Imperial College London

K. Long, 15 March, 2006

The international scoping study

– status, plans, prospects

Acknowledgements: Grateful to all ISS speakers from whom I have taken material.

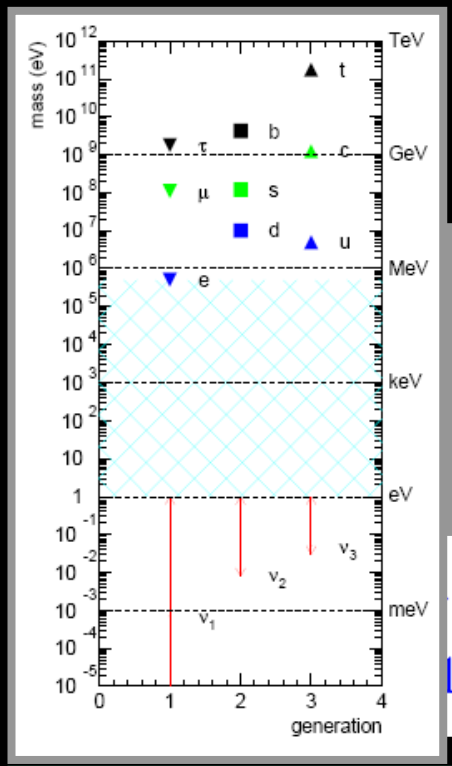
Contents

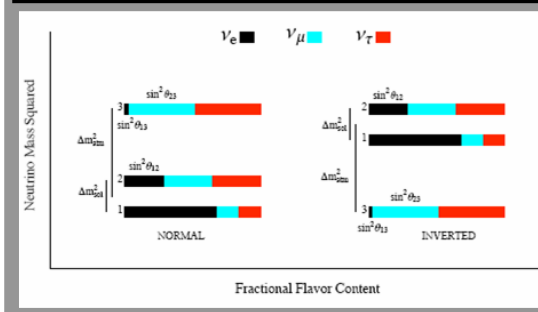
- Motivation for the ISS
  - International scoping study of a future Neutrino Factory and super-beam facility
- Organisation of the ISS
- Status of the ISS:
  - Physics Group
  - Accelerator Group
  - Detector Group
- ISS: next steps
- Beyond the ISS
- Conclusions

ISS: motivation – background

- **Standard neutrino Model:**
  - **Mixing among three mass eigenstates**
- **Present knowledge:**
  - **Neutrino mass much smaller than charged lepton or quark**
  - **Neutrino mixing matrix very different from that of the quarks**

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





$+0.41$
-0.22)

10^{-2}

$$V_{MNS} \sim \begin{pmatrix} 0.8 & 0.5 & \mathbf{0.2} \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix} \qquad V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.001 \\ 0.2 & 1 & 0.01 \\ 0.001 & 0.01 & 1 \end{pmatrix}$$

$[|(V_{MNS})_{e3}| < 0.2]$

Elements: key issues in particle physics

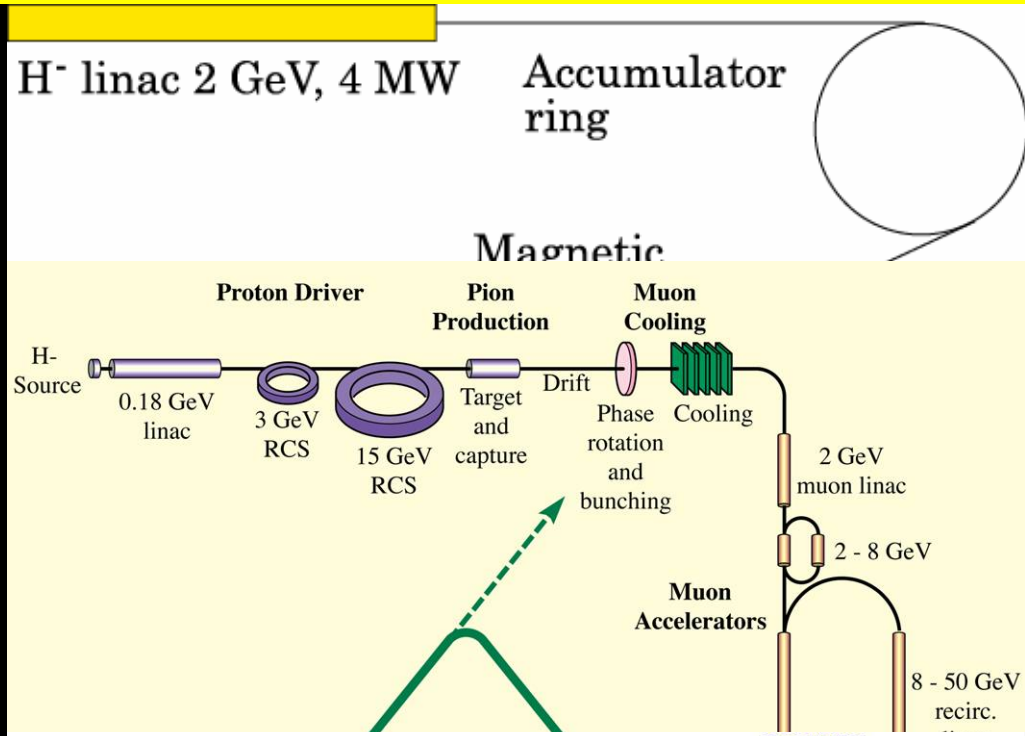
- The origin of mass
  - Neutrino mass very small
    - Different origin to quark and lepton mass?
    - ‘Natural’ explanation in ‘see-saw’ models?
- The origin of flavour
  - Neutrino mixing different from quark mixing
    - Different origin to quark mixing?
    - ‘Natural’ explanation in ‘see-saw’ models?
- The quest for unification
  - ‘Unified’ theories relate quarks to leptons
    - Generating relationships between quark and lepton mixing angles

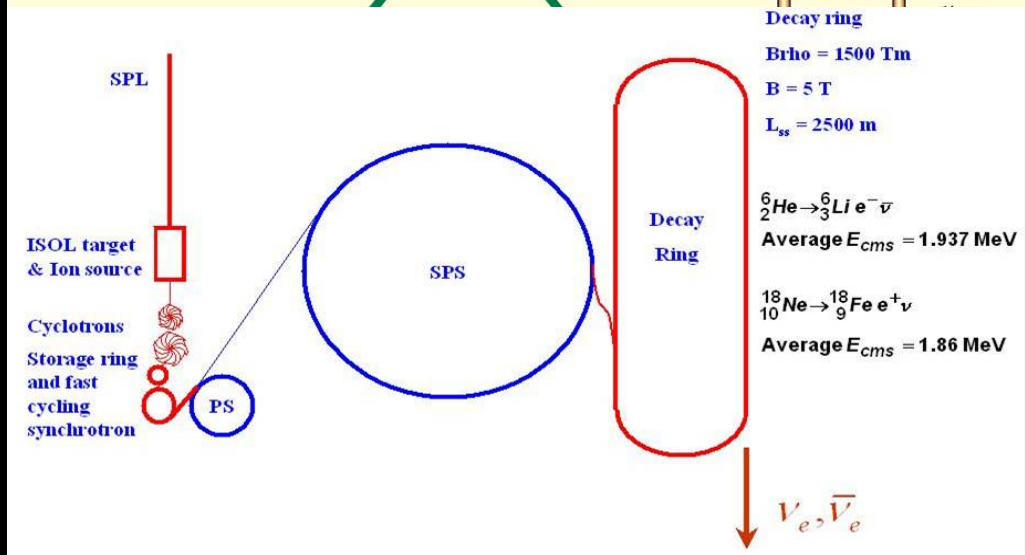
Elements: key issues in cosmology

- The origin of dark matter & dark energy
  - ~96% of matter/energy is not understood
  - Neutrinos:
    - Contribution as large as baryonic matter?
    - In some models neutrinos impact on dark energy
- The absence of anti-matter
  - CP violation in lepton sector underpins removal of anti-matter
    - 'Dirac' phase, δ, not directly responsible, but,
    - Relationship of relevant (Majorana) phases to δ is model dependent
- Explanation of (absence of) large-scale structure
  - Neutrino interacts only weakly – possible means of communication across large distances?
  - In some models, super-symmetric partner to neutrino may be responsible for inflation

Neutrino source – options:

- Second generation super-beam
  - CERN, FNAL, BNL, J-PARC II
- Neutrino Factory
- Beta-beam





ISS: motivation

- Neutrino Factory – prior to launch of ISS
  - Several studies at the turn of the century
    - US Studies I, II, IIa
    - ECFA/CERN Study
    - NuFact-J Study

    established feasibility & R&D programme

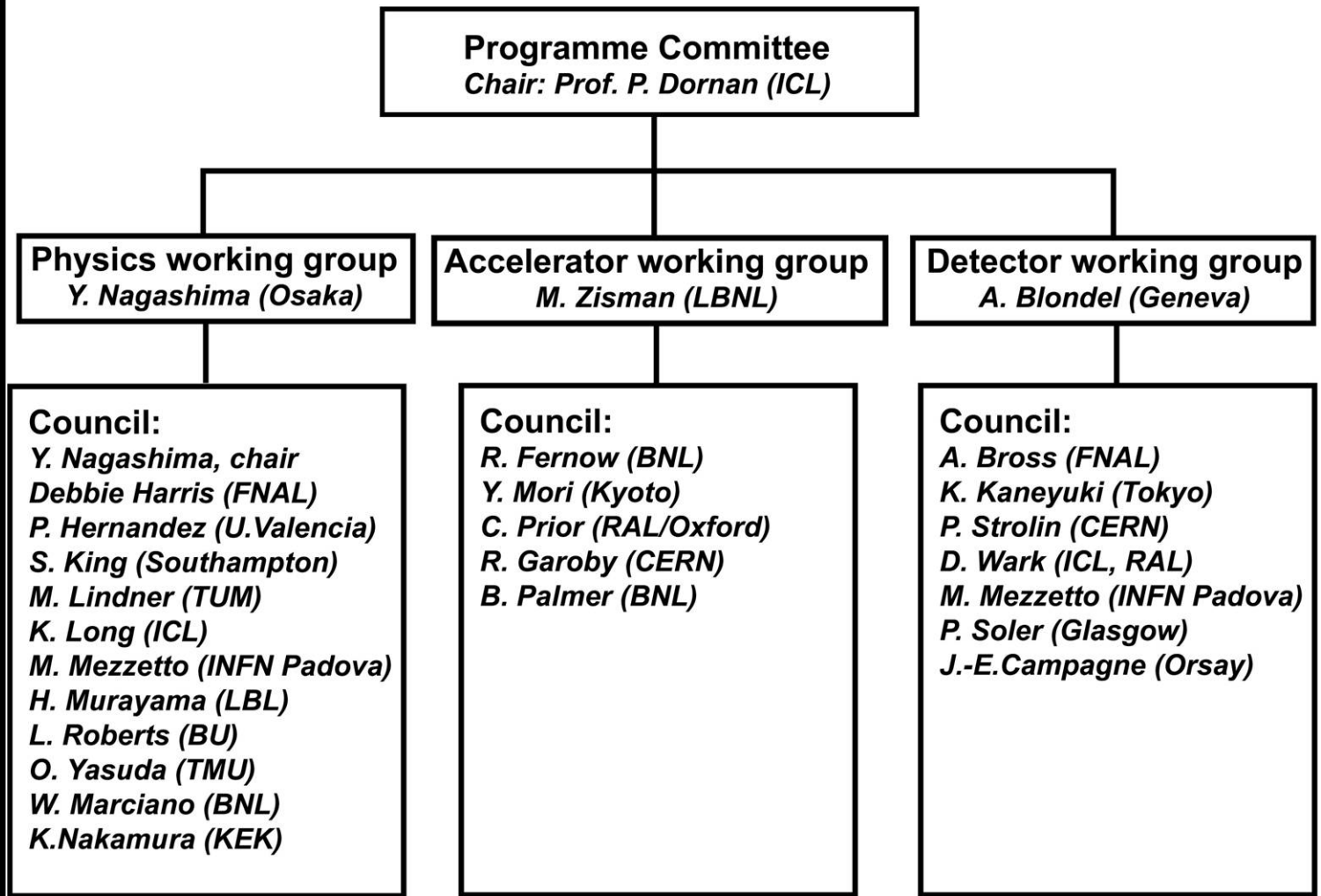
  - R&D programme defined in these studies now maturing and being carried out by international collaborations:
    - International Muon Ionisation Cooling Experiment – MICE
    - International high-power targetry experiment – MERIT
    - International rapid acceleration (FFAG) programme – EMMA

ISS: motivation

- Goal: timely completion of conceptual design
  - Significant *international* effort taking several years
    - Requires successful bids to provide the resources
- Preparation for design study; require to:
  - Review (test strength of) physics case
    - $\Rightarrow$ Critical comparison of options
    - Emphasis: roadmap for design-study phase
  - Review options for accelerator complex:
    - Identify interfaces between subsystems and determine desirable ranges for the relevant parameters
    - Prepare concept-development and hardware-R&D roadmaps for design-study phase
  - Review options for neutrino-detection systems
    - Emphasis: identify concept-development and hardware-R&D roadmaps for design-study phase

ISS: organisation

Scoping study for a future neutrino complex
organisational chart



ISS: organisation – momentum

- Plenary meetings to date:
  - CERN: 22 – 24 September 2005
    - Attendance: 92
    - Americas: 15 Asia: 12 Europe 65
  - KEK: 23 – 26 January 2006
    - Attendance: 67
    - Americas: 11 Asia: 28 Europe 28
- Working groups:
  - Physics:
    - Workshops: Imperial: 14 – 21 November 2005
    - Phone meetings
  - Accelerator:
    - Workshops: BNL: 07 – 12 December 2005
    - Phone meetings
  - Detector:
    - Phone meetings
    - Detector/Physics parallel at Physics workshops

