IOTA/FAST Collaboration Meeting - Intro

Vladimir SHILTSEV, AD/APC

IOTA/FAST Workshop and Collaboration meeting

9 May 2018

General Perspective on IOTA/FAST

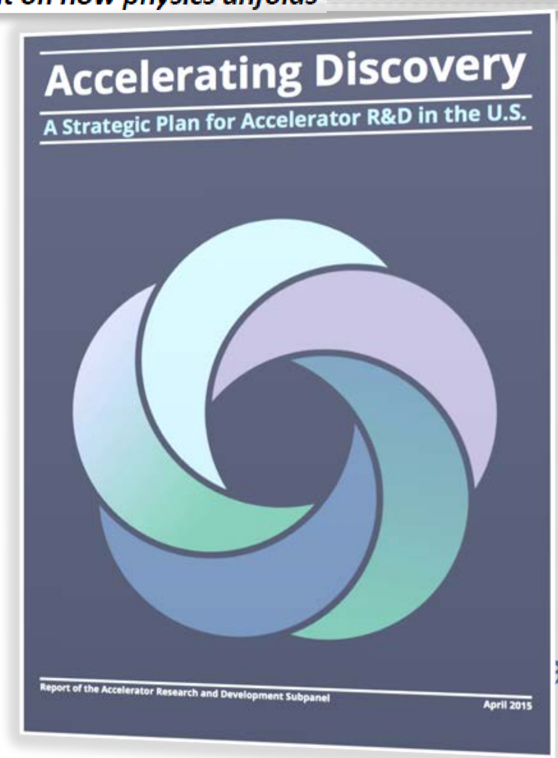
P5 (2014): US HEP Community Plan

	Intensity Frontier Accelerators	Hadron Colliders	e^+e^- Colliders
Current Efforts 0-10 yrs	PIP	LHC	
	PIP-II	HL-LHC	ILC
Next Steps 10-20 yrs	Multi-MW proton beam	Very high-energy *pp* collider	1 TeV class energy upgrade of ILC*
Further Future Goals 20+ yrs	Neutrino factory*	Higher-energy upgrade	Multi-TeV collider*

***dependent on how physics unfolds**

Accelerator R&D (GARD)Thrusts:

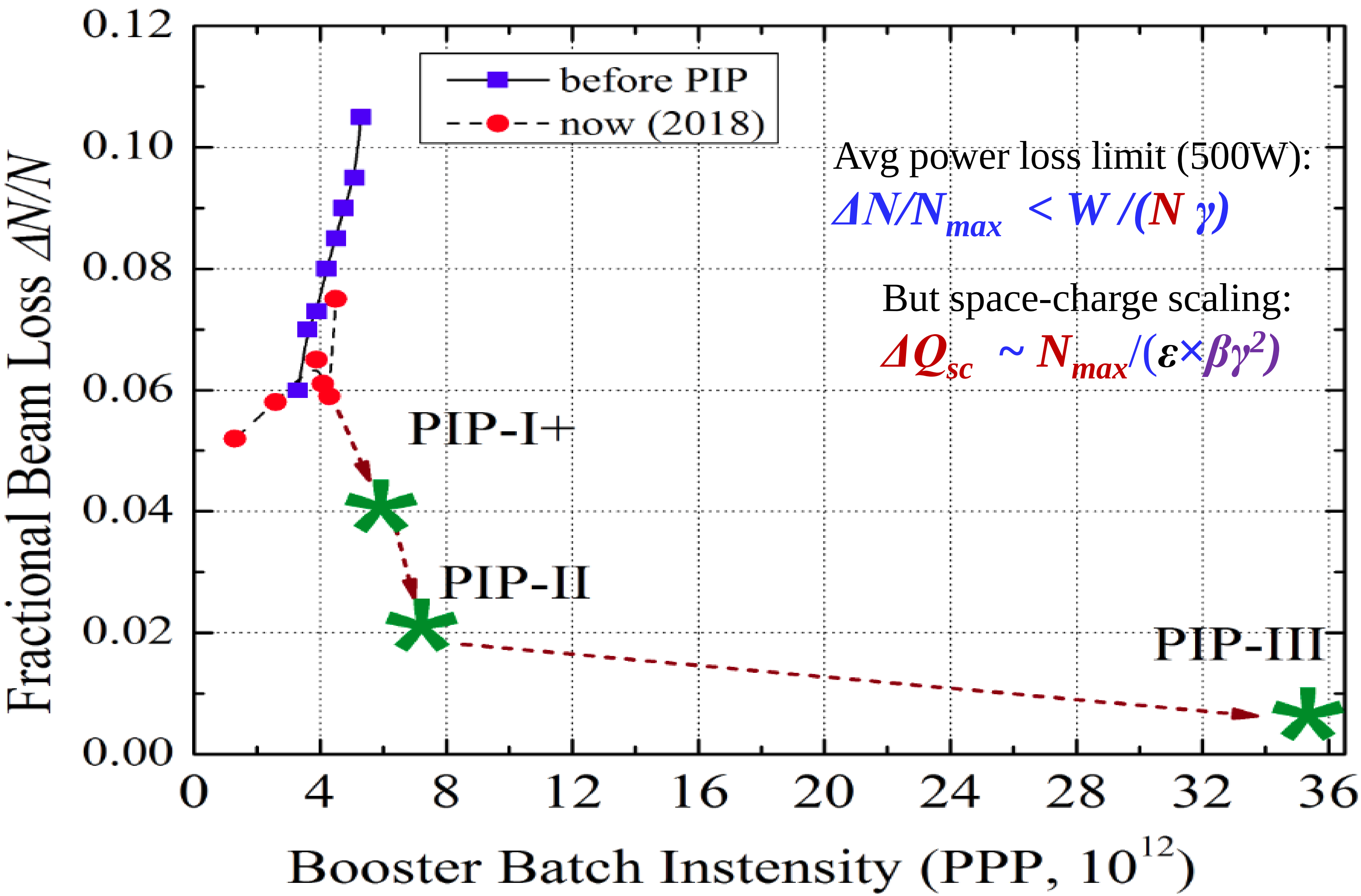
- Accelerator and Beam Physics
  - Experimental R&D at IOTA/FAST
  - Theory, modeling & studies
- MW+ Targetry R&D
- High-Field Magnets and Materials
- SRF Accelerator Technology



HEPAP GARD Plan (2015)

Booster *Protons Per Pulse* Challenge:

PIP → PIP-I+ → PIP-II → PIP-III



IOTA/FAST Timeline:

- 5 MeV e- beam – 2015
- 50 MeV e- beam – 2016
  - First experimental journal pubs
- 300 MeV e- beam – 2017
  - Beam thru 1.3GHz CM to dump (Nov.); experimental program
- 1st e- beam in IOTA – 2018
  - 1st IOTA experiments begin
- 1st *p*+ beam in IOTA – 2019
- Experimental R&D program
  - For several (5+?) years
  - many experiments (*e*-, *p*+)

S. Antipov et al 2017 JINST 12 T03002

IOTA (Integrable Optics Test Accelerator): Facility and Experimental Beam Physics Program

Sergei Antipov, Daniel Broemmelsiek, David Bruhwiler*, Dean Edstrom, Elvin Harms, Valery Lebedev, Jerry Leibfritz, Sergei Nagaitsev, Chong-Shik Park, Henryk Piekarz, Philippe Piot**, Eric Prebys, Alexander Romanov, Jinhao Ruan, Tanaji Sen, Giulio Stancari, Charles Thangaraj, Randy Thurman-Keup, Alexander Valishev, Vladimir Shiltsev***

