Short-Range Wake Fields, HOMS, and Other Experimental Programs

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FAST Mtg

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50 MeV Considerations

- FAST team is about to commission the linac with CC1 and CC2 to generate ~50 MeV beams.
- After basic commissioning of loss monitors, MPS, diagnostics, and transmission of 50 MeV to the spectrometer, beam studies and experiments would occur.
- Transport of beam through center of cavities is needed to mitigate emittance growth due to short range and long range wake fields.
- Higher order mode (HOM) detectors and beam size and position monitors can be used as first diagnostics.
- Bunch length monitors after commissioning can be used as comprehensive diagnostics for experiments.

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Higher Order Modes (HOMs)

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- HOMs are induced by off-center steering in rf cavity.
- Investigate long range deflecting dipole mode acting within the macropulse; ~10-μs range. Vary bunch #.
- The magnitude of the HOMs can be increased by steering transversely off axis in cavity, intentionally or unintentionally, Q dep., and result in emittance growth.
- Commission HOM detectors in CC1 and CC2. (Nathan and Peter plus Ops.) (2)
- Perform initial long range effects search with HOM detectors, various offsets, charges, and beam size/pos. tracking after CC2 in (X107), X108, X121. (Alex, Jinhao, Chip, Dan, Nathan). CC1,CC2 Transfer matrix input? (2)
- Bunch by bunch rf BPM readings requested. CCD gates.

Short-range Dipole Wake Fields

- Investigate short range deflecting dipole mode wake field acting within a single micropulse; 1-20 ps range.
- Use 1-10 micropulses to look for effects initially.
- The magnitude of this wake field can be increased by steering transversely off axis in cavity, intentionally or unintentionally, Q dep., and results in emittance growth.
- Perform initial short range wake field search with (HOM detectors), various offsets, charges, and beam size/pos. tracking after CC2 in (X107), X108, X121. (Alex, Jinhao, Chip, Dan, Randy). CC2 Transfer matrix input? (2)
- X107 slit images may show kick angle effects at X108.
- If/when correlated beam size growth with offsets seen at X121, then pursue the streak camera studies to clarify.

TESLA-1: Short Range Wake Field

- **Use short range transverse wake formula for one middle cell of 9-cell TESLA cavity with aperture, a=35 mm radius,with s = the distance after the drive charge, Z_0=free space impedance, c =speed of light.**

$$w_{\perp}(s) = \frac{2}{a^2}\frac{\sqrt{2}Z_0 c}{\pi^2 a}\sqrt{\bar{g}s} = 235 s^{0.5}[V/pC/m],$$

where $\bar{g}$ is "effective" cavity gap, $\bar{g} = 0.84L$, expressed through the cell period $L = 10.54cm$ in the TESLA cavity. As we see relation (1) holds exactly.

