Status of the Neutrino Factory Accelerator Design Studies

Gersende Prior (CERN)
on behalf of the
EUROnu and IDS-NF
collaborations

THE INTERNATIONAL DESIGN STUDY FOR THE NEUTRINO FACTORY

March 2011: publication of the Interim Design Report (IDR), documenting in details the Neutrino Factory Design Study:

International Design Study for the
Neutrino Factory

IDS-NF-020

Interim Design Report

The IDS-NF collaboration

March 26, 2011

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Switzerland	CERN, University of Geneva
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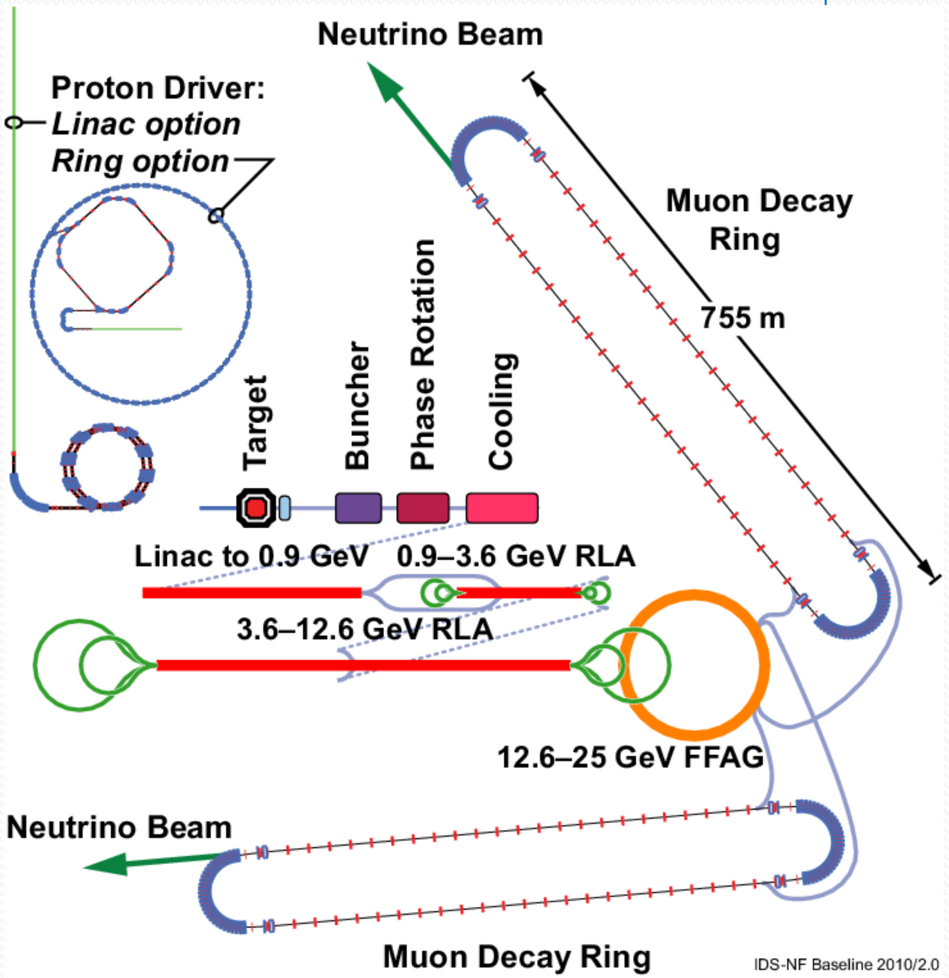
USA	Brookhaven National Laboratory, Fermi National Laboratory, Jefferson Laboratory, Laurence Berkeley National Laboratory, University of Mississippi, Michigan State University, Muons Inc., Northwestern University, Oak Ridge National Laboratory, Princeton University, University of California at Riverside, Stony Brook University, University of South Carolina, Virginia Polytechnique Institute, University of California at Los Angeles

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

Plan

- The Neutrino Factory: wish-list and constraints
- Proton driver & annexes
  - CERN SPL-based scenario
  - Fermilab (upgrade to Project X) scheme
  - RAL (upgrade to ISIS) scenario
- Target system
  - Hg-jet target developments
  - alternative/mitigation options
- Front-end system
  - Front end status
  - alternative/mitigation cooling options
- Muon acceleration
  - linac and RLA's
  - FFAG ring
  - decay rings
- From the IDR to the RDR



NF Wish-list & Constraints

- We want a machine capable of:
  - performing precision measurement of the last unknown mixing angle θ_{13}.
  - search for CP-invariance violation in neutrino oscillations.
  - determine the sign of Δm^2_{31}.
  - measure all the oscillation parameters with an unprecedented precision.

- It requires an intense (4 MW, 10^{21} υ/year), high-energy (> 20 GeV) neutrino and anti-neutrino beams. Therefore putting the following constraints on the target & accelerator systems:
  - the target should be able to withstand beam-induced shocks.
  - the muon beam should be bunched (allow both muon signs transport in different RF buckets), rotated (reducing the energy spread) and cooled (reduction of the beam emittance) over a small distance.
  - a rapid muon acceleration system able to transport the muons beam to two decay rings with minimum beam losses.

- The feasibility study will determine:
  - if we can overcome its technical challenges.
  - the cost driving factors & risk mitigation solutions.