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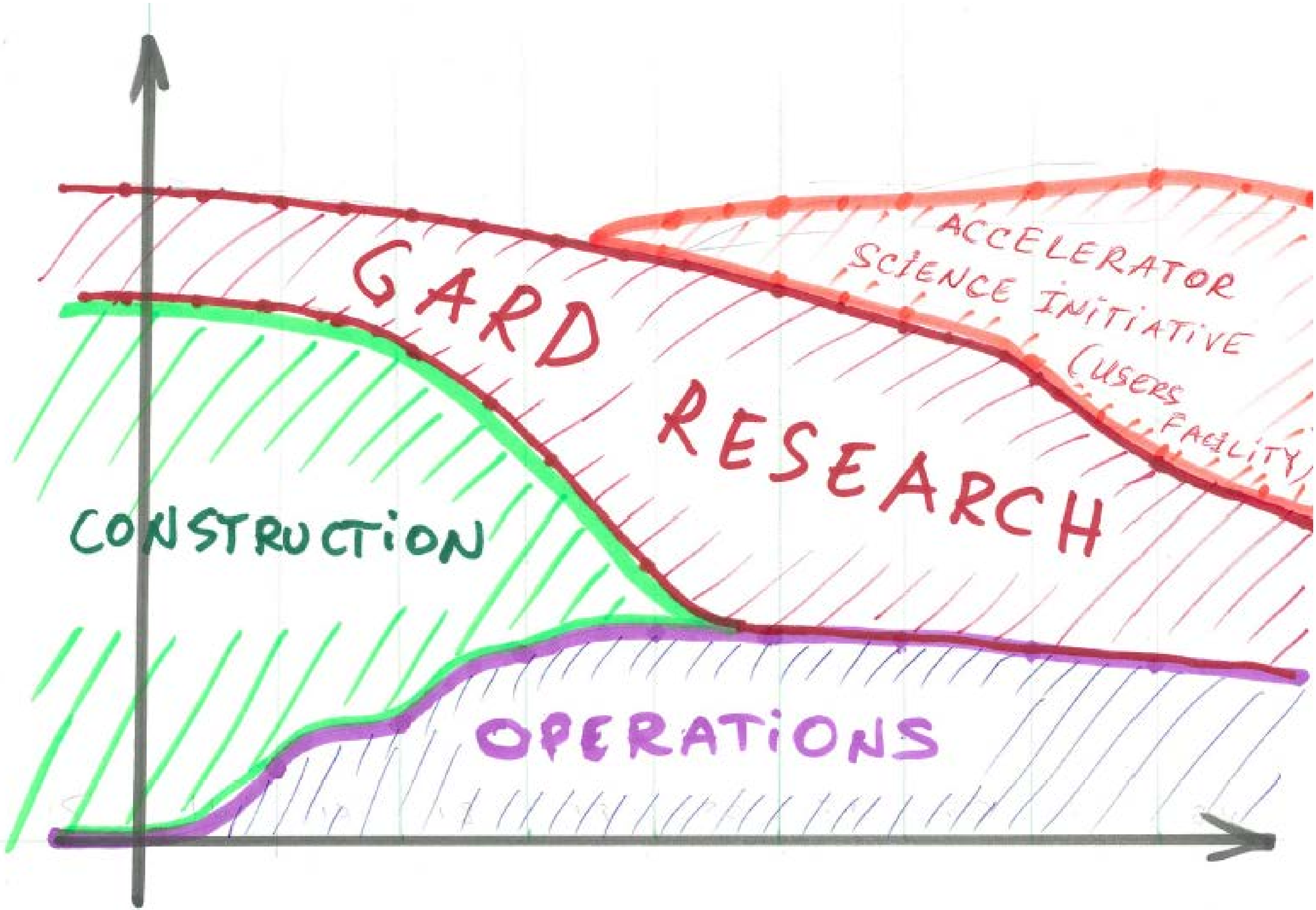
ABSTRACT: Integrable Optics Test Accelerator (IOTA) is a storage ring for advanced beam physics research currently being built and commissioned at Fermilab. It will operate with protons and electrons and, correspondingly, employ 70 – 150 MeV/c proton and electron injectors. The research program includes the study of nonlinear focusing integrable optical beam lattices based on special magnets and electron lenses, beam dynamics of ultimate space-charge effects and their compensation, optical stochastic cooling, and several other experiments. In this article we present the design and main parameters of the facility, outline progress to date and the timeline of the construction, commissioning and research, and describe the physical principles, design, and hardware implementation plans for the IOTA experiments.

KEYWORDS: Accelerators, Synchrotrons, Magnets, Integrable Optics, Electron Lenses, Space-charge Effects, Instabilities, Collimation, Beam Instrumentation, Photo-injectors, Neutrino.

(CDR-type document)

Longer Term Perspective on IOTA/FAST



#1: IOTA GARD Experiment (2018-)

- ***Physics of Intergrable Optics***:
  - PIs: A.Valishev and S.Nagaitsev
  - Will start in 2018 – first, limited integrability (with octupoles), then with NL magnets, then with protons
- Experiment planning:
  - Stage (1) – theory, modeling, physics specs – mostly done, continue IOTA specific simulations
  - Stage (2) – technical specs and design - done
  - Stage (3) – fabrication and construction – mostly done
  - Stage (4) – installation and commissioning – 2018*
  - Stage (5) – physics research – 2019-

* "Will happen" , independent of the 2M$ supplemental

- Collaboration:
  - Very strong (simulations, fabrication, beam diagnostics, etc)
  - Fermilab, NIU, U.Chicago, RadiaSoft, LBNL, RadiaBeams, et al
  - Regular meetings

#2: IOTA GARD Experiment (2019-)

- ***Space-charge compensation by electron lenses:***
  - PIs: G.Stancari and V.Shiltsev
  - Will start in 2019 – first, limited integrability (with octupoles), then with NL magnets, then with protons
- Experiment planning:
  - Stage (1) – theory, modeling, physics specs – IOTA specific simulations started
  - Stage (2) – technical specs and design – to be finished in 2019
  - Stage (3) – fabrication and construction – 2019 *
  - Stage (4) – installation and commissioning – 2019 *
  - Stage (5) – physics research – 2020-
- Collaboration:
  - Strong on simulations (FNAL SCD and APC)
  - Fabrication and construction $$ *contingent on resources* available after IOTA/FAST constr'n/commiss'ng and IO exp't

* That's why supplemental 2M$ critically important

#3: IOTA GARD Experiment (2019-)

- ***Optical Stochastic Cooling:***
  - PIs: V.Lebedev, J.Jarvis and S.Chattopadhyay
  - Will start in 2019 – though first test of synchrotron light optics and measurements in IOTA in 2018
- Experiment planning:
  - Stage (1) – theory, modeling, physics specs – done
  - Stage (2) – technical specs and design – to be finished in 2018
  - Stage (3) – fabrication and construction – 2018-19
  - Stage (4) – installation and commissioning – 2019
  - Stage (5) – physics research – 2020-
- Collaboration:
  - Strong on simulations, technical design and fabrication
  - NIU, Fermilab, U.Chicago, etc
  - External funding thru DOE/NSF grants; regular meetings

Remarkable Accomplishment - 2017

300 MeV from FAST Linac – Nov. 15 , 2017

- ILC-type cryomodule acceleration by 255$\pm$5 MeV
  - Over 31.5 MV/m
- Total beam energy 300 MeV in the HE beam absorber

CM-2/FAST Linac Performance vs ILC specs

Parameter	FAST Nov. 2017	ILC specs 2007 RDR/2013TDR	Comments
Total beam energy gain per CM	255 MeV* 31.8 MV/m 8 cavities	252 MeV 31.5 MV/m in each 8/9 cavities	above the spec!
Q_0	0.8 e10	1 e10	Two cavities have >1e10
Pulse length (beam)	0.1 ms	1.0 ms	had 1 ms in other studies
Pulse rep rate	1 Hz	5 Hz	had 5Hz in other studies
# bunches per pulse	10	2625 / 1312	had 1000 bunches in other studies
Bunch intensity	0.2 nC	3.2 nC	1.5nC per bunch in other studies

* compare with European XFEL: there are several CMs in operating at 200+ MeV. The highest gain/CM is 237 MeV.

