Fundamental Aspects of Muon Beams

J.-P. Delahaye[1], D. Stratakis[2], R.D. Ryne[3]
[1]SLAC, BNL[2], LBNL[3]

Fundamental Aspects of Muon Beams

A proposed GARD effort for consideration starting in FY16

- Not "MAP lite" but instead a fundamentally different thrust
  - MAP Design & Simulation focused on Initial Baselines

- GARD effort would address:

Fundamental aspects on the generation and manipulation of muon beams
explored through advanced simulations and theory

Instead of facility designs, our principal thrusts moving forward are to answer questions such as:

- What are the intensity limits of muon beam generation?
- What are the emittance limits of muon beam cooling?
- What are the fundamental limits for rapid acceleration of muons?

Answering these questions would enable us to understand the performance that could be achieved for future muon sources and precision neutrino sources

Importance of Maintaining OHEP Expertise in Fundamental Aspects of Muon Beams

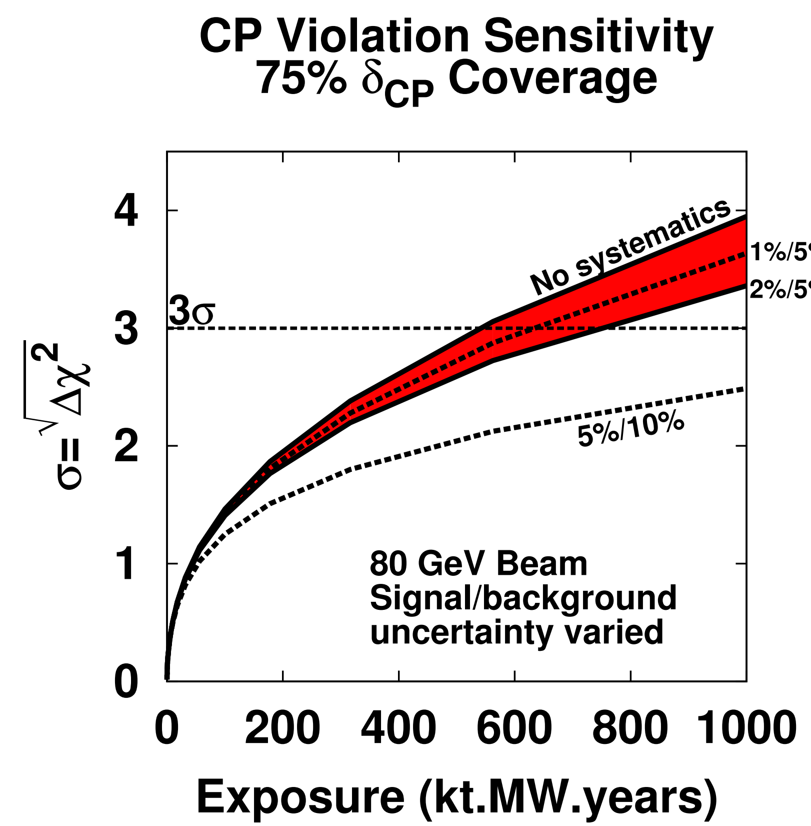
- Neutrino beams are key to US Intensity Frontier thrust
  - US program is reorienting vigorously to provide better neutrino beams
    - Critical element of the P5 vision
    - Also key to international efforts
  - In the near-to-mid term, superbeams sufficient
  - But to produce best neutrino beams we need muons

