Concept of RF Linac for Intra-Pulse Multi-Energy Scan

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Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Outline

Introduction
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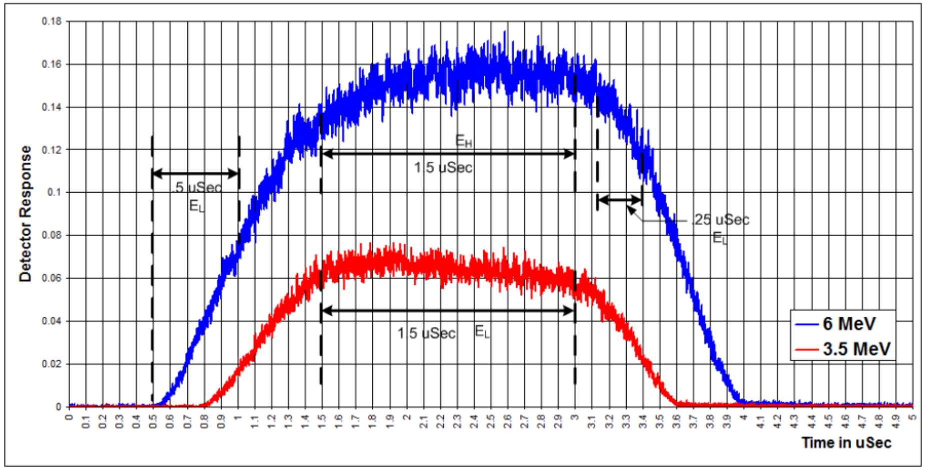
Introduction

- It has been proposed* that an array of fast detectors can resolve the temporal X-ray flux structure resulting from a ramped energy pulse. This can provide attenuation data versus beam energy that has been delivered during a pulse.

*Dr A. Arodzero, RadiaBeam

Linac in 3.5/6.0 MeV Interlaced Mode

- Preliminary R&D for such a detector system was conducted via a Linatron linac. The linac is based on a standing wave accelerating waveguide with a pulsed magnetron RF power source. An X-ray beam pulse after a converter has a ramp energy due to a electron slippage effects in accelerating structure.



- Neither beam current (X-ray flux) nor rate energy ramp can be controlled during the pulse mode of operation in the Linatron linac.

Introduction: Benefits of Ramped Energy Linac

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- Concept offers:

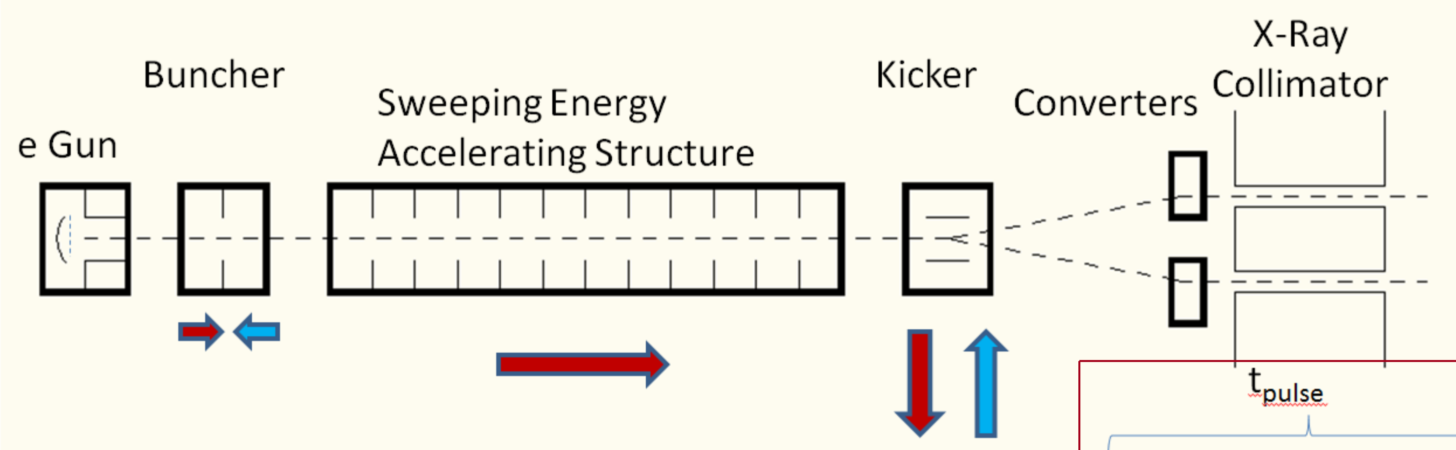
  - Adaptive control, selection, and maintain of the output of electron beam energy (and x-ray accordingly)

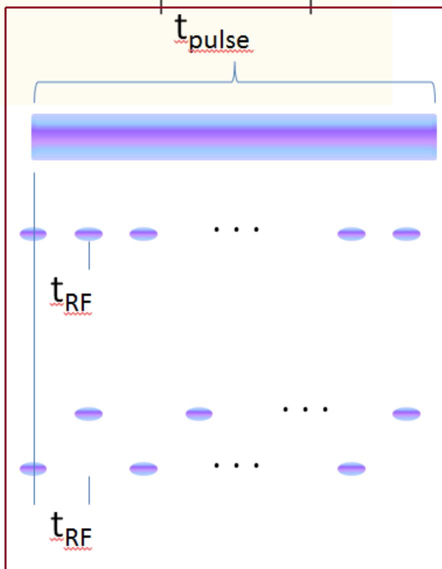
  - Adaptive control, selection, and maintain of the beam pulse width (and x-ray accordingly)

  - Adaptive control, selection, and maintain of the output of electron beam current (and x-ray flux).

