PIP-I+ Task Force Report : Overview

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For the PIP-I+ Task Force
Fermilab AAC, Dec 6-8, 2016

PIP-I+ Task Force Charge (from S.N. 07/15/2016):

…To explore the physics and technology issues and limitations, related to operating the Fermilab accelerator complex at ***~1 MW beam power level****. This should be viewed as a continuation of PIP-I and a stepping stone towards PIP-II. I expect the first report(s) to be presented at the AAC meeting (Dec 4-6). The areas to explore should include (but not limited to):*

1. Booster
2. Recycler
3. MI
4. NuMI beam line
5. Target systems
6. Infrastructure

PIP-I+ Boundary Conditions:

Time scale:

Start (in parallel and after PIP) 2019

Ends (before PIP-II) <2026

$$ Scale:

(none at this stage, PIP numbers for reference)

	FY17	FY18	FY19	FY20	FY21	FY22	FY23
PIP-I	$9M	$10.4M	$6M	$4M	0	0	0
PIP-I+	0	0	?	?	?	?	?

PIP-I+ Task Force: People

V.Shiltsev, lead	*APC Dir.*
M.Convery	*Assoc. Div. Head / Accel. Systems*
S.Holmes	*Assoc. Div. Head / Intensity Upgrades*
P.Czarapata	*Deputy Div. Head*
P.Derwent	*PIP-II Department Head*
V.Lebedev	*PIP-II Project Scientists*
W.Pellico	*Prot.Source Dept. Head / PIP manager*
I.Kourbanis	*Main Injector Dept. Head*
R.Zwaska	*Target Systems Dept. Head*
C.Moore	*External Beams Dept. Head*

(invited for discussion on particular topics: T.Kobilarcik, A.Valishev, C.Crawley and Yu.Alexahin)

What is PIP-I+

- Possible plan to upgrade Fermilab accelerator complex performance before PIP-II:
  - Booster PPP 4.3e12 → 5.5e12 28%
  - MI cycle 1.33 s → 1.2 s 11%
- Performance improvements:
  - Beam to NoVA 700 kW x (1.28 x 1.11) = 992 kW

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Synopsis of PIP-I+ : 16 Elements, Costs (M$), Risks

	Element	TotCost	M&S	FTEyr	Yrs	PPP	1.2s	20Hz	Risk	PIPII
PS1	Booster ramped dogleg	1.5	1	2	1.5	o			perf	√
PS2	B- transverse dampers	0.3	0.1	0.8	1	o			perf	√
PS3	Booster collimators	1.8	0.8	4	1	o			perf	√
PS4	B&Linac HW @ 20 Hz	1.7	1.2	2	1			o	none	√
PS5	New tank 1/RFQ	6.2	5	5	2.5	o			cost	
PS6	400 MeV collimator	1.1	0.6	2	1.5	o			none	
PS7	New D-magnets Booster	12.1	9.6	10	5	o		o	**COST**	√
MR1	1.2s MI PS/RF modif'n	0.15	0.1	0.2	0.5		o		none	√
MR2	MI gamma-t jump	1.2	0.8	1.5	1.5			o	none	√
MR3	RR RF for 20 Hz	3.2	1.9	5	2			o	none	√
T1	Window, Baffle, Target	0.6	0.23	1.5	1.2	o	o		perf	
T2	Horns, Power Supplies,…	1.2	0.7	1.3	1.6	o	o		perf	
T3	RAW Protection	2.1	1.25	2.3	1.8	o	o		perf	
T4	Decay pipe window	1.0	0.3	2.7	1.2	o	o		perf	
T5	Targetry Instrumentation	0.6	0.25	1.2	0.9	o	o		perf	
I1	20 Hz controls/diagnostcs	5.5	3.5	8	2			o	cost	√

PIP-I+ Elements: "slide/element" in back-ups also - to be presented in detail

Charge Question #3, coordinator: Vladimir Shiltsev

3. Considerations for increased beam power of up to 900 kW to NOvA substantially before PIP-II are being technically evaluated. Assuming that the physics motivation is sound, please comment and provide guidance whether these considerations are worth pursuing.

