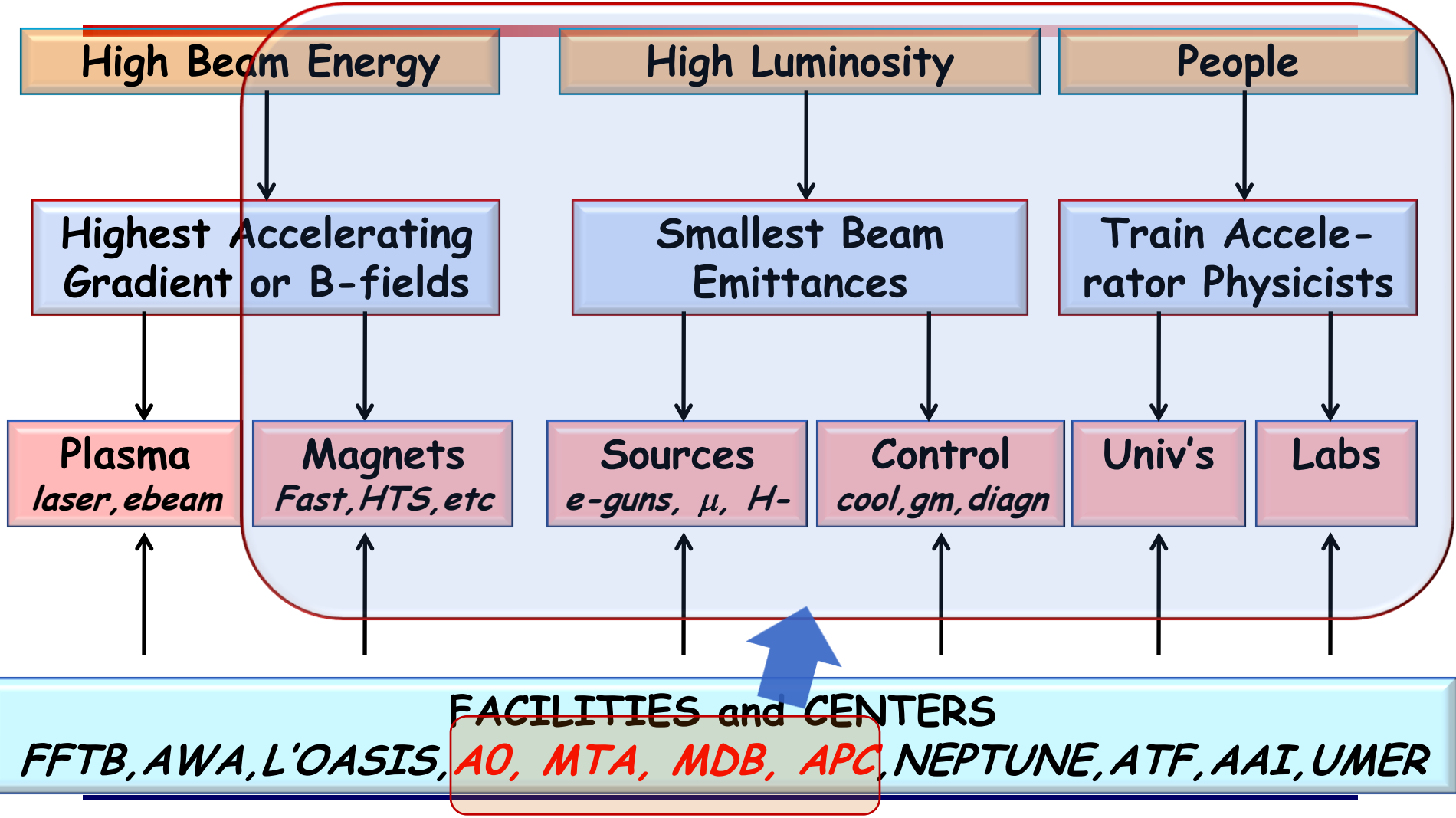
The Fermilab Accelerator Science Program: Accelerator and Beam Physics Activities in APC

Vladimir Shiltsev
Fermilab
December 3, 2008

Outline

- Introduction: connection to future HEP facilities, main “themes”
- Organization and Personnel
- Recent Accomplishments
- Proposal for FY2009-2011
- Budget Request

Future HEP Facilities: Needs

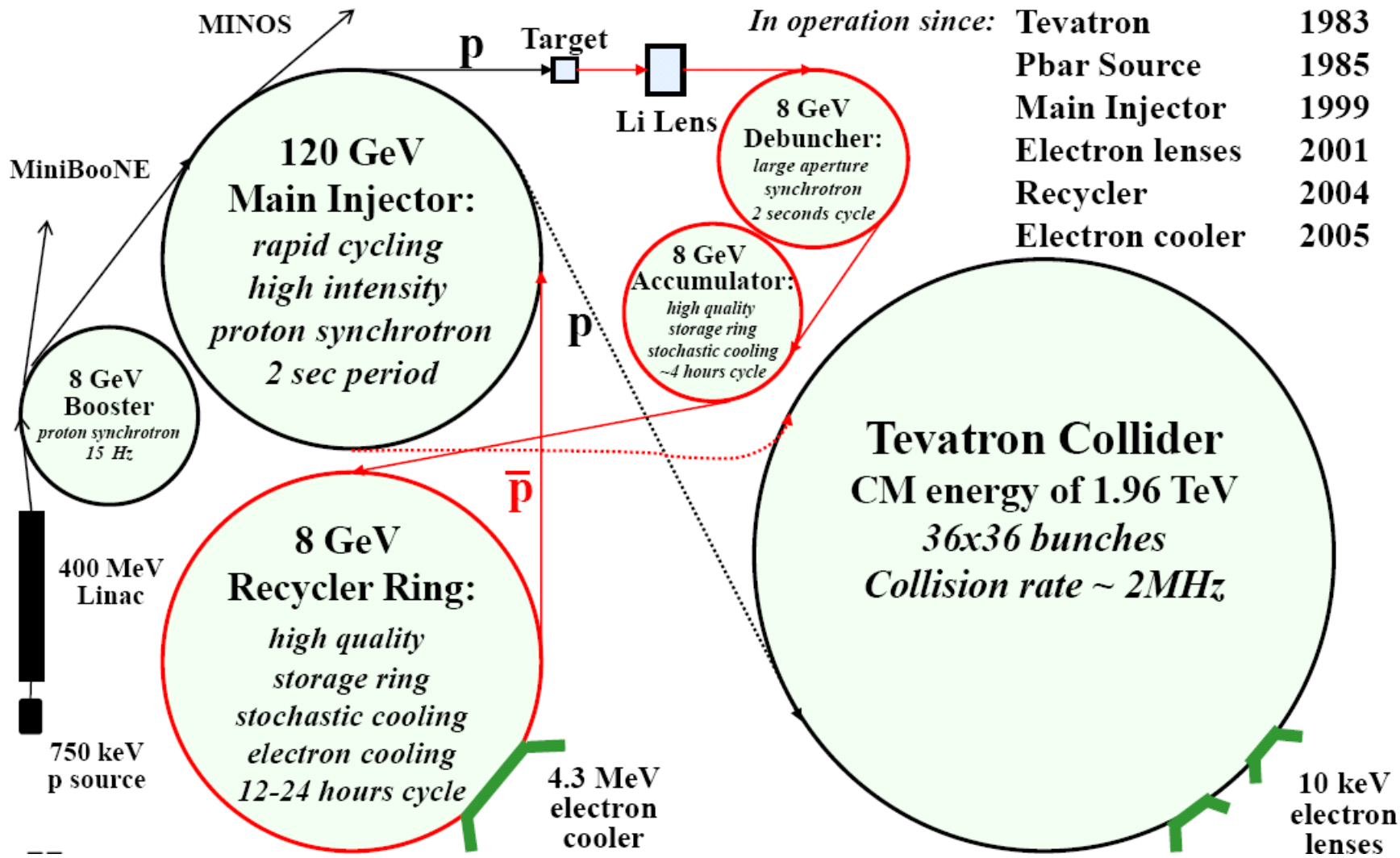


P5 Report (2008)

"… The panel recommends a broad strategic program in accelerator R&D, including work on ILC technologies, superconducting rf, high gradient normal-conducting accelerators, neutrino factories and muon colliders, plasma and laser acceleration, and other enabling technologies, along with support of basic accelerator science."

"…the field must *address the critical lack of accelerator test facilities that R&D requires*. Historically, much accelerator R&D took place using operating high-energy physics facilities. However, *as the operating facilities have turned off in the US, the opportunities for experimental demonstrations have correspondingly decreased*. Some dedicated facilities have been proposed; and, while such facilities tend to be expensive to operate, they are essential for progress".

FNAL Complex Now: 10 Machines



In operation since:	
Tevatron	1983
Pbar Source	1985
Main Injector	1999
Electron lenses	2001
Recycler	2004
Electron cooler	2005

Beams at Fermilab: keep up!

