Feasibility of Laser-induced Microbunching at ASTA

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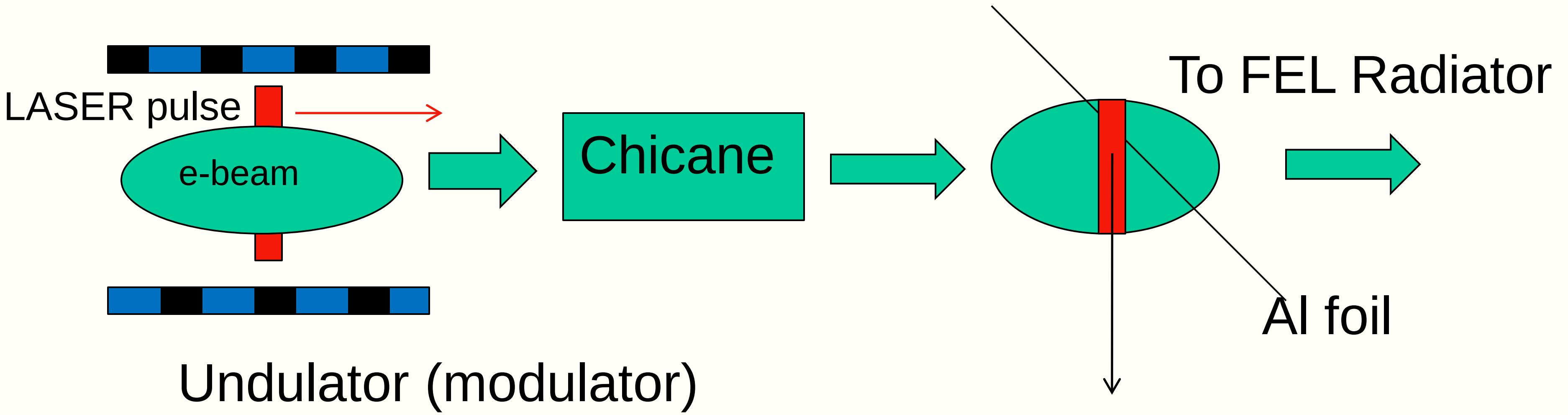
Laser-Induced Microbunching

- A seed laser can be co-propagated with the e-beam through a short undulator to modulate the energy.
- A chicane then is used to make this a density modulation via the R_{56} term.
- The microbunched portion of the beam can then be sensed by COTR, COSR, or CUR and is base of FELs.
- The baseline plan is to use COTR (and COSR) after the chicane to assess microbunching factors.
- By scanning the arrival time of a short-pulse laser, one can also obtain slice transverse beam size measurements with ~100-fs sampling intervals or use a long-pulse laser for bunch-length measurement.
- Related to optical replica mode with an Und. radiator.

Laser-Induced Microbunching

- **Use laser to selectively energy modulate a slice of the longitudinal profile or the whole profile within the short undulator. The Chicane's R_{56} then converts this to density modulation in z direction or microbunching.**



Slice x,y beam size, centroid, energy spread (microbunching harmonics)

Also possible to use COSR from dipole bend

Microbunching Mechanisms

- Microbunching of an electron beam, or a z-dependent density modulation with a period λ, can be generated by several mechanisms:
  - The Long.Space Charge-induced microbunching (LSCIM) starts from noise fluctuations in the charge distribution which causes an energy modulation that converts to density modulation following Chicane compression. This is a broadband case.

    (Not good for FEL as described in May 2011 APC seminar)
  - The laser-induced microbunching (LIM) occurs at the laser resonant wavelength (and harmonics) as the e-beam co-propagates through the undulator with the laser beam followed by Chicane compression. This is narrow-band. (This topic)
  - In self-amplified spontaneous emission (SASE) induced microbunching (SIM) the electron beam is also bunched at resonant wavelength and harmonics. This is narrow band.
- A microbunched beam radiates coherently. (COTR, COSR,CUR)