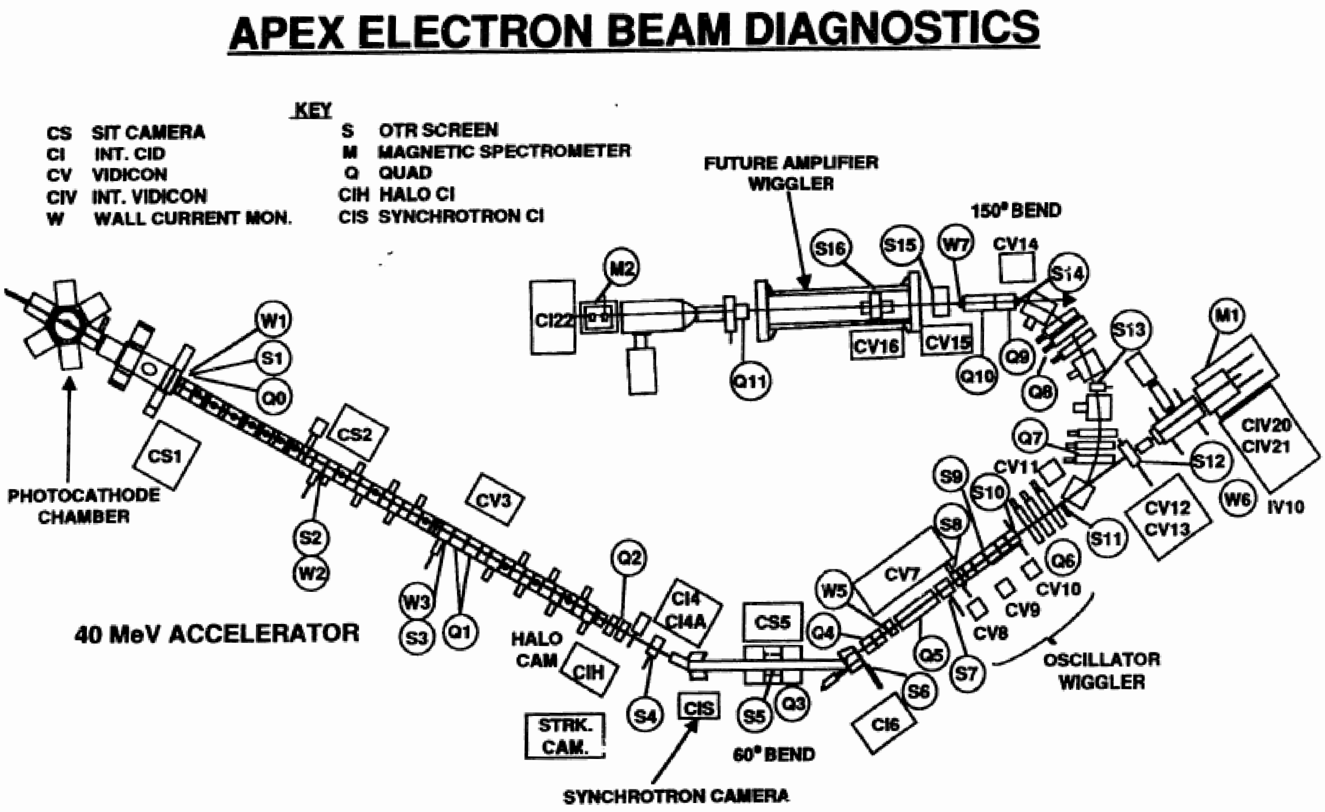
T. Weiland, I. Zagorodnov TESLA 2003-19

Estimate: w_{perp}= 235 $s^{1/2}$ x offset (m) x drive charge (pC) x cells [V/pC/m/cell]
= 235 $(5\ mm)^{1/2}$ x 10^{-3}m x 100 pC x 1 V/pC/m

w_{perp} = 1.66 V Case 1, per B. Carlsten email (LANL)

LANL Wakes 1

- **Suite of diagnostics available in FEL facility (1992).**



A.H. Lumpkin, NIMA (1993)

