Bunch Arrival-time Monitors

Limitations & Developments

Topics:

Longitudinal Aspects of Electron Bunches

Bunch Arrival-time Monitors

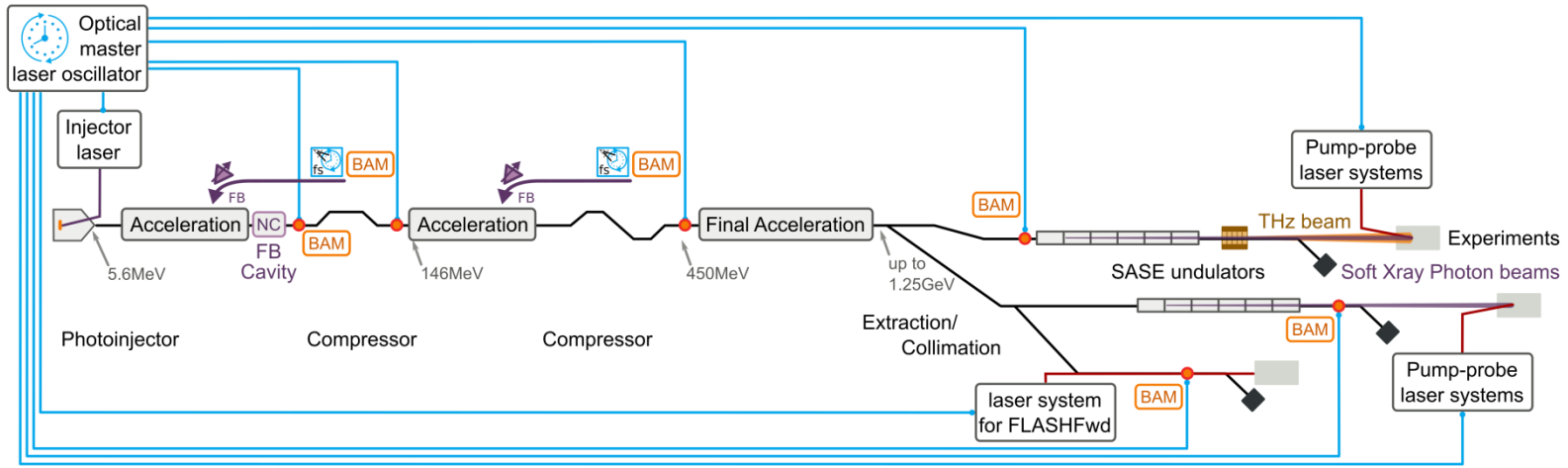
Function, Performance, Limitations, Developments

BAM and Longitudinal Diagnostics now and in FLASH2020+

2020-06-25
Marie K. Czwalinna
On behalf of the Special Diagnostics Team

Longitudinal Aspects

Interrelation of Bunch Properties and FEL Properties



Longitudinal Bunch Properties

Energy/Energy Gain
Charge Distribution
Compression (Length)
Shape/Profile

Timing

- .. of Bunches:
  - Cascaded acceleration
  - Energy gain in following modules
- .. of FEL-to-laser pulses
  - Longitudinal position of lasing slice

Energy

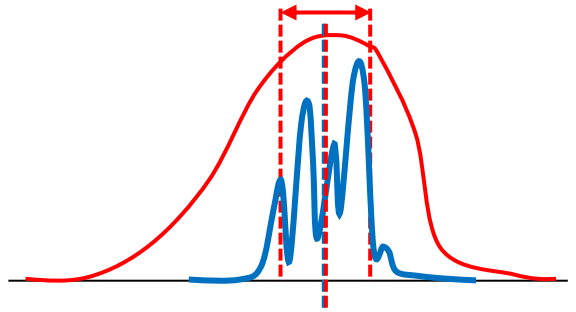
- FEL energy → center wavelength
- Bandwidth of the spectrum

Peak Current/Current Profile

- Intensity of FEL pulses
- Number of modes
- …

FEL in saturation:

$T_{ph}(FWHM) = \sigma_e(rms)$



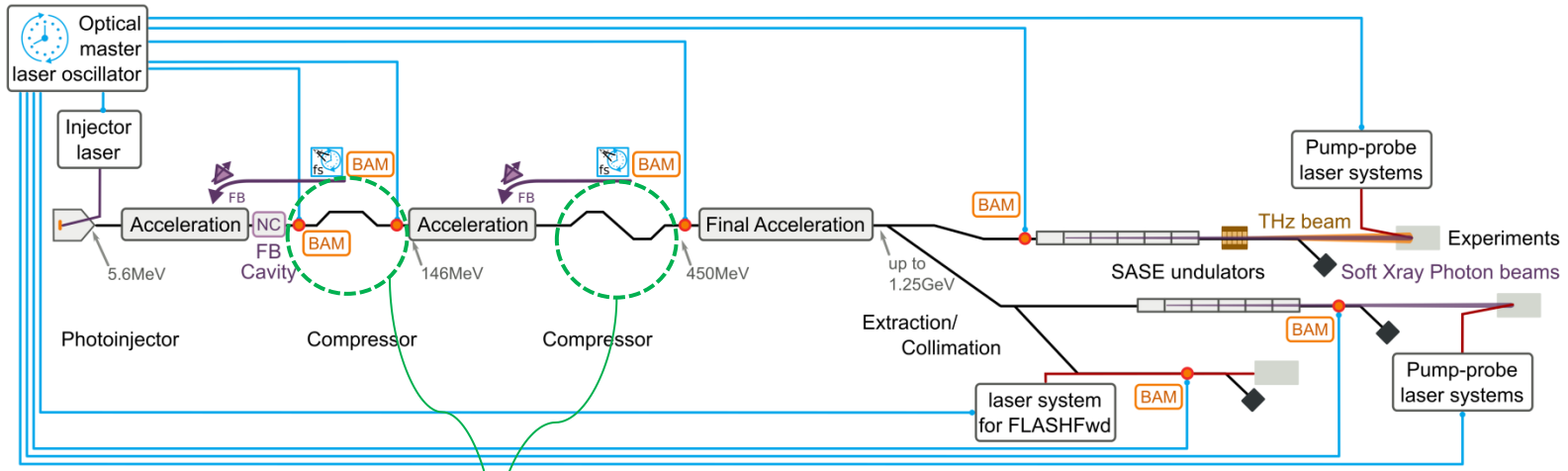
Timing Relation Bunch to FEL

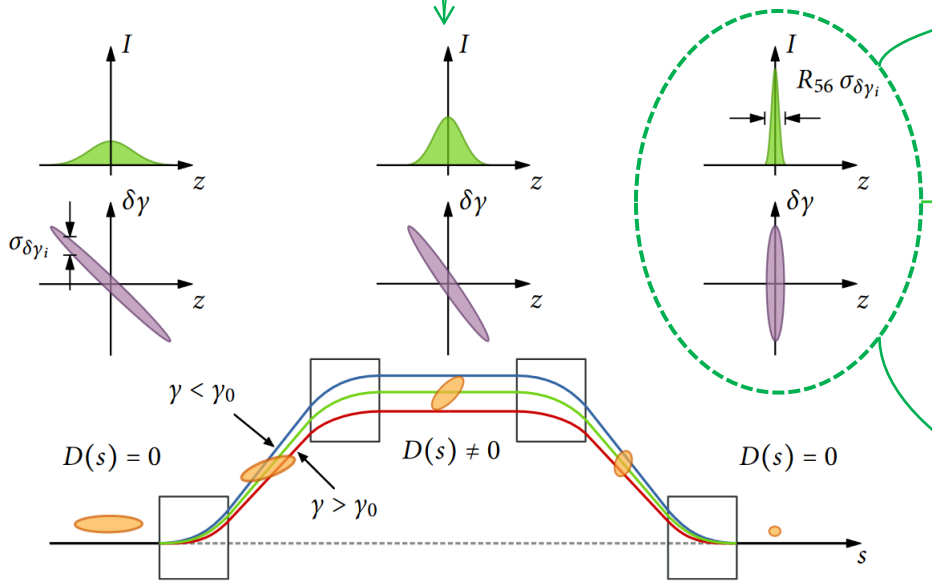
$\langle t_e \rangle \rightarrow \langle t_{ph} \rangle$

Is this valid?
And to what extent?

Longitudinal Aspects & Diagnostics

Interrelation of Bunch Properties and FEL Properties





Q(z), δE(z)

Δt, ΔE

C, σt

CRD (THz Spectrometer)
EOSD (Electro-optical Spectral Decoding)
XTDS (x-band Transverse Deflecting Structure)

- 1d profiles

BAM = bunch arrival time monitor

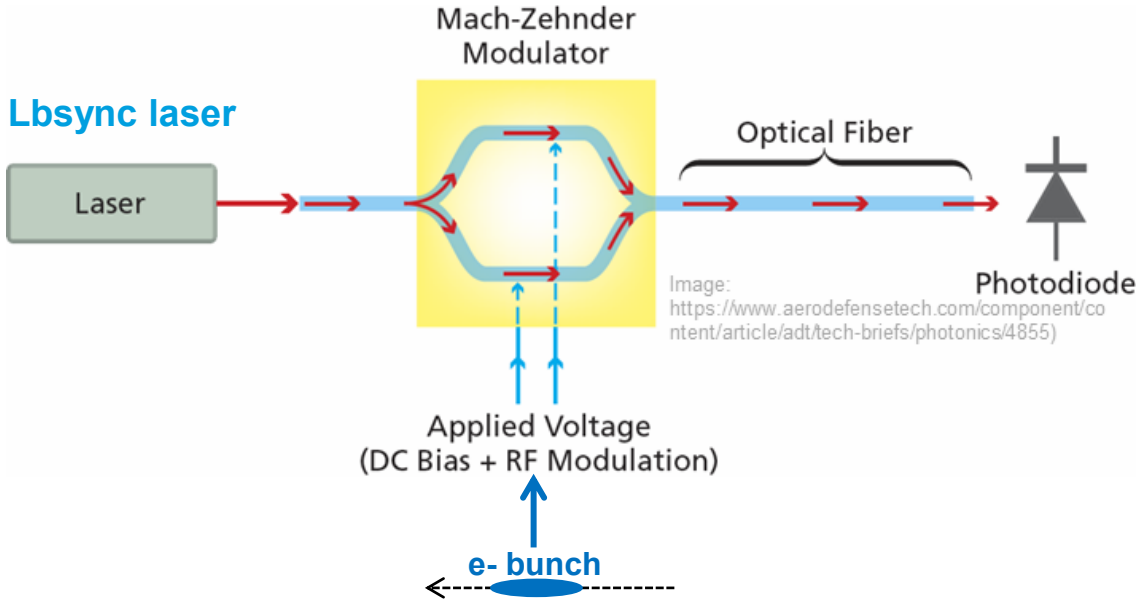
- Single value per bunch → suited for fast feedback
- Timing of center of charge
  - System bandwidth not sensitive to sub-structures
- **Relative** timing : **bunch-to-lbsync laser**

