Status and Plans for H^- Injection

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Project X Fall Collaboration Meeting

October 25, 2011

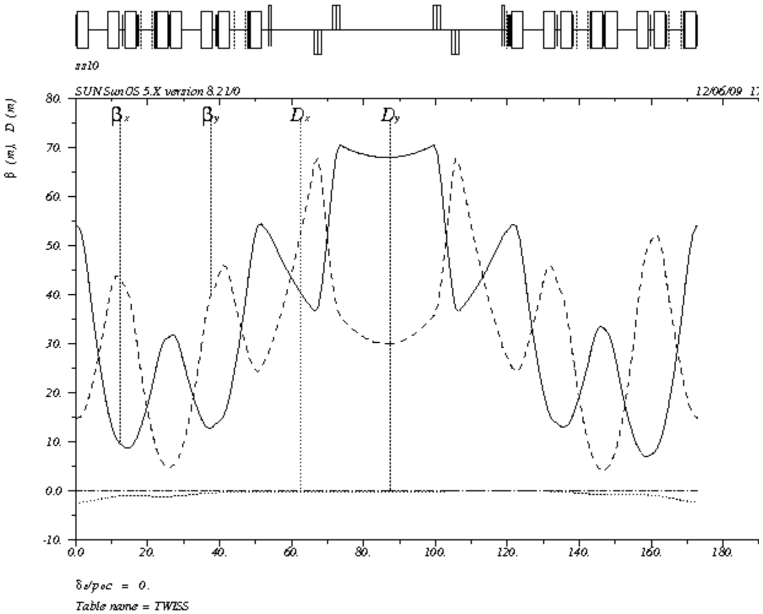
Contents

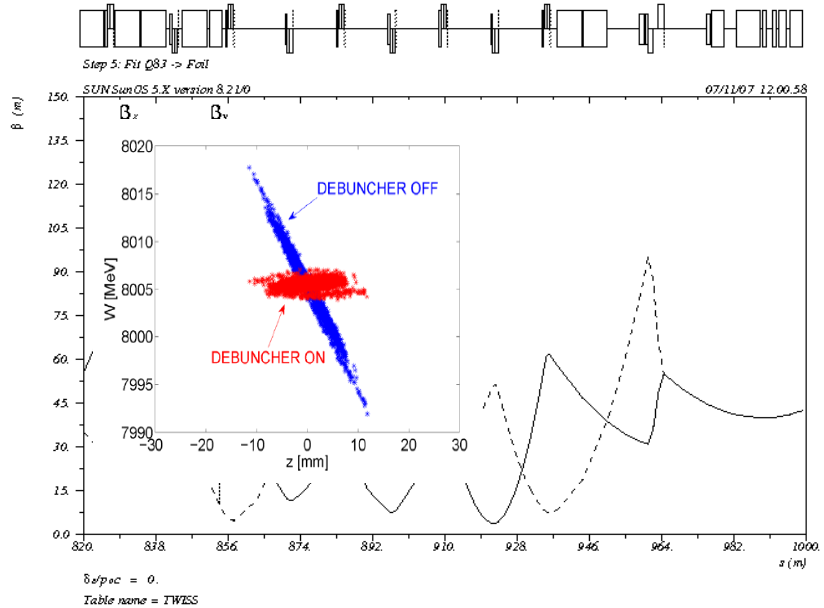
- Brief description of the current RDR injection configuration
- Alternate injection Configuration (long pulse)
  - Main Injector
- Advanced stripping techniques
- Plans for FY 12

Current RDR Injection Configuration

- 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

Recycler Injection Straight Section

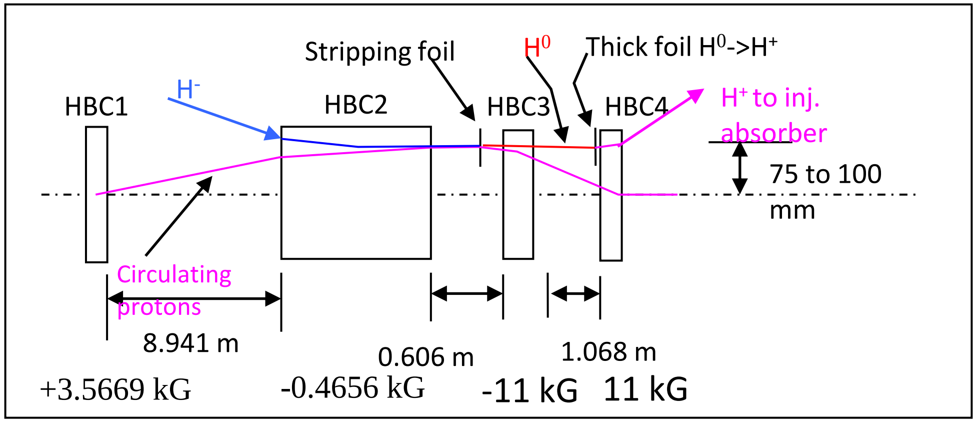


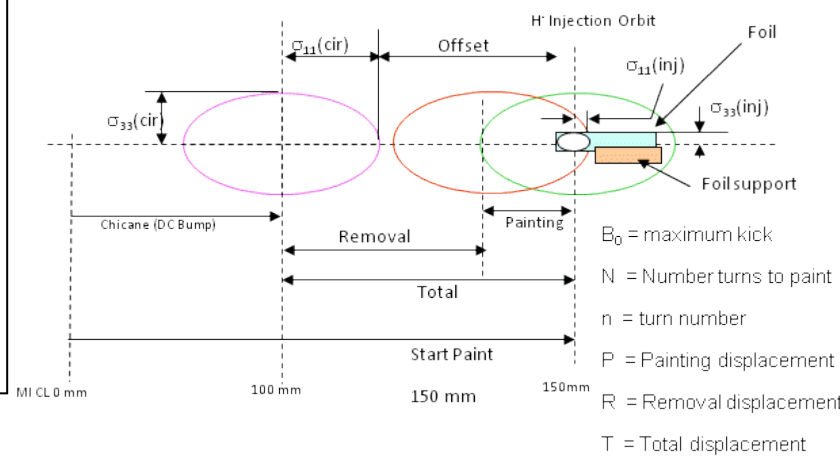


- Linac: emittance(95%) 2.5 π dpop +/- 2 MeV Bunch length 20 mm (26 ps rms)
- Injected beam β = 40 m for this exercise with 3σ = 4mm

