FCC-ee Feedback System Design Update

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Topics

- Preliminary comments and requirements
- Instability foreseen by simulations
- From lepton collider feedback legacy: standard design, option A
- Feedback performance limits
- How to bypass the performance limits: scalable and innovative designs
- 2nd proposed design: option B
- 3rd proposed design: option C
- Conclusion

Preliminary comment

- The bunch by bunch feedback systems for FCC-ee should be designed on the basis of the experience developed working on the lepton circular colliders in the last two decades.
- Along the past years a common way to approach these systems has been carried on for PEP-II, KEKB, DAFNE, and, later, for SuperB and SuperKEKB.
- Nevertheless the advance of the technology as well as the very high performance required by FCC-ee specifications recommend to evaluate improved project scenarios.

Basics ideas

- Common problems and limits have been discussed in the past between the feedback teams to find the best solutions.
- It must be noted that feedback systems for circular light sources are only apparently very similar, nevertheless they have to cope with different issues, performance requirements and beam currents.
- Having in mind the approach developed for the previous lepton colliders, what is necessary to damp the beam oscillations in FCC-ee is "simply" getting the position displacement (transverse and longitudinal) for each bunch in every turn, and, after computing the correction signal, applying it to the selected bunch as soon as possible.
- The systems will be designed to work in time domain without considering in detail which modes are acting in the ring but only taking in care the worst modal growth rate.
- Of course working bunch by bunch leads to a design that is mainly digital.

Other requirements

- Before to discuss how to proceed to approach the different cases, there are some preliminary requirements to consider.
- First of all it is necessary a very good beta function at the pickups to have a decent signal to noise ratio before processing it.
- Also a good beta at the kicker is required to have the best performance by the voltage applied to each bunch.
- About the tune value, it is important to note that if it is too small (<.10), the correction signal computing will become slower, because more acquisitions are necessary to fill the response filter.

Courtesy of E.Belli, FCC week 2017

E. Belli - Impedance model and collective effects for FCC-ee

Transverse coupled bunch instability

- Growth rate for the μ-th mode

$$\frac{1}{\tau_{\mu,\perp}} = -\frac{ecI}{4\pi E Q_\beta} \sum_q Re[Z_\perp(\omega_q)] G_\perp\left(\frac{\sigma_z}{c}\omega'_q\right) = 1$$

with

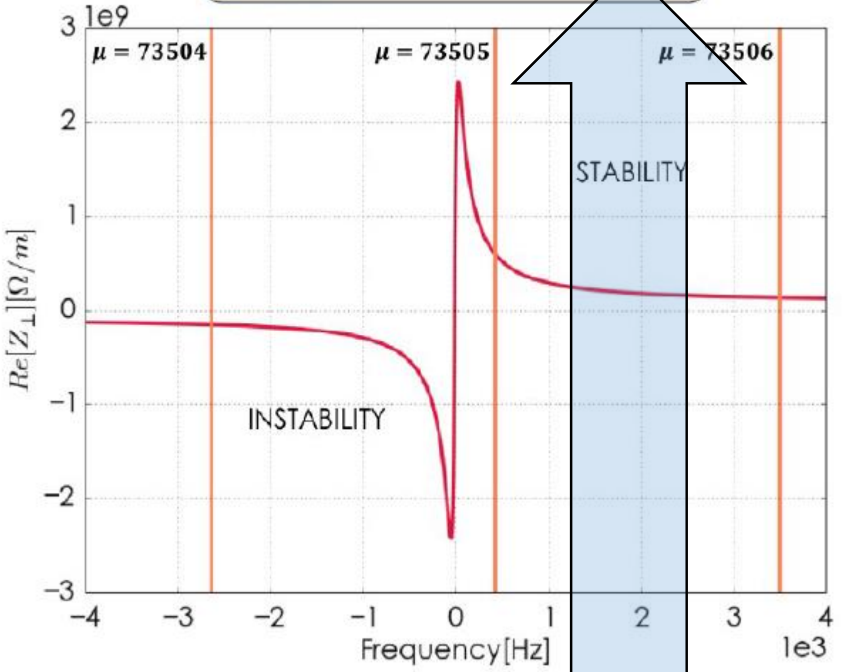
$$\omega_q = (qM + \mu + Q_\beta)\omega_0$$