Proposed Technical Approach

Concept for Intra-Pulse Multi-Energy Mode

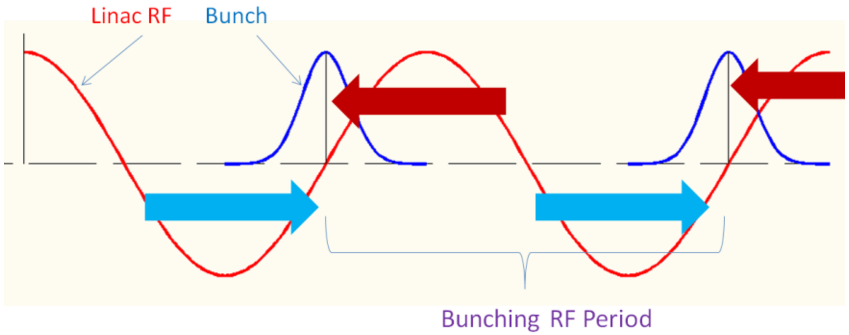




- e- Gun produces a continual electron flow during a pulse.
- The buncher creates a longitudinal modulation (bunch train) at the accelerating structure frequency.
- The energy of bunch train is increased in the RF accelerating structure.
- A transverse RF field at a sub harmonic frequency in the kicker separates the bunches.
- Electrons of each bunch converts into X-Rays at converters.

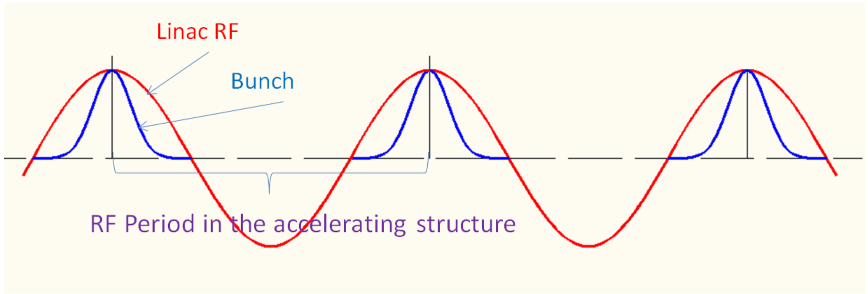
Bunching and Accelerating of Packed Beam

Longitudinal Beam Bunching



Electrons are accelerated in half of RF period and slowed in other half

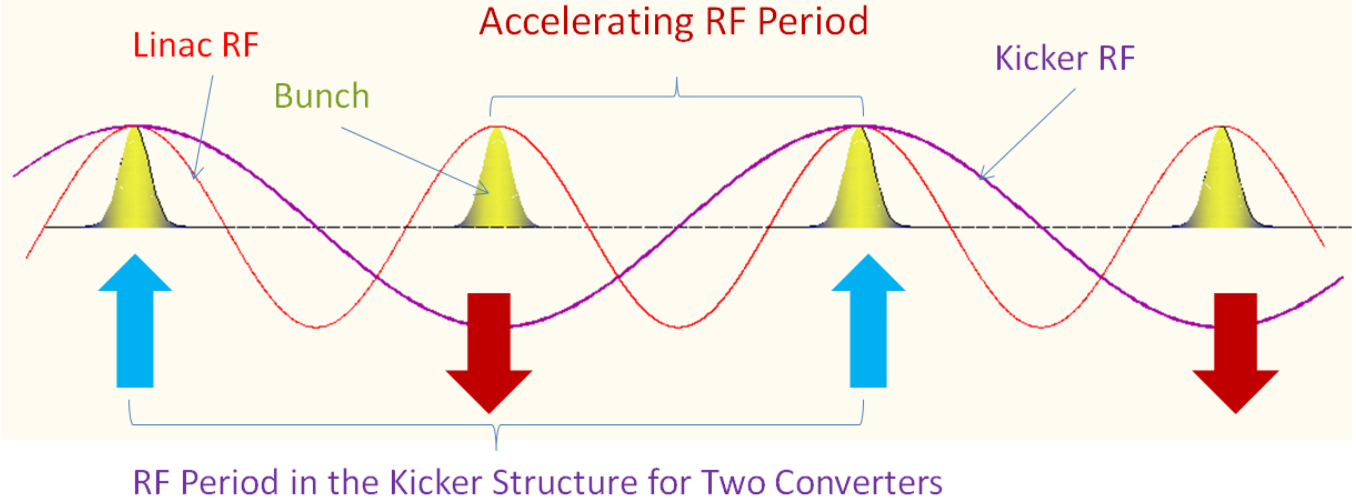
RF Acceleration of Bunch Train



A bunched train is set at the crest of the RF amplitude. Each bunch gets a maximum longitudinal momentum.

EM Fields in Kicker

Bunch Separation in RF Kicker



The natural frequency in the kicker structure is a sub harmonic frequency of the accelerating structure.

f_acc = n*f_kicker, where n is a number of converters

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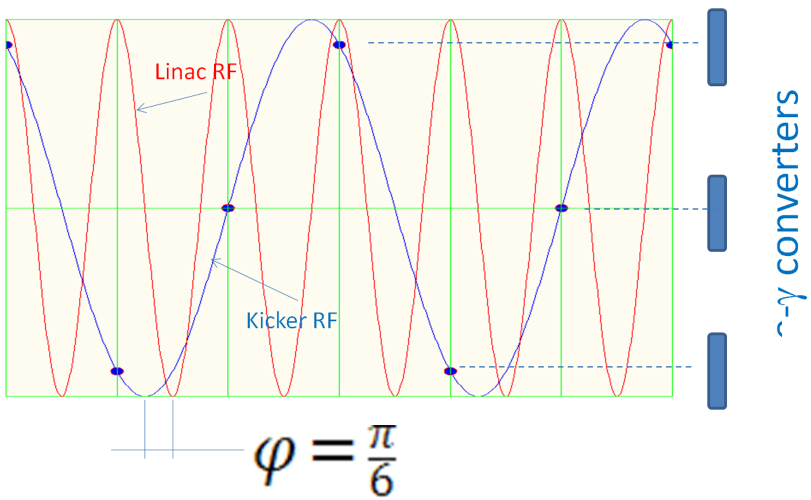
Relative RF Phases for 3 and 4 X-ray Beams

