Linac Laser Notcher Project in the Proton Improvement Plan (PIP)

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Accelerator Physics and Technology Seminar

Topics

- Booster Notching
- Current Booster Notching System
- Laser Notching (concepts and benefits)
- Location of current notching experiment
- Photoneutralization
- Requirements/Techniques for Laser Notching System
- Laser System – design and status
- Beam Shaping
- Optical Cavity
- Installation concept
- Current Plans
- Issues
- Cost/Schedule
- Summary

Booster Notching

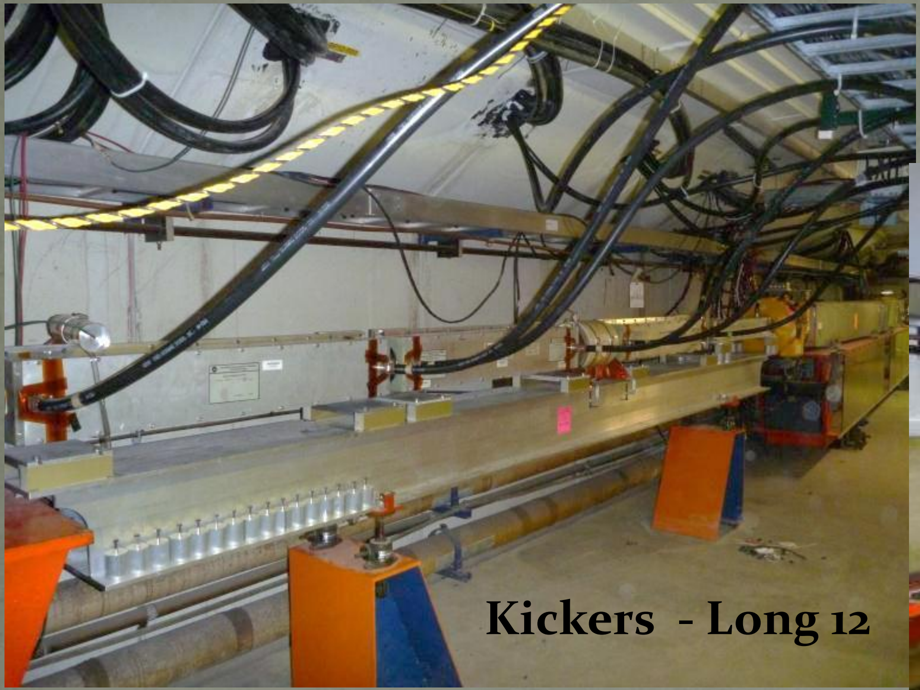
- Booster utilizes multi-turn injection of H- ions where the Linac pulse length is determined by $N^*\tau_{REV}$.
- A “notch” must be created in the continuous Booster bunch structure to allow for the rise time of the extraction kicker. We need approx 40-50 ns notch.
- Current technique is to use fast kickers in the Booster to remove a section of the Booster beam (40-50 ns out of ~2.2 μs) at an energy of 400 to 700 MeV and deposit it in a shielded absorber in the ring.
  - New system installed 2013… commissioning underway…..

→Next slide….

New Booster Notcher Tunnel Devices

- Pictures courtesy of Salah Chaurize

Installed just this last shutdown (2013)
Commissioning underway



➢ Since the Booster must increase its throughput (x2) to satisfy new demands…

➢ We would like to create notches outside the Booster tunnel at an energy low enough to <u>eliminate</u> the activation of components entirely (i.e. 750 keV, the energy of the Linac RFQ). This is the basis of this presentation…

Laser Notching of Linac H-

- Concept/History:
  - Removal of weakly bound outer electron by photodetachment using appropriate laser wavelength, temporal and spatial profile.
  - Concept proven by Ray Tomlin (circa 2001). Next slide…
  - Additional notcher proposals were described in 2005 by Xi Yang to notch the linac beam at the Booster injection RF frequency (FN-0765-AD) and at the revolution frequency utilizing a pumped recirculating cavity (FN-0767-AD). Neither of these proposals were implemented.
  - Most recently proposed by Bob Zwaska and further developed with input from a number of Fermilab colleagues , laser experts, and manufacturers.
- Benefits:
  - Laser pulses may be formed to match bunch pattern (broad band
  - Fast rise time (may be tailored to individual bunches)
  - Doesn't require high power pulsers /delay lines to create ns pulses
  - System can have a reasonably small footprint
  - Advances laser technology for accelerator applications (laser stripping, laser notching, laser chopping, photoinjector, laser diagnostics, etc…
  - ++++

First Laser Notching Experiment

- In 2001, Ray Tomlin reported on a successful experiment to create notches in the CW linac beam in the H- 750 keV beam line and have this notch survive at Booster injection.
- He created a 25 ns notch utilizing a 200 mJ 5 ns laser pulse.
- To create multiple notches in the linac pulse he proposed a
  - "4 pass bow-tie cavity some 665 meters long (with a storage time of 2.22 μs)". Large Pockels cells would shuttle the laser to and from the delay line.
- A disk gain section would restore optical losses.
- Average laser pulse energy of 103 mJ
- Peak power of ~20 MW to strip 99.9% of the ions.
- This was not implemented.

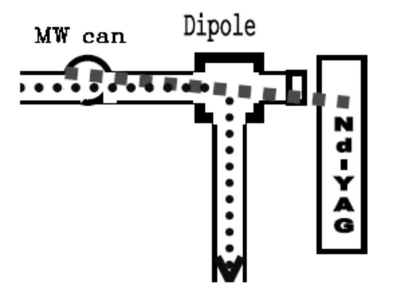


Figure 1

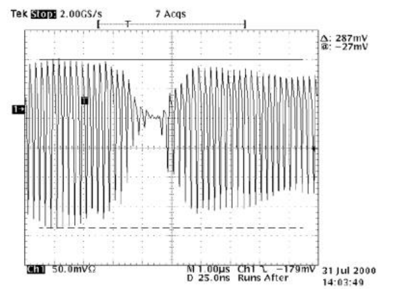
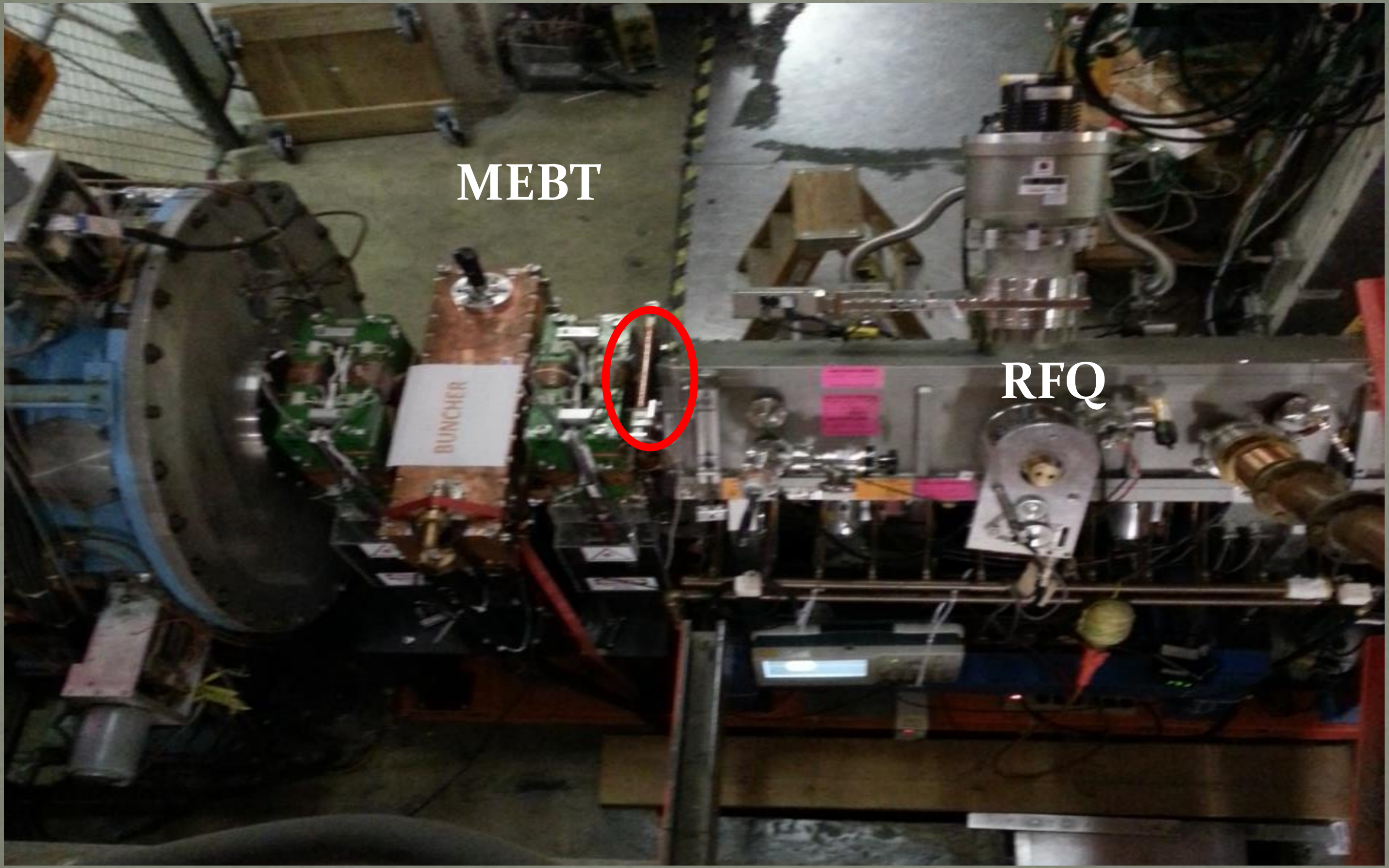


Figure 2: 200 MHz bunch signal from a BPM plate at the end of RF tank two in FNAL Linac shows a 99% notch. This is a 200 mJ, 5 ns pulse crossing at an angle.

Location of Linac Notcher in PIP Era

- Move loss due to notching OUT of the Booster tunnel
- Minimum transverse size – bunched at 201.25 MHz



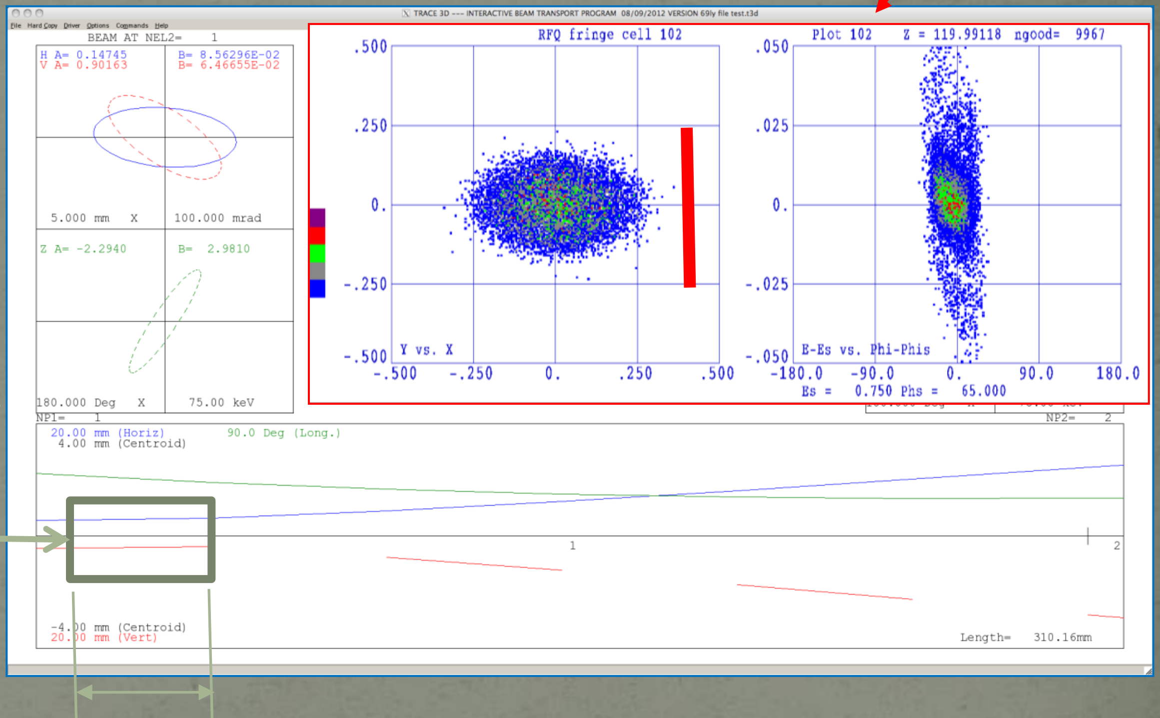
Location of Notcher

Must fit in this space

Expected Beam Dimensions

- Trace 3D back calculation of beam size at exit of RFQ based upon emittance measurement at 178 kW power <u>August 9, 2012 CY Tan</u>.

- Phase space simulation at end of RFQ (figure 4.40 of 750 KeV Upgrade Plan)



Laser beam vertical profile ($1/e^2$) ~ 5 mm.

Initial design assumed that the vertical laser beam dimension of 1 cm. Beam measurements indicate vertical laser size could be reduced to 6 mm

Photoneutralization (1)

The fraction of electrons that are detached from the moving H- ions is:

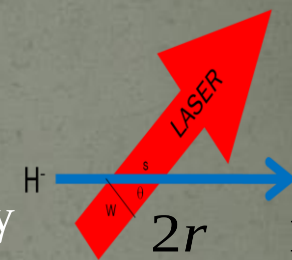
$$F_1 = {N}/{N_0} = (1 - e^{-f_{CM} * \sigma(E) * \tau_{crosssing}})$$

The photon flux (generated by the laser) in the lab frame [photons/cm²/sec]

$$f_{LAB} = \left(\frac{E_{laser}\lambda_{LAB}}{hc\tau_{laser}}\right)\left(\frac{1}{\pi r^2}\right)$$

The photon flux in the lab frame is transformed into the rest frame of moving ion as:

$$f_{cm} = \gamma f_{LAB}(1 - \beta\cos\theta)$$



The interaction (crossing) time is just the ion path length/ ion velocity

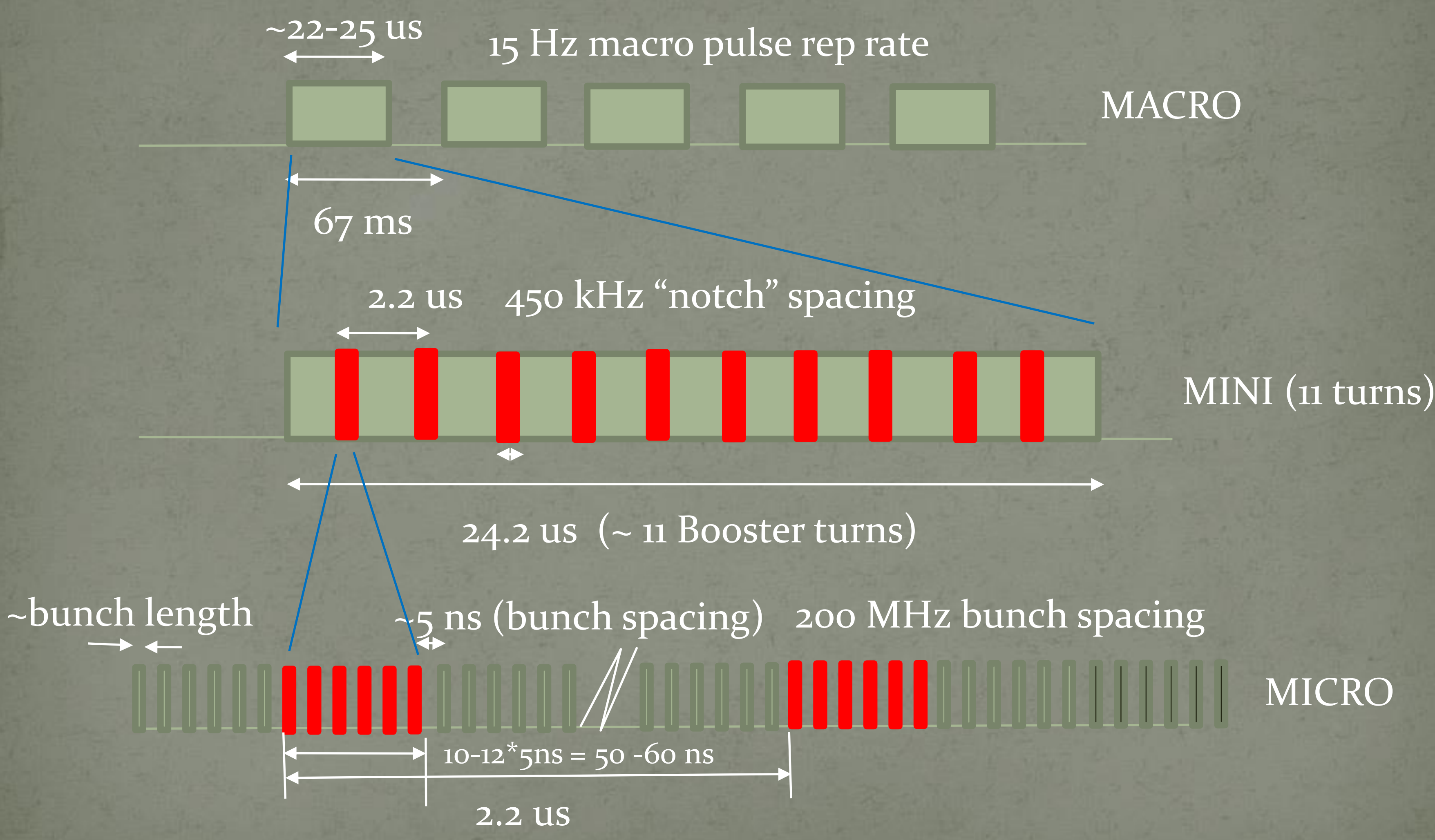
$$\tau_{crossing} = \frac{2r}{\sin\theta}\frac{1}{v_{H-}}$$