LANL Wakes 2

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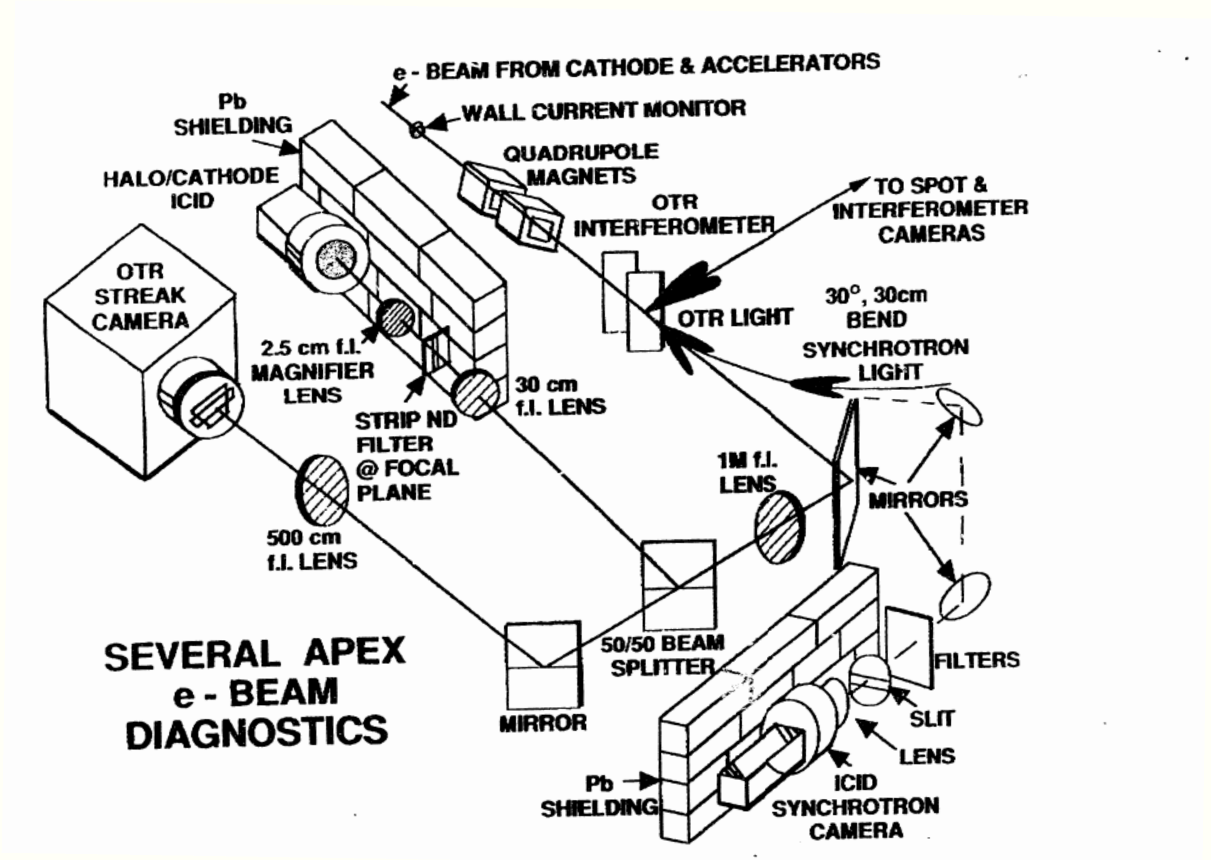
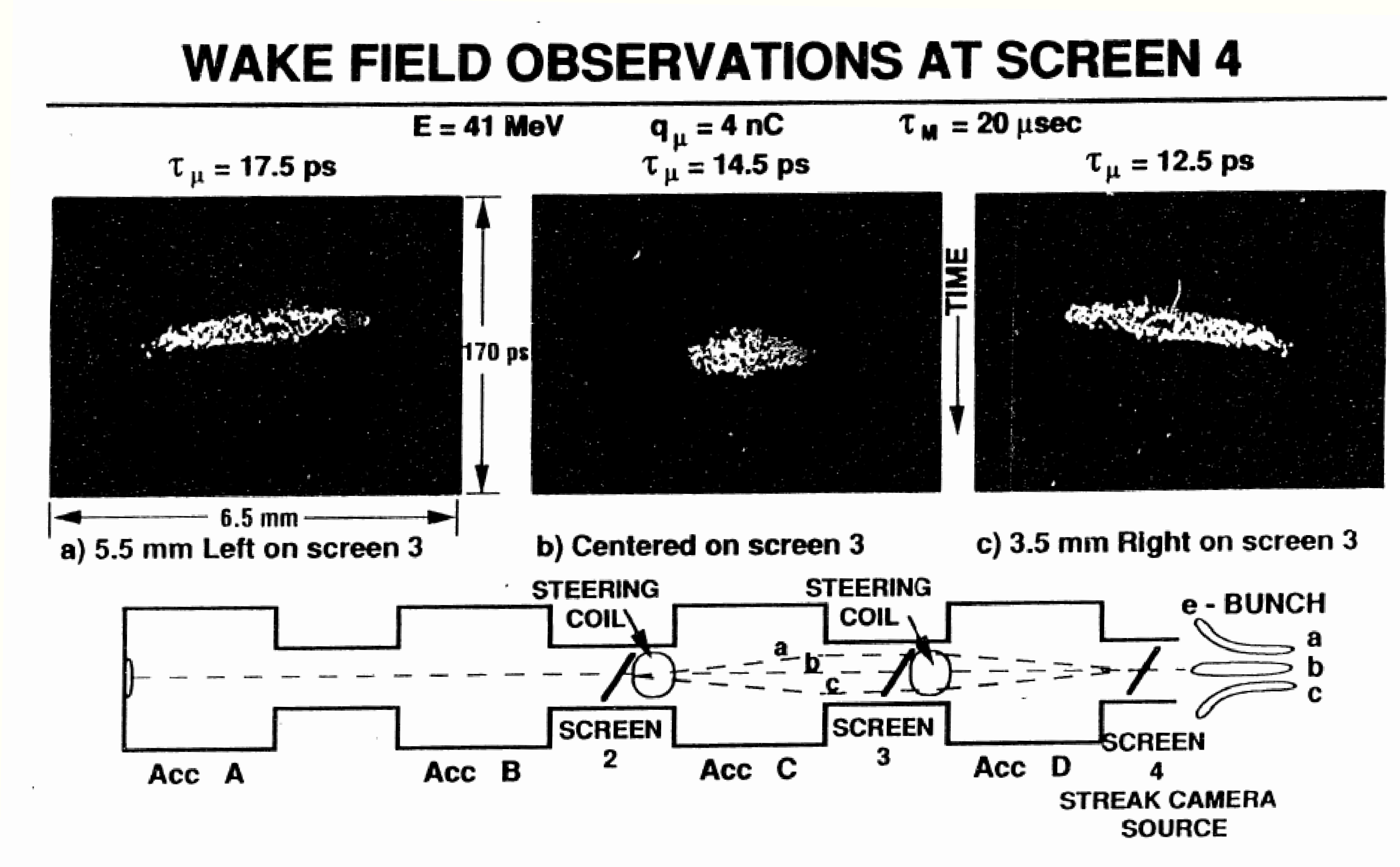
- Intensified cameras and streak camera in linac.



