Fermilab

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Fermilab Accelerator R&D Program

Vladimir Shiltsev, Accelerator Physics Center

Institutional Review of the Fermi National Accelerator Laboratory

11 February 2015

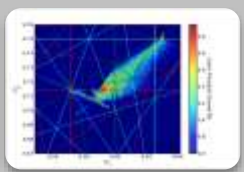
Fermilab Accelerator Program: P5-Aligned

Operational Support and Complex Upgrade (PIP-II)

- Provide accelerator physics and technology support for operation and upgrades of the Fermilab's accelerator complex, ν and μ experiments

Advanced Accelerator R&D Towards Next Generation Machine

- Develop and explore transformative concepts and technologies for beyond next-generation multi-MW accelerators at IOTA/ASTA and in the area of SRF



Accelerator and Beam Physics

- Contribute to the fundamental understanding of beam dynamics through experiment , simulation and theory

Exploratory Long-term R&D

- Assess feasibility and demonstrate technologies for future 100 TeV pp collider and conclude ionization cooling demo for possible future muon facility

Accelerators Training and Education

- Educate the next generation of accelerator designers and builders through the USPAS and Fermilab programs

Map of Fermilab's Accelerator R&D Activities

- Beam physics at operations machines
- R&D for Projects/Facilities: PIP-II, LCLS-II, ILC *– session 3E*
- GARD (General Accelerator R&D):
  - High-field Magnets and Materials *– session 7A*
  - IOTA Research Towards Multi-MW Beams *– session 6A*
  - High Power Targets R&D
  - Cost-Effective SRF Technology *– session 3E*
  - Accelerator Science, Modeling & Design *– session 5C*
- Accelerator Training and Education
- Accelerator R&D Programs: MAP and LARP *– session 6A*
- Accelerator Test Facilities Operation and IARC

Accelerator Science – Lab Goals (see Nigel's talk Tue)

- **Extend the scientific reach of existing accelerator facilities**
  - Improved performance of Fermilab accelerators with intense beams and low losses are critical to achieving the muon and neutrino programmatic goals.
- **Launch a test facility to enable 'transformative' Accelerator Science**
  - The Integrable Optics Test Accelerator **(IOTA)** is needed to address key questions related to affordable future accelerators at the intensity frontier and engage the community in frontier accelerator science research.
- **Explore scientific limits to gradients and Q0 for future SRF accelerators**
  - Future accelerators (e.g. PIP-II, LCLS-II, ILC, FCC, industrial linacs) need to be energy efficient and cost-effective (i.e. rapid acceleration and low loss).
- **Establish Fermilab as essential contributor to future large accelerators**
  - Advanced capabilities in high-field magnets, SRF accelerators and beam dynamics will position the Lab as an essential contributor to future high-energy physics facilities (e.g. TeV-class *e+e-* and *100 TeV pp* colliders).
- **Show importance of accelerator science & HEP to US competitiveness**
  - Important aspect of **IARC** is to apply HEP technologies to industrial and societal challenges in health, security, energy, and the environment.

Content

- Highlights of 2012-2014:
  - Studies, achievements, team, education, collaborators
- Current Issues and Challenges:
  - Instabilities, targetry, collimation, ED, modeling
- Shaping Post-PIPII Future:
  - Options for multi-MW complex upgrade (PIP-III)
  - IOTA R&D program
- Long-term R&D Towards HEP Frontier:
  - FCC research
  - MAP/MICE ramp-down

Highlights of Fermilab's Accelerator Program

2012-2014

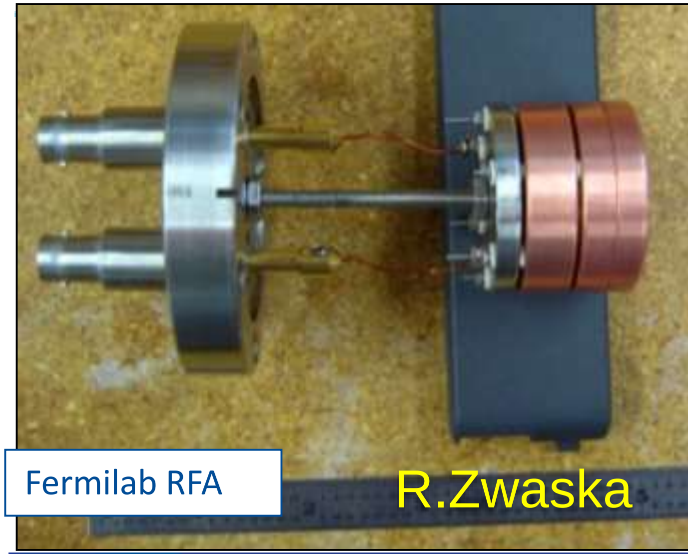
FNAL Accelerator Program: Major Drivers/Developments

- Beam physics limitations on the FNAL accelerator complex performance:
  - PIP, beam studies
- Document Tevatron legacy in beam physics
  - for the benefit of accelerator science and future colliders
- R&D and design effort toward next facility:
  - ILC → Project-X → ***PIP-II***
  - Integral part of community planning (Snowmass, P5)
- Establish R&D beam facilities for the next- and generation-after next machines:
  - NML→ ASTA→***IOTA***
- Collaboration with Universities & Training

Main Injector: *e-* Cloud Experimental Station

E-Cloud Station in Main Injector :

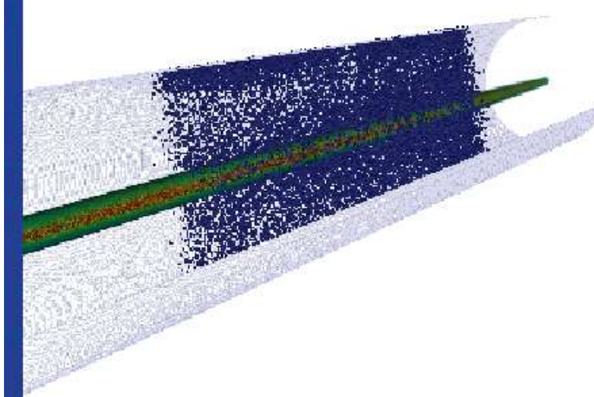
- 2 experimental Chambers (coated and SS)
  - Test various coatings for ECloud suppression
  - Measure spatial extinction of ECloud
- 3 Fermilab and 1 Argonne RFA
  - Retarding Field Analyzers
  - Directly measure electron flux
- 3 microwave antennas and 2 absorbers
  - Measure ECloud density by phase delay of microwaves
- So far, three materials tested:
  - TiN (2009-10) – suppressed vs. Stainless (5-1000x)
  - α-C (2010-12, from CERN) – similar suppression as TiN
  - DLC (2013-, from KEK) – Awaiting the return of beam



Augmented by comprehensive simulations

- Utilization of SYNERGIA and ComPASS tools :
  - *ComPASS VORPAL e-cloud simulation of MI experiments*
- Model microwave experiment (only possible with ComPASS tools), RFA response
- Code comparisons with "standard" tools such as POSINST

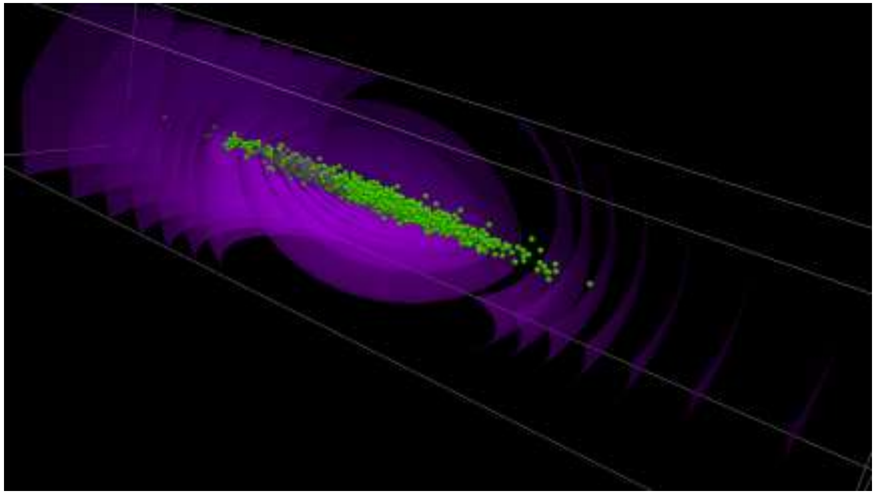
P.Lebrun, J.Amundson, P.Spentzouris, et al



Synergia: Accelerator Modeling Tool

Beam Dynamics Framework

- Developed at Fermilab with support from SciDAC
- Collective effects
- Fully nonlinear single-particle dynamics



Synergia run on everything from laptops to supercomputers

- MIC and GPU versions in development

Modeling Fermilab and CERN Machines

- Booster
  - Space charge + wakefields
- Main Injector and Recycler
  - Slip stacking with space charge
- CERN Injectors for HL-HLC
  - Space charge

(more in parallel Session 5C)

P.Spentzouris, J.Amundson, E.Stern, et al

Six-Cavity Test @ HINS

D.Wildman, J.Steimel, V.Scarpine, M.Chung, et al

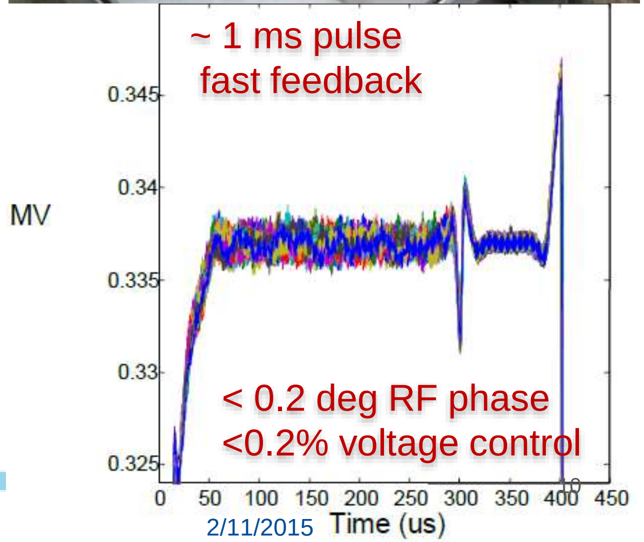
- "Six-Cavity Test' has demonstrated the use of high power ***RF vector modulators*** to control 6 RF cavities + RFQ driven by a ***single high power klystron***
- demonstrated the energy stability with a 7-mA proton beam accelerated through the six cavities from 2.5 MeV to 3.4 MeV.

Diagnostics development and tests:

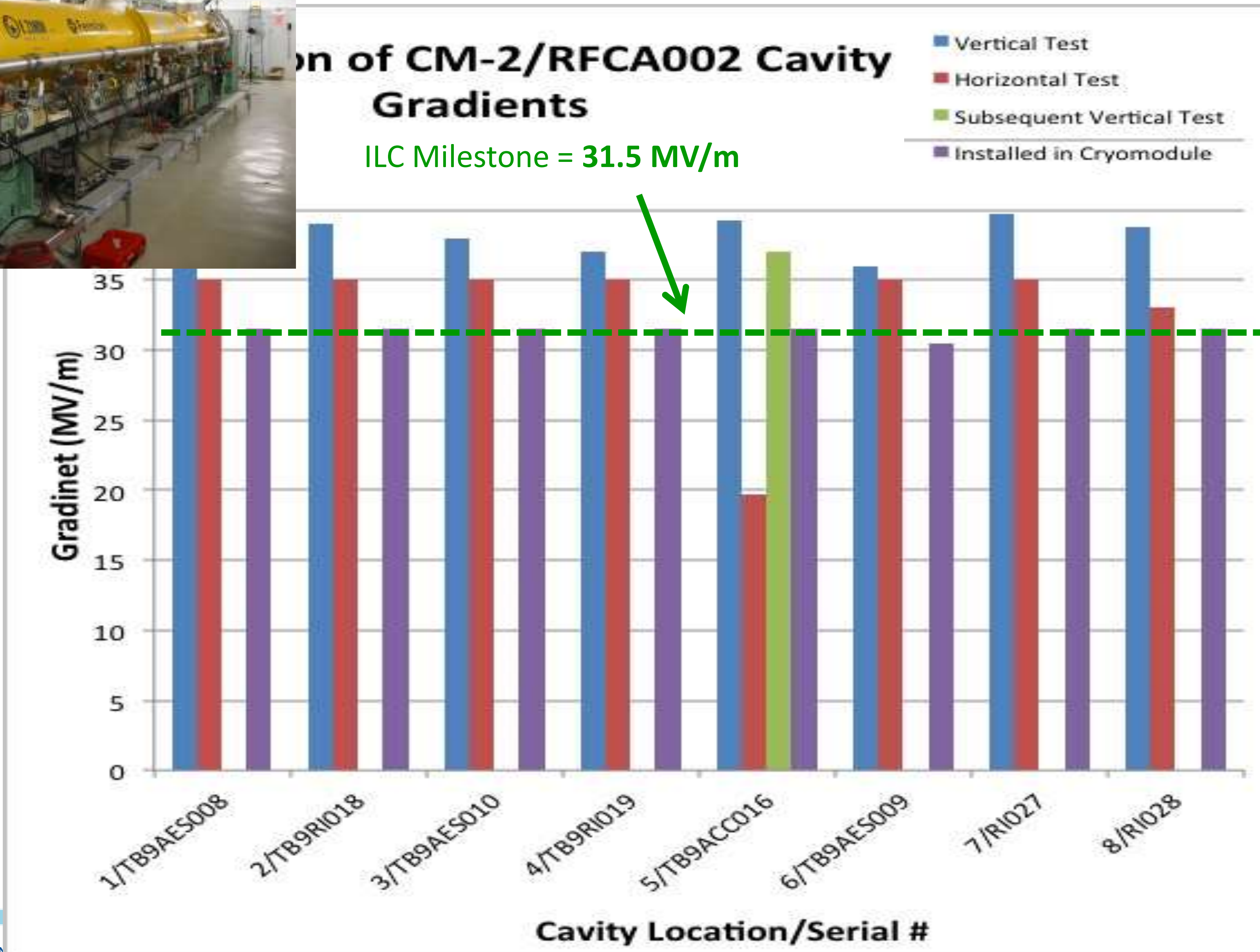
- together with RAL and Argonne

Finished operation Jan'2013

Will move to ASTA (*p*'s for IOTA)