"High-impact" paper in preparation (2018)

Exciting 255MeV/CM2 Result *("ILC specs with beam")*

IOTA/FAST
Collaboration and Collaborators

IOTA/FAST Collaboration

- **29 Partners:**
  – ANL, Berkeley, BNL, BINP, CEA/Saclay, CERN, Chicago, Colorado State, Fermilab, DESY, IAP Frankfurt, JAI, JLab JINR, Kansas, KEK, LANL, LBNL, ORNL, Maryland, U. de Guantajuato Mexico, NIU, Michigan State, Oxford, Radia Beam Tech, RadiaSoft LLC, Tech-X, Tennessee, Vanderbilt
- **NIU-FNAL:** Joint R&D Cluster
- Publications, presentations at conferences, workshops, etc
- **EIC/MARIE/BES:** many critical tests are possible

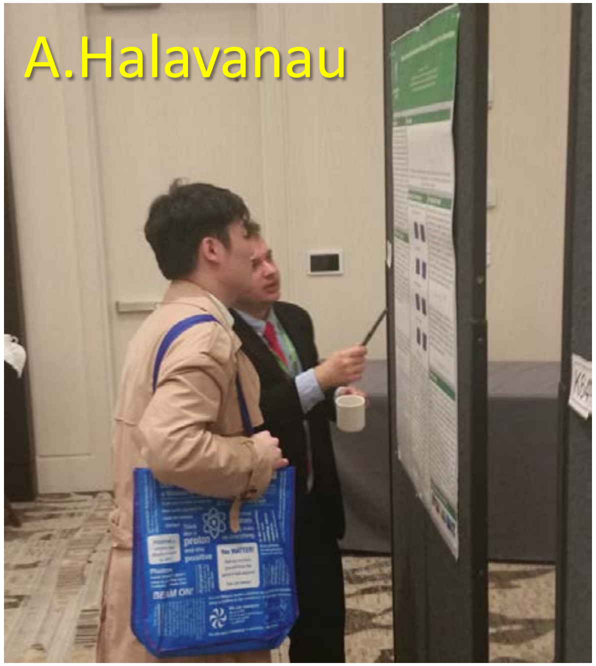
• IOTA/FAST at IPAC18 (Vancouver)

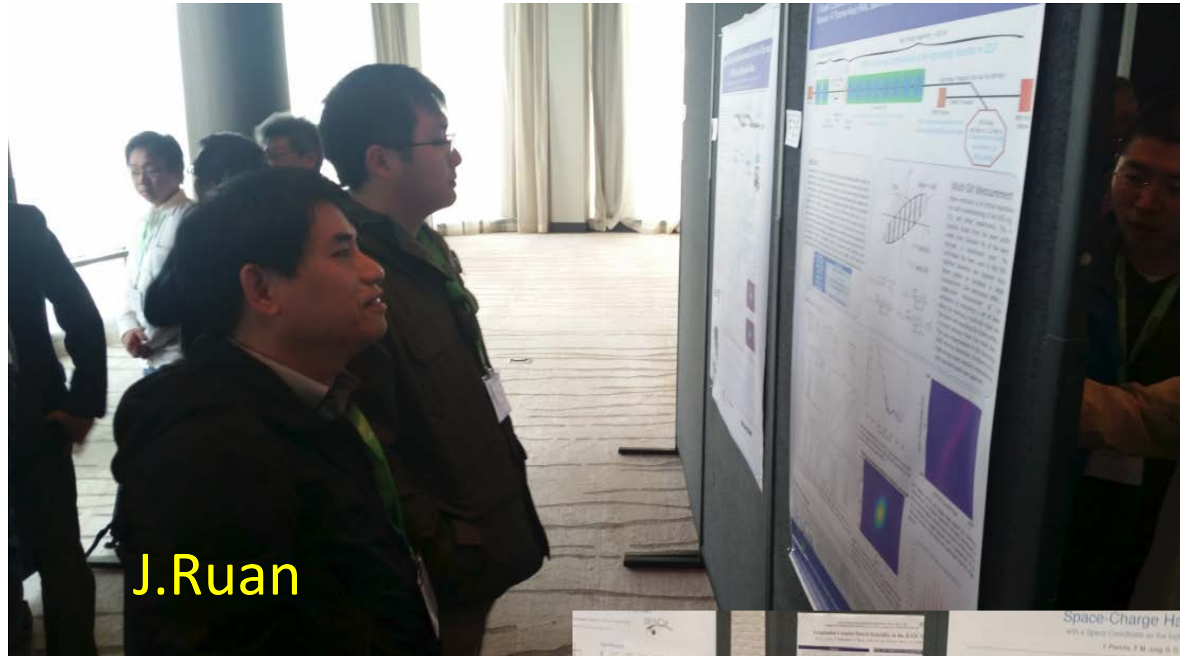
- *Contr Oral:* TUXGBF2 Higher-Order-Mode Effects in Tesla-Type SCRF Cavities on Electron Beam Quality (A.Lumpkin et al)
- *Contr Oral:* THYGBD4 Landau Damping by Electron Lenses: Outperforming Thousands of Octupoles (A.Burov et al)
- *Contr Oral:* THYGBE2 Results and Discussion of Recent Applications of Neural Network-Based Approaches to the Modeling and Control of Particle Accelerators (A.Morin et al)

