Normal conducting cavity for arrival time stabilization

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Motivation

- Improve synchronization pump-laser

  requested from users < 10 fs FWHM (4fs rms)

- Seeding & slicing and bunch manipulation

  better control on seeded portion of electron beam < 10fs desired

- Plasma acceleration (synchronization plasma laser)

  bubble regime requires ideally ~ 2-3 fs rms synchronization

- Ultra-short pulses (< 20fs)

  better control on compression & arrival

  synchronization jitter < electron bunch duration

- Accelerator R&D

  limit for arrival time stability in SRF system!

  7 fs rms stability @ FLASH == dV/V < 1e-5

Question: how can we improve

Courtesy: M. Bock

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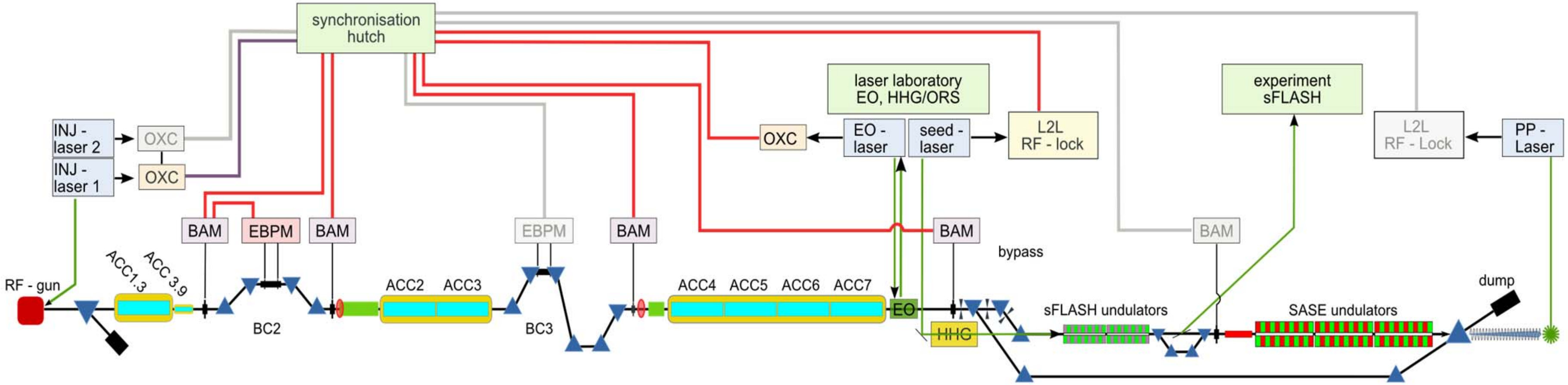
Overview for FLASH



- Optical synchronization system provides fs stability
- BAM allows for femtosecond measurement of arrival time
- L2L to lock lasers with femtosecond precision