$$\omega'_q = \omega_q + \xi\frac{\omega_\beta}{\eta}$$

$$Re\,[Z_\perp(\omega)] = sgn(\omega)\frac{C}{2\pi b^3}\sqrt{\frac{2Z_0 c}{\sigma_c|\omega|}}$$

- Negative ω → **unstable** mode with exponential growth
- Positive ω → **stable** mode with damped oscillations
- The most dangerous coupled mode when $\omega_q \approx 0$
  - $\mu = -qM - Q_0 - 1 = 73504$

$$\frac{1}{\tau_{73504}} = 494.8\ s^{-1} \simeq 6\ turns$$



Robust feedback for instability suppression

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Growth rates as foreseen by the impedance model (without considering e-cloud effects)

Three design cases

Going to FCC-ee design and looking to what we foresee about the beam dynamics, three possible cases can be considered:

Case A → slow or fast instabilities (growth rates slower than 10 revolution turns)

Case B → very fast instabilities (growth rates up to 3 revolution turns)

Case C → extremely fast instabilities (growth rates around 1-2 turns o even less).

Case A: design option A

- Going to discuss the three cases described, and wishing to maintain the standard mixed analog and digital technologies developed for the feedback in the past, only the case A could be based on the usual well known approach, used in the previous lepton colliders, in which many parts are commercially available.
- Nevertheless the present systems are able to process up to few thousands of buckets.
- Note also that usually all the bucket signals are acquired and handled even if they are empty. This is to make simpler and faster the real time computation.
- As a consequence new and more powerful processing units have to be built even in the case A to cope with a very high harmonic number (of the order of 100k).
- Another possible issue can rise due to the possible very low frequency of the modes that have to be damped. Of course kickers and power amplifiers feeding the correction signal must have the appropriate bandwidth.
- Even if power amplifiers are commercial devices, they have to be checked carefully to work at the low frequencies and same check for the kickers.
- This "standard" feedback design is foreseen to have a damping rate of 10 revolution turns as the experience done in the other colliders has shown.

Case B: design option B

- Analyzing the case B, that considers instability growth rates up to 3 revolution turns, a different scheme must be implemented.
- Indeed only one feedback system does not guarantee to manage enough power to damp.
- The experience done at DAFNE in 2007 by implementing two complete feedbacks in the same horizontal plane as reported in the next slide, clearly highlights that the feedback damping rate is limited mainly by the noise entering in the loop from the pickup.
- High beam current makes worse the signal-to-noise ratio leading to the feedback saturation.
- Moreover saturation or excess of feedback gain can induce enlargement of the bunch dimension.
- This effect is more dangerous in the vertical plane and it can be also amplified by the kick given by beam-beam collisions. Implementing four systems spaced by a distance of a quarter of main ring can bypass the gain saturation limit with the goal to achieve a feedback damping rate of the order of 10/4=2.5 revolution turns.

- **DAFNE, year 2008**
- **New e+ Transverse Horizontal Feedback**
- The damping times of the two feedback's add up linearly
- Damping time measured:
- ~100 ms-1 (1 FBKs) ➔ fb damps in 30 revolution periods (~10 us)
- ~200 ms-1 (2 FBKs) ➔ fb damps in 15 revolution periods (~ 5 us)
- The power of the H FBK has been doubled

