MI/RR Working Group Report

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10/27/11

MI/RR Issues /modifications

- Recycler lattice modifications
- H- stripping
- Space charge in MI/RR
- Electron cloud effects
- New rf systems (53&106 MHz)
- Transition crossing in MI.

R&D Plan for FY12

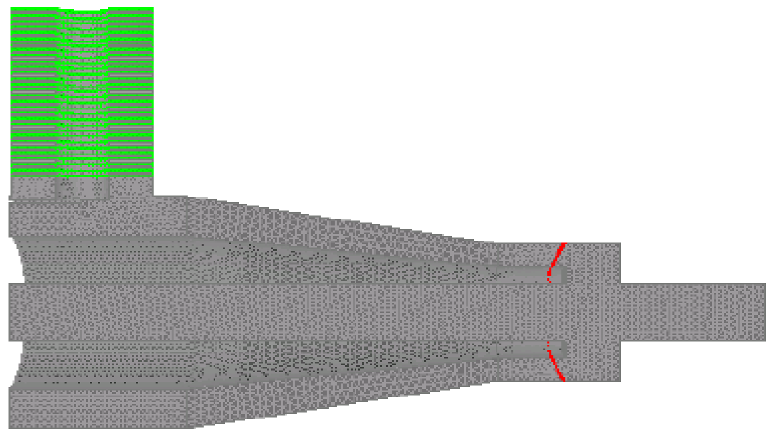
- Continue the MI/RR Cavity Design effort.
- Coatings for e-cloud and SEY beam measurements.
- Space charge simulations and beam measurements.
- Rotating foil and laser stripping investigations.
- Instrumentation

MI/RR New RF Systems

Parameter	Value	Units
Frequency	52.617-53.104	MHz
Max. Acc. Rate	240	GeV/sec
Frequency Slew Rate	1.6	MHz/sec
Acceleration Voltage	2.7	MV
Peak Beam Power	6.2	MW
Average Beam Power	3	MW
Peak Voltage	4.7	MV
Average Beam Current	2.3	A
Fundamental RF Current	3.7-4.1	A

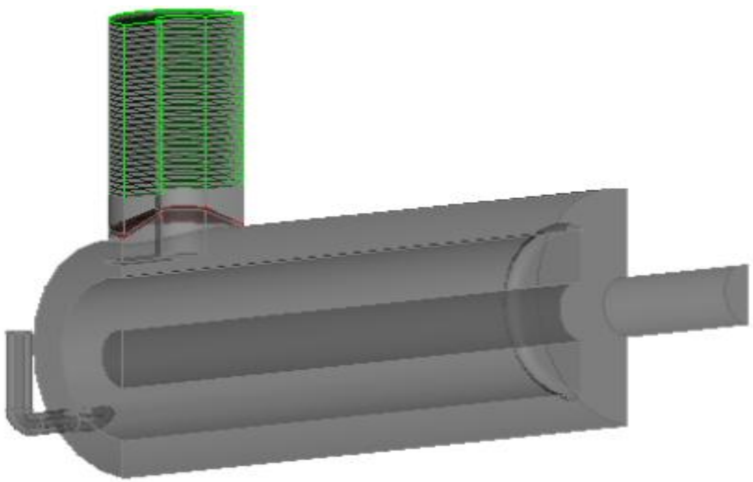
Fundamental RF Specifications

J. Dey, L. Xiao

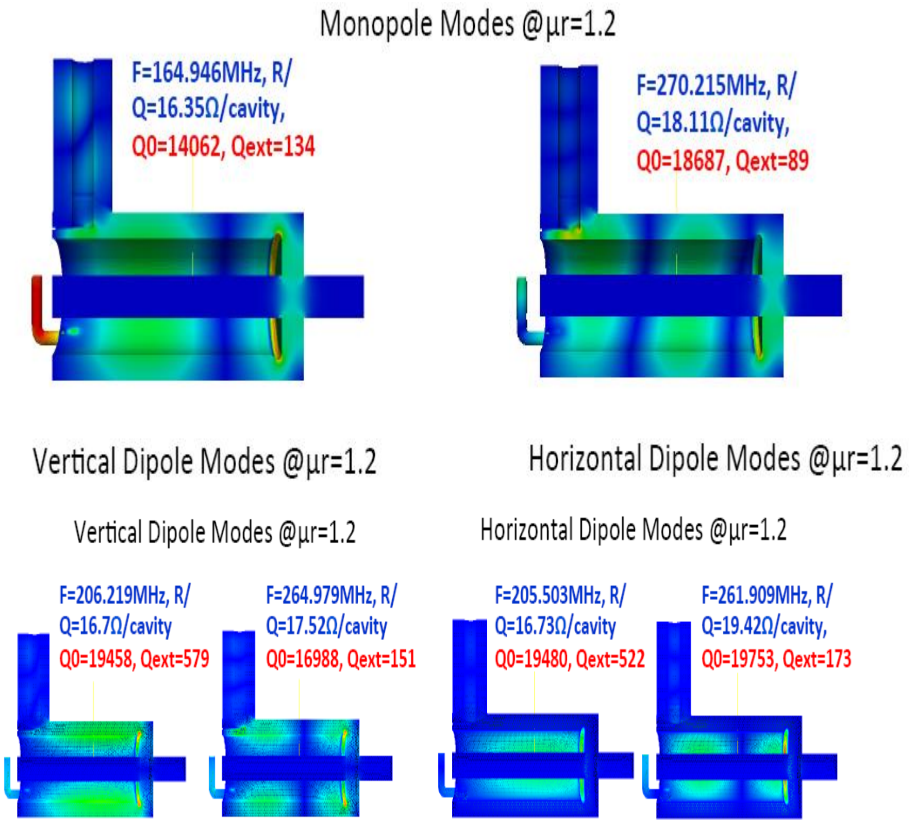


Two cavities designs.
R/Q~50Ohms; 1 MHz tuning range

HOM Damping



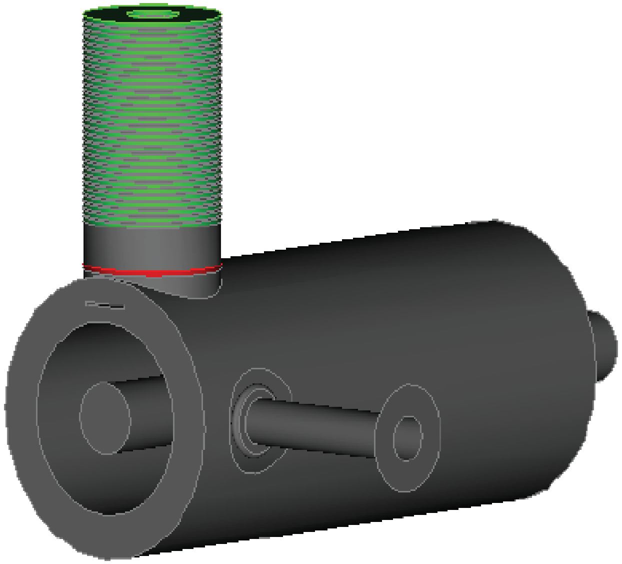
Cavity I with two mirrored HOM dampers w/o filter



