Plans for ramping up the complex before PIP-II

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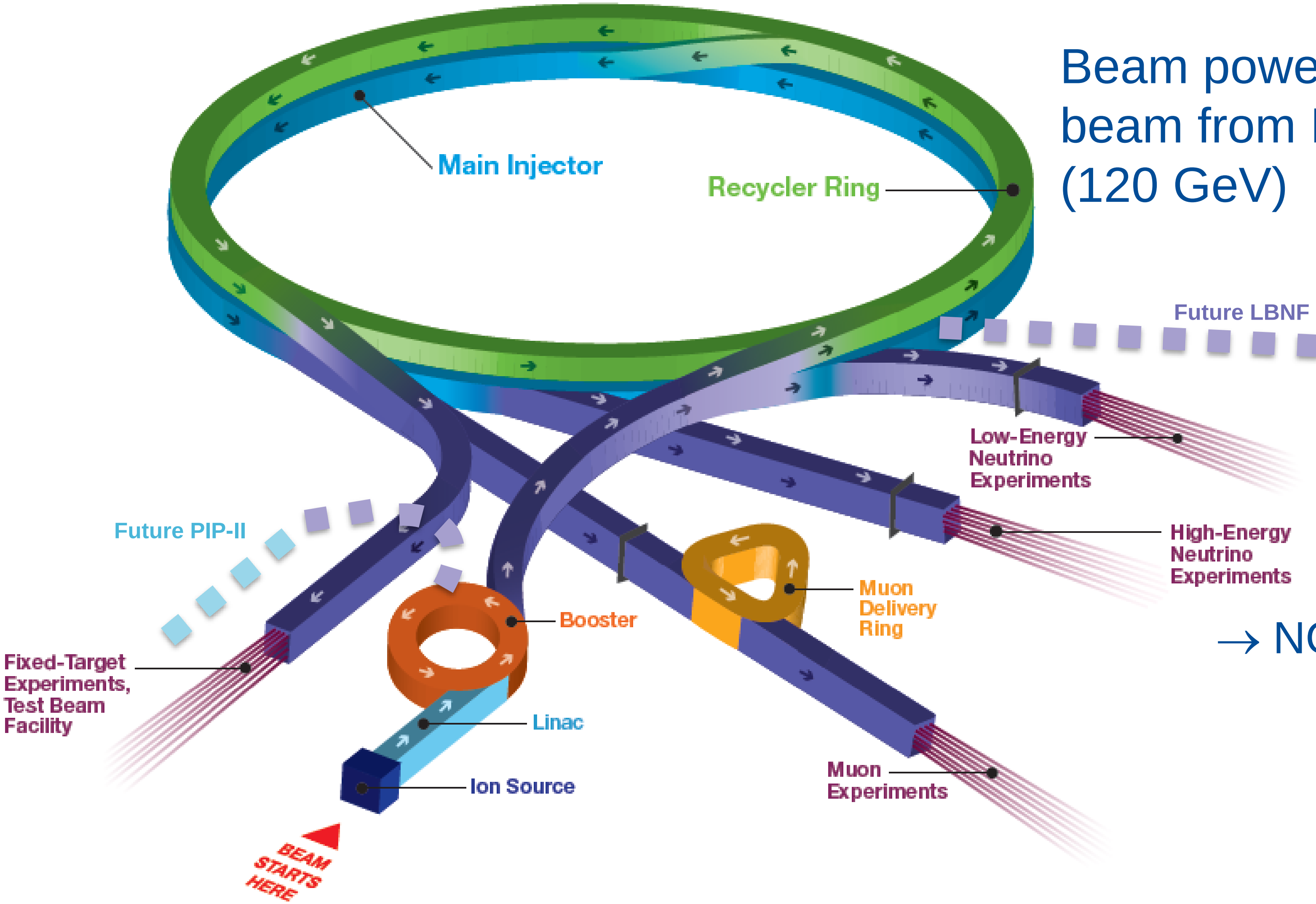
Fermilab Workshop on Megawatt Rings & IOTA/FAST Collaboration Meeting

