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High Power Proton beam for DUNE

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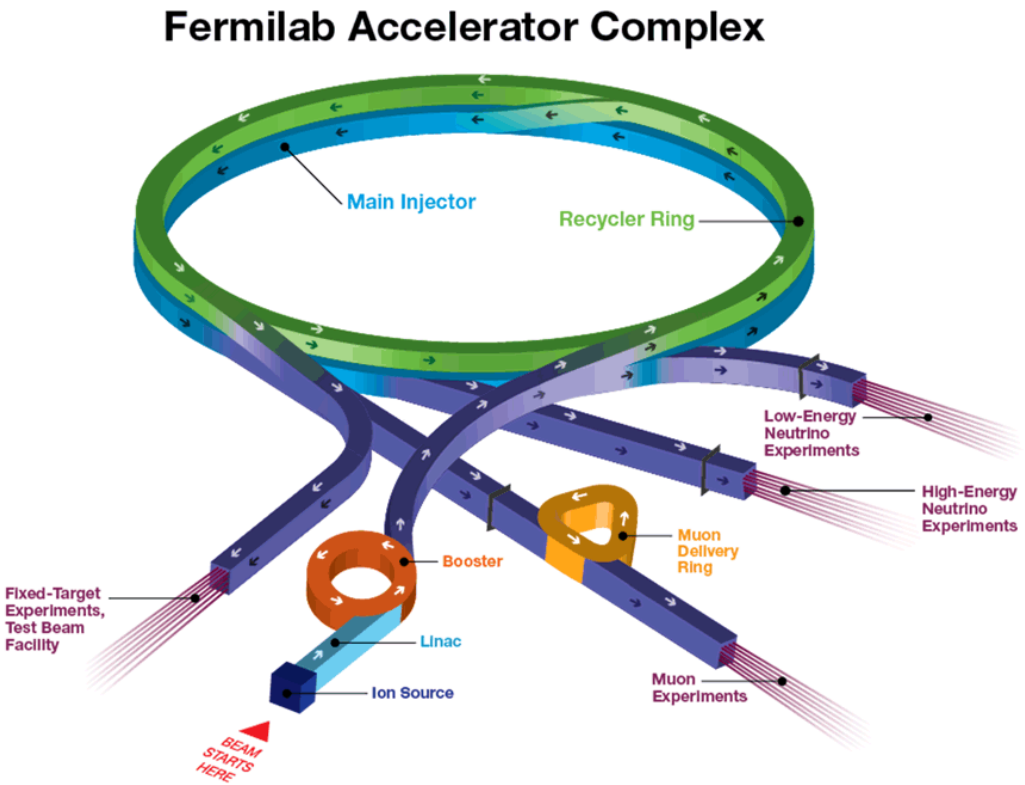
Outline

- Accelerator complex
  - Recycler & Main Injector
  - Slip-stacking
- The path to 1.2 MW (PIPII)
- Beyond PIPII - towards 2.4MW
  - Linac option
  - RCS option

Accelerator Complex

- H^- linac
- Booster
  - h = 84
  - 15 Hz
  - 400 MeV -> 8 GeV
- Recycler
  - h = 588
  - Slip-stack 12 batches (double bunch intensity)
- Main Injector
  - 8 GeV -> 120 GeV



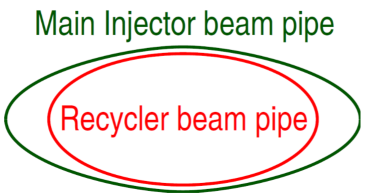
Recycler and Main Injector

Recycler

- Recycler is a permanent magnet storage ring
- Shares the tunnel with the Main Injector
- Originally named to recycle antiprotons from Tevatron which it never did!
- Eventually it stored and cooled antiprotons
- Contributed greatly towards increased Tevatron luminosity

