Imperial College London

K. Long,
3 December, 2012

International perspective:

Contents:

- R. Heuer closing ICHEP'13
- IDS-NF and incremental approach
- Europe
- The Americas
- ASIA
- ICFA
- Conclusions

Next decades

Road beyond the Standard Model

- At the intensity frontier:

“Super” b-factories, rare decay experiments,

. . . ., and

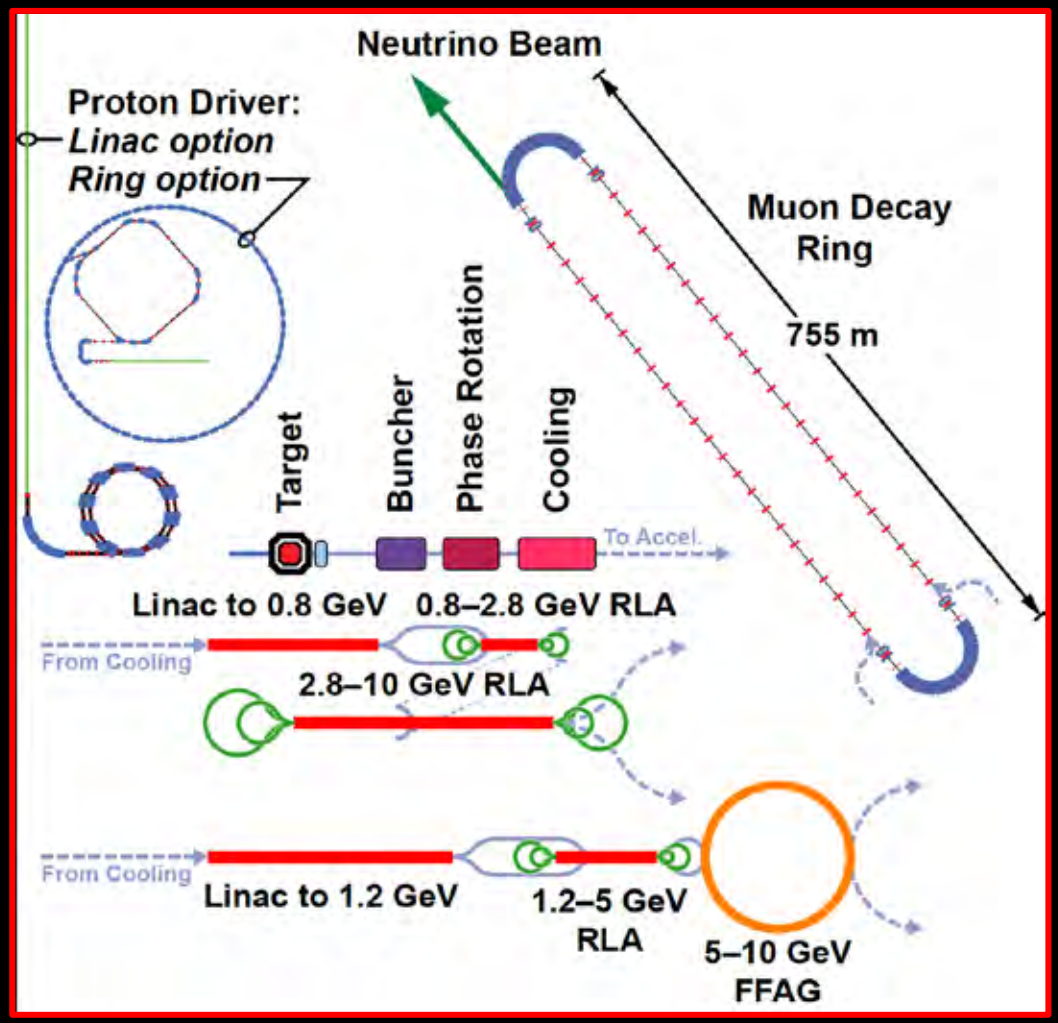
Neutrino Facilities

Options:

- Conventional super-beams:
  - Wide-band, long baseline: e.g. LBNE, LBNO
    - $\langle E_\mu \rangle$ ~ 2—3 GeV; matched to LAr or magn.Fe calorimeter;
    - Long-baseline allows observation of first and second maximum
    - Near detector exploited to reduce systematic errors
  - Narrow-band, short baseline: e.g. T2HK, SPL
    - $\langle E_\mu \rangle$ ~ 0.5 GeV; matched to H_20 Cherenkov;
    - Short-baseline allows observation of first maximum
    - Near detector exploited to reduce systematic errors
- Beta-beam, short baseline:
  - $\langle E_\mu \rangle$ ~ 0.5 GeV; matched to H_20 Cherenkov;
  - Short-baseline allows observation of first maximum
  - Requires short-baseline super-beam to deliver competitive performance

Neutrino Factory:

- Optimise discovery potential for CP and MH:
  - Requirements:
    - Large ν_e ($\bar{\nu}_e$) flux
      - Detailed study of sub-leading effects
- Unique:
    - (Large) high-energy ν_e ($\bar{\nu}_e$) flux
      - Optimise event rate at fixed *L/E*
      - Optimise MH sensitivity
      - Optimise CP sensitivity



Scenario of a staged programme:

- Large value of θ_{13}, makes it likely that the next generation long-baseline experiments will determine the neutrino mass hierarchy;
  - However, sensitivity to CP violation will be limited;
- In the first instance, a combination of long-baseline (wide-band beam) experiments (e.g. LBNE/LBNO) and short baseline experiments (e.g. T2HK) may offer an attractive way forward:
  - In such an approach:
    - CP reach is limited by systematic effects;
    - Hints of CP violation would require follow up by the Neutrino Factory.