- The end of Collider program will make many machines not needed after FY2010:
  - Tevatron
  - Debuncher
  - Antiproton Accumulator
  - Pelletron (e-cooling)
  - Two Tevatron electron lenses
- We plan to keep up the number of beam facilities to support present, near-future and future accelerator based programs:
  - A0 photoinjector (upgraded, moving to NML in 2011-12)
  - 60 MeV HINS H- linac (under construction, not *KA15 01 02*)
  - Mucool Test Area (MTA) with linac beam (under commissioning)
  - Project-X accelerators (>2014, not *KA15 01 02*)
  - Muon Collider Test Facility (front-end of NF or/and MC)

APC leads or involved in all

APC "Themes" under KA150102

- **Emittance control and EM beam effects:**
  - Space-charge and Beam-beam effects; compensation by e-lenses and e-columns
  - E-cloud effects and cures; other instabilities and feedback
  - Ground Motion studies
- **Halo Control**
  - 2 stage collimation systems
  - Bent crystal studies T980
  - Hollow electron beam collimator
- **Novel Accelerator Schemes**
  - Cooling schemes : ionization, OSC, ODR for e-stochastic cooling
  - Facilities with HTS magnets
- **Beam Theory, Modeling & Simulations**
- **Education**
  - US PAS office (under KA150102 since FY09, KA140104 before)
  - Internships and Accelerator PhD program
- **Muon Collider and Neutrino Factory R&D (to be presented separately)**
- **AARD at A0 photoinjector (to be presented separately)**

Fermilab's APC Created June 1, 2007

APC Mission

- Coordinate and conduct accelerator R&D aimed at next-generation and beyond accelerator facilities
- Provide accelerator physics support for existing operational programs and the evolution thereof
- Train accelerator scientists and engineers
- Provide leadership and coordination in establishing the necessary facilities for a broad range of accelerator R&D that can be accessed by both Fermilab and the world HEP community

APC's Program

- APC's program is very diverse, we play primary role in:
  - Muon collider design R&D, development of MTA test facility
  - Development of generic theoretical and simulation tools for advanced accelerator calculations in areas of energy deposition, beam-beam and space-charge effects, linac emittance evolution, etc. (with CD)
  - Advanced accelerator R&D at the A0 facility and elsewhere
  - Accelerator theory and education: Host the USPAS Office, Accelerator PhD program, Peoples Fellows, and other accelerator education initiatives
  - LARP Acc. Syst. instruments, commissioning, upgrade *(not KA15)*
  - HINS design and 60 MeV H- MDB test facility (*not KA15*)

APC's Program

- Programs supported by the APC include (*not KA150102*):
  - Accelerator physics for Run II, ANU and Project X
  - Simulations, design support & beam experiments for ILC
- Other divisions (AD, TD, CD and PPD) staff participate in the APC activities (~12 FTEs in 2008 from ~40 people). AD and TD provide engineering and technical support for APC.
- The APC is responsible for coordination of inter-institutional collaborations in Advanced Accelerator R&D
  - with ANL, BNL, LBNL, ORNL, Cornell, CERN, IHEP, BINP, Japan
  - with SBIR companies (Muons Inc, Tech-X, PBL)

Organization and Personnel

ACCELERATOR PHYSICS CENTER
V.Shiltsev, Director
M.Church, Deputy Director
M.Bruce, Admin Associate
(A.Nestander), Budget Mgr.

Theory/Simulation Group
Yu.Alexahin (GL)

Energy Deposition Group
N.Mokhov (GL)

LHC Accelerator Group
T.Sen (GL)

(CD/CPA Group)
(P.Spenzouris, GL)

SCRF Facility Design Department
(N.Solyak), Head

Muon Accelerator R&D Department
S.Geer, Head

MCTF Experiment Group
A.Jansson (GL)
NFMCC Group
A.Bross (GL)

HINS Department
R.Webber, Head

AARD Department
M.Church, Head

US PAS Office
S.Winchester (GL)
W.Barletta, Director (GS)

Accel.Education Dept.
(V.Lebedev), Head

Accel.PhD Program
(A.Tollestrup, Chair)

Peoples Fellowship
(M.Church, Comm.Chair)

Lee Teng Internship
(E.Prebys, Comm.Chair)

Accel.Summer Students
(A.Shemyakin, Prgm.Ldr.)

APC Personnel Profile

Category	2008 10/01	FTEs KA15
Scientists/Physicists	26	9.2
Post Docs	4	1.6
Engineers	4	0.8
Technicians	1	-
Computer Prof.	1	0.7
Admin. Staff	3	2
Guest Sci. & Eng.	4	1.5
TOTAL	43	15.8*
Joint Appointments	3	1.5
PhD students	5	-

*** 15.8FTEs = 7.3 Muon R&D + 2.5 A0PI + 6 General Accel R&D**

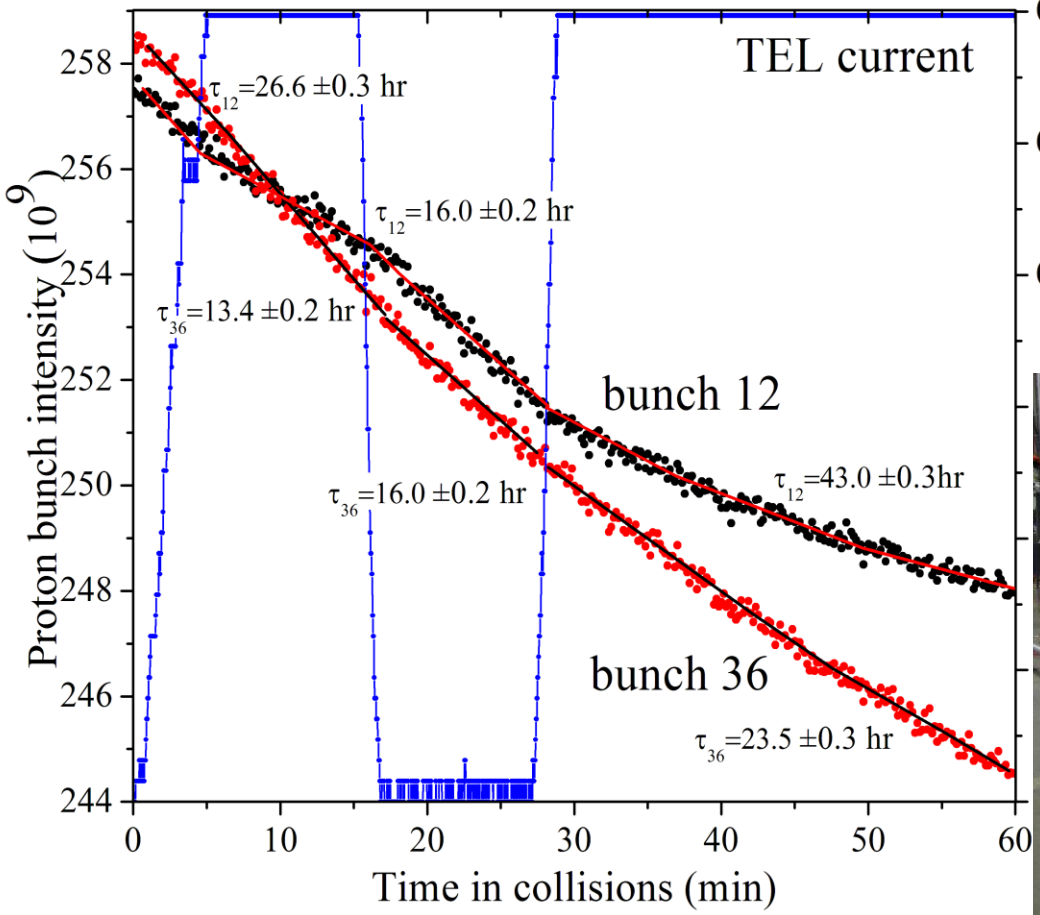
Major Recent Accomplishments

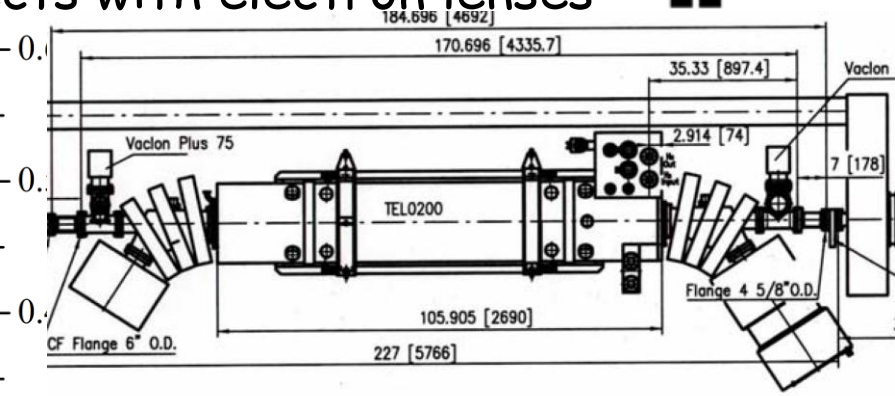
- Beam-beam compensation demo by TELs (x2 in p-lifetime)
- Beam-beam lifetime simulations which agree with Tevatron
- SC modeling with Math-MAD for Booster, RR and MI
- Bent crystal channeling of 980 GeV protons
- Tevatron AC dipole measured CDF and D0 beta*
- Ground motion HLS data from Tev and MINOS tunnel
- E-cloud thresholds studied in MI and Tevatron
- Lee Teng Internship launched in Summer'08
- *(Muon and A0 Photoinjector R&D – see following talks)*
- *See more in the FNAL Proposal*

