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Timing and LLRF for the Argonne Short X-Ray Pulse Beamline

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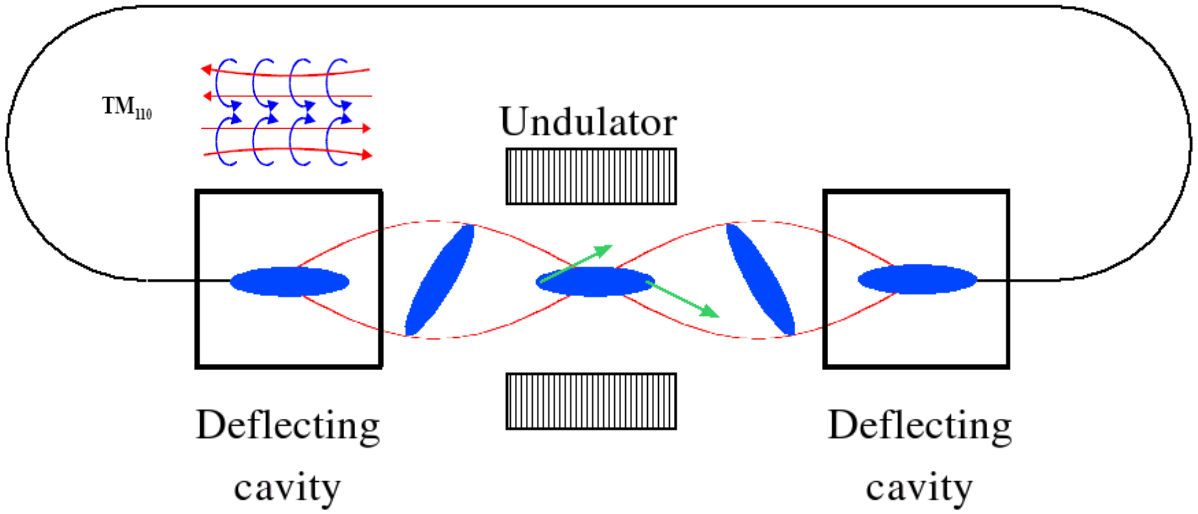
Advanced Photon Source

The SPX Project

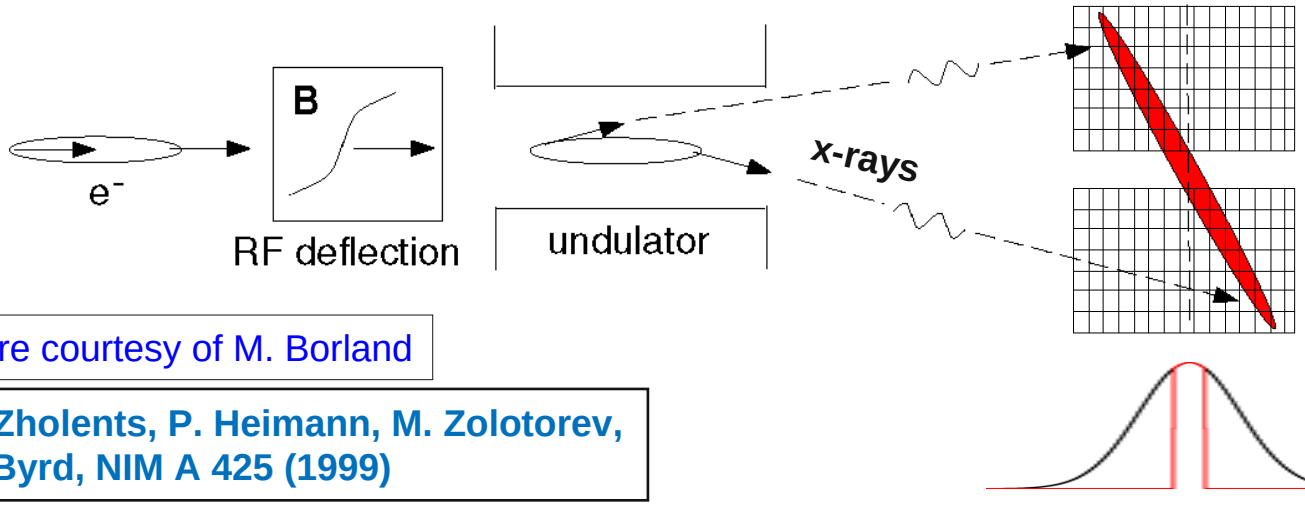
- SPX: Short Pulse X-Ray
- Objective: Use the APS to provide high flux rate, energy tunable ~picosecond scale x-ray pulses for time resolved experiments
- Strategy: Install crab cavities in the storage ring driven by pulsed 2815 MHz
  - Crab cavities will chirp a single isolated bunch
  - 2815 MHz = 8 X SR RF
  - Crab cavity design is being developed
  - Hybrid fill pattern will be used
    - *Single 16 mA bunch separated by 1.3 microseconds upstream and downstream from the rest of the fill pattern*
- 2 Phase Approach
  - Phase 1: 120 Hz pulsed source
  - Phase 2: 1 kHz pulsed source

Short-pulse generation with rf deflection†



Deflecting cavity introduces angle-time correlation, "chirping" the beam

Second cavity at nπ phase cancels "chirp"; rest of the storage ring unaffected



Slits can be used to clip out a short pulse.

Can also use asymmetric cut crystal to compress the pulse.