Stored muons are the key to producing precision neutrino beams

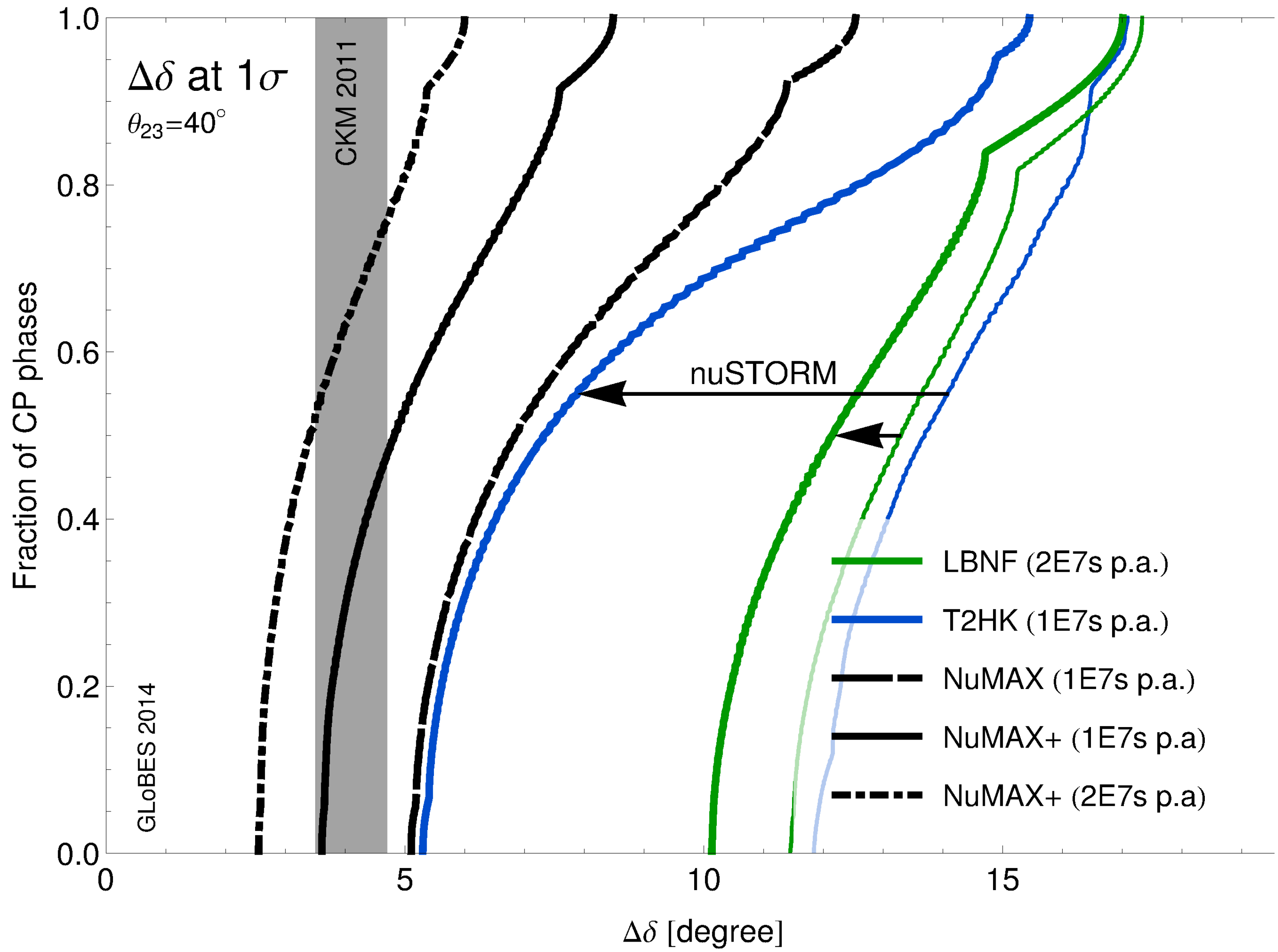
nuSTORM and δ_{cp} coverage @ DUNE

- Besides the long-term need for muon expertise to produce precision neutrino beams, there is growing appreciation that there may be a nearer-term need

- To reach 75% coverage of δ_{cp} a ν oscillation experiment (P5 req.) in a reasonable exposure time, systematic uncertainties at < 1% level are necessary.
- Figure shows degradation of the systematic uncertainty to 5% level corresponds to an exposure increase of roughly 200-300 %, which occurs in a very non-linear fashion.
- To date, reaching a 2% uncertainty in ν expts has not been achieved.



Example: Muon storage ring (nuSTORM) enhances physics reach of neutrino facility by providing better systematics



Additional (broader) benefit

- Synergistic with efforts for neutrino superbeams
  - exploring fundamental aspects of muon beams involves
    - tertiary beam production and beam handling
    - simulating & mitigating collective effects
    - controlling beam loss & energy deposition
    - manipulating large-emittance beams
    - fast acceleration systems