  with β adjustable to 10m -> 3σ = 2mm
- Recycler ring lattice βx = 70 m βy = 30 m 3σx = 17.2 3σy=10.7
- Recycler rev. period 11.13 μs (h=588) beam pulse 10.34 μs (546 53 Mhz bunches/turn)
- Injection beam power 34 kW per injection (2.6E13/injection x 6 = 1.54E14)

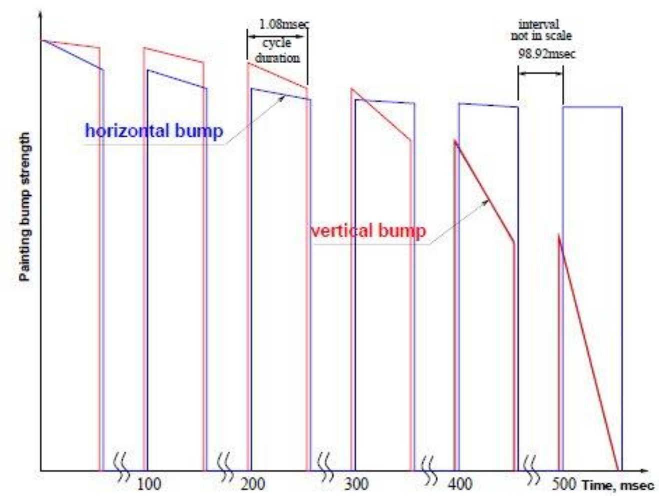
Recycler Injection



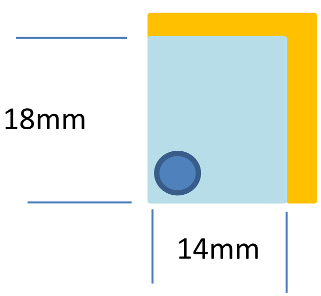


KEK (anti-correlated) H paint V steer

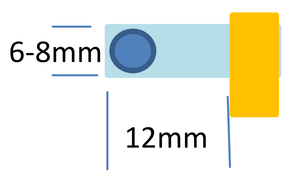
$$B = B_0\left[\frac{R}{T} - \frac{P}{T}\left(1 - \sqrt{\frac{2n}{N} - \left(\frac{n}{N}\right)^2}\right)\right] \quad y' = \left(\sigma_{44}^{cir} - \sigma_{44}^{inj}\right)\left[\sqrt{\frac{2N-n}{N} - \left(\frac{N-n}{N}\right)^2}\right]$$



Foil orientation (corner foil used in present simulation)

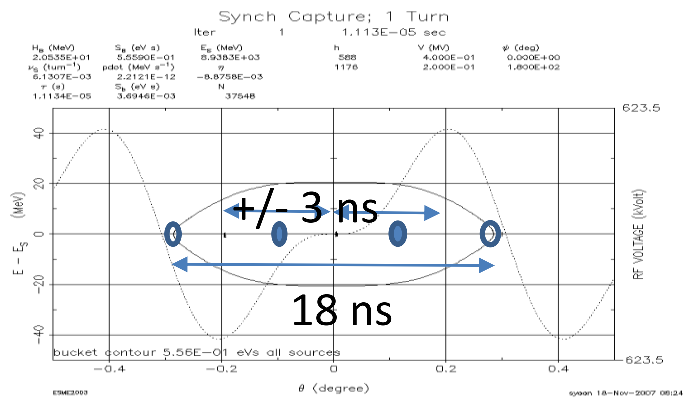


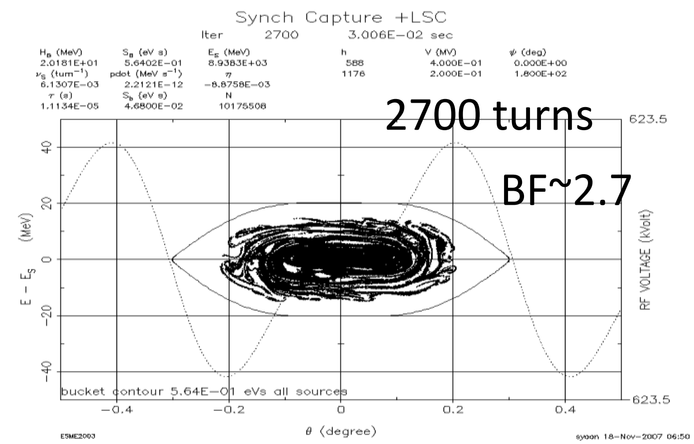
Hor. Strip foil (matched to size of beam)



Current RDR Configuration(3)

- Longitudinal phase space painting in both phase (fit into central 12 ns of ring RF bucket) and energy considered
- Ring RF frequency options (new 53 Mhz cavities from Nova)
  - Current 53 Mhz (not harmonic) parasitic phase shift during injection process
  - New cavities with harmonic (3) of 162.5 Mhz (54.166 Mhz)
- Second harmonic cavity to flatten RF





ESME Simulation (325Mhz bunches) with space charge but without broadband impedance

