Muon Acceleration for Neutrino Physics

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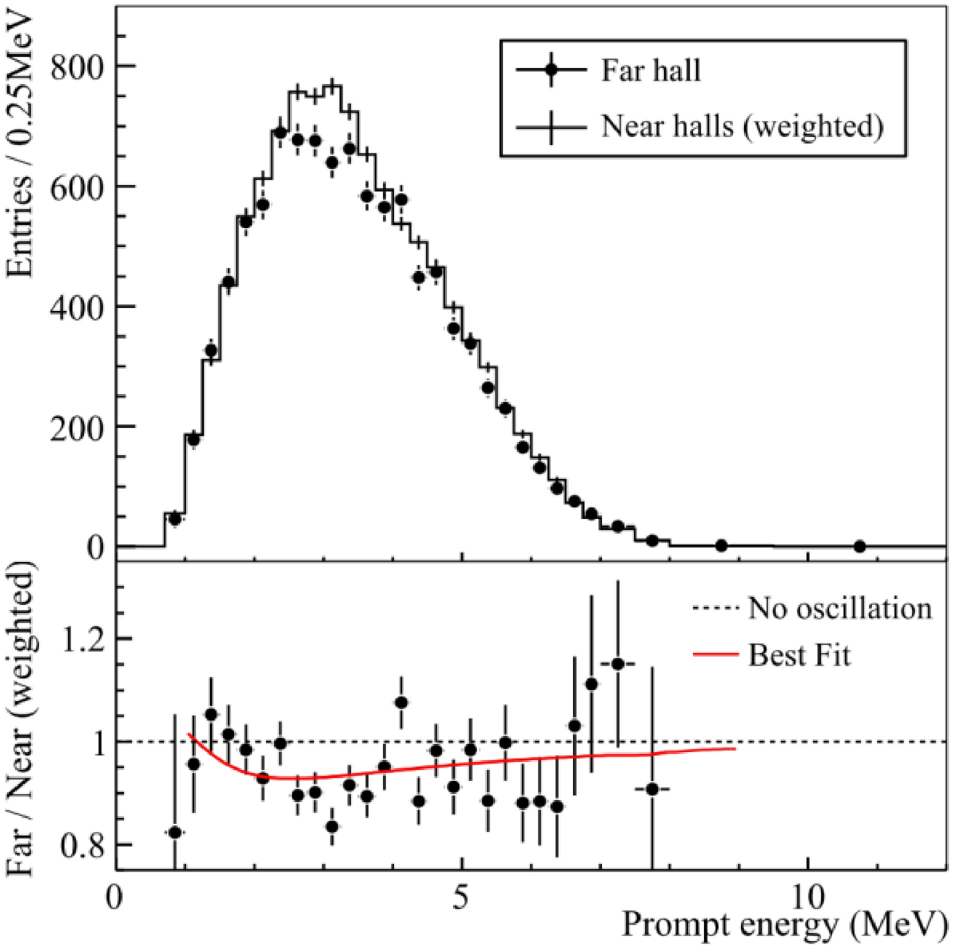
Outline

- Accelerator driven neutrino physics program
  - Neutrino Factory
    - CP violation search
    - UK has world leadership
  - NuStorm
    - Sterile neutrino and cross section measurement
    - Opportunity for major UK involvement
  - Strong collaboration with US and Europe
  - Synergy with
    - Muon Collider
    - COMET/PRISM and Mu2e
    - g-2
    - SuperBeam (LBNO, LBNE)
    - Project-X

Discovery of the Large θ_{13}



Daya Bay oscillation result, from arXiv: 1203.1669v2 [hep-ex] 2 April 2012

PMTs in the Daya Bay detector, (from Nature News)

	$\sin^2 2\theta_{13}$		
	Value	**Statistical**	**Systematic**
D-Chooz	0.086	0.041	0.030
Daya Bay	0.092	0.016	0.005
RENO	0.113	0.013	0.019
Mean	***0.098***	***0.013***	

Neutrino Factory Facility

Neutrino Factory:

• Facility for ultimate precision neutrino oscillation physics based on accelerated and stored muons.

• May serve as a front end for Muon Collider.

• Requires multi-MW proton Source.

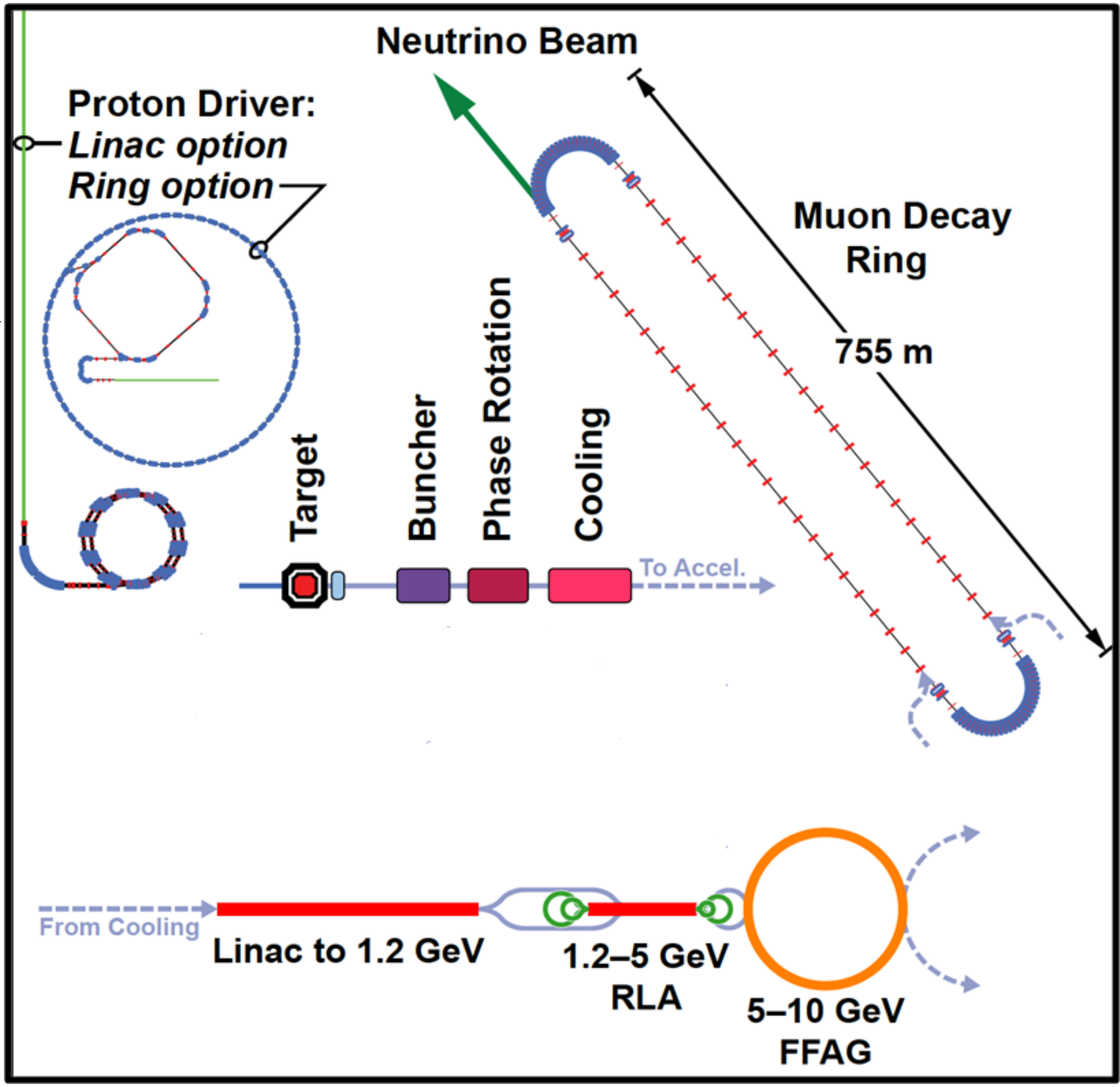
• Can be built in stages.