15min: V. Shiltsev - Introduction & Scope

15min: W. Pellico - Proton Source

15min: I. Kourbanis - MI/RR and Muon Campus

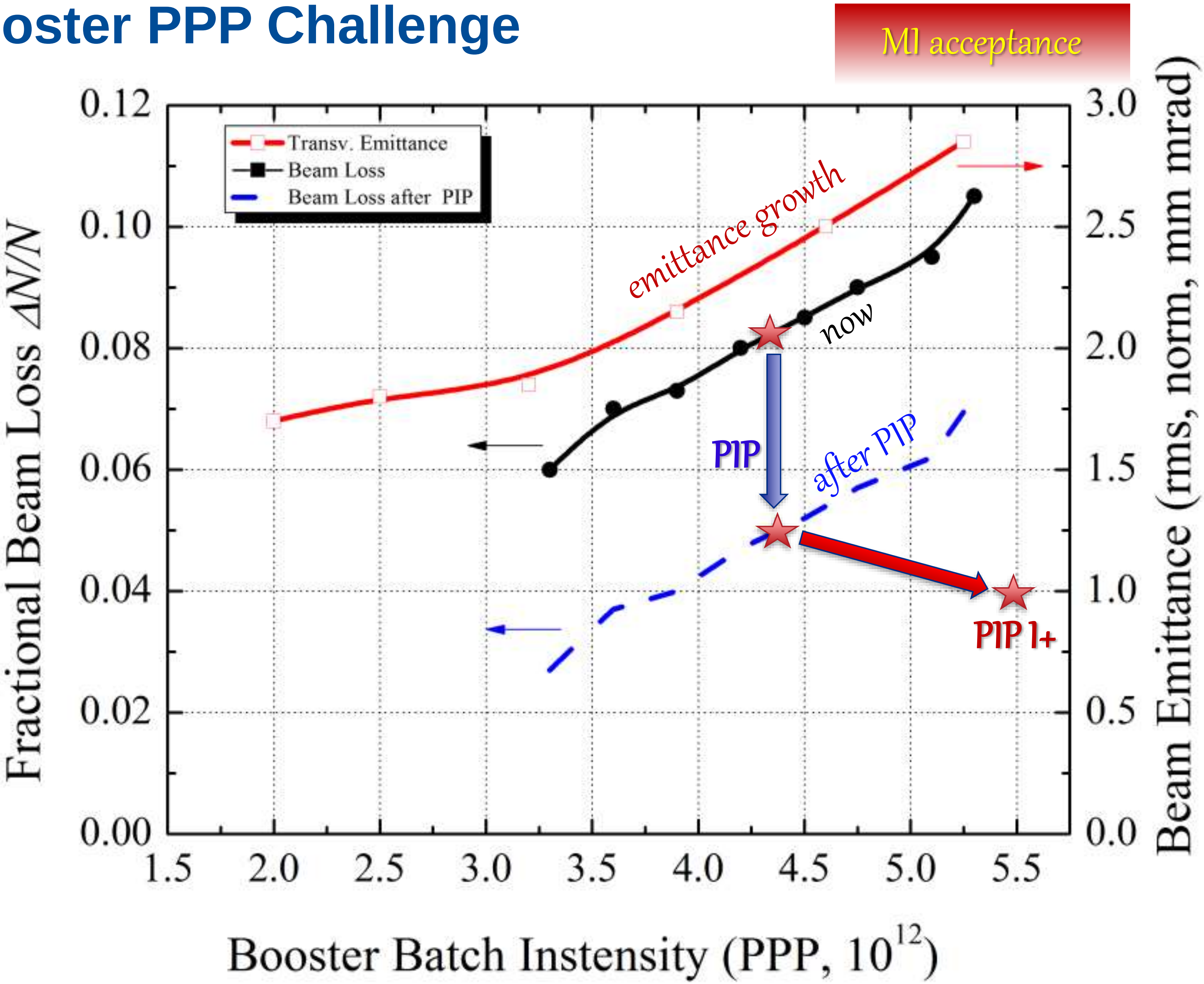
15min: R. Zwaska - Targetry

60min: Discussion

PIP-I+ : Highest Risk Elements

- Performance Risk:
  - Proton Source (PS#) elements to assure Booster PPP increase from 4.3e12 to 5.5e12
  - Targetry (T#) elements: upgrade ~700kW capable system to ~1MW system with good lifetime
- Largest Cost Items:
  - Element PS7: Construct and install new D-magnets in the Booster to increase apertures – upto 12M$
  - Elements PS4 and MR3: Modify Linac, Booster and Recycler, and Accelerator Controls for 20 Hz Booster cycle operation – > 11M$ combined