A Kicker Case "by 3" Separation



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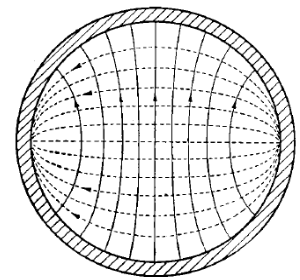
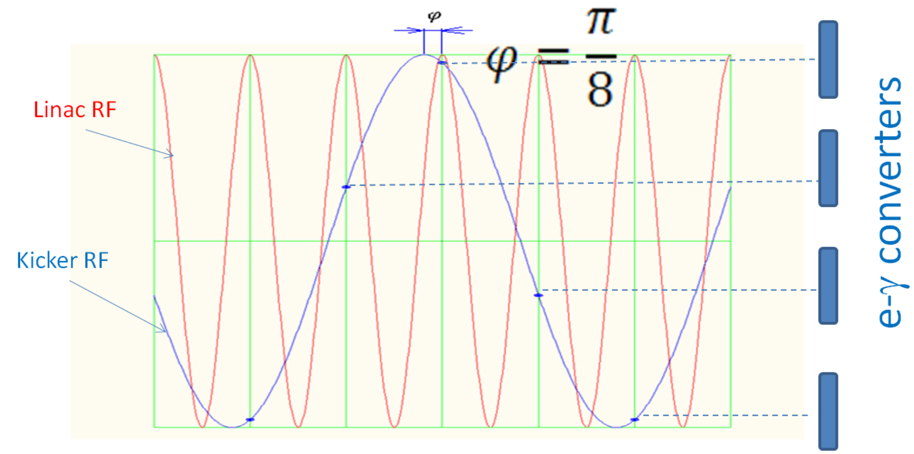


TE11 mode,
for example

A Kicker Case "by 4" Separation



For example, S-band (2.856GHz) is a kicker RF frequency and X-Band (11.434GHz) is an RF frequency of the accelerating structure

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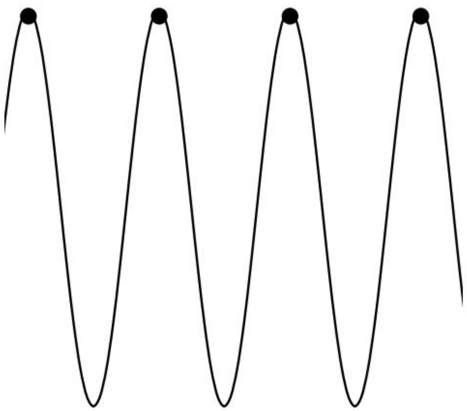
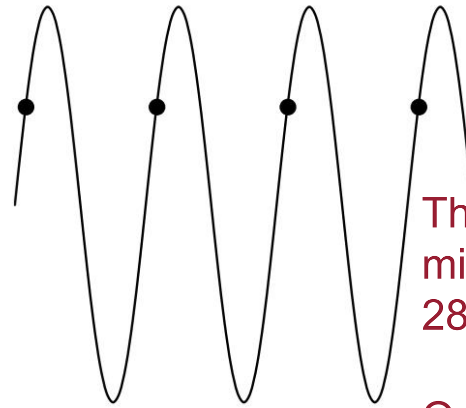
Bunches on ON/OFF RF Crest, Bunches with RF AM and FM

A



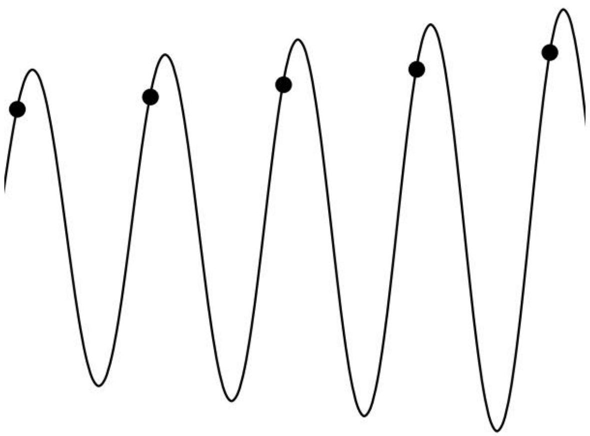
B



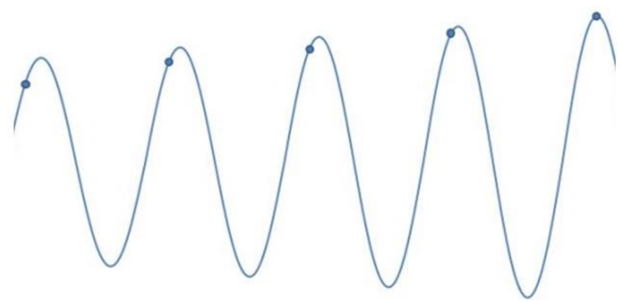
The pulse length is 4 to 10 microseconds (~9000 to 28000 RF periods).

Only few RF cycles and bunches are shown

C



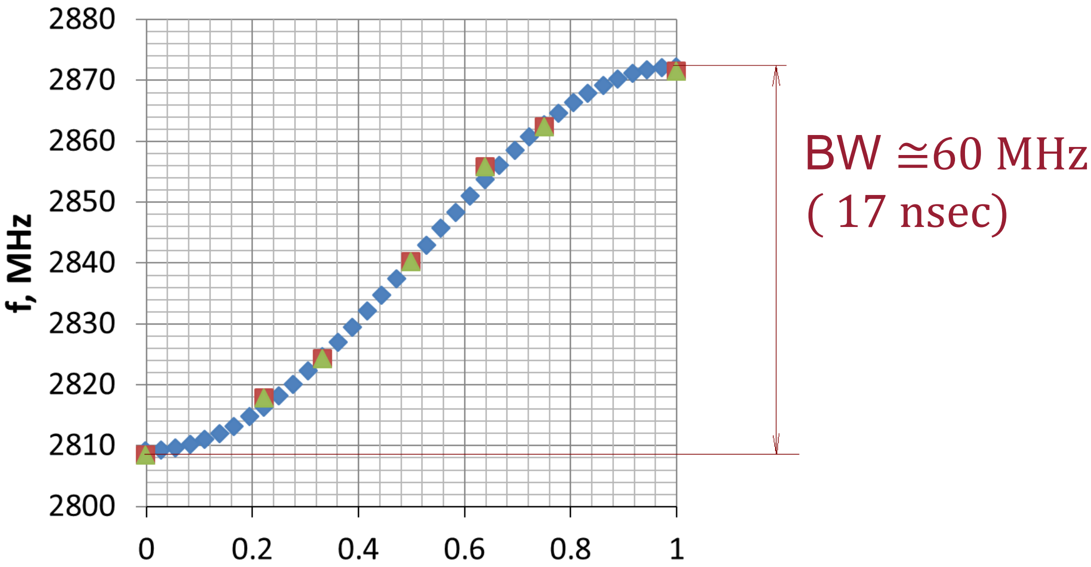
D



Adaptive selecting, control and maintain the output electron beam energy would be feasible if the system BW is wide enough