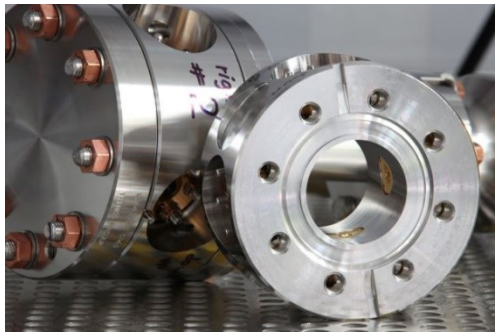
BCM = bunch compression monitor

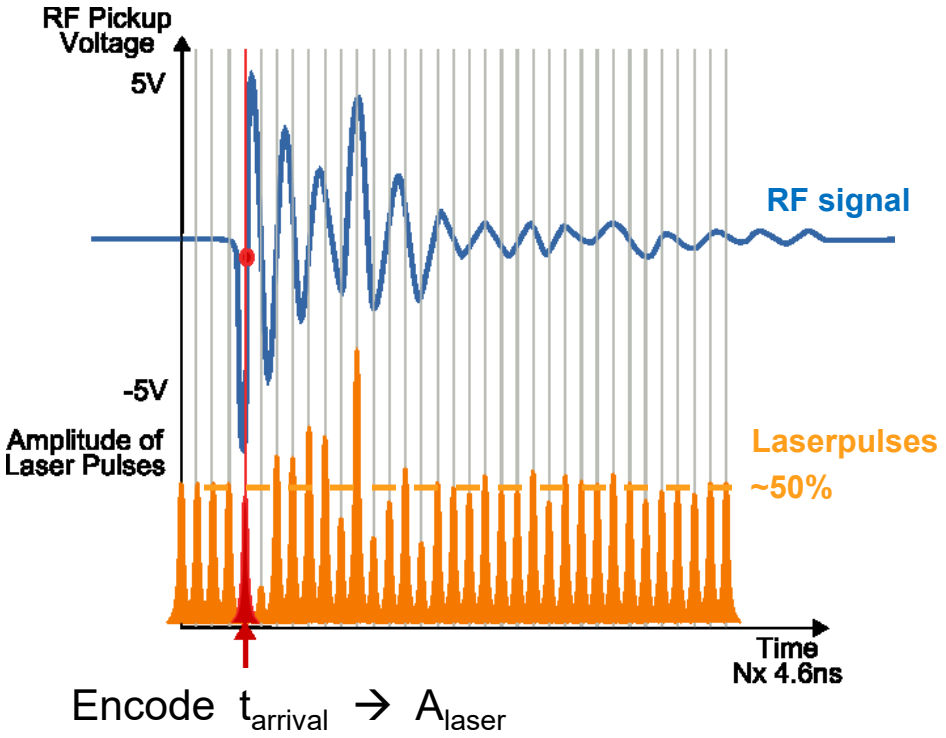
- Single value per bunch → suited for fast feedback
- But highly non-linear

Bunch Arrival-time Monitor

Function







Encode $t_{arrival} \rightarrow A_{laser}$

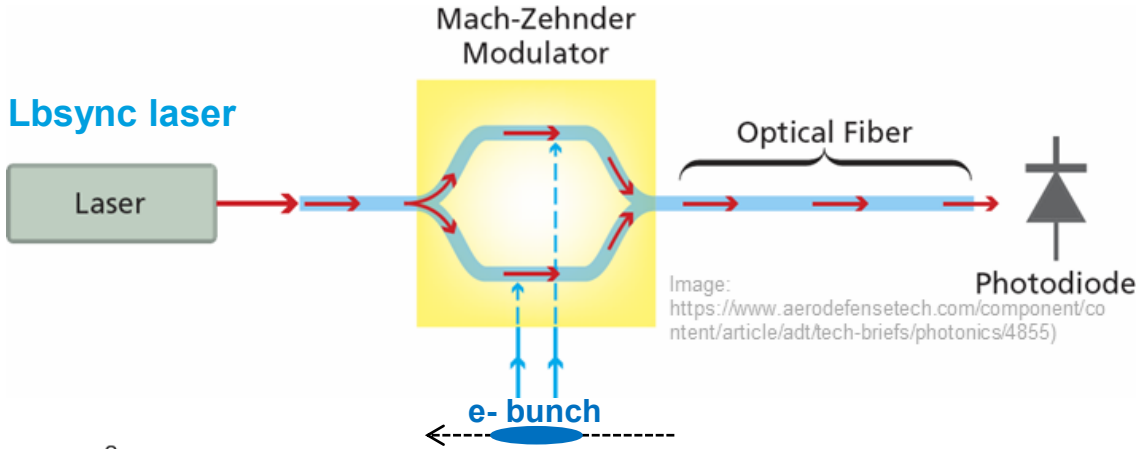
- Slight dependence on beam position
- 2nd order effect