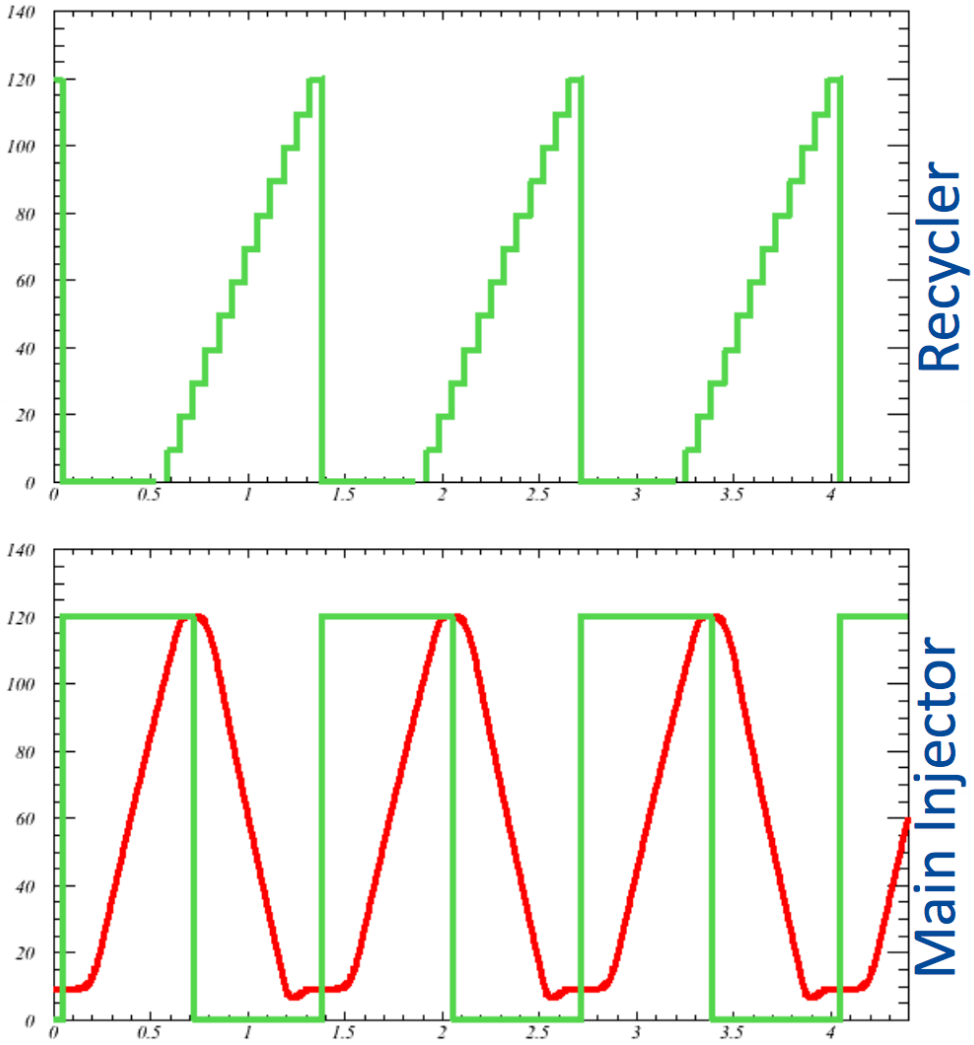
Never designed for its current purpose

Main Injector



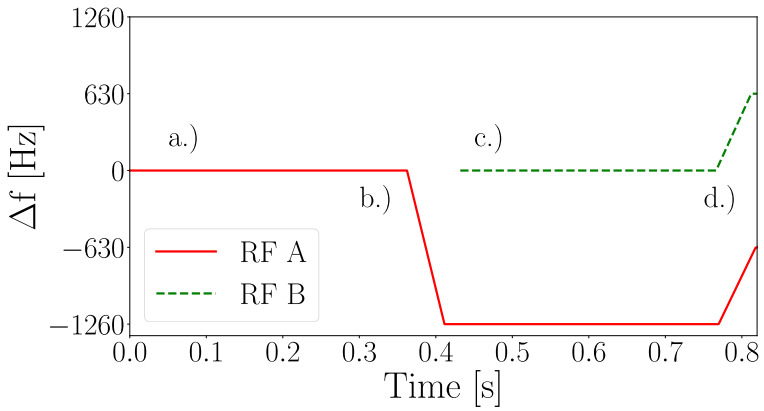
Using the Recycler as a stacker

- Slip-stack in the Recycler
- Increase the MI ramp rate (204 GeV/s to 240 GeV/s)
  - 2.2->1.33 s cycle time
- Achieve 700 kW with just a 10% increase in beam intensity from MI only
- Cycle time reduced to 1.2s since 2019