Figure courtesy of M. Borland

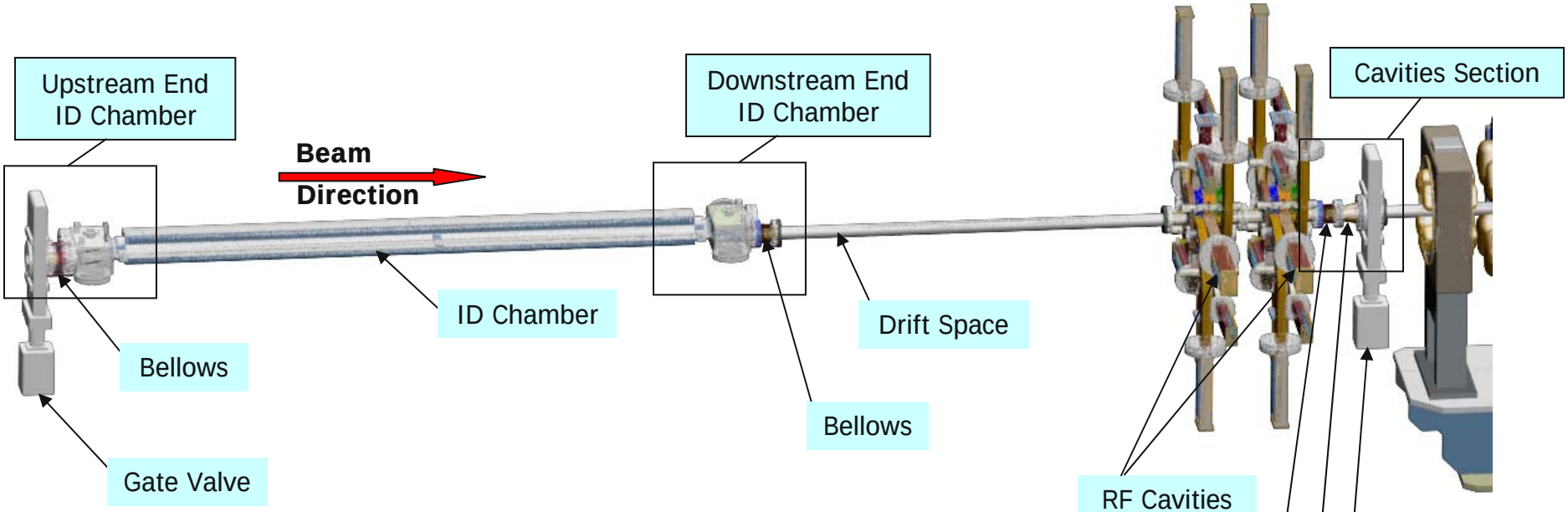
† A. Zholents, P. Heimann, M. Zolotorev, J. Byrd, NIM A 425 (1999)

Layout, 2 Sector APS Implementation*

Sector 6, Section 6

Sector 7, Girders 1 thru 5

Sector 7, Section 6



*Courtesy: L. Morrsion

Timing/Phase Reference Requirements

- Provide phase stable rf references
  - Cavity LLRF (2815 MHz)
    - *8 x storage ring rf (351.9MHz)*
  - Beamline laser (88 MHz)
  - Streak camera (117 MHz)
- Provide programmable timing triggers
  - LLRF
  - Beamline
  - BPM system
  - S35 diagnostics

*Tolerances**

- **Tolerances for Crab Cavities**

Quantity	120 Hz	1 kHz
Common-Mode Phase Relative to Bunch Arrival	+/- 10 degrees	+/- 10 degrees
Differential Phase	+/- 0.16 degrees	+/- 0.05 degrees
Common-Mode Voltage	+/- 1%	+/- 1%
Differential Voltage	+/- 0.29%	+/- 0.13%

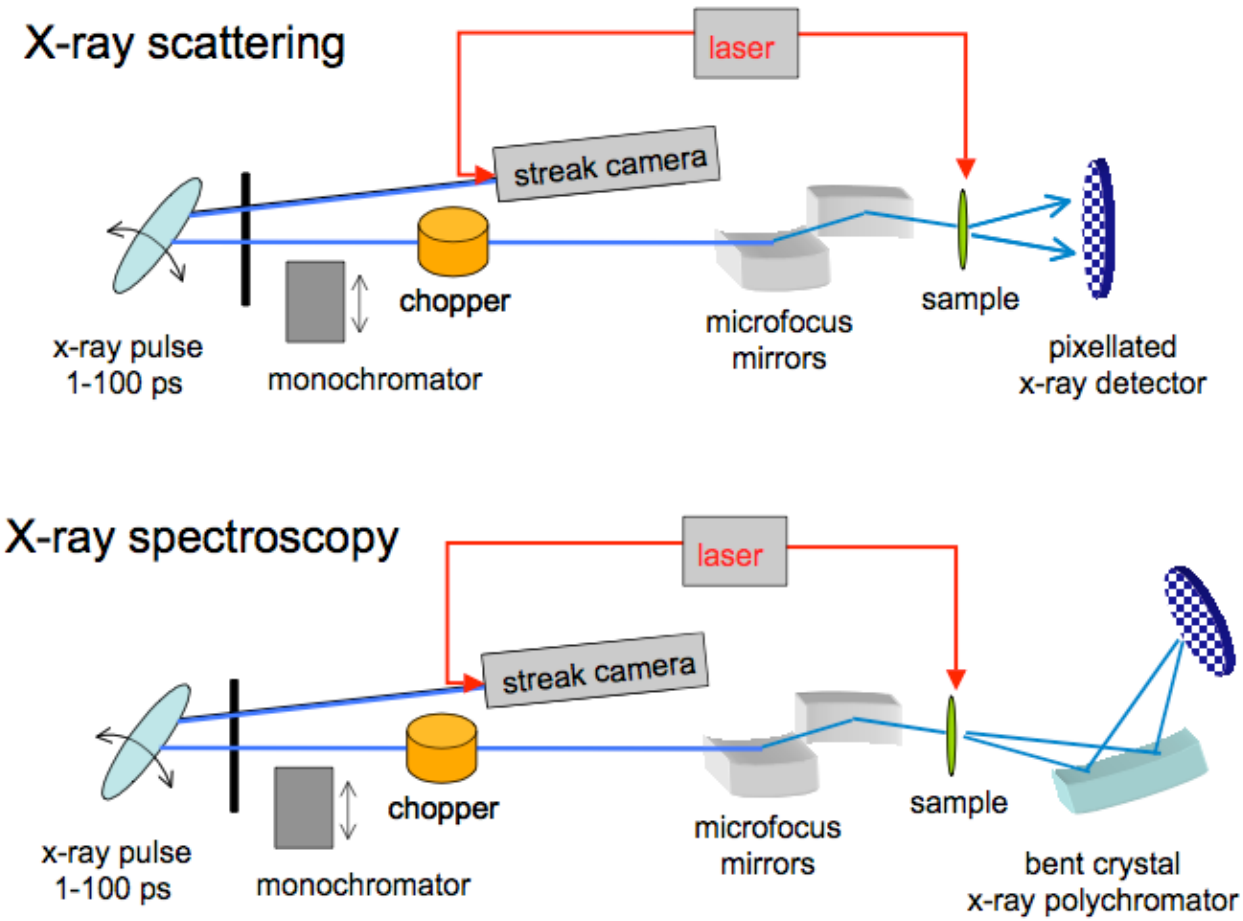
- **Tolerance on timing signal from crab cavity to users: +/- 0.9 degrees**
  - **Addresses X-ray beam arrival time relative to laser firing**
  - **Which addresses phase stability of cavity 2815 MHz to laser 88 MHz**

