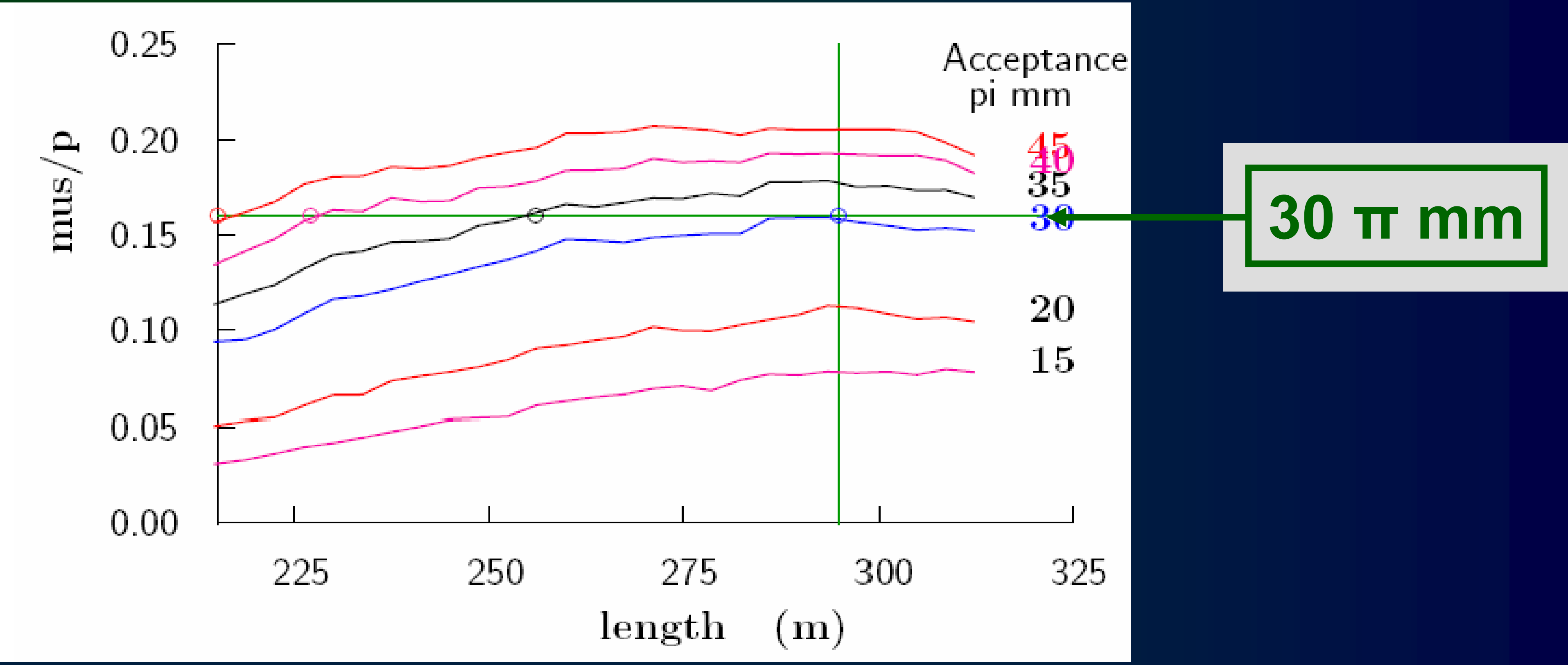
Fig. 30. Schematic layout of ISS baseline front end.

Table 15. Properties of ISS baseline front end.

Parameter	Value
L (m)	295
No. of solenoids	460
No. of RF cavities	210
Accepted muons per proton-GeV	0.0083
Transverse normalized acceptance, ε_{TN} (π mm-rad)	7.4
Helicity	0.08
σ_p/p	0.105



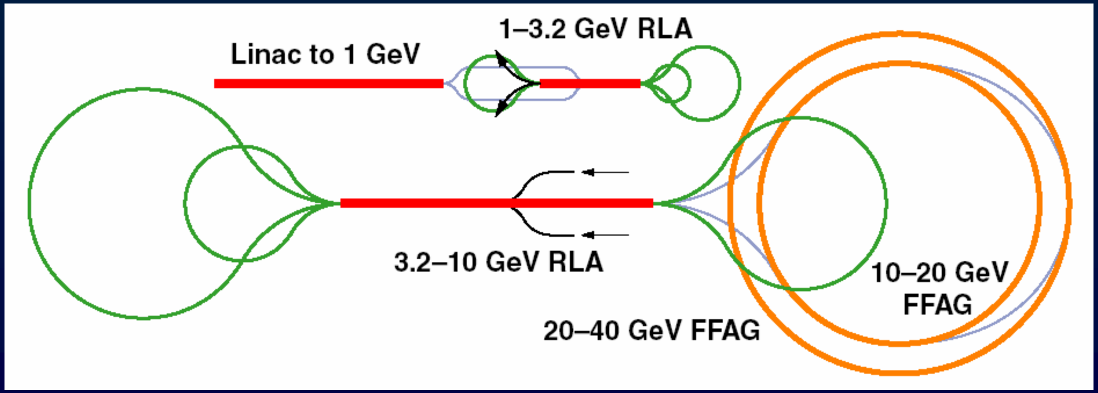
Cooling vs acceptance



- **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:

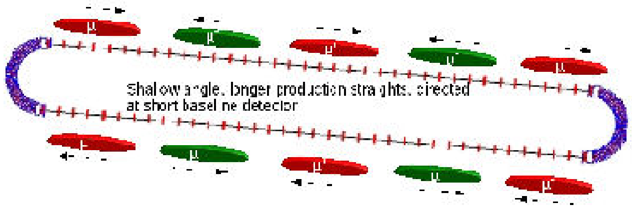
- Compare different schemes *on an even footing*
  - RLA, scaling FFAG, non-scaling FFAG
    - consider implications of keeping both sign muons
    - consider not only performance but relative costs
  - bring scaling FFAG design to same level as non-scaling design
- Look at implications of increasing acceptance
  - transverse and longitudinal
    - acceptance issues have arisen in non-scaling case
      - leading to exploration of a revised acceleration scenario



DECAY RINGS

Working hypothesis :

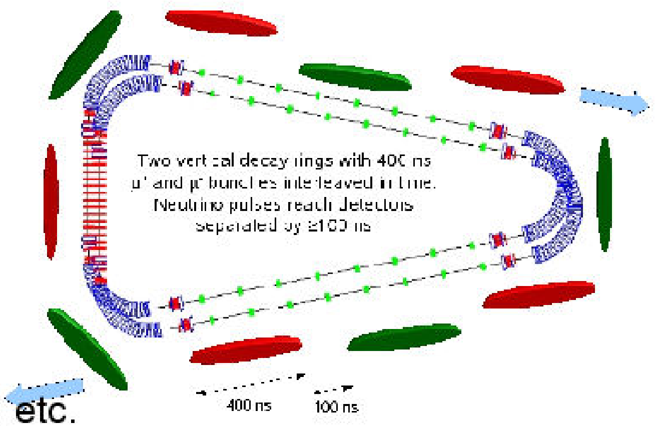
- Compare alternatives and trade-offs, racetrack and triangular
- Implications of final energy (20 GeV, 50 GeV) on design
- Allow 3 π cm stored emittance
- Assume both signs muons $\rightarrow$ one or two rings.
- Consider double baseline
- Radiation issues at $10^{21}\mu/10^7$s



Goal : decide on racetrack versus triangle

Some fundamental criteria considered at the present stage :

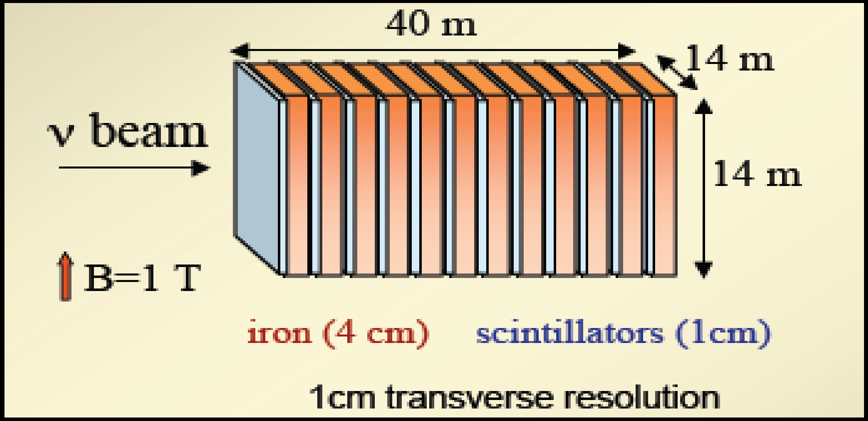
- Efficiency
- Number of rings, number of tunnels, for two detectors
- Constraint of geometry on baseline angles.
  Flexibility in choice of site
- Construction - 10-15 degs. to horizontal / near vertical
- Total depth ($\approx 0.25 - 0.3\mathcal{C}$)
- Muon bunch structure - impact on efficiency, ring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



Detectors and instrumentation

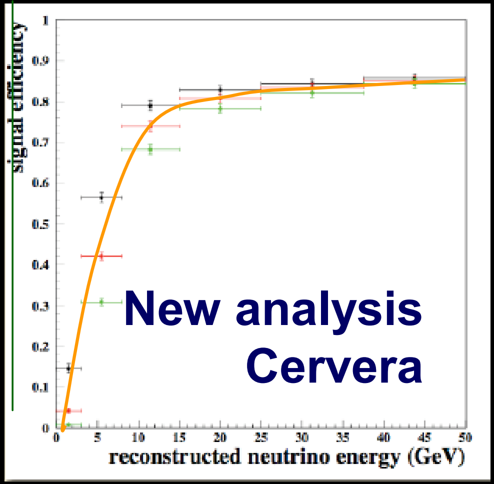
ISS baseline: Magnetised Iron Neutrino Detector (MIND)