Longitudinal painting block has been implemented in ORBIT by Leonid Vorobiev so that simulations may be carried out in six-dimensional phase space.
Results are in general agreement with ESME 1D simulation

Issues to address

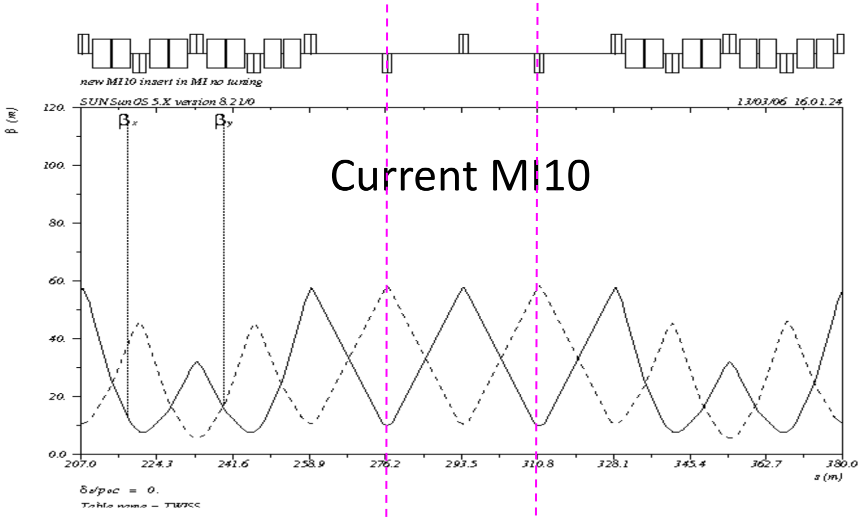
- More detailed painting simulations
  - Transverse (ORBIT / STRUCT)
    - Painting algorithms
    - Foil interactions
    - Realistic magnetic fields
    - Space charge
    - Wideband impedence
  - Longitudinal (ESME / ORBIT)
    - Space charge
    - Wideband impendence
    - New bunch structure
    - Both phase and energy painting
- Foil Issues
  - Temperature
  - Losses
- Electron collection
- Dynamic aperture studies (preliminary report show space charge not an issue during injection…. But need to verify with new bunch parameters
- Ring collimation (for injection losses) – the need to be addressed in with ORBIT and STRUCT.

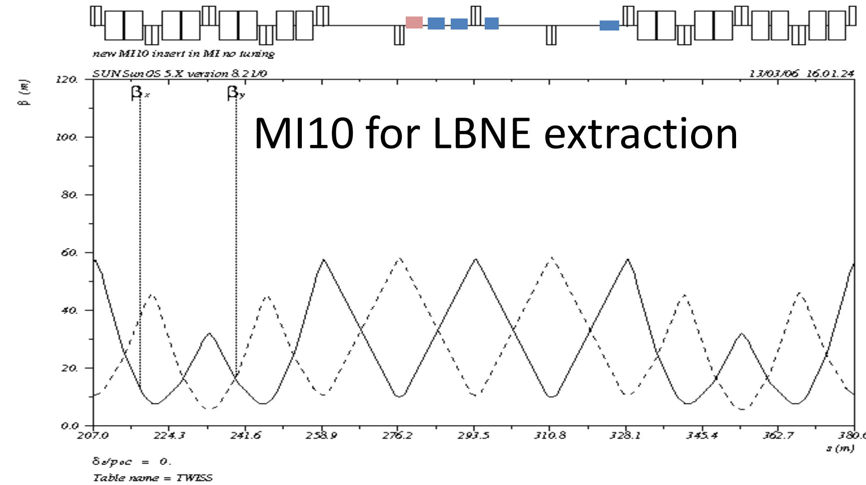
Project X

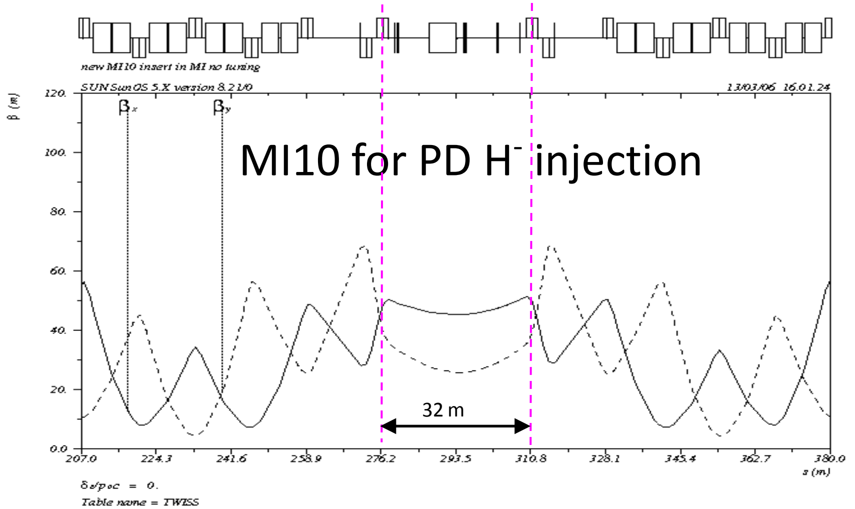
Alternate Injection Configuration

- 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)