Slip-stacking

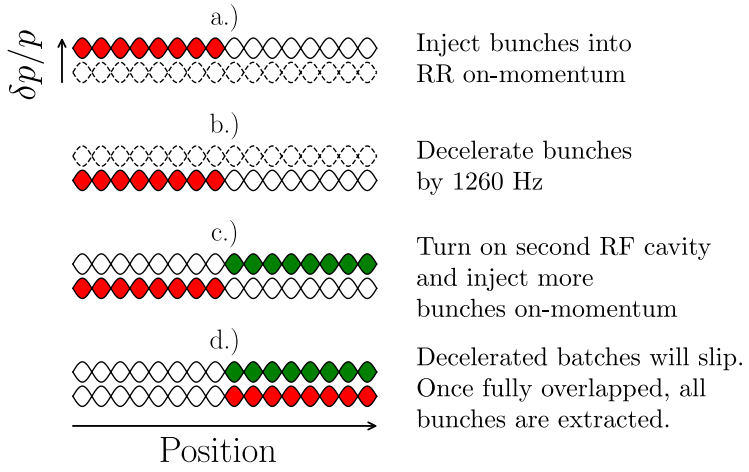
- Slip-stacking allows us to double the intensity of the bunches in the Recycler



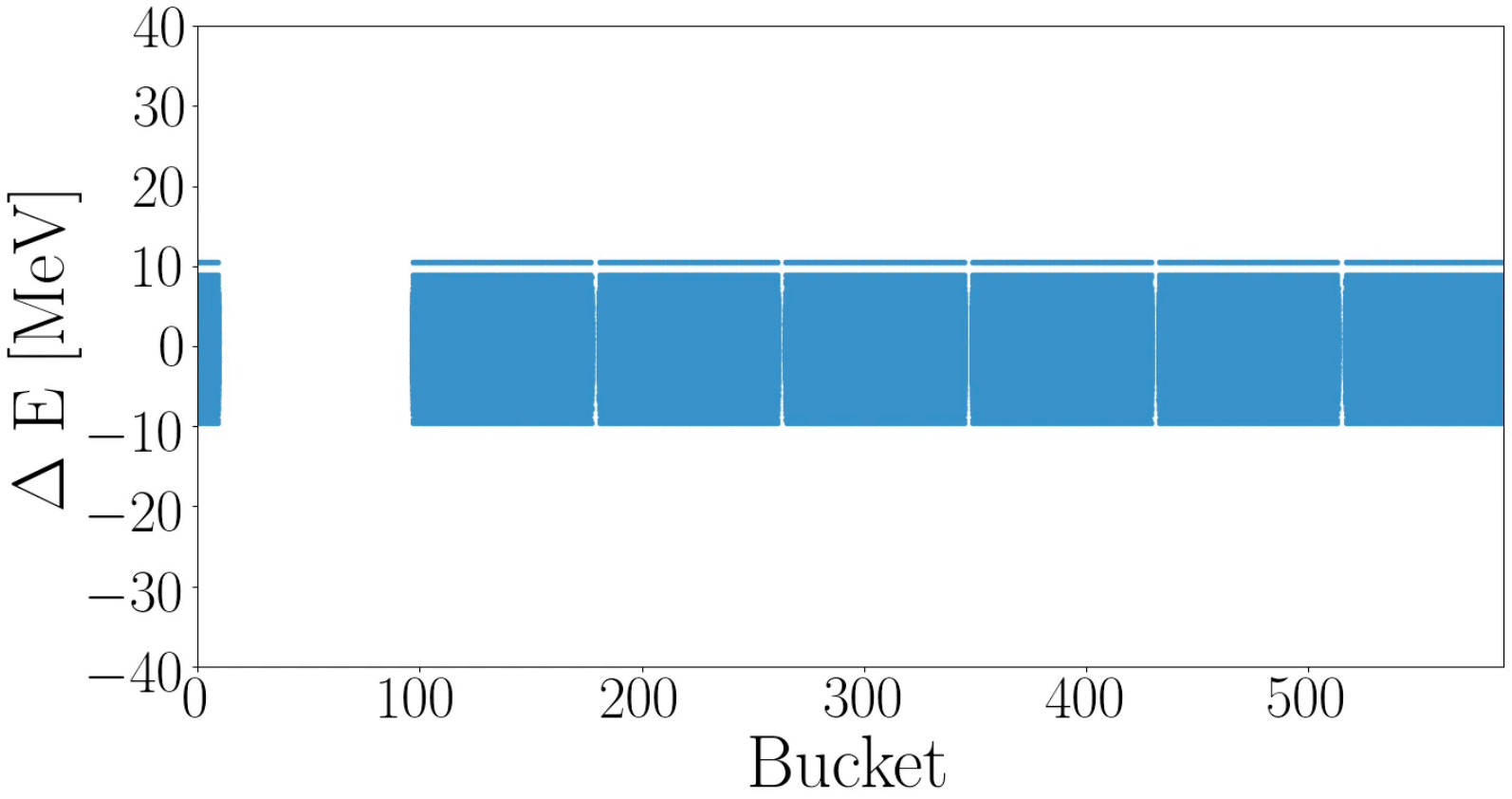
$$\Delta f = h_b f_b$$

$h_b = 84$

