An 8 GeV FFAG Fermilab Proton Driver?

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July 9, 2003

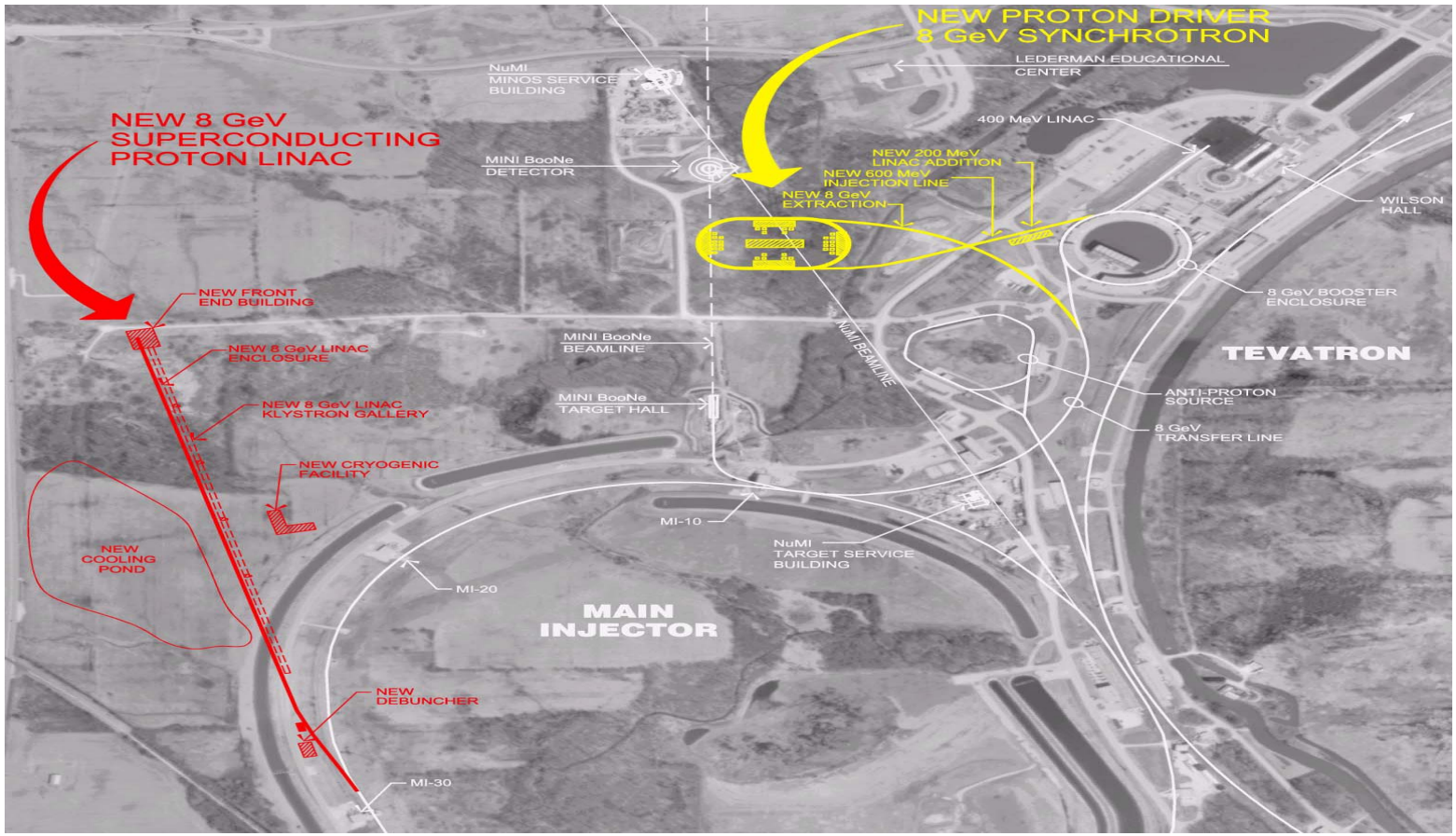
FFAG03 Workshop, Working Group 1

Charge from Fermilab Director

- On January 10, 2002, Fermilab Director issued a charge requesting a design report consisting of three parts:
  - An 8-GeV linac based proton driver
  - An 8-GeV synchrotron based proton driver
  - A 2-MW upgrade of the Main Injector
- Such a high average power, medium energy proton facility was considered to be a possible candidate for a construction project in the U.S. starting in the middle of this decade.