*Reference: “Long Term Tracking, X-Ray Predictions and Tolerances,” M. Borland, 8/07 Design Review

Challenges

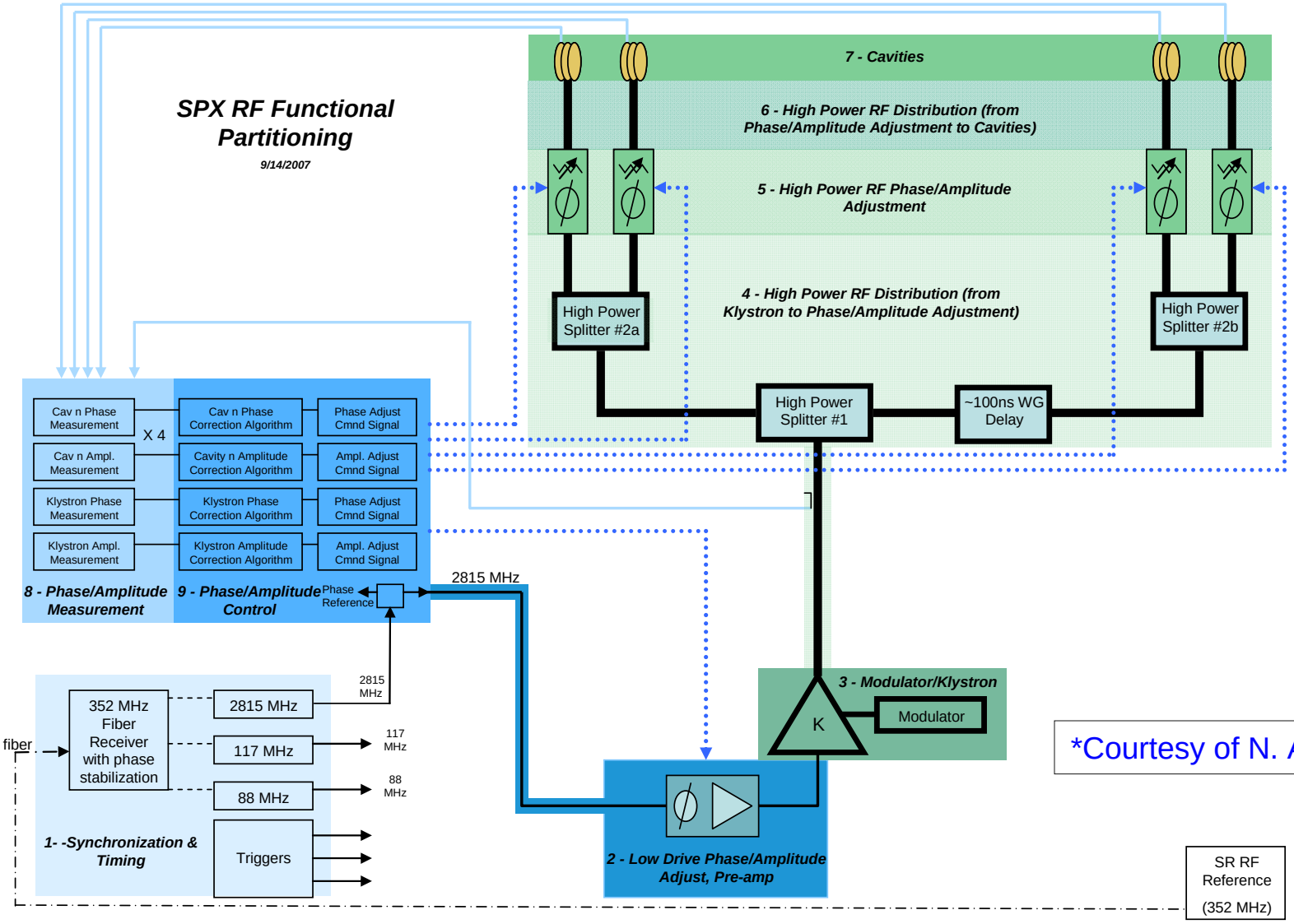
- Establish and maintain stable phase relationship between cavity 2815 MHz reference and 88 MHz beamline laser RF reference
  - Addresses laser-to-x-ray beam timing
- Establish and maintain stable phase relationship between storage ring rf and cavity 2815 MHz reference
  - Addresses x-ray beam to electron beam timing
- LLRF: cavity phase/amplitude measurement