A.H. Lumpkin, NIMA (1993)

LANL Wakes 3

- **Observed x-t tilt and x-size growth with beam offsets.**



A.H. Lumpkin, NIMA (1993)

LANL Wakes 4

- **Diagnostic shows observed emittance growth and reduction with steering through cavity 4.**

~Case 8 in Table 1

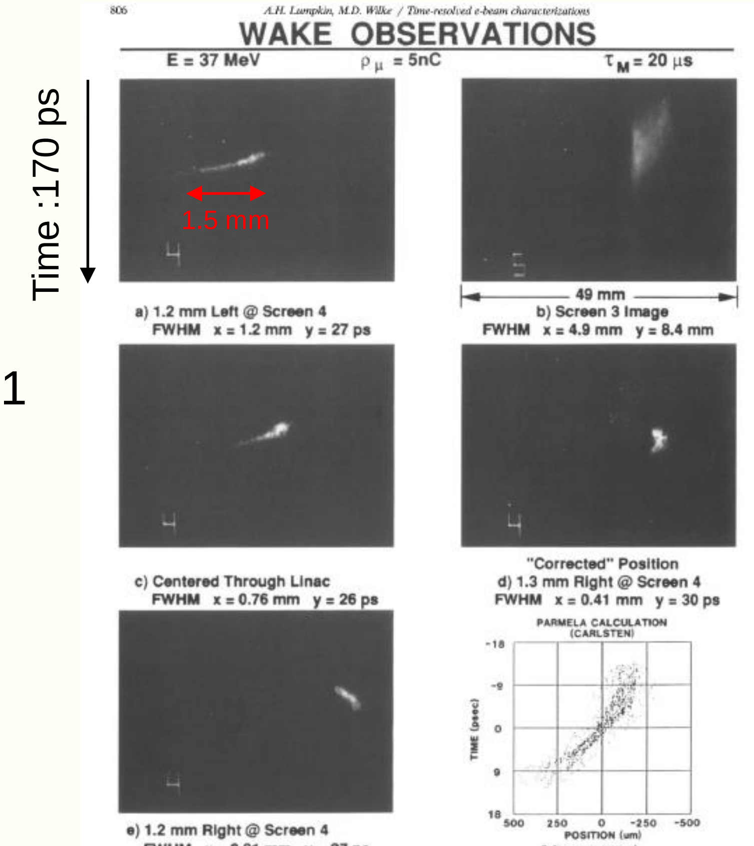
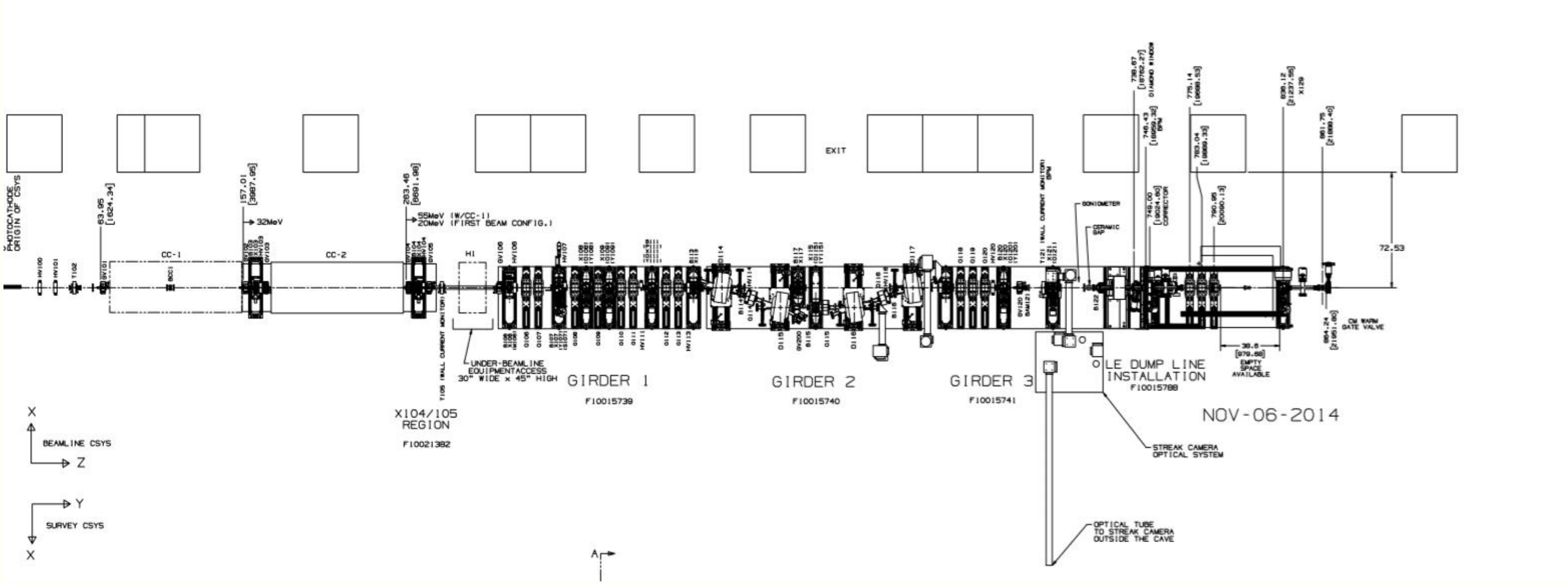


Fig. 6. A composite of streak images at station 4 for steering horizontally "left to right" across the scene. Note the flip in the direction of the head-to-tail kick. Time increases going down on the vertical axis.