- The Neutrino Factory seems the facility of choice;
  - Consensus (?):
    - Will be required to:
      - Complete the Standard Neutrino Model and to test whether it is a good description of nature
- But, stored muon beams have not yet been shown to be capable of serving a world-class neutrino programme:
  - Require to push through R&D and complete IDS-NF, considering an incremental implementation in parallel; and
  - Establish a first, realistic, scientifically first-rate neutrino experiment based on a stored muon beam

Next decades

Road beyond Standard Model

- At the energy frontier:

through synergy of

hadron - hadron colliders

lepton - lepton colliders

LHC results will guide the way at the energy frontier


LHC

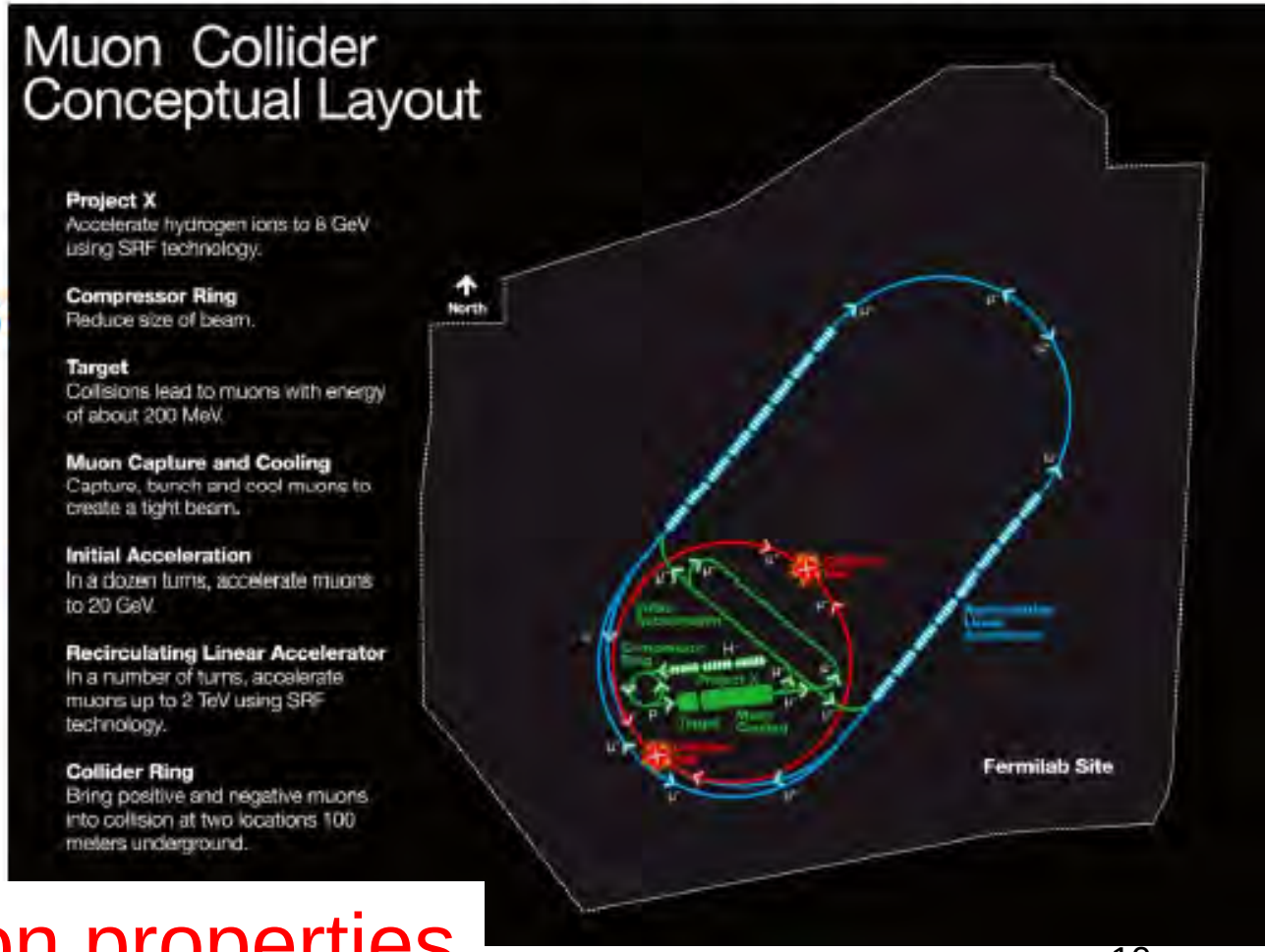

beyond LHC ?

Lepton Colliders: Muon Collider

- Compact facility accelerating muons with recirculating linacs

Major Challenges

1. Muon generation
2. Cooling of muons
3. Cost-efficient acceleration
4. Collider ring and backgrounds from decays



- Higgs Boson properties

Outreach!

Take-home messages?