Fast feedbacks for diagnostics and mitigation of e-cloud instability

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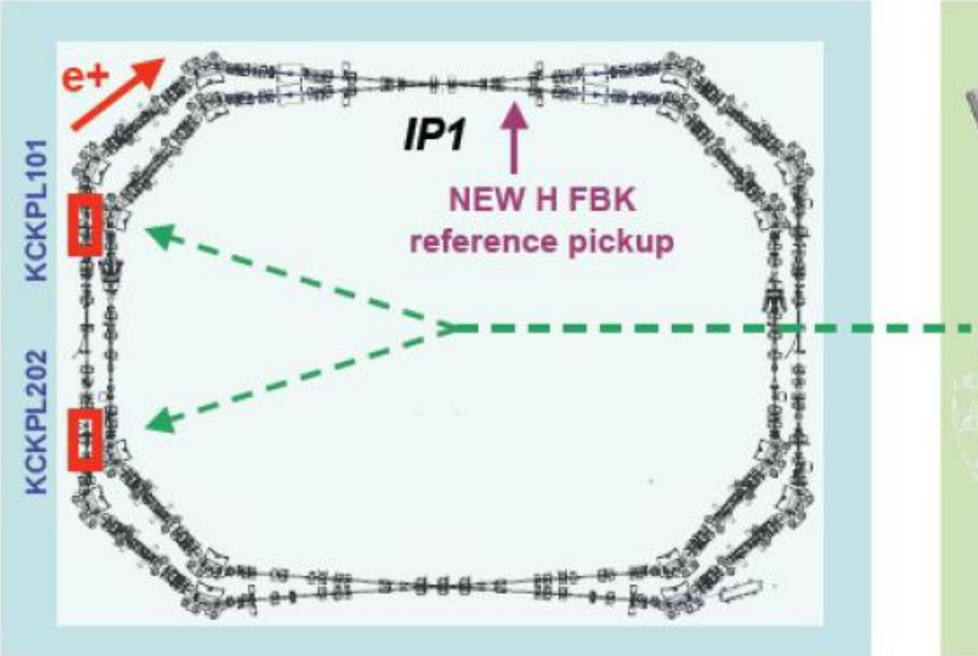
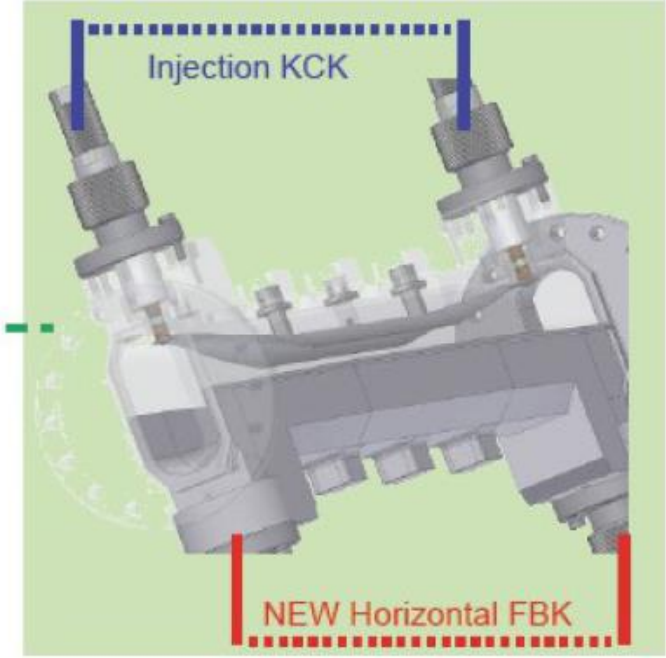
INFN-LNF

