



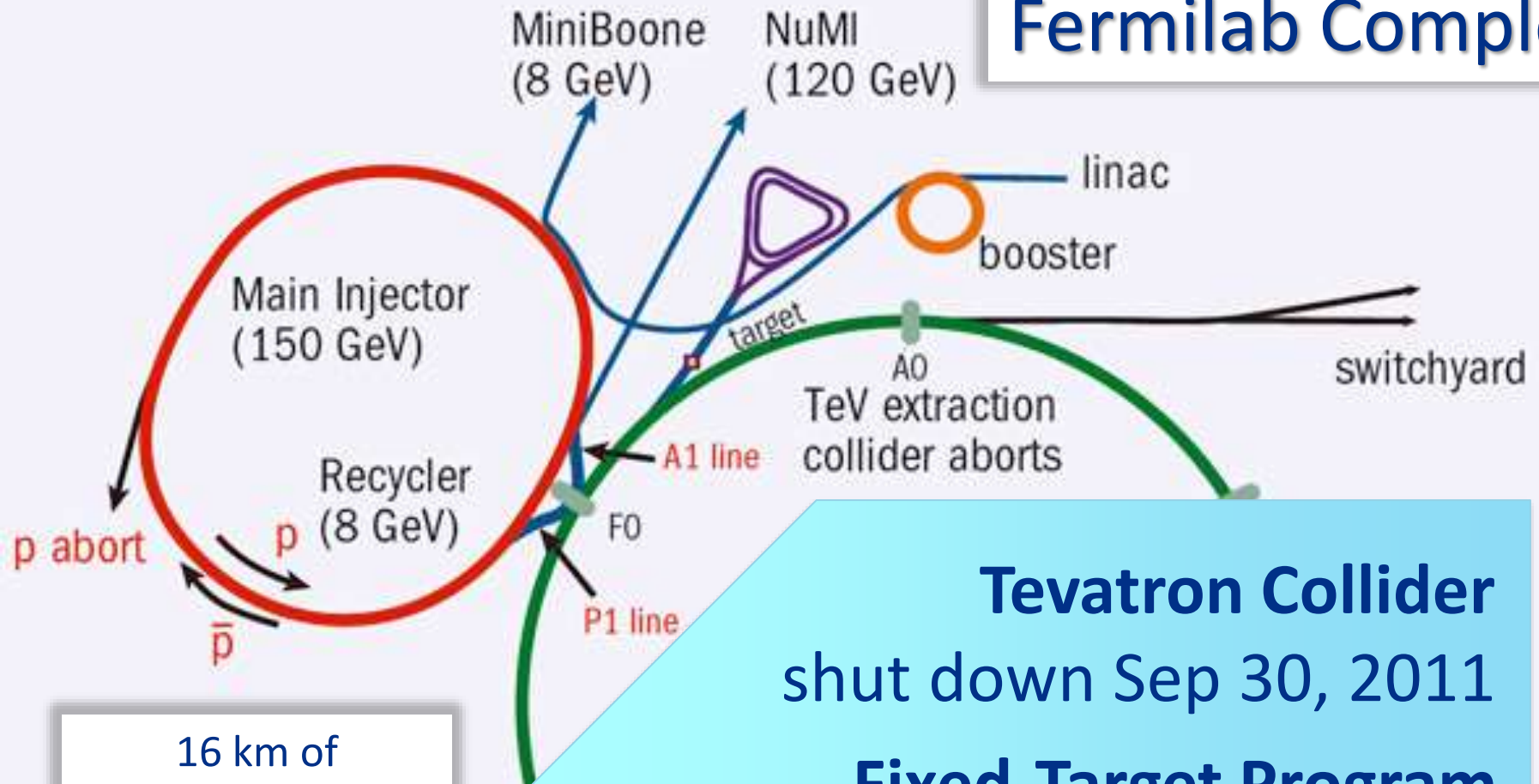
Improvement Plans of Fermilab's Proton Accelerator Complex

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Fermilab Complex



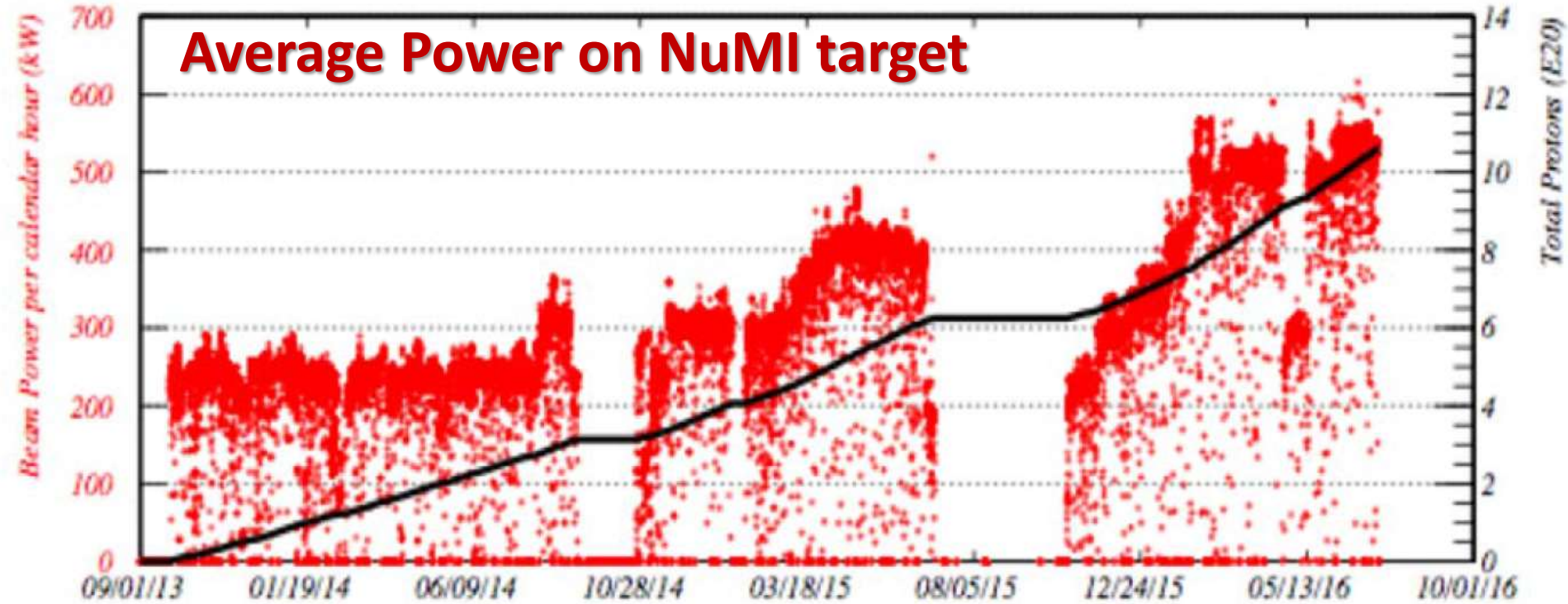
16 km of
accelerators and
beamlines,
two high power
targets, several
low power target
stations...