Proof of Concept Demonstrations (PoCD): Bandwidth Issues

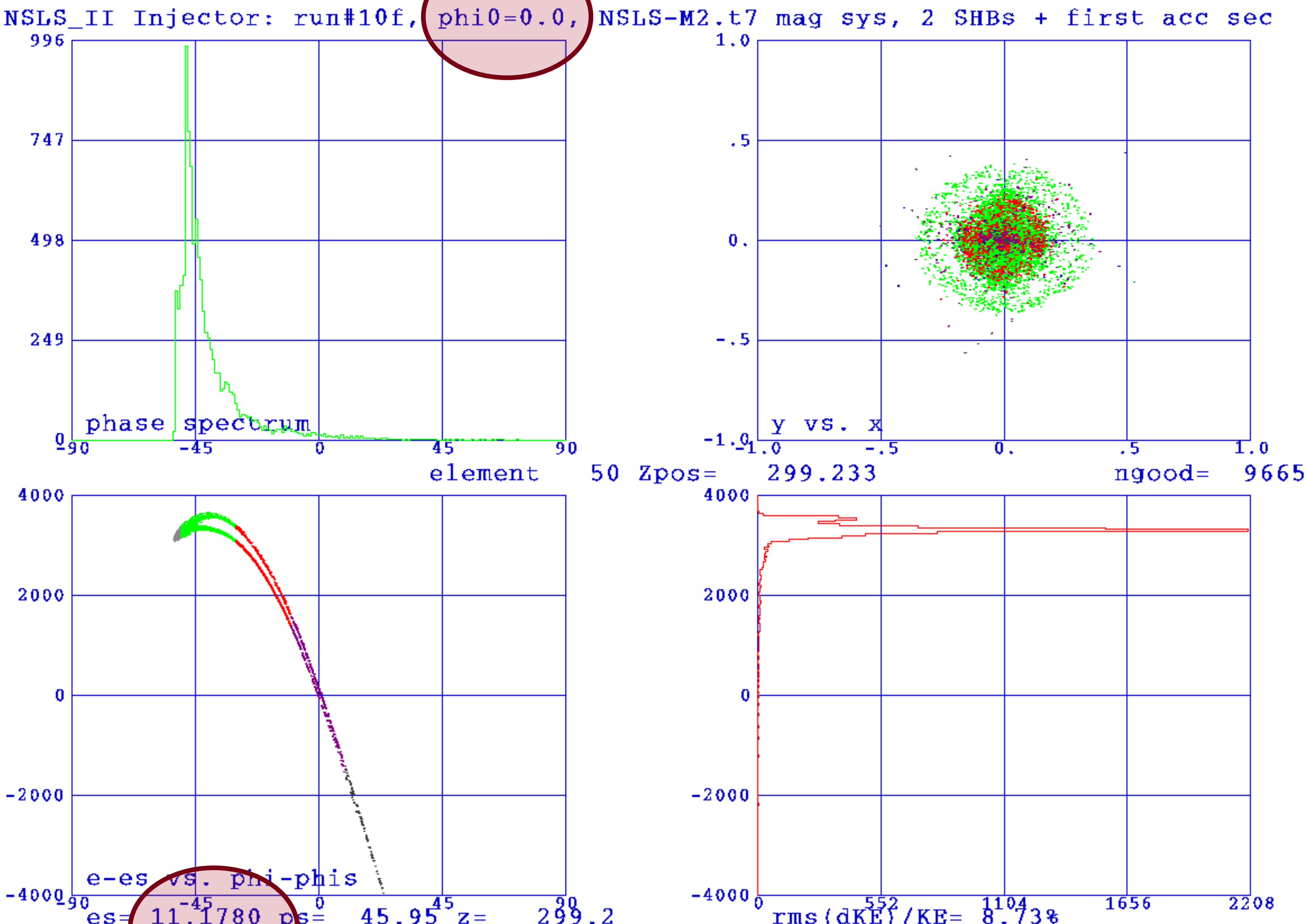
- High Power Klystrons: BW of RF sources are much wider against of DLWGs
- Accelerating Section:



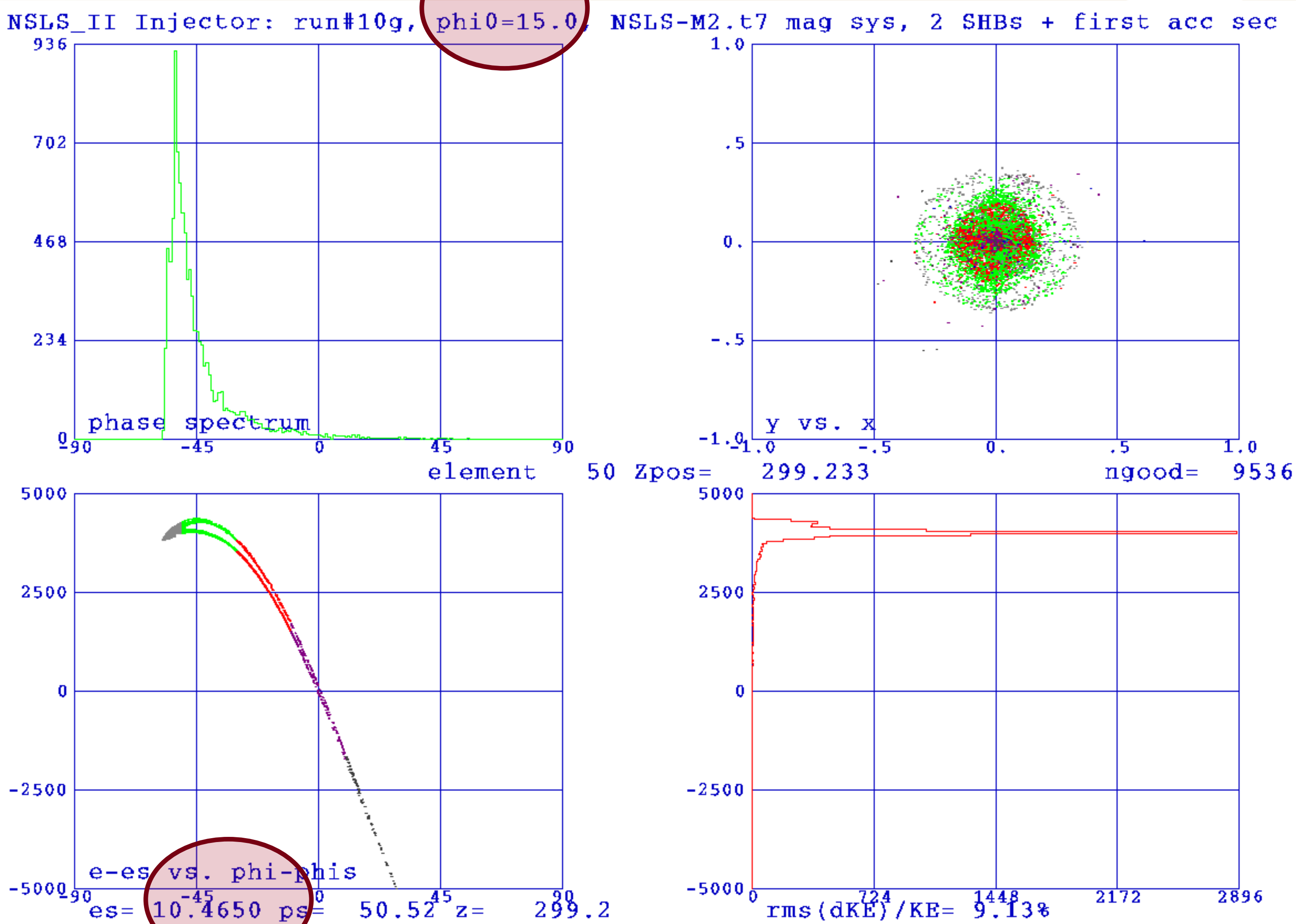
Dispersion curve for SLAC traveling wave accelerating cells

The BW of linac hardware (RF Source and Accelerating Structure) can be matched with the X-ray detector system based on modern X-Ray detectors

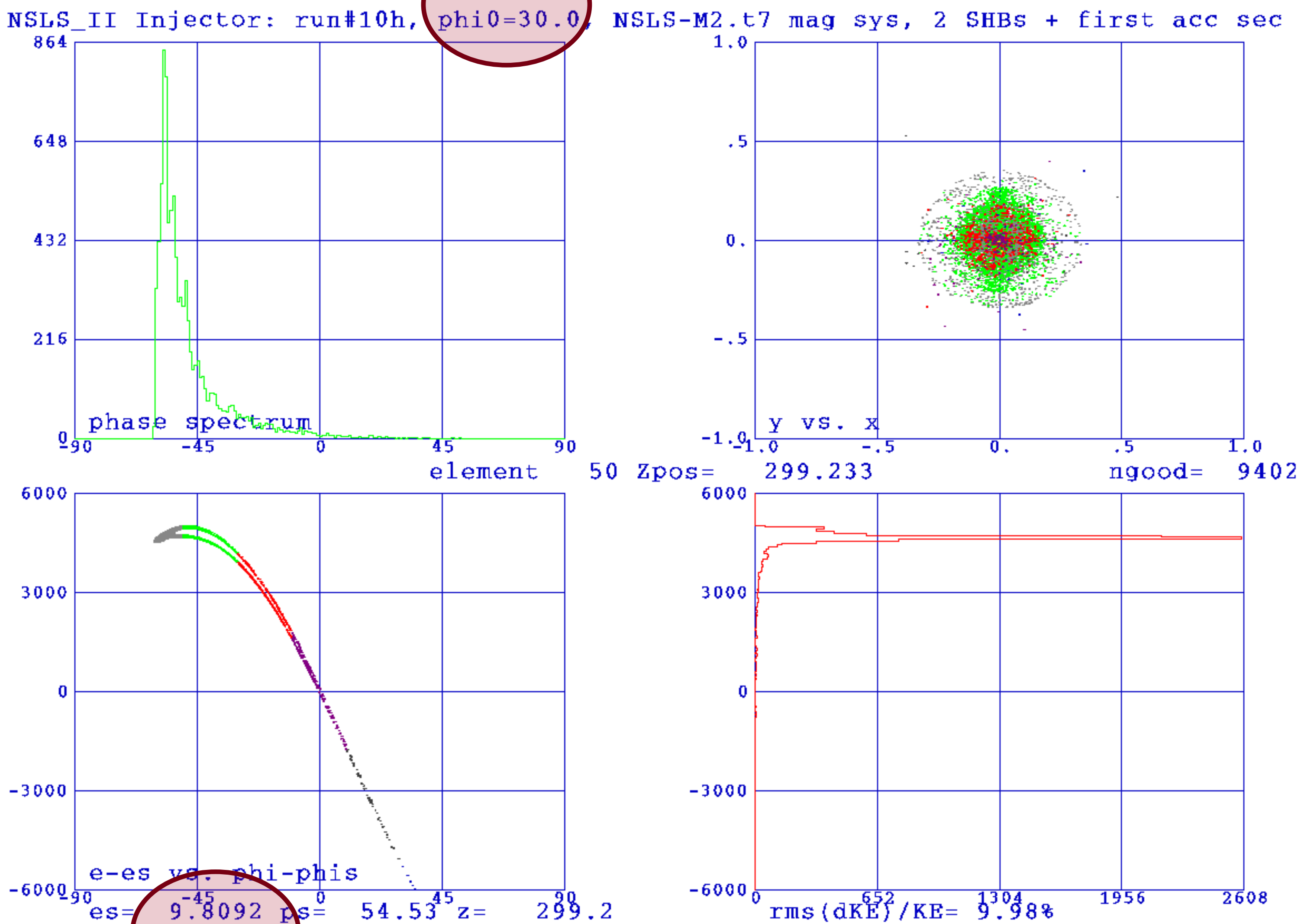
PoCD: Example of Parmela Simulation Phase Ramp