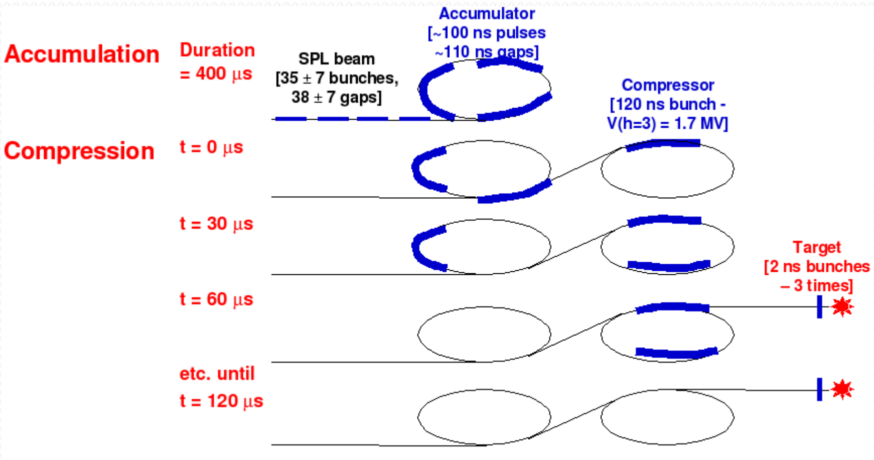
The neutrino factory feasibility study is on the road toward muon colliders.

V. Shiltsev "Toward a Muon Collider" (Friday – Plenary)

Proton driver & annexes status (1/3)

- CERN SPL-based proton driver:
  - H^- linac.
  - bunch frequency 352.2 MHz.
  - repetition rate 50 Hz.
  - high-speed chopper < 2ns (including rise & fall times).

- Option 1:
  - 2.25 MW (2.5 GeV) or 4.5 MW (5 GeV).
  - 1.1 x 10^{14} protons/pulse.
  - average pulse current 20 mA.
  - pulse duration 0.9 ms.



- Option 2:
  - 5 MW (2.5 GeV) and 4 MW (5 GeV).
  - 2 x 10^{14} protons/pulse (2.5 GeV) and 1 x 10^{14} protons/pulse (5 GeV).
  - average pulse current 40 mA.
  - pulse duration 1 ms (2.5 GeV) and 0.4 ms (5 GeV).

- Progress:
  - beam instabilities studies in the accumulator investigated for 3 bunches.
  - accumulator & compressor rings MADX lattice available for 3 bunches case.
  - starting to list accumulator & compressor rings elements for the costing.

R. Garoby "Proton drivers for Neutrino Beams…" (Friday – plenary)

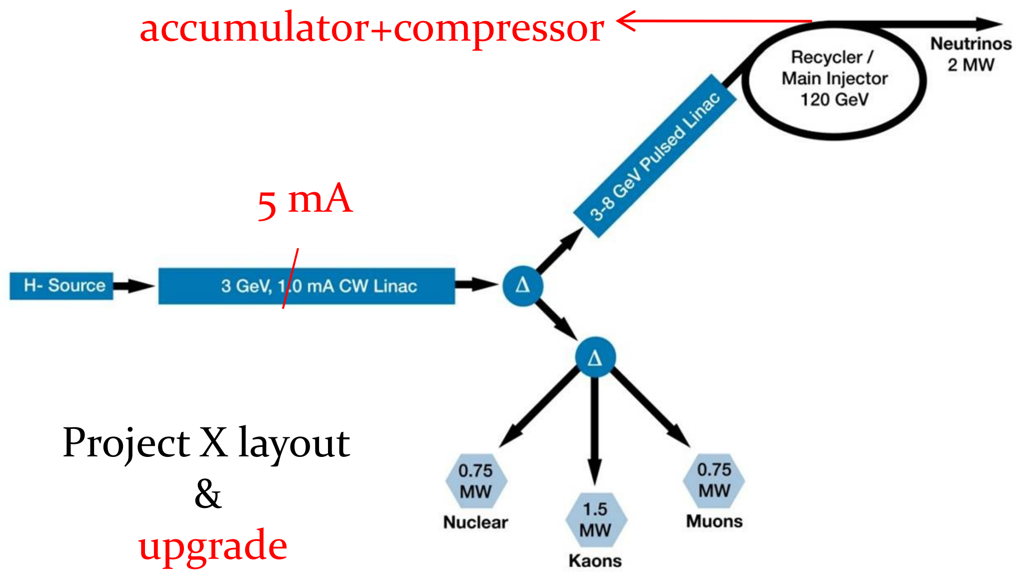
Proton driver & annexes status (2/3)

- Fermilab Project X-upgrade-based proton driver, 4 MW at 8 GeV:
  - increase the CW linac average current to 5 mA.
  - need to increase pulsed linac duty factor to ~10% (Project X is ~5%).
  - need to increase number of particles per linac bunch.
  - add an accumulator ring.
  - add a compressor ring.

- Accumulator:
  - ~250 m circumference.
  - 14 bunches ~100 ns long.
  - 1.3 x 10^{13} protons/bunch.
  - stripping with foil or laser.

- Compressor:
  - at entrance ~50 ns bunches.
  - debunch in ~ few ns bunches.

- Challenges & tasks:
  - stripping foil survival or laser technique demonstration.
  - instabilities/space charge studies.
  - beam size and angle at target optimization.