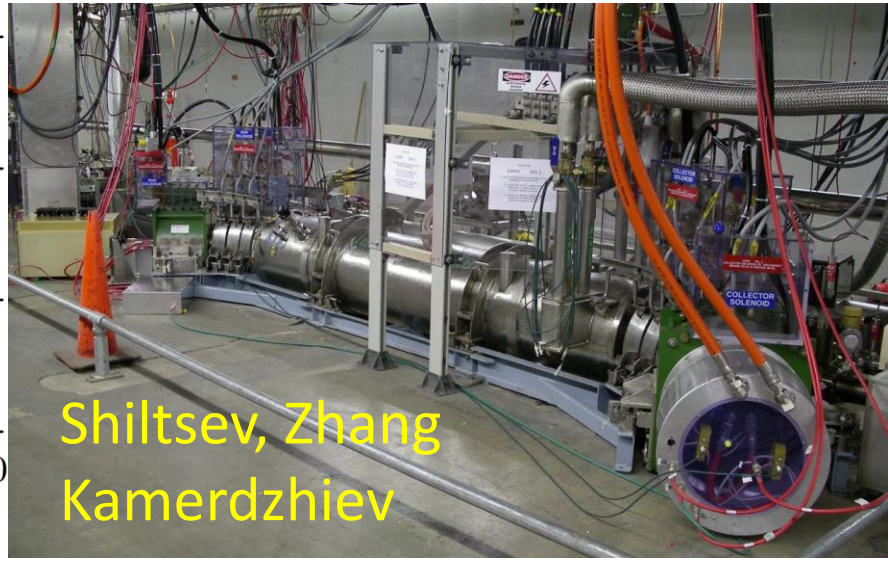
Compensation of Beam-Beam Effects

relevant to Tevatron, RHIC and LHC

Active compensation of beam-beam effects with electron lenses





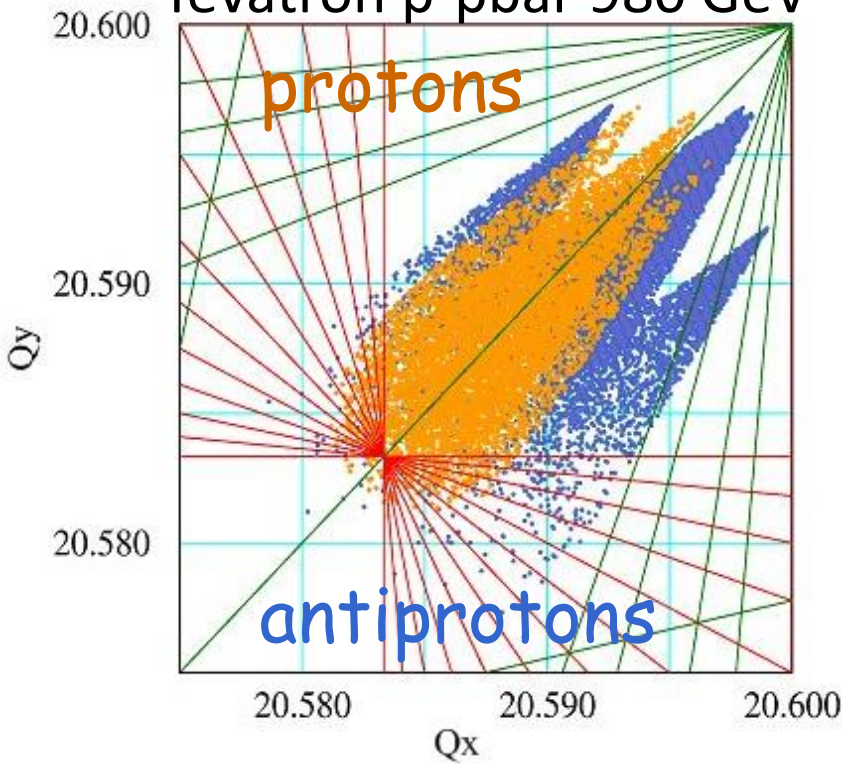


- Proton lifetime improved by factor of 2, luminosity integral – by 5-10%

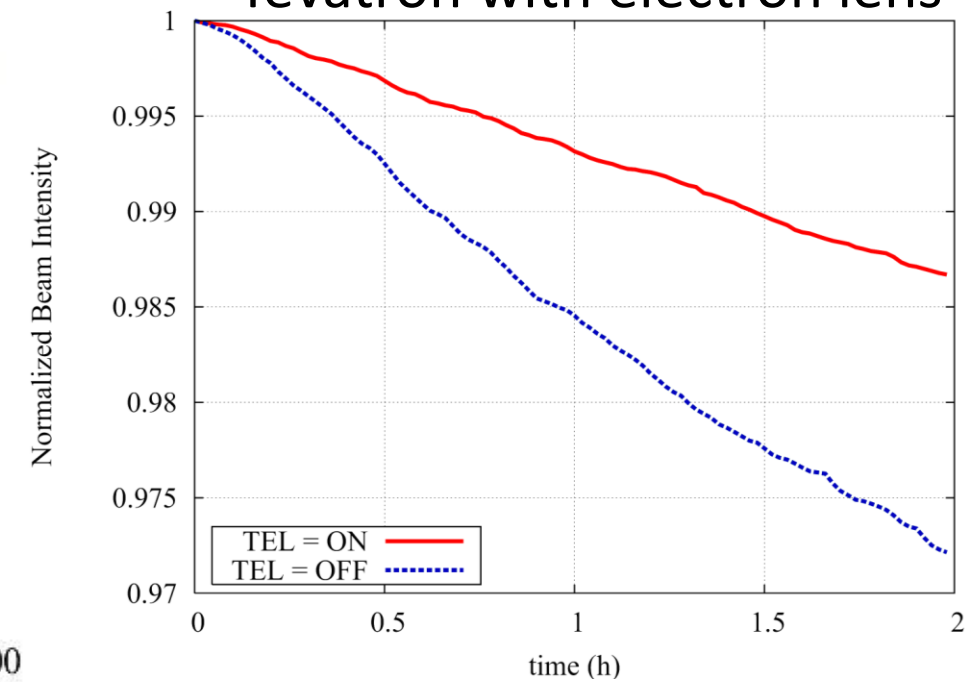
Predictive Beam-Beam Simulations

relevant to Tevatron, RHIC and LHC

Tevatron p-pbar 980 GeV



Tevatron with electron lens

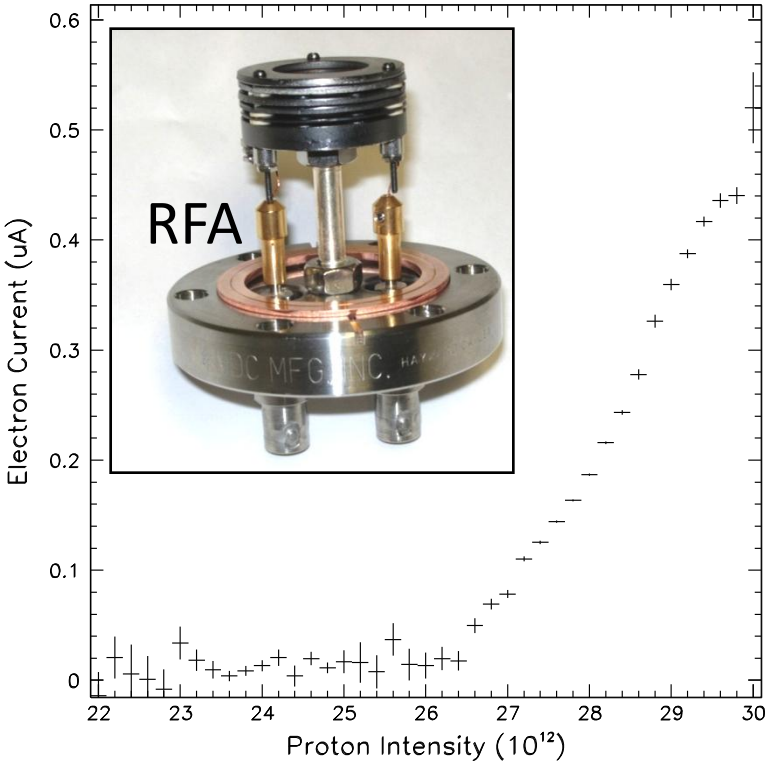


- LIFETRAC code explain and predicts effects of chromaticity and Q", coupling, helix separation, electron lens, size mismatch, etc