Broad applicability to Accelerator R&D

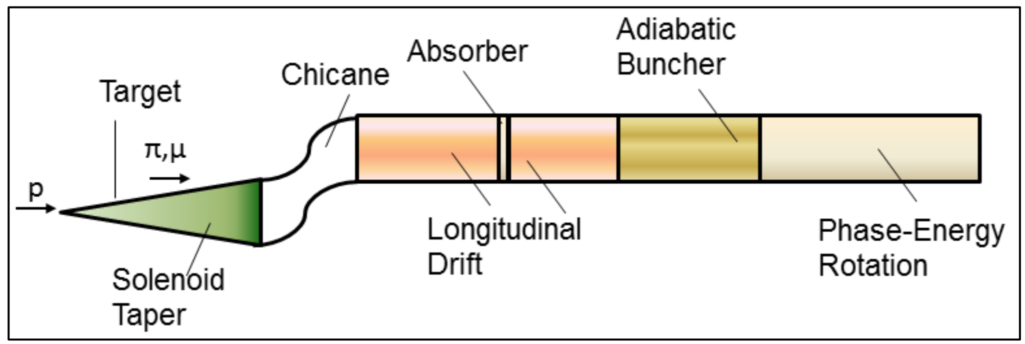
- Also synergistic with future upgrades to precision muon expts

Key areas of the Fundamental Aspects proposal

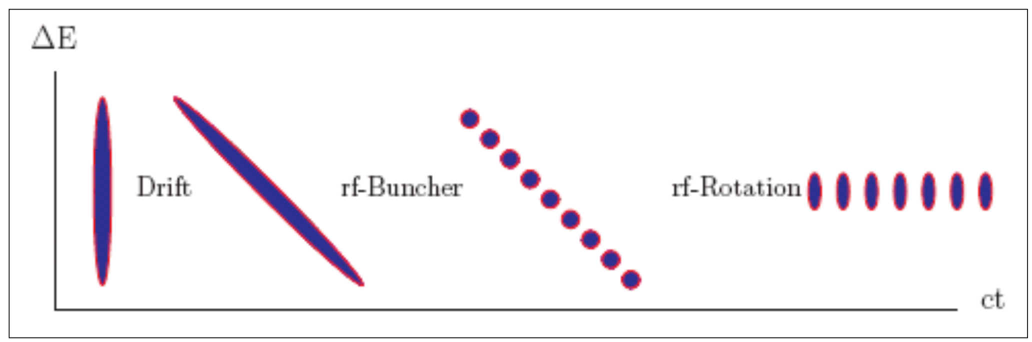
- Ultimate performance reach in
  ① muon beam intensity
  ② muon beam brightness
  ③ muon acceleration and storage

Ultimate performance reach in muon beam intensity

- Goals of a high-intensity muon source
  - Capture muons that result from the decay of pions that are produced by a high intensity proton beam impacting a target
  - Perform initial phase space manipulation of these muons to make them well-suited to subsequent accelerator systems and/or experiments



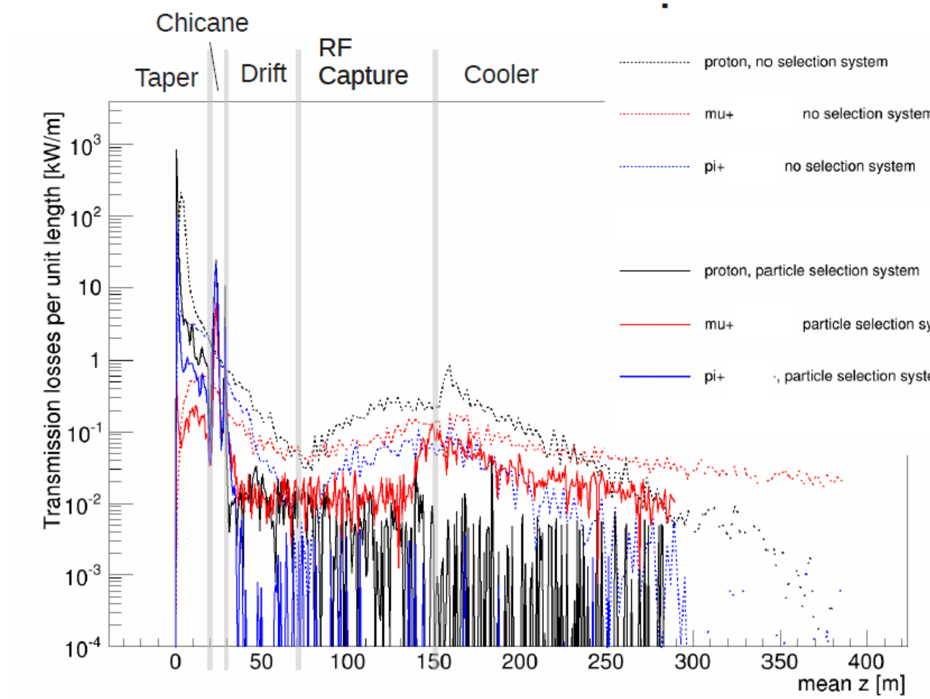
- Key issues:
  - Energy deposition from unwanted particles in accelerator components
  - Intensity limits of muon beams imposed from the buncher and phase-rotator sections

