Precision Synchronization for Ultra-Fast Science

S. Pfeiffer on behalf of LLRF and LbSynch Team at DESY

1st EuCARD-2 Annual Meeting
DESY, Hamburg, 19-23 May 2014

EuCARD-2 is co-funded by the partners and the European Commission under Capacities 7th Framework Programme, Grant Agreement 312453

Outline

1. FEL overview
2. Laser Based Synchronization
3. Bunch Arrival Time Monitor
4. Ultra-Fast Beam-Based Feedbacks
5. Conclusion

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1. **FEL overview**
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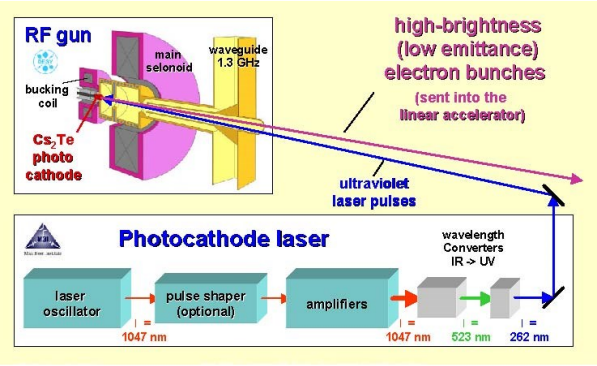
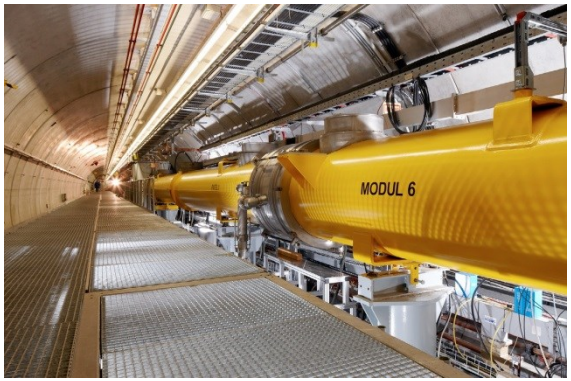
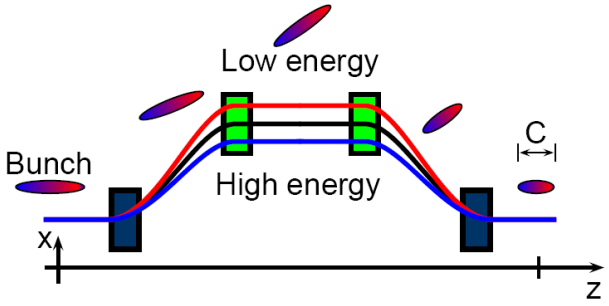
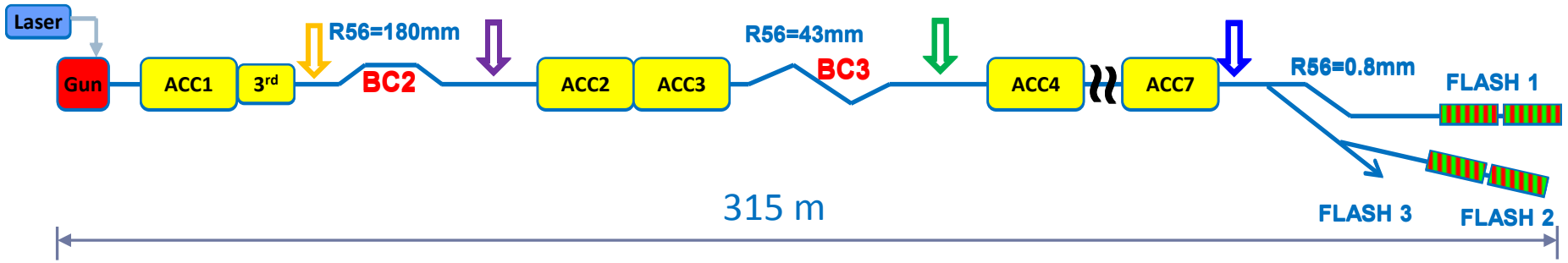
Example FLASH Free-Electron LASer in Hamburg

- Basic Components FEL:
  - RF GUN, Accelerating modules, Bunch Compressors
- Length: 315 m, E < 1.25 GeV, λ > 4.12 nm









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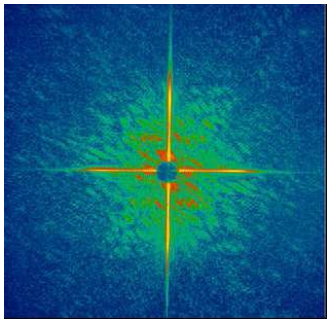
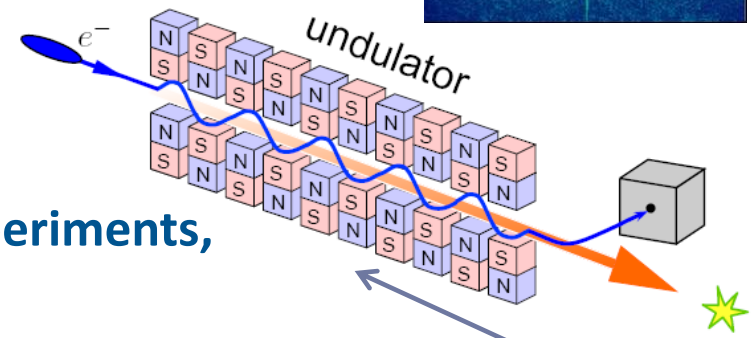
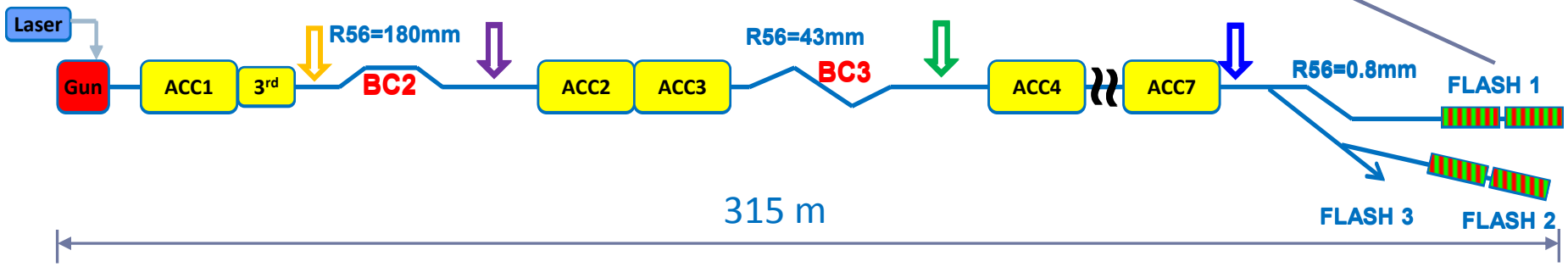
[Chapman et al., 2006]





Precision synchronization for pump-probe experiments,



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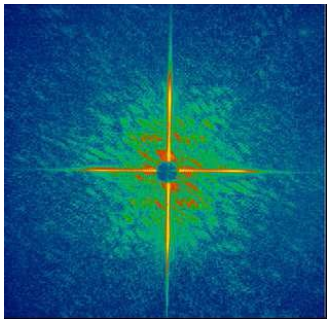
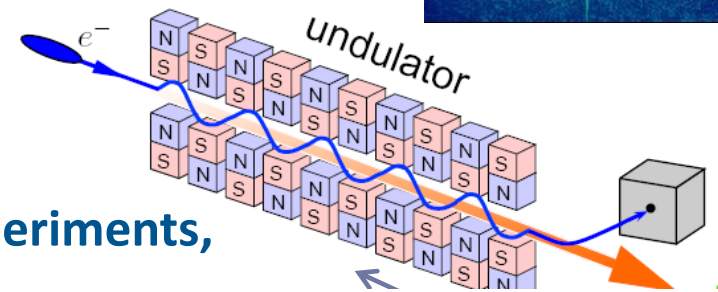
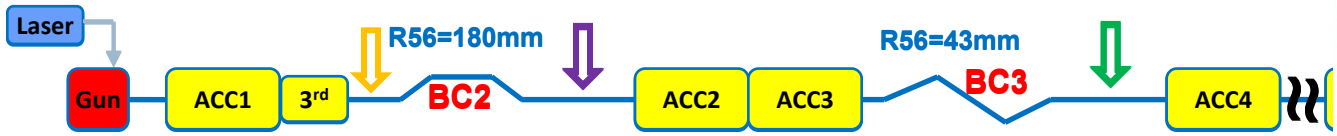
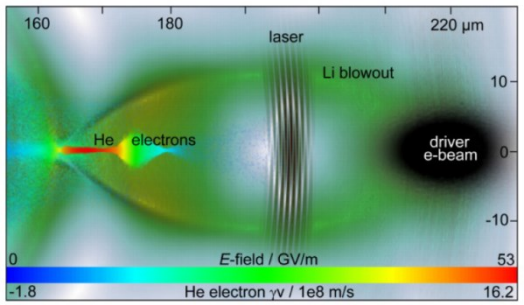




Precision synchronization for pump-probe experiments, seeding schemes, external injection in plasma, …