8 May 2018

Fermilab accelerator complex



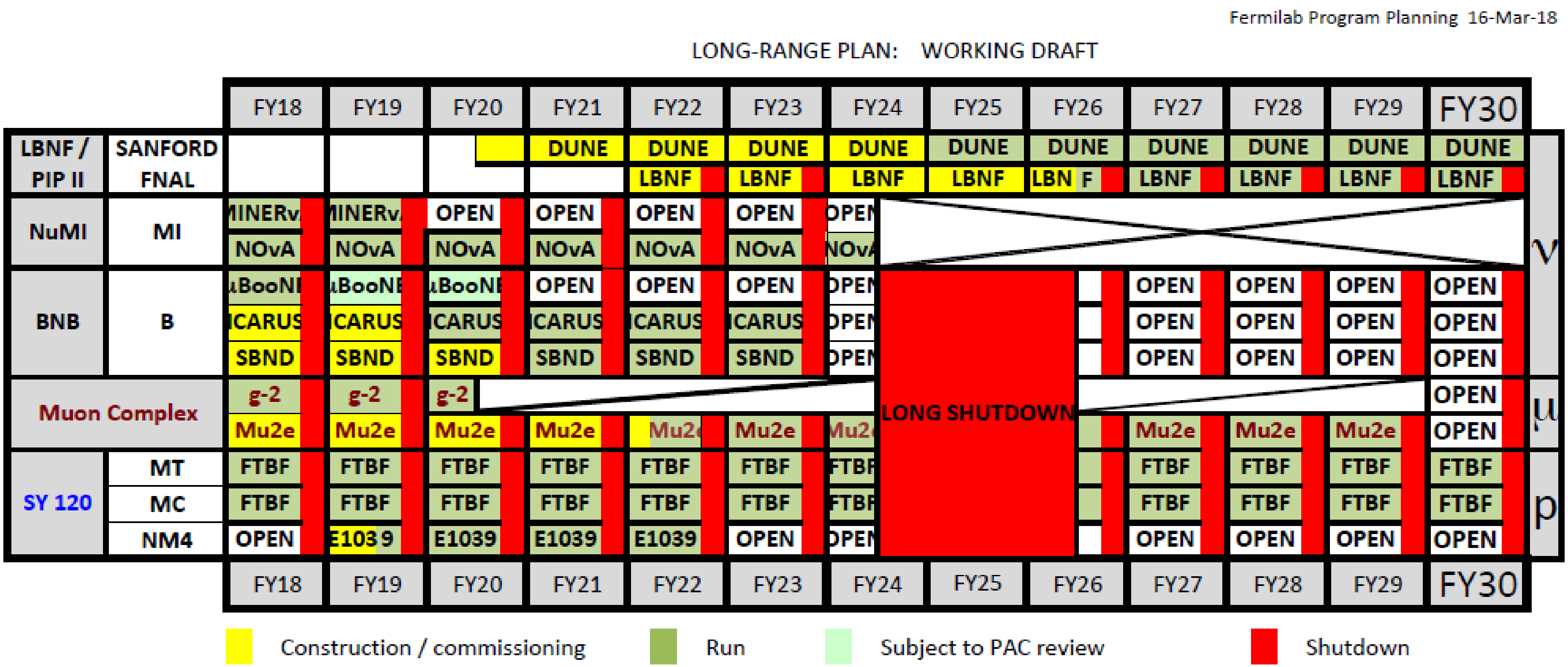
Beam power refers to beam from Main Injector (120 GeV)

→ Future DUNE

→ NOvA

Fermilab long baseline neutrino experiments

- FNAL accelerator complex now provides 700 kW proton beam to the NOvA experiment in the NuMI beamline
- PIP-II will provide 1.2 MW to DUNE in the LBNF beamline



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Increasing beam power keeps NOvA competitive