- Golden channel signature: “wrong-sign” muons in magnetised calorimeter



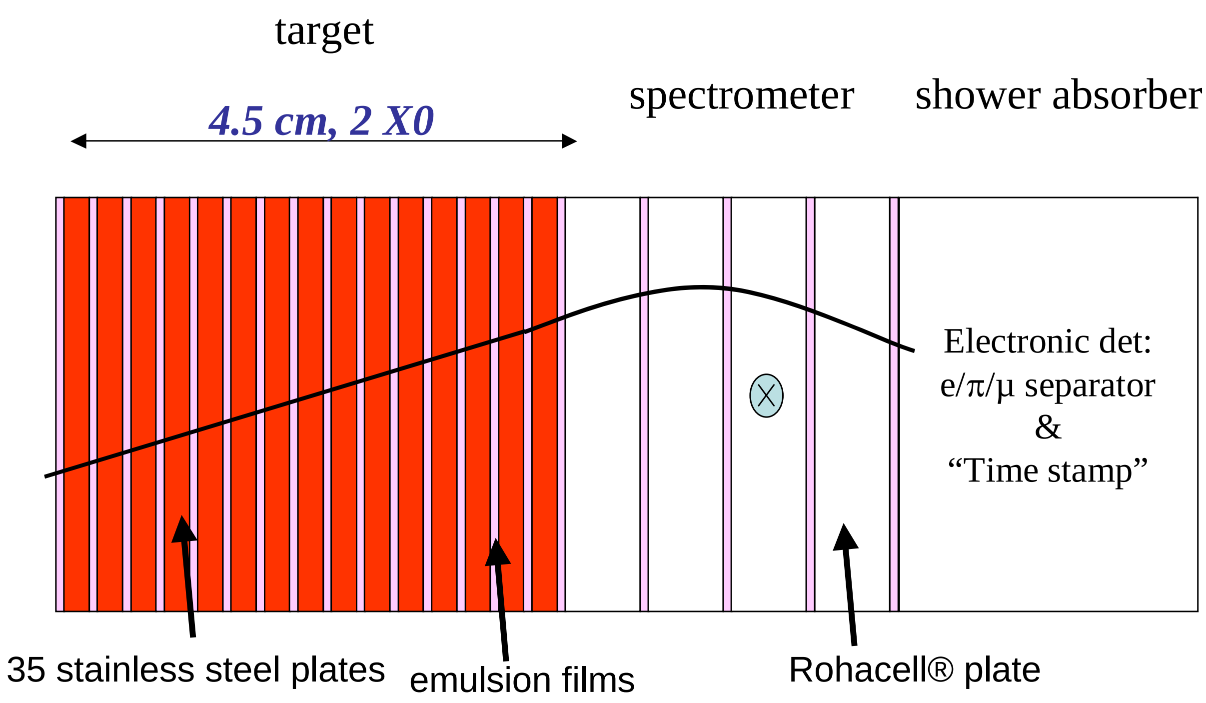
9xMINOS (5.4 kT)

- 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



Tau detection:

- Tau neutrino appearance powerful for study of non-standard mechanisms
- Baseline: Magnetised Emulsion Cloud Chamber (MECC) at the ‘4000 km’ detector



We have focused on the “target + spectrometer” optimization

ISS outcomes:

- The ISS:
  - Made the case for the high-sensitivity programme of neutrino-oscillation measurement
  - Demonstrated the need to evaluate the performance of cost of the various facilities, and the Neutrino Factory in particular, on the timescale of 2012
  - Developed an internationally agreed baseline for the Neutrino Factory accelerator complex
  - Developed an internationally agreed baseline for the Neutrino Factory neutrino-detection systems
- This is the launch point for the IDS-NF

The International Design Study for the Neutrino Factory

- The goal of the IDS-NF is to produce a ‘Reference Design Report’ for the Neutrino Factory by 2012:
  - The RDR is conceived as the document that will allow the ‘decision makers’ to consider initiating the Neutrino Factory project
- The IDS-NF, therefore, differs from the ISS in that the emphasis will increasingly be placed on engineering design to:
  - Demonstrate the technical feasibility of the various systems; and
  - Evaluate the cost of the facility at the 30—50% level

IDS-NF organisation so far:

International Design Study of the **Neutrino Factory**

Steering Group

A.Blondel, K.Long (chair), M.Zisman, Y.Kuno,

Physics and Performance Evaluation:
A.Donini, P.Huber, S.Pascoli, W.Winter,

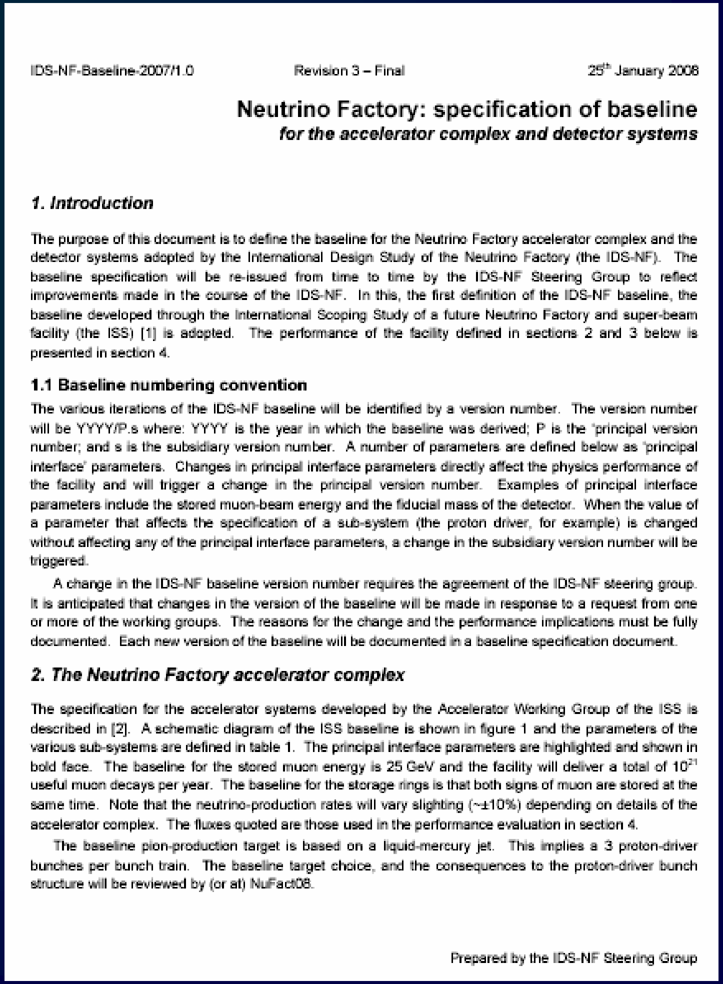
Accelerator:
S.Berg, M.Medahi, Y.Mori, C.Prior,

Detector:
A.Bross, A.Cervera, N.Mondal, P.Soler

- **WWW page for communication:**
  - http://www.hep.ph.ic.ac.uk/ids/
- **Meetings to date:**
  - CERN: 29–31Mar07: initial ISS → IDS-NF transition meeting
  - RAL: 16–17Jan08: Plenary meeting #1 …
  - FNAL: 10–12Jun08: Plenary meeting #2
    - All welcome to contribute

IDS-NF plenary #1: achievements:

- **Agreed first version of the IDS-NF baseline:**
  - **See http://www.hep.ph.ic.ac.uk/ids/docs/IDS-NF-Baseline-2007-1.0R3-Final.pdf**
- **Also, agreed job list for period to NuFact08, Valencia, 30Jun—05Jul**
  - **See (for example) http://www.cap.bnl.gov/mumu/project/IDS/workplan.html**
- **IDS-NF starting (albeit a little slowly)**



IDS-NF-Baseline-2007/1.0 Revision 3 – Final 25th January 2008

Neutrino Factory: specification of baseline
for the accelerator complex and detector systems

1. Introduction

The purpose of this document is to define the baseline for the Neutrino Factory accelerator complex and the detector systems adopted by the International Design Study of the Neutrino Factory (the IDS-NF). The baseline specification will be re-issued from time to time by the IDS-NF Steering Group to reflect improvements made in the course of the IDS-NF. In this, the first definition of the IDS-NF baseline, the baseline developed through the International Scoping Study of a future Neutrino Factory and super-beam facility (the ISS) [1] is adopted. The performance of the facility defined in sections 2 and 3 below is presented in section 4.

1.1 Baseline numbering convention

The various iterations of the IDS-NF baseline will be identified by a version number. The version number will be YYYY/P.s where: YYYY is the year in which the baseline was derived; P is the 'principal version number; and s is the subsidiary version number. A number of parameters are defined below as 'principal interface' parameters. Changes in principal interface parameters directly affect the physics performance of the facility and will trigger a change in the principal version number. Examples of principal interface parameters include the stored muon-beam energy and the fiducial mass of the detector. When the value of a parameter that affects the specification of a sub-system (the proton driver, for example) is changed without affecting any of the principal interface parameters, a change in the subsidiary version number will be triggered.

A change in the IDS-NF baseline version number requires the agreement of the IDS-NF steering group. It is anticipated that changes in the version of the baseline will be made in response to a request from one or more of the working groups. The reasons for the change and the performance implications must be fully documented. Each new version of the baseline will be documented in a baseline specification document.

2. The Neutrino Factory accelerator complex

The specification for the accelerator systems developed by the Accelerator Working Group of the ISS is described in [2]. A schematic diagram of the ISS baseline is shown in figure 1 and the parameters of the various sub-systems are defined in table 1. The principal interface parameters are highlighted and shown in bold face. The baseline for the stored muon energy is 25 GeV and the facility will deliver a total of 10^{21} useful muon decays per year. The baseline for the storage rings is that both signs of muon are stored at the same time. Note that the neutrino-production rates will vary slighting (~±10%) depending on details of the accelerator complex. The fluxes quoted are those used in the performance evaluation in section 4.

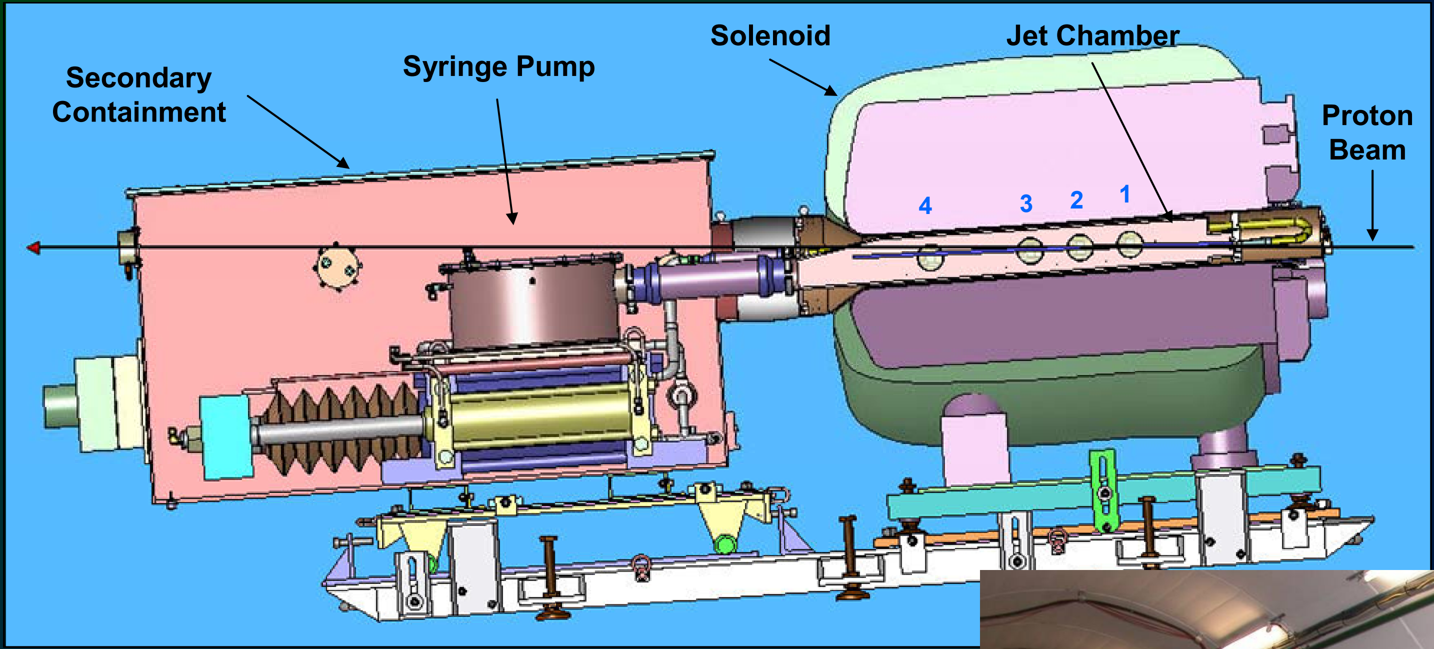
The baseline pion-production target is based on a liquid-mercury jet. This implies a 3 proton-driver bunches per bunch train. The baseline target choice, and the consequences to the proton-driver bunch structure will be reviewed by (or at) NuFact08.