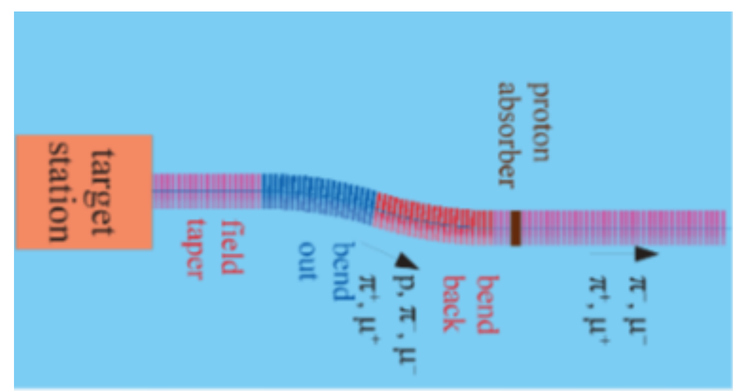


Controlling energy deposition is critical to performance of high power Front End

- MAP results encouraging – 10x reduction in energy deposition

- Questions remain:
  - What are acceptable limits of downstream proton transmission?
  - What flux is achievable within acceptable energy deposition limits?
  - What is the best shielding solution for the chicane system?



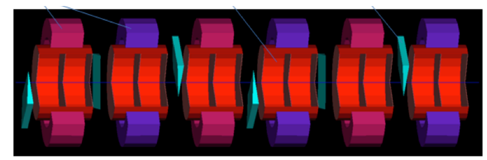


High Intensity + Low Emittance ⇨ High Brightness

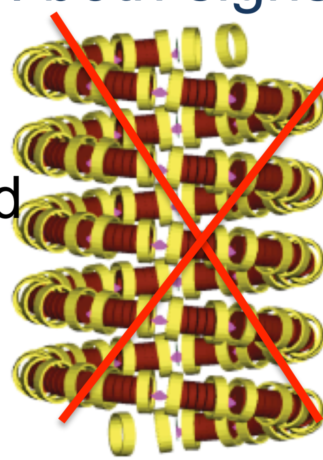
- Progress of last few years has dramatically advanced our understanding and approach to muon cooling
  - Several techniques address RF breakdown in B-field:
    - Careful cavity design
    - Beryllium
    - High pressure RF (HPRF) cavities
    - Magnetic lattice design

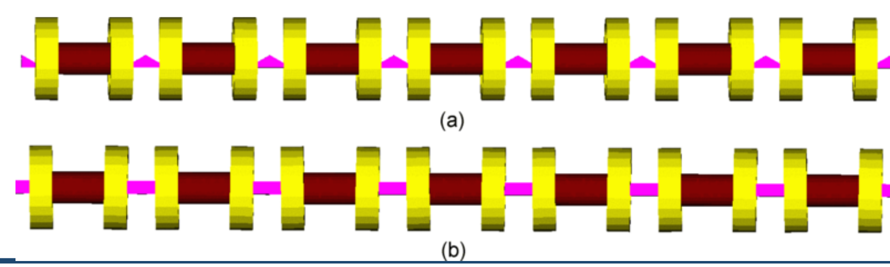
Hybrid approaches would combine various features

  - Designs that cool both signs simultaneously



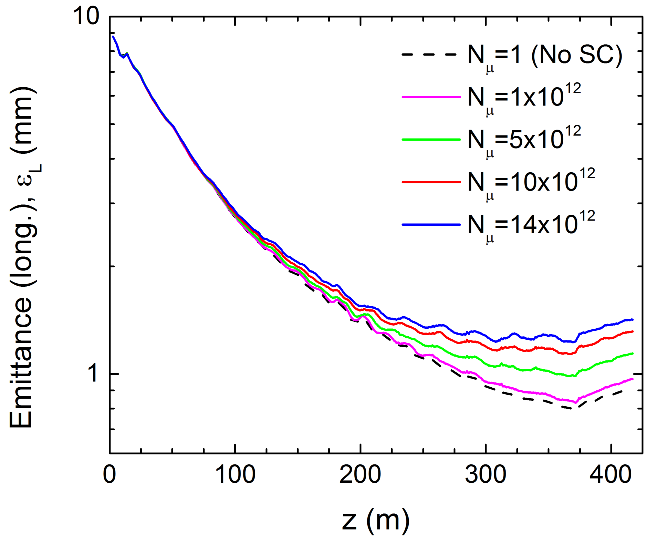
- Difficult-to-build concepts like Guggenheim replaced by rectilinear designs w/ comparable performance