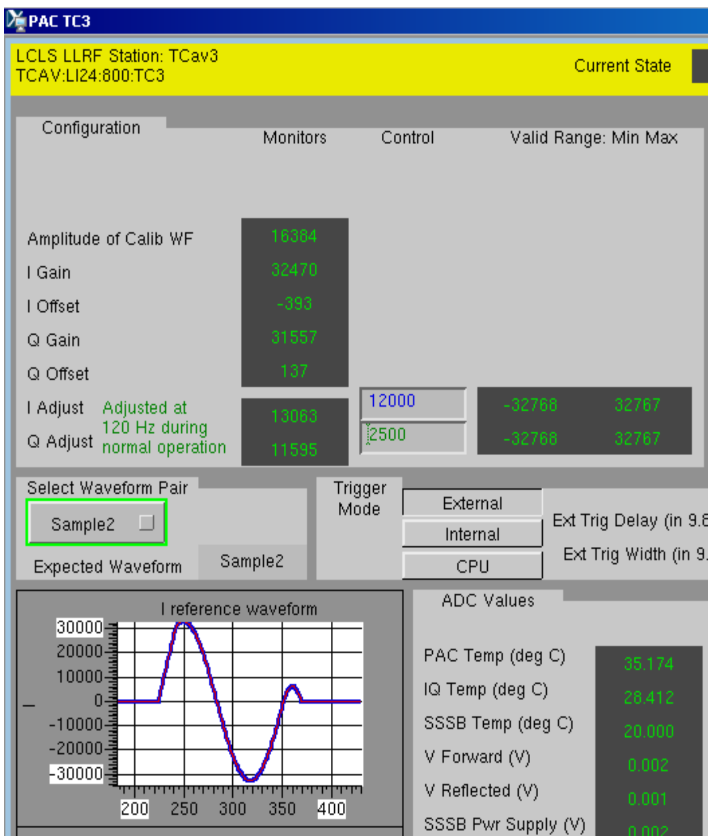
Example of Parmela Simulation Phase Ramp (cont.)

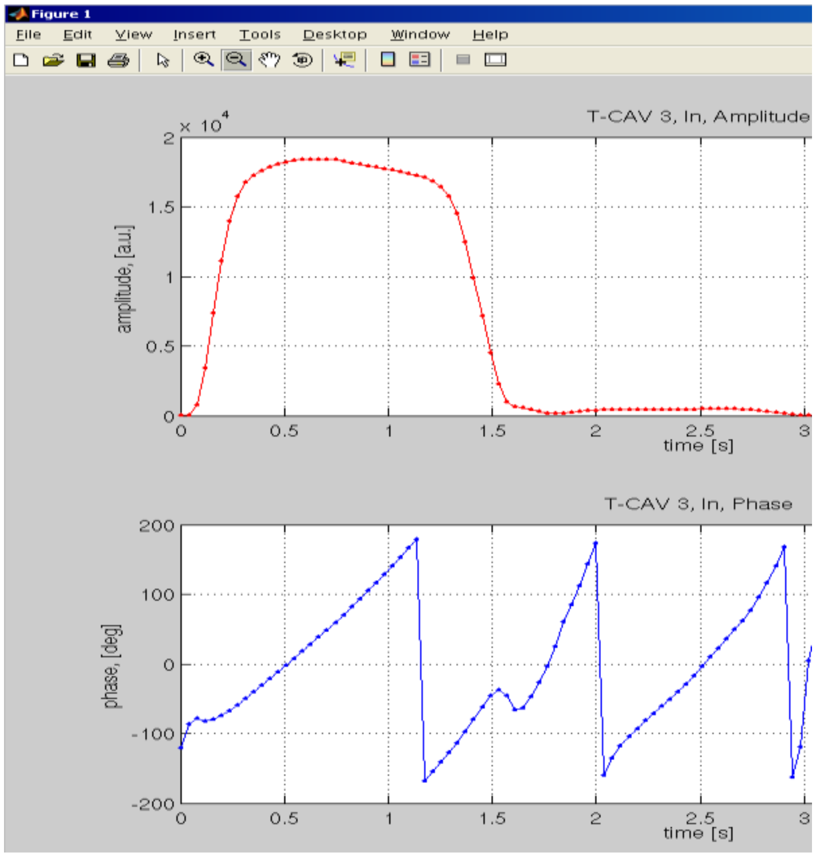


Example of Parmela Simulation Phase Ramp (cont.)



