



Neutrino Factories

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Fermilab Accelerator Complex Evolution (ACE) Science Workshop

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This talk will (mostly) be a review of the history of the NF

Live, Die, Repeat?

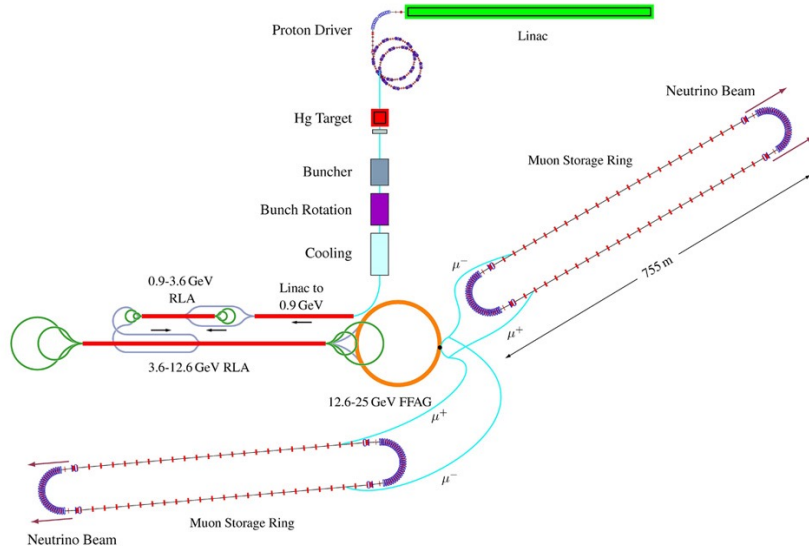
- The neutrino factory concept has been around for ~ 50 years
- It has had ups and downs
 - And numerous design studies (8+)
- In its last life (MAP), the physics potential, facility design, and the technological underpinnings were developed in detail.
- Then it stopped
 - *But no blue goo*

Is it back? Should it be? Do we remember?

“Those who cannot remember the past are condemned to repeat it.”



NF Design circa 2007 (International Design Study for a NF)



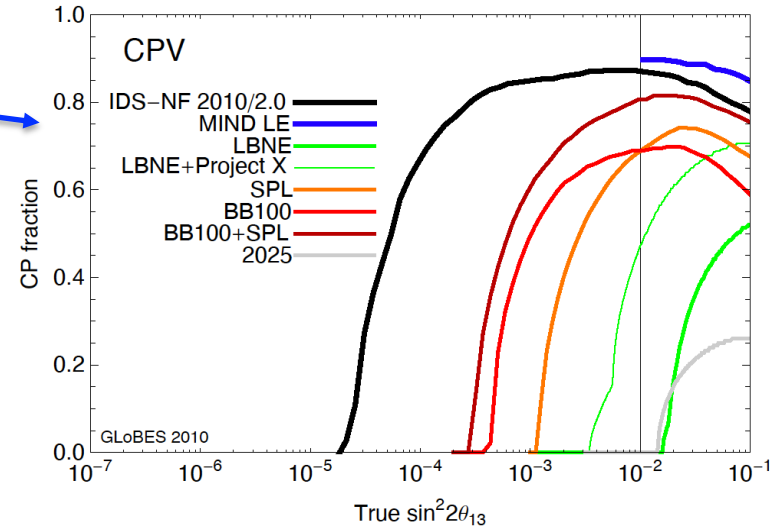
$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$	$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$	
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$	$\nu_\mu \rightarrow \nu_\mu$	disappearance
$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$	$\nu_\mu \rightarrow \nu_e$	appearance (challenging)
$\bar{\nu}_\mu \rightarrow \bar{\nu}_\tau$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

- High power: Up to 4 MW
- Simultaneously feed two detectors at different baselines
 - 4000 & 7500 km baselines
 - 100kt MIND detectors
 - Very aggressive near detectors

"Golden" → Sign of μ observed in detector opposite to that stored in decay ring
 $\mu^+ \rightarrow \nu_e \Rightarrow \nu_\mu n \rightarrow \mu^- p$ (Magnetic detector)