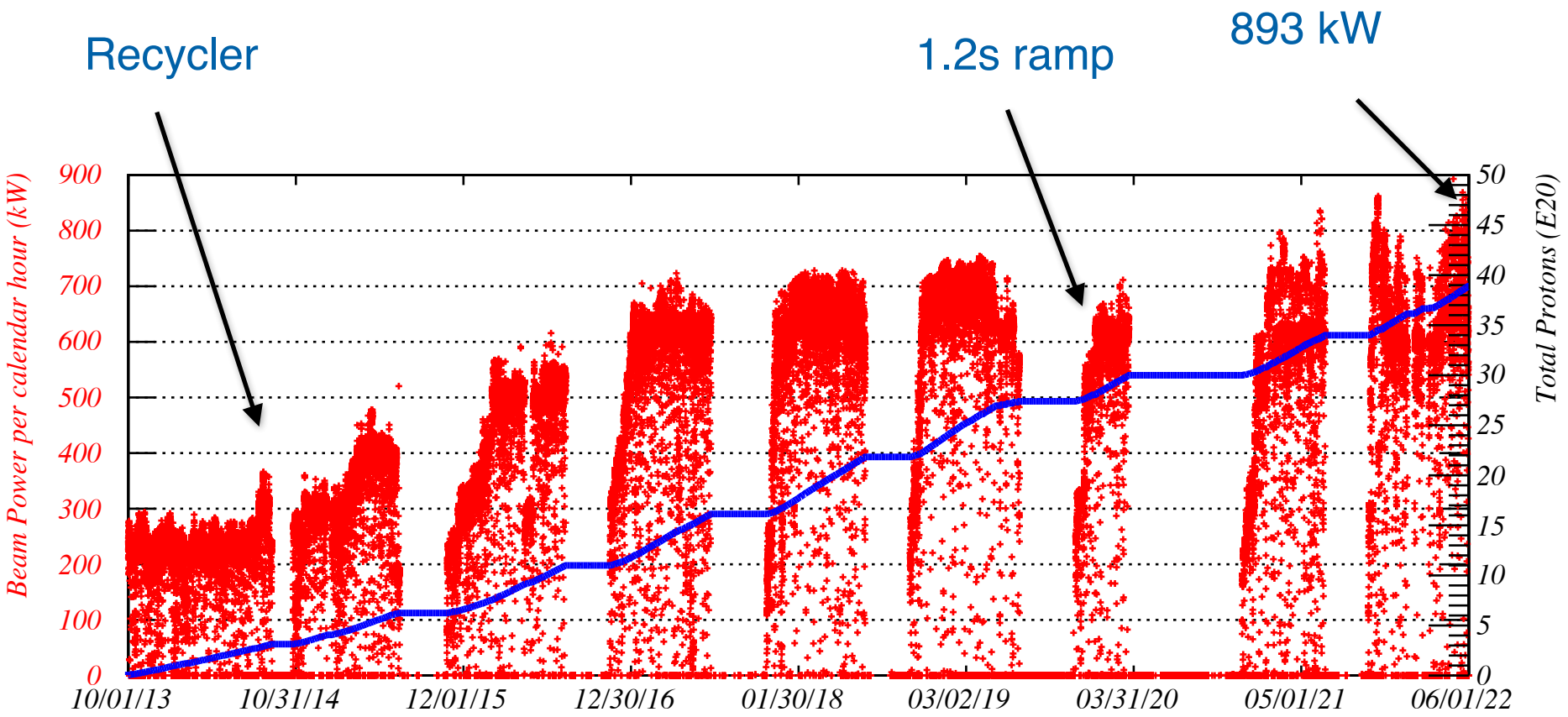
$f_b = 15\text{Hz}$



Slip-stacking



Current performance



Path to 1.2 MW - PIP II

PIPII

PIP-II will provide a highly capable, reliable, upgradeable and expandable scientific infrastructure