Attendance high and sustained

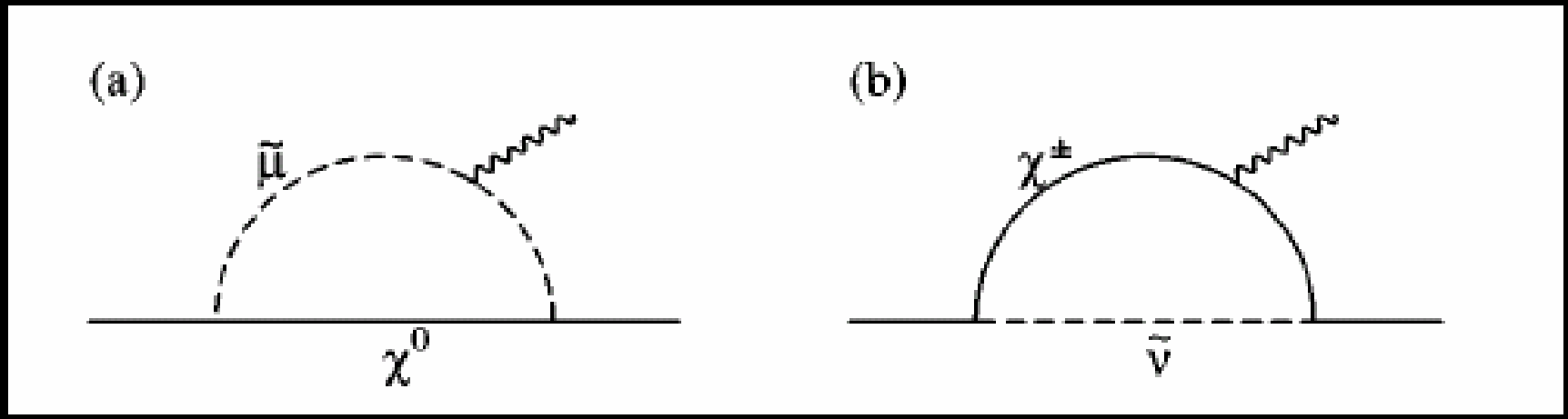
Strong feeling of motivation and 'buy in'

ISS: status – Physics Group

- Theory subgroup – mission:
  - Establish the case for high-precision, high-sensitivity neutrino-oscillation programme
    - Robust arguments for peers
    - 'Elevator pitch' for decision makers
  - Discovery – θ_{13}, sign(Δm_{23}^2), δ
    - The case for sensitivity
  - What is the new physics
    - The case for precision
      - Need to distinguish between alternative theories
- Phenomenological subgroup – mission
  - Review models purporting to describe neutrino oscillations and identify measurables that distinguish between them
    - Assess the precision required
- Experimental subgroup:
  - Use realistic assumptions on the performance of accelerator and detector to:
    - Evaluate performance of the super-beam, beta-beam and Neutrino Factory alone or in combination

ISS: status – Physics Group

- Muon physics subgroup:
  - Lepton-flavour violating processes – clear synergy with neutrino oscillations



  - Neutrino Factory could provide copious source of muons for:
    - Rare decays:

$$\mu^- A \rightarrow e^- A$$

$$\mu^+ \rightarrow e^+ \gamma$$

$$\mu^+ \rightarrow e^+ e^- e^+$$

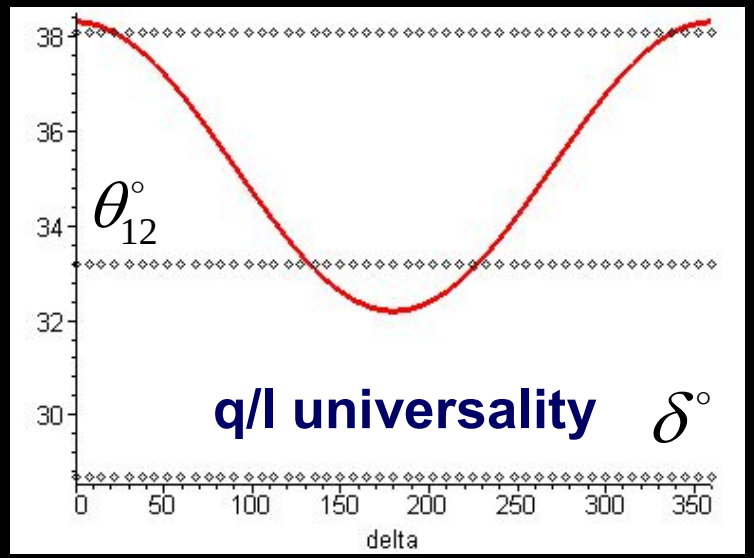
    - Flavour-change in scattering

$$\mu^+ e^- \rightarrow \mu^- e^+$$

Alternative theories (examples)

- Flavour symmetry:
  - Quarks and charged leptons do not carry the same hidden quantum numbers
  - All neutrinos carry the same hidden quantum numbers
    - Allows differences in mass hierarchies and mixing matrices to be explained through symmetry breaking
    - Random sampling of many such models indicates that large θ_{13} is favoured
- Quark-lepton complementarity
  - GUTs motivate relationships between the quark and lepton mixing matrices
  - Measurable relations, examples:

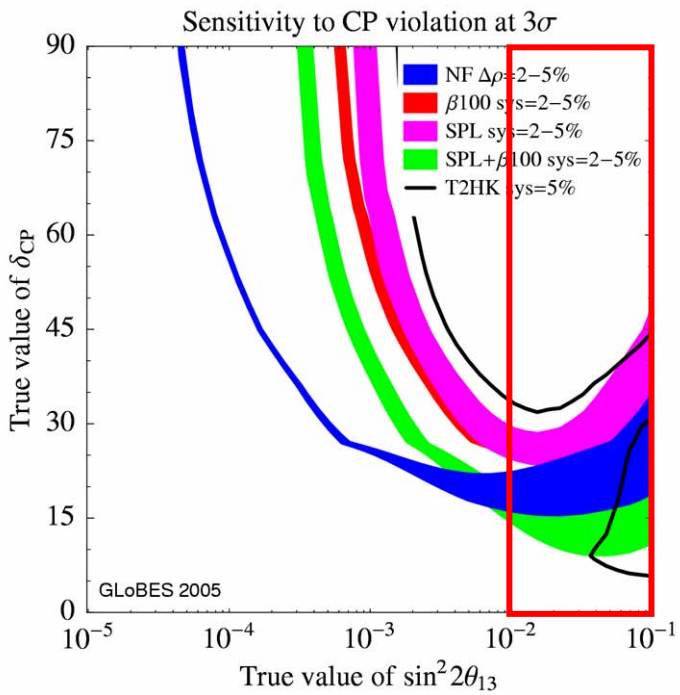
$$\theta_{12} + \theta_{\text{Cabbibo}} = \theta_{23} = \frac{\pi}{4}$$

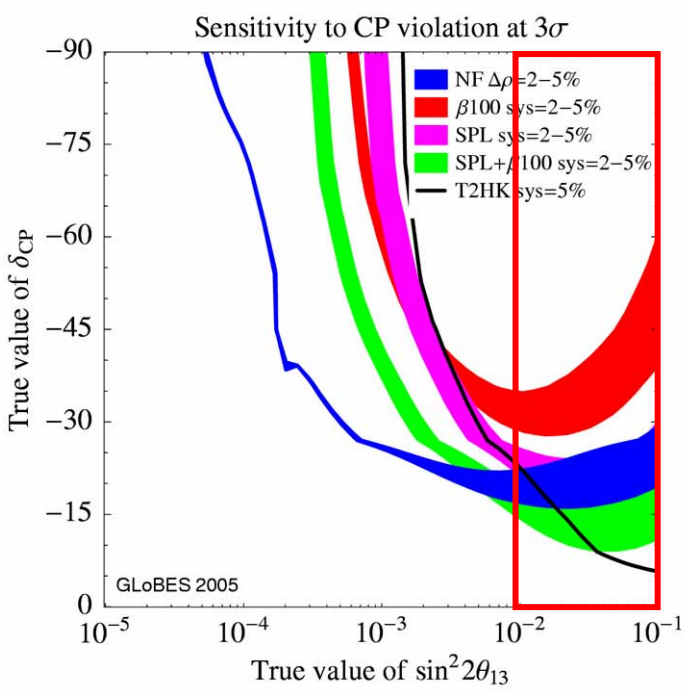


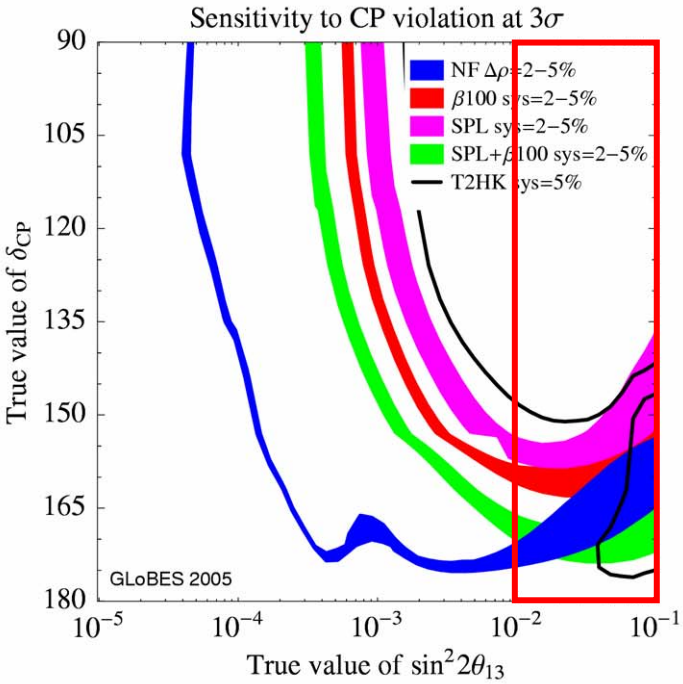
Towards a performance comparison

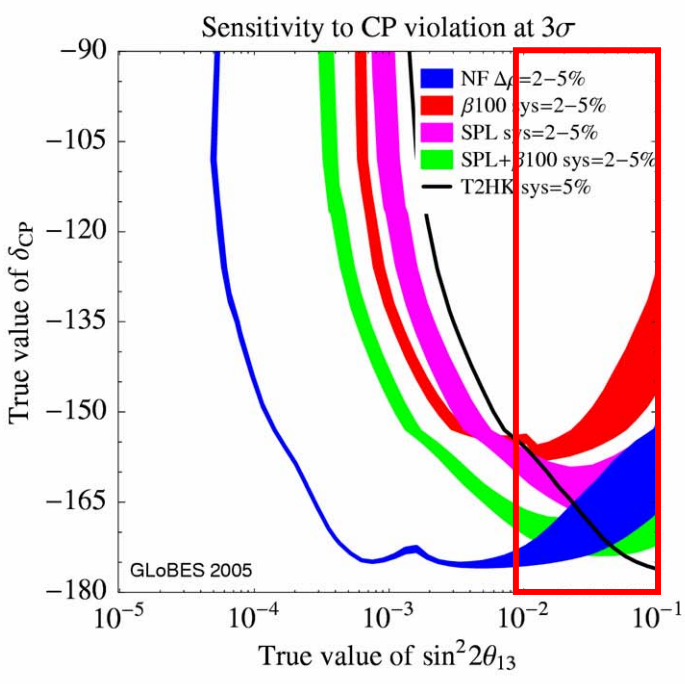
- Requires realistic assumptions:
  - Accelerator: flux, energy spectrum
  - Detector: E_{thresh}, E_{Res} (background, x-sect. uncertainty…)

  and optimised facility (accelerator, baseline, & detectors)
- Cases considered: (work in progress)
  - Off axis super-beam:
    - T2HK taken as example
      - Plan to explore different options (essentially vary *E* and *L*)
      - Seeking i/p on long baseline and wide-band beam option
  - Beta beam:
    - Low γ: $\gamma = 100$ and $L = 130$ km
      - High flux (~10^{18} decays per year) and high flux (10^{19} dpy)
    - High γ: $\gamma = 350$ and $L = 700$ km
      - High flux (~10^{18} decays per year) and high flux (10^{19} dpy)
  - Neutrino Factory
    - Performance studied as a function of:
      - *E* and *L*
      - E_{thresh} and E_{Res}

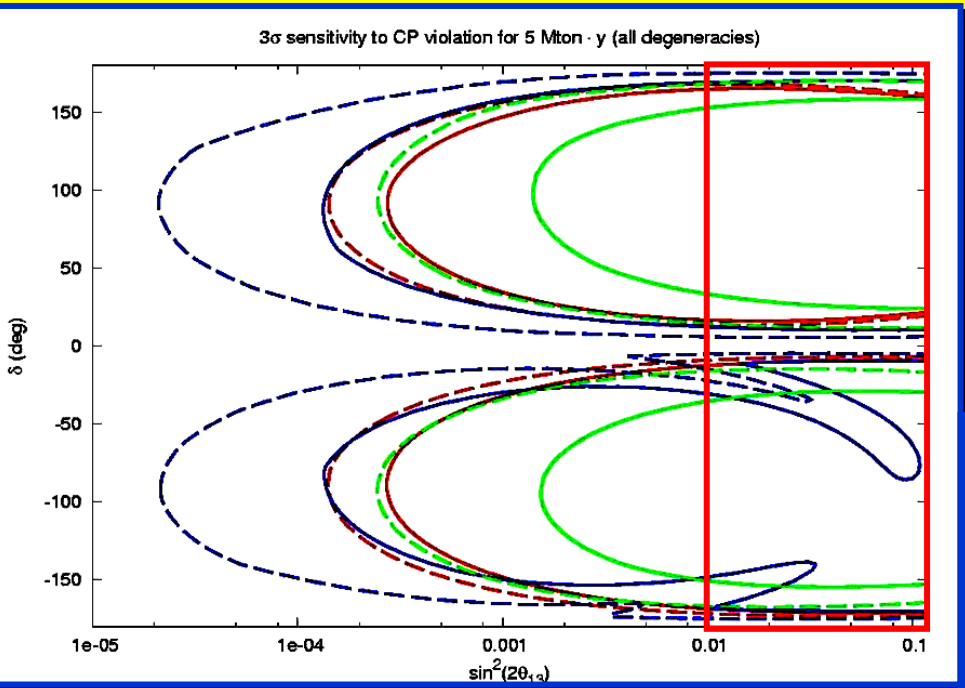

Sensitivity to CP violation at 3σ
NF Δρ=2−5%
β100 sys=2−5%
SPL sys=2−5%
SPL+β100 sys=2−5%
T2HK sys=5%
GLoBES 2005
True value of δCP
True value of sin²2θ13