315 m

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3. Bunch Arrival Time Monitor
4. Ultra-Fast Beam-Based Feedbacks
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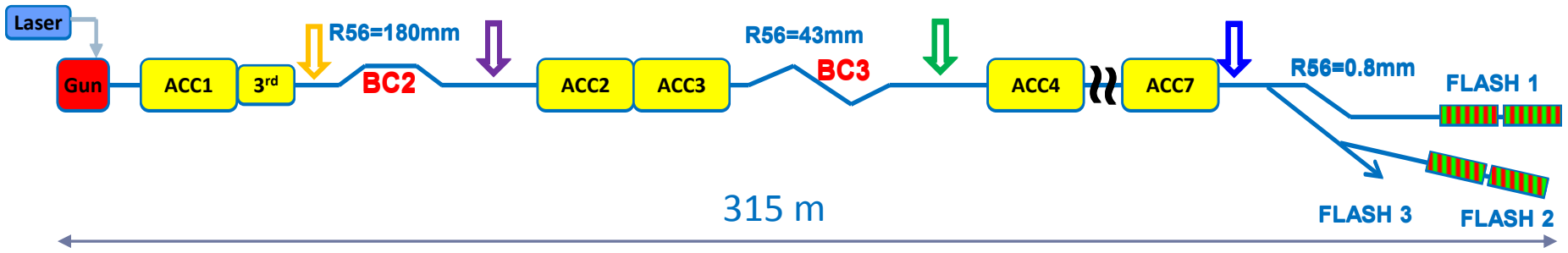

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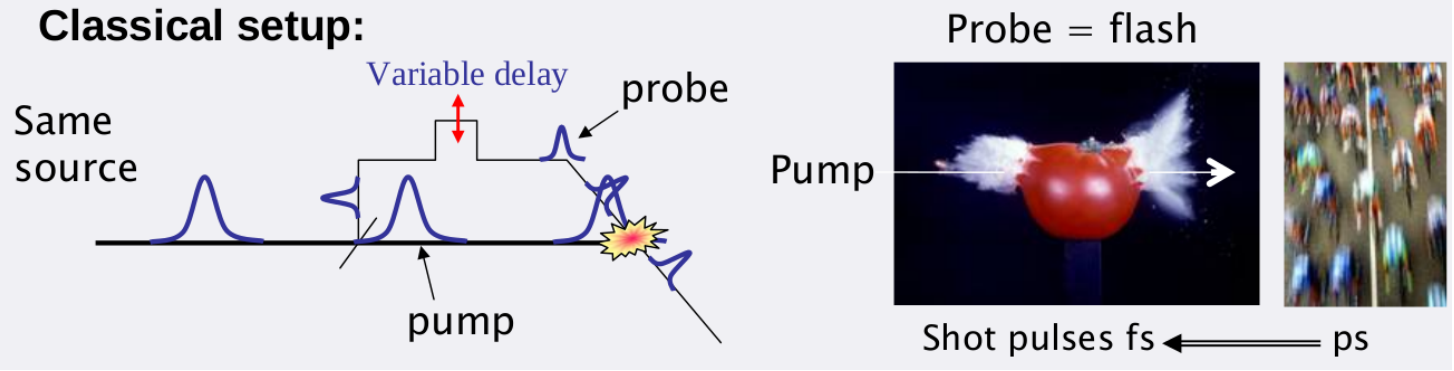
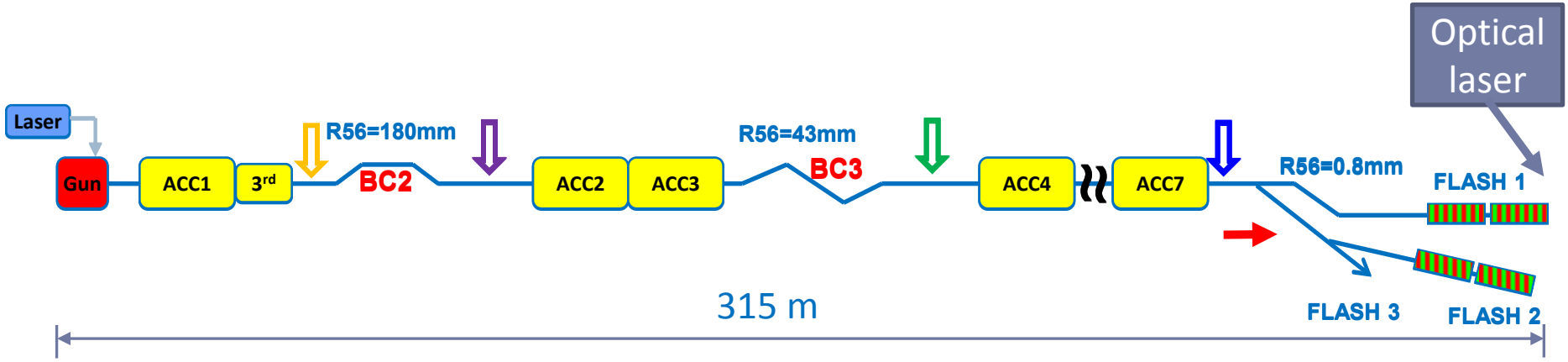


Pump pulse initiate reaction

Probe pulse records current state

- Problem: two different pulse sources: FEL and optical laser



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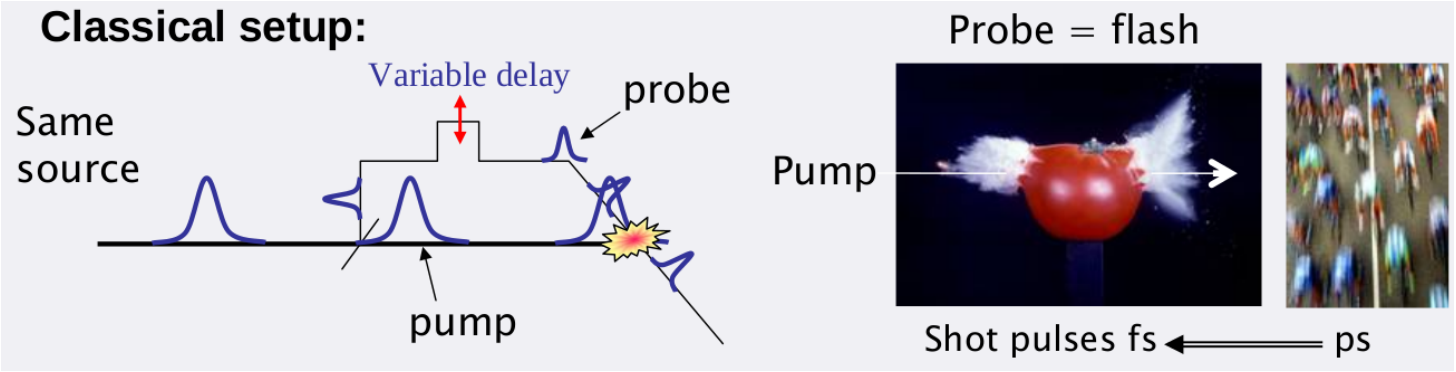

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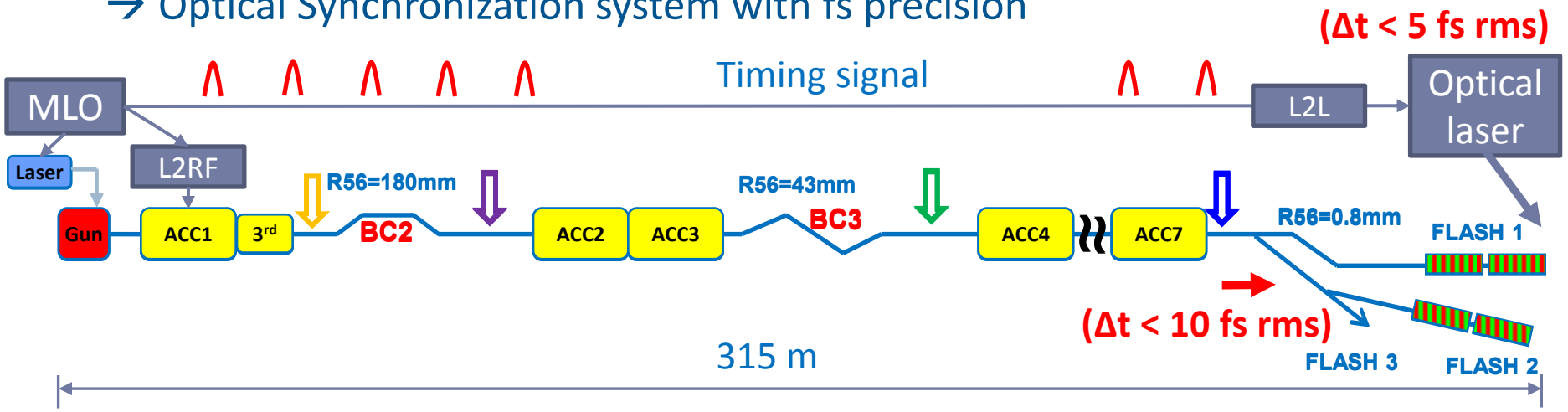
- Problem: two different pulse sources: FEL and optical laser
  → Optical Synchronization system with fs precision