Respond to the Charge – 2 Designs

(Fermilab-TM-2169)



Circular *vs.* Linear

Synchrotron: cheaper, more secure

- Strengths
  - A lot of the work completed - Three design iterations, all documented
  - More matured technology (*"Boring is good"*)
  - Less expensive (TEC $230M, including 15% EDIA, 13% overhead, 30% contingency)
  - Fit the existing complex better
  - Better use of Fermilab's expertise
  - R&D helps improve the performance of existing machines
- Weaknesses
  - Less innovative (less attractive to universities)
  - Longer injection time to the MI
- Possible improvement
  - To investigate ac superconducting magnet technology

Linac: better, more challenging

- Strengths
  - Natural connection to a TESLA type LC
  - More intense beam intensity possible
  - More versatile physics (p, e, X-FEL)
- Weaknesses
  - More expensive
  - Two critical technical issues:
    - 1 klystron driving multiple cavities
    - 8 GeV H^- injection into the MI
  - Difficult to use the MiniBooNE beam line
  - To be a true "proton driver" (i.e., serving a neutrino factory), the linac needs a compressor ring.
- Possible improvement
  - To have a cost review
  - To carefully investigate these technical issues

FFAG as a 3rd Option for Proton Driver

FFAG features	Useful for Proton Driver?
Large acceptance	Yes or No
High intensity	Yes
High repetition rate	Yes

FFAG as a 3rd Option (cont…)

- Keep the same energy (8 GeV), circumference (474.2 m) and protons per bunch (3×10^{11})
- Increase the rep rate by a factor of 7:
  - PD2: 15 Hz
  - FFAG: 105 Hz
- Reduce harmonic number by a factor of 7 by using low frequency RF:
  - PD2: h = 84, f = 53 MHz
  - FFAG: h = 12, f = 7.5 MHz
- Increase number of injection to the Main Injector by a factor of 7:
  - PD2: n = 6 (injection time = 400 ms)
  - FFAG: n = 42 (injection time = 400 ms)

FFAG Parameters

Parameters	Proton Driver (PD2)	FFAG
Extraction kinetic energy (GeV)	8	8
Repetition rate (Hz)	15	105
Protons per bunch	3×10^{11}	3×10^{11}
Number of bunches	84	12
Protons per cycle	2.5×10^{13}	3.6×10^{12}
Protons per hour	1.36×10^{18}	1.36×10^{18}
Normalized transverse emittance (mm-mrad)	40π	40π
Longitudinal emittance (eV-s)	0.2	0.2
RF frequency (MHz)	53	7.5
Average beam current (μA)	60	60
Beam power (MW)	0.5	0.5

Advantages and Concerns of FFAG

- Advantages:
  - Low beam intensity
  - No eddy current problem
  - DC power supply
- Concerns:
  - The present linac may not be used (only operate at 15 Hz)
  - May need more than one ring to reach 8 GeV
  - Need a bunch rotation in the FFAG in order to inject 7.5 MHz bunch into the MI 53 MHz bucket
  - Longitudinal emittance must be controlled below 0.4 eV-s (acceptance of the MI)

Questions & Partial Answers

- What is a reasonable assumption of the FFAG dynamic energy range?
  - In 1964 Frank Cole headed a MURA proposal for an FFAG design that had a dynamic range of 1:21 (200 MeV to 12.5 GeV)
- What are the requirements of a new injection linac?
  - sc or warm, not decided yet
  - Probably can still live with 600 MeV
- Radial or spiral?
  - Phil has solutions for both
  - Radial has more usable space in straight sections
  - Spiral has stronger vertical focusing
  - SC magnet 4 Tesla and –2 Tesla
  - 64 or 32 periods
  - No transition crossing (k = 160, $\gamma_t = \sqrt{(k+1)} = 12.7$)

Questions & Partial Answers (cont…)

- Scaling or non-scaling?
  - Phil's code works for scaling machines only
- What is the required RF peak power?
  - The same power to beam as in PD2 – ramp rate x 7, no. protons x 1/7
  - 7.5 MHz, 200 kW RF built
- How to compare this option to the other two options (synchrotron and linac)?
- Can we have a rough cost estimate?
  - S. Martin's estimate for a 5 MW 2.5 GeV FFAG