Sensitivity to CP violation at 3σ
NF Δρ=2−5%
β100 sys=2−5%
SPL sys=2−5%
SPL+β100 sys=2−5%
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GLoBES 2005
True value of δCP
True value of sin²2θ13

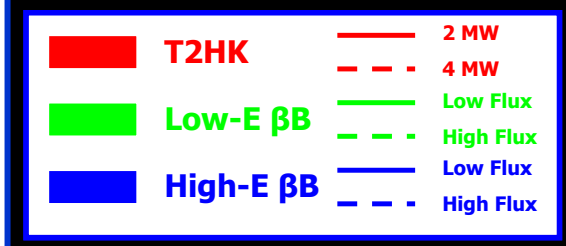

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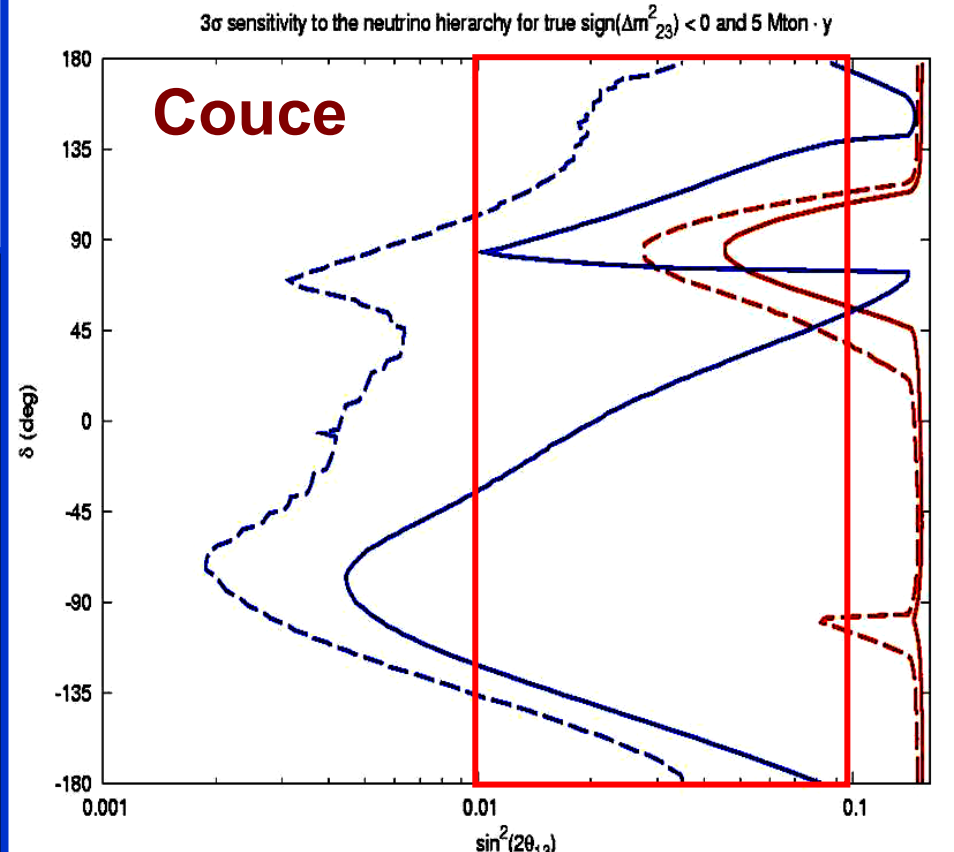
Beta beam, super beam comparison



Preliminary! Need to include better treatment of background and sys. err.



- High θ_{13}:
  - Beta beam & super beam alone:
    - δ sensitivity good
    - Poor sign(Δm_{23}^2) sensitivity



Neutrino Factory: optimisation

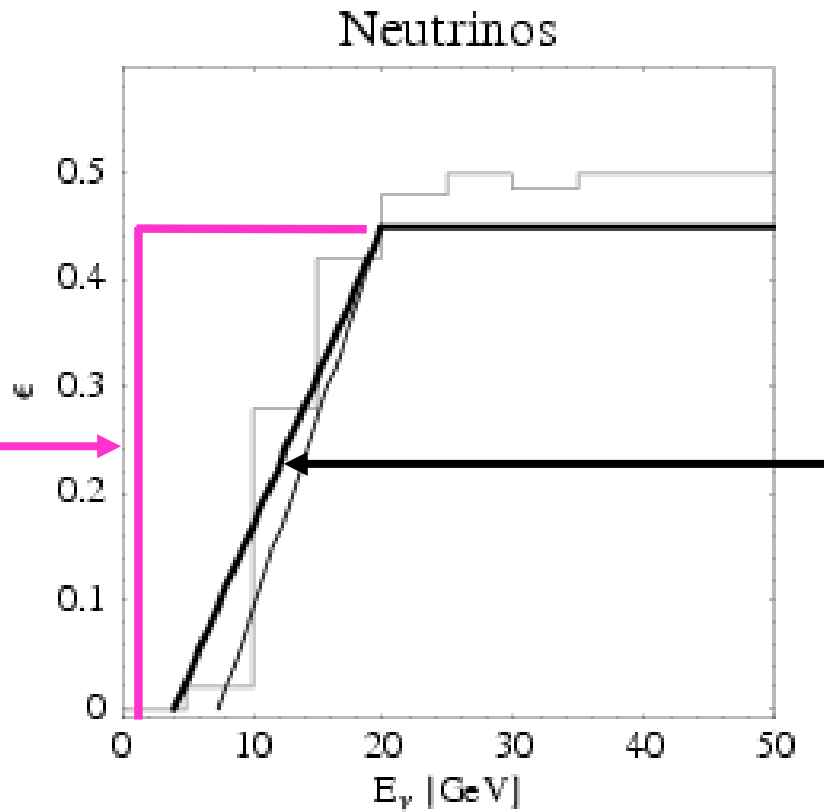
- Study performance as a function of muon energy and baseline
- Detector:
  - 100 kton, magetised iron
  - Two performance assumptions:

Threshold more important than resolution

'Better':

– Threshold

– Resolut^{n} $E_{Res} = \frac{5\%}{\sqrt{E}}$



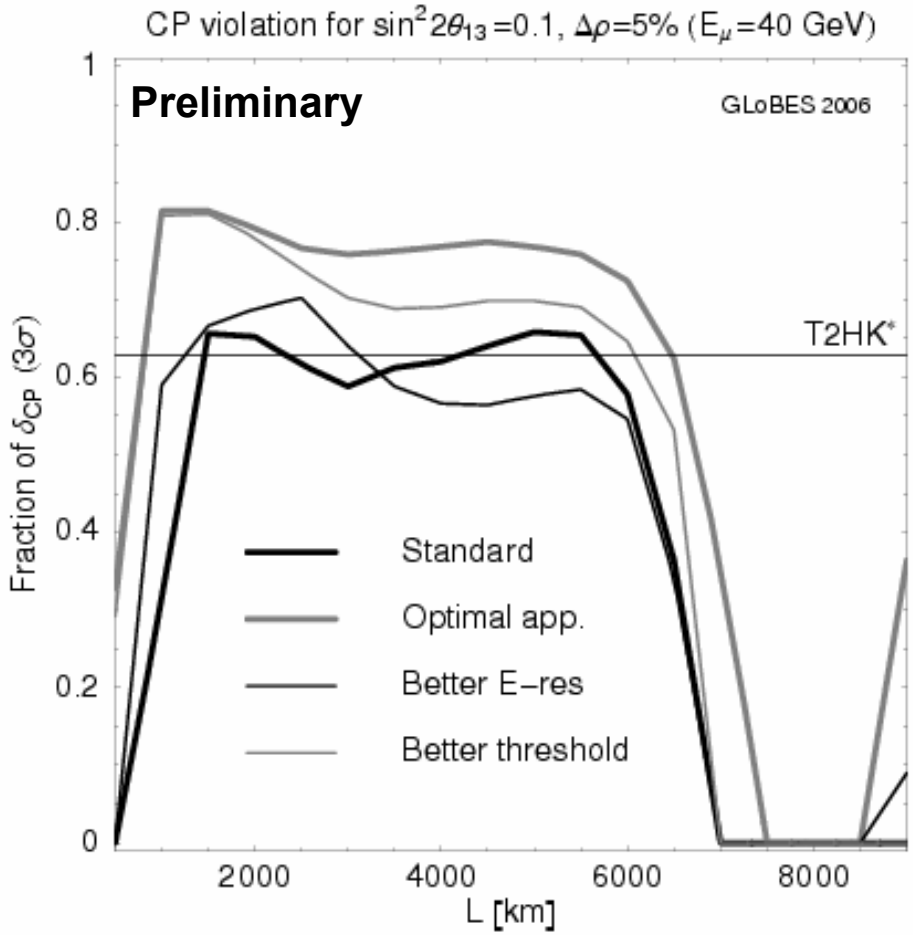
'Baseline':