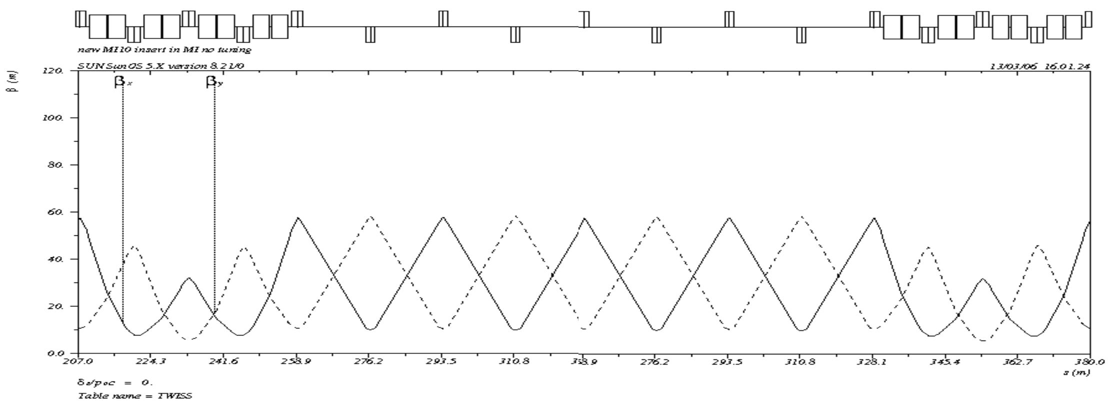
The Problem with MI -10







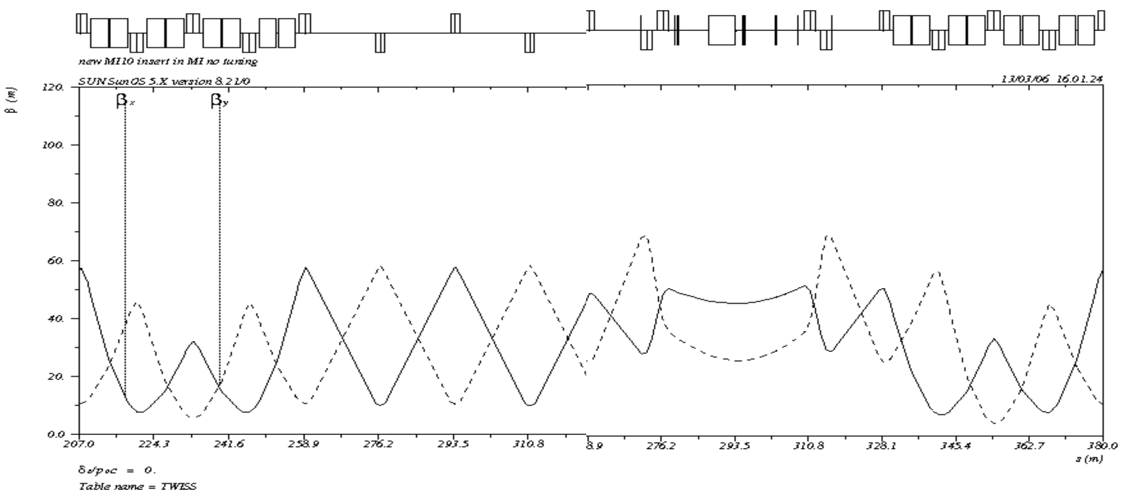
Potential Modification to MI-10



Not Easy !