CM2 – World's Highest Gradient CM



W.Shappert, E.Harms, N.Solyak, et al

Beam Physics @ Tevatron

Journal of Instrumentation

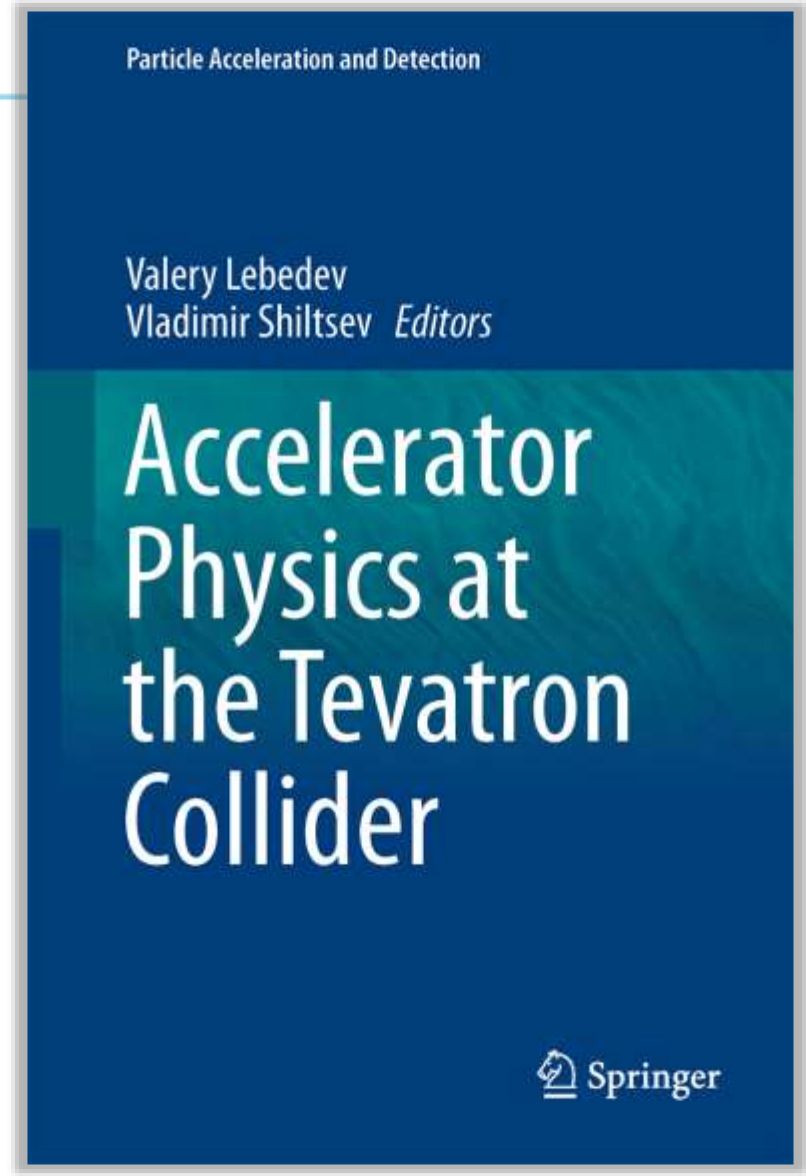
Special Issue

JINST

Tevatron Accelerators

For almost 25 years, the Tevatron at Fermi National Accelerator Laboratory (Bat... it began operation in December 1985 until it was overtaken by the LHC in 2009. ... explore the elementary particle physics phenomena with center of mass proton-antiproton collision energies of up to 1.96 TeV. The initial design luminosity of the Tevatron was 1e30 cm^{-2} s^{-1}, however due to many upgrades and improvements the accelerator has been able to deliver more than 400 times higher luminosity to each of two experiments, CDF and D0. The Tevatron collider is scheduled to be shut off at the end of September 2011. It is one of the most complex scientific instruments ever to reach the operation stage and recognized by its achievements at the frontier of a number of technologies. In this special issue of JINST, we present technical papers that reflect the work carried out by the Tevatron team over the past decades in the field of beam physics and accelerator technology.

- Operation of the intensity monitors in beam transport lines at Fermilab during Run II
- Synchrotron radiation based beam diagnostics at the Fermilab Tevatron
- The Tevatron wide band longitudinal coupled bunch mode dampers — an account from its commissioning to its decommissioning
- Ambient betatron motion and its excitation by "ghost lines" in Tevatron
- Emittance growth mechanisms in the Tevatron beams
- Tevatron beam halo collimation system: design, operational experience and new methods
- Experiences with permanent magnets at the Fermilab recycler ring
- Implementation of stochastic cooling hardware at Fermilab's Tevatron collider
- Overview of the Tevatron collider complex: goals, operations and performance



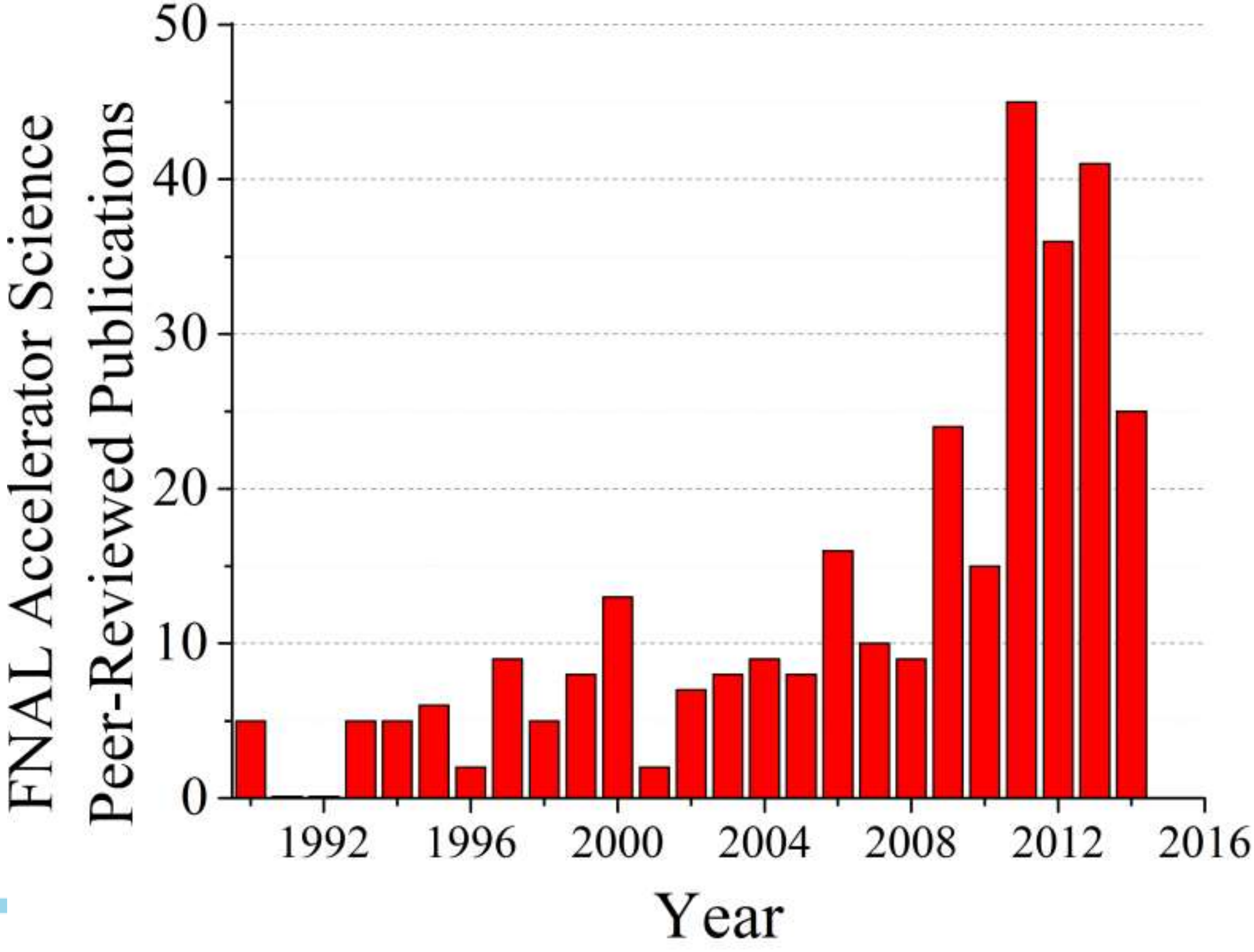
Available on *Amazon.com*

Beam Theory and Simulations

- **A number of outstanding advances in beam theory:**
  - A series of works by Burov, Balbekov,and Lebedev on beam dynamics of longitudinal and transverse instabilities with space-charge
  - Theory of nonlinear but integrable (stable) beam optics
  - *"Outstanding" PRSTAB Article of 2010*: V. Danilov, S. N., PRSTAB, 13, 084002 (2010)
  - *"Outstanding" PRSTAB Article of 2011*: P. Piot, Y.-E Sun, J. G. Power, and M. Rihaoui, PRSTAB 14, 022801 (2011).
- **A suite of modeling tools, developed at Fermilab:**

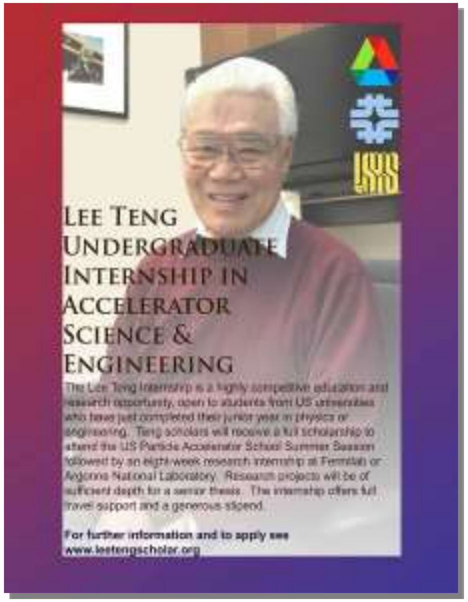
– MARS	300 users,	40 institutions
– Synergia	30	8
– OPTIM	20	5
– Lifetrac	10	5

FNAL Peer-reviewed Accelerator Sci & Tech publications



Accelerator Training

- Host US PAS :
  - Office, >40 instructors +assistants in 2009-2014
- Summer Internships – Lee Teng :
  - 5+5 jointly with ANL (E.Prebys, chair)



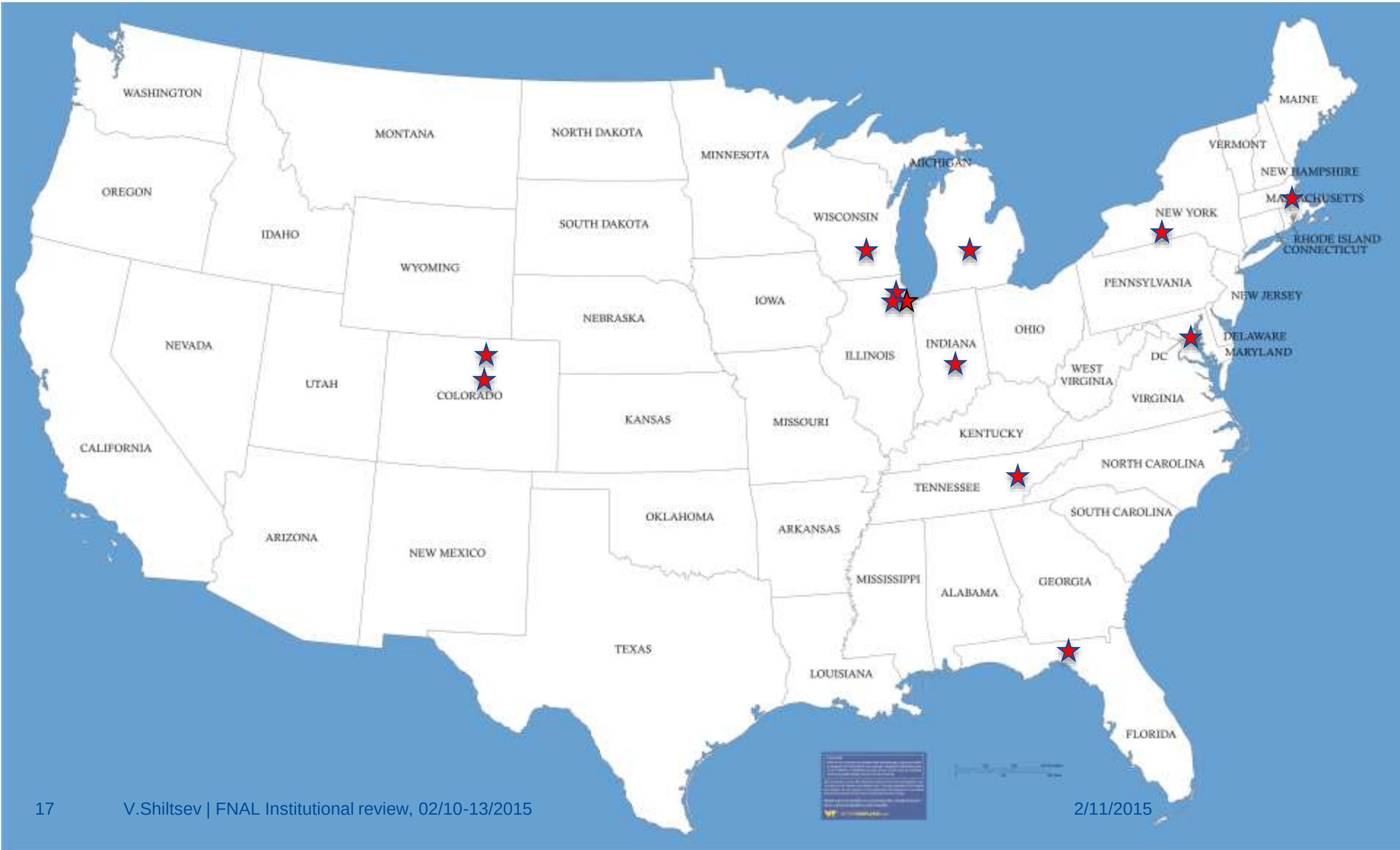
- Peoples Fellows (now 3):
  - "Future leaders" in accelerators (tenure track)
- Bardeen Fellows (2):
  - For outstanding engineering graduates
- Joint Appointments (4):
  - "50-50" arrangements , now NIU & IIT
- Joint University-FNAL PhD Program:
  - 6-8 students to carry out accelerator physics and technology R&D at Fermilab