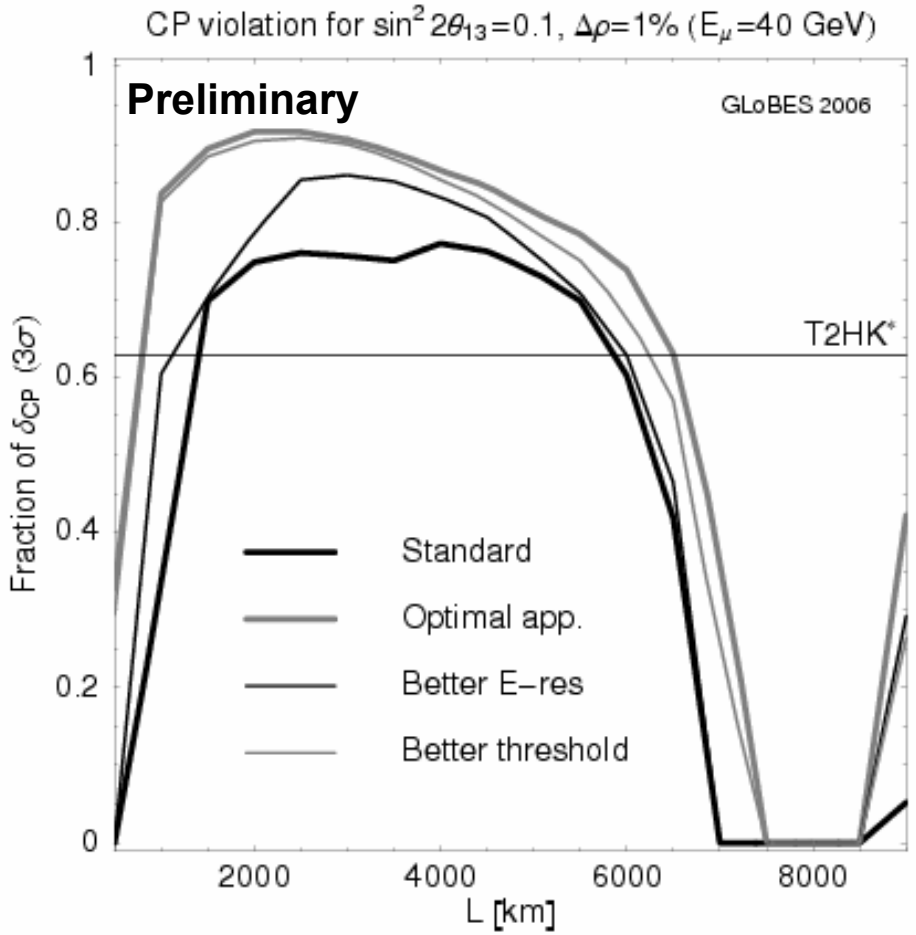
– Threshold

– Resolut^{n} $E_{Res} = \frac{15\%}{\sqrt{E}}$

Neutrino Factory optimisation

- **Large θ_{13}** — **Winter**





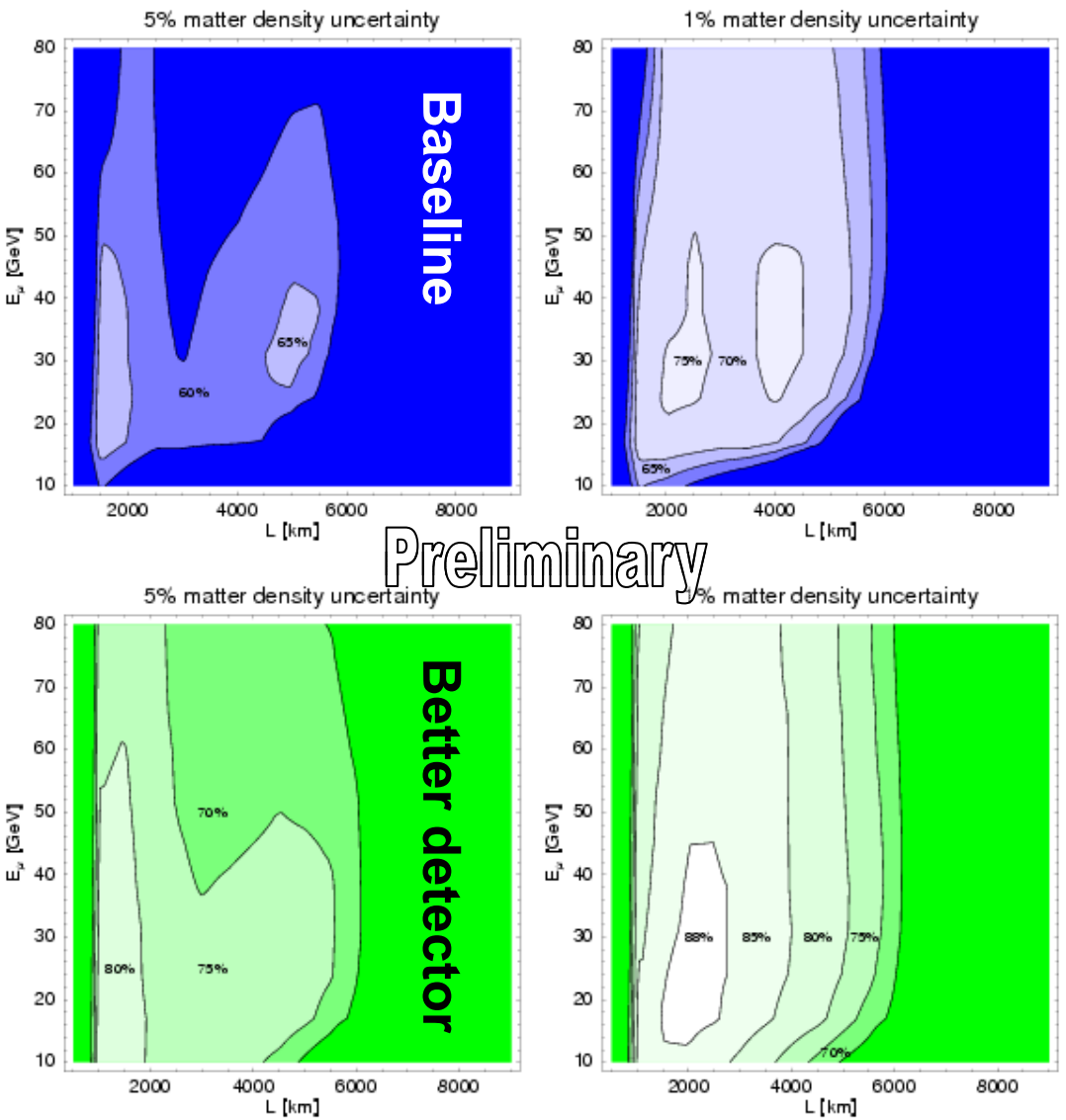
- Both better Eres and threshold useful
- Both better detector and smaller matter density uncertainty useful
- Either or combination sufficient to compete with the superbeam upgrades (prel.)
- Large $\Delta\rho$+better detector prefers shorter baselines (1000-2000km); E_μ small OK

Neutrino Factory optimisation

- Large θ_{13}

Winter

CP coverage

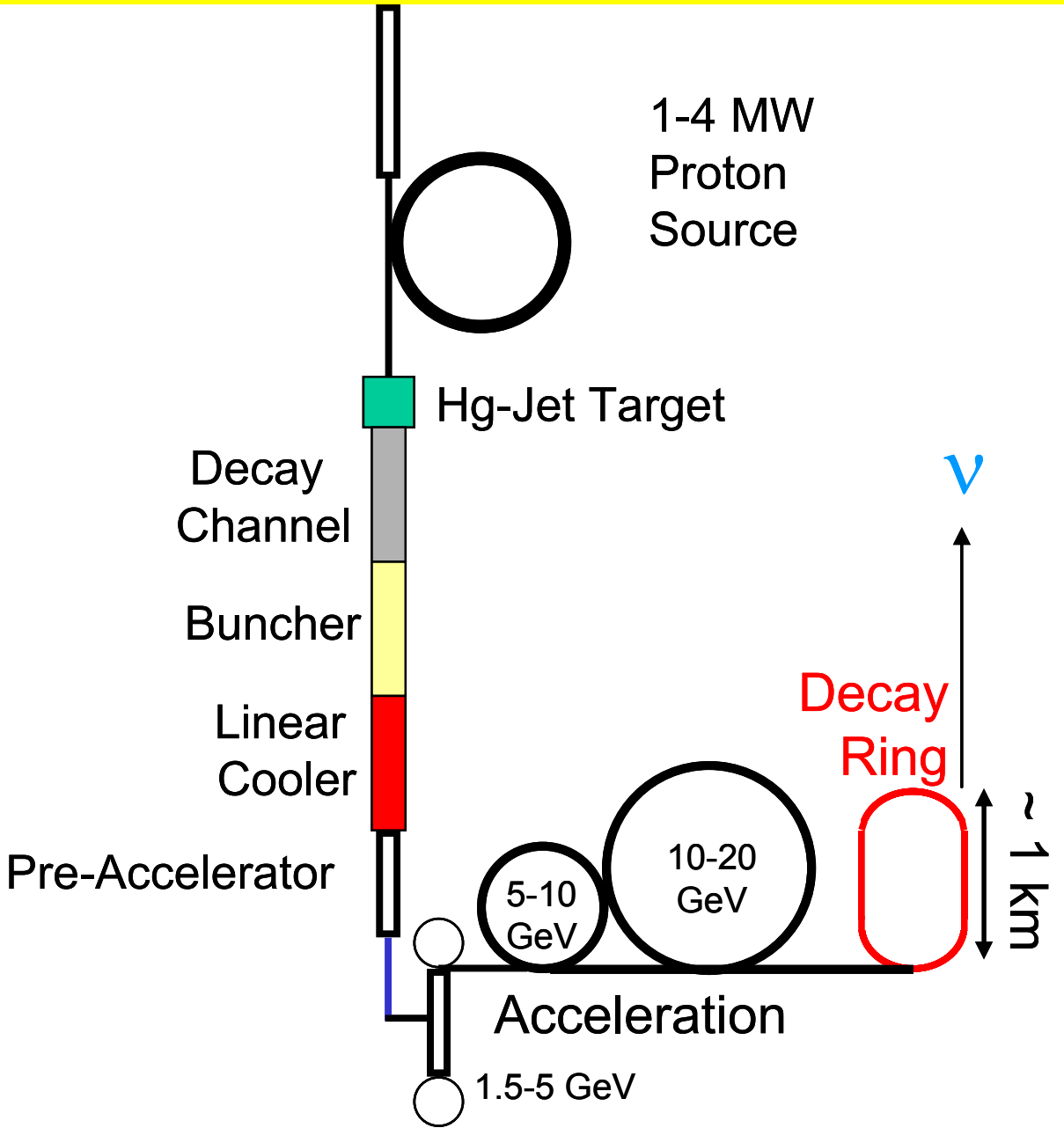


- Work in progress, but:
  - For large θ_{13} "optimal appearance" experiment
    - L = 1000 km
    - E_μ = 20 GeV

    looks good

ISS status: Accelerator Group

- Subsystems & subgroups
  - Proton driver
  - Target and capture
  - Front end
    - Bunching and phase rotation
    - Cooling
  - Acceleration
  - Decay ring



Accelerator Group – mission

- Two phase approach:
  - Phase 1:
    - Study alternative configurations; arrive at baseline specifications
    - Develop tools required for end-to-end simulations
    - 'Top-down' cost evaluation required to guide choices
  - Phase 2:
    - Focus on selected option(s)
      - Begin to consider engineering issues
    - Through initial engineering studies, identify R&D required in 'International Design Study' phase
- Presently working through Phase 1
  - Highlights →

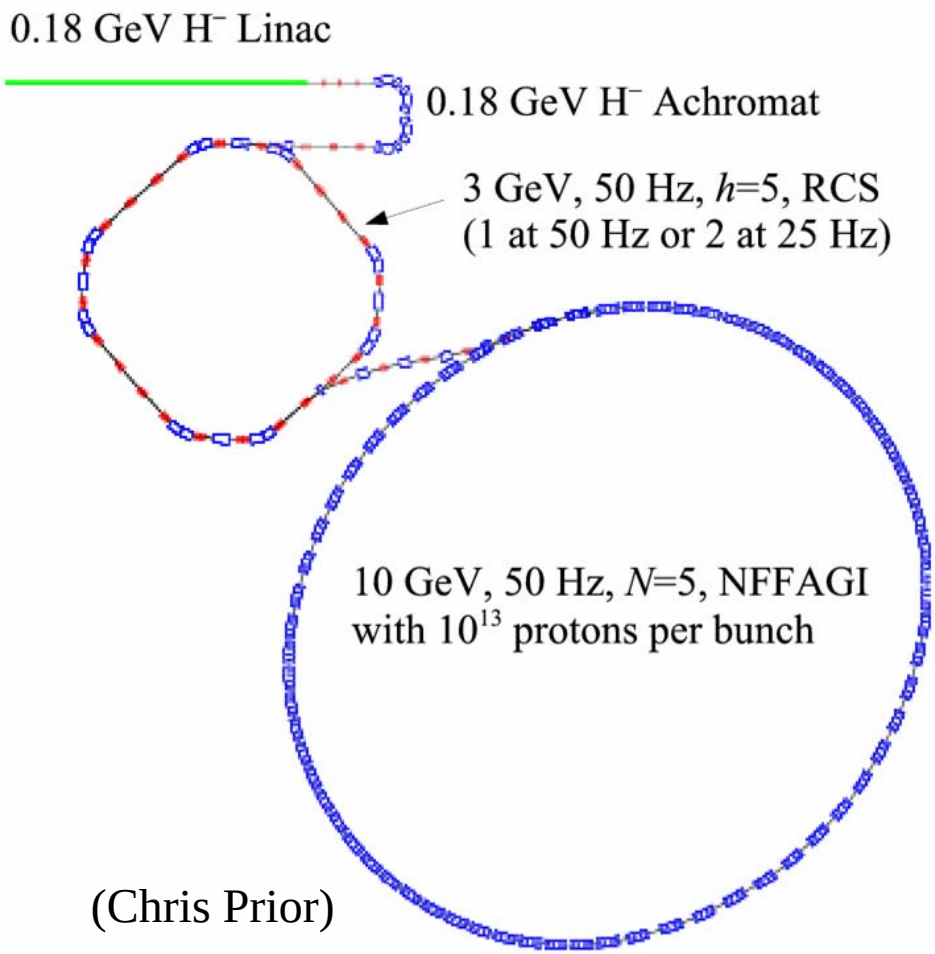
Proton driver:

- **Key issues for Neutrino Factory proton driver:**
  - **Beam current limitations**
  - **Creation of short bunches**
  - **Repetition rate limitations**
  - **Space charge limitations**
  - **Tolerances**

  Largely driven by downstream constraints
- **Survey carried out:**

1.	SPL	3.5 GeV	50 Hz	4 MW	
2.	JPARC	50 GeV	0.33 Hz	0.6 -> 4 MW	
3.	AGS	24 GeV	0.5 Hz	0.2 -> 4 MW	
4.	FNAL SCL	8 GeV	10 Hz	0.5 -> 2 MW	
5.	RAL RCS	5 GeV	50 Hz	4 MW	
6.	RAL RCS	15 GeV	25 Hz	4 MW	
7.	RAL FFAG	10 GeV	50 Hz	4 MW	New
8.	KEK/Kyoto	3 GeV	1 kHz	1 MW	
9.	A. Ruggiero FFAG	12 GeV	100 Hz	18 MW	
10.	A. Ruggiero FFAG	1 GeV	1 kHz	10 MW	

RAL 4 MW FFAG Proton Driver



(Chris Prior)

- RAL design
- 5 bunches per pulse
- 50 Hz repetition rate
- 10 GeV
- FFAG with insertions

- RF system naturally gives 2 ns rms pulse
- need to add 6th harmonic to get 1 ns rms

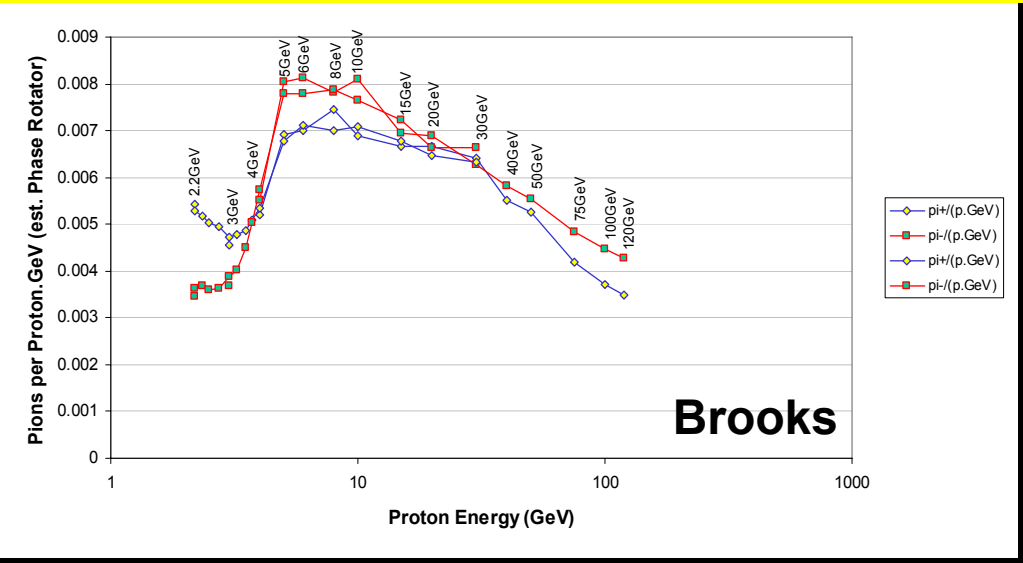
Issue:

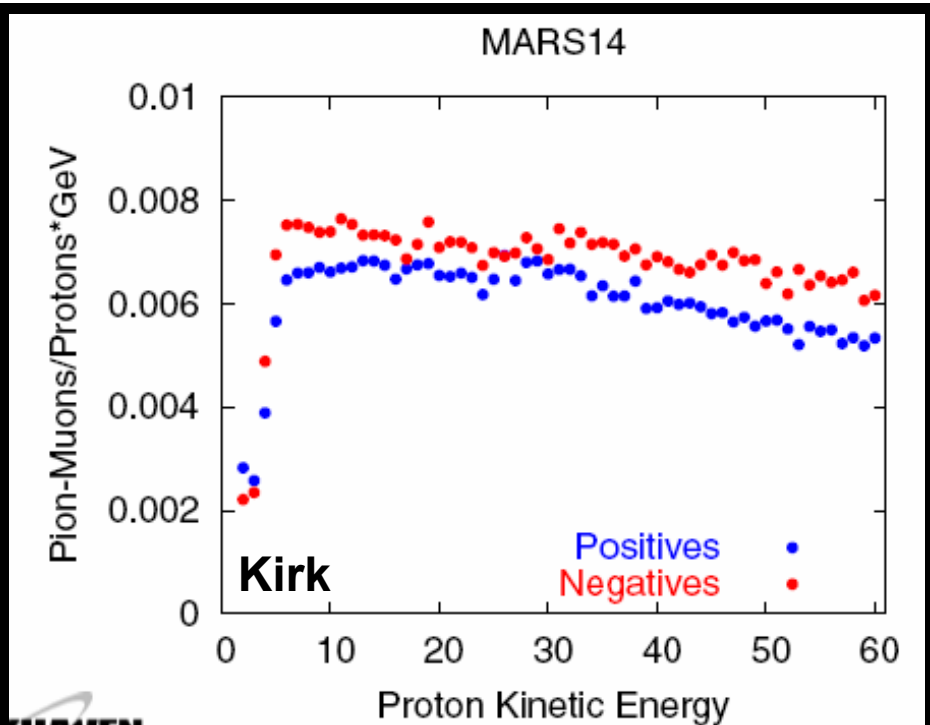
Bunch length at injection

Target and capture

- Key issues for target and capture system:
  - Optimum proton-driver energy
  - Optimum target material
  - Constraints on target operation at 4 MW
    - Proton bunch intensity
    - Proton bunch length
    - Repetition rate
- Review of materials carried out:
  - Liquid mercury preferred for high-power operation
  - Solid tantalum may be an option
  - Carbon probably OK up to 1 MW

Target and capture: proton energy

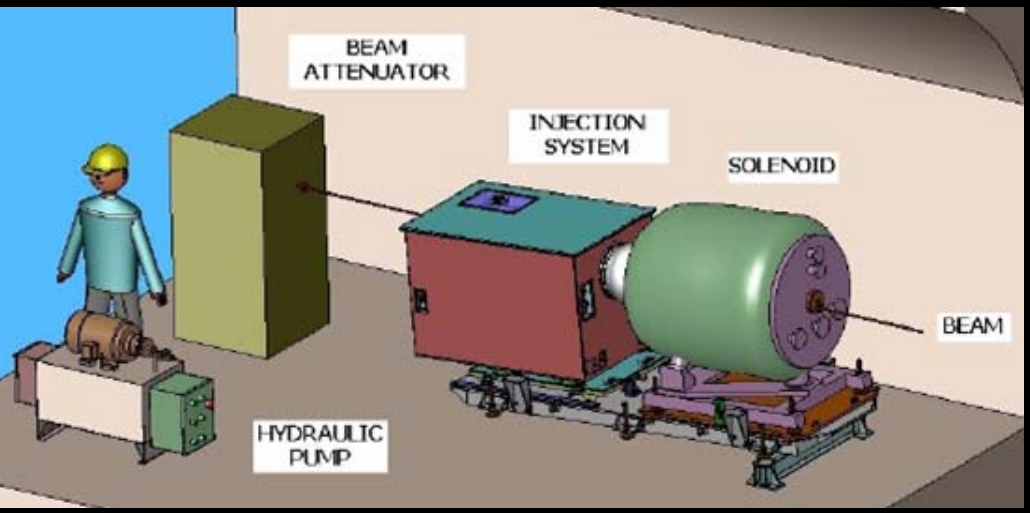


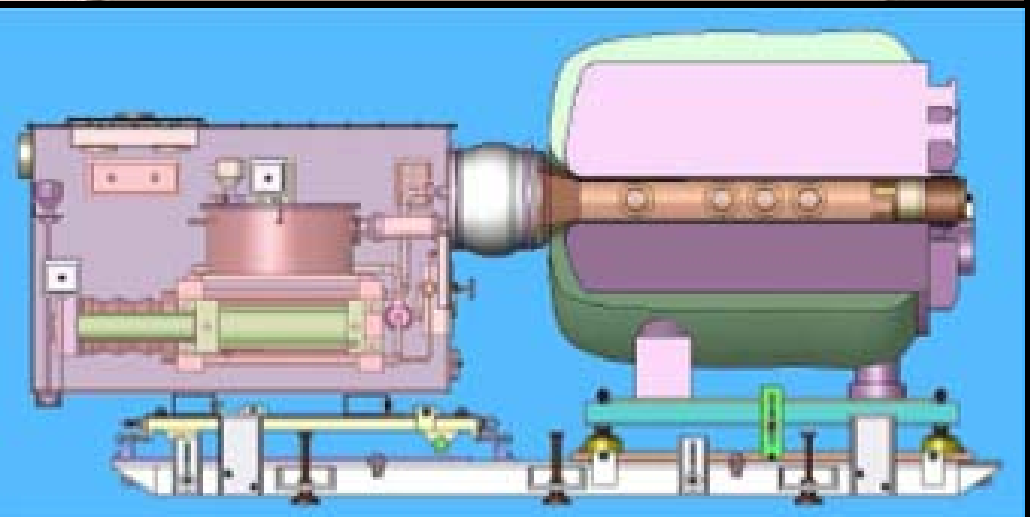


- Different simulations disagree
  - MARS
  - Geant4
- Preliminary conclusion:
  - Proton driver energy in range 5 – 15 GeV

Target and capture

- MERIT experiment at CERN
  - High-power liquid-mercury jet target engineering demonstration





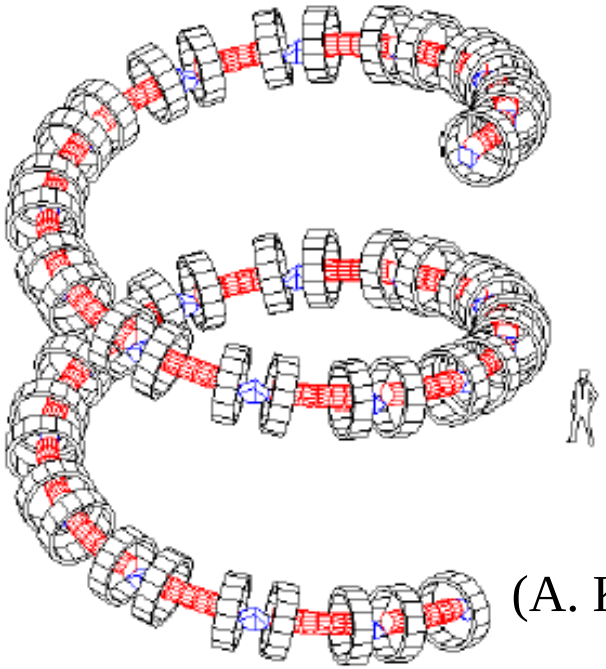


First data: April 2007

Front-end

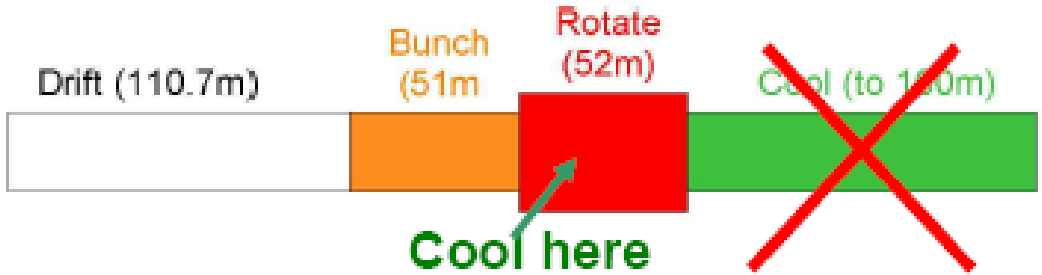
- Review and compare performance of existing schemes (CERN, KEK, US)
  - Initial comparison made
  - Conclusions will require cost model to be developed
- Evaluate trade-offs between degree of cooling and downstream acceptance
  - Figure of merit (muons per proton)
  - Need to define options for acceptance downstream of cooling channel
    - Small, medium, and large?
  - Optimisations:
    - Minimise RF required
    - Optimum choice of materials for absorber in cooling channel
  - Evaluate cost optimum

Front end: new configurations



(A. Klier)

- "Guggenheim" cooling channel
- provides longitudinal cooling
- solves problems with injection, absorber heating
- can taper parameters

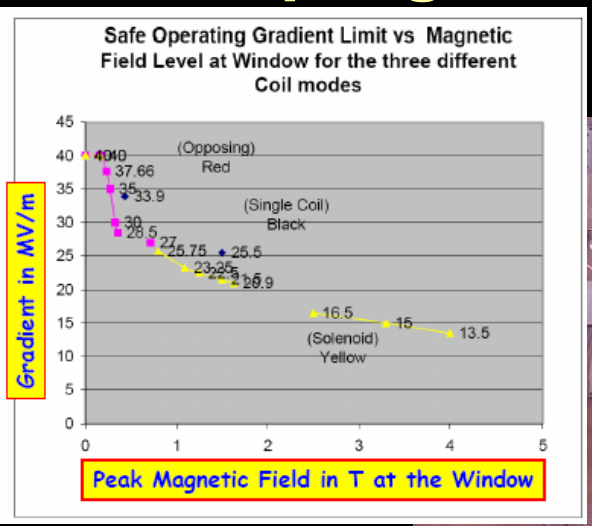


(D. Neuffer)

- cool while doing phase rotation
- cost savings
- 150 atm hydrogen (room temp)
- 24 MV/m RF
- performance looks promising

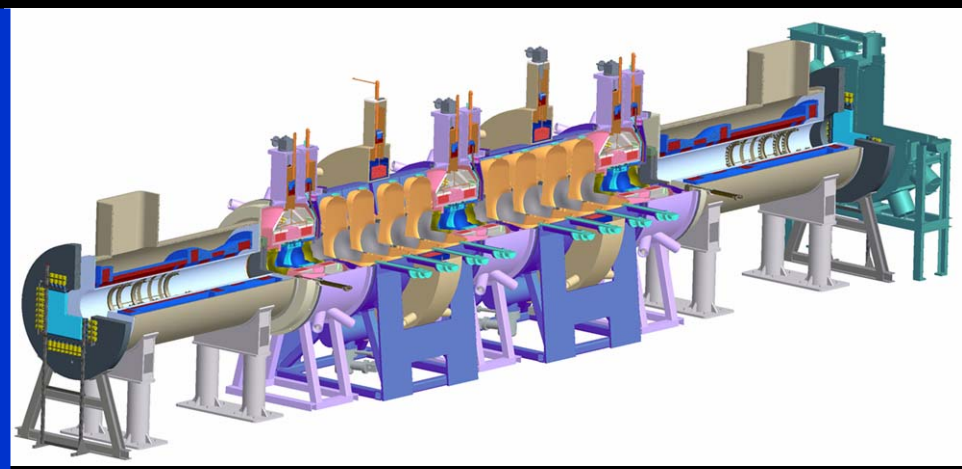
Cooling: hardware R&D programme

- Complementary programmes:
  - MuCool:
    - Design, prototype, and test – using an intense proton beam – cooling channel components
  - MICE:
    - Design, construct, commission, and operate – in a muon beam – a section of cooling channel and measure its performance in a variety of modes
- Both programmes well advanced





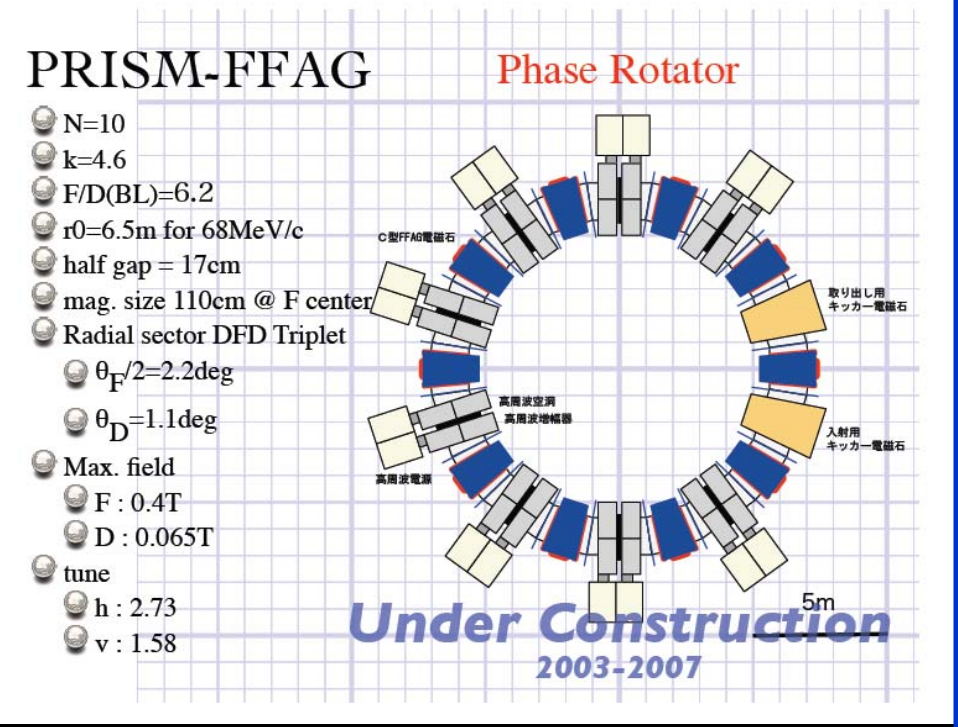
MuCool



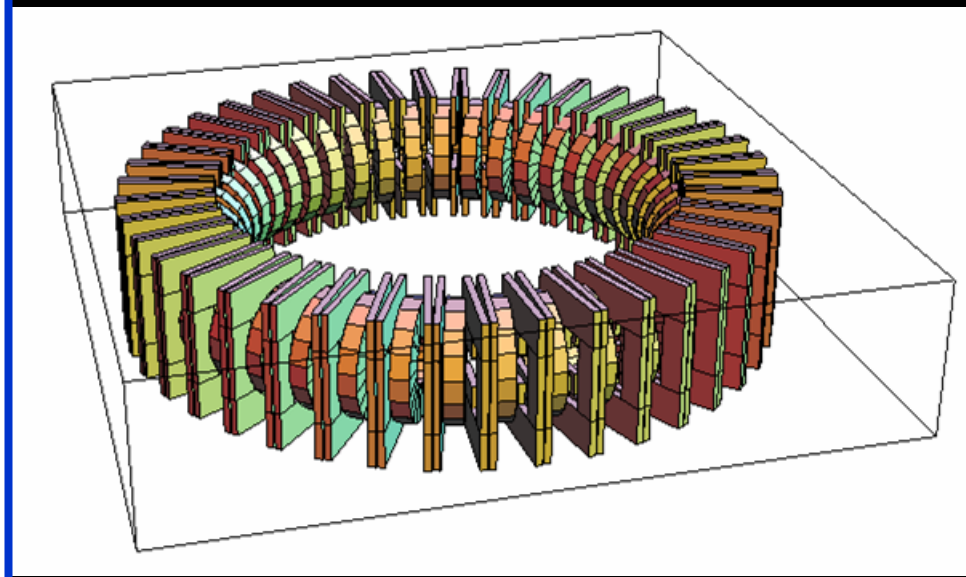
MICE: first beam 2007

Acceleration: FFAG development

- **PRISM:**
  - Phase rotated intense muon source
    - Under construction in Osaka
    - Commissioning 2007