Prepared by the IDS-NF Steering Group

Status of NF accelerator R&D:

- Demonstration of baseline target concept:
  - Liquid-mercury jet
- MEcuRy Intense Target (MERIT) experiment
  - BNL, FNAL, ORNL, Princeton, CERN, RAL
  - Jet parameters:
    - Diameter: 1 cm
    - Velocity: 20 m/s
    - Jet w.r.t. solenoid axis: 33 mrad
  - Proton-beam parameters:
    - Source: CERN PS
    - Energy: 14 and 24 GeV
    - Bunch structure: ~0.1 μs bunch
    - Extraction: can be single bunch train or ‘pump probe’

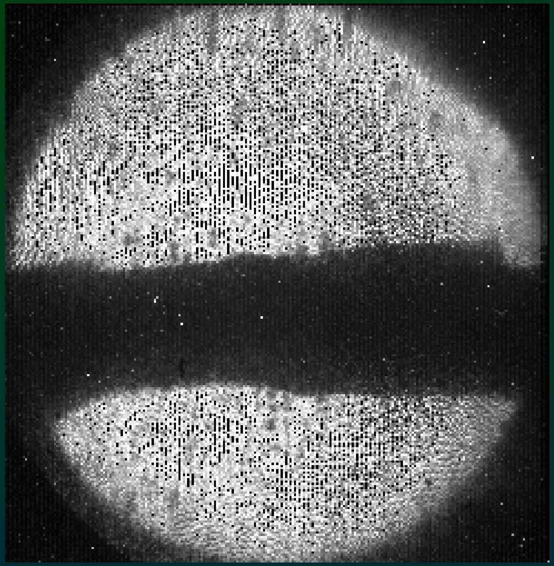
MERIT experiment:



Start data taking Oct08

- Various diagnostics:
  - Cameras to view jet
  - Particle detectors to measure produced particle flux
  - Beam current transformed to measure beam intensity

MERIT: sample result:



Oct. 27, 2007, solenoid field 5T
Viewport 2

Beam 5016, Hg 15m/s,
100µs/frame, Total 1.6ms

- From the analysis of the pictures so far, the MERIT team:
  - Confirmed mercury jet stablisation by magnetic field
  - Measured 'disruption length'
  - Have observed 'cavitation'
- Over-all, MERIT team claim their data demonstrate the liquid-mercury jet concept at a beam power of 4 MW

Technology development for cooling channel:

MuCool:

- Mission
  - Design, prototype and test all cooling channel components
    - 201 MHz RF Cavities, LH_2 absorbers, SC solenoids
  - Support MICE (cooling demonstration experiment)
  - Perform high beam-power engineering test of cooling section components

- Consists of 10 institutions from the US, UK and Japan

RF Development
ANL
Cockcroft Institute
Fermilab
IIT
JLAB
LBNL
Mississippi

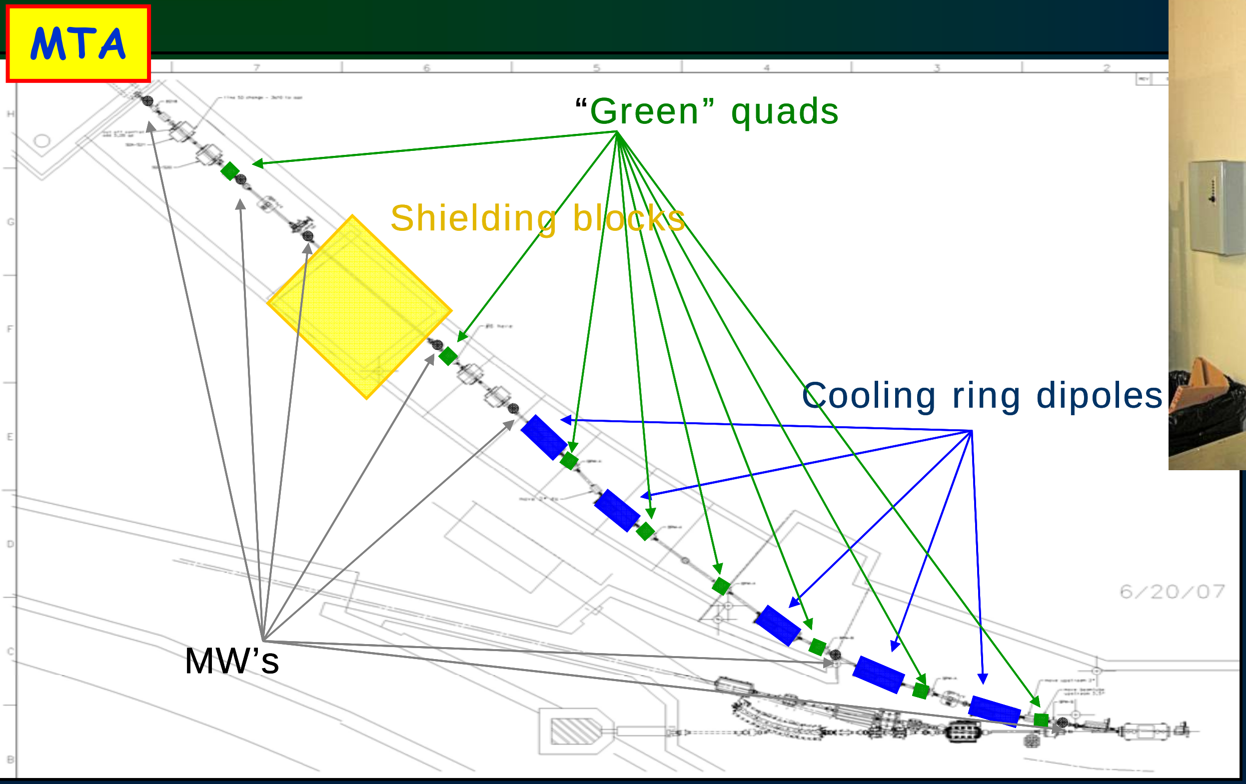
Solenoids
LBNL
Mississippi

Absorber R&D
Fermilab
IIT
KEK
NIU
Mississippi
Osaka

MuCool: Phase I:

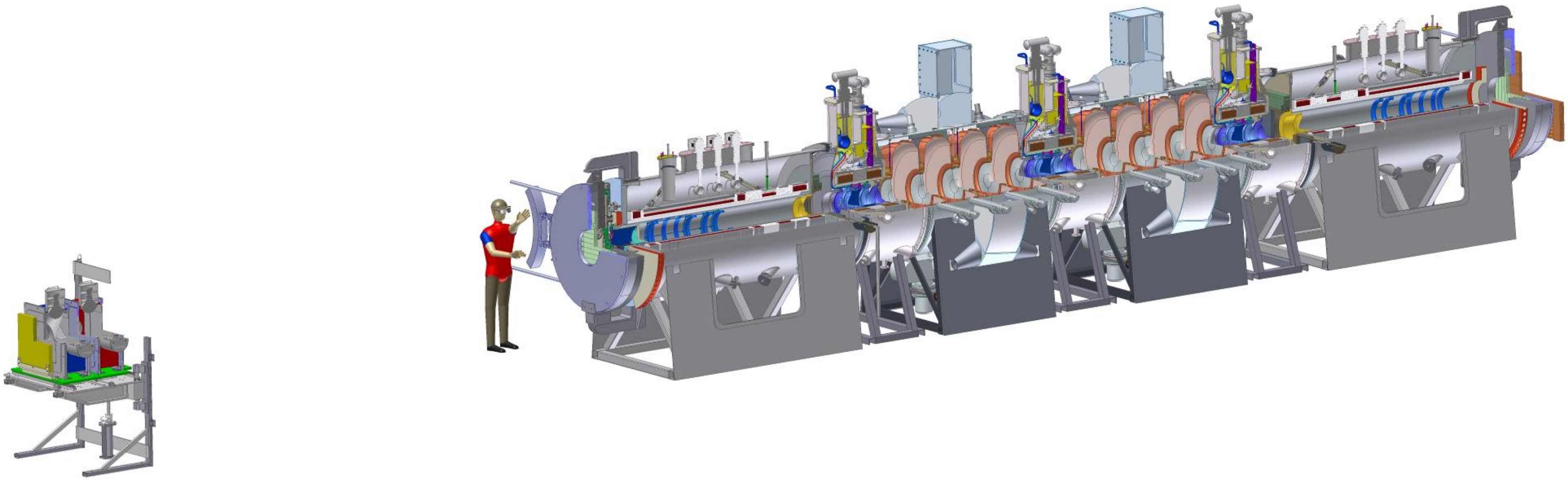
- High-gradient copper cavity work:
  - Have demonstrated that maximum operating gradient of 805 MHz cavity is reduced by factor ~2 when cavity exposed to magnetic field of ~2T
    - Effect of surface on accelerating gradient being studied using buttons
  - 201 MHz cavity of the kind required by the MICE cooling channel has been run at 19 MV/m
    - Limitted by i/p power
    - Full tests of 201 MHz cavity in magnetic field awaits delivery of first coupling coil (in manufacture, collaboration LBNL with Harbin)
  - High-pressure hydrogen-filled cavity tests
- Absorber R&D:
  - Tests of liquid-hydrogen absorbers:
    - Convective cooling demonstrated, designs for forced-flow absorber which can take more heat load
  - Just starting LiH absorber test programme

MuCool: Phase II



- Test of components with proton beam from FNAL linac
  - Full linac power (~600 W) can be accommodated
  - Beam-line commissioning early 2008
    - First beam summer 2008