The neutralization factor for an ion crossing on axis of the laser beam may be written in terms of lab frame parameters

$$F_{neut} = (1 - e^{\frac{-E_{laser}\lambda_{LAB}\sigma(E)(2r)}{h\beta c^2\tau_{laser}\pi r^2}\underbrace{\frac{\gamma(1-\beta\cos\theta)}{\sin\theta}}})$$

For θ ~ 90° term -> ~γ

Linac Beam Bunch Structure



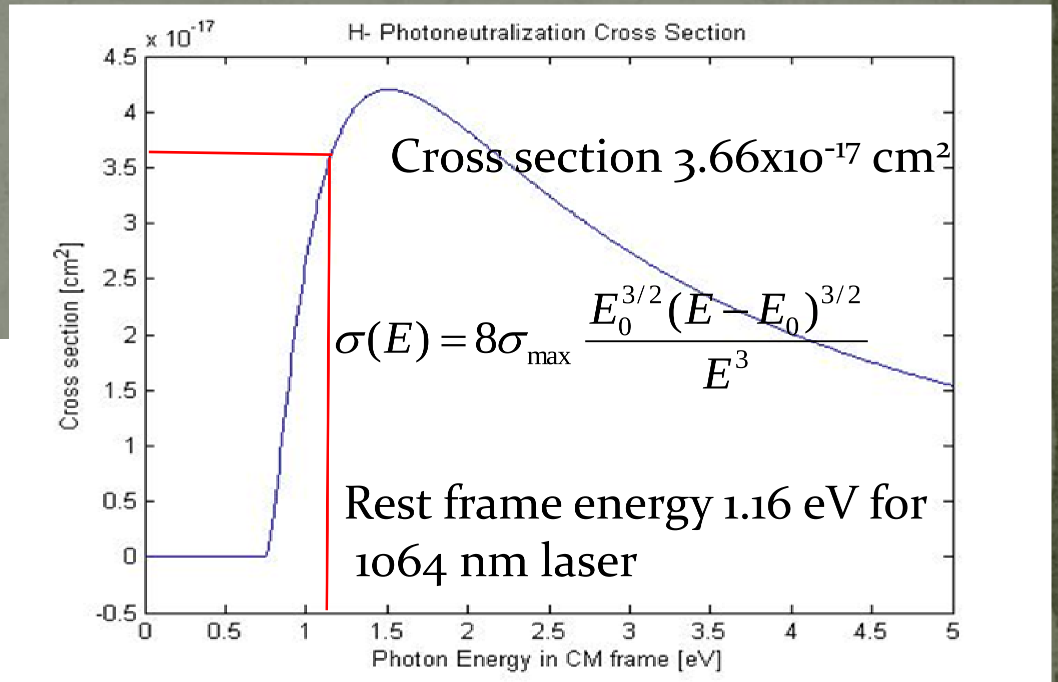
Photoneutralization (2)

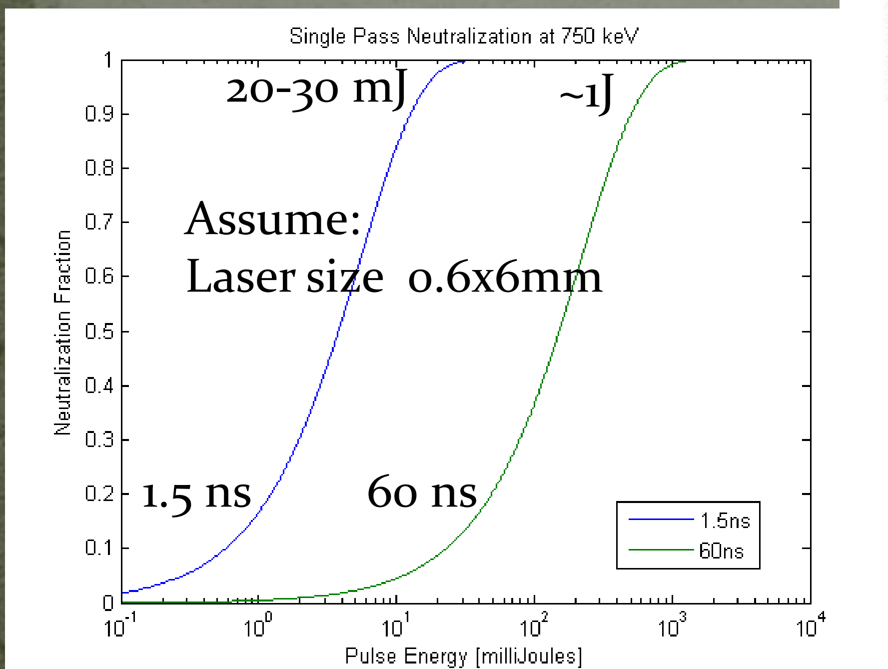
fixed

To maximize the neutralization probability->maximize the product $f_{CM}\sigma(E)\tau_{interaction}$

To maximize f_{CM}

- increase pulse energy -> minimize
- reduce pulse length -> bunch length
- reduce laser spot size -> ion size





To maximize τ for a given H- ion energy

- increase horizontal laser beam size or
- increase the number of laser interactions with the ion bunch

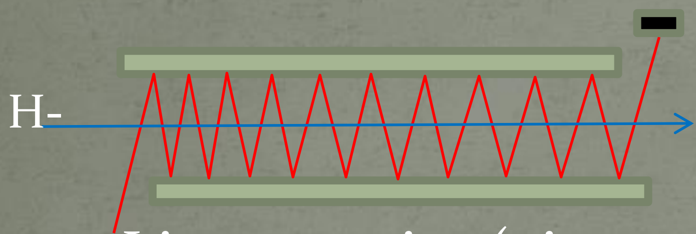
Reduction of Pulse Energy

- To reduce the required pulse energy we can effectively increase the interaction time by utilizing an optical cavity such that the laser interacts with the ion beam multiple times.

$$F_N = 1-(1-F_1)^N$$

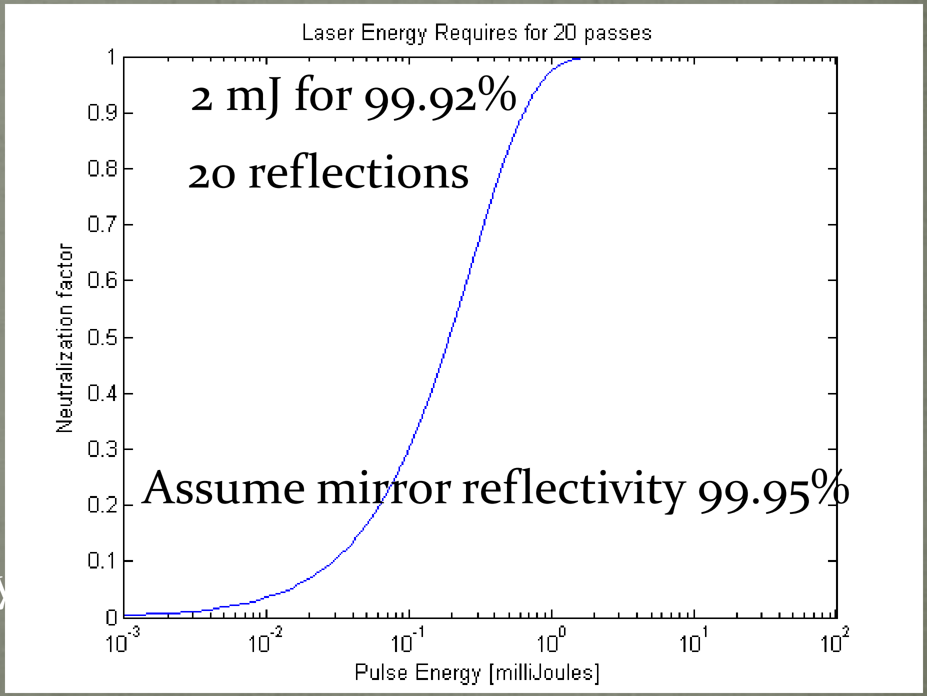
R. Shafer , 1998 BIW

$$F_1 = (1-e^{-flux*\sigma*\tau})$$



Linear cavity (zig-zag)

- Laser follows ion to interact many times (increase τ)
- Cavity length proportional to number of interactions
- Laser pulse length = notch length
- Cavity dimensions determined by ion velocity and bunch spacing
- Reduces required laser pulse energy by ~ number of interactions

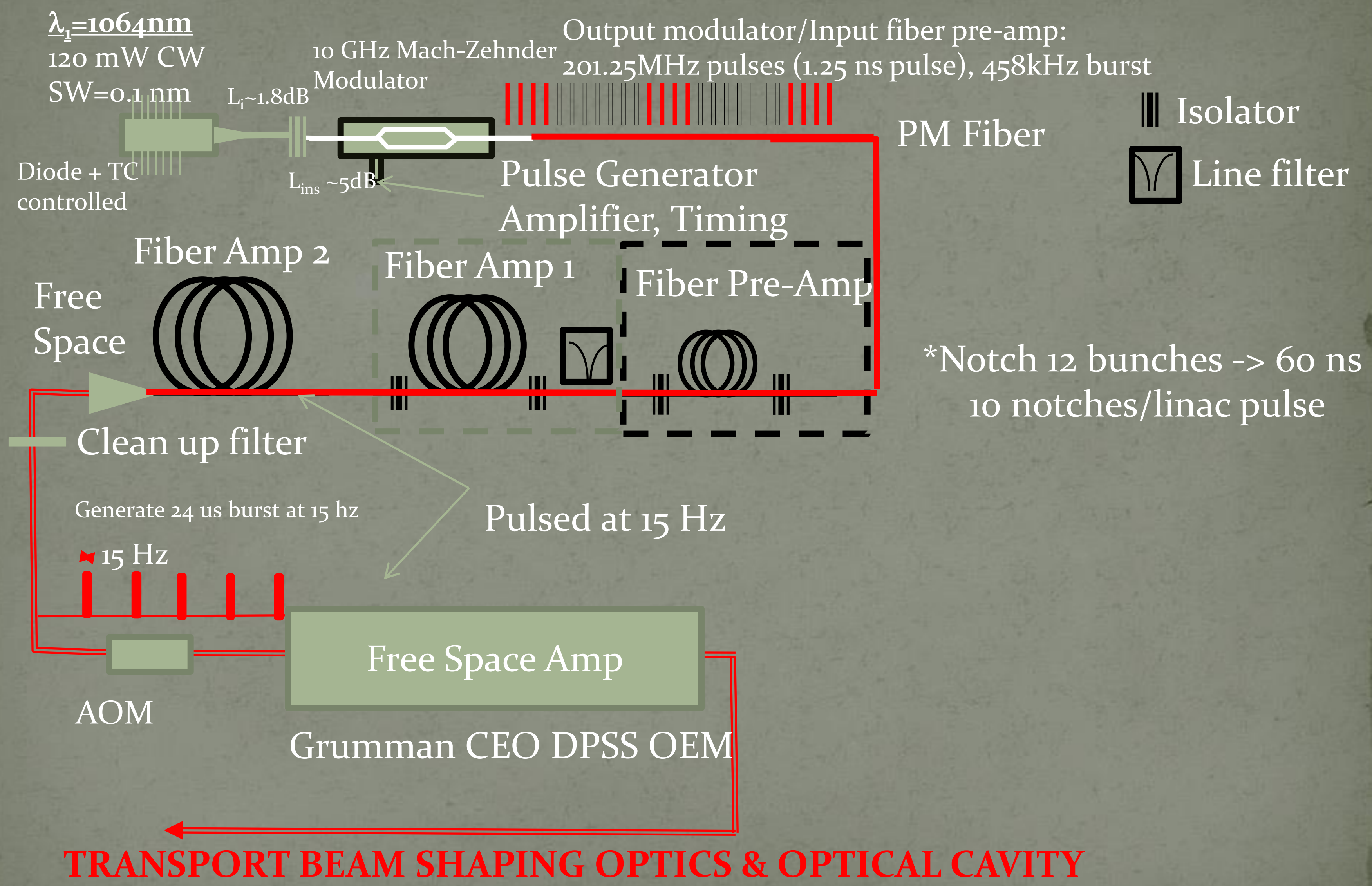


Requirements and Technique of Laser Notching of H-

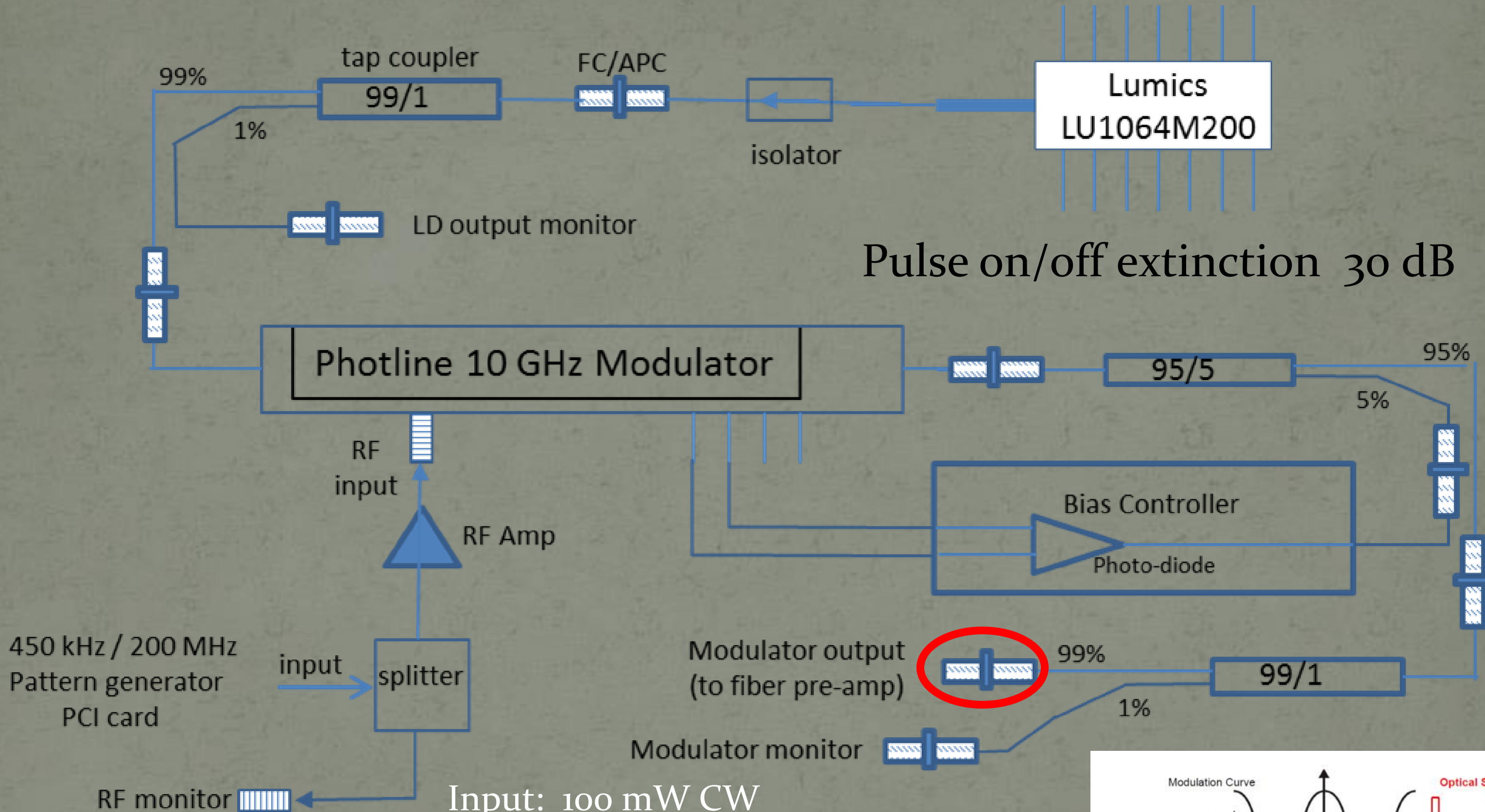
- **Requirements**
  - All ions in bunch should see the same photon density
  - The 201.25 MHz laser pulses must be phased with the RFQ
  - The laser pulse length > bunch length
  - Uniform temporal profile
  - The burst of 201.25 MHz pulses must match the Booster inj rev. freq.
  - The 450 kHz burst must have appropriate timing within the linac pulse
  - The pulse energy should neutralize > 99% of ions in each bunch

- **Technique**
  - Utilize a CW seed laser and wave-guide modulator to create required laser pulse pattern (both 200 MHz and 450 kHz) at low pulse energies (pJ)
  - Amplify pulse pattern using a three-stage fiber amplifier (nJ to uJ)
  - Further amplify using a free-space solid state amplifier (mJ)
  - Create a spatially uniform photon beam
  - Insert laser pulse into a linear zig-zag interaction cavity where the laser reflections inside the cavity match the ion velocity
    - to reduce required pulse energy by the number N of reflections in the cavity.