- **EMMA:**
  - Electron model of muon acceleration
    - Proof of principle 'non-scaling' FFAG
    - Proposal being developed



Sato

Decay ring:

- Issues:
  - Racetrack or triangle geometry
  - 20 GeV or 50 GeV or 20 GeV-upgradable
  - How to handle both muon charges (1 ring or 2)
  - Length of μ bunch train (constrains circumference)
  - RF to maintain bunch structure
  - Beam loading (~MW μ beams)
  - Shielding from μ decays
- Two designs prepared:
  - C. Johnstone:
    - racetrack geometry
    - both 20 GeV and 50 GeV use same lattice
    - production straight
      - 496 m long, quad focusing
    - arcs
      - maximum beta = 16 m
      - 6.4 T dipole fields
      - uses sextupole correctors
  - G. Rees:
    - isosceles triangle geometry
    - design for MW intensities
    - introduce μ beam loss collection
    - use combined function magnets in arcs
    - use solenoid focusing in two production straights
    - use matching section bends
    - must make small lattice changes when upgrading 20 -> 50 GeV

ISS status: 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 – talk by C. Yanagisawa
  - Liquid argon
  - Emulsion
  - Magnetic sampling calorimeter
  - Near detector
- Further instrumentation issues:
  - Flux, muon-polarisation measurement

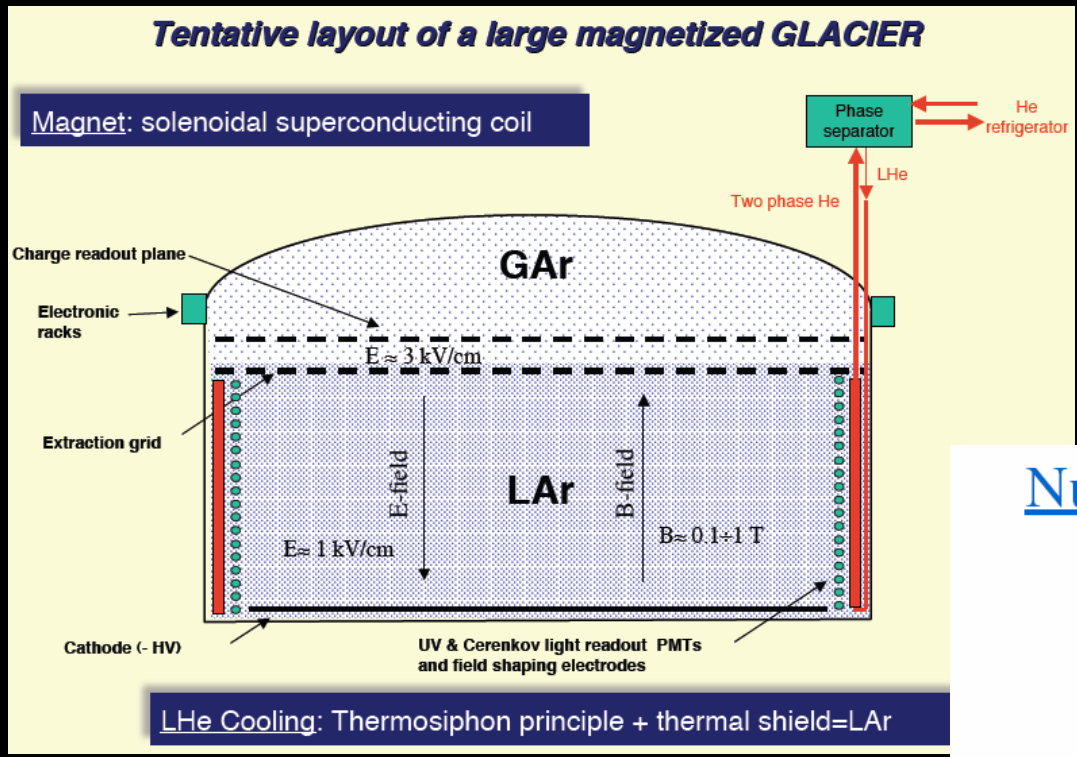
Detector technology: summary

Detector	Mass kt	Solar	SN	Atm	Nucleon decay	Superbeam, β-beam subGeV	GeV	10's GeV	ν-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 (μ-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	μ'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?

Liquid argon

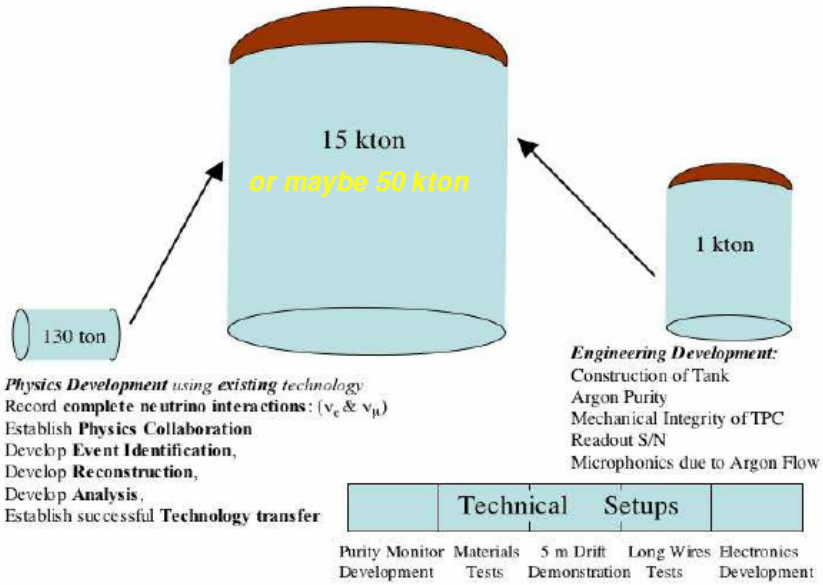
- Detector concepts:



- Various configurations being studied in ISS:
  - Glacier
  - T2K-LAr (near det.)
  - NuMI LArTPC

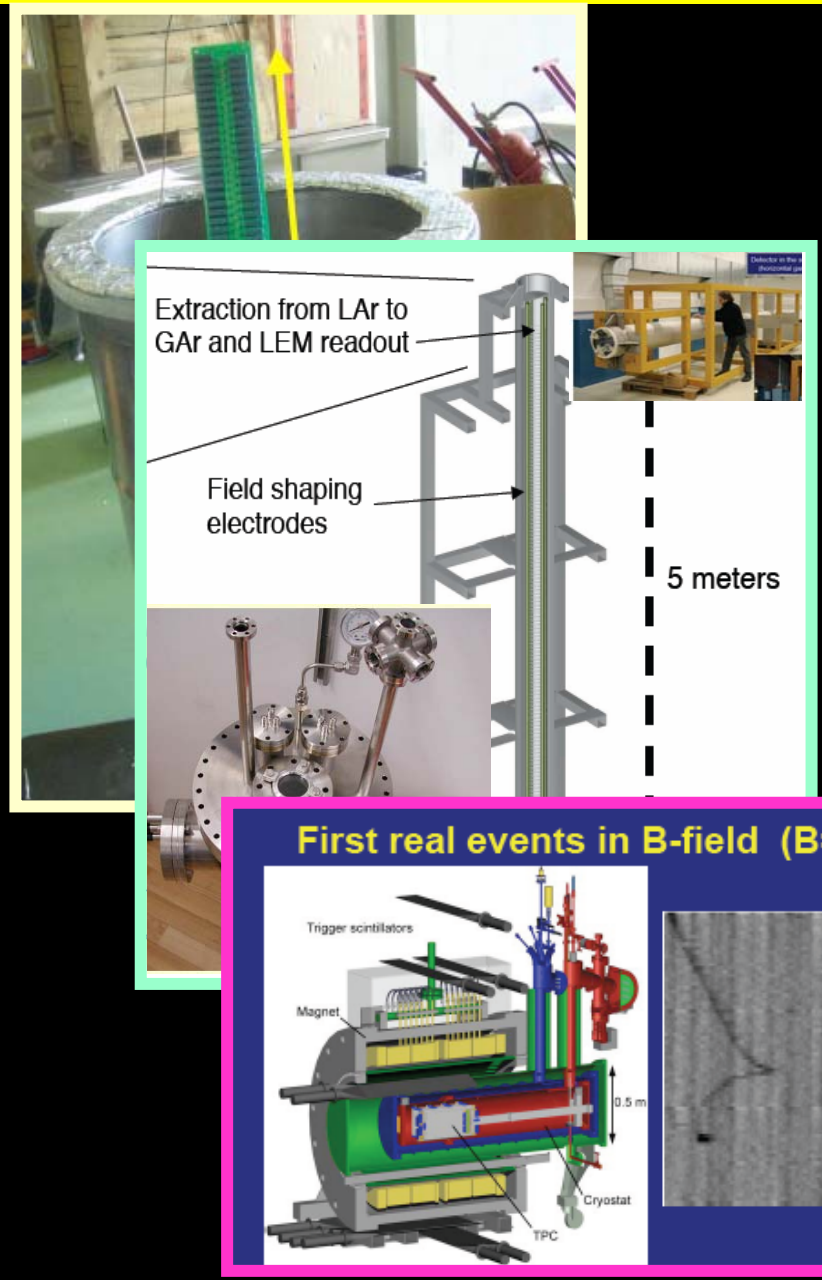
- Concept development
- Hardware R&D crucial