Some LIM basics

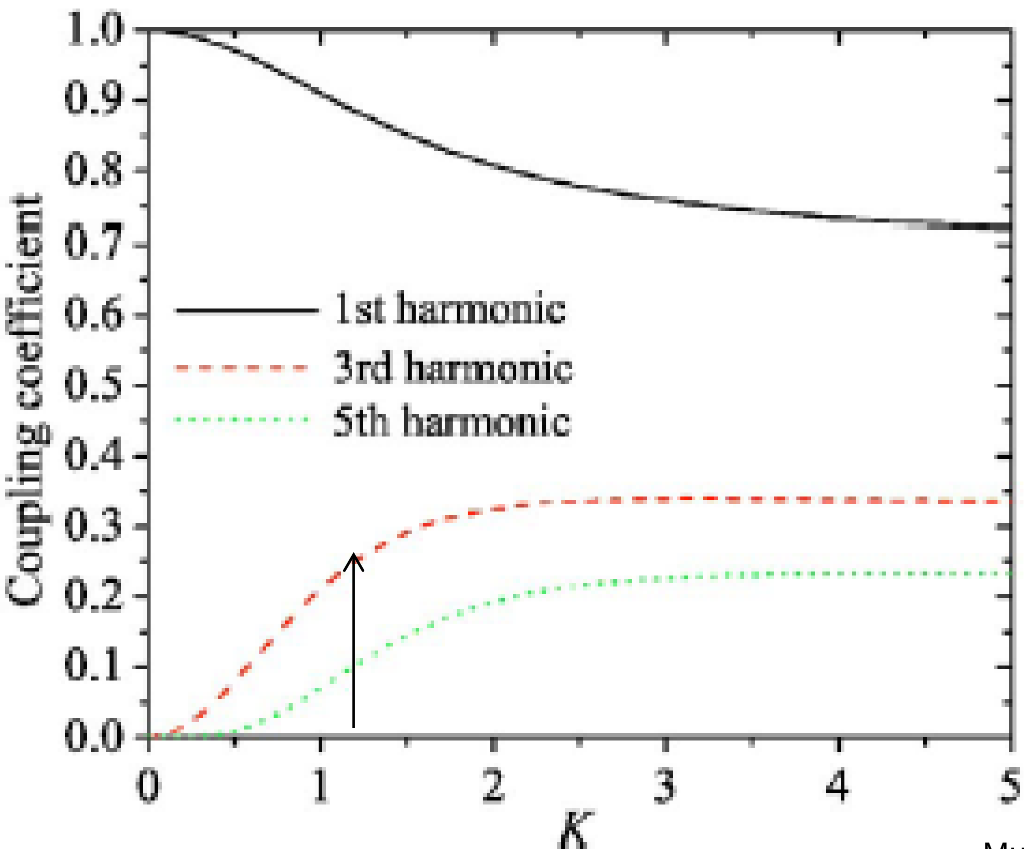
- **LIM is based on the modulation of intrinsic electron beam longitudinal structure at the resonant wavelength as e-beam co-propagates with optical fields in undulator.**

$$\lambda_n = \lambda_u \,(1 + K^2/2)/2n\gamma^2,$$

Where λ is the resonant wavelength (for microbunching)
λ_u is the undulator period
K is the undulator field parameter
n is the harmonic number
γ is the Lorentz factor

Undulator Coupling Coefficients

- **Coupling coefficients on harmonics allow planar undulator use with 800-nm laser at gamma=90.**