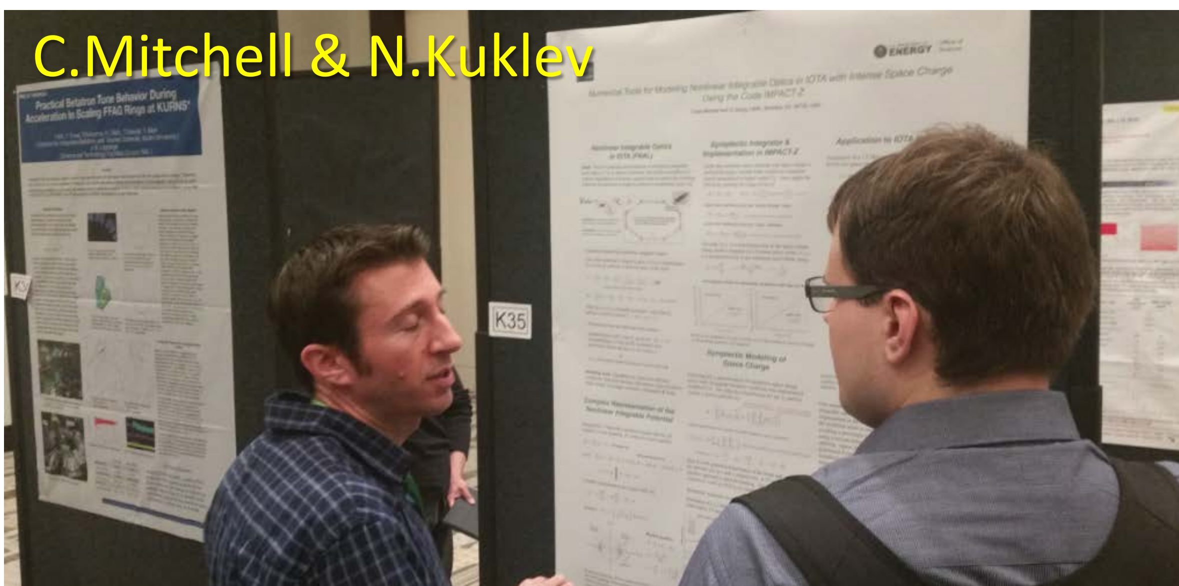
– *Posters (25):*

- TUPAF073 Simulation of Integrable Synchrotron with SC and Chromatic (J.Eldred)
- TUPAL043 e-Column in IOTA (B.Freemire)
- WEPAF040, *SUSPL054* Neural Network Virtual Diagnostic & Tuning for FAST LEBL (A.Edelen)
- WEPAG005, *SUSPF100* Synchrotron Radiation Beam Diagnostics IOTA (N.Kuklev)
- WEPAL065, *SUSPL050* Development of a Gas Sheet Beam Profiler for IOTA (S.Szustkowski)
- THPAF067 Effects of Synchrotron Motion on Nonlinear Integrable Optics (J.Eldred)
- THPAF068 Suppression of Instabilities by an Anti-Damper in IOTA (A.Macridin)
- THPAF071 McMillan Lens in a System with Space Charge (S.Nagaitsev)
- THPAF073 Tomography FAST (A.Romanov)
- THPAF075 SCC with an Electron Lens (E.Stern)
- THPAK082 Perturbative Effects in IOTA (N.Cook)
- THPAK083 An s-Based Symplectic SC (N.Cook)
- THPAK036 Accurate Modeling of Fringe Field Effects on Nonlinear Integrable Optics in IOTA (C.Mitchell)
- THPAK061 Magnetized and Flat Beam Generation at the Fermilab's FAST Facility (A.Halavanau)
- THPAK062 Compression Flat Beams (A.Halavanau)
- THPMF024 Commissioning and Operation of FAST Electron Linac at Fermilab (A.Romanov)
- THPMF025 Emittance Study at FAST (J.Ruan)
- THPMF027 Electron-Beam Characterization in Support of a γ-Ray ICS at the FAST (J.Ruan)
- THPMF028 Coherent Stacking Scheme for ICS at MHz Repetition Rates (J.Ruan)
- THPMF029 Studies of the Novel MCP Based Electron Source (V.Shiltsev)
- THPMK036 Final Focus for a Gamma-Ray Source Based on ICS at FAST (A.Murokh)
- THPML063 Micro-Bunched Beam Production at FAST for Narrow Band THz (J.Hyun)
- THPAK057 Simulation of OSC (M.Andorf)
- THPAK058 Detection and amplification of infrared synchrotron radiation (M.Andorf)
- THPAK035 Modeling Nonlinear Integrable Optics in IOTA with Intense SC Using the Code IMPACT-Z (C.Mitchell)

IOTA/FAST at IPAC18







IOTA/FAST @ IOPAC18 - Authorship

- 65 authors
- 32 collaborators:
  - 13 from Universities
    - U.Chicago: PI's – Y.K. Kim, S.Nagaitsev
    - CSU: PI – S.Biedron
    - NIU: PI's – S. Chattopadhyay, P.Piot
  - 5 from abroad: France, UK, Japan, Korea
  - 4 from LBNL
  - 2 from LANL
  - 6 from RadiaSoft LLC
  - 2 from RadiaBeam
- 34 from Fermilab

Collaborator : Sergey Antipov – APS Award !

Outstanding Doctoral Thesis Research in Beam Physics Award

Division of Physics of Beams

APS physics

- Ph.D. in 2017 – U.Chicago (adv. Y.K.Kim, S.Nagaitsev)
- investigated the fast transverse instability observed in Recycler
- participated in the design of IOTA and performed numerical simulations of single-particle dynamics in its nonlinear focusing lattice
- Now a Fellow at CERN.

IOTA/FAST-related Peer-Reviewed Publications

- D.Broemmelsiek, et al, *Record High-Gradient SRF Beam Acceleration at Fermilab,* (in work, 2018)
- A. H. Lumpkin, B. E. Carlsten et al, *Submacropulse electron-beam dynamics correlated with higher-order modes in Tesla-type superconducting rf cavities* (accepted, PRAB, 2018)
- M.B. Andorf, V.A. Lebedev, P. Piot, J. Ruan, *Wave-Optics Modeling of the Optical-Transport Line for Passive Optical Stochastic Cooling*, NIM-A 883 119 (2018);
- D. Mihalcea, A. Murokh, P. Piot, J. Ruan, *Development of a Watt-level Gamma-Ray Source based on High-Repetition-Rate Inverse Compton Scattering* NIM-B 402 212 (2017);
- V. Shiltsev, Y. Alexahin, A. Burov, *Landau Damping of Beam Instabilities by Electron Lenses* and A. Valishev Phys. Rev. Lett. 119, 134802 (2017)
- *Analysis and Measurement of the Transfer Matrix of a 9-cell 1.3-GHz Superconducting Cavity* A. Halavanau et al., PRAB, 20 (2017) 040102
- S. Antipov, S. Nagaitsev, A. Valishev, *Single-particle dynamics in a nonlinear accelerator lattice: attaining a large tune spread with octupoles in IOTA,* JINST, V.12 (2017)
- S.Antipov, et al *IOTA (Integrable Optics Test Accelerator): Facility and Experimental Beam Physics Program* (2017) JINST 12 T03002