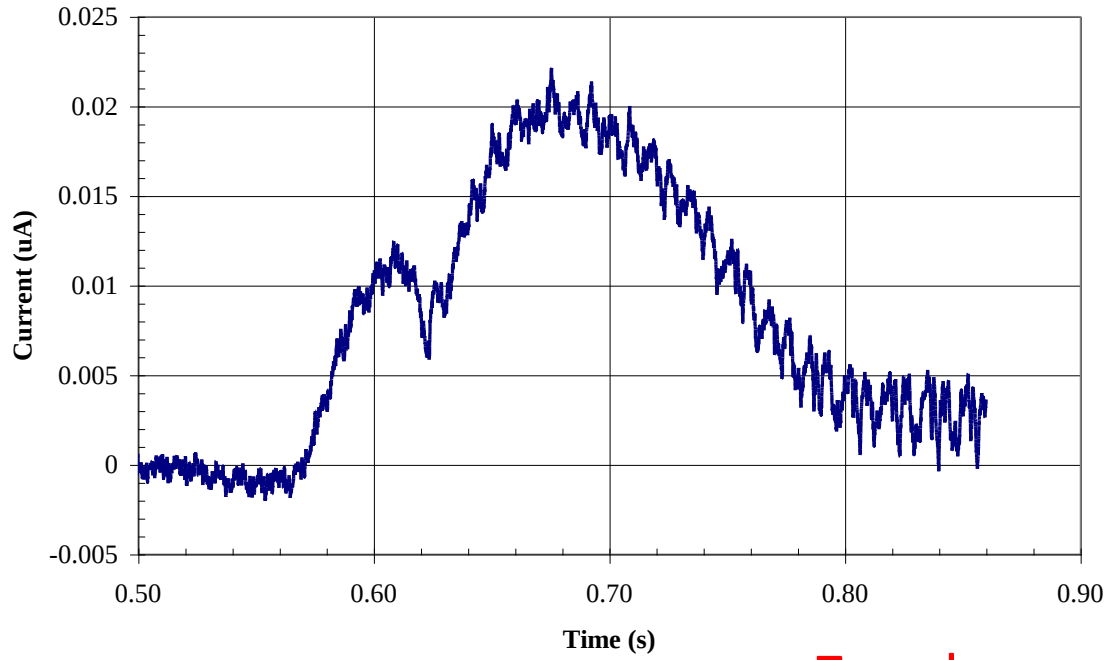
Alexahin, Valishev, Stern, Kim, Sen

Electron Cloud in Main Injector

relevant to Tevatron, RHIC and LHC



e-cloud signal on MI ramp

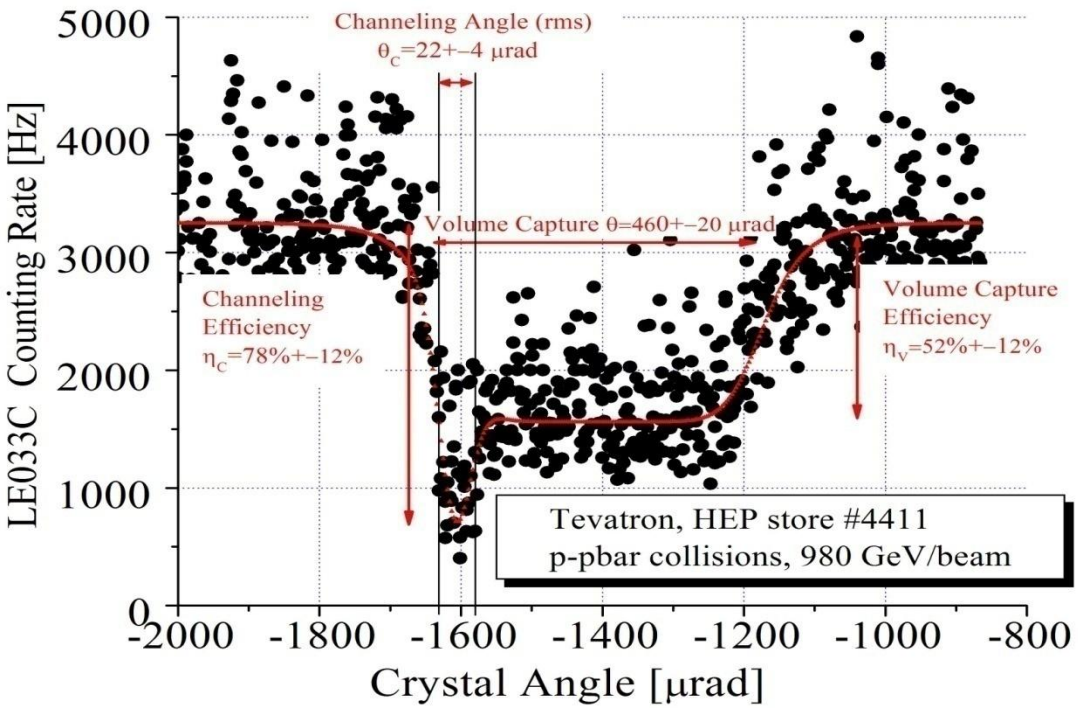


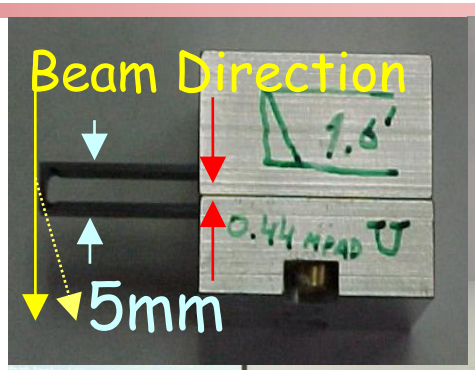
Zwaska, Zhang

- Developed RFA diagnostic, studied e-cloud in Main Injector , instability threshold explored at different energies, dEmm/dt studied in Tev, simulations with LBNL

Crystal Channeling of 980 GeV p's

relevant to Tevatron, RHIC,ILC,MC and LHC

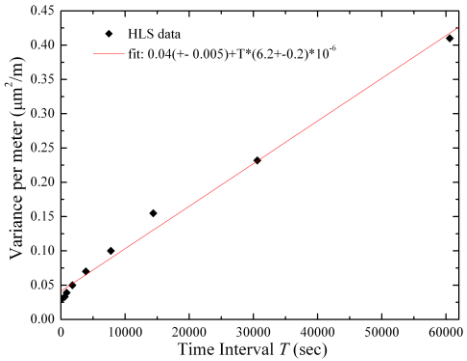


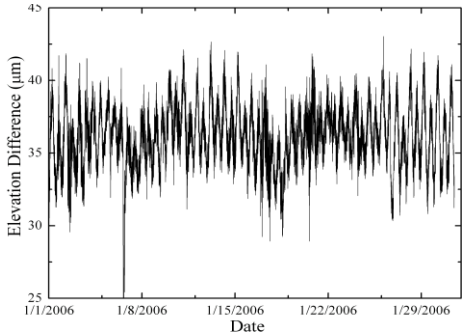


- Crystals for HEP collimation (p,e,muon)
- 0.45mrad crystal system in TeV, channeling observed and studied; new volume reflection, DC beam effects, T980

Mokhov,Still,Annala,Drozhdin
Johnson, Scandale, Carrigan

Ground Motion Instruments and Studies

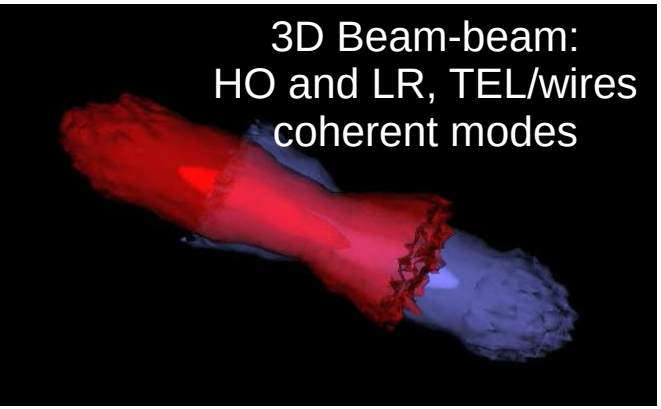




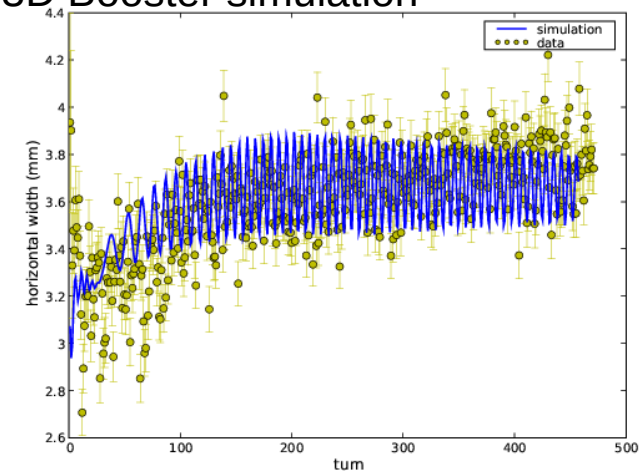
- 0.1 um resolution HLS developed, installed in Tevatron, Aurora dolomite mine, MINOS hall
- Drifts due to temp, tides, rains, blasts + slow diffusion

Volk, Prescod
Singatulin

Modeling and Simulations



3D Booster simulation



* **CHEF, SYNERGIA, MARS, BEAM-BEAM 3D**, ORBIT, VORPAL, MAD:

- Space-charge
- Beam-beam
- Electron cloud
- Linac emittance growth
- Collimation/*E*-deposition

*** Part of SciDAC**

- **Cartoon Cluster**
  - 16 Sun Solaris servers
  - 6 Intel/AMD Linux servers
  - 300+ users
- **Heimdall Cluster**
  - 64 slave nodes, grow
  - 60+ users and growing

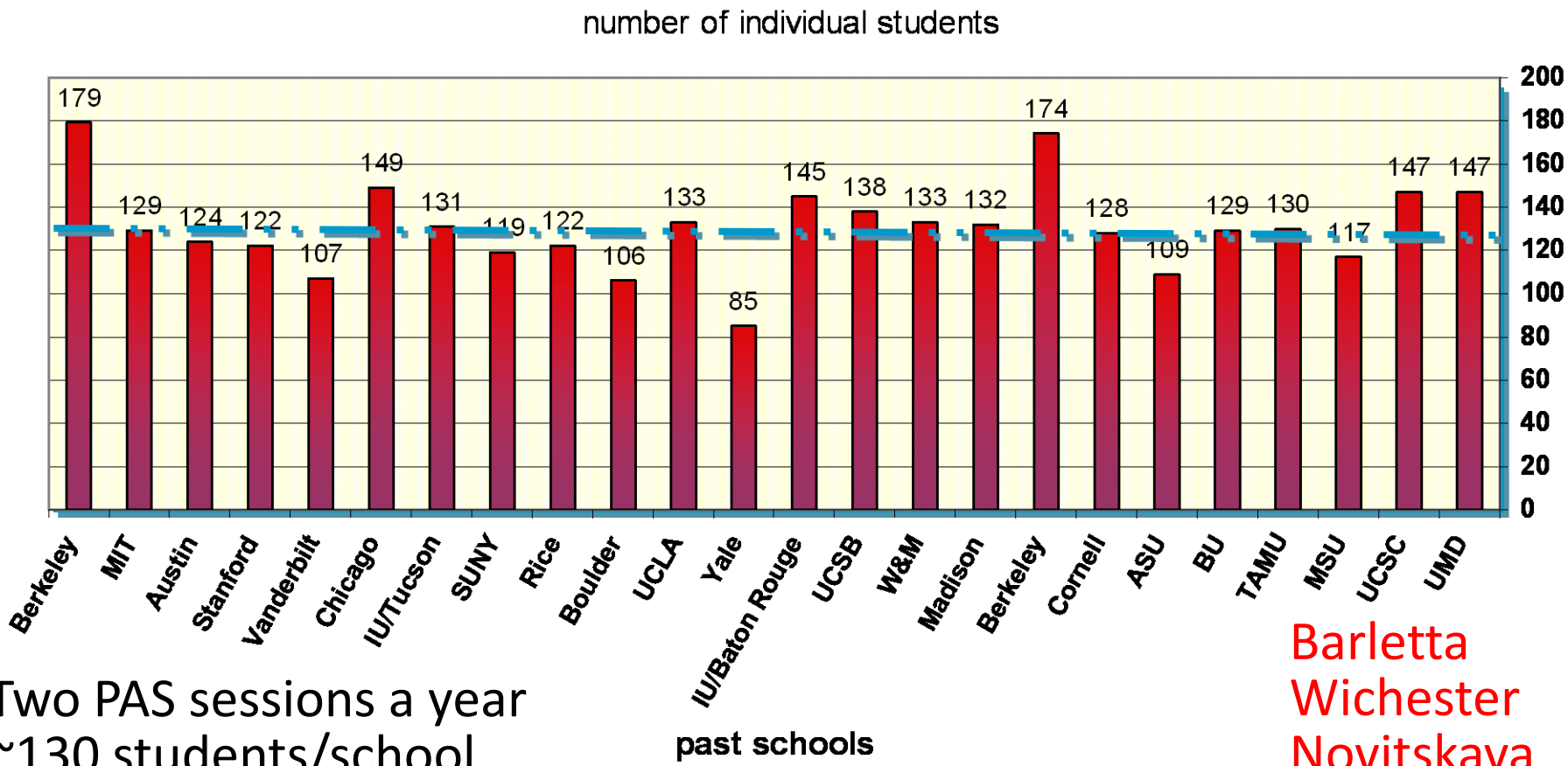
Spentsouris, Sen
Mokhov,Valishev
Ostiguy, Solyak
Amudson, Stern
Vorobiev, Kriss