- Recognition that neutrino physics:
  - Is a window on undiscovered phenomena
  - Has become a precise science;
    - And in the future will require drive to ever increasing sensitivity and precision
- Recognition that muon storage rings offer:
  - Route to exquisite sensitivity and precision at the Neutrino Factory
  - Route to multi-TeV lepton/anti-lepton collisions
- Recognition that an incremental programme could start now (nuSTORM) with:
  - Discovery potential (steriles); and
  - A first-rate cross section measurement programme

International perspective:

The IDS-NF

https://www.ids-nf.org/wiki/FrontPage/Documentation/IDR

ds-nf.org/wiki/GLA-2012-04-08

EUROnu

R. Edgecock

I. Efthymiopoulos

E. Wildner

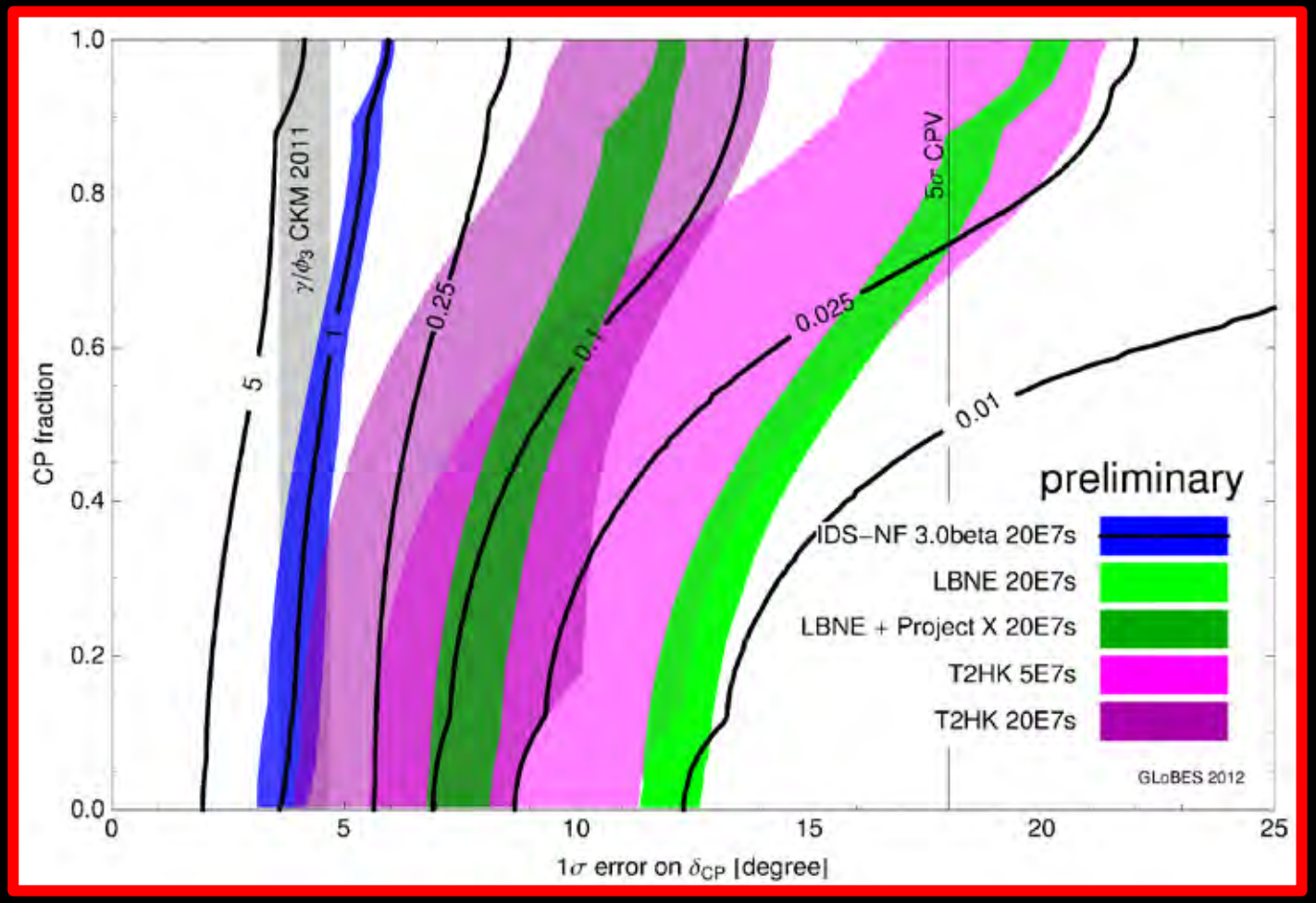
K. Long

pan

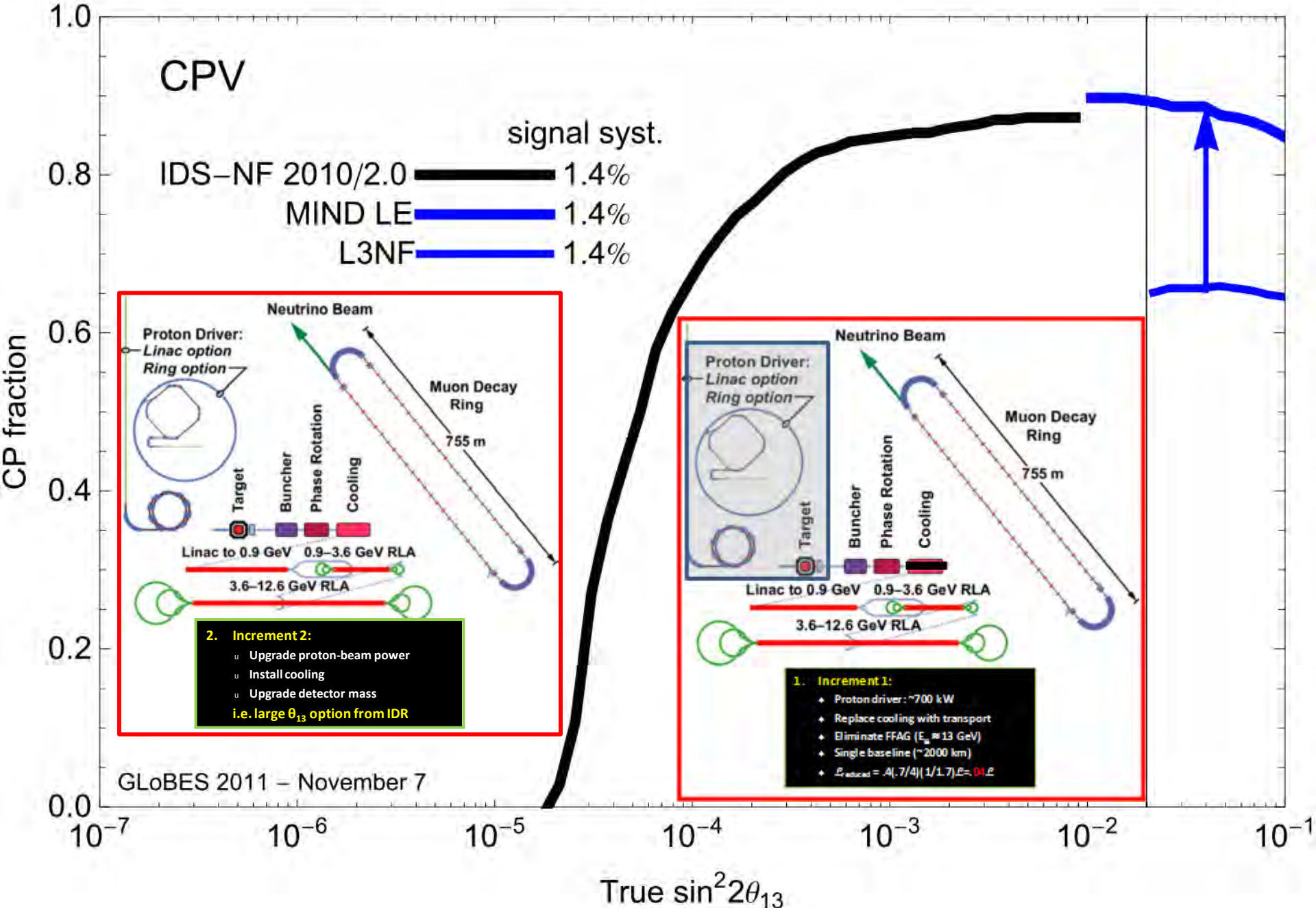
- India
- (in the future: China …)
- Europe
  - EUROnu

Huber

Comparison:

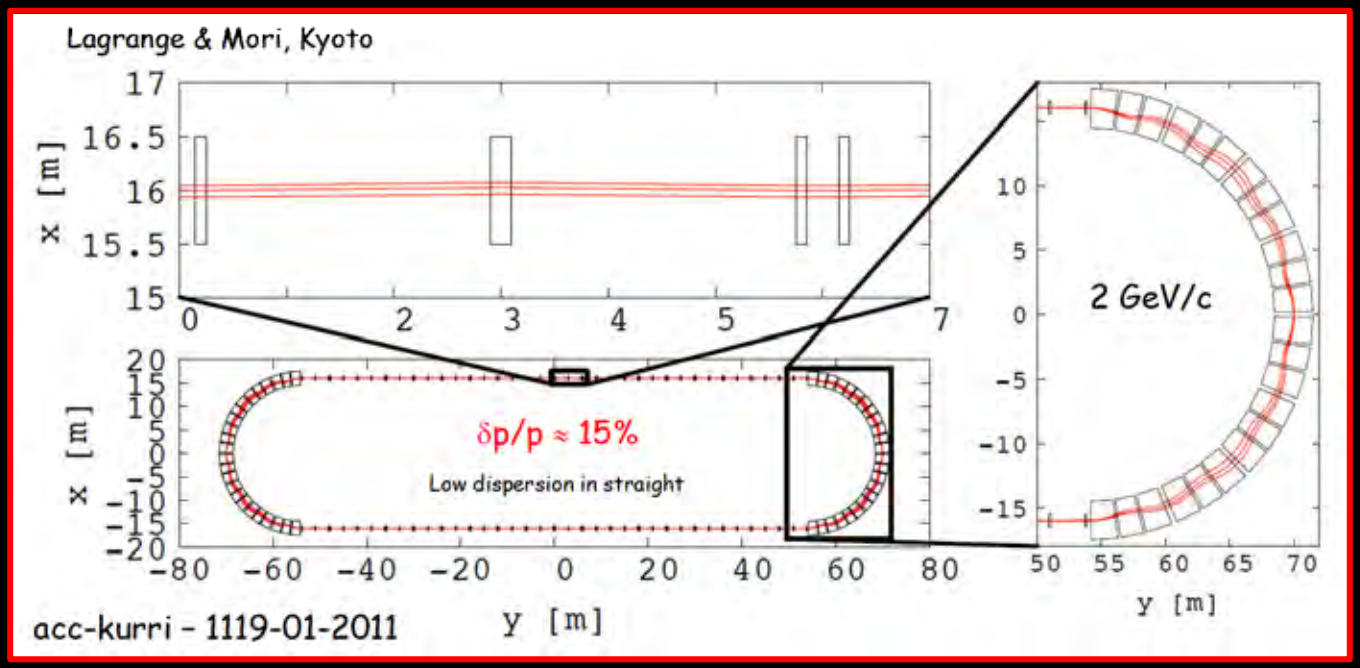


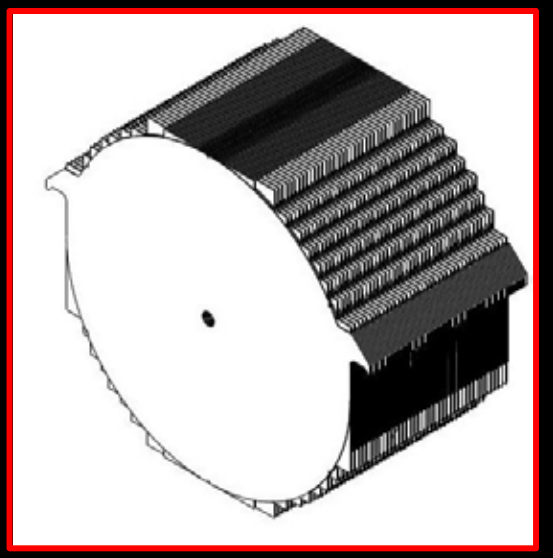
- **Benefit of luminosity:**
  - **Solid black lines show effect on precision of scaling luminosity from baseline 10^{21} decays per year**
  - **Potential for definition of staged upgrade programme**


CPV
signal syst.
IDS–NF 2010/2.0 1.4%
MIND LE 1.4%
L3NF 1.4%
CP fraction
True sin²2θ13
1.0
0.8
0.6
0.4
0.2
0.0
10⁻⁷
10⁻⁶
10⁻⁵
10⁻⁴
10⁻³
10⁻²
10⁻¹
Neutrino Beam
Proton Driver:
Linac option
Ring option
Muon Decay Ring
755 m
Target
Buncher
Phase Rotation
Cooling
Linac to 0.9 GeV
0.9–3.6 GeV RLA
3.6–12.6 GeV RLA
2. Increment 2:
Upgrade proton-beam power
Install cooling
Upgrade detector mass
i.e. large θ13 option from IDR
1. Increment 1:
Proton driver: ~700 kW
Replace cooling with transport
Eliminate FFAG (E ≈ 13 GeV)
Single baseline (~2000 km)
GLoBES 2011 – November 7

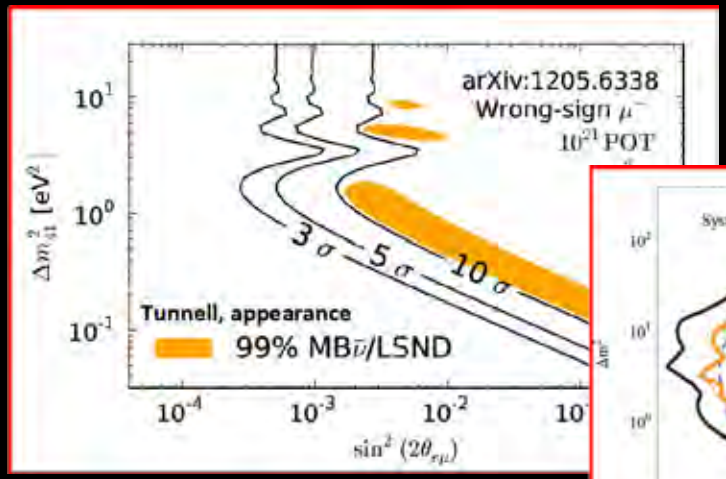
LOI [Bross et al];
Fermilab proposal P-1080 &
arXiv:1206.0294

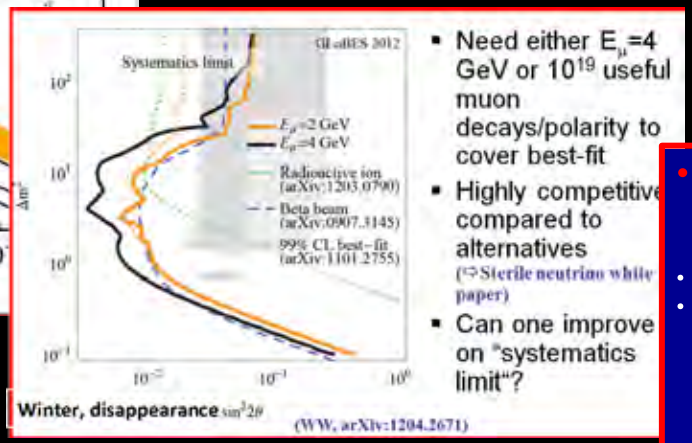
nuSTORM: conceptual design:





- Magnetized Iron
  - 1 kT fiducial volume
    - Following MINOS ND ME design
    - 1 cm Fe plate
    - 5 m diameter
  - Utilize superconducting transmission line for excitation
    - Developed 10 years ago for VLHC
  - Extruded scintillator +SiPM