Booster PPP Challenge



In back-ups: “Traveler” for Each Element

Goal:

(what we want to achive)

Scope of work:

1. (what needs to be done)
2. (what needs to be done)
3. (what needs to be done)

2. **Potential**
   - Expected changes
   - Expected performace gain
3. **Budget/Resources**
   - *XXX*M$ M&S
   - *YYY* FTEs
4. **Time**
   - ZZZ yrs
5. **Issues/Required R&D**
   - Studies
   - Simulations
   - Modeling

Back up slides –

all PIP-I+ Elements

PS #1: Booster Ramped Doglegs

Goal: Rampdown extraction dogleg magnets so field is zero at injection

Scope of work:

1. analyze existing HW and PSs ?
2. Install and commission necessary HW and PSs ?
3. Perform studies and simulations to quantify the benefits ?

2. Potential
   - Losses at Injection reduced by a factor of 2 ?
   - Lower ζ at inj
3. Budget/Resources
   - 1M$ M&S
   - 1.5-2 FTEs
4. Time
   - 1.5 yrs ?
5. Issues/Required R&D
   - Studies at inj with dogleg off and optics symmetrized ?
   - Simulations ?

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PS #2: Booster Dampers - Transverse

Goal: build and install new transverse damper

Scope of work:

Take measurements with present system (injection)

1. Determine capability with present system
2. How many units of chromaticity
3. Impact on beam loss

- New system necessary
  - Simulations
  - Damper design
    - Power system
    - Controls

2. Potential
   - Lower ζ at inj
   - Inj losses down ?%
3. Budget/Resources
   - 60-100k M&S
   - 0.4-0.8 FTEs
4. Time
   - 1 yr for cavity & testing
5. Issues/Required R&D
   - Testing of present system
   - Studies to evaluate losses vs ζ at injection
   - Simulations/design possibly new cavity

- Question – is HT an issue

PS #3: Booster Collimators

Goal: upgrade Booster collimation system

Scope of work:

Determine if new 2 stage design can improve present system.

1. Continue effort on understanding present system (PIP)
2. Move to new effort on studies to understand if 2nd stage can work in a new configuration
   - IF yes – design 2 stage with PIP II intensities in mind
3. build, install and commiss. it

2. Potential
   - Collimate PIP II intensities with reduced losses
     - Ring losses
     - Surface losses (shielding)
3. Budget/Resources
   - 800 K M&S
   - 3 - 4 FTEs
4. Time
   - .5 yr to determine if useful
   - 1 year to build
5. Issues/Required R&D
   - Testing of present system
   - Simulation of new design

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PS #4: Booster/Linac 20 Hz

<u>Goal: </u>make Linac and Booster run at 20 Hz

<u>Scope of work:</u>

Continue to determine issues related to operating Linac/Booster @ 20 Hz.

1. Determine Linac Limitations (quads, RF)
2. Resume previous testing – Girder setup
3. Determine if upgrades to allow 15 Hz is feasible – Linac?