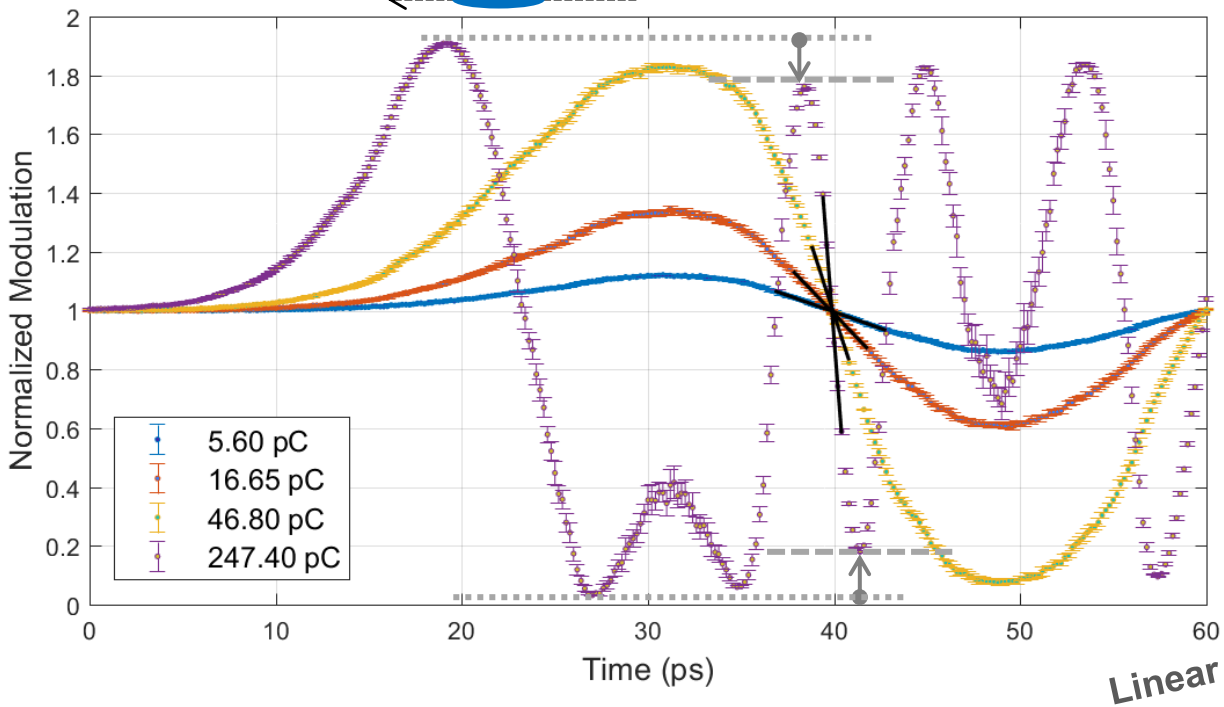
- **< 30 as / µm**

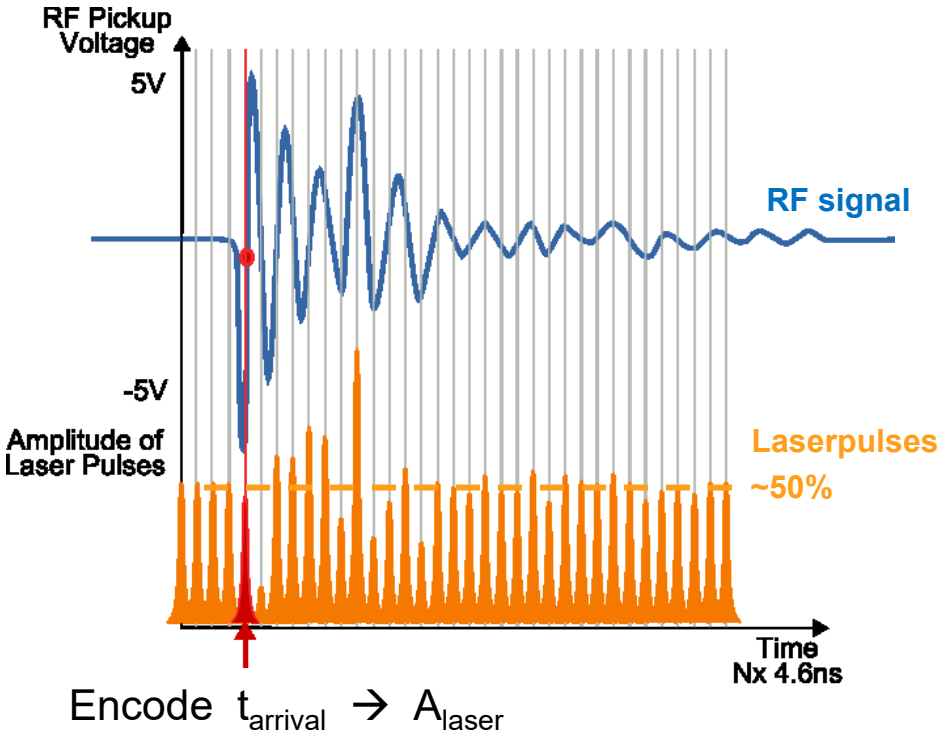
One laser pulse carries the arrival time information.

Bunch Arrival-time Monitor

Function







Encode $t_{arrival} \rightarrow A_{laser}$

One laser pulse carries the arrival time information.

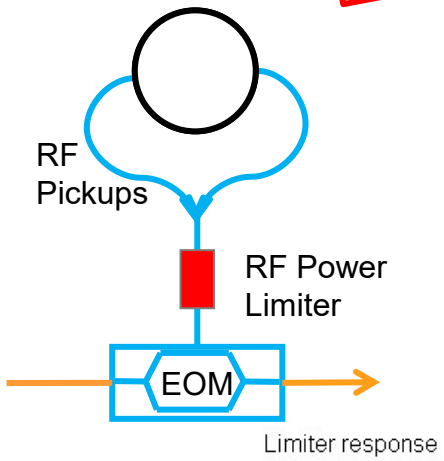
Linear slope → Sensitivity

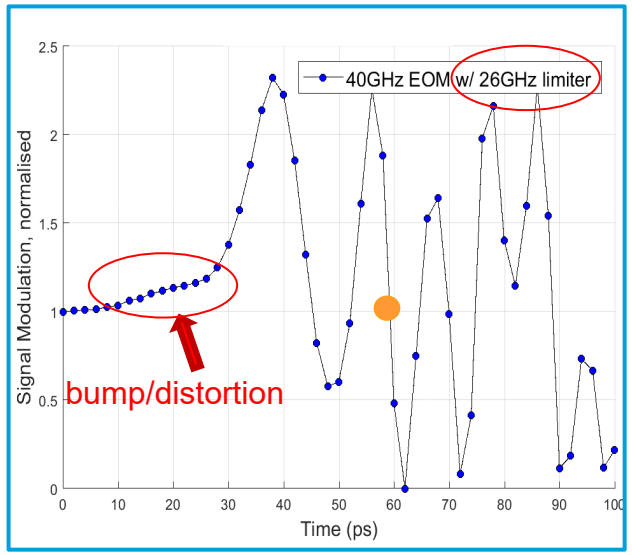
- Slope steepness increases with higher voltage amplitude
- Dynamic range decreases again at high charges