Project X layout & upgrade

Proton driver & annexes status (3/3)

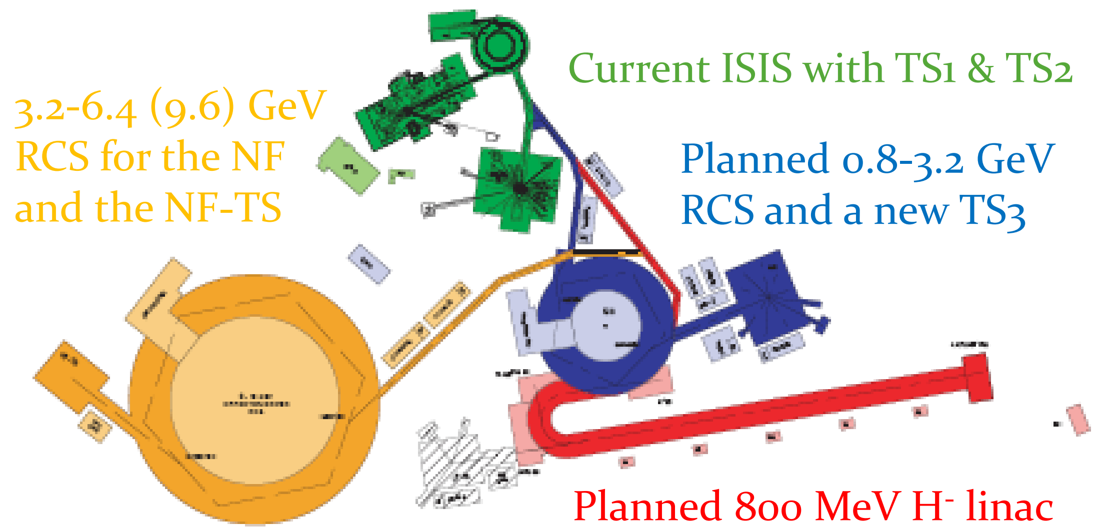
- Upgrade of the Rutherford Appleton Lab (RAL), ISIS (neutron spallation source) to provide beam powers of 2-5 MW in the few GeV energy range.

- Could be shared between a short pulse-spallation neutron source and the Neutrino Factory.

- Would require an additional RCS or FFAG booster in order to:
  - bring the proton beam to the necessary energy
  - perform appropriate bunch compression

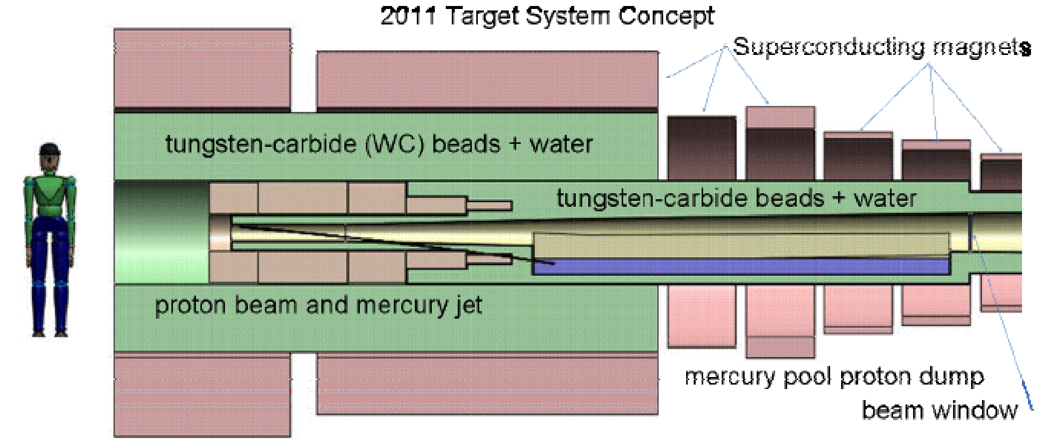
- Current studies:
  - lattice and high-intensity studies for a ~3.3 GeV booster synchrotron and beam lines
  - 800 MeV high-intensity linac design
  - RCS and FFAG lattice studies for a main ring accelerator

- R&D needs:
  - high-power front-end (FETS)
  - RF systems
  - stripping foils
  - diagnostics
  - kickers



Target systems (1/2)

- Hg-jet target scheme:
  - muon capture in 20 T solenoid followed by an adiabatic taper to 1.5 T.
- Previous design (IDR):
  - simulations (MARS15 & FLUKA) results showing high levels of energy deposition in the magnets (~2.4 MW need to be dissipated in the shielding).
  - both the Hg-jet and proton beam disrupt the Hg pool (need splash mitigation).
- Redesign:
  - better shielding of the SC magnets from radiation
  - splash mitigation being handled.
  - mechanical support under improvement.
- R&D:
  - MERIT (2007) validated 4 MW proton beam operation in Hg.

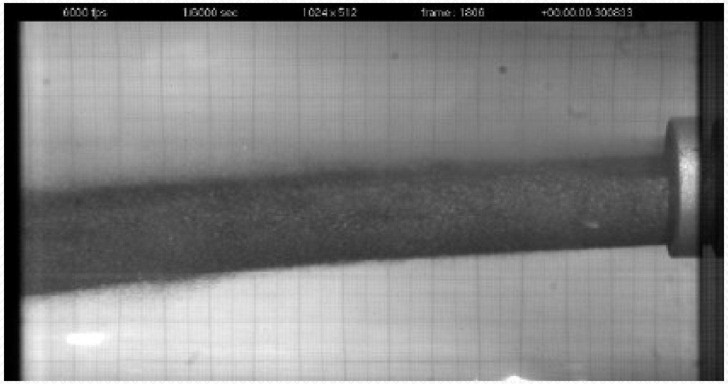


- Target tasks:
  - define target station infrastructure, including outer shielding, remote handling, Hg cooling loop, beam windows and beam dump.