Burst mode seed pulses to Fiber Amplifier followed by Free Space Amp



Optical Pattern Generator



Pulse on/off extinction 30 dB

Input: 100 mW CW
Output: 54 pJ (1.5 ns/200 MHz)
294 uW avg power at 450 kHz

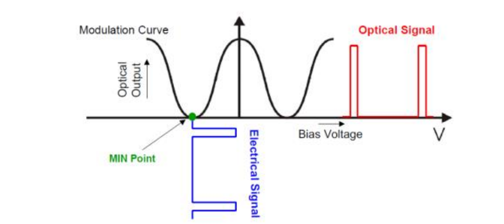
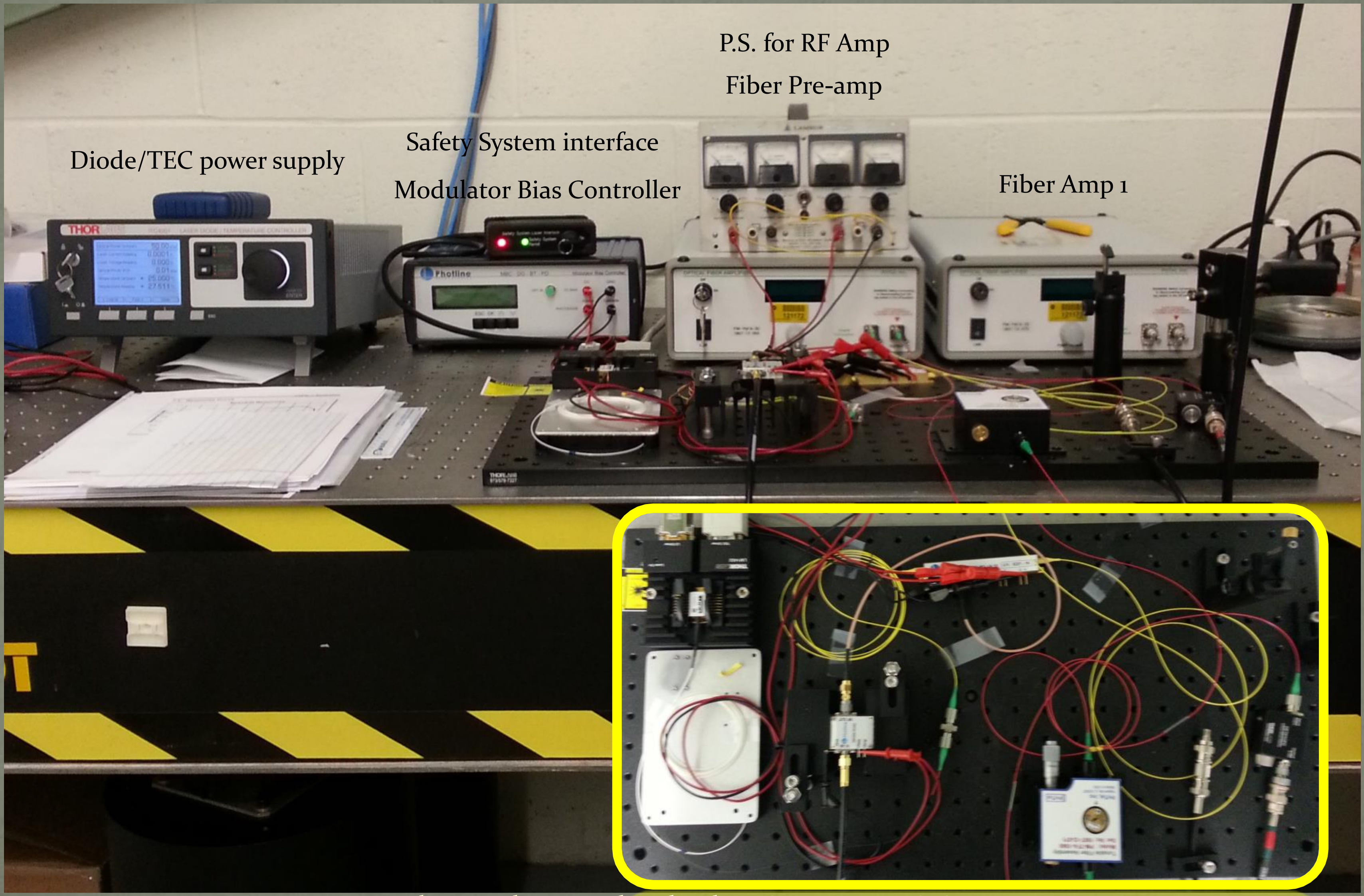


Figure 1 : Transfer function of a Mach-Zehnder modulator and output signal vs input signal at MIN operating point

OPG Fiber Amp Components on Bench

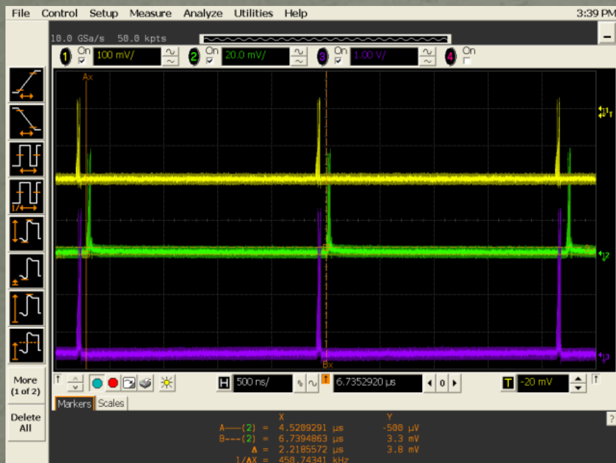


New OPG module

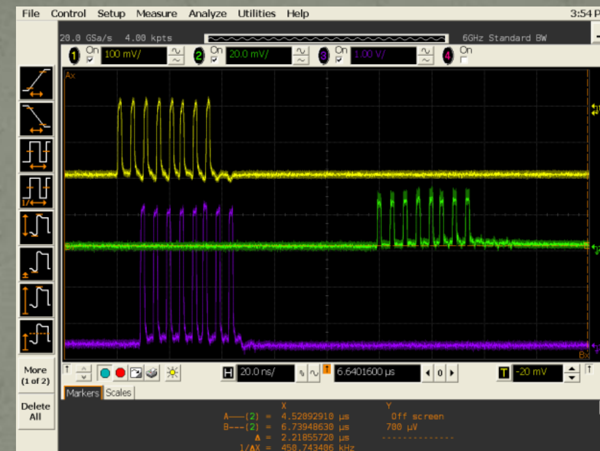
Andrea Saewert

Optical Pattern Generation

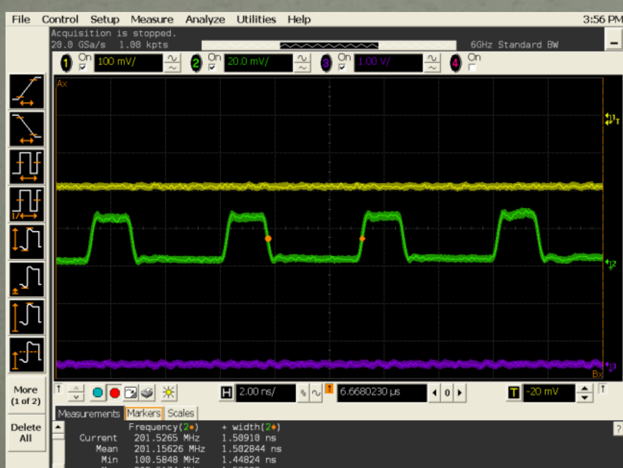
Yellow- AWG   Purple- RF Amp out   AWG: Chase Scientific DA12000 & CG6000 module
Green – signal form 1.2 GHz (free-space)PD →laser pulses out of fiber pre-amplifier



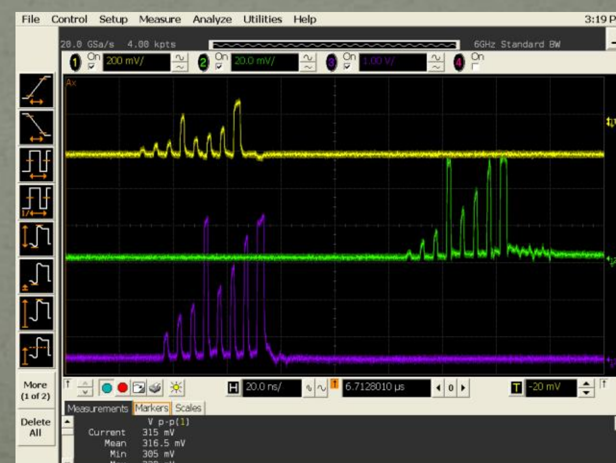
450.75 kHz burst of 201 MHz pulses



One set of 201.25 MHz pulses

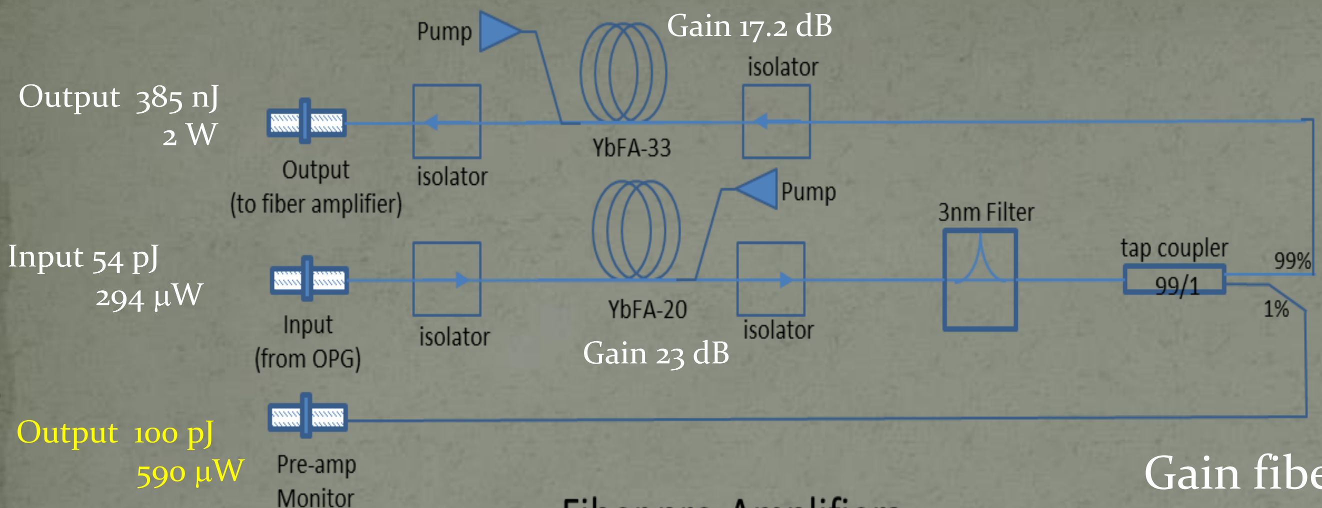


Individual 201.25 MHz temporally uniform pulses



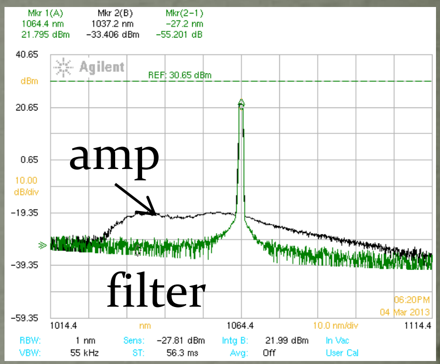
Pre-distortion of EOM pulses

Fiber Pre- Amplifier System

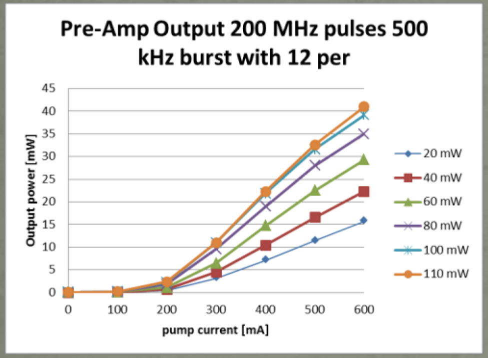


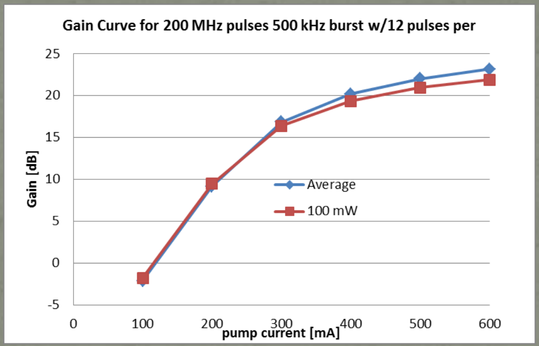
Fiber pre-Amplifiers

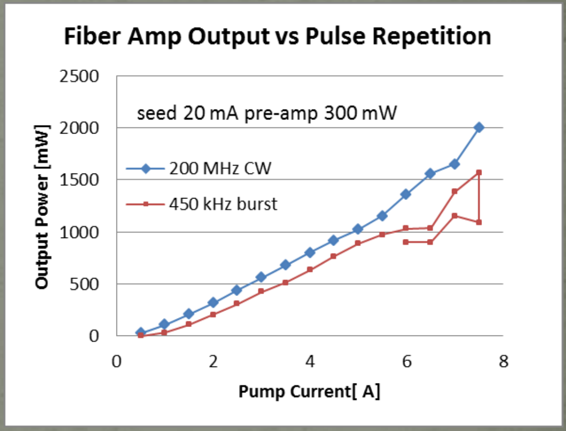
PriTel



Gain fiber is Yb doped
6mm core/125 um cladding







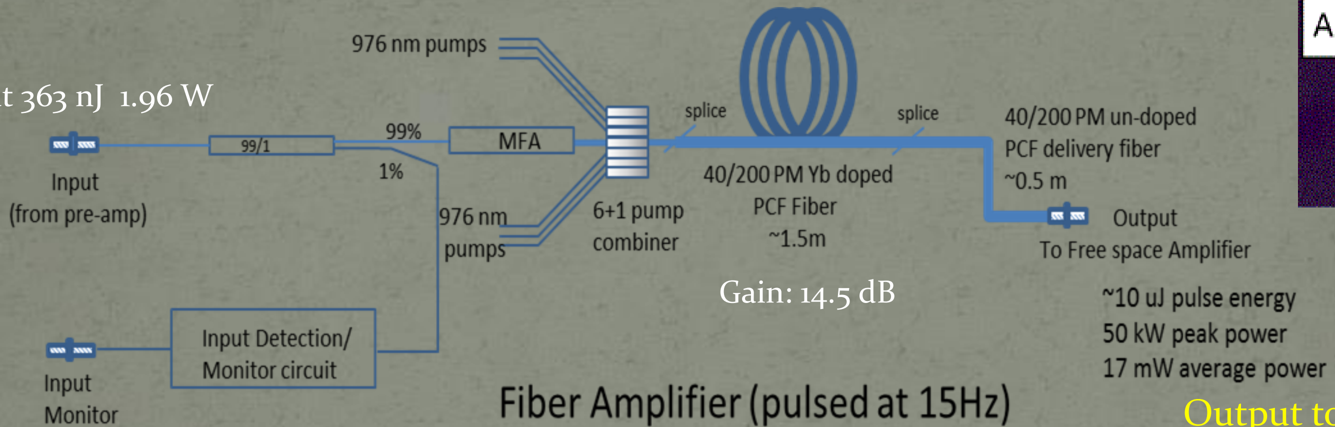
System to be re-package in 19” rack mount with
Computer control/readback and “auto shutdown” for YbFA-33 amplifier.