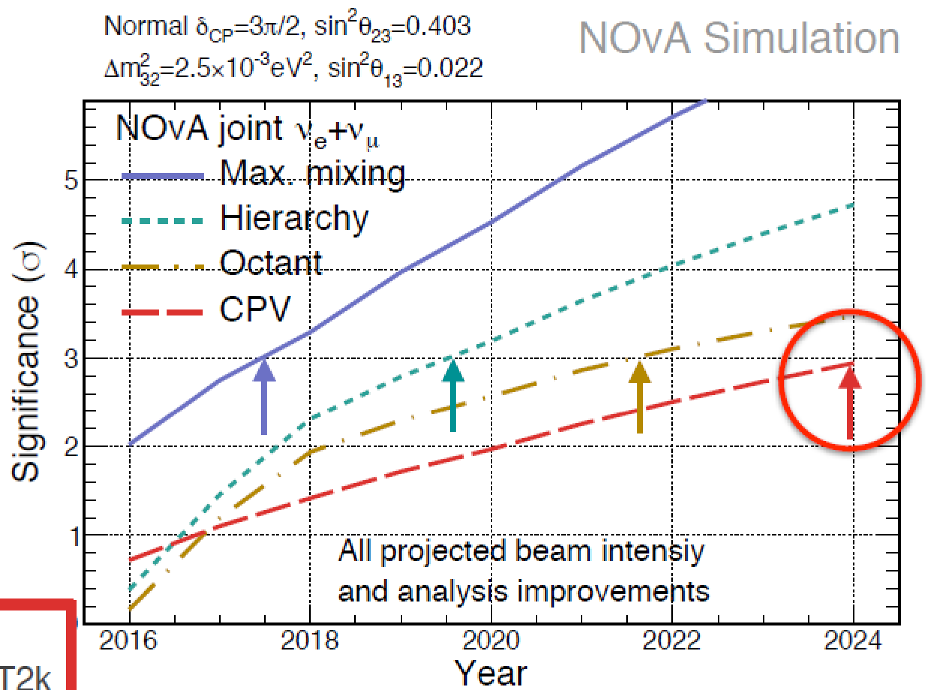
What we could learn from NOvA: Extended Reach

2017: 3σ on the max. mixing
forward by 1 yr over nominal

2019: 3σ on the mass hierarchy
forward by 2 yrs over nominal

2022: 3σ on the octant
possible now in 5 yrs

2024: 3σ CPV
can remain competitive with T2k



NOvA can remain competitive with T2K and beat ORCA/JUNO to the mass hierarchy, but upgrades are required.

Enable 3σ on octant and CPV and gain 1 yr on max. mixing and 3yrs on mass hierarchy

PIP1+, NuMI power ramp from 700kW to 900kW

How could we increase beam power to NOvA?

- Shorten Main Injector (MI) cycle time to 1.2s
  - 11% increase from design (1.33s→1.2s)
  - This capability is close to being available, but…
  - Cuts rate to Muon Campus experiments in half unless also increase repetition rate to 20 Hz
- Increase intensity from Proton Source
  - 28% increase (4.3 E12 → 5.5 E12 protons per pulse)
  - Requires improvements to keep beam quality up and reduce losses even further than achieved by PIP
- Increase rep rate from 15 Hz to 20 Hz
  - Requires significant control system changes
  - Requires RF upgrades in Linac, Booster and MI/Recycler
- All of these require a target station that is robust at 1 MW

Task force led by Vladimir Shiltsev looked at options

- Evaluated cost, duration, risk, compatibility with PIP-II

V Shiltsev 2016 Task Force Report beams-doc-5948

	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	√

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Selected items based on guidance from DOE

- No investment in existing Linac → no 20 Hz
- Compatible with PIP-II (except target station)

V Shiltsev 2016 Task Force Report beams-doc-5948

		Element	TotCost	M&S	FTEyr	Yrs	PPP	1.2s	20Hz	Risk	PIPII
Booster Intensity AIP	PS1	Booster ramped dogleg	1.5	1	2	1.5	o			perf	√
Booster Intensity AIP	PS2	B- transverse dampers	0.3	0.1	0.8	1	o			perf	√
Booster Intensity AIP	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	
Booster Magnet AIP	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	√
Main Injector AIP	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	√
NuMI Target Systems AIP	T1	Window, Baffle, Target	0.6	0.23	1.5	1.2	o	o		perf	
NuMI Target Systems AIP	T2	Horns, Power Supplies,…	1.2	0.7	1.3	1.6	o	o		perf	
NuMI Target Systems AIP	T3	RAW Protection	2.1	1.25	2.3	1.8	o	o		perf	
NuMI Target Systems AIP	T4	Decay pipe window	1.0	0.3	2.7	1.2	o	o		perf	
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Selected strategy to increase beam power to NOvA

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Plan for upgrades for 900kW

- Series of independent Accelerator Improvement Projects

	FY18	FY19	FY20	FY21	FY22	FY23	FY24
NuMI Target Systems	■	■	■				
Booster Intensity	■	■	■				
Booster Magnets		■	■	■	■		
Main Injector			■	■			
Booster RF			■	■	■	■	■