*compare with 2014-2017 average : 4.2/yr for FACET, 11.0/yr for BELLA

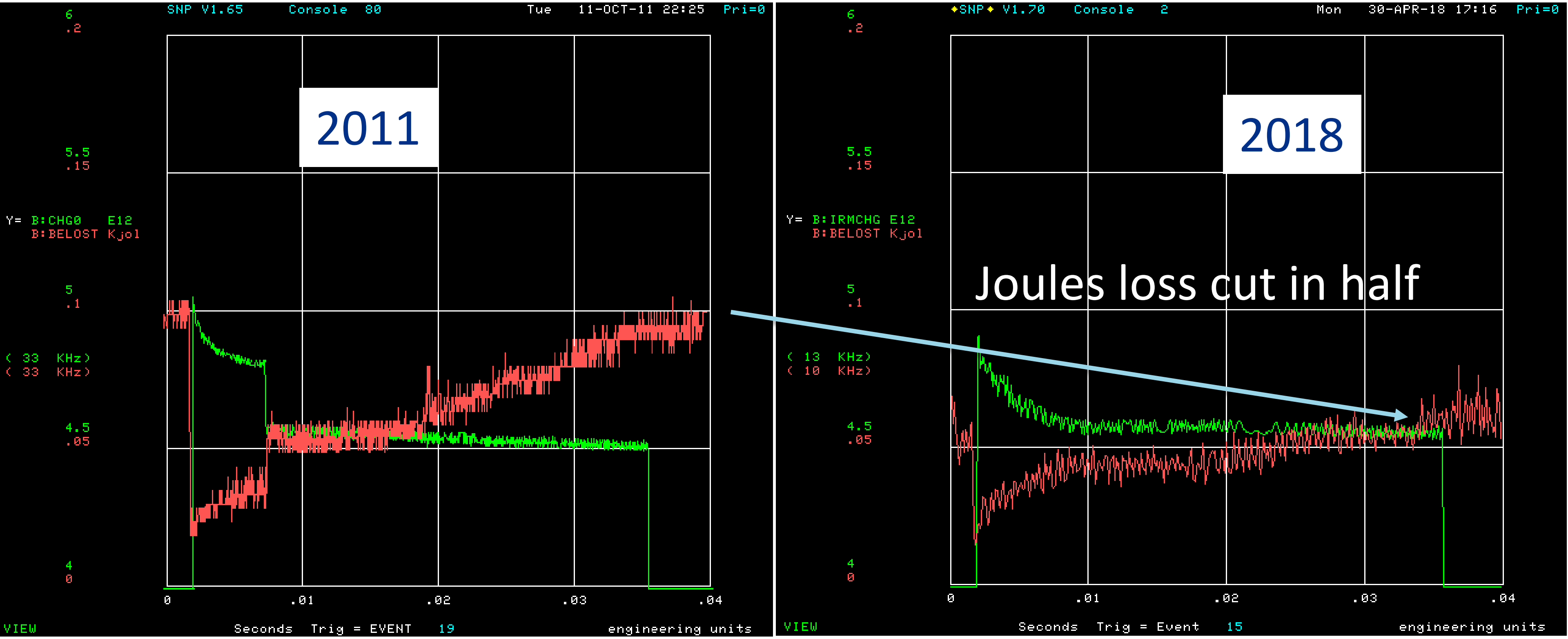
IOTA/FAST

Goals the 6th Collaboration Meeting

- **Preceding two days:** *Workshop on Megawatt Rings*
  - wtatus and plans on Megawatt beams at Fermilab and elsewhere (CERN, JPARC)
  - a lot of input for us: experiment, theory, modeling
  - beam instabilities, space-charge effects, longitudinal dynamics, losses and collimation, beam optics, etc.
- **Today:**
  - overview technical/construction progress
  - review ongoing IOTA research
  - new proposals
- **Tomorrow (Thursday, in the *Wilson Hall, 1 West*) :**
  - "Accelerator Science Initiative" at FAST
  - 2017 experiments; new experimental proposals

Back Up Slides

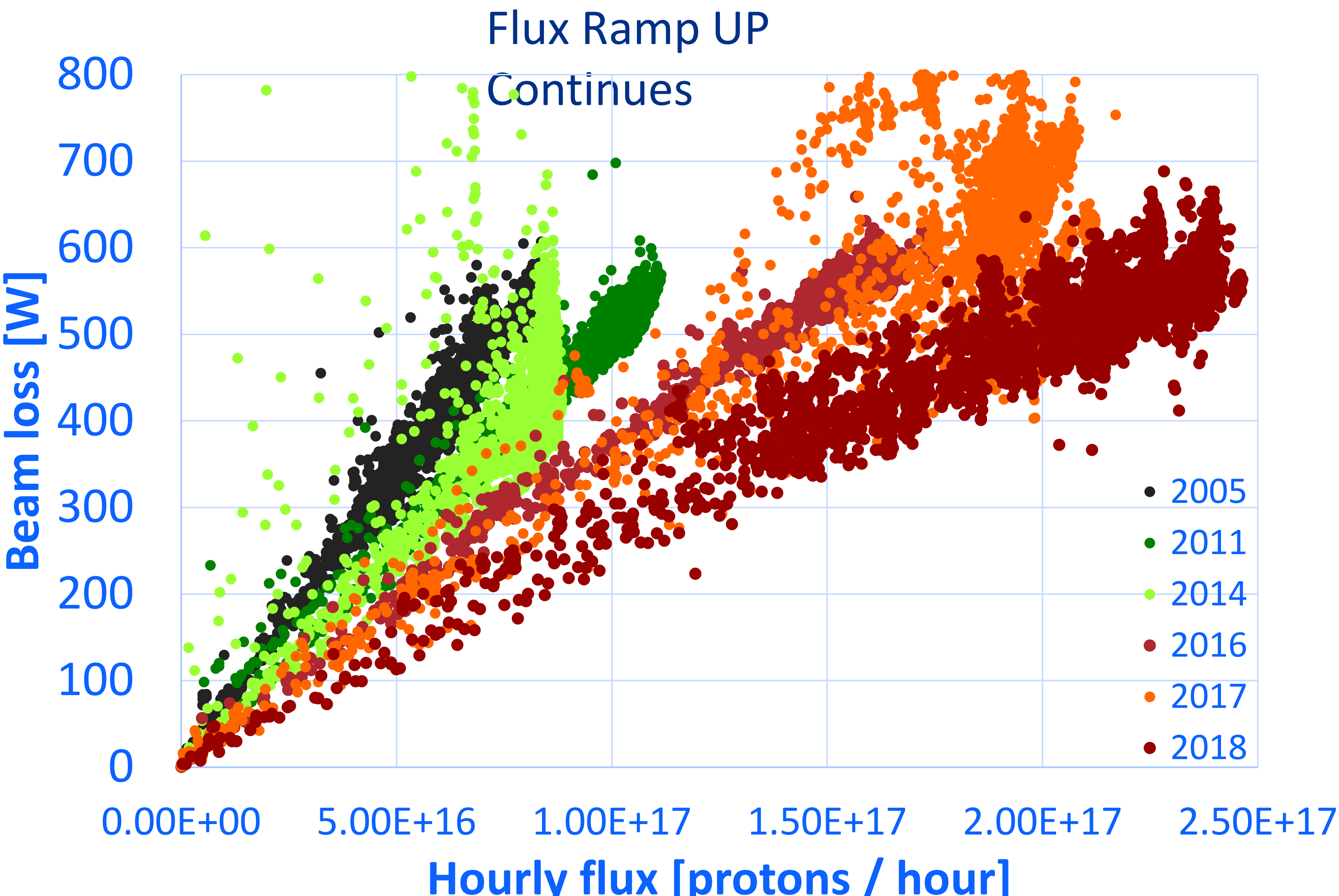
PIP: Highlights – Plots of Beam Charge and Calc Energy Loss



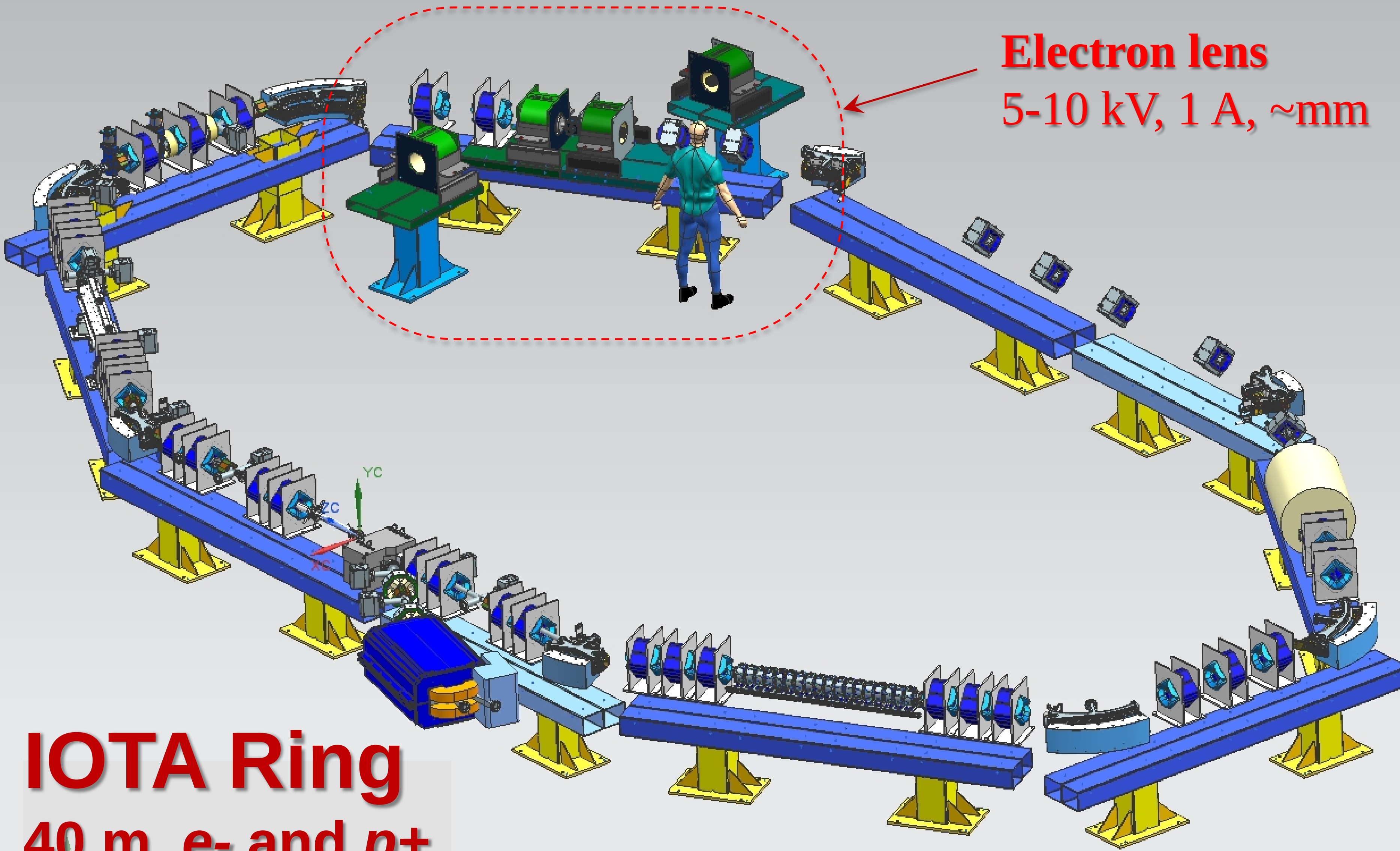
If you have to double the flux and keep beam loss energy the same:

1. Reduce Booster cycle loss by 50%
2. Control the loss point in critical areas

Loss Limit reaching PIP goal of 2.4E17 pph – running above 2.1E17 pph

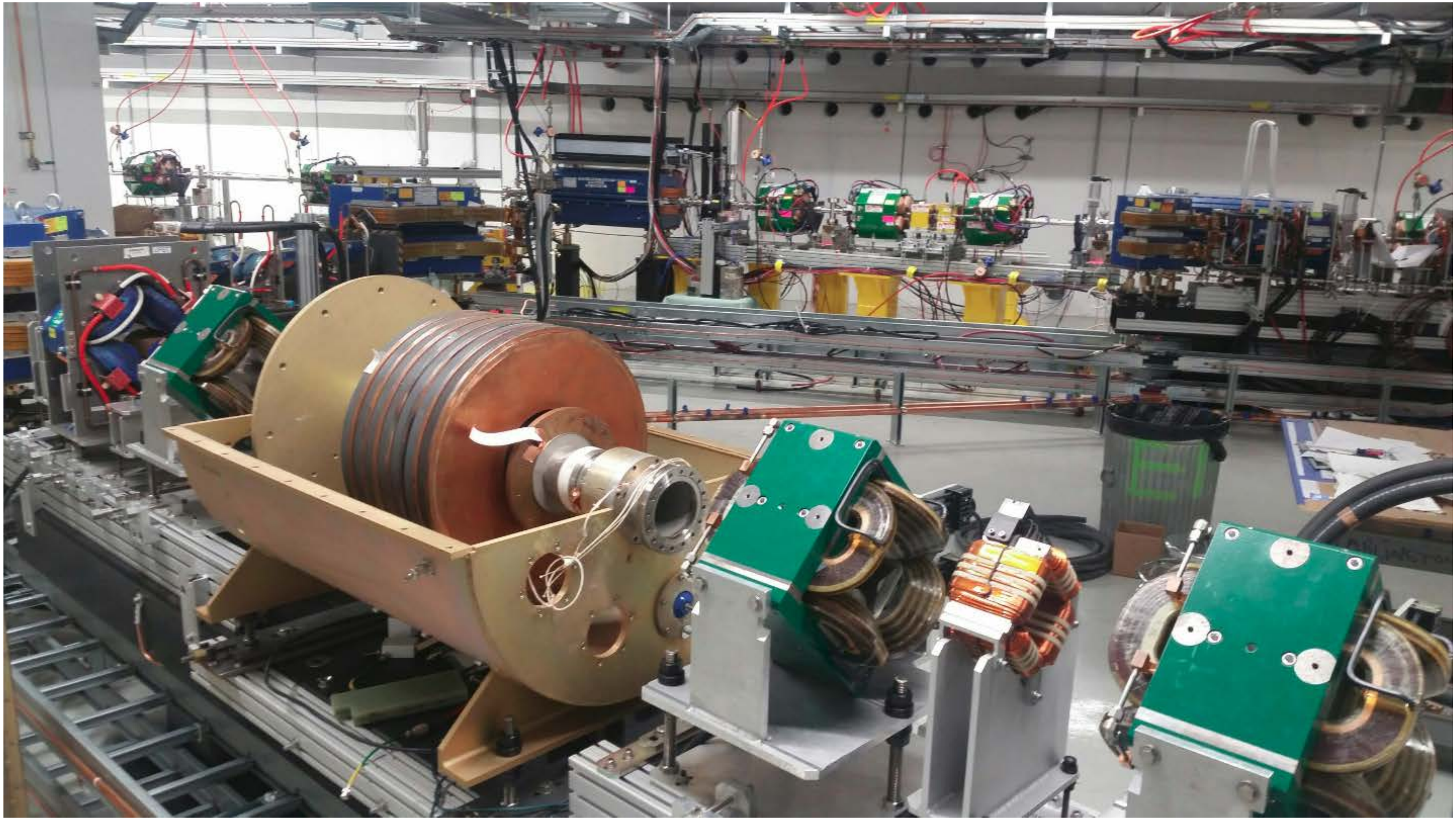


Beam tests possible at RHIC and IOTA

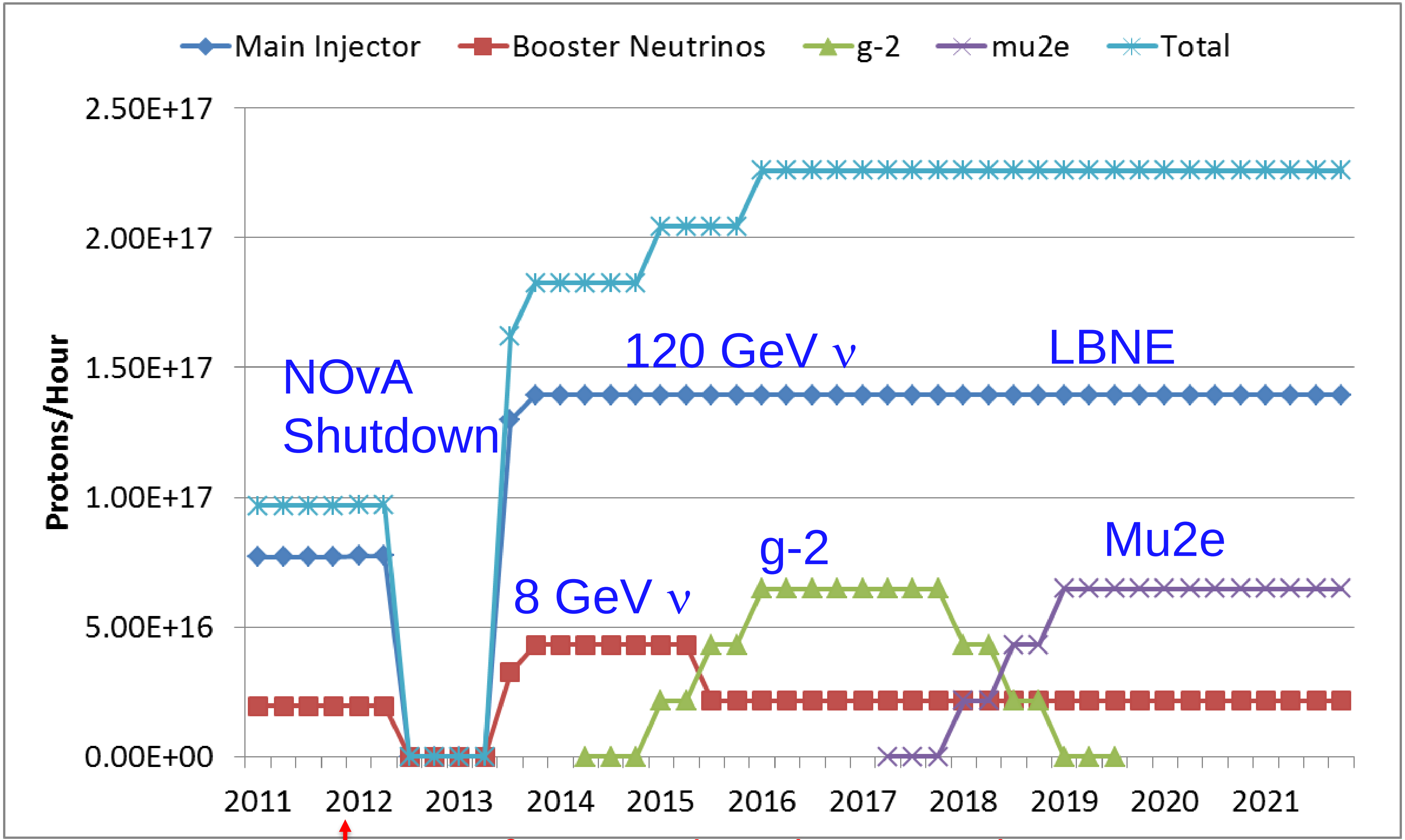


IOTA Ring
40 m, *e*- and *p*+
Fermilab

IOTA Ring : Beam Start-up This Summer



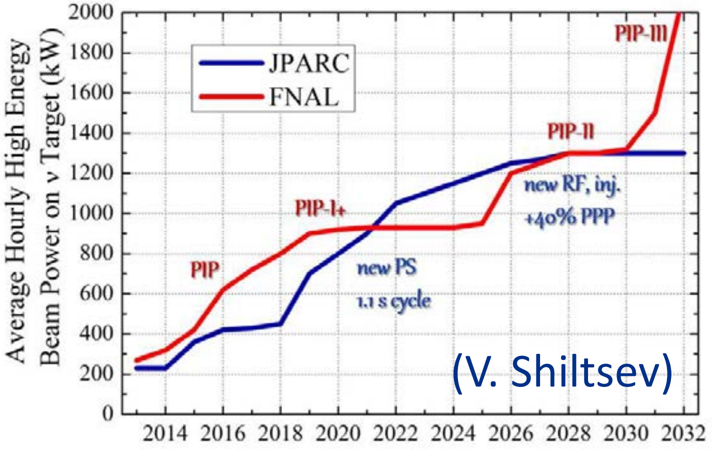
PIP: HEP needs Nov 2011



Start of PIP – Did not leave much time

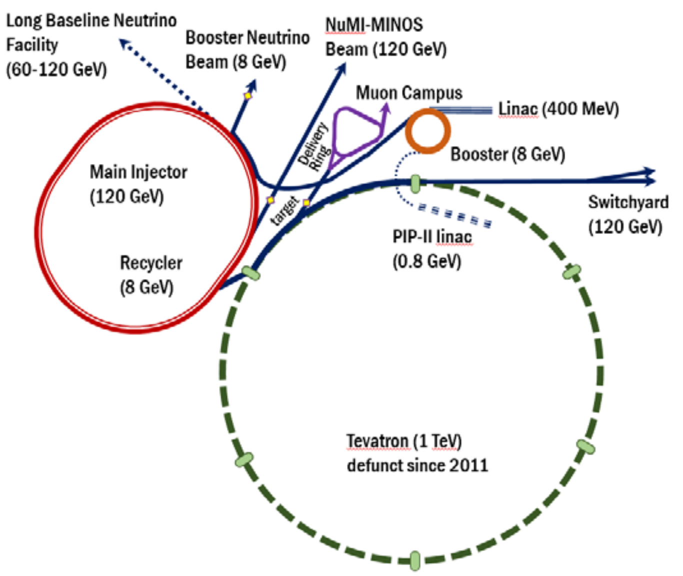
Strategic Landscape for Beam Physics:

Robust FNAL R&D in beam physics is a key factor for the success of future high-power accelerators.



Strategic Goals for FNAL in Beam Physics:

- Leadership in beam physics and a reputation for excellence; achieving MW and multi-MW beams is at the core of this leadership
- Enable technological and strategic leaps in HEP through improved beam-physics understanding; translation of concepts to operational systems that serve mid- and long-term FNAL/HEP mission
- Foster an innovative culture in beam-physics R&D; FNAL as the center supported by university, inter-lab and corporate partnerships
- Identify expanded opportunities for FNAL expertise to enhance the field



Primary Areas for Beam-Physics R&D:

- Power, Stability, Fast Beam Cooling, Instrumentation and Control

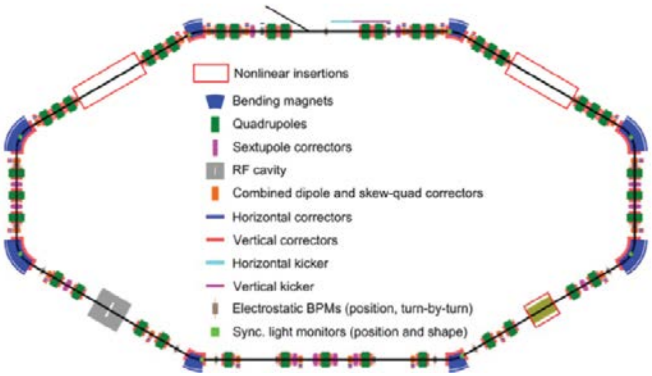