Current Neutrino Factory baseline scenario for the large θ_{13}:

-2000 km,

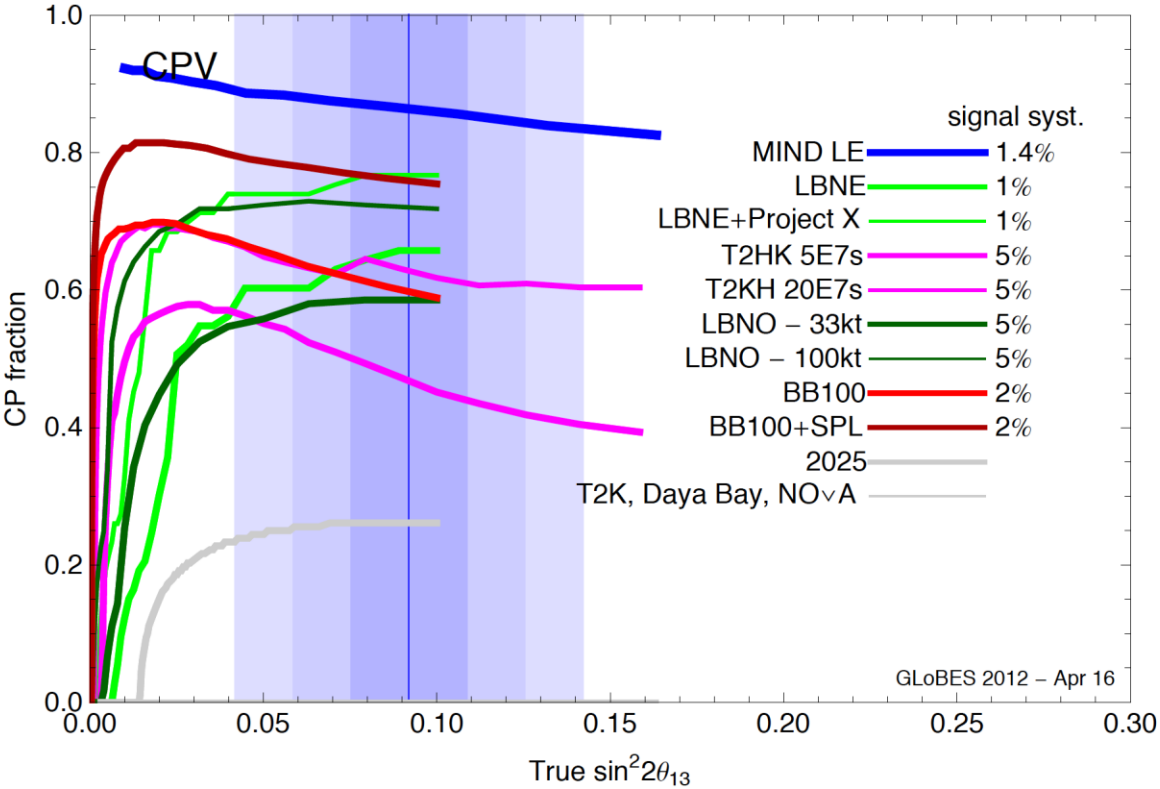
-10 GeV,

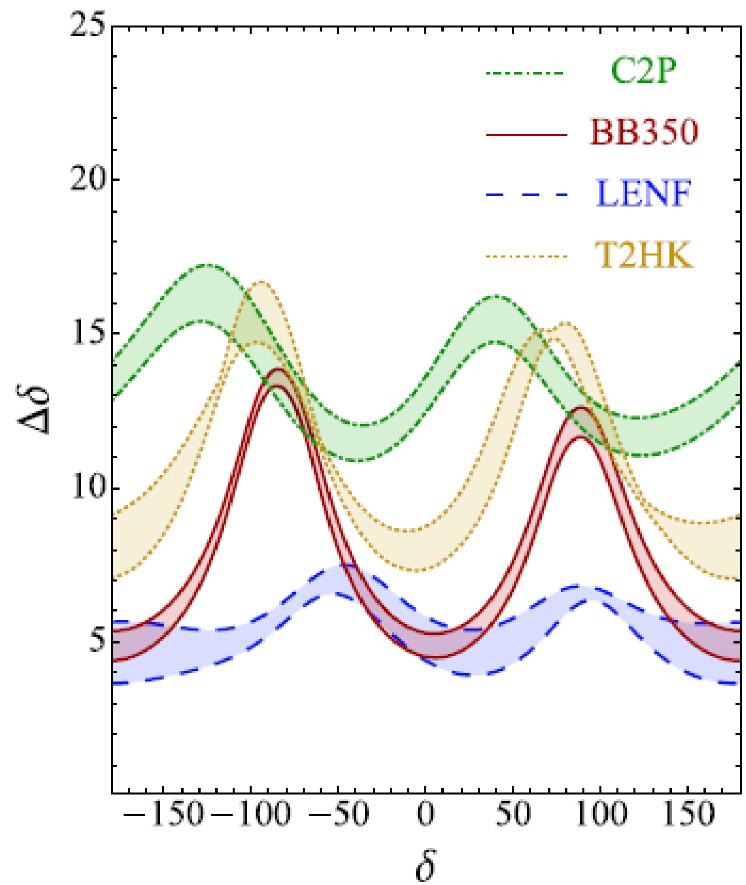
-single decay ring.