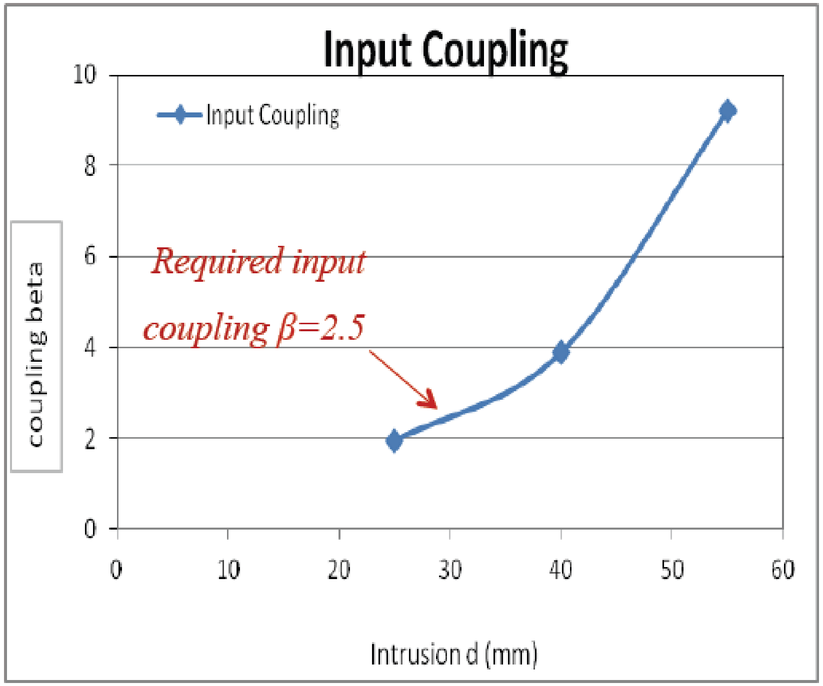
- A Coaxial damper with a large loop located at the rear end of the cavity is used to damp the HOMs.

Cavity power coupling

- *Eimac 8973 power tetrode is chosen as the power source for the new MI cavity.*
- *It can operate at both 53MHz and 106 MHz with more than 1MW output power.*
- *E-probe coupling is adopted in MI cavity power input coupler design.*
- *The input coupling should be matched when the maximum beam current is accelerated.*



Cavity I with a coax input coupler



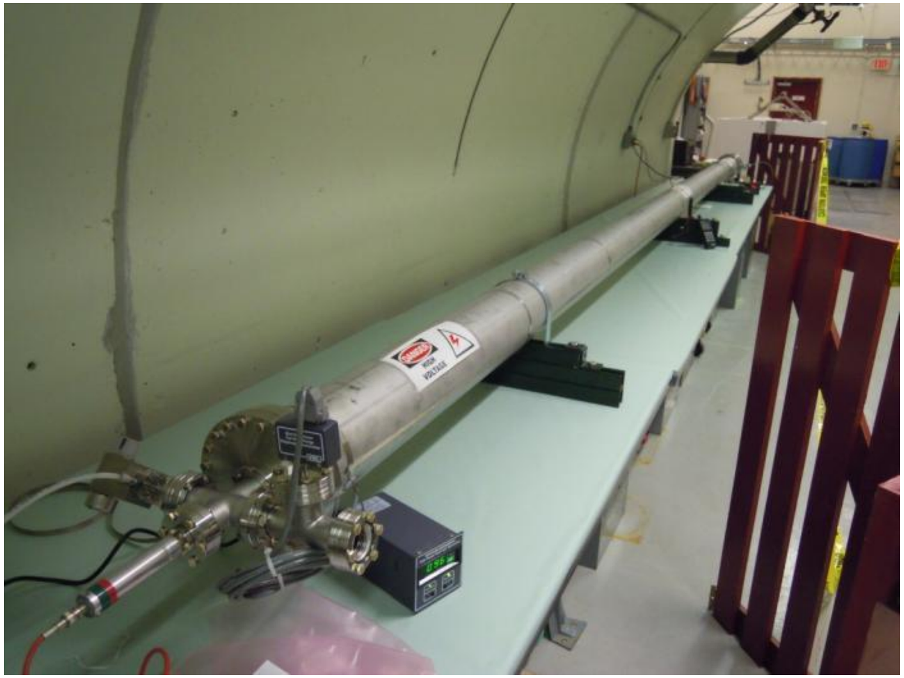
FY12 Plan for MI/RR RF

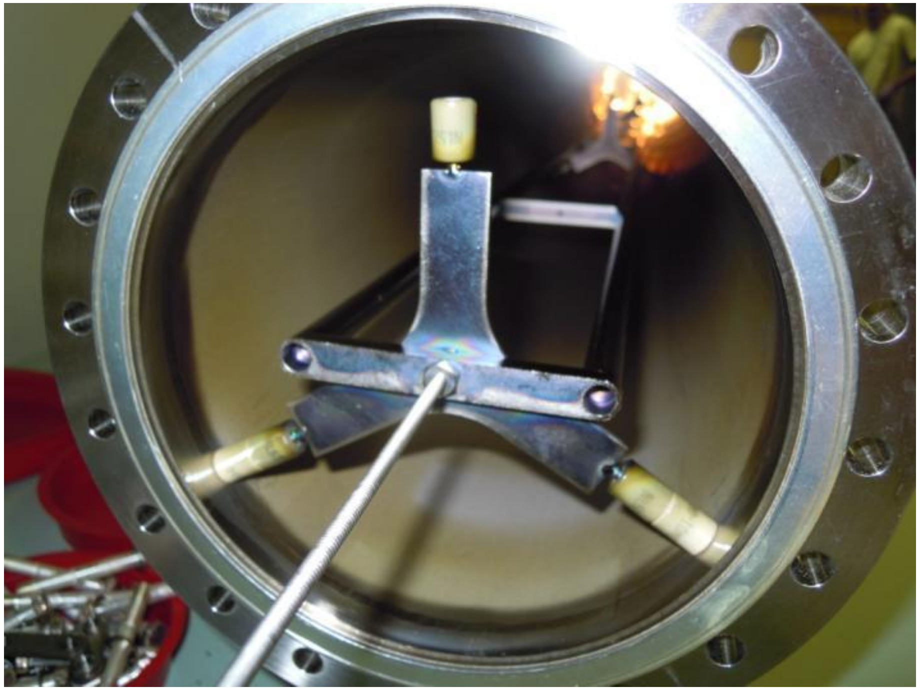
- Build a copper mockup of 53MHz cavity.
  - Look at higher order modes, R/Q and coupling issues.
  - Look at cavity response with dampers
- Simulate the temperature response of the 53 MHz cavity.
- Start simulations for a second harmonic cavity (106 MHz).