PIP-II performance

Injection into Booster	Current Performance	PIP-II (LBNF)
Booster Injection Energy	400 MeV	800 MeV
Particles per Pulse	4.7×10^{12}	6.7×10^{12}
Linac Beam Current	25 mA	2 mA
Linac Pulse Length	30 μs	550 μs
Pulse Repetition Rate	15 Hz	20 Hz

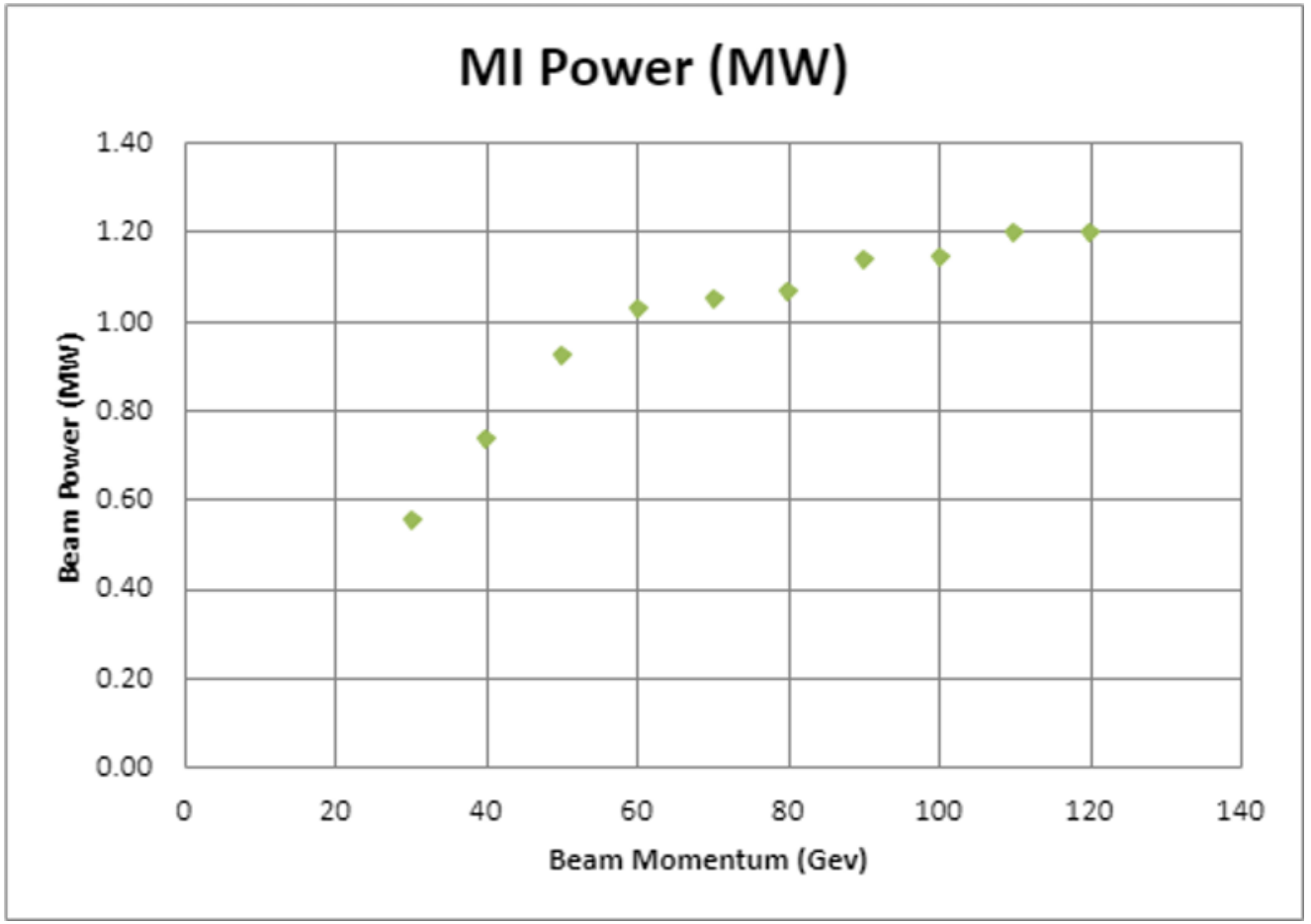
Main Injector	Current Performance	PIP-II
Beam Energy	120 GeV	60-120 GeV
Cycle time	1.2 sec	1.2 sec
Beam Power (60 - 120 GeV)	0.9 MW	1.03 - 1.2 MW

PIP-II Upgradability	Linac	Beam on LBNF target
Upgrade potential	CW, 2 MW @ 1GeV, E_{beam} > 1GeV	2.4 MW @ 120 GeV

Upgrades in current Accelerators required for PIPII.