K. McDonald "Simulation of Dynamic Interaction of…" (Wednesday – Parallel)
K. McDonald "Multi-MW target and capture design for NF" (Thursday- Plenary)

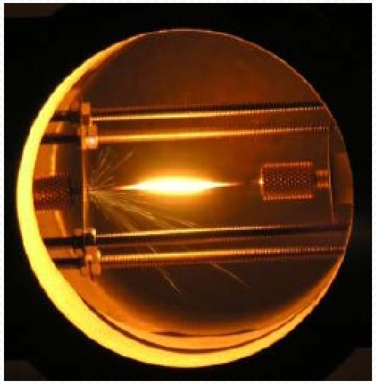
Target systems (2/2)

- Alternative target systems under consideration:
  - a metal-powder-jet
  - a system of solid tungsten bars that are exchanged between beam pulses



- Metal-powder-jet:
  - test rig at RAL with 100 kg W powder (grain size < 250 µm) ~20 min continuous operation.
  - coherent free flow jet P ~ 2 bars.
  - validation of results with simulations.

- Solid target:
  - shock study using high-currents in thin W (Ta) wires.
  - results in agreement with LS-DYNA simulations.
  - preliminary target change system engineering underway.



- Future R&D:
  - flow improvement with mitigation of flux breakdown or phase separation for the powder target.
  - irradiation study for tungsten powder and tungsten pebble bed at the CERN HiRadMat facility.

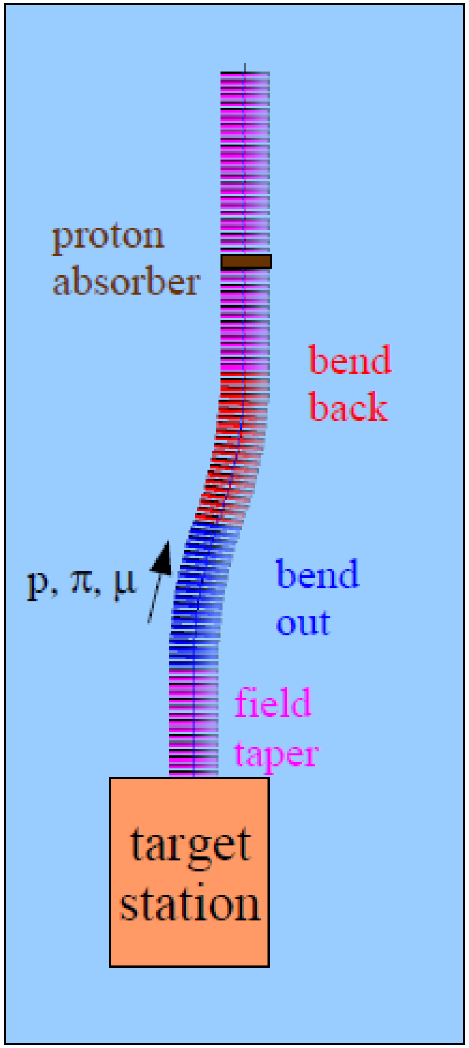
C. Densham "Target options for NF" (Wednesday – Parallel)

Front-end status

- Revised (IDR) lattice optimization - need to get rid early of unwanted particles:
  - proton absorber for low-momentum protons.
  - chicane for high-momentum particles.
  - transverse collimation.

- Started to take the reference lattice parameters for:
  - engineering study
  - costing exercise

- Remaining tasks:
  - determine realistic operational RF gradient limits (R&D @MTA).
  - assess and mitigate energy deposition from particle losses.
  - optimize lattice matching sections.
  - develop engineering design for magnets, RF and absorbers.



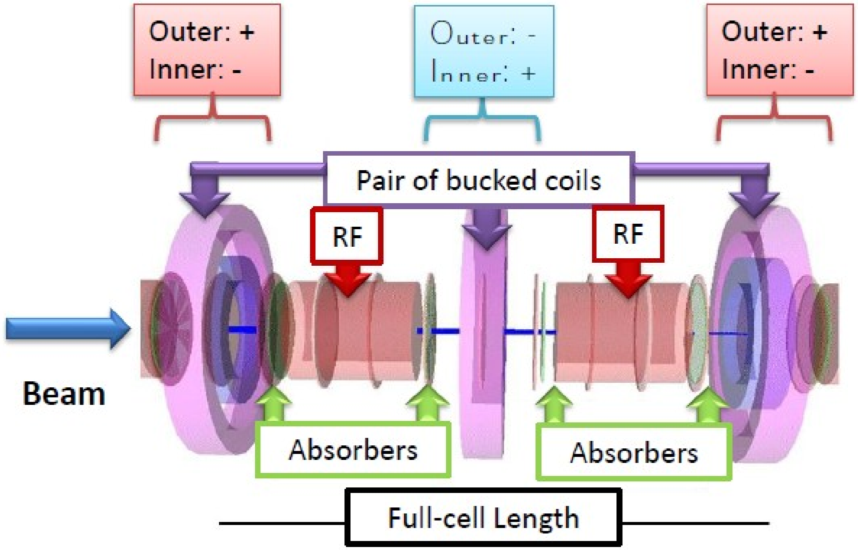
K. Yonehara "Commissioning and status of the MTA…" (Wednesday – Parallel)
D. Neuffer "Neutrino Factory Front-end…" (Thursday – Parallel)

Alternative cooling lattices (1/3)

- The RF cavities sit in high (9-16 MV/m) magnetic field increasing the risk of breakdown as suggested by experiments performed at the Muon Test Area (MTA) at Fermilab.

- Three alternative scenarios are under study as alternative to the breakdown problem.
  - bucked coil lattice
  - magnetically insulated lattice
  - HPRF lattice

- bucked coil lattice:
  - reduced magnetic field in the RF.
  - 1.80 m or 2.10 m long cell.
  - different current configurations.
  - 2 cooling cells simulation in G4MICE.
  - tested with both reduced (1000 muons) and full statistics.