Fermilab Coating Facility

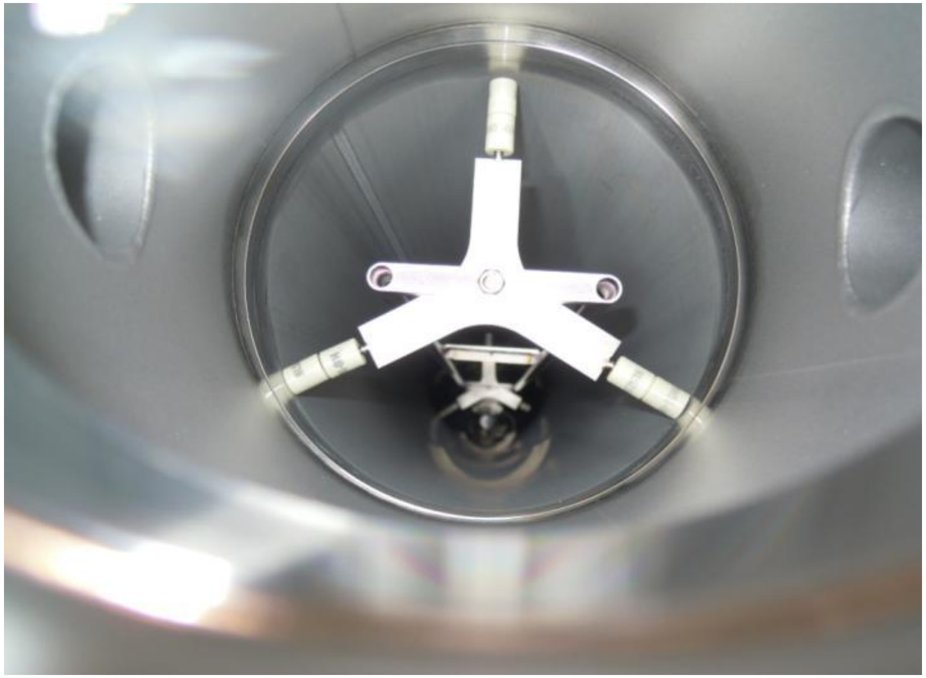
D. Capista, L. Valerio

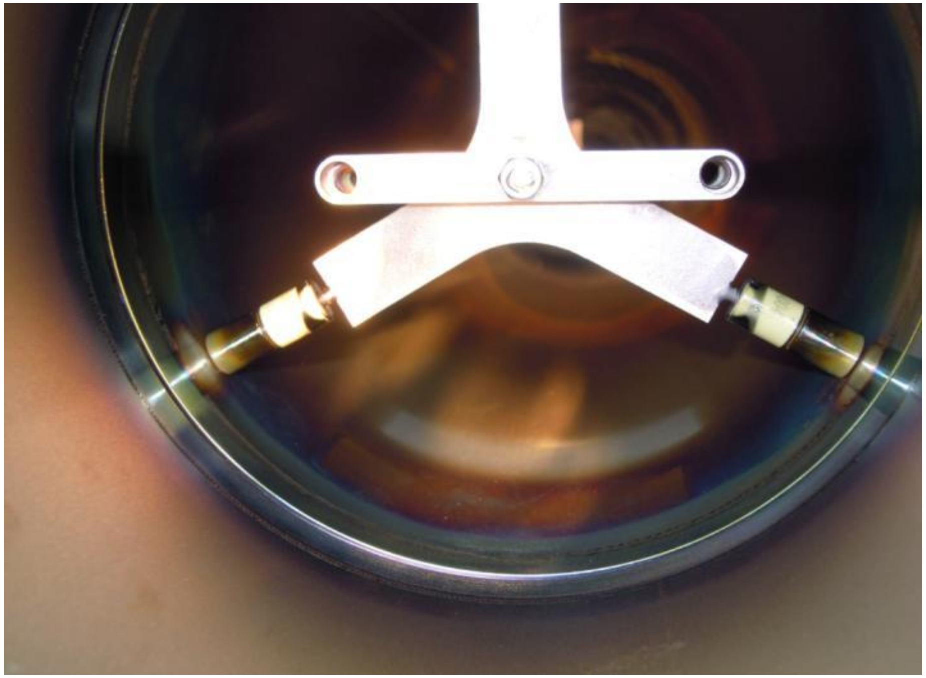
- Began in early 2011 setting up the E4R service building for TiN coatings of a round beam tube
- Coatings started in summer 2011

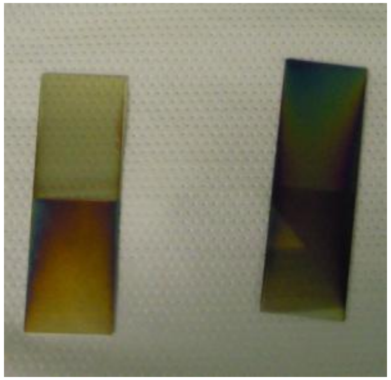




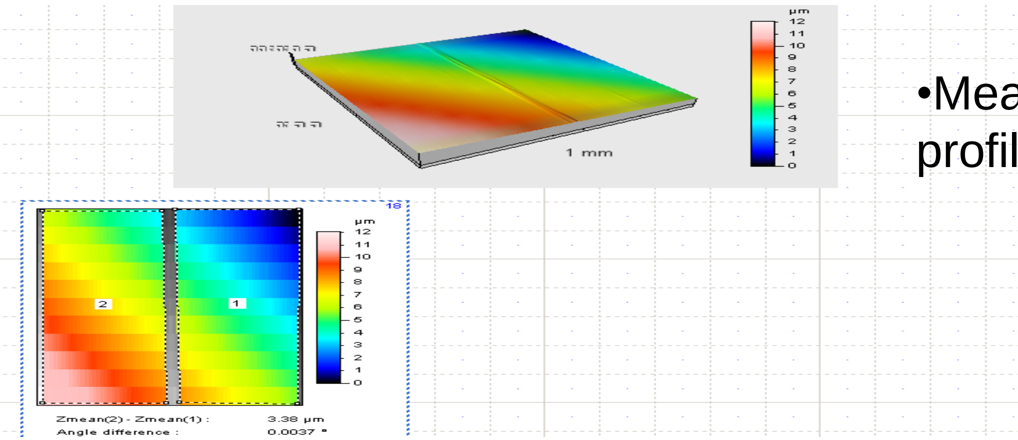
Beam pipe coating with TiN







Coating thickness measurements



- Measured with a stylus profilometer and laser profilometer

Coupon location	Pressure	Coating thickness
Upstream (leak source)	200 mTorr	3560nm stylus 6665nm laser
Downstream	300 mTorr	3380nm stylus 4028nm laser