Neutrino Factory-Physics Reach

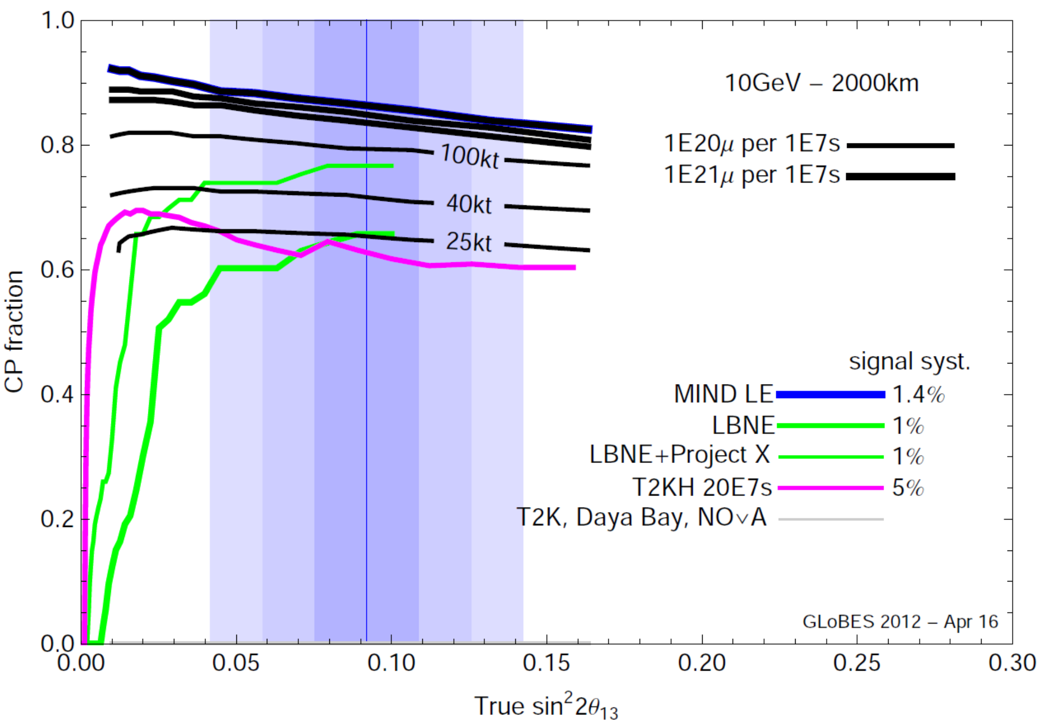
• Neutrino Factory outperforms all other scenarios in CP-violation discovery reach, in particular all proposed superbeams.
• It cal also achieve the best precision, which is essential to compare with future theoretical predictions.