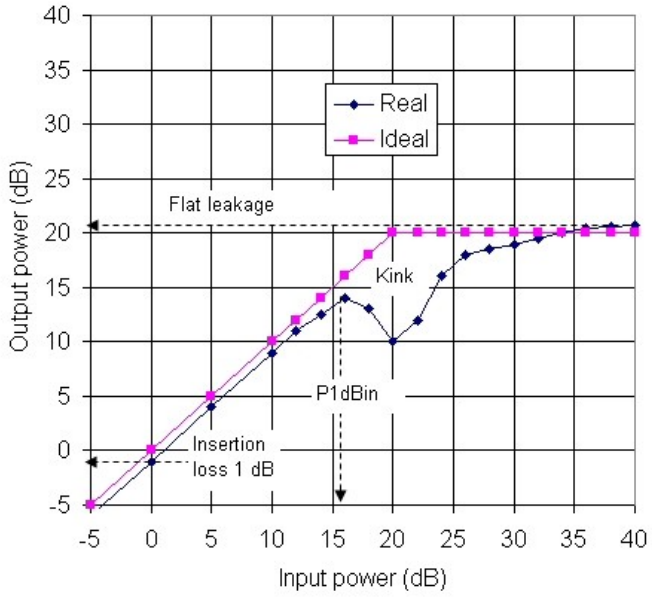
Bunch Arrival-time Monitor

Improvement

2018



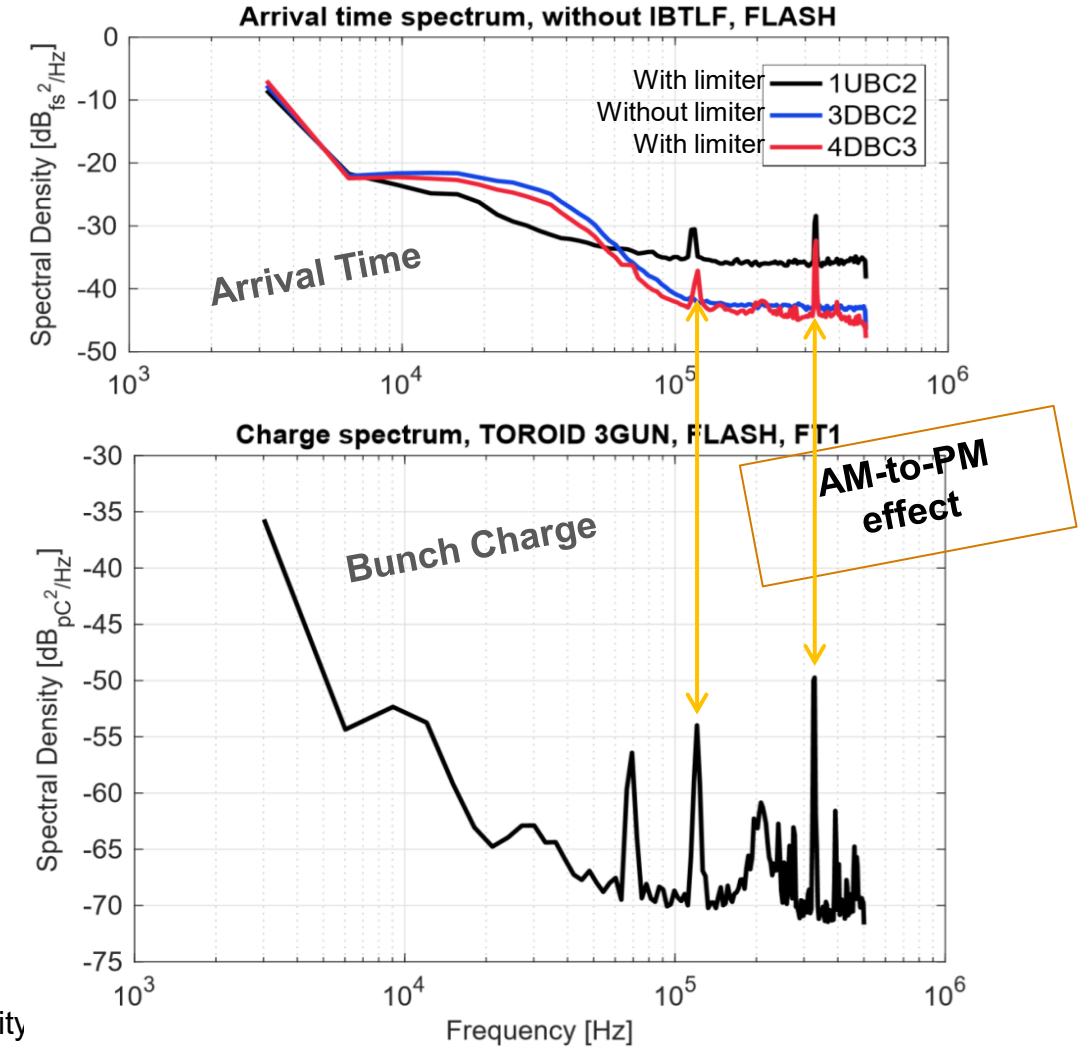




https://www.everythingrf.com/community/what-is-an-rf-limiter

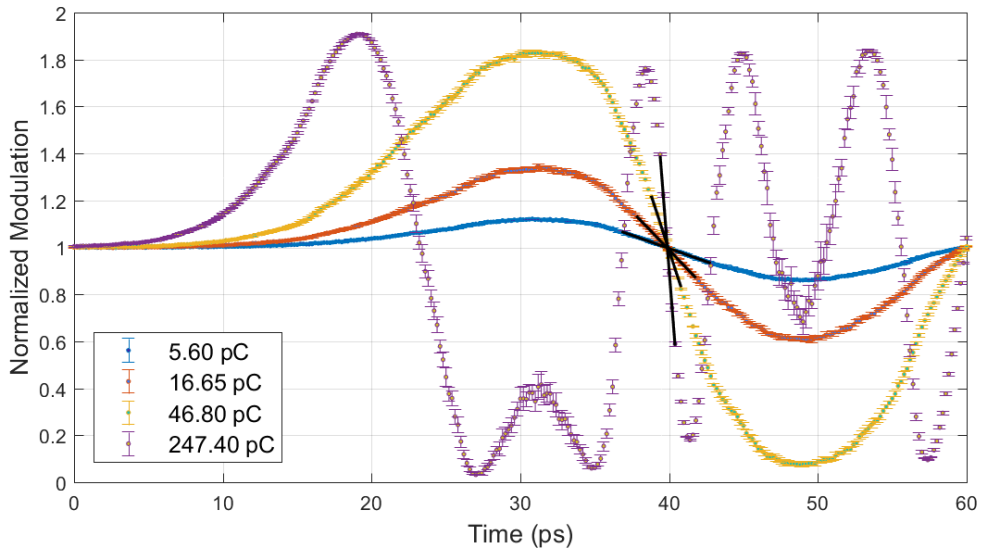
RF Limiter (PIN diode), drawbacks

- Semiconductor with AM-to-PM effect
- ✓ Removal of limiter eliminated this nonlinearity