NuMI LArTPC Status - Hardware



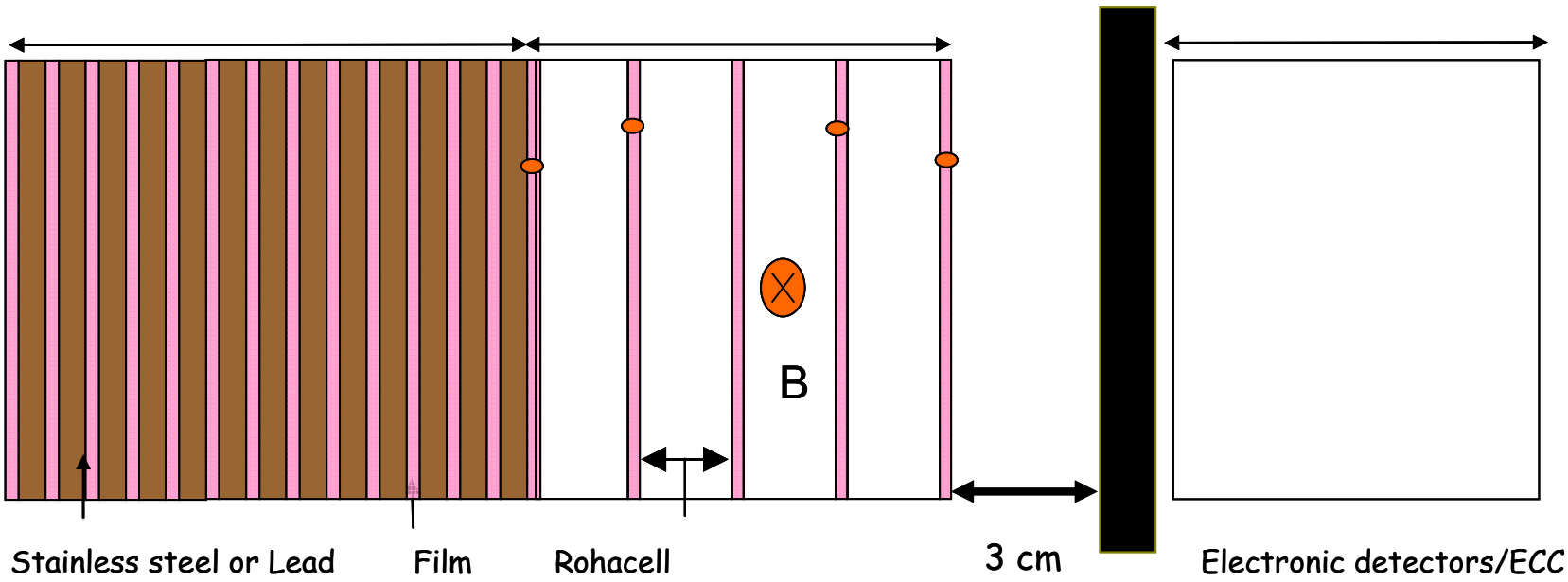
Liquid argon R&D

- Field ‘degrader’:
- Drift under pressure:
- Effect of magnetic field on drift



Emulsion detector – MECC

DONUT/OPERA type target + Emulsion spectrometer + TT + Electron/pi discriminator

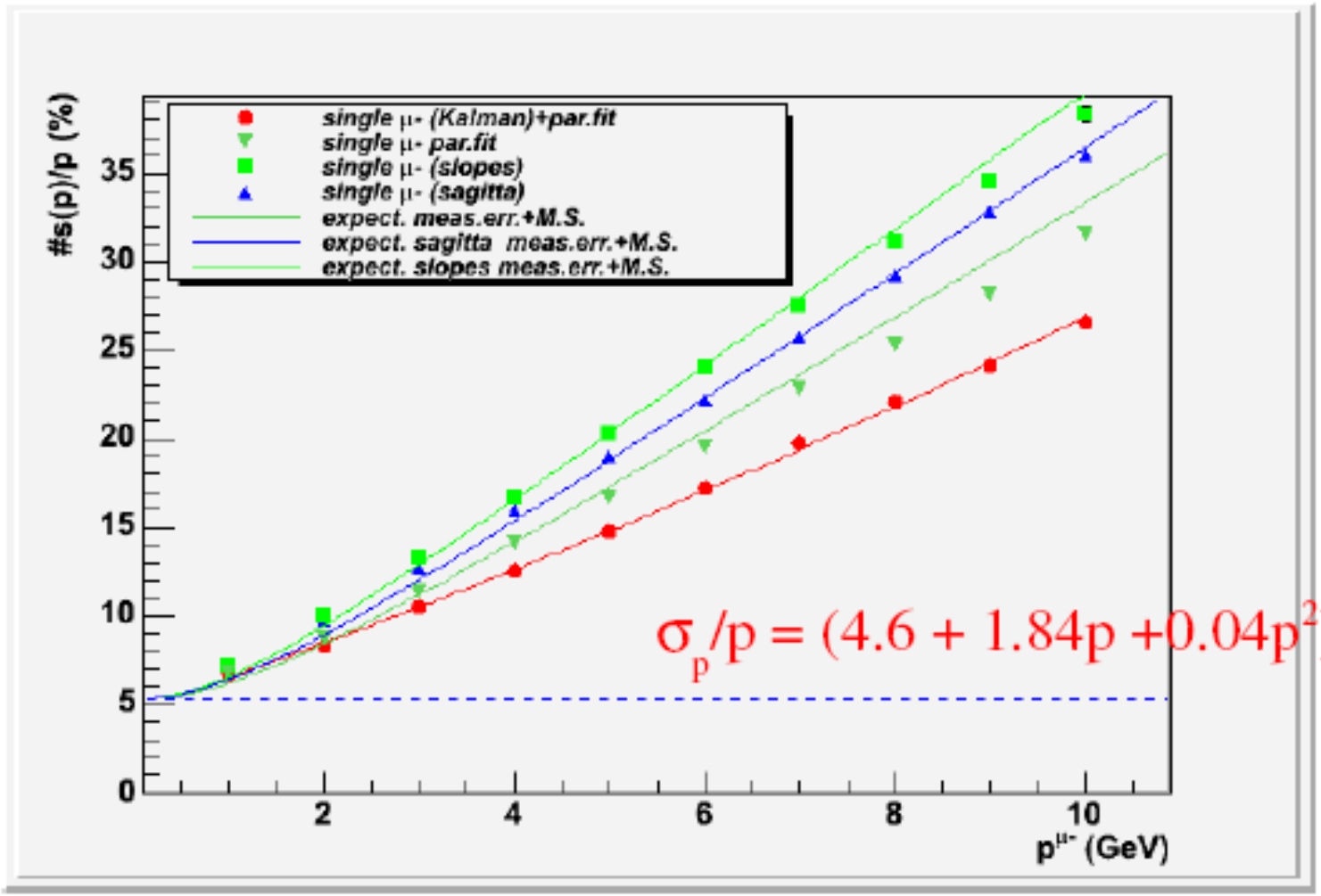


Assumption: accuracy of film by film alignment = 10 micron (conservative)

13 lead plates (~2.5 X_0) + 4 spacers (2 cm gap) (NB in the future we plan to study stainless steel as well. May be it will be the baseline solution: lighter target)

The geometry of the MECC is being optimized

MECC: momentum resolution



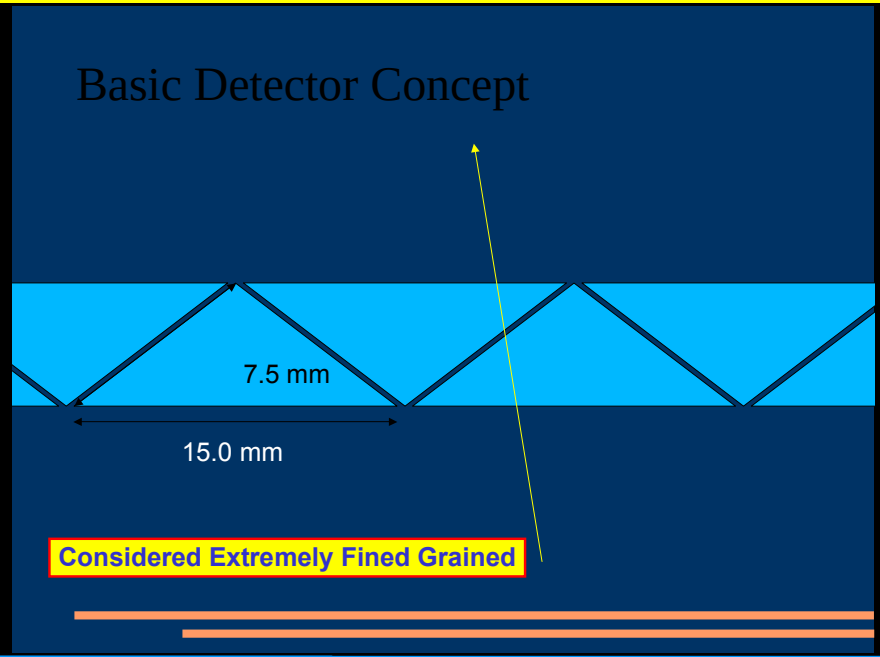
$\sigma_p/p = (4.6 + 1.84p + 0.04p^2)$ % "pol2 fit"

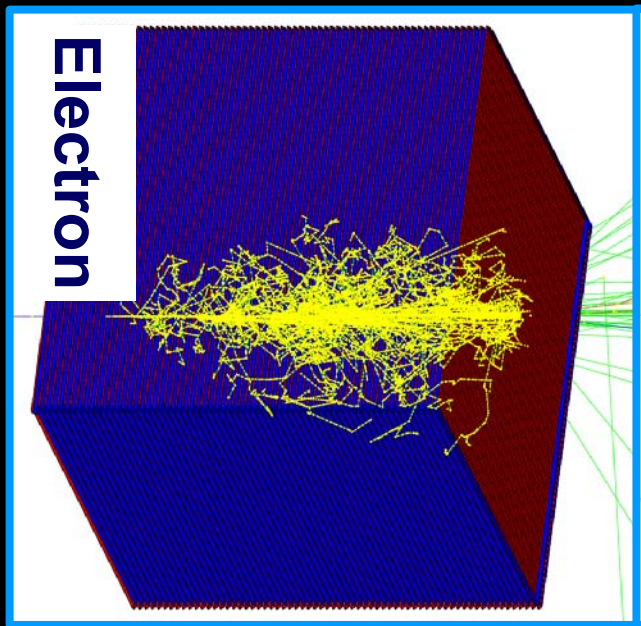
each point:
5000 evt

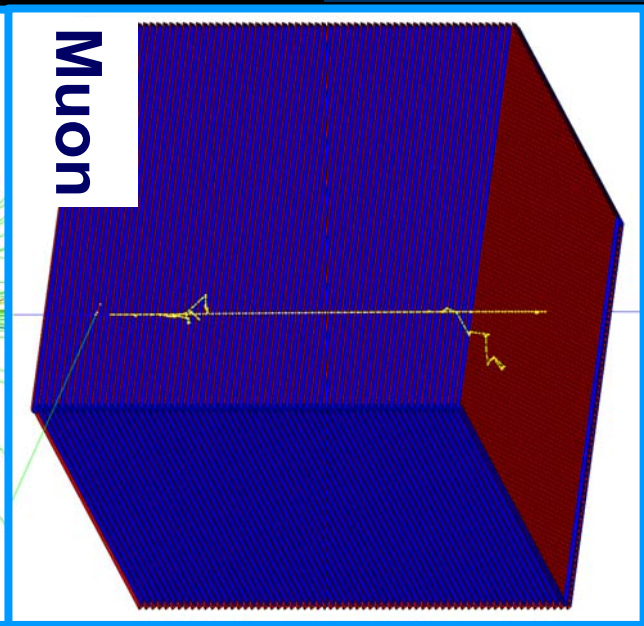
- "predictions" according to previous formulas (also M.S.)

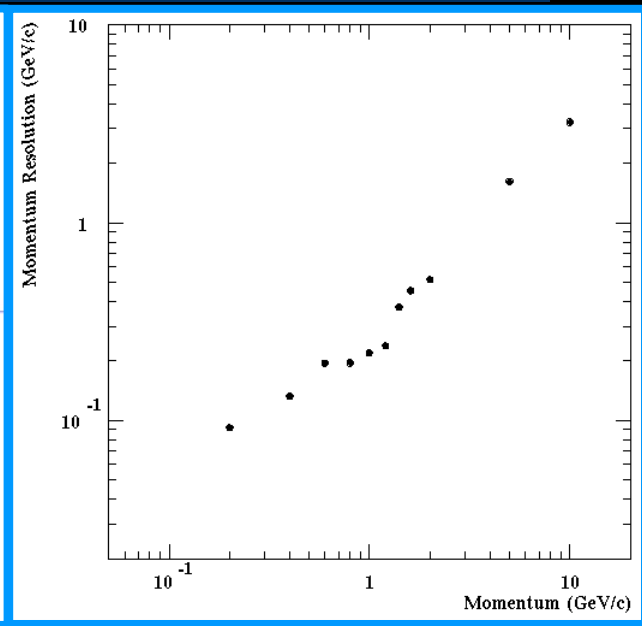
Magnetic sampling calorimeter

- Concept:
  - Magnetised iron?
    - Sampling fraction?
  - Air toroid
  - Cost
    - ~ $300M
- Simulation:



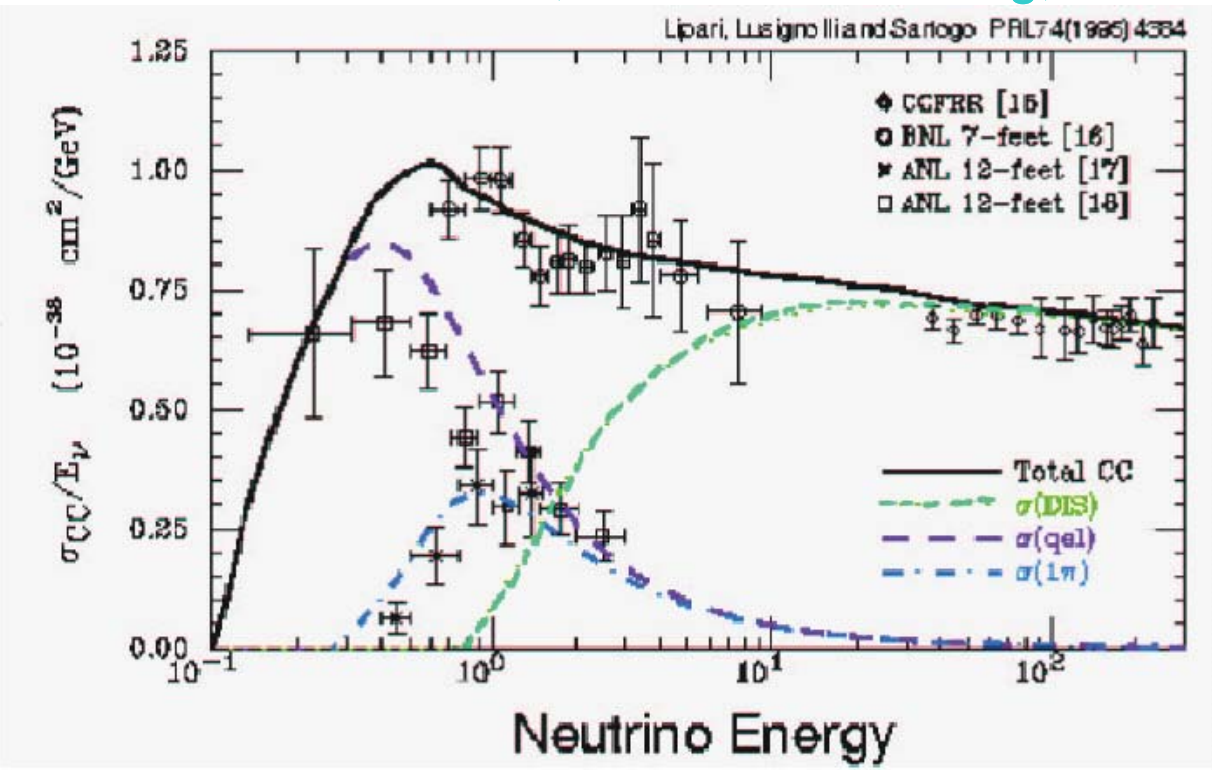






Near detector

- Measurement of cross sections in DIS, QE and RES.
- Coherent π
- Different nuclear targets: H_2, D_2
- Nuclear effects, nuclear shadowing, reinteractions