Continuously upgraded

Courtesy: M. Bock

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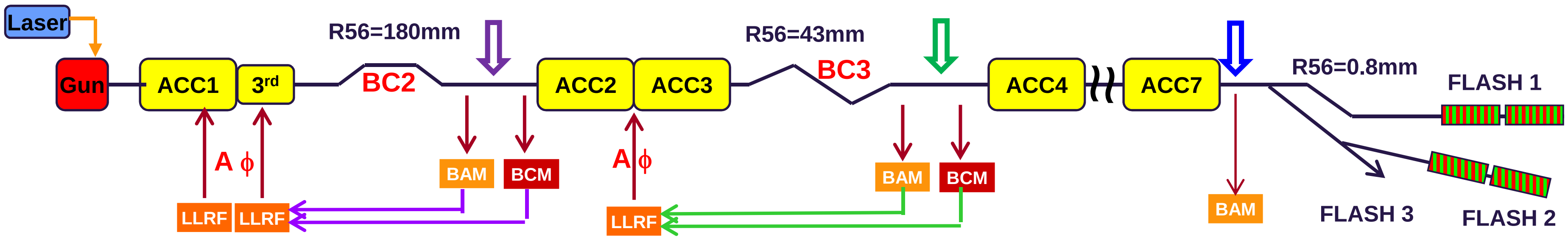
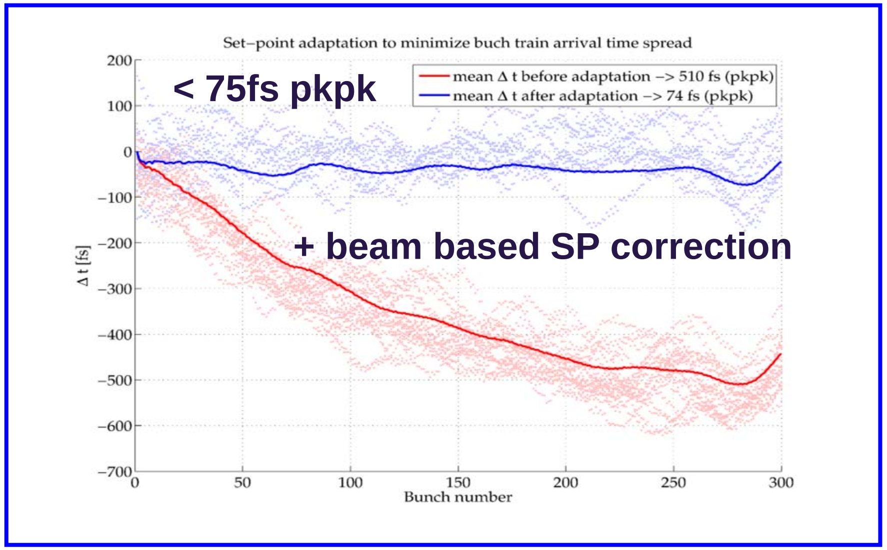
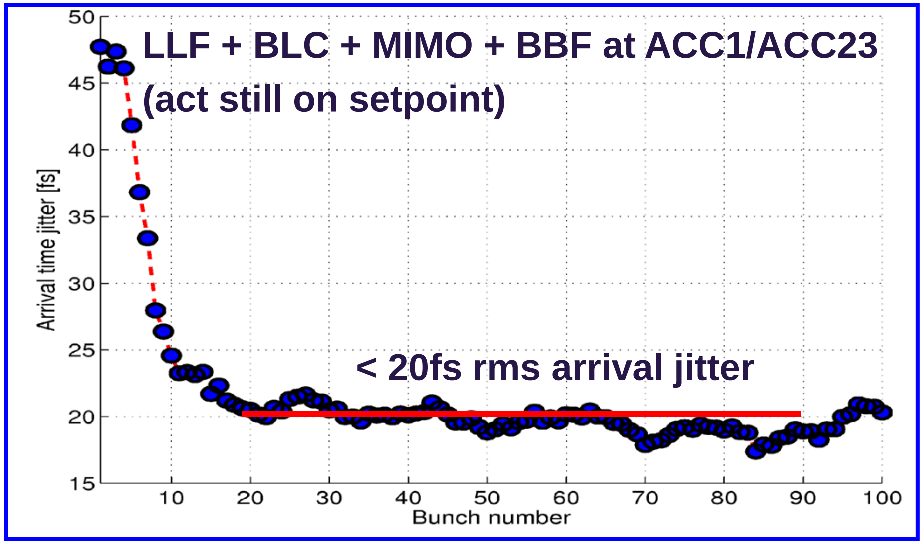
Beam based feedback



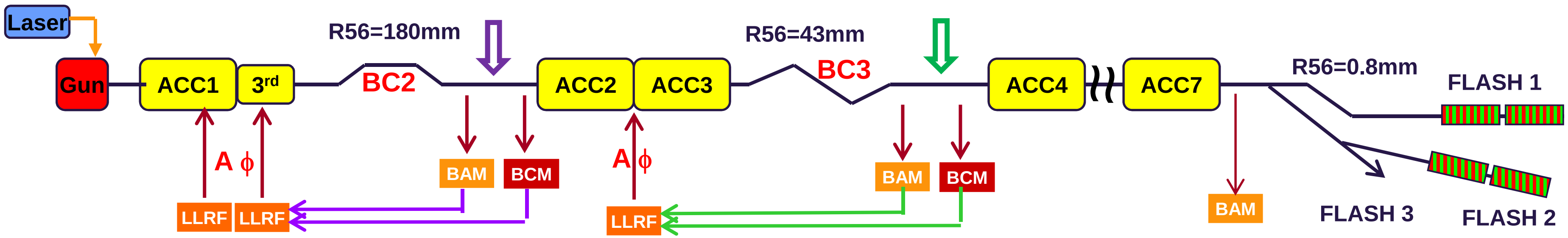
Beam Based Feedbacks:

- BAM and BCM after BC2 ⇒ amplitude and phase in ACC1 and ACC39
- BAM and BCM after BC3 ⇒ amplitude and phase in ACC23





Beam based feedback



Beam Based Feedbacks:

- BAM and BCM after BC2 ⇒ amplitude and phase in ACC1 and ACC39
- BAM and BCM after BC3 ⇒ amplitude and phase in ACC23

Timing jitter behind BC2

Voltage | Phase | Incoming

$$\Sigma_{t,f}^2 = \underbrace{\left(\frac{R_{56}}{c_0}\right)^2 \cdot \frac{\sigma_{V_1}^2}{V_1^2}}_{\text{FLASH: 7.0ps/\%}} + \underbrace{\left(\frac{C-1}{C}\right)^2 \cdot \frac{\sigma_{\phi_1}^2}{\omega_{rf}^2}}_{\text{2 ps/deg L-band}} + \underbrace{\left(\frac{1}{C}\right)^2 \cdot \Sigma_{t,i}^2}_{\text{0.05 ps/ps C=20}}$$

compression factor C ~5 … 20

Case 2: $\phi_2 \approx 0°$, $E_2' \ll E_1'$:

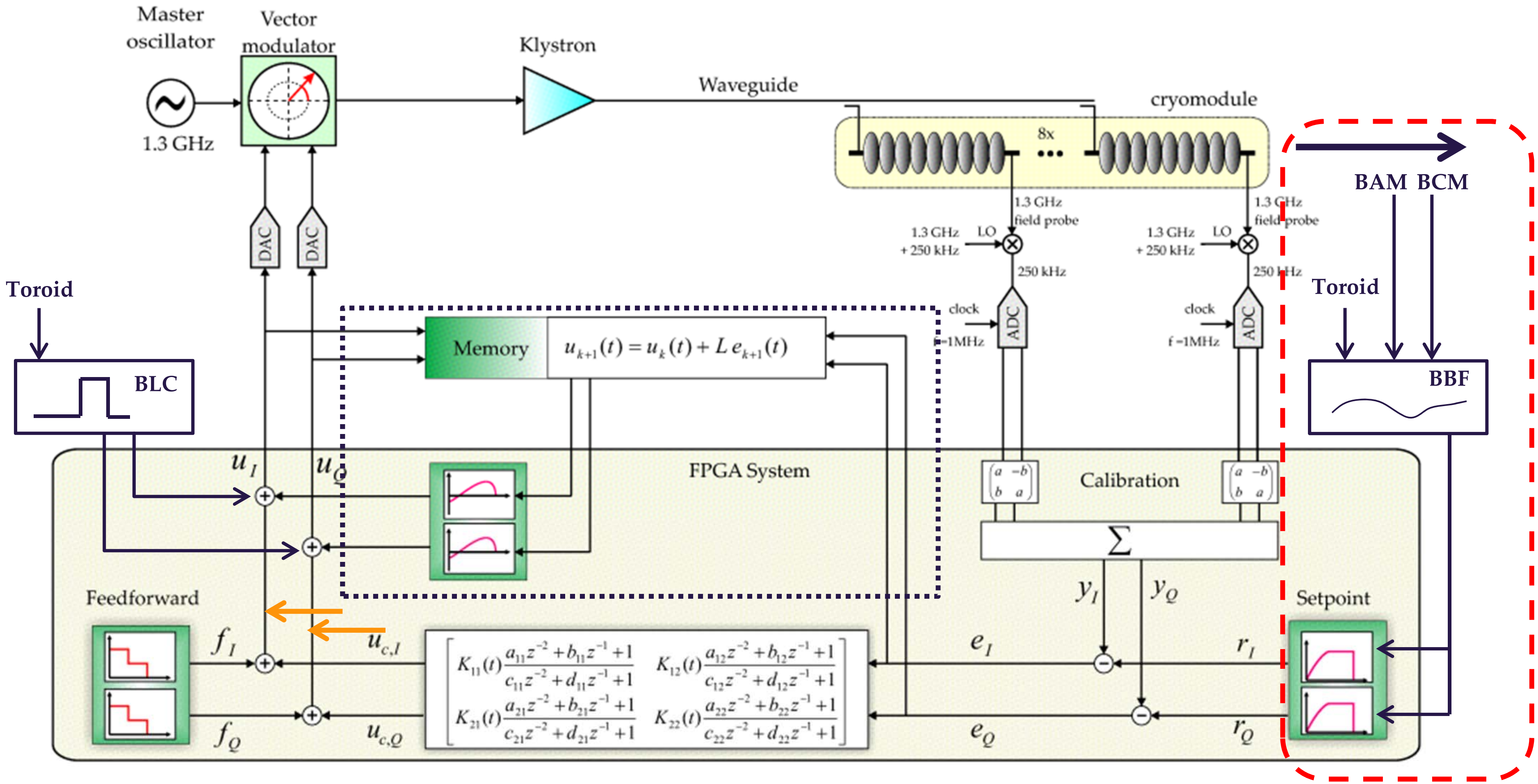
Jitter from BC2 largely remains + additive jitter!