NF physics reach

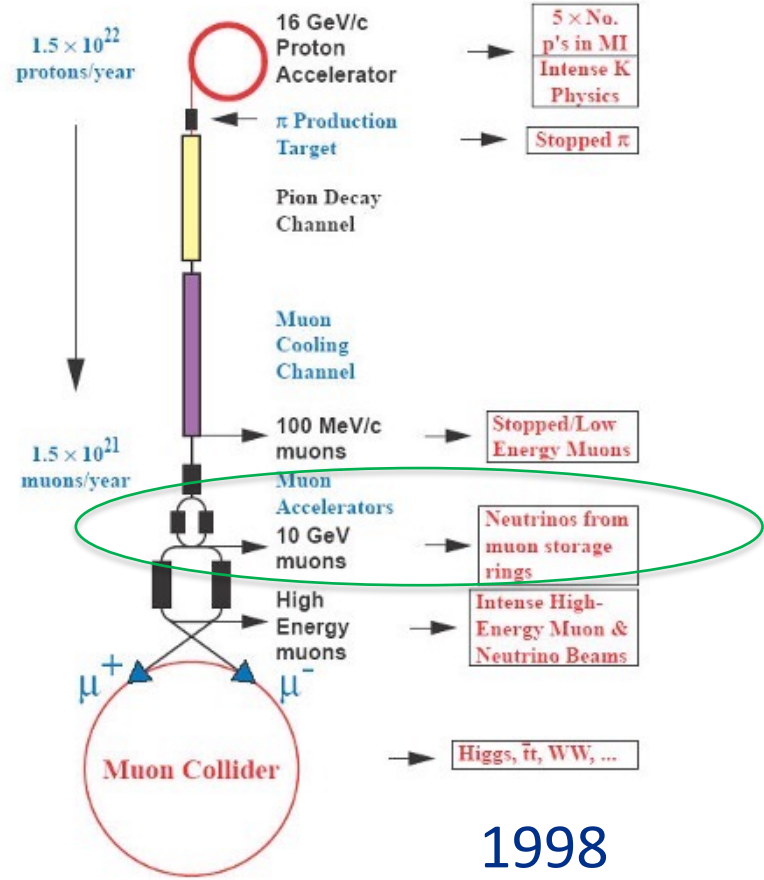
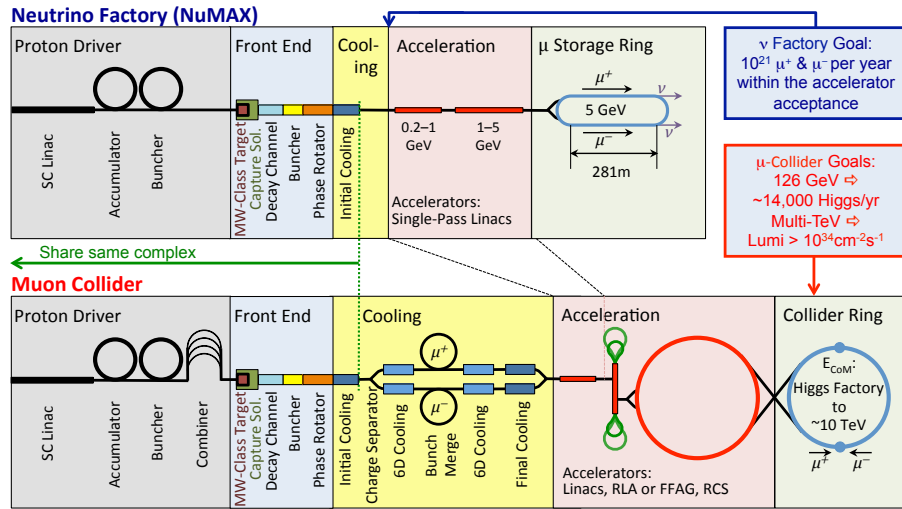
- Much of the original physics motivation for the NF is gone
- After θ_{13} was measured, designed changed (lower E, single BL)
 - International Design Study \rightarrow Muon Accelerator Program
- Is there strong motivation for a NF now?
 - André just provided one
 - But in particular, if there is need to go to very high energy (10s of GeV) ν beams, the NF is the way to go
 - Why is the NF superior/unique here?