PhD Degrees based on research at Fermilab : 13 over 2009-2014

Gene Kafka	2014	IIT
Timofei Zolkin	2014	University of Chicago
Julia Trenikhina	2014	IIT
Ben Freemire	2013	IIT
Denise Ford	2013	Northwestern
Timothy Maxwell	2012	Northern Illinois University
Alexey Petrenko	2012	Budker Institute of Nuclear Physics
Arun Saini	2012	University of Delhi
W.-M. Tam	2010	Indiana University
Dan McCarron	2010	Illinois Institute of Technology
Igor Tropin	2010	Tomsk University
Uros Mavric	2009	University of Ljubljana
Timothy Koeth	2009	Rutgers University

- Currently – ***6 students*** in *Joint University-Fermilab Accelerator PhD program,*
- **4 Joint Appointments**: NIU: P.Piot, Y.M.Shin, S.Chattopadhyay; IIT: P.Snopok
- Adjunct/Visiting Professorships: S.Nagaitsev (UC), V.Shiltsev (NIU)

Universities – Collaborators in FNAL-based Accel. R&D



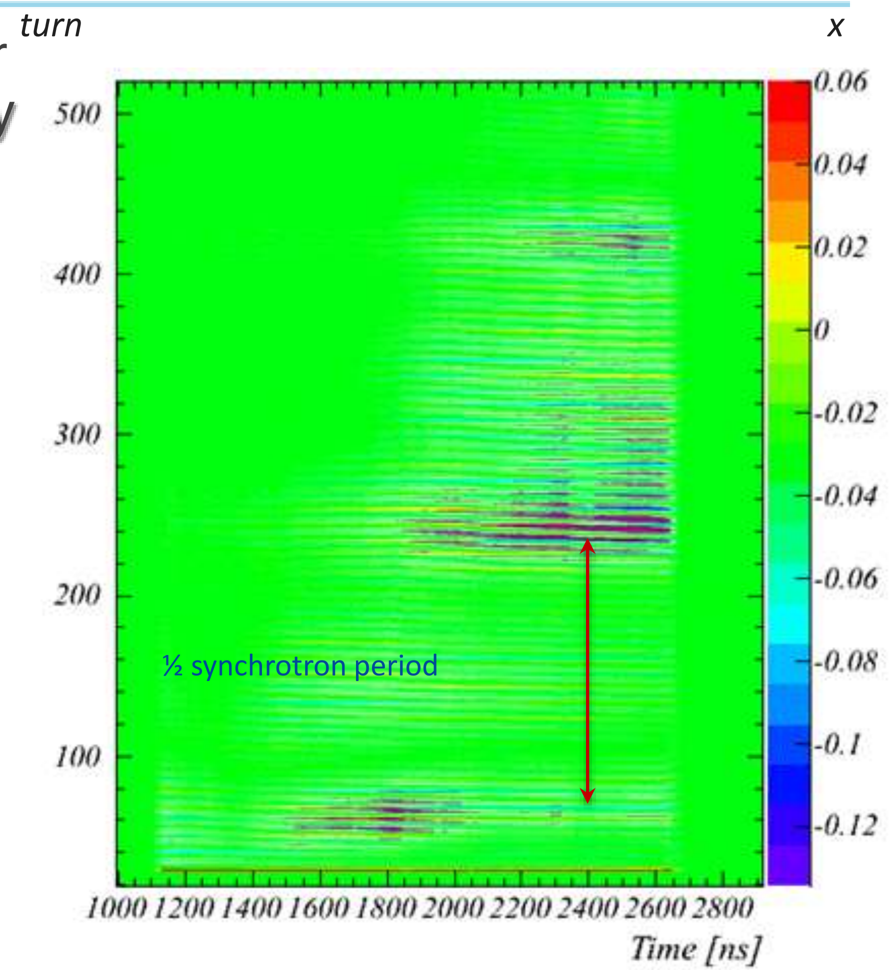
University	Primary Topic(s)	Funding Agency
IIT	SRF technology; machine concepts; Novel Accelerator technology	DOE-HEP grant, NSF
U. of Chicago	Beam dynamics (IOTA)	Fermilab, NSF, U.of Chi
NIU	SRF technology; beam dynamics (IOTA); Accelerator technology	DOE-HEP grant, NSF, DOD, NIU
IU	Beam dynamics; machine concepts	DOE-HEP grant
U. of MD	Beam dynamics	DOE-HEP grant, NSF,ONR
U. Tenn.	Accelerator technology; beam dynamics	DOE-HEP grant
U. Wisc.	SRF technology	DOE-HEP grant
MSU	SRF technology; beam dynamics; machine concepts	DOE-HEP grant; NSF
U. Of Colorado	Beam dynamics; accelerator technology	DOE-SBIR
Colorado State	SRF technology	ONR, High-Energy Laser Joint Tech Office
Cornell	SRF technology	DOE; NSF
MIT	Machine concepts	NSF

Current Accelerator Issues and Challenges

2015-

Recycler Instability Studies

- Last year (before shutdown) Recycler suffered from fast horizontal instability
  - had 10-20 turns growth rate
  - affected bunches in the second half of the injected batch
  - depended strongly on bunch length
  - had no obvious tune / chromaticity dependence
  - could be averted by first weak batch
- Task force formed to investigate
  - Experimental and theoretical studies ruled out all potential sources of the instability except for e-cloud
    - Don't yet have an explanation for the details of the observed behavior
- Does not hamper operations now
  - studies are necessary to understand the implications for PIP-II parameters



Onset of instability after injection of a single batch of nominal intensity $4 \cdot 10^{12}$

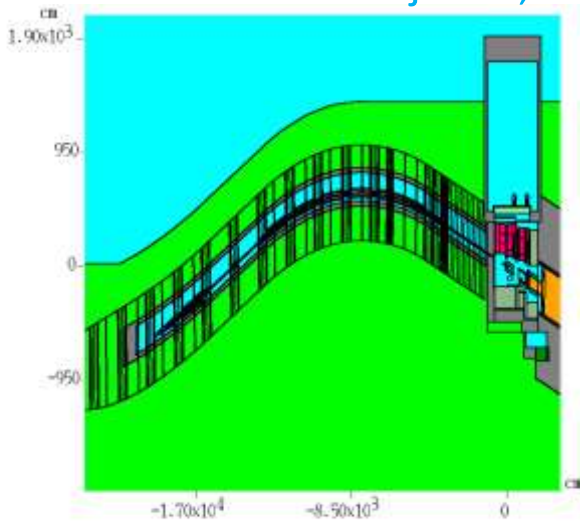
P.Adamson, Yu.Alexahin, et al

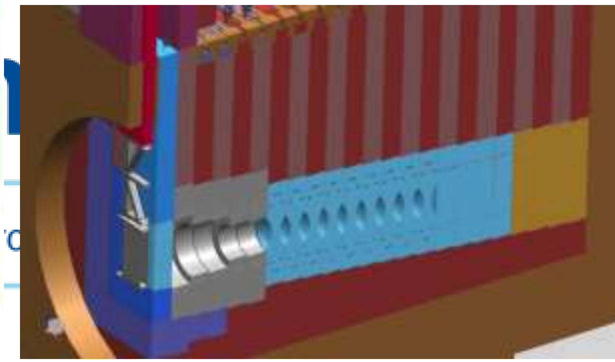
Treatment of Beam Losses: ED & Collimation

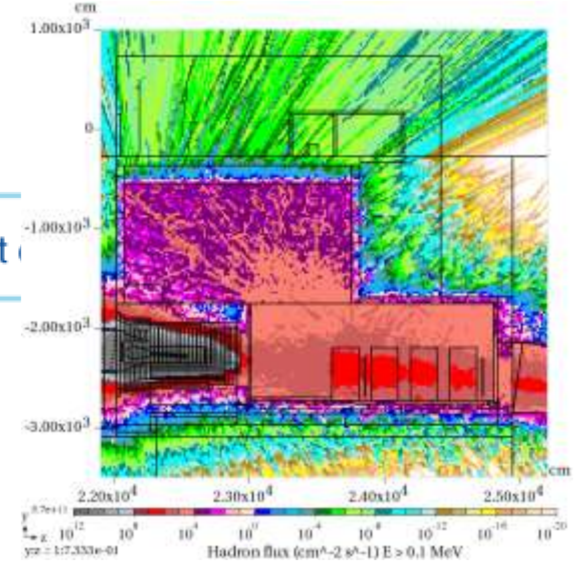
- Coupled MAD and MARS for precise multi-turn tracking and energy deposition / radiation modeling in accelerators for beam loss studies and collimator design
- Several **collimation systems** were MARS-designed and set in Tevatron, Main Injector, MI-8 beamline and Booster.
- Currently being applied to Recycler and Booster.
- Energy Deposition (ED) studies for projects: development of physics modules for even better description of meson and neutrino production in applications with 0.5 to 120 GeV beams (Mu2e, g-2, ELBNF, PIP-I and PIP-II) thoroughly benchmarked against data including recent MIPP's one.
    - See next slide

Recent MARS-Based Design Breakthroughs

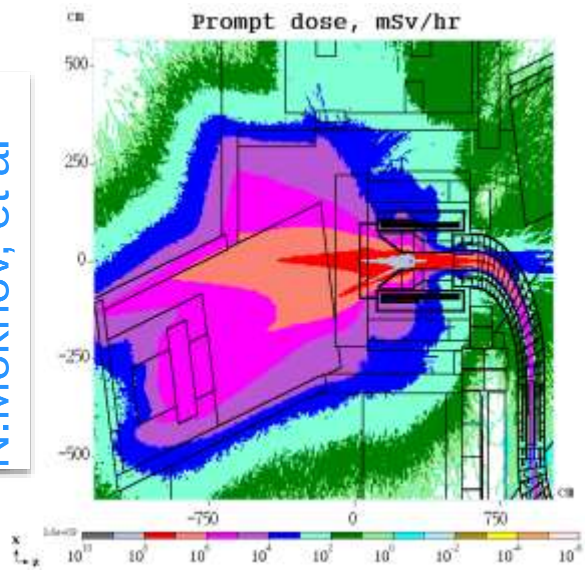
ELBNF: from Main Injector, through primary/neutrino beamlines and absorber to Near Detector



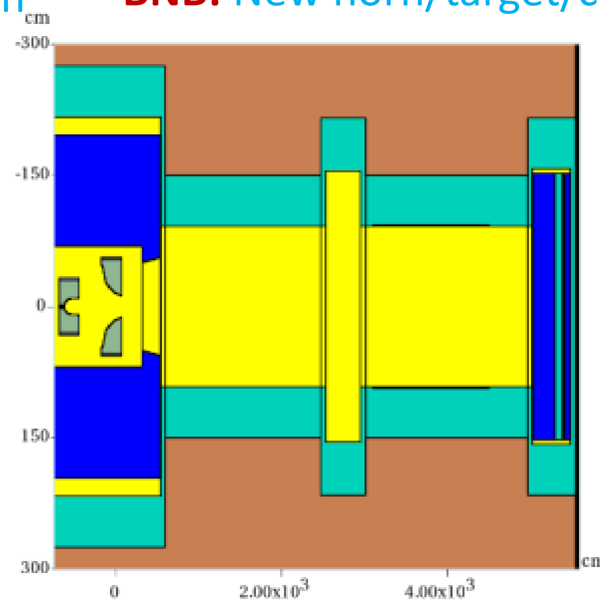


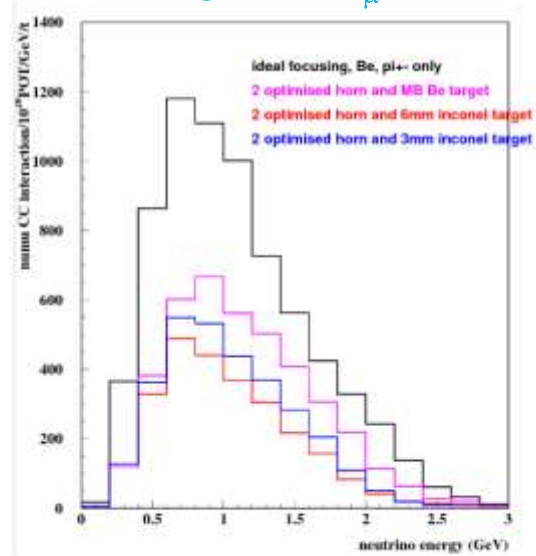


Mu2e CD2/3 quality target station



BNB: New horn/target/collimator design and ν_μ CC rate





N.Mokhov, et al

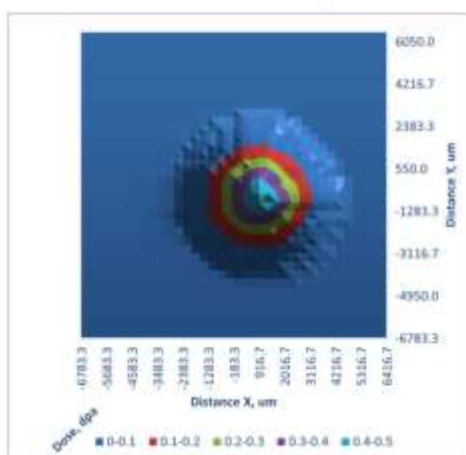
High Power Targetry R&D Status and Plans

- **RaDIATE Collaboration** (Radiation Damage in Accelerator Target Environments)
  - MOU revision (adding 7 institutions) received DOE approval
    - NuMI beryllium beam window Post-Irradiation Examination (PIE) at Oxford
    - Planning for low-energy ion irradiation studies at various universities
    - Continuing PIE at BNL of irradiated graphite (2009)
  - Other activities
    - Design of compact fatigue tester for hot cell use
    - Evaluation of new/upgraded irradiation facilities for HEP-HPT purposes