FY12 Plan for Coatings

•Better understand thickness measurements

•Understand the effect of gas pressure on the coating thickness for a specified run time, nm/hr

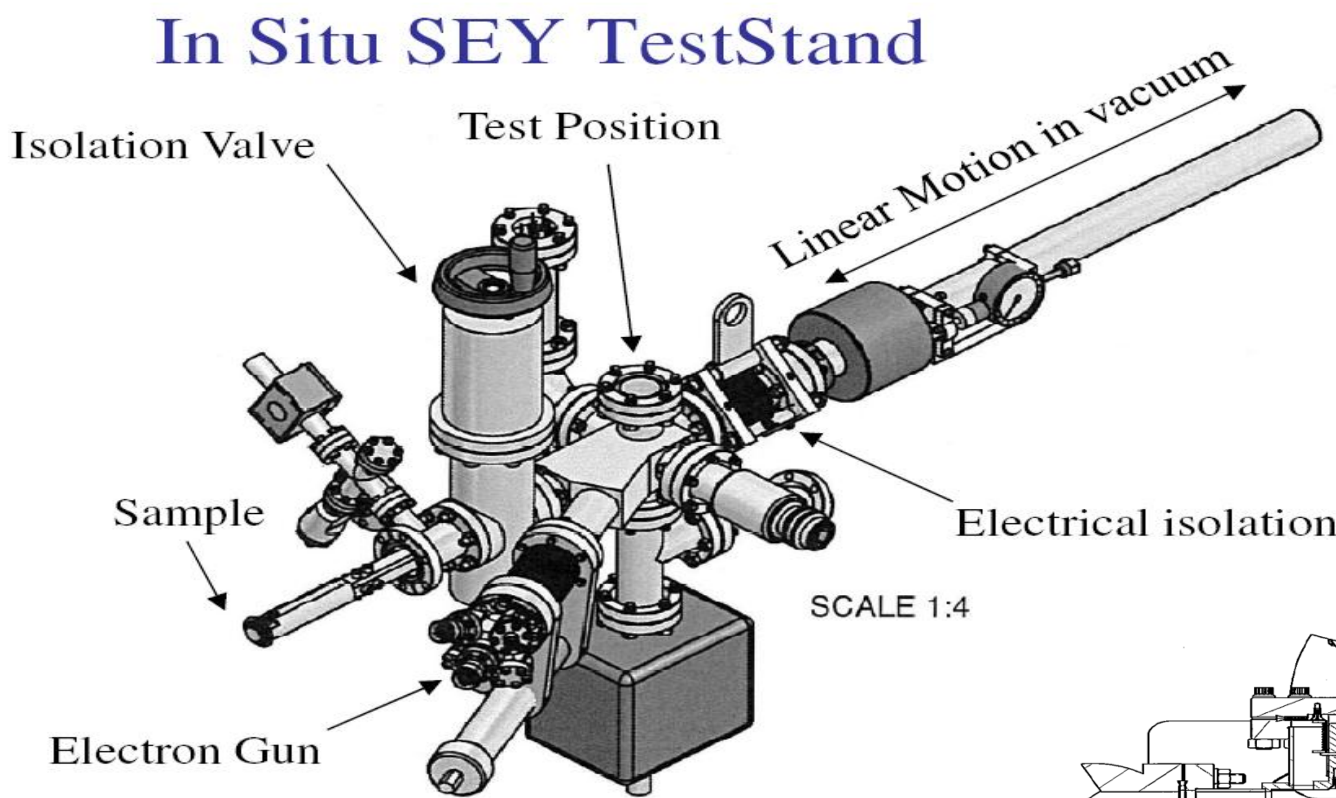
•Estimate effort to in situ coat the Main Injector given the current understanding of this coating process

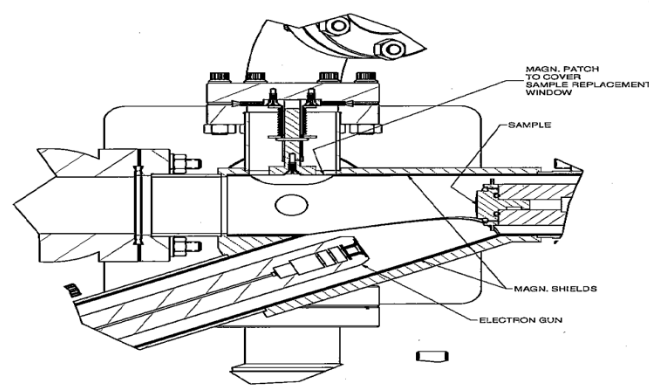
•Coat test coupons for SEY measurements in MI.

•Understand the engineering involved to make a cathode that accommodates the bend angle of the MI dipoles

E-Cloud (Measurements)