Fiber Amplifier System

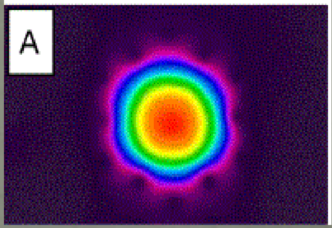
Optical Engines

System on order- due for delivery later this month.

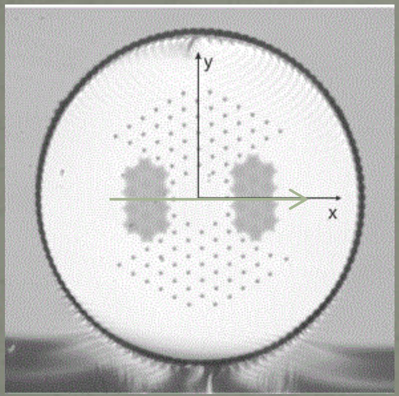
Input 363 nJ 1.96 W



Gain: 14.5 dB



Output to include mode stripper (to remove any pump light) and optics to match into first FS amp.



Micrograph of PCF fiber

Single mode, single polarization
Small NA (~0.03)
Large mode area
High peak power levels
High pump absorption (~10 dB/m)
High reliability

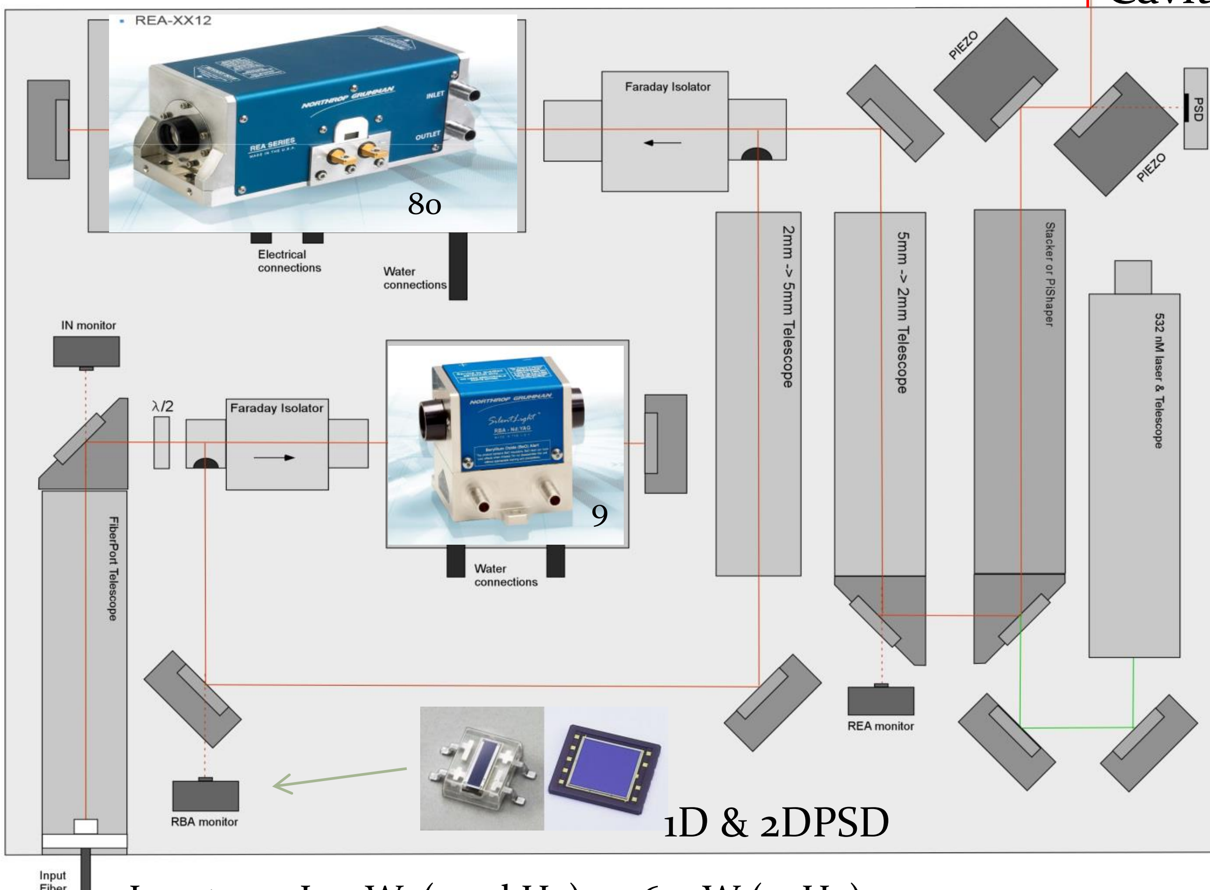
Free Space Amplifier System

Current design -> could change depending of fiber amp performance

Pulsed at 15 Hz

Gain: ~ 23 dB (total for both modules)
Output: 2 mJ 10 kW (450 kHZ) 3.2 mW (15 Hz)

To Optical Cavity



Input: 10 uJ 55W (450 kHz) 16 mW (15 Hz)

Faraday Isolator to protect previous stage and aid in double pass operation.

- Class 4 laser system
- Difficult to operate with lid off
- Need to heavily instrument

Beam Shaping

(modification of the transverse beam profile in the optical cavity)

- We would like to demonstrate > 99% neutralization efficiency for all ions in the bunch, therefore we would like all ions to “see” the same photon flux regardless of their transverse amplitude. (i.e roof-top laser profile)

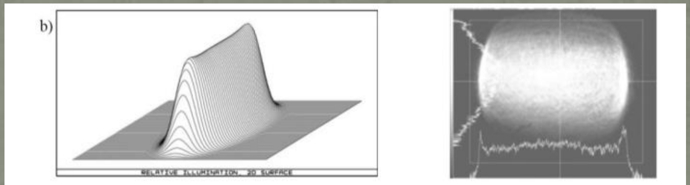


Figure 7 To creating a Roof-like intensity profile with *πShaper 6_6*, left – theory, right – experiment:
a) Input - elliptic TEM_{00} beam, $D_H = 6$ mm ($1/e^2$), $D_V = 3$ mm ($1/e^2$),
b) Output – Roof-like profile, flattop in horizontal direction and Gaussian in vertical one

  - The vertical size of the laser beam should be ~ > 6σ of the ion bunch or about 6 mm (the horizontal size should be < 1 mm
- We have investigated two techniques to create this roof-top profile through the interaction cavity.
  - πShaper – refractive beam shaping optics
  - Beam stacker – splitting a Gaussian beam into H and V polarized beams with a birefringent crystal, a technique proposed by Todd Johnson

πShaper (AdlOptica GmbH)

- Refractive optical system
- Output beam is free of aberration
- Collimated output beam
- Resulting beam profile is stable over large distance
- Galilean design

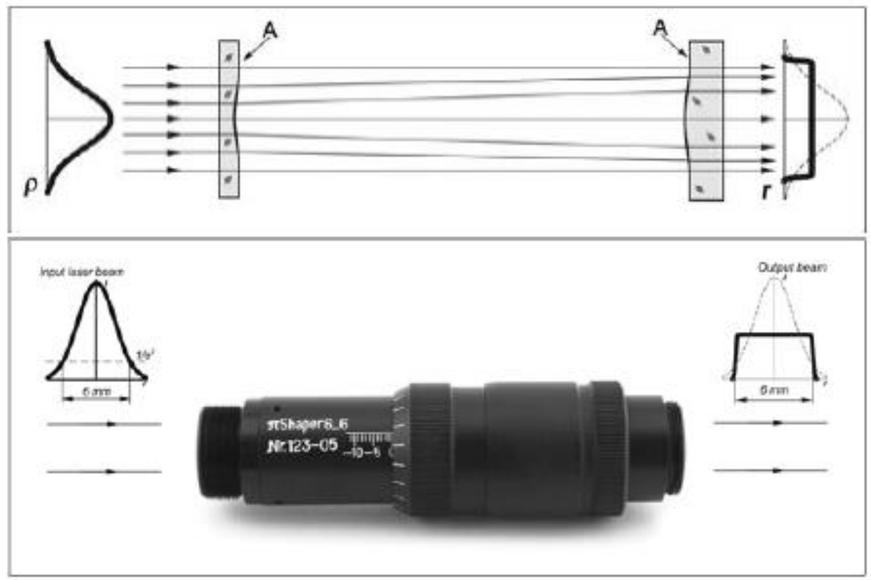
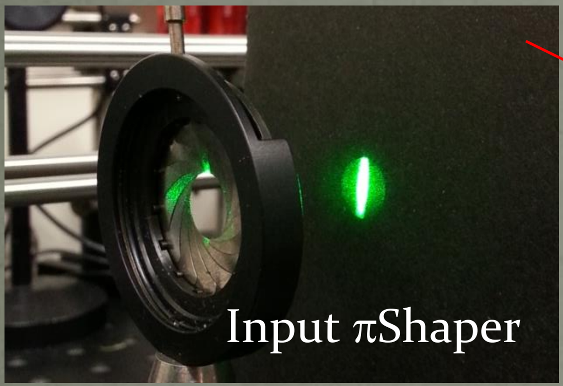
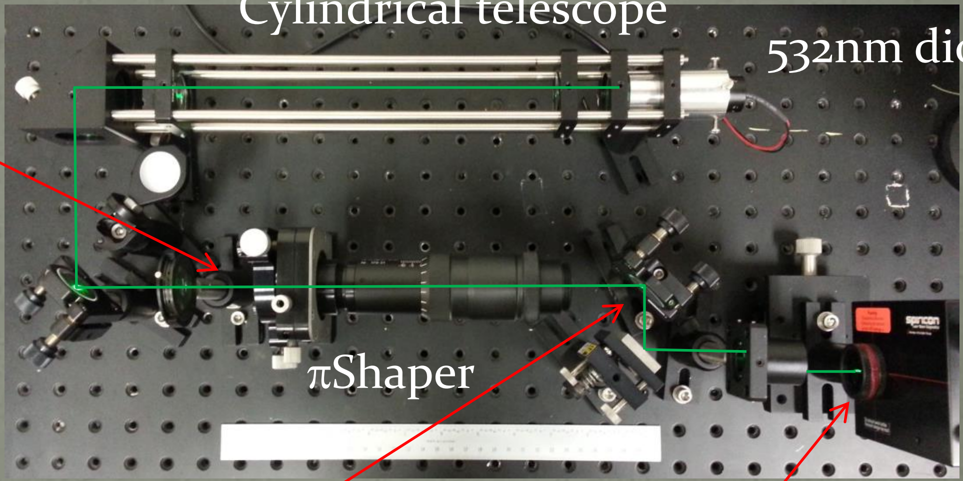
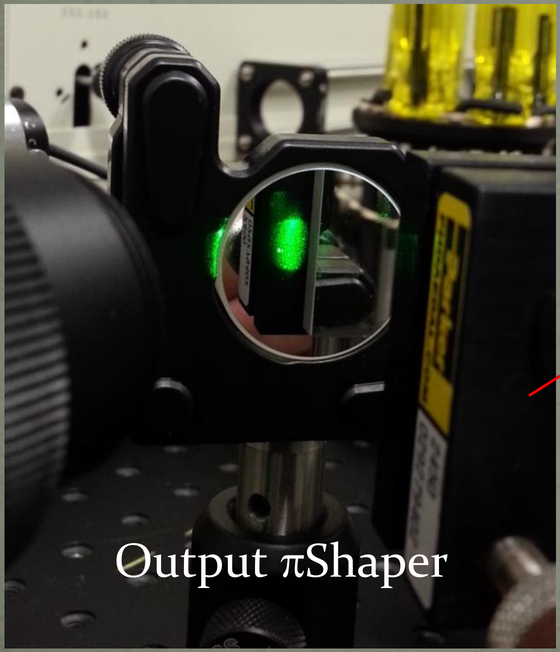


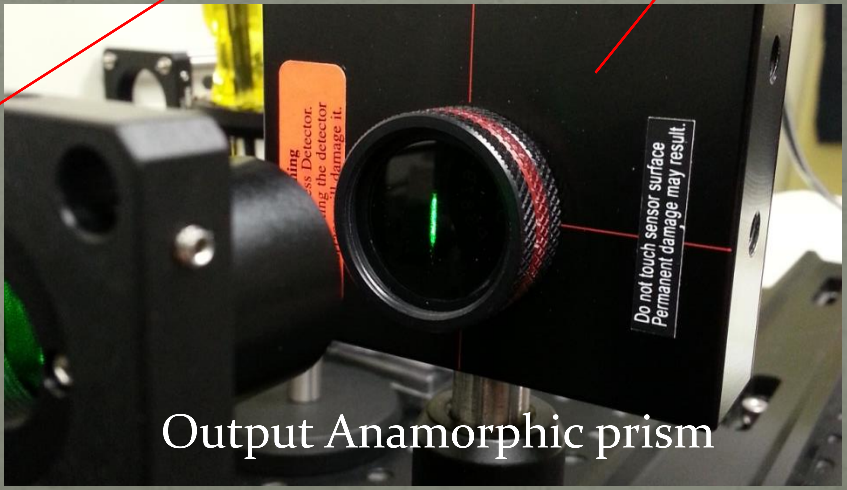
Figure 1 Refractive field mapping beam shaper *πShaper*

Beam Shaping w/ πShaper… the layout









πShaper Propagation

- Intensity distribution varies with distance due to diffraction effects.
- For visible light and flattop beam diameter of 6 mm the distance where the deviation in uniformity doesn't exceed +/-10% is about 200-300mm.
- This distance is inversely proportional to wavelength -> for 1064 nm we should expect only 120 to 180 mm.

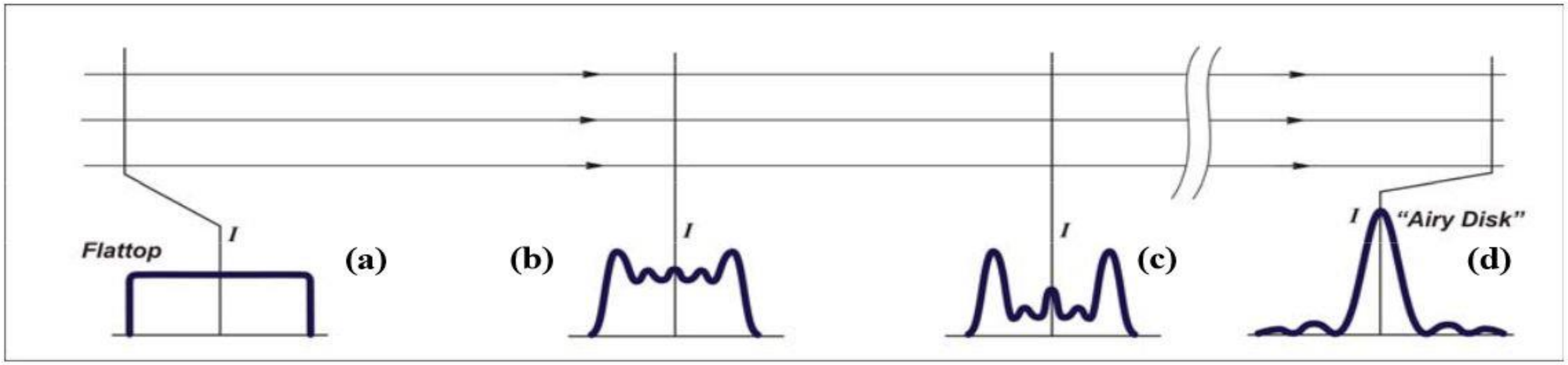
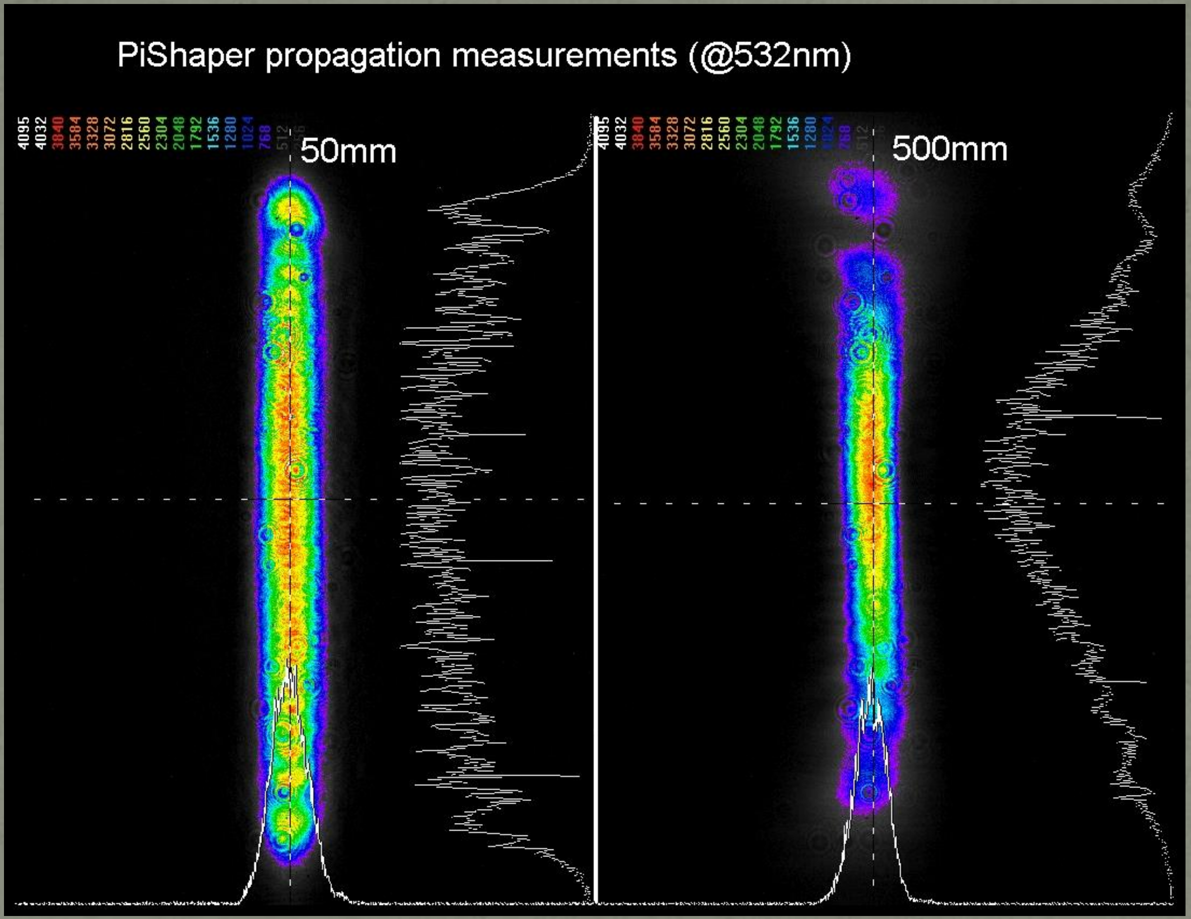


Fig. 1 Intensity profile variation by a flattop beam propagation.