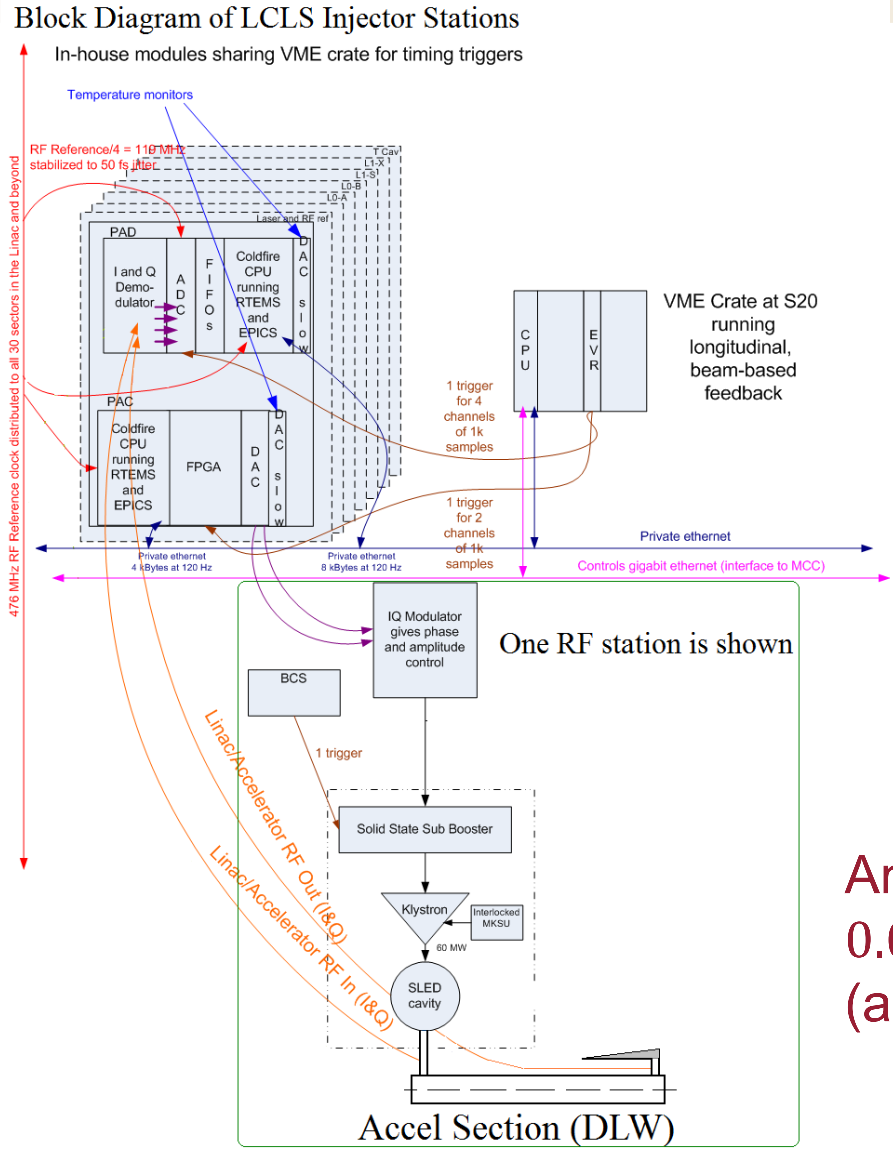
PoCD: Phase Modulation Experiment at T-Cav3 (LCLS)

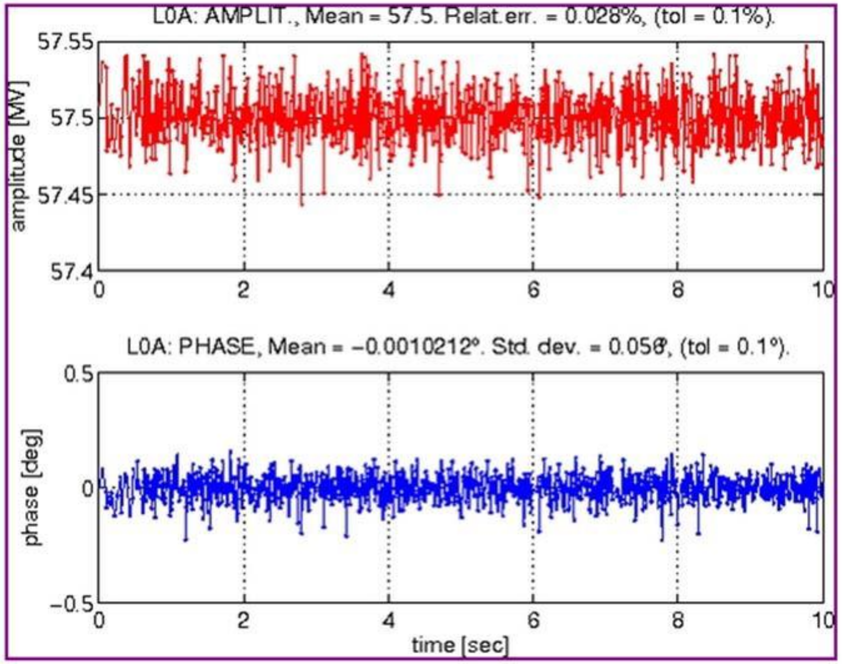




Concept of RF Linac for Intra-Pulse Multi-Energy Scan

PoCD: RF Amplitude and Phase Stability Issues

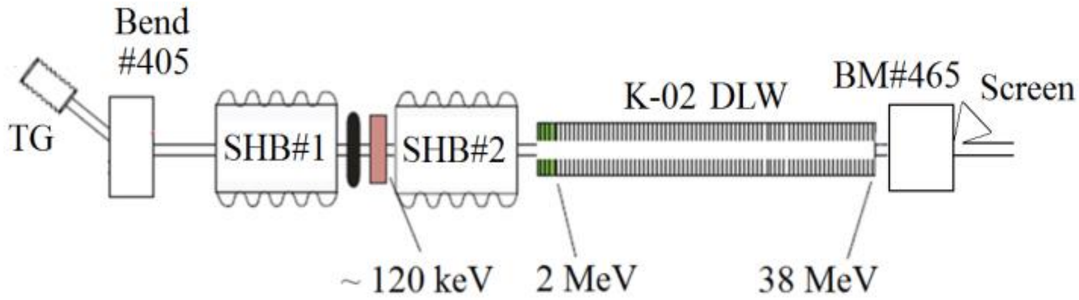


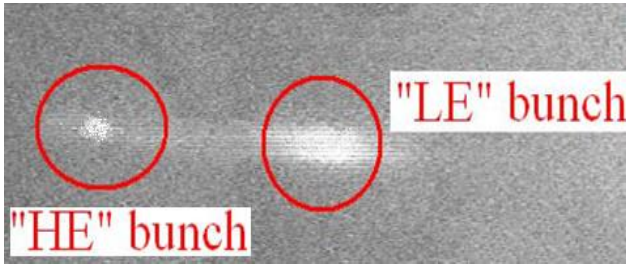


An RF amplitude stability of 0.03% with 0.06^{o} STD of phase is demonstrated (at 2856 MHz and 120 PPS)