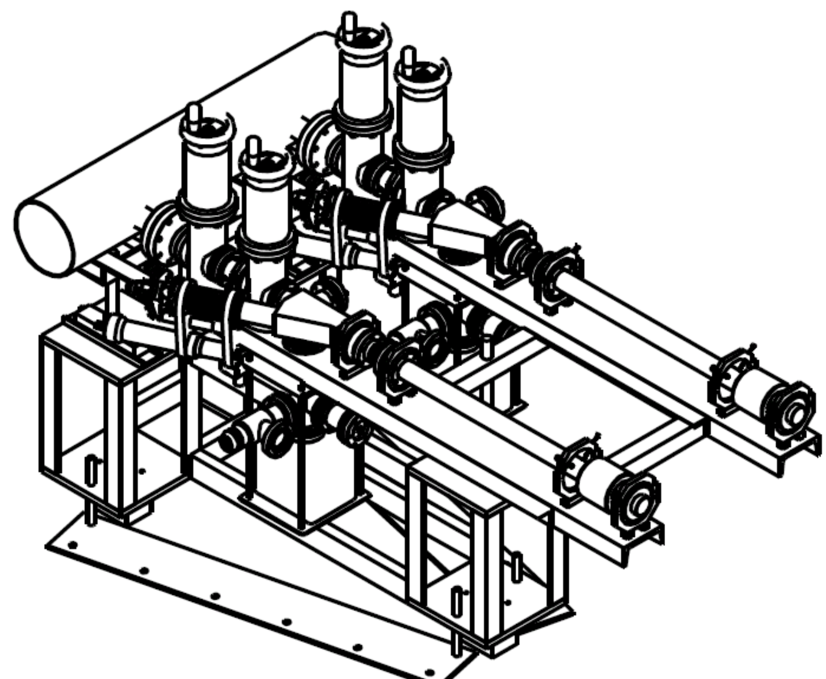
B. Zwaska





SEY Station Prep

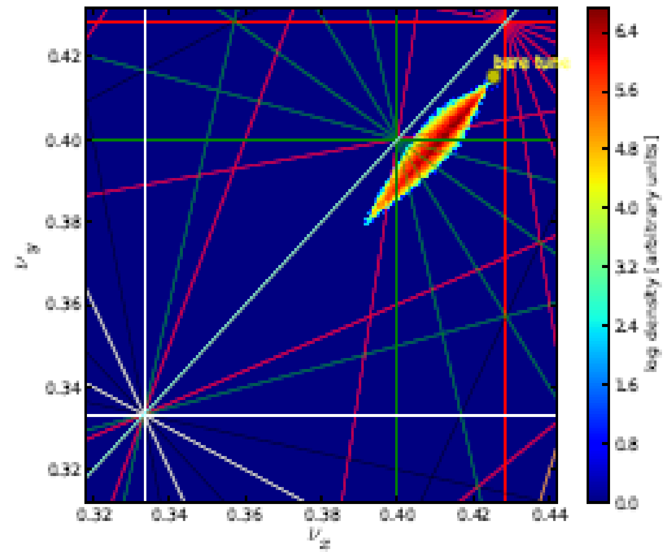
- Arms being staged at A0
  - Have been pumped down for a few weeks
  - Full integration with beam pipe is starting now
  - Plan to do several test measurements and practice sample changeouts
- On temporary stand now
  - Final stand will allow simple installation to MI



Space Charge Simulations

E. Stern

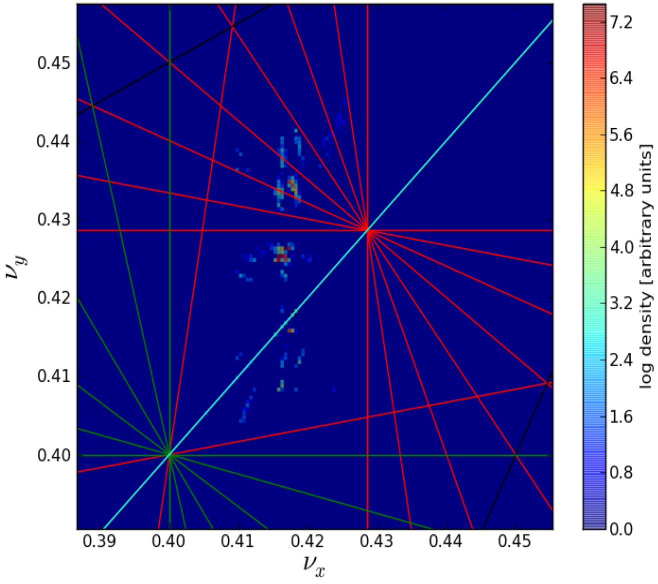
- Continue the simulations with SYNERGIA and IMPACT (LBNL).
  - Include realistic apertures and magnet multipoles.
  - Compare beam loss with beam measurements.
  - Continue beam measurements of tune scans at different bunch intensities.



Tune footprint with SC and 1E11ppb

First simulations with multipoles

- Results of one run 2000 turns, no space charge
- Currently, only dipole magnet multipoles active.
- Have implemented 3 basic apertures so far.