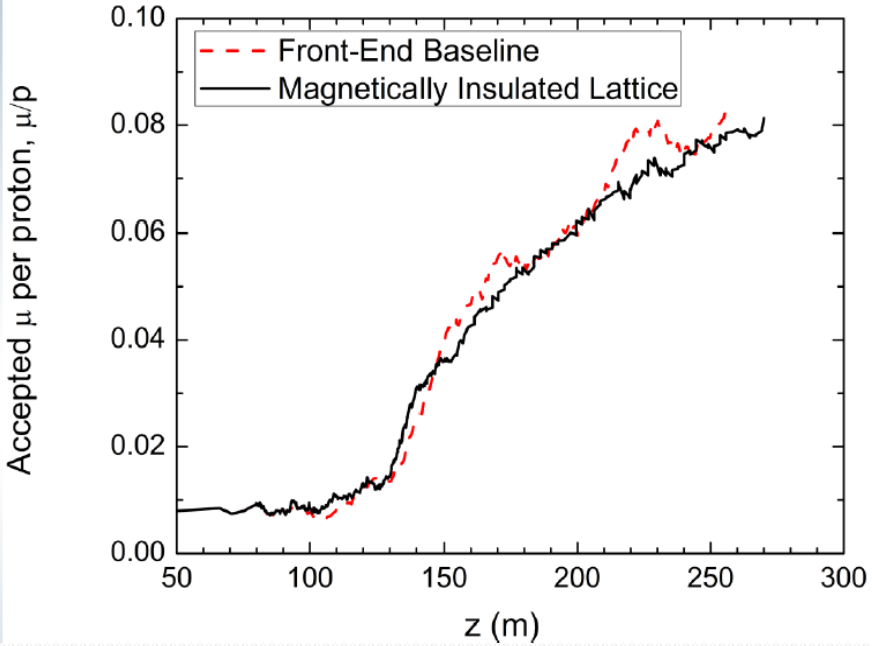
-> good transmission in comparison with the ISS lattice.

A. Alekou " Performance comparison between FS2A..." (Wednesday – Parallel)

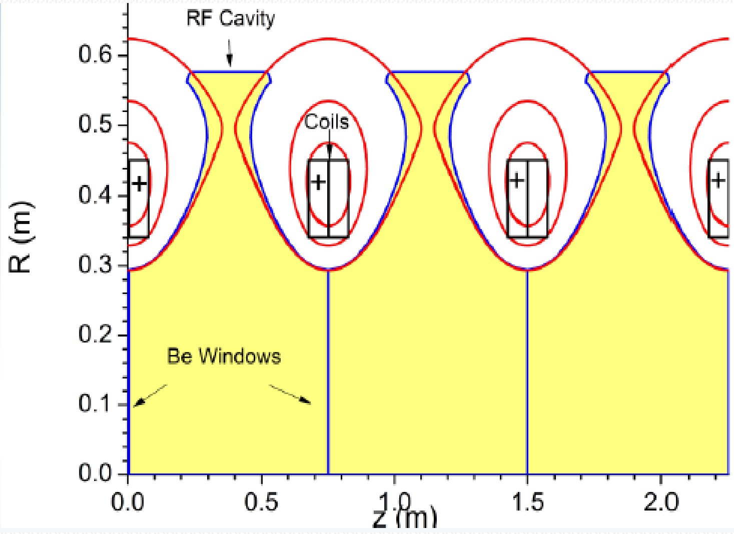
Alternative cooling lattices (2/3)

- Magnetically insulated lattice:
  - E ⊥ B field in cavity
  - similar performance to the ISS lattice
  - tested E to B angle at the MTA.

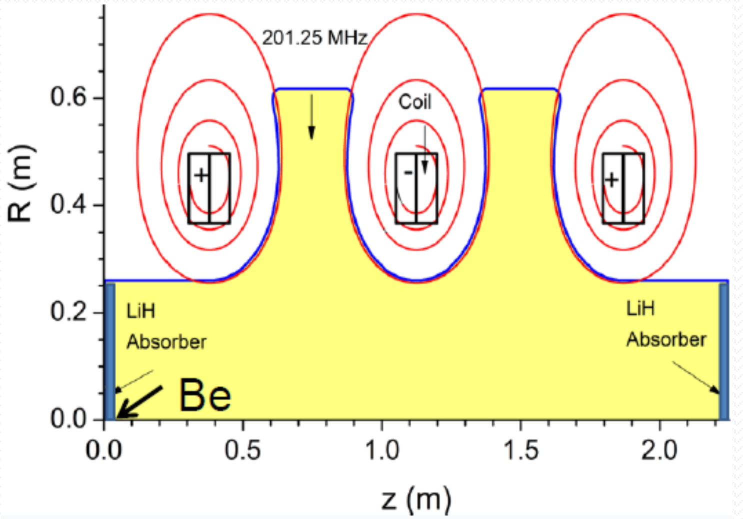
-> tolerance to coil misalignement <2 mm.
-> multipactoring & power consumption issues to address.