- ✓ Spectral analysis now offers quick check of the operation point (time overlap laser -to-RF pulse)



Bunch Arrival-time Monitor

Performance and its limitations



Resolution: σ_t = Sensitivity · σ_{Laser}

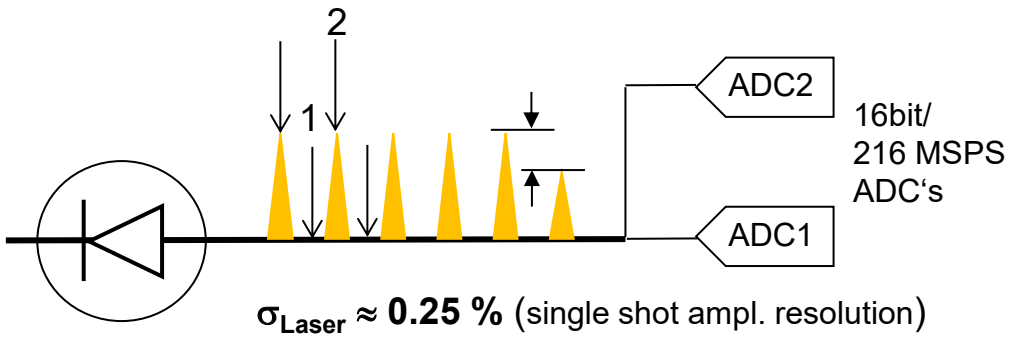
Amplitude noise is a hard limit

- It is not stable (varies over time)
- Main sources are not identified yet

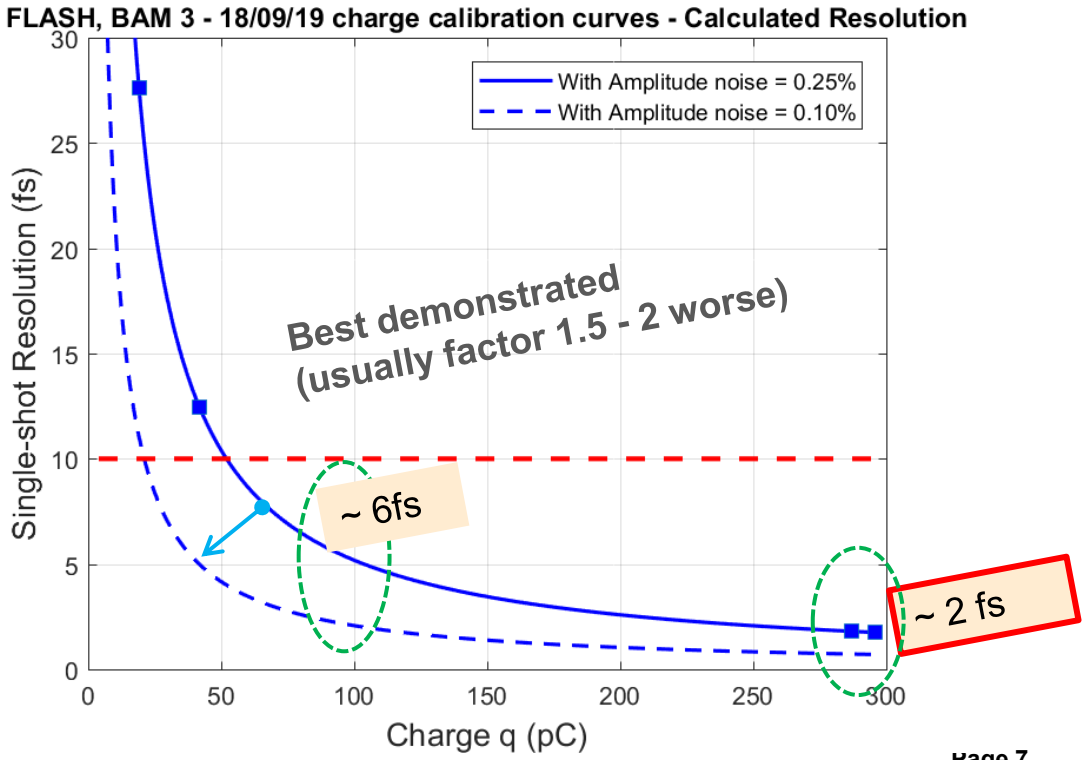
The higher the sensitivity, the lower the dynamic range