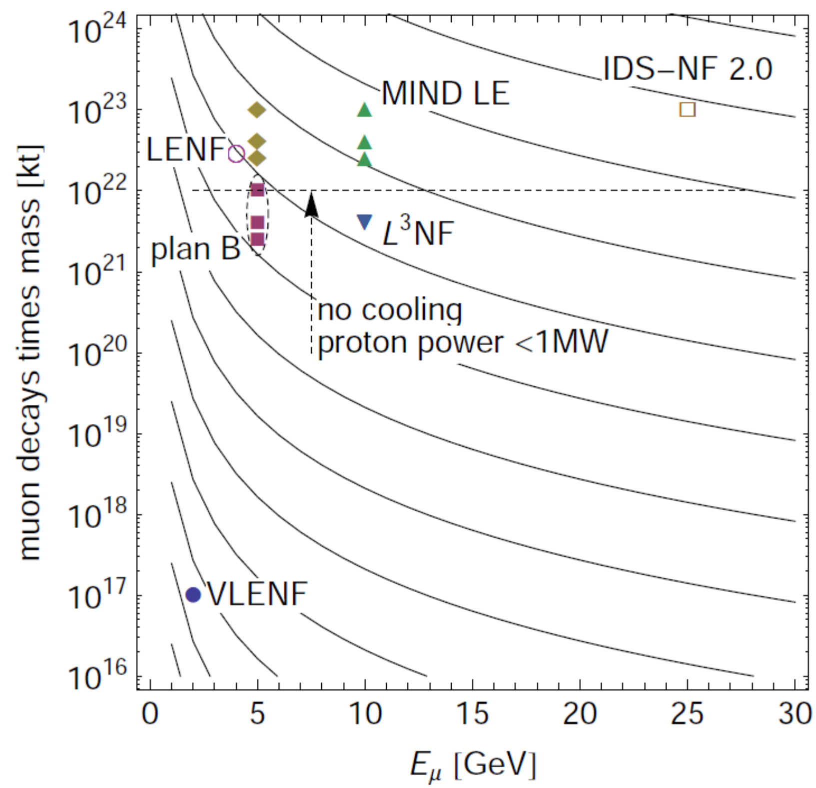




Neutrino Factory - Staging

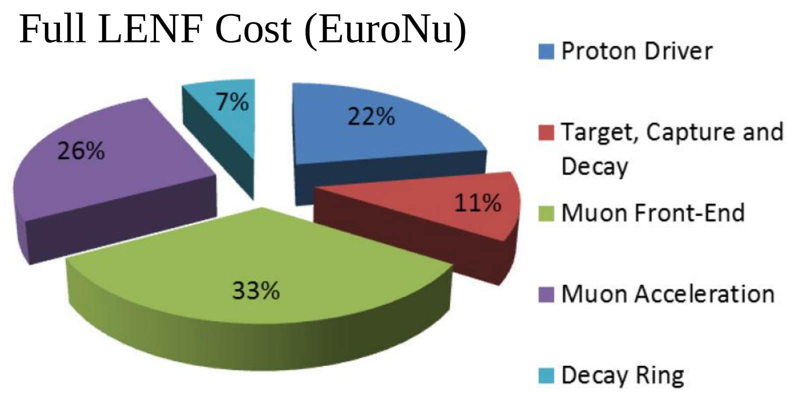
- 1/20 Neutrino Factory comparable to CP violation coverage of superbeams
- Staging approach can be implemented by starting with existing proton driver, using horn, reducing or postponing the use of cooling, introducing an intermediate acceleration stage.





NF Staging Scheme - Costs

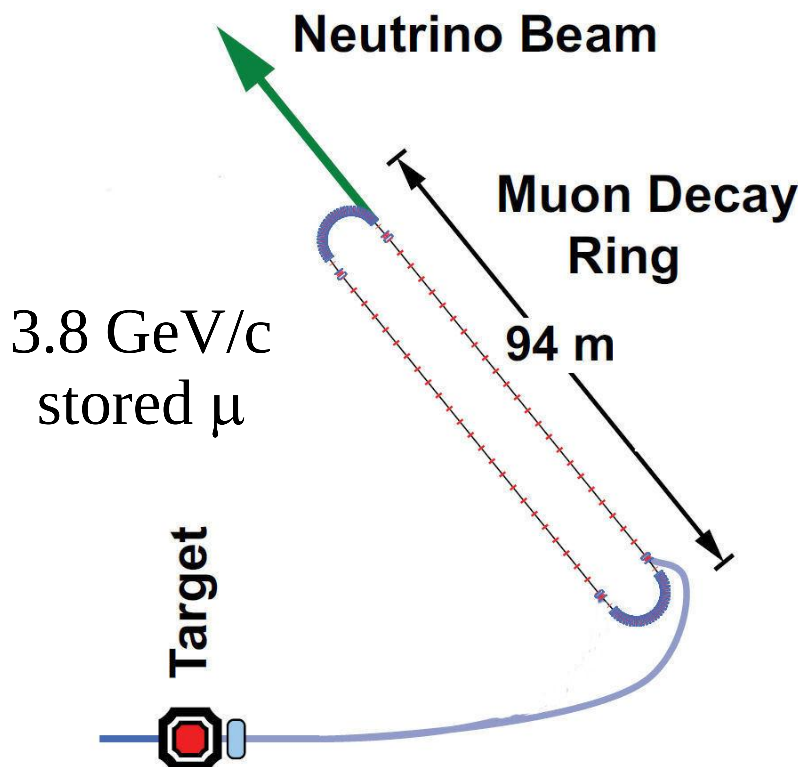
- LENF I
  - Use existing/near proton driver
    - Say Fermilab booster @ 700 kW
    - ~1/5 rate
    - Needs bunch compressor?
  - Remove cooling channel
    - ~1/2 rate
  - Use horn-type target
    - ~1/2 rate
- Overall ~ 1/20 rate
  - Comparable physics to superbeam
  - Removes main technical risk
    - Solenoidal focussing on target
    - Ionisation cooling
    - 4 MW proton driver
  - @ 50% of standard LENF cost
  - Upgradable to full NF
    - @ 60% of standard LENF cost



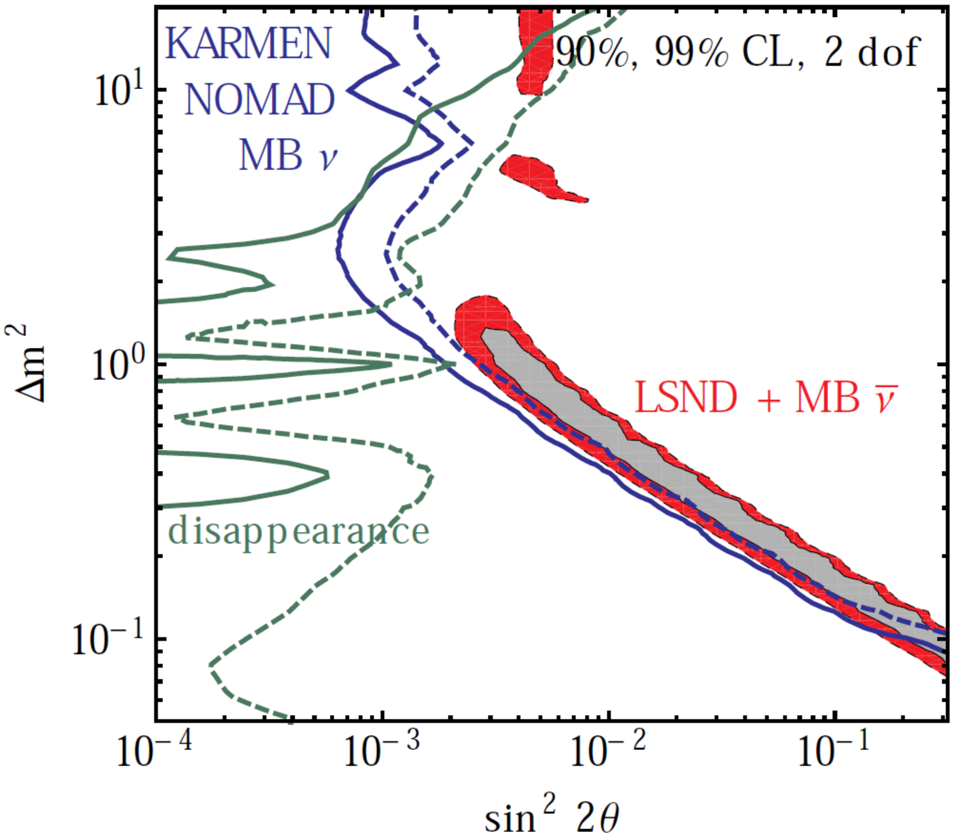
	LENF I	LENF II
Proton driver	5%	22%
Target, capture, decay	5%	11%
Front End	10%	23%
Acceleration	26%	0%
Decay Ring	7%	0%
Total	53%	55%