Recent Publications

- Publications: >30 in refereed journals during 2005-2008, including:
  - 3 in Phys Rev Lett and New Journal Phys
  - 14 in Phys Rev ST-AB and D
  - 8 in NIM-A
  - 8 in others

  (see Appendix I of the FNAL Proposal)
- More than 400 conference proceedings and preprints

FNAL Hosts US-PAS Office



Two PAS sessions a year
~130 students/school

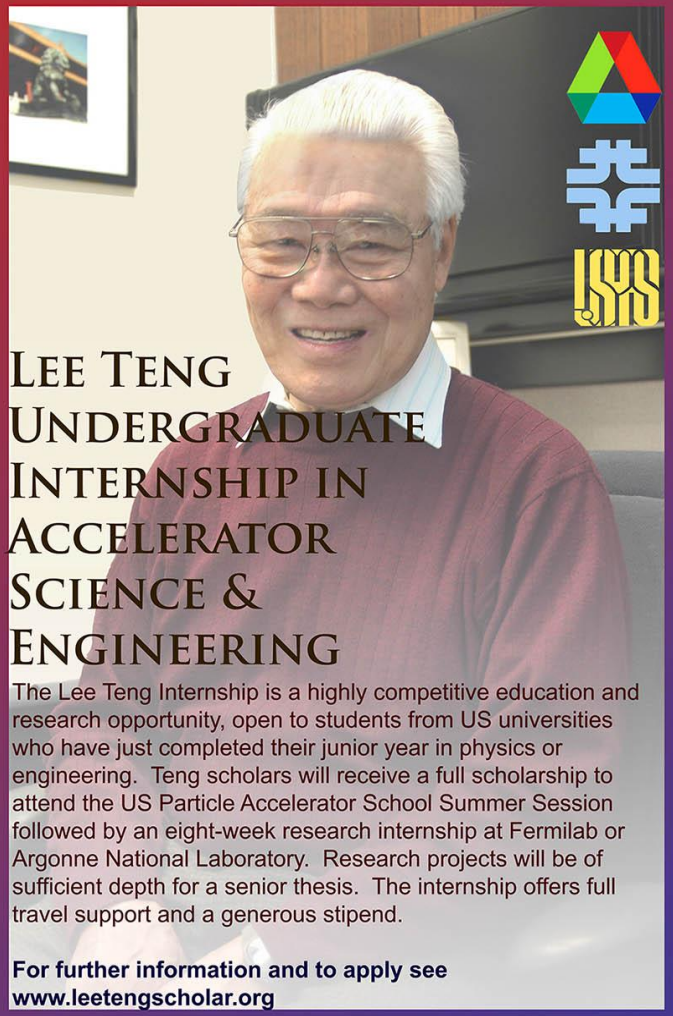
Barletta
Wichester
Novitskaya

There is a steady interest in accelerator science

US-PAS 2008 Highlights

- **Mike Syphers: USPAS "Iron-man" recognition**
  - 408 students in 11 classes
  - New course introduced: "Optics of High Energy Accelerators"

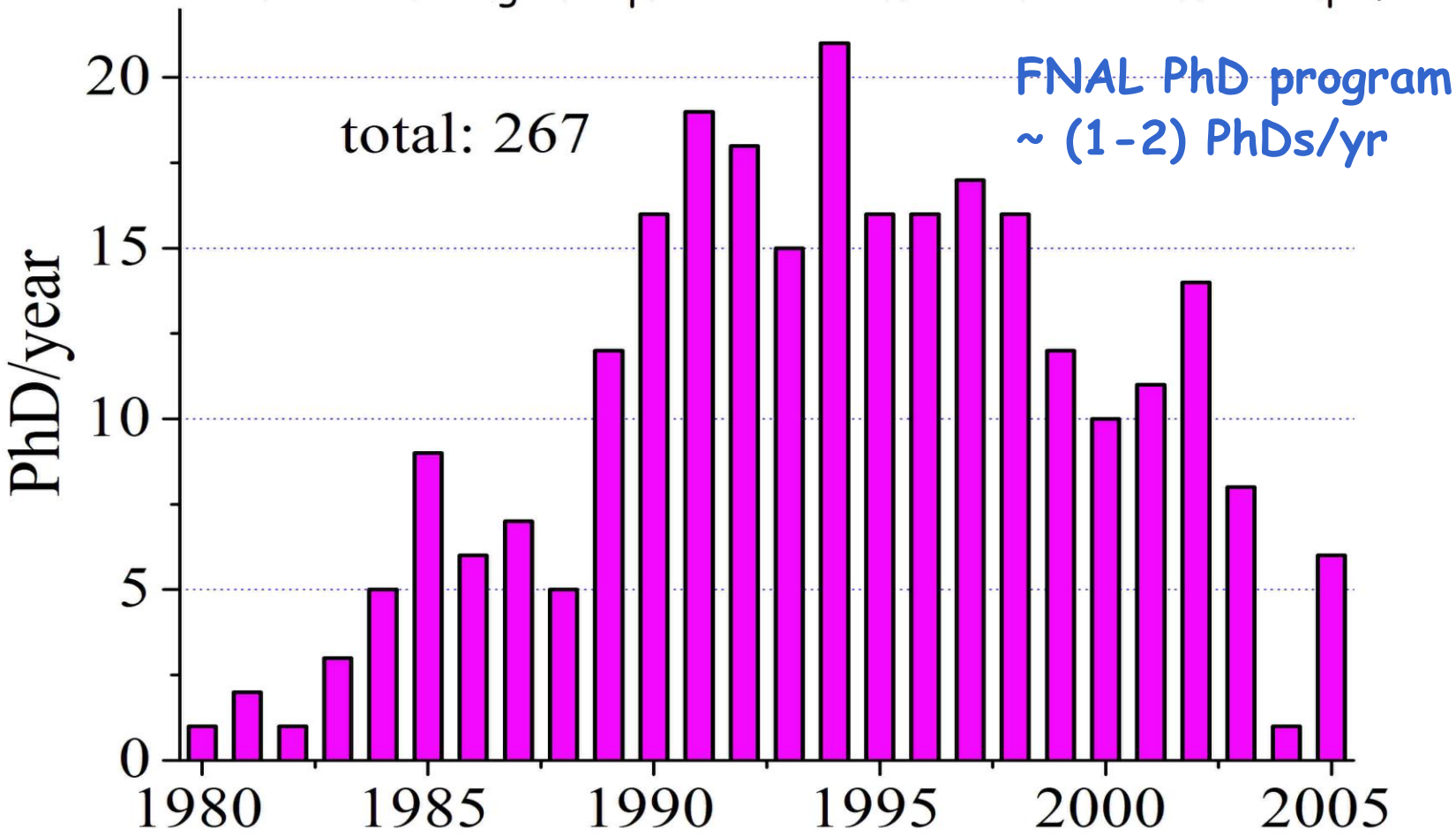
Undergraduate outreach: Teng Internship at FNAL and ANL



- Engage highly promising post-junior undergrads to study accelerator S&T
- Interns study “Fundamentals” at USPAS, undertake research project at the labs for ~2 mos in the summer
- ANL&FNAL selected 11 interns (2008)

Accelerator Physics PhD Production in the US

DOE Advanced Technology R&D Yearbook
-www.science.doe.gov/hep/AdvTechR&D2005/TechR&D2005.pdf



Recent FNAL PhD Graduates

- Accelerator PhD Program: 4 graduates in 2007-2008
  - Pavel Snopok (2007), Michigan State University
    "Capture of a Large Phase Space Beam"
  - Phil Yoon (2007), University of Rochester
    "Error-Induced Beam Degradation in Fermilab's Accelerators"
  - Alexei Poklonsky (2008), Michigan State University
    "Optimization and Control of Tevatron Parameters"
  - Ryoichi Miyamoto (2008), University of Texas, Austin
    "AC Dipole Diagnostics of Fermilab's Tevatron"
- See complete list in Appendix II