- Adds complexity to the system to cope with large charge range
- Needs sophisticated automation.

Laser pulse train readout & processing in FPGA (high-pass filter scheme).



$\sigma_{Laser} \approx$ **0.25 %** (single shot ampl. resolution)

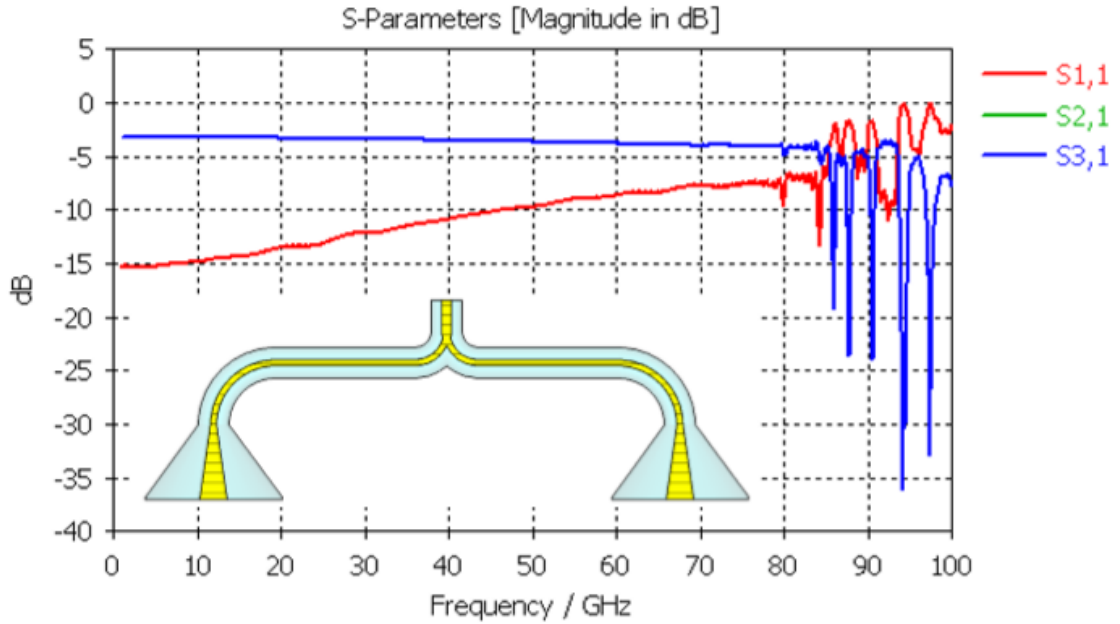


Advanced Bunch Arrival-time Monitor

Further Developments

- for ultra-low bunch charges
  Goal : 1fs resolution @1pC

- Collaboration with THM, KIT, TUD, HZDR



(BMBF) contract no. 05K19RO1.

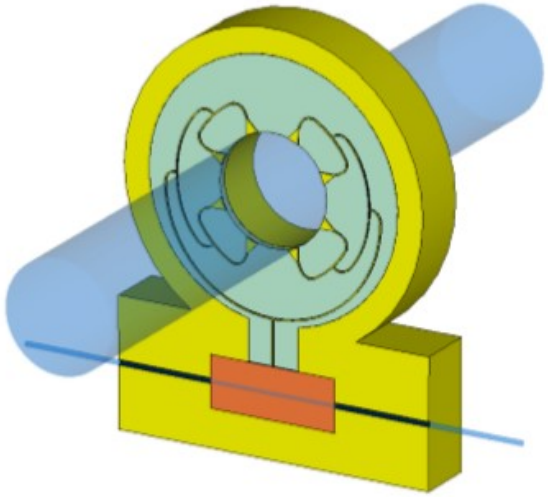
Subproject-leader: **Broadband, ultra-low-charge BAM-Pickup Geometry**
Prof. Dr.-Ing Andreas Penirschke