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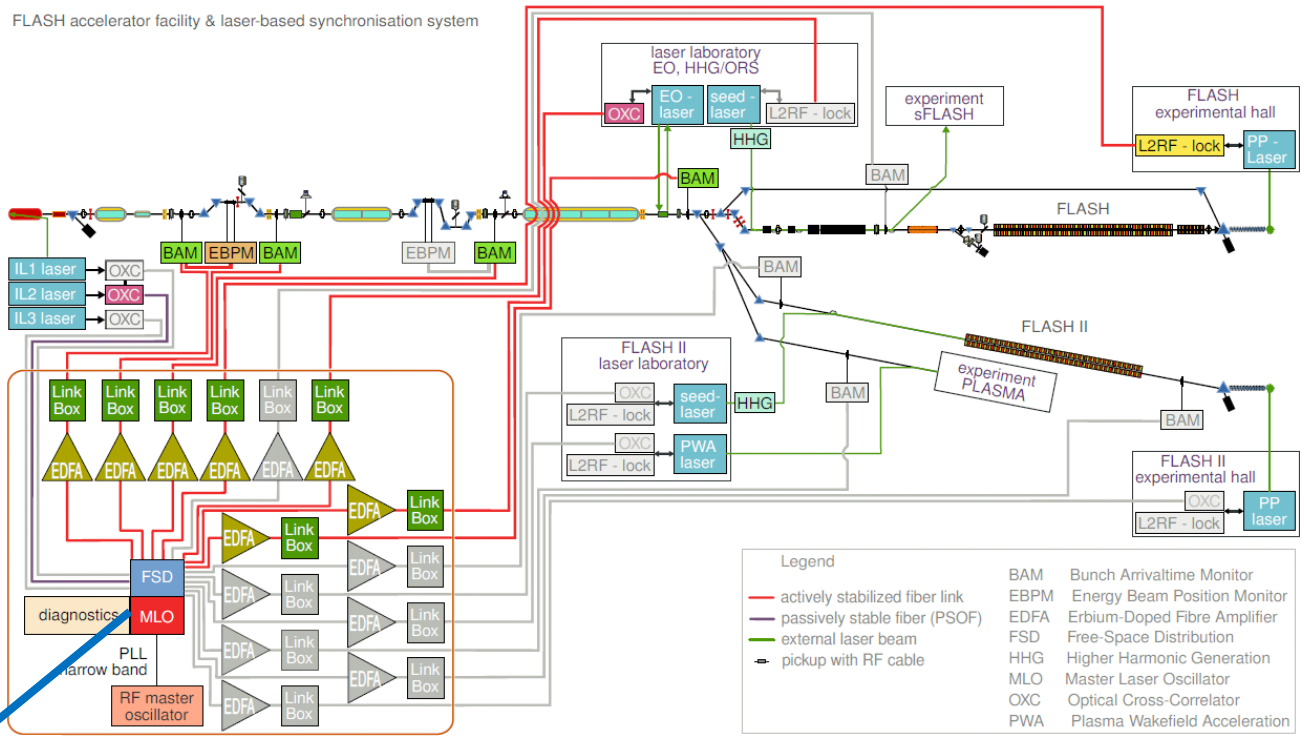
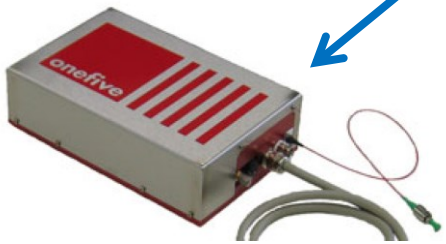


Master Laser
~ 5fs rms phase noise



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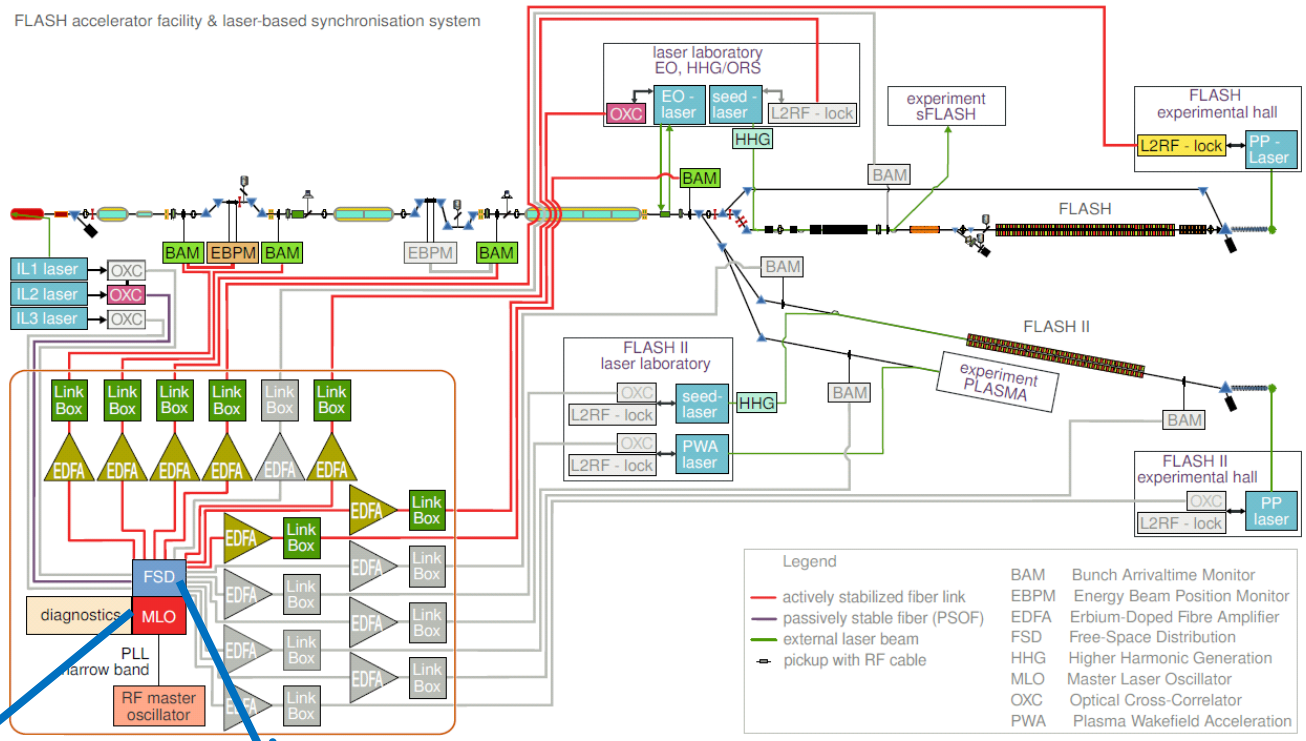

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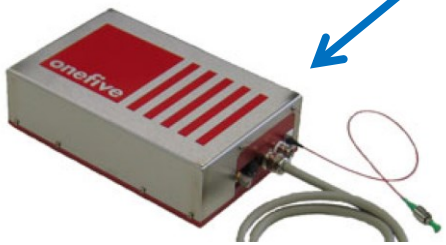
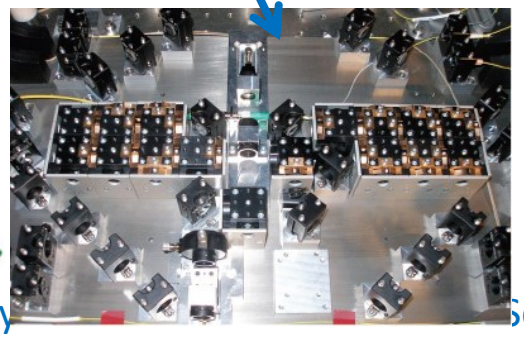
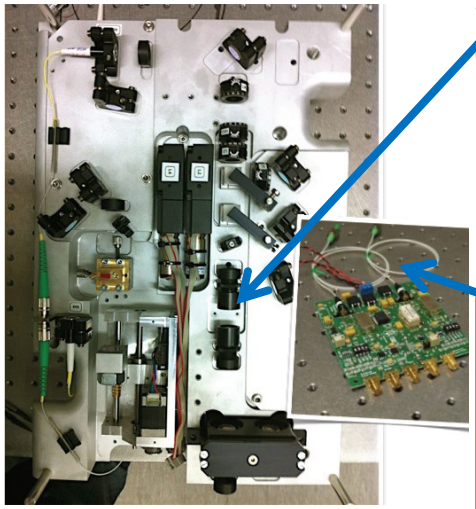
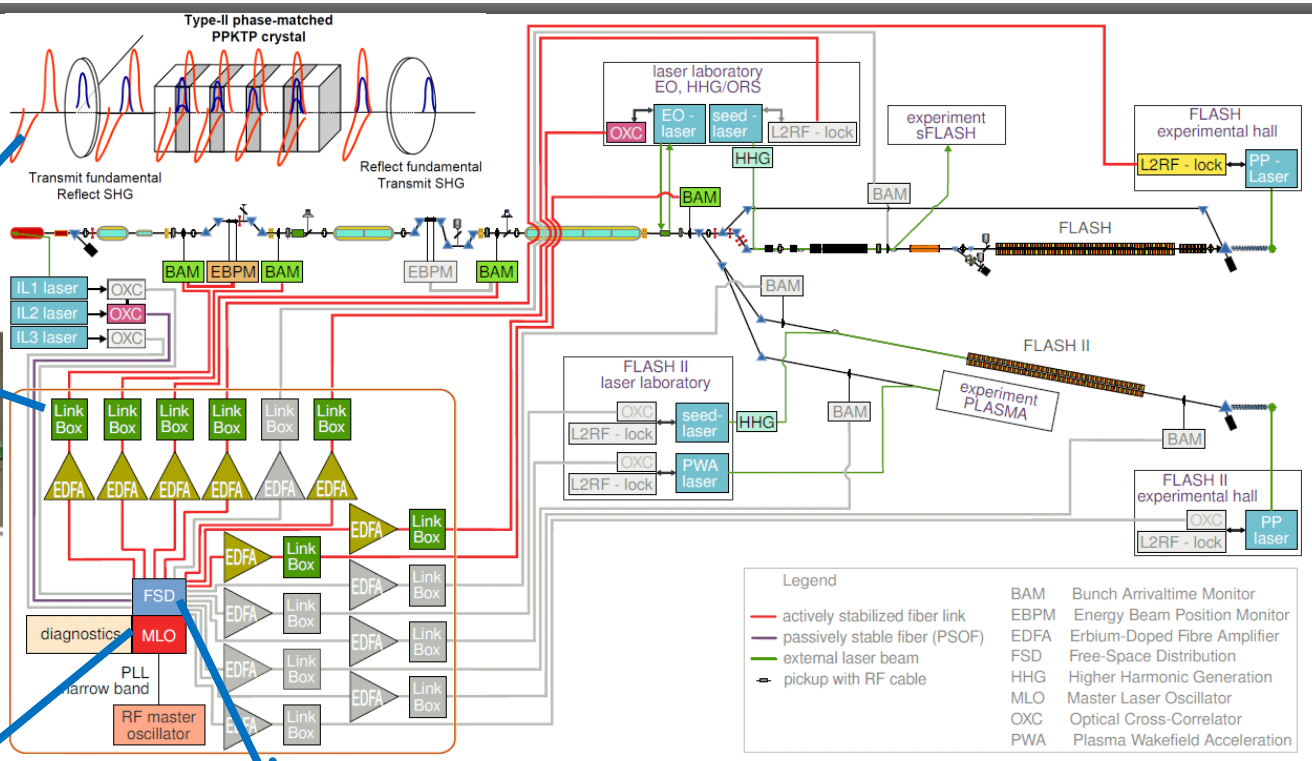