- With modest size targets can obtain very large statistics
- What is lowest energy we can achieve? E.g. with LAr can go down to ~MeV

- **Concept being developed**
  - **Charm and beauty being measurement considered too**

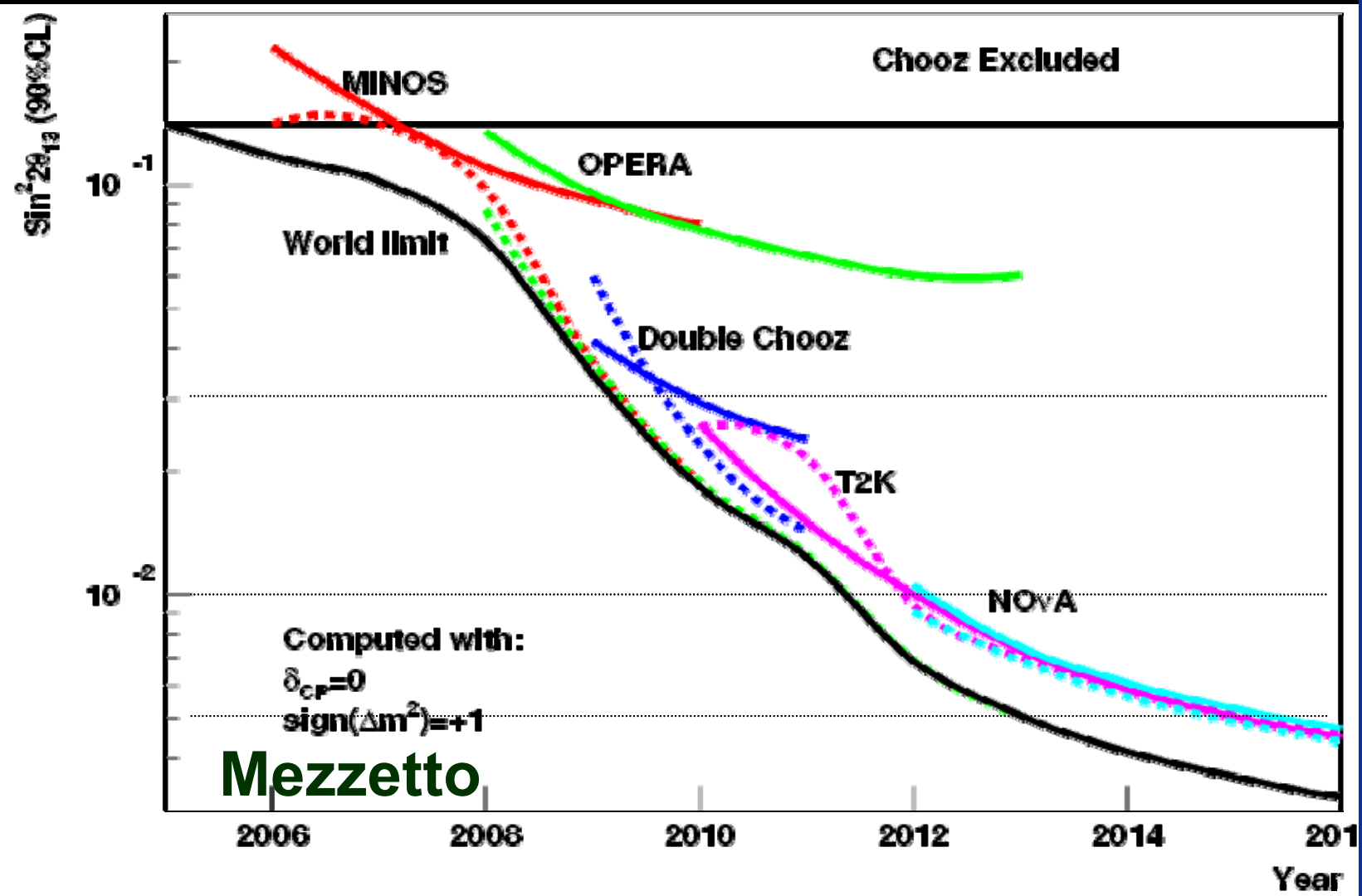
ISS status: next steps

- **Working now to prepare 3rd ISS Plenary**

	Sunday 23-Apr-06	Monday 24-Apr-06	Tuesday 25-Apr-06	Wednesday 26-Apr-06	Thursday 27-Apr-06	Friday 28-Apr-06
09:00	Available for w/g meetings	Available for w/g meetings	***Plenary session 1*** Welcome Introductory presentations	***Parallel session 4*** Joint session: Accelerator and detector Physics group in parallel	***Parallel session 7*** Working groups meet on their own	***BENE0: FP7 #1*** Introduction to FP7 Discussion
10:00						
11:00	Available for w/g meetings	Available for w/g meetings	***Parallel session 1*** Working groups meet on their own	***Parallel session 5*** Joint session: Physics and detector Accelerator group in parallel	***Plenary session 2*** Keynote presentations	***BENE0: FP7 #2*** Discussion
12:00						
13:00	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch
14:00	Available for w/g meetings	Available for w/g meetings	***Parallel session 2*** Working groups meet on their own	***Parallel session 6*** Working groups meet on their own	***Plenary session 3*** Summary presentations	
15:00						
16:00	Available for w/g meetings	Available for w/g meetings	***Parallel session 3*** Joint session: Physics and accelerator Detector group in parallel	***'Plenary parallel'*** Joint session of all groups	***Closing plenary*** Discussion: e.g. preparatoins for meeting in Irvine and preparation of report	
17:00						
18:00	Adjourn	Adjourn	Adjourn	Adjourn	Adjourn	Adjourn
19:00			***Welcome reception***	***Workshop dinner***		

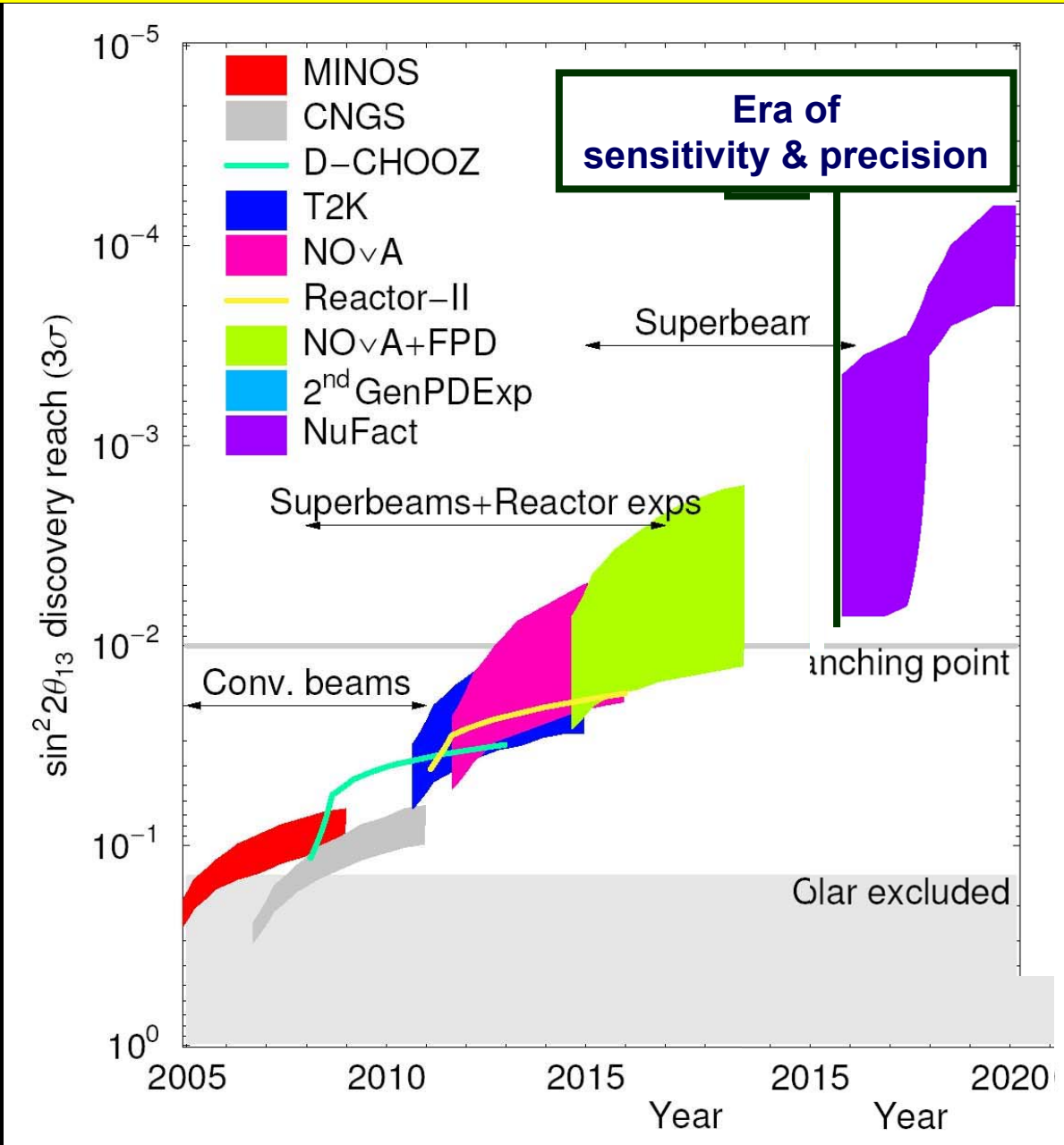
Draft report due September 2006

Beyond the ISS: timescales



Require 2nd generation facility in second half of next decade

Timescales: the challenge



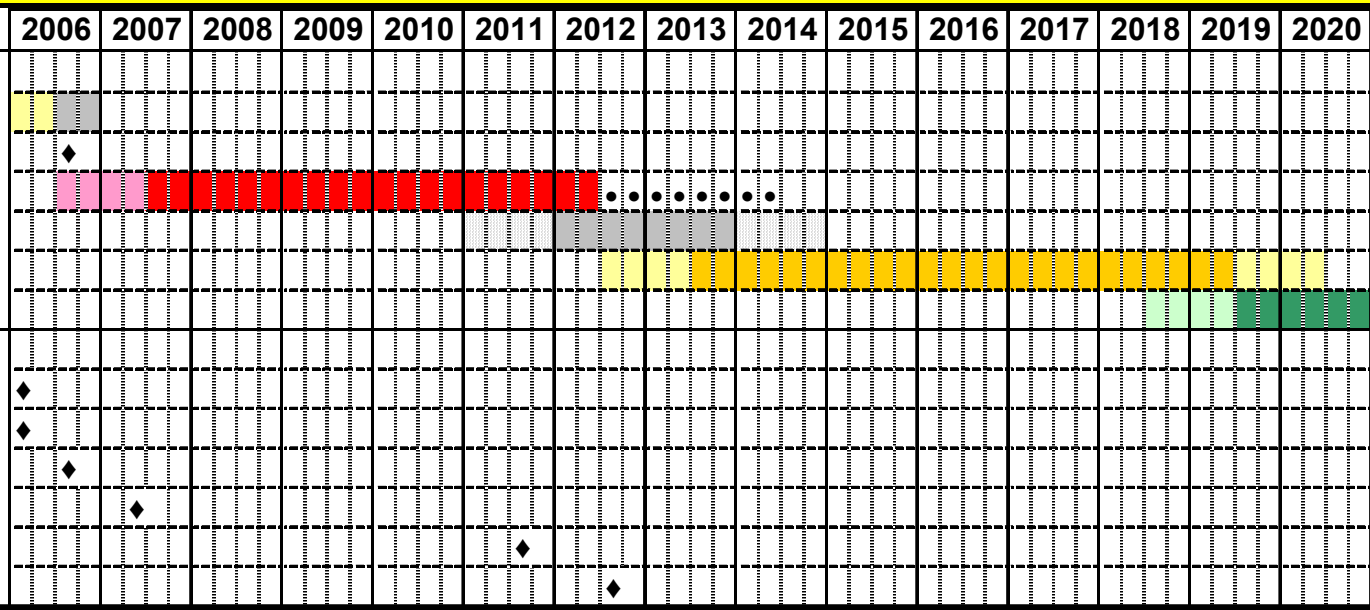
- Optimum schedule
  - Science driven
  - Potential match to funding window
- Challenge:
  - To make the case!
- International scoping study
  - Only a step on the way

NF roadmap: assumptions

- The Neutrino Factory will be required
  - Of the three classes of source
    - Super-beam #2, beta-beam, Neutrino Factory

    the Neutrino Factory gives the best performance
- The Neutrino Factory will be built
  - Physics programme of fundamental importance
  - Complementary to LHC or ILC
- The Neutrino Factory is cost effective
  - Integrated cost of incremental (staged) approach greater than Neutrino Factory
- Length of build phase 6 – 7 years
  - SNS 6-year build, J-PARC 7-year build (projected)
- 5-year international R&D and Design Study programme essential
  - Develop techniques and expertise
  - Establish optimal solution (and achieve consensus)

NF roadmap: key decision points



- Ambitious, science-driven schedule
  - Perhaps a match to funding opportunities?
- Issue now is to establish vibrant R&D programme
- Vision for International Design Study phase:
  - International collaboration; coordinated effort:
    - Concept development – full system
    - Accelerator R&D programme built on present national and international programmes
    - Detector R&D programme:
      - RD experiment programme set up to for LHC detector development a model?

Conclusions:

- International scoping study:
  - Has become established
  - Is raising, and beginning to address, key issues
  - Report will lay the foundations for the more detailed design-study phase
- International Design Study of the Neutrino Factory
  - Required to follow the ISS to:
    - Prepare reference (baseline) design by ~2011
    - Prepare first conceptual design by ~2013
- In parallel, design studies for alternative facilities *must* be carried forward:
  - To allow best possible facility to be identified
- The ISS, together with MICE, MERIT, and EMMA
  - An exciting R&D programme …
  - With a first-rate scientific goal

Imperative that the international community *delivers the full design-study programme*