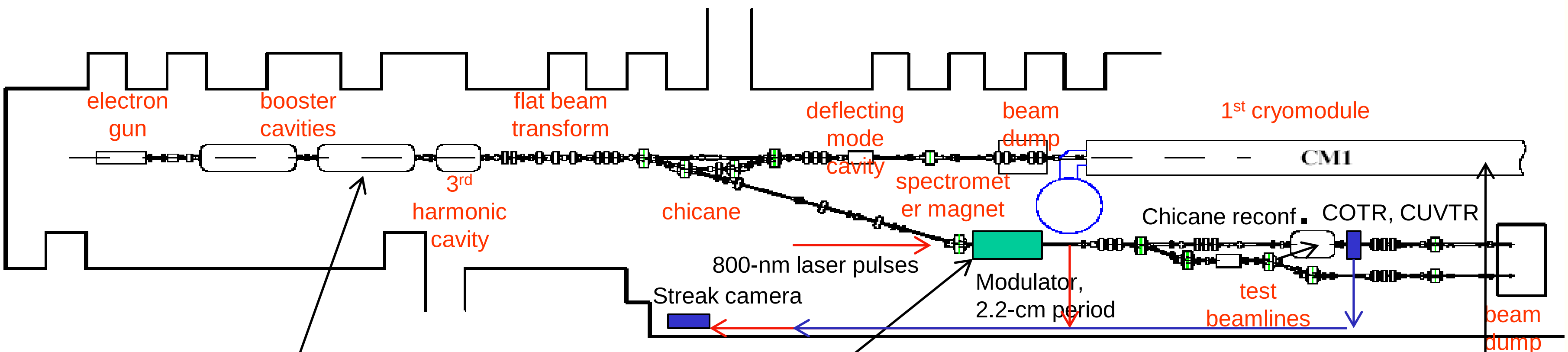


Musumeci et al., PRST-AB 2005

50-MeV Injector at ASTA/FNAL

- **User beamline could support LIM experiments.**

40-MeV Injector



Possible COTR-Microbunching Experiments

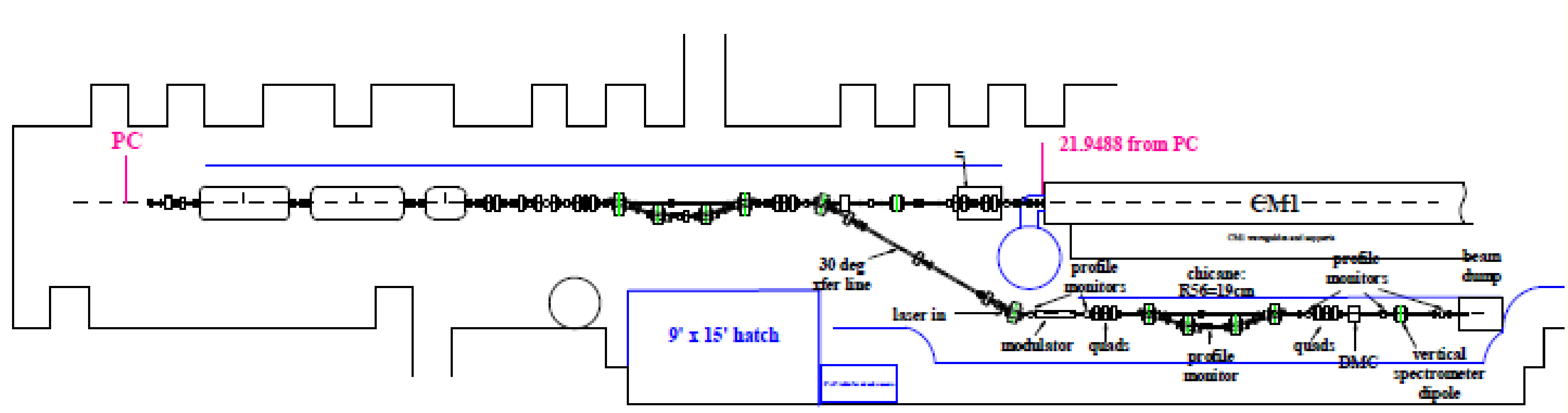
Booster cavity 2 (from DESY and Saclay) installed in NML

A.H. Lumpkin et al., FEL10, revised from M. Church

First cryomodule (from DESY) installed at NML.