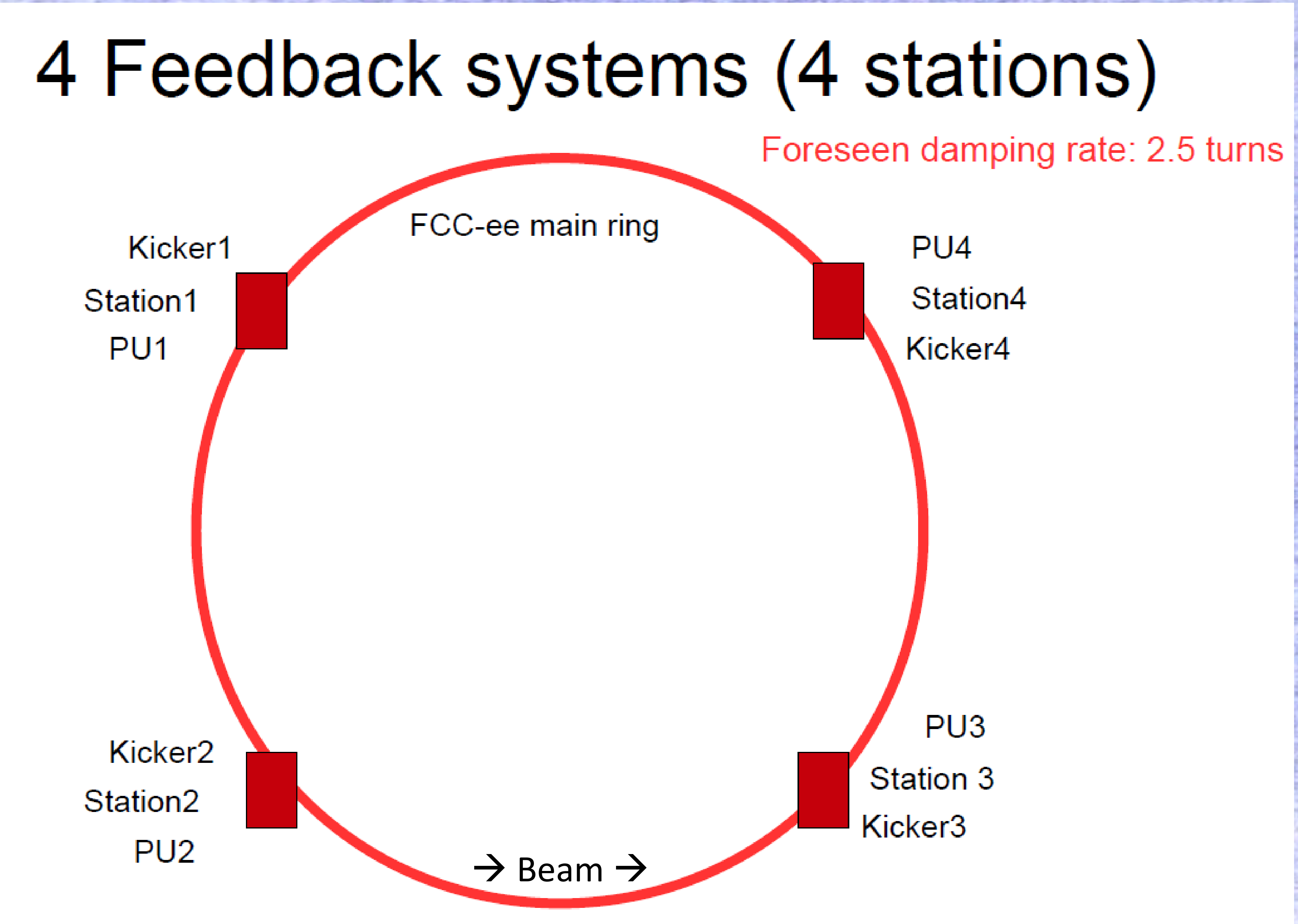
International Linear Collider Workshop 2008
LCWS08 & ILC08
ILC08 Damping Ring session