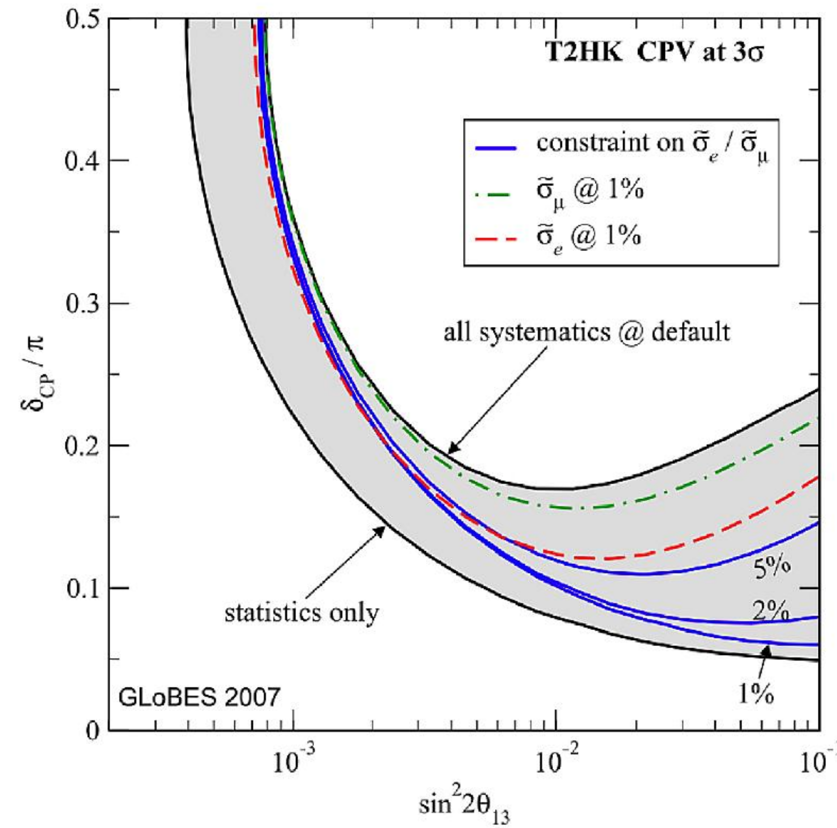
NuStorm

- νSTORM (Neutrinos from Stored Muons) – possibly the first muon storage ring for neutrino physics (proposal in preparation - 2013)
- Entirely based on existing technology
- 100 kW Target Station
  - Assume 60 GeV proton
    - Fermilab PIP era
  - Ta target
    - Optimization on-going
  - Horn collection after target
    - Li lens has also been explored
- Collection/transport channel
  - Two options
    - Stochastic injection of π
    - Kicker with $\pi \rightarrow \mu$ decay channel
    - At present nsidering simultaneous collection of both signs
- Decay ring options
  - Large aperture FODO or
  - Racetrack FFAG
  - Instrumentation
    - BCTs, mag-Spec in arc, polarimeter