Tevatron Collider
shut down Sep 30, 2011
Fixed-Target Program
after modifications, since '13
Priorities set up by P5
Many accelerator improvements

Fermilab Accelerator Complex Users

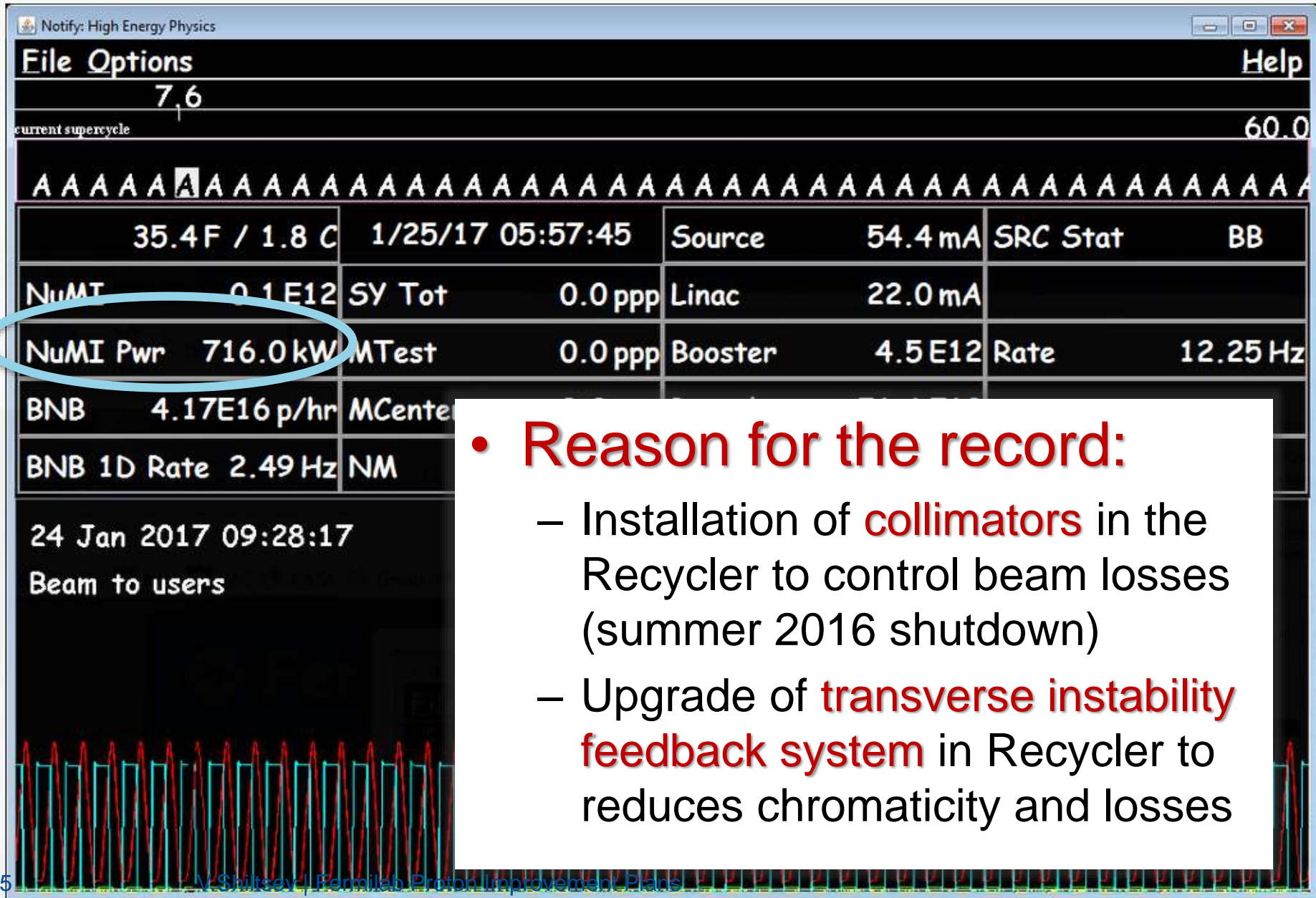
- **Proton Source (8 GeV Booster ring):**
 - 8 GeV Booster Neutrino Beam (BNB)
 - ANNIE
 - MicroBooNE
 - MiniBooNE
 - MITPC
 - SciBath
 - **ICARUS (future)**
 - **SBND (future)**
- **120 GeV Main Injector / 8 GeV Recycler:**
 - NuMI: MINOS+, MINERvA, NOvA
 - **LBNF/DUNE (future)... P5 goal of 900 MW × Year × ktons**
 - Fixed Target: SeaQuest, LArIAT, Test Beam Facility
 - Muon: g-2, **Mu2e (future)**