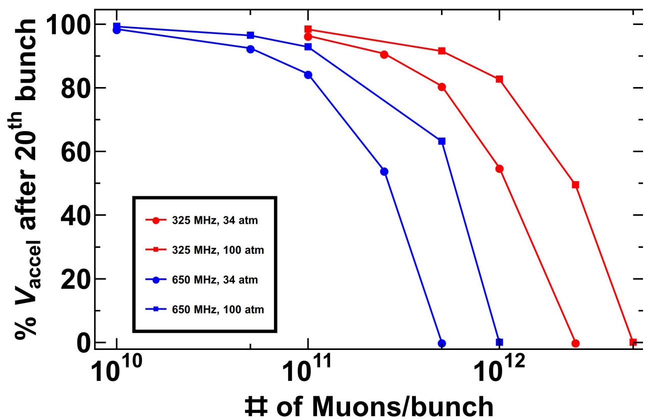


Achievable Brightness: Phenomena that limit muon cooling

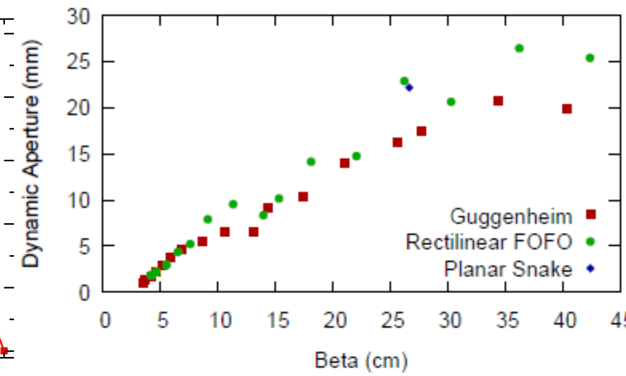
Space-Charge perf



Plasma loading perf

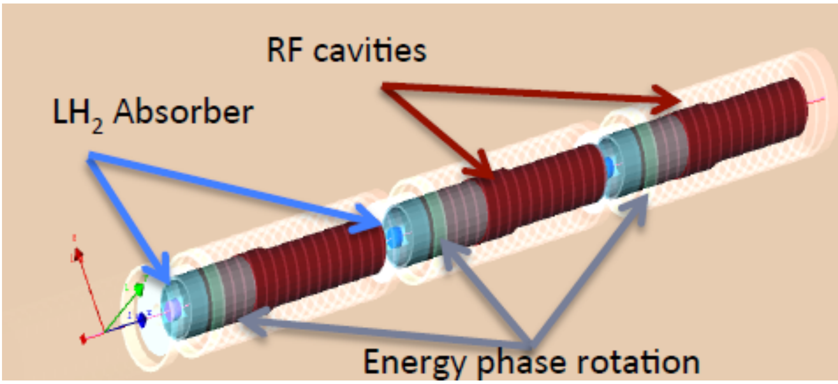


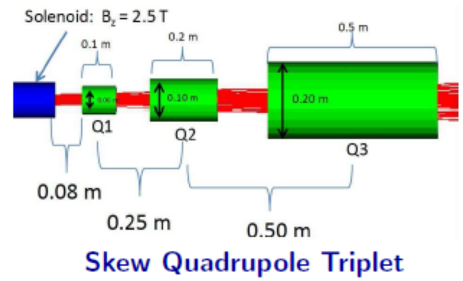
Dynamic aperture perf

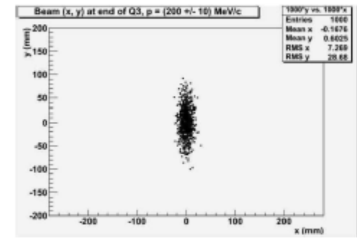


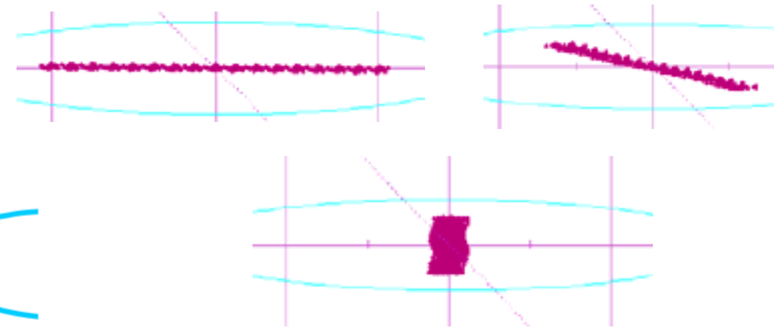
- What is the impact of collective effects such as space-charge and wakefields?
- What are the impact of beam-plasma interactions?
- Mitigation strategies? How they impact performance?