A.H. Lumpkin and M. Wilke NIMA (1993)

FAST Linac Layout

- **CC1 added to linac for 50 MeV ops.**

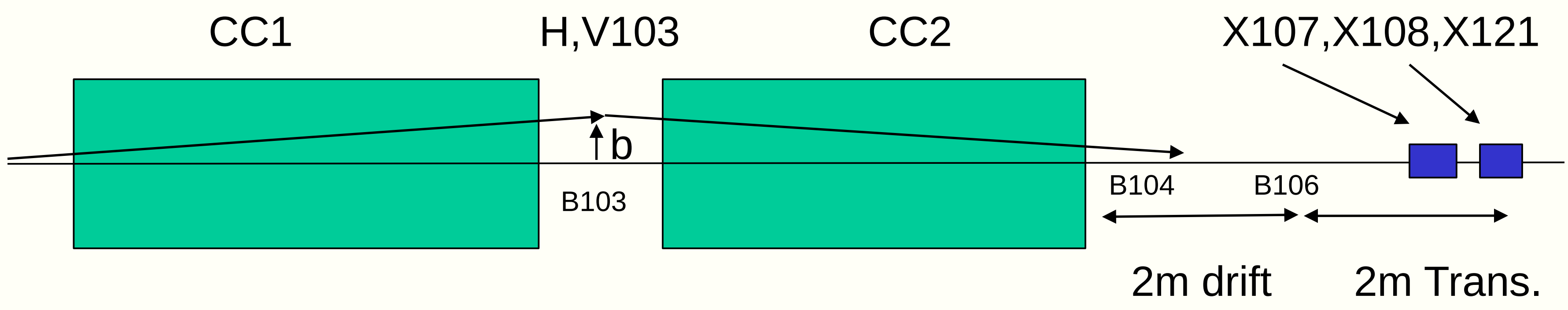


From Curtis B.

FAST Offset Examples

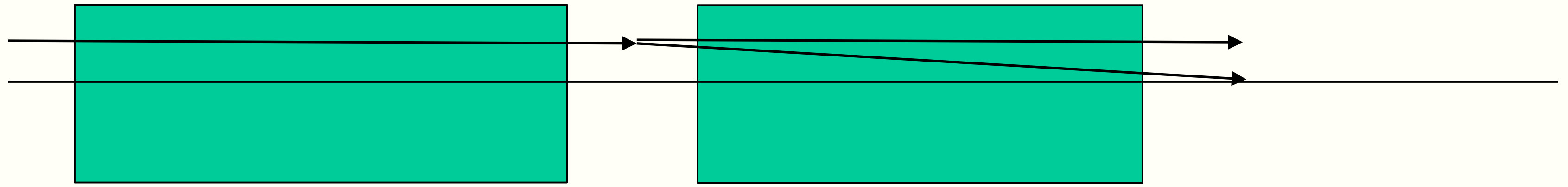
- **Some Kick and translation options, need b=0-5 mm offsets at B103 between cavities.**

A) Kicks (Case 4, b=2.5 mm, b_{ave}=1.2 mm)



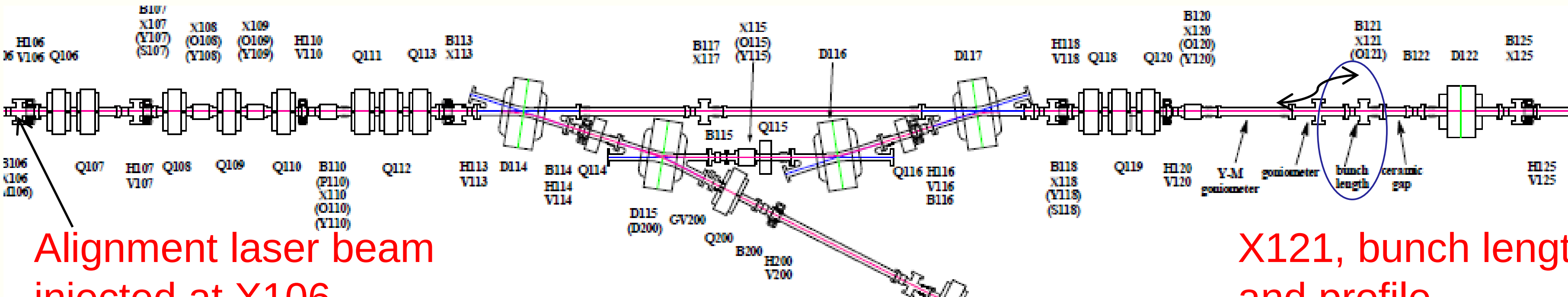
B) Translation w or w/o kick after CC1

Note: MATLAB Version of ImageTool (JR) needed.