Timing jitter behind BC3

$$\Sigma_{t,2}^2 = \underbrace{\left(\frac{R_{56,2}}{c_0}\right)^2 \frac{\sigma_{V_2}^2}{V_2^2}}_{\text{FLASH: 0.9ps/\%}} + \left(\frac{C_1C_2-1}{C_2(C_1-1)}\right)^2 \left(\left(\frac{R_{56,1}}{c_0}\right)^2 \frac{\sigma_{V_1}^2}{V_1^2} + \left(\frac{C_1-1}{C_1}\right)^2 \frac{\sigma_{\phi_1}^2}{\omega_{rf}^2}\right) + \left(\frac{1}{C_1C_2}\right)^2 \Sigma_{t,0}^2$$

FLASH: 0.9ps/% for $dV_2/V_2 < 2.5e\text{-}5$ with uTCA => 2fs rms

Implementation of beam based feedback into LLRF controller



- **present implementation of BBF into LLRF**
  ⇒ only via set-point correction (robust but not optimal due to RF controller design)
- **new implementation: acts in addition directly on feed forward**
  ⇒different controller design, lower latency, MIMO including BBF

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Drawback using SRF

SRF cavities have low bandwidth (very stable!)

Parameter		
Frequency	f_0	1300 MHz
Loaded Q	Q_L	3e6
Bandwidth (-3dB)	$\delta f = f_0/(2Q_L)$	216 Hz
Rise/fall time	τ	735 us
r/Q	r/Q	1041 Ω

Fast correction may required due to

- Transients induced by cavity passband modes (dE/E ~ 3e-5)
- Multi-bunch longitudinal wakefields
- Rapid variation in photo injector lasers / RF gun (pulse form/shape)
- Beam loading changes due to rapid bunch charge variations
- Fast oscillations of arrival time has been observed (~100kHz)
- 8/9pi mode requires roll off of LLRF FB controller

Power for fast corrections

- Large klystron power variations required
- Power changes Pfor/Pref at main coupler => orbit
- Sophisticated exception handling required

0.01%

$$\frac{\Delta P}{P} = 2\boxed{\frac{\Delta V}{V}}\frac{\tau}{\Delta t}$$

1μs

dP/P ~ 14%

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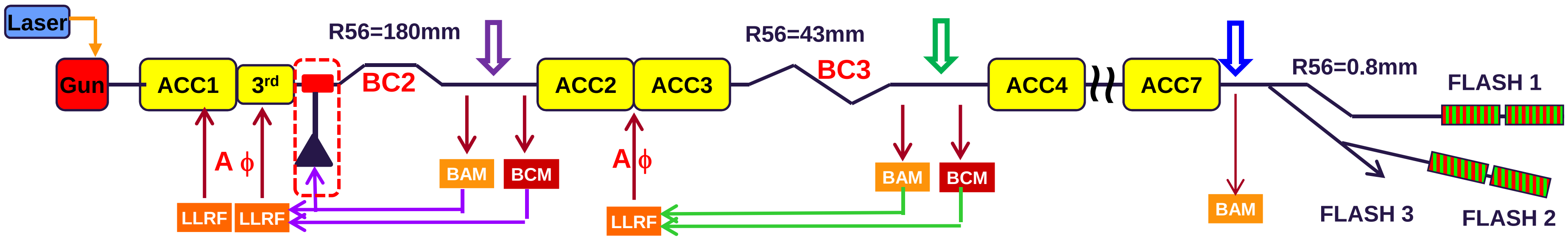
Beam based feedback: new topology