Future Beam-Physics R&D for FNAL:

IOTA/FAST facility as a collaborative center of beam-physics innovation

- *Nonlinear Integrable Optics*: Demonstration of core principles and translation into fundamentally new designs for high-power machines.
- *Space-charge compensation*: Innovation in electron lenses to enhance stability of high-power beams
- *High-Bandwidth Beam Cooling*: Demonstration of Optical Stochastic Cooling (10^3-10^4 increase in cooling rate); Presents opportunities for long-term, cross-office involvement and benefits (HEP/NP)
- *Beam dynamics in SRF linacs*: high-fidelity exploration for machines such as ILC, MARIE, EIC
- *Novel beam-diagnostics development*

Additional areas of development:

- Enabling technologies for a future muon collider, e.g. ionization cooling (cf. MICE)
- Innovative control schemes to unlock magnetrons for use in high-power accelerators



IOTA ring

Accelerator Science strategy

- Expand beyond U.S. particle physics needs. Identify and build external partnerships to bring Accelerator Science initiative (AS) focus to the current R&D portfolio.

- A critical time when HEP (LHC, FCC, ILC, CLIC) projects are mostly off-shore, technology heavy and could ebb away our national accelerator science strength. A unique opportunity at a crucial juncture. A wide array of experiments in the pipeline.