November 16-20, 2008
University of Illinois at Chicago



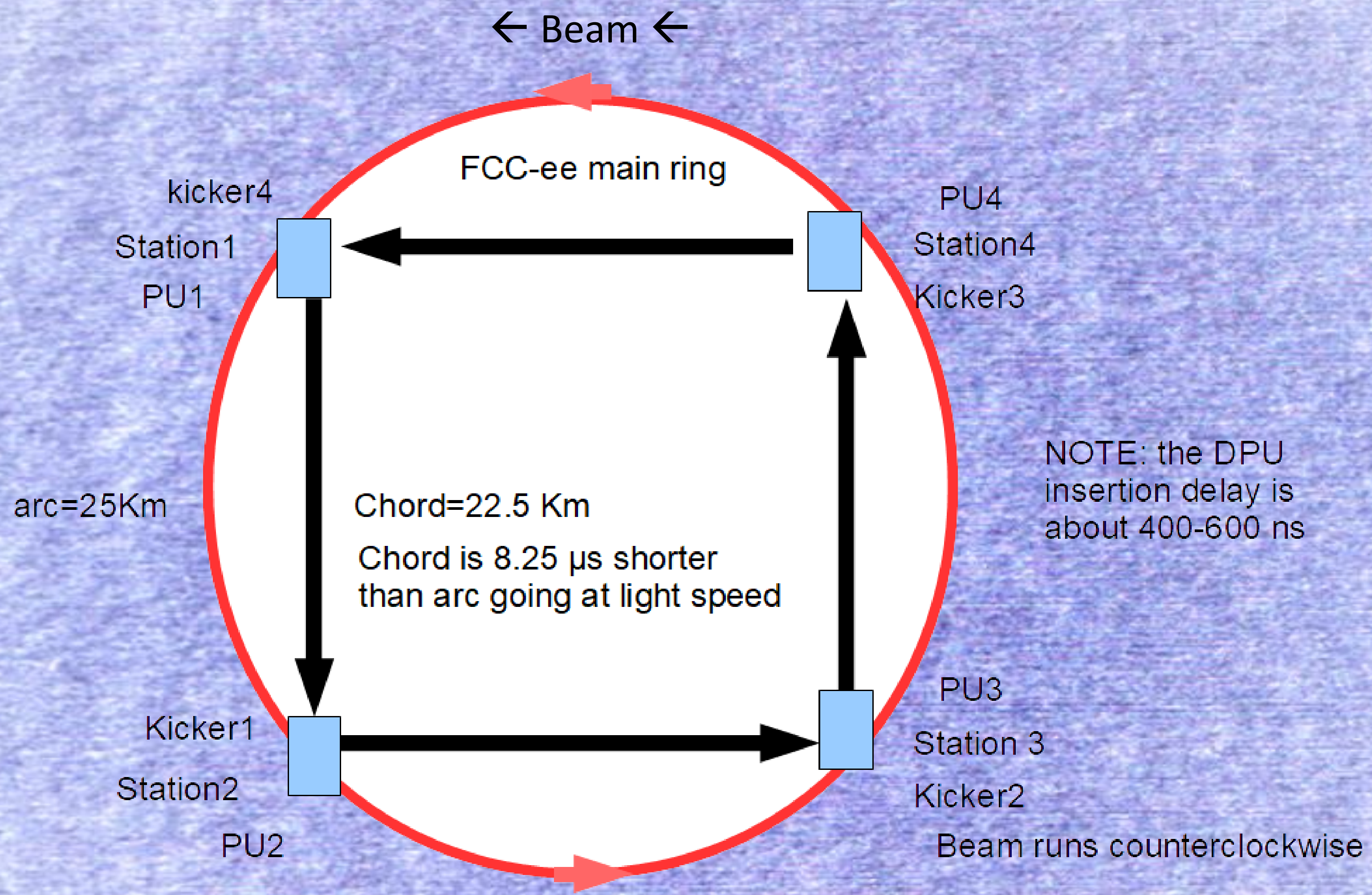


Option B


4 Feedback systems (4 stations)
Foreseen damping rate: 2.5 turns
FCC-ee main ring
Kicker1
Station1
PU1
PU4
Station4
Kicker4
Kicker2
Station2
PU2
PU3
Station 3
Kicker3
→ Beam →