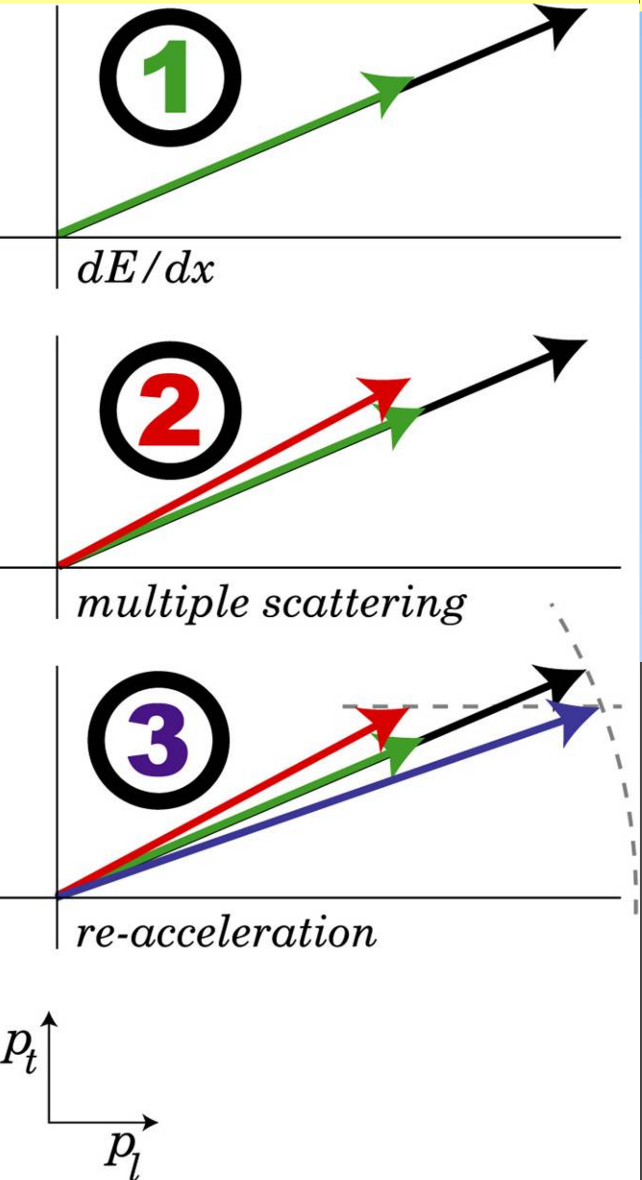
MICE in new 200 MeV/*c* muon beam at RAL



Section of *Cooling Channel* + *Emittance measurements* + *PID*

Ionisation cooling

Principle



Practice

MICE:

- Design, build, commission and operate a realistic section of cooling channel
- Measure its performance in a variety of modes of operation and beam conditions

i.e. results will allow NuFact complex to be optimised

THE MICE COLLABORATION -128 collaborators-

Universite Catholique de Louvain, Belgium

University of Sofia, Bulgaria

The Harbin Institute for Super Conducting Technologies PR China

INFN Milano, INFN Napoli, INFN Pavia, INFN Roma III, INFN Trieste, Italy

KEK, Kyoto University, Osaka University, Japan

NIKHEF, The Netherlands

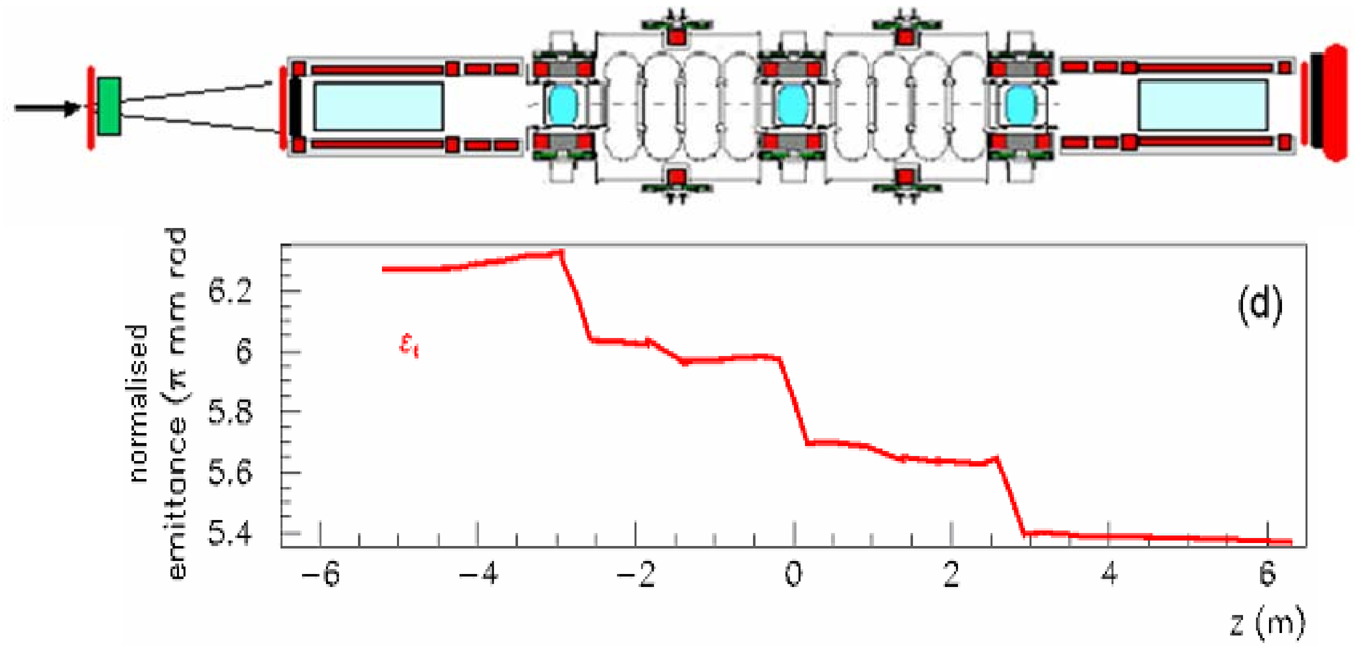
CERN

Geneva University, Paul Scherrer Institut Switzerland

Brunel, Cockcroft/Lancaster, Glasgow, Liverpool, ICL London, Oxford, Darsbury, RAL, Sheffield UK

Argonne National Laboratory, Brookhaven National Laboratory, Fairfield University,
University of Chicago, Enrico Fermi Institute, Fermilab, Illinois Institute of Technology,
Jefferson Lab, Lawrence Berkeley National Laboratory, UCLA, Northern Illinois University,
University of Iowa, University of Mississippi, UC Riverside,
University of Illinois at Urbana-Champaign USA +Muons Inc (13Feb08)

EXPECTED PERFORMANCE



Change in emittance at absorber $\Delta\varepsilon / \varepsilon = -(\Delta p/p)(1-\varepsilon_0/\varepsilon)$

5% momentum loss in each absorber ➔ 15% cooling for large ε beam

Equilibrium emittance for H_2 $\varepsilon_0 \sim 2.5\ (\pi)$ mm-radians

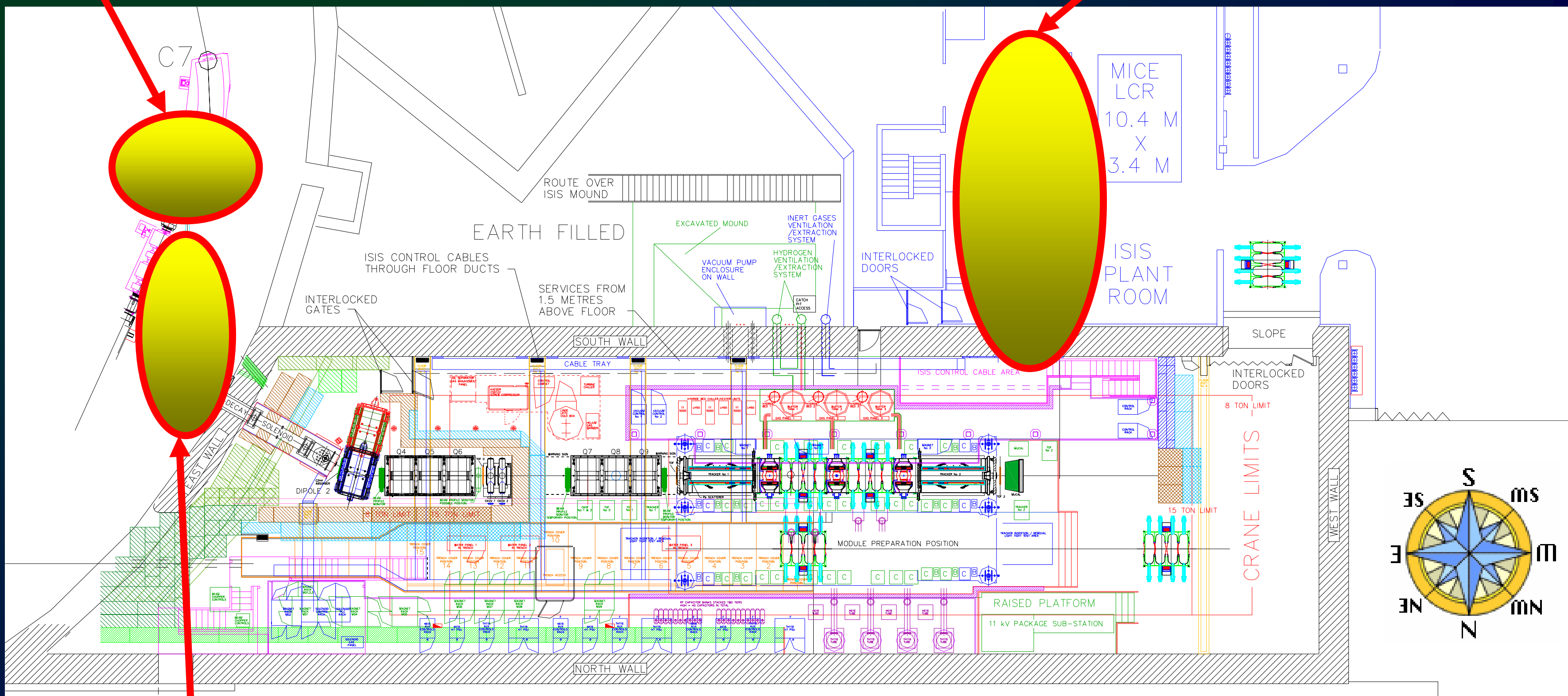
(acceptance of accelerators in NF 15 – 30 (π) mm-radians)