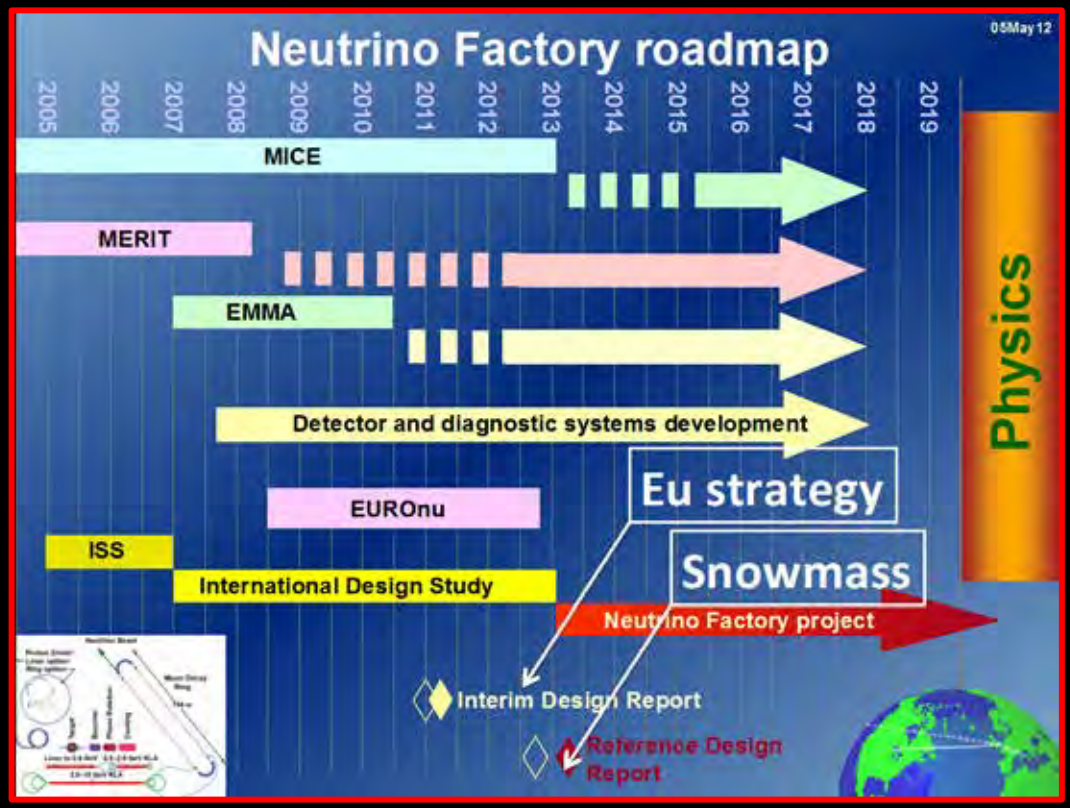
- Need either E_μ=4 GeV or 10^{19} useful muon decays/polarity to cover best-fit
- Highly competitive compared to alternatives (⇒Sterile neutrino white paper)
- Can one improve on "systematics limit"?

(WW, arXiv:1204.2671)

- **Unique opportunity to measure electron-neutrino cross sections**
- Also, measure muon-neutrino cross sections
- Full set of neutrino-scattering physics:
  - QCD
  - Structure functions & form factors
  - Electroweak
  - …

IDS-NF next steps:

- Major revision in the light of θ_{13} measurement:
  - 10 GeV and single baseline at 2000 km
- Discussion of appropriate staging scenarios important aspect of next IDS-NF plenary meeting:
  - 08—10 Oct12 at FNAL
- Then need to develop appropriate scenarios for presentation in, or alongside, the RDR
  - And at Snowmass



International perspective:

Europe

EUROPEAN STRATEGY FOR ACCELERATOR BASED NEUTRINO PHYSICS

Prepared by the program committee of the Neutrino 'town meeting', CERN, 14-16 May 2012:
Sergio Bertolucci (CERN), Alain Blondel[1] (DPNC, Geneva), Anselmo Cervera (IFIC, Valencia), Andrea Donini (IFT-UAM, Madrid), Marcos Dracos (IPNS, Strasbourg), Dominique Duchesneau (LAPP, Annecy), Fanny Dufour (DPNC, Geneva), Rob Edgecock (STFC, RAL), Ilias Efthymiopoulos (CERN), Edda Gschwendtner (CERN), Yury Kudenko (INR, Moscow), Ken Long (ICL, London), Jukka Maalampi (Jyväskylä), Mauro Mezzetto (INFN, Padova), Silvia Pascoli (IPP, Durham), Vittorio Palladino (Napoli), Ewa Rondio (Warsaw), Andre Rubbia (ETH Zurich), Carlo Rubbia (CERN), Achim Stahl (RWTH, Aachen), Luca Stanco (INFN Padova), Jenny Thomas (UCL London), David Wark (ICL & RAL), Elena Wildner (CERN), Marco Zito(CEA Saclay).

- **The coherence and quality of this program calls for the continuation of neutrino beams at CERN after the CNGS, and for a high priority support from CERN and the member states to the experiments and R&D program.**
- **The determination of the neutrino mass hierarchy and the determination of the CP phase are the next steps in long baseline neutrino experiments. These fundamental measurements require and justify dedicated long baseline accelerator-based experiments.**

The European Strategy for Particle Physics must therefore provide for European participation in the programme required for a Neutrino Factory proposal to be prepared in time for the next update of the European Strategy.

This programme must encompass:

-- The completion of the necessary hardware and system R&D including the MICE experiment;

-- The experimental demonstration that stored muons can serve a first-rate neutrino programme with the percent precision measurement of the $\nu_{e,\mu}$ N and $\overline{\nu}_{e,\mu}$ N scattering cross sections and the search for sterile neutrinos using the nuSTORM experiment ;

-- All relevant design work, including consideration of the implementation of the facility at CERN.

EUROnu i/p to European Strategy update:

In consequence, EUROnu strongly recommends the construction and operation of a 10 GeV Neutrino Factory as soon as possible, implemented using the staged approach described below.