Implementation: buy, install, commission HW, PSs, control system

2. Potential
   - Allow 20 Hz to begin before PIP II – fully functional!
   - More beam to users & Lower SS loss
     - MI – 60 GeV operations?
3. Budget/Resources
   - 1.2 M M&S (Booster GMPS)
   - 0.4-0.8 FTEs
   - Linac – uncertain 500ish quads…RF limitations?
   - In task I1 – account "Controls – Booster/Linac"
     - 2 – 3 M
     - 3 – 5 FTEs
4. Time
   - 1 yr for Booster (1.5 FTE)
   - Linac .5 investigate?
   - Controls – 3 FTE
5. Issues/Required R&D
   - Continue testing of present Linac system
   - Finish studies on Girder 20 Hz
   - Controls – engineer 20 Hz upgrade

PS #5: New Tank 1/RFQ

Goal: replace Tank1/RFQ

Scope of work:

Determine a replacement for tank 1 and associated RFQ

1. Determine if tank 1 can be shortened – to remove first 21 aperture limiting quads - If not possible – new design of higher inj. energy DTL tank 1
2. Design a new RFQ that matches DTL 1 replacement

Implement (build, install, commission) replacement for tank 1 and associated RFQ

2. Potential
   - Reduced emittances (50%)
     - Reduced Linac losses
     - Reduced Booster losses
3. Budget/Resources
   - 5 M M&S
   - 4 - 5 FTEs
4. Time
   - 1 yr for Linac DTL investigation
   - 1.5 yr for RFQ/Lattice design
5. Issues/Required R&D
   - Can tank 1 be cut at quad 21 (2.1 MeV)
   - RFQ design for 2.1 MeV 20 Hz

PS #6: 400 MeV Collimator

Goal: install 400 MeV collimator

Scope of work:

Determine if a collimator can fit into 400 MeV line and help reduce tails lost in the Booster injection region.

Implement (build, install, commission HW,control system, etc)

2. Potential
   - Reduced Booster injection losses
     - Injection losses are small but will increase with duty rate/turns
     - Tails on beam are scrapped off in injection region/Gradient magnets
3. Budget/Resources
   - .6 M M&S
   - 2 FTEs
4. Time
   - 1 yr investigation/design
   - Install – 6 months
5. Issues/Required R&D
   - Qualify extent of beam loss associated with Linac beam -
   - Limited space in 400 MeV line – feasibility of improving/reducing injection losses

PS #7: Booster D magnet

Goal: replace some/all Booster D-magnets

Scope of work:

Build some number of replacement magnets for D style combined function magnet.

1. Design 3 inch aperture replacement magnet
2. New lattice that includes 2 to 24 magnets
   1. Lattice constraints
   2. Impedance
   3. Beam pipe (eddy current)
   4. Injection/Extraction

Install and commission

- Potential
  - Larger injection/Extraction regions
    - Fit PIP II injection
    - Fit injection beam dump
    - Larger dogleg separation
  - Longer straight sections
    - Helps collimation upgrade
    - Additional extraction kicker (reduced voltage)
  - Improved aperture
    - Reduced losses
      - Limiting aperture in ring
      - Opens extraction aperture
    - Reduced impedance
- Budget
    - 200k per magnet
    - 2 FTE development, 2 FTE build

MI/RR #1: MI PS/RF Upgrade for 1.2 s Ramp

Goal: make 1.2s MI ramp

Scope of work:

1. Build a 1.2 sec MI ramp by speeding up the early parabola.
2. Measure the tuner voltage limit at lower frequencies on the spare MI RF cavity.
3. Perform Power supplies and MECAR studies with the new ramp.
4. Commission the new ramp with beam.

2. Potential
   - Increase the MI beam power by 11%.
3. Budget/Resources
   - $50K M&S
   - 0.2 FTEs
4. Time
   - 0.5yrs
5. Issues/Required R&D
   - ?

Targetry #1: Beam, Window, Baffle, & Target

Goal: Modify beam parameters, vacuum window, baffle, & target for up to 1 MW

Scope of work:

1. Determine optimal proton beam parameters
2. Validate beam parameters with experiments
3. Redesign and replace pre-target window
4. Redesign & replace baffle
5. Retrofit target with enlarged segments

2. Potential
   - Increase operating envelope to 1000 kW for these devices
   - Reduce risk from uncompliant beam window
3. Budget / Resources
   - 230k$ Direct M&S
   - 1.5 FTE.yrs
4. Minimum Duration
   - 1.2 yrs
5. Issues/Required R&D
   - Beam parameter validation
   - Thermal simulations
   - Window fabrication technique