➔ *Measure $\Delta\varepsilon$ to 1%*

Layout of MICE hall

Target

MICE Local Control Room

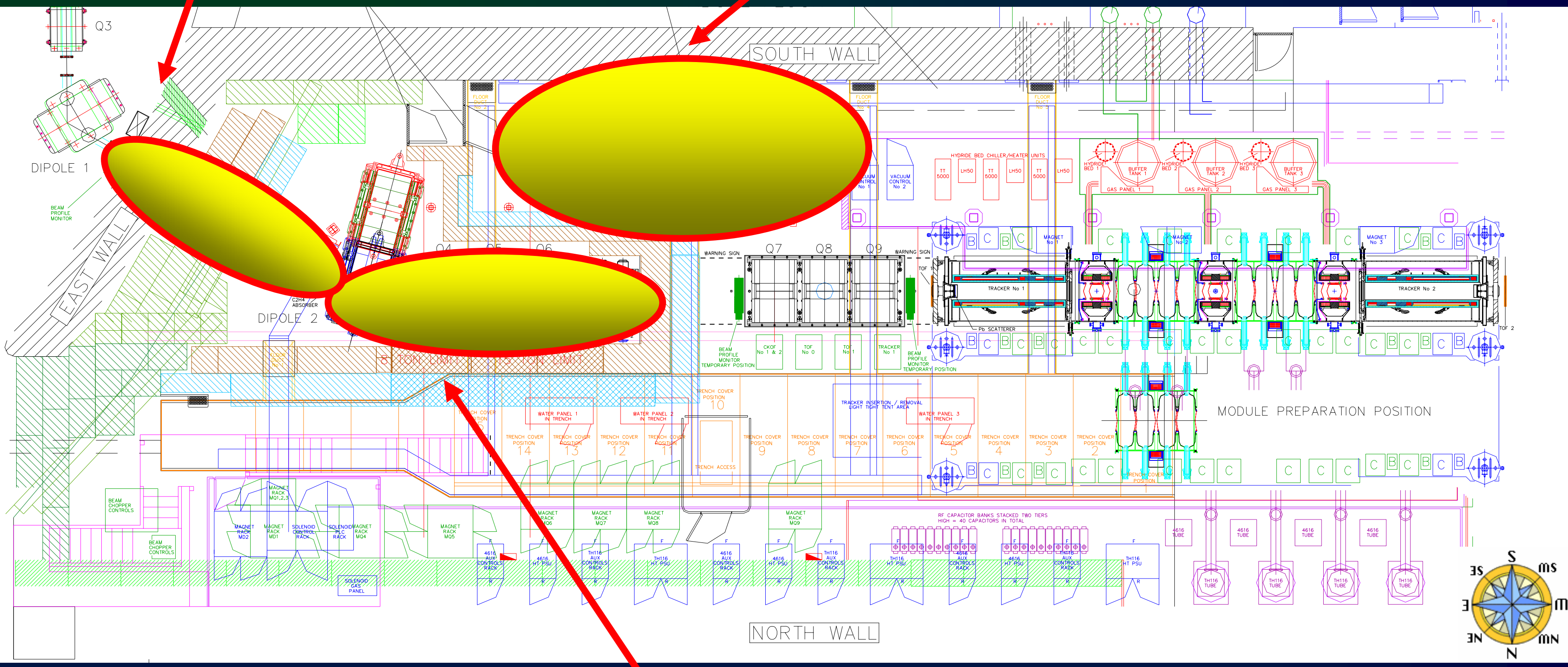


Upstream beamline

Layout of MICE hall

Decay solenoid

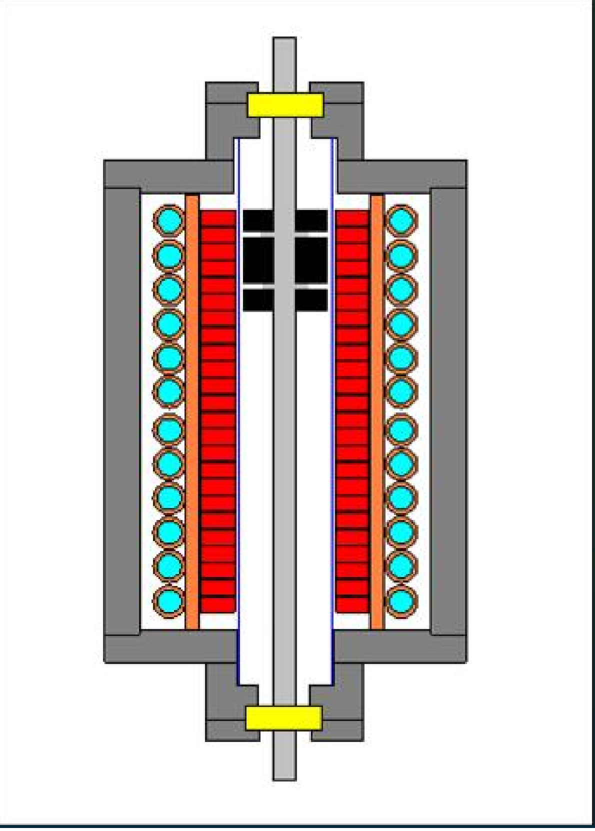
Linde refrigerator

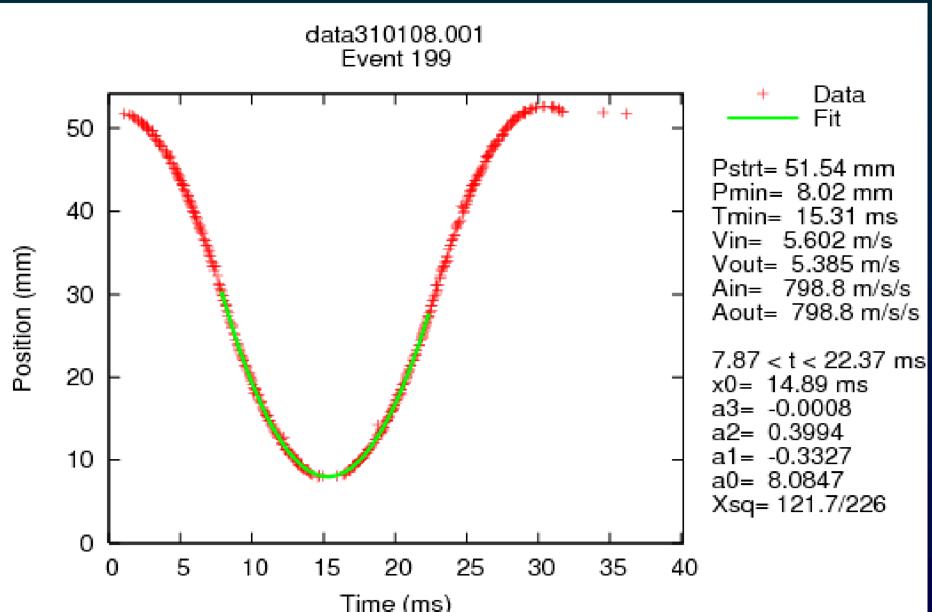


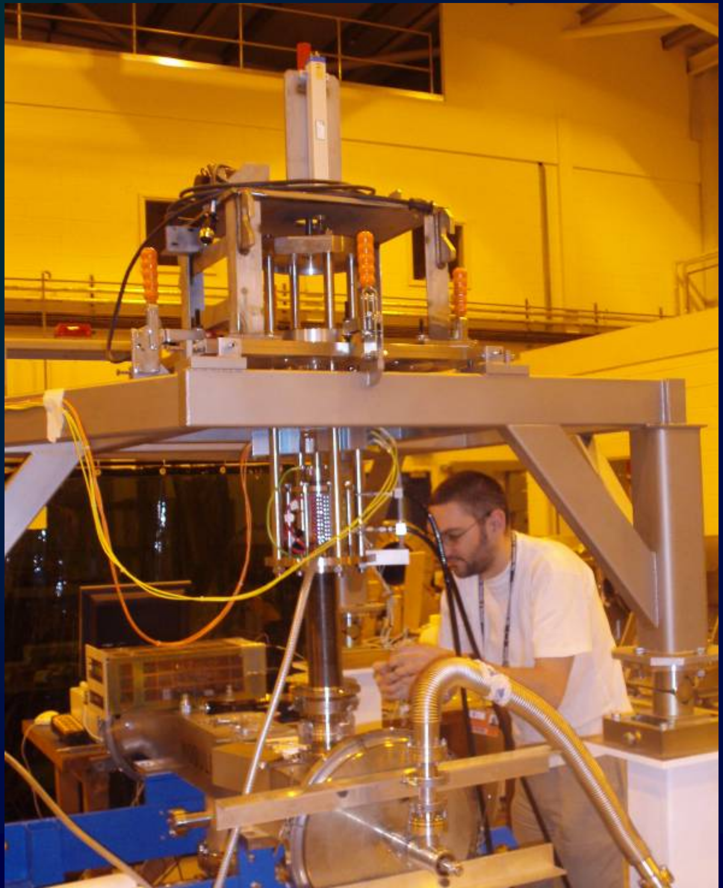
Downstream beamline

Target:

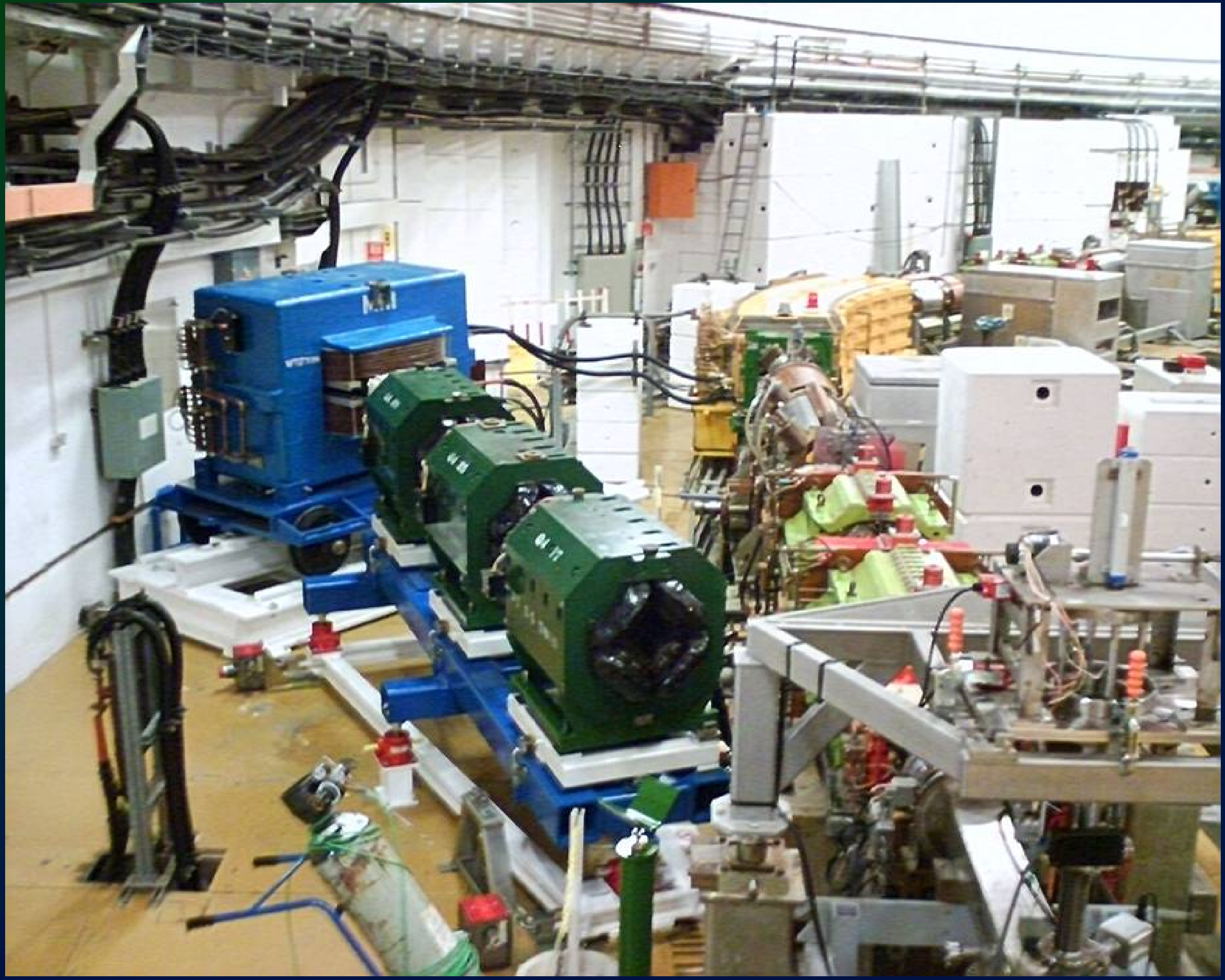
- Linear drive:
  - Accelerates target into beam:
    - Acceleration 80g