P.Hurh, R.Zwaska, et al

Dosimetry map

MARS calculations map



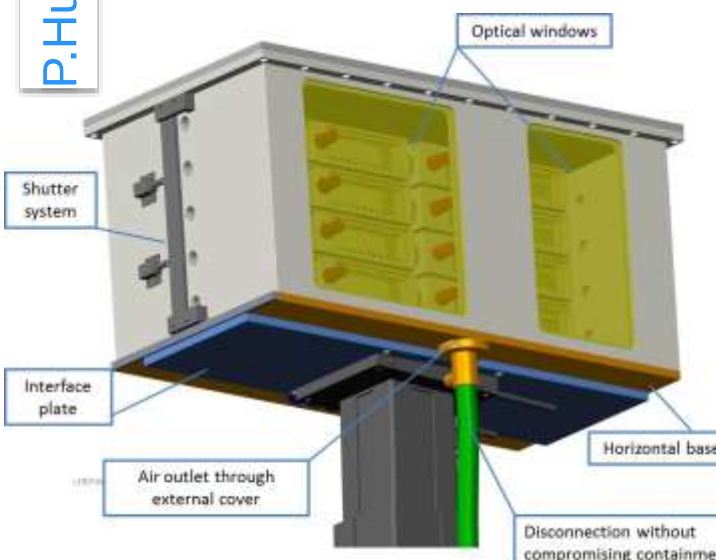
NuMI primary beam Be window dose map comparison

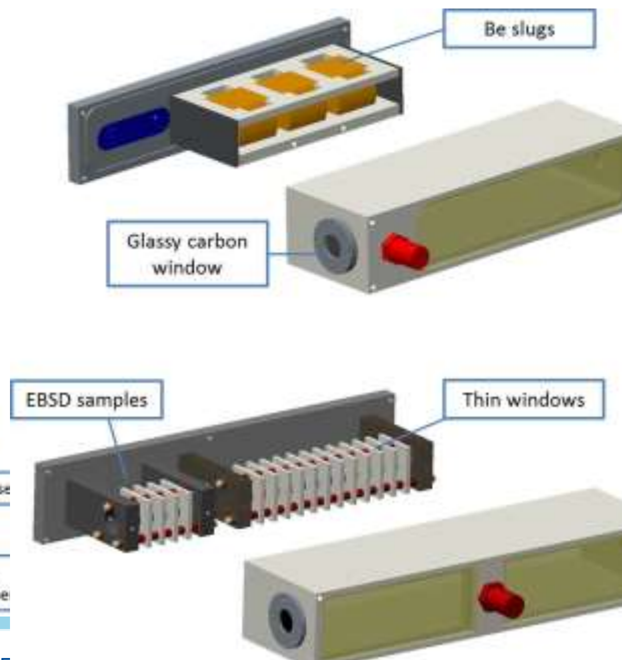
- Radiographic film (left) versus MARS calculation (right) shows good agreement
- Undergoing micromechanical evaluation of material properties

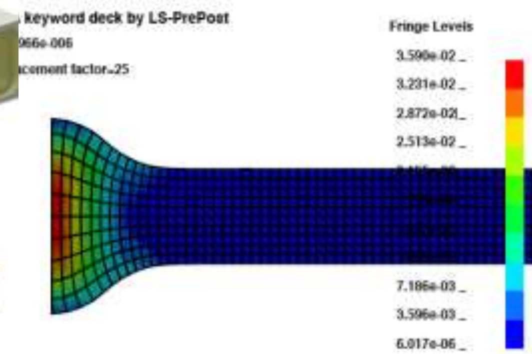
High Power Targetry R&D Status and Plans

P.Hurh, R.Zwaska, et al

- Thermal Shock R&D activities
  - Approval of BeGrid experiment at CERN's HiRadMat beamline
  - Test 4 grades of beryllium to varying intensity HE proton beam
  - Objectives of the 4 institution study (FNAL, RAL-STFC, Oxford, CERN):
    - Study the initiation of small scale damage from high intensity, single pulses
    - Explore failure limits of Be
    - Compare response of various grades/forms of Be
    - Validate simulation techniques and strength/damage material models







$t = 7.2\mu s, T_{max} \sim 1050^{\circ}C$

End of pulse

Shaping Post-PIP-II Future

“Decade of R&D”

P5 Report (2014): Strategic Considerations

- (Near Future domestic program = PIP-II and LBNF)
- Neutrinos: aim at **~600 kTon*MW*yr**
- "Power upgrades beyond PIP-II will require R&D for high average power proton linacs and target systems."
- "Support the discipline of accelerator science through advanced accelerator facilities and through funding for university programs."
- "Focus on outcomes and capabilities that will dramatically improve cost effectiveness for mid-term and far-term future."
- "Strengthen University - National lab partnerships."
- Incorporate the balance of mid-term vs far-term R&D as well as impacts.

- →created HEPAP Subpanel to assess GARD program and recommend alignment to P5 priorities

R&D to address future of FNAL complex

How to get to **~600 kTon*MW*yr ? →**

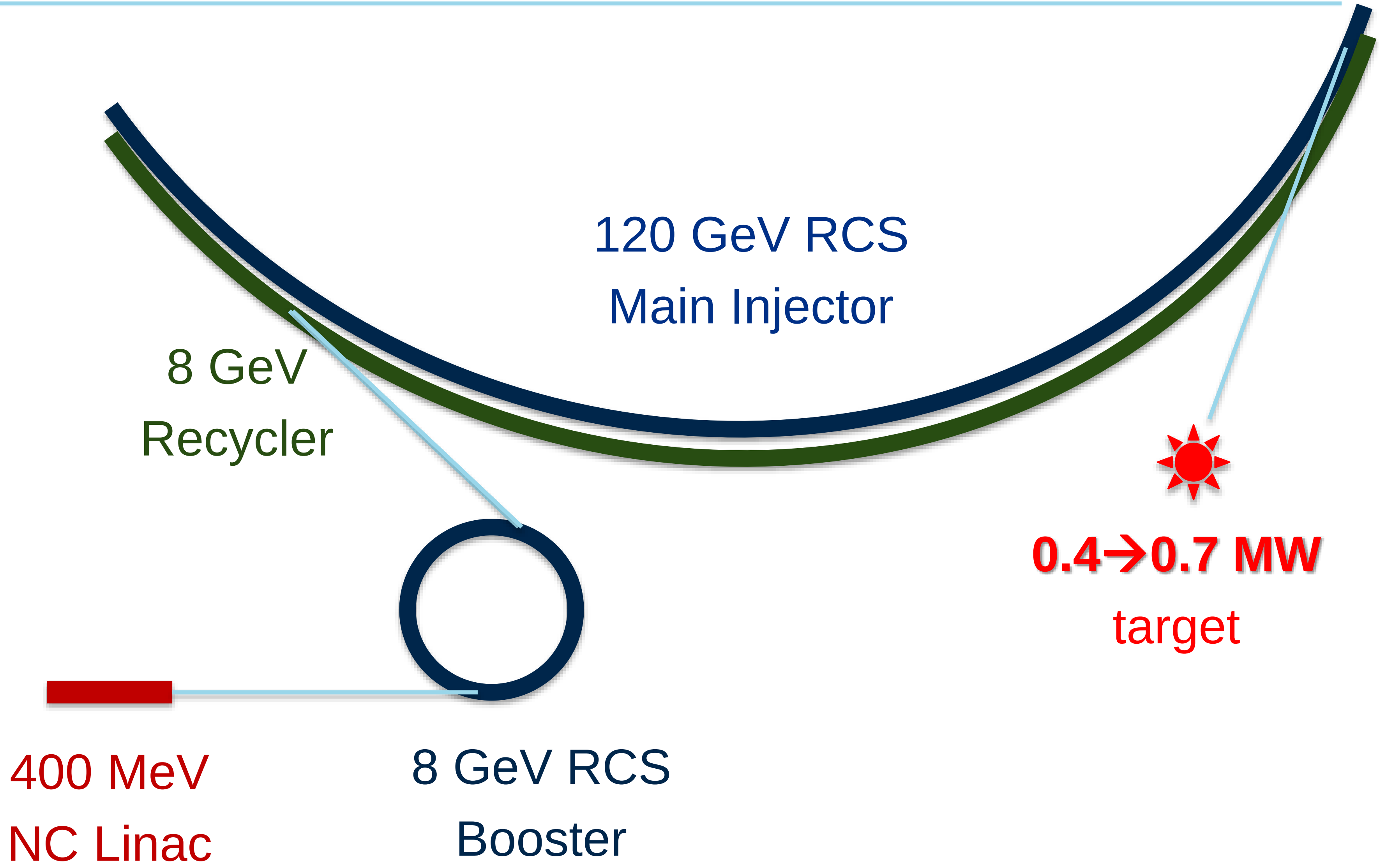
The need in novel techniques for multi-MW beams and targets

PIP-II | Beyond PIP-II (mid-term)

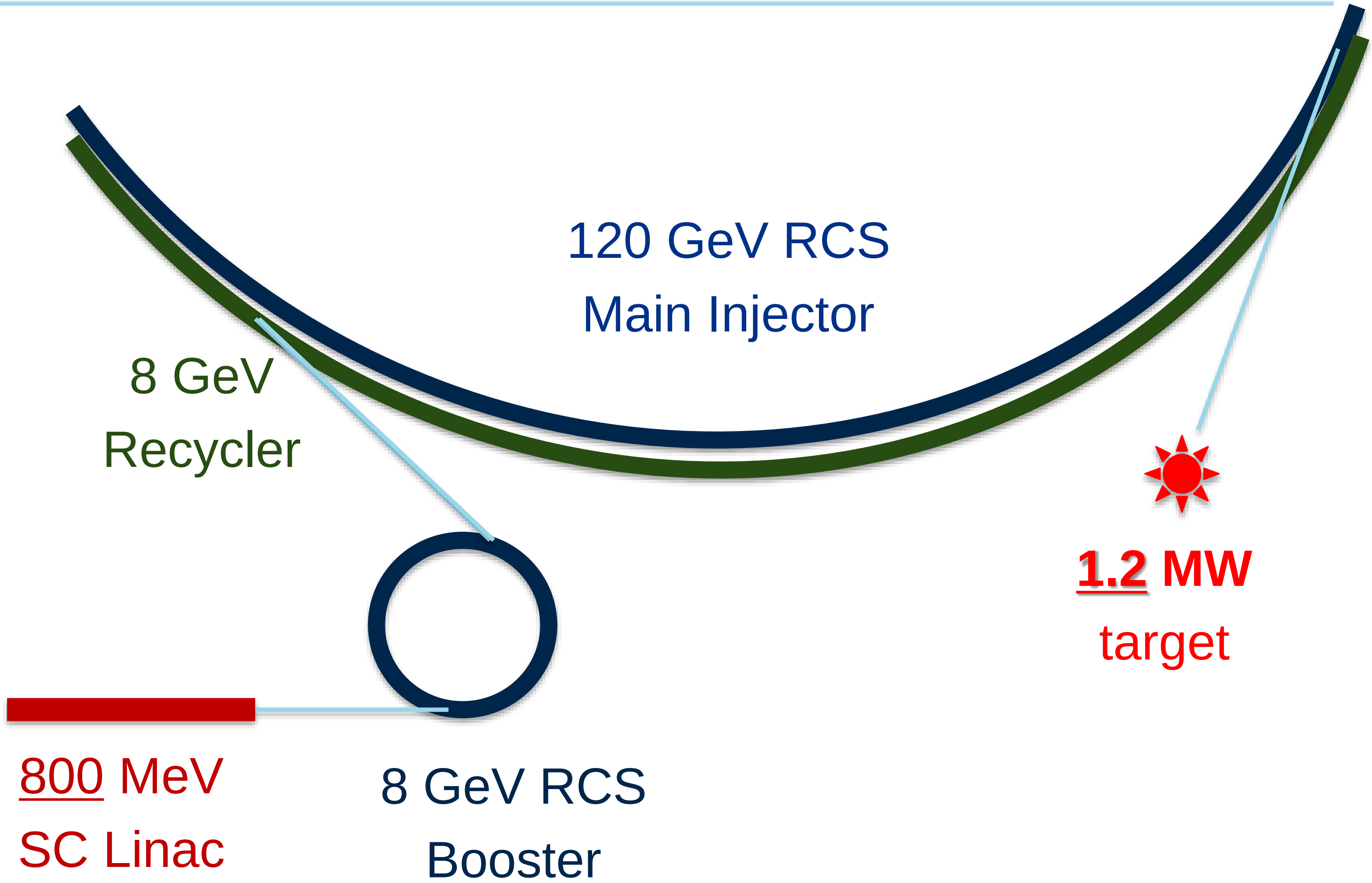
	1st 10 years	2nd 10 years		
To Achieve :	100 kT-MW-year	500 kT-MW-year		
We combine :		Option 1	Option 2	Option 3
Mass	10 kT	50 kT	20 kT	10 kT
Power	1 MW	1 MW	2.5 MW	5 MW

– Mid-term strategy after PIP-II depends on the technical feasibility of each option and the analysis of costs/kiloton versus costs/MW

