Accelerator Frontier

Panel 4

Medium- and Small-scale Accelerator Facilities

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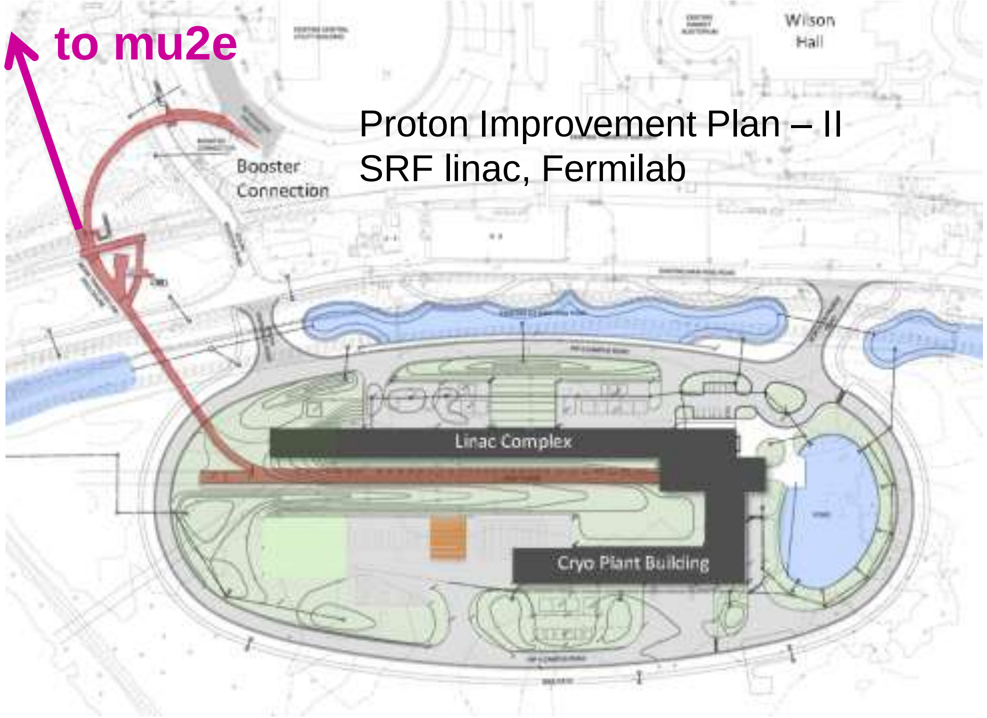
(Snowmass'21 AF Conveners*)*

Accelerators for Rare Process

Snowmass 2021

We should efficiently utilize existing and upcoming facilities to explore dedicated or parasitic opportunities for rare process measurements - examples:



Existing SLAC SRF linac

4-8 GeV e- for LDMX

Upcoming PIPII SRF linac

800 MeV protons

Beam ops in 2028-29

162.5 MHz bunches

upto 2mA → 1.6 MW possible

~17 kW for LBNF/DUNE ν's

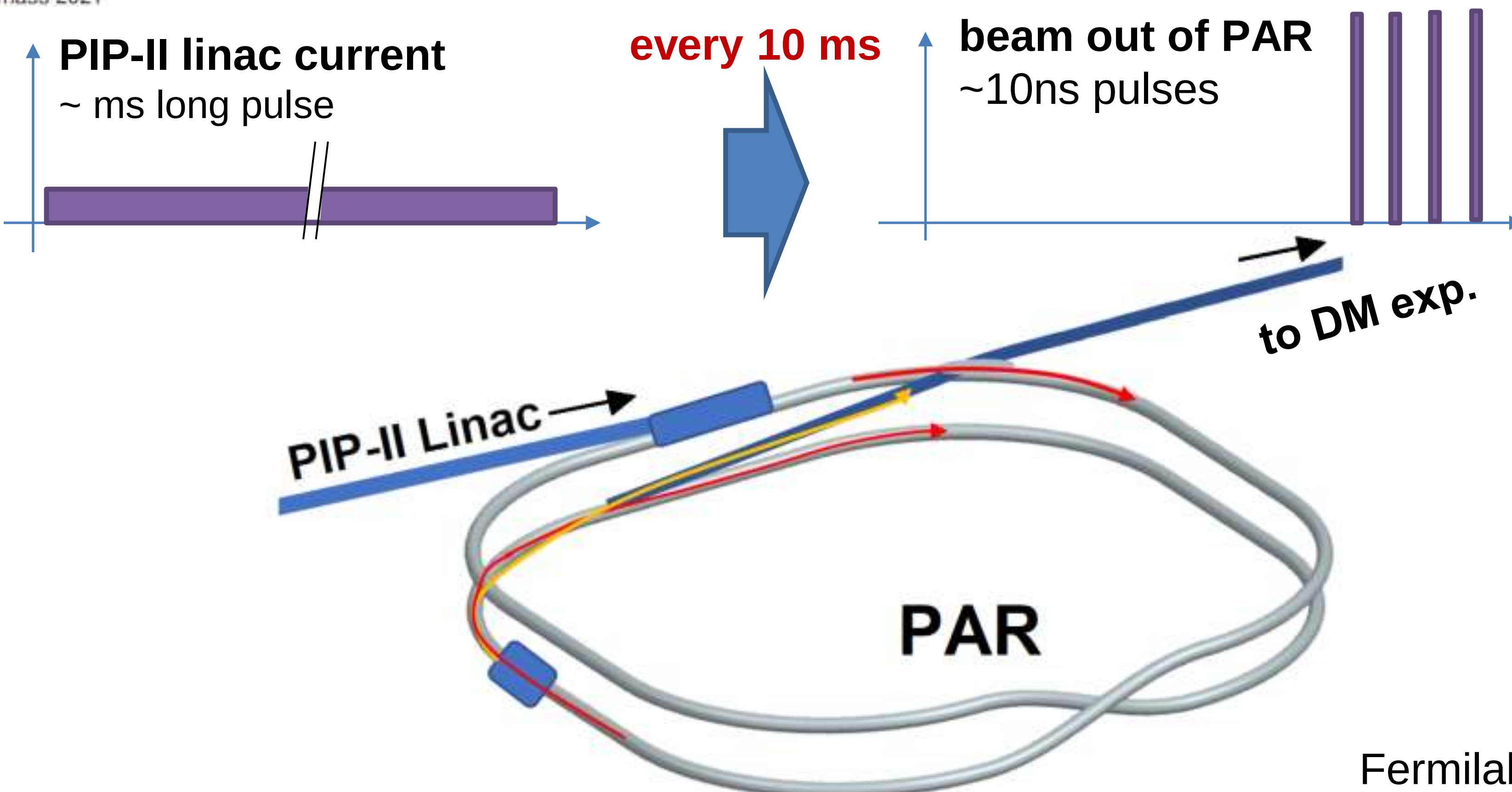
(resulting in 1.2MW in MI)

The PIP-II scope enables the accelerator complex to reach design proton power on LBNF target, but still leaves 98.8% of the beam for other users!

PIP-II Possibilities

- RF or magnet beam switch(es) to send 800 MeV protons to various experiments:
  - For example: CLFV experiments, e.g., mu2e-II can utilize ~100kW of beam power if it comes in special format (81 MHz = ½ of 162.5 MHz bunches, very short, with 20 Hz rep rate… most mature)
- Or a dedicated PIP-II Accumulation Ring (PAR)
  - Transforms long, low current PIP-II linac pulse into few (4) short very intense bunches for one-by-one extraction:
  - Also can deliver ~100kW of avg beam power

PIP-II Accumulator Ring (PAR)



https://arxiv.org/abs/2203.07339

Features:

- Fixed E=0.8-1.0 GeV proton storage ring
- C=480m in the form of a *folded figure 8*
- Power 100 kW for **Dark Sector** program, 100Hz
- There is also compact version C=120m, which would better serve CLFV experiments