Mike's Initial Layout at 50 MeV

- **Preliminary look at the beamline configuration for LIM.**



Courtesy of M. Church

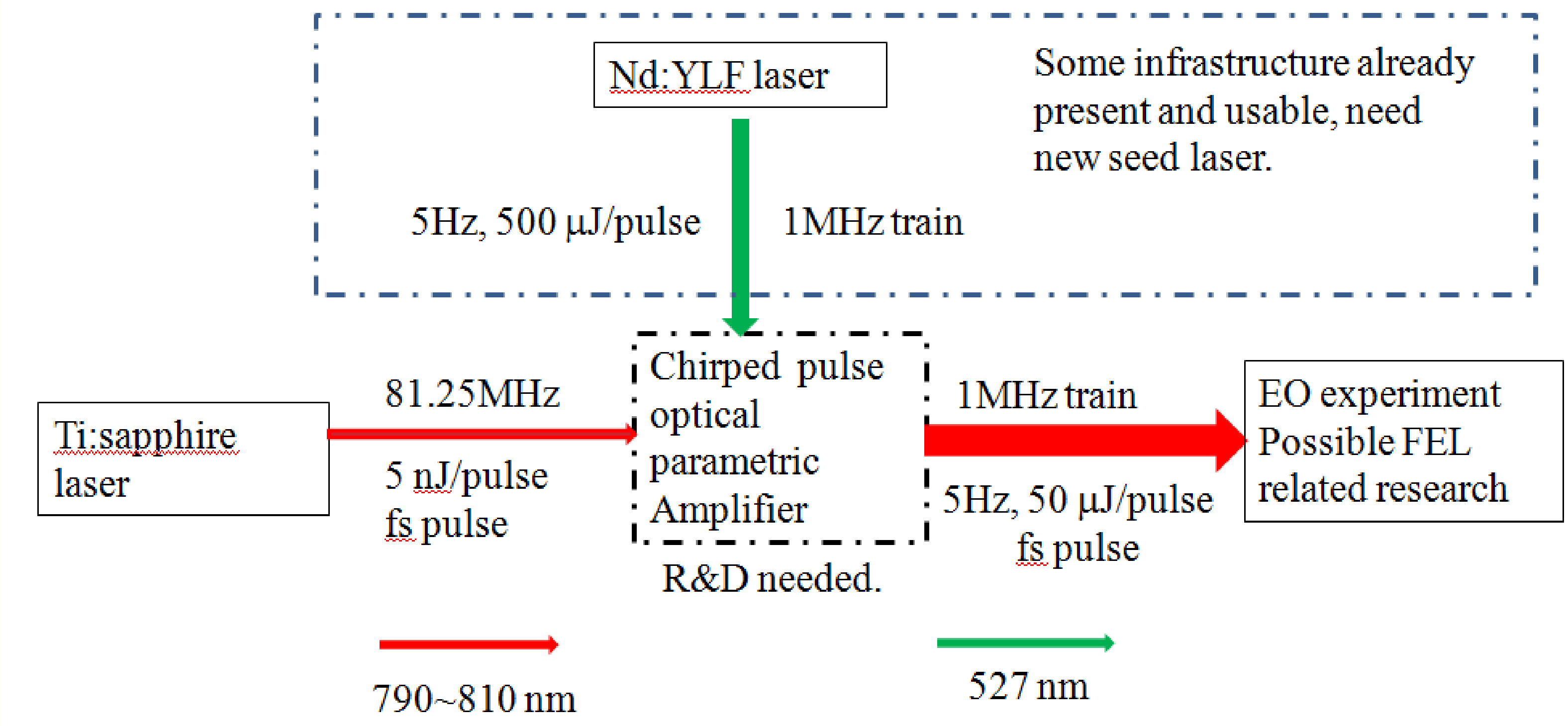
Required Beam Parameters

- **Table 1. Summary of beam parameters for initial experiments at 45 MeV in User beamline.**

Parameter	Value/Range	Units
Beam Energy	45/44-50	MeV
Bunch Charge	250/100-3000	nC
Bunch repetition rate	3	MHz
Number of micropulses/macropulse	100	
Transverse emittance/spot size	2 / 200	mm mrad/μm
Bunch length	3	ps
Fractional momentum spread	10^{-4}	

Proposed Laser Configuration

- **Optical parametric amplifier (OPA) combined with existing lasers from FNAL.**



Initial Phases: 1a, 1b

- Tests at 45 MeV are feasible using third harmonic coupling coefficient in LBNL loaner modulator with 2.2-cm period, 1-m length.
- Use streak camera for synchronization of laser pulse and e-beam micropulse and slice e-beam tests.
- Use standard visible-UV optics and camera to evaluate

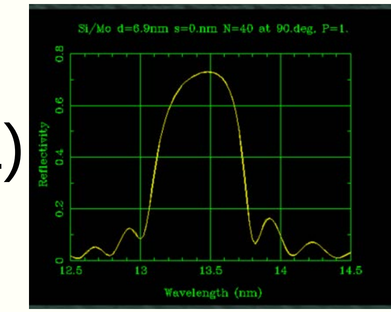
  n= 2,3,4 at 400, 266, and 200 nm, respectively.
- Explore slice electron beam parameters such as beam profile, centroid, energy spread (microbunching factors).
- Use in-vacuum MCP for detection of VUV harmonics, hopefully to n= 8,9,10 at 100, 89, 80 nm.
- Intrinsic energy spread is a parameter of import.
- Benchmark codes on microbunching factors.
- Use TM_{110} cavity for slice e-beam tests after chicane.