Targetry #2: Horns, Power Supply, Stripline, & Modules

<u>**Goal:**</u> Improve cooling of horn connections and stripline; module refurbishment; power supply optimization

<u>Scope of work:</u>

1. Retrofit horn 1 with better-cooled stripline connections
2. Refurbish modules, understand misalignments
3. Add air cooling for stripline penetrations
4. Rewire power supply for shorter pulse

2. Potential
   - Increase operating envelope to 1000 kW for these devices
   - Regain motion capability of modules
3. Budget / Resources
   - 700k$ Direct M&S
   - 1.3 FTE.yrs
4. Minimum Duration
   - 1.6 yrs
5. Issues/Required R&D
   - Thermal simulations
   - Reliance on air cooling
   - Operation of horn system at higher voltage

Targetry #3: Air, Water, & Radiation Protection

Goal: Improve air & water cooling systems; better control radiation sources

Scope of work:

1. Upgrade all RAW systems (pumps, heat exchangers, filters, instrumentation)
2. Replace chiller with heat exchanger to ICW
3. Add heat exchanger coils to air circulation system, replace fan motor
4. Produce additional temporary, local shielding
5. Add further air, water, and dehumidification systems for tritium control

2. Potential
   - Increase operating envelope to 1000 kW for these devices
   - Keep tritium releases and worker dose ALARA
3. Budget / Resources
   - 1250k$ Direct M&S
   - 2.3 FTE.yrs
4. Minimum Duration
   - 0.8 yrs
5. Issues/Required R&D
   - Absorber and decay pipe cooling redundancy reduced
   - Corrosion control limited by prompt water production
   - Airborne releases

Targetry #4: Decay Pipe Window

Goal: Develop and implement replacement decay pipe window

Scope of work:

1. Develop replacement window and analyze for 1000 kW
2. Develop robotic replacement system
3. Replace window

2. Potential
   - Increase operating envelope to 1000 kW for these devices
   - Reduce risk from observed corrosion on existing window
3. Budget / Resources
   - 300k$ Direct M&S
   - 2.7 FTE.yrs
4. Minimum Duration
   - 1.2 yrs
5. Issues/Required R&D
   - Window not person-accessible
   - Energy deposition calculations need to be updated with more accurate models
   - Necessity of replacement to be resolved

Targetry #5: Instrumentation

Goal: Develop and implement replacement instrumentation necessary for beam operation

Scope of work:

1. Develop replacement Hadron Monitor
2. Install Hadron Monitor
3. Upgrade other instrumentation as needed

2. Potential
   - Increase operating envelope to 1000 kW for these devices
   - Reduce operational complexity from radiation-damaged hadron monitor inputs
3. Budget / Resources
   - 250k$ Direct M&S
   - 1.2 FTE.yrs
4. Minimum Duration
   - 0.9 yrs
5. Issues/Required R&D
   - Existing design requires re-engineering for construction
   - Alternate technologies not ready for construction

I #1: 20 Hz Controls

Goal: upgrade controls/beam diagnostics to run at 20 Hz everywhere : Linac, Booster, RR, MI, beamlines

Scope of work:

- determine issues related to operating complex @ 20 Hz.

- implementation: commission control system

2. Potential
   - Allow 20 Hz to begin before PIP II – fully functional!
   - More beam to users
3. Budget/Resources
   - 3.5 M M&S
   - ~8 FTEs
4. Time
   - 2 yrs
5. Issues/Required R&D
   - Controls – engineer the 20 Hz upgrade