πShaper Propagation



We think this would work, but…

We would like to do better that this for propagation of a uniform profile….

Beam Stacker Concept (Todd Johnson)

Based upon a birefringent crystal where the index of refraction is dependent on polarization

Here the half-wave plate rotates linear polarized beam to 45° and the crystal displaces V pol and H pol remains un-deflected.

$$\tan(\alpha) = \left(1 - \frac{n_o^2}{n_e^2}\right) \cdot \frac{\tan(\theta)}{1 + \frac{n_o^2}{n_e^2} \cdot \tan^2(\theta)}$$

$$d = L \cdot \tan(\alpha)$$

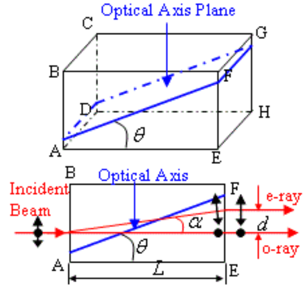
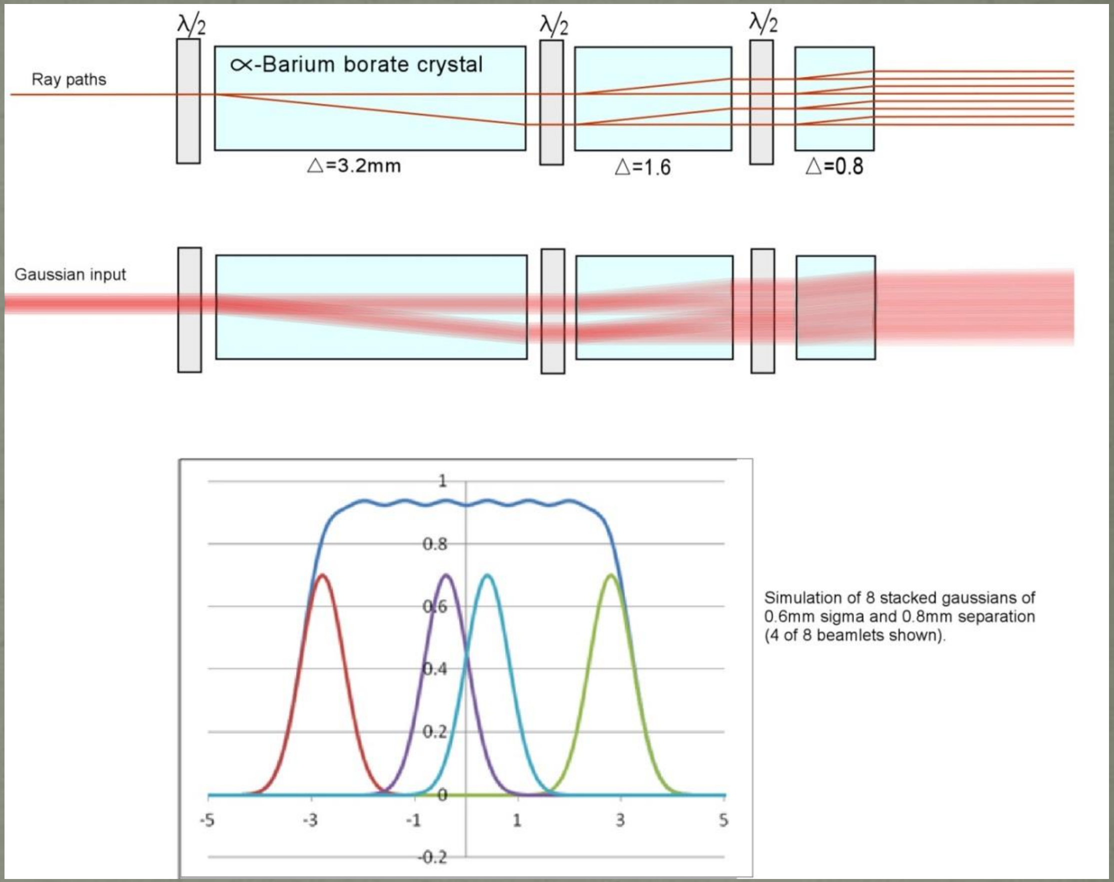
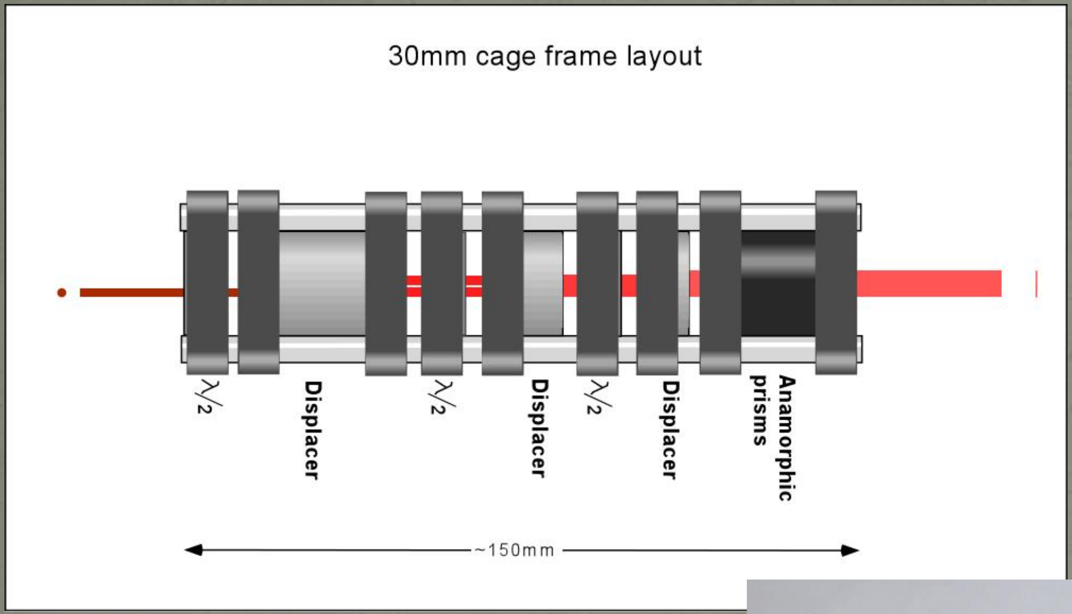
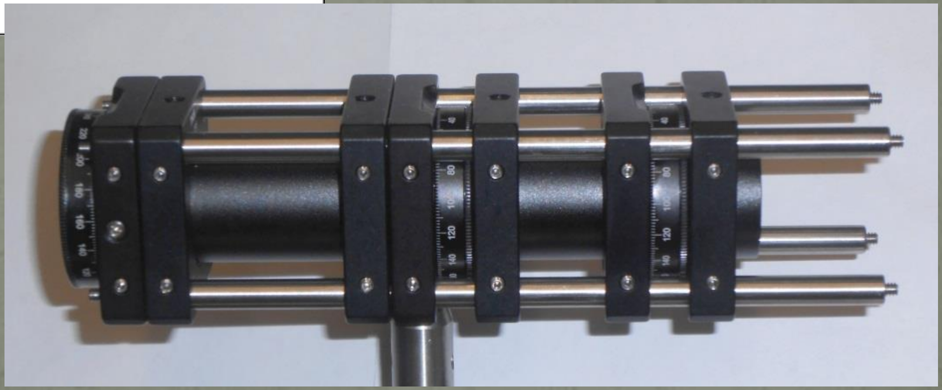


Figure 2: A drawing for beam separation calculation



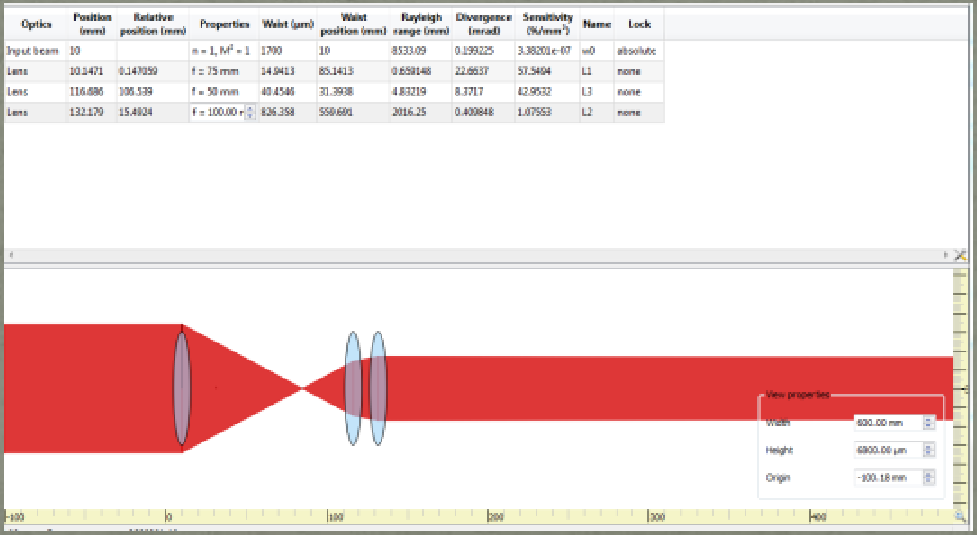
Layout of the Beam Stacker





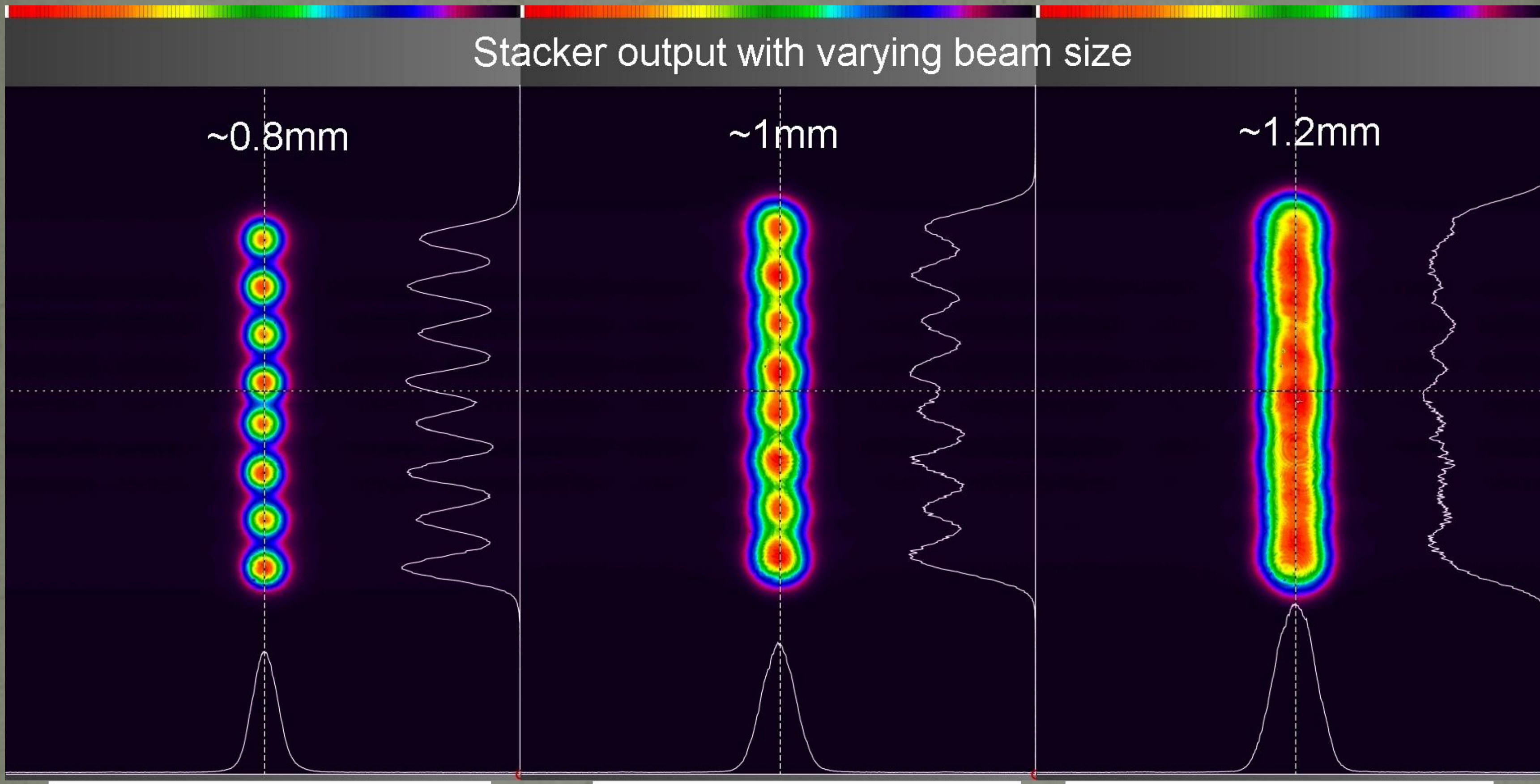
Telescope to Match Diode to Stacker

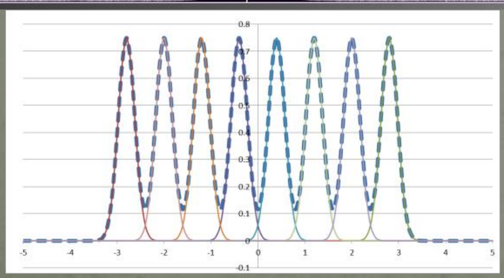
- We use CW diode to test the beam stacker concept.
- Ultimately the input to the Stacker will be from the Free Space Amplifier.
- Since the output of the Free Space Amplifier will have a $1/e^2$ diameter of 5.1 mm we will need a telescope to match the stacker.