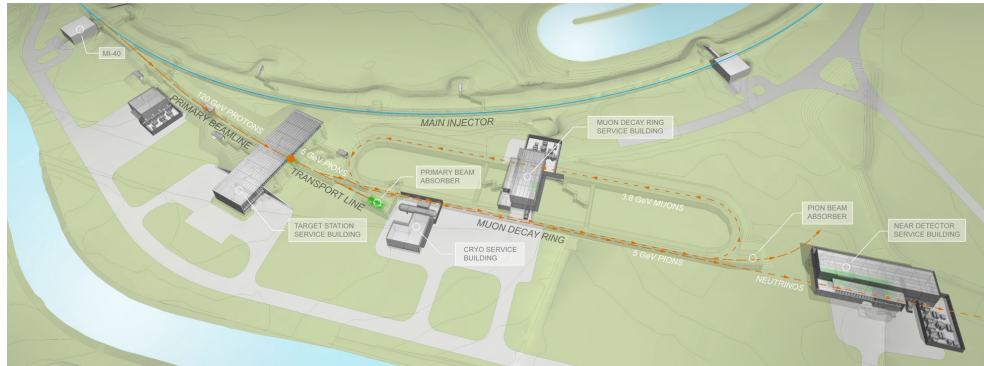
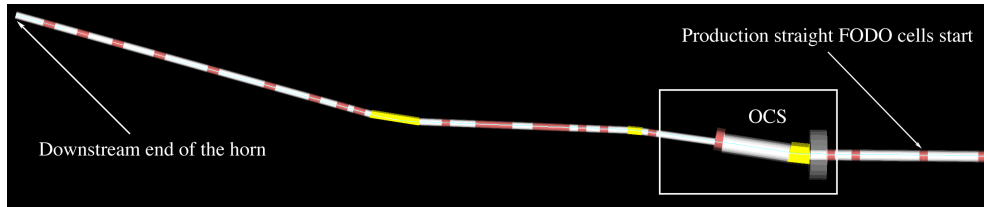
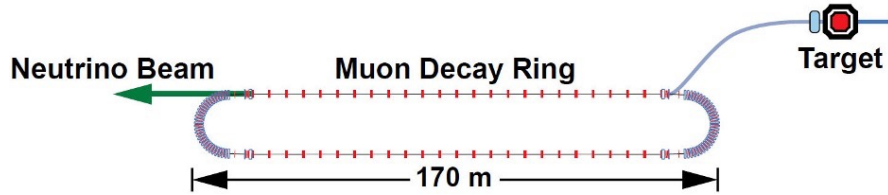
The only facility that could reach the very small values of $\sin^2 2\theta_{13}$ that was “motivated” at the time

NF and a Muon accelerator facility

- The figure to the right is from the MC study in the late 1990s
 - The NF was also shown as an option
- Below: From the output of the Muon Accelerator Program (MAP) ~2015



Entry level NF: nuSTORM and iMCC demonstrator

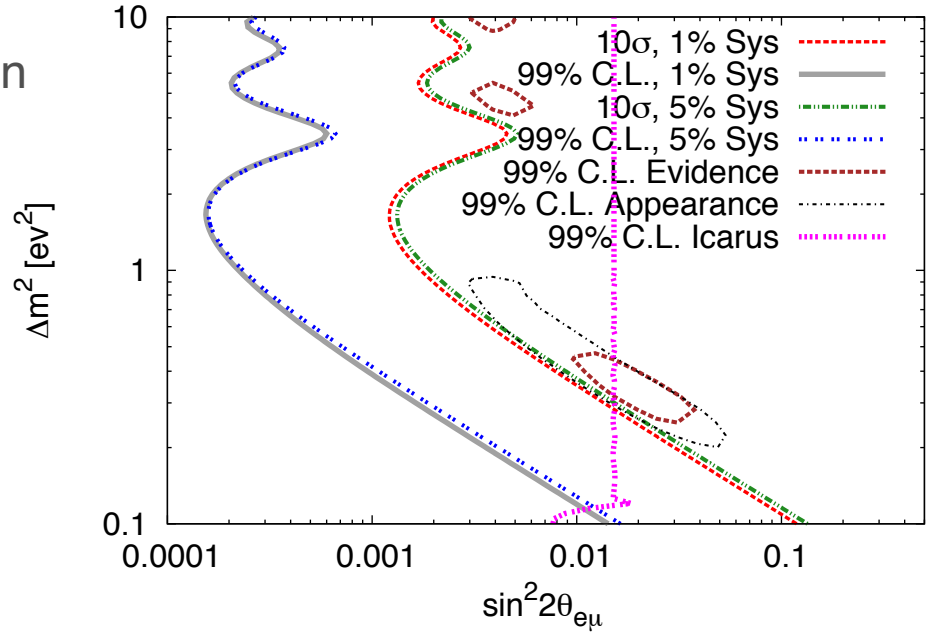
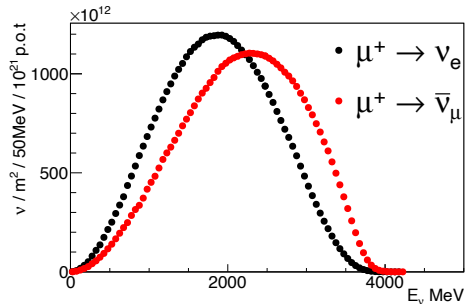


- Probes the SBL, large δm^2 ν -oscillation regime with excellent reach
- Provides a beam for precision ν interaction physics
 - $\approx 1\%$ systematic uncertainty on beam
- Accelerator & Detector technology test bed