Fermilab

Medium- and Small-Scale Facilities

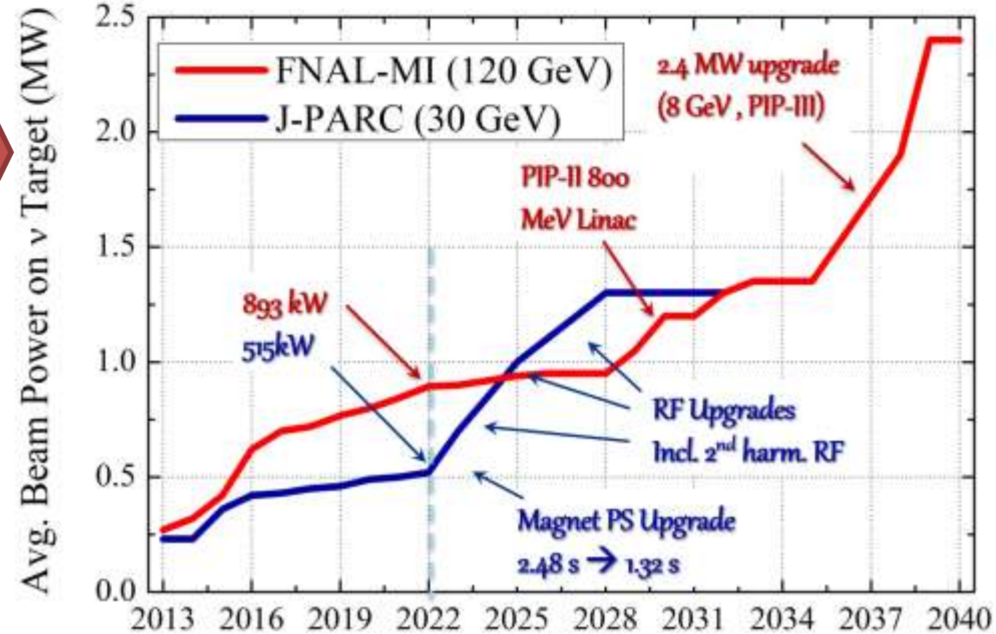
Snowmass 2021

- #1: We have a broad array of accelerator technologies and expertise to design and construct prioritized medium- and small-scale HEP accelerator projects (“can start design now”). Expect P5 to tell us “what”.
- #2: We support RPF aspirations to establish a program to fully utilize ~MW of 0.8 GeV proton beam power to be available after PIP-II construction.
- #3: The Booster replacement (part of the 2.4 MW LBNF/DUNE Phase II, late 2030’s) – either RCS or SRF Linac – will offer additional opportunities (spigots) for the far future medium- & small-scale experiments. and such opportunities should be considered in its design

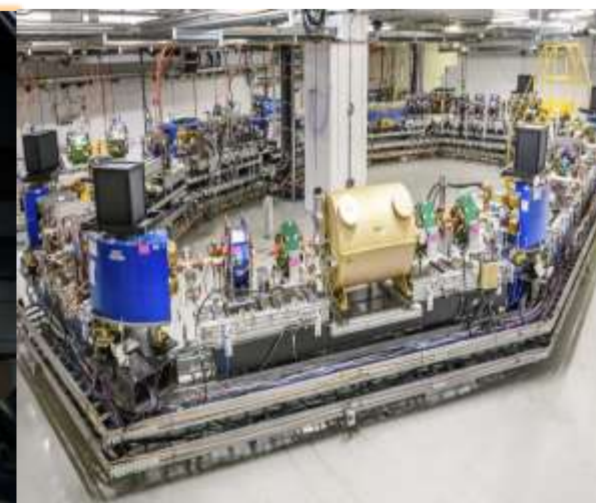
Back up slides

2.4 MW Upgrade: Challenges

- Competition with Hyper-K / J-PARC
- Short timeline, design Q:
  - Other spigots ($\mu 2e$-II, DM and RPF, MuCollider)
- Cost challenge
- The rest of the complex
  - Main Injector RF upgrade
  - 2.4 MW target R&D
- Performance risk (beam losses):
  - Instabilities
  - Injection, collimation
  - Space-charge effects
    - IOTA-ring *p* R&D