Impact of the 1.2 sec MI cycle on the different experiments

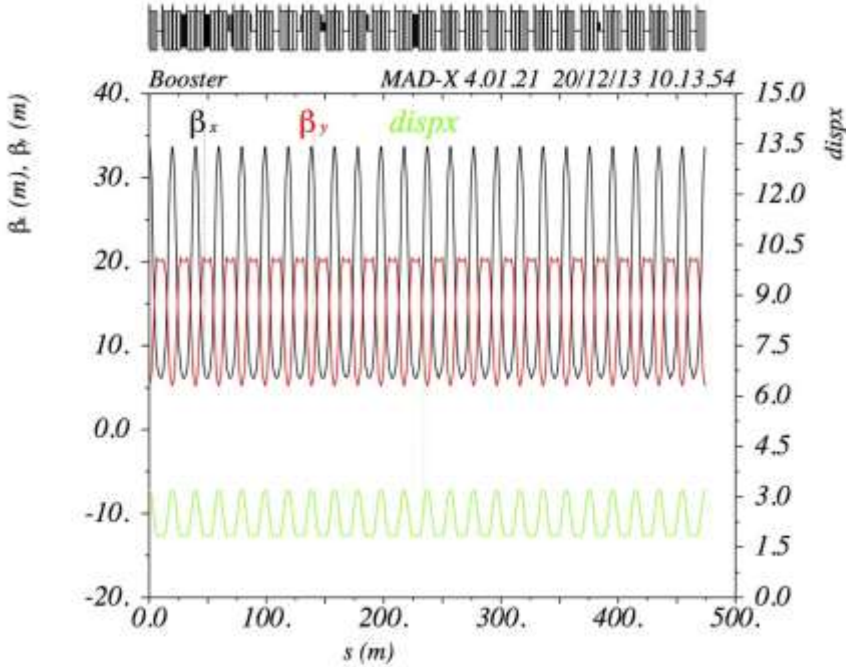
(below, for illustration, we assume same PPP (4.3e12) and only vary MI cyckle time and Booster Rep rate)

	Now	1.2 sec (15Hz)	1.2 sec (20Hz)
NOvA (KW)	665	776	776
BNB* (Hz)	3.57-5.00	3.33-3.33	6.7-8.3
g-2 (E16p/hr)	4.11	2.26	4.77
Mu2e (E16p/hr)	2.06	1.13	2.4

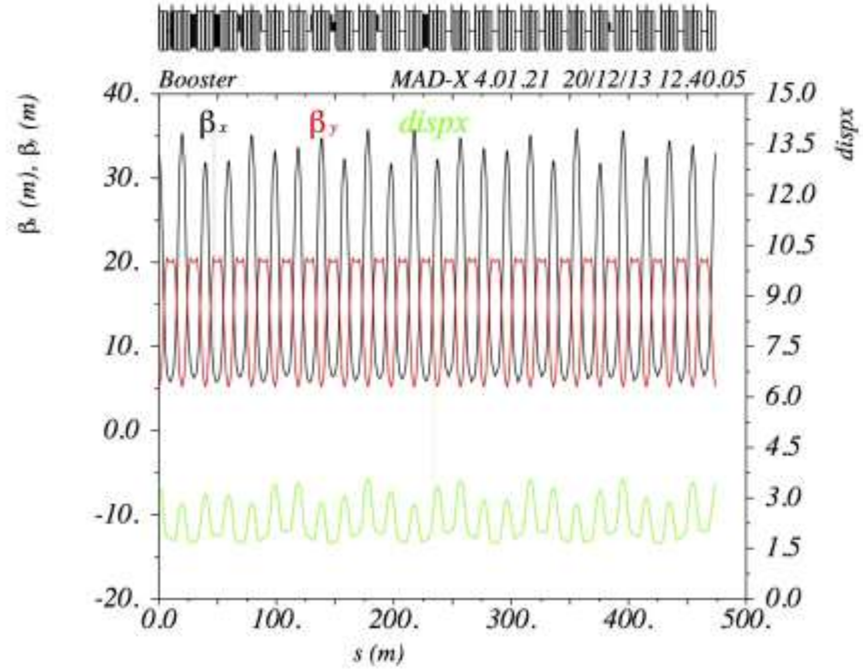
***Intensity on BNB Cycles varies. Rep. rate depends on mode of operation. Rep rate for g-2/Mu2e running in red/green.**

Element PS #1: Booster Ramped Doglegs

Lattice error due to dogleg



Ideal lattice



After turning on dogleg

- Simulations show that "ramping down" the dog-leg magnets (no field at injection) will allow to achieve highly symmetric P=24 beam optics and, as a consequence, much lower fractional losses with space-charge tune-shift parameter dQ_sc increased from current value of -0.35 to about -0.5