Beam Based Feedbacks:

- BAM and BCM after BC2 ⇒ amplitude and phase in ACC1 and ACC39

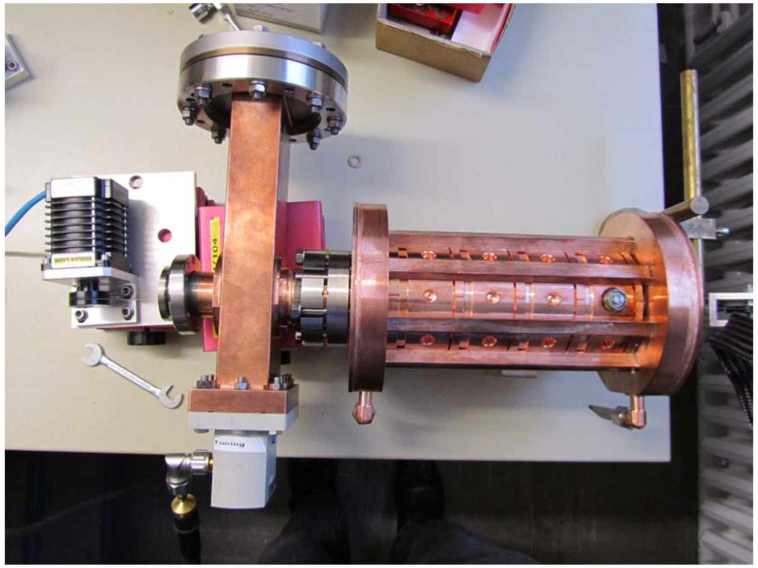
  but mainly slow variations, systematic & repetitive errors <~20kHz
- BAM and BCM after BC3 ⇒ amplitude and phase in ACC23
- BAM after BC2 ⇒ feed forward drive for normal conduction cavity

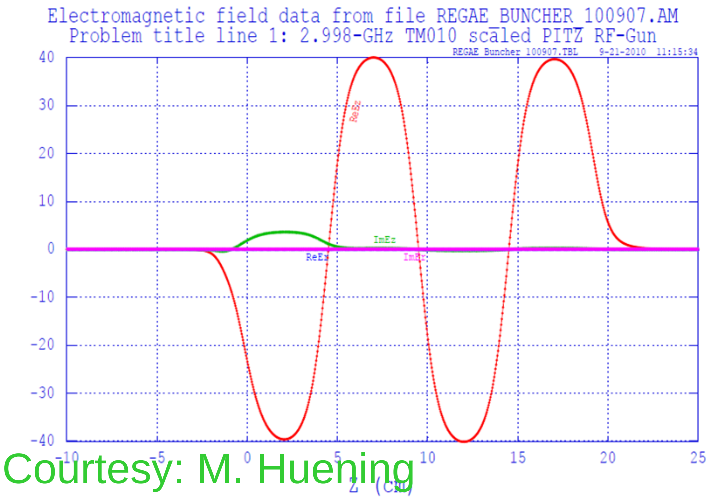
Remark to fast long FB:

- Only location possible prior to BC2: large R56 at small energy (150MeV)
- Typically ~ 50-100 kV @ 1000 x large cavity bandwidth
- Short cables, fast processing time, only semi-conducting amplifier
- Latency < 1 us
- Shoot for FB bandwidth > 100 kHz

Normal RF FB cavity with large bandwidth

Option: Regae buncher cavity (design ready, parts can remanufactored)





Courtesy: M. Huening

Parameter		
Quality factor	Q0	8346
Frequency	f_0	2997.2 MHz
Number of cells	Ncell	4
Coupling	β	1
Loaded Q	Q_L	4173
Bandwidth (-3dB)	$\delta f = f_0/(2^*Q_L)$	360 kHz
Amplifier Power	Pmax	1 kW
Maximum Voltage	Vmax	99.7kV (±400fs)
Rise/fall time	τ	440ns
r/Q	r/Q	610.2 Ω