D. Stratakis et al., PRSTAB 14, 011001 (2011)



Buncher/Rotator cell

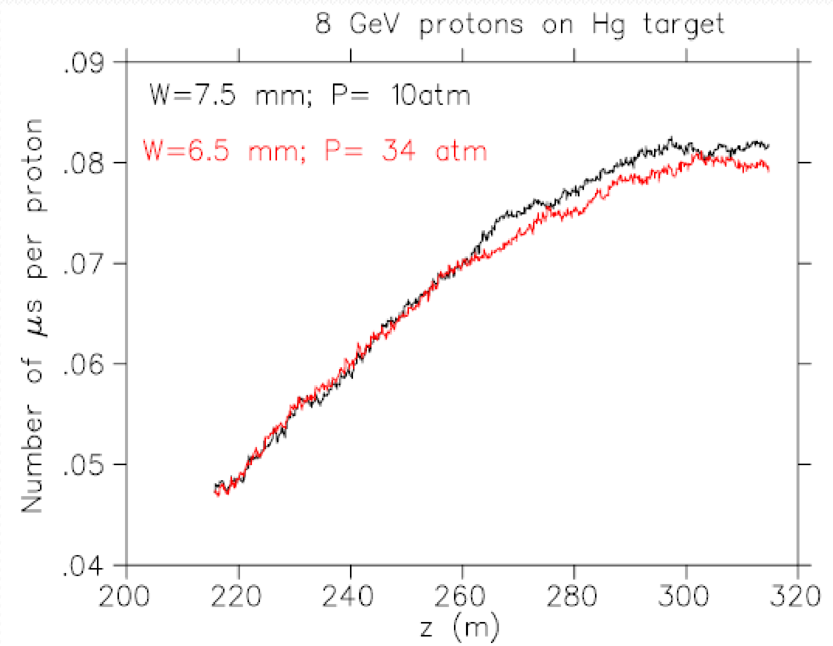


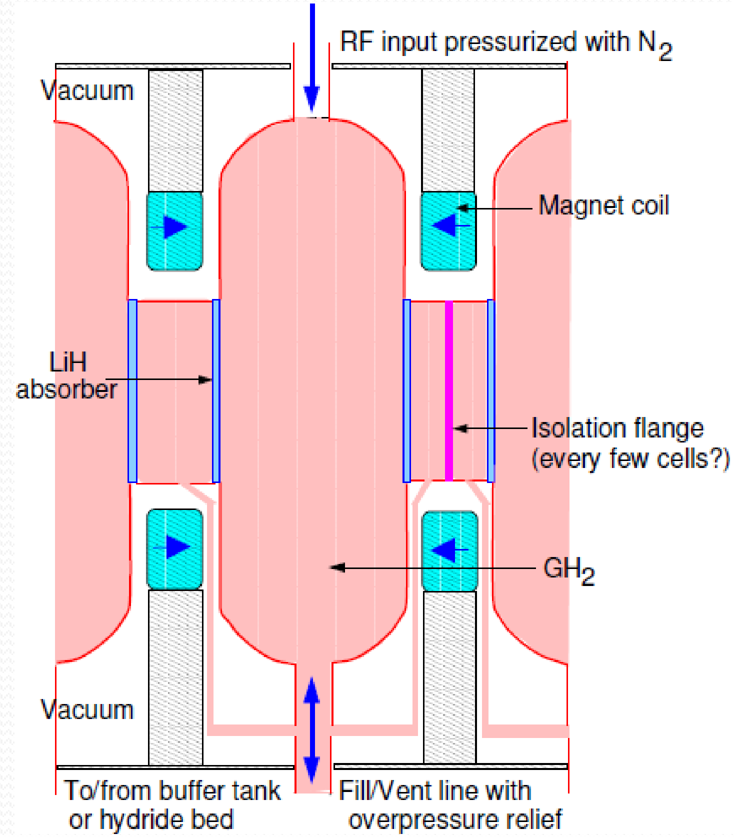
Cooling cell

Alternative cooling lattice (3/3)

- HPRF lattice (M. Zisman/J. Gallardo):
  - cavity filled with high-pressure H_2 gas
  - use LiH absorbers for muon cooling
  - study of windows material
  - study of pressure and windows thickness

-> tests with a gas-filled cavity were done at the MTA.



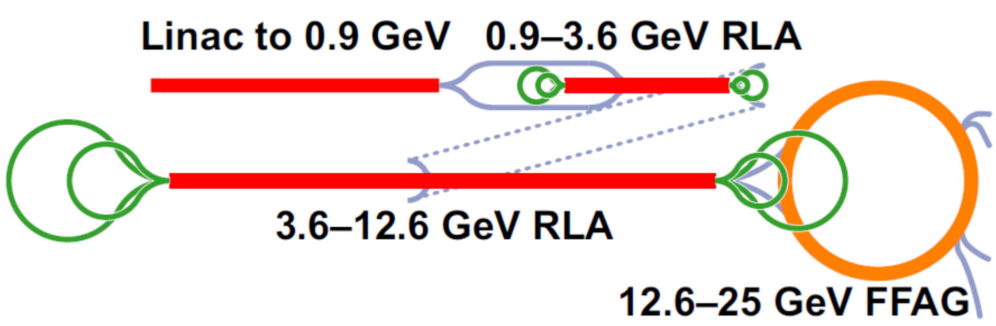


M. Zisman "Accelerator for Future Neutrino…" (Monday – Plenary)

Acceleration system: linac and RLAs

- Acceleration system:
  - need to start by a linac for low-energies (below 0.9 GeV).
  - followed by two RLAs allowing multiple passes (to 12.6 GeV).
  - final acceleration to 25 GeV in FFAG.

- Linac:
  - short (3 m, 3.8 MV/m), medium (5 m, 5.1 MV/m) and long (8 m, 6.4 Mv/m) cells made of SC RF and solenoids.
  - focusing with solenoids (better for low-energy, large emittance beams).
  - increase acceleration rate by moving toward crest.



- RLAs:
  - dogbone shape provide greater separation at switchyard (over racetrack).
  - made of SC RF and quadrupoles.
  - inject into linac center.
  - 4.5 passes per linac.

- Linac & RLAs task:
  - validation of the switchyard design.
  - complete lattice design (matching sections, injection, overall layout).
  - track through all subsystems with realistic errors.
  - complete the engineering design for all the components (magnets, RF…).