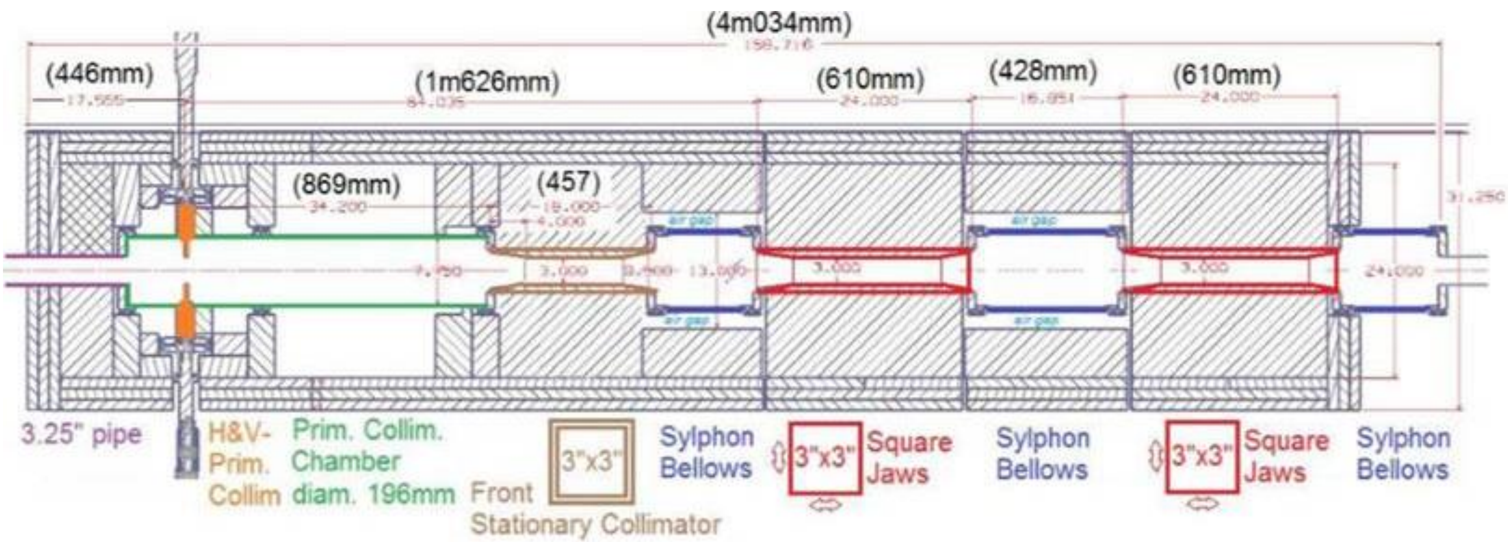
- Includes production and installation of new Booster RF cavities which were prototyped on PIP
  - Larger aperture, 20-Hz capable for PIP-II

NuMI Target Systems AIP

- Temperatures and stresses due to beam heating
  - Pre-target beam window
  - Target core and baffle
  - Horn stripline cooling and horn power supplies
  - Radioactive water systems, target chase air handling, chiller
  - Hadron absorber temperature monitoring
- Increased radioactivation
  - Add shielding to the RAW room and target chase
  - Review NuMI shielding and tritium production assessment for 1MW
  - Retrofit or expand existing tritium mitigation systems
  - New radiation-hard Hadron Monitors
- Aging infrastructure (in radioactive environment)
  - Decay pipe window spare and replacement mechanism
  - Target/horn module positioning drives

Booster Intensity AIP

- Booster dampers
  - Lower chromaticity at injection to reduce losses
- Booster collimators
  - Capture losses (reduce tunnel activation and need for shielding)



- Booster beam physics studies
  - Lattice, aperture scans, high-intensity studies

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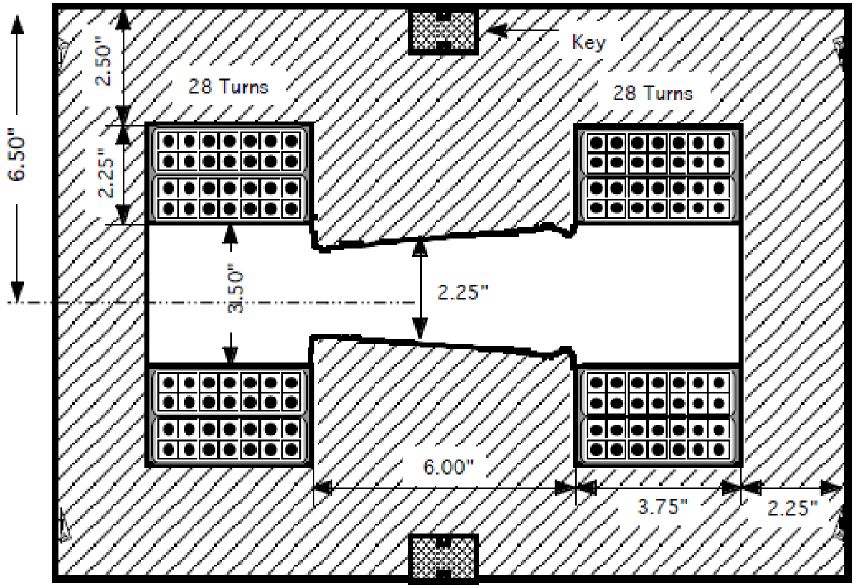
Booster Magnets AIP