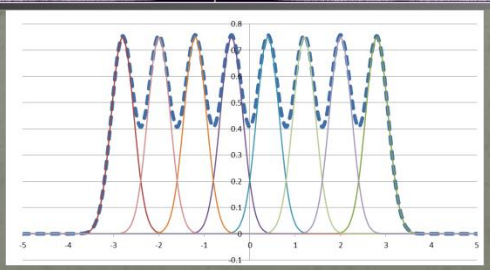


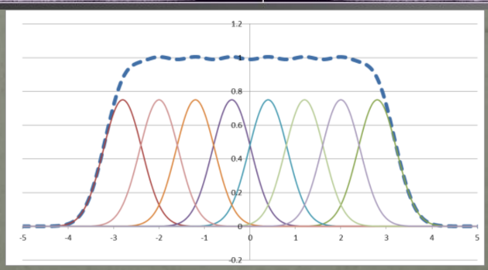
Optics	Position (mm)	Relative position (mm)	Properties	Waist (µm)	Waist position (mm)	Rayleigh range (mm)	Divergence (mrad)	Sensitivity (%/mm²)	Name	Lock
Input beam	10		n = 1, M² = 1	1700	10	8533.09	0.199225	3.38201e-07	w0	absolute
Lens	10.1471	0.147059	f = 75 mm	14.9413	85.1413	0.659148	22.6637	57.5494	L1	none
Lens	116.686	106.539	f = 50 mm	40.4546	31.3938	4.83219	8.3717	42.9532	L3	none
Lens	132.179	15.4924	f = 100.00 r	826.358	559.691	2016.25	0.409848	1.07553	L2	none

Beam Stacker – merging beamlets

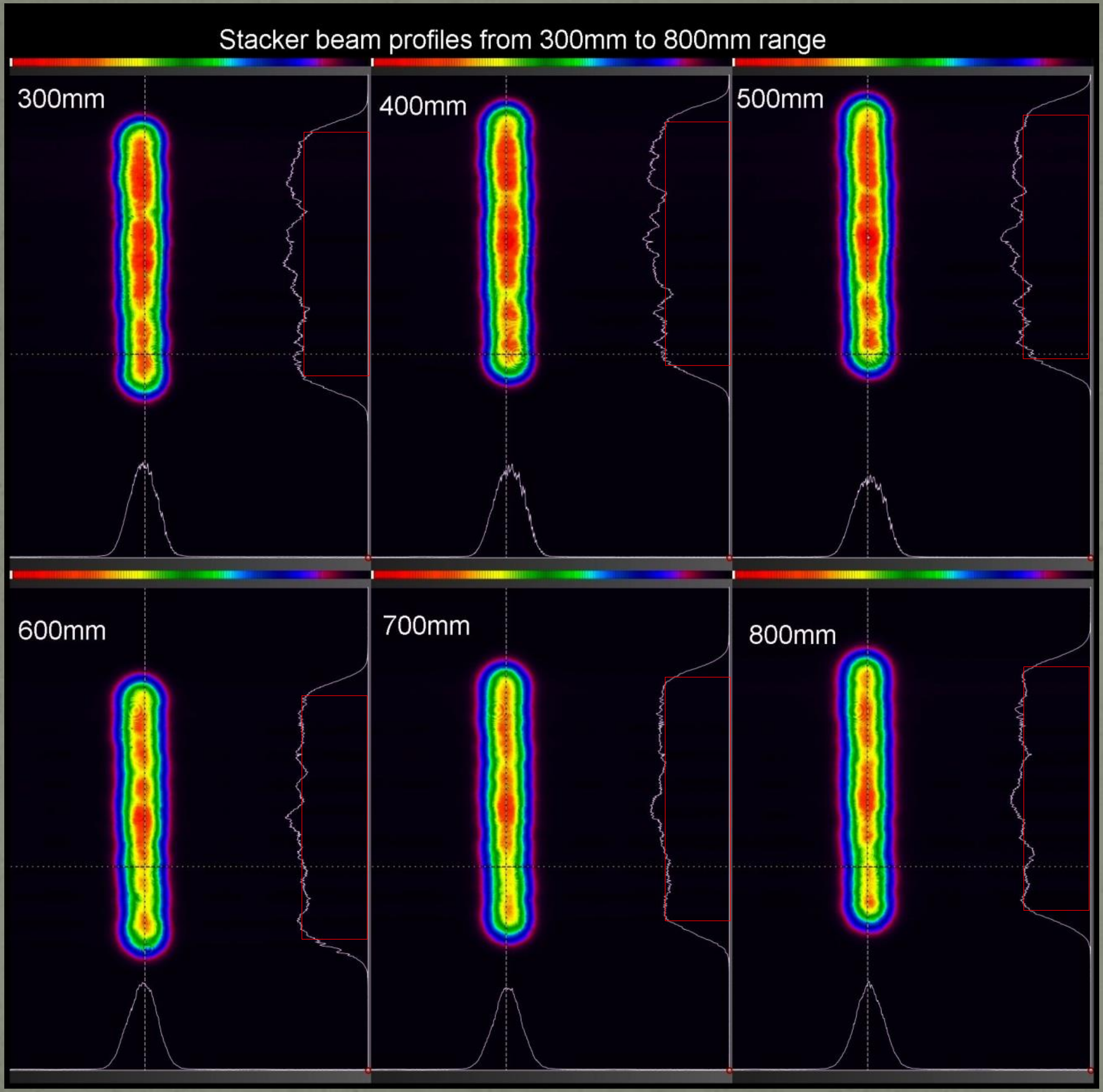






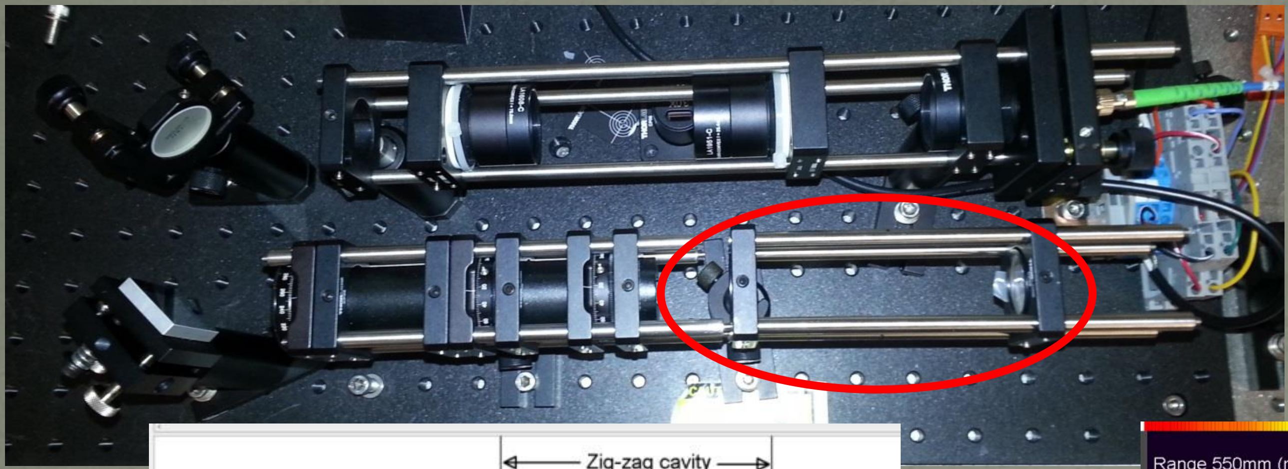


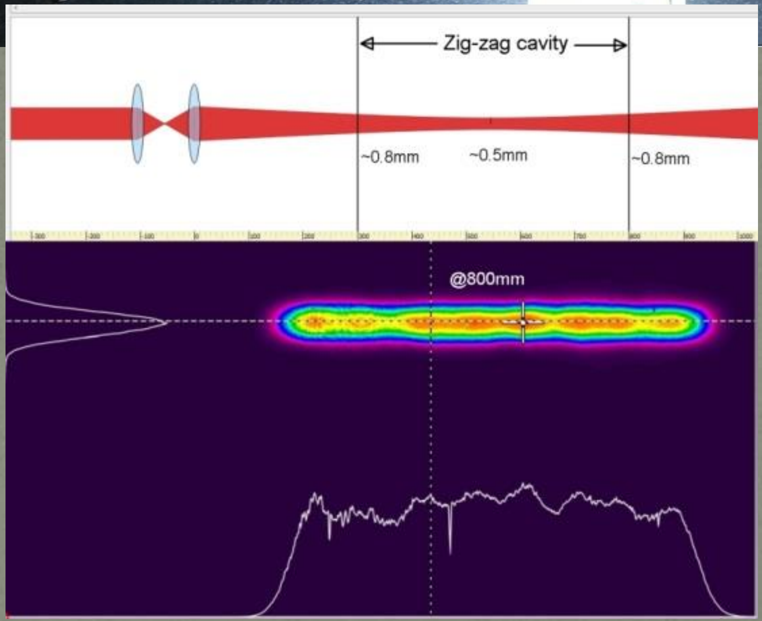
Beam Stacker - Propagation

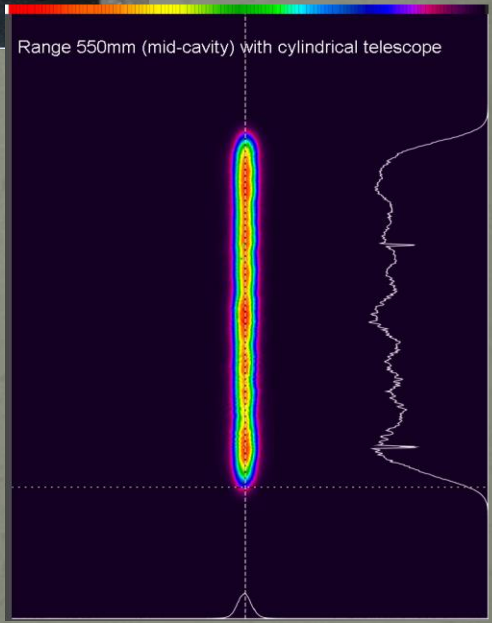


Represents 6 mm vertical dimension with constant intensity

Add Cylindrical Telescope to Stacker

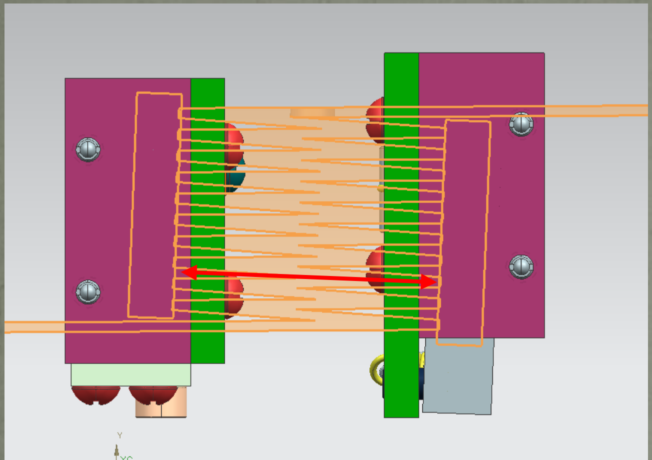




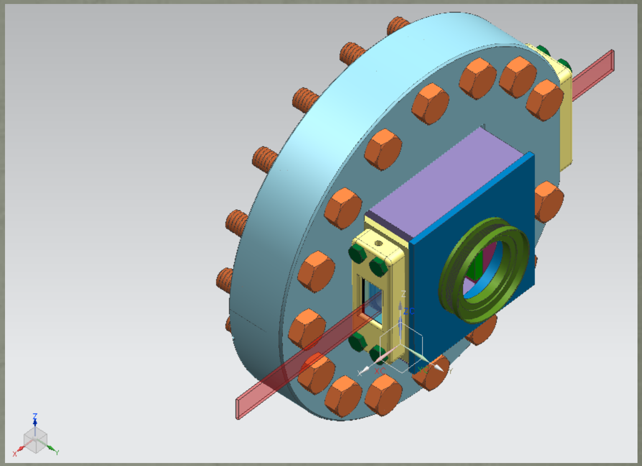


Optical Cavity

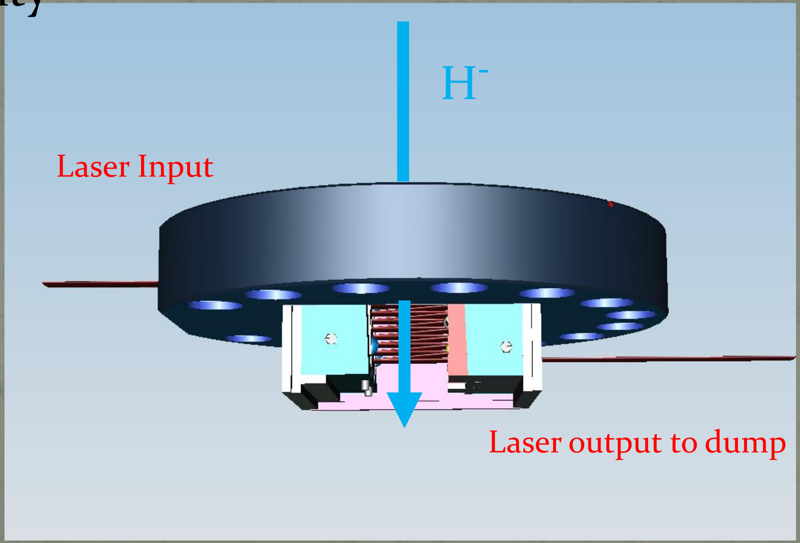
John Sobolewski and Fred Mach



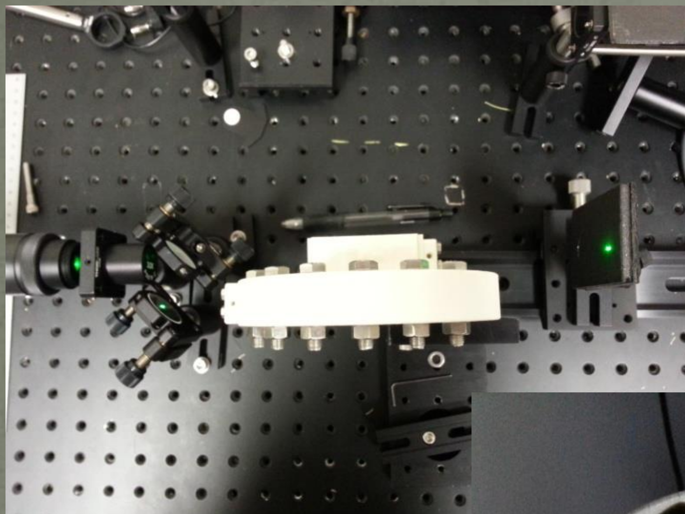
Mirror separation matched to ion velocity