Complex Performance: 2013-2016



- Progress due to Proton Improvement Plan (PIP):
 - Full 15 Hz beam operation of 8 GeV Booster (was 7)
 - Recycler Ring reconfigured for to operate with high-intensity proton beams (instead of low intensity pbars... RF, inj., etc)
 - Total of 1.2e21 protons delivered to NuMI target since 2013

Last week's record : >700kW of 120 GeV beam on ν target

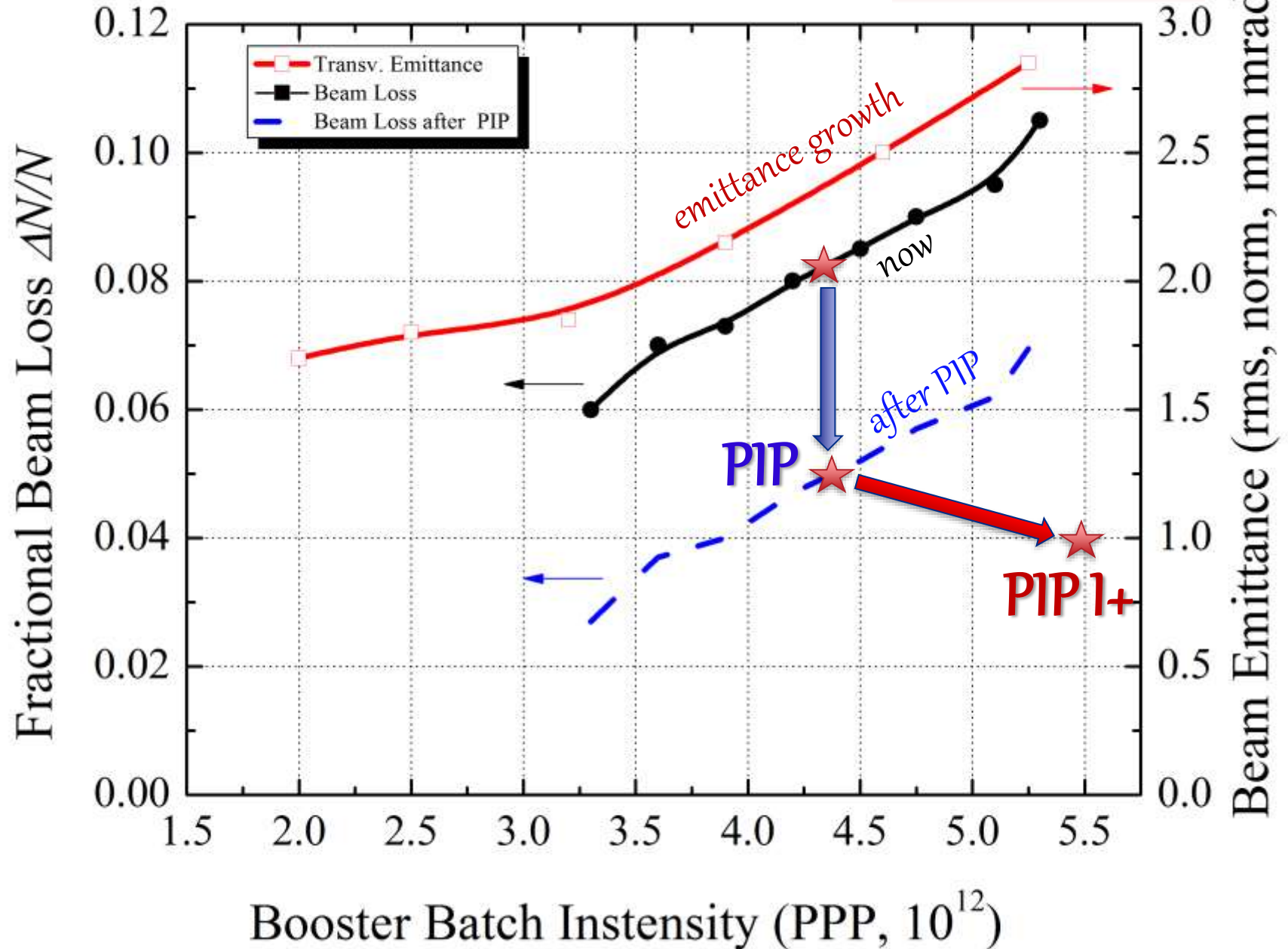


Next Step : **PIP-I+** to ~900 kW power

- Plan to upgrade the complex performance via :
 - Booster PPP $4.3\text{e}12 \rightarrow 5.5\text{e}12$ 28%
 - MI cycle $1.33\text{ s} \rightarrow 1.2\text{ s}$ 11%
 - 20 Hz PS/RR/MI $15\text{ Hz} \rightarrow 20\text{ Hz}$
- Performance improvements:
 - Beam to NoVA $700\text{ kW} \times (1.28 \times 1.11) \leq 992\text{ kW}$
 - Beam elsewhere
 - BNB & Muon Campus $55\% \text{ of plan} \rightarrow 110\% \text{ of plan}$
- That will require:
 - >dozen improvements in the Booster, Recycler, Main Injector, and Targetry as well changing all Controls to 20 Hz
 - Some 3-4 years and ~30M\$
 - PIP-I+ team, budget and schedule are being formed by AD