- Cavity excellent well suited ~ 100kV
- LO generation for 2.9972 GHz (TDS PITZ available)
- Semi-conductor Preamplifier with 1kW sufficient
- Water cooling only for tuning required (<5W average)
- May bandwidth increased by over-coupling
- Installation length ~ 35cm (critical)

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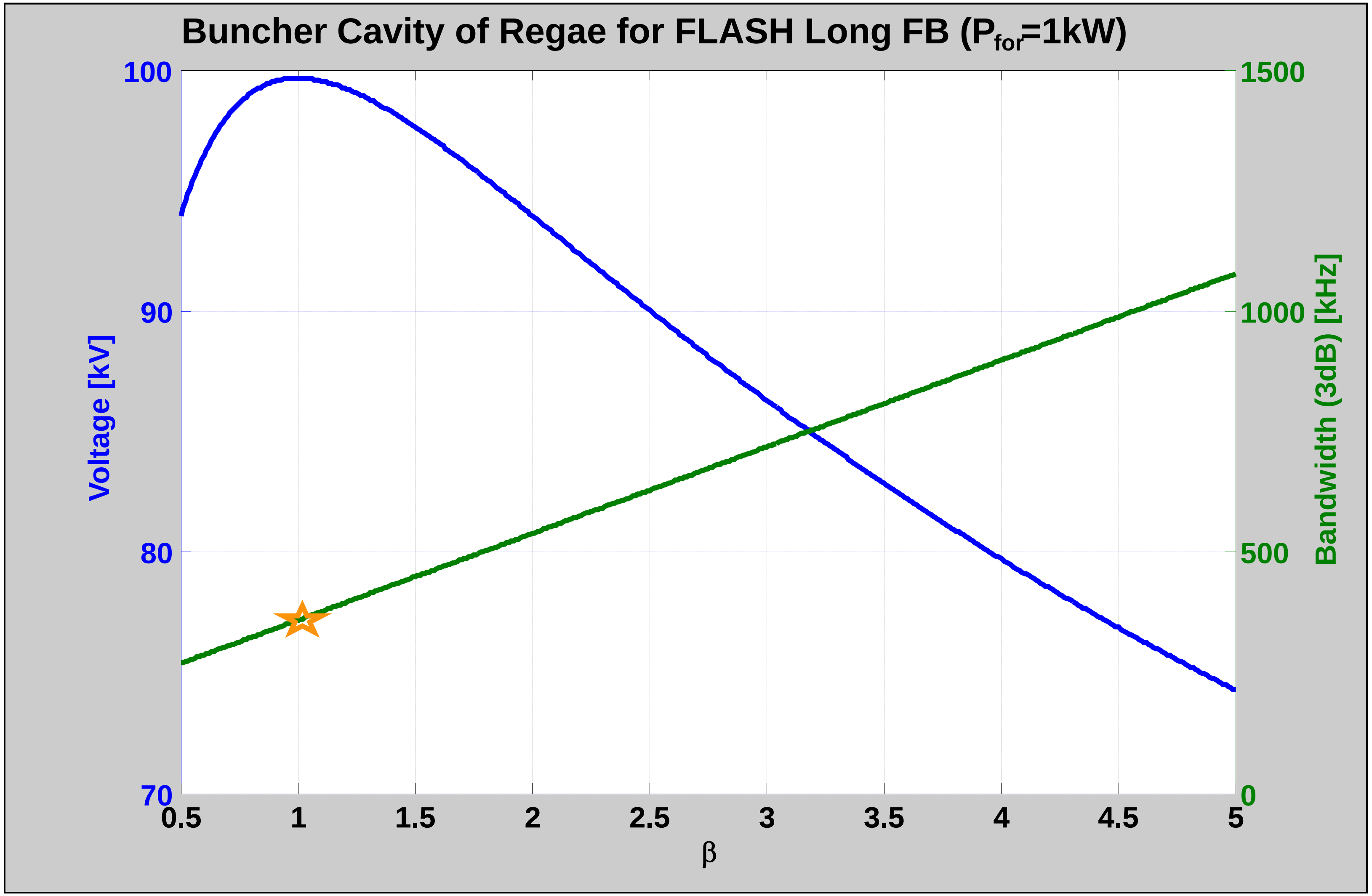
FB cavity with large bandwidth



Thanks for your attention