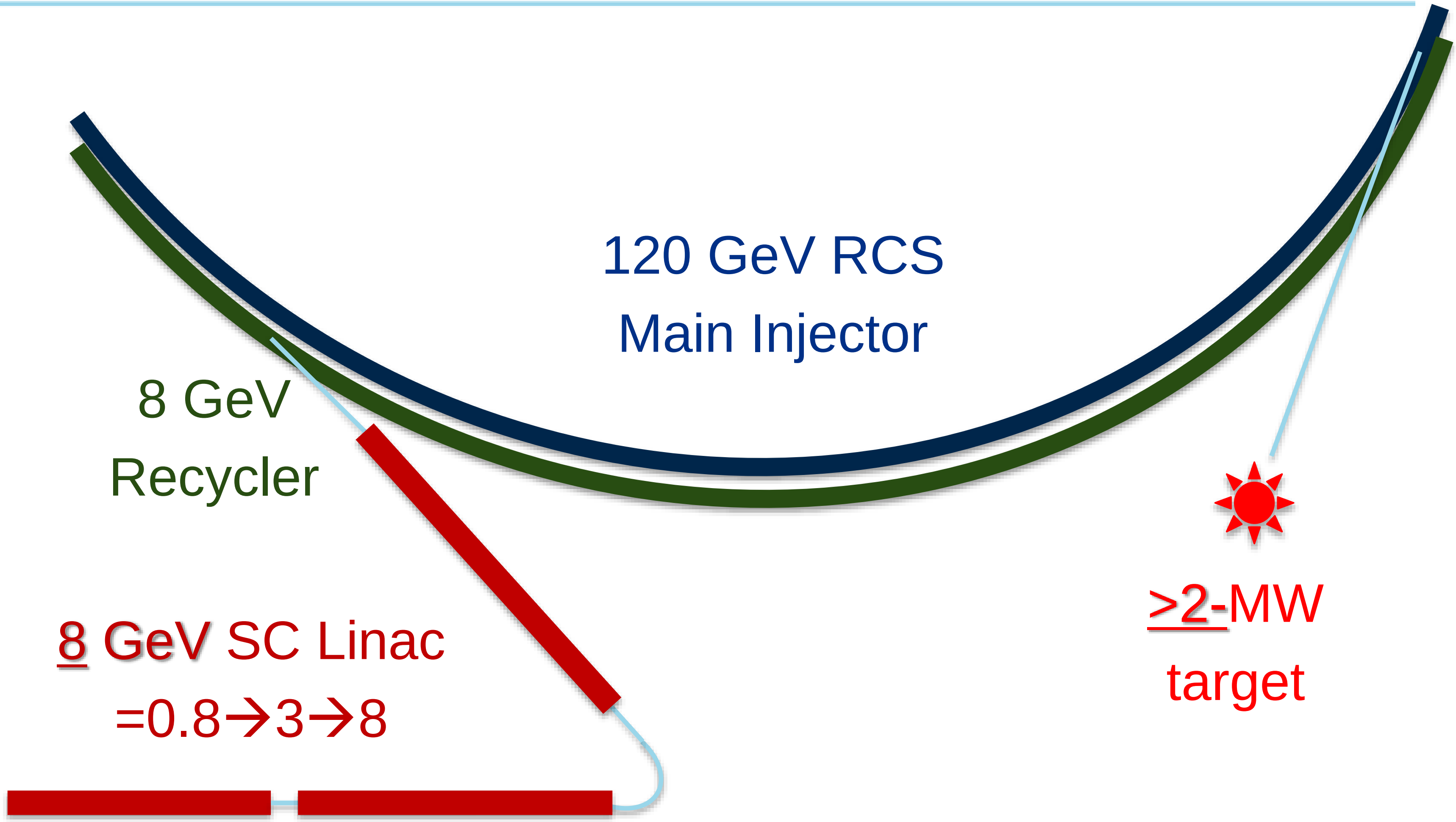
Accelerator Complex Now



“Near future”, PIP-II , ca 2023-24

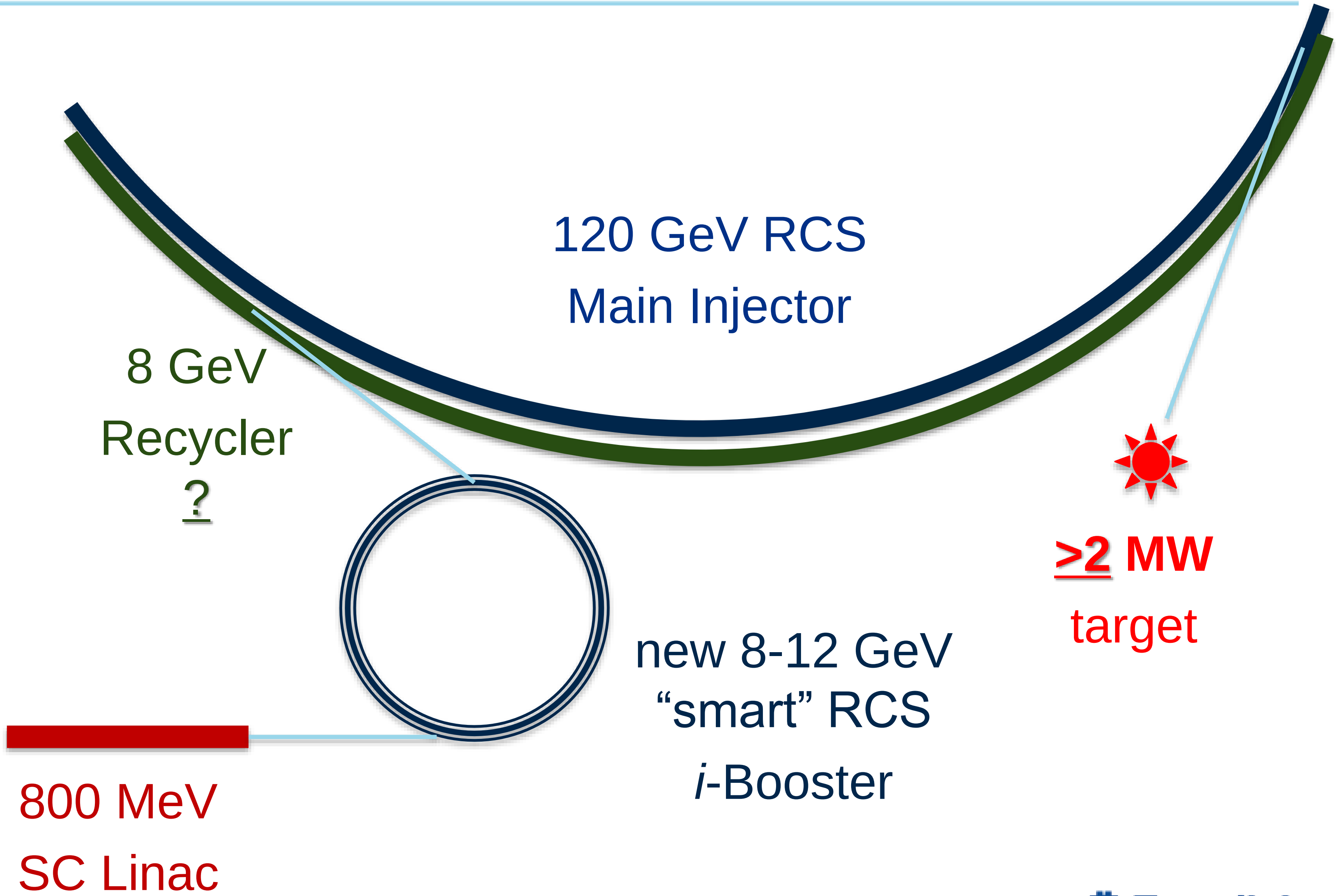


PIP-III "multi-MW" - Option A: 8 GeV linac



Fermilab

PIP-III "multi-MW"- Option B: 8+ GeV smart RCS



Post PIP-II : PIP-III -?

So far – a “thinking” towards:

- Accelerator complex performance increased to “multi-MW”
  - >2 MW… up to 5 MW
- At “affordable” cost
  - Do we know what’s affordable?
    - E.g., 1.5B$ TPC Project-X was not
    - 0.97 B$ LCLS-II is “affordable” for DOE-BES
    - 0.4B$ PIP-II TPC to DOE-OHEP is “affordable”

The choice requires analysis, planning and R&D

PIP-III: Intelligent choice requires analysis and R&D

- Either increase performance of the synchrotrons by a **factor of 3-4**:
  - E.g. ***dQ_sc >1*** → need R&D
  - Instabilities/losses/RF/vacuum/collimation
  - (see below on IOTA/ASTA R&D)
- Or reduce cost of the **SRF / GeV** by a **factor of 3-4**:
  - Several opportunities → need R&D
  - (see Alex Romanenko’s talk, session 3E)
- And – in any scenario – develop **multi-MW** targets:
  - They do not exist now → extensive R&D needed

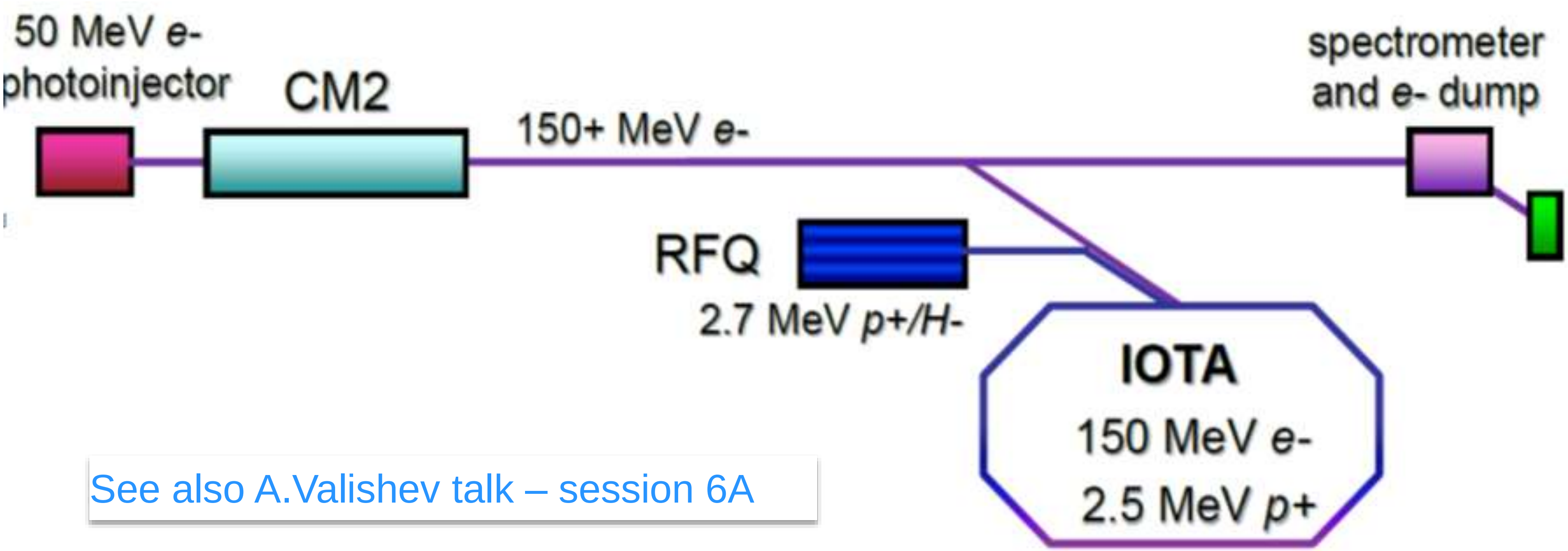
IOTA R&D Facility is (being) built to address feasibility of multi-MW proton synchrotrons

* I’ll give just basic facts – more detail tomorrow in A.Valishev’s talk

IOTA = Integrable Optics Test Accelerator

IOTA Schematic

- **IOTA/ASTA facility:**
  - IOTA storage ring
  - electron injector based on existing ASTA electron linac
  - proton injector based on existing HINS proton source.



See also A.Valishev talk – session 6A

- The cost to complete construction ~6.5M$ in FY15-17

IOTA/ASTA : Fermilab's Major Accelerator R&D Beam Facility

Unique R&D facility close to completion: IOTA ring, high-brightness photo-injector, SRF cryomodule, proton/H- RQF

~90M$ invested by OHEP since 2006

- **Science goal:** Experimentally demonstrate novel techniques of integrable beam optics and space charge compensation, SRF research
- **Technical challenge:** fabrication high-precision nonlinear magnets; injector for delivery of pencil electron beam and high-current low energy proton beam, beam thru SRF CM
- **FY14 highlights:** Big part of IOTA ring built; commissioned 5 MeV e-injector and SRF CM2 at 250 MV

Operations start: 2017 (full IOTA)

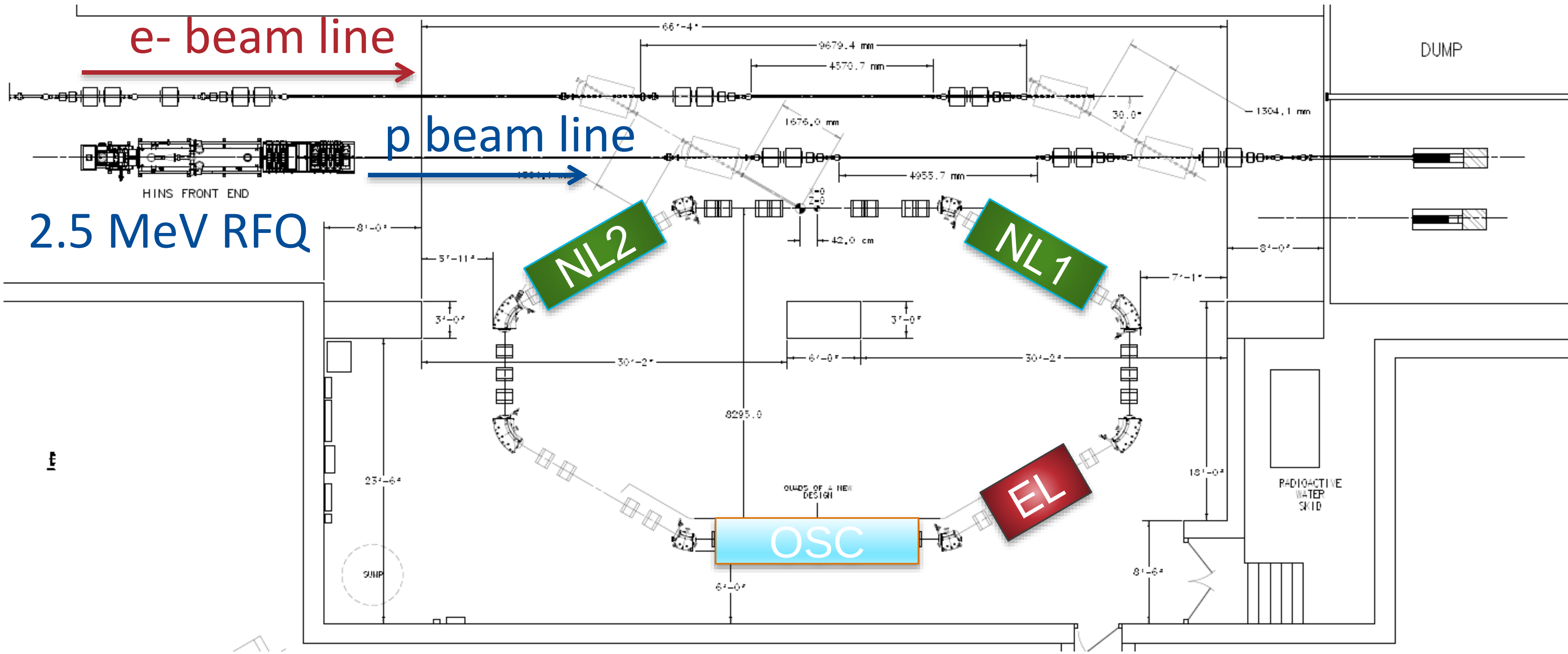
Partnerships

DOE labs: ANL,BNL,ORNL,Jlab,LBNL

U.S. universities: 6

International: 4

IOTA Ring: 40 m ; 2.5 MeV *p*+ or 150 MeV *e*-



IOTA/ASTA Construction Plan

- **FY14:**
  - **Beam studies** @ 5 MeV photoinjector injector
  - Completed 25 MeV injector
  - CM2 RF commissioning studies (no beam)
- **FY15:**
  - 25-50 MeV beam thru full injector to beam dump, 1st experiments
  - Start installation high-energy beamline from CM2 to HE dump
  - Construction/fabrication of remaining IOTA elements
- **FY16:**
  - Finish HE beamline, ~300 MeV beam from CM2 to dump
  - Finish IOTA construction & installation, 150 MeV e-beam to IOTA
  - Move and install the HINS proton injector (50% completion)
- **FY17:**
  - HINS commissioned, inject protons in IOTA
  - **Full accelerator research program at IOTA** (first – with electrons)

IOTA/ASTA Collaboration

participants of the 2nd ASTA Collaboration Meeting, June 2014

IOTA/ASTA – Centerpiece for Academic Partnership:
Collaborations with NIU, Universities of Chicago and Maryland

Cluster of research excellence is being established under direction of *S. Chattopadhyay,* joint appointee between *FNAL and NIU*

S.Chattopadhyay, et al

Four NIU faculty working collaboratively with FNAL: three joint appointees with FNAL (S. Chattopadhyay, P. Piot and Y. Shin). The fourth collaborator (B. Erdelyi) a joint appointee of NIU and ANL;

APC Director V. Shiltsev an Adjunct Professor at NIU;

Three new faculty to be recruited for the NIU-FNAL accelerator research cluster;

NIU-FNAL research cluster faculty are to work seamlessly with FNAL accelerator and engineering staff on :

(i) beam dynamics and technology problems of FNAL accelerator complex;

(ii) develop an advanced scientific program on IOTA;

(iii) enhance and stimulate further education, training and outreach in accelerators;

Collaboration with *Univ. of Chicago*

– The first accelerator science 'professor part-time' from FNAL appointed: S. Nagaitsev. Research program under evolution.