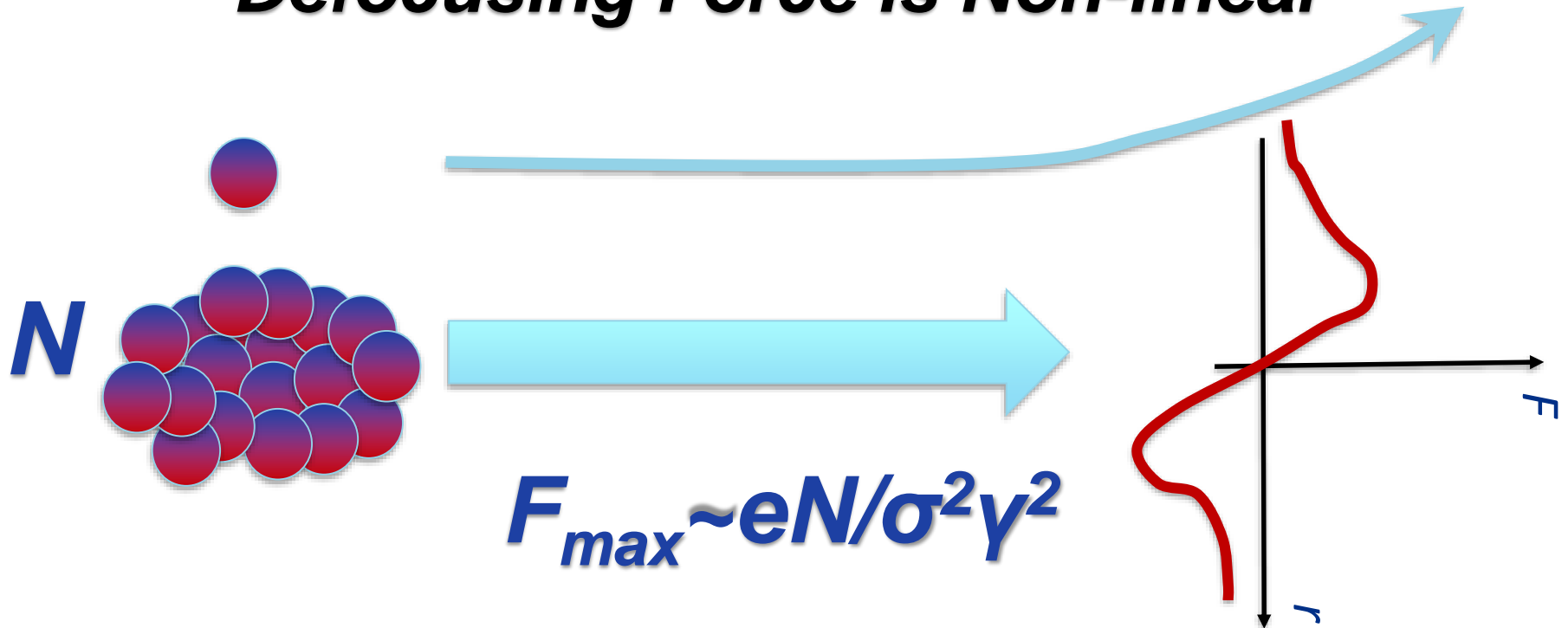
Booster PPP Challenge

MI acceptance



Intense Beams : Forces and Losses

Defocusing Force is Non-linear



Space-charge effect (emittance growth, losses):

- a) proportional to current (N)**
- b) scales inversely with beam size (σ)**
- c) scales with time at low energies (γ)**

Linacs 5-20 MeV/m
Rings 2-10 MeV/km

Proton Improvement Plan-II (PIP-II)

- **Key elements:**

- Replace existing 400 MeV linac with an 800 MeV linac capable of CW operation.
 - Higher energy + painting = more beam in Booster
- Increased Booster rate of 20 Hz
- “Modest” improvements to Recycler and MI
- Significant contributions from India

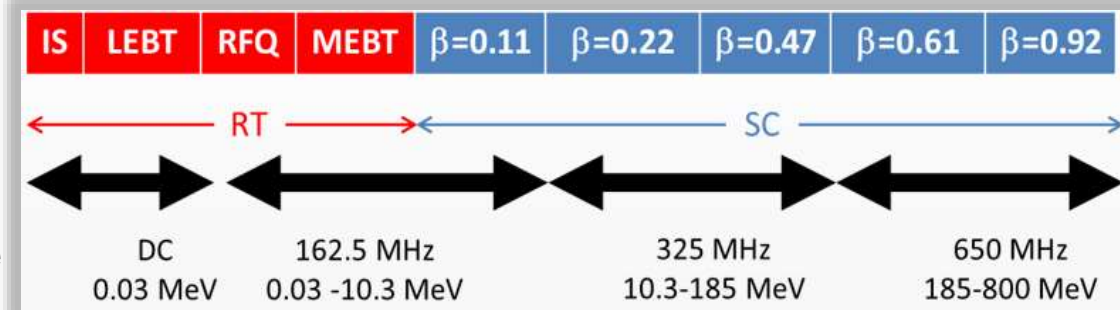
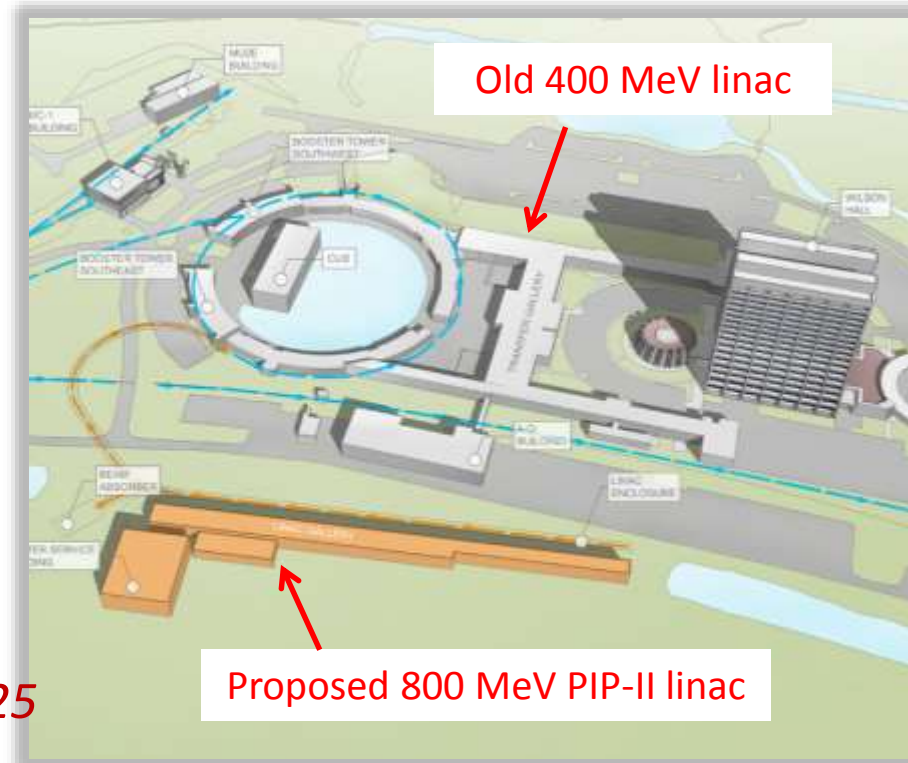
- **Goals:**