Mirrors at 2.288° wrt H- beam
showing 21 interactions

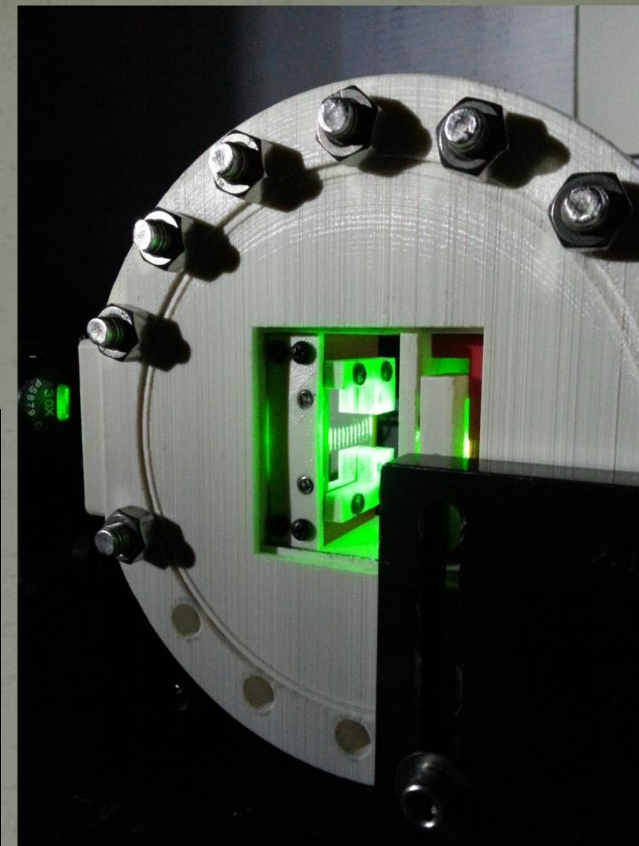


Optical cavity tests



Test set-up

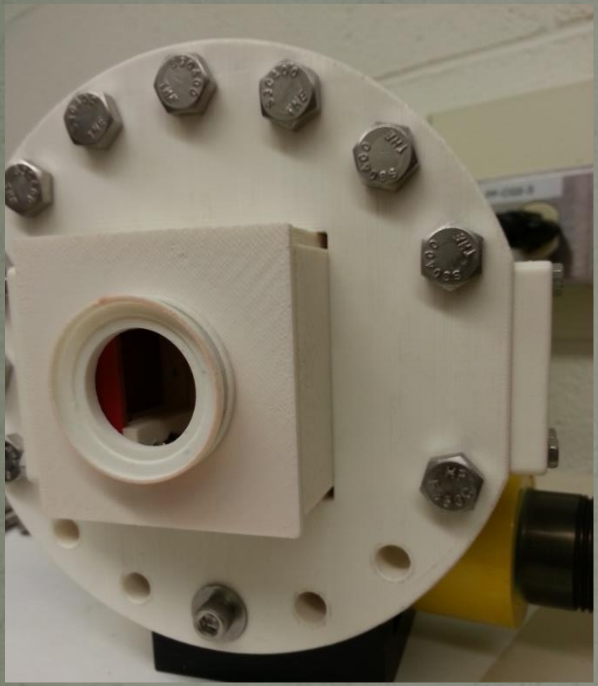
Moveable mirror

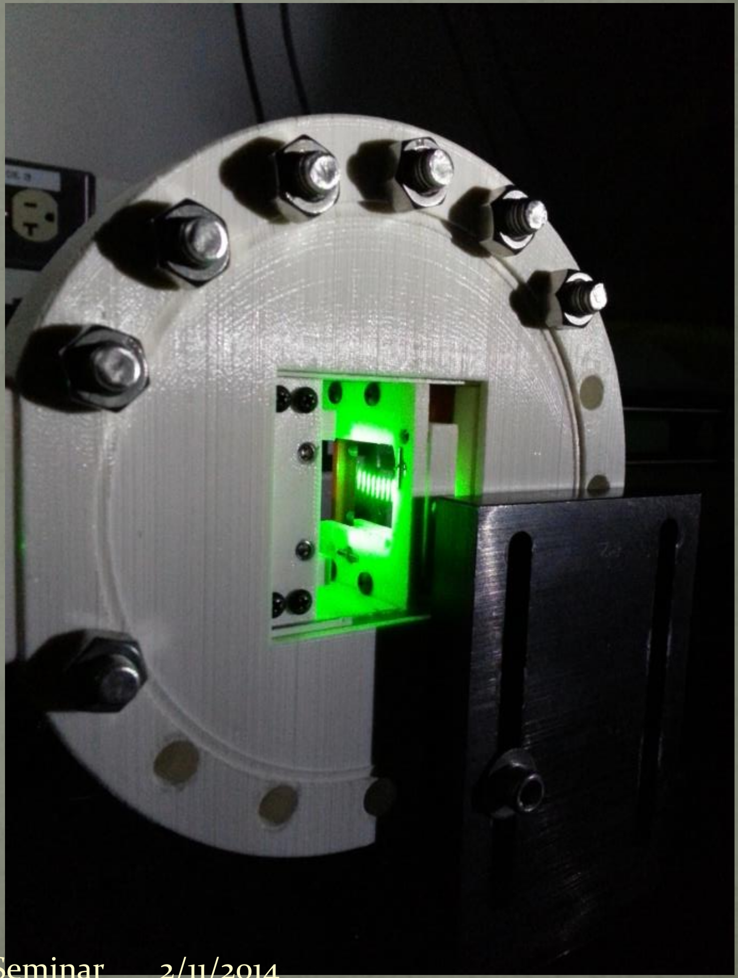


Fixed mirror

Optical Cavity prototype

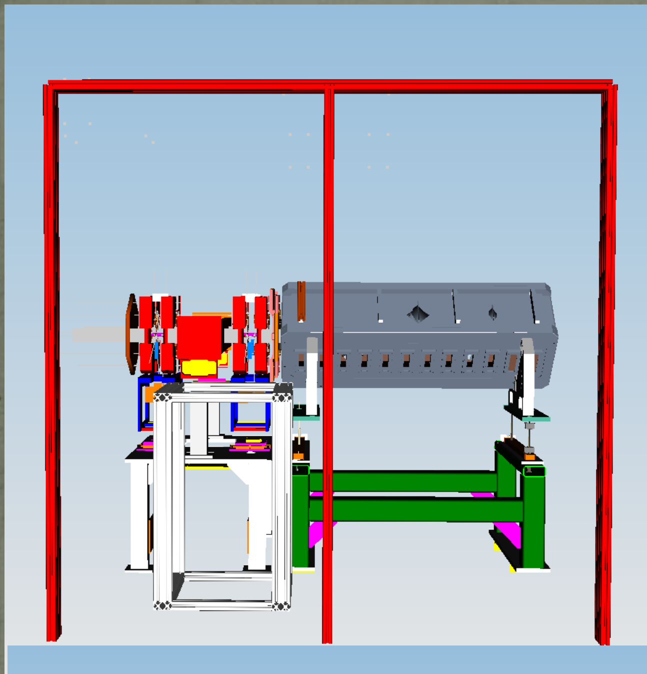
- We printed a 3D model to test design

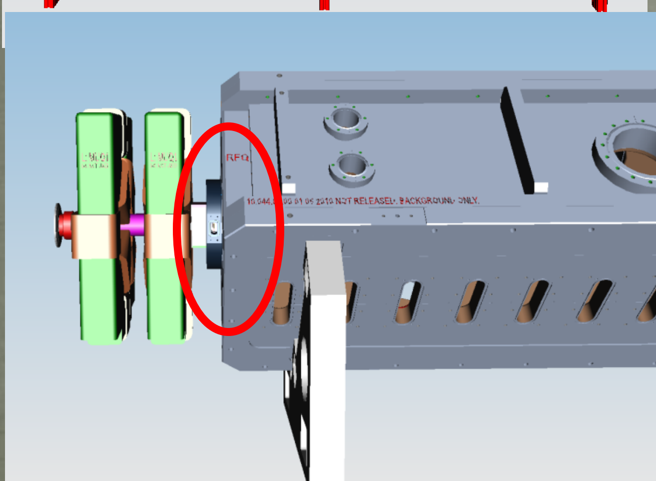




This was very useful as it pointed out several improvements/modifications to the design.

Installation .... Currently set for April 2015





Laser Notcher Rack Layout (01-10-14)

U	Rack slot
1	Rack mount computer (1U)
	LCD/Keyboard (1U)
3	PCI Expansion Chassis (2U) PCI slots (AWG/clock /expansion)
5	4slot VME (2U) Timing card/moto5500 controller/8ch D/A
7	OPG (2U) LD- USB interface / MOD&BIAS - USB interface
9	PriTel fiber amplifiers (2U) USB interface
11	Reserved (2U) for potential AOM
13	RBA controller (2U) RS-232 interface
15	RBA PS (1U) Tdk-Lambda GEN50-30E
	REA controller (2U) RS-232 interface
17	REA PS (1U) Tdk-Lambda GEN100-24
19	REA PS (1U) Tdk-Lambda GEN100-24
	SPARE 1U

1.75" x 20U = 35"

Issues:

- Moveable for MEBT maintenance
- Electrical requirements
- Cooling requirements
- Effects of ion source sparking

Near term Plans

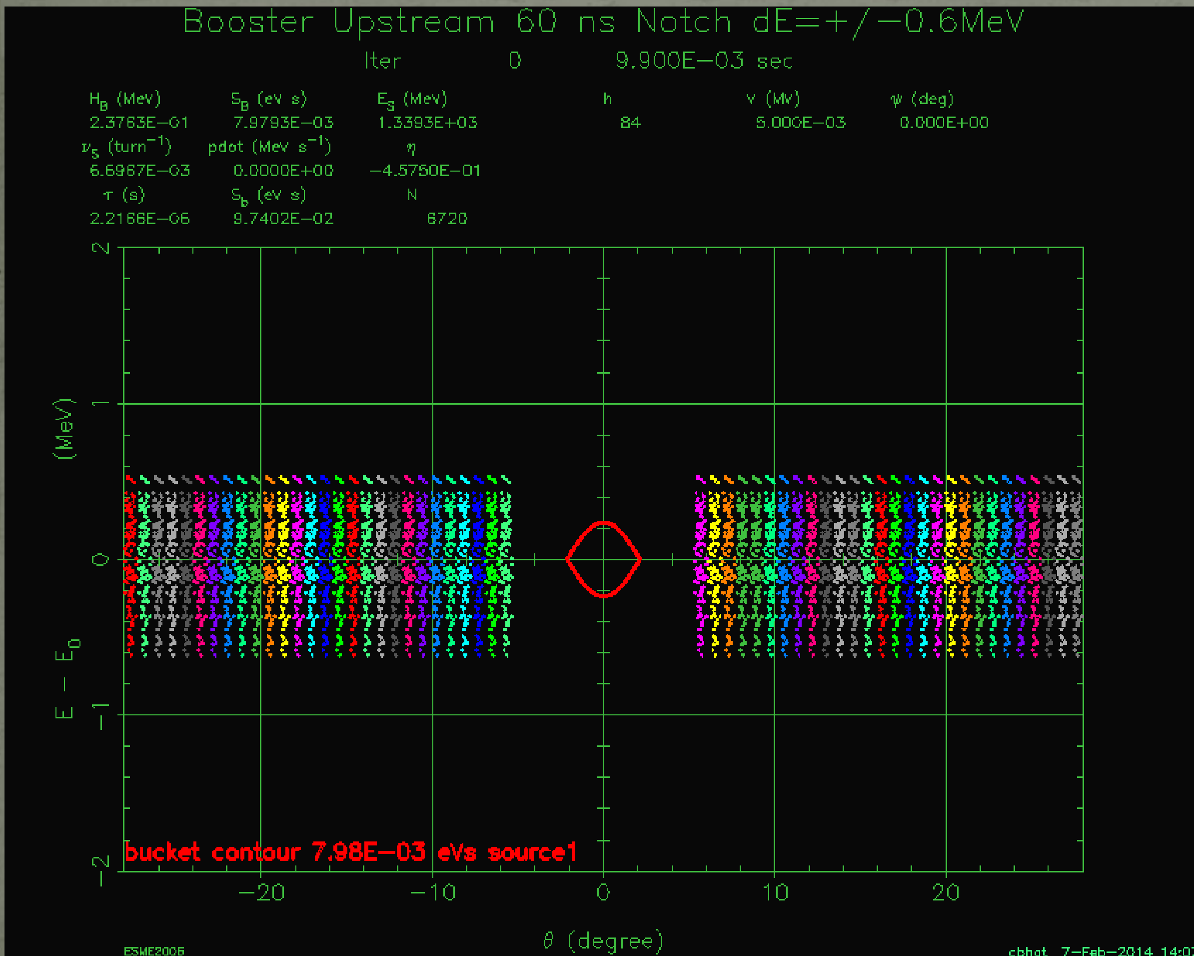
- Goal complete laser in LAB — end of FY14
- Finish packaging OPG and test — end of Feb
- Repackage Fiber pre-amps(s) — end of Feb
- Receive Fiber Amplifier — end of Feb
- Test Fiber stages with OPG — mid March
  - Determine FA output to determine FS
- Finalize design of Free Space Amplifier — end March
  - Order components for amplifier (14 week delivery for amp modules)
- Continue optimization of Beam Shaping — on going
- Start diagnostics electronics design — May
- Finalize mechanical design of Optical Cavity
  - Generate manufacturing prints — mid April
- Construct optics box stand and relay rack — mid March
- Continue discussion on timing system

Issues

- Notch survivability in Booster (see next slides)
  - Start of RF capture
  - Capture parameters
- Not achieving design pulse intensity (next slides)
- Reliability of system
- Impact of ion source sparks on electronics - TBD
- Portability and alignment
- Pre-distortion of laser pulses for fiber and DPSS stages
- Impact of optical cavity in quad fringe field
  - Estimation shows it to be not a problem
  - Simulation electron trajectories by Vladimir Kashikhin

200 MHz bunches in Booster

Chandra Bhat



Evolution of 200 MHz bunches during 17 turn injection

Assume full energy spread of injected beam +/- 0.6 MeV

Momentum Spread*

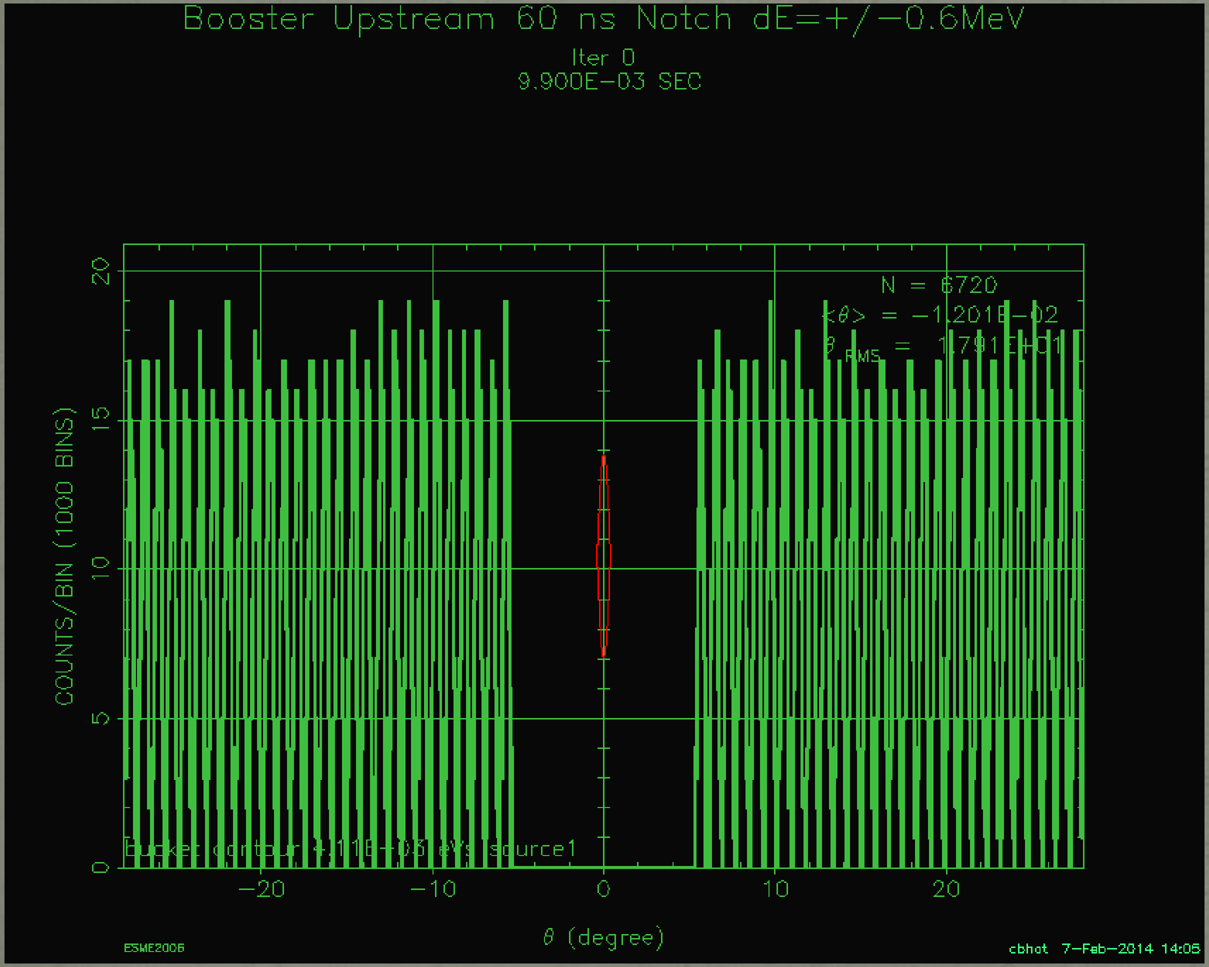
$$\frac{dp}{p} = \frac{1}{\beta^2}\frac{dE}{E}$$

$$\frac{dp}{p} = 0.18\%$$

*Measured value in Booster

Total time ~ 53 ms injection

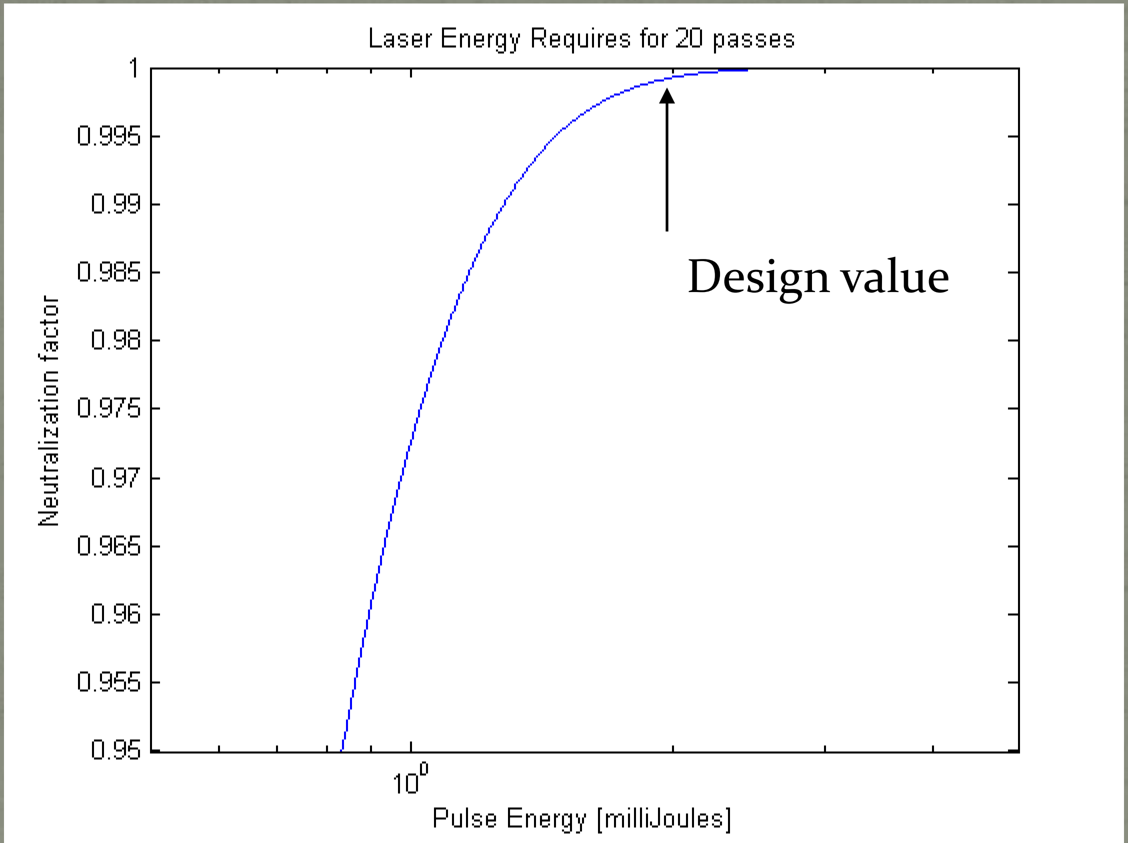
Evolution of the Notch in Booster



Total of 17 turns injected over ~ 34 us

Total time ~ 53 μs of simulation

Neutralization vs Pulse Energy



Budget

WBS	TASK	M&S*	contingency
.01.02.03.01	Initial Design	$0	
.01.02.03.02	Optical Pulse Generator	$35,000	$6,000
.01.02.03.03	Fiber Amplification Stage	$100,000	$16,000
.01.02.03.04	Free-Space Amplification and optics	$160,000	$40,000
.01.02.03.05	Optical cavity and vacuum chamber*	$20,000	---
.01.02.03.06	Beam shaping/transport/diagnostics	$25,000	$5,000
.01.02.03.07	Timing and Controls	$24,000	$10,000
.01.02.03.08	Installation	$18,000	$6,000
.01.02.03.09	R&D Lab supplies and materials	$7,750	----
	TOTAL (*unburdened)	$389,750	$83,000