PoCD: Block Diagram of the Beam-Based Experiment

SLAC





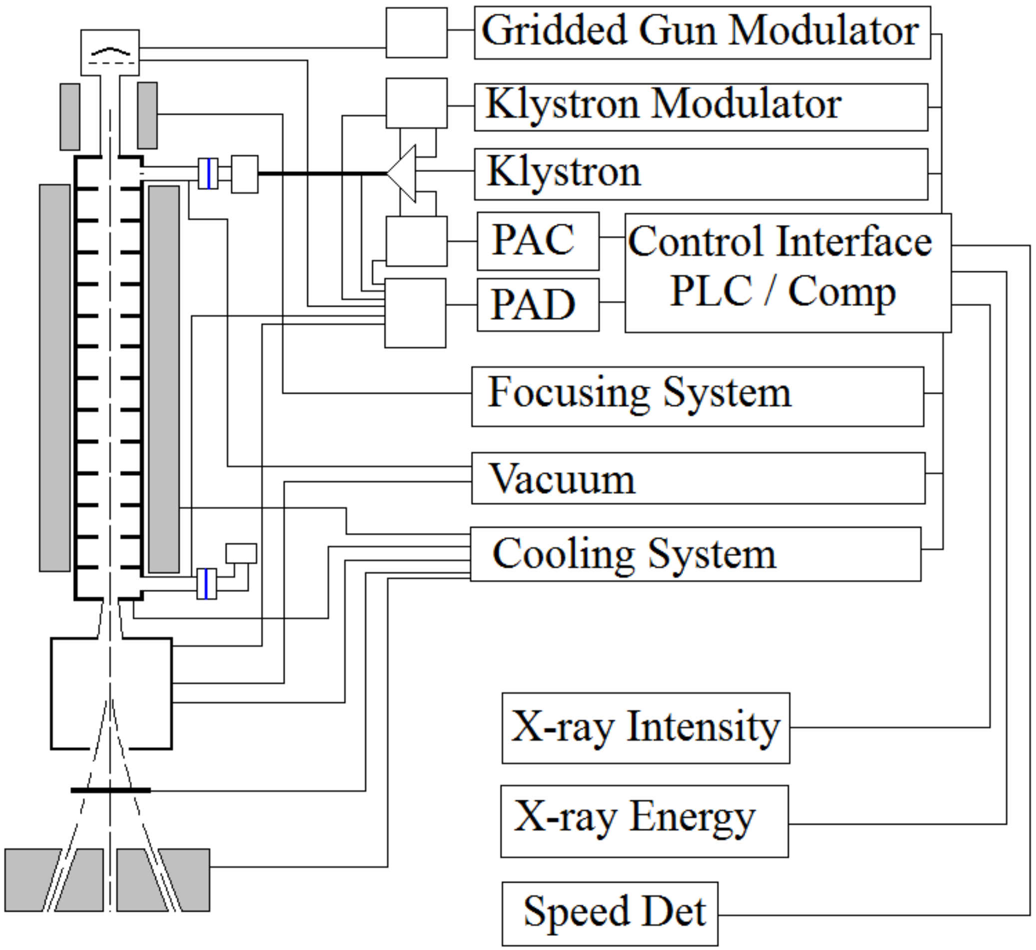
The phase and amplitude modulation experiment with two bunches separated by approximately 600 nanoseconds.

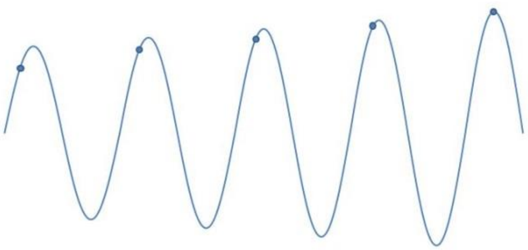
Bunches were placed in the same RF pulse but in different accelerating phases.

The separation between the two bunches is more than 17,000 RF periods.

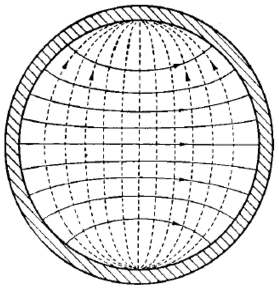
Both bunches were accelerated in the same beam focusing channel.

Linac System Layout





f_{rf}



$$f_{kick} = \frac{f_{rf}}{n}$$

with TE11 mode

Common Comments for the Concept

If the other things being equal than a multi target system on the linac output will require higher beam average power compared to the single target case.

$$P_{av} \leq \frac{c B_Z G}{W_\perp} \mathcal{F}$$

A pulse duration and a bunch population are parameters (should be optimized).

A bunch population depends on a/λ, f_0, G (a limitation is a short range of $W_\perp$).

A bunch separation depends on long-range $W_\perp$.

An acceptance of the accelerating structure should be optimized for a wide range of the electron energy (from 1 MeV to 10 MeV) and a wide range of the beam current.

Conclusion

An adaptive X-ray source concept based on a controllable electron beam energy and beam intensity was discussed.

The X-ray source contains the traditional accelerator components: electron source, bunching and accelerating section, beam kicker/spreader, and converter.

A specific feature of proposed source is its mode of operation. The intra-pulse multi-energy scan mode is feasible if the frequency bandwidth of RF components (buncher, accelerating, kicker, etc.) is in a 50-100 MHz range.

This mode of operation offers a combination of X-ray parameters to give high resolution images, better material discrimination, high scan speed, low dose, i.e. a controllable flexibility during the duration of the scan pulse.

In combination with fast detectors (which are adequate to the bandwidth of the linac components) this concept provides the information needed for material discrimination in a single X-ray pulse.

Acknowledgments

I would like to thank

- Dr. A. Arodzero for a linac problem origination,
- SLAC linac operators for support during the beam-based experiments

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