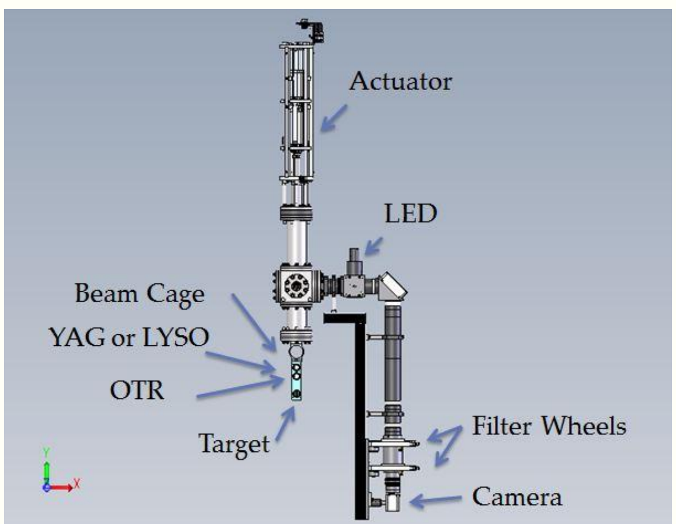
Injector Beamline After CC2

- Diagnostics available for beam commissioning. (X107), X108, X109,X110, X120, X121, X124, rf BPMs, loss monitor.



Alignment laser beam injected at X106

X121, bunch length and profile



SCRF Cavity Dipole Wakefields

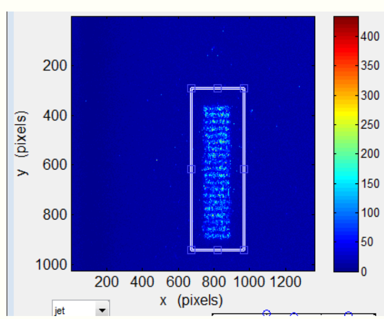
- The magnitude of the dipole wakes in CC1-CC2 will be evaluated at the submicropulse level for off center trajectories through the cavities in y plane.
- Initially use 4 ps (sig) pulse with our sub-ps resolution linac streak camera to obtain y-t images.
- Look for centroid kick within the micropulse time. Images should be tilted in this space when fields are strong enough. This results in emittance growth on ave.
- Extend experiments with α-BBO generated modulations of about 25 ps flattop or two 10 ps wide doublets separated by 20 ps. Combinations will probe the extent of short range wakefields.
- Extend studies with chicane compression if indicated.

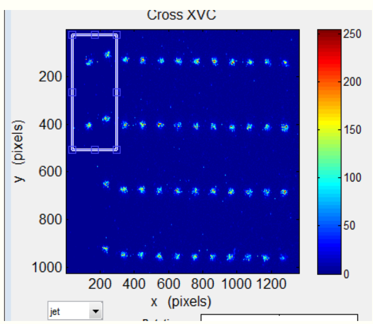
Streak Camera Diagnostic Modes for HOM and Wakefield Studies

- **Table 2: Summary of streak camera configurations.**

Effect	Mode	Temporal resolution	Spatial res. (μm, est.*)	Wake Range
Sub-Micropulse, y-t	Synchroscan,V	1ps	50-100	short
Sub-macropulse, y-t,T	dual sweep,H,V	1ps, H axis selectable	50-100	short
Sub-macropulse, y-T	Slow sweep,V	100 ps	50-100	long
Sub-macropulse, x,y-T	Framing Mode	100 ps	50-100	long

UV laser pulse train demos





*Bunch-by-bunch techniques can be applied to IOTA beam turn by turn.

* Spatial effects will be referenced to effects seen on the X121 YAG screen.

Long Range Transverse Wakes

- **Look for dipole effects over longer macropulses with different offsets through cavities.**
- **Need bunch-by-bunch sampling of beam position. (Same techniques applicable to turn-by turn IOTA data)**
- **rf BPM system needs new firmware feature for bunch by bunch data per Nathan. 2 months for Ning to get to it.**
- **Slow streak of X121 OTR provides y-T dependence during macropulse. Once done at LANL/Boeing FELS.**
- **MHz framing technique with linac streak camera viewing X121 OTR screen images could provide extended centroid and size tracking details. New appl., also IOTA.**
- **Challenges for micropulse signal and beam shape info.**
- **Use X121 YAG:Ce for reference cal of spatial effects.**

Bunch Length Monitors

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- Prior to 50-MeV beam the multi-function bunch length monitor station will be reconfigured:
  - the Martin-Puplett Interferometer (MPI) will be installed and aligned (RT-K).
  - Switching mirrors with remote control added to select radiation sources from chicane dipoles 3 and 4. (CSR, OSR) and X121 (OTR,CTR,CDR).
  - Read back on absolute position of X121 vertical actuator will be added.
  - Paths for OSR and OTR to the streak camera will be aligned. Additional radiation splitting mirror added
  - In addition, Ceramic gap monitor will be reinstalled.