- **1.2 MW @ 120 GeV for LBNF/DUNE**

- Additional power:

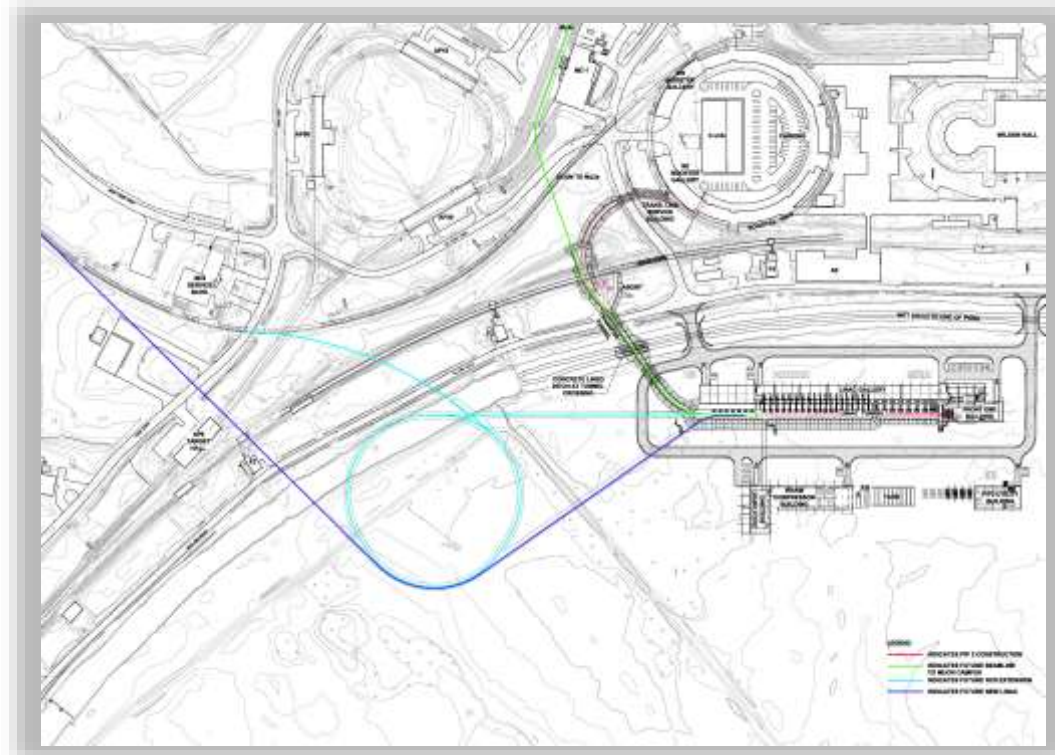
- 82 kW @ 8 GeV
 - Neutrinos (and kaons?)
- ~100 kW @ 800 MeV
 - Arbitrary bunch structure
 - Muons ($\mu 2e^*$)