Proposed Beamline Layout



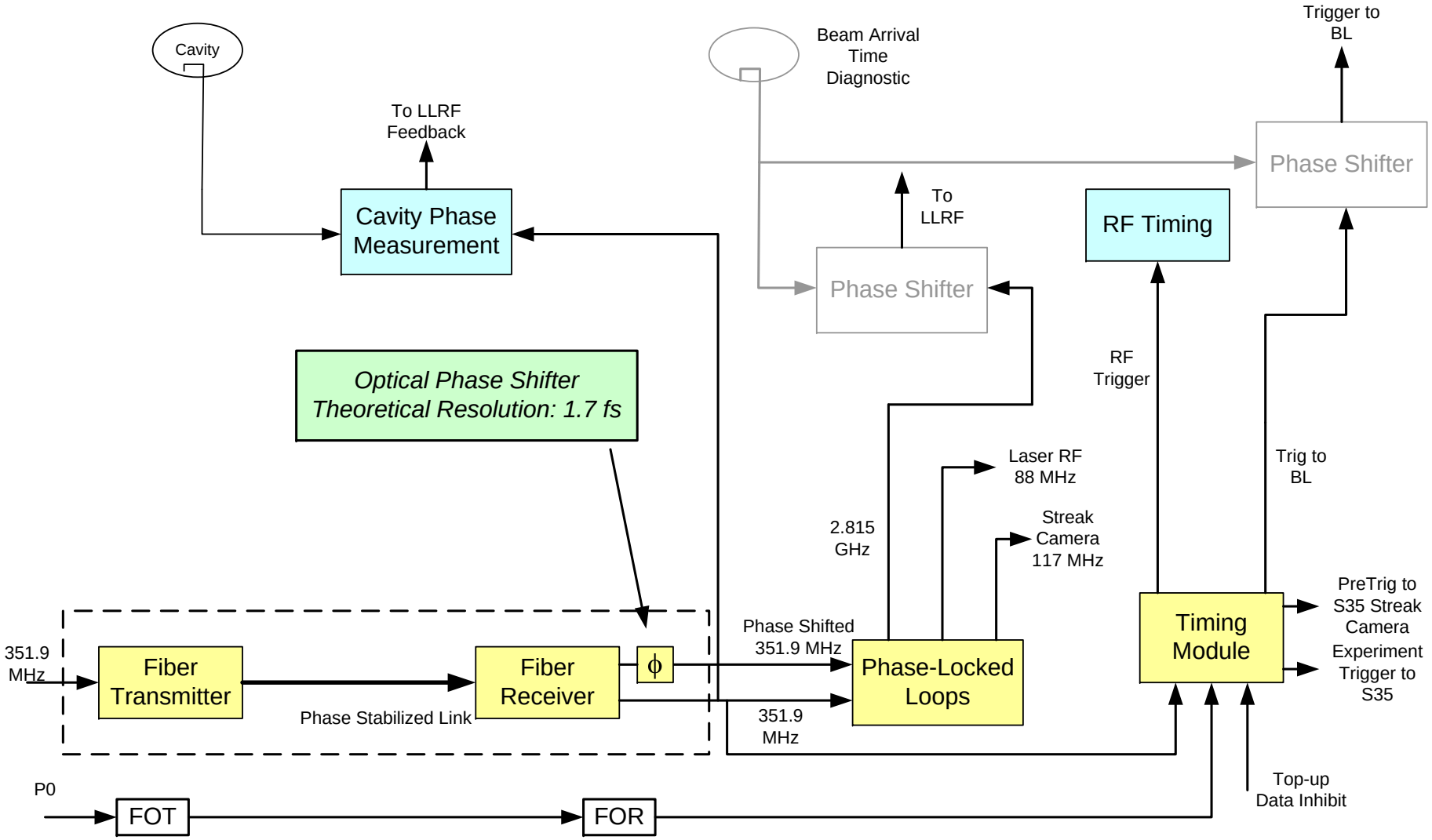
Eric Landahl "Transient Methods for X-Ray Studies Under Extreme Conditions" 10/2006