Staged approach to a Neutrino Factory

We envisage a staged approach to delivering a 4 MW, 10 GeV Neutrino Factory, with important physics possibilities at each step. The stages are:

1) nSTORM [12]. This project will use an existing proton driver of around 300 kW beam power to create pions in a target. Forward going pions with an energy of 5 GeV (±10%) will be focussed into a transport line, before injection into a straight of a storage ring. Muons of around 3.8 GeV from the decay will then be transported around the ring and the neutrinos from their decay used for the following studies:
   - the search for sterile neutrinos,
   - the measurement of $\nu_e N$ scattering cross-sections,
   - neutrino detector development.

   In addition, this facility will be a valuable prototype for the Neutrino Factory construction. An LoI for nSTORM has recently been submitted to the FNAL PAC [12].
2) A low power version of the Neutrino Factory, using an existing proton driver, without muon cooling and using a lower mass MIND detector, around 20kt. This will already have a very competitive physics potential [13].
3) A 4 MW Neutrino Factory using 10 GeV muons and a 100 kt MIND detector at a baseline of around 2000 km.

UK i/p to European Strategy update:

4. Strategy for development of European contributions to the long-baseline oscillation programme

The European Strategy for Particle Physics must provide for European scientists and engineers to make decisive contributions to the strategic priorities of the long-baseline programme: the search for leptonic-CP-invariance violation and the determination of the mass hierarchy. Europe is well placed to make leading contributions to the field by exploiting the unique infrastructure available at CERN and developing a deep underground neutrino detector at Pyhäsalmi in Finland. Such developments offer the potential to build a powerful long-baseline programme encompassing a wide-band conventional beam and the staged implementation of the Neutrino Factory.

- Europe has established a strong, world-class, long-baseline activity that encompasses CNGS, MINOS/MINOS+, NOvA and T2K. European personnel have played seminal roles in the establishment of the international programme and individuals and groups enjoy internationally-recognised positions of leadership. The European Strategy for Particle Physics must maintain and enhance this vibrant and influential programme.
- With $\theta_{13} \sim 0.1$, the strategic priorities for the long-baseline neutrino-oscillation programme are to expedite the search for leptonic-CP-invariance violation (CPV) and the determination of the mass hierarchy. The European strategy must be optimised to allow European scientists and engineers to make decisive contributions to the priority programmes.
- European contributions to the international programme should exploit:
  - The unique infrastructure that exists at CERN and other European national laboratories;
  - The uniquely-long baseline offered by a large underground detector at Pyhäsalmi in Finland served by a neutrino beam from CERN; and
  - The warm and effective collaborations that have been established with Japan and the USA.
- The European Strategy for Particle Physics should therefore provide for:
  - The development of a proposal for a large detector at Pyhäsalmi served by a wide-band conventional neutrino beam from CERN;
  - Preparatory work, including detector and accelerator R&D, towards a long-baseline neutrino programme in Europe, which would also underpin European contributions to, and leadership in, programmes in Asia and the Americas (MINOS+, NOvA, LBNE, GLADE and T2HK); and
  - European contributions to the programme required for a Neutrino Factory proposal to be prepared in time for the next update of the European Strategy. This programme must encompass the experimental demonstration that stored muons can serve a first-rate neutrino programme; the necessary hardware and system R&D, including completion of the MICE experiment; and all relevant design work, including consideration of the implementation of the facility at CERN.

νSTORM: input to the update of the European Strategy for Particle Physics

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- Interest at CERN too, but, during the Strategy update, people feel constrained to hold their peace;
- Strategy update:
  - May allow CERN participation in projects elsewhere
- nuSTORM EOI to CERN?
  - Explain how CERN could:
    - Contribute to nuSTORM at FNAL
    - Implement nuSTORM at CERN
      - Rests on extraction at 40 GeV from SPS to North Area
        - » Will be tested in coming months for NESSIE
- Active in developing further links

Input to STFC Programmatic Review:

Professor Phillip Burrows
Chair, Particle Physics Advisory Panel
Denys Wilkinson Building
Keble Road
Oxford OX1 3RH
UK

vSTORM

September 22, 2012

UK interest in nuSTORM

Dear Phil,

We, the undersigned, are writing to draw the attention of the Particle Physics Advisory Panel to the nuSTORM project and to the UK interest in it. nuSTORM, "neutrinos from STORed Muons", is a facility that has been proposed to:

- Carry out a unique programme of ν_e and ν_μ cross-section measurements in the kinematic region of interest to present and future long-baseline neutrino oscillation experiments;
- Carry out exquisitely sensitive searches for sterile neutrinos using a technique that is qualitatively different to LSND, MiniBOONE and other operating or proposed experiments; and
- Support a programme of accelerator and detector R&D towards future long-baseline neutrino facilities, the Neutrino Factory and the Muon Collider.

A Letter of Intent[1] has recently been submitted to the Fermilab Physics Advisory Committee. The LOI was very well received[2] and the collaboration encouraged to work towards a full proposal. The total estimated cost of the facility is $126M. There will be a workshop at Fermilab later this month at which the formation of a collaboration and the tentative division of responsibilities will begin to be discussed.