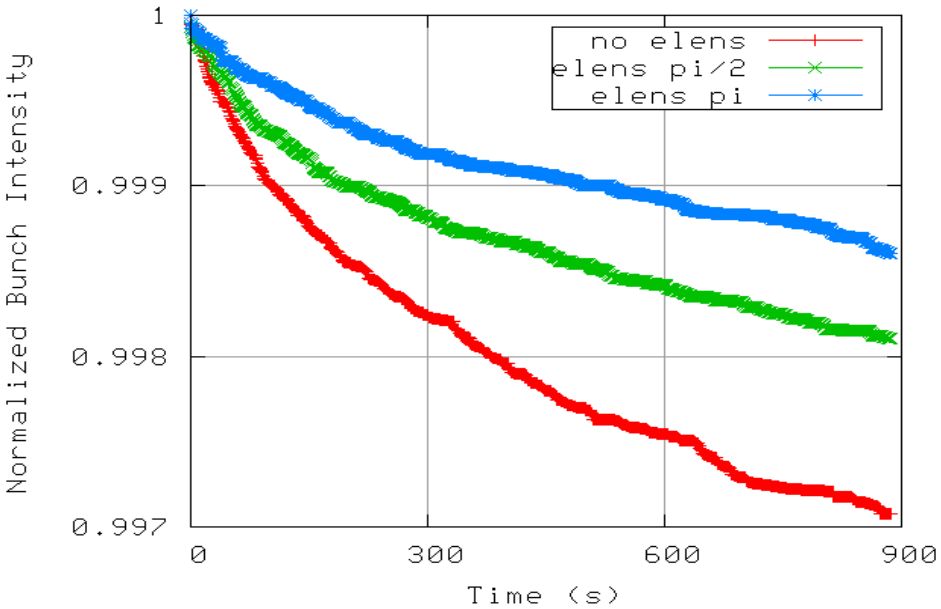
Proposal for FY2009-2011

Electron Lenses and Electron Columns

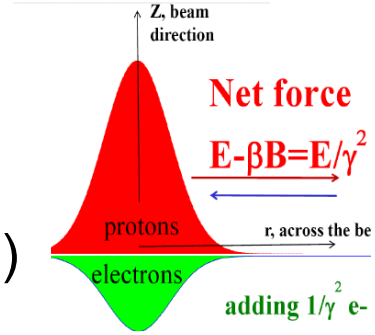
collaboration with US-LARP and BNL

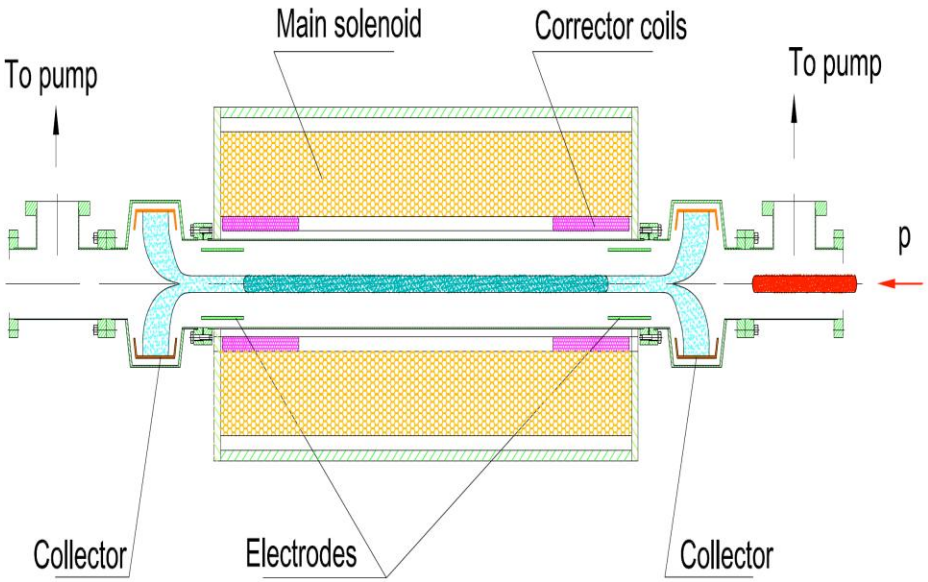
- Deliverable: new technique for compensation of beam-beam effects (lenses) and space-charge effects (columns)

LIFETRAC head-on eLens
LHC ξ=0.0075/IP, RHIC



Column of ionization electrons in strong *B* space-charge com-pensat'n(Proc.AAC'09)





e-Lenses/e-Columns 2009-2011

- Technical goals and milestones:
  - FY2009: Commissioning fast HV modulators for TEL-2; electron columns studies in Tevatron complete
  - FY2010: Operational compensation long-range of the beam-beam effects in Tevatron;
  - FY2011: relocation of the TELs to BNL after the end of Tevatron Run II; numerical and experimental studies of beam dynamics with electron columns complete; design of prototype electron column for SCC in MI complete;
  - FY2012: first round of head-on beam-beam compensation experiments in RHIC; MI electron column SC magnet built.

Rapid Cycling Conductor & Magnet

collaboration with CERN

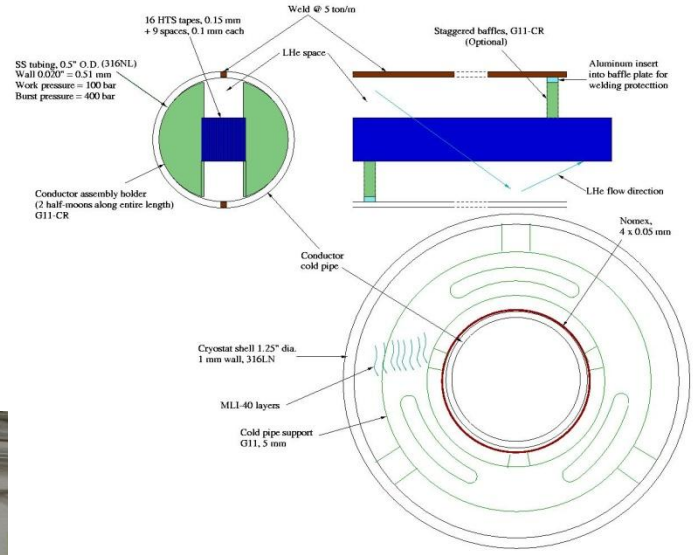
- This enabling technology for rapid cycling accelerators for ,e.g., Muon Collider buncher ring, Project-X, 480 GeV proton ring in Tev tunnel, LHC Upgarde (CERN – L.Bottura), VLHC, etc

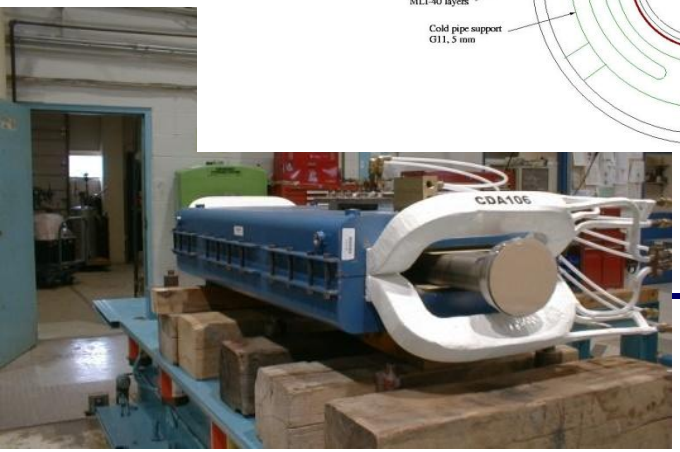
FY09: set up E4R test facility; first HTS conductor tests in external 2T/s field

a) Test conductor will consists of 16, 344S HTS tapes of 130 cm length each I_t ~ 11 kA @ 25 K in dB/dt ~2T/m ; dependence of AC loss on angle

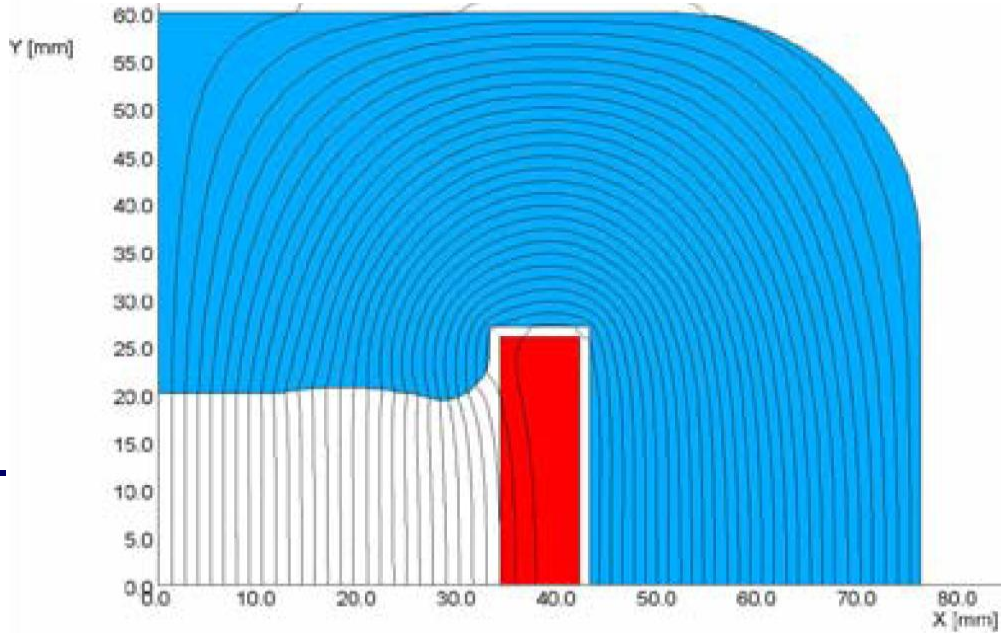
b) Compare HTS and LTS conductors

c) Build short superferric magnet (HTS and LTS)