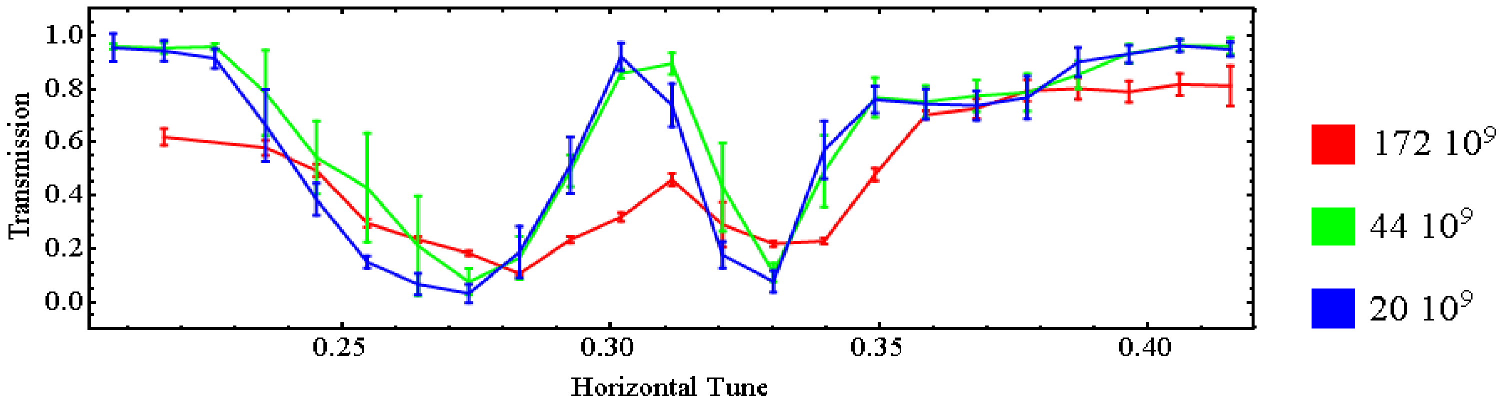


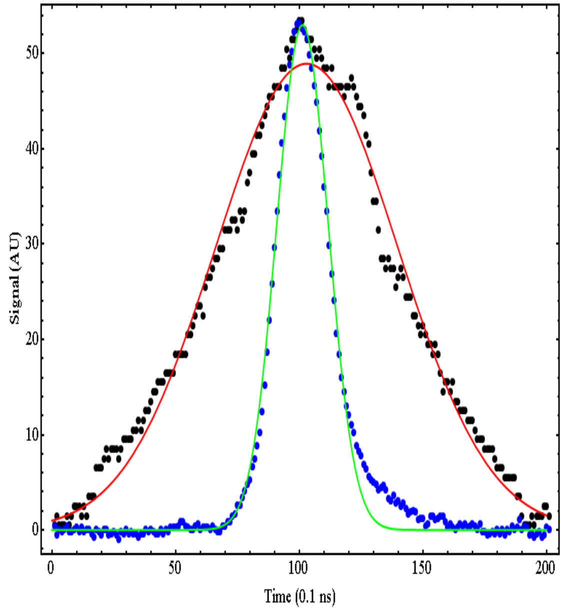
FY12 Plan for e-cloud Measurements

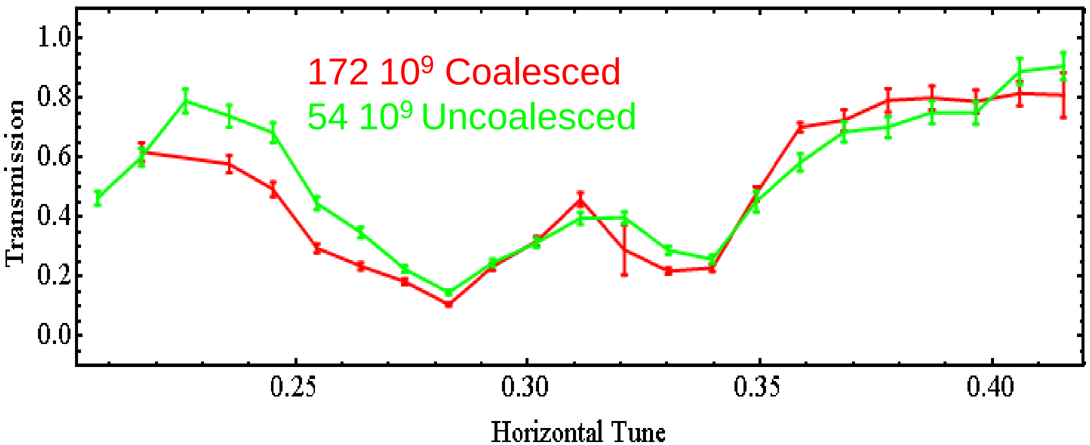
- Finish the preparation and install the two SEY measuring devices in MI.
- Install a new beam pipe coated with Diamond-like carbon from Japan.
- Continue the efforts for e-cloud measurements in a magnetic field.
- Continue R&D effort for microwave measurements

Space charge beam measurements

D. Scott





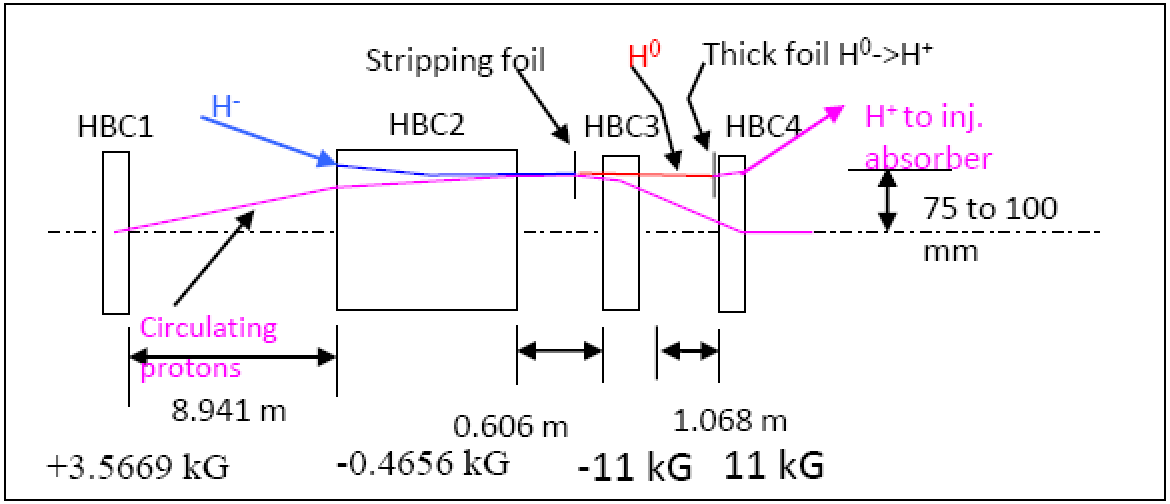


- Similar transmission with factor of 3.2 increase in intensity
- However Bunch length increased by factor 3.4

H- Stripping

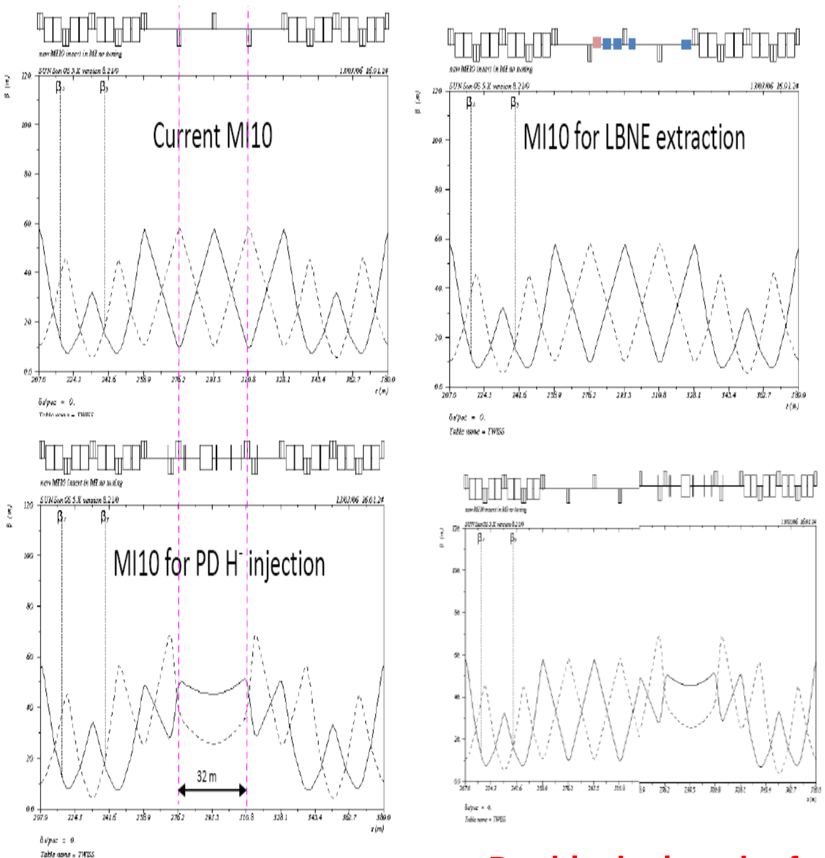
D. Johnson

- Current injection into the Recycler for accumulation followed by immediate injection into the MI
- Carbon foil Stripping
- Linac Beam Structure
  - 1 mA 4.3 ms 6 injections (~26 mA-ms)
  - Bunch spacing 6.2 ns (162.5 Mhz)
  - Broadband chopper for abort gap and elimination of bunches which fall on MI RF separatrix.
  - Bunch length ~ 20 ps (rms) needs to be verified for new lattice
  - Pulsed linac rep rate 10 Hz
  - Pulsed linac final energy 8 GeV kinetic +/- 10 MeV
- Transverse and longitudinal phase space painting



Alternative Injection Schemes

- There is a desire to be able to inject directly into the MI to eliminate the Recycler as an accumulator
  - This requires a single injection from the linac to keep the MI cycle time small for the Neutrino Program
    - Due to the small linac beam current -> long injection time (~ 26 ms) -> called long pulse option
  - Current MI injection energy 8 GeV, lowering it to 6 GeV thought to save $$ by shortening pulsed linac
  - Numerous alternate injection points into the MI have been suggested (MI60 and MI62) although none have been deemed workable (at least up to now)
  - Best injection point still MI-10 (at least up to now)



Double the length of MI-10?!