Bunch Length Monitor Modes

- After commissioning of MPI and streak camera at sub-ps level, one can benchmark ceramic gap in this regime.(4)
- The MPI can be used to detect longitudinal modulation from X115 slits with X121 CTR first, then CDR as non-intercepting mode. (2)
- The streak camera can measure OSR from D3 and D4 potentially with 50 MeV beams. D3,4 have CSR sources.
- The X121 CTR and CDR can be used as potential phase diagnostic via pyro detector for beam based feedback.
- Ceramic gap monitor signals may have phase info under some conditions.
- Comprehensive wake field studies may be done with streak camera configurations. (short and long range) (5)

SUMMARY-1

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- Proposed investigation of HOM effects in CC1 and CC2 on beam size and emittance at FAST.

  (rf BPMs bunch by bunch, pulse number, CCD gate)
- Short range wakefield dependencies on iris, distance behind drive charge, beam offset in cavities, and drive charge estimated.
- Use HOM detectors and beam line imaging stations to map out regimes of interest.
- Once seen at X121 YAG screen, use streak camera configurations to display sub-micropulse kick effects as at LANL and long range effects. Simulations welcome.
- Significant opportunity at FAST to explore HOM and wake field effects with unique and comprehensive diag.

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Discussion

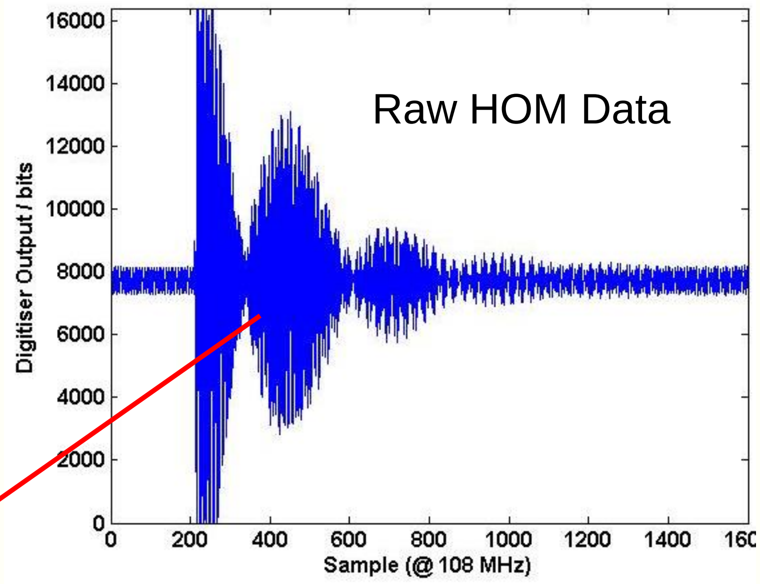
- The goal is to mitigate emittance growth due to short range and long range wake fields induced by steering offsets in CC1 and CC2.
- The HOM detectors are viewed as critical to putting the beam on the cavity field centerlines.
- The channeling radiation experiments require best available emittance since Tanaji said they wish/need 100 nm emittance at 10s of pC. These are not expected FAST beam numbers simultaneously.
- It was noted that the rf BPMs have a 50-pC threshold.
- The proposed bunch-by-bunch diagnostics of rf BPMS, slow streak sweep, and streak camera framing mode also could be used for IOTA turn-by-turn position, size.

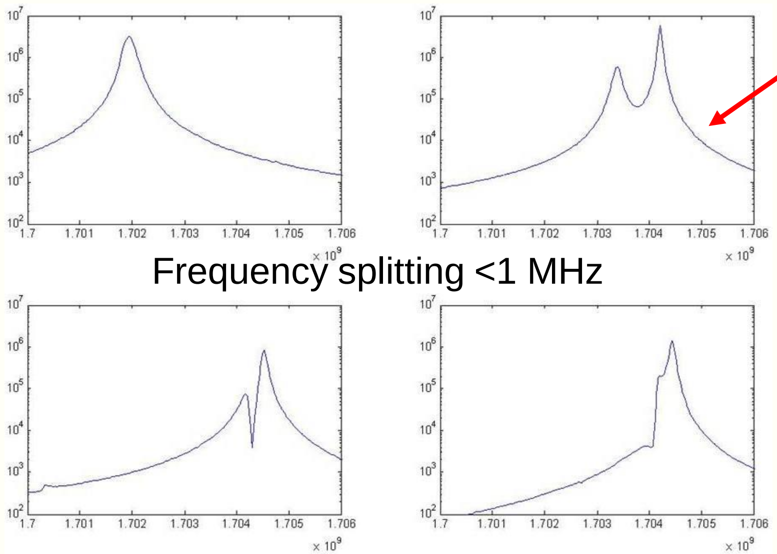
Narrow-band BPM System

Dipole modes exist in two polarisations corresponding to orthogonal transverse directions.