May require substantial changes to MI lattice and tunnel

- Double the length of MI10 to make room for both LBNE and Project X



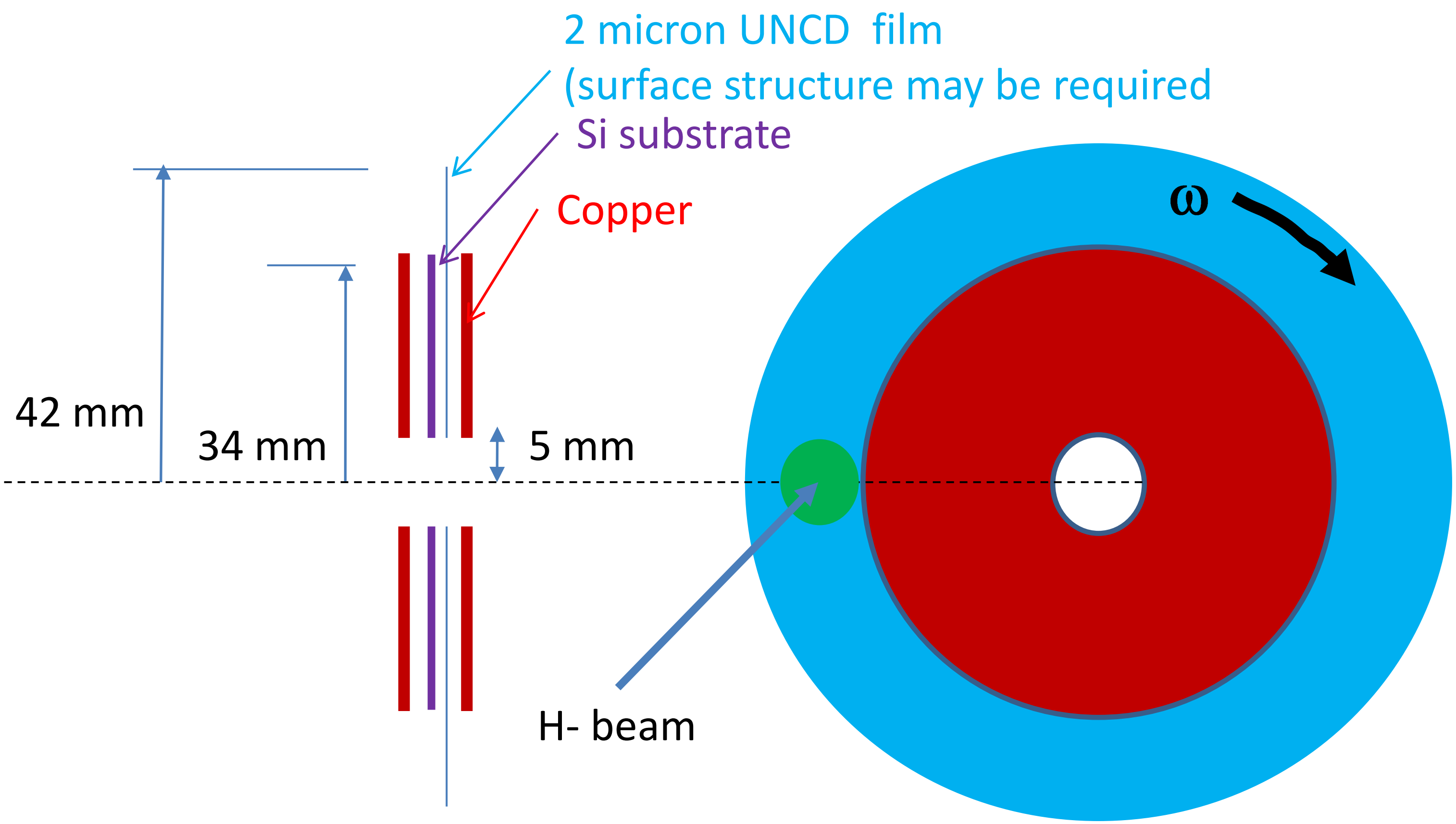
Advanced Stripping Techniques

- 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 Diamond Foil Assembly for H- Stripping



τ = 30 ms
ω = 2,000 rpm

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

Temperature Reduction of Rotating Foil

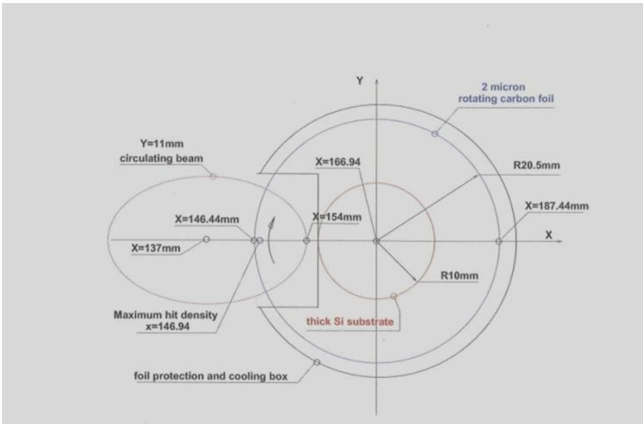
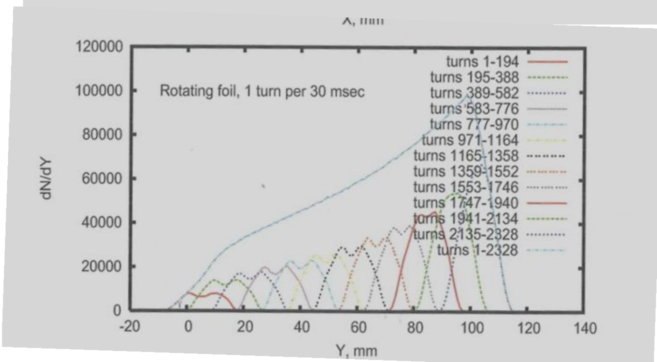


Figure 25: Rotating foil disk. Disk rotates with rate of one turn per 26-50 msec.



Preliminary model of Rotating foil and hit density using STRUCT (Sasha Drozhdin)