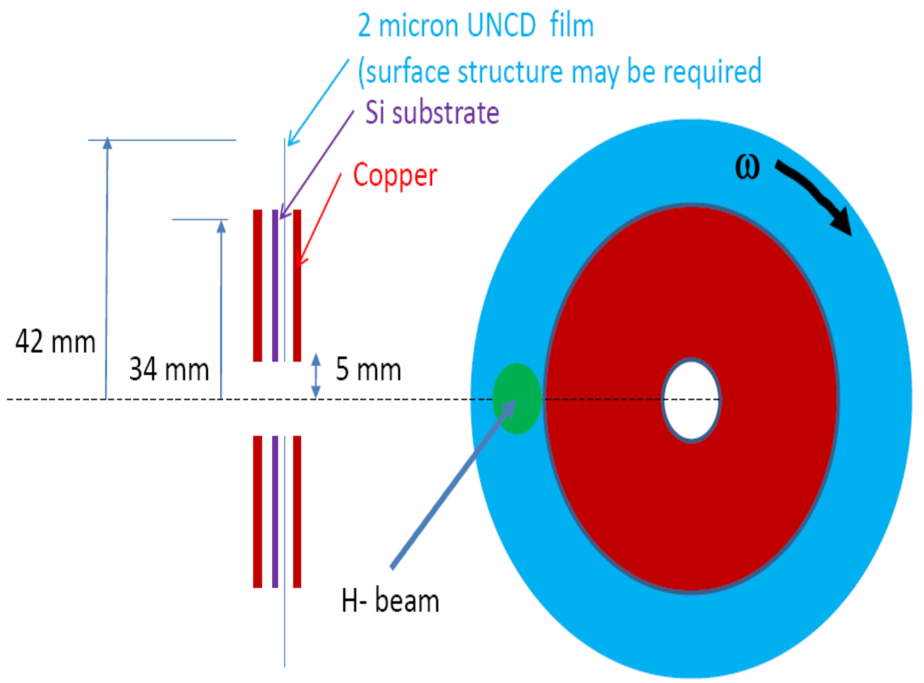
Overcoming foil temp. limitations

- Various techniques have been suggested as a means of overcoming foil temperature limitations
  - Liquid Li jet - being developed at ANL
  - Gas jet
  - Rotating foils
  - Multiple foils
  - Resonant foil bypass
  - Laser assisted stripping - Being developed at SNS

M.Popovic, C.Ankenbrandt, R.P. Johnson, "CW SRF H- Linac as a Proton Driver for Muon Colliders and Neutrino Factories", Proc. Workshop on Applications of HIPA, p.155 (2009)

- Although all the above have the potential of surviving long pulse operation, only the last technique removes the physical mass from the interaction hence "eliminates" interaction with circulating beam

Rotating foil concept



τ = 30 ms
ω = 2,000 rpm

The Si substrate and UNCD film are sandwiched between two copper disks

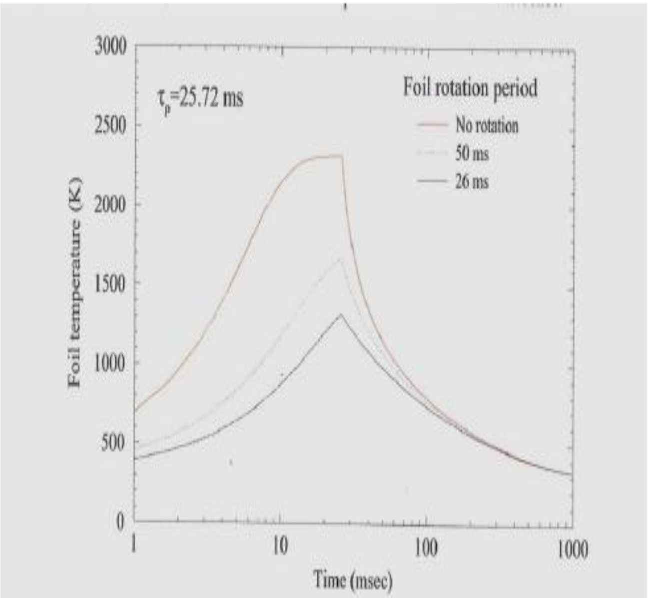


Figure 10: Calculated temperature distributions for the 600-$\mu g/cm^2$ stationary and rotating carbon foils (painting scenario *D*) irradiated with an 8-GeV proton beam at normal incidence.

Argon Center for Nanoscale Materials

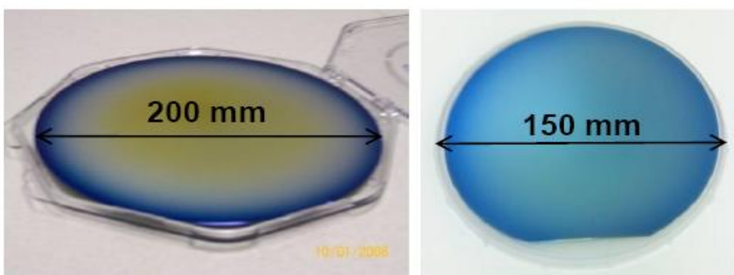
Diamond Thin Film Synthesis Capability at CNM

Scientific contact: Dr. Anirudha V. Sumant (sumant@anl.gov)

Large area 915 MHz Microwave Plasma Chemical Vapor Deposition System (MPCVD) system

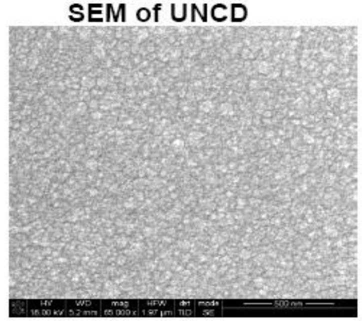
Unique Features:

- 915 MHz, 15 kW microwave plasma reactor
- Synthesis of diamond films on 200 mm and 150 mm diameter silicon wafers with excellent thickness uniformity
- Ability to synthesize nitrogen doped diamond films
- Fully automated recipe driven operation
- Coupled with Optical emission spectroscopy (OES) for *in-situ* growth species diagnostic studies
- Located inside the clean room



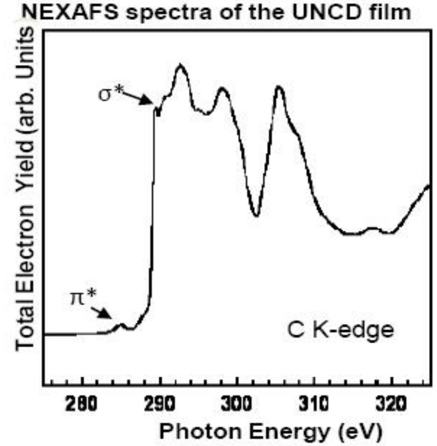
Ultrananocrystalline diamond (UNCD) film on 8” and 6” diameter silicon wafers