- How do technology issues (gas pressure, achievable B-field) impact the achievable brightness?

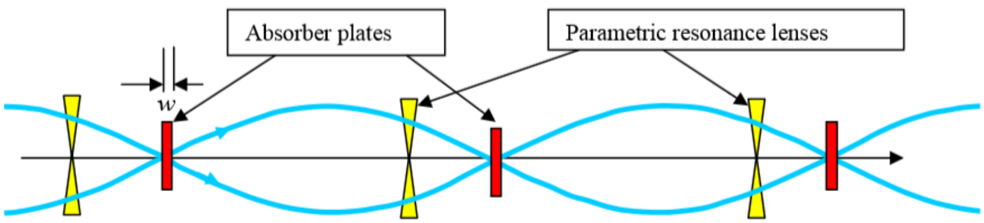
Achievable brightness: Toward micron-scale emittances











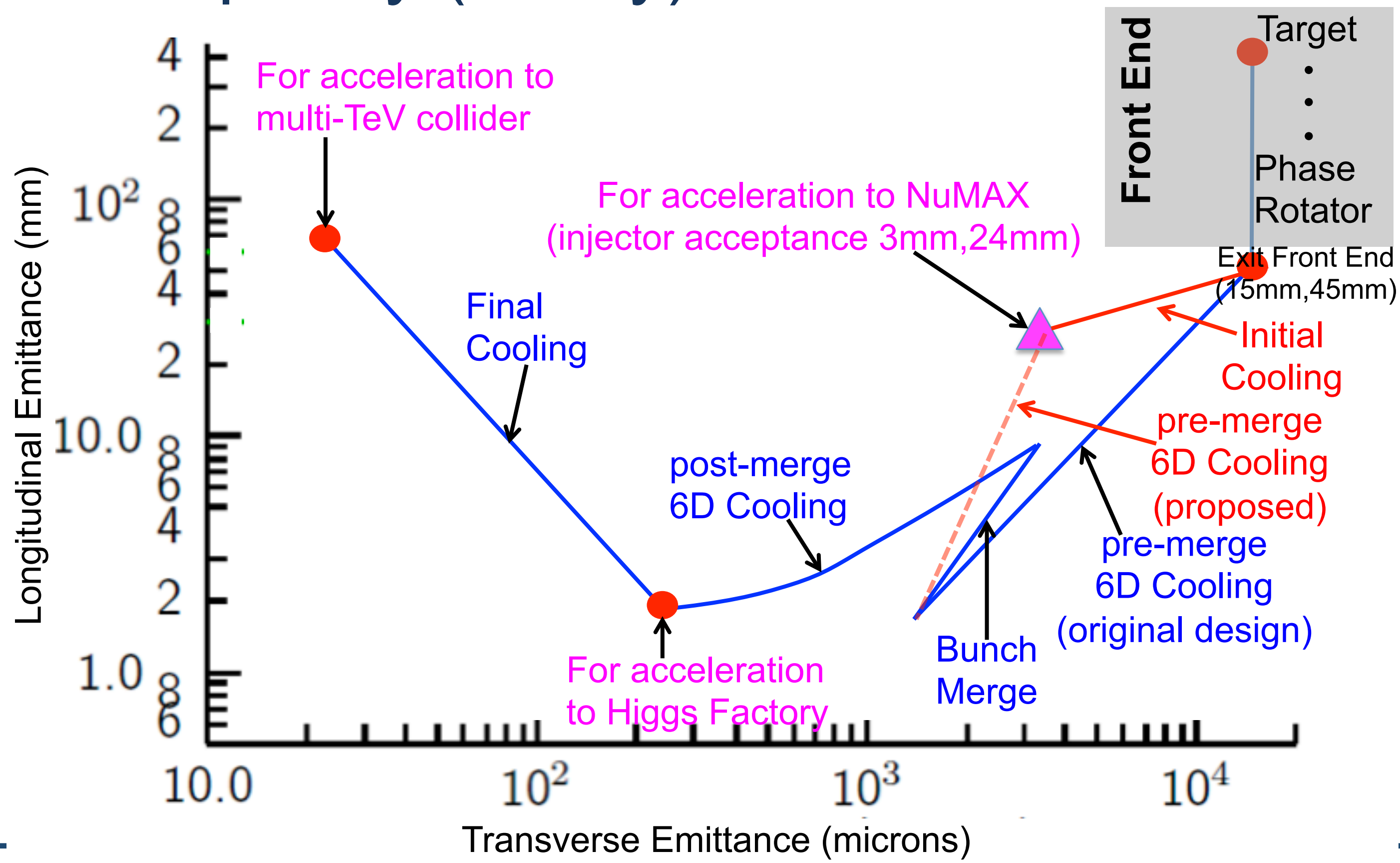
- Several options: high-field solenoids, use of half-integer resonances, longitudinal slicer
- Several concepts considered but a detailed study far from complete. Key questions:
  - What is the final achievable emittance? Is it adequate for the downstream accelerator systems?