It is not possible at present to explain the roles that UK institutes will seek to take and so it is not possible to indicate the likely cost to the UK. However, we believe that the UK is uniquely well placed to:

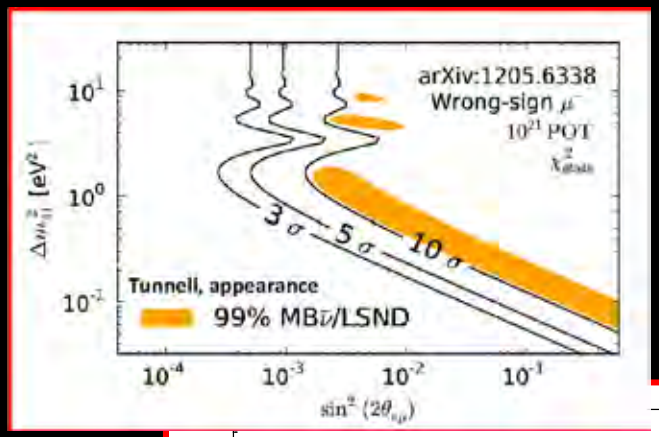
- Contribute to the development of the accelerator facility and the neutrino detectors as well as the neutrino physics and to benefit from the accelerator and detector R&D programmes that the facility will support; and
- Nurture the growth of the European and international collaborations that will be required for the facility to be realised.

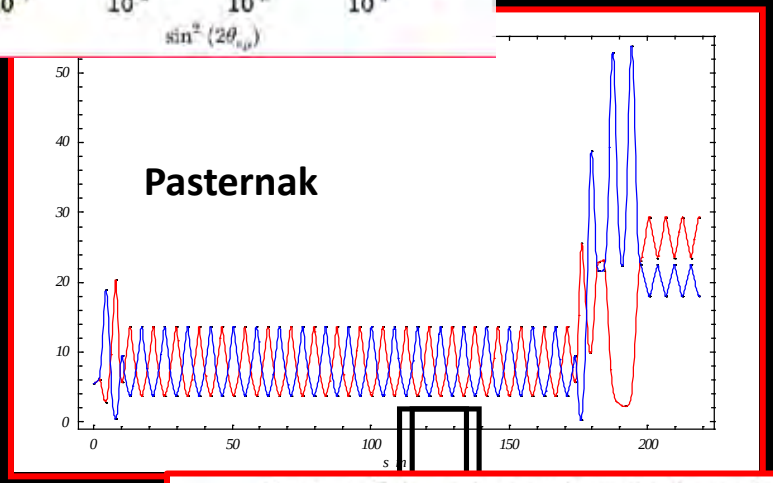
It is our intention to bring forward an SoI for UK participation in nuSTORM at the appropriate time. To allow the facility to be considered in the Programmatic Review we draw the Panel's attention to the short document that was prepared as input to the update of the European Strategy for Particle Physics (attached).

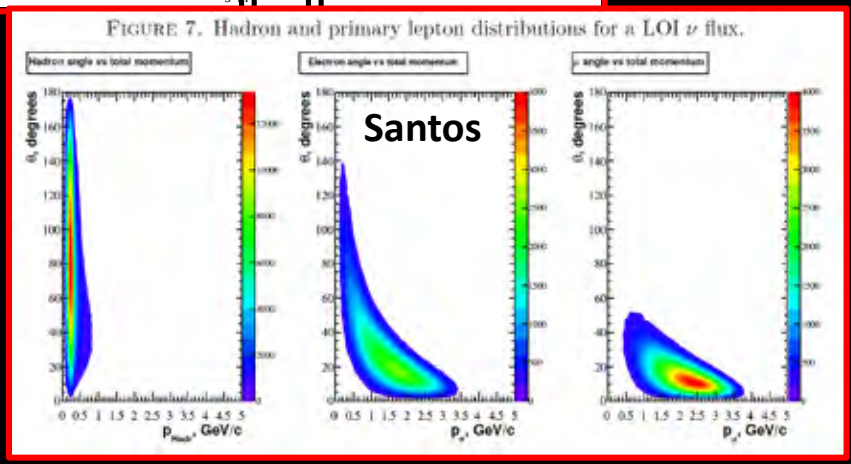
We would, of course, be very happy to provide such further information as the Panel may require.

So far:

- Sterile neutrino search [Tunnell, Cobb, …];
- FFAG ring design [Pasternak, …];
- Cross section measurement (just starting) [Santos, …]







International perspective:

The Americas

The United States of America:

- Clearly, the leading contributions from the USA …

Canada:

- Strong Canadian participation in T2K
- Recognition of benefit of cross section measurements
- Interest from York [and perhaps Toronto]
- Proposal in preparation (Bhadra, Long) to Royal Society (London) for travel resources to:
  - Inform and consult Canadian community;
  - Visit and discuss with TRIUMF

International perspective:

Asia

Asia:

- Strong interest and contributions from Japan
- Liaison with India on the near detector in the context of LBNE
- Are there other avenues for enhanced collaboration?
  - IHEP?

International perspective:

ICFA

ICFA neutrino panel:

- ICFA has mandated a neutrino panel:

> To promote international cooperation in the development of the accelerator-based neutrino-oscillation program and to promote international collaboration in the development a neutrino factory as a future intense source of neutrinos for particle physics experiments.

- Cooperation:
  - Large θ_{13} places premium on understanding and control of systematics:
    - nuSTORM is uniquely critical to this programme
- Collaboration:
  - Need to see nuSTORM as part of the incremental development of the Neutrino Factory?

International perspective:

Conclusions

Conclusions:

- The unique aspects of nuSTORM:
  - Sterile neutrino search;
  - Electron-neutrino cross section measurements;
  - Facility for R&D for muon beams for particle physics & novel neutrino detectors

  has attracted a breadth of interest
- Range of areas in which international contributions can strengthen and enhance the programme
- … so …
  - I am optimistic that a strong international collaboration can be attracted;
    - Likely that ongoing study of long and short baseline experiments will continue to strengthen the case for nuSTORM