The polarisations may be degenerate in frequency, or may be split by the perturbing affect of the couplers, cavity imperfections, etc.

Makes determination of mode amplitudes difficult using traditional techniques





Frequency splitting <1 MHz

Mode Splitting in Different Cavities

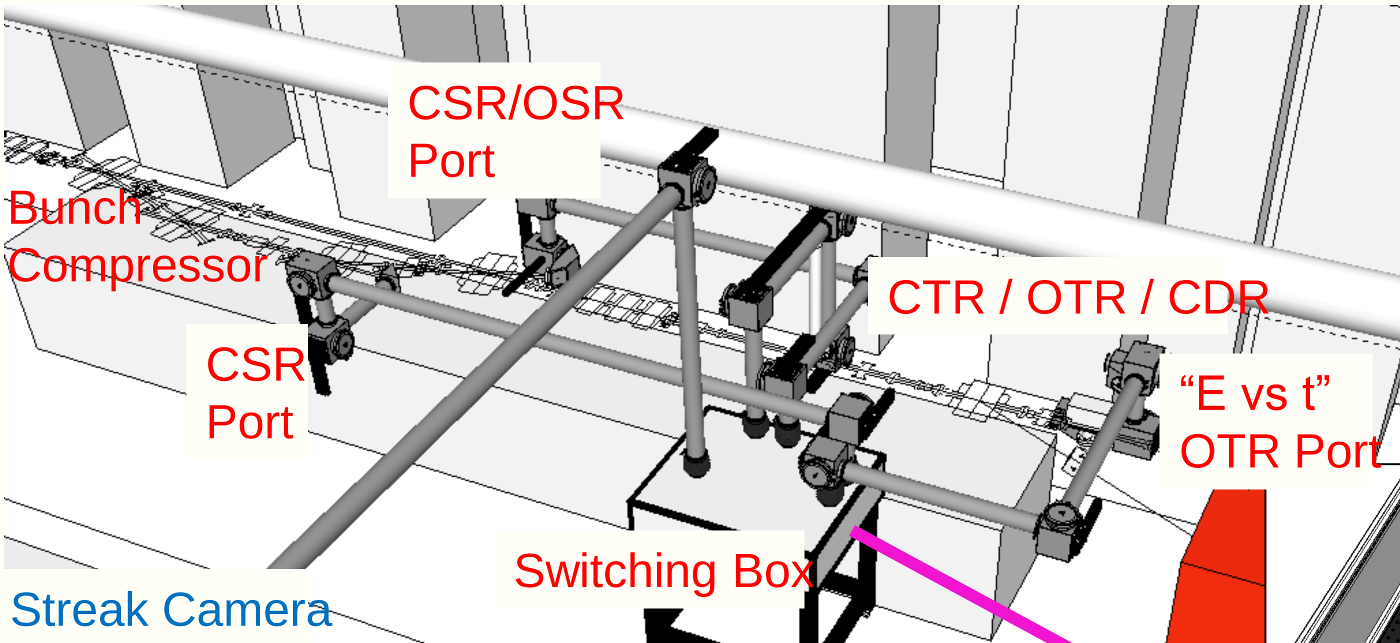
Need to calibrate the HOM response against positions from the BPMs

Use SVD to find orthogonal modes then regress the mode amplitudes against BPMs to determine calibration matrix

Multi-bunch data requires subtracting predicted amplitudes from previous bunch

Longitudinal Diagnostics

Pipes are SS with sanitary-style flanges



First Steps with Chicane Compression

- Linac Streak camera with current R1 speed will be recommissioned with chicane compression data.
- Then the R1 sweep speed will be adjusted from 0.38 ps/pix to about 0.15 ps/pix and a long pass filter (LPF) added to limit chromatic temporal dispersion effects.
- Expect about 0.6-0.8 ps (sigma) resolution.
- Bunch lengths of <1 ps will be generated using the rf chirp, chicane, and lower charges (<100 pC per micropulse). Streak camera commissioned.
- The MPI pyro detectors and the interferometer will be commissioned with the sub-ps length micropulses.
- With the streak camera and MPI commissioned, the ceramic gap monitor will be benchmarked against them.

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Beam Based Feedback

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- Evaluate rf amplitudes and phase stability within pulse train using diagnostics and consider for feedback.
- rf BPM at B115 in dispersive point (need firmware)
- THz signals from D4 and X121
- CSR and CDR into pyro detector of MPI -rf phase
- No BAM installed so use X121 OTR with synchroscan streak camera as BAM at 200 fs jitter (new application)
- Ceramic gap signal for some phase conditions- which?