2. Laser Based Synchronization

Link stabilization





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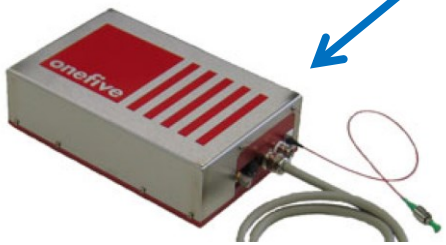

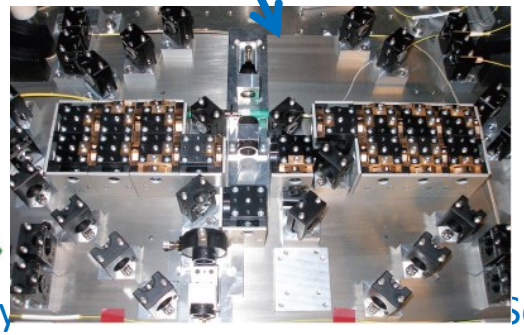

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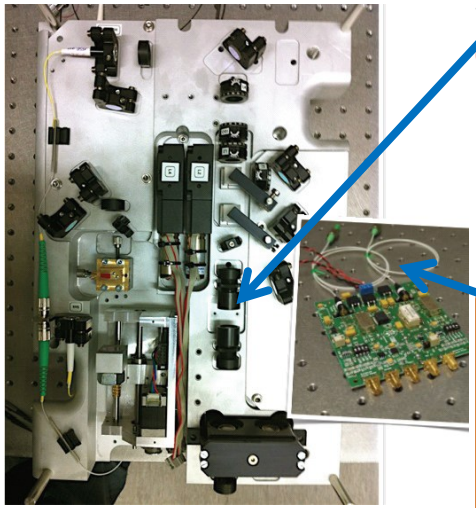

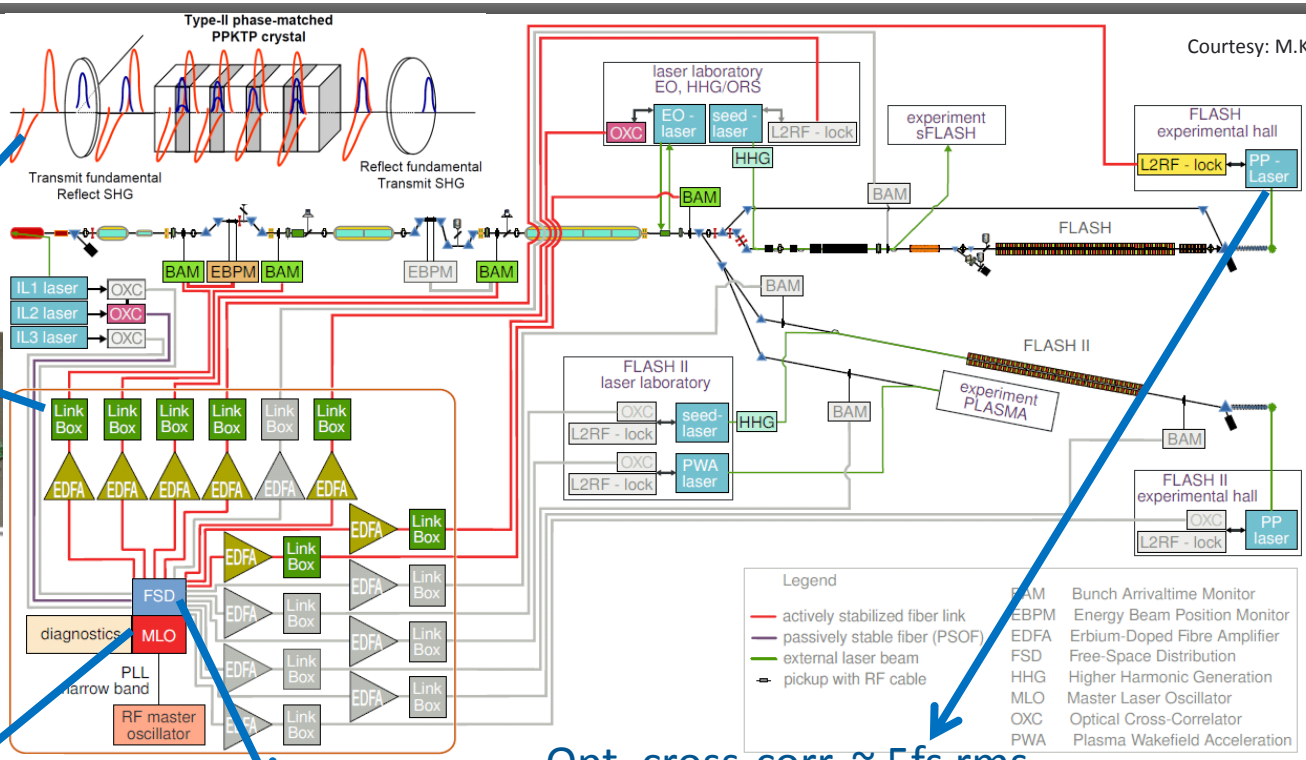

Courtesy: M.K. Czwalinna

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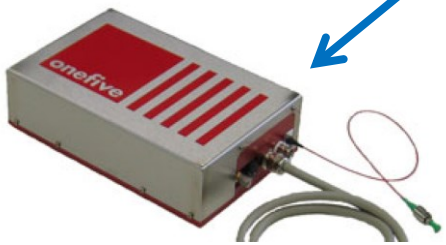
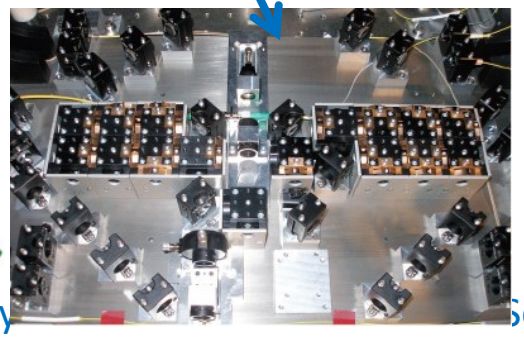
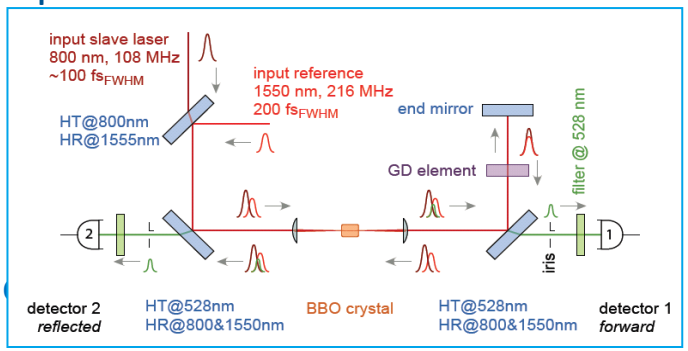