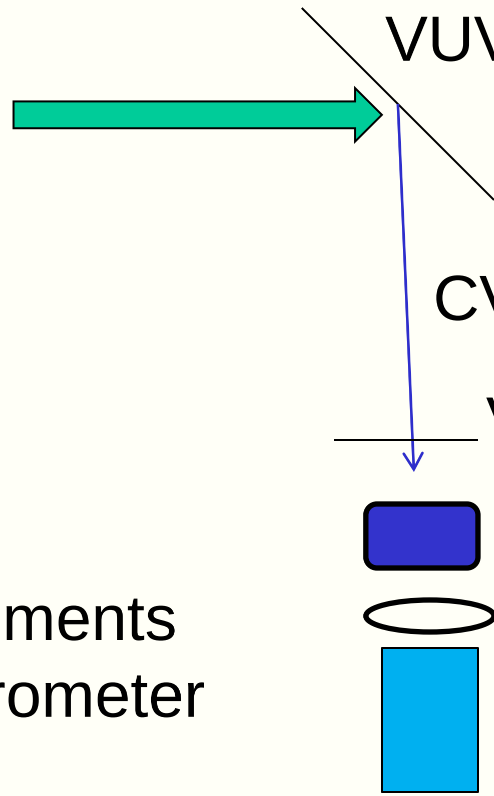
Schematic of VUV test station

- **Narrowband reflectivity VUV mirror selects harmonic.**

Microbunched
e beam

Multilayer metal
VUV mirror (LBNL)





CVUVTR Harmonic

Visible BP and blocking Filter

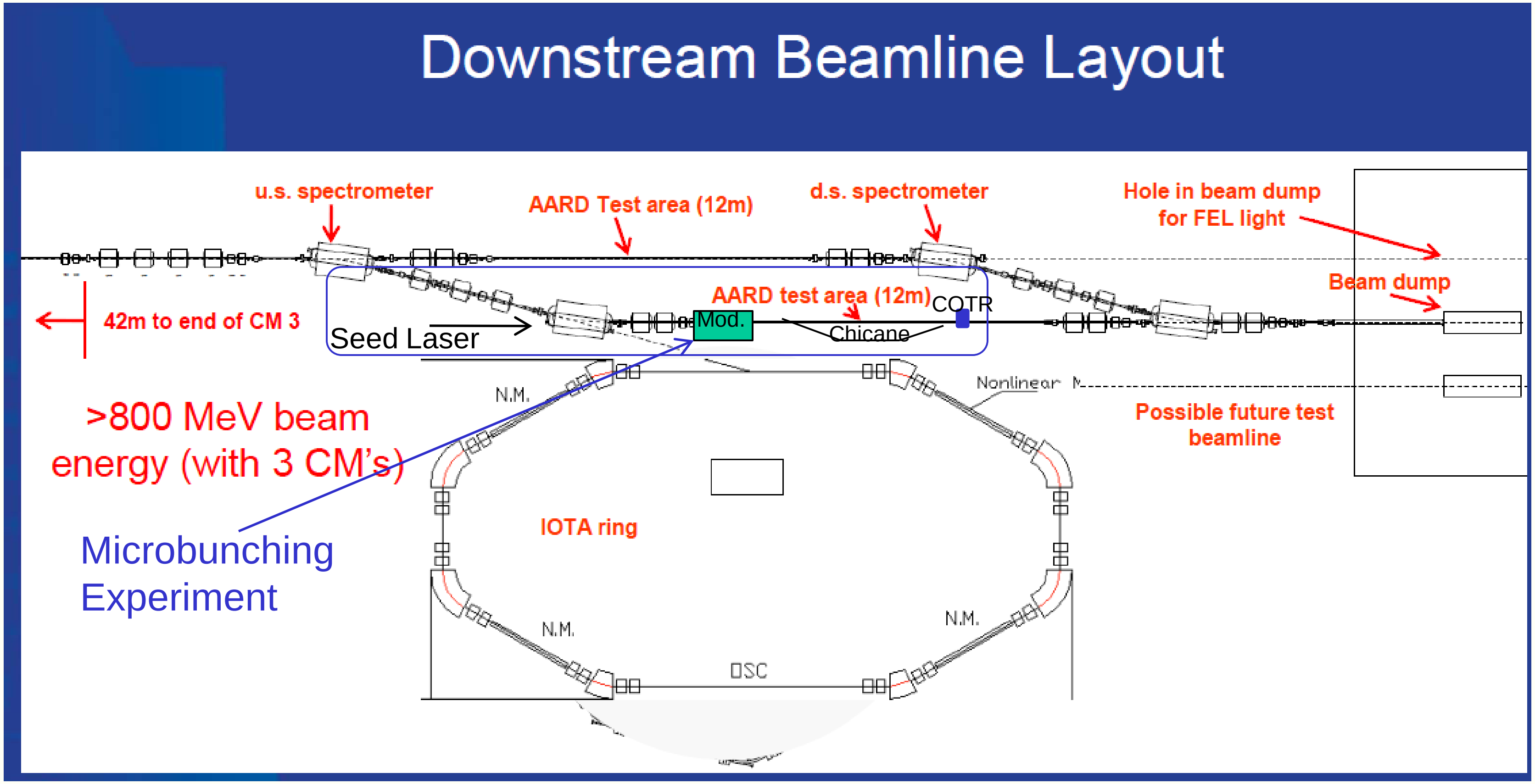
VUV MCP (FNAL)
Lens
CCD
(Angular Distribution)