ca 2025



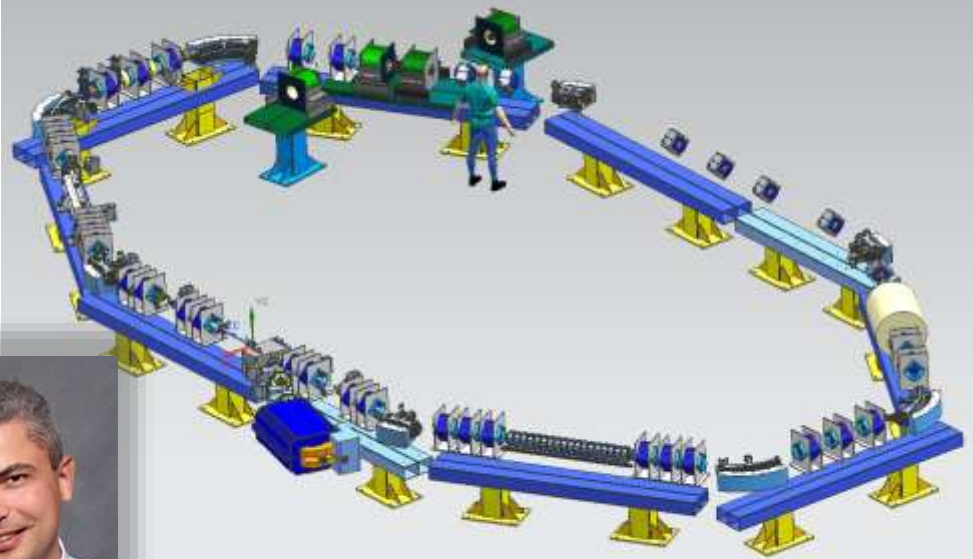
Future Upgrade: PIP-III

- 2.4 MW after 2030
- Key elements:
 - **Replace Booster** (it's a bottleneck)
 - **Affordable Cost**
 - Use **PIP-II**
 - Use **Main Injector**
- Concept development and R&D just started:
 - supported by DOE via GARD program (P5 recommendation)

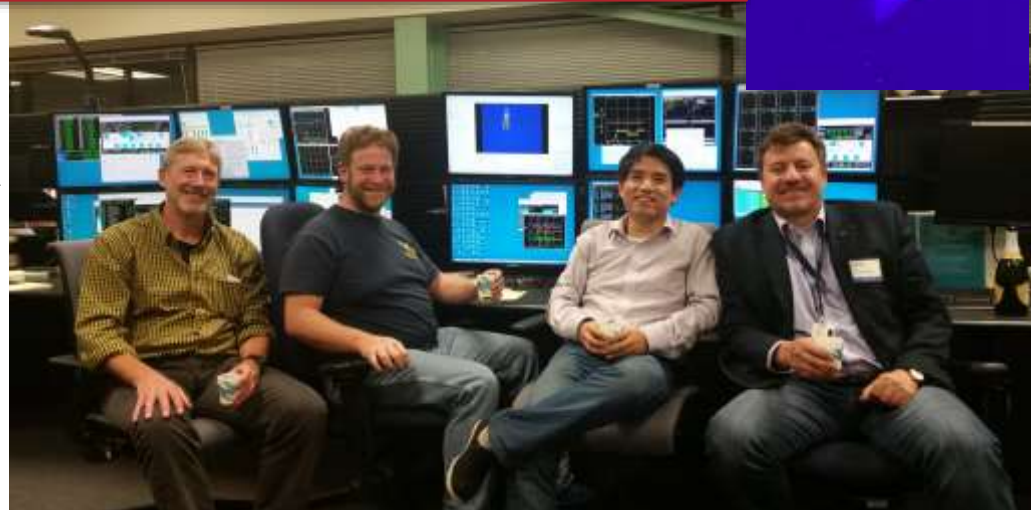
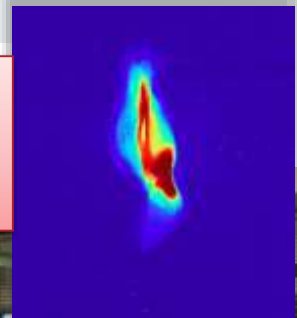


IOTA Ring R&D

- Build IOTA ring
 - 40 m storage ring
 - 70-150 MeV/c p^+ and e^-
- Two novel ideas
 - Integrable optics
 - Electron lens SCC
- 26 collaborating institutes
 - Nat'l Labs, Universities, International, SBIR, ECA
 - led by Alex Valishev and Vladimir Shiltsev
 - 1st IOTA beam in FY18