Opt. cross-corr. ~ 5fs rms



Precision Sy… Sci…

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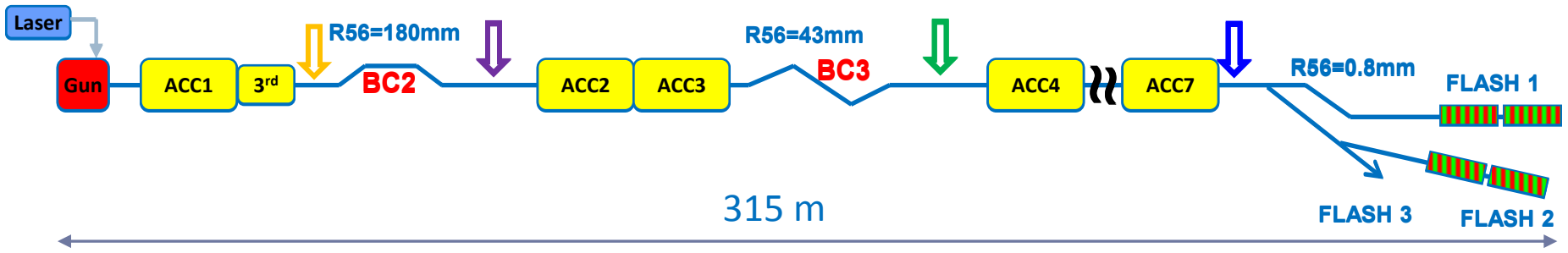
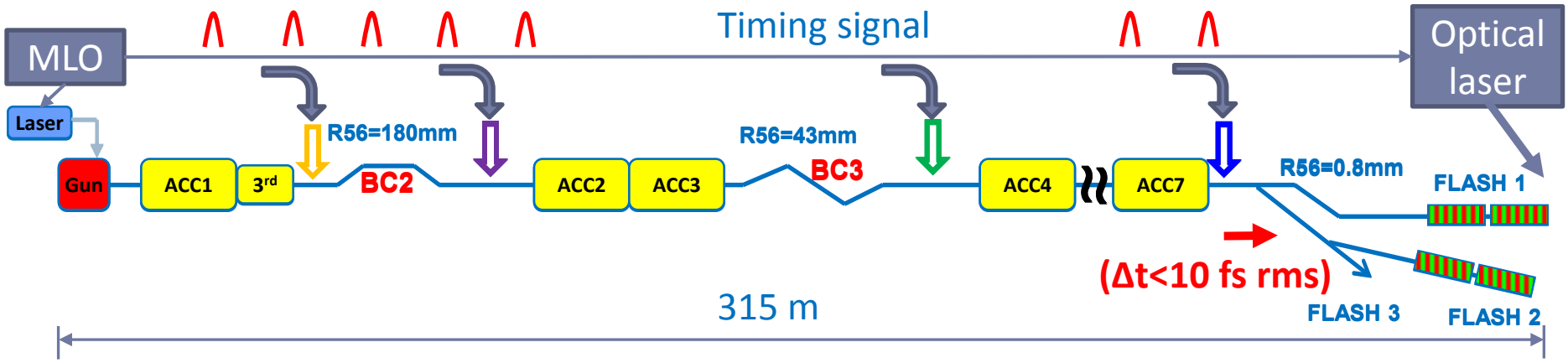


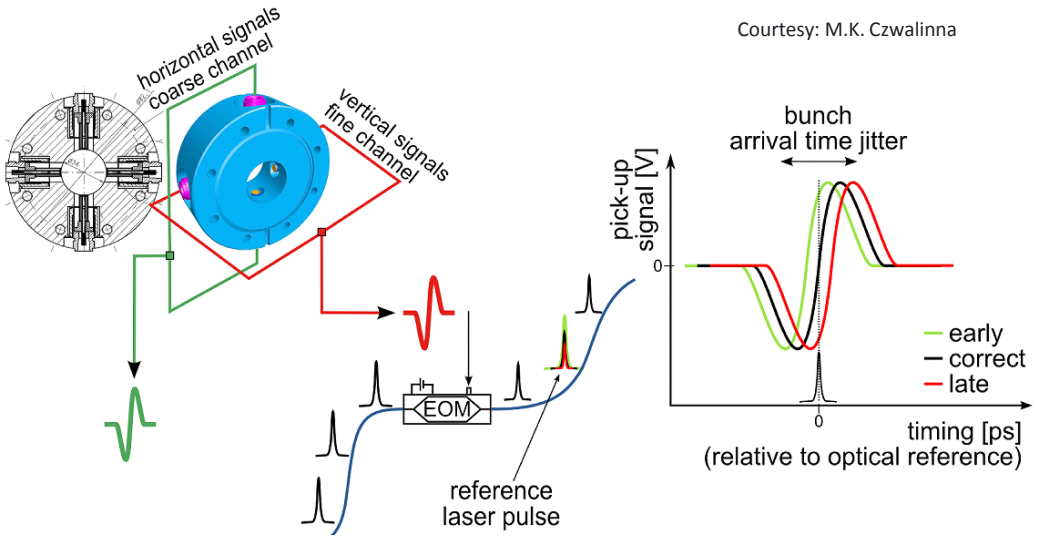
3. Bunch Arrival Time Monitor

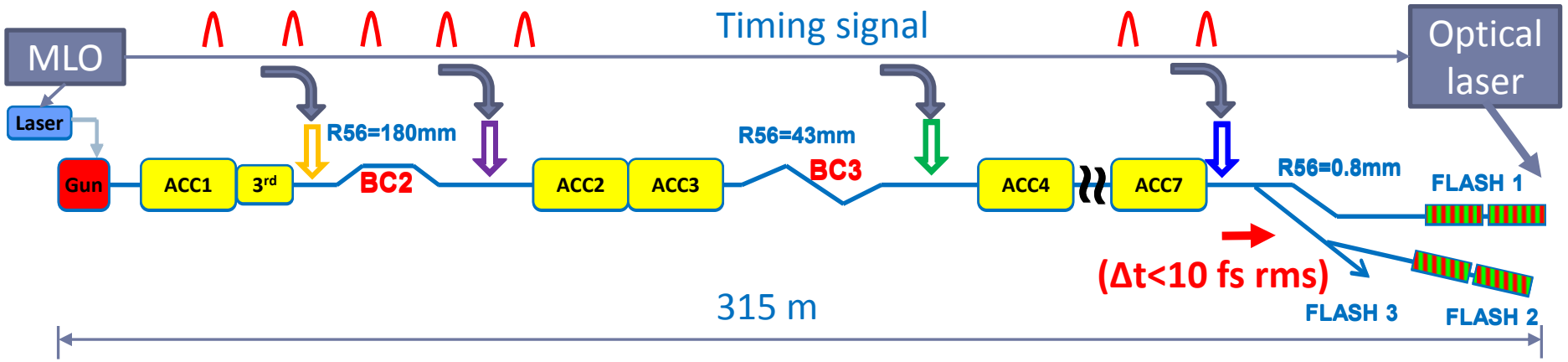
- Optical Synchronization system with fs precision



3. Bunch Arrival Time Monitor

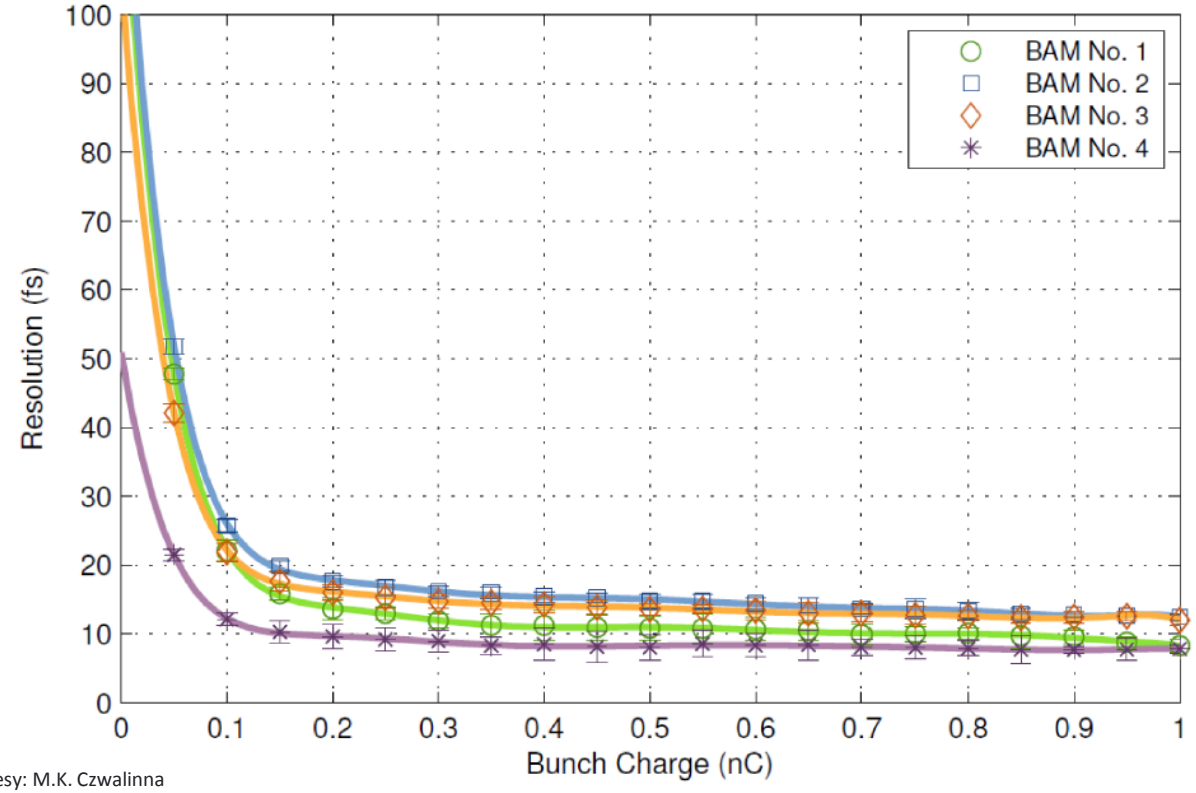
- Optical Synchronization system with fs precision
- BAM
  - Pick-up mounted in beam line
  - Electrical signal modulates laser pulse by EOM
  - Amplitude changes w.r.t. bunch arrival time





3. Bunch Arrival Time Monitor

- Short pulse operation: 1nC ⇒ 20pC



Courtesy: M.K. Czwalinna

4 BAMs at FLASH
Resolution
1 nC ~ 7-12 fs
20 pC ~ 40-100 fs

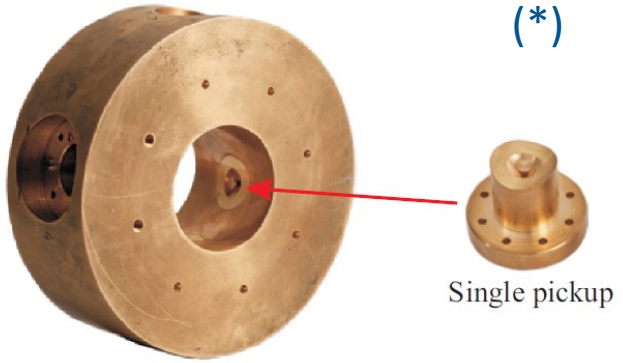
Not sufficient for stability of 10 fs for low charges!!!