Superferric fast cycling magnet



Rapid Cycling Magnets 2009-2011

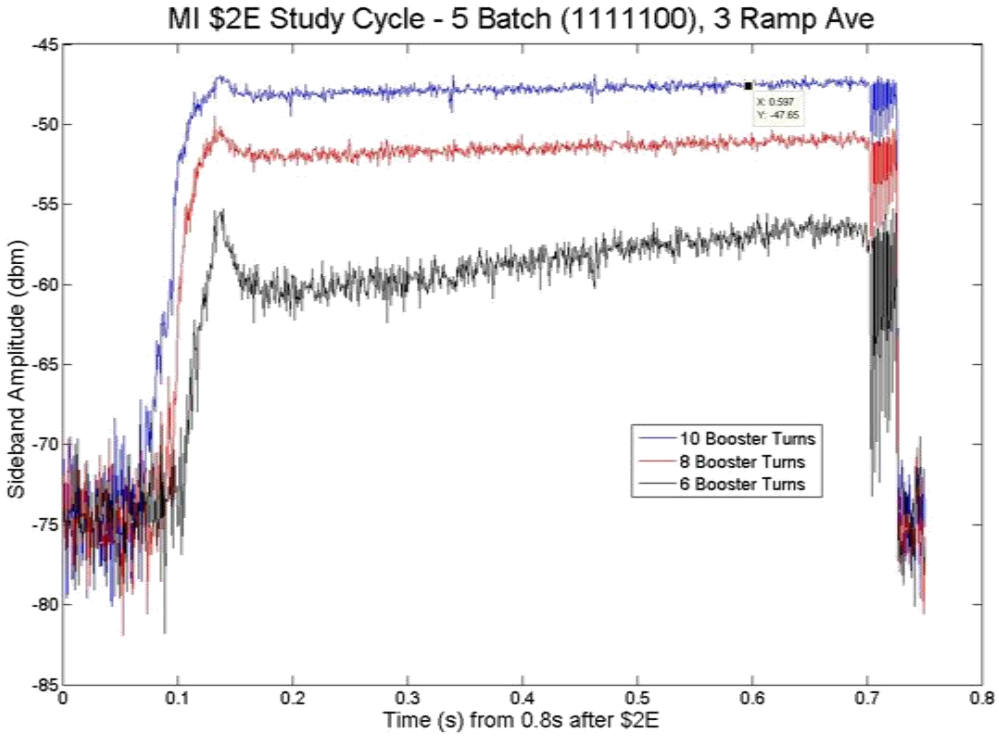
- Technical goals and milestones:
  - FY2009: test facility established in E4R; first HTS conductor tests in external 2T/s magnetic field complete;
  - FY2010: fabrication of the 40-80 mm gap prototype transmission line HTS magnet and AC test at E4R; design of 120mm bore 2T/s magnet complete;
  - FY2011: development of 5Hz PS with elements of quench protection complete; 120 mm gap prototype transmission line HTS magnet fabricated;
  - FY2012: 120 mm gap prototype transmission line HTS magnet fully tested at max ramping rate (>5Hz, >2T/s)

Electron Cloud

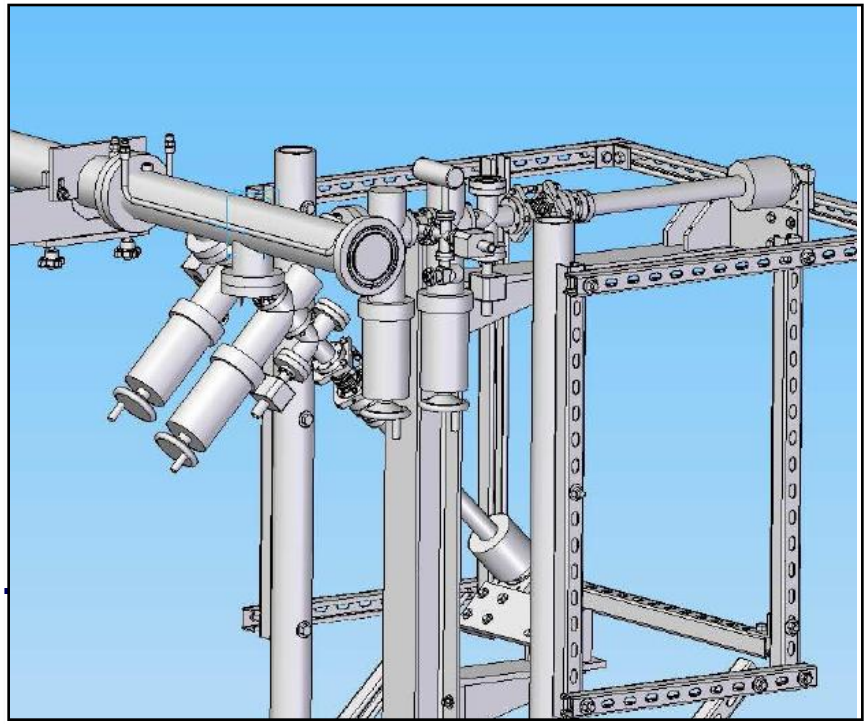
collaboration with Cornell and LBNL

- Deliverable: results of e-cloud studies in MI, CESR-TA and SPS and in simulations, new diagnostics; development of the most effective mitigation technique(s)

Microwave propagation in MI



e-cloud test stand



Electron Cloud 2009-2011

- Technical goals and milestones:
  - FY2009: RF waveguide electron cloud diagnostics developed and tested in MI. Coatings and new electron cloud analyzers tested in MI. Participation in the CESR-TA (electron cloud suppression electrode)
  - FY2010: Participate in CESR-TA electron cloud measurement and analysis, including results of the suppression electrode. New simulation codes reproduce beam feedback results. MI measurements continue
  - FY2011: SLAC e-cloud system moved to MI from CESR-TA. Measurements of e-cloud now made with higher intensity NOvA beams in Recycler and MI, results used to benchmark simulation codes.
  - FY2012: MI and Recycler electron cloud studies continue at the highest proton bunch intensities for application to buncher rings. If available, measurements will be extended to the Accumulator and Debuncher rings.

Ground Motion 2009-2011

collaboration with BINP and SLAC

- Technical goals and milestones:
  - FY2009: installation and commissioning of a system of new type hydrostatic level sensors (HLS) on CDF quadrupoles; few sensor system tests for DUSEL GM studies complete;
  - FY2010: installation and commissioning of the HLS system on the prospective Project X linac construction site; the first data analysis presented; installation and commissioning of the HLS system at the DUSEL site;
  - FY2011: extension of the DUSEL site system by the HLSs from the Tevatron tunnel becoming available after the Tevatron shutdown;
  - FY2012: data taking from full scale systems of HLSs and analysis of slow ground motion at Fermilab Project-X and at the DUSEL site complete;

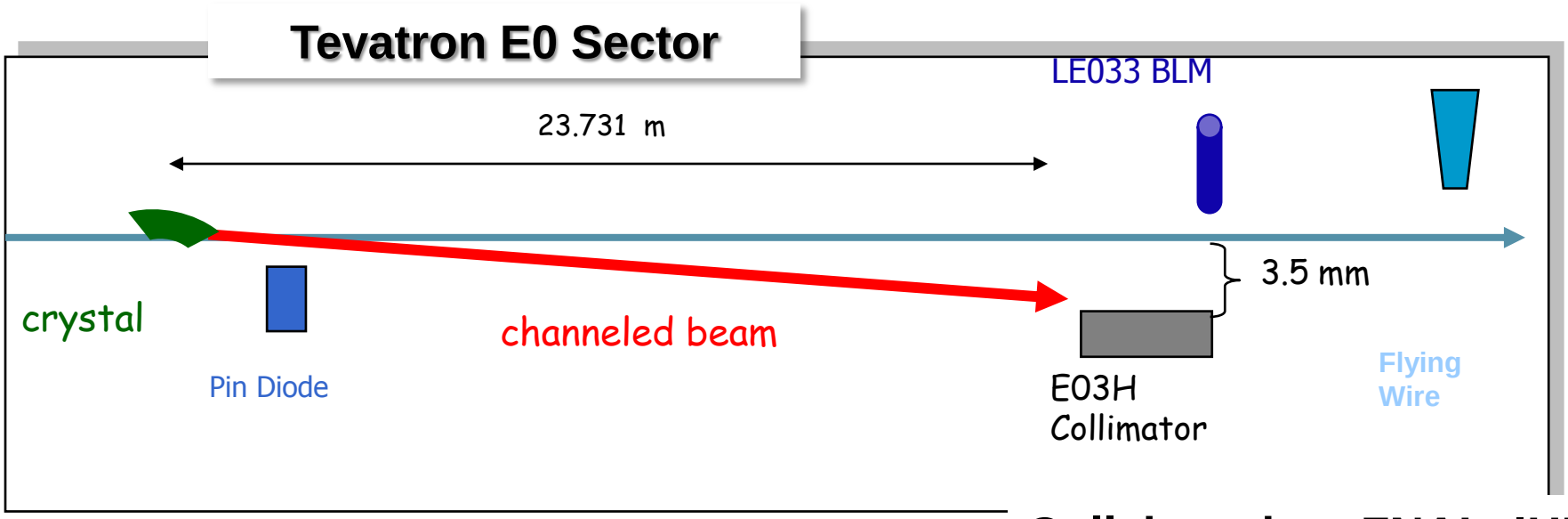
Accelerator Education 2009-2011

- Technical goals and milestones:
  - FY2009: two sessions of US PAS;
    Lee Teng Internship program in the summer
  - FY2010: two sessions of US PAS;
    Lee Teng Internship program in the summer
  - FY2011: two sessions of US PAS;
    Lee Teng Internship program in the summer
  - FY2012: two sessions of US PAS;
    Lee Teng Internship program in the summer

General Accelerator R&D

- **Deliverables:**
  - theoretical studies and numerical simulations of integrable solutions for beam-beam effects suppression, fast ionization cooling, optical stochastic cooling, noise spectra in high intensity bunched beams (dozens GHz to optical).
  - development of new methods of particle collimation for colliding and high intensity beam facilities including bent crystal collimators and hollow electron beam collimators.