Ultra Broadband Electro-Optical Modulator

Prof. Dr. Anke-Susanne Müller, KIT LAS

Prof. Dr. Christian Koos, KIT IPQ

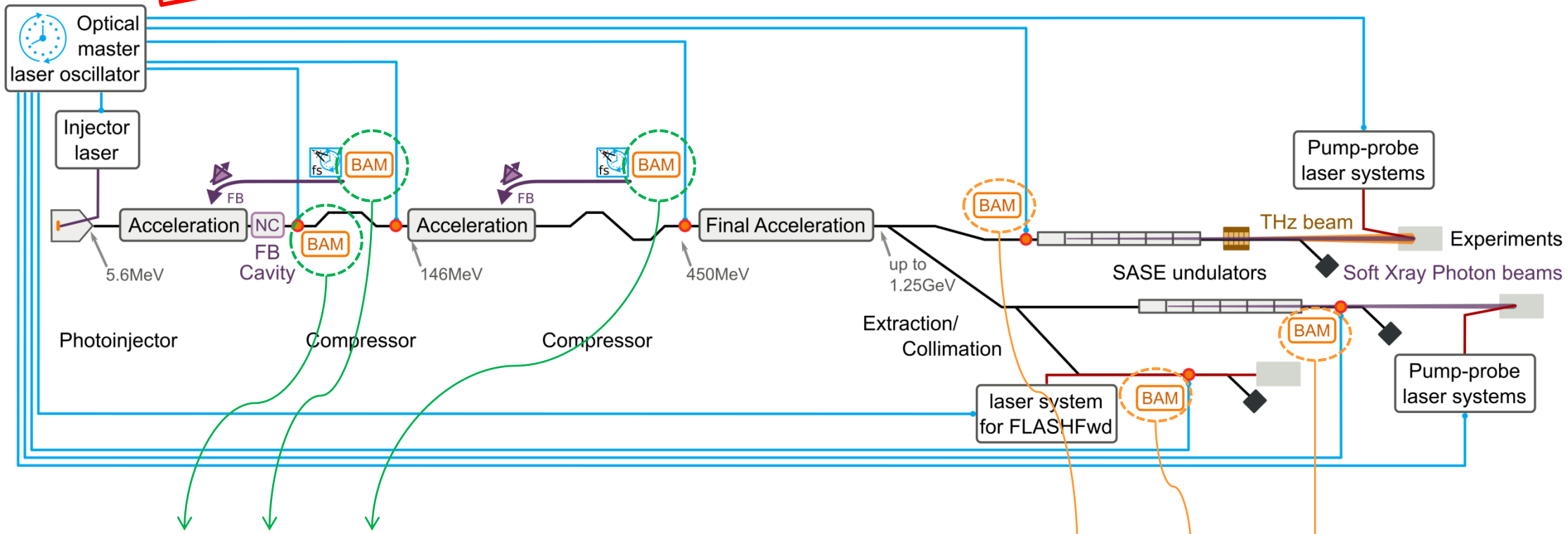
- Possible solution, 8 pickup geometry
- 1mm coaxial connector (50Ω) direct input to EOM
- Up to 100GHz system bandwidth
- Status as proof of concept



BAMs @FLASH

Current state

2019



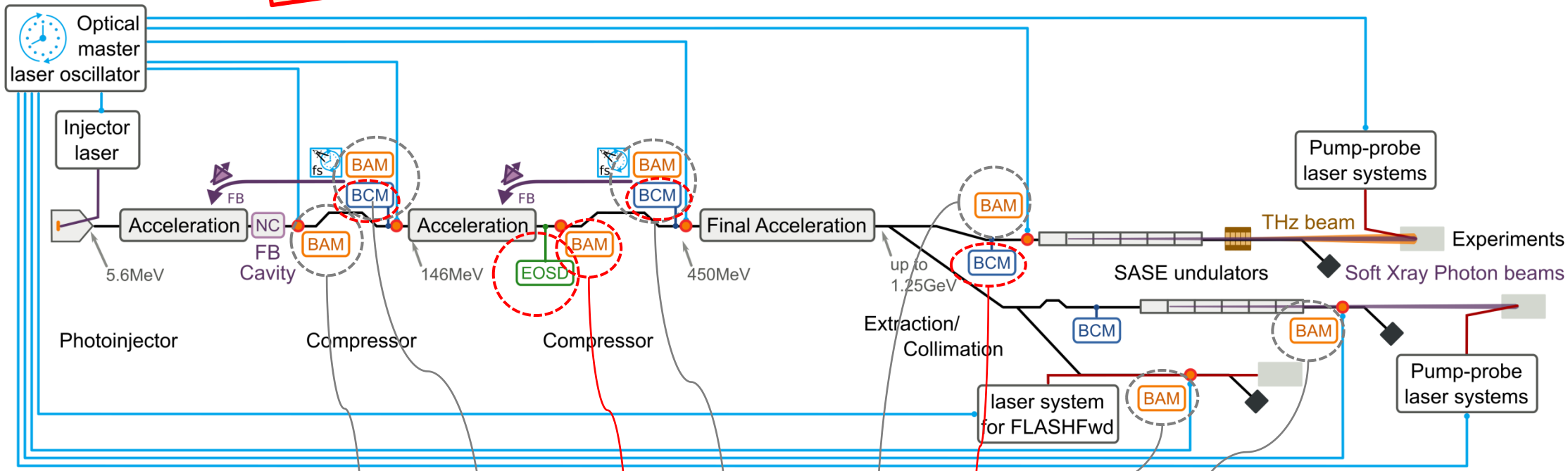
BAMs	1UBC2	3DBC2	4DBC3
In operation ?	yes	yes	yes
Used for feedbacks?	(no)	yes	yes

BAMs	1SFELC	7FLFMAFF	8FL2XTDS
In operation ?	nearly	no	yes
Used for feedbacks?	no	no	no

Longitudinal Diagnostics for Fast Beam-based Feedbacks

Outlook FLASH2020+

In planning



BAMs	**FL0UBC1** (1UBC2)	**FL0DBC1** (3DBC2)	**FL0UBC2** New (2022)	**FL0DBC2** (4DBC3)	FL1 (1SFELC)	FLASH2 (7FLFMAFF)	FLASH3 (8FL2XTDS)
Refurbished BCMs		FL0DBC1 (2021/22)		FL0DBC2 (2021/22)	FL1, New (2024 ?)		
Fast feedback data (direct link to RF Control)	only BAM	BAM+BCM via 1 link	only BAM	BAM+BCM via 1 link	- / -	- / -	- / -

same (MTCA) crate

same (MTCA) crate

same (MTCA) crate

Might want to shift upstream?