The performance of muon acceleration schemes depends on initial beam parameters

- Muon acceleration very challenging
  - very large longitudinal & transverse emittances
  - must be done quickly (decay)

MAP looked for a feasible, realistic cooling path for neutrino storage rings and muon colliders

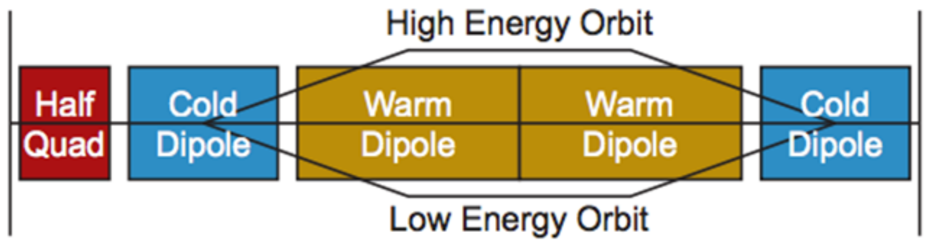
Under GARD we would study interplay between performance, acceleration, and cooling



Muon Acceleration and Storage

Under GARD we would:

- Explore performance limits of rapid acceleration of muons incl. hybrid schemes



hybrid synchrotron cell

- Study acceleration & control of large longitudinal emittances
- Analyze performance of muon storage rings for precision neutrino sources

nuSTORM decay ring

HPC tools have had a huge impact on MAP

- Under MAP we
  - parallelized key codes
  - saw performance improvements up to 35000x !
  - developed capabilities for parallel optimization
- The codes are not just for design, but also for
  - optimization
  - exploration
  - inference
  - insight

Hopper supercomputer at NERSC

- GARD effort would make use of these tools

Notable Publications FY14-15

- D. Stratakis and R. B Palmer, Rectilinear six-dimensional ionization cooling channel for a muon collider: A theoretical and numerical study, Phys. Rev. ST – Accel. Beams 18, 031003 (2015) **Editors' Suggestion**
- D. Stratakis, R. Palmer, D. Grote, Influence of space-charge fields on the cooling process of muon beams, Phys. Rev. ST – Accel. Beams (in press) **Editors' Suggestion**
- D. Stratakis, R. C. Fernow, J. S. Berg, R. B Palmer, Tapered channel for six dimensional beam cooling towards micron scale emittances, Phys. Rev. ST – Accel. Beams 16, 091001 (2013) **Editors' Suggestion**
- H. K. Sayed and J.S. Berg, Optimized capture section for a muon accelerator front end, Phys. Rev. ST – Accel Beams 17, 070102 (2014) **Editors' Suggestion**
- D. Stratakis, D. V. Neuffer, Compact muon production and collection scheme for high-energy physics experiments, J. of Phys. G 41, 125002 (2014) **Editors' Suggestion**

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Compact muon production and collection scheme for high-energy physics experiments

by Diktys Stratakis and David V Neuffer

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