Case C: design option C

- Finally considering the case C with instability growth rate of the order of 1-2 turns or even less, a very different design scheme is necessary.
- Indeed the solution found for the case B is not sufficient.
- To achieve a faster damping rate it is necessary to apply the correction signal earlier than by implementing the previous scheme (that kicks in one revolution period).
- Again four systems are necessary but they are not enough.
- The way to implement the Option C scheme consists in putting the kicker with a distance of a quarter of the ring downstream the feedback pickup.
- To be effective the correction signal has to arrive to the kicker BEFORE the bunch.
- This is possible because the path along the chord (for the signal) is shorter than the path along the arc (for the beam).



proposed feedback scheme for Option C

Option C

- In order to implement the option C design, a signal transmission system with a speed close to the light speed is necessary.
- RF o laser communication systems have been considered even if optical fiber based transmission systems offer more ease and flexibility from practical point of view.
- Actually commercial optical fibers have a signal propagation speed of about 0.7 c that is 31% slower speed in silica glass than in vacuum
- A new technology, the hollow optical fiber transmission, seems in this moment the state-of art solution to achieve the goal.
- By implementing this technique, the feedback damping rate should be able to up to be effective in 0.625 revolution turns (10/4/4=0.625).

Nature photonics 7, 2013

Transmission by optical fibers at 99.9% of light speed is now possible !

R&D are in progress in many laboratory...

Air guidance in hollow core fibers can reduce latency very significantly.

nature photonics

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NATURE PHOTONICS | LETTER

日本語要約

Towards high-capacity fibre-optic communications at the speed of light in vacuum

F. Poletti, N. V. Wheeler, M. N. Petrovich, N. Baddela, E. Numkam Fokoua, J. R. Hayes, D. R. Gray, Z. Li, R. Slavík & D. J. Richardson

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Abstract

Abstract • References • Author information

Wide-bandwidth signal transmission with low latency is emerging as a key requirement in a number of applications, including the development of future exaflop-scale supercomputers, financial algorithmic trading and cloud computing[1, 2, 3]. Optical fibres provide unsurpassed transmission bandwidth, but light propagates 31% slower in a silica glass fibre than in vacuum, thus compromising latency. Air guidance in hollow-core fibres can reduce fibre latency very

Option C

- A signal transmission system with a speed close to the light speed is necessary but not sufficient condition.
- Indeed the correction signal has to be transmitted in digital format and not in analog → at least 16 bits every 2 ns.
- This requirement asks to a modification of the usual feedback architecture that has to be split in two parts.
- The first one before the optical link (composed by pick-up, analog front end, ADC, FIR, timing, bunch labelling, transmitter).
- The second part after the transmission (composed by receiver, timing, decoder, DAC, analog back end, power amplifiers and kicker).

Option A,B,C comparison

- In conclusion instability growth rates of the order of one revolution turn require strong R&D efforts to implement the above proposed innovative design.
- Less critical instability growth rates can be coped by a more moderate R&D program.
- From the ring impedance point of view, it is important to underline that the three feedback design options have different impact.
- The option A requires only one cavity kicker for the longitudinal case and two stripline kickers for the transverse planes (1 H + 1 V).
- On the contrary, both options B and C need four cavity kickers and eight stripline kickers increasing consequently the ring impedance.
- However every feedback (H,V,L) system can be implemented independently by the design option that is more adapt to cope with the related instability grow rate.

Conclusion

- The bunch by bunch feedback systems for FCC-ee should be designed on the basis of the experience developed working on the lepton circular colliders in the last two decades.
- Nevertheless the advance of the technology as well as the very high performance required by FCC-ee specifications recommend to evaluate improved project scenarios.
- Three compatible but with different complexity level designs are presented in this proposal in order to be able to damp instability grow rates slower than 10 revolution turns (option A), or up to 3 revolution turns (option B) or even slightly faster than 1 revolution turn (option C).
- The impact on the ring impedance is higher for the option B and C.
- Anyway an R&D program plan will be necessary for the first two design options.
- The third and more advanced project scheme will require very strong R&D efforts.

Thanks for the attention!