Synergistic Collaboration with *Univ. of Maryland*

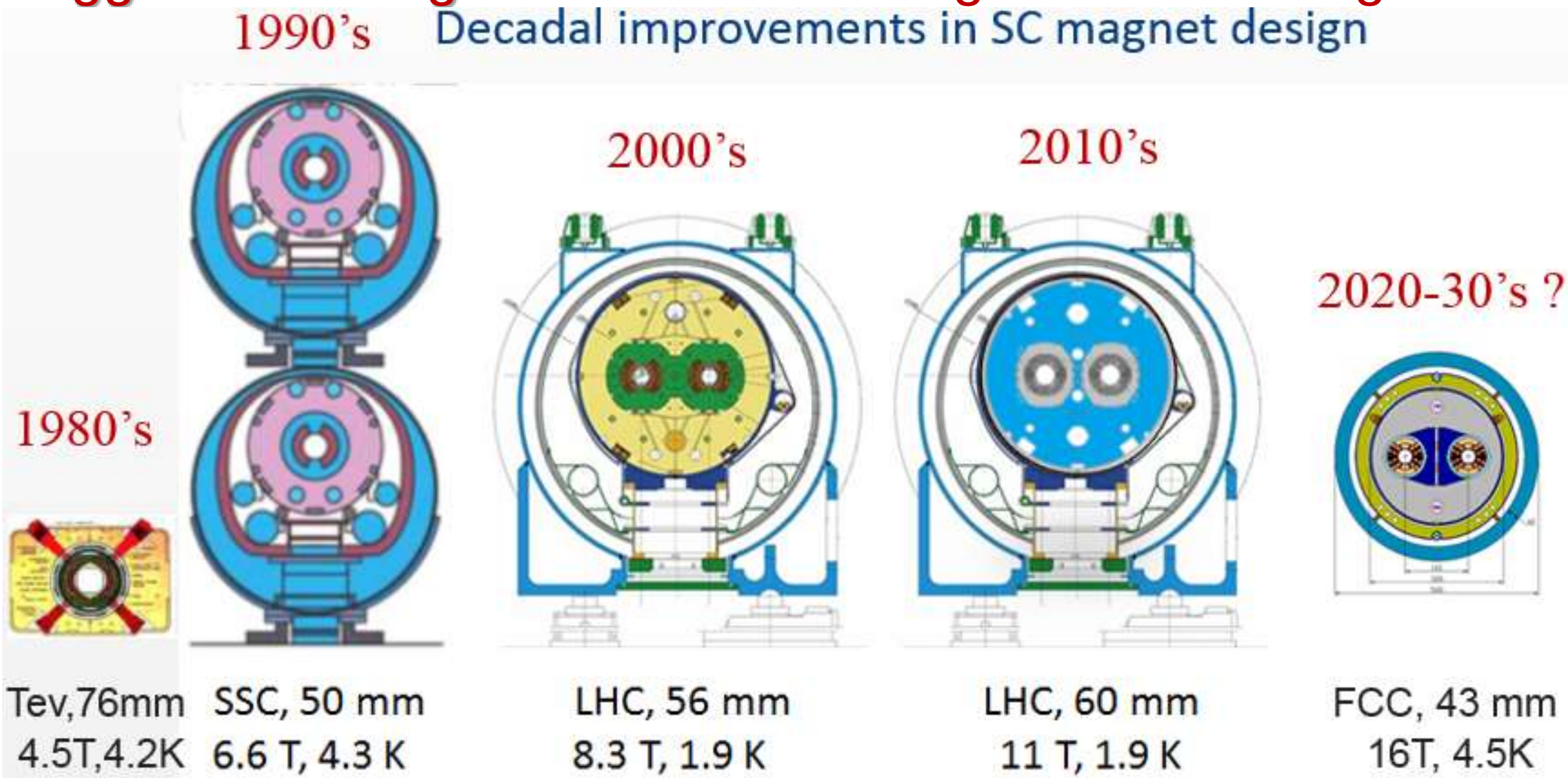
– Investigation of space-charge dominated nonlinear dynamics in novel "smart boosters" via complementary research on IOTA and UMER: (R. Kishek et al)

Far Future HEP Accelerators,

Long-term Accelerator R&D

P5 Priority: Future 100 TeV Scale p-p Collider R&D

- Biggest Challenge: Cost Effective High Field SC Magnets



- Major goal for FNAL HFM GARD Program: ~16 T SC Magnet Development – see A.Zlobin's talk , session 7A
- Many serious beam physics issues (B-B, SR, MDI, etc): modest involvement to capitalize on the Tevatron experience

A.Zlobin, G.Apollinari, T.Sen, et al

P5 item: Muon Accelerator Program and MICE

- After the P5 recommendations, OHEP (J.Siegrist) requested a review to determine how to handle the MAP recommendations:

This memorandum is to request that you organize and conduct a special Management and Technical review of the U.S. Muon Accelerator Program (MAP). This review is in response to the U.S. Particle Physics Project Prioritization Panel (P5) Report which recommended to:

> *Reassess the Muon Accelerator Program (MAP). Incorporate into the GARD program the MAP activities that are of general importance to accelerator R&D, and consult with international partners on the early termination of MICE.*

In particular, the panel recommends to "*realign activities in accelerator R&D with the P5 strategic plan. Redirect muon collider R&D and consult with international partners on the early termination of the MICE muon cooling R&D facility.*"

Therefore we are planning for an orderly ramp-down of MICE activities, with an annual funding Profile of $9M, $6M and $3M over the next three years, subject to availability of funds; and identifying and preserving the most critical generic accelerator R&D activities via redirection to the General Accelerator R&D (GARD) program.

Review 08/12-14/14: a) support "reduced" MICE effort to demonstrate ionization energy loss combined with RF re-acceleration of the muons (the complete cooling process) by 2017; b) GARD items identified

M.Palmer, K.Yonehara, D.Bowring, et al

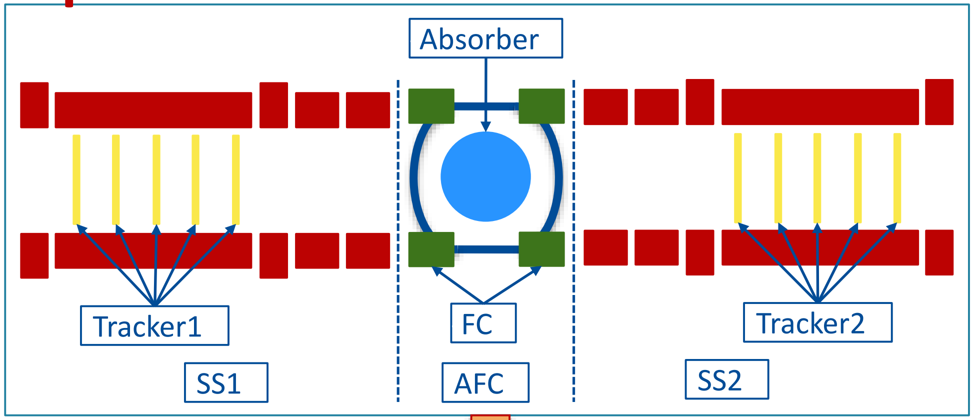
MICE-”4.5”: Expedited Muon Cooling Demonstration

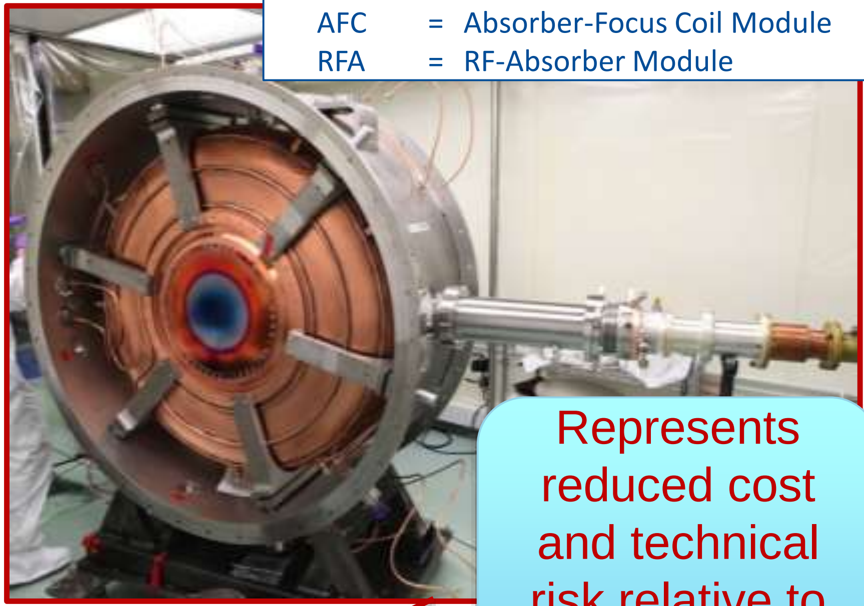
Plan developed in response to P5 recommendations

Legend:

- SS = Spectrometer Solenoid
- FC = Focus Coil
- AFC = Absorber-Focus Coil Module
- RFA = RF-Absorber Module

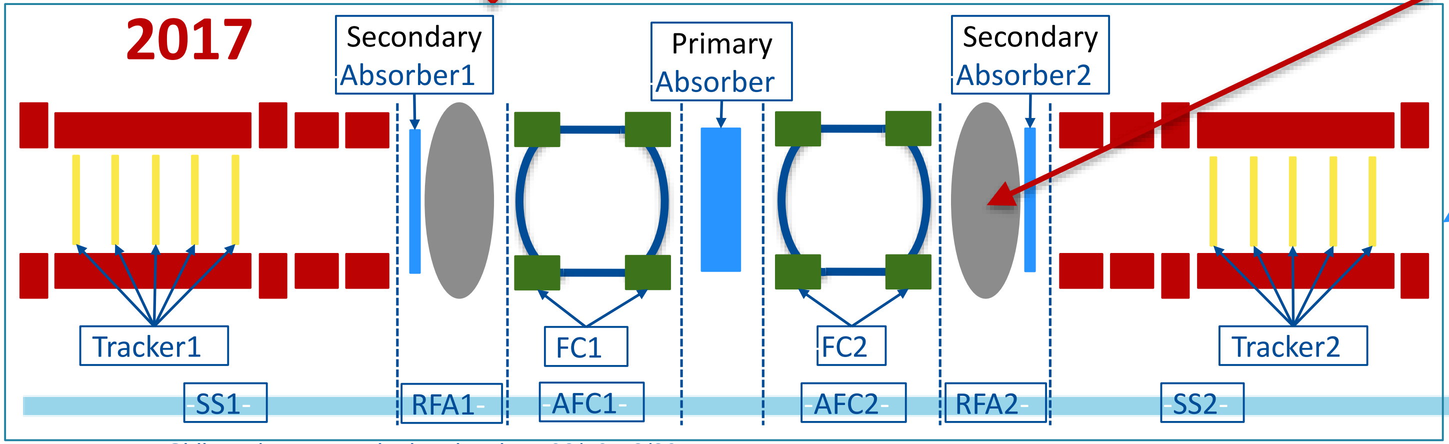
Operational 2015





Represents reduced cost and technical risk relative to MICE Step V

Operational 2017



NEW
Expedited MICE Final Configuration

Summary

- Fermilab is a world leader in Accelerator Science and Tech
- Lab's Accelerator R&D program is (being) realigned to address the P5 report recommendations, with focus on:
  - Cost-effective approaches to multi-MW proton beams
    - SRF and space-charge dominated rings
  - High power targets
  - High field magnets for 100-TeV scale pp collider
  - Maintain core competencies in accelerator science, design and modeling; accelerator training
- IOTA - the leading accelerator R&D beam facility - is being built and commissioned in FY15-17
- Collaboration with Universities in accelerator science and technology is healthy and growing