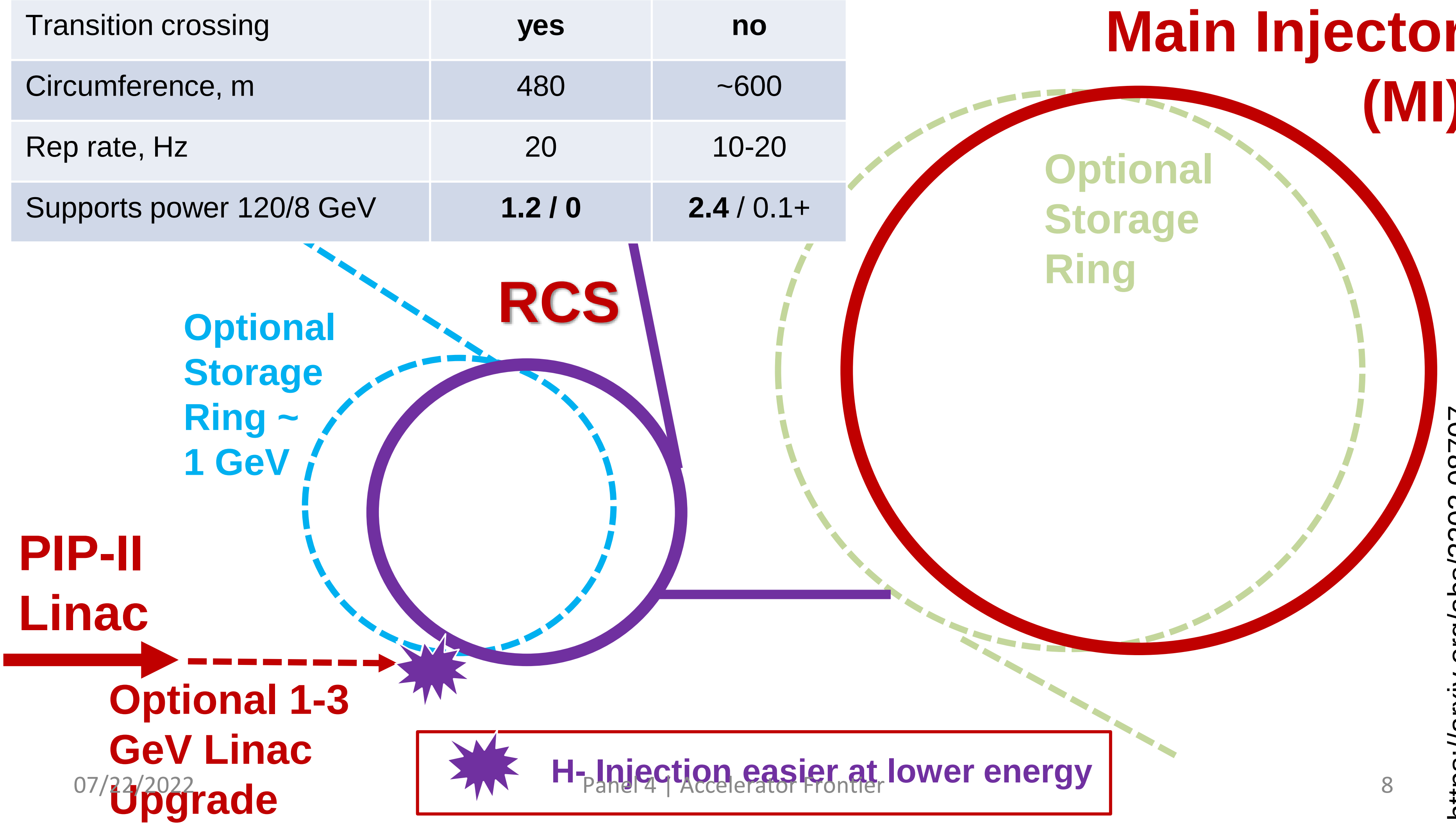
NUMI horn 0.9MW



Space-charge dominated ring IOTA

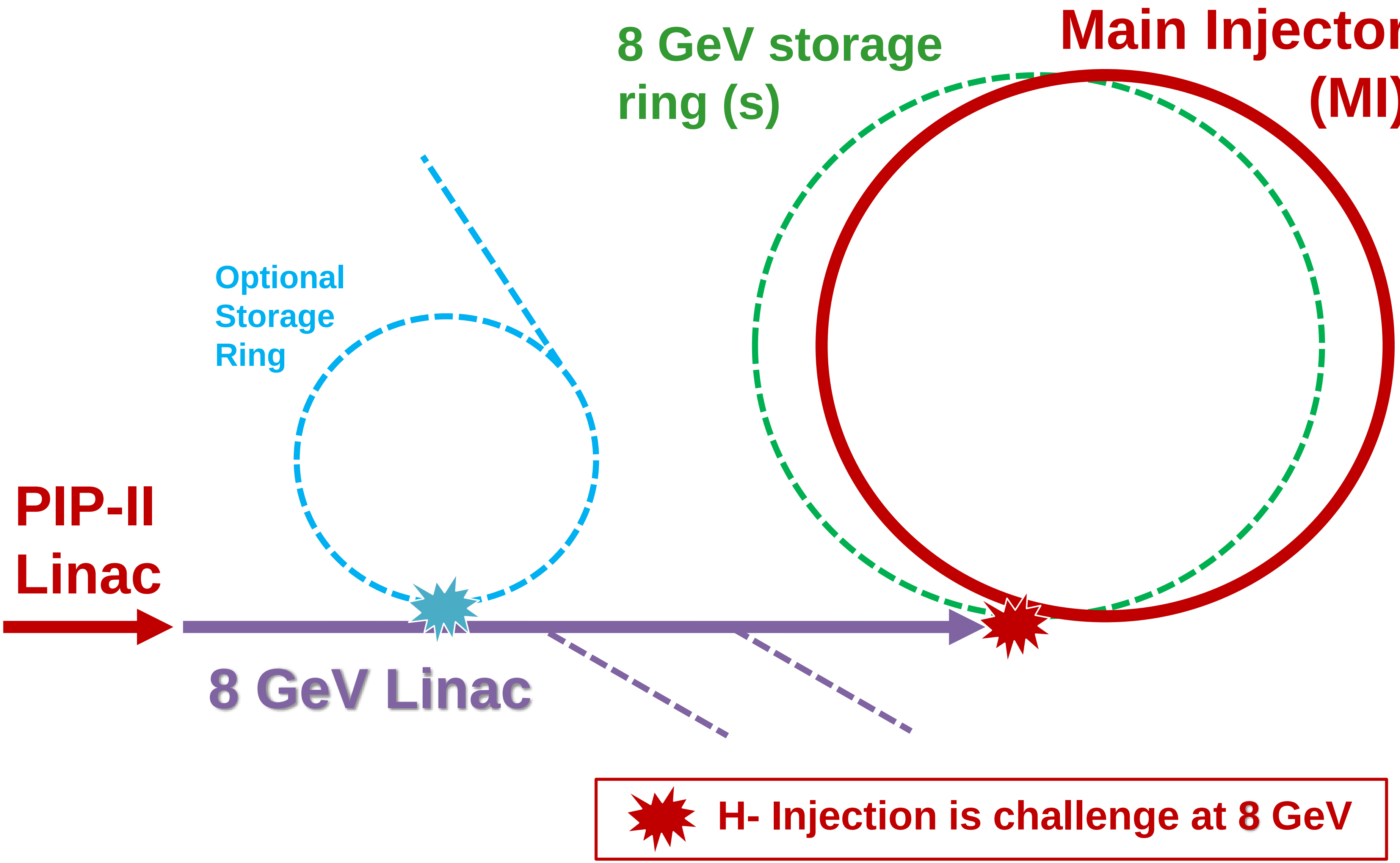
2.4 MW: Rapid-Cycling Synchrotron (RCS) Option

	8 GeV Booster	8 GeV RCS
Injection energy, GeV	**0.8**	**1-3**
Transition crossing	**yes**	**no**
Circumference, m	480	~600
Rep rate, Hz	20	10-20
Supports power 120/8 GeV	**1.2 / 0**	**2.4** / 0.1+



https://arxiv.org/abs/2203.08707

Path to 2.4 MW: 8 GeV Linac Option



II: >20 Proposed Experiments For Rare Processes

(most via Snowmass Whitepapers)

Searches for DM, axions, EDMs, CLFV experiments, muons, light mesons, beam dump experiments…calls for corresponding beam facilities @FNAL,SLAC,Jlab,SNS