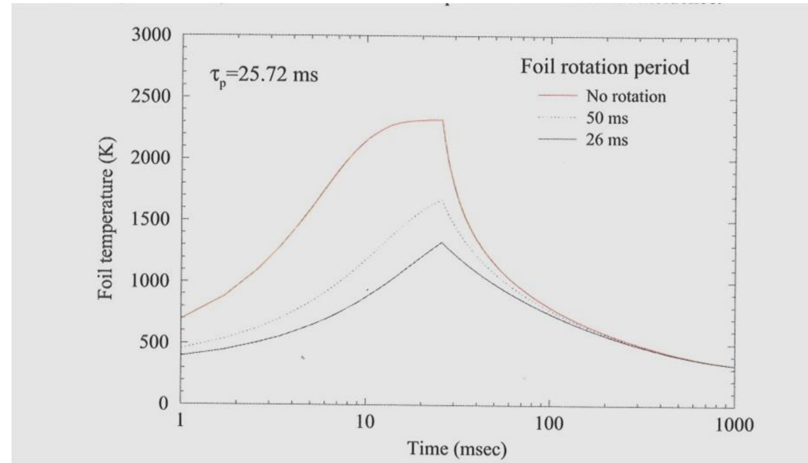


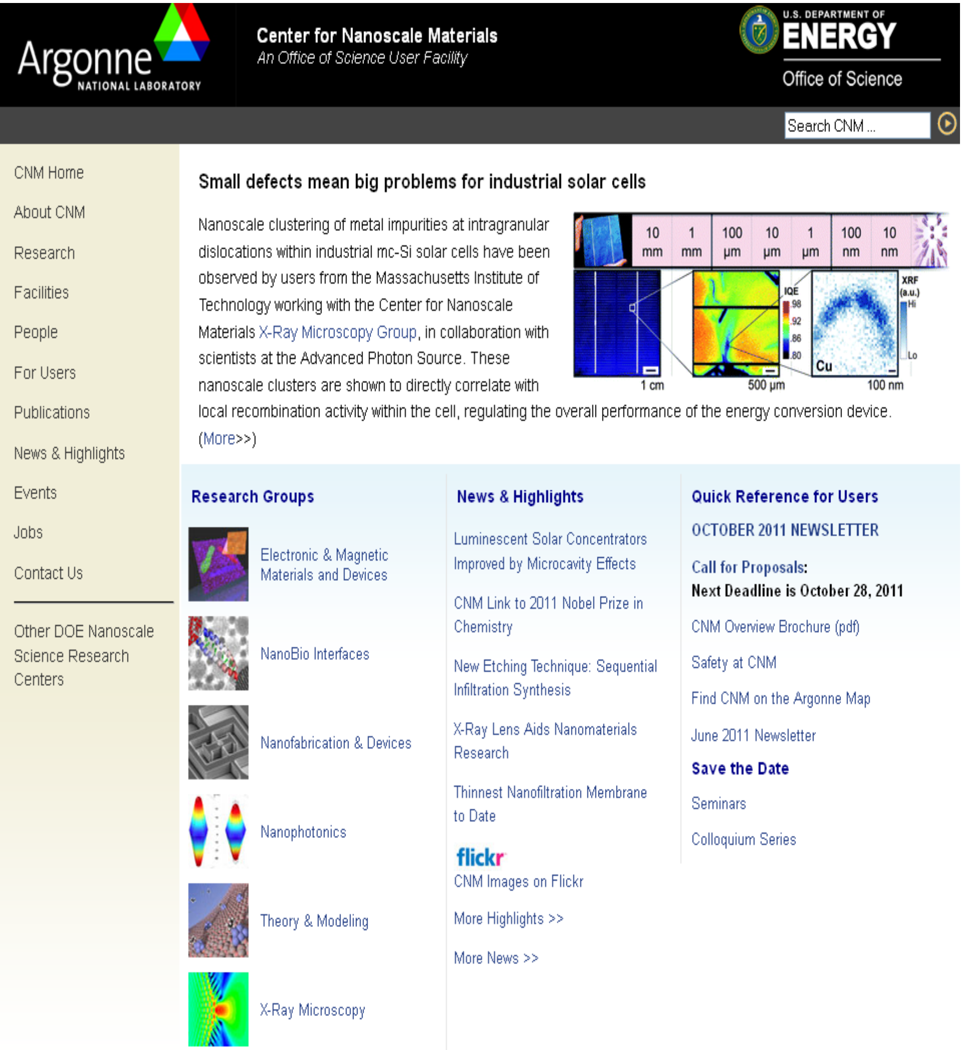
Figure 10: Calculated temperature distributions for the 600-$\mu g/cm^2$ stationary and rotating carbon foils (painting scenario *D*) irradiated with an 8-GeV proton beam at normal incidence.

Comparison of foil temperature for 26ms Injection for stationary and rotating foil based Upon hit density from STRUCT. (Igor Rakhno)

Increasing diameter of foil to ~ 3” should reduce Temp by ~ factor 2.

*Plot from Fermilab-FN-0899-APC August 2011

Center for Nanoscale Materials



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Other DOE Nanoscale Science Research Centers

Small defects mean big problems for industrial solar cells

Nanoscale clustering of metal impurities at intragranular dislocations within industrial mc-Si solar cells have been observed by users from the Massachusetts Institute of Technology working with the Center for Nanoscale Materials X-Ray Microscopy Group, in collaboration with scientists at the Advanced Photon Source. These nanoscale clusters are shown to directly correlate with local recombination activity within the cell, regulating the overall performance of the energy conversion device. (More>>)

Research Groups

- Electronic & Magnetic Materials and Devices
- NanoBio Interfaces
- Nanofabrication & Devices
- Nanophotonics
- Theory & Modeling
- X-Ray Microscopy

News & Highlights

- Luminescent Solar Concentrators Improved by Microcavity Effects
- CNM Link to 2011 Nobel Prize in Chemistry
- New Etching Technique: Sequential Infiltration Synthesis
- X-Ray Lens Aids Nanomaterials Research
- Thinnest Nanofiltration Membrane to Date

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More Highlights >>

More News >>

Quick Reference for Users

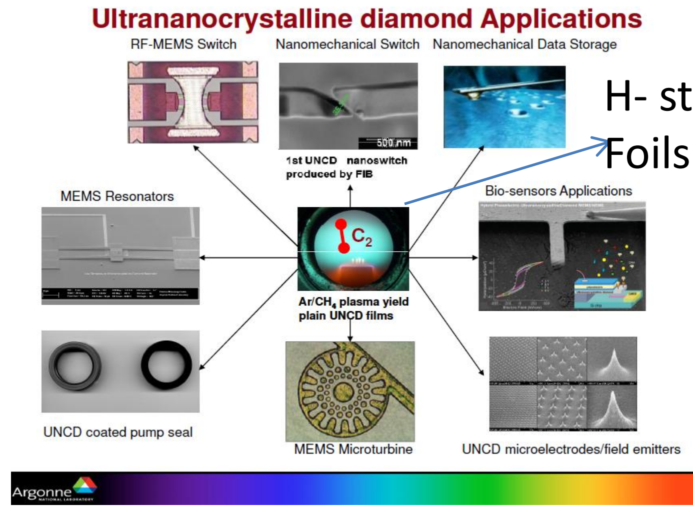
OCTOBER 2011 NEWSLETTER

Call for Proposals:
Next Deadline is October 28, 2011

- CNM Overview Brochure (pdf)
- Safety at CNM
- Find CNM on the Argonne Map
- June 2011 Newsletter

Save the Date

- Seminars
- Colloquium Series



H- stripping Foils ????