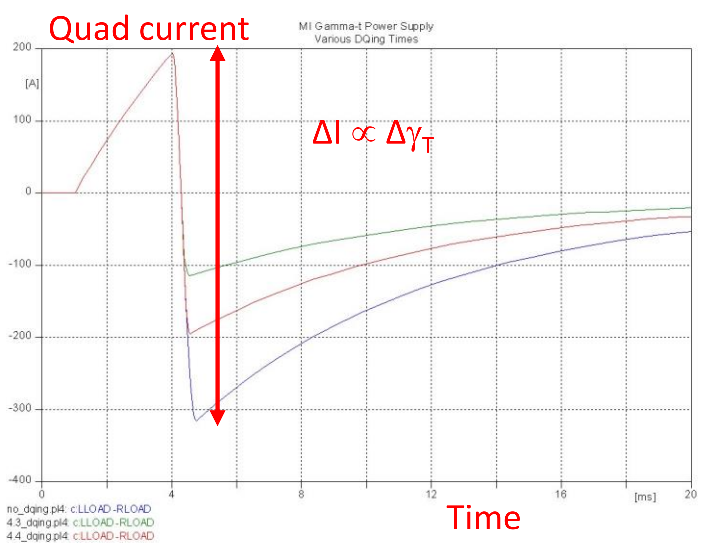
- New Booster defocusing-type combined function magnets, shorter with larger aperture
- Design could also benefit PIP-II injection



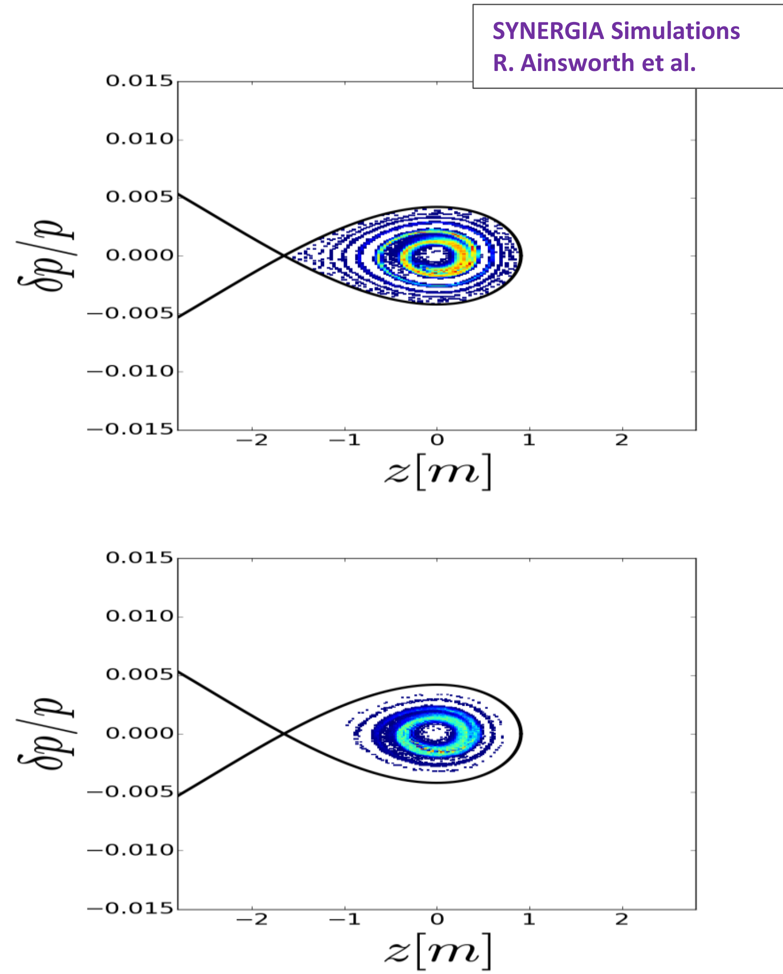
cross section of existing D-magnets

Main Injector AIP

- γ_t jump
  – Design, build, and install new quadrupole magnets to cross transition more quickly to reduce transition losses