➔ Requires improvement of Bunch Arrival time Monitor (BAM)

3. Bunch Arrival Time Monitor

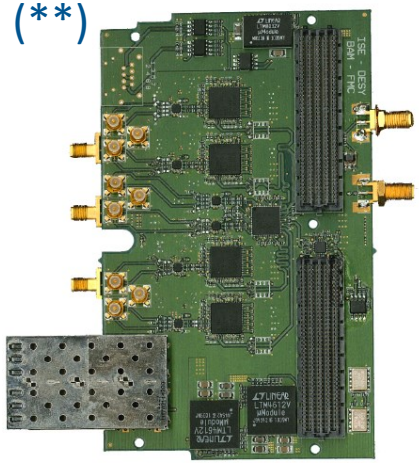
- Short pulse operation: 1nC ⇒ 20pC
- Started in 2013 with
  - New broad band pickups (*)
  - New front-end electronics (MTCA) (**)

(*)

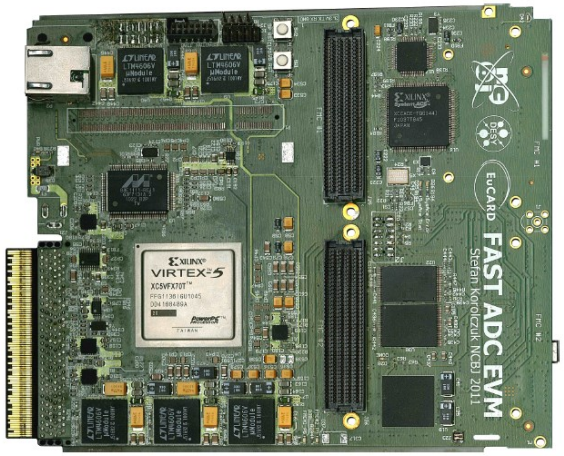


Pickup body with four pickups

(**)



(b) Prototype dual FMC mezzanine card.



(a) Prototype FPGA based dual FMC carrier board.

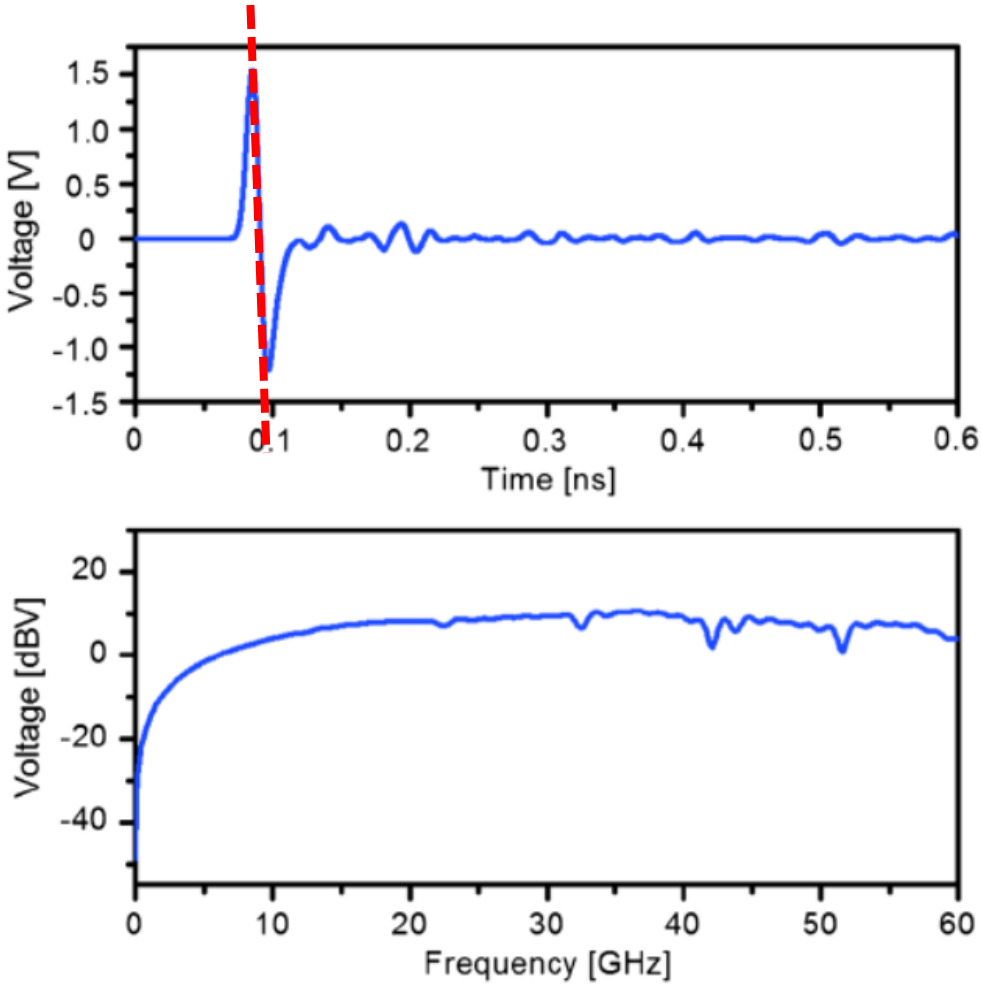
(*) A. Angelovski et al., *PICKUP SIGNAL IMPROVEMENT FOR HIGH BANDWIDTH BAMS FOR FLASH AND EUROPEAN – XFEL*, IBIC 2013
(**) M.K. Czwalinna et al., *NEW DESIGN OF THE 40 GHz BUNCH ARRIVAL TIME MONITOR USING MTCA.4 ELECTRONICS AT FLASH AND FOR THE EUROPEAN XFEL*, IBIC 2013

BAM upgrade - Simulation

BAM upgrade

- increased signal slope:
  ≥450 mV/ps @ 20 pC
  (> x10 improvement)
- RF bandwidth of 40 GHz
- suppressed ringing
  (matched to 50 Ω)

First measurement shows very good agreement…



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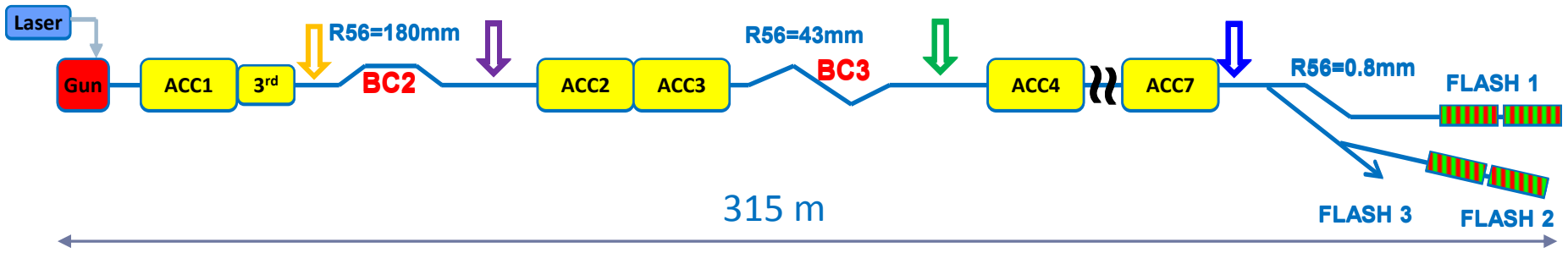
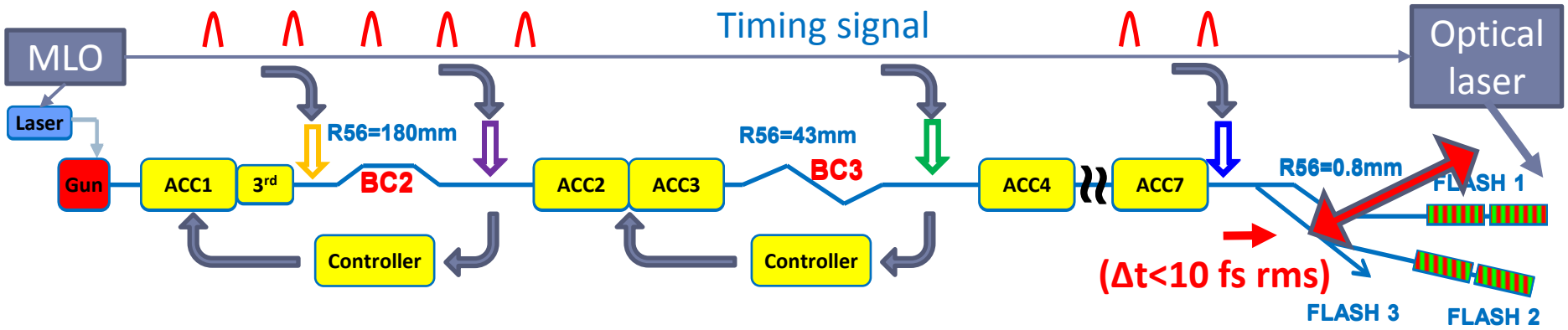