SEM of UNCD



Unmatched thickness and phase uniformity

NEXAFS spectra of the UNCD film

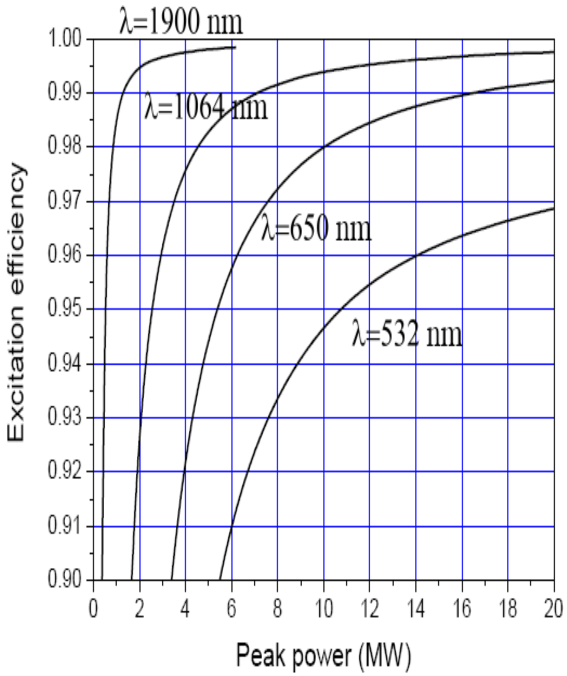


Laser Stripping

- Being pioneered and developed at SNS in
  - Proof of principal experiment validated theoretical estimates (stripped only a single 400 MHz bunch)
  - the advancement of theoretical predictions
  - the advancement of laser technology and accelerator and laser techniques to reduce required laser power
  - An intermediate experiment planned to demonstrate >90% efficiency in 1 μs long pulse
- Stripping requirements for several beam scenarios in Project X have been estimated by Timofey Gorlov (SNS)
- FNAL is keenly interested in the successful results of the SNS intermediate stripping experiment

Laser Parameters

- Peak power levels of the Laser stripping process using the standard 3 step process in the absence of a magnetic field.



Required Laser Parameters for 98% stripping Efficiency *Timofey Gorlov (SNS)

Wavelength [nm]	1900	1064	1900	1064	1900	1064
	elliptical		circular		Strong Field	
Incidence angle [deg]	49.8	94.6	49.8	94.6	49.8	94.6
Peak Power, P0 [MW]	1.1	5	1.1	5.5	2.1	10
Micropulse energy [mJ]	0.08	0.3	0.08	0.4	0.14	0.7
Power at 325 Mhz [kW]	26	100	26	130	47	230
Power at 162.5 Mhz [kW]	13	50	13	65	24	115
Micropulse duration (rms) [ps]	29	28	29	28	27	28
X-rms size [mm]	4.3	5.0	2.1	2	2	2
Y-rms size [mm]	1.9	1.9	2.1	2	2	2
X'-divergence [mr]	1.4	0.6	1.7	.8	0	0
Y'-divergence [mr]	0.9	0.6	1.7	.8	0	0

Timofey Gorlov

Snake Creek Lasers

- Pioneering work in cooling solid-state laser crystals to cryogenic temperatures.
  - Very significant power scaling
  - Reduced thermal aberration
- Awarded Phase I SBIR for "High Average Power (HAP) Cryogenic Laser for Laser Stripping Applications"
  - Generate scaled up HAP Design for 1029 nm Yb:YAG Cryogenic Laser
  - Experimentally verify Yb:YAG Cryogenic Laser Scaling
  - Generate Detailed Design for HAP Ho:YAG Laser
  - Generate Detailed Design for HAP OPO System

  ~ 2 micron
- FNAL Continues to work with Snake Creek in the development of a potential system that can be utilized for laser stripping

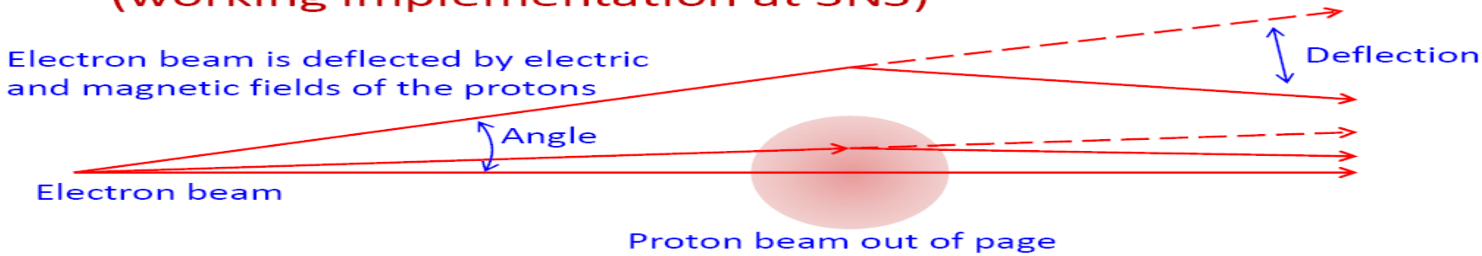
FY12 Plan for H- Injection

- Further optimize RDR configuration
  - Transverse and longitudinal painting
  - 3D magnet end field design and tracking
- Rotating Foil R&D
  - Continue tracking efforts to better estimate hit densities
  - Initiate collaboration with Center for Nanoscale Materials (at ANL) for the design of a UNCD foil and ultimate prototype
  - Start ANSYS model for thermal and stress analysis based upon UNCD properties at elevated temperatures provided by CNM
  - Begin to think about implementation (vacuum chamber and
- Laser stripping
  - Continue to work with Snake Creek lasers in their effort to develop and cryogenic laser amplifier suitable for laser stripping at FNAL (or SNS)
  - Collaborate with SNS on their intermediate laser stripping experiment
  - Continue to refine FNAL conceptual system

Electron Beam Profile Scanner

R. Thurman-Keup

- High beam power in MI/RR implies the need for non-invasive instrumentation
  - Electron beam deflection technique is one choice (working implementation at SNS)



- Deflection vs. Angle provides information about the proton beam transverse profile
- Various techniques for measuring deflection
  - Fast scan through peak of bunch
    - Requires fast deflector (< 1 ns sweep time)
    - Camera to image sweep
  - Slow scan, akin to flying wires (most likely solution in short time frame of Nova)
    - Position the beam and record the maximum deflection as the beam passes by
      - Camera readout (possibly need intensified version to see the peak deflection)
      - Strip readout
        - » Conductive strips provide deflection position
        - » If designed carefully, can extract longitudinal bunch shape as well (Need ~ 1 GHz bandwidth)
- Collaborating with Wim Blokland at SNS who is doing simulations of the various techniques

Test set-up and tunnel installation configurations