Extend measurements
With VUV spectrometer
if possible.

PLANS

- Phase 1 tests at 40-50 MeV:
  - Develop the high repetition rate seed laser
  - Explore slice e-beam properties
  - Explore COSR potential diagnostics
  - Investigate harmonics, n=2-10 and demonstrate diagnostics
    - Benchmark codes on bunching fractions.
- Phase 2 tests with one cryomodule at E>250 MeV:
  - Extend tests with different modulator and fundamental,
  - Use drive laser and diagnostics concepts from Phase 1,
  - Develop HGHG or EEHG Configurations
- Phase 3 tests with E>500 MeV, Oscillator configuration?
- Phase 4 tests with E>800 MeV

High Energy: LIM Phase 2



Revised M. Church Layout

Possible LIM Tests at ASTA

- **Phased approach tracks with increases in beam energy.**

Phase #	Beam Energy (MeV)	Laser Fundamental (nm)	Und. Period (cm), K, n	Microbunching Harmonics (nm)
1a	44.5	800	2.18, 1.2, 3	400,266, 200
1b	44.5	800	2.18, 1.2, 3	100,90,80
2	200 250	266 800	5,1.2,1 20, 1.36,1	48, 29,26 400,266,200,80
2 2 3-HGHG 4-SASE	500 500 900 900	-- 266 TBD --	5,1.2,1 5,1.2,3 TBD 1.1,0.9,1	--- 48,29,26 3

Personnel Involved

Fermilab

- **Collaborations of FNAL and LBNL**

	Planning	Experiment/Laser	Diagnostics	Analysis	Simulation
A. Lumpkin	yes	Experiment	yes	yes	
J. Ruan	yes	Laser	yes	yes	
R.Wilcox	yes	Laser		yes	
J. Byrd	yes	Experiment		yes	yes

At FNAL, A. Lumpkin is a microbunching experimentalist, and J. Ruan is a laser expert. R. Wilcox is a laser system expert at LBNL who would work on the OPA, and J. Byrd is a beam dynamics expert.

SUMMARY

- Present FEL seeding configurations such as HGHG and EEHG could be elucidated by complementary electron beam microbunching measurements.
  - Strong COTR and COSR emissions at laser fundamental and harmonic wavelengths expected due to beam microbunching.
  - Studies of COTR strength after the modulator plus chicane and after a radiator needed. 2-D spatial imaging, 2-D angular distributions, x,y-spectral imaging, longitudinal imaging are possible. Gives slice electron beam properties as well.
  - Initial COTR tests in FY12 at Shanghai DUV FEL.
    - Benchmark codes on bunching fractions.
- Diagnostics techniques should be extended to VUV and soft x-ray regime where possible at ASTA into harmonic frontier. (several technology challenges: mirrors, optics, detectors, filters, e-beam and laser pulse trains)