K. Beard " Linac & RLA design status and simulations" (Thursday – Parallel)

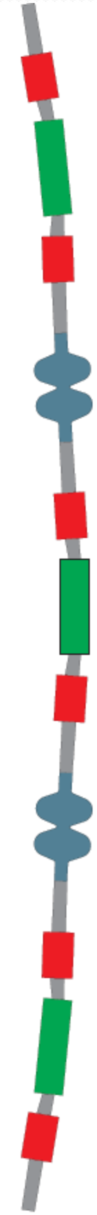
Acceleration systems: FFAG

- Linear non-scaling FFAG:
  - single arc with large energy acceptance.
  - consists entirely of identical FDF triplets.
  - almost all drifts contain SC cavities or injection/extraction hardware.

- Injection/Extraction:
  - kickers shared for both muons signs.
  - inject from inside/extract to outside.
  - slightly bigger magnet apertures in injection/extraction regions.

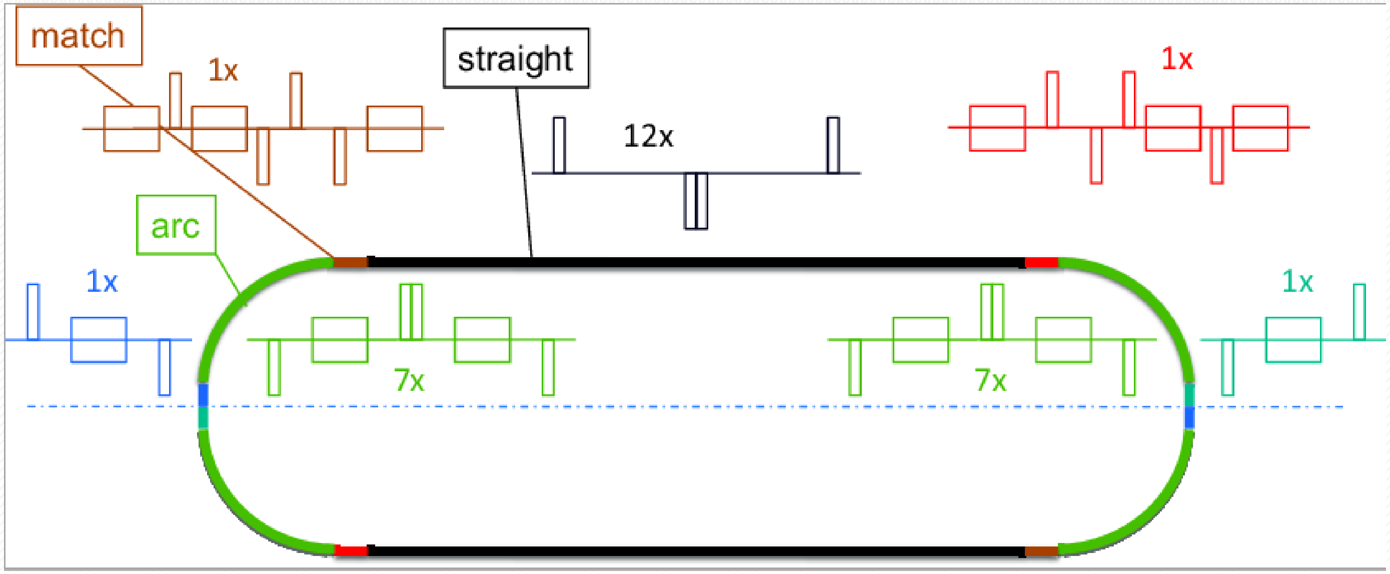
- FFAG tasks:
  - finalize the chromatic correction scheme.
  - determine optimal longitudinal phase space matching.
  - design matching to upstream and downstream systems.
  - complete 6D tracking with errors.
  - design main components (magnets, RF, injection/extraction).
  - make cost comparison with equivalent RLA solution.

J. Pasternak "Recent development on the…" (Thursday – Parallel)



Decay rings (1/2)

- Design criteria:
  - two (one per detector) racetrack shaped rings.
  - 3 x train of ~50 bunches, 25 GeV.
  - muons decay in straight which is a large fraction of the circumference.
  - store both muon signs simultaneously.
  - beam divergence from the lattice at most 0.1/γ.
  - 1609 m circumference, 599 m straights.
  - tilt angles of 36° (7500 km detector) and 18° (4000 km detector).
  - depths of 440 m and 240 m respectively.
  - β is 150 m in the straights and 13 m in the arcs.



Decay rings (2/2)

- Beam diagnostics:
  - polarimeter to measure decay electrons
    - use g-2 muon spin precession
    - high-precision beam energy measurement
    - gives also the energy spread
  - divergence measurement with in-beam devices
    - cherenkov with He gas
    - optical transition radiation (OTR) device

-> challenging to get to the desired precision level (natural $1/\gamma$ is 4 mrad).

- Decay rings task:
  - design the injection system.
  - assess needs for chromatic corrections and beam abort scheme.
  - design study of diagnostics and specifications (polarimeter, OTR…).
  - consider whether beam abort is necessary.
  - design means to measure neutrino flux spectrum at far detectors.

A. Blondel "Neutrino flux monitoring in the NF" (Tuesday – Parallel)

From the IDR to the RDR

- Review of the Neutrino Factory design study:
  - The European Committee for Future Accelerators (ECFA) Review Panel was mandated to review the EUROnu Mid-term Report and the IDS-NF Interim Design Report (IDR).
  - Review meeting at STFC, Daresbury May 5-6, 2011.

  - Review will be presented in a written report (available soon), a report summary that will be given to the CERN council, and was presented at the ECFA-EPS joint session (Grenoble, 23 July 2011).

- Steps toward the Reference Design Report (RDR):
  - develop a complete and technically feasible design having the required performance.
  - carry out the end to end tracking of the entire facility to validate performance estimate.
  - perform a cost estimate for the whole facility.