Upstream beam line:



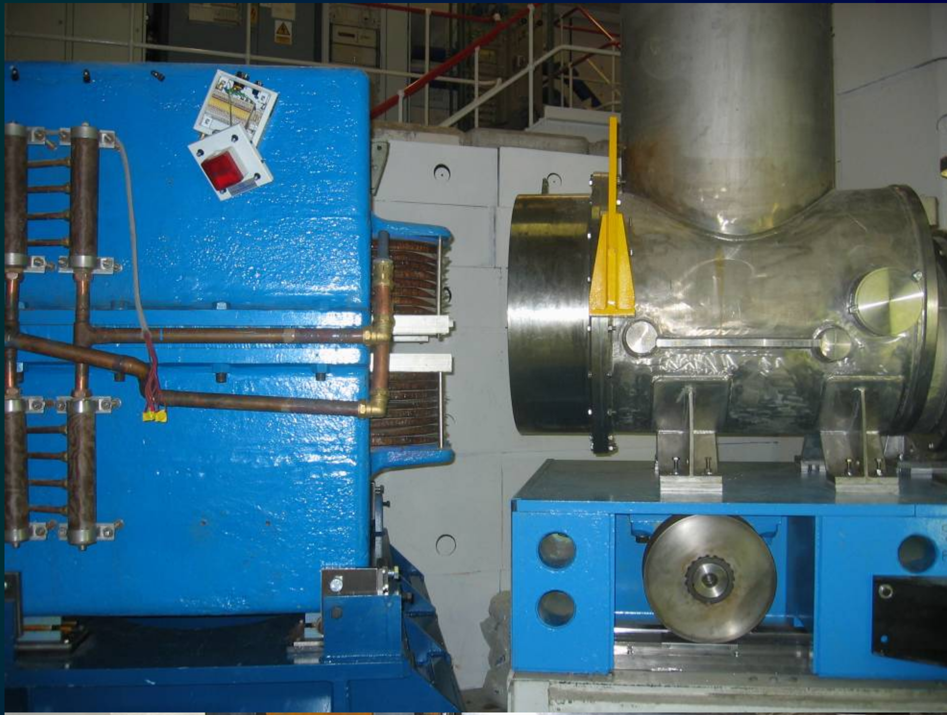
- Beam-line elements installed:
  - Services connected

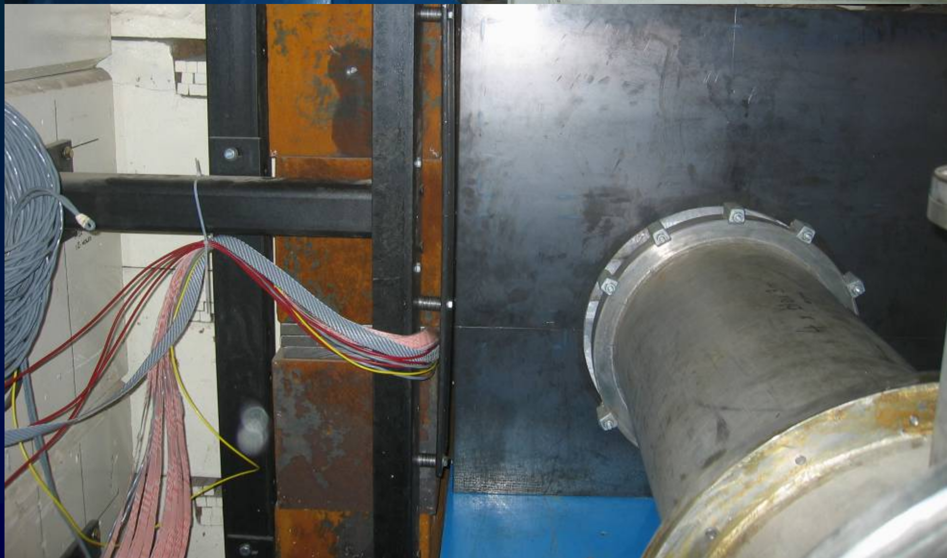
Downstream beam line:

- Half of downstream beam line (inside DSA) installed
  - Power connected
  - Water services to be completed

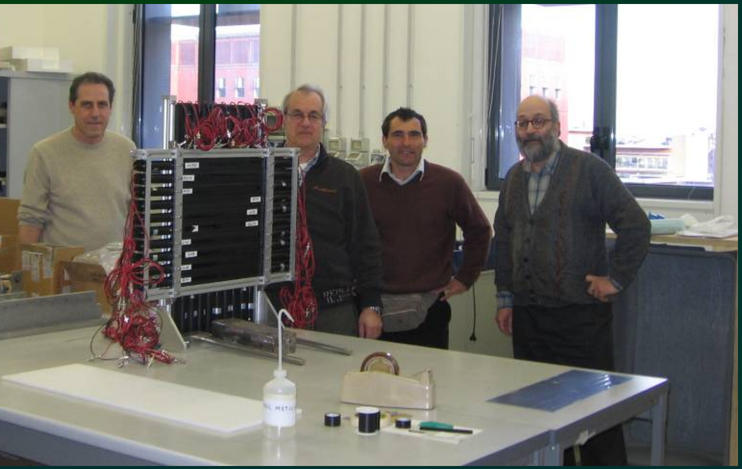
Down-stream beam line:

- Pion-decay solenoid (from PSI):
  - Installed
  - Cold-testing before installation got down to ~40 K
    - No problems
- Refrigerator:
  - Installation complete
  - Gremlins getting specified cooling power
    - But working on it!
- Remaining beam-line elements will be installed by the beginning of March

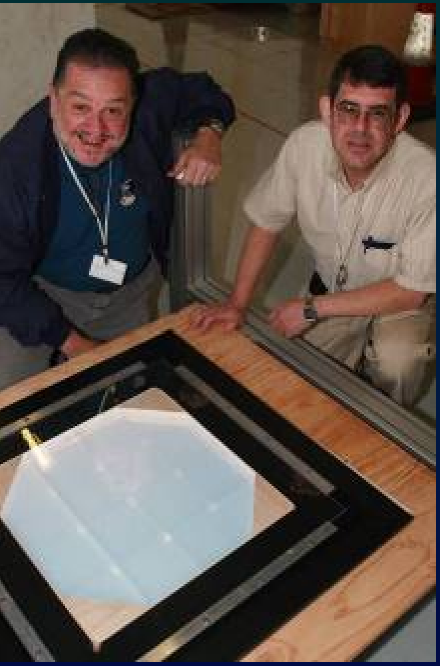




Spectrometer and instrumentation:

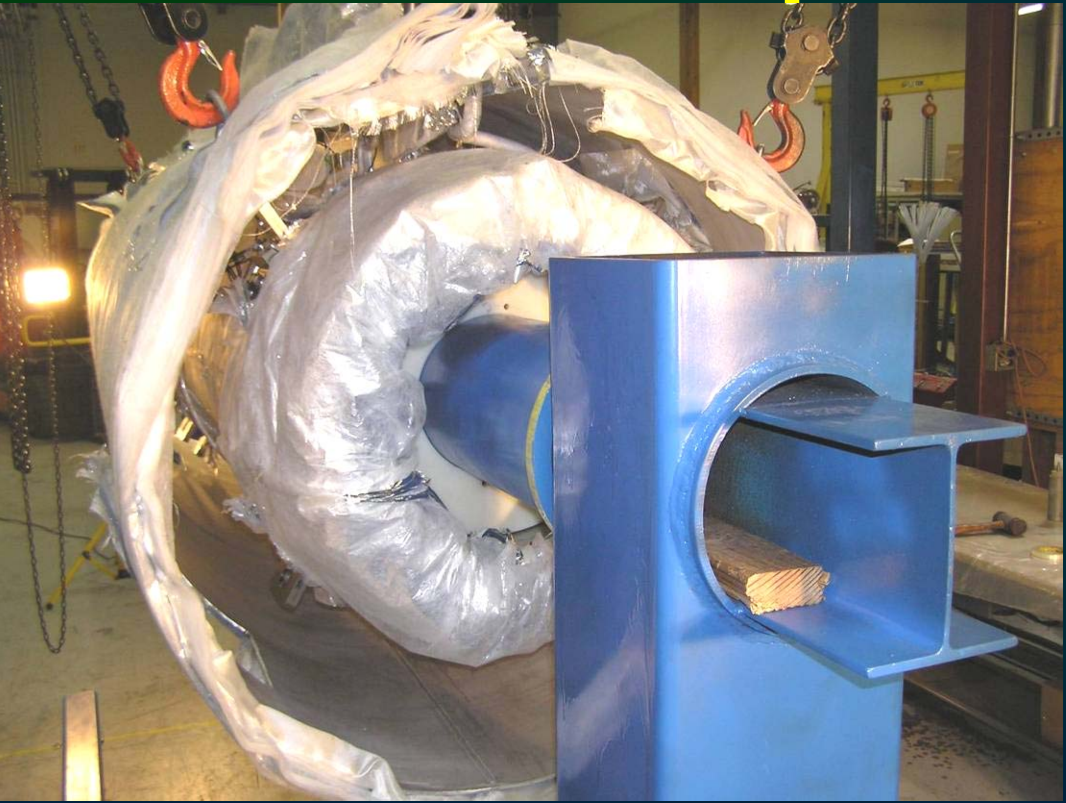


- First time-of-flight counter prepared at Milan
  - Will be shipped soon
- Second (of three) counters to follow



- Both Cherenkov counters complete at RAL
- DAQ installed in MICE Local Control Room
- Data and controls networks to be installed this week

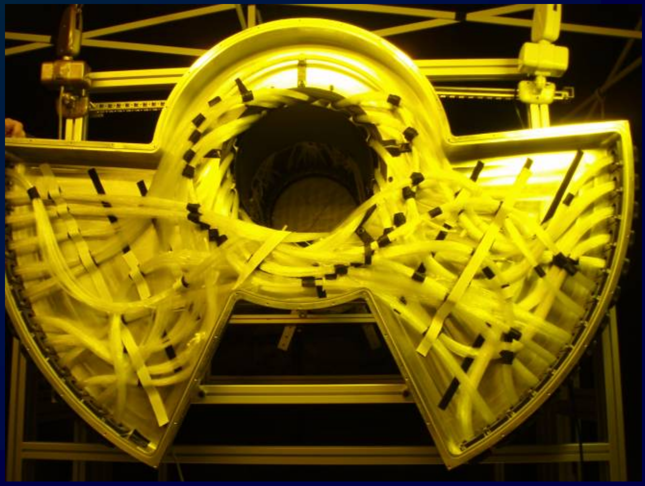
Spectrometer solenoid:



- Manufacture of solenoid #1 advanced
  - Expect delivery to FNAL for field mapping in March
  - Delivery to RAL May/June
- Manufacture of solenoid #2 progressing well
  - Expect delivery 2 to 3 months after first