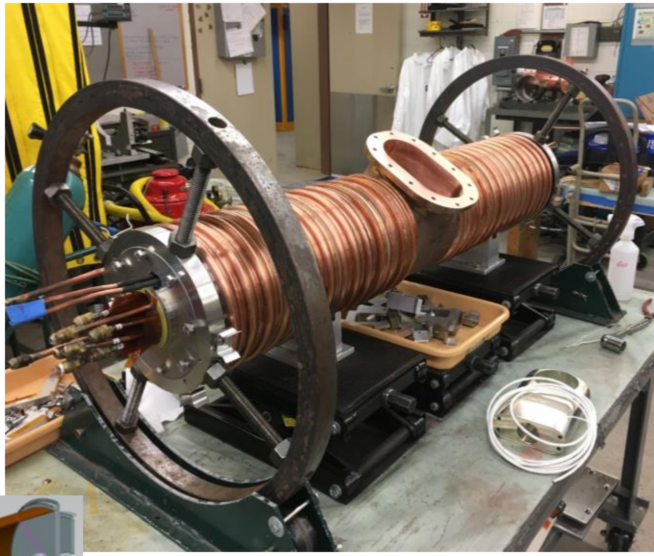


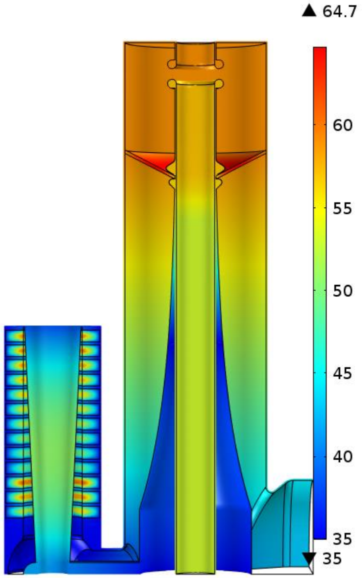
Longitudinal Distributions at 40 GeV

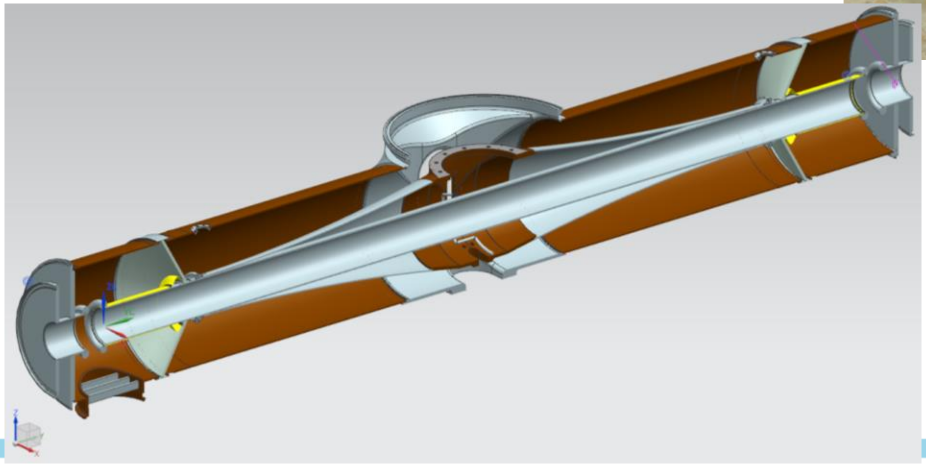


Booster RF AIP

- 20 new cavities, 60 kV, also larger aperture
- Was on PIP, but delayed to get benefits of 900 kW sooner
  - Complete prototyping on PIP this year
- Needed for 20 Hz running with PIP-II
- Could support running at 15 Hz as refurbished cavities continue to age







Conclusions

- Have a plan to increase beam power to 900 kW
- Many of the improvements are needed for PIP-II
- Expect funding to start the NuMI Target Systems AIP and the Intensity AIP this month
- Will step up intensities periodically if possible as improvements are made
- Expect target station to be ready for up to 1 MW after 2020 shutdown and Booster ready to send higher intensity beam on same timescale
- Other improvements will continue beyond 2020 which may be needed to reach highest beam power