- Live: nuSTORM_v1:
 - David Neuffer (1980) [non-interacting ν (Maurons) search] (1982 Die)
- Live: nuSTORM_v2:
 - At Fermilab (Die 2013)
- Live: nuSTORM_v3: At CERN

nuSTORM physics reach

- Using the appearance of a wrong-sign muon (magnetized detector: MIND) nuSTORM (5 years @ 120kW on target) excluded at 10σ the SBL anomaly.
 - Small sensitivity to underlying systematics (1% \rightarrow 5%)
- ν interaction physics limited by detector(s)

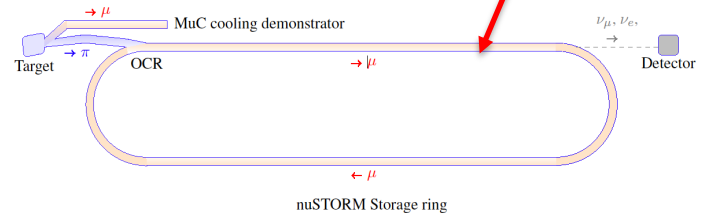
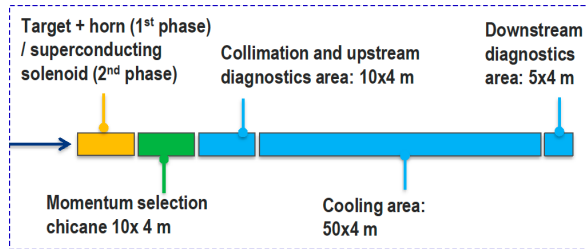
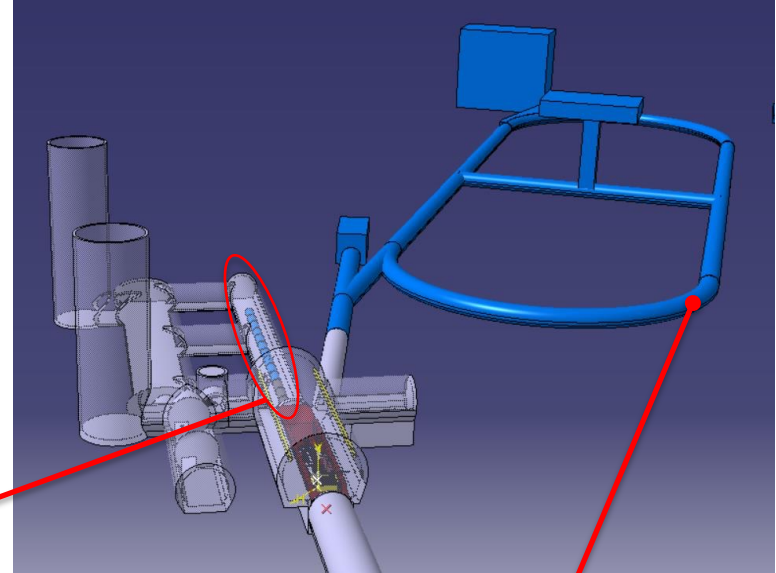


“How can you show 10 σ contours when you don’t know what you don’t know.”
 Actual quote from a colleague

And: “It ain’t over ‘til it’s over”

International Muon Collider Collaboration Demonstrator

- A cooling demonstrator is part of the iMCC study and Daniel described.
 - Later-stage cooling
- Layout study at CERN has been completed
 - Can incorporate a nuSTORM and/or ENUBET neutrino source
 - The same target complex would be used profiting from its shielding and general target systems infrastructure, utilities, and accesses.
 - The double deflection of the beamline could reduce radiation streaming towards the nuSTORM ring.
 - Synergies between experiments would reduce costs on both sides.



Conclusions

- The idea of producing a ν beam from a stored muon beam has been around a long time.
- MAP produced a NF design that was well beyond the “conceptual” stage.
 - The International Design Study did also.
- The physics landscape has changed and motivation for a NF is not strong at the moment.
- With the renewed interest in the Muon Collider, the NF again presents itself as an interim step or secondary program.
 - If a physics case can be made & gain community support. The μ storage ring for a NF is costly.
- The need for a Cooling Demonstrator Facility (CDF) as part of a Muon Collider R&D program might breathe new life into the nuSTORM concept (or extension of).
 - nuSTORM @CERN has generated some interest
 - Preliminary engineering is complete.
 - nuSTORM @Fermilab would benefit from ACE, the original siting plan is still valid and would accommodate the full program need at the CDF.

Thank you