Scintillating-fibre trackers:

- Tracker #1 complete and ready for cosmic tests
- Second tracker will be completed by March
- Light yield measured in QA rig:
  - 11 P.E.
  - Uniform response
  - All stations good



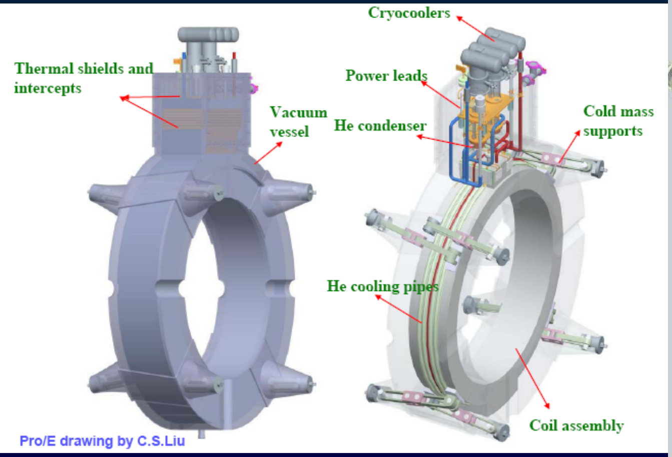
Calorimeter:

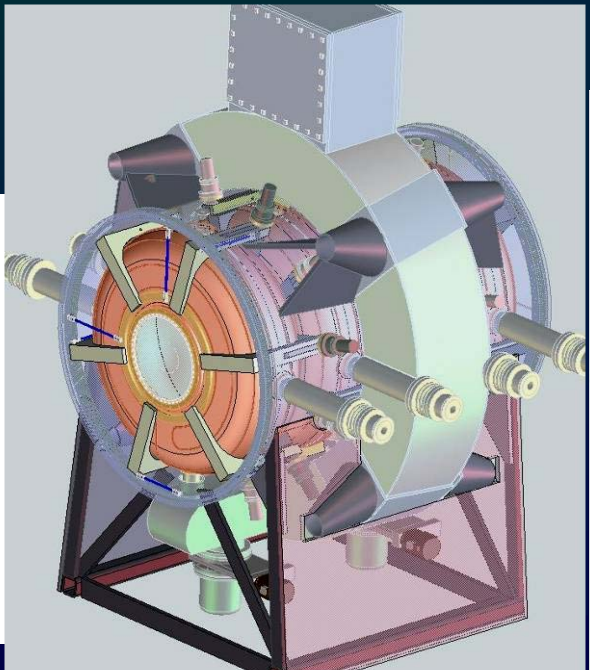
- KLOE light pre-shower detector complete in Rome
  - Will be shipped soon

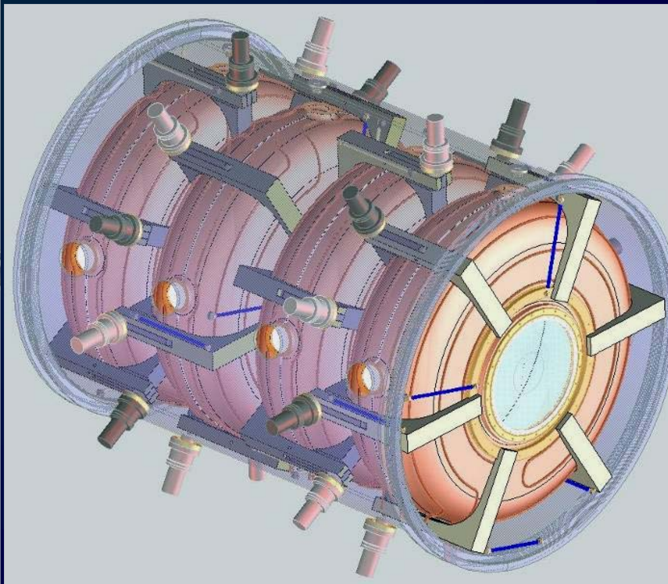
- Sandwich calorimeter prototype constructed
  - Production SW FNAL, GVA, and Trieste

Cooling channel components:

- RFCC module:
  - CC design and fabrication done in collaboration by LBNL and ICST in Harbin, China
    - conductor ready to order
  - RF cavities will be similar to existing MuCool prototype
    - fabrication to get under way shortly
  - MuCool 201 MHz cavity R&D:
    - Without field no have 19 MV/M

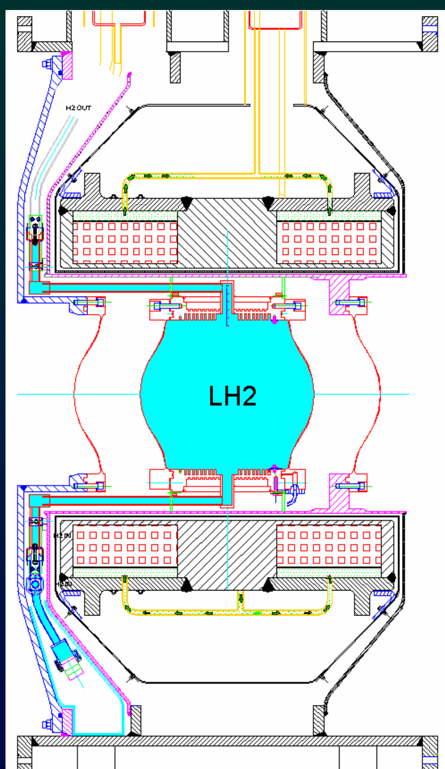


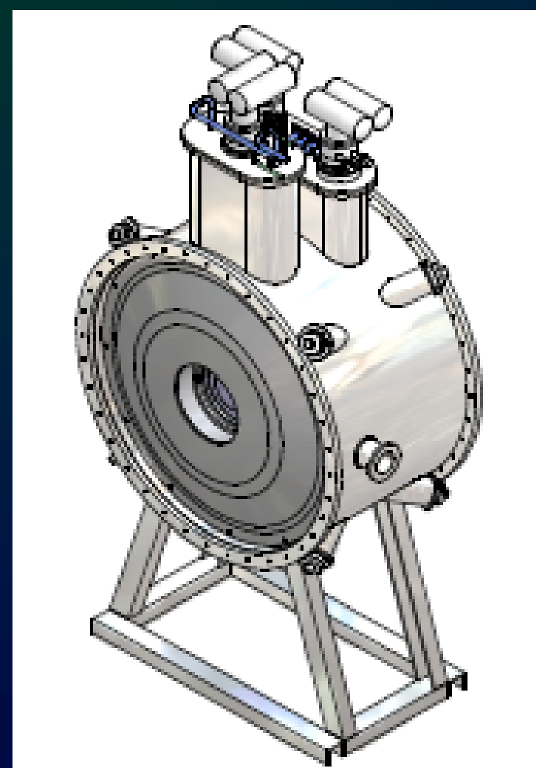




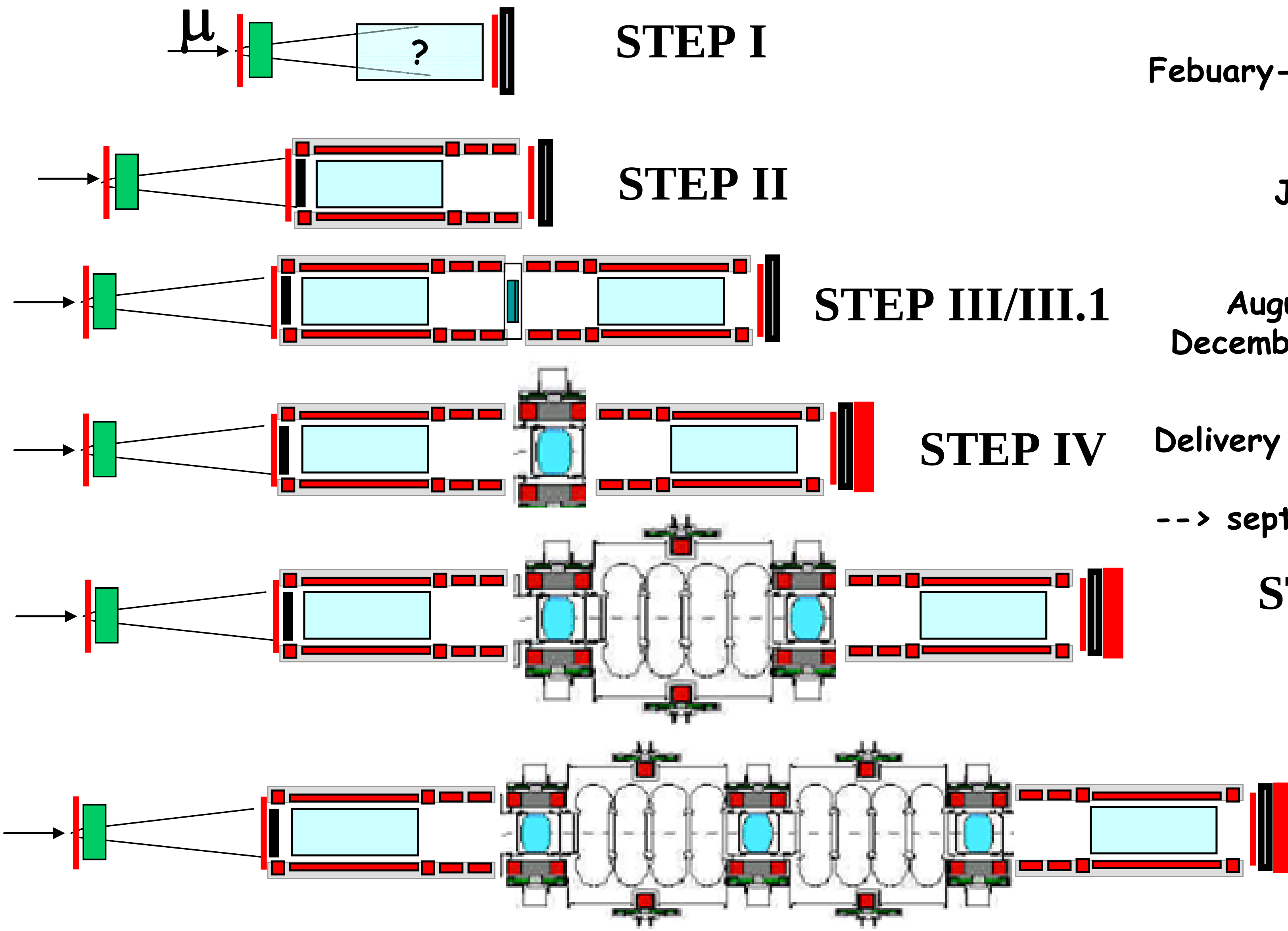
Cooling channel components:

- AFC module:
  - Focus coil module presently out for tender
    - anticipate contract award in September 2007
    - two coils that can run with same or opposite polarity
      - 20-L LH_2 absorber (plus safety windows) fits inside





MICE schedule:



STEP I — Febuary-May 2008

STEP II — June 2008

STEP III/III.1 — August/ December 2008

STEP IV — Delivery of 1st FC --> september 2009!