Goal:	Help OHEP to become the go-to office on accelerators for the DOE
FAST-IOTA	Develop into a National User Facility with appropriate structures in place. Excellence has to be demonstrated in scientific output.
USPAS	Sustain our leadership. Identify and tap talent.
Universities	Grow beyond Mid-West.
Ph.D. program	Expand to 10-15 students
Non-HEP	Growing sector. Capture AS initiatives in NP/BES. Leverage IARC.
International	Work with OHEP for collaboration with CERN, US-Japan

Accelerator Science strategy

- ❑ Deliberate, systematic development of Accelerator Science at FNAL
- ❑ Enable future projects, discoveries and innovation (for ALL partners)
- ❑ Disrupt existing technology paradigms, where possible (cost, efficiency)

Partnership development:

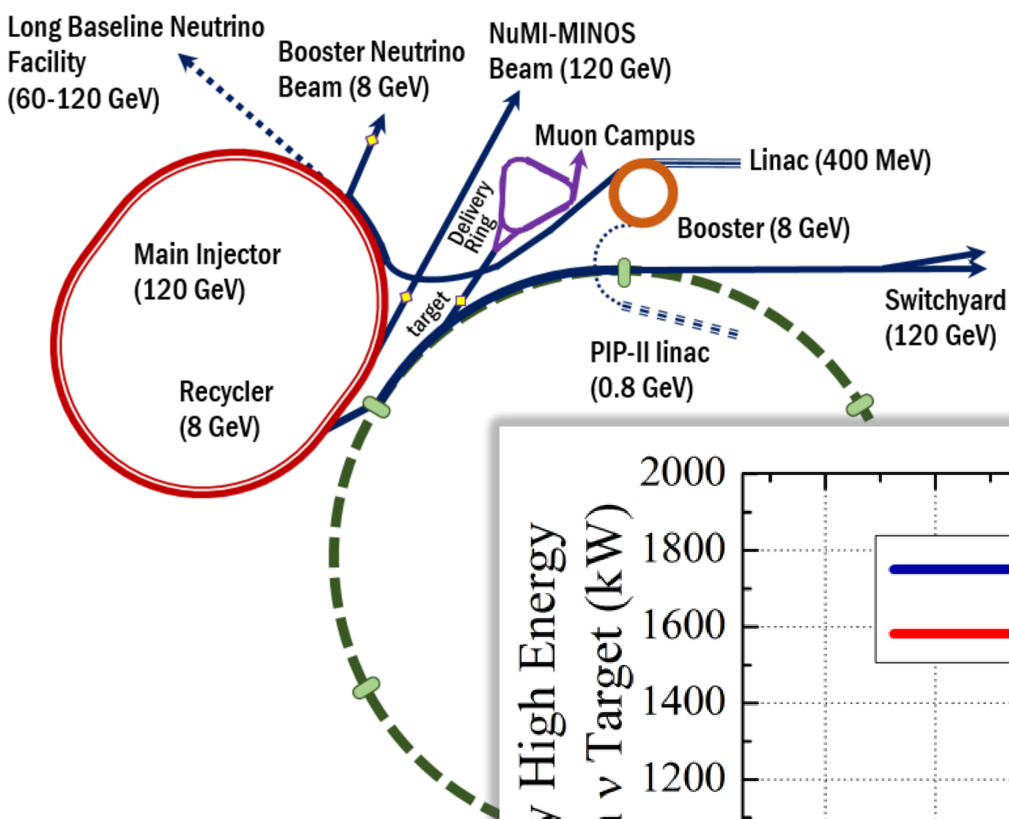
- Join the LCLS-II commissioning and welcome SLAC colleagues to FAST – unique ILC like test bed.
- Join FACET-II experiments; FAST as complementary facility (discussions with UCLA/SLAC)
- Formulate key regional collaborations with non-HEP labs: SNS, ANL, FRIB
- Leverage IARC research portfolio

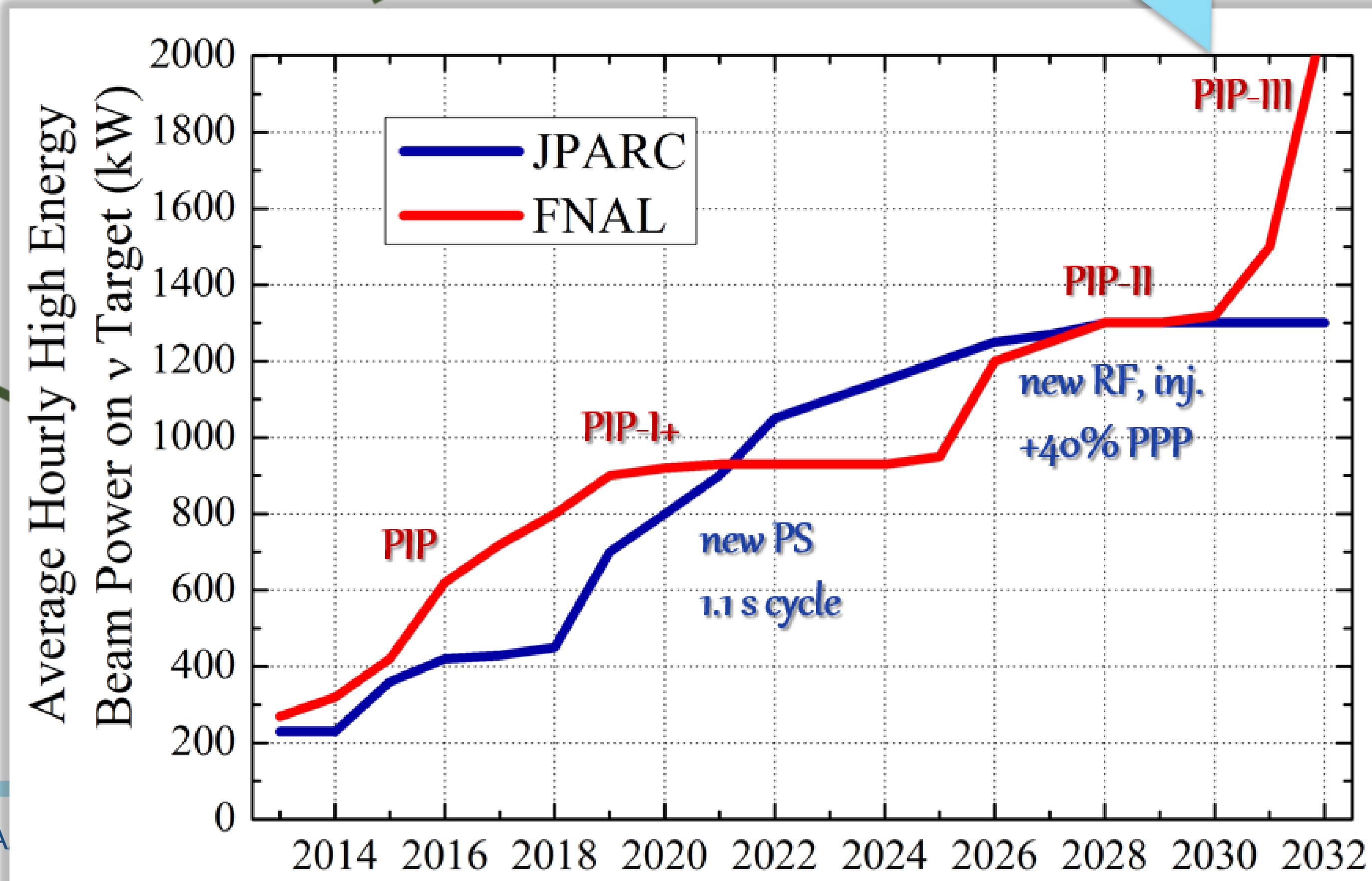
Fermilab Workshop on Megawatt Rings & IOTA/FAST Collaboration Meeting
7-10 May 2018

Program development:

- Advanced beam manipulation
- THz and inverse Compton scattering in FAST linac
- Plasma acceleration (collaboration with UCLA, SLAC, UK)
- Laser stripping (collaborations with SNS, UTenn, J-PARC)
- Crystals and nanotubes – channeling, radiation, etc
- Advanced muon techniques for PIP-II experiments
- Single-electron quantum experiments in IOTA

Motivation for IOTA/FAST: (Race to) ***Multi-MW*** Beams





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