NuStorm Physics

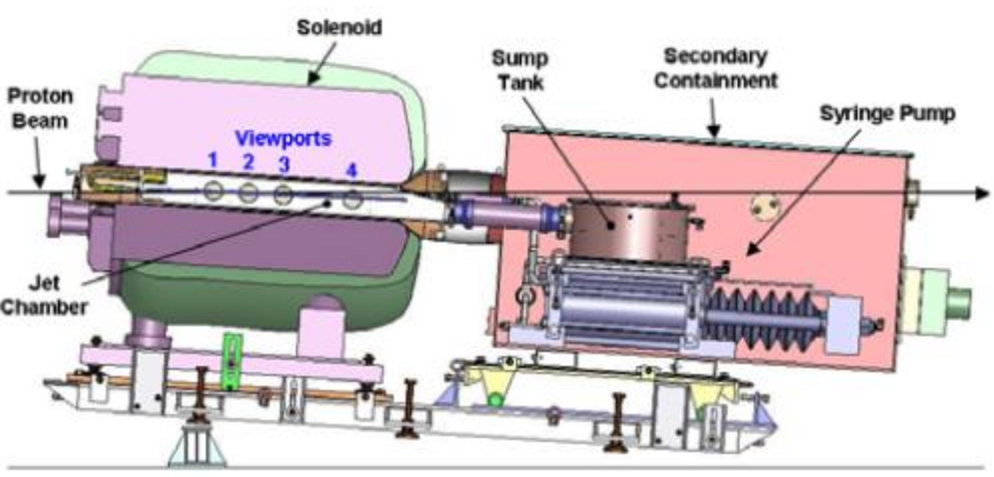


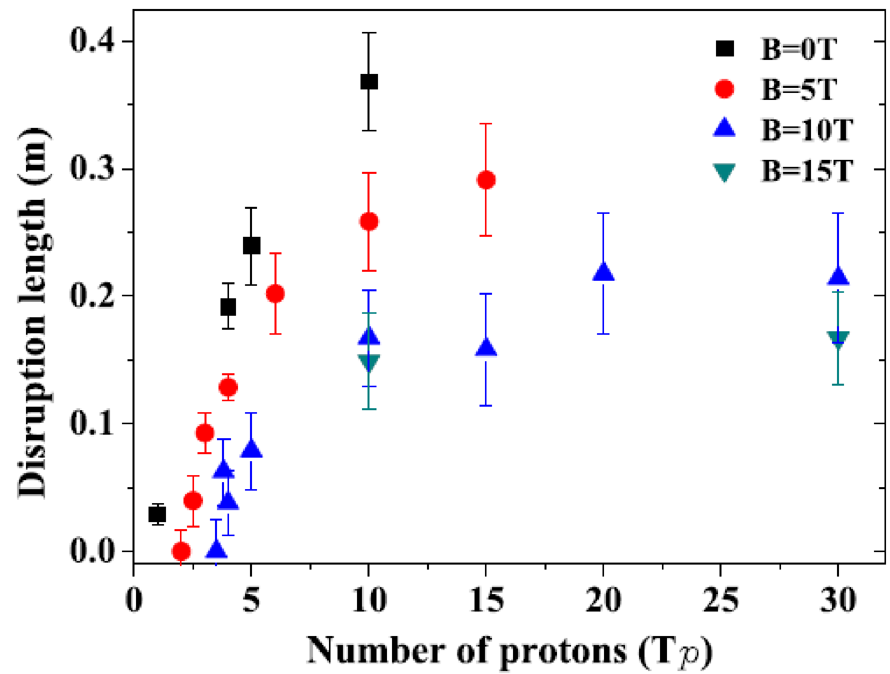


- Sterile neutrino search
- ν_e and ν_e cross-section measurements

MERIT

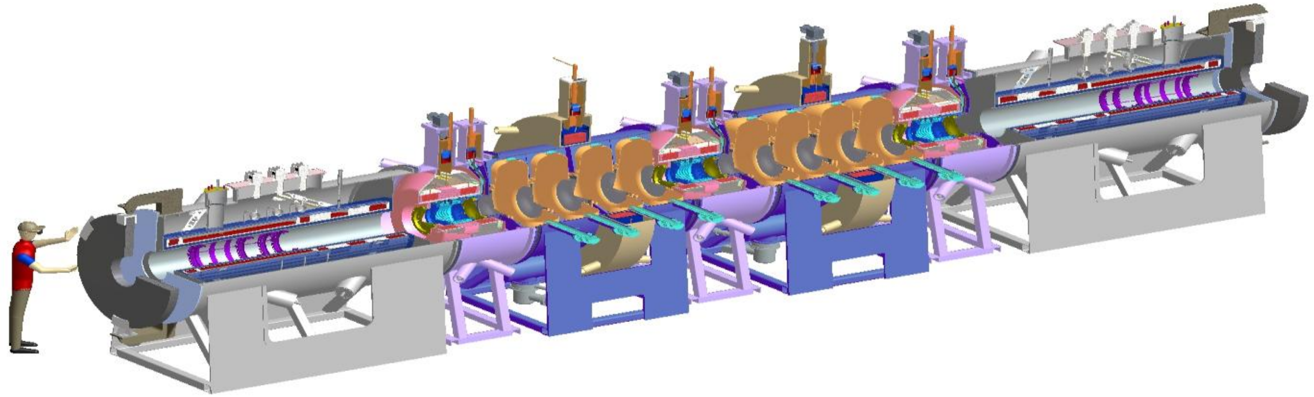
- MERIT at CERN established proof-of-principle of the system for generating intense muon beams by interaction of free mercury jet with multi-MW proton beam in high magnetic filed.
- The disruption length was measured to be less than the overlap and was reduced by magnetic field. Time scale of observed disruptions was too long to affect pion production and the damage to the containment vessel by mercury speed was negligible.





MICE

- World first ionisation cooling device
  - Unique high acceptance solenoidal focussing lattice
  - Choice of Lithium Hydride or liquid Hydrogen emittance absorbers
  - High gradient 201 MHz RF system
  - Advanced diagnostic system to measure full 6D phase space of beam
  - Under construction at Rutherford Appleton Laboratory
  - Essential for the Neutrino Factory and Muon Collider.



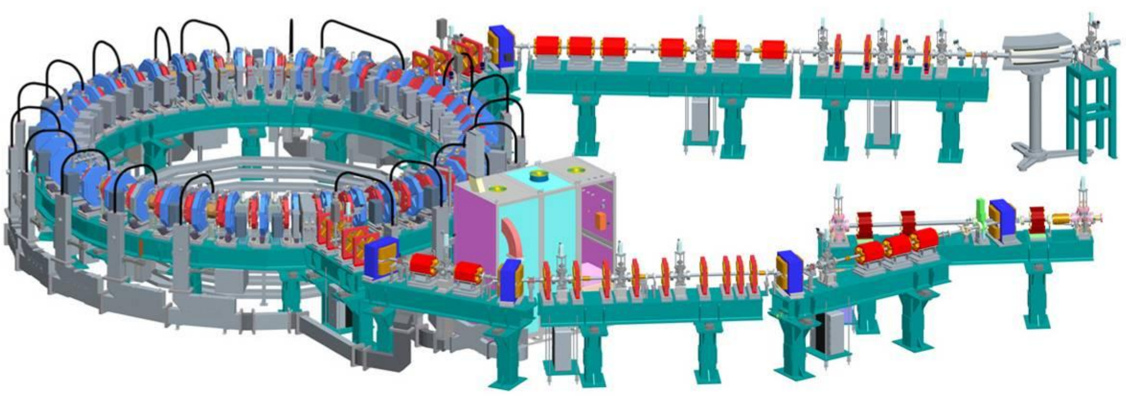
EMMA

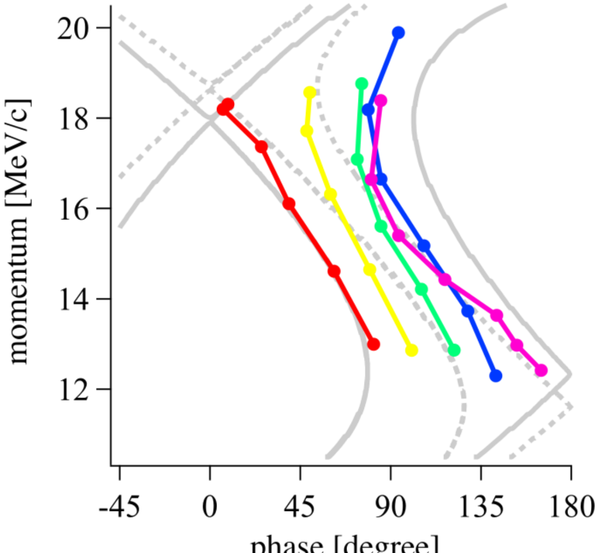
- EMMA - the *Electron Model for Many Applications,* is the first Non-Scaling Fixed Field Alternating Gradient Accelerator (NS-FFAG) in operation at DL.
- EMMA has 3 main goals:

  -to demonstrate a novel acceleration in serpentine channel (outside rf bucket) in around 10 turns (published in NP),

  -to test large tune variation due to natural chromaticity during acceleration.