- Booster has to accommodate beam stripping from the new Linac and accelerate 50% more beam.
  - New injection girder with a new stripping system and absorber.
  - New RF cavities (higher voltage, larger aperture).
  - Damper and collimator upgrades.
  - 20 Hz modifications.
- Recycles has to slip stack 50% more beam at 1680 Hz separation
  - New 53 MHz cavities for slip stacking (Higher voltage; CW capability).
- MI has to accelerate 50% more beam.
  - RF Power.
  - Gamma-t jump.

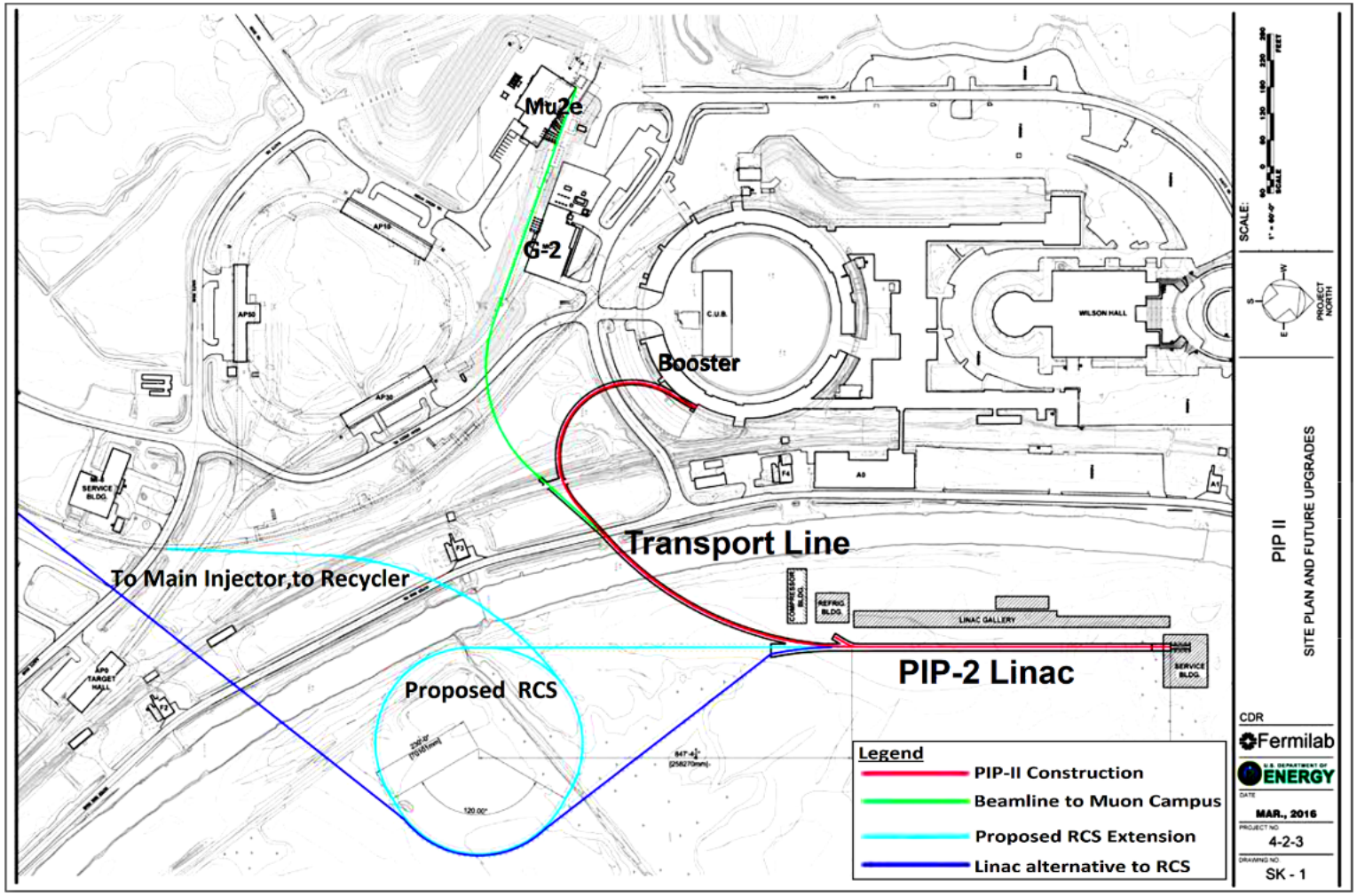
MI beam power vs momentum



Beyond PIP II - pushing to 2.4 MW

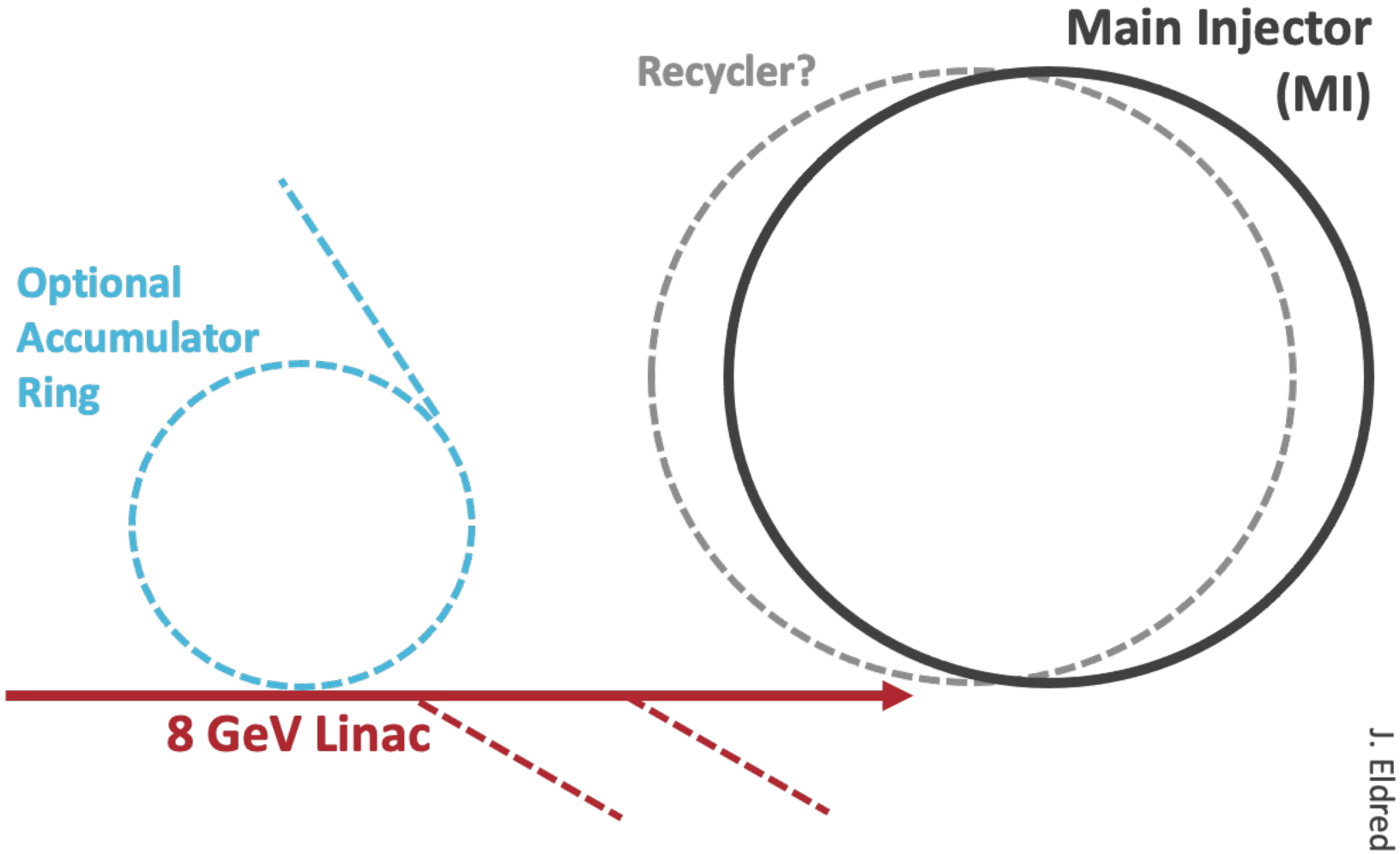
Time to replace the booster….

Beyond PIP II

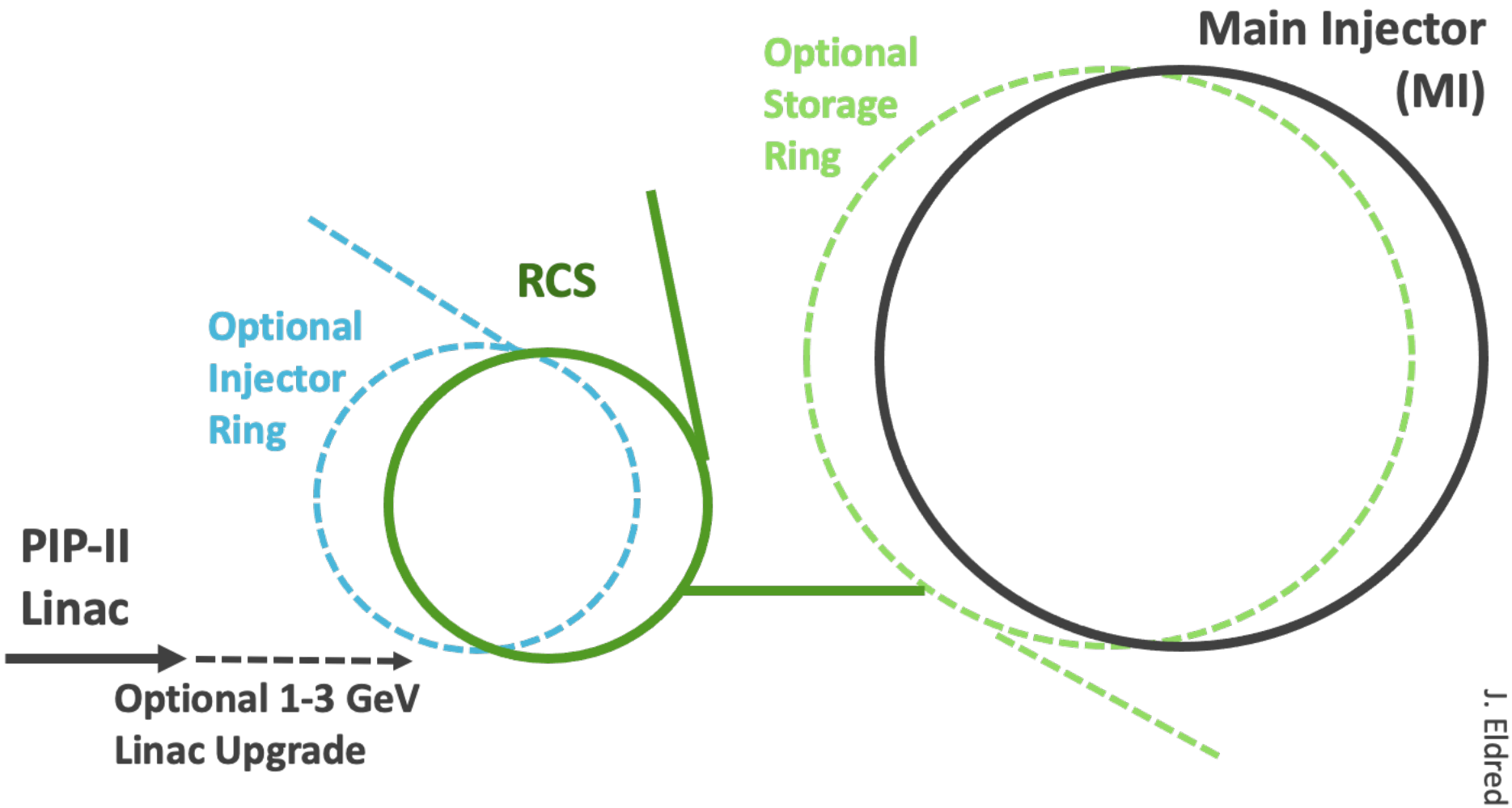


(Linac and RCS not to scale)

Linac option



Rapid Cycling Synchrotron (RCS) option



Summary

- FNAL accelerator complex currently capable of achieving ~900 kW
- PIPII upgrades will push this to 1.2 MW
- Investigating options for going to 2.4MW in the future
  - Linac option vs RCS option