Nanocarbon Synthesis Facilities
at
Center for Nanoscale Materials
Argonne National Laboratory

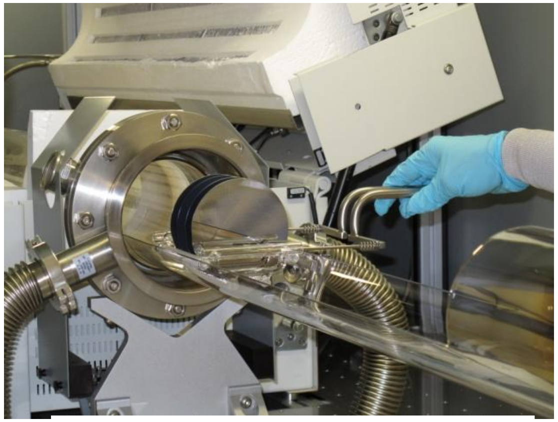
Scientific Contact: Dr. Anirudha Sumant

Access through user proposal

Large Area Graphene Synthesis at CNM

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

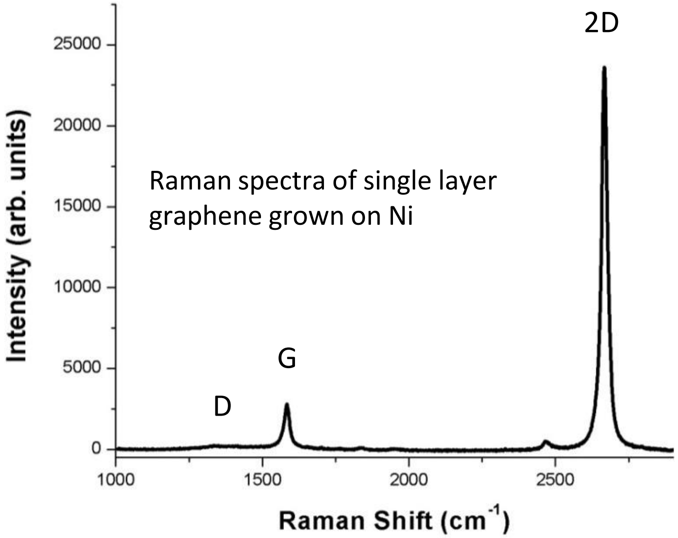
Large area graphene growth using Atomate's Thermal/PECVD tool installed in the CNM clean room



Graphene growth on multiple 4" wafers in a single run

Remote RF-Plasma assisted growth/*in-situ* functionalization

Single layer graphene grown on 4" diameter Ni/SiO_2/Si wafer



Raman spectra of single layer graphene grown on Ni

Unique features:

- Wafer scale(100 mm) synthesis of single and few layer graphene .
- Ability to functionalize graphene surface
- *in- situ* using remote RF-plasma source.
- Ability to synthesize graphene using isotopically pure carbon source.

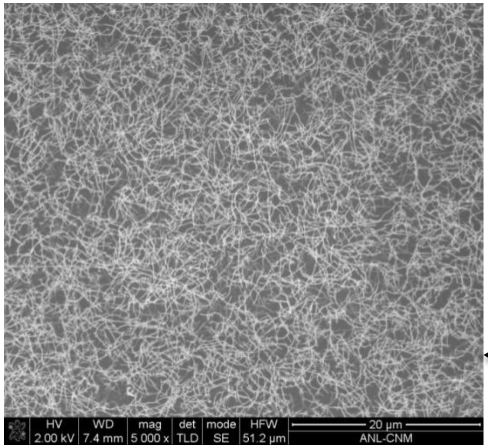
Atomate's Large Area Carbon Nanotube CVD System

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

Atomate's large area CNT synthesis tool in the CNM clean room

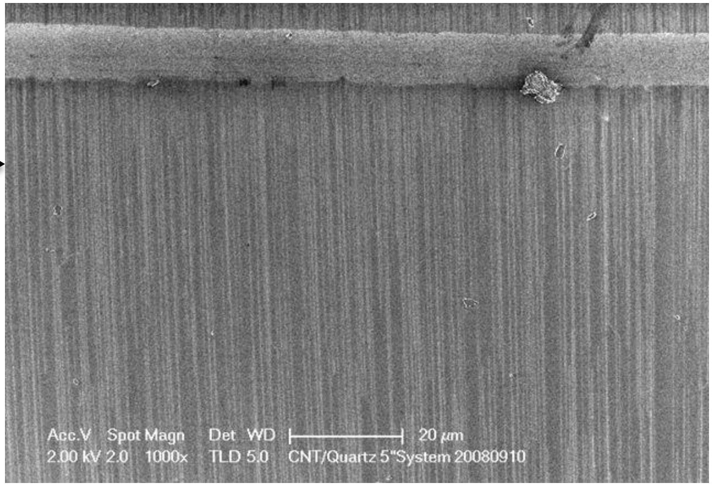
Unique Features:

- Large area synthesis of CNT on multiple 100 mm diameter wafers in a single deposition run.
- Synthesis using thermal CVD including RF-plasma CVD for *in-situ* plasma processing and functionalization of CNT.
- Gas delivery module with 8-channel MFC and expandable up to 12 channels.
- Automatic process control with adaptive control mode.
- Fully enclosed, clean room compatible system with safety interlocks and equipped with hazardous gas sensor monitors.