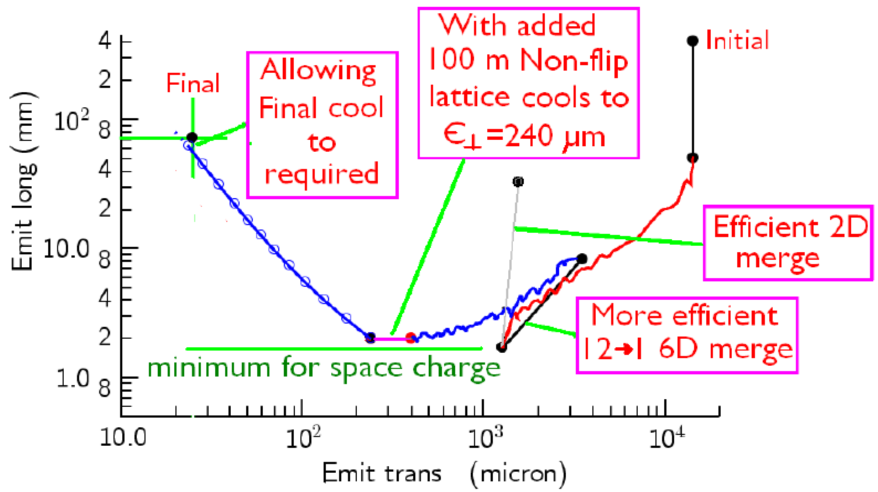
  -to verify large acceptance for huge (muon) beam emittance.
- EMMA is essential for future muon accelerators (NF, Muon Collider, etc.) and it should be continued beyond March 2013.

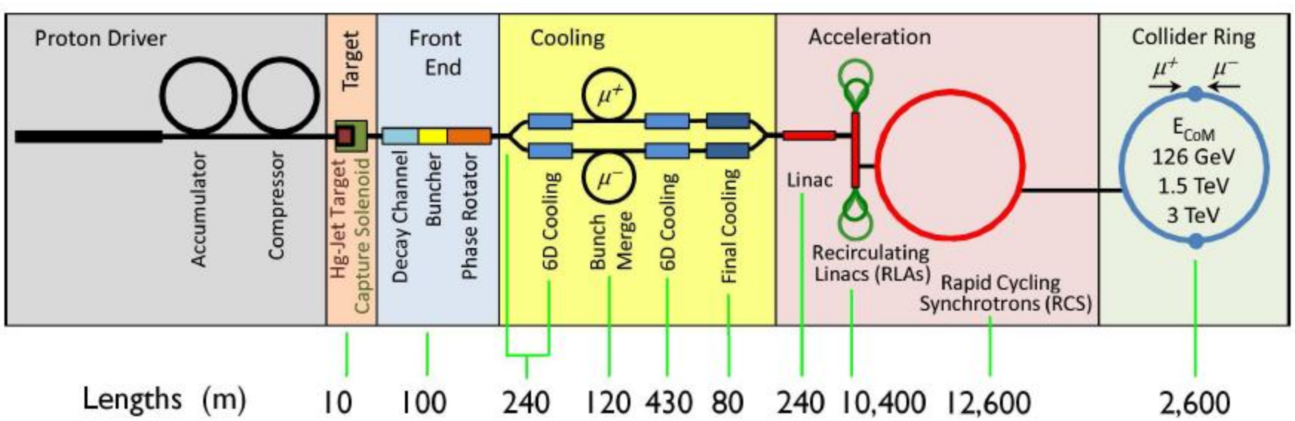




Muon Collider Facility

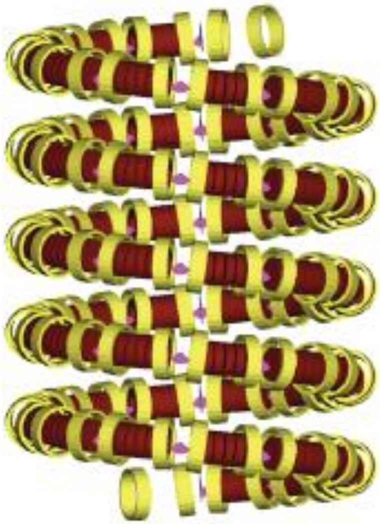
• Muon Collider will provide collider physics using leptons with high quality beams and compact footprint.
• The scenarios for low and high luminosity have been sketched but intensive R&D studies are required.
• The studies on Muon Collider have a strong synergy with the Neutrino Factory program.
• First demonstration of ionisation cooling (MICE) is essential, but must be followed by tests of the next cooling stages to proof the feasibility.



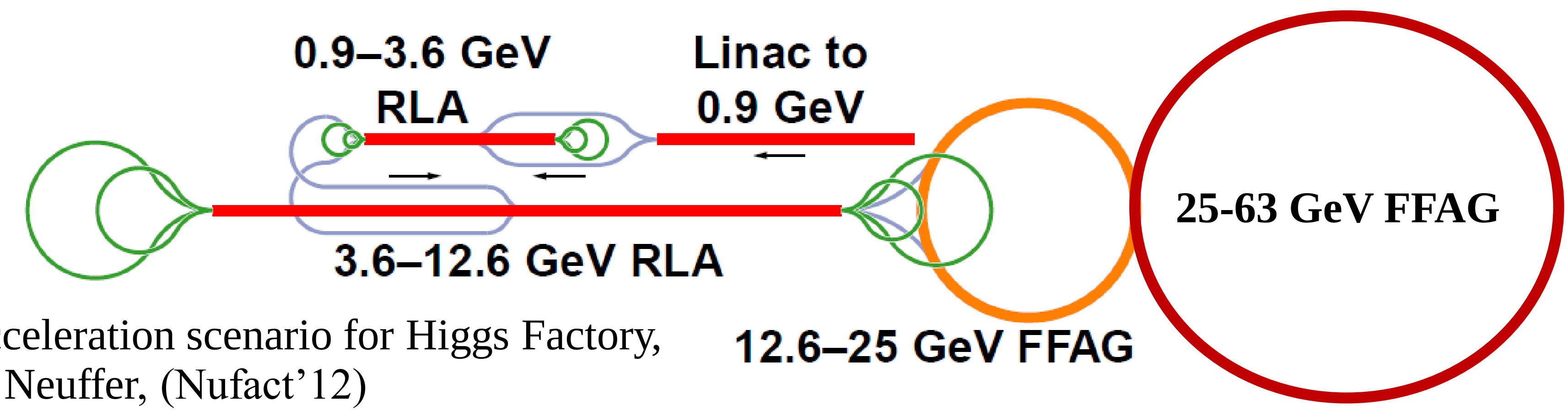


Higgs Factory at 125 GeV COM

•Discovery of Higgs-like boson at LHC opens a possibility to use muon collisions at the resonance for Higgs production.
• Required collider ring could be very compact (C=350 m).
•Still substantial beam cooling is required. MICE results are essential and R&D studies beyond MICE are needed.
•Acceleration can be based on straightforward extrapolation from the Neutrino Factory and will use RLAs and NS-FFAGs (continuation of EMMA is essential).