Back up slides

16 *APS Fellows* are involved in Fermilab’s Accelerator R&D

E.Barzi

A.Bross

S.Geer

E. Prebys

H.Edwards

H.Padamsee

S.Holmes

S.Mishra

V.Lebedev

N.Mokhov

S.Nagaitsev

D.Neuffer

V.Shiltsev

A.Tollestrup

V.Yarba

A.Zlobin

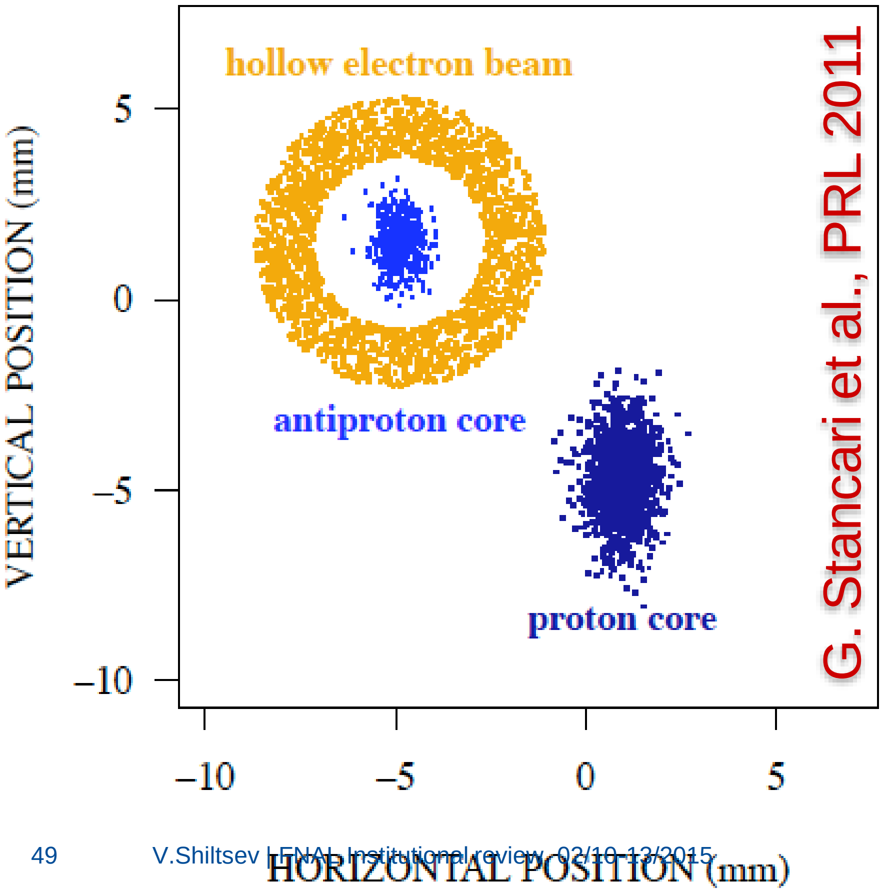
Also…

- ***Awards:***
  - *APS Wilson Prize 2014 H.Padamsee*
  - *DOE Early Career 2013 A. Grassellino*
  - *DOE Early Career 2012 P.Snopok, T.M.Shen, A.Romanenko*
  - *APS Thesis 2010 R.Miyamoto*
  - *IEEE PAST 2009 K.Seyia*
- ***Editors and Editorial Boards***
  - W.Chou *ICFA Beam Dynamics Newsletter , RAST*
  - L.Cooley *Superconductor Science and Technology*
  - V.Shiltsev *Phys. Rev. ST-AB, JINST*
- ***Referees for Peer-Review Journals***
  - Phys. Rev. Letters, Phys. Rev. ST-AB, JINST, NIM-A, IEEE Trans. Nucl. Sci., Review of Scientific Instruments, European Physical Journal, Physics Procedia, NIM-B, NIM-B Proc, Prog. Nucl.Sci.Tech.
  - *APS Outstanding Referee* - V.Lebedev 2015, T.Sen 2013 ,
- ***Membership in Program and Organizing Committees of all major accelerator conferences and workshops:***
  - IPACs, NA-PACs, AAC, HB, BIW, LINAC, RESMM, SRF, MT, etc

Novel Halo Collimation Methods

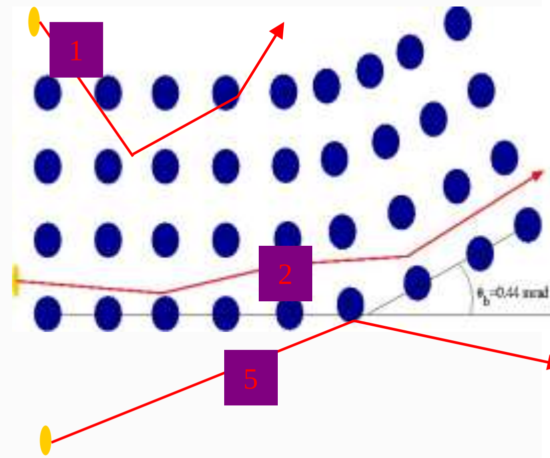
Hollow Electron Beam

A hollow el beam (Tevatron electron Lens)
No E-field inside
Strong E-field ouside drives resonances
Fast diffusion = "soft collimator" effect
Works near beam as well (no material)

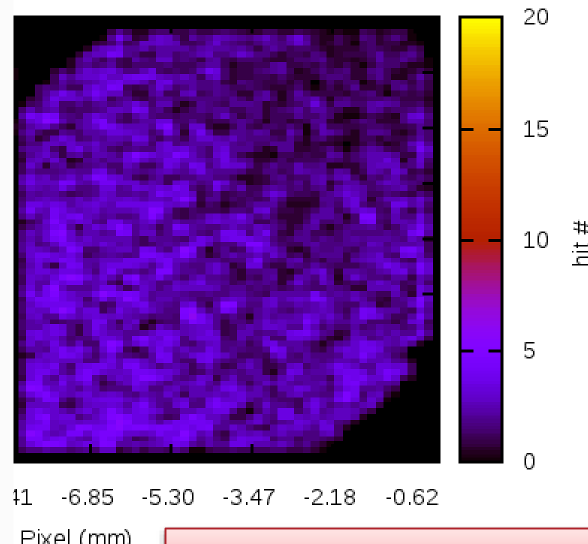


G. Stancari et al., PRL 2011

Bent Crystal Collimation



N.Mokhov, et al JINST 6 T08005 (2011).



Channeled beam image on pixel detector

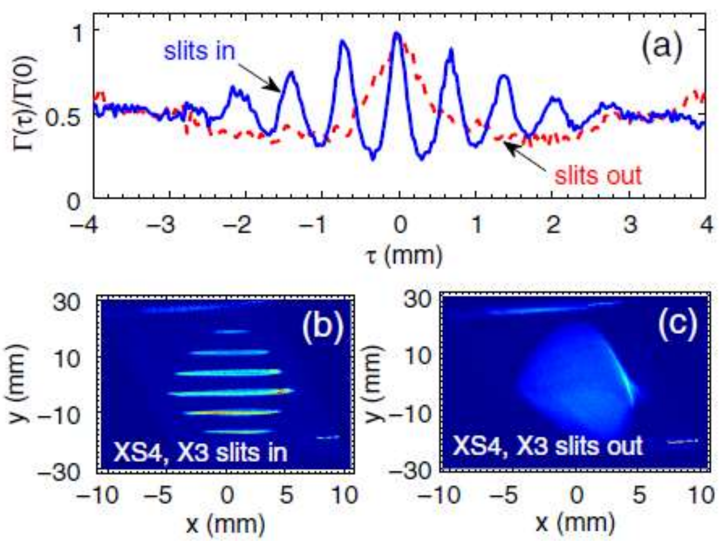
T980 Results
D. Still et al. IPAC12

Transverse-to-longitudinal phase space exchange

- Demonstrated transverse to longitudinal emittance exchanges

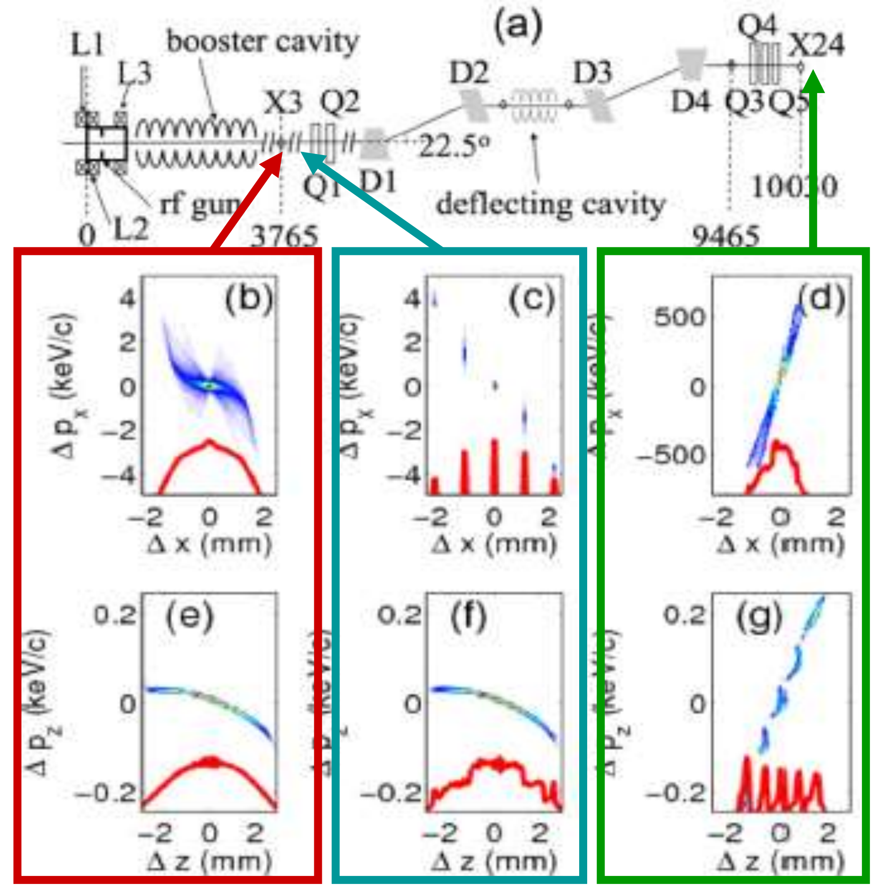
Y.-E. Sun et al., PRL 105, 234801 (2010)
P. Piot et al., PRSTAB 14, 022801 (2011)

	Simulated		Measured	
	In	Out	In	Out
ε_x^n	2.9	13.2	2.9 ± 0.1	11.3 ± 1.1
ε_y^n	2.4	2.4	2.4 ± 0.1	2.9 ± 0.5
ε_z^n	13.1	3.2	13.1 ± 1.3	3.1 ± 0.3



- Demonstrated bunch current profile shaping

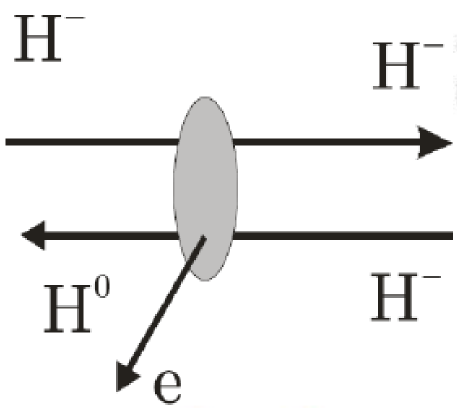
J. Ruan et al., PRL 106 244801 (2011)

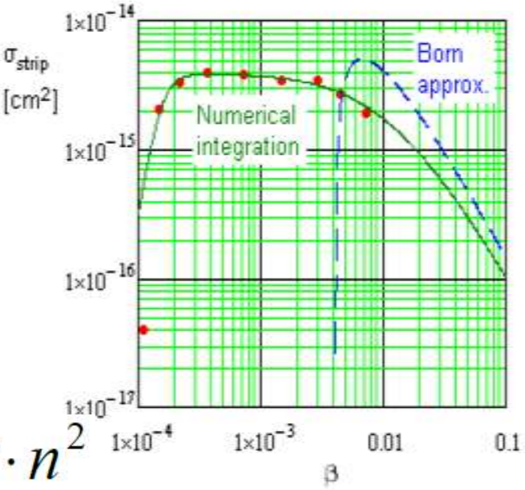


Fermilab

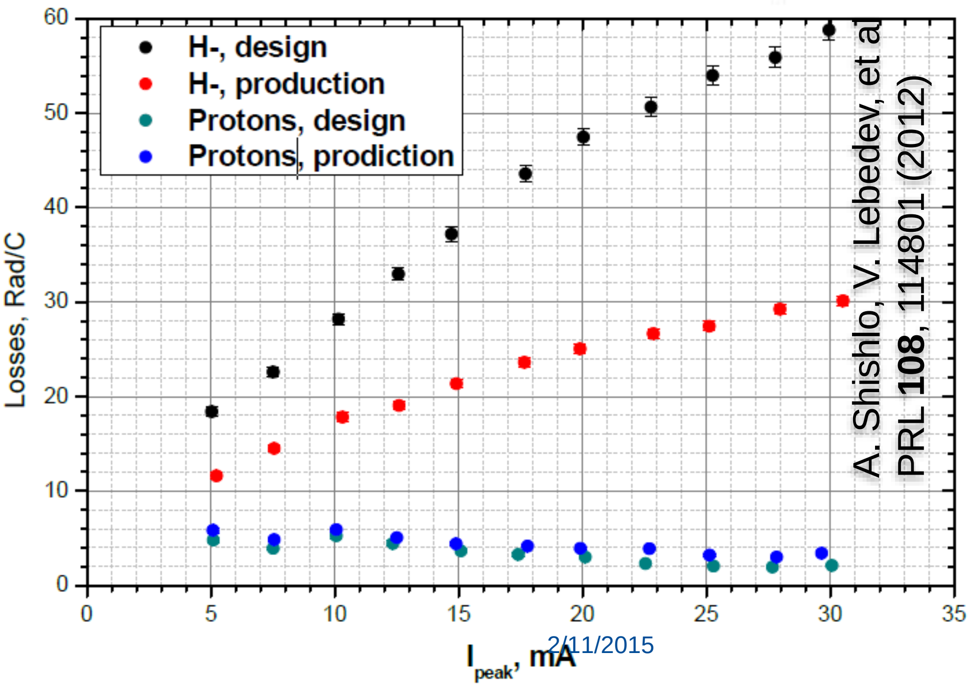
New Effect: Intrabeam Stripping of H- in linacs

- Predicted by V.Lebedev:
  $H^- + H^- \rightarrow H^- + H^0 + e$ (intrabeam stripping) leads to losses and can explain higher than expected losses i in the SNS linac
- Theory was developed together with SNS colleagues
- Experimental beam studies:
  - comparison of beam loss in the superconducting part (SCL) of the SNS for H^- anc protons
  - observed significant reduction in the beam loss for protons





$$dn/dt \propto \sigma \cdot n^2$$



GARD Thrusts (FNAL Proposal to the GARD Subpanel)