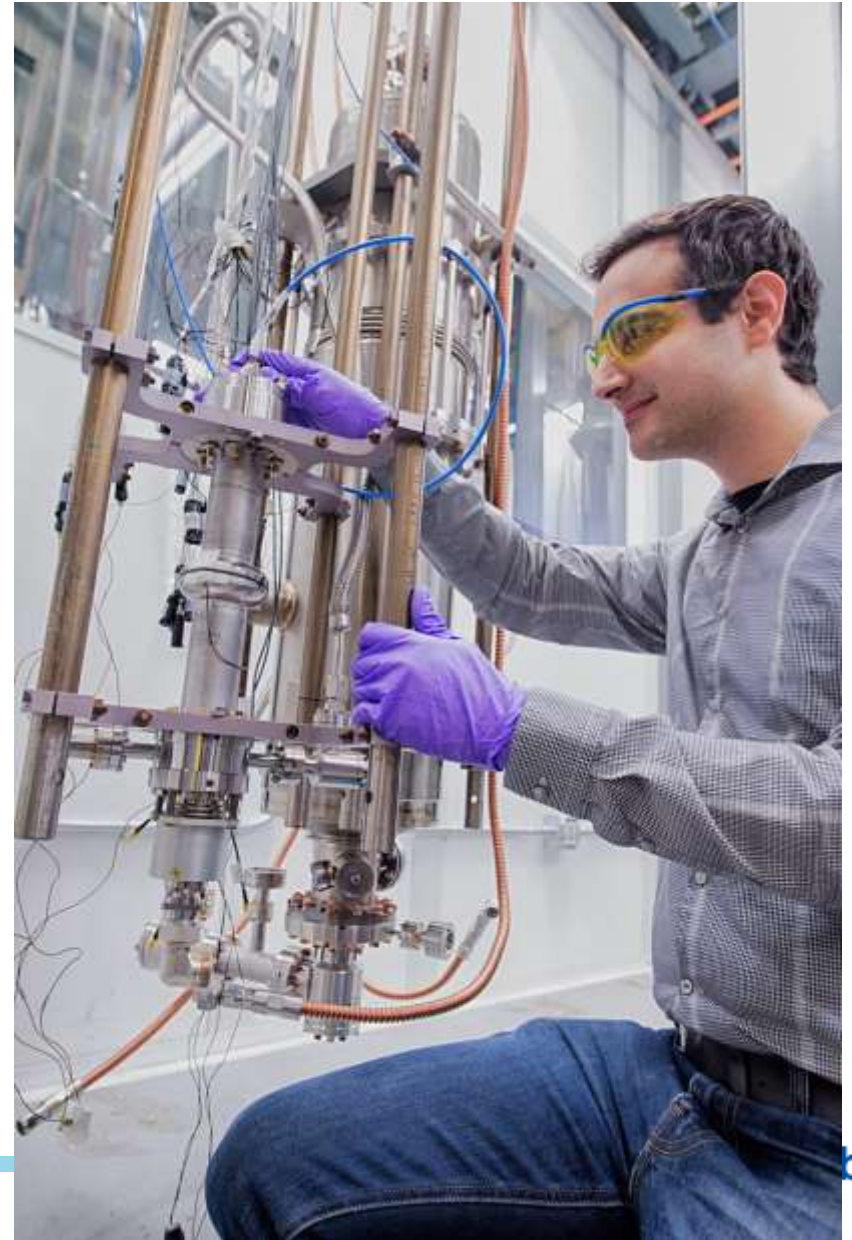


May 16, 2016: Beam accelerated by both SRF Capture Cavities #1 and #2: 4.5 MeV (gun)+28MeV+20MeV



Cost Efficient Superconducting RF R&D

- Reduce cost of SRF by substantial factor via:
 - Nb on Cu (lower cost)
 - Nb₃Sn (higher gradients)
 - high Q_0 via N₂ doping
- SRF collaboration
 - Nat'l Labs, Universities (Cornell), etc
 - led by Alex Romanenko and Sam Posen



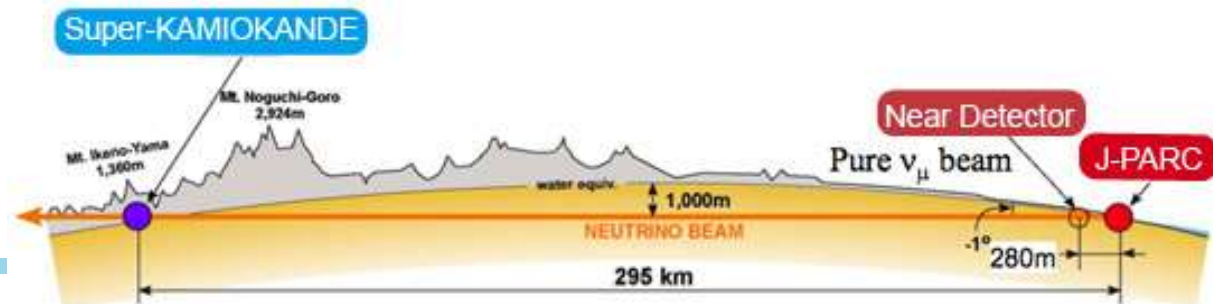
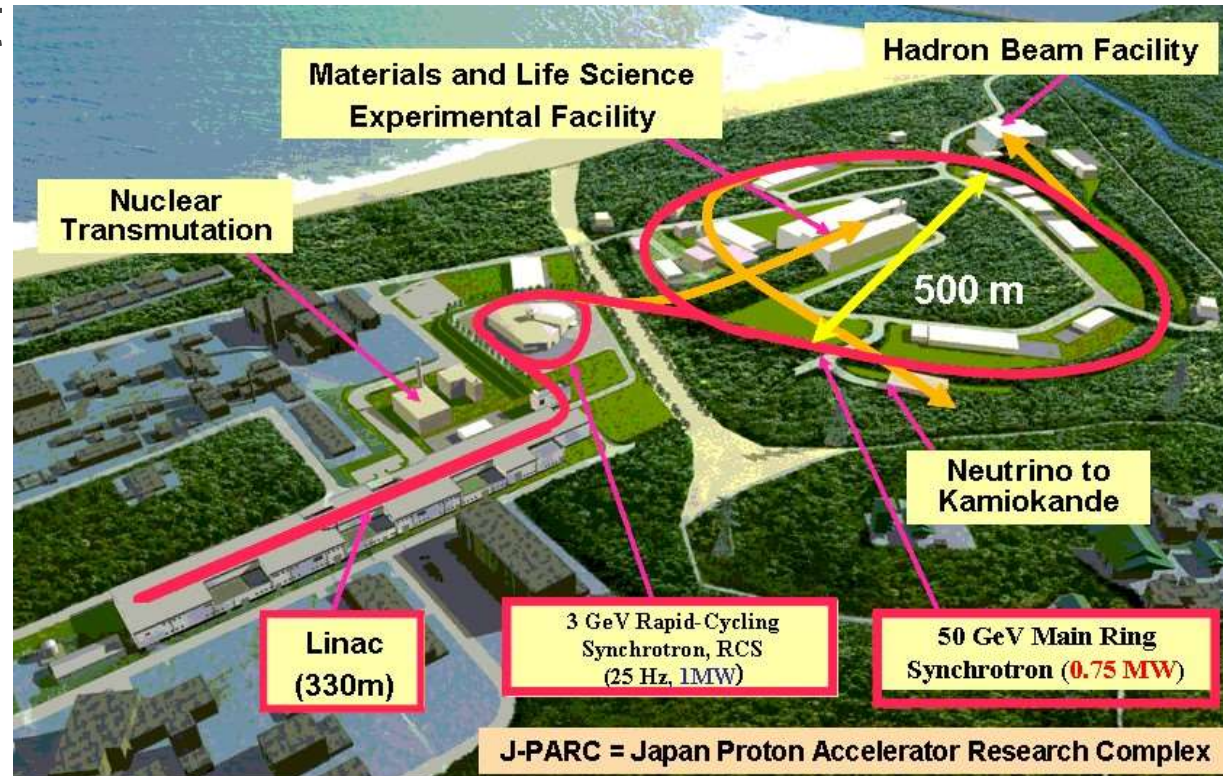
Multi-MW Beam Targetry R&D Program