Random growth of CNT on SiO_2/Si substrate

Horizontally aligned growth of CNT on quartz substrate



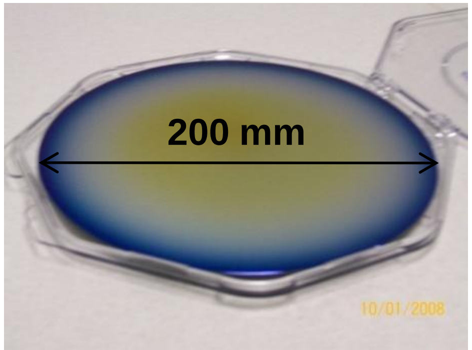
Diamond Thin Film Synthesis Capability at CNM

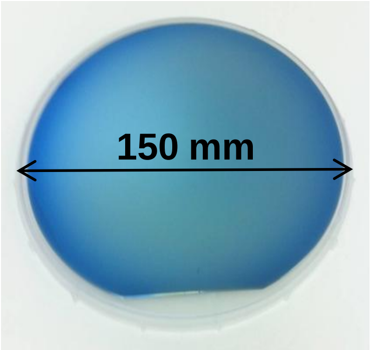
Scientific contact: Dr. Anirudha V. Sumant (sumant@anl.gov)

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

Unique Features:

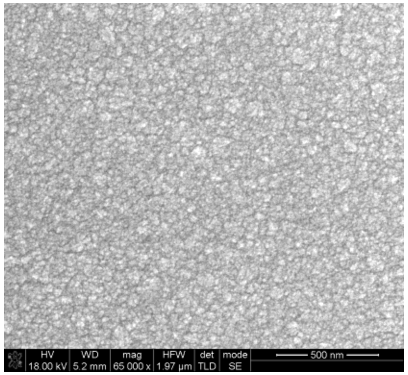
- 915 MHz, 15 kW microwave plasma reactor
- Synthesis of diamond films on 200 mm and 150 mm diameter silicon wafers with excellent thickness uniformity
- Ability to synthesize nitrogen doped diamond films
- Fully automated recipe driven operation
- Coupled with Optical emission spectroscopy (OES) for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





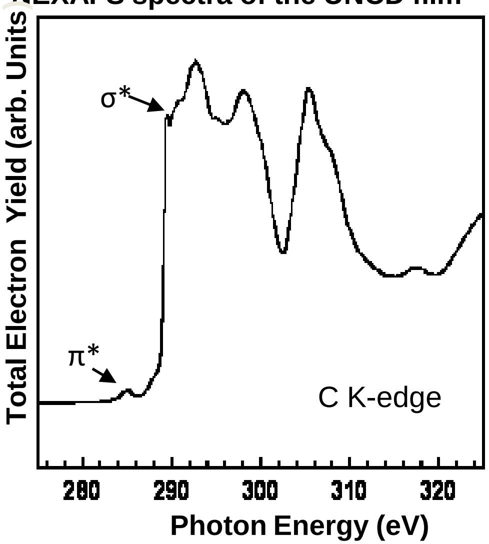
Ultrananocrystalline diamond (UNCD) film on 8” and 6” diameter silicon wafers

SEM of UNCD



Unmatched thickness and phase uniformity

NEXAFS spectra of the UNCD film

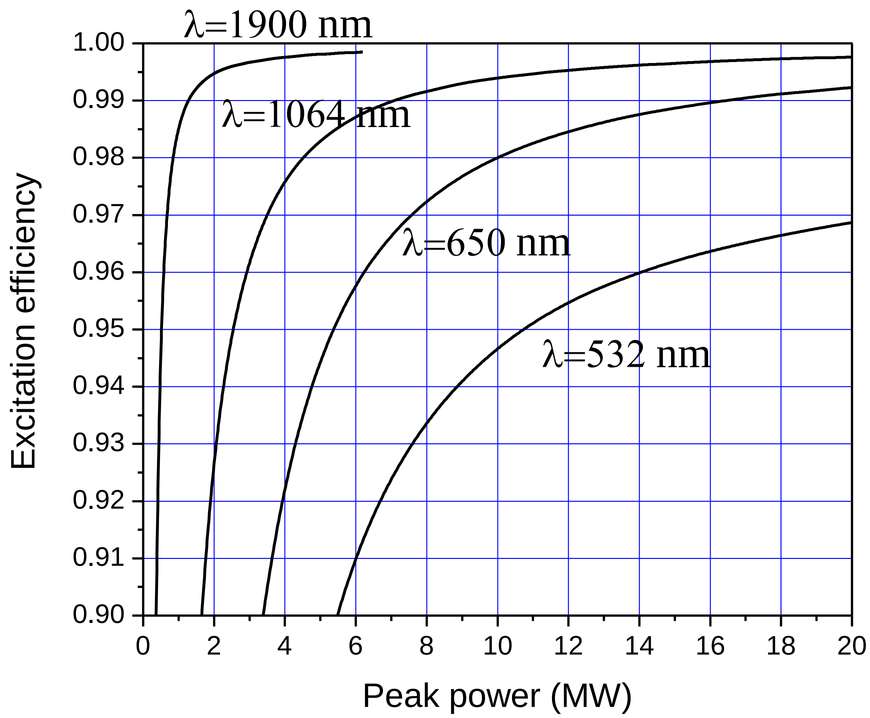


Laser Assisted Stripping

- 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

Excitation Efficiency

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



Timofey Gorlov

Laser Power Estimates for 8 GeV laser Assisted Stripping

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

Laser System Requirements

- Many technical issues
  - Wavefront distortion (mirror deformation) important for build-up cavity
  - Dielectric coating behavior in vacuum (more problematic for SNS)
  - Efficient harmonic conversion (in the case of SNS)
  - Radiation damage to optics and optical coatings
  - Acceptable spatial profile ($M^2 \sim 1$) gaussian or top hat
  - Reliability 27/7 365 days with maintaince
  - High peak powers 1 to 10 MW
  - Large pulse energies 80 μJ to 700 μJ
  - High average powers 10 to 100 kW
  - Long macro-pulse length 1 to 26 ms
  - High repetition rates 10 Hz to .7 Hz
- Many techniques such as
  - Build up cavities
  - Fiber amplification
  - Laser re-circulation
  - Cryogenic amplification
- Work being carried out
  - at private companies under SBIR program
  - National Labs (LBL and SNS and soon FNAL)

Project X

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

Injection Plans for FY12 (1)

- 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 rotation mechanism

Injection Plans for FY12 (2)

- 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

- Thank You
- Questions ?