RF Functional Diagram*

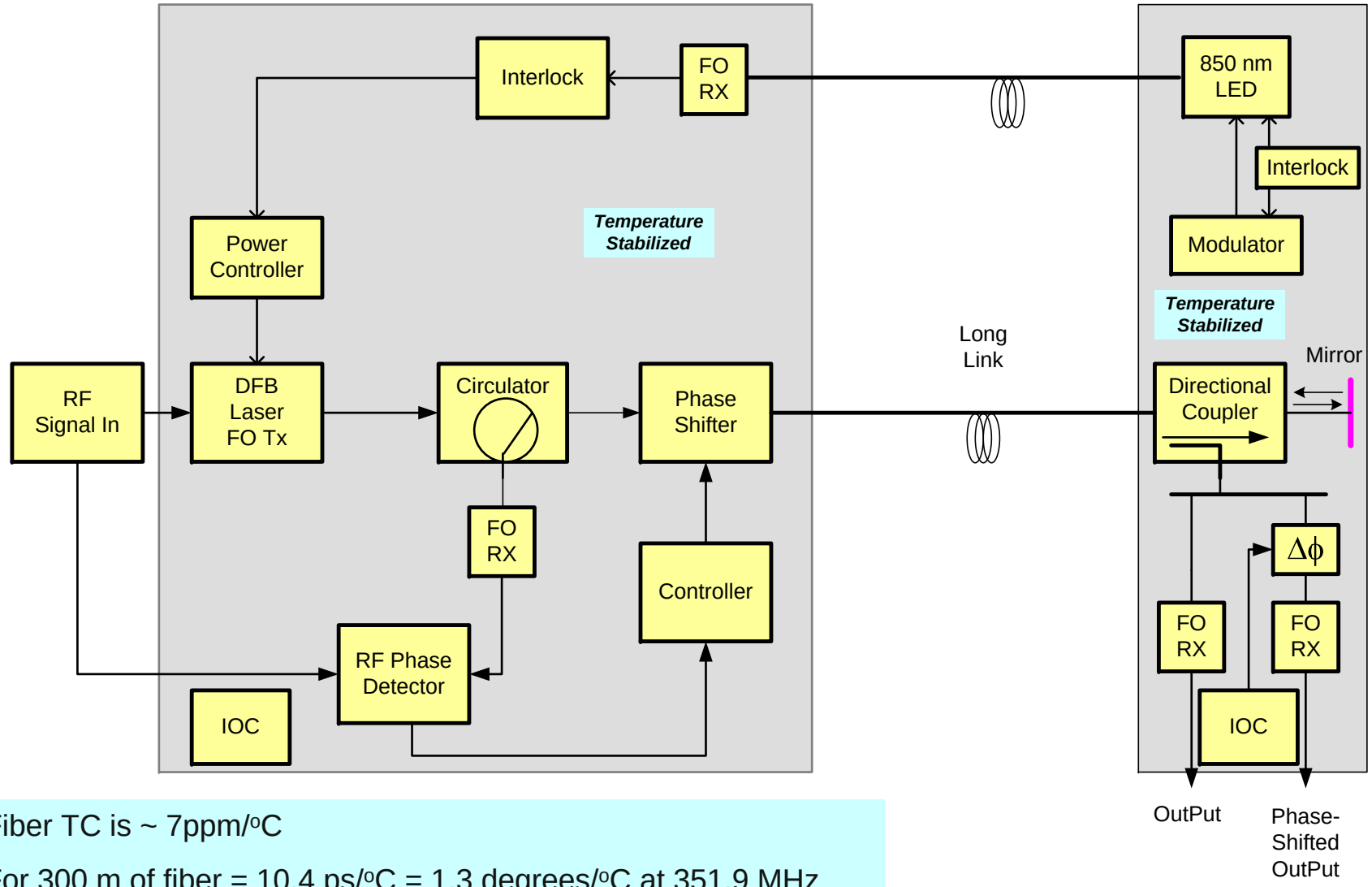


*Courtesy of N. Arnold

Timing/Phase Reference Overview



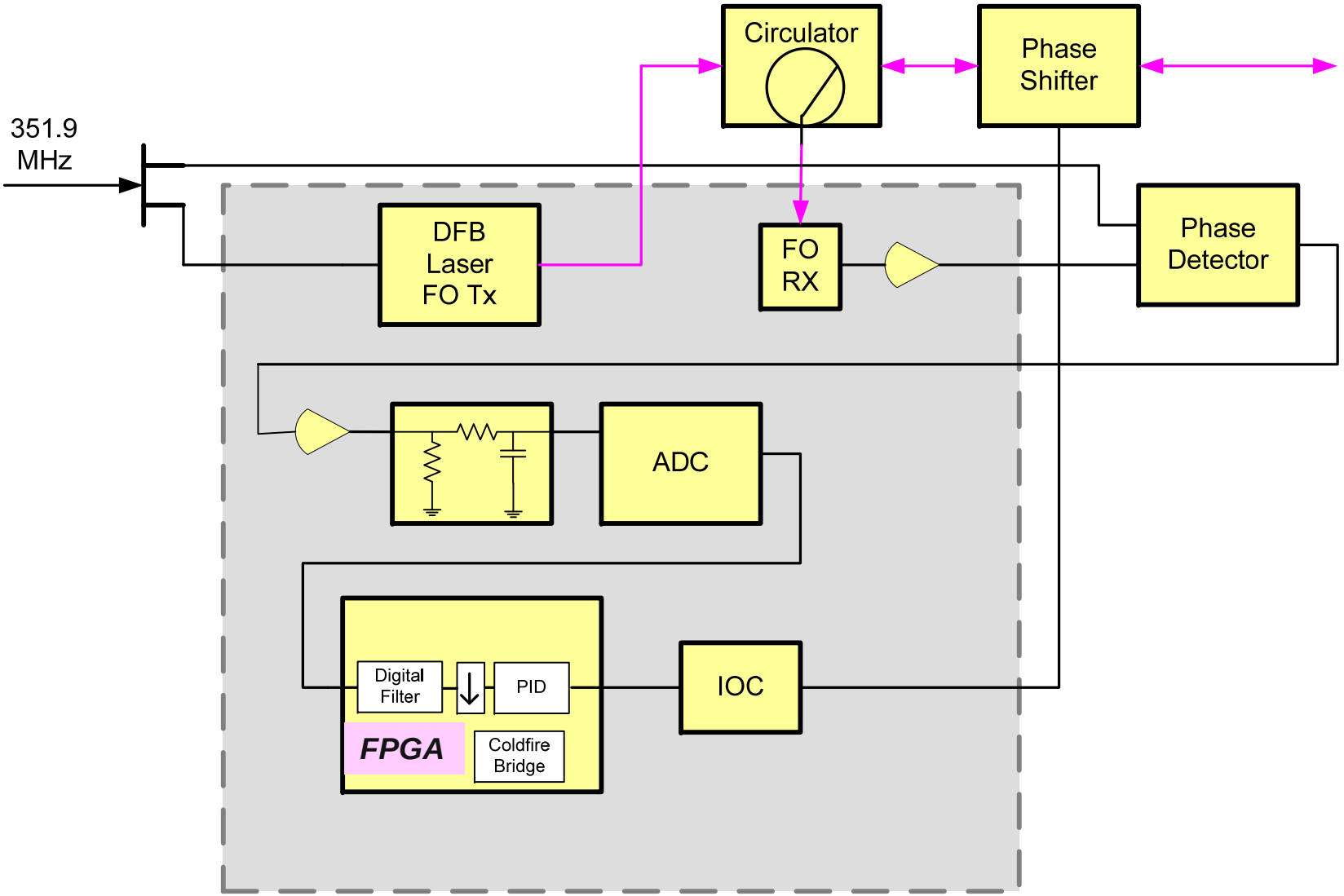
Phase Stabilized Link with Interlock



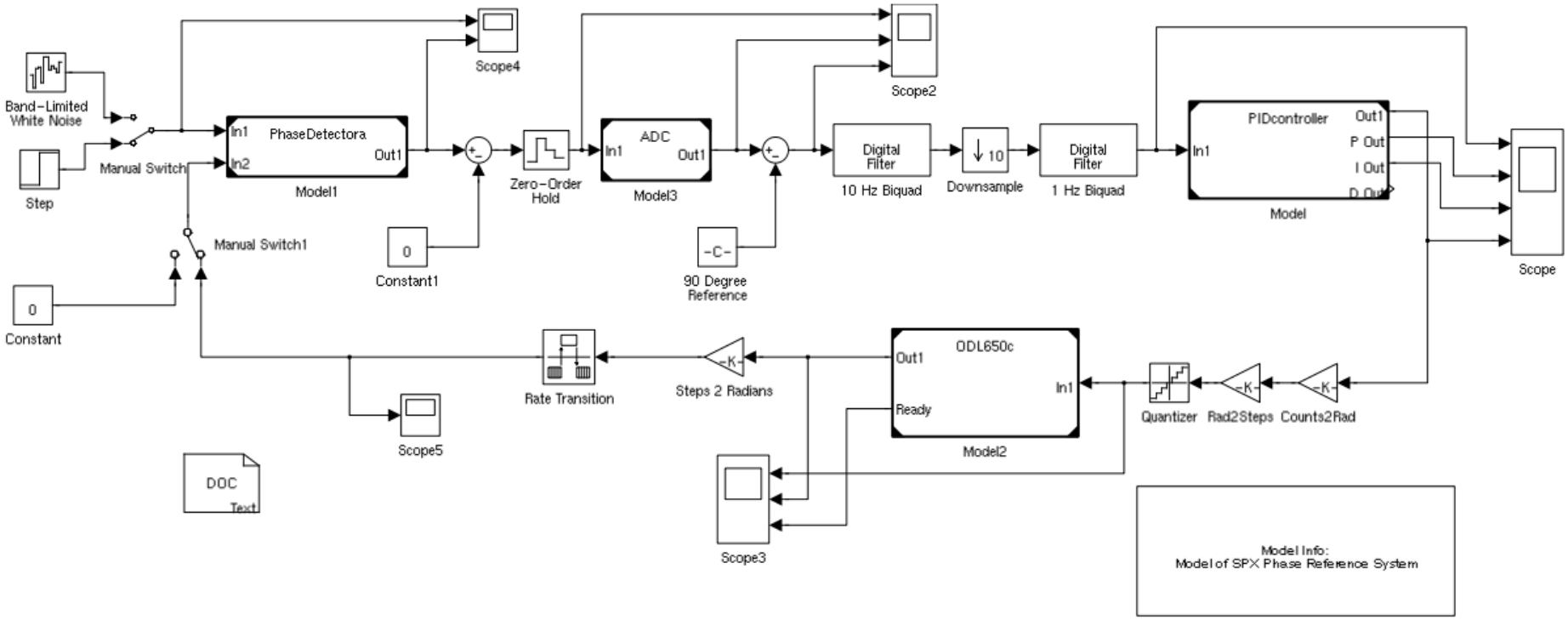
Fiber TC is ~ 7ppm/^{o}C

For 300 m of fiber = 10.4 ps/^{o}C = 1.3 degrees/^{o}C at 351.9 MHz

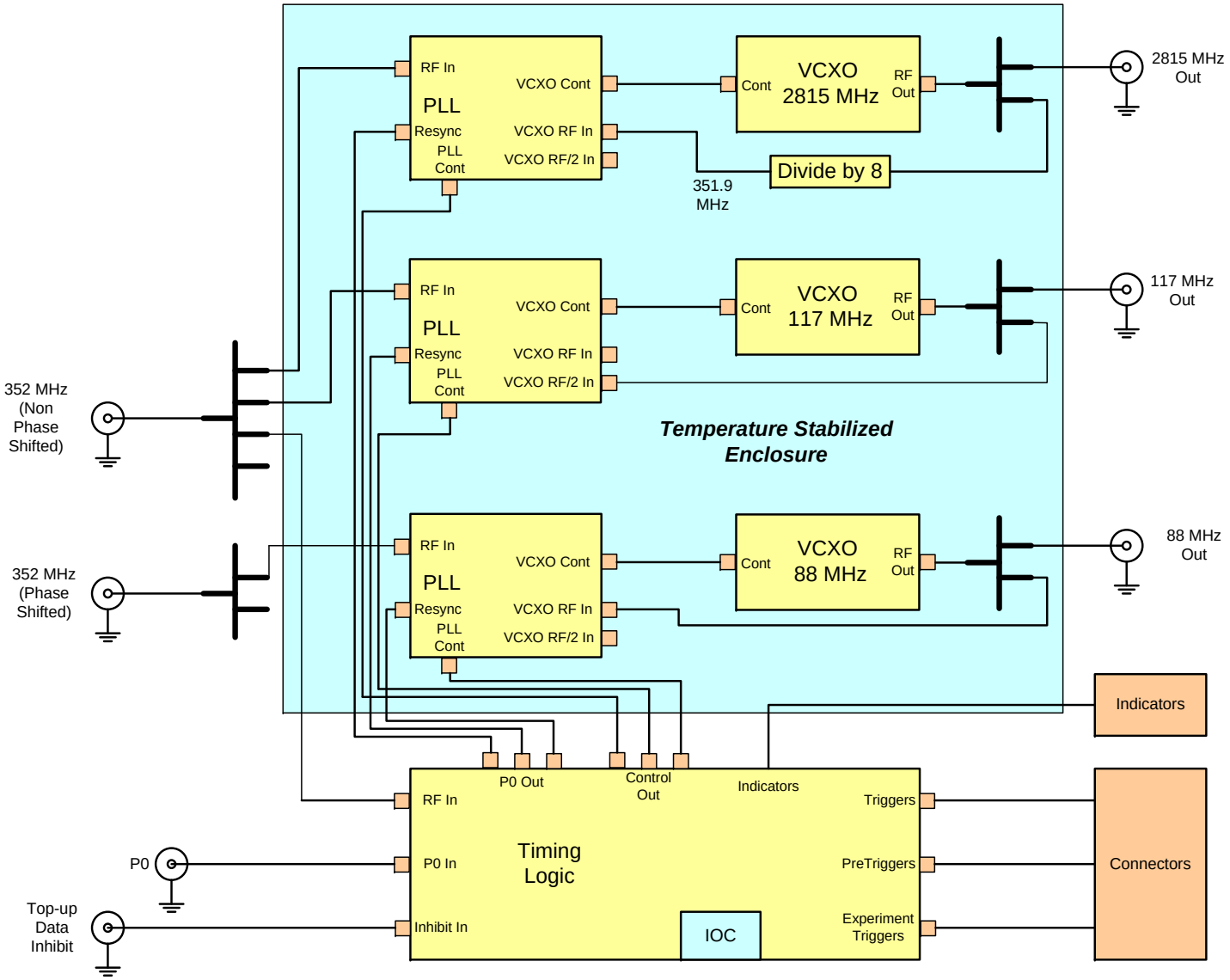
Fiber Transmitter Details



Simulink Model of Phase Stabilized Link



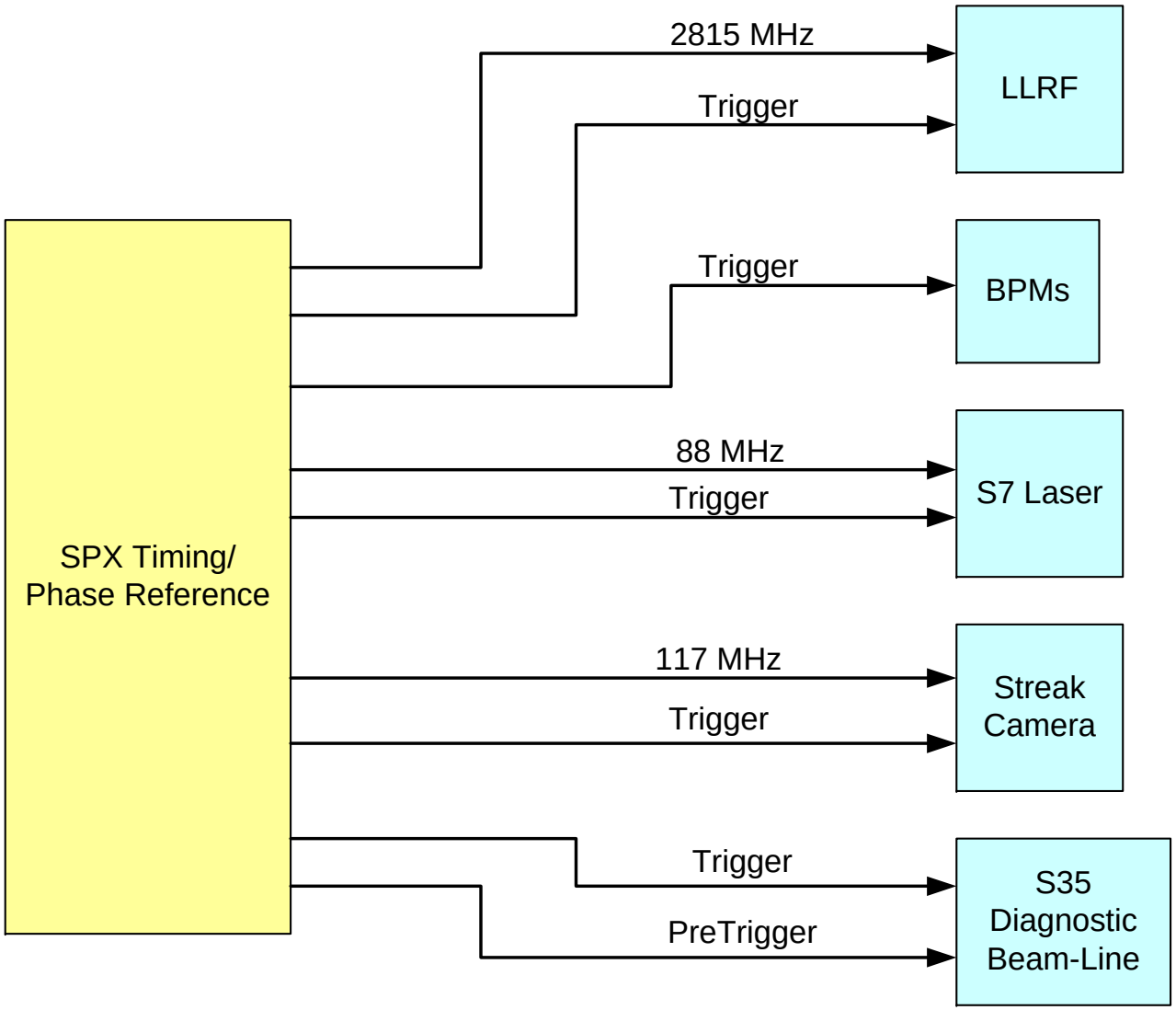
Timing/RF references



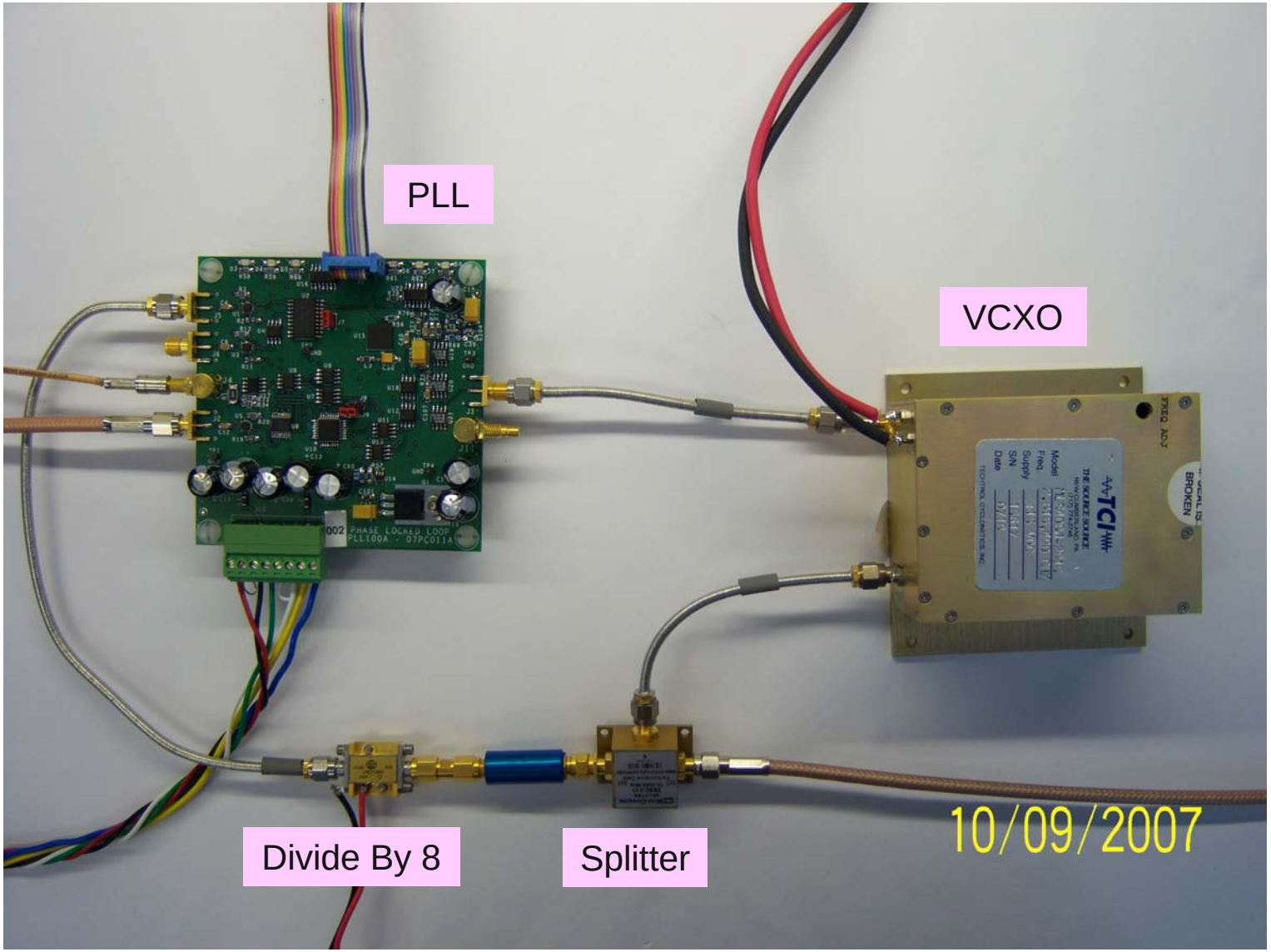