4. Ultra-Fast Beam-Based Feedbacks

- Control timing difference of FEL pulse with optical laser



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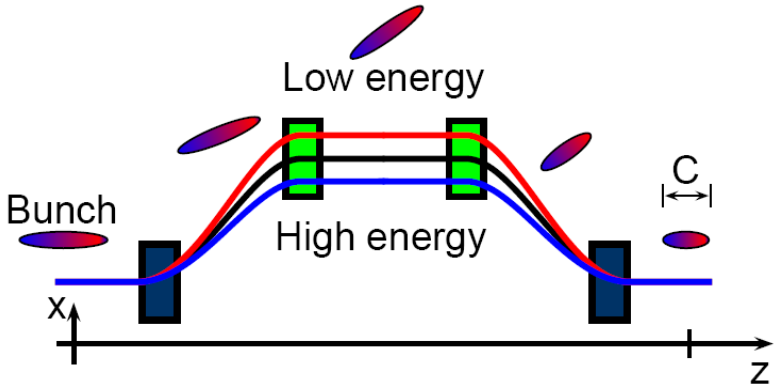
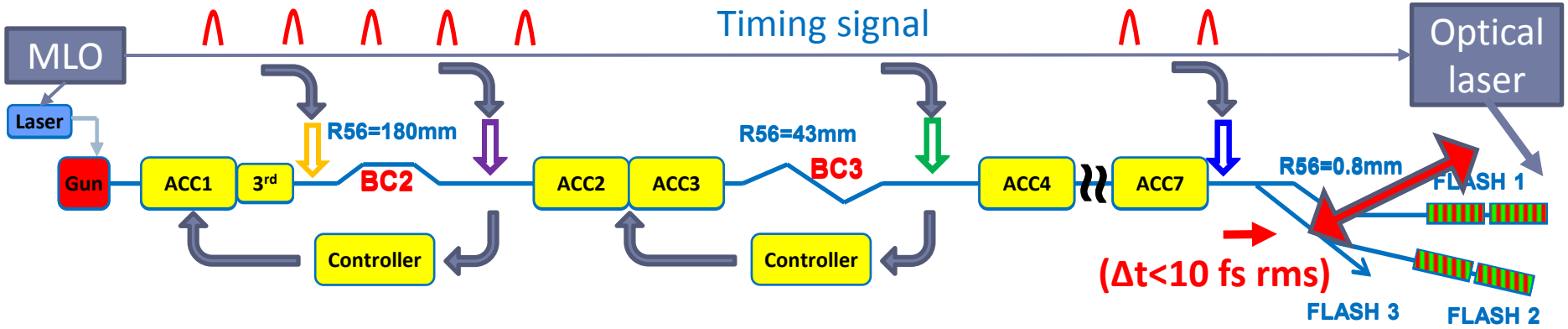


- Adjustment of accelerating voltage to control bunch arrival time
- Fast beam feedbacks for arrival time stabilization (~usec bunch spacing)

→ **Key feature of all SRF accelerators**



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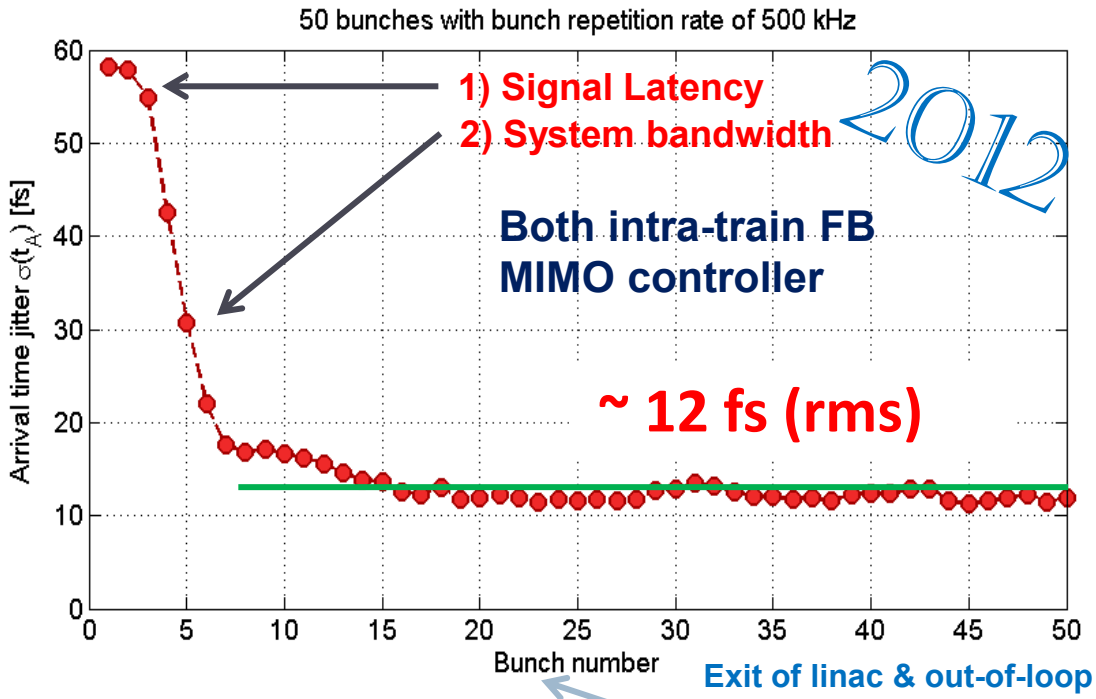
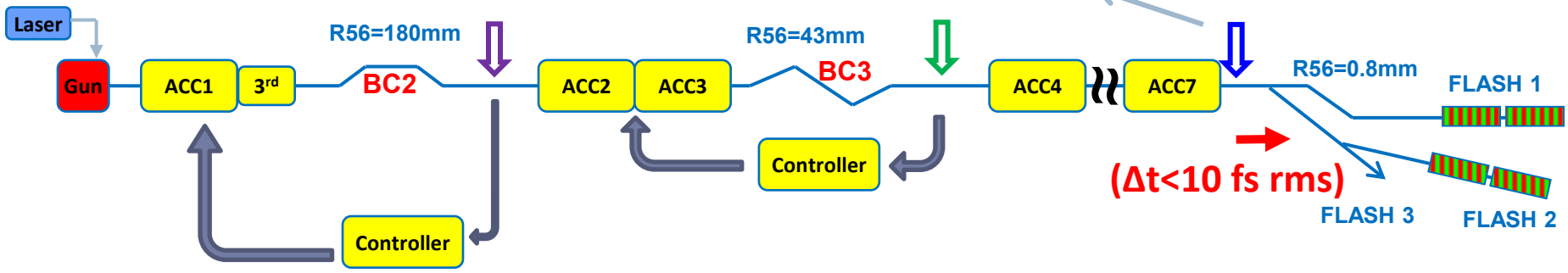




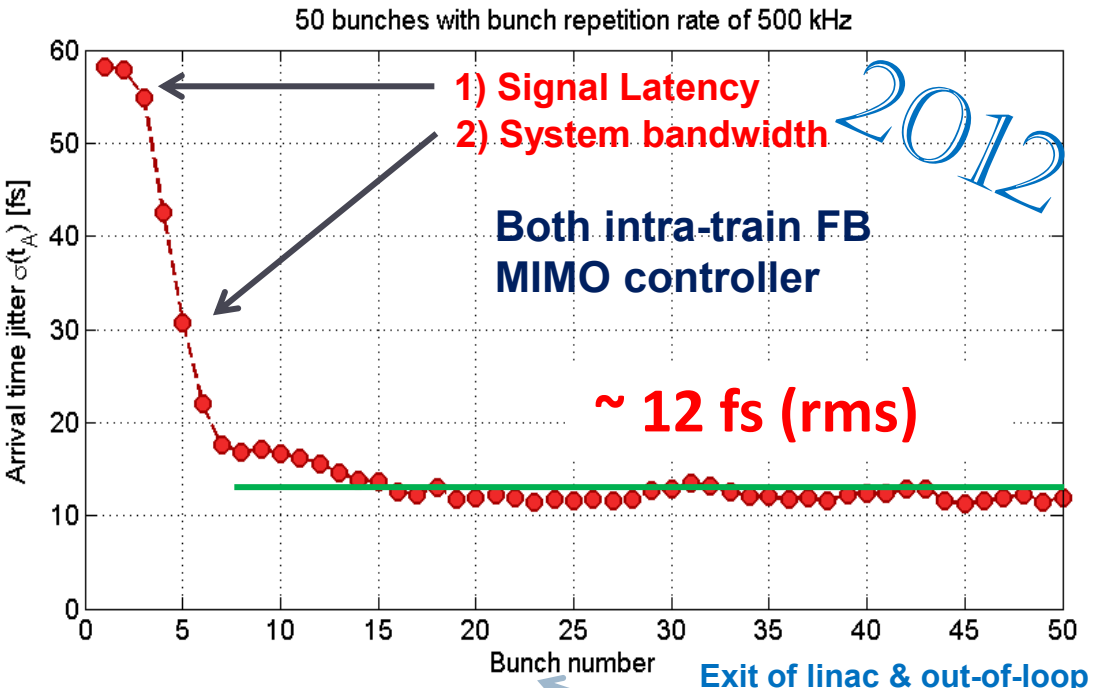
4. Ultra-Fast Beam-Based Feedbacks

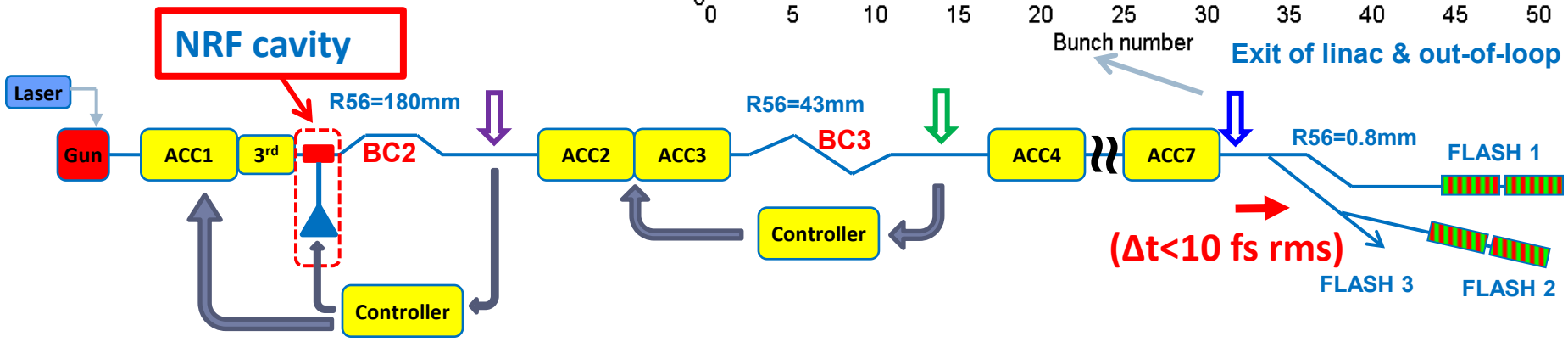
WP13.3:

Integration of normal conducting cavity (NRF)

- Low Latency ~ 0.7us
- Increased actuator bandwidth: NRF (0.5–1.0MHz)
- No influence on orbit
- **Goal: < 5fs rms**

→ Demonstrated by simulations





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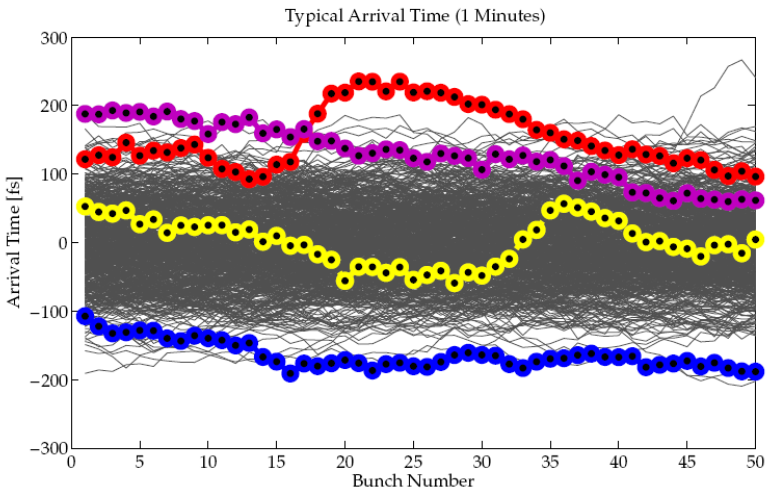
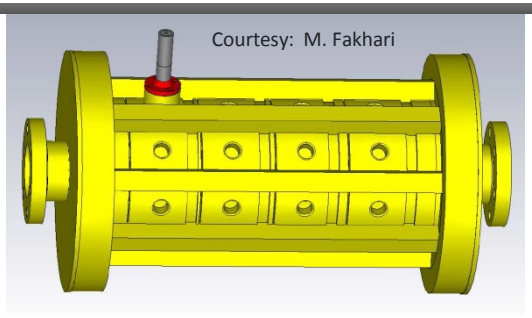


Design progress



- 4 cell copper cavity

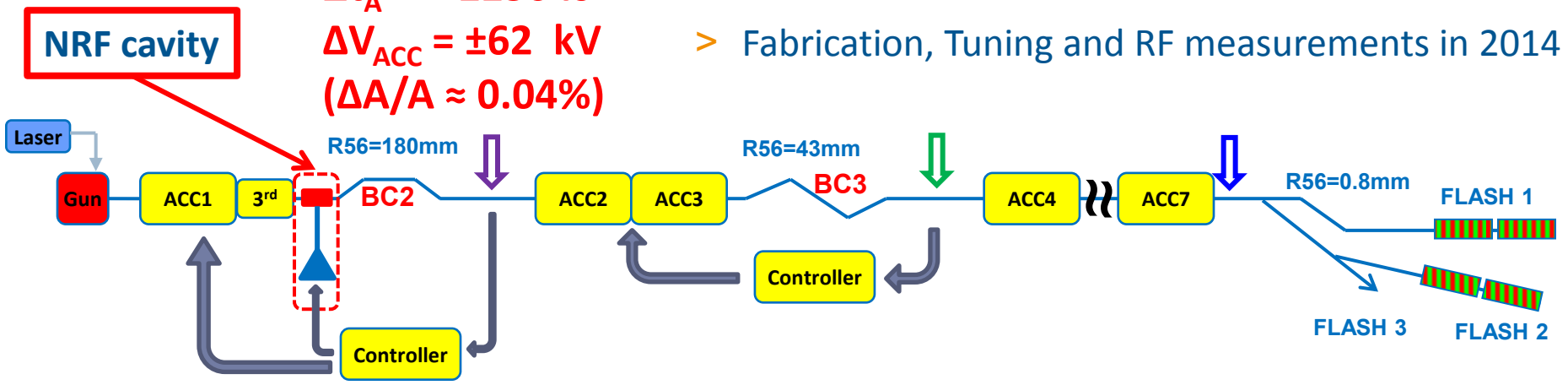
  (3 GHz, 1 kW)

- 2D and 3D Parameter Optimization using special software (*Superfish, Microwave Studio, ASTRA*)
  - W.r.t. geometry, multi-beam effects (long. and transverse wakefields), …
- Fabrication, Tuning and RF measurements in 2014

$\Delta t_A = \pm 250$ fs

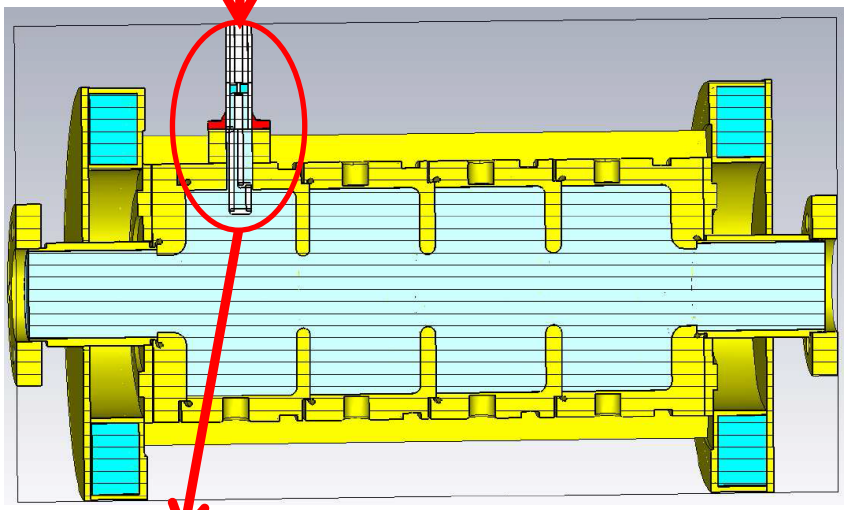
$\Delta V_{ACC} = \pm 62$ kV

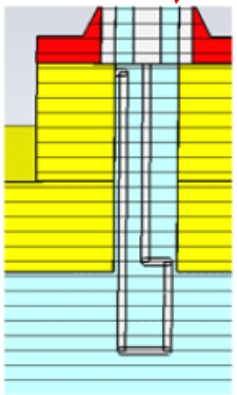
$(\Delta A/A \approx 0.04\%)$



4. Ultra-Fast Beam-Based Feedbacks

Typ. power from
HV amplifier: 1kW





Magnetic loop coupling

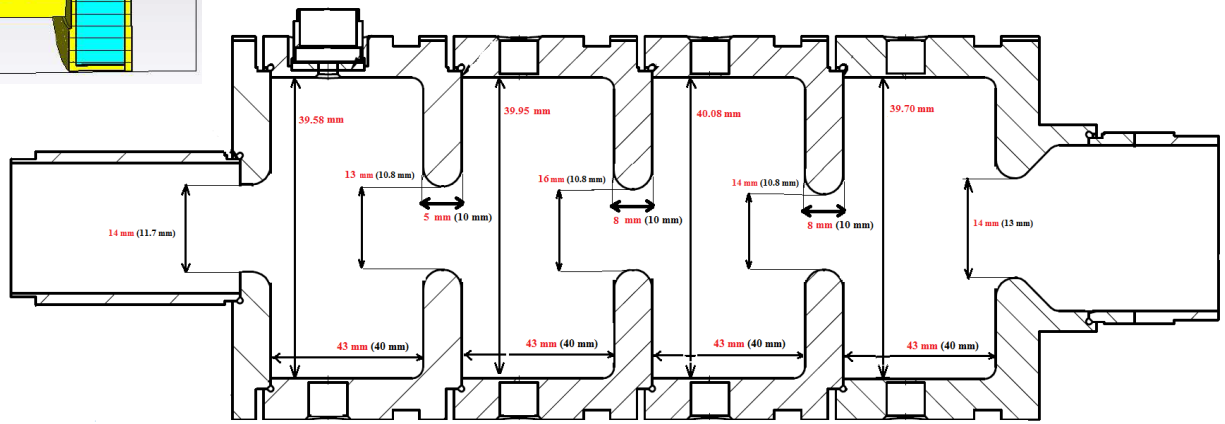
Courtesy: M. Fakhari

Tuning Parameters:

Cell dimensions

Considerations:

- Cell to cell RF field distribution
- Longitudinal and transverse wakefields
- Additional passband modes
- …



5. Conclusion

- Precision synchronization for ultra-fast science with FLASH as test bench
  - Optical synchronization system
  - Bunch arrival time monitor upgrade
  - Design and integration of NRF feedback cavity
  - …

What timing stability can be established?

Is 1 fs possible?

Acknowledgements

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THANK YOU FOR YOUR ATTENTION!