1. High-field magnets and materials
2. Multi-MW beams and targets
3. Cost-Effective SRF Technology
4. Advanced Accelerator Concepts
5. Accelerator Science, Modeling & Design
6. Core Accelerator Competencies

GARD Thrusts: Rationale and Goals

1. High-field magnets and materials
   - Long-term; maintain US leadership in SC magnets; Nb_3Sn, HTS
   - Significant T*m cost reduction, modest support of global design
2. Novel techniques for multi-MW beams and targets

PIP-II — Beyond PIP-II (mid-term)

	1st 10 years	2nd 10 years		
To Achieve :	100 kT-MW-year	500 kT-MW-year		
We combine :		Option 1	Option 2	Option 3
Mass	10 kT	50 kT	20 kT	10 kT
Power	1 MW	1 MW	2.5 MW	5 MW

   - Mid-term strategy after PIP-II depends on the technical feasibility of each option and the analysis of costs/kiloton versus costs/MW
   - R&D on effective control of beam losses in proton machines with significantly higher currents (Q_{SC}) and on multi-MW targets

GARD Thrusts: Rationale and Goals (2)

3. Cost-Effective SRF Technology
   – Crucial enabling technology for accelerators
   – Aim at a substantial reduction in construction and operation costs
   – Improve gradients, increase Q-factor, study new materials;
   – Affects both far- and mid-term accelerators

4. Advanced Accelerator Concepts
   – Conceptual and technical feasibility of advanced collider concepts; aim at HEP applications and significant **total** cost reduction
   – Intense secondary beams for next-generation precisions experiments (such as “beyond mu2e”, “beyond g-2” and a NF)
   – Both long- and mid-term

GARD Thrusts: Rationale and Goals (3)

5. Accelerator Science, Modeling and Design
   - Conceptual design and modeling of new machines
   - Cross-cutting accelerator theory and experiments
   - Excellence in high-performance high-fidelity computer modeling
   - Combination of both mid-term and long-term efforts

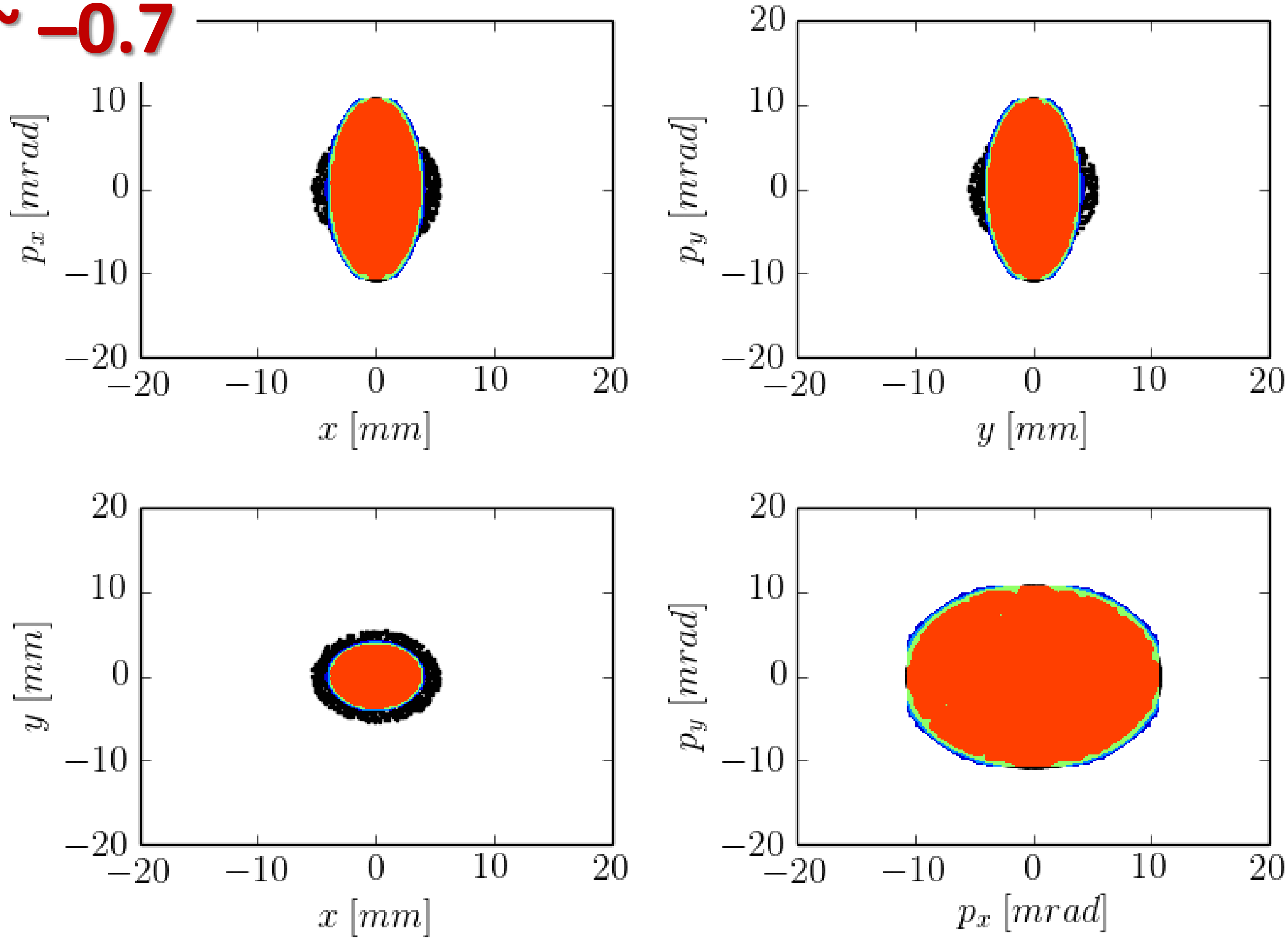
6. Core Accelerator Competencies
   - Accelerator training and education for HEP and beyond
     - Jointly - Universities and National Labs
   - Novel particle sources; Advanced beam instrumentation
   - NC rf and cost-effective rf sources
   - Both mid-term and long-term efforts

Integrable Optics

Space Charge in Linear Optics

- System: linear FOFO 100 A linear KV w/mismatch
- Result: quickly drives test-particles into the halo

$\Delta Q_{sc} \sim -0.7$

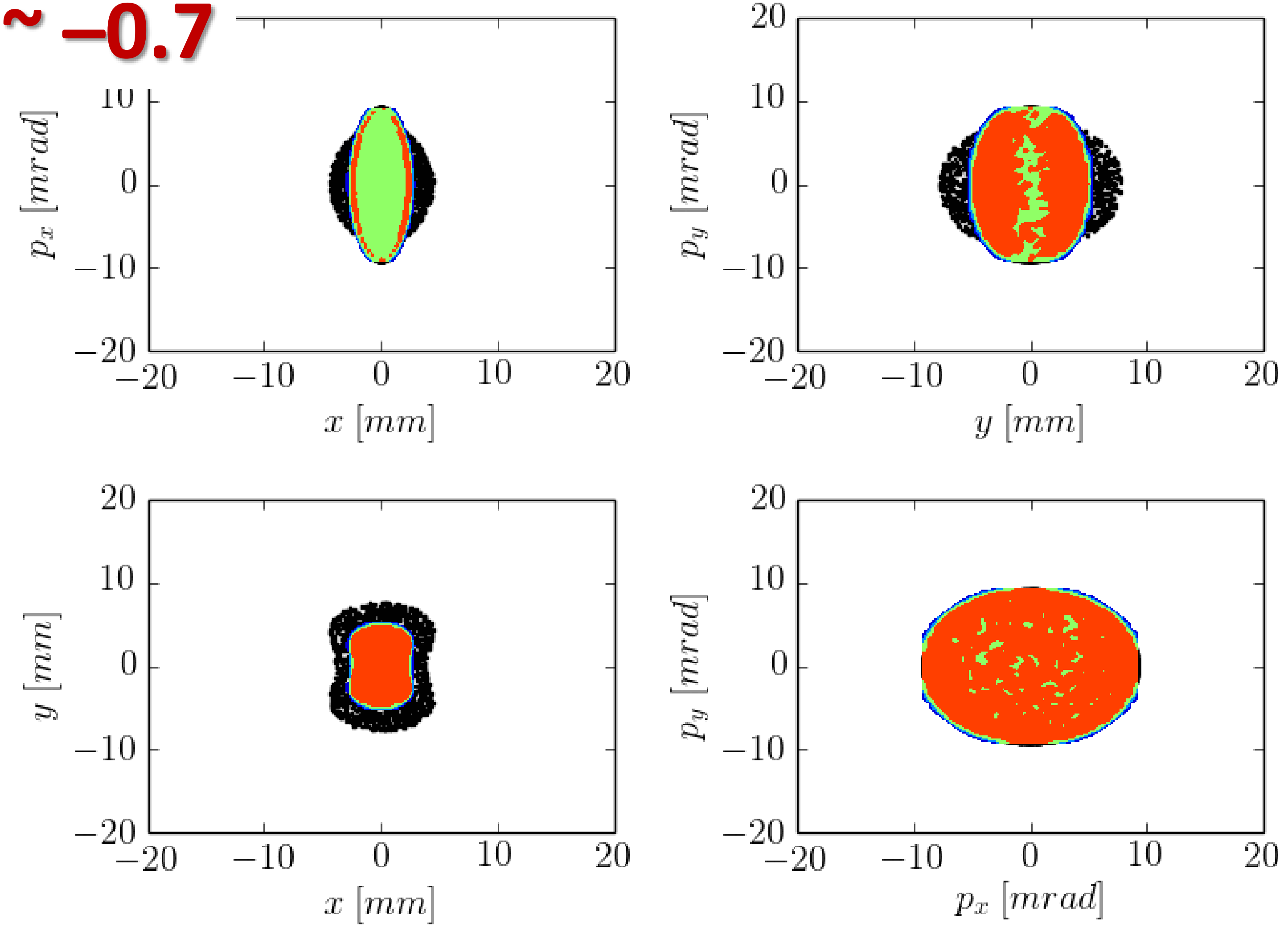


Tech-X, RadiaSoft simulation

Space Charge in NL Integrable Optics

- System: linear FOFO 100 A linear KV w/mismatch
- Result: nonlinear decoherence suppresses halo

$\Delta Q_{sc} \sim -0.7$



Tech-X, RadiaSoft simulation

	FY15	FY16	FY17	Sum
e⁻ injector (finish HE beamline)	6.8 FTE 540k$ M&S 2,100k$			6.8 FTE 540k$ 2,100k$
IOTA (build and commission)	2.9FTE 580k$ M&S 1,230k$	2.2 FTE 270k$ M&S 770k$		5.1 FTE 850k$ 2,000k$
p injector (move and commission)		2.4 FTE 680k$ M&S 1,230k$	2.4 FTE 580k$ M&S 1,130k$	4.8 FTE 1,260k$ 2,360k$
Total Construction	**9.7 FTE** **1,120k$ M&S** **3,330k$**	**3.6 FTE** **950k$ M&S** **2,000k$**	**2.4 FTE** **580k$ M&S** **1,130k$**	**15.7 FTE** **2,650k$** **6,460k$**
Research	4.4 FTE 0k$ M&S 1,140k$	5.2 FTE 160k$ M&S 1,410k$	5.5 FTE 360k$ M&S 1,800k$	
User Support	4.6 FTE 160k$ M&S 1,220k$	6.0 FTE 350k$ M&S 1,730k$	6.8 FTE 350k$ M&S 1,910k$	
Facility Operations	2.5 FTE 320k$ M&S 890k$	3.5 FTE 650k$ M&S 1,450k$	4.5 FTE 670k$ M&S 1,590k$	
TOTAL	**6,580k$**	**6,590k$**	**6,430k$**	**19,600**

Proposed ASTA Funding in FY 15, 16, 17

	FY15	FY16	FY17	Comm.
TOTAL Req'd	**6,580k$**	**6,590k$**	**6,430k$**	(see previous slide, bottom)
GARD for ASTA	2,250k$	2,300k$	2,300k$	
SRF & 18 (scenario 1)	3.0FTE=690k$ M&S =330k$ 1,020k$			
AD NML Facility Ops**	3.3FTE=760k$ M&S =0k$ 760k$	3.3FTE=760k$ M&S =0k$ 760k$	3.3FTE=760k$ M&S =0k$ 760k$	
NEED DOE suppl	**2,550k$**	**3,530k$**	**3,370k$**	9,450k$

Fermilab

IOTA/ASTA Resources in FY18 and beyond

	FY18
Research	5.5 FTE 420k$ M&S 1,860k$
User Support	7.3 FTE 350k$ M&S 2,070k$
Facility Operations	4.8 FTE 670k$ M&S 1,590k$
Total ASTA	**17.6 FTE** **1,440k$ M&S** **5,660k$**
Out of: KA2501012 KA2202021	4,900k$ 760k$

Accelerator R&D and Test Facilities

Facility	Purpose	Beam-type	Energy	uniqueness	status
ASTA	SRF, energy & intensity frontier	e^-	50 MeV and 300 MeV	High repetition rate, high peak & average bright-ness beam	Commissioning, ~20 MeV electrons expected in CY 2014
IOTA	R&D towards multi-MW beams	e^-/p	2.5 MeV (p) 150 MeV (e^-)	Ring suited for integrable optics and SC-compen-sation expt's	Under construction, operational estimated in 2017
PXIE	PIP-II, intensity frontier	p	30 MeV	High-I CW, SRF, chopped beams	Ion source operational
CMTS-1	SRF cryomodule testing	n/a	n/a	CW and pulsed RF at various frequencies	Under construction, operational FY2016
VTS	SRF, energy frontier	n/a	n/a	325/650/1300 MHz bare cavities	2/3 stands operational
MDB	SRF, energy & intensity frontier	n/a	n/a	325/650/1300/ 3900 MHz dressed cavities and couplers	3/4 areas operational
SC magnet	Energy frontier	n/a	n/a	1.9K-4.5K, 30kA ∅0.6m x 3.7m	Operational
HBESL	e^- source R&D, stewardship, education, energy frontier	e^-	≤5 MeV	Electron source coupled with multiple laser systems, emittance exchange	Operational
MI-8 targetry	High Power Targetry, intensity frontier	n/a	n/a	200 kA pulsed PS for horn testing, CNC TIG welder	Operational
MTA	Muon source R&D	p/H-	400 MeV	Combination of beam, RF, SC magnet, cryo	Operational