Bent Crystal Collimation Experiment in Tevatron (T980)



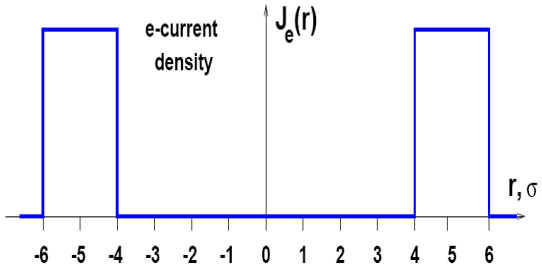
Collaboration: FNAL, IHEP UChi, CERN, LARP, INFN

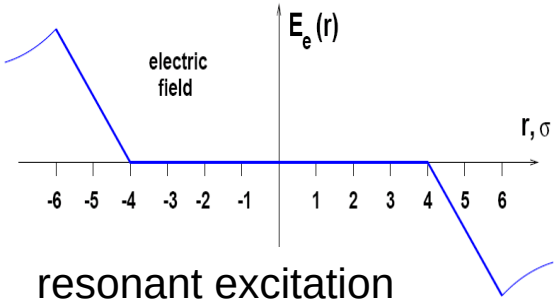
- Goals:

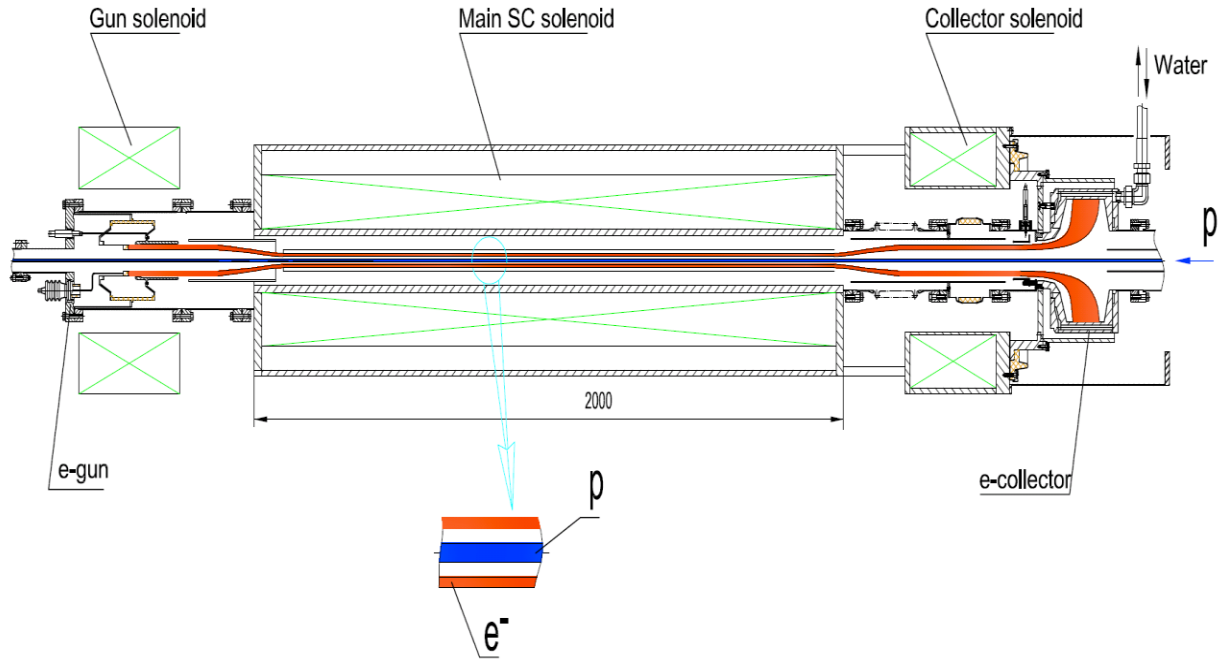
1. Measure channeled, volume-reflected, volume-captured and scattered beams as well as beam losses downstream of the crystal setup in comparison with simulations.
2. Demonstrate reproducible beam loss reduction in the B0 and D0 in comparison with simulations, aiming at a routine use of the crystal based collimation in Tevatron stores

Hollow Electron Beam Collimator

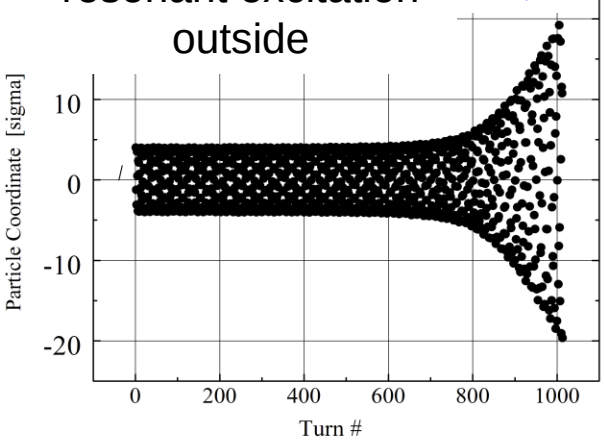
no field inside

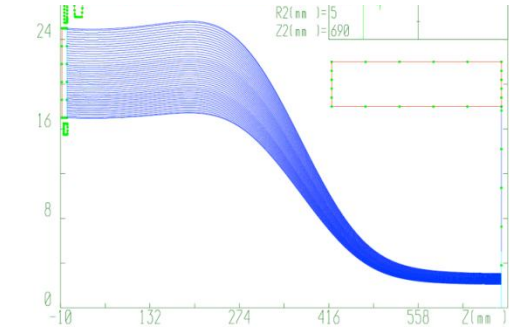


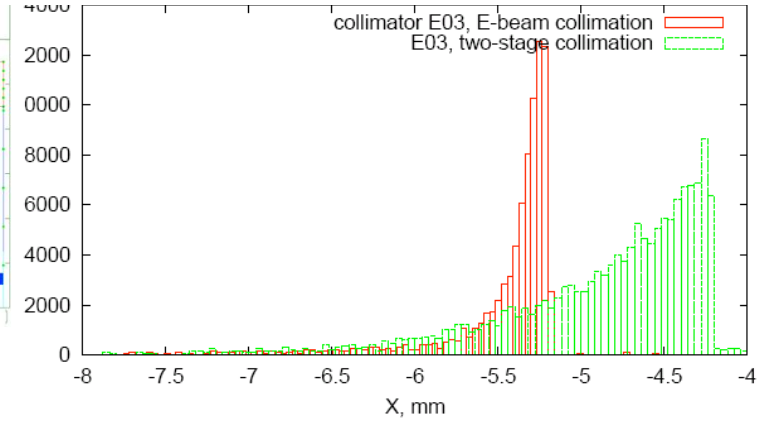




resonant excitation
outside







General Accelerator R&D 2009-2011

- Technical goals and milestones:
  - FY2009: Tevatron bent crystal collimator experiment (T980) data taking; theoretical analysis started on feasibility of i) optical stochastic cooling (OSC) test experiment at FNAL NML test facility or at CESR-TA or at the CTF-3 at CERN (**FNAL-LBNL-CESR-MIT-CERN collaboration),** ii) measurements of the HF longitudinal fluctuations spectra in high intensity bunched proton beams with optical diffraction radiation monitors (ODRs); iii) experimental test of space-charge effects in resonant half-integer linear focusing optics channels.
  - FY2010: T980 data taking and analysis finished; theoretical analysis and computer modeling of the three feasibility studies complete; noise spectra ODRs experiments performed in the Tevatron and/or RHIC; computer simulations of the hollow electron beam collimator complete for MI and RHIC;
  - FY2011: design and construction of the OSC test ring starts (if proven feasible in FY2009-10) ; design and construction of a low energy half-integer resonance test beam line test ring starts (if proven feasible in FY2009-10); prototype ring cathode electron gun built for hollow electron beam collimation.

FNAL APC Accelerator R&D in National Context

- APC's R&D program relevant to (P5 thrusts):
  - Muon Collider and Neutrino Factory
    - e-cloud, sc effects, theory/simulations, μ-cooling, magnets, FFAG
    - centered around MTA (Mucool Test Area) facility
  - High intensity proton sources
    - e-cloud, sc effects, theory/simulations
    - centered around MDB/HINS facility
  - e+e- linear collider; linac light sources
    - CSR, ultra-low emittance, short bunch wakes, theory/simulations
    - centered around A0 Photoinjector facility
  - LHC+VLHC+SLHC
    - Beam-beam effects and compensation, sc effects and compensation theory/simulations, stochastic cooling, collimation methods

Budget Request FY2009-2011

		FY09	FY10	FY11
Electron Lenses/Columns				
	SWF	162	172	180
	M&S	72	44	140
Rapid Cyclyng Accelerators				
	SWF	142	180	240
	M&S	110	270	250
Electron Cloud R&D				
	SWF	54	58	62
	M&S	25	26	35
Ground Motion Studies				
	SWF	42	64	68
	M&S	5	22	48
Accelerator Education				
	SWF	593	622	647
	M&S	94	97	99
Beam Theory/AARD				
	SWF	82	142	184
	M&S	16	42	160
TOTAL		1397	1739	2113
	SWF	1075	1238	1381
	M&S	322	501	732

Summary

- FNAL Accelerator Physic Center pursues broad and diverse program in Accelerator R&D aligned with P5 recommendations, with emphasis on:
  - Advanced accelerator research at experimental beam facilities
  - Beam theory and modeling
  - Raise next generations of accelerator scientists
- The APC leads and coordinates a number of inter-institutional collaborations in Accelerator R&D with other Nat'l Labs, Universities and International, with particular strength in:
  - Muon Accelerator R&D (following talks)
  - Advanced Accelerator R&D at A0 (following talks)
  - Accelerator Education (US PAS, Lee Teng Internship, etc)
- The APC general accelerator physics proposal for 2009-11 will support development of:
  - Novel beam manipulation methods (electron lenses and columns)
  - Novel collimation schemes (bent crystals and hollow beam)
  - Rapid cycling accelerators for HEP
  - Advanced theory and modeling tools