- Prove feasibility of multi-MW beam targets:
 - new materials
 - new target engineering
 - beam/radiation testing
- RADIATE collaboration
 - led by Bob Zwaska and Pat Hurh
 - FNAL, BNL, ORNL, LBNL, CERN, RAL, etc

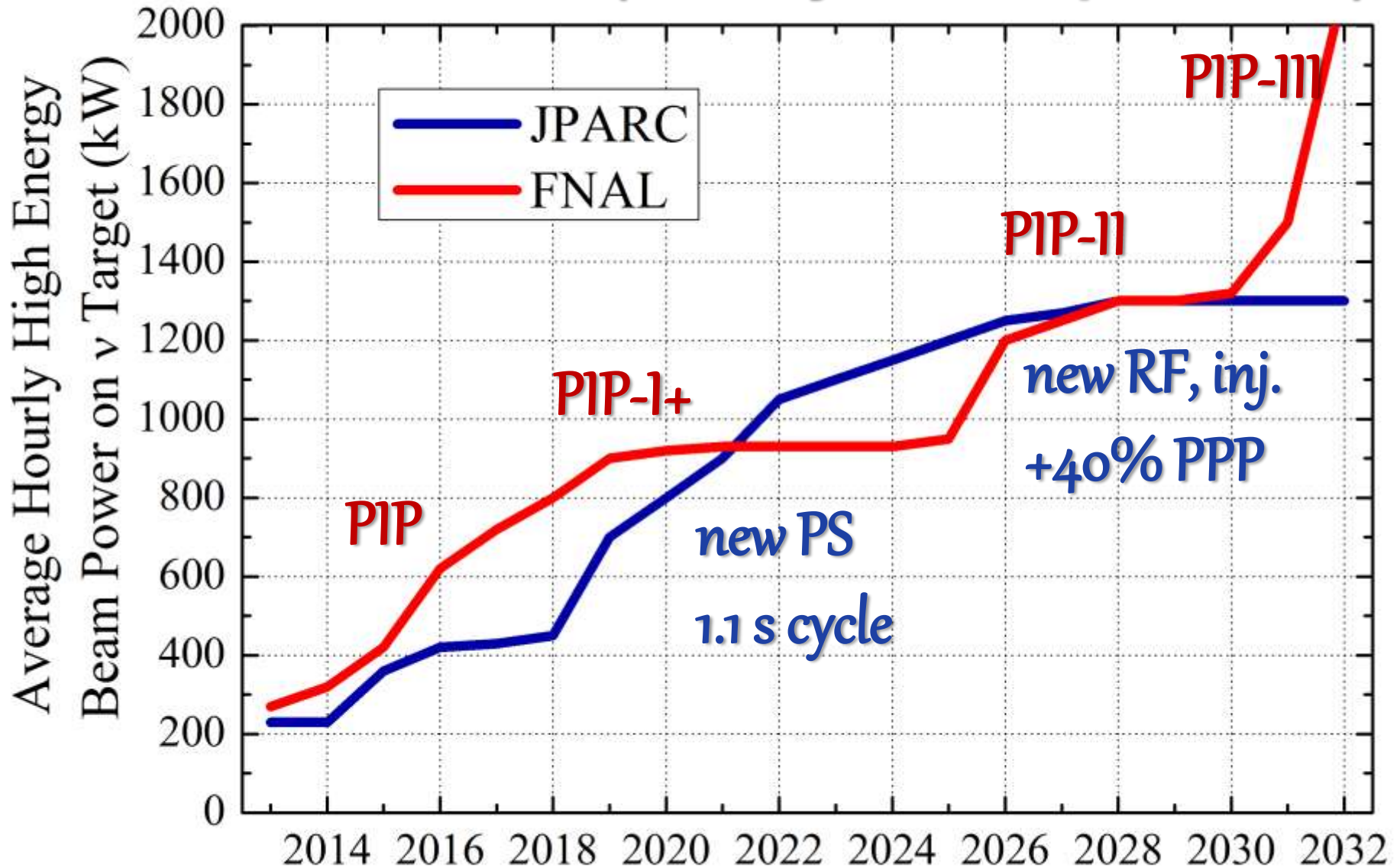


Competition: JPARC (Japan) and T2K

- “Main Ring” - Fast Cycling Proton Synchrotron
- 30 GeV protons on neutrino target
- Reached 420kW
 - every 2.5 s
 - 2.2×10^{14} per pulse
- Plan for 1.3 MW
 - 1.1 s cycle
 - 3.1×10^{14} per pulse



Beam Power Race (Reality and Aspirations)



Summary

- Fermilab moved into the area of Intensity Frontier HEP to lead it
 - NuMI
 - LBNF/DUNE
- Series of upgrades (Proton Improvement Plans):
 - achieved > 700kW on neutrino target (2017, **PIP**)
 - aims at >900kW in 3-4 years (**PIP-I+** goal)
 - ~1.2MW for LBNF/DUNE with **PIP-II** (800 MeV SRF Linac)
 - aspire for ~2.4MW after Booster replacement (**PIP-III**)
- Extensive accelerator R&D program launched to address cost and performance risks:
 - IOTA ring novel space-charge mitigation methods
 - Cost effective superconducting RF and multi-MW beam targets
- International competition FNAL/NuMI and JPARC/T2C is real
 - Makes us to work hard(er) and move fast(er)