STEP V — 2010

STEP VI — 2010/11

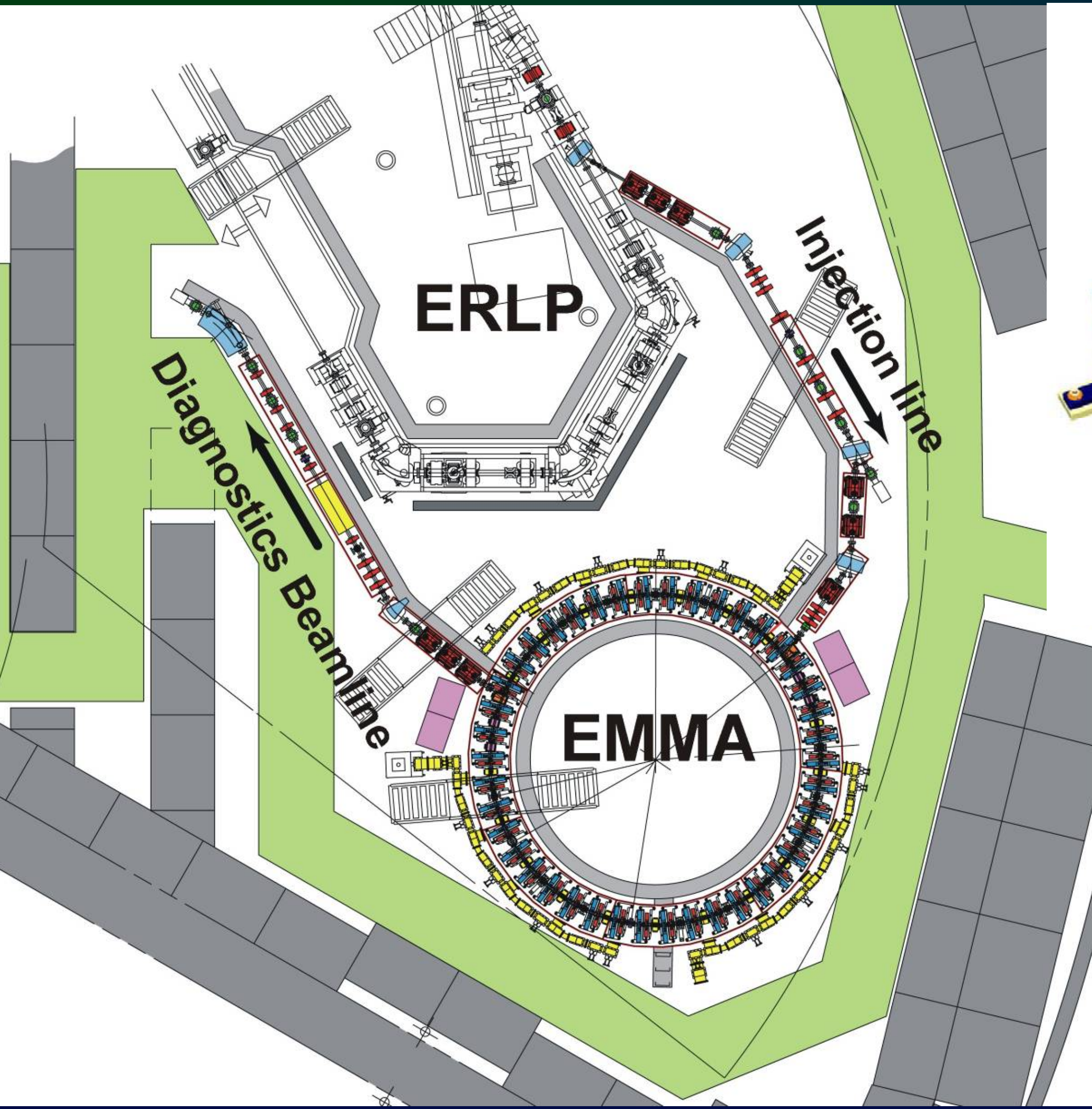
Rapid acceleration:

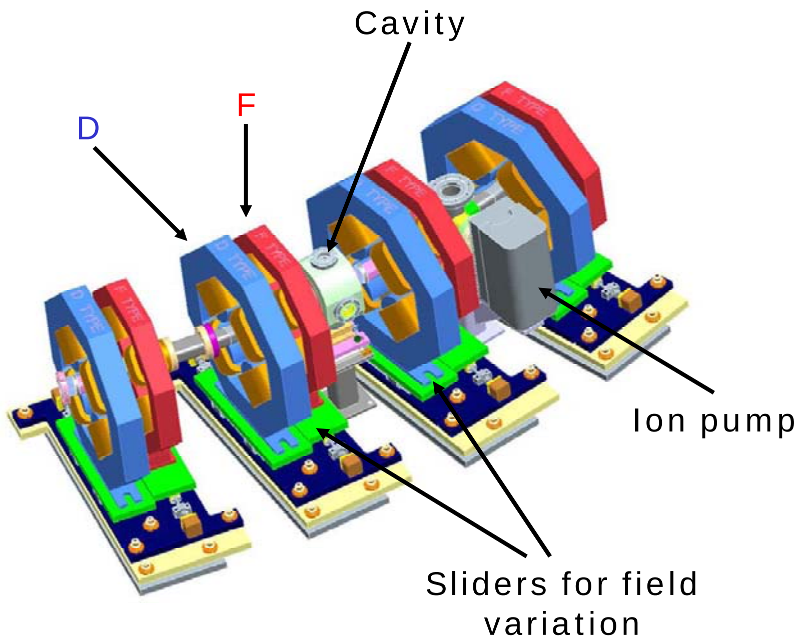
- FFAG – Fixed Field Alternating Gradient acceleration:
  - Novel: field fixed, so no need to ramp magnets
  - Two types:
    - Scaling — PRISM (Osaka)
    - Non-scaling — EMMA (Daresbury Laboratory)
- PRISM
  - Major recent milestone:
    - Transmission of αs around 6-cell PRISM ring
- EMMA:
  - Electron Model of Muon Acceleration
    - Demonstration of FFAG required in baseline Neutrino Factory

EMMA:

- Collaboration:
  - BNL, CERN, CI, FNAL, JAI, LPSC, STFC, TRIUMF
- Goals:
  - Demonstrate non-scaling optics
  - Study resonances (and resonance crossing)
  - Study longitudinal dynamics
  - Check transverse dynamics
- Milestones:
  - Delivery of major components 01Aug08
  - Construction complete 23Jul09
  - Start experimental programme 18Sep09
  - EMMA Phase I programme complete 09Jul10

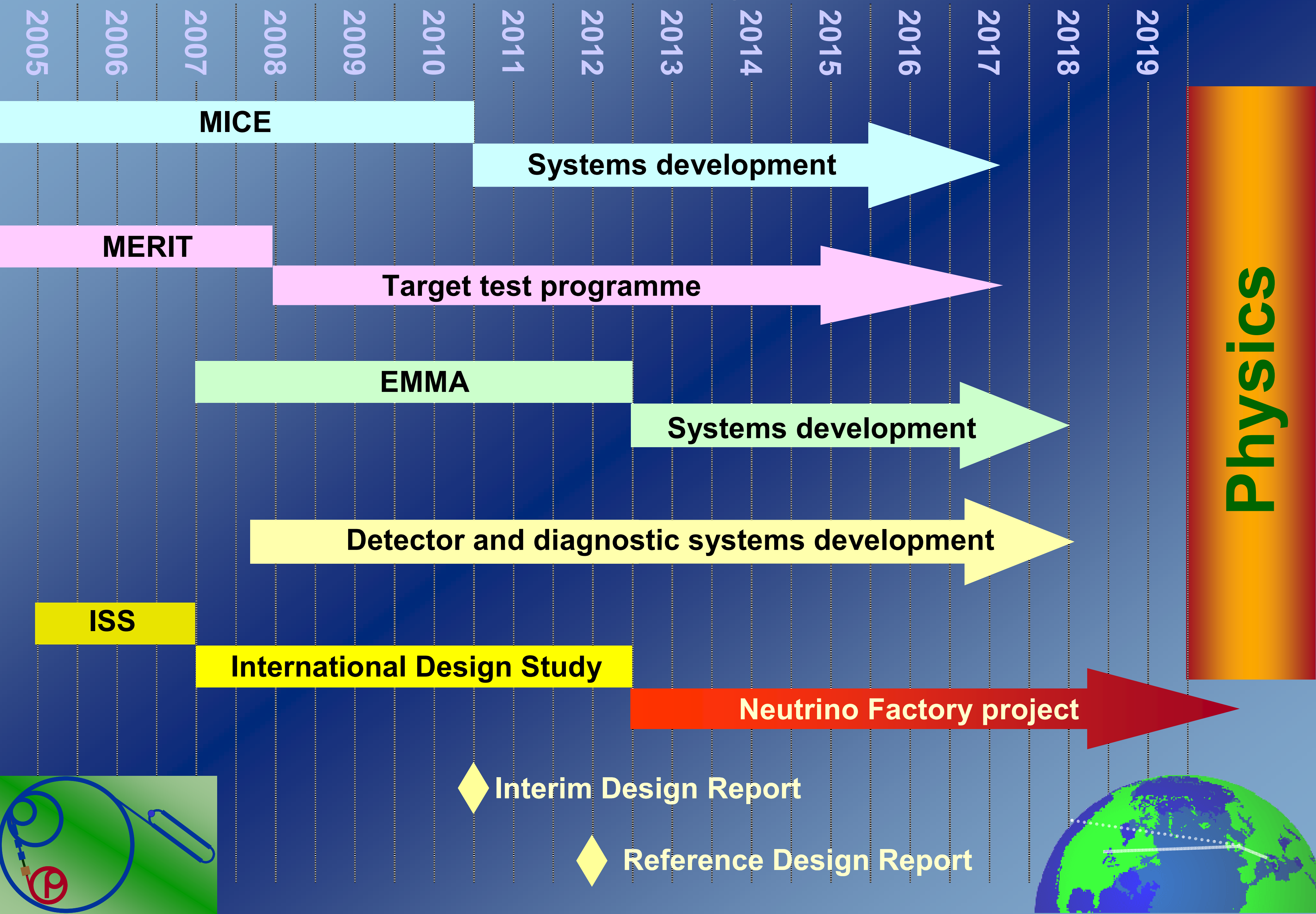
EMMA:





- Design of septum, cavity, magnet, etc. complete
- Prototype quads manufactured and satisfactory

Neutrino Factory roadmap



Conclusions:

- The Neutrino Factory:
  - Precision tool:
    - Best CP discovery potential if θ_{13} small ($<10^{-3}$)
      - Low energy Neutrino Factory gives options for large θ_{13}
  - Part of the programme required to understand the Physics of Flavour
- Now have an internationally agreed baseline for the machine and detectors
  - Baseline actively being developed through IDS-NF
  - IDS-NF goal: RDR by ~2012
  - Internationally coordinated accelerator R&D programme mature and addressing each of the major technological or systems issues
  - Internationally coordinated detector-development programme being established
- Neutrino sector, historically, full of surprise; the Neutrino Factory has the flexibility to adapt
  - The goal is (and must remain) to make the Neutrino Factory an option for the field on the timescale of 2012