Goal is to publish the RDR by the end of 2012/13.

~514 days left until December 31, 2012.

A big THANKS for the help providing material for this presentation to my EUROnu & IDS-NF colleagues:

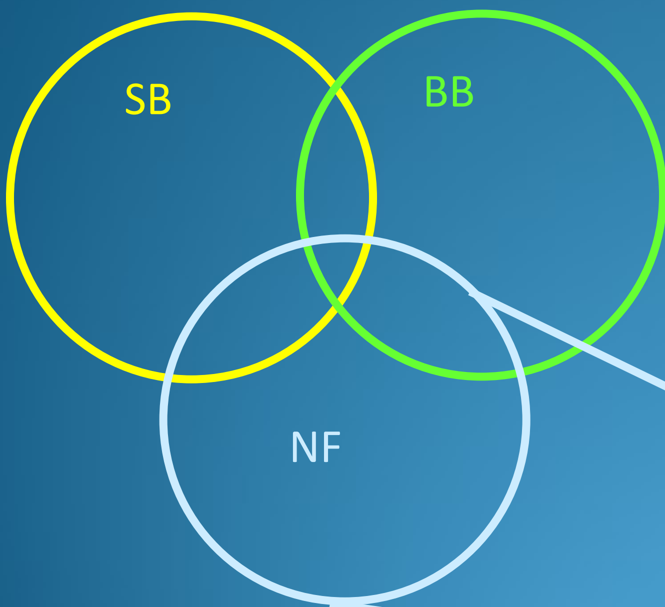
A. Alekou, C. Ankenbrandt, J. Back, S. Berg,
N. Charitonidis, R. Garoby, K. Gollwitzer, K. Long,
K. McDonald, D. Neuffer, J. Pasternak, C. Rogers,
D. Stratakis, J. Thomason, M. Zisman

…

BACKUP SLIDES

IDS-NF and EUROnu structures:

EUROnu



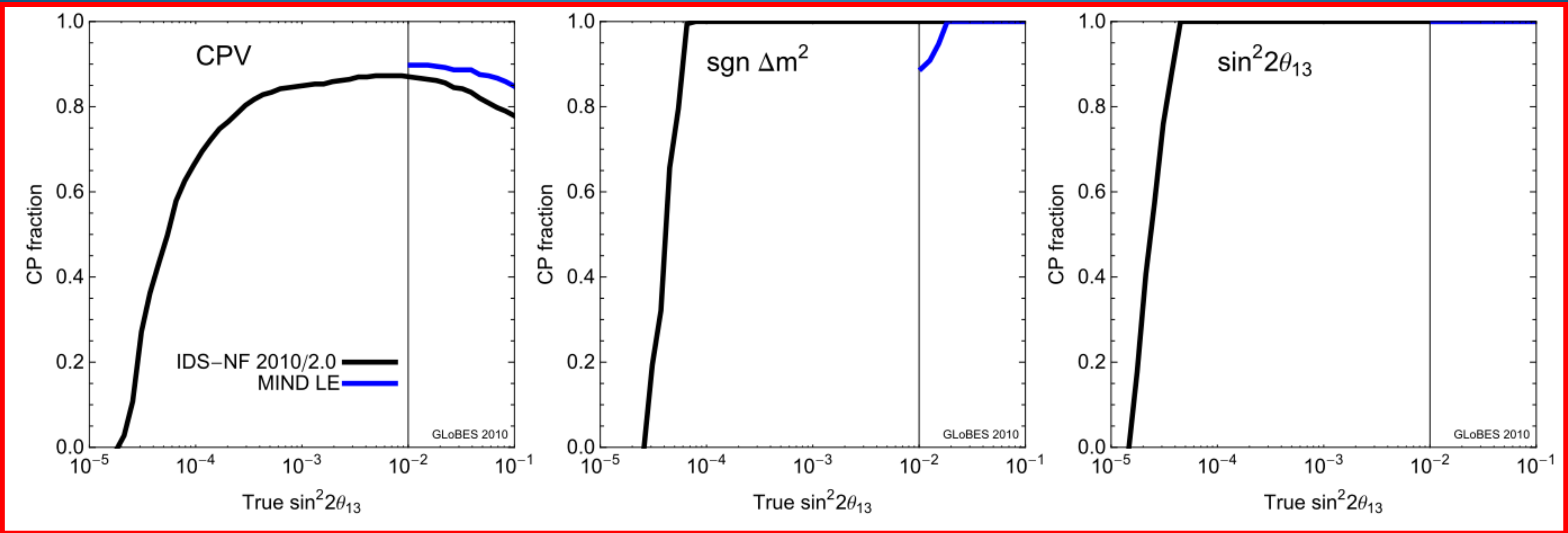
IDS-NF

- **The Americas**
  - **Canada**
  - **USA**
- **Asia**
  - **Japan**
  - **India**
  - **(in the future: China …)**
- **Europe**
  - **EUROnu**

Neutrino factory physics potential:

Channel multiplicity:

Stored $\mu^- \to e^- \nu_\mu \bar{\nu}_e$	
Disappearance	**Appearance**
$\bar{\nu}_e \to \bar{\nu}_e \to e^+$	$\bar{\nu}_e \to \bar{\nu}_\mu \to \mu^+$ $\bar{\nu}_e \to \bar{\nu}_\tau \to \tau^+$
$\nu_\mu \to \nu_\mu \to \mu^-$	$\nu_\mu \to \nu_e \to e^-$ $\nu_\mu \to \nu_\tau \to \tau^-$



Discovery potential at 3σ for CP violation (left), mass hierarchy (middle) and $\sin^2\theta_{13}$(right).