Timing Features

- Triggers are synchronized to SR 352 MHz and Revolution Clock
- Programmable trigger rate
  - 66 Hz to 1 kHz
- LLRF and BPM triggers
  - Pre-trigger
  - Trigger
    - *Delayed from pre-trigger*
      - Up to 255 turns
      - Bucket delay (0-1295 buckets)
- Separate triggers for diagnostic beamline
  - Synchronous to LLRF trigger
  - Programmable subharmonic of LLRF trigger
  - Independent pre-trigger/trigger programming
- Timing logic in FPGA
  - All trigger outputs resynchronized to 352MHz via ECL FFs

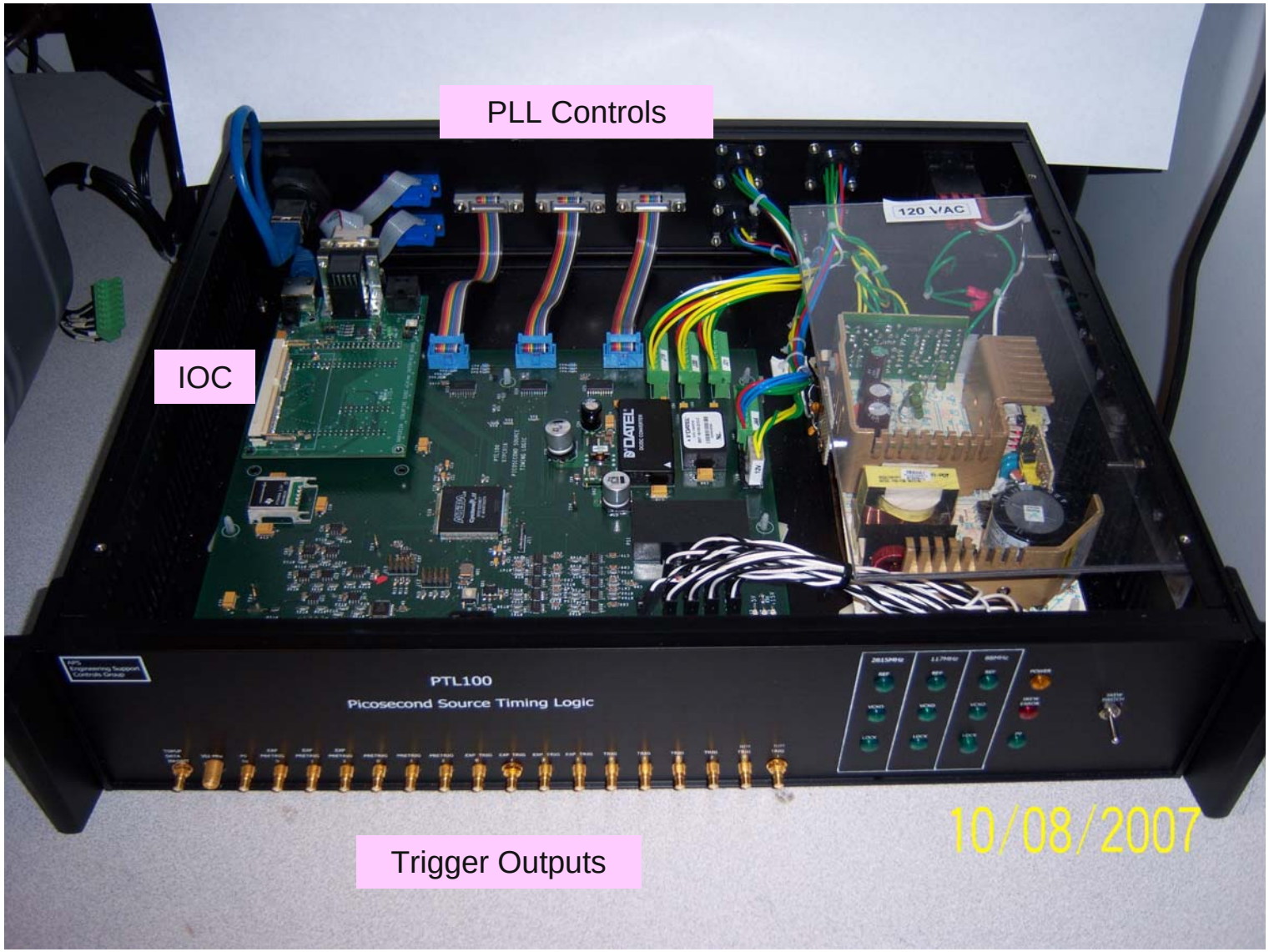
Timing Distribution



2.815 GHz PLL Prototype



Timing Trigger Chassis



Initial Results

- 2815 MHz PLL testing
- Computed 2815 MHz VCXO RMS jitter from vendor-supplied data
  - ~90 femtoseconds (10 Hz to 270 kHz) (0.09 degrees @ 2815 MHz)
- Crude measurement
  - 770 femtoseconds (0.5 Hz to 4 GHz) Agilent 54854A DSO, 4 GHz, 20 GSa/s (corrected for reference and DSO jitter)
- Computed
  - 595 femtoseconds (10 Hz to 4 GHz)

LLRF

- In light of the tight cavity-to-cavity tolerances, cavity phase and amplitude measurement is a critical area
- Different techniques are being studied/evaluated
  - A simulation effort is underway
- Considering using controller boards developed at FERMI and DESY
- Amplitude/phase or I/Q??

References

- Frisch, J., Bernstein, D., Brown, D., Cisneros, E. “A High Stability, Low Noise RF Distribution System,” Proceedings of PAC2001, pp 816-818.
- Czuba K., Eints F., Felber M., Dobrowolski J., Simrock S., First Generation of Optical Fiber Phase Reference Distribution System for TESLA, TESLA Report 2005-08 Hamburg 28.02.2005.