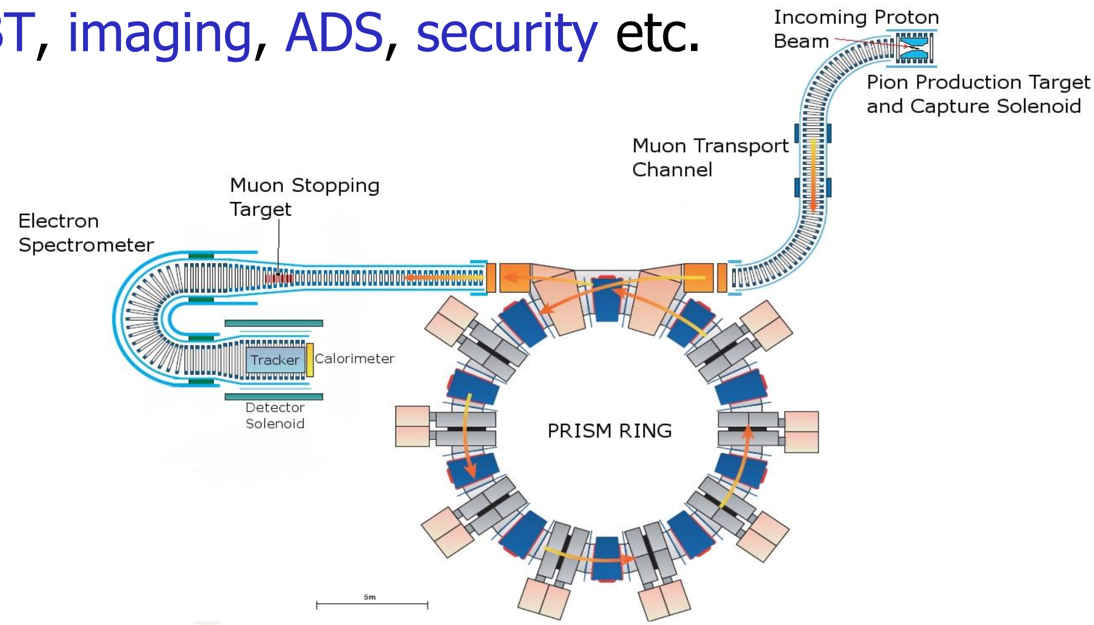
One of the proposed 6D cooling channels



Acceleration scenario for Higgs Factory, D. Neuffer, (Nufact'12)

Other Synergies

- Experiments searching for muon to electron conversion (COMET/PRISM, Mu2e)-similar target and collection issues, magnet system, diagnostics, FFAG technology.
- Superbeam projects (proton driver, target system, activation handling)
- Project-X (accelerator technology)
- Muon accelerator studies induces progress in accelerator/detector systems with applications to PBT, imaging, ADS, security etc.



Layout of PRISM

Conclusions of EuroNu

The recent measurement of the neutrino oscillation parameter θ_{13} and the demonstration that this angle is large, around 9º, has shown that a number of extremely important physics goals could now be within reach. These include:

- The discovery of CP violation in the lepton sector and a precise measurement of the CP phase, δ.
- The neutrino mass hierarchy.
- Precise measurement of other oscillation parameters, thereby testing, for example, the unitarity of the mixing matrix.

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The FP7 Design Study EUROnu will complete this year the conceptual design of three possible high intensity facilities: a conventional very high power Super Beam and two novel neutrino beams, a Neutrino Factory and a Beta Beam.

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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 [above].

Collaboration

- Europe is preparing the neutrino program
  - Strong collaboration established by EUROnu
  - Opportunity to collaborate on R&D topics
  - Could join the Superbeam project (LBNO?)
- US has leadership in NuStorm
  - Opportunity for strong and productive collaboration for UK
  - Excellent opportunity
- US has a strong Muon Collider program:
  - Keep and strengthen the existing connections via MICE and IDS-NF
  - Opportunity to join future R&D studies
- Japan has a leadership in COMET
  - Opportunity to strengthen already existing collaboration (COMET/PRISM)

Long term staging plan

- Construct and operate the NuStorm - perform the proof-of-principle experiment for muon storage ring based neutrino experiment and explore its physics reach.

  - Test relevant accelerator and detector techniques in real life experiment.
- Move towards the first stage of the Neutrino Factory.

  - Explore other use of high quality muon beams (future muon experiments).
- Perform upgrades on the path to the ultimate precision Neutrino Factory (4 MW proton beam, with ionisation cooling, at 10 GeV muon storage energy and 2000 km baseline).

  -Test relevant technology for Muon Collider
- Proceed to the construction of Muon Collider using the NF as a front end.

Conclusions

- Muon accelerators are important part of the current UK effort (MICE, EMMA, IDS-NF).
- Neutrino experiments based on muon storage ring are the best way to achieve an ultimate precision in the neutrino oscillation parameters and to search for the leptonic CP violation.
- Muon accelerators are important tools in HEP and future advances will offer new opportunities with high quality beams (next generation lepton flavour violation searches, rare decays, g-2).
- Muon Collider offers an opportunity to make fundamental collider physics at the energy frontier with leptons or to be used as a precision tool in Higgs physics.
- R&D efforts (MICE, EMMA, etc.) need to be continued in order to be ready for a future.

Long journey starts with the first step:
NuStorm.