Experiment	Experiment type	Primary beam particle	Beam Energy [GeV]	Beam power [kW]	Beam time structure
Proton Storage Ring: EDM and Axion Searches	Precision tests, Dark Matter	proton	0.7 GeV/c beam momentum	1e11 polarized protons per fill	Fill the ring every 1000s
Physics with Muonium	Precision tests	proton (producing surface muons)	0.8 GeV	1e13pm1 POT per second	CW
Nucleon Electromagnetic Form Factors from Lepton Scattering	Neutrino	electron or proton (producing muons)	0.85 GeV to 2 GeV	1 nA to 10 microA for electrons, 10^7 to 10^9 per second for muons	A continuous or pulsed structure (ideally with a duty factor of 1% or larger) should be sufficient
Rare Decays of Light Mesons (REDTOP)	Precision tests	proton	1.8-2.2 GeV (Run I), 0.8-0.92 (Run II), 1.7 (Run III)	0.03-0.05 (Run I), 200 (Runs II and III)	CW, slow extraction for Run I
Ultra-cold Neutron Source for Fundamental Physics Experiments, Including Neutron-Anti-Neutron Oscillations	Precision tests	proton	0.8-2	1,000	quasi-continuous
CLFV with Muon Decays	CLFV	proton	Not critical 0.8 to a few GeV	100 or more	continous beam on the timescale of the muon lifetime i.e. proton pulses separated by a microsecond or less. The more continuous the better
Mu2e II	CLFV	proton	1 to 3	100	pulse width 10s of ns or better separated by 200 to 2000 ns. Flexible time structure and minimal pulse-to-pulse variation
Fixed Target Searches for new physics with O(1 GeV) Proton Beam Dump	Dark Sector, Neutrino	proton	0.8 to 1.5 GeV	100 or more	<O(1 micro s) pulse width for neutrino measurements, <O(30 ns) pulse width for dark matter searches, 10^(-5) or better duty factor
PRISM-like Charged Lepton Flavor Violation	CLFV	proton	1-3 GeV	up to 2 MW	15ns pulses at a rep rate of about 1 kHz
Electron Missing Momentum (LDMX)	Dark Sector	electron	~3 GeV to ~20 GeV	O(1 electron per RF bucket at 53 MHz)	CW-ish
Electron Beam Dumps	Dark Sector	electron	few GeV	10^(20) electrons on target over the experiment al runtime	Pulsed beam (duty factor not specified)
Proton Irradiation Facility	R&D	proton	Energy is not very important	1e18 protons in a few hours	Pulsed beam (duty factor not specified)
SBN	Neutrino	proton	8	32	20Hz
Mu2e	CLFV	proton	8	8	<10^(-10) extinction
Fixed Target Searches for new physics with O(10 GeV) Proton Beam Dump	Dark Sector, Neutrino	proton	8	up to 115	Beam spills less than a few microsec with separation between spills greater than 50 microsec
Muon beam dump	Dark Sector	proton (producing muons)	3 GeV muons	3e14 muons in total on target for the whole run	CW
Muon Collider R&D and Neutrino Factory	R&D	proton	5 - 30GeV	1e12 to 1e13 protons per bunch	10 - 50 Hz rep rate and bunch length 1-3 ns
Muon Missing Momentum	Dark Sector	proton (producing muons)	few 10s of GeV	10^(10) muons per experimental runtime	Pulsed beam (duty factor not specified)
High Energy Proton Fixed Target	Dark Sector, Neutrino	proton	O(100 GeV)	1e12 POT/s therefore ~20 kW	CW via resonant extraction. "If we could up the duty factor that would be even better"(?)
Test-Beam Facility	R&D	proton	120, lower energies would also be beneficial	10 to 100 kHz on the testing apparatus	Pulsed beam (duty factor not specified)
Tau Neutrinos	Neutrino	proton	120	1200 or higher	MI time structure

Electron beams:

~ GeV to multi-GeV

Proton beams:

~2 GeV CW-capable beam

~2 GeV pulsed beam from storage ring ~1MW

~8 GeV pulsed beam ~1MW

120 GeV Slow extraction or LBNF beam

In many cases, existing or planned facilities can be and should be fully utilized!

Panel Charge

Panel discussion 4: [formerly panel **3]**

Frontiers: CF, NF, RPF, UF, EF, AF

Title: Mid and Small scale Experiments/Facilities and the proposed timelines

Abstract: Drawing on the proposed experiments and facilities as discussed in the panel on physics highlights from Frontiers, the presentation from each participating Frontier will cover the following topics:

1. Which physics goal(s) does the facility/experiment support
2. Elaborate on the timelines for R&D (machines and detectors [as applicable]), construction and data collection
3. Discuss machine and design challenges which have been solved and make the facility viable in the near future. [2025-2035]
4. Discuss machine and design challenges which still need to be solved and proposed timeline for the R&D. Would these be in the 2025-2035 frame, or are they severely technologically limited and remain as long term challenges to be embarked upon ie, 2035+?