"Contingency" numbers are amounts above what we "expect" to spend in each of the Tasks… but then there are unforeseen expenses

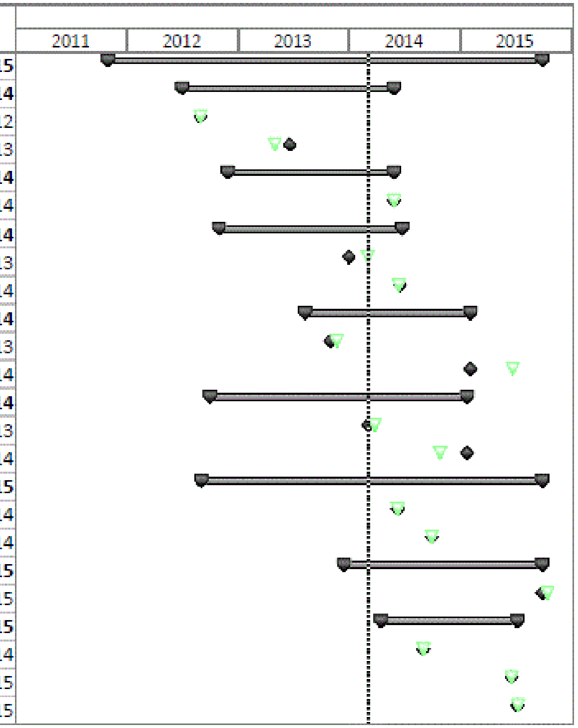
We have obligated ~$192K to date. The next largest purchase will be for the free-space amplifier and associated optical components (est. to be ~< $100K).

Schedule

Linac Notcher
Milestones

2/10/14

ID	WBS	Task Name	Start	Finish
288	**1.01.02.03**	**Linac Notch Creation**	**8/1/11**	**6/29/15**
292	**1.01.02.03.02**	**Optical Pulse Generator (OPG)**	**4/2/12**	**2/26/14**
294	1.01.02.03.02.02	MILESTONE: Linac Notch Creation OPG o	6/1/12	6/1/12
305	1.01.02.03.02.13	MILESTONE: Certify Operation of Linac N	3/20/13	3/20/13
306	**1.01.02.03.02.14**	**RF Pulse Generator (RFPG)**	**8/29/12**	**2/26/14**
319	1.01.02.03.02.14.13	MILESTONE: OPG module ready for i	2/26/14	2/26/14
320	**1.01.02.03.03**	**Fiber Amplifier (FA)**	**8/1/12**	**3/24/14**
332	1.01.02.03.03.12	MILESTONE: 1st two stages fiber comple	10/1/13	10/1/13
339	1.01.02.03.03.19	MILESTONE: Certify all three stagesready	3/18/14	3/18/14
340	**1.01.02.03.04**	**Free Space Laser Amplifier (FSLA)**	**5/10/13**	**11/4/14**
343	1.01.02.03.04.03	MILESTONE: Free space laser technology	8/1/13	8/1/13
353	1.01.02.03.04.13	MILESTONE: FSA operational on bench re	11/4/14	11/4/14
354	**1.01.02.03.05**	**Optical Cavity/Vacuum Chamber (OC)**	**7/2/12**	**10/24/14**
363	1.01.02.03.05.09	MILESTONE: Linac Notch Prototype optic	12/4/13	12/4/13
388	1.01.02.03.05.34	MILESTONE: Linac Notch Final Optical Ca	10/24/14	10/24/14
389	**1.01.02.03.06**	**Transport/Beam Shaping Optics (BSO)**	**6/4/12**	**6/29/15**
404	1.01.02.03.06.15	MILESTONE: Beam shaping technology cl	3/10/14	3/10/14
421	1.01.02.03.06.32	MILESTONE: Beam shaping/launch,diagn	6/30/14	6/30/14
422	**1.01.02.03.06.33**	**Timing & Controls**	**9/16/13**	**6/29/15**
439	1.01.02.03.06.33.17	MILESTONE: All hardware integrated	6/29/15	6/29/15
440	**1.01.02.03.06.34**	**Installation & Commissioning**	**1/15/14**	**4/8/15**
455	1.01.02.03.06.34.15	MILESTONE: Complete Notcher syste	6/2/14	6/2/14
460	1.01.02.03.06.34.20	MILESTONE: Tunnel ready for installa	3/20/15	3/20/15
463	1.01.02.03.06.34.23	MILESTONE: Linac Notcher System In	4/8/15	4/8/15



Summary

- We have described our motivation for moving the process of notching outside the Booster tunnel.
- We have described the requirements for the laser system to create the notches.
- We have described the laser system design to accomplish the goal of creating notches.
- We have described the status of the components and system.
- We have the front-end laser system with the final fiber amplifier on order and are in the process of R&D on beam shaping and working on the final design of the optical cavity.
- We would like to have laser system operational in lab by end FY14.
- The current plan is to install the system in Q2 of Fy15.

Acknowledgements

- Dave Baird
- Dan Bollinger
- Ken Domann
- Fernanda Garcia
- Mike Kucera
- Ray Lewis
- Bill Pellico
- Peter Prieto
- Matt Quinn
- Jinhao Ruan
- Jamie Santucci
- Vic Scarpine
- C.Y. Tan
- Bob Zwaska

Thank you

Laser Parameters

- Laser Parameter Requirements entering interaction chamber:
- Laser Energy 2.0 [mJoules]
- Pulse length 1.500000e+03 [ps]
- Spot size: H 0.0600 [cm] V 0.6000 [cm]
- Laser beam area 3.600000e-02 [cm^2]
- Lab Frame Photon wavelength 1064.00 nm
- Lab Frame Photon Energy 1.868068e-19 [J] 1.165139e+00 [eV]
- Photons per pulse 1.070625e+16
- Photon rate 7.137500e+24 [photons/sec]
- Photon fluence 2.973958e+17 [photons/cm^2]
- Photon flux 1.982639e+26 [photons/cm^2/sec]
- Laser Peak pulse power 1.333333e+00 [MW]

Optical Cavity Parameers

- Distance between crossings 1.188000e-01 [cm]
- Distance between reflections on mirror 2.376000e-01 [cm]
- distance laser travel between crossing 1.487310e+00 [cm]
- cavity radius 1.486124e+00 [cm]
- cavity diameter 2.972247e+00 [cm]
- Incident angle 2.288880e+00 [degrees]
- Crossing angle 87.71 [degrees]
- Lorentz Factor 9.992022e-01
- Rest frame photon energy 1.164210e+00 [eV]
- Rest frame wavelength 1.064850e+03
- Cross section in rest frame 3.660952e-17 [cm2]

Laser/cavity Parameters

- crossing time 5.015246e-11 [sec]
- Number of passes 20.000000
- Photon flux in H- rest frame 1.981057e+26 [p/cm^2/sec]
- Mirror Reflectivity 9.995000e-01
- Average Neutralization factor per interaction 3.024028e-01
- Total Neutralization 9.992551e-01
- Multipass insertion length 2.257200e+00 [cm]
- Total laser path length 5.651779e-01 [m]

DPSS output for pump timing

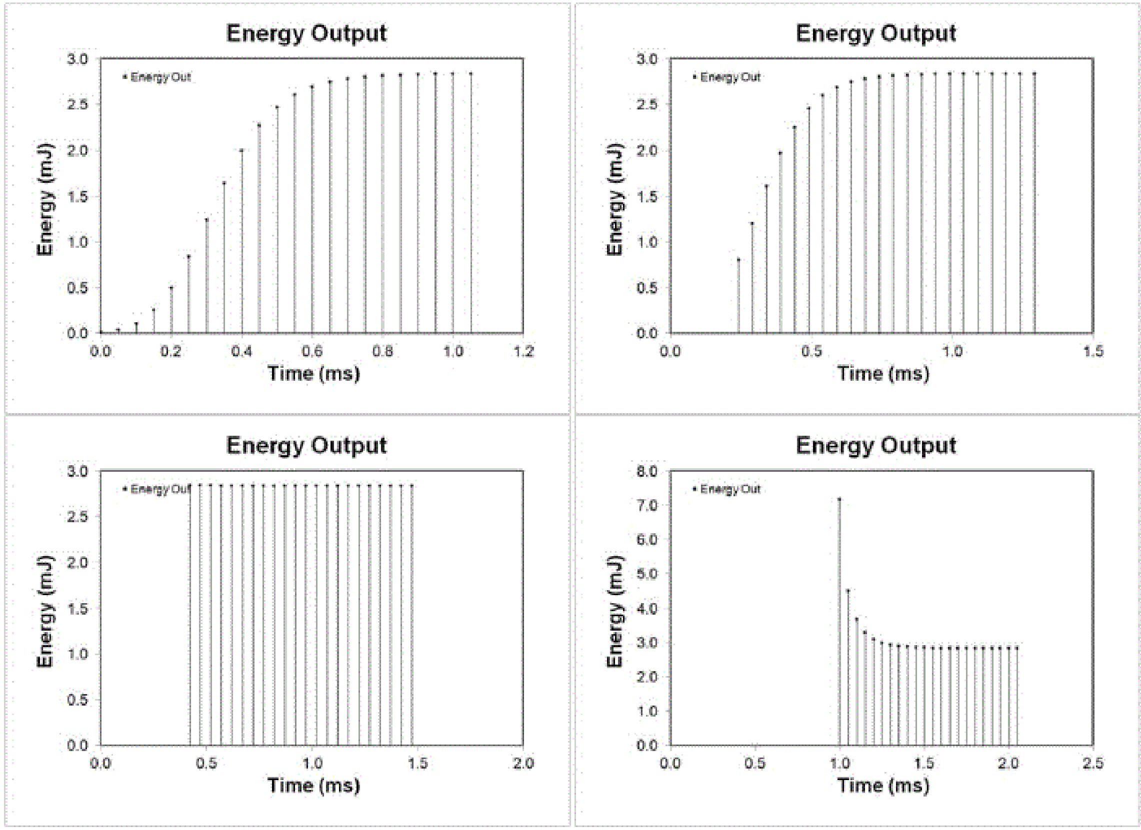
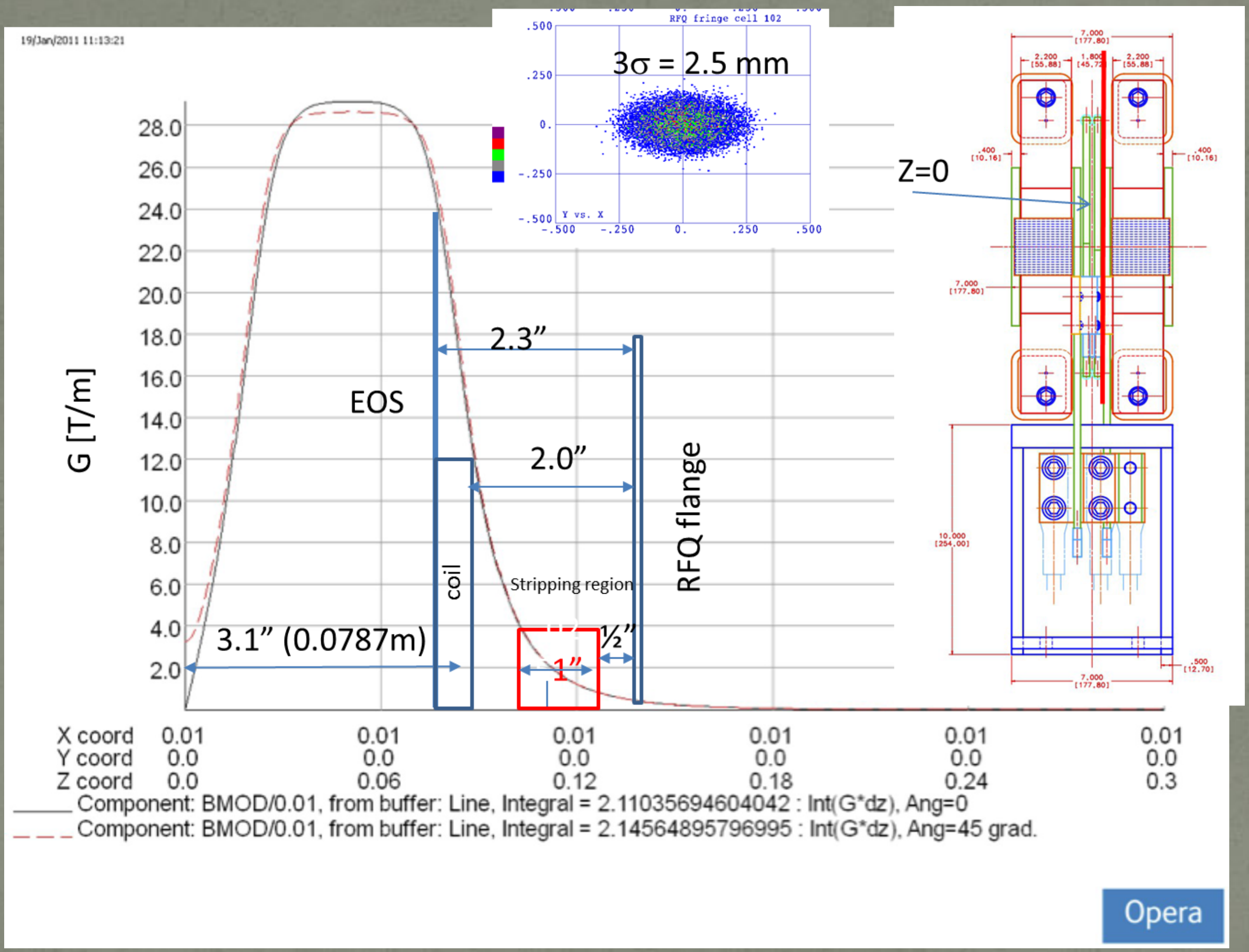


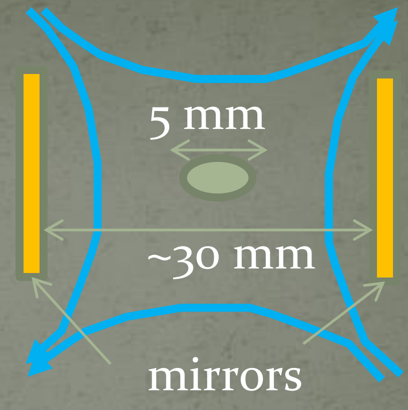
Figure 2. Simulation of a 2 pass pulse train amplification for different phasing of pump and pulse train starts. The pulse train start delay with respect to the pump pulse start is 0, 240µs, 420µs, and 1ms for the upper left, upper right, lower left, and lower right figures respectively.

Cavity in Quad fringe field



Electron in fringe field

K.E. (H-) 750 keV
Electron energy 409 eV
Velocity 1.198E7 m/s
Electron bend radius in field B r → $(\frac{m}{e})\frac{1}{B}v_e$
H^- 1σ ~ 0.83 mm -> 3σ < ~ 2.5 mm
Field at particle amplitude -> G*amplitude



First quad in doublet is H focusing for H^- and e^-

Assume end-field shape is the same as between pole tips