Project X
ICD evolution and ACD

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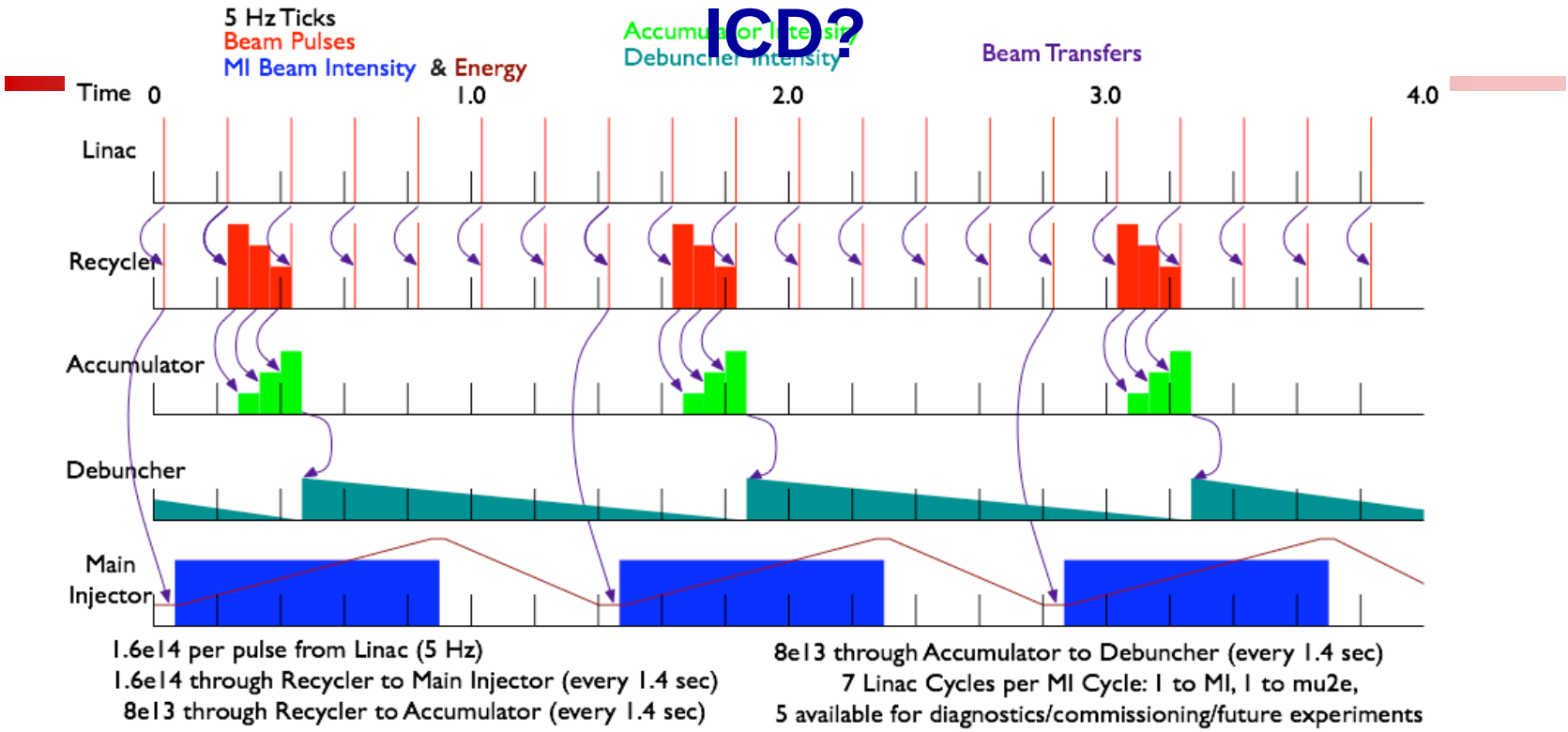
Design Criteria

- Derived from 3 missions of Project X
- Neutrino program with MI: 2 MW at 60-120 GeV
  - Deliver 1.6e14 protons every 0.8 sec (with specific beam requirements);
- Mu2e experiment at 8 GeV: 150 kW slow extraction
  - Specific beam requirement
  - Deliver 1.4e13 protons per spill cycle (15-20 Hz)

Baseline missions

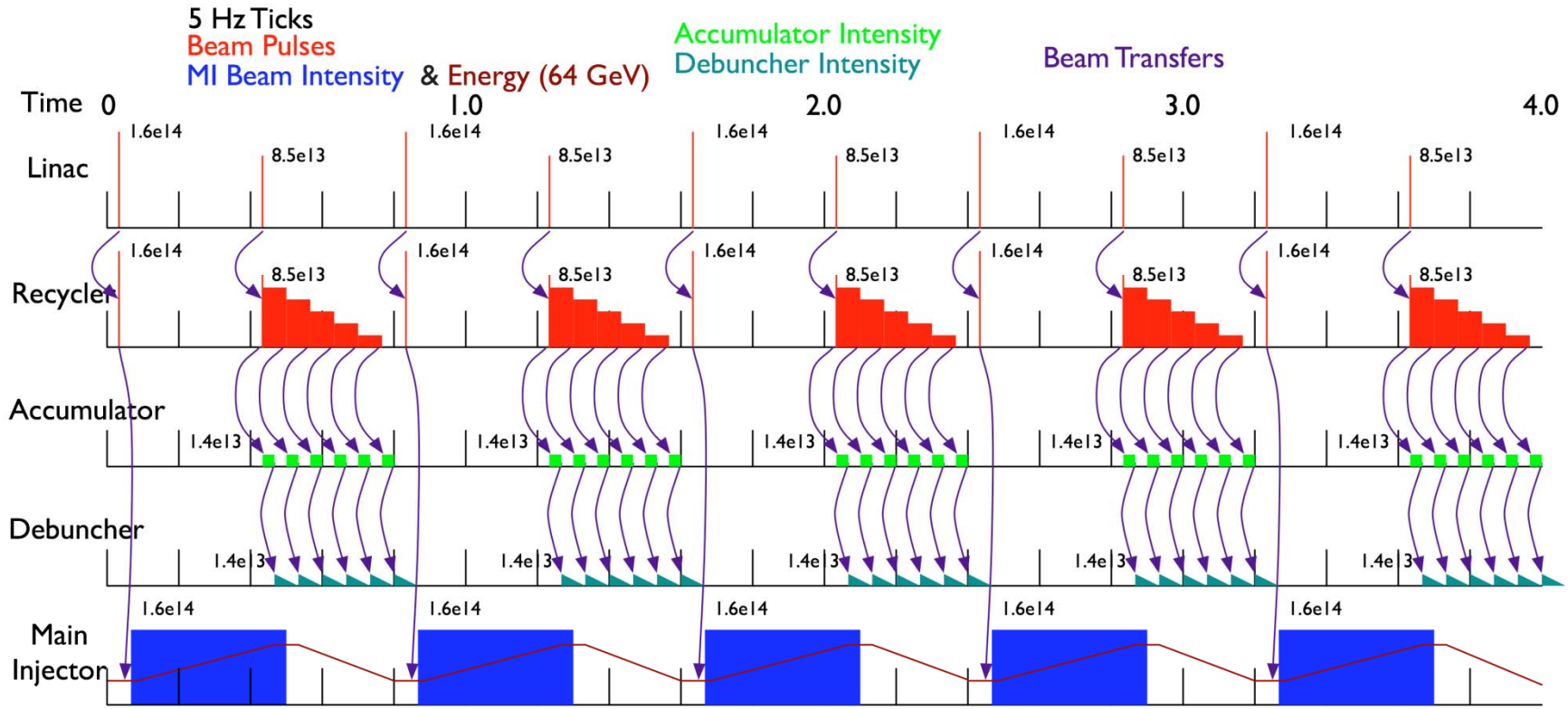
- Provide a plausible self-consistent path to a 2-MW (and higher) proton source for a muon collider
  - single bunch, 2-ns rms, 15 Hz, 2mm rms spot size on target, 8-20 GeV
- We have concluded that the total Project X beam power of 0.5MW at 8 GeV is sufficient to meet first 2 criteria

What is wrong with operating scenario in ICD?



1. Five out of seven linac pulses are unused.
2. 8e13 every 1.4 sec to Mu2e does not work – (1) high tune shift in Debuncher, (2) long emittance too high (150 eV-s)
3. Incorrect linac chopping pattern to extract 3 batches from Recycler
4. Note: Mu2e beam power in this scenario is 75 kW

Operations scenario (60 GeV MI)



1.6e14 per pulse from Linac (2.5 Hz)
1.6e14 through Recycler to Main Injector (every 0.8 sec)
1.4e13 through Recycler to Accumulator (every 67 msec)

1.4e13 through Accumulator to Debuncher (every 67 msec)
2 Linac Cycles per MI Cycle: 1 to MI, 1 to mu2e,
2.12MW for neutrino, 136 kW to mu2e

Assumes 15 Hz transfers to Accumulator
Could use 17.5 Hz transfers (7 instead of 6 every 0.4 seconds)
159 kW to mu2e

Alternative configurations

- Alternative configuration studies are mandated by the DOE project Critical Decision process.
- ACD and its cost range estimate is being created in parallel/series to the ICD by the same people.
- Work on the ACD is part of the RD&D plan
- ACD is considered:
  - in support of baseline design criteria (neutrino and mu2e missions);
    - Examples: 1-ms pulse vs. 3-ms, TSR vs. L-band elliptical cavities
  - in support of future upgrades;
    - Path to 2 → 4 MW
  - in support of project scope changes;
    - not covered in this talk

Why ACD for baseline missions?

- The Recycler is far from being ideal for the proton accumulation:
  - fixed energy, permanent magnets;
  - small acceptance;
  - Large transverse impedance because of wall resistivity;
  - very long (3.3 km) for an 8 GeV ring;
  - no solution found for slow extraction;
- Space-charge tune shift is an issue
  - The maximum tune shift is limited by how much beam losses one can tolerate
  - Fermilab Booster has a tune shift of -0.3 at injection (400 MeV); it looses 10-15% of particles at injection or 300 W (at 7.5 Hz operation)
  - Fermilab MI presently has a tune shift of -0.18 at injection (w/ slip stacking); it looses 5% of particles (mostly because of slip stacking) at injection or 1.5 kW. Number of protons per bunch: 10e10

Tune shift

- 2 MW operation in the MI requires 1.6e14 protons at injection in the Recycler and MI or 3e10 ppb → 3 times what we have now.
- If do nothing -- beam losses will be too high.
- Our solution in the ICD – painting (transverse and longitudinal):
  - Make transverse distribution uniform (by "painting")
  - Make transv. emittance bigger: 15 to 25 μm (100%)
  - Make bunches longer (long. emittance increase, two-harmonic rf)

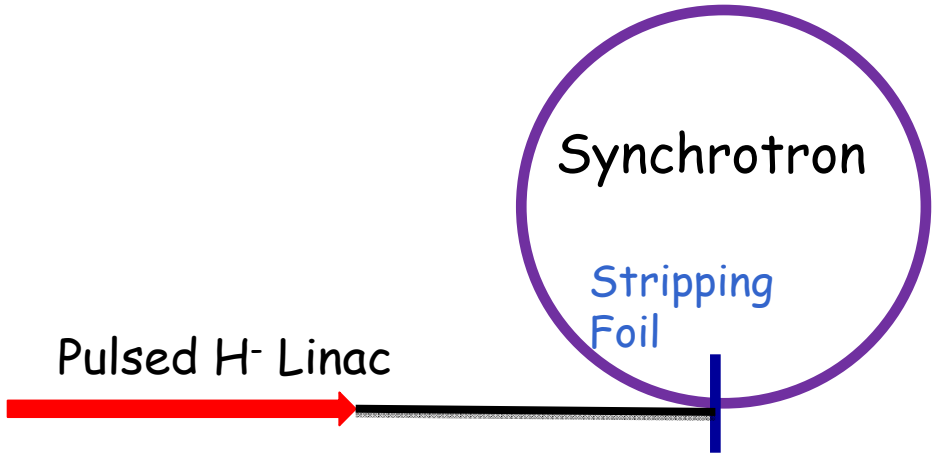
Uniform distribution : $A = \frac{1}{2}$; ε_n is 100% emittance
Gaussian distribution : $A = \frac{3}{2}$; ε_n is 95% emittance

$$\Delta\nu = -\frac{A N_b C r_p}{\pi\beta\gamma^2\varepsilon_n\sqrt{2\pi}\sigma_b}$$

- Ultimately, no more beam power upgrades for MI unless the injection energy is increased.

Alternative configurations

- Are based on the idea that one can reduce the linac energy by making a smaller-size ring with bigger acceptance



- A good alternative appears to be an 800-m Rapidly Cycling Synchrotron (1/4 of MI) with a 2-GeV injection

Cartoon for scale

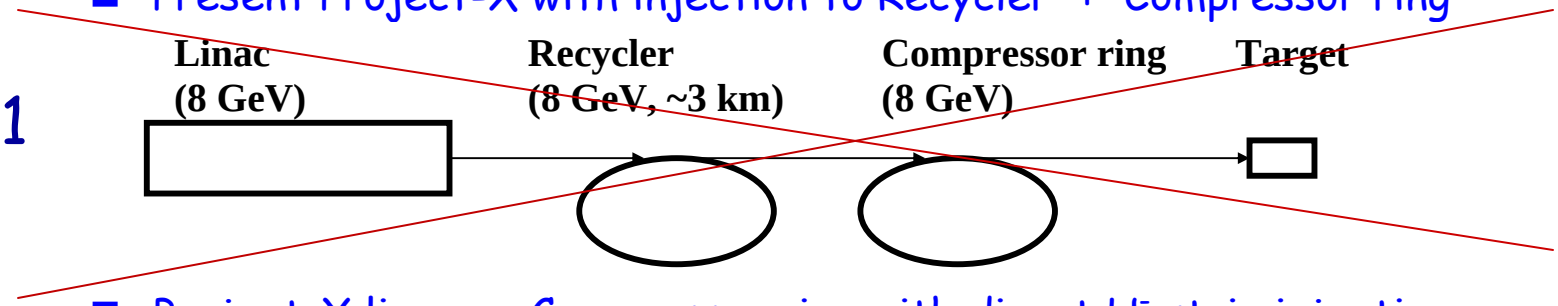
Upgrade path

- Provide a plausible self-consistent path to a 2-MW (and higher to 4 MW) proton source for a muon collider
- Project X ->
  - Neutrino factory -> Muon collider
- We have to anticipate a coherent upgrade path
  - Energy choice
  - Initial infrastructure choice
  - Future developments
- The most general structure for Muon collider proton source
  - Linac -> Synchrotron (?) -> Accumulator ring (?) -> Compressor ring
  - single bunch, 2-ns rms, 15 Hz (or higher), 5-20 GeV, 2mm rms spot size on target

Alternatives to be considered

- Present Project-X with injection to Recycler + Compressor ring

1



- Project-X linac + Compressor ring with direct H^- strip injection

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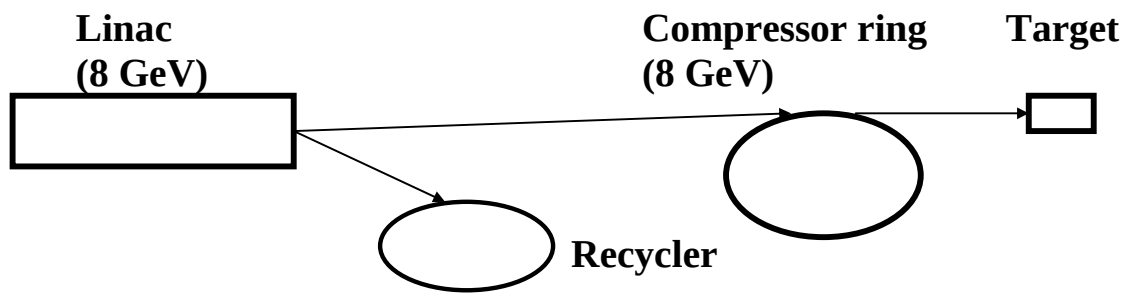

- Alternative Project-X + compressor ring

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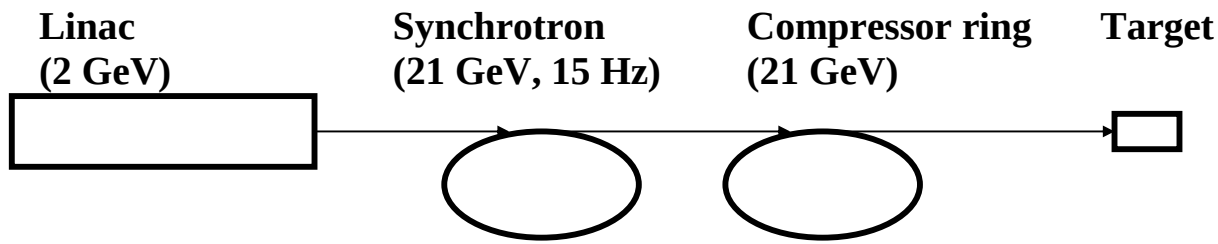

ICD and ACD

ICD

Linac energy	8 GeV
Max. linac current (no chopping)	30 mA
Average linac current (53 MHz chopping)	20 mA
Pulse duration	1.25 ms
Repetition rate	5 Hz
Power	1 MW

ACD(preliminary)

	Stage 1	Stage 2
Linac energy	2 GeV	
Synchrotron energy, GeV	8	21
Average linac current (53 MHz chopping)	20 mA	
Pulse duration	0.32 ms	
Repetition rate, Hz	15	15
Power, MW	0.5	2.2

Meets design criteria for nu and mu2e

Conclusions for upgrades study
(preliminary)

- Option 1 does not work
- Option 2 has a limited beam power reach: 1 MW for 8 GeV, 15 Hz, single bunch (2-ns rms, 2-mm rms size)
- Option 3 has a power reach to 4 MW at 21 GeV, allows to increase the beam power in the MI beyond 2 MW by increasing injection energy to 21 GeV.

Summary

- The design criteria and general requirements of Project X are defined
- From the general requirements:
  - The scope of Project X is defined
  - The requirements of the technical subsystems are derived
- The system requirements drive the design and development plan goals.
- A RD&D team was assembled to formulate and execute the design and development plan.
- The updated RD&D plan will be released by the end of February, and will incorporate input from this meeting
- Specific goals for each sub